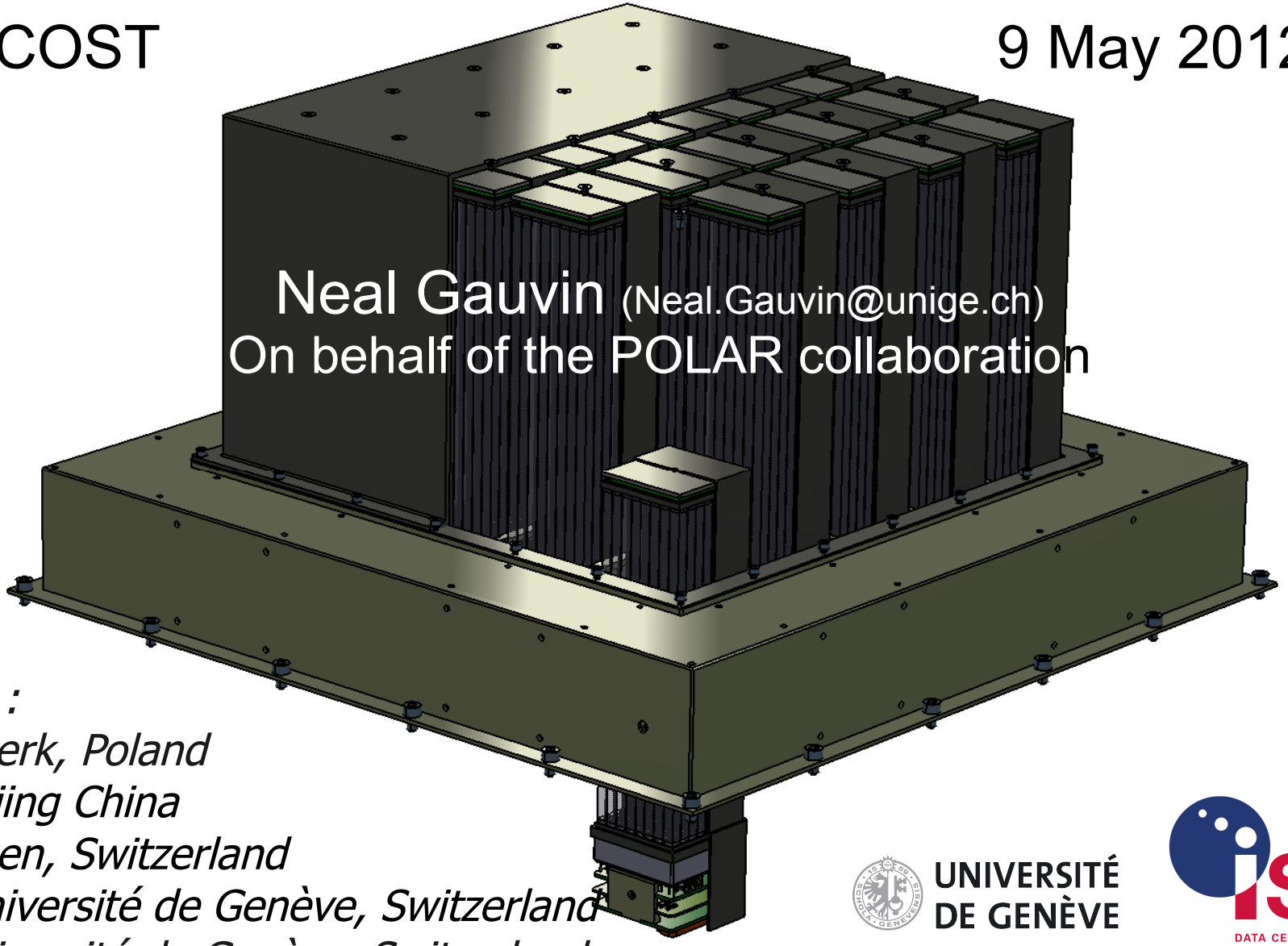
POLAR: an Instrument to measure Gamma Ray Bursts Polarisation

COST

9 May 2012

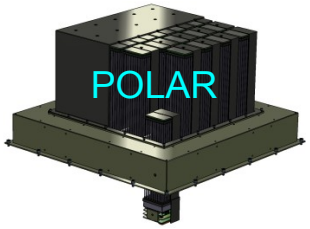


Neal Gauvin (Neal.Gauvin@unige.ch)
On behalf of the POLAR collaboration

Members :
NCBJ Świerk, Poland
IHEP, Beijing China
PSI, Villigen, Switzerland
DPNC, Université de Genève, Switzerland
ISDC, Université de Genève, Switzerland

UNIVERSITÉ DE GENÈVE

ISDC DATA CENTRE FOR ASTROPHYSICS



What are Gamma Ray Bursts ?

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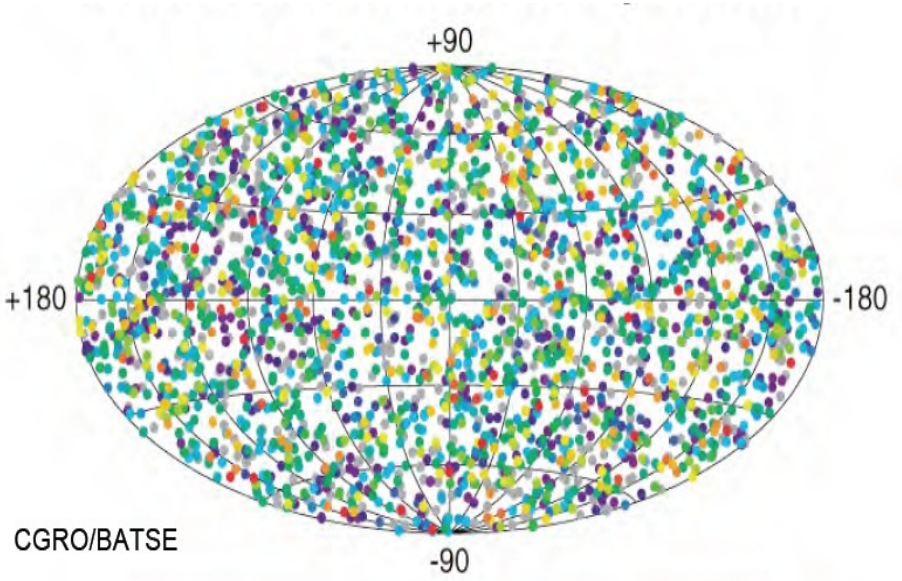
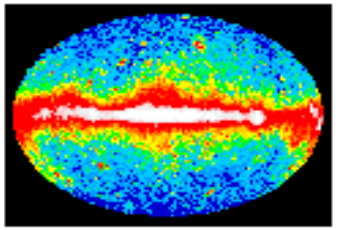
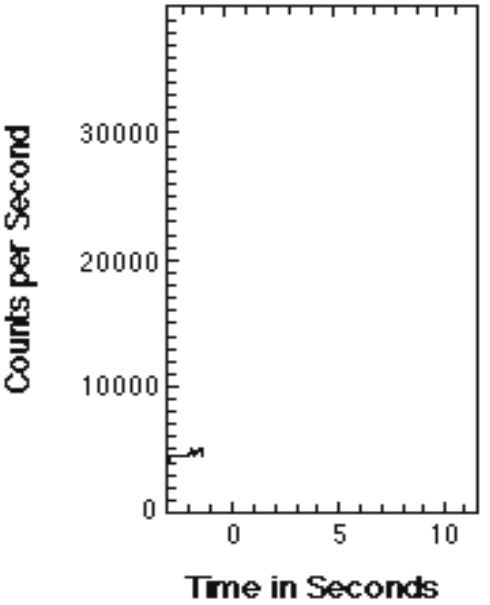
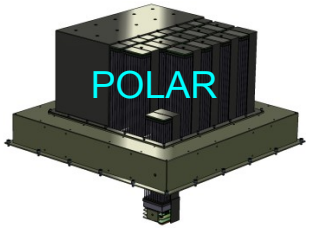
- Gamma ray bursts (GRB) are flashes of gamma rays randomly distributed in the sky and time.
- Brightest events in the universe since Big Bang
  some releasing more energy in 10 seconds than what the Sun will emit in its entire 10 billion year lifetime!
- About 1 GRB/day observed









