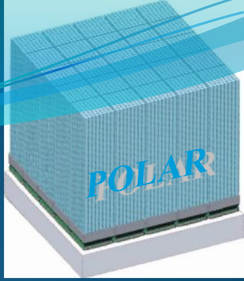

POLAR

A SPACE BORNE WIDE FIELD X-RAY POLARIMETER FOR GRB's STUDY

Jean-Pierre VIALLE[1],

S.Basa[6], Y. Dong[7], S.M. Gierlik[2], D. Haas[5], W. Hajdas[3], R. Hermel[1], H. Hofer[4], G. Lamanna[1], J. Liu[7], C. Lechanoine-Leluc[4], R. Marcinkowski[2], A. Mazure[6],A. Mtchedlishvili[3], S. Orsi[4], M. Pohl[4], N. Produit[5], D. Rapin[4], E. Suarez[4], B.Wu[7], S.N. Zhang[8], Y.Zhang[7],

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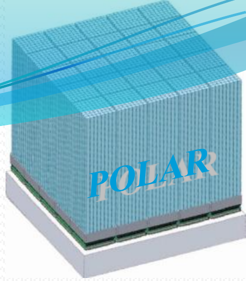
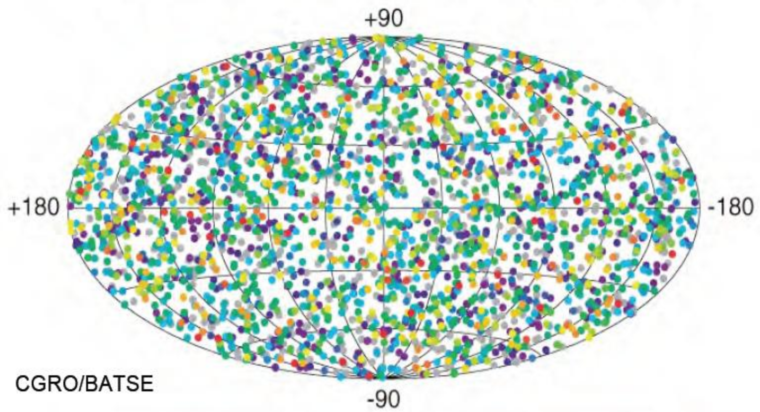
[2] IPJ, Swierk/Otwock, Poland;
[3] PSI, Villigen, Switzerland;
[4] DPNC, Universite de Geneve, Switzerland;
[5] ISDC, Universite de Geneve, Switzerland;
[6] LAM (INSU/CNRS), Marseille, France;
[7] key lab. for particle astrophysics, I.H.E.P., C.A.S., Beijing, P.R. China
[8] Dept of Physics and Center for Astrophysics, Tsinghua University, Beijing , P.R. China

Gamma Ray Burst (GRB)



Most violent, cataclysmic explosions in the universe.



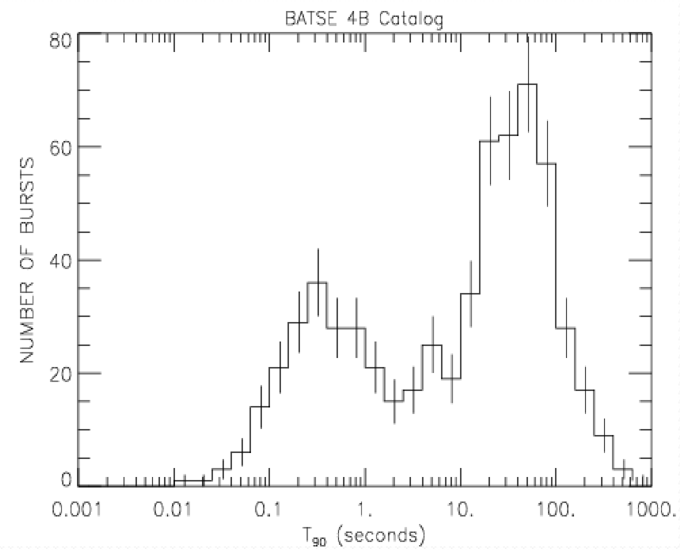
- Produces collimated energetic bursts of gamma rays.
- The energy released in a second can be equivalent to the mass of Sun
- GRB randomly distributed in the sky and in time

Two types of GRBs:

Hard spectrum Short burst < 2sec.
(merger of compact star binaries: ns-ns; ns-bh..)

2) Soft-spectrum Long burst. up to 200 sec.
(death of massive stars)

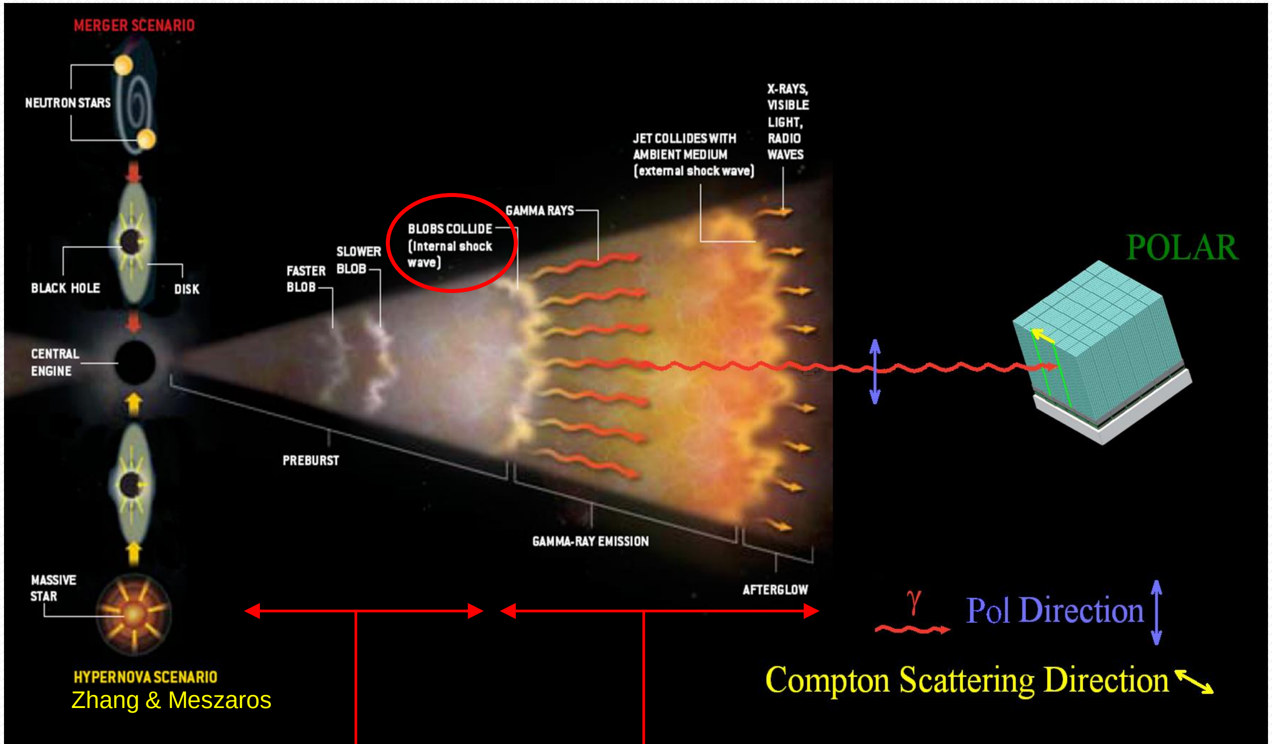
The prompt signal is followed by an afterglow which can last weeks …



