

Effects of Neutrons on HXD-PIN Background onboard *Suzaku*

Takao Kitaguchi¹,

Kazuhiro Nakazawa¹, Kazuo Makishima^{1,2}, Shin Watanabe³,
Motohide Kokubun³, Yukikatsu Terada⁴, Harufumi Tuchiya²,
and the HXD team

1. Univ. of Tokyo, 2. RIKEN, 3. ISAS/JAXA, 4. Saitama Univ.

~ Contents ~

1. *Suzaku*/HXD introduction
2. HXD photon response construction
3. HXD-PIN background estimation

1.1 *Suzaku* Satellite

- Japanese 5th cosmic X-ray observatory
- Launch on 10/07/2005 in Japan
- Altitude: 580 km, Inclination: 34 deg
- Active mission

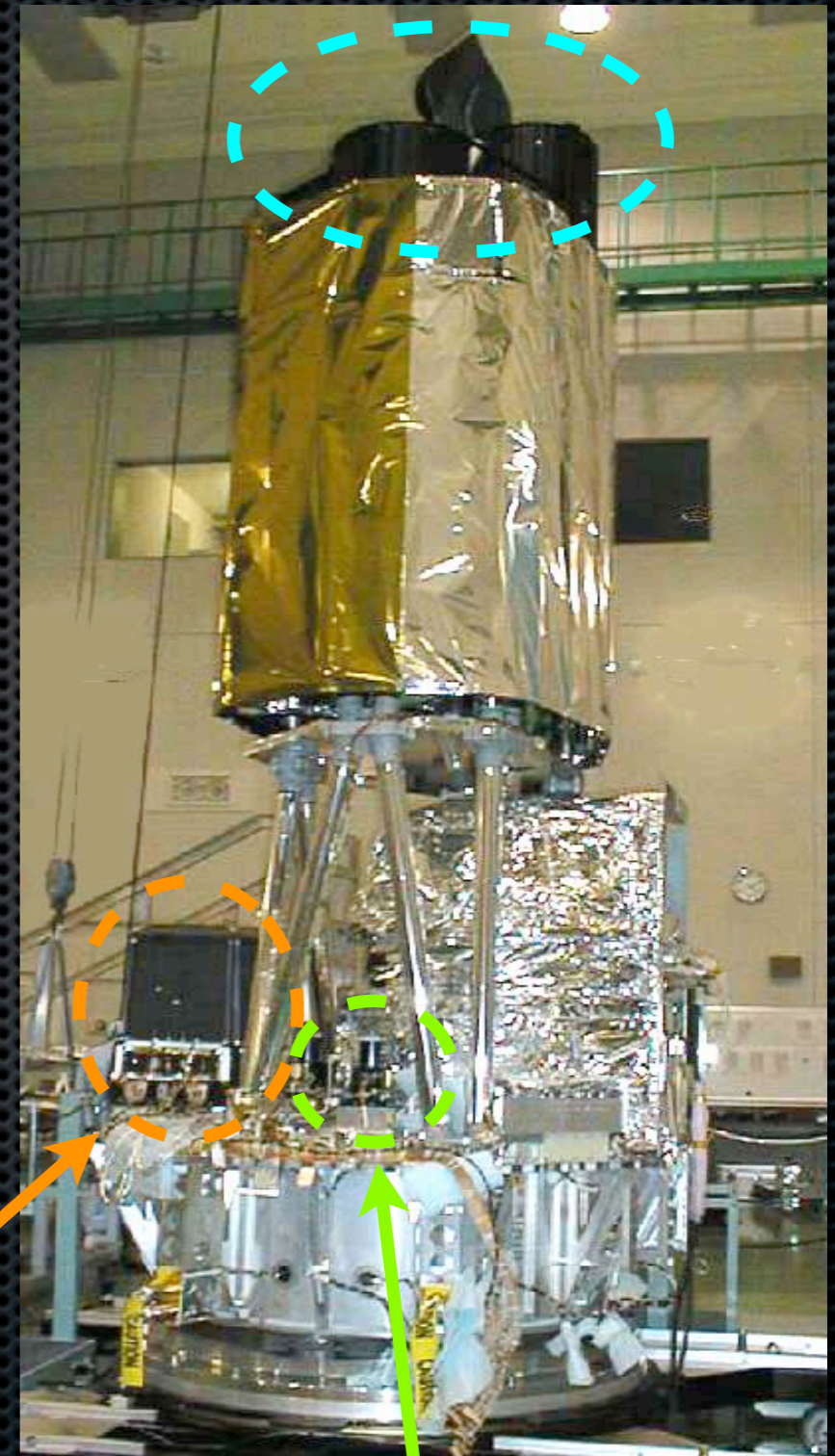


Hard X-ray Detector (HXD)
non-imaging spectrometer
(10 - 600 keV)

Suzaku characteristics

- Wide energy range of 0.2-600 keV
- Low and stable background
→ Suitable for detecting low-flux objects

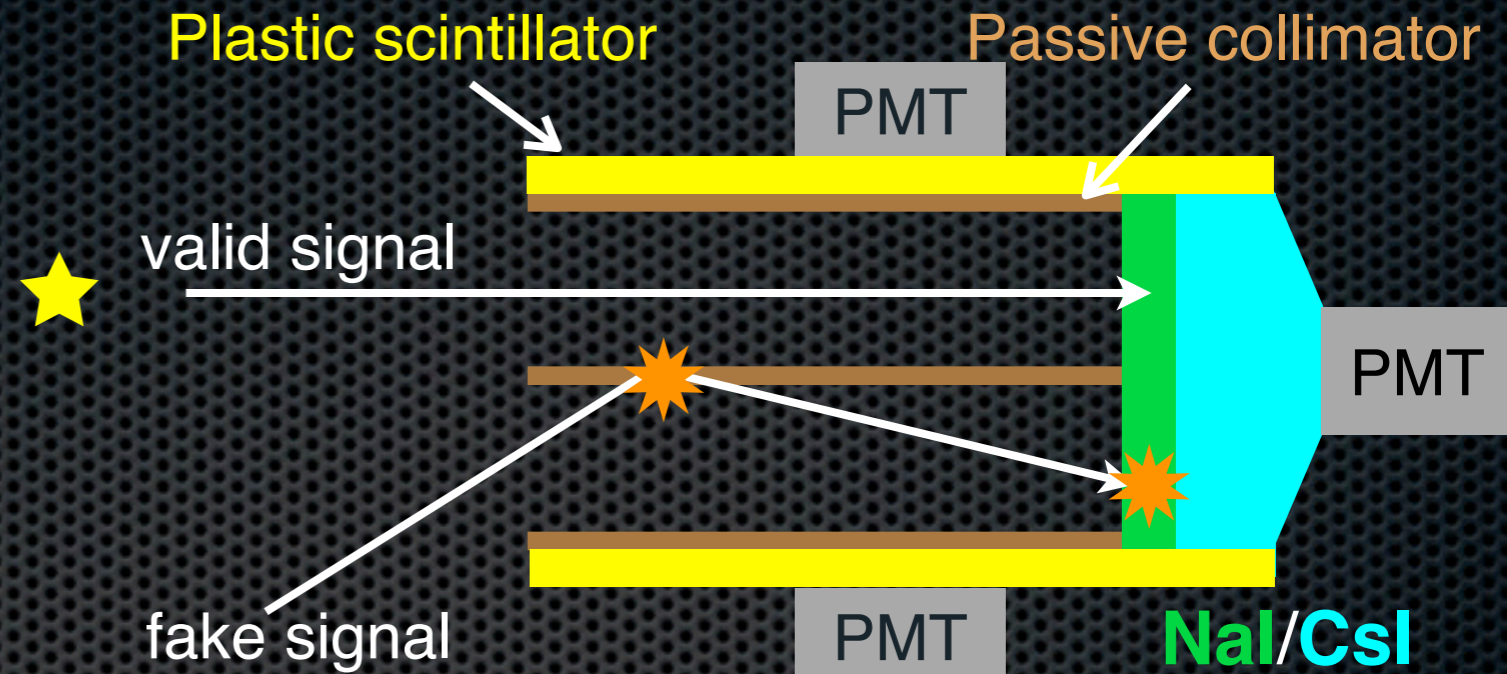
X-ray Telescope x 4



1.2 Hard X-ray Detector onboard *Suzaku*

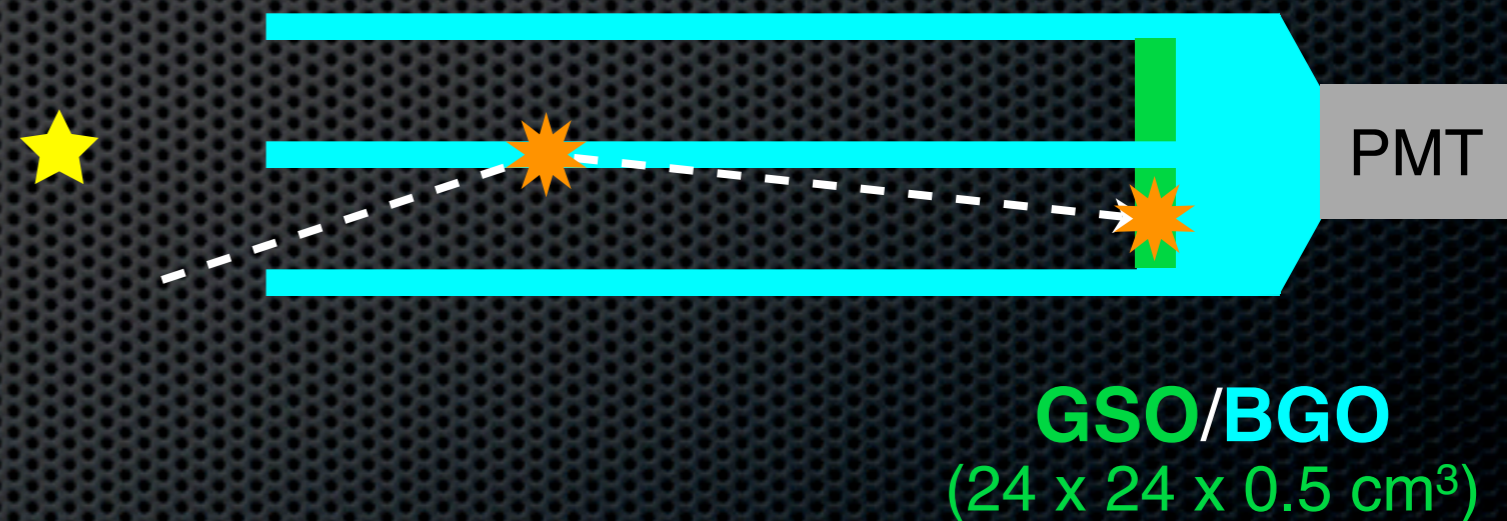
Conventional hard X-ray sensor

- **NaI/CsI** phoswich
- Plastic active shield
- Passive collimator



Suzaku HXD

- **GSO/BGO** phoswich
- High detection efficiency
- Low activation
- Narrow-collimated active shield
can suppress signals due to Compton-scattering and activation

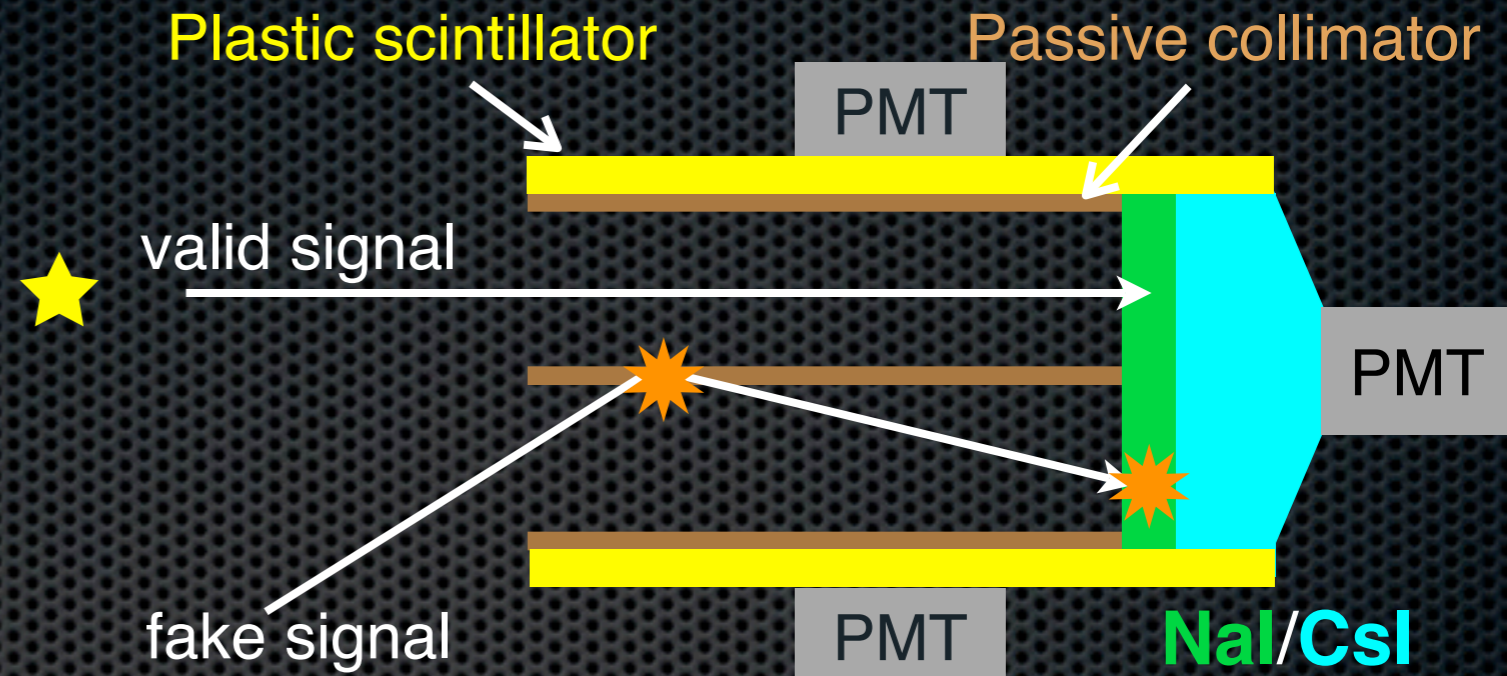


GSO/BGO
(24 x 24 x 0.5 cm³)

