Linear Polarization and Angular Distribution of Ly-α_1 Radiation in H-like Uranium

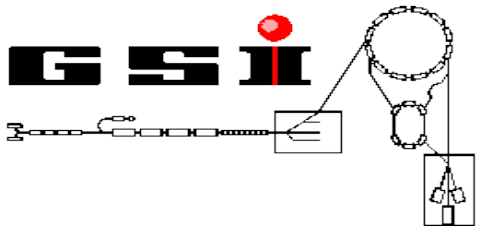
Günter Weber[1,2]

H. Bräuning[1], S. Hess[1,3], U. Spillmann[1,3], A. Surzhykov[2], S. Fritzsche[2], R. Märtin[1,3], S. Geyer[1,3], R. Reuschl[1,3], S. Trotsenko[1,3], S. Hagmann[1], D. Winters[1] and Th. Stöhlker[1,2]

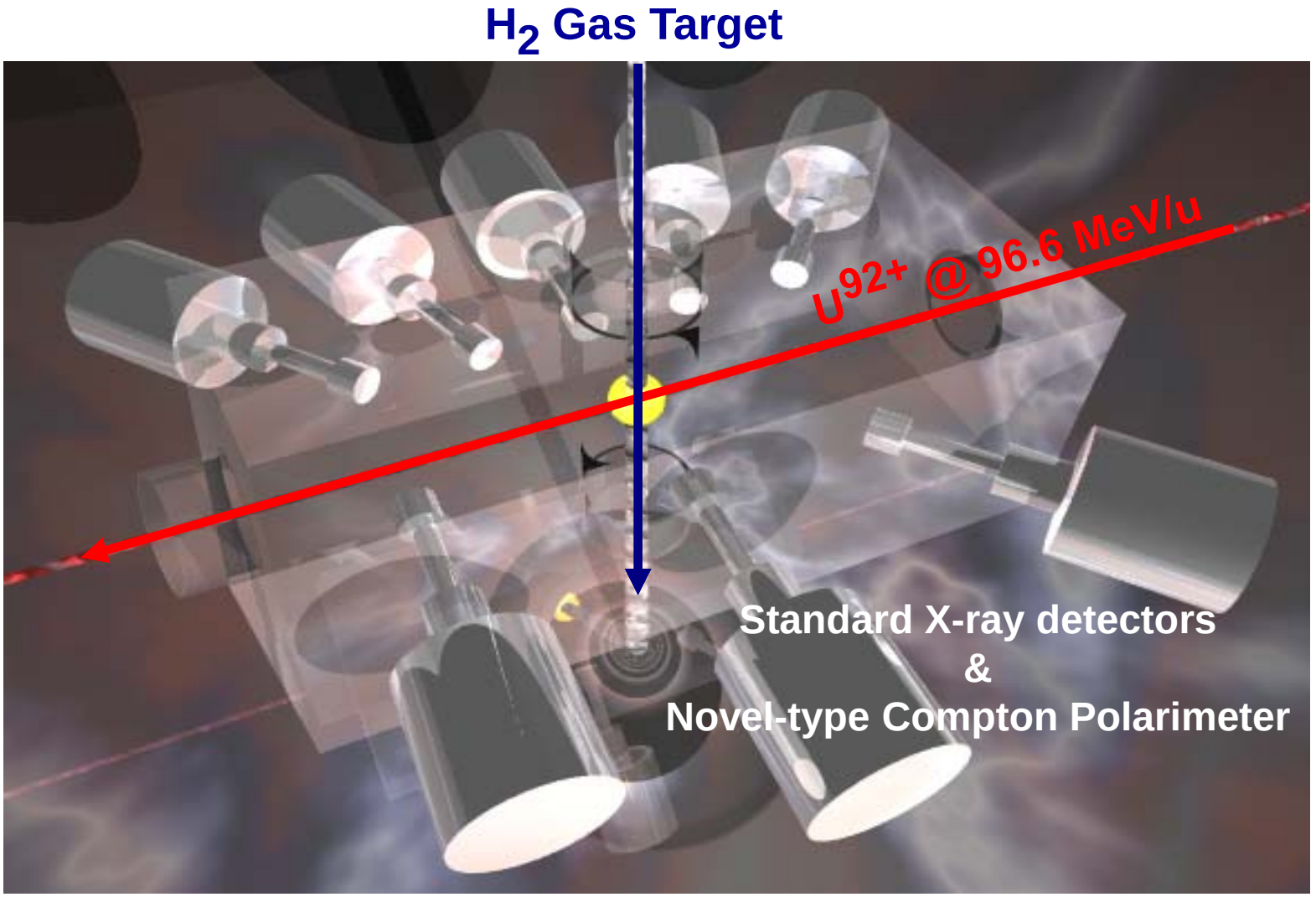
[1] **Gesellschaft für Schwerionenforschung, 64291 Darmstadt, Germany**

[2] **Universität Heidelberg, 69120 Heidelberg, Germany**

[3] **Universität Frankfurt, 60235 Frankfurt, Germany**

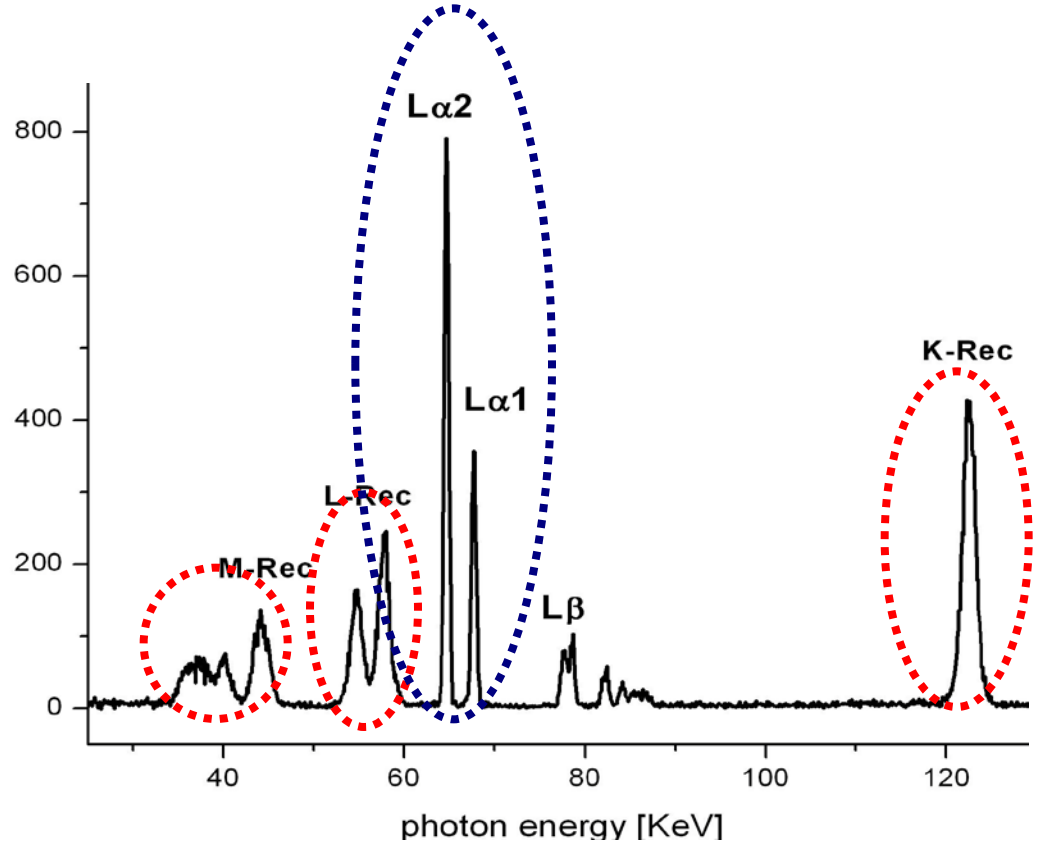


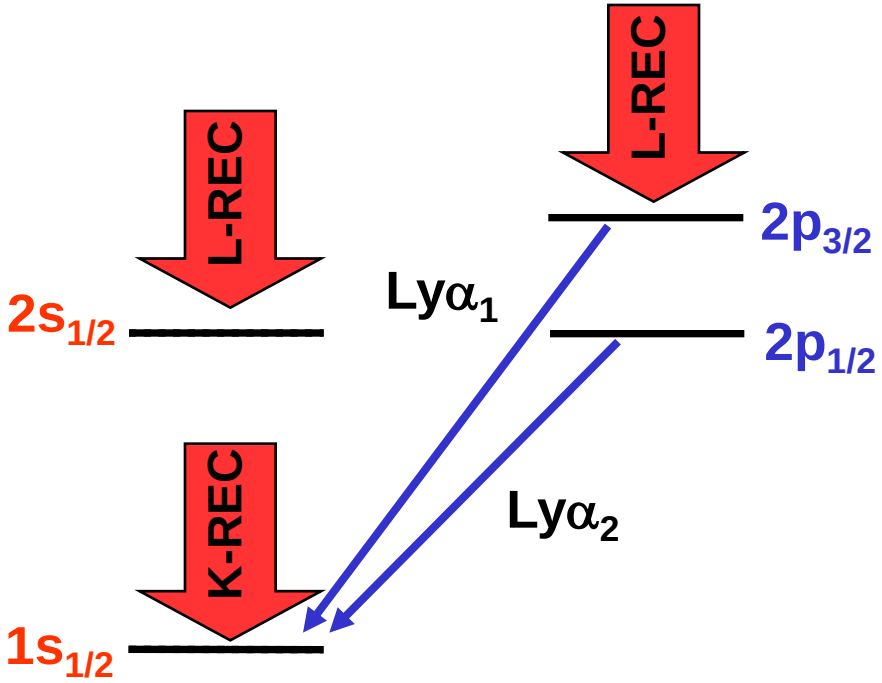
Experimental Setup at the ESR Storage Ring



