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

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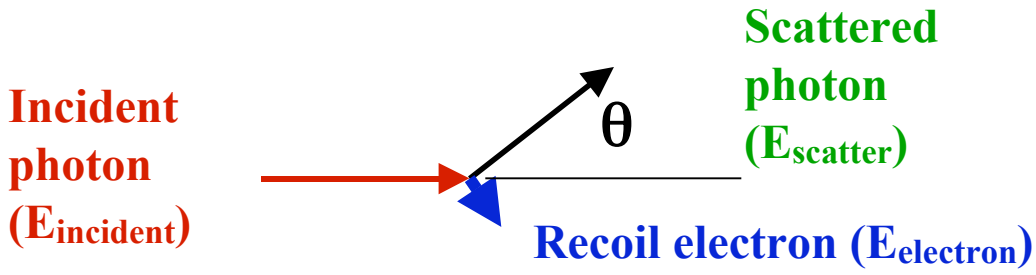
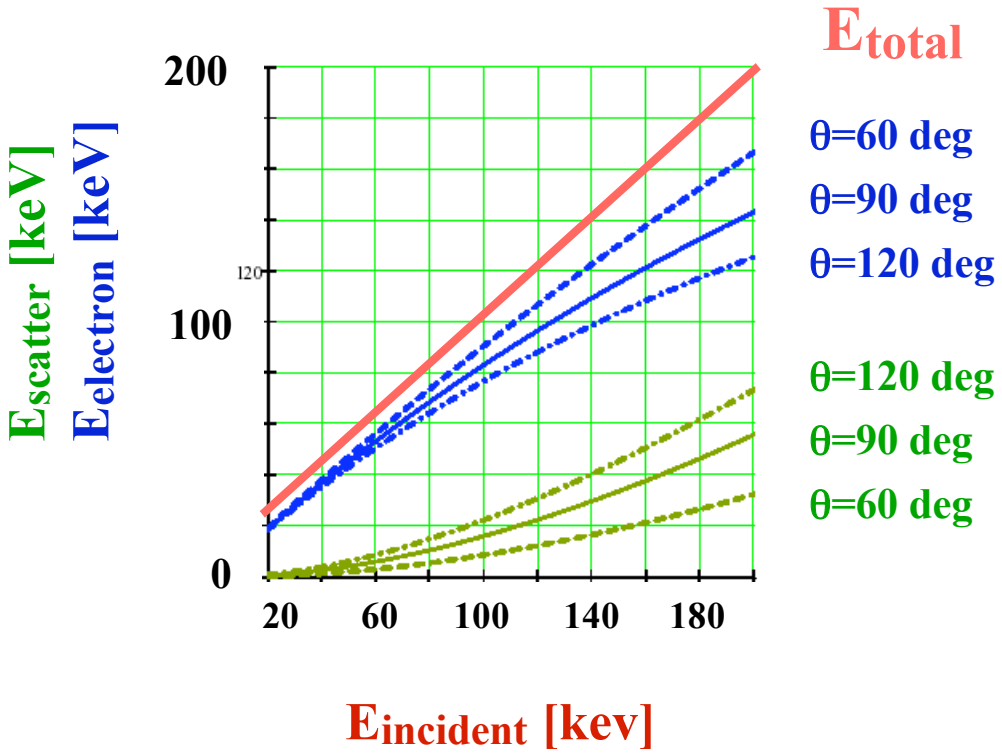
Introduction to PoGO

- Instrument to measure polarization in E=25-200 keV by Compton scatt.
- Has a narrow FOV (5 deg^2) and suppresses background to 10mCrab level.
- Sensitive to pol = 6-10% in 100 mCrab sources in a 6-hr balloon exp.
- Selected by NASA as a Research Opportunities in Space Science program
- Has no consumable and easily upgradable to a satellite prject.

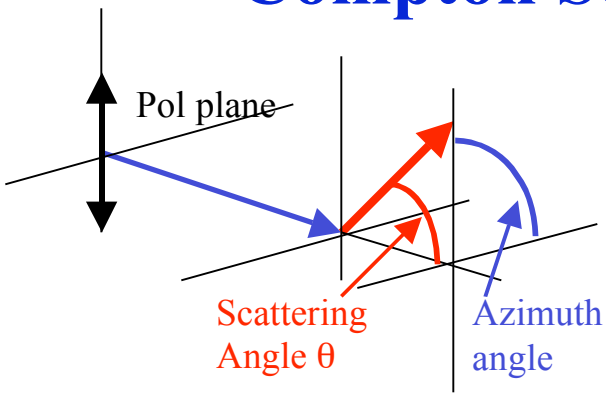
Compton Scattering: Energy Deposition





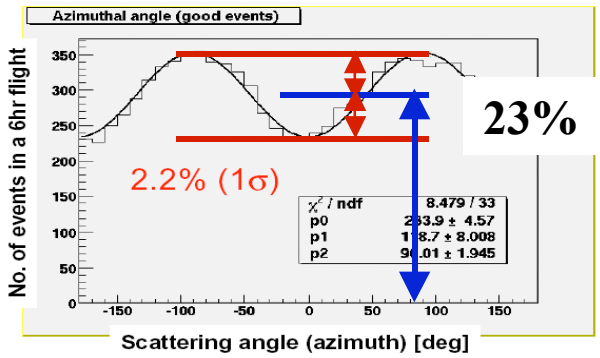
Crude measurement of $E_{scatter}$ and $E_{electron}$ by plastic scintillation counters (fwhm~50-100%) can differentiate the scattering site and the photo-absorption site of the scattered photon.

Compton Scattering: Modulation Factor



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

A design of PoGO (EGS4)



