CALETによる10年間の太陽変調観測

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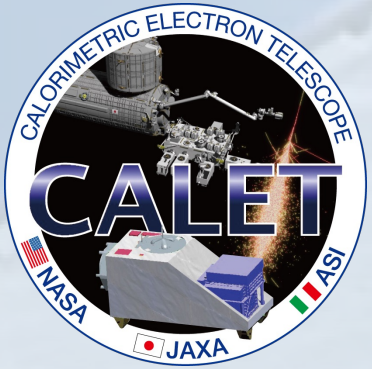
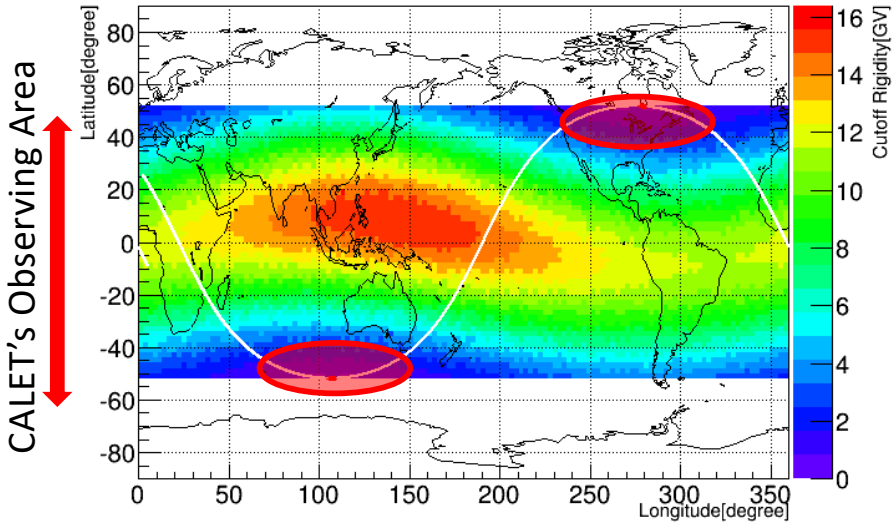


Measurements of Low-Energy CRs by the CALET

Low-energy electron shower trigger mode (LEE-Trigger):

- Energy thresholds are set to detect shower events with energies over 1.0 GeV.
- Measurement of low energy electrons (1GeV ~ 10GeV) with LE-trigger, which is active only at high latitude where the maximum cutoff rigidity is 5.0GV.
  → LE mode operates twice for 90 sec. in one ISS orbit.

Cutoff rigidity map and ISS orbit



http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html

Oct. 13, 2015 ~ Dec. 31, 2024

Total Live Time: ~ 1367 [hours]

Total events : $\sim 1.5 \times 10^8$ [events]

We have analyzed …

- CR e^-+e^+ flux for each Carrington rotation
- Count rates of electrons and protons with an average rigidity of ~3.8GV for each Carrington rotation
- Daily count rates of electrons and protons with an average rigidity of ~3.8GV

Analysis Procedure for Low-Energy Electrons and Protons

Event-selection criteria:

(a) Off-line trigger condition: IMC7-8 and TASC top layer
- Trigger GeV-energy events

(b) Tracking condition: IMC
- Kalman filter track reconstruction with IMC

(c) Geometrical condition: IMC
- Entire trajectory is inside IMC and TASC

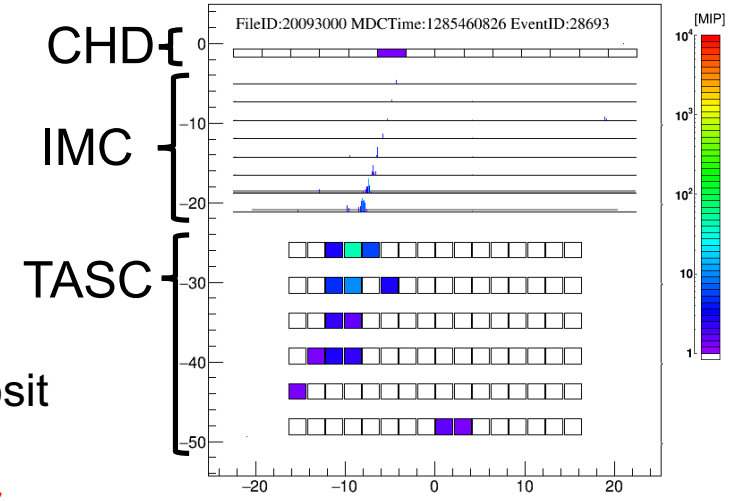
(d) Charge determination: CHD
- CHD energy deposit to remove Z>=2

(e) Energy deposit condition: IMC and TASC
- Exclude events passing through the layer without energy deposit

(f) e/p separation:
- Energy deposit and Shower concentration in IMC bottom layer only for electron/positron (e^- + e^+) event selection
- Lateral shower development in TASC top layer

(g) Cutoff rigidity (COR) condition
- Select events with the estimated energy well exceeding COR

