Gamma-ray burst polarization experiment onboard China's Spacelab: POLAR

Bobing Wu (吴伯冰)

Institute of High Energy Physics, CAS, China

On behalf of the POLAR Collaboration

Institute of High Energy Physics (China)

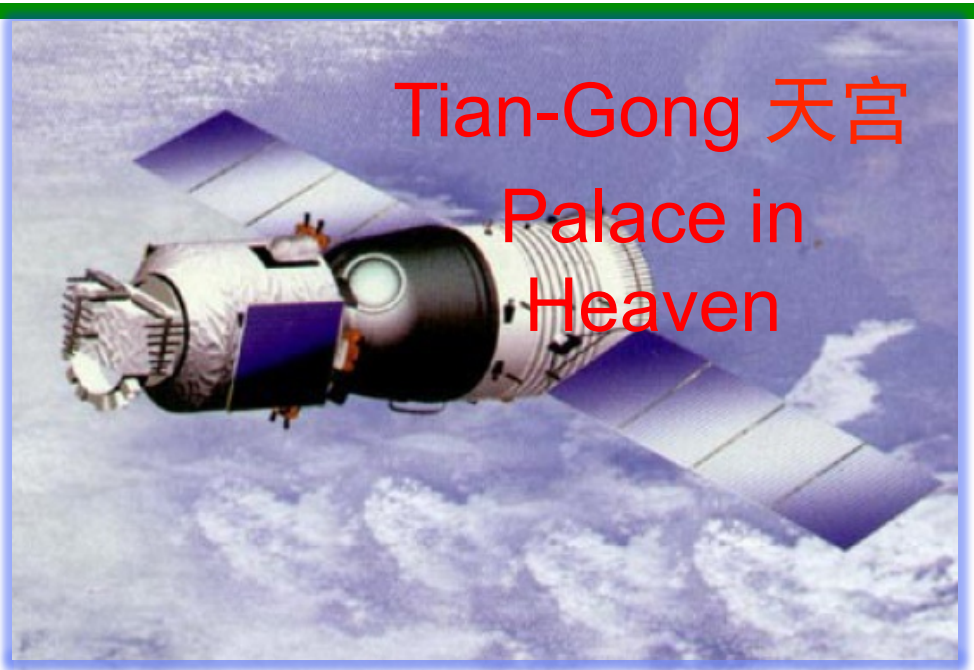
Univ. de Genéve; ISDC; PSI (Switzerland)

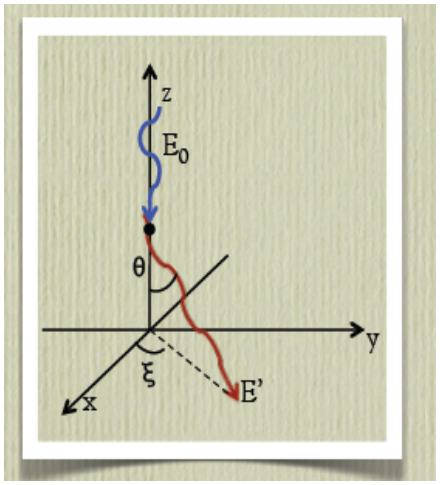
NCBJ (Poland)

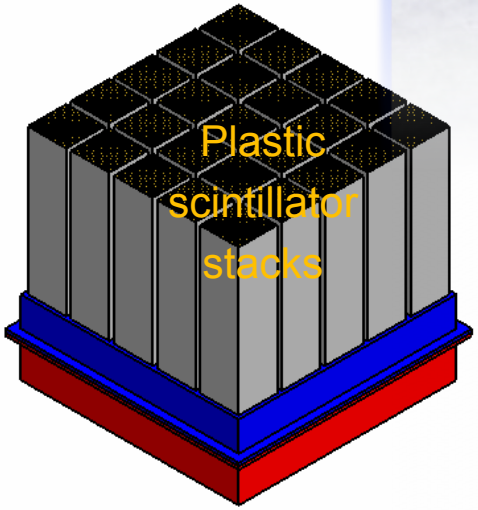
LAPP Annecy (France)

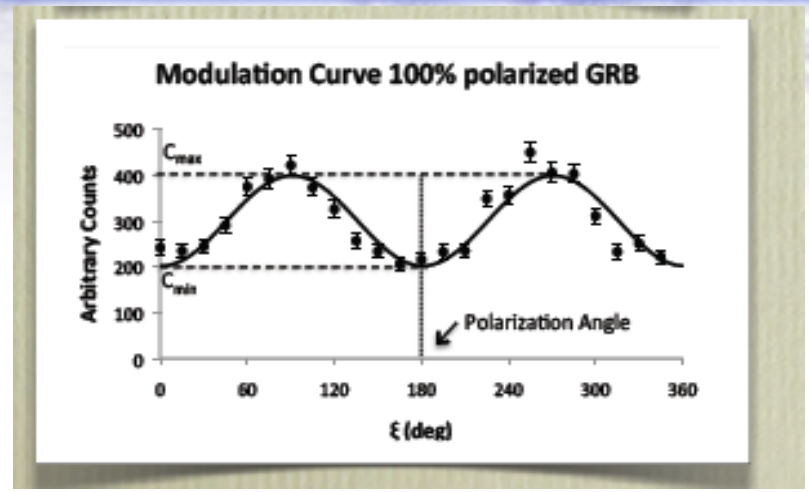
POLAR onboard China's Spacelab

- Onboard China's spacelab TG-2: launch time ~2015
- A China-led international collaboration (Switzerland, France, Poland)
- FOV of POLAR: ~½ sky
- PI: Shuangnan ZHANG









Instrument concept proposed by N. Produit, et al., NIM (2005)

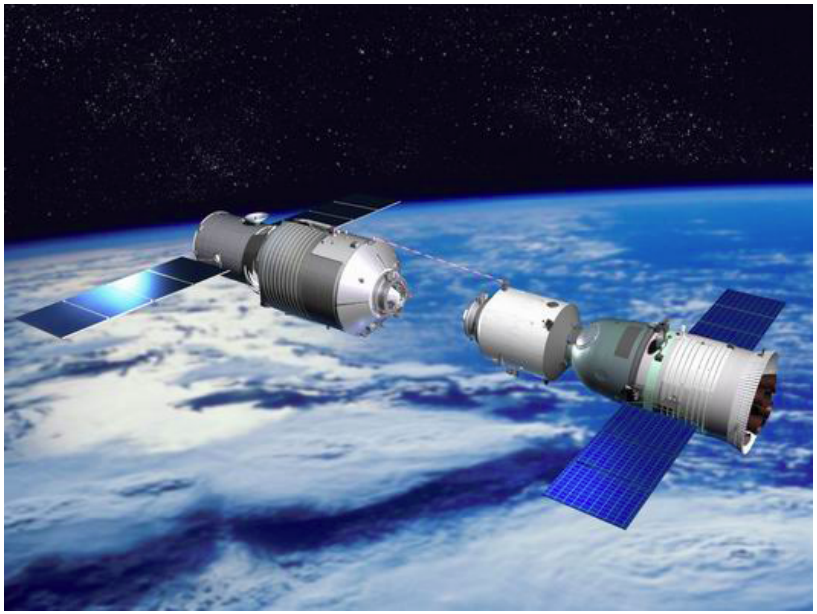
China's Space Station Program

- Three phases
  - 1st phase: so far 10 Chinese astronauts have been sent out and returned back successfully; many space science research has been done. Completed successfully.
  - 2nd phase: spacelab: docking of 3 spaceships with astronauts delivering and installing scientific instruments. 1st launch on Sept. 29, 2011.
  - 3rd phase: spacestation: several large experimental cabins with astronauts working onboard constantly. 1st launch ~2020.

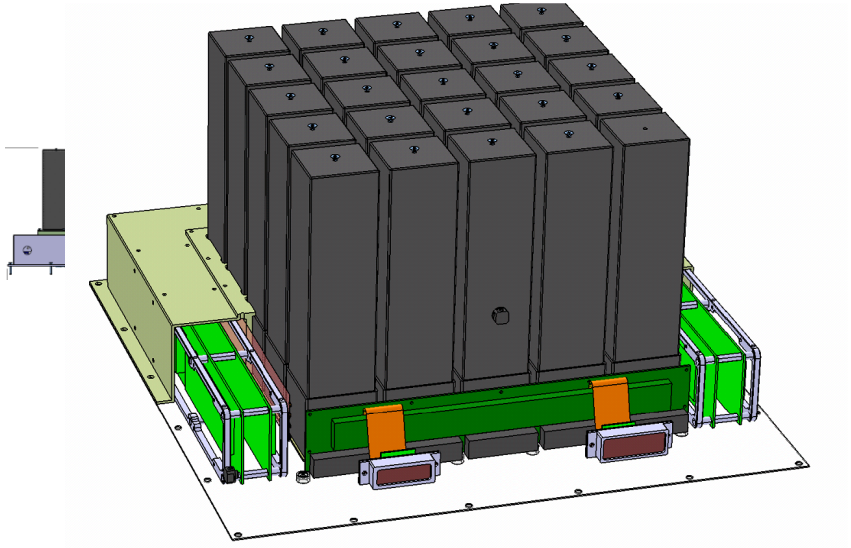
International collaborations on space science research have been and will continue to be an important part.

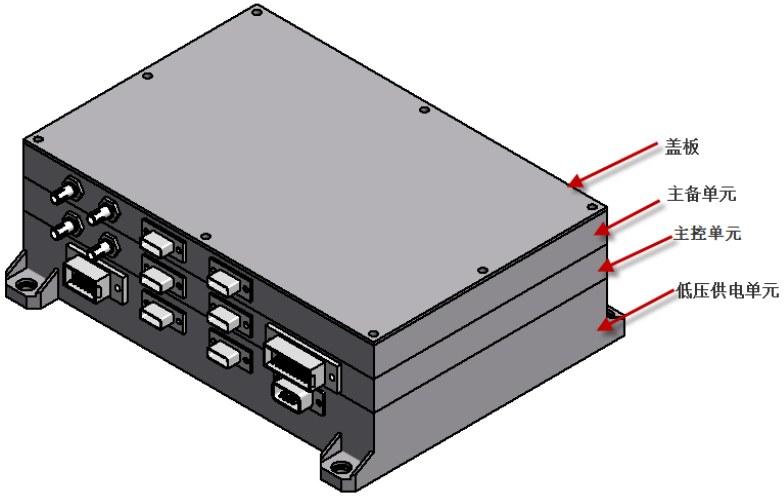
China's Spacelab: TG-1 & TG-2

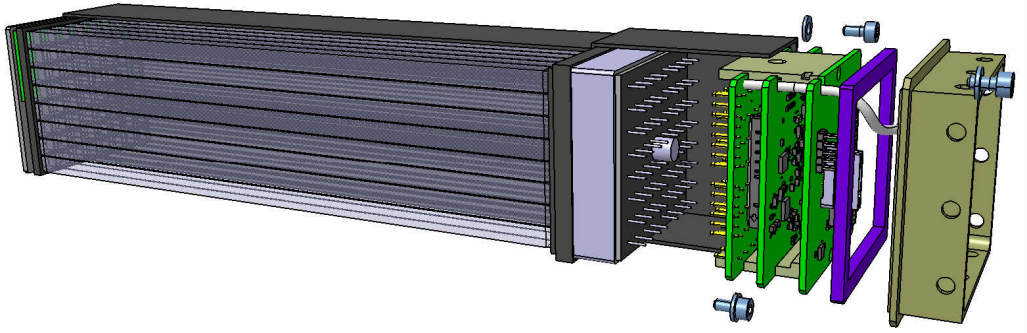
- 2011.9.29: TG-1 launched
- 2011.11: TG-1 & SZ-8 unmanned docking
- 2012.6: TG-1 & SZ-9 manned docking
- 2013 summer: TG-1 & SZ-10 manned docking
- 2015 Dec.: TG-2 launchTG-2 (with POLAR)



