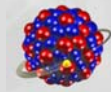




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on the New International  
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at Darmstadt,  
Warsaw, November 24, 2003



# Atomic Physics

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## Atomic Physics at the New International Accelerator Facility at GSI in Darmstadt



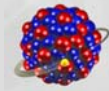
## Atomic Physics under Extreme Conditions

**Andrzej Warczak**

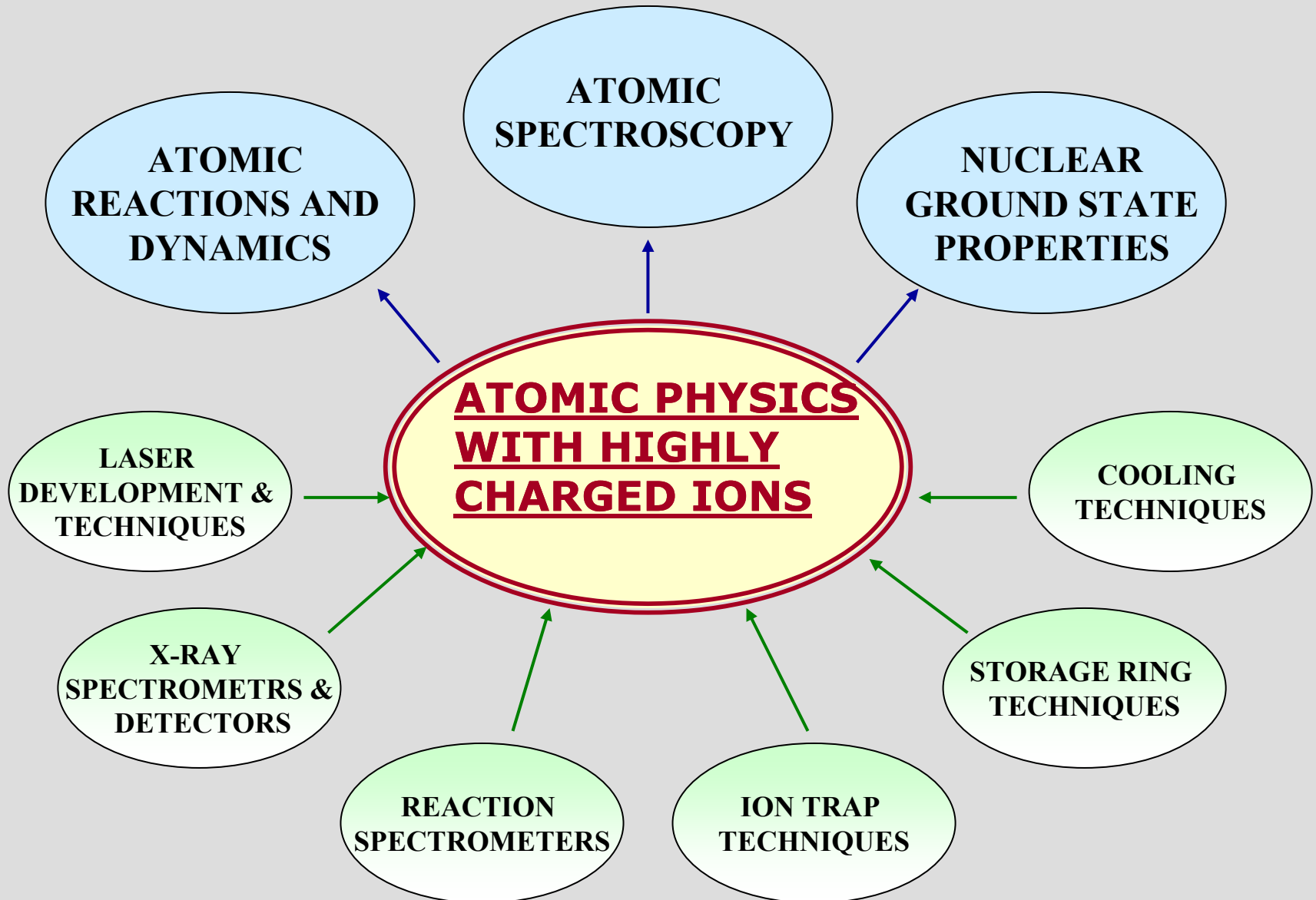
**Jagiellonian University, Institute of Physics, Kraków, Poland**



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Accelerator Facility  
at Darmstadt,  
Warsaw, November 24, 2003

