TCP - Trapped Charged Particles Conference 2022

Report of Abstracts

Abstract ID : **2**

Theoretical study of rotation sensing with a compact Penning trapped calcium ion crystal system

Content

In traditional mechanics, harmonic oscillators could be utilized for force, acceleration or rotation measurement. The traditional harmonic oscillators usually composed of a mass block. Here we describe a quantum harmonic oscillator based on trapped ion crystal. These trapped ions are trapped in a penning trap and they can form a 2D ion crystal. The calcium ions are cooled through lasers and driven by RF electronic magnetic field. The spins of the ions and the harmonic motion are coupled through a laser. Just like the traditional oscillators, we try to figure out if the trapped ions could form a rotation sensor. We also will show the compact penning trap design in our lab. In the penning trap, the super conducting magnet will be replaced by permanent magnet. The cost and the volume of the trap are greatly reduced.

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Presenter: Mr CHEN, yao (Xi'an Jiaotong University)

Status: SUBMITTED

Submitted by **CHEN, yao** on **Monday 21 February 2022**

Abstract ID : **3**

Symmetry-violating nuclear properties from single molecular ions in a Penning trap

Content

This contribution introduces a novel Penning ion trap for precision studies of single molecular ions. The strong magnetic fields of the Penning trap are used to bring molecular opposite-parity states of trapped particles into near degeneracy. This phenomenon enhances the sensitivity to electroweak nuclear properties, like the nuclear anapole moment, by more than 11 orders of magnitude compared to atomic systems [Altuntas, E. et al. Phys. Rev. Lett. 120, 142501 (2018)]. These so-far unknown properties are, on the one hand, critical in the understanding of the nuclear force and structure but also provide precise low-energy tests of the standard model of particle physics and the violation of fundamental symmetries. I will present our proof-of-principle experiment at MIT with preliminary results of our first laser spectroscopy in the trap.

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Submitted by **KARTHEIN, Jonas** on **Thursday 03 March 2022**

Abstract ID : **4**

Towards a trapped electron quantum computer

Content

We explore the feasibility of processing quantum information encoded in the spin of electrons trapped ion a Paul trap. The main idea is to replace the ions in a QCCD (quantum charge-coupled device) ion trap quantum computer with electrons. The combination of the low mass and simple internal structure enables high-speed operation while allowing for high-fidelity operation. In particular, our simulation of common two-qubit error sources show that error rates of less than 1E-4 at clock speeds of close to 1 MHz for transport and quantum gates might be feasible.

Towards this goal, we trap single to few electrons in a millimeter-sized quadrupole Paul trap driven at 1.6 GHz in a room-temperature ultra-high vacuum setup. Electrons with sub-5 meV energies are introduced into the trap by near-resonant photoionisation of an atomic calcium beam and confined by microwave and static electric fields for several tens of milliseconds. A fraction of electrons remains trapped and shows no measurable loss for measurement times up to a second. Electronic excitation of the motion reveals secular frequencies from several tens to hundreds of MHz. Operating an electron Paul trap in a cryogenic environment may provide a platform for all-electric quantum computing with trapped electron spin
qubits.

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Submitted by **HAEFFNER, Hartmut** on **Friday 01 April 2022**

Abstract ID : **5**

The N=126 Factory: A new multi-nucleon transfer reaction facility at Argonne National Laboratory

Content

Multi-nucleon transfer (MNT) reactions between two heavy ions offer an effective method of producing heavy, neutron-rich nuclei that cannot be effectively accessed using traditional projectile-fragmentation, target-fragmentation or fission production techniques [1]. Such nuclei are important for understanding many astrophysical phenomena; for example, the neutron-rich nuclei near the $N = 126$ shell closure are critical to the understanding of the r-process pathway, particularly the formation of the $A \sim 195$ abundance peak [2]. The $N = 126$ Factory currently under construction at Argonne National Laboratory's ATLAS facility will make use of these reactions to allow for the study of these nuclei [3]. Due to the wide angular distribution of MNT reaction products, a large-volume gas catcher will be used to convert these reaction products into a continuous low-energy beam. This beam will undergo preliminary separation in a magnetic dipole of resolving power $R \sim 10^3$ before passing through an RFQ cooler-buncher and MR-TOF system of resolving power $R > 10^5$, sufficient to suppress isobaric contaminants. This isotopically separated, bunched low energy beams will then be available for experimental systems at ATLAS such as the CPT mass spectrometer for precision mass measurements. Results of commissioning the components devices will be presented, as will the status of the final assembly and commissioning of the facility, which is expected to be operational this year.

This work is supported in part by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357; by NSERC (Canada), Application No. SAPPJ-2018-00028; by the National Science Foundation under Grant No. PHY-2011890; by the University of Notre Dame; and with resources of ANL's ATLAS facility, an Office of Science User Facility.

[1] V. Zagrebaev and W. Greiner. *Phys. Rev. Lett.*, 101:122701, 2008.
[2] M.R. Mumpower, R. Surman, G.C. McLaughlin, and A. Aprahamian. *Prog. Part. Nucl. Phys.*, 86:86–126, 2016.
[3] G. Savard, M. Brodeur, J.A. Clark, R.A. Knaack, and A.A. Valverde. *Nucl. Instr. Meth. Phys. Res. B*, 463:258 – 261, 2020.

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Status: SUBMITTED

Submitted by **VALVERDE, Adrian** on **Friday 08 April 2022**

Abstract ID : **6**

Sympathetic cooling of a single proton in a Penning trap by laser-cooled beryllium ions

Content

One of the major driving forces of the improved precision of AMO experiments has been the ability to prepare cold particles. While direct laser-cooling has been applied very successfully in this regard, many particles of interest do not have suitable laser cooling transitions. For example, the BASE collaboration performs high-precision Penning trap measurements of the g-factors and q/m of the proton and antiproton to test CPT in the baryonic sector [1]. The latest measurement of the proton g-factor is limited by the statistical uncertainty [2], which stems from the finite particle temperature of about 1K. The use of sympathetic cooling methods has so far relied on co-trapping another laser-cooled species, which is often detrimental to the precision measurement.

Recently our group has published the first proof-of-principle measurement on sympathetically cooling a single proton from 17.0(2.4)K to 2.6(2.5)K with beryllium ions located in a macroscopically separated trap [3]. The coupling was achieved via a superconducting resonator, which is normally used for particle detection. We have developed simulation code to optimize experimental parameters and study different cooling schemes [4]. A comparison between simulation and existing experimental data yields good agreement. We find that temperatures in the 10mK-regime with cooling time constants of about 10s are feasible with dedicated cooling schemes. On the experimental side, at the time of this abstract a setup is being commissioned with which we anticipate to measure the expected mK temperatures.

This contribution will give an overview of the BASE-Mainz experiment with a focus on the schemes proposed in [4] towards cooling a single proton in a Penning trap.

[1] C. Smorra et al., The European Physical Journal Special Topics, 224, 16, 2015.
[2] G. Schneider et al., Science, 358, 6366, 2017.
[3] M. Bohman et al., Nature, 596, 514–518, 2021.
[4] C. Will et al., NJP 24 033021 (2022)

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Status: SUBMITTED

Submitted by **WILL, Christian** on **Wednesday 20 April 2022**

Abstract ID : **7**

Optical atomic clocks in search of new physics

Content

Optical clocks are based on precision spectroscopy of narrow-linewidth atomic transitions. In the best clocks, perturbations to the atomic transition frequency can be controlled and evaluated to within a fractional uncertainty of just 1 part in 10^18. This exceptional stability and accuracy has enabled optical clocks to be used in precision tests of fundamental physics. Of all the optical clocks developed so far, the ytterbium ion clock frequency at 642 THz (467 nm) has the strongest sensitivity to any changes in the fine structure constant. This makes ytterbium ion clocks particularly well-suited to searching for variations in fundamental constants, which would provide evidence of physics beyond the Standard Model.

In this talk, I will present how optical clocks at the National Physical Laboratory and other institutes have made measurements that place new limits on the magnitude of variations in fundamental constants. I will also describe a new project "QSNET" [1] that is underway in the UK to develop a network of optical clocks based on more exotic species such as highly charged ions, molecular ions, and neutral molecules trapped in an optical lattice. These new clocks are expected to be at least an order of magnitude more sensitive in detecting variations of the fine structure constant, α, and the electron-to-proton mass ratio, μ. These measurements could either reveal new physics or impose tighter constraints on theories beyond the Standard Model, including dark matter and dark energy models.

[1] "Measuring the stability of fundamental constants with a network of clocks", G. Barontini *et al.*, arXiv: 2112.10618

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Status: SUBMITTED

Submitted by **GODUN, Rachel** on **Friday 22 April 2022**

Abstract ID : **8**

Sympathetic Cooling of a Single Trapped Proton

Content

Precise tests of the CPT symmetry in the baryon sector are performed by high-precision measurements of the fundamental properties of protons and antiprotons [1, 2, 3]. The most precise measurement of the proton magnetic moment, performed at the proton g-factor experiment in Mainz, is currently at 300 ppt, predominantly limited by statistics [1]. The reason for that is the use of sub-thermal cooling by a resistive method in the preparation of a single cold proton, which is extremely time-consuming and leads to cycle times of hours.

To overcome this limitation, sympathetic cooling by laser-cooled 9Be+ ions stored in a separate Penning trap and connected by a common-end-cap, is being developed [4, 5]. The method not only promises to produce single protons and antiprotons with mK temperatures within tens of seconds but also ensures separation of the cooled ion and the refrigerator ions.

We present initial experiments on sympathetic cooling of a single proton to a temperature of 2.6(2.5) K [6]. In these experiments, coupling of laser-cooled 9Be+ ions and a single proton is achieved with the help of a common LC resonator. This enhances the coupling strength compared to the common-end-cap coupling significantly, but also leads to additional heating effects.

We further discuss recently installed upgrades of the proton g-factor experiment such as a dedicated cyclotron temperature measurement trap with higher temperature resolution and report on the status of ongoing measurements.

[1] Schneider, G. et al., Science 358, 1081 (2017)
[2] Smorra, C. et al., Nature 550, 371 (2017)
[3] Borchert, M. J. et al., Nature 601, 53 (2022)
[4] Heinzen, D. J. & Wineland, D. J., Phys. Rev. A 42, 2977 (1990)
[5] Bohman, M. et al., J. Mod. Opt. 65, 568 (2017)
[6] Bohman, M. et al., Nature 596, 514 (2021)

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Status: SUBMITTED

Submitted by **WIESINGER, Markus** on **Friday 22 April 2022**

Abstract ID : **9**

Exploring exotic nuclei by high-precision MRTOF mass measurements: The new ion catcher and mass spectrograph at RIKEN's RIBF facility

Content

Exploiting closed-path ion trajectories in an electrostatic ion trap, the multi-reflection time-of-flight mass spectrograph (MRTOF-MS) [1] is one of the most promising techniques for precise mass measurements of short-lived isotopes. Exotic ions produced at radioisotope facilities are stored in an electrostatic trap at kinetic energies on the order of a few keV, reflected back and forth between two electrostatic ion mirrors, and ultimately ejected to a detector for time-of-flight (TOF) determination. By comparison of precise TOF data obtained from ions of well-known mass, the mass of an unknown ion can be calculated with relative uncertainties reaching $\delta m/m < 5 \cdot 10^{-8}$ using state-of-the-art technology.
At the RIBF/BigRIPS facility of RIKEN (Wako, Japan) the new ZD-MRTOF system [2,3] located downstream of RIBF's ZeroDegree (ZD) spectrometer has been put into operation. The precision mass spectrometer is coupled to a cryogenic helium-gas filled ion catcher [4], where the initially relativistic reaction products are stopped, thermalized, and extracted as ions to be forwarded to the MRTOF-MS.
Since autumn 2020 exotic ion beams are delivered to our new setup, and previously unknown radioactive isotope masses, or those with large mass uncertainty, have been newly determined with high precision and accuracy. This contribution will focus on the success of this setup and the achievements for nuclear mass spectroscopy. The recent physics results and an outlook with the near-future program will be presented.
Furthermore, new efforts have been made to improve the wide-band mass accuracy of the MRTOF system. The presently known causes of uncertainties for wide-band mass measurements in MRTOF-MS, possible solutions, and technical challenges will be discussed.

[1] H. Wollnik and M. Przewloka, Int. J. Mass Spectrom. Ion Proc. 96, 267 (1990)

[2] M. Rosenbusch et al., Nucl. Instr. Meth A (under review), arXiv:2110.11507

[3] M. Rosenbusch et al., Nucl. Instr. Meth B 463, 184 (2019)

[4] A. Takamine et al., Acc. Prog. Rep. 52, 139 (2019)

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Status: SUBMITTED

Submitted by **ROSENBUSCH, Marco** on **Sunday 24 April 2022**

Abstract ID : **10**

High-precision Penning-trap experiment PENTATRAP

Content

High-precision Penning trap mass spectrometry is the most precise technique employed to measure masses of nuclides with half-lives as short as a few ten ms. Currently, there are about a dozen high-precision Penning-trap mass spectrometers located in North America and Europe. The majority of them are part of various Rare Ion Beam (RIB) facilities and aim at measurements of masses of short-lived nuclides with fractional uncertainties down to 10-9. The other group encompasses four ultra-precise Penning trap mass spectrometers. Their major goal are mass-ratio measurements on long-lived and stable nuclides with fractional uncertainties of as small as a few ppt.
In this second group the PENTATRAP experiment is probably the most advanced. It is located at the Max-Planck Institute for nuclear physics and aims to perform mass-ratio measurements on a very broad range of long-lived nuclides to assist, e.g., experiments on the determination of the neutrino mass, on the search for the fifth force, on the investigation of atomic metastable states that can be suitable ion clock transitions and so on. In this talk I will (after a quite detailed introduction of Penning-trap mass spectrometry) present latest achievements and future plans with PENTATRAP.

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Status: SUBMITTED

Submitted by **ELISEEV, Sergey** on **Monday 25 April 2022**

Abstract ID : **11**

The PUMA Experiment: Investigating Short-lived Nuclei with Antiprotons

Content

The antiProton Unstable Matter Annihilation (PUMA) experiment is a new nuclear physics experiment at CERN which will provide the ratio of protons and neutrons in the nuclear density tail as a new observable to test nuclear structure theories [1]. To determine this ratio, the concept of antiprotonic atoms is used. After capture onto an antiprotonic orbital, the antiproton cascades towards the nucleus and eventually annihilates with a nucleon. This annihilation conserves the total charge, so that the annihilated nucleon can be identified by detecting all pions produced in the annihilation. The process takes place at higher distances to the center of the nucleus than other nuclear reactions (e.g. nucleon removal reactions), making this method particularly interesting for nuclei with a high proton-to-neutron asymmetry, i.e. short-lived nuclei close to the driplines, halo nuclei and nuclei with a thick neutron skin. As there is no joint facility for antiprotons and short-lived nuclei available, PUMA aims at storing antiprotons in a transportable Penning trap at the Antimatter Factory of CERN and bringing them to ISOLDE/CERN for studies with radioactive nuclei.
This talk will give an overview over the motivations, the experimental setup and the current status of the experiment.
[1] PUMA collaboration, accepted in EPJA (2022)

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Comments:

Can the author be 'Jonas Fischer for the PUMA collaboration'?

Status: SUBMITTED

Submitted by **FISCHER, Jonas** on **Monday 25 April 2022**

Abstract ID : **13**

Highly Charged Ion Optical Clocks to Test Fundamental Physics

Content

Highly charged ions (HCI) have many favorable properties for tests of fundamental physics and as potential next-generation optical atomic frequency standards. However, up until recently the most accurate laser spectroscopy on any HCI was performed on the 17 Hz wide fine-structure transition in Ar^{13+} with 400 MHz resolution, lagging almost twelve orders of magnitude behind state-of-the-art optical clocks. We present the first coherent laser spectroscopy of an HCI using techniques developed in the context of quantum information processing with trapped ions. A novel quantum algorithmic cooling scheme has been developed and implemented, which reduces motional shifts to below the 10^{-18} level. We have performed an absolute frequency measurement, including a full error budget for the Ar^{13+} HCI clock, which demonstrates that HCI optical clocks with systematic uncertainty below 10-18 become feasible. Finally, prospects for 5th force tests based on isotope shift spectroscopy of Ca^{+}/Ca^{14+} isotopes and the high-sensitivity search for a variation of the fine-structure constant using HCI will be presented. This work paves the way towards optical clocks based on highly charged ions with a high sensitivity to a change in fundamental constants and other tests of beyond standard model physics.

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Presenter: SCHMIDT, Piet (PTB & LUH)

Status: SUBMITTED

Submitted by **SCHMIDT, Piet** on **Monday 25 April 2022**

Abstract ID : **14**

Beam Preparation for Mass Spectrometry of Neutron-Rich Heavy Nuclides

Content

With the NEXT project at the University of Groningen, we aim to investigate Neutron-rich EXotic nuclei produced in multinucleon Transfer reactions, whose masses provide valuable input for nuclear structure and nuclear astrophysics studies. The experiments will utilize primary beams delivered from the cyclotron AGOR at PARTREC in Groningen, the Netherlands. Nuclides of interest will be separated from unwanted reaction products by a solenoid magnet. The ions will then be slowed down from MeV to eV energies by a gas catcher. Afterwards, the ions will enter the low energy part of the setup, which we will present in detail in this contribution. It consists of an ion guide to cool and bunch the ions, several einzel lenses to transport and focus them, and a Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF MS) for isobaric separation and mass measurements. In particular, a novel design of the ion guide will be presented, which is based on a stack of ring electrodes with varying apertures, and accordingly, thicknesses and spaces in between [1]. The ion guide is driven by square-wave RF voltages for ions' radial confinement overlaid with a traveling wave for their axial transports. A power supply system for the generation of square-wave RF voltages is under development. A standalone setup with an offline ion source is being designed and manufactured to test the ion guide and the MR-ToF MS.

[1] X. Chen *et al.*, *Int. J. Mass Spectrom.* **477**, 116856 (2022).

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Presenter: CHEN, Xiangcheng (University of Groningen)

Status: SUBMITTED

Submitted by **CHEN, Xiangcheng** on **Tuesday 26 April 2022**

Abstract ID : **15**

Single-mode coherence of light scattered from ensembles of independent atoms

Content

Experiments with large ensembles of ions provide a testbed for the investigation of a rich variety of optical phenomena. We achieved a new optical emission regime where the mutually phase-incoherent independent atomic scatterers contribute collectively to the observation of the bunched photons.

The experimental characterization is based on the detection of light from noninteracting independent single-photon emitters represented by trapped ion crystals formed from Ca^+ ions in a linear Paul trap. The ions in these configurations scatter the light from the exciting 397 nm laser beam with further emitting photons that were collected using an optical objective with a numerical aperture of 0.2 and coupled into a single-mode optical fiber. The polarization filter consisting of a quarter-waveplate and a polarization beam splitter was used before coupling into an optical fiber to transmit only one polarization. The second-order optical coherence is accessed using the measurement of photon statistical properties on the set of two single-photon avalanche photodiodes arranged in a Hanbury-Brown and Twiss configuration with a balanced beam-splitter.

For the defined ion configurations, it was observed unambiguous evidence of indistinguishable emission from ion crystals by measurement of photon bunching. The measured value of the $g^{(2)}(\tau = 0)$ gradually increases from a single-ion sub-Possonian value to approximately 1.5 for the ion configurations containing more than 180 ions. These results present an important step towards the realization of control of coherent optical phenomena with many independent atoms on the possibilities of emulations of complex quantum collective scattering.

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Status: SUBMITTED

Submitted by **KOVALENKO, Artem** on **Tuesday 26 April 2022**

Abstract ID : **16**

High-precision g-factor measurements of $^3He^+$ and $^3He^{2+}$

Content

^3He NMR probes are a possible candidate for a new absolute magnetometry standard due to their insensitivity to systematic effects compared to water NMR probes. So far magnetic moment measurements independent of water NMR probes have been lacking.
In our poster, we will present the results of our recent measurement campaign in which we measured the ground-state hyperfine transitions of $^3He^+$ in a cryogenic double Penning trap setup. The obtained transition frequencies were then used to extract the nuclear g-factor with a precision of 900 ppt. Additionally, the bound-electron g-factor, the zero-field hyperfine splitting, and the Zemach radius were determined with precisions of 200 ppt, 30 ppt, and 0.7%, respectively.
Furthermore, the developments for g-factor measurements on $^3He^{2+}$ and other light ions will be presented.

