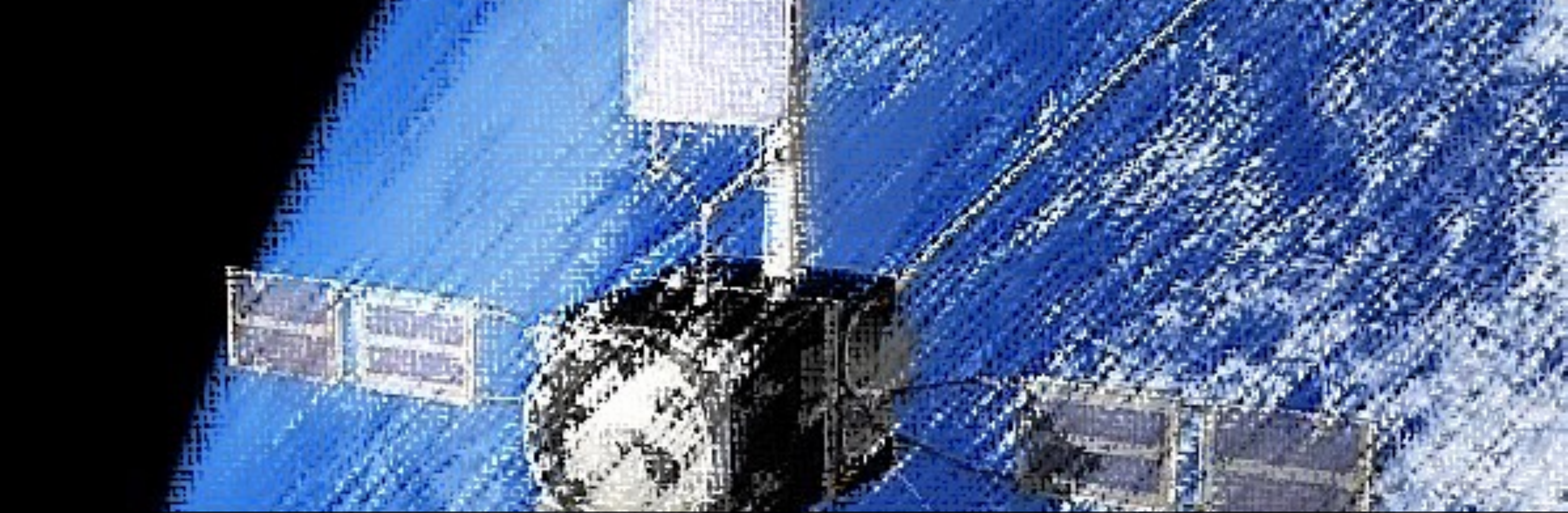
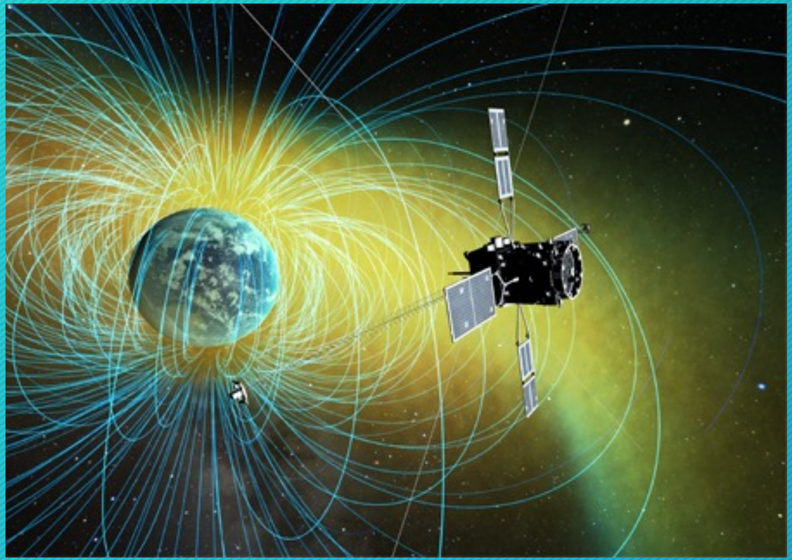


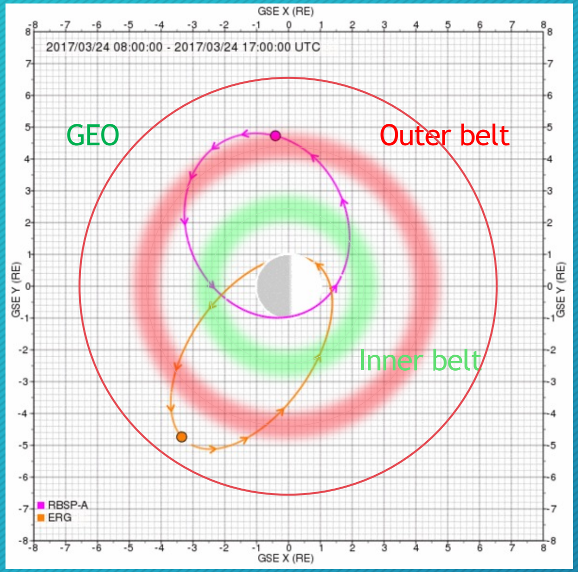
Calibration of radiation belt electron data observed by Arase satellite using Geant4 simulation

National Institute of Information and Communications Technology (NICT, Japan)
Space weather laboratory / Researcher - Park Inchun

2024. 3. 12. GSICS meeting

ARASE satellite (ERG mission)



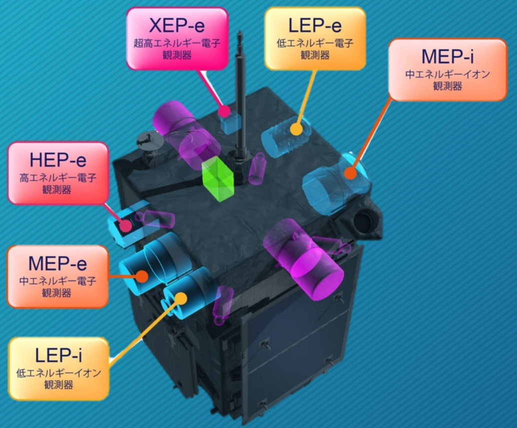


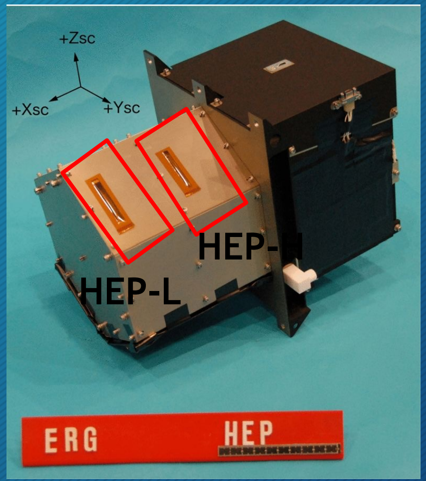
Launch	Date	20 December 2016 **(Observation start: March 2017)**
	Location	Uchinoura Space Center (USC)
	Launch Vehicle	Epsilon
Nominal Mission Life		>1 yr
Orbit	Altitude	**Perigee: about 460 km, Apogee: about 32,110 km**
	Inclination	**31°**
	Type of Orbit	Elliptical orbit
	Period	**about 9 hours** (565 min)
Attitude	Stabilization	Spin-stabilized
	Spin Direction	Sun-oriented
	Spin period	**8 s** (7.5 rpm)
Satellite Bus		SPRINT bus
Configuration	Weight	350 kg

