MIP Calibration and the Long-term Stability of CALET onboard the International Space Station

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In August 2015, the CALorimetric Electron Telescope (CALET) docked with the International Space Station (ISS). CALET will measure the cosmic ray electron spectrum over the energy range of 1 GeV to 20 TeV with a very high resolution of 2% above 100 GeV.
This report describes the specific calibration methods, focusing on the calibration of the energy deposit of each channel to obtain an ADC unit to energy conversion factor using Minimum Ionizing Particles (MIP), known as "the MIP calibration." Following these corrections for the position and temperature dependence, and also using events extracted using event selection based on likelihood analysis, it was possible to find the energy conversion factor. With the excellent agreement between the conversion factors obtained from proton and helium MIP data, the validity of the absolute calibration of the energy conversion factor was confirmed. In the end, this report describes the analysis of the long term stability of the MIP calibration, from which it was concluded that the time dependence of the MIP peak value was successfully removed.

CALET Overview

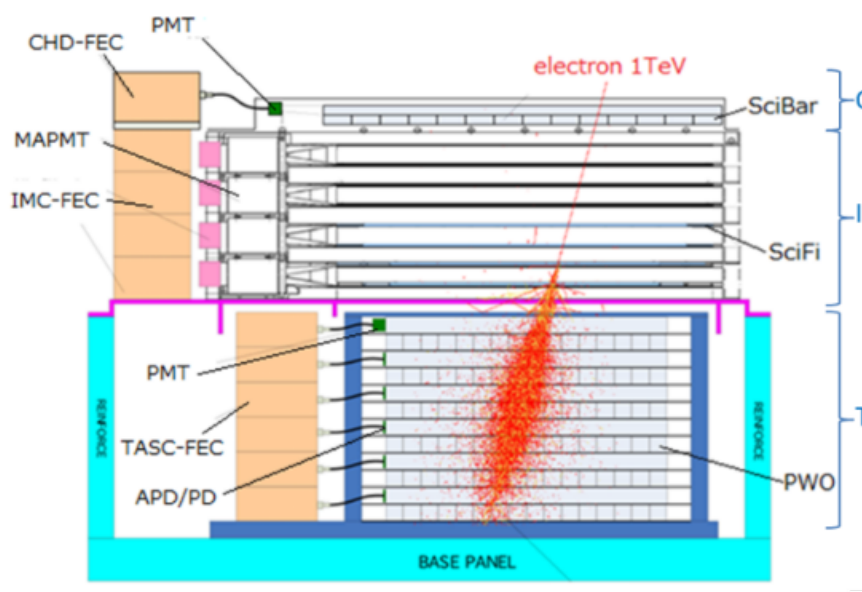
CALET: CALorimetric Electron Telescope

- ✓ August 2015 Docked with the ISS
- ✓ October 2015 Initial operation begins
- ✓ December 2015 Steady-state operation begins

Objective	Observation Target
Identification of nearby acceleration source of cosmic ray	Electron energy spectrum in the TeV region
Search for dark matter	The "abnormality" of the electron and gamma ray energy spectrum in the 100GeV-10TeV region
Investigation of the origin and propagation process of cosmic ray	Energy spectrum of electron and proton, and flux of superheavy nuclei
Investigation of the propagation process of cosmic ray in the Galaxy	Energy dependence of B/C ratio
Study of Sun magnetosphere	Long and short term variation of low energy (<10GeV) electron flux
Study of gamma-ray burst	X-ray and gamma-ray burst in the 7KeV～20MeV region

■ Characteristics of CALET

Thick 30 radiation length calorimeter
- ➢ High electron/proton separation ability
- ➢ High energy resolution ~2%(>100GeV)



