Large-Area Balloon-Borne Polarized Gamma Ray Observer (PoGO)

DOE Review (June 3, 2004)
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for the PoGO collaboration
(SLAC-Goddard-Princeton-Japan-Sweden-France)

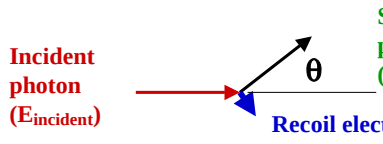
1. Introduction
2. Design of PoGO
3. Beam Test Results with a Prototype at APS
4. Background Elimination Tests with Radioactive Sources
5. Science with PoGO
6. Summary and Future Prospect

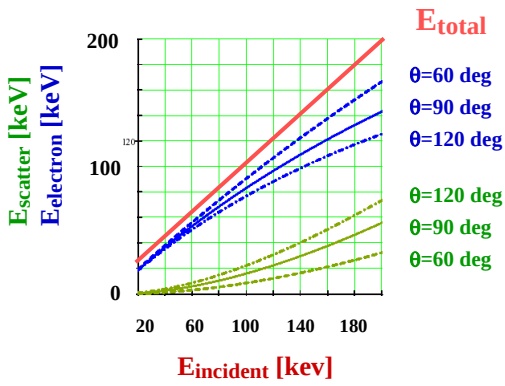
Main Features of PoGO

- ✓ Sensitive in the energy band (25-80 keV) where highest polarization is expected by Compton scattering around Black Holes, Neutron Stars & AGNs.
- ✓ Narrow FOV Well-type Phoswich Design for low background (<10mCrab).
- ✓ Inexpensive and easy-to-maintain: plastic scinti., BGO, and PMTs.
- ✓ Sensitive to pol = 6-10% in 100 mCrab sources in a 6-hr balloon flight.

- ➢ Selected by NASA as a Research Opportunities in Space Science program
- ➢ Selected by Monkasho (Japan) as a Grant-in-Aid project.
- ➢ Application for funds submitted in Sweden.
- ➢ Will submit another proposal for balloon flights to NASA.

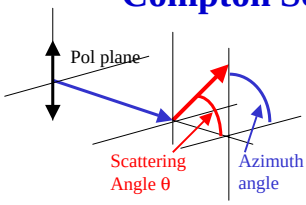
Compton Scattering: Energy Deposition





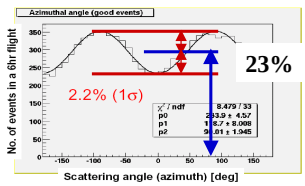
Crude measurement of $E_{scatter}$ and $E_{electron}$ by plastic scintillation counters (fwhm~50-100%) can differentiate the scattering site and the photo-absorption site of the scattered photon.

Compton Scattering: Modulation Factor



Mod factor (fraction) = (Max-Min)/(Max+Min)

A design of PoGO (EGS4)



Mod factor: Compton scatt vs angle and $E_{incident}$

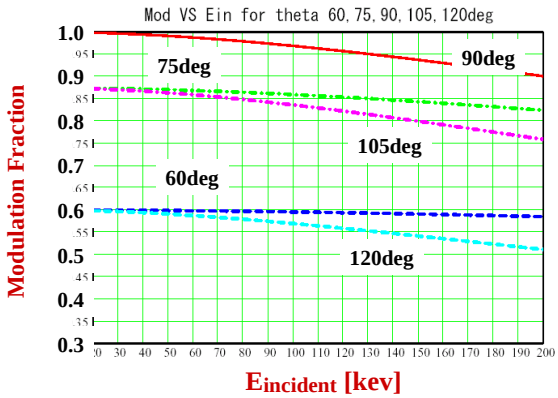


Figure: Modulation factor of Compton scattering vs. the incident energy: scattering angle (theta)=60 deg(blue dash), 75 deg(green dot-dash), 90 deg(red solid), 105 deg(purple dot-dash), 120deg(magenta dash).

