Development of the Tracking Compton/Pair-Creation Camera based on a Gaseous TPC and a Scintillation Camera

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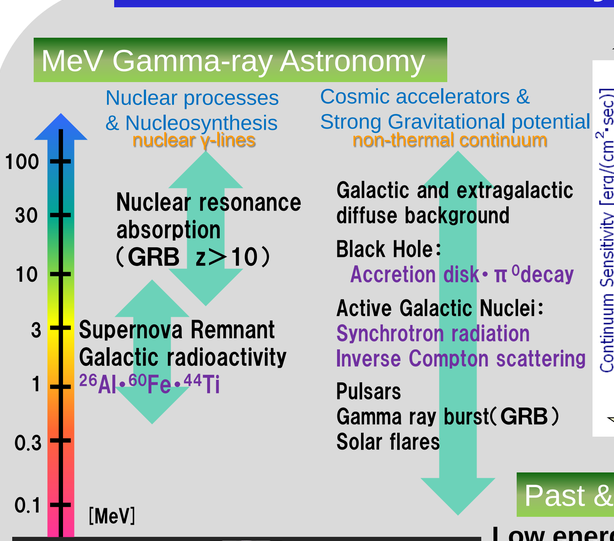
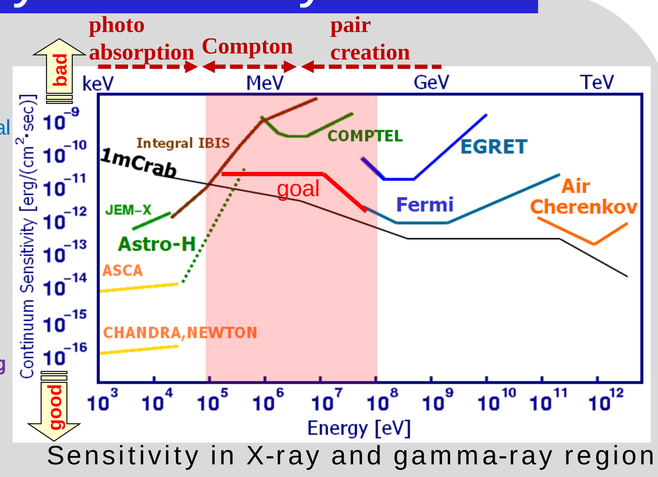
Abstract

We have developed a tracking Compton/pair-creation gamma-ray camera using a gaseous micro time projection chamber (micro-TPC) and a scintillation camera. Several prototypes of the camera with a detection volume of 10cm×10cm×10cm were developed and their performance in Compton mode were studied. Because the micro-TPC can detect large number of hits from charged particles, has a good position resolution of about 0.2mm, and is based on gas, the influence of multiple scattering is small and pair creation events can be determined clearly. We began development of the camera with the size of 10cm×10cm×15cm for pair-creation mode. Using this camera, we performed a proof-of-principle experiment with laser inverse Compton gamma rays at National Institute of Advanced Industrial Science and Technology (AIST) and succeeded in tracking electrons and positrons and reconstructing of gamma rays. In this poster, we report the fundamental performance of the gamma-ray camera with pair-creation mode.

1. MeV Gamma-ray Astronomy

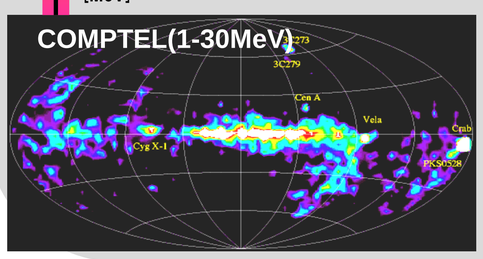
MeV Gamma-ray Astronomy





Sensitivity in X-ray and gamma-ray region

Past & Current observation



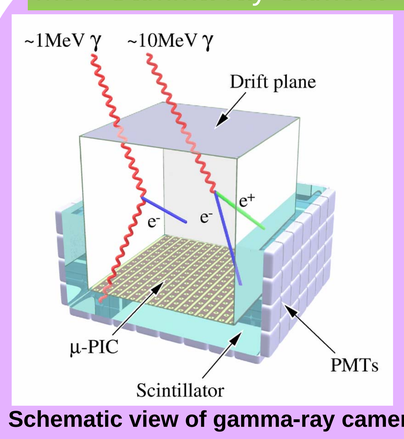
Low energy (<~10 MeV)
COMPTEL (CGRO)[1] Classical Compton Imaging
IBIS, SPI (INTEGRAL)[2] Coded Aperture Imaging
⇒large background ⇒ low sensitivity

High energy (10 – 100 MeV)
EGRET (CGRO)[3]Spark Chamber
LAT (FERMI)[4] Si strip
⇒multiple scattering ⇒ bad angular resolution

