



SPARC
Stored Particle Atomic Research Collaboration

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Queen's University, Belfast
UK Coordinator and Member of Collaboration Board

The SPARC-Collaboration:

<http://www.gsi.de/sparc>

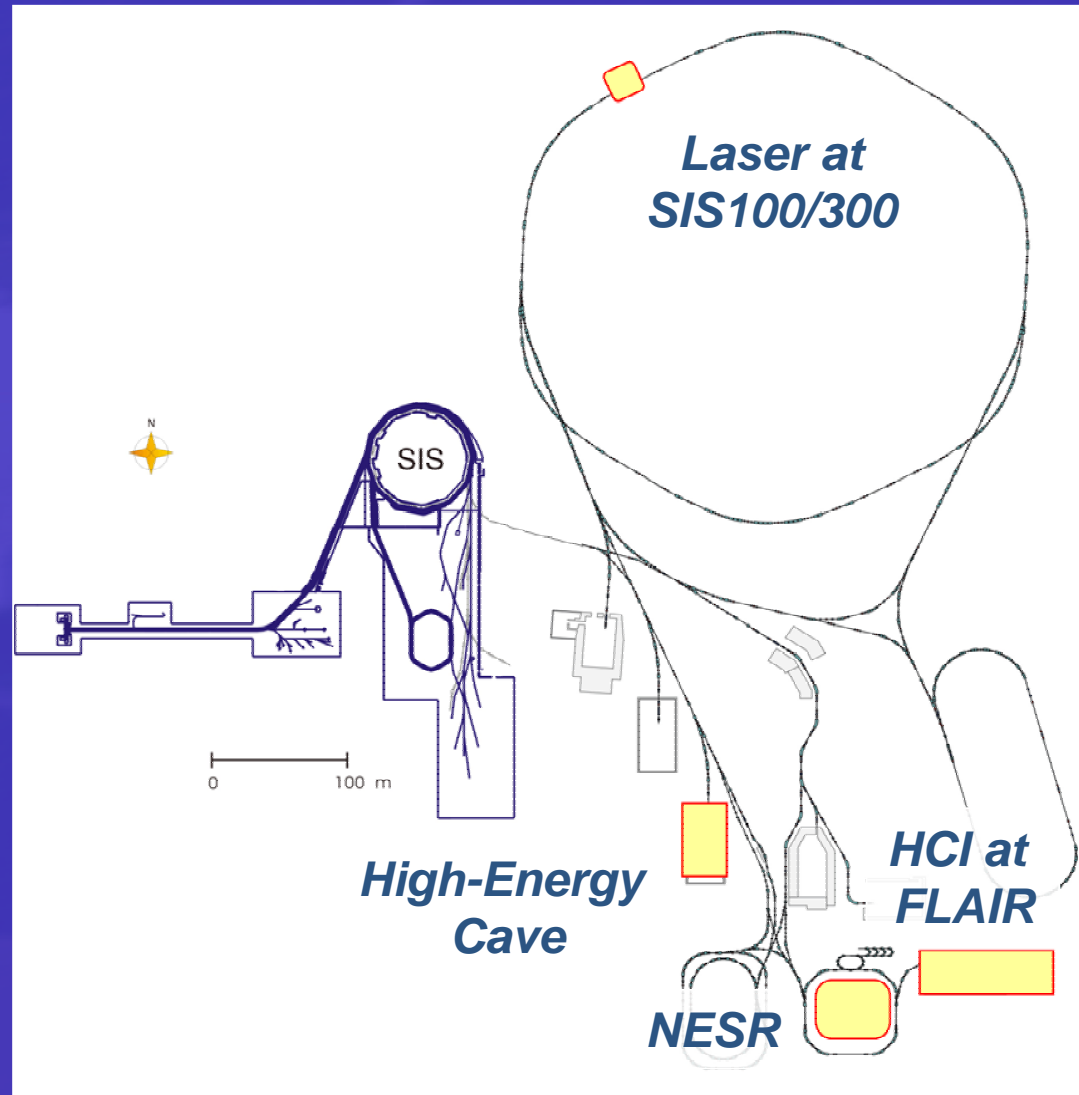
SPARC

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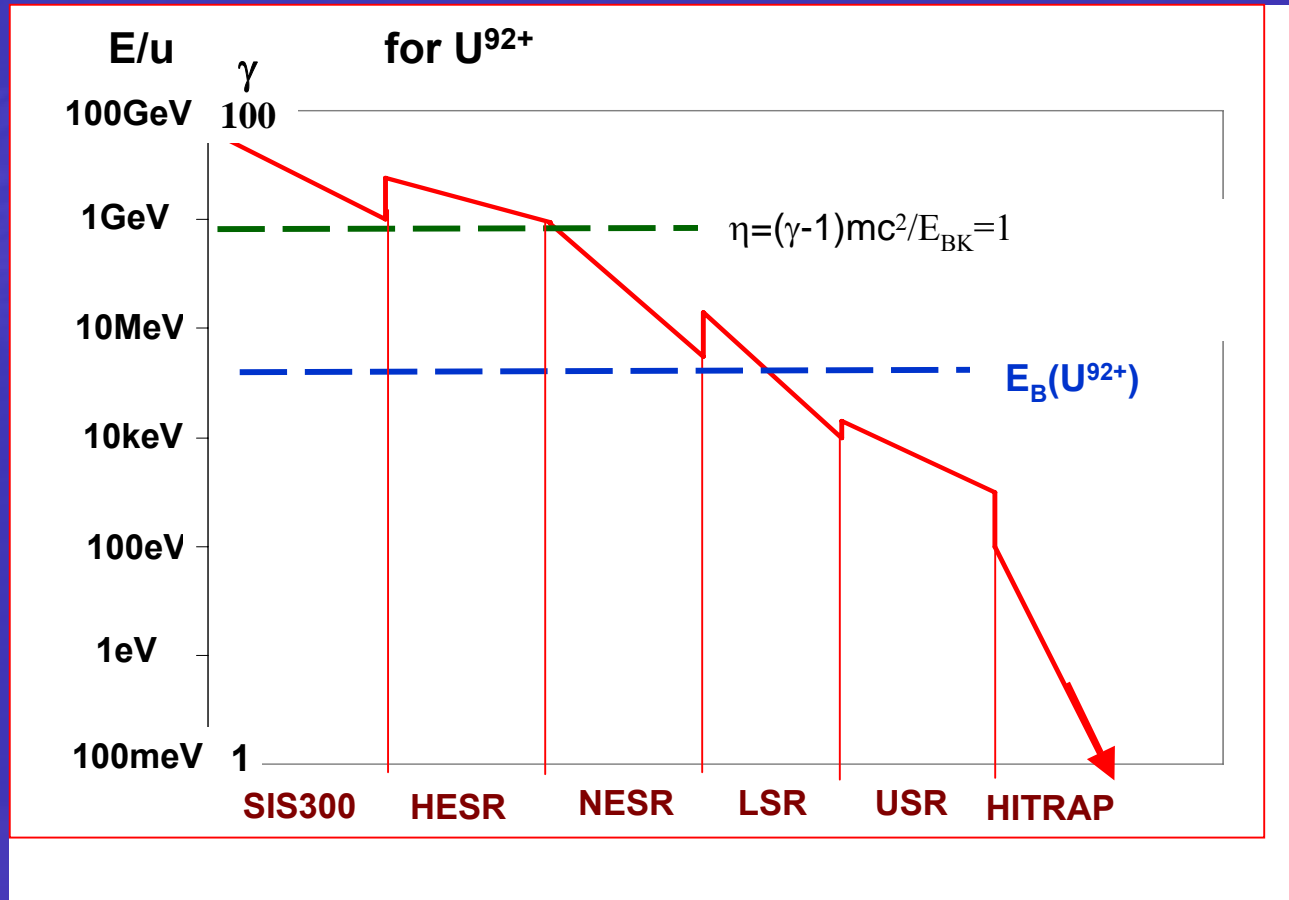
210 members, 23 countries

Physics Program Highlights:

- QED in strong fields
- Dynamics in energetic (\rightarrow relativistic) Collisions
- Slow HC Ions far from Equilibrium hitting Clusters, Nano-Capillaries...

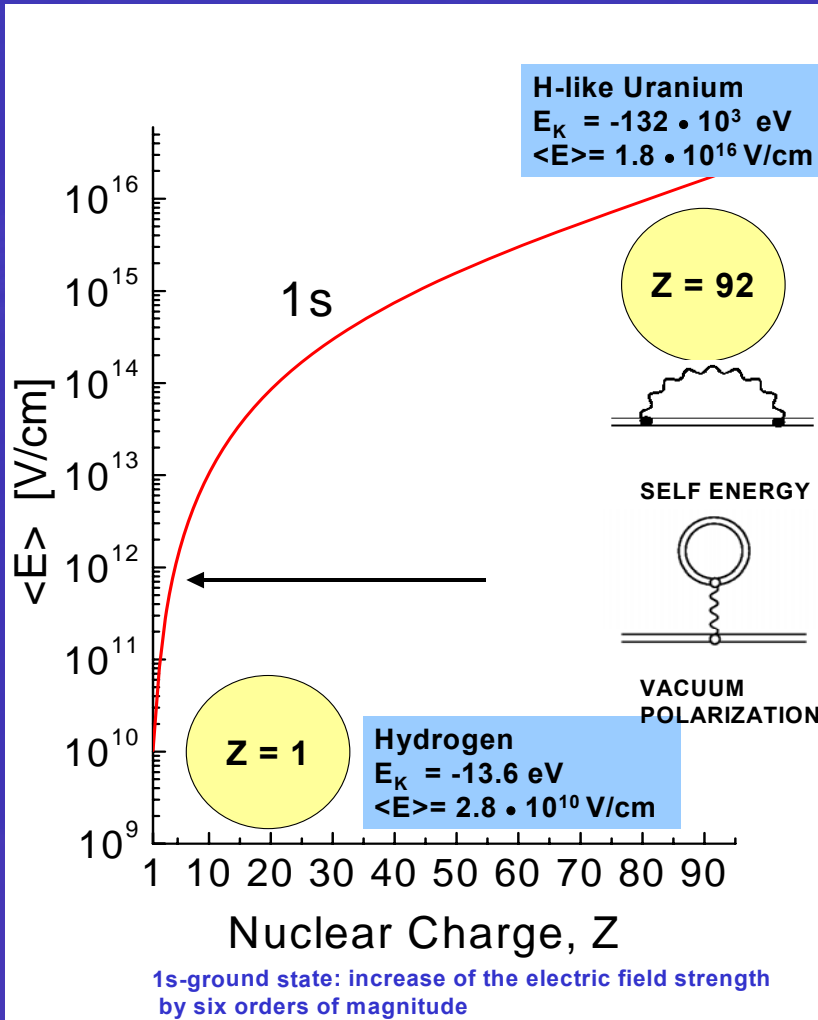


Exploit range of velocities



Electromagnetic Phenomena in Extreme & Unusual Conditions

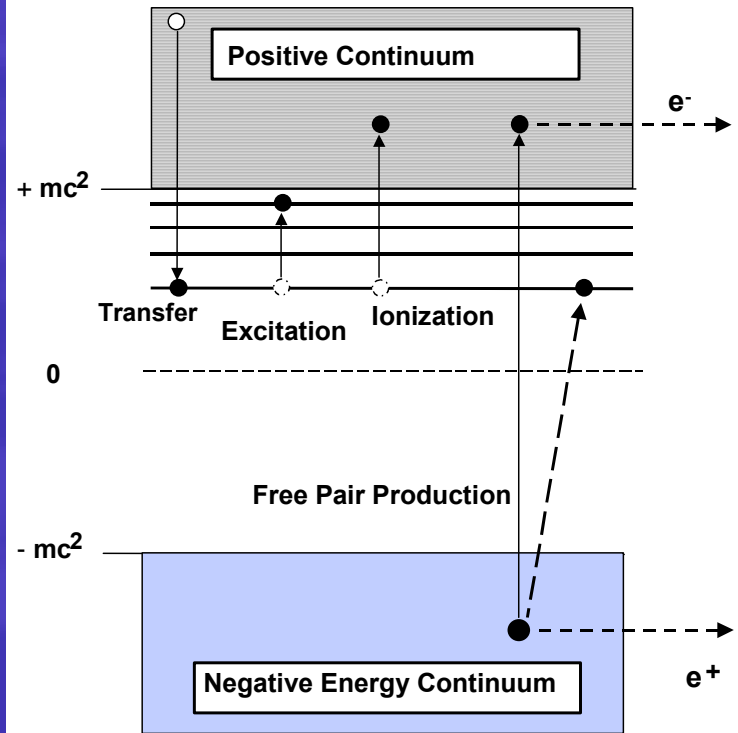
High- Z



High- γ

Collision Dynamics of Relativistic Heavy Ions

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



Extreme Electromagnetic Fields

at SIS 100/300

relativistic ions $\gamma \rightarrow 30$,
Z and q up to 92

at NESR (800-3MeV/u)

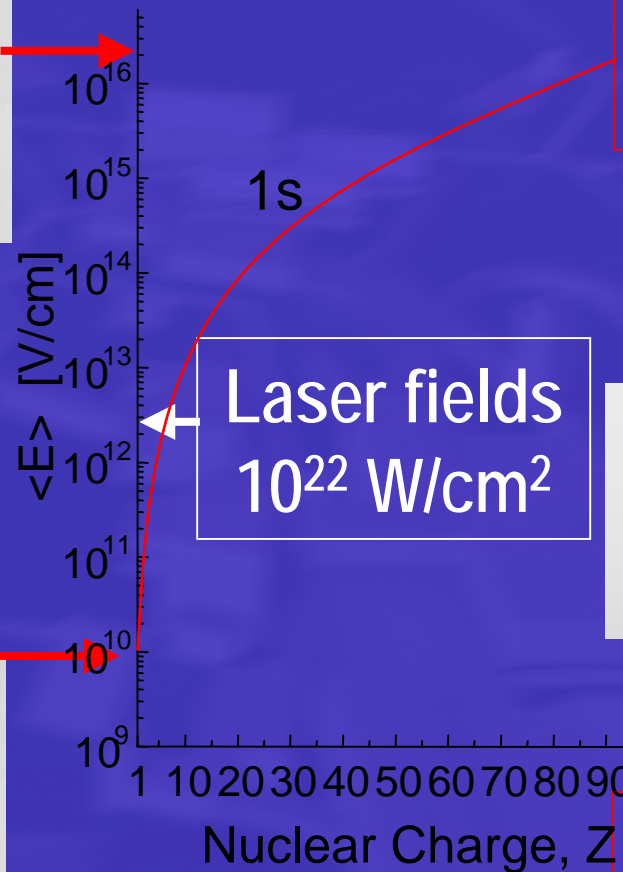
Cooled highly charged heavy ions probed with photons, electrons, and atoms.

