Status Report: APPA

From Fundamental to Applied Research

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Helmholtz Institute Jena and Friedrich-Schiller University, Jena
and Atomic Physics Division, GSI

GSI Atomic Physics

HI JENA Helmholtz Institute Jena

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

APPA: Matter under Extreme Conditions

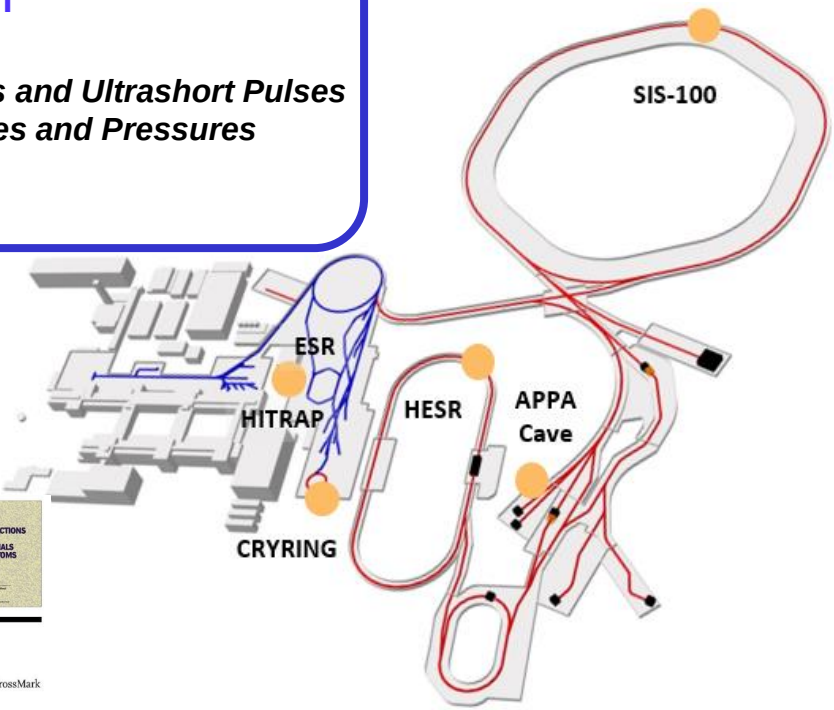
FACILITY CAPABILITY

Highest Charge States
Relativistic Energies
High Intensities
High Charge at Low Velocity
Low-Energy Anti-Protons

⇔

SCIENTIFIC CAPABILITY

Extreme Static Fields
Extreme Dynamical Fields and Ultrashort Pulses
Very High Energy Densities and Pressures
Large Energy Deposition
Antimatter Research



HED FAIR
Plasma Physics
200 members from 11 countries

sparc
Atomic and Fundamental Physics
439 members from 26 countries

APPA
White Paper
NIMB 365 (2015) 680


Contents lists available at ScienceDirect
Nuclear Instruments and Methods in Physics Research B
journal homepage: www.elsevier.com/locate/nimb
ELSEVIER
BEAM INTERACTIONS WITH MATERIALS AND ATOMS

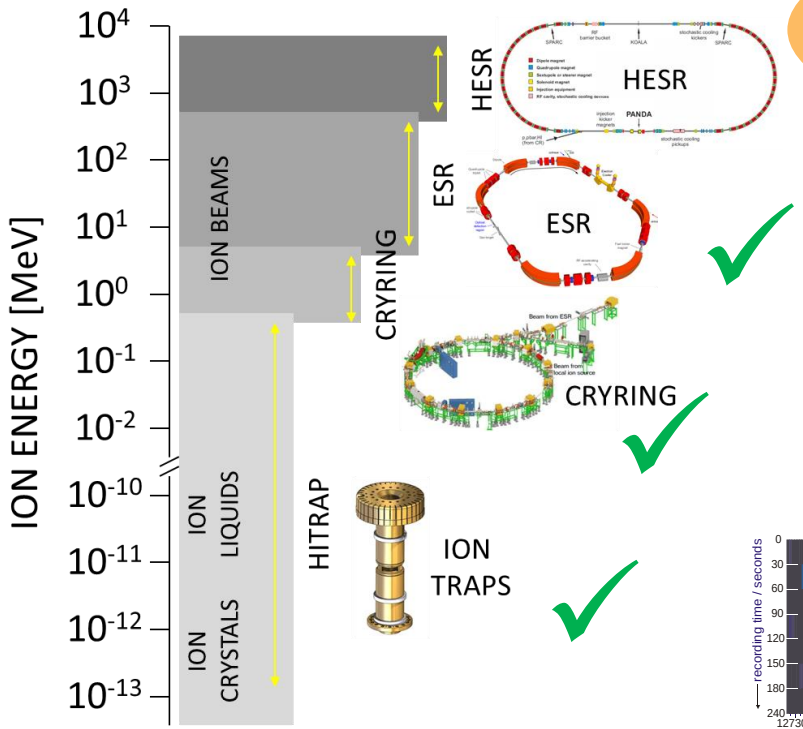
APPA at FAIR: From fundamental to applied research

