Cosmic Matter Laboratory
FAIR, FZJ, GSI, HIM

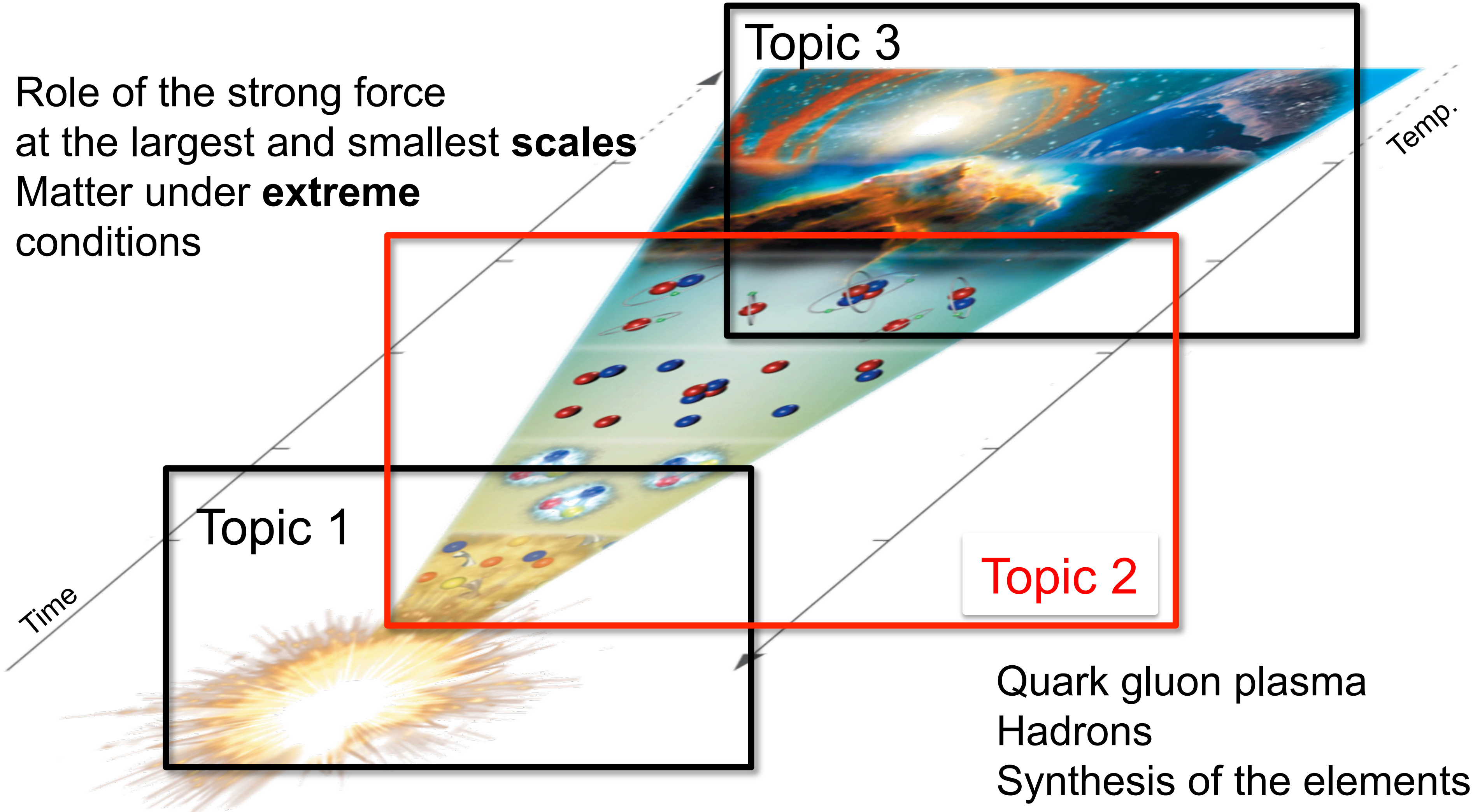
Frank Maas – Helmholtz Institute Mainz

HELMHOLTZ ASSOCIATION


Strong force
Bringing cosmic matter into the laboratory

Evolution of the Universe

Role of the strong force
at the largest and smallest **scales**
Matter under **extreme**
conditions



Quark gluon plasma
Hadrons
Synthesis of the elements

Grand Challenges

- **Emergence** of matter from the strong interaction
- Role of fundamental **symmetries**
- Generation of the **mass of hadrons**
- Complexity of **hadronic structure**
- Properties of matter under **extreme conditions**

Grand Challenges in Strong QCD

- Quark-gluon dynamics and phases in very dense and/ or very hot nuclear matter (“hot QCD”, heavy ion coll.)
- The dynamics, structure and stability of hadrons, the mechanism of hadronization, and strong CP-violation (“cold QCD”, hadron spectrum, hadron structure)
- The generation of complex clusters of elementary matter and chemical elements and the limits of stability for exotic nuclei (“neutron rich”, “proton rich”, “superheavy elements”)
- Test of fundamental symmetries, the symmetry between matter and antimatter (EDMs), beyond standard model searches

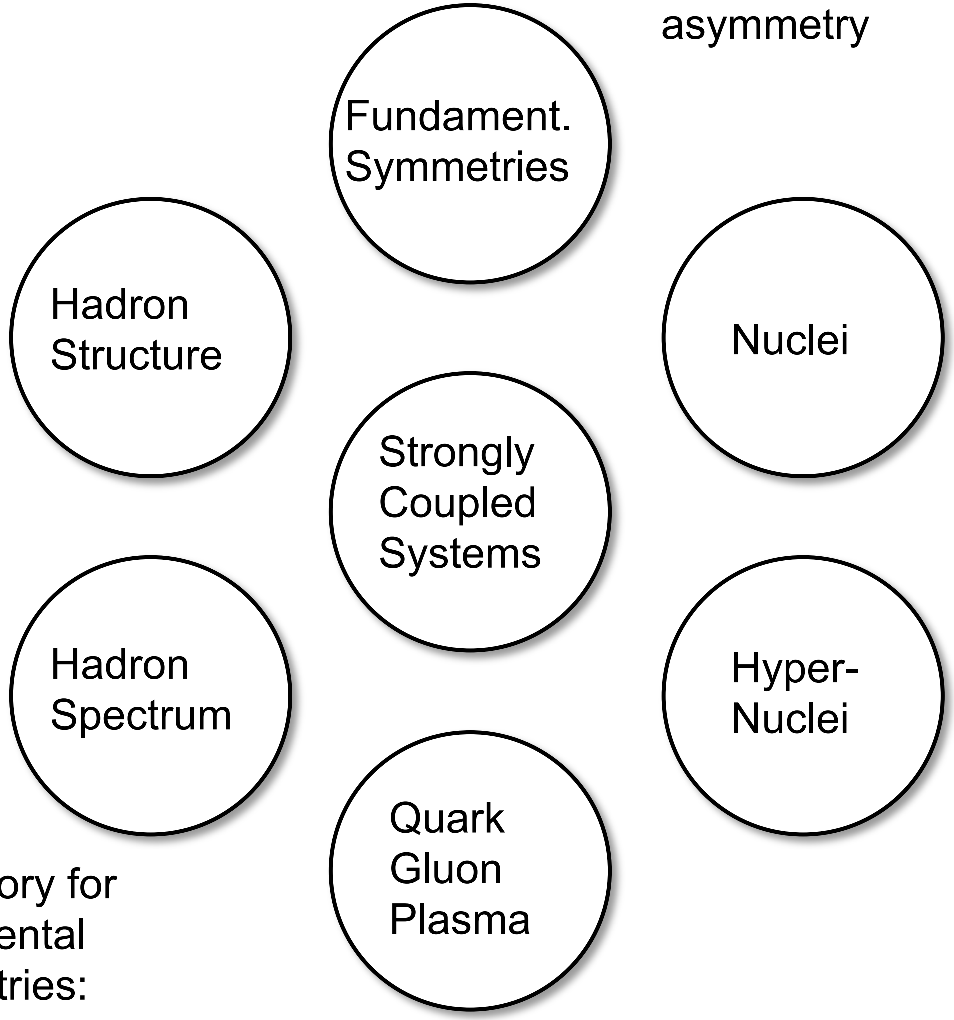
Impact of Strong Interaction Investigations

