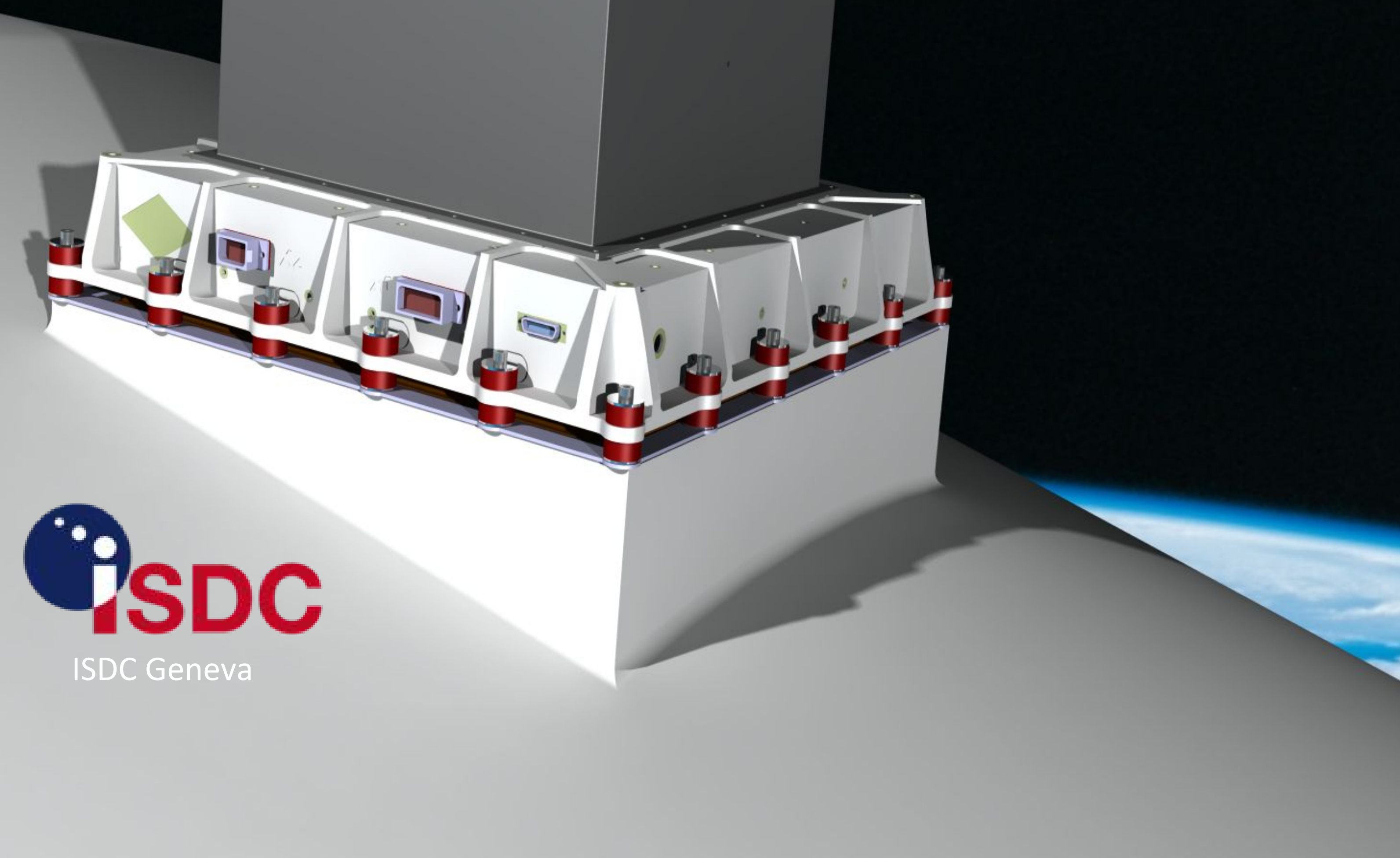
GRB polarization with the POLAR detector.



Univ. Geneva

PSI Zurich

IHEP Beijing

NCBJ Poland

ISDC Geneva

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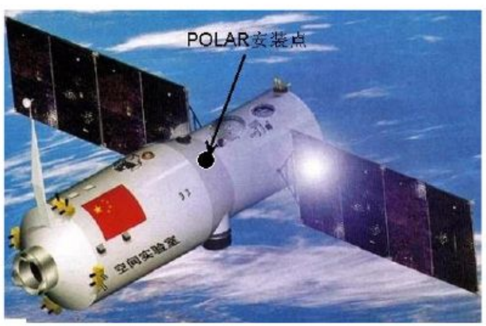
Tiangong 2 (天宫二号)



2011: TG-1 Launched
2012&2013 Docked successfully
TG 2: July-August 2016 from Jiuquan with POLAR on board

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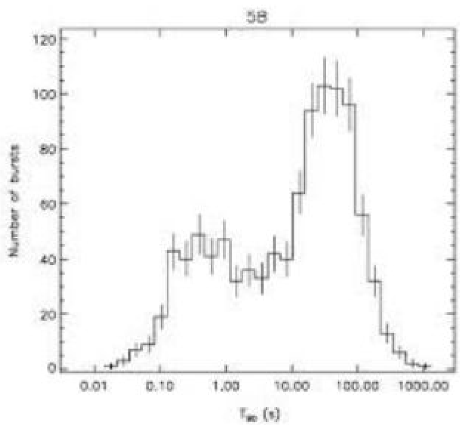
GRB observables up to now

