Development of a prototype liquid argon Compton camera

Satoshi Takashima (Osaka U)

K. Ishiwata, H. Odaka, K. Shirahama, M. Tanaka, T. Hakamada, M. Yoshimoto (Osaka U), S. Arai, M. Ichihashi, T. Kato,
A. Bamba (U Tokyo), K. Aoyama, T. Shimizu, H. Taniguchi, R. Nakajima, K. Yorita (Waseda U), T. Tamba,
S. Watanabe (JAXA/ISAS), K. Okuma, T. Nakazawa (Nagoya U), H. Yoneda (U of Würzburg), GRAMS collaboration

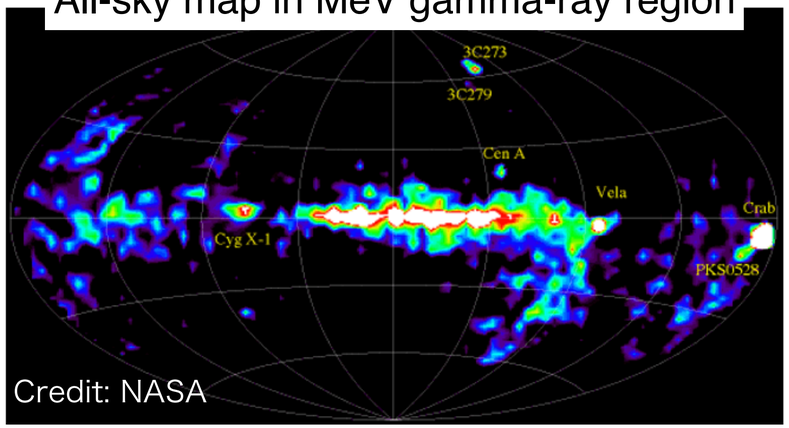
Introduction

GRAMS (Gamma-Ray and AntiMatter Survey)

Cosmic gamma-ray observation

Indirect DM search

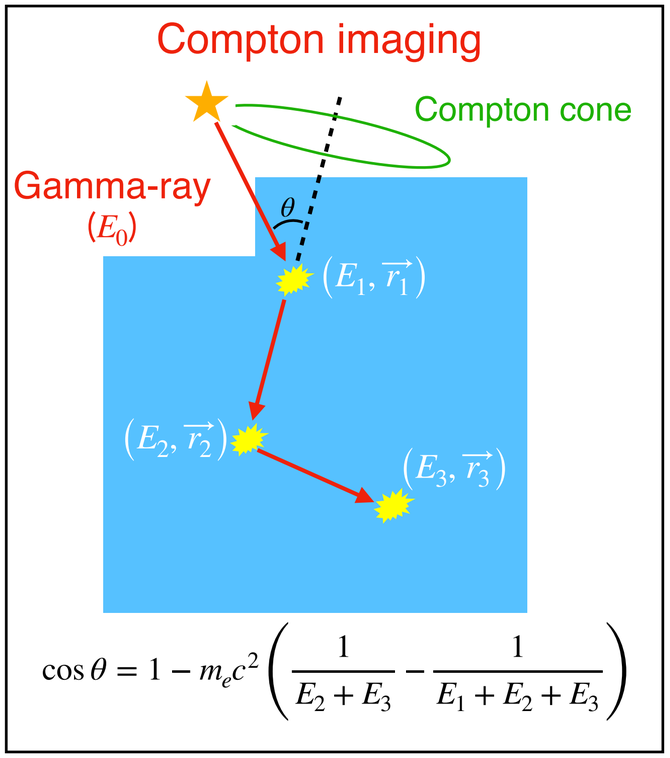
All-sky map in MeV gamma-ray region



The GRAMS instrument is a liquid argon time projection chamber (LArTPC), which is utilized as a Compton camera

We have developed a prototype of a LAr Compton camera (NanoGRAMS)

Compton imaging



$$\cos\theta = 1 - m_e c^2 \left(\frac{1}{E_2 + E_3} - \frac{1}{E_1 + E_2 + E_3} \right)$$