Gamma Ray Bursts

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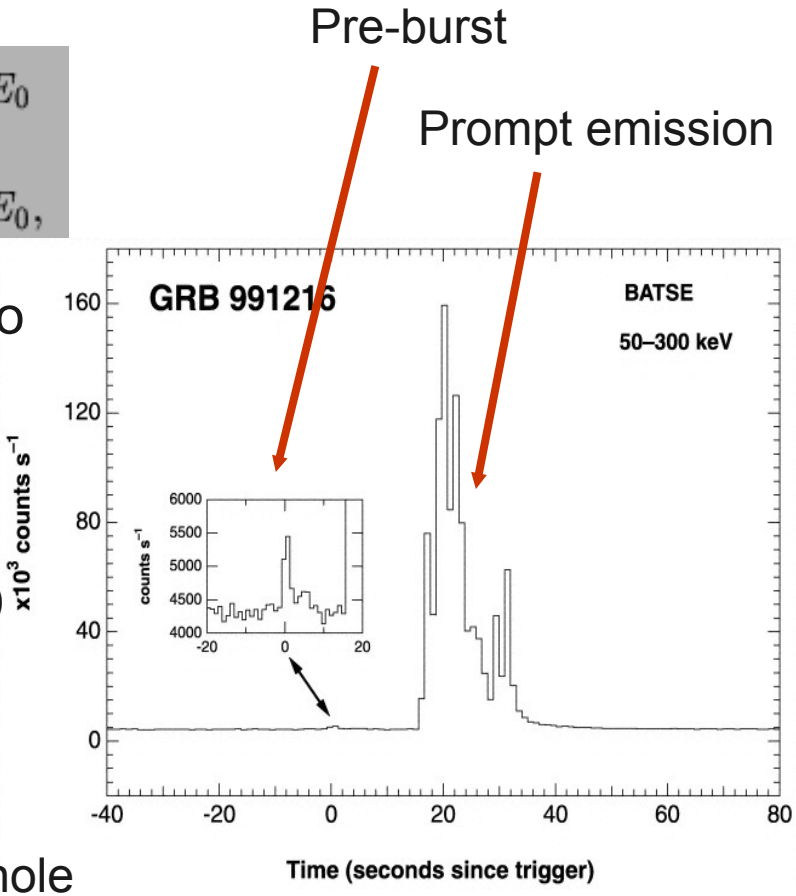
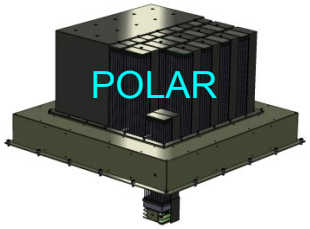
- Spectrum usually described by a class of functions similar to a broken power law

$$N(E) = N_0 \begin{cases} (E)^{\alpha} \exp(-\frac{E}{E_0}), & for E < (\alpha - \beta)E_0 \\ ((\alpha - \beta)E_0)^{(\alpha-\beta)} (E)^{\beta} \exp(\beta - \alpha), & for E \geq (\alpha - \beta)E_0, \end{cases}$$

- Light-curves, although very different from GRB to GRB, show three parts:
  - Pre-burst
  - Prompt emission (γ, X,ν ?)
  - Broadband long-lasting afterglow (X,optical,radio)
- Two main models of GRB origin :
  - Merging of binary neutron stars into black hole short GRB < 2-5 s
  - Hypernova: high-mass star collapsing into black hole long GRB > 5 s



Typical light-curve



Origin of GRBs

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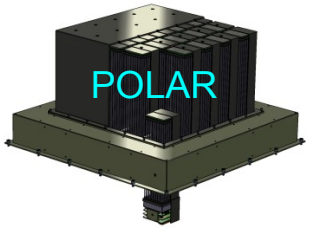
The GRB is produced by internal dissipation within the relativistic jet launched from the centre of the explosion.

MERGER SCENARIO
NEUTRON STARS
BLACK HOLE
DISK
CENTRAL ENGINE
MASSIVE STAR
HYPERNOVA SCENARIO
FASTER BLOB
SLOWER BLOB
BLOBS COLLIDE (Internal shock wave)
GAMMA RAYS
JET COLLIDES WITH AMBIENT MEDIUM (external shock wave)
X-RAYS, VISIBLE LIGHT, RADIO WAVES
PREBURST
GAMMA-RAY EMISSION
AFTERGLOW
POLAR
γ
Pol Direction
Compton Scattering Direction

The afterglow is the synchrotron emission of electrons accelerated in a collision-less shock driven by the interaction of the jet with the surrounding medium *(Zhang 2007).*



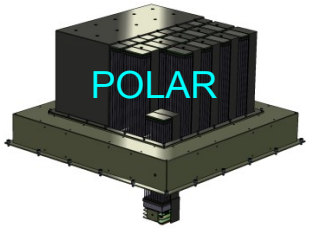
Importance of Polarisation

- The emission mechanism of prompt signal (and the origin and structure of magnetic fields in GRBs) is an open question.
- In spite of extensive observational efforts, these questions are difficult or even impossible to infer with the spectral and lightcurve information currently collected.
- Polarimetric observations of GRBs can address the following:
  - Magnetic composition of GRB jets

    It is highly speculated that strong magnetic fields are generated at the GRB central engine, and may play an essential role in the launch of the relativistic jets. However, it is unclear whether the burst emission region is penetrated by a globally structured, dynamically important magnetic field, and whether the burst is due to shock dissipation or magnetic reconnection (*Lyutikov et al. 2003*).
  - Geometric structure of GRB jets

    Although it is generally believed that GRB outflows are collimated, the distribution of the jet opening angles, the observer's viewing direction, and whether there are small-scale structures within the global jet are not well understood.
- Emission mechanisms of the bursts

  They can be constrained by using the statistical properties of GRB polarisations



Emission mechanisms of GRBs

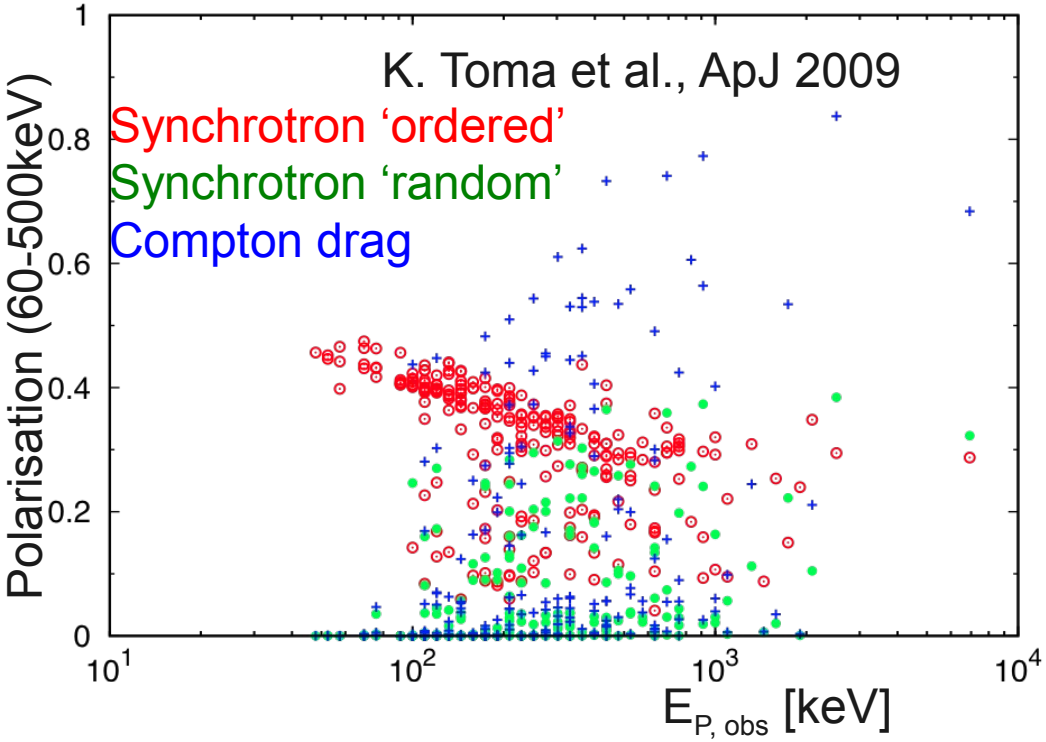
...Emission mechanisms of the bursts can be constrained by using the statistical properties of GRB polarisations

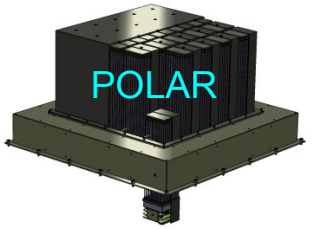
The leading models are :

- Synchrotron emission from relativistic electrons in a globally ordered magnetic field carried from the central engine *(Lyutikov et al. 2003)*, or
- random magnetic fields generated in-situ in the shock dissipation region *(Rees & Mészáros 1994)*.