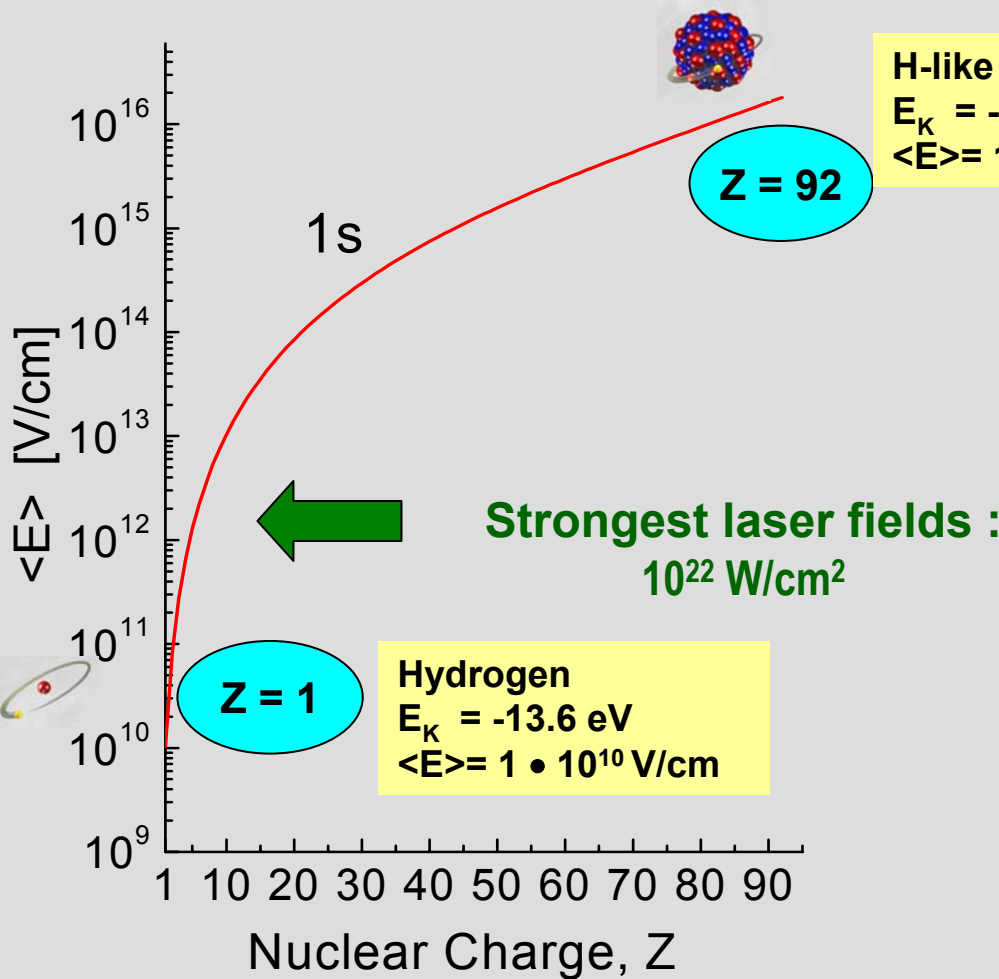


# Atomic Physics

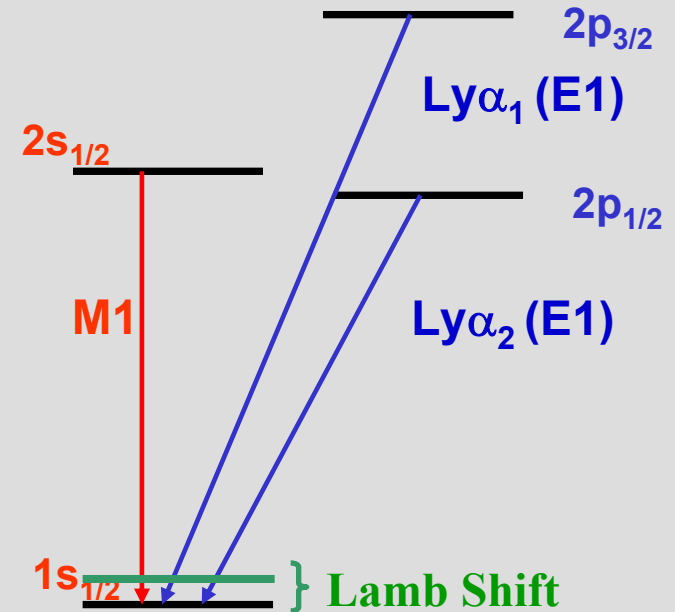




# Extreme Static Fields

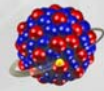


## Quantum Electro- Dynamics



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

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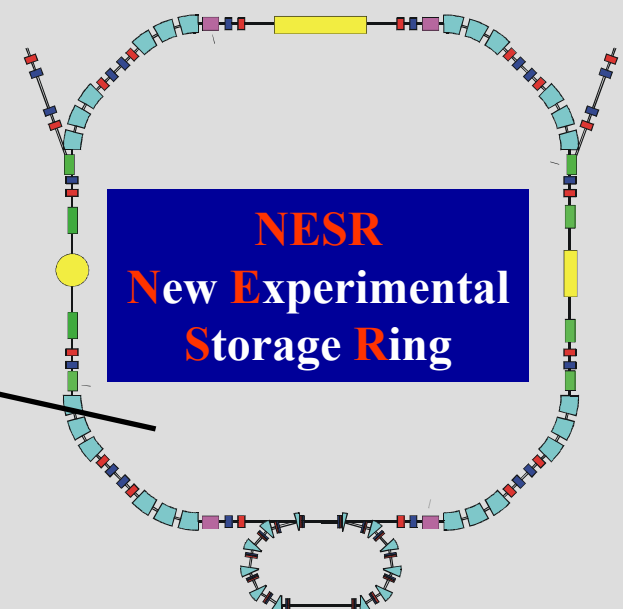
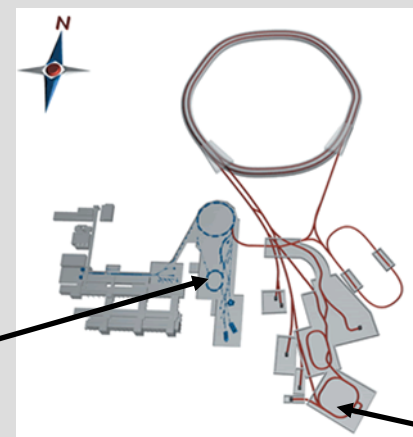
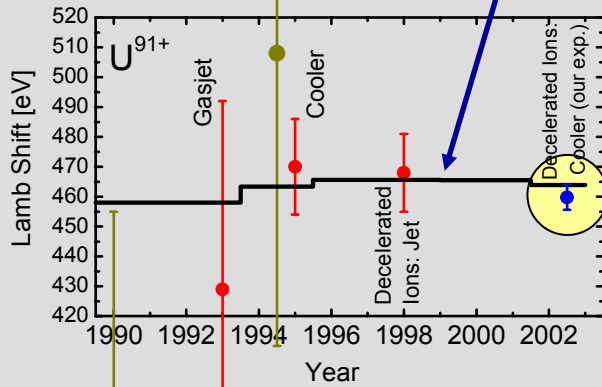


# The ground state Lamb shift of H-like uranium

**About 20 Joint Papers**

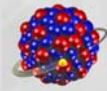
**Theory:  $463,95 \pm 1$  eV**  
V. A. Yerokhin and V. M. Shabayev(2001)

**Experiment:  $459.8 \pm 4.8$  eV**  
The recently achieved accuracy of 4.8 eV is a  
considerable improvement by a factor of 3  
compared to the most precise value up to now.





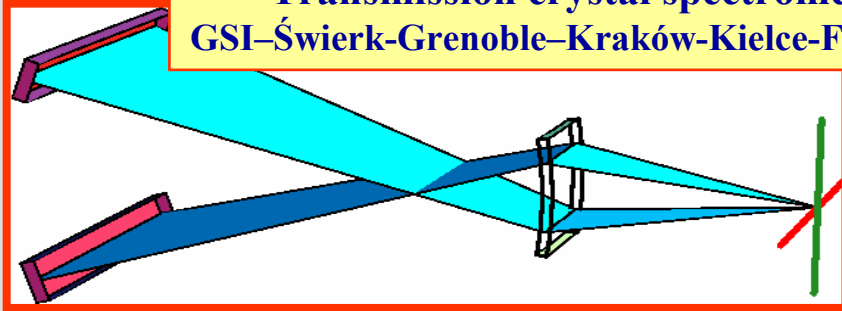
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# Towards an Accuracy of 1 eV

## Development of x-ray detection techniques

**Transmission crystal spectrometer**  
GSI–Świerk–Grenoble–Kraków–Kielce–Frankfurt



Harvard – Smithsonian  
Center for Astrophysics  
Lamb Shift Experiment



Harvard-GSI

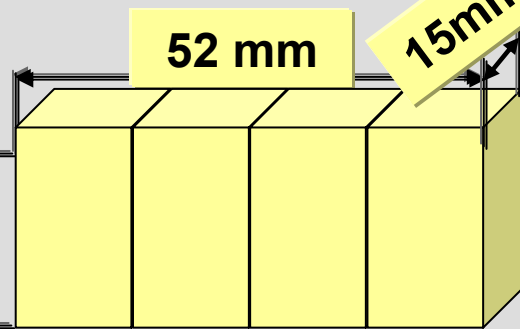


Segmented Ge(i) detectors

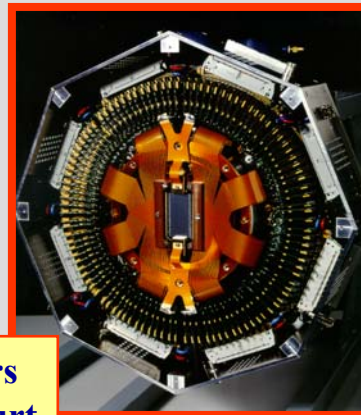
52 mm

15mm

30 mm



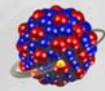
**Micro-strip Ge(i) detectors and polarimeters**  
Juelich–GSI–Świerk–Kraków–Kielce–Frankfurt



