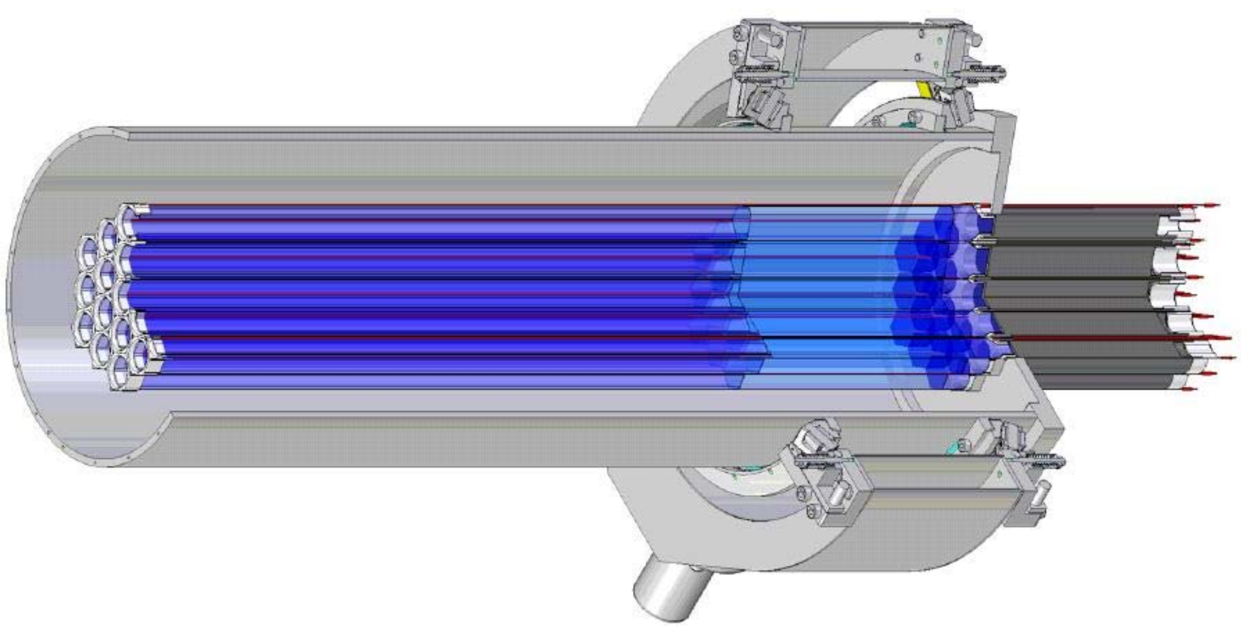
PoGOLite and Simulation of Inverse Compton Scattering

Tomas Ekeberg & Bianca Iwan



GLAST Lunch Meeting – December 14th, 2006

Outline

- PoGOLite – the Polarized Gamma-ray Observer
- The detector
- The Star Tracker System
- Polarimetry measurements
- Simulations of Inverse Compton Scattering

PoGOLite (1)

- International Collaboration between USA, Sweden, Japan, France
- Balloon-borne experiment for measuring polarization of hard X-rays from different astronomical objects (25 – 100keV)
- Consists of 217 Phoswich Detector Cells (PDC‘s)
- Side and bottom anti-coincidence shielding with BGO crystals
- Effective detector area: 243 cm^2 ; Field of view: 5 deg^2
- Polarization measured through coincident detection of Compton Scattering and photoabsorption
- Detects 10% polarization from a 100 mCrab source in a 6 h flight

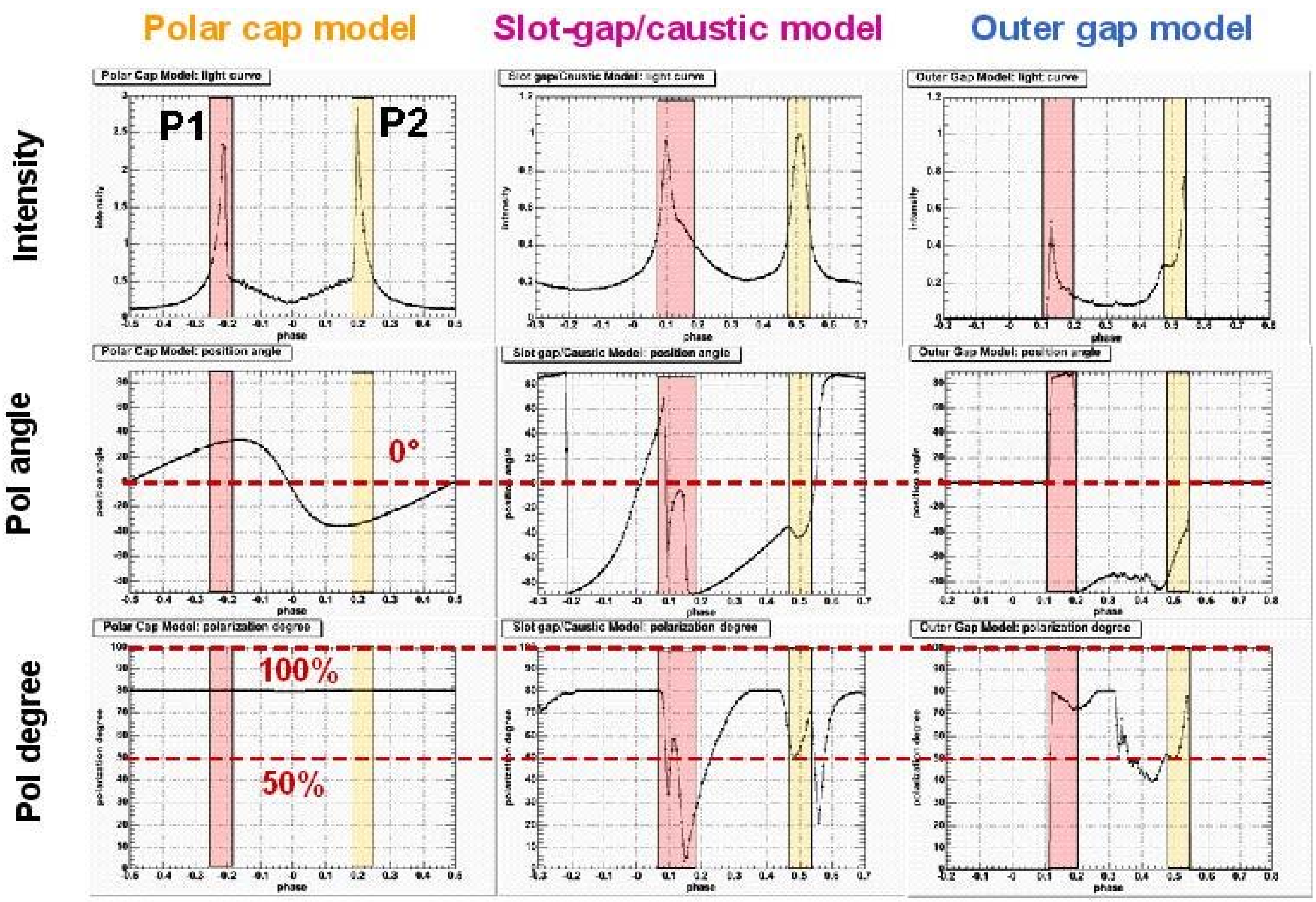
PoGOLite (2)

Emission mechanisms for polarization:

- Synchrotron radiation:
  - Rotation powered neutron stars (Crab pulsar)
  - Pulsar nebulae (Crab nebula)
  - Jets in AGN‘s and micro-quasars (Mkn 501)
- Compton Scattering:
  - Accretion disks around BH‘s and neutron stars (Cygnus X-1)
- Magnetized neutron stars:
  - Surface of highly magnetized neutron stars (Her X-1)

⇨ Sensitive polarimeter necessary!

PoGOLite (3)



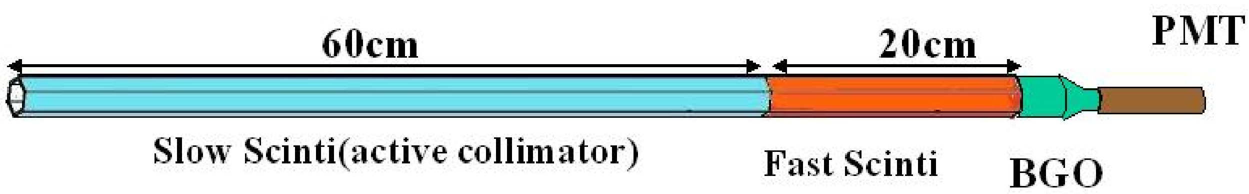
Polar cap model
Slot-gap/caustic model
Outer gap model
Intensity
Pol angle
Pol degree
Polar Cap Model: light curve
Slot gap/Caustic Model: light curve
Outer Gap Model: light curve
P1
P2
Polar Cap Model: position angle
Slot gap/Caustic Model: position angle
Outer Gap Model: position angle
0°
Polar Cap Model: polarization degree
Slot gap/Caustic Model: polarization degree
Outer Gap Model: polarization degree
100%
50%
phase

Detector Units (1)

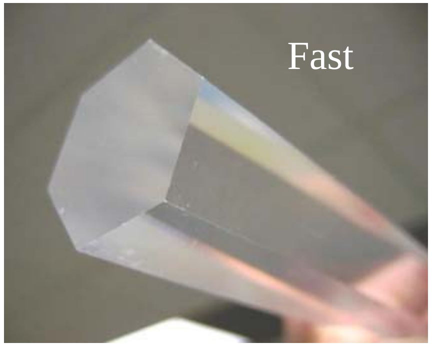
Phoswich-Detector-Cell:

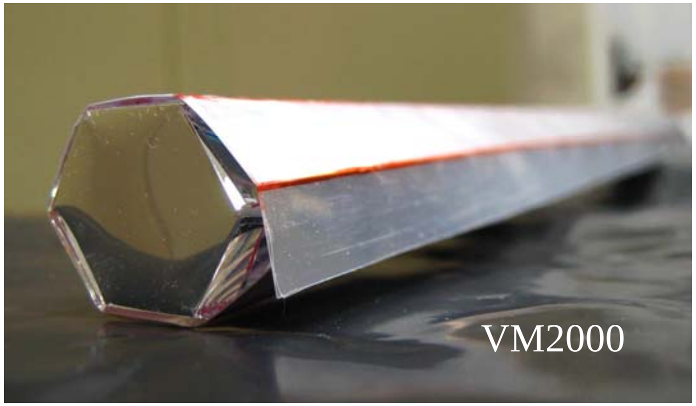
- **Fast scintillator:** Detection of photo-absorption and Compton Scattering
- **Slow Scintillator:** Rejection of cosmic-ray induced events

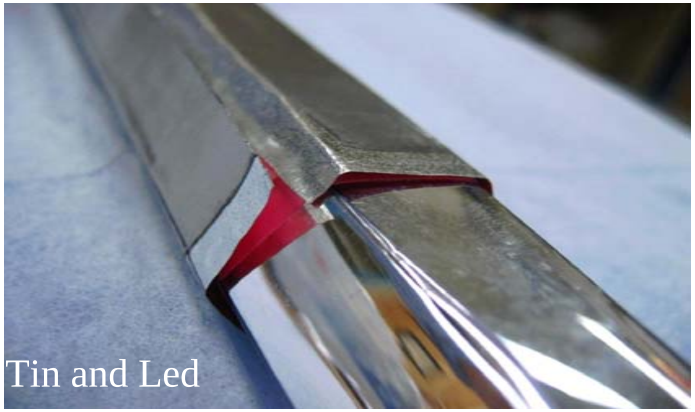
  → Relativistic charged particle deposit more than 200keV
- **BGO bottom:** Rejection of background from the bottom
- **BGO shield:** Rejection of cosmic-ray induced events and shielding from background gamma-rays.

