

Atomic Physics Perspectives of SPARC@FAIR



Stored Particles Atomic Physics Research Collaboration

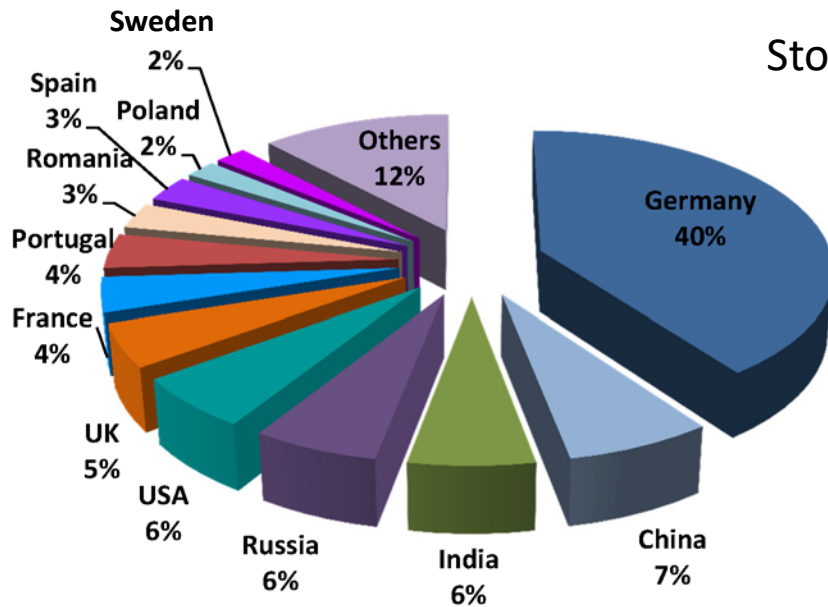
Stefan Schippers



On behalf of the SPARC collaboration

Atomic Physics: The SPARC Collaboration

Stored Particles Atomic Physics Research Collaboration



419 members



13th SPARC Topical Workshop, 16-20 September 2016, Krakow, Poland

SPARC in Germany

APPA R&D „Verbundforschung“

<http://appa-rd.fair-center.eu>



SPONSORED BY THE



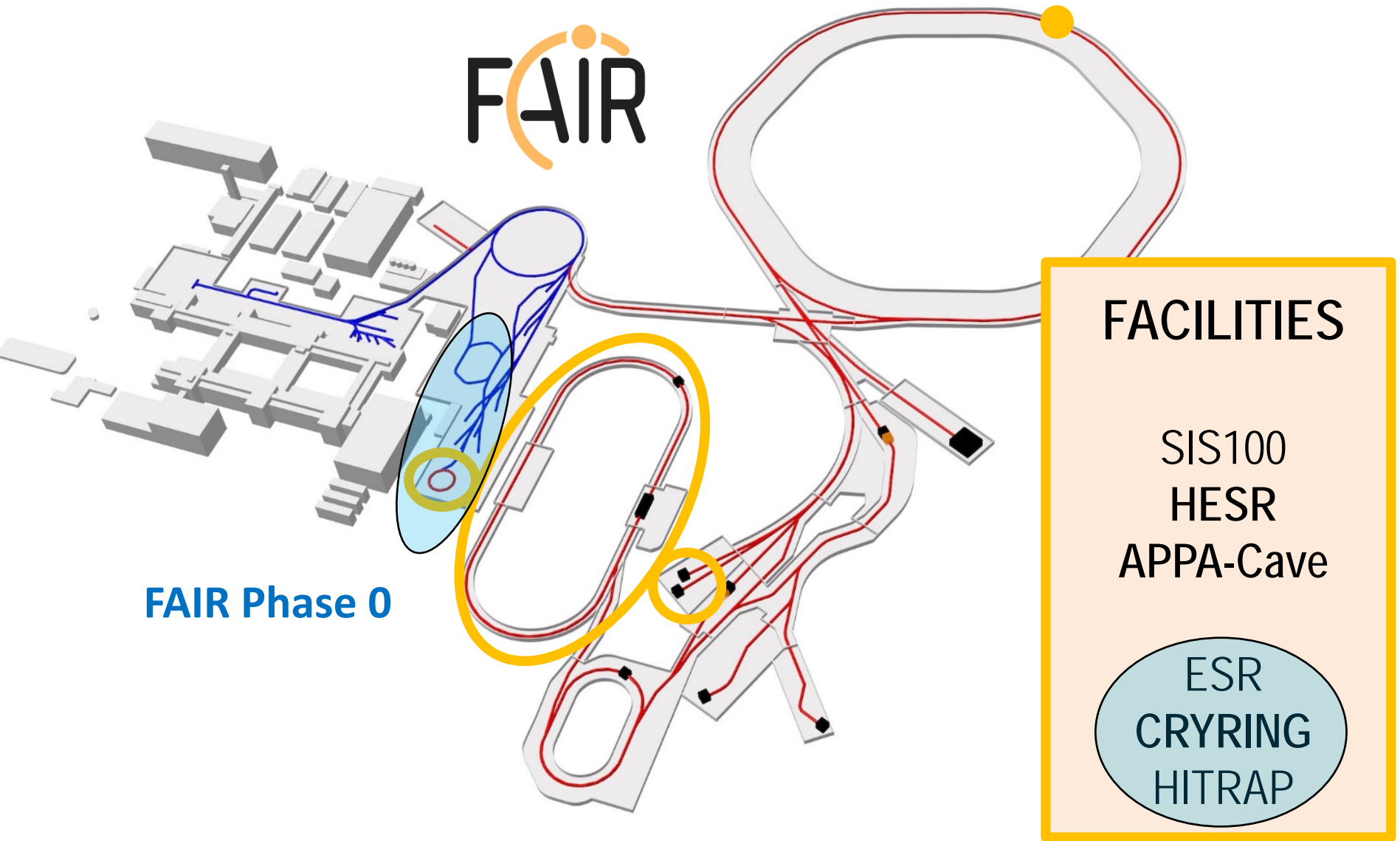
Federal Ministry
of Education
and Research