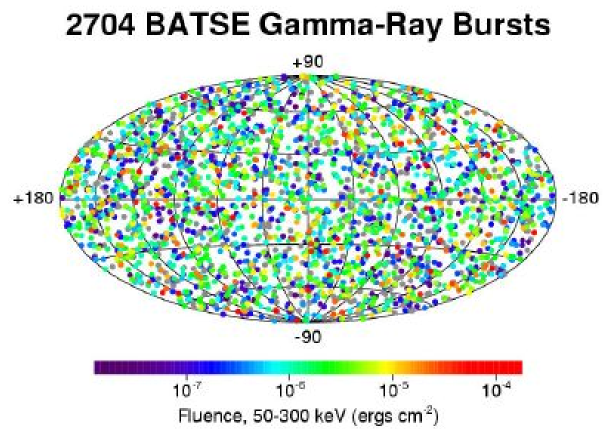
Duration

positions

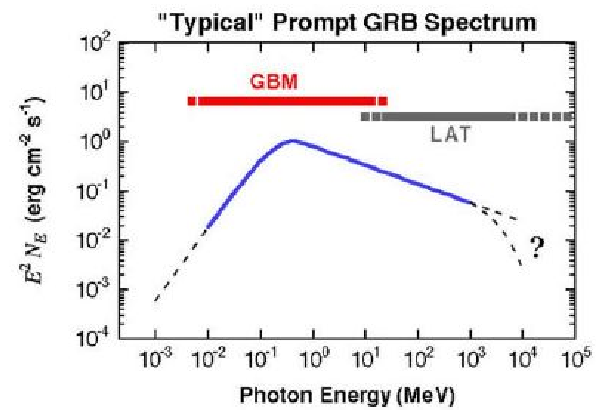
Energy



Bing Zhang et al., IJMPA 2004

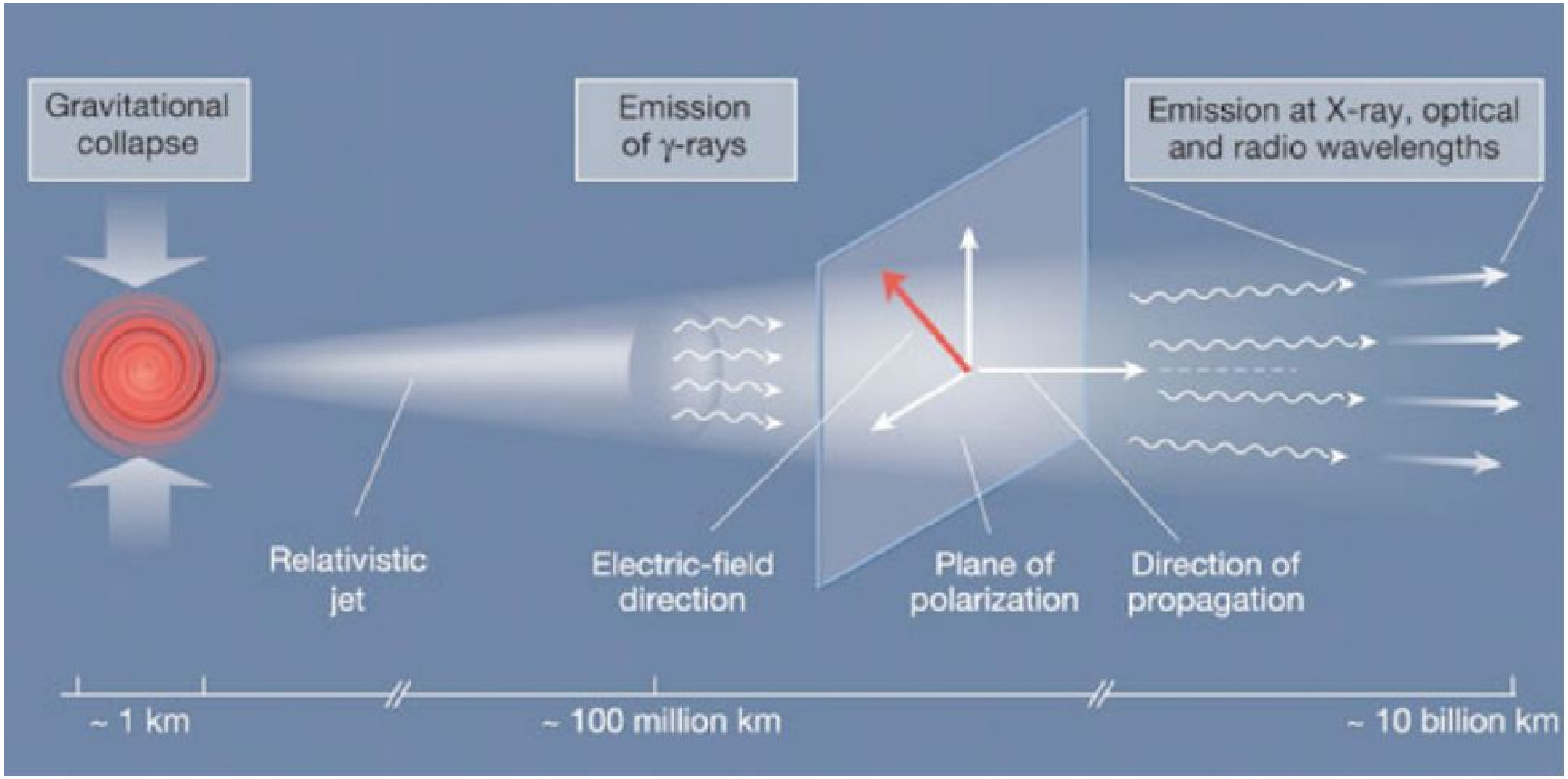


G. Fishman et al., BATSE, CGRO, NASA



source: http://polywww.in2p3.fr

GRB prompt emission



E. Waxman, Nature 423 (2006) 388

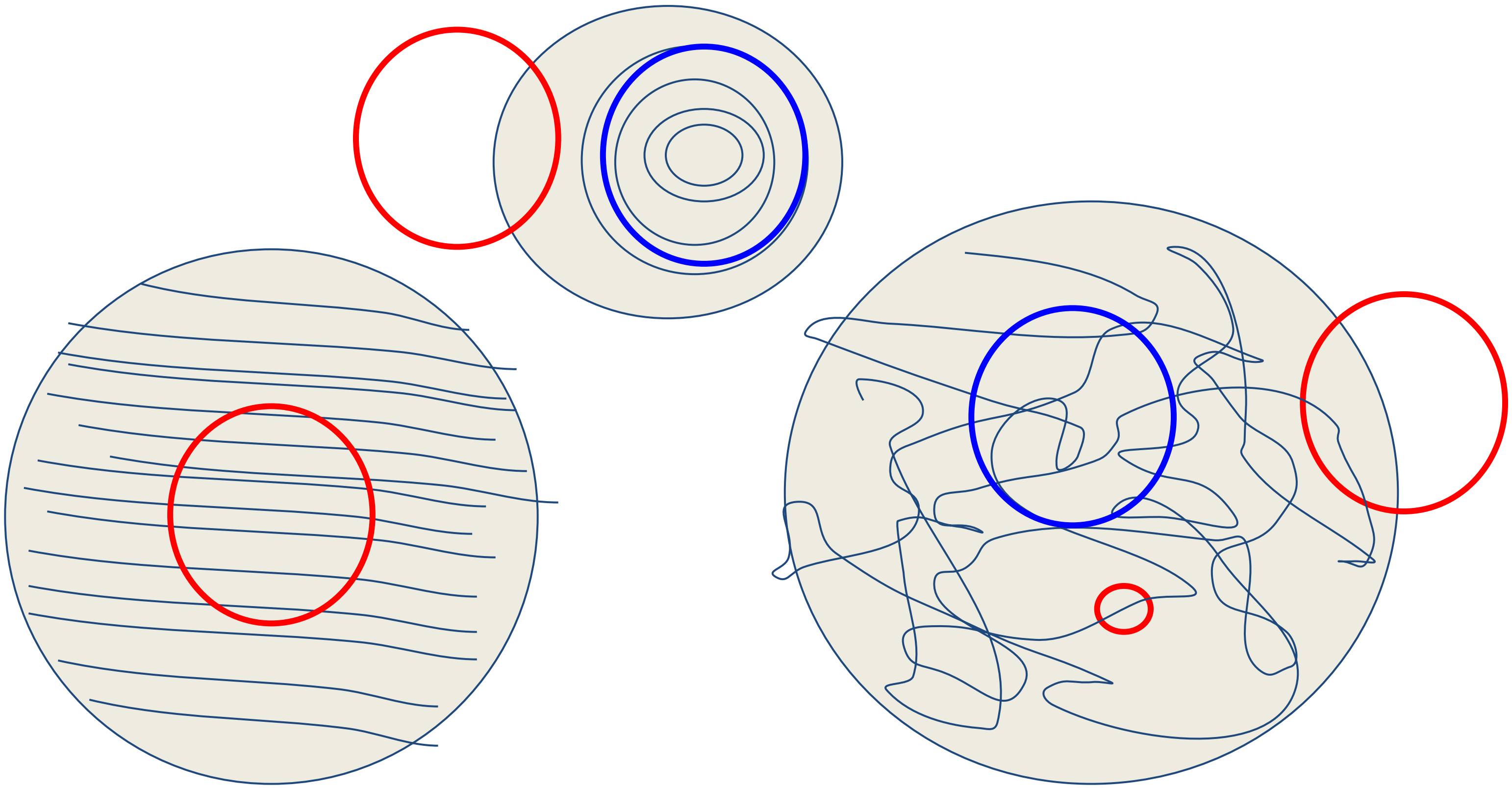
Polarization theory (Prompt)

Existence of a collimated jet.
Band spectrum (power law with breaks)
What is ejected:

- Matter dominated Kinetic energy >> EM energy -> internal shock (need shell with different Γ factor)
- Poynting flux   Kinetic energy << EM energy -> EM instability, magnetic reconnections

Magnetic reconnection or internal shock accelerates particle. Electrons in B field create gamma rays (synchrotron)
Some scenario possible with Compton scattering (Cannon ball)
If gamma rays produced in a region of high opacity then gamma ray are converted in a thermal spectrum (sometimes observed?)

If Poynting flux then we do expect order in magnetic field.
If internal shock some order is possible (B field in the shock plane)
Depend on geometry (sharp edges) and size of the visible emitting region relativistic beaming 1/Γ)



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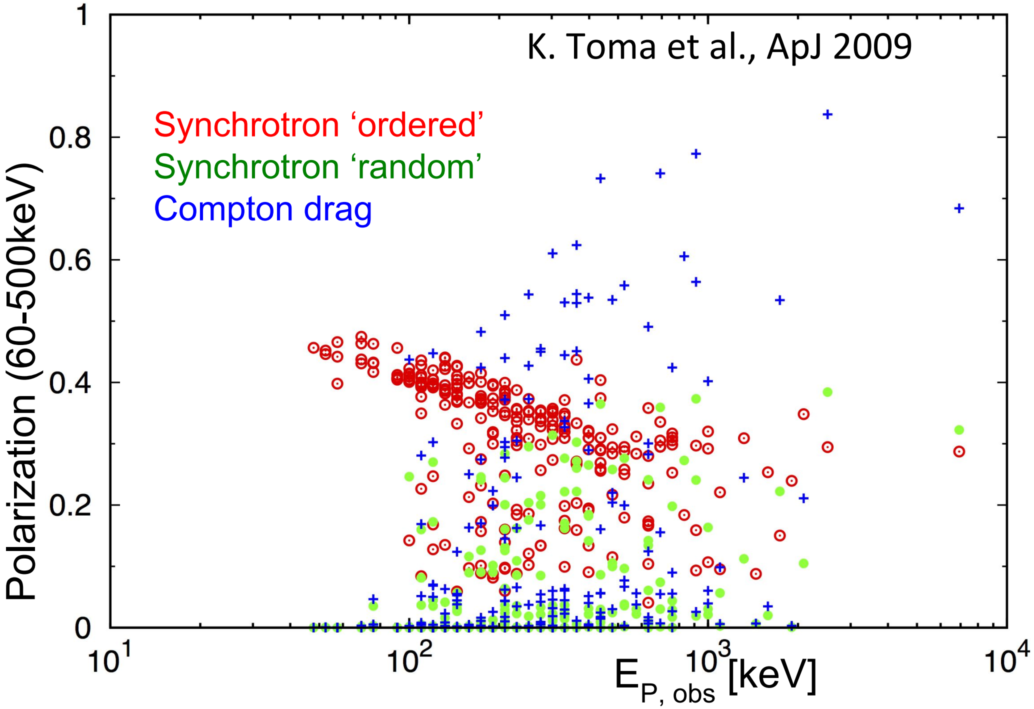
Predictions

- If p> 60% => Inverse Compton
- p> 10% <60% Synchrotron or Synchrotron self Compton with organized B fields
- p<10% random B fields

GRB Prompt signal Models and Polarization

To discriminate between models, it is important to be able to measure reliably Π ~ 10% (MDP)



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Previous measurements

GRB	Instru/Satellites	Pol degree(%)	Energy range(keV)	Comments
110721A	GAP/IKAROS	84^{+16}_{-28}	70-300	@3.3 σ , with constant pol direction
110301A	GAP/IKAROS	70±22	70-300	@3.7 σ , with constant pol direction
100826A	GAP/IKAROS	27±11	70-300	@2.9 σ , with inconstant pol direction
021206	RHESSI	80±20; 41^{+57}_{-44}	150-2000	With a very big systematic error
140206A	IBIS/INTEGRAL	>48	200-400	Unable to restrict the GBR model
061122	IBIS/INTEGRAL	>60; >65; >52	250-800; 250-350; 350-800	Unable to restrict the GBR model
041219A	IBIS/INTEGRAL IBIS/INTEGRAL SPI/INTEGRAL	<4; 43±25; 98±33	200-800; 200-800; 100-350	With inconstant pol direction
960924	BATSE/CGRO	>50	20-1000	Unable to restrict the GRB model
930131	BATSE/CGRO	>35	20-1000	Unable to restrict the GRB model

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Other use: birefringence of vacuum

Quantum loop gravity predict birefringence of vacuum (speed of light depend on polarization and energy)

Can create polarization from unpolarized signal (One pulse -> two identical pulses 100% circular polarized)

Can destroy linear polarization of a polarized signal in source => if we see polarization it gives limits on birefringence of vacuum

GRB are ideal because they are: cosmological, emit in all bandwidth
Prompt signal is better: short pulse, high energy

Afterglow: less interesting (long), dust can create polarization of optical light

Polarization of Crab can gives already interesting limits. (But Crab is near).

Best limits for the moment are direct measurement of enery dependent speed in a GRB

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Our goal

Measure 10 GRB linear polarization fraction
with an error < 10% per year

We will fly at least 3 years

This goal has been confirmed by Monte Carlo simulation of
the full realistic detector

This is enough to make a distribution and decide about models

POLAR is a polarimeter, it has terrible energy resolution

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Polarization & Compton Scattering

- Photons tend to Compton scatter at right angles to the incident polarization direction (Klein-Nishina formula)

$$\frac{d\sigma}{d\Omega}(\theta,\eta)=\frac{r_0^2}{2}\left(\frac{E'}{E}\right)^2\cdot\left(\frac{E'}{E}+\frac{E}{E'}-2\sin^2\vartheta\cdot\cos^2\eta\right)$$