2. Gamma-ray Camera

MeV Gamma-ray Camera

0.1 – ~10 MeV : Use Compton Scattering (Compton mode)
~10 – 100 MeV: Use Pair Creation (Pair-creation mode)



Schematic view of gamma-ray camera

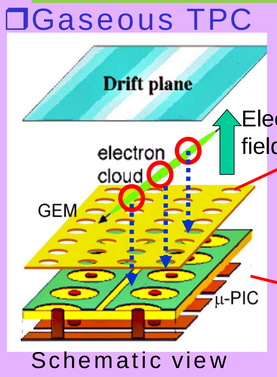
- **Gaseous TPC** (Time projection chamber with μ-PIC)
  Compton mode: track and energy of recoil electron
  Pair-creation mode: track of electron-positron pair
- **Scintillation Camera**
  Compton mode: absorption point and energy of scattered gamma ray
  Pair-creation mode: energy of electron-positron pair

- Reconstruction of incident gamma ray event by event
- Kinematical background rejection
- Small multiple scattering
- Large field of view(~3str)

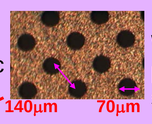
Gaseous TPC & Scintillation Camera

❒Gaseous TPC

2D-readout (μPIC 400μm pitch) + **Drift time** (100MHz)
→ **3D-track and energy**

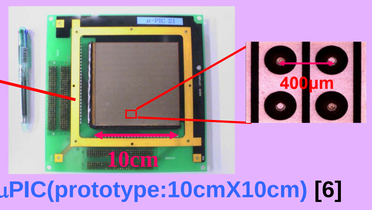


Schematic view of gaseous TPC



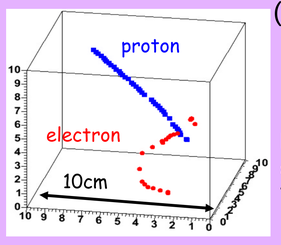
We use the GEM as a pre-amplifier to obtain stable high gain.

GEM (F.Sauli 1997) (10cmX10cm)[5]



μPIC(prototype:10cmX10cm) [6]

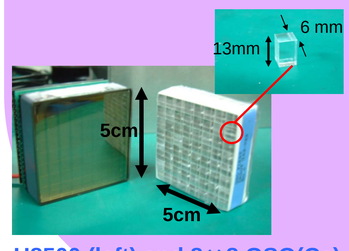
- ▶Volume : 10cm×10cm×10cm (prototype)
- ▶Position resolution : 200μm
- ▶Stable gas gain : ~30000 (μPIC ~3000 GEM ~10)



Example of 3D-tracks of an electron and proton in the μ-TPC

❒Scintillation camera

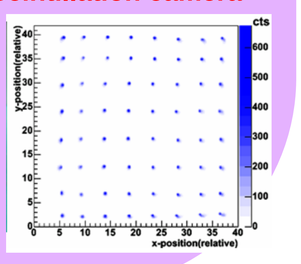
Multi Anode PMT + **Pixel Scintillator Array** → **Scintillation camera**



H8500 (left) and 8×8 GSO(Ce) pixel array (right) [7]

- ▶Scintillator : GSO(Ce)
- ▶Photon sensor : H8500 (HPK)
- ▶Position resolution : 6mm
- ▶Energy resolution : ~11%(FWHM) @ 662keV

Typical image from 137Cs using charge division method



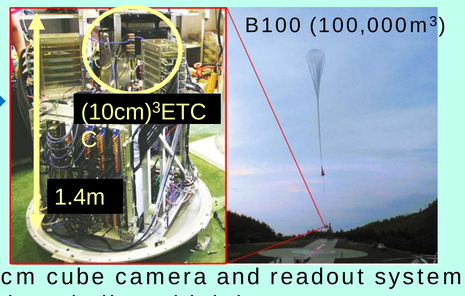
3. SMILE project

Sub MeV to MeV gamma-ray Imaging Loaded-on-balloon Experiment

Roadmap of the SMILE

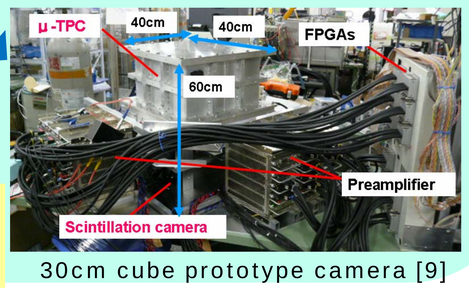
- 2006 10cm cube camera with Compton mode [8]
  0.1～1MeV @Sanriku, Japan 4hours
  ▶Operation test @ balloon altitude
  ▶Observation of diffuse cosmic/atmospheric gamma rays
- 2011～ 30cm cube camera with Compton mode
  0.1～1MeV@Taiki, Japan 6hours
  ▶Observation of Crab/Cyg X-1
- 2013～ 40cm cube camera with Compton/Pair mode
  0.1～100MeV
  @Brazil 6hours, or
  Long duration observation with super pressure balloon
  ▶Galactic plane/center survey 4 times or more / 7 years
- 2020～ 50cm cube camera with Compton/Pair mode
  0.1～100MeV on a satellite
  ▶All sky survey

