Atomic Physics

Atomic Physics at GSI: An Outlook

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[2]GSI-Darmstadt , Germany
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AP WORKSHOP 2002, GSI

GSI
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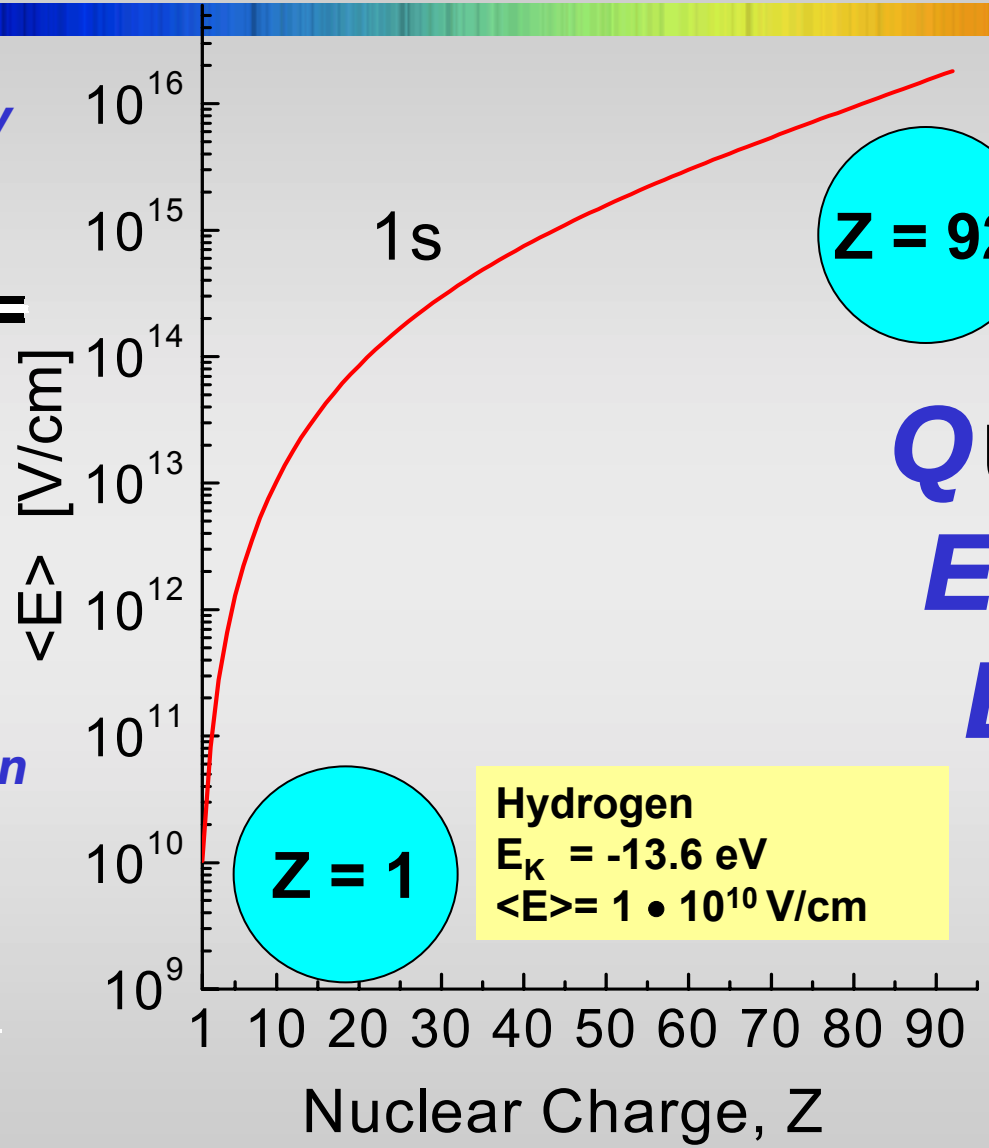
Atomic Physics in Extremly Strong Coulomb Fields

H-like Uranium
E_K = -132 • 10^3 eV
<E>= 1.8 • 10^{16} V/cm

Self Energy

Vacuum Polarization



Hydrogen
E_K = -13.6 eV
<E>= 1 • 10^{10} V/cm

Quantum Electro-Dynamics

1s-ground state: increase of the electric field strength by six orders of magnitude

Th. Stöhlker, Workshop on Atomic Physics Research at the Future GSI-Facility, GSI, 2002