Th. Stöhlker [a,b,c,*], V. Bagnoud [a,b], K. Blaum [d], A. Blazevic [a], A. Bräuning-Demian [a,e], M. Durante [a], F. Herfurth [a], M. Lestinsky [a], Y. Litvinov [a], S. Neff [a,f], R. Pleskac [a], R. Schuch [g], S. Schippers [h], D. Severin [a], A. Tauschwitz [a], C. Trautmann [a,f], D. Varentsov [a], E. Widmann [i], on behalf of the APPA Collaborations

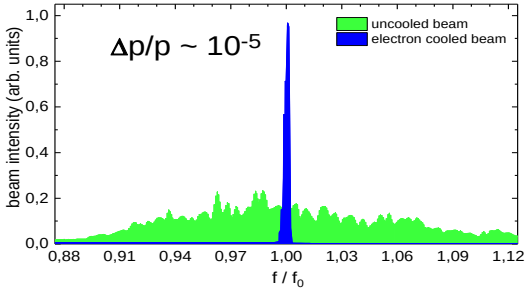
Precision Physics, Traping & Storage
Quantum, Fundamental and Atomic Physics

Unique research potential !

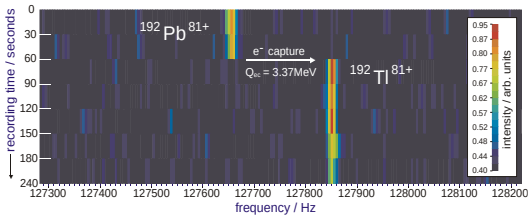
From rest to relativistic energies (up to 4.9 GeV/u)



QED at the Schwinger-Limit
Correlated multi-body dynamics
Astrophysical phenomena involving exotic ions/nuclei
Borderline between atomic and nuclear physics
Fundamentals



Cooling: key for precision

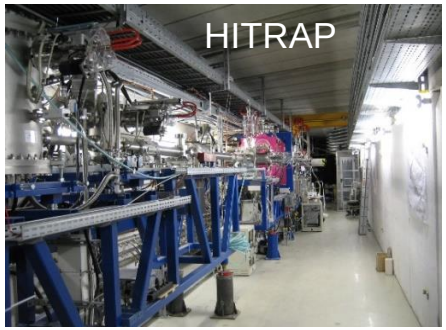


From single ions to highest intensities

FAIR Phase-0 (2017-2020)

ESR, CRYRING@ESR & HITRAP are part of the Modularized Start Version (MSV)

Storage & Trapping of Highly Charged, Heavy Ions and Exotic Nuclei



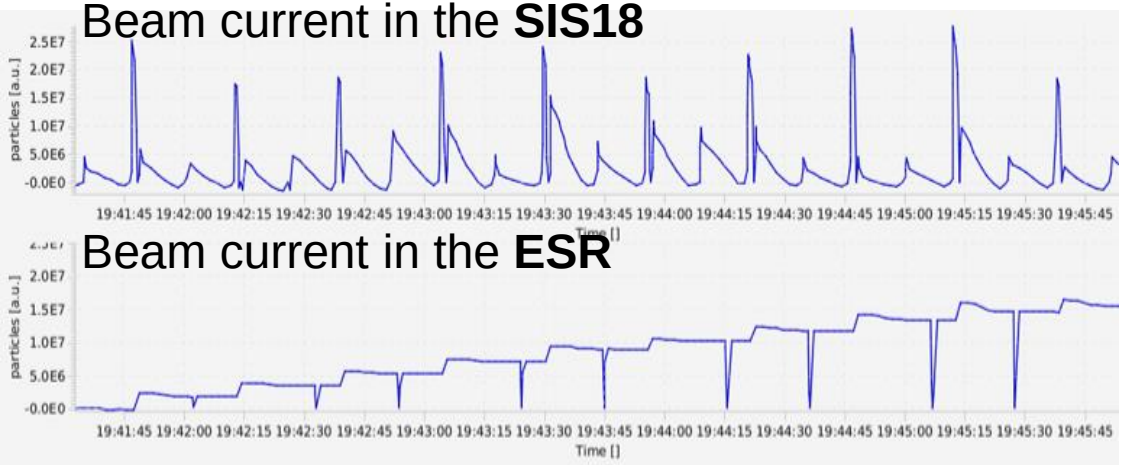
- GPAC 2017: Category A 186 shifts / 62 days
- Delay by more than two years
- ESR / CRYRING@ESR: Substantial progress in 2020 (despite COVID-19): commissioning and first experiments
- HITRAP: Is expect to be available for experiments in 2022

substantial financial support provided by e.g.