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

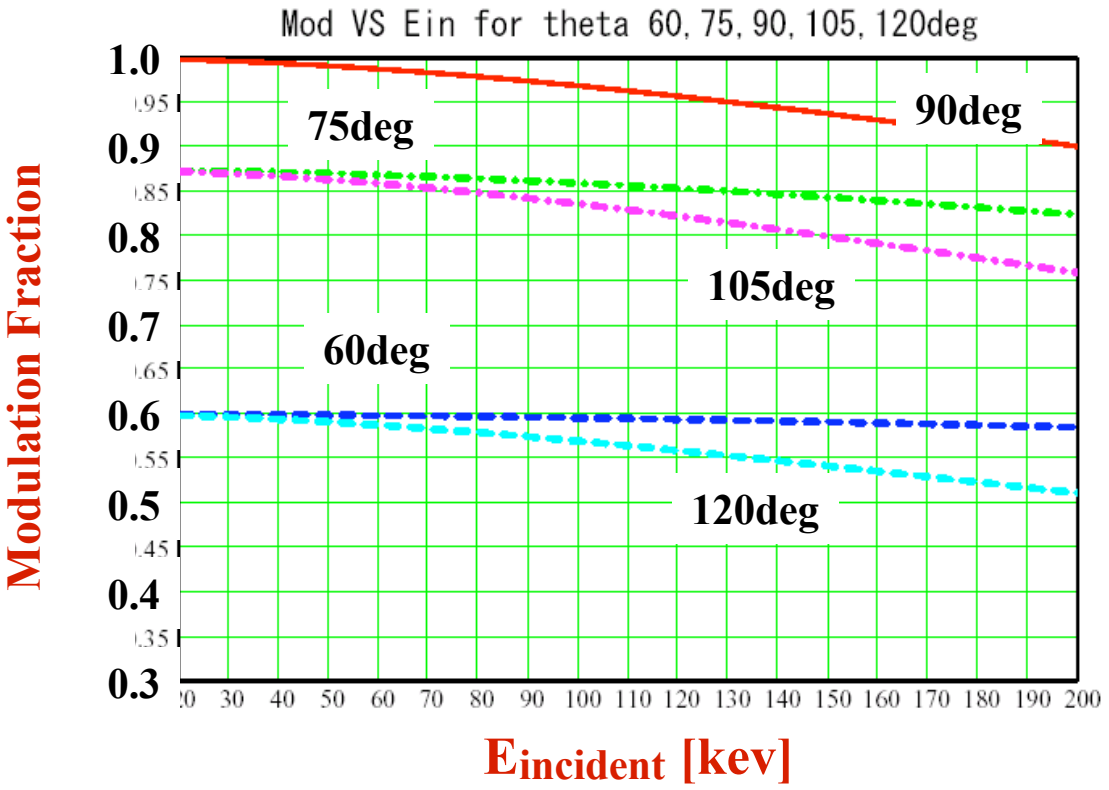


Figure: Modulation factor of Compton scattering vs. the incident energy: scattering angle (theta)=60 deg(blue dash), 75 deg(green dot-dash), 90 deg(red solid), 105 deg(purple dot-dash), 120deg(magenta dash).

Design of PoGO: Basic Strategy

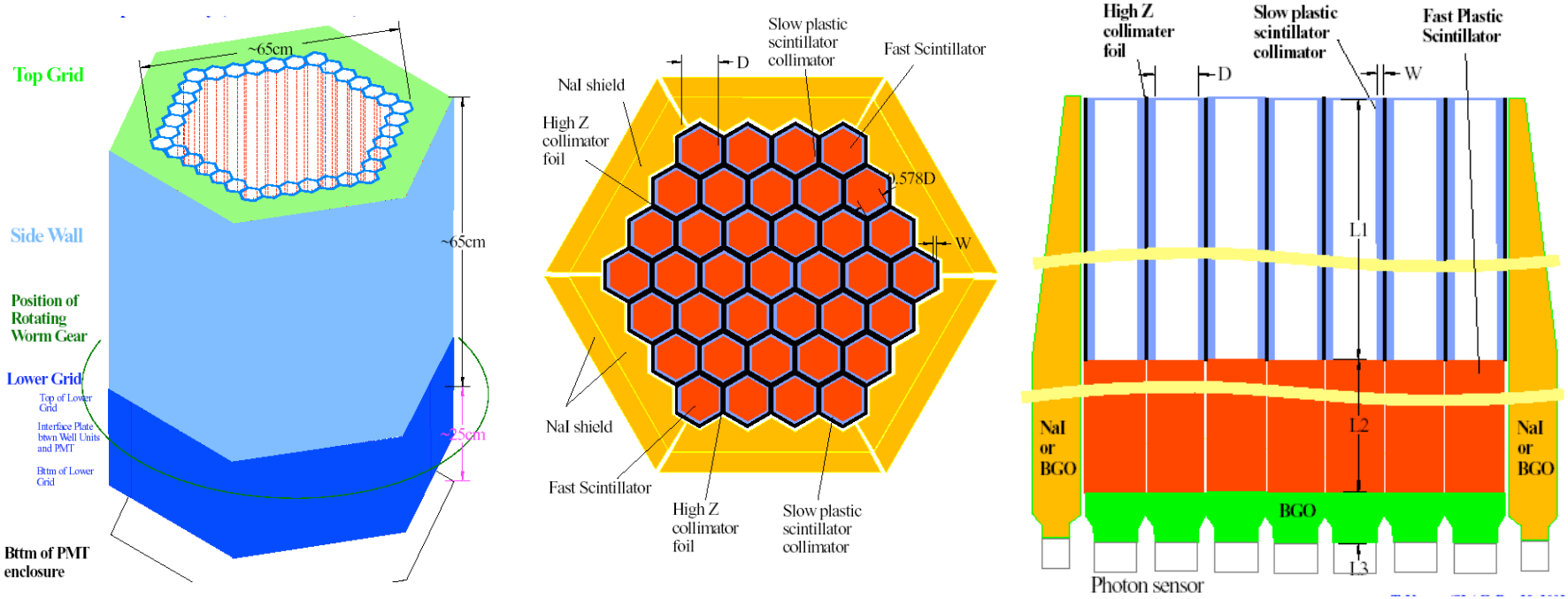
Fig. of merit = Expected modulation factor x Expected S/N

From the pioneering experiment by Weisskopf et al., we learn that the fig. of merit defined above must be >>1 to make a reliable measurement. This implies:

- **Maximize modulation factor**
- **Maximize S/N ratio**
- **Extend energy coverage low (~25keV) within Compton regime**
  (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

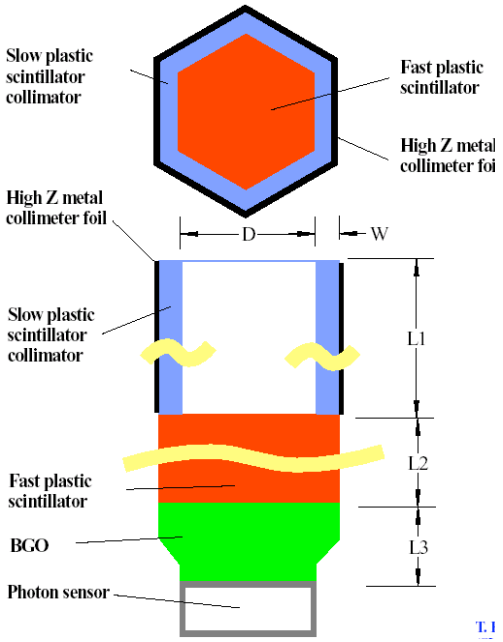


(a) (b) (c)

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.

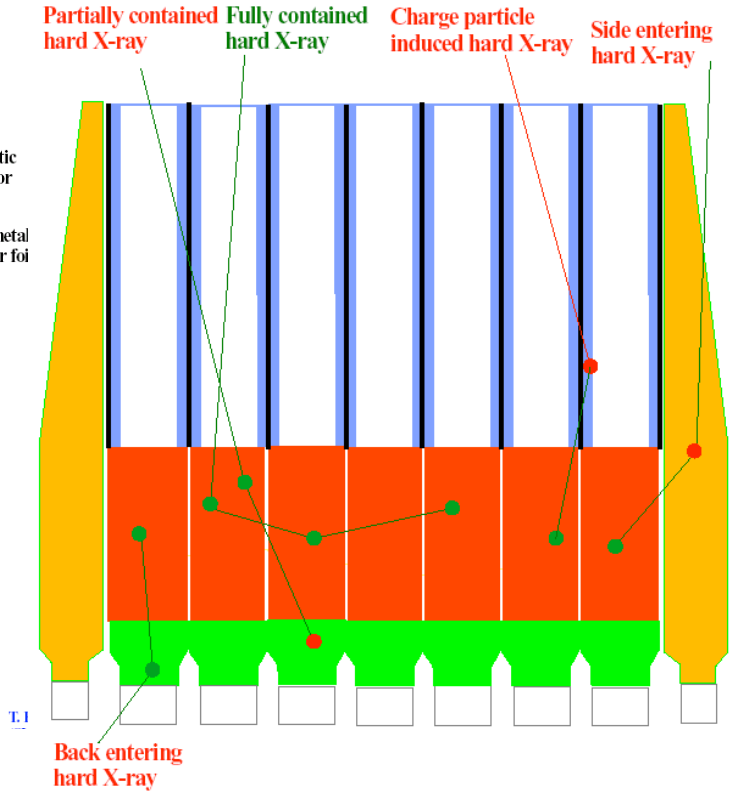
Design of PoGO: Concept #2 - Trigger Strategy

