Bremsstrahlung polarization correlations and their application for polarimetry of electron beams

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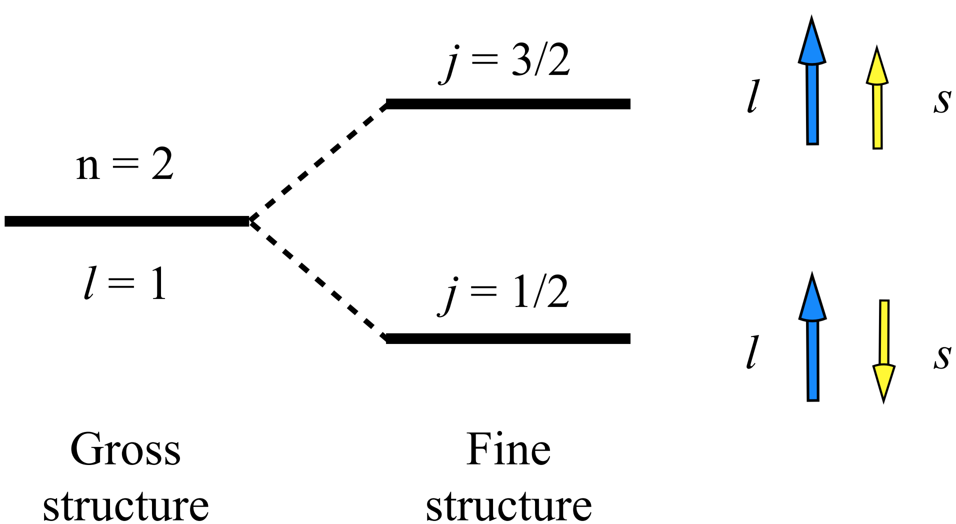
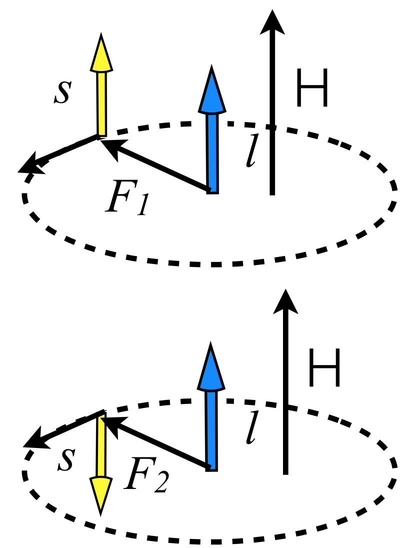
Emmy Noether-Programm
Deutsche Forschungsgemeinschaft
DFG



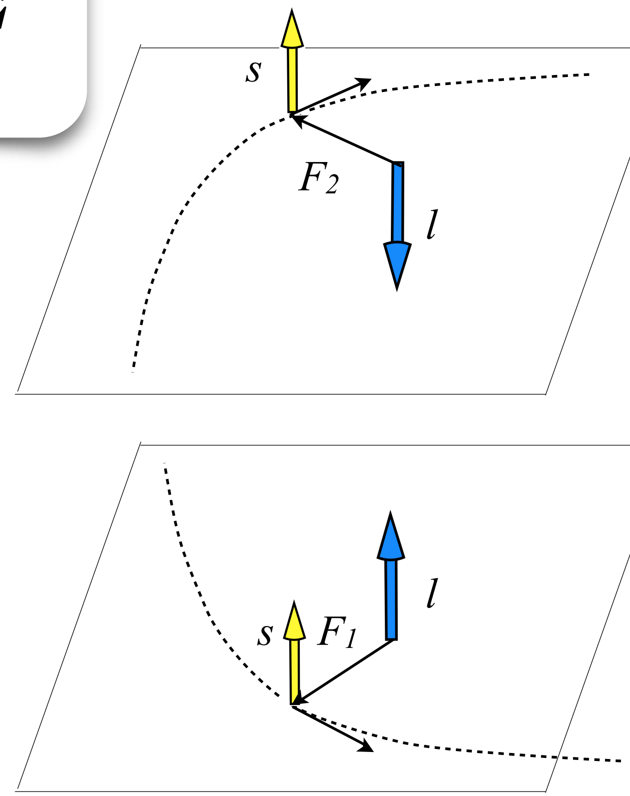


The Spin-Orbit interaction
★ modifies the effective binding potential
★ causes the Fine Structure splitting

Spin dynamics in Coulomb scattering and bremsstrahlung

$$V_{so} \propto \vec{L} \cdot \vec{S}$$

The spin-orbit interaction causes the Mott scattering asymmetry when $l \parallel s$



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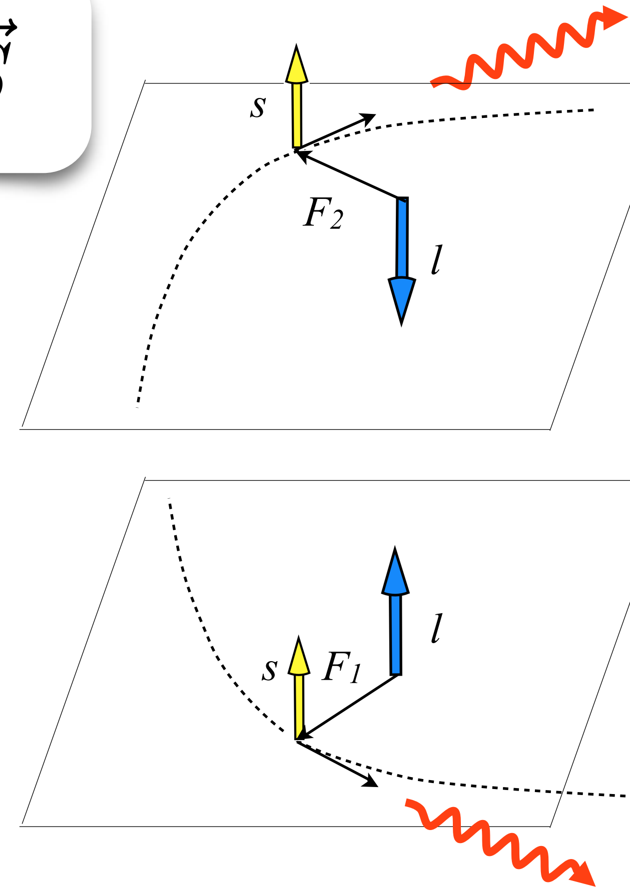
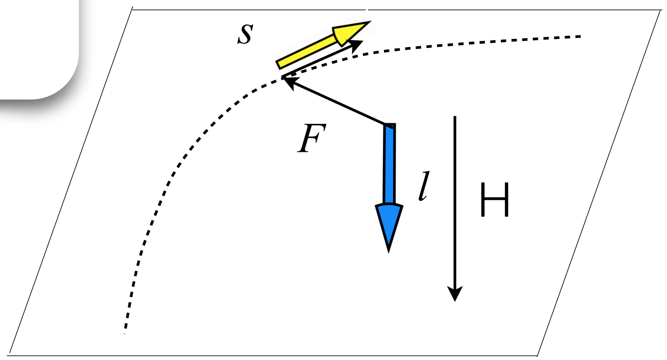


Similar asymmetry is observed in the emitted bremsstrahlung photons

Spin dynamics in Coulomb scattering and bremsstrahlung

$$V_{so} \propto \vec{L} \cdot \vec{S}$$

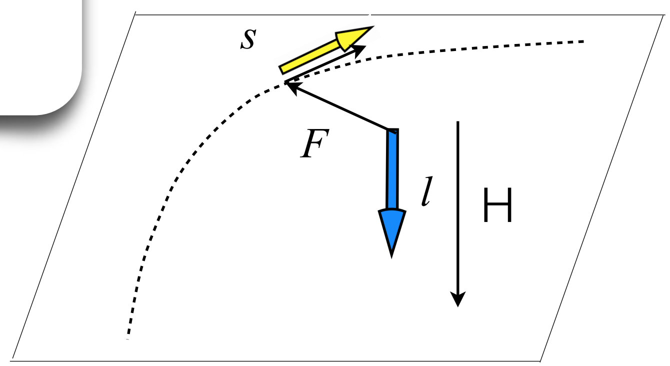
When the spin and the orbital momentum are not parallel, they both precess about the total orbital momentum ***J***



Spin dynamics in Coulomb scattering and bremsstrahlung

$$\frac{d\vec{S}}{dt} \propto \vec{L} \times \vec{S}$$

When the spin and the orbital momentum are not parallel, they both precess about the total orbital momentum ***J***



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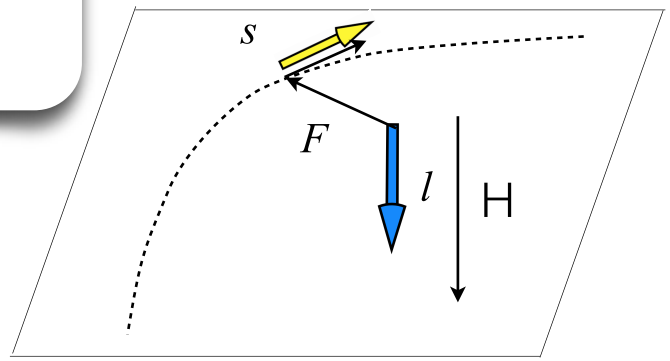

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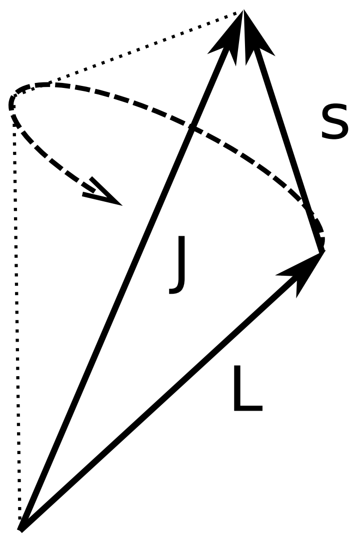

Spin dynamics in Coulomb scattering and bremsstrahlung

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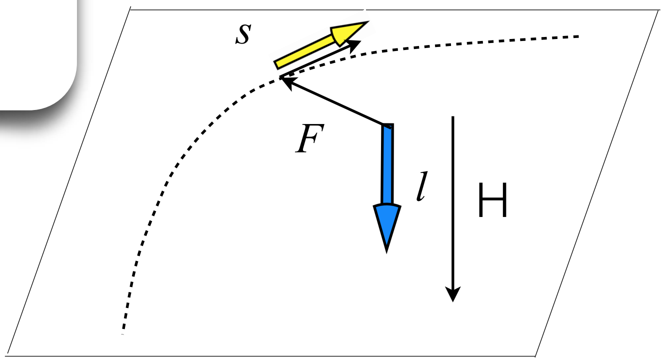

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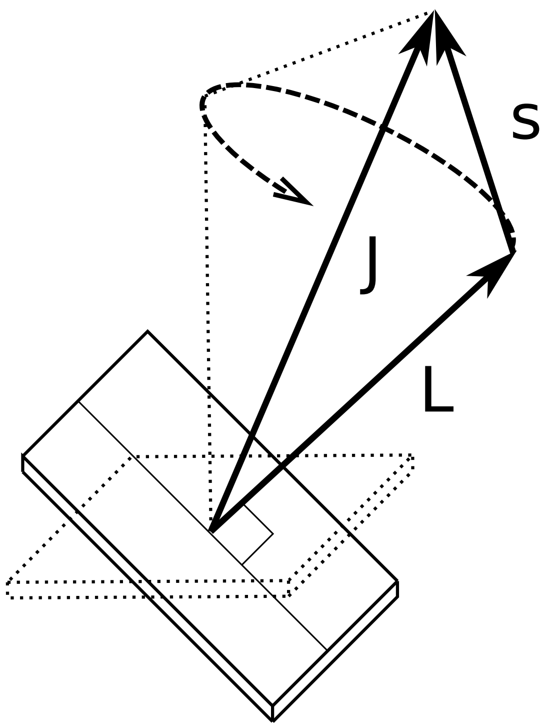
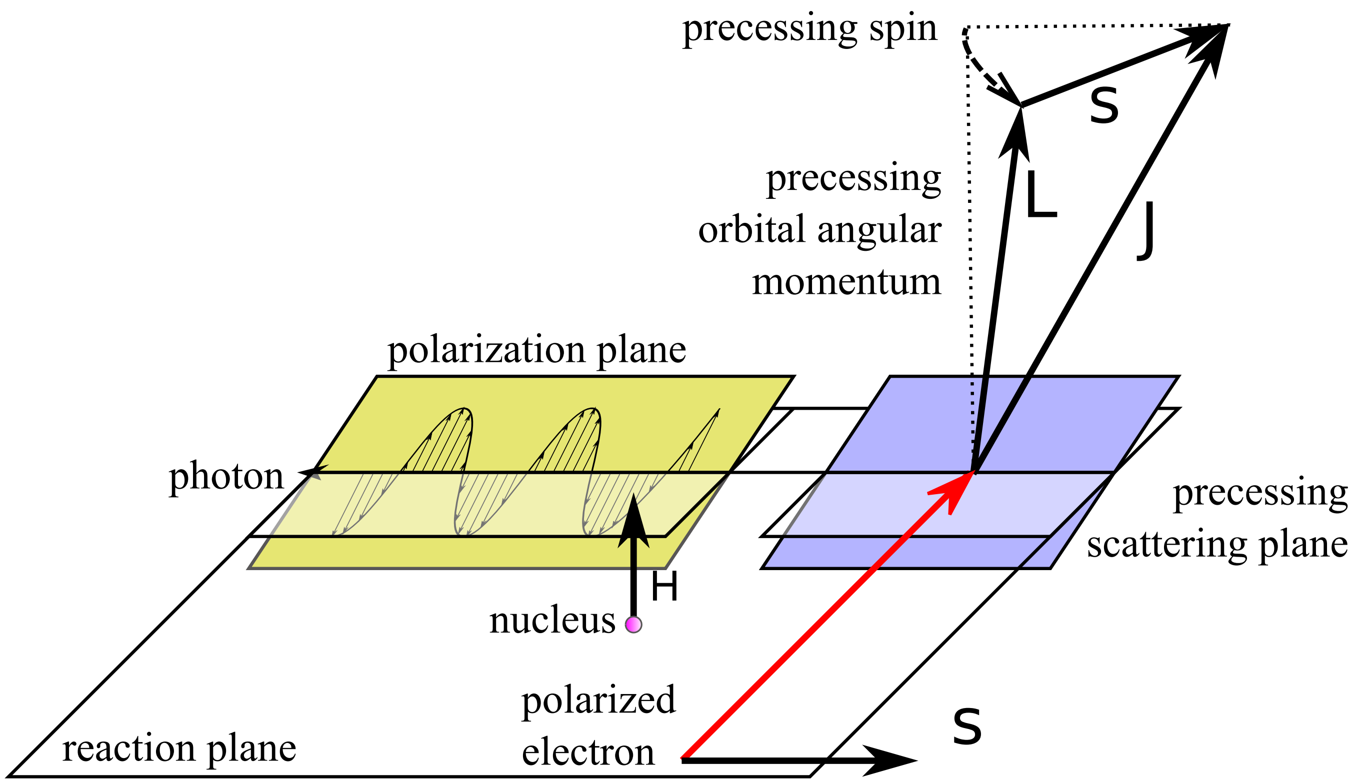


