Photoelectric Effect

- Introduce polar angle distribution.

  In the actual class the direction of the photoelectron is assigned to the photon direction.
  At low energy the photoelectron have the tendency to be eject in the electric field direction => ⊥ to photon direction.

- Introduce Polarization.

  The cross section was obtained using the Stokes parameters.
  Introduce azimuthal angle distribution.

Polar angle distribution

The polar angle is sample from the K-shell cross section derived by Sauter using K-shell hydrogenic electron wave function:

$$\frac{d\sigma}{d\Omega} = \alpha^4 r_e^2 \left(\frac{Z}{k}\right)^5 \frac{\beta^3}{\gamma} \frac{\sin^2\theta}{(1-\beta\cos\theta)^4} \left[1 + \frac{1}{2}\gamma(\gamma-1)(\gamma-2)(1-\beta\cos\theta)\right]$$

Where: k is the photon energy in mc^2 units, $\gamma = 1 + E/(mc^2)$

and $\beta = \frac{\sqrt{E(E+2mc^2)}}{E+2mc^2}$; E is the electron energy.

Azimuthal angle distribution

To obtain the cross section for polarized photon -> Stokes parameters.

The matrix for the Photoelectric effects is:

$$T = \alpha^4 Z^5 r_o^2 \frac{E}{k^2} \frac{\sin^2\theta}{(1-\beta\cos\theta)^3} \begin{bmatrix} 1+D & -D & 0 & 0 \\ 0 & 0 & 0 & -A \\ 0 & 0 & 0 & B \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Where:

$$D = \frac{1}{k}\left[\frac{2}{k\,E(1-\beta\cos\theta)} - 1\right]$$

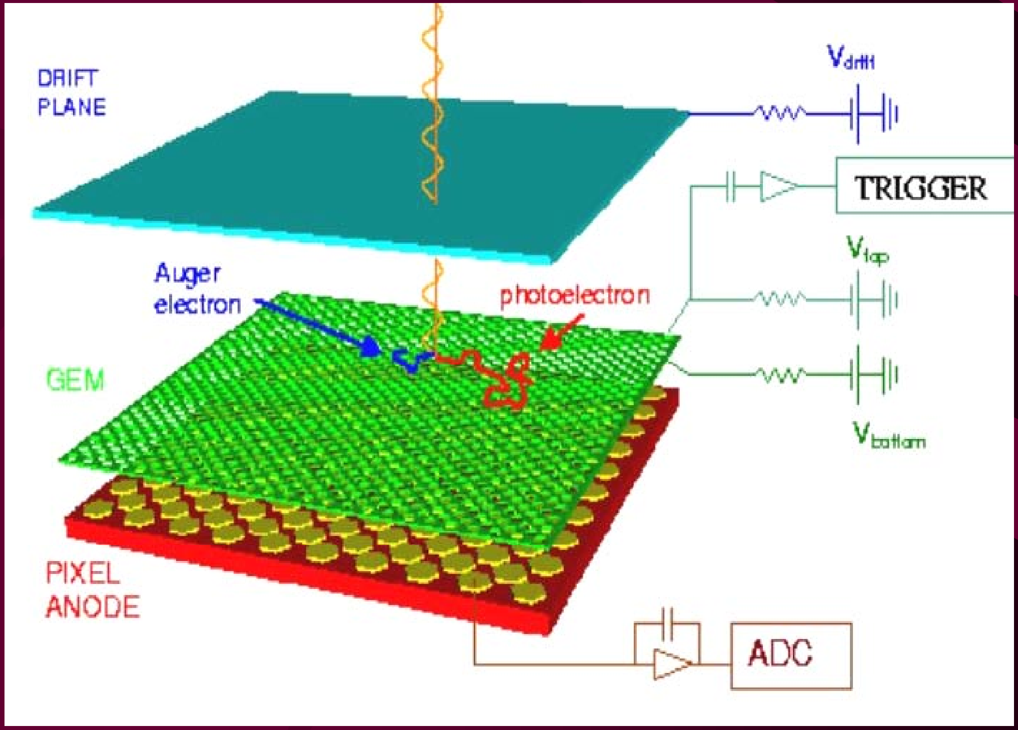
So the cross section for polarized incident radiation is:

$$d\sigma = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix} T \begin{bmatrix} 1 \\ -\cos 2\phi \\ -\sin 2\phi \\ 0 \end{bmatrix} \approx 1 + 2D\cos^2\phi$$