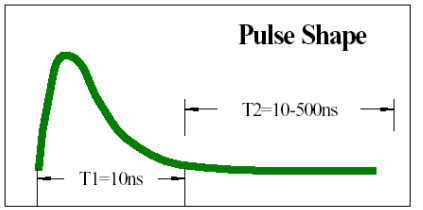
Trigger and Pulse-Shape-Discrimination: L0, L1, L2



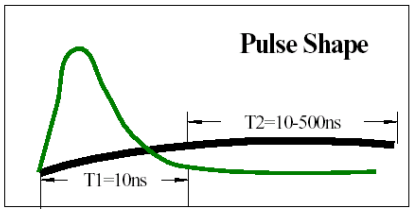
1 inch PMT

Unit





Fast Scintillator Only



Slow Scintillator and BGO

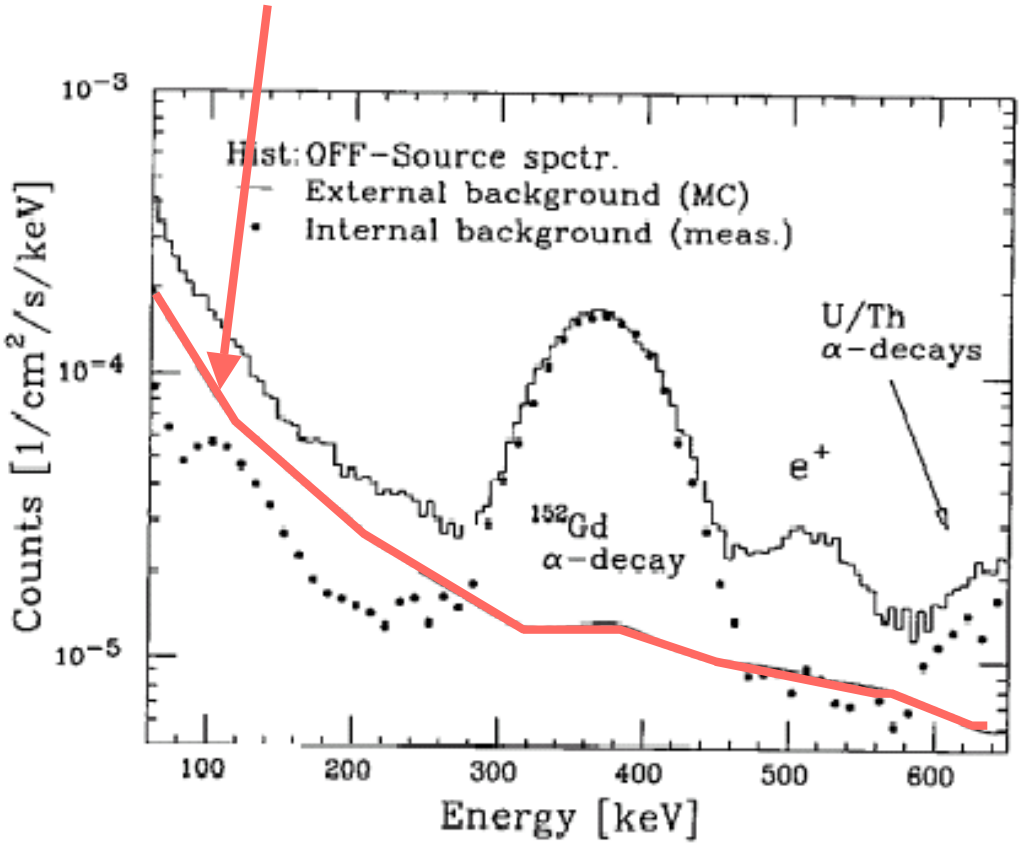
Design of PoGO: Heritage from Welcome-1 and Astro-E HXD

Lowest background achieved in the hard X-ray band

Spectrum observed with Welcome-1 in the background field: FOV=14x14 deg

A series of balloon experiments in Brazil

- **Upper limit to Co57 from SN1997A**
- **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**

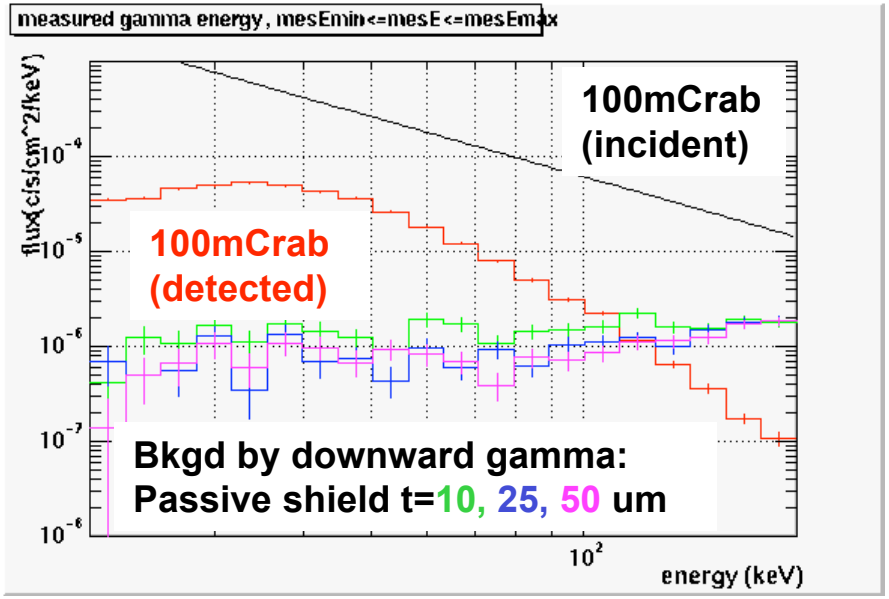


Design of PoGO: Expected Background

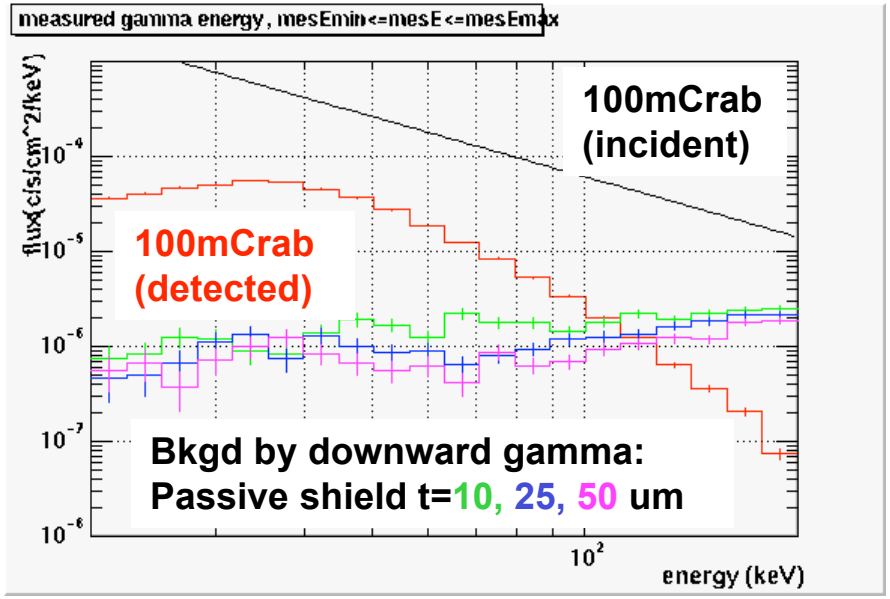
Background is expected to be much lower than Welcome-1 because:
1) FOV = 5/200; 2) Radioactivity is not an issue with plastic scintillator_