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Suzaku HXD

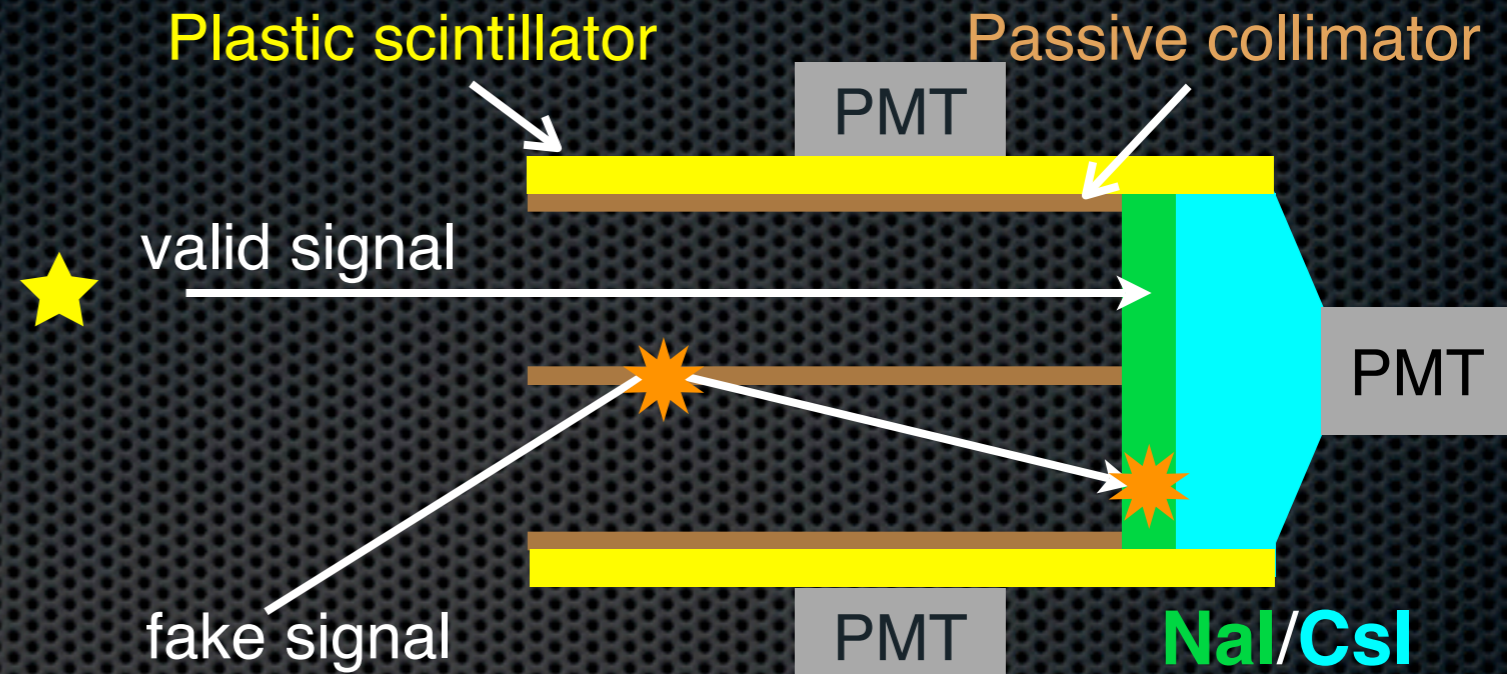
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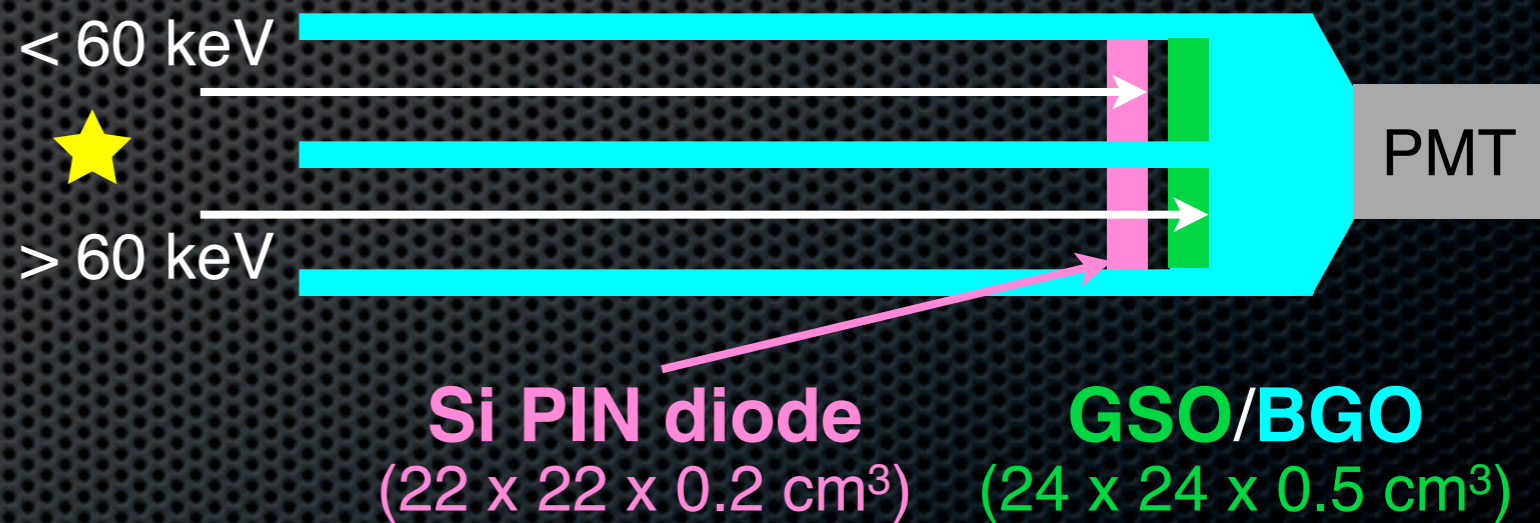
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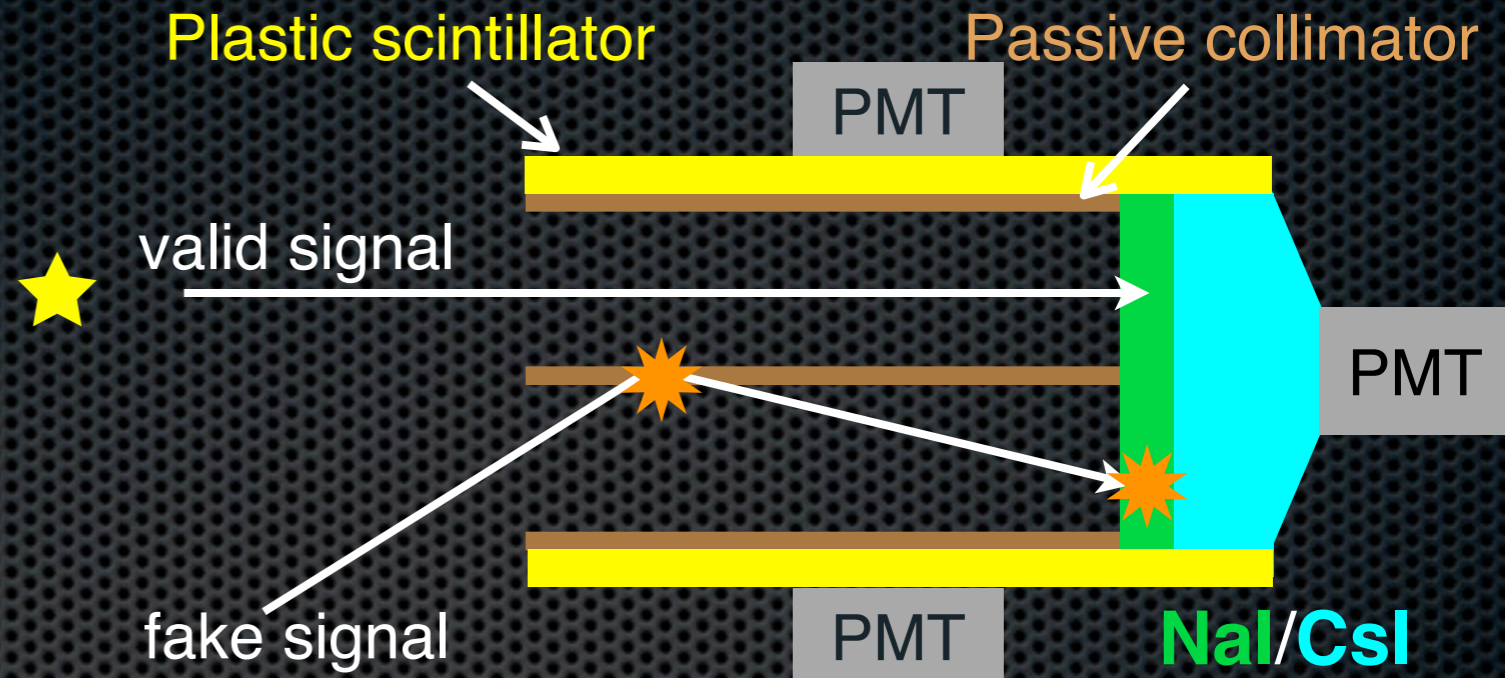
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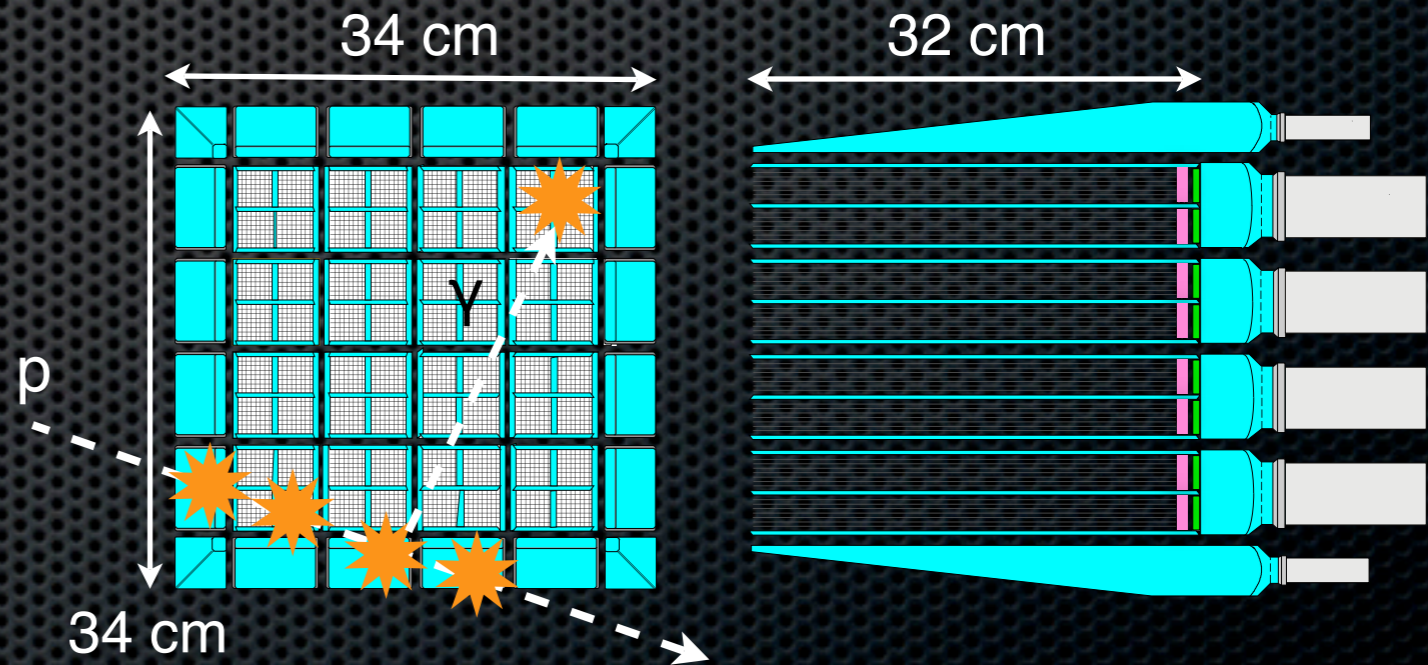
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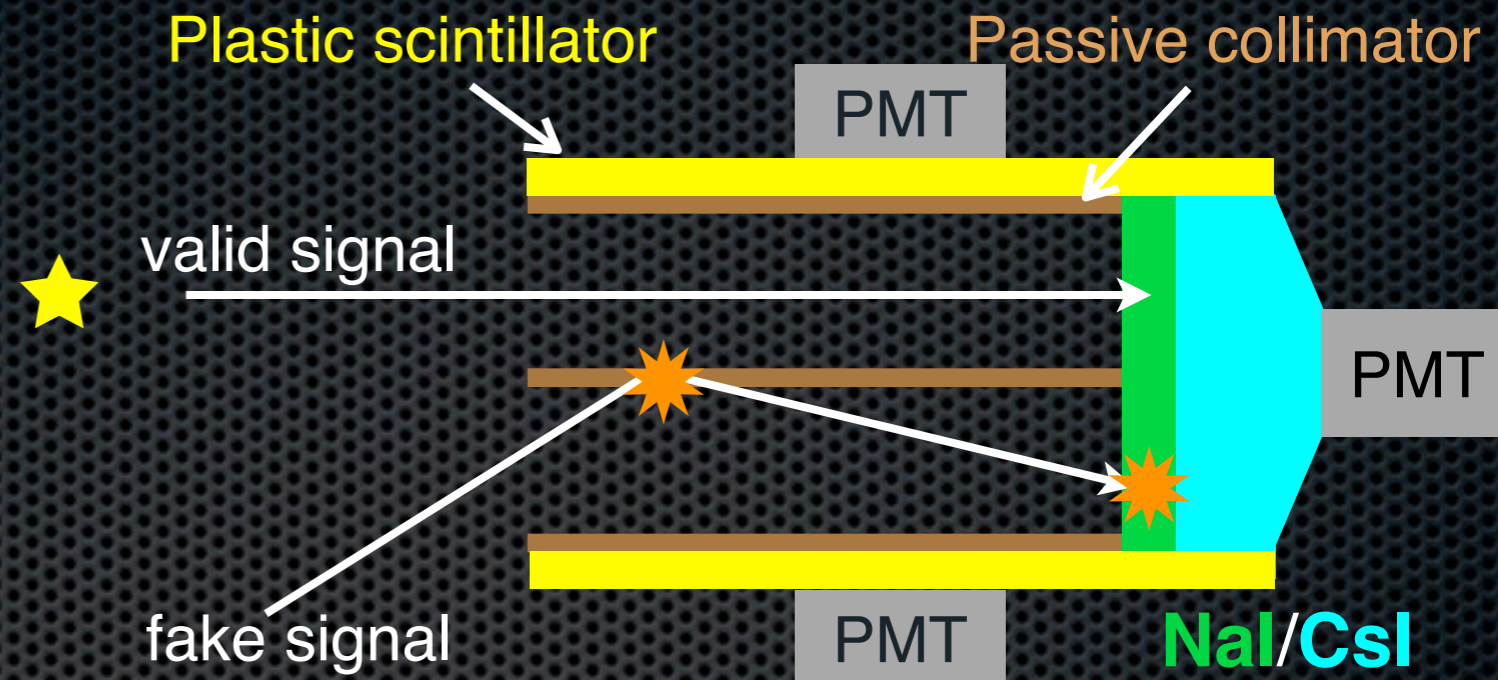
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- Compound-eye configuration
 - Anti-coincidence
 - Large effective area with low dead time



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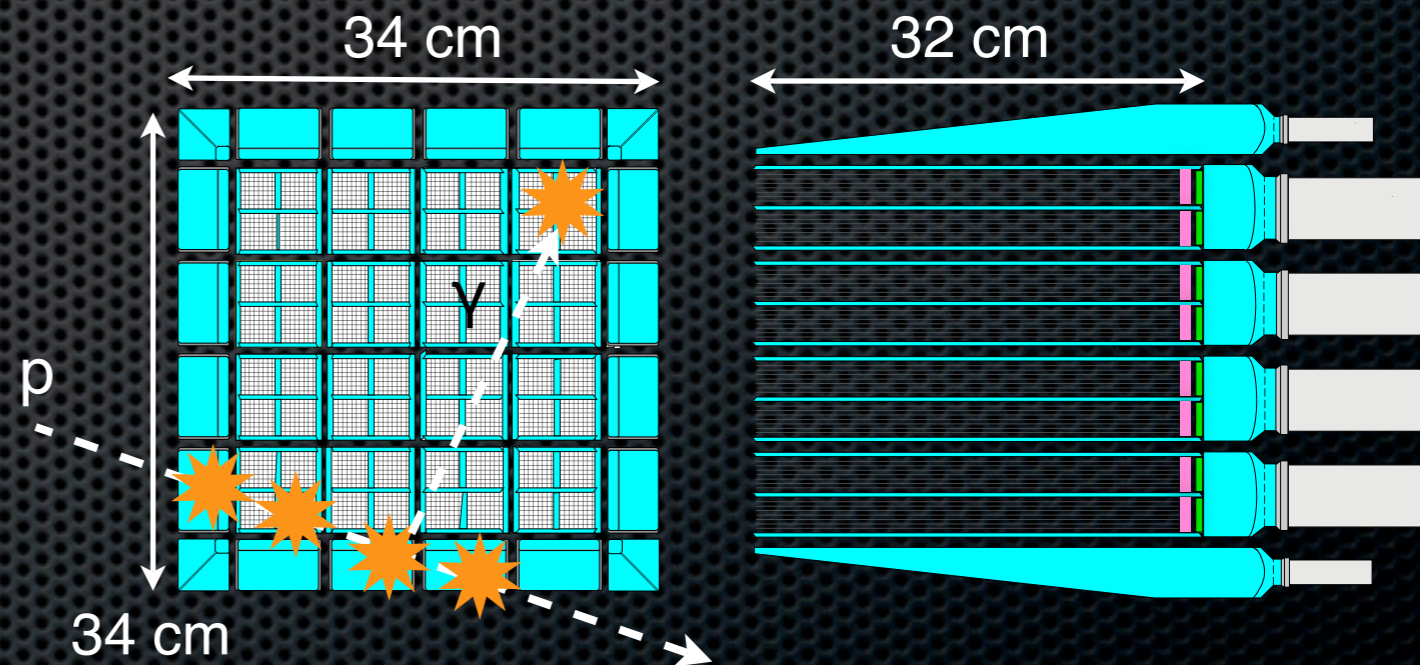
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Need to understand HXD's responses to cosmic X-ray signals and radiation background