Federal Ministry of Education and Research

Start of FAIR Phase-0 at the Storage Rings: ESR

- Experiments at the ESR
  - E135: $^{86}Kr^{32+}$ (laser)
  - E132: ^{124}Xe (deceleration, Xe gas-jet, e- spectrometer)
  - E127: ^{124}Xe, ^{118}Te (FRS, stochastic cooling, deceleration, H_2 gas-jet, DSSD detector setup)
  - E121: ^{205}Tl (FRS, stochastic cooling, accumulation, Ar gas-jet, CsISiPHOS detector, long storage times)



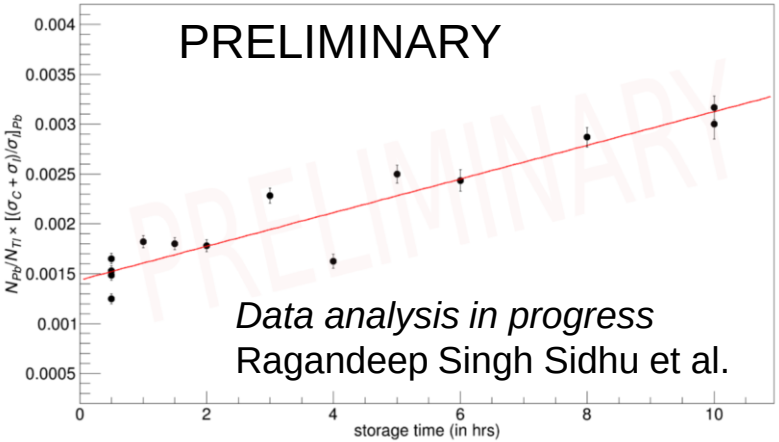
Accumulation of secondary ^{205}Tl beam in the ESR

- ✓ All major manipulation capabilities and instrumentations of the ESR were taken into operation during setting up of the experiments.
- ✓ Stable operation during experiments.

E121: Bound-state Beta Decay of $^{205}Tl^{81+}$ Ions

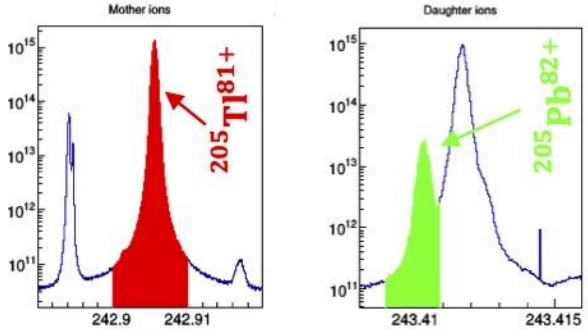
The half-life of secondary ions of about 100 d is addressed

- Successful production and separation in the FRS
- Successful cooling and accumulation in the ESR
- Breeding times of up to 10 hours

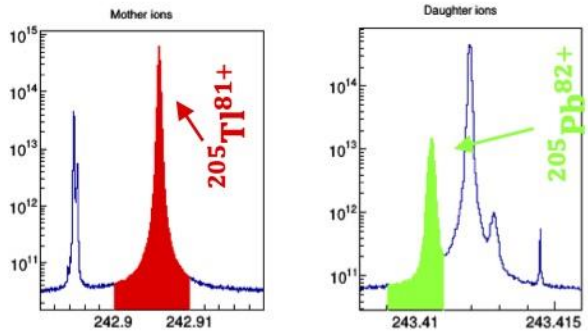


Data analysis in progress
Ragandeep Singh Sidhu et al.

Number of $^{205}Pb^{82+}$ ions as a function of breeding time

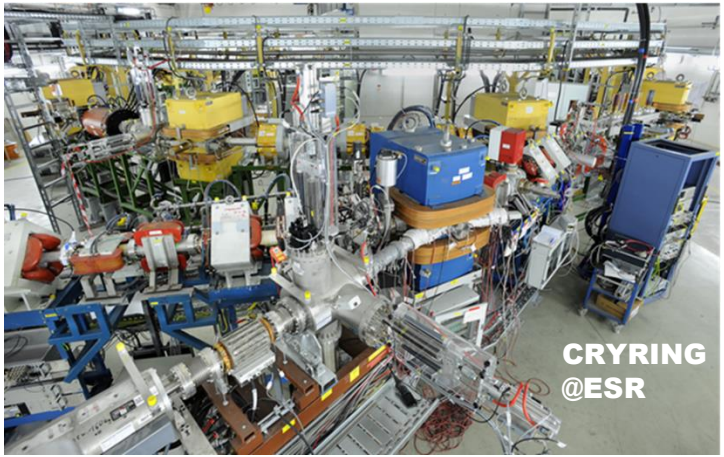


Waiting time 0 hours



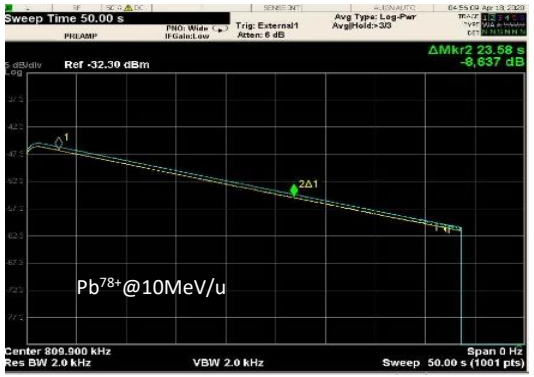
Waiting time 10 hours

Start of FAIR Phase-0 at the Storage Rings: CRYRING@ESR



Beam times

- Mg^{+} : Laser spectroscopy
- D^{+} : Machine studies
- Pb^{78+} from ESR: Xray spectroscopy, DR tests
- Pb^{82+}: X-ray spectroscopy test



