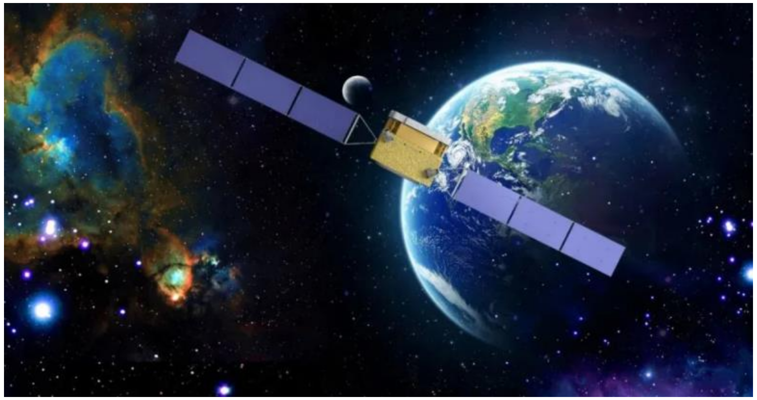


Observations of Forbush decreases of cosmic ray electrons and positrons (CREs) with DAMPE

Jingjing Zang[1,2], Qiang Yuan[2], Chengrui Zhu[2]
on behalf of the DAMPE collaboration

1. School of Physics and Electronic Engineering, Linyi University, Linyi 276000, China
2. Key Laboratory of Dark Matter and Space Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210023, China