SPARC, PLASMA

22 funded proposals (2015-2018)

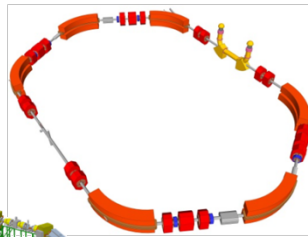
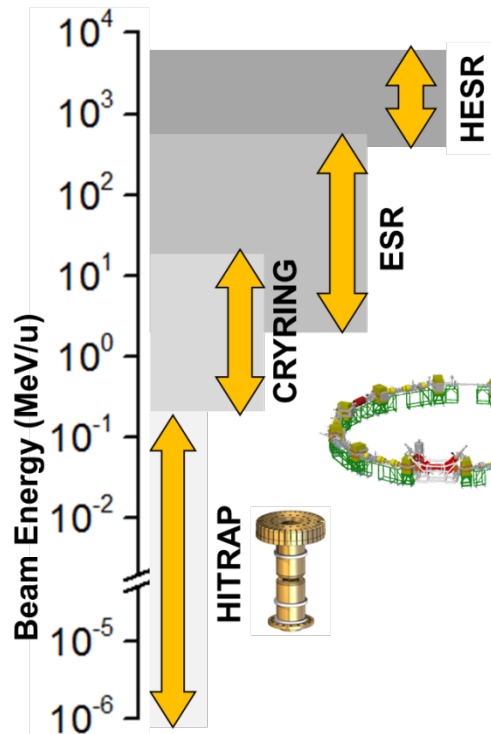
“Physik der kleinsten Teilchen”

BMBF has committed itself to provide
“Verbundforschung” funds for
SPARC experiments at FAIR amounting
to **2.38 M€** (in prices of 2005).

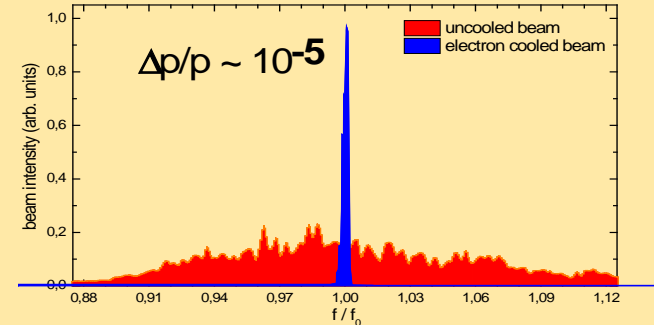


Worldwide
Unique

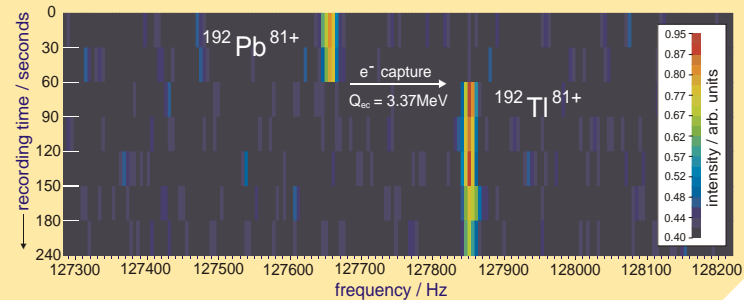
Stored and Cooled
Highly-Charged Ions (e.g. U^{92+}) and Exotic Nuclei
From Rest to Relativistic Energies (up to 4.9 GeV/u)



