Performance Study of Large CsI(Tl) Scintillator with MPPC Readout

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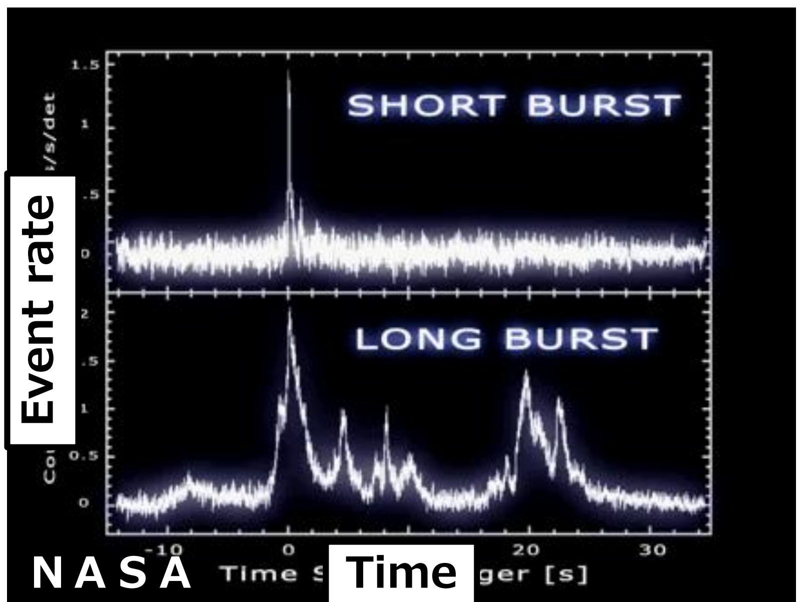
EM follow-up of GW transients

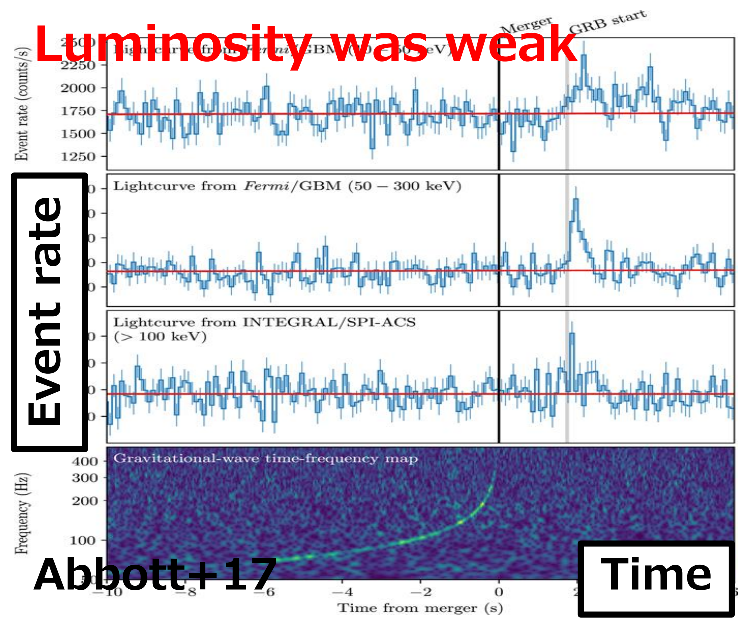
- GW170817 was the first observation of electromagnetic (EM) counterpart of the binary neutron star merger
- Gigantic campaign of follow-up observation in any EM wavelengths successfully carried out and found an EM counterpart as a kilonova
- Nominal short gamma-ray burst (SGRB) association is still ambiguous

GRB: the largest explosive phenomena in the universe and the origin is still not understood

- More detections/follow-up observations are needed for modeling and to find a SGRB association