Motivations
and
Status of FD research

What is Forbush Decrease?

In 1937, Scott E. Forbush found the intensity of CRs decrease dramatically during geomagnetic storm and recover gradually in several days.
These short-term transients in cosmic-ray intensity are named <u>Forbush Decrease</u>.

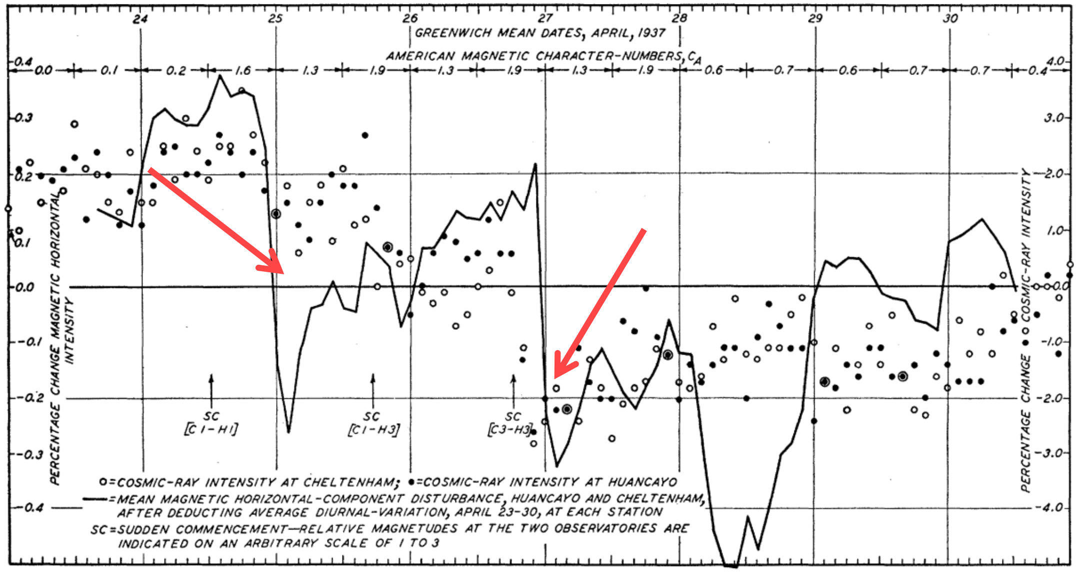
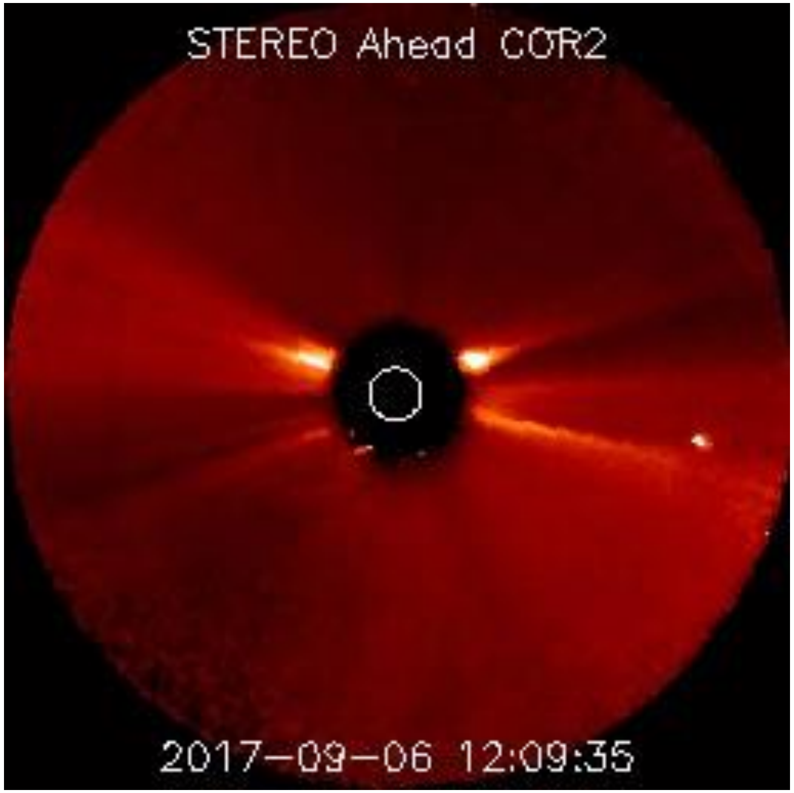