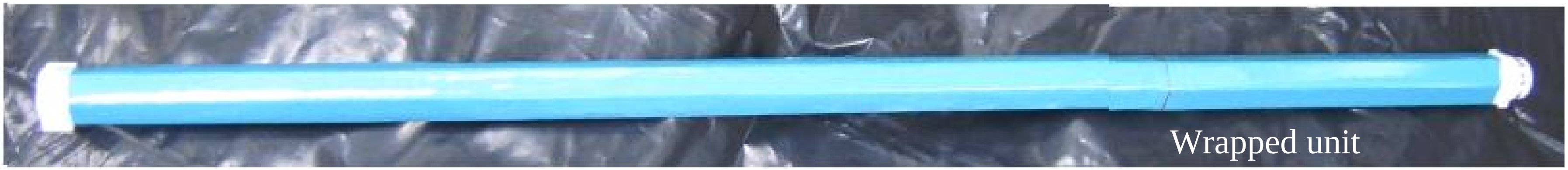


Detector Units (2)







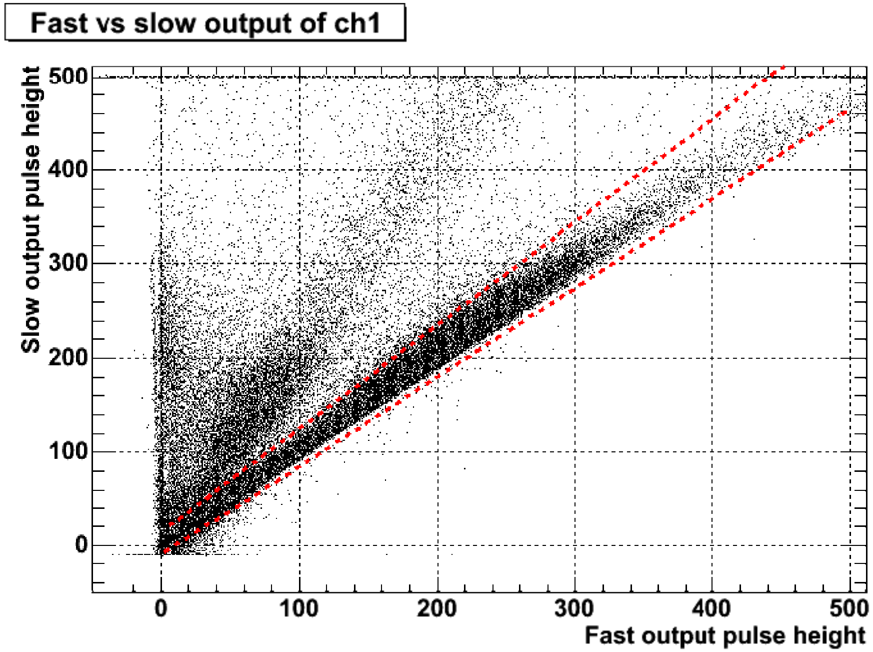


Detector units (3)

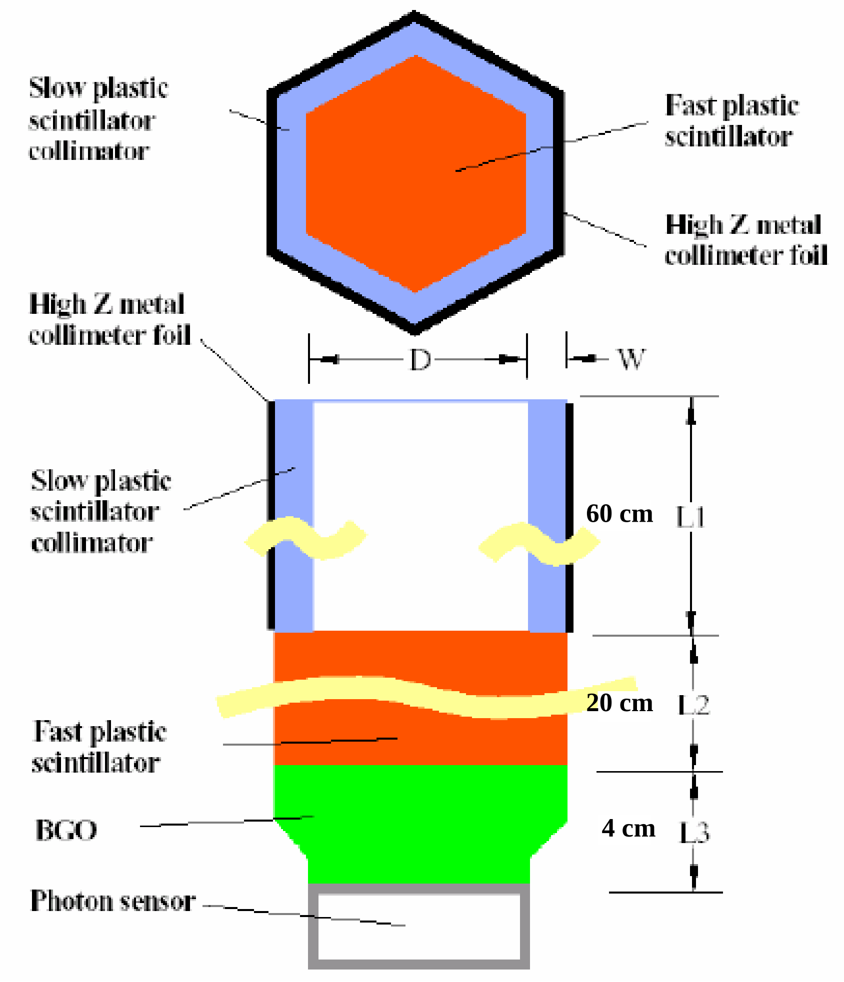
Pulse shape discrimination:

In the **fast** shaping amplifier the whole signal from the fast scintillator is integrated and therefore dominant. BGO and slow scintillator play a minor role

In the **slow** shaping amplifier the whole signal from all scintillators are integrated, but the total contribution from the fast scintillator is smaller

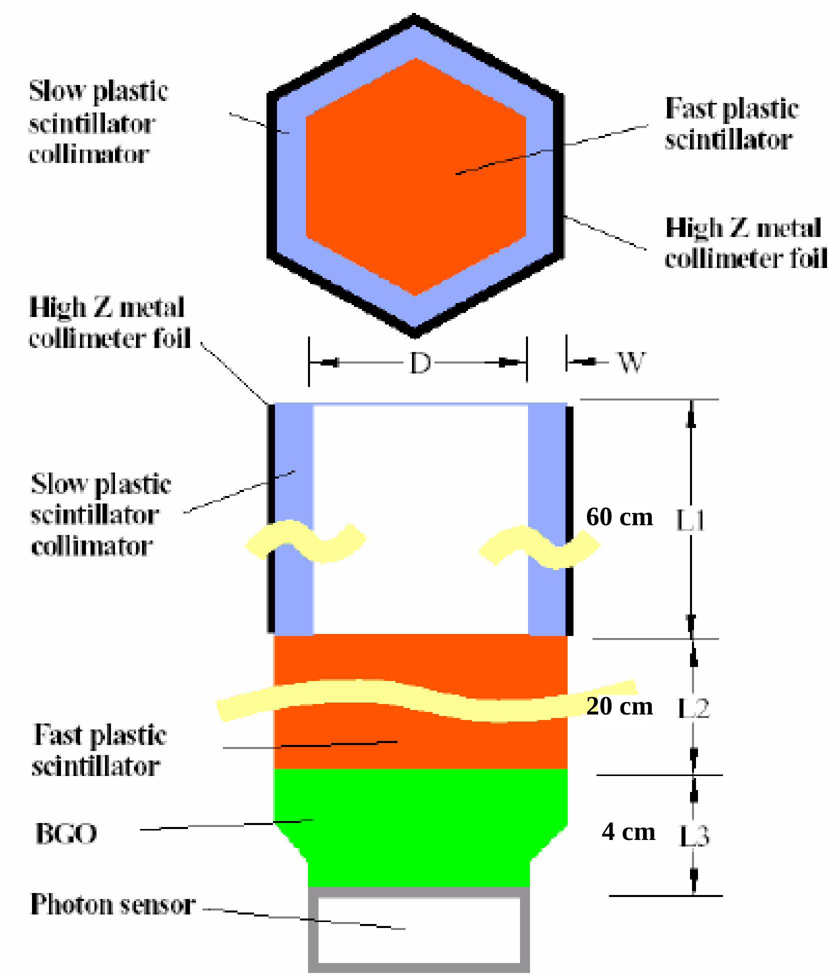


Detector Unit (4)

