HITRAP Workshop

December 11, 2002, GSI-Darmstadt

X-Ray Spectroscopy of Highly Charged Ions

Andrzej Warczak

Jagiellonian University, Institute of Physics
Krakow, Poland

Contents

- **X-rays - messengers of atomic processes**

  Fundamental learning goals:

  - matter in strong Coulomb fields (Lamb shift)
  - interaction of radiation with matter (photoionization investigated via REC)
  - polarization of hard x-rays (REC photons)

- **Why do we need HITRAP ?**

  Most important arguments:

  - highly charged ions (simple atomic systems)
  - slow ions (reduced Doppler effect, photoionization close to the threshold)
  - high beam intensities

HITRAP

- **Position sensitive solid state x-ray detectors**

  Main advantages:

  - efficient photon detection
  - reduction of Doppler broadening
  - unique tool for polarization studies via Compton effect

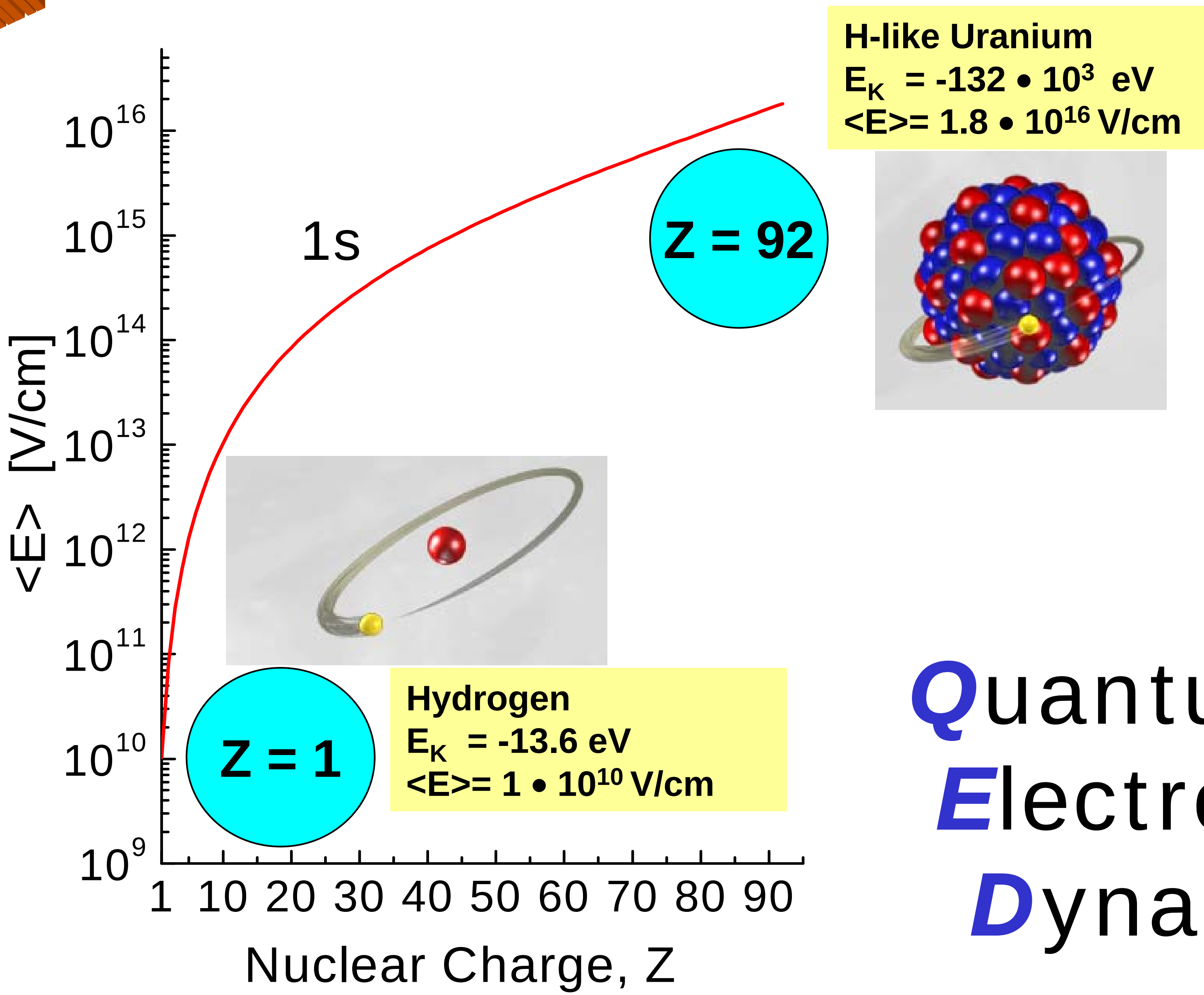
- **Tasks of the Krakow team within the HITRAP collaboration**

  *- signal processing for position sensitive x-ray detectors and developemet of electronic circuits (**main tasks**)*
  *- construction of a versatile UHV chamber for ion-surface interaction studies (**supporting task**)*

