

# *Atomic Physics at GSI: An Outlook*

H. Backe<sup>1</sup>, H.F. Beyer<sup>2</sup>, F. Bosch<sup>2</sup>, A. Bräuning-Demian<sup>2</sup>, S. Hagmann<sup>2,3</sup>, D.C. Ionescu<sup>2</sup>,  
K. Jungmann<sup>2</sup>, H.-J. Kluge<sup>2</sup>, C. Kozhuharov<sup>2</sup>, Th. Kühl<sup>2</sup>, D. Liesen<sup>2</sup>, R. Mann<sup>2</sup>,  
P.H. Mokler<sup>2</sup>, W. Quint<sup>2</sup>, **Th. Stöhlker<sup>2,3</sup>**

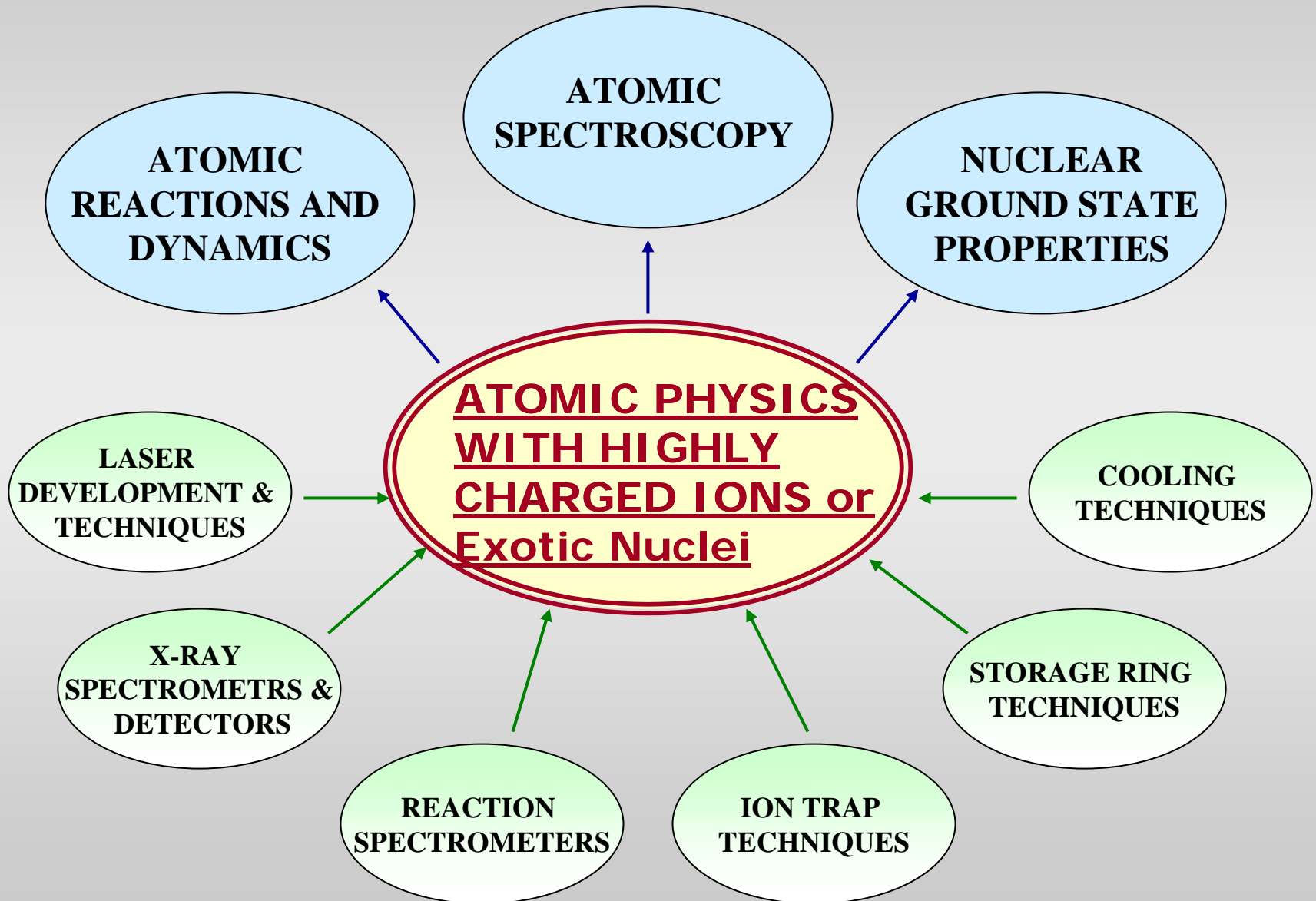
<sup>1</sup>Universität Mainz, Germany

<sup>2</sup>GSI-Darmstadt, Germany

<sup>3</sup>IKF, Universität Frankfurt, Germany

**AP WORKSHOP 2002, GSI**

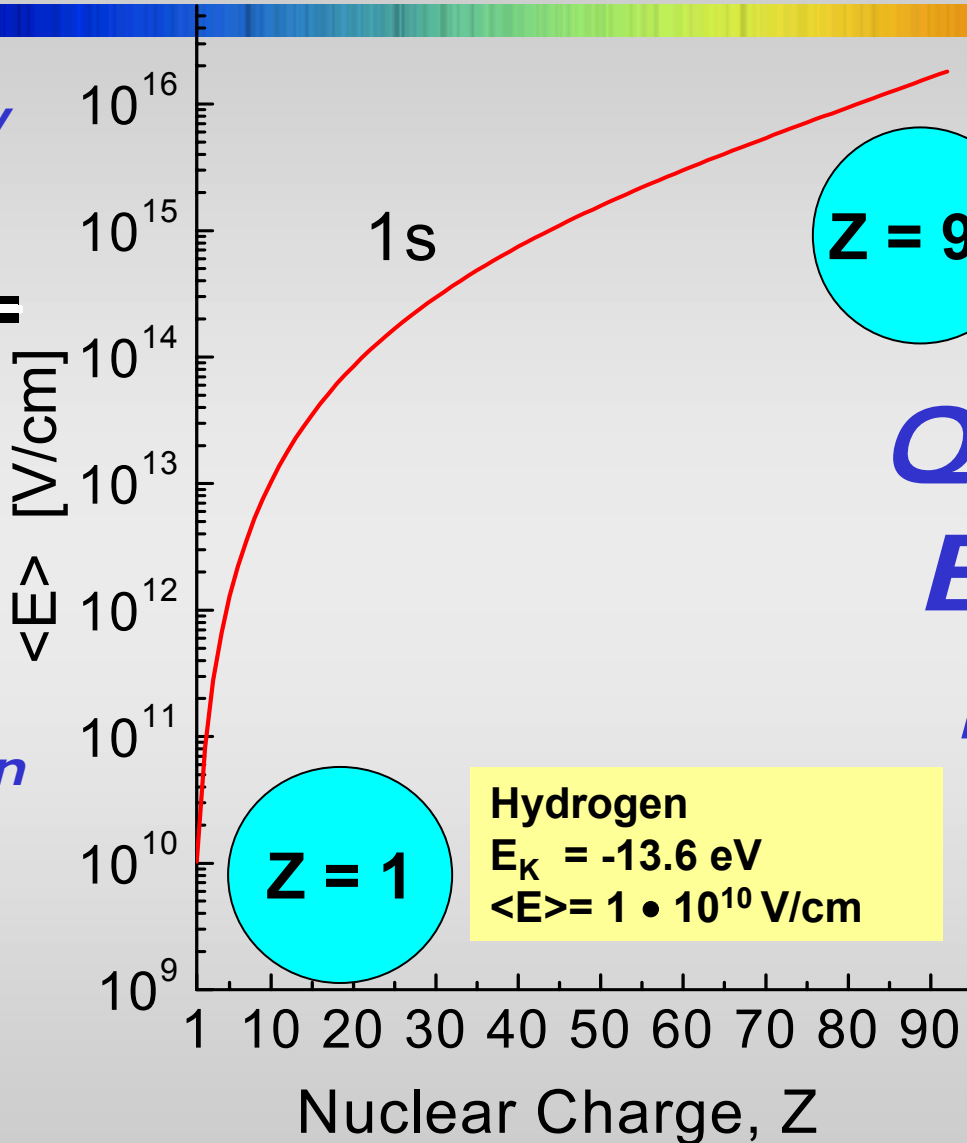
# Atomic Physics at Accelerators



*Self Energy*



*Vacuum Polarization*



H-like Uranium  
 $E_K = -132 \cdot 10^3 \text{ eV}$   
 $\langle E \rangle = 1.8 \cdot 10^{16} \text{ V/cm}$

**Z = 92**

Quantum  
Electro-  
Dynamics

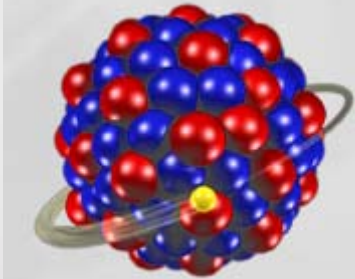
**Z = 1**

Hydrogen  
 $E_K = -13.6 \text{ eV}$   
 $\langle E \rangle = 1 \cdot 10^{10} \text{ V/cm}$

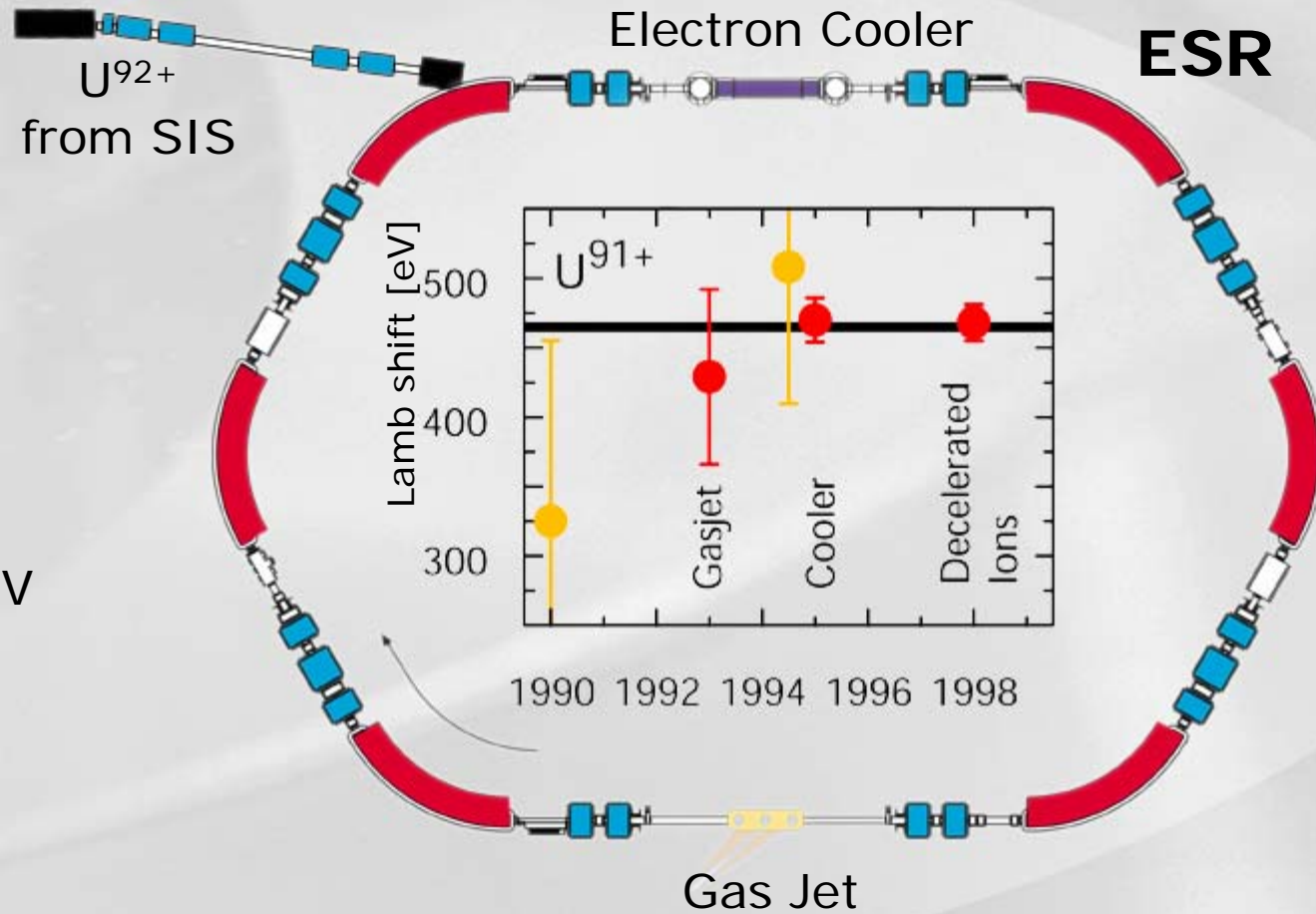
*1s-ground state: increase of the electric field strength by six orders of magnitude*