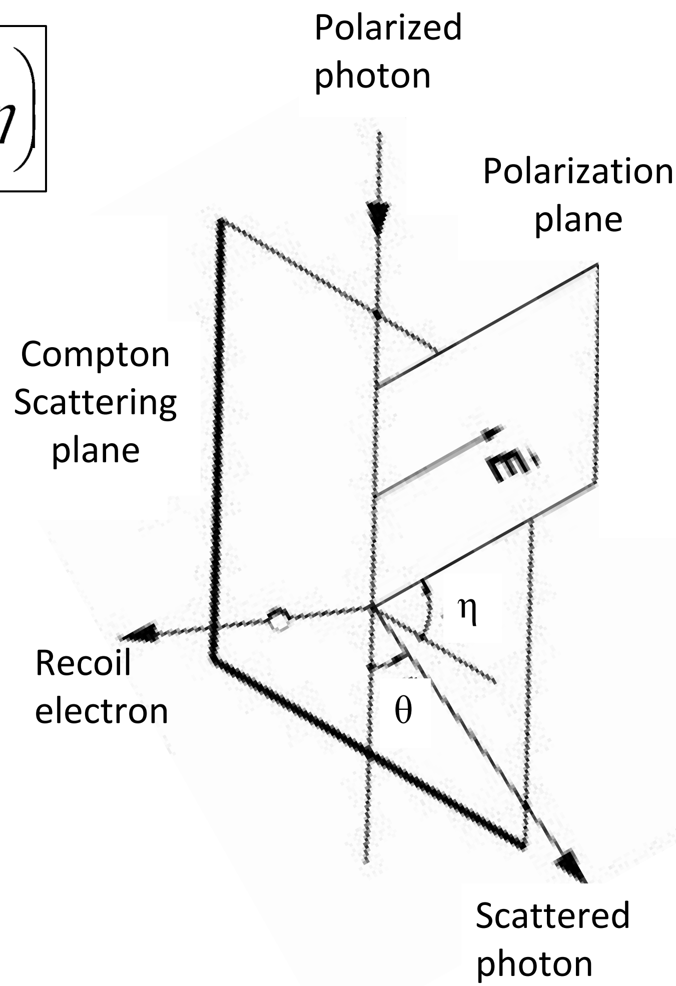
θ: Compton scattering angle
η: Azimuthal angle

$$\frac{d\sigma}{d\Omega}(\theta,\eta)=\frac{r_0^2}{2}\left(\frac{E'}{E}\right)^2\cdot\alpha\cdot\left(1-\frac{\sin^2\vartheta}{\alpha}\cdot\cos 2\eta\right)$$

$$\alpha=\left(\frac{E'}{E}+\frac{E}{E'}-\sin^2\vartheta\right)$$

$$\frac{d\sigma}{d\Omega}(\eta)=A\cdot(1-B\cdot\cos 2\eta)$$

Modulation of η (period π)



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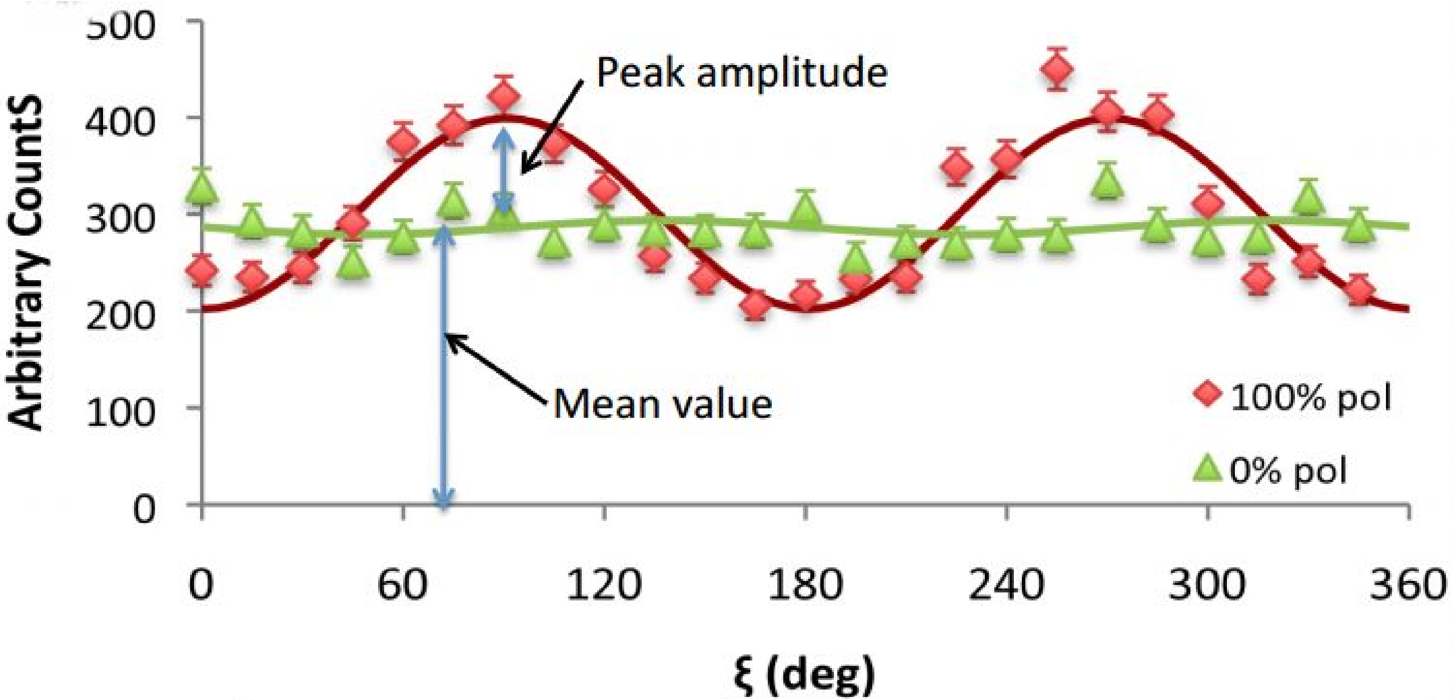
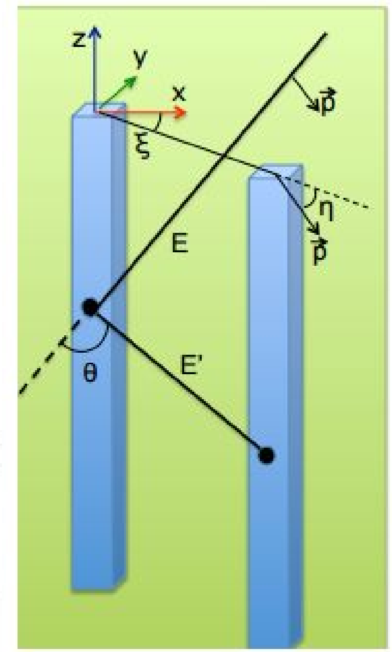
Modulation curve and principle of measurement





Fit function: $f(x) = A\{1 + \mu_{100} \cdot cos[2(\xi - \xi_0) + \pi]\}$

Modulation factor: $\mu = \frac{\text{Peak amplitude}}{\text{Mean value}}$

Polarization $= \mu / \mu_{100}$

Mod. angle : ξ_0

where μ_{100} is the modulation factor for 100% polarized photons

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POLAR concept

POLAR is a all plastic Compton polarimeter.

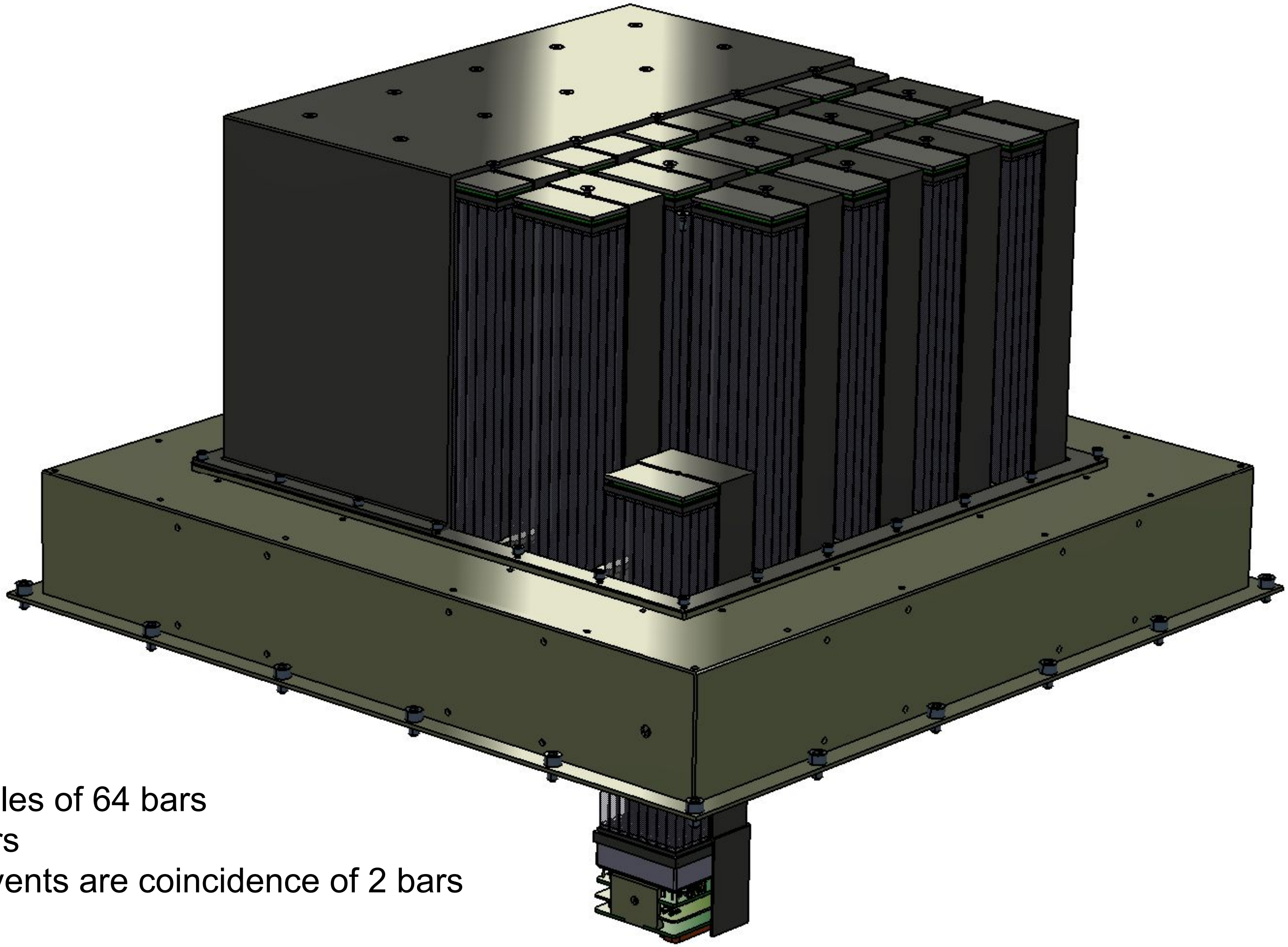
It will measure prompt polarization of GRB (several per year with a precision on linear polarization fraction better than 10%)

We will do the easy stuff:

- We expect possible large polarization in GRB.
- We don't have to do imaging (point source).
- We don't have to do long exposure...
- We use very fast coincidence (50 nsec)

But collect large background from diffuse sky (3 sr)