1.3 *simHXD* (Monte Carlo Simulator for HXD)

Geant4

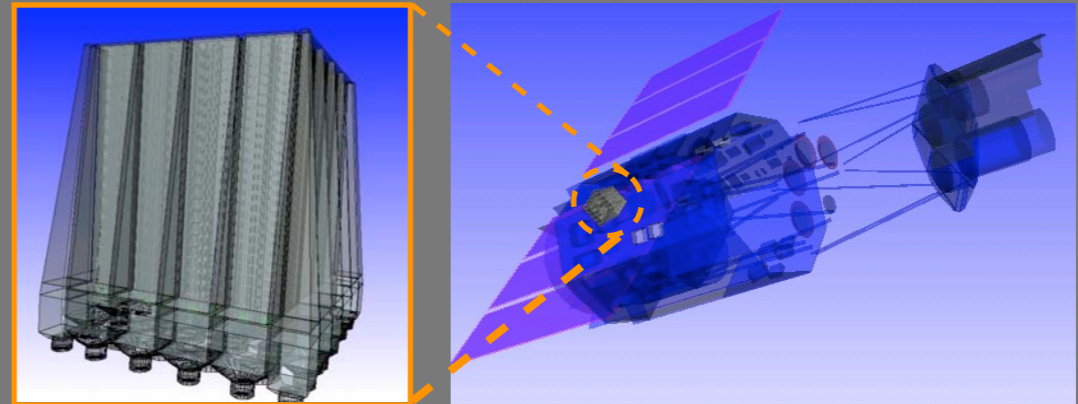
Primary particle generation



Monte Carlo Simulation



HXD and *Suzaku* mass model (Terada+ 2004)



Simulated onboard hardware

- Energy to ADC channel
- Trigger generation



Simulated event list



Same analysis as actual data

- Fine event selection
- Histogram extraction



Database

Hardware calibration

- Sensor characteristics
- Electronics response

Hardware settings

- Trigger level
- Anti-coincidence level

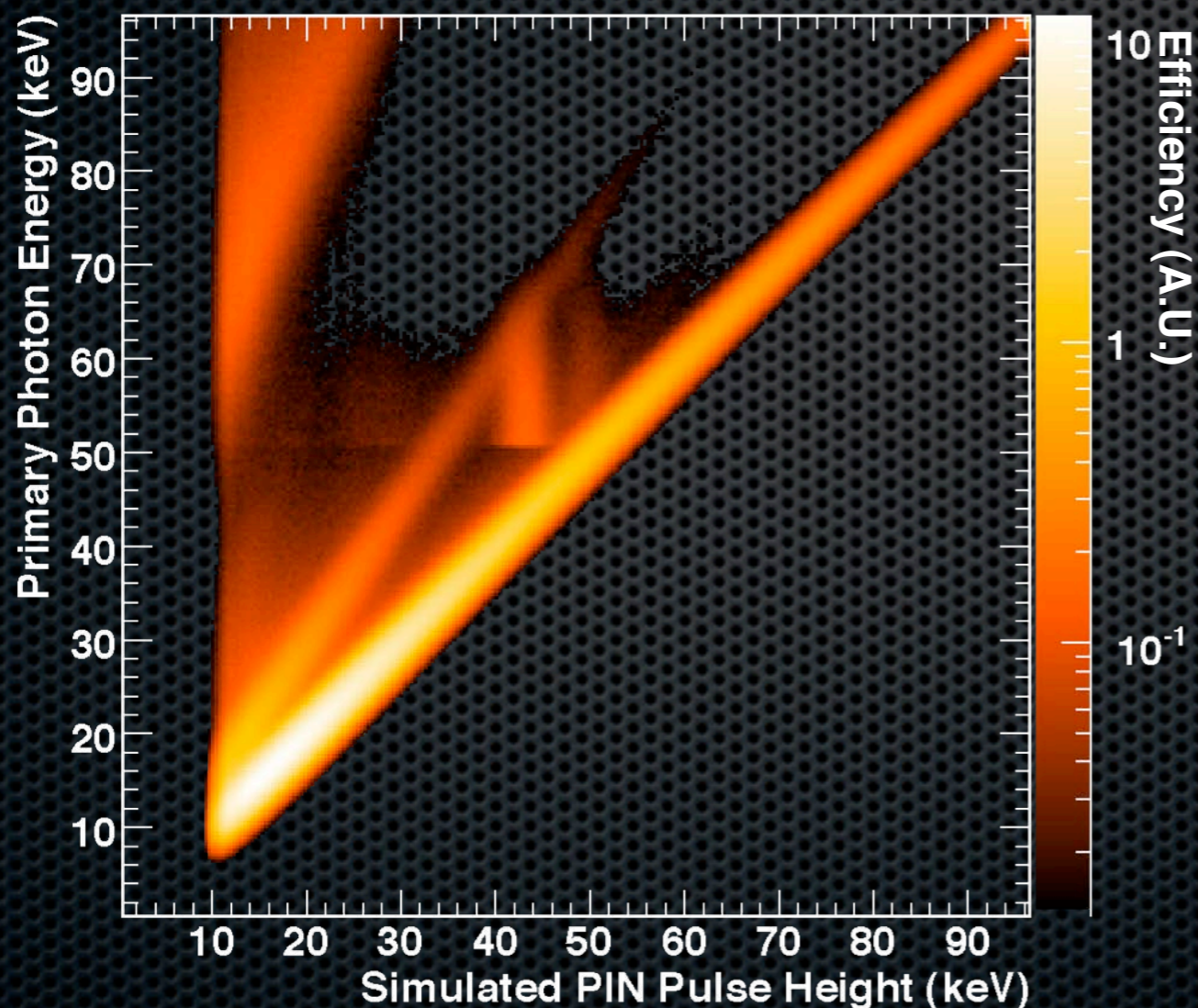
Products

- Detector response
- Simulated energy spectrum

2.1 Detail of PIN Response to Hard X-ray Signals

- Primary particle: 5×10^9 photons (< 1 MeV)
- Physics process: low energy electromagnetic physics package in Geant4
- Pulse height: poor charge collection near guard-ring electrode
→ sub peak

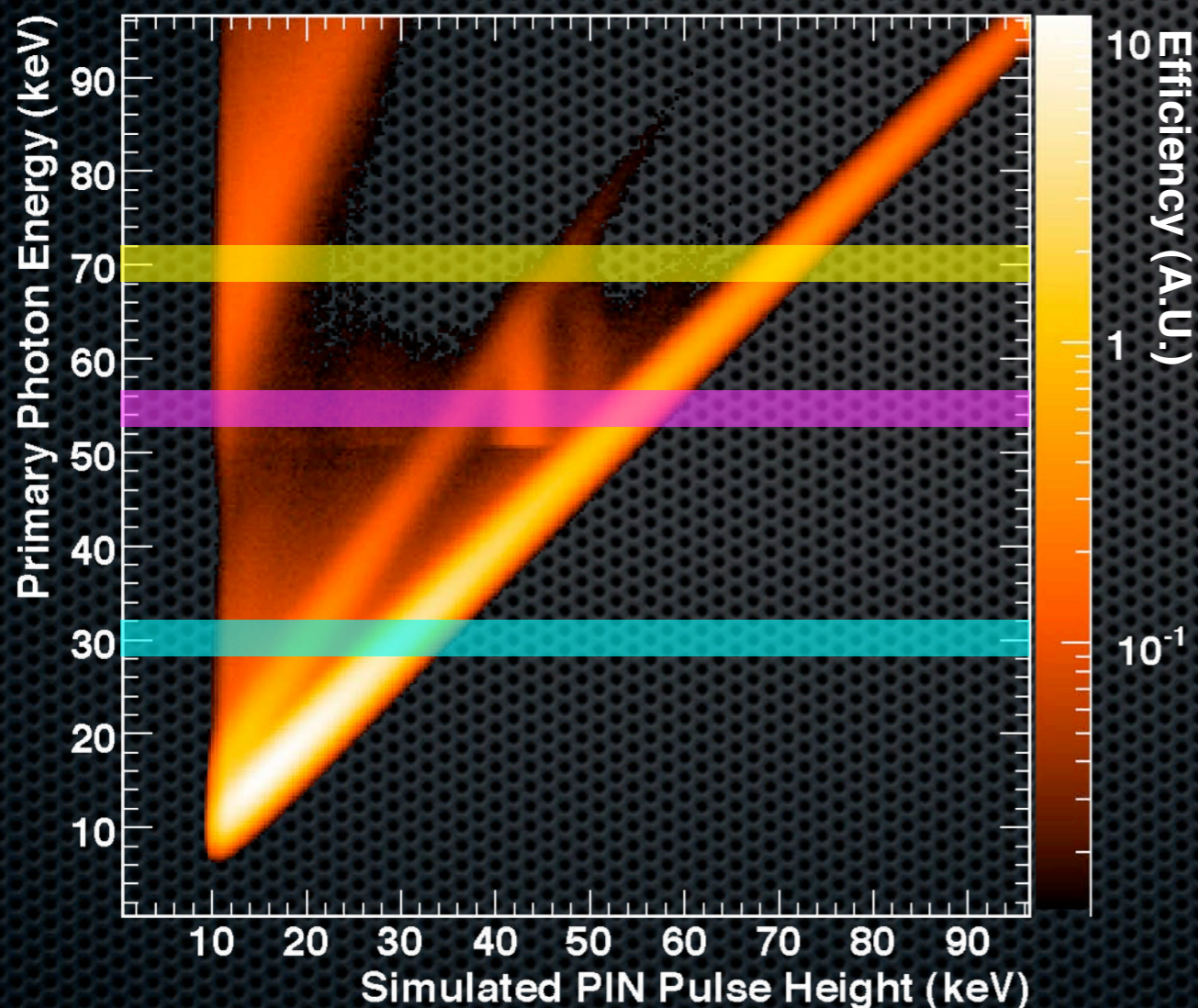
PIN response matrix



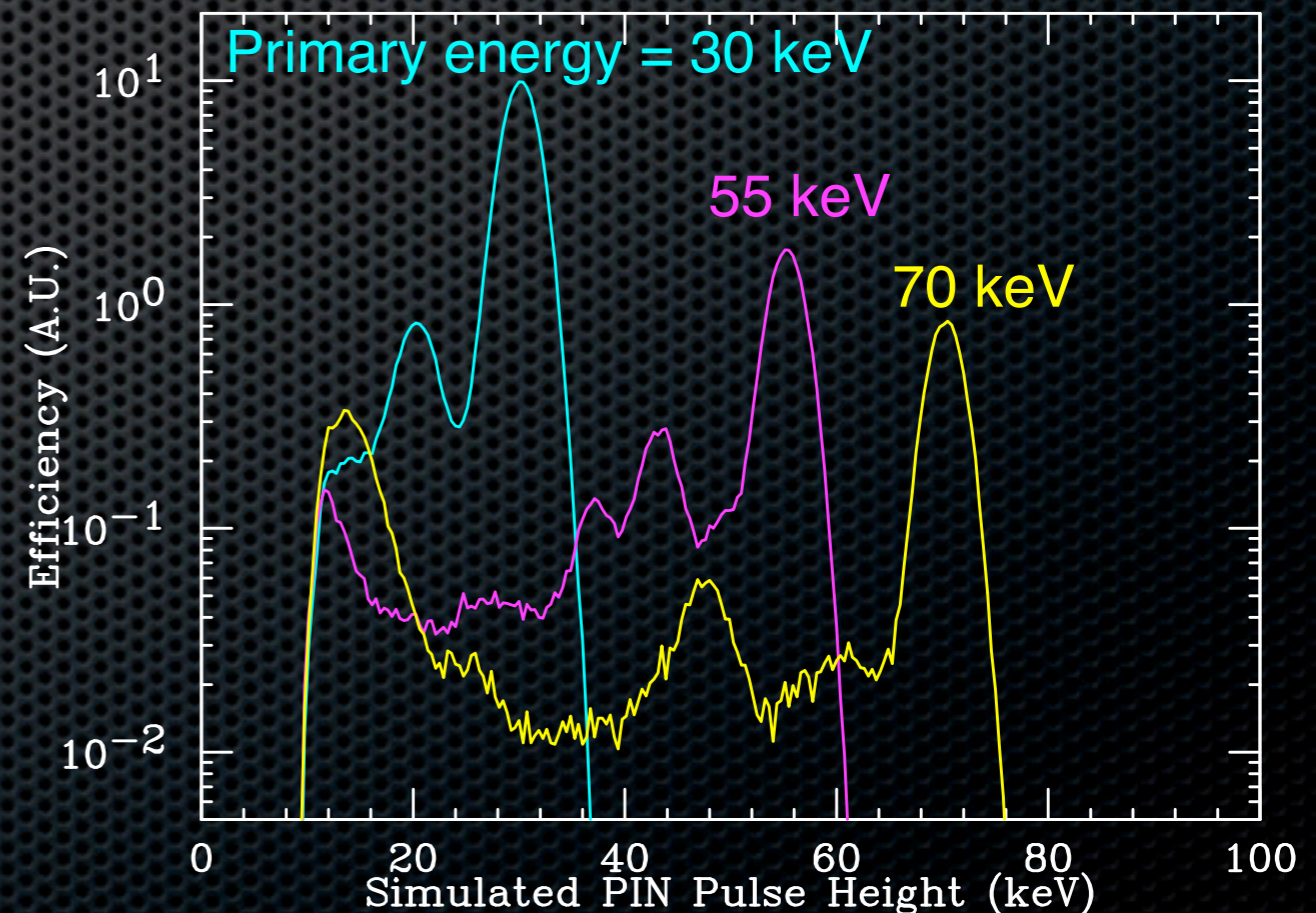
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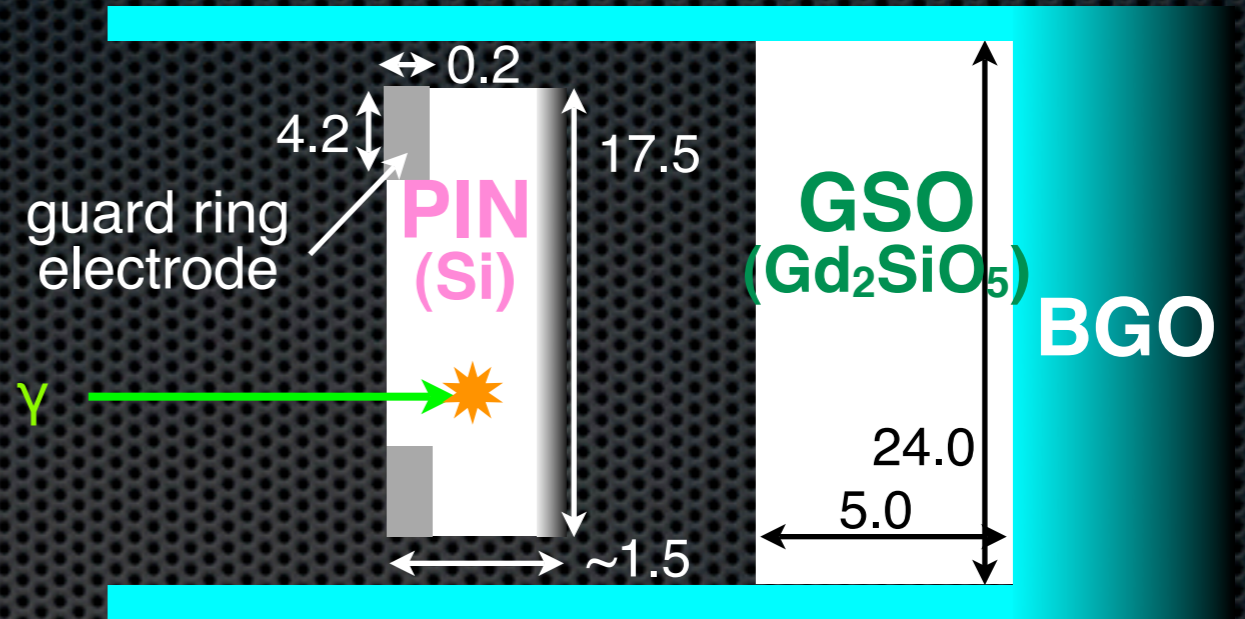