## Test of Quantum Electrodynamics

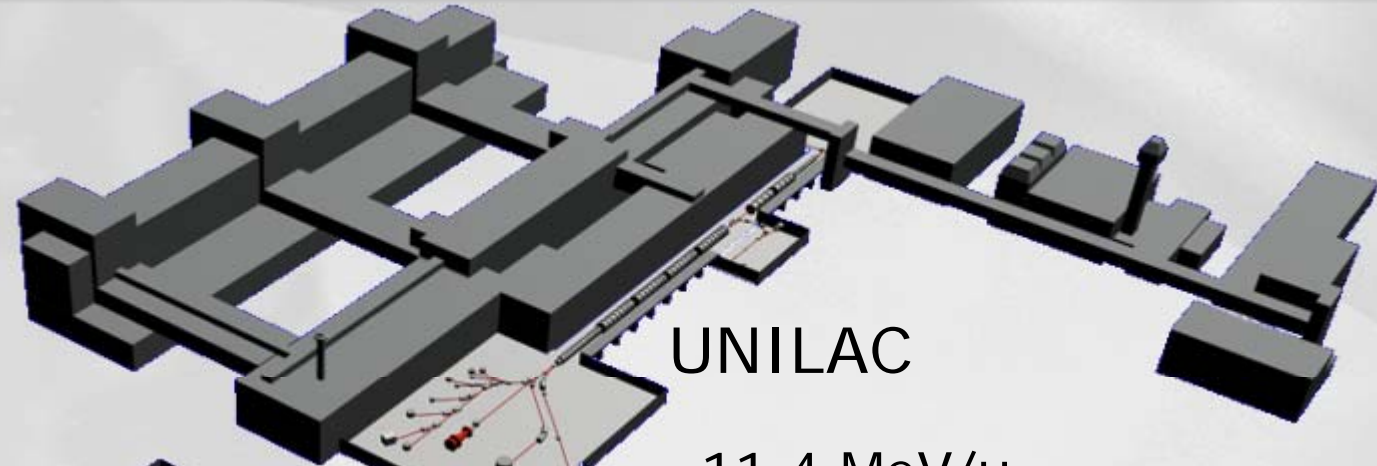
### Uranium-Ion



$Z=92$ ;  $E_b = 132 \text{ KeV}$   
 $Z \cdot \alpha \approx 1$



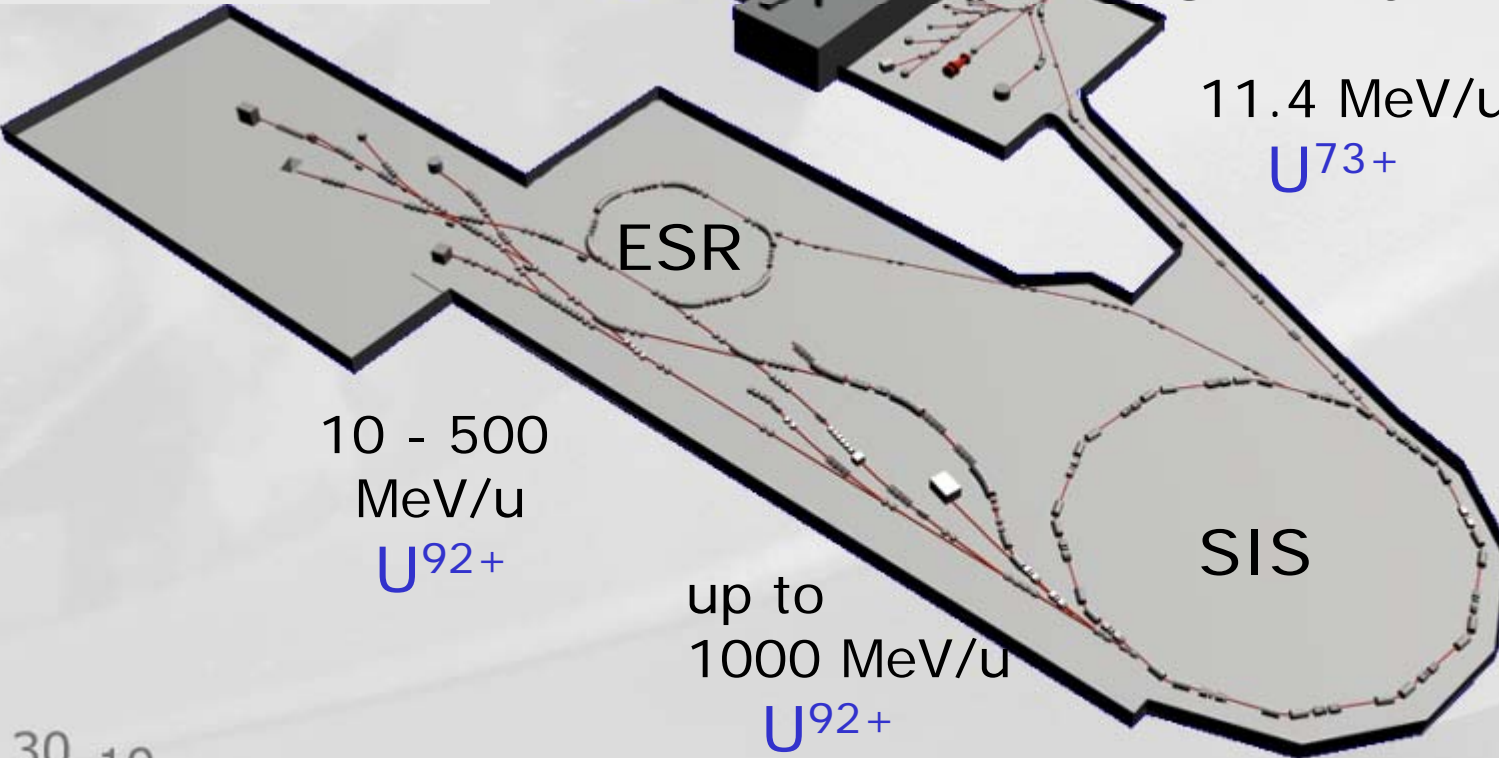
# GSI - Accelerator Facility



UNILAC

11.4 MeV/u

$U^{73+}$



10 - 500  
MeV/u

$U^{92+}$

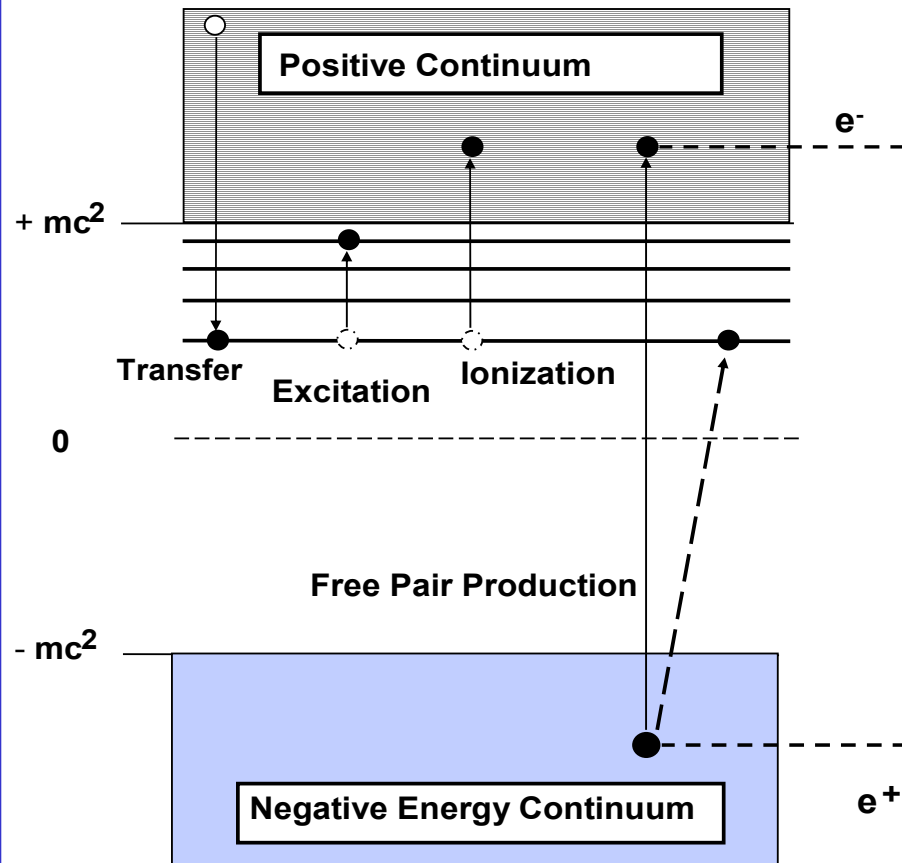
up to  
1000 MeV/u

$U^{92+}$

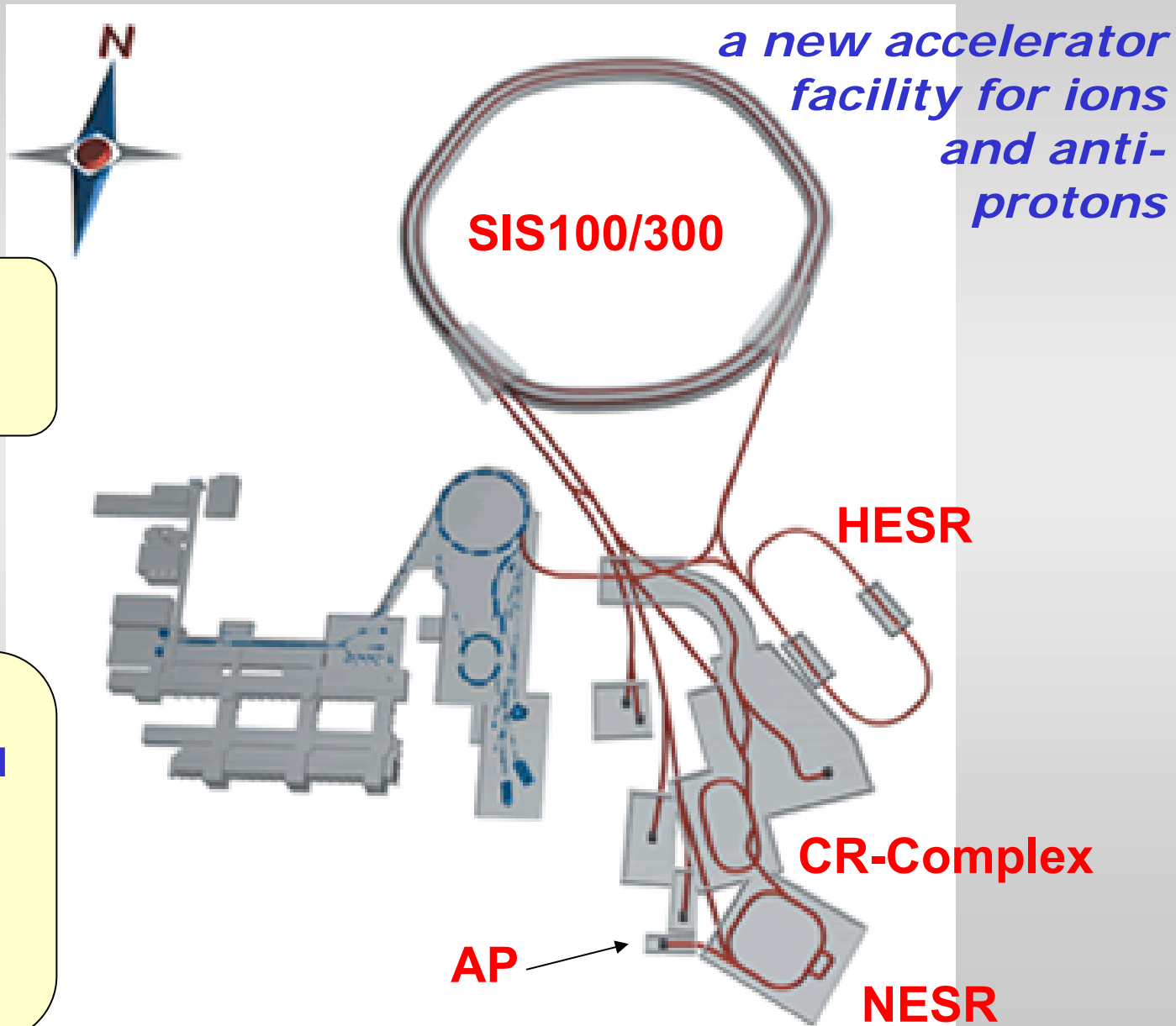
SIS

## High- $\gamma$

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



# The New GSI Accelerator Project



$1 \times 10^{12}$  1/s  
for  $U^{28+}$  at  
1 GeV/u

**Parameter**  
stored and cooled  
antiprotons

90 GeV protons  
34 GeV/u  $U^{92+}$