ARASE instruments

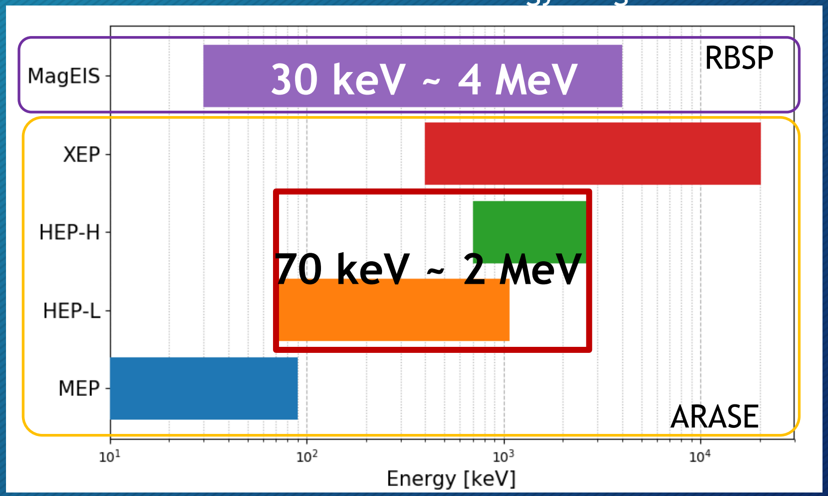
- Low-Energy Particle Experiments - Electron Analyzer (LEP-e)
- Low-Energy Particle Experiments - Ion Mass Analyzer (LEP-i)
- Medium-Energy Particle Experiments - Electron Analyzer (MEP-e)
- Medium-Energy Particle Experiments - Ion Mass Analyzer (MEP-i)
- **High-Energy Electron Experiments (HEP-L, HEP-H)**
- Extremely High-Energy Electron Experiments (XEP)

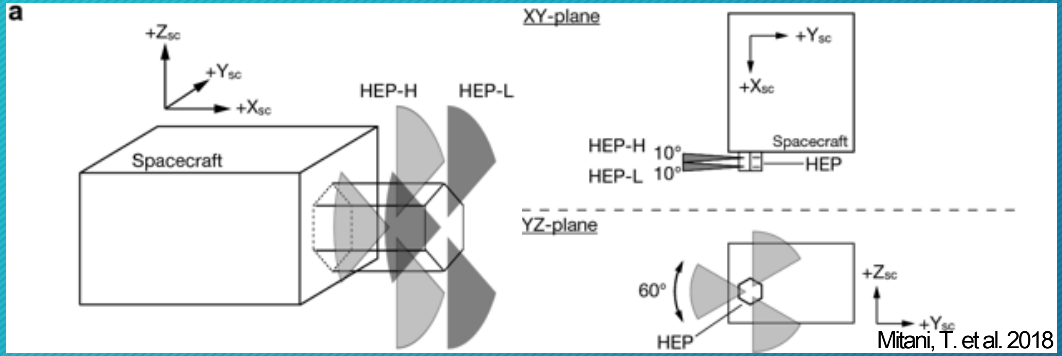
- Plasma Wave Experiment (PWE)
- Magnetic Field Experiment (MGF)
- Software-Type Wave Particle Interaction Analyzer (S-WPIA)





Electron detectors energy range

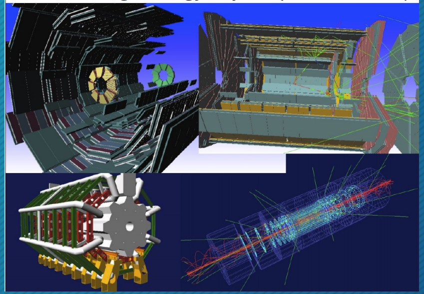




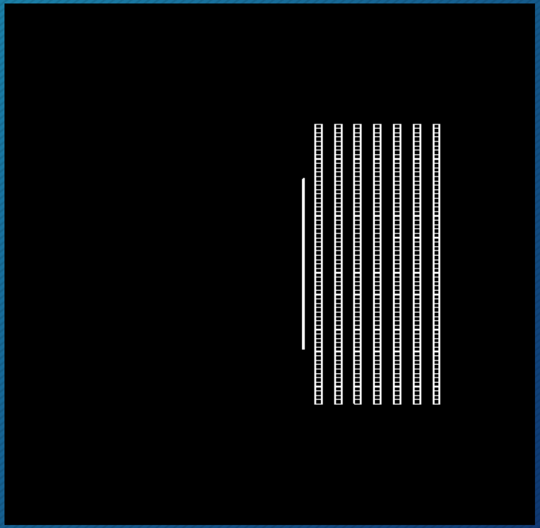
Calibration of radiation belt electron data observed by Arase satellite using **Geant4** simulation

- Purpose of the Study
  - In-flight ARASE HEP instrument data calibration and performance verification

Geant4 in High Energy Physics (ATLAS at LHC)



- What is **Geant4?**
  - Geant4 (for GEometry ANd Tracking)
  - Developed by CERN,INFN,KEK,SLAC(ver1 released 1994, now 11.1)
  - Monte Carlo simulation tool for particle physics
  - Simulate interactions when elementary particles passing through and interacting with matter



Data Calibration Process

✓ Raw data: HEP electron count rate [Counts/s]

✓ Calibrate the count rate depending on the Energy

- Restore electron energy changed by Al window, structure factors
- Using simulated **response function**

✓ Convert to Differential flux [Counts/mm^2・ str・ keV・ s]

- Depends on detector's characteristics
- **G-factor** [mm・ str] : change count rate to differential flux