Atomic Physics in Strong Electromagnetic Fields

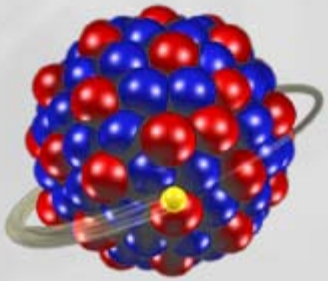
Test of Quantum Electrodynamics

Hydrogen-Atom

$Z=1$; $E_b = 13.6$ eV

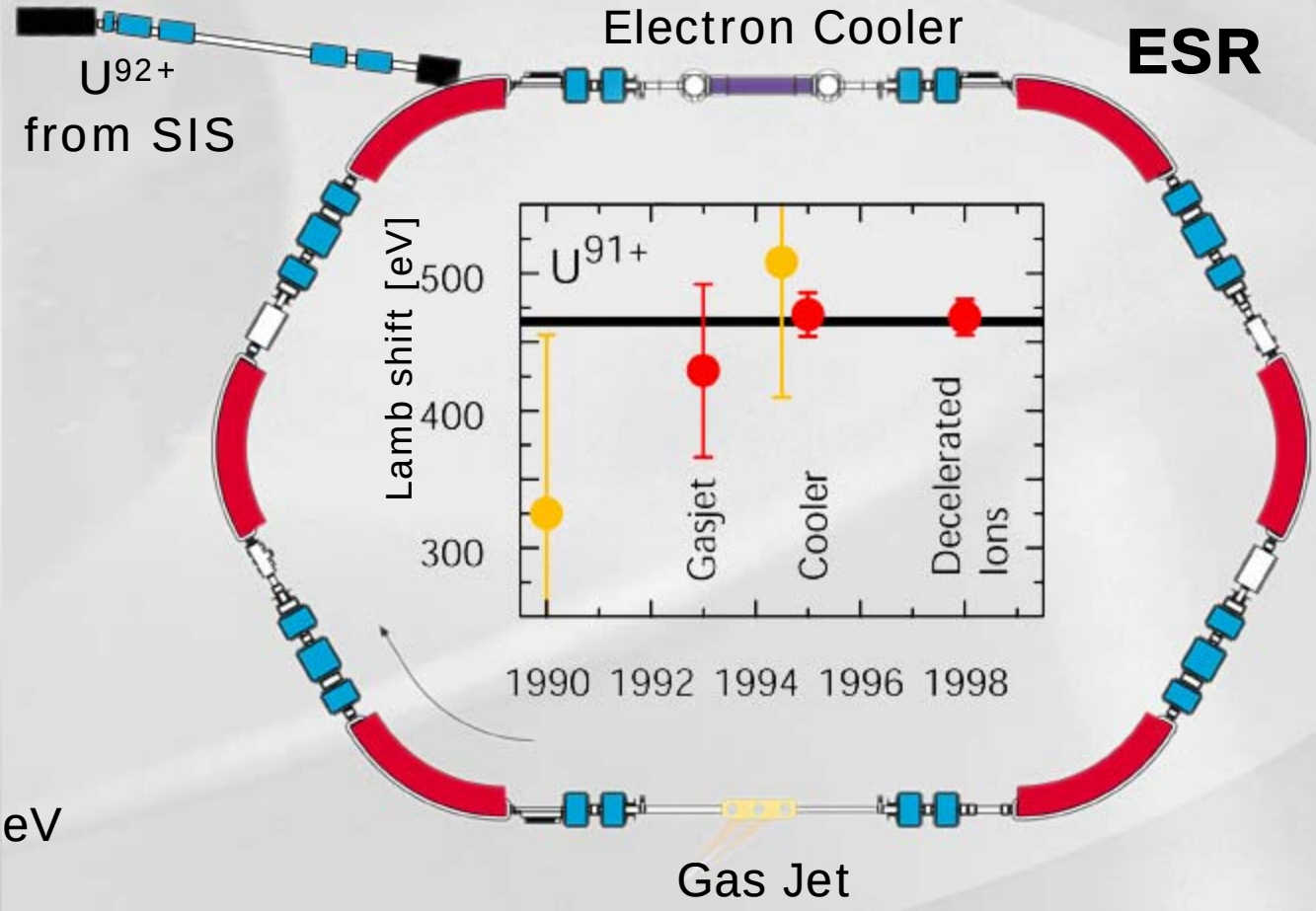
$Z \cdot \alpha \ll 1$

Uranium-Ion



$Z=92$; $E_b = 132$ KeV

$Z \cdot \alpha \approx 1$



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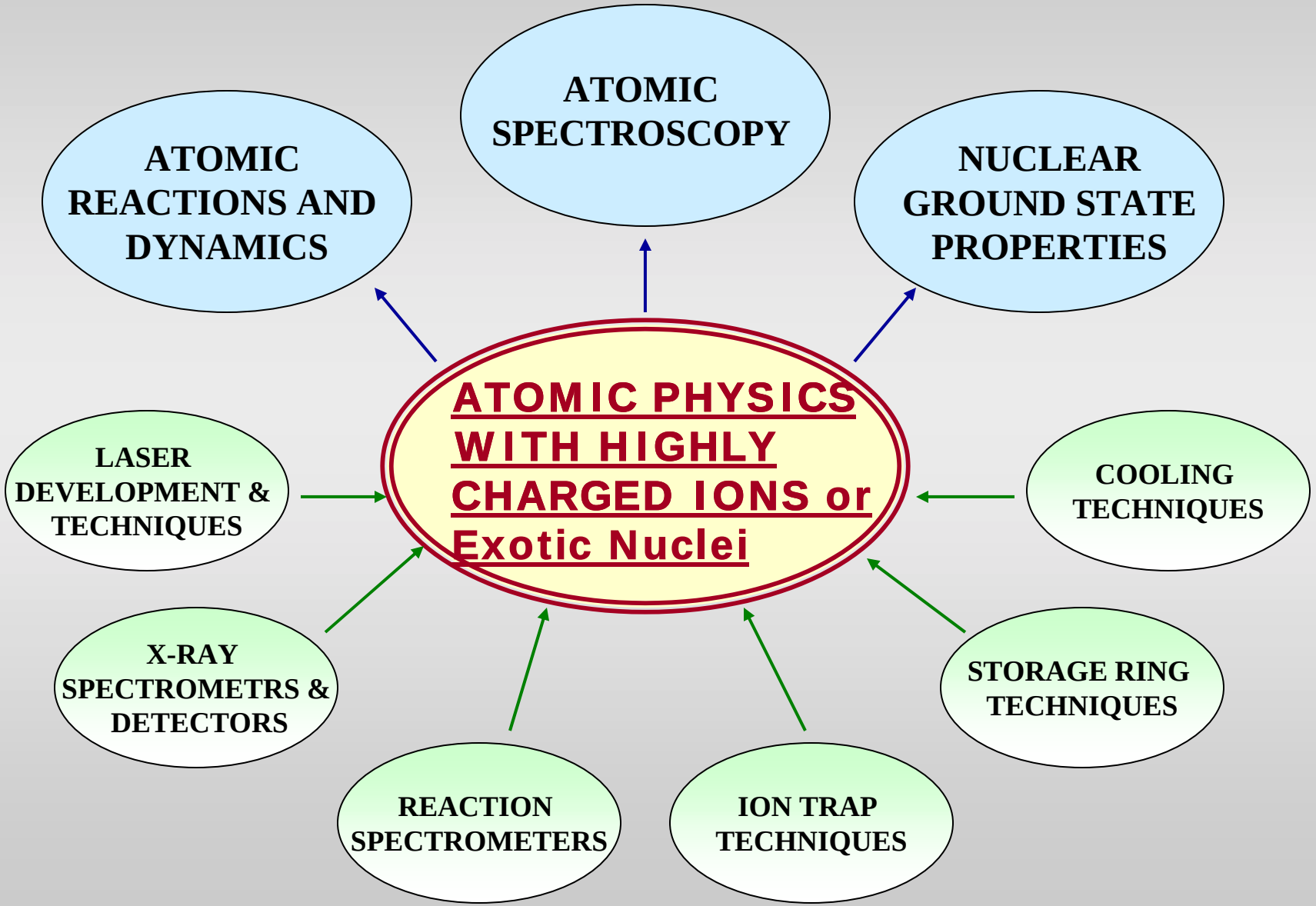
Atomic Physics at Accelerators



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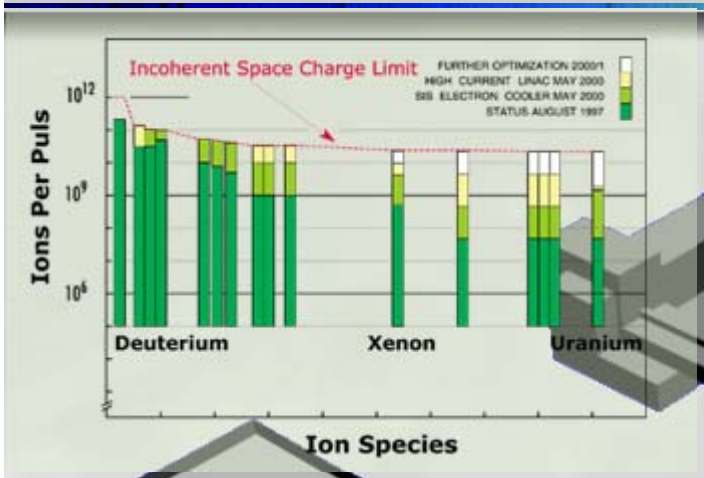
GSI-Accelerator Facility



