Simulation study of the 511 keV annihilation line observation with the Soft Gamma-ray Detector onboard ASTRO-H

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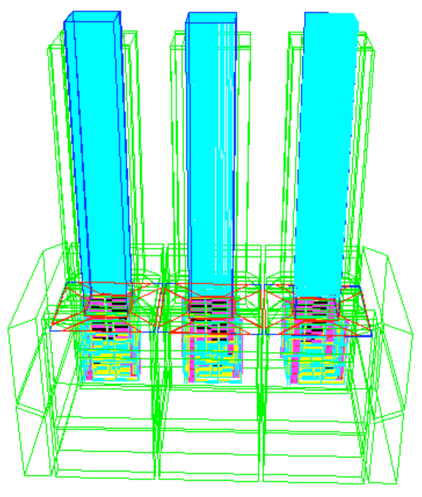
International Workshop on Positrons in Astrophysics
March 20-23, 2012 - Mürren, Switzerland

1. Introduction

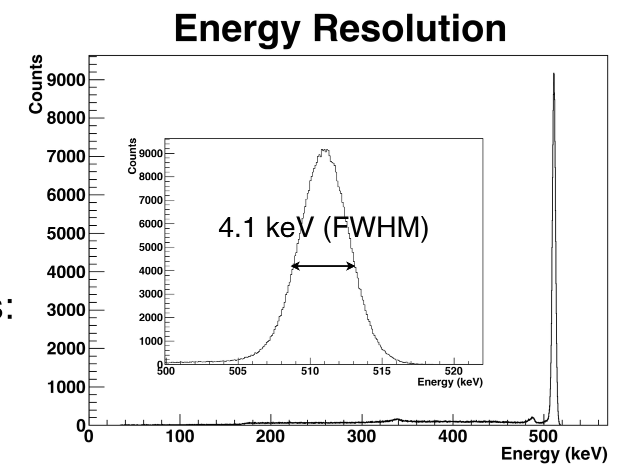
The 511 keV annihilation line is the one of the key targets of the Soft Gamma-ray Detector (SGD) onboard ASTRO-H. The soft gamma-ray band, including the 511 keV annihilation line, is less explored than the hard X-ray or GeV gamma-ray bands, due to 1) high in-orbit background and 2) low detection efficiency. To overcome these observational difficulties, the SGD adopts a new concept of "narrow field-of-view (FOV) Compton camera". In order to study the SGD performance at 511 keV, we conducted detailed Monte-Carlo simulations with full implementation of the detector mass model and event analysis, considering realistic activation background estimation based on the radiation environment at the low Earth orbit.

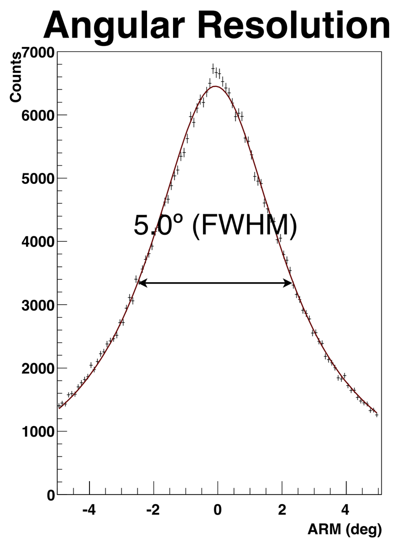
SGD performance at 511 keV



- -- Energy Resolution: 4.1 keV
- -- Angular Resolution: ~5.0 deg
- -- Effective Area: 2.7 cm²
- -- Background: 2-4x10^{-5} counts/sec/keV

In the simulations, we assumed following parameters:
-- Obserbation time: 1Msec
-- Energy cut range: 511.0 ± 4.1 keV
-- Theta cut range: -5.0 - 5.0 deg