Engineering balloon flight

- The observation must be conducted as a balloon/satellite experiment

- We launched a LArTPC aboard a balloon at Hokkaido Taiki town on 2023/7/27

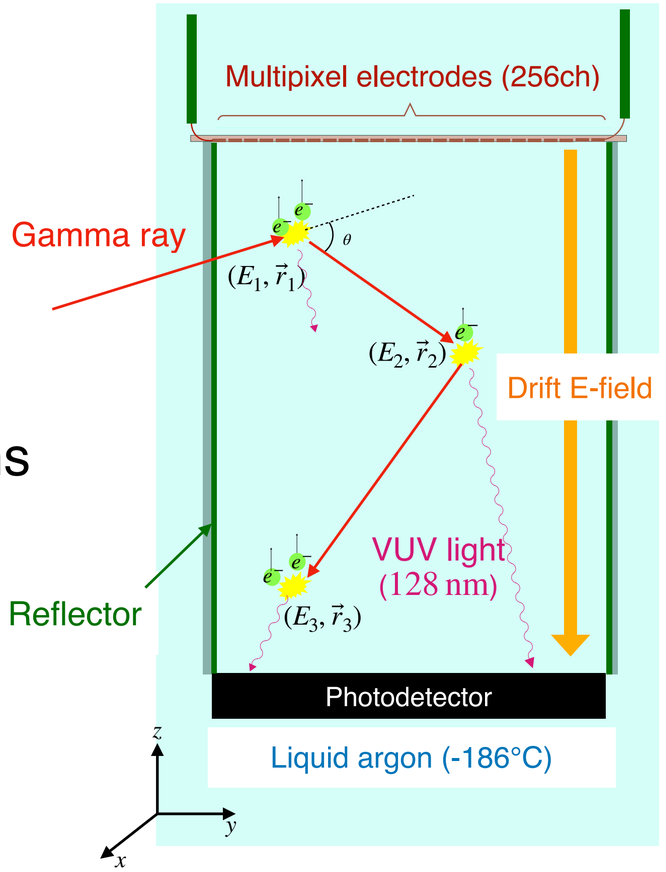
- 40 min level flight at an altitude of 29 km

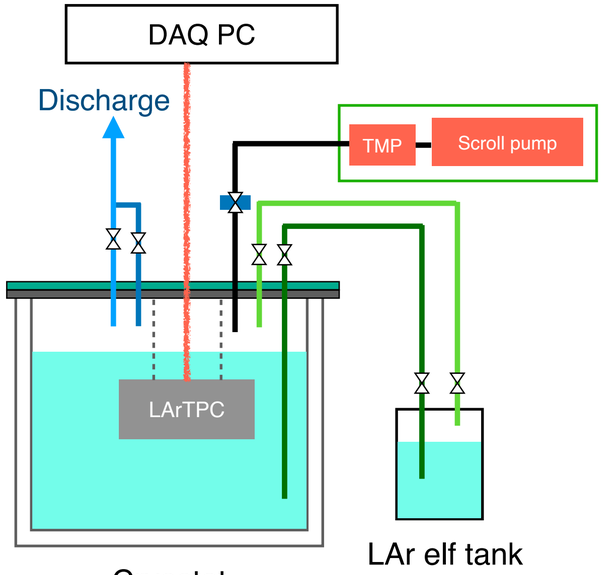
- We succeeded to control the LArTPC and measured background radiations

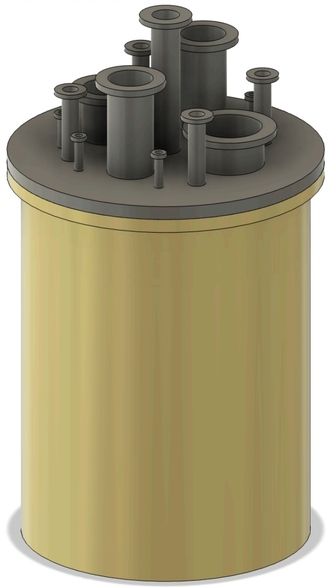
LAr Compton camera

- Gamma rays cause multiple hits (Compton scattering/photoabsorption) in LAr
- Each hit generates lots of scintillation light (~128nm) and ionized electrons
- Precise measurements of the light and electrons are essential for Compton imaging

	Scintillation	Electron
Trigger	○	
xy position		○
z position	○	○
Energy deposit	○	○