at LSR (20-0.2 MeV/u)

Slow highly charged heavy ions colliding with electrons, and atoms.

at HITRAP (500-0keV/u)

Cooled highly charged ions at rest



$$\Delta E \approx 500 \text{ eV}$$

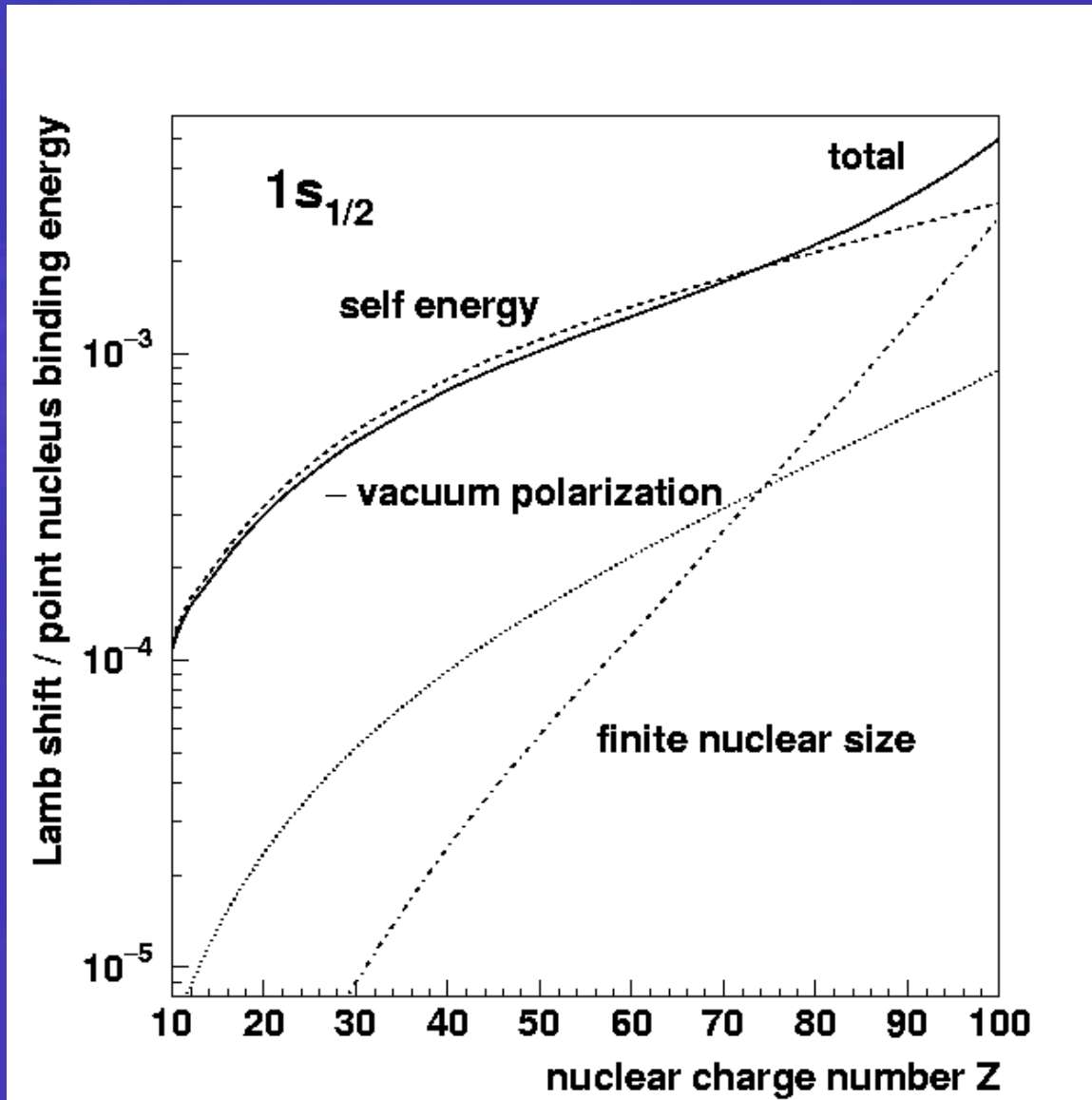
$$Z \cdot \alpha \approx 1$$

Quantum
Electro-
Dynamics

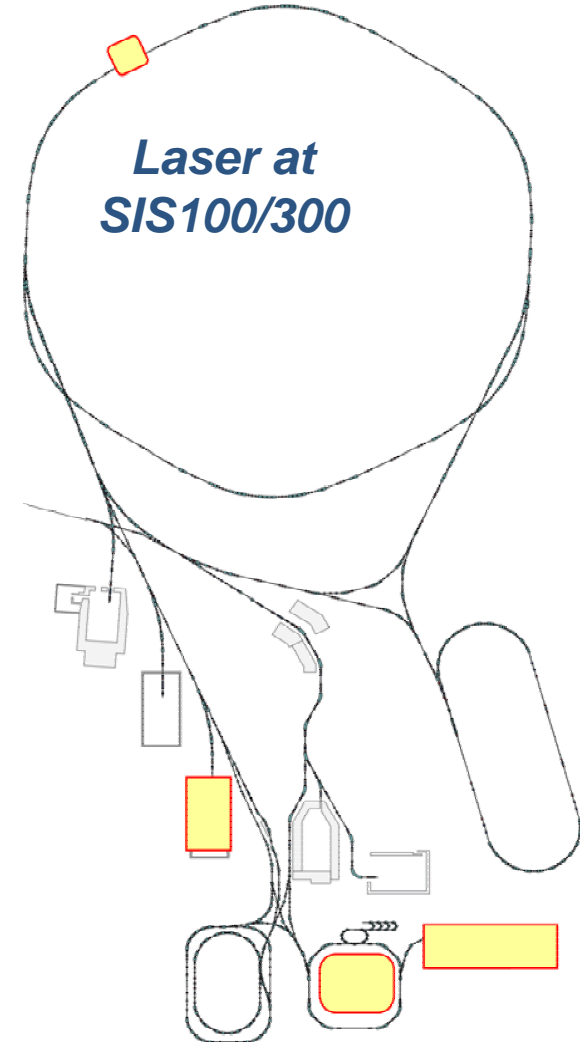
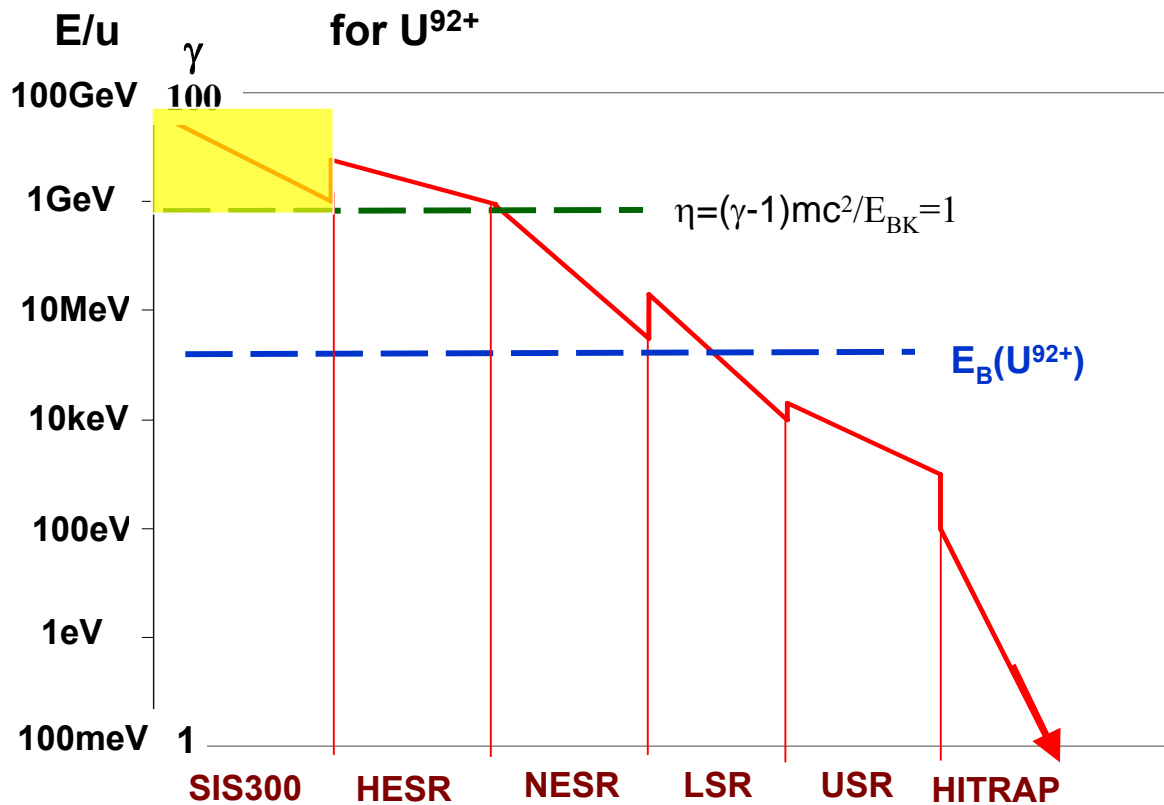
$$\Delta E \approx 10^{-6} \text{ eV}$$

