Photon Polarization for Electron Capture in Relativistic Ion-Atom Collisions

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Gesellschaft für Schwerionenforschung (GSI)/Darmstadt and University of Frankfurt

in collaboration with

Experiment

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Theory

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GSI-Darmstadt, Germany
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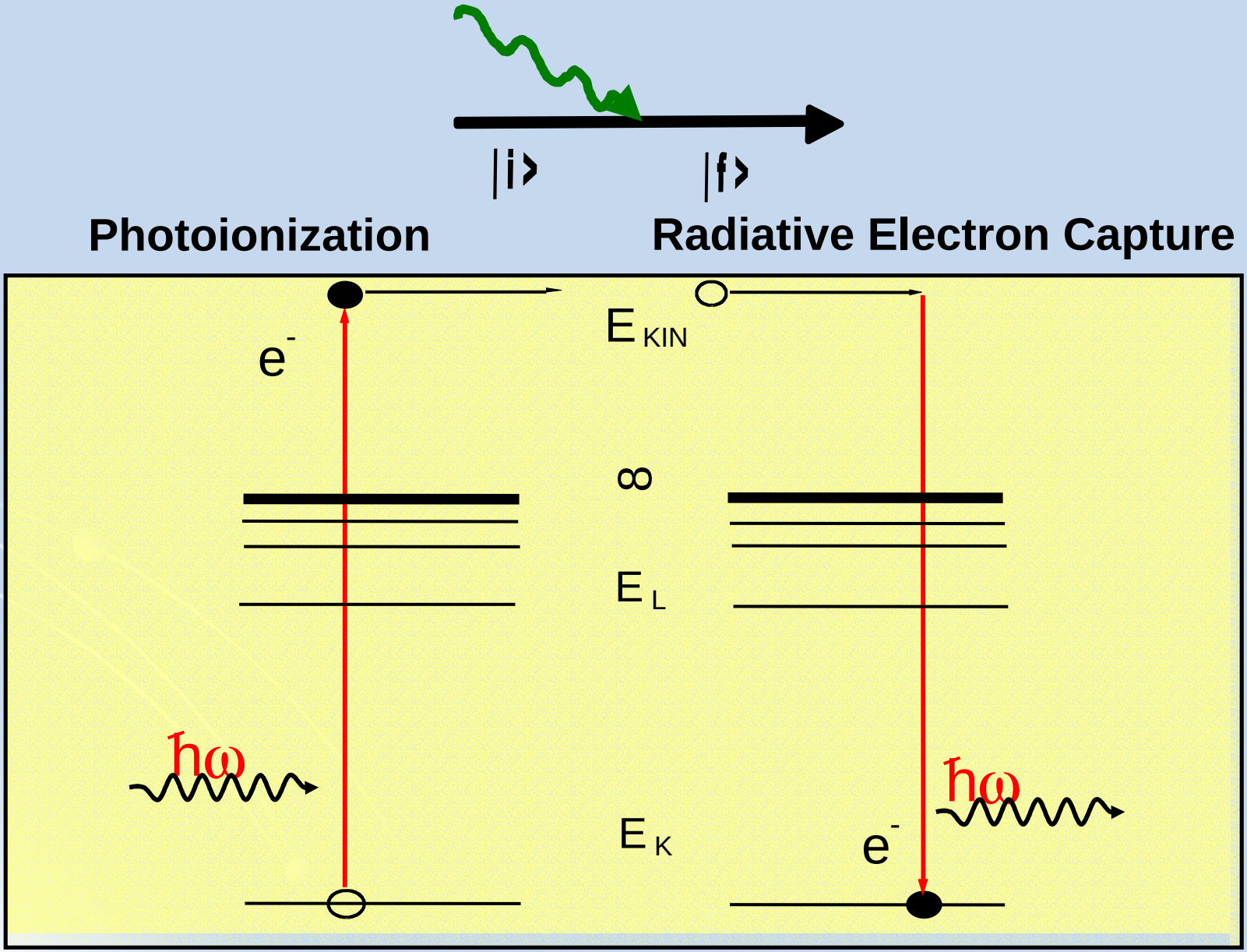
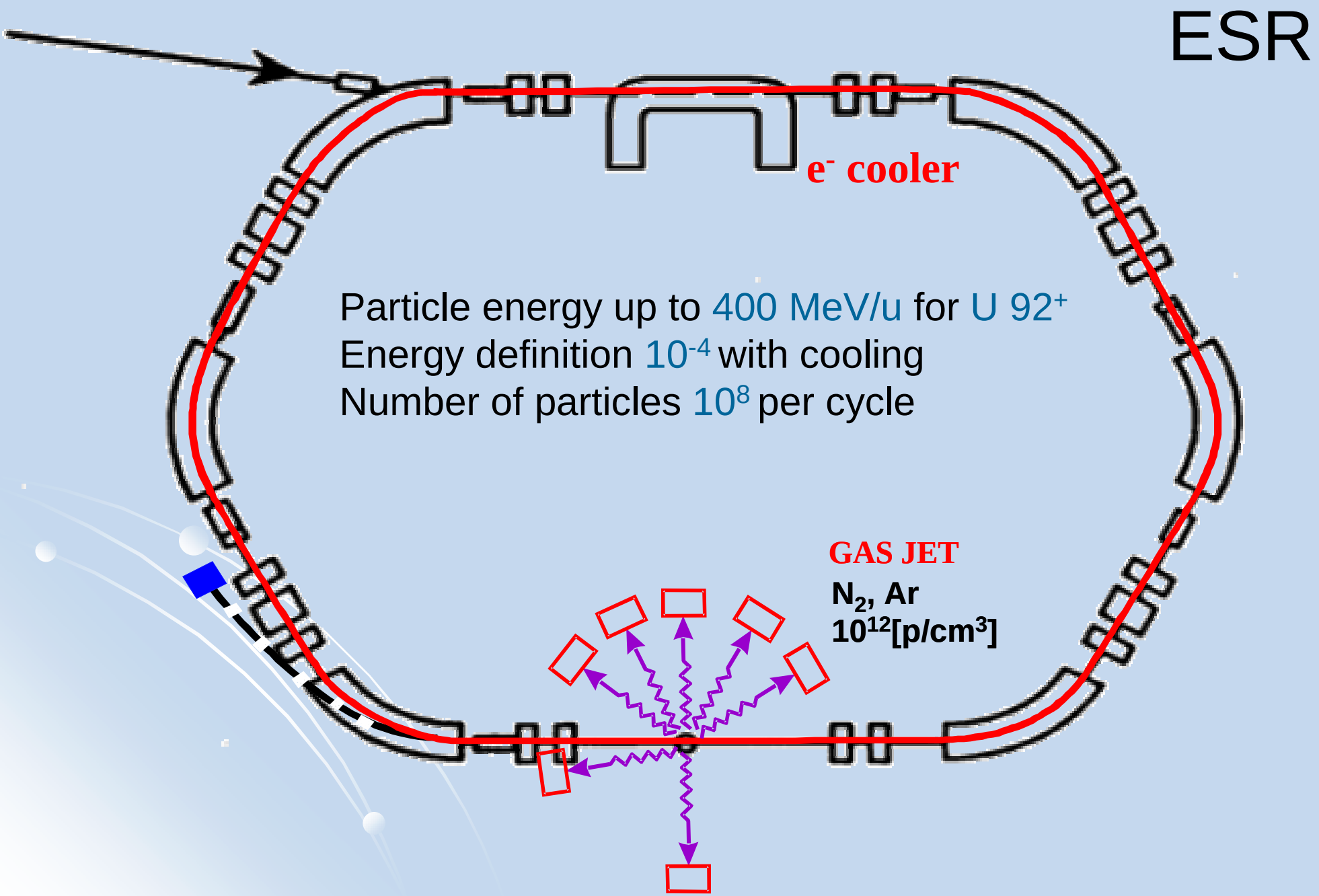
Photon-Matter Interaction in the Relativistic Regime

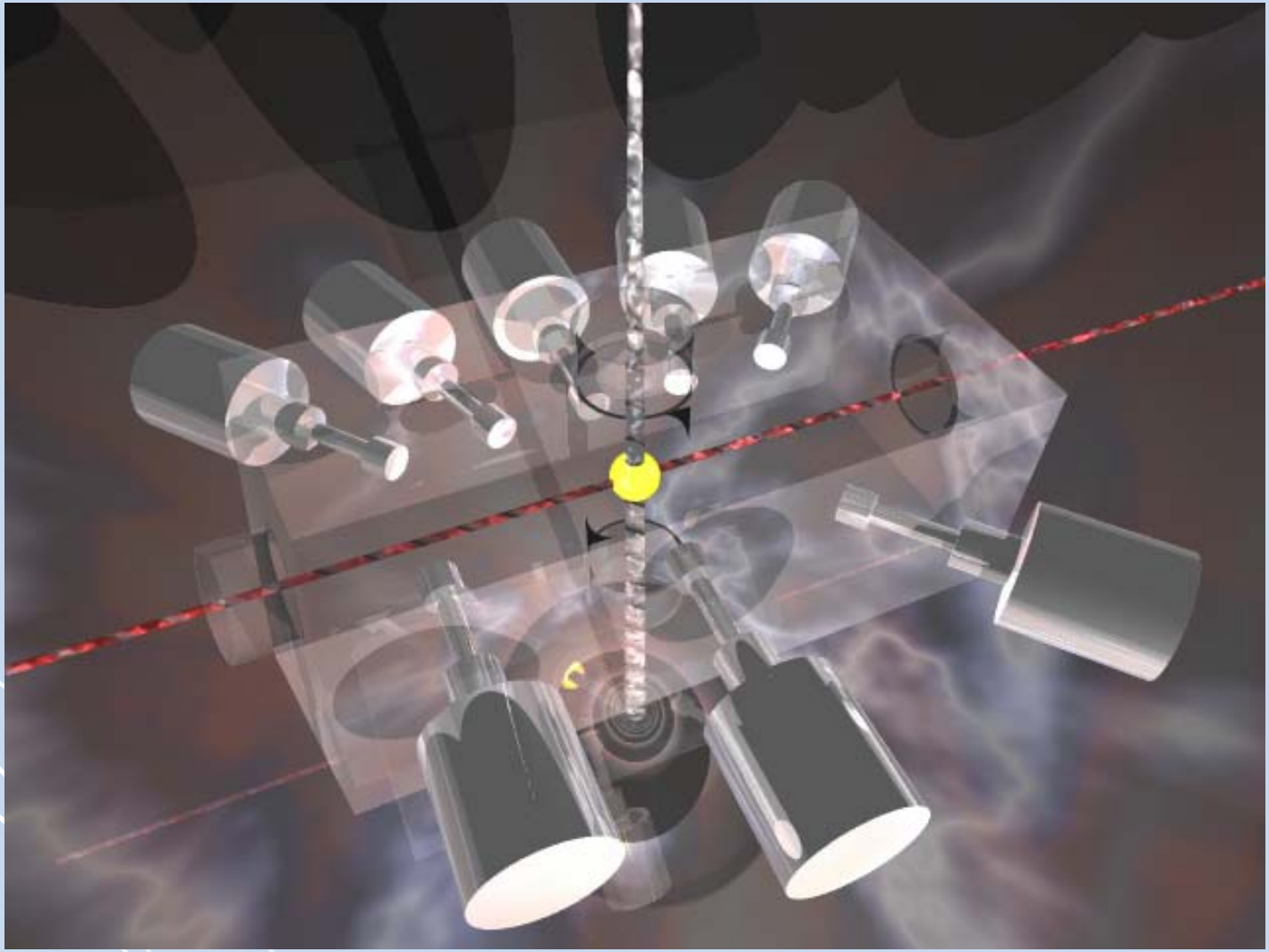
Radiative Electron Capture (K-REC)