**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**



## High Energy Synchrotron (SIS100/300)

Parameter  
90 GeV protons  
34 GeV/u U<sup>92+</sup>

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]

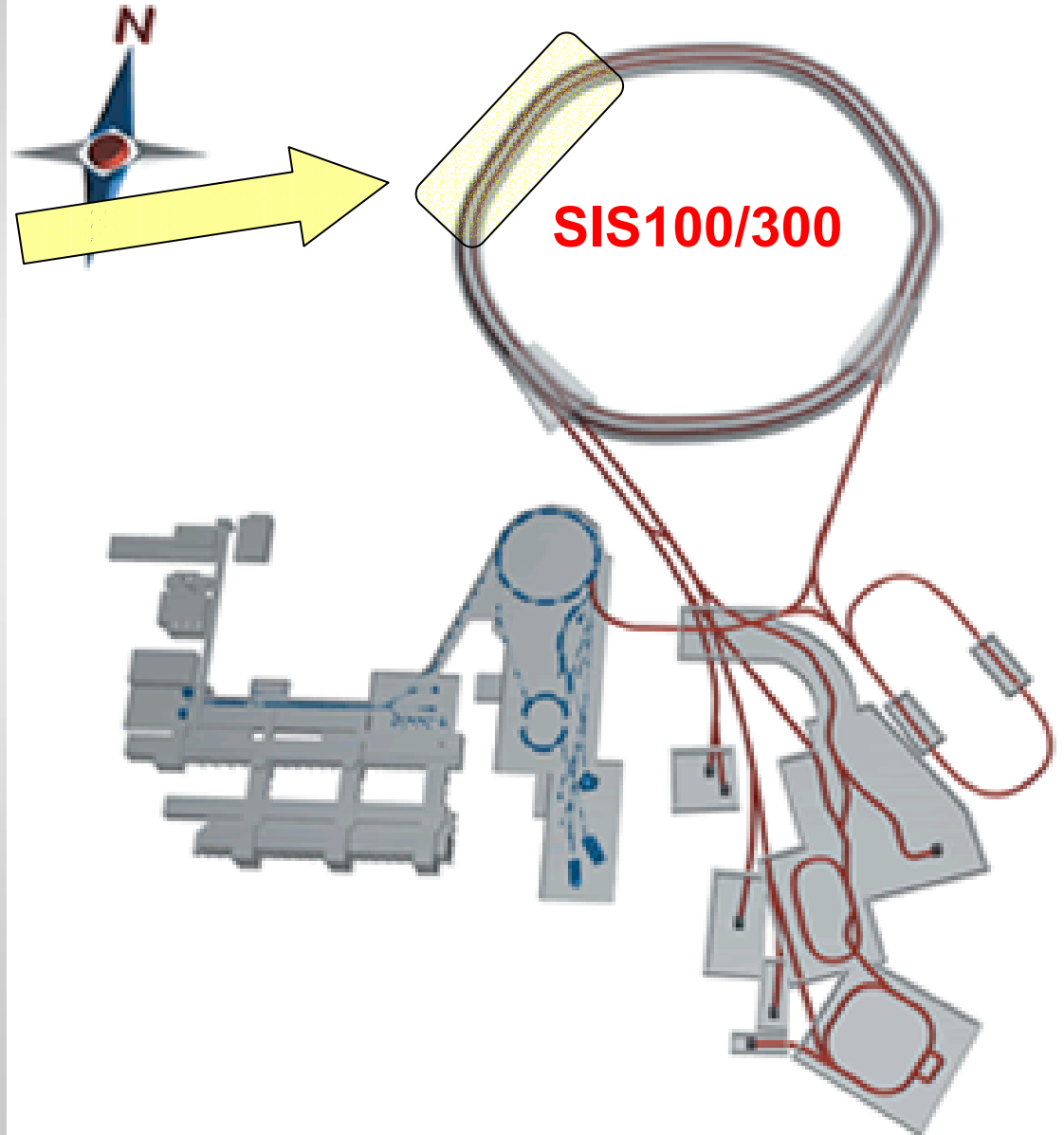
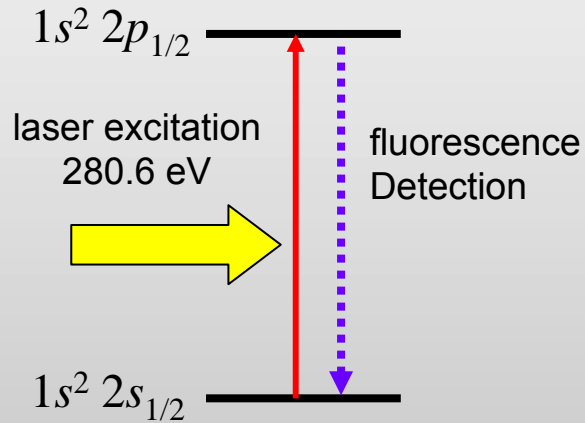
**New Experimental Storage Ring (NESR)**  
[energies between 840 MeV/u down to 3 MeV/u]

Internal and external  
installations

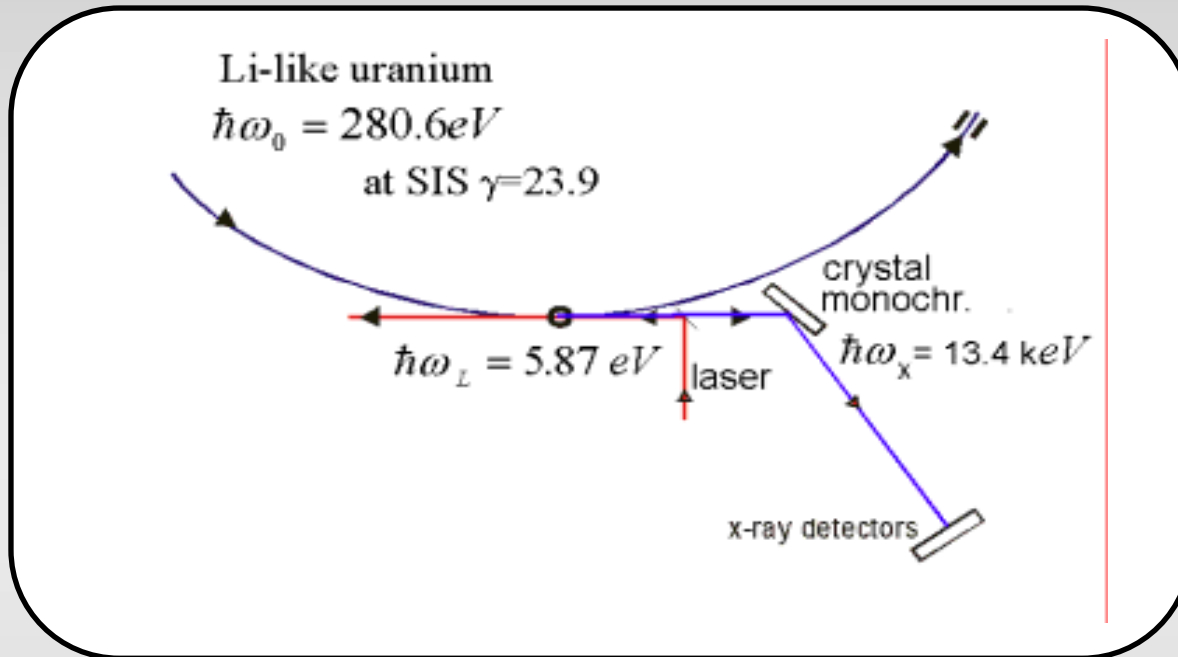
**High Energy Experimental Storage Ring (HESR)**  
[for antiprotons at energies up to 14 GeV]  
Optional: heavy ions beams up to 6 GeV/u

**Optional:** internal target  
experiments with HCl

High Precision Laser Spectroscopy by using the large Lorentz energy shift at high  $\gamma$  values