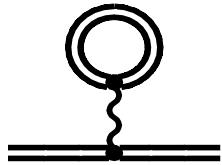
Cooling: The Key for Precision



From Single Ions to Highest Intensities



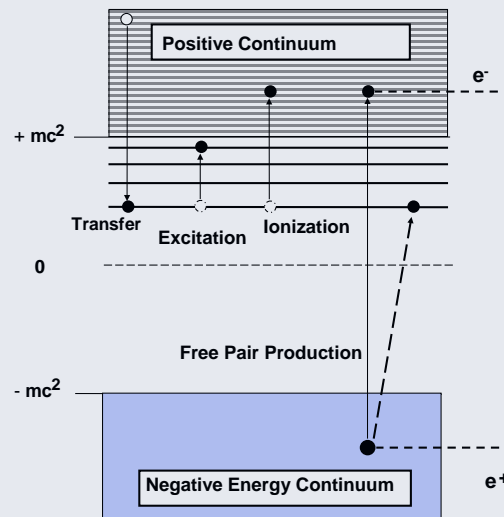
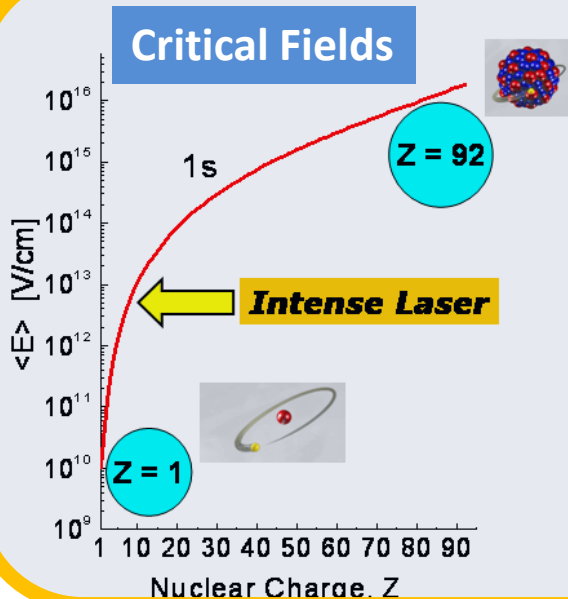
Interplay between Relativity, Correlation, and QED in the Non-Perturbative Regime



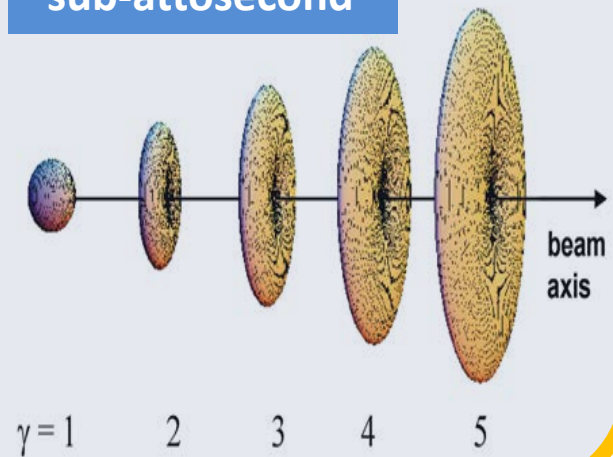
$$\alpha Z \approx 1$$



- Radiative corrections in the non-perturbative regime
- Correlated multi-body dynamics for atoms and ions
- Precision determination of fundamental constants
- Influence of atomic structure on nuclear decay properties



Ultrashort Pulses "sub-attosecond"



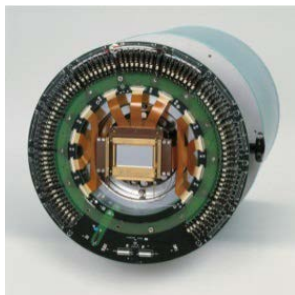
Sophisticated & Versatile Instrumentation



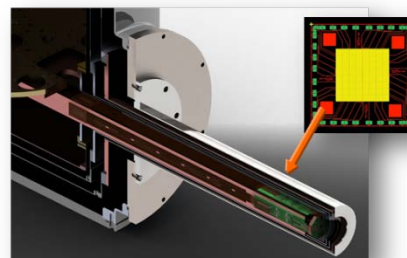
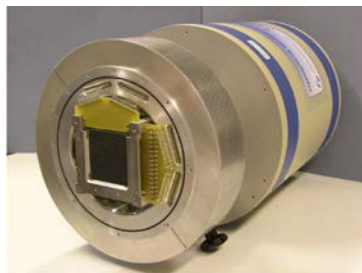
Observables: Photons, electrons, positrons, ions



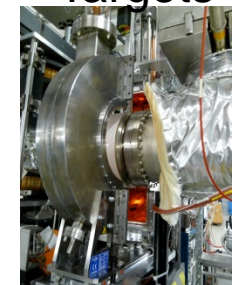
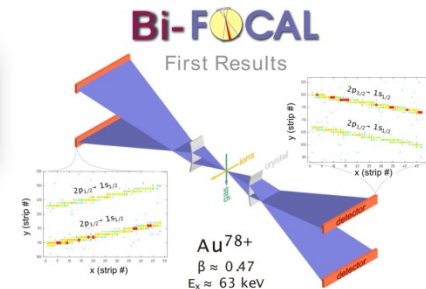
Targets



