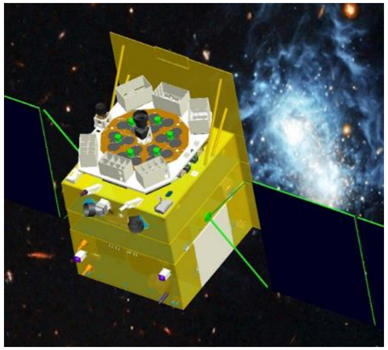
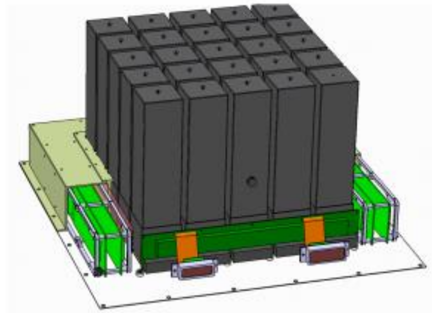
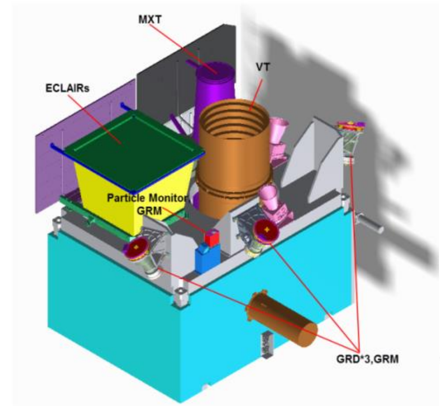


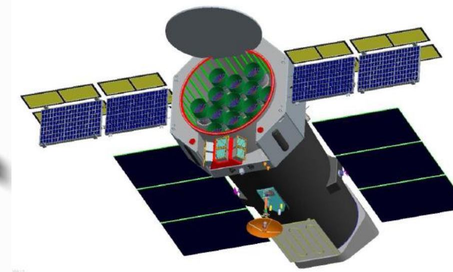
HXMT(2017)



POLAR
(2016onboard TG-2)



SVOM/GRM (~2021)



eXTP(202?)

Space Missions in IHEP & Geant4 Applications

Juan Zhang, Gang Li , Xiaobo Li

Institute of High Energy Physics, Chinese Academy of Sciences

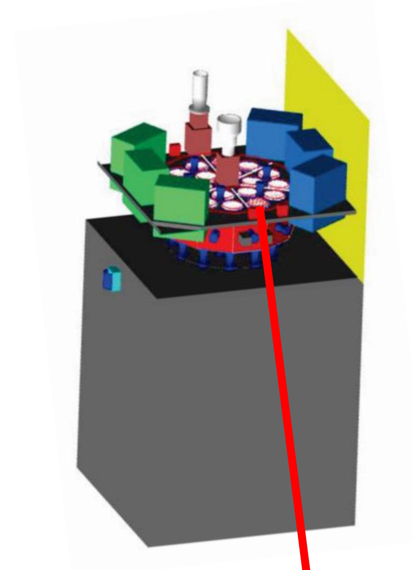
OUTLINE

- **Space Missions in IHEP**
  - **HXMT, POLAR, SVOM/GRM, eXTP, …**

- **Application of Geant4 simulation on these instruments**
  - **background estimation、calibration(arf&rmf)、data analysis、design optimization、shielding etc.**

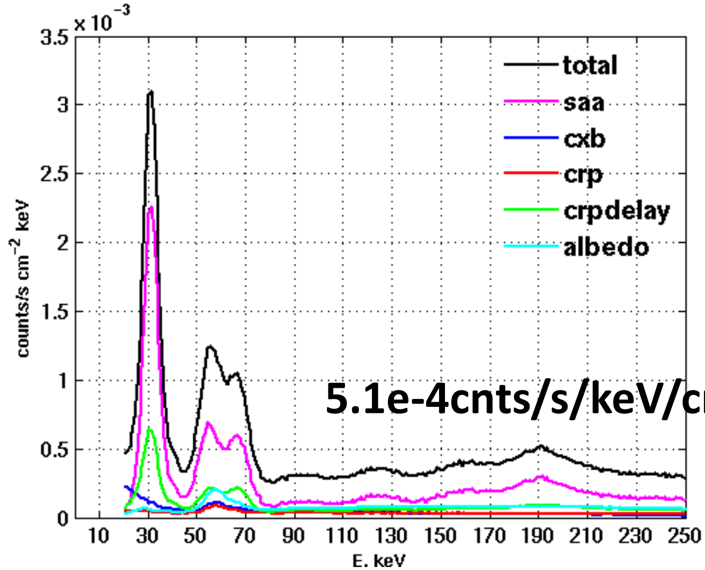
Hard **X**-Ray **M**odulation **T**elescope

- **HXMT:**
  - **Orbit: ~550km, ~43°**
  - **Collimated X-ray telescope**
  - **1~250keV**
  - **Launch time 2017 June**



- **Payloads:**
  - **HE(NaI/CsI, 20-250keV)**
  - **ME(Si-Pin,5-30keV)**
  - **LE(SCD,1-15keV)**
  - **SEM(space environment monitor)**
  - **Particle Monitors**

In-orbit Background Simulation for HXMT



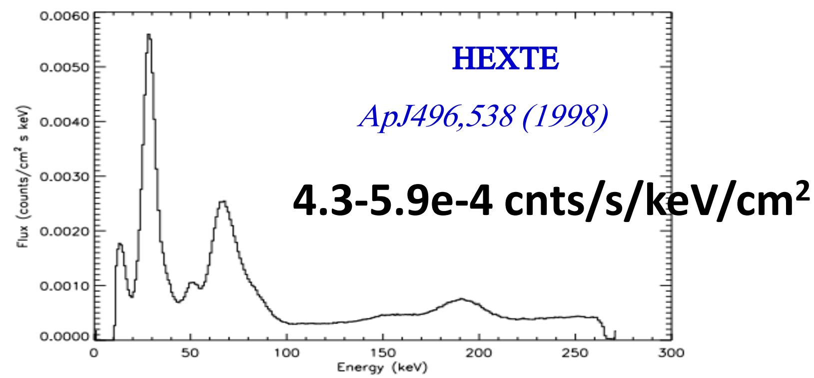
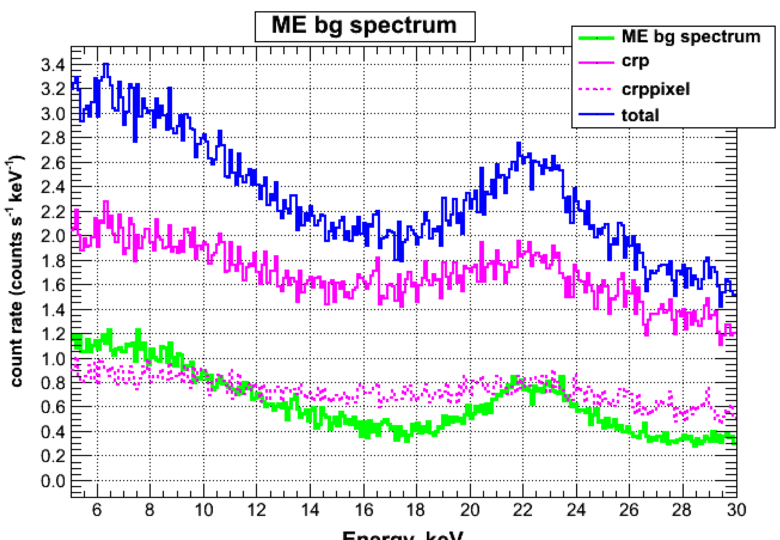
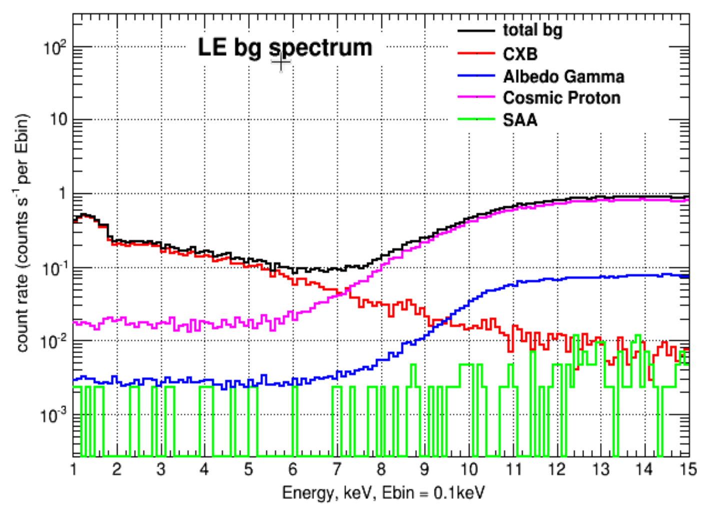


FIG. 6.—HEXTE background for a single detector plotted versus energy. Background lines due to activation of the iodine by cosmic and trapped radiation are evident at 30, 55, 66, and ∼190 keV, as are the $K_{\alpha\beta}$ lines at 74 and 85 keV from fluorescence of the lead collimator. The data are from a 7.5 hr observation of blank sky fields.