Currently about 2 to 3 GRBs detected per week

Gamma Ray Burst (GRB)

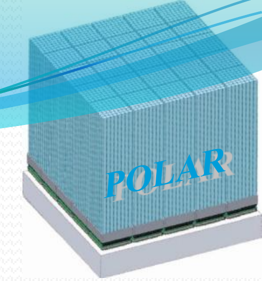
- Both result in a Black Hole formation and regardless of the progenitor a "fireball" central engine would be responsible of a relativistic jet from the center of the explosion (bulk Lorentz factor $\Gamma > 100$.)



Swift

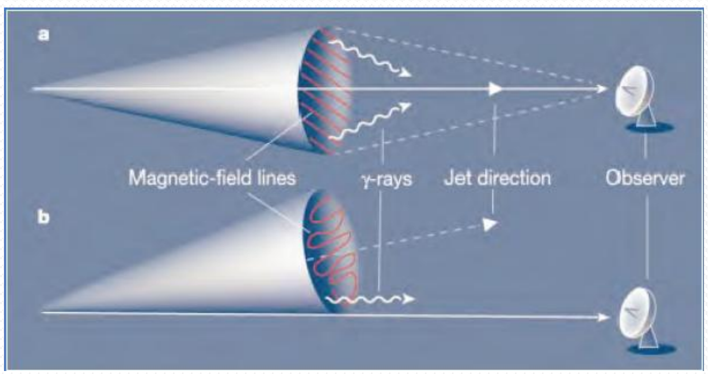
POLAR will use polarimetry to analyse the "PROMPT SIGNAL" : the only possible means of probing the structure of the central engine of the expanding fireball closest to the nascent black hole.

Gamma Ray Burst (GRB)



Theories on the GRB production mechanism can be constrained by different degrees of linear polarization (Π):

Π ~ > 80% Inverse Compton jet model
20%< Π <60% synchrotron emission is the dominant source of radiation. (**EM model**)
Low degrees of polarization: flux with a high degree of polarization experiencing partial depolarization e.g. electrons in a randomly oriented magnetic field. (**IS model**)

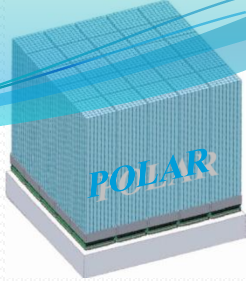


In general models fall into:
-Physical: globally ordered B field and synchrotron emission-> net polarization

-Geometrical: random B field and electrons-> No-net polarization except…when viewing ~ $1/\Gamma$ outside the jet cone (loss of emission symmetry) *(but random viewing angles make high Π significantly smaller)*

Other POLAR scientific Goals: Solar Flares, Soft Gamma Repeaters….

Polarimetry



Polarization provide key information about the radiation mechanism

High theoretical interest (>100 citations)

Difficult to measure with existing detectors

A few measurements have been published, but they are uncertain and sometimes controversial:

- GRB 021206: Wrong measurement published (claim 80%+- 20% . accidental coincidences)
- GRB 930131 (35% $\leq \Pi \leq$ 100%) and GRB 960924 (50% $\leq \Pi \leq$ 100%) by BATSE/CGRO from gamma back-scattered on the rim of the atmosphere
- GRB 041219a $\Pi = 96 \pm 40$ % from INTEGRAL.

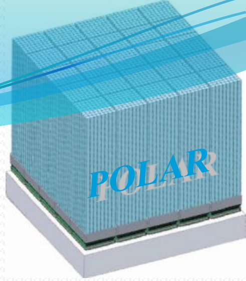
None of these results is a direct measurement, and experimental effects make these numbers questionable.

Polarization of the afterglow observed in the visible range in a number of GRB's, but never at times early enough.

An instrument dedicated to polarimetry and with wide field acceptance in order to catch the prompt signal is mandatory.

Repeated measurements are necessary to distinguish between various scenarii and to get rid of the effect of observation angle wrt jet axis

The POLAR detector



POLAR is a Compton hard X-ray GRB polarimeter using proven technologies:

homogeneous array of low Z scintillator plastic bars and PM detectors

Requirements:

- relies on given burst position and spectrum or provides a crude estimate in case of unique observation

Allow GRB prompt signal polarization measurement thanks to:

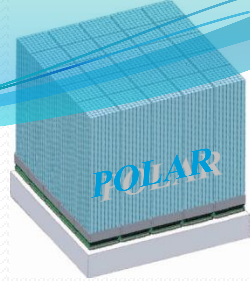
Large : area / modulation factor / field of view

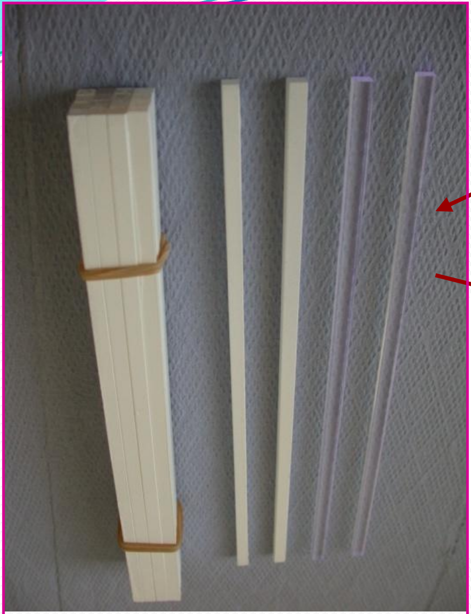
The scientific objectives lead to the following instrument specifications:

Effective detection area	400 cm2 (at 200 keV)
Incoming photon energy	50 keV to 500 keV
A large modulation factor	~40% (at 200 keV)
A large FOV (deep space view)	1/3 of the sky
Total Mass	< 30 kg
Mean power Consumption	< 30 W
Telemetry (continuous readout)	< 100 kBit/s

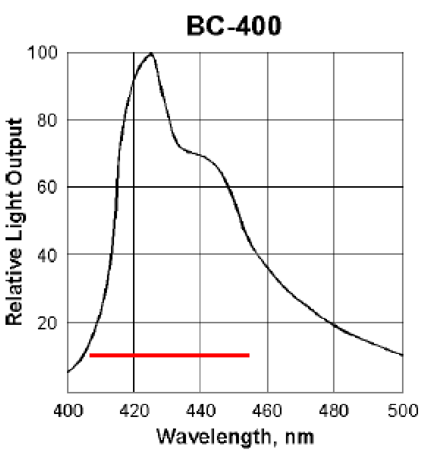
The aim is to perform the first ever successful polarization measurement of hard X photons in space with high statistical significance and controlled systematic effects.

THE POLAR DETECTOR

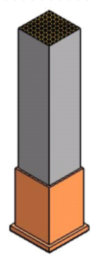


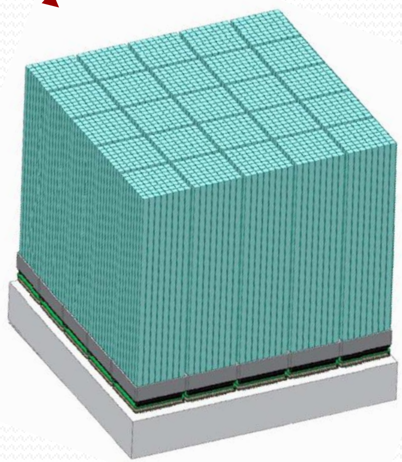


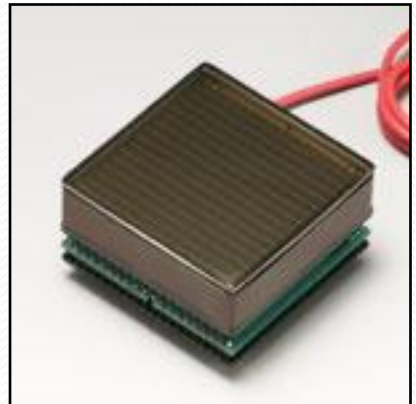
BC400: rad-hard and chemically stable



1600 PS bars: 25 x 8x8*6mm*6mm*20cm





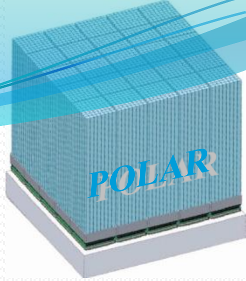


MAPM H8500 (8*8 anode pixel)

Wavelength (Peak)	420 nm
Uniformity	2-3

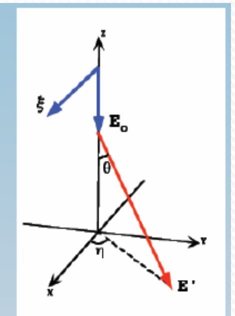
PS Bars	PMT (cm)	Weight (kg)	Dimension (cm)
40*40	5*5	20	30*30

COMPTON POLARIMETRY: BASIC PRINCIPLES



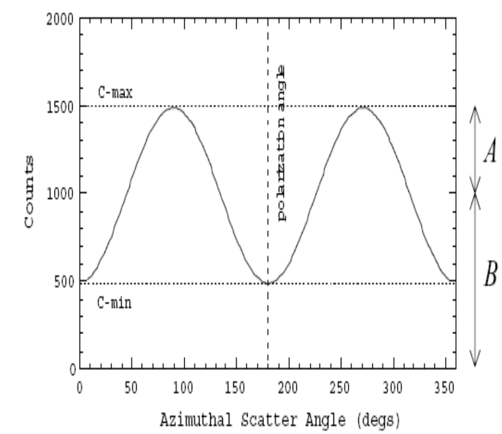
Utilizes Compton scattering;
photons scatter at right angles to initial polarization vector;
θ - Compton Scatter Angle
η - Azimuthal Scatter Angle

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



Signature from distribution in azimuth scatter angle

$$C(\eta) = A\cos 2(\eta-\varphi) + B$$



Modulation Factor for 100% polarization defines polarimeter:

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

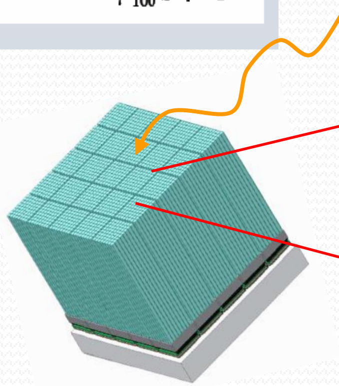
Instrument determines level of polarization as

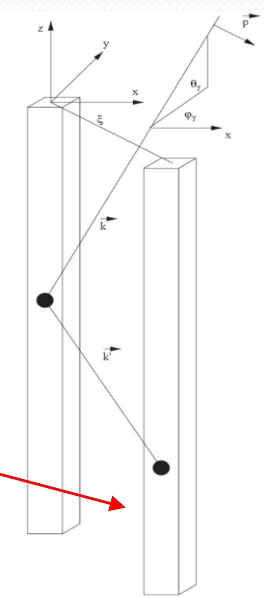
$$P = \frac{\mu_P}{\mu_{100}} = \frac{1}{\mu_{100}}\left(\frac{C_{max}(P) - C_{min}(P)}{C_{max}(P) + C_{min}(P)}\right)$$

Minimum Detectable Polarization for instrument is a function of:
S, B: source and background rate, T: observation time, μ_{100}: Modulation Factor

$$MDP = \frac{n_\sigma}{\mu_{100}\, S}\sqrt{\frac{S+B}{T}}$$

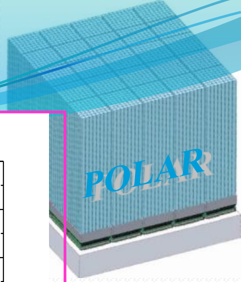
Geometry of the large angle Compton scattering.
The strategy is to look for the two bars where interactions occur: first Compton and second Compton or Photoelectric.