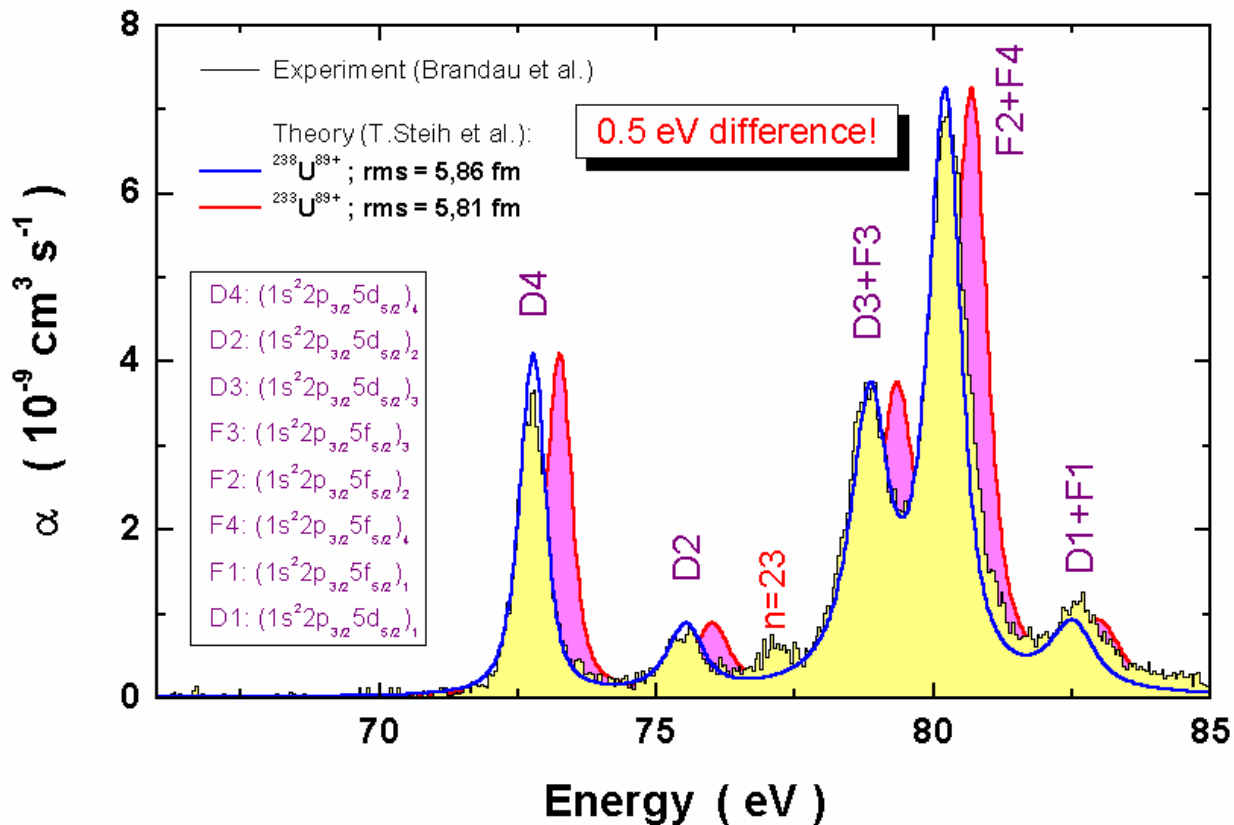
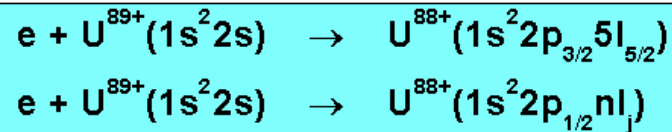
Calorimeters

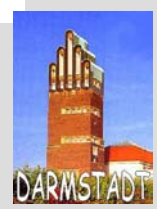
Mainz-GSI



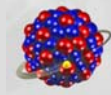


## Sensitivity of DR Experiments on Nuclear Effects

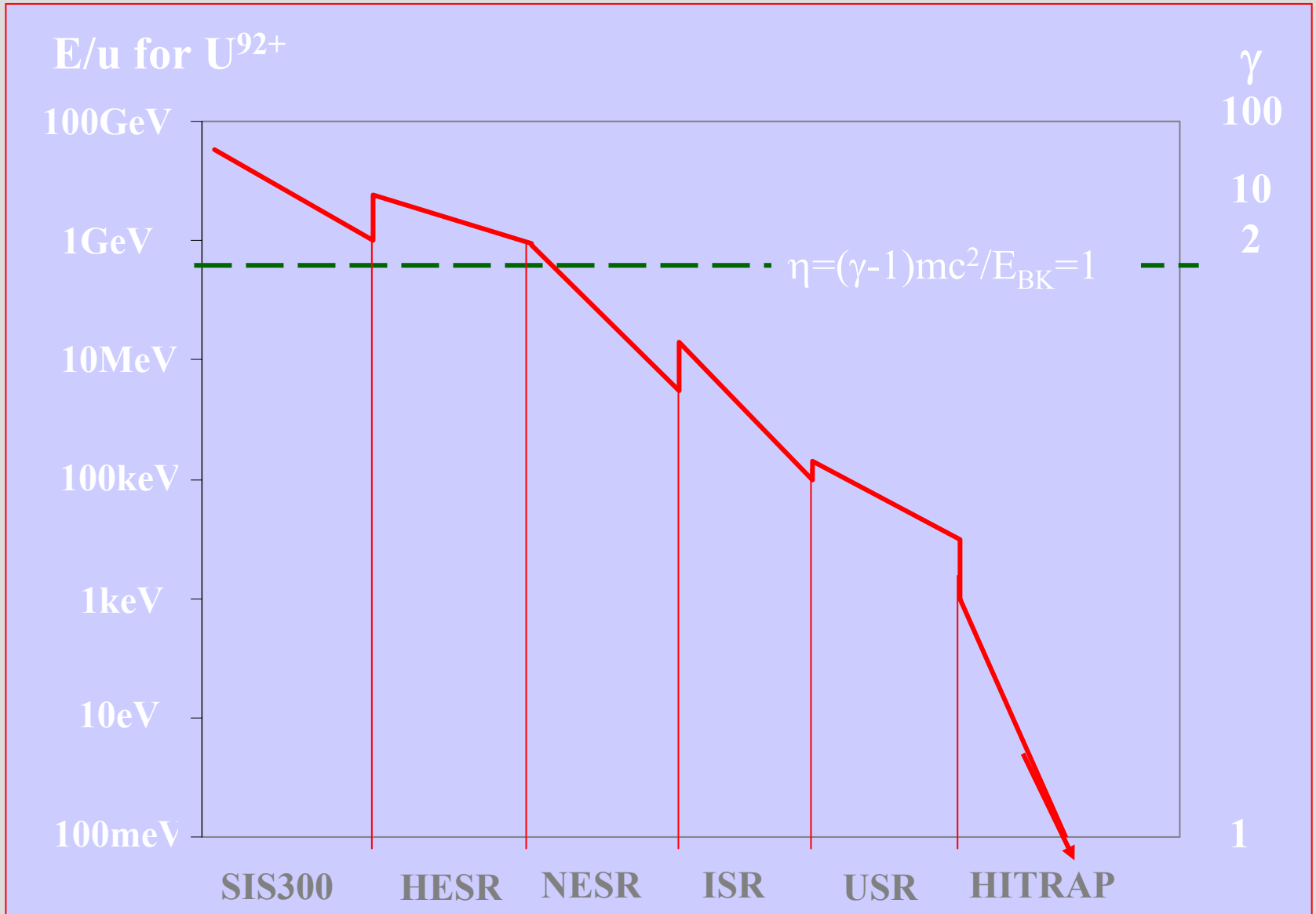




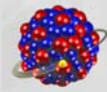
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 at Darmstadt,  
 Warsaw, November 24, 2003