Matter-Antimatter asymmetry

Hadronic structure as input to high energy frontier: Physics beyond the Standard Model

Laboratory for fundamental symmetries

Industrial, medical Applications



Hadronic structure as input to precision frontier: Physics beyond The Standard Model

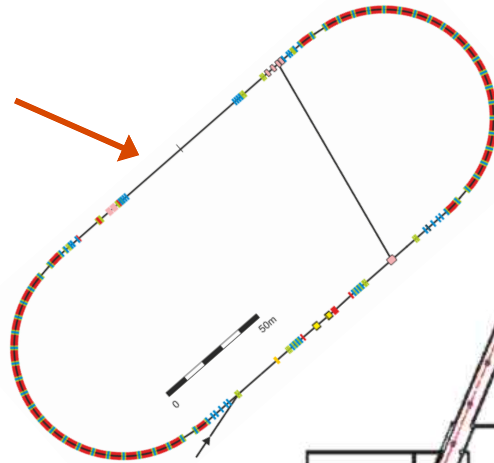
Implications for astrophysics

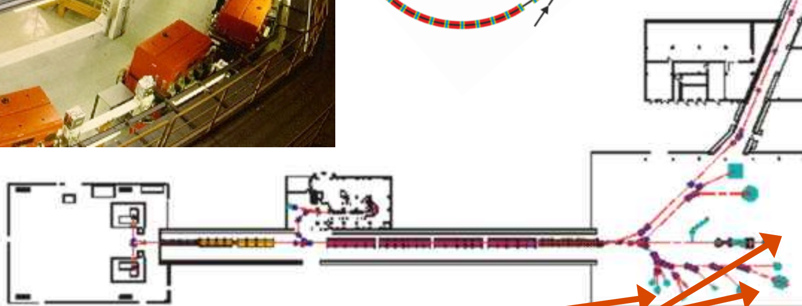
Laboratory for fundamental Symmetries: Physics beyond The Standard Model

Propagation of cosmic radiation

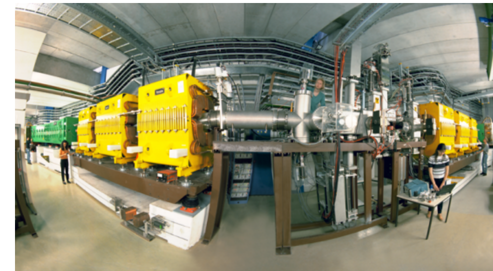
Facilities at FZJ and GSI (not complete)