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Comments:

Poster contribution

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Submitted by **MÜLLER, Marius** on **Wednesday 27 April 2022**

Abstract ID : **17**

Trapping and cooling of single H2+-Be+ ion pairs

Content

The complexity and variety of molecules offer opportunities for metrology and quantum information that go beyond what is possible with atomic systems. The hydrogen molecular ion is the simplest of all molecules and can thus be calculated ab initio to very high precision [1]. Combined with spectroscopy this allows to determine fundamental constants and test fundamental theory at record precision [2–4]. Spectroscopy of the hydrogen molecular ion should improve substantially by performing experiments with single hydrogen molecular ions, reducing systematic uncertainties and improving signal strength. This necessitates quantum control.
I will present our progress towards full quantum control of a single hydrogen molecular ion. Our most recent results demonstrate the co-trapping of single H_2^+ and $^9Be^+$ ions. We observe H_2^+ trapping lifetimes of $\approx 10\text{h}$. We perform ground-state cooling of the ion pair's axial in-phase mode of motion, resulting in an average phonon number of 0.088(4), corresponding to a temperature of 24.8(4) μK.
The experimental apparatus features a cryogenic ultra-high vacuum chamber, housing a microfabricated monolithic linear Paul trap. H_2^+ is loaded into the trap by electron bombardment of H_2. We aim to use He buffer gas cooling in combination with quantum logic spectroscopy to initialize the internal state of H_2^+ in a pure quantum state and implement non-destructive readout [5, 6].

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Submitted by **KIENZLER, Daniel** on **Wednesday 27 April 2022**

Abstract ID : **18**

Improved precision on the measurements of low energy antimatter in the ALPHA experiment

Content

Antihydrogen is one of the most simple pure antimatter bound states, which can be synthesised and trapped for extended periods of time by the ALPHA collaboration since 2010 [1]. A consequence of CPT symmetry is that antimatter bound states will present the same energy spectrum as their matter equivalents, and over the last five years ALPHA have measured antihydrogen transitions as a direct test of this fundamental symmetry [2][3][4]. Through upgrading metrology instrumentation at ALPHA it will become possible to measure antihydrogen transition energies with the best precision yet. Specifically, the collaboration intends to improve the frequency reference precision by two orders of magnitude via the inclusion of a Caesium fountain clock and Hydrogen maser to replace the GPS-disciplined quartz oscillator reference. The metrology upgrades alongside the recent implementation of laser cooling antihydrogen [5] will significantly improve the precision on the measurement of the 1S-2S antihydrogen transition, in the bid to one day reach parity or surpass the precision of similar measurements made with hydrogen

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Status: SUBMITTED

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Abstract ID : **19**

Probing Physics Beyond the Standard Model with the JILA eEDM Experiments

Content

The Standard Model of particle physics is one of the most successful models that we use to describe the universe, yet it is known to be incomplete. Substantial efforts on the theoretical front introduce new physics through extensions of the Standard Model, and these new physics models make predictions on the value of the electric dipole moment of the electron (eEDM). Measurements of (or improved limit on) the eEDM places constraints on these new theories. The eEDM experiments at JILA take advantage of the long trapping time of ions to tap the long coherence times of the eEDM-sensitive states in our molecular ions of choice: HfF^+ and ThF^+. The ongoing experiment using HfF^+ is an upgraded version of our 2017 experiment [1], using a bigger trap for more ions, amongst other improvements for better statistics. The upcoming experiment using ThF^+ has recently completed spectroscopy of the molecule [2,3,4], and we are now setting up a prototype experiment to demonstrate much longer coherence times than HfF^+, promised to us by the eEDM-sensitive ground state in ThF^+ [2,4]. Herein, we present updates on our studies on systematics on the upgraded HfF^+ system, and provide a teaser on the demonstration of long coherence times in ThF^+.

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Submitted by **NG, Kia Boon** on **Wednesday 27 April 2022**

Abstract ID : **20**

Molecular dynamics and spectroscopy at storage rings

Content

We have studied isolated molecular ions in a vacuum by taking advantage of two electrostatic ion storage rings, RICE in the cryogenic condition and TMU E-ring at room temperature over the years. We have focused on the deexcitation dynamics of laser-excited carbon clusters (C_n^-) and understood them based on statistical descriptions. This strategy was successfully applied for larger molecules, i.e., pentacene anions ($C_{22}H_{14}^-$) [1].
Recently, we have started rovibrational state-selective observation of the deexcitation of small molecular ions using a wavelength-tunable pulsed laser. The first example is the vibrational cooling of triatomic molecular ions N_2O^+ in the range of several seconds. We found that the deexcitation dynamics drastically deviate from the statistical description based on a Boltzmann-type distribution [2,3]. We also observed deexcitation of the simple iso-nuclear diatomic negative molecule C_2^- in the tens of millisecond range. An iso-nuclear diatomic molecule has zero dipole moment, and the vibration transition is prohibited due to its symmetry. However, it is de-excited via spontaneous infrared radiation between electric excited and ground states. The time evolution of the population at specific vibrational states was measured up to 60 milliseconds, providing the first quantitative experimental support for long-standing theoretical predictions [4]. We also tackled Si_2^- on the micro-second time region. To our surprise, the excitation spectra show well-resolved rovibronic structures exclusively in the delayed time region [5].

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Submitted by **AZUMA, Toshiyuki** on **Thursday 28 April 2022**

Abstract ID : **21**

Quantum Logic Control of a Single Molecular Ion

Content

Quantum Logic Control of a Single Molecular Ion

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An amazing level of quantum control is routinely reached in modern experiments with atoms, but similar control over molecules has been an elusive goal. A method based on quantum logic spectroscopy [1] can address this challenge for a wide class of molecular ions [2,3]. We have now realized the basic elements of this proposal.

In our demonstration, we trap a calcium ion together with a calcium hydride ion (CaH+) that is a convenient stand-in for more general molecular ions. We laser-cool the two-ion crystal to its motional ground state and then drive Raman-transitions or mm-wave transitions in the molecular ion. Laser-based transitions in the molecule can deposit a single quantum of excitation in the motion of the ion pair when a motional "sideband" is driven. We can efficiently detect this single quantum of excitation with the calcium ion, which projects the molecule into the final state of the sideband transition, a known, pure quantum state.

The molecule can be coherently manipulated after preparation by a first projection, and after attempting a transition, the resulting molecular state can be read out by another quantum logic state detection. We demonstrate this by driving Rabi oscillations between different rotational states [4, 5] and by entangling the molecular ion with the logic ion [6]. Many transitions in the molecule are either driven by a single, far off-resonant continuous-wave laser or by a far-off-resonant frequency comb. This makes the approach suitable for quantum control and precision measurement of a large class of molecular ions.

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Status: SUBMITTED

Submitted by **Ms JÄGER, Miriam** on **Thursday 28 April 2022**

Abstract ID : **22**

The PUMA Trap System: Storing Antiprotons and Short-Lived Isotopes

Content

The antiProton Unstable Matter Annihilation (PUMA) experiment is a new nuclear physics experiment at CERN which will investigate short-lived isotopes by annihilations with antiprotons. To initiate the annihilation processes, both antiprotons and short-lived nuclei have to be stored in an ion trap with spatial overlap. Currently, there is no research facility that provides both short-lived nuclei and antiprotons at once and the storage time of radioactive nuclei is limited by their natural lifetime. Thus, the only way to perform such experiments is to first accumulate antiprotons at the ELENA ring of the Antimatter Factory of CERN in a Penning trap to then transport them to the radioactive ion-beam facility ISOLDE for experiments. As typical time scales for accumulating at ELENA, transporting and performing experiments at ISOLDE are in the order of 20 to 30 days, the trap system needs to provide sufficiently long storage times for antiprotons. This time is limited by the pressure in the trap, as the number of stored antiprotons gradually decreases due to annihilations on residual gas molecules. To avoid significant losses, a cryogenic trap setup will be used, where the cold electrodes and chamber walls act as an additional vacuum pump.

This poster will give an overview of the design of the cryogenic double Penning trap system of the PUMA Experiment.

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Comments:

Could it say "Alexander Schmidt for the PUMA Collaboration" in the author list, so I don't have to add all members by hand?

Status: SUBMITTED

Submitted by **SCHMIDT, Alexander** on **Thursday 28 April 2022**

Abstract ID : **23**

Mass of Zr-80 reveals a deformed double shell closure at N=Z=40

Content

The nuclei that lie along the N = Z line form a rich laboratory for nuclear structure. The protons and neutrons in these nuclei occupy the same shell model orbitals, resulting in a large spatial overlap of single-particle wavefunctions and, therefore, permit unique isospin studies. In addition, midway along the N = Z line between the double-shell closures at Ni-56 and Sn-100, a rapid change in nuclear shape is observed, giving rise to the most deformed ground states in the nuclear chart. These structural phenomena leave imprints on the binding energy that can be studied through mass spectroscopy. However, mass data in the upper N=Z region is sparse primarily due to low production yields.

In this presentation I will report on a recent experiment performed at the National Superconducting Cyclotron Laboratory that yielded the first Penning trap mass measurement of Zr-80, with N=Z=40. Our new mass values show that this nucleus is significantly lighter, and thus more bound than previously predicted. Through binding-energy indicators, we attribute this mass anomaly to the existence of a deformed double-shell closure at N=Z=40 and an increase in the Wigner energy of this exotic system. I will also show how several global nuclear mass models demonstrate difficulties with reproducing the observed phenomena and discuss our plans to revisit this region with the upcoming FRIB facility.

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Submitted by **RINGLE, Ryan** on **Thursday 28 April 2022**

Abstract ID : **24**

Optical tweezers for trapped ion quantum simulations

Content

We present progress on our experimental setup, where we will use novel optical microtraps – derived from spatial light modulators – to manipulate the phonon spectrum of ions in a Paul trap [1]. This allows us to control the effective spin-spin interactions between the ions and with that realize and study various Hamiltonians of interest. In one-dimensional ion chains, optical tweezers can be combined with oscillating electric fields in order to realize two-qubit geometrical phase gates [3]. Furthermore, in 2D crystals, this can be used to quantum simulate spin Hamiltonians on a kagome lattice [2].
This novel approach, combined with other well-established techniques, can be used to realize a new architecture for quantum simulations using trapped ions.

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Status: SUBMITTED

Submitted by **SCHÜSSLER, Rima** on **Thursday 28 April 2022**

Abstract ID : **25**

Scalable arrays of micro-fabricated Penning traps for quantum computation and simulation

Content

Although radio-frequency (r.f.) traps have been widely used in trapped-ion quantum information and simulation, they face some inherent challenges in scaling up the number of qubits. Precise alignment of static and r.f. field nulls is necessary to achieve confinement of the ions without r.f. driven motion. As the r.f. null is inherently 1-dimensional, attempts at scaling into 2-d are beset by micromotion.

Instead we propose to use a two-dimensional array of Penning traps, implemented by micro-fabricated electrodes. Applying suitable electrical potentials to the surface electrodes generates an array of quadrupole fields above the chip, with a single ion trapped at each. This allows for individual control of secular frequencies and trapping heights with coupling provided by the Coulomb interaction. Micromotion and bulk crystal rotation are absent in this approach.

We have constructed an experimental apparatus containing the first micro-fabricated planar Penning trap in a 3 T field. The trap can produce a potential with two trap sites separated radially. To achieve ultra-high vacuum and low ion heating rates, the trap is held at cryogenic temperatures of around 6 K, with optics to allow for imaging and laser manipulation of ions as part of the cryogenic structure as well.

We report on our current efforts to initially trap $^9\mathrm{Be}^+$ ions in this setup. Potential challenges that may prevent successful trapping are identified. We attempt cooling of the radial motion by the axialisation technique, coupling the cyclotron and magnetron motions. The required strength of the weak coupling r.f. field is predicted as well as the precision of positioning of the r.f. null. Stray electric potentials may lead to unstable trapping conditions as well as perturb the axialisation frequency, requiring appropriate compensation. Neutral Be atoms are produced by pulsed-laser ablation, a process we have studied in depth.

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Presenter: SÄGESSER, Tobias (Trapped Ion Quantum Information Group, ETH Zürich)

Status: SUBMITTED

Submitted by **SÄGESSER, Tobias** on **Thursday 28 April 2022**

Abstract ID : **26**

Precision Atomic Mass Ratios of Light Ions

Content

The relative masses of the proton, deuteron, triton and helion are fundamental constants impacting several areas of physics. In particular, a high-precision value for the mass difference between tritium and helium-3 is important for testing systematics in the ongoing KATRIN neutrino mass experiment, while the deuteron/proton mass ratio is important for interpreting the results of recent high-precision laser and terahertz spectroscopy of the HD+ molecular ion, leading to an improved value of the electron/proton mass ratio or, alternatively, limits on beyond-standard-model nucleon-nucleon interactions. At Florida State University we precisely measure mass ratios of ions from their cyclotron frequency ratios, trapping the two ions simultaneously in a single Penning trap. For most of our measurements we alternate each ion between the center of the trap, where its cyclotron frequency is measured, and a large cyclotron "parking" orbit. Our previous measurements on mass-3 ions, besides providing the important Q-value for KATRIN, revealed significant errors in previously accepted values for the masses of *p*, *d* and *h*. In the case of measurements of H2+ against D+, we achieved sufficient resolution to distinguish different vibrational levels of H2+ by their difference in mass, and also to observe vibrational Stark quenching [1]. We then placed an H2+ and D+ in a coupled magnetron orbit and measured their cyclotron frequencies simultaneously [2]. This suppressed the effect of variation in the magnetic field by several orders of magnitude. It also reduced uncertainty related to measurement of the ions' axial frequencies. Using this technique we partly resolved H2+ rotational energy through the change in mass. This resulted in a value for the deuteron/proton mass ratio at 5 ppt and a proton atomic mass at 10 ppt. Progress towards an improved measurement of the tritium helium-3 mass difference will also be presented.

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Abstract ID : **27**

Doppler- and sympathetic cooling for the investigation of short-lived radionuclides

Content

Ever since its introduction in the mid 1970s, laser cooling has become a fundamental technique to prepare and control ions and atoms for a wide range of precision experiments. In the realm of rare isotope science, for instance, specific atom species of short-lived radionuclides have been laser-cooled for fundamental-symmetries studies [1] or for measurements of hyperfine-structure constants [2] and nuclear charge radii [3].
Nevertheless, because of its simplicity and element-universality, buffer-gas cooling in a linear, room-temperature Paul trap is more commonly used at contemporary radioactive ion beam (RIB) facilities. Recent advances in experimental RIB techniques, especially in laser spectroscopy and mass spectrometry, would however strongly benefit from ion beams at much lower beam temperature which could be achieved by laser cooling. In addition, sympathetic cooling of ions which are co-trapped with a laser-cooled ion species could open a path for a wide range of sub-Kelvin RIBs.
Within the MIRACLS low-energy apparatus [4], we demonstrate that laser cooling is compatible with the timescale imposed by short-lived radionuclides as well as with existing instrumentation at RIB facilities. To this end, a beam of hot $^{24}Mg^{+}$ ions is injected into a linear Paul trap in which the ions are cooled by a combination of a low-pressure buffer gas and a 10-mW, cw laser beam of ~280 nm. Despite an initial kinetic energy of the incoming ions of several eV at the trap's entrance, temporal widths of the extracted ion bunch corresponding to an ion-beam temperature of around 6 K are obtained within a cooling time of 200 ms. Moreover, sympathetic cooling of co-trapped K^{+} and O_2^{+} ions was demonstrated. As a first application, a laser-cooled ion bunch is transferred into a multi-reflection time-of-flight mass spectrometer. This improved the mass resolving power by a factor of 4.5 compared to conventional buffer-gas cooling.
This contribution will present the experimental results of our laser-cooling studies as well as a comparison to our 3D simulations of the cooling process which paved the way for further improvements of the technique. An outlook to future experiments with laser- and sympathetically cooled ions at radioactive ion beam facilities will be given.

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Status: SUBMITTED

Submitted by **MAIER, Franziska Maria** on **Friday 29 April 2022**

Abstract ID : **28**

High-precision photodetachment spectroscopy in an MR-ToF device

Content

The electron affinity (EA) reflects the released energy when an electron is attached to a neutral atom. An experimental determination of this quantity can serve as an important benchmark for atomic models describing electron-correlation effects [1]. A comprehensive understanding of these effects is also critical for the accurate calculation of the specific mass shift, which is required to extract nuclear charge radii from measurable total isotope shifts. By measuring small changes in the EA between different isotopes of the same chemical element, the isotope shifts of the EA, atomic models can be further constrained. However, isotope shifts in the EA have been experimentally determined only for very few stable nuclides so far, and only with modest precision. As an example, the isotope shift between the two stable chlorine (Cl) isotopes is more precisely predicted in theory [2] than experimentally measured [3].

Exploiting the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) low-energy setup [4] we have initiated a high-precision measurement of the isotope shift in the electron affinity between stable Cl isotopes as well as the long-lived ^{36}Cl isotope. This can be achieved by photodetachment threshold spectroscopy of negative Cl ions. By trapping ion bunches between the two electrostatic mirrors of MIRACLS' multi-reflection time-of-flight (MR-ToF) device, the same ion bunch is probed by the spectroscopic laser repeatedly compared to a single passage in traditional measurement schemes. As a result, the photodetachment efficiency can be significantly increased. Thus, instead of conventionally used pulsed high-power lasers with a large linewidth, narrow-bandwidth continuous-wave (cw) lasers can be employed. Consequently, the measurement precision will be improved.

By confining the Cl^{-} ions for a few 10,000s of revolutions in the MR-ToF device, neutralised atoms have been experimentally detected following the laser photodetachment. For wavelengths with 3 nm above threshold, a cw laser power as low as 0.8 mW has been demonstrated to be sufficient to observe the process of photodetachment. Thus, our novel measurement scheme paves the way for precision measurements of isotope shifts in the electron affinity between stable and ultimately radioactive Cl isotopes.

The novel technique will be introduced and the first experimental results will be presented.

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Status: SUBMITTED

Submitted by **MAIER, Franziska Maria** on **Friday 29 April 2022**

Abstract ID : **29**

New limits on Lorentz violation from a single trapped ytterbium ion

Content

In an attempt to unify all fundamental forces at the Planck scale, it is suggested that spontaneous breaking of Lorentz symmetry might occur. Such a Lorentz violation could lead to energy shifts of atomic states with non-spherical electron orbitals. With high-precision spectroscopy of such states in a Michelson-Morley type experiment, using Earth's orbit itself to probe different directions in the universe, we search for Lorentz violation. We directly compare the nearly orthogonally oriented substates of the highly sensitive $^2F_{7/2}$ Zeeman manifold with rf Ramsey spectroscopy and investigate the isotropy of space-time within a single ion. With a robust composite pulse sequence, we suppress the influence of ambient noise and achieve coherence times of more than 1s. As a result, we reach the highest sensitivity to Lorentz violation using precision spectroscopy to date and set new constraints on the symmetry breaking coefficients at the 10^{-21} level. These results represent the most stringent test of this type of Lorentz violation in the combined electron-photon sector. The method is readily applicable to ion Coulomb crystals for improved tests of Lorentz symmetry in the search for new physics.

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Status: SUBMITTED

Submitted by **DREISSEN, Laura** on **Friday 29 April 2022**

Abstract ID : **30**

Simultaneous storage of ions and electrons in the HITRAP cooling trap

Content

Simultaneous storage of ions and electrons in the HITRAP cooling trap

The HITRAP decelerator facility at the GSI Helmholtzzentrum für Schwerionenforschung in Germany aims to decelerate and cool heavy, highly-charged ions (HCI) like U^{92+} [1]. After creation of the high charge states at relativistic energies, HITRAP decelerates these ions via consecutive arrangement of a linear deceleration stage and a cylindrical Penning trap. Within this trap, the ions can be cooled to low temperatures before they are ejected and transported to various precision experiments. The used cooling mechanism in the seven-electrode cooling trap is sympathetic cooling with a cold electron plasma in a nested trap configuration.
We present the current status of the cooling trap and the ongoing progress to demonstrate electron cooling of extended amounts of heavy HCI for the first time. After optimization of the local pulsed electron source we manage to produce up to $2x10^9$ electrons per pulse. These pulses are transported in a guiding magnetic field to the 40 cm long trap, which is situated in a cold bore of a superconducting magnet with a field strength of up to 6 T. By using the retarding field method when ejecting electrons onto a microchannel plate (MCP), it is possible to measure the energy loss due to synchrotron radiation and the space charge of the trapped electron cloud.
Besides the local electron source, HITRAP is also equipped with a small EBIT ion source for commissioning of the cooling trap. This EBIT with permanent magnets can generate different ion species with medium or high charge states (e.g. Ar^{16+}), which can be transported through a low energy beamline towards the cooling trap [2]. We achieved simultaneous storage of EBIT ions and electrons from the local source. In these experiments it has been found that the ions influence the co-trapped electrons, but so far no energy loss of the ions could be observed.
The next step is the enhancement of the ion-electron interaction and demonstration of electron cooling. This can, for example, be done by optimizing the injection settings or varying the ion and electron number. In addition, application of non-destructive detection methods can help to further analyze the interaction.
This work is supported by BMBF under contract number 05P21RDFA1.

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Submitted by **HORST, Max** on **Friday 29 April 2022**

Abstract ID : **32**

Precision determination of the ground-state hyperfine splitting of trapped 113Cd+ and 171Yb+ ions

Content

A microwave frequency standard based on laser-cooled $^{113}\mathrm{Cd}^{+}$ ions has been developed at Tsinghua University for twelve years. Recently, the ground-state hyperfine splitting frequency of $^{113}\mathrm{Cd}^{+}$ was determined to be 15199862855.02799(27) Hz with a fractional frequency uncertainty of 1.8×10^{-14}. The ions were trapped and laser-cooled in a linear quadrupole Paul trap. The fractional frequency stability was measured to be $4.2 \times 10^{-13}/\sqrt{\tau}$, obtained from Ramsey fringes of high signal-to-noise ratios and taken over a measurement time of nearly 5 h, which is close to the short-term stability limit estimated from the Dick effect. Our result is consistent with previously reported values, but the measurement precision is four times better than the best result obtained to date.