Position-sensitive solid-state detectors



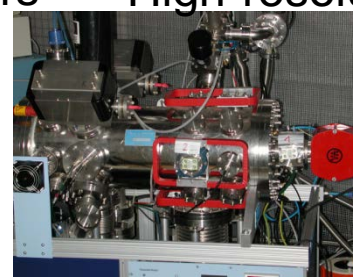
High-resolution spectrometers



Particle detectors



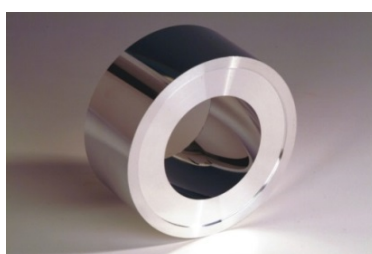
Particle spectrometers



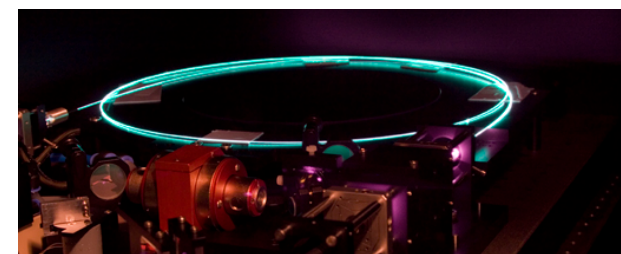
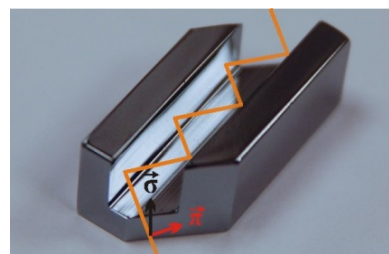
High pressure cell