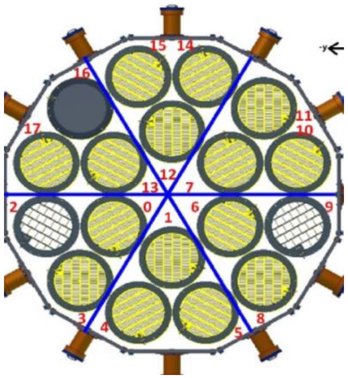


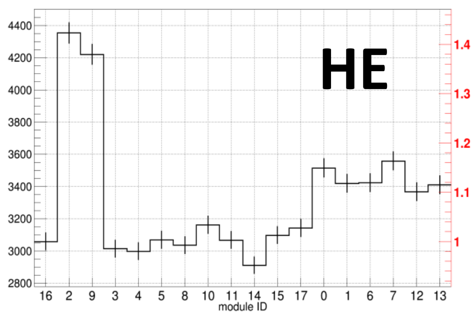
ME bkg spectrum

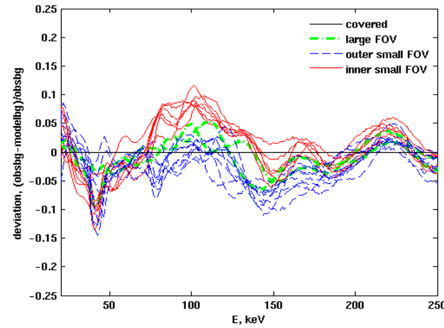


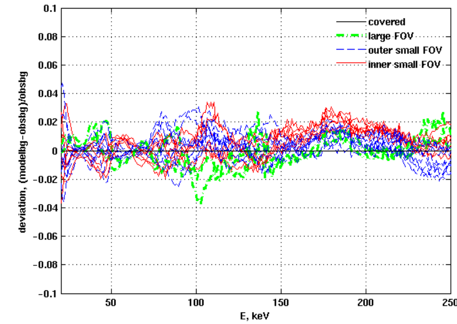
LE bkg spectrum

Geant4 Simulation Helps to Determine the In-orbit Background Estimation Methods

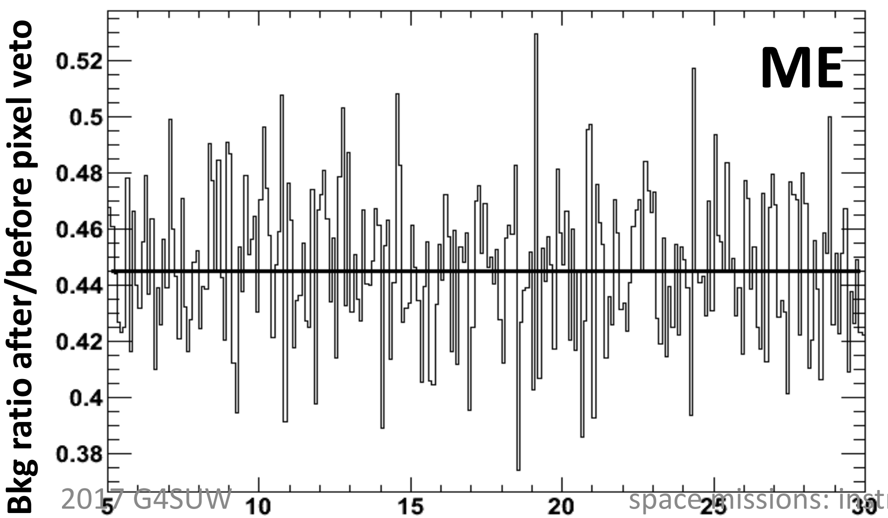








Difference of the particle background between different FOV/position detectors can be used to determine the background analysis method and its uncertainties. Using in-orbit observation data to determine these bias



component	rate, cnts/s	rate after veto between pixels, cnts/s
cxb	15.2	14.9
crp	39.9	17.1

Cosmic ray protons background can be reduced to ~50% after veto between pixels.

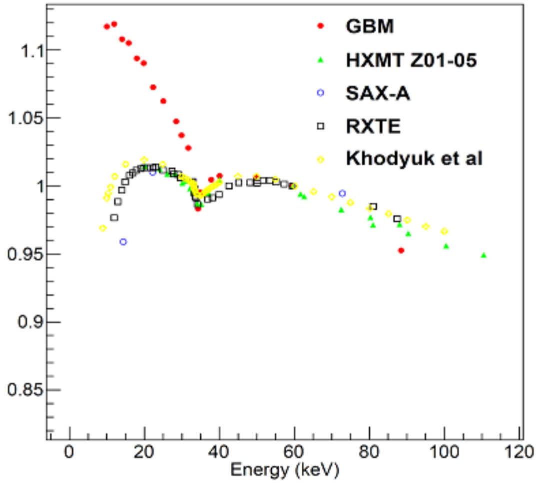
HXMT calibration

- Experiment + MC
  - E-channel relation
  - Energy resolution
  - Effective area
  - Response matrix
  - Etc…

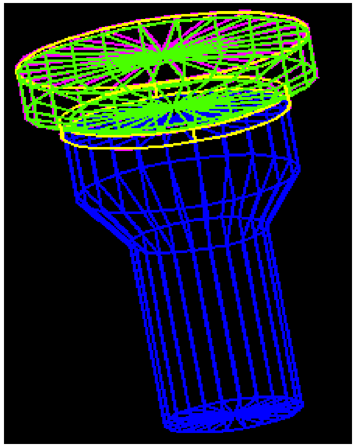
Ground Calibration of HXMT/HE

- For each energy point, the X-ray beam was sequentially poured into the 27 points sampled on the phoswich plane.
- The accumulated spectrum from these 27 points was considered as the response of the detector plane to a parallel X-ray beam uniformly illuminating the surface of HE.

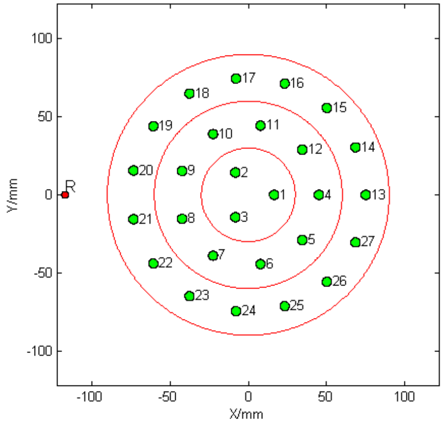
Nonlinearity response of X-ray to NaI:



Visualization of
HE main detector

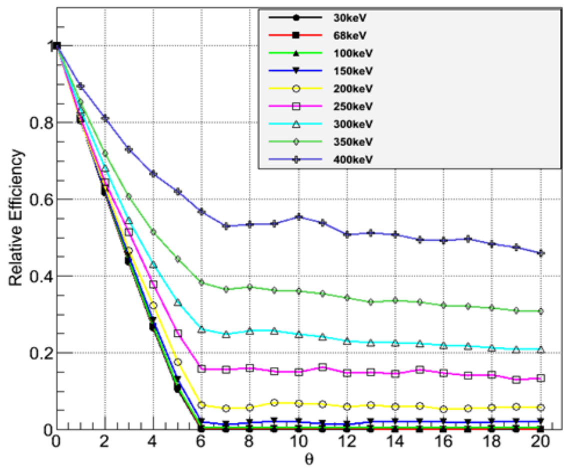


Position of incident X-ray:

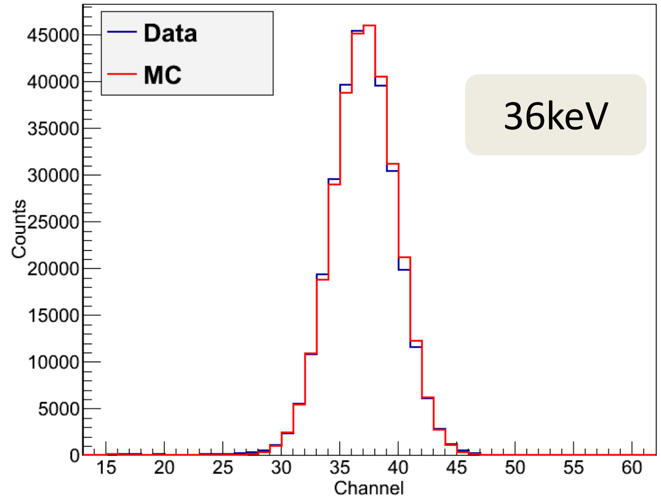


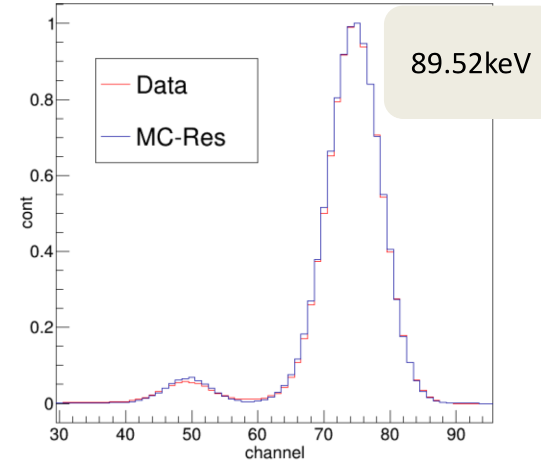
MC vs Data

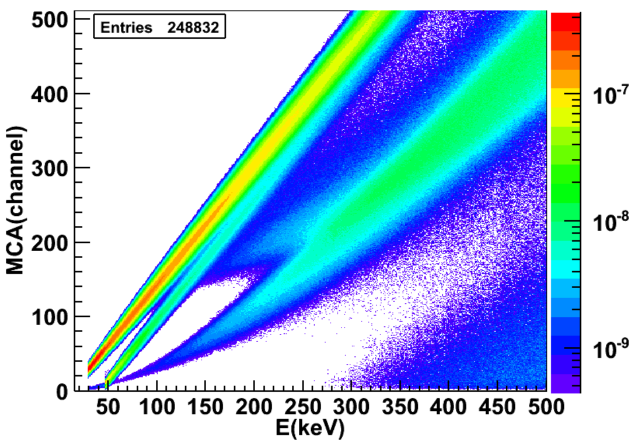
PSF of HE detectors



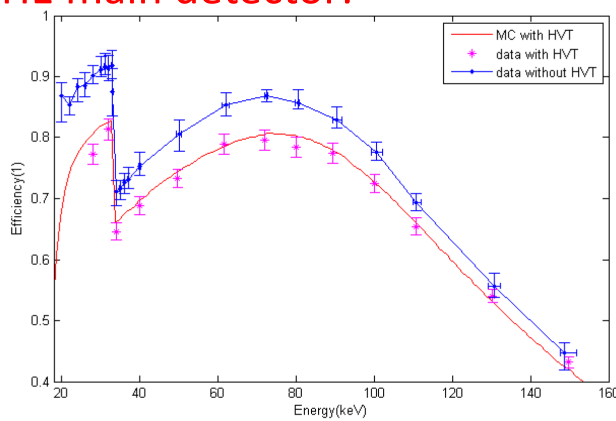
Energy spectrum of HE detector:



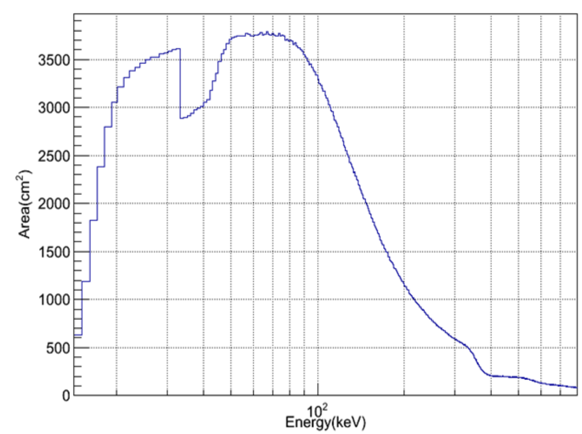




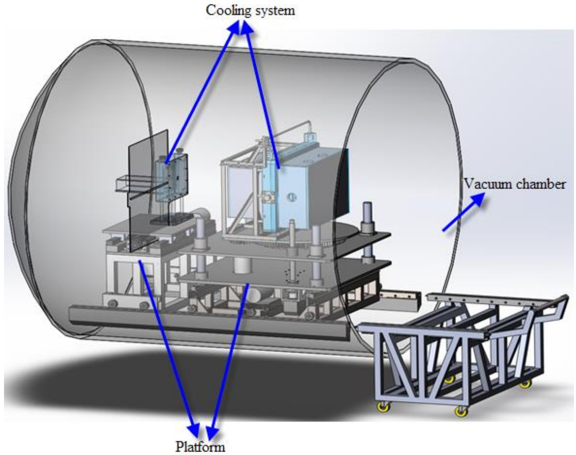
Efficiency of full energy peak of HE main detector:



Effective areas of HE detectors:

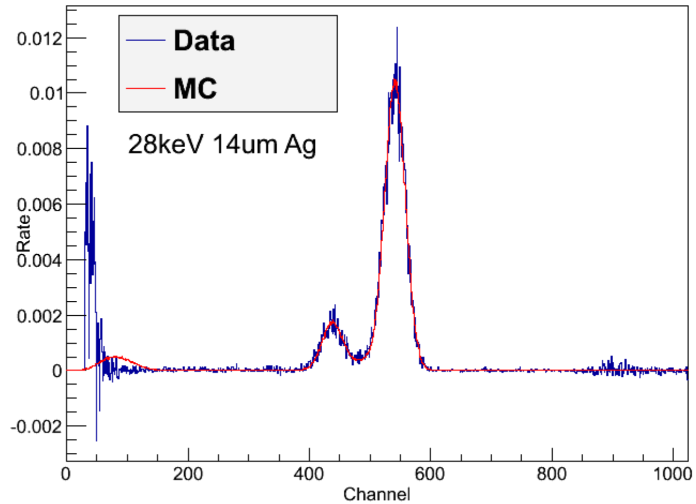


Ground Calibration and MC of ME

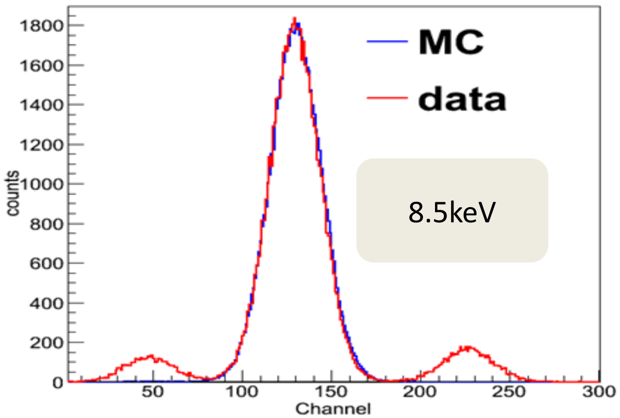


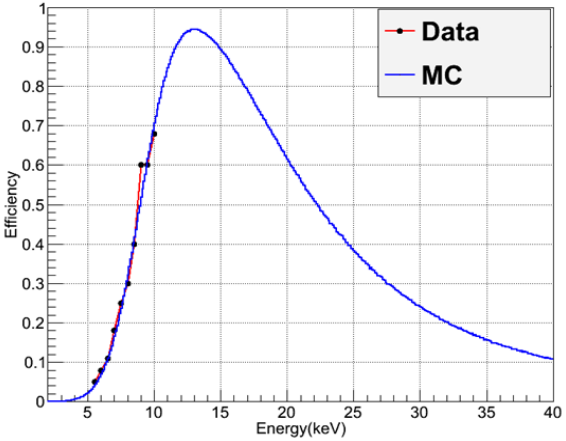
Schematic view of the calibration vacuum chamber

ME also used the double crystal monochromator for its calibration.