Other suggestions :

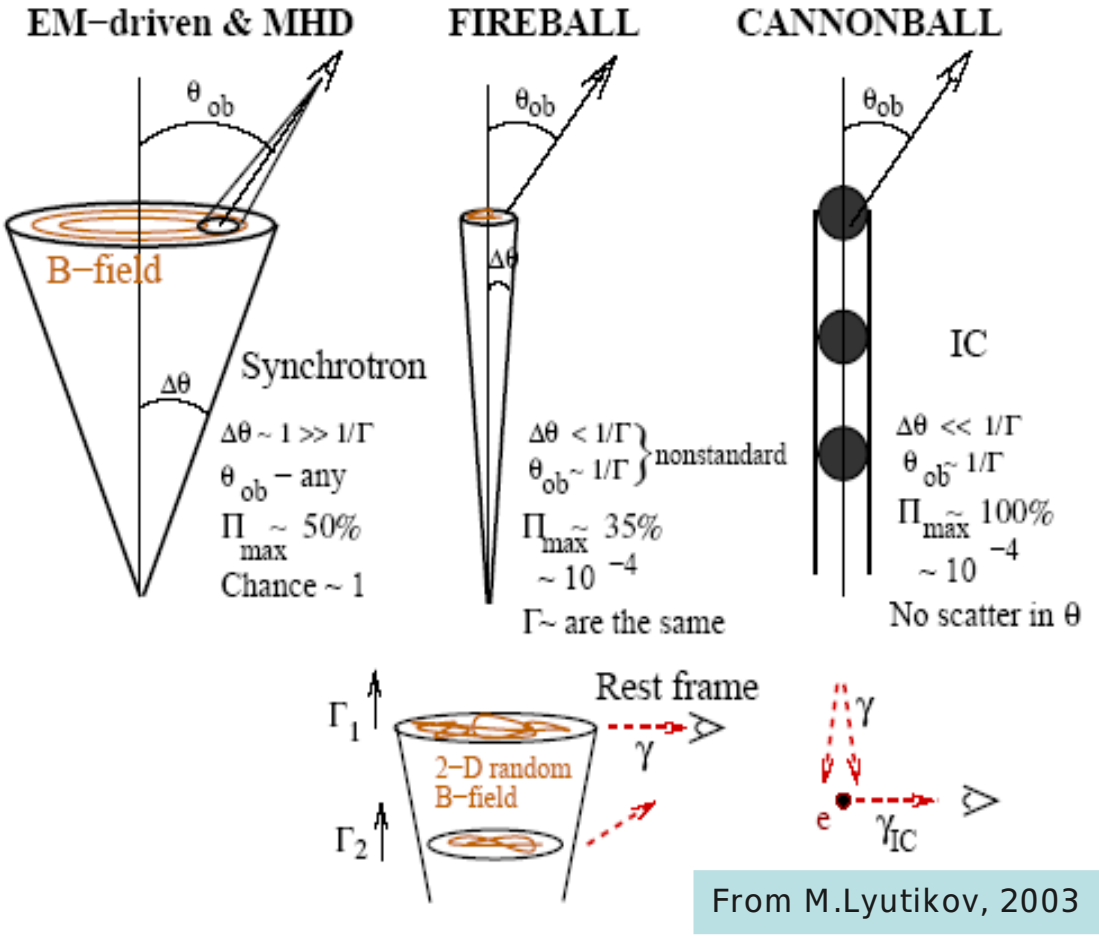
- Compton drag of ambient soft photons *(Lazzati et al. 2004)*,
- synchrotron self-Compton emission *(Panaitescu & Meszaros 2000)*,
- the combination of a thermal component from the photosphere and a non-thermal component (e.g., synchrotron) *(Ioka et al. 2007)*.





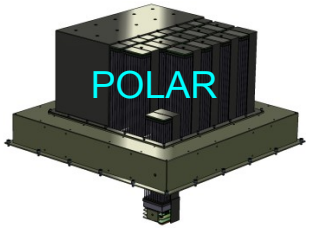
GRBs Theoretical Model Polarisation Predictions

- Fireball Model
  high values excluded
  P_{lin} ~ 10-20 %
- Cannonball Model
  full range possible
  P_{lin} = 0 - 100%
- Electromagnetic Model
  well defined, moderate
  P_{lin} ~ 50 %



From M.Lyutikov, 2003

See papers discussing various models:
T.Piran, A.Dar, M.Lyutikov, D.Eichler, G.Ghisellini, D.Lazzatti, M.Medvedev, E.Rossi, Kenji Tomas etc.



Actual Experimental Situation

So far, polarisation measurement has been neglected.

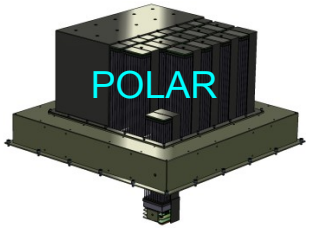
Only one conclusive measurement :

- GAP on board IKAROS. GRB 100826A 27±11 % (2.9 σ CL).

Other find mostly important polarisation, but systematic effects poses difficult problems :

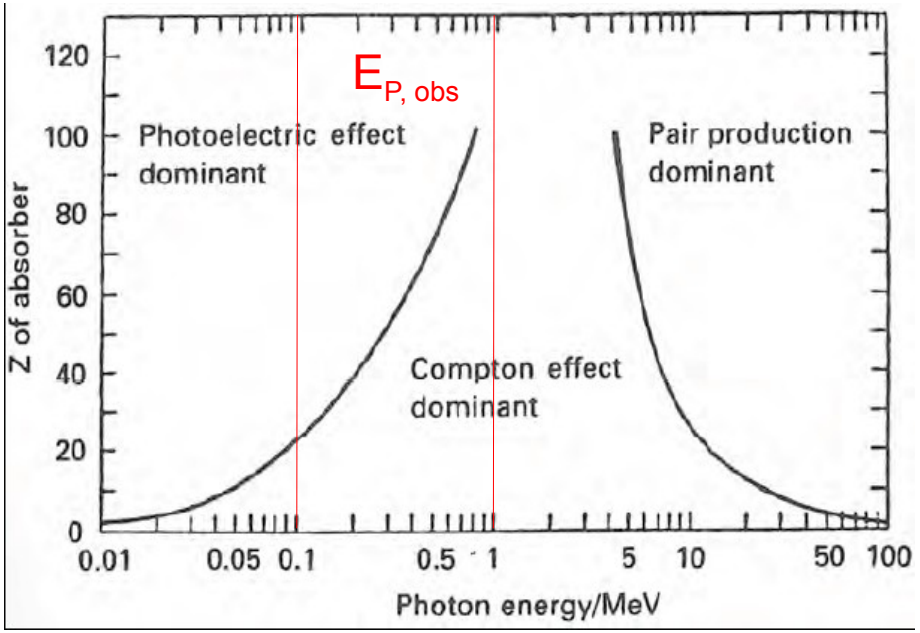
- Coburn Boggs 2003 GRB 021206 80±20%
  Proven wrong. Final correct (Wigger) 30±30%
- BATSE using Earth reflection GRB 930131 > 30%
- GRB 960924 > 50%. Difficult to trust because of systematics due to Earth atmosph. sim.
- INTEGRAL GRB 041219A 96±40%. Cannot exclude Systematic effects.
- SPI GRB061122 <60%
- An other group (Goetz at al) find time varying polarisation