POLAR Instrument

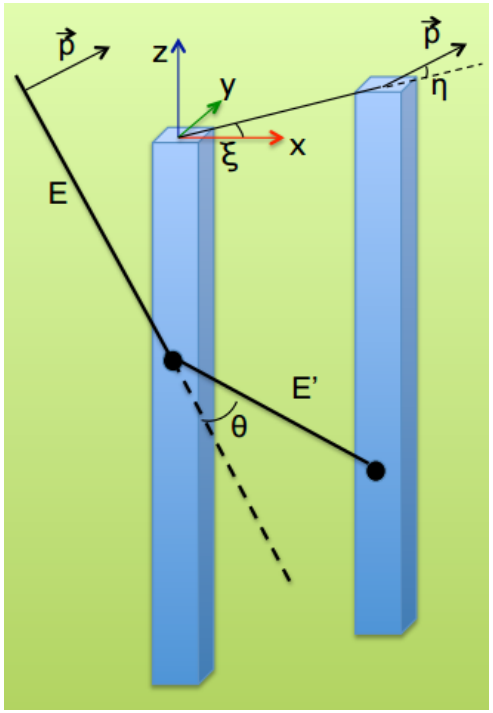




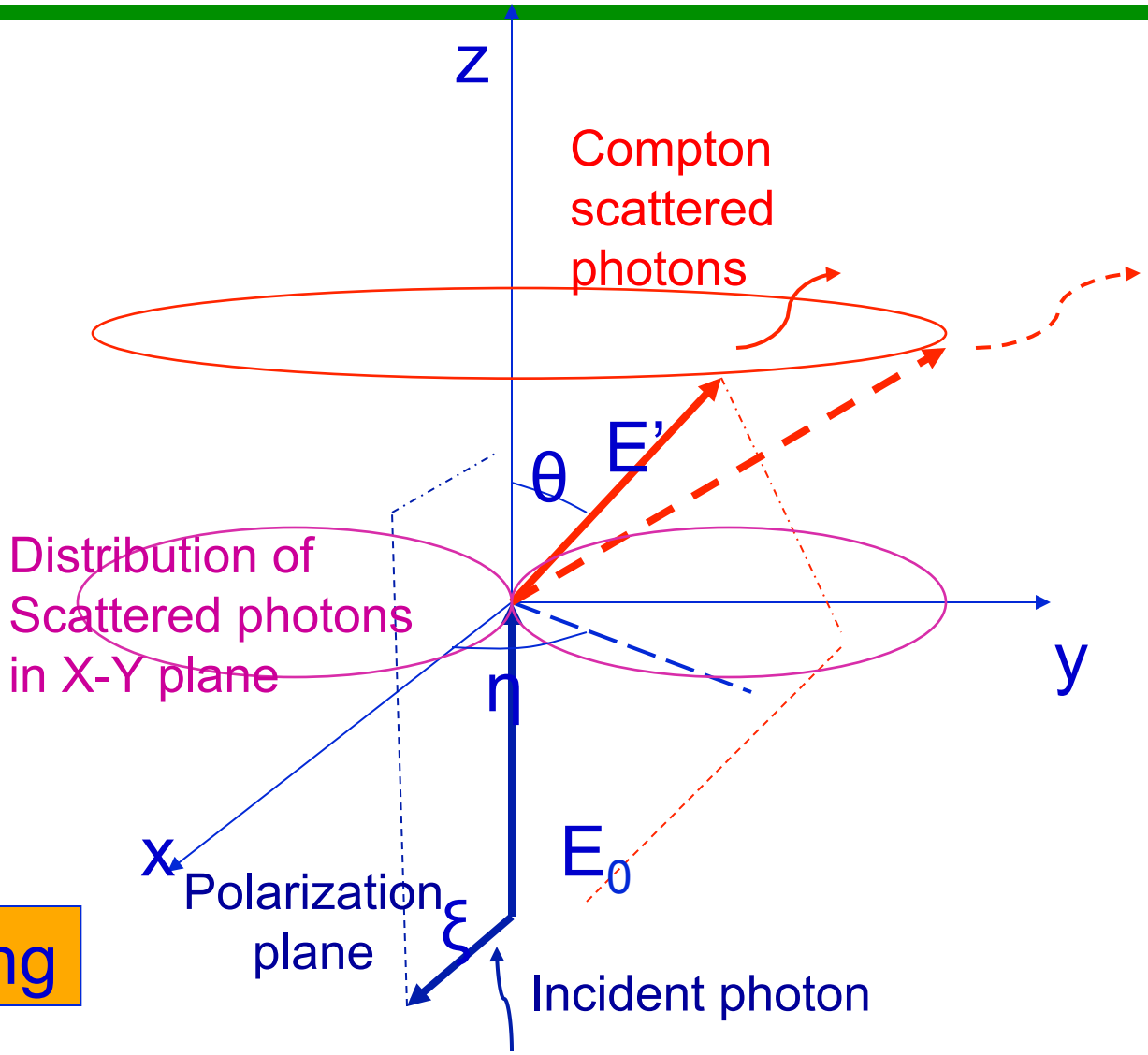


- POLAR: 25 modules
- Each module: 64 bars (6x6x176mm), one multi-anode photomultiplier H8500 + ASIC readout electronics

Polarization measurement: Compton scattering



Compton scattering



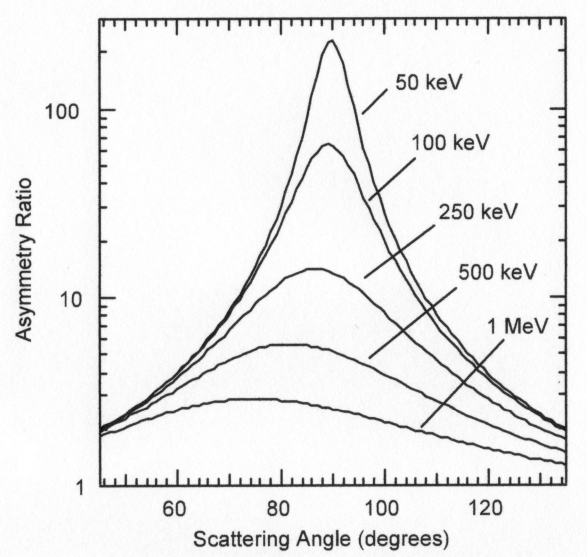
Compton scattering is the dominant process in plastic scintillators in the energy range of interest

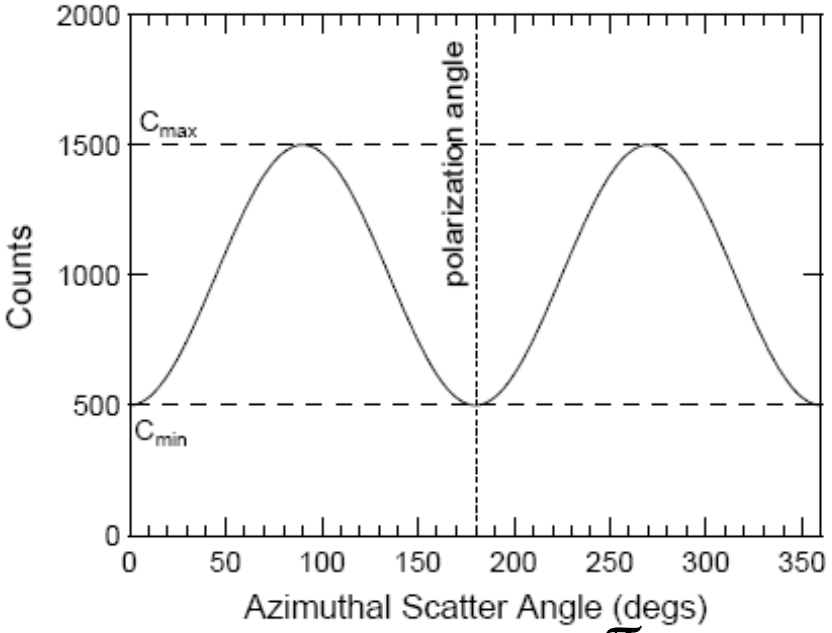
Position angle distribution of scattered photons

$$d\sigma = \frac{r_o^2}{2} d\Omega \left(\frac{E'}{E_o}\right)^2 \left(\frac{E_o}{E'} + \frac{E'}{E_o} - 2\sin^2\theta\cos^2\eta\right)$$

θ is the Compton Scatter Angle

η is the Azimuthal Scatter Angle





$$C(\eta) = A\cos(2(\eta - \varphi + \frac{\pi}{2})) + B$$

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

Scattered photons are distributed preferentially in the plane normal to the polarization plane of incident photons