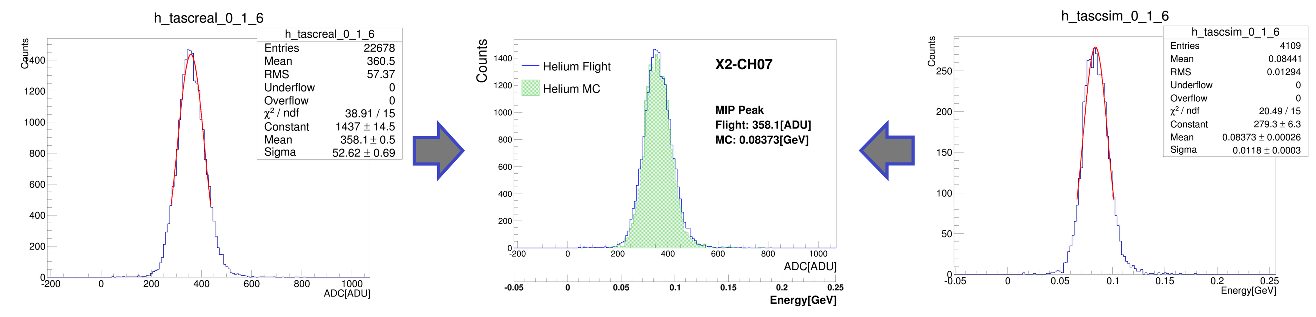
Principle of MIP Calibration

MIP Calibration

The peak of non-interacting proton and helium events is defined as MIP
With the comparison of MIP peaks with the simulation, the energy conversion factor from ADU to GeV can be found

Analysis Procedure

1. Selection of non-interacting proton/helium events
2. Correction due to the surrounding environment
   - ⅰ. Position Dependence: due to the incident position of the particle ~10%
   - ⅱ. Temperature Dependence: due to the time variation of the detector temperature ~3%
3. Deciding the conversion factor by comparing the flight and simulation data



Distribution of ADC value from flight data | Comparison of flight data and MC simulation | Distribution of energy deposit from MC simulation

Selection of Non-Interacting Events

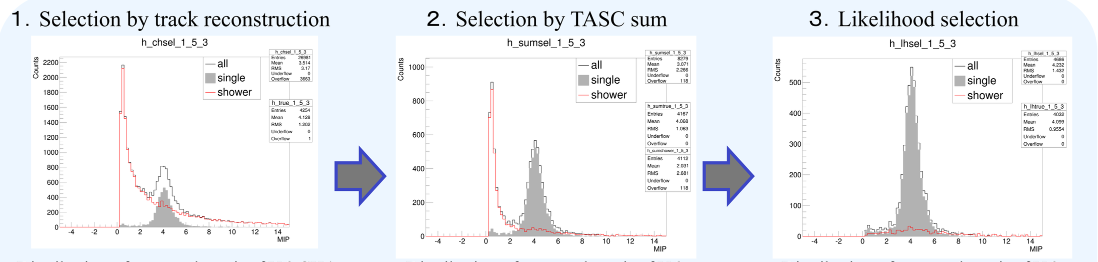
Monte Carlo Simulation

- ■ Modeling of the flux of proton and helium by the calculation of ATMNC3
- ■ By simulating the geomagnetism, the energy distribution of proton and helium is described

3 steps of selecting the non-interacting events

1. Selection of events that passed only one channel by track reconstruction
   selection of events that passed both upper and lower surface of PWO
2. Cut of high energy shower events by TASC signal sum
   events with the TASC energy sum over 35 MIP are excluded
3. Single event selction by likelihood
   selection with the signal sum of the TASC channel the track passed

1. Selection by track reconstruction | 2. Selection by TASC sum | 3. Likelihood selection



Distribution of energy deposit of Y6-CH4 after selection by track reconstruction | Distribution of energy deposit of Y6-CH4 after selection by TASC sum | Distribution of energy deposit of Y6-CH4 after selection by likelihood

Position Dependence

Analysis Procedure

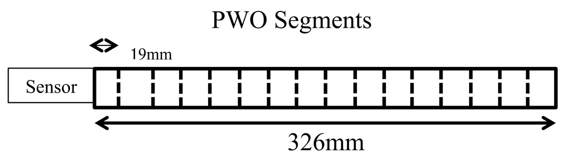
- Each channel of TASC is divided into 16 segments
- From the output value of each segment, the relative value for each position was calculated
- The position dependence was parameterized with an exponential function

Cause of the position dependence
･damping of scintillation light
･temperature gradient in the scintillator bar