- **Summary**

HITRAP

Atomic Physics in Extremly Strong Coulomb Fields

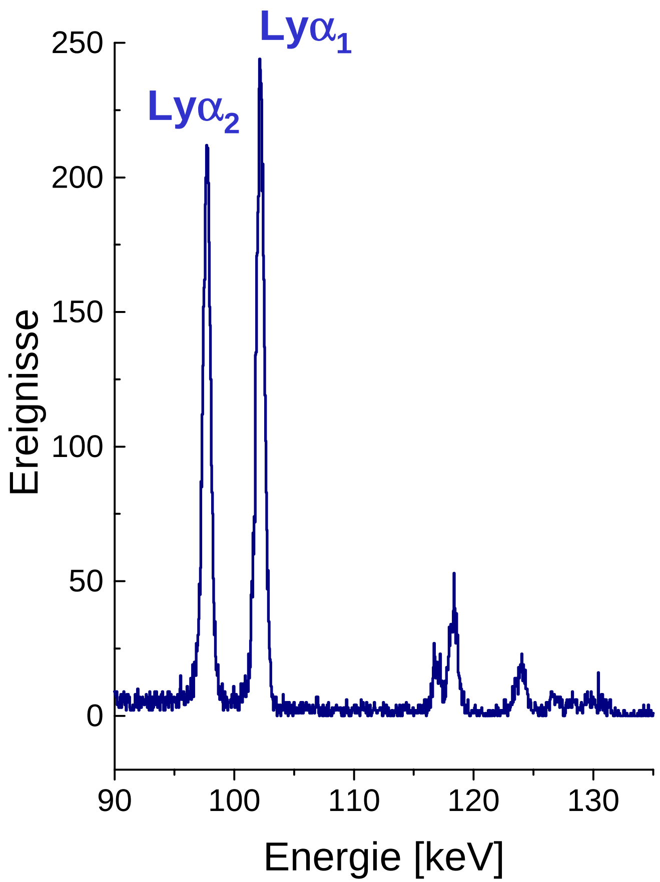


Quantum
Electro-
Dynamics

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

Lamb Shift-Experiment at the Jet-Target

Geometry	$\Delta\beta$	Fit
±8.5 eV	±2.6 eV	± 9.7 eV



1s Lamb shift

Experiment: 468 eV ± 13 eV

Th. Stoehlker, et al., Phys. Rev. Lett. **85,** 3109 (2000)