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

- **Measure 6-10% pol of 100mCrab sources in one 6hr balloon experiment**
- **Reduction of background to ~10mCrab level**

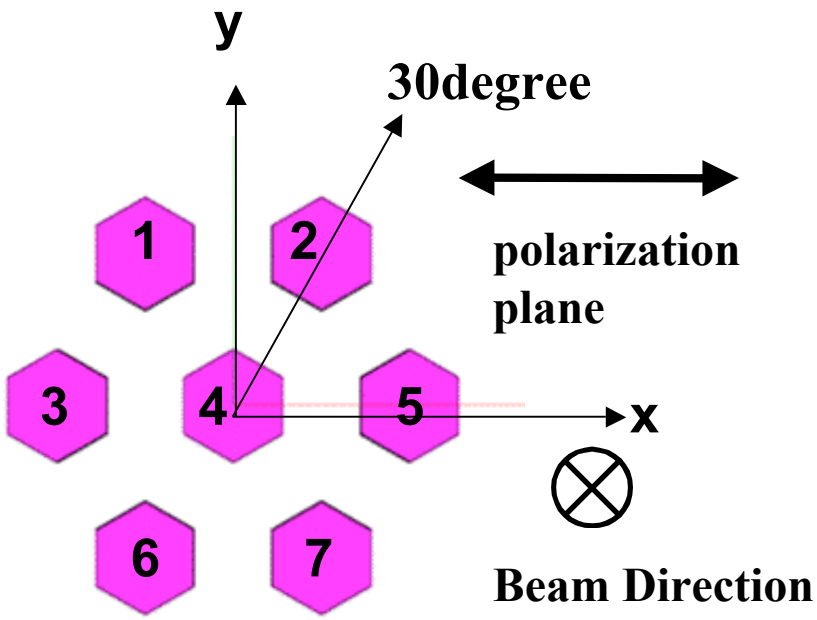
	Design-397	Design-217
Energy band	25-200keV	25-200keV
Geometric area	1709cm**2	934cm**2
Eff. area for pol meas. (for 40-50keV)	460cm**2	230cm**2
Instr. background (for 40-50keV)	~10mCrab	~10mCrab
Mod. factor for 100% pol. 100mCrab	25.1%	24.3%
Sensitivity to pol. for 100mCrab (1sigma)	2.0%	3.0%

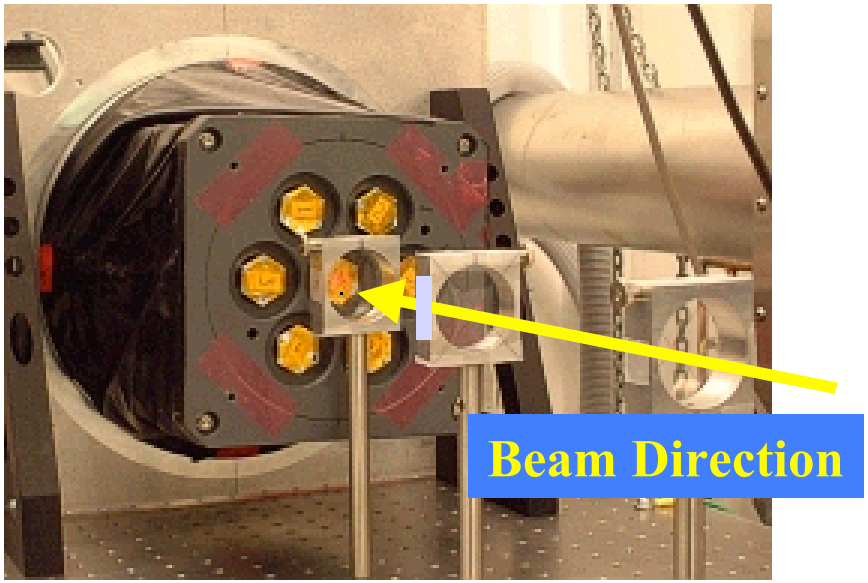
Beam Test Results: Prototype at Advanced Photon Source (Argonne Natn'l Lab.)