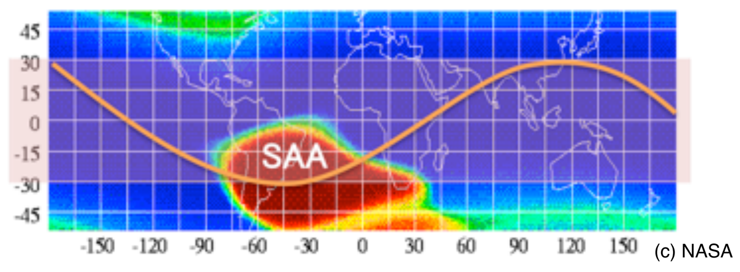
→ H. Odaka's talk on Friday

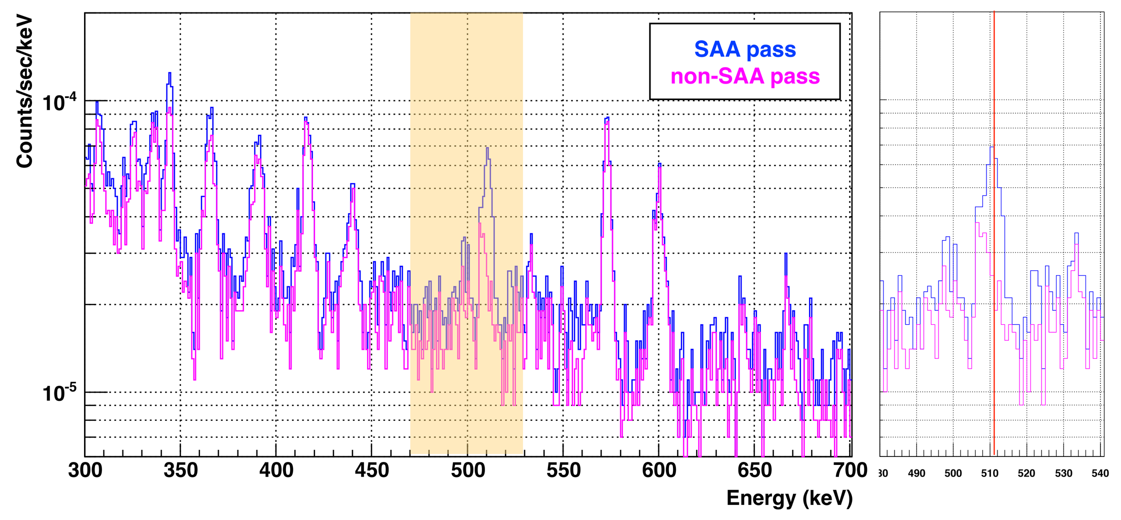
2. How to reduce the backgrounds?

There are many background / noise origins

-- Proton, CXB, etc... coming from outside of the line of sight toward the target
-- Photon escaped from the detector after Compton Scattered by the detector
-- Gamma-rays or electrons emitted by the radioisotopes generated inside the detectors themselves due to **radioactivation** by trapped protons (**the most dominant background origin for the 511 keV observation**)

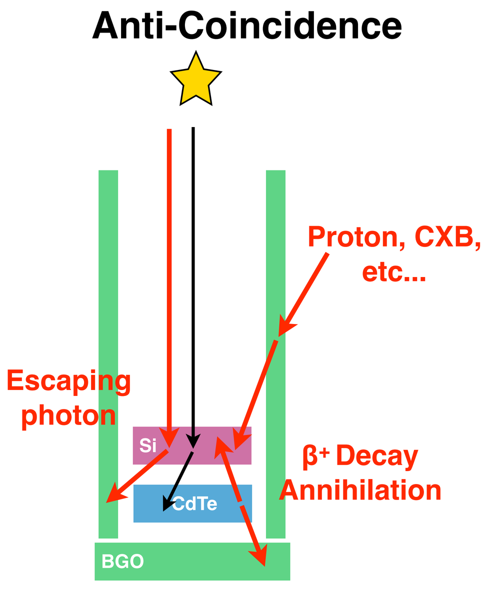
Soon after the satellite passes the SAA (South Atlantic Anomaly), the detector material is radioactivated, resulting in high background level at 511 keV. In this simulation, in order to achieve higher sensitivity, we selected the events 30000 sec after passage of the SAA.