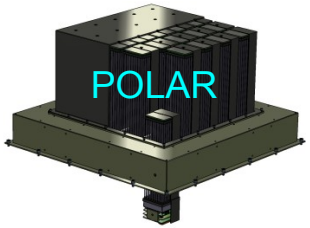
Solid INTEGRAL measurement of Crab nebula polarisation 46±10%



Detector Requirements

- Compton polarimeter made as a simple, compact instrument
- Dedicated for GRB observations only
- Large area, large modulation factor and large field of view
- Relies on given burst position and spectrum
- Signal to background ratio optimised





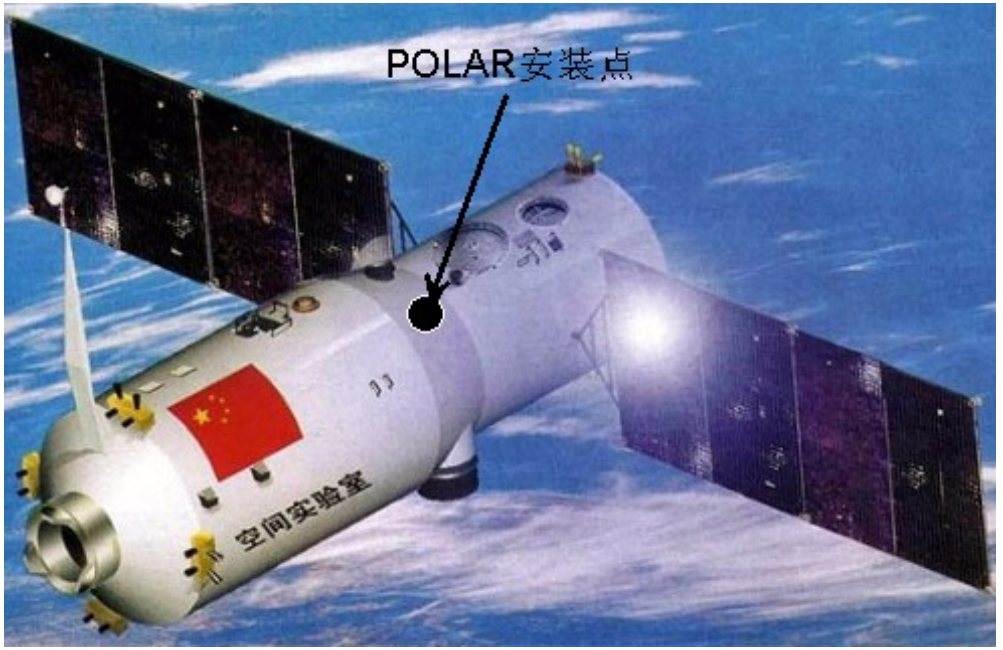
POLAR Experiment

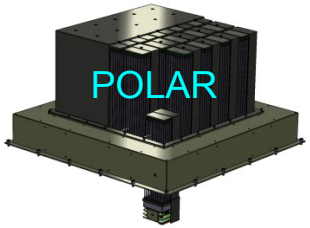
POLAR is a Compton polarimeter devoted to study the prompt emission of GRBs in the energy range 50–500 keV *(N. Produit, et al., NIM (2005))*

- Compact (~30kg, ~30x30x30 cm^3)
- Field of view: ~1/3 full sky
- Min. detectable polarisation (MDP): < ~10%

} ~10 GRB / year

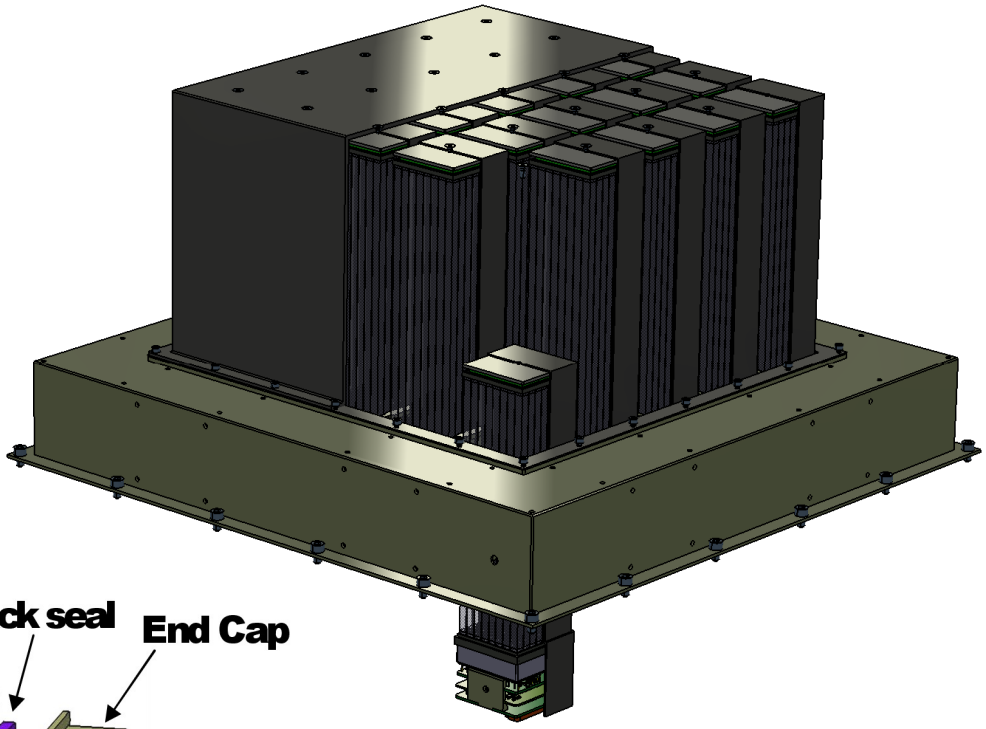
- Assembly of qualification model (QM) ongoing (due summer 2012).
- Space qualification campaign end 2012.
- Mounted on Chinese spacelab TG-2 (atmosphere opaque for X-rays)
- Launch expected in 2014.
- Lifespan : 2 years

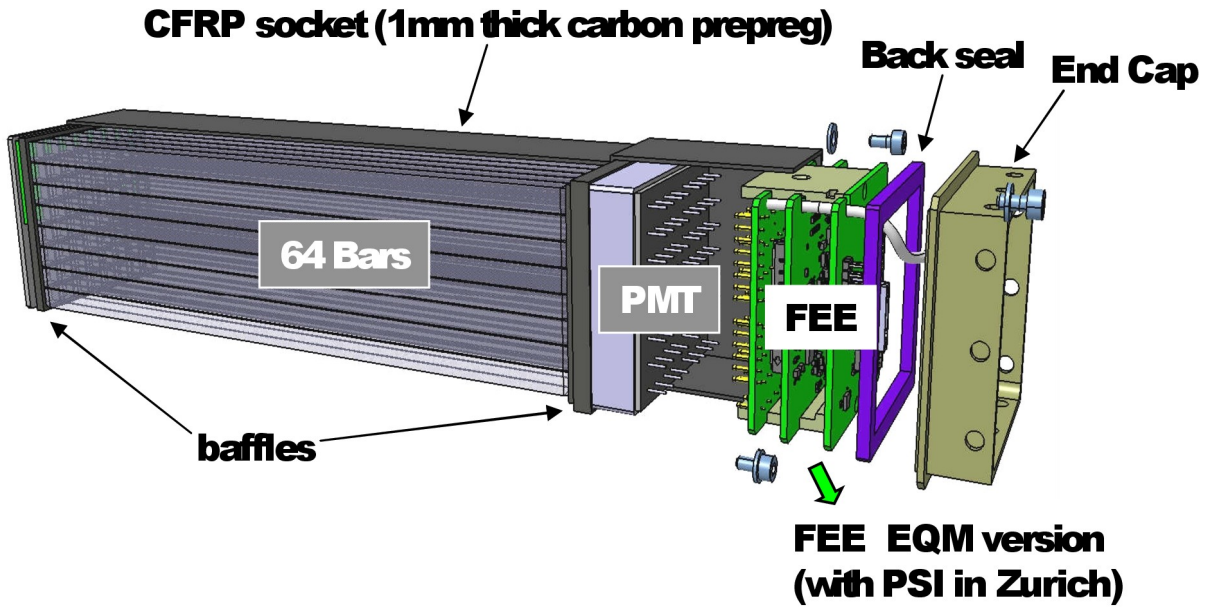


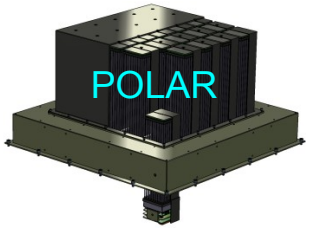


POLAR Detector

- Consists of 25 modular units
- Each modular unit composed of 8x8 plastic scintillator bars (6x6x176mm3) read-out by one Multi Anode PMT and ASIC readout electronics.
- Total: 1600 plastic scintillator bars + 25 MAPMT