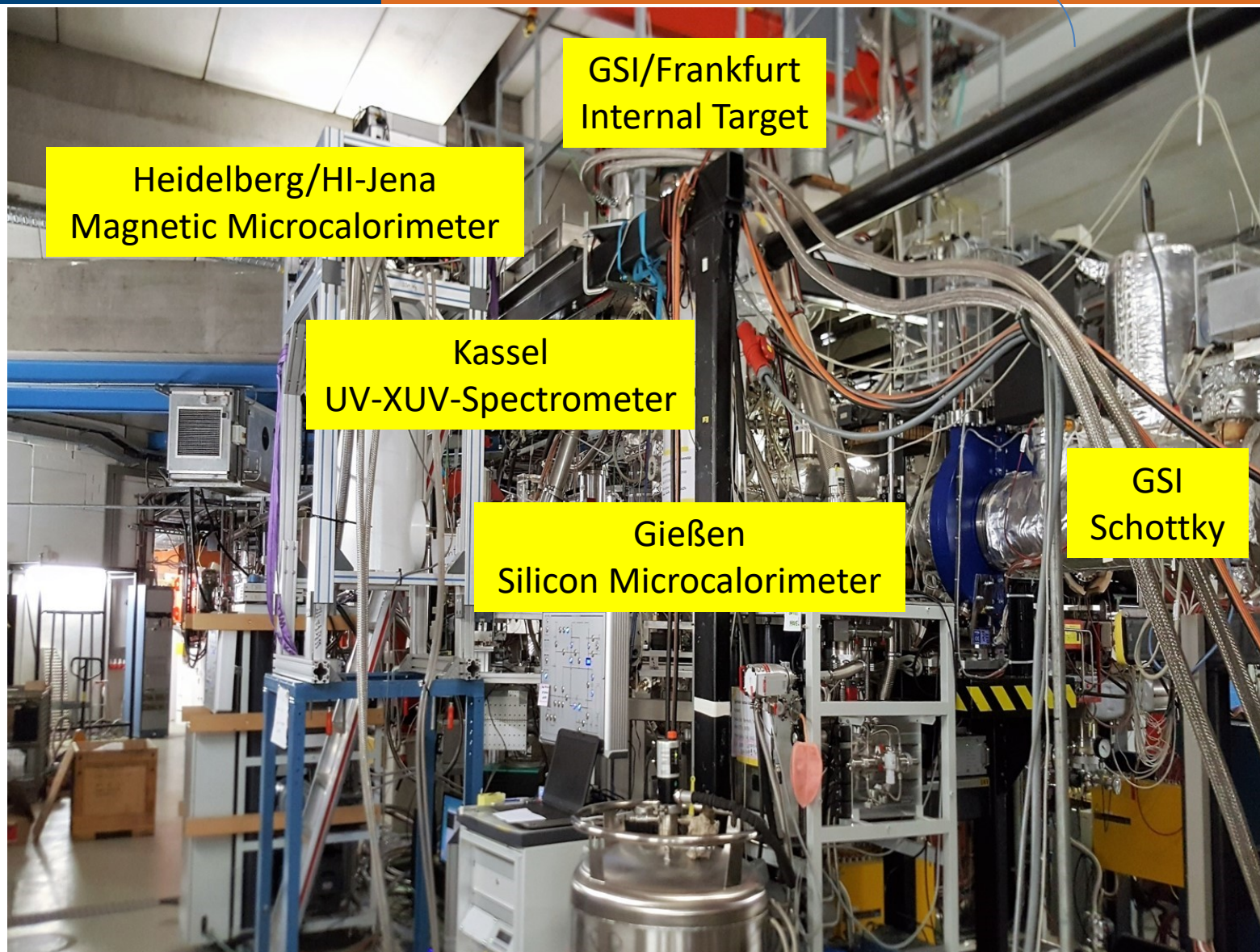
Traps



X-ray optics, channel-cut crystals



Laser systems



Heidelberg/HI-Jena
Magnetic Microcalorimeter

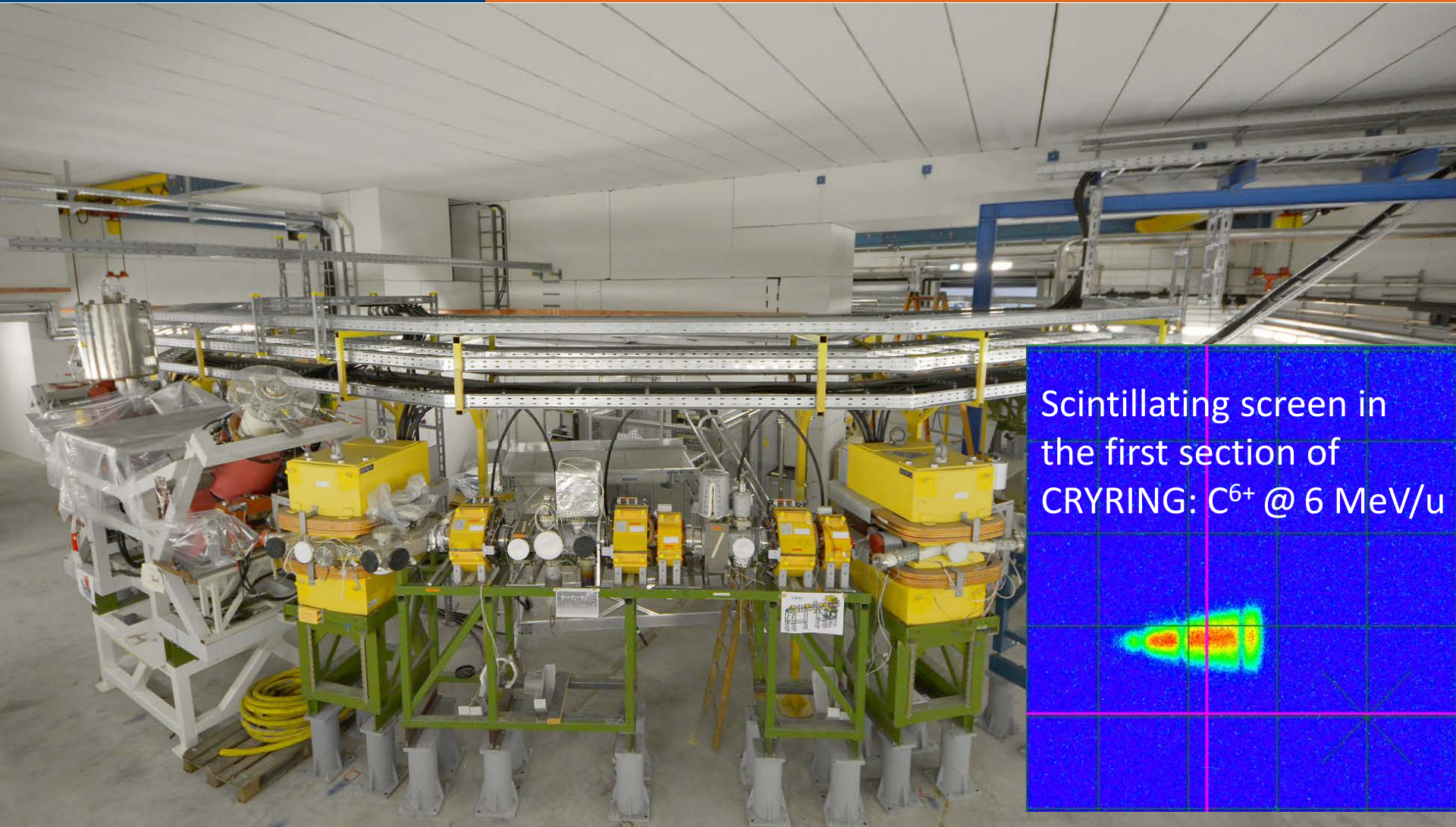
GSI/Frankfurt
Internal Target

Kassel
UV-XUV-Spectrometer

Gießen
Silicon Microcalorimeter

GSI
Schottky

FAIR Phase 0: CRYRING@ESR



Scintillating screen in
the first section of
CRYRING: C^{6+} @ 6 MeV/u

Beam completed first turn on October 26, 2016

Commissioning ongoing

FAIR Phase 0: CRYRING@ESR



The European Physical Journal

EPJ ST

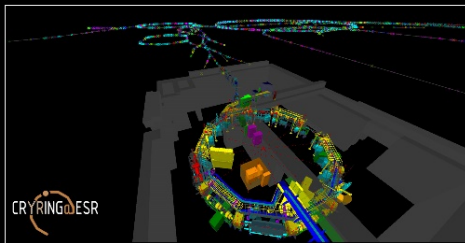


Recognized by European Physical Society

Special Topics

Physics book: CRYRING@ESR

M. Lestinsky, Y. Litvinov and T. Stöhlker (Eds.)



edp sciences

Springer

EPJ ST **225**, 797 (2016)