Simulated PIN spectrum with irradiation of monochrome photons

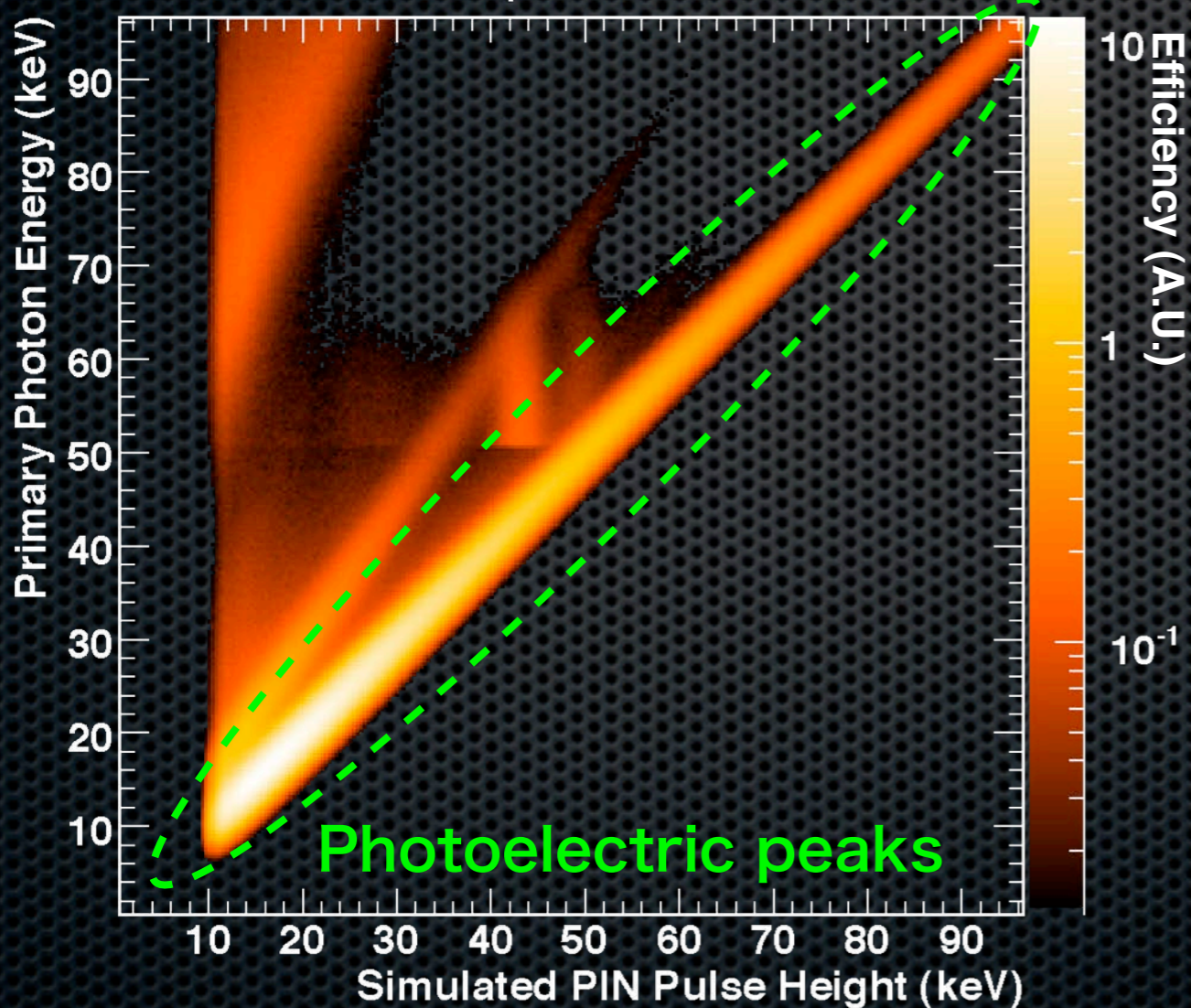


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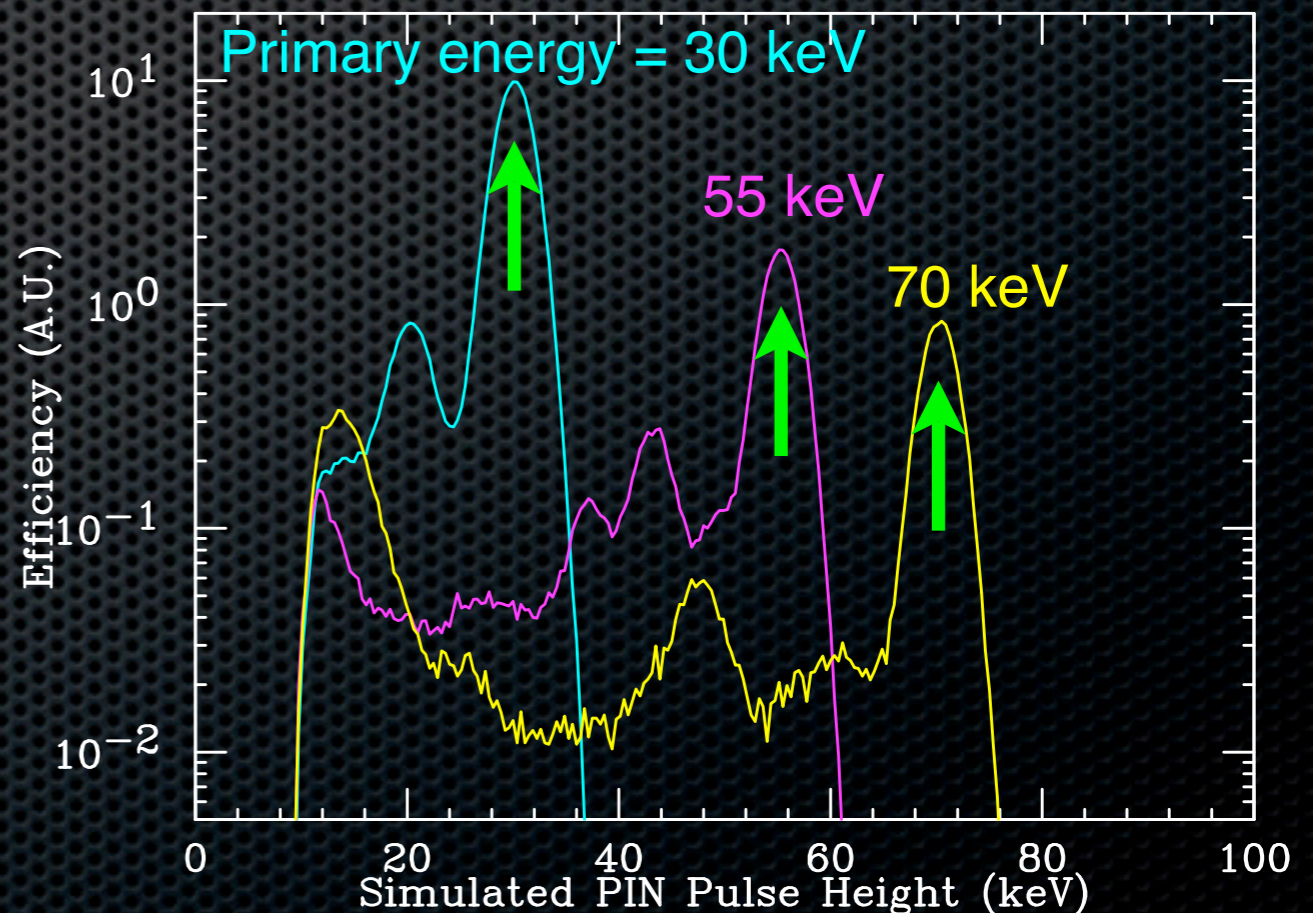
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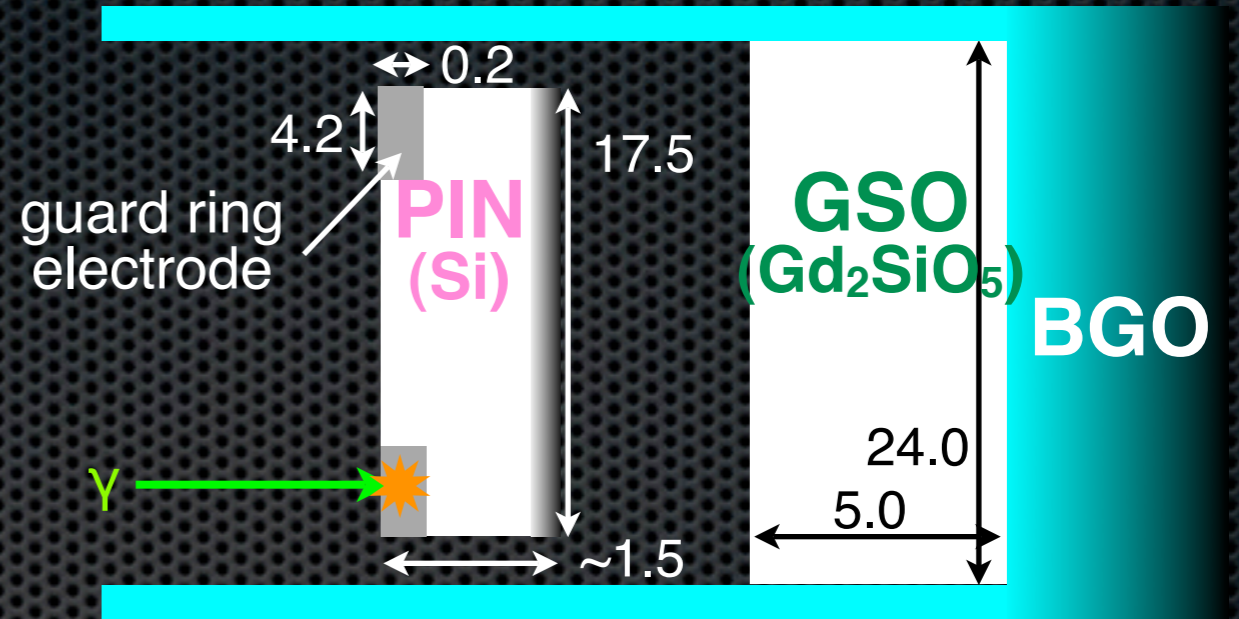


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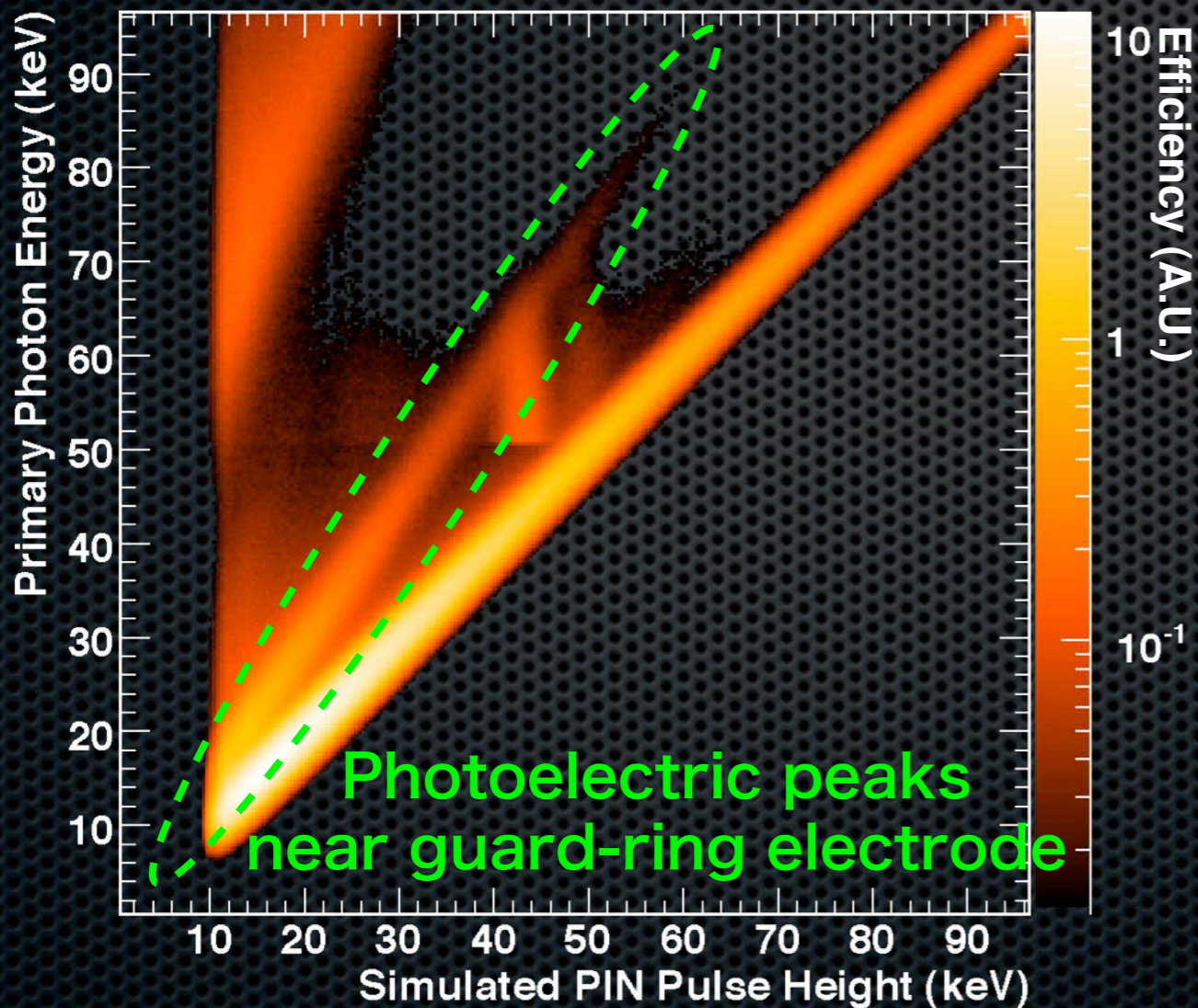