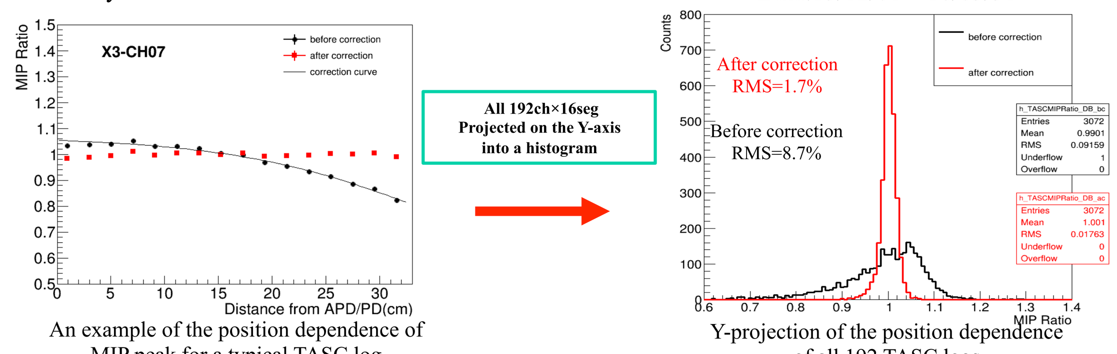
Analysis Condition

- He flight data (4 times higher light output than proton, more statistics than proton)
- Trigger: Single
- Geometry Condition: Top layer of CHD and bottom layer of TASC

PWO Segments



Data:15/12/01～16/03/31

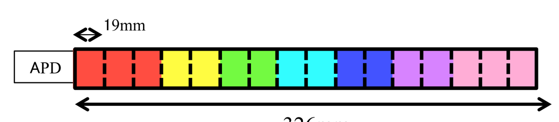


An example of the position dependence of MIP peak for a typical TASC log | Y-projection of the position dependence of all 192 TASC logs

Temperature Dependence

Analysis Procedure

- Events were classified depending on the position of particle incidence, as shown by different colors in the diagram
- Since the temperature variation of CALET in one orbit is kept at about 1℃ by ATCS, the rate of change of the output per 1℃ was calculated



Analysis Condition

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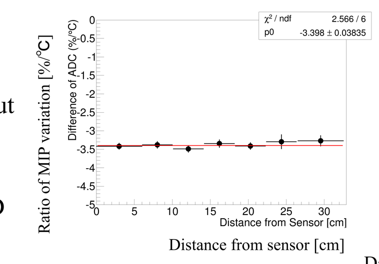
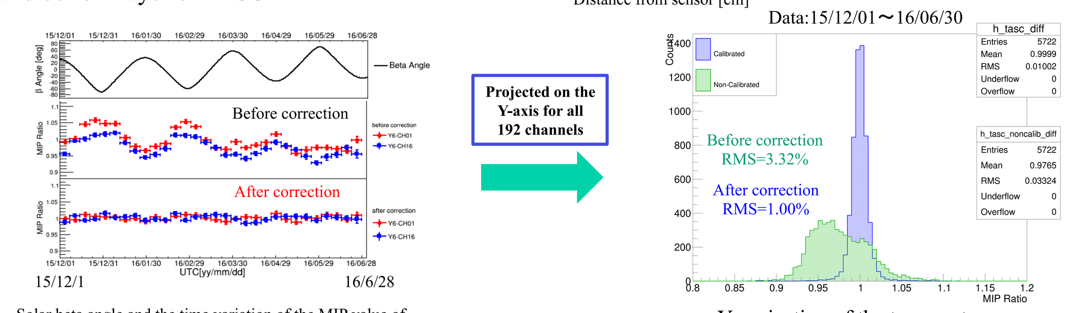


TASC X1	PMT 16ch
Others	APD 176ch

Temperature Dependence
PMT 1.9% (Avg. of 16ch)
APD 3.4% (Avg. of 176ch)

Data:15/12/01～16/06/30



Solar beta angle and the time variation of the MIP value of TASC Y6-CH1 and Y6-CH16 within 7 months | Y-projection of the temperature dependence of all 192 TASC logs