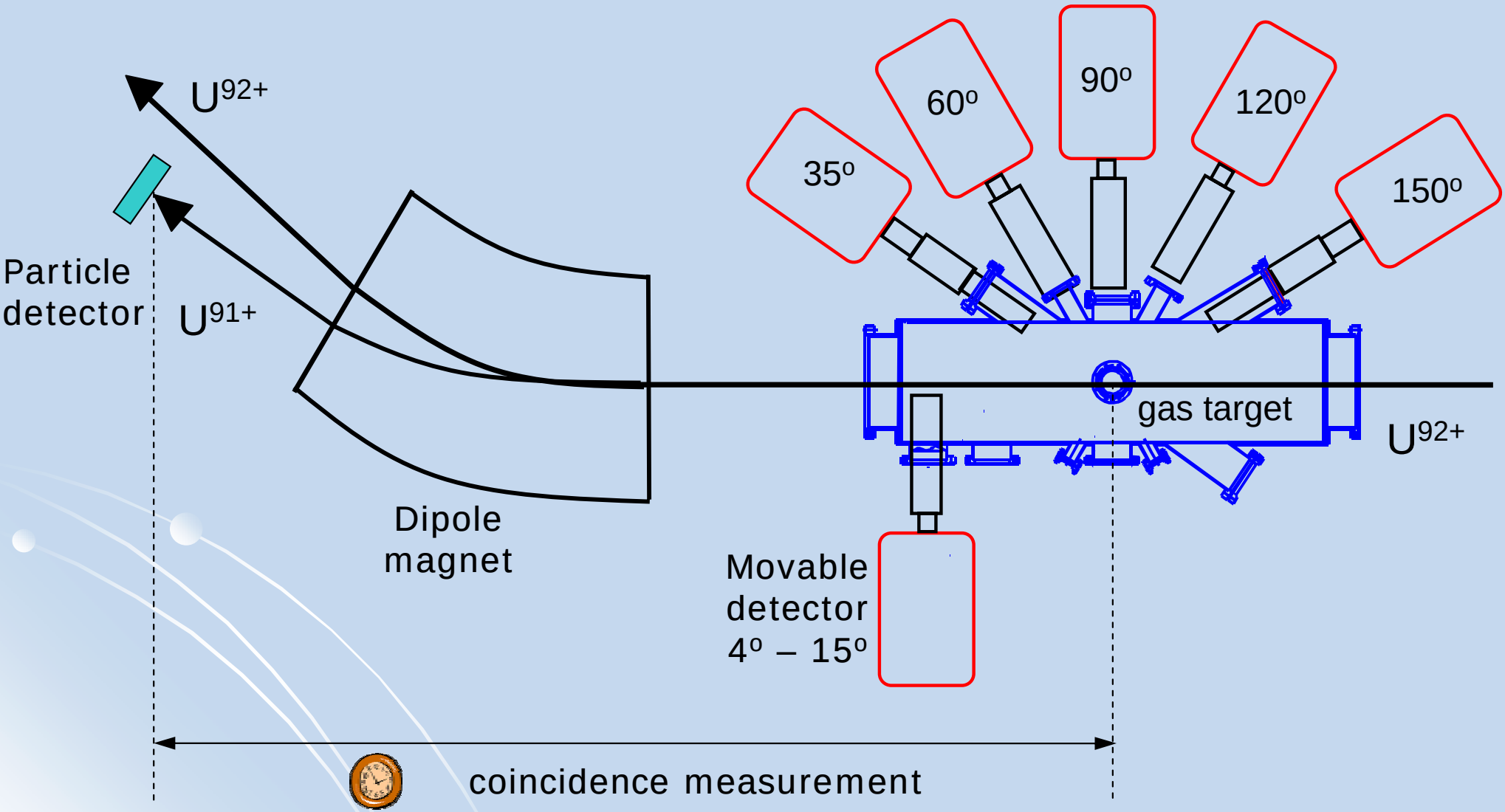
X-Ray Spectroscopy at the ESR



Gas Jet target

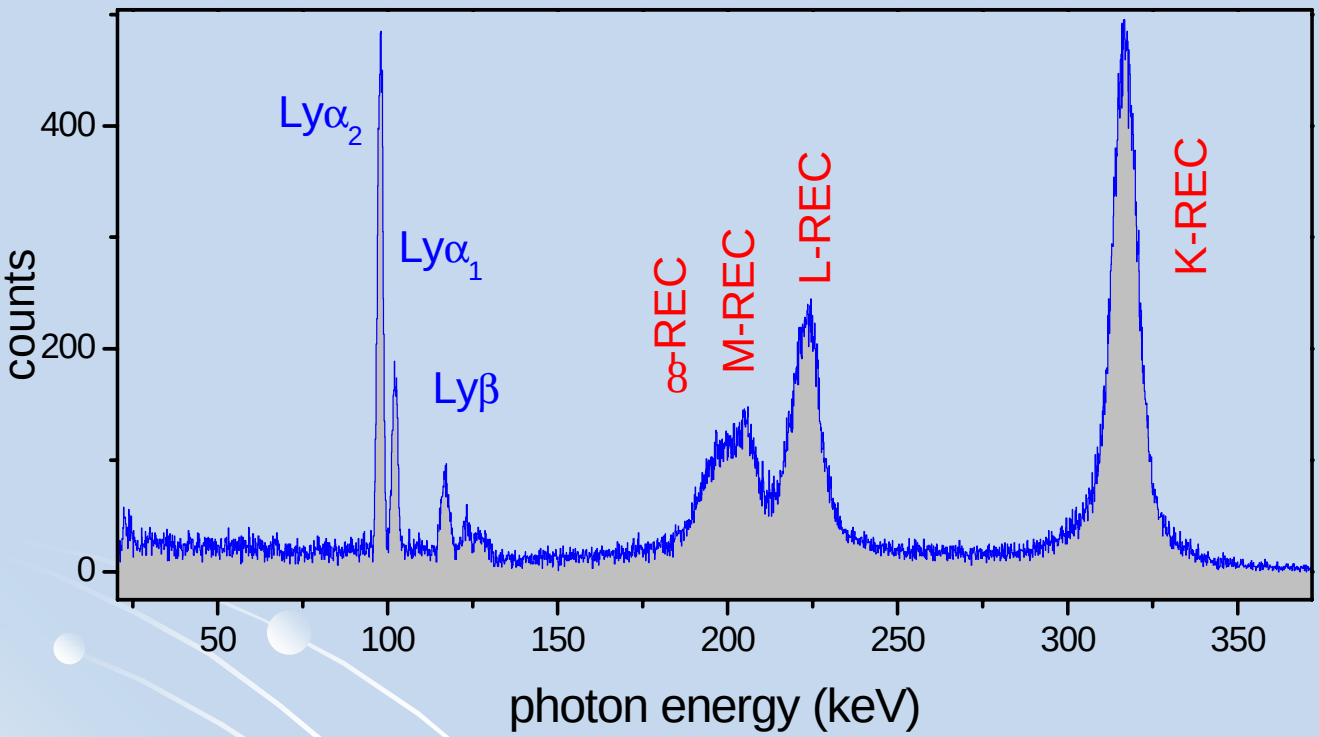


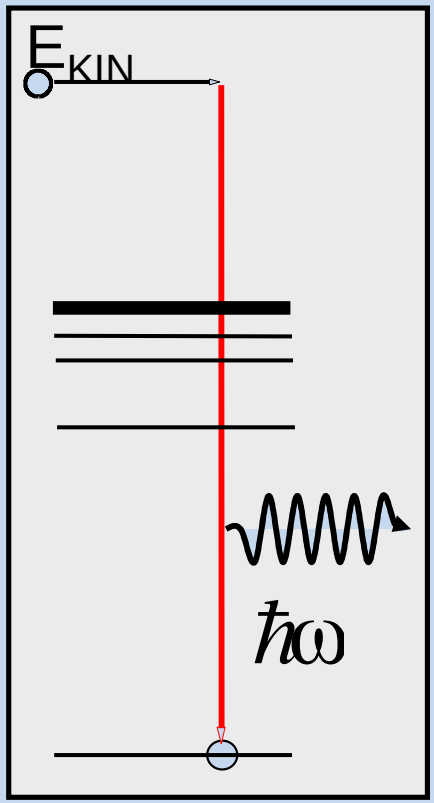
Measurements with coincidences



Radiative Electron Capture Capture of Quasifree Targetelectrons

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



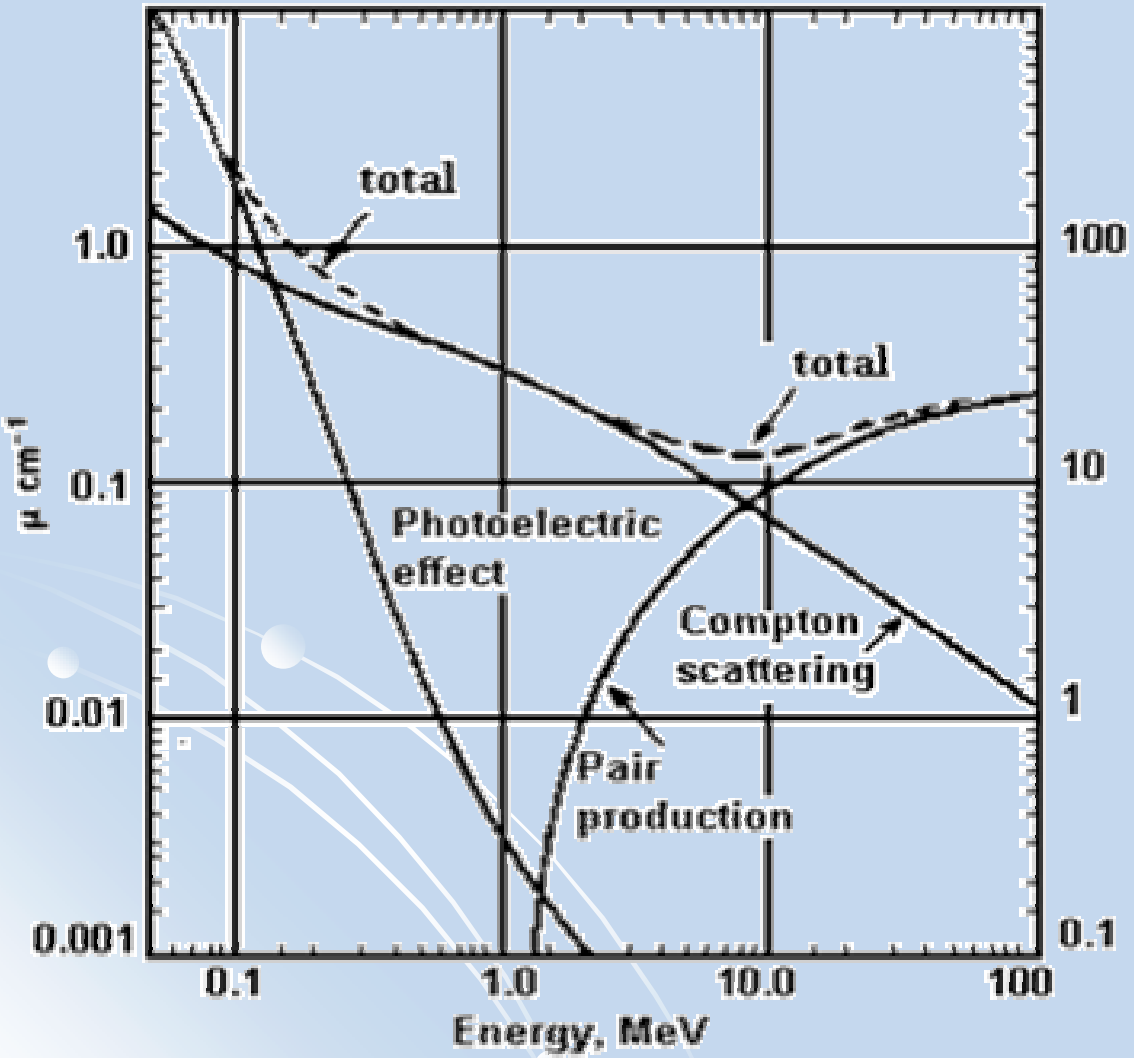


REC photon energy

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

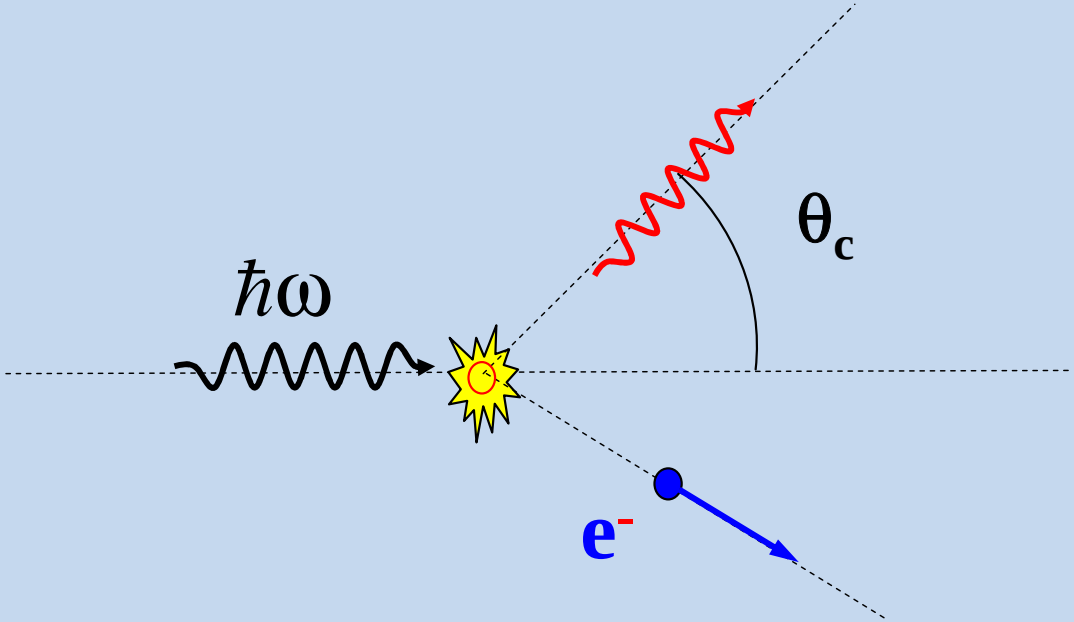
Shape and width of REC lines are determined by the momentum distribution of the target electrons

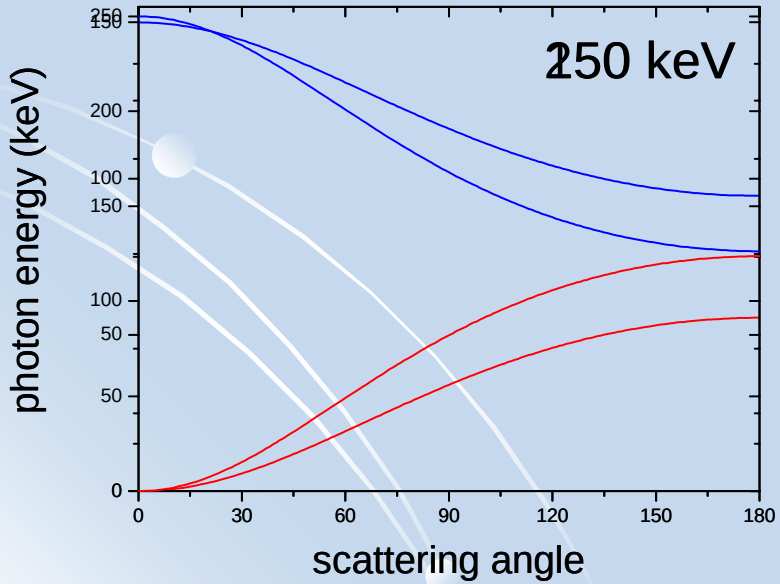
Interaction of electro-magnetic radiation with matter