FIG. 1. Bi-hourly departures expressed in percentage of absolute values for cosmic-ray intensity and for disturbance of horizontal magnetic component April 23–30, 1937, Huancayo and Cheltenham magnetic observatories.

doi:10.1103/physrev.51.1108.3

Mechanism of Forbush Decrease and Analysis motivations

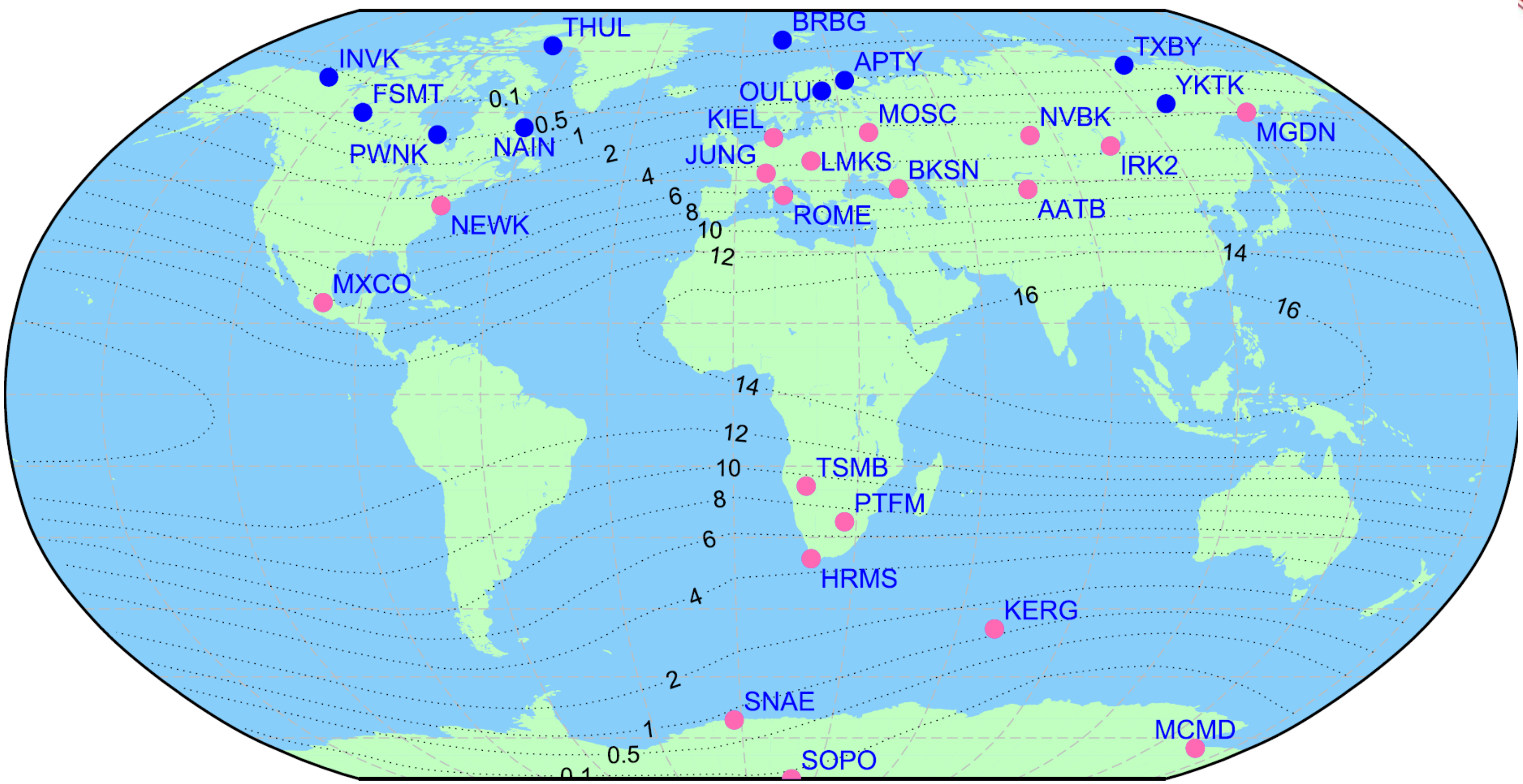


Enhanced magnetic field in the region between shock front and leading edge of interplanetary CME (ICME) causes CR flux decease.
Then Forbush Decrease should depend on rigidity, so does time structure.

FD is an universal phenomenon, measured at Mars or at 84 AU away from the Sun(by Voyage-II)