UNILAC

11.4 MeV/u

U^{73+}

ESR

10 - 500 MeV/u

U^{92+}

SIS

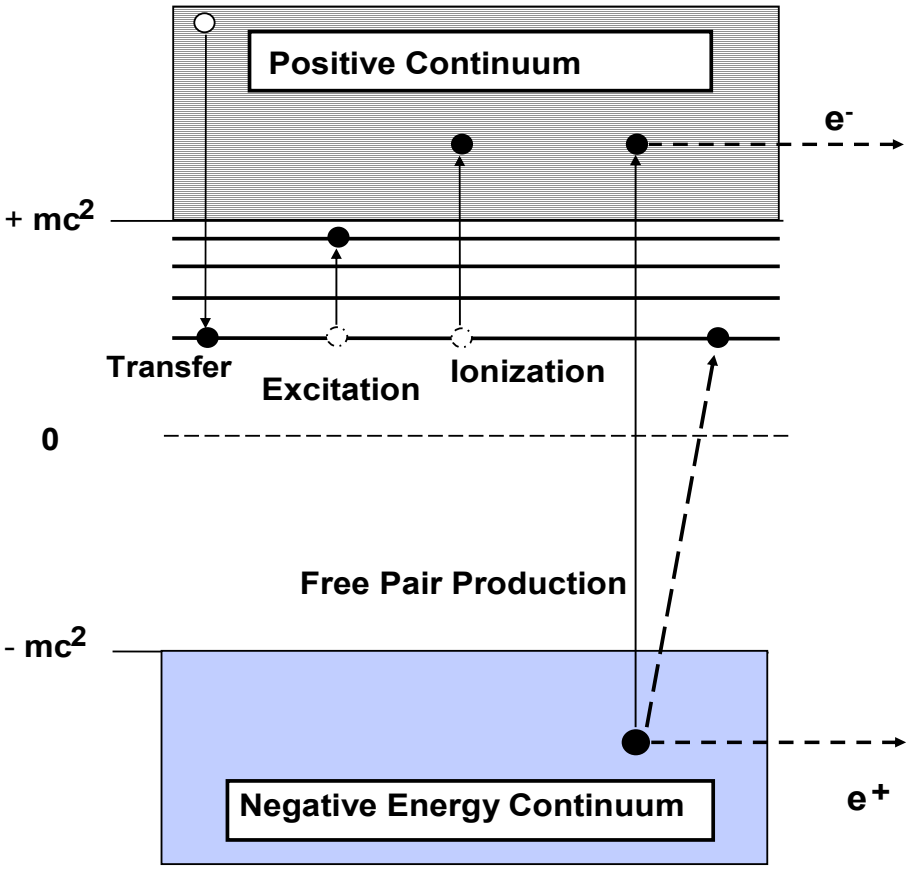
up to 1000 MeV/u

U^{92+}

Electromagnetic Phenomena under Extreme & Unusual Conditions

High- γ

Collision times in the sub-attosecond regime
(10^{-22} s < t < 10^{-18}s)



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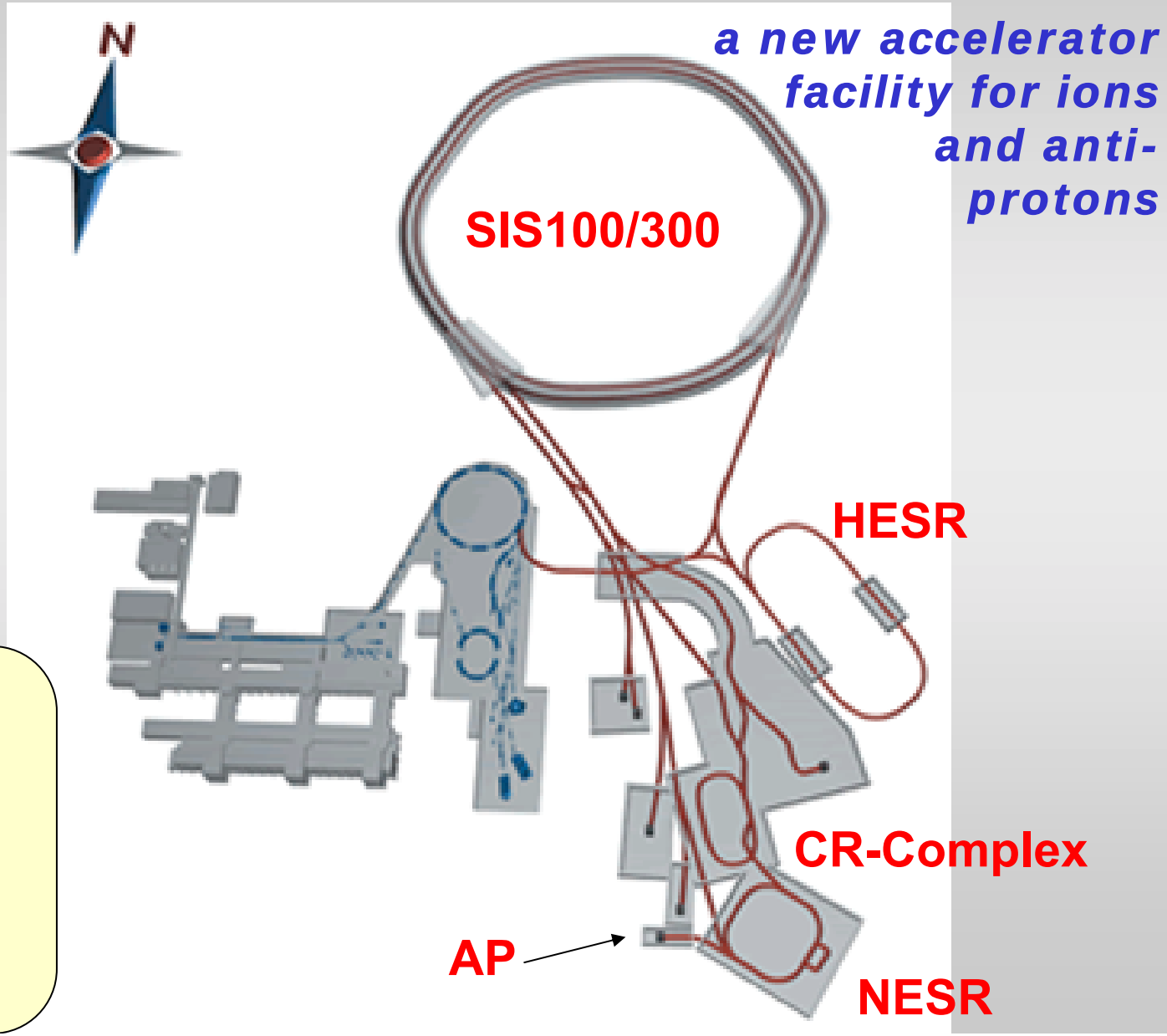
The New GSI Accelerator Project



Parameter
stored and cooled antiprotons
up to 30 GeV
90 GeV protons
34 GeV/u U^{92+}

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Central Research Topics for AP

Relativistic Collision Dynamics in Strong Electromagnetic Fields

Test of Quantum Electrodynamics in Strong Fields

Atomic Physics Techniques Applied to Nuclear Physics

Atomic Physics Techniques Applied to Fundamental Tests other than QED

Ions and Electrons in Highly-Intense, Femtosecond Laser Fields

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Experimental Installations for AP at New GSI Accelerator Project

High Intensity Synchrotron (SIS300)
Parameter
90 GeV protons; 29 GeV antiprotons
34 GeV/u U $^{92+}$

⇐ **laser ion-beam interaction zone**

high-energy cave

New Fragment Separator (SFRS)
[production of fragment beams]

Collector Ring Complex (CR)
[stochastic cooling for fragment beams]

New Experimental Storage Ring (NESR)
[energies between 840 MeV/u down to 3 MeV/u]

⇐ **Internal and external installations**

High Energy Experimental Storage Ring (HESR)
[for anti-protons at energies up to 14 GeV]
Optional: heavy ions beams up to 6 GeV/u