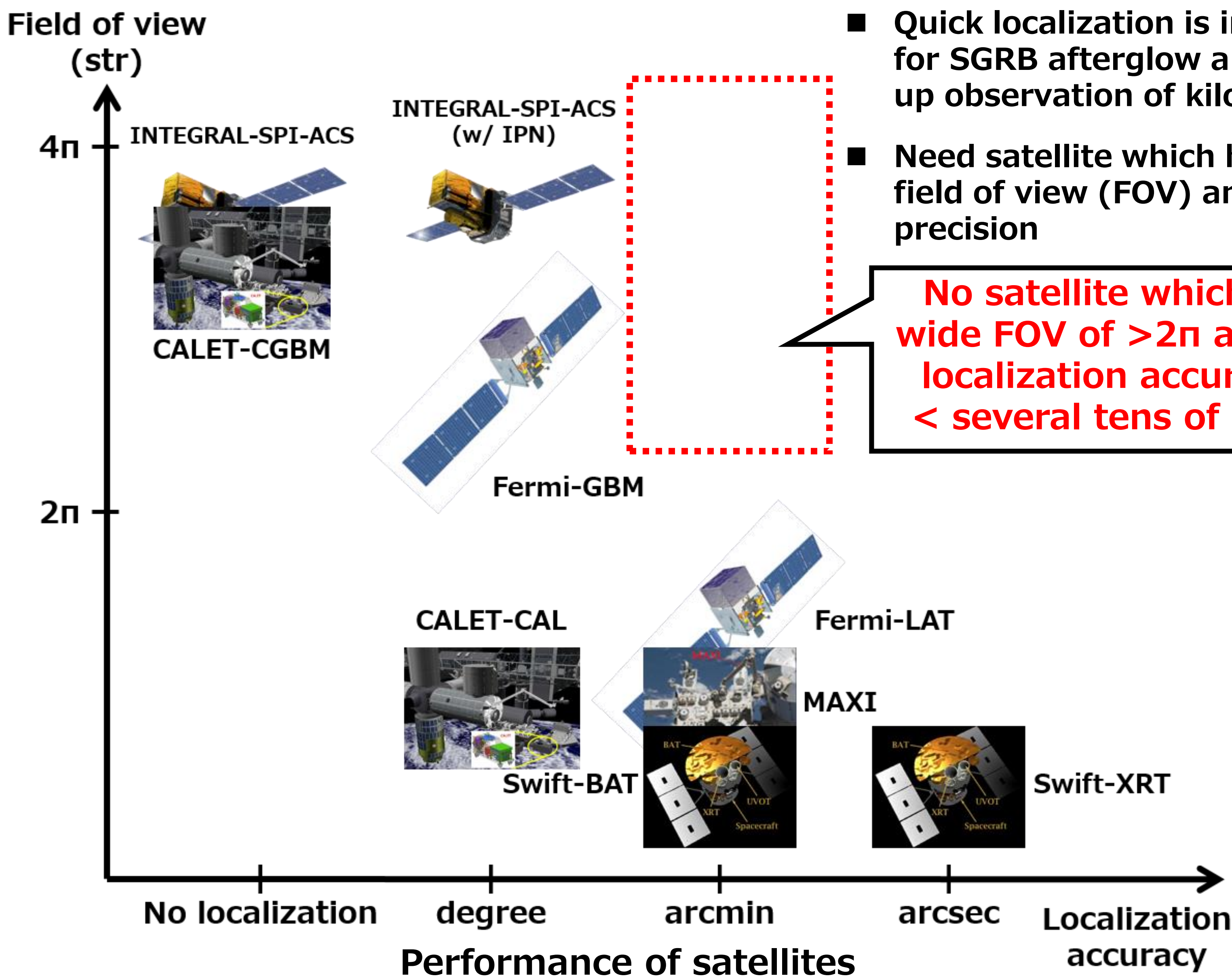


Typical light curves of GRB



Light curves of GRB 170817A

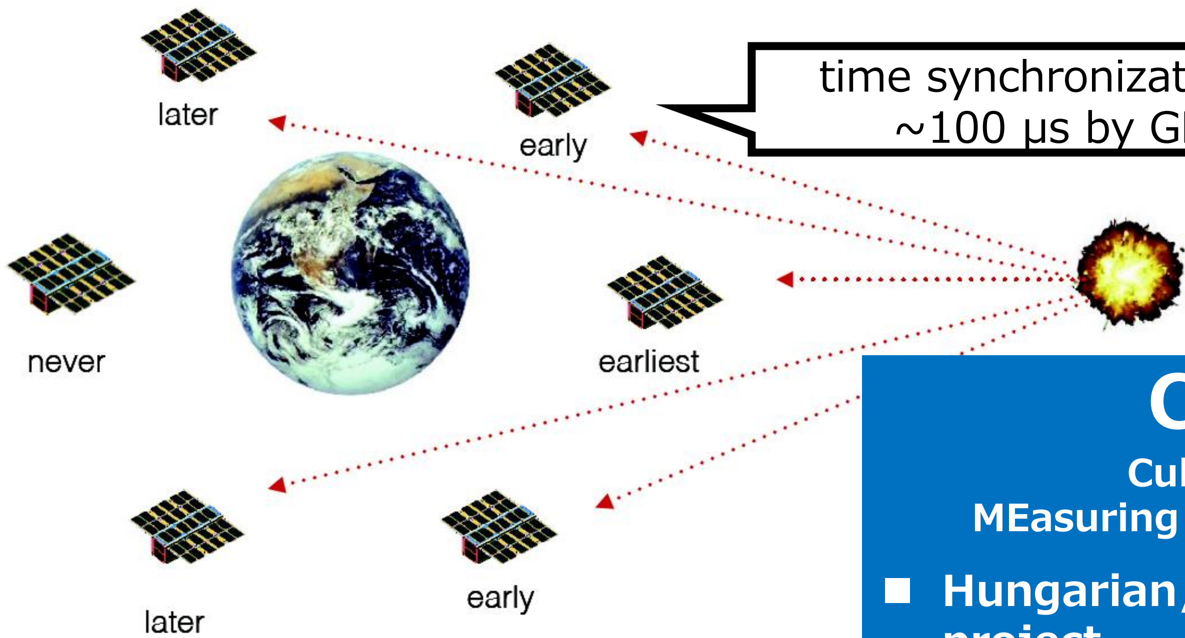
What do we need?



- Quick localization is important for SGRB afterglow and follow-up observation of kilonova
- Need satellite which has wide field of view (FOV) and localizing precision

No satellite which have wide FOV of >2π and high localization accuracy of < several tens of arcmin

Solution



CAMELOT

CubeSats Applied for MEasuring and LOcalizing Transients

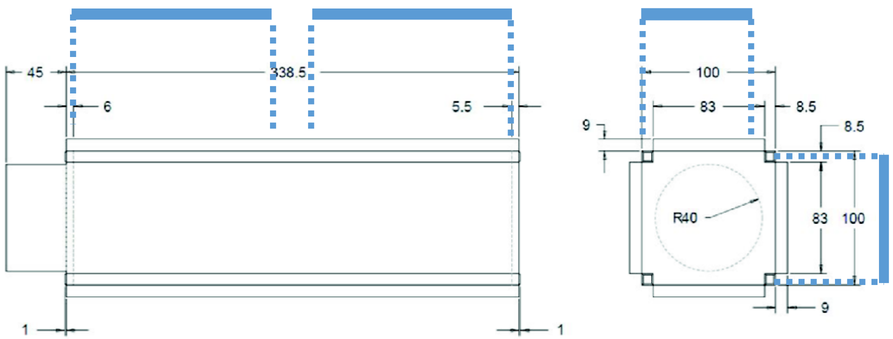
- **Hungarian/Japanese collaboration project**
- **Measure arrival time difference with a fleet of nanosatellites**

	FOV (str)	Accuracy
CAMELOT	**4π**	**Several tens of arcmin**
Fermi-GBM	**3π**	**3°**
Swift-BAT	**0.4π**	**4 arcmin**

It is expected that CAMELOT achieves all-sky monitoring and good localization accuracy