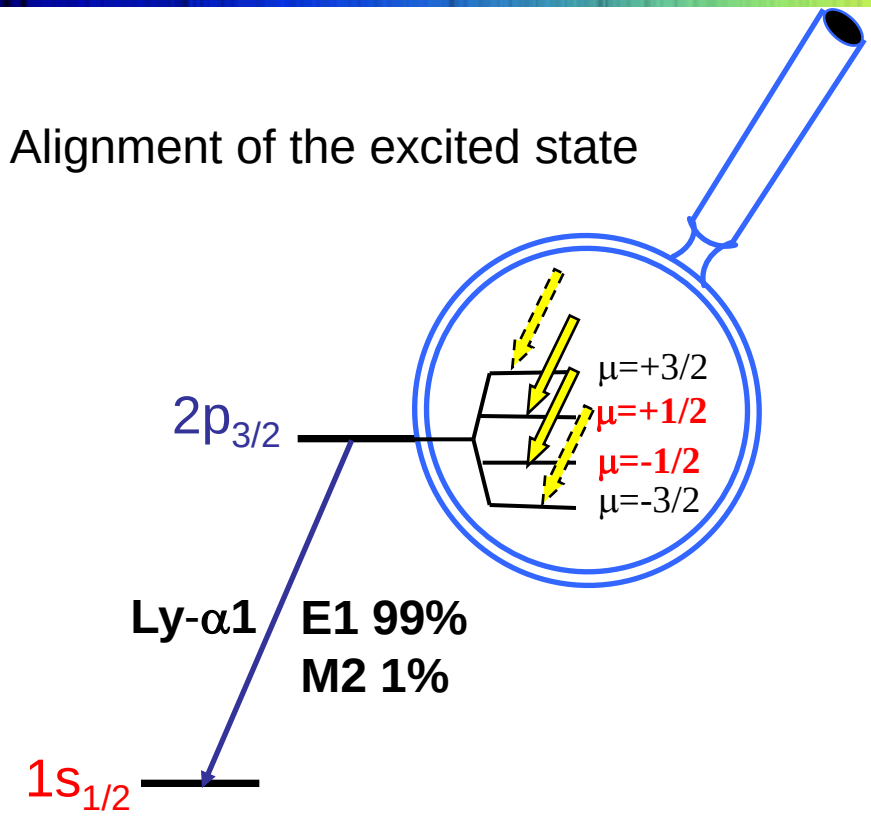
REC and Lyman-α Radiation

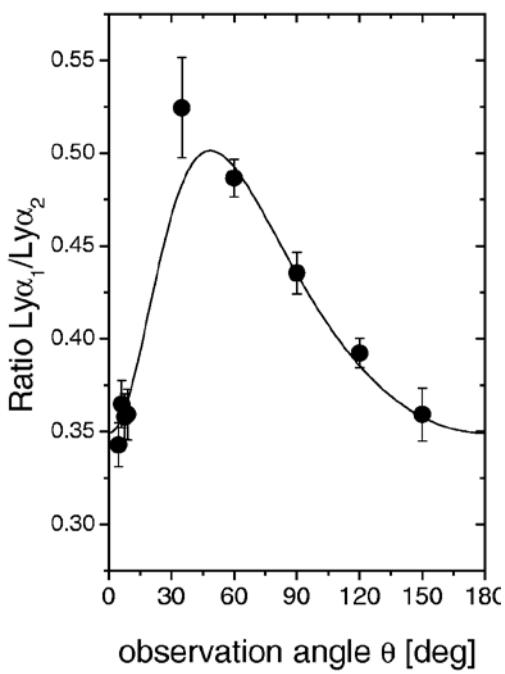
X-ray Spectra recorded at 150° with respect to the ion beam axis:





$2p_{3/2}$ Alignment -> Lyman-α_1 Anisotropy





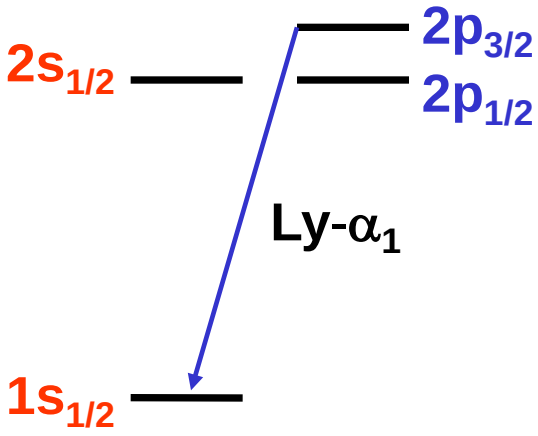
$$W(\theta) \propto 1+\beta_{20}\left[1-\frac{3}{2}\sin^2\theta\right]$$

$$\beta_{20}=\frac{1}{2}\,\frac{\sigma\left(\frac{3}{2}\frac{3}{2}\right)-\sigma\left(\frac{3}{2}\frac{1}{2}\right)}{\sigma\left(\frac{3}{2}\frac{3}{2}\right)+\sigma\left(\frac{3}{2}\frac{1}{2}\right)}$$

Non-statistical population of the $2p_{3/2}$ substates leads to asymmetry and polarization of Ly-α_1 radiation.

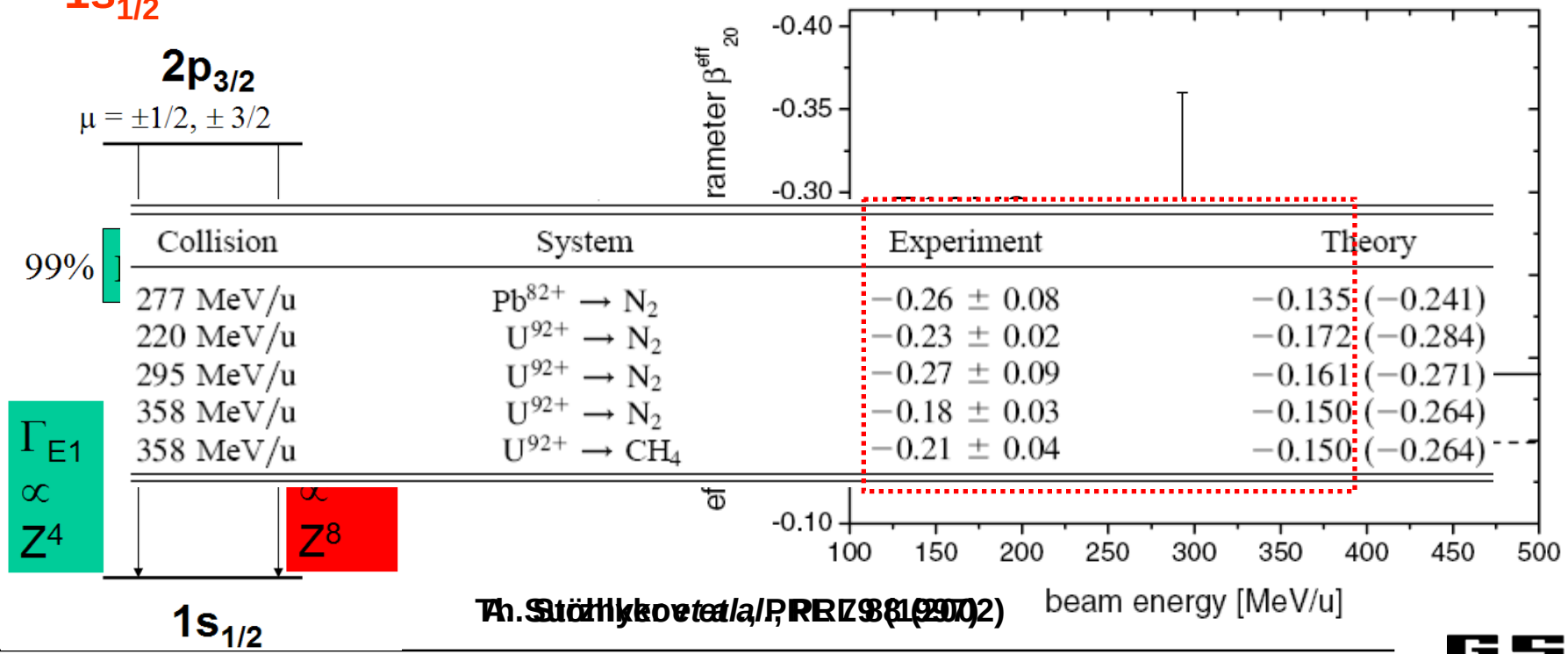
-> a tool to study the dynamics of the population process!