The scattering plane at any moment is defined by the orbital momentum L

Precession of L corresponds to the precession of the instantaneous scattering plane

Polarization of bremsstrahlung radiation



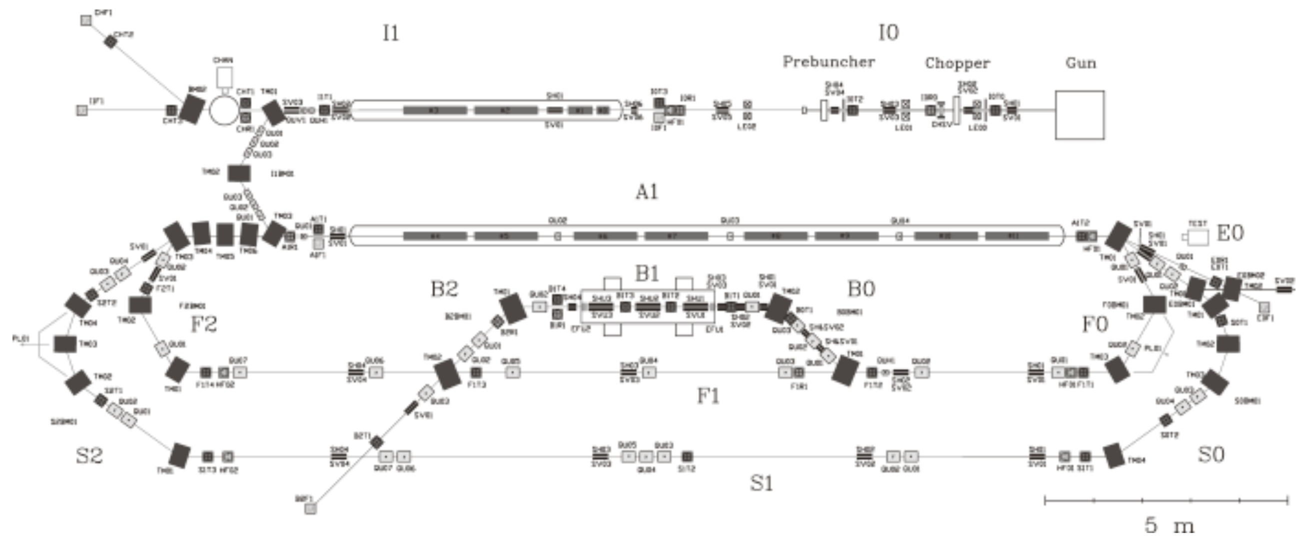
Bremsstrahlung photon is:

★ emitted close to the nucleus

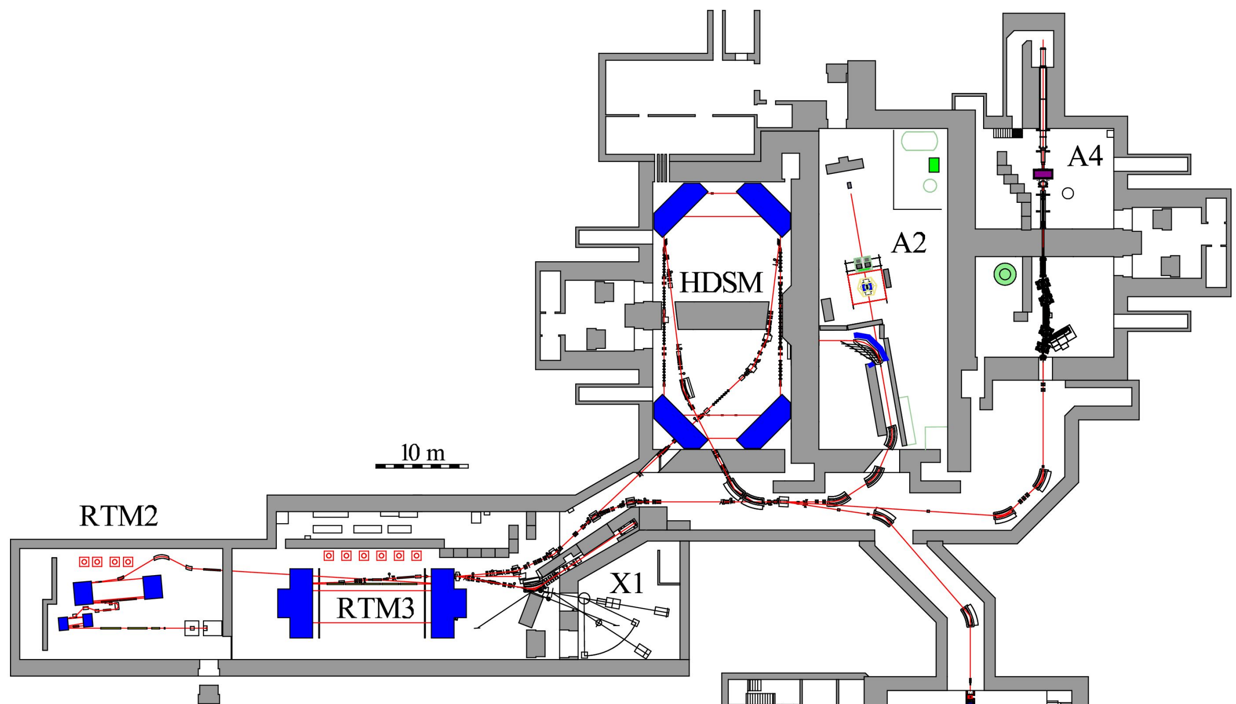
★ polarized within the scattering plane at that moment

Bremsstrahlung studies at electron accelerators with polarised beams

TECHNISCHE UNIVERSITÄT DARMSTADT

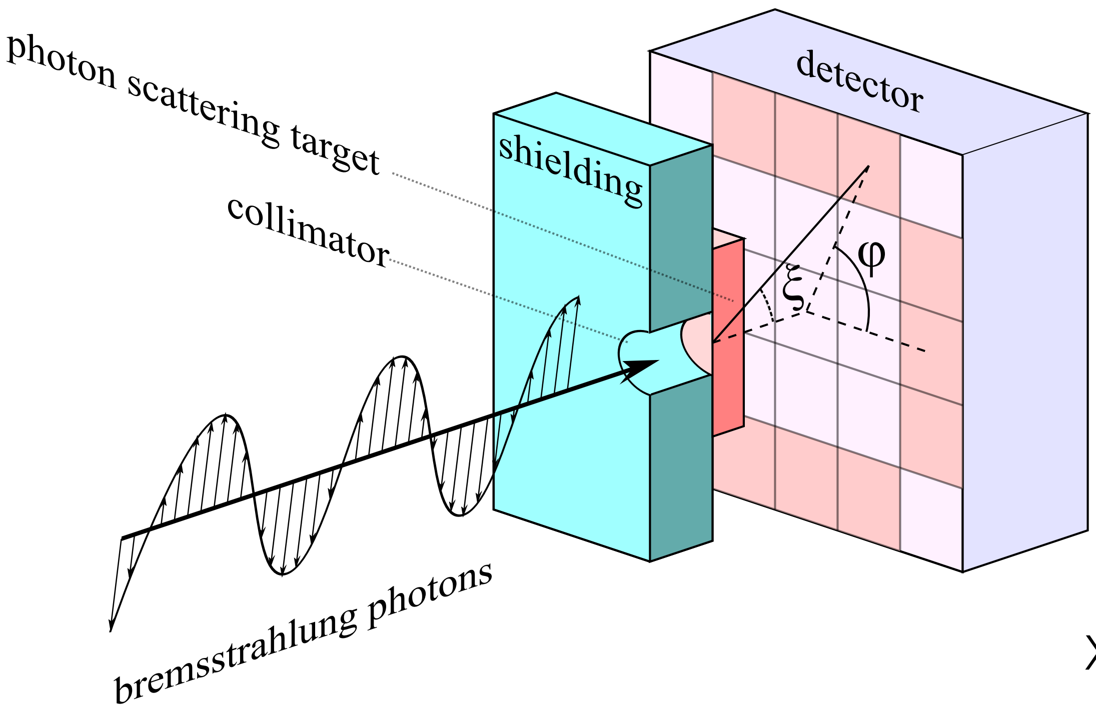


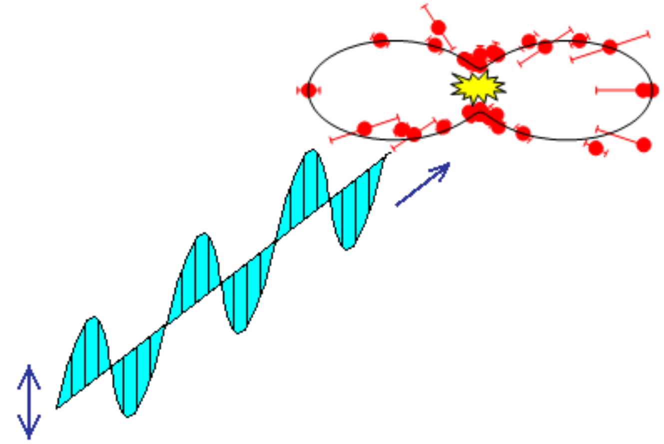
Mainz University



Rayleigh and Compton polarimetry techniques

(Electron energy 100 keV)





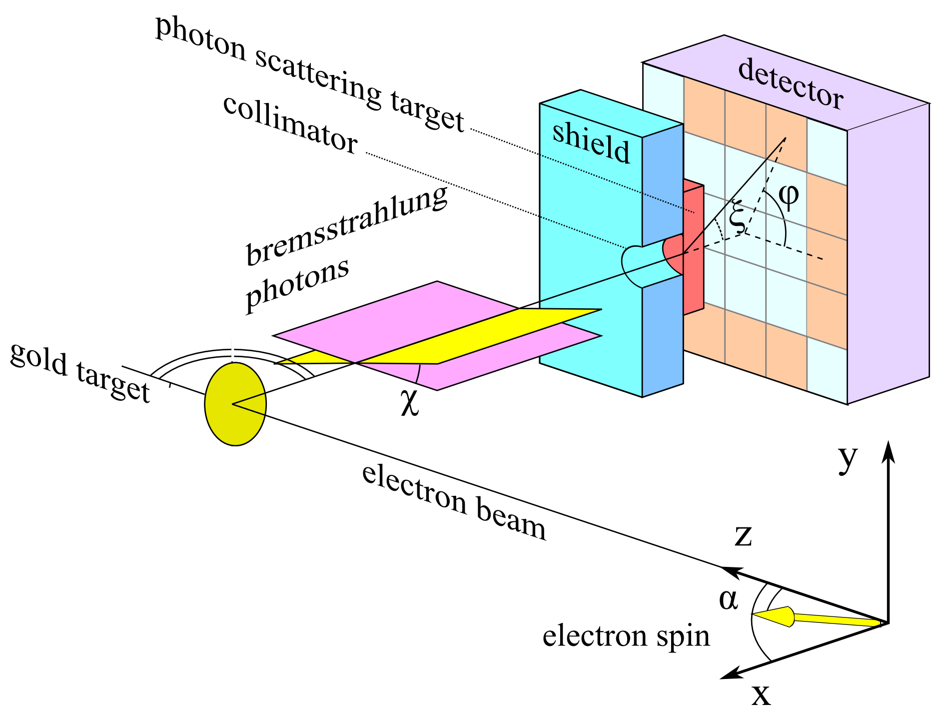
X-rays scatter predominantly perpendicular to the polarization plane