Modular design



25 modules of 64 bars
1600 bars
useful events are coincidence of 2 bars

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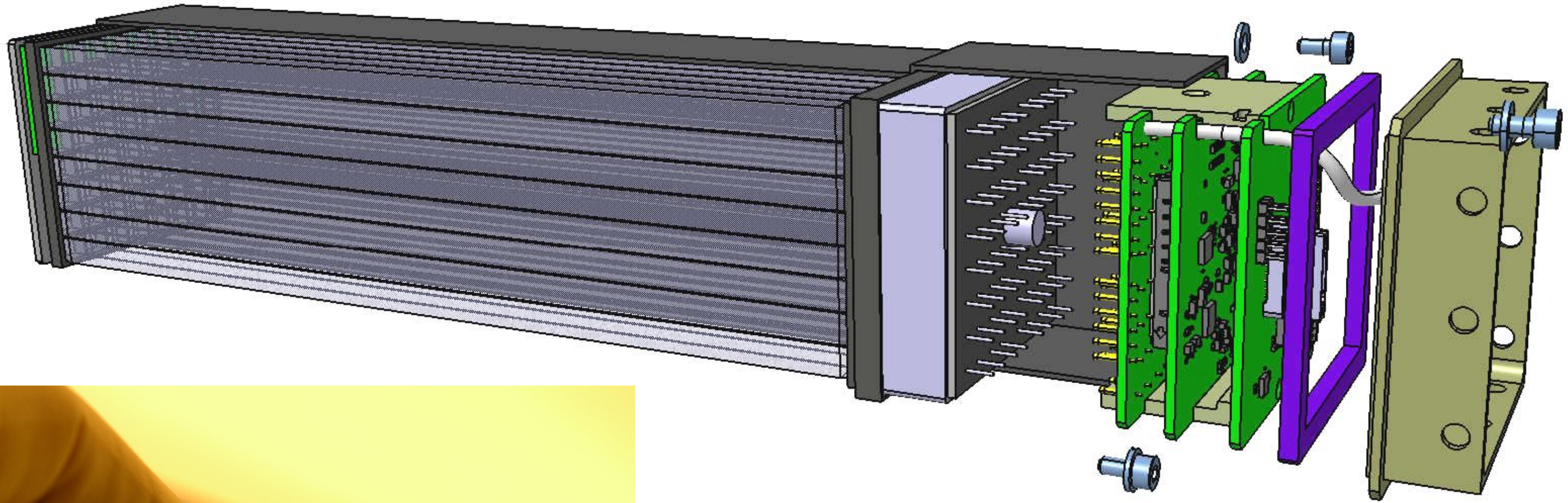
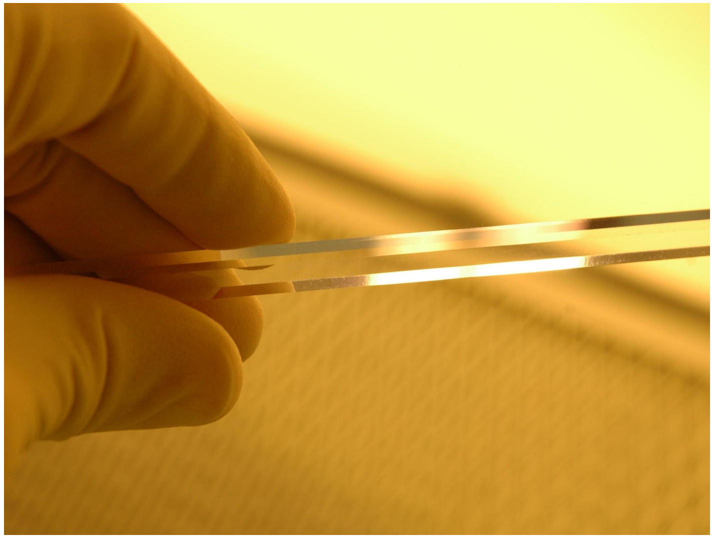
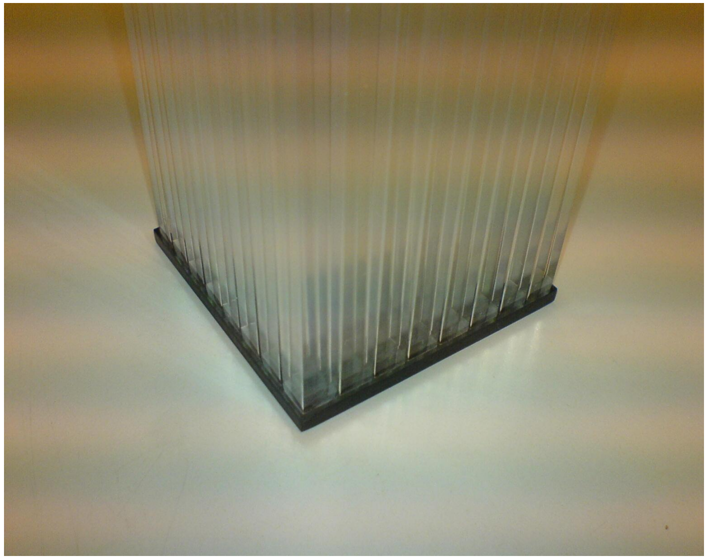
Module construction







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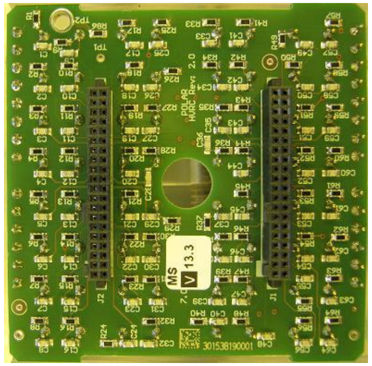
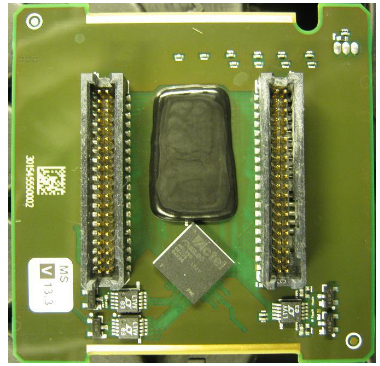
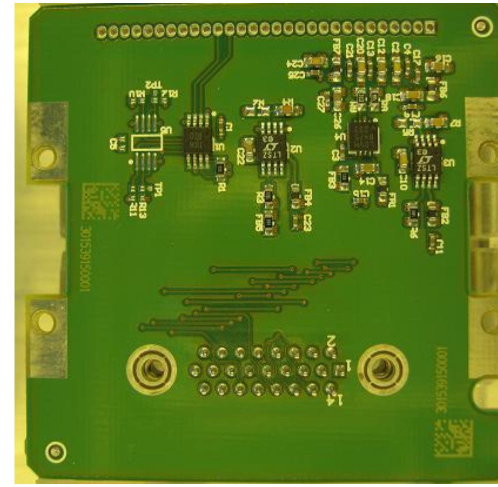
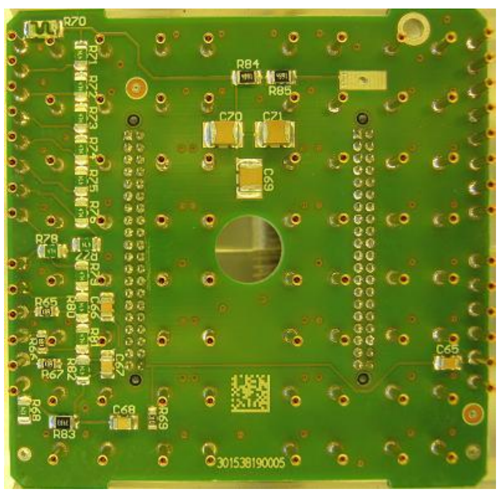
Module electronic

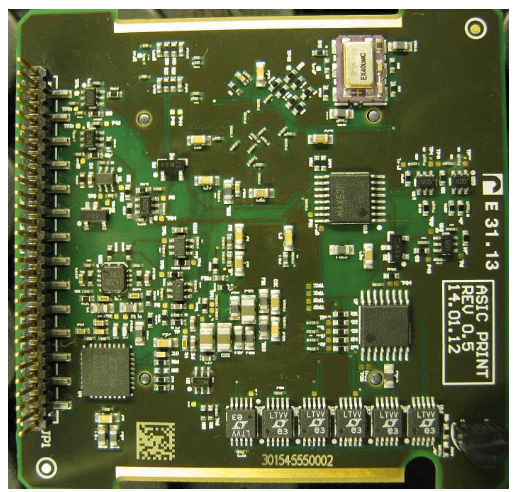
FEE: HV, ASCI and Interface PCBs

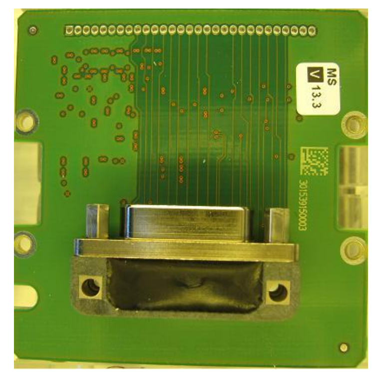












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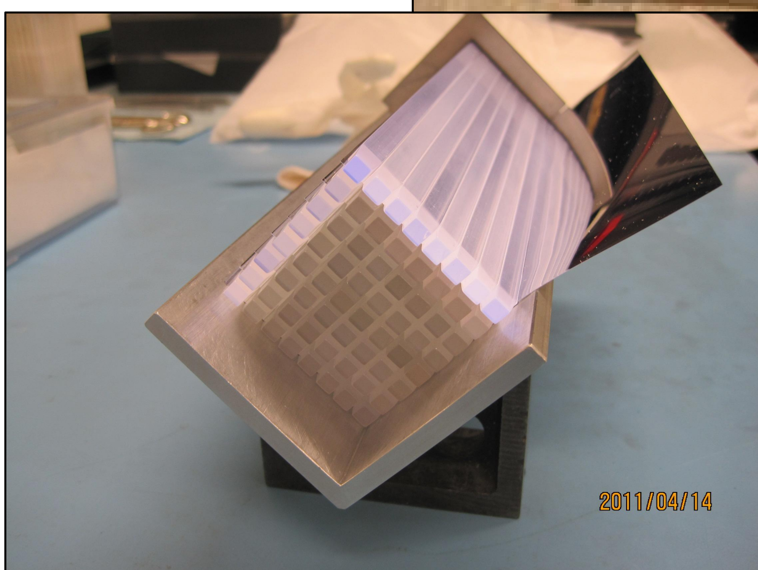
Module



