Performance Improvement of an Electron-Tracking Compton Camera by a New Track Reconstruction Method

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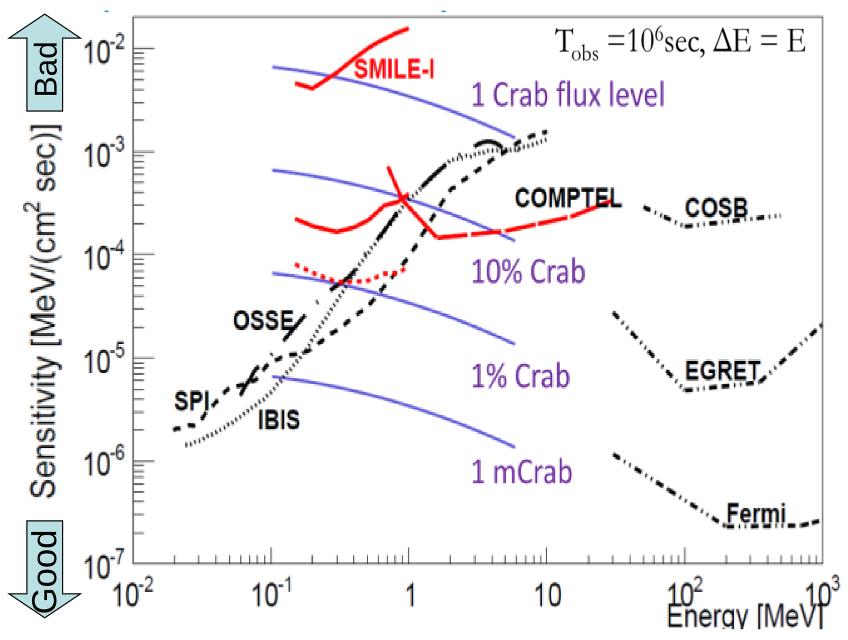
1. Introduction



Continuum Sensitivity in X-ray and gamma-ray region

◆ **Targets in Sub-MeV/MeV gamma-ray band**

GRBs, nucleosynthesis in supernovae, particle acceleration in AGN, etc

◆ **Previous observations**

- COMPTEL (CGRO) Classical Compton Imaging
- IBIS, SPI (INTEGRAL) Coded Aperture Imaging

the problem of high background

⇒ low sensitivity

Background reduction is IMPORTANT

◆ **Our Detector** [1]

Electron Tracking Compton Imaging

- Powerful background rejection ability

◆ **Our Observations**

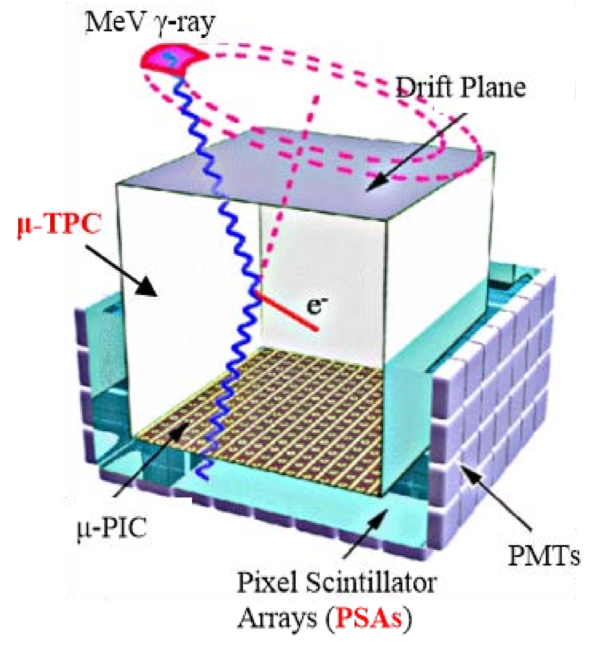
SMILE (Sub-MeV gamma ray Imaging Loaded-on-balloon Experiment)

- SMILE-I (2006) 10cm-cube ETCC @ Sanriku, Japan
  Observation of diffuse cosmic / atmospheric gamma rays
  Effective area ~ 0.01 cm² (150 keV-1.5 MeV) [2]
- SMILE-II (2014-) 30cm-cube ETCC
  Observation of Crab nebula / Cyg X-1
  Required effective area > 0.5 cm² *(@ angular resolution ~ 10°)*

Effective area must be improved ~ 50 times.