Detector design

CsI

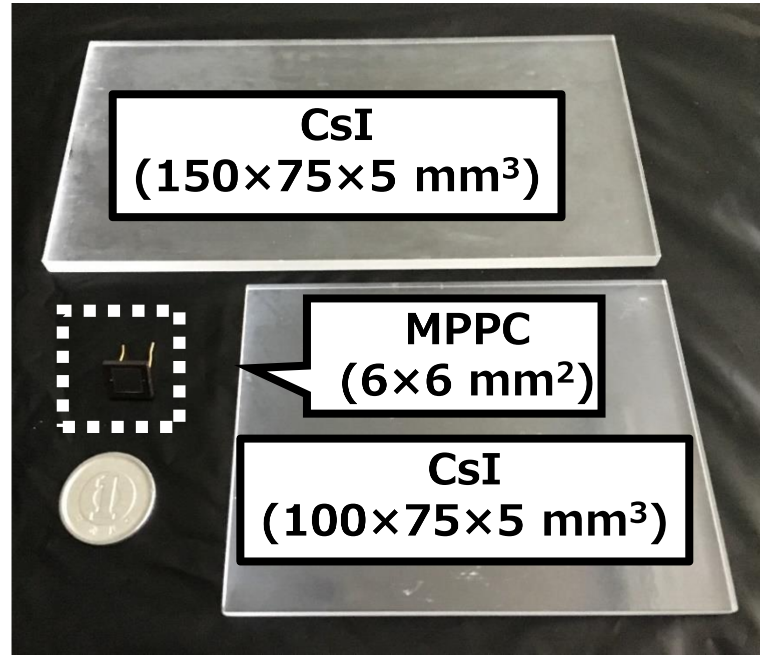


3U CubeSat platform（mm）

- Under the limitation of size, we need to use thin and large scintillators and small photodetectors
- We want to lower the energy threshold to achieve good localization accuracy

We plan to use CsI(Tl) scintillator and MPPC, and evaluate the readout system

Maximum size to mount ↓



- ☐ **CsI: Amcrys**
- ☐ **MPPC: Hamamatsu Photonics S13360-6050CS**

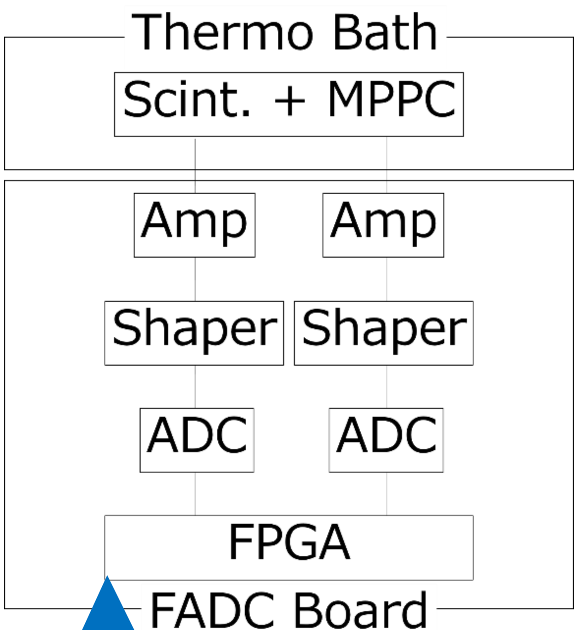
Measurement items

1. **Scintillator-size dependence of the light yield**
2. **Energy threshold**
3. **Uniformity**
4. **Optimum position of MPPCs**
5. **Effect of proton damage on MPPC in orbit**

We need the detector which has large area and high light yield

Setup of readout system

We developed multiple readout system to improve the light yield and reduced the noise by using coincidence technique

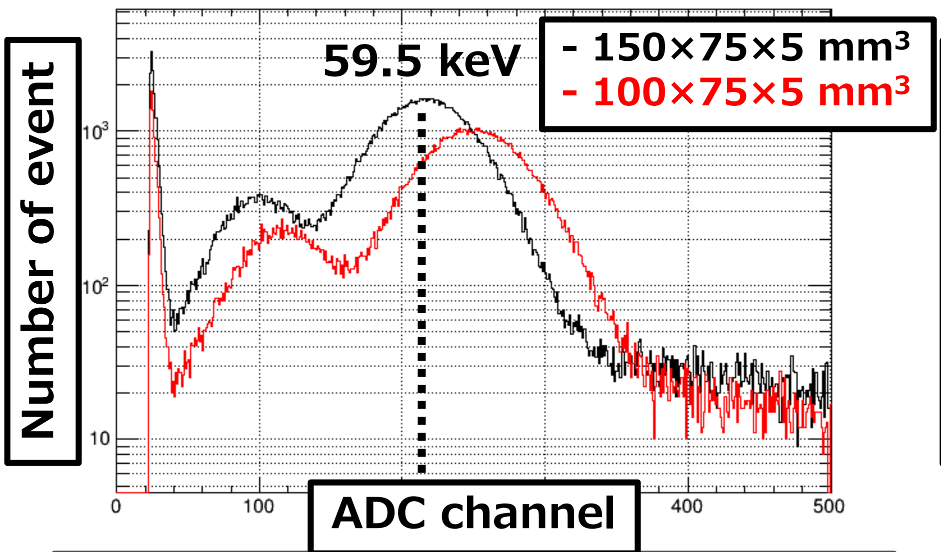


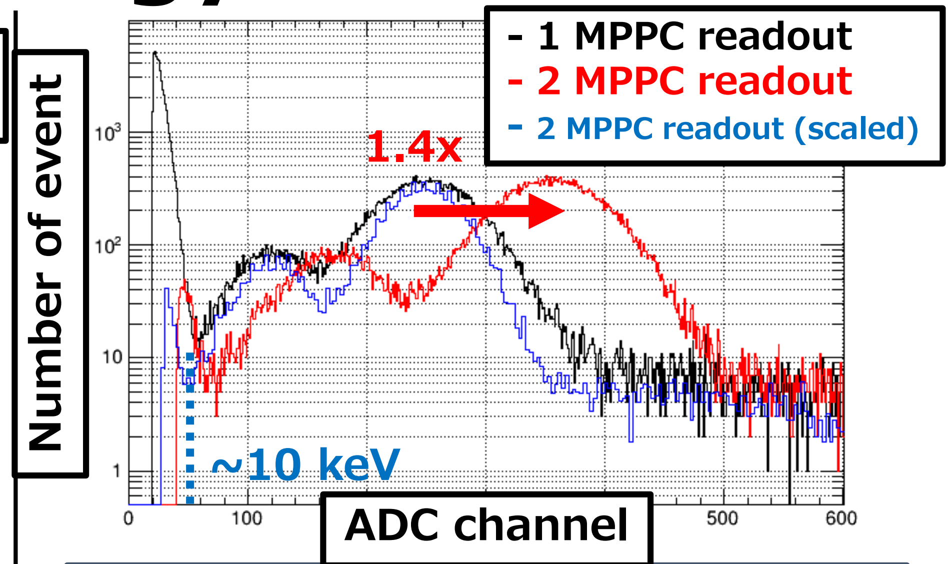
- **Record waveforms and trigger time**
- **Sum signals detected within 5 us**