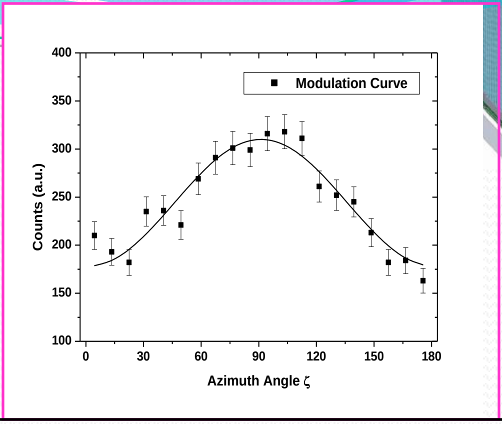


Monte Carlo Results

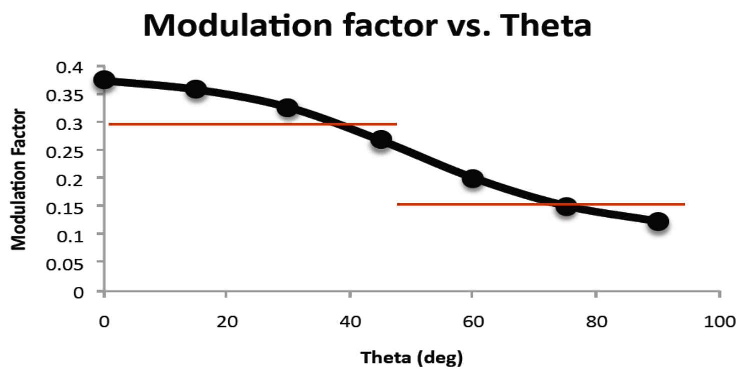
(GEANT4 full simulation)

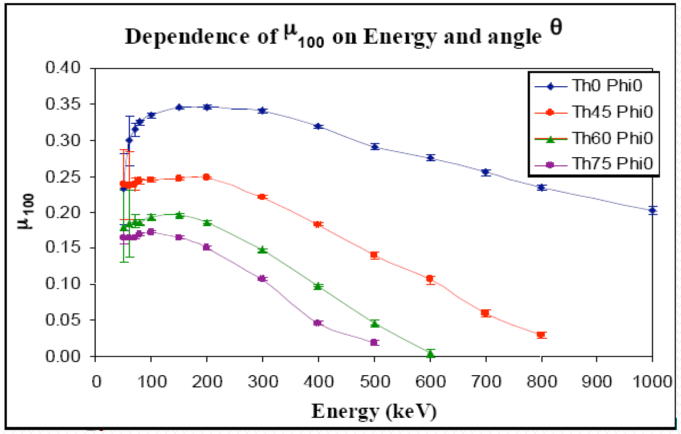


- Analysis uses two largest energy deposits with E_{thr}= 5 keV (corresponding to electron recoil energy from 50 keV photon scattered at 90°) (trigger activation: at least 2 channels)
- GRB position is known
- Optical insulation and thin (≈ 1 mm) carbon fiber outside shielding (stopping electrons with E< 500 keV or protons E< 13 MeV)
- No active shielding; but outer layers can be used if needed for a ("topological") trigger
- Upper threshold E_{sum}< 300+ keV (total sum) (TBC)



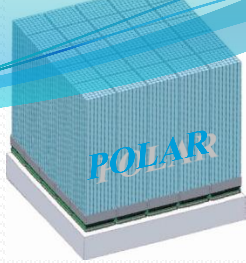
Fit function: $N=A\cdot\cos(2(\eta-\phi)+\frac{1}{2}\pi)+B$





- Maximum effective area for monochromatic photons $\varepsilon\cdot A = A_{eff} \approx 350\ cm^2$
- Polar angular dependence varies within 15% only
- Maximum Modulation Factor is 30% - 40%
- Constant values kept up to more then θ_γ= 30° for off-axis GRB

Monte Carlo Results



Background:

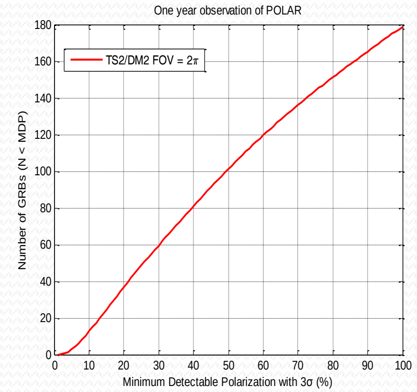
- Cosmic rays removed by upper energy threshold
- Diffuse background $E_{\gamma,bg}$>10 keV F_{dif}=2.46 /cm^2/sr/s – 430 coinc./s
- Non-GRB γ sources – e.g. Crab F_{Crab}=0.7 /cm^2/sr/s
- S/C induced γ's – ISGRI estimated F_{ind}=0.02 /cm^2/sr/s

GRB signals:

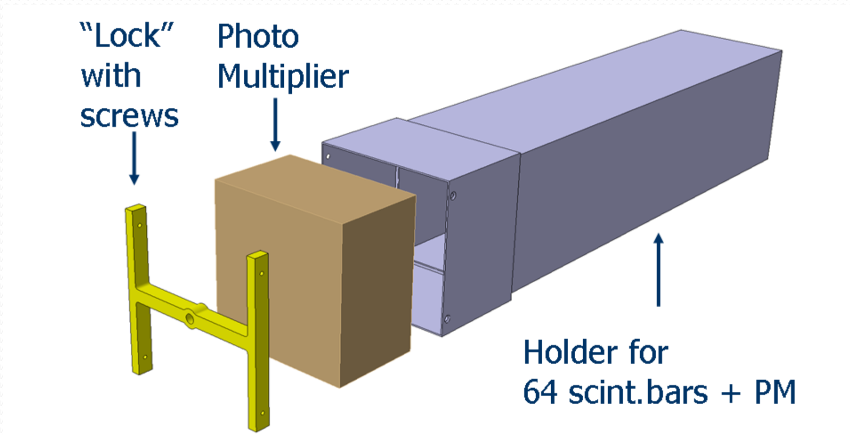
- MDP = $n_\sigma / \mu_{100} S \cdot \sqrt{(S+B)/T}$ E=10^{-5} erg/cm^2 → $MDP_{3\sigma}$ ≈ 10%
  (example LTC GRB060418 by RHESSI)
- Statistics based on BATSE catalogue