Lyman-α_1 Anisotropy



Theory for Z=92: $f = 1.28$

$$W(\theta) \propto 1 + \beta_{20} \bullet \left[1 - \frac{3}{2} \sin^2\theta \right] \quad \sin^2\theta$$

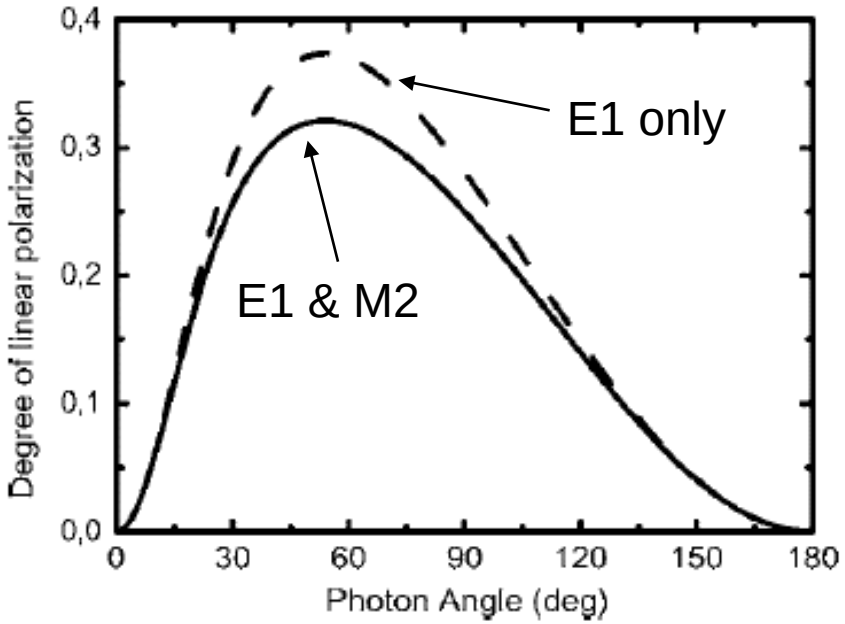


Collision	System	Experiment	Theory
277 MeV/u	$Pb^{82+} \rightarrow N_2$	-0.26 ± 0.08	$-0.135\ (-0.241)$
220 MeV/u	$U^{92+} \rightarrow N_2$	-0.23 ± 0.02	$-0.172\ (-0.284)$
295 MeV/u	$U^{92+} \rightarrow N_2$	-0.27 ± 0.09	$-0.161\ (-0.271)$
358 MeV/u	$U^{92+} \rightarrow N_2$	-0.18 ± 0.03	$-0.150\ (-0.264)$
358 MeV/u	$U^{92+} \rightarrow CH_4$	-0.21 ± 0.04	$-0.150\ (-0.264)$

Th. Stöhlker *et al.*, PRL 85 (2000) 2960

Lyman-α_1 Polarization of U^{91+}

$$Pol(\theta) \propto \frac{-\frac{3}{2}\beta_{20} f \bullet \sin^2\theta}{1+\beta_{20} f \bullet P_2(\cos\theta)}$$



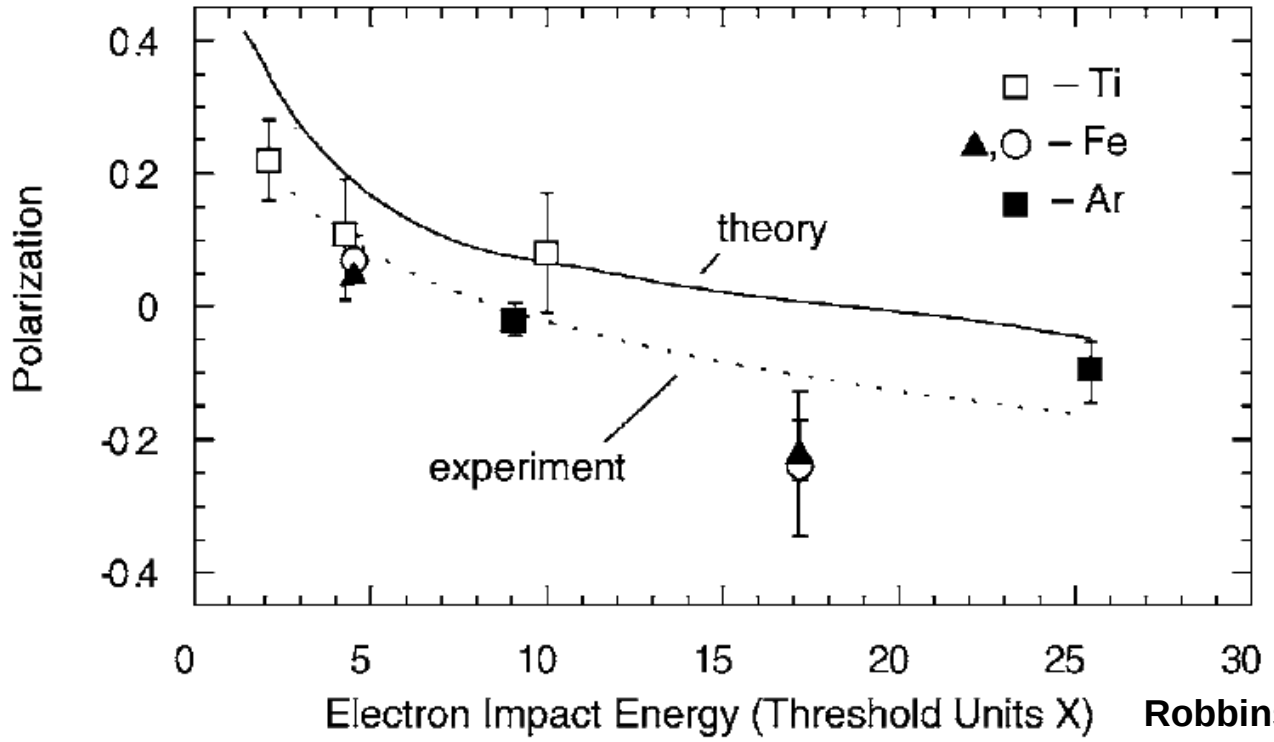
Surzhykov *et al.* (2003):

E1-M2 interference in Ly-α_1 leads to

→ **Increased Anisotropy**

→ **Decreased Polarization**

Previous Lyman-α_1 Polarization Measurements



Robbins *et al.*, PRA 74 (2006)

EBIT experiments:

- **low and mid-Z ions, 90 deg observation angle**
- **different population mechanism (electron impact ionization)**

Polarization Measurement Techniques

Liquid Crystals

Crystal Optics

Bragg Reflection

Photoabsorption

Thomson Scattering

Compton Scattering

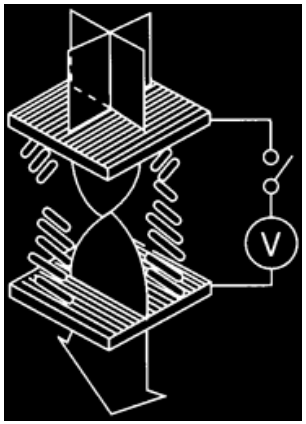
U^{91+} Ly-α

mid-Z ions

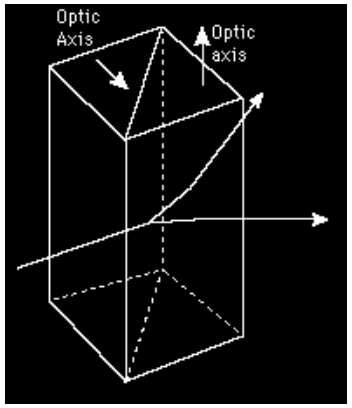
Pair Production

10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7}

photon energy [keV]



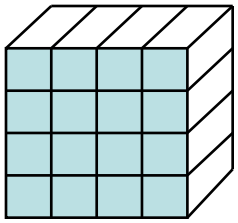
LCD



Prism

Micropattern Gas Counters

x-ray Optics

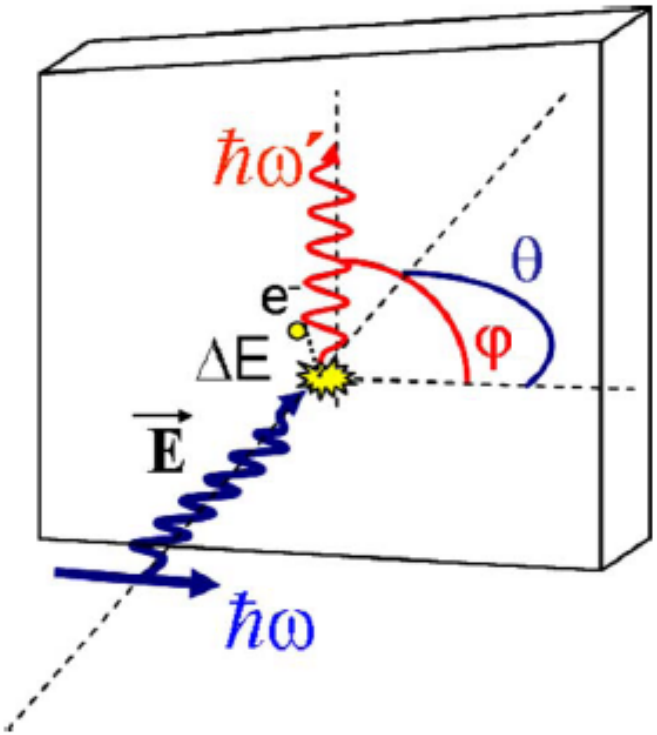


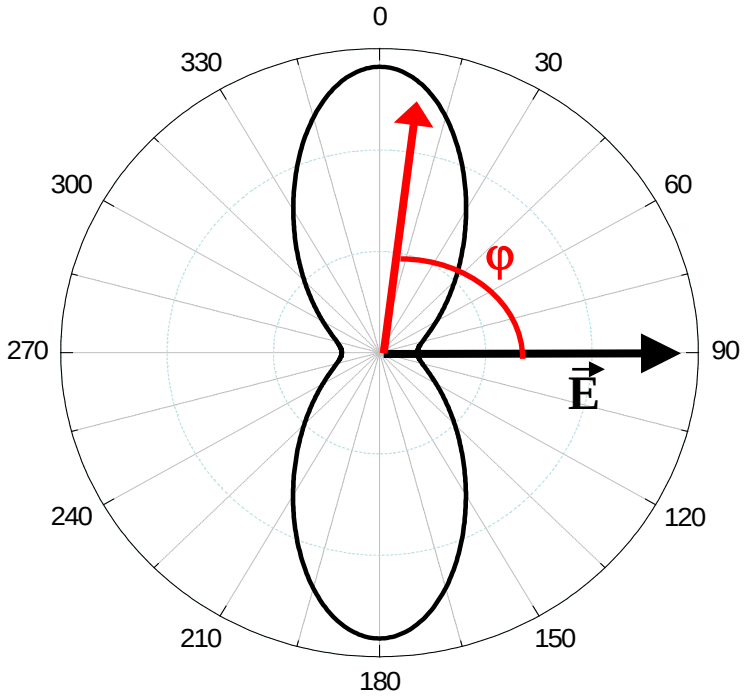
Segmented Solid State Detectors

Polarization Measurement via Compton Scattering

Klein-Nishina Equation for Compton Scattering:

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





Compton Polarimetry

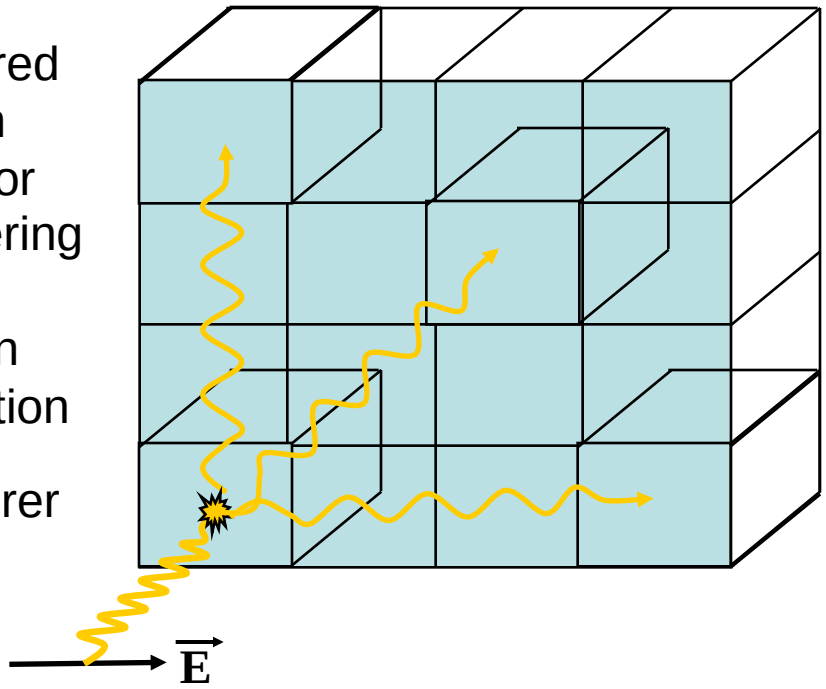
Si(Li) 2D Segmented X-Ray Detector

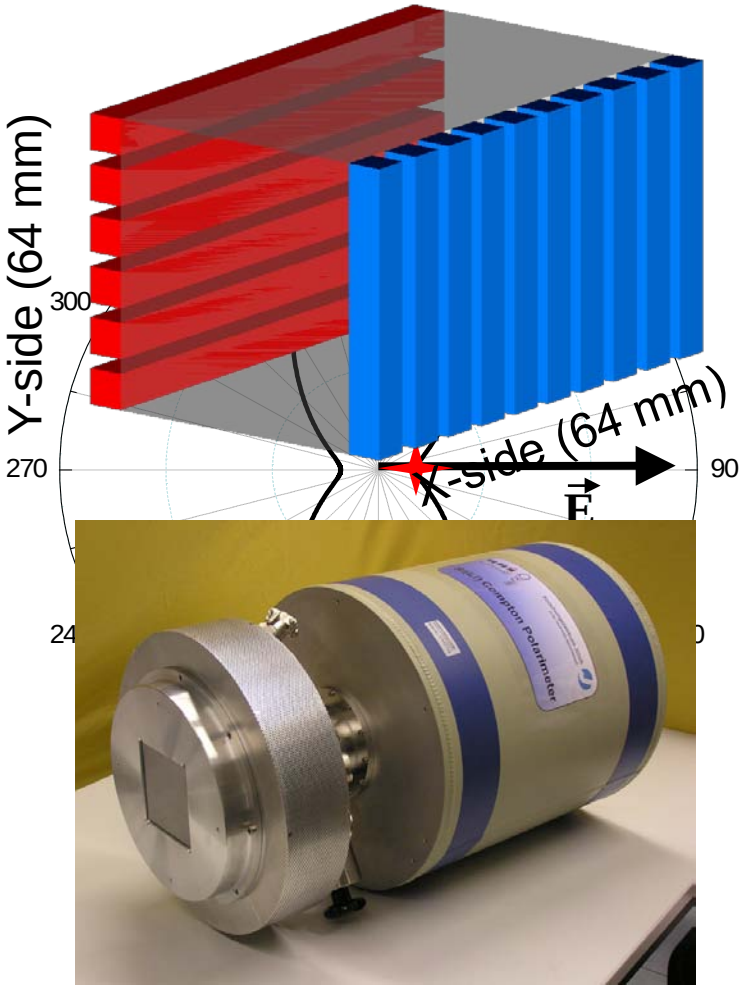
Standard Solid State Detectors

Scattered Photon Detector

Scattering and Photon Detection

Scatterer

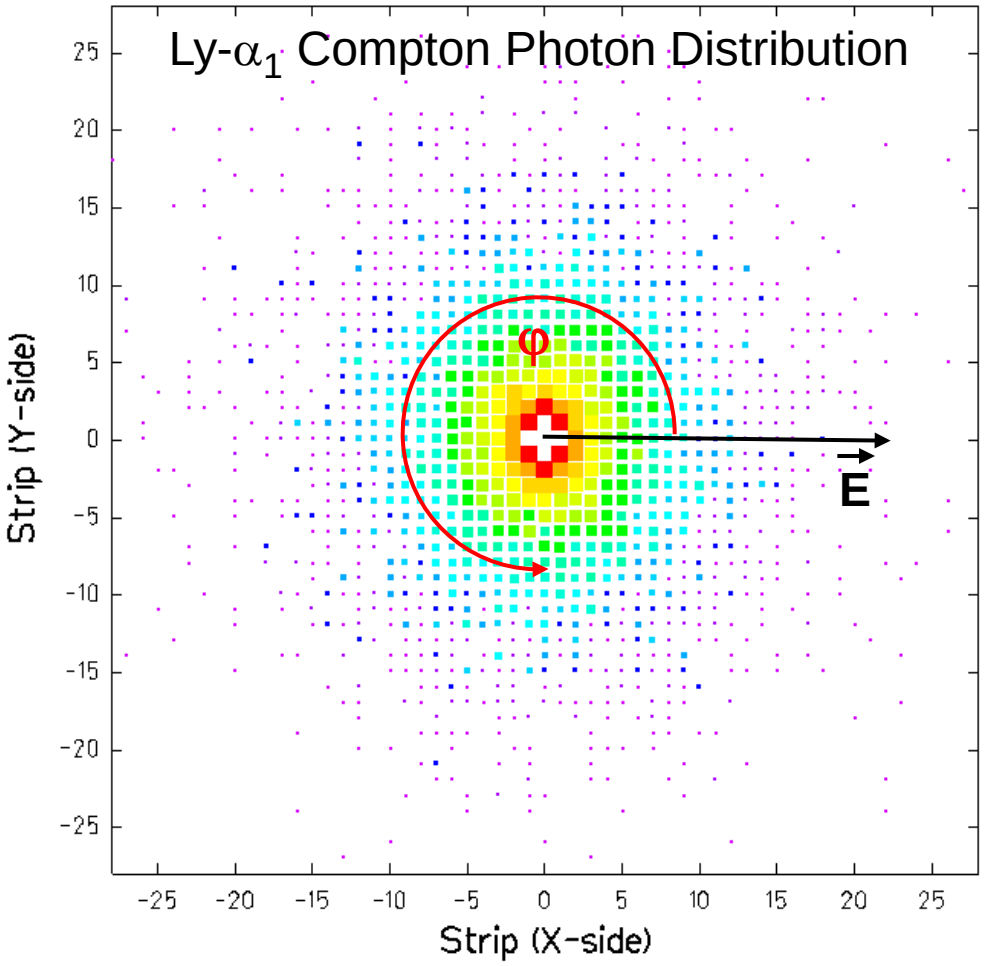




32 x 32 strips = 1024 pixels

active area: 4096 mm^2

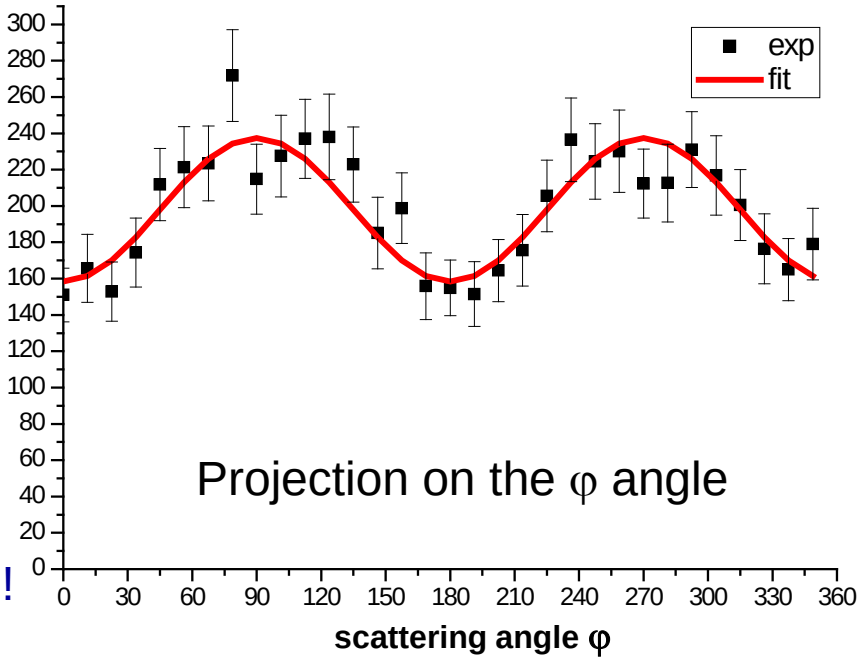
From φ Distribution to Polarization



Klein-Nishina formular:

$$\frac{d\sigma}{d\Omega} = \frac{r_e^2}{2}\left(\frac{E'}{E}\right)^2\left(\frac{E'}{E} + \frac{E}{E'} - 2\sin^2\vartheta\cos^2\varphi\right)$$

$$\cos^2\varphi \rightarrow \frac{1}{2}(1-P) + P\cos^2\varphi$$



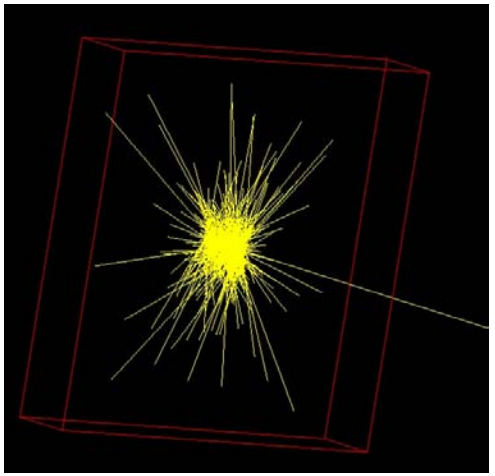
Projection on the φ angle

Online analysis already yields qualitative results!

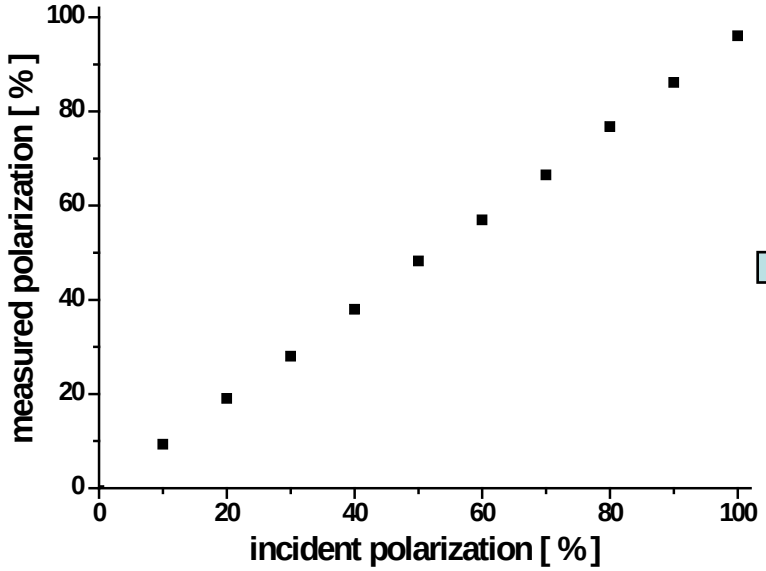
EGS5 – Monte Carlo Simulation

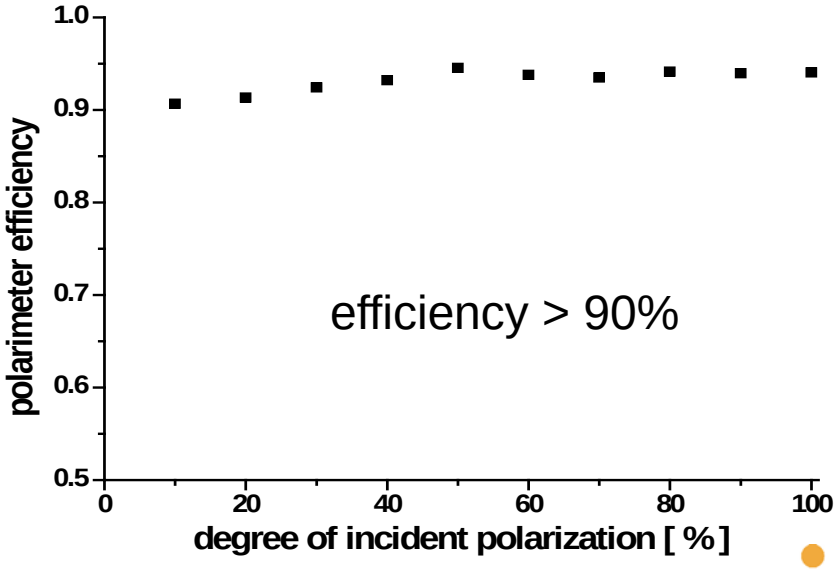
Simulation code includes:

- ✓ Photon-matter interactions (absorption, scattering)
- ✓ Electronic noise
- ✓ Charge splitting
- ✓ Doppler shift/broadening (for moving sources)



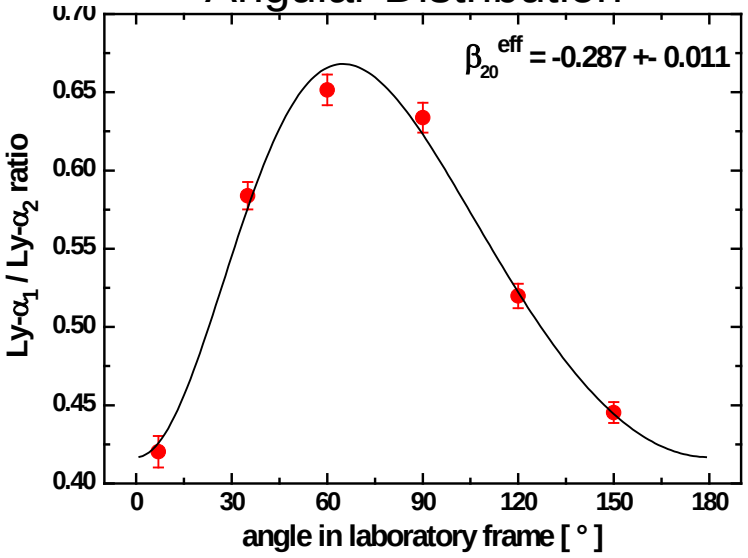
Example: 2D Si(Li) Polarimeter, 100 keV incident photons



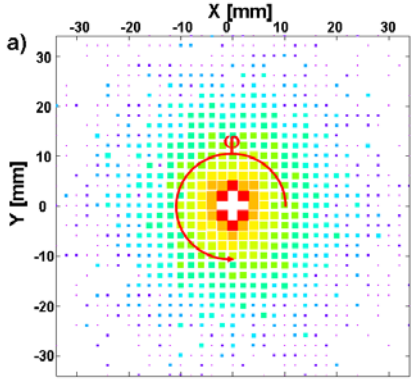


U^{91+} Lyman-α_1 results

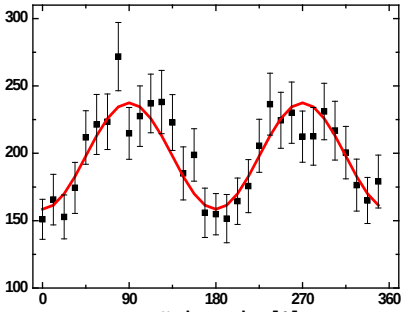
Angular Distribution



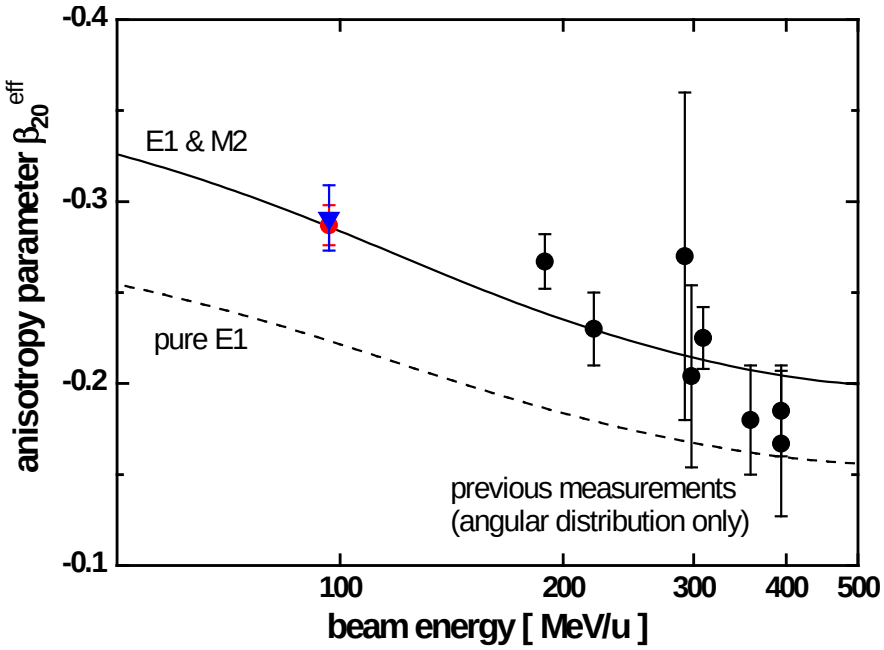
Ly-α_1 Polarization



β_{20}^{eff} = -0.291 +- 0.018



Preliminary !