SMILE-1 → B100 (100,000m3)



SMILE-2 → SMILE-3

10cm cube camera and readout system (left) and our balloon (right)



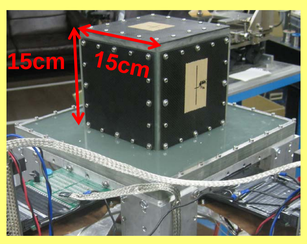
30cm cube prototype camera [9]

In SMILE-3, we will use pair-creation mode for detecting high energy gamma rays. The proof-of-principle experiment of pair-creation mode was done in this work.

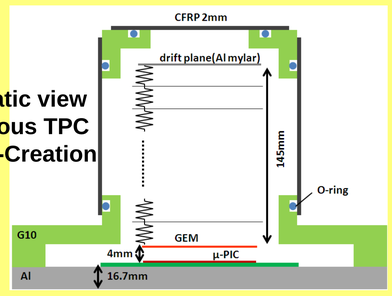
4. Proof-of-Principle Experiment for Pair-Creation Mode

Gamma-ray Camera with Pair-Creation mode

Gaseous TPC



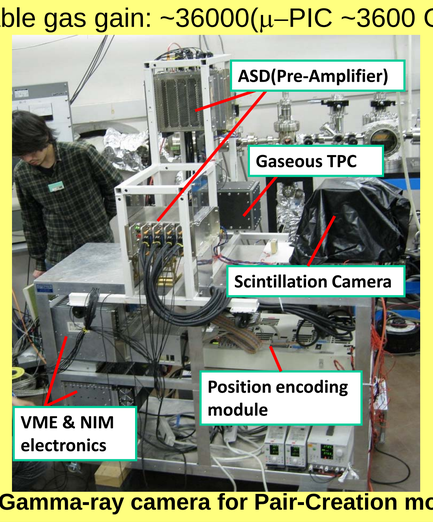
Schematic view of gaseous TPC for Pair-Creation mode



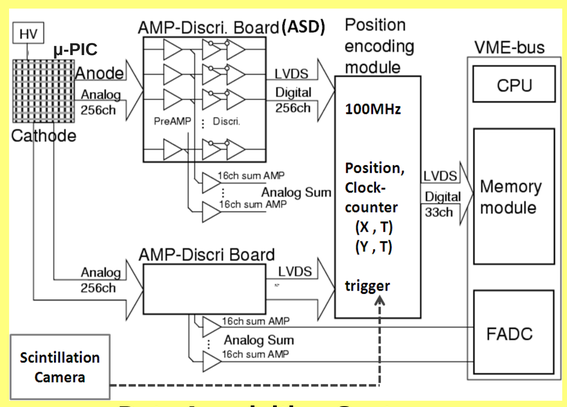
Scintillation Camera

8 scintillation camera (See section 2)

■Volume:10cm×10cm×15cm ■Gas:Ar 90% + C_2H_6 10% 1atm (sealed)
■Position resolution: 200μm ■Energy resolution:28%(FWHM)@31keV
■Stable gas gain: ~36000(μ–PIC ~3600 GEM ~10)



Gamma-ray camera for Pair-Creation mode

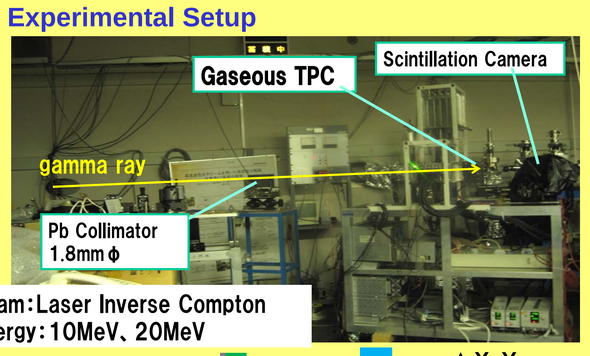


Data Acquisition System

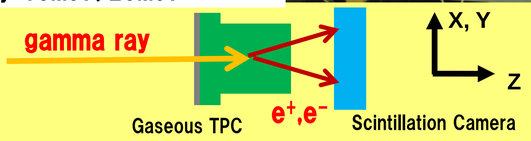
Beam Experiment at Advanced Industrial Science and Technology (AIST)

We had a proof-of-principle experiment of Pair-creation mode using the laser inverse Compton beam on 13-14, Oct., 2009 at AIST.