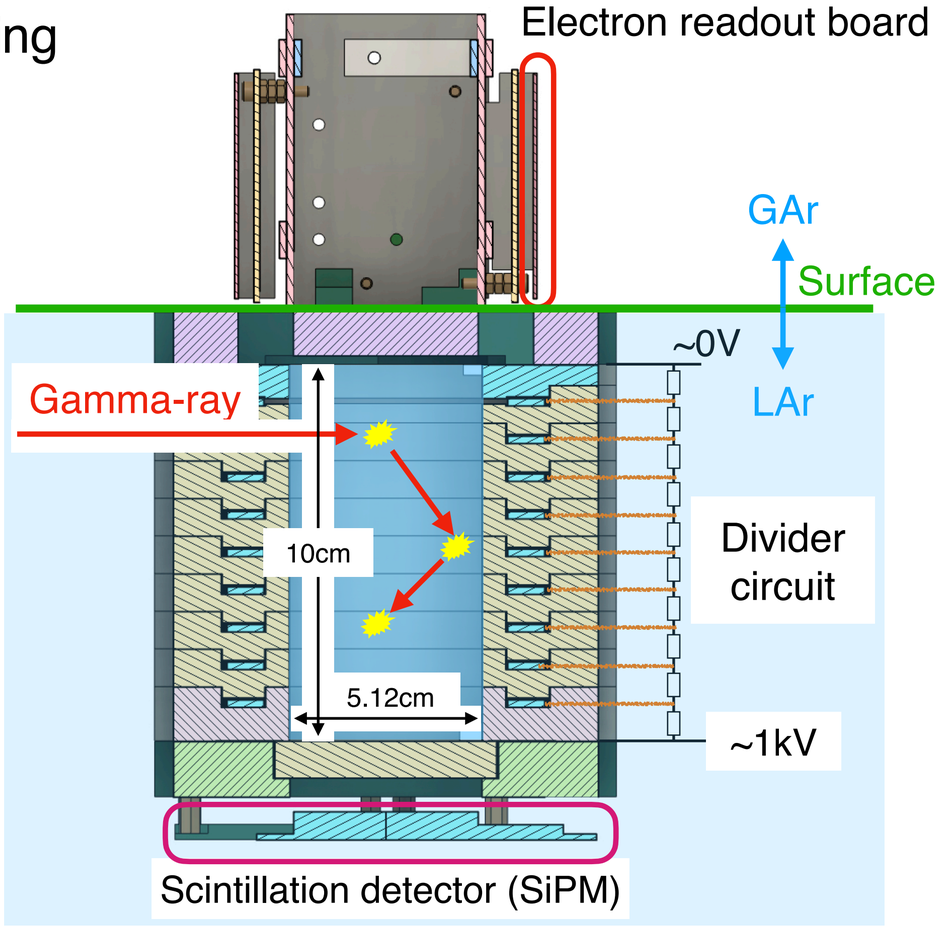


NanoGRAMS

- Develop a LArTPC (fiducial volume: $5.12 \times 5.12 \times 10\,\mathrm{cm}$) for the imaging

- Detection of scintillation light
  - Use of SiPMs for visible light
    VUV photons ($\sim 128\,\mathrm{nm}$) are converted into visible light ($\sim 420\,\mathrm{nm}$)
  - Fast timing response of detectors is required to reject neutron backgrounds

- Detection of ionized electrons
  - Detection of point-like energy deposit requires a low noise readout system
  - An anode electrode contains 256 pixels (3.2x3.2mm)