Comparison with experiment

To test the new class -> comparison with experimental data published in Nature (vol. 411, 2001) by E. Costa et. al. : “An efficient photoelectric X-ray polarimeter for the study of black holes and neutron stars” and related publications.

The experiment →



Gas: 80% Ne, 20% dimethylether at 1 atm.

GEM hole geometry: 40 µm diameter, 60 µm pitch.

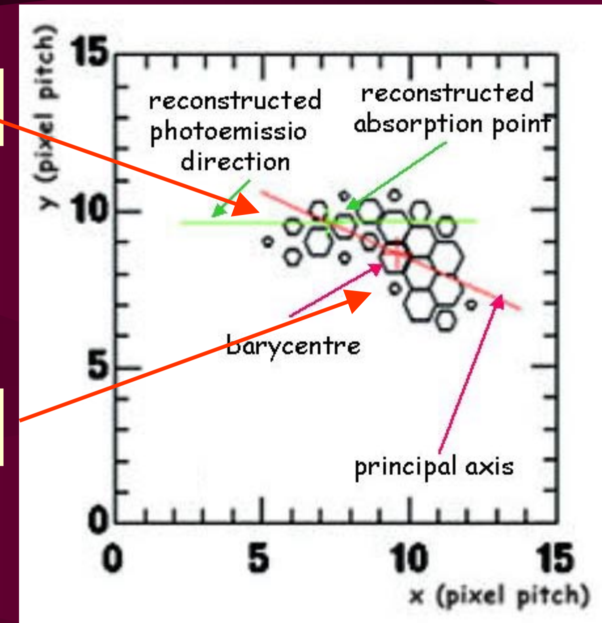
128 anodes with a pitch of 200 µm

Drift/absortion gap: 6 mm.

Experimental results

Measure of a single photoelectron track.

The dimension of the hexagons is proportional to the energy deposited

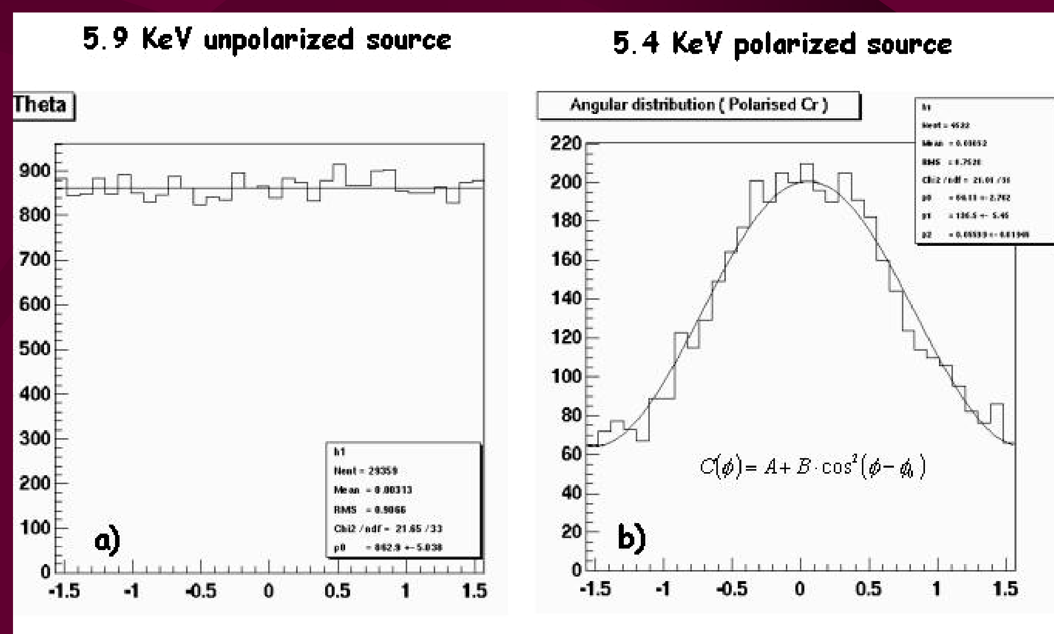


Azimuthal distribution of the charge barycentre.