COSY

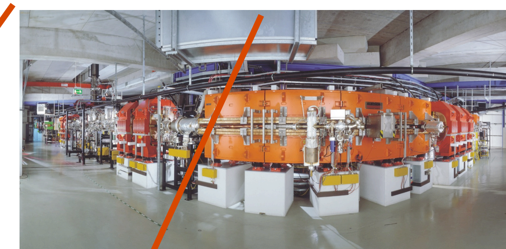




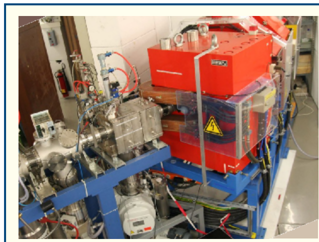
FRS



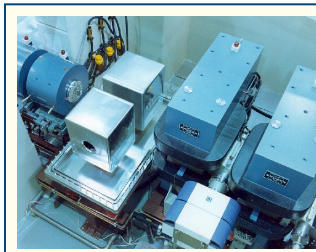
ESR+CRYRING



Artesia TASCA SHIP



TASCA

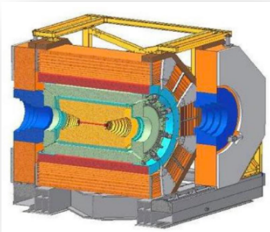


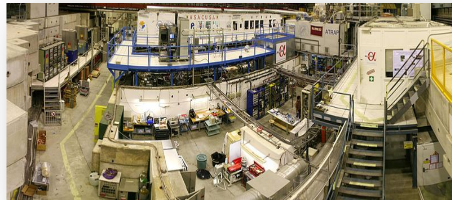
SHIP

HADES

R3B

Additional Infrastructures


Beijing
Electron
Spectrometer

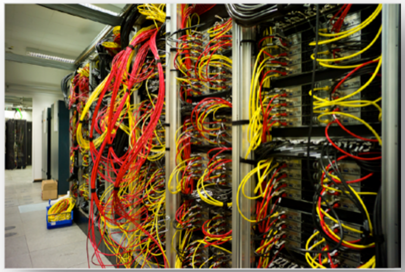

Antiproton
Decelerator
CERN


UNILAC
SIS18
ESR at GSI

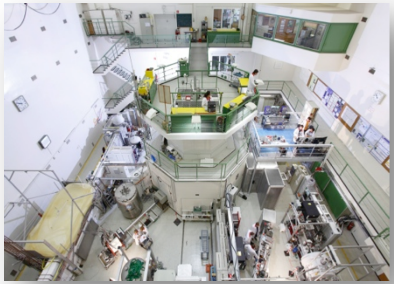

Cooler
Synchrotron
COSY

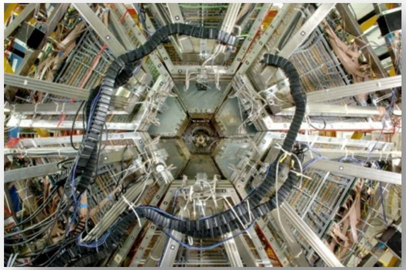

Jülich
Supercomputing
Center


GSI
Compute
Cluster


HIM
Computing


MAMI-C
1.5 GeV electrons


TRIGA
Research reactor


HADES
At GSI


ALICE
at LHC

Upcoming international facility FAIR

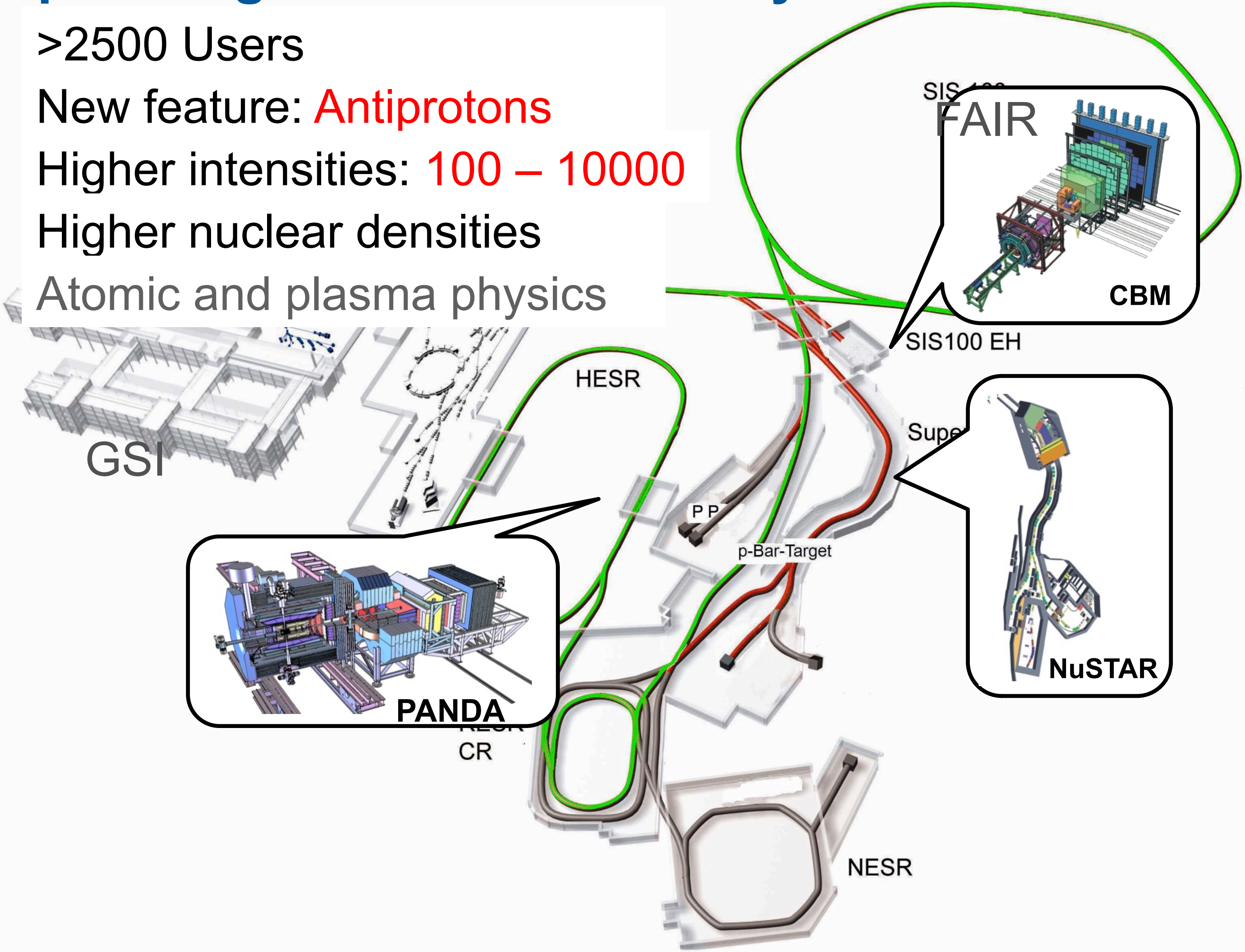
>2500 Users

New feature: Antiprotons

Higher intensities: 100 – 10000

Higher nuclear densities

Atomic and plasma physics



Other aspects

- Interplay between theory and experiment
- PhD-programme: former HGS HIRE is continued
- HIC4FAIR, HIM, EMMI,
- Excellence Initiative: Several proposals for excellence clusters in preparation in Mainz, Darmstadt, Frankfurt

Time schedule during POF-IV

- Start of FAIR operation during POF-IV
- GSI research program in POF-IV using existing facilities and FAIR detectors: FAIR PHASE 0
- During Phase 0: Completion of construction of PHASE 1 experiments (Hades/CBM, NUSTAR, PANDA)
- Research using FAIR and FAIR detectors: FAIR PHASE 1
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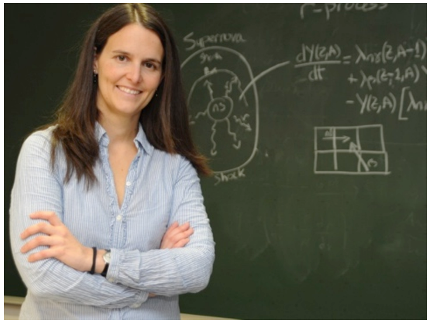


Simulation of nucleosynthesis processes in stellar objects

Almudena Arcones, ERC Starting Grant

Experimental Determination of nuclear properties for stellar nucleosynthesis using storage rings

Yuri Litvinov, ERC Consolidator Grant

Search for transient and oscillating signals from dark matter and dark energy with magnetic resonance and magnetometry (Dark-OST)

Dmitry Budker, ERC Advanced Grant

Search for Electric Dipole Moments using Storage Rings (srEDM)

Hans Ströher, ERC Advanced Grant

COSY – Precision Physics Era

srEDM (Electric Dipole Moments): achievements (JEDI collaboration)

CERN Courier September 2016

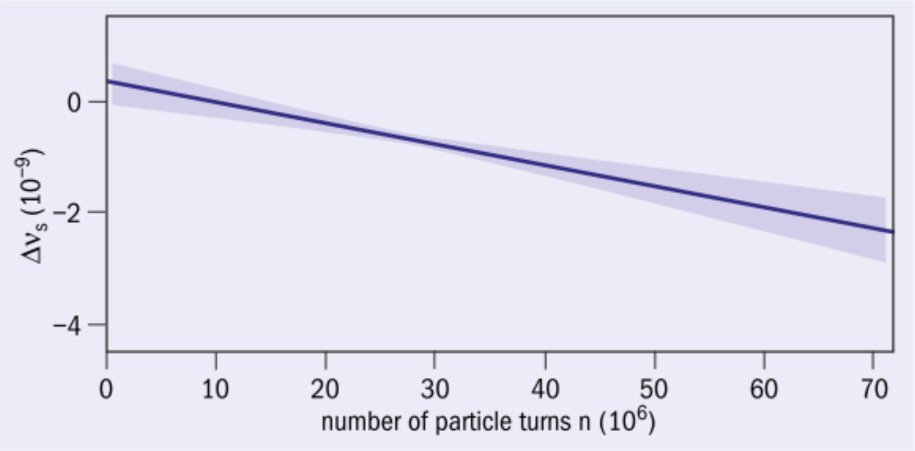


Fig. 2. Deviation of the spin tune ν_s, which is defined as the number of spin precessions per turn, as a function of the number of turns in the ring. At $t = 38$ s (about 28×10^6 turns), the interpolated spin tune amounts to $16097540628.3 \pm 9.7 \times 10^{-11}$, which represents the most precise measurement of this quantity ever performed. The previous best measurement, performed for the muon at the (g–2) experiment, had a precision of 3×10^{-8} per year. The higher precision achieved here is mainly attributed to the much longer measurement time of 100 s compared with 600 μs in the (g–2) experiment.