To obtain the required effective area for SMILE-II, we have improved the electron track reconstruction method by *updating the track data encoding logic* and *developed a simple track analysis for the new logic*. In this poster, we report the performance improvement of ETCCs by using the new track reconstruction method.

2. Our Detector : Electron Tracking Compton Camera



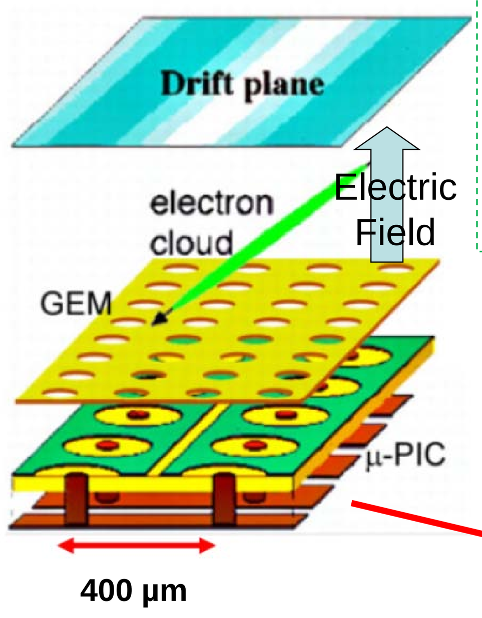
Schematic view of the ETCC

◆ **Principle**

- **Electron Tracker : μ-TPC**
  Time **P**rojection **C**hamber based on **μ**-PIC
  3D track and energy deposit of a recoil electron
- **Photo Absorber : PSAs**
  Pixel **S**cintilater **A**rrays
  Energy and direction of a scattered gamma ray

✓ Reconstruction of incident photon event by event
✓ **Kinematical background rejection**
✓ **Particle identification by dE/dX (BG rejection)**
✓ Large field of view (~3 str)

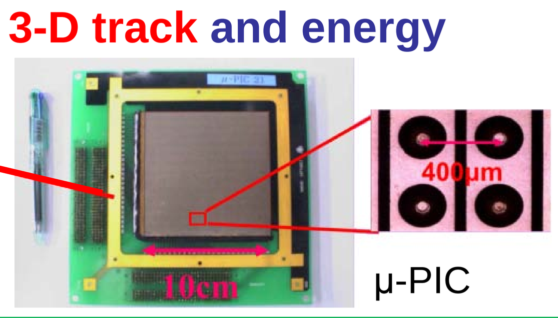
◆ **μ-TPC**



Schematic view of the μ-TPC

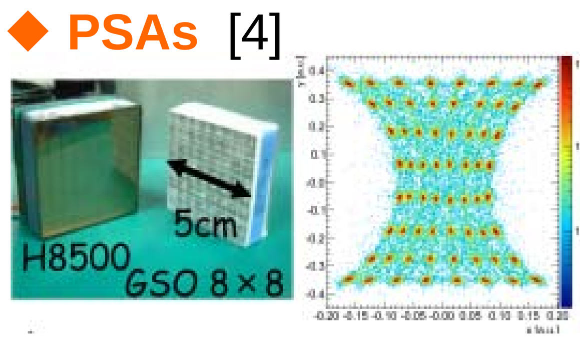
✓ μ-PIC (Micro Pixel Chamber) [3]
A gaseous 2D imaging detector with strip read out
✓ Pixel pitch : 400 μm
✓ Detection area : 10 x 10 cm², 30 x 30 cm²
✓ First amplifier : Gas Electron Multiplier (GEM)
✓ Typical gas gain : ~ 3000 (u-PIC) x 10 (GEM)
✓ Drift velocity : ~ 4 cm / μsec

2D-readout (μ-PIC 400 μm pitch)
+ Drift time (100 MHz)
⇒ **3-D track and energy**



μ-PIC

◆ **PSAs** [4]