CALET Calorimeter with an LE event candidate with energy of ～3.9 GeV



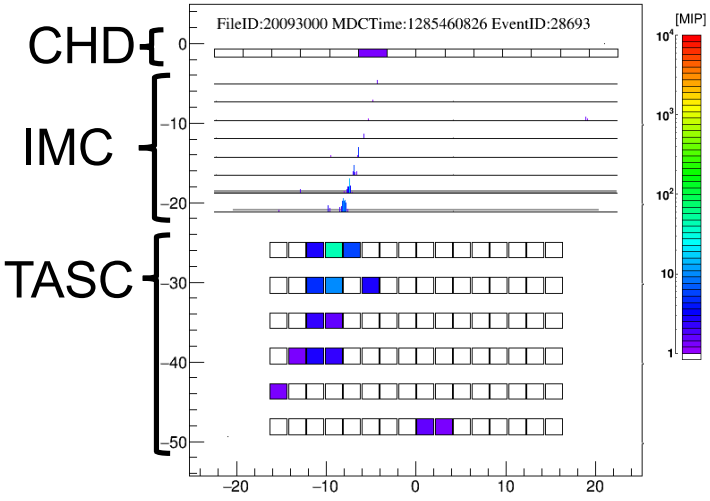
Analysis Procedure for Low-Energy Electrons and Protons

Event-selection criteria:

(a) Off-line trigger condition: IMC7-8 and TASC top layer
(b) Tracking condition: IMC
(c) Geometrical condition: IMC
(d) Charge determination: CHD
(e) Energy deposit condition: IMC and TASC
(f) e/p separation:
(g) **Cutoff rigidity (COR) condition**

- We calculate the COR by back-tracing particle's orbits in the model magnetosphere defined by the IGRF-13 and TS05 empirical models.
- The COR is calculated for every incident direction of particle reconstructed from the observed data.
- In order to minimize the count rate variation due to the COR, we choose periods in which the COR is much lower than the detection threshold rigidity.

CALET Calorimeter with an LE event candidate with energy of ～3.9 GeV



Analysis Procedure for Low-Energy Electrons and Protons

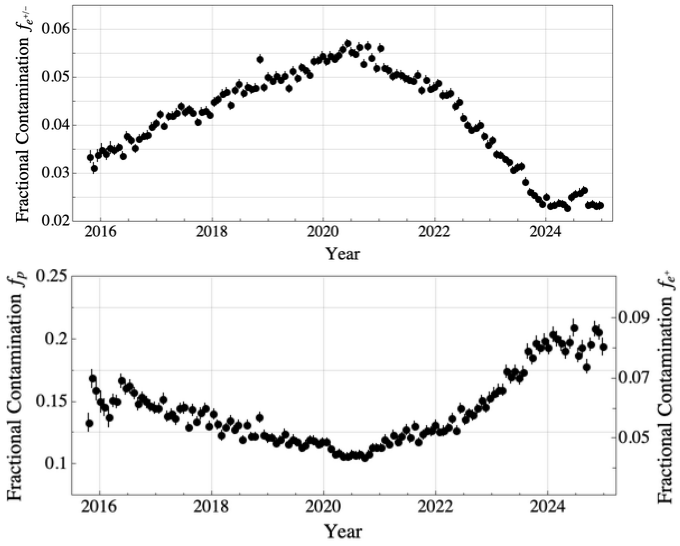
Event-selection criteria:

(a) Off-line trigger condition: IMC7-8 and TASC top layer
(b) Tracking condition: IMC
(c) Geometrical condition: IMC
(d) Charge determination: CHD
(e) Energy deposit condition: IMC and TASC
(f) e/p separation:

- Energy deposit and Shower concentration in IMC bottom layer only for electron event selection
- **lateral shower development** in TASC top layer
  - By using the fractional contribution from proton (e^-+e^+) in e^-+e^+ (proton) candidates, f_p ($f_{e^-+e^+}$), we correct proton (e^-+e^+) count rate for the contamination of e^-+e^+ (proton).
  - In addition, counts of corrected electrons are evaluated by estimating fractional contamination from positrons in e^-+e^+ candidates using f_p.

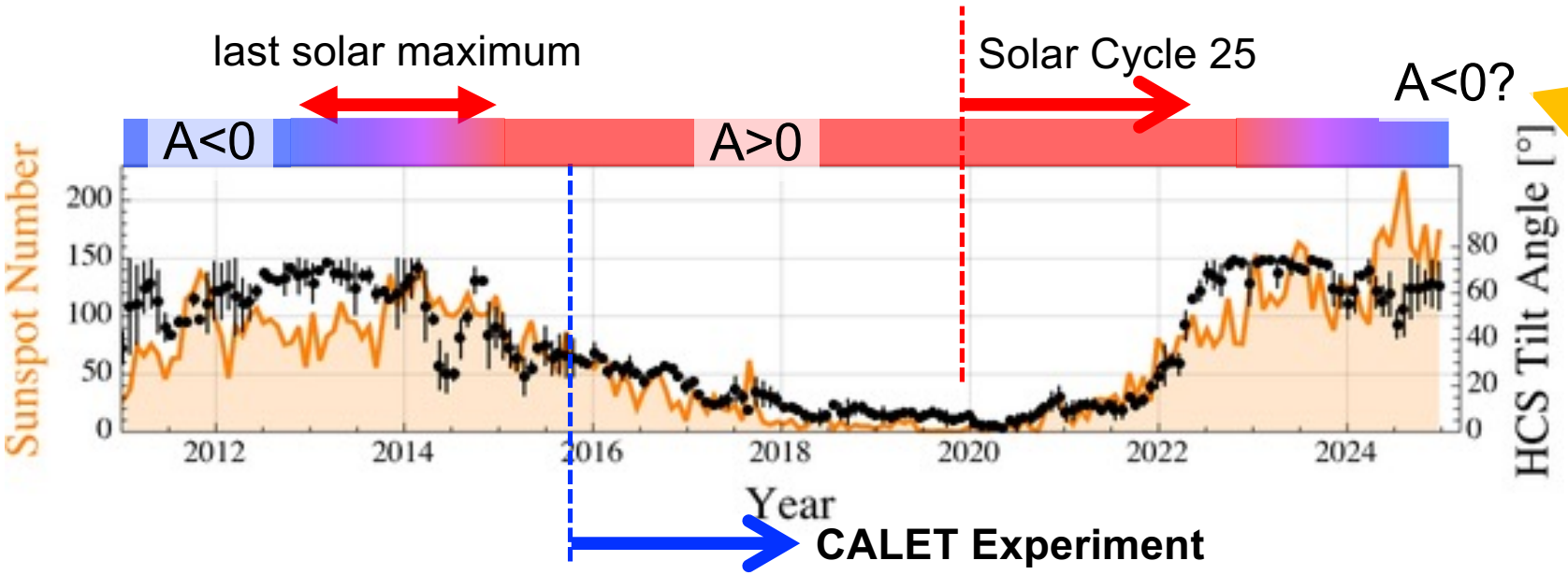
(g) Cutoff rigidity (COR) condition:

Fractional contaminations $f_{e^-+e^+}$ in p candidates (top panel) and Fractional contaminations f_p and f_{e^+} in e^-+e^+ candidates (bottom panel)



Recent Solar Cycle

Time profile of the sunspot number and the HCS tilt angle



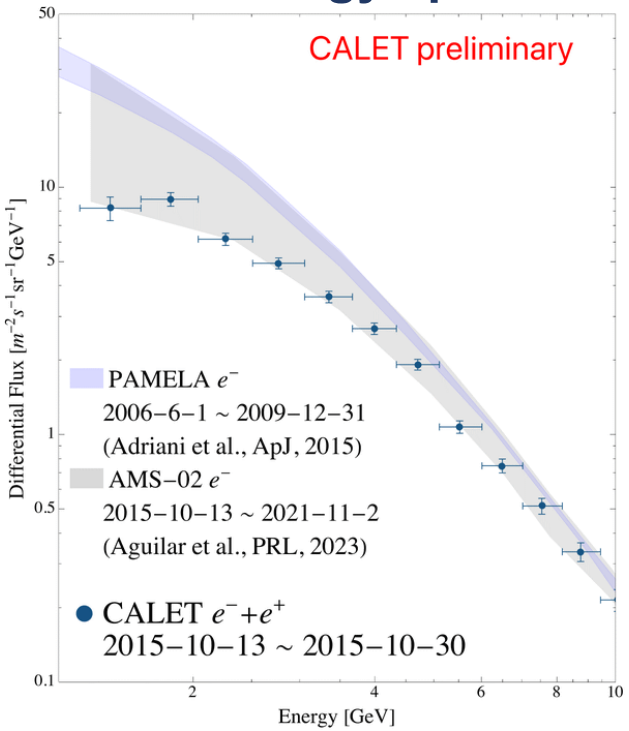
The magnetic polarity has reversed in late 2023 ??

- 25th solar cycle begins in December 2019（Solar minimum）.
- The solar activity has rapidly increased since 2022.
- Since late 2023, the Sun's polar magnetic field strength has declined rapidly.
  →It appears that the solar magnetic polarity has reversed from A>0 to A<0.

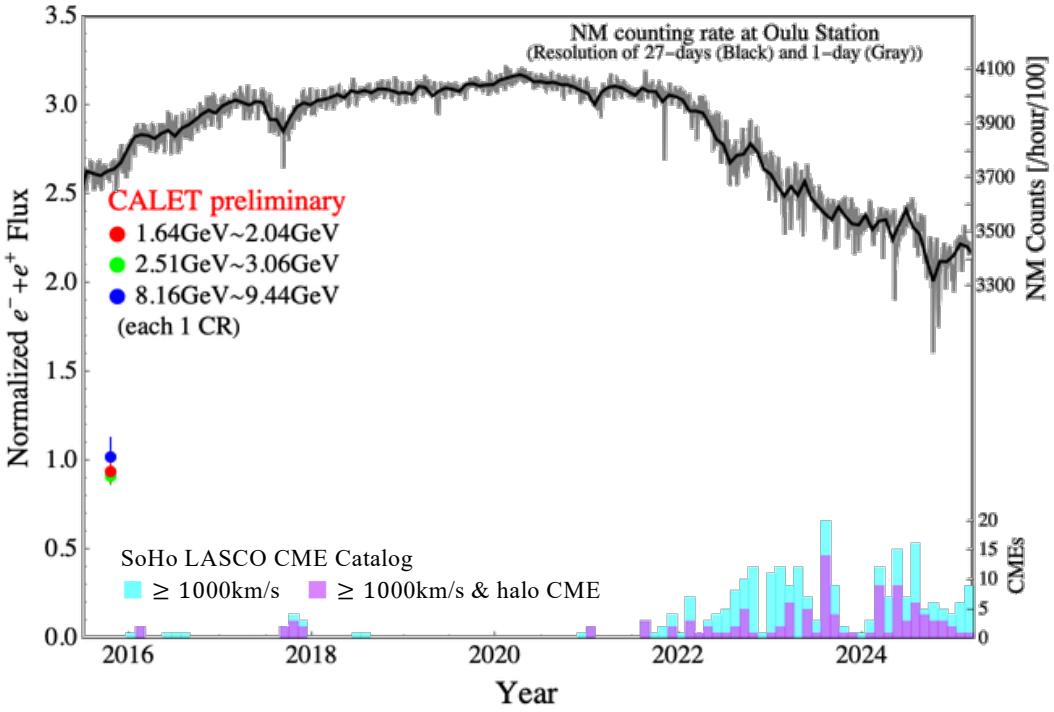
Long-Term Variation of the CR e^- + e^+ Flux

Since the beginning of the 25th solar cycle (December 2019), e^- + e^+ flux in the 1-10 GeV region has continued to decrease, and the lowest values have been detected in 2024.