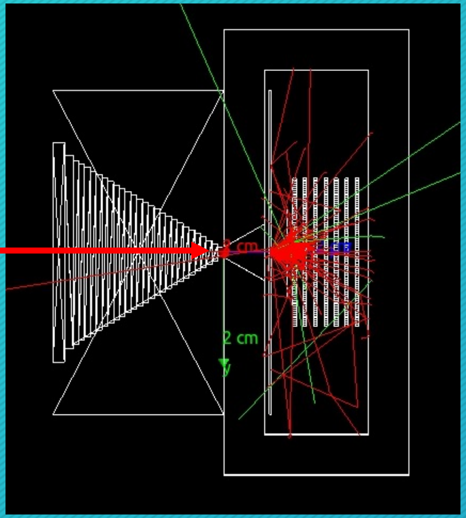
Geant4 simulation

Lv2 Data Produce

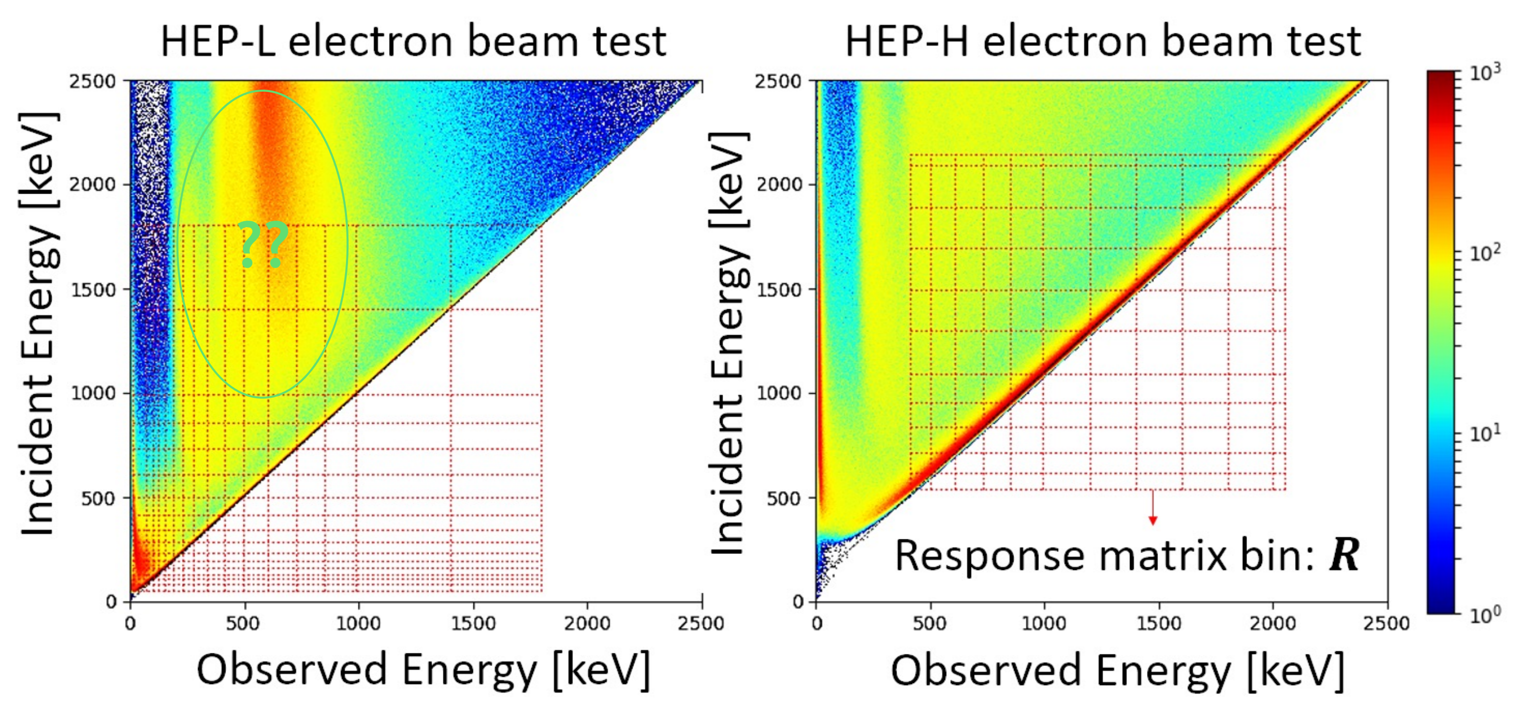
Calibrate the count rate depending on the Energy

<Simulation status>

e⁻ Pencil beam
1~3000 keV
10^5 events



<Simulation results>

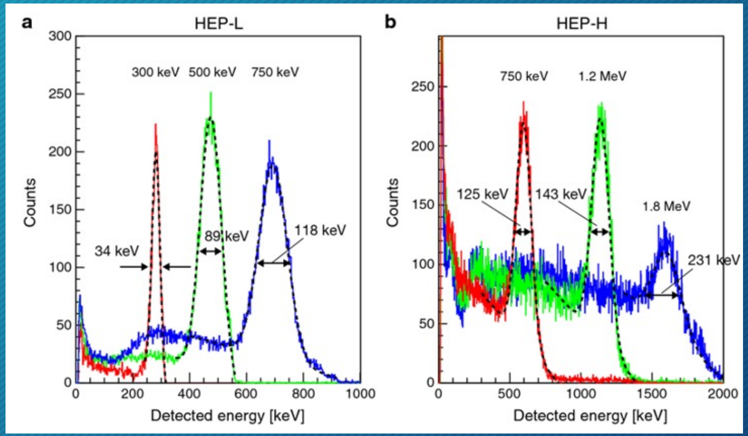


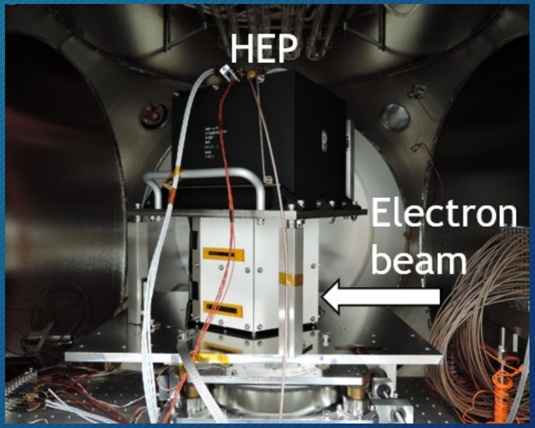
Calibrate the count rate depending on the Energy

- Spectrum structure analysis
  - Beam test and simulation have dent structure
  - Thin and long SSD structure makes loss detection area
  - Energy deposit depends on thickness of loss detection area
    (scatter angle > 60° → Energy deposit > 450keV)