MDP	5%	10%	15%	20%	25%	30%
Number of GRB in 1 year	2.9	12.7	24.4	36.8	48.6	59.4

(GEANT4 full simulation)

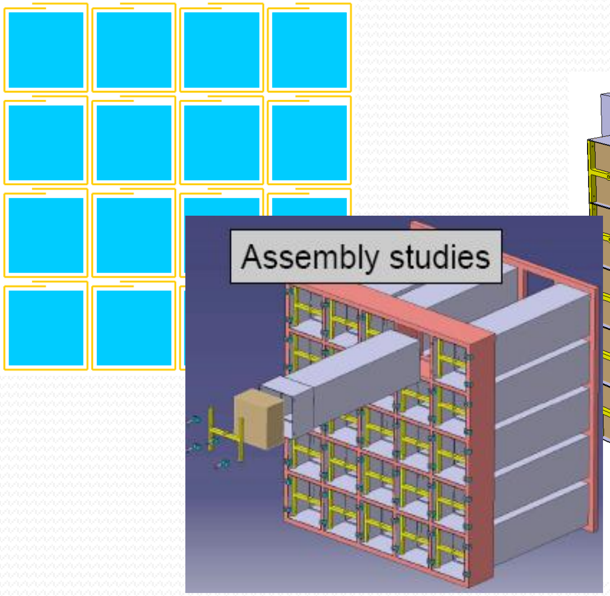


Mechanics

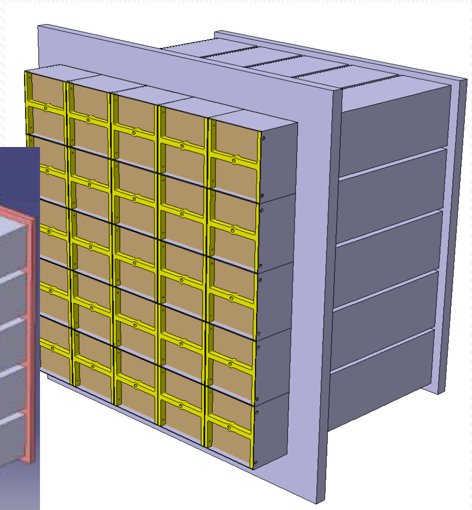


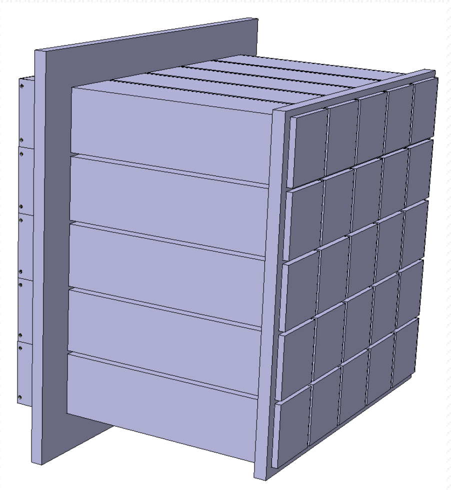
"Lock" with screws
Photo Multiplier
Holder for 64 scint.bars + PM

Module in Carbon Fiber
8x8 bars
MAPM H8500



Assembly studies

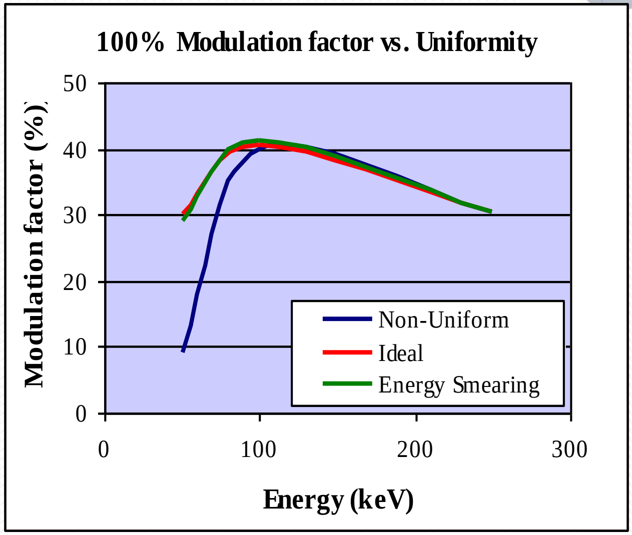




MAPRA ASIC PROJECT

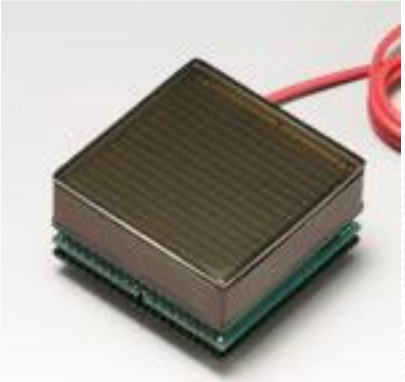
MAPRA: Multi Anode Polar Readout Asic, based on the MAROC -LAL-**IN2P3 (OMEGA)**
(64 channels ASIC for ATLAS (CERN) luminometer)

- Characteristics
  - 64 PMT channels input
  - Variable gain
  - 64 GTL outputs
  - Multiplexed direct signal output
  - 3 thresholds loaded
- Technology : AMS SiGe 0.35µm
  - Area 12 mm²
  - Dissipation O(100 mW)