⇐ **Optional: internal target experiments with HCI**

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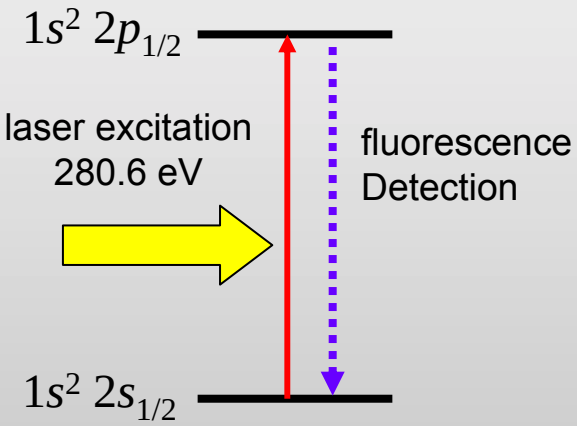
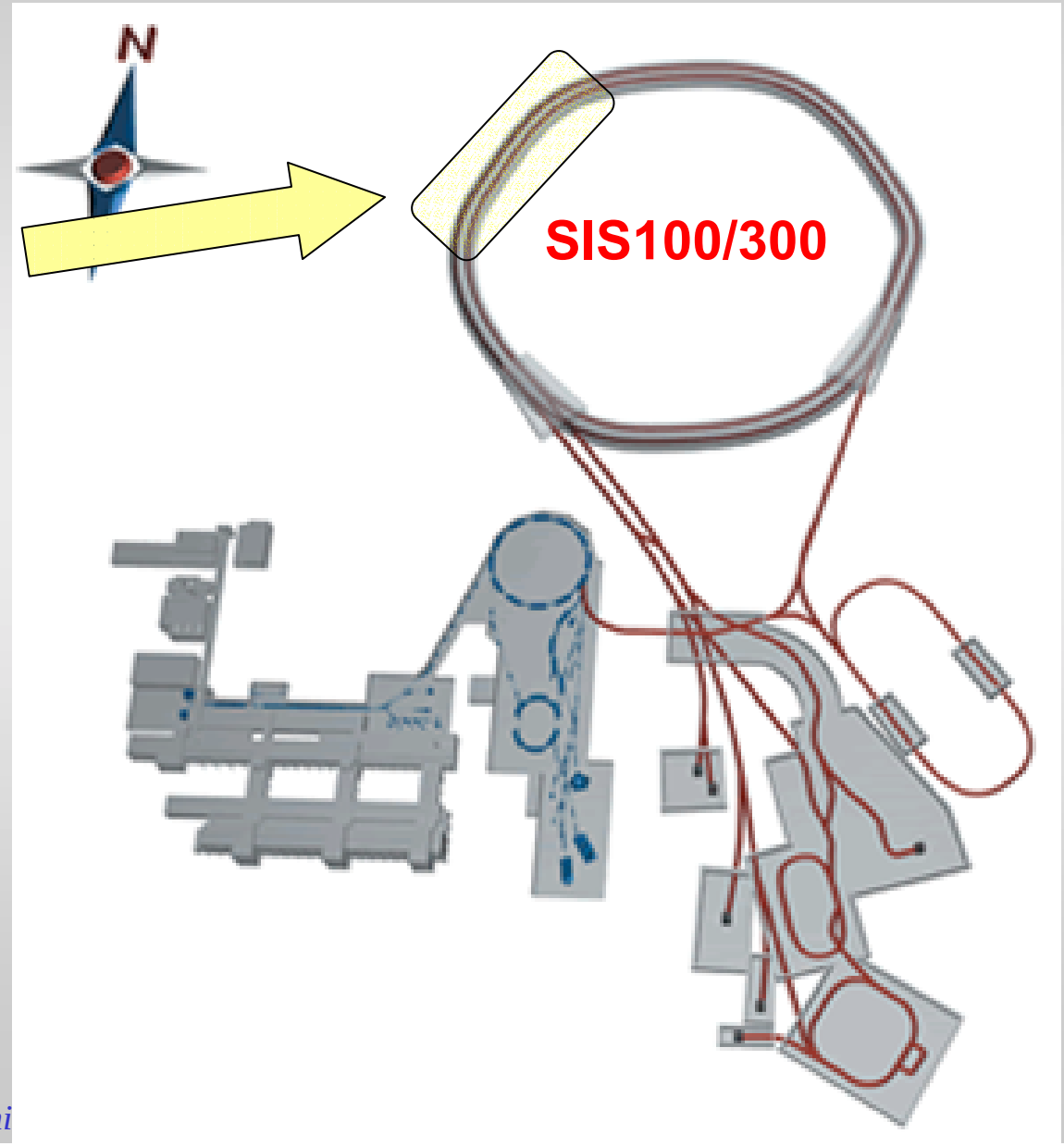
Laser Spectroscopy & Cooling at SIS 300

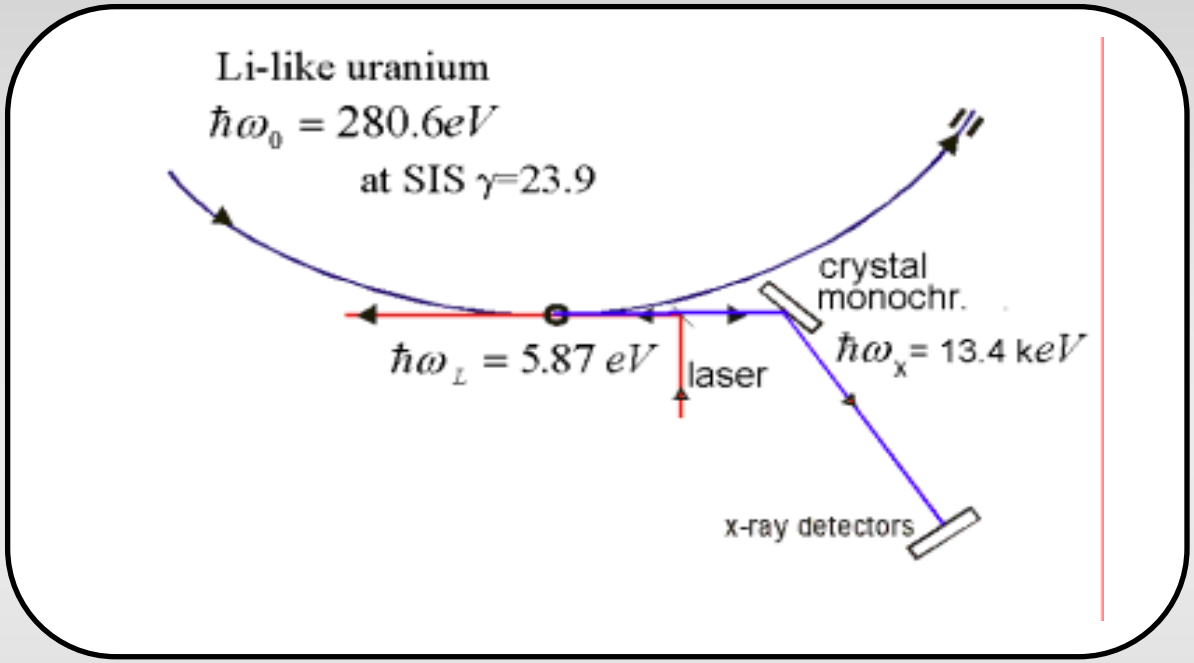
High Precision Laser Spectroscopy by using the large Lorentz energy shift at high γ values





Laser Spectroscopy & Cooling at SIS 300

Precision Tests of QED in Strong Fields High-Z Li-Like Ions



Lab. System (laser)

$$\hbar\omega_L = 5.87eV$$

γ=23.9

Projectile frame excitation

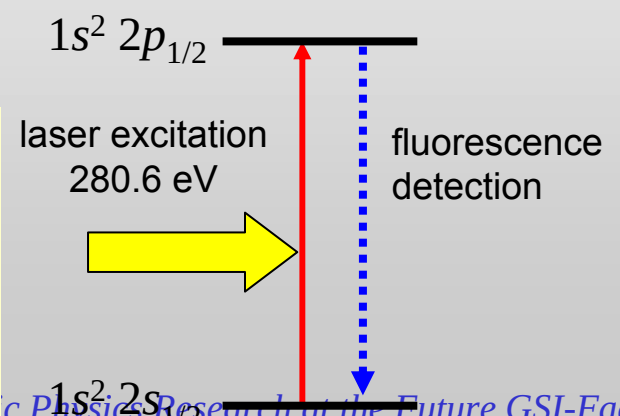
$$\hbar\omega_0 = 280.6eV$$

fluorescence

γ=23.9

Lab. System fluorescence

$$\hbar\omega_X = 13384eV$$



The large Doppler shift allows to use visible laser sources to excite transitions in the energy range up to 280 eV, e.g. 2s-2p transitions in lithium-like heavy ions