$$p = \frac{M}{M_{100}}$$

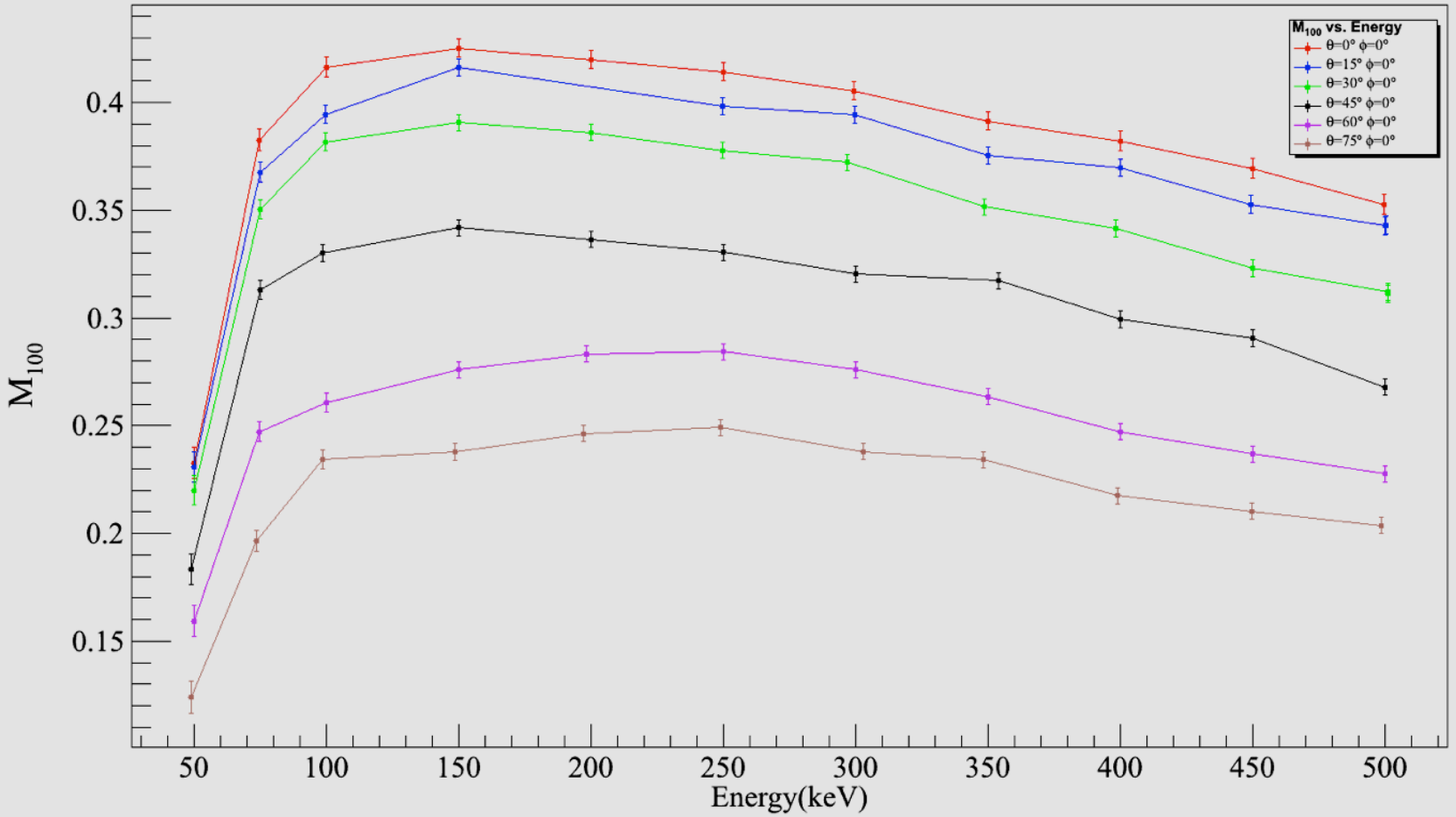
POLAR Performance Simulation

- Minimum Detectable Polarization (MDP):

$$MDP = \frac{n_\sigma}{M_{100} S} \sqrt{\frac{2(S+B)}{T}}$$

- n_σ: significance, M_{100}: modulation factor of 100%polarized photons, S: total source count rate, B: total background count rate, T: observation time.

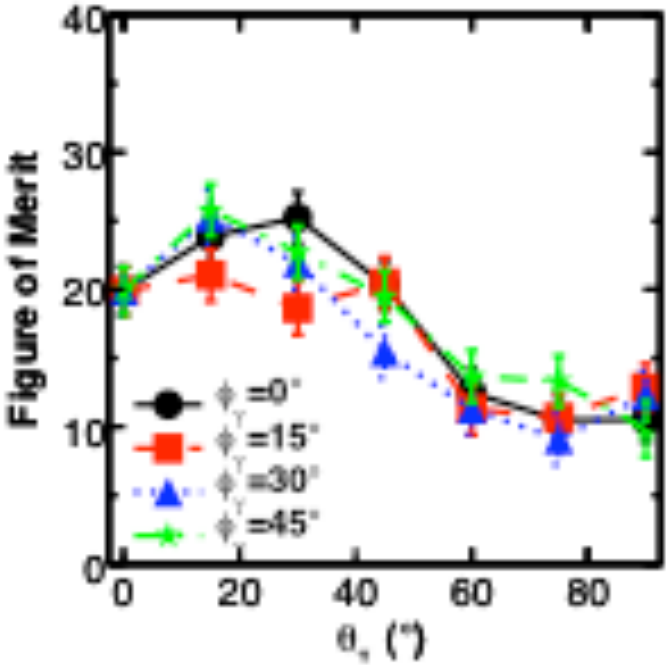
Modulation factor vs energy

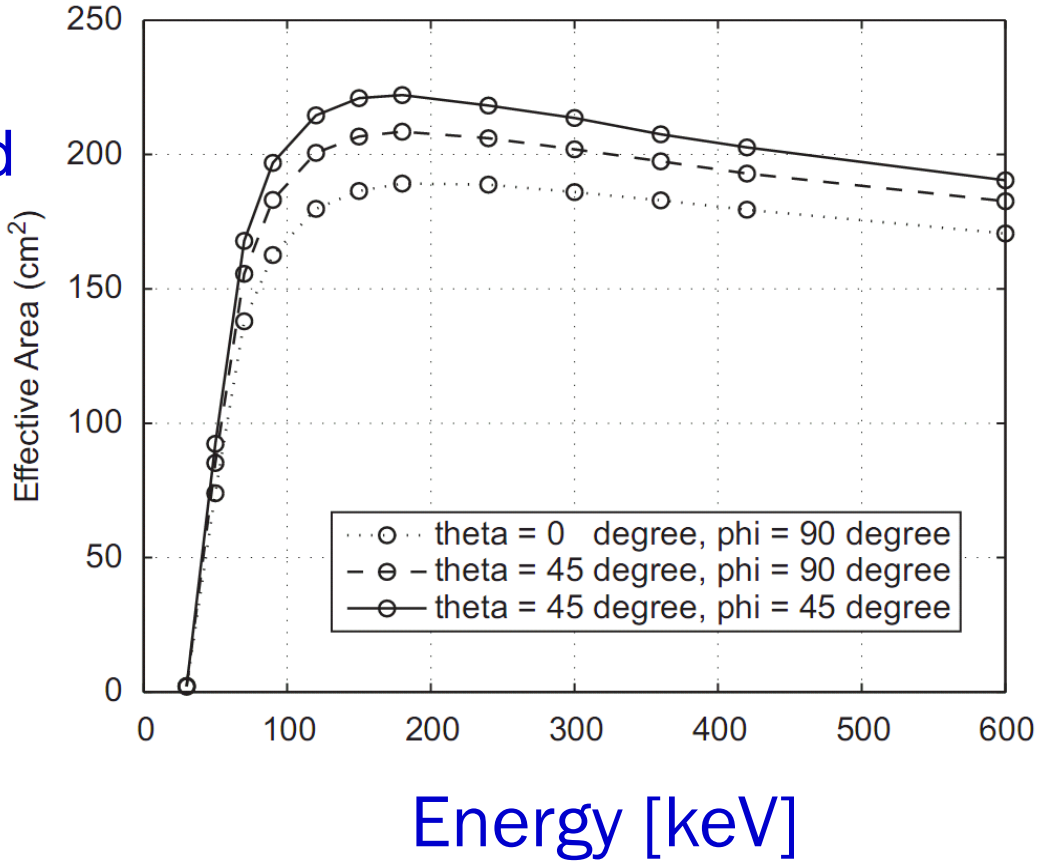


M100 vs 100% monoenergetic polarized photons with different incident angles

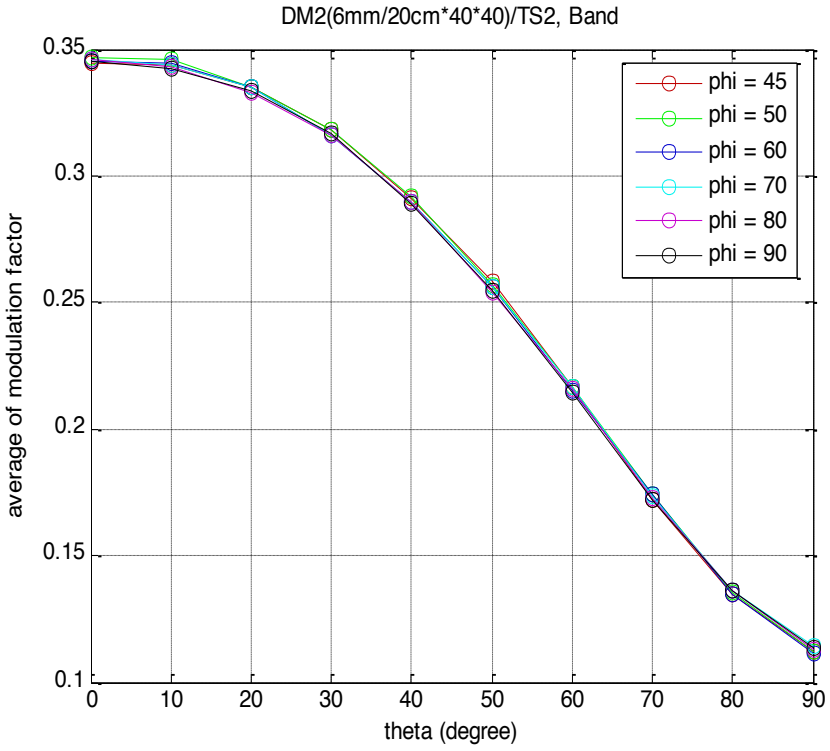
Effective area

- Monte Carlo based study
- A_{eff} is dependent on E and incoming photon angle
- Figure of merit: A_{eff} x μ_{100}

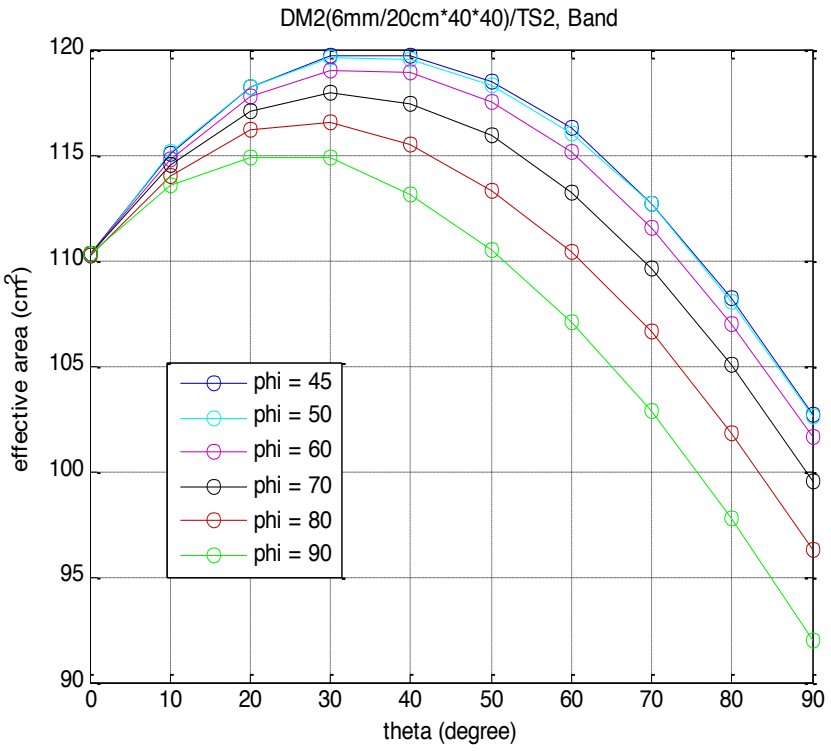




Modulation factor & Effective area (Band spectrum)