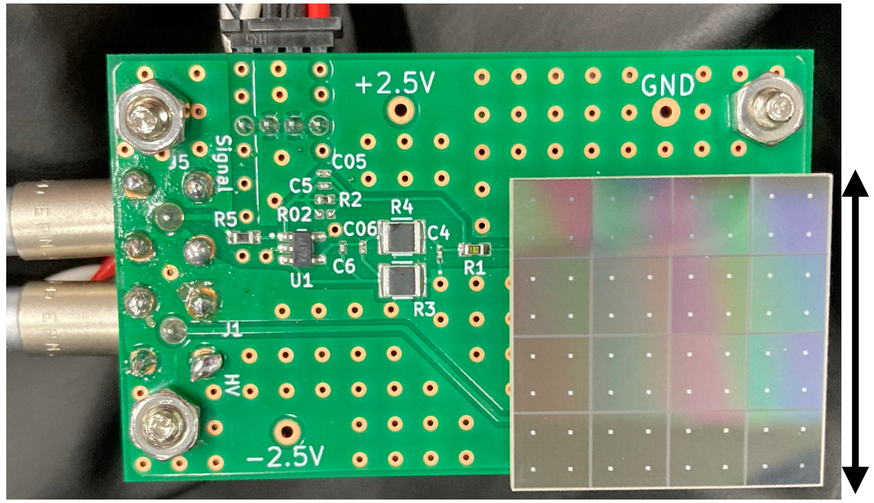
Arrayed SiPM board

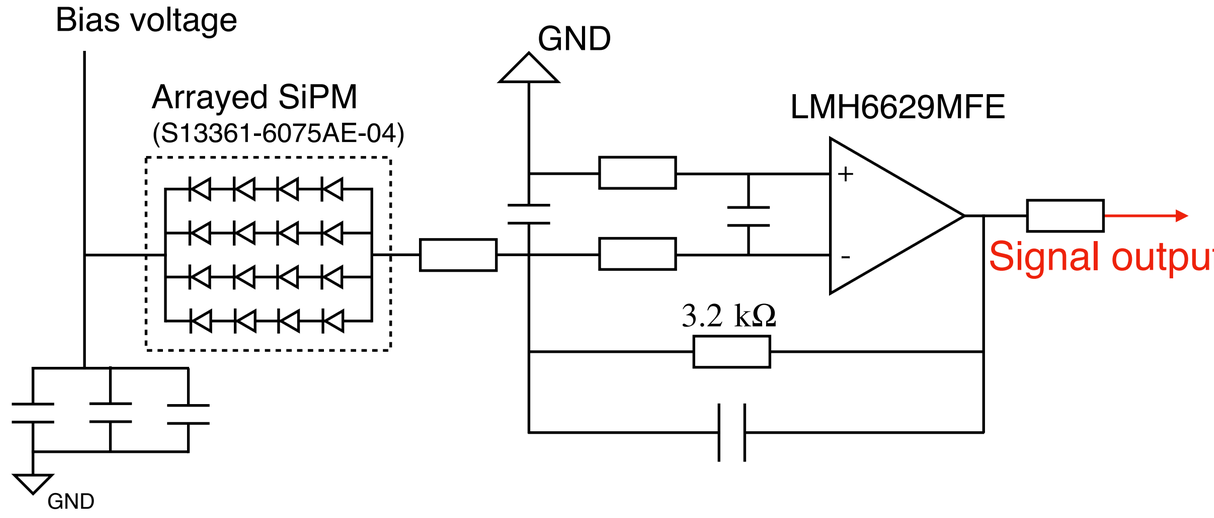
- SiPM readout boards for the scintillation light in LAr temperature (-186°C).

- Visible light SiPM array (2.4x2.4cm) manufactured by Hamamatsu Photonics.
  - Single line configuration
  - Response time: ~77 ns, Gain: $\sim 2 \times 10^6$

- The board also contains a transimpedance amplifier (TIA) to convert the current into voltage signals

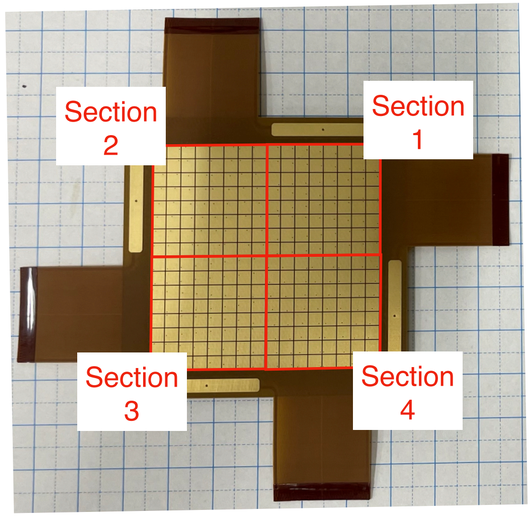
The next speaker (K. Shirahama) will detail this detector