Theory: 463,95 ± 0,50 eV

V. A. Yerokhin and V. M. Shabayev, Phys. Rev. **A64**, 062507 (2001)

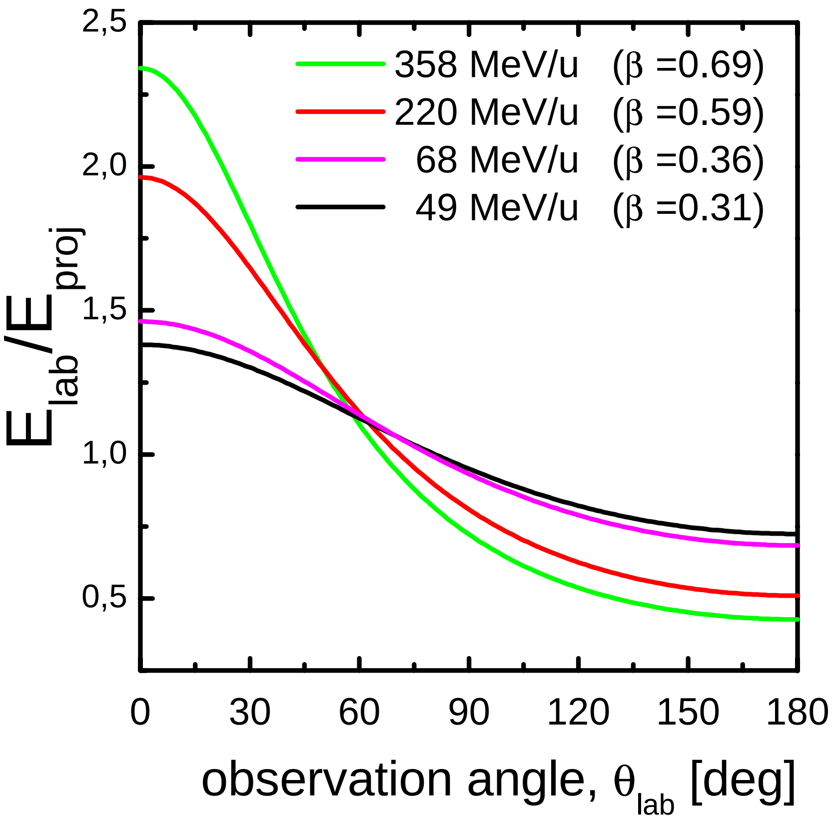
The Experimental Challenge

Relativistic Doppler-Transformation

$$E_{lab} = \frac{E_{proj}}{\gamma \cdot (1 - \beta \cdot \cos\theta_{lab})}$$

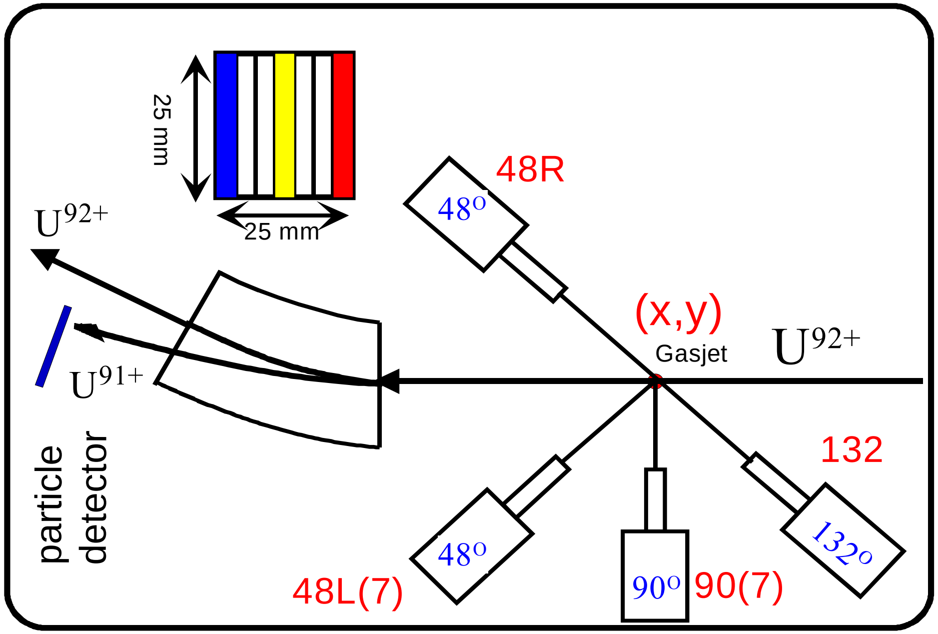
E_{lab}: Photon energy in the laboratory system
E_{proj}: Photon energy in the emitter system

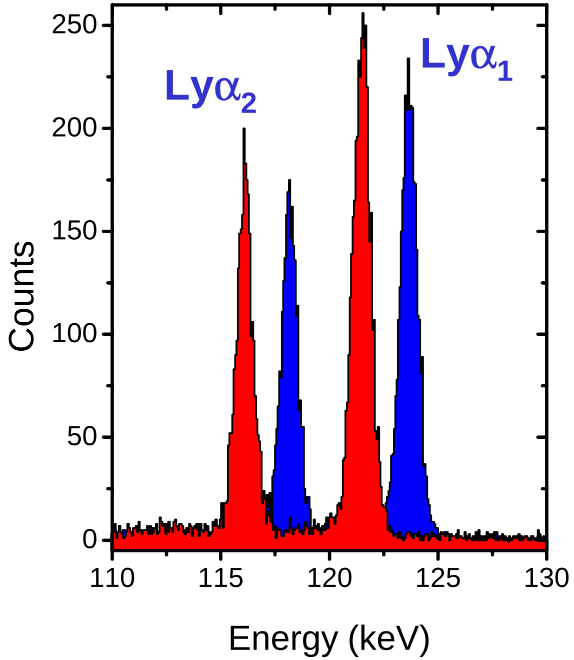
Doppler-Correction: *Strong dependence on velocity and the observation angle* θ_{LAB}



Solution of the Problem

Segmented Ge(i) detector **+** **decelerated ions**





• ***Simultaneous observation at various angles***

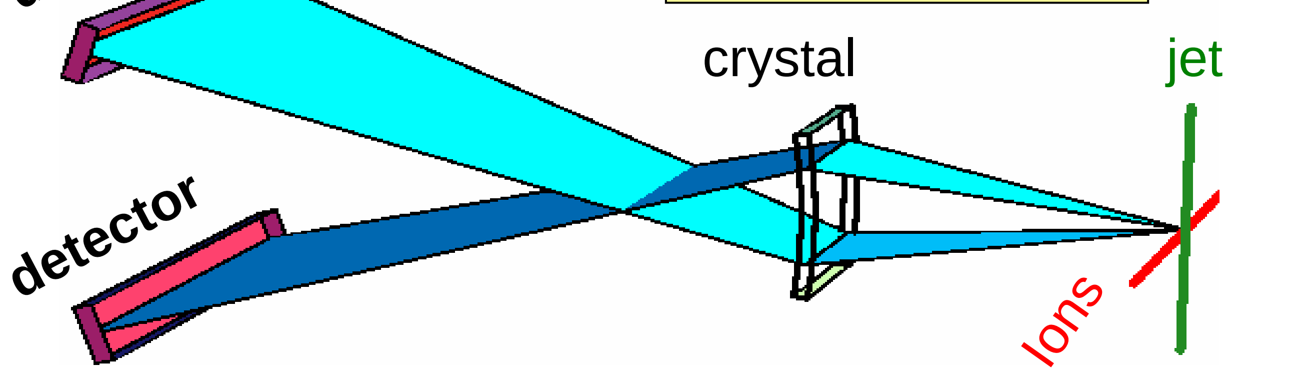
$\Delta\theta \approx 3.0$ deg

Solution of the Problem

towards an accuracy of 1 eV

Bragg-Laue relation

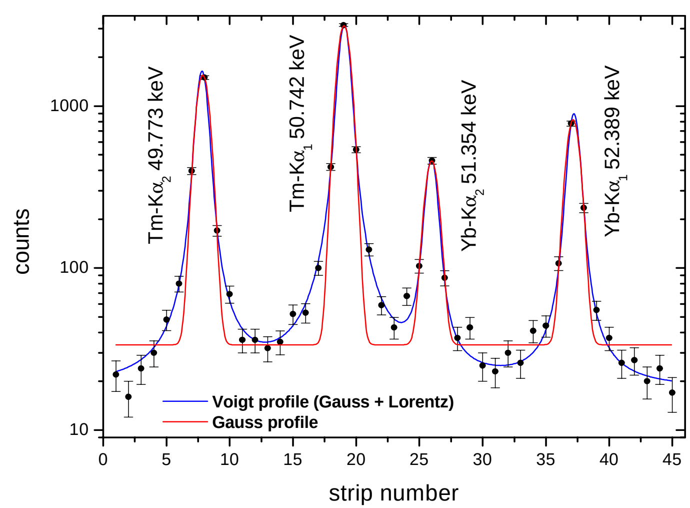
$$n \cdot \lambda = 2 \cdot d \cdot \sin\theta$$