$$Z \cdot \alpha \approx 10^{-2}$$

1s Lamb Shift

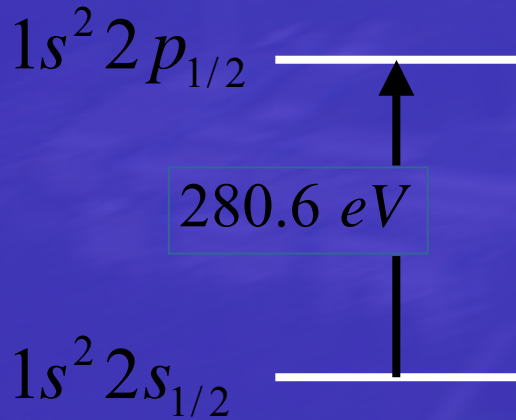


Laser at SIS100/300

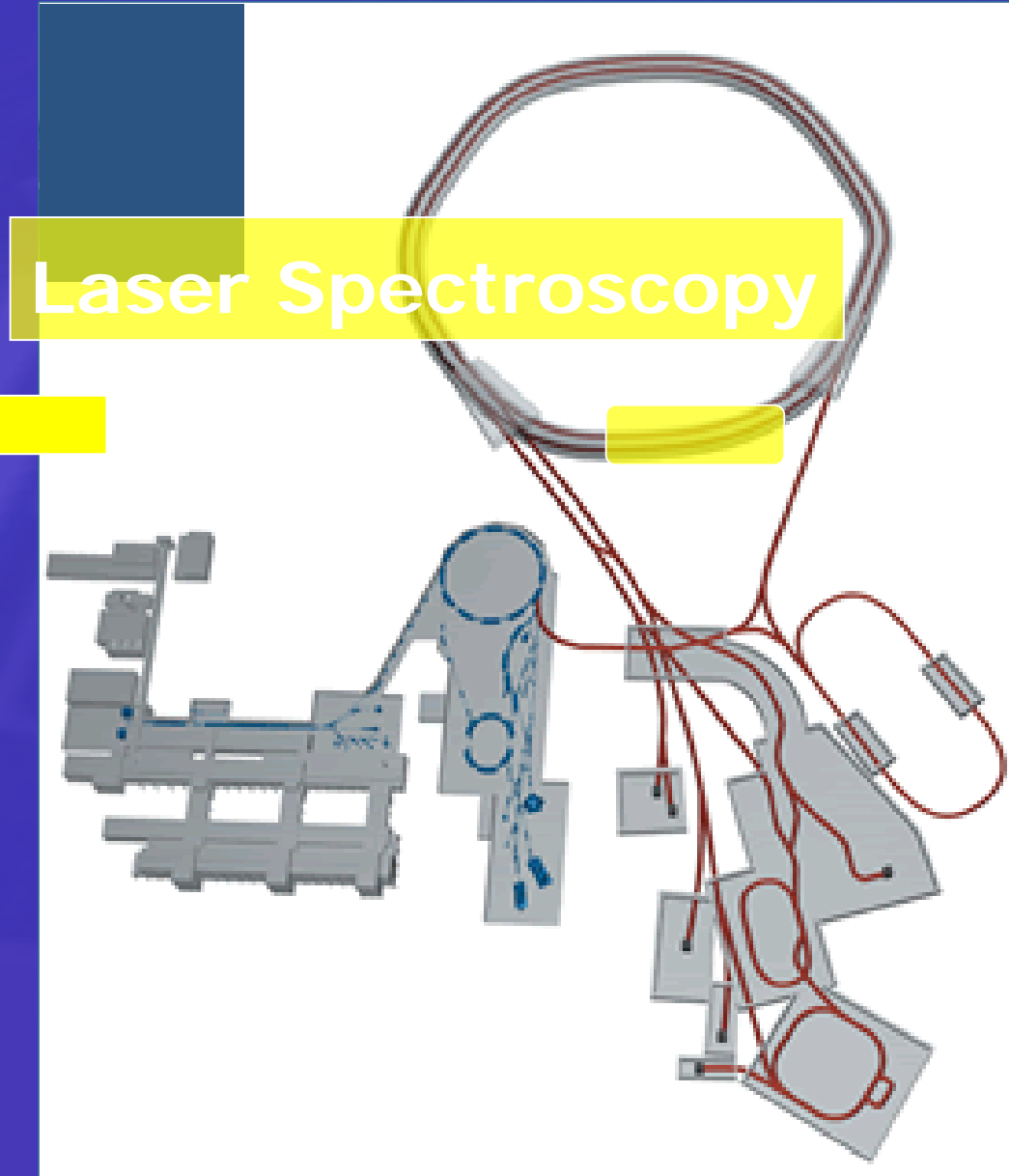


Quantum Electrodynamics

Three Electrons
in Uranium

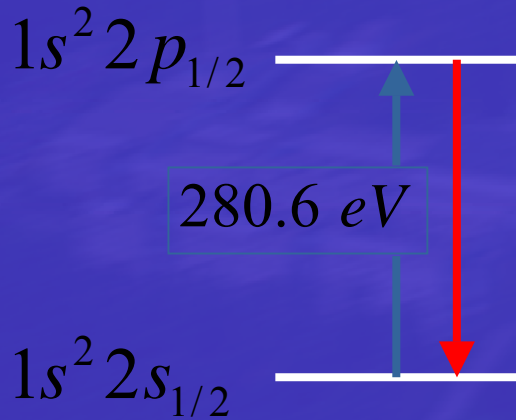


QED in Li-like
systems



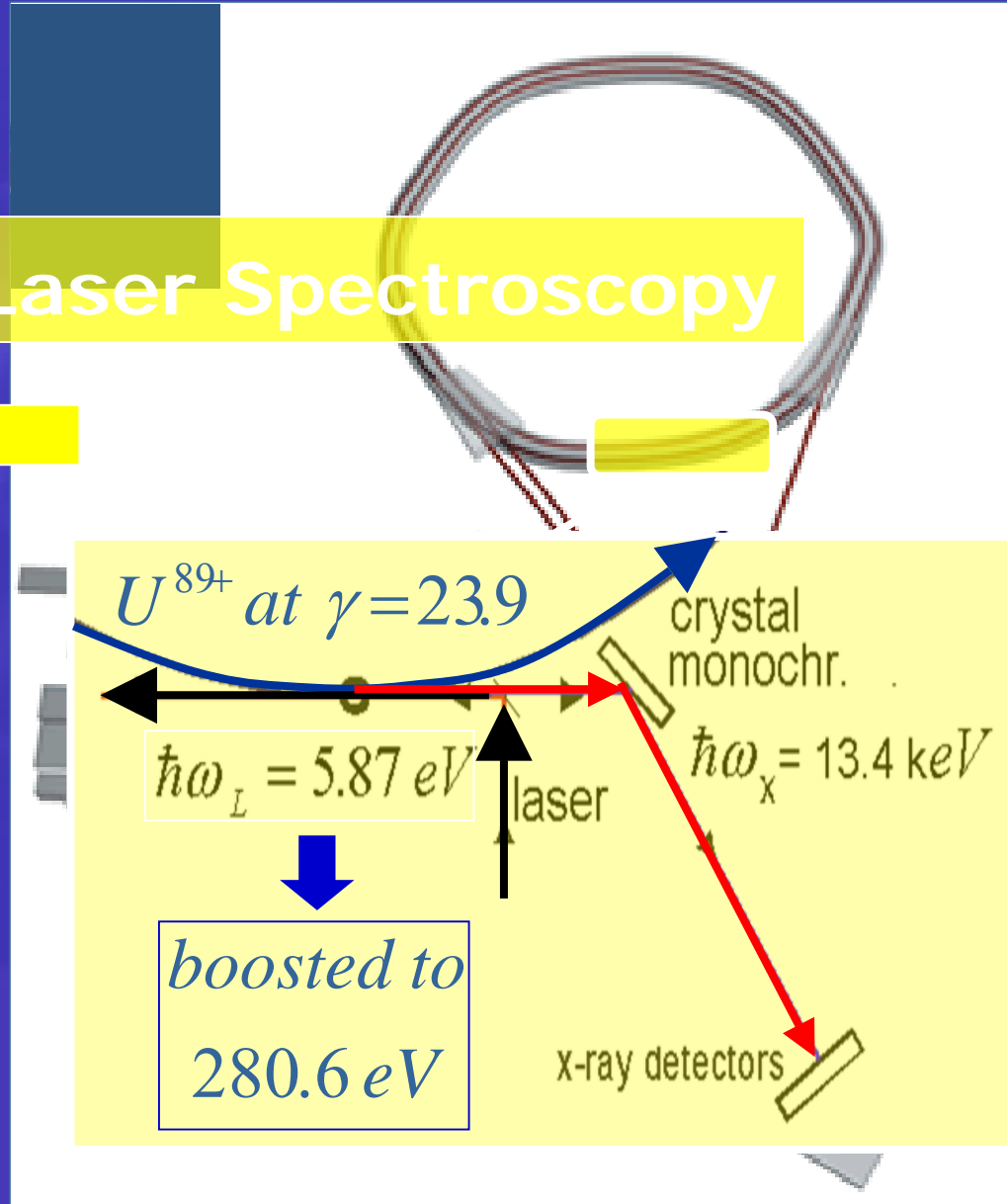
Quantum Electrodynamics

Three Electrons in Uranium

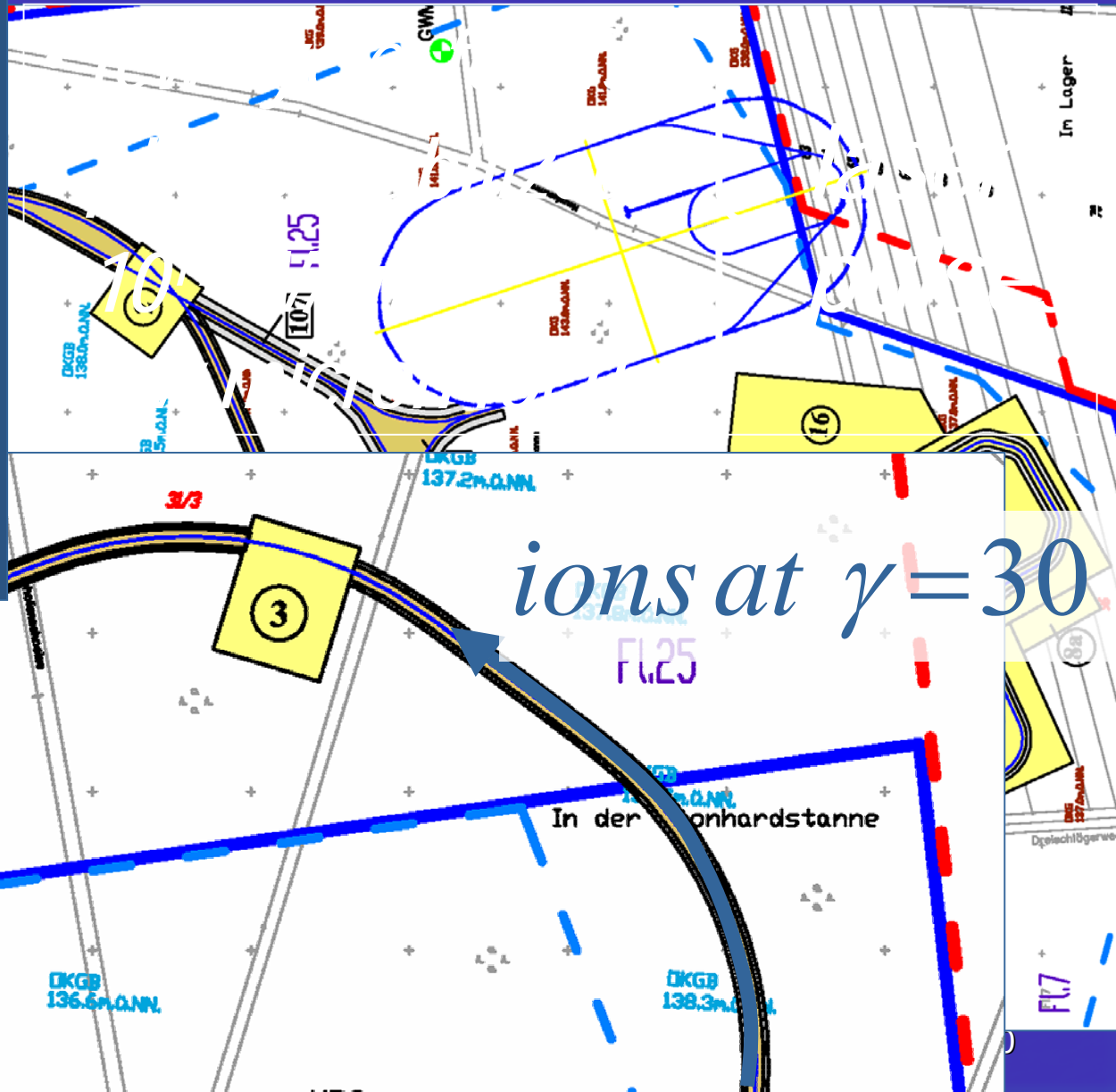
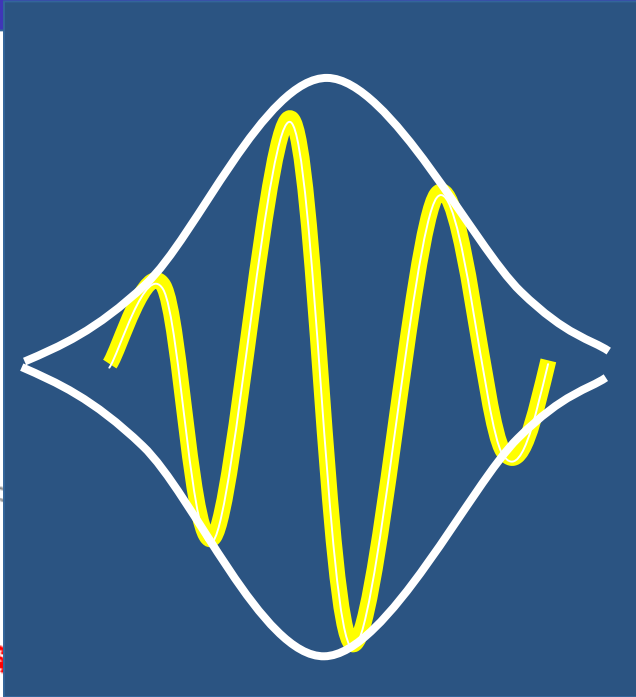


QED in Li-like systems

Laser Spectroscopy



Attosecond Pump-Probe



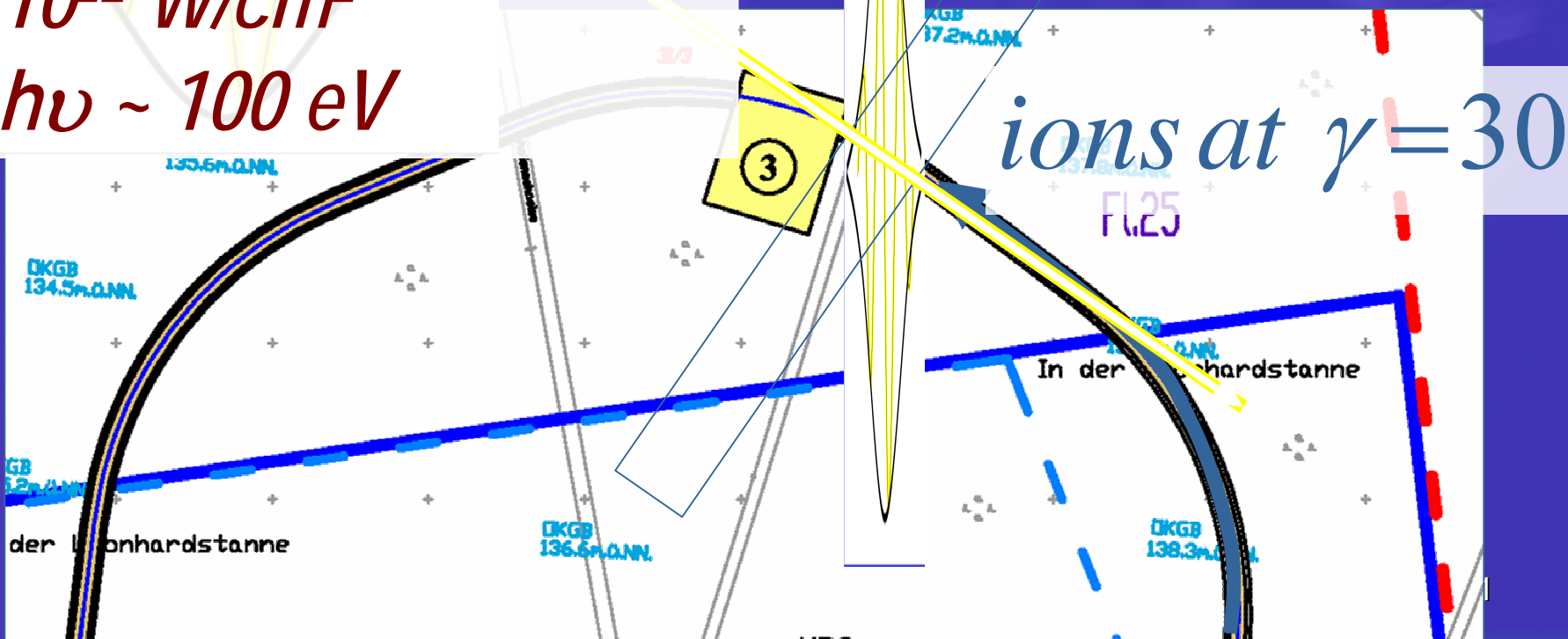
Attosecond Pump-Probe

Lorentz-boosted to

- *< 100 attoseconds*
- *phase stabilized*
- *10^{22} W/cm^2*
- *$h\nu \sim 100 \text{ eV}$*