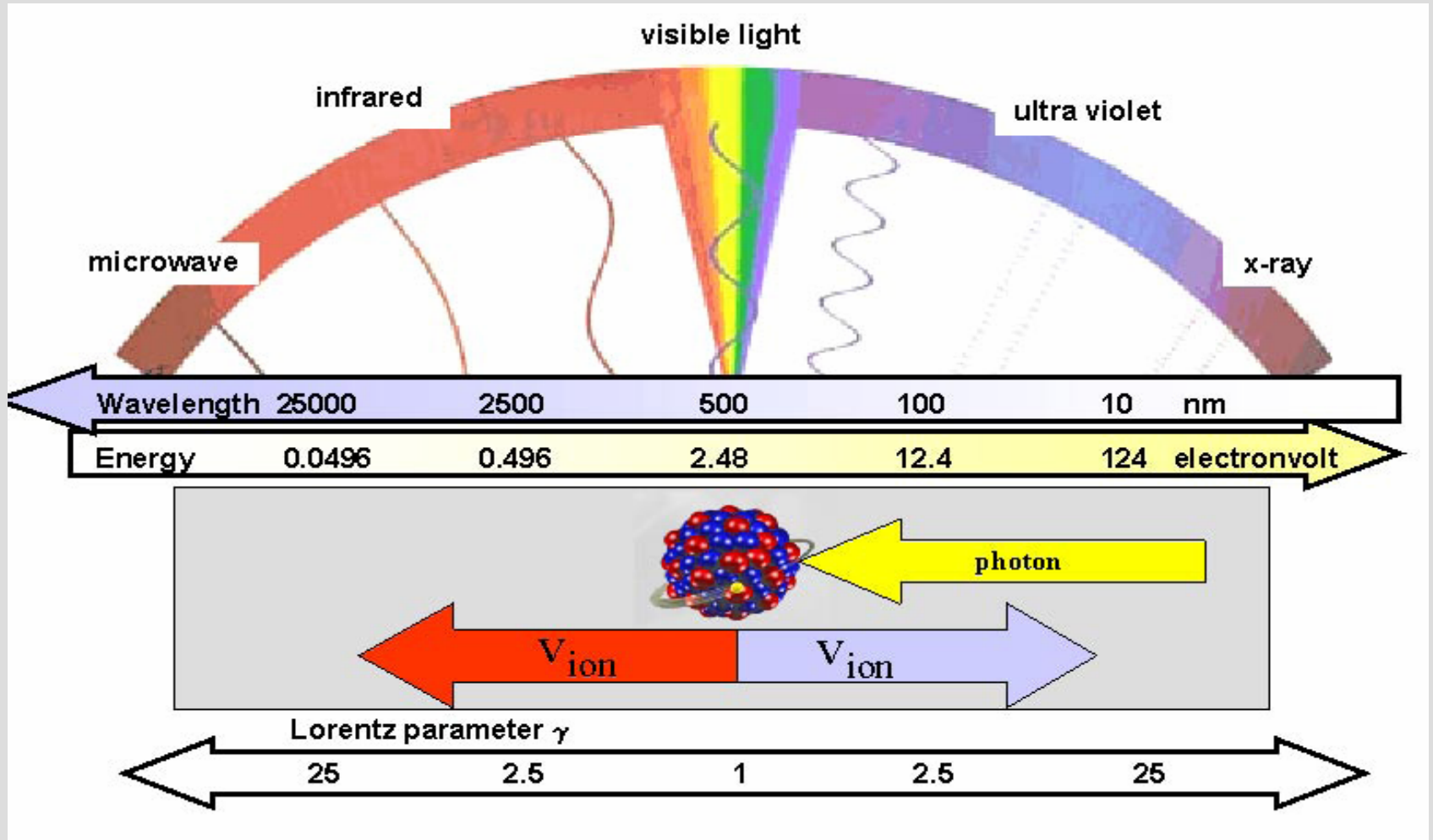
# Extreme Velocities Extreme Dynamic Fields



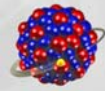




## Lorentz Shifted ( $\gamma$ -boosted) Laser Cooling/ Spectroscopy

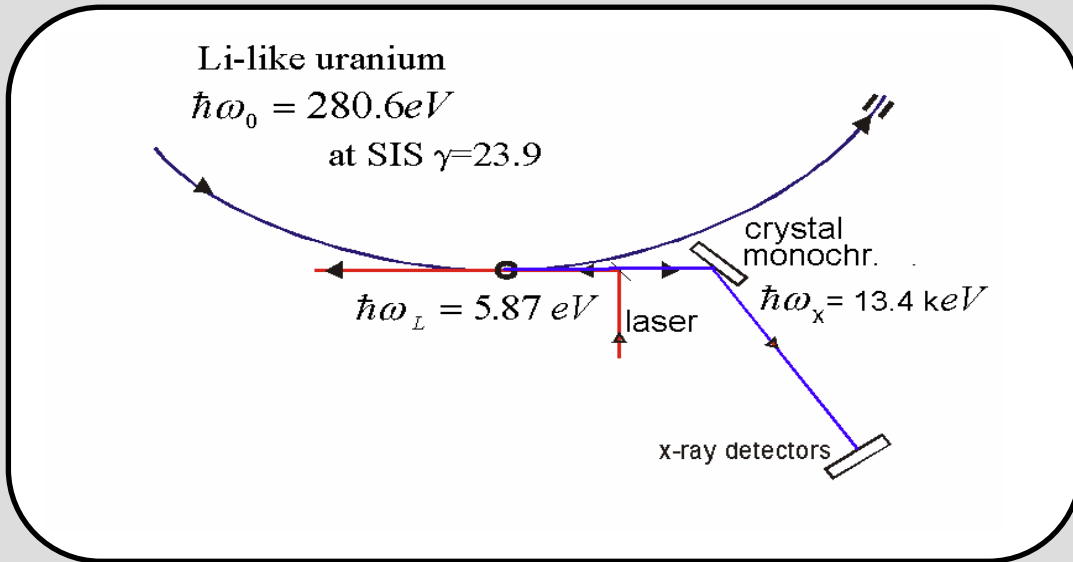






# Extreme Velocities

## Precision Measurements of 2s Lamb Shift in Strong Fields of High-Z Li-like Ions



Lab.System (laser)

$$\hbar\omega_L = 5.87 eV$$

$\gamma = 23.9$  ↓

Projectile frame  
excitation

$$\hbar\omega_0 = 280.6 eV$$

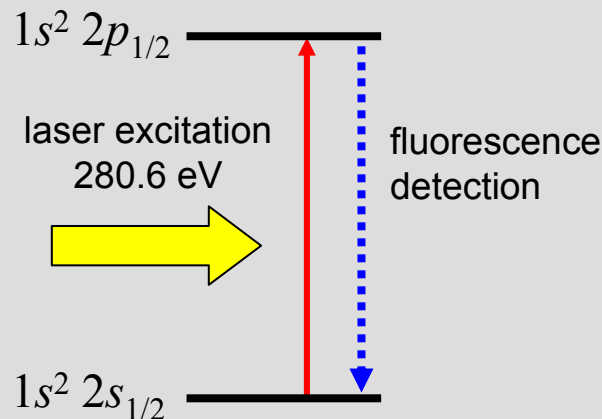
fluorescence

$\gamma = 23.9$  ↓

Lab. System  
fluorescence

$$\hbar\omega_X = 13384 eV$$

The **large Doppler shift**  
allows us 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