- **photoelectric effect**
- ***Compton scattering***
- **pair production**

Compton scattering



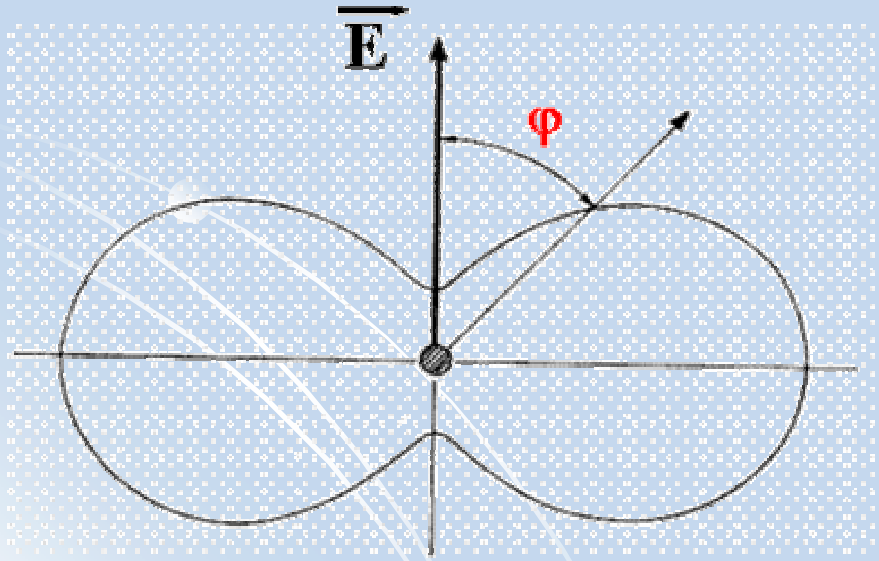


$$\hbar\omega' = \frac{\hbar\omega}{1 + \frac{\hbar\omega}{m_{el}c^2}(1 - \cos\theta_c)}$$

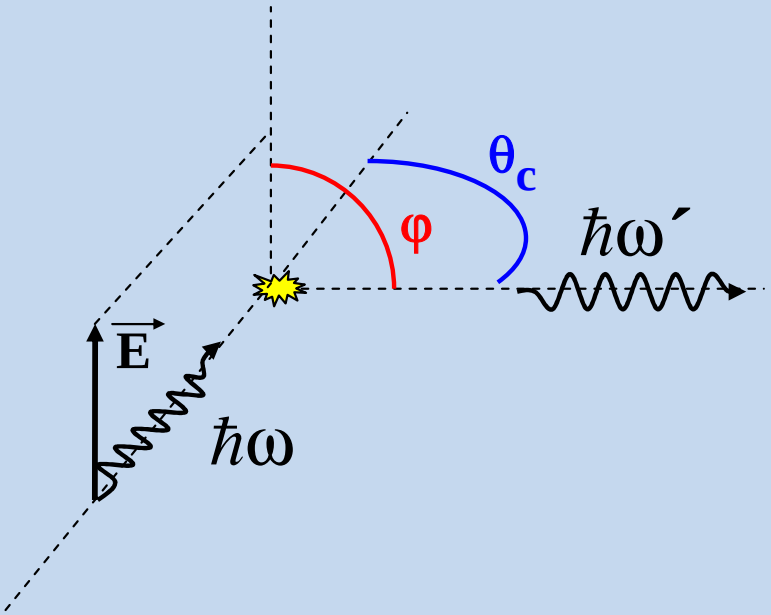
Polarization Measurements by Means of Compton Scattering

Klein-Nishina formula

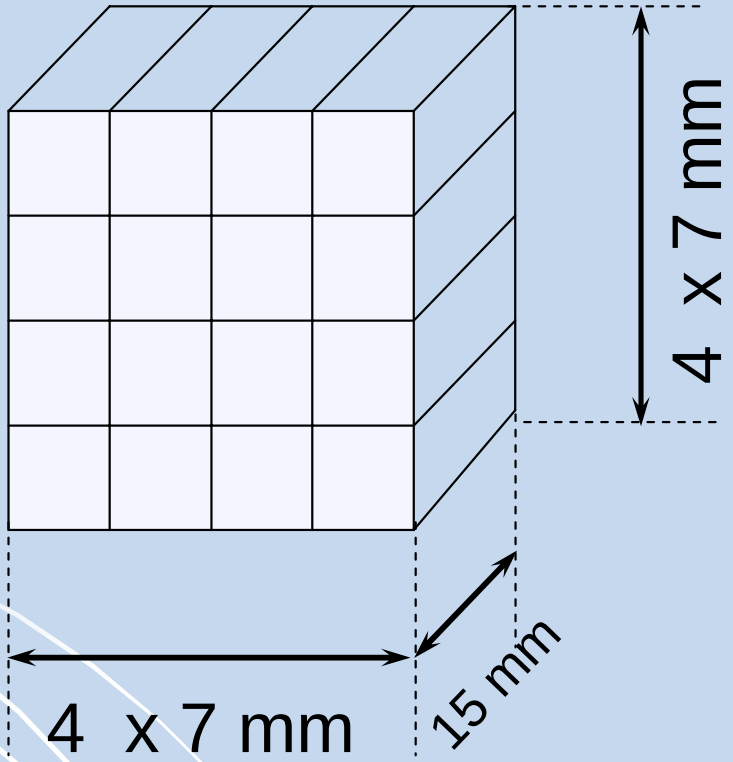
$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \left(\frac{\hbar\omega'}{\hbar\omega}\right)^2 \left(\frac{\hbar\omega'}{\hbar\omega} + \frac{\hbar\omega}{\hbar\omega'} - 2\sin^2\theta_c \cos^2\varphi\right)$$