CR e^-+e^+ energy spectrum



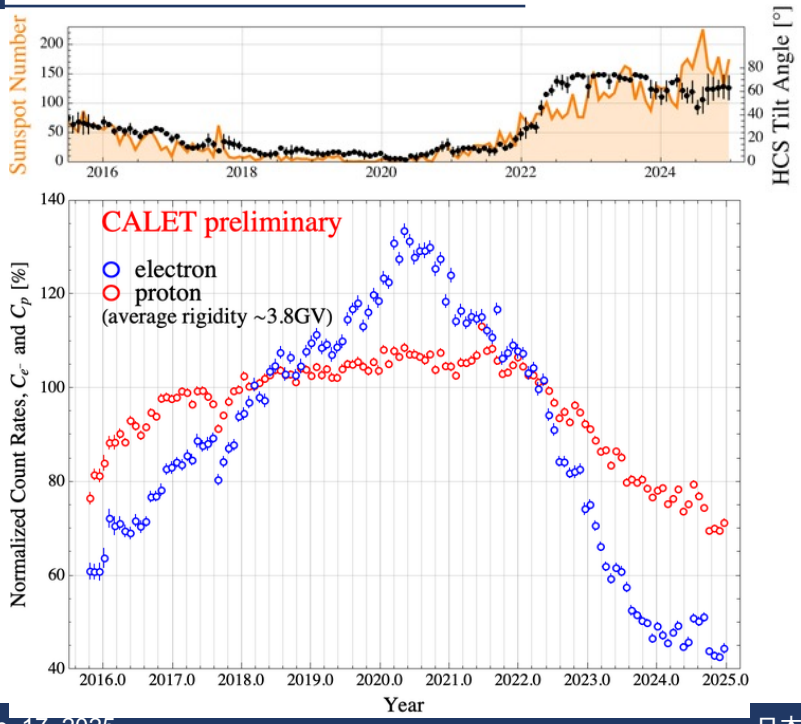
Time profile of the CR e^-+e^+ flux



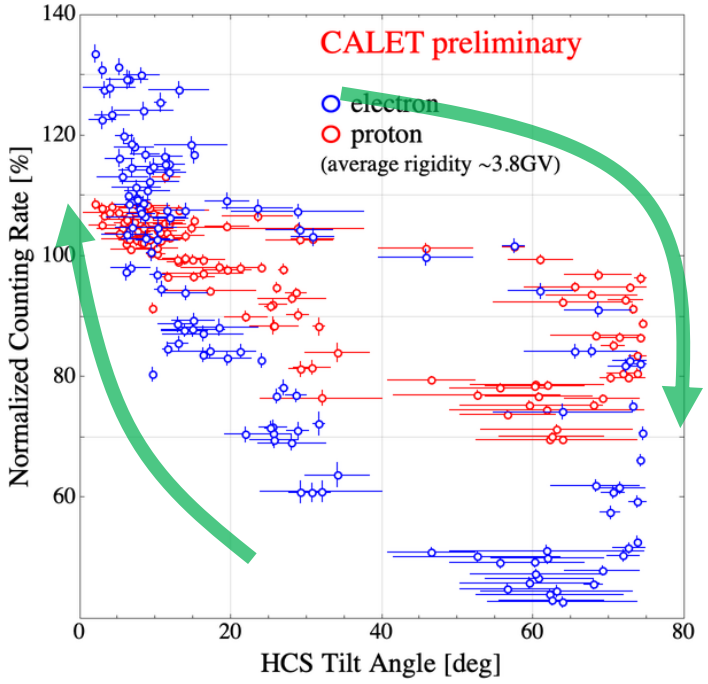
Charge-Sign Dependence of the Solar Modulation

- The lowest proton count rate since the beginning of CALET observations was detected.

Time profile of the count rate of CR protons and electrons



Correlation with count rate of CR protons/electrons and HCS tilt angle

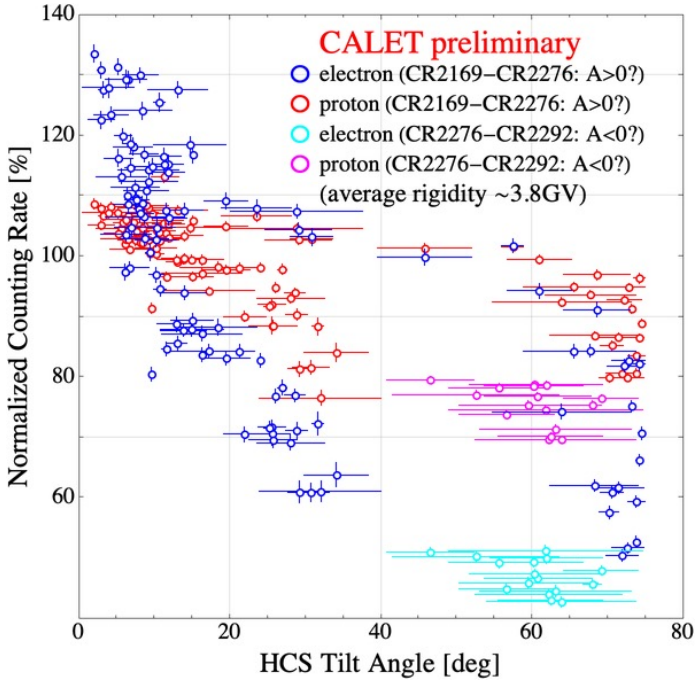


Charge-Sign Dependence of the Solar Modulation

- The lowest proton count rate since the beginning of CALET observations was detected.
- Since the solar maximum, CALET observed a clear hysteresis structure that appears between CR intensity and HCS tilt angle over the ascending and descending phases of the solar cycle.