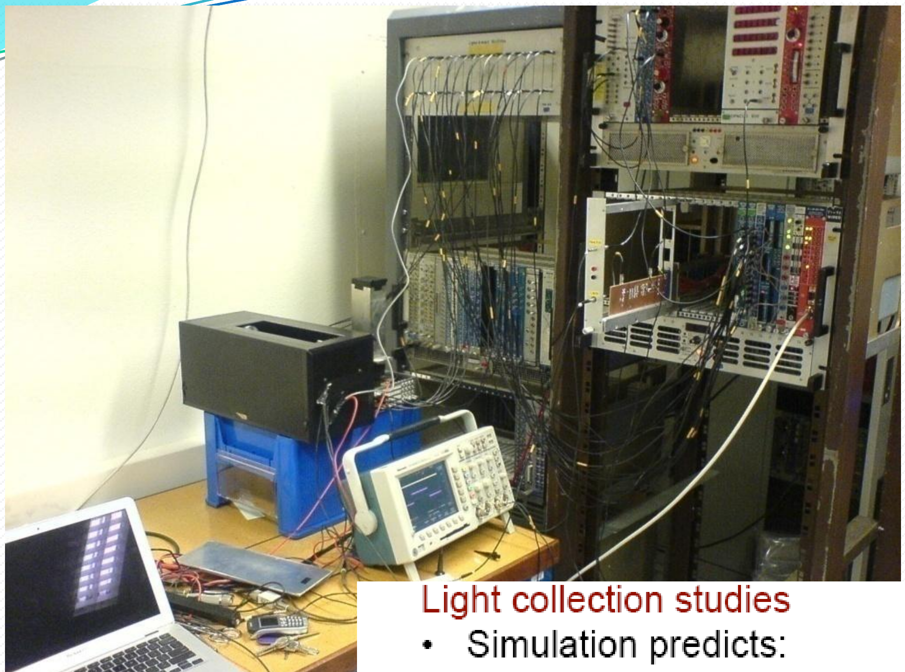


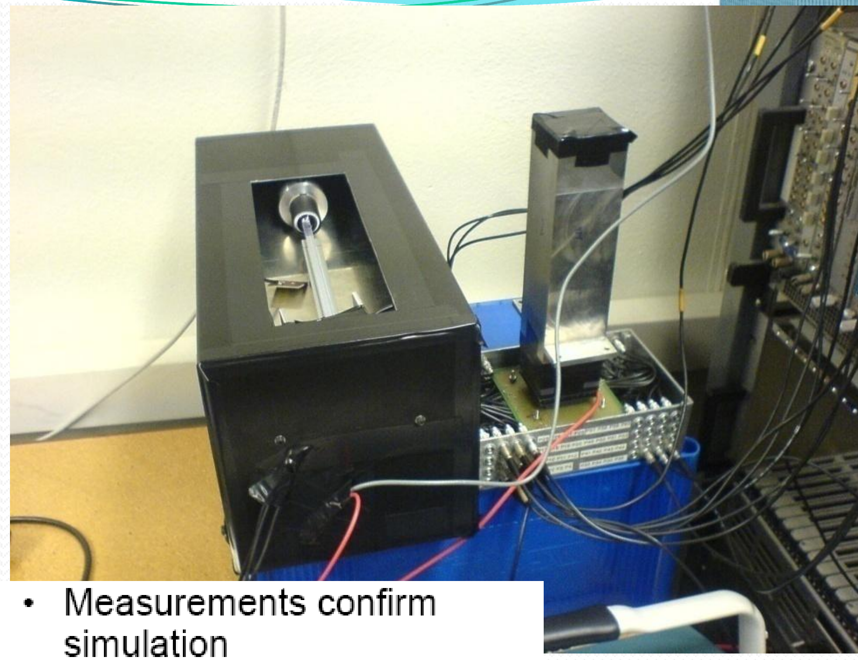
- Lack of uniformity affects the modulation factor: Non-Uniformity of PM has a strong influence

R. Hermel, N. Fouque with support from Omega



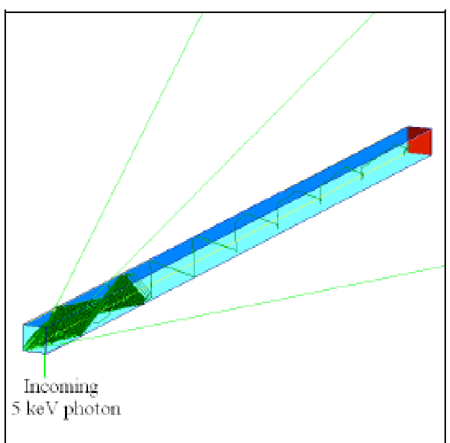
Laboratory Tests

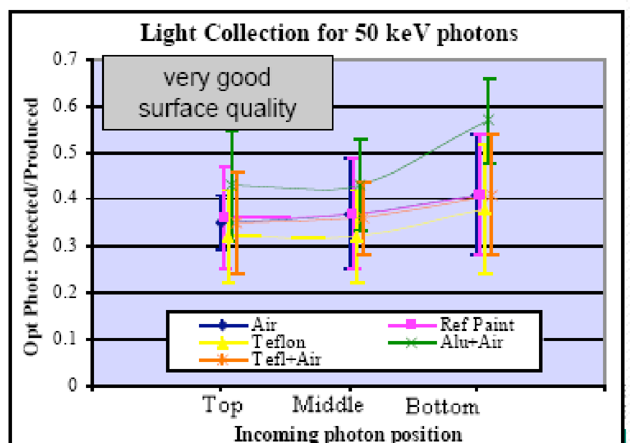




Light collection studies

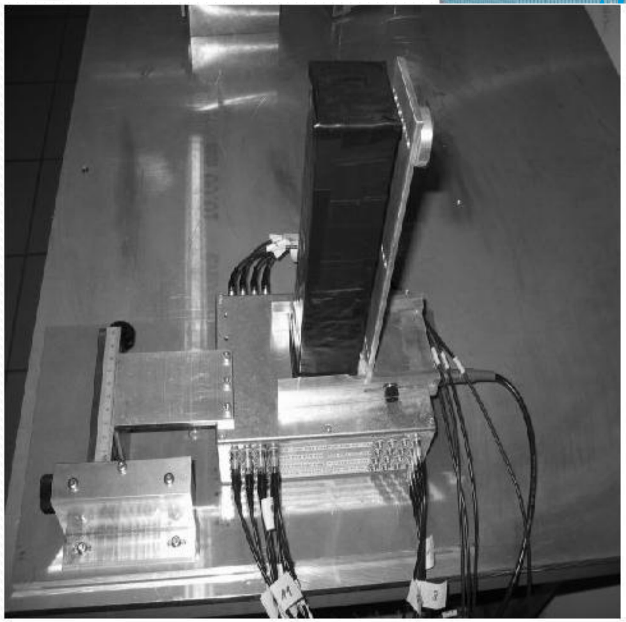
- Simulation predicts:
  - ~45% γ's reach PM
  - 10-20% difference top/bottom
  - Surface quality essential
- Measurements confirm simulation
  - different wrapping tested
  - use Vikuiti (Alu-like, but even higher reflectivity