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



Lab. System (laser)

$$\hbar\omega_L = 5.87\text{eV}$$

$\gamma=23.9$



Projectile frame  
excitation

$$\hbar\omega_0 = 280.6\text{eV}$$

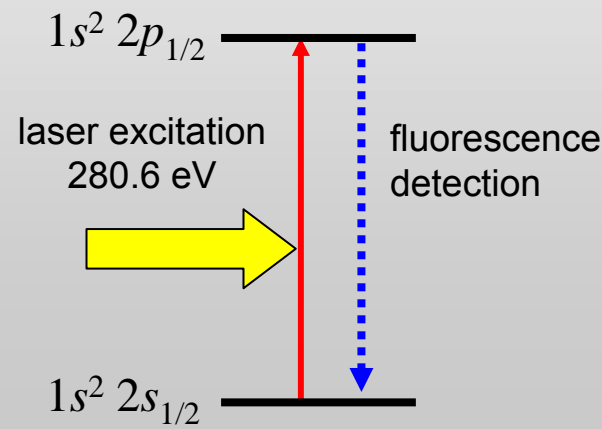
fluorescence

$\gamma=23.9$



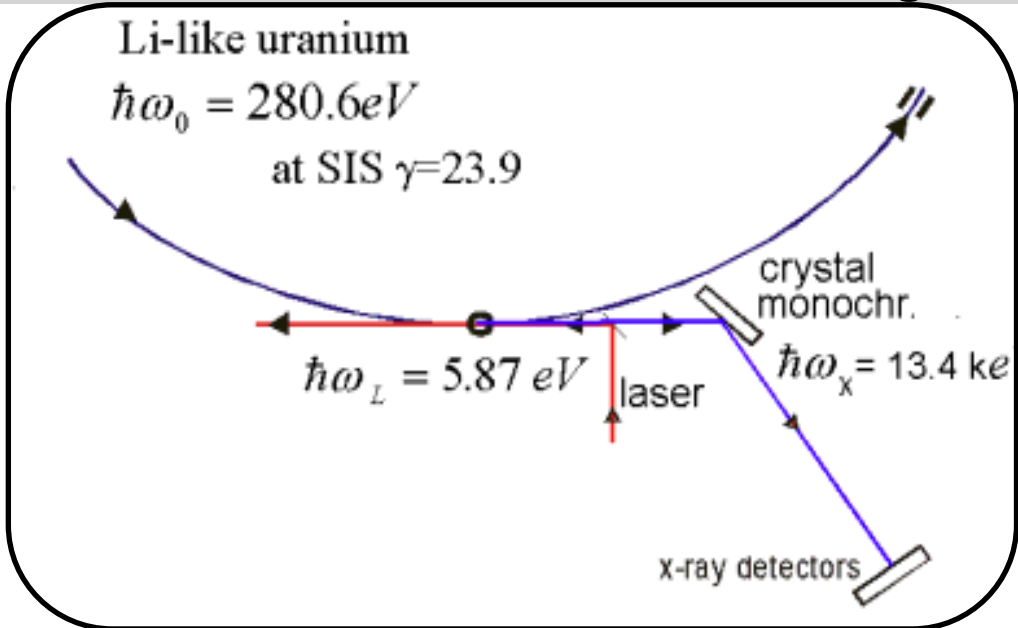
Lab. System  
fluorescence

$$\hbar\omega_x = 13384\text{eV}$$



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

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



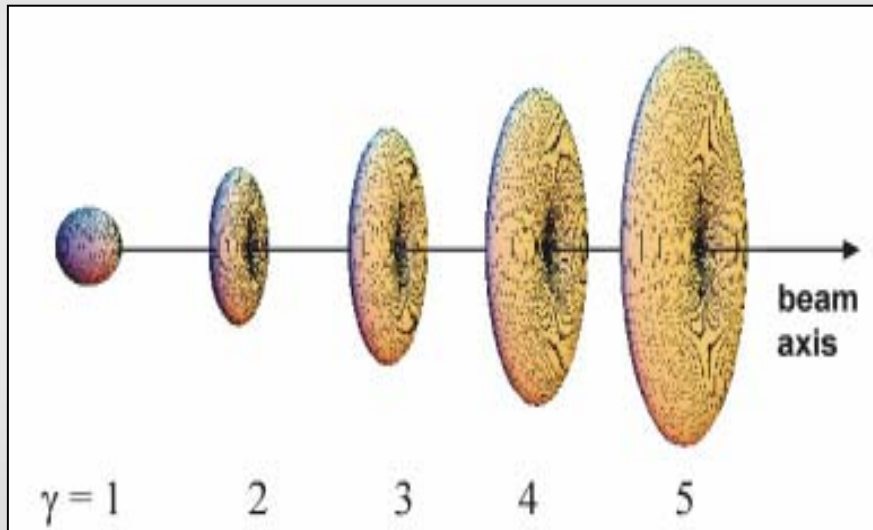
**Expected accuracy for the 280 eV transition: 0.007 eV (currently best value:  $280.59 \pm 0.09\text{ eV}$ )**

**Only 100 ions are required**

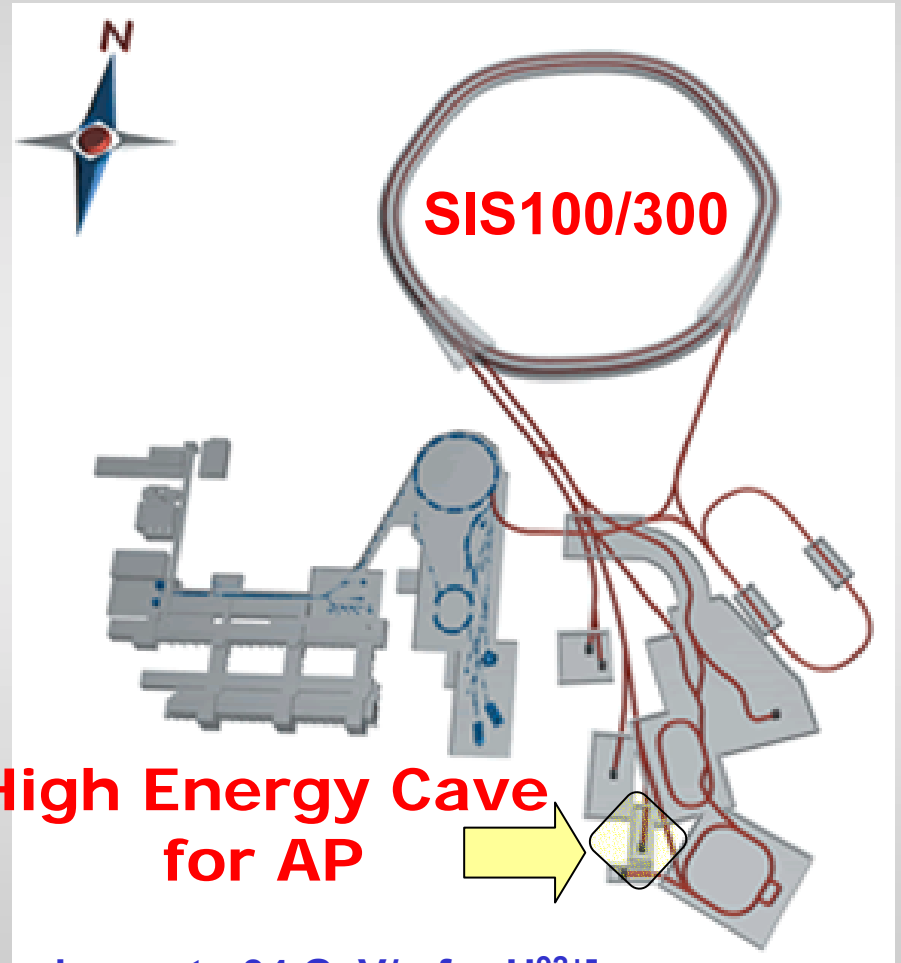
### Further Applications

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

## Electromagnetic Phenomena under Extreme & Unusual Conditions



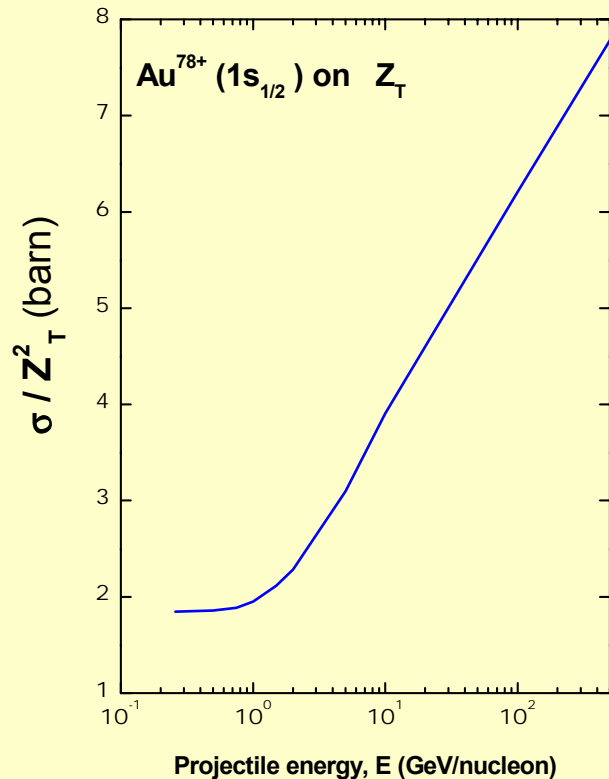
Dependence of the radial electric field strength for a point charge on the Lorentz factor  $\gamma$



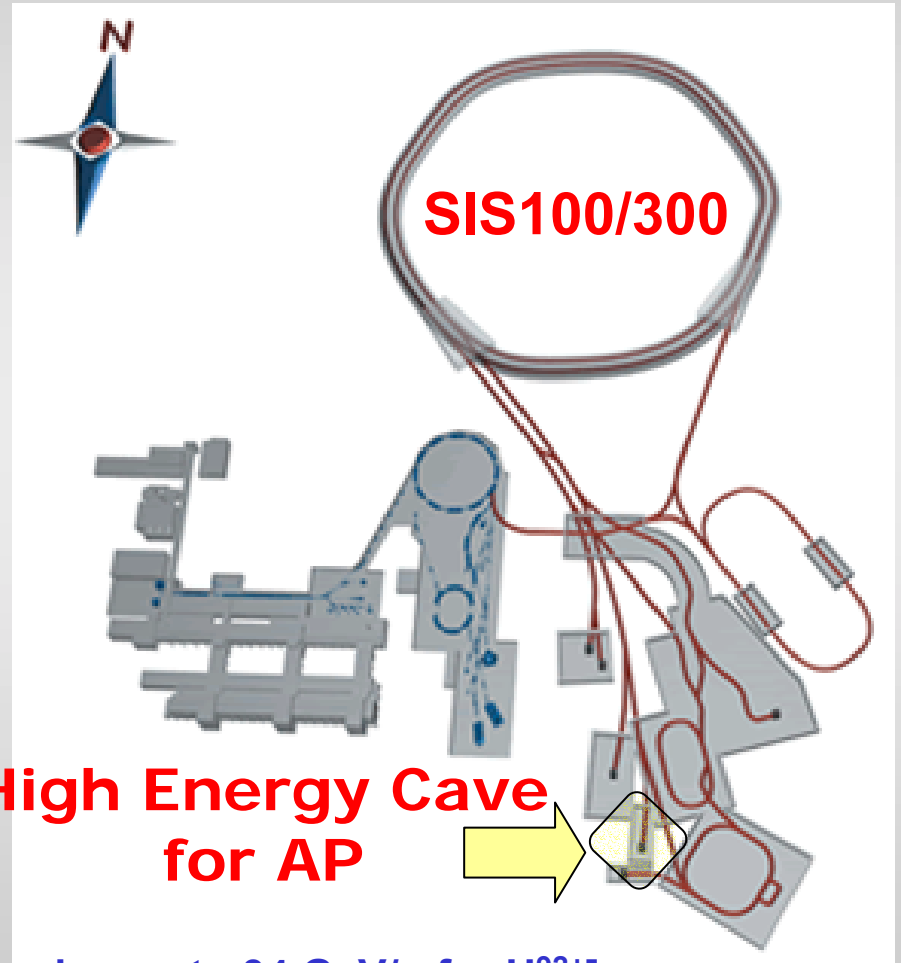
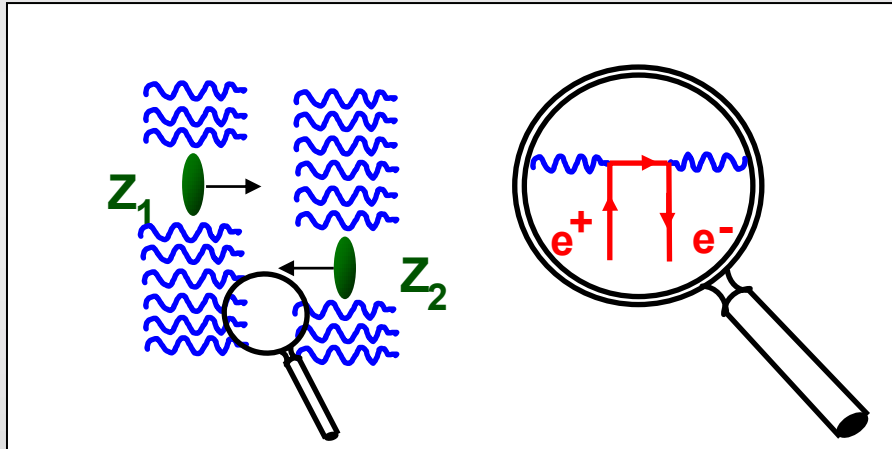
[energies up to 34 GeV/u for  $U^{92+}$ ]