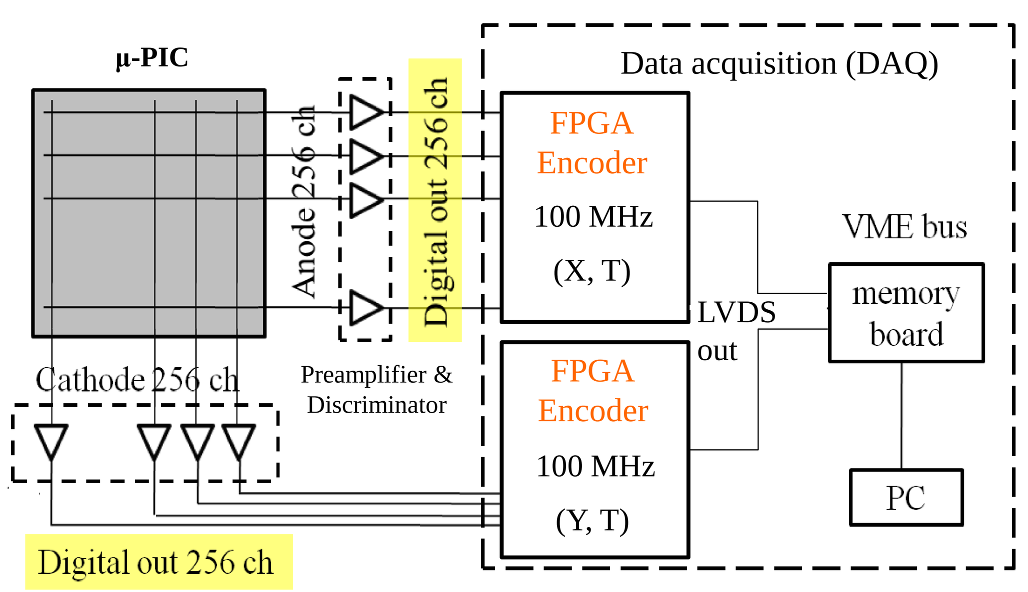
✓ 4 channels readout with resistor chain in each PMT
✓ Hit pixel is determined by center of gravity of 4 ADC data.

Scintillator	GSO:Ce (6.71 g/cm³)
Pixel size	6 x 6 x 13 mm³
Dynamic range	80 keV-1.3 MeV
Energy Resolution	10% @ 662 keV (FWHM)

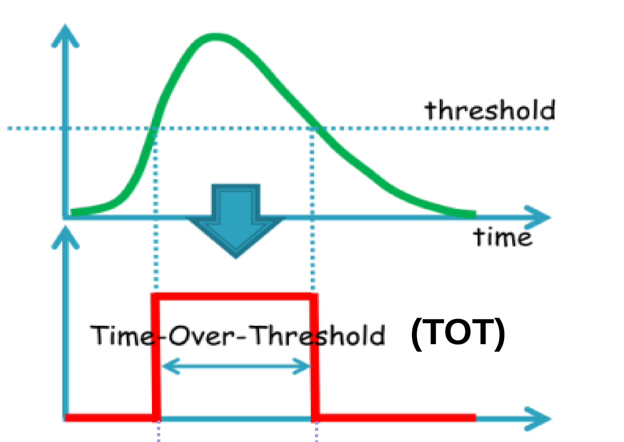
3. Updating the track data encoding logic

All the signals from the anode (X) and cathode (Y) strips on the μ-PIC were discriminated, and they are sent to the following **FPGA encoding module** with an internal clock of 100 MHz.

Data acquisition of μ-TPC



Data encoding per signal



0 0 1 0 0 0 0 0 0 0 **Previous logic**
0 0 1 1 1 1 1 1 0 0 **New logic**
(100 MHz clock)

◆ **Previous encoding logic** [5]

i. Detect the leading edges of all digital signals with 100 MHz clock.
ii. **Coincide with detected anode(X) and cathode(Y) positions** in one clock interval 10 nsec.
iii. Record only the two edge positions among the coincident hit positions with the hit timing.

Encoded Track Data
(X_{min}, Y_{min}, X_{max}, Y_{max}, T)

A 10 nsec gate is too restricted for the coincidence of μ-PIC signals, and it caused **the considerable loss of hit points (~70%)** due to the time-walk of preamplifiers and the delay on FPGAs. **This loss degraded the efficiency of an ETCC** [6].