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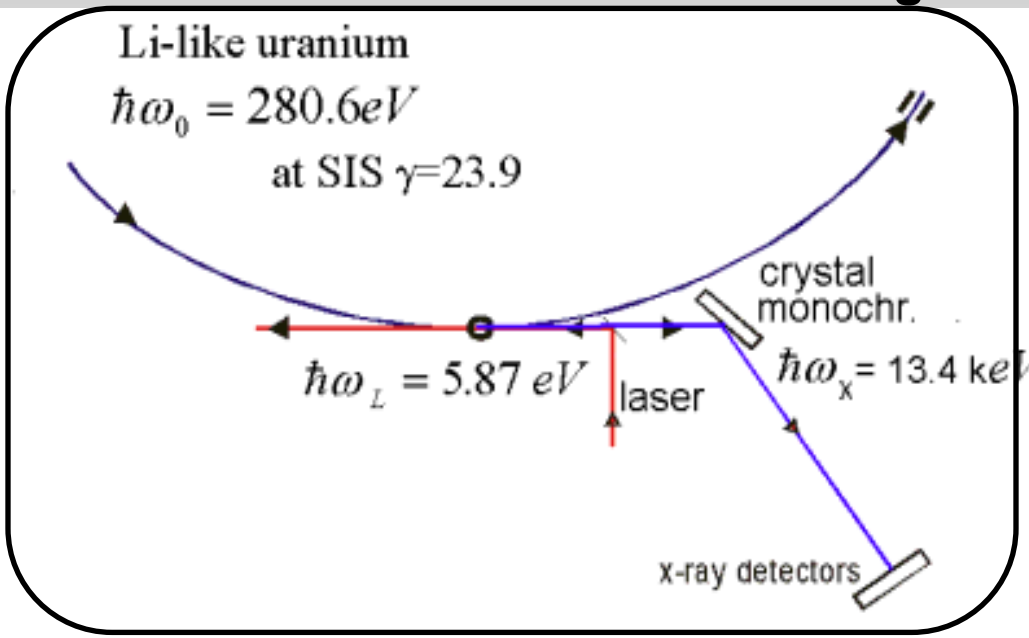
Laser Spectroscopy at SIS 300

Precision Tests of QED in Strong Fields High-Z Li-Like Ions



Expected accuracy for the 280 eV transition: 0.007 eV (currently best value: 280.59 ± 0.09 eV)

Only 100 ions are required

Further Applications

- **measurement of nuclear charge radii for radioactive ion beams**
- **magnetic nuclear moments (hyperfine structure)**

Spectroscopy: H. Backe *mic Physics Research at the Future GSI-Fa* ***Cooling: U. Schramm***

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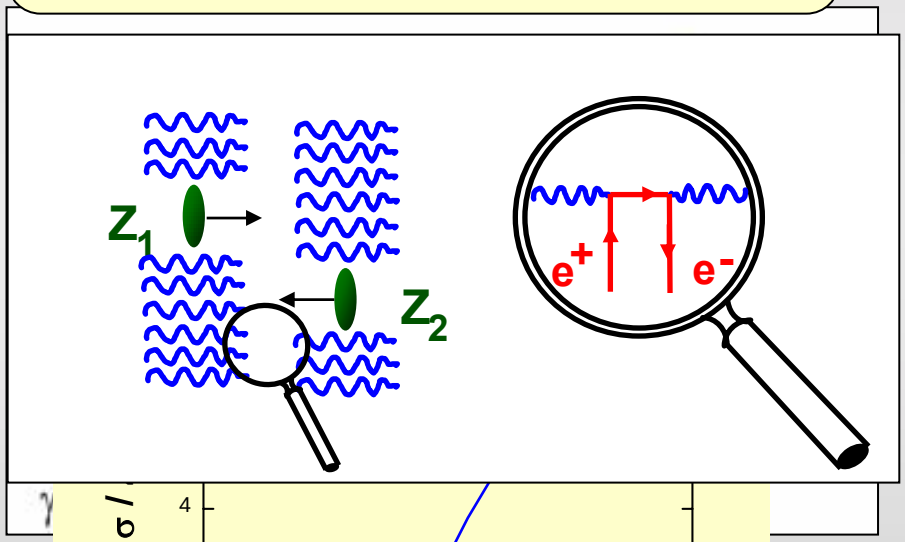
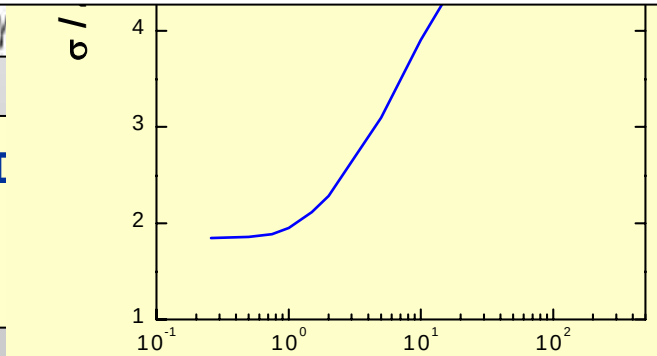
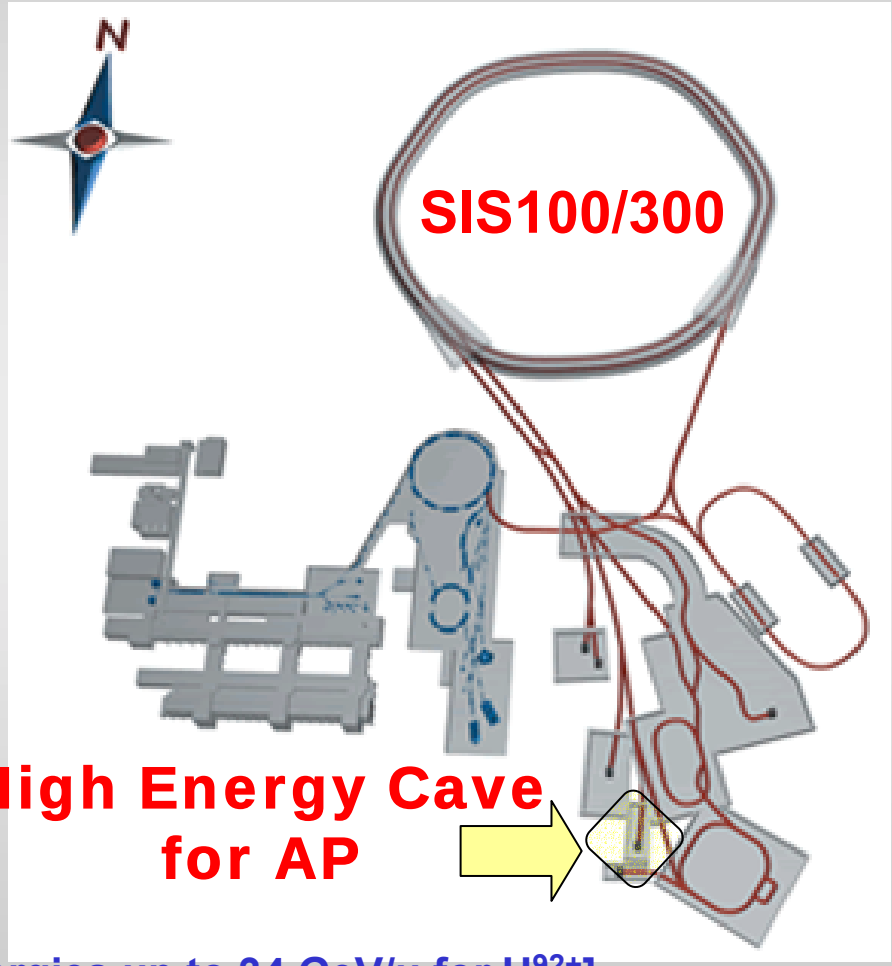
Collision Experiments at SIS 300

Electromagnetic Phenomena under Extreme & Unusual

ln(γ) cross-section increase for all excitation like processes such as *ionization or e^+-e^- pair creation*







[energies up to 34 GeV/u for U^{92+}]