Modulation factor for 100% linearly polarized radiation:

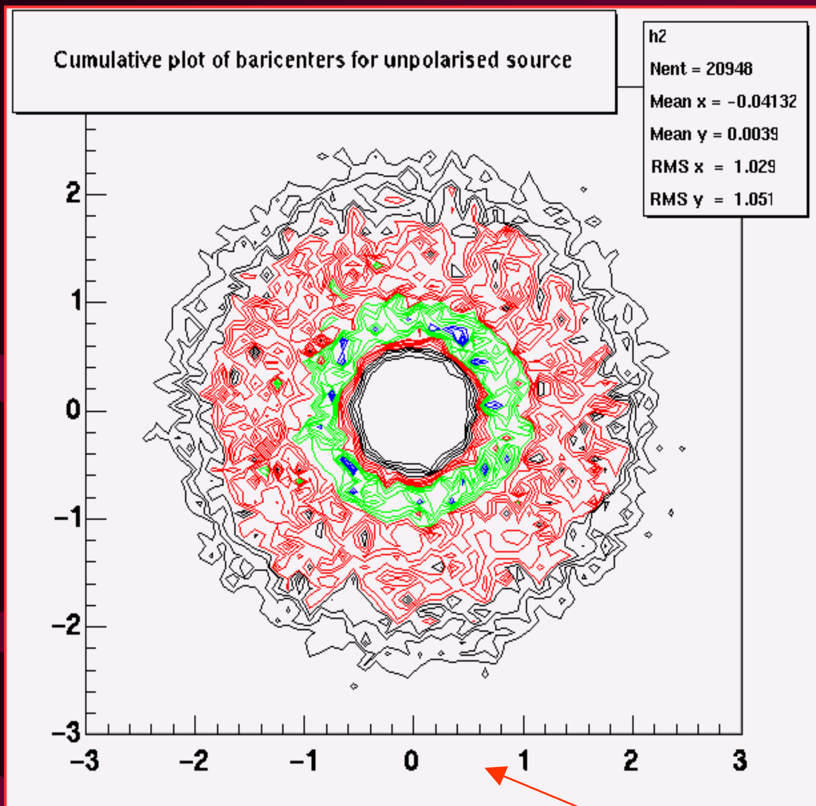
$$\mu = \frac{C_{max} - C_{min}}{C_{max} + C_{min}} = \frac{B}{2A + B}$$