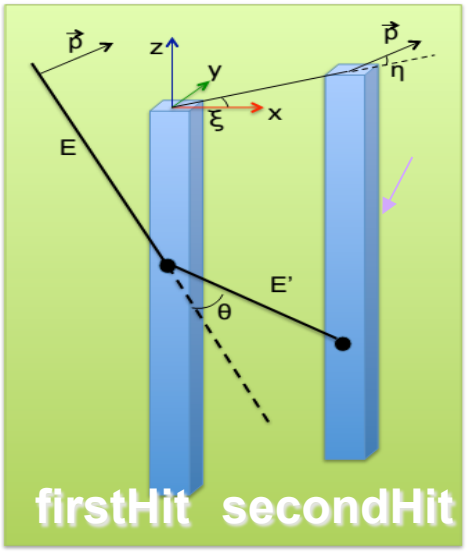


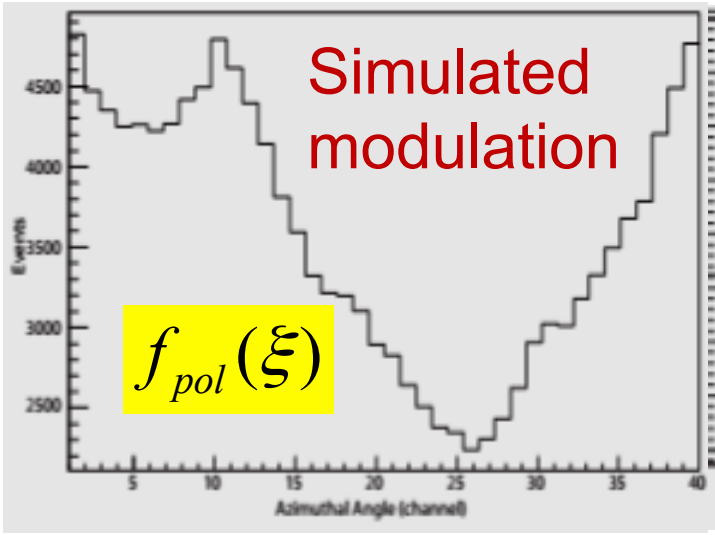
Modulation factor vs incident angle (25 modules)

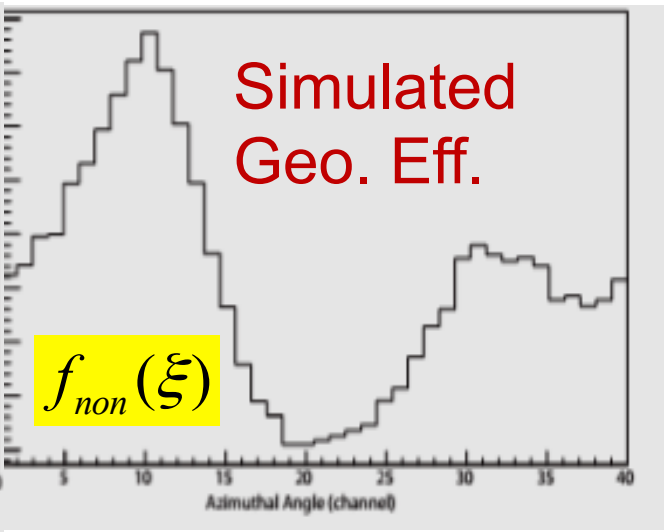


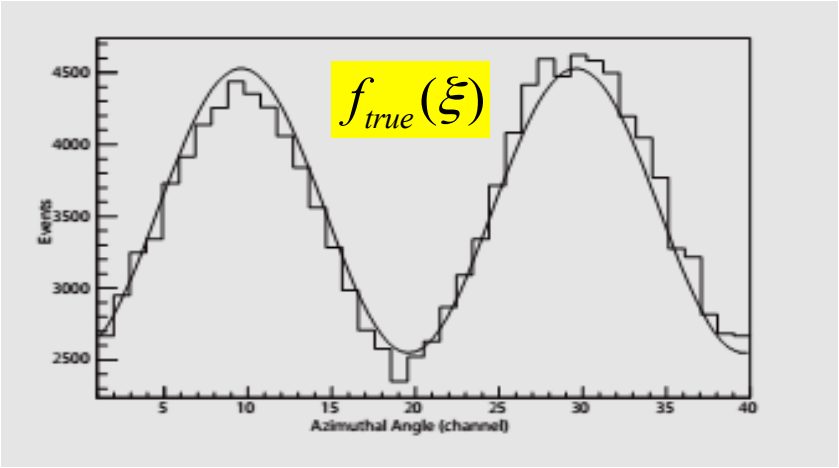
Effective area vs incident angle (25 modules)

Correction of geometrical effect





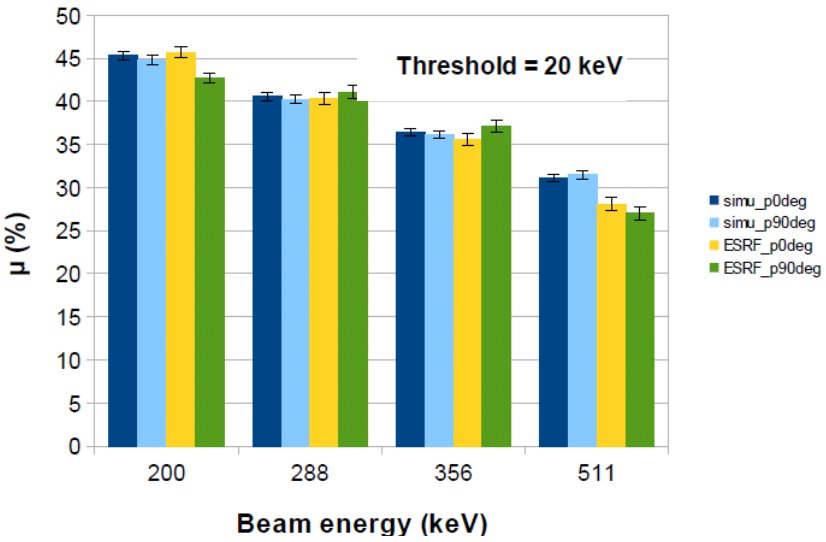


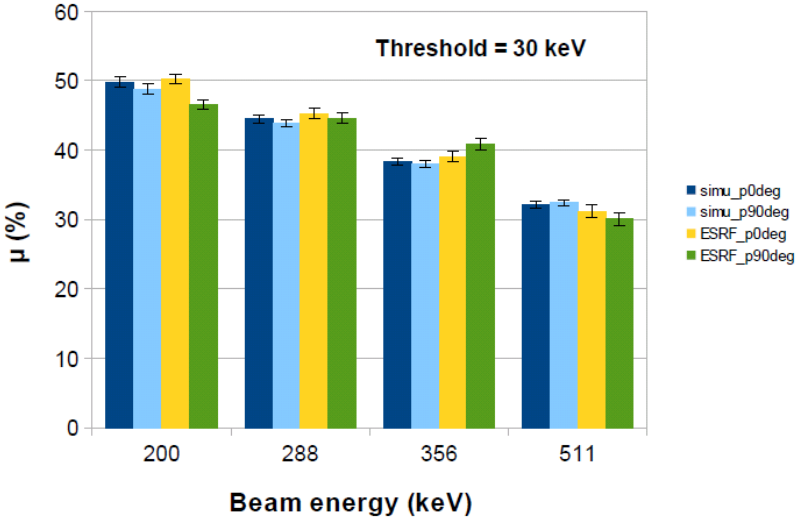


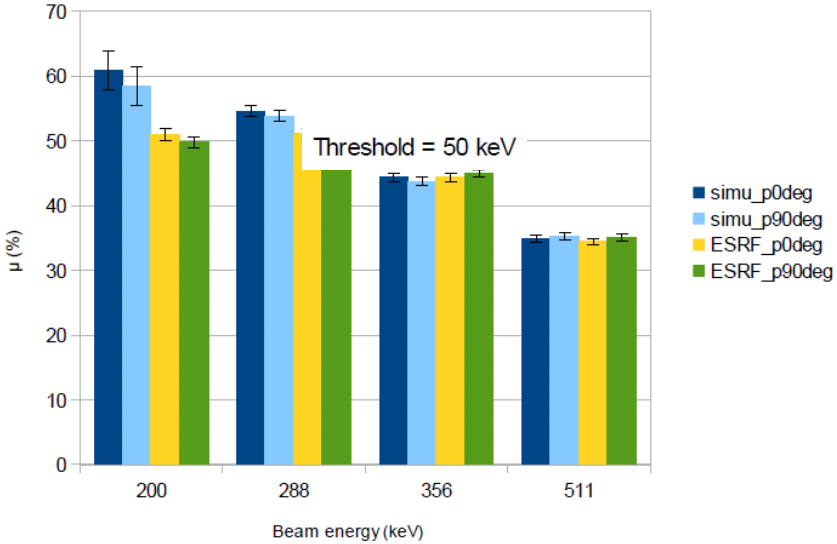
$$f_{true}(\xi) = N_{norm}\frac{f_{pol}(\xi)}{f_{non}(\xi)}$$

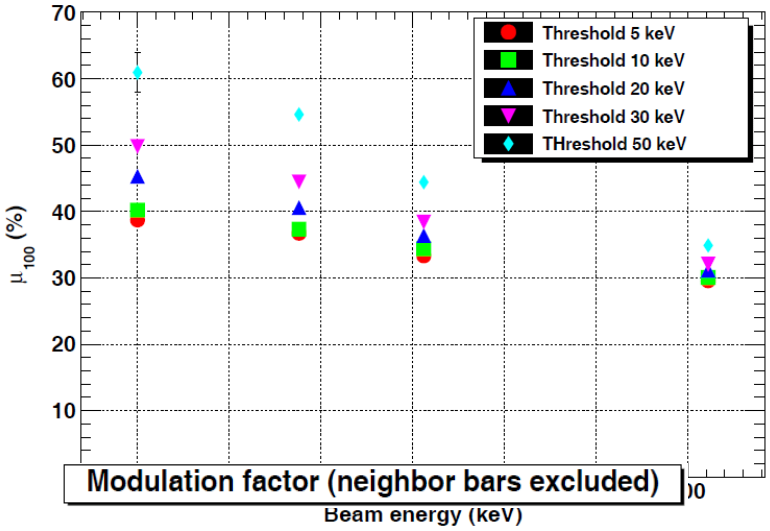
$$f(\xi) = \mathrm{A}\cos(2(\xi - \mathrm{C} + \pi/2)) + \mathrm{B}$$