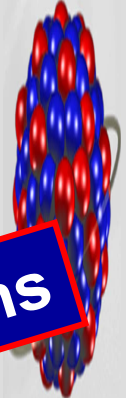
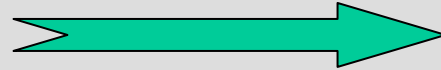
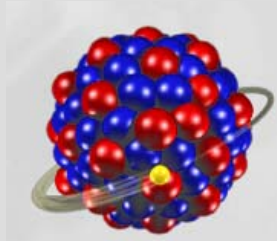




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# Extreme Dynamic Fields



$E(t)$

Fourier-  
Transform

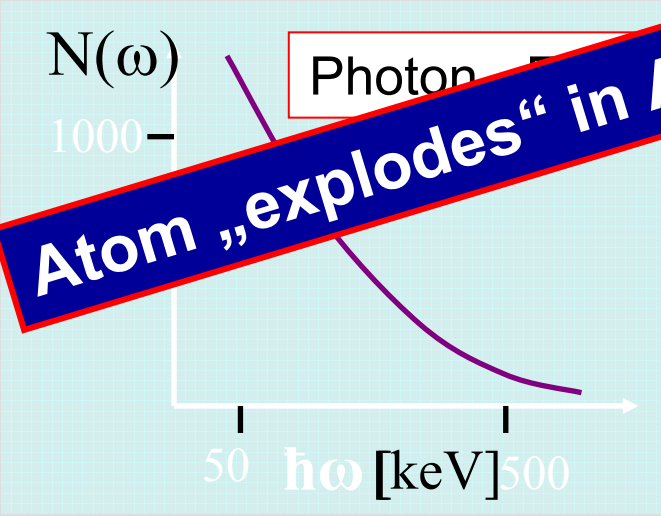
Quantization

$N(\omega)$

Weizsäcker (1934)

$t \leq 0.1$  as

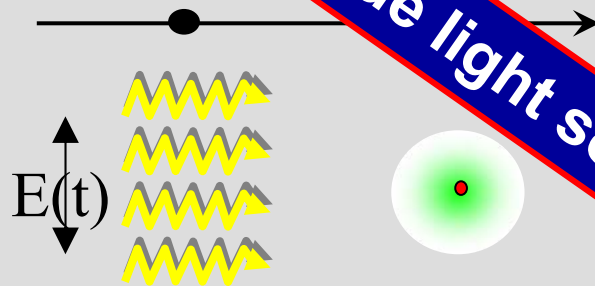
$E = \gamma Z / b^2$

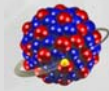


**Atom „explodes“ in Attosecond Pulse of virtual Photons**

**A unique light source**

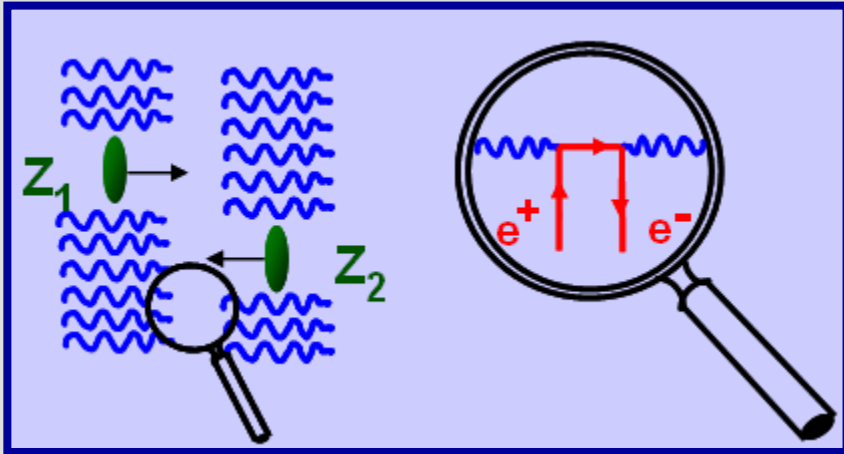
Photoionization ...  
virtual photon field  $I \geq 10^{20}$  W/cm<sup>2</sup>