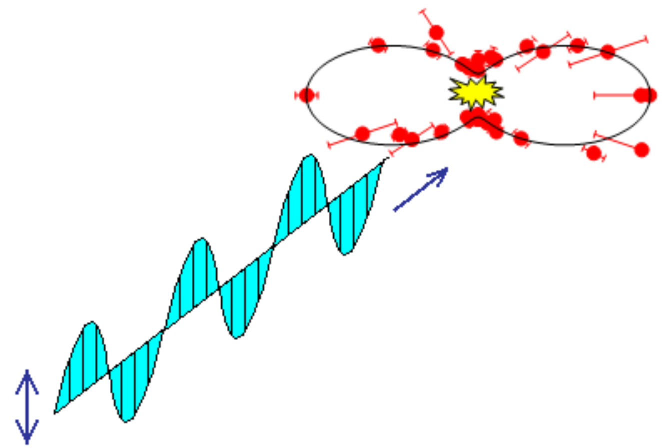
Planar segmented germanium detector

S. Tashenov et al., PRL 107, 173201 (2011)
S. Tashenov et al., NIM A 600 (2009) 599

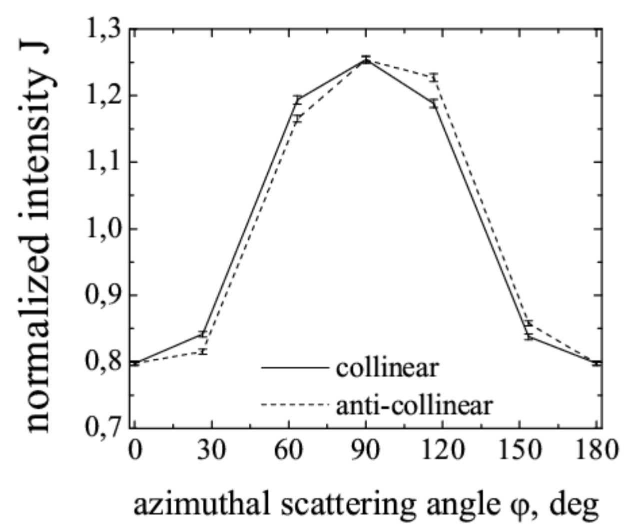
Rayleigh and Compton polarimetry techniques

(Electron energy 100 keV)





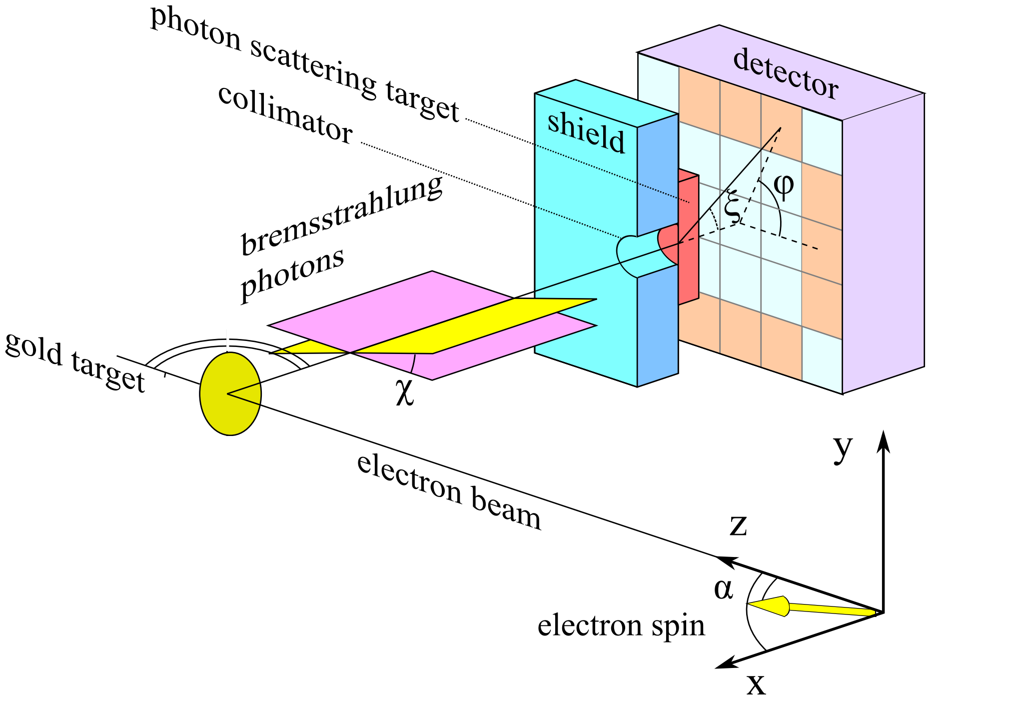
Experiment at the polarized electron injector of S-DALINAC accelerator in TU-Darmstadt

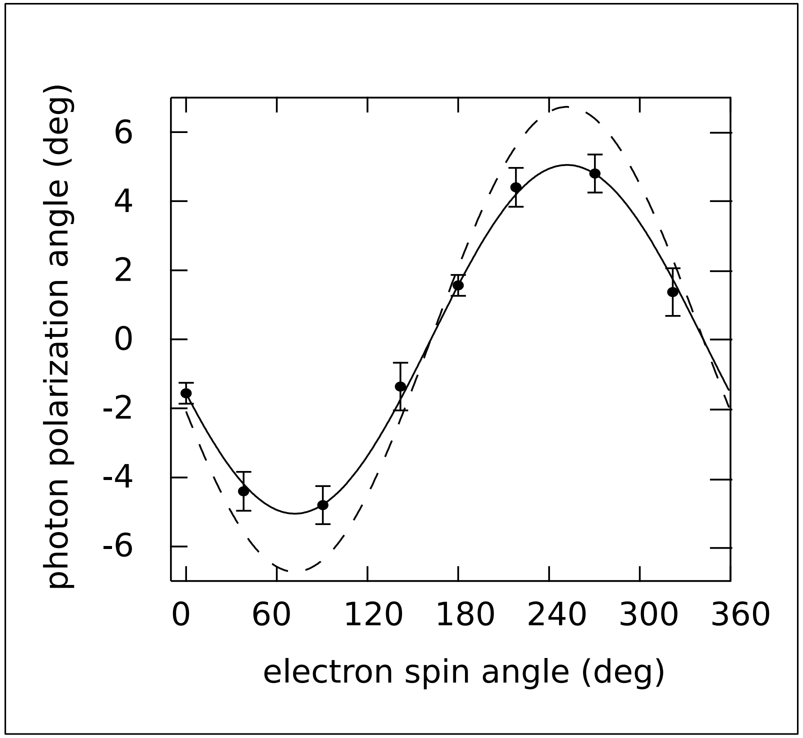


Polarization angle resolution 0.3 deg

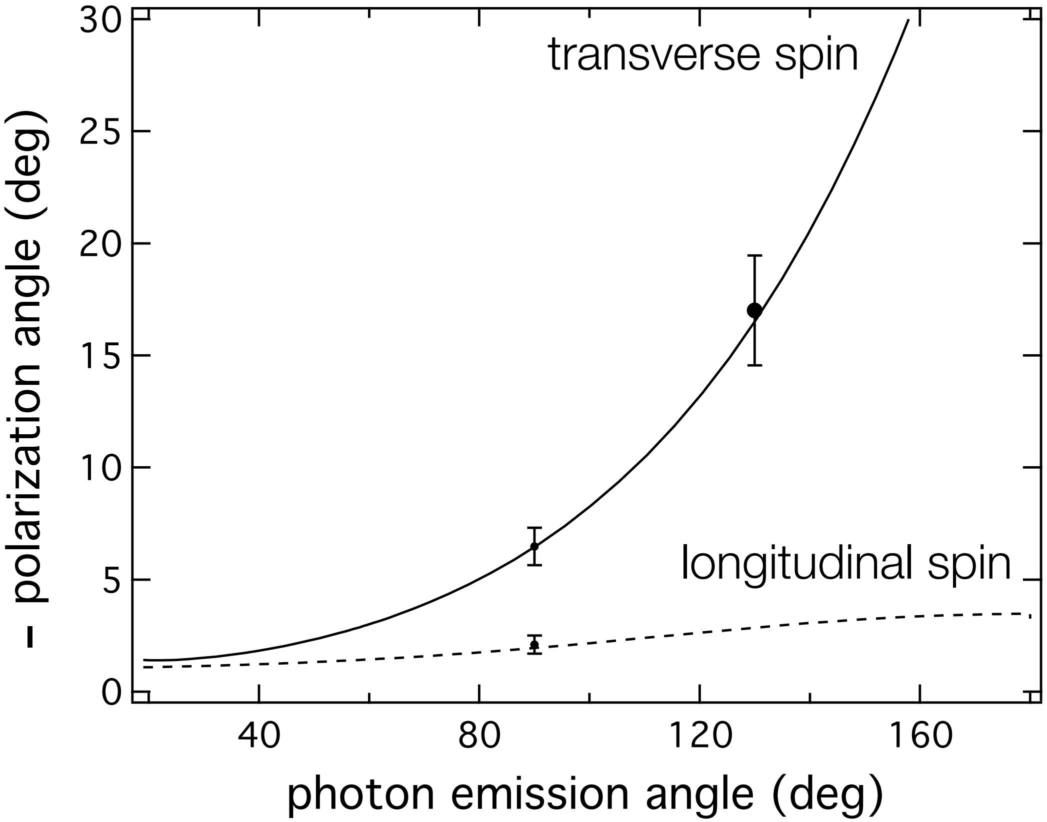
S. Tashenov et al., PRL 107, 173201 (2011)
S. Tashenov et al., NIM A 600 (2009) 599

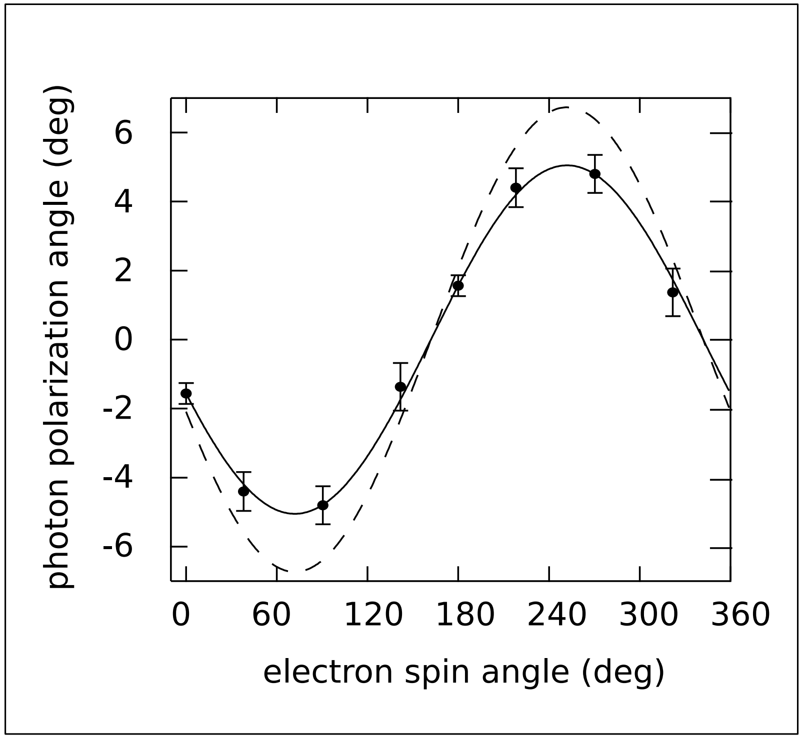
Measurement of bremsstrahlung polarization correlations (Electron energy 100 keV)





Summary of the results (Electron energy 100 keV)



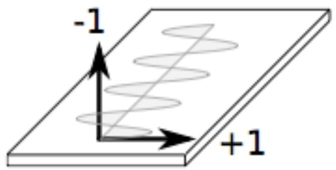
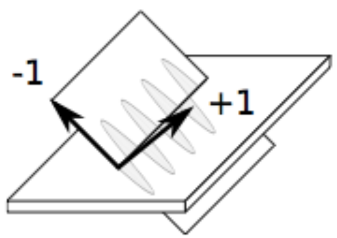
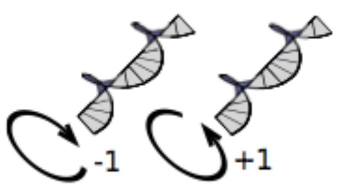


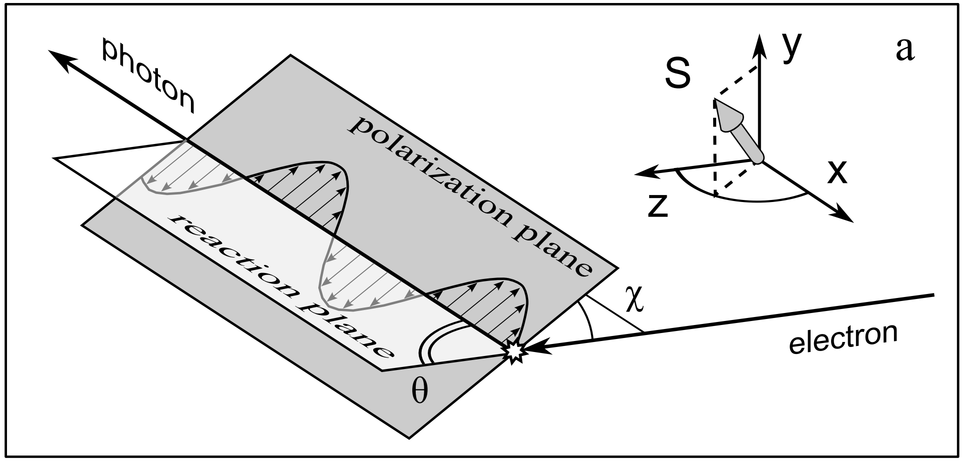
S. Tashenov et al., Phys. Rev. Lett. 107, 173201 (2011)
S. Tashenov et al., Phys. Rev. A 87, 022707 (2013)