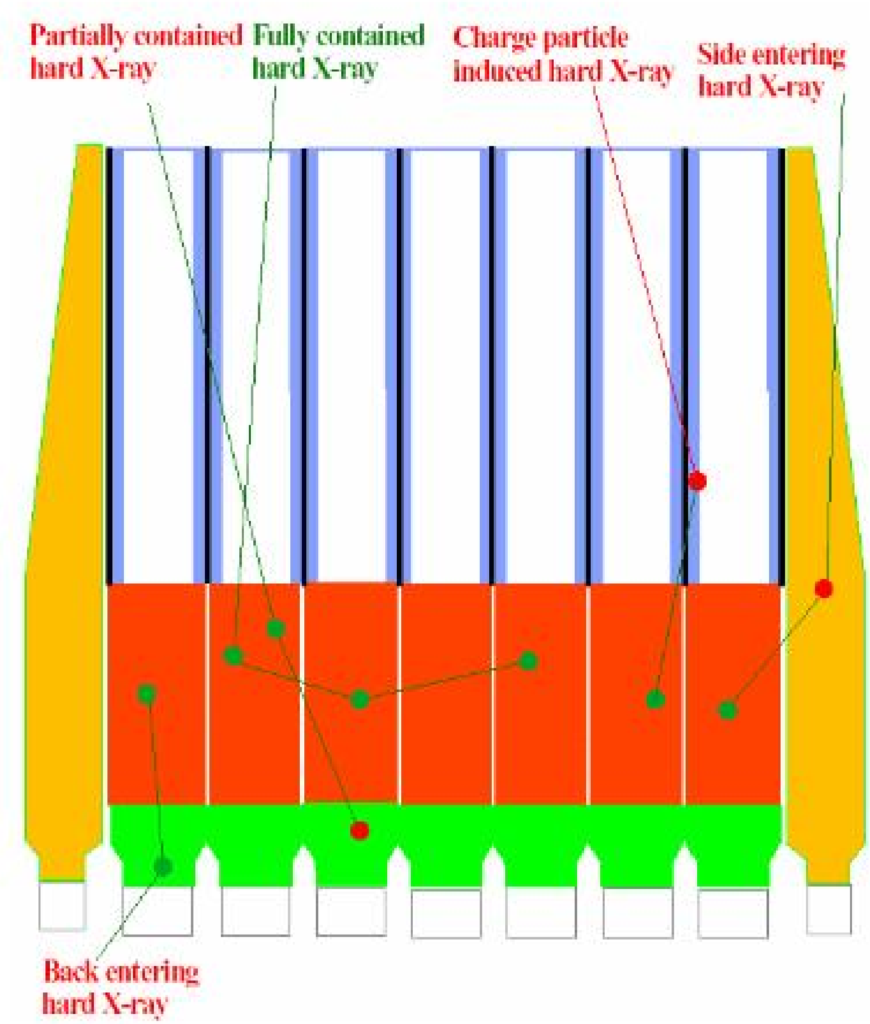


Well-type Phoswich Detector Cell
(PDC)

Detector Unit (4)

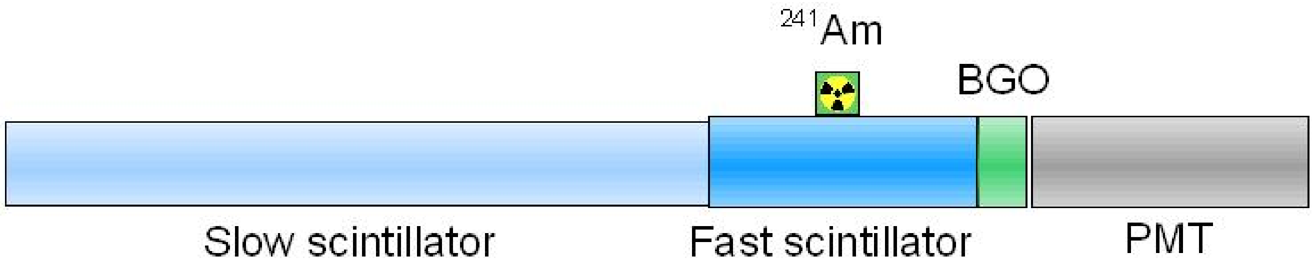


Well-type Phoswich Detector Cell (PDC)

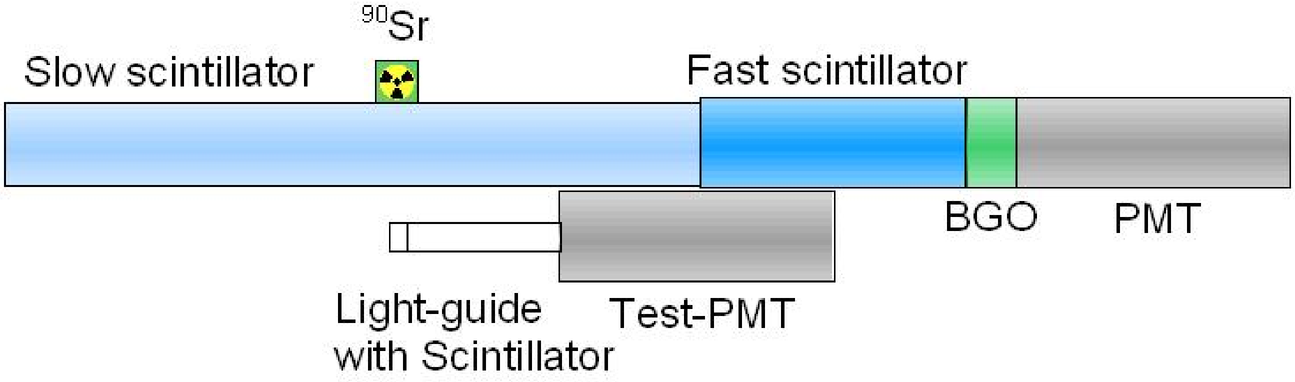


Sketch of the detector array

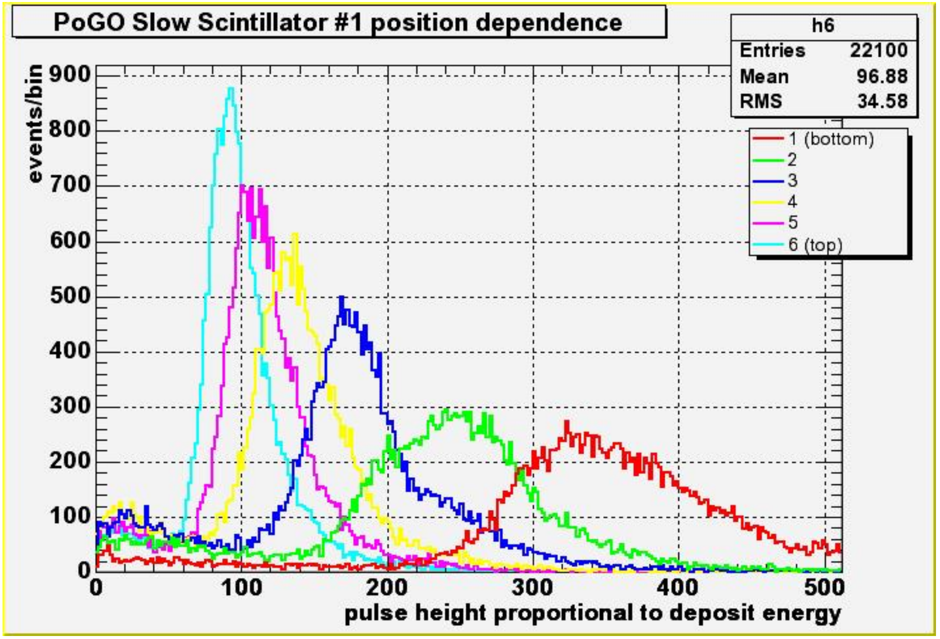
Detector Unit (5)



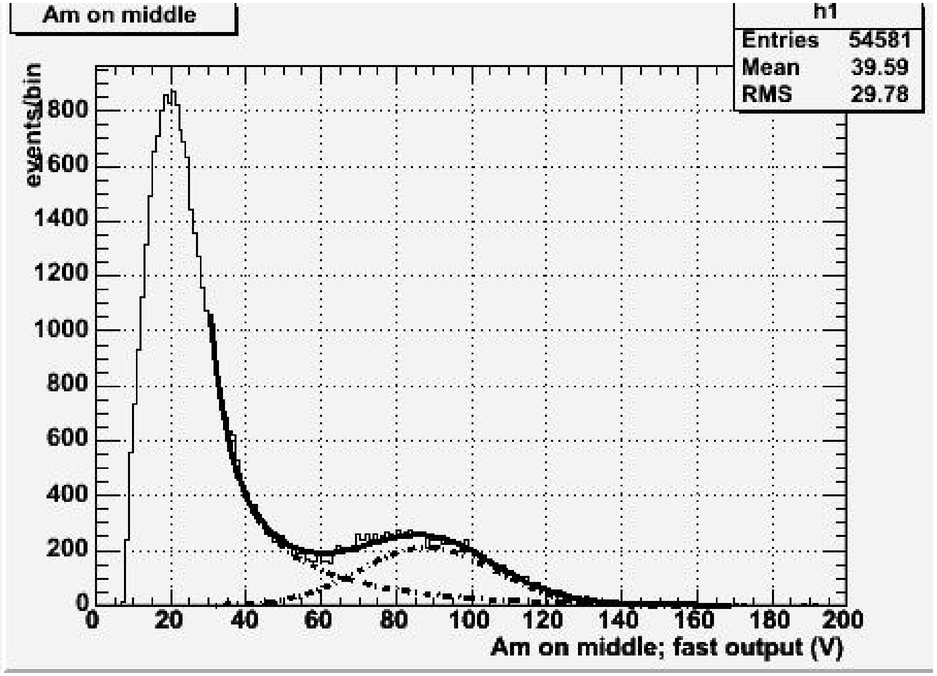
Light-yield measurement performed on the fast and the slow Scintillator.



Detector Unit (6)



Position dependency for the slow scintillator



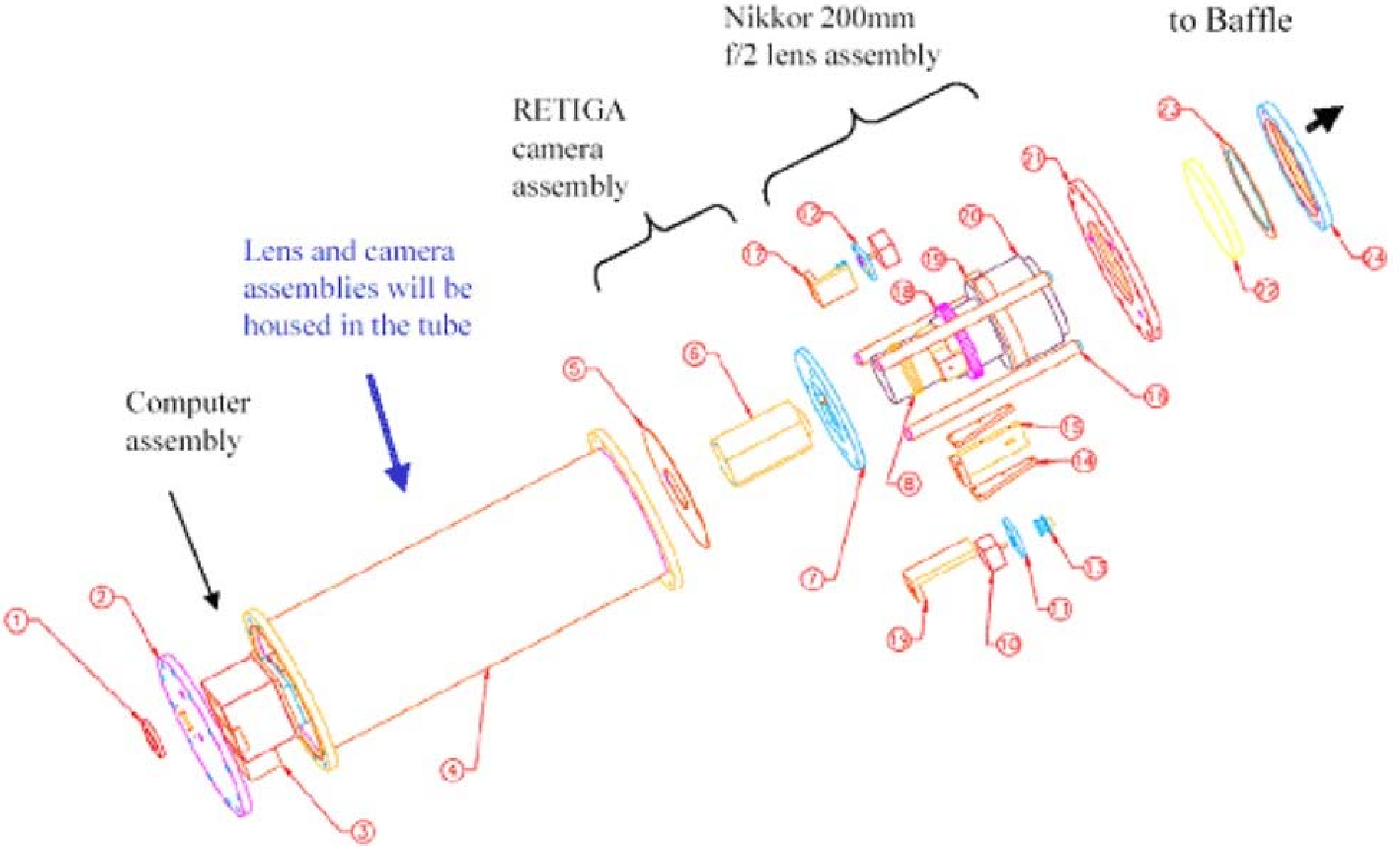
Light-yield results for the fast scintillator
– middle position