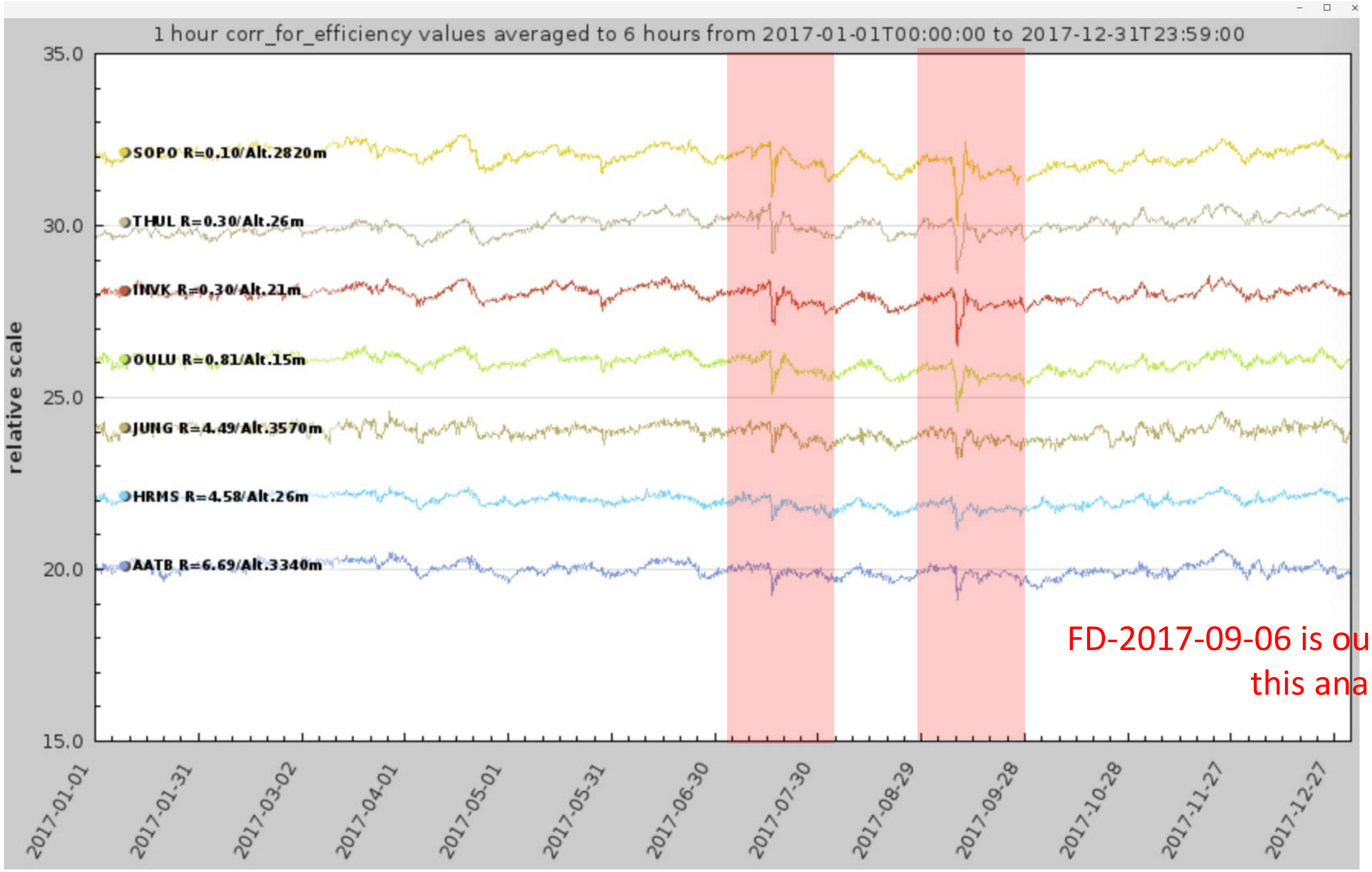
Precise measurements of FDs will enable us to diagnose the propagation of GCRs and their interplay with complex environment in the heliosphere

FDs measured by on-ground Neutron Monitors



- Neutron monitors detect secondary neutrons from interaction between cosmic ray and atmosphere
- Rigidity cutoffs provide energy info