R. Märtin et al., Phys. Rev. Lett. 108, 264801 (2012)

V. Yerokhin and A. Surzhykov, Phys. Rev. A 82, 062702 (2010)

Stokes parameters

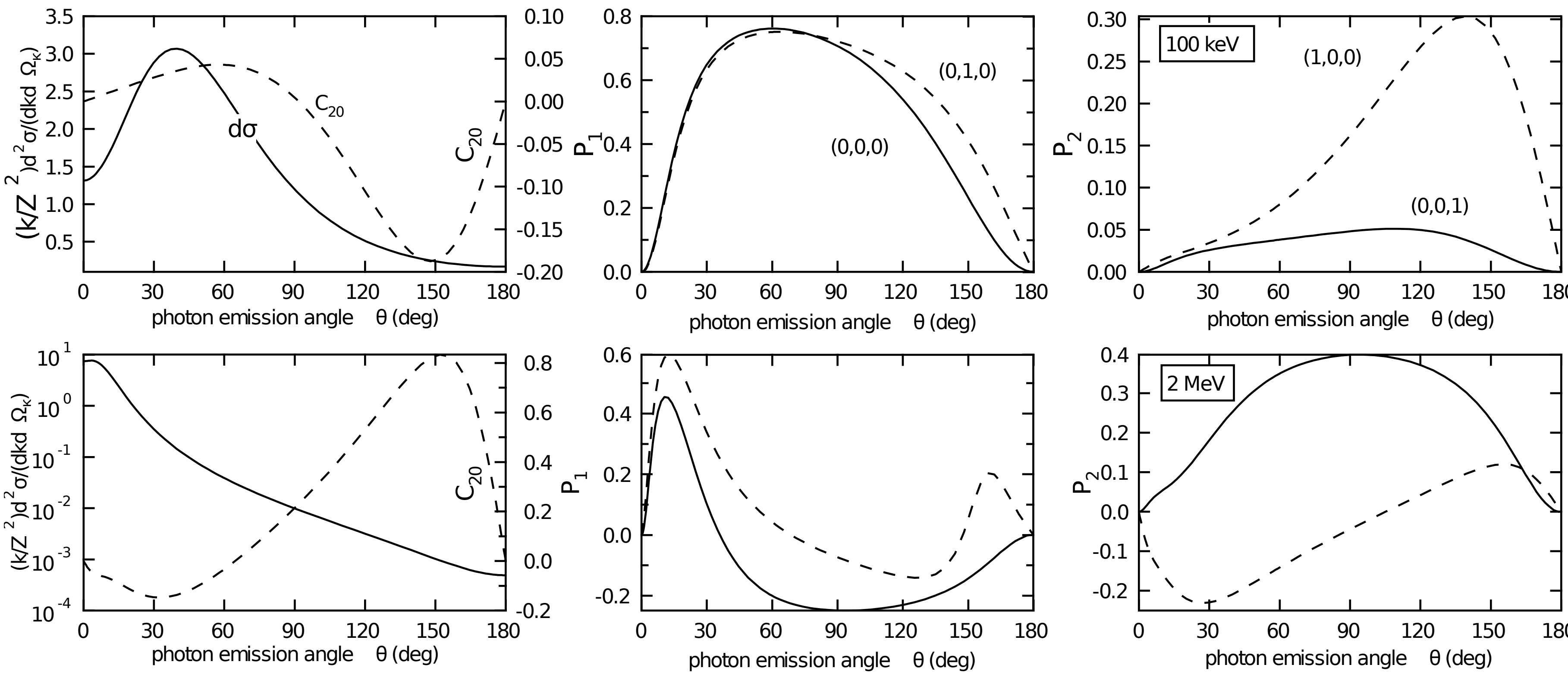
<table>
<tr><th>Parameter</th><th>Illustration</th><th>Value</th><th>Meaning</th></tr>
<tr><td>P_1</td><td>
</td><td>+1
-1</td><td>Linear polarization within the scattering plane
Linear polarization perpendicular to the scattering plane</td></tr>
<tr><td>P_2</td><td>
</td><td>+1
-1</td><td>Linear polarization within the plane turned out of the scattering plane by 45° counterclockwise
Linear polarization within the plane turned out of the scattering plane by 45° clockwise</td></tr>
<tr><td>P_3</td><td>
</td><td>+1
-1</td><td>Left-handed circular polarization
Right-handed circular polarization</td></tr>
</table>



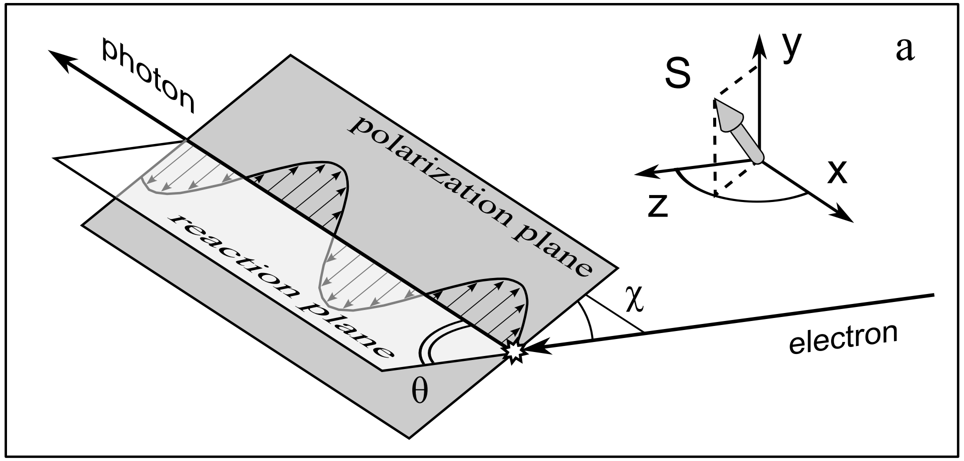
$$C_{20} = 1 - \frac{d\sigma(0,1,0)}{d\sigma(0,0,0)} \qquad P = \sqrt{P_1^2 + P_2^2} \qquad \sin 2\chi = \frac{P_2}{P}$$

100 keV

2 MeV



S. Tashenov et al., Phys. Rev. A 87, 022707 (2013)



$$d\sigma = d\sigma(0,0,0)\,(1 - S_y C_{20})$$

$$P_1 = \frac{P_1(0,0,0)(1-S_y) + P_1(0,1,0)(1-C_{20})S_y}{1 - S_y C_{20}}$$

$$P_2 = \frac{P_2(1,0,0)S_x + P_2(0,0,1)S_z}{1 - S_y C_{20}}$$

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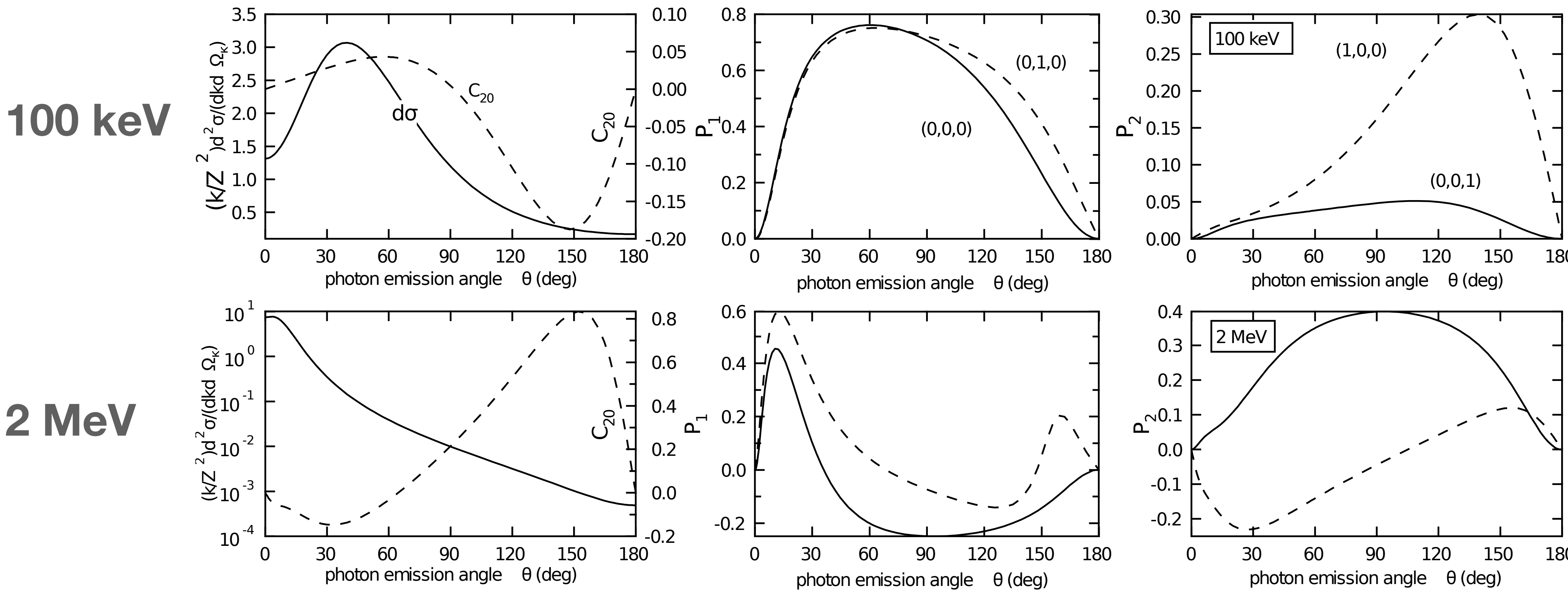
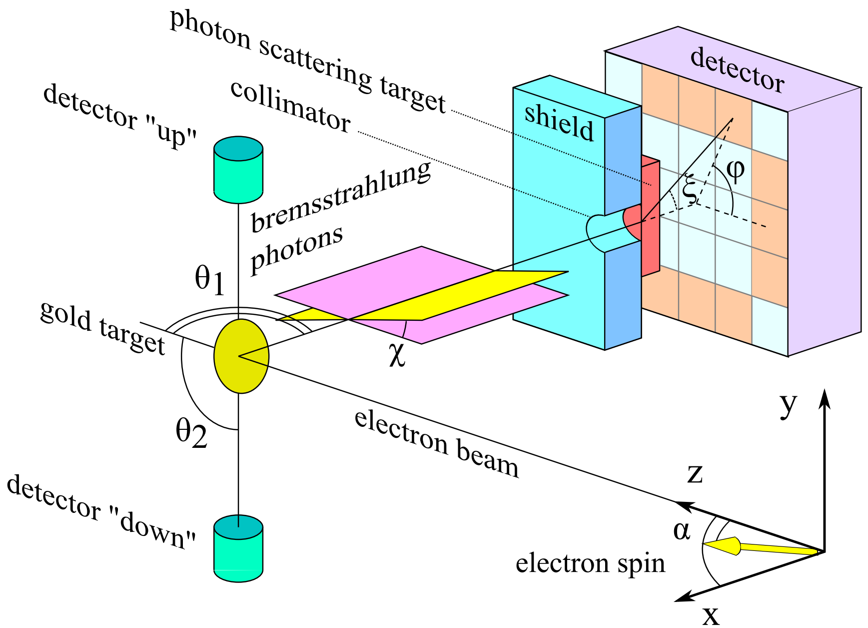


S. Tashenov et al., Phys. Rev. A 87, 022707 (2013)

Electron polarimetry with bremsstrahlung



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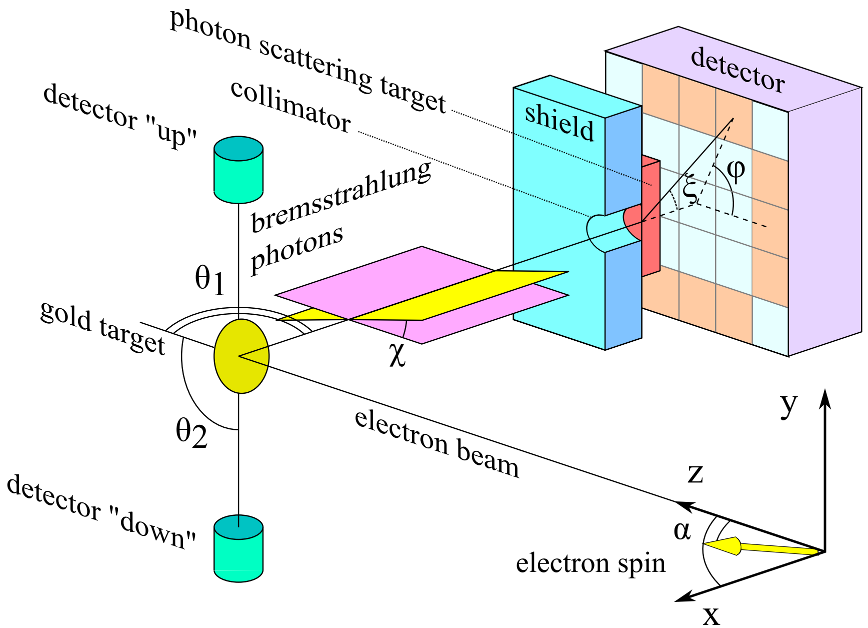

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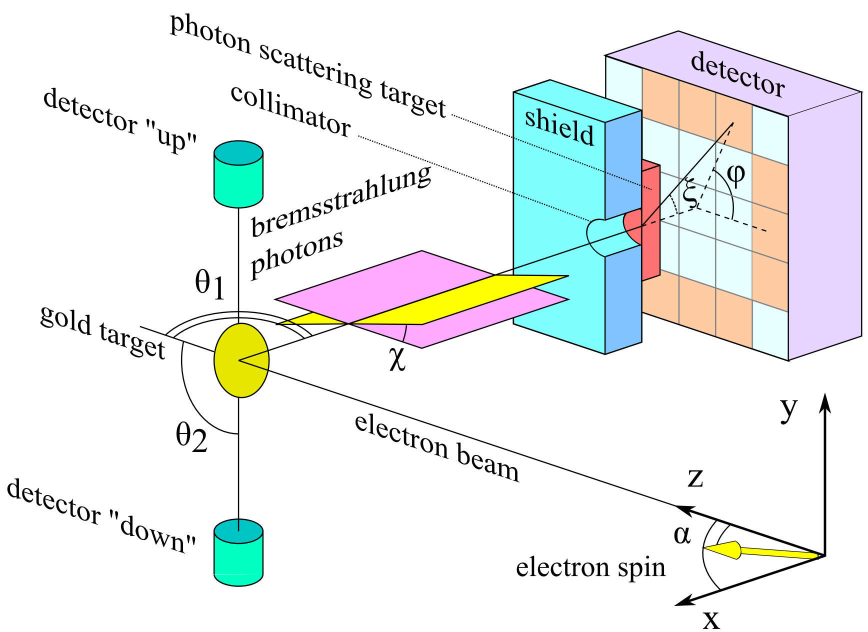