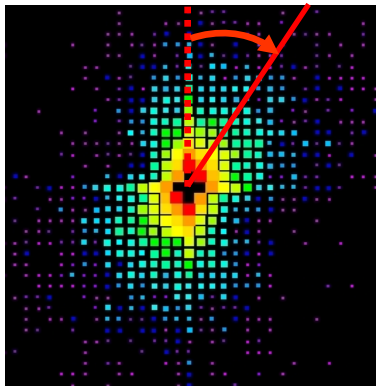


Two indenpendent determinations of β_{20}^{eff}

-> probe of REC process as well as atomic structure at high-Z

Summary

- ✓ Effifcient Compton Polarimeters are now avaiable (only small systematic corrections needed)
- ✓ Prediction for U^{91+} Ly-α_1 polarization confirmed
- ✓ Experiments can revisit a variety of radiative processes with respect to linear polarization (e.g. REC, Lyman, Bremsstrahlung)
- ✓ Possible application:
  Control of spin-polarized ion beams at GSI/FAIR

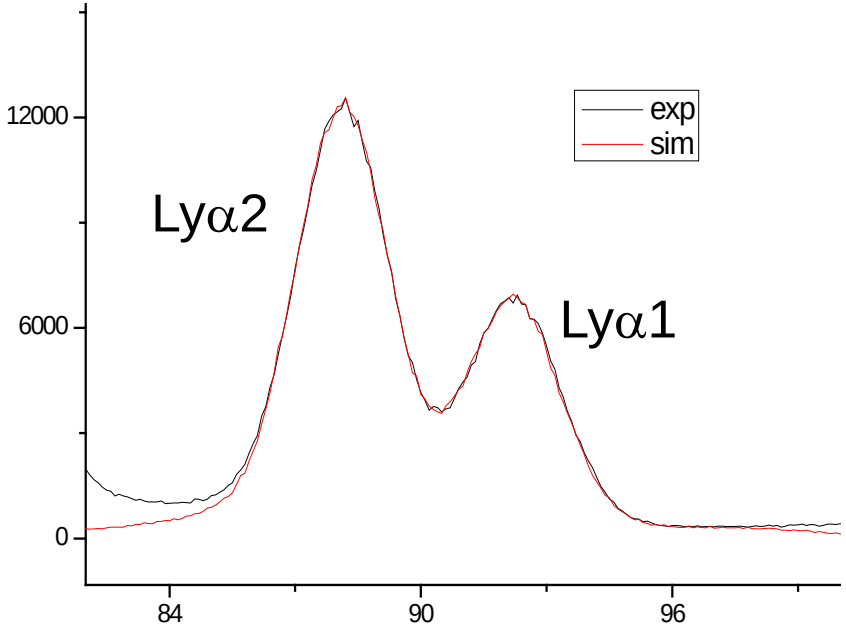


Simulation for 100 keV x-rays

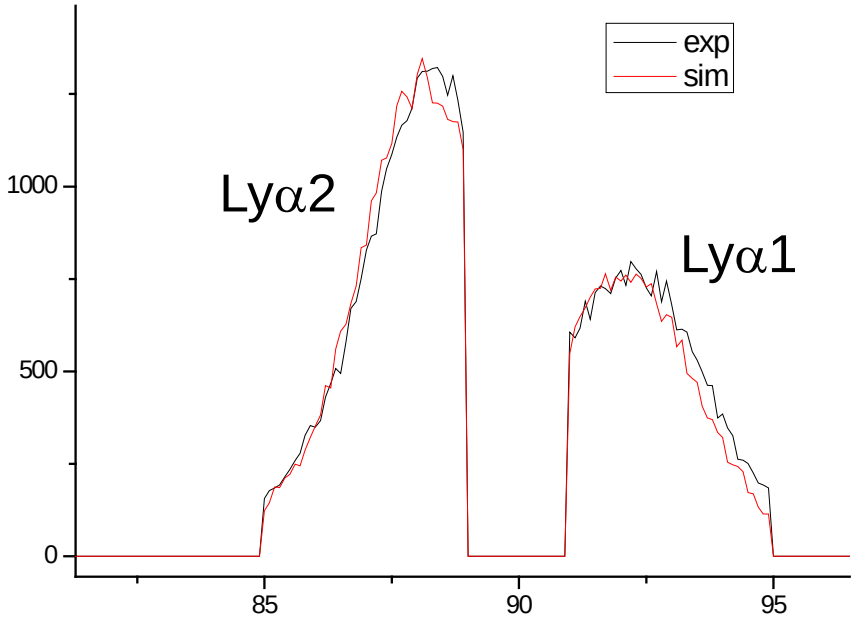
Thank you for your attention!

Can we simulate our detector with EGS5?

Photoabsorption



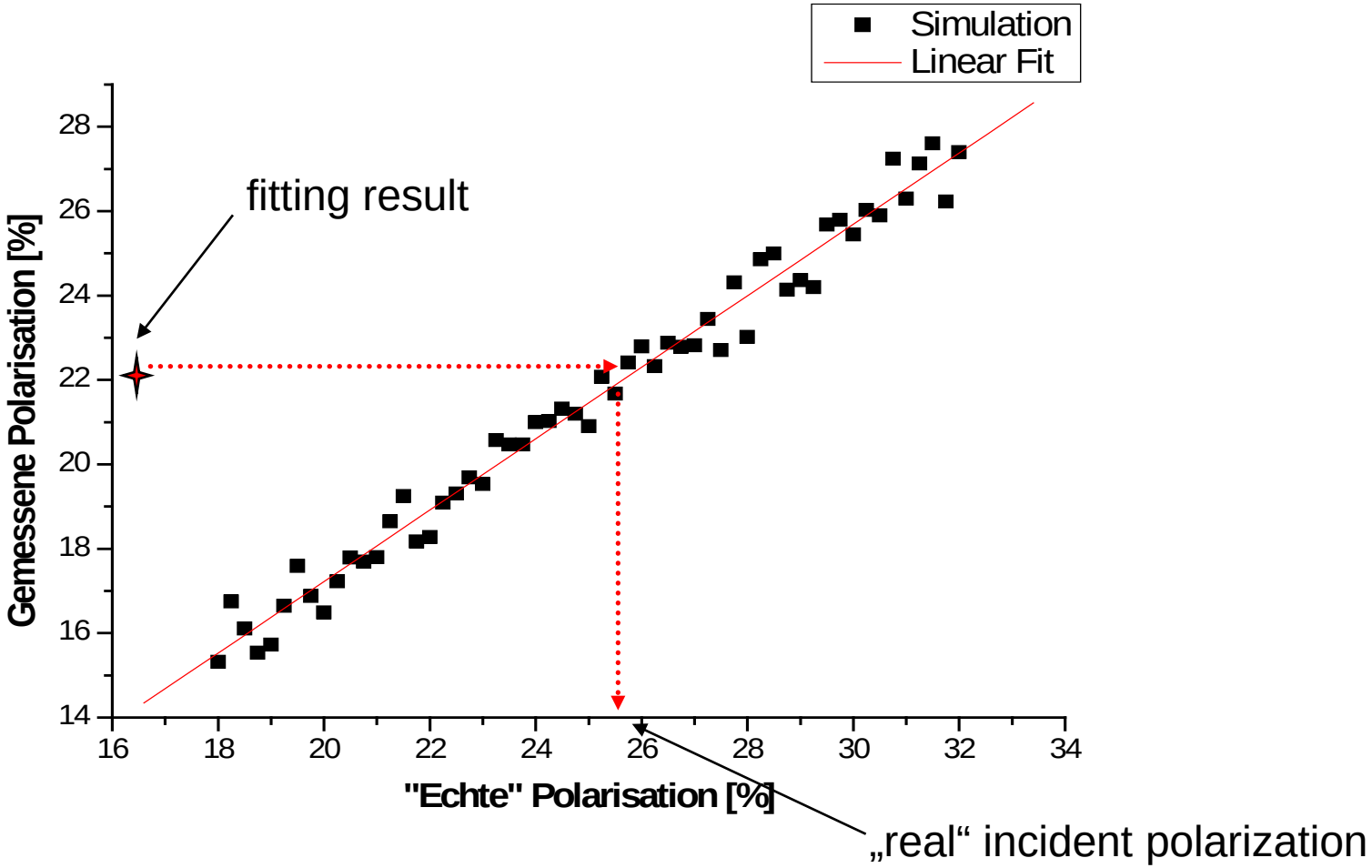
Reconstructed Compton Events



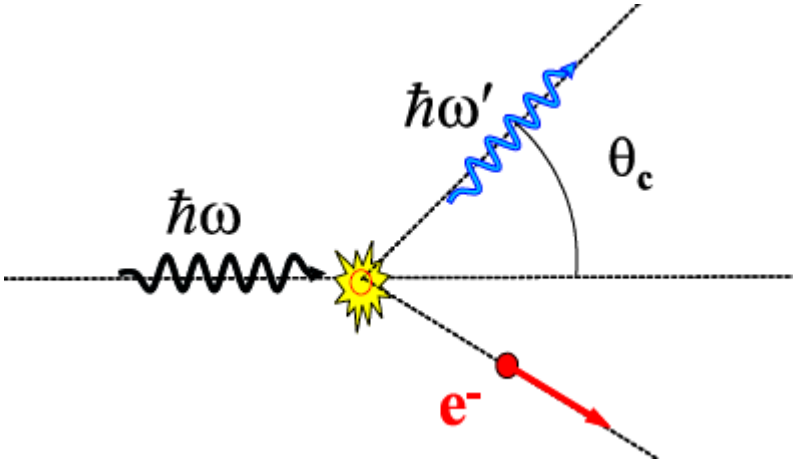
Simulation: Lya1: 25.5%
Lya2: 0%
Background: 0%

-> Yes, we can!