Moreover, a microwave frequency standard based on laser-cooled $^{171}\mathrm{Yb}^{+}$ ions has also been developed in our laboratory since 2021. More than 10^{5} $^{171}\mathrm{Yb}^{+}$ ions were stably trapped for over 40 hours. The short-term instability of our system was measured to be $8.5 \times 10^{-13}/\sqrt{\tau}$.The ground-state hyperfine splitting frequency of $^{171}\mathrm{Yb}^{+}$ was determined to be 12642812118.4674(8) Hz with a fractional frequency uncertainty of 6.33×10^{-14}. Our work is in a continuous line with that of other scholars, while the short-term instability is promoted into a new record level.

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Status: SUBMITTED

Submitted by **Dr MIAO, Shengnan** on **Friday 29 April 2022**

Abstract ID : **33**

Alkali-earth Confined for Optical and Radiofrequency spectroscopy for Nuclear moments (ACORN)

Content

Nuclear moments have proved to be excellent probes for nuclear configurations and thus act as excellent benchmarks for nuclear theory. The magnetic octupole moment, which has for now only been measured for 19 stable isotopes, is very promising for the study of magnetization currents and the distribution of nucleons. We present the construction of the ACORN (Alkali-earth ions Confined for Optical and Radiofrequency spectroscopy for Nuclear moments) experiment, a new Paul trap experiment for the measurement of the nuclear magnetic octupole moment of alkali-earth ions. We discuss the trap and photocollection design, and their challenges in our aim to perform the first magnetic octupole measurements of stable and radioisotopes. We also discuss the choice of the first element the ACORN experiment will be performed on, and its corresponding laser system.

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Status: SUBMITTED

Submitted by **DORNE, Anais** on **Friday 29 April 2022**

Abstract ID : **34**

Towards testing Local Lorentz Invariance in a Coulomb crystal of Ytterbium ions

Content

We present our progress towards a test of local Lorentz invariance (LLI) in a Coulomb crystal of ions. We recently demonstrated a test of LLI with a single trapped $^{172}\mathrm{Yb}^{+}$ ion, using high-precision rf spectroscopy in the F-manifold with a robust spin-echoed Ramsey scheme. Due to the long-achieved coherence time and the high intrinsic susceptibility of this state, we reached an unprecedented sensitivity to this type of Lorentz violation, even with a single ion. The experimental method is readily applicable to N ions in a Coulomb crystal, enabling a test of LLI with a $\sqrt{N}$ times higher sensitivity. In preparation of this measurement, we characterize homogeneities of both the quantization magnetic field and the rf driving field in the trap using ions as precise quantum sensors. We find that the required homogeneities for the implemented rf pulse sequence, which is highly robust against spatial and temporal variations of the fields, are easily met for a crystal of 100 μm spatial extent ($N \sim 10$). In addition, we present our efforts to coherently excite multiple ions into the F-manifold via the highly forbidden octupole transition for state preparation and readout. In particular, the large AC-Stark shift of this transition poses high demands on the excitation beam, allowing for less than 2% intensity deviation over the full extent of the Coulomb crystal.

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Status: SUBMITTED

Submitted by **YEH, Chih-Han** on **Friday 29 April 2022**

Abstract ID : **35**

Microwave Frequency Standard and Precision Spectroscopy Based on Sympathetically Cooled Cadmium Ions

Content

1 Introduction
Sympathetic cooling technology has greatly advanced the development of precision metrology. We have demonstrated sympathetically-cooled large ion crystals and obtained the two-component ion crystal base on $^{113}\mathrm{Cd}^{+}$ sympathetically cooled by $^{40}\mathrm{Ca}^{+}$ with the temperature of 36 mK. We applied sympathetically cooled ion crystal to microwave frequency standard and precision spectroscopy, getting better performance than before.

2 Sympathetically Cooled Cadmium Ion Microwave Frequency Standards
Compared with directly laser cooling ion microwave frequency standards, sympathetic cooled ion clock has less dead time in loop, longer free evolution time and lower temperature of ions, suppressing the Dick effect and second-order Doppler shift and improving the stability and accuracy of the frequency standard. This work report a microwave frequency standard based on cadmium ions. The close-loop clock get a short-term stability of $3.48 \times 10^{-13}/\sqrt{\tau}$ over 5 hours, close to the level of that of the laser-cooled $^{199}\mathrm{Hg}^{+}$ clock, although the clock transition frequency of $^{113}\mathrm{Cd}^{+}$ is about one third of that of $^{199}\mathrm{Hg}^{+}$. The ultimate short-term stability we measured is $1.36 \times 10^{-13}/\sqrt{\tau}$ with 50 second free evolution time. The total uncertainty of the sympathetic cooling clock is 1.5×10^{-14}, better than that of laser cooled cadmium clock.

3 Isotope Shifts Measurement Based on Sympathetic Cooling
Compared with directly laser cooling, the isotope shifts of 214.5-nm transition in Cd^{+} can be measured with higher accuracy using sympathetic cooling technique. Based on the new IS, a systematic King-plot analysis is performed to determine the atomic IS factors. The accuracy of the determined atomic IS factors are improved nearly four times compared with previous results. Further, the state-of-the-art CI+MBPT calculations are performed to cross-check the accuracy and reliability of the extracted atomic IS factors. New $\delta\langle r^2\rangle$ and R_{ch} of $^{100-130}$Cd are then extracted using the atomic IS factors given in this work. In the neutron-rich region, the accuracy of R_{ch} improved by nearly five times. The R_{ch} values reported in this work reveal hidden discrepancies with previous density functional predictions and set stringent constraints and pose challenges to current nuclear theories, in which newly-developed density functional calculations, HFB-24 and Fy(Δr), fail to reproduce the present results perfectly. In addition, accurate R_{ch} may help future investigations of Cd shell closure with neutron number.

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Submitted by **QIN, Haoran** on **Friday 29 April 2022**

Abstract ID : **36**

Search for CP violation with Trapped and Polarized ions: First experiments with MORA setup at JYFL, Finland

Content

The MORA project focuses on ion manipulation in traps and laser orientation methods for the searches of New Physics (NP) in nuclear beta decay, looking for possible hints to explain the matter-antimatter asymmetry observed in the Universe. The JYFL Accelerator Laboratory and more specifically the IGISOL facility, provides an ideal environment for the initial phase of the MORA experiment. The precise measurement of the so-called triple D correlation is sensitive to Time reversal violation, and via the CPT theorem, to CP violation. The D correlation parameter is particularly sensitive to the existence of Leptoquarks, which are hypothetical gauge bosons appearing in the first theories of baryogenesis. They are now actively searched for at the LHC, the measurements at which provide competitive and complementary constraints. MORA will use an innovative in-trap laser polarization technique for the precision measurement of the D correlation in the beta decay of ^{23}Mg.

In this regard, the first test experiment with a ^{23}Mg beam has been carried out in the IGISOL facility in Feb, 22. First, ^{23}Na ions from the RF cooler buncher were slowed down to 100 eV and could be nicely optimized for the trapping with an efficiency ranging from 5 to 50% during 500 ms. During the beam time, copious amount of ^{23}Mg could be produced;10^5 ions per μA of primary proton beam. A 90 mW laser beam which was circularly polarized was injected and aligned within the trap. Despite these achievements, a large contamination of ^{23}Na and a high RF noise on the recoil ion detectors hindered the recording of β-recoil coincidences. To tackle these issues, a new RF generator and amplifier have been recently employed which suppressed the related noise on the Detectors. New target heads and ion guides are being prepared to get rid of the sodium contamination.
We will resume the experimental campaign in the end of May, 22. With an improved beam purity and acceptable background, we should be able to assess the performances of the innovative in-trap laser polarization technique. Along with an overall description of the project, I will be discussing the recent progresses of the MORA experiment.

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Status: SUBMITTED

Submitted by **GOYAL, Nishu** on **Friday 29 April 2022**

Abstract ID : **37**

Characterization of materials from additive manufacturing for precision experiments

Content

Additive manufacturing revolutionizes production of complex parts. It compliments conventional machining and is especially useful for fast prototyping. More concepts are getting established, the number of available materials is increasing, and the quality of produced parts improves thereby broadening the applicability of 3D-printing.
Precision physics including charged particle trapping is a highly specialized field relying on precise and complex machining and requiring specific conditions like ultra high vacuum (UHV) and cryogenic temperatures. Construction of experimental apparatuses can benefit from the possibilities opened up by additive manufacturing, however properties of the materials under these specific conditions can hardly be found on the datasheets.
The Stefan Meyer Institute has acquired a 3D printer based on so-called hot lithography, which is capable of producing precise high-performance polymer parts. A UHV and a cryogenic test chamber have been set up to investigate outgassing rates by residual gas analysis as well as thermal conduction and expansion at both cryogenic and room temperature. In addition to the materials of the aforementioned machine those of filament printers and printed ceramics as well as reference materials from conventional production are getting compared.
The test chambers, methodology, and first results from these characterizations and comparisons will be presented.

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Comments:

intended as poster contribution

Status: SUBMITTED

Submitted by **SIMON, Martin** on **Friday 29 April 2022**

Abstract ID : **38**

Precision experiments of nuclear and astrophysics relevance at storage rings

Content

Storage rings are powerful tools for precision experiments with stored highly-charged stable and radioactive ions in the realm of nuclear structure and astrophysics. The storage rings at GSI Helmholtz Center in Darmstadt, Germany (GSI), namely, the heavy-ion storage ring - Experimental Storage Ring (ESR), and the low energy storage ring - CRYRING provide unique possibilities to enable the most efficient use of rare ion species. Beam manipulation techniques like bunching, accumulation, and deceleration aids to store sufficient intensity of ions of interest in the relevant energy regime, thanks to the ultra-high vacuum conditions, 10^{-11}-10^{-12} mbar, and efficient beam cooling techniques. With enormously rich physics cases, the focus of the talk will be on the most recent highlight results achieved within the FAIR-Phase 0 research program at the ESR and the CRYRING.

Firstly, the first-ever direct measurement of the bound-state beta decay of fully-ionized $^{205}Tl^{81+}$ ions (with no electron) will be reported. After almost three decades of its proposal, the measurement was successfully performed in the ESR, employing the entire accelerator chain at GSI. At present, the ESR is the only instrument that enables high precision studies of such exotic decay modes which reflect atom-nucleus interactions and are relevant for atomic physics and nuclear structure as well as for the nucleosynthesis in stellar objects.

Secondly, the current status of a new detector system, CRYRING Array for Reaction Measurements (CARME), will be given. CARME was recently installed and commissioned in the CRYRING. This detector system will be used to measure nuclear reactions of interest occurring in novae explosions that control the production of elements ejected into the cosmos and isotopic ratios measured in pre-solar grains found in meteorites.

In the end, the recently performed experiments will be put together in the context of the present research programs at GSI/FAIR, and in a broader, worldwide context, an overview of the new upcoming storage ring projects will be given.

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Submitted by **SIDHU, Ragandeep Singh** on **Friday 29 April 2022**

Abstract ID : **39**

Development of YBCO-based LC circuits for the image current detection of the cyclotron mode of a single antiproton

Content

Development of YBCO-based LC circuits for the image current detection of the cyclotron mode of a single antiproton

Image current detectors are required to observe the trapped particles in the Penning trap, and determine their frequencies with high precision (1).
Currently, the image current detection system was built with superconducting toroidal coils and cryogenic amplifiers. And we obtained a good Q factor which is a highly sensitive to detect a single trapped particle, such as 60 000 and 15 000 for the Axial and Cyclotron detectors, respectively. However, since this is a handmade coil, wire thermalization and quality of the soldering joint are dependent on the experience and training of the person building the coil. As a result, the detector preparation can be time consuming or the Q value can drop dramatically with the number of cooling cycles and becomes unstable over time.
As a consequence, we are moving towards a new production method cyclotron detection system for the transportable trap BASE-STEP. This detection system, is composed of YBCO planar coils made of YBCO film deposited sapphire substrate and connected to cryogenic amplifiers. YBCO coils have been used for LC circuit in (2), (3), and have shown to reach a Q factor of 90 000 at 30_90 MHz. We anticipate that YBCO will have a higher Q-value and be more reliable. I will present the current status of these developments.

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Status: SUBMITTED

Submitted by **ABBASS, Fatma** on **Friday 29 April 2022**

Abstract ID : **40**

Status and Operation of CURIE: Cryogenic Radioactive Isotope Extreme High Vacuum Trap at University of Maryland

Content

CURIE was designed to generate, transport, and trap a small cohort of highly charged radioactive isotopes which decay through electron capture for non-destructive longitudinal studies. The trap will be commissioned to study decay rates of various ^{7}Be charge states, initially prepared as neutral atoms via laser ablation. Several unique features of the system include a pulsed electron beam ion trap (EBIT) adapted for size and component replacement in the event of contamination, modified Einzel lenses (or Sikler lenses) which allow for simultaneous beam focusing and steering, and a cryovalve which isolates the cryogenic XHV environment to extend ion storage times. This poster will present the most recent status of CURIE trap construction and development. We will also present data from the optimization and room-temperature commissioning of the full trap system, including data from each unique component and cryogenic electronics.

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Comments:

PI: Tim Koeth. This work is related to another abstract submitted by Scott Moroch: "Electron Capture Decay Rate" and could potentially be shown in tandem as one presentation.

Status: SUBMITTED

Submitted by **BUSSIO, Ariana** on **Friday 29 April 2022**

Abstract ID : **41**

Recent developments on quantum logic inspired techniques for high-precision Penning trap experiments

Content

As part of the BASE collaboration [1], our aim is to contribute to high-precision proton/antiproton magnetic moment comparisons to test the fundamental CPT invariance [2]. Certain difficulties of current experiments lie in the time-consuming preparation of sub -0.1 K particles with high spin state detection fidelities [3]. Laser based techniques have been proposed to overcome these difficulties [4]. At BASE Hannover sympathetic laser cooling schemes are developed to cool (anti-)protons to their ground state of motion, by coupling them to a logic ion in a double-well potential. Additionally, this process can be used for spin state readout by using quantum logic inspired techniques.

In this contribution, we report on recent results on resolved sideband spectroscopy of a single $^{9}Be^{+}$ ion in our 5 Tesla cryogenic Penning trap, by using a two-photon stimulated Raman transition. With this technique, we were able to perform sideband cooling and thus reducing the average phonon number in the axial mode of a single $^{9}Be^{+}$ ion to values close to the ground state. Along with the demonstrated adiabatic transport of a single ion between different zones of our Penning trap stack, we completed two essential requirements for the implementation of quantum-logic inspired techniques in (anti-)proton g-factor measurements.

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Comments:

Contribution type: talk

Status: SUBMITTED

Submitted by **COENDERS, Julia-Aileen** on **Saturday 30 April 2022**

Abstract ID : **42**

Limits on the interaction of antiprotons with axion-like dark matter

Content

The observation of dark matter and the matter-antimatter asymmetry in our universe comprise a challenge to the Standard Model of particle physics, which does not provide satisfying explanations for these observations. Furthermore, the Standard Model tests for new physics by our laboratory experiments have not provided no clear explanations for these observations. We need to increase the sensitivity of our search methods and find new ways to uncover the nature of these phenomena. Noteworthy, there are only a few tests with antiparticles that verify CPT invariance as fundamental symmetry of the Standard Model at the low-energy frontier.

The BASE collaboration has conducted high-precision measurements on single trapped antiprotons and protons and recently reported improved limits on CPT violation in the baryon sector. To this end, we compared the antiproton and proton charge-to-mass ratios with 16 parts-per-trillion precision [1], and their magnetic moments with 3000-fold higher sensitivity than in competing efforts [2, 3]. We have used the antiproton magnetic moment data to test for a potential interaction between axion-like dark matter and antiprotons for the first time [4]. We derived experimental limits on a potential antiproton-axion coupling for axion masses below 0.04 feV and astrophysical limits for axion masses up to 30 MeV. Our analysis tests for an asymmetric coupling of protons and antiprotons to the axion field that could potentially arise from a non-local fundamental theory. To our knowledge, this work constitutes the first direct dark-matter search using antiparticles.

In my presentation, I will motivate and present the results of this search and discuss perspectives for improvements and alternative search concepts.

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Status: SUBMITTED

Submitted by **SMORRA, Christian** on **Saturday 30 April 2022**

Abstract ID : **43**

Fission isomer half-lives measurements at the FRS Ion Catcher

Content

Recently an experiment for measuring the fission isomer half-lives and excitation energies has been performed at GSI. This experiment uses for the first time projectile fragmentation to produce fission isomers. The projectile fragmentation at relativistic energies offers rapid and universal production, hence access to isomers with short half-lives (down to 50 ns), and most importantly, high-purity beams of exotic nuclei and event-by-event identification.
A wide half-life range (50 ns to 50 ms) was covered using two different detection methods. Shortest half-lives (ns to μs) have been accessed by implanting fragmentation products in a fast plastic scintillator, long half-lives ($\sim$ms) have been measured by mass spectrometry, i.e. the FRS Ion Catcher. Here, the isotopes are thermalized in the Cryogenic Stopping Cell (CSC) before being extracted to the Multiple-Reflection Time-of-Flight Mass Spectrometer (MR-TOF-MS) in which a special detector (α-ToF detector) [1] was installed that allows for alpha spectroscopy and time-of-flight mass spectrometry at the same time. Fission isomers can be unambiguously identified by measuring their decay energy with the detector; using this information allows to suppress the stable background in the mass spectrum by many orders of magnitude. For fission isomers ^{235f}U is here of special interest due to its isomeric half-life of $11(3)$ ms that has recently been re-analyzed and does not agree with the original analysis [2] and needs independent confirmation. To measure ^{235f}U and other fission isomers with ms half-live range at the FRS Ion Catcher Facility [3], a special electrode construction in the CSC was installed to reduce the extraction time and moreover, in this configuration the system handled higher beam intensities. The improvements have been first tested by ground state mass measurements of light actinides.

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Comments:

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Status: SUBMITTED

Submitted by **TORTORELLI, Nazarena** on **Sunday 01 May 2022**

Abstract ID : **44**

Commissioning of the HITRAP cooling trap with offline ions

Content

The HITRAP facility at the GSI Helmholtzzentrum für Schwerionenforschung (GSI) in Germany is designed to decelerate and cool a bunch of about 10^5 heavy, highly charged ions (HCI). Produced by stripping at high energy, the HCI are decelerated eventually in a linear decelerator down to 6 keV/u and captured within a cylindrical Penning trap. In that trap the HCI can be cooled using electron cooling before being transferred to subsequent experiments [1]. If ions and electrons are stored simultaneously in a so-called nested trap, energy transfer can take place. The electrons cool the transferred energy off by synchrotron radiation in the strong magnetic field of up to 6 T [2].
We present the current status of the HITRAP cooling trap and the next steps of commissioning this setup with offline ions as well as the results of the recent online beam time. Recently, a new electrode layout has been installed to improve reliability of the trap operation. Our tests show that the new seven-electrode design is more stable and less error prone than the old 21 electrode design.
We were able to investigate the storage of argon ions in various charge states, delivered by a small EBIT based on permanent magnets with an energy of 4 keV/q. With the approximately 40 cm long trap it was possible to capture more than 10^5 highly charged ions. Dependencies of the charge state and kinetic energy were observed as they are both influence the lifetime of the stored ions. By applying the magnetron frequency of stored ions to a quartered ring electrode we were also able to excite the ion cloud inside the trap. Moreover, in order to achieve electron cooling it was possible for the first time to store ions and electrons simultaneously in this setup, although no cooling effect was observed so far.
The next steps will be the improvement of the trap settings for both electrons and ions and the proof of electron cooling. This includes the cooling of argon ions from the local ion source and commissioning the trap setup for the first time in a GSI beam time with bare ^{58}Ni. One of the main challenges during this beam time is the separation of high energy and low energy beam with a new detector, as the linear decelerator stage of the HITRAP facility will only decelerate parts of the incoming 4 MeV/u beam to the desired energy of 6 keV/u [3].
This work is supported by BMBF under contract number 05P21RDFA1.

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Status: SUBMITTED

Submitted by **RAUSCH, Simon** on **Monday 02 May 2022**

Abstract ID : **45**

Towards mass measurements on actinides using PI-ICR at TRIGA-Trap

Content

The TRIGA-Trap setup [1,2] is a double Penning-trap mass spectrometer at the research reactor TRIGA Mainz. Recently, a new cylindrical measurement trap was installed, which enabled the implementation of the phase-imaging ion cyclotron resonance (PI-ICR) technique [3], originally developed at SHIPTRAP.
Instead of scanning the sideband-frequency and recording time-of-flight, in PI-ICR the total phase of a trapped ion is measured by projecting the ion motion onto a delay-line MCP detector. The new technique features higher mass resolving power, it allows to check for the presence of contaminant ion species, useful in tuning the harmonicity of the trapping potential and in aligning the trap symmetry axis with respect to the magnetic field by visualizing the radial ion motion. Next we will apply PI-ICR to perform high-precision mass measurements on long-lived transuranium isotopes. The current status including results on several long-lived actinide isotopes will be presented. Our results find application in nuclear structure studies and provide reliable atomic mass anchor points in the transuranium region.