◆ **New encoding logic**

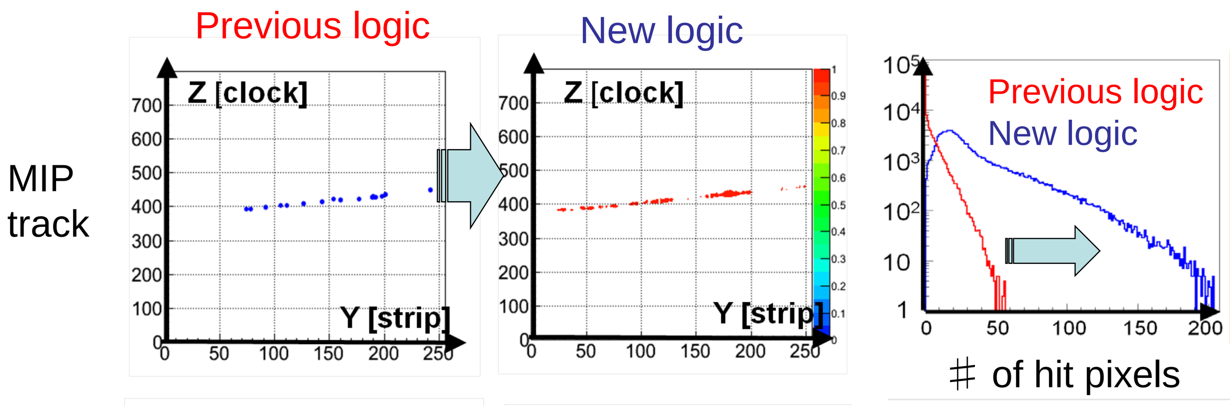
i. Detect the high level of all digital signals with 100 MHz clock.
ii. Record all of the detected positions with the hit timing.
Don't take coincidence.

Encoded Track Data
(X, T), (Y, T)

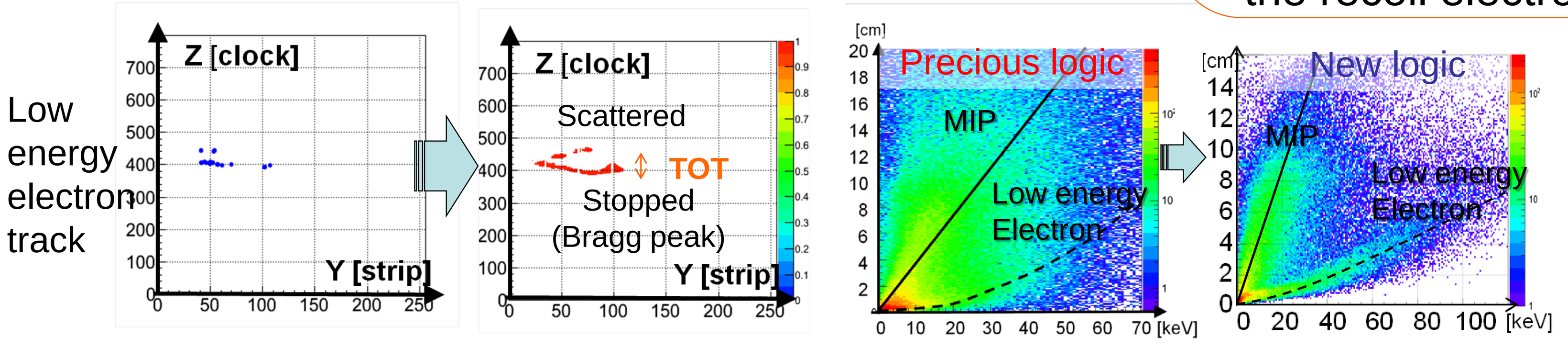
The electron track are expected to be measured **more precisely**.
In addition, we are able to estimated the energy deposition using the **Time Over Threshold (TOT)**, time between leading and trailing edges.

4. Performance improvement of μ-TPC

◆ **Experiment data of 10cm-cube μ-TPC (irradiate ^{137}Cs)**



- The track has much more hit points. (~ 30 times)
- We can detect the Bragg peak by the TOT.
- New dE/dX map provides us better identification of the recoil electron.