Energy Spectrum:

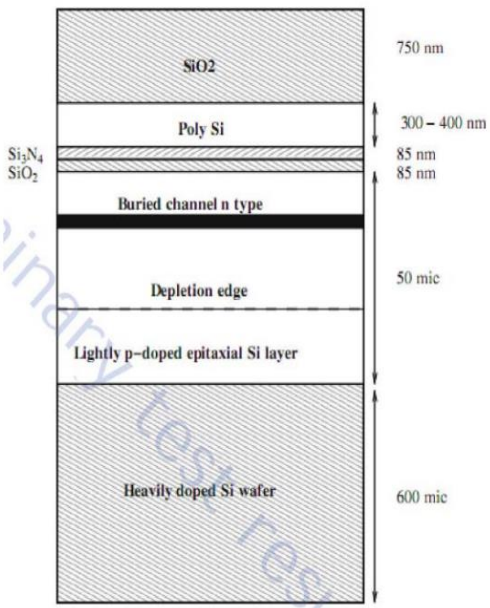




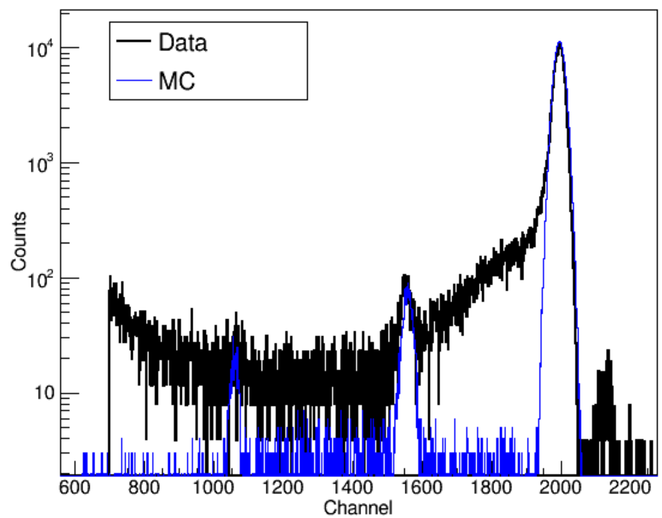
Efficiency

LE： Swept Charge Devices

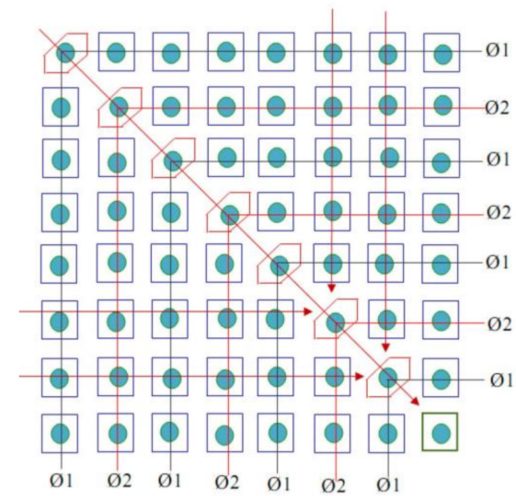
Materials in one pixel of LE:



Only take the interaction of X-ray and materials:



Readout mechanism of LE:



- **The process of charge transport in Swept Charge Devices is very important to understand the nature of the spectral distribution function, especially to explain the *shoulder on the left side of the main peak*. The events on the shoulder are almost split events.**
- **Simulation method of LE:**
  - **Interaction of X-ray and materials in LE (primary position of deposit energy, by Geant4) + charge transport (Analytical model)+ Readout mechanism of LE**

LE： Charge transport process

The method similar to Chandra and XRT (Townsley et al. 2002, Godet et al. 2009)
Reference: NIM A 428(1999)348-366

Depletion Region:

$$r_{\mathrm{i}} = 0.0044\left(\frac{E_{\mathrm{f}}}{1\ \mathrm{keV}}\right)^{1.75}\ \mu\mathrm{m} \qquad r_{\mathrm{d}} = 10^4\sqrt{\frac{2kT\epsilon_s}{e^2N_a}\ln\frac{d_d+\epsilon}{d_d-z_0+\epsilon}}\,\mu\mathrm{m}$$

$$Q_{ij}(x_0,y_0) = \frac{Q_0}{4}\left[\mathrm{erf}\left(\frac{a_{i+1}-x_0}{\sqrt{r_{\mathrm{i}}^2+r_{\mathrm{d}}^2}}\right)-\mathrm{erf}\left(\frac{a_i-x_0}{\sqrt{r_{\mathrm{i}}^2+r_{\mathrm{d}}^2}}\right)\right]\times\left[\mathrm{erf}\left(\frac{b_{i+1}-y_0}{\sqrt{r_{\mathrm{i}}^2+r_{\mathrm{d}}^2}}\right)-\mathrm{erf}\left(\frac{b_i-y_0}{\sqrt{r_{\mathrm{i}}^2+r_{\mathrm{d}}^2}}\right)\right]$$

Field Free Region:

$$Q_{ij}(x_0,y_0) = \frac{Q_0}{4\pi^{1/2}}\int_0^\infty \frac{\mathrm{d}\tau}{\tau^{3/2}}G_i(\alpha,\xi_0,\tau)G_j(\beta,\eta_0,\tau)\,S(\zeta,\tau)\exp\left(-\frac{\tau}{4\Lambda^2}\right)$$

$$G_i(\alpha,\xi_0,\tau) = \mathrm{erf}\left(\frac{\alpha_{i+1}-\xi_0}{\sqrt{\tau+\tau_d}}\right)-\mathrm{erf}\left(\frac{\alpha_i-\xi_0}{\sqrt{\tau+\tau_d}}\right)$$

$$S(\zeta,\tau) = \sum_{m=-\infty}^{\infty} C_m\,(\zeta-2m)\exp\left[-\frac{(\zeta-2m)^2}{\tau}\right]$$

Method 1 -> time consuming!

The method similar to Chandrayaan-2
(Athiray et al. 2012)

$$r_{\mathrm{ff}} = \sqrt{2d_{\mathrm{ff}}L\left[\tanh\left(\frac{d_{\mathrm{ff}}}{L}\right)-\left(1-\frac{z_0-d_{\mathrm{d}}}{d_{\mathrm{ff}}}\right)\tanh\left(\frac{d_{\mathrm{ff}}-z_0+d_{\mathrm{d}}}{L}\right)\right]}$$

$$r = \sqrt{r_{\mathrm{i}}^2+r_{\mathrm{d}}^2+r_{\mathrm{ff}}^2}$$

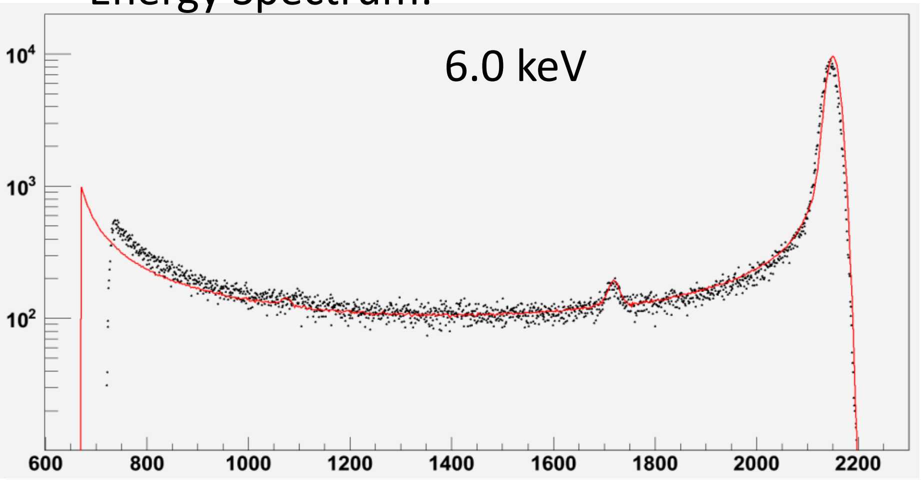
$$Q_{ij}(x_0,y_0) = \frac{Q_0}{4}\left[\mathrm{erf}\left(\frac{a_{i+1}-x_0}{r}\right)-\mathrm{erf}\left(\frac{a_i-x_0}{r}\right)\right]\left[\mathrm{erf}\left(\frac{b_{i+1}-y_0}{r}\right)-\mathrm{erf}\left(\frac{b_i-y_0}{r}\right)\right]$$