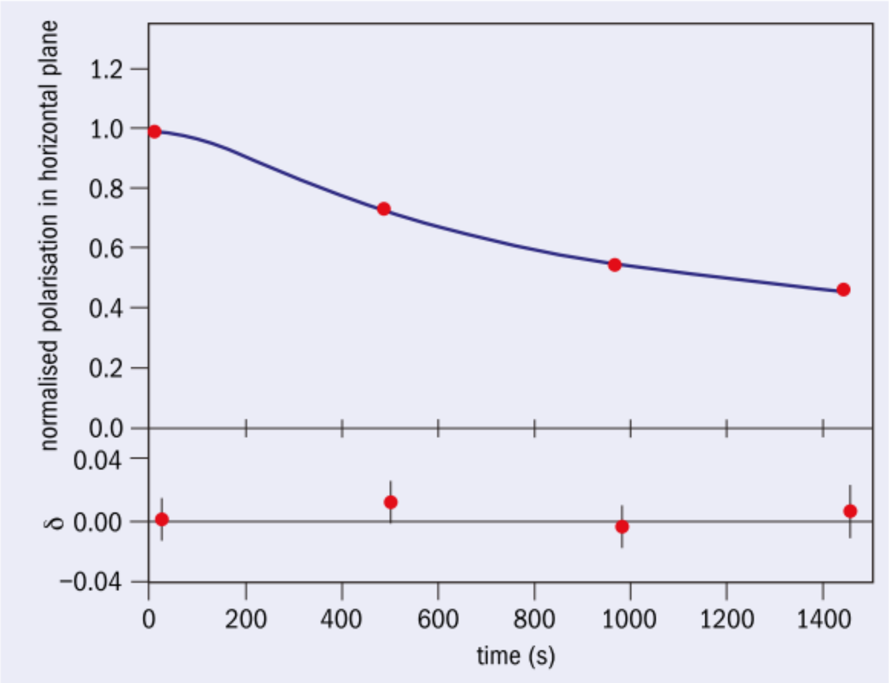
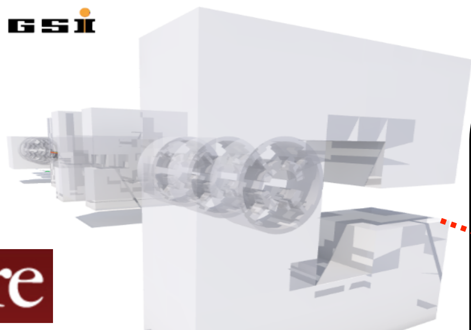


Fig. 3. One of the longest polarisation lifetimes recorded for the COSY ring. Measurements made at four separate times (to conserve beam) are matched to a depolarisation curve that assumes a Gaussian distribution of transverse oscillation amplitudes. The half-life of the polarisation is 1173±172 s, which is three orders of magnitude longer than previous results using electron beams. δ shows the difference between the model and

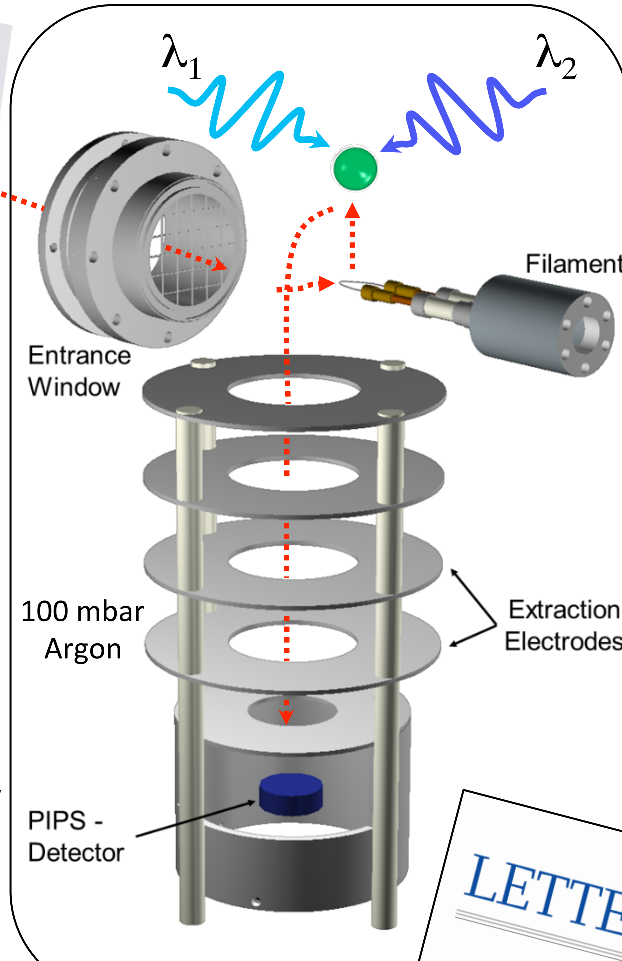
First spectroscopic investigation of nobelium (Z=102)