Time profile of the count rate of CR protons and electrons

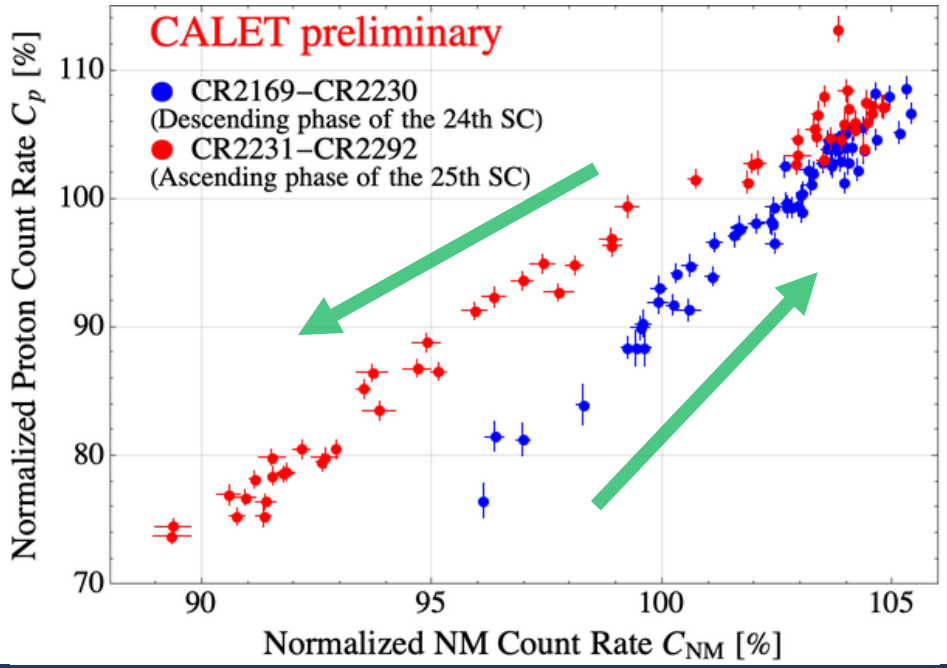
Correlation with count rate of CR protons/electrons and HCS tilt angle



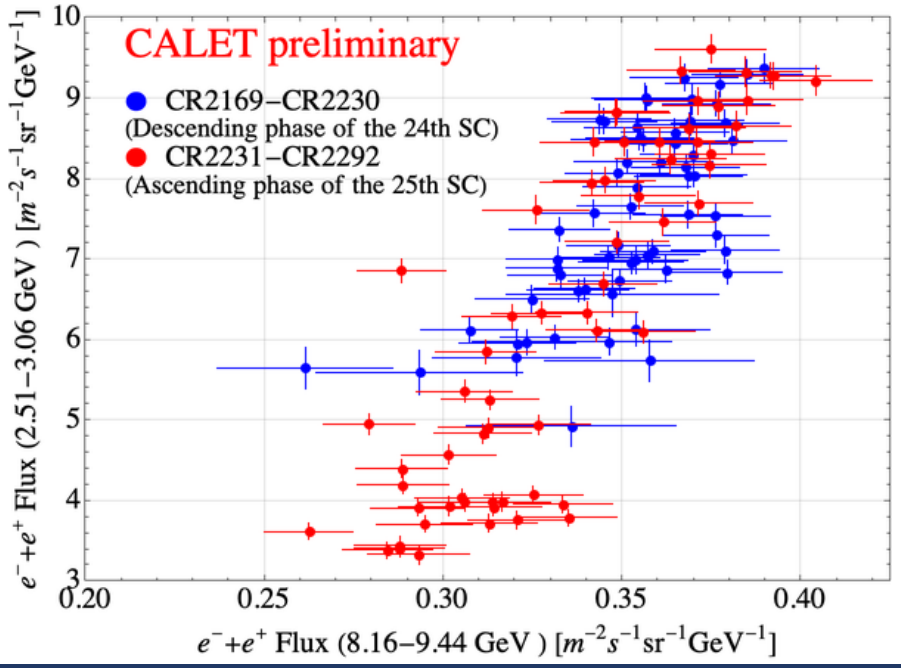
Rigidity Dependence

Proton count rates show different rigidity dependencies in the descending and ascending phases of the solar cycle, while such a significant difference is not seen in the electron flux.