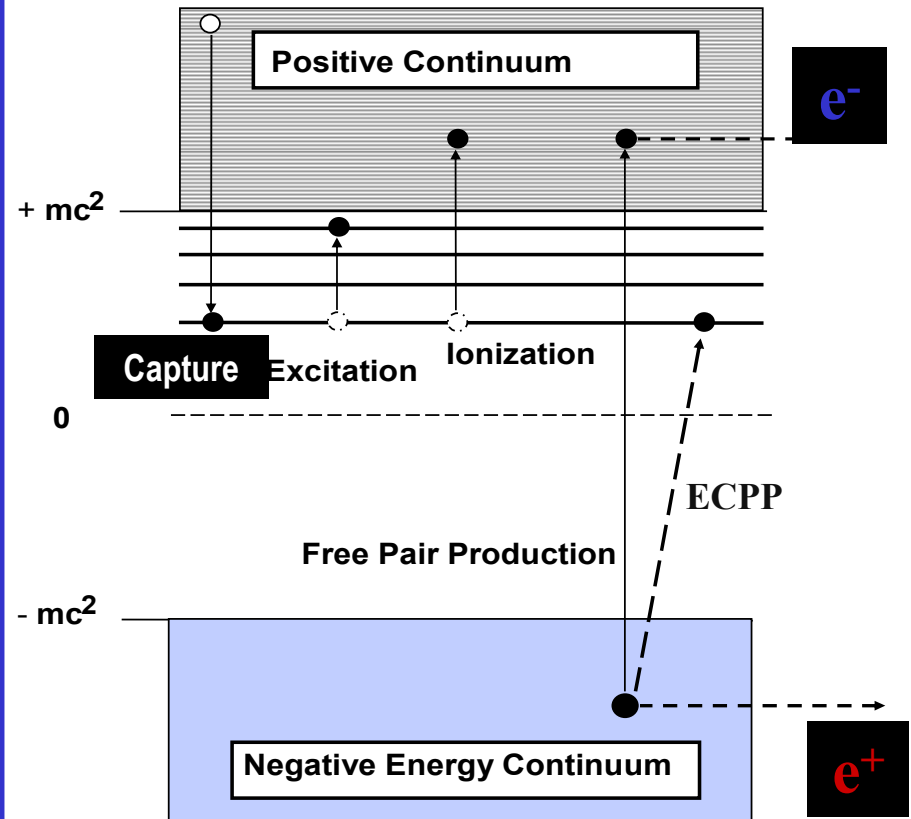
# Extreme Dynamic Fields

## High- $\gamma$



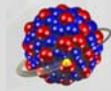
$$E \approx \frac{\gamma Z}{b^2}$$

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

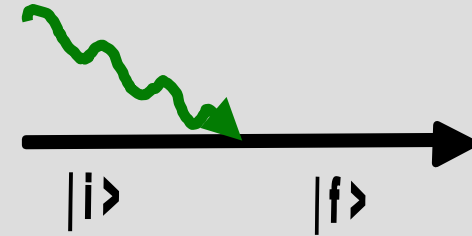




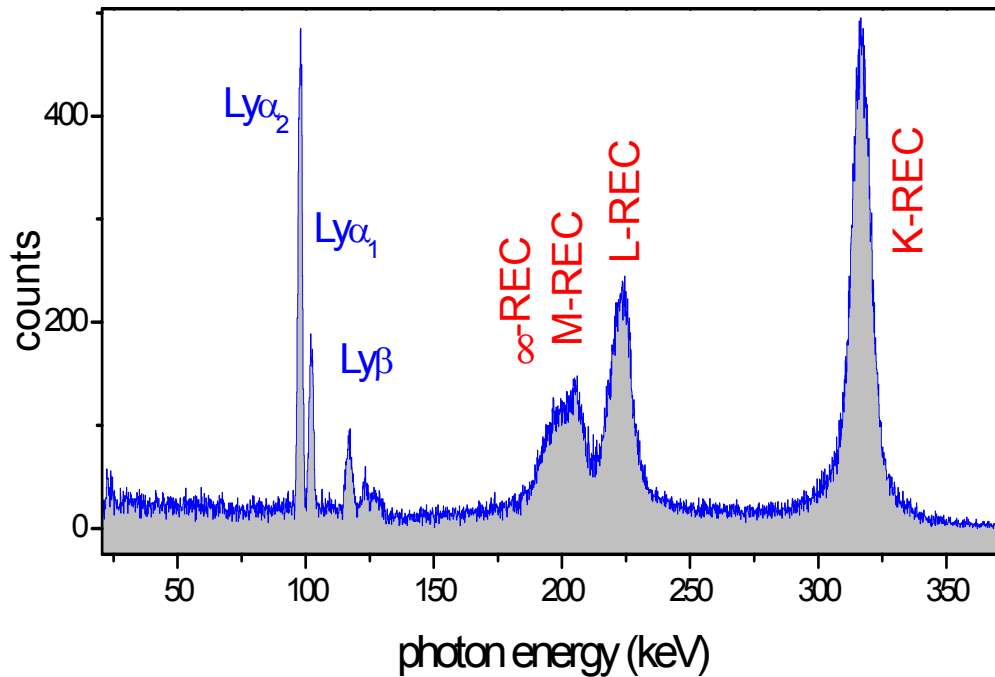
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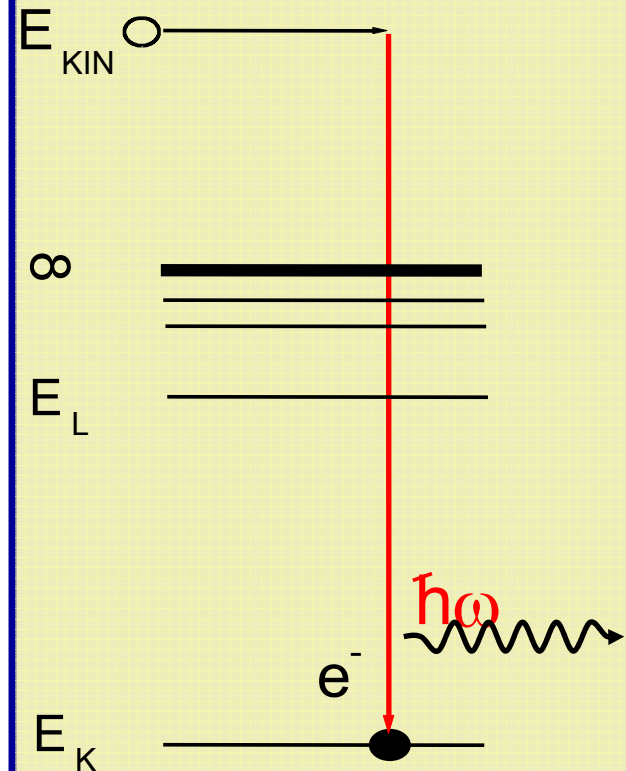
# Photon-Matter Interaction in the Relativistic Regime

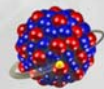


$U^{92+} \Rightarrow N_2, 358 \text{ MeV/u}$



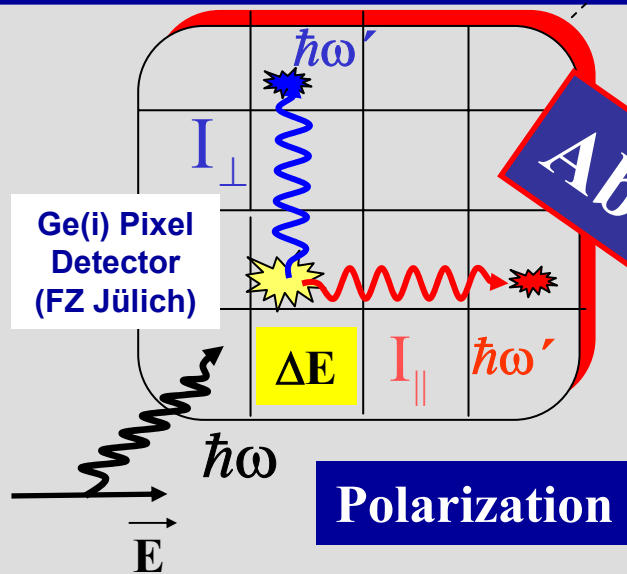
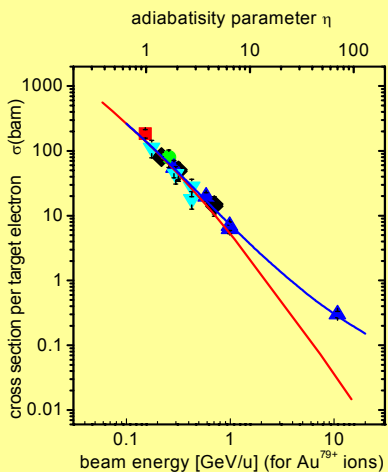
## Radiative Electron Capture