In this case, μ = 0.44

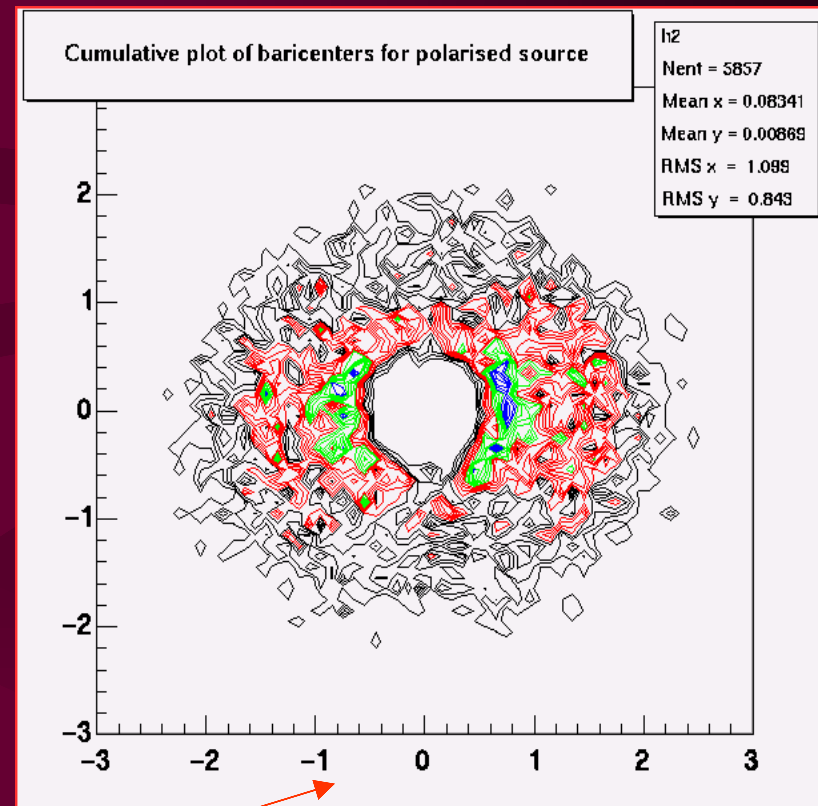


Spatial distribution of barycentre for unpolarized and polarized source.