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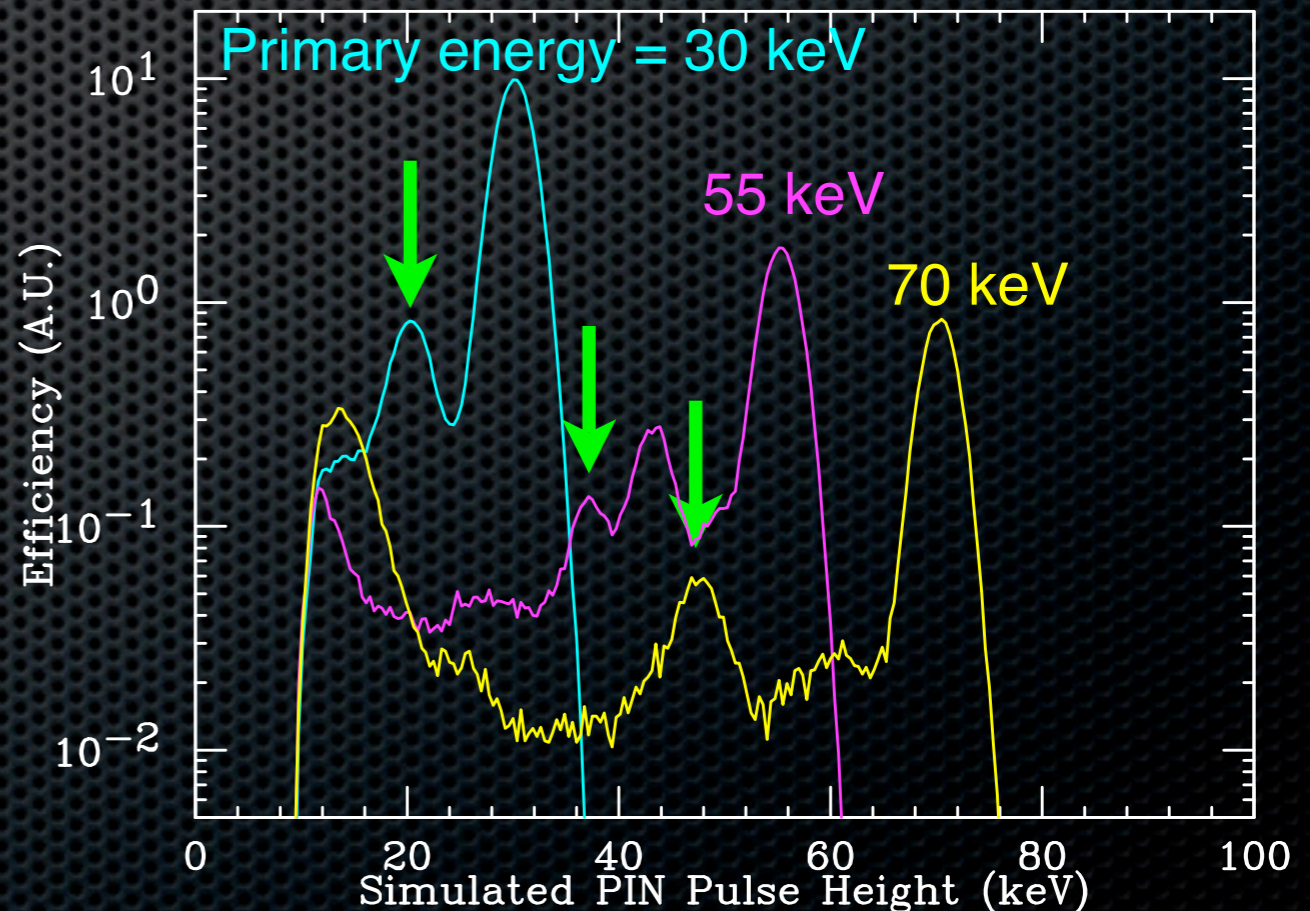
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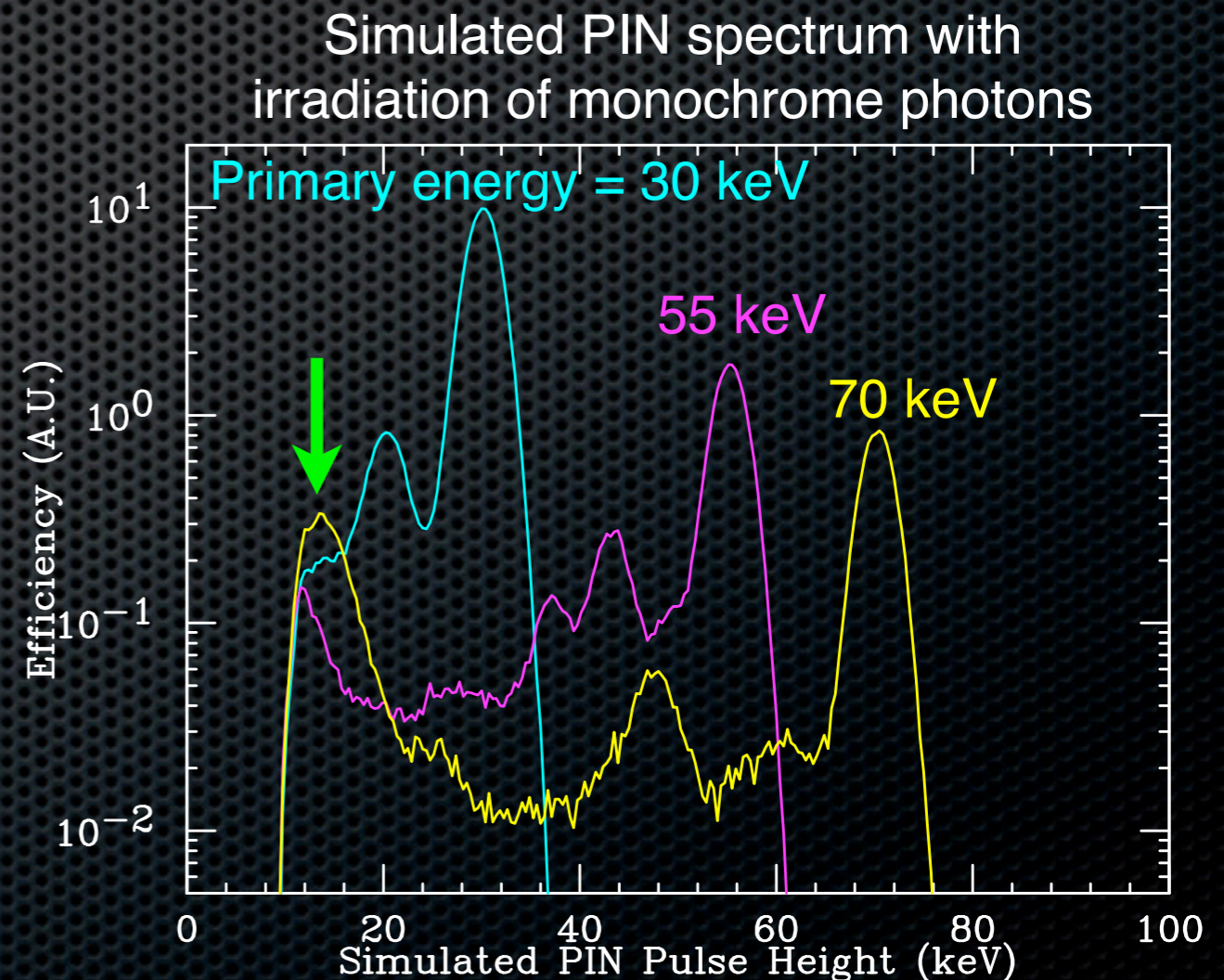
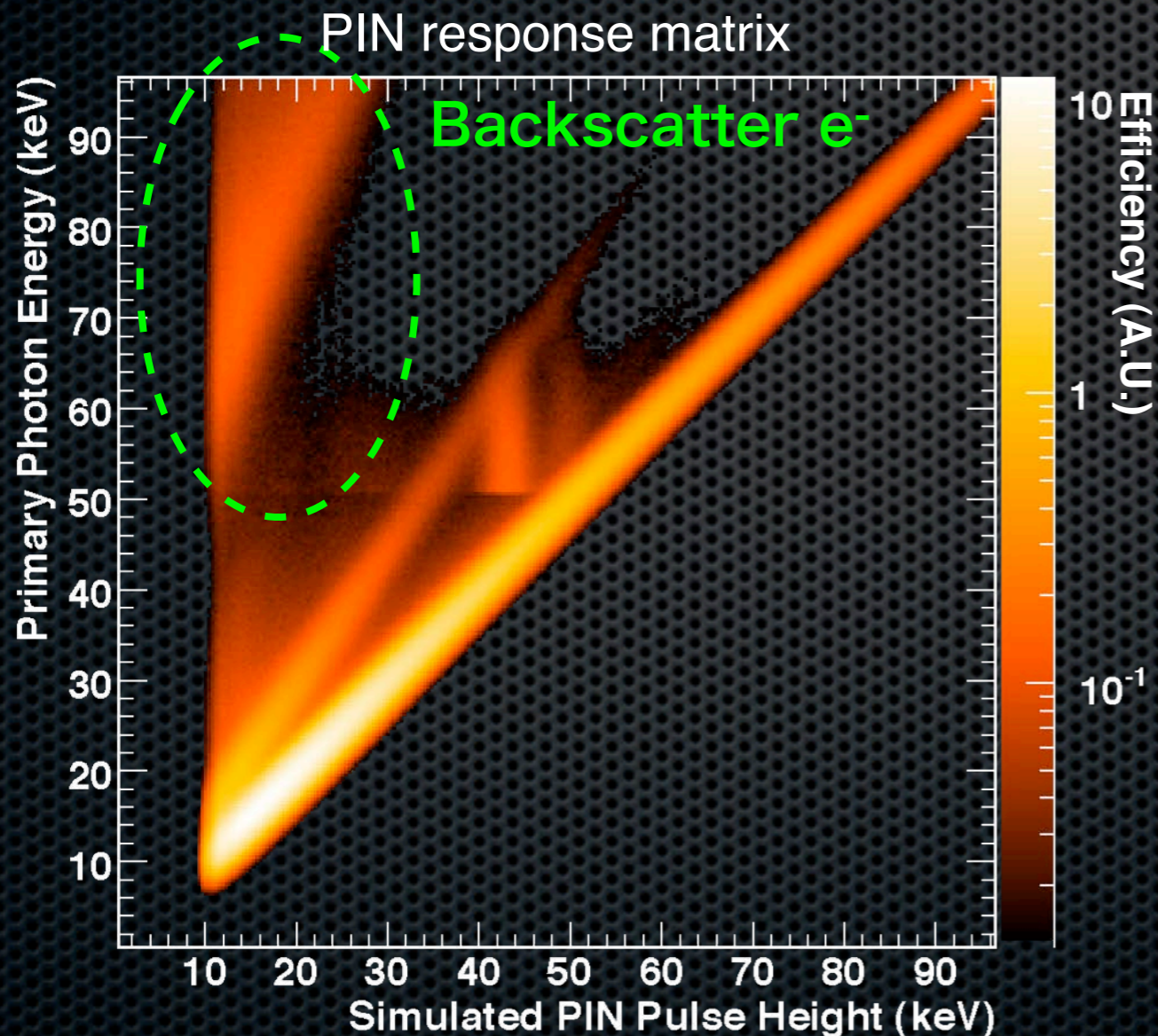
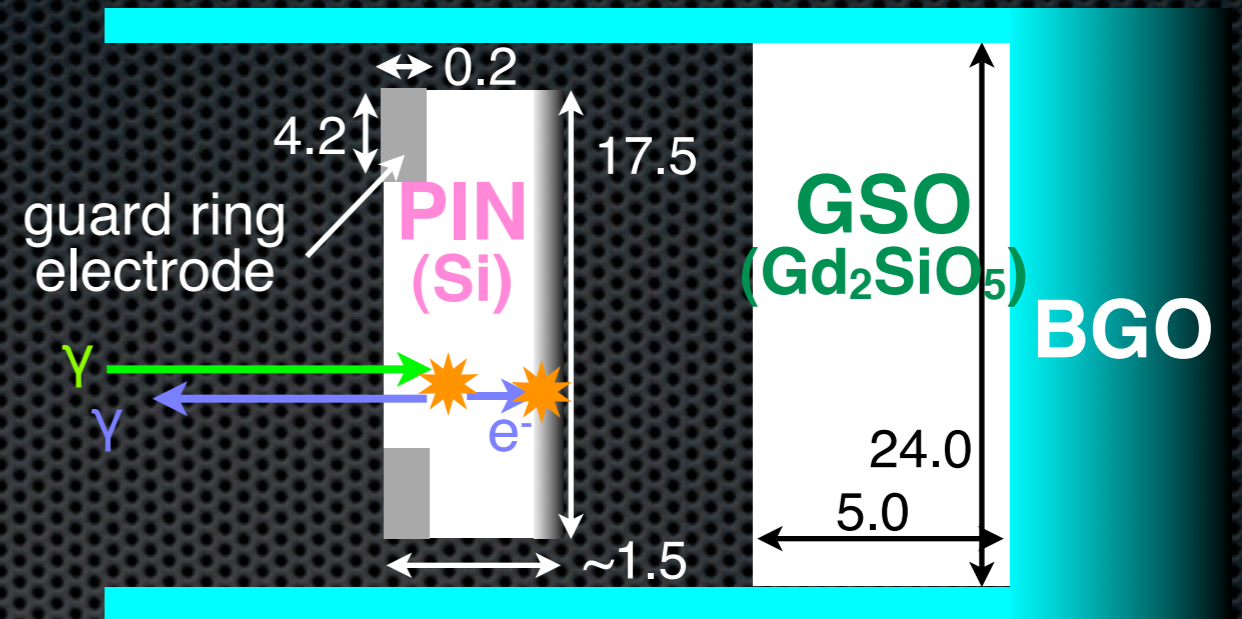


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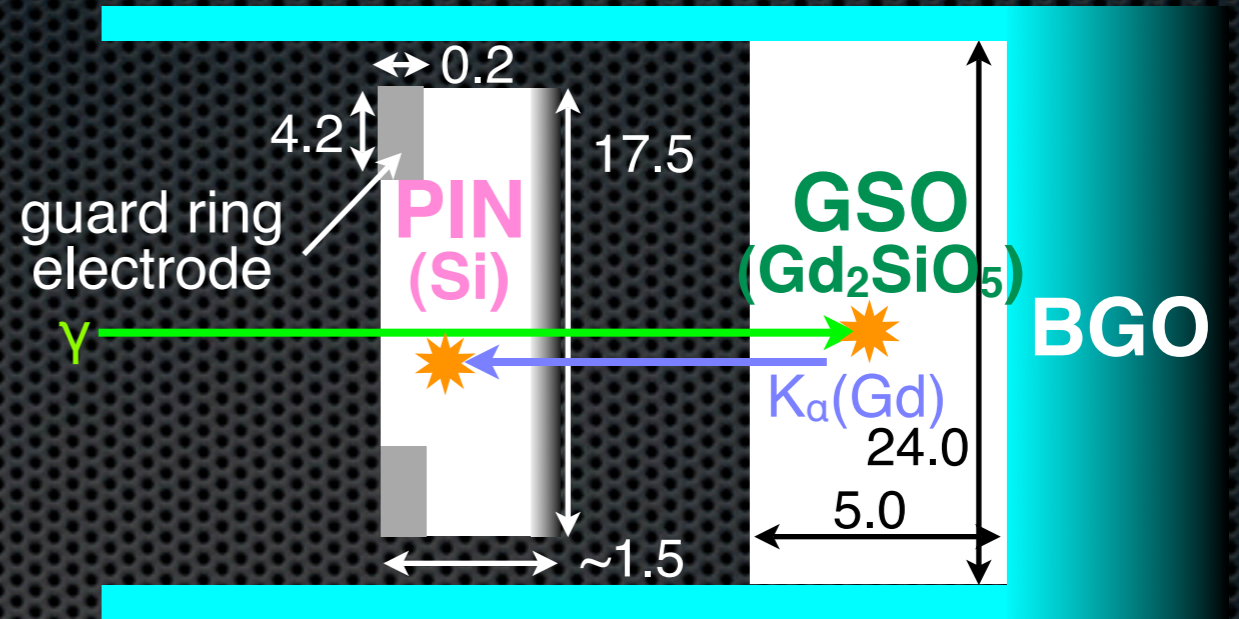
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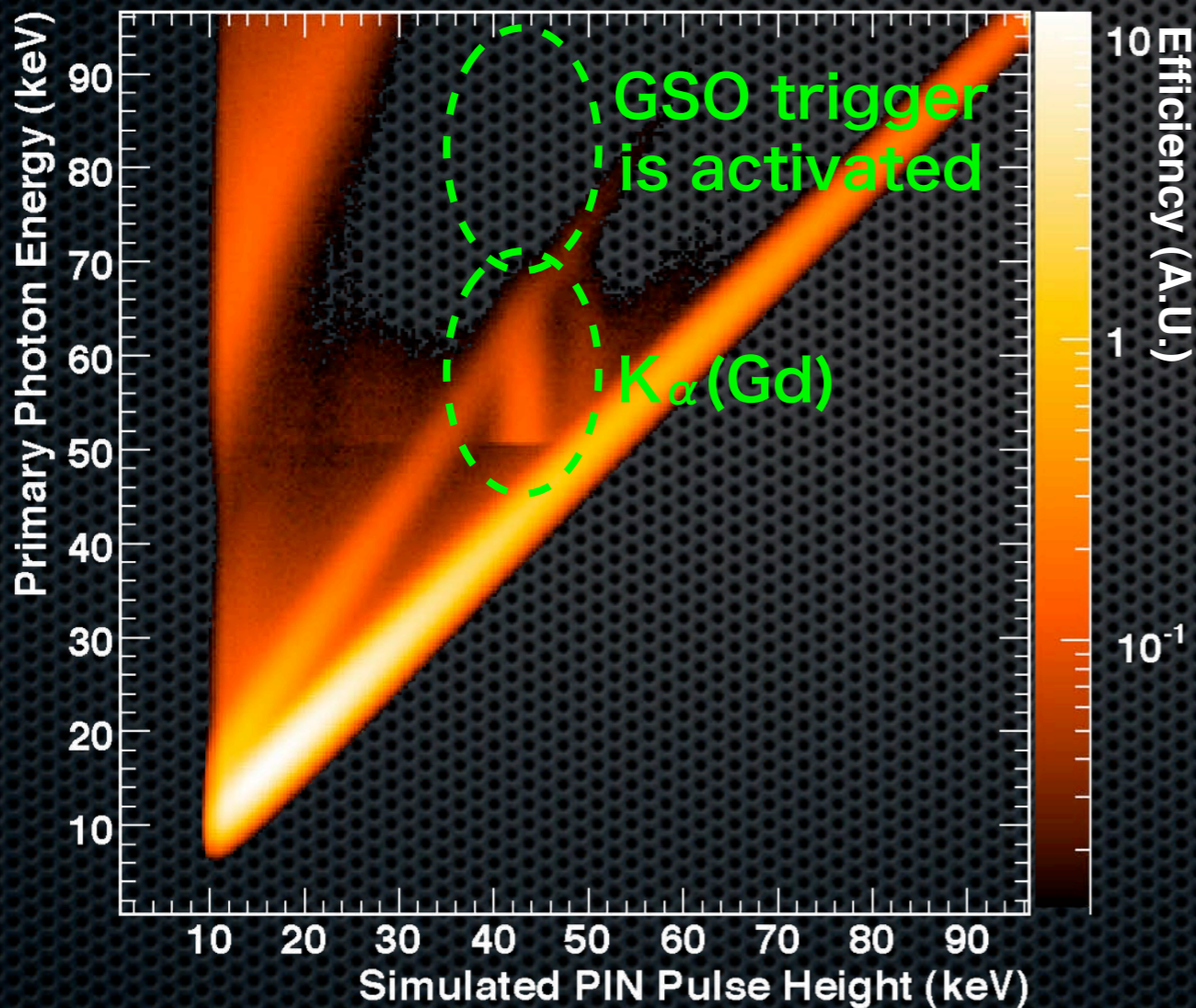