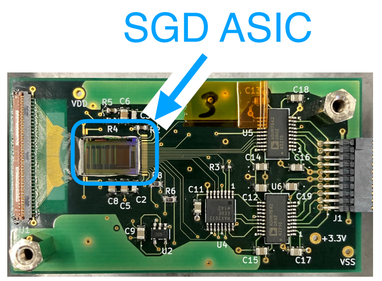




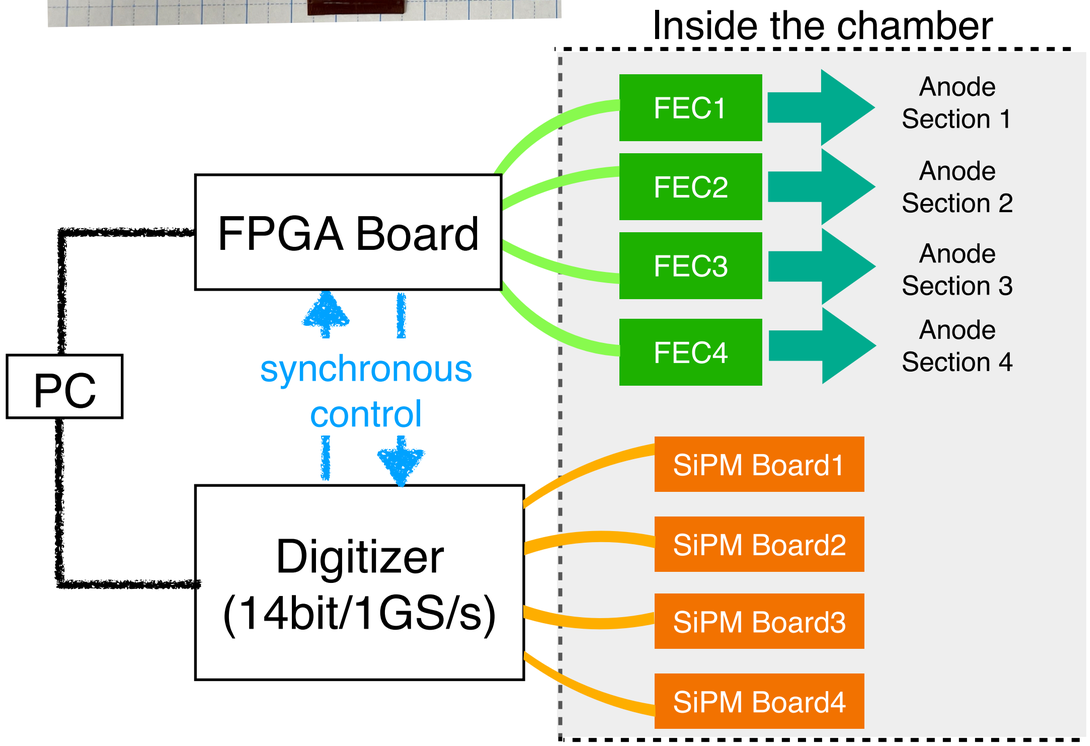
Electron readout system

- Signals of ionized electrons are processed by Front End Cards (FECs) that hold SGD ASICs
  - Measure electron signals with low noises
- We have developed a DAQ system to synchronize the scintillation signals
- We are trying to understand properties of noises and energy resolutions that depend on each pixel





Front End Card (FEC)