5.9 KeV unpolarized source



5.4 KeV polarized source



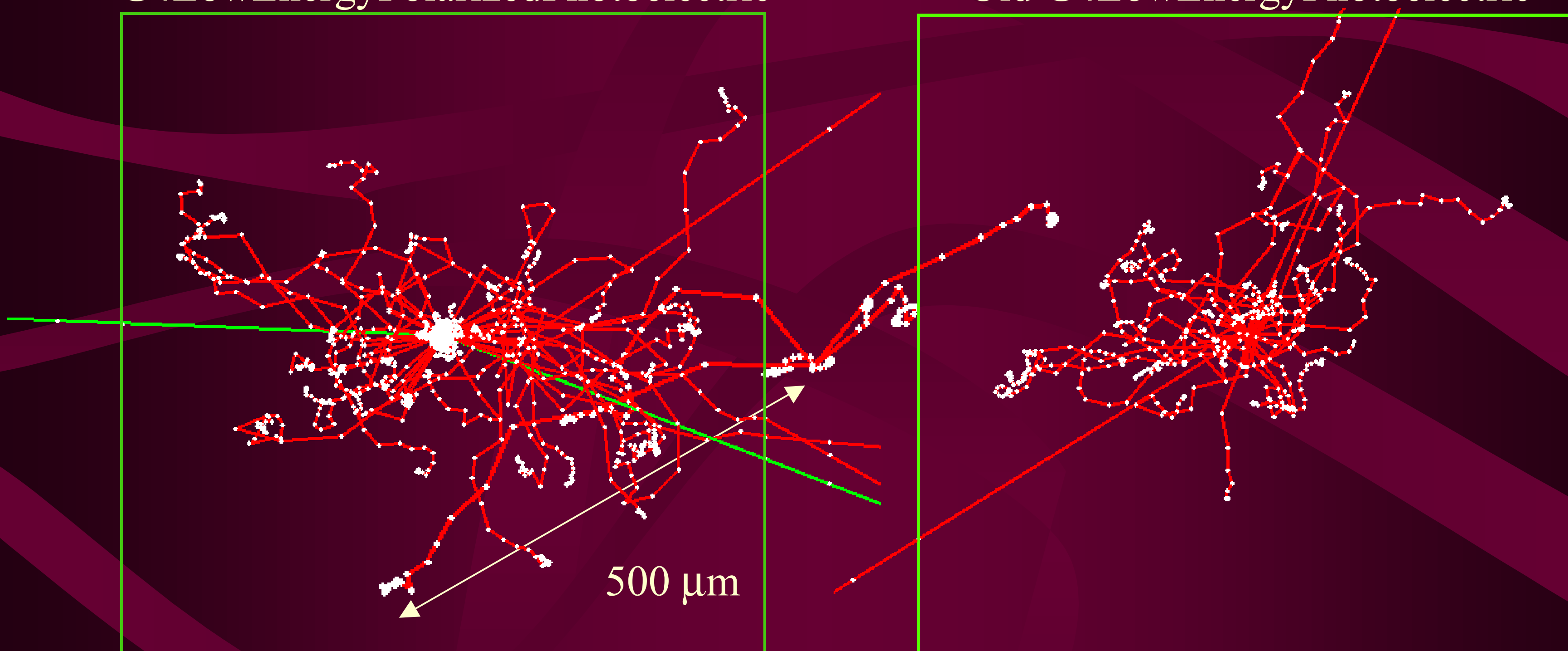
Scale in pixel. 1 pixel = 260 μm

The polarized source was obtain by Rayleigh scattering at 90º on a Li target of photons produced by an X-ray tube with Cr anode.

Simulation

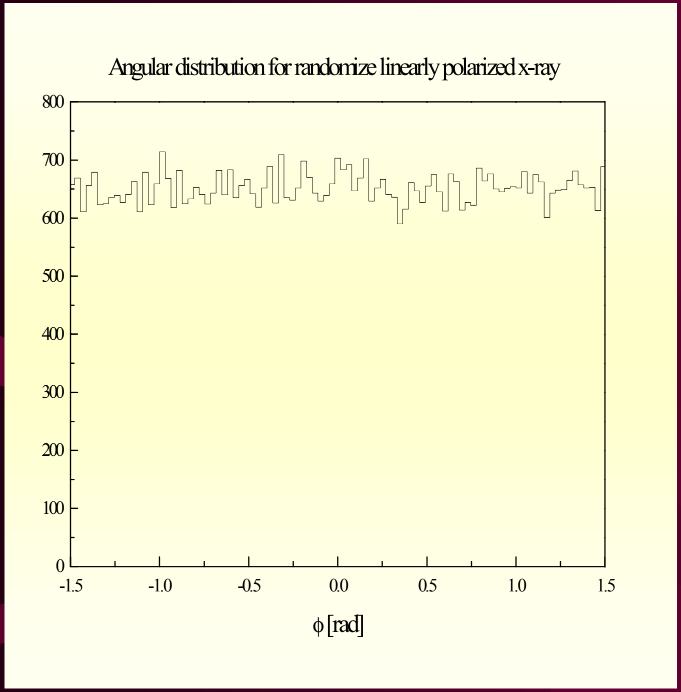
Geometry → Box of 10 x 1 x 1 mm^3 with 80% Ne and 20% dimethylether