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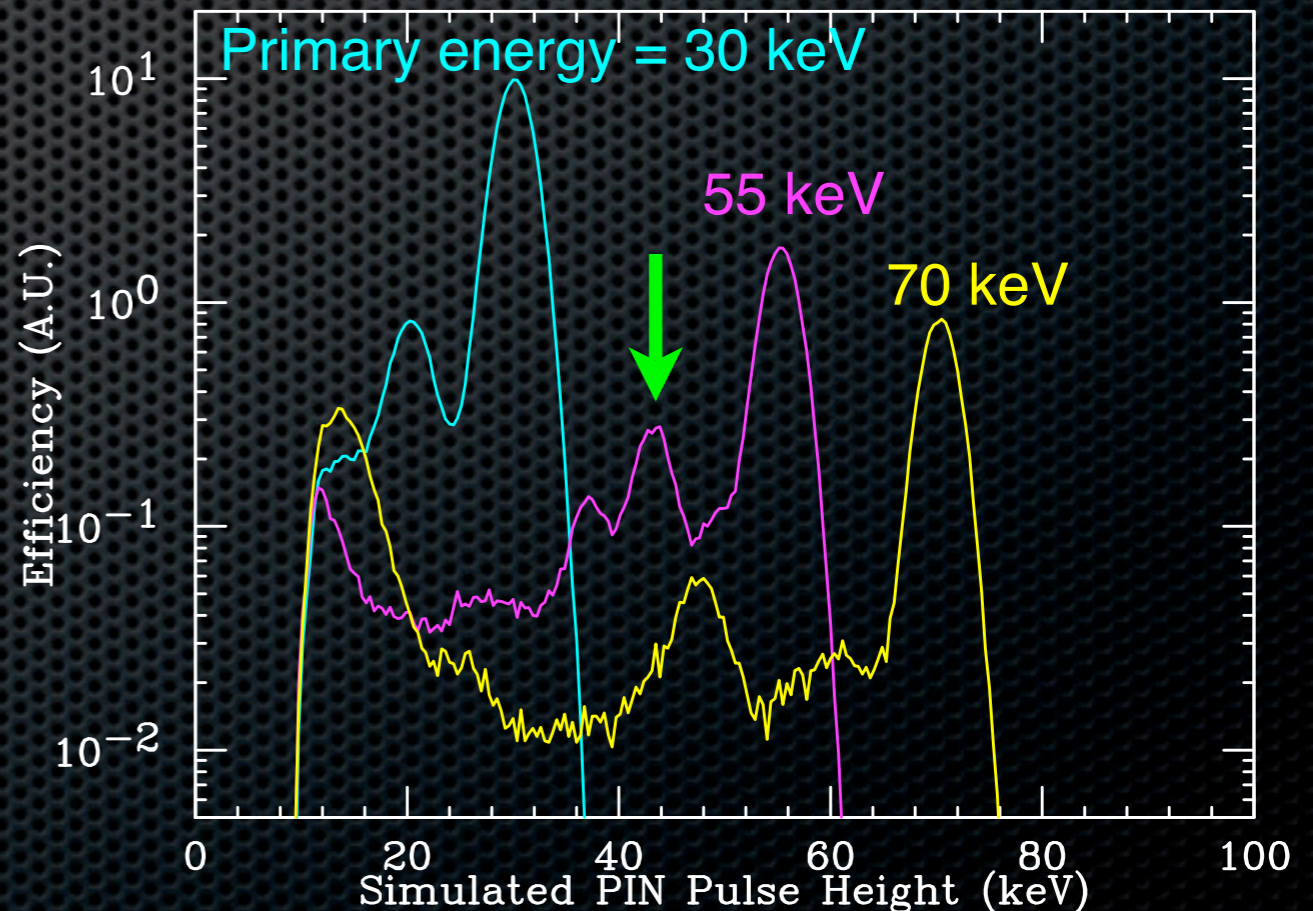
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PIN response matrix

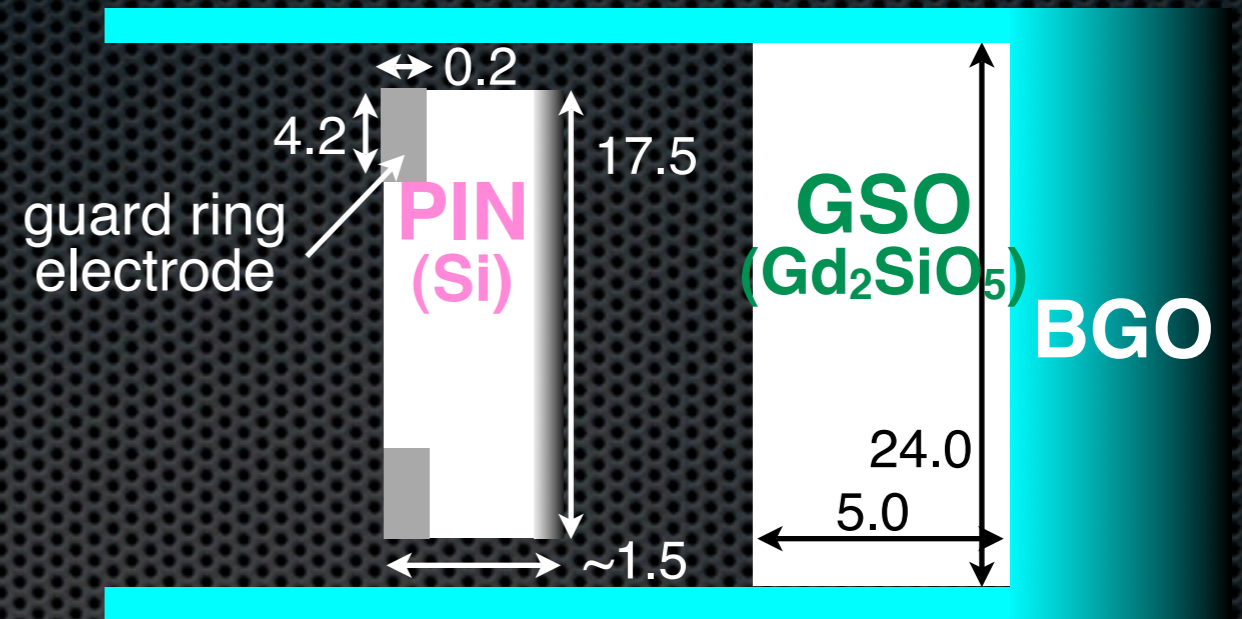


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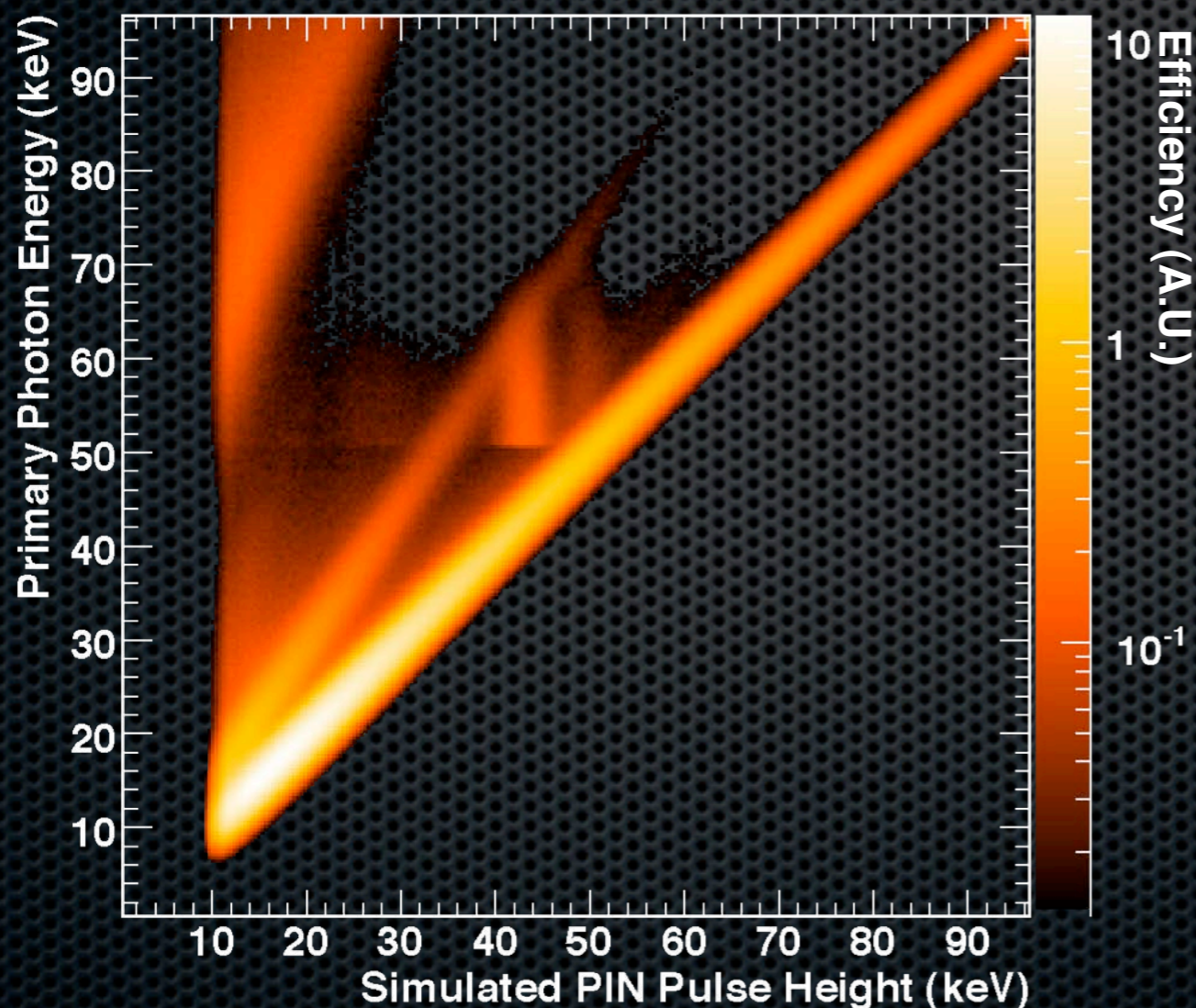


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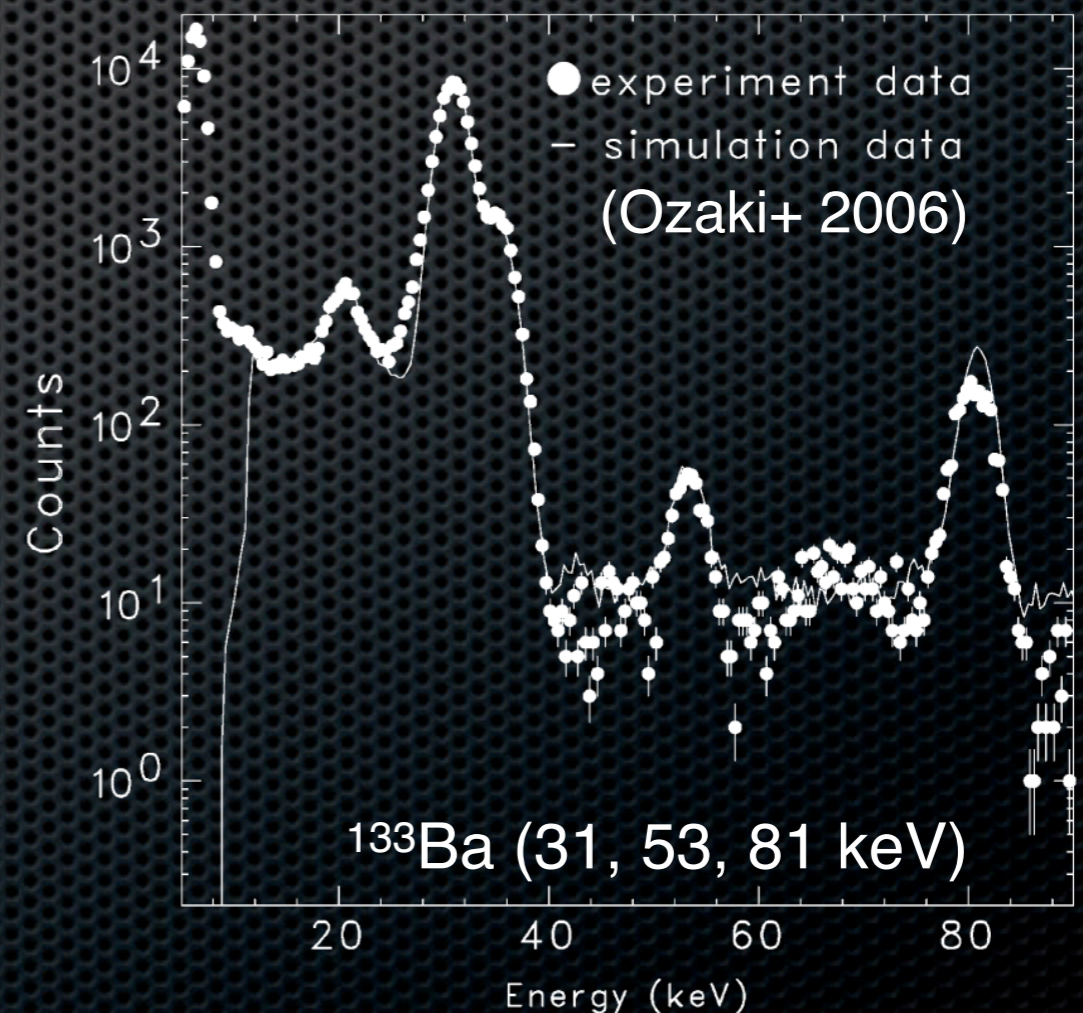
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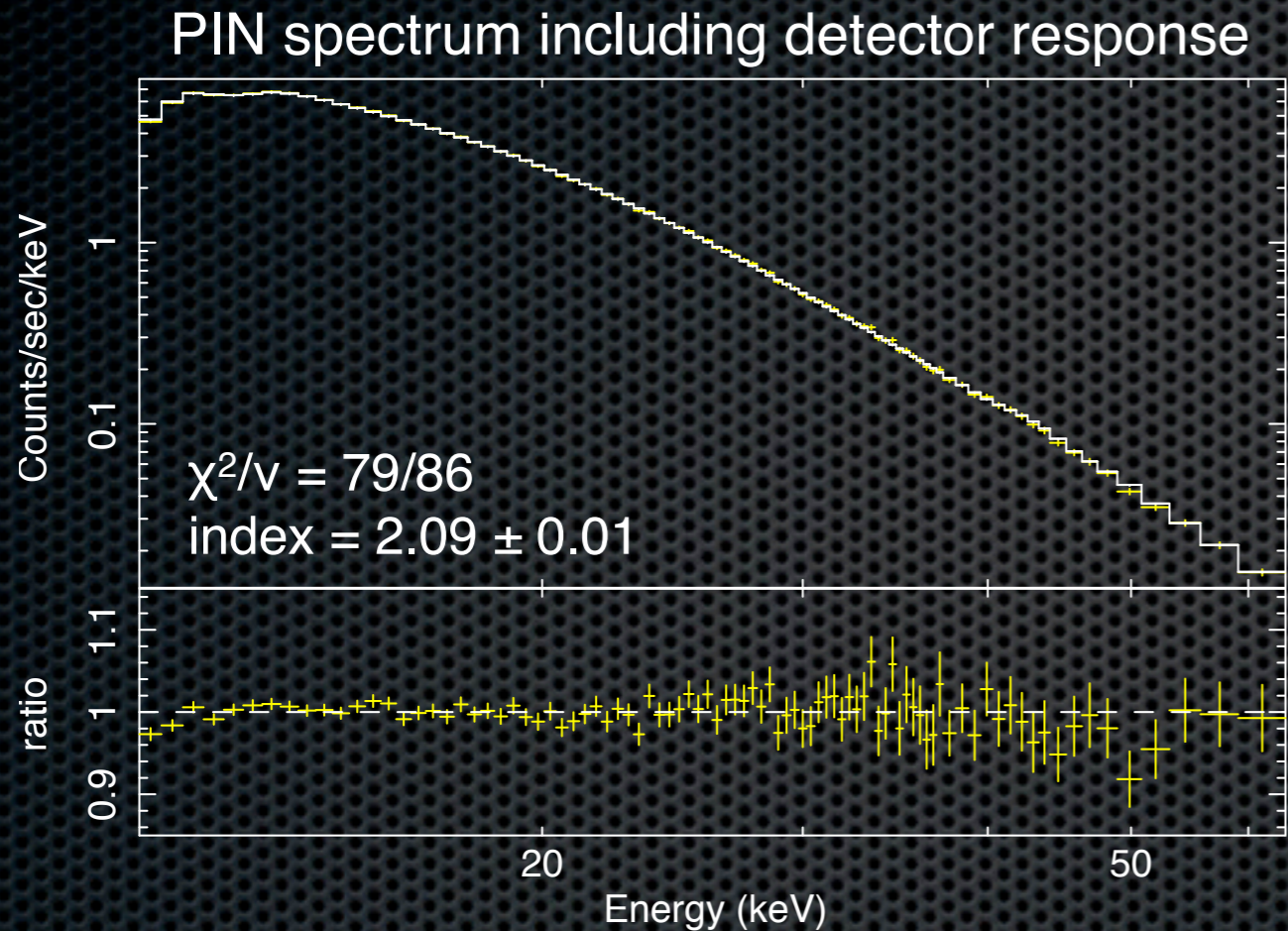