angular distribution of scattered photons



Segmented planar Ge detector



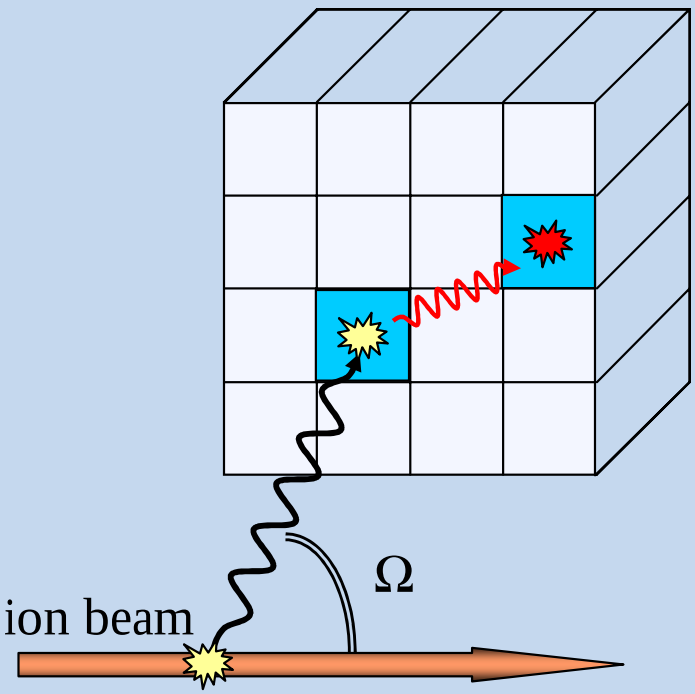
Pixel matrix 4x4

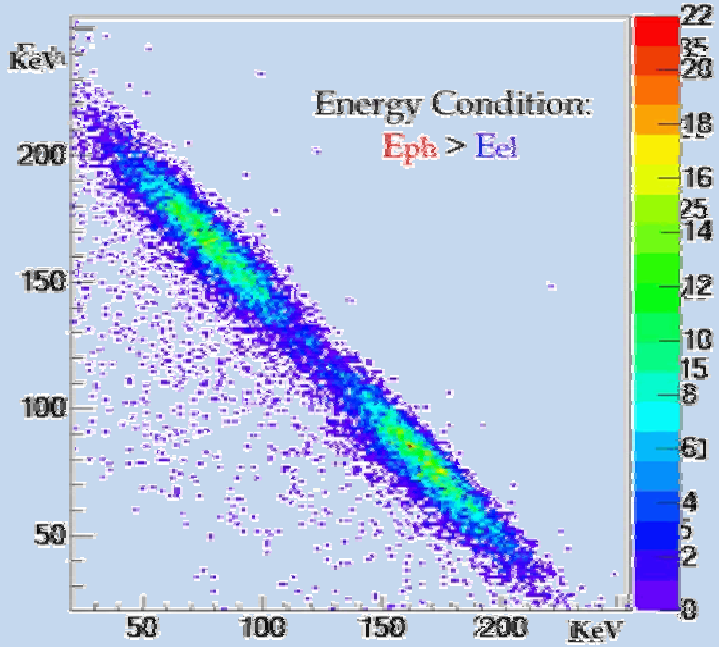
Pixel size 7x7 mm

Energy resolution 2 KeV

D. Protic, FZ-Jülich

Reconstructing of Compton scattering events



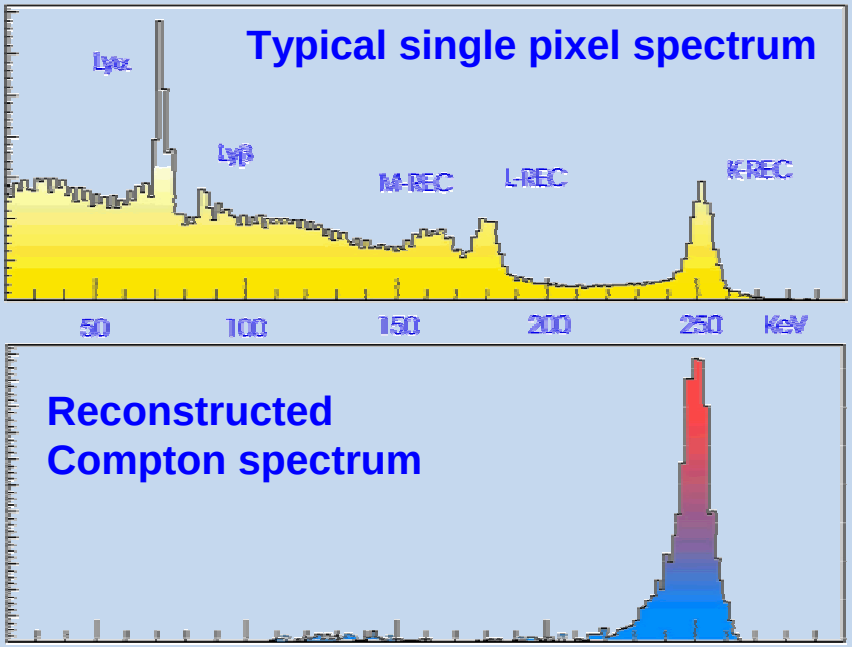


Two pixel coincidence registration

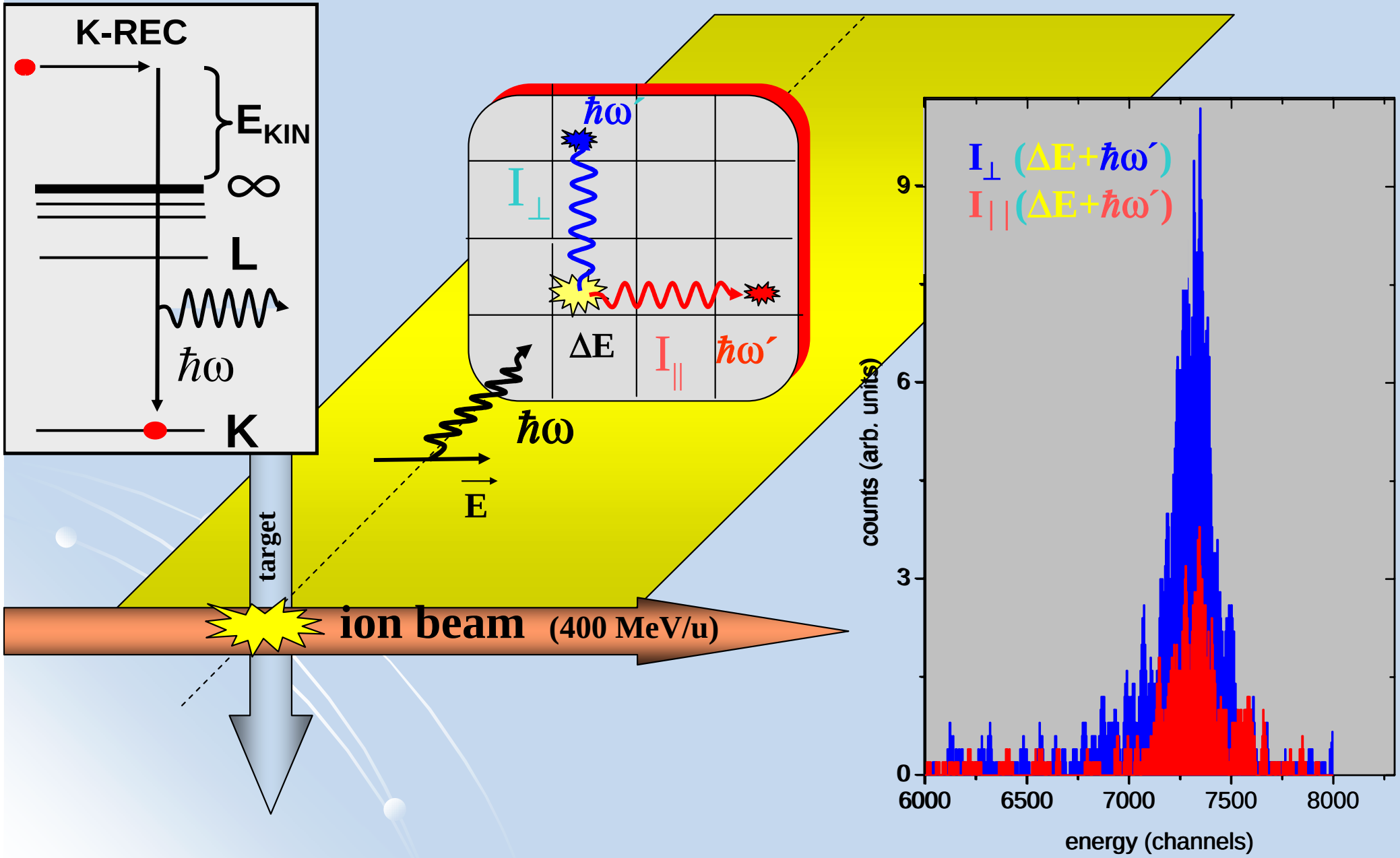
Energy condition $E_{ph} > E_{el}$

Reconstruction of the Compton event

Pixel-to-pixel Doppler correction

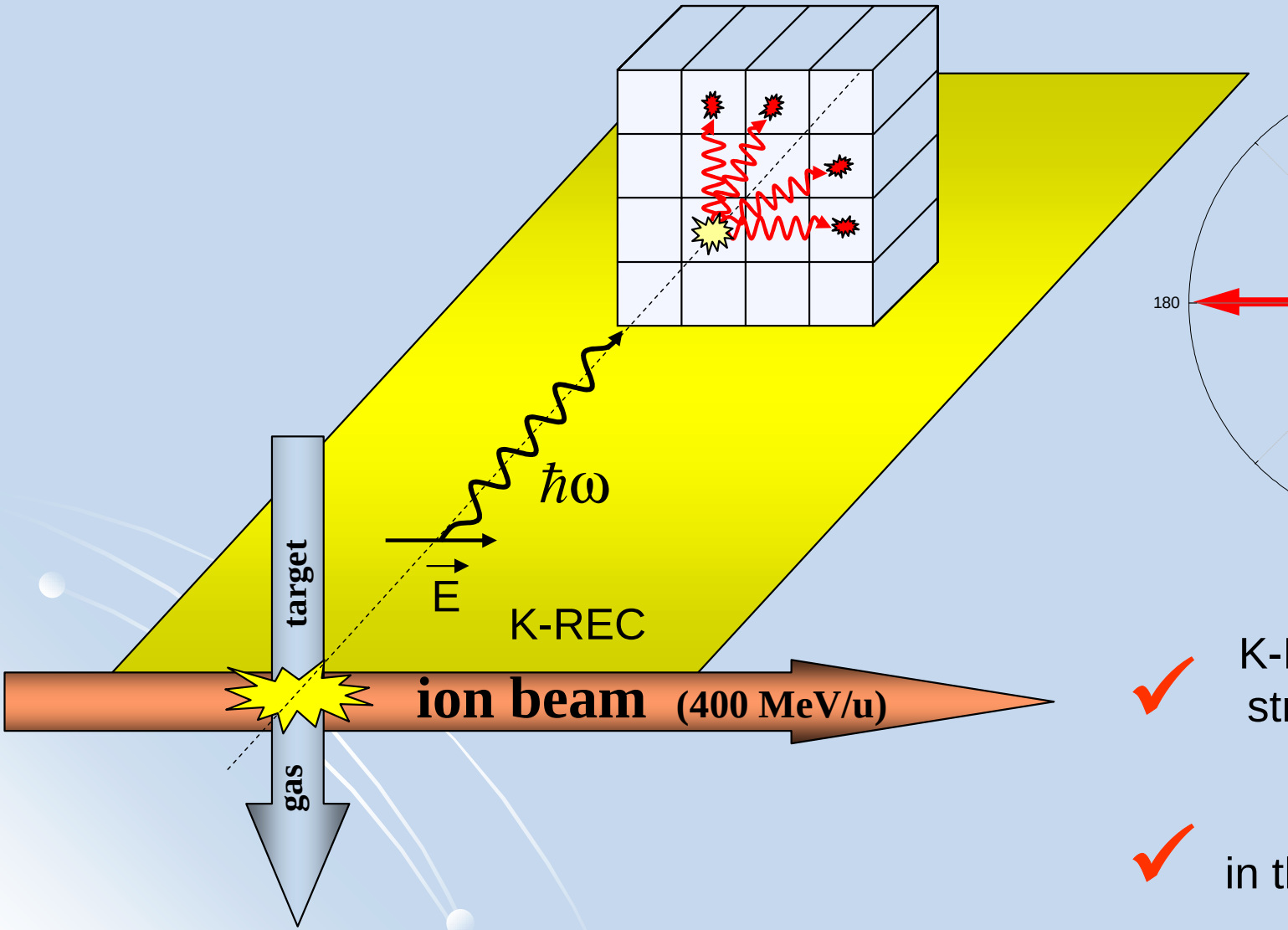


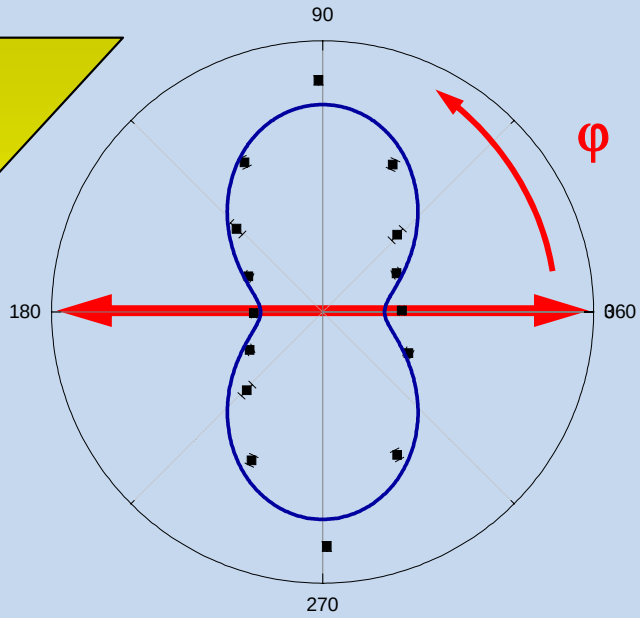
First Polarization Measurement for Radiative Recombination Transitions ($U^{92+} + e^- \Rightarrow U^{91+} + hw$)



preliminary data from the ESR beam time May 2002

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





✓ K-REC radiation is strongly polarized

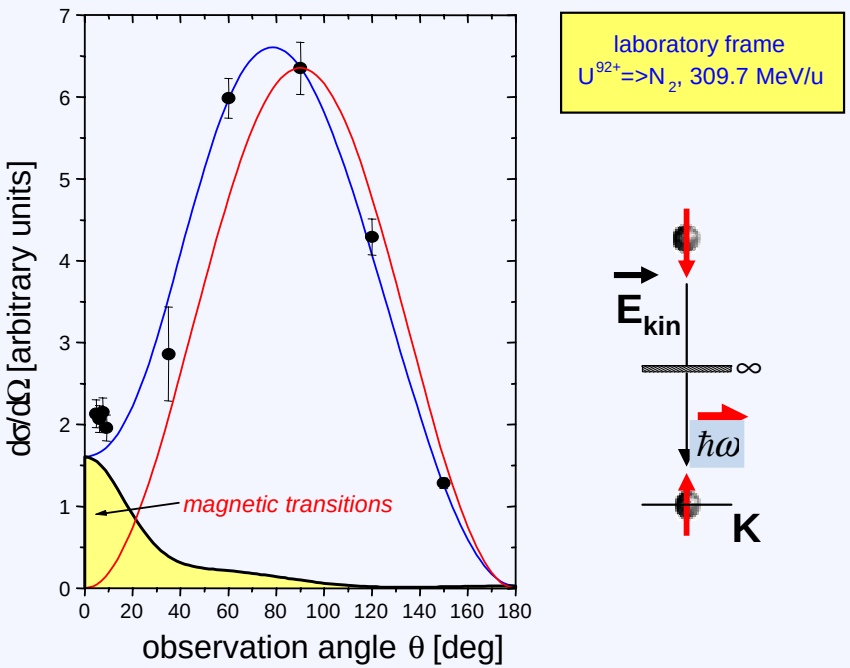
✓ Polarization is in the reaction plane

preliminary data from the ESR beam time October 2002

Theoretical predictions for the polarization of K-REC radiation($U^{92+} + e^- \Rightarrow U^{91+} + \hbar\omega$)

photon angular distribution studies for REC

Kinematical Identification of Spin-Flip Transitions from Continuum States into the 1s-Ground State



complete relativistic calculations (Eichler et al.)

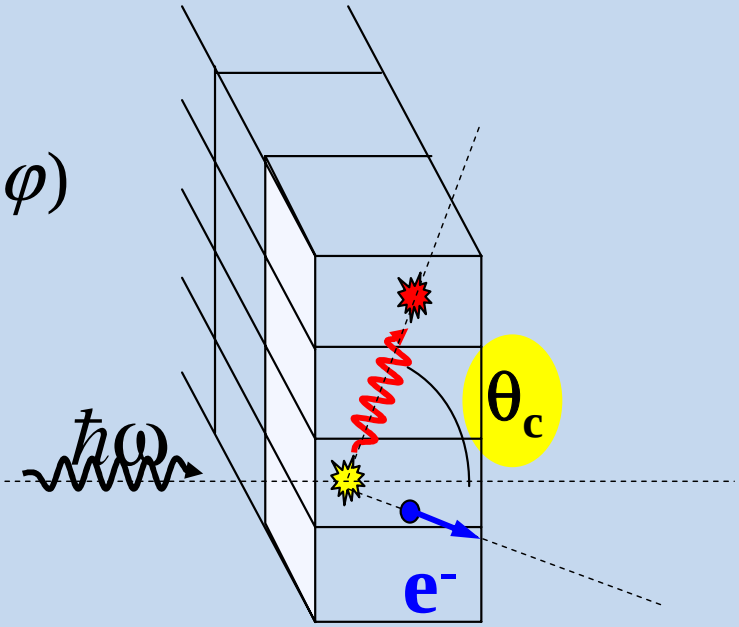
nonrelativistic dipole distribution

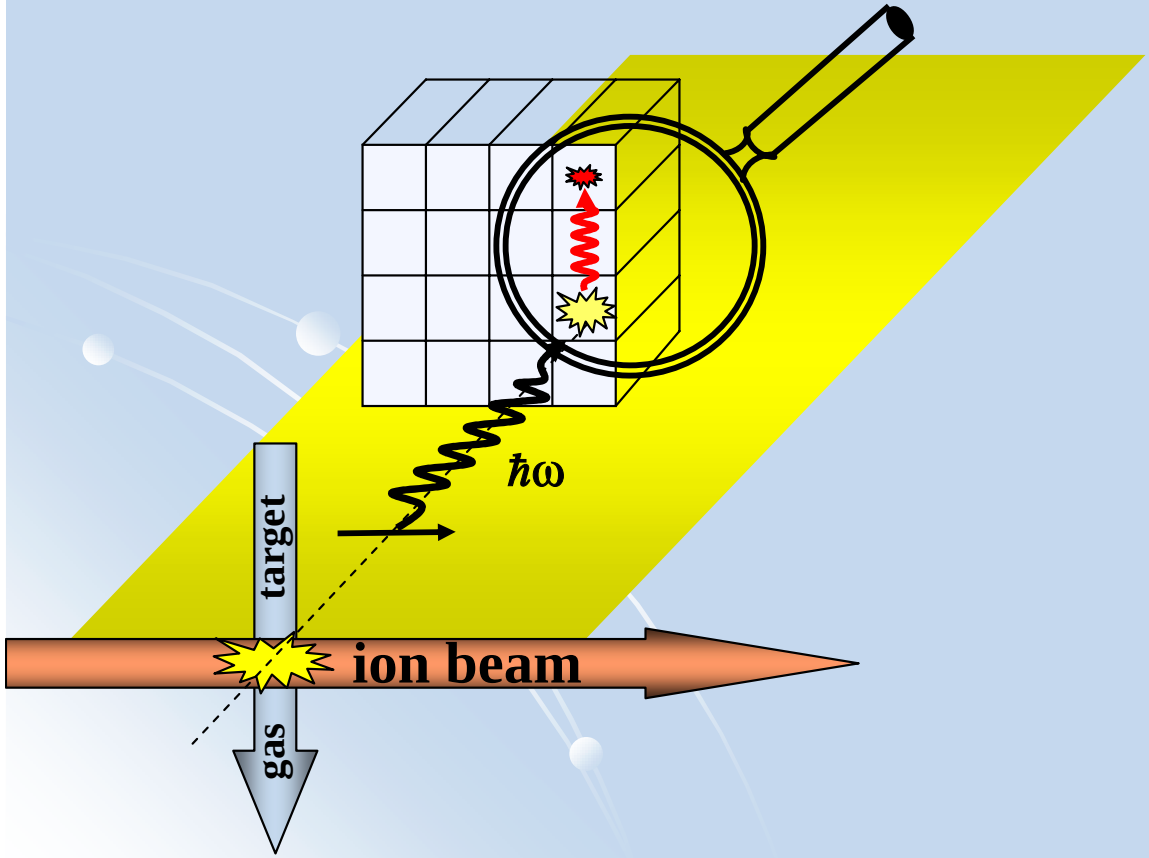
Polarization measurement is a precise method to study relativistic contributions to KREC process