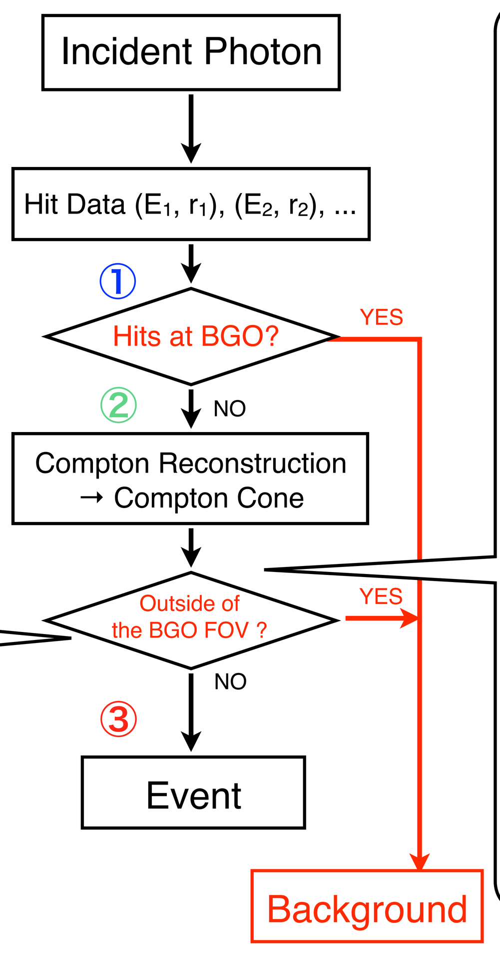


The SGD achieves high sensitivity by the powerful background rejection

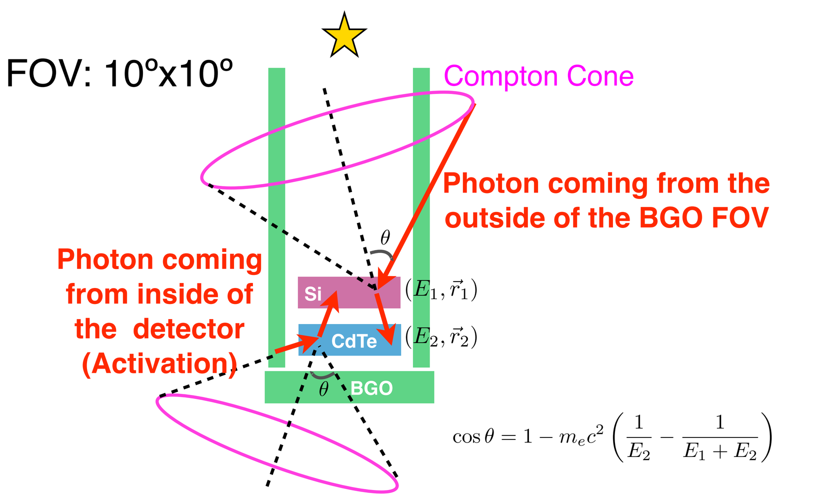
Narrow FOV



When SGD detects an event including some BGO hits, this event is rejected as background.