✓ **FAIR Phase-0, Spring 2020**: final commissioning goal was achieved highly charged heavy ions from ESR @10 MeV/u) were stored, cooled and decelerated in the CRYRING

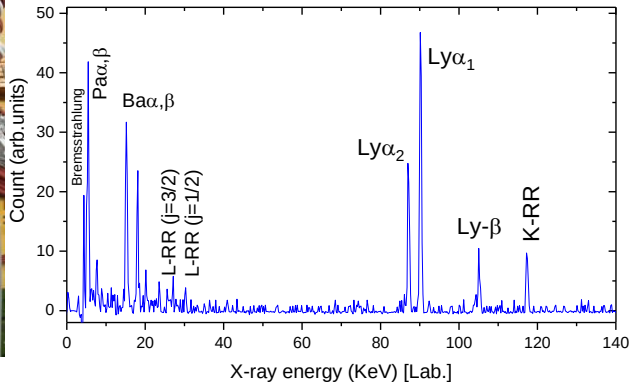
Towards E138 1s Lamb Shift in H-like Uranium

(test of non-perturbative QED on the 1 eV level)

test run for E138 with Pb^{82+}:
X-ray emission at CRYRING@ESR (electron cooler)

$$Pb^{82+} + e^- \rightarrow Pb^{81+} + \hbar\omega$$

X-ray viewport;
Be window



- Viewports at 0 deg and 180 deg
  (conventional Ge(i) detectors)
- Intense Lyman ground-state transitions
- Intense Balmer transitions (not affected by QED)

ESR

400 MeV/u
Stochastic Cooling
Electron Cooling

↓

10 MeV/u
Electron Cooling
Extraction

↓

CRYRING
Injection
Cooling

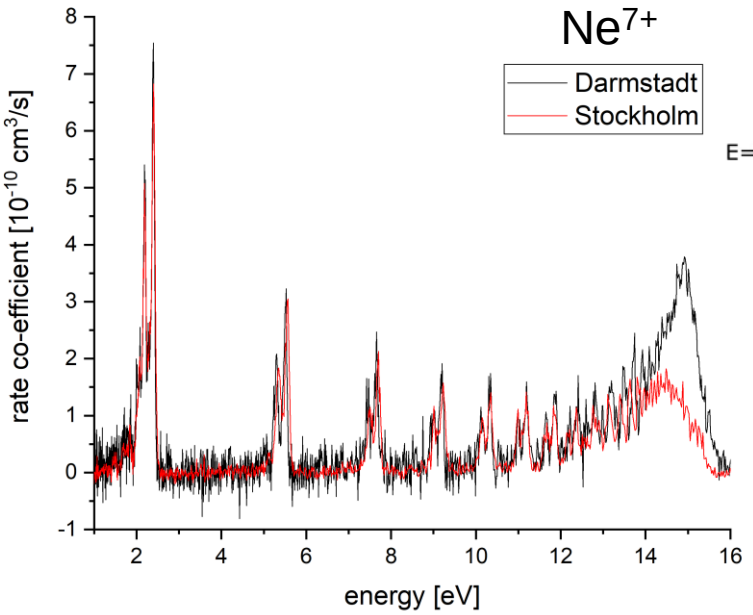
Implementation of novel high-resolution, cryogenic μ-calorimeters with pixel areas
(detectors are currently assembled)

FAIR Phase 0 Research Program

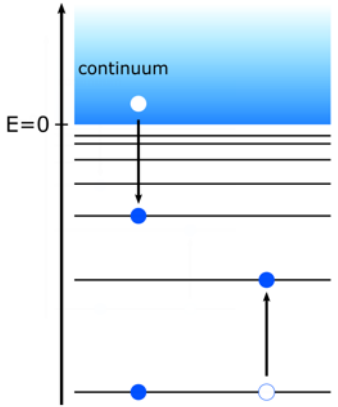
Federal Ministry of Education and Research

CRYRING@ESR: Ne^{7+} DR Measurement

- rate coefficient
  - Stockholm: absolute measurement
  - Darmstadt: relative rates scaled to Stockholm data
- energy shift
  - ~0.2 eV
  - possible causes: calibration and/or measurement method
- more counts at series limit
  - longer flight time and lower dipole field
  - higher ionization cut-off