The Star Tracker System

Star Tracker (1)

- Modelled after the HEFT Star Tracking system
- Used for position determination in addition to other attitude control devices on board
- Must provide absolut reference information for any random star field
- Reference information is very accurate and provides long-term attitude control
- Two trackers – 1st on axis, 2nd offset by ~30° - scan the sky in search for star pattern

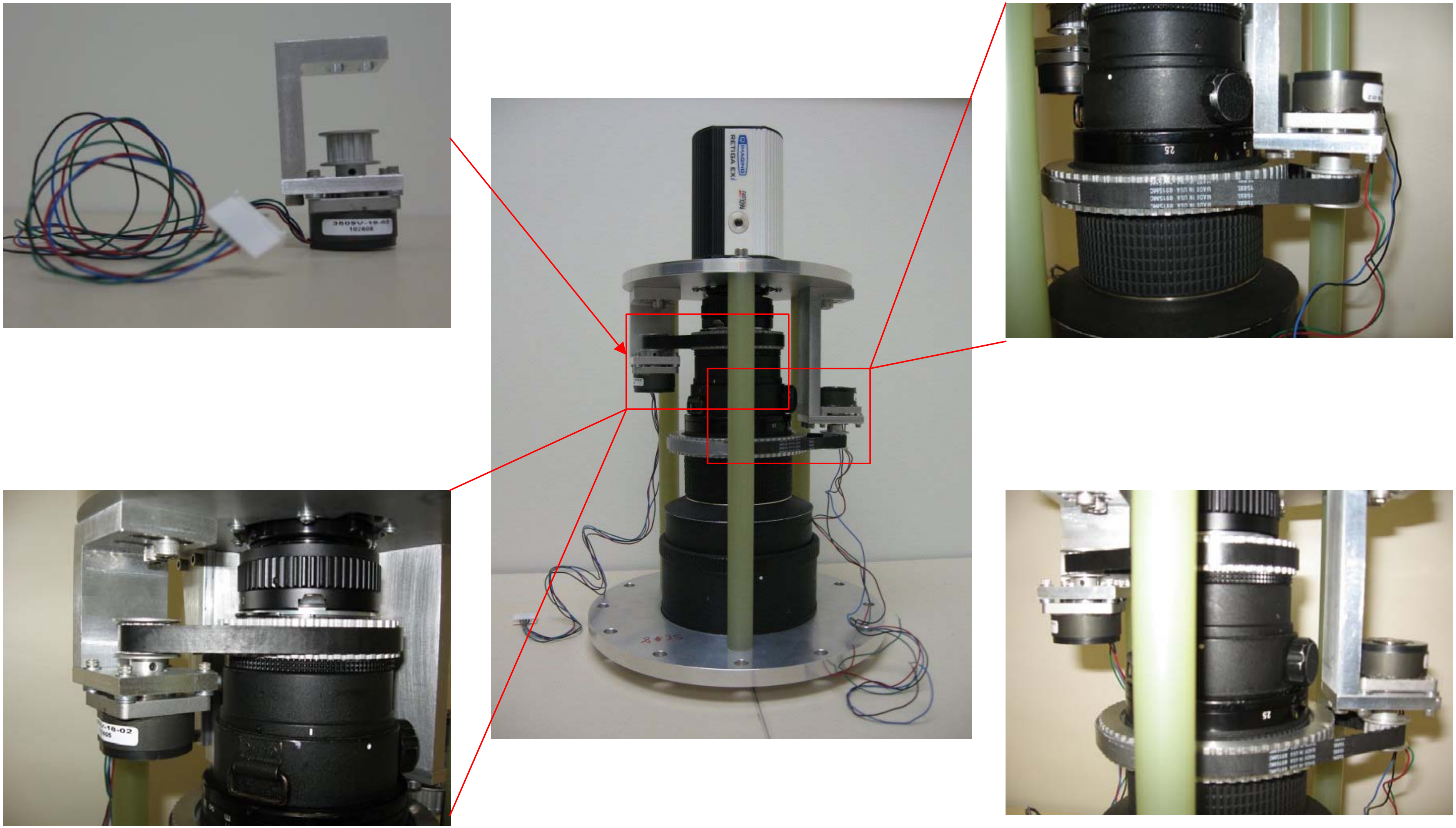
Star Tracker (2)



Star Tracker (3)

- Tracker-components:
  - Very high sensitivity QImaging Retiga EXi Digital CCD-camera
  - Nikon Nikkor 200mm f/2 IF-ED photo lense
  - Stepping motors for adjusting aperture and focus

Star Tracker (4)



Star pattern matching

- Matching code used for matching a random star-pattern with data from a star-catalogue (e.g. HST Guide Star catalogue)
- Code is able to match two patterns even if one is rotated, flipped or has a different scale

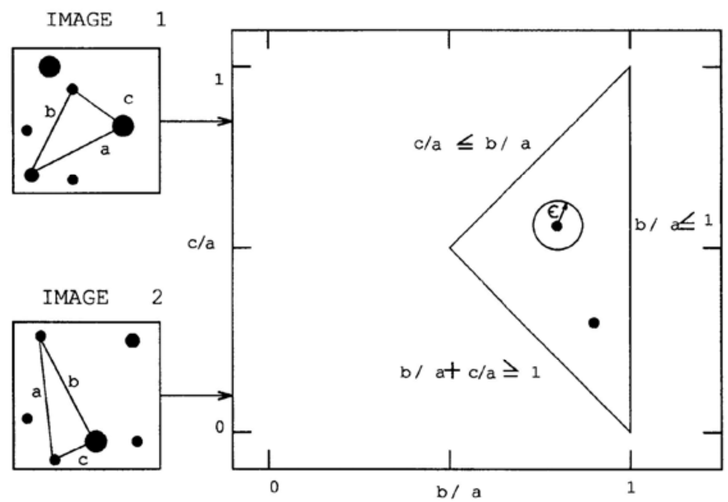
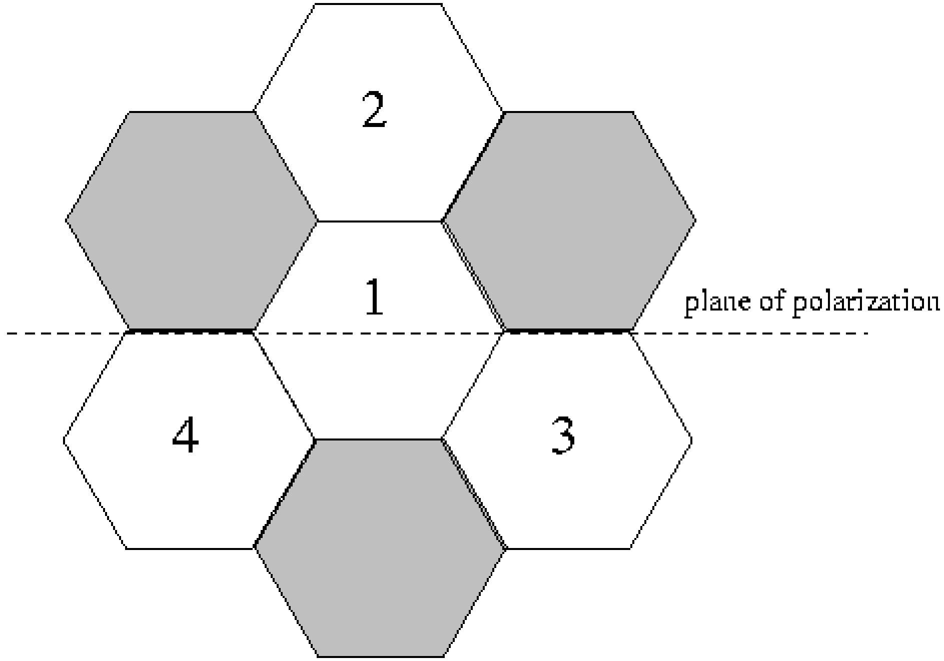
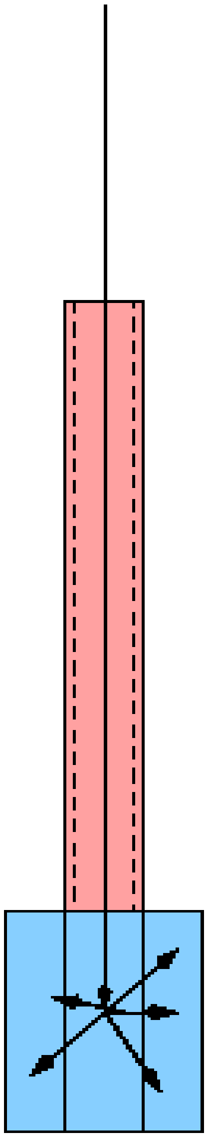


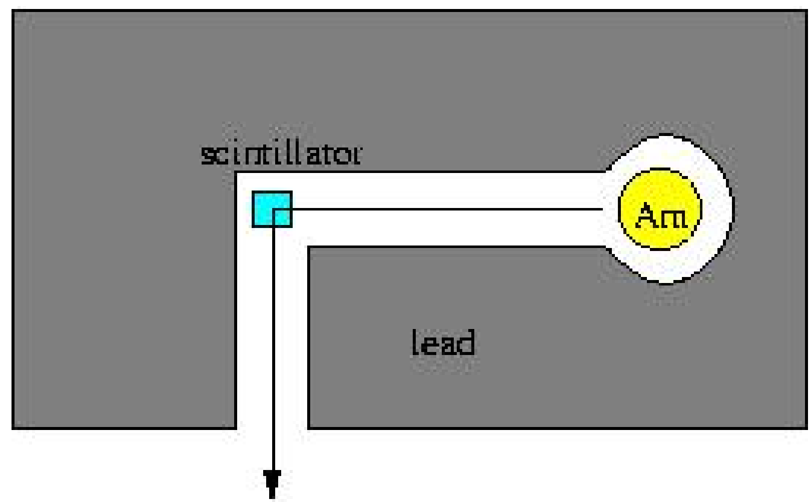
FIG. 1—Representation of triangles in *triangle space*. The lengths of the triangle sides are used to form the ratios b/a and c/a and these ratios define a two-dimensional space. Because of the ordering of the lengths the triangle coordinates will only occupy the indicated triangular region. Triangles from two images are matched when they are within a distance ϵ of each other in the triangle space.