See the poster by T.Mizuno et al (PoGO) for further details

- 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



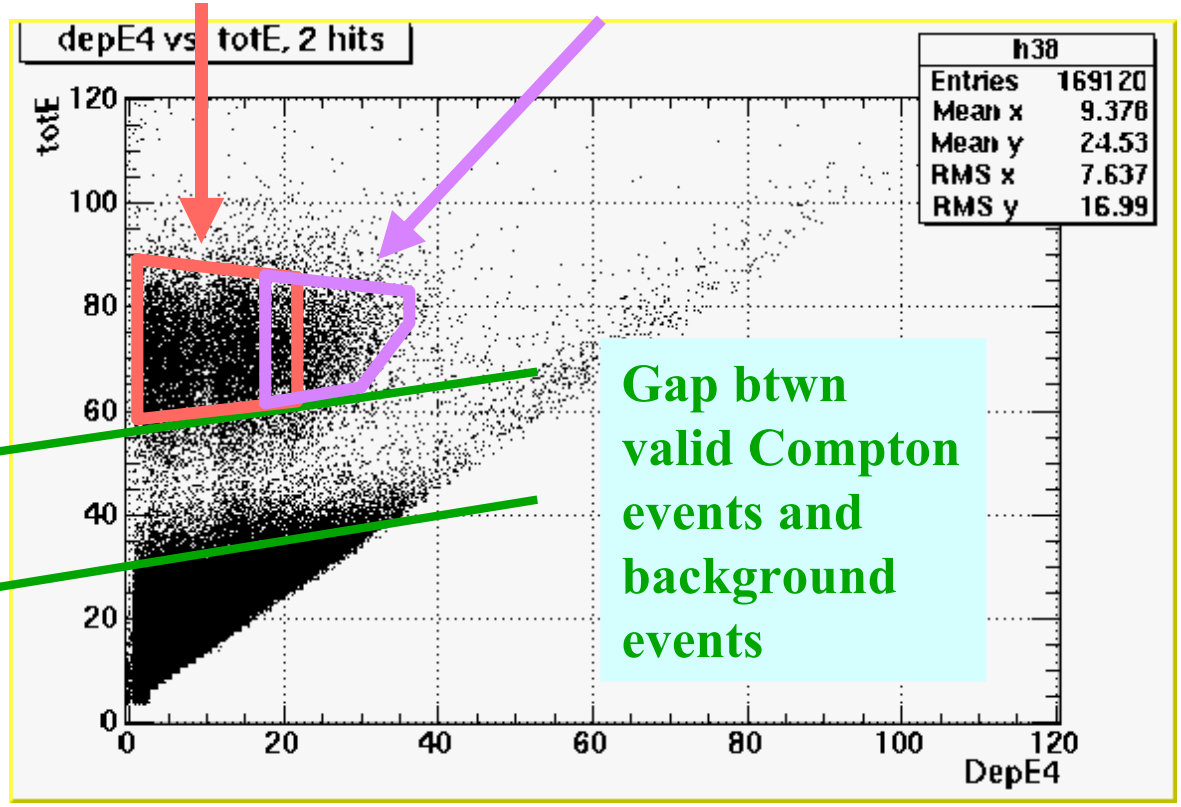


Beam Test Results: Coincidence Trigger

Consistent with single Compton scatt. in #4

Likely to have scattered more than once in #4

73.2keV



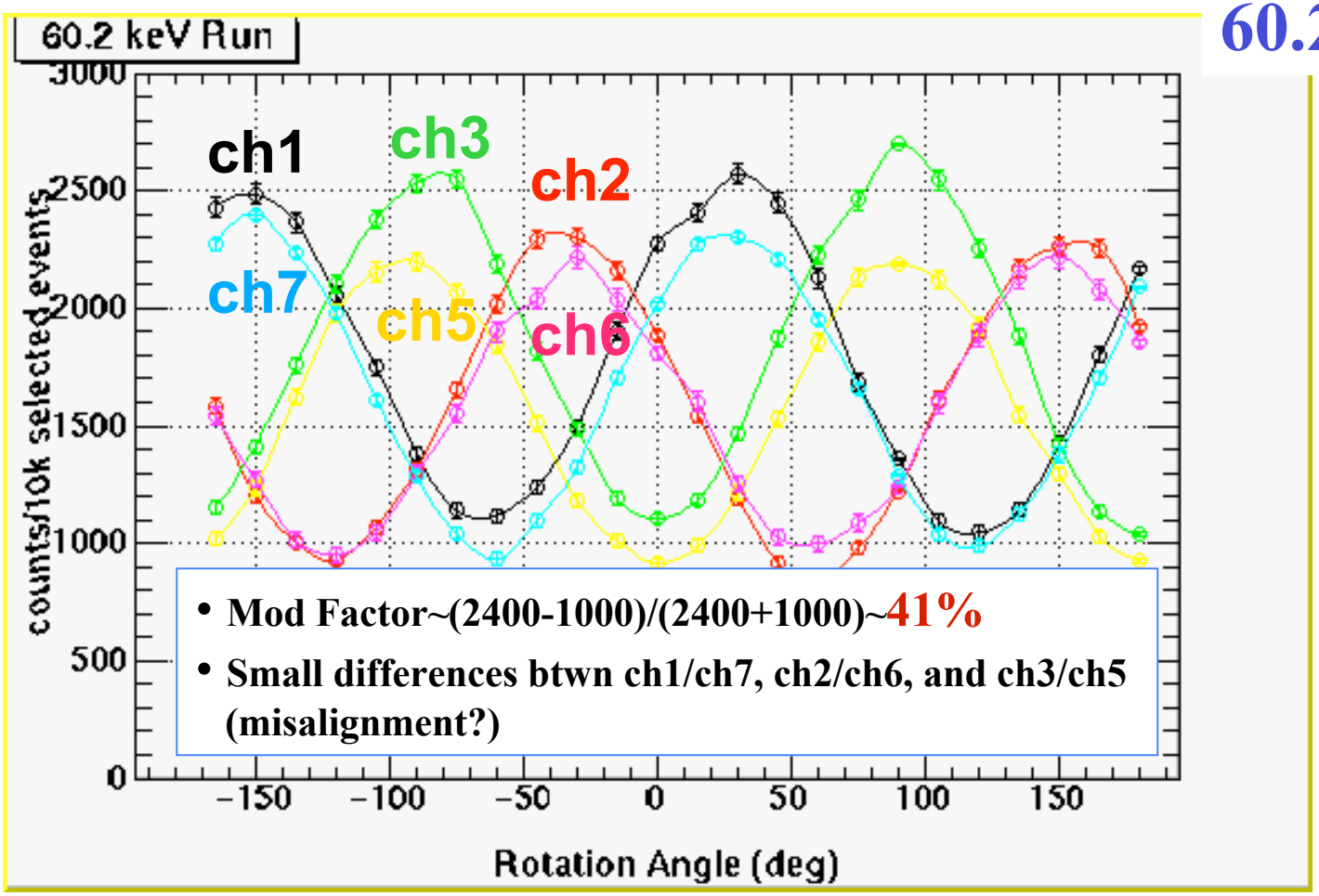
Sum of the 2 ADC readings

ADC reading of Unit#4

Beam Test Results: Modulation Factor for 60.2keV

Coincidence efficiency varied for 6 peripheral units probably due to misalignment.