- Identify the causes of spectral changes
  ➡ Instrument structure affects the Spectroscopic performance

<Electron Beam test>



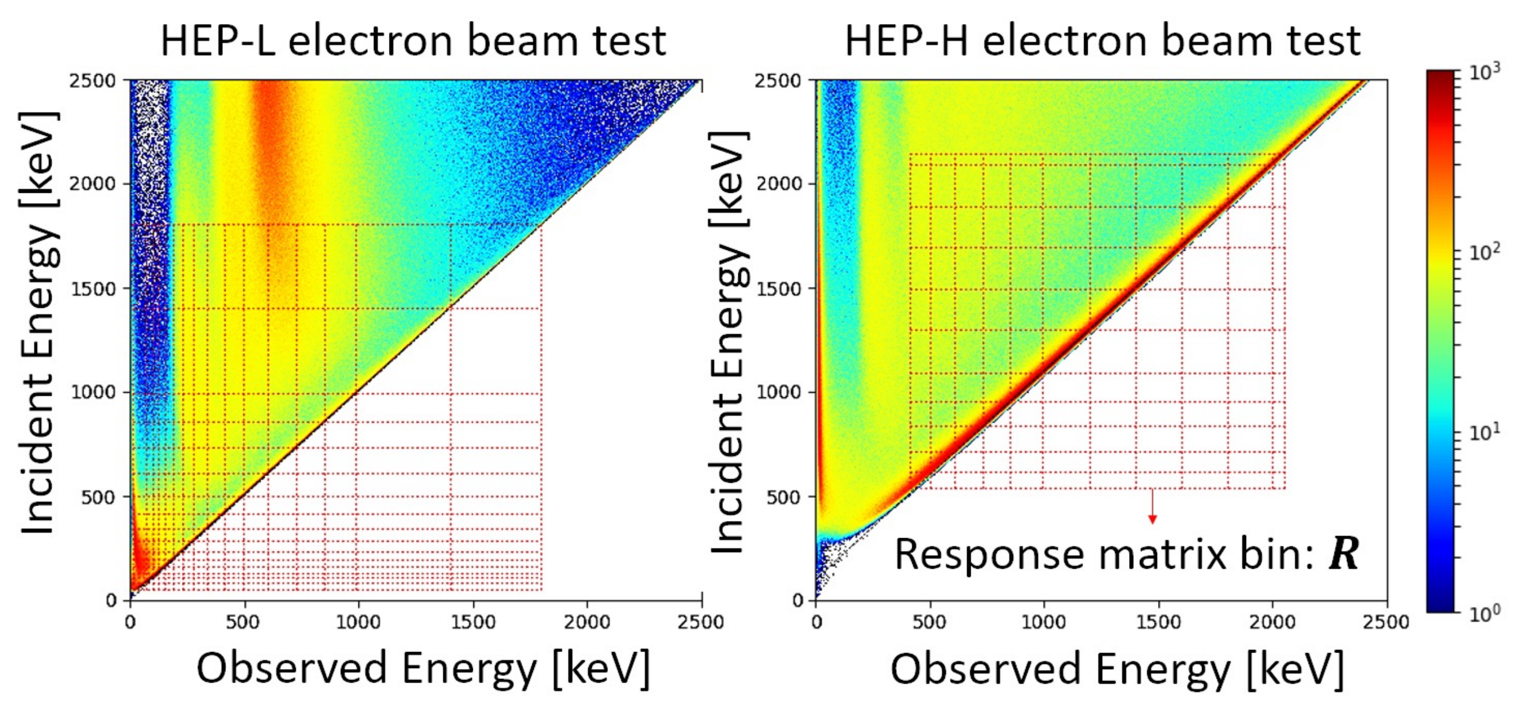


Calibrate the count rate depending on the Energy

- Using the inversion matrix method, incident energy spectra restored from observed particle counts.

$$C_{true}(E_i) = \boldsymbol{R}^{-1} \cdot C_{obs}(E_o)$$

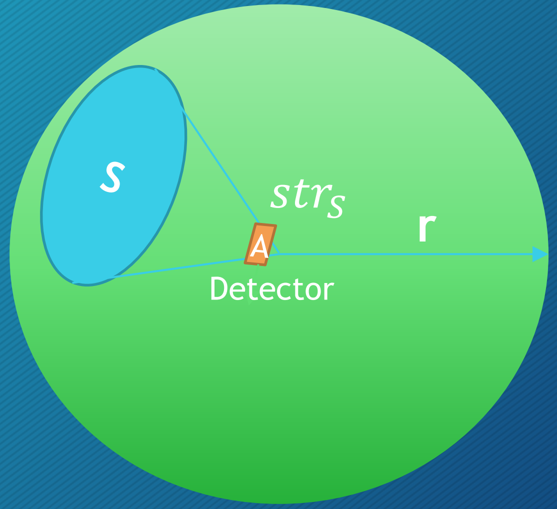
※ R: Response function
$C_{true}(E_i)$: Energy spectra of incident electron counts
$C_{obs}(E_o)$: Energy spectra of observed electron counts



Convert to Differential flux (G-factor)

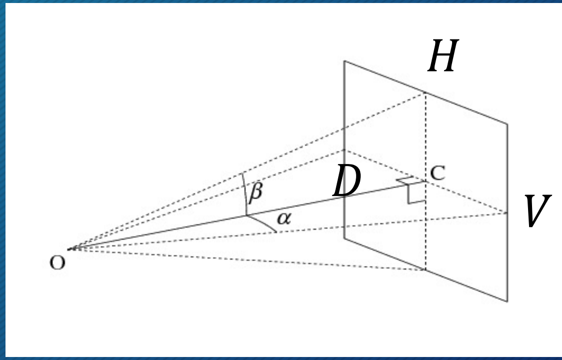
- G-factor?
  - The constant of detector to calculate differential flux.
  - FOV of detector(str_S) x Detector surface area(A)

Pre cal HEP-H G-factor : 0.037 $cm^2 str$



- How to calculate str_S?
  - 1. From the formula
    - Using FOV $str_S = 4\sin^{-1}(\sin\alpha\sin\beta)$
    - Using collimator geometry(Pre cal method)

$$str_S = 4\cos^{-1}\sqrt{\frac{1+\left(\frac{V}{2D}\right)^2+\left(\frac{H}{2D}\right)^2}{\left(1+\left(\frac{V}{2D}\right)^2\right)\left(1+\left(\frac{H}{2D}\right)^2\right)}}$$