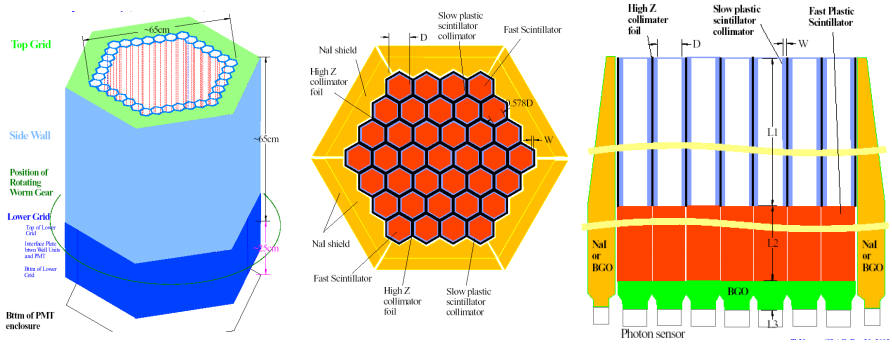
Design of PoGO: Basic Strategy

Fig. of merit = Expected modulation factor x Expected S/N

- **Modulation factor: PoGO ~0.23-0.25**
- **S/N ratio: PoGO ~100 (Cyg X-1) to ~10 (Mkn501)**

- **Extend energy coverage as low as possible: PoGO ~25keV**
  (Counting rate is proportional to 1/E(2-3) for most sources)**
- **Maximizing effective area is less important than the above.**

Design of PoGO: Concept #1 – Well-type Phoswich Counters

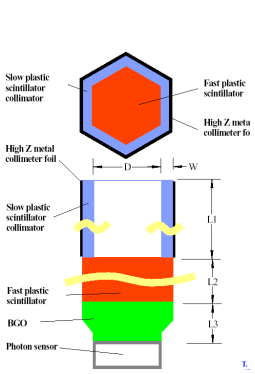


(a) **(b)** **(c)**

Conceptual design of the instrument (number of units will be greater than shown here): a) Isometric view; (b) View from the front of the instrument; (c) Vertical cross-section of the instrument. The proposed instrument will have 200-400 units and L1 + L2 in (c) will be ~60cm.

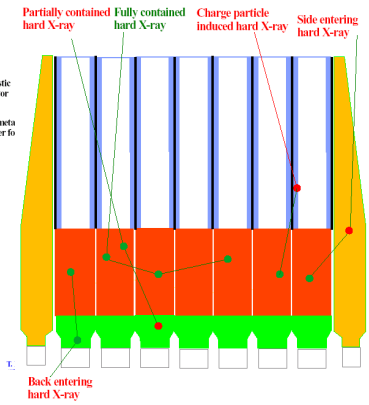
Design of PoGO: Concept #2 - Trigger Strategy

Trigger and Pulse-Shape-Discrimination: L0, L1, L2

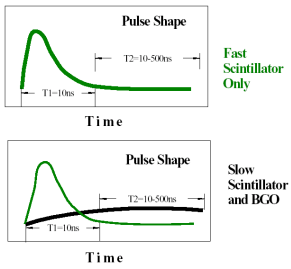


1 inch PMT

Unit



Detector Assembly



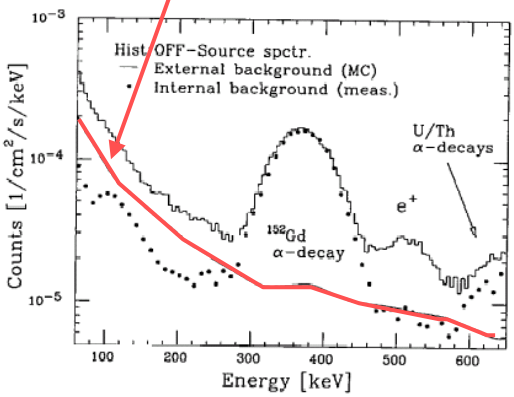
Pulse-Shape Discrimination

Design of PoGO

- Heritage from 3 successful balloon experiments -

Lowest background achieved in the hard X-ray band

Backgrnd with Welcome-1
FOV=14x14 deg=200 deg^2



A series of balloon experiments in Brazil

- **First detection in hard X-ray of PSR 1509**
- **Detection of H.E. cutoff of CenA**
- **First detection of high latitude Galactic diffuse emission for 20<E<500keV**

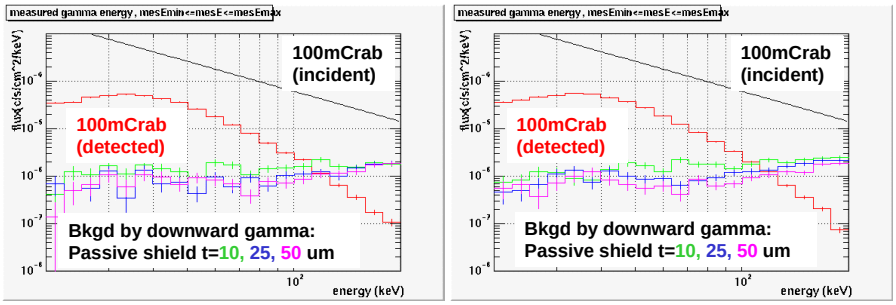
Design of PoGO: Expected Background

Background is expected to be much lower than Welcome-1 because:

1) **Much smaller FOV = 5/200: Bkgnd from FOV will be 1/40 of Welcome-1.**
2) **Coincidence imposes Compton kinematics: Eliminate all high energy γ bkgnd.**
3) **Radioactivity is not an issue with plastic scintillator**

Geant 4 Simulation for the 217 and 397 unit designs with the cosmic-ray background model "calibrated" to reproduce the GLAST-BFEM balloon experiment. Background level will be ~10mCrab between E=25-80keV.

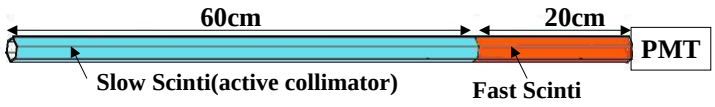
Design-217 (217 units) **Design-397 (397 units)**



Design of PoGO: Key Parameters for 2 Sample Designs

Design-397 with 397 units and Design-217 with 217 units:

One unit: 60cm long slow scint. hex. tube + 20cm long fast scint. + 3cm BGO + 1-inch PMT

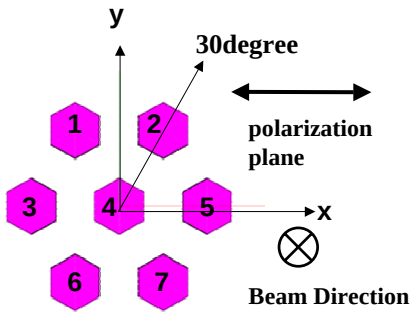


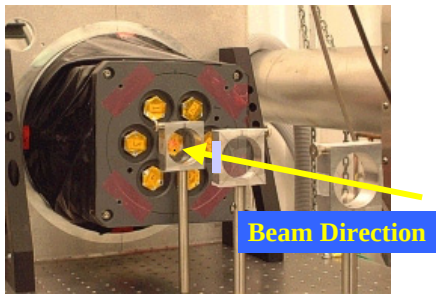
	Design-397	Design-217
Energy band	25-200keV	25-200keV
Geometric area	1709cm**2	934cm**2
Eff. area for pol meas. (for 40-50keV)	460cm**2	230cm**2
Instr. background (for 40-50keV)	~10mCrab	~10mCrab
Mod. factor for 100% pol. 100mCrab	25.1%	24.3%
Sensitivity to pol. for 100mCrab (1sigma)	2.0%	3.0%

Beam Test Results
- A Prototype at Advanced Photon Source -

- Beam goes into the slide at the center of Unit#4.
- Polarization plane is along x-axis.
- Set-up rotated about the beam at 30 deg steps.

- Coincidence between #4 and a peripheral counter
- $E_{incident}$=60.2, 73.2, 83.5 keV