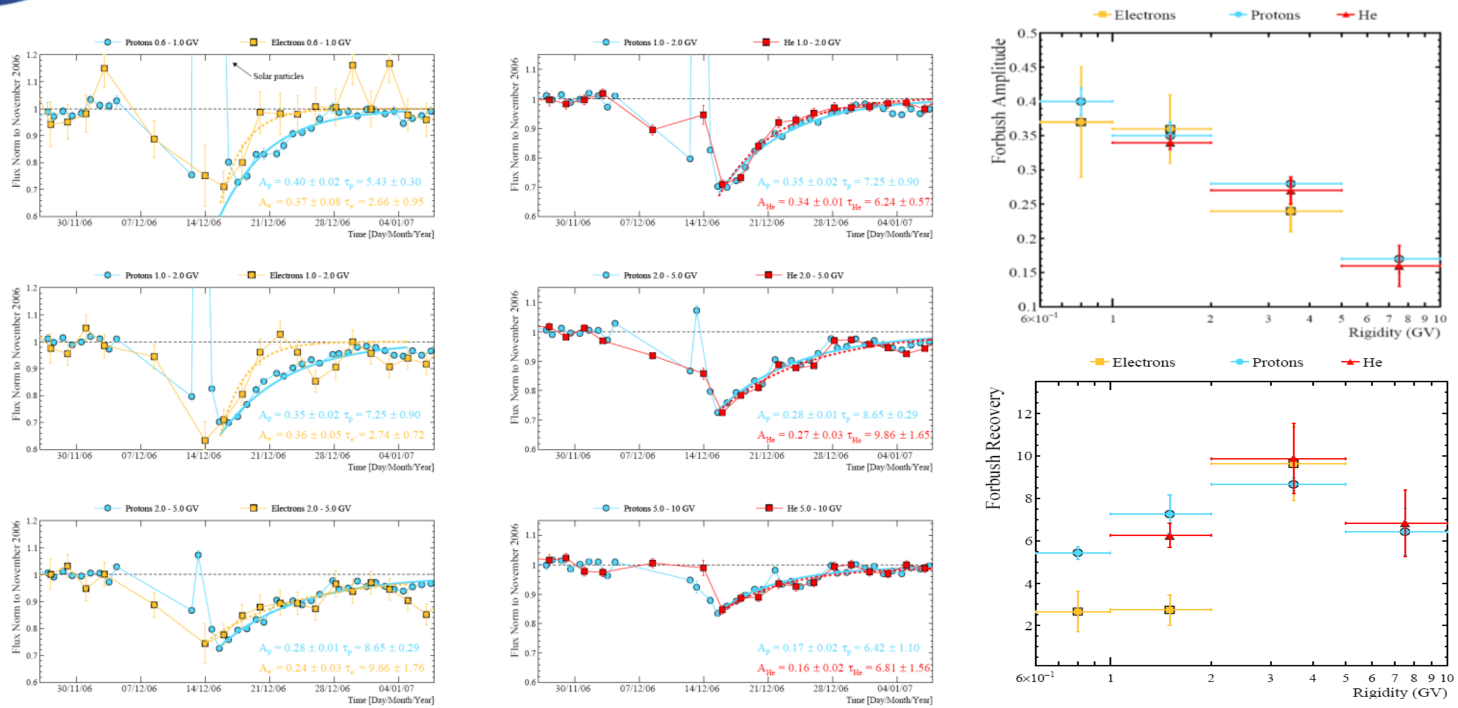
Neutron monitor counting rate during 2017



FD-2017-09-06 is our target event of this analysis

mainly represent all cosmic ray intensity w/o particle species, less energy precision.

Recent results from space (e.g. PAMELA)



Result1: same rigidity dependence of A_P for p, He, e-

Result2: e- recover faster than p and Helium

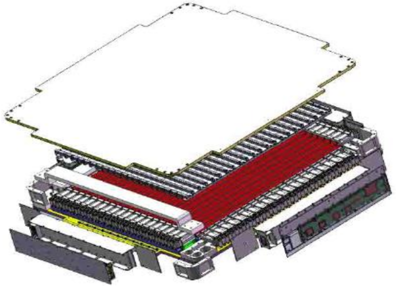
Small geometry factor, Limited statistics for electron

2 days per dot and 3 energy bins for e$^-$

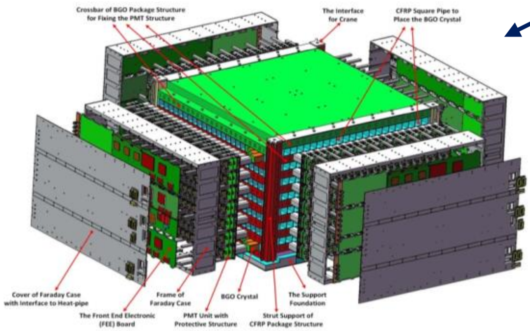
The Astrophysical Journal, Volume 853, Issue 1, article id. 76, 11 pp. (2018).