  - 2. Using simulation

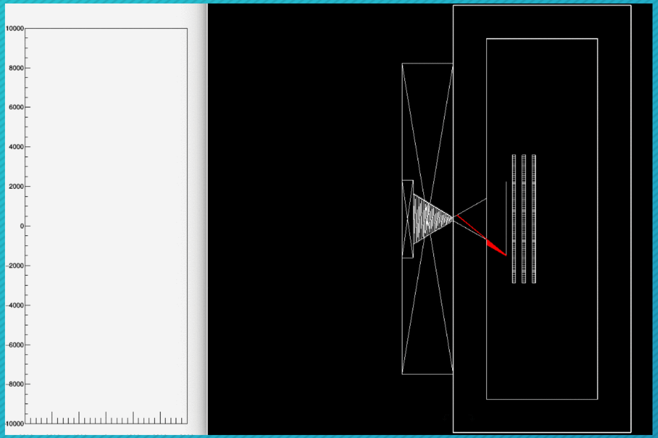
$$str_S = \frac{S}{r^2}$$

Convert to Differential flux (G-factor)

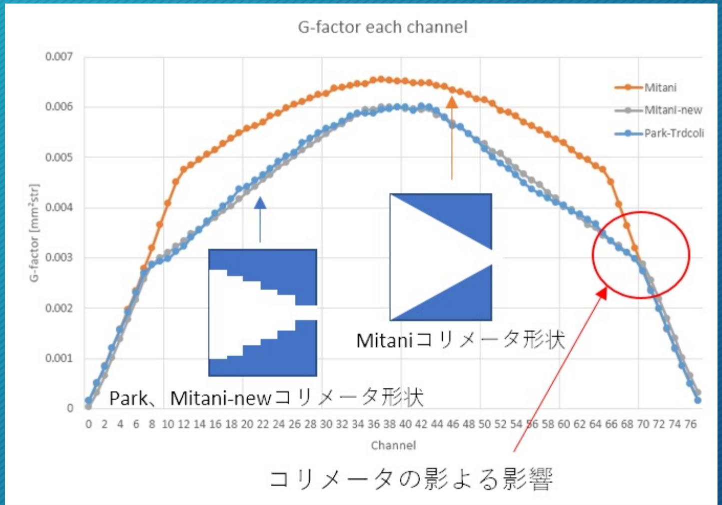
- Calculation of G-factor from the simulation

$$G\text{-}factor \simeq 2\pi \times Sensor\ area \times \frac{Escaped\ particle}{Irradiated\ particle}\ [\mathrm{mm^2sr}]$$