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Status: SUBMITTED

Submitted by **NAGY, Szilard** on **Monday 02 May 2022**

Abstract ID : **46**

HILITE - Compact Penning trap for high-intensity-laser experiments

Content

The interaction of particles with laser radiation at relativistic intensities beyond 10^{19}W/cm^2 is a well-elaborated topic in theory. Nevertheless, there still is a lack in precise measurements of the ionisation rate to test the theory. Suitable candidates for laser-particle- interaction measurements are highly-charged ions, especially hydrogen-like ions such as O^7 or Ne^9, as the electric field between the nucleus and the 1s-electron is here comparable to the electric field of the laser pulses.
In order to prepare well-defined ion targets, we have devised the HILITE (High-Intensity Laser Ion-Trap Experiment) Penning trap, where we can store some thousands of ions arranged in a compact single-species ion cloud. The ion cloud is then well-defined with respect to ion density and shape which will allow for precise calculation of the ionisation rate of the single ion. For ion cloud formation we use common procedures, such as resistive cooling, SWIFT, FT-ICR, and Rotating wall. As the ions will be stored for several tens of seconds before the laser-ion interaction takes place, they are completely relaxed to their ground state and hence a well-defined quantum state. The whole setup is designed in a transportable fashion to be connected to any available laser facility or laser system and is equipped with an Electron-beam ion trap (EBIT) as source for highly charged ions.
The ion trap has seven electrodes and is able to cancel out the lower anharmonicity parameters c_4 and c_6 to provide a harmonic potential. The outer electrodes have a free aperture of 4 mm and a separation of 23.4 mm to allow tight focussing of the laser beam.
We will present the performance of the ion trap measured with stored highly charged ions and will give an outlook for the planned laser-ion experiments at the Jena high-power laser system JETI200.

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Status: SUBMITTED

Submitted by **RINGLEB, Stefan** on **Monday 02 May 2022**

Abstract ID : **47**

Towards an improved proton g-factor measurement

Content

The observed matter-antimatter asymmetry in the universe has yet to be understood. The experiments of the BASE Collaboration are dedicated to rigorous tests of the fundamental CPT symmetry in order to tackle this mystery. For this purpose, BASE compares the properties of the proton and the antiproton with highest accuracy, specifically the magnetic moments/g-factors [1,2] and the charge-to-mass ratios [3]. The most accurate proton g-factor measurement was carried out by our group in 2017 with an uncertainty of 300 ppt [1]. This number is limited by statistics at a level of about 268 ppt. However, the systematic uncertainty also contributes with 123 ppt to the overall uncertainty. Both limitations must be considerably reduced for the next-generation measurement which aims at an overall uncertainty level of about 30 ppt. A major upgrade was started recently, among others introducing sympathetic cooling of the proton with laser-cooled beryllium ions [4]. First, this will reduce the preparation time for cold particles and improve the spin-flip detection fidelity, thereby increasing the statistics that can be acquired in a given measurement time. Second, the new cooling scheme will reduce the relativistic contribution to the systematic uncertainty due to the finite cyclotron motion. Further important advances will deal with the reduction of the linewidth of the g-factor resonance by improving on the magnetic field homogeneity, a careful optimization of the Larmor drive amplitude, and improving the magnetic field stability as well as the axial motional frequency stability of the confined proton.

This contribution will review the limitations of the last proton g-factor measurement and discuss the necessary steps and upgrades to reach an improved uncertainty level.

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Status: SUBMITTED

Submitted by **YILDIZ, Hüseyin** on **Monday 02 May 2022**

Abstract ID : **48**

Precision measurements of superallowed mirror transitions with St. Benedict

Content

Precise measurements of nuclear beta decays provide a unique insight into the Standard Model due to their connection to electroweak interactions. These decays can provide constraints on the unitarity or non-unitarity of the Cabbibo-Kobayashi-Maskawa (CKM) quark mixing matrix, where non-unitarity would signal potential physics Beyond the Standard Model. At the Nuclear Science Laboratory (NSL) at the University of Notre Dame, the Superallowed Transition Beta-Neutrino Decay Ion Coincidence Trap (St. Benedict) is being constructed to determine the beta-neutrino angular correlation parameter of various superallowed mixed mirror beta decays. We plan on measuring this correction parameter for the beta decays of nuclei ranging from ^{11}C to ^{41}Sc using radioactive ion beams from the NSL's TwinSol separator, which will result in significantly improved precision of the V$_{ud}$ element of the CKM matrix from superallowed mirror transitions. The status of the development of St. Benedict will be presented.

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Status: SUBMITTED

Submitted by **PORTER, Sam** on **Monday 02 May 2022**

Abstract ID : **49**

Latest results of ASACUSA's Cusp experiment

Content

The ASACUSA collaboration aims to perform a ppm measurement of the ground-state hyperfine structure of antihydrogen in a field free region, using a spin-polarized antihydrogen beam [1]. Antihydrogen production is done by merging positrons and antiprotons in the unique double Cusp trap, which, due to its strong magnetic field gradient, polarizes the antihydrogen beam by defocusing antiatoms in high-field seeking states and focusing the ones in low-field seeking states.
For the measurement a sufficient amount of antihydrogen in the ground state is necessary [2]. For this, it is important to have reproducible control over the density and temperature of the positron plasma [3]. Two improvements were made in the experiment to achieve this: Firstly, a new positron system was installed to accumulate a high number of positrons. Secondly, we've commissioned a new mixing trap and cold bore where very low plasma and trap temperatures are obtained. While the majority of antiatoms are created in Rydberg states, these may be collisionally deexcited by a sufficiently cold and dense positron plasma. To investigate the energy as well as the principle quantum number of the antihydrogen, the new trap contains two field ionizers in addition to the external field ionizer, which was used previously to measure the quantum state distribution [4]. With the two additional in-trap field ionizers we can perform the measurement at multiple points along the antiatom trajectory and additionally, we can measure the time of flight of the antihydrogen atoms.
This talk will cover the ASACUSA experimental setup in general, the new trap design, plasma cooling and manipulation, as well as the latest results achieved during the ongoing beamtime at CERN.

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Comments:

On behalf of the ASACUSA collaboration

Status: SUBMITTED

Submitted by **LANZ, Andreas** on **Monday 02 May 2022**

Abstract ID : **50**

Electronic bridge processes with the 229Th nuclear clock transition

Content

Incredibly precise nuclear clocks may soon outperform and replace the present atomic clocks that define the global time standard. The only known nuclear transition in the range of vacuum-ultraviolet (VUV) lasers occurs in 229Thorium and promises such a novel and unprecedently precise nuclear clock. The nuclear excited level is a metastable state with energy of 8.19(12) eV, allowing driving with VUV lasers. As a high-precision oscillator whose frequency is predominantly determined by the strong interaction, the 229Thorium transition also offers an increased precision for the determination of fundamental constant variations.

The talk will follow the newest theoretical developments on employing electronic bridge processes for the driving or quenching of the nuclear clock transition. The electronic bridge is one of the mechanism coupling the nuclear isomeric transition to the electronic shell. First, we will discuss the prospects of electronic bridge in highly charged 229Th ions. This process can be used to populate the Th isomer in highly charged ions produced in an electron beam ion trap using a tunable UV laser. With the absorbed laser photon energy directly related to the isomer energy, this mechanism promises the determination of the latter with an improved accuracy of 10−4 eV and is feasible under presently available experimental parameters [1]. Second, an alternative electronic bridge process in crystals will be introduced. In VUV-transparent crystals this process is facilitated by defects, i.e., states appearing in the band gap close to the isomeric energy and caused by the Th doping itself. Excitation rates far above direct photoexcitation can be achieved with current technology [2]. The impact of using electronic bridge to quench the isomeric state for the accuracy of a future nuclear clock is discussed.

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Submitted by **PALFFY-BUß, Adriana** on **Wednesday 04 May 2022**

Abstract ID : **51**

Developments towards offline eEDM searches using radium-224-monofliride produced in a miniature stopping cell

Content

Radioactive molecules (RaM) offer unique opportunities to study new aspects of the standard model such as the electric dipole moment (EDM) of the electron. In certain molecules symmetry violations with respect to parity and time-reversal are enhanced by several orders of magnitude compared to atomic systems due to the resulting strong internal electric fields [Nature Phys 14 (2018) 890]. A promising candidate is Radium monofluoride (RaF). Recent studies investigated suitable transitions for laser cooling and isotope shifts of RaF [Nature 581 (2020) 396, Phys Rev Lett 127 (2021) 033001], which was produced by reacting tetrafluoromethane (CF4) gas with Ra atoms inside an activated UCx production target; heated to 2000K, at the ISOLDE radioactive beam (RIB) facility. Under the extreme conditions at the production target (high temperature, strong radiation fields, presence of nuclides of all elements) the final production of radioactive molecules is gathered through many possible production routes. Further, impurities in the production target, either present from target production or produced in-situ by nuclear reactions, may change the yields of radioactive molecules and are hard to control.

Here, we propose to create radioactive molecules in the ultrapure and cold environment of a helium gas filled cryogenic stopping cell, rather than in a hot RIB production target. To do so, we plan to controllably introduce traces amounts of the molecular partner species into the ultrapure helium gas of the stopping cell. This approach decouples the production of the radioactive ion from the formation of the radioactive molecule and mimics the methodology commonly used in chemical reaction cells in analytical mass spectrometry, but is tailored for the application and coupling to radioactive beam facilities.

In this contribution we will present the developments and first results of a prototype (room temperature) miniature stopping cell at the University of Edinburgh. The new device is being commissioned using stable barium ions, a chemical homologe to radium, before being equipped with an open Thorium-229 recoil source for offline production of Radium-224 monofluoride. Being able to produce reliable beams of RaF offline will be a key towards future electron-EDM experiment using RaF. In the near future, the new miniature cell will be exploited within the MIT-TRIUMF-Edinburgh collaboration.

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Submitted by **REITER, Moritz Pascal** on **Thursday 05 May 2022**

Abstract ID : **52**

BASE-STEP and the Permanent Magnet Trap

Content

The ERC Project STE$\bar{P}$, "Symmetry Tests in Experiments with Portable Antiprotons", targets the development of transportable antiproton traps to enhance the sensitivity of CPT invariance tests with antiprotons that are conducted in the BASE collaboration.
To enable antiproton measurements with improved precision, we are commissioning the transportable trap system BASE-STE$\bar{P}$ in the AD/ELENA facility, so that future measurements can be conducted outside of the Antiproton Decelerator hall at CERN to circumvent limitations by magnetic field fluctuations.
To achieve this, BASE-STE$\bar{P}$ uses a transportable superconducting magnet with 1 T field strength with a two-stage Penning trap system on a portable experiment frame.
In addition, we designed a permanent magnet set-up, consisting of two aubert-magnets with a field strength of $\sim$280mT in the homogeneous region at $\sim$4K. This set-up was conceived as an alternative to a superconducting magnet since the transportation of antiprotons does not require very high field strengths and would also be a much cheaper trap.
In this contribution, I will present the BASE-STE$\bar{P}$ project, its motivation and the work done until now. I will also take a closer look on the permanent magnet trap.

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Comments:

Would be a Poster

Status: SUBMITTED

Submitted by **POPPER, Daniel** on **Monday 09 May 2022**

Abstract ID : **53**

Particle Traps for Ion Beam Purification and Cooling for the PUMA Experiment

Content

Using low-energy antiprotons, the antiProton Unstable Matter Annihilation (PUMA) experiment [1] aims to probe the isospin composition in the density tail of radioactive nuclei. For this purpose, the isotopes of interested are brought together with an antiprotonic cloud, trapped in a Penning trap. By analyzing the residuals of subsequent annihilation reactions, the experiment will be able to investigate neutron skins of neutron-rich nuclei and to study both neutron and proton halo nuclei.

Before radioactive isotopes are studied, the experimental technique is first applied to stable nuclei. These include experiments investigating the proton-to-neutron ratio on the surface of e.g. 208Pb [2] or its evolution in the chain of stable tin isotopes. For the generation of the isotopes of interest, a versatile offline ion source is needed that must be able to generate isotopically pure and cooled ion bunches of about 10^5 particles. A multi-reflection time-of-flight mass spectrometer [3] and a Paul trap are therefore integrated downstream of the ion source region. They are used for mass separation, accumulation, and cooling of the ion beam before it is injected into the PUMA Penning trap loaded with antiprotons.

The poster gives an overview of the offline ion source beamline and presents first measurements investigating the properties of the ejected ion bunches.

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Status: SUBMITTED

Submitted by **SCHLAICH, Moritz** on **Monday 09 May 2022**

Abstract ID : **54**

Towards laser spectroscopy of stored hydrogen-like 208Bi82+ ions

Content

The measurement of the so-called specific difference between the hyperfine structures (hfs) in hydrogen-like $^{209}Bi^{82+}$ and lithium-like $^{209}Bi^{80+}$ is supposed to be the most significant QED test in the magnetic sector of strong-field QED. Our most recent measurement showed a large deviation (> 7σ) from the theoretical prediction, but a new determination of the nuclear magnetic moment in ^{209}Bi resolved this puzzle and brought the theoretical prediction in agreement with experiment. The specific difference is calculated and measured in order to remove the influence of the nuclear magnetic moment distribution onto the hyperfine structure splitting. Taking the difference of two electronic systems (H-like and Li-like) with the same nucleus is expected to cancel. To test this cancelation experimentally, it was proposed to extend these kind of hyperfine studies to the radioactive isotope of ^{208}Bi.

While writing this abstract, we work on the implementation of the experiment at the Experimental Storage Ring (ESR) at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt. About 10^5 $^{208}Bi^{82+}$ ions are expected to be produced in-flight by the accelerator facility and stored in the ESR at about 410 MeV/u ($\beta = 0.72$). We will then apply electron cooling to significantly reduce the initial velocity spread. Pulses of a Nd:YAG-pumped dye laser are superimposed with the ion bunch revolving in the ESR in a counter-propagating geometry. In this way we can operate the laser at 550 nm to excite the hyperfine transition in the ion frame, which has a predicted wavelength at about 222 nm. We will monitor the fluorescence emitted by the ions using UV photomultipiers and an XUV-detector and record their signal as function of the laser wavelength. The concept of the experiment and results from the beamtime will be reported.

This work is supported by BMBF under contract numbers 05P21RDFA1.

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Status: SUBMITTED

Submitted by **SANCHEZ, Rodolfo** on **Tuesday 10 May 2022**

Abstract ID : **55**

Electron Capture Decay Rate Perturbations in a Cryogenic Penning Ion Trap

Content

In 1948, Segrè suggested that the half-life of radioisotopes that decay by electron capture ($e^- + {}^7\mathrm{Be} \rightarrow {}^7\mathrm{Li} + \nu$) depends on the electron density at the nucleus and, therefore, should be alterable in the laboratory [1]. Many experiments have measured perturbations on the order of 1-2%, by implanting electron-capture isotopes in different chemical structures [2]. We describe a cryogenic (4 K) Penning ion trap at the University of Maryland that stores and measures the half-life of ${}^7\mathrm{Be}$ in different ionization states. While several proposals have been presented to perform such experiments in a storage ring, where large ensembles (10^8 ions) can be stored for ~5 mins, recent developments have demonstrated month-long ion storage times in cryogenic Penning traps [3], enabling a measurement to be done with a small (10^3 ions) ensemble. The system under development includes a room-temperature Electron Beam Ion Trap (EBIT), a low energy beam transport line, and a cylindrical, cryogenic Penning trap in a 3 T field. This poster will focus on the design of the apparatus and experiments. Of particular interest is the half-life of hydrogen-like ${}^7\mathrm{Be}$, which is expected to be ~106 days, twice that of neutral ${}^7\mathrm{Be}$. We are developing a method that takes advantage of the recoil energy of the ${}^7\mathrm{Li}$ upon the decay of ${}^7\mathrm{Be}^{3+}$. A discussion of the simulations and relevant calculations will be presented along with the principles upon which they are based.

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Submitted by **MOROCH, Scott** on **Tuesday 10 May 2022**

Abstract ID : **56**

Shedding Light on Nuclear Structure in Rare Isotopes through High-Precision-Mass Spectrometry at ISOLTRAP

Content

Nuclei located far away from the valley of stability can exhibit vastly different nuclear properties upon comparison to less exotic isotopes. Some observed effects, e.g. the appearance or quenching of magic numbers, mutually enhanced magicity in doubly magic nuclei, as well as shape coexistence within nuclei of similar excitation energies, can be probed through the evolution of the nuclear shell across many isotopes or isotones. The ISOLTRAP experiment [1] located at ISOLDE/CERN has significantly contributed to our understanding of such nuclear matter questions over the last thirty years. Using state-of-the-art mass-spectrometry tools such as the phase-imaging ion-cyclotron resonance [2] and multi-reflection time-of-flight techniques [3], ever more rare nuclei now become available for examination. In this contribution, some of the most recent experimental results on nuclear structure are presented, including indium isotopes in the 100Sn region [4], cadmium isotopes just below the N=50 and Z=82 shell closure [5], and chromium isotopes close to the N=40 island of inversion [6]. These results are further put into a larger context by comparison to modern phenomenological and ab initio shell model calculations

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Lukas Nies for the ISOLTRAP collaboration

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Status: SUBMITTED

Submitted by **NIES, Lukas** on **Tuesday 10 May 2022**

Abstract ID : **57**

Development of the double Penning trap mass spectrometer PIPERADE for the future DESIR/SPIRAL2 facility

Content

The GANIL (Grand Accélérateur National d'Ions Lourds) Accelerator Laboratory, France, is being extended with the SPIRAL2 facility which includes three experimental halls: NFS (Neutrons for Science), S3 (Super Separator Spectrometer) and DESIR (Decay, Excitation and Storage of Radioactive Ions) hall. The main aim of DESIR will be to study nuclear structure, astrophysics and weak interaction utilizing low-energy (30-60 keV) radioactive ion beams (RIBs) provided by S3 and the upgraded SPIRAL1 facility. S3 produces neutron-deficient nuclei via fusion-evaporation reactions and SPIRAL1 light nuclei via fragmentation. The DESIR hall is designed to house various experimental setups dedicated to β-decay spectroscopy, laser spectroscopy and trap-based experiments.

At the entrance of the DESIR hall a RFQ cooler-buncher called GPIB (General Purpose Ion Buncher) [1] will be able to provide to the various experimental setups of DESIR low-emittance and, if necessary, bunched ion beams. One of such setups benefitting from bunched ion beams will be the PIPERADE (PIèges de PEnning pour les RAdionucléides à DESIR) double Penning trap mass spectrometer [2]. At DESIR, PIPERADE will be used for beam purification (isobars, but also long-lived isomers), after which the purified ion sample can be directed to other measurement setups. PIPERADE will also be used for high-accuracy mass measurements. Both devices, GPIB and PIPERADE, are under commissioning at the LP2i Bordeaux laboratory.

PIPERADE consists of two cylindrical Penning traps: a purification trap (PT) for beam purification utilizing helium buffer gas and a measurement trap (MT), operated in high vacuum, for accumulating ions, high-resolution purification and/or for precision mass measurements. Using the main ion beam purification technique of PIPERADE, called the buffer gas cooling method [3], a mass resolving power of $M/\Delta M \approx 10^5$ has been achieved. Recently the time-of-flight ion-cyclotron-resonance technique (ToF-ICR) [4] has been successfully implemented at the PIPERADE Penning trap. Systematic studies of the ToF-ICR technique at PIPERADE are ongoing.

In this contribution, recent technical developments and achievements of the GPIB and PIPERADE Penning trap will be presented.

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[4] M. König *et al.*, *Int. J. Mass. Spectrom.* **31**, 95 (1995).

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Submitted by **HUKKANEN, Marjut** on **Tuesday 10 May 2022**

Abstract ID : **58**

Studies of atomic and molecular species produced by laser ablation of Th samples prepared by different methods

Content

Thorium became an element of interest for various studies of fundamental physics, partly due to thorium 229m [1], which is the lowest-lying known nuclear isomer [2]. On the other hand, macroscopic quantities of a chain of thorium isotopes are available, which can serve as a basis for the search for physics beyond the standard model, e.g., via King-plot analysis [3]. Finally, thorium-containing molecules are also becoming a topic of more interest recently [4]. Within the TACTICa project at Johannes Gutenberg-University Mainz on Trapping And Cooling of Thorium Ions in Calcium crystals [5], thorium ions provided by different sources are trapped in a Paul trap, sympathetically cooled in a Ca^+ ion crystal and studied via high-precision spectroscopy. So far, singly-charged thorium 232 ions were produced by laser-ablation from a metallic thorium sample. In the future, already available isotopes as well as isotopes produced in the alpha-decay of uranium precursors, including thorium-229m, will be studied [6,7]. Isotopes other than thorium 232 are not available in metallic form, necessitating ion-production from other samples.