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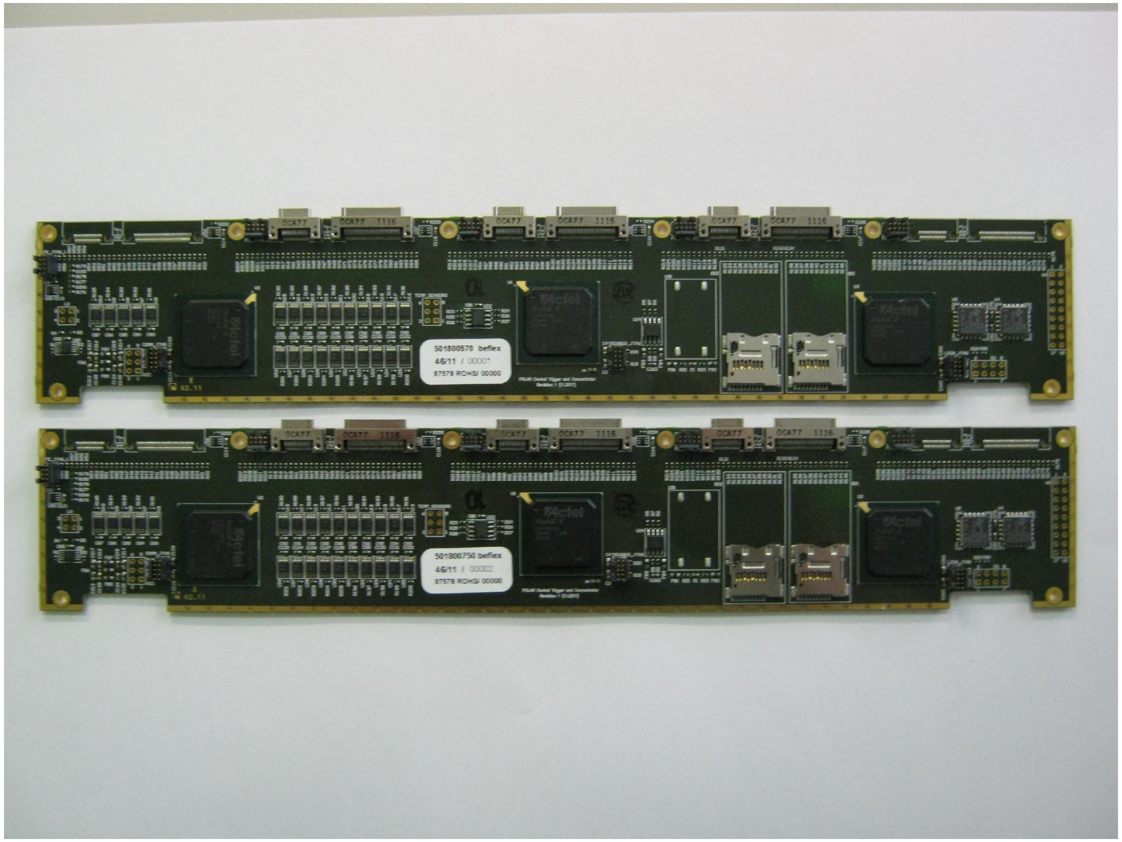
Central computer (cold redundant)



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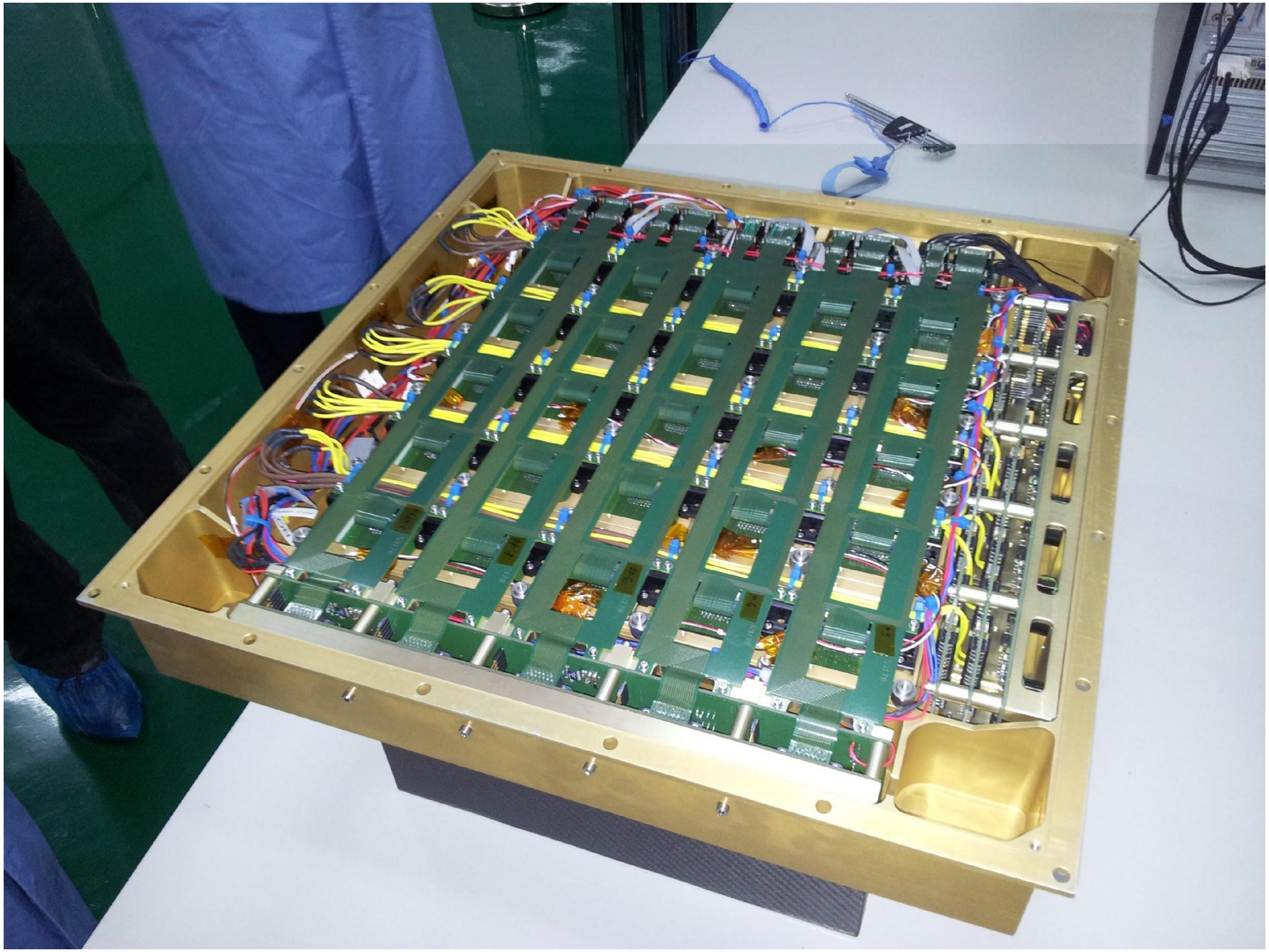
Overall detector, view from back



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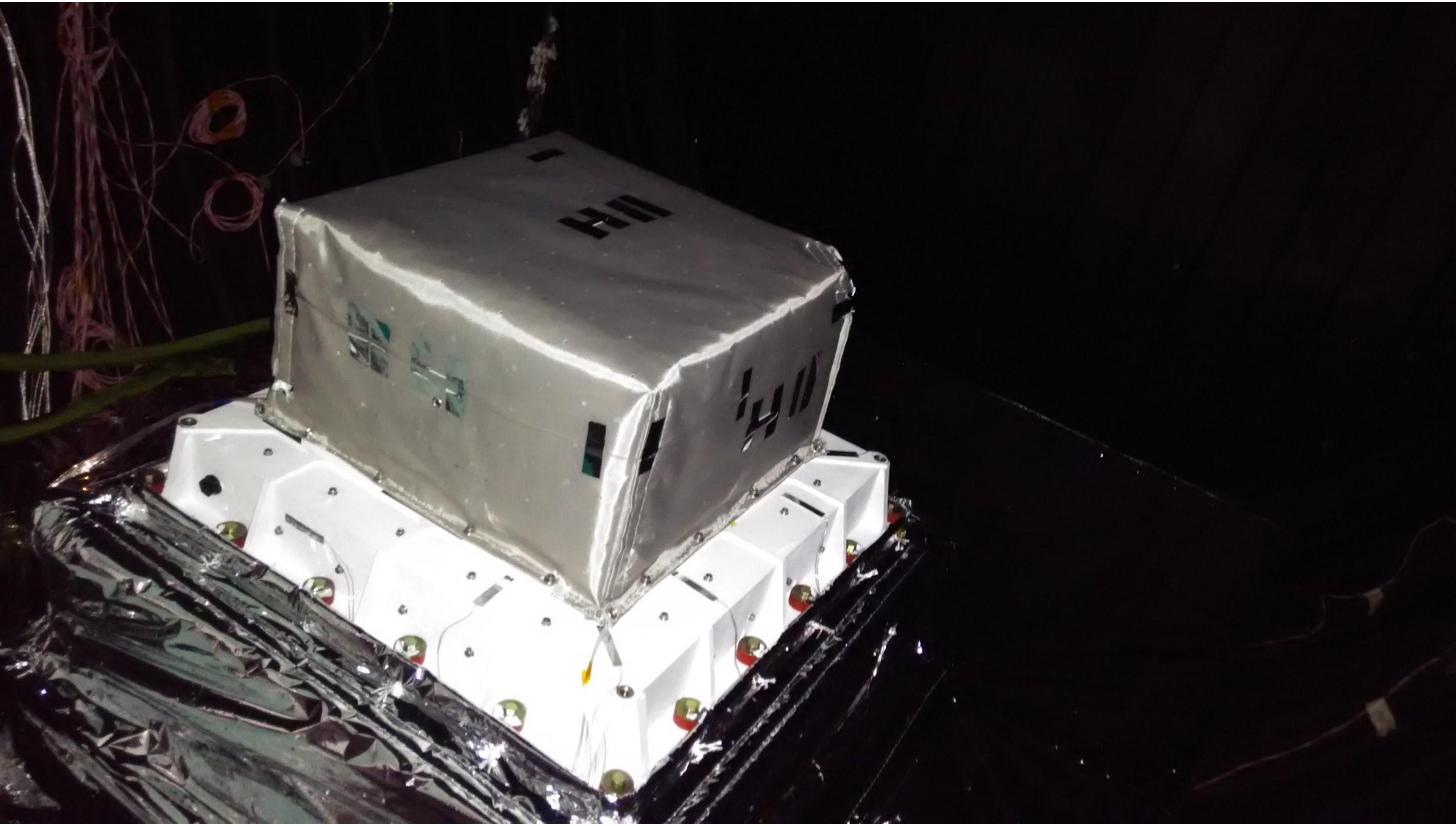
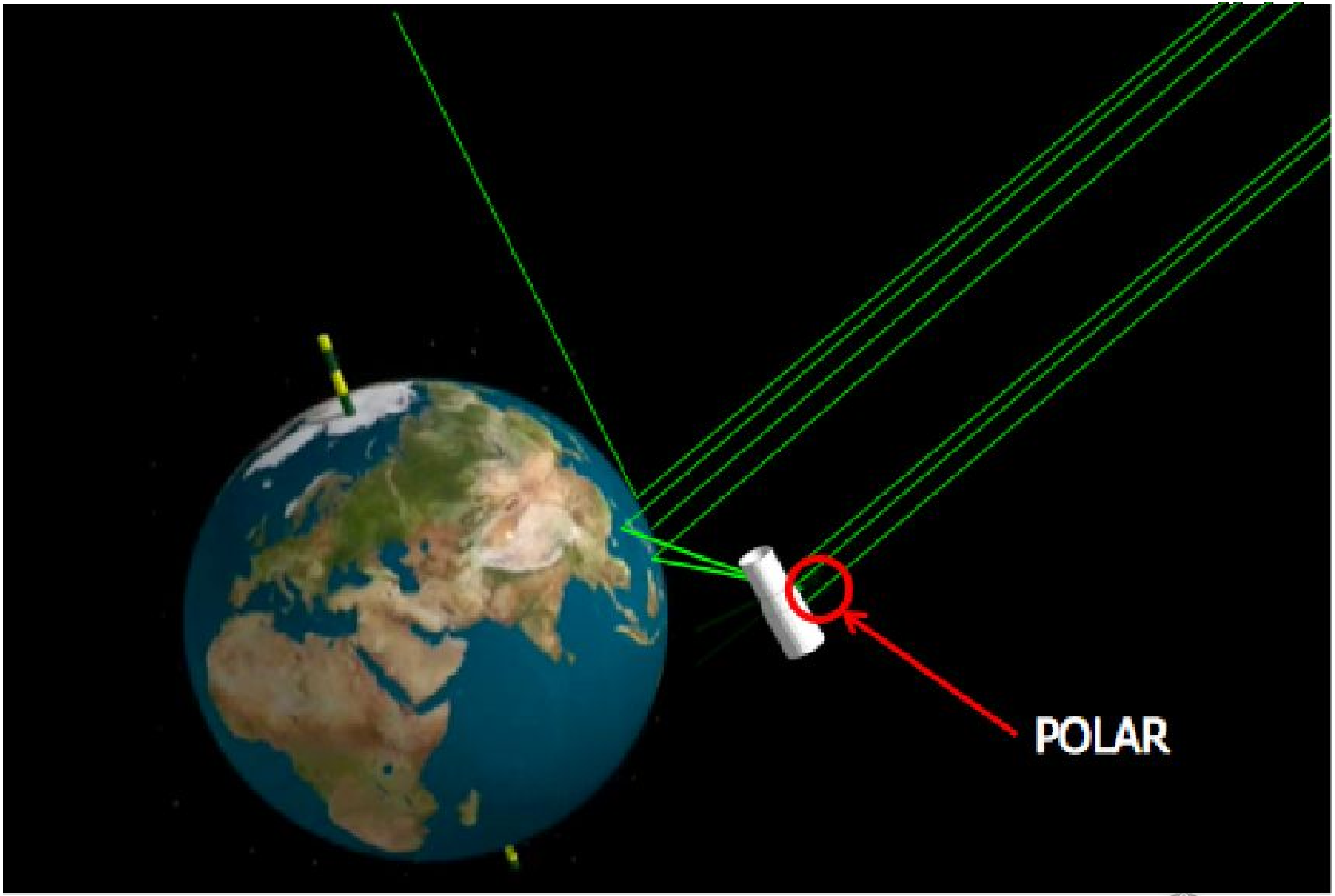
FMS during thermal balance in Shanghai (April 2015)