Theory: S. Fritzsche, A. Surzhykov

Simulating of the detector responce

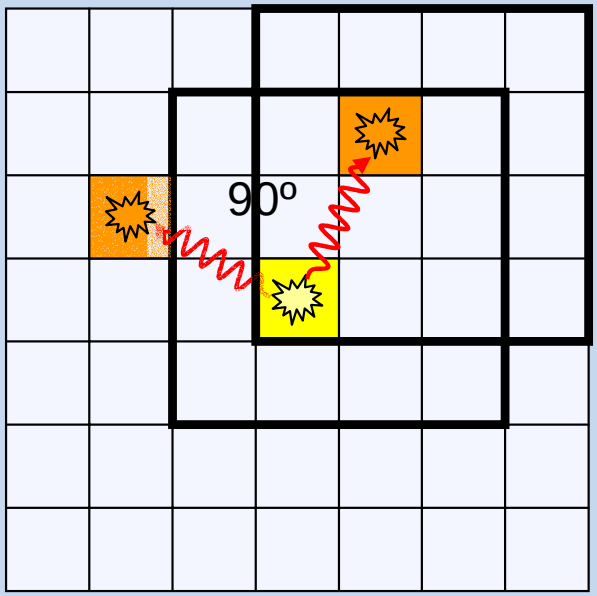
$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \left(\frac{\hbar\omega'}{\hbar\omega}\right)^2 \left(\frac{\hbar\omega'}{\hbar\omega} + \frac{\hbar\omega}{\hbar\omega'} - 2\sin^2\theta_c \cos^2\varphi\right)$$



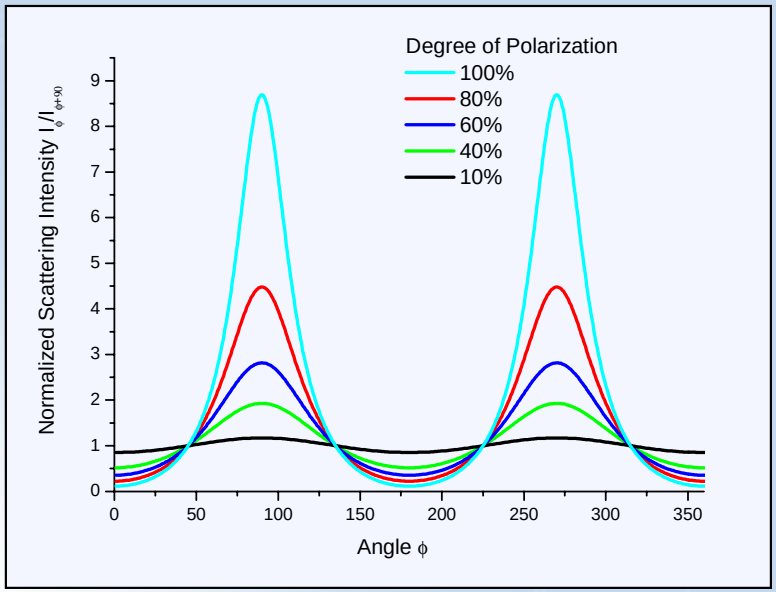


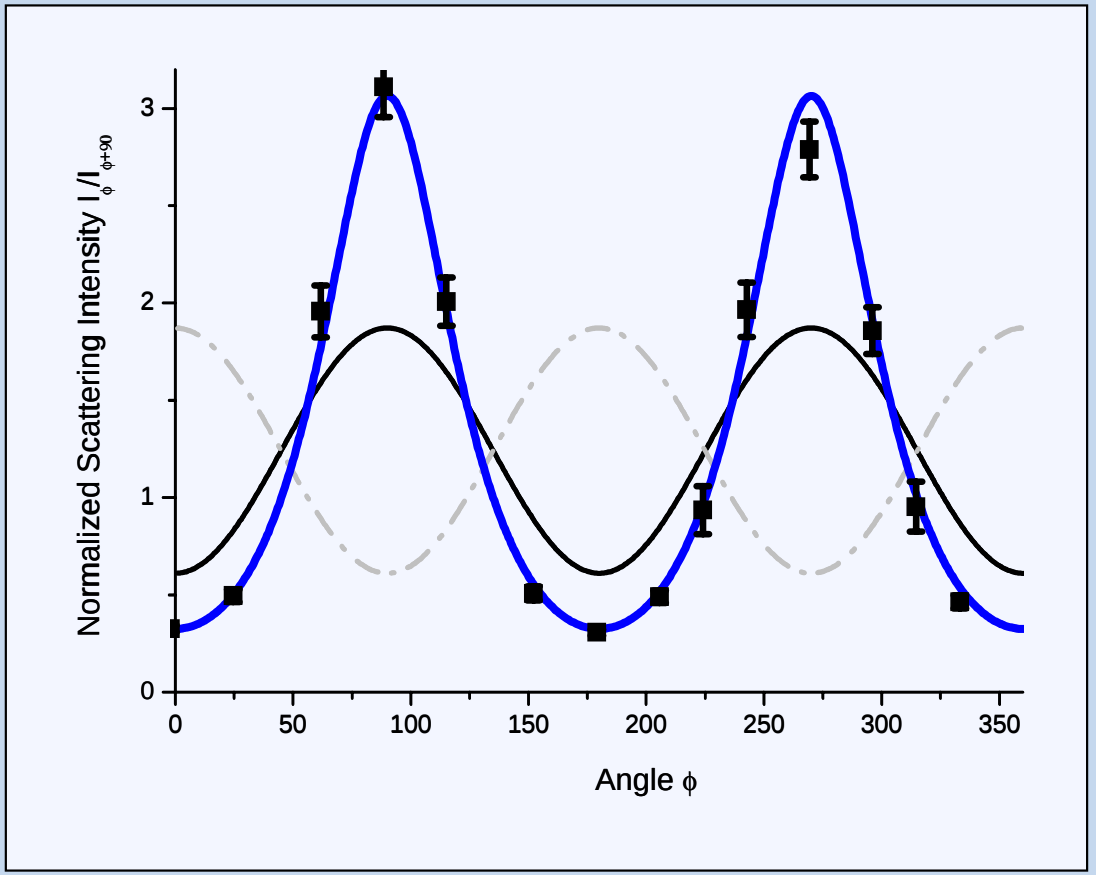
$$\hbar\omega' = \frac{\hbar\omega}{1 + \frac{\hbar\omega}{m_{el}c^2}(1 - \cos\theta_c)}$$

7x7 scattering pattern



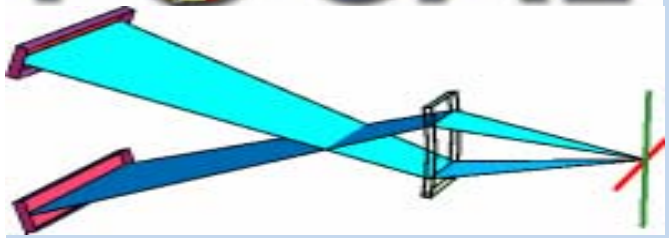
$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \left(\frac{\hbar\omega'}{\hbar\omega}\right)^2 \left(\frac{\hbar\omega'}{\hbar\omega} + \frac{\hbar\omega}{\hbar\omega'} - 2\sin^2\theta_c \cos^2\varphi\right)$$



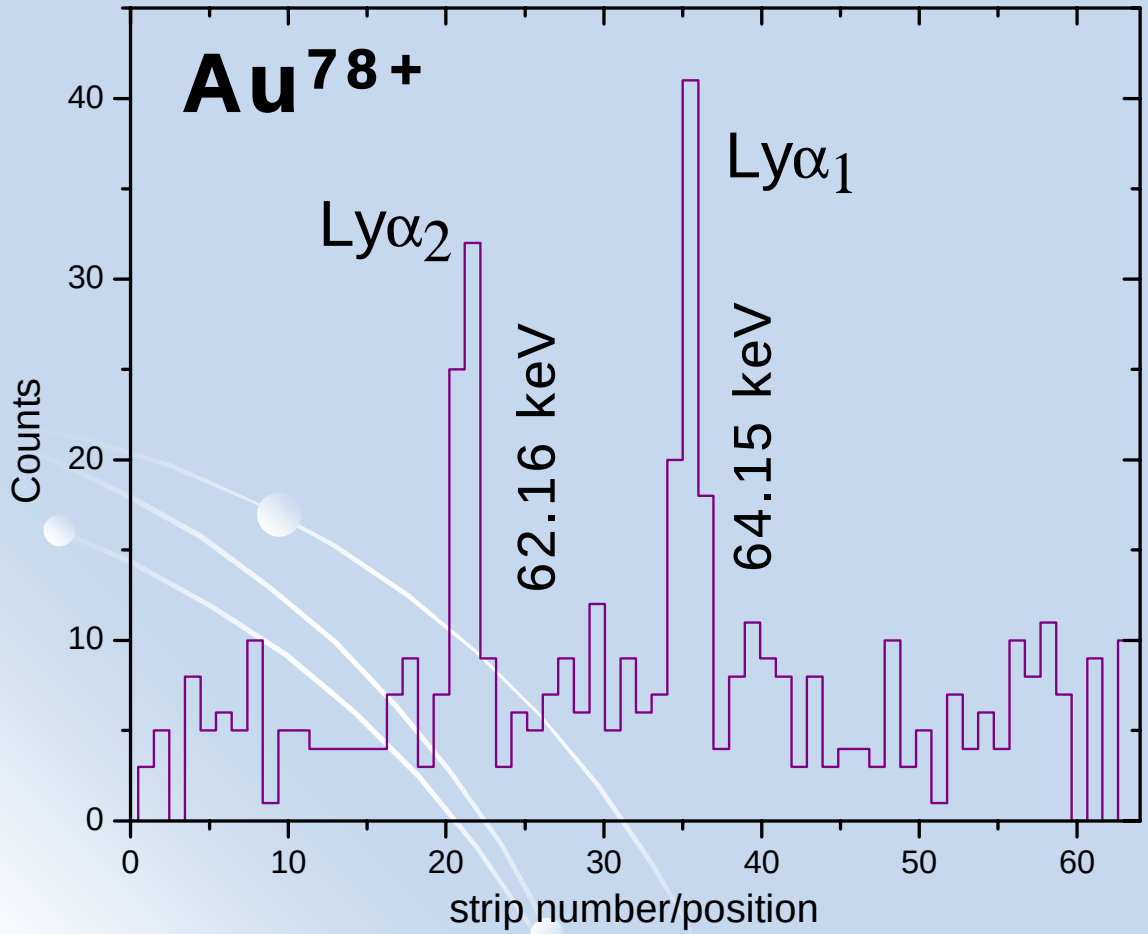


High Resolution Spectroscopy of High-Z H-Like Ions

FOCAL



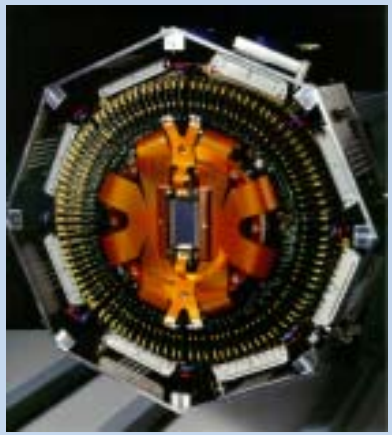
Preliminary



1D position resolution

Energy resolution

Timing

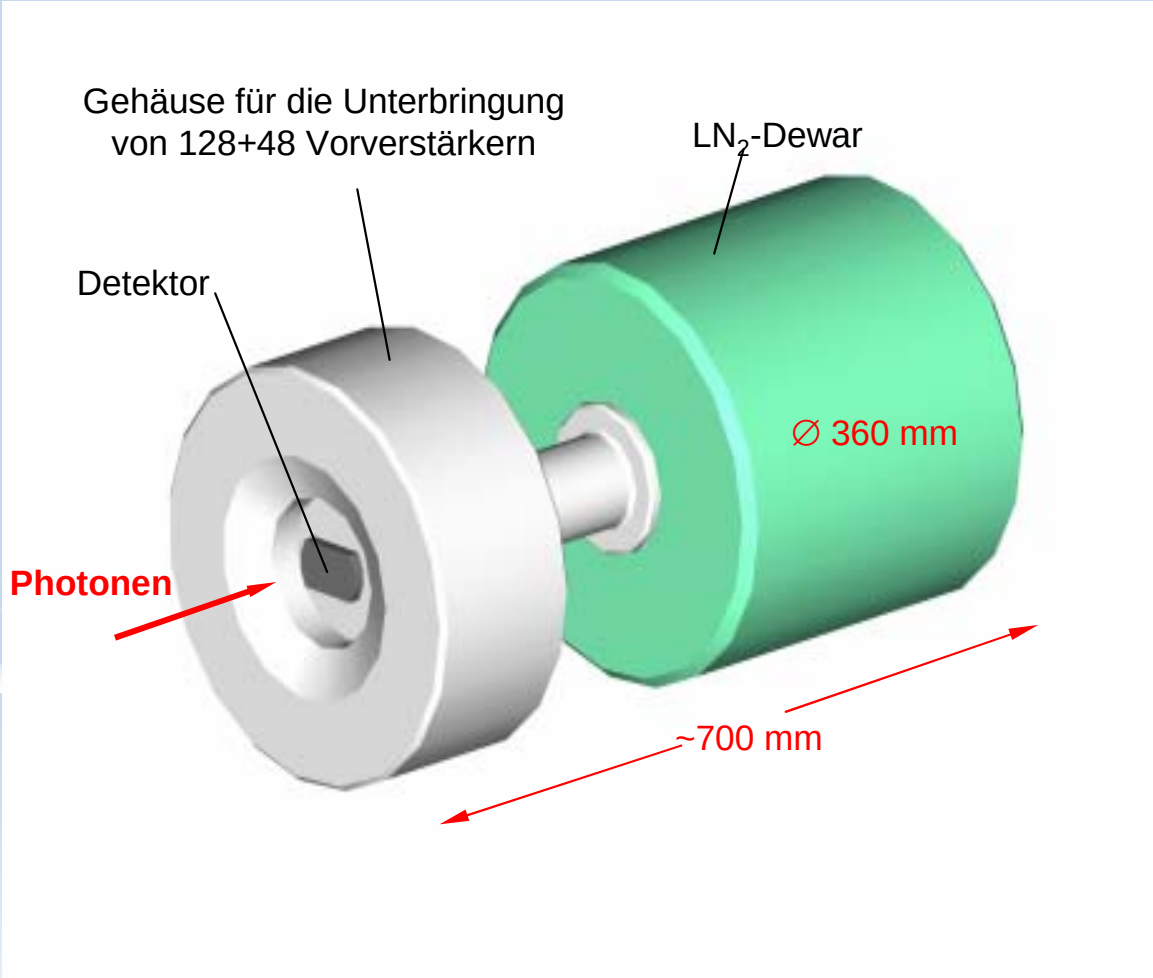


ESR beam time March 2003

μSTRIP

GSI

Compton/Gamma Camera



double sided Ge(i)
strip detector
(3D position sensitive)