Modulation factor comparison between ESRF beam test and MC simulation results



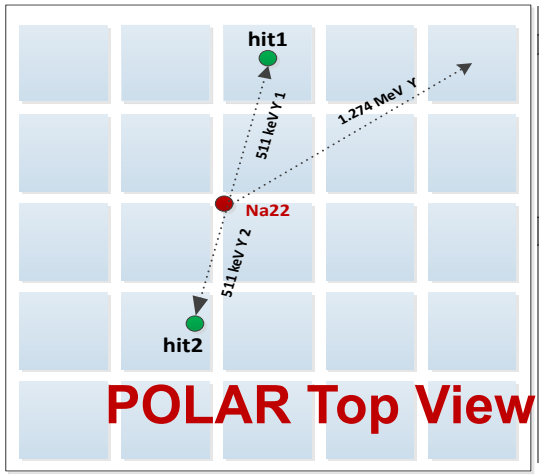


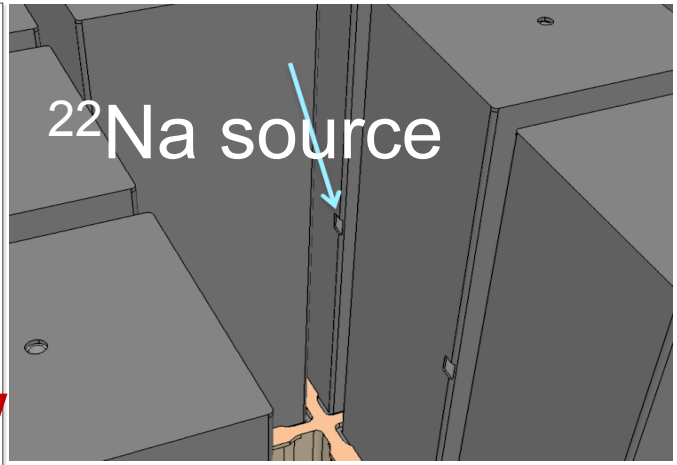


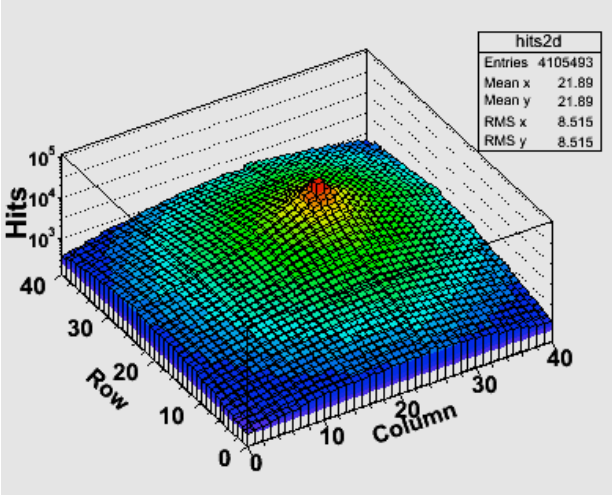


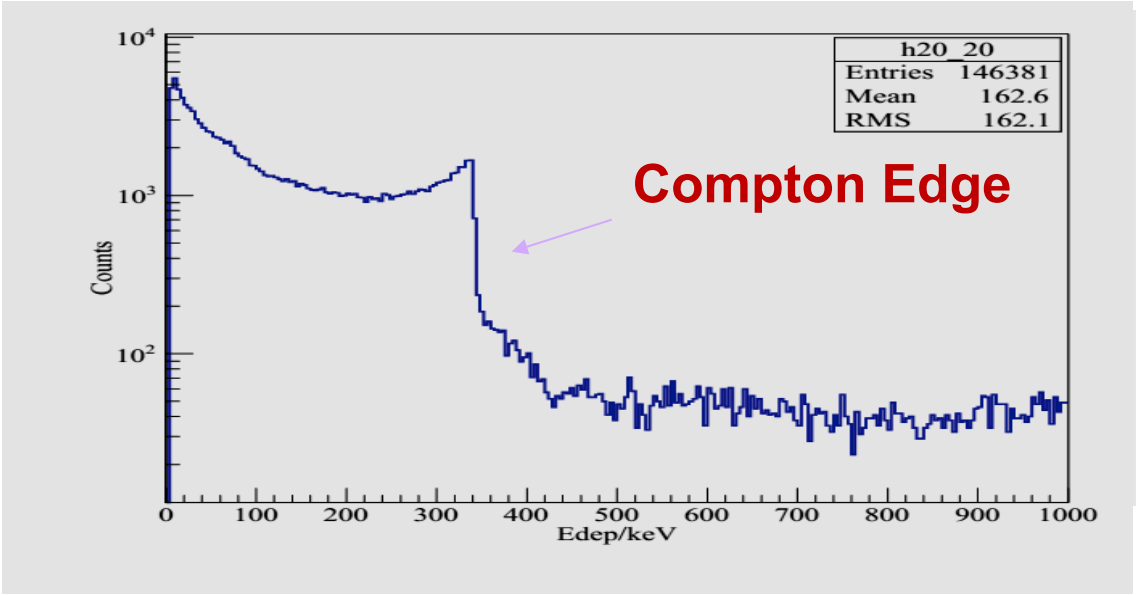
the left two bars are the MC simulation results, while the right two bars are the ESRF beam test results. They are consistentwith each other.

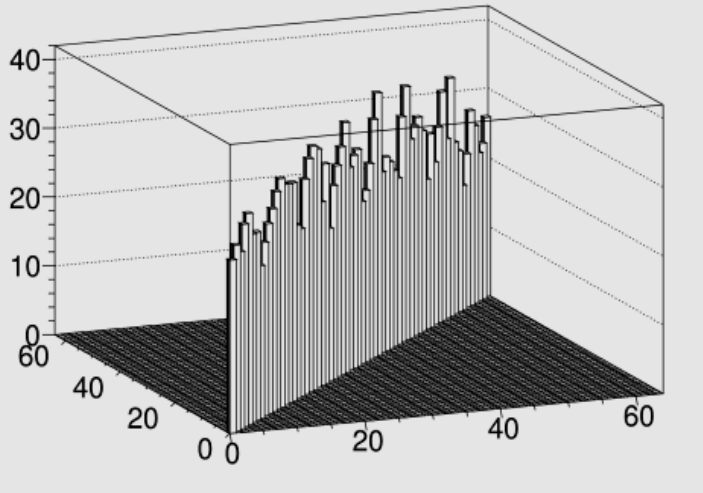
In orbit energy calibration







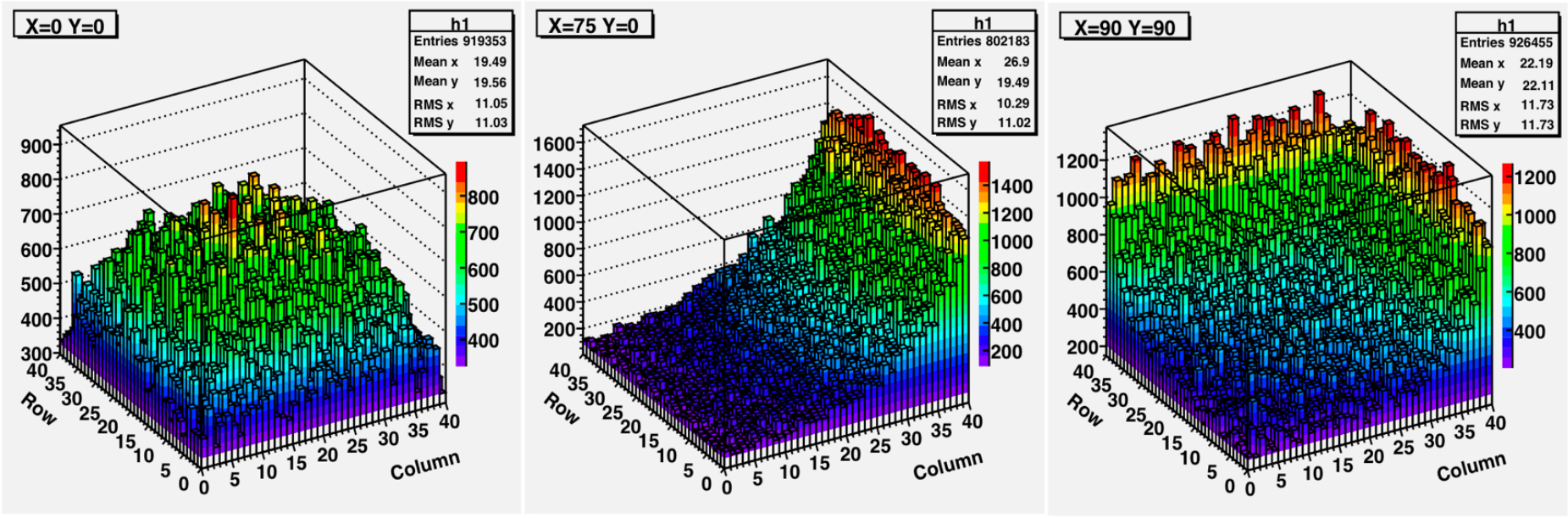




The 2 photons of 511keV photon emits simultaneously in opposite direction, the integrated concidence spectrum can be used for calibration.

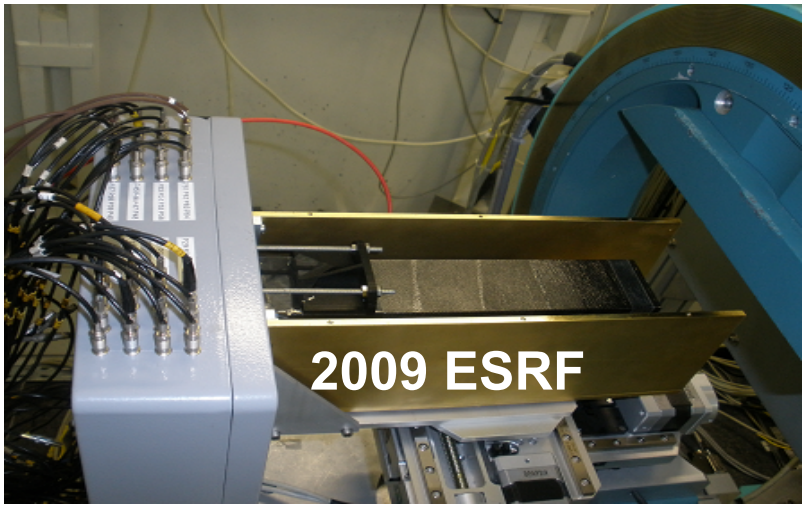
GRB Localization

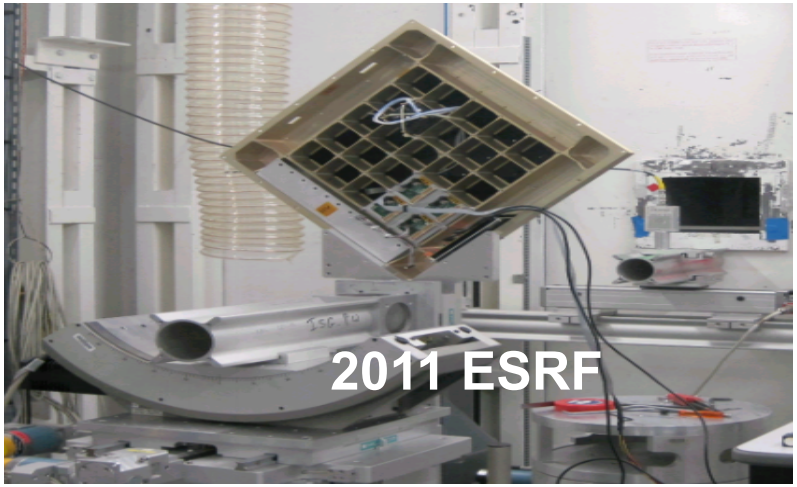
- On one side POLAR relies on other missions to get GRB spectra and precise localization
- Using the counting rate in the 25 modules POLAR can reconstruct the position of GRB within few degrees
  - This localization induces a relative systematic error <10% in measuring the polarization (GRB fluence > 10^{-5} erg cm^{-2})
- POLAR is able to measure polarization of GRBs not seen by oher missions