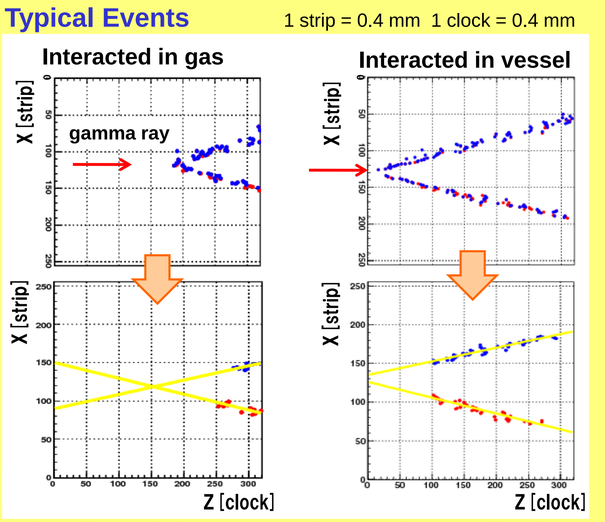
Experimental Setup



Beam:Laser Inverse Compton
Energy:10MeV、20MeV



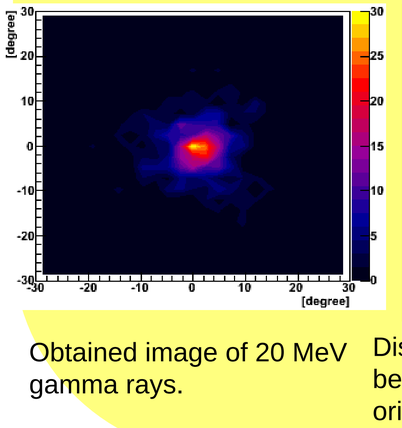
Typical Events 1 strip = 0.4 mm 1 clock = 0.4 mm



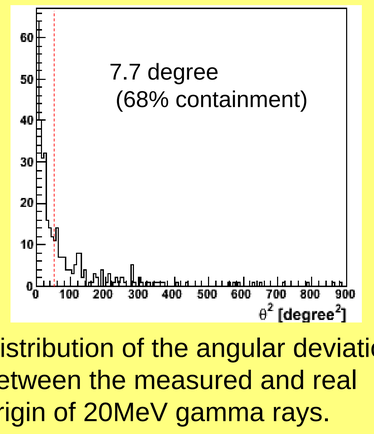
Hit points of electron-positron pair were fitted with straight lines to determine the direction of each track.

Reconstruction and performance

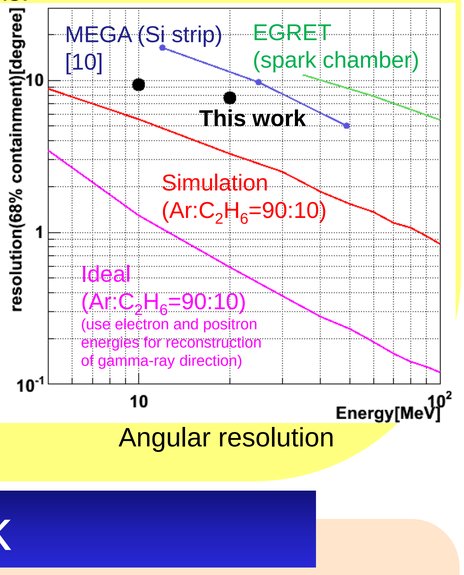
If the opening angle of electron-positron pair is small, the direction of incident gamma ray is approximately given by $\vec{e}_{inc.} \sim \vec{e}_{electron} + \vec{e}_{positron}$ where $\vec{e}_{inc.}$, $\vec{e}_{electron}$, and $\vec{e}_{positron}$ are unit vectors of incident gamma ray, electron, and positron, respectively. In this experiment, we used this expression to reconstruct the gamma rays and obtained the angular resolutions.



Obtained image of 20 MeV gamma rays.



Distribution of the angular deviation between the measured and real origin of 20MeV gamma rays.



Angular resolution

5. Summary & Future Work

We have succeeded in imaging of gamma rays using Pair-creation mode. We obtained angular resolutions of 9.4 and 7.7 degrees (68% containment) at 10 and 20 MeV, respectively. These resolutions are better by factor of about 1.4 than those of the silicon strip detector. This result is the best in the cameras which use pair creation at present.

In the future, we will tune the gamma-ray camera and improve the analysis method in order to achieve close to the resolution of the simulation.

[References]

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