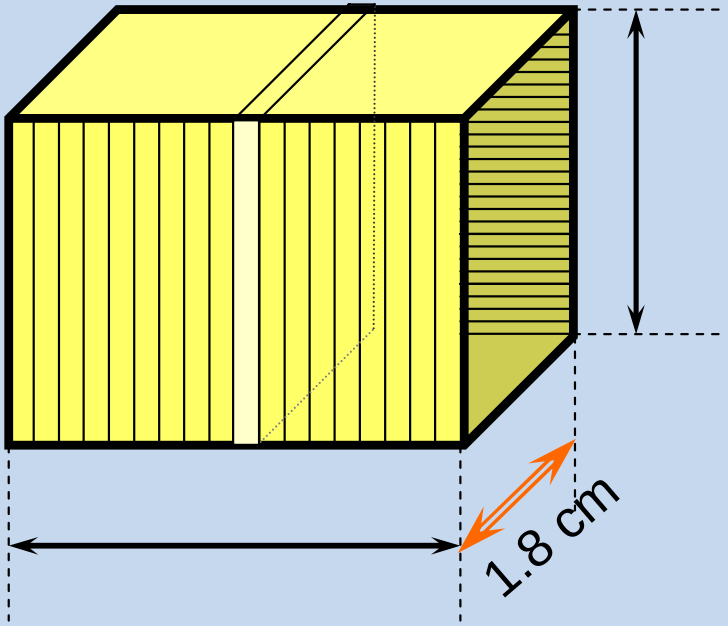
Improved
geometry resolution

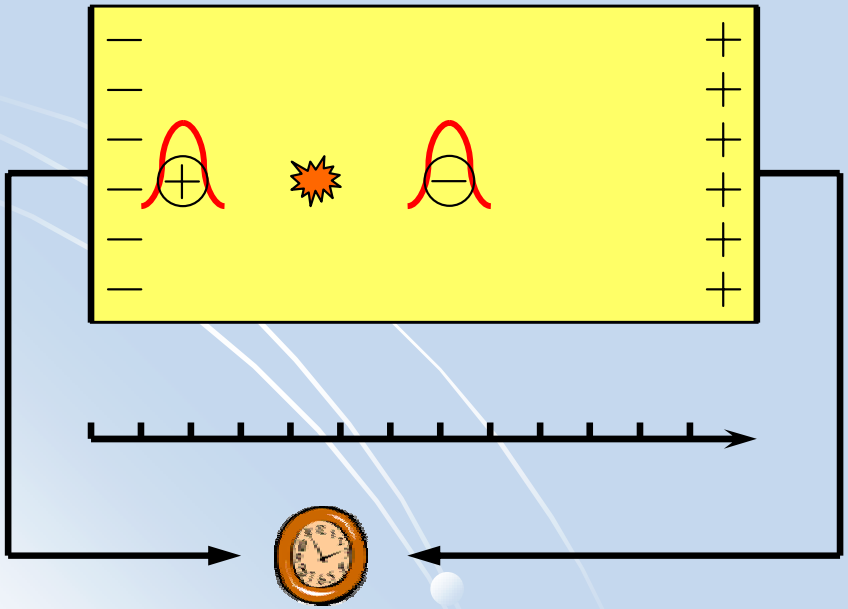
D. Protic, FZ-Jülich

Approach to a 3D germanium detector

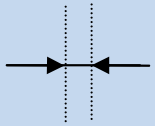
Measuring the drift time difference...

...makes 2 dimensional
stripe detector
3D position sensitive

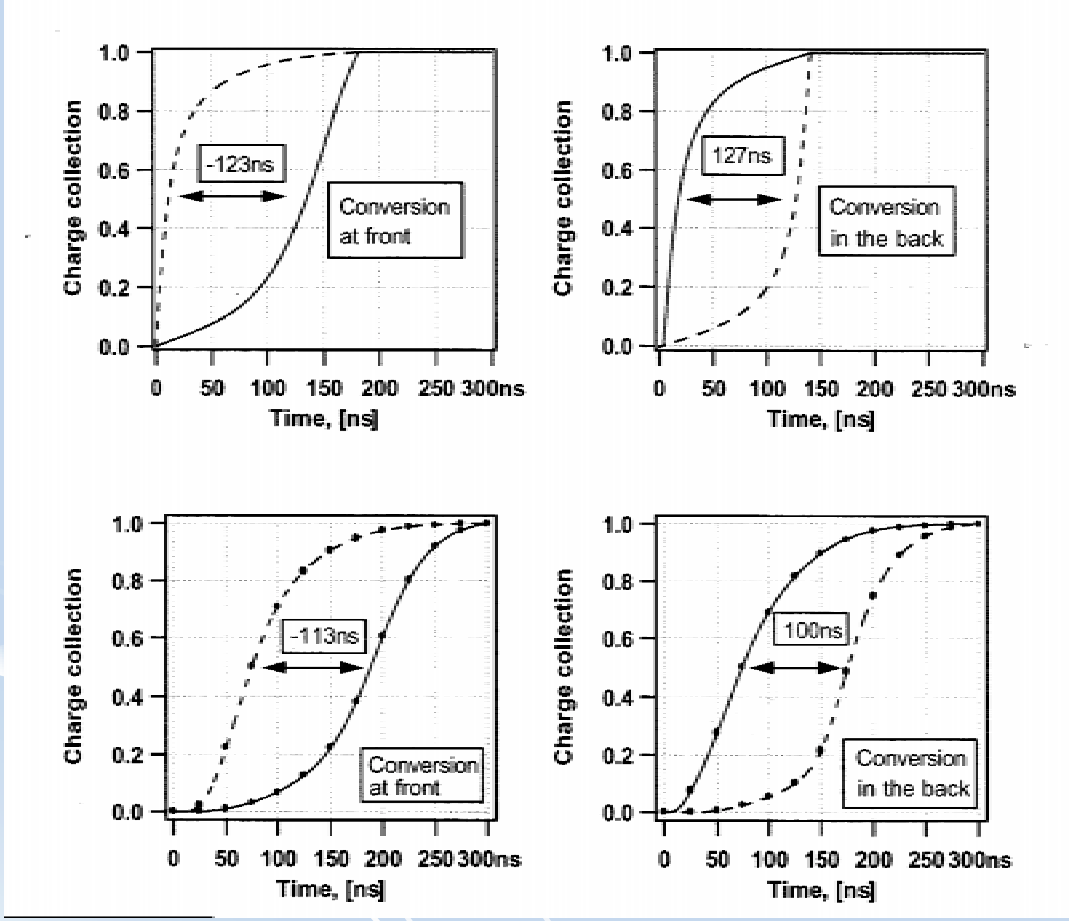


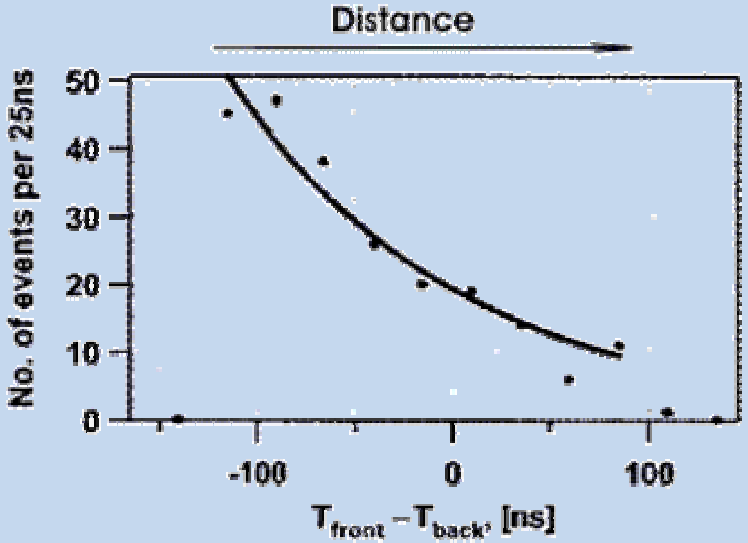


"Small Pixel Effect"



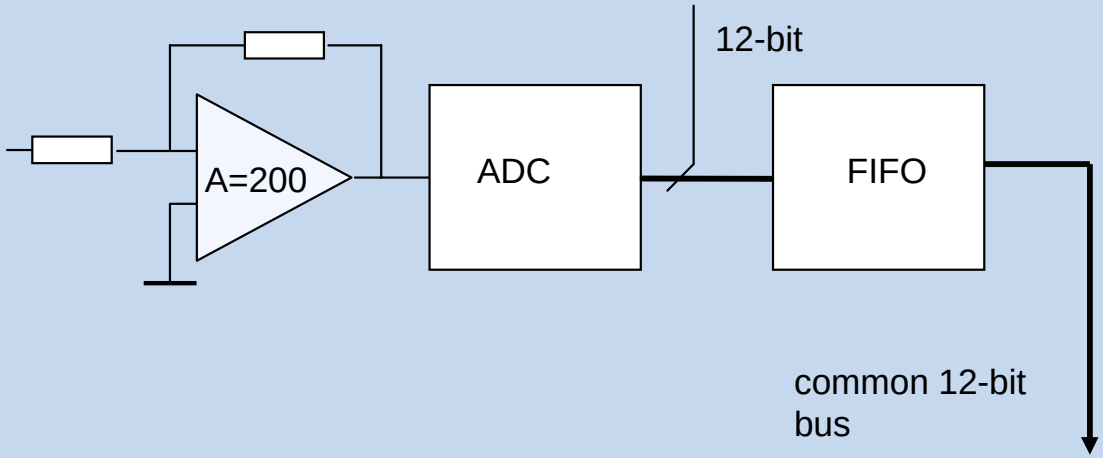
Signal pulse shape analysis





M. Momayezi et al. 1999

Digital read out Electronics for segmented detectors

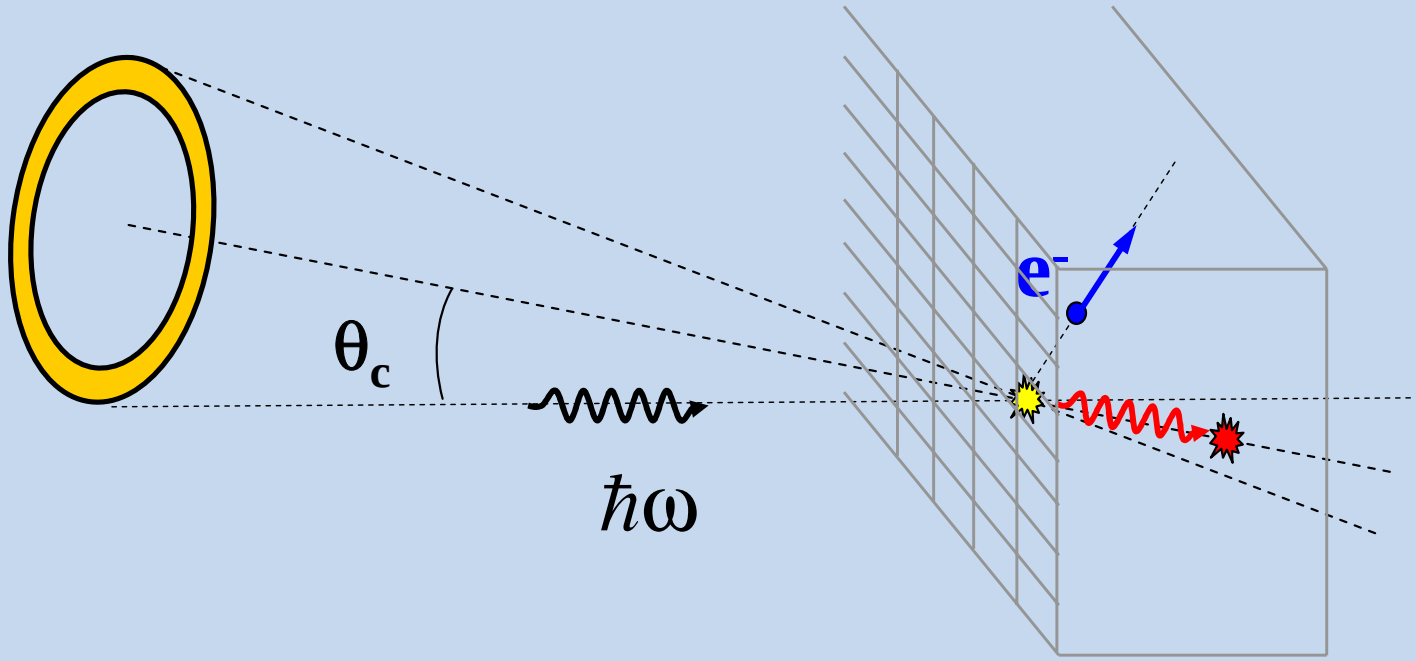


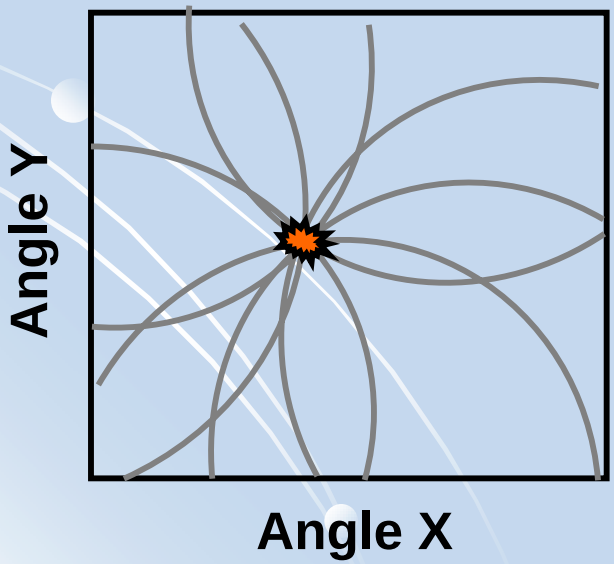
- 16-channel boards
- 12 bit ADC
- 65 MHz sampling rate