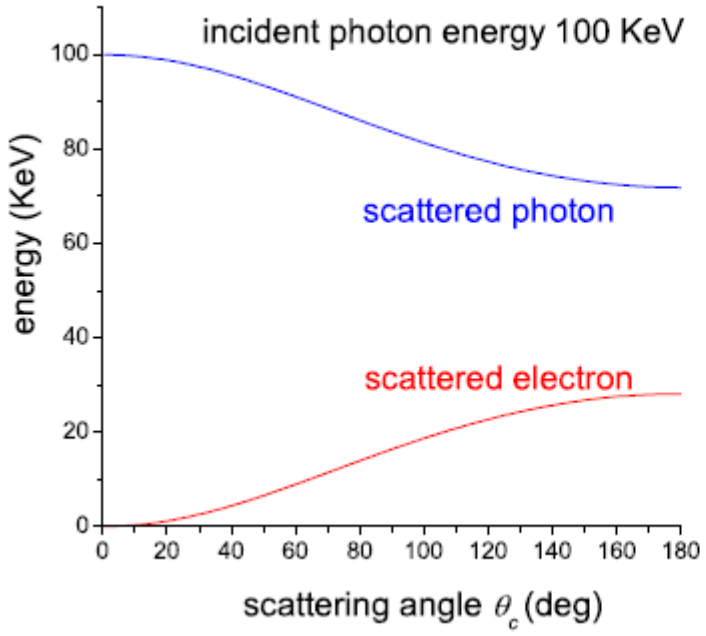
Detector Calibration via Simulation

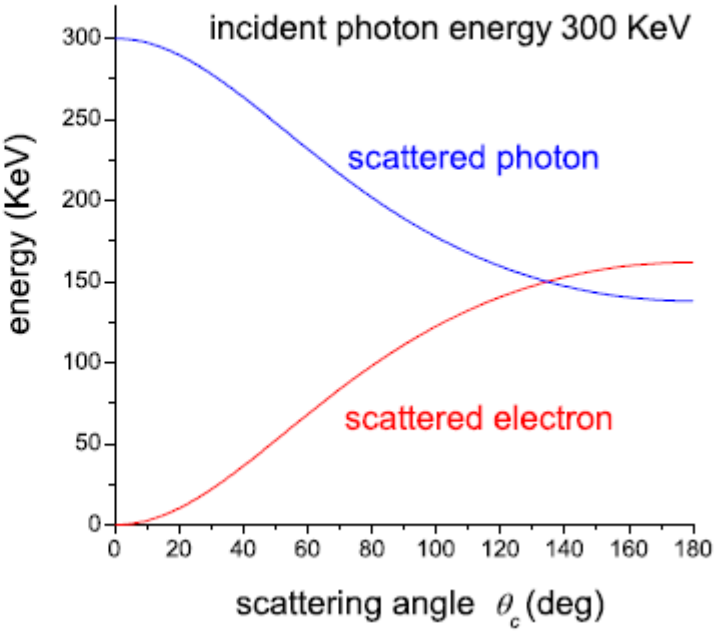


Compton Scattering

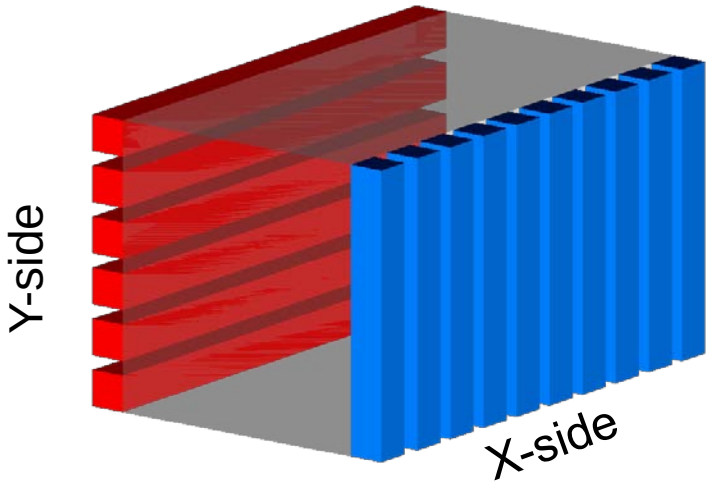


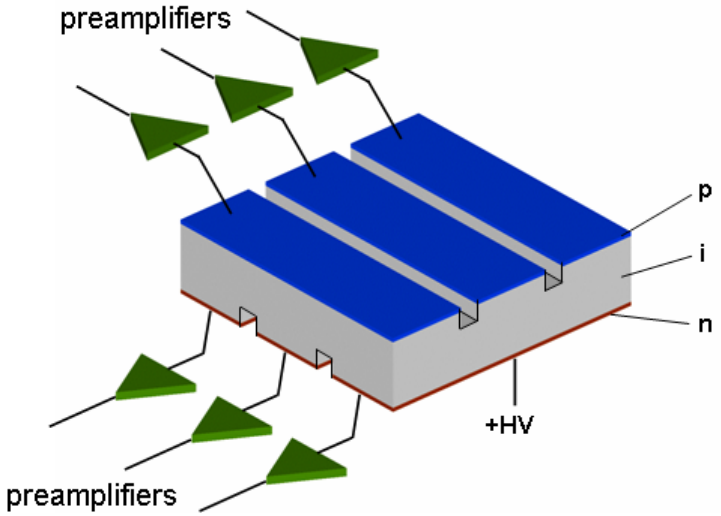
$$\hbar\omega' = \frac{\hbar\omega}{1 + \frac{\hbar\omega}{m_e c^2}(1 - \cos\theta)}$$