Dielectronic Recombination

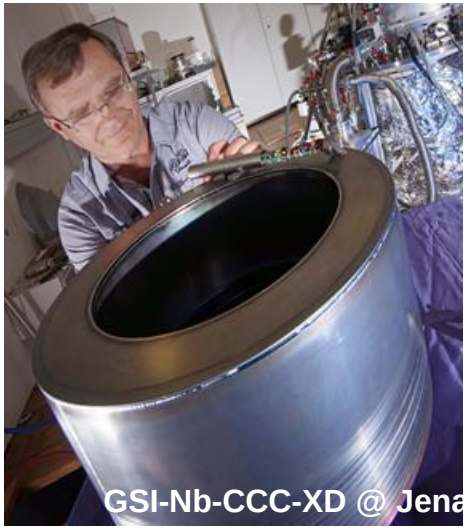


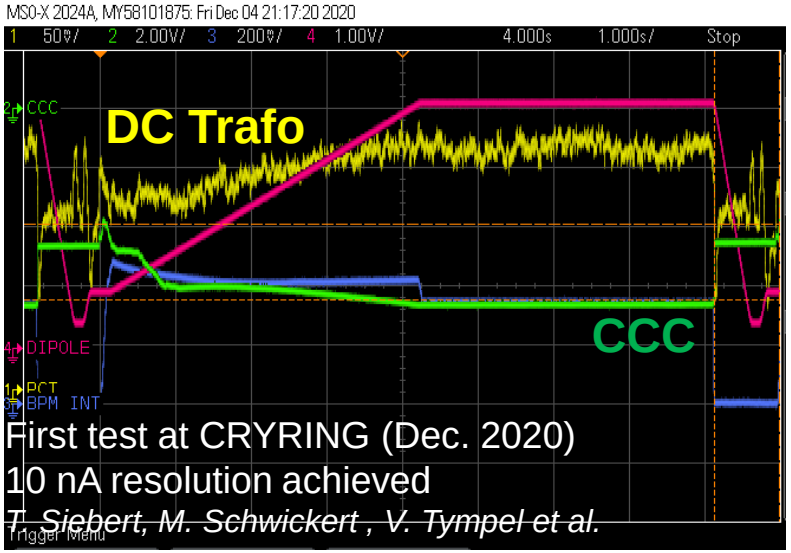
Esther Menz, Michael Lestinsky et al.

Stockholm data from Böhm et al. (2005)
(A&A, **2005***, 437,* 1151-1157)

FAIR beam diagnostics: Cryogenic Current Comparator
Absolut and highly accurate ion current measurements

- **C**ryogenic **C**urrent **C**omparator – e**x**tended **d**imensions
- Non-destructive nA-lab-resolution measured
- FAIR-beamline cryostat test at CRYRING@ESR





First test at CRYRING (Dec. 2020)
10 nA resolution achieved
T. Siebert, M. Schwickert , V. Tympel et al.

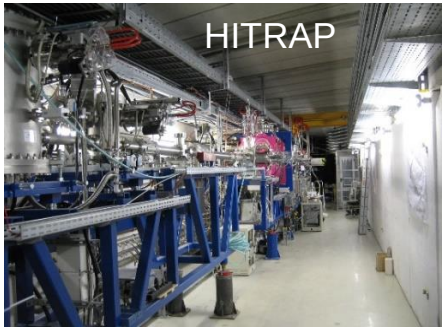
HI JENA HELMHOLTZ Helmholtz Institut Jena

GSI (beam diagnostics)

sparc

Federal Ministry of Education and Research

GPAC 2020 (2021 & 2022): Beam Time Requests and Recommendations



Collaboration	Shifts requested	Recommendations	
	total main+(sec+para)/10	A	A-
APPA / SPARC	927 (153)	420	136

Numbers in parentheses are shifts granted by G-PAC43 to the unchanged **rank A** re-submissions.
Secondary and parasitic shifts count 1/10 of main shifts

17th Topical Workshop of SPARC
(14th to 16th of September 2020, ONLINE)

Topics

- Atomic Collisions with Highly Charged Ions
- Critical and Super-critical Fields
- Laser and X-ray Spectroscopy
- Fundamental constants
- Cross-link between Atomic and Nuclear Physics
- Astrophysics with Highly Charged Ions
- Novel Instrumentation
- Beam times in 2021/2022

SPARC PhD Prize 2020

Zuzana Slavkovská
Goethe University Frankfurt, Germany

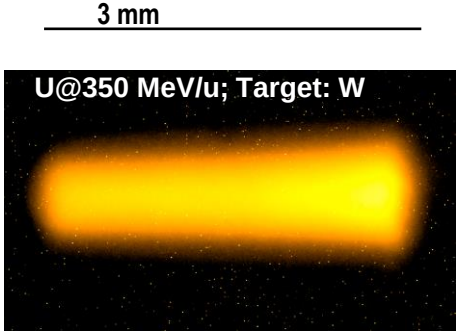
for her thesis

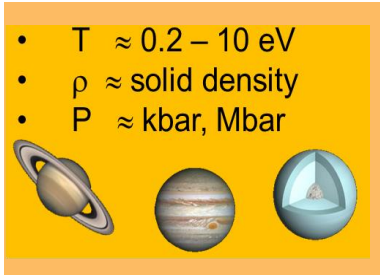
The ^{124}Xe (p,γ) ^{125}Cs Reaction Measured in Inverse Kinematics at a Storage Ring