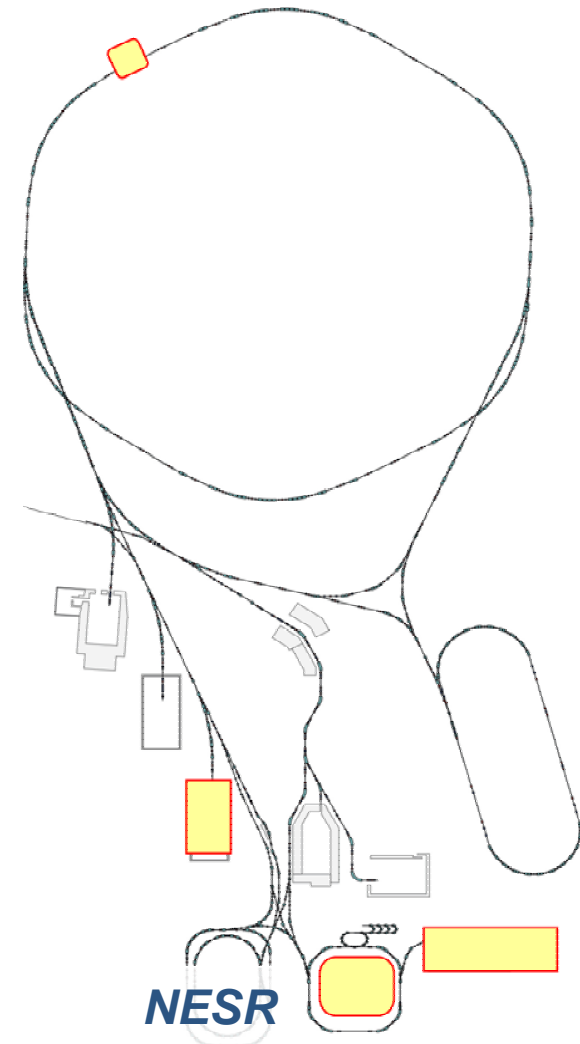
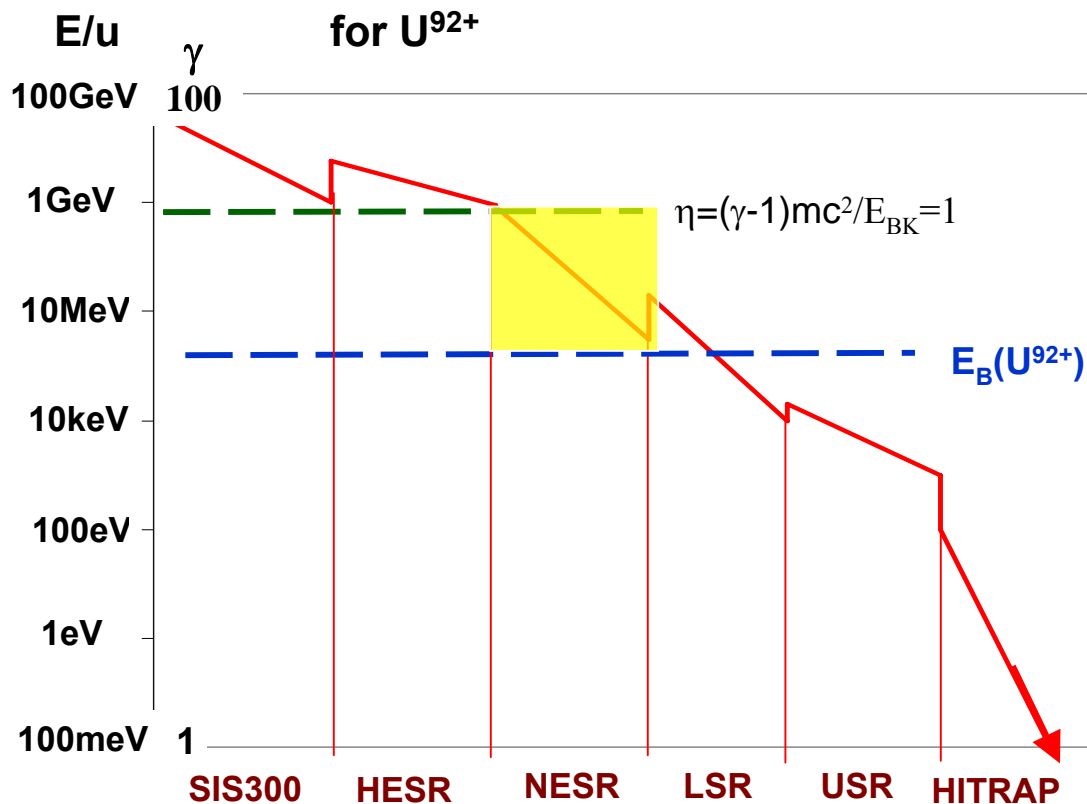
few cycle, few fs

well controlled
attosecond physics
few micron focus

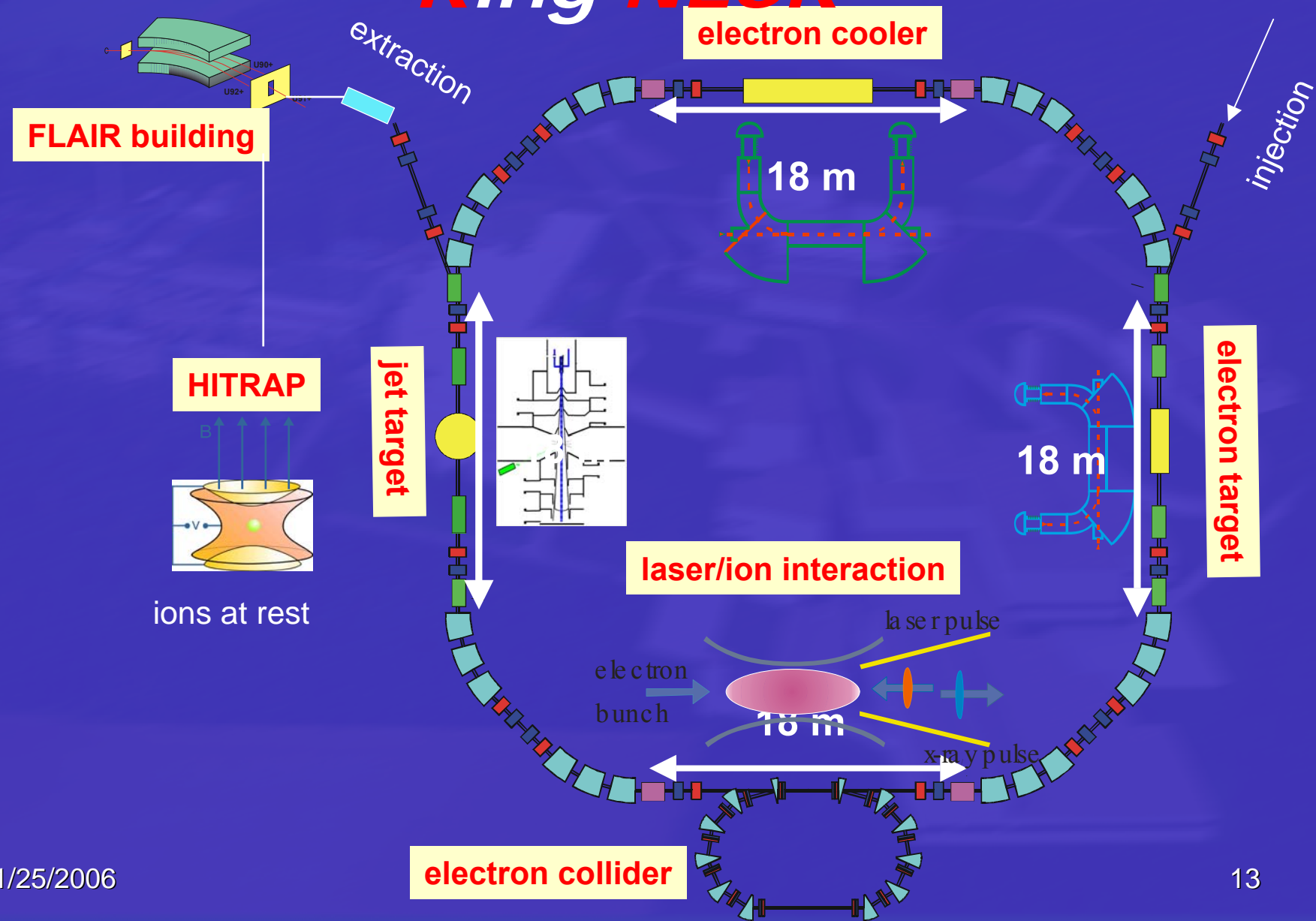


ions at $\gamma=30$

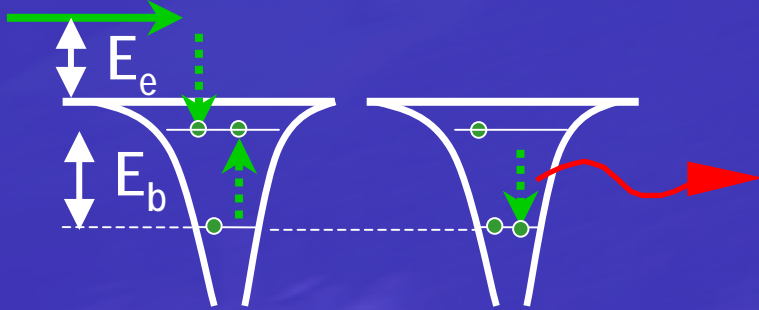
New Experimental Storage Ring (NESR)



The *New Experimental Storage Ring NESR*

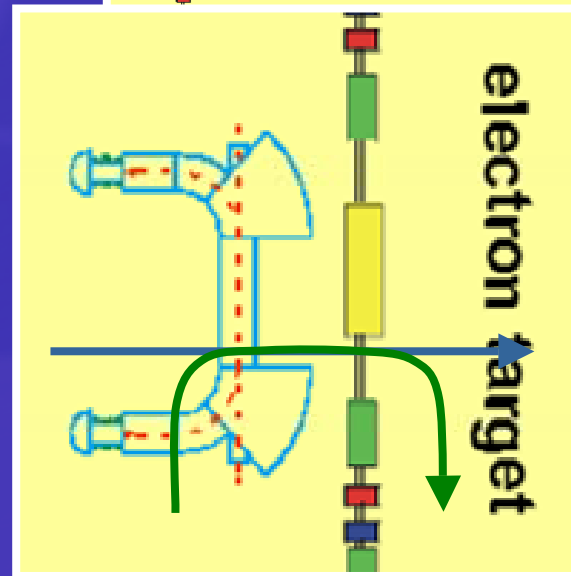
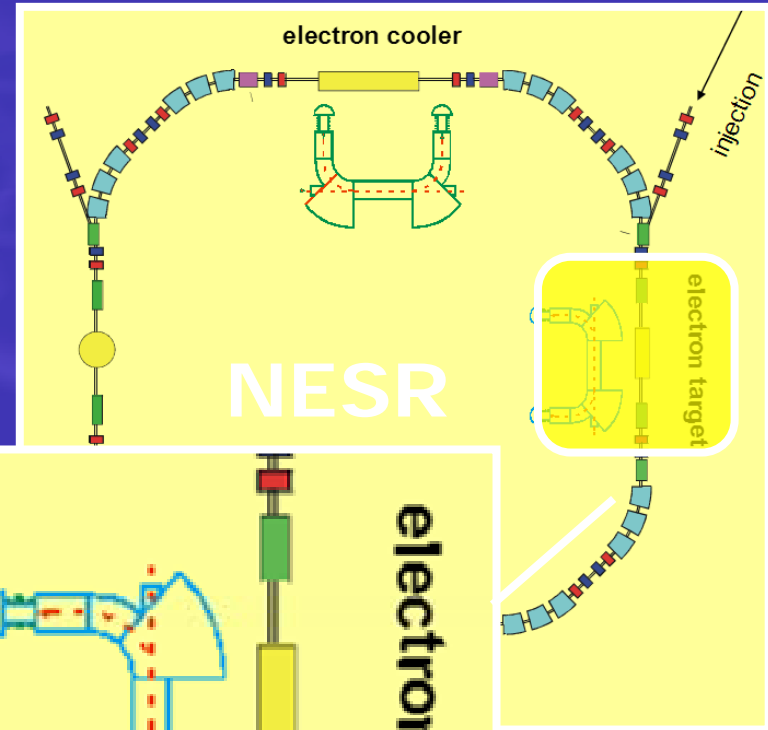


Dielectronic Recombination (DR)

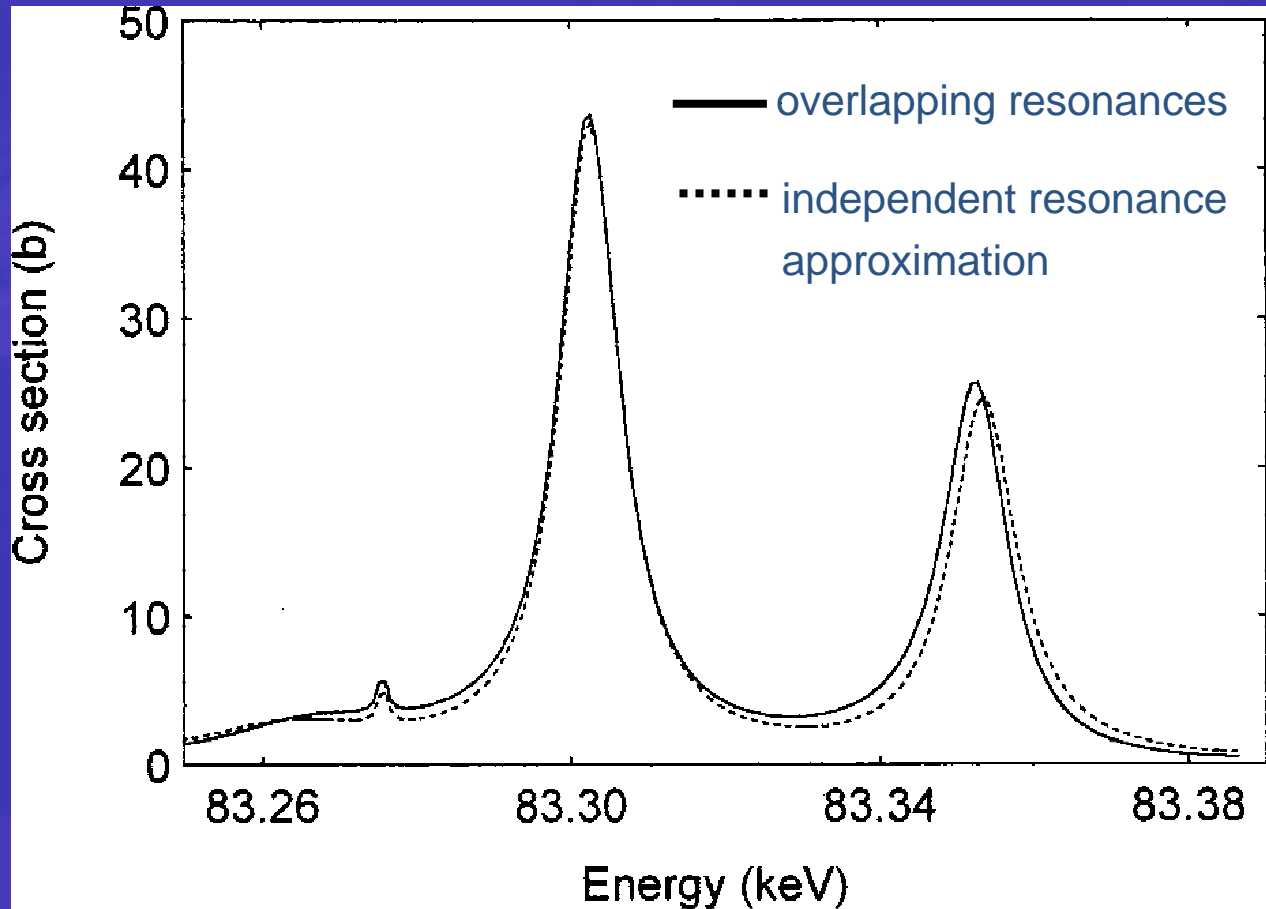


Measure resonance profiles due to dielectronic recombination to a level where QED effects manifest in the observed line-shapes, thereby providing significant new tests of dynamical QED.

Separate cooler and target provides energy range to access all dielectronic recombination resonance systems.