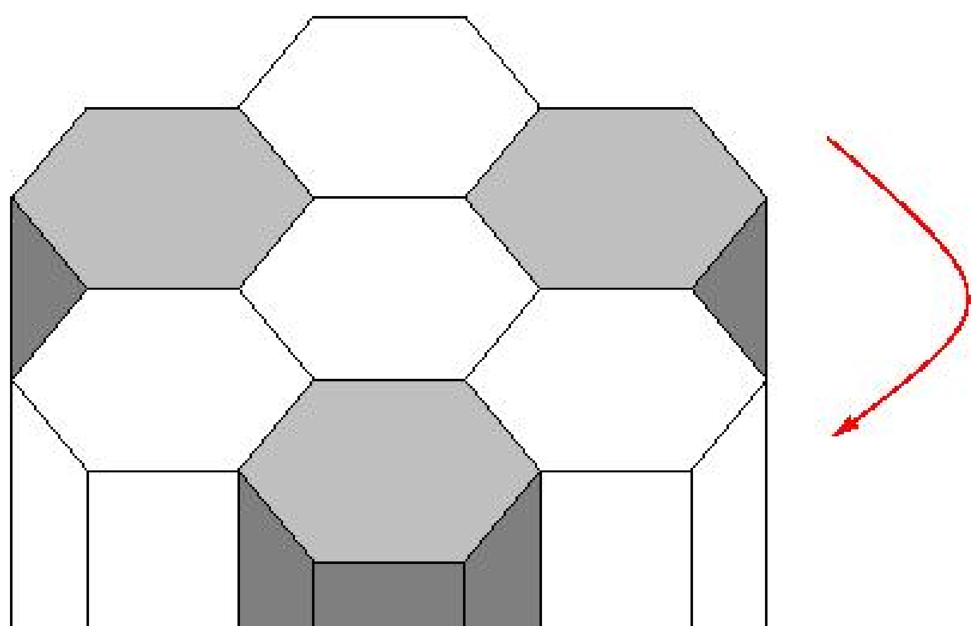
The PoGO-lite prototype



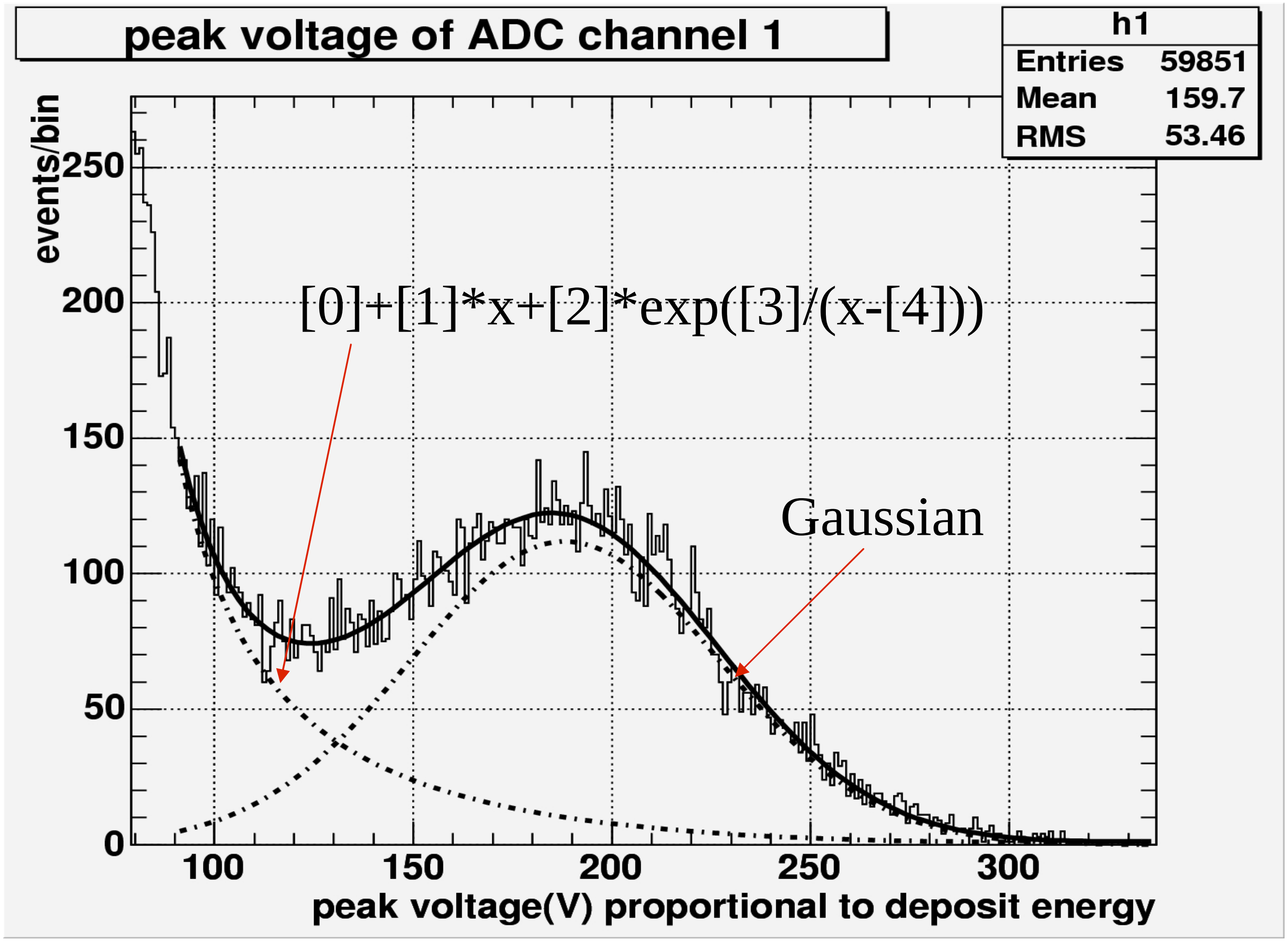


Polarimetry measurements



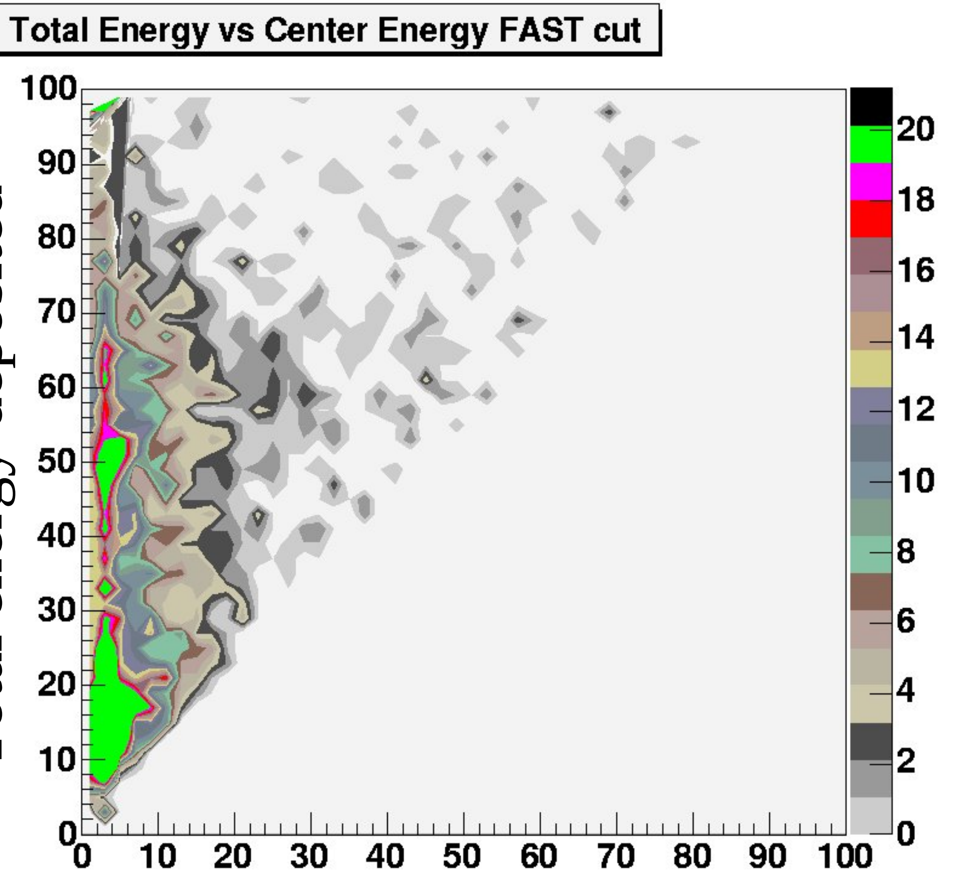


Calibration



Data analysis

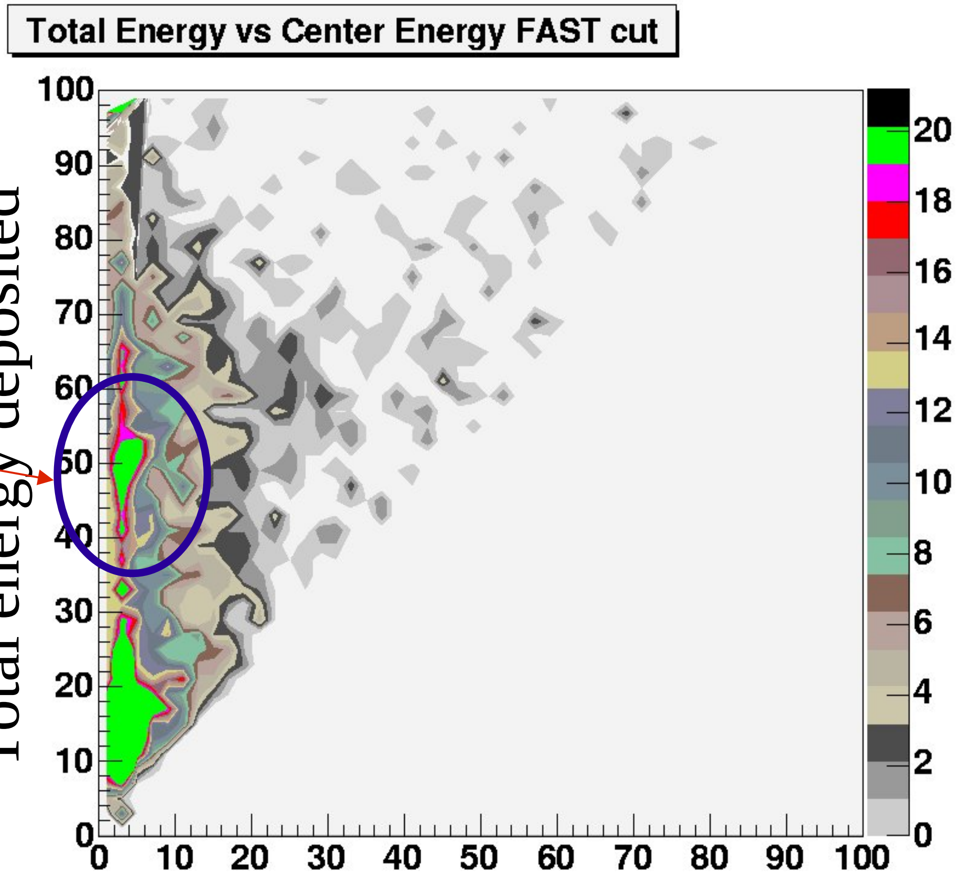
Total energy deposited



Energy deposited in central unit

Data analysis

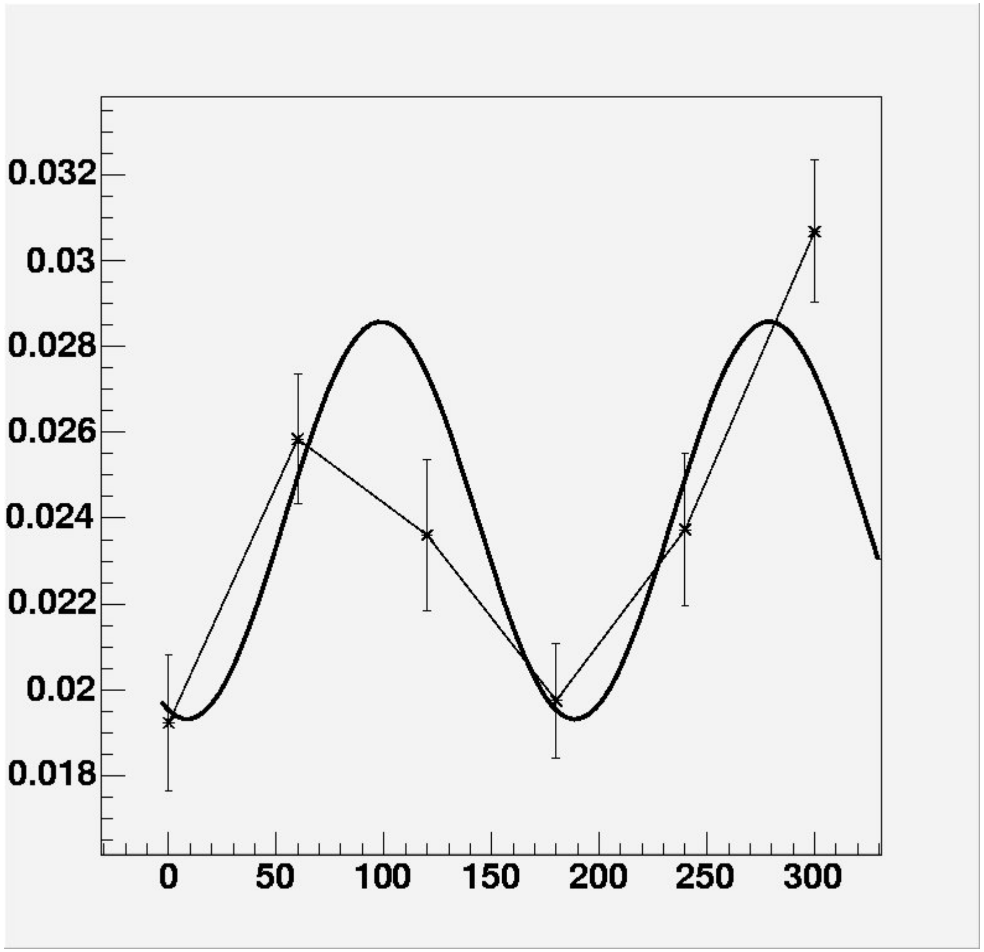
Compton scattering in the central unit and photoabsorption in an outer unit