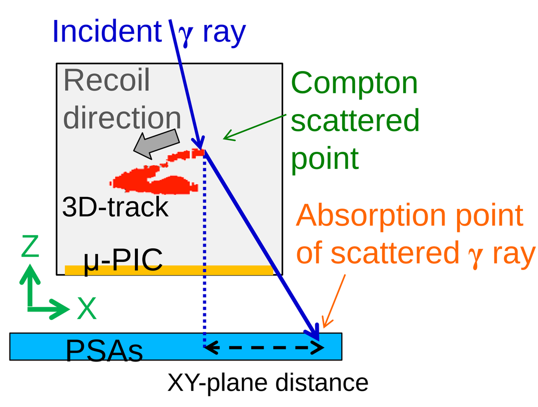


dE/dX map
—— MIP theoretical curve
- - - - Low energy electron theoretical curve

5. Simple track analysis for the new encoding logic

To reconstruct the incident gamma-ray, we need the information of the Compton scattered point and the recoil direction using the obtained 2D-track, (X,Z) and (Y,Z).

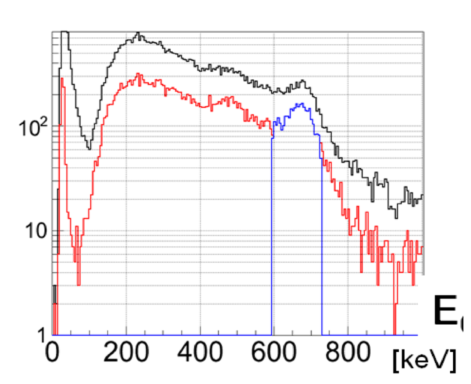
① Reconstruction of 3D-track
Coincide with obtained 2D-track in an adequate gate (10-20 ns) using the software.
② Determination of Compton scattered point
Simple kinematic method. The closest hit point by XY-plane distance from the absorption point of scattered gamma ray.
③ Determination of the recoil direction
The direction connecting the scattered point to the hit point which is farthest from the scattered point within 5 mm.



6. Performance improvement of an ETCC

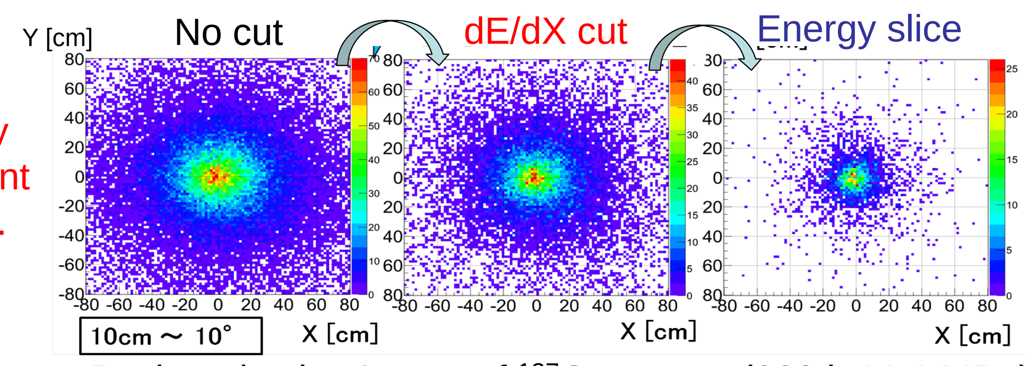
◆ **Experiment Data of 10cm-cube ETCC (irradiate ^{137}Cs source at 60 cm above)**

- Demonstration of Gamma-ray Reconstruction using a new logic



Energy Spectra

No cut
Extract low energy electron component using dE/dX map. (dE/dX cut)
Energy slice
662 keV±10%