Overlapping Resonances in the KLn-DR of U^{91+} (dynamical QED)



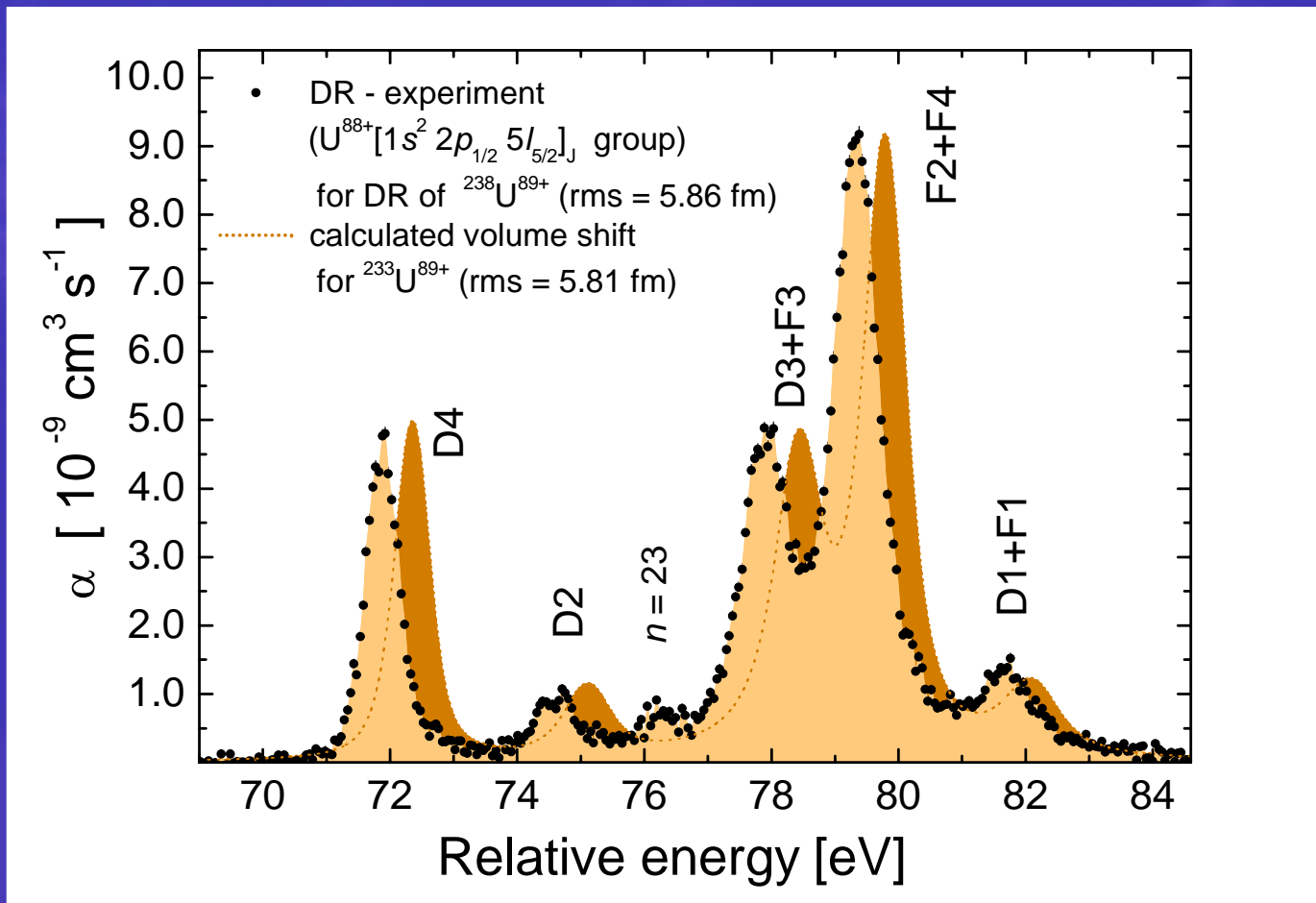
A. V. Nefiodov, L. N. Labzowsky, D. L. Moores, Phys. Rev. A **60** (1999), 2069.

1/25/2006

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Explore the Nucleus

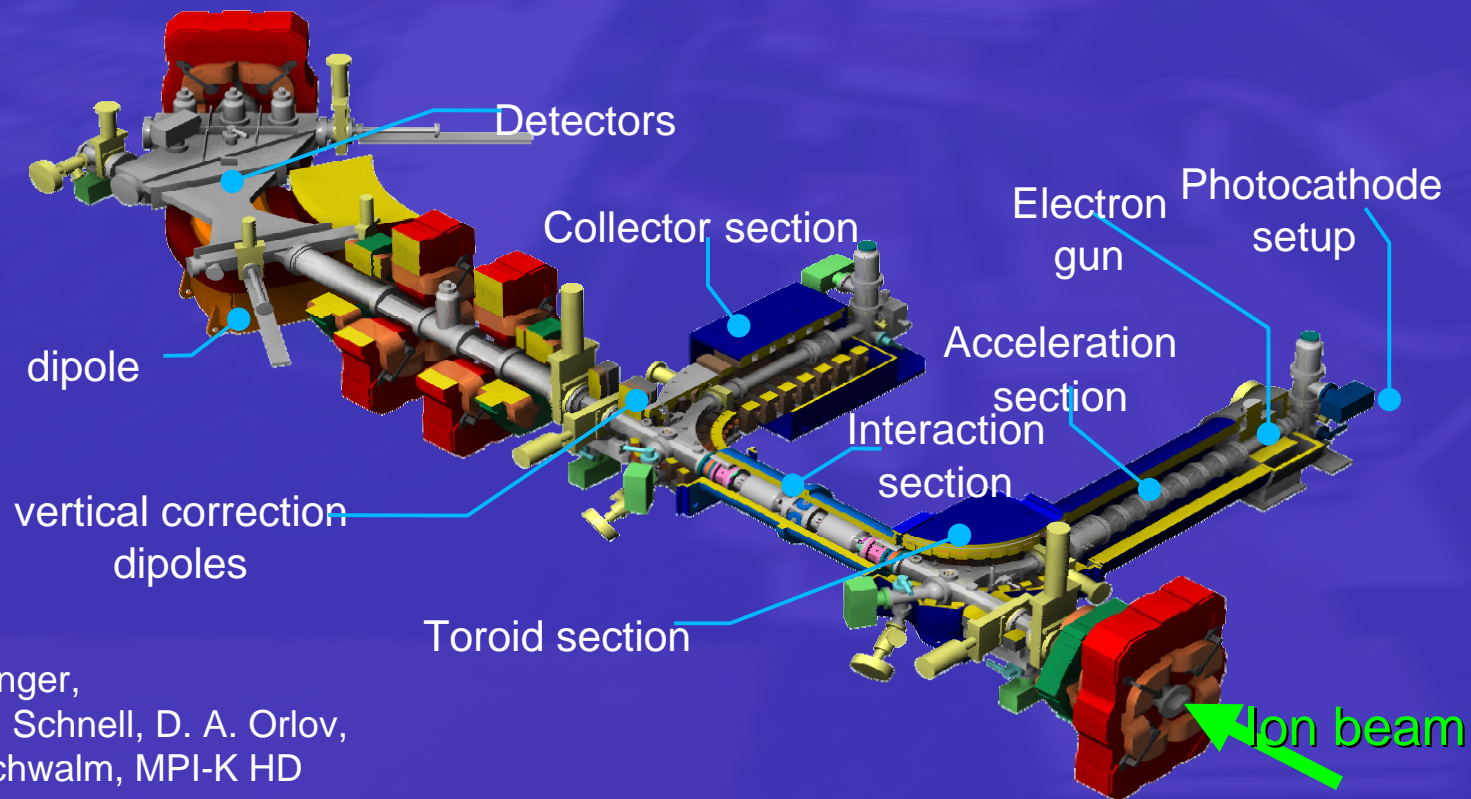
Experimental data for DR of Li-like $^{238}\text{U}^{89+}$ and calculated isotopic shift for $^{233}\text{U}^{89+}$ (volume shift only).



The Heidelberg (TSR)

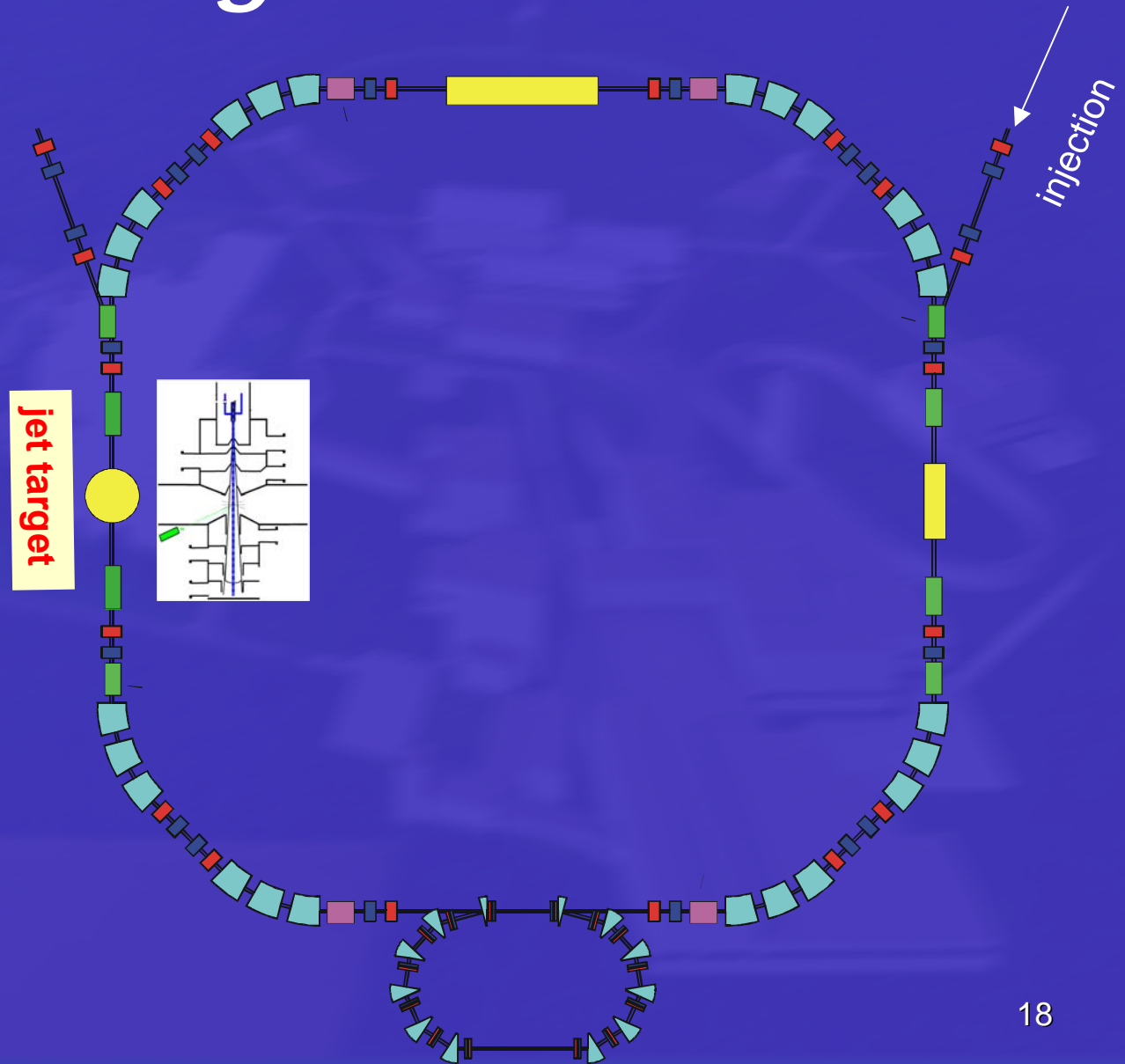
Ultracold Electron Target

3rd generation electron target (dedicated and optimized with respect to experiments)
Adiabatic expansion / adiabatic acceleration of electrons
Photocathode option for the production of initially cold electrons



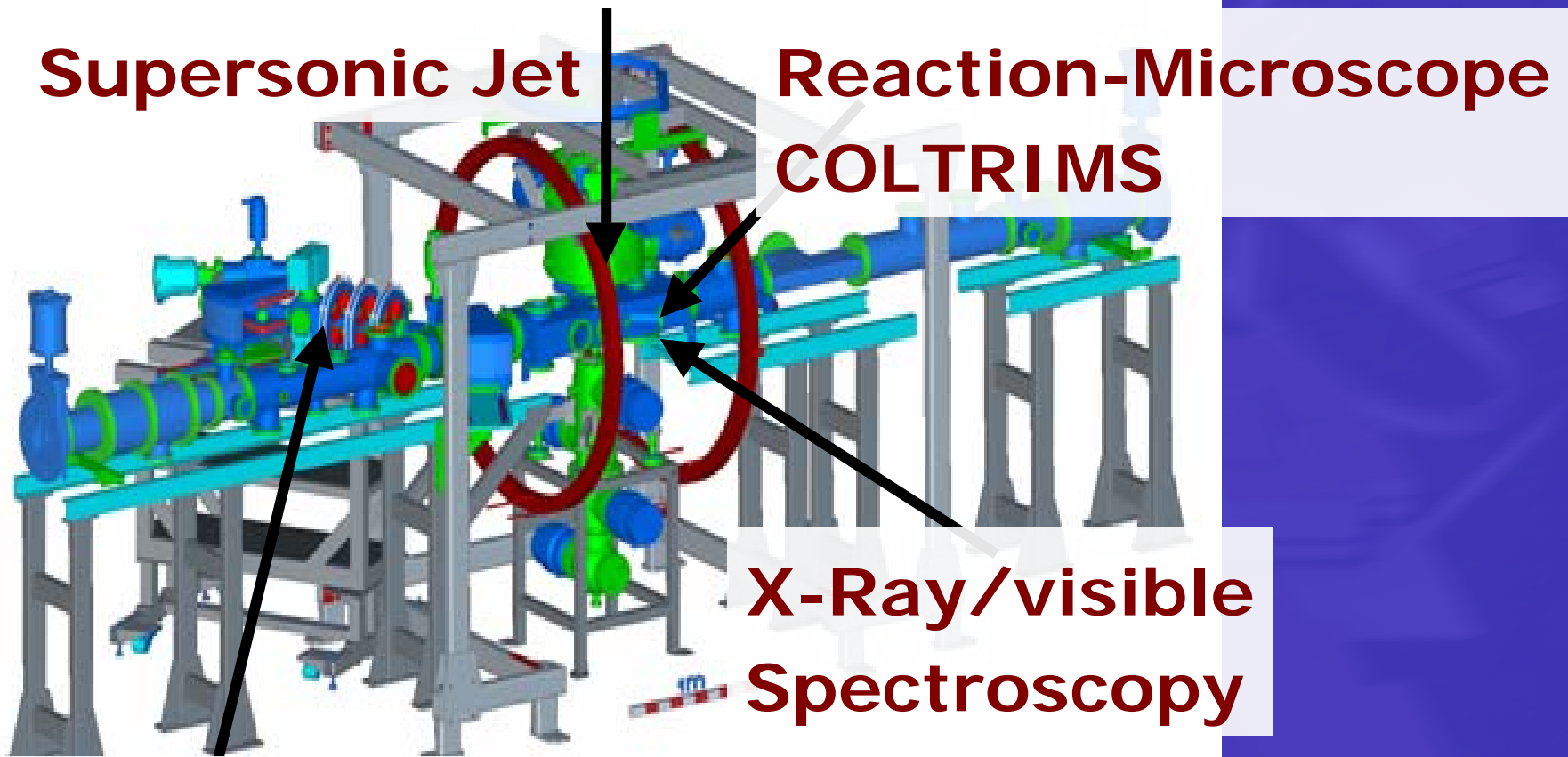
A. Wolf, F. Sprenger,
M. Lestinsky, M. Schnell, D. A. Orlov,
U. Weigel, D. Schwalm, MPI-K HD