Monte Carlo



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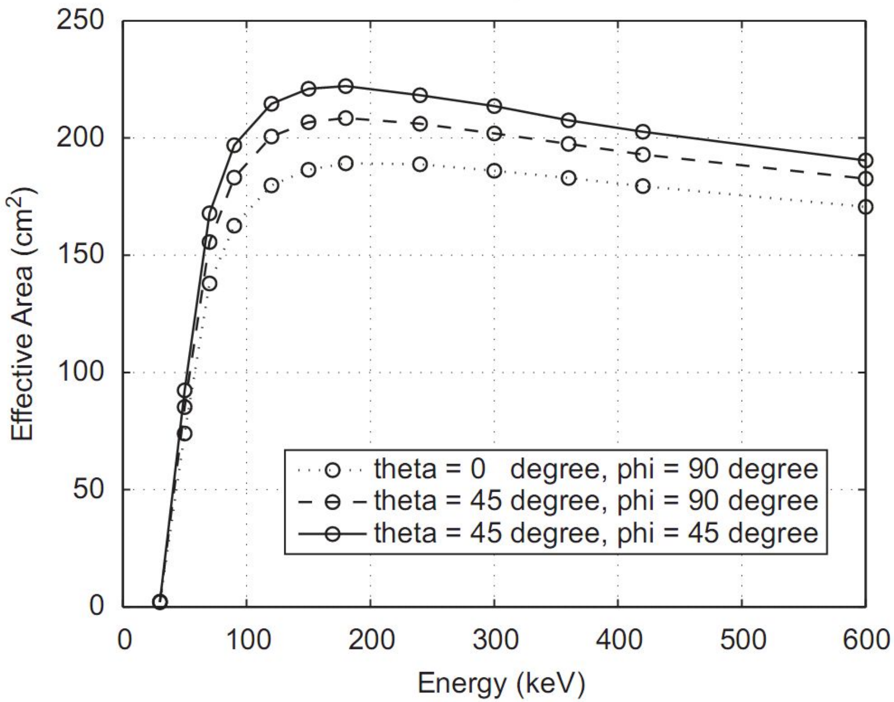
Effective area

- Monte Carlo based study
- A_{eff} is dependent on E and incoming photon angle
- Figure of merit: $A_{eff} \times \mu_{100}$

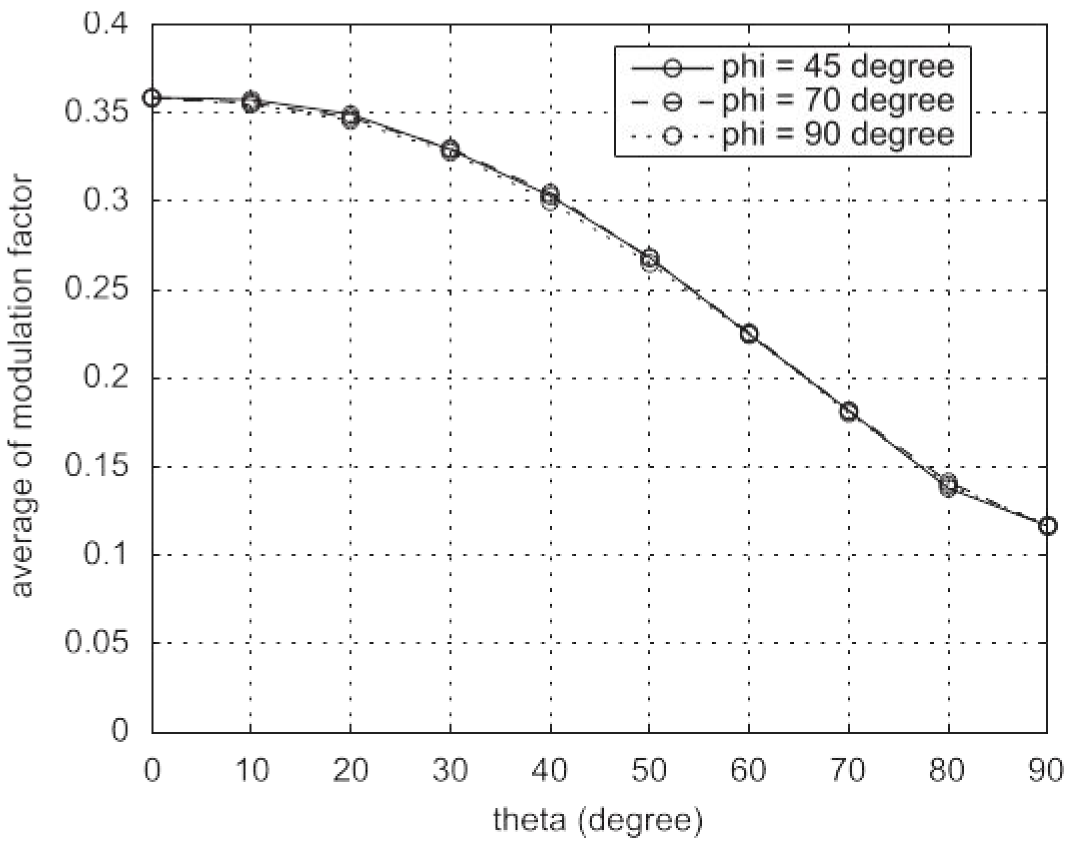


E. Suarez Garcia,
Ph.D. Thesis,
Univ. de Genève, 2010

S. Xiong et al., Expected performance of a hard X-ray polarimeter (POLAR) by Monte Carlo simulation, Nucl. Instr. and Meth. A 606 (2009) 552

Monte Carlo Field of view

- The spacecraft is in Low-Earth Orbit: POLAR sees half sky (2π)
- POLAR is designed to have maximum performance when GRBs are at its zenith; performances degrade for larger angles



Field of View (FoV)
Definition:
0° ≤ ϑ ≤ 70°

FoV: 4/3 π
(2/3 of visible sky)

Xiong et al., NIM A 606 (2009) 552-559

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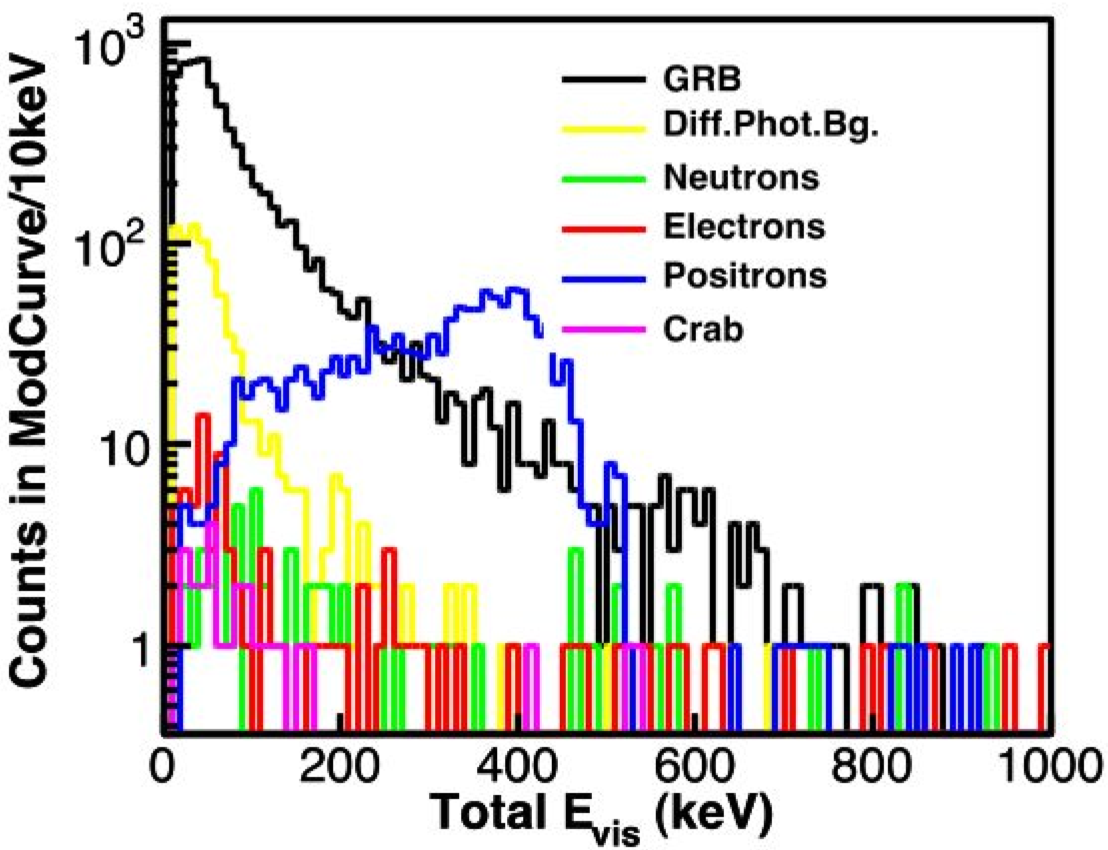
Background during flight