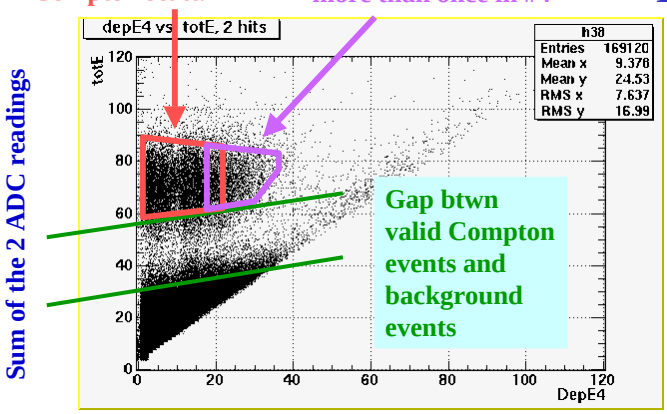


Beam Test Results: Coincidence Trigger

Consistent with single Compton scatt. in #4

Likely to have scattered more than once in #4

E_X=73.2keV



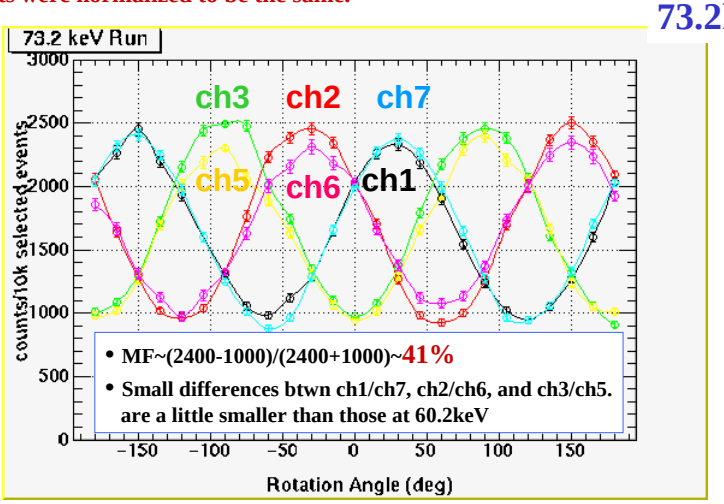
Sum of the 2 ADC readings

ADC reading of Unit#4

Beam Test Results: Modulation Factor for 73.2keV

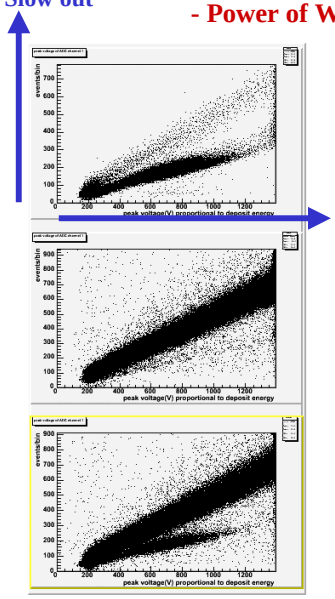
Since coincidence efficiency varied for 6 peripheral units, the numbers of events were normalized to be the same.

73.2keV



Background Elimination

- Power of Well-type Phoswich Technology -



Signal: E=60keV and <keV hard X-rays from Am^{241} irradiated from the aperture.

Background: Emax=2.28MeV electrons from Sr^{90} on the slow scintillator. Rate >10 X Signal

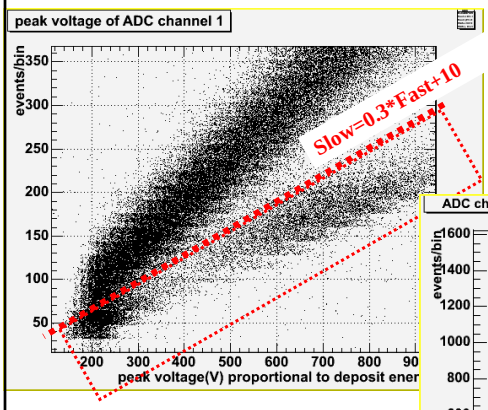
Signal + Background: 60keV signal in Emax in >10 times cosmic-ray background.

In PoGO, BGO anti-coincidence counters provides nearly hermetic protection, rejecting background at the trigger levels, L0 and L1.

Background Elimination

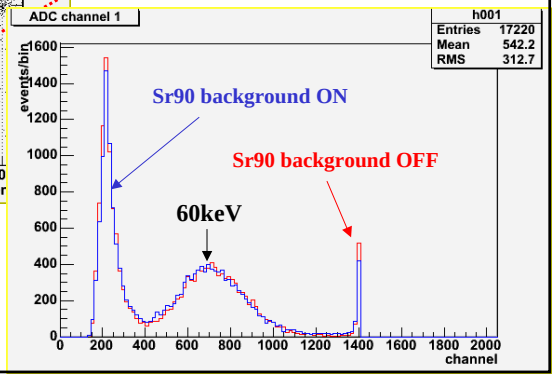
- Power of Well-type Phoswich Technology -

Scatter plot: Fast-out vs Slow-out



In PoGO, BGO anti-coincidence counters provides nearly hermetic protection, rejecting background at the trigger levels, L0 and L1.