HEP-L: ~0.0031 mm^2str / HEP-H: ~0.031cm^2str

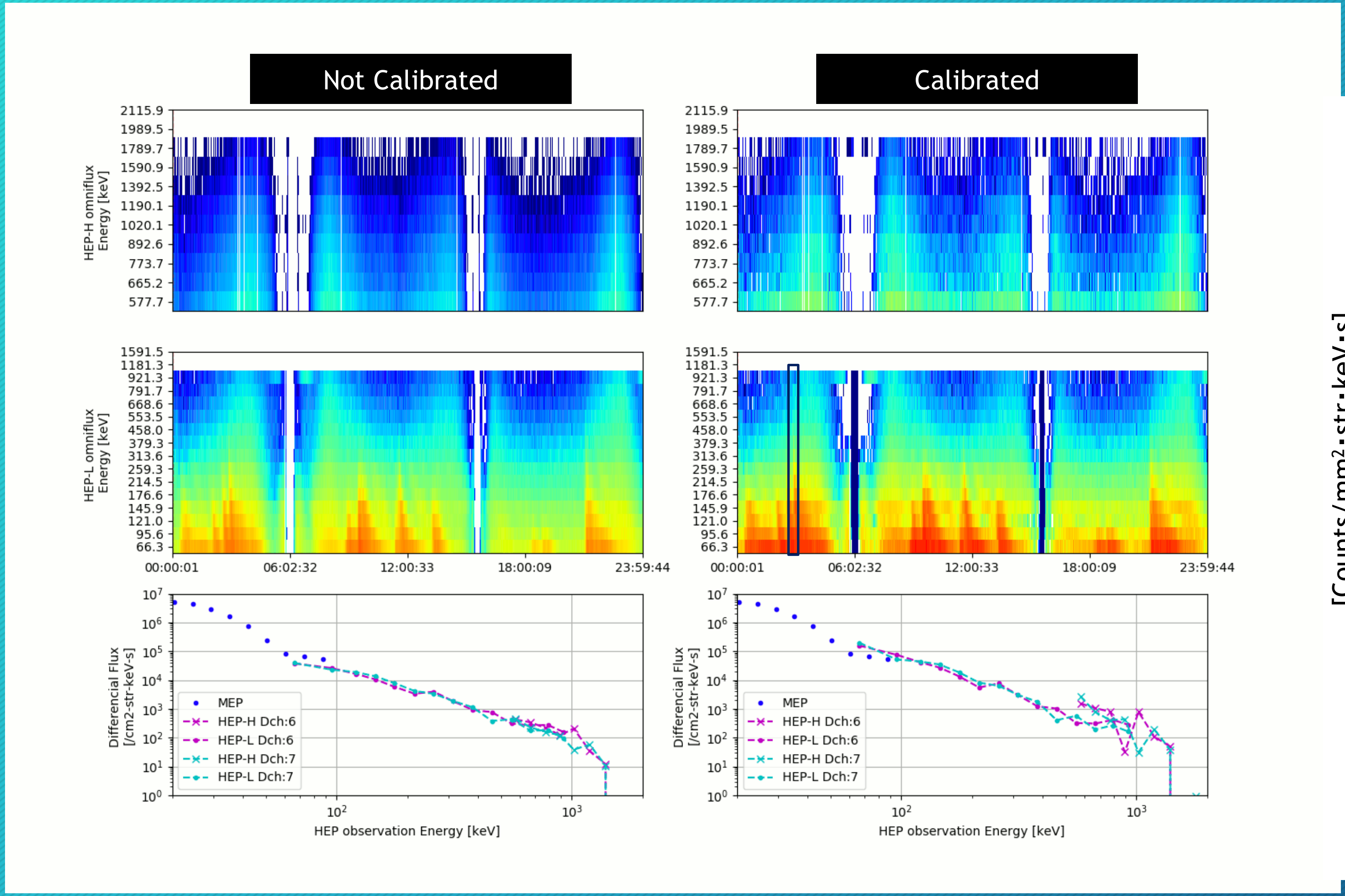


<15m 離れた壁に投影した影>

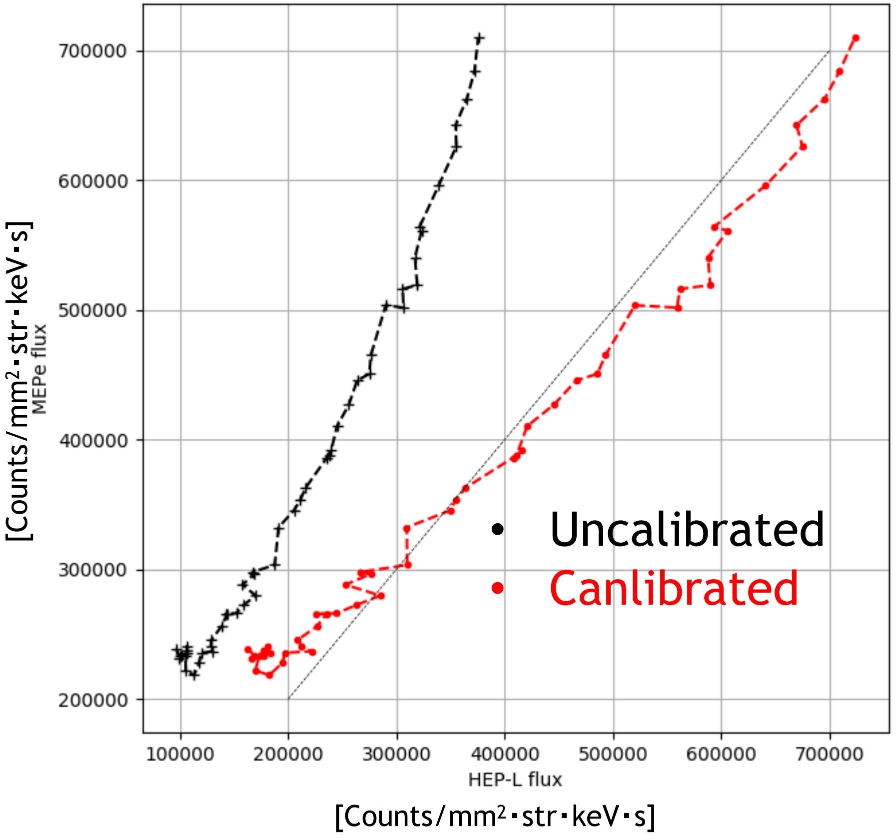


✓ Simulation founded that the detailed geometry affect the result (Collimator shape, slit thickness)

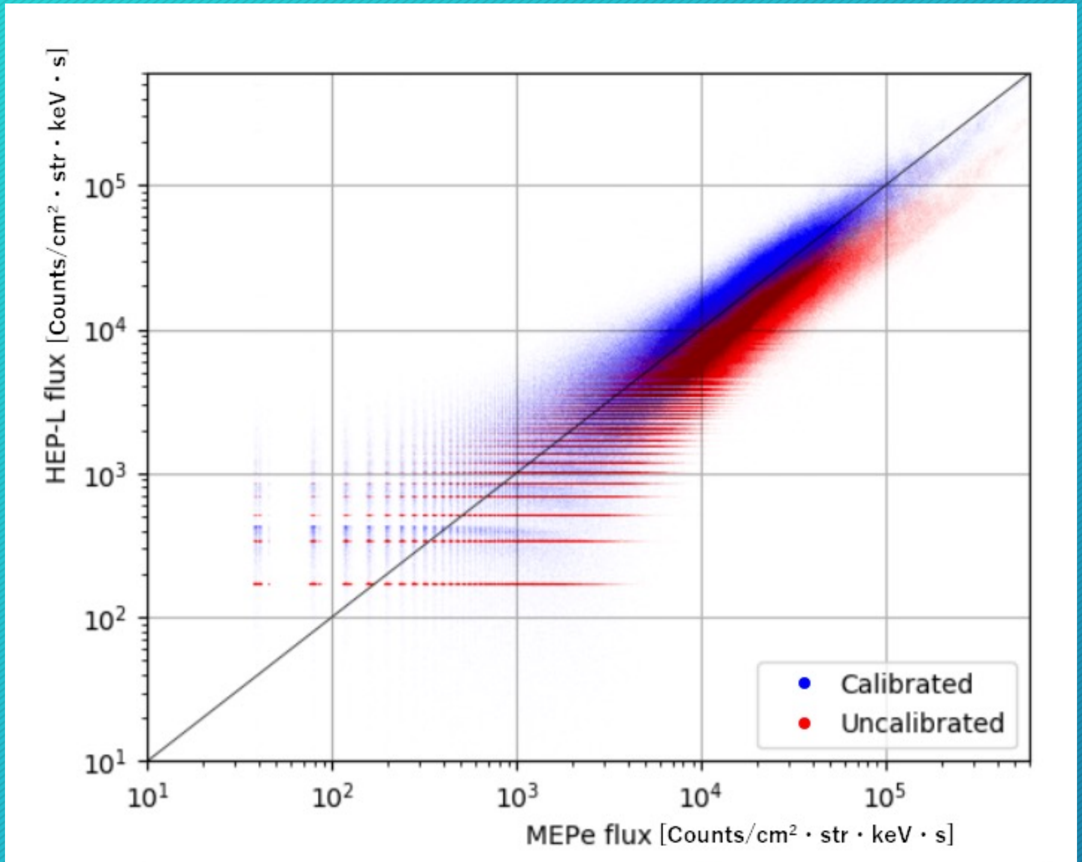
Calibration results(1 day)