Configurations

- **Shaping time: 2.2 μs**
- **Temperature: 25 ℃**
- **Operational voltage: 53.4 V**
- **Breakdown voltage: 50.87 V, 50.82 V**
- **Radiation source: ^{241}Am (59.5 keV)**

Light yield and energy threshold





Scintillator-size dependence

- **Light yield of 150×75×5 mm³ CsI is ~87 % of 100×75×5 mm³ CsI despite the size ratio of 1.5 times**

→ the bigger CsI is better suited to the nanosatellites

- **Absolute light yield: ~3.5 p.e./keV**
  (evaluated by comparing the pulse height with that of obtained by a calibrated 10 mm cubic CsI)

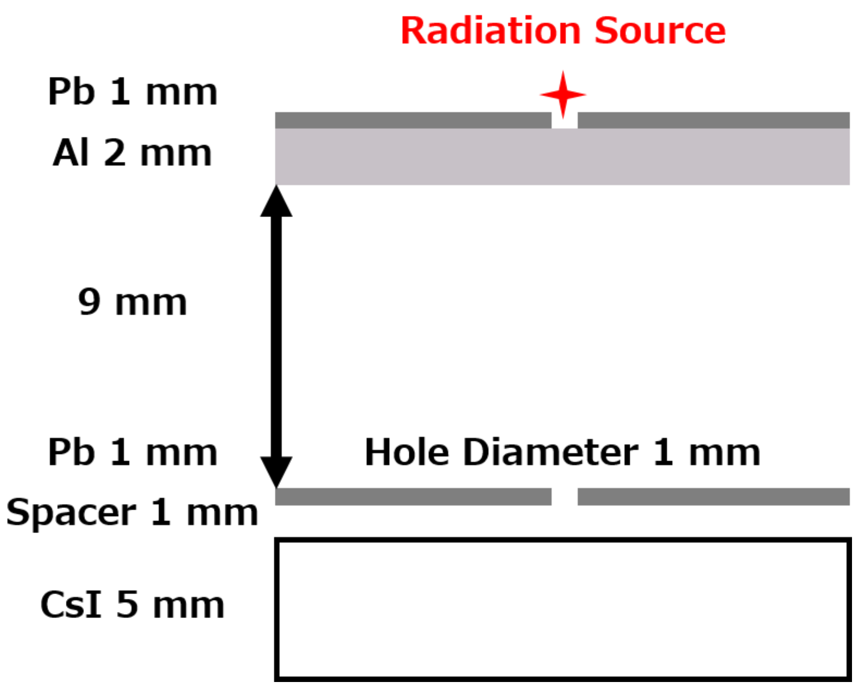
One- vs. two-MPPC readout

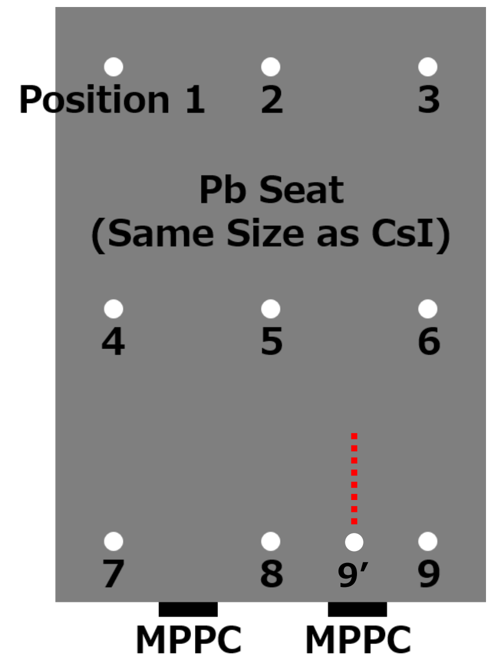
For two-MPPC readout,

- **Light yield increased by 1.4 times**
- **Energy resolution: ~36 % → ~29 %**
- **Energy threshold: <10 keV**

Configuration for measuring uniformity

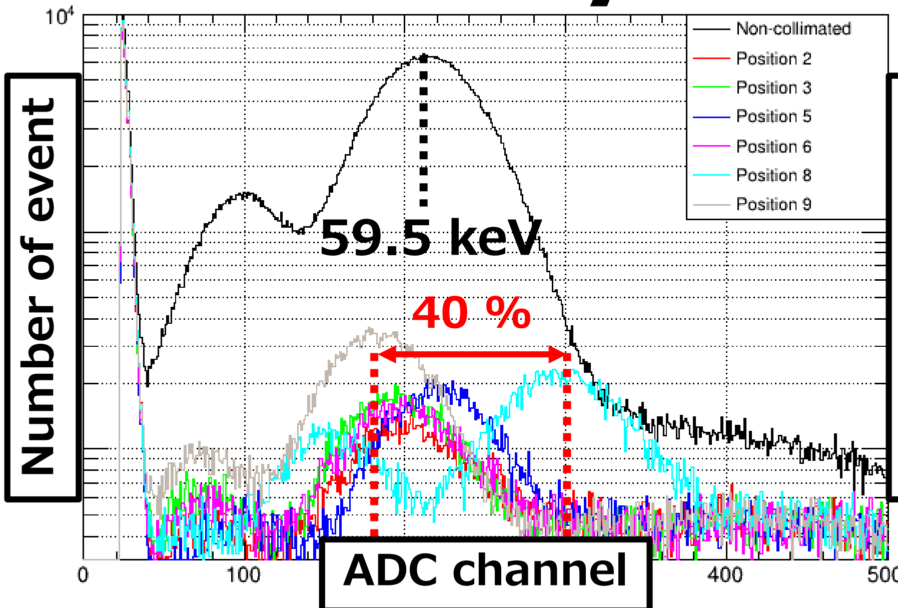
We measured position dependence of the light yield and used two lead sheets each containing ten holes that are ~1 mm in diameter.