Pulse height of Am241 (60keV) after the cut



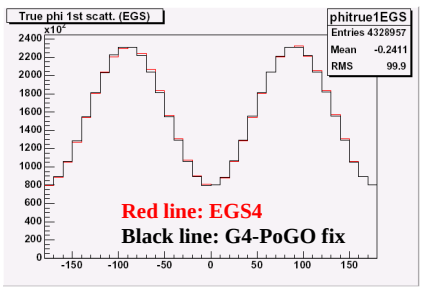
EGS4 vs G4: Important fixes made to G4

Credit:
Y. Fukazawa,
T. Mizuno,
H. Tajima

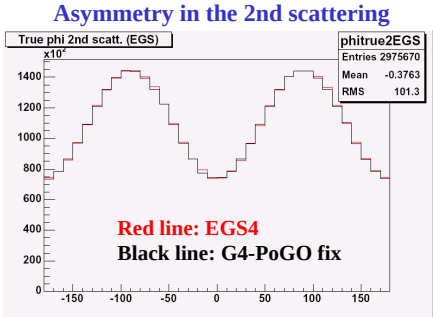
- **G4 lost polarization after the 1st scattering. – PoGO fix made**
- **G4 lost polarization after a Rayleigh scattering. – PoGO fix made**
- **Comparison between G4 and EGS4 for a test setup**

	G4	EGS4
1st Compton Scatt.	49.42+-0.19%	49.29+-0.05%
2nd Compton Scatt.	32.29+-0.24%	32.57+-0.07%

Asymmetry in the 1st scattering



Asymmetry in the 2nd scattering



Possible Targets for PoGO: Many Interesting Objects

- **Isolated pulsars:** Pulsar X/γ emission models, effect of strong B-field (eg. Crab, PSRB1509)
- **Galactic X-ray binaries:** Inverse-Compton reflection model, geometry around Galactic BHs (eg. CygX-1, GRS1915+105, GX339-4)
- **Accreting neutron stars with strong cyclotron line features:** Influence of high B-field on X/γ propagation (eg. Her X-1, 4U0115, CenX-3)
- **Blazar flares:** X/γ emission mechanism, synchrotron, IC, SSC, orientation of B-field (eg. Mkn501, PKS2155)
- **Seyfert galaxies:** Inverse-Compton reflection model, geometry around SMBH (eg. NGC4151, NGC4945)
- **Solar flares and coronae:** Emission mechanism, geometry of B-field

Possible Targets for PoGO: Crab pulsar (1/2)

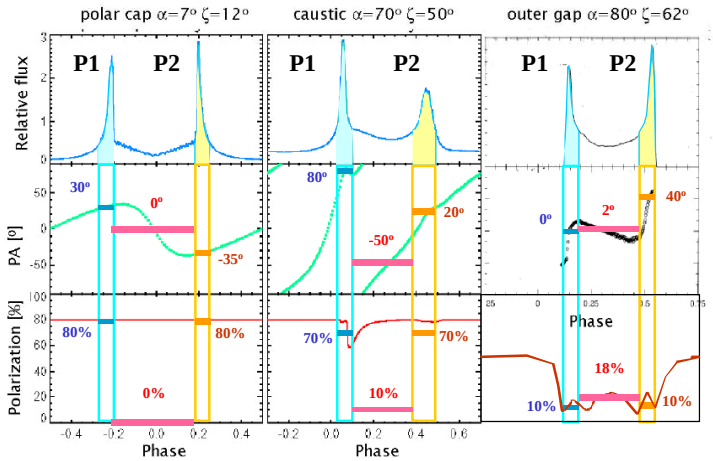
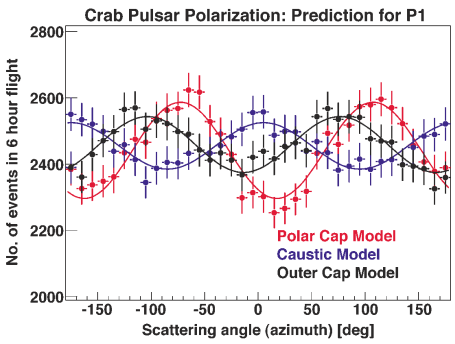


Figure: Simulations of pulse profile, polarization angle and percent polarization for Crab Pulsar. Polar cap and caustic models simulations assume constant emission along field lines [Dyks and Rudak03]. The outer gap model results are from [Romani and Yadigaroglu95]. The percent polarization from the model has been assumed to follow the optical measurements [Smith88].

Possible Targets for PoGO: Crab Pulsar (2/2)

Can determine the Pulsar Model at ~20σ in one 6hr balloon flight !!