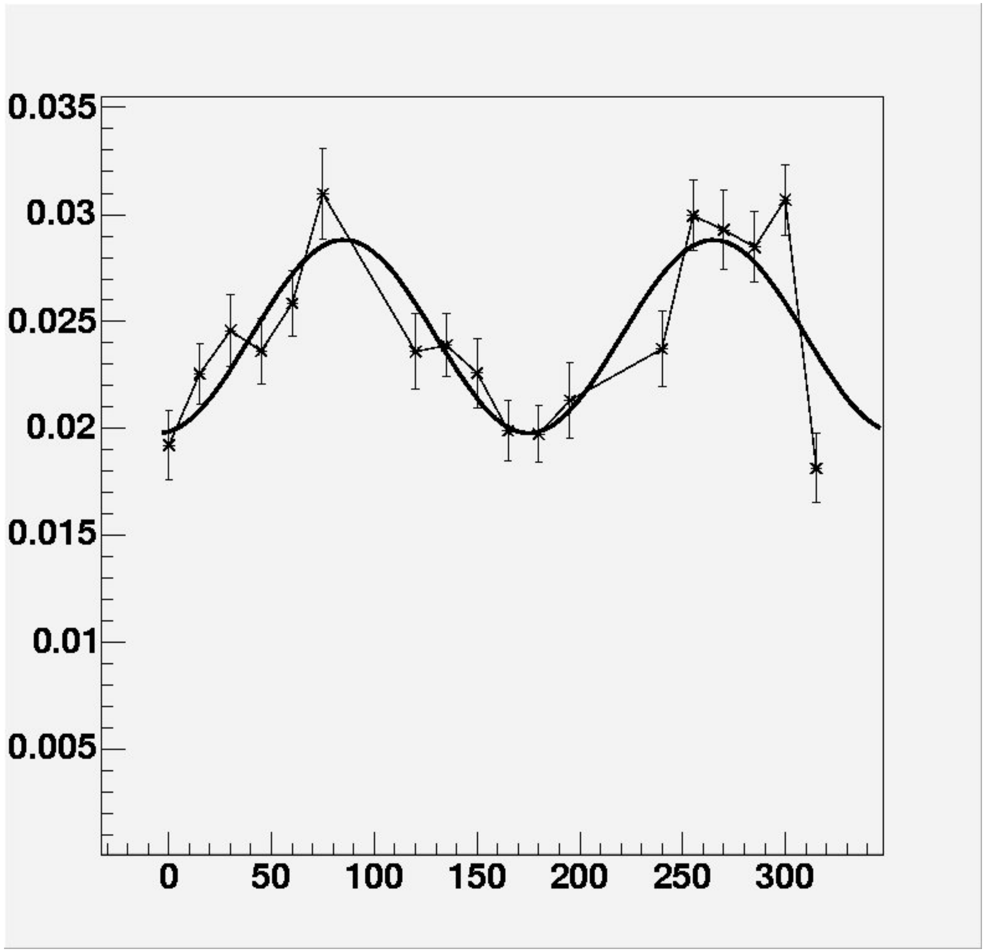


Total energy deposited

Energy deposited in central unit

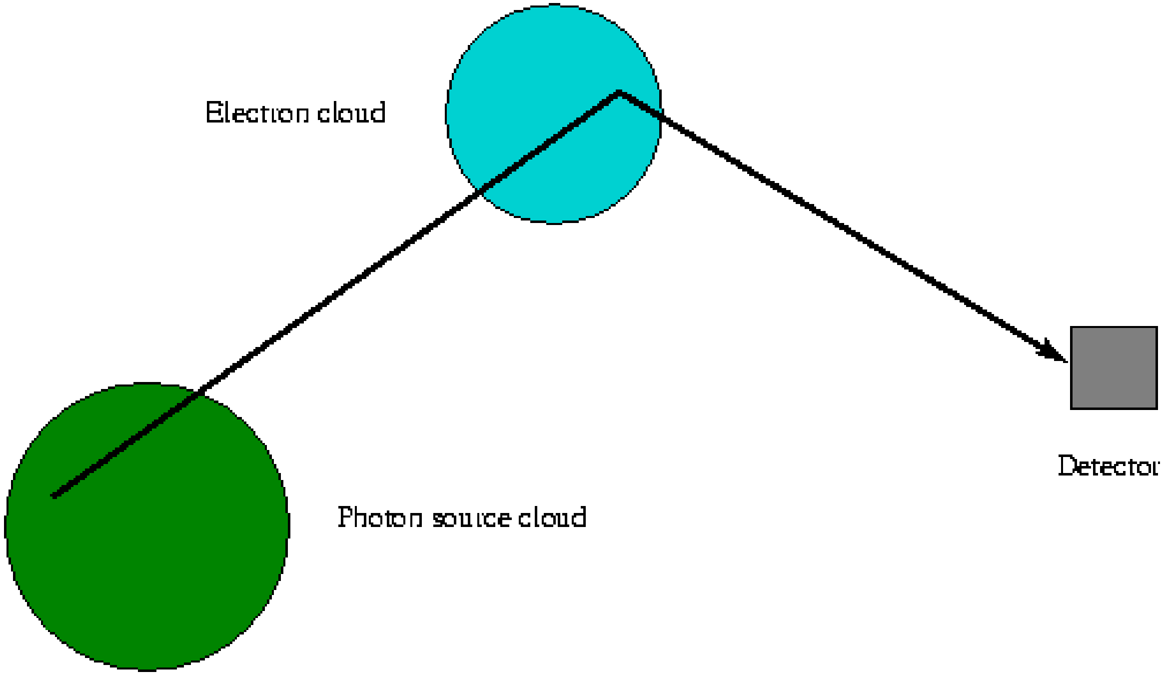
Data analysis





Inverse Compton Scattering

- The spectra detected by the detector
- The angle and degree of polarization



Inverse Compton Scattering

- I. Moskalenko and A. Strong (2000)
  - High electron energy approximation
- G. Brunetti (2000)
  - Exact formula for several special cases