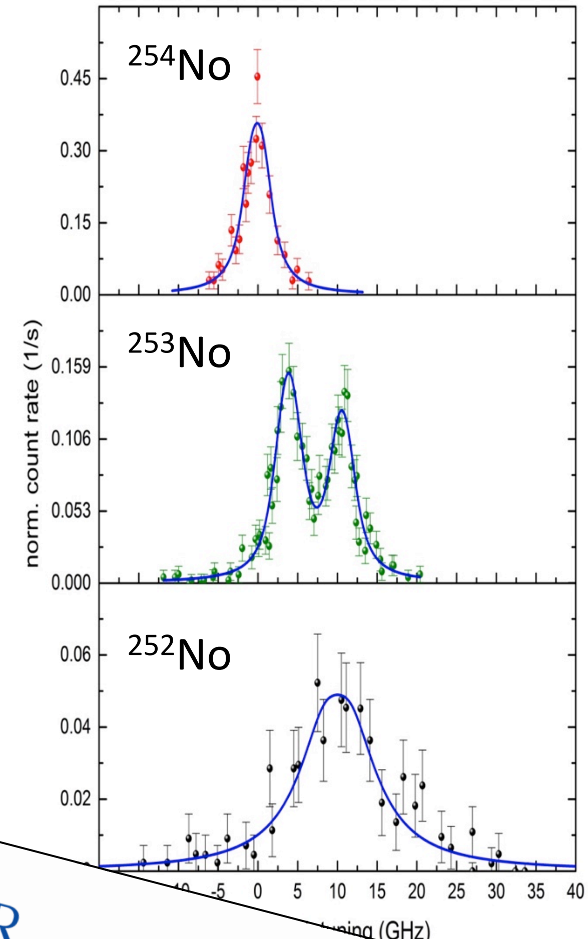


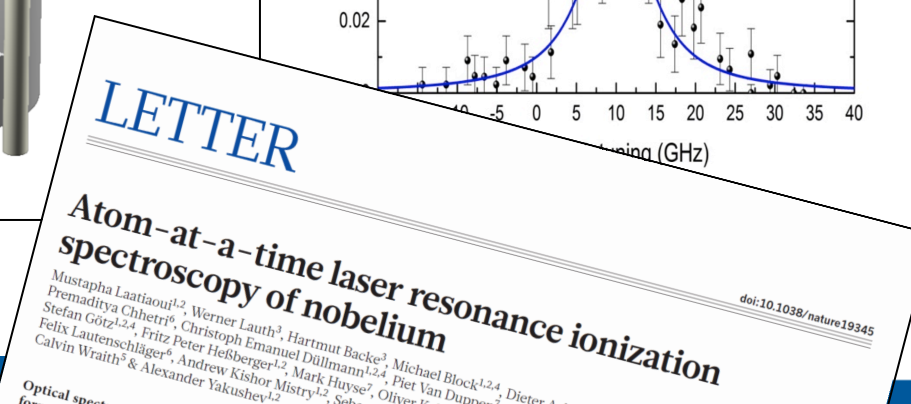
nature
doi:10.1038/nature19345

Achievements:

- First ever successful laser spectroscopy beyond fermium
- Production rates: ~ 1 atom/s
- Overall efficiency up to 10%
- First ionization potential of nobelium precisely measured
- Nuclear spin and moments extracted for the isotope ^{253}No





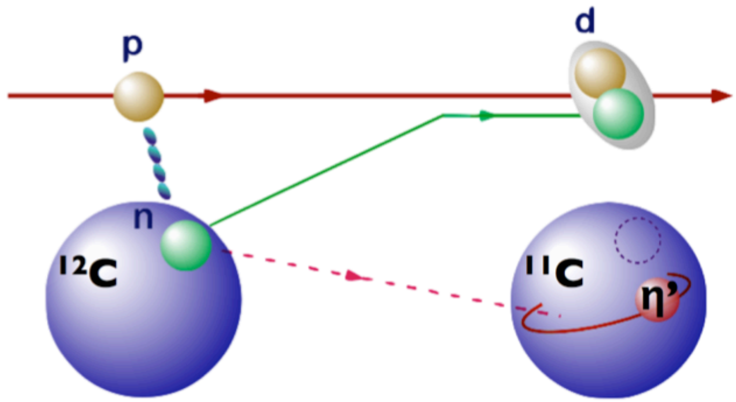

LETTER

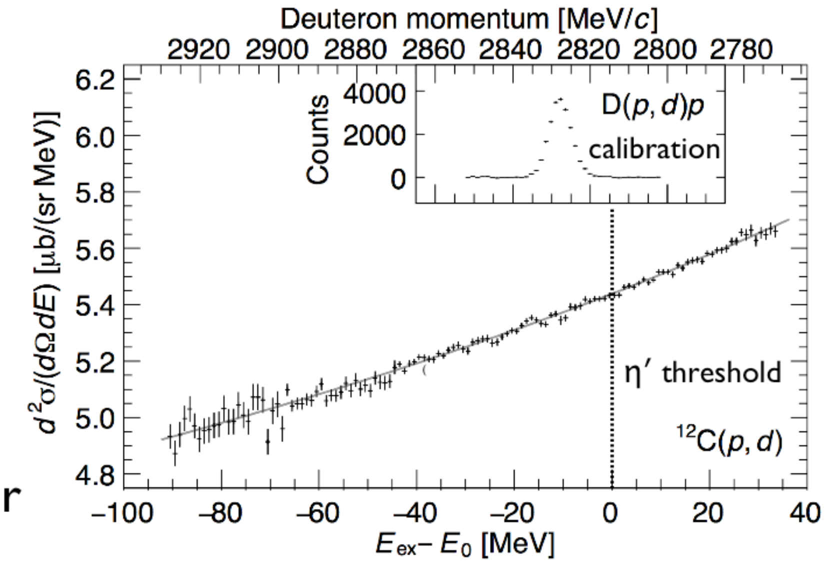
doi:10.1038/nature19345

Atom-at-a-time laser resonance ionization spectroscopy of nobelium

Mustapha Laatiaoui[1,2], Werner Lauth[3], Hartmut Backe[3], Michael Block[1,2,4], Dieter ...
Premaditya Chhetri[6], Christoph Emanuel Düllmann[1,2,4], Piet Van Duppen ...
Stefan Götz[1,2,4], Fritz Peter Heßberger[1,2], Mark Huyse[7], Oliver ...
Felix Lautenschläger[6], Andrew Kishor Mistry[1,2], Seb...
Calvin Wraith[5] & Alexander Yakushev[1,2]

Search for η‘ mesic nuclei by spectroscopy of $^{12}C(p,d)$ reaction with FRS





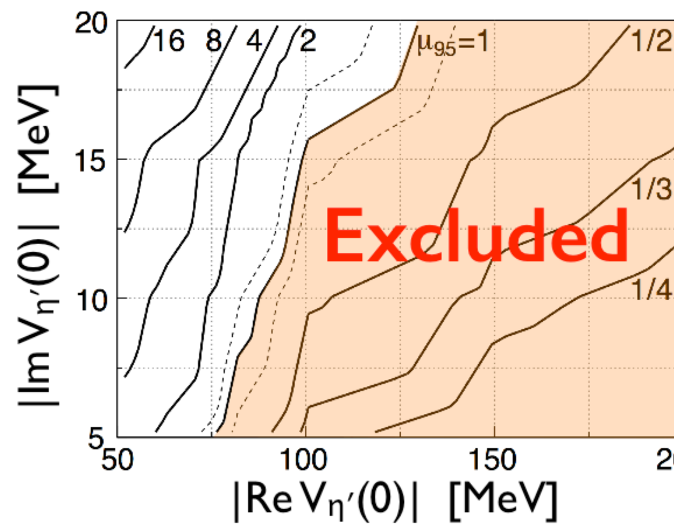
- ◇ FRS used as high-resolution spectrometer
- ◇ extremely good statistics achieved
- ◇ stringent constraints on η′-nucleus potential