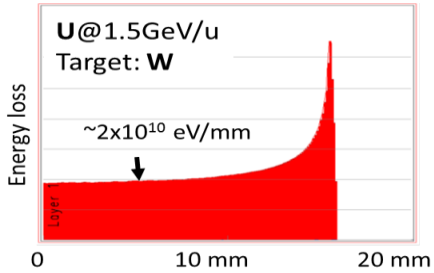
166 participants from 13 countries
18 oral presentation and **66** poster

Plasma Physics at FAIR: HED@FAIR

Interaction of ions and photons with plasmas
Equation of state, phase transitions, transport phenomena
Matter under high pressure
Coupling of intense light with matter







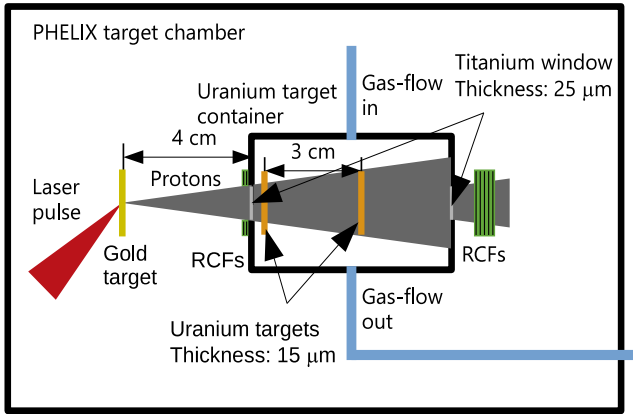
- large volume of sample (mm³)
- fairly uniform physical conditions
- high entropy @ high densities
- high rep. rate and reproducibility
- any target material

- FAIR will produce the largest volume of uniform WDM worldwide.
- Compared to GSI, FAIR will provide a specific intensity and energy deposition increase by a factor of 100.
- FAIR will host the worlds highest resolution proton microscope.

Highlight: Laser-Acceleration at PHELIX

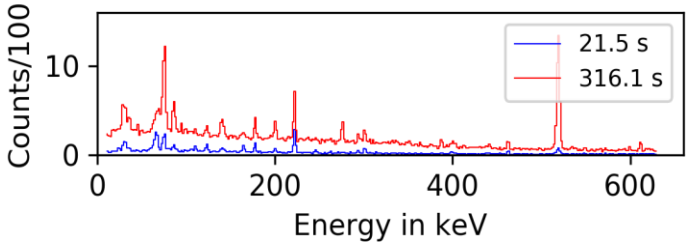
First on-line detection of radioactive fission isotopes produced by laser-accelerated protons

- PHELIX generates high proton flux (10^{12} p^+/pulse)
- Laser-induced nuclear physics
  - Fission in HED Environment
  - Relevant for Nuclear Astrophysics
- Identified short-lived nuclides ^{134}I, ^{136}I, ^{137}Xe, ^{138}Xe, ^{139}Xe and ^{140}Cs (half-lives shorter than 40 s)



PHELIX parameters

Energy: 200 J
Duration: 400 fs



Gamma spectrum

time-resolved spectra facilitate nuclide identification

P. Boller et al., Sci Rep 10 (2020) 17183

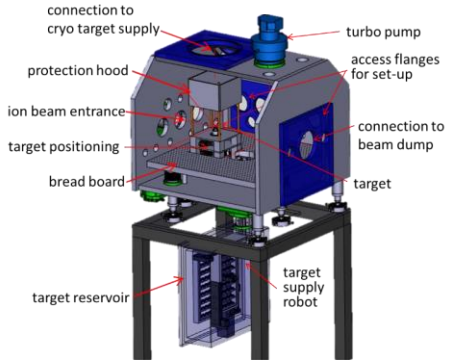
Coupled Laser-Ion Experiments at HHT Scheduled for 2022

Target chamber under construction

Delivery scheduled for spring of 2021

Vacuum components have been ordered

Beam tube & Clean room cabin



Target chamber

Beamline from PHELIX to HHT under construction

Most beam transport tubes have been installed

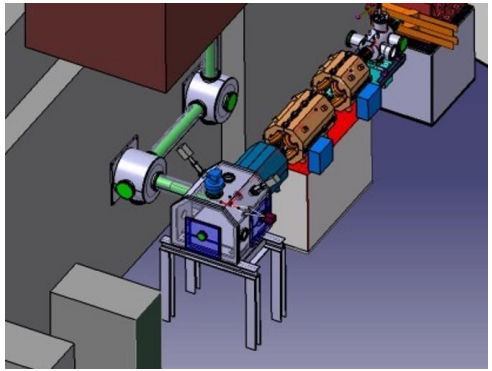
Clean room installed, most optics have been ordered

