Study on light collection method of on-board anti-coincidence scintillation counter for SMILE-3

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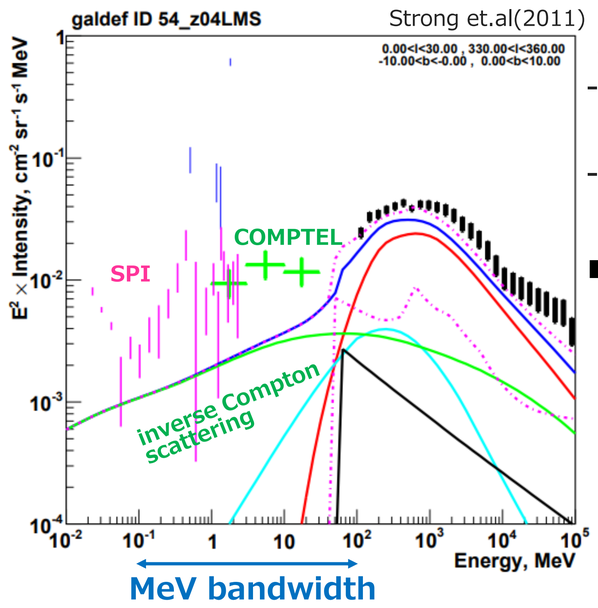
1.Introduction



➢ Continuous component in the MeV bandwidth(0.1-100MeV)

- Observations excess the model of inverse Compton scattering
- No known astronomical species can account for this radiation

■ Possible Candidates for Identity

- Uncertainty in interaction of cosmic rays with the interstellar medium
- Collection of many celestial bodies
- Dark Matter
- Primordial Black Holes

Examining its spatial morphology provides insight into its origin

➢ COMPTEL Observation Schoenfelder et.al(1999)

- All-sky observation in the MeV region
- **32 steady sources** were detected
- **31 gamma-ray burst (GRB)** were detected

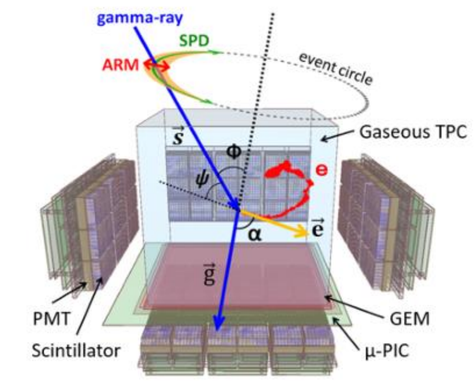
} Half of the objects observed by COMPTEL are GRB

2.SMILE-3 Project

Sub-MeV/MeV gamma-ray Imaging Loaded-on-balloon Experiments

-Balloon observation using Compton camera to observe the galactic center for about 1 day

➢ Electron-Tracking Compton Camera(ETCC)

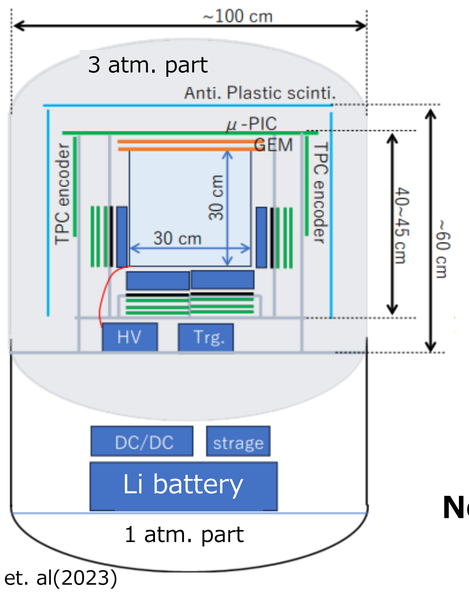


■ **Gas Track Detector**
Compton recoil electron tracks and energies

■ **Pixel Scintillator Array**
Absorption points and energies of Compton-scattered gamma rays

- Uniquely determines energy and direction of arrival
- Reconstruction of incident gamma-ray for each event

➢ SMILE-3 equipment configuration



Takada et. al(2023)

ETCC size: about 50 cm

The number of charged particles is large compared to the number of gamma rays, and they become noise and interfere with the analysis

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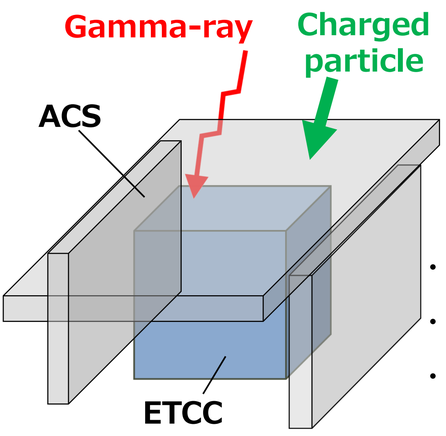
Need a system to detect charged particles