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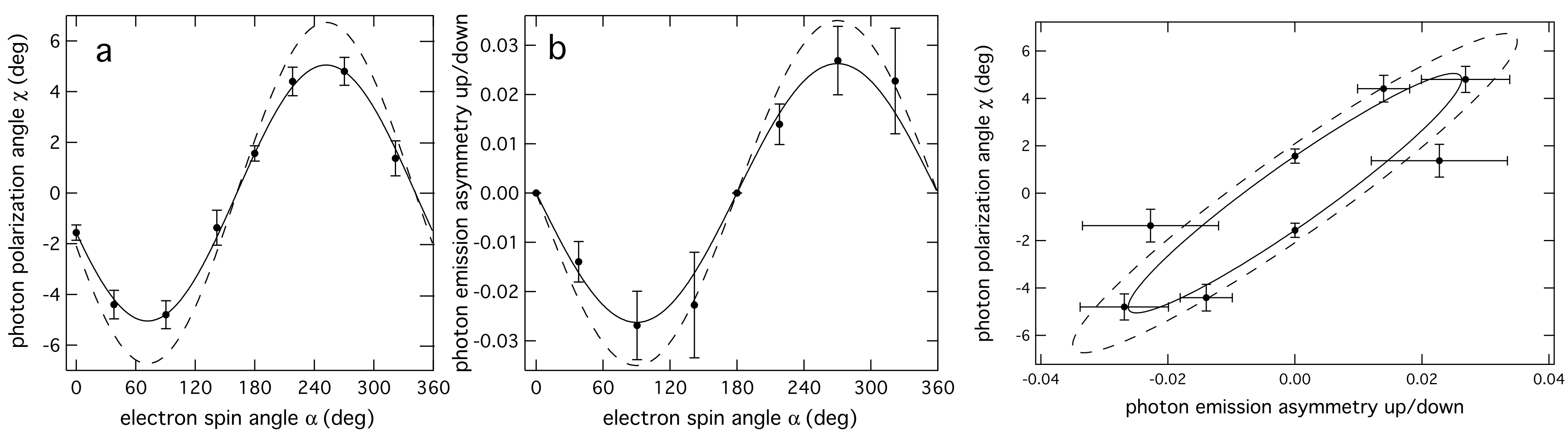

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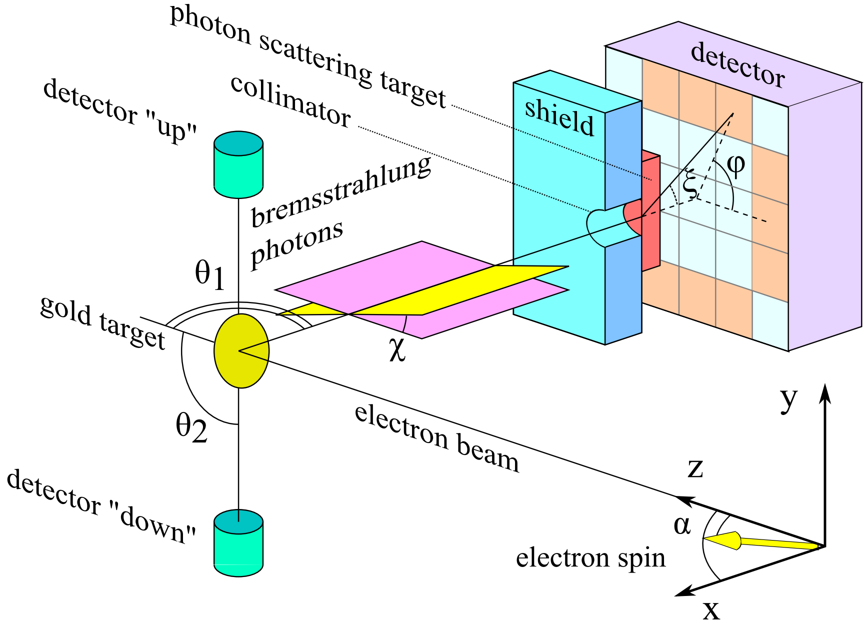
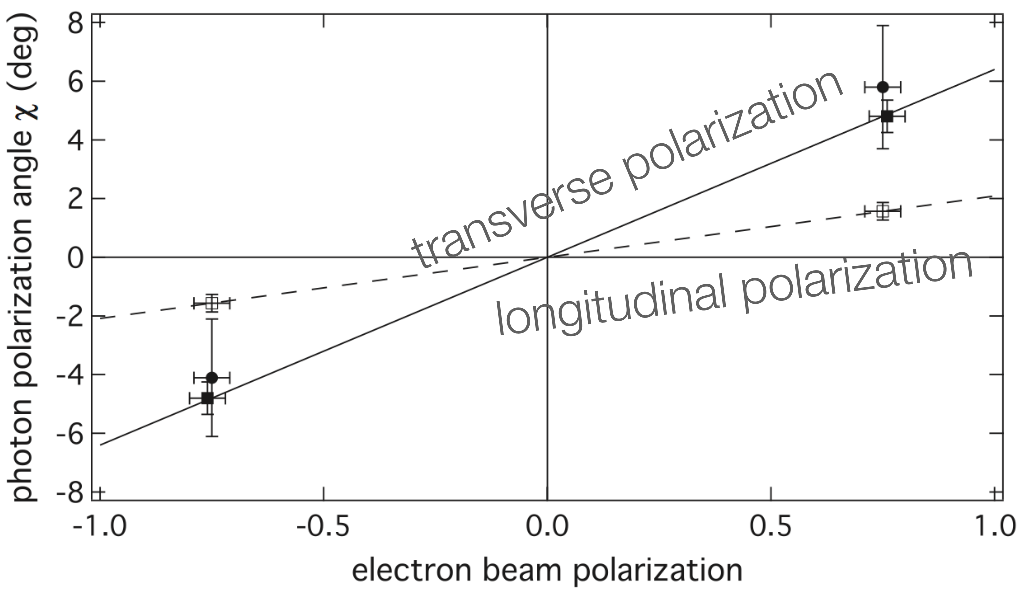




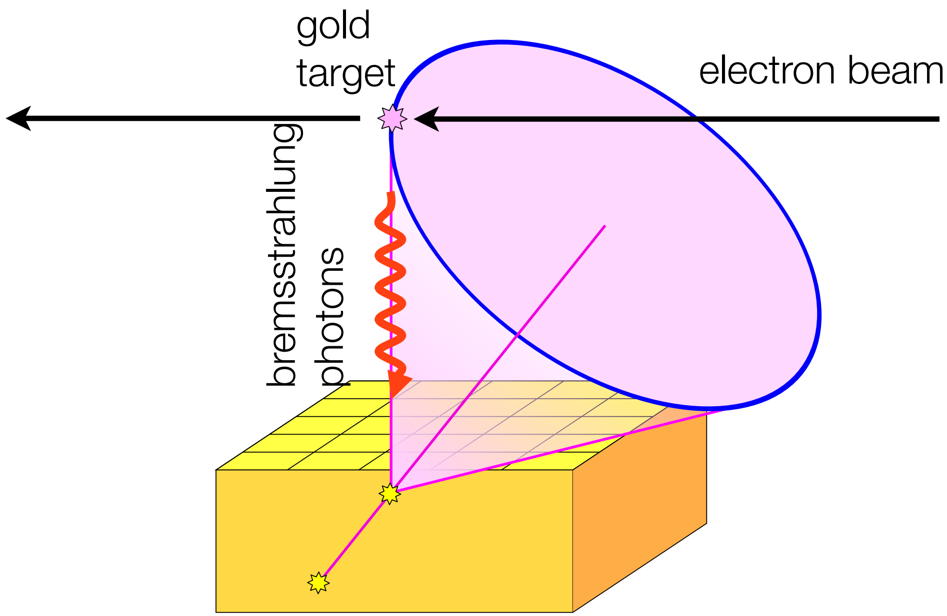
$S = 0.72 \pm 0.14$ Transverse polarization

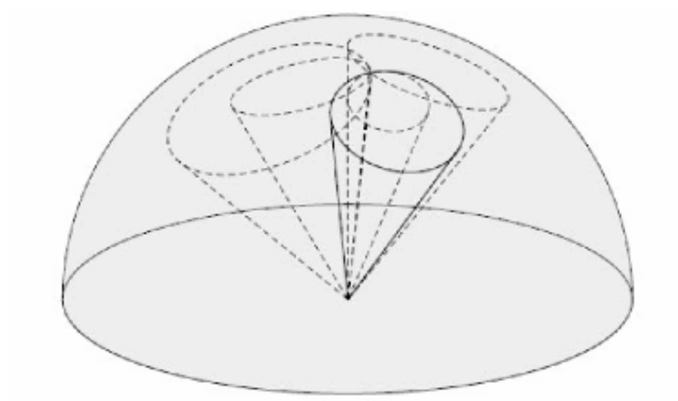
$S = 0.75 \pm 0.09$ Longitudinal polarization