Design-397



Design-397

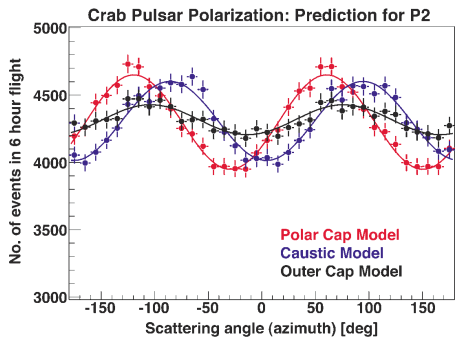
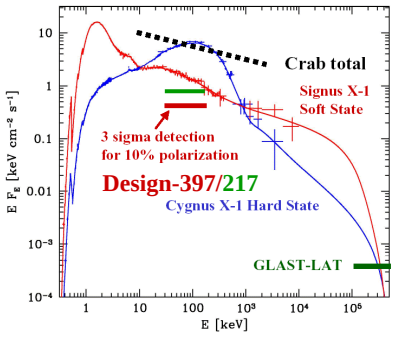


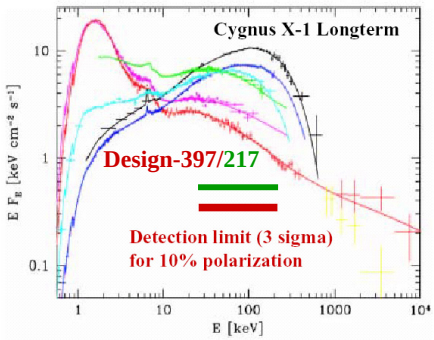
Figure: Simulated data that typifies the statistical accuracy expected from a 6-hour observation by PoGO.

Possible Targets for PoGO: Galactic BHs & Neutron Stars

Can measure Pol of Cygnus X-1 to 2-5% in all states in a 6hr balloon flight !!

Cygnus X-1 hard state: stays in the hard state for a few months to a few years





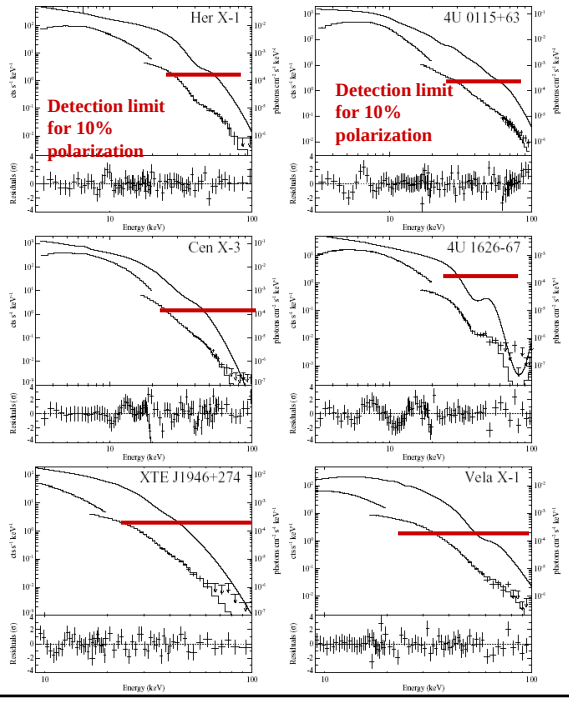
Possible Targets for PoGO:

Neutron Stars with Cyclotron Absorp. Features

Nonlinear QED processes (photon splitting etc) and the magnetic field on the Neutron Star.

Binary pulsars with Cyclotron Res. and Scattering Feature (CRSF)

Design-397



Summary and Future Prospect

- **PoGO is made of well-tested detector elements: plastic scinti., BGO, and PMTs.**
  Records Compton scattering down to ~25keV.
- **PoGO is based on the well-type phoswich technology:**
  Reduces non-FOV background to ~10mCrab level.
- **PoGO is designed for a short balloon flights: in one 6-hr flight**
  Detect 6-10% polarization in 100mCrab sources (397-217 units)
- **PoGO is inexpensive to build and requires minimum maintenance:**
  Can fly within a week of onsets of flares and high states.
- **PoGO is internationally supported and funded:**
  Funded by NASA and Monkasho (Japan); being reviewed in Sweden.

- **Plan: FY2004-2006: Detector development and beam tests**
  FY2007-8: First Balloon Flight

PoGO will measure polarization of hard X-rays from Galactic black holes and pulsars, unravel the emission mechanism, and establish a new genre of astrophysics by 2008.