H.F. Beyer et al., GSI Report 2000

+

D. Protic et al., 2000

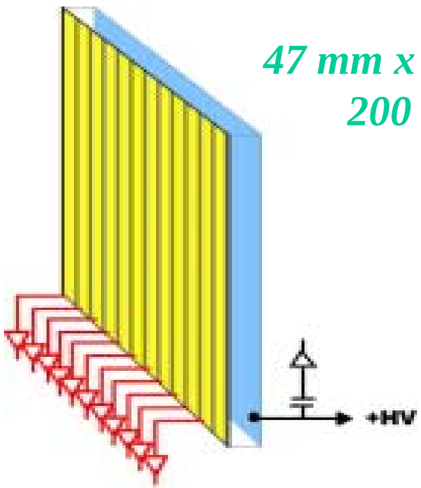


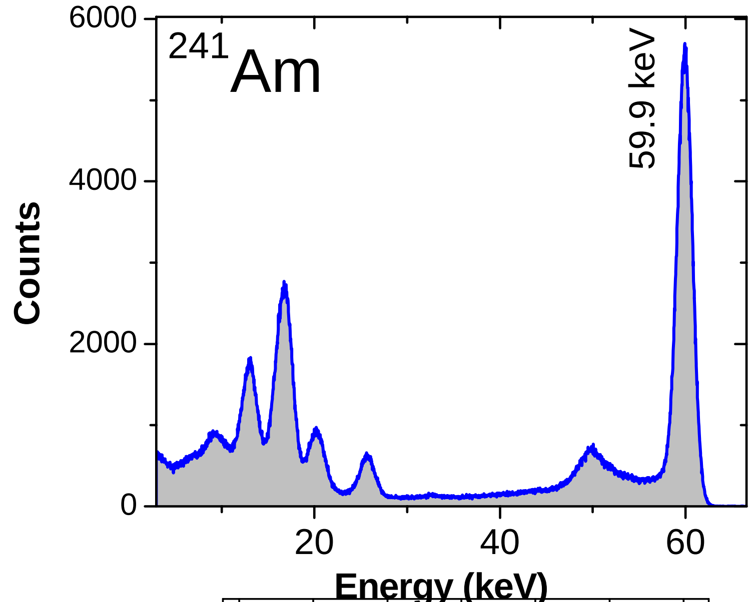
Combined energy resolution better than 100 eV

natural line width:38±9 eV

(50 µm: 18.9 eV:
1 strip: 89 eV)

Micro-Stripe Germanium Detectors (an example)



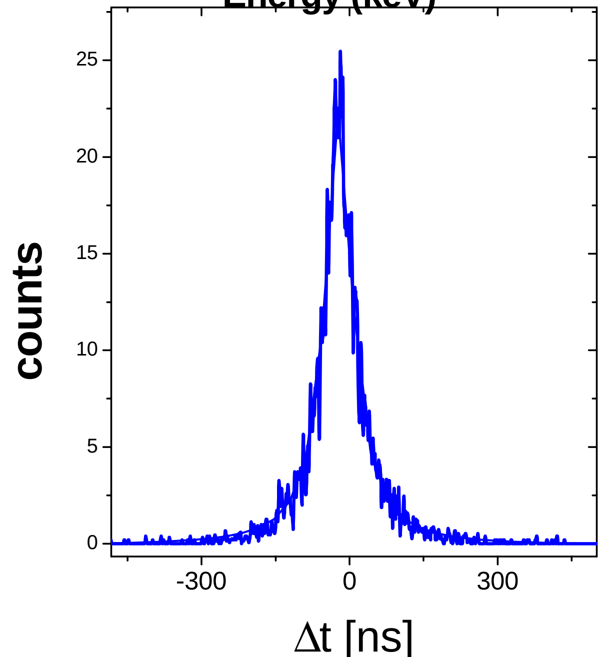


Energy

Energy resolution
1.6 keV @ 60 keV
(for a single stripe)