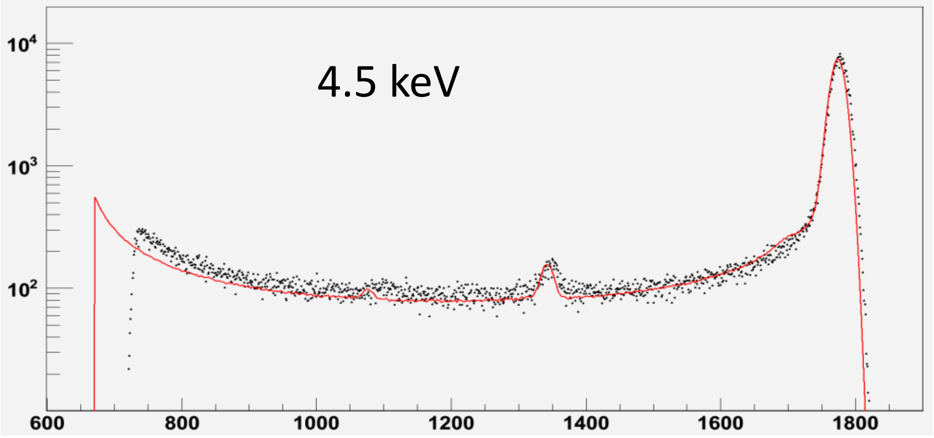
Method 2

Some results of LE

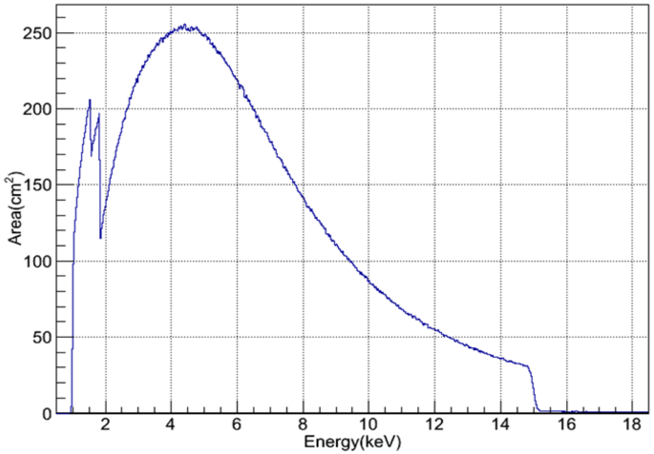
Geant4 simulation+ Charge Transport+ Readout Mechanism

Energy Spectrum:

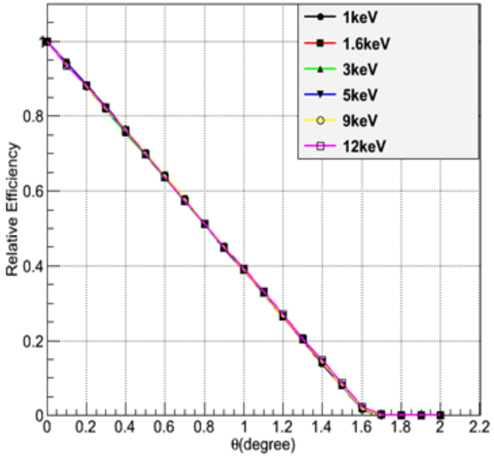




Effective areas of LE detectors:

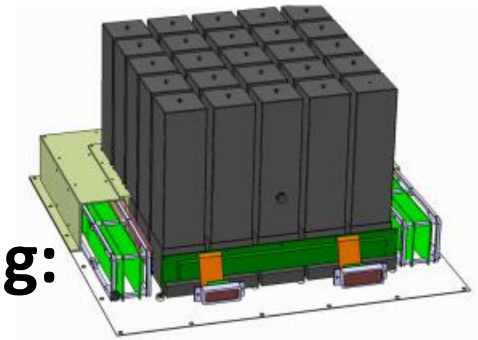


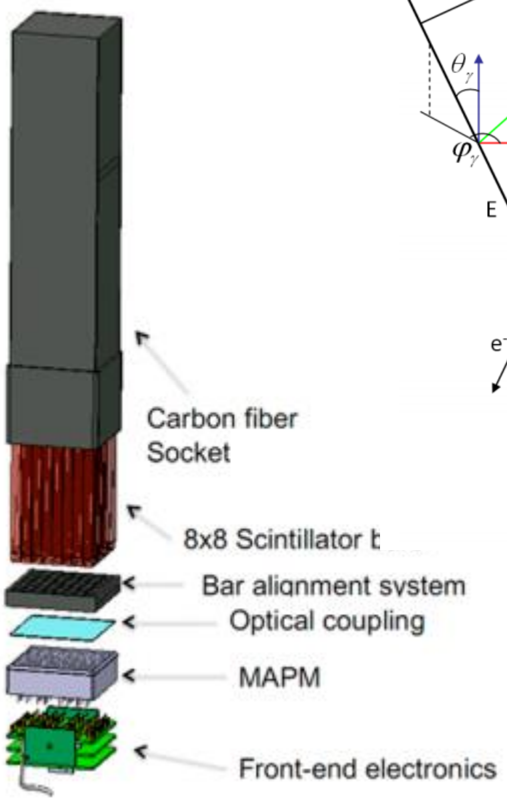
PSF:

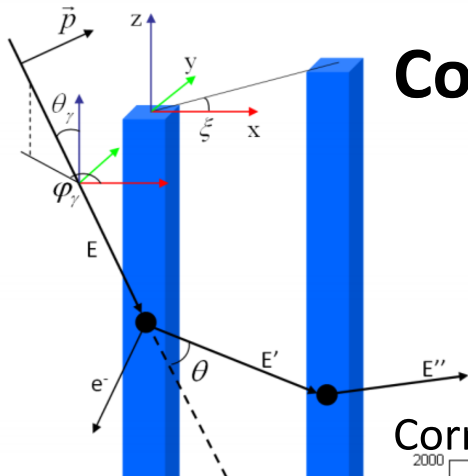


POLAR: Gamma-ray Burst Polarimeter

- **Determine polarization by direction distribution of photon Compton scattering**
- **1600 channels (5×5 modules, 8×8 bars per module)**
- **Energy range 50 - 500 keV**



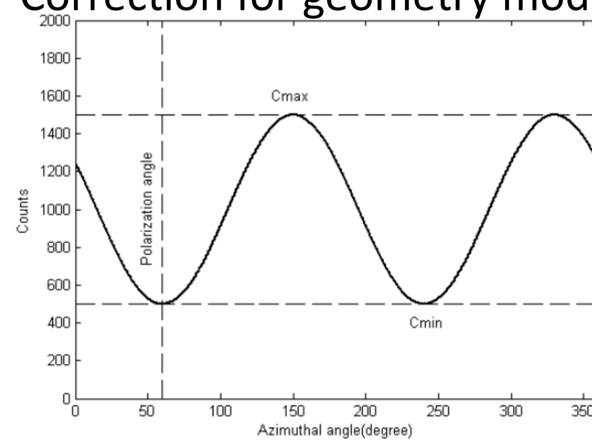




Compton scattering:

$$\frac{d\sigma}{d\Omega} = \frac{r_0^2}{2}\varepsilon^2[\varepsilon + \varepsilon^{-1} - 2\sin^2\theta\cos^2\eta]$$
$$= \frac{r_0^2}{2}\varepsilon^2[\varepsilon + \varepsilon^{-1} - \sin^2\theta + \sin^2\theta\cos(2(\eta + \frac{\pi}{2}))]$$