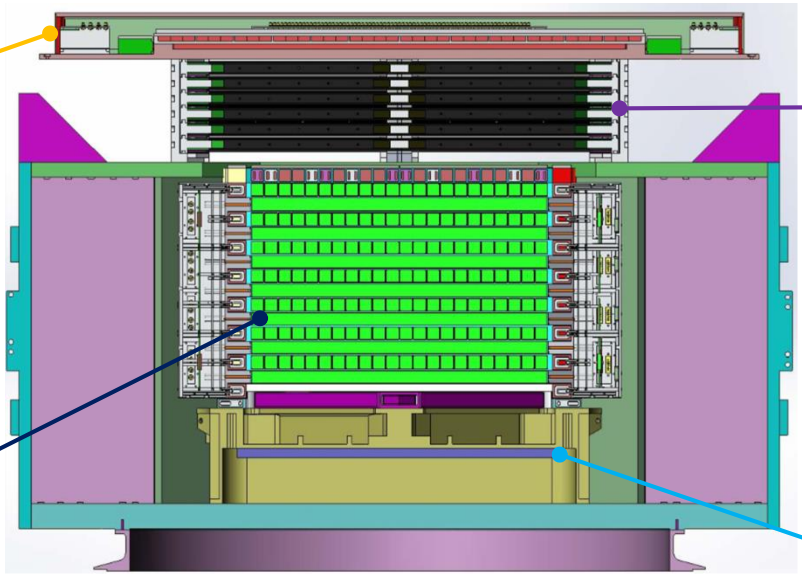
DAMPE Experiment

Plastic Scintillator Detector(PSD)
- γ anticoincidence
- Z-measurement

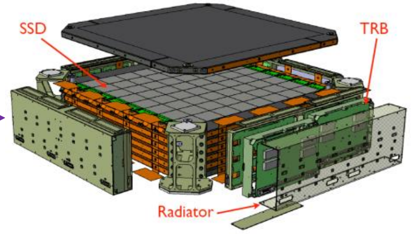


BGO Calorimeter(BGO)
- Calorimeter ($32X_0$&$1.6\lambda_I$)
- e/p separation
- Trigger primitives

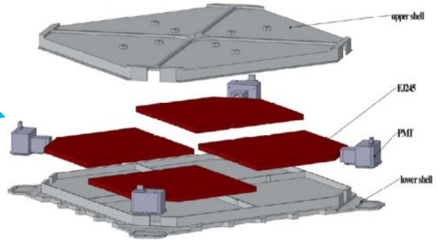




Silicon Tungsten Tracker(STK)
- γ convertor, particle track
- Z-measurement



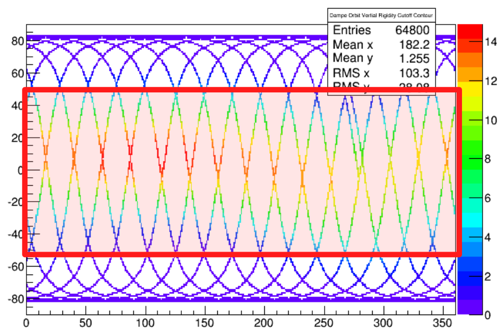
Neutron Detector(NUD)
- e/p separation



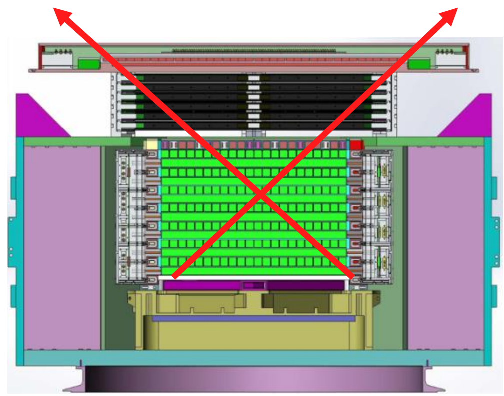
The Astroparticle Physics, Volume 95, October 2017, Pages 6-24