Position resolution
200 μm

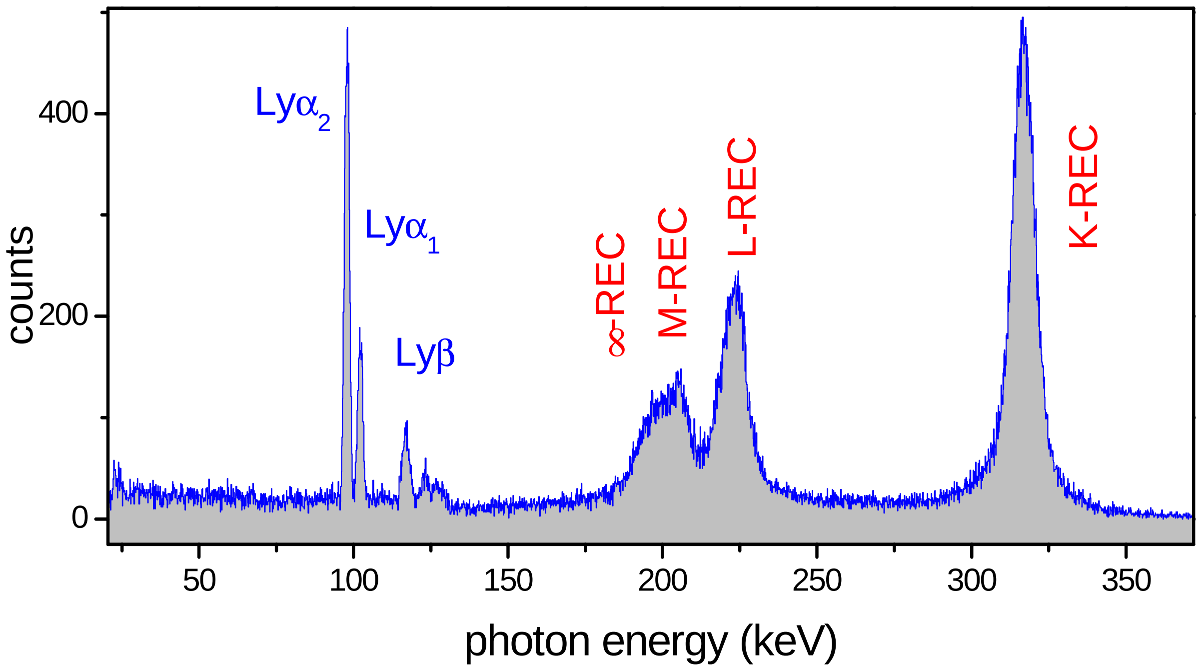
Time resolution
50 ns

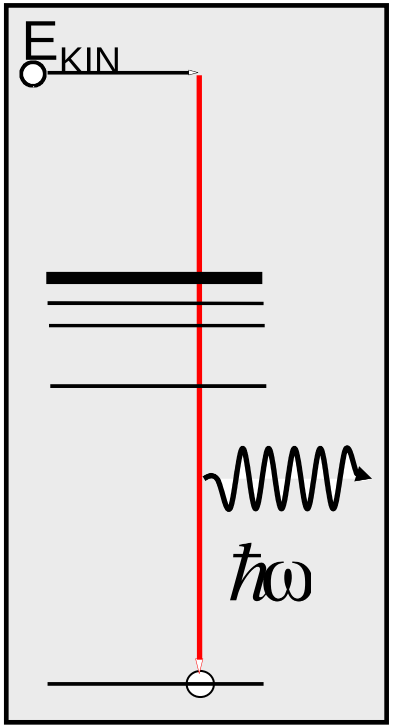


Timing

Radiative Electron Capture Capture of Quasifree Targetelectrons

U^{92+} => N_2, 358 MeV/u



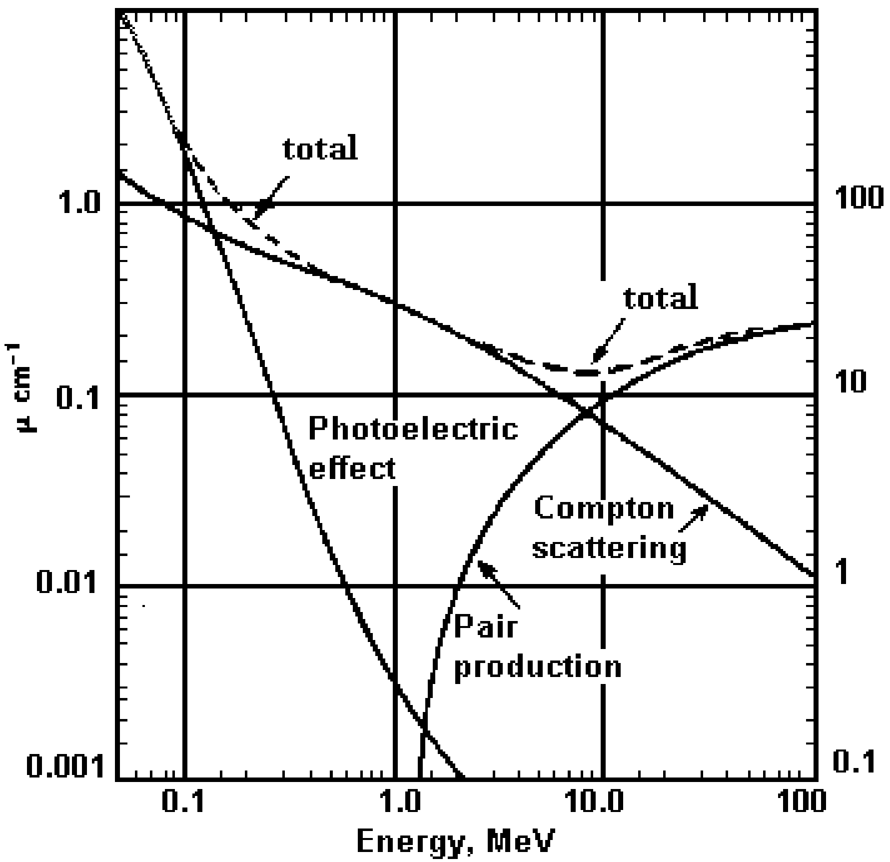


REC photon energy

$$\hbar\omega_{REC} = E_B + m_e c^2(\gamma - 1) + \gamma(v_i p_z - E_T)$$

Shape and width of REC lines are determined by the momentum distribution of the target electrons