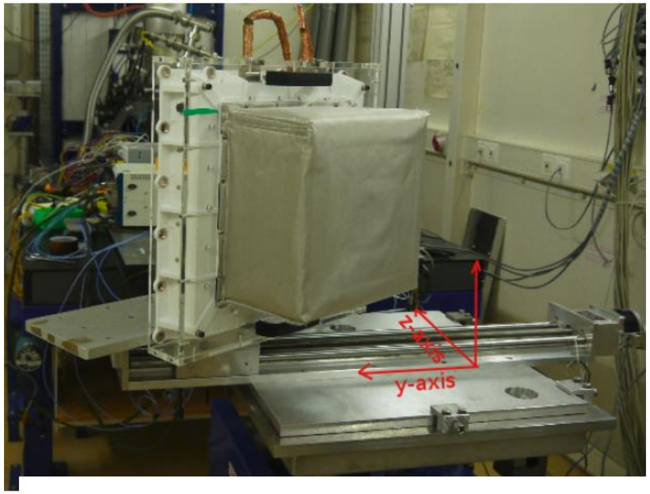
Correction for geometry modulation

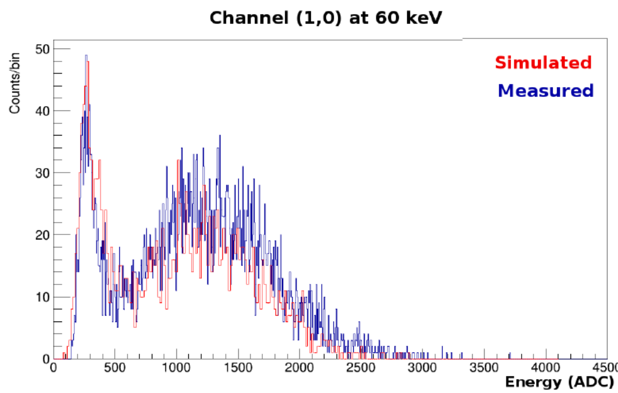


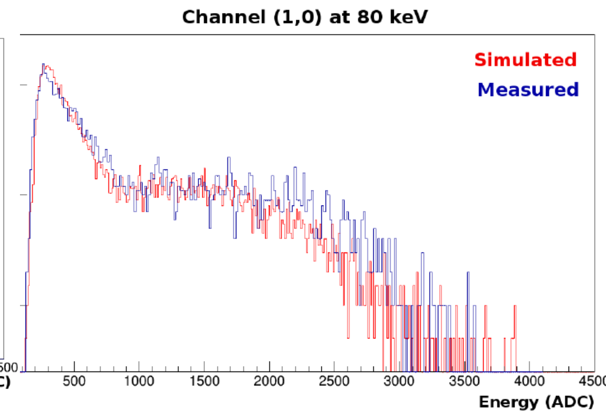
$$\mu = \frac{C_{max} - C_{min}}{C_{max} + C_{min}} = \frac{A}{B}$$

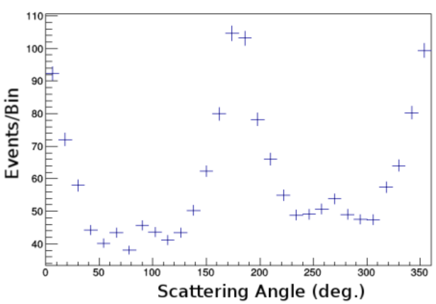
$$\Pi = \frac{\mu}{\mu_{100}}$$

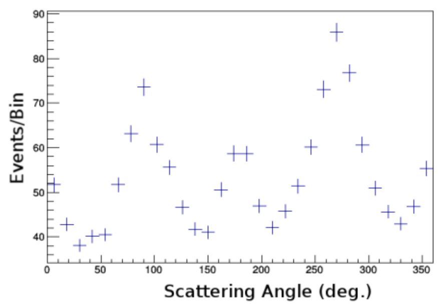
ESRF on-Ground data vs MC

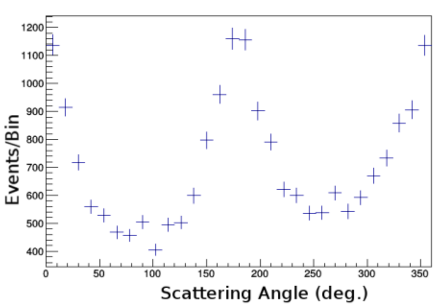


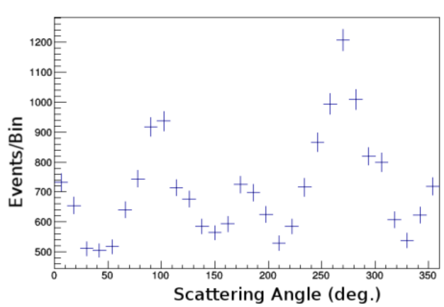












Geant4 simulation + digitization of electronics

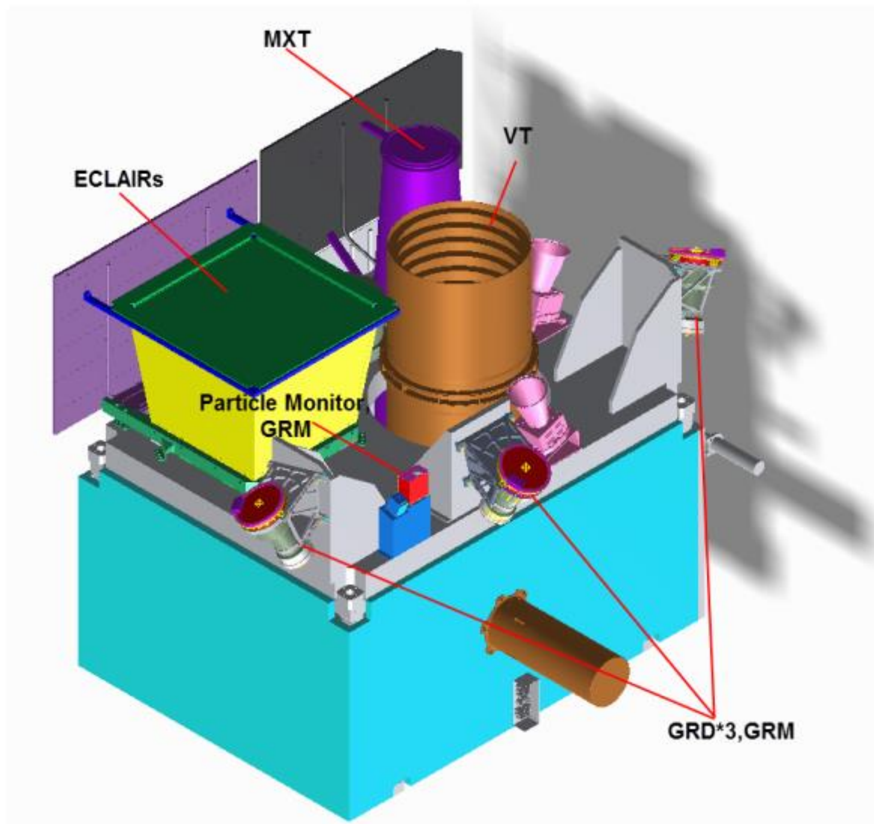
Reproduce the on-Ground data

Use the simulation + digitization software to generate the in-orbit geometry modulation curve and the μ_{100} of GRBs