3. Anti-Coincidence Scintillation Counter System (ACS)

5 sides around the ETCC are covered with scintillators of about 60 cm each side

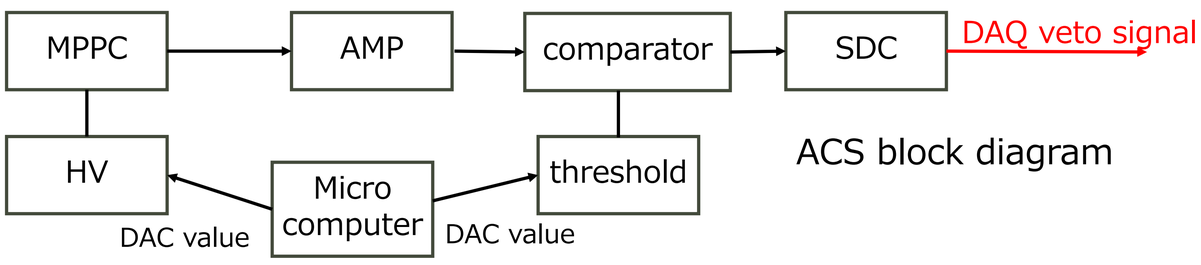


■ Detection of charged particles
→ veto as background event

■ Detection of increase of gamma-ray counts
→ capable of detecting GRBs

➢ Request to ACS

- charged particle detection efficiency : 99%~99.99%
- charged particle: to be detected with ionizing loss
- gamma ray: pass through a scintillator and are detected by ETCC
- rise time jitter: 3~5ns
- lightweight and compact signal readout device



ACS block diagram

4. Bread Board Model of ACS

➢ Plastic scintillator

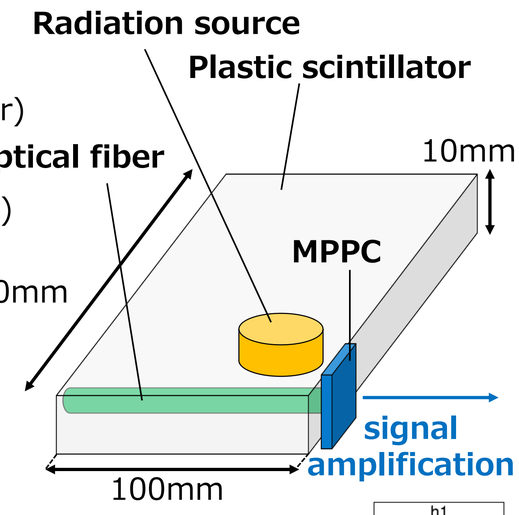
- Type No. : EJ-200 (Eljen)
- size: 100*200*10 mm
- light read position: 2-mm from the top (optical fiber)

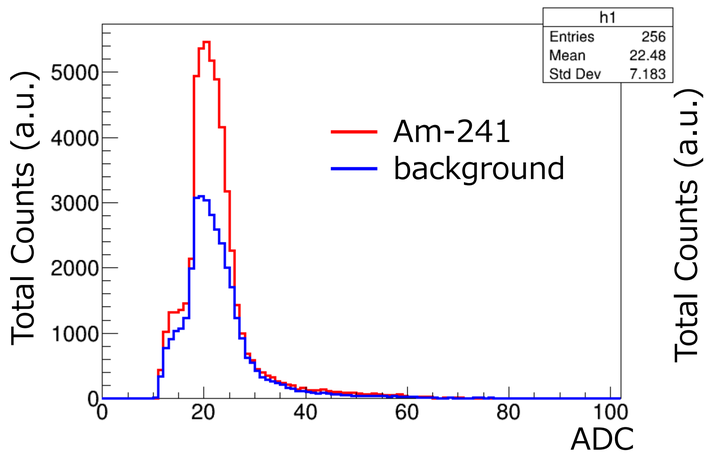
➢ MPPC (Multi Pixel Photon Counter)

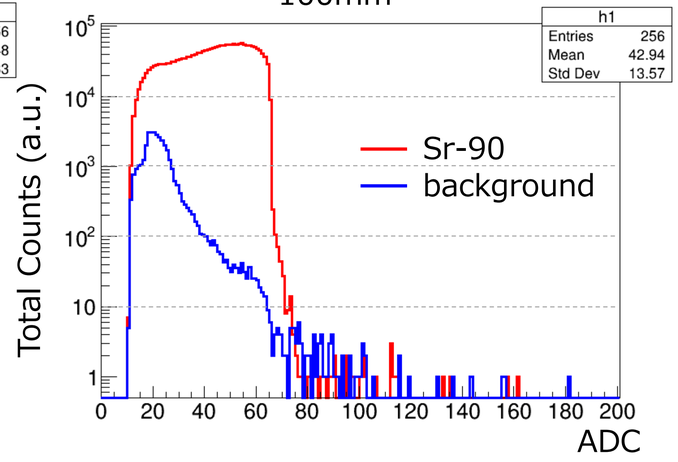
- Type No. : S13360-6050CS (Hamamatsu photonics)
- Photodetector size: 6.0*6.0 mm²