  (time between samples 15.6 ns)

M. Kajetanowicz, 2003

Imaging with the Compton Camera

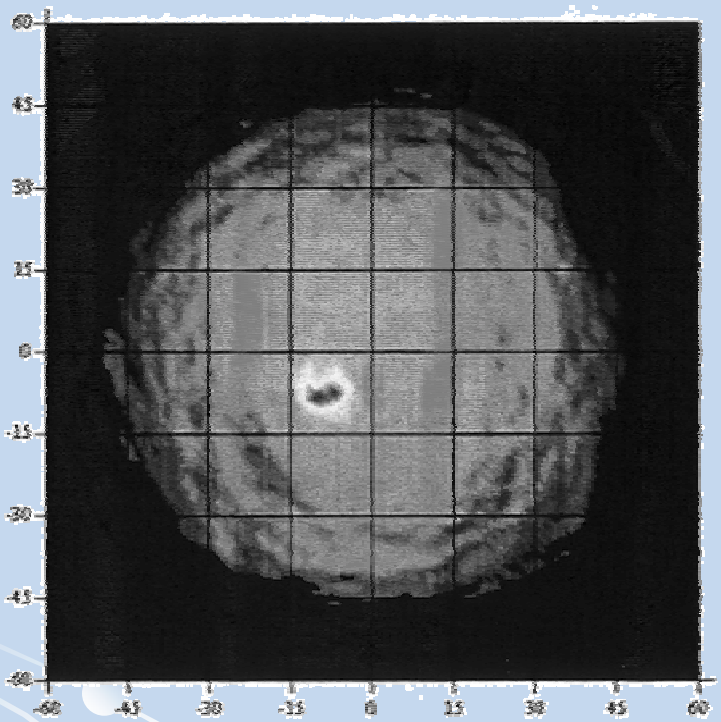




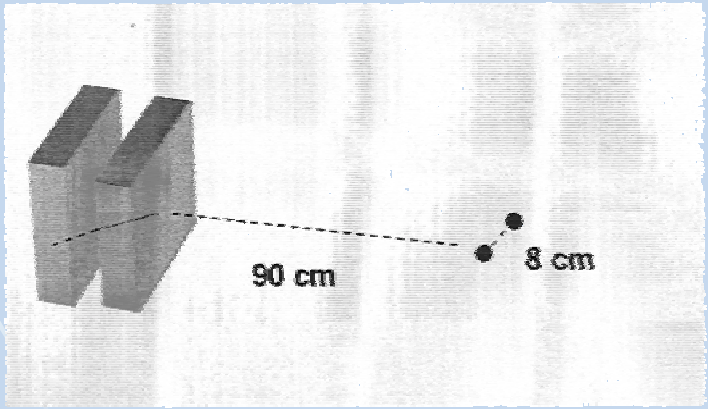
$$\cos\theta_c = 1 - m_{el}c^2\left(\frac{1}{\hbar\omega'} - \frac{1}{\hbar\omega}\right)$$

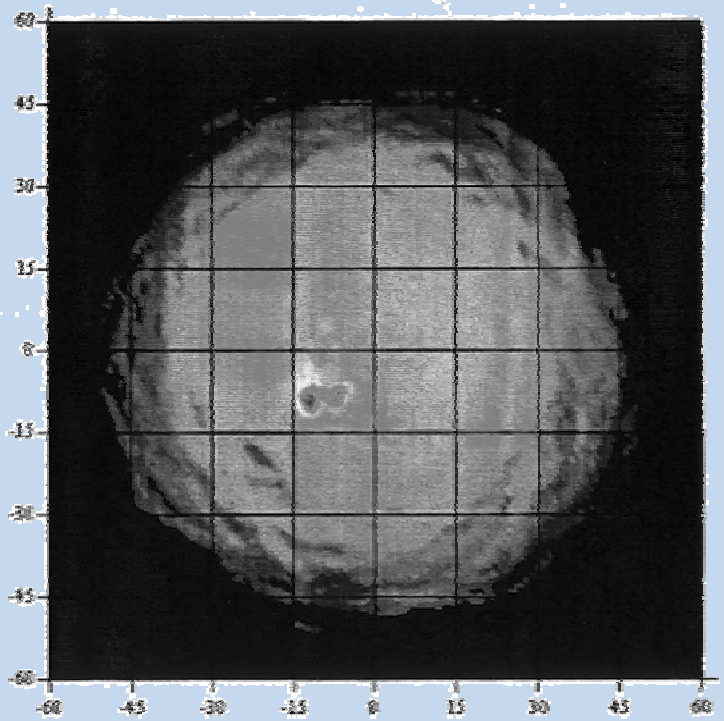
Compton Telescope

Resolving between two point sources (each 662 keV)



3.8° separation





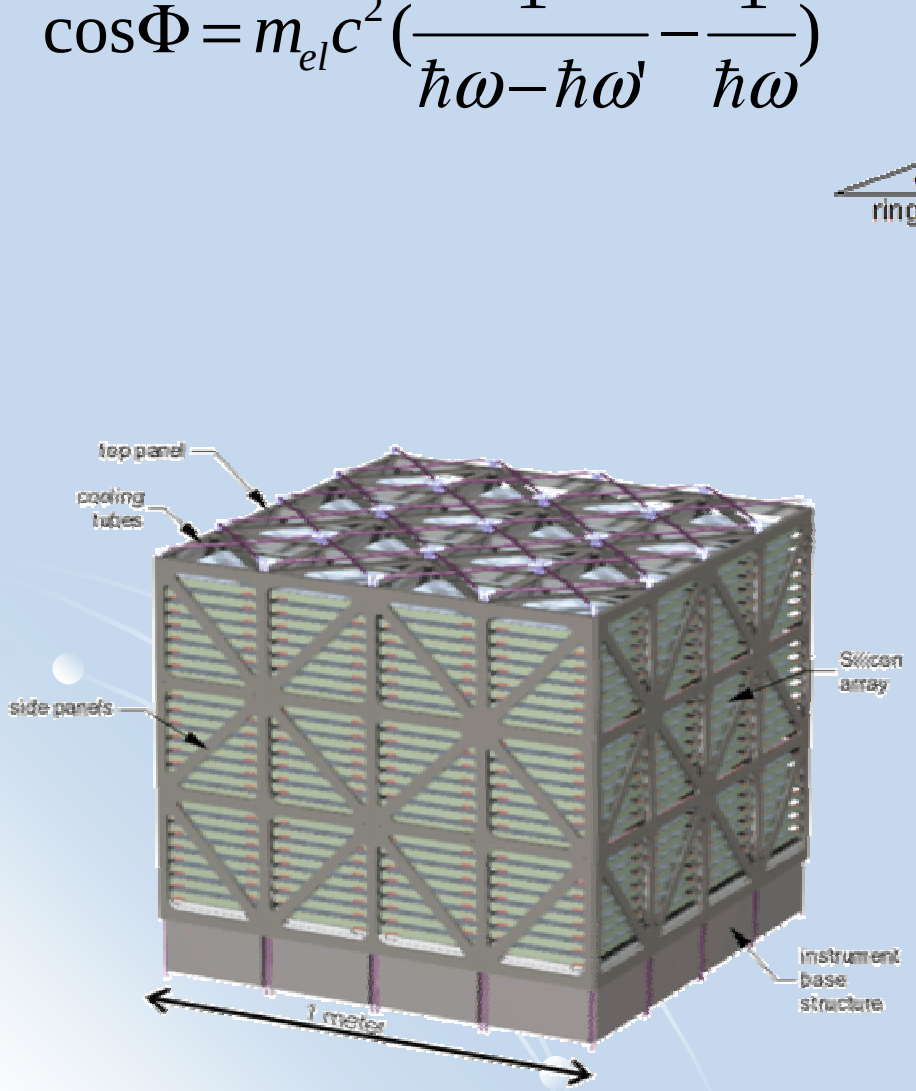
5° separation

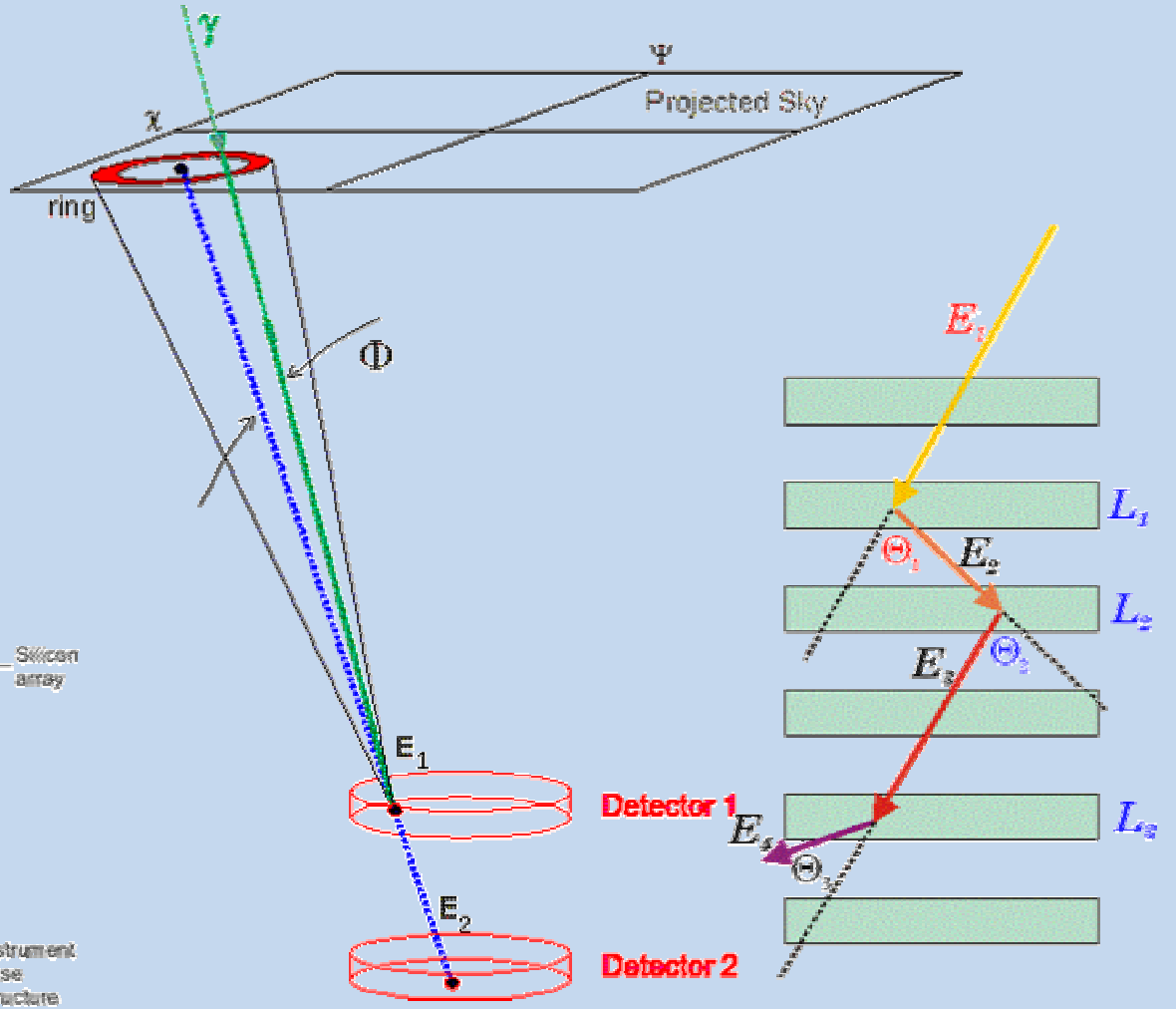
Source size ~1.3°

(LBL, Burke et al. NRL; Kroeger et al.)