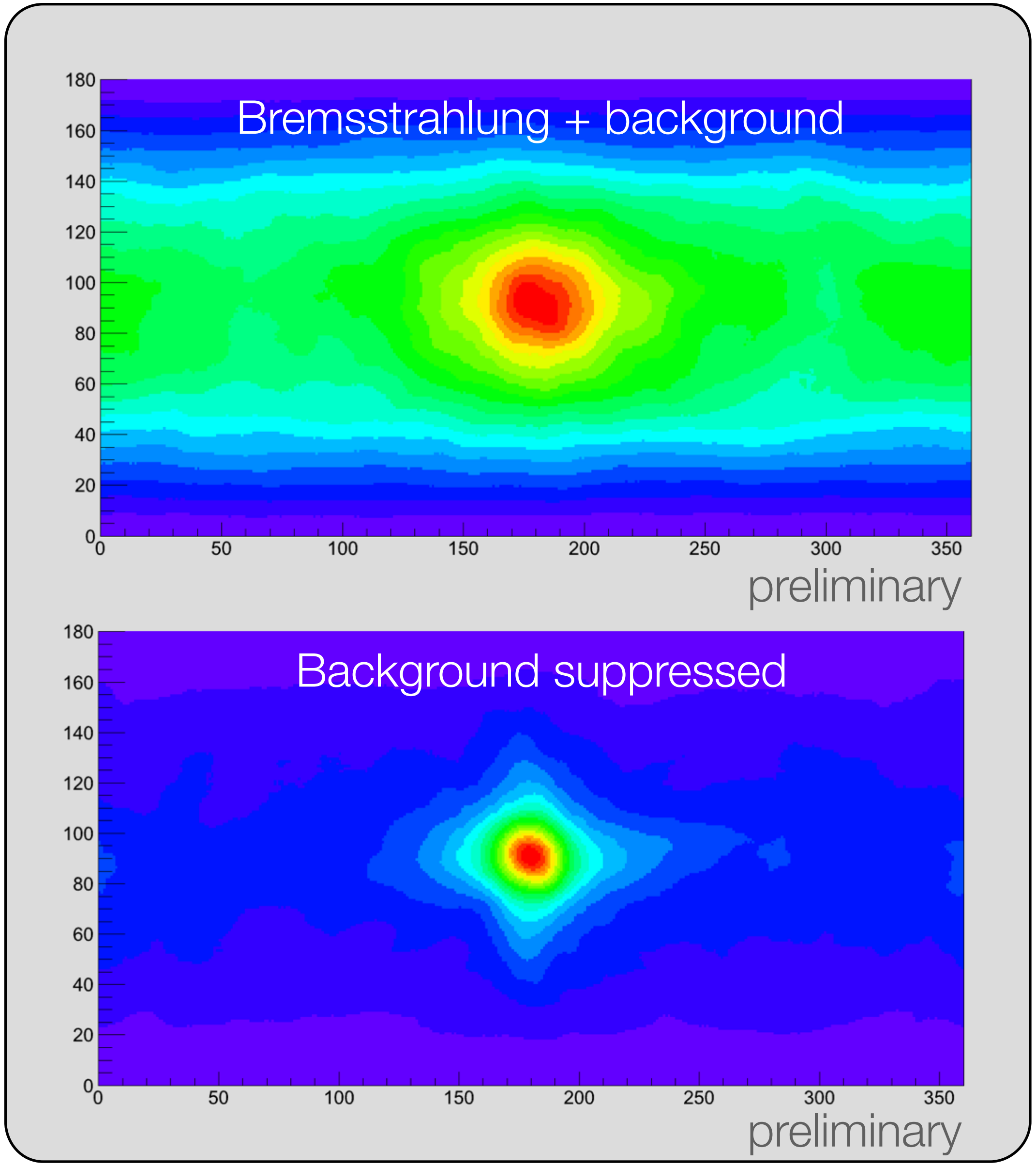
$S = 0.75 \pm 0.04$ Mott polarimetry

Measurement of bremsstrahlung polarization correlations at **2 MeV**

Experiment at Mainz Microtron MAMI



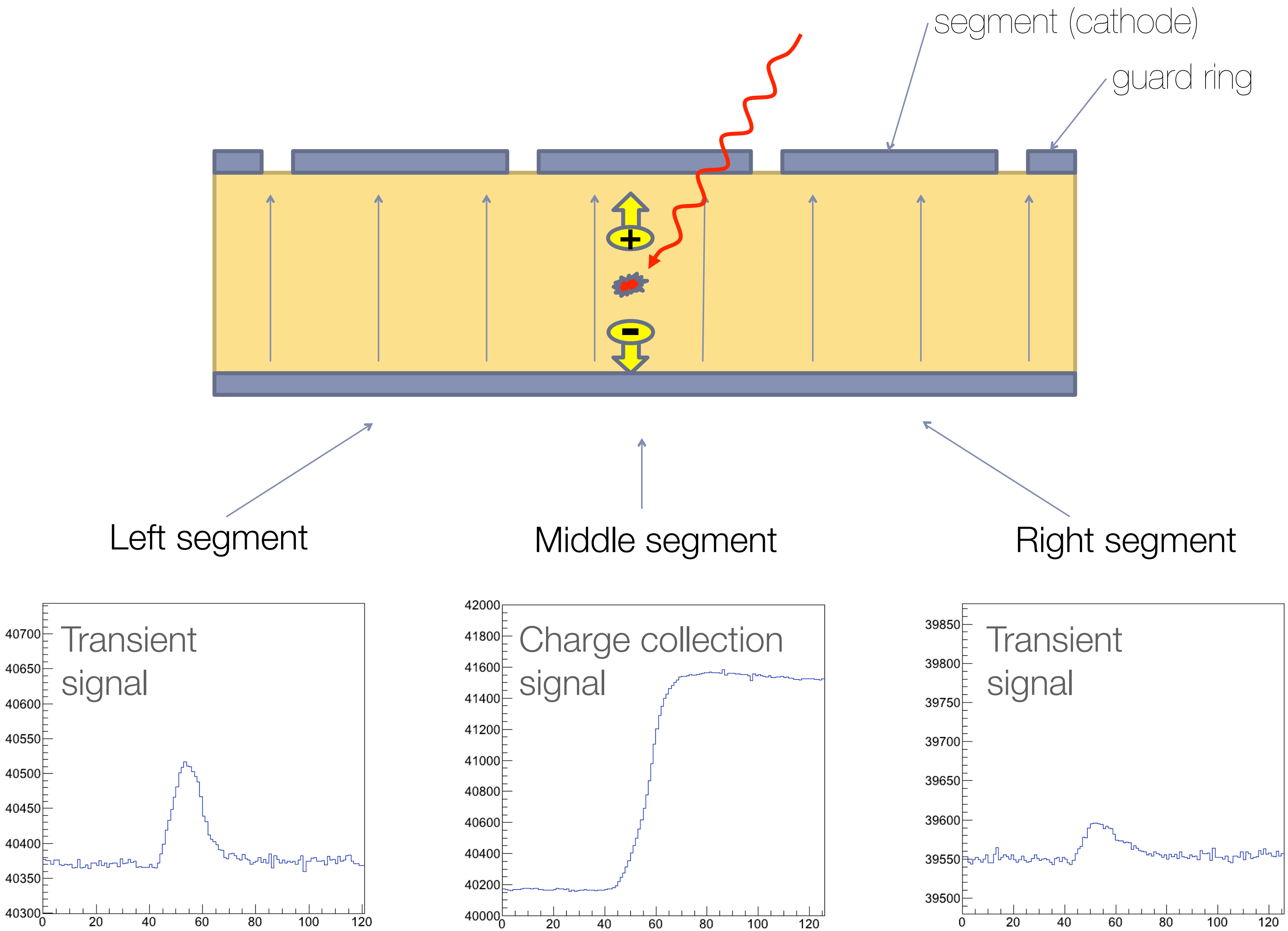




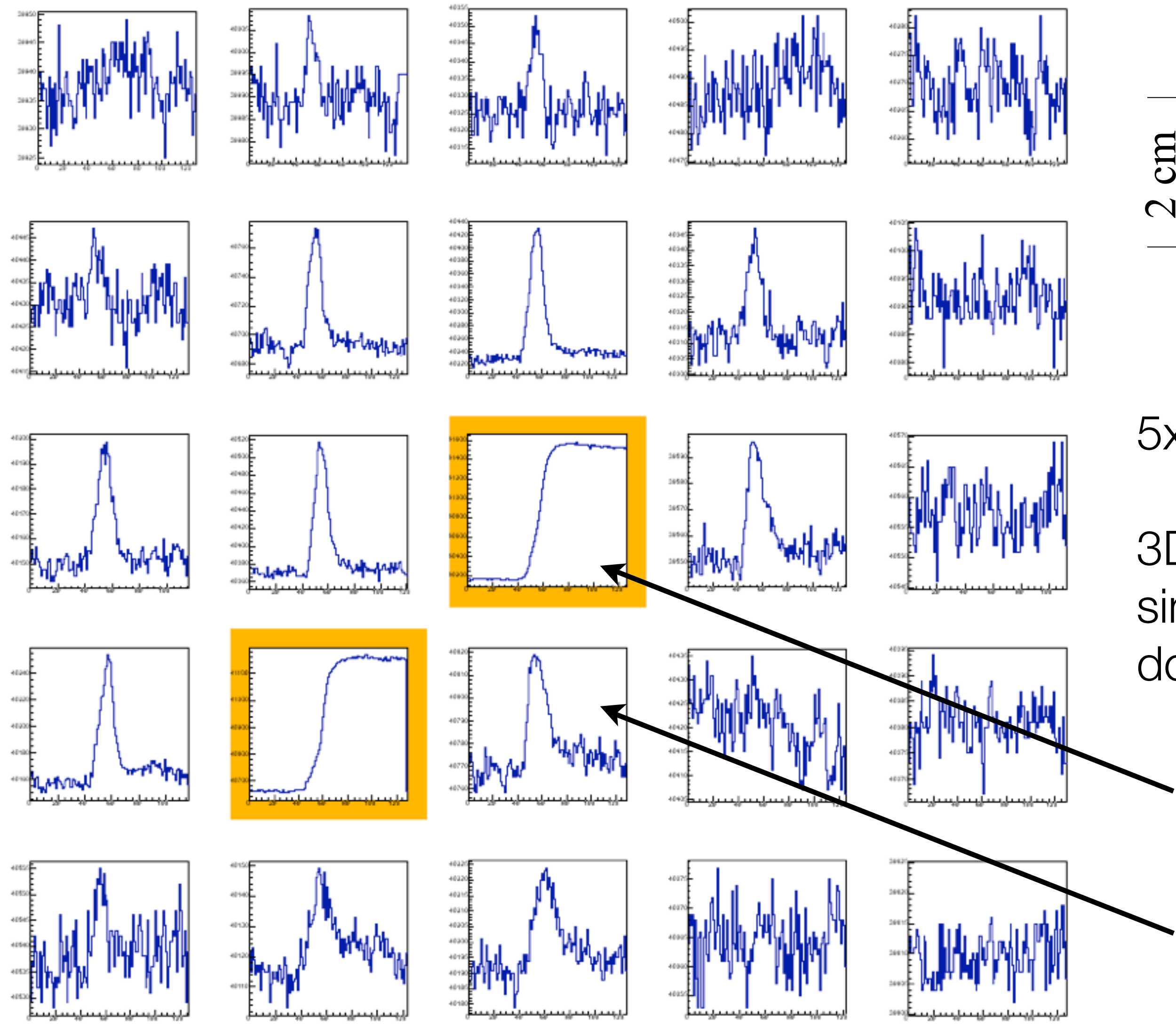
Radiation background suppression via **Compton Imaging**

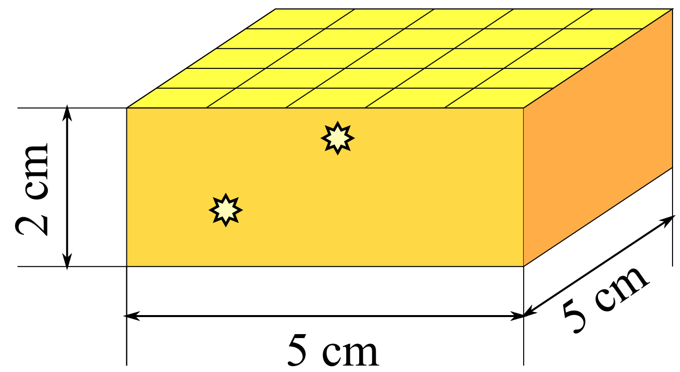
First-time use of the Compton Imaging in a laboratory physics experiment

Charge collection and transient detector pulses



Typical pulse pattern for 25-pixel detector and a Pulse Shape Analysis technique

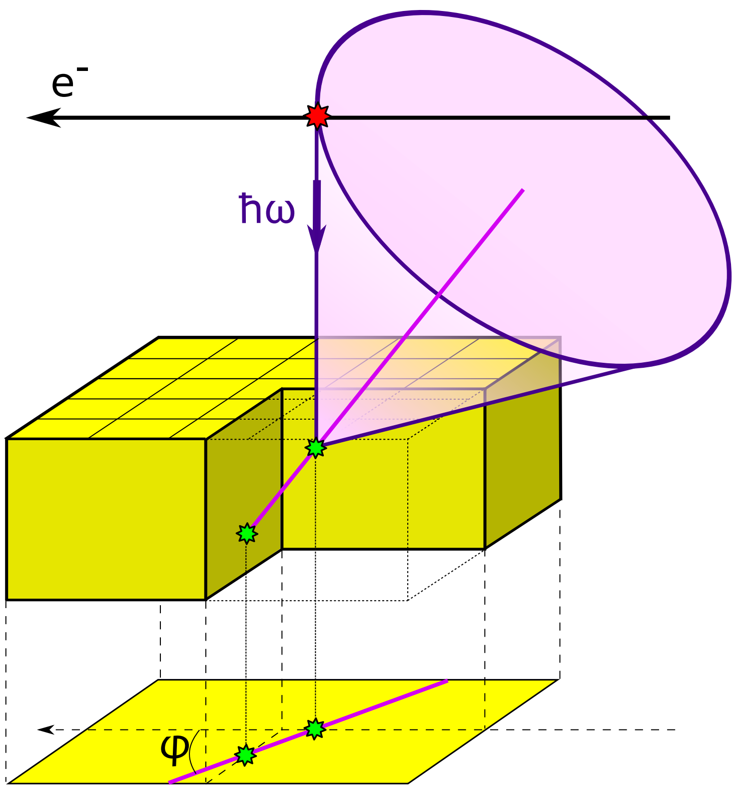


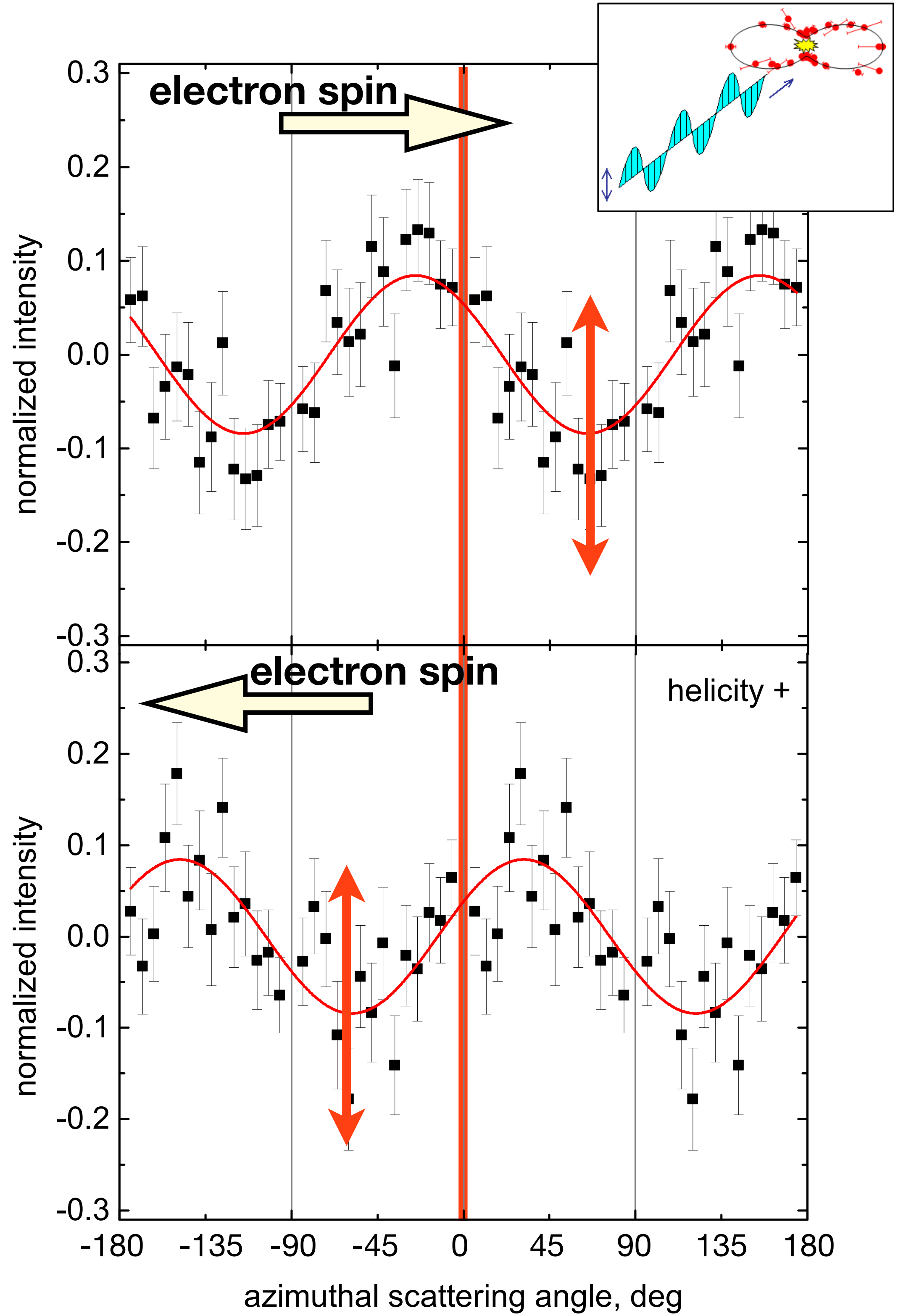


5x5 matrix of 10x10x20 mm pixels

3D Position resolution
single interactions - 1x1x1 mm
double interactions - 3x3x3 mm