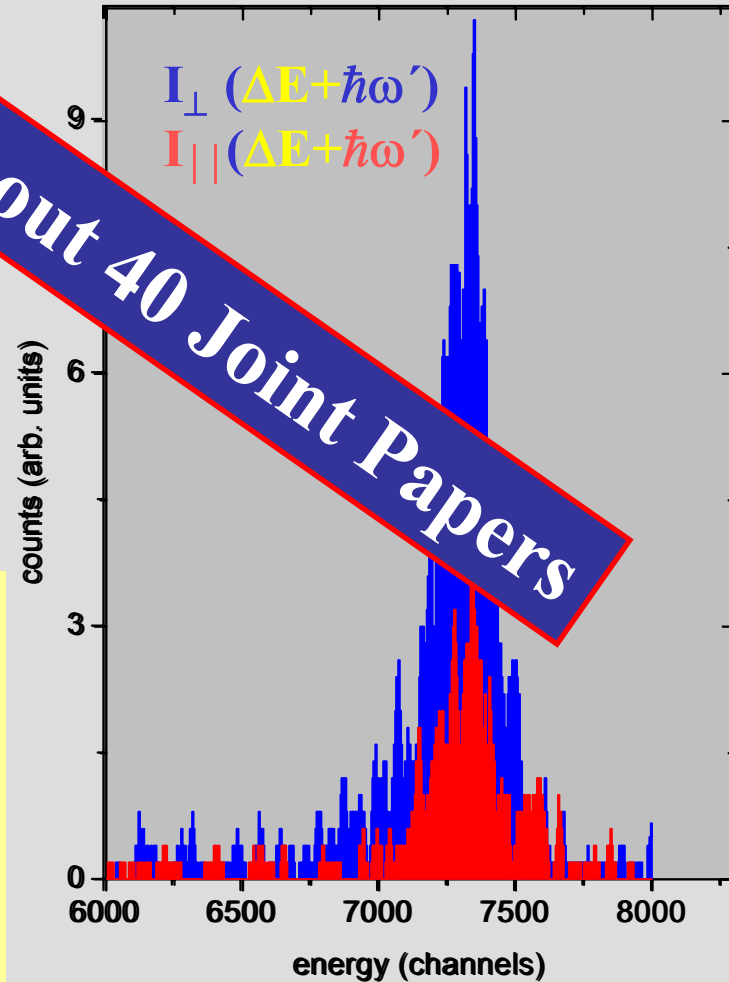


# Photon-Matter Interaction in the Relativistic Regime

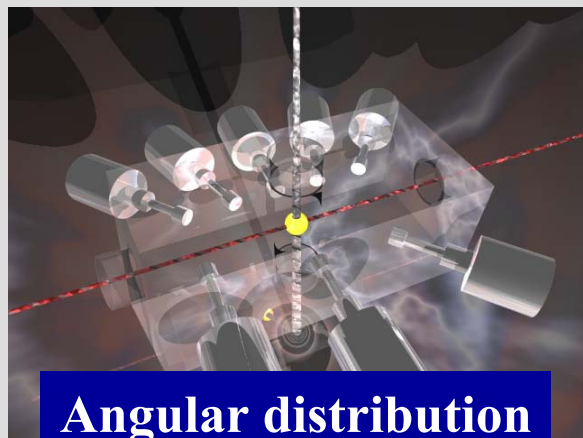
## Total cross sections



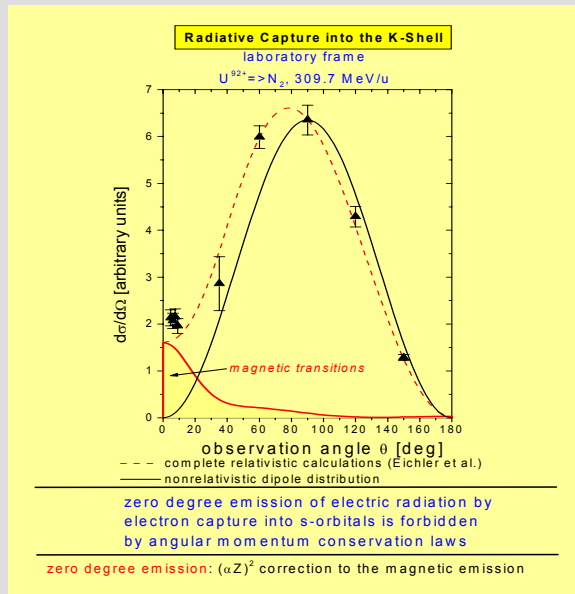
About 40 Joint Papers



## Gas Jet target



## Angular distribution



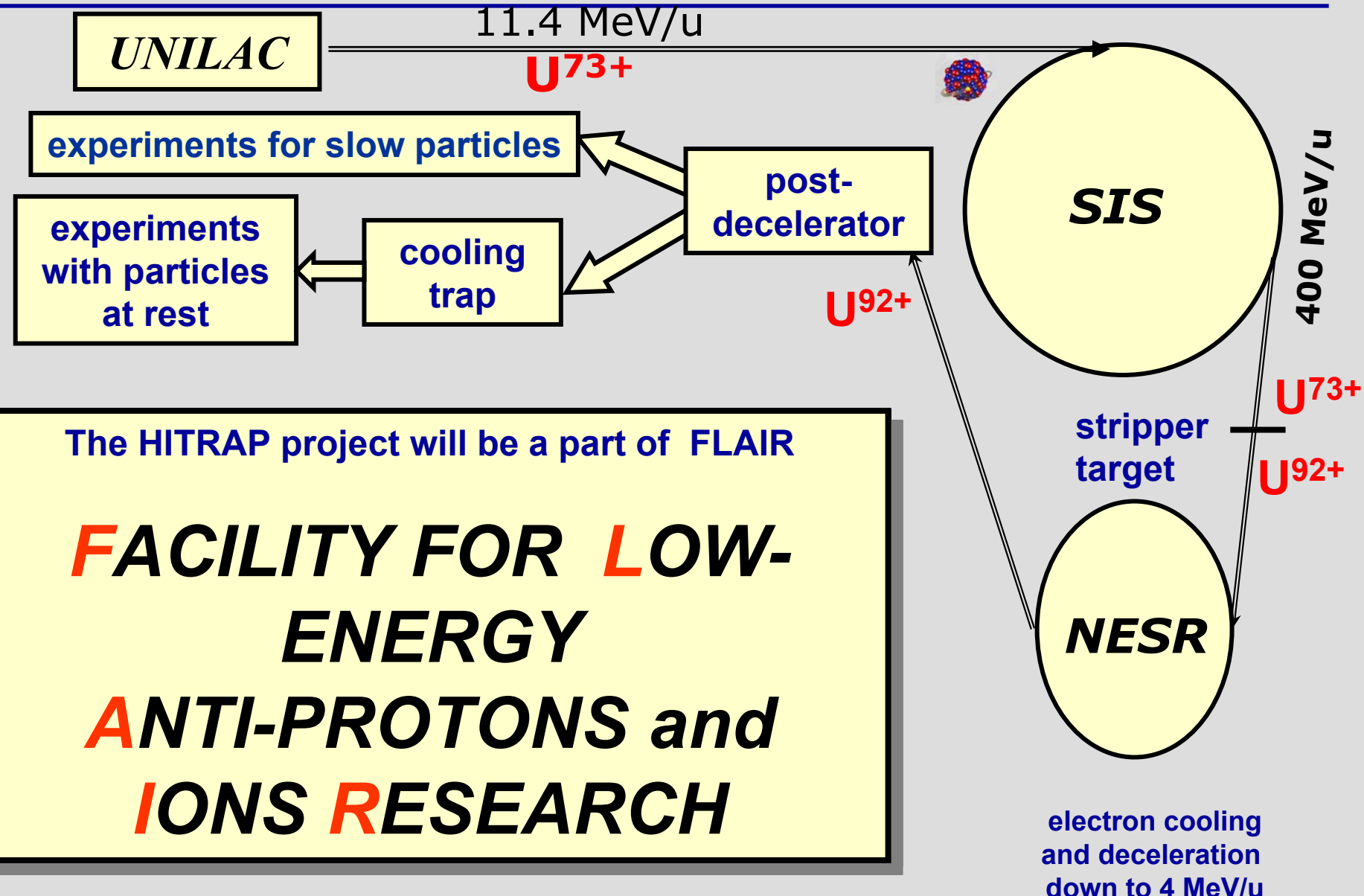
Frankfurt-GSI-Krakow-Kielce-Świerk  
Lanzhou-Argonne-Kassel-Berlin