The *New Experimental Storage Ring NESR*



In-Ring Spectrometers

The "Cloud Chamber" of Atomic Physics



Electron Spectroscopy

1/25/2006

Recoil Ion Momentum Spectroscopy

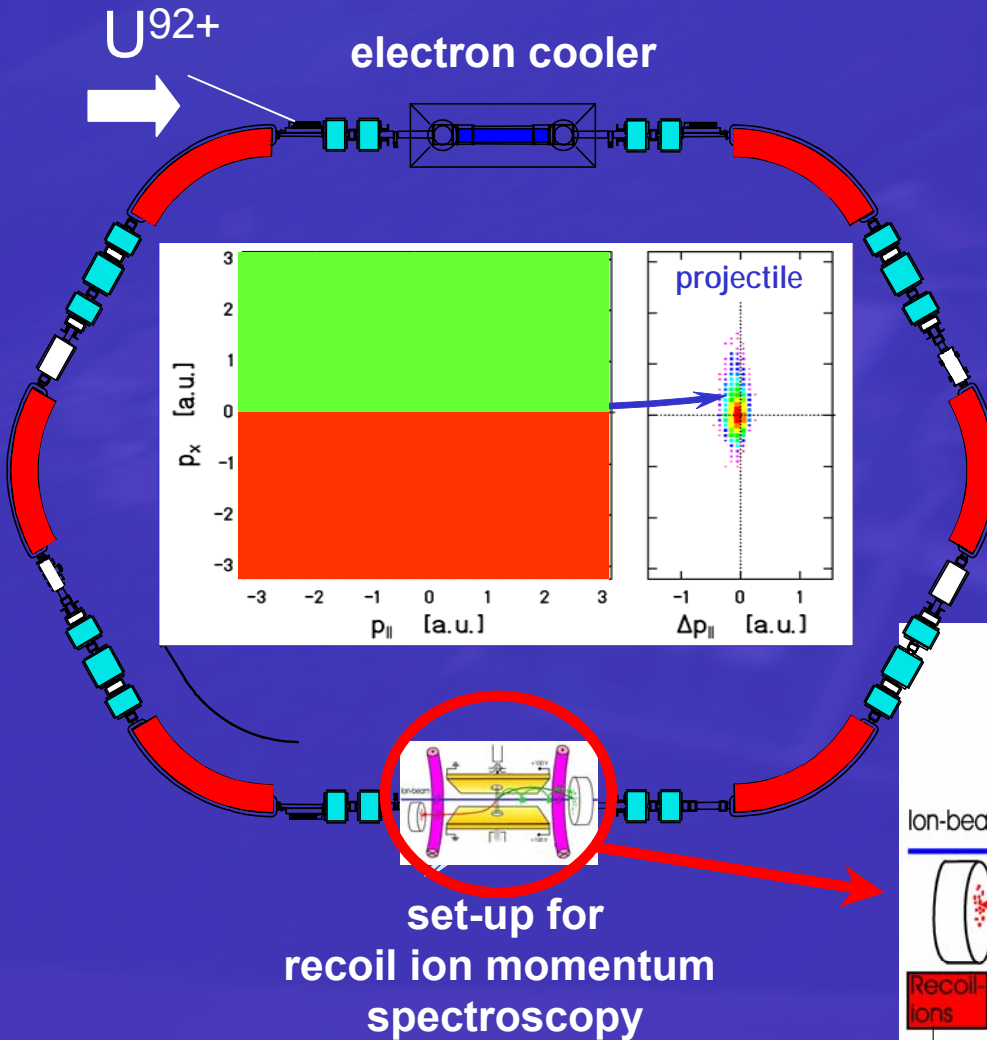
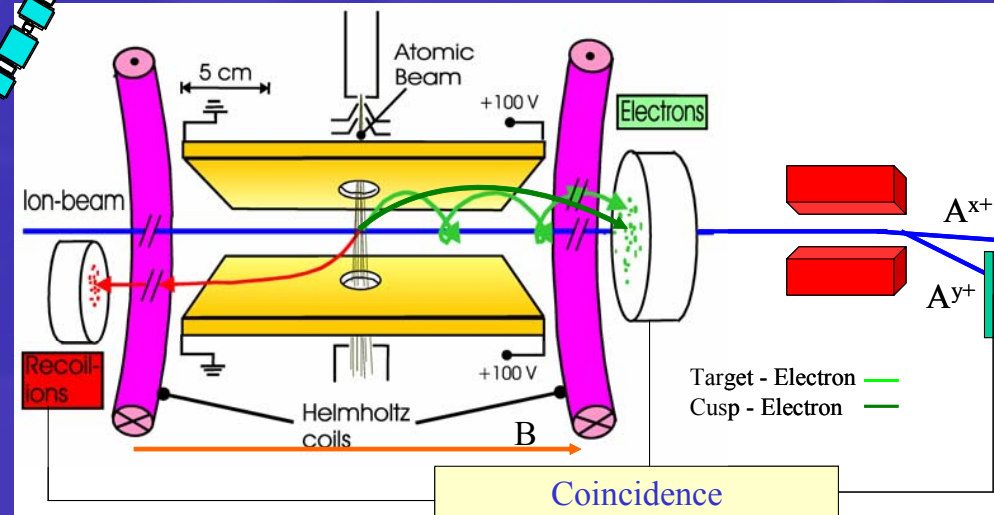


Photo ionization by
ultra-short
0.1 attosecond (10^{-19} s) pulses

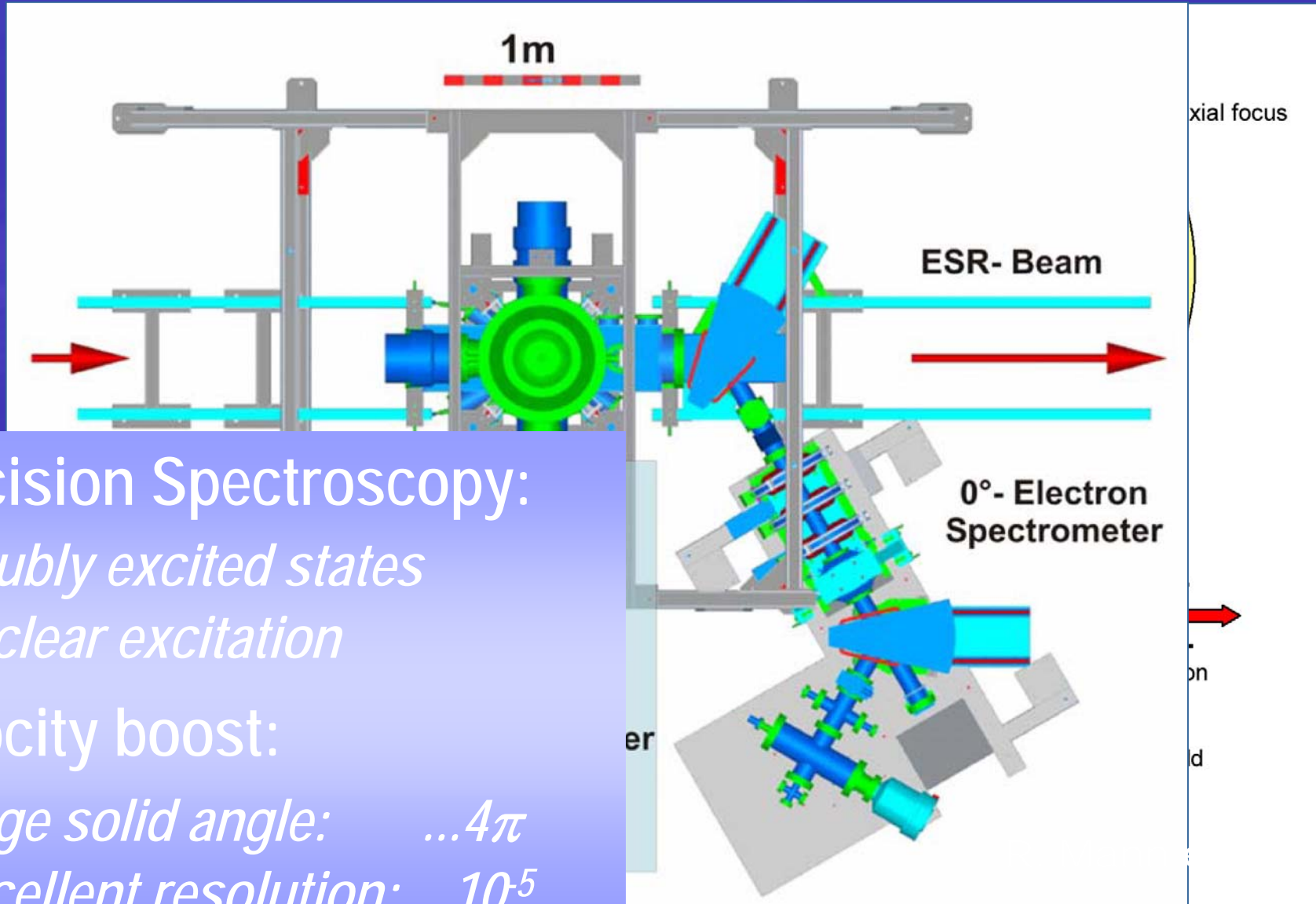
multiple ionization

exploration of correlated
wave function

no ab-initio theory
even for helium



Forward Emitted Electrons



Precision Spectroscopy:

- *doubly excited states*
- *nuclear excitation*

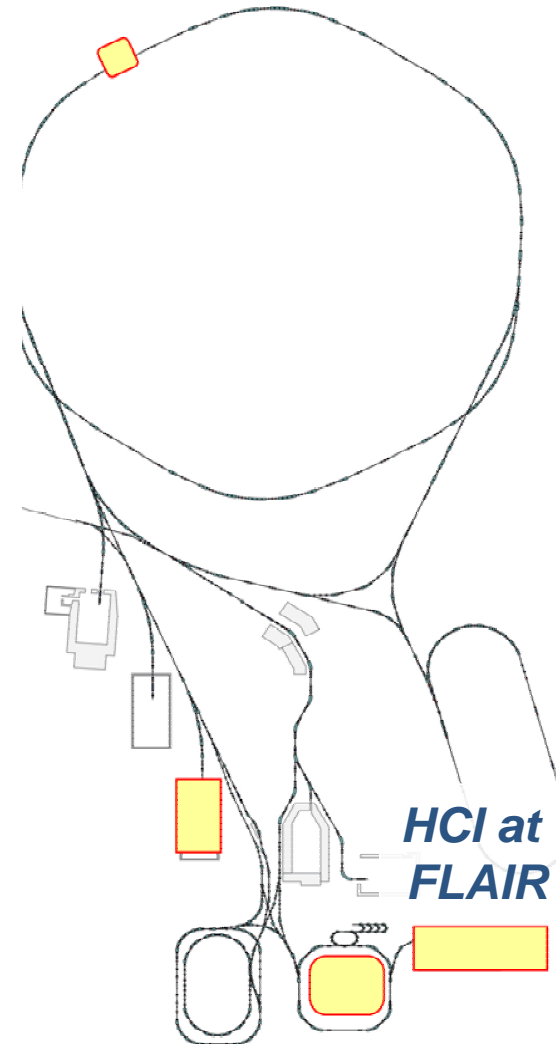
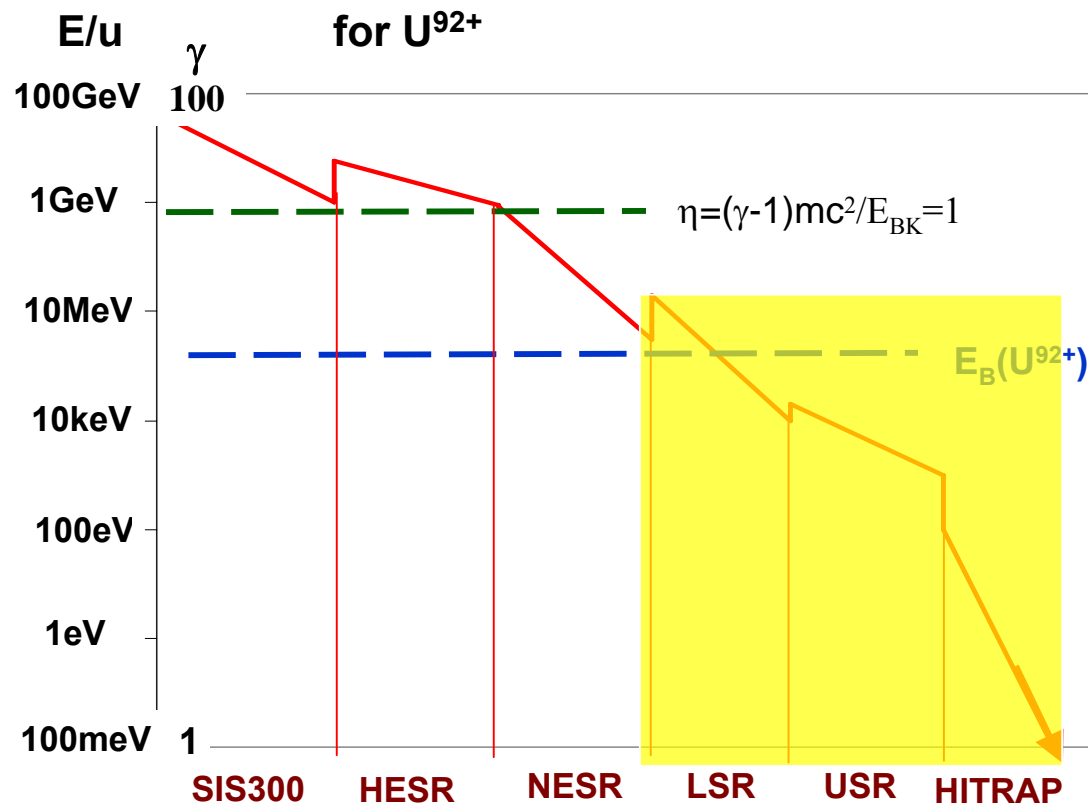
Velocity boost:

- *large solid angle: ... 4π*
- *excellent resolution: ... 10^{-5}*

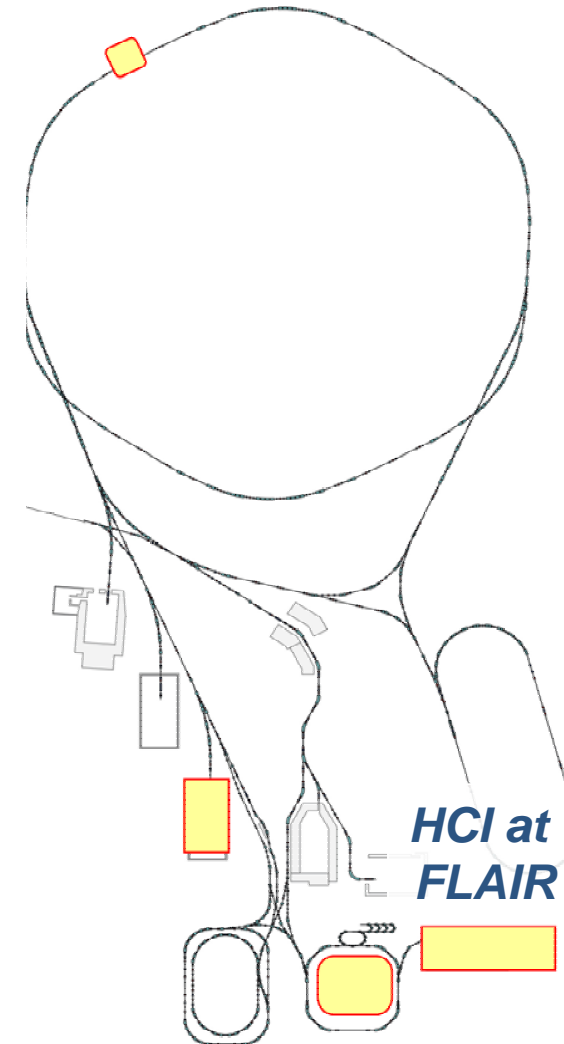
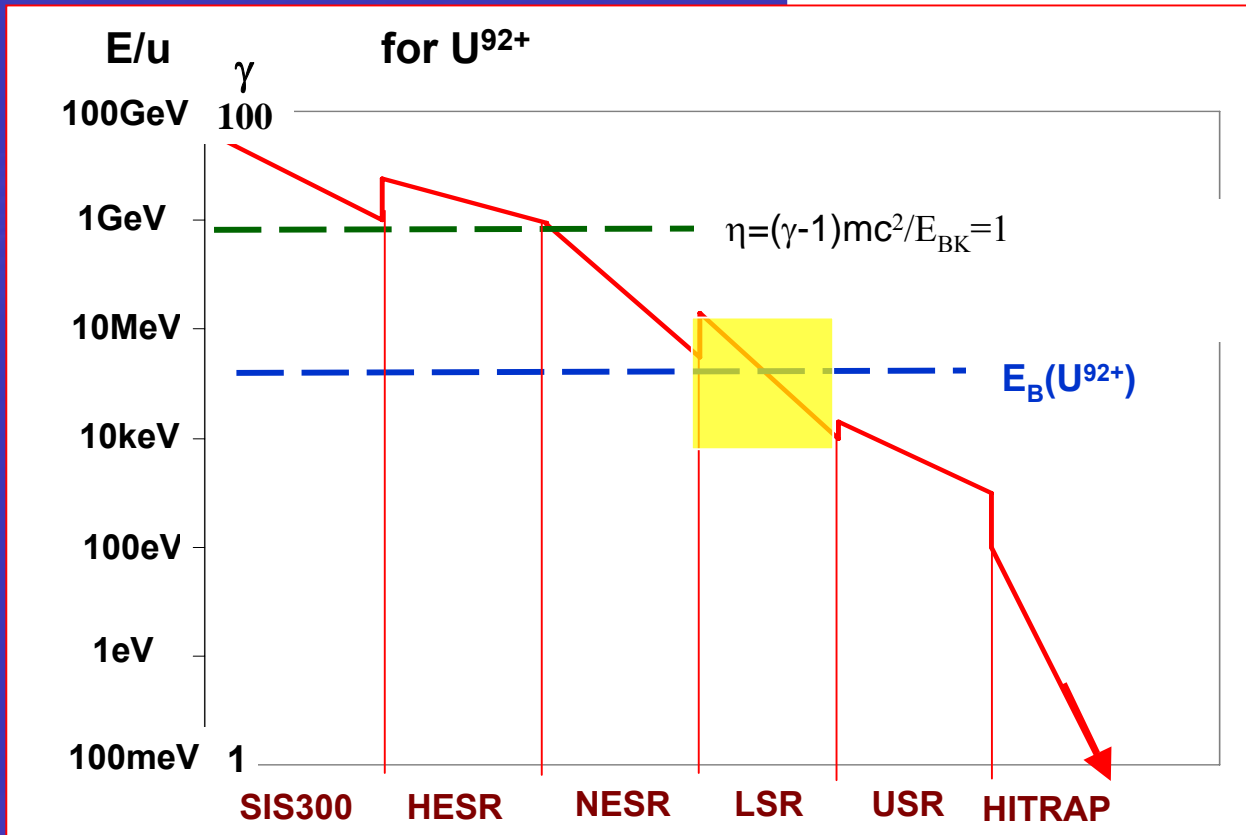
New Instrumentation

- Hard X-ray polarisation-sensitive detectors
- Microcalorimeters for high resolution broad band detection
- X-ray optics for efficient collection
- Suite of spectrometers
- etc.

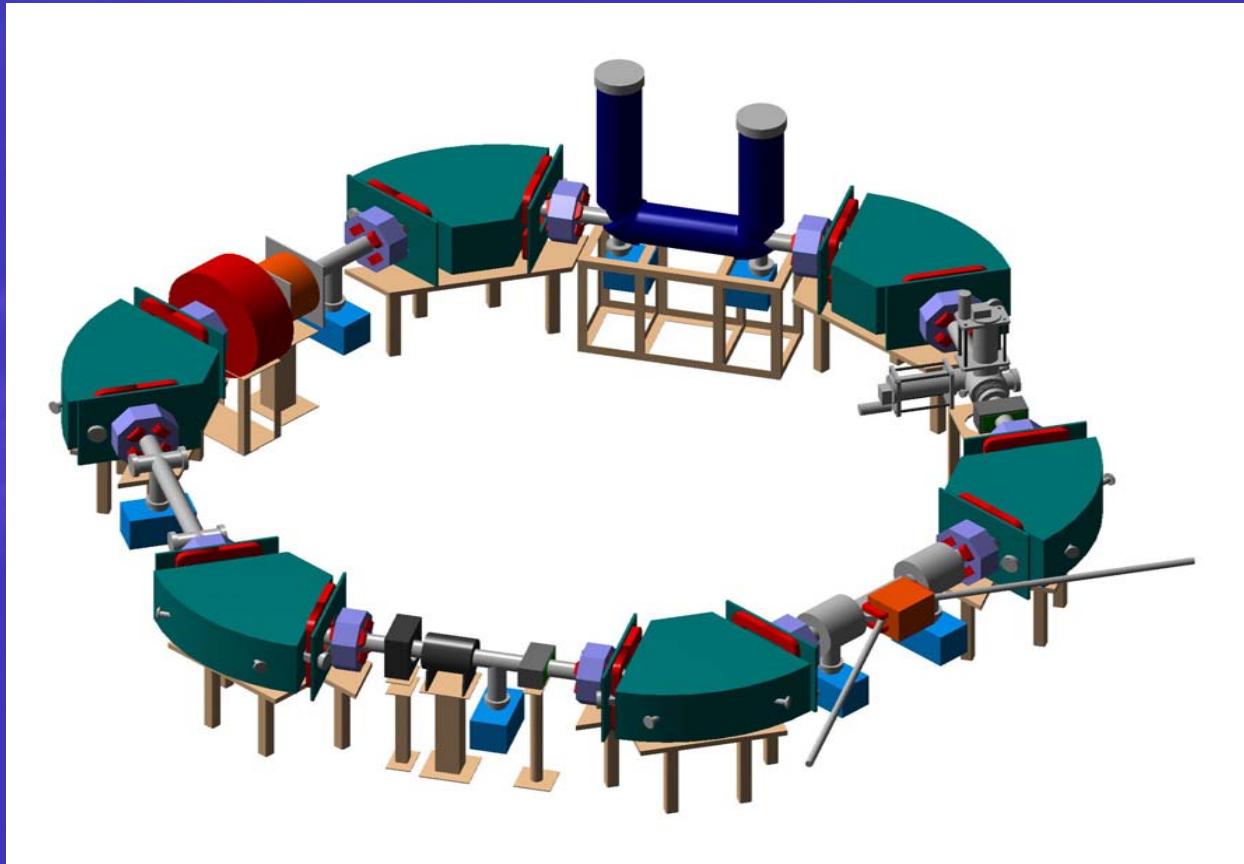
Facility for Low-energy Antiproton and Ion Research (FLAIR)



Low-Energy Storage Ring

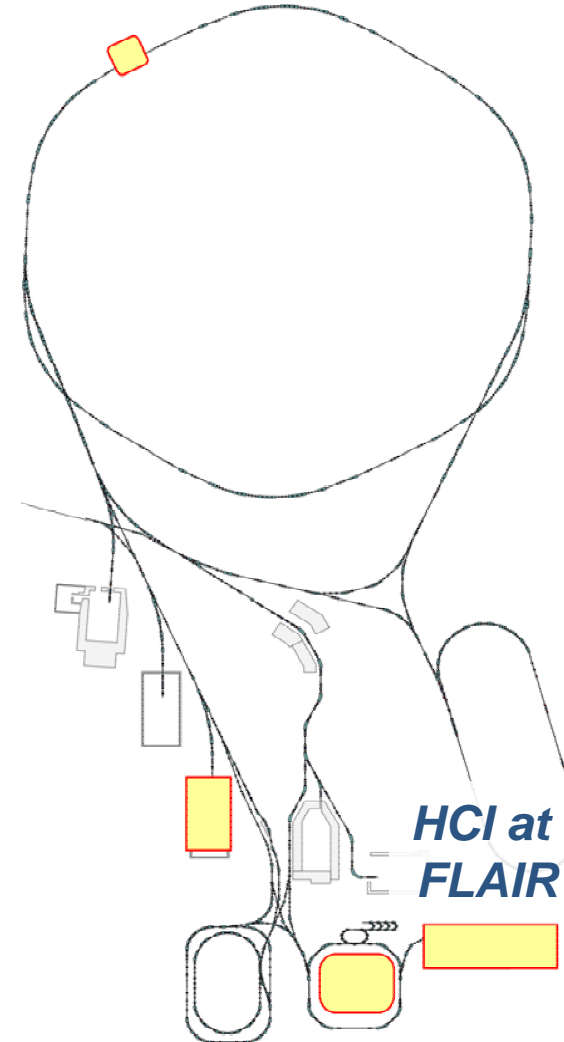
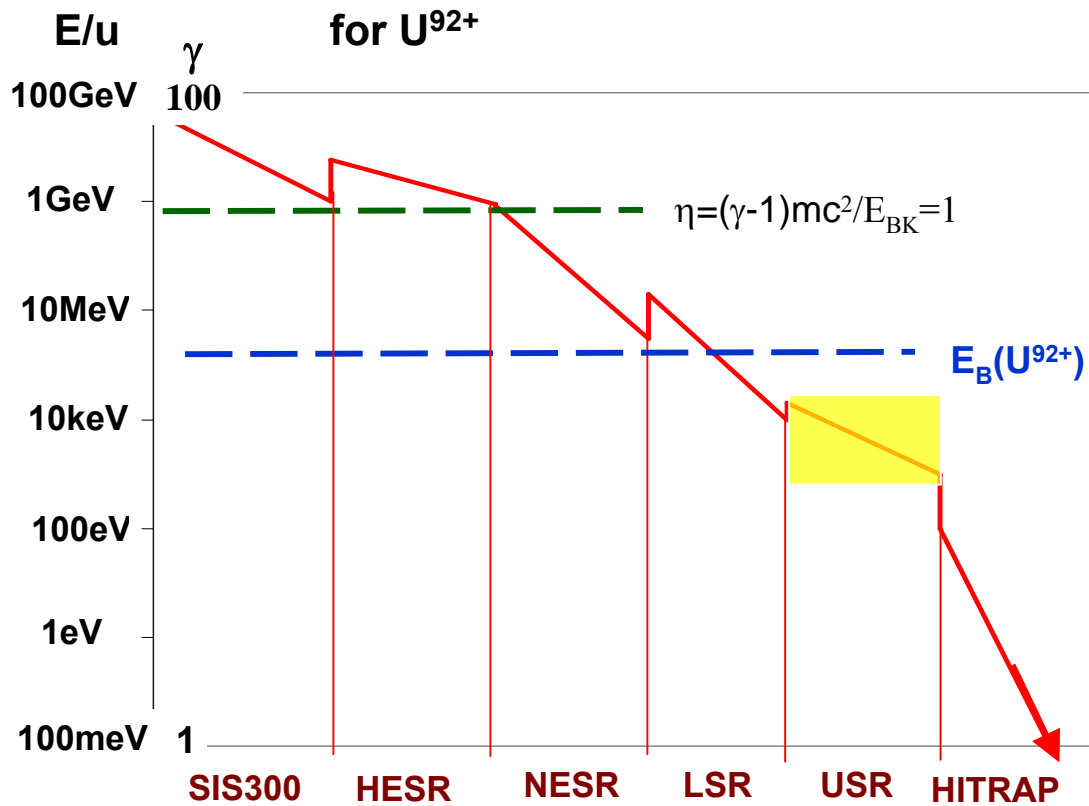


The Low-Energy Storage Ring LSR



- LSR: A cooler storage ring: CRYRING
- medium to low energies
 - in-ring experiments: gas target, "reaction microscope"
 - ns beam pulses for ionization experiments