## Electromagnetic Phenomena under Extreme & Unusual Conditions

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



*Electromagnetic Phenomena  
under Extreme & Unusual  
Conditions*



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

R. Schuch  
Y. Yamazaki

## The New ESR

Storage and Cooler Ring for  
HCI, Antiprotons, Fragment Beams

Energies: 840 to 3 MeV/u

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

Straight sections for exp. installations  
18 m

### Experimental installations

electron target

internal jet-target

laser-ion interaction zone

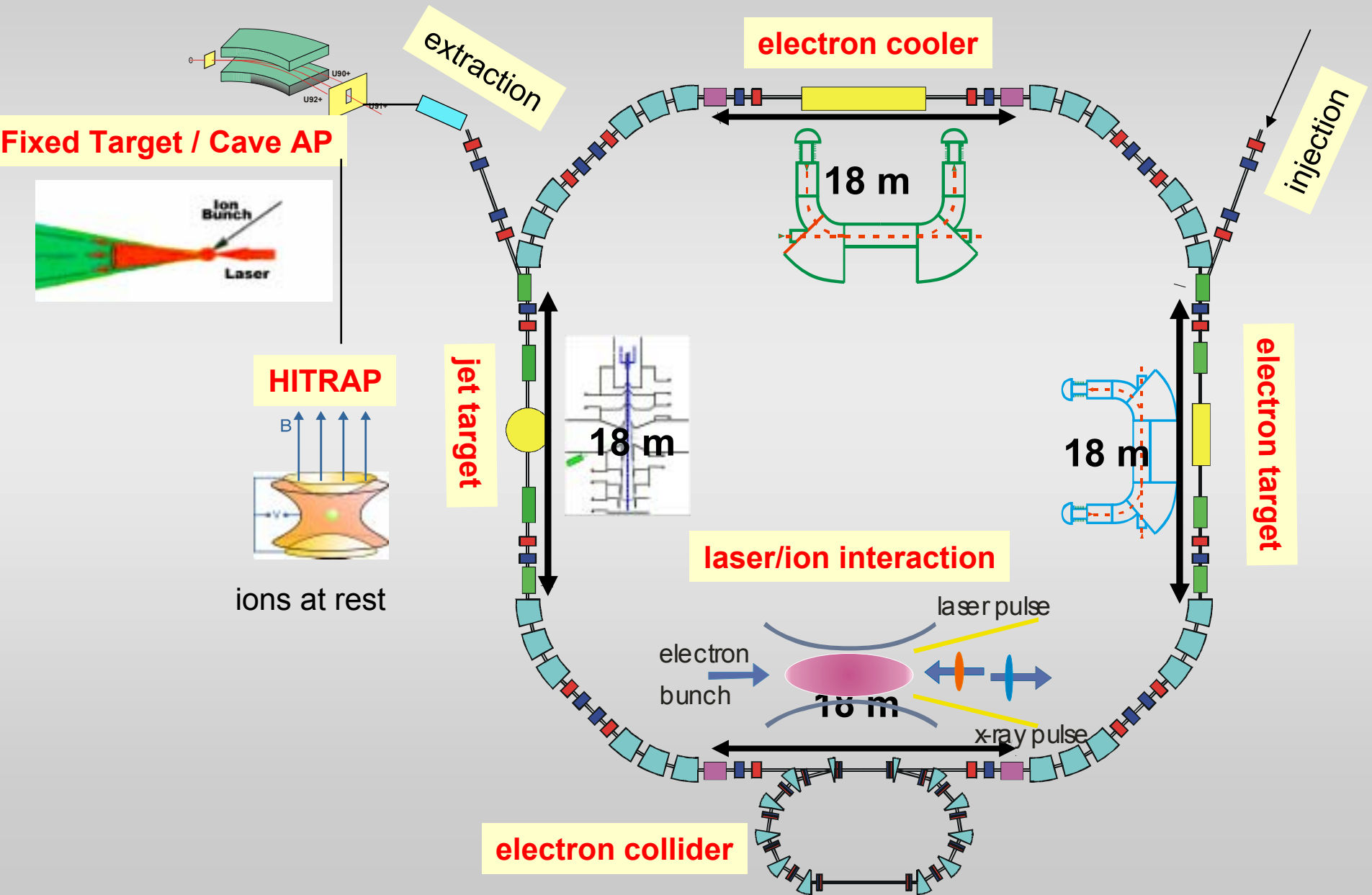
low-energy cave: cooled extracted ions

HITRAP



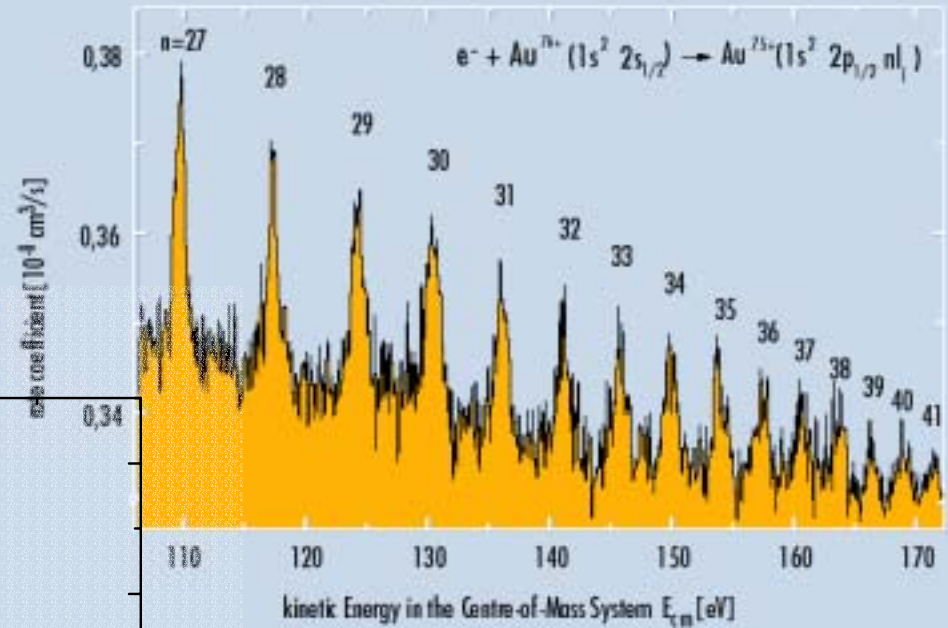
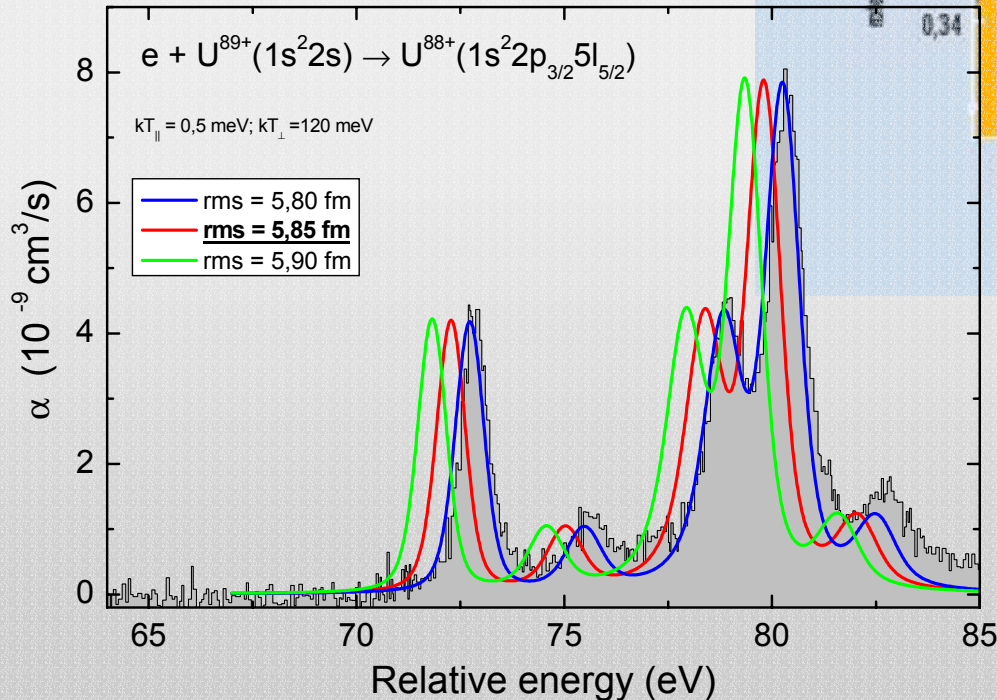


# The New Experimental Storage Ring **NESR**



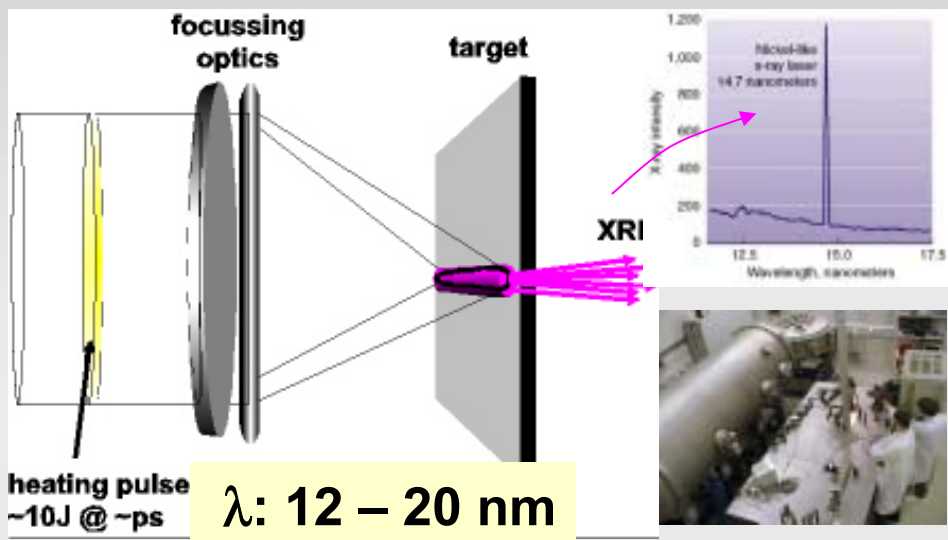
DR experiments for Li-like heavy ions at the ESR:

The already achieved accuracy is comparable with the most precise x-ray experiments



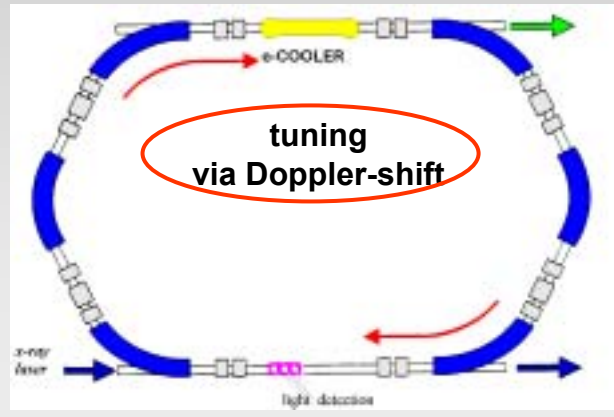
Experiment and theory for three different rms radii of  $^{238}\text{U}$