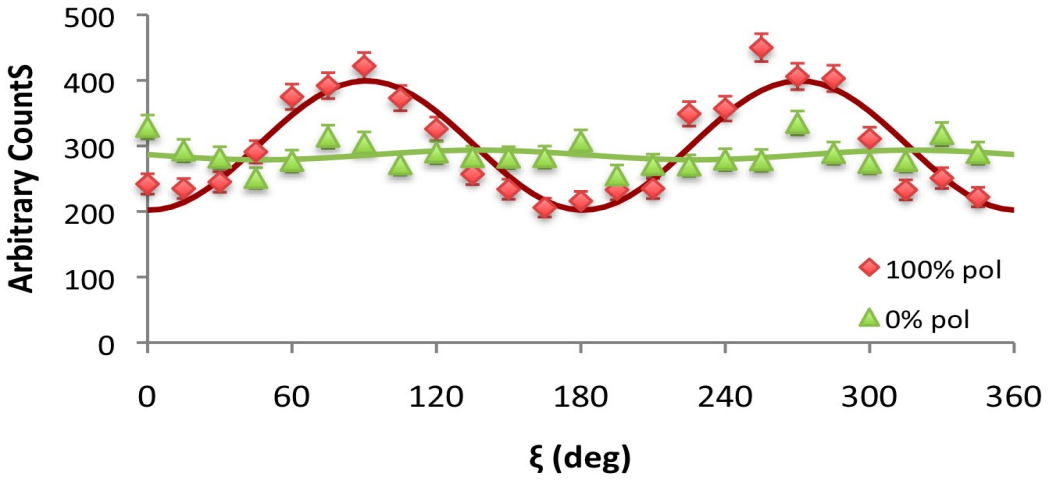
Compton Polarimetry

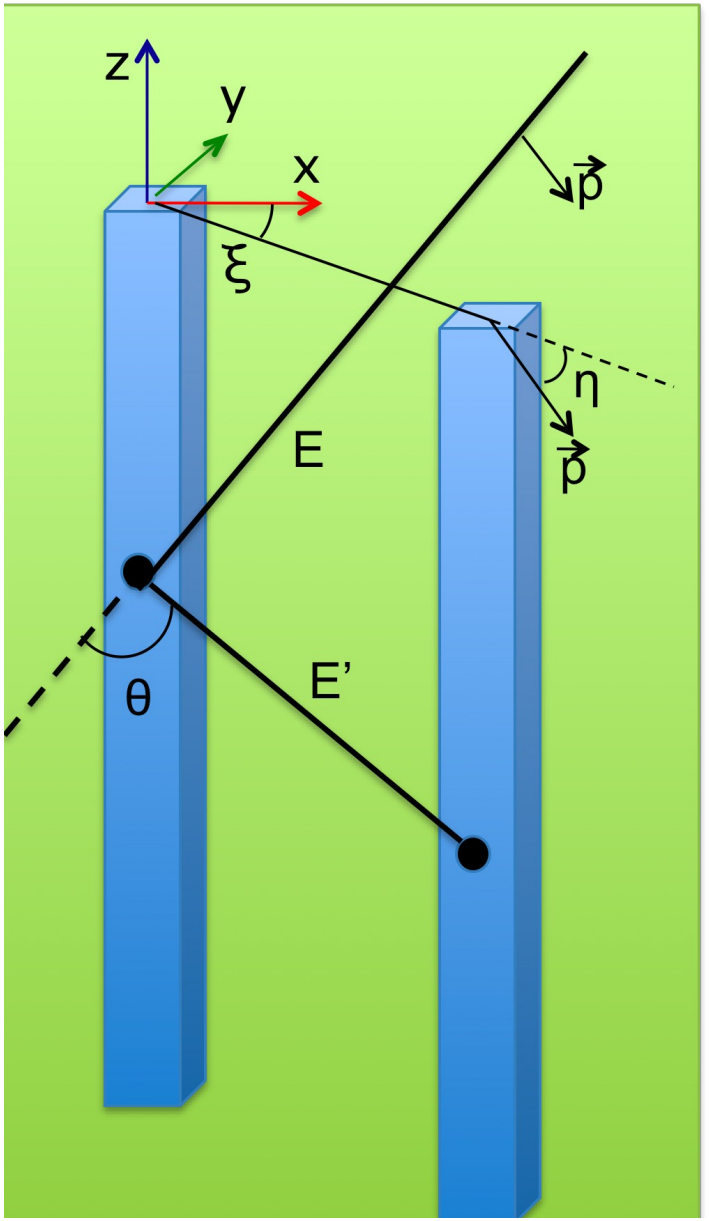
Photons tend to Compton scatter at right angles to the incident polarisation direction:
(Klein-Nishina equation)

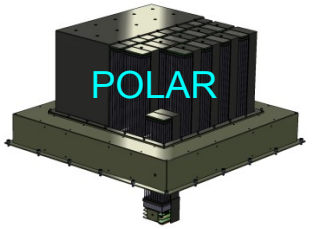
$$d\sigma = \frac{r_o^2}{2} d\Omega \left(\frac{E'}{E_o}\right)^2 \left(\frac{E_o}{E'} + \frac{E'}{E_o} - 2\sin^2\theta\cos^2\eta\right)$$

Where:

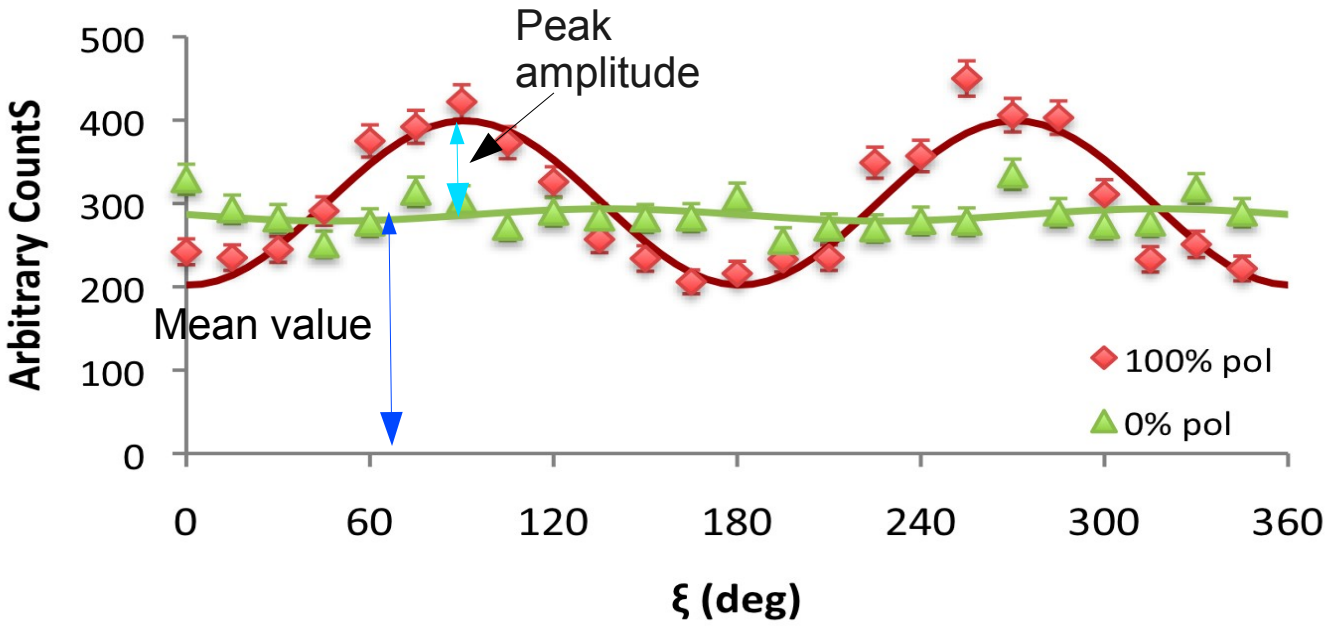
- η - Azimuthal Scatter Angle !
- θ - Compton Scatter Angle