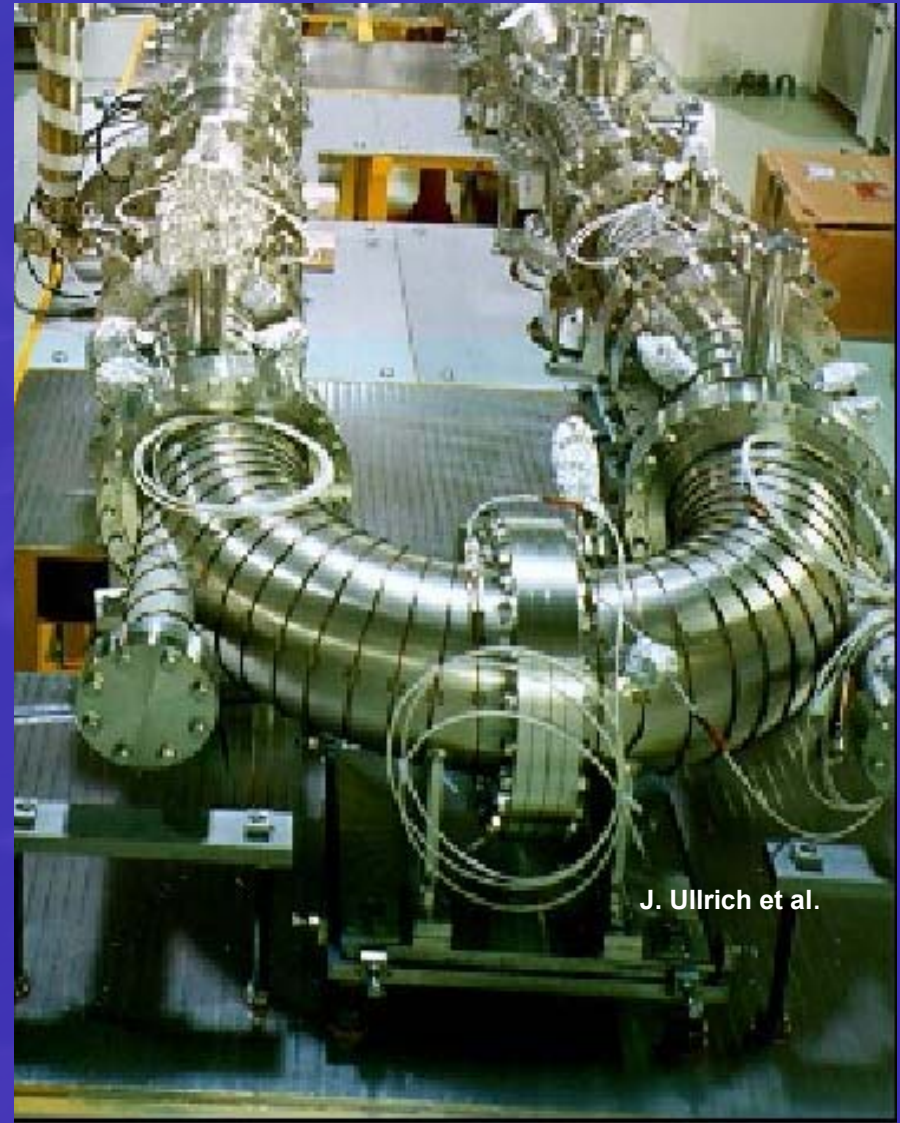
Ultra-Low Energy Storage Ring



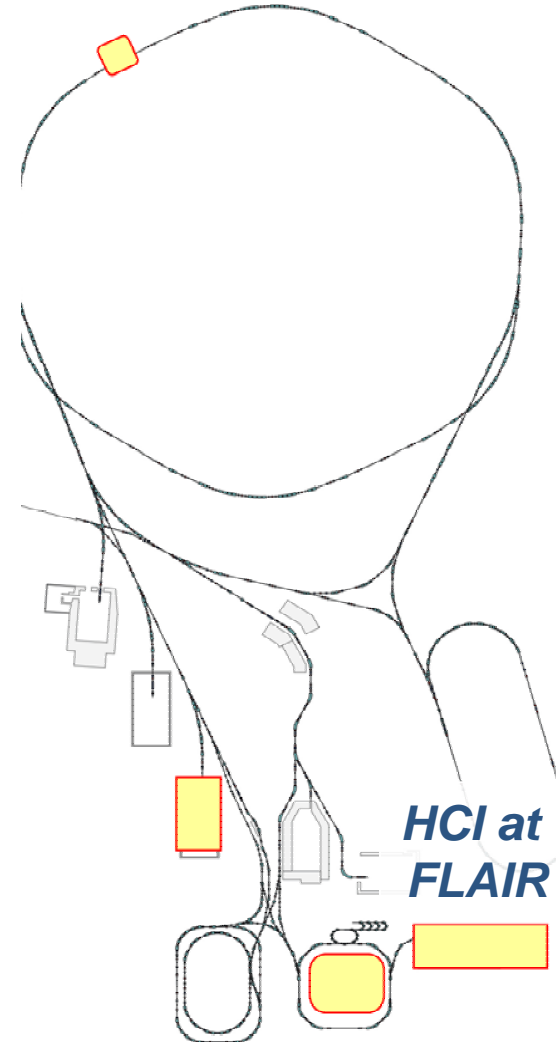
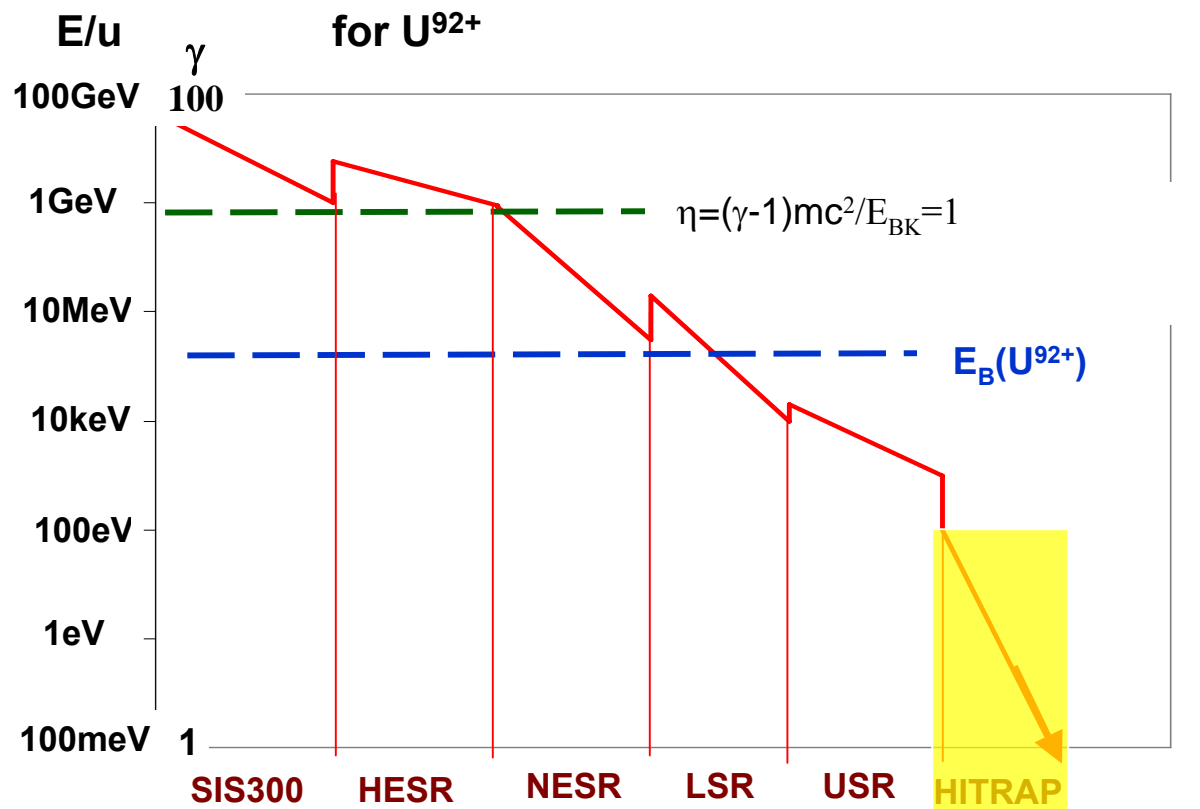
The Electrostatic Storage Ring USR for Antiprotons and Ions at Ultra-Low Energy

USR: A novel low-energy electrostatic storage ring

- low to ultra-low energies
- in-ring experiments:
 - gas target
 - "reaction microscope"
- excellent beam quality
- high luminosity for in-ring experiments



HI-TRAP



Precision Experiments in Penning Traps

g-Factor of bound electron in highly charged ions @HITRAP

High-Precision Ion Trap Techniques:

- Single highly charged ion stored in Penning trap at $T = 4$ K
- Measurement of the *ion cyclotron frequency* and of *Larmor precession frequency* of the bound electron with an accuracy of 7×10^{-10}

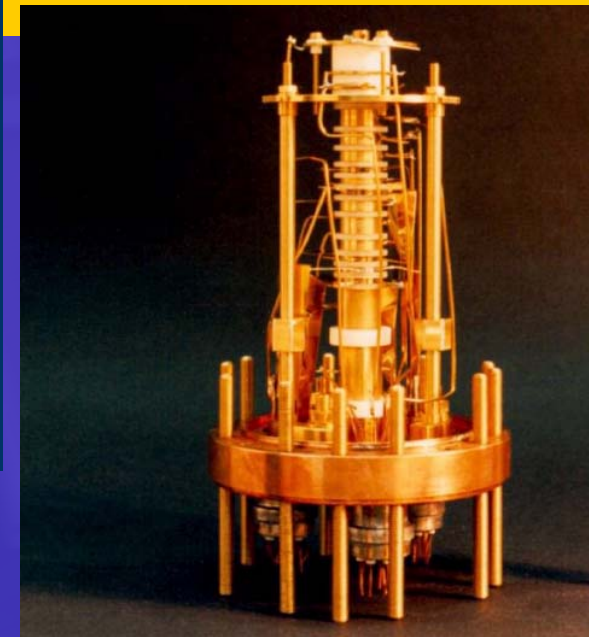
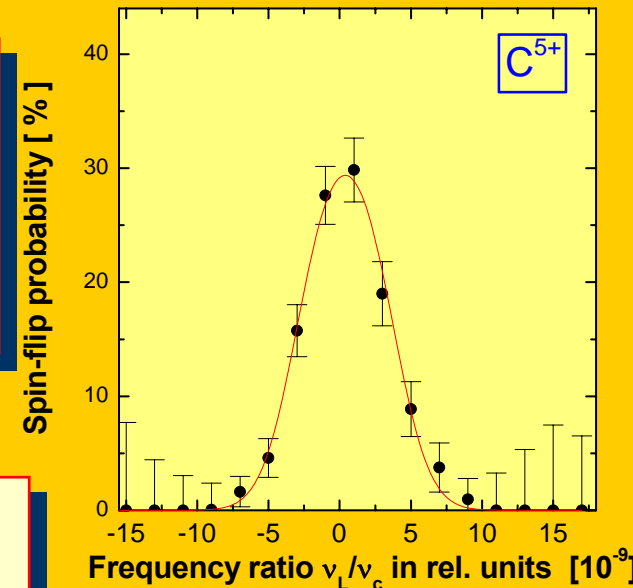
Bound-state QED and atomic-structure investigations:

g-Factor of the bound electron in hydrogen-like ions up to U^{91+}

- Fundamental constants (α , m_e)
- Nuclear moments, diamagnetic shielding, charge radii
- Determination of atomic binding energies via *ion cyclotron frequency* measurements in different charge state

J. Kluge, W. Quint, G. Werth et al.

1/25/2006



Timeline and Milestones

- 2006 September: SPARC open session @ HCI-2006 Belfast
- 2007 HITRAP in operation at ESR
- 2008 Jet-target for NESR at ESR in operation
- 2009/10 Electron target/cooler ready for NESR
- 2010 Transfer of CRYRING
- 2011 High-energy AP cave: commissioning
- 2011 Installation of internal target at NESR, Commissioning of NESR
- 2011 Commissioning of LSR
- 2012 Commissioning of low-energy cave, Experiments at NESR
- 2012/13 HITRAP at NESR



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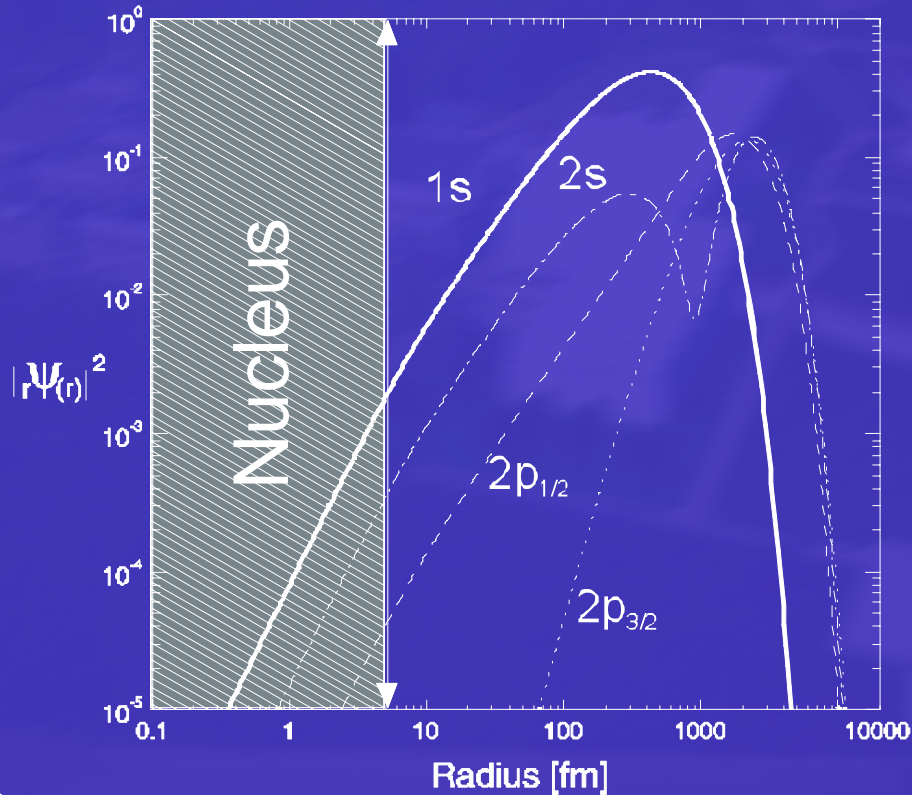
Thank you for your time and attention

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<http://www.gsi.de/sparc>

Electrons of Heavy Highly-Charged Ions as a Probe for the Nucleus

wavefunctions of low-lying
electron orbitals in U^{91+}



in heavy few-electron
systems :

significant overlap of
s- and $p_{1/2}$ -electronic
wavefunction with the
atomic nucleus

⇒ bound electrons
are a sensitive probe
of the nucleus
(charge distribution,
nuclear spin)

New Experimental Possibilities for DR at Super-FRS/NESR

large production rates of radioactive nuclei