On-ground verification of the response

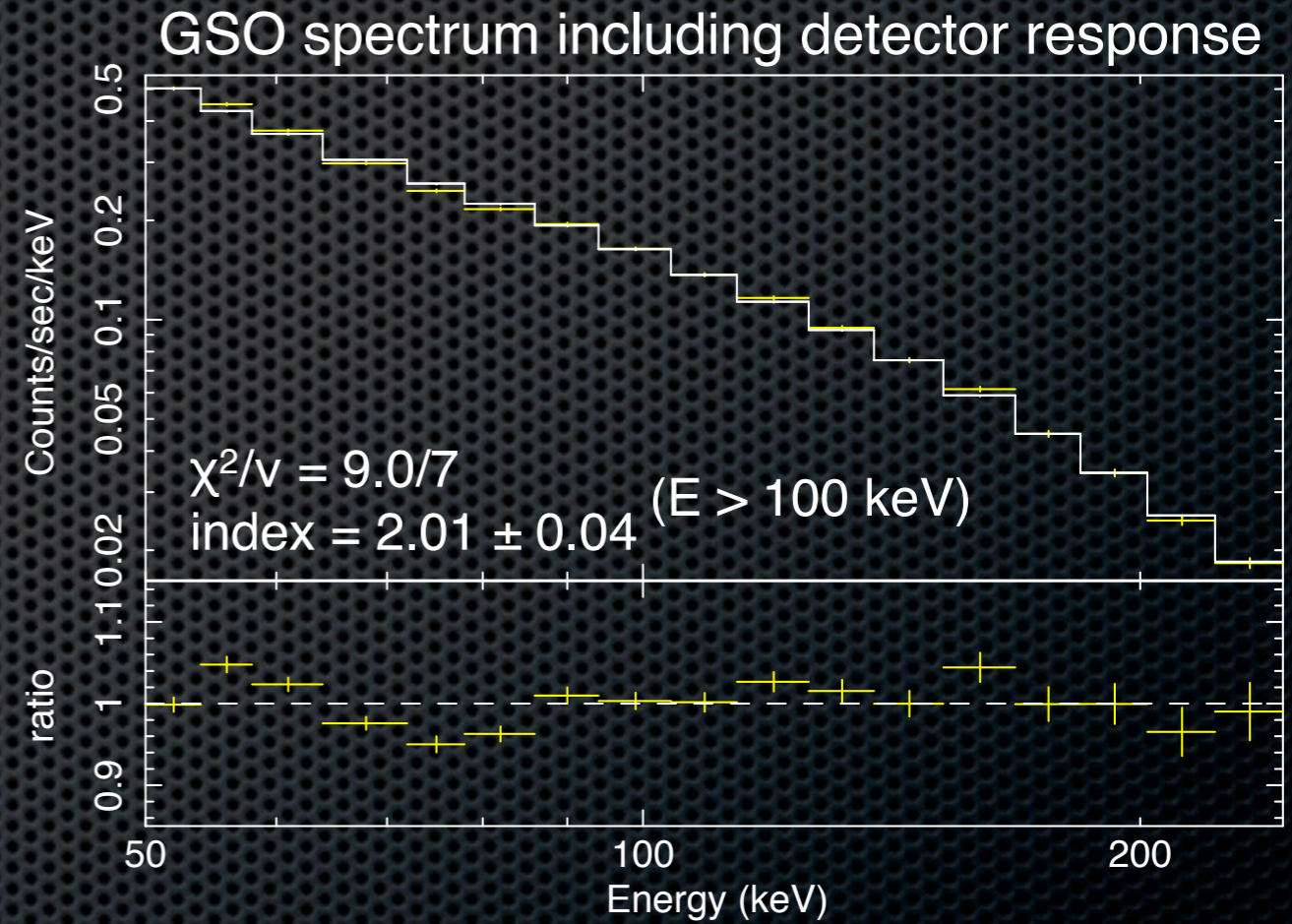


2.2 In-orbit Verification of Response to Hard X-ray Signals

- Observation target: the Crab Nebula (X-ray standard candle)
- Fitting model: single power law with photon index of ~ 2.1
- Spectral fitting: observed spectrum is fitted by a model convolved with the detector response.



Observed PIN spectrum is well reproduced



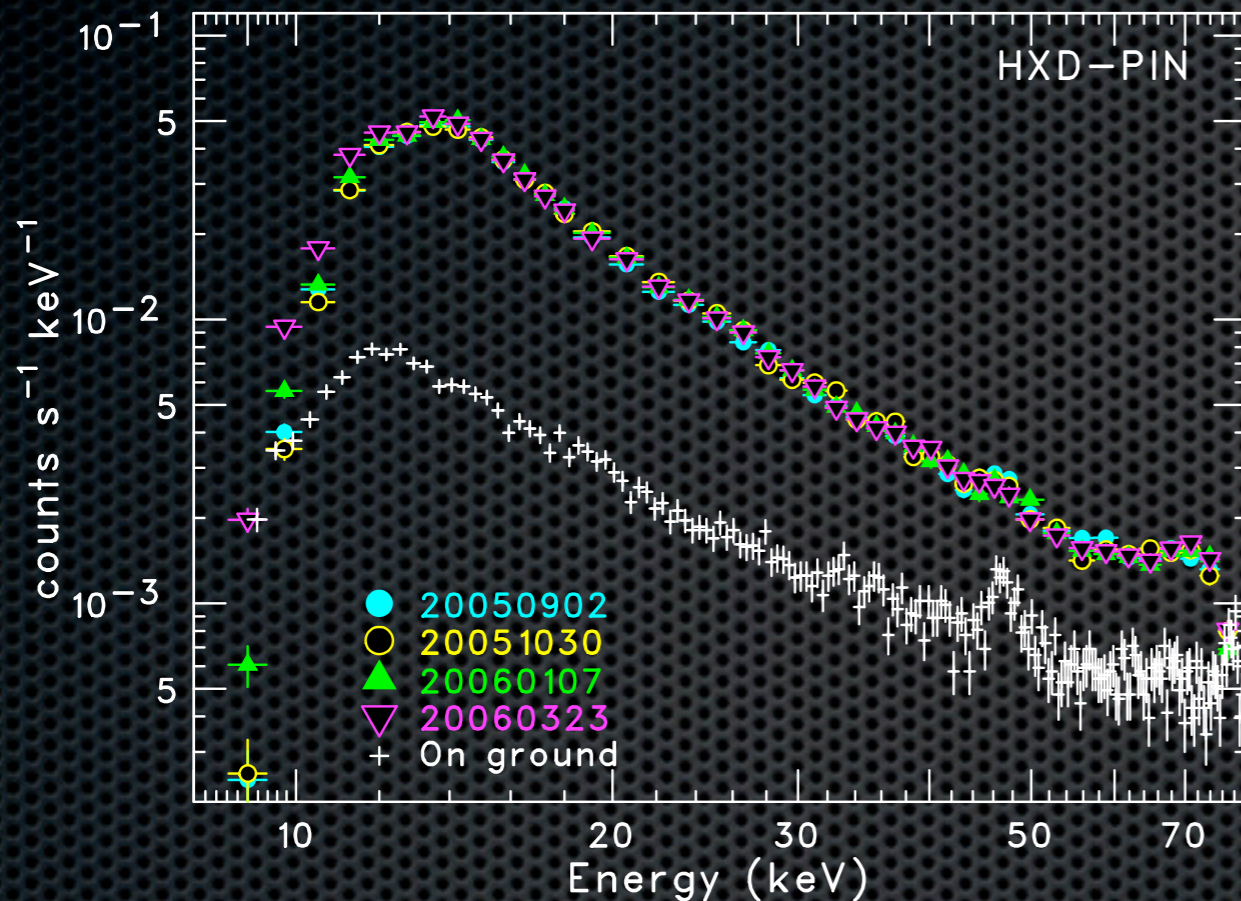
Good fit above 100 keV

Both responses have been distributed to all *Suzaku* observers.

3.1 In-orbit PIN Background

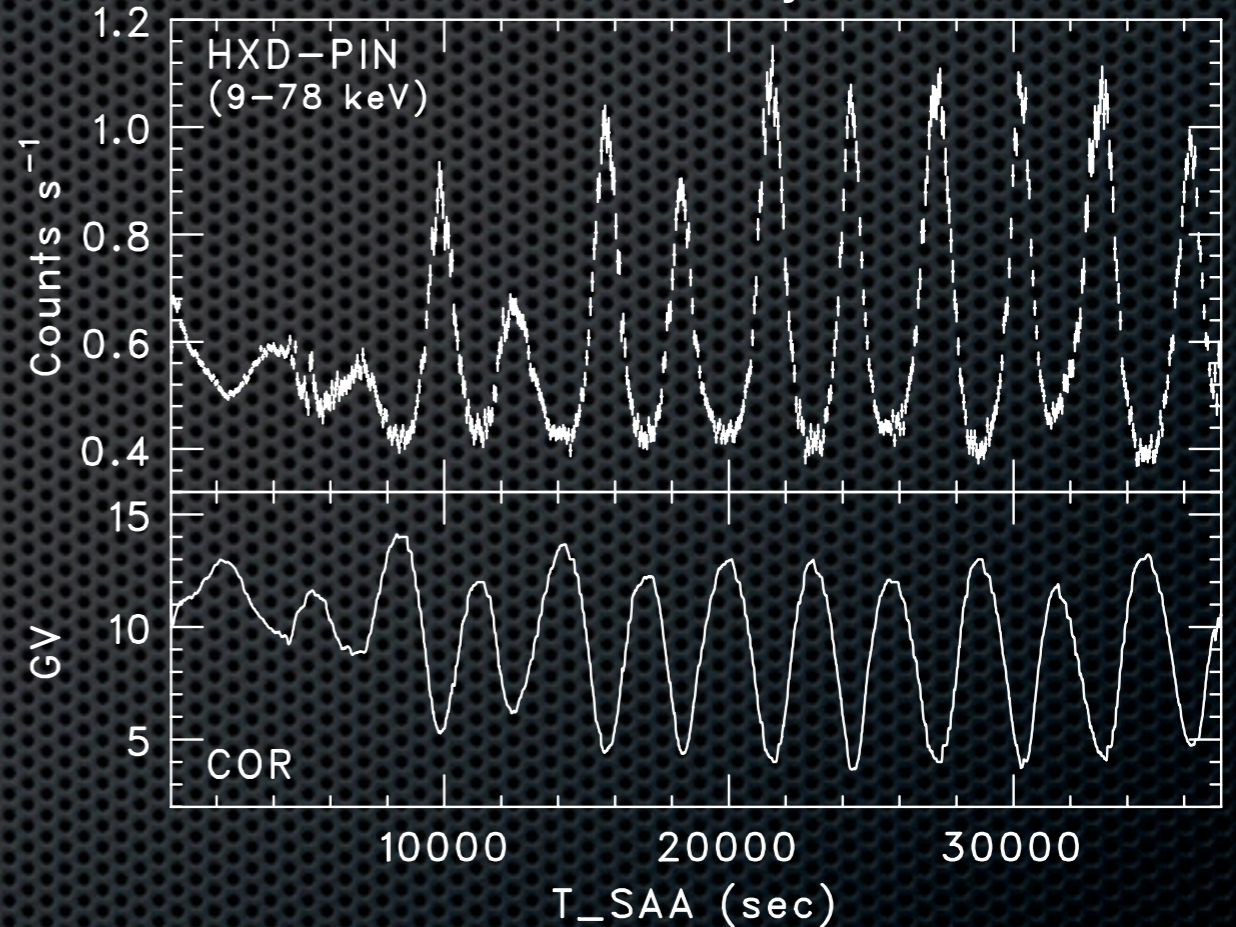
- $S/B \sim 0.1 \rightarrow$ need for high accuracy of BGD subtraction
- Database observed during earth occultations \rightarrow HXD BGD model
- High sensitivity of the HXD \rightarrow high reproducibility of the BGD model \rightarrow full understanding of the BGD origin

Long-term stability of PIN BGD



In-orbit BGD is an order of magnitude higher than ground measured one, but has neither long-term (over one month) build-up nor activation lines.

Short-term variability of PIN BGD



BGD rate is ~ 0.6 cps and varies by a factor of 2 anti-correlated with cut-off rigidity (COR).

What is the origin of PIN background and its variation?