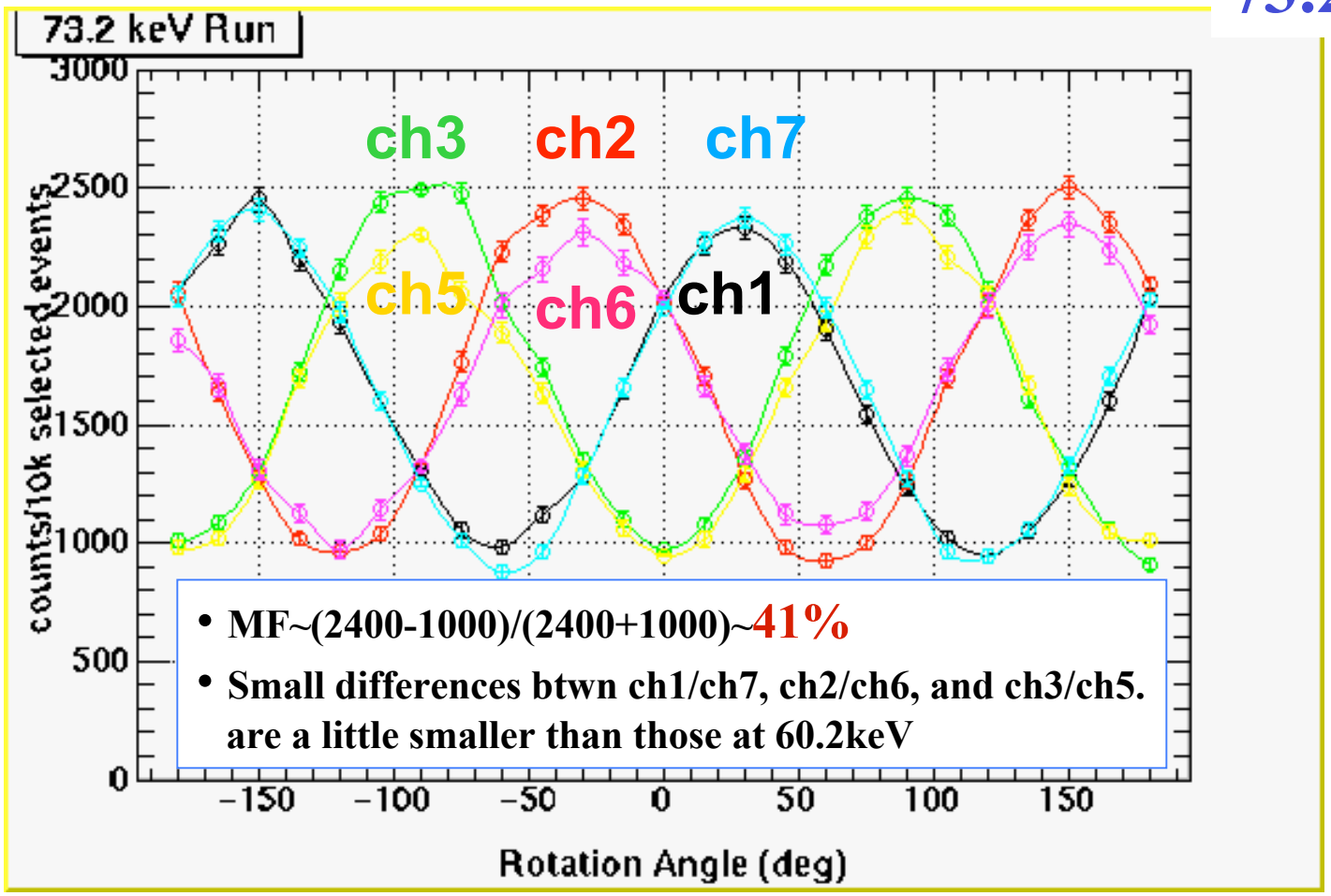
60.2keV



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

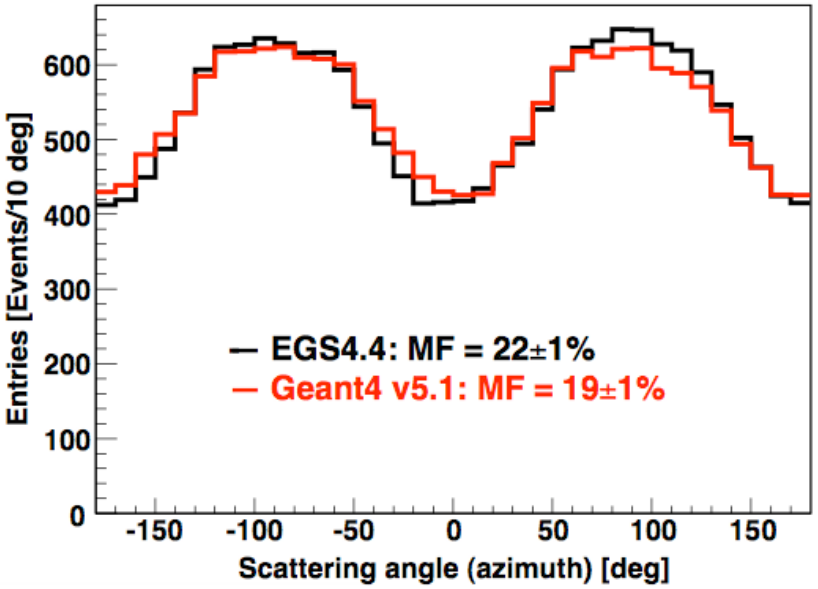


EGS4 vs G4: Consistent to ~3% after PoGO-Fix to G4

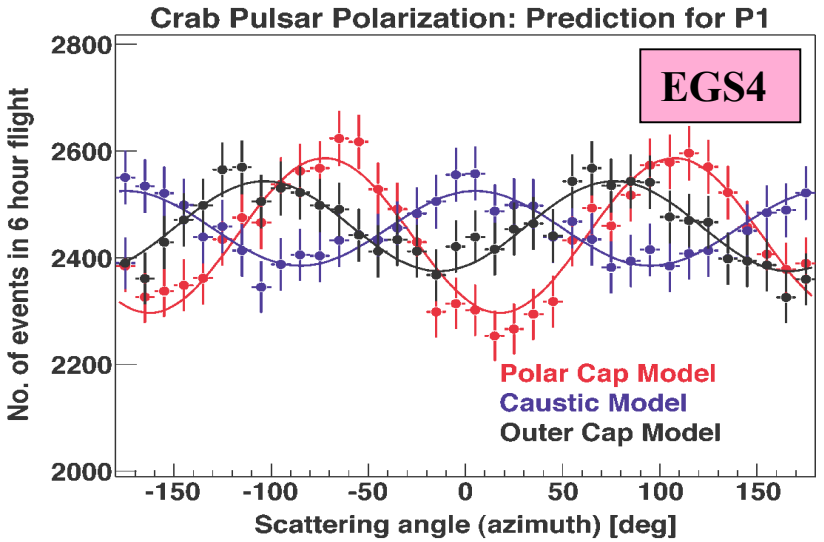
Credit: Y. Fukazawa,
Tsunefumi Mizuno,
Hiroyasu Tajima
Will be reported to G4 Team

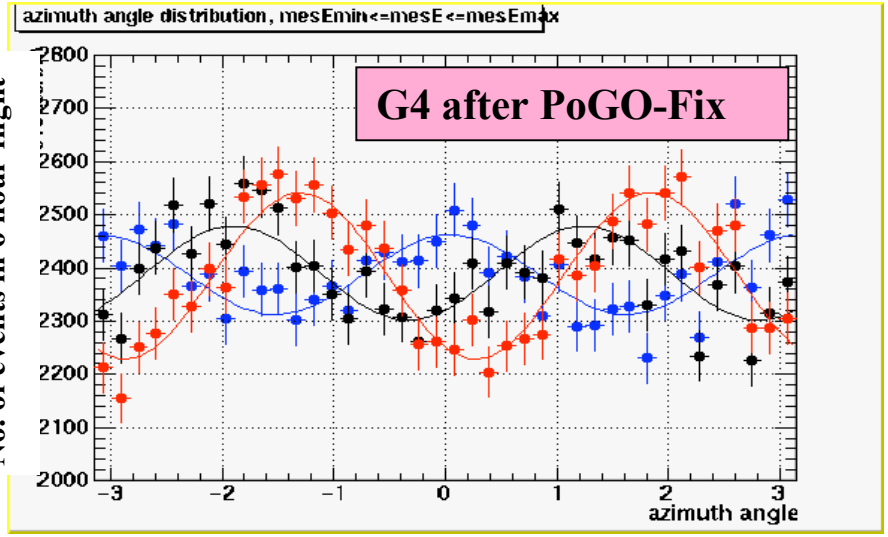
See the poster by Mizuno et al. for comparison with the beam test results.

Comparison for a test setup



Crab Pulsar Polarization:P1





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)