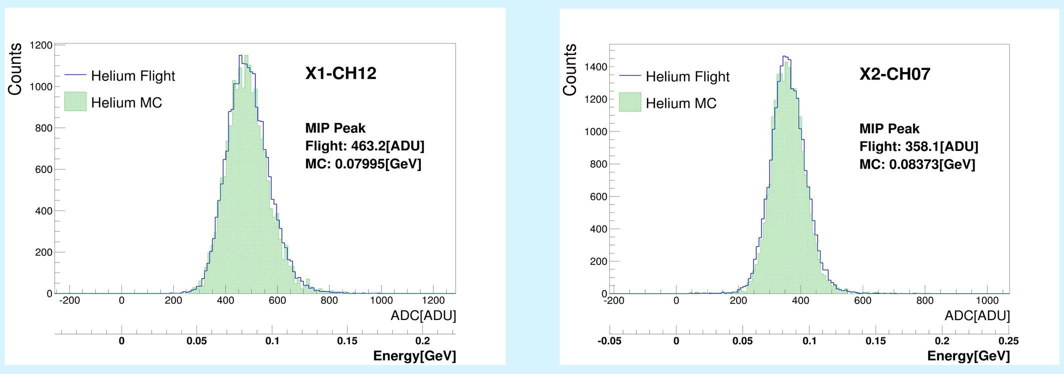
Determination of the Energy Conversion Factor

Calculated the energy conversion factor from the ABC of Monte Carlo and flight data

Blue: flight data (ADC[ADU])
Green: Monte Carlo Simulation (Energy[GeV])

PMT | APD

He



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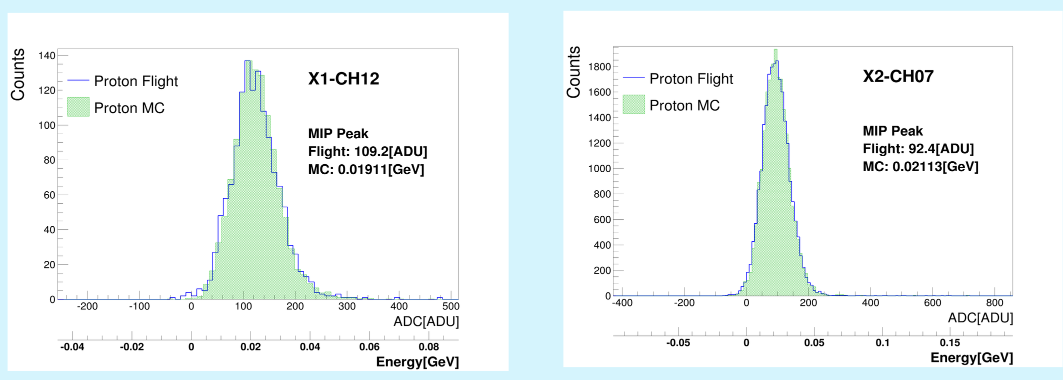
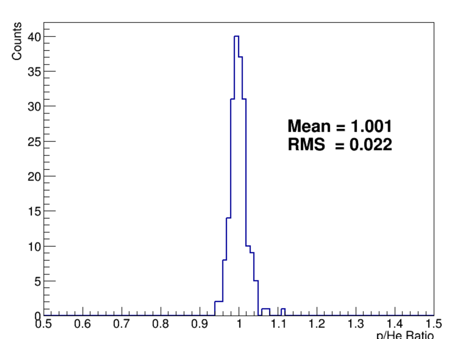


The distributions match between flight data and MC simulation

Noise is applied into the simulation
PMT: pedestal noise + fluctuation of photoelectron statistic
APD: pedestal noise

Comparison of the conversion factors



Ratio of the conversion factors of proton and helium

Energy conversion factors match within proton and helium

➡ Taking the effect of the cut-off rigidity into account, the MIP value of proton and helium match within 0.1%

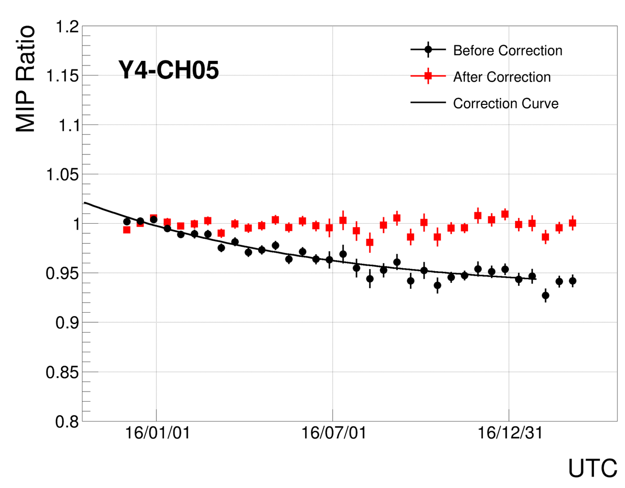
Long Term Stability of the MIP Calibration