PRL 117, 202501 (2016) PHYSICAL REVIEW LETTERS week ending 11 NOVEMBER 2016

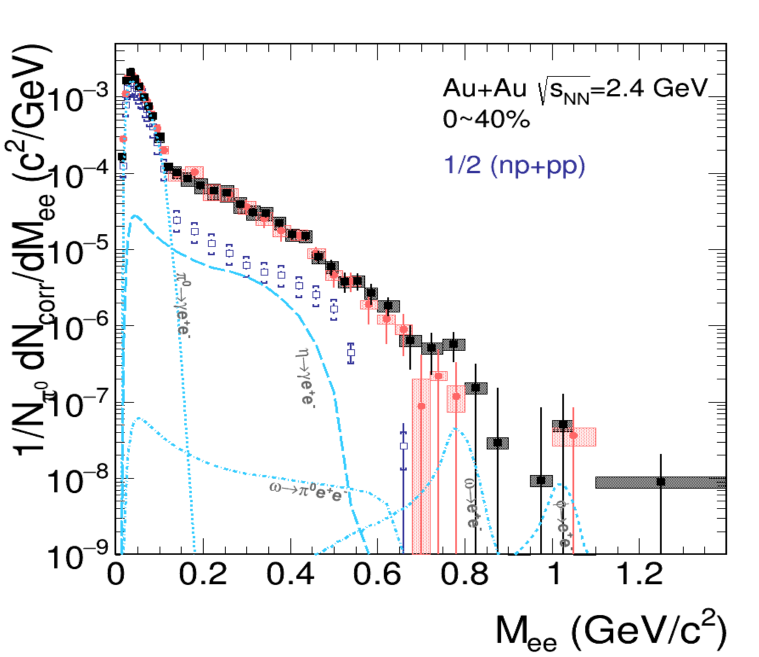
Measurement of Excitation Spectra in the $^{12}C(p, d)$ Reaction near the η' Emission Threshold

Y. K. Tanaka,[1,*] K. Itahashi,[2,†] H. Fujioka,[3,‡] Y. Ayyad,[4] J. Benlliure,[5] K.-T. Brinkmann,[6] S. Friedrich,[6] H. Geissel,[6,7] J. Gellanki,[8] C. Guo,[9] E. Gutz,[6] E. Haettner,[7] M. N. Harakeh,[8] R. S. Hayano,[1] Y. Higashi,[10] S. Hirenzaki,[10] C. Hornung,[6] Y. Igarashi,[11] N. Ikeno,[12] M. Iwasaki,[2] D. Jido,[13] N. Kalantar-Nayestanaki,[8] R. Kanungo,[14] R. Knöbel,[6,7] N. Kurz,[7] V. Metag,[6] I. Mukha,[7] T. Nagae,[3] H. Nagahiro,[10] M. Nanova,[6] T. Nishi,[2] H. J. Ong,[4] S. Pietri,[7] A. Prochazka,[7] C. Rappold,[7] M. P. Reiter,[7] J. L. Rodríguez-Sánchez,[5] C. Scheidenberger,[6,7] H. Simon,[7] B. Sitar,[15] P. Strmen,[15] B. Sun,[9] K. Suzuki,[16] I. Szarka,[15] M. Takechi,[17] I. Tanihata,[4,9] S. Terashima,[9] Y. N. Watanabe,[1] H. Weick,[7] E. Widmann,[16] J. S. Winfield,[7] X. Xu,[6,7] H. Yamakami,[3] and J. Zhao[9]

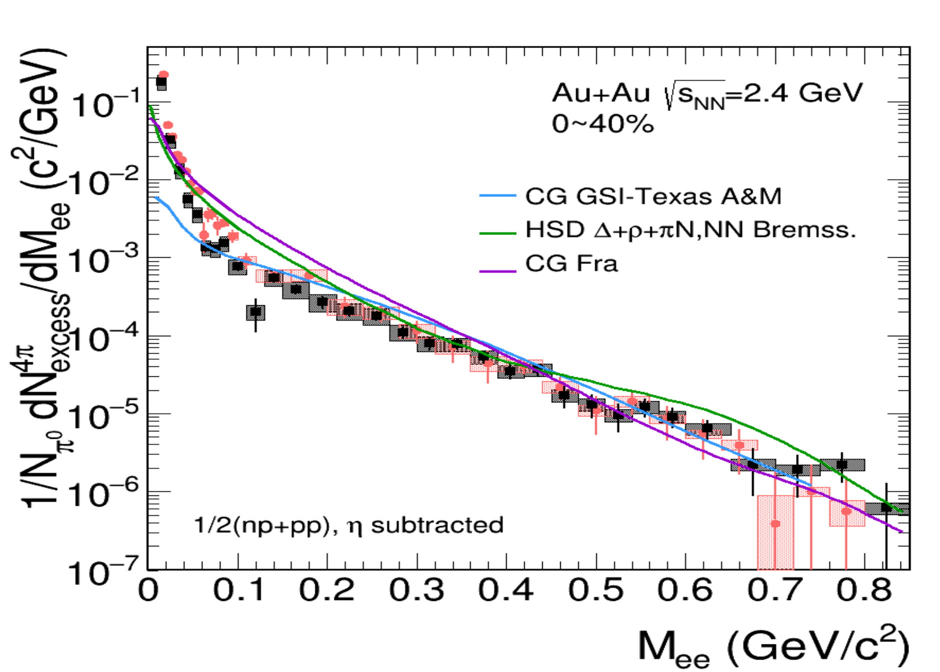
(η-PRiME/Super-FRS Collaboration)



Virtual photon radiation off Au+Au collisions



- Observed **radiation of virtual photons much more intense** as expected from assuming incoherent superposition of photons emitted in NN collisions
  - → Regeneration of baryonic resonances
  - → Strong modification of spectral functions
- Excess yield driven by temperature and size/ lifetime (four-volume integral)



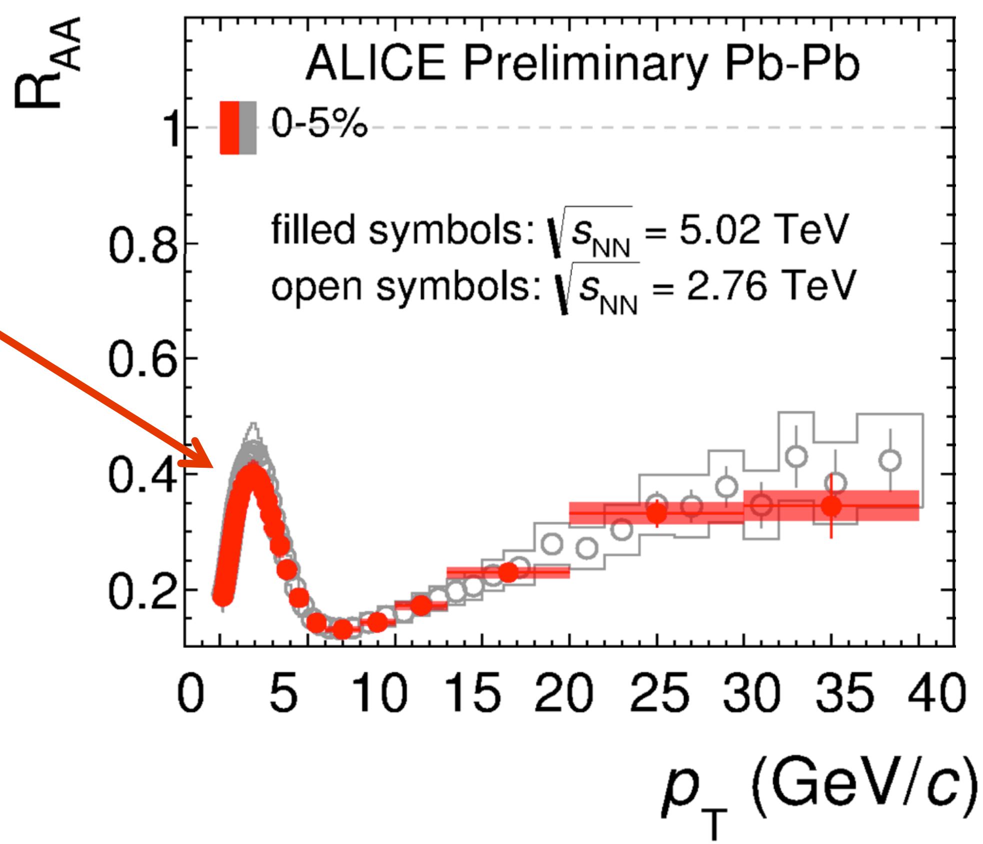
- Inclusive excess mass spectrum
  - all known sources subtracted
  - fully corrected for acceptance
- Almost exponential spectrum up to vector meson region.
- Fit to $dN / dM \propto M^{3/2} \times e^{-M/T}$ → $T_{\text{emitting Source}} = 95 \pm 5$ MeV