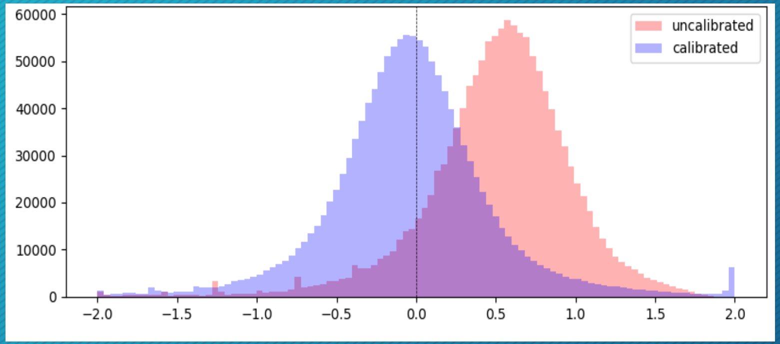


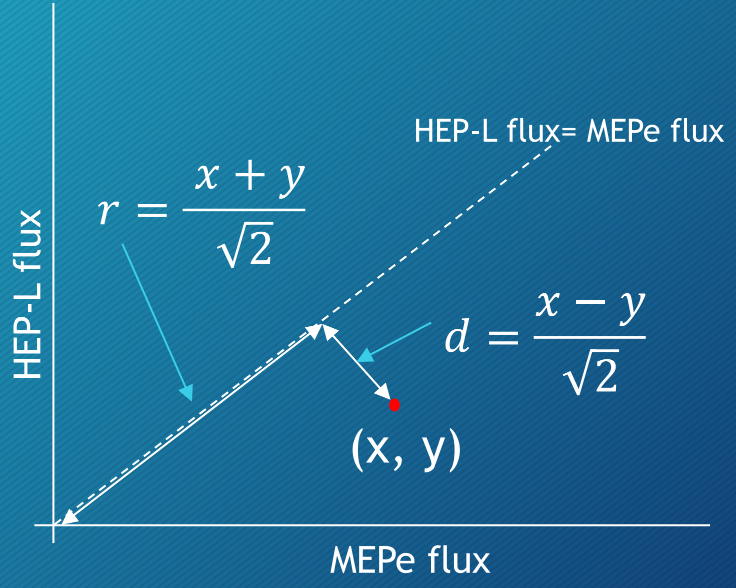
95 keV electron MEPe:HEPe



Calibration results(Long-term, 1year)

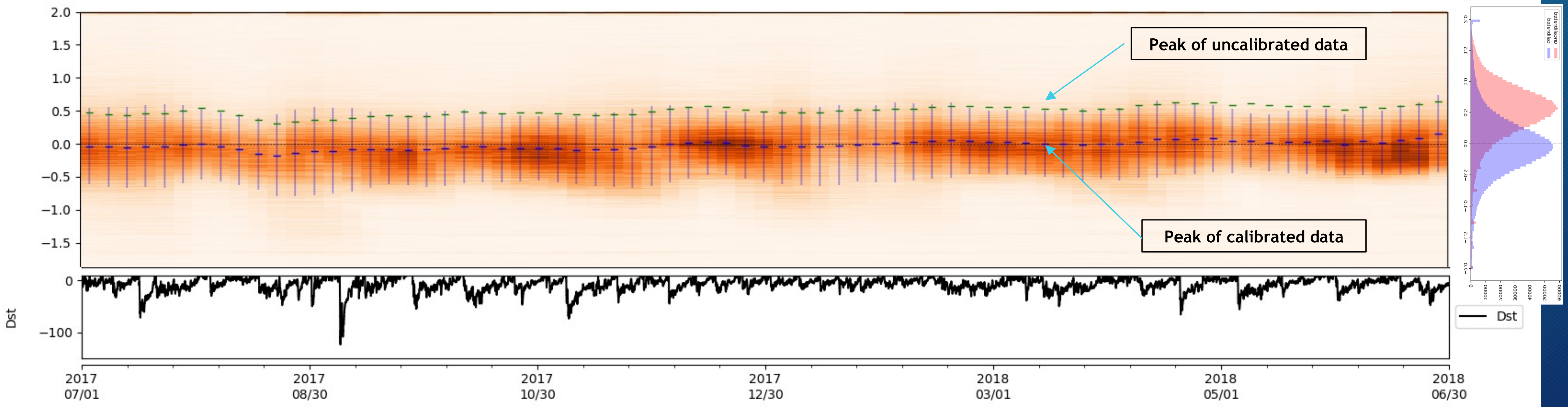






$$Comparison\ ratio = \frac{d}{r} = \frac{x-y}{x+y}$$

Calibration results(Long-term, 1year)

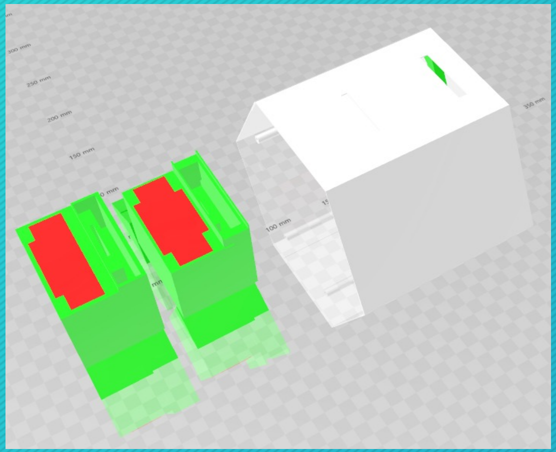


The calibrated data showed a stable state for one year without depending on the Dst index.