**Principle of an X-Ray Laser (XRL)**

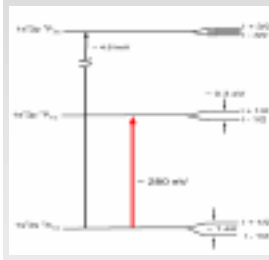


$\lambda: 12 - 20 \text{ nm}$

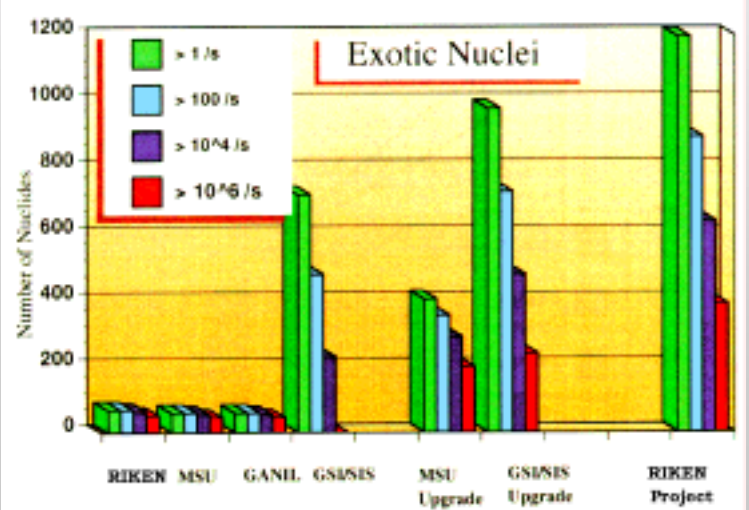
**Excitation in the ESR/NESR**



up to Z=92 possible



**At NESR:**  
Wide Range of Accessible Ions



$\Delta p/p \sim 5 \times 10^{-5}$   
 $\Delta E_{\text{Dopp.}}/E \sim 10^{-4} \dots 10^{-5}$

*E. Gaul*

## ELECTRON SPECTROSCOPY

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

Poster S. Hagmann et al.  
R. Mann et al.

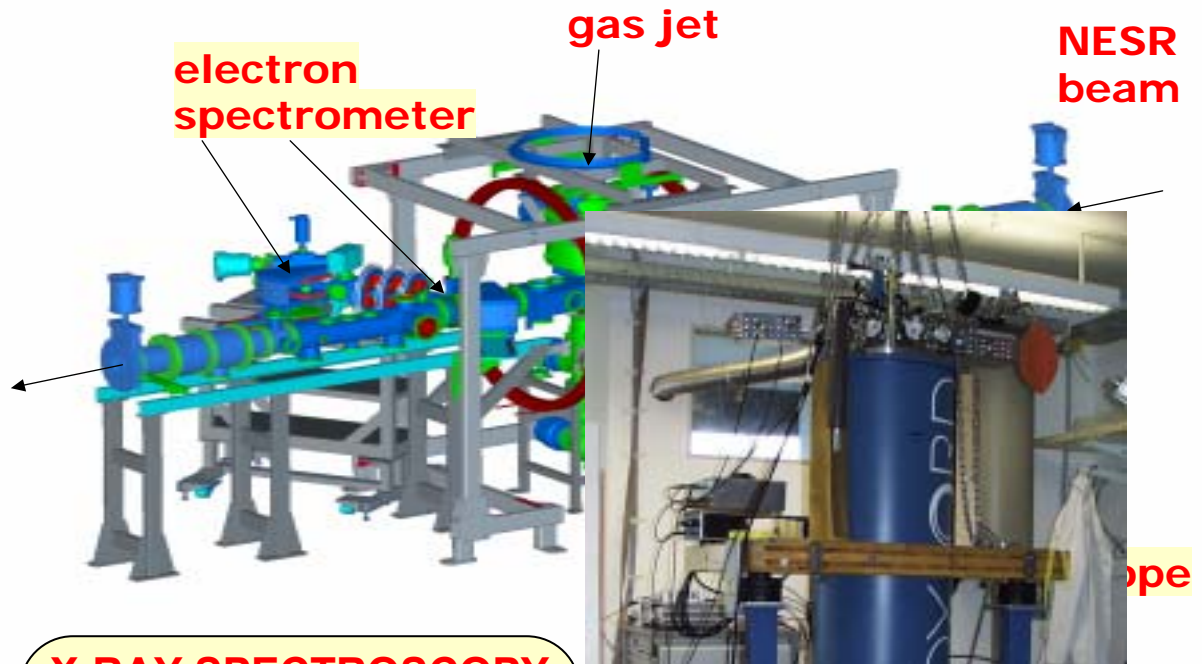
## RECOIL ION MOMENTUM SPECTROSCOPY

e.g.

impact parameter sensitive studies  
(e,2e) processes in HCl atom collisions

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

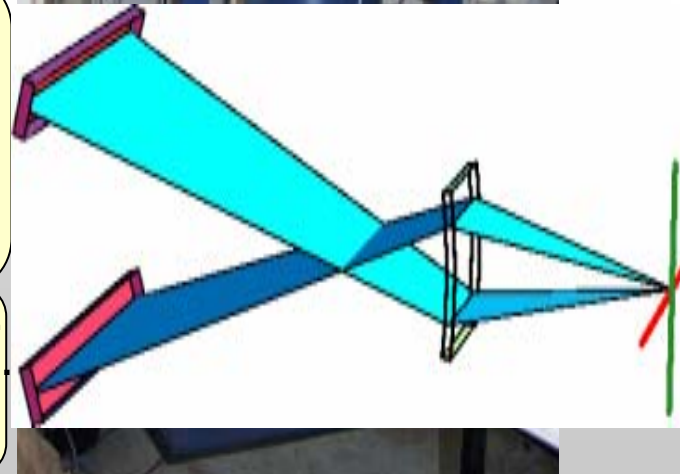
*J. Ullrich*



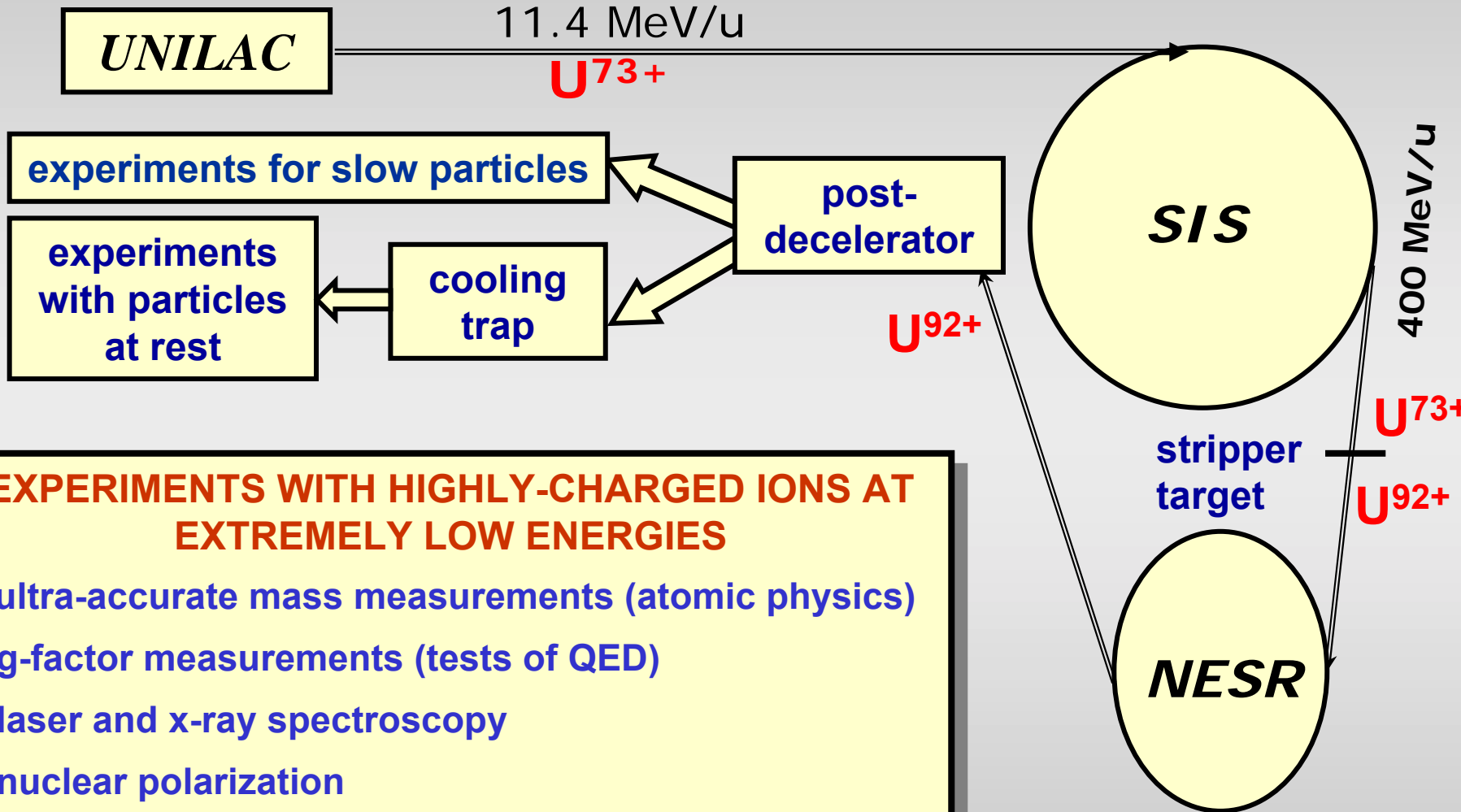
## X-RAY SPECTROSCOPY

e.g.  
precision spectroscopy  
photon correlation studies  
polarization phenomena

