New concept of Si semiconductor Compton Camera

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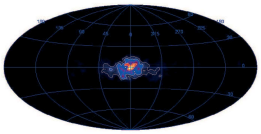
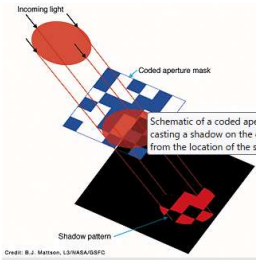
1. DM signal from the Galactic center

Dark matter signal from the Galactic center is promising for Gamma-ray Astronomy.
Currently, INTEGRAL satellites detected 511 keV diffuse gamma-ray emission from the Galactic center.
However, angular resolution is > 1 degree, and thus contribution from astronomical sources cannot be distinguished. In the near future, COSI satellite will observe withbetter sensitivity, but the angular resolurtion is still > 1 degree. **Good angular resolution of < 1 degree is important to constrain the DM signal.**



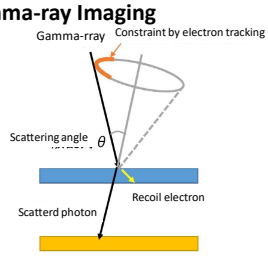
511 keV emission from the Galactic plane observed with INTEGRAL satellite(Knoldseder et al. 2005)

2. Previous Gamma-ray Imaging



Coded Mask

Good angular resolution of several arcmin.
Not good sensitivity due to background event.
Field of view (FOV) is limited.
e.g. INTEGRAL, Swift/BAT



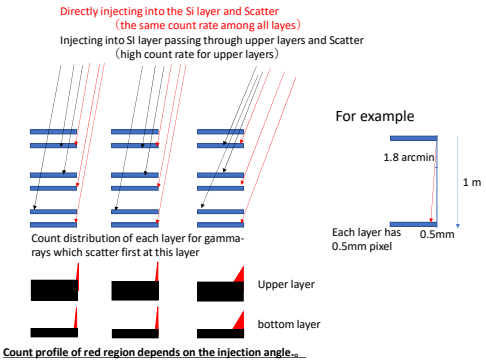
$$\cos\theta = 1 - \frac{m_e c^2}{E_2(E_1+E_2)}E_1$$

Compton Reconstruction

Not good angular resolution of several degree.
Good sensitivity by background rejection.
FOV can be large.
e.g. CGRO/OSSE, Hitomi/SGD, COSI

3. New concept:

Multi-Column Compton Camera (MCCC)

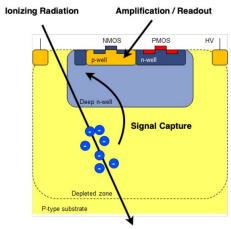


Count profile of red region depends on the injection angle.

This is a 2-dim array of columns of Si semiconductor sensors. Each column is a Compton camera. When gamma-rays enter without inclination against the vertical direction, they pass through some layers and scatter. On the other hand, when gamma-rays enter with an inclination angle agaist the vertical direction, some gamma-rays directly enter all layers and scatter. The count distribution of such scattering in each layer depends on the inclination angle.Fo3r example, in the case that the position resolution of Si sensors is 0.5 mm and the height of column is 1 m, we can distinguish 5/10000 rad = 0.03 deg = 1.8 arcmin by measuring the count distribution of each layer, Gamma-rays with an energy of several 0.1 to several MeV will scatter in multiple positions in this system, but the first scattering positio can be derived by Compton reconstruction. Photon statistics of counts in each leyer is poor,and thus as many layers and columns as possible are needed.

Good angular resolution.
Good sensitivity by background rejection.
FOV: small for good angular resolution
large for normal Compton mode.

4. HV-CMOS: AstroPix for MCCC



Version 3:
0.5mm*0.5mm pisel
2 x 2 cm2 (35 x 35 pix2)
1.06 mW/cm2
CSA, TOT output
0.5mm thickness

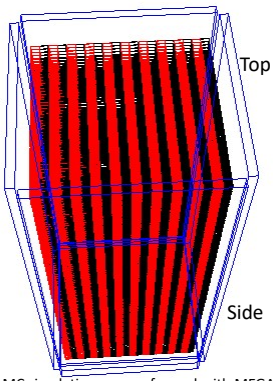
MCCC needs many Si sensors with moderate position resolution.

DSSDs need external signal processing circuits which consume much power and the external circuit is not preferred to construct this system.