ALICE: LHC run 2, Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV

Characteristics of quark-gluon plasma produced at the highest energy ever.

Nuclear modification factor of inclusive charged particles. Substantial reduction of systematic uncertainties wrt previous analyses!

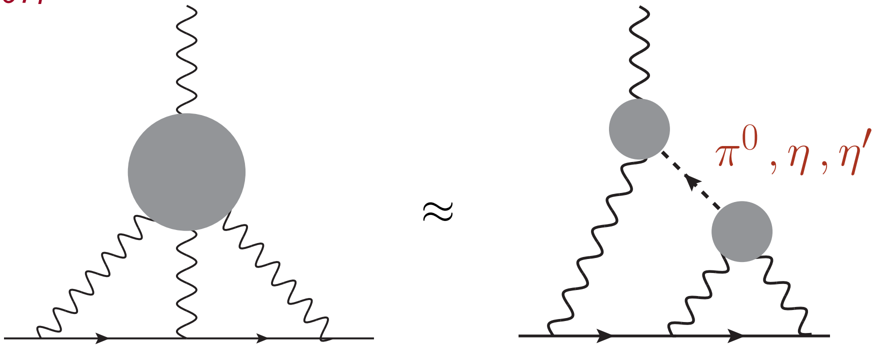
Transverse momentum spectrum harder than at lower energy: similar R_{AA} means **stronger energy loss in denser medium.**



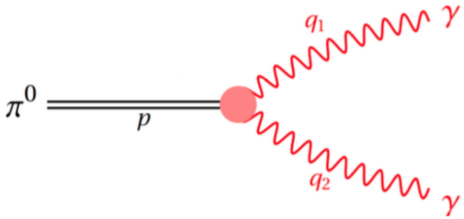
Highlights from Lattice QCD: $(g\text{-}2)_\mu$

[A. Gérardin, H.B. Meyer and A. Nyffeler, Phys Rev D94 (2016) 074507]

- Pseudoscalar meson exchange expected to dominate hadronic light-by-light scattering contribution to the muon *g* – 2



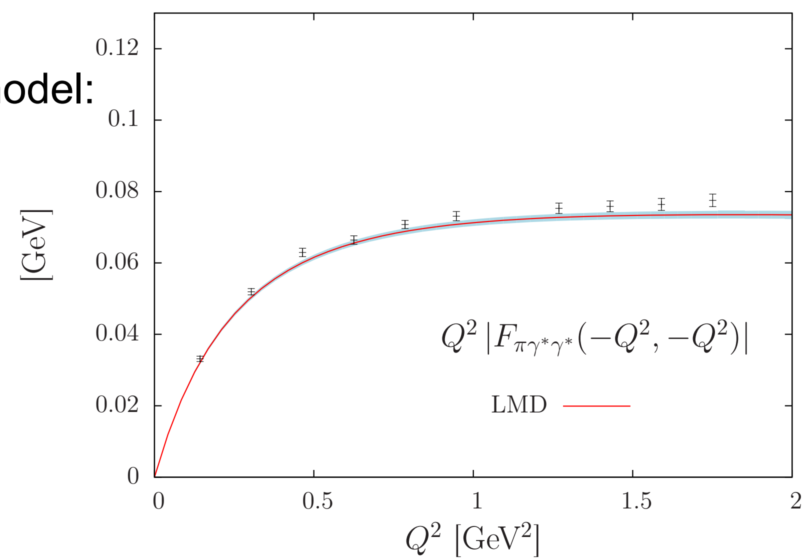
- Compute transition form factor between π^0 and two off-shell photons



$$\epsilon_{\mu\nu\alpha\beta}\, q_1^\alpha q_2^\beta\, \mathcal{F}_{\pi^0\gamma^*\gamma^*}(m_\pi^2; q_1^2, q_2^2) \equiv M_{\mu\nu}$$

- Fit form factor data to lowest meson dominance model:

$$(a_\mu^{\mathrm{hlbl}})_{\pi^0} = \begin{cases} (68.2 \pm 7.4) \cdot 10^{-11} & \text{(LMD)} \\ (65.0 \pm 8.3) \cdot 10^{-11} & \text{(LMD+V)} \end{cases}$$