We have started a systematic study of the laser-ablation production of atomic and molecular thorium ions. The source of thorium ions is based on a commercial ion gun [5] into which different samples of thorium isotopes, metallic as well as salt-based, can be inserted. The ablation behavior as a function of the laser wavelength (visible to deeper UV) and power, in the pressure range from 10^{-4} to 10^{-7} mbar of inert (for atomic ion formation) as well as reactive gas (for molecule formation) are being studied. The status of these studies will be discussed at the conference.

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Comments:

If it is possible, I would like to have a short talk about my work, because I believe we will get interesting results to present in the conference.

Status: SUBMITTED

Submitted by **STRICKER, Jonas** on **Tuesday 10 May 2022**

Abstract ID : **59**

Trapping and Cooling Thorium Ions with Calcium (TACTICa): Th ion spectroscopy

Content

The ^{229}Th became a nuclide of high interest [1] because it features the lowest-lying known isomeric state, the ^{229m}Th [2]. It is an interesting nuclide in the search for new physics [3,4]. The Trapping And Cooling of Thorium Ions in Calcium crystals (TACTICa) project aims at investigating ions of different thorium isotopes as well as the ^{229m}Th with respect to precise determination of the nuclear moments, hyperfine intervals, and isotope shifts that are key to using this system for fundamental-physics tests.

Th ions are trapped and cooled down using sympathetic cooling with a trapped Ca^+ ions [5], and will be identified by using the fluorescence calorimetry of an ion crystal technique to tag incoming intruders [6]. We plan for reading out Th ion spectroscopy using a variation of quantum logic spectroscopy, which allows for interrogating transitions where direct detection is impractical. For this, a pair of optical lattice beams generates a dipolar force [7], resulting in a motional excitation of common modes of vibration in the ion crystal which can be interrogated by the Ca^+. We aim for the E1 transition near 402 nm and the E2 near 392 nm transition in Th^+, respectively. Taking advantage of the Department of Chemistry's TRIGA Site and the wealth of radioactive isotopes and charge states available from novel sources [8], we plan to investigate nuclear deformations, hyperfine and isotope/isomer shifts. The status and advancements of these experiments will be discussed at the conference.

Refs:
[1] M.S. Safronova, D. Budker, D. DeMille, Derek F. Jackson Kimball, A. Derevianko, and C. W. Clark, Search for New Physics with Atoms and Molecules, Rev. Mod. Phys. 90, 025008 (2018).
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Status: SUBMITTED

Submitted by **TRIMECHE, Azer** on **Tuesday 10 May 2022**

Abstract ID : **60**

Precision mass measurements of neutron-rich refractory nuclei at JYFLTRAP

Content

The region around A $\approx$ 100 is known as a transitional region where rapid changes in deformation occur and some of the nuclei are predicted to exhibit triaxial shapes [1,2]. This region is also known for the presence of low-lying isomeric states. If the isomeric states are unresolved, this could cause a shift in the measured mass value or the measured mass value could be assigned to a wrong state. The changes in deformation can be studied for example via observing the trend exhibited by two-neutron separation energies. The rapid neutron capture process, in short the r-process [3], is one of the main processes responsible for the heavy-element abundances beyond iron. To simulate the r-process, precise mass values of the neutron-rich elements far from stability are needed.

At the IGISOL facility of the Accelerator Laboratory of the University of Jyväskylä (JYFL-ACCLAB), high-precision mass measurements on neutron-rich refractory nuclei were performed using the JYFLTRAP double Penning trap mass spectrometer [4]. The neutron-rich refractory nuclei were produced via proton induced fission on uranium, mass-separated and prepared with an RFQ cooler-buncher before injection into the JYLFTRAP Penning trap. Two different types of techniques for precision mass measurements are utilized at JYFLTRAP: Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique [5,6] and Time-of-Flight Ion-Cyclotron-Resonance (TOF-ICR) technique [7].

The PI-ICR technique was used to separate and measure the ground states and low-lying isomeric states in neutron-rich odd-odd Rh isotopes. Most exotic nuclei in the isotopic chains from yttrium and molybdenum were measured with the TOF-ICR technique. In total eight masses were measured for the first time and the precision of several literature values were improved. In this contribution the results of the measurement campaign and their implications on nuclear structure and astrophysics will be presented.

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[7] M. König et al., *Int. J. Mass Spectrom. Ion Process.* **142**, 95 (1995).

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Submitted by **HUKKANEN, Marjut** on **Tuesday 10 May 2022**

Abstract ID : **61**

Measurement and simulation of laser cooling of relativistic O5+ ions at CSRe

Content

Laser cooling of O5+ ion beams with an energy of 275.7 MeV/u was successfully achieved at the storage ring CSRe in Lanzhou, China [1, 2]. To the best of our knowledge, the Li-like O5+ ions are the highest charge state, the highest transition energy and the fastest ions (~ 64% of the speed of light) that have ever been laser-cooled. In the experiment, the dynamics of laser cooling processes have been investigated systematically by detuning the bunching RF frequency, while keeping the laser frequency fixed. At the same time, the Schottky spectra were recorded for measuring the momentum spread and the cooling effect. To explain the experimental results, we simulate the Schottky spectrum of laser-cooled bunched O5+ ions by employing the multi-particle tracking method. In the simulation, both the transverse oscillation and the photon-ion resonant interaction process are considered. The simulation results show good agreement with the experimental results, providing a precise method to determine the momentum spread of the laser-cooled O5+ ion beams. With most of the ions laser-cooled to the center of the bucket, the relative longitudinal momentum spread of the O5+ ion beams reached Δp/p ≈ 1.5 × 10^−6, which is limited by the resolution of the Schottky diagnostics for bunched ion beams. These observations were made for an ion beam lifetime of only 35 seconds. Besides, the Schottky power of the central peak in the experiment is about several orders of magnitude higher than that of the sidebands, which is attributed to the 'coherent effect'. In the simulations, we systematically studied the dependence of the Schottky power on the number of stored ions at different bunching and observation harmonics, and the 'coherent effect' has been interpreted for the first time [3].The experiment and simulation will benefit the further laser cooling and precision laser spectroscopy experiments at storage rings and also at the Gamma Factory at CERN [4].

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Submitted by **Dr WANG, Hanbing** on **Wednesday 11 May 2022**

Abstract ID : **62**

A universal gate-set for trapped-ion logical qubits

Content

Quantum error correction promises to address the concerns about error accumulation in quantum information processing. Here, quantum information of a single qubit is redundantly stored as a so-called logical qubit in several physical qubits. While logical qubits have been realized on various systems to date, a universal gate-set acting on such logical qubits has not been realized yet. In this presentation we will describe the first realization of such a universal gate-set in an ion-trap based quantum computing.

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Submitted by **Ms JÄGER, Miriam** on **Wednesday 11 May 2022**

Abstract ID : **63**

Physics opportunities with the Gamma Factory

Content

The Gamma Factory initiative, which is a part of the Physics Beyond Colliders project, proposes to develop novel research tools at CERN by producing, accelerating, and storing highly relativistic, partially stripped ion beams in the SPS and LHC storage rings. By exciting the electronic degrees of freedom of the stored ions with lasers, high energy narrow-band, fully polarized photon beams will be produced. Their intensities, up to 10^{17} photons per second, will be several orders of magnitude higher than those of the presently operating light sources in the particularly interesting gamma-ray energy domain reaching up to 400 MeV, inaccessible with sources based on free-electron lasers. Multiple unprecedented opportunities in atomic, nuclear, particle, and applied physics may be afforded by utilizing the primary beams for spectroscopy of partially stripped ions circulating in the storage ring, as well as by the use of the secondary high-energy photon beams.

More details can be found in a special issue of Annalen der Physik "Physics Opportunities with the Gamma Factory" that is available online (https://onlinelibrary.wiley.com/toc/15213889/2022/534/3).

Talk to be given by Andrey Surzhykov representing the Gamma Factory study group.

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Submitted by **SURZHYKOV, Andrey** on **Wednesday 11 May 2022**

Abstract ID : **64**

A single 40Ca+ ion as a Quantum Sensor for Motional State Metrology

Content

We have developed a new technique for the detection of any single ion's motional frequency from the oscillation amplitude of a ⁴⁰Ca⁺ ion that can be laser-addressed [1]. The ion of interest is first sympathetically cooled by the laser-cooled ⁴⁰Ca⁺. Then, laser-cooling is switched off and a Rabi- or Ramsey-type excitation is applied over the ion of interest or the two-ion crystal. In a first experiment, the ion's amplitude is recorded through the fluorescence pattern of the ⁴⁰Ca⁺ ion, registered in an EMCCD camera. The technique is universal, since any motional frequency can be measured. The measurable ion's amplitude is only limited by the resolution of the optical system, leading to an ultra-sensitive detection and mitigating possible systematic effects.
In this contribution, we will present the sensor ion's characterization in the Doppler regime [2,3]. The response of ⁴⁰Ca⁺ to external electric fields constitute a direct measurement of its cyclotron frequency and can also be used to simulate the interaction with the ion of interest when both ions are in the same or in different traps. We will also present the roadmap towards the implementation of the technique in the quantum regime [4,5]. Further improvement in precision is foreseen when quantum protocols for motional-state readout are used once the ions are cooled to the ground-state of motion. An ULE-cavity coupled to a Ti:Sa laser is being commissioned in order to address the qubit transition [6], in parallel to an upgrade of the trap system for operation at cryogenic temperature.

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Submitted by **BERROCAL SÁNCHEZ, Joaquín** on **Wednesday 11 May 2022**

Abstract ID : **65**

Progress on Ytterbium-ion Optical Clock Development at IUCAA, India

Content

Optical atomic clocks have reached an unprecedented level of accuracy in a few parts in 10^20, which are realized either by probing highly-forbidden optical transitions of neutral atoms localized in an optical lattice or using a single atomic ion trapped in an electrodynamic trap. We have started developing an optical clock based on its octupole (E3) transition at the 467 nm wavelength. Upon development, we intended to use the optical clock as a sensitive sensor for measuring the constancy of the fundamental constants and violation of the fundamental symmetries by national as well as international clock-intercomparison. The setting up of the experiment involves the indigenization of several instruments, some such examples are a precision ion trap, reference optical cavity, and optical fibers phase stabilization. As these building blocks are responsible for achieving the desired level of clock accuracy, testing the design ideas through rigorous simulations is a prerequisite. We have completed some such critical designs, for example, the ion-trap systems; the reference Fabry-Perot cavity, and so on, which are under fabrication at present. I shall present the overall progress of our optical clock development at the Precision & Quantum Measurement laboratory (PQM-lab: https://pqmlab.iucaa.in/), IUCAA, India.

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Abstract ID : **66**

High-Precision Mass Measurements of Light Atomic Nuclei: The Helium-4 Atomic Mass

Content

The LIONTRAP experiment focuses on high precision mass measurements of light atomic nuclei. Measurements on light ions are challenging due to the relatively large ratio of kinetic energies compared to the low rest mass. The measurement principle at LIONTRAP is based on a comparison of the cyclotron frequency of the ion of interest to the cyclotron frequency of a reference ion. This reference ion could be an ion of ^{12}C, enabling the mass measurement of the ion of interest in atomic mass units (amu). The results at LIONTRAP include the atomic mass measurements of the proton [1], the deuteron and the HD^+ molecular ion [2]. The deuteron mass was measured to a relative precision of 8.5 ppt [2]. Our results show an excellent agreement with values that were extracted from laser spectroscopy of HD^+ [3]. This comparison is currently limited by the precision of the electron's mass in amu, derived from a measurement of the bound electron g-factor in $^{12}C^{5+}$ [4]. ^{4}He is a prime candidate for a future improvement, as it is far less sensitive to higher-order terms of quantum electrodynamics (QED) and to the charge radius of the nucleus. Currently, we are measuring the atomic mass of ^{4}He to support such a determination of the electron mass in amu. In this contribution, the results of a measurement of ^{4}He atomic mass will be discussed.

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Submitted by **SASIDHARAN, Sangeetha** on **Thursday 12 May 2022**

Abstract ID : **67**

Towards High-Precision Spectroscopy of the 1S-2S Transition in He^+

Content

Precise tests of a physical theory require a system whose properties can be both measured and calculated with very high precision. One famous example is the hydrogen atom which can be precisely described by bound-state quantum electrodynamics (QED) and whose transition frequencies can be accurately measured by laser spectroscopy. Two physical constants, the Rydberg constant and the nuclear charge radius, are determined by fitting the theory expression for the energy levels to the experimental data [1]. Comparing the physical constants extracted from different combinations of measurements then serves as a consistency check for the theory itself.

We are currently setting up an experiment to perform spectroscopy on the 1S-2S transition in the simplest hydrogen-like ion, He^+. By combining the 1S-2S transition frequency with an accurate value of the helium nuclear charge radius measured by muonic helium spectroscopy [2], we will be able to make an independent determination of the Rydberg constant. This value will then be compared with the value obtained from hydrogen spectroscopy [1], serving as one of the most stringent tests of QED. Due to their charge, He^+ ions can be held near-motionless in the field-free environment of a Paul trap, providing ideal conditions for a high precision measurement. Furthermore, interesting higher-order QED corrections scale with large exponents of the nuclear charge which makes this measurement much more sensitive to these corrections compared to the hydrogen case [3].

The main challenge of the experiment is that driving the 1S-2S transition in He^+ requires narrow-band radiation at 61 nm. This lies in the extreme ultraviolet (XUV) spectral range where no transparent solids and no cw laser sources exist. Our approach is to use two-photon direct frequency comb spectroscopy [4] with an XUV frequency comb. The comb is generated from an infrared high power frequency comb using intracavity high harmonic generation [5]. The spectroscopy target will be a small number of He^+ ions which are trapped in a linear Paul trap and sympathetically cooled by co-trapped Be^+ ions.

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Abstract ID : **68**

MR-TOF-MS OF THE FRS ION CATCHER: RECENT PROGRESS AND FUTURE UPGRADES

Content

Mass measurements of short-lived nuclei with yields as small as few events per hour require an experimental device with excellent performance parameters: high sensitivity and accuracy, short cycle times of only few ms, high mass resolving power and possibility of simultaneous measurements of different nuclei. At the FRagment Separator (FRS) [1] at GSI, such measurements are performed with the Multiple-Reflection Time-Of-Flight Mass Spectrometer (MR-TOF-MS) combined with a Cryogenic Stopping Cell (CSC) [2] at the FRS Ion Catcher [2, 3]. At the Low-Energy Branch (LEB) of the Super-FRS at the Facility for Antiproton and Ion Research (FAIR), the MR-TOF-MS will be employed for mass measurements within the MATS [4] collaboration as well as for ultra-high-resolution mass separator to prepare isomerically and isobarically clean ion beams [5] for other experiments within the MATS and LaSpec [6] collaborations.

Recent progress with the MR-TOF-MS has resulted in high mass resolving power of almost 10^6 and relative mass uncertainties as small as $2 * 10^{-8}$ [7]. Currently, several technical upgrades are implemented in the MR-TOF-MS, including the installation of a position-sensitive detector and a Laser Ablation Carbon Cluster Ion (LACCI) source for highly-accurate mass calibration and systematic studies of the mass accuracy over a wide mass range. Furthermore, the beamline behind the TOF analyser is extended by adding an energy buncher, deceleration system and accumulation trap for transport of ion beams to experiments downstream of the MR-TOF-MS. Moreover, a new prototype Radio-Frequency Quadrupole (RFQ) beamline and trap system for the MR-TOF-MS is under development. In the new system, RFQs are printed on regular Printed Circuit Boards (PCBs), which allows for a compact and robust system. High DC transport efficiency was reached and work on producing narrow ion bunches is ongoing. Results of the aforementioned upgrades will be reported in this contribution.

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Submitted by **ZADVORNAYA, Alexandra** on **Thursday 12 May 2022**

Abstract ID : **69**

Cryogenic stopping cell for the Super-FRS at FAIR: status and outlook

Content

A cryogenic stopping cell (CSC) at the Low-Energy Branch (LEB) of the Super-FRS [1] at FAIR will be the key device to enable the scientific program of several collaborations – MATS [2], LaSpec [3] and Super-FRS EC [4]. The experiments will include collinear laser spectroscopy, nuclear reaction studies, mass measurements, and in-trap and trap-assisted spectroscopy. A fast and efficient conversion of intense radioactive isotope beams produced at relativistic energies of up to 1.5 GeV/u into low-energy and low-emittance beams is a prerequisite for these experiments.

A novel high areal density two-stage orthogonal extraction (HADO-CSC) concept has been developed [5] to achieve the unprecedented design performance parameters of areal densities of up to 40 mg/cm^2 for stopping efficiencies of almost unity, fast ion extraction time down to 10 ms, and a rate capability of up to 10^7 ions per second. Detailed simulations of the CSC are verified and projected from the performance of the prototype CSC, which is being successfully used in online experiments as a part of the FRS Ion Catcher [6,7] at GSI.

In this contribution, the status of the major components of the LEB CSC will be presented, including the new fine-pitched radio-frequency carpet design, simulations of ion trajectories traversed by gas jets, a cryogen-free cooling system and an ultra-clean buffer gas recovery system.

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Submitted by **AMANBAYEV, Daler** on **Thursday 12 May 2022**

Abstract ID : **70**

729 nm laser systems for motional quantum metrology in Paul and Penning traps

Content

A laser-cooled ⁴⁰Ca⁺ to be used as sensor ion for motional frequency measurements in a 7-tesla Penning trap setup [1, 2, 3] has been recently characterized in the Doppler limit at the University of Granada [4]. At this stage, the electric quadrupole “clock” transition at 729 nm has to be addressed to use the sensor in the quantum regime for the maximum sensitivity to external fields [5]. In this context, a linear Paul trap has been set up as a test bench for the implementation of quantum-enhanced protocols to determine the ion’s motional frequencies as shown e.g., in Ref. [6]. For this purpose, we have implemented two ultra-stable, narrow laser setups to address the “clock” transition in the Paul and Penning trap experiments. The former consists of a compact laser system comprised of a commercial, tapered-amplified 729 nm diode laser and a high-finesse ULE cavity. The latter setup comprises a broadband, high-power Ti:Sa laser coupled to a commercial, high-finesse ULE cavity.

In this contribution, we will underline the key elements of both laser setups. We will show the characterization of the ULE cavities and the performance of the Pound-Drever-Hall lock in terms of the frequency stability of both lasers. We will also present the most recent results obtained with a single, laser-cooled ⁴⁰Ca⁺ ion in the Paul trap, where sideband spectroscopy of the “clock” transition has been achieved, and the prospects in the short-term future.

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Comments:

Poster contribution

Status: SUBMITTED

Submitted by **DOMÍNGUEZ, Francisco** on **Friday 13 May 2022**

Abstract ID : **71**

The first application of mass measurements with the Rare-RI Ring Mass measurement for the 123Pd

Content

The sites for the r-processes which produce almost about one-half of the elements heavier than iron are still ambiguous. To model the r-process, nuclear properties of neutron-rich nuclides are needed. Nuclear mass is one of the most important input properties for the r-process calculation. Mass measurements of neutron-rich nuclei not only provide reliable data for the calculation but also can help improve the mass models predicting the mass of exotic nuclei which cannot be produced in the lab up to now.
The Rare-RI Ring (R3) is a recently commissioned isochronous mass spectrometer dedicated at Radioactive Isotope Beam Factory (RIBF) in RIKEN. Thanks to the highest radioactive beam intensity at RIBF, the R3 can measure the mass of very exotic nuclei far from stability. Based on the Isotope-Selectable Self-triggered Injection technique, the pre-identified ions can be selected and injected into R3 event by event. The mass precision of 10−6 is expected to be achieved within less than 1 ms.

In this contribution, the first application of mass measurements with the Rare-RI Ring will be reported. In the experiment, 5 isotones, 127Sn, 126In, 125Cd, 124Ag, and 123Pd, were injected into R3 and extracted successfully. The mass uncertainty of 123Pd is improved and the final relative uncertainty is 2.3 x 10-6. Based on the new mass data, the A=122 and A=123 element abundance ratios in twenty r-process trajectories, reflecting a neutron star merger event, is calculated with the PRISM reaction network model.