Correlation between count rates of CR protons and NM count rate



Correlation between ~2.8GeV e^-+e^+ flux and ~8.5 GeV e^-+e^+ flux

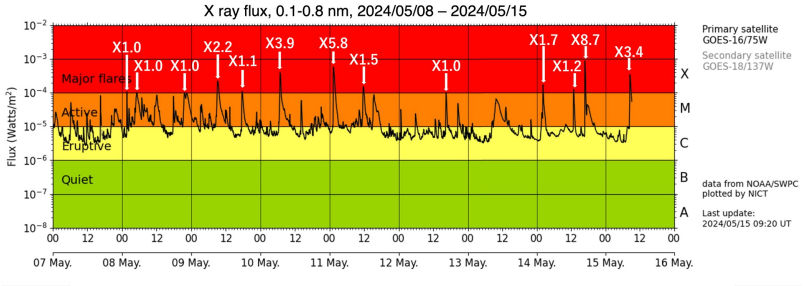


Forbush Decreases (FDs) of CR Protons and Electrons

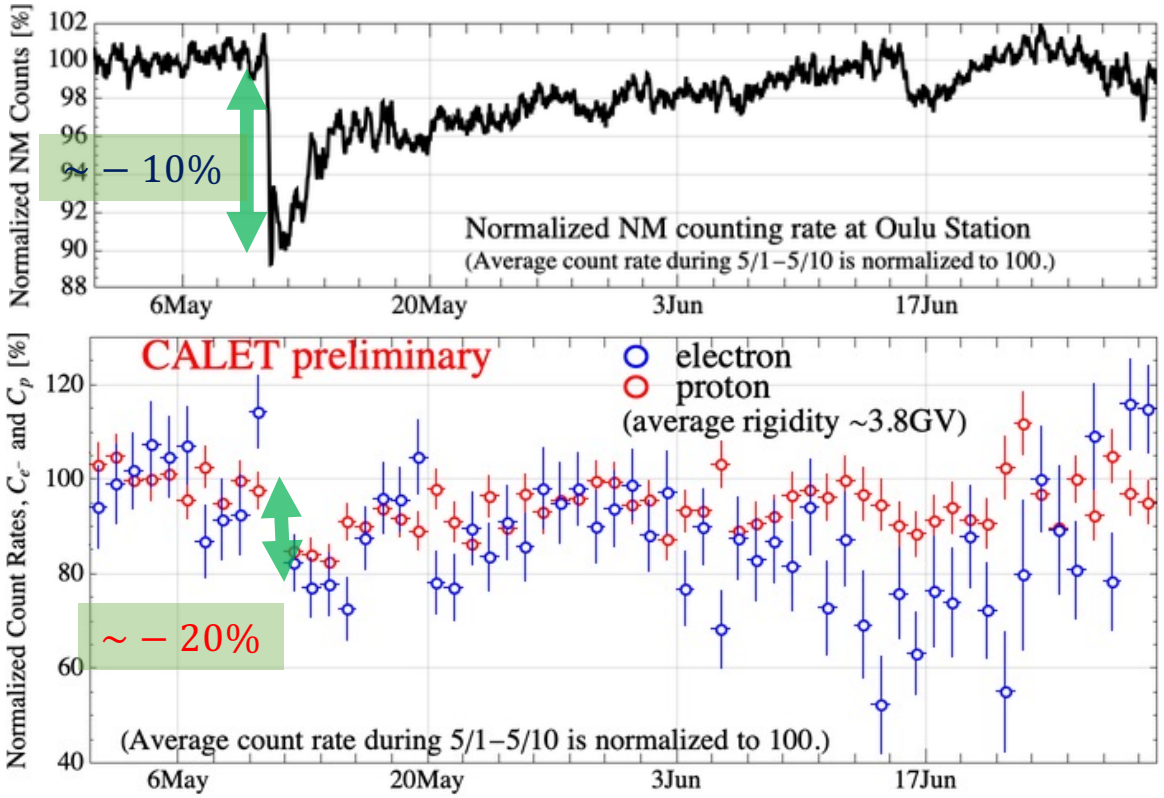
CALET also detected Forbush decreases each at a timing consistent with the ground-based neutron monitors.

May 2024

GOES X-ray flux (NOAA)