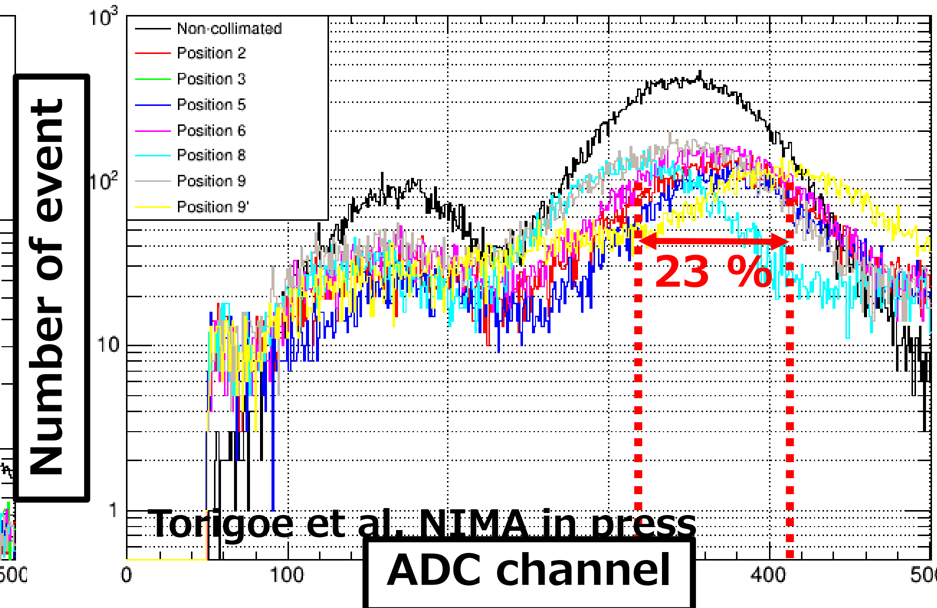


We numbered each position of the holes

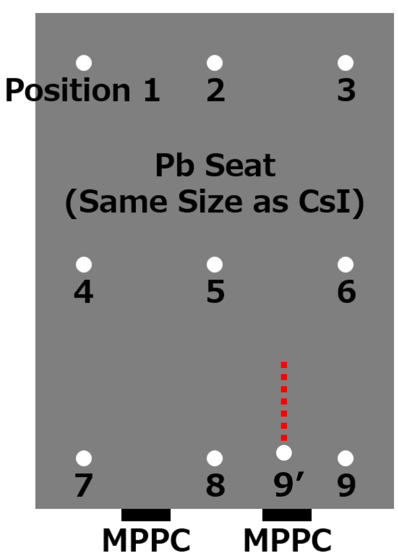
Uniformity



Uniformity (one-MPPC)



Uniformity (two-MPPC)



We measured the spectra at each positions, and defined **non-uniformity as the peak-to-peak difference** of the 59.5 keV line among the each positions

The non-uniformity changed from ~40 % to ~23 % by using the two-MPPC readout

→ the uniformity was improved with the two-MPPC readout

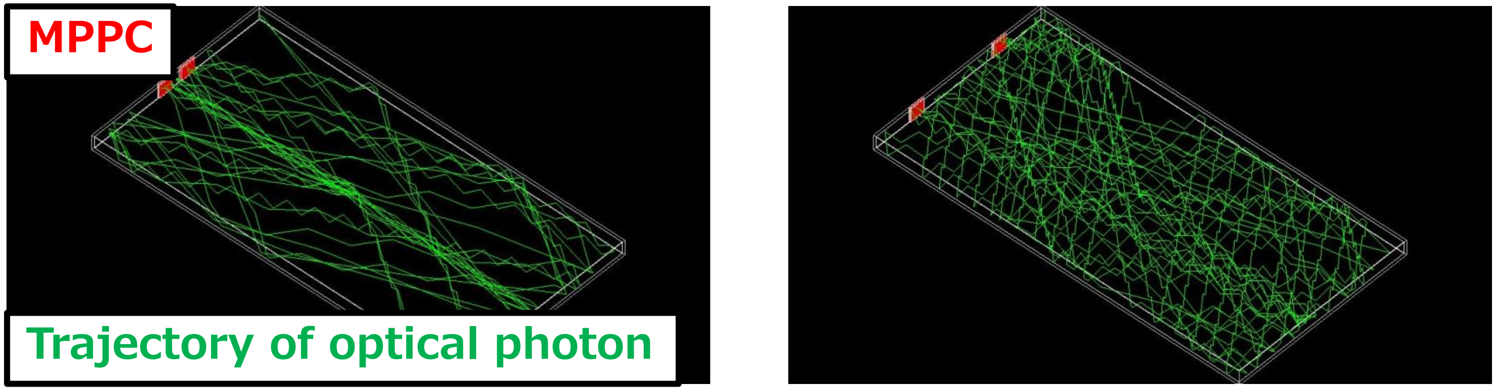
Optimum position of MPPCs

We investigated the optimum position of the two MPPCs which gives the highest light output

- simulated a propagation of scintillation lights inside the scintillator to the MPPC by Geant4, ray-tracing Monte Carlo simulator
- compared the number of detected photon while changing the position of the two MPPCs

Configurations

- **Beam energy: 59.5 keV**
- **Number of the beam (set): 20000 (8)**
- **Generation position of the beam: 20 cm above the CsI surface**
- **Scintillation yield: 65 photon/keV**
- **Reflectivity: 99.9 %**
- **Absorption length of scintillation lights: 300 cm**