- Permanent background:
  - Diffuse photons
  - electrons (SAA)
  - neutrons
  - positrons
  - protons
  - He
- Transients
  - Crab
  - Solar flares
  - SAA
- During GRB
  - Earth backscattering
  - Satellite backscattering



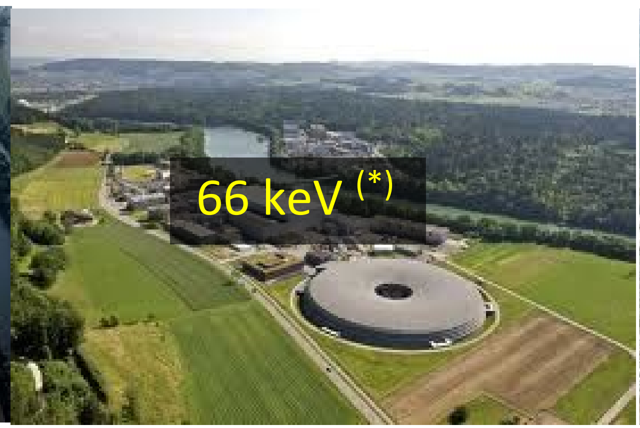
E. Suarez Garcia, X-Ray Polarization: RHESSI Results and POLAR Prospects,Ph.D. Thesis, Université de Genève, 2010

Calibrations with polarized photons

Calibration confirm basic parameters from Monte Carlo

ESRF, France
(2009, 2011,
2012, 2014, 2015)
Range: 30 – 700 keV

(+): presence of harmonics



SLS / PSI, Switzerland
(twice in 2011)
E range: 5 – 22.5 keV

(s*): 3rd harmonic

SSRF, China
(2012, 2014)
E range: 8 – 72.5 keV

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Conclusion

Constructing a polarimeter is difficult

It seems that we will be able to reach performance as described in our Monte Carlo papers.

We look forward to a launch in 2016

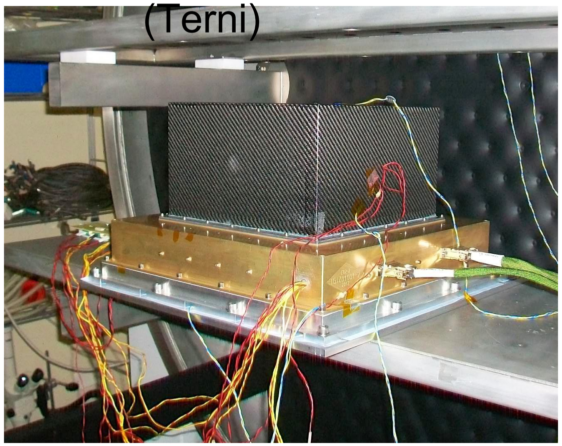
POLAR opened several collaboration opportunities with China for university of Geneva (DAMPE, HERD, PANGU)

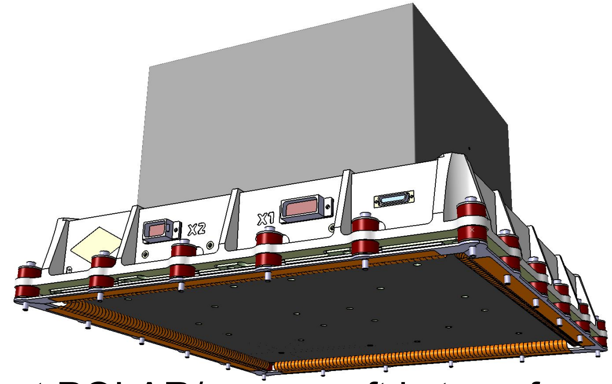
My personal feeling is that future is with Chinese launchers or with commercial launchers

Additional slides

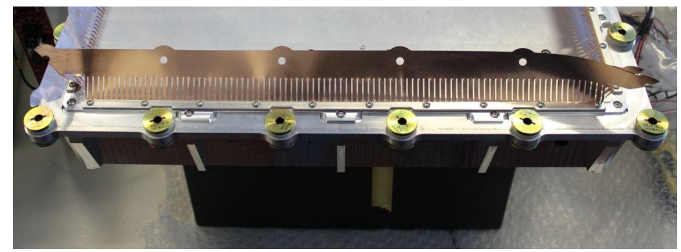
Thermal testing

POLAR in the thermal vacuum chamber (Terni)



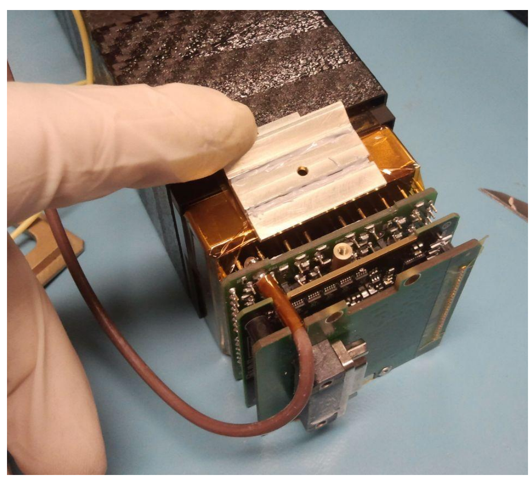


Heat POLAR/spacecraft is transferred through copper+PGS strips

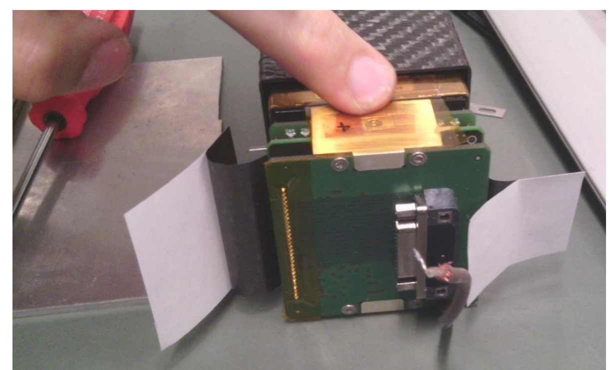


POLAR in climatic chamber: Thermal test (CERN)

Thermal grease in FEE



PGS sheets in FEE (pyrolytic graphite sheets)



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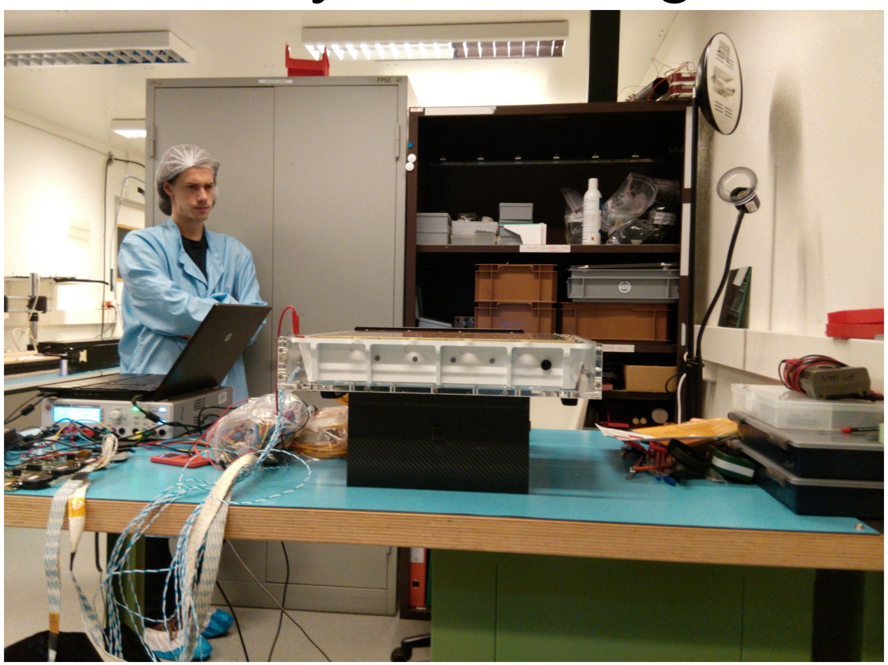
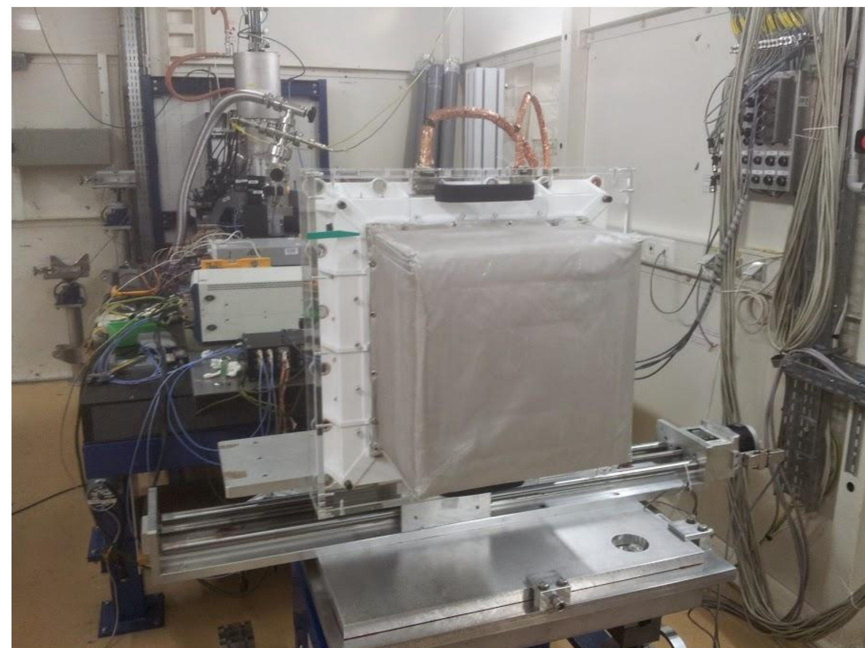
Flight Model (FM)