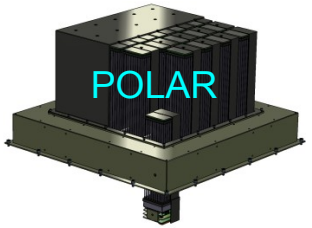
Modulation Curve



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

$$\text{Polarization: } \Pi = \frac{\mu}{\mu_{100}}$$

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



ESRF 2011 Beam Tests

Europeam Synchrotron Radiation Facility

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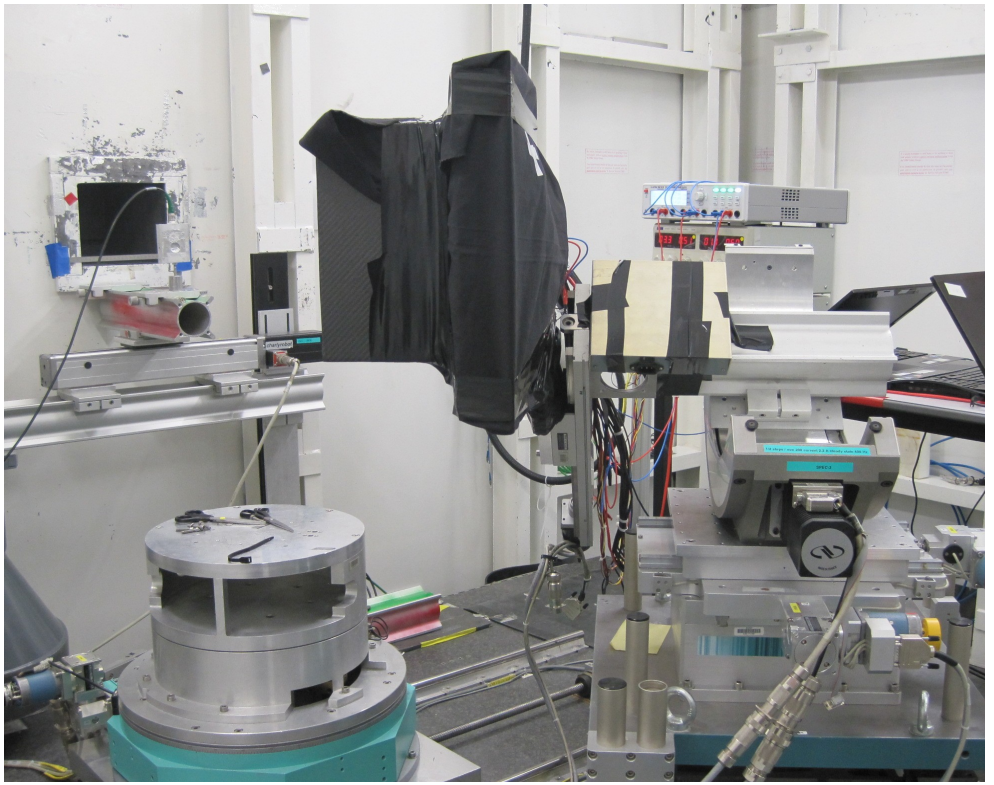
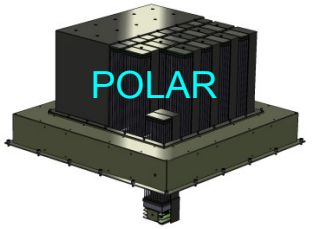
- Available energies at beamline:
  30 keV - ~ 500 keV
- Used energies:
  122, 200, 288, 356, 511 keV
- Minimum useful energy in 2009:
  200keV (CE 88 keV)
- Minimum energy in 2011:
  122keV (CE 39 keV)
- Beam off-axis:
  θ = 0 °, 15 °, 30 °, 45 °and 60°



6 modular units, FE electronics:

- 4: PSI, built early 2011
- 1: PSI, built Nov 2011 (prototype of QM)
- 1: IHEP

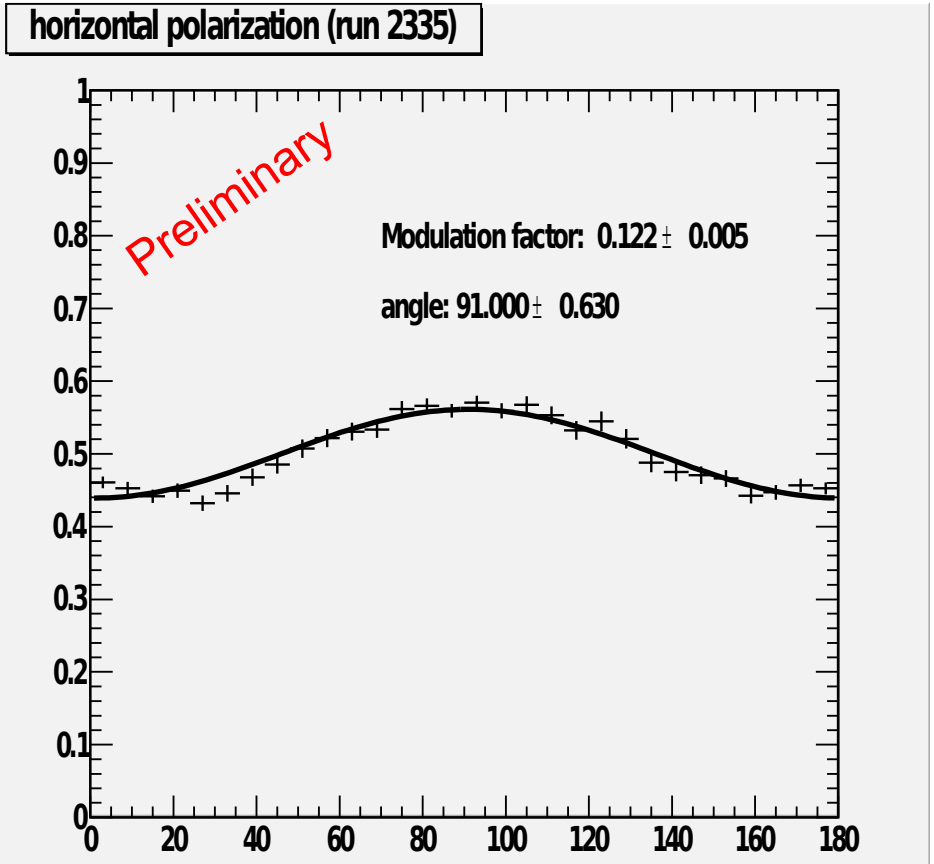
Processing of the data ongoing...