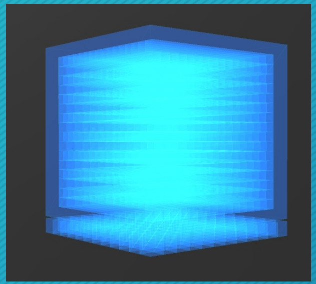
Advanced Geant4 application development

Example of GAG simulations

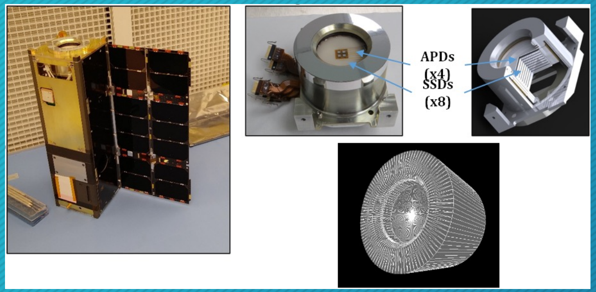
HEP



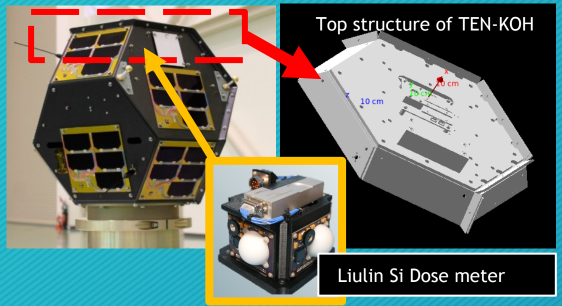
GAGG detector



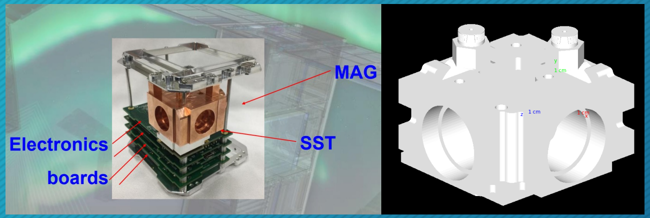
CeREs



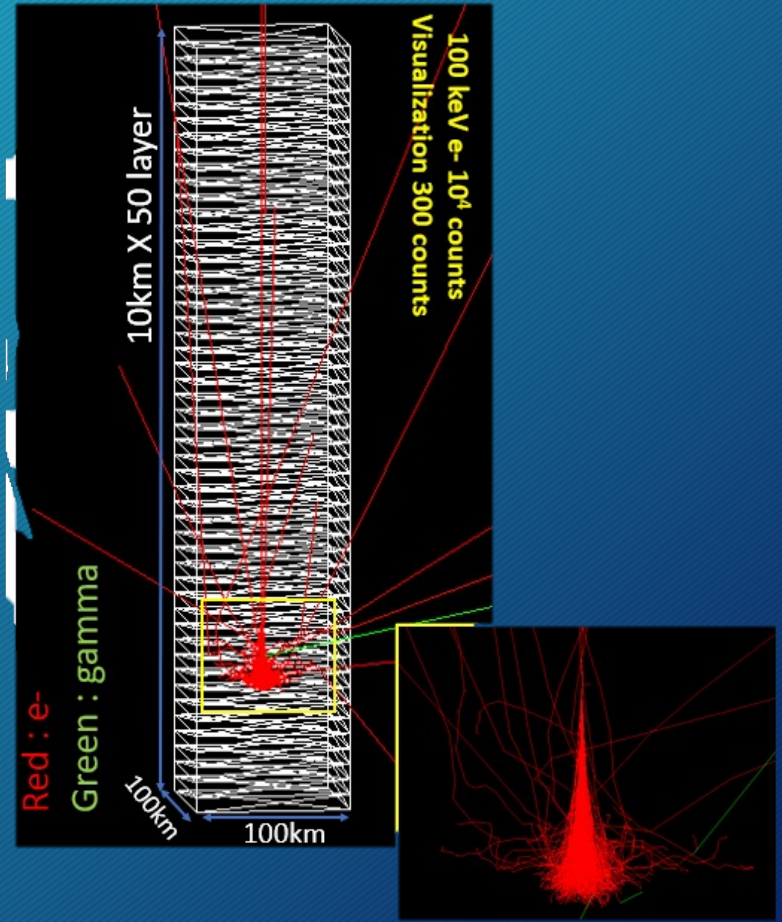
TEN-KOH



SNIPE

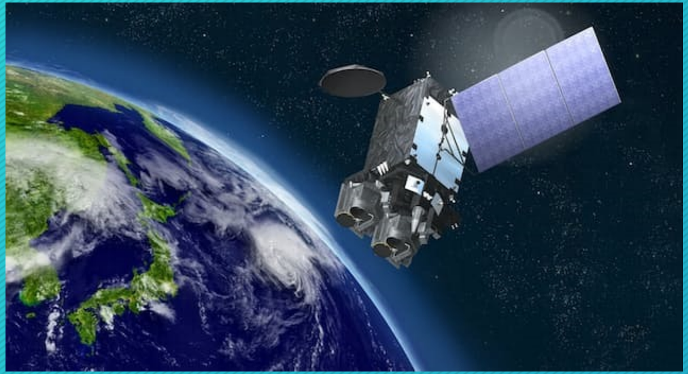


Airshower model



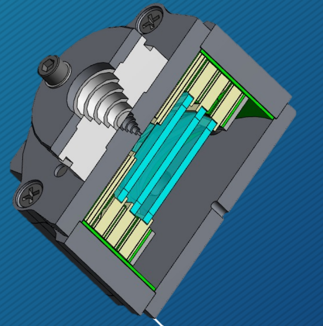
Calibration of GEO satellite observation

- High-Energy Particle Sensors for Space Weather Applications Onboard the Next Japanese Meteorological Satellite



Radiation Monitors for Space Weather (RMS)

- Operation start : FY2028
- Orbit: GEO
- Observe energy range
  - Proton: 10 MeV ~ 1 GeV
  - Elenctron: 50 keV~ 5 MeV



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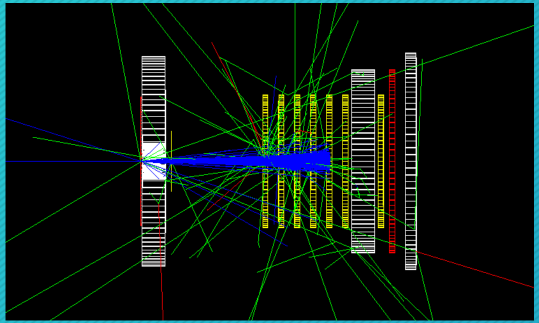

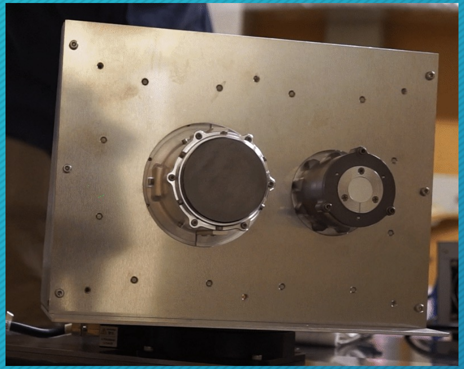

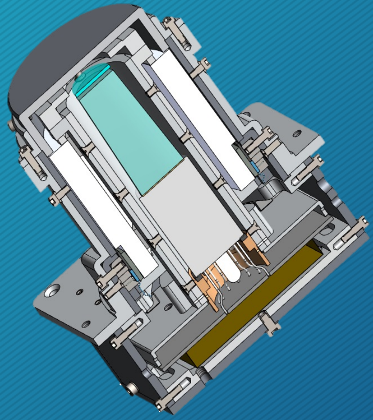

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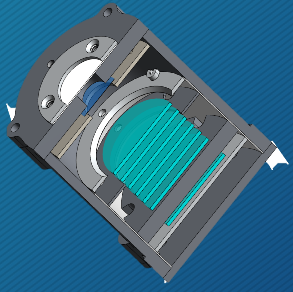

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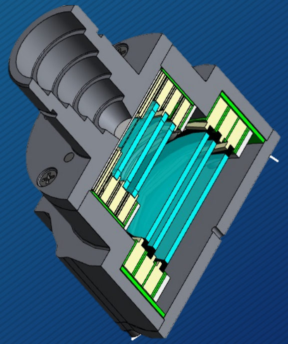

<RMS-e-hi>

Summary

- The HEP calibration successfully match to MEP-e observation and it reliable for long term observation, not depending on magnetic storms
- From the inheritance of the calibration, we applied a G4 simulation to several instruments which has complicated geometry.
- The Radiation Monitors for Space Weather(RMS) onboard the next Japanese Meteorological satellite planned to cross calibrate with ARASE or GEO satellite