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



# 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

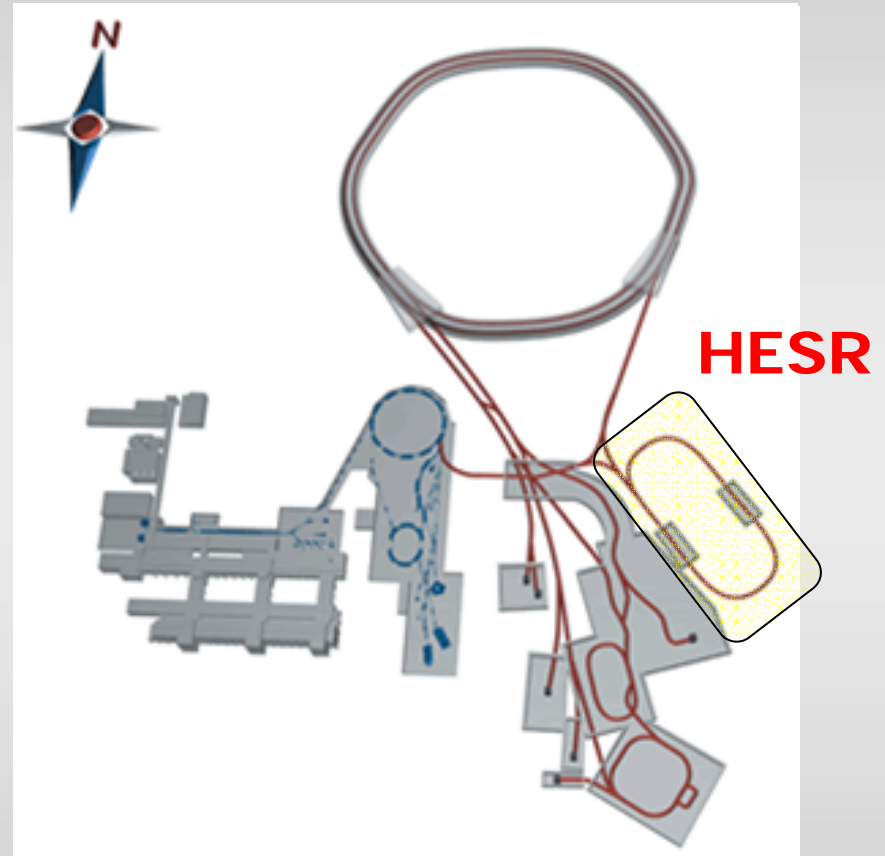
**HITRAP  
WORKSHOP**

## HESR

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

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

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

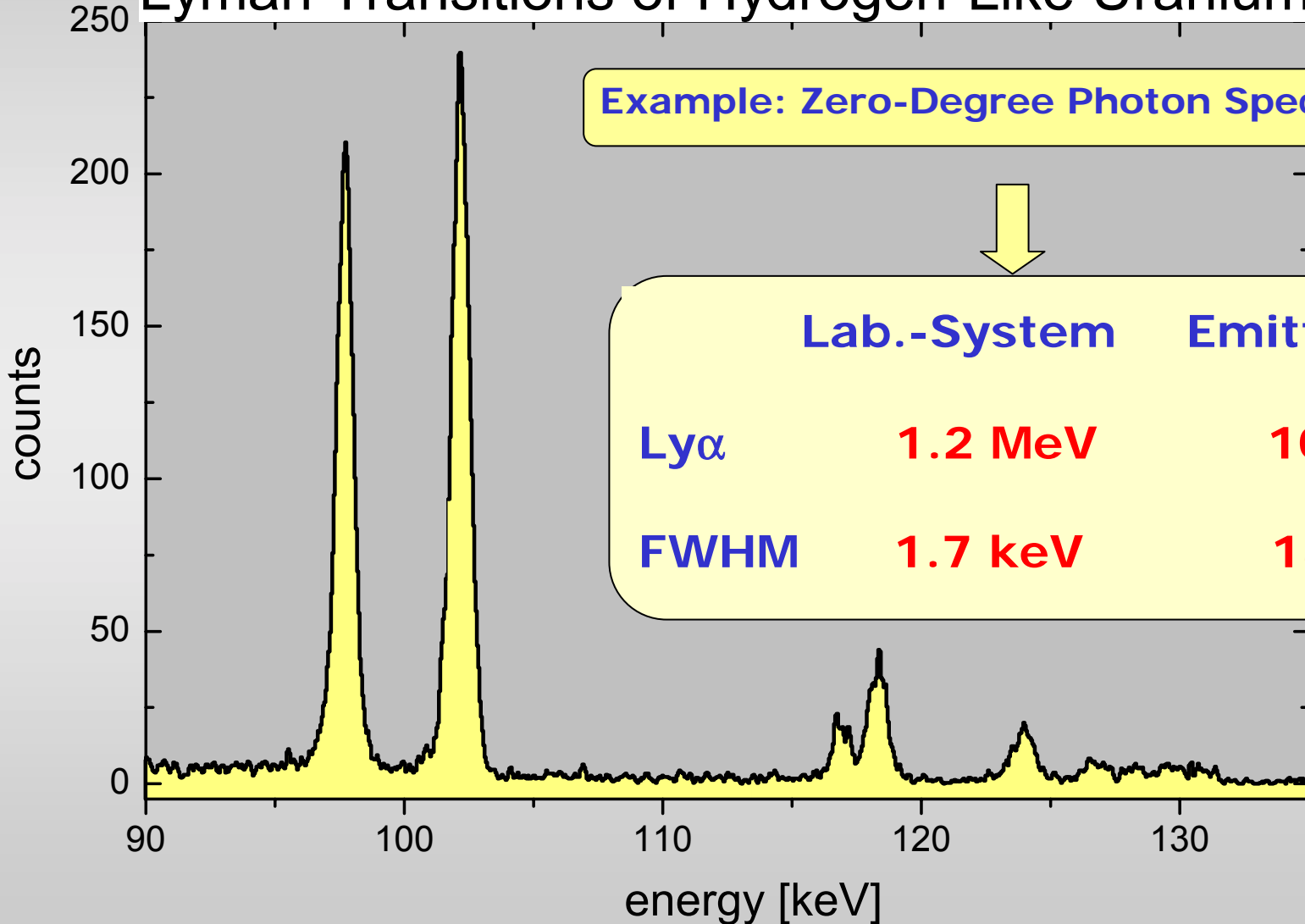


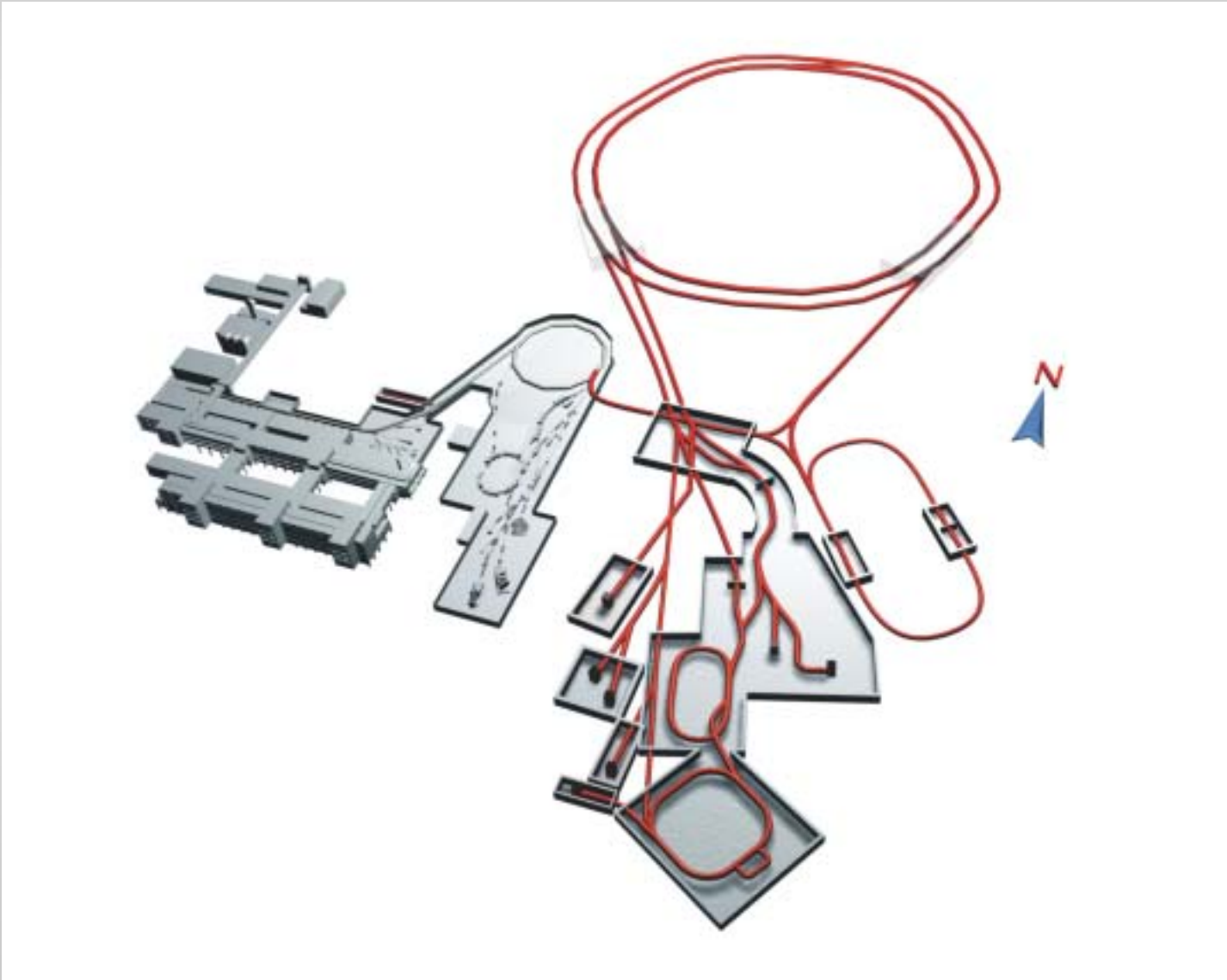
# Lyman Transitions of Hydrogen-Like Uranium

Example: Zero-Degree Photon Spectroscopy



	Lab.-System	Emittersys.
<b>Ly<math>\alpha</math></b>	<b>1.2 MeV</b>	<b>100 keV</b>
<b>FWHM</b>	<b>1.7 keV</b>	<b>145 eV</b>