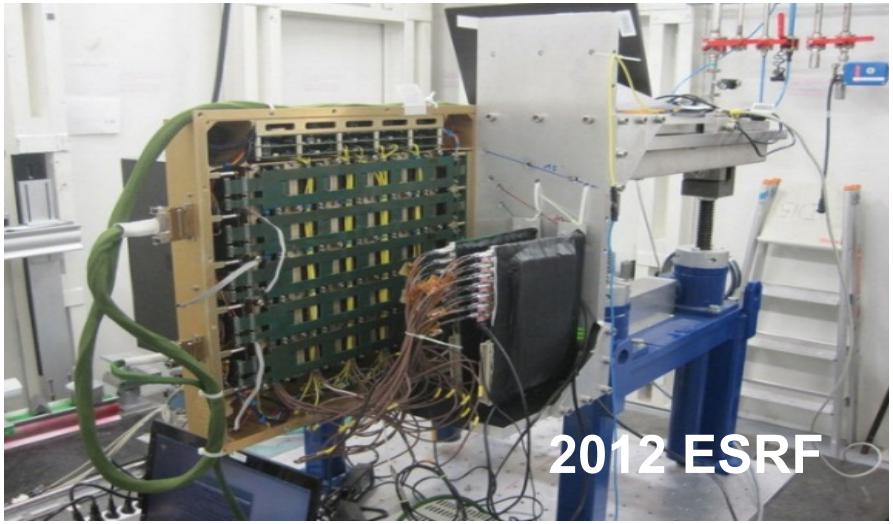


E. Suarez Garcia et al., A method to localize GRBs using POLAR, NIM. A 624 (3) (2010) 624

ESRF beam tests

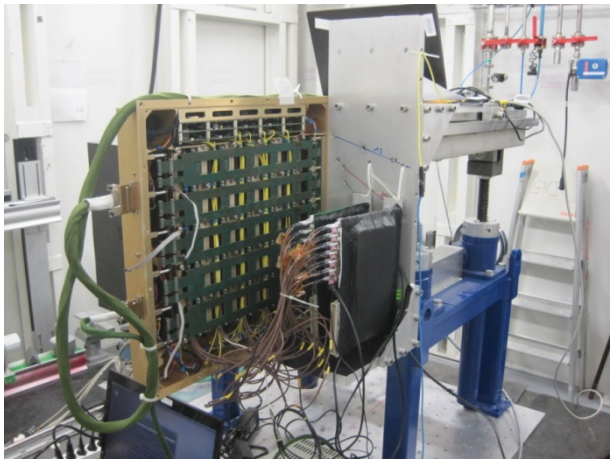






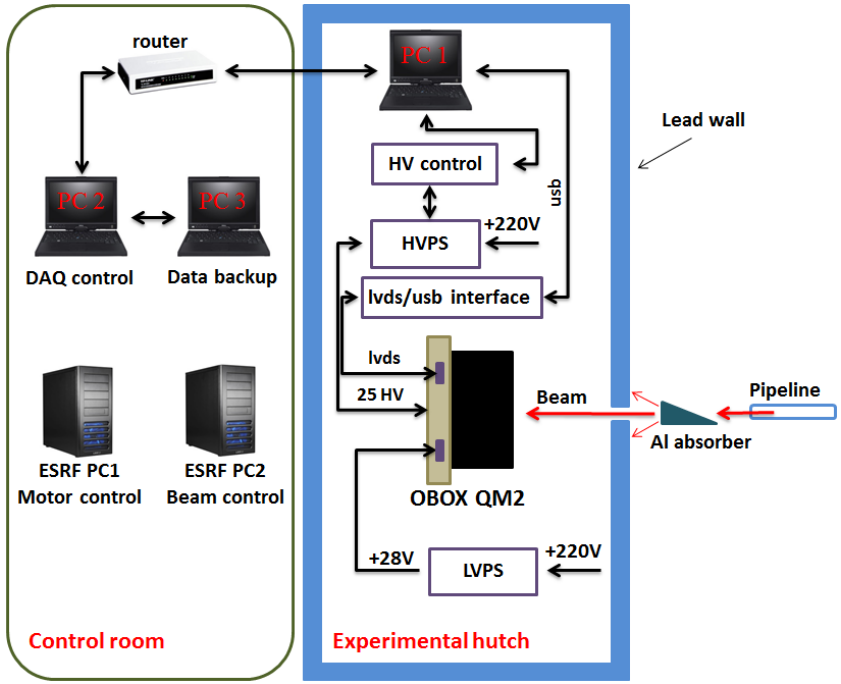
Next ESRF beam test in 2014: in preparation

ESRF beam test – Introduction



ESRF beam test in 2012. Top: top view; Bottom: back view

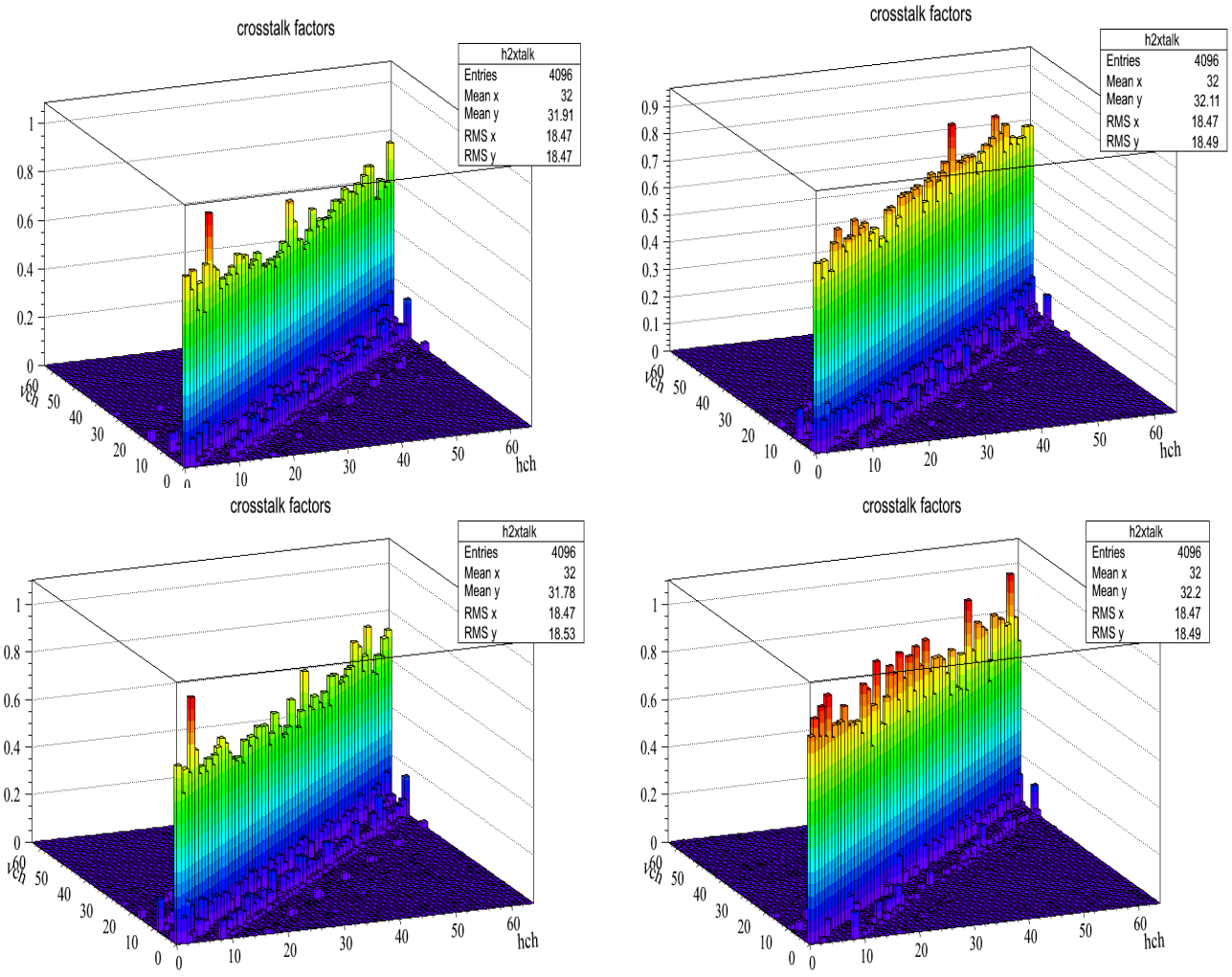
ESRF: European Synchrotron Radiation Facility, which is X-ray light source for Europe. it is located in Grenoble, France



Experimental setup. A full OBOX were used during the beam test

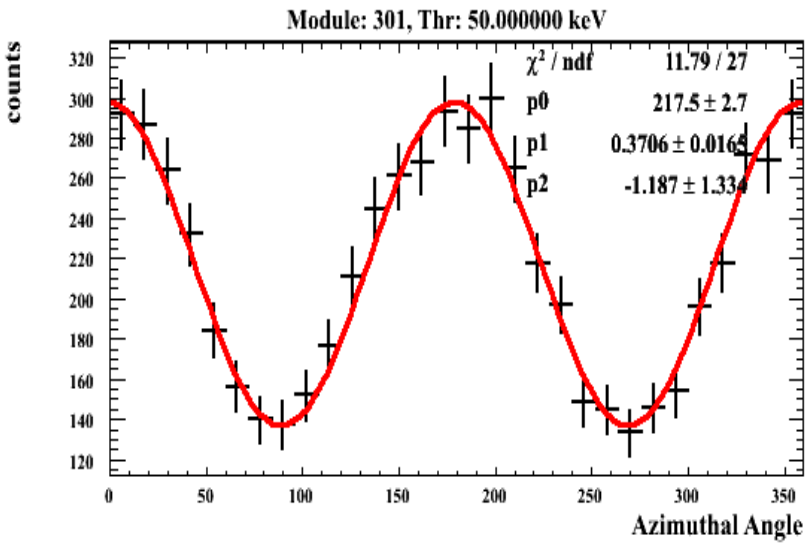
- Beamline: ID15A
- Energy range: 30~511 keV
- Flux: ~10^{13} photons/s
- Beam size: $\leqslant 0.5 \times 0.5$ mm^2
- Polarization degree: 100%
- Polarization direction: horizontal

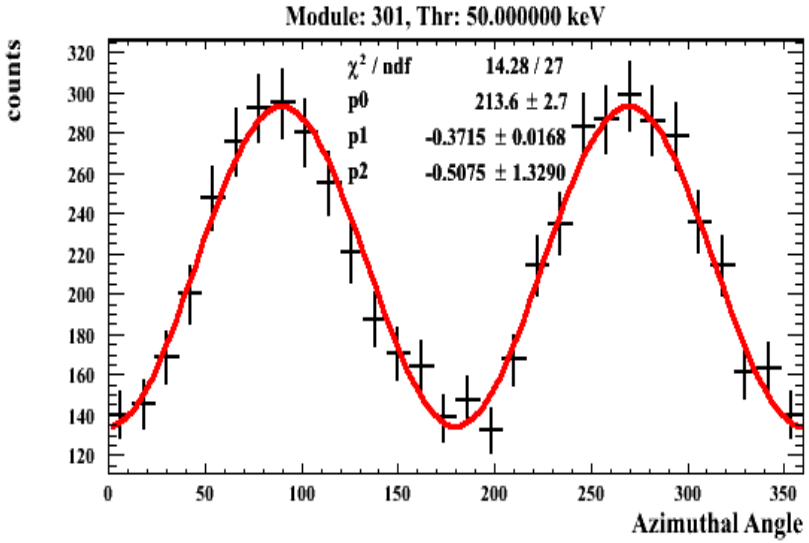
ESRF beam test result—Crosstalk



Crosstalk matrix of 4 modules measured during the ESRF beam test. 64×64 elements for each matrix, and will be used for the data correction.