Preliminary results

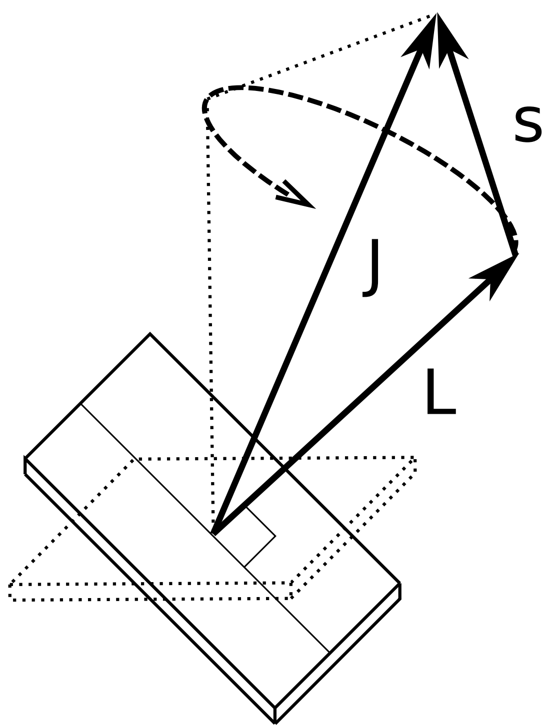


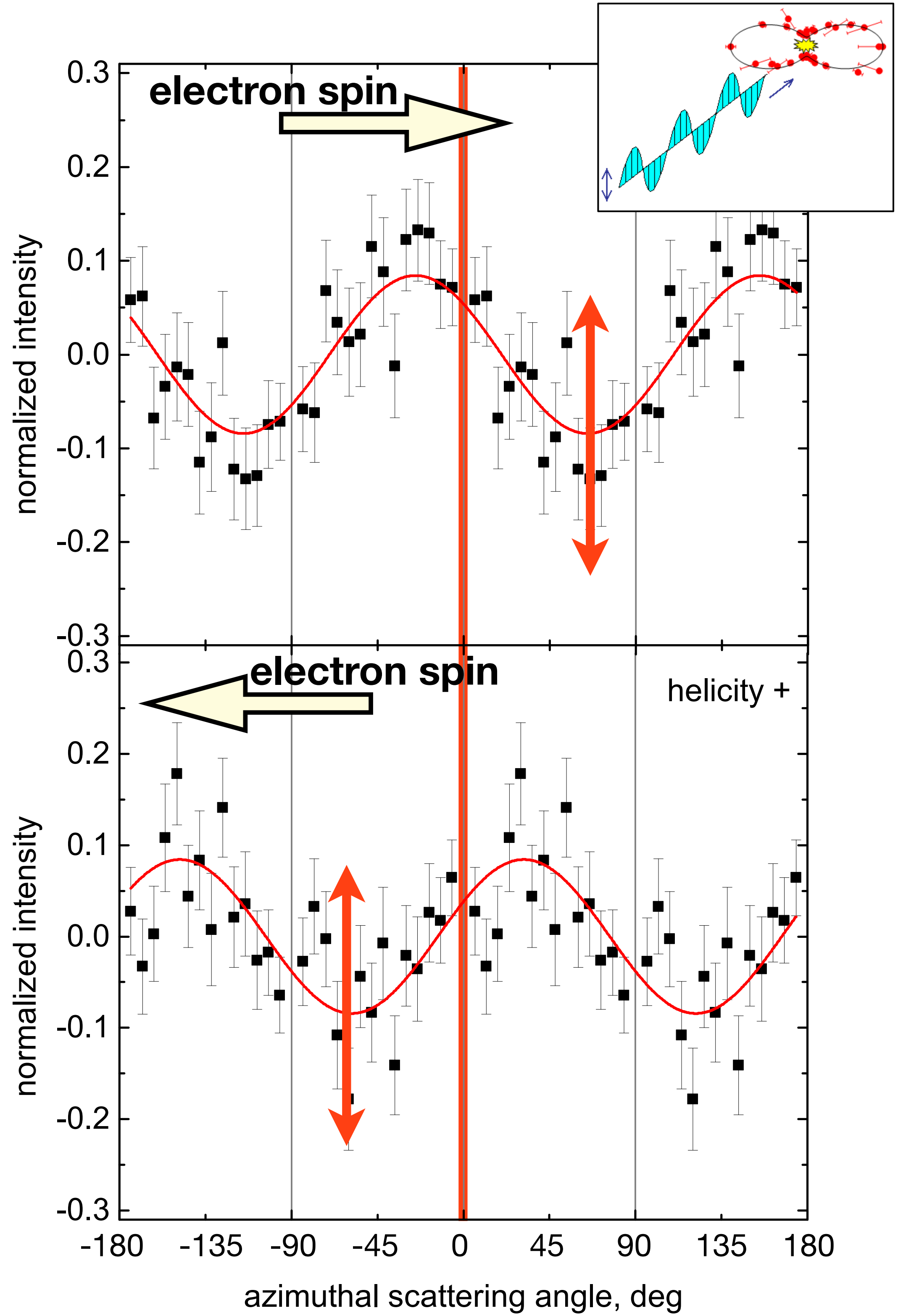


Preliminary results

The polarization plane rotates by tens of degrees

Dramatically enhanced effect of the spin-orbit interaction

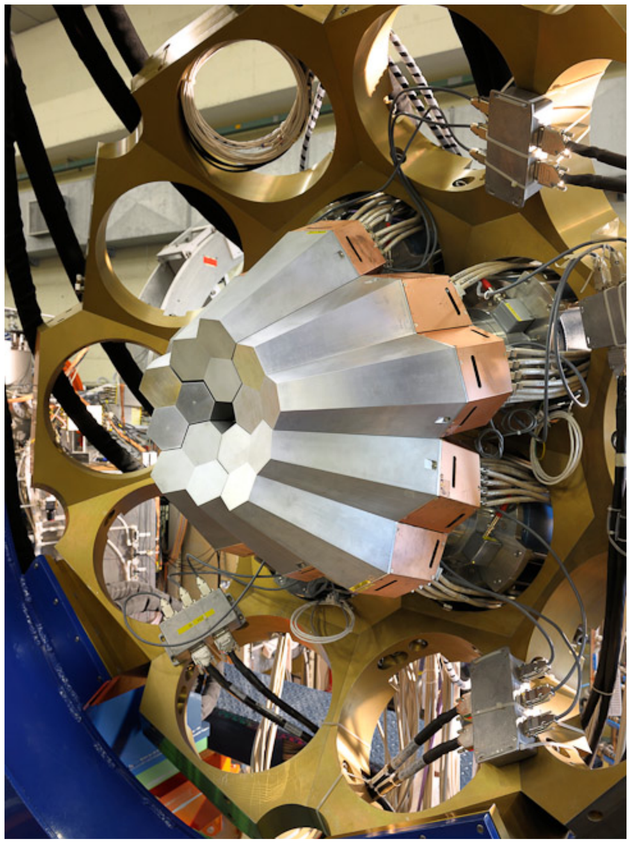


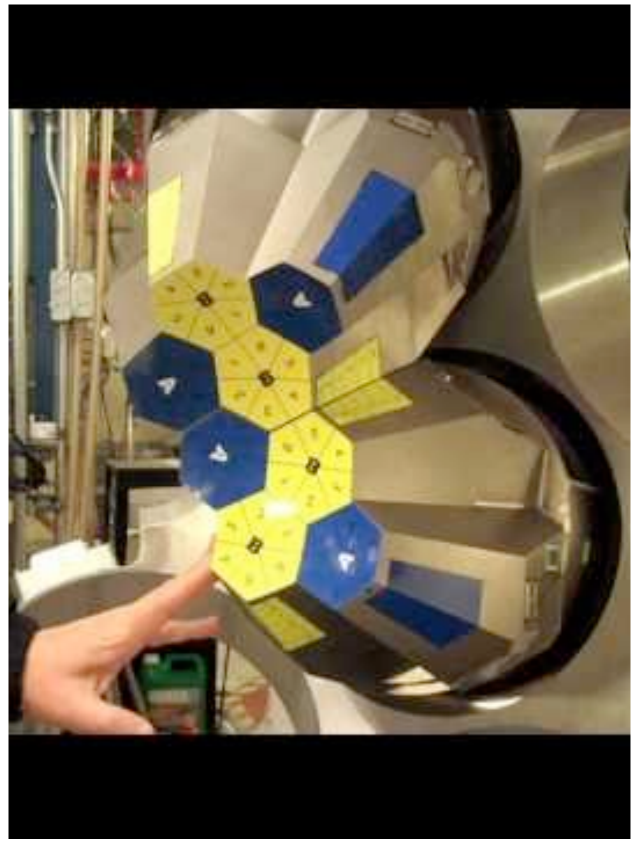


Currently developed large germanium spectrometers

AGATA (Europe)

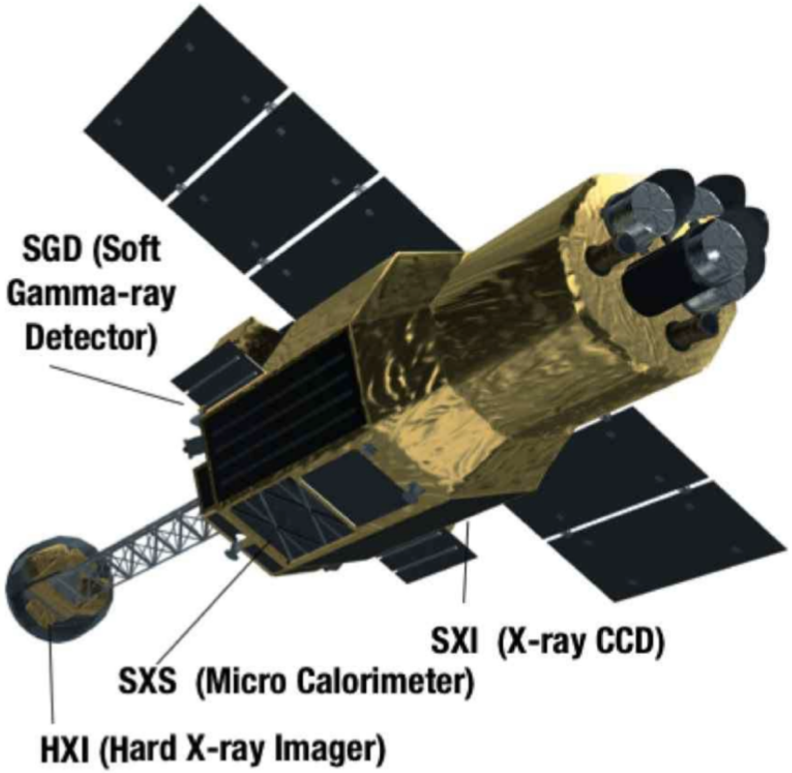
GRETA (USA)

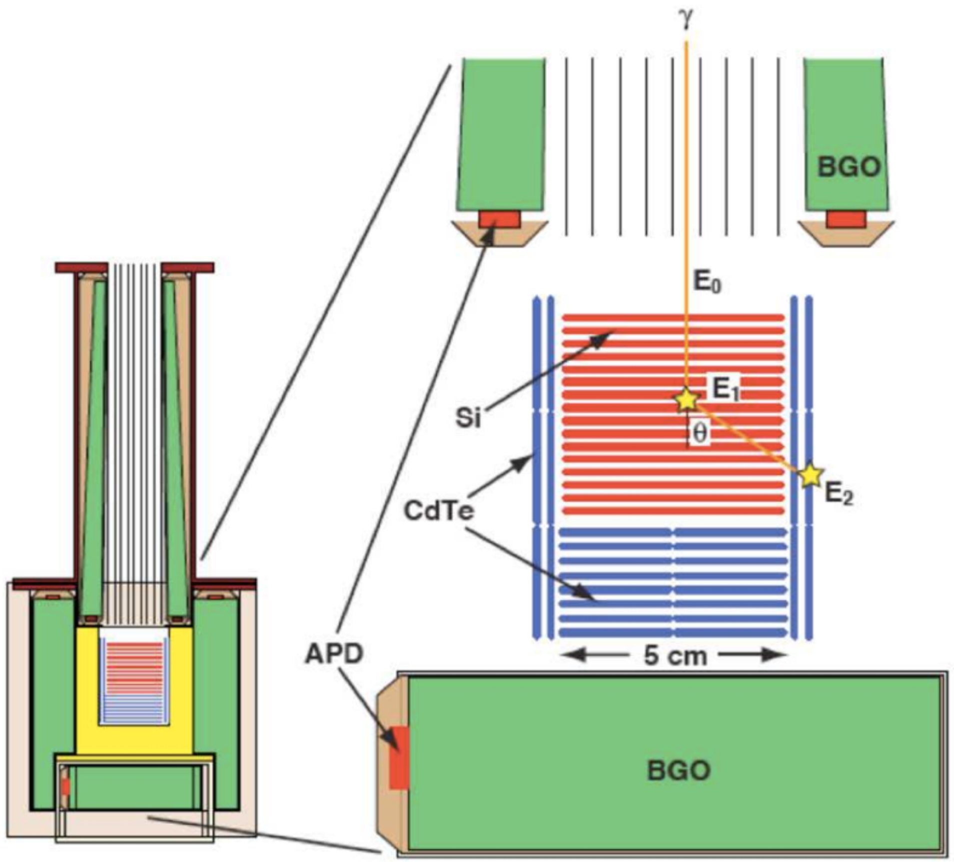




Capable of Pulse Shape Analysis,
Compton imaging and polarimetry

ASTRO-H X-ray Observatory (to be launched in 2015)