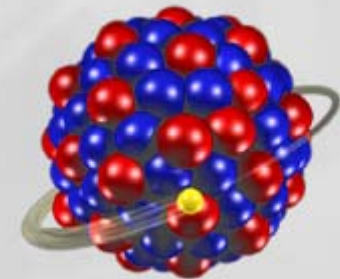
## Test of Quantum Electrodynamics

### Hydrogen-Atom

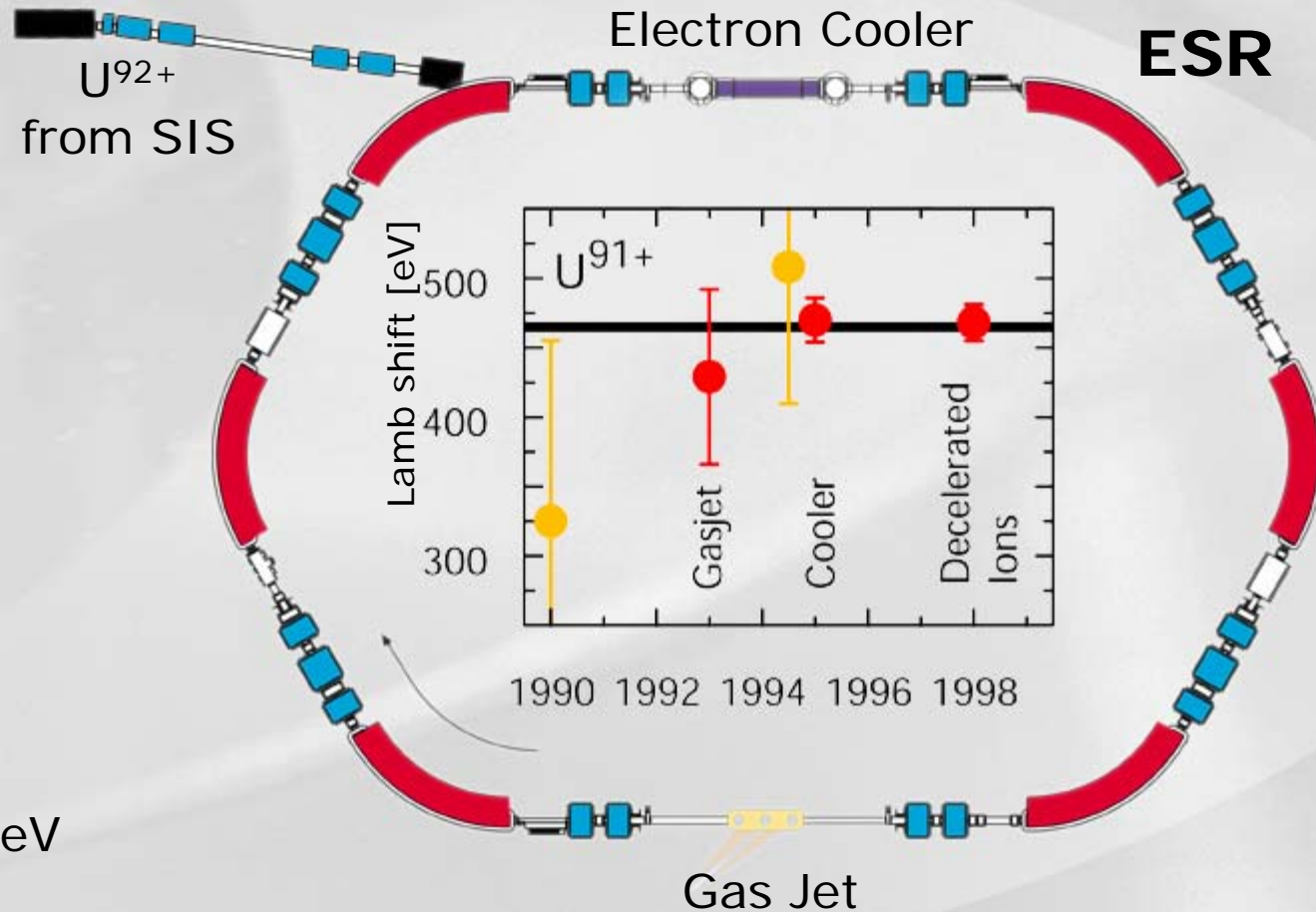


$Z=1$ ;  $E_b = 13.6 \text{ eV}$   
 $Z \cdot \alpha \ll 1$

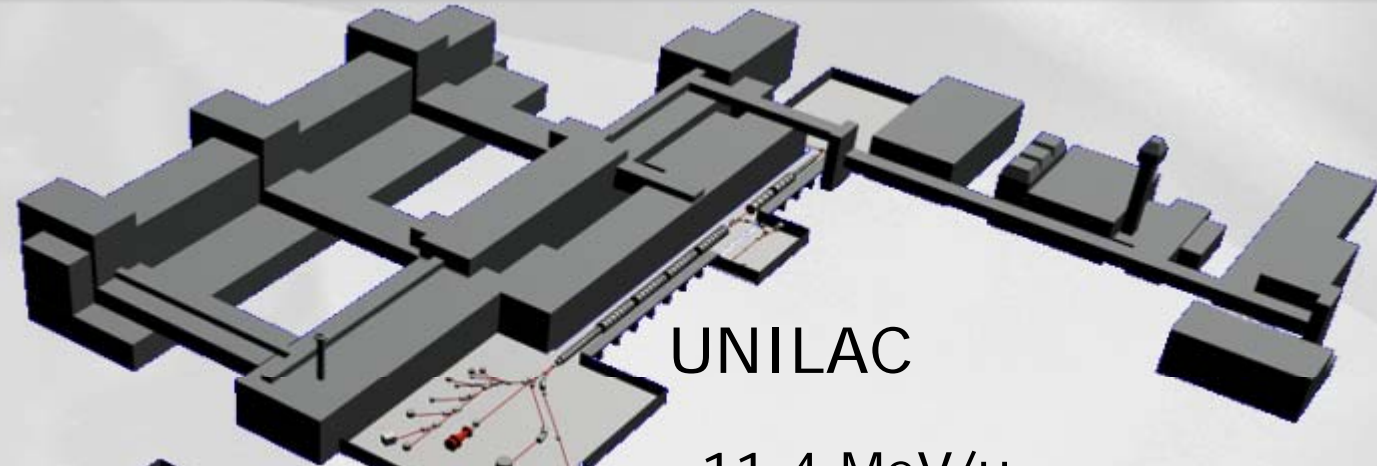
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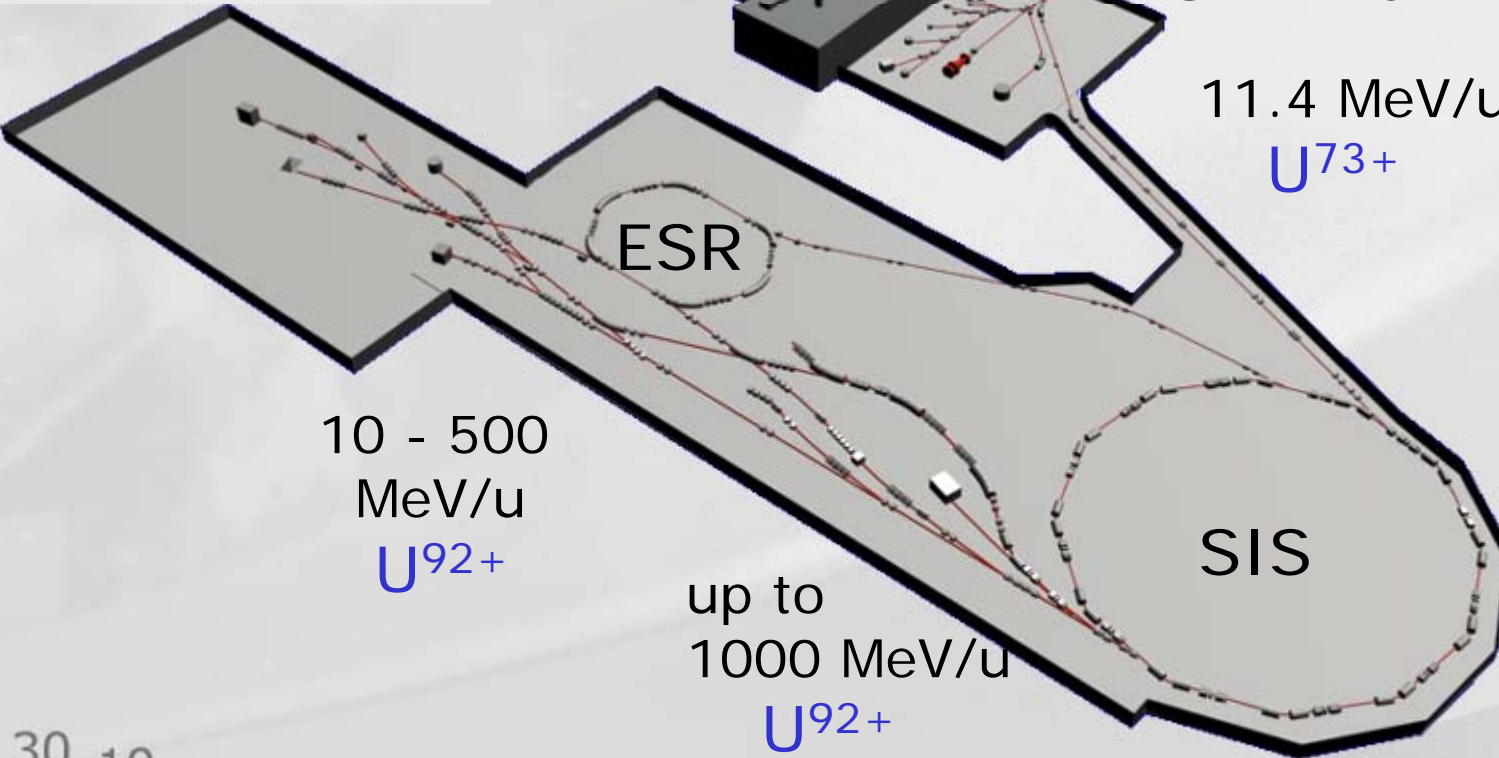
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10 - 500  
MeV/u

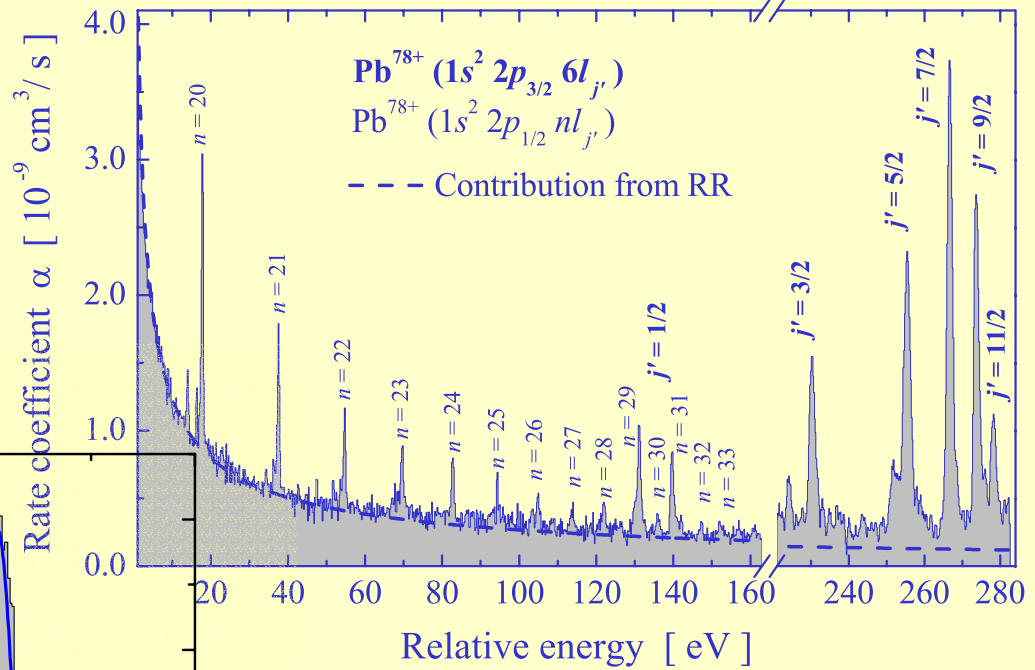
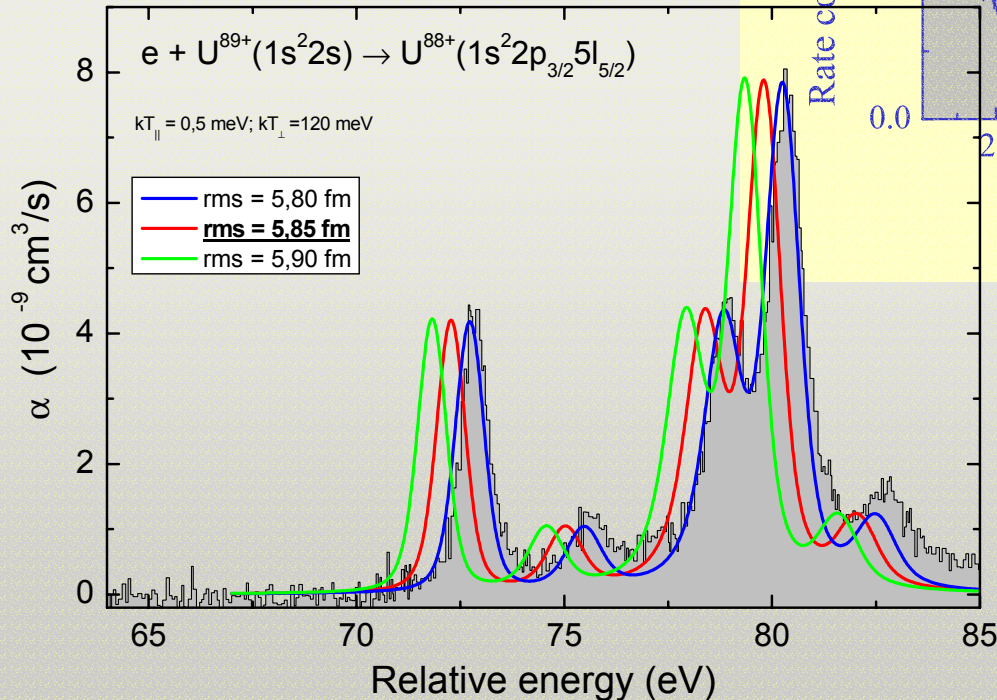
$U^{92+}$

up to  
1000 MeV/u

$U^{92+}$

SIS

**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  $^{238}\text{U}$**