Development of an electron-tracking Compton camera based on a gaseous TPC and a scintillation camera for a balloon-borne experiment

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Abstract
We have developed an Electron-Tracking Compton Camera (ETCC) based on a gaseous micro Time Projection Chamber (μ-TPC) which measures the direction and the energy of the Compton recoil electron and a GSO(Ce) scintillation camera which surrounds the μ-TPC and measures the Compton scattered gamma ray. Measuring the direction of the recoil electron reduces the Compton cone to a point, and thus reconstructs the incident direction completely for a single photon and realizes the strong background area for the next balloon experiment. Using the ETCC with a detection volume of about 10cm × 10cm × 15cm, we had a balloon-borne experiment in 2006 for the purpose of the observation of diffuse cosmic and astrophysical gamma rays. The experiment was successful. On the basis of the results, we are developing a large size ETCC in order to improve the detection area and report the fundamental performances of the large size ETCC.

1. Observation in MeV gamma-ray Astronomy

- **Universe in MeV gamma ray**
  - Nucleosynthesis
    - SNR : Radio-isotopes : 26Ni (0.158/0.812), 56Co (0.847/1.238), 44Ti (0.089/0.781/1.157)
  - Galactic plane : 56Ni (1.8), 56Fe (1.173/1.333)
  - Acceleration
  - Jet (AGN), GRB
  - Synchronous radiation
  - Inverse Compton scattering
  - Strong Gravitational Potential
  - Black Hole : accretion disk, Black Hole

- **Event selection with ℓ±**
  - The angle \( \hat{\ell} \) is defined by the direction of 1 photon, the sensitivity was restricted by background.

- **Past observations**
  - **COMPTEL (CGRO)**
  - Classical Compton Imaging
  - Detected ~30 steady sources
  - **BIS, SPI (INTEGRAL)**
  - Coded Aperture Imaging in MeV gamma-ray region, sensitivity is worse than that of COMPTEL.

2. Electron-Tracking Compton Camera

- **Electron Tracking Compton Camera (ETCC)**
  - The camera consists of a gaseous time projection chamber (TPC), which detects the 3D-track and the energy of the Compton scattered gamma-ray. By using these four pieces of information, we can completely reconstruct the Compton scattering event by event, and obtain a fully ray-traced gamma-ray image.
  - Obtained flux vs/ and preceding measurement (error bar is statistical data).

3. Gaseous TPC and scintillator

- **Gaseous TPC (μ-TPC)**
  - 2D-readout (μPIC 400μm pitch)
  - Drift time (100MHz)
  - Volume : 10cm × 10cm × 15cm (prototype)
  - Position resolution : 400μm
  - Stable gas gain : ~30000 γ/μPIC @3000 γ/MU ~1MeV

- **Scintillation camera**
  - Schematic view of μ-TPC
  - Signals from anode and cathode electrode strips are pre-amplified, shaped, and digitized. All digital signals are individually fed to FPGAs, and the two dimensional position of electrodes is simultaneously calculated with a 100MHz clock.

4. SMILE project

- **SMILE**
  - Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment
  - For the sub MeV to MeV gamma-ray observation in astronomy, a detector must be launched in the space. Then, we have planned the balloon experiments, SMILE. At the first step, using the (10cm)³ ETCC, we confirmed the gamma-ray detection by the observation of diffusive cosmic and atmospheric gamma rays. At the second step, we are developing the (30cm)³ ETCC in order to enlarge the effective area for the observation of a bright source. In the future, we will construct the larger ETCC and have all sky survey with some balloons or a satellite.

5. (30cm)³ ETCC

- **3D-track and energy**
  - Example of 3D-tracks of the electron and the photon in the μ-TPC.
  - Volume : 30cm × 30cm × 30cm
  - Gas : Ar 90% + C2H6 10% 1atm
  - Energy resolution : 46% (FWHM) @631keV
  - Position resolution : 400μm
  - Stable gas gain : ~30000 γ/μPIC @3000 γ/MU ~1MeV

6. Future work

- **Tuning**
  - improve the ARM and the energy resolution to those of (10cm)³ ETCC.
  - Test : widen the dynamic range of 100keV to a few MeV, and investigate the detection efficiency and FOV.
  - For the next balloon : start the design of next flight model of the ETCC.
  - Furthermore : enlarge the size of the ETCC to (60cm)³ for a super pressure balloon or a satellite experiment.

Roadmap of the SMILE

Test : widen the dynamic range of 100keV to a few MeV, and investigate the detection efficiency and FOV.

- **Operation test of ETCC @ 35km**
  - Observation of Crab or Cyg X-1

- **Measurement of Diffuse cosmic and atmospheric gamma rays**
  - expectation : 0.1~1MeV ~200photons @ 35km, 3hours

- **ETCC**
  - Super pressure balloon ~10days
  - All sky survey (50cm)² ETCC
  - ORBITING balloon ~30days or satellite

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