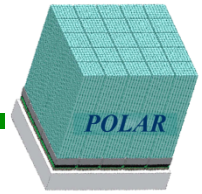
Polarization measurement—Results with 511 keV photons beam (on-axis incident)

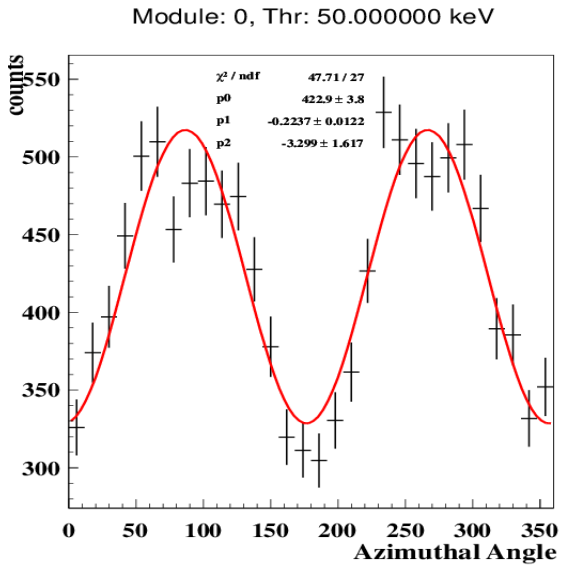


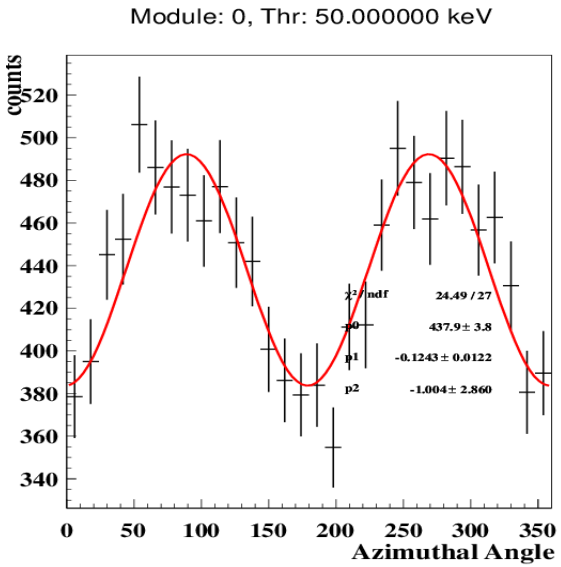


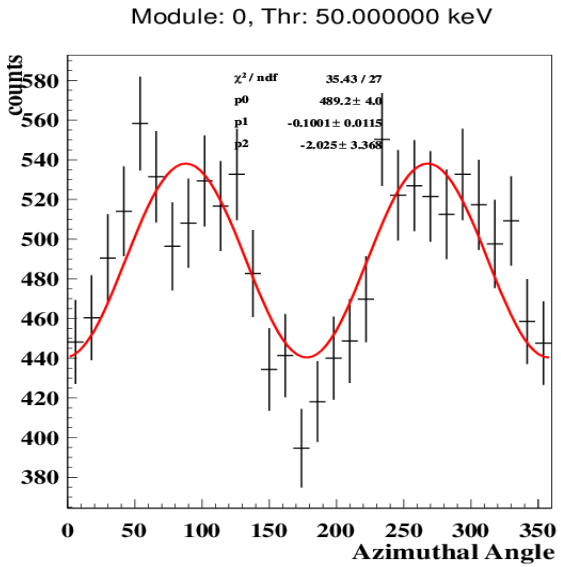
Modulation curve measured with 511 keV photons beam (for one module). The beam is 100% polarized and on-axis incident with respect to the detector。Left: Polarization angle 90° measurement result; Right: Polarization angle 0° measurement result (turning the detector by 90°). The reconstructed modulation factor is ~37.2%。

Polarization measurement—Results with 511 keV photons beam (off-axis incident)



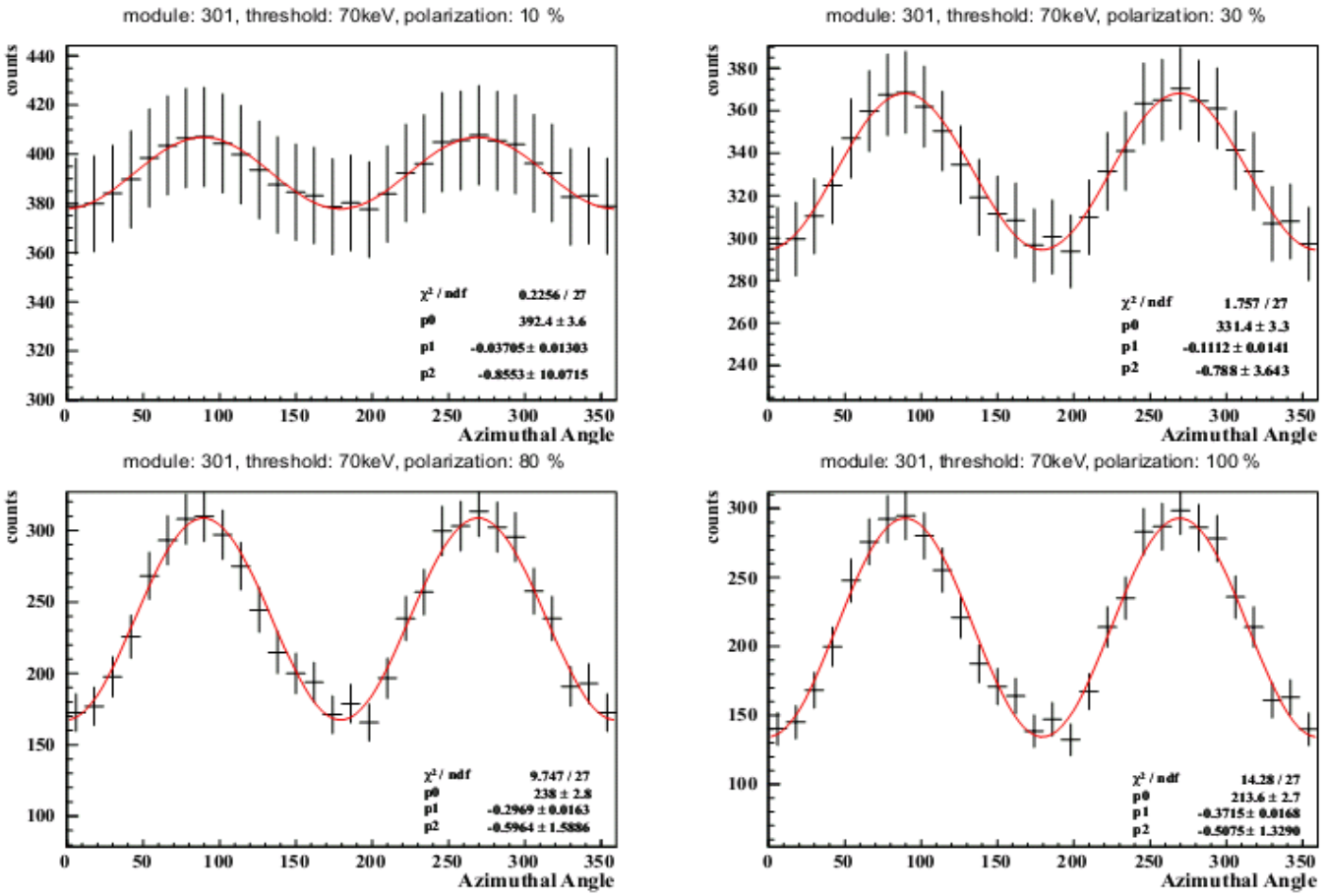






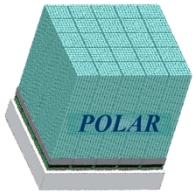
Modulation curve measured with 511 keV photons beam (for one module). The beam is 100% polarized and off-axis incident with respect to the detector。Left: off-axis angle 15° , modulation factor ~22.4%; Middle: off-axis angle 30° , modulation factor ~ 12.4%; Right: off-axis angle 45° , modulation factor ~ 10%.

Polarization measurement—Results of different polarization degree



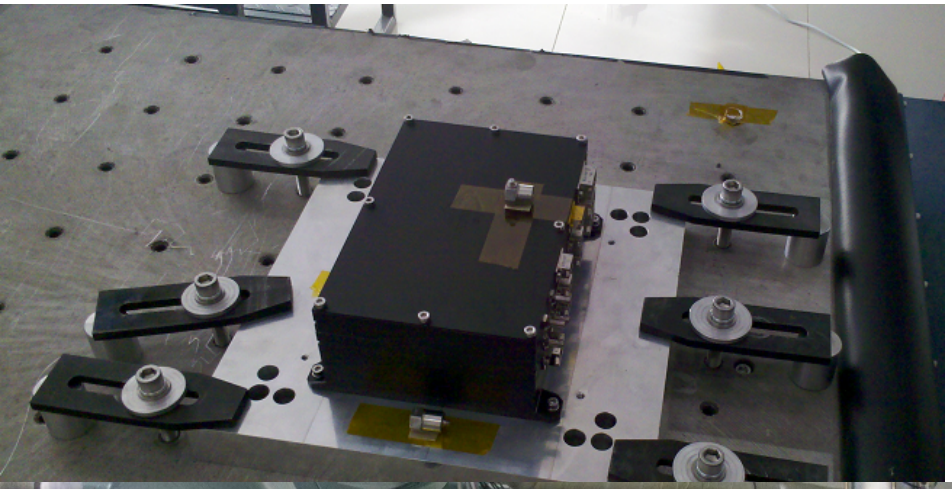
Modulation curves measured with different polarization degree (by mixing data from 0° and 90° polarization angle). Top-left: polarization degree 10%, modulation factor ~3.7%; Top-right: 30%, modulation factor~11.1%; Bottom-left: polarization degree 80%, modulation factor ~29.7%; Bottom-right: polarization degree 100%, modulation factor ~37.2%.