Interaction of electromagnetic radiation with matter

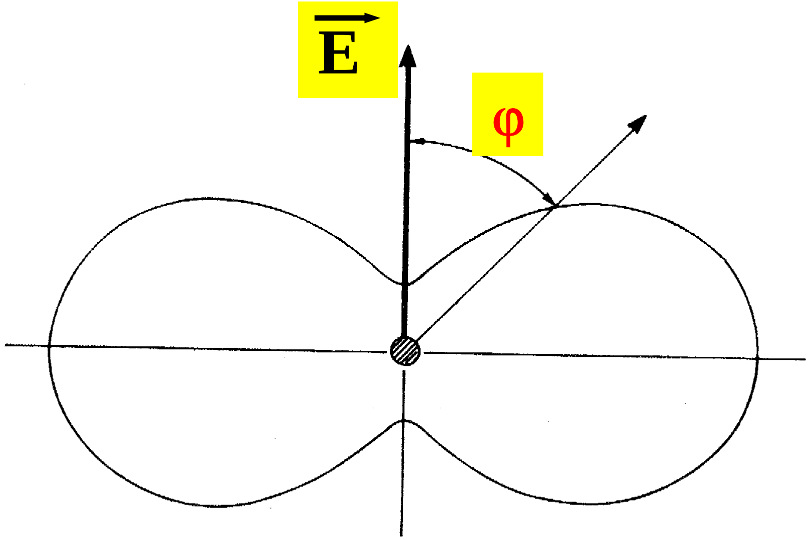


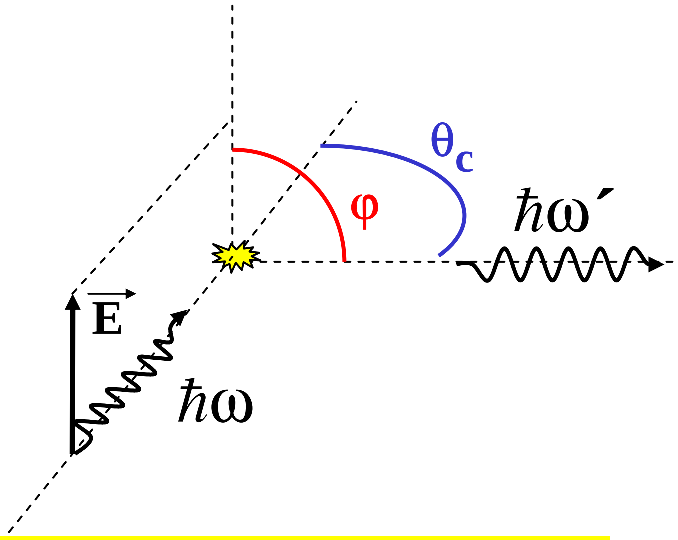
- photoelectric effect
- *Compton scattering*
- pair production

Polarization Measurements by Means of Compton Scattering

Klein-Nishina formula

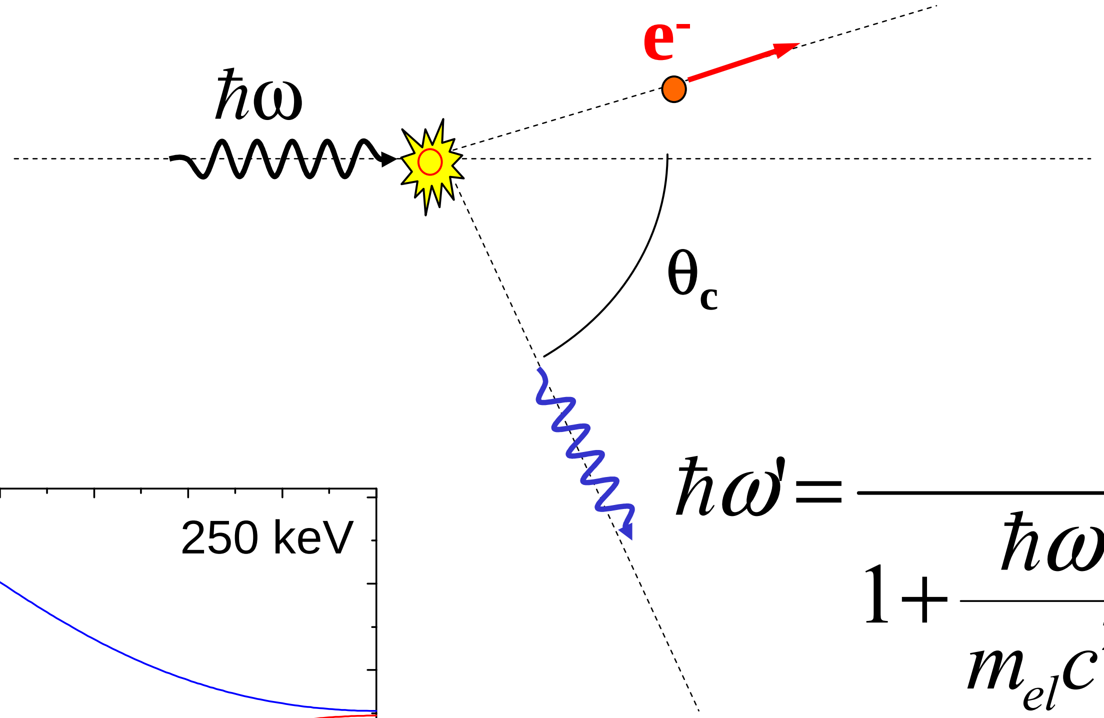
$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \left(\frac{\hbar\omega'}{\hbar\omega}\right)^2 \left(\frac{\hbar\omega'}{\hbar\omega} + \frac{\hbar\omega}{\hbar\omega'} - 2\sin^2\theta_c \cos^2\varphi\right)$$