Precision X-ray spectroscopy

Electron-ion collision spectroscopy

Laser spectroscopy

Photoionization of stored ions

Atomic lifetimes

Supercritical fields

Polarization spectroscopy of hyperfine transitions

Magnetic interaction and retardation effects

Inelastic Electron Scattering in Inverse Kinematics

High-energy endpoint of bremsstrahlung

Complete atomic fragmentation in heavy-ion collisions

Collision of highly-charged ions with a hot, dense plasma

Laser-induced recombination: Inverse above threshold ionization

Nuclear properties of stable nuclei and radio-isotopes

Search for the NEEC process

Laser-induced polarization of ions in storage rings

Combining laser spectroscopy with dielectronic recombination

FAIR Phase 0

Beam completed first turn on October 26, 2016

Commissioning ongoing

Using novel XUV laser systems, e.g. Li-like ions up to uranium are accessible !

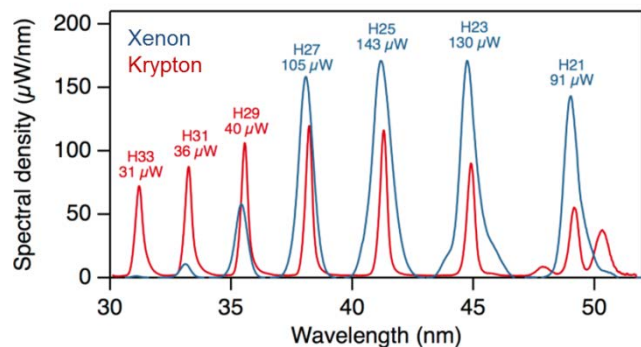
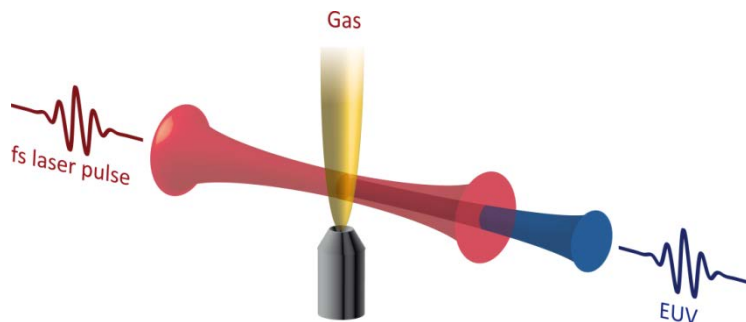
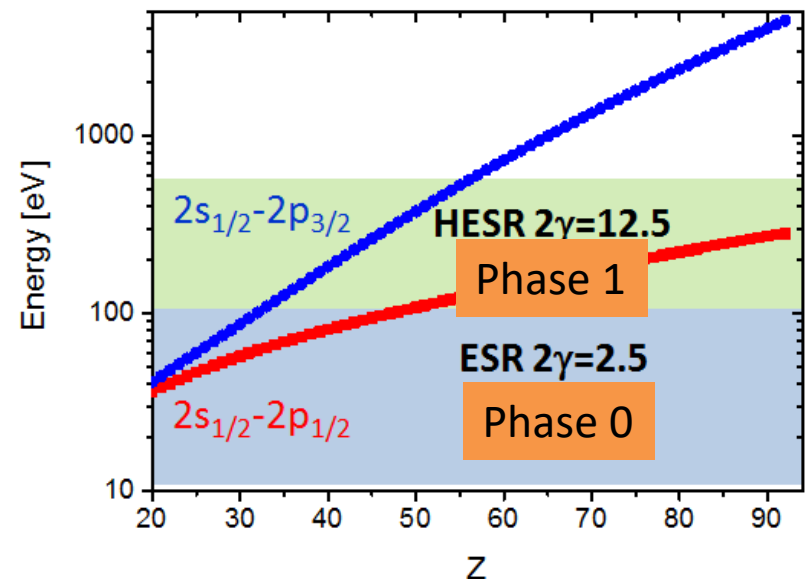


table-top source of high photon flux
fs and attosecond pulses

$$\omega = 2\gamma\omega_{\text{lab}}$$

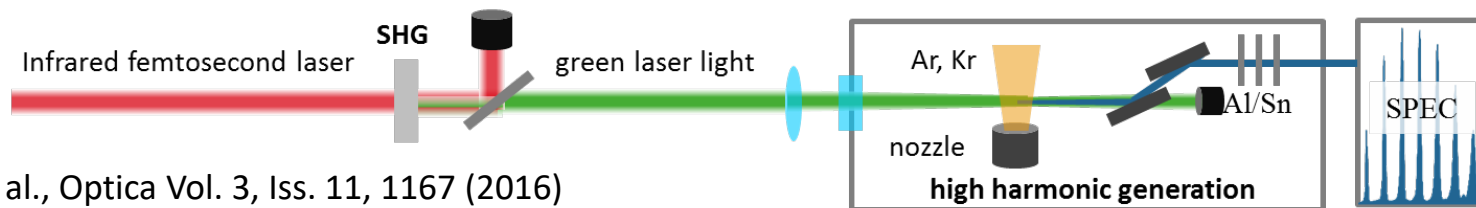
Li-like ions, 40 eV laser



First experiments:

- Record high photon flux: **832 μW @ 21.7 eV, $2.4 \cdot 10^{14}$ ph/s**
- High repetition rate: **100 kHz**
- Narrow bandwidth: **$\Delta E/E = 1.8 \cdot 10^{-3}$ @ 26.6 eV**

Dedicated to storage rings
Source is available for
GSI/FAIR mid/end of 2017



R. Klas et al., Optica Vol. 3, Iss. 11, 1167 (2016)




SPONSORED BY THE

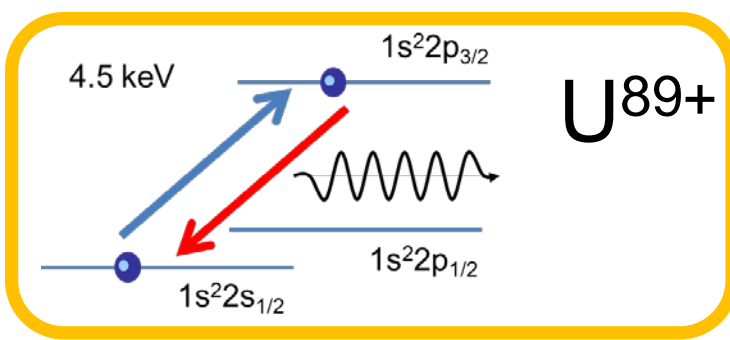
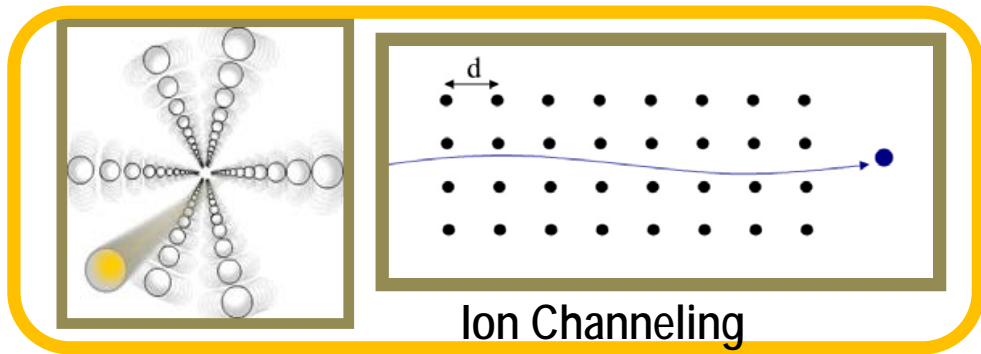


Federal Ministry
of Education
and Research

FAIR Phase 1: High Energies at APPA Cave



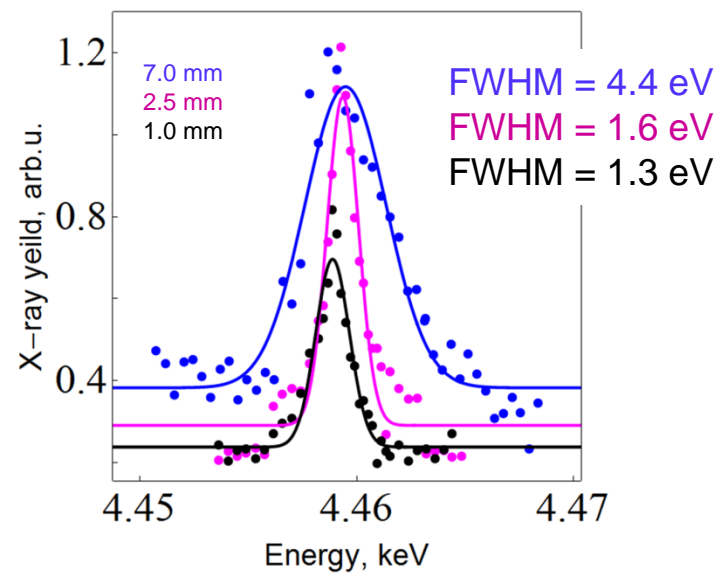
Resonant Coherent Excitation at relativistic energies (test@SIS18/ESR: 2014)