Plots are from M. Kole's paper, preparing

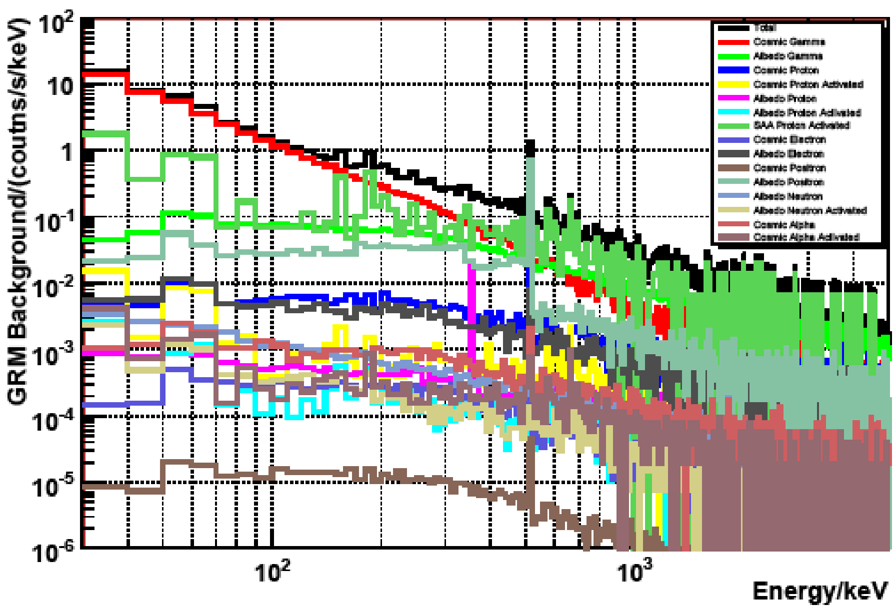
SVOM/GBM

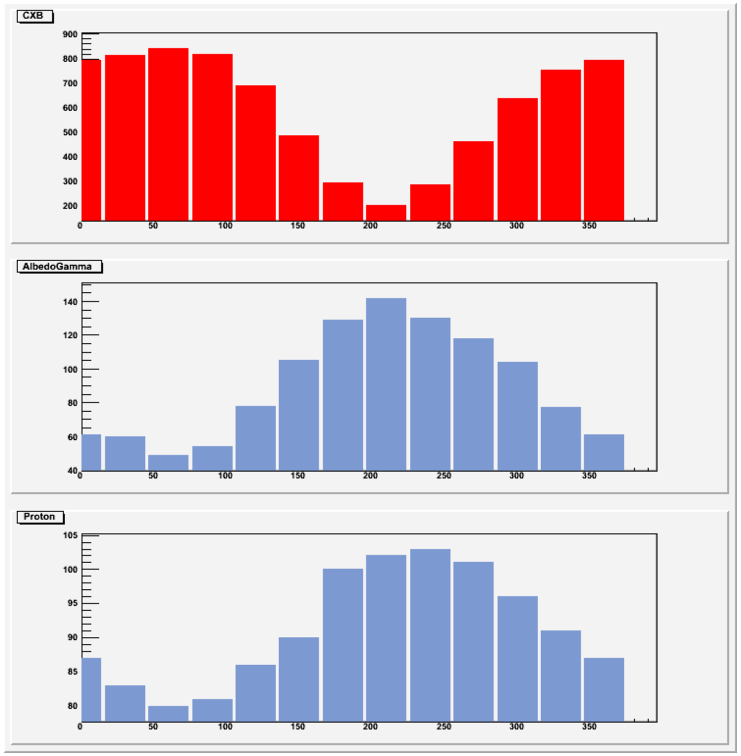
- Space-based multiband astronomical Variable Objects Monitor
- Orbit: ~635km, 30°
- GBM: 15-5000 keV
  - 3 GRDs
  - PS/NaI detector



Background simulation of SVOM

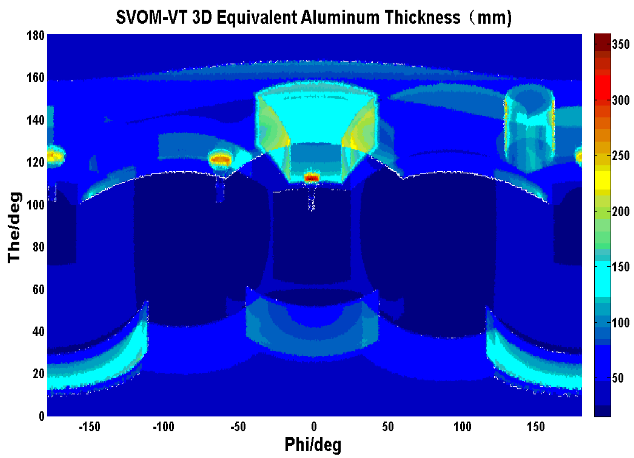
Component	Count rate(count/s)
CXB (prompt)	795
Albedo Gamma (prompt)	61
Cosmic Proton (prompt/delayed)	87/22
SAA (delayed)	116
Cosmic Electron (prompt/delayed)	5.97/0.048
Albedo Neutron (prompt/delayed)	1.08/0.67
Total	~ 1088

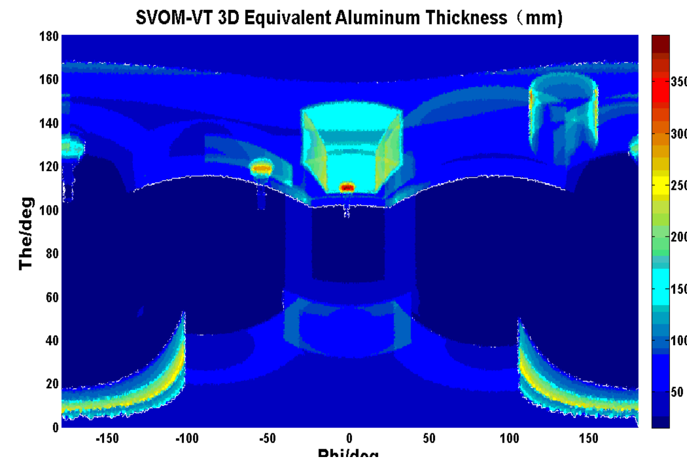


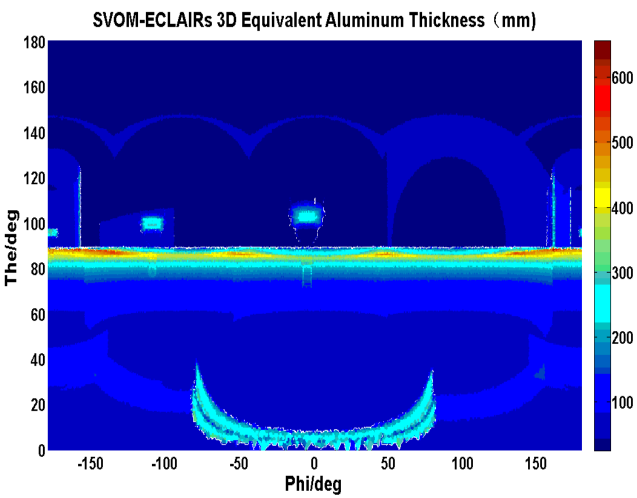


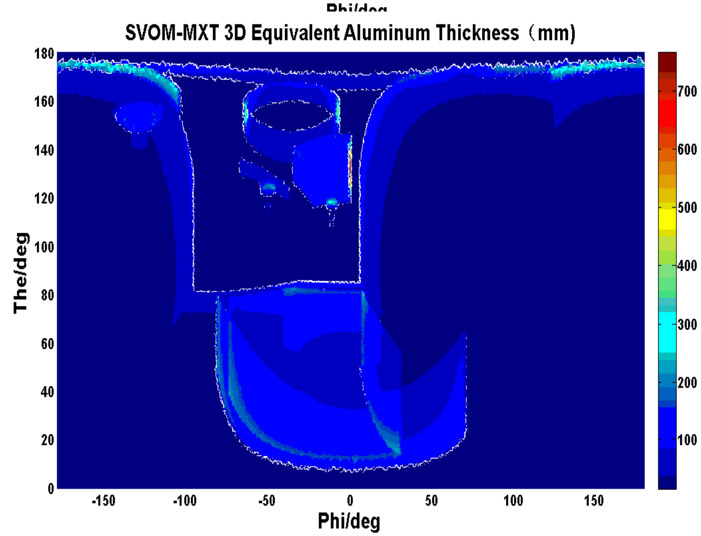
Bkg variation with zenith angle

3D equivalent aluminum thickness based on simplified mass model used for Total Ionization Dose