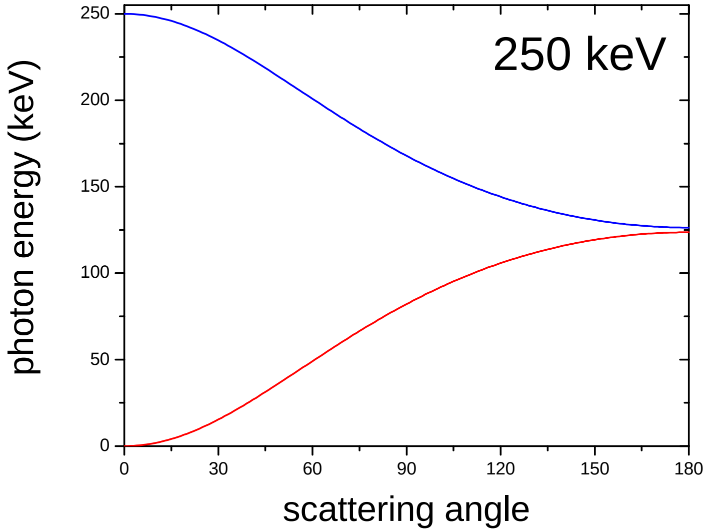


Angular distribution of scattered photons - a fingerprint of polarization
Observation has to be done inside the detector