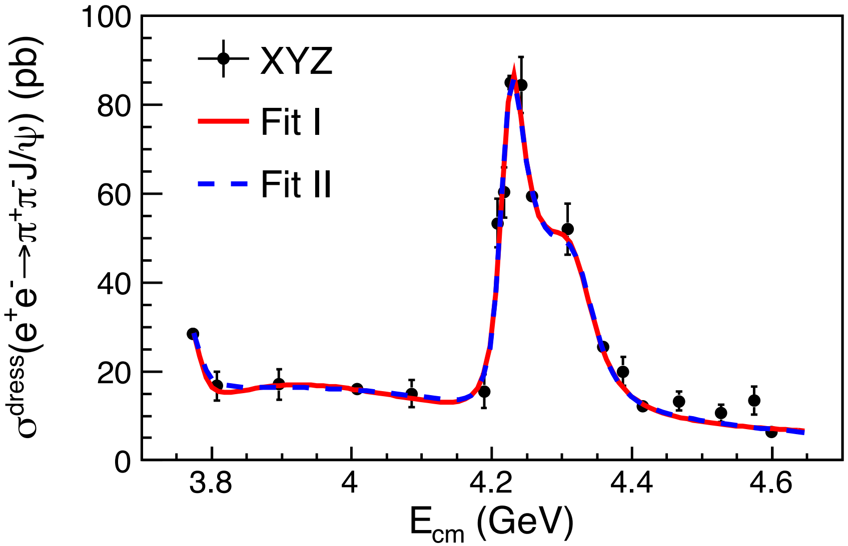


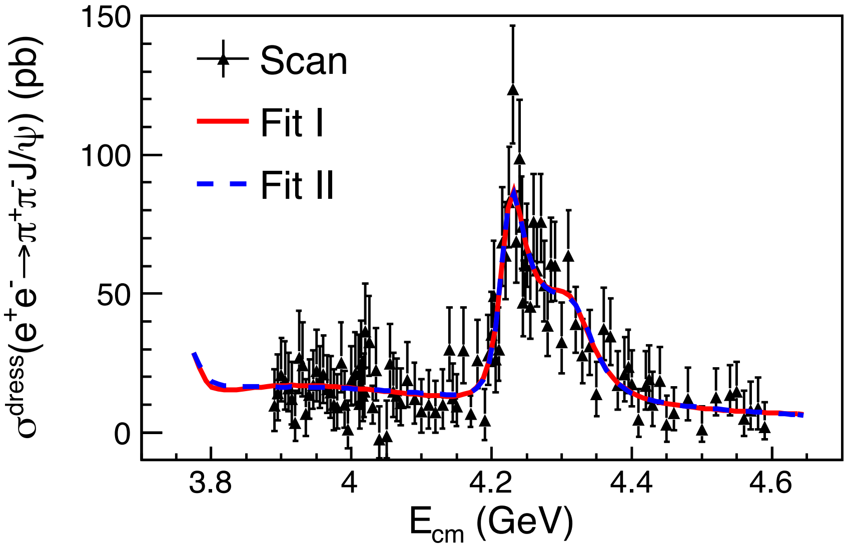
- Pseudoscalar meson exchange contributes about 50% of the estimated total light-by-light scattering part

- Agrees well with phenomenological studies

Highlights from HIM BES-III Analysis: New Resonance discovered

Precise cross section measurement of $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ from 3.77 to 4.60 GeV at BESIII



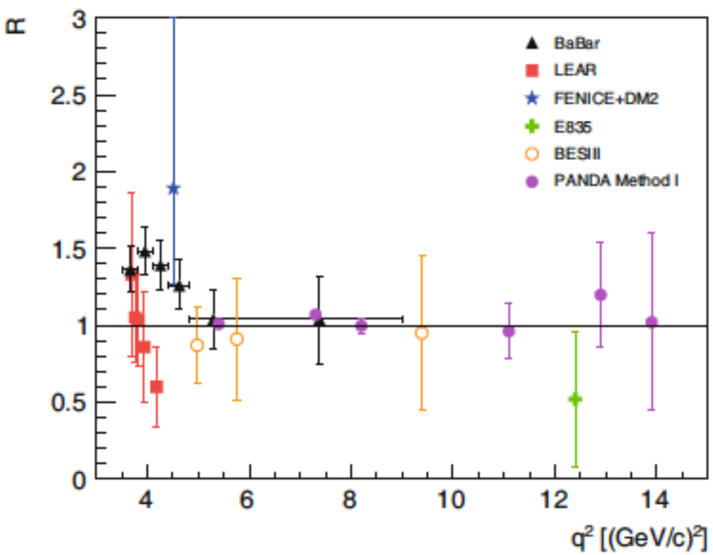


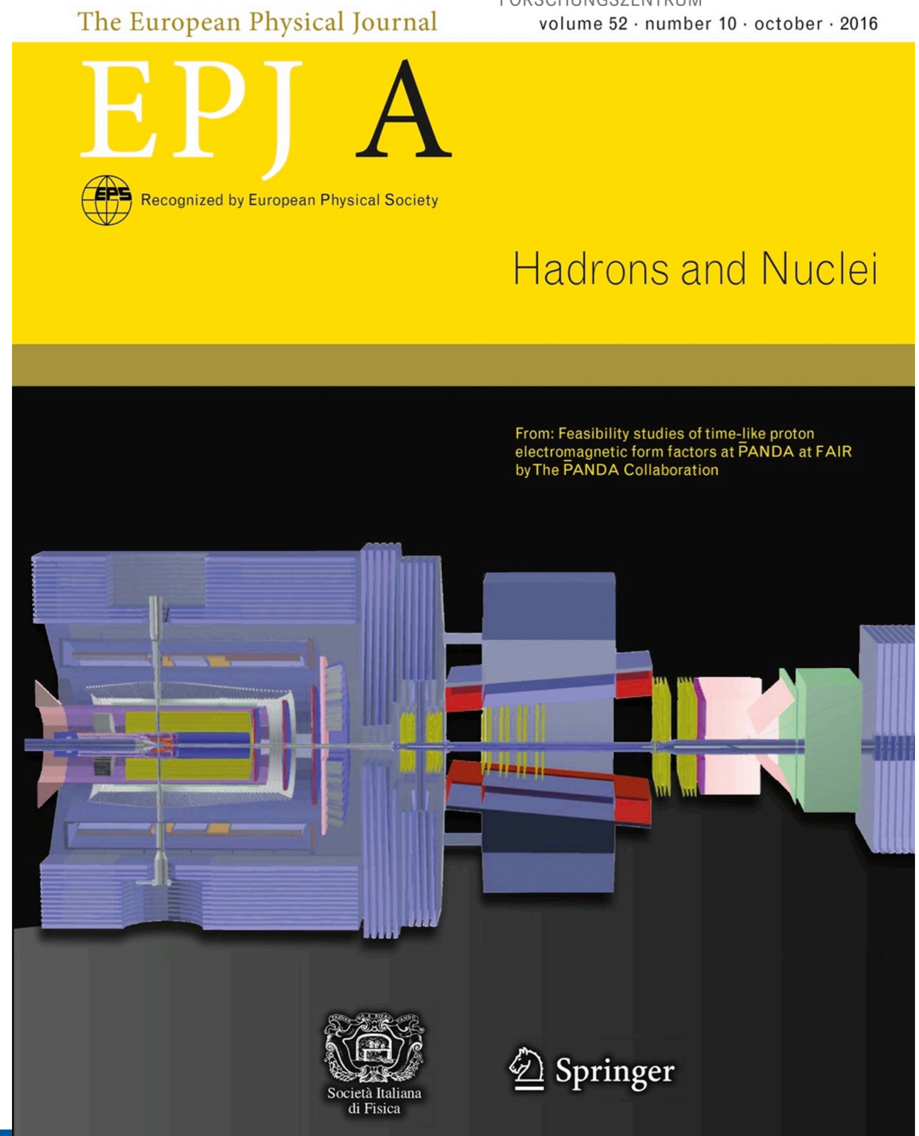
- The $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ cross section was measured with unprecedented precision with BESIII data.
- The mass & width precision of the Y(4260) resonance was improved by a factor of ~3; a new resonance near 4.32 GeV/c^2 was observed for the first time with 7.6σ significance.

arXiv:1611.01317, BES-III collaboration, corresponding author: Z. Liu, HIM

Highlights from studies for PANDA

EPJ A Highlight
COVER EPJA October issue (2016)
“Feasibility studies of time-like proton electromagnetic form factors at PANDA at FAIR”
Corresponding author:
D. Khaneft (PhD-Student HIM)
A. Dbeyssi (Helmholtz-Postdoc HIM)





Time schedule during POF-IV

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