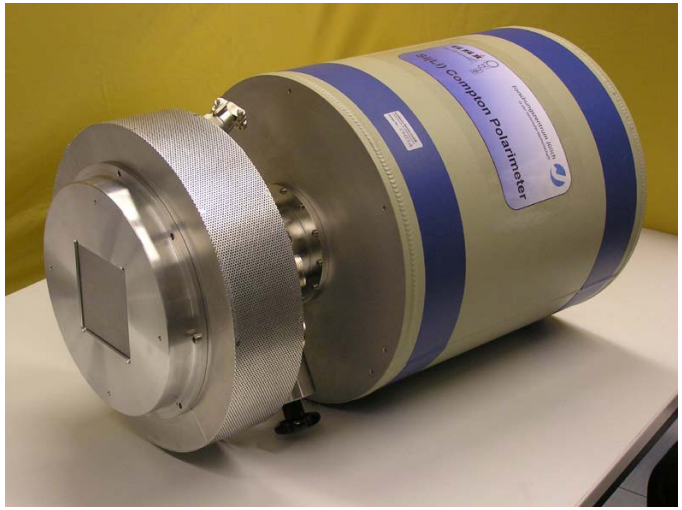




Segmented X-Ray Detectors for Compton Polarimetry





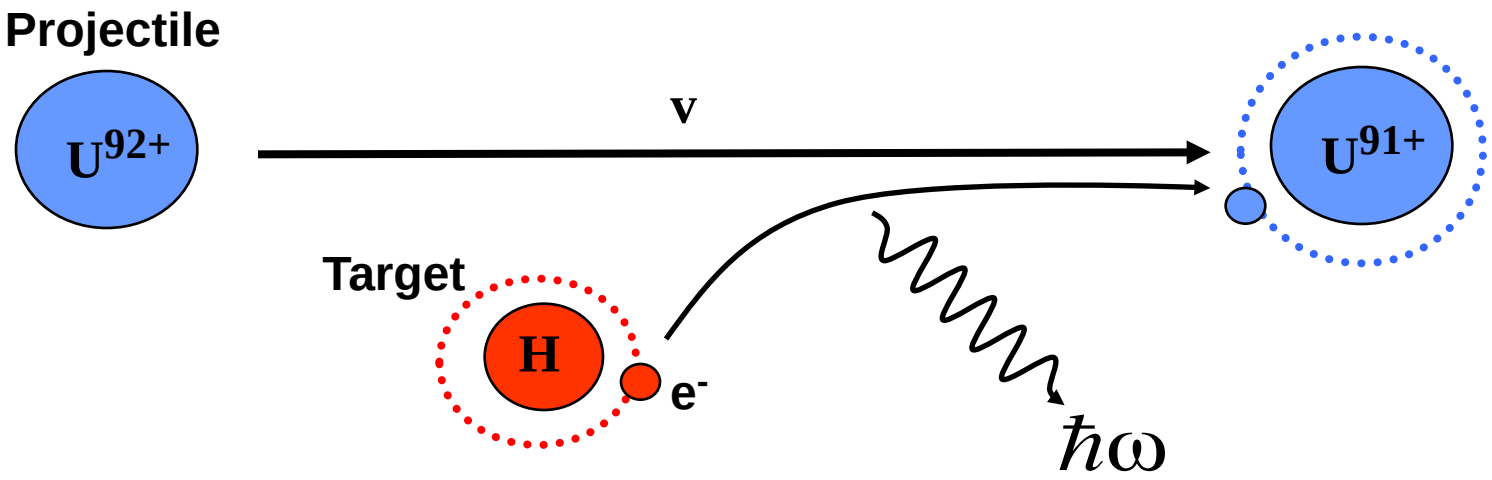


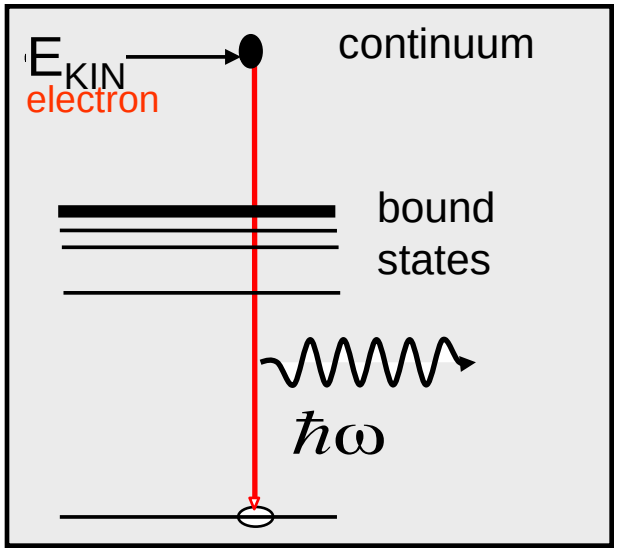
Si(Li) 2D Segmented X-Ray Detector

32x32 strips = 1024 pixel

Energy + Timing + 2D Position + Multihit

Radiative Electron Recombination (REC)

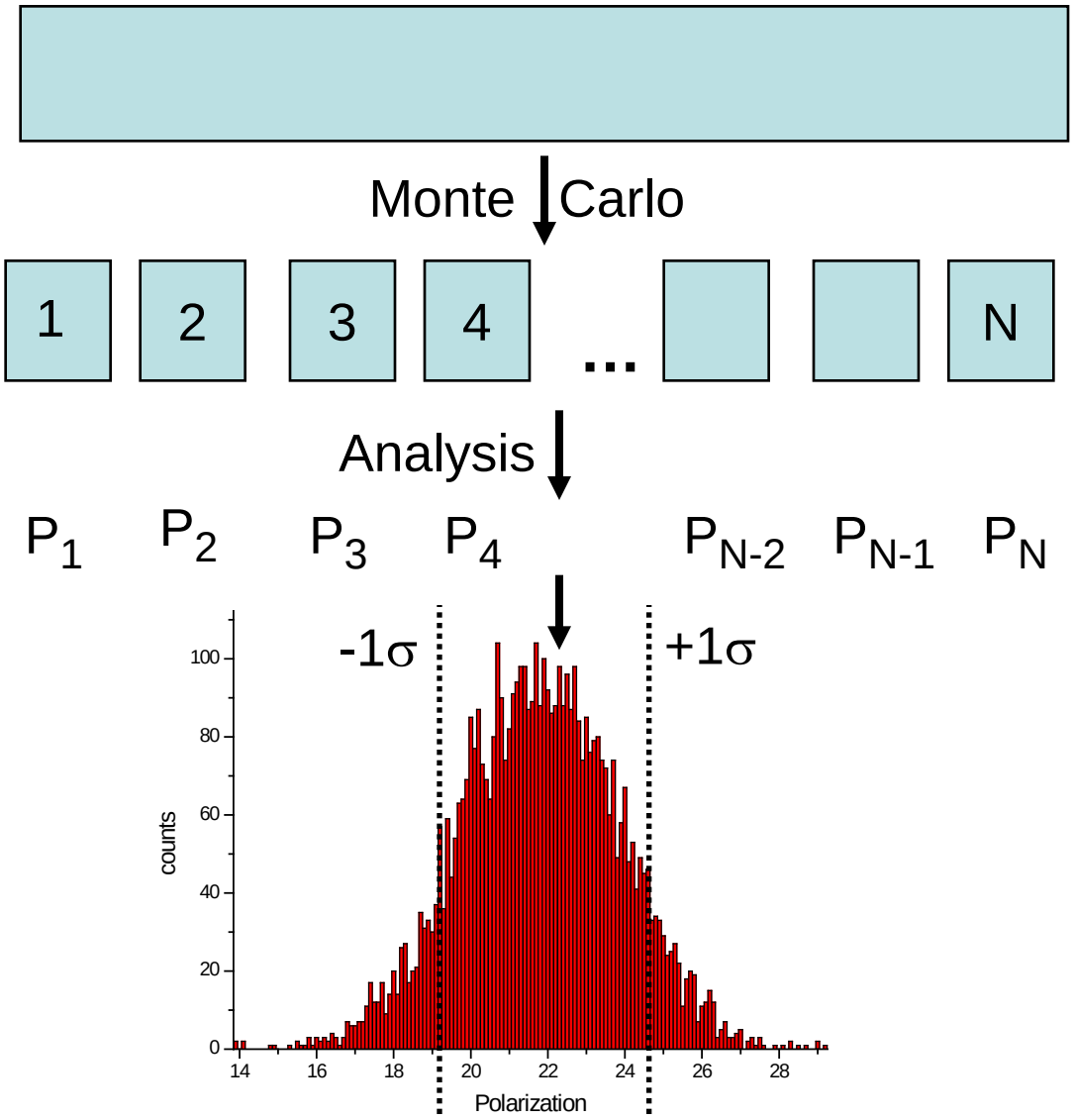




$$\text{X-ray energy}$$

$$\hbar\omega = E_B + E_{KIN}$$

Bootstrapping



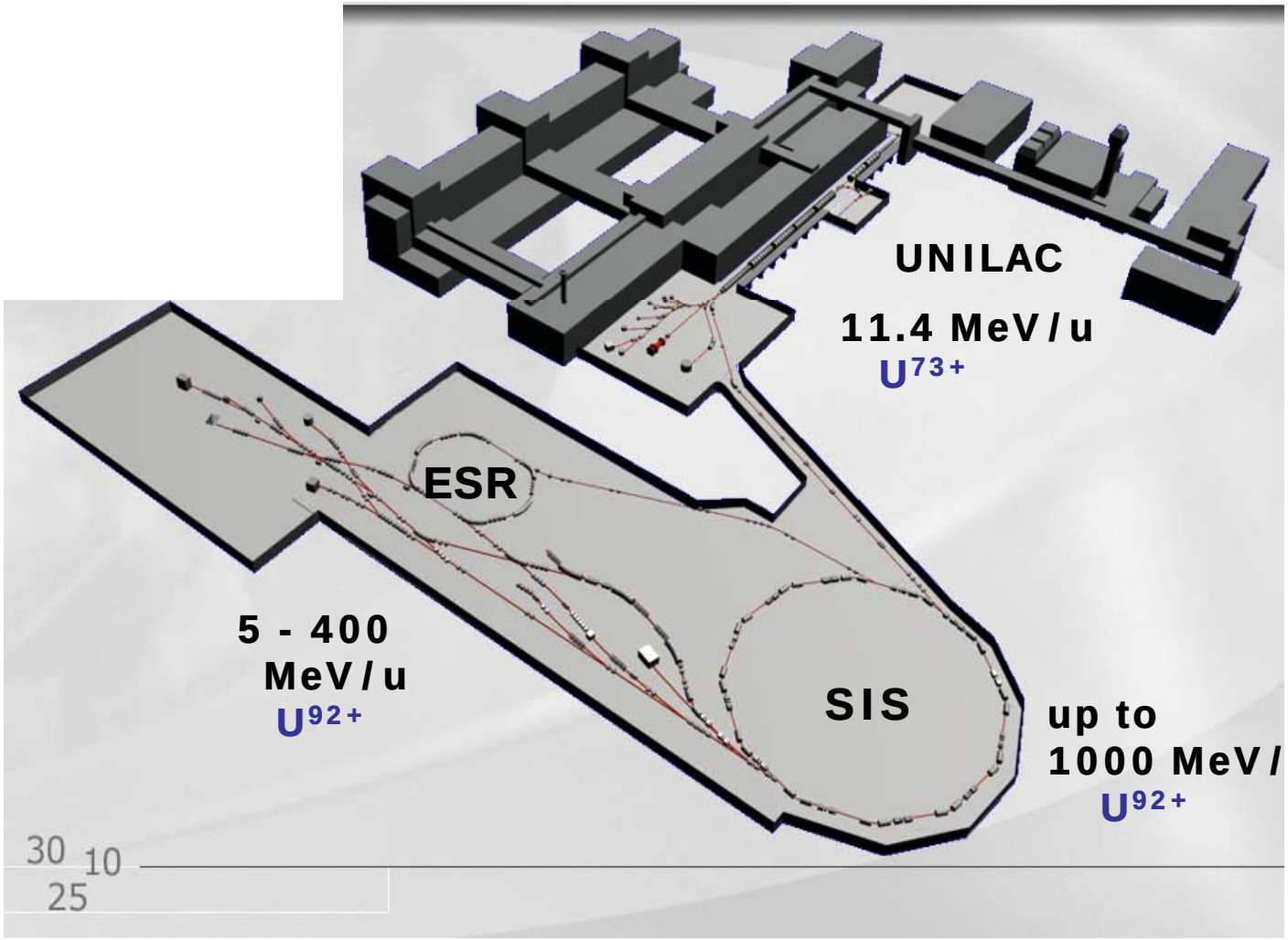
1. generate/measure a data set with good statistics

2. generate a sufficient number (~1000) of „daughter“ data sets with statistics equal to the experiment

3. estimate the observable of interest for each data set

4. estimate the statistics of the obeservable

The GSI Accelerator Facility



Compton Photon Angular Distribution