R. Schuch
Y. Yamazaki

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The New Experimental Storage Ring NESR

The New ESR

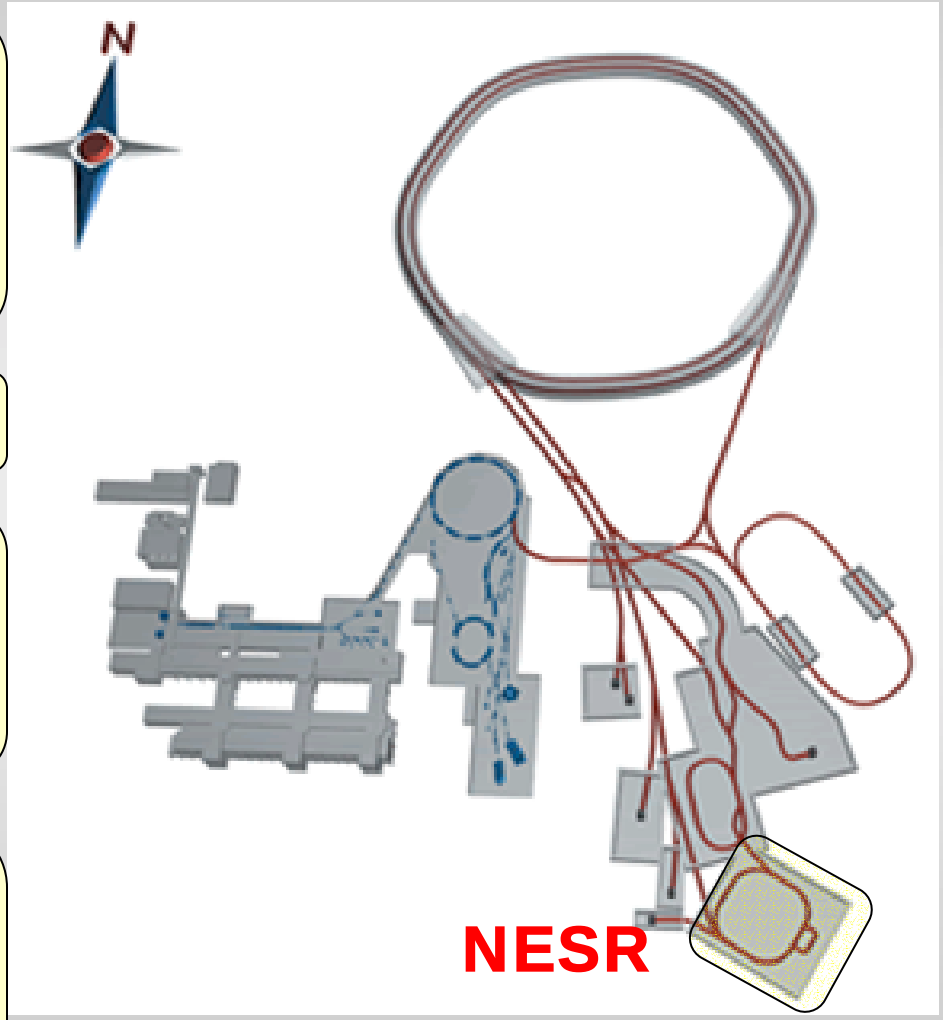
Storage and Cooler Ring for
HCI, Antiprotons, Fragment Beams

Energies: 840 to 3 MeV/u

Circumfence: **211 m** (ESR:108 m)

Straight sections for exp. installations
18 m

Experimental installations
electron target
internal jet-target
laser-ion interaction zone
low-energy cave: cooled extracted ions
HITRAP



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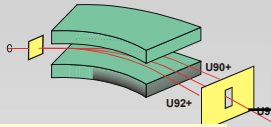
The New Experimental Storage Ring NESR

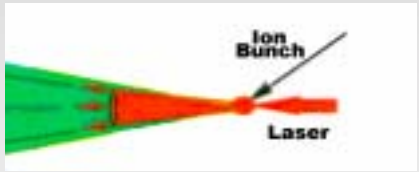


extraction

electron cooler

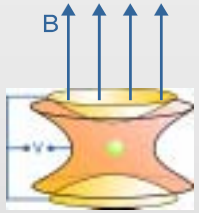
injection

Fixed Target / Cave AP



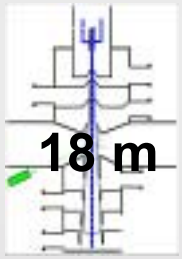
18 m

HITRAP



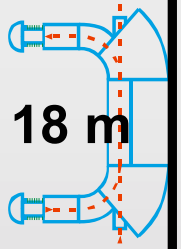
ions at rest

jet target



18 m

18 m



electron target

laser pulse

electron bunch

18 m

x-ray pulse

electron collider

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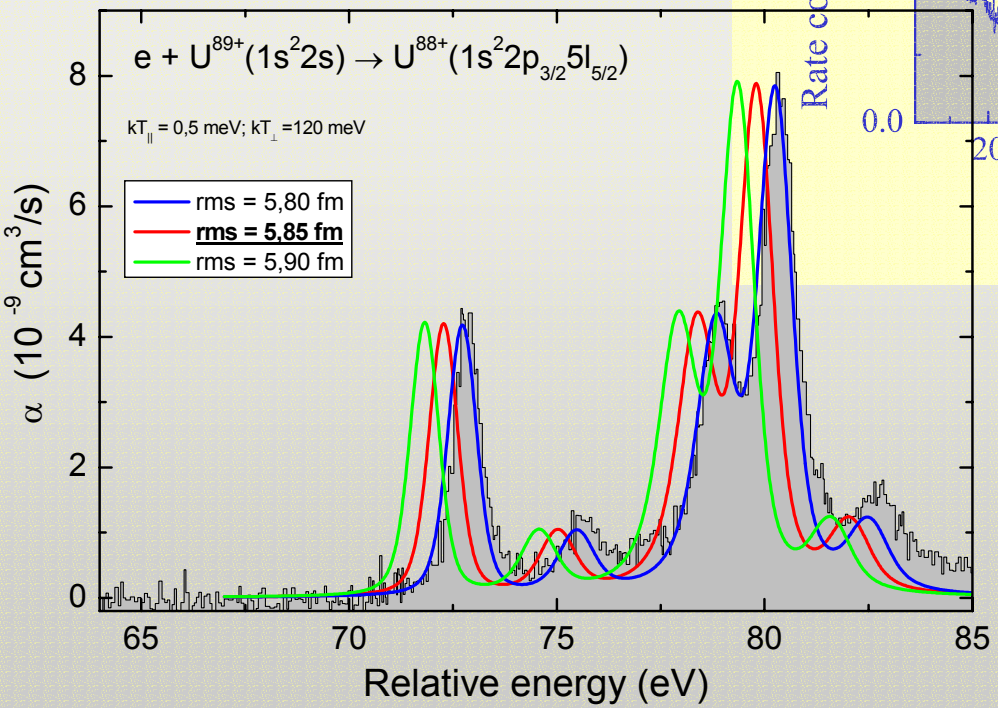
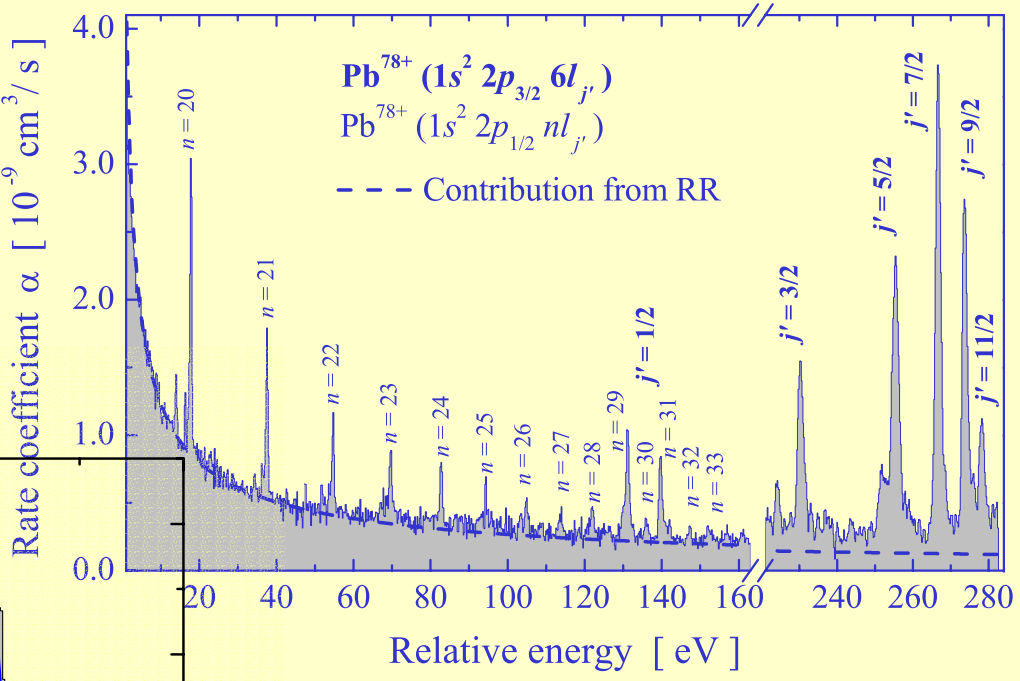
Dielectronic Recombination Experiments – Experiments at the Electron Target