FD caused by merged CMEs associated with X-class flares

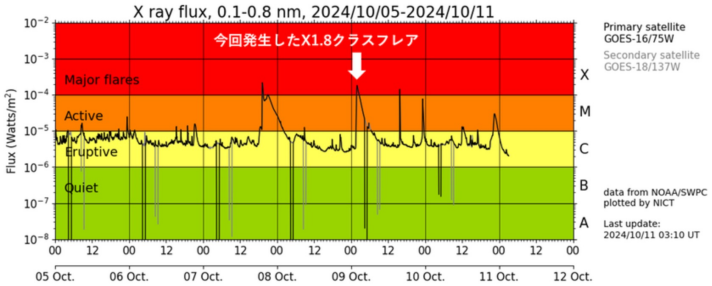


Forbush Decreases (FDs) of CR Protons and Electrons

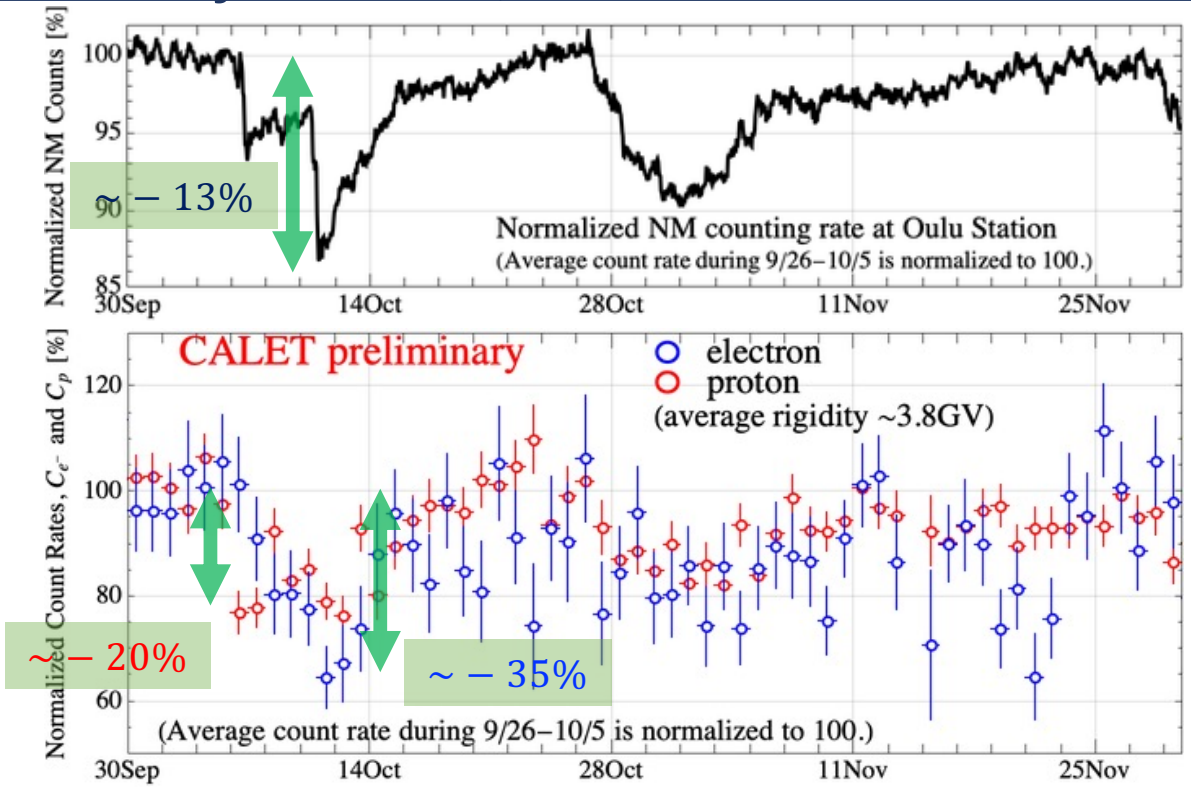
CALET also detected Forbush decreases each at a timing consistent with the ground-based neutron monitors.

October 2024

GOES X-ray flux (NOAA)



FD caused by two CMEs, one associated with X-class flares

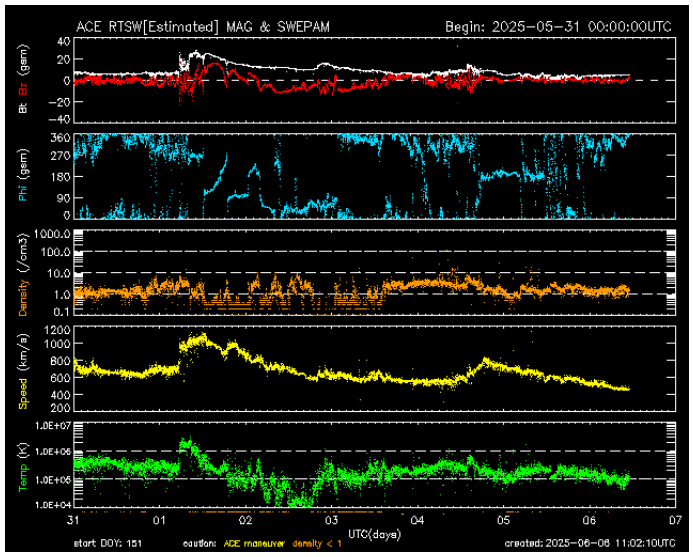


Forbush Decreases (FDs) of CR Protons and Electrons

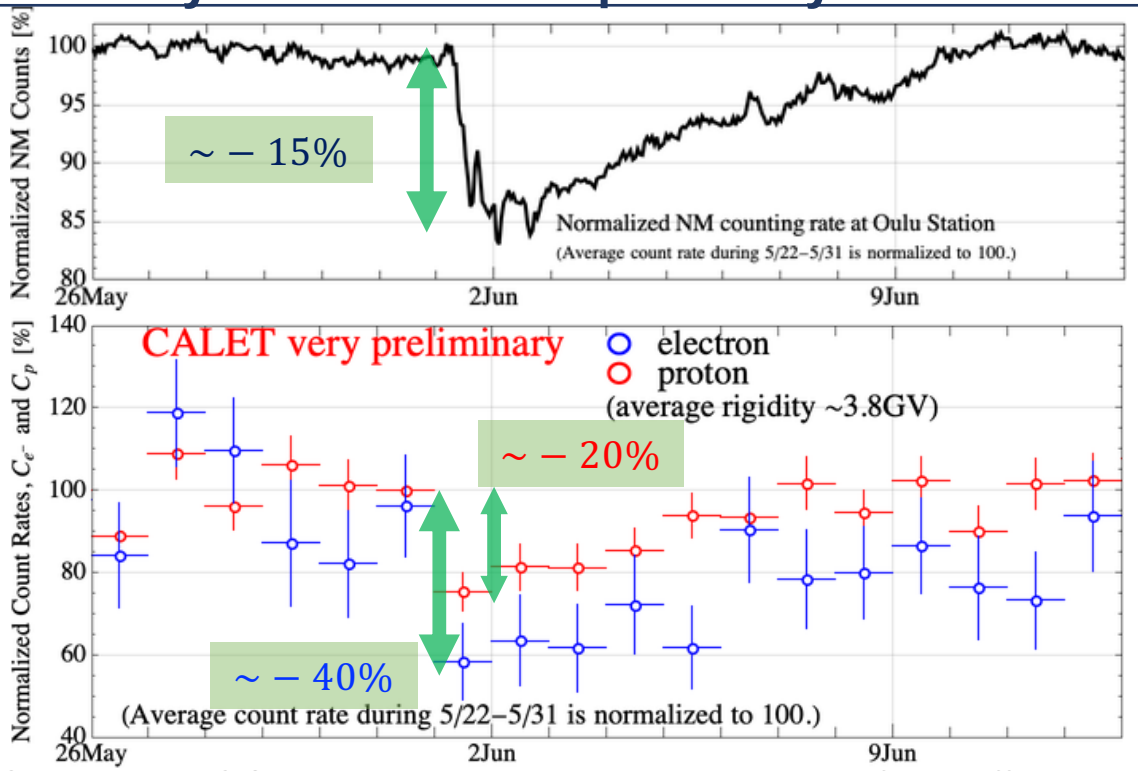
CALET also detected Forbush decreases each at a timing consistent with the ground-based neutron monitors.