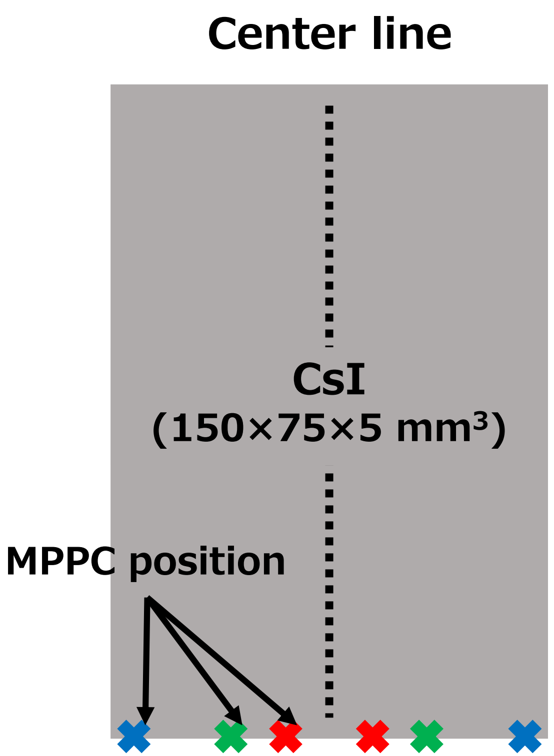
Optimum position of MPPCs

Firstly, we compared the result of simulation with that of experiment
(number of detected photon at simulation) ∝ (peak channel at experiment)

	1-MPPC readout	2-MPPC Readout	ratio
Simulation (number of detected photon)	35800±2000	56200±2400	~1.6
Experiment (peak channel)	251	354	~1.4

Good agreement

Simulation is reliable!



We compared the number of detected photon at three configurations

Distance from the center line (mm)	Number of detected photon
5	56200±2400
18.75	57500±3300
32.5	55100±1000

Symmetrical configuration gives similar light yield independent of the each MPPC position

We are investigating further optimization

Effect of proton damage on MPPC in orbit

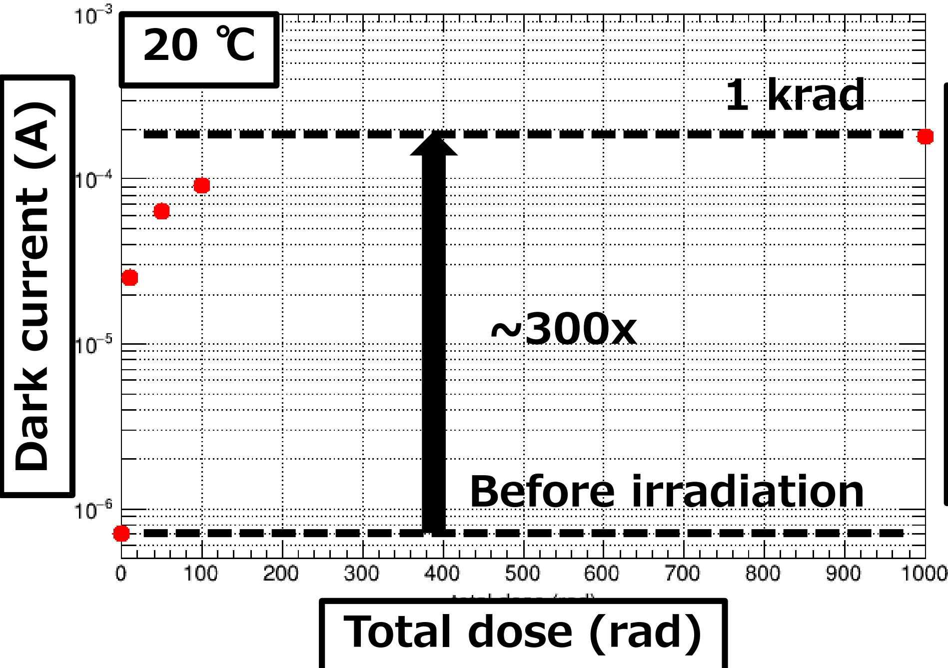
- irradiated 200 MeV proton beam on MPPC (S13360-6050CS) at total dose of 10, 50, 100, 1000 rad (~1 krad is the total dose in one year)
- evaluated the dark current, energy spectrum and threshold by using 10 mm cubic CsI(Tl) scintillator

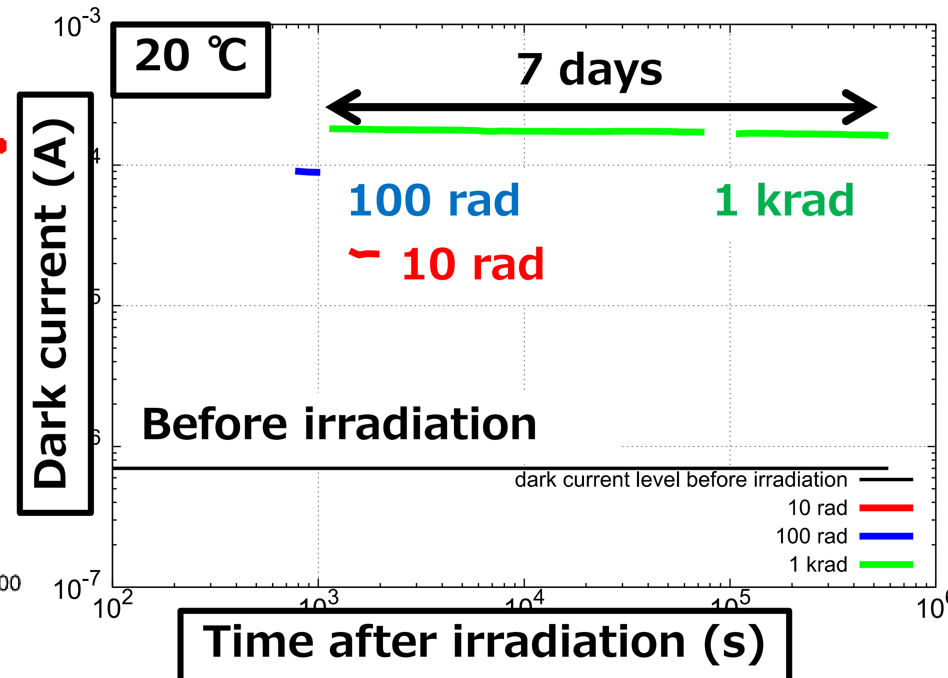
Configurations

- **Shaping time: 1 μs**
- **Temperature: 20 to -30 ℃**
- **Operational voltage: 55.0 V**
- **Breakdown voltage: 51.73 V**