Advantages of DAMPE on measuring CRE forbush decease

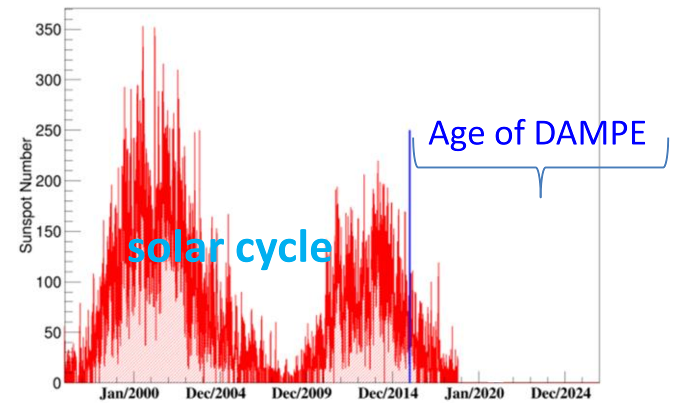
Key of measuring CRE FD:
Collect sufficient statistics within short time.



Orbit inclination 97°
reach polar region, limit affect from geomagnetic rigidity cutoff.



Large acceptance
Collect sufficient statistic within several hours.

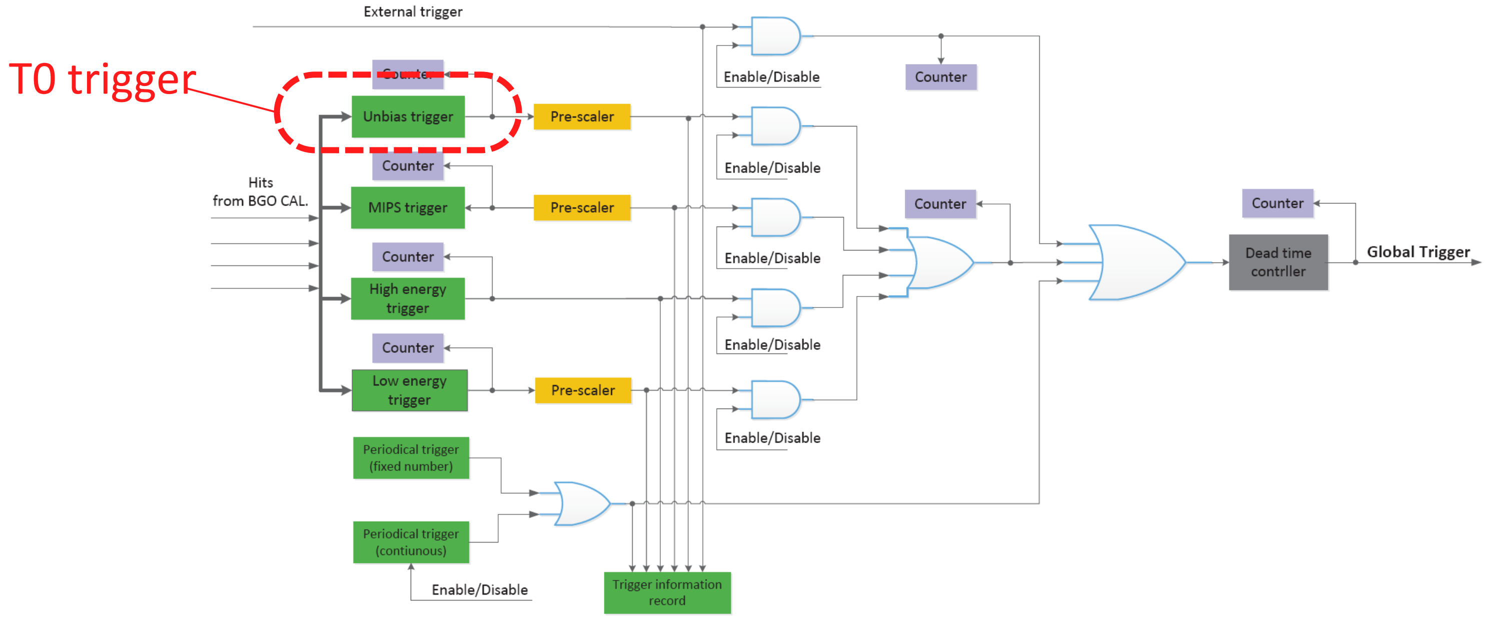


Quiet stage of solar cycle
Slower Intensity change w.r.t. the period of high solar activity