NRL Advanced Compton Telescope

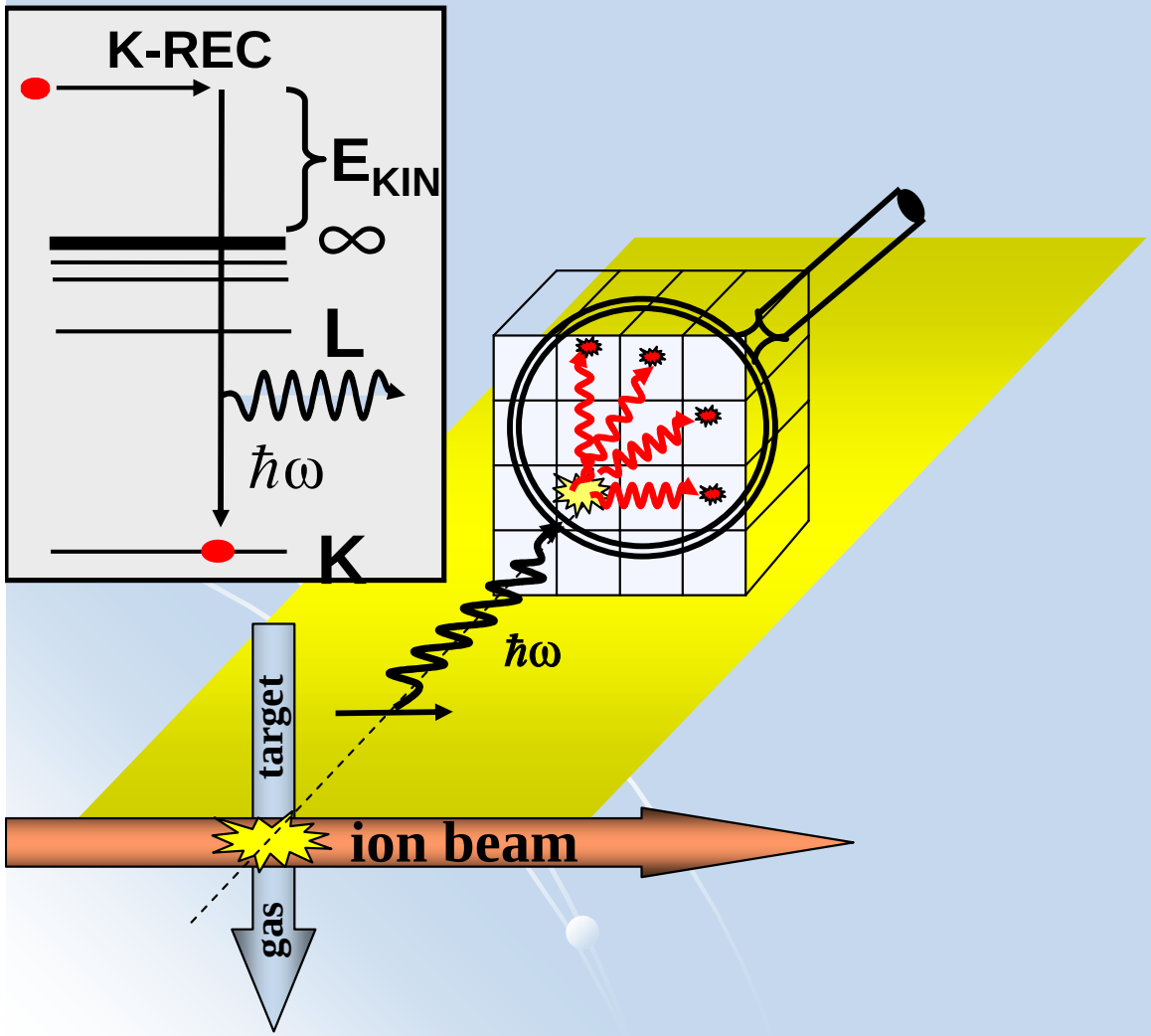
$$\cos\Phi = m_{el}c^2\left(\frac{1}{\hbar\omega - \hbar\omega'} - \frac{1}{\hbar\omega}\right)$$

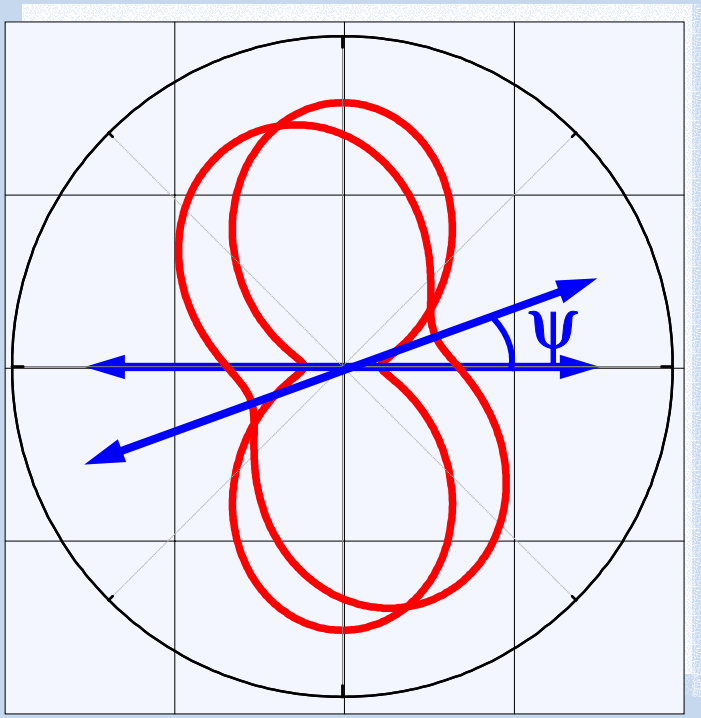




(LBL, Burke et al. NRL; Kroeger et al.)

Detection of the Ion Beam polarization



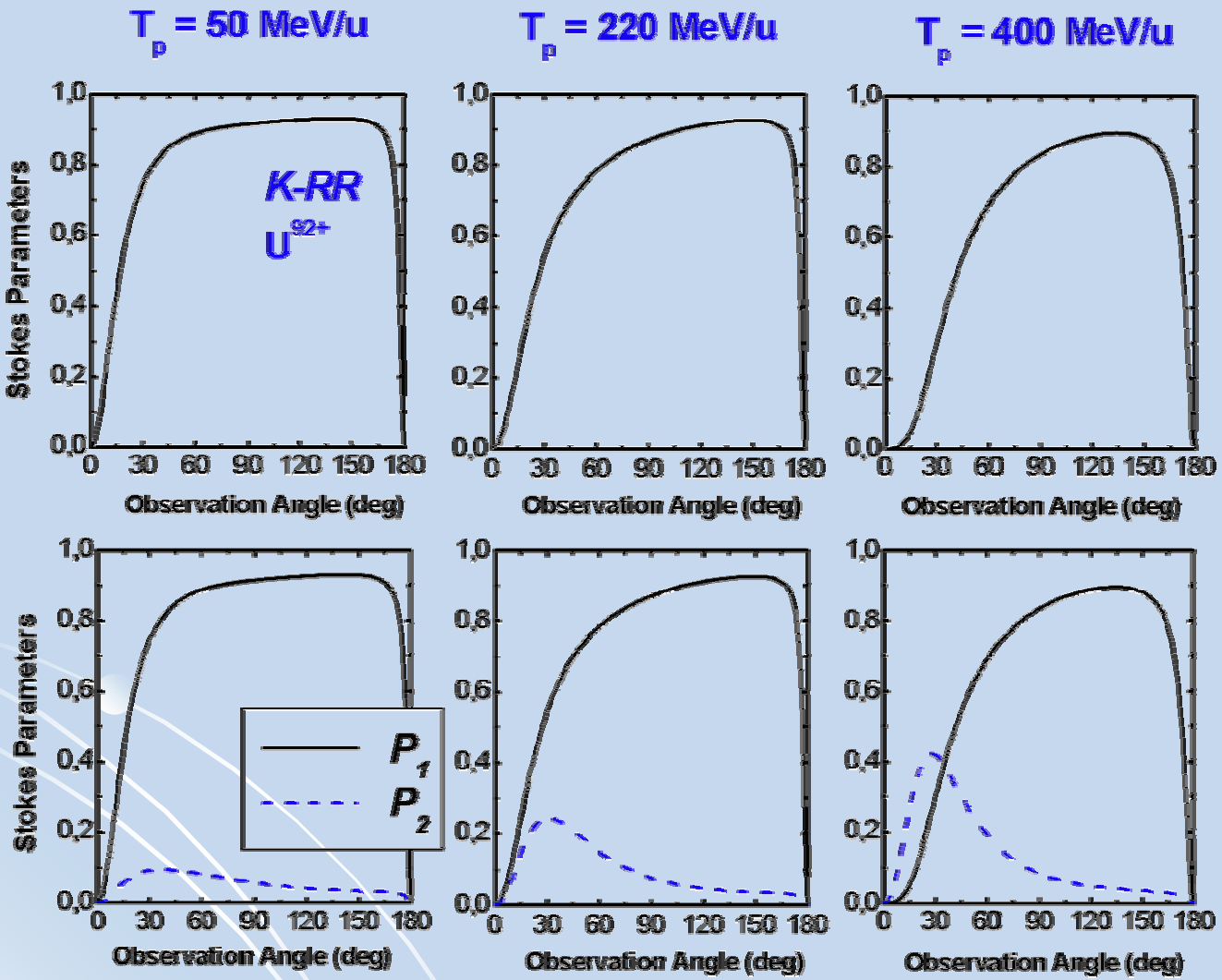


<Polarized ion beam>

<Unpolarized ion beam>

ψ	degree of ion beam polarization

Polarization Stokes parameters

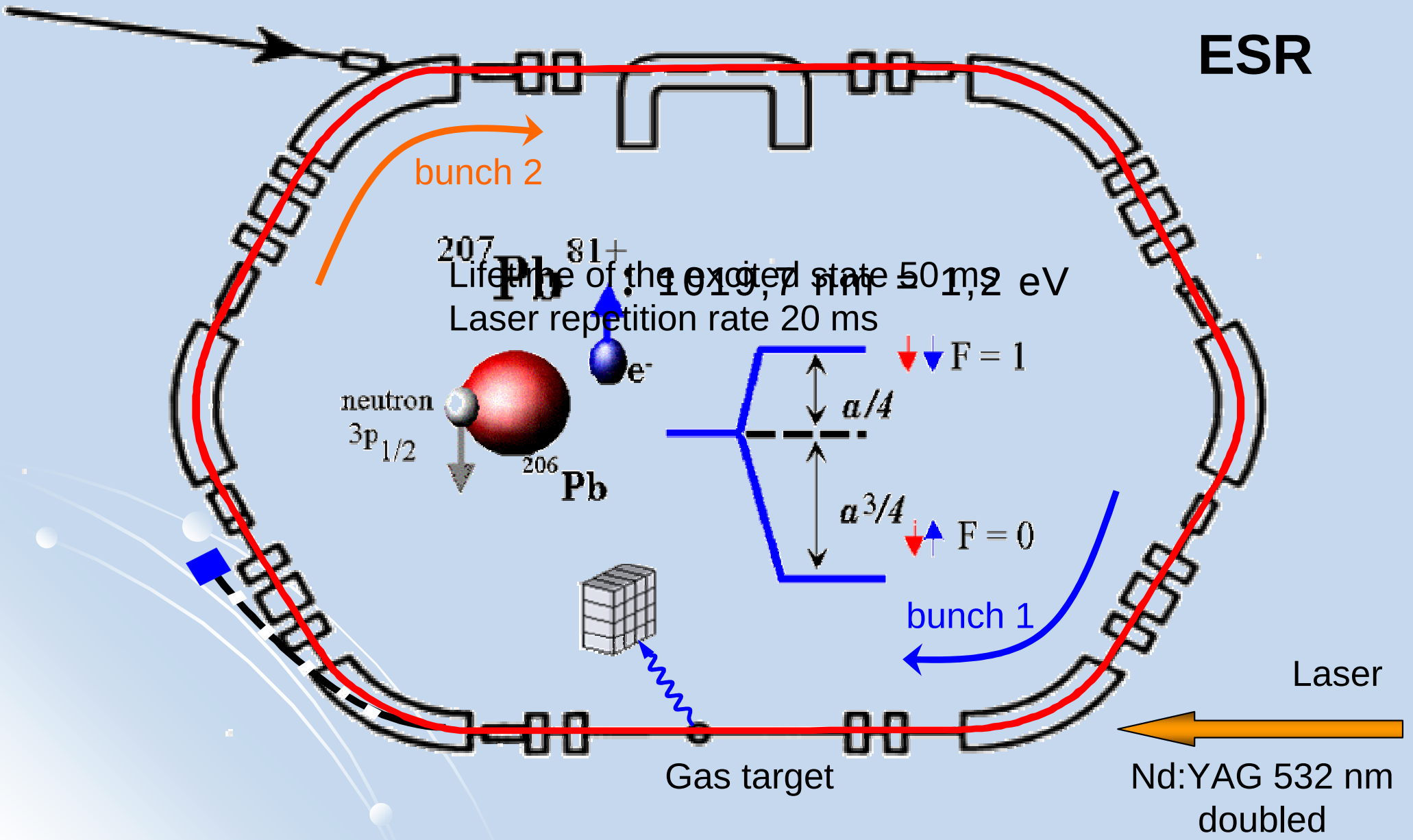


$$P_1 = \frac{I_0 - I_{90}}{I_0 + I_{90}}$$

$$P_2 = \frac{I_{45} - I_{135}}{I_{45} + I_{135}}$$

A.Surzhykov, Kassel Uni

A possible experiment for the ion beam polarization and detection



Summary

- the first polarization measurement of the K-REC radiation in relativistic regime was performed

<u>Segmented Ge detectors provide:</u>

- an excellent tool for polarization studies in the hard X-Ray regime
- a new technique for the telescopes development
- the unique instrument for an ion beam polarization diagnostic