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Submitted by **LI, HONGFU** on **Friday 13 May 2022**

Abstract ID : **72**

Ion Trapping Developments using Printed Circuit Board Radio-Frequency Quadrupoles

Content

Ion Trapping Developments using Printed Circuit Board Radio-Frequency Quadrupoles
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Radiofrequency quadrupoles (RFQ) are a widely used ion trapping device. They are an essential part of many precision experiments in nuclear physics research. They are used as cooler bunched devises in mass spectrometry and laser spectroscopy, used as stand-alone ion traps to provide insights into double beta decay modes and quantum research or in applications for chemistry and analytical sciences combined e.g. with gas chromatography [1,2]. They feature high transport efficiencies and are able to produce narrow ion bunches, which makes them ideal injection traps for state of the art Multiple-Reflection Time-of-Flight Mass-Spectrometers (MR-TOF-MS).
Common RFQ devices rely on round rods to create an almost ideal quadrupolar field. To guide ions along the structure the rods are typically segmented, which allows the generation of a voltage gradient as well as local trapping minima. These standard designs require tight mechanical tolerances and precise alignment of the individual segments to ensure highest quality quadrupole fields and reduced field-boundary effect. Furthermore, for a smooth field to be created from segmented pieces, a large number of segments must be used [3,4]. This can make traditional RFQs difficult to manufacture. The University of Edinburgh aims to rectify these difficulties using a printed circuit board radio-frequency quadrupole (PCB RFQ).
Based on an initial simple PCB RFQ design [5], we have maximised the quadrupolar terms whilst minimising higher order field components using a multipole expansion code. Using the optimized aspect ratio we have manufactured a simple 10 cm long prototype ion trapping system. The new PCB RFQ has been commissioned using ^{133}Cs ions. It features a high efficiency and was able to create bunch widths of about 50ns.
In this contribution we will outline current ion trapping developments undertaken at the University of Edinburgh with regards to PCB RFQ. By optimizing our prototype PCB RFQ system further we aim to reduce the bunch width. Ultimately using novel PCB RFQs as injection to perform high mass measurements as part of a MR-TOF-MS system at the FRS Ion Catcher, GSI, Germany.

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[5] Maria Allers et al. International Journal of Mass Spectrometry (2019) 443:32−40

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Submitted by **FOWLER-DAVIS, Tayemar** on **Friday 13 May 2022**

Abstract ID : **73**

Multi-Reflection Time-of-Flight Mass Spectrometer at the Ion-Guide Isotope Separator On-Line (IGISOL) facility

Content

At the Ion Guide Isotope Separator On-Line (IGISOL) facility [1], exotic nuclei are typically produced via fusion-evaporation reactions or proton-induced fission on uranium. Studies of exotic nuclei are often challenging due to their low production rates and overwhelming background of unavoidably co-produced undesired isobars, consisting of equal number of nucleons (A) but different number of neutrons (N) and protons (Z). Samples consisting of only single ion species are desirable, especially for high-precision mass measurements. A universal method of isolating the ions of interest from the background of isobaric and other possible contaminants is instrumental in realizing such measurements.
A Multi-Reflection Time-of-Flight Mass Spectrometer (MR-TOF-MS) [2] has been commissioned at IGISOL in order to be used for the selection of the ions of interest for further studies with the JYFLTRAP Penning trap [3], or for decay or laser spectroscopy experiments. The MR-TOF-MS can also be used to measure masses of ion species more exotic than currently in reach of JYFLTRAP. The first on-line separation of fission fragments produced with the K130-cyclotron and the IGISOL fission ion-guide has been successfully performed reaching mass resolving powers in the 105 range, demonstrating that the setup is ready for the purification and mass measurements of exotic isobaric ion samples. In this contribution, I will present the MR-TOF-MS at the IGISOL facility, along with results from its off-line and on-line commissioning, including the Mini RFQ buncher, mass selective ejection from the MR-TOF-MS, and on-line produced A = 107 refractory fission product spectra separated with the MR-TOF-MS.

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[3] T. Eronen et al., European Physical Journal A 48, 46 (2012)

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Status: SUBMITTED

Submitted by **VIRTANEN, Ville** on **Friday 13 May 2022**

Abstract ID : **74**

Search for low Q value decay candidates for neutrino mass determination with JYFLTRAP

Content

The overall scale of neutrino masses is a matter of paramount importance in the search for generalizations of the standard model, as well as for cosmology. Experiments on neutrino oscillations allow extraction of non-zero differences between the neutrino masses squared but these experiments are insensitive to the absolute scale of neutrino masses. Nuclear beta decay and electron capture (EC) are the only direct and model-independent methods allowing deduction of neutrino mass. Currently, the most significant efforts concentrate on study of β^- decay of tritium (KATRIN experiment [1]) and EC of ^{163}Ho (ECHo and HOLMES experiments [2,3]). These experiments measure the electron-(anti)neutrino mass through observing the slight distortion of the decay spectrum near the decay endpoint, shifted by the (anti)neutrino mass. A small decay energy (Q value) is essential. Smaller the Q value, more decay events land near the endpoint helping accumulation of relevant statistics.

There are several decay candidates that potentially could be utilized in the future [4]. These are ground-to-excited state decays that should have an ultralow Q value (< 1 keV) and a reasonable decay branch. The suitability assessment is an on-going worldwide effort requiring ground-to-ground-state (gs-to-gs) Q value and the excited state energy with precision of ~100 eV or better.

With the double Penning trap mass spectrometer JYFLTRAP at University of Jyväskylä, Finland [5], we have measured several gs-to-gs Q values mostly with the phase-imaging ion-cyclotron resonance (PI-ICR) technique [6]. Our results combined with nuclear energy level data and nuclear and atomic many-body calculations allow the assessment of suitability of these decays. In this contribution, results (for example ^{159}Dy [7]) from our measurement campaign will be presented.

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[6] S. Eliseev *et al.*, Phys. Rev. Lett. **110**, 082501 (2013).
[7] Z. Ge *et al.*, Phys. Rev. Lett.**127**, 272301 (2021).

Primary authors: ERONEN, Tommi (University of Jyvaskyla); Dr GE, Zhuang (GSI Helmholtzzentrum für Schwerionenforschung GmbH); Dr DE ROUBIN, Antoine (KU Leuven, Instituut voor Kernen Stralingsfysica); KANKAINEN, Anu (University of Jyväskylä); NESTERENKO, Dmitrii (University of Jyväskylä, Department of Physics); Prof. SUHONEN, Jouni (University of Jyväskylä); IGISOL COLLABORATION

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Status: SUBMITTED

Submitted by **ERONEN, Tommi** on **Friday 13 May 2022**

Abstract ID : **75**

Trapped Chiral Molecular Ions for Probing Parity Violation

Content

The symmetry between left and right handed chiral molecules is predicted to be broken by the weak interaction. Some theories suggest that this small energy difference has seeded the homo-chirality observed in nature, though such predictions are controversial. We are building a new experiment aimed at observing weak force parity violation (PV) for the first time molecules. We will use the charged version of chiral molecules which can be easily trapped providing long interrogation times. We will present our novel ideas to extract the PV signature through Ramsey spectroscopy on a mixed racemic ensemble of the trapped molecular ions. This work may lead to a new platform to search for beyond Standard Model Physics.

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Presenter: Prof. SHAGAM, Yuval (Technion - IIT)

Comments:

We are a new group studying trapped and quantum controlled chiral molecular ions.

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Submitted by **SHAGAM, Yuval** on **Saturday 14 May 2022**

Abstract ID : **76**

Evaluating states in trapped ions with local correlation between internal and motional degrees of freedom

Content

We propose and demonstrate a scalable scheme for the simultaneous determination of internal and motional states in trapped ions with single-site resolution. The scheme is applied to the study of polaritonic excitations in the Jaynes–Cummings–Hubbard model with trapped ions, in which the internal and motional states of the ions are strongly correlated. We observe quantum phase crossovers of polaritonic excitations in two ions by directly evaluating their variances per ion site. Our work establishes an essential technological method for large-scale quantum simulations of polaritonic systems.

In our work, we demonstrate the measurement of local motional states conditioned
on the internal states by shelving part of the ions to a long-lived internal state. In this method, fluorescence cycles are not used to determine the internal states, and the probability amplitudes that are of no interest are simply hidden in the auxiliary long-lived internal state. Therefore, this method does not suffer from mutual heating among ion sites as explained above and is applicable to the measurement of local motional states in a multi-ion crystal. In this work, this method is applied to determine the polariton number and its variance in the JCH model while the system parameters are changed. The method is scalable with
respect to the number of ion sites, i.e., the same time sequence can be used in principle for an arbitrary number of ions in the chain.

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Status: SUBMITTED

Submitted by **MURALIDHARAN, Silpa** on **Saturday 14 May 2022**

Abstract ID : **78**

Mass measurements of exotic nuclei with the FRS Ion Catcher

Content

Mass measurements of exotic nuclei have been performed with the FRS Ion Catcher [1,2] at GSI. The nuclei have been produced at relativistic velocities by projectile fragmentation or fission at the entrance of the projectile fragment separator FRS [3], separated in flight, slowed down and thermalized in a cryogenic stopping cell (CSC). The exotic nuclei have then been measured using a multiple-reflection time-of-flight mass-spectrometer (MR-TOF-MS), which is a high-performance isochronous electrostatic ion trap. The MR-TOF-MS features mass resolving powers of up to one million and relative mass measurement accuracies of down to 2×10^{-8}, a performance level previously reached by Penning trap mass spectrometry only, however now with measurement times of merely a few tens of milliseconds [4]. At mass resolving powers of a few 10^5, broadband mass measurements can cover more than 20 mass units, and nuclides with half-lives of a few milliseconds are accessible. Furthermore, the device can also be employed as an isobar and isomer separator [5].

Mass measurements at the borders of the known nuclear landscape have been performed [4,6,7] on nuclides with production cross sections down to a few nanobarn and rates down to two counts per hour. The measurements include neutron-deficient light lanthanides close to the proton drip line and neutron-rich nuclei around the N=126 shell closure. Newly measured masses of ground and isomeric states of nuclei close to the N=Z line and below ^{100}Sn shed light on nuclear structure and the proton-neutron interaction. Furthermore, from a ^{252}Cf source mounted in the CSC, masses and yields of spontaneous fission products have been obtained.

The presentation will give an overview of the setup, recent experimental highlights, and upcoming technical advances and experiments.

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[6] S. Ayet San Andrés et al., Phys. Rev. C 99 (2019) 064313.
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Status: SUBMITTED

Submitted by **Dr PLAß, Wolfgang** on **Saturday 14 May 2022**

Abstract ID : **79**

High-precision mass measurements of neutron-deficient Ag isotopes at JYFLTRAP

Content

The heavy $N = Z$ nuclei and the nuclei in their vicinity have been actively investigated both theoretically and experimentally due to their importance in nuclear structure studies and high impact in modelling nuclear astrophysical processes. The recently commissioned inductively heated hot-cavity catcher laser ion source in IGISOL [1] enables the production of extremely exotic neutron-deficient silver isotopes. The atomic masses of $^{95-97}$Ag and the low-lying isomeric state in ^{96}Ag have been measured with the JYFLTRAP double Penning trap [2] with a high-precision of ~ 1 keV/c^2. The conventional time-of-flight ion-cyclotron resonance (TOF-ICR) [3] and the newly-completed phase-imaging ion-cyclotron-resonance (PI-ICR) method [4,5] were employed in the measurements.
With the PI-ICR technique, atomic masses of long predicted β-decaying 2^+ and 8^+ states in ^{96}Ag have been identified and measured for the first time. The newly measured masses of $^{95-97}$Ag have been utilized to investigate the N = 50 neutron shell closure and the proton-neutron interaction. The N = 50 nuclear shell closure is confirmed to be robust. The empirical shell-gap energies are compared to the-state-of-the-art ab initio calculations. Preliminary results of the new mass values used as inputs for modelling the astrophysical rapid proton-capture process will also be discussed.

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[4] S. Eliseev et al., Phys. Rev. Lett. 110, 082501 (2013).
[5] D. A. Nesterenko et al., Eur. Phys. J. A 54, 154 (2018).

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Status: SUBMITTED

Submitted by **GE, zhuang** on **Saturday 14 May 2022**

Abstract ID : **80**

Studies with radioactive highly charged ions at TITAN

Content

TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) boasts four on-line ion traps for atomic mass determinations and in-trap spectroscopy of radioactive ions. Its electron beam ion trap, a fast charge breeder, serves three purposes. First, as the charge state increases, the available nuclear decay channels change. For example, nuclear excitation by electron capture becomes available. The associated change in nuclear lifetime affects astrophysical abundance calculations.

Second, for lithium- and sodium-like charge states, the electronic transitions in the extreme ultraviolet regime can be used to determine the absolute nuclear charge density. This information is requisite for tests of the standard model, like electric dipole moments searches.

Third, the high charge states improve the performance of Penning trap mass spectrometry. The boost in precision is appreciated for studies of fundamental symmetries, where the Q-value or difference in atomic masses must be known to precisions of order ~10^{-10}.

I will present an overview of TITAN with an emphasis on the technical work for and scientific studies of radioactive highly charged ions.

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Presenter: KWIATKOWSKI, Anna (TRIUMF)

Status: SUBMITTED

Submitted by **KWIATKOWSKI, Anna** on **Sunday 15 May 2022**

Abstract ID : **81**

First laser spectroscopy at CRYRING@ESR: Studies of Hyperfine population transfer

Content

In storage ring experiments different effects contribute to the velocity distribution of the ions. Usually, radio-frequency (RF) structures are utilized to provide ion bunches and for acceleration and deceleration. Additionally, electron cooling is frequently applied to reduce the longitudinal momentum spread of the ions. Since the resonance frequency of an atomic transition is a function of the ion velocity, laser spectroscopy is a decisive tool to investigate dynamic effects on the velocity of the ions. Moreover, provided that the rest-frame transition frequency is known, studies on the electron space-charge potential inside the electron cooler section can be carried out.

A new laser spectroscopy setup has been installed at the low-energy storage ring CRYRING@ESR at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt. In our first beamtime we used an electron-cooled and bunched beam of Mg^{+} ions. About 10^{6} $^{25}Mg^{+}$ ions were stored in CRYRING@ESR at about 160 keV/u (β = 0.018). When we superimposed the continuous-wave (cw) laser in collinear or anticollinear geometry we observed a continuous population transfer between the two hyperfine ground states F=2 and F=3. In our contribution we discuss the impact of synchrotron oscillations on the observed phenomenon and give an outlook for future perspectives of the experiment.

This work is supported by the BMBF under contract numbers 05P19RDFAA, 05P21RDFA1 and 05P19PMFA1.

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Status: SUBMITTED

Submitted by **MOHR, Konstantin** on **Sunday 15 May 2022**

Abstract ID : **82**

Sympathetic cooling of positrons for cold antihydrogen formation

Content

Antihydrogen physics has entered a fascinating new era where more and more measurements are becoming realistic and where these measurements are already starting to set new limits on some fundamental parameters. A key development behind many of the most recent results is efficient synthesis and trapping of antihydrogen atoms. Vital to these efforts have so far been the ability to provide cold positron plasmas for formation for antihydrogen. We have recently demonstrated sympathetic cooling of positrons using laser-cooled Beryllium ions in the ALPHA trap for antihydrogen synthesis and trapping. The first round of results shows some challenges for cooling many positrons, but also that we can cool them to about three times lower temperatures that the typical temperatures seen during the most efficient trapping cycles. The strong scaling the favours lower positron temperatures means that we expect improvements of up to a factor 10 in our trapping cycles when this new technique is combined with antihydrogen trapping - something that would be a game changer for the type of experiments possible with antihydrogen and therefore the potential physics discoveries.

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Comments:

for the ALPHA collaboration.

Status: SUBMITTED

Submitted by **MADSEN, Niels** on **Sunday 15 May 2022**

Abstract ID : **83**

Recent mass measurements of neutron-rich Ag and In isotopes at JYFLTRAP

Content

Masses of neutron-rich silver (Z=47) and indium (Z=49) isotopes are relevant for both nuclear structure and astrophysics. Most of these isotopes have long-living isomeric states, which in addition to the ground states, can provide information on the evolution of nuclear structure close to the closed proton (Z=50) and neutron (N=82) shells. However, excitation energies for many beta-decaying isomers have remained unknown. The isomeric states have been challenging to resolve and study with the conventional Time-of-Flight Ion Cyclotron Resonance technique at Penning traps. As a result, the ground-state mass-excess values have remained less accurate, hampering the calculations for the astrophysical rapid neutron capture process.

We have recently studied neutron-rich silver and indium isotopes with the JYFLTRAP double Penning trap [1] at the Ion Guide Isotope Separator On-Line (IGISOL) facility [2]. We have discovered a new high-spin isomer in 128In [3] and extended silver mass measurements to 124,125Ag. To resolve very low-lying isomeric states, we applied the newer Phase-Imaging Ion Cyclotron Resonance (PI-ICR) technique at JYFLTRAP [4,5]. A large number of low-lying isomeric states were resolved and their excitation energies measured, together with the mass-excess values for the ground and isomeric states. In many cases, the mass measurements were further supported by laser or post-trap decay spectroscopy to identify the studied states. In this contribution, I will present the results from these experiments on neutron-rich silver and indium isotopes at IGISOL.

[1] T. Eronen et al., Eur. Phys. J A 48 (2012) 46.
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[3] D.A. Nesterenko, A. Kankainen et al., Phys. Lett. B 808 (2020) 135642.
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Status: SUBMITTED

Submitted by **KANKAINEN, Anu** on **Sunday 15 May 2022**

Abstract ID : **84**

Status of the MLLTRAP Project: A Penning trap beamline for mass measurement of neutron rich nuclei at ALTO

Content

The double Penning trap mass spectrometer (PTMS) MLLTRAP, initially commissioned off-line at the Maier-Leibnitz Laboratory (MLL) in Garching, Germany, is currently being setup at the Accélerateur Linéaire et Tandem à Orsay (ALTO facility) in France. The ISOL facility ALTO provides neutron-rich radioactive ion beams from the interaction of a γ-flux induced by a 50 MeV 10 μA electron beam in a uranium carbide target. A magnetic dipole mass separator and a resonance ionization laser ion source allow selecting the ions of interest. Currently, the Front-End is being upgraded in order to produce low energy beams with an energy up to 60 keV. The new beamline dedicated for MLLTRAP will transport the low energy beams to a linear segmented Paul trap (RFQCB) where the ions are cooled and bunched. When ejected from the RFQCB, the bunched beam is decelerated before being injected into the PTMS. In addition to the first on-line commissioning and before the move of the setup to SPIRAL2/DESIR at Caen, MLLTRAP will perform high-precision mass measurements of silver isotopes at ALTO, towards the N=82 neutron shell closure. These masses will allow exploring the possible weakening of the shell gap for Z < 50 and its impact on the A = 130 r- process elemental abundances. In this contribution, the progress on the assembly and the off-line commissioning of the different sections of MLLTRAP will be presented as well as the timeline for the first measurements campaign at ALTO.

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Presenter: MINAYA RAMIREZ, Enrique (IJCLab)

Status: SUBMITTED

Submitted by **MINAYA RAMIREZ, Enrique** on **Sunday 15 May 2022**

Abstract ID : **86**

Towards Ramsey-Comb Spectroscopy of the 1S-2S Transition in Singly-Ionized Helium

Content

The 1S-2S transition of hydrogenic systems is a benchmark for tests of fundamental physics. The most prominent example is the 1S-2S transition in atomic hydrogen, where impressive relative accuracies have been achieved [1]. Nowadays these fundamental physics tests are hampered by the uncertainty in the value of the proton charge radius and by estimates of uncalculated higher-order QED terms [2].

An independent approach to contribute and further improve these fundamental physics tests is to measure the 1S-2S transition in He^+. Since He^+ has twice the nuclear charge of hydrogen, some interesting QED contributions are strongly enhanced and can therefore be tested more precisely. Furthermore nuclear properties such as e.g. the alpha particle charge radius or nuclear polarizability contributions can also be probed.

We want to measure the extreme ultraviolet (XUV) 2-photon 1S-2S transition in He^+ via Ramsey-comb spectroscopy (RCS) [3, 4]. RCS uses two amplified and up-converted pulses of a frequency comb to perform a Ramsey-like excitation. We will excite the two-photon transition with a fundamental photon at 790nm and its 25^{th} harmonic at 32nm. The He^+ ion will be trapped in a Paul trap and sympathetically cooled with a Be^+ ion. Systematics which are constant between different pulse pairs, such as the AC Stark shift, cancel. Any frequency shift due to the motion of the helium ion is significantly reduced by synchronizing the repetition rate of the laser with the secular frequency of the trap. Using the RCS method we aim to do a first 1S-2S measurement of He^+ with an accuracy of 10 kHz, while an accuracy of better than 50 Hz should be ultimately achievable.

We are currently in the process of calibrating our XUV and the He^+ 1S-2S transition rate in a beam of He atoms before we install the Paul trap.

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[3] Morgenweg et al., Nat. Phys. 10, 30–33 (2014)
[4] Dreissen et al., Phys. Rev. Lett. 123, 143001 (2019)

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Status: SUBMITTED

Submitted by **GRÜNDEMAN, Elmer** on **Sunday 15 May 2022**

Abstract ID : **87**

Ion trapping for cluster research

Content

Ion traps of various kinds are valuable tools for the preparation and investigation of atomic clusters, which are the particles that bridge the gap between single atoms and condensed matter.

Examples will be given of experiments with Penning and Paul traps for

- the study of the atomic clusters fission of polyanionic metal clusters (including recent time-resolved observations of delayed photofission) and
- the preparation of polyanionic clusters for photoelectron spectroscopy (where the Coulomb barrier allows for metastable systems of negative electron affinities), respectively.

Furthermore, an electrostatic ion beam trap operated as a Multi-Refection Time-of-Flight Mass Spectrometer has been adopted for

- the observation of the photodecay channels of (lead-doped) bismuth clusters, as well as for
- the determination of details of the abundance spectra of (poly-)cationic fullerenes produced by laser ablation from glassy-carbon targets.