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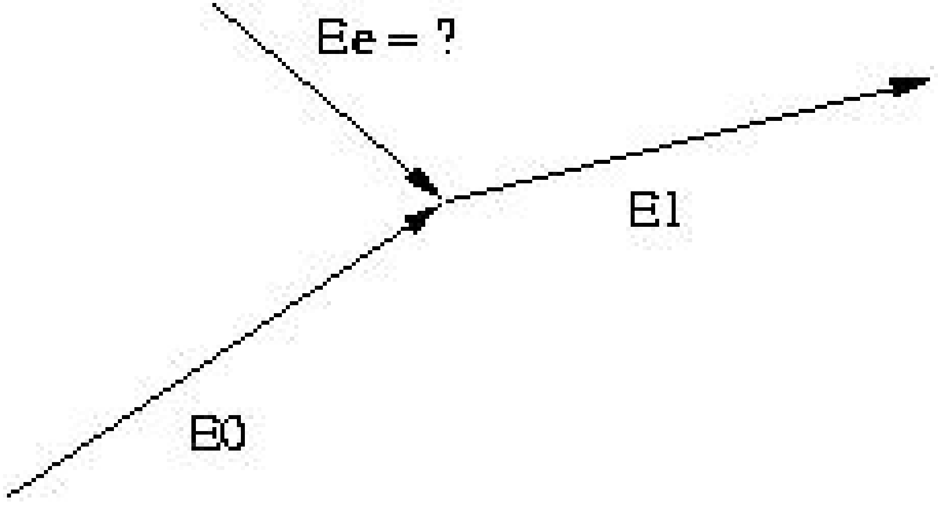


$$j(\Omega_{SC}, \epsilon_1) = \int d\epsilon' d^2\Omega'_{ph} d^2\Omega_e d\gamma \frac{d^3 n'(\epsilon', \Omega'_{ph}; \epsilon, \Omega_{ph})}{d\epsilon' d^2\Omega'_{ph}} \frac{d^2\Omega'_{SC} d\epsilon'_1 dt'}{d^2\Omega_{SC} d\epsilon_1 dt} \frac{d^3\sigma}{d^2\Omega'_{SC} d\epsilon'_1} \epsilon_1 N_e(\gamma, \Omega_e)$$

$$\boxed{j(\Omega_{SC}, \epsilon_1) = \int d\epsilon d^2\Omega_e \frac{r_0^2 n}{2\gamma^2} \frac{\epsilon_1}{L_1} \beta\gamma^3 J N_e(\gamma, \Omega_e) \left(\left(1 + \frac{\epsilon_1}{m} \frac{k_3 - 1}{\gamma L} \right)^{-1} + \left(1 + \frac{k_3 - 1^{\,2}}{\gamma^2 L L_1} + \frac{\epsilon}{m} \frac{k_3 - 1}{\gamma L} \right) \right)}$$

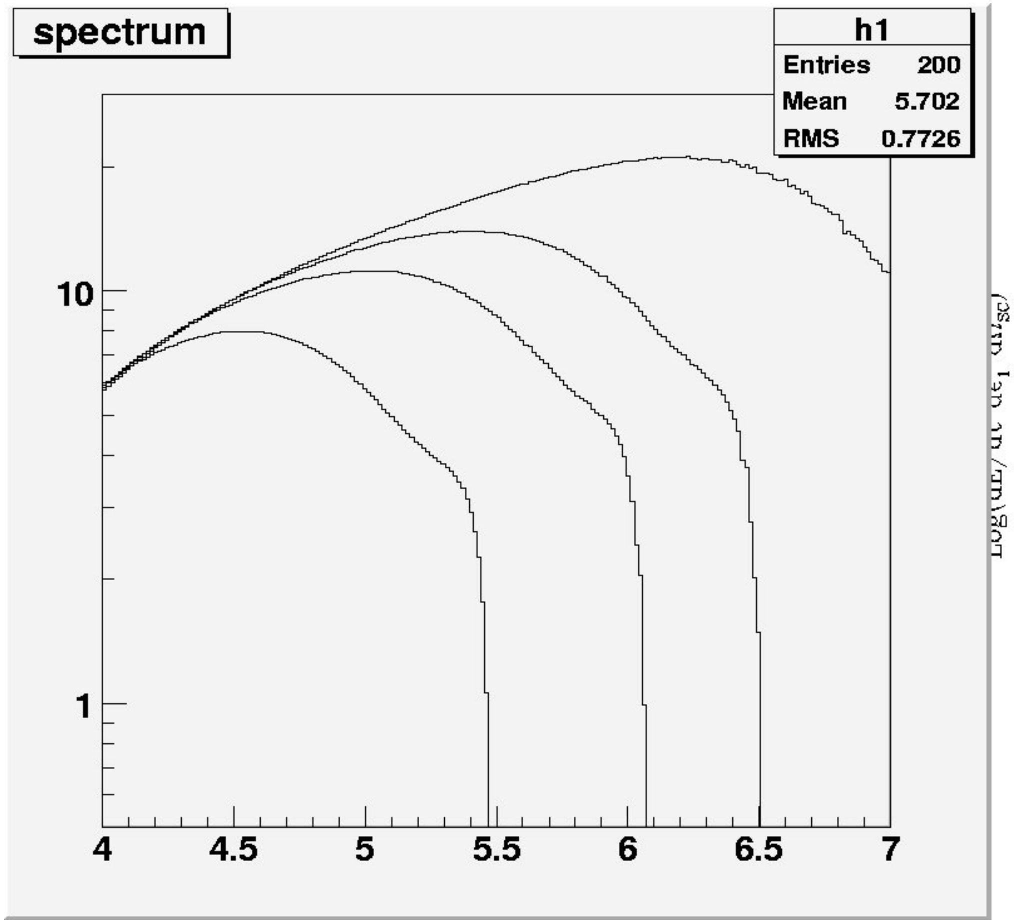
$$j(\Omega_{SC},\epsilon_1) = \int d\epsilon' d^2\Omega'_{ph} d^2\Omega_e d\gamma \frac{d^3 n'(\epsilon',\Omega'_{ph};\epsilon,\Omega_{ph})}{d\epsilon' d^2\Omega'_{ph}} \frac{d^2\Omega'_{SC} d\epsilon'_1 dt'}{d^2\Omega_{SC} d\epsilon_1 dt} \frac{d^3\sigma}{d^2\Omega'_{SC} d\epsilon'_1} \epsilon_1 N_e(\gamma,\Omega_e)$$

$$\boxed{j(\Omega_{SC},\epsilon_1) = \int d\epsilon d^2\Omega_e \frac{r_0^2 n}{2\gamma^2}\frac{\epsilon_1}{L_1}\beta\gamma^3 J N_e(\gamma,\Omega_e)\left(\left(1+\frac{\epsilon_1}{m}\frac{k_3-1}{\gamma L}\right)^{-1} + \left(1+{\frac{k_3-1}{\gamma^2 L L_1}}^{2} + \frac{\epsilon}{m}\frac{k_3-1}{\gamma L}\right)\right)}$$

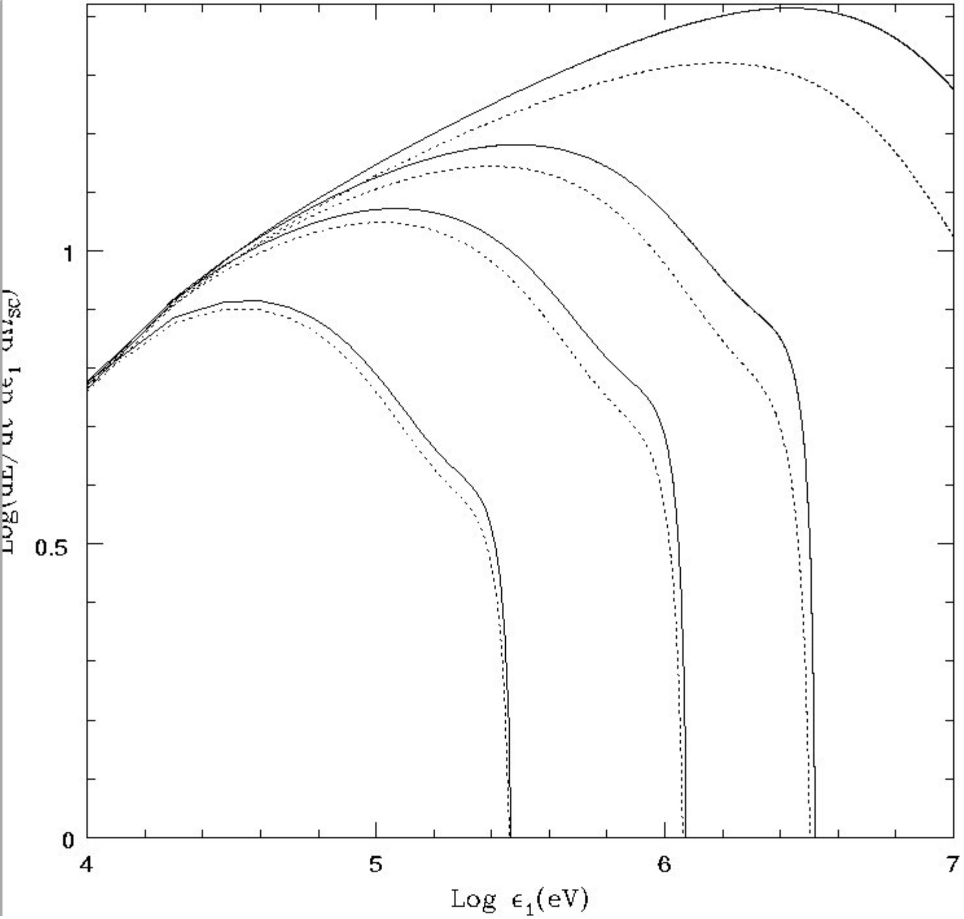
Monte-Carlo integrate

Validating the result

Collision between a beam of electrons and a beam of photons.