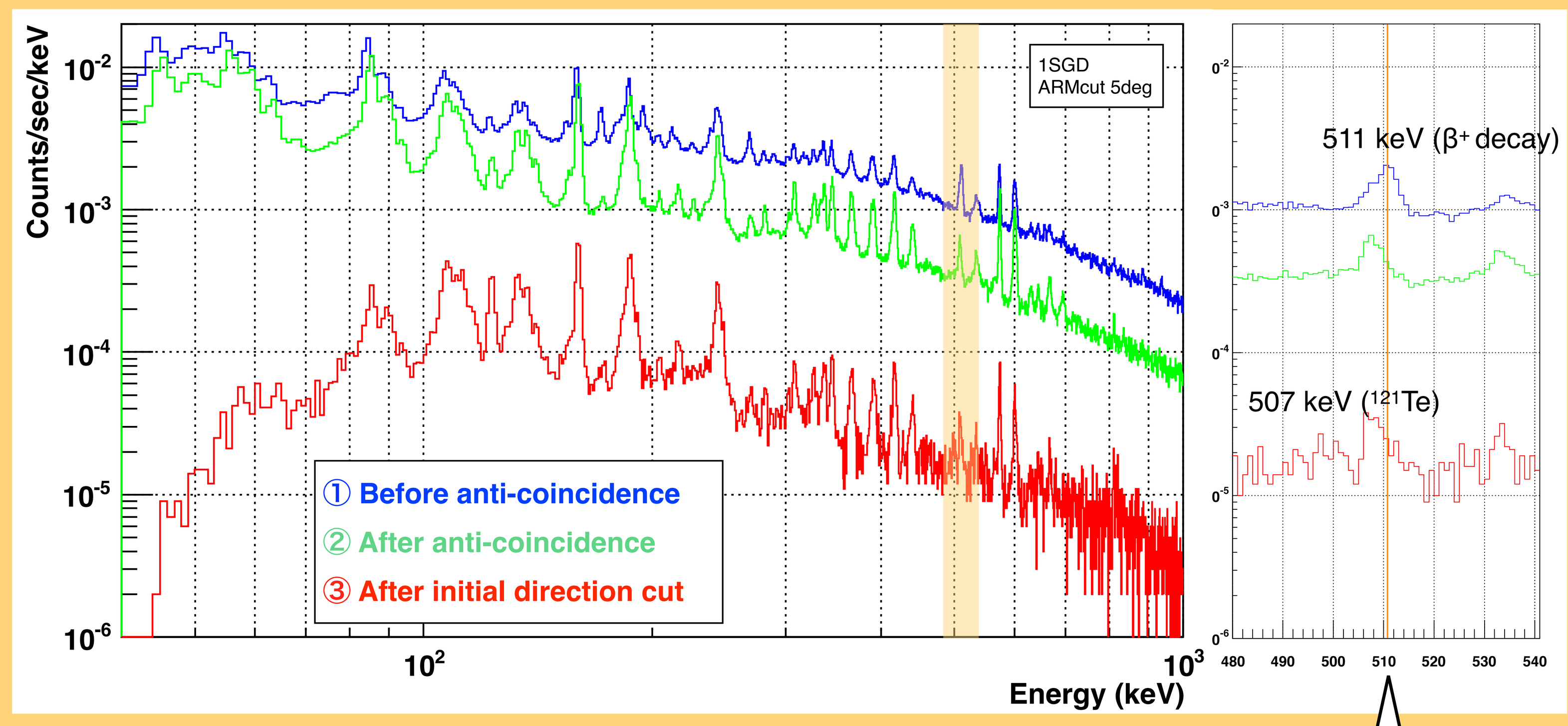
Compton Camera



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

By using the information on deposited energy and interacted positions, we can limit the incident direction of the photon that is consistent with the Compton Kinematics (Compton Cone). If this direction is not in the BGO FOV, this event will be rejected as background.

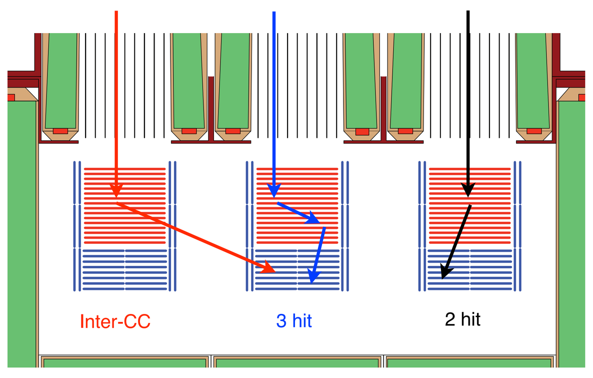
Simulated Background Spectrum (non-SAA pass)