At Wakasa-wan energy research center

Dark current change



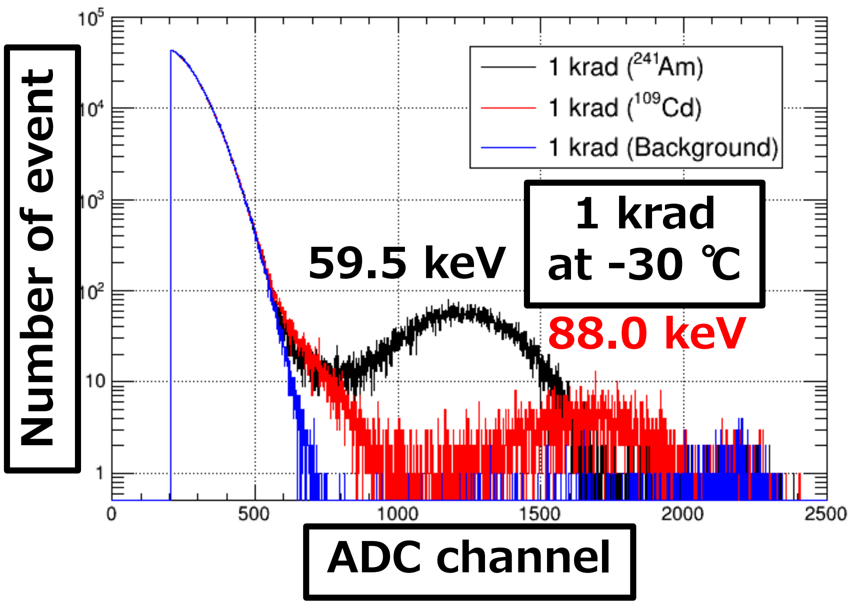


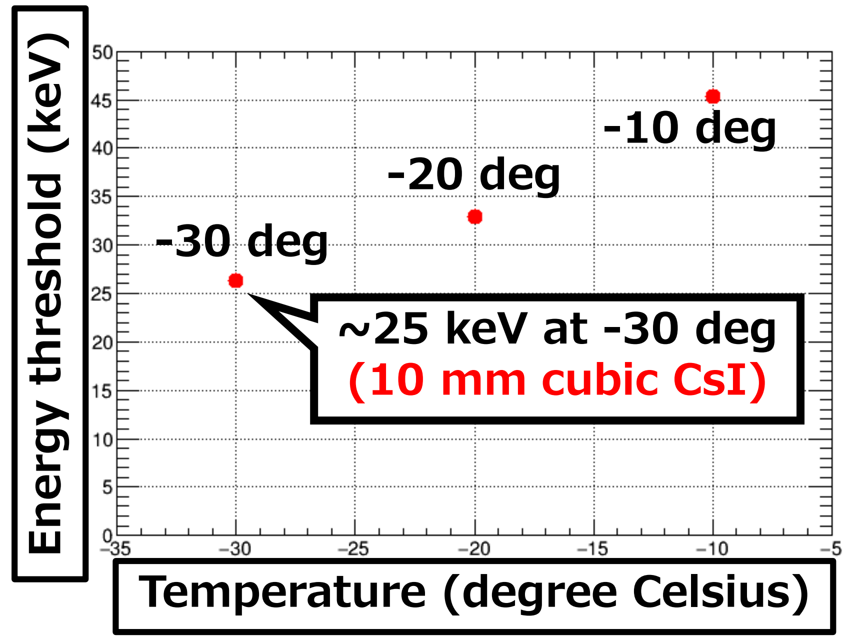
Dark current change by total dose

Dark current change by elapsed time

Dark current increased by ~300 times at total dose of 1 krad and has barely changed for 7 days

Energy threshold





Energy spectra at total dose of 1 krad at -30 ℃

Energy threshold at total dose of 1 krad

light yield of 10 mm cubic CsI is higher than that of $150 \times 75 \times 5$ mm^3 CsI by 3.6 times

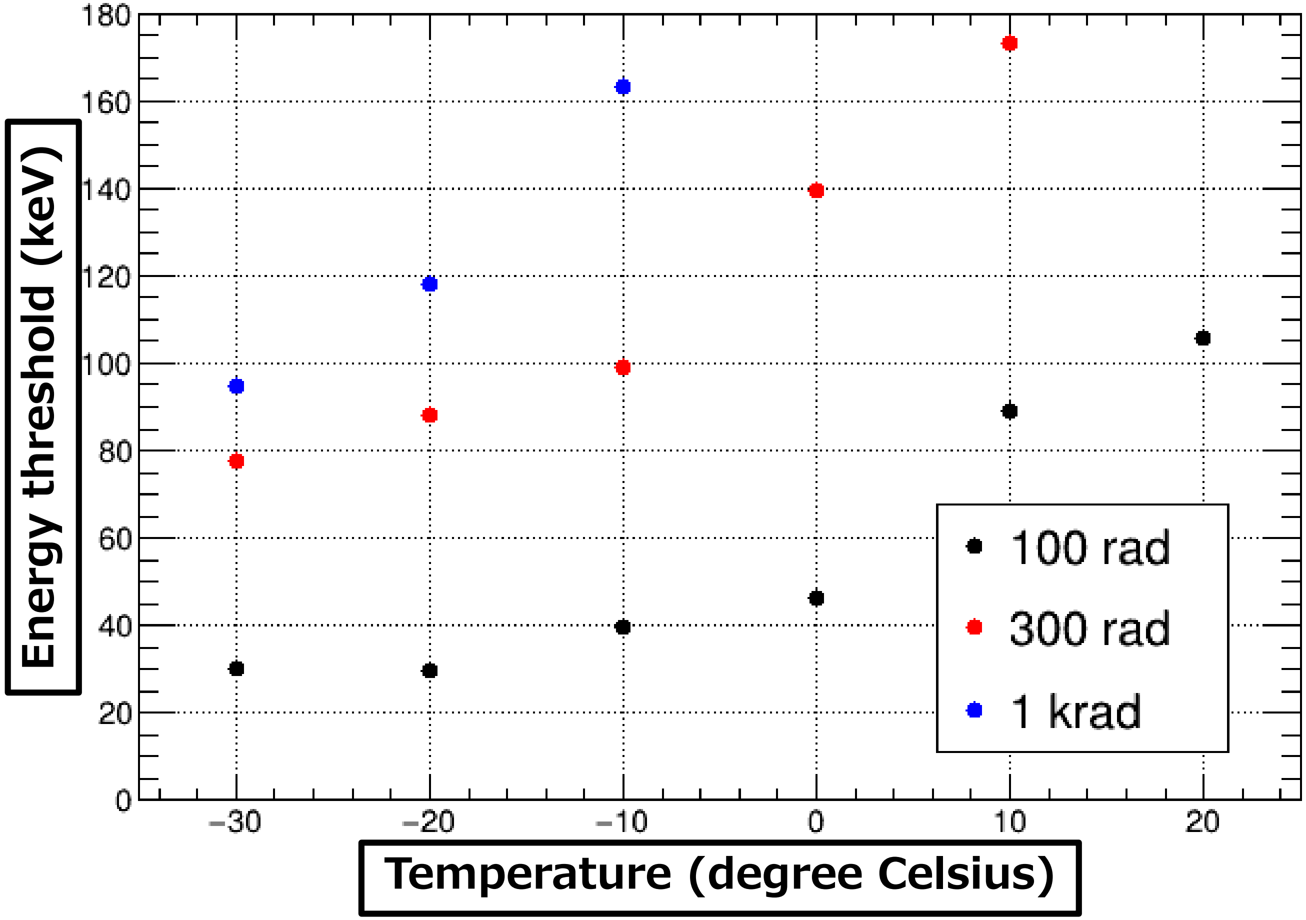
Energy threshold at -30 ℃ is estimated to <100 keV at large CsI