APPA-Cave

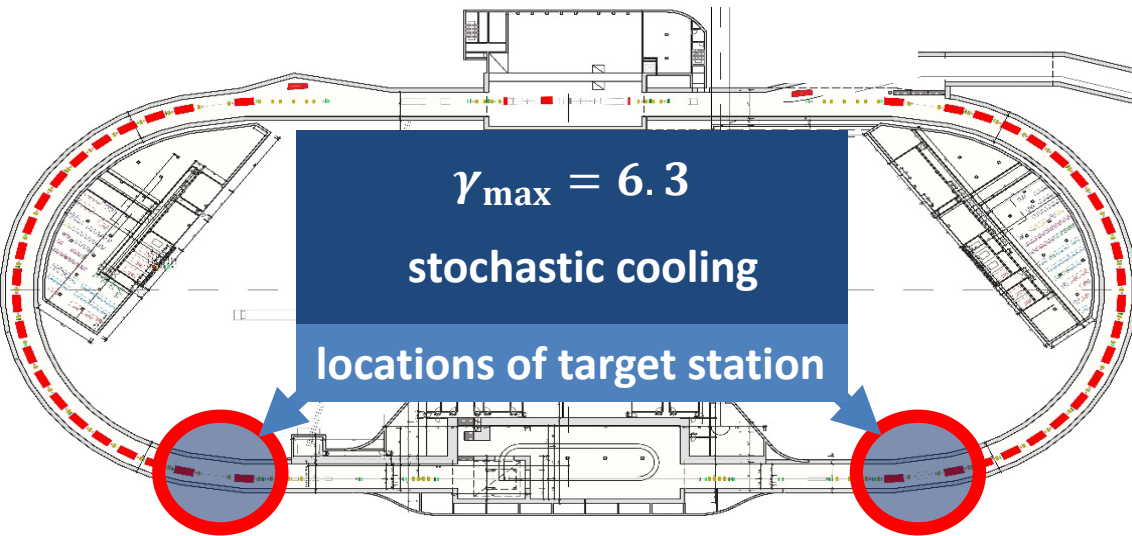


$$\Delta E = h \frac{v\gamma}{d}$$

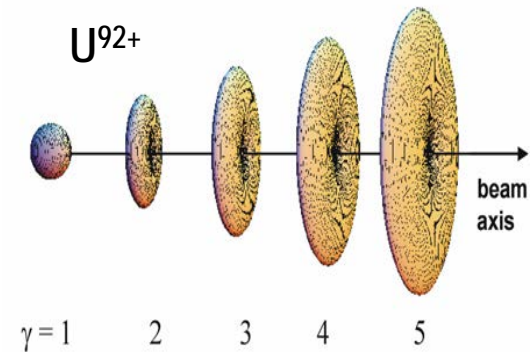


Only moderate beam intensities are required !

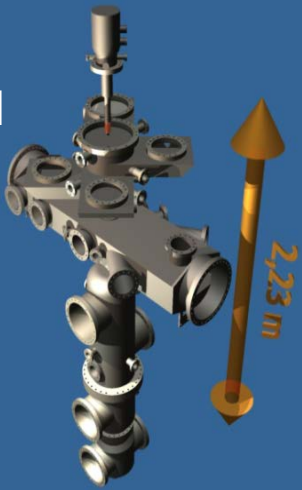
FAIR SIS100: Excitation of 1s-2p in U^{91+} via RCE possible for the first time.



Worldwide premiere:
Precision experiments using
cooled relativistic ion beams



SPARC
Internal
Target



Some Selected Physics Cases

- Laser spectroscopy (Day-1)
- Multi-body dynamics / Recoil ion spectroscopy
- Pair creation in strong fields / Negative continuum DR
- Relativistic photon-matter interaction / X-ray & electron spectr.
- Test of Special Relativity

Competitiveness with Other Facilities World Wide

(in operation or under construction)



Atomic Physics (SPARC)

SPARC	RIBF (RIKEN)	SPIRAL-2	FRIB (MSU)	TRIUMF	IMP (China)	NICA (JINR)	TSR (CERN)	EBIT Labs	FAIR (MSV)
Laser spectroscopy of fine and hyperfine transitions of HCl	Red	Red	Red	Red	Red	Red	Red	Yellow	Green
Negative continuum dielectronic recombination	Red	Red	Red	Red	Red	Red	Red	Red	Green
Correlated electron motion (sub-attosecond collision spectroscopy)	Red	Red	Red	Red	Red	Yellow	Red	Red	Green
Channeling/RCE investigations with HCl	Yellow	Red	Red	Red	Red	Yellow	Red	Red	Green
Studies of two-body beta decays of heavy radionuclides	Red	Red	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Green
Dielectronic recombination on Th, U isotopes (ultra-cold electrons)	Red	Red	Red	Red	Red	Red	Red	Yellow	Green
Bound-state g-factor for U^{91+}	Red	Red	Red	Red	Red	Red	Red	Yellow	Green

excellent

limited (lower energies, lower intensities, lower Z)

not possible

- For the next decade and beyond FAIR offers novel, worldwide unique research opportunities and challenges with **large discovery potential** for SPARC research
- SPARC will contribute significantly to the **very first experiments** at FAIR
(CRYRING, APPA cave, HESR).
- **Rapid technological advances** in fields like laser, optics, x-ray detectors, and biomedical application implies a **permanent scrutiny** and update of the experimental methods and setups proposed by SPARC. => **R&D is still needed.**
- **Focused, continuous research** at the current GSI facilities is of utmost importance for the success of the FAIR project.
=> **GSI/FAIR needs to have an active phase 0 research program for the time until FAIR is online!**

SPARC is ready for a rich FAIR phase-0 research program which has a large discovery potential and which will be continued and readily expanded to the new facilities in FAIR phase 1.



Thank you for your attention !