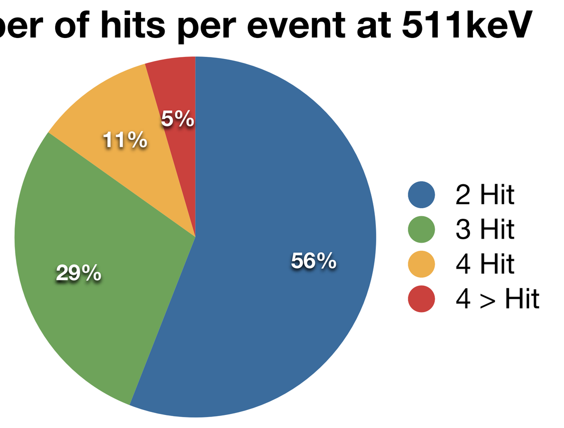


Background is suppressed by 1/20 with Compton Reconstruction

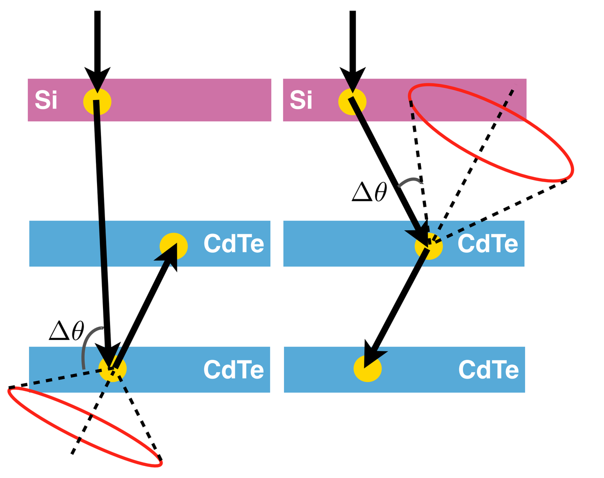
One β+ decay positron annihilates into two 511 keV lines. Background rejection efficiency of the active shields for such events is better than that for fluorescence lines or Gamma decay lines.

3. To Improve the Detection Efficiency





Si-CdTe-CdTe event reconstruction

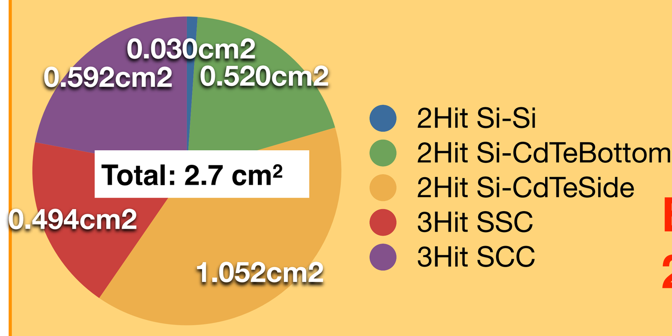


The Si hit is regarded as the first Compton scattering. 2 possibilities Si-CdTe₁-CdTe₂ and Si-CdTe₂-CdTe₁ are compared in the point of view which is more physically consistent. By reconstructing each last two CdTe-CdTe events regarding the first Si hit as the source, we can calculate the Δθ (ARM). We choose the possibility of which Δθ is smaller than the other.

3 or more hit Compton Events

When the incident photon energy is high (> 400 keV), the ratio of number of 3 or more hit events to the number of 2 hit events becomes larger. Currently, Si-Si-CdTe (SSC) events and Si-CdTe-CdTe (SCC) events are included in the analysis.