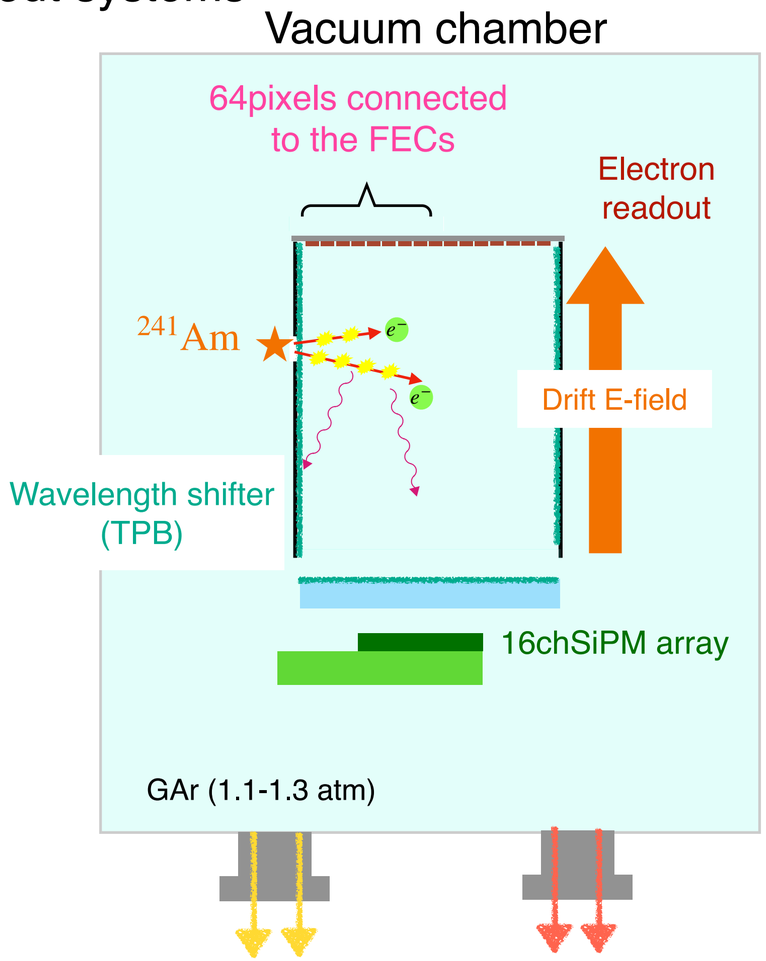


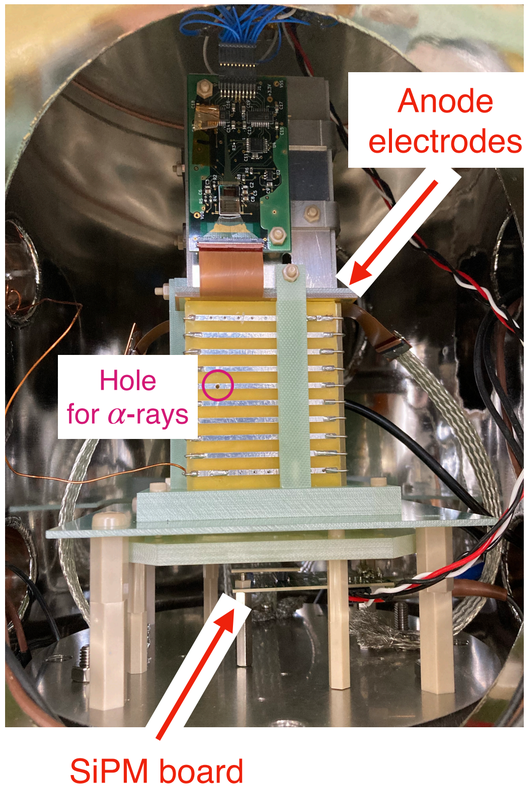
Detection of α-ray signals in GAr

- Confirm the ability of the SiPM board and electron readout systems for the Ar signals

- A simple TPC (fiducial volume: 5.12x5.12x6cm) located in a chamber filled by gas Ar
  - 64/256ch pixels are connected to the FEC
  - The single SiPM boards is put under the TPC

- Gas Ar was filled in chamber
  α-rays from ^{241}Am are collimated via a hole of the TPC



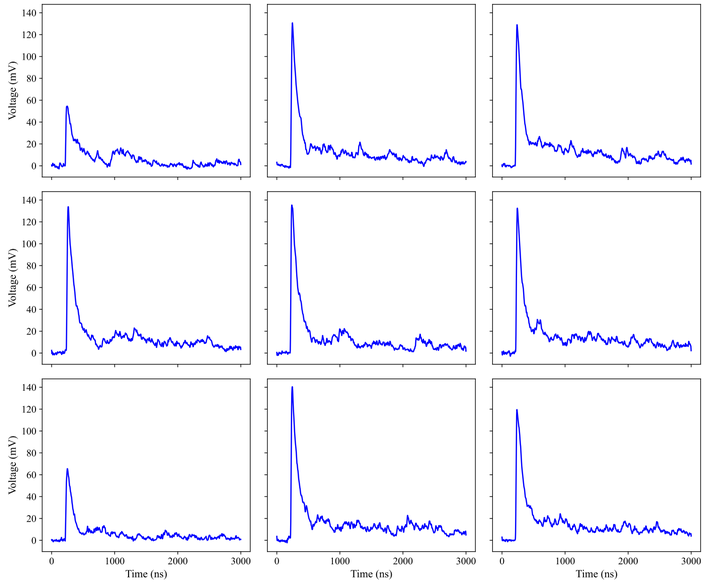


- Power supply forASIC/TIA
- Bias voltage of the TPC

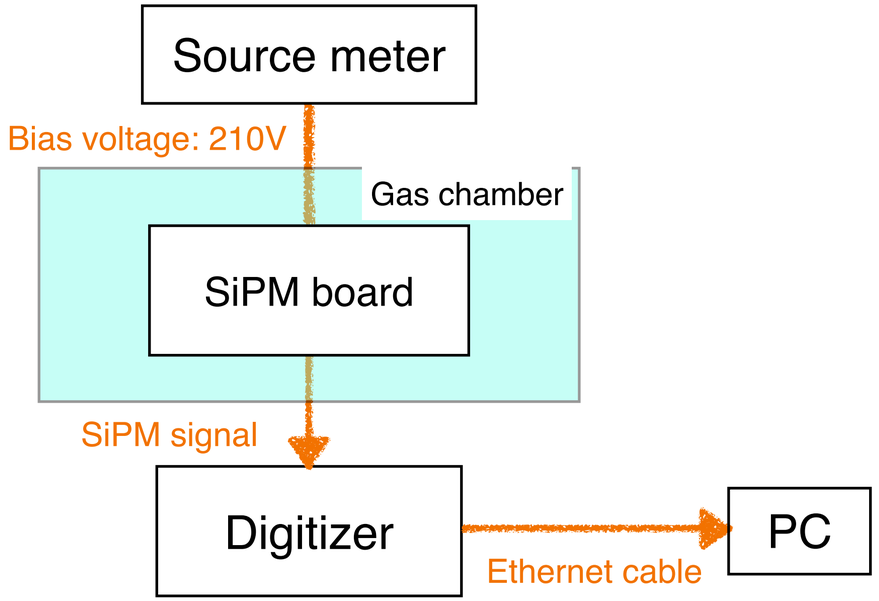
- TIA output
- Bias voltage of the SiPM

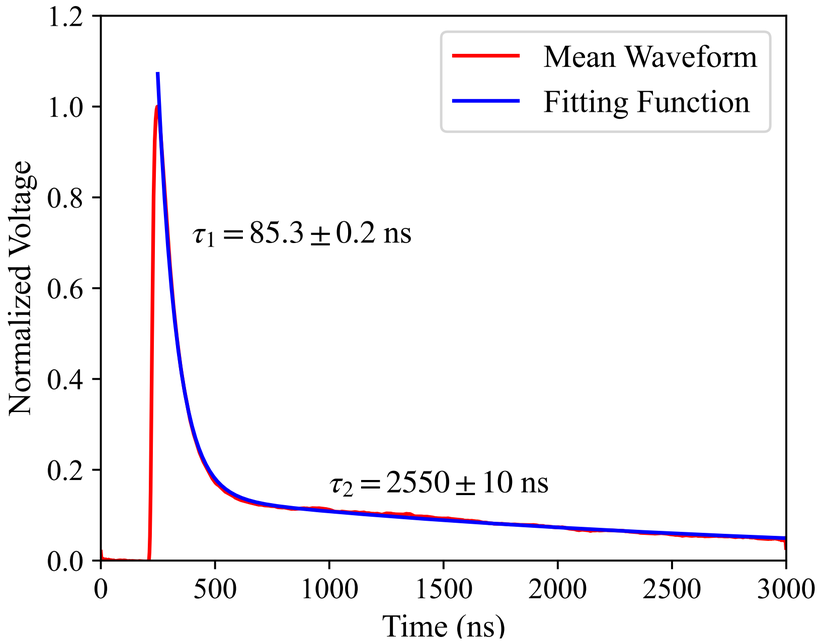
Detection of Ar scintillation light

- In GAr, we applied 52.5V per single SiPM and set a threshold to avoid dark current events
- After the GAr filling, scintillation signals were detected
- Two components with different decay times are distinguished. Essential for rejection of background neutron events



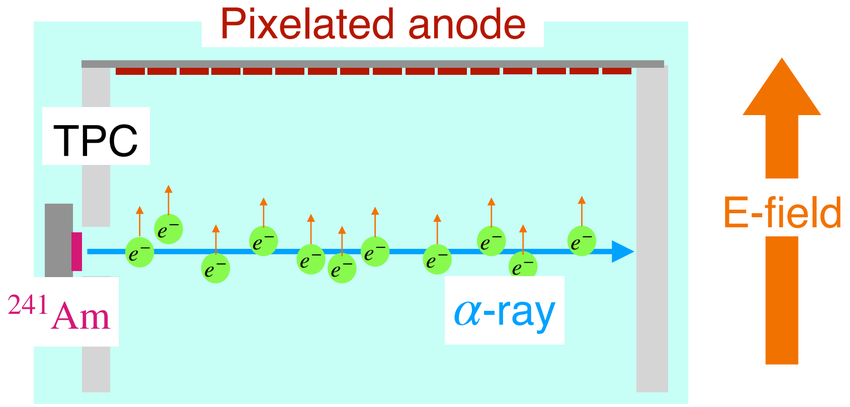
Examples of acquired waveforms

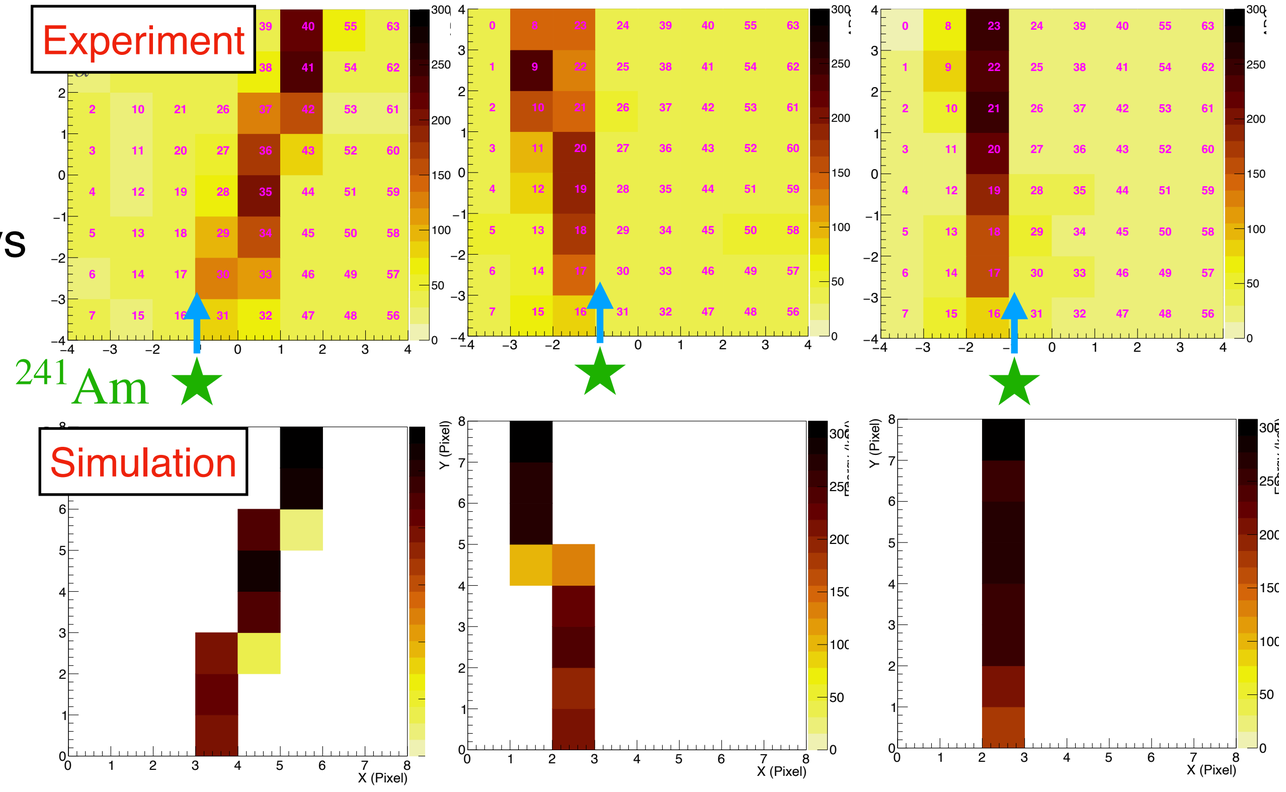




Detection of Ar electrons

- Applied E-field takes electrons, which are generated by α-rays, to anode electrodes
- Electron tracks observed along the collimated direction
- Consistent with quick Geant4 simulations
- We will develop a dense LArTPC to detect photoabsorption/Compton scatterings from gamma rays





Summary

- We have conducted a proof-of-concept demonstration for the world's first "Liquid Argon Compton camera". Current works are the development of a LAr experimental facility and the NanoGRAMS

- The SiPM boards show the response time of ~$77\ \mathrm{ns}$, Gain: ~2×10^6 in -186°C

- Performance evaluation of the electron readout system is on-going

- A small TPC (5.12x5.12x6cm) is installed to a chamber filled with GAr
  - Scintillation light and ionized electrons from Ar using α-particle source are detected

- We plan to construct a LArTPC to achieve Compton imaging.