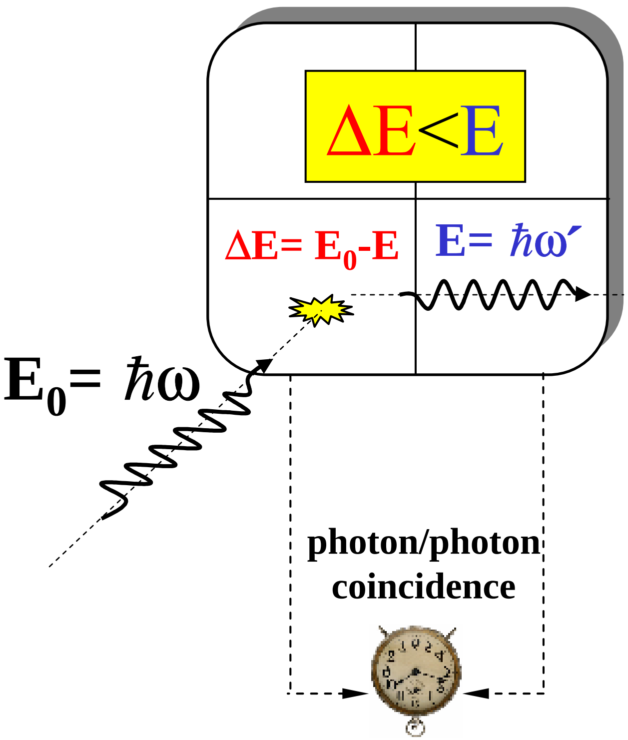
Compton scattering

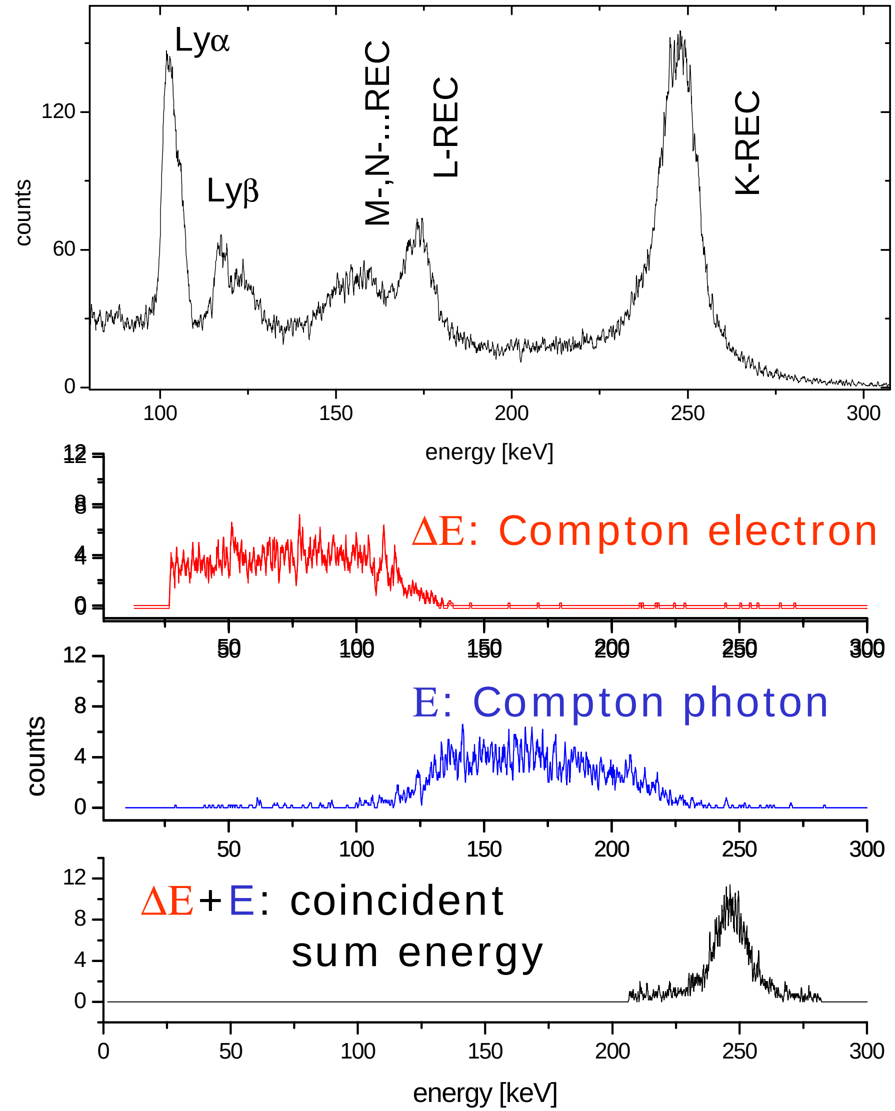


$$\hbar\omega' = \frac{\hbar\omega}{1 + \frac{\hbar\omega}{m_{el}c^2}(1-\cos\theta_c)}$$



Compton scattered photons

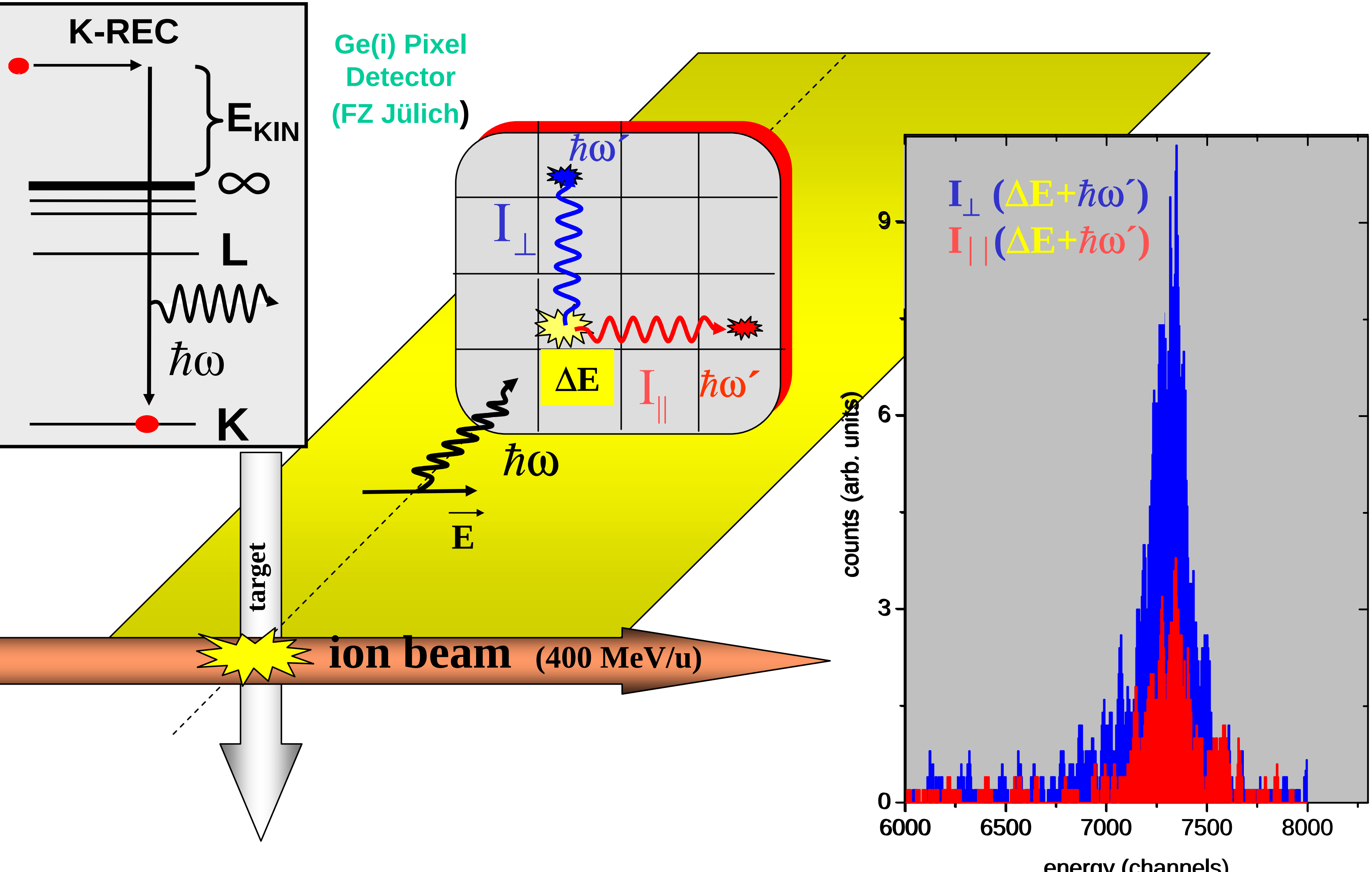




energy deposition in two independent parts of the detector

reconstruction of compton events

First Polarization Measurement for Radiative Recombination Transitions ($U^{92+} + e^- \Rightarrow U^{91+} + \hbar\omega$)



preliminary data from the ESR beam time May 2002

HITRAP

Summary

Position Sensitive Ge(i) Detectors provide a strong support for experiments with ions delivered by HITRAP. These detectors are:

1. **Important tools for accurate precision spectroscopy in atomic collisions with highly charged ions.**

2. **Unique tools to perform polarization studies for photon energies above 200 keV**