DR experiments for Li-like heavy ions at the ESR: The already achieved accuracy is comparable with the most precise x-ray experiments





Experiment and theory for three different rms radii of ^{238}U

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A. Müller

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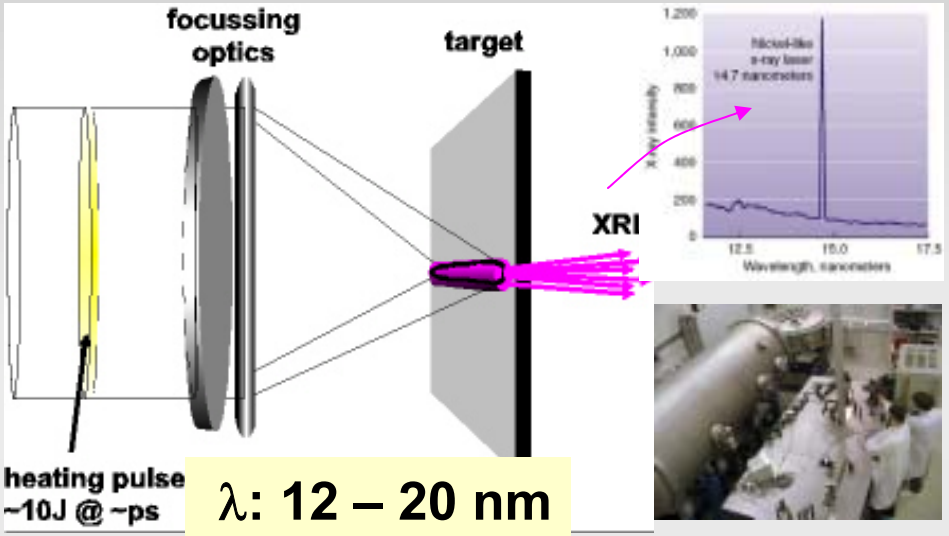
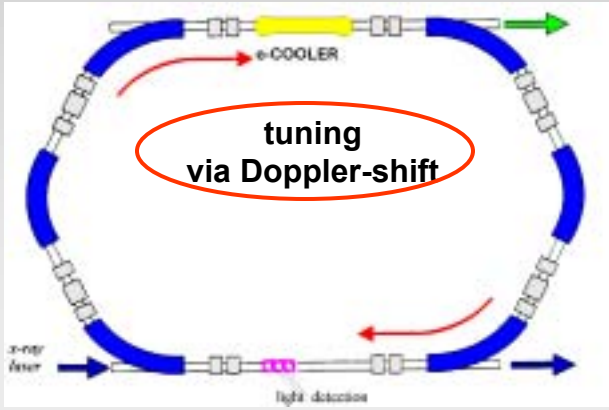
X-Ray Laser Spectroscopy on Lithium-like Radioactive Nuclei

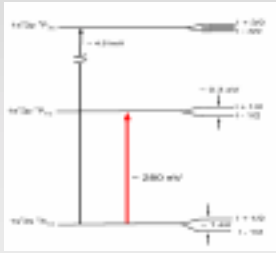
Principle of an X-Ray Laser (XRL)



λ: 12 – 20 nm

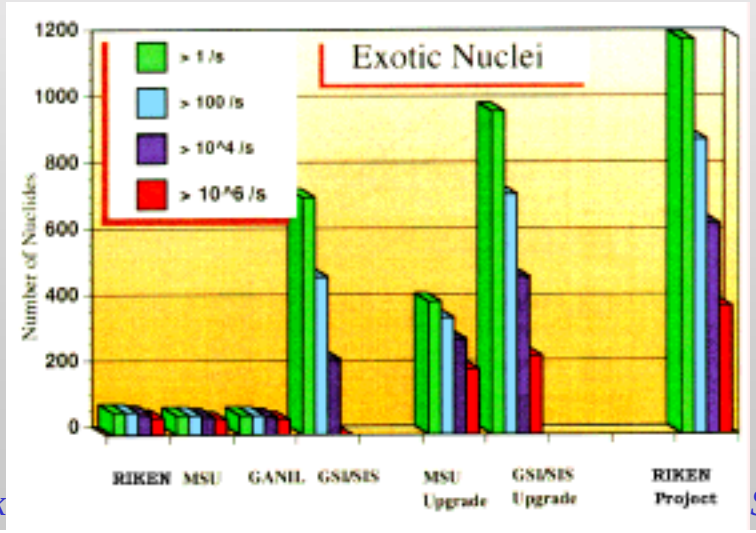
Excitation in the ESR / NESR





up to Z=92 possible

At NESR: Wide Range of Accessible Ions



$\Delta p/p \sim 5 \times 10^{-5}$

$\Delta E_{Dopp.}/E \sim 10^{-4} \ldots 10^{-5}$

E. Gaul

Th. Stöhlker, Work *SI-Facility, GSI, 2002*

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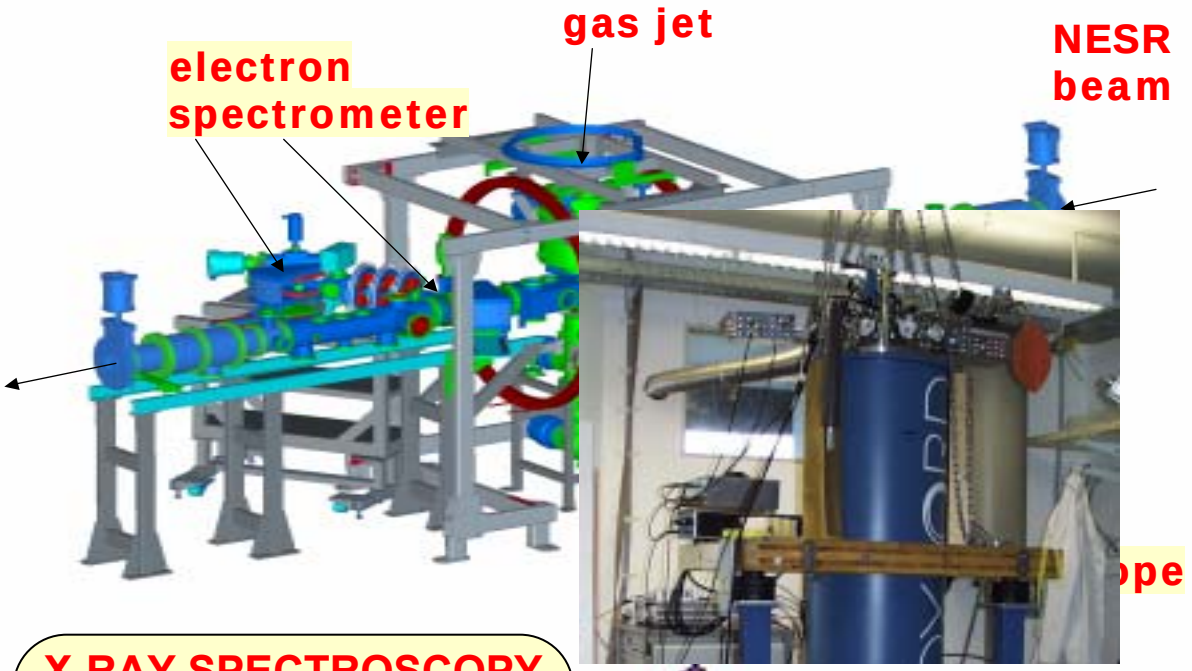
Experiments at the Jet-Target of the NESR (Collision Dynamics with HCI and Antiprotons)