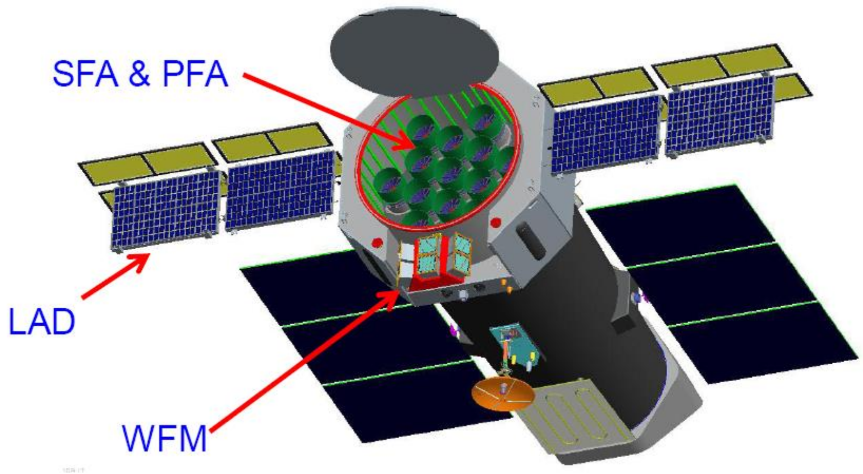






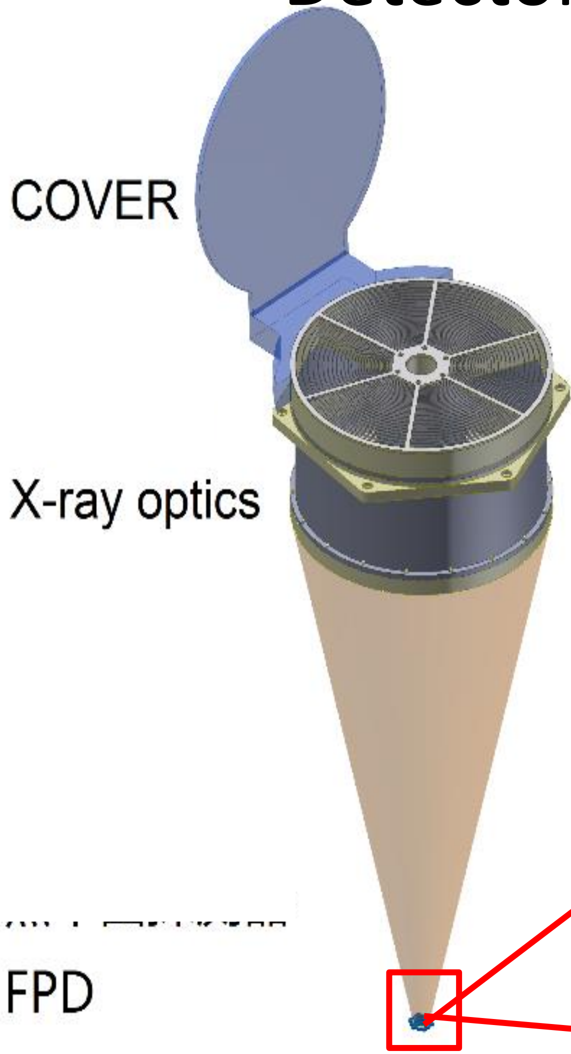


enhanced X-ray Timing and Polarimetry (eXTP)

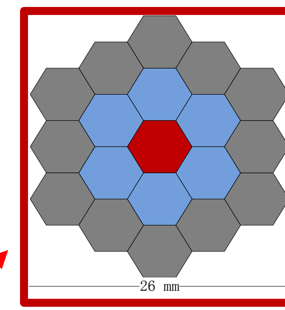


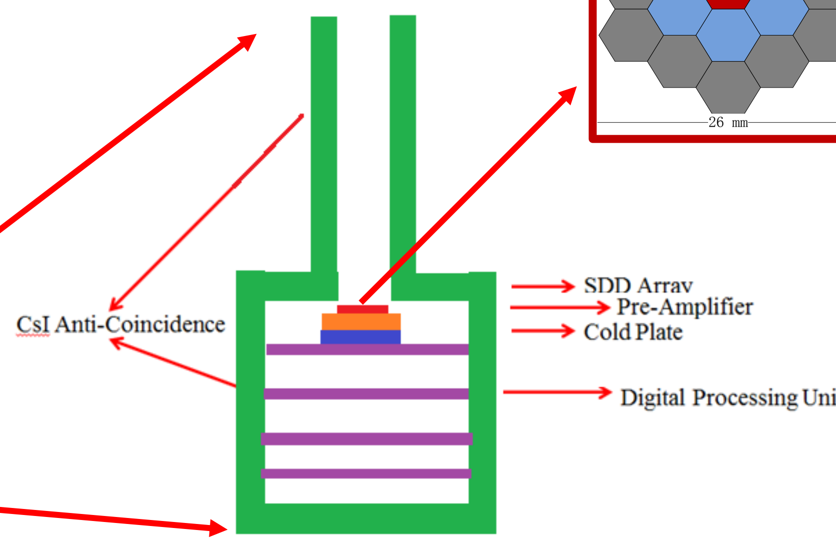
Payload	Configuration	Optics	Detectors
Spectroscopic Focusing Array (SFA)	9 telescopes	Nickel/SGO	SDD
Large Area Detector (LAD)	40 modules	MCP collimator	SDD
Polarimetry Focusing Array (PFA)	4 telescopes	Nickel	GPD
Wide Field Monitor (WFM)	6 cameras	1.5D coded mask	SDD
Gamma Ray Burst Monitor (GRM) (optional)	3 units	-	Scintillator

Preliminary configuration of SFA Focal Plane Detector used for simulation



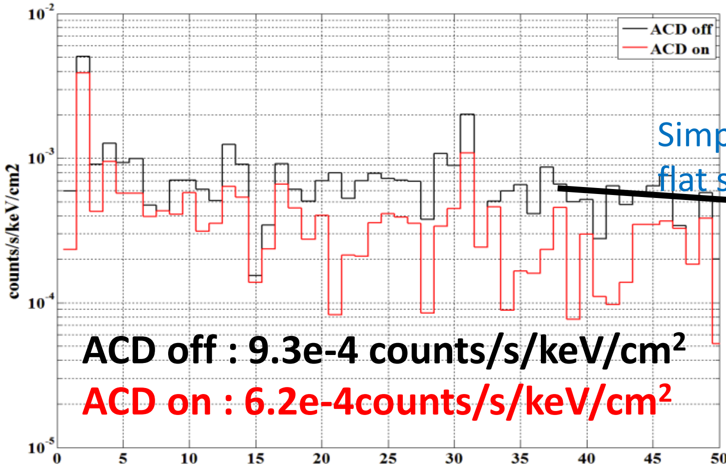
Pixelized SDD detector.
Hexagon pixels of a side length of 3.2 mm, 26.6 mm^2, 15.5 $arcmin^2$. The full FOV is 19’ in diameter.





A simple configuration of the FPD unit

Particle Background Level Estimate using Geant4

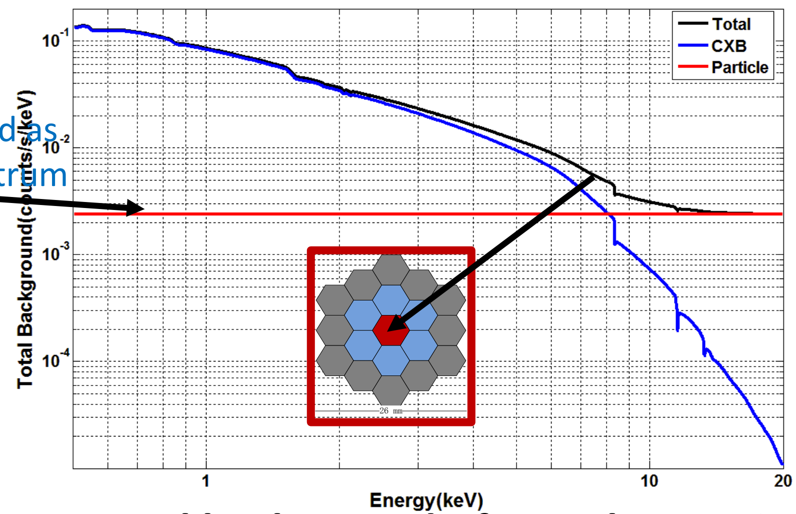


ACD off : 9.3e-4 counts/s/keV/cm^2

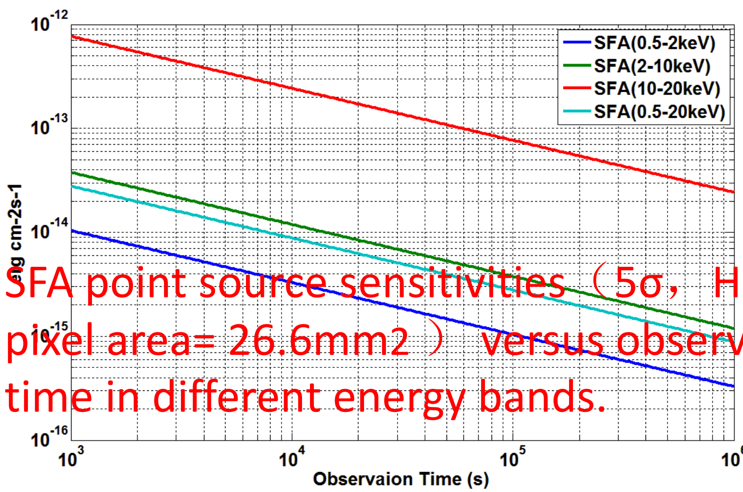
ACD on : 6.2e-4counts/s/keV/cm^2

Simplified as flat spectrum

Charged particle background level



Total background of SFA observations of point-like sources.pixel size (26.6mm^2) is comparable with the size of PSF (W90)



SFA point source sensitivities（5σ，HPD=1’, pixel area= 26.6mm2 ） versus observation time in different energy bands.

summary

- **Simulations of the bkg level, spectrum, components ratio, variation modulated by orbit are useful to determine the performance and bkg reconstruction on orbit.**
- **The Response Matrix benefit from simulations of detector response to x-ray when using limited energy points especially in high energy range.**
- **Detailed and accurate simulation and verification experiment are needed to achieve optimized design of FPD with lower bkg. For example, grade-Z shielding or low energy secondary charged particle shielding.**