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Presenter: SCHWEIKHARD, Lutz (Univ. of Greifswald)

Status: SUBMITTED

Submitted by **SCHWEIKHARD, Lutz** on **Sunday 15 May 2022**

Abstract ID : **88**

A multicell trap for the creation of high density off-axial plasmas

Content

For the formation of an electron-positron plasma unprecedented quantities of positrons need to be accumulated. To trap and store large numbers of positrons the APEX-collaboration has build a prototype multicell trap. The idea of this trap design is to separate the positrons space charge into multiple radially displaced small diameter traps. This prototype trap is used for three main purposes: 1. To demonstrate the capability to operate multiple off-axis cell simultaneously.2. To increase the off-axis transfer rate and test suitable protocols for a future MCT at NEPOMUC. 3. To create high off-axis space charge plasmas by stacking multiple displaced plasmas.
In this contribution, we will present the prototype trap and show that the simultaneous confinement of electron plasmas in different storage cells was successful. Studies of the plasma expansion, when displaced and expanded over master- and storage-cell are presented, as well as possible techniques to increase the amount of the transferred plasma.

Primary authors: SINGER, Martin (Max-Planck Institut für Plasmaphysik); Prof. SCHWEIKHARD, Lutz (Universität Greifswald); Prof. PEDERSEN, Thomas Sunn (Max-Planck Institut für Plasmaphysik)

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Status: SUBMITTED

Submitted by **SINGER, Martin** on **Sunday 15 May 2022**

Abstract ID : **89**

The first experiments at CRYRING@ESR

Content

The low-energy heavy ion storage ring CRYRING has been transported from Stockholm to Darmstadt, modernised and reconfigured, and has been integrated downstream from ESR into the accelerator complex at GSI/FAIR, where it now operates as CRYRING@ESR. Next to serving as a test platform for new technology of FAIR, it is a user facility for research in many domains.
Ions can be injected injected either in low charge states from a local ion source through a 300 keV/u RFQ linac, or in high charge states through ESR. This allows for a very broad access to ions across the entire periodic system. CRYRING@ESR is able to de- or accelerate the ions and store beams of isotopically pure species in a desired charge state. With the powerful electron cooling method, the spatial and momentum spread are reduced to provide brilliant beams to the specification of the experimentalists. This gives an unprecedented access to precision spectroscopy in highly charged ions, for studying the dynamics of slow collisions in strong fields, for measuring nuclear reactions in the Gamow window, or in materials science for surface modifications by slow HCI beams, and more¹.
All major elements of the facility are now in service and routine operation as a user facility has been established. The SPARC collaboration has prepared several experimental installations for merged beams electron-ion collisions, for atomic collisions in a dense gas-jet target, and on collinear laser spectroscopy. The first period of serving beamtimes to experiment proposals approved by the General Program Advisory Committee has now been completed. While the data analysis is still largely ongoing, these first experiments are already showing that the high expectations on achievable resolution in spectroscopy experiments have been fulfilled.
We will review our present setup of the ring, discuss the data from our first experiments and review the planned experiments upcoming new installations in the coming years.

References:

1. M. Lestinsky, Y. Litvinov, T. Stöhlker (eds.), Eur. Phys. J. Spec. Top 225 (2016)

Primary author: LESTINSKY, Michael (GSI Helmholtzzentrum für Schwerionenforschung GmbH)

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Comments:

for SPARC and the CRYRING@ESR collaboration

Status: SUBMITTED

Submitted by **LESTINSKY, Michael** on **Sunday 15 May 2022**

Abstract ID : **90**

Towards Measurements of Parity-Violating Moments using Single Molecular Ions in a Penning Trap

Content

This poster presents the development of a novel Penning ion trap for precision spectroscopy of symmetry-violating electroweak properties using single trapped molecular ions. The high magnetic field of a superconducting magnet can be used to Zeeman shift two molecular states of opposite parity to near degeneracy, enhancing the sensitivity of parity-violating nuclear properties by more than 11 orders of magnitude [1]. Hence, our proposed experimental setup is expected to provide highly sensitive measurements of symmetry violating nuclear properties across the nuclear chart. This contribution will describe the commissioning of a proof-of-principle, room-temperature Penning trap for demonstrating the molecular state superposition using SiO+ molecules, as well as the development of a cryogenic upgrade allowing for superior stability and accuracy.

[1] Altuntas, E. et al. Phys. Rev. Lett. 120, 142501 (2018)

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Status: SUBMITTED

Submitted by **MOROCH, Scott** on **Sunday 15 May 2022**

Abstract ID : **91**

Progress at the antimatter on a chip project

Content

Measurements on antimatter allow for the investigation of fundamental questions regarding the matter-antimatter asymmetry in our universe. In this context, of interests is, for example, investigation of the gravitational and inertial mass of antimatter as well as its interactions with normal matter. The antimatter on a chip (AMOC) project aims to create, manipulate and measure the properties of anti-hydrogen and its interactions in completely new ways, and to enable novel fundamental studies of antimatter with minimal dependence on accelerator facilities. Here we report on our numerical simulations of a two-frequency Paul trap suitable for trapping charged particle species with widely different charge-to-mass ratios and we present our implementation of such a trap [1,2]. Current work is aimed at loading positrons from a Na-22 source with the future addition of transportable antiproton traps developed at the University of Mainz [3]. Unlocking these technologies will pave the way for high-precision table-top experiments on antimatter.

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[2] N. Leefer et al., Hyperfine Interact 238, 12 (2016).
[3] C. Smorra et al., International Journal of Mass Spectrometry 389, 10 (2015).

Primary authors: BEKKER, Hendrik (HIM); BUDKER, Dmitry; Prof. SCHMIDT-KALER, Ferdinand (Institut für Physik, QUANTUM, Johannes Gutenberg-Universität Mainz); SMORRA, C (Institut für Physik, Johannes Gutenberg-Universität, Staudingerweg 7, D-55128 Mainz, Germany); QU, Guofeng (Helmholtz institute Mainz); FOLMAN, Ron (Ben-Gurion University of the Negev); HÄFFNER, Hartmut (University of California, Berkeley); KRIMMEL, Kai (Johannes-Gutenberg-Universität Mainz, Helmholtz institute Mainz); LEEFER, Nathan (Helmholtz institute Mainz); QIN, Jianan (Johannes-Gutenberg-Universität Mainz, Helmholtz institute Mainz)

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Status: SUBMITTED

Submitted by **BEKKER, Hendrik** on **Sunday 15 May 2022**

Abstract ID : **92**

Laser Photodetachment Studies in a Storage Ring and Application to Mass Spectrometry

Content

Negative ions play an important role in high sensitive mass spectrometry. Notably accelerator mass spectrometry (AMS) depends strongly on negative ions due to its use as a selective filter. Laser pho- todetachment of negative ions can be used as an additional element selective filter to suppress atomic or molecular isobars. To this end, photons interact with the negative ions and remove the extra electron if the photon energy exceeds the electron affinity (EA) of the negative ion. As the EA solely depends on the electron configuration this process is element selective.
For most atomic negative ions the EA is well known. However, in the case of molecular negative ions this is not the case. Especially for AMS relevant molecules the lack of spectroscopic information of molecular negative ions is evident. One reason for this are the internal degrees of freedom of molecules. In that case more effort has to be taken in gathering the required spectroscopic information. One possibility is the use of low−energy storage rings, where the internal degrees of molecules can be cooled during storage. Recently, the electrostatic storage ring FLSR [1] was equipped with a negative ion source. Photons from a high−repetitive tuneable Ti:sapphire laser are directed to one of the interaction point of the storage ring, which was equipped with optical grade vacuum windows. The neutralised particles are further downstream detected with a position−sensitive silicon strip detector. By varying the laser wavelength the detachment threshold of the negative ion and therefore the EA can be studied. First tests have been performed with stored oxygen anions and show promising results. Further tests with molecular hydroxide anions will be performed. In a later stage of the project, a sputter ion source will be used to produce the molecules relevant for mass spectrometry.
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[2] O. Forstner et al., Opportunities for negative ions studies at the Frankfurt Low−energy Storage Ring (FLSR), Hyp. Int. 241, 53 (2020)

Primary authors: FORSTNER, Oliver (Friedrich-Schiller-Universität Jena); GADELSHIN, Vadim (Johannes Gutenberg−Universität Mainz); Dr SCHMIDT, Lothar (Goethe−Universität Frankfurt); Dr STIEBING, Kurt (Goethe−Universität Frankfurt); STUDER, Dominik (Johannes Gutenberg−Universität Mainz); WENDT, Klaus (Johannes Gutenberg−Universität Mainz)

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Status: SUBMITTED

Submitted by **FORSTNER, Oliver** on **Sunday 15 May 2022**

Abstract ID : **93**

Study of Highly Charged Ions for the Test of Bound-State QED in the ARTEMIS Penning Trap

Content

The high-precision measurement of the Zeeman splitting of fine and hyper fine-structure levels can be measured using spectroscopy techniques. The Penning trap ARTEMIS at the HITRAP facility at GSI utilises such a method called Laser-Microwave double-resonance spectroscopy to measure the magnetic moment and to test bound-state QED calculations by the g-factor measurements of heavy, highly-charged ions like Ar13+ and Bi82+. After cooling the stored ion cloud in the trap by resistive cooling, non-destructive detection technique is used to detect the presence of ions. Different ions in the trap are resolved according to their charge-to-mass ratio by fixing the frequency and ramping over a range of voltages. By using Stored Waveform Inverse Fourier Transform (SWIFT) method, Ar13+ ions are isolated from the ion cloud for the g-factor measurements. Studies are also done to determine the phase transition of dense ion cloud due to the discontinuous behaviour of spectral features during cooling.

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Status: SUBMITTED

Submitted by **CHAMBATH, Manasa** on **Sunday 15 May 2022**

Abstract ID : **94**

Latest Results of the High-Precision Penning-Trap Mass Spectrometer Pentatrap

Content

This contribution presents the latest achievements obtained with the Penning-trap mass spectrometer Pentatrap [1] located at the Max Planck Institute for Nuclear Physics in Heidelberg. Pentatrap has proved its capabilities of performing mass-ratio measurements on highly charged ions of long-lived nuclides with a relative uncertainty of a few ppt [2, 3]. With a broad measurement program Pentatrap plans to contribute to experiments on tests of special relativity, bound-state QED [2], neutrino-physics [3] and 5th force research [4]. Achieving this level of precision requires using a cryogenic image-current detection system with single-ion phase-sensitive detection methods in combination with highly charged ions provided by external ion sources. The stack of five identical Penning-traps allow for direct systematic checks and our in-house designed voltage source provides ultra-stable trapping potentials.

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[4] Counts, I. et al. Phys. Rev. Lett. 125, 123002 (2020)

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Status: SUBMITTED

Submitted by **DOOR, Menno** on **Sunday 15 May 2022**

Abstract ID : **95**

Search of the Exotic Nuclear Two-Photon Decay in Isochronous Heavy Ion Storage Rings

Content

The nuclear two-photon (2γ) decay is a rare decay mode in atomic nuclei whereby a nucleus in an excited state emits two gamma rays simultaneously. First order processes usually dominate the decay, however two-photon emission may become significant when first order processes are forbidden or strongly retarded, which can be achieved at the experimental storage ring ESR (GSI/FAIR).

Within this work we will present the implemented methodology and the obtained results of two beam times performed in 2021, when for the first time the isochronous mode of the ESR alongside two non-destructive Schottky detectors were operated for the study of short-lived isomer production yields and lifetimes. We investigated specifically the isotope 72Ge, as it is the most easily accessible nucleus having a first excited 0+ state below the pair creation threshold paramount for the study of 2γ decay without competition of first order decays.
Preliminary results point out that its half-life is considerably shorter than expected, therefore new theoretical investigations are required. In addition, the nuclei 70Se and 72Br were studied in the search for new shape-isomers. Our successful measurement at the ESR paves the way to further studies of exotic decay modes which in turn will facilitate our understanding of electron-shell-nucleus interactions.

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Comments:

I would prefer to contribute with a poster, although a talk is also possible.

Status: SUBMITTED

Submitted by **FREIRE FERNÁNDEZ, David** on **Sunday 15 May 2022**

Abstract ID : **96**

Electron cyclotron resonance (ECR) magnetometry for experiments with Antihydrogen

Content

The Antihydrogen Laser Physics Apparatus (ALPHA) is based at the European Centre for Nuclear Research (CERN) antiproton decelerator facility. Using low energy antiprotons we produce, trap, and study the bound state of an antiproton and positron, antihydrogen [1]. Given the long history of atomic physics experiments with hydrogen, spectroscopy experiments with antihydrogen offer some of the most precise tests of quantum electrodynamics and charge-parity-time symmetry [1]. A test of the weak equivalence principle is also on the horizon with a major addition to the ALPHA experiment, ALPHAg, aiming to measure the free fall of antihydrogen [2].

All experiments in ALPHA require precise measurements of the magnetic field inside the apparatus. A technique developed in ALPHA determines the in situ magnetic fields by measuring the cyclotron frequency of a small electron plasma. Microwave pulses on resonance with the electron cyclotron frequency, which is magnetic field dependent, heat the plasma [3]. A campaign to characterize the precision and accuracy of this technique in a high magnetic field gradient is required before a successful measurement of the effect of Earth's gravity on antimatter can be made.

I will show recent progress made towards realising this goal including the first application of this technique in a strong magnetic field gradient and methods used to experimentally distinguish the cyclotron frequency from a sideband structure.

1. Characterization of the 1S–2S transition in antihydrogen, ALPHA Collaboration, Nature, 557, 71, (2018)
2. Description And First Application Of A New Technique To Measure The Gravitational Mass Of Antihydrogen, ALPHA Collaboration, Nature Communications 4, 1785 (2013)
3. Electron Cyclotron Resonance (ECR) Magnetometry with a Plasma Reservoir, E. D. Hunter and A. Christensen and J. Fajans and T. Friesen and E. Kur and J. S. Wurtele Physics of Plasmas 27, 032106 (2020)

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Status: SUBMITTED

Submitted by **Mr POWELL, Adam** on **Sunday 15 May 2022**

Abstract ID : **97**

LIONTRAP: Towards a High Precision Atomic Mass Measurement of the Helium-3 Nucleus

Content

LIONTRAP is a Penning trap mass spectrometer, optimized for measuring atomic masses of light ions with a relative precision of a few parts per trillion (ppt). Ultra-precise measurements of the rest masses of light atomic nuclei serve as essential parameters for sensitive tests of fundamental physics. For example, the tritium and helium-3 mass difference is used as a consistency check for the model of systematics used by the KATRIN experiment [1].

The most precise mass measurements in this regime, performed by different groups, revealed an inconsistency of about 5 standard deviations. This is also known as "light ion mass puzzle". In order to resolve this puzzle, we have performed ultra-high precision measurements of the atomic masses of the proton [2], deuteron and the HD+ molecular ion [3] at LIONTRAP. Our values are consistent with values reported by FSU [4]. However, the inconsistency of about 3 standard deviations remains when the values are combined with the literature value of helium-3 mass, which motivates its independent measurement.

In this contribution, the current status of LIONTRAP is reviewed, including the helium-3 source preparation for the upcoming mass measurement campaign.

References:

[1] M. Aker et al., Nat. Phys. **18**, 160–166 (2022)
[2] F. Heiße et al., Phys. Rev. A **100**, 022518 (2019)
[3] S. Rau et al., Nature **585**, 43–47 (2020)
[4] D.J. Fink et al., Phys. Rev. Lett. **127**, 243001 (2021)

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Status: SUBMITTED

Submitted by **BEZRODNOVA, Olesia** on **Sunday 15 May 2022**

Abstract ID : **98**

Trapping and sympathetic cooling of the Thorium-229 Isomer for high-resolution spectroscopy

Content

Thorium-229 features a unique, low-lying nuclear-exited state with various prospects for improved optical clocks and for measurements to uncover physics beyond the standard model. One crucial ingredient is a precise knowledge of nuclear moments, which is, for example, required to determine the sensitivity of the nuclear transition frequency to a potential temporal variation of the fine-structure constant alpha.
In our setup, thorium-229 ions are produced as recoil ions from the alpha decay of a uranium-233 source via alpha decay, featuring a 2% branching to the isomer. The recoil ions are slowed down in helium buffer gas in an RF funnel. A quadrupole mass filter is used to separate the thorium ions from other uranium-233 decay products, molecular ions, and co-sputtered uranium ions. The thorium-229 ions are transferred into a linear Paul trap, where they are trapped together with 88Sr+. Sympathetic cooling of Th3+ in a Coulomb crystal of laser-cooled 88Sr+ ions allows for Doppler-free spectroscopy of thorium ions. We will report on the most recent status of this experiment and our progress on high-resolution hyperfine spectroscopy to investigate nuclear moments.

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Status: SUBMITTED

Submitted by **TIEDAU, Johannes** on **Sunday 15 May 2022**

Abstract ID : **99**

Exploring the region of neutron-deficient heavy nuclei above lead with PTMS at SHIPTRAP

Content

Probing the limit of existence at the uppermost corner of the nuclear chart requires a deep understanding of nuclear properties of the very heavy nuclides and their evolution towards the superheavy region. In the framework of the FAIR phase-0 program, we have directly measured the masses of heavy nuclei to investigate the evolution of the N=152 shell closure in different elements with the Penning-trap mass spectrometer SHIPTRAP at GSI Darmstadt, Germany. Moreover, several heavy nuclides above the Z=82 and N=126 shell closures have been recently investigated. In this region, many nuclei display deformed shapes and complex configurations with often more than one metastable level at low energies. Such states have traditionally been studied by decay and laser spectroscopy, as for instance the ²⁰⁶Fr-²⁰²At-¹⁹⁸Bi and ²⁰⁴Fr-²⁰⁰At-¹⁹⁶Bi chains. At SHIPTRAP the excitation energies of metastable states populated in nuclides of these decay chains have been finally directly measured, allowing to benchmark the proposed level and decay schemes.

In this contribution the latest results of these measurements and systematic uncertainties connected to such measurements will be presented. Ongoing technical upgrades to further boost the efficiency of the setup, and future plans will be also discussed.

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Status: SUBMITTED

Submitted by **Dr GUTIÉRREZ, Manuel J.** on **Sunday 15 May 2022**

Abstract ID : **100**

Revealing low-lying isomers in the heaviest elements by mass spectrometry

Content

Heavy and superheavy nuclei are characterized by a very complex nuclear structure and feature often metastable excited states with half-lives that can exceed the one of the ground state.
Long-lived isomeric states can have excitation energies of only few tens of keV or below, therefore their identification is challenging, especially in decay-based measurements. Alternatively, Penning trap mass spectrometry can provide sufficient resolving power to allow the separation of isomeric states when they are populated in the same reaction as the ground state.
The SHIPTRAP spectrometer at GSI Darmstadt, Germany is devoted to the investigations of heavy and superheavy nuclides via mass measurements. In the latest experimental campaigns within the FAIR phase-0 program at GSI, several Cf (Z=98), No (Z=102), Lr (Z=103), Rf (Z=104), and Db (Z=105) isotopes have been studied under challenging conditions of low production rates and high mass resolving power. The binding energies of these nuclei have been directly measured. In addition, low-lying and long-lived isomeric states have been identified, and their excitation energy determined accurately
In this contribution an overview of recent results will be presented illustrating the performance of the method, and future perspectives will be addressed.

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Submitted by **GIACOPPO, Francesca** on **Sunday 15 May 2022**

Abstract ID : **101**

RF spectroscopy on hyperfine structure of HD+ ion

Content

HD+ molecular ions is a three-body atomic system, which can be modeled with high accuracy from ab initio calculations enabling an improved determination of the proton-electron mass ratio. Recent experiment on Doppler-free two-photon laser spectroscopy of ro-vibrational transitions in molecular HD+ has revealed a 4.2σ discrepancy [1]. It can originate from yet unrecognized systematic effects in previous experiments, flaws in the fundamental QED theory that describes the hyperfine structure, or even some ununderstood behavior of the deuteron.
In order to experimentally test the contribution of the hyperfine structure to the ro-vibrational transition frequency we perform RF spectroscopy inducing electron spin-flip transitions within the hyperfine structure at ground (v=0, N=3) and excited (v=9, N=3) ro-vibrational states. Then we compare the difference in photo-dissociation losses of HD+ molecular ions induced by laser beams with wavelengths corresponding to the ro-vibrational and electronic transitions.
An open-shell electronic structure of HD+ causes high sensitivity of Zeeman component of each energy level to external magnetic field. Therefore, we utilize well-known spin-flip transition frequency of 2S1/2 of Be+ ions which are also present in the ion trap for sympathetic cooling and have similar sensitivity to Zeeman effect.
In current study we perform RF spectroscopy on multiple magnetic transitions within hyperfine structure of HD+ at ground vibrational state.