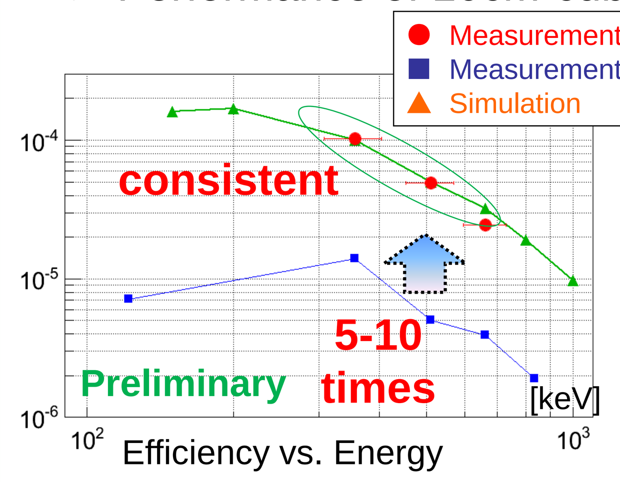


Back projection Image of ^{137}Cs source (662 keV, 1 MBq)

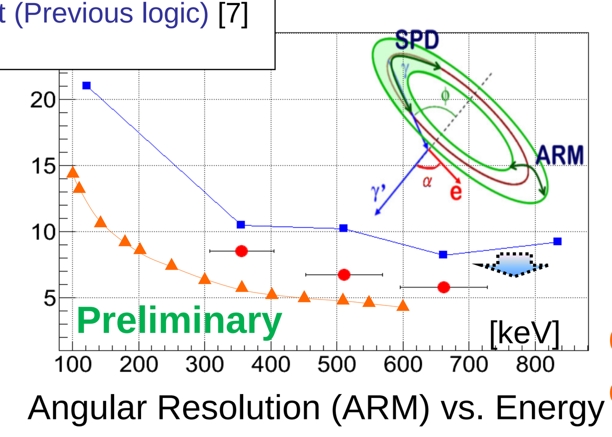
Most of background have been rejected only by two simple cuts.

- Performance of 10cm-cube ETCC using a new logic

● Measurement (New logic)
■ Measurement (Previous logic) [7]
▲ Simulation

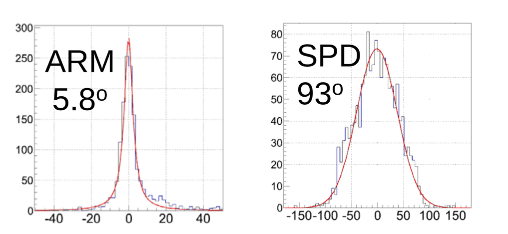


Efficiency vs. Energy



Angular Resolution (ARM) vs. Energy

New logic @662keV



Previous logic @ 662 keV
SPD 90-200°

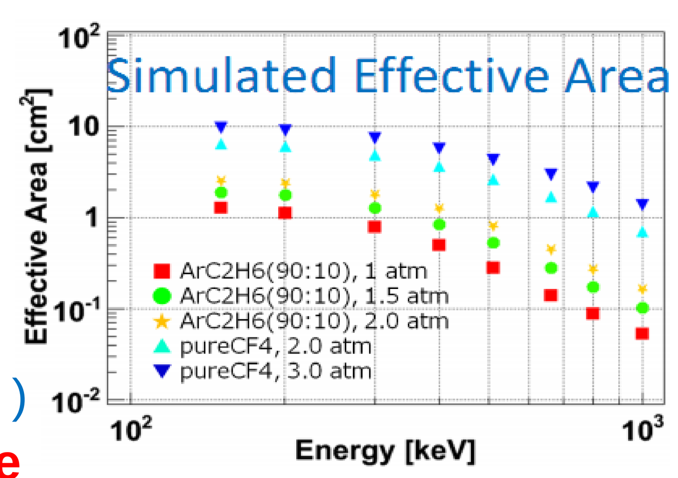
Great improvement of efficiency and angular resolution

7. Summary & Future Work

- Measured efficiencies are 5-10 times higher than using the previous logic and looked consistent with the simulated efficiency.
- Measured angular resolutions, ARM and SPD, were improved remarkably.
  (ARM : 8.2°→ 5.8°, SPD : 90°-200° → 93° @ 662 keV)

⇒ **the 30cm-cube ETCC for SMILE-II will achieve 1cm² effective area and more than 3 times better sensitivity.**
⇒ **This sensitivity enables us to detect Crab nebula with 5 sigma level for several-hour observation** [8].

- In a few years, we will achieve 10 cm² effective area by changing the kind of gas and increasing the gas pressure.



8. Reference

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