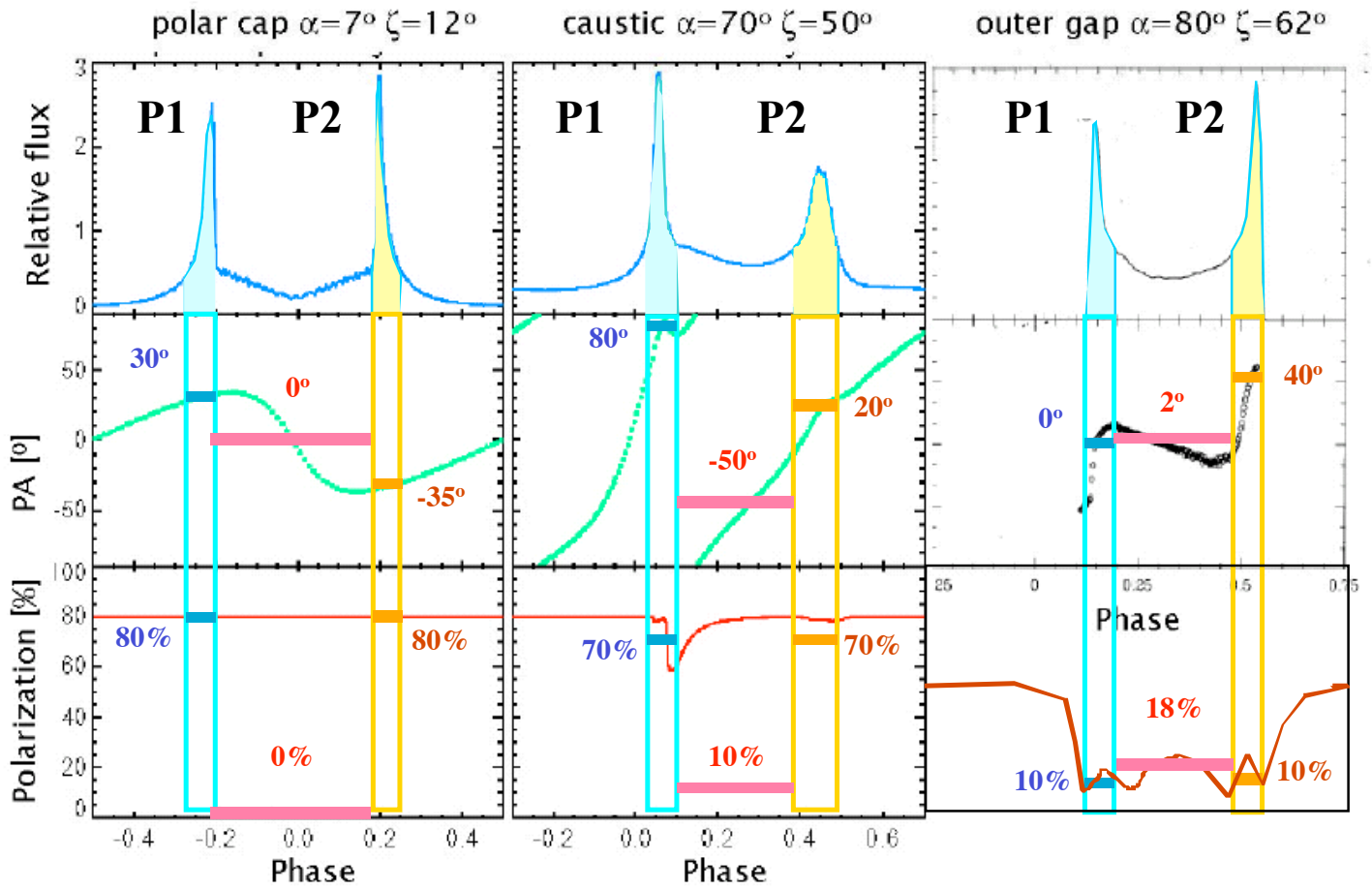
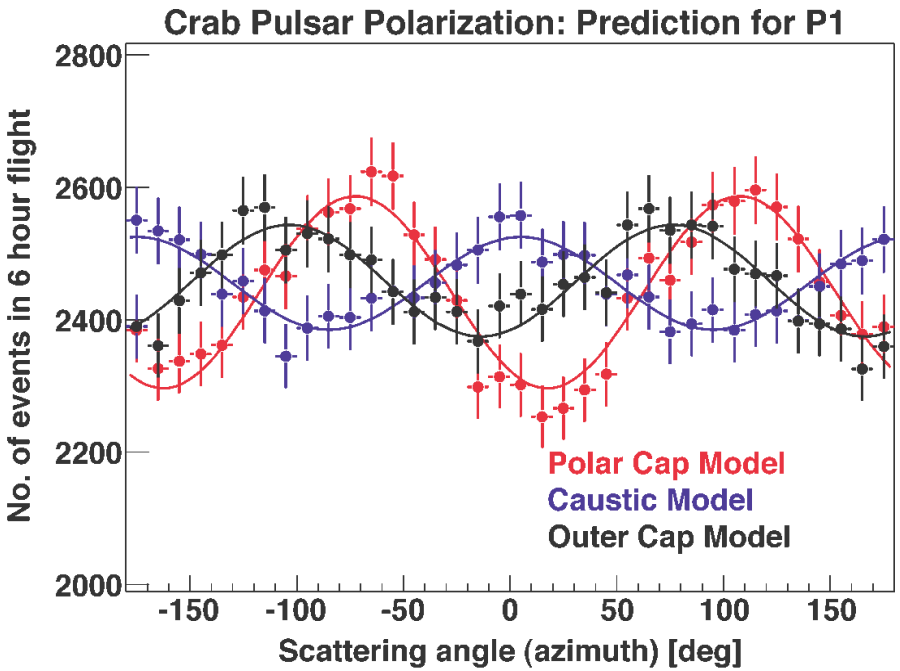


Figure: Simulations of pulse profile, polarization angle and percent polarization for Crab Pulsar. Polar cap and caustic models simulations assume constant emission along field lines [Dyks and Rudak03]. The outer gap model results are from [Romani and Yadigaroglu95]. The percent polarization from the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

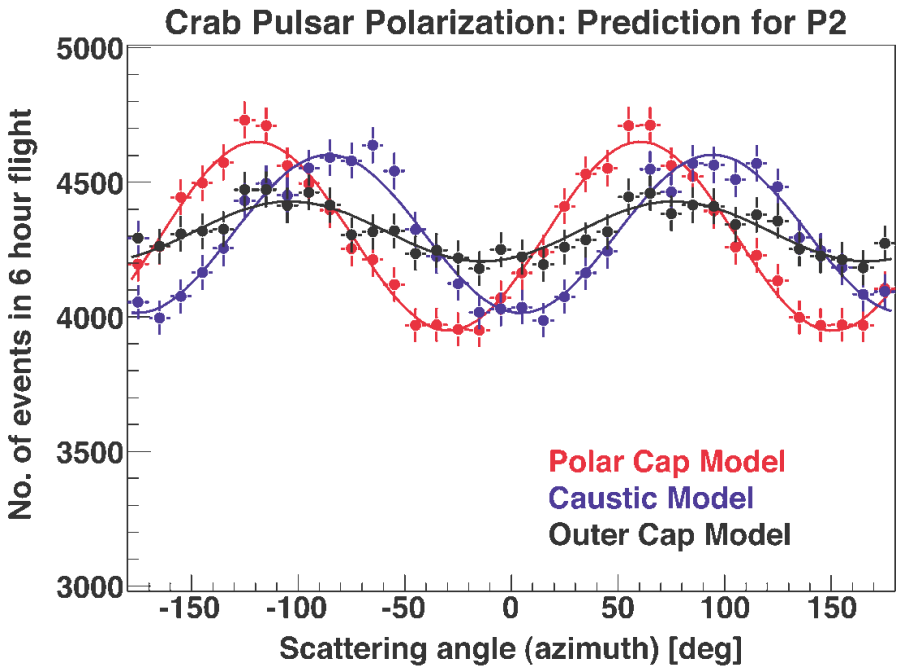
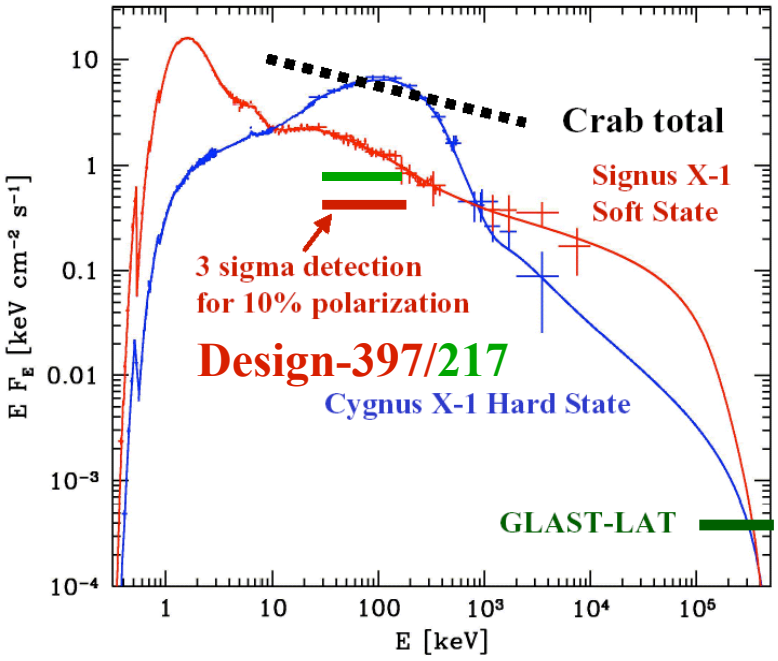