Analysis Procedure

- Plotted the time variation of TASC MIP value for every 2 weeks between the time period of 2015/12 − 2017/01 (position and temperature dependence corrected)
- Fitting by an exponential function ($\exp(p_0+p_1*x)+p_2$) was done for each PWO log

Analysis Condition

- He flight data (4 times higher light output than proton, more statistics than proton)
- Trigger: Single
- Geometry Condition: Top layer of CHD and bottom layer

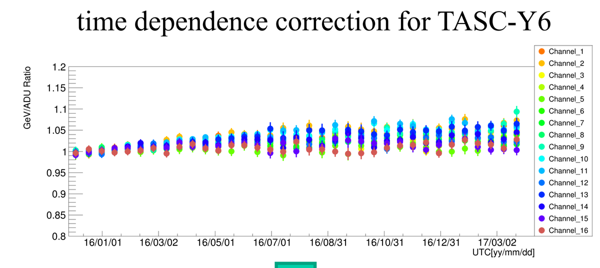


Stability of the Conversion Factor

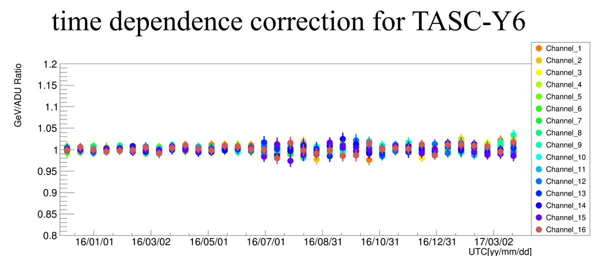
1. Position dependence corrected ~10%
2. Temperature dependence corrected -1.9% /℃ for PMT channels, -3.4% /℃ for APD/PD channels
3. Time dependence corrected
   - ➢ Fitting by exponential function

⇒calculated the conversion factor for every 2 weeks between 2015/12~2017/03

Time variation of conversion factor before time dependence correction for TASC-Y6

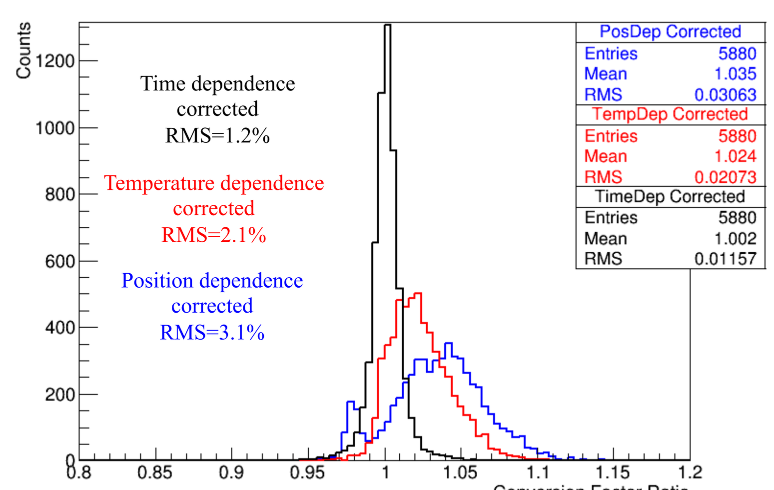


Time variation of conversion factor after time dependence correction for TASC-Y6



(*) The statistics is smaller due to the reduction of calibration run after 2016/07

Data:15/12/01～17/03/31



Y-projection of the time variation of the conversion factor in each state of the corrections

(*) Y5 ch9-16 not included since 2016/07

Conclusion

Energy calibration of the CALET, launched to the ISS in August 2015 and accumulating scientific data since October 2015, was performed using both flight data and calibration data acquired on the ground before launch. By taking advantage of the fully-active total absorption calorimeter, absolute calibration between ADC units and energy was possible with an accuracy of a few percent, using penetrating particles. The systematic error in the energy scale was also estimated based on the calibration results and was found to be less than 2%. With the removal of the time dependence of the MIP peak value, the long term stability of the MIP calibration was confirmed.

Y.Asaoka for the CALET Collaboration, "Energy Calibration of CALET Onboard the International Space Station", Astroparticle Physics. 91(2017)1-10

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