Normal CMOS sensors have good position and thus power consumption is large. On the other hand, one of HV-CMOS sensors and they are not sensitive to Compton scattering,

AstroPix, is bein g developed, This has a moderate position resolution. Supplying several 100 V bias, ful depletion of 0.5 mm thickness can be available, leading to being sensitive to gamma-ray. Tartget power is <1mW/cm2. Therefore, AstroPix is a good candidate for this system. (Steinhebel et al. 2022, SPIE 12181, 121816Y),

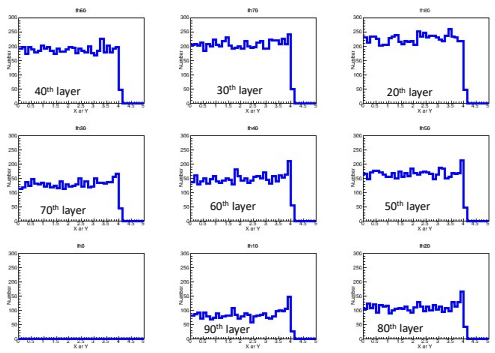
5 . MC simulation with MEGALib



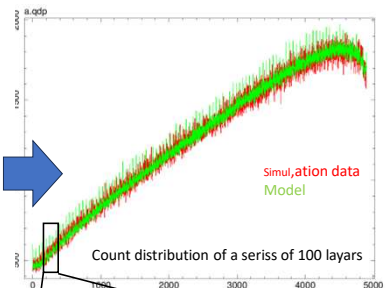
Simulation geometry :
0.5mm pixel, 1cm*1cm sensor
10x20 sensors for each layer
X direction; 10 sensors with 1cm separation
Y-direction: 20 sensors no gap.
100 layers within 60 cm height.
CZT 1cm sensors surround Si sensors for 4 sides and bottom

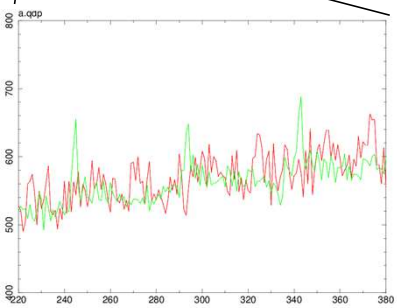
.**600 keV** gamma-ray injection.

MC simulation was performed with MEGALib, which is a Geant 4 based simulator kit. In addition, MEGALib proveds a Compton reconstruction algorith. Gamma-rays are injected from the top side with various inclination angle. Based on hits information, Compton reconstruction is performed to obtain the first scattering point. Hereafter, this first scattering points are used for analysis.



Count distribution of the first scattering points n in the X direction for each layer. Y-direction counts are projected. Counts in10 sensrs are added.

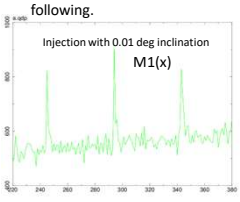


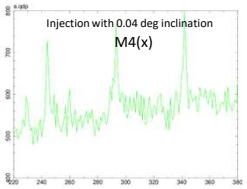


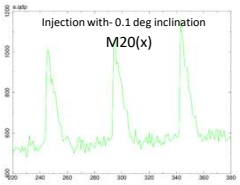
Fitted with $\sum_i AiMi(x)$

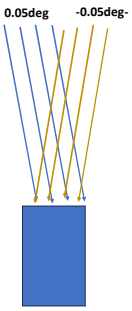
Plot each coefficient Ai obtained by fitting.

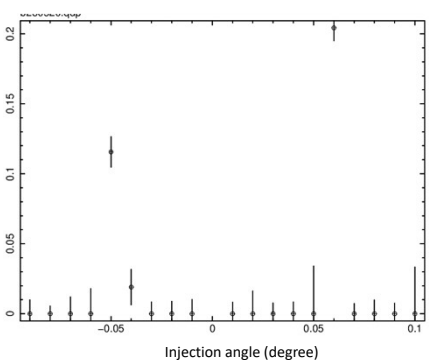
Mi(x) is the response of gamma-ray injection with various inclibnation angle as shown in the following.











600 keV gamma-rays are injected with 0.05 deg and -0.05 deg inclination simultaneously. Count distributions of the first scattering points in each layer are fitted as shown in the right. Then, we obtained the gamma-ray injection distribution as shown above. Two sources with a separation of 0.1 deg can be distinguished by this system.