Galactic Cosmic Rays intensity from DAMPE

DAMPE ---- T0 trigger

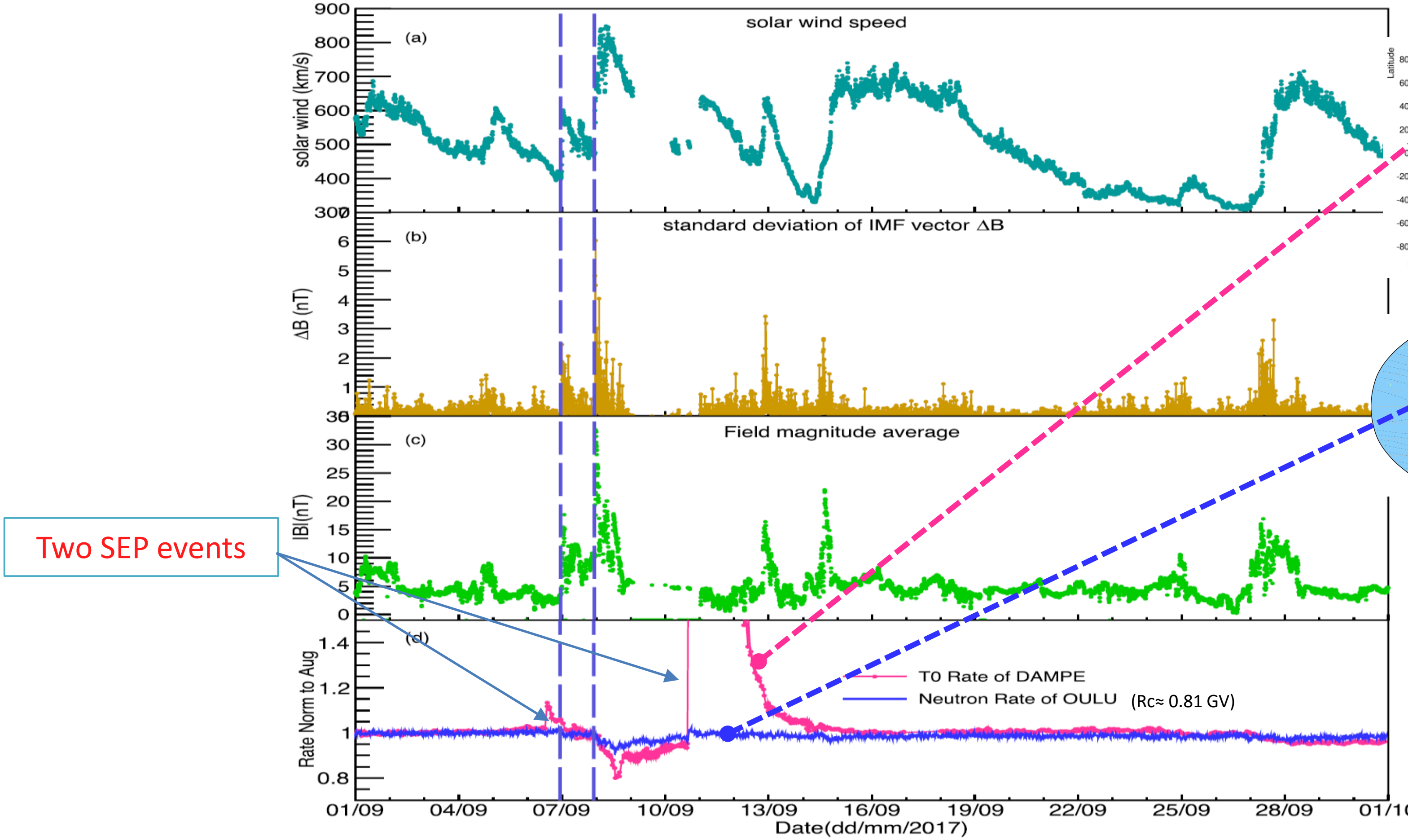
The trigger logic scheme of DAMPE