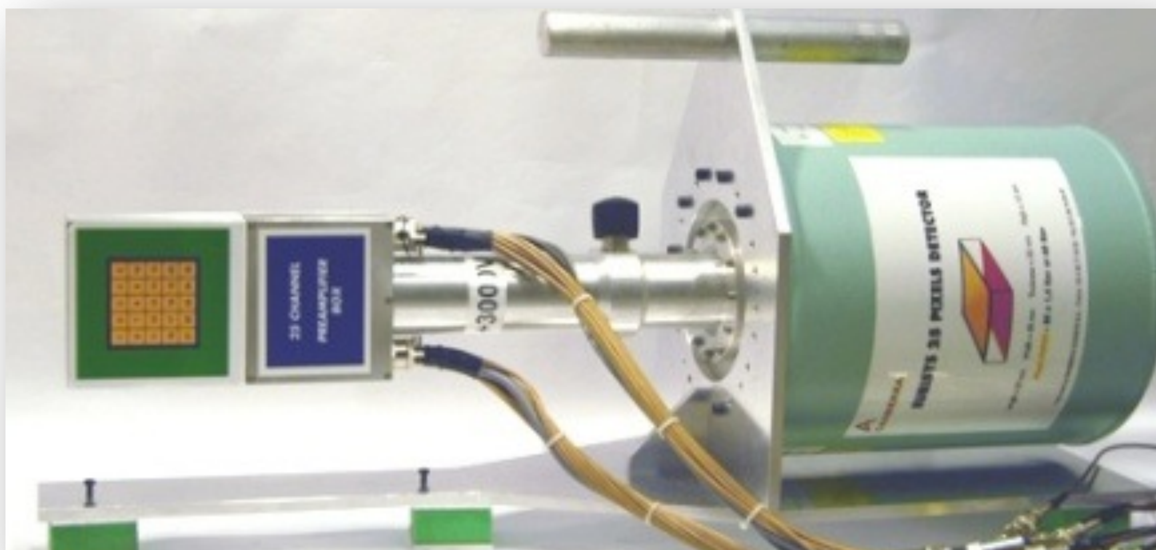


The largest x-ray observatory in a decade, built by Japanese space agency with participation of NASA, ESA and a number of Universities

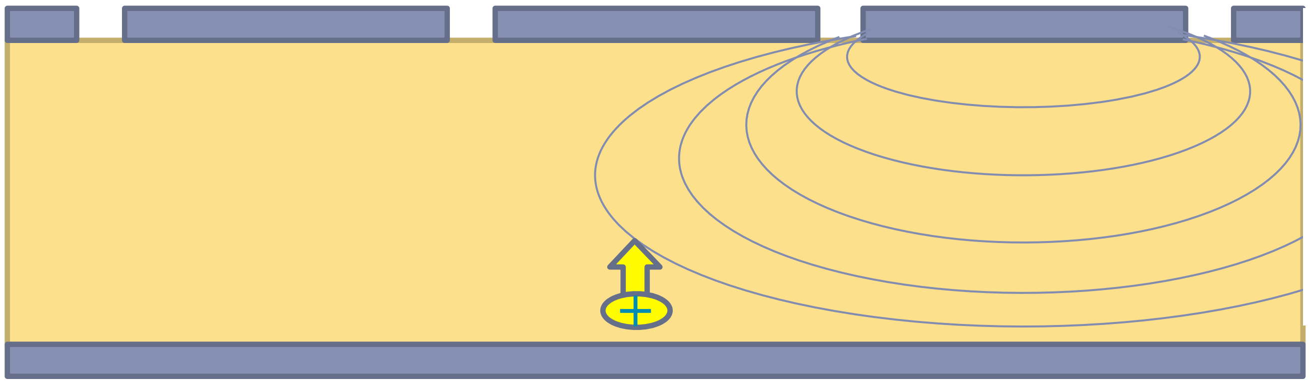
Soft gamma-ray detector

Narrow Field of View Compton Telescope

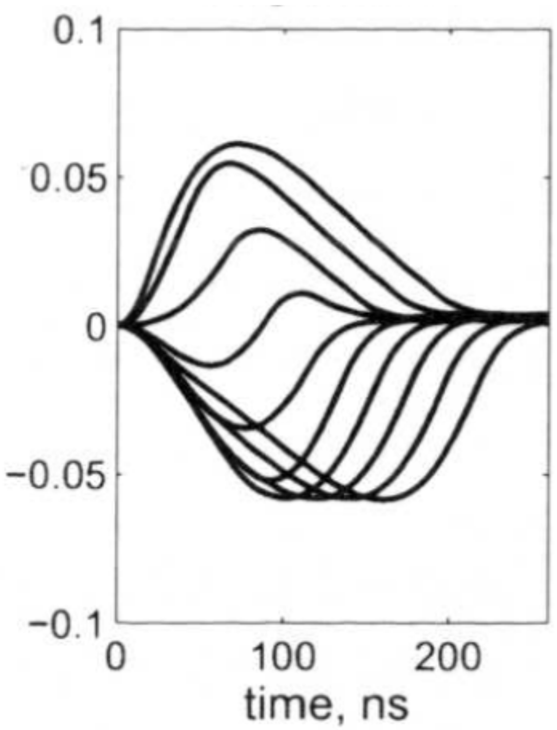
25-pixel planar germanium detector



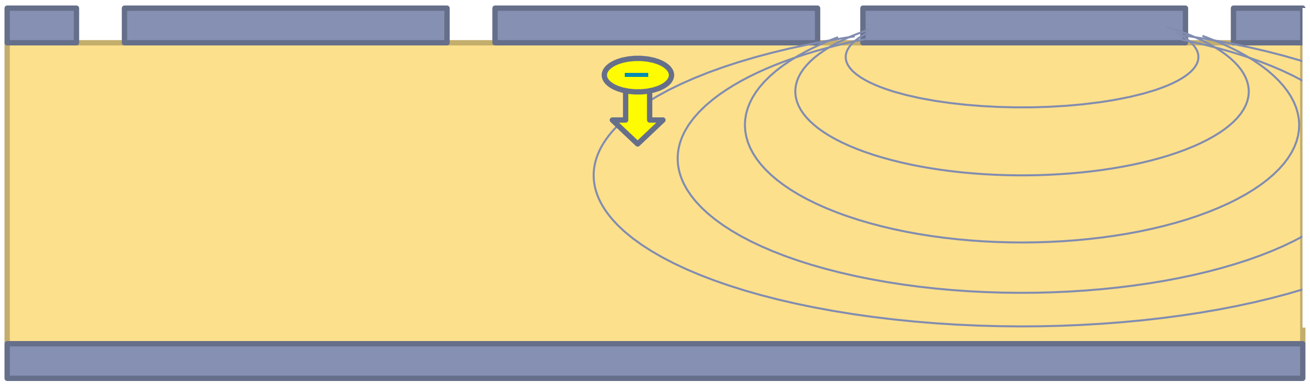
Shockley-Ramo theorem



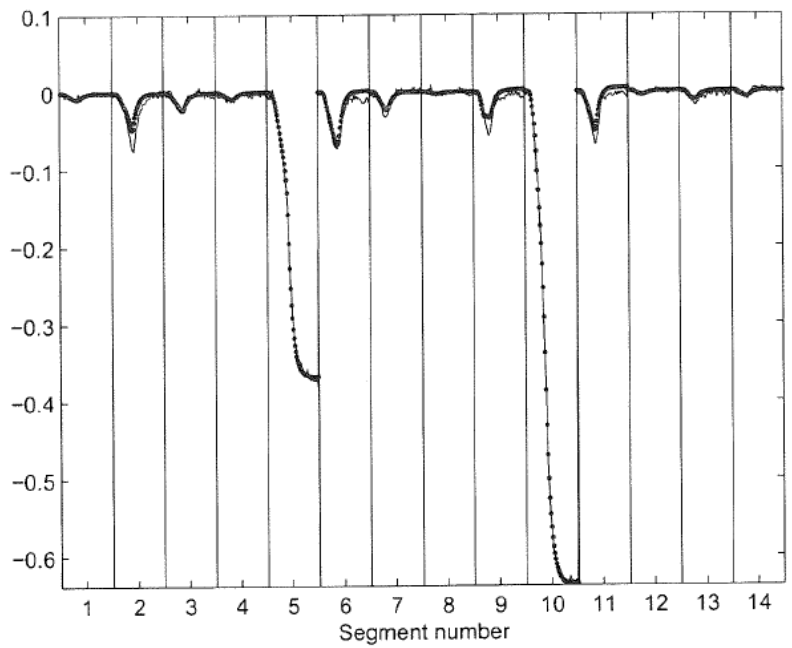
Weighting potential



$$I = q\vec{V} \times \vec{E}_w$$



Pulse Shape Analysis: The Matrix Method



$\overline{x}$ List of energies from all possible locations

$\overline{s}$ Combined signal waveform

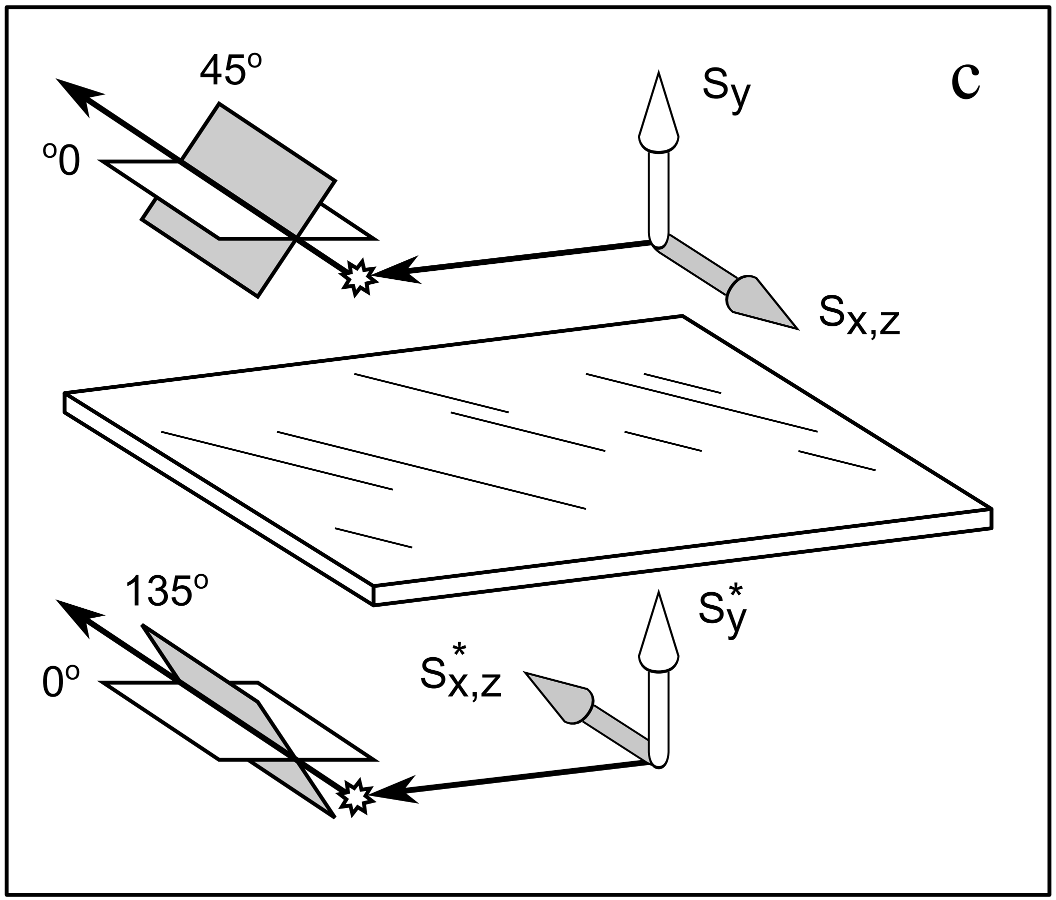
$$M \times \overline{x} = \overline{s}$$

$$\overline{x} = M^{-1} \times \overline{s}$$

M is a matrix of signal waveforms for every potential interaction position

A. Khaplanov, PhD thesis, KTH Stockholm (2010)

Parity conservation in bremsstrahlung



Parity-forbidden correlations

$$d\sigma(0,0,0) = d\sigma(1,0,0) = d\sigma(0,0,1),$$

$$P_1(0,0,0) = P_1(1,0,0) = P_1(0,0,1),$$

$$P_2(0,0,0) = P_2(0,1,0) = 0,$$

Parity-allowed correlations

$$C_{00} = d\sigma(0,0,0),$$

$$C_{03} = P_1(0,0,0),$$

$$C_{11} = -P_2(1,0,0),$$

$$C_{23} = P_1(0,0,0) - P_1(0,1,0),$$

$$C_{31} = P_2(0,0,1),$$

$$C_{20} = 1 - \frac{d\sigma(0,1,0)}{d\sigma(0,0,0)}.$$

COMPTEL telescope
on board of the Compton Gamma Ray Observatory (1991-2000)