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# The HITRAP Project at GSI



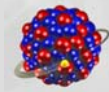
The HITRAP project will be a part of FLAIR

**FACILITY FOR LOW-ENERGY ANTI-PROTONS and IONS RESEARCH**





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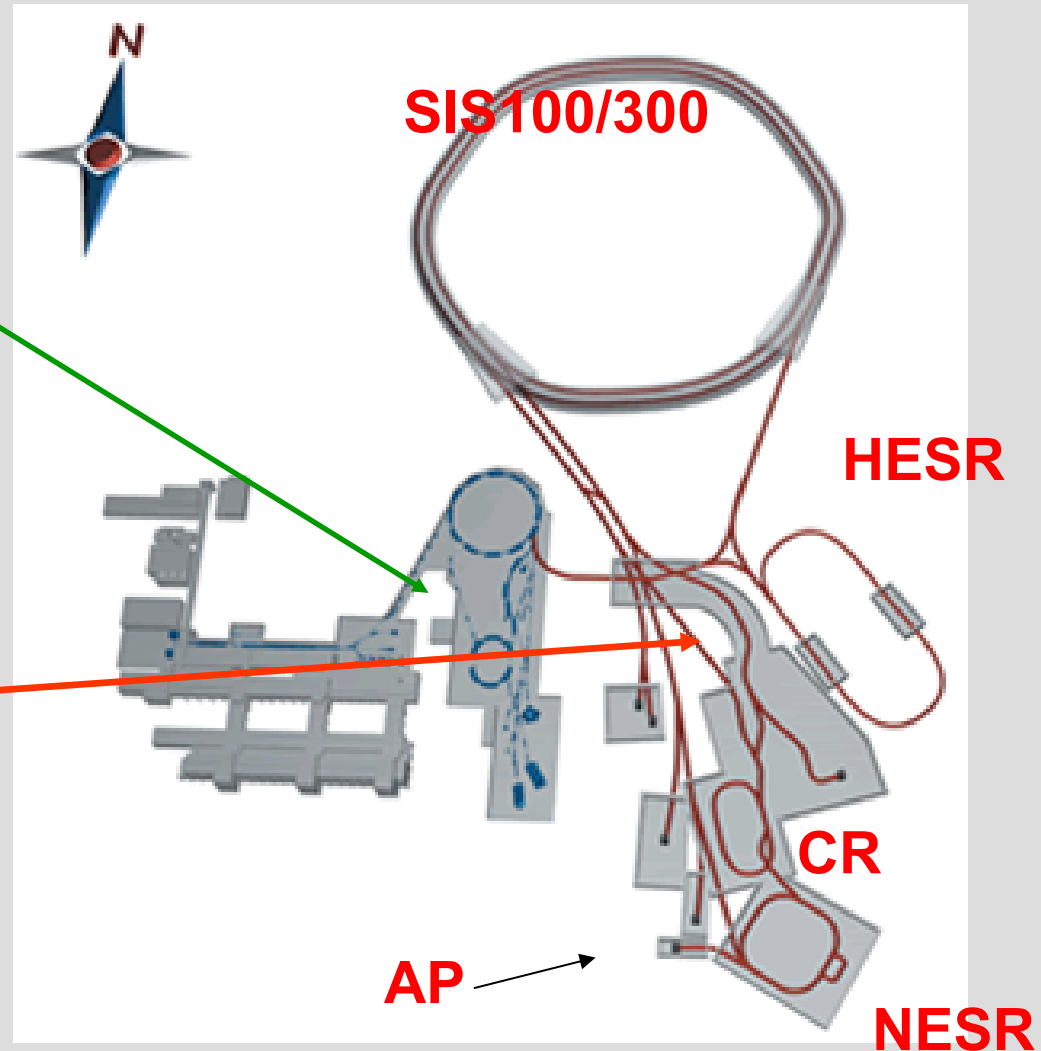
# Antiproton Factory

**Z – range**  
**1 => 92**

*New accelerator facility*

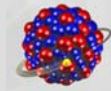
**Z – range**  
**-1 => 92**

**Parameters:**  
antiprotons  
up to 30 GeV,  
stored and cooled



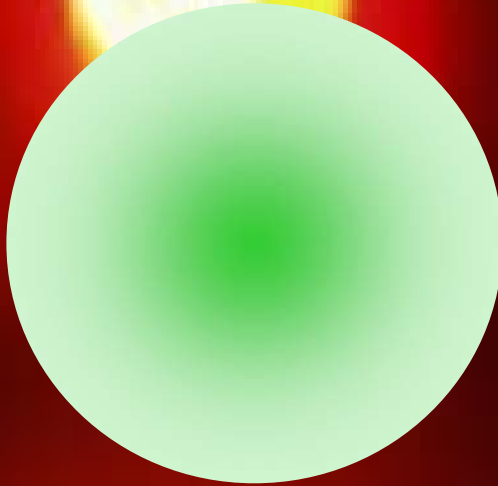


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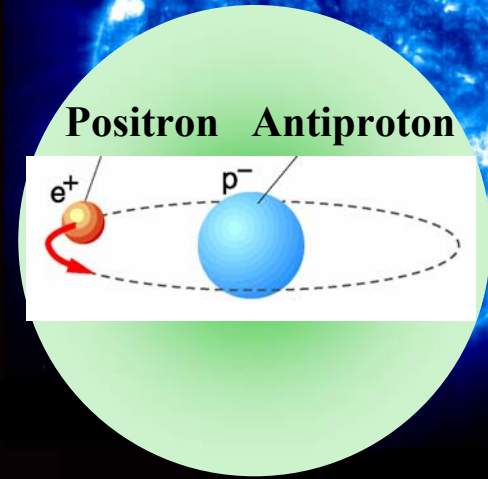


# Ultra-Slow and Trapped Antiprotons

## Hydrogen



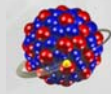
## Antihydrogen



**Why is there no Antimatter**  
 GSI will provide the Most Intense  
**in the Universe?**  
 Source of Antiprotons



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# Ultra-Slow and Trapped Antiprotons

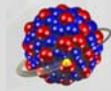
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## *What to Do with FLAIR*

- **Test of fundamental symmetries: CPT**
- **Exotic systems: “Atomcules”**
- **Interaction of matter with antimatter**



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# Atomic Physics

## Stored Particles Atomic Research Collaboration

*Atomic Physics Group, GSI, Darmstadt, Germany*  
*University of Frankfurt, Germany*  
*Jagiellonian University, Kraków, Poland*

*Institute of Nuclear Physics, PAN, Kraków, Poland*  
*Kansas State University, Kansas, USA*

*Institute of Nuclear Studies, Świerk, Poland*

*Institute of Modern Physics, Lanzhou, China*

*Tbilisi State University, Tbilisi, Georgia*

*Świętokrzyska Academy, Kielce, Poland*

*Fudan University, Shanghai, China,*

*University of Giessen, Germany*

*University of Tokyo, Japan*

*LBNL, Berkeley, USA*

*LLNL, Livermore, USA*

*Lebedev Institute, Moscow, Russia*  
*University of Dresden, Germany*

*MPI Heidelberg, Germany*

*University of Heidelberg, Germany*

*University of Mainz, Germany*

*University of Stockholm, Sweden*

*Warsaw University, Warsaw, Poland*

*ANL, Argonne, USA*

*HMI, Berlin, Germany*

*University of St. Petersburg, Russia*

*University of Kassel, Germany*