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Submitted by **Dr KLIUKIN, Dmitrii** on **Monday 16 May 2022**

Abstract ID : **102**

Precision spectroscopy of molecular hydrogen ions

Content

Molecular hydrogen ions (MHI), the simplest molecules, are three-body quantum systems composed of two simple nuclei and one electron. They are of high interest for fundamental physics and metrology because they provide the missing link between the fields of mass and g-factor measurements with Penning traps and spectroscopy of hydrogen-like atoms.

From a fundamental point of view, the new ingredient introduced by the MHI is the long-range nucleus-nucleus interaction, absent in the hydrogen atom, and the quantized motion of the nuclei.

Precision spectroscopy of the MHI can thus furnish novel results: (1) on the masses of proton and deuteron (in the future, also of tritium), (2) set limits for exotic forces, (3) verify the wave character of matter, and (4) test alternative theories of quantum mechanics. This is performed by comparing or matching experimental and theoretical rotational and/or vibrational frequencies. The comparison is enhanced by the availability of several recently measured transition frequencies and recent advances in ab initio theory.

An additional opportunity for probing the interactions between the particles within the MHI is the precision measurement of its hyperfine structure (HFS). Only the synthesis of the HFS of the hydrogen atom, of the deuterium atom and of the molecular hydrogen ion allows probing the physics of HFS
at the finest level, resolving the issue of the uncalculable nuclear contributions.

We present recent results of our spectroscopy of sympathetically cooled MHI, its results and interpretation. An outlook on near-future studies is also given.

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Status: SUBMITTED

Submitted by **Prof. SCHILLER, Stephan** on **Monday 16 May 2022**

Abstract ID : **104**

Towards Single Ion Sensitivity for Rare Isotope Mass Spectrometry using SIPT

Content

Precision mass measurements of rare isotopes are needed in almost all areas of nuclear physics research. In particular, mass measurements that will have the greatest impact on nuclear structure and astrophysics require access to isotopes far beyond the valley of stability [1,2]. The recent opening of the Facility for Rare Isotope Beams (FRIB) will bring many isotopes of interest within reach. The Low Energy Beam Ion Trapping (LEBIT) facility at FRIB (formerly the National Superconducting Cyclotron Laboratory) has been performing mass measurements using Penning trap mass spectrometry: the most precise method known to date [3]. However, the most exotic isotopes may only be delivered on the order of 1 ion per day, which necessitates a technique for performing mass measurements of isotopes with extremely low rates. To this end, the single ion Penning Trap (SIPT) makes use of the non-destructive narrowband Fourier transform ion cyclotron resonance (FT-ICR) technique [4]. Specifically, SIPT uses a high quality factor ($Q > 2000$) superconducting LC resonator to detect the image charge current created by a single ion on the electrodes of the Penning trap. The resulting signal can be weak for a single ion in the trap, and may be subject to noise on the order of the signal itself. Consequently, recovering the relevant information from the signal's frequency domain is non-trivial. Current work uses a priori knowledge and supervised machine learning to differentiate real signals from noise. Additionally, neural networks trained with data simulated to match SIPT characteristics are used to determine the percent composition for different numbers of ions composing a signal. This is ultimately used to validate the single ion resolution for SIPT. The specifics of these algorithms and neural networks, their performance, and results on experimental data will be presented.

This work was conducted with the support of Michigan State University and the National Science Foundation under Grants No. PHY-1102511, No. PHY-1126282, and PHY-2111185.

[1] B. A. Brown and W. A. Richter, Phys. Rev. C 74, 034315 (2006). [2] H. Schatz and W. J. Ong, Astrophys. J. 84, 2 (2017). [3] K. Blaum, Phys. Rep. 425, 1 (2006). [4] A. G. Marshall and C. L. Hendrickson, Int. J. Mass Spectrom. 215, 59 (2002).

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Comments:

This abstract is for consideration as a poster presentation

Status: SUBMITTED

Submitted by **CAMPBELL, Scott** on **Monday 16 May 2022**

Abstract ID : **106**

Commissioning of a Multiple-Reflection Time-of-Flight Mass-Spectrometer for Barium-tagging using a spatially resolved multi-element ion source

Content

A spatially resolved multi-element laser ablation ion source (LAS) is used to selectively ablate different materials for the calibration of a multiple-reflection time-of-flight mass-spectrometer (MRTOF). The LAS uses a motorized mirror mount to precisely position an ablation laser spot on the surface of a stationary target. By assembling a target of different materials, specific elements can be selectively ablated with a spatial resolution of $\sim 50\ \mu$m for injection into the MRTOF. It is further possible to scan the laser spot over the surface of the target in a rasterized grid and perform mass imaging microscopy. However, since the MRTOF is sensitive to changes in the initial ion-bunch conditions, performance may differ between scan locations.

The MRTOF is being commissioned as part of a larger ion-transport and trapping system for Ba-tagging, which is being developed for a potential future upgrade to the nEXO experiment. The proposed nEXO experiment aims to search for neutrinoless double beta decay ($0\nu\beta\beta$) in ^{136}Xe with a five-tonne enriched liquid Xe time-projection chamber. The addition of barium tagging will allow for the positive identification of a candidate $0\nu\beta\beta$ event as a true Xe $\beta\beta$ decay, by extracting and identifying the daughter Ba ion. Progress towards the development of mass imaging microscopy with the MRTOF will be discussed as well as the status of the Ba-tagging developments.

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Status: SUBMITTED

Submitted by **MURRAY, Kevin** on **Monday 16 May 2022**

Abstract ID : **108**

High-precision experimental nuclear physics with the upgraded TITAN Penning trap

Content

Nuclear-physics experiments probe nuclear structure, nucleosynthesis and fundamental interactions, for which high precision and accurate mass measurements are critical inputs. TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) facility employs the Measurement Penning Trap (MPET) to measure masses of exotic nuclei to high precision and accuracy up to ~1e-10. To improve the resolving power and to reduce the statistical uncertainty in the mass measurement, a higher charge state of the ions can be used. This and other benefits of charge breeding radionuclides like improved beam purification can be realized only at TITAN as it alone combines radioactive ions, charge breeding, and a Penning trap. To fully leverage these advantages, MPET is undergoing an upgrade to a new cryogenic vacuum system compatible with ions in charge states over 20+. The status of MPET will be presented.

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Status: SUBMITTED

Submitted by **KAKKAR, Sakshi** on **Tuesday 17 May 2022**

Abstract ID : **109**

Beta-decay Paul Trap Mk. IV Commissioning

Content

The Beta-decay Paul Trap (BPT) is a linear Paul trap at Argonne National Lab that measures the beta-neutrino angular correlation coefficient $a_{\beta\nu}$ in the decay of ^{8}Li and ^{8}B to search for a tensor contribution to the weak interaction, a beyond-Standard Model possibility. The BPT has an ultimate measurement goal of 0.1% uncertainty in $a_{\beta\nu}$. A new BPT Mk. IV trap was designed to reduce systematic uncertainties associated with electron scattering and features other improvements through use of carbon electrodes. Results from a recent commissioning run with ^{8}Li will be presented.

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Presenter: VARRIANO, Louis

Status: SUBMITTED

Submitted by **VARRIANO, Louis** on **Wednesday 18 May 2022**

Abstract ID : **111**

Resonant Photoexcitation of X-ray Transitions in Trapped Fe XVII

Content

Spectroscopic observations in the UV and X-ray bands with the newest generation of high-resolution instruments onboard current and future satellite observatories have the potential to reveal previously inaccessible details of processes in astrophysical plasmas, essential for advancing our understanding of extreme environments and the evolution of the universe. The interpretation of spectral line features depends on models, which are often based on atomic-structure calculations. These have to be benchmarked by laboratory experiments, and the ubiquitous ions of iron are of highest priority. For decades, astrophysical observations as well as laboratory measurements of the oscillator strength ratios of the resonance line 3C, $(2p^5)_{1/2}3d_{3/2}$ (J=1) to $2p^6$ (J=0), and the intercombination line 3D, $(2p^5)_{3/2}3d_{3/2}$ (J=1) to $2p^6$ (J=0), in Ne-like iron Fe XVII have disagreed significantly with theoretical values, which has raised questions about the reliability of calculated line intensities. This was complicated by the fact that the primary excitation mechanism in experiments was electron impact, which introduces a plethora of phenomena that have to be taken into account.

In the experiments presented this was addressed by using an electron beam ion trap (EBIT) to provide targets of trapped Fe XVII ions for ultrabrilliant photon beams from x-ray light sources. By observing resonantly excited fluorescence high-resolution spectra can be recorded. First pioneering experiments of this kind were conducted at the Linac Coherent Light Source (LCLS) free-electron laser, and their results seemed to hint at shortcomings of atomic-structure calculations. However, possible systematic effects in the LCLS measurements were pointed out. These were excluded in recent experiments at the synchrotron facility PETRA III. They were conducted using the novel compact PolarX-EBIT and the high-resolution monochromator of beamline P04, which led to much improved spectral resolving powers and signal-to-noise ratios, uncovering hitherto unaccounted-for contributions to the measured line shapes. When these are taken into account, measured and newest calculated oscillator strength agree, which is underpinned by simultaneous determinations of the natural linewidths of 3C and 3D. This has finally provided a satisfactory resolution to the 3C/3D oscillator strength problem.

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Submitted by **BERNITT, Sonja** on **Thursday 19 May 2022**

Abstract ID : **112**

Observation of the structural transition between a Coulomb crystal and a charged quantum rotor

Content

The shape of a Coulomb crystal strongly depends on the confinement potential, and the ions can undergo structural transitions as the ratios between the different trapping frequencies are changed. A celebrated example is the transition between a linear crystal and a zig-zag configuration, which occurs when the axial confinement of the ions is increased.
We report on the experimental observation of a structural transition between a two-dimensional Coulomb crystal and a charged quantum rotor.
The specific geometry of the electrodes in our trap makes it possible to continuously change the arrangement of the ions from a one-dimensional string to a two-dimensional Coulomb crystal by changing a DC voltage, while keeping the ions always in a two-dimensional plane. When the confining potential is made isotropic in the plane, we observe that the ions undergo a structural transition from a Coulomb crystal to a quantum rotor, in which the particles are no longer localized in space, but are rather delocalized along circular trajectories. The rotation is initiated by thermal fluctuations, and we characterize its occurrence under different conditions. In particular, the range of parameters for which the transition occurs depends on the number of trapped ions – an effect that is directly related to the mesoscopic size of the sample, which approaches the bulk limit as the number of ions is increased. Interestingly, for a sufficiently large number of ions two or more concentric rings are populated, and the rings can exhibit independent dynamics. The presence of one ion of a different isotope causes the localization of the ions in the ring, while the ions in other rings can simultaneously rotate, thus creating complex structures in which a charged quantum rotor and a Coulomb crystal co-exist.

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Submitted by **SIAS, Carlo** on **Friday 20 May 2022**

Abstract ID : **113**

Site-resolved ion imaging and precision beam positioning for Penning-trap quantum simulation and sensing

Content

Coherently manipulated large ion crystals in a Penning trap are a promising candidate for near-term quantum simulation of complex many-body phenomena as well as the search for dark matter using quantum sensing [1,2]. At the University of Sydney, we have recently developed a Penning trap to perform such experiments with crystals containing hundreds of beryllium ions [3]. To this end we have implemented a high bandwidth time-correlated single-photon-counting camera which allows efficient single-site detection of individual ions in large 2D ion crystals, a prerequisite to investigate spatial correlations in many-body quantum systems. The large amount of image data is analysed by an object detection algorithm using an artificial neural network. Next, to overcome the issue of precise entangling laser beam alignment in the difficult-to-access Penning trap system, we have developed a laser beam delivery system based on compact piezo-actuated optical mirrors which allows an efficient beam position tuning. This system also enables us to maximize the ratio of spin-spin interaction strength to spontaneous emission, a critical ratio for experiments with beryllium ions in a Penning trap. I will give an overview of the experimental setup, recent technical developments and present first results.

[1] M. Gärttner et al., Nat. Phys. 13, 781 (2017)
[2] K. A. Gilmore et al., Science 373, 673 (2021)
[3] H. Ball et al., Rev. Sci. Instrum. 90, 053103 (2019)

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Status: SUBMITTED

Submitted by **WOLF, Robert** on **Friday 20 May 2022**

Abstract ID : **114**

Towards Cf highly charged ion clocks

Content

Recent experimental breakthroughs allow highly charged Ions (HCIs) to be cooled and trapped to temperatures below 1 mK. This opens up the possibility of creating clocks based on highly charged ions that are less sensitive to external perturbations.
At the University of Birmingham, we develop Californium HCI clocks. Optical transition with values of |K_alpha| ⊠ 45 are predicted to exist in the ionization states Cf15+ and Cf17+. It makes this clock particularly interesting for measuring variations of K_alpha in comparison with other clocks in the QSNET project.

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Status: SUBMITTED

Submitted by **PROKHOROV, Leonid** on **Friday 20 May 2022**

Abstract ID : **115**

Observation of emergent hydrodynamics on a programmable trapped ion quantum simulator

Content

In the past few decades, technical advancements in controlling quantum systems with a high fidelity have triggered worldwide hope to demonstrate the functionality of fully controllable quantum computers and simulators, which aim to achieve quantum advantages. Trapped ion systems have a great level of isolation from surrounding perturbations and coherent control can be achieved with high fidelity. Controlling long ion strings for quantum simulation is of interests for achieving quantum advantages. In this presentation, I will give a brief overview of how to control long ion strings in a trapped ion system [1]. I will also present some recent results from our laboratory, where we studied spin dynamics in a controllable infinite temperature quantum state subjected to quench dynamics, which led us to observe emergent hydrodynamics on a 51-ion programmable quantum simulator [2].
[1] F. Kranzl et al., Phys. Rev. A, 105, 052426 (2022).
[2] M. K. Joshi et al., Science, 376, 720 (2022).

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Status: SUBMITTED

Submitted by **JOSHI, Manoj Kumar** on **Friday 20 May 2022**

Abstract ID : **116**

Precision Spectroscopy of X-Ray Transitions in He-like Uranium using novel Microcalorimeter Detectors

Content

Helium-like ions are the simplest atomic multibody systems and their study along the isoelectronic sequence provides a unique testing ground for the interplay of the effects of correlation, relativity and quantum electrodynamics. However, for high-Z ions with nuclear charge Z > 54, where K-transition energies reach up to 100 keV, there are currently very few precision data available to challenge state-of-the-art theory [1]. In this context the recent development of metallic magnetic calorimeter (MMC) detectors is of particular importance. Their high spectral resolution of a few tens of eV FWHM at 100 keV incident photon energy in combination with a broad spectral acceptance down to a few keV will enable new types of precision x-ray studies [2].

We report on the first application of MMC detectors for high resolution x-ray spectroscopy at the electron cooler of the low energy storage ring CRYRING@ESR at GSI, Darmstadt. Within this experiment, the x-ray emission associated with radiative recombination of cooler electrons and stored hydrogen-like uranium ions was studied. Two MMC detectors developed within the SPARC collaboration [3] were placed under 0° and 180° with respect to the ion beam axis. Special emphasis will be given to the achieved spectral resolution of better than 90 eV at x-ray energies close to 100 keV which enables for the very first time to resolve the substructure of the Ka1 and Ka2 lines as well as to the various unique aspects resulting from the selected detection geometry in combination with the broad spectral acceptance.

[1] P. Beiersdorfer and G.V. Brown, Phys. Rev. A 91, 032514 (2015).
[2] S. Kraft-Bermuth et al., Atoms 2018, 59 (2018)
[3] D. Hengstler et al., Phys. Scr. 2015, 014054 (2015)

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Status: SUBMITTED

Submitted by **WEBER, Günter** on **Friday 20 May 2022**

Abstract ID : **117**

Cold Valve at ARTEMIS in HITRAP – Separating 300 K and 10-9 mbar from 4 K less than 10-13 mbar

Content

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In ARTEMIS (AsymmetRic Trap for measurement of Electron Magnetic moment in IonS), at HITRAP, we aim to perform the g-factor measurements of medium to heavy, highly charged ions (HCIs), such as 209Bi82+. It serves as a test of QED in strong fields and we do this using laser-microwave double resonance spectroscopy in our cryogenic Penning trap facility at Darmstadt. Currently, we have completed the final adjustments of attaching the cold valve to ARTEMIS which connects the experiment to external Electron Beam Ion Trap (EBIT) sources and the HITRAP facility. The cold valve serves as a separation between the pressure of 10-9 mbar in the beam-line and a pressure better than 10-13 mbar in the trap chamber. Additionally, it allows for a temperature gradient of 4 K to 300 K across itself without the heat conduction through the valve exceeding the power rating of the cryostat of under 1W at 4K. Upon its closure, a virtually complete blockage of gas flux into the trap chamber is achieved. This also stops the entry of the direct flux of gas from the room-temperature section of the beam-line. Gas can only enter the trap in the magnetically-controlled short intervals whilst the ions are injected. In this way, a virtually unlimited storage time can be achieved, which is vital to work with HCIs.

The working principle of the cold valve is that two magnets turn on a thin tube, which in turn is connected to the actual closing mechanism. The thin drive tube of the valve has a socket on the underside on which two pins are attached. By generating a magnetic field, the eccentrics are drawn into the magnetic field and thus pull on the pin of the can. This causes the drive tube to rotate around its own axis. The magnets are controlled by a control unit and can be triggered externally. A round plate is attached to the top of the drive tube, which serves to guide the pins of the bolt mechanism.

The rotation of the thin drive tube twists the two pins of the locking mechanism, causing an attached
copper bolt to move. This rotates against a plate which has a hole as an opening. If the copper bar is
exactly over the opening, the valve is closed. In order to open the valve, the copper bar must be moved
by rotating the drive tube so that the opening is released. This is the first fast-switching (≈few ms) cryogenic cold valve in the world capable of enabling virtually infinite storage times of arbitrary, externally injected HCIs with the precision associated with an automated magnetic control

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Submitted by **Ms JÄGER, Miriam** on **Monday 23 May 2022**

Abstract ID : **118**

Nuclear astrophysics with storage rings

Content

Most of the time, stars gain their energy from fusion of the very light left-overs of the Big Bang into heavier elements over long periods of time. The observation of radioactive isotopes in different regions of the Universe is an indicator of this ongoing nucleosynthesis. In addition, short-lived nuclei are often intermediate steps during the nucleosynthesis in stars. A quantitative analysis of these relations requires a precise knowledge of reaction cross sections involving unstable nuclei. The corresponding measurements are very demanding and the applied techniques therefore manifold.
Ion storage rings offer unprecedented possibilities to investigate radioactive isotopes of astrophysical importance in inverse kinematics. During the last years, a series of pioneering experiments proofed the feasibility of this concept at the Experimental Storage Ring (ESR) at GSI. I will present recent experiments and ideas for future setups for the investigation of capture reactions with astrophysical motivation.

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Submitted by **Ms JÄGER, Miriam** on **Friday 17 June 2022**

Abstract ID : **119**

Entanglement of trapped ions over a 510 m link

Content

Entanglement-based quantum networks hold out the promise of new capabilities for secure communication, distributed quantum computing, and interconnected quantum sensors. However, only a handful of elementary quantum networks have been realized to date. I will present recent results from our prototype network, in which two calcium ions are entangled with one another over a distance of 510(2) m, via an optical fiber channel linking two buildings. The ion-ion entanglement is based on ion-photon entanglement mediated by coherent Raman processes in optical cavities. I will discuss the advantages of trapped ions for quantum networks and the role that cavities can play as quantum interfaces between light and matter at network nodes. After examining the key metrics for remote entanglement, we will consider how this work may be extended to more complex protocols.

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Submitted by **Ms JÄGER, Miriam** on **Monday 20 June 2022**

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Segmented multi-ion trap for a transportable optical clock

Content

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Single ion clocks mark the today's best frequency standards with an accuracy on the order of 10^{-18} [1]. A *transportable* single ion clock that surpasses the accuracy of transportable H-Masers by about one order of magnitude was developed as part of the opticlock project [2]. That optical clock is based on a laser cooled Ytterbium ion trapped in a ring shaped Paul-trap.

As part of the opticlock project we developed a novel ion trap setup that shall serve as the basis for a future N -ion clock, thus reducing the required averaging time by a factor 1/N . In order to trap up to dozens of ions while maintaining low micro motion, a linear four layer ion trap was designed with 14 segments. A total of 56 electrodes and additional 16 connections for sensors that allow for registering the temperature behaviour of the different trap layer are mounted on an aluminium nitride board. The ceramic board serves both as chip carrier and, at the same time, as a highly compact vacuum interface. With its high thermal conductivity it furthermore helps stabilizing the trap's temperature. Using a rectangular-shaped cuvette together with the ceramic board allows for good optical access. Here the cuvette serves as a view-port for detecting the ions' resonance fluorescence as well as providing optical access for laser beams from three different axes.
We present the multi-ion setup, experimental results for the trapping time, the vacuum quality and the micromotion of trapped Ytterbium ions, as well as latest results on the further characterization of this novel trap.

References

1. N. Huntemann, C. Sanner, B. Lipphardt, Chr. Tamm, and E. Peik; Phys. Rev. Lett. 116, 063001 (2016).
2. https://www.opticlock.de . opticlock was supported by the BMBF under grant no. 13N14385.

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