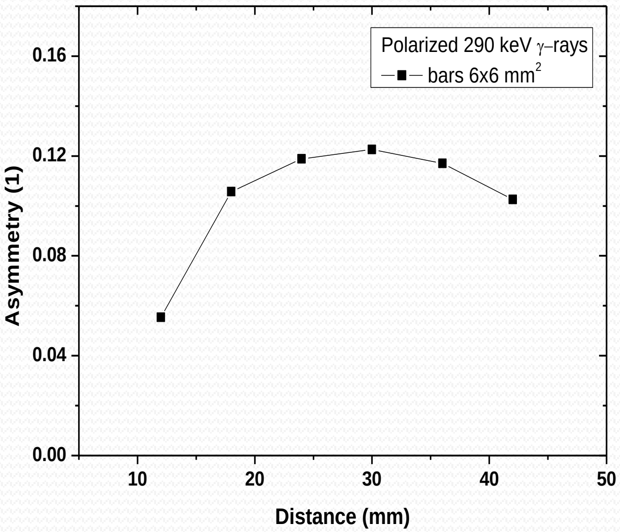
Laboratory Tests

- Tagged γ-ray polarized source
  - 90° scattering of photons on large scintillator
  - Strong ^{137}Cs source (37 MBq)
  - γ-rays ($E_{90DEG} \approx 290$ keV, $P_{AV} \approx 40\%$, $P_{MAX} \approx 60\%$)



- Measured asymmetry up to 12% (depending on distance between plastics)

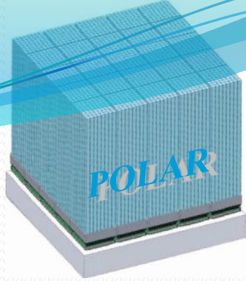
$$Asymmetry = \frac{N_{90} - N_0}{N_{90} + N_0}$$



- Corresponding to (0.12 / 0.3 =) 40 % polarization

Measured asymmetry (~modulation factor) confirming the validity of working principle

POLAR STATUS

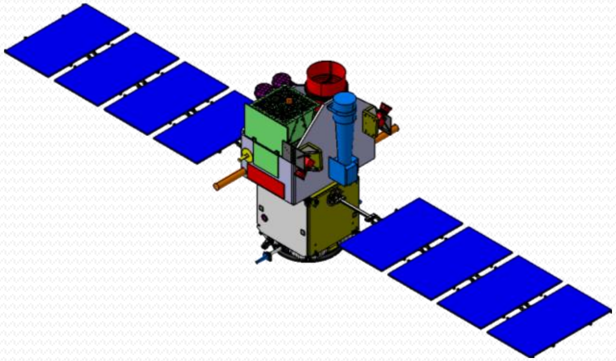


Demonstrator is under test on polarized beam and an Engineering Model (EM) is under development

Preliminary Technical Design Report produced for all sub-projects: Meca, Elec, etc..

MAPRA ASIC prototype sent to foundry

SVOM as a trigger for POLAR



The SVOM community strongly supports POLAR as a low cost "natural" complementary device for an extremely important complementary scientific measurement.

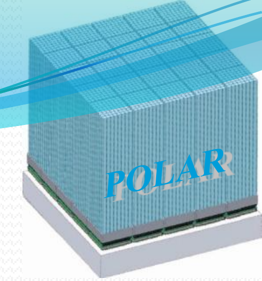
Flight opportunity

Tian-Gong
天宫
Palace in Heaven

IHEP-*proposing POLAR a Chinese experiment*

and a flight onboard the Chinese SpaceLab in 2013.

The joint spacelab-TG POLAR team

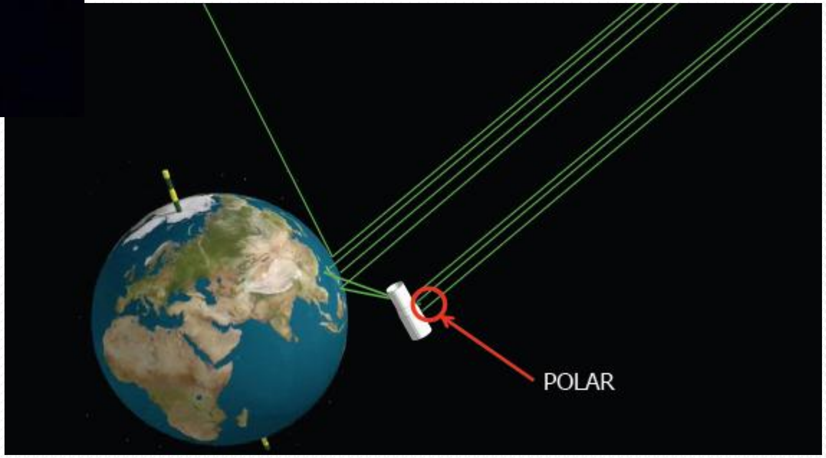


- China Tsinghua/IHEP: Shuang Nan Zhang (PI)
- China IHEP: B. Wu, Y. Dong, Y. Zhang, J. Liu
- France LAPP: G. Lamanna, J.-P. Vialle
- France LAM: Stéphane Basa, Alain Mazure
- Swizerland ISDC: N. Produit (Co-PI), T. Courvoisier, D. Haas
- Switzerland PSI: W. Hajdas, A. Mitchedlishvili
- Switzerland DPNC: H. Hofer, C. Leluc, S. Orsi, M. Pohl, D. Rapin, E. Suarez
- Poland IPJ: M. Gierlik, R. Marcinkowski,

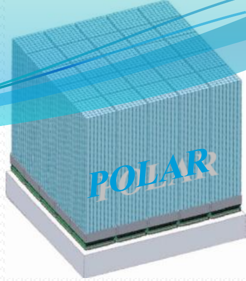
SPACELAB

- Chinese space-flight opportunity. *SpaceLab in 2013.*

Space radiation environment MC studies:
-Photons scattered by the SpaceLab
-Polarized photons back-splashed from Earth.