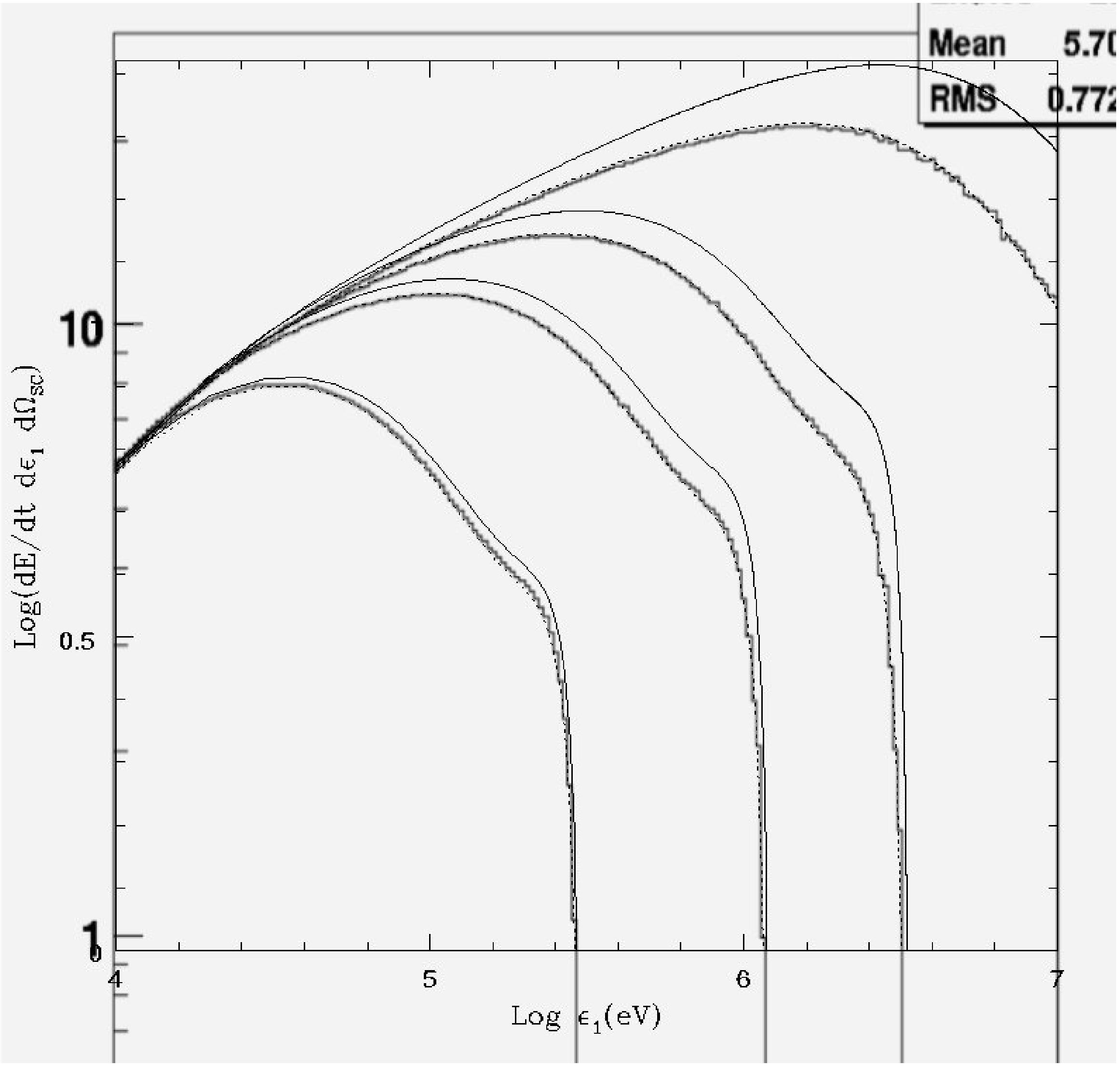


Our result



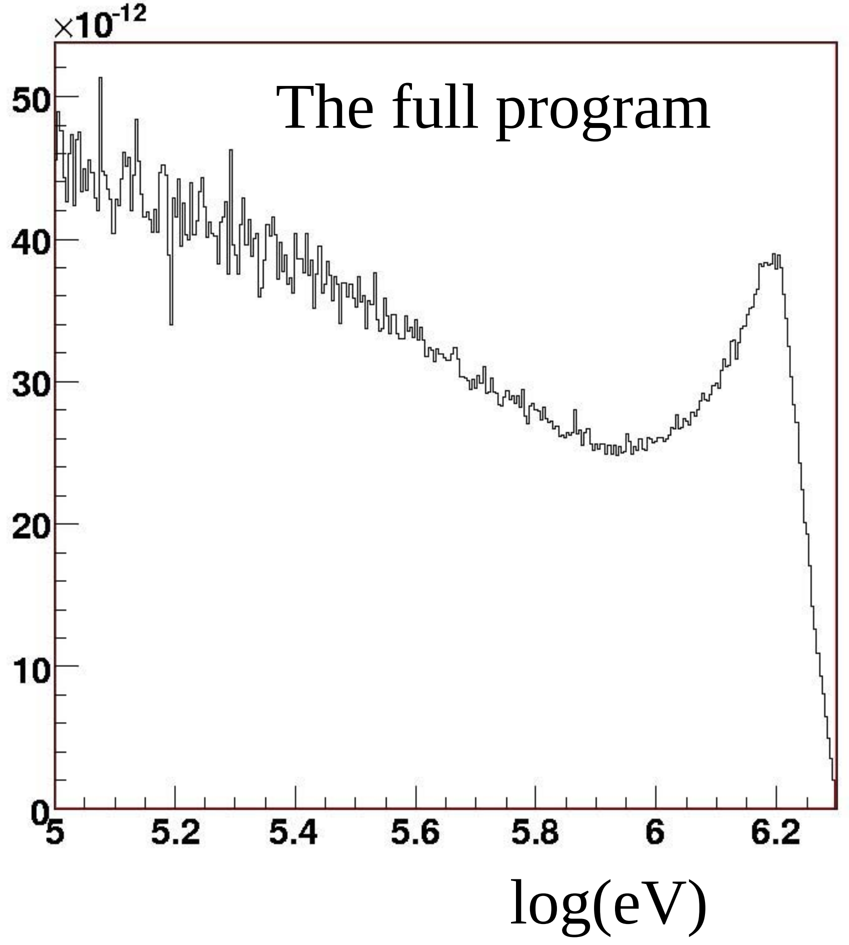
The result from Brunettis paper

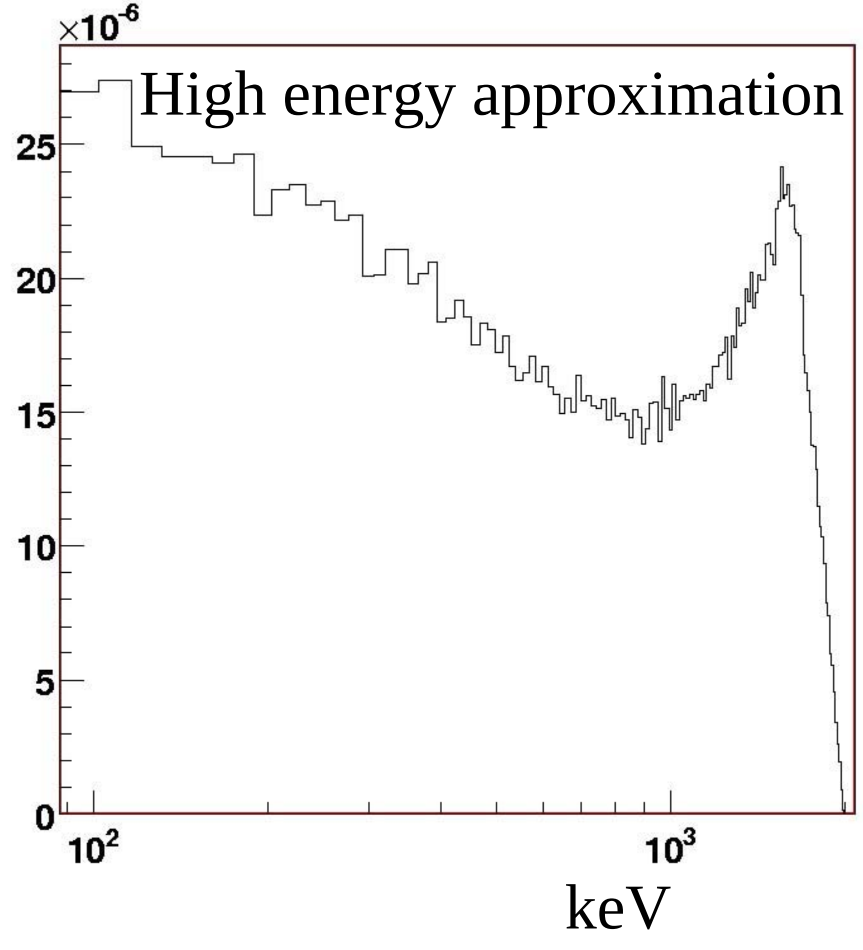
Validating the result



Validating the result

Collision between an electron beam and a photon beam.
gamma between 900 and 1000

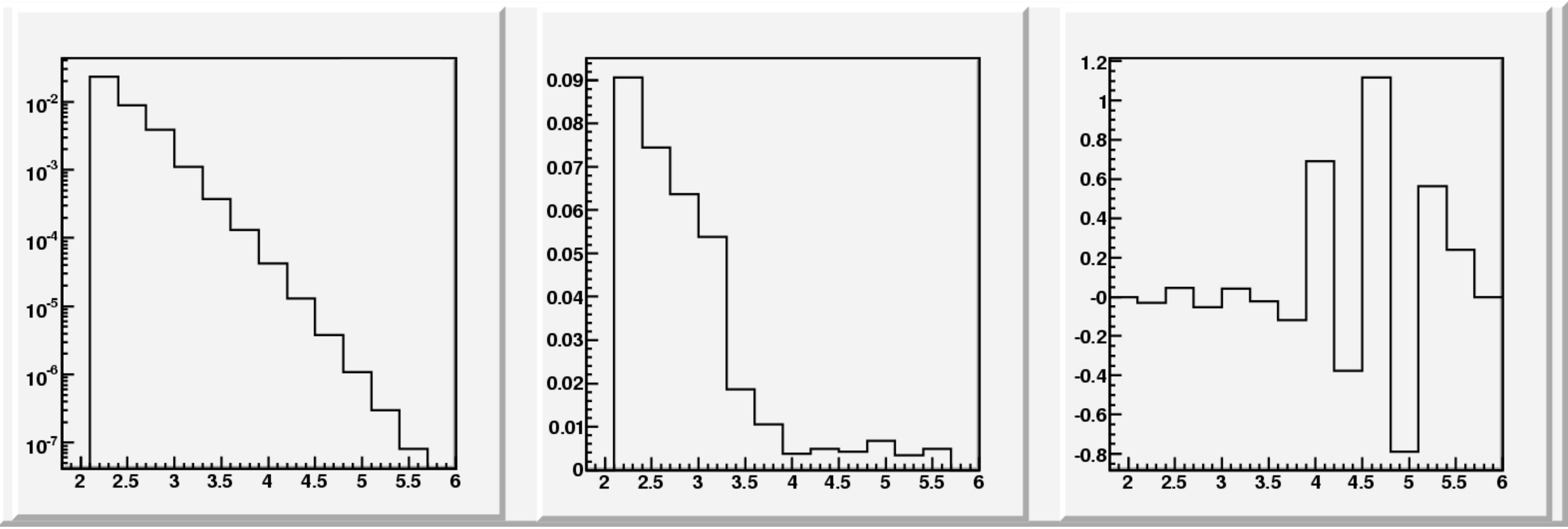




Polarization

- Paper by D. Nagirner and J. Poutanen (1993)
- Calculates the matrix that transforms the Stokes vector due to inverse Compton scattering.

Example



10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
2 2.5 3 3.5 4 4.5 5 5.5 6
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2 2.5 3 3.5 4 4.5 5 5.5 6
1.2
1
0.8
0.6
0.4
0.2
-0
-0.2
-0.4
-0.6
-0.8
2 2.5 3 3.5 4 4.5 5 5.5 6

The future

- Work on the star tracker will be continued in Stockholm
- A prototype including 19 phoswich detectors is planned to be build during 2007
- PoGO will (hopefully) be launched in 2009.