June 2025

ACE Real-Time Solar Wind (NOAA)



FD caused by an ICME accompanied by >1000 km/sec V_{SW}



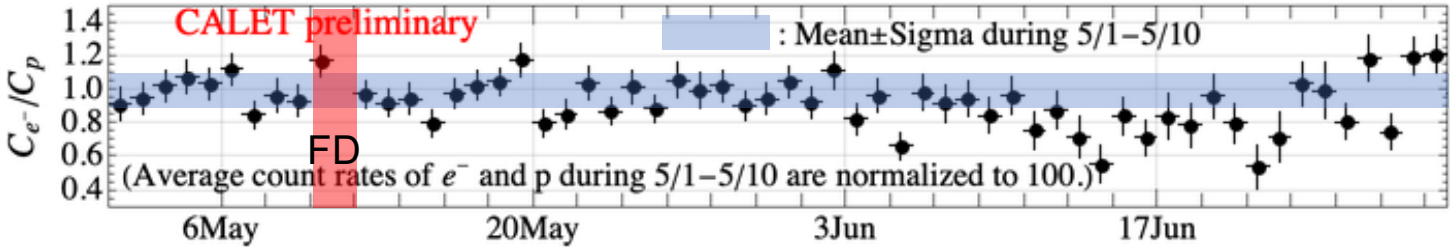
（For the analysis of the FD in June 2025, Stoermer's COR has been considered instead of the effective COR.）

Charge-Sign Dependence of the Forbush Decreases

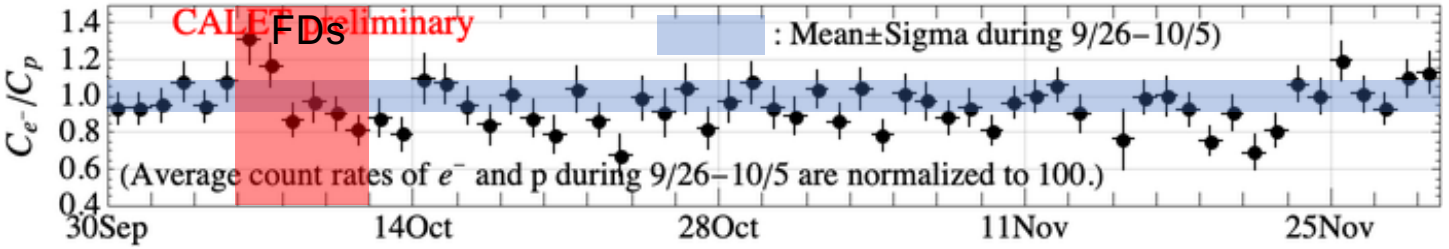
Careful analyses of detail features of these Forbush decreases, including the charge sign dependence, are currently ongoing.

Electron and proton ratios C_{e^-}/C_p of the daily count rates

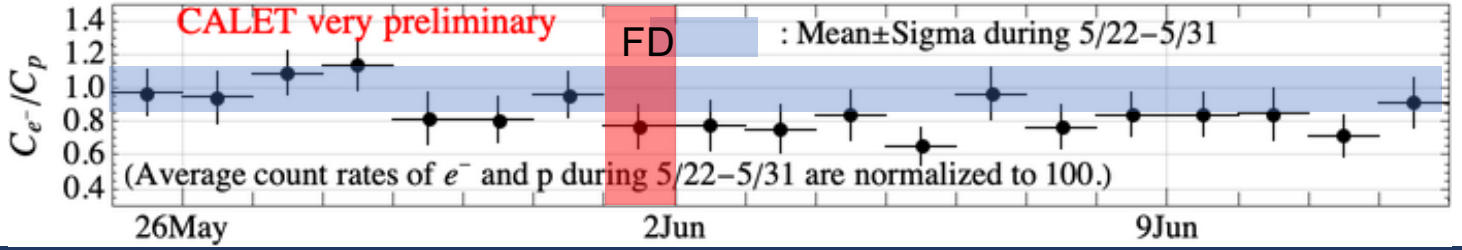
May 2024



Oct. 2024



June 2025



Summary

- Continuous observation by CALET has been performed stably for about 10 years.
- Since the beginning of the 25th solar cycle in December 2019, $e^- + e^+$ flux in the 1-10 GeV region has continued to decrease, and the lowest values have been detected in 2024.
- The lowest proton count rate was also detected in 2024.
- CALET observed a clear hysteresis structure that appears between CR intensity and HCS Tilt angle over the ascending and descending phases of the solar cycle.
- Proton count rates show different rigidity dependencies in the descending and ascending phases of the solar cycle, while the electron flux does not show such a significant difference.
- CALET also detected Forbush decreases each at a timing consistent with the ground-based neutron monitors. Careful analyses of detail features of these Forbush decreases, including the charge sign dependence, are currently ongoing.