SUMMARY



- POLAR – Compton hard X-ray GRB polarimeter using low Z scintillators
- 40x40 homogeneous array of 6x6x200 mm^3 plastic bars

- FoV ≈ ⅓ of the sky and low γ energy threshold E_{MIN} < 50 keV
- $A_{EFF} \approx 400\ cm^2$ and $\mu_{100} \approx 40\%$ at 200 keV
- $MDP_{3\sigma} \approx 10\%$ for GRB total energy of $10^{-5}\ erg/cm^2$; tens of detections/year

- First asymmetry results obtained demonstrating polarimetric capability

- Engineering Qualification Model under development
- Demonstrator will be tested in Beam-tests

POLAR should fly onboard the Chinese spacelab *Tian Gong* around 2013

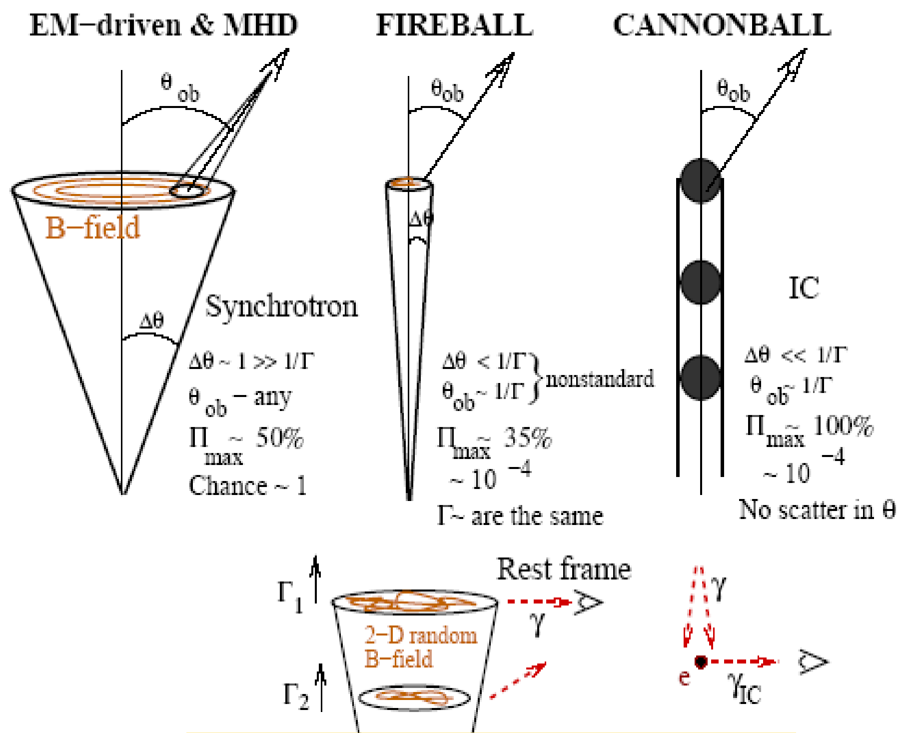
lapp

THANK YOU

SPARES

GRB prompt emission polarization:
one of the last observables of GRBs

- Different GRB models
  - E-M Model: well defined, moderate P_{lin} ~ 50%
  - Fireball Model: high values excluded P_{lin} ~ 10-20 %
  - Cannon ball Model: full range possible P_{lin} = 0 - 100%
- Probe quantum gravity (???):
  - Amelino-Camelia G., 2000, Nature, 408, 661
  - Amelino-Camelia G., et al., 1998, Nature, 393, 763
  - Piran T, 2005, Lect. Notes Phys, 669, 351
  - Fan, Y-Z; Wei, D-M; Xu, D. 2007, MNRAS, 376, 1857



From M. Lyutikov, 2003

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

Critical values of Π to discriminate between models

$\Pi < 1\,\%$ → IS, EMBH

$\Pi < 10\%$ → IS, EM, CB

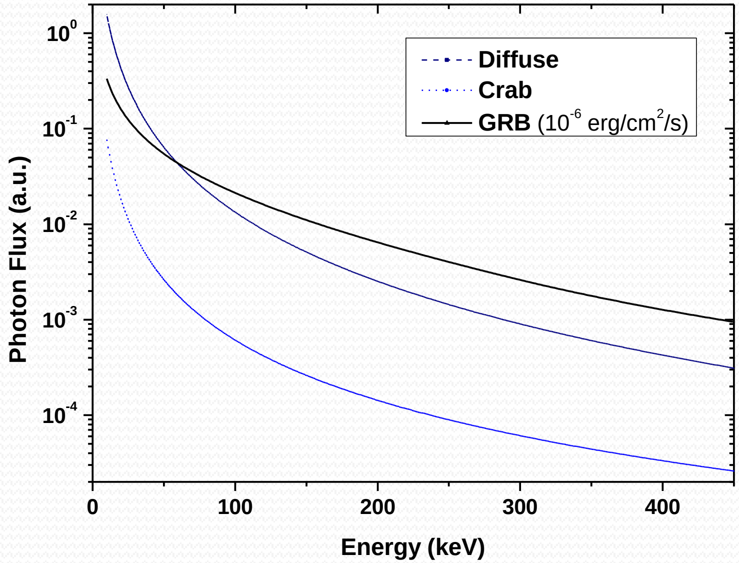
$\Pi > 10\%$ → IS, EM, CB

$\Pi > 50\%$ → EM, CB

Essential to have constraints at the level of polarization $\Pi \sim 10\%$

BACKGROUND SOURCES

- Cosmic rays removed by upper energy threshold
- Diffuse background $E_{\gamma,bg}$>10 keV
  F_{dif}=2.46 /cm^2/sr/s – 430 coinc./s
- Non-GRB γ sources – e.g. Crab
  F_{Crab}=0.7 /cm^2/s
- S/C induced γ's – ISGRI estimated
  F_{ind}=0.02 /cm^2/sr/s
- Weaker GRBs at lower energies require careful background subtraction



Monte Carlo Results

- Analysis uses two largest energy deposits with E_{THR}= 5 keV
  (corresponding to electron recoil energy from 50 keV photon scattered at 90°)
- GRB position is known (e.g. GCN)
- Fit function:

  $$N = A \cdot \cos(2(\eta - \phi) + \tfrac{1}{2}\pi) + B$$

  ϕ – polarization direction
- MC predicts clear modulation signal with period π
- Unpolarized photons create pattern with period $\pi/2$

Direction and Spectrum known
Implies less systematic, less MC simulated cases for cross-checks…