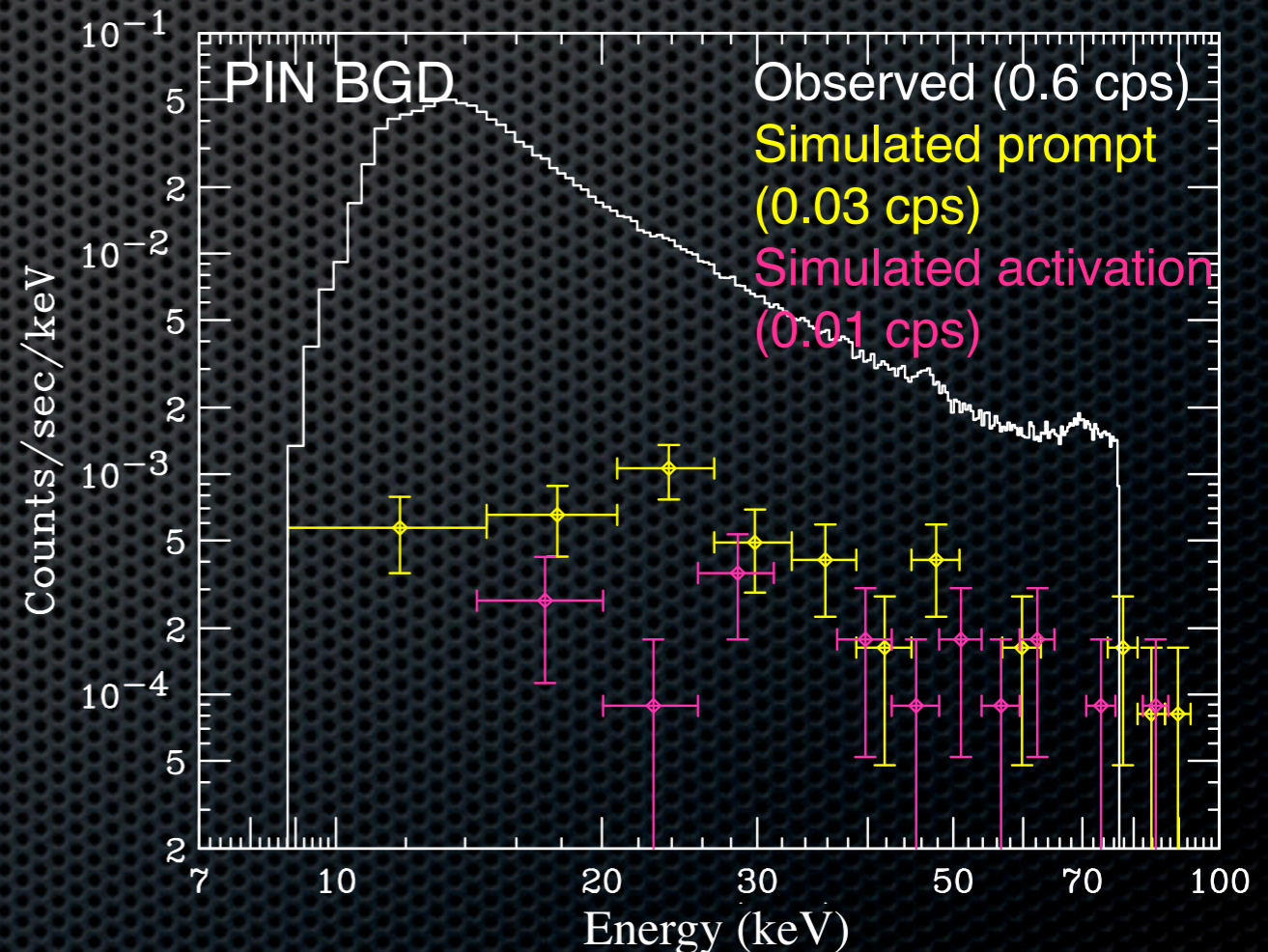
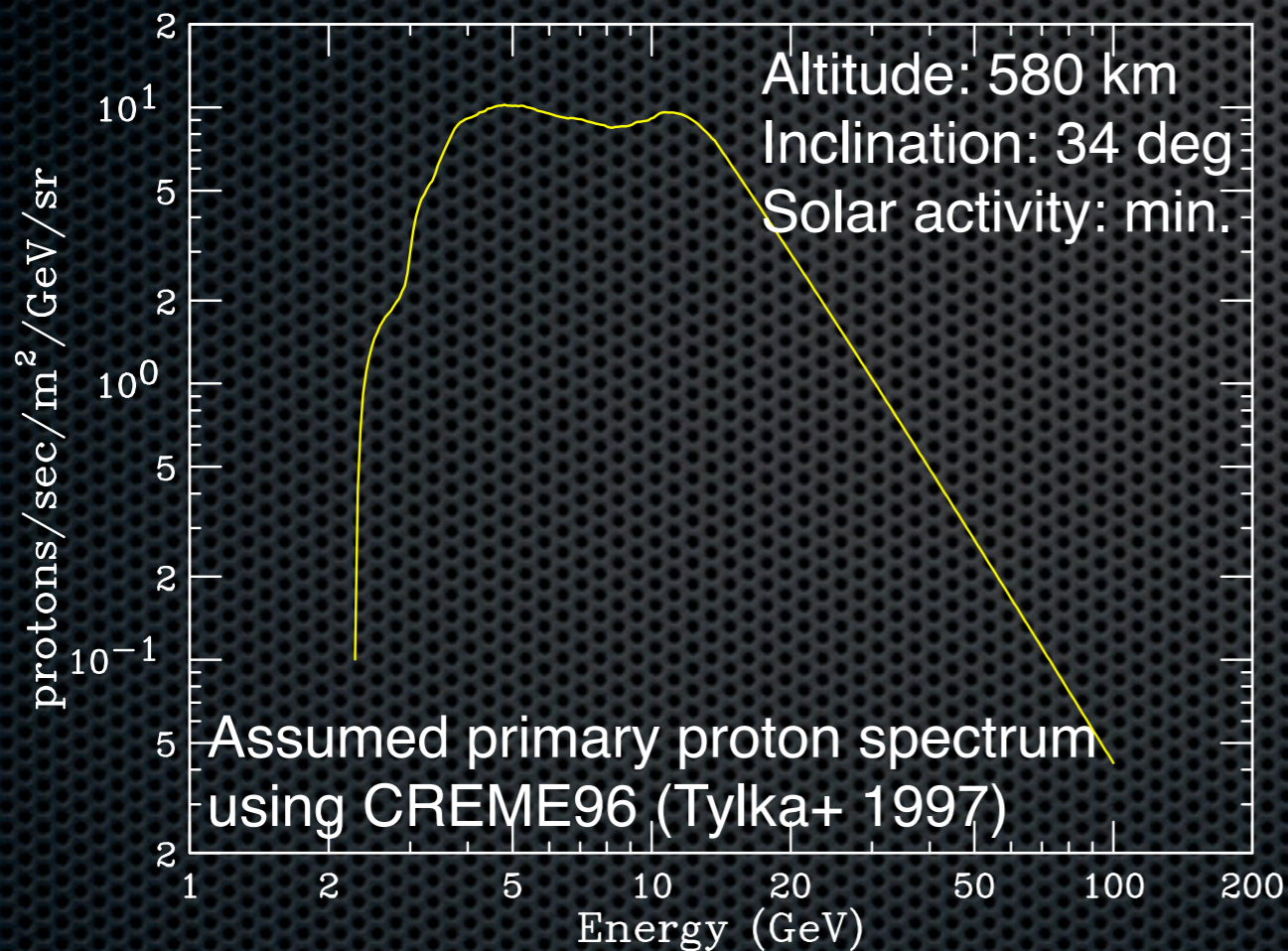
3.2 Simulation of Backgrounds by Cosmic Ray Protons

Prediction

- The negative correlation with COR → primary cosmic ray protons?
- Active shield vetoes most of the **prompt** BGD by charged particles → short-lived radioisotopes from nuclear **activation**?

Simulation using MGGPOD (Weidenspointner+ 2005) based on Geant3

- Designed for background simulation of in-orbit gamma-ray detectors
- Calculate **activation** as well as **prompt** signals by inputting radiation history
- Verification on *WINDS*, *INTEGRAL*, and *RHESSI* satellites



- **Prompt** and **activation** BGD is an order of magnitude lower than observed one.
- **Prompt** BGD is mostly caused by elastic scattering of secondary neutrons.

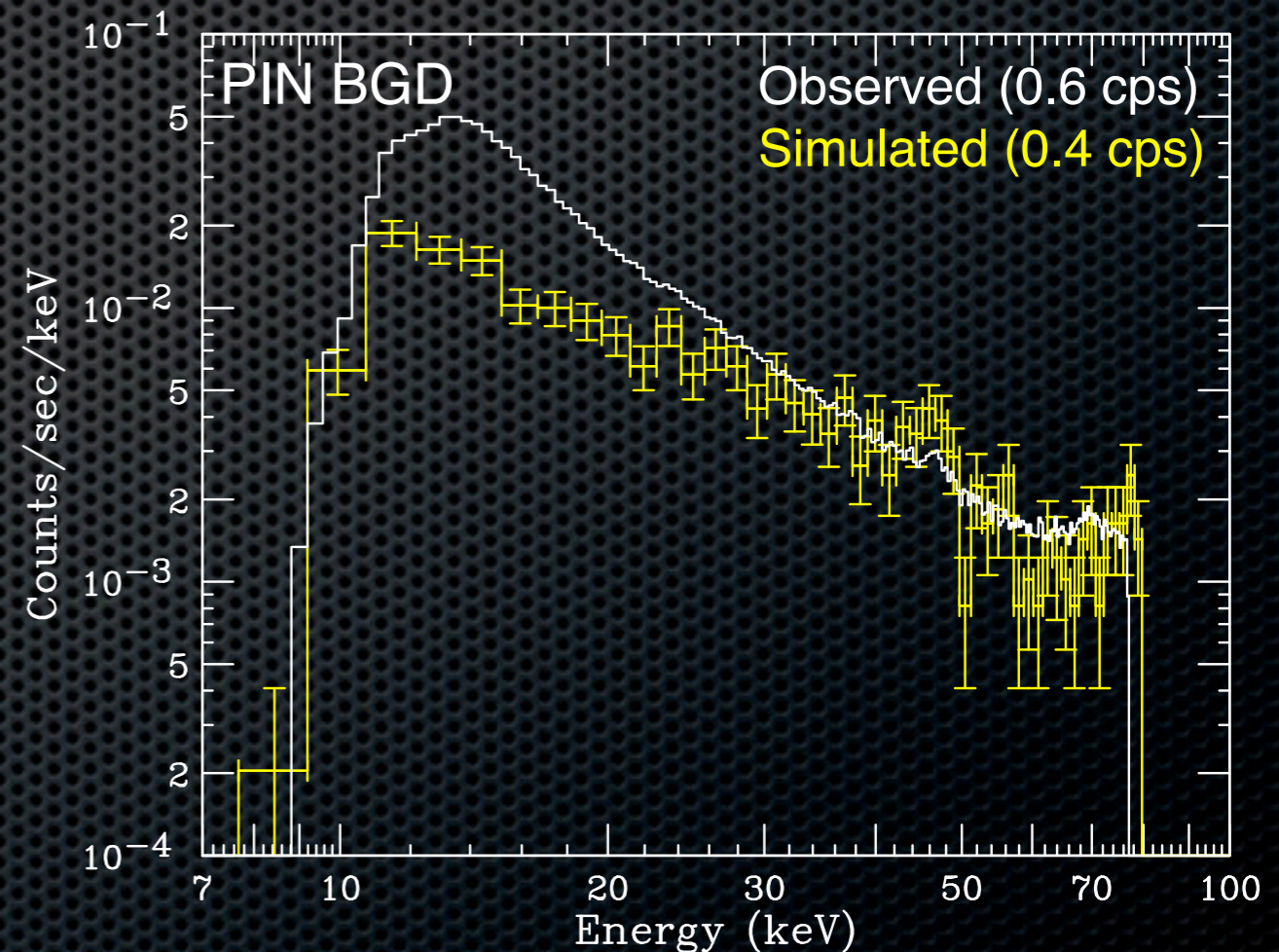
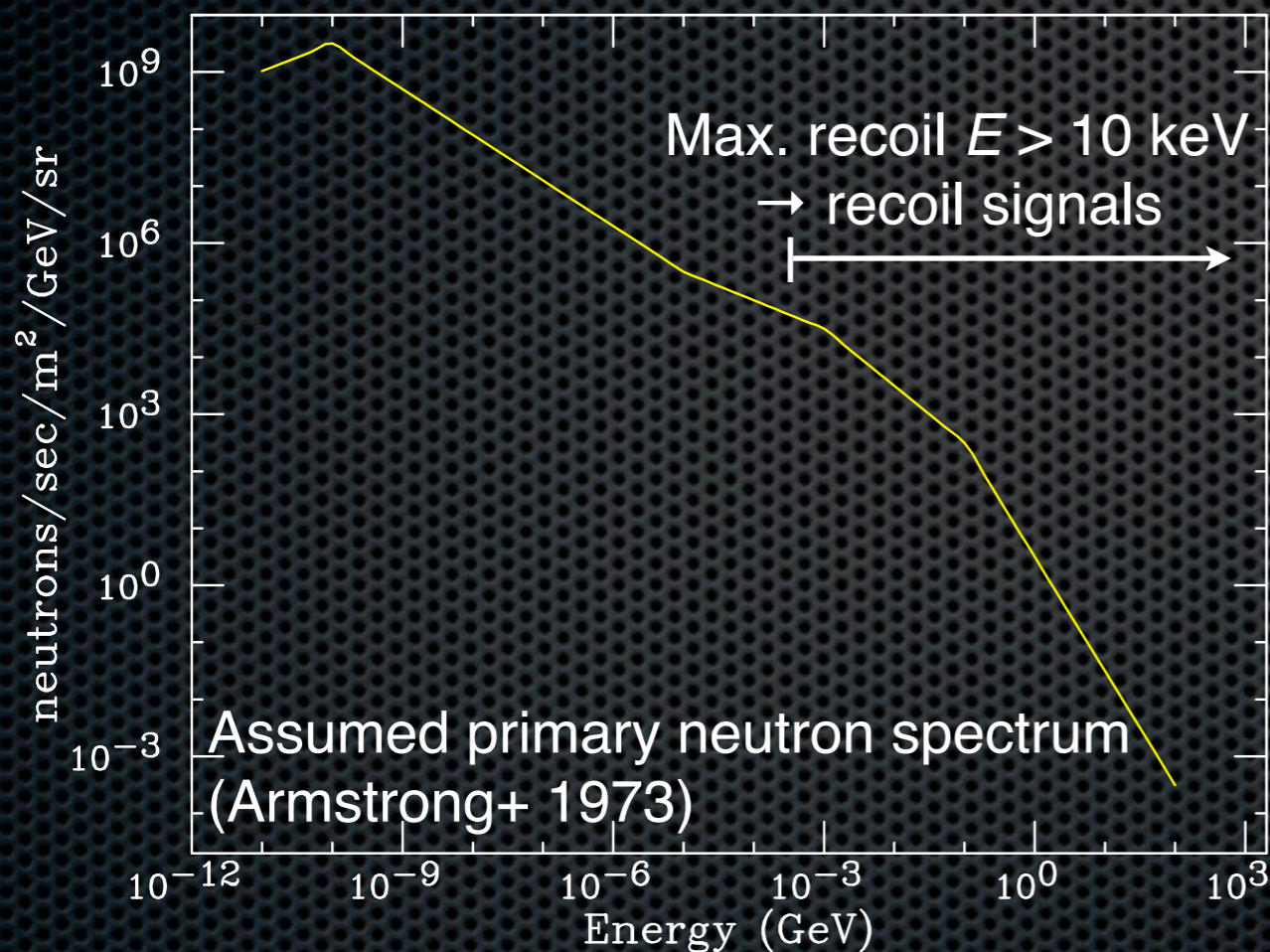
3.3 Simulation of Backgrounds by Albedo Neutrons

Prediction

- Cosmic ray protons produce neutrons in the atmosphere
- The neutrons elastically collide with Si nuclei → recoil signals
- Expected BGD rate $\sim 1 \text{ cps/cm}^2 \times 1 \text{ barn} \times 1 \text{ mol} = 0.1 \text{ cps}$ (observed $\sim 0.6 \text{ cps}$)

Simulation

- Physics process: G4NeutronHPorLElastic ($< 20 \text{ MeV}$)
G4HadronElastic ($> 20 \text{ MeV}$)



Albedo neutrons can explain a large fraction of the PIN background

Summary

- Using Monte Carlo simulation, we evaluated detector responses of the HXD onboard the *Suzaku* satellite to hard X-ray, cosmic ray protons, and albedo neutrons.
- The detector responses of HXD-PIN and HXD-GSO to hard X-ray signals has been verified on the actual Crab Nebula data.
- Cosmic ray protons and albedo neutrons produce ~10% and ~70% of the observed HXD-PIN background, respectively.