Commissioning planned for 2021, first coupled experiments in 2022

	2020				2021				2022			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Manufacturing/odering/delivery												
mechanical design												
vacuum components												
cleanroom cabin												
optics												
Implementation												
vacuum components												
cleanroom cabin												
optics												
other (HHTS, PHELIX cleanroom 1000, fire satefy, escape routes)												
Commissioning												
HHTS												
First light at HHT												
Backlighter optimisation at HHT												
Synchronization with ion beam												
Preparations + first HIHEX experiment												

Schedule for beamline to HHT experimental area

Laser beam parameters at HHT
- 200 J
- 527 nm
- 0.33-1 ns,… up to ~10 ns
- 15 cm beam diameter



Setup at HHT experimental area

Federal Ministry of Education and Research

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

TECHNISCHE UNIVERSITÄT DARMSTADT

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

PRIOR – Proton Microscope for FAIR

- Main PRIOR-II components (quadrupole magnets and power converters) are delivered, installed and successfully tested at the HHT area of GSI in Oct 2020
- Beam time proposals for the PRIOR Phase-0 physics experiments are accepted by PPAC/GPAC (S440 and S448)
- Beam time commissioning of the PRIOR-II facility and its first dynamic experiment S440 *“Proton Microscopy of Underwater Electrical Wire Explosion”* are scheduled in Feb 2021

Proposal for Heavy-Ion Heating Experiments Submitted to GPAC

Several different experiment proposals were combined into „community“-proposal

- All experiments use the intense HI-beam volumetrically heat solid targets
- All from members of the HED@FAIR-collaboration
- Vetting & endorsement by collaboration (via CB)

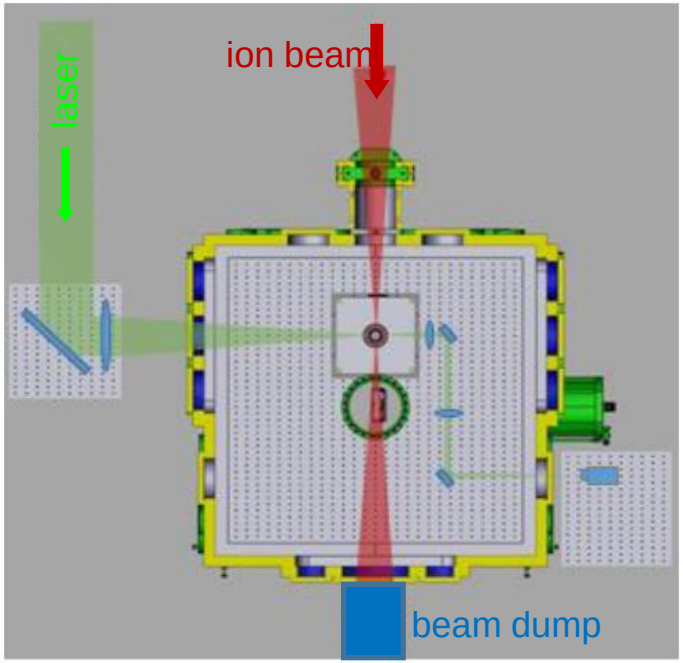
Scientific objectives

- Super-heating of iron (D. Riley, Queen‘s Univ. Belfast) **A**
- Graphitization of diamond (D. Kraus, Univ. Rostock) **A**
- K-edge shifts in WDM (Zhao Y., Xi'an Jiaotong University) **A-**
- High-entropy alloys (M. Tomut, GSU/Univ. Münster) **A-**

combined laser-ion experiments *)