Final FM was built starting January 2015
We did a calibration with synchrotron radiation May 2015 (ESRF)
Delivery of FM August 2015





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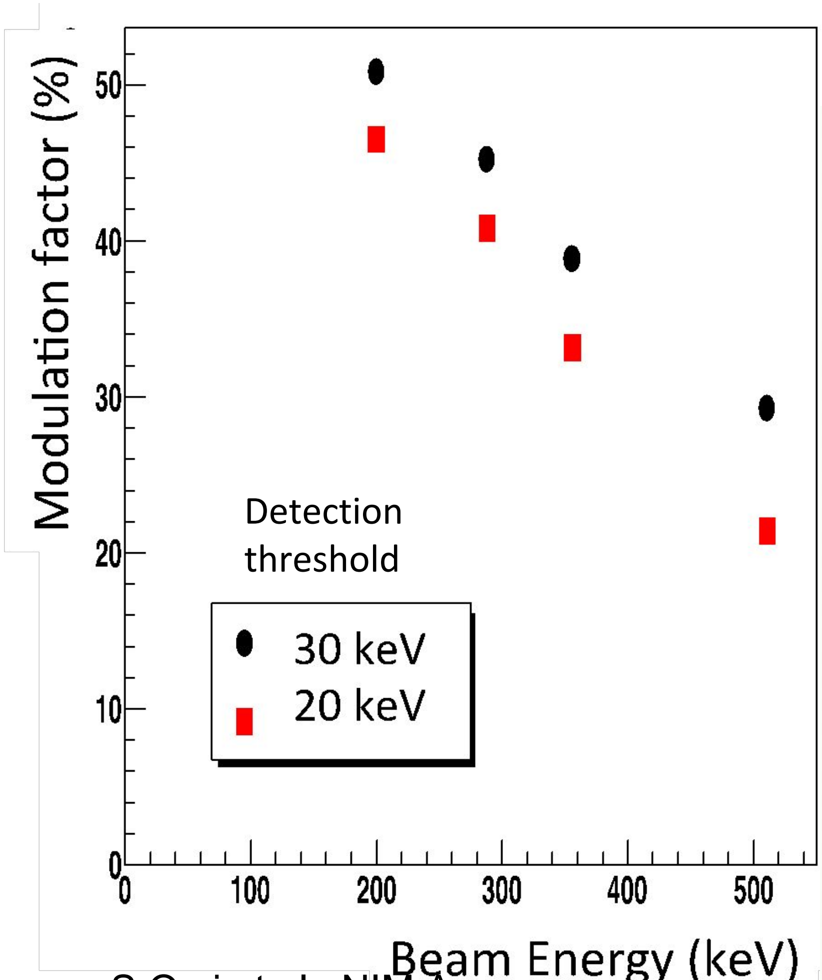
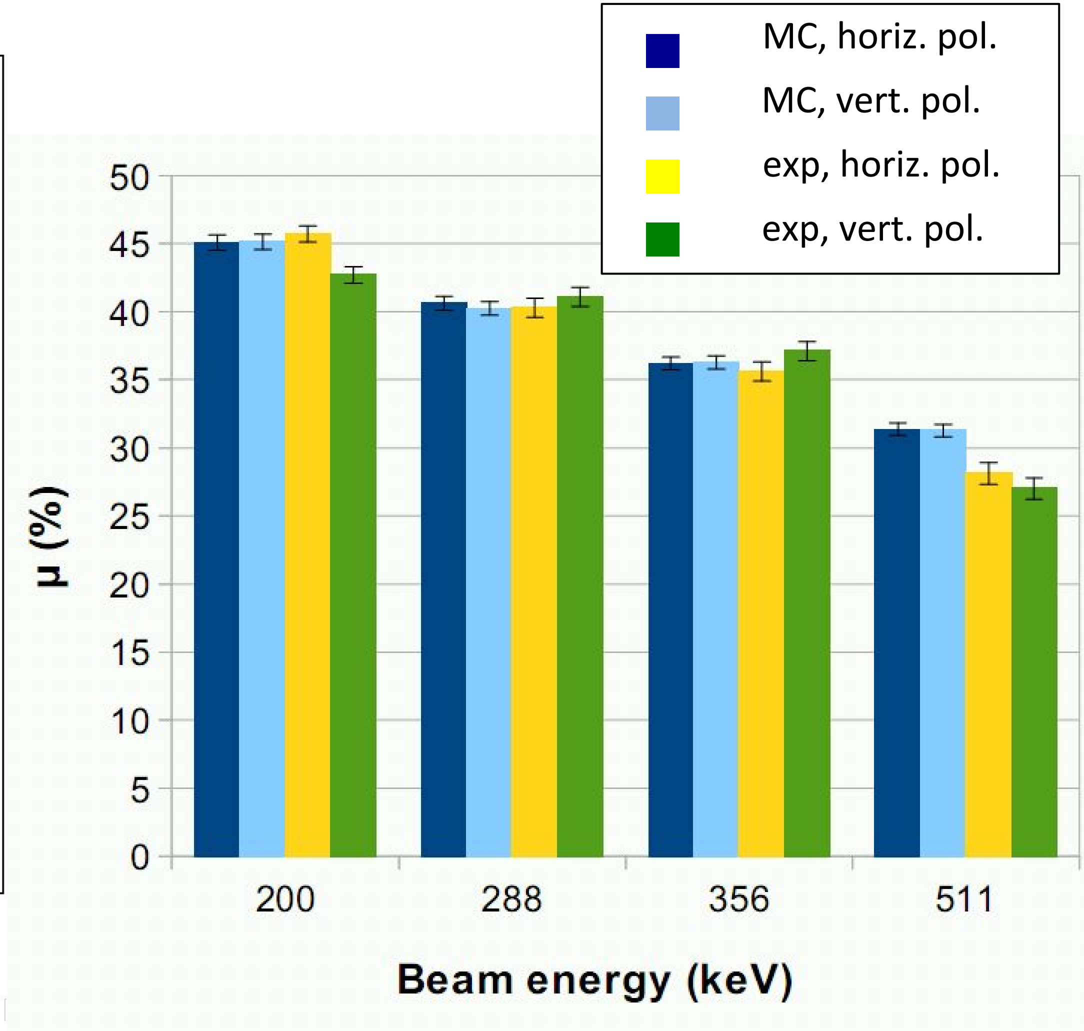
Modulation factors



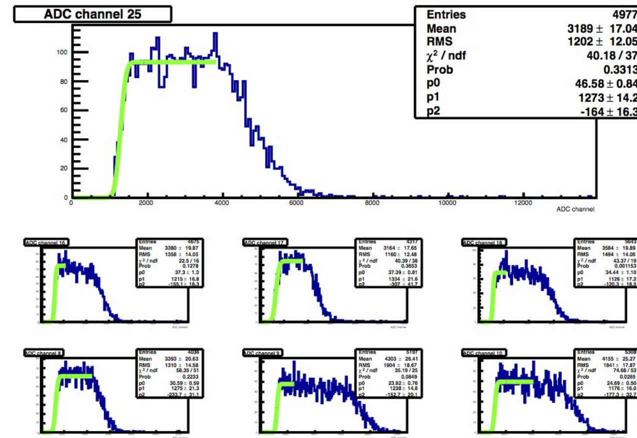


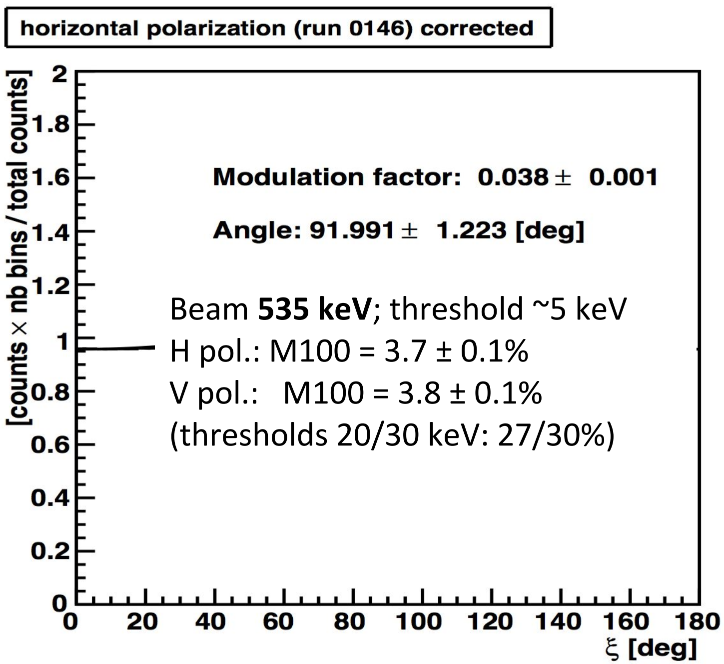
S.Orsi et al., NIM A
648 (2011) 139-154

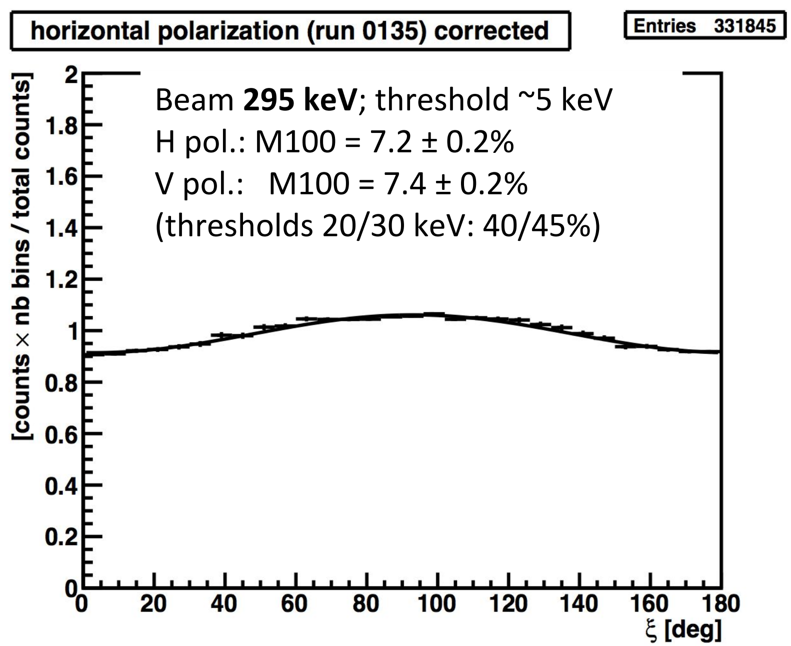
Detection threshold

- Thresholds optimized for 2 modules for beam test ESRF2014
- Thresholds: 4.6 ± 3.0 keV
- Data analysis ongoing
- Mod. factor depends on threshold

Fit of detection thresholds with triggered events







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