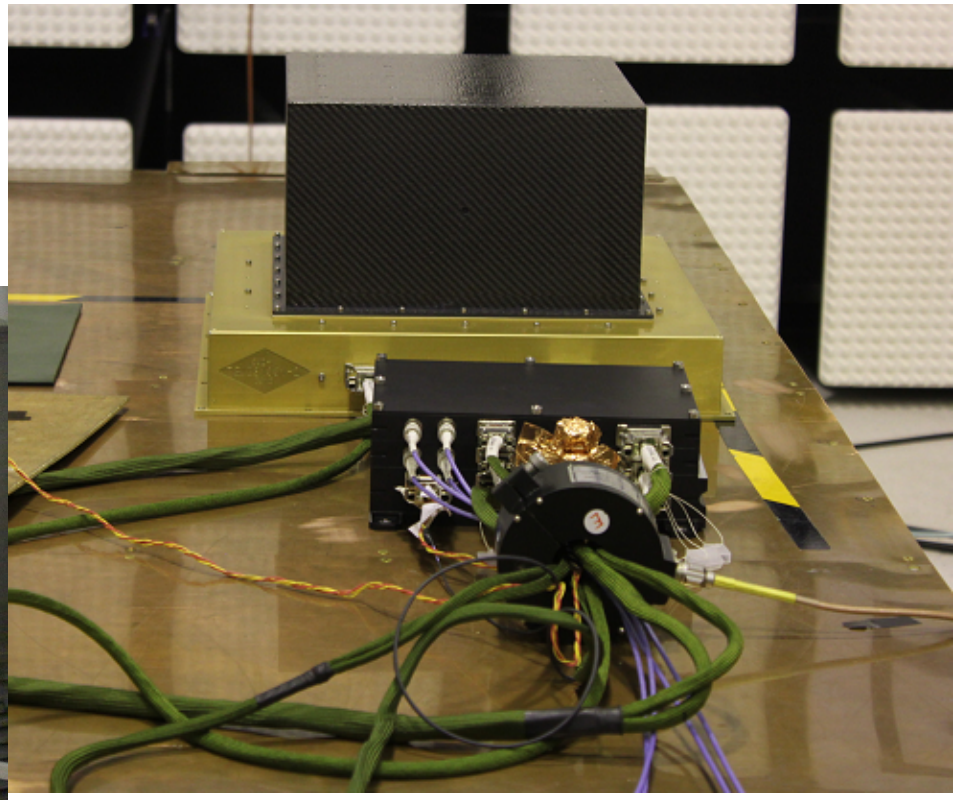
Summary for beam test



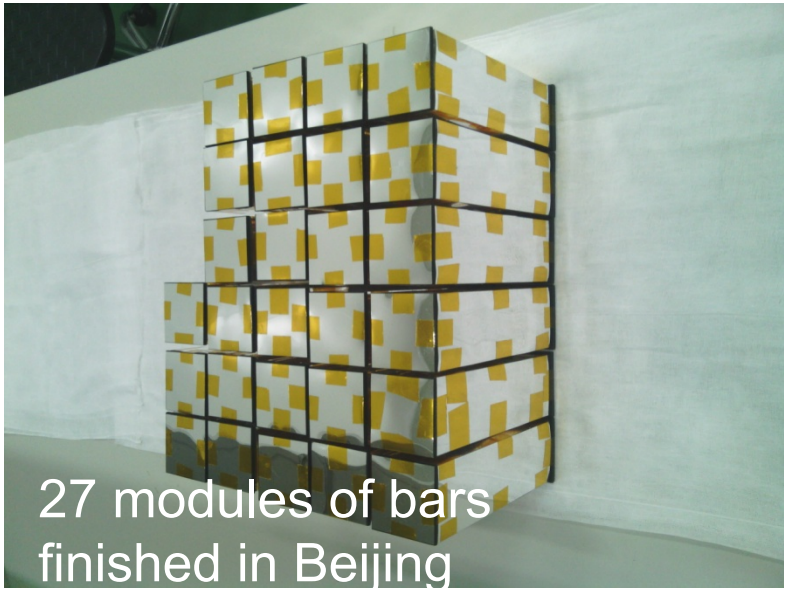
- Performed several beam tests: ESRF (at Grenoble in France)
- The beam tests results show that POLAR has good polarization measurement (modulation factor > 40% @200keV), lower threshold (few keV to dozens of keV), good gain uniformity (average 2:1) and lower noise (few keV)
- POLAR will perform a full beam calibration on FM at both ESRF .

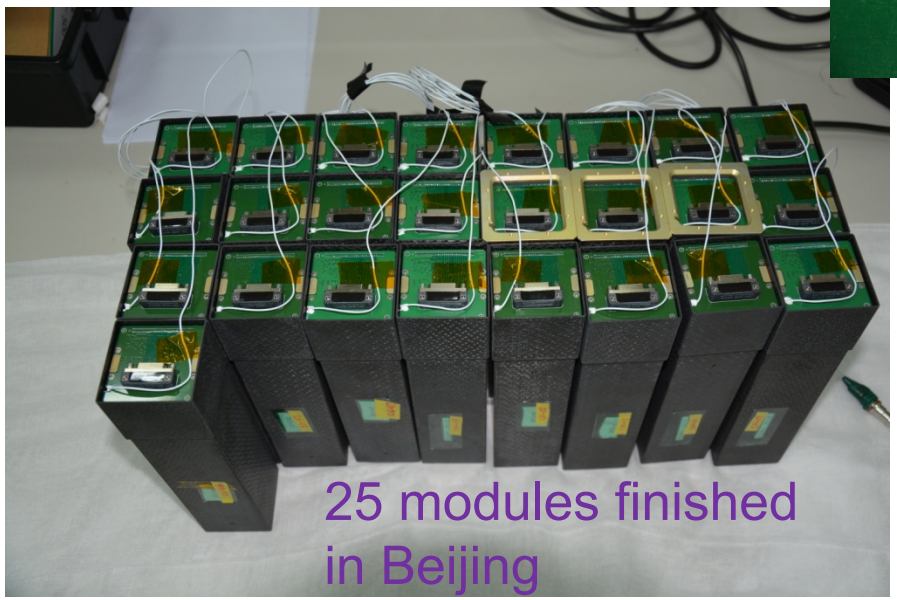
POLAR qualification model tests





Flight model hardware in final stage





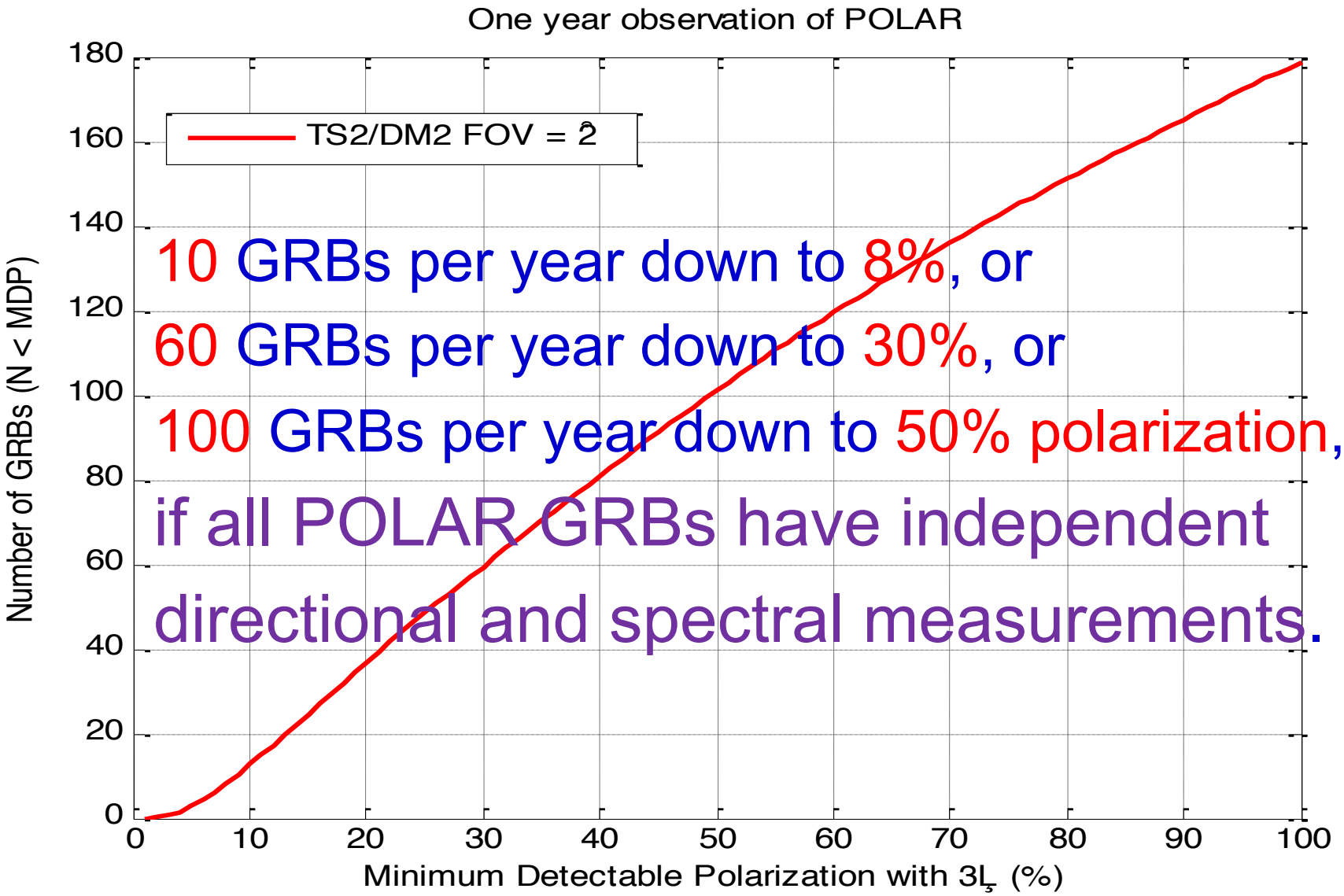
To select 25 modules from 50 modules (25 each side) as flight modules for final integration of the POLAR flight model; the rest as backup.

Engineering and Performance Parameters

Detector material	Plastic scintillator EJ-248
Detector dimension	Scintillator bar 5.9×5.9×176 mm^3 One module: 64 bars; total 25 modules
Energy range	～50－500 keV
Geometrical area	~430 cm^2 (normal incidence)
Field of View (effective)	±70°×±70°(effective ~1/3 sky)
MDP	～10% （$Flux_{total} \geq 3\times10^{-5}$erg cm^{-2}）
Mass	Outside: 28.5kg; inside: 3.5 kg; total 32 kg
POLAR dimension	Outside: 450×450×250 mm^3 Inside: 240×160×82 mm^3
Power consumption	～72 W
Timing (wrt UTC)	±1ms

Launch expected in Dec. 2015

Simulated POLAR Capability (BATSE catalog)



10 GRBs per year down to 8%, or

60 GRBs per year down to 30%, or

100 GRBs per year down to 50% polarization,

if all POLAR GRBs have independent directional and spectral measurements.

The need for coordinated observations

- POLAR has limited capability in determining incident GRB directions and spectra.
  - Independent data can improve GRB polarization measurement accuracy.
- TG data transmissions to users are usually on request and very slow.
  - We are negotiating with TG management to have automatic and faster data transmission ~ 24 h.
  - Then polarization calculation and broadcasting.

Thanks for your attention!