➢ Setup

- Cover the scintillator with Teflon reflective material
- Connect MPPC to readout device to detect photons
- Measurement time: 17 min



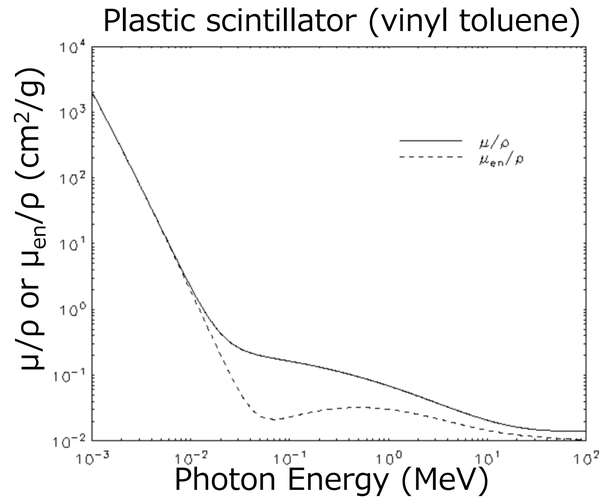




Background and source spectra are clearly different

→ **This plastic scintillator can be used to detect gamma-ray and beta-ray**

5. GRB sensitivity calculation



➢ Calculation conditions

- Scintillator density: 1.023 g/cm³
- Scintillator thickness: 10 mm
- Find of view **Ω**: 3 sr
- Lower limit of acquisition $\mathbf{E_1}$: 60 keV
- Upper limit of acquisition $\mathbf{E_2}$: 1000 keV
- Assuming 3-mm Al in front of scintillator
- GRB spectrum:
  Band function (**α**=-1, **β**=-2.3)
- Integration time **Δt**: 1sec
- Effective area **A**: 60.6*60.6 cm²

➢ Calculation Procedure

1. Obtain collection efficiency ε(E) for peak energy from NIST XCOM
   ε (E) = 1- exp (- μ/ρ * density * thickness)
2. Define band function $N_B(E)$ for CXB(Cosmic X-ray Background)

$$\mathbf{N_B(E) = \frac{0.01015}{\left(\frac{E}{29.99keV}\right)^{1.32} + \left(\frac{x}{29.99keV}\right)^{2.88}}}$$

Ajello et.al (2008)

3. Using Eq(1), find the background count rate B(E)
4. Using Eq(3), find the flux F_T for each peak energy ($\sigma_0=8\sigma$)

$$B(E) = \varepsilon(E)\Omega f_{mask} N_B(E) + B_{int} \quad (1)$$

$$\sigma_0 = \frac{A f_{det} f_{mask} \Delta t \int_{E_1}^{E_2} \varepsilon(E) N_T(E) dE}{\sqrt{A f_{det} \Delta t \int_{E_1}^{E_2} B(E) dE}} \quad (2)$$

$$F_T = \frac{\int_{E_l}^{E_h} N_T(E) dE}{\int_{E_1}^{E_2} \varepsilon(E) N_T(E) dE} \frac{\sigma_0 \sqrt{\int_{E_1}^{E_2} B(E) dE}}{f_{mask} \sqrt{A f_{det} \Delta t}} \quad (3)$$

Band et.al(2002)

➢ Calculation Result

- The change in slope of the sensitivity curve can be seen at 60 keV
- Swift/BAT and SMILE-3/ACS sensitivity curves are roughly the same

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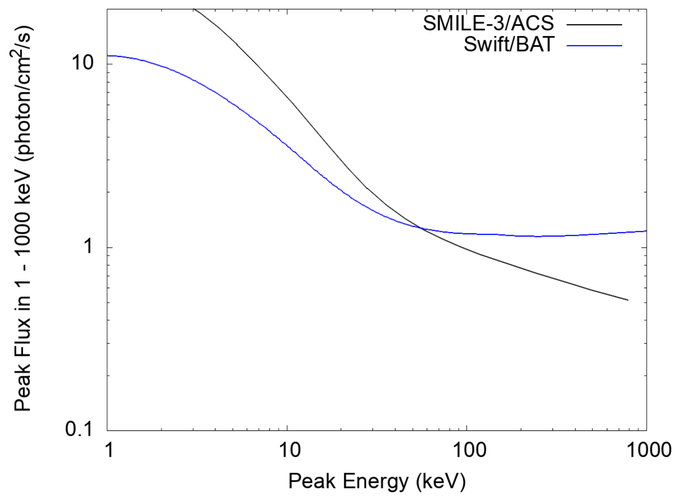
Given the same sensitivity as Swift/BAT, GRBs are expected to be detected as often as once a week



6.Conclusion・Future work

✓ Bread board model of ACS is able to detect gamma-ray and beta-ray

✓ With ACS, there is sensitivity to detect GRBs as often as once a week

✓ Considering the exact conditions and performing detailed calculations to obtain the expected GRB detection sensitivity

✓ To develop an engineering model