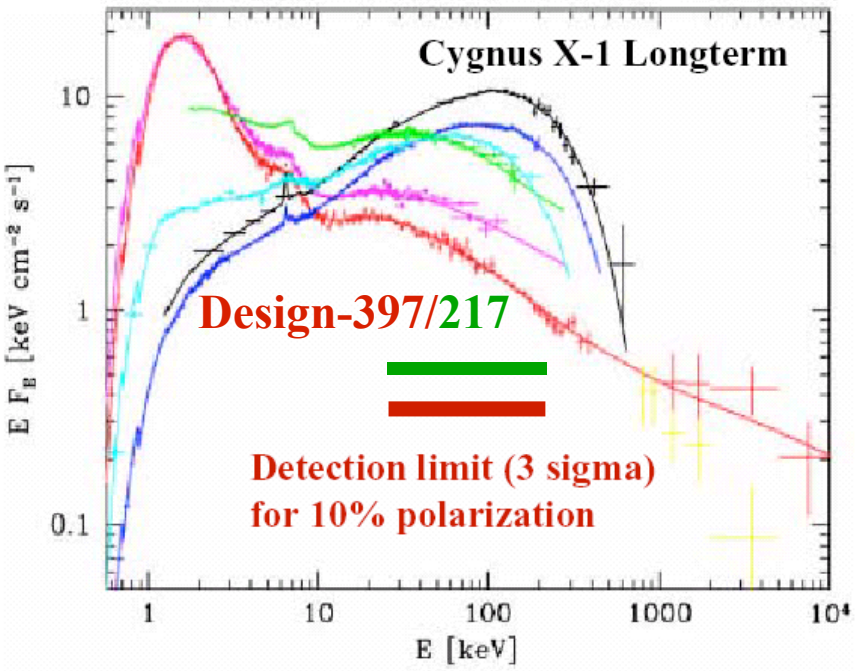
Figure: Simulated data that typifies the statistical accuracy expected from a 6-hour observation by PoGO.

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





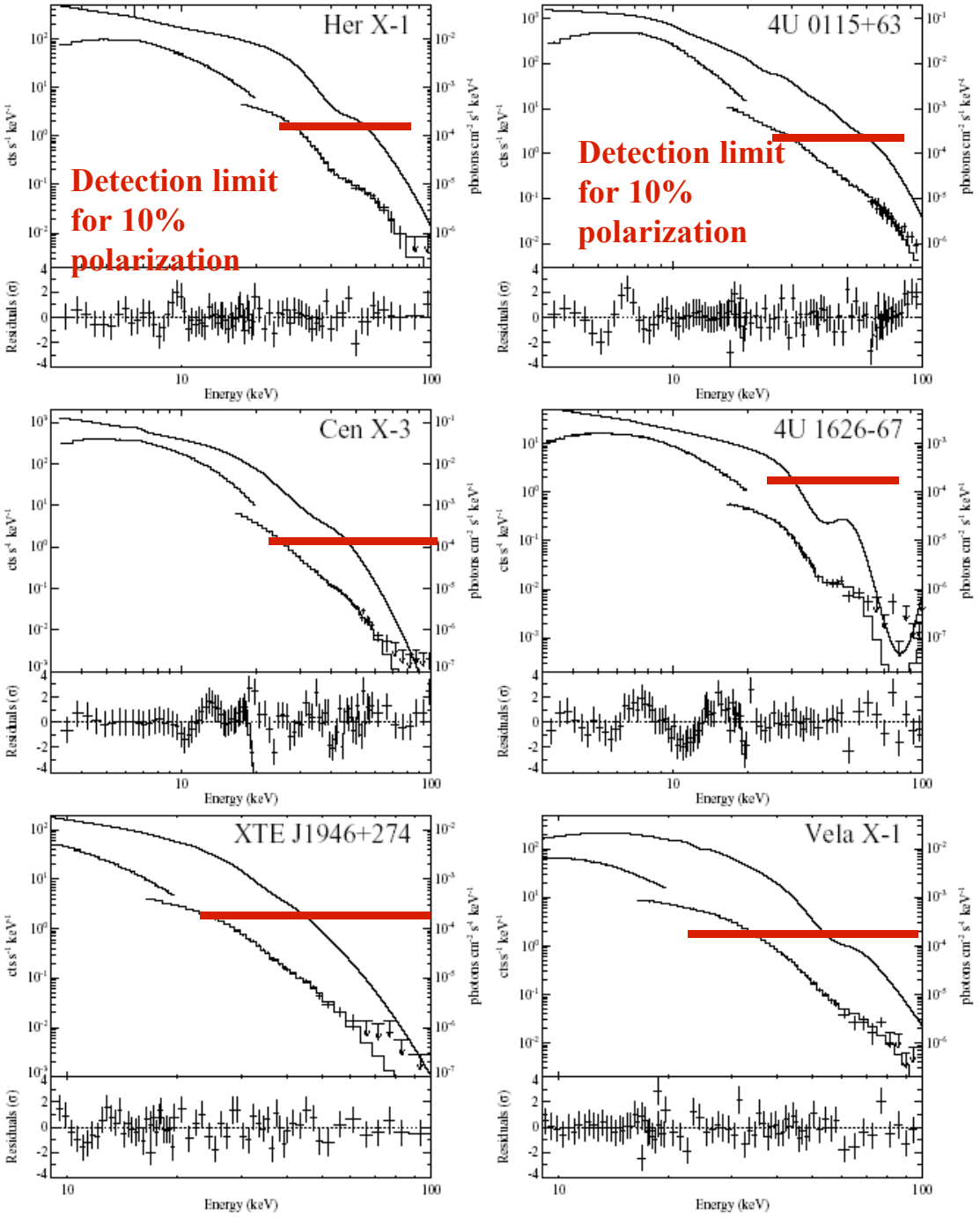
Possible Targets for PoGO:

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 plastic scintillators, BGO, and PMTs:**
  Can record Compton scattering down to ~25keV.

- **PoGO is based on the well-type phoswich technology:**
  Can reduce non-FOV background to ~10mCrab level.

- **PoGO is made of scalable units:**
  Can detect 10% polarization in 100mCrab sources (217 units) or
  6% polarization in 100mCrab sources (397 units)
  in a 6hr balloon flight.

- **PoGO requires minimum maintenance:**
  Can fly within a week of onsets of flares and high states.

- **PoGO can be upgrade with APD arrays:**
  Can improve sensitivity near 20-30keV by a factor of 2-3.

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