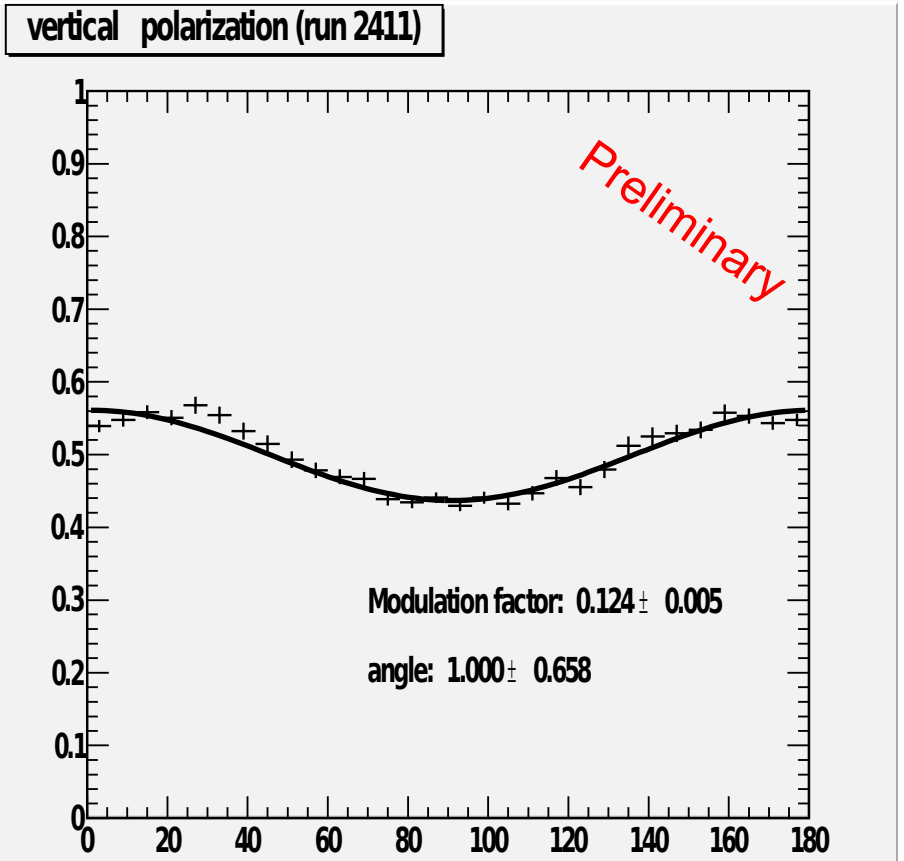


ESRF Data Preliminary Results

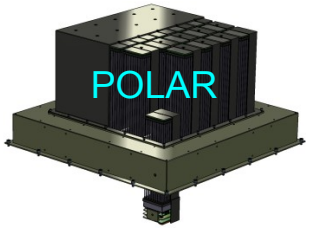
Ratio of modulation curves (polarized data / unpolarized data)
Systematics effects greatly reduced

Energy threshold 5 keV





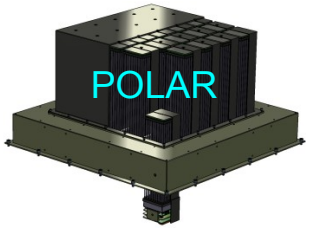
Distribution of scattering angle (ξ), incoming photons energy Eγ=356 keV



Summary

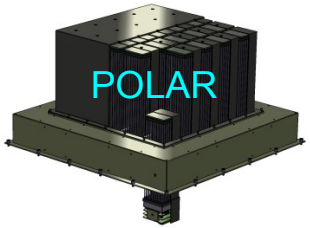
- POLAR is a novel and compact Compton polarimeter devoted to study the prompt emission of GRBs in the energy range 50 – 500 keV.
- Successful beam test with 100% polarized synchrotron radiation in Nov 2011
- Construction and assembly of qualification model (QM) ongoing.
- Launch on the Chinese Spacelab TG-2 in 2014
- Lifetime: 2 years

Backup Slides



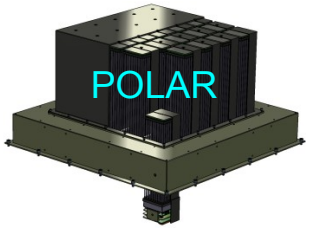
Project Approach

- Answer a very important scientific question
- Do it simple and trustworthy
- Use proven and reliable technologies
- Do it fast keeping all quality assurance
- Describe the smallest model that is still able to do science (design modular so can be increased)



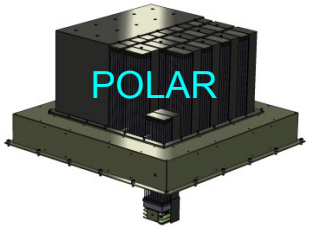
Experimental Goal

Perform first ever successful polarisation measurement of hard photons in space with high statistical significance and controlled systematic effects.



Other Physics

- If speed of light depends on polarisation (some models of quantum gravity)
then polarisation get destroyed
- Polarisation of source (Crab) can be used to calibrate



Polarimetry in Space

GAP on board IKAROS;*D. Yonetoku et al.*

PENGUIN-M solar flare on board Coronas-Photon;*V.A. Dergachev et al.*

GRAPE Gamma Ray Polarisation Experiment: Low Z - high Z hybrid, 50-300 keV; *M.McConnell et al.*

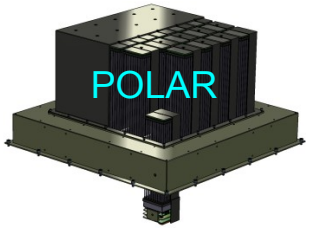
PoGO Polarized Gamma-ray Observer: phoswich of slow-fast units with AC, 30-100 keV; *T.Mizuno et al.*

SGD Soft Gamma-ray Detector: Compton telescope of Si-strips and CdTe pixels and AC, E<300 keV; *H.Tajima*

CIPHER Coded Imager and Polarimeter for High Energy Radiation: CdTe array, E<1 MeV; *R.Curado da Silva*

RHESSI High Energy Solar Spectrometric Imager: 9 large Ge, active/passive modes, E>10 keV; *M.McConnell, C.Wigger*

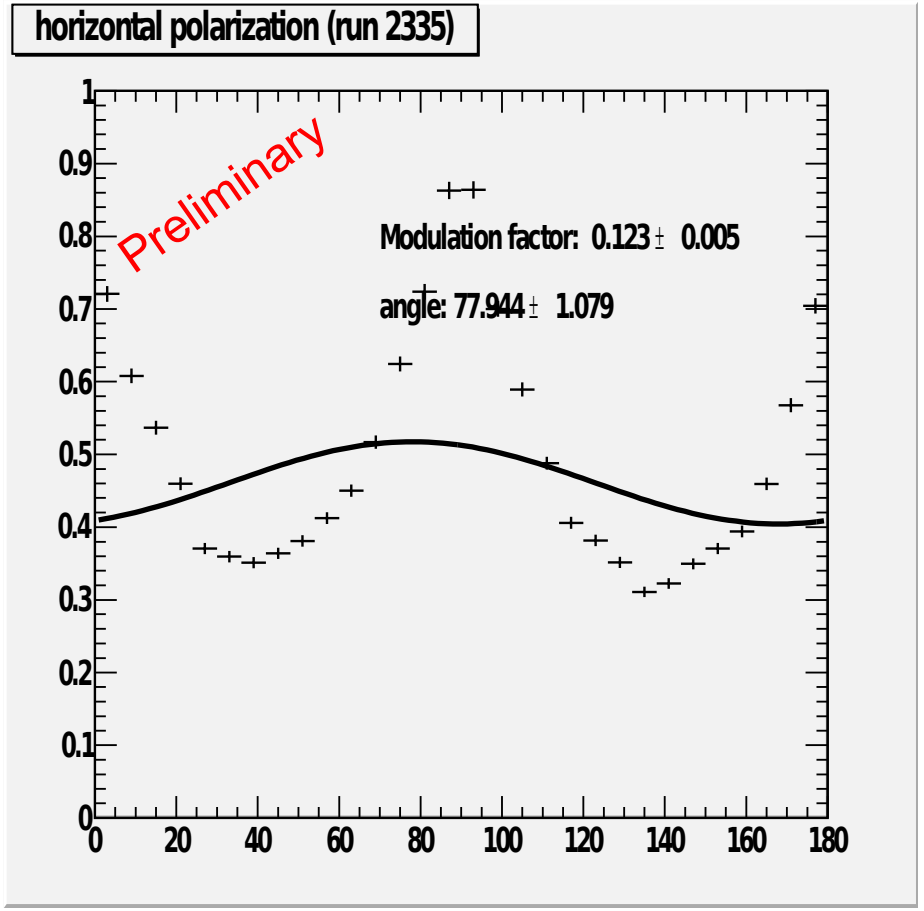
Athena, GRIPS... future payloads and 2020 ESA cosmic vision…