G4LowEnergyPolarizedPhotoelectric   Old G4LowEnergyPhotoelectric

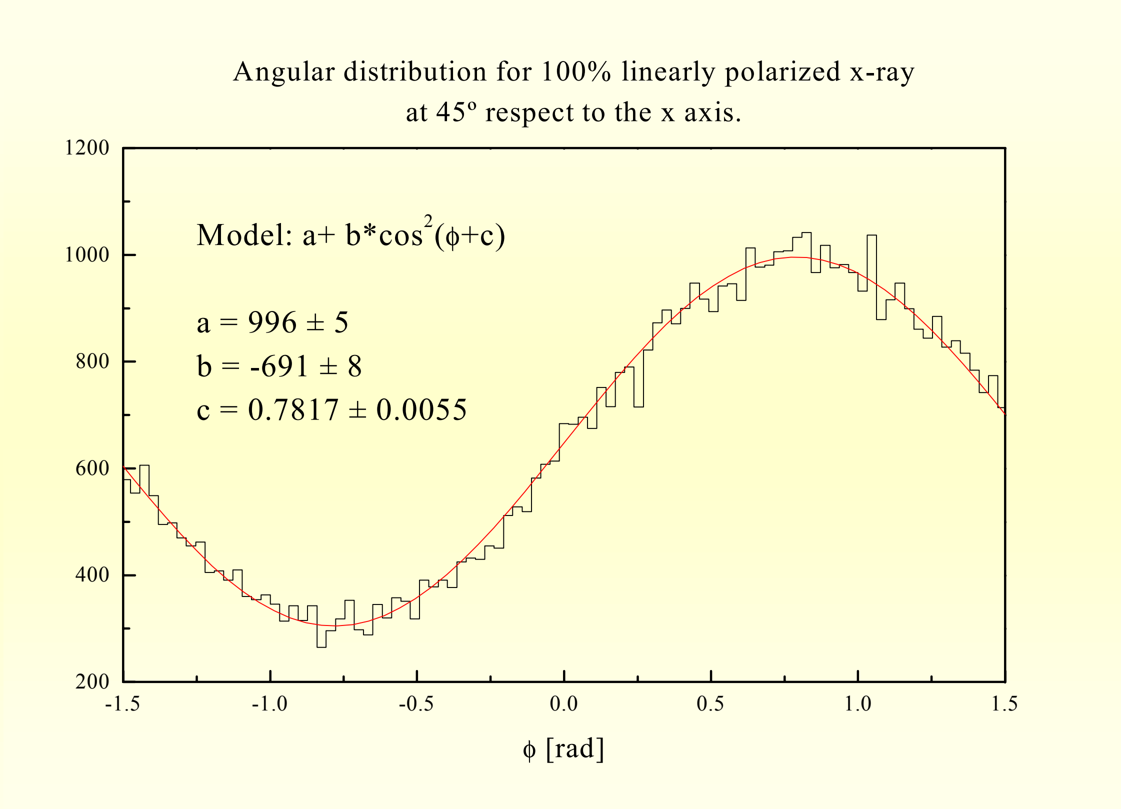


Azimuthal distribution of barycentre

Unpolarized



Polarized



Modulation factor $\mu = 0.41$

Impact point: $x = 0$, $y = 0$.

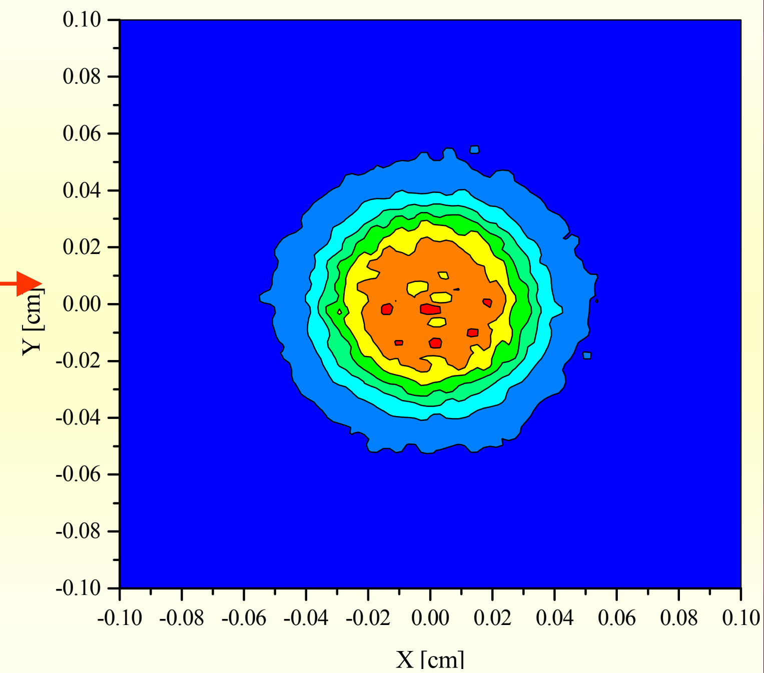
Charge Barycentre:

$$x_b = \sum \frac{x_i E_i}{E_T} \qquad y_b = \sum \frac{y_i E_i}{E_T}$$

=> the azimuthal angle $\phi = \mathrm{atan}(y_b/x_b)$

Spatial distribution of barycentre

Unpolarized



Polarized:

$\phi = 0^{o}$

$\phi = 45^{o}$