ELECTRON SPECTROSCOPY

high-resolution electron spectroscopy complementray to the x-ray channel

Poster S. Hagmann et al.
R. Mannet al.



RECOIL ION MOMENTUM SPECTROSCOPY

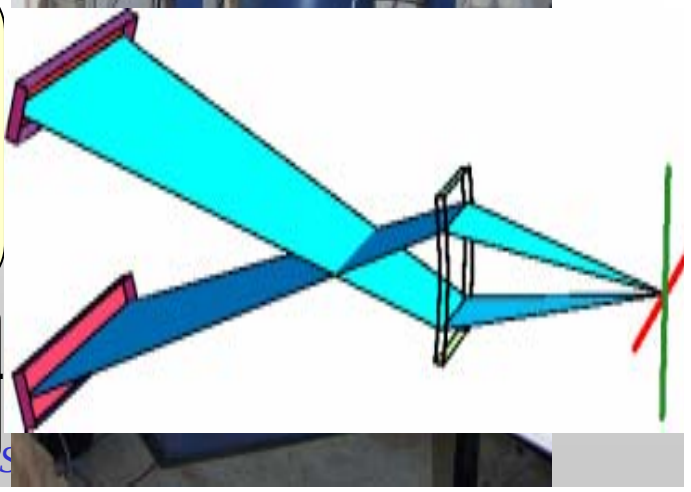
e.g.
impact parameter sensitive studies
(e,2e) processes in HCI atom collisions

Poster S. Hagmann et al.
H. Kollmus et al.
R. Moshammer et al.
A. Dorn et al.

X-RAY SPECTROSCOPY

e.g.
precision spectroscropy
photon correlation studies
polarization phenomena

Poster A. Gumberidze et al.
A. Orsic Muthig et al.
Th. Stöhlker et al.
A. Surzhykov t al.



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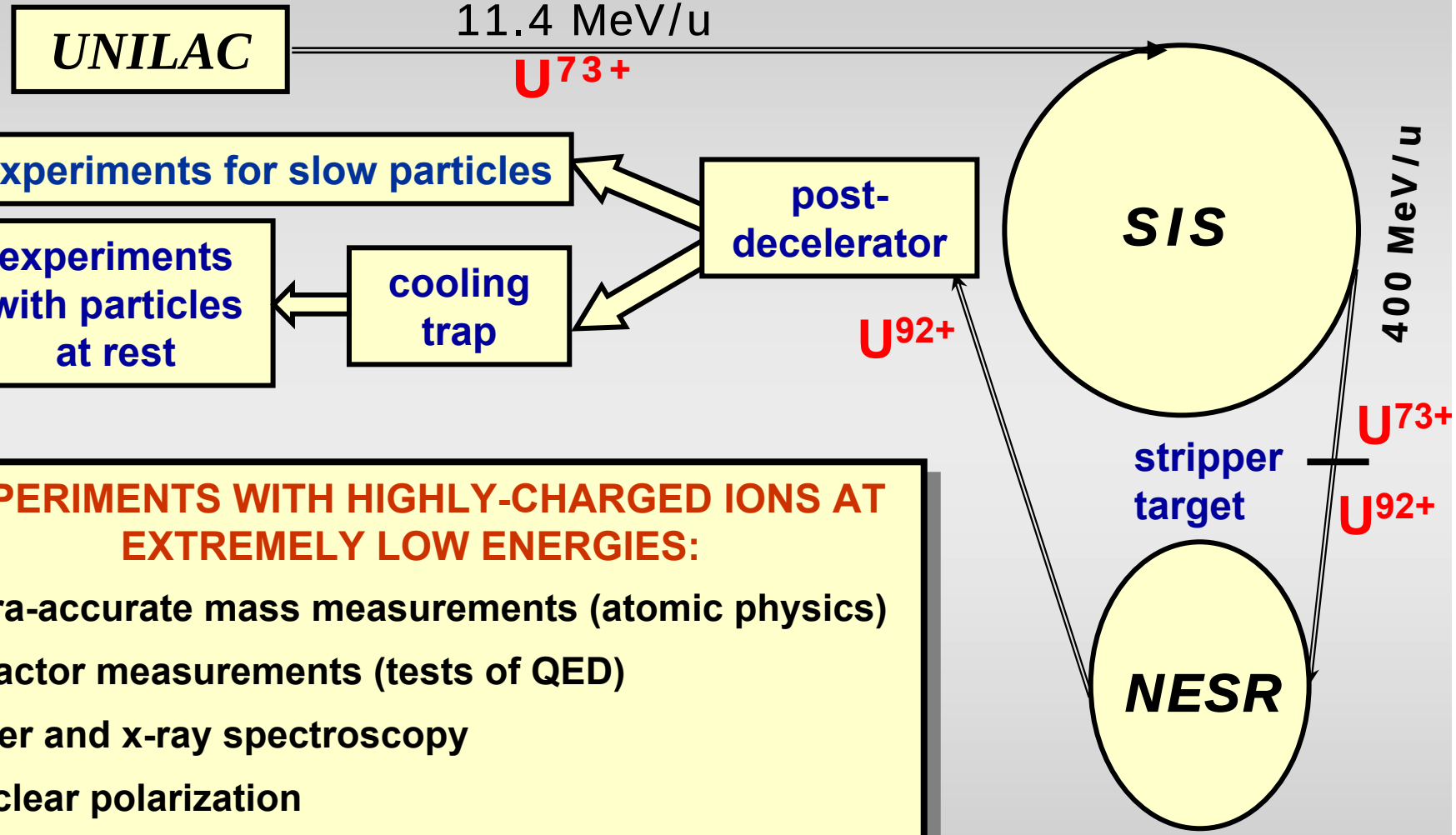
The HITRAP Project at GSI



EXPERIMENTS WITH HIGHLY-CHARGED IONS AT EXTREMELY LOW ENERGIES:

- ultra-accurate mass measurements (atomic physics)
- g-factor measurements (tests of QED)
- laser and x-ray spectroscopy
- nuclear polarization
- surface studies and hollow-atom spectroscopy
- collisions at very low velocities
- experiments with antiprotons at the NESR

acility, (

HITRAP
WORKSHOP

OPTION: Heavy Ions Stored in the HESR at $\gamma \approx 6$

HESR

Experiments with cooled relativistic HCI up to a Lorentz factor of $\gamma \approx 6$

Electron, positron, and photon spectroscopy (e^+-e^- pairs) at the internal target

Relativistic kinematics results in a strongly enhanced resolution for electron, positron, and photon spectroscopy