Effective Area at 511 keV



Effective Area: 2.7 cm² (Total)

Effective area is highly improved by using the 3 hit Compton Events

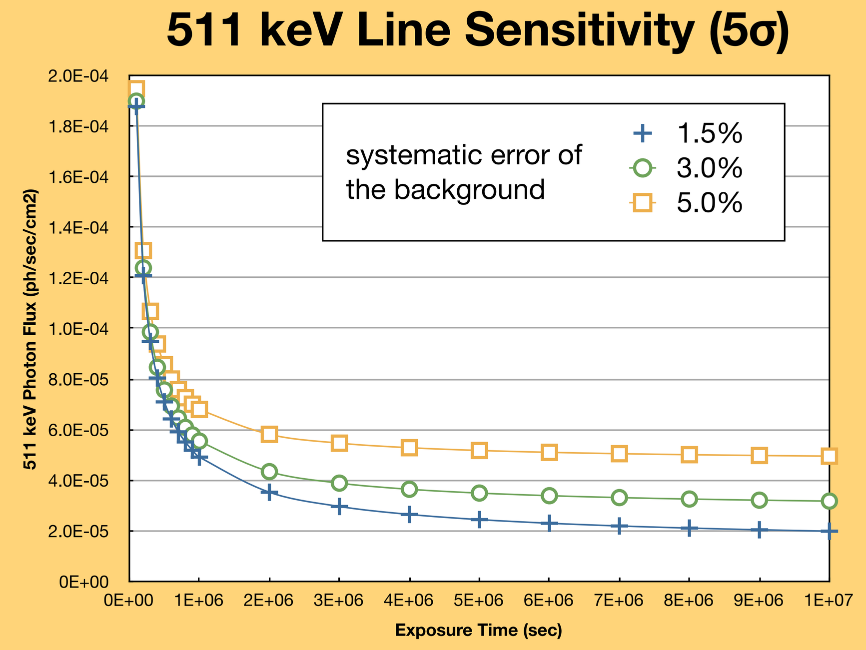
4. SGD Sensitivity for the 511 keV Line

The sensitivity of the SGD for the 511 keV annihilation line reaches to the 5-7x10^{-5} ph/sec/cm² with exposure of 1 Msec (depends on the systematic error of the background).

511 keV candidates

Source	511 keV Flux (10^{-5} ph/cm²/sec)
GC, bulge	100
GC, Disk	47
LMXB	~1
BH Binary	40 (Cyg X-1)
Nova	10

511 keV Line Sensitivity (5σ)

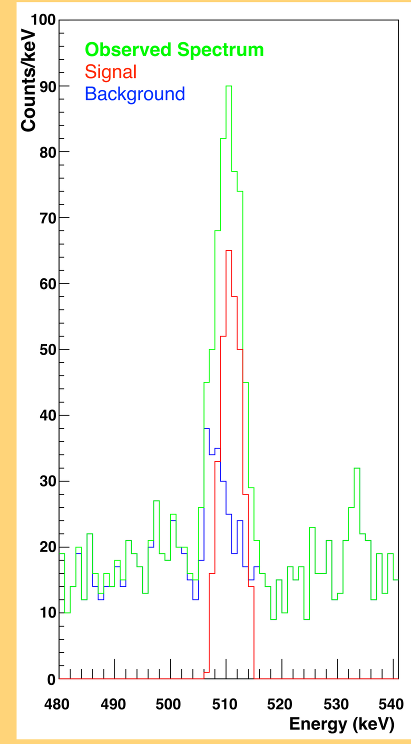


non-SAA pass
Energy cut range 511.0 ± 4.1 keV
(based on 1 Msec simulation data)

Case: Galactic Center

Galactic Center Bulge Region
Radius: 3 deg
Flux: 1x10^{-3} ph/sec/cm²
Line width: 2.4 keV (FWHM)
Exposure: 1 Msec

24σ Detection



5. Conclusions

- **The Background rejection technique for the SGD reduces the activation background count by 1/100.**
- **The SGD will enable precise measurement of 511 keV line flux from the GC bulge.**
- **The SGD 1Msec sensitivity for the 511 keV annihilation line will be ~5x10^{-5} ph/cm²/sec.**