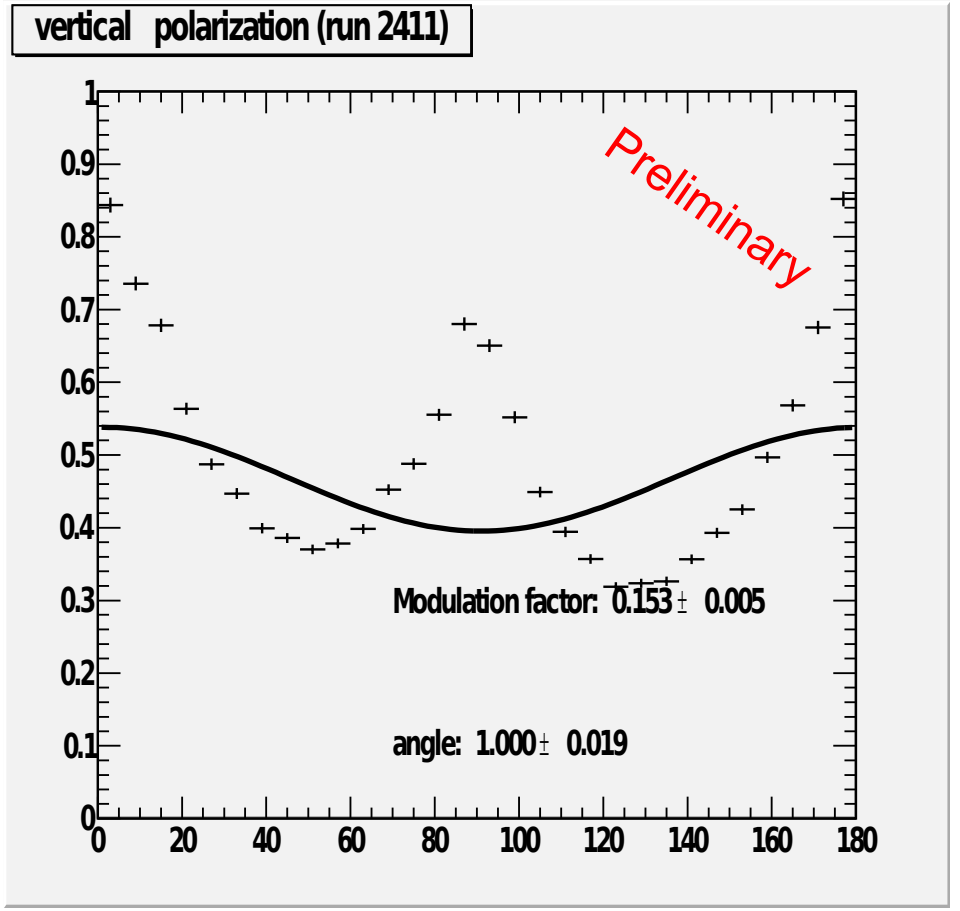


ESRF Data Preliminary Results

First modulation curves...

Energy threshold 5 keV





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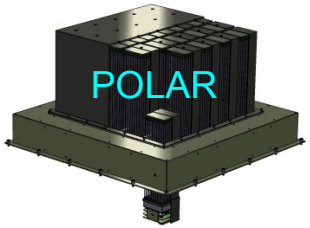
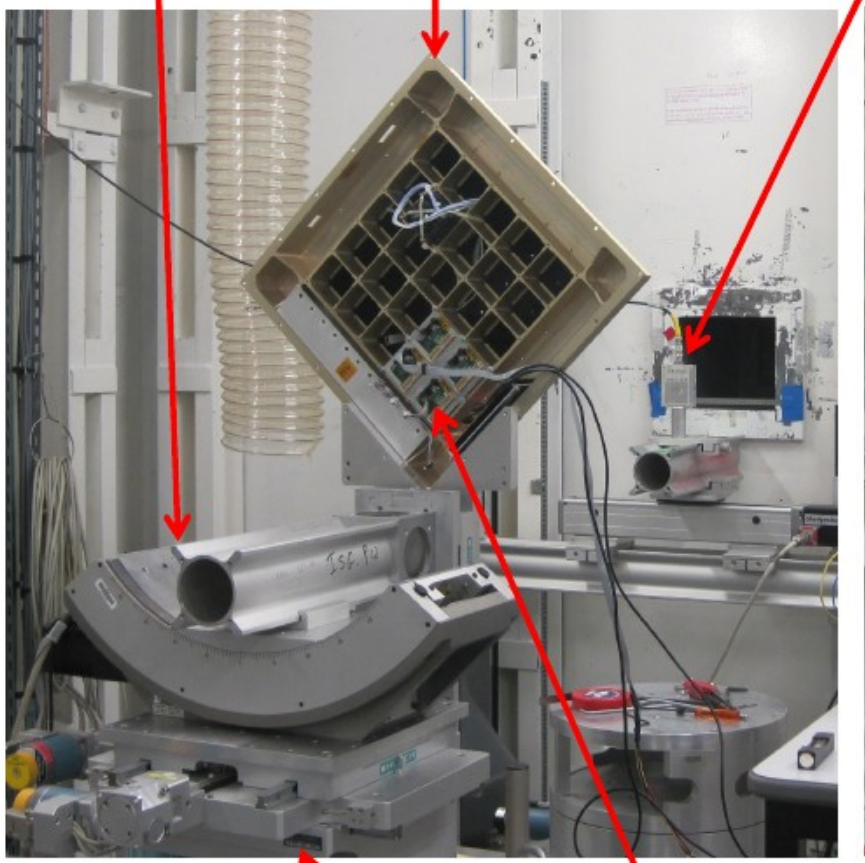
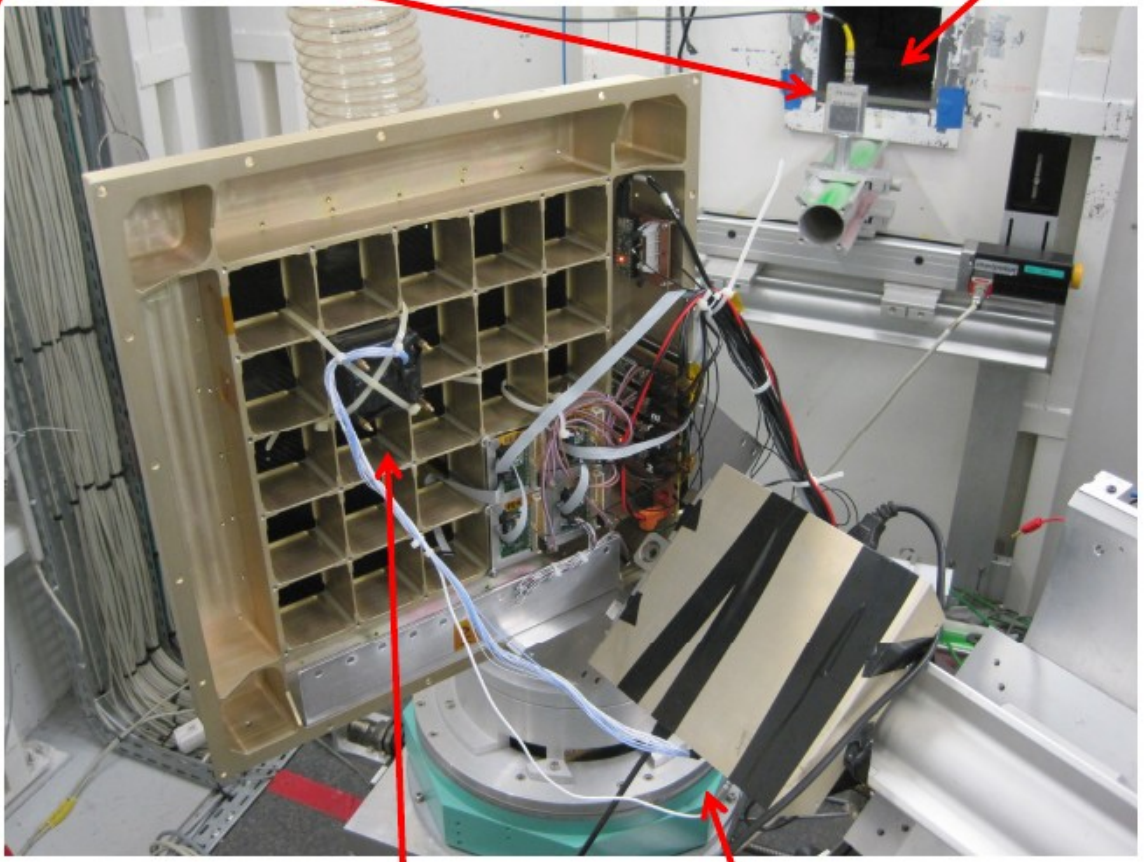


Experimental Hutch

ISDC
DATA CENTRE FOR ASTROPHYSICS

tilt
Aluminum grid
photodiode
beam





4 modular units
Translating table
M odular unit from IHEP +electronics

ESRF 2011 Experimental Setup