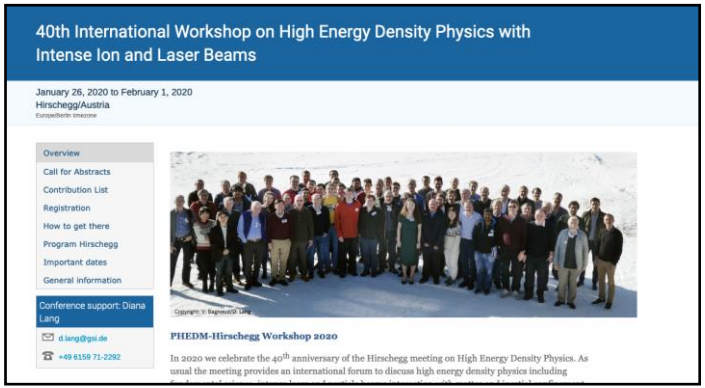
Technical developments

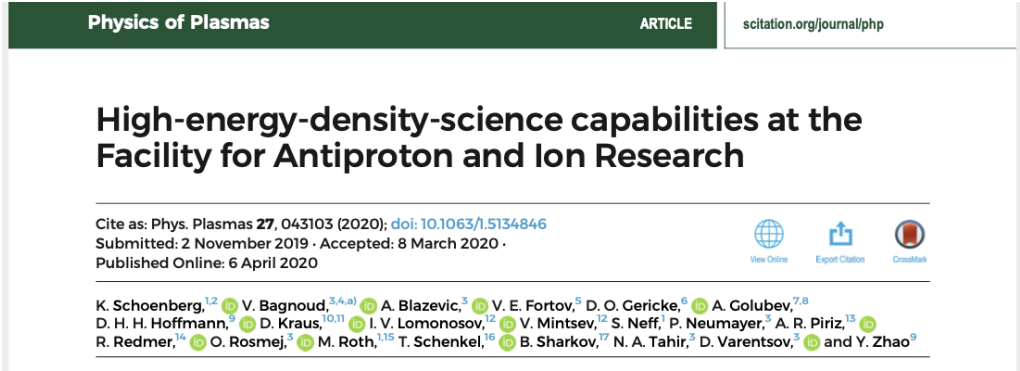
- Commissioning of laser-driven x-ray backlighters **A**
- Exotic states of lead (D. Nikolaev, IPCP Chernogolovka) **A-**
- Windows under HI-irradiation **A-**
- XCOT commisioning **A-**



*) this is „first“ at HHT!

40th High Energy Density Workshop (January 2020) & Paper on Science Program of HED@FAIR





Phys. Plasmas **27**, 043103 (2020)

Topics

- Properties of high energy density matter created (EOS, phase transitions in dense plasmas, transport, and relaxation)
- Beam-plasma interactions (lasers, ion beams, pulsed power)
- Particle acceleration and generation of intense beams
- Relativistic laser-plasma interactions
- Accelerator issues of intense beams
- New and upcoming HED facilities
- Diagnostic methods for high energy density matter
- Experiments at FAIR

APPA: Status of TDR`s and Funding

	APPA	TDR	Cost [k€2005]	Funding	Construction	Date completion	Test/ Commissioning
Day-1	SPARC, CRYRING installation		3,801			04/2017	
	SPARC, CRYRING experiments		2,268			04/2023	
	SPARC in APPA cave		933			09/2023	
	SPARC at SIS100		466			04/2024	
	SPARC at HESR		2,727			07/2024	
	HED@FAIR		6,998			06/2023	
	BIOMAT		1,228			04/2024	
		85.4% *value weighted*	18,421	85.5% *secured*	49.3% *value weighted*		

Collaboration	Total expected	Approved	Submitted	To be submitted	
				for Day 1	in total
	27	19	1	5	7
SPARC	14	11	1	1	2
HED@FAIR	9	8	0	0	1
BIOMAT	4	0	0	4	4

Current BMBF Funding of German University Groups

SPONSORED BY THE
Federal Ministry of Education and Research

EruM-FSP T05 “Aufbau von APPA bei FAIR”

Spokesperson: Stefan Schippers
Justus-Liebig-Universität Gießen

HED @ FAIR & sparc

SPARC, HED@FAIR (2018-2021)
32 applications, 16 funded by the program
“Physics of the Smallest Particles”
coordinated by S. Schippers (Giessen)

6.3 M€ (16 FTE)

MAT Users (2019-2022)
8 applications, 2 funded by the program
“Condensed Matter”
coordinated by M. Schleberger (Duisburg-Essen)

1.4 M€

Applications to BMBF for 2021 - 2024

"Physics of the Smallest Particles"
13 Universities, 32 Projects
SPARC, HED@FAIR
Funds asked for: 15 M€

HED @ FAIR & sparc

WWU MÜNSTER
Universität Rostock Traditio et Innovatio
UNIKASSEL VERSITÄT
LEUPHANA UNIVERSITÄT LÜNEBURG
HUMBOLDT-UNIVERSITÄT ZU BERLIN
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
FRIEDRICH-SCHILLER-UNIVERSITÄT JENA
TECHNISCHE UNIVERSITÄT DRESDEN
GOETHE UNIVERSITÄT FRANKFURT AM MAIN
THM TECHNISCHE HOCHSCHULE MITTELHESSEN
TECHNISCHE UNIVERSITÄT DARMSTADT
UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Thank you for your attention !

Backup

Covid-19 Pandemic impact experiment activities

HED @ FAIR

sparc

- Scheduled beam times for the 2020 block were postponed; beam time 2021 could be also difficult to realize under special corona conditions.
- Participation of university groups to GSI activities: impeded by specific travel and access regulations.
- Experiment Installation and testing on the GSI campus conducted under strict hygiene rules and by strongly reduced manpower.
- In view of the current COVD-19 situation: A dedicated HTML server has been installed (SPARC) to allow for remote participation in online data acquisition and experiment control.