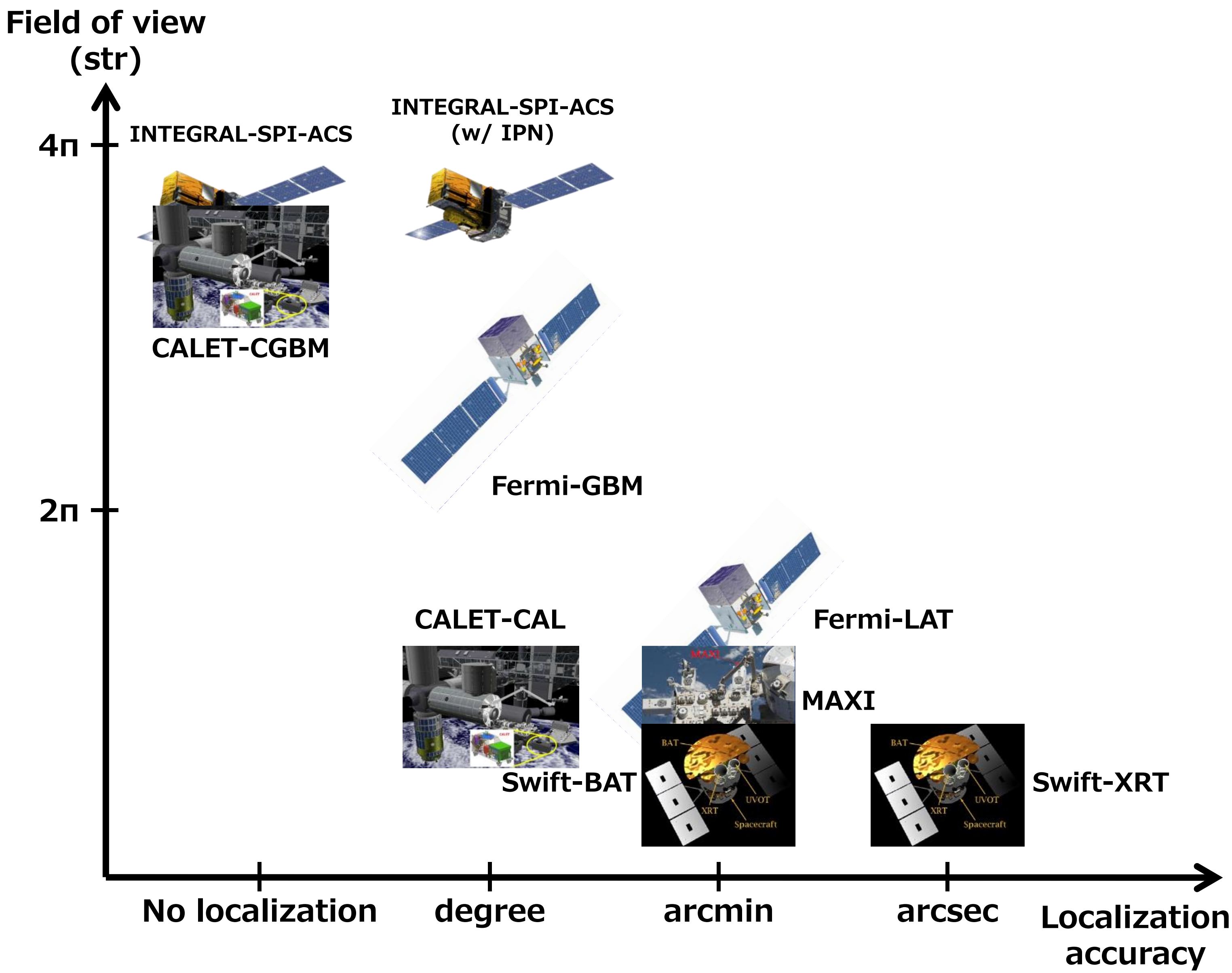
→ **need cooling and shielding of MPPCs**

Summary and future works

- Light yield of 150×75×5 mm^3 CsI is ~87 % of 100×75×5 mm^3 CsI
- Achieved low energy threshold <10 keV at 25 ℃ on the ground
- Uniformity was improved with the two-MPPC readout
- Symmetrical configuration of two MPPCs gives similar light yield
- Dark current increased by ~300 times at total dose of 1 krad and has barely changed for 7days
- Energy threshold at total dose of 1 krad is <100 keV at -30 ℃
  → analyzing the results of the experiments of proton damage test in detail and will compare that with previous studies

Energy threshold




Field of view
(str)
4π
2π
INTEGRAL-SPI-ACS
INTEGRAL-SPI-ACS
(w/ IPN)
CALET-CGBM
Fermi-GBM
CALET-CAL
Fermi-LAT
MAXI
Swift-BAT
Swift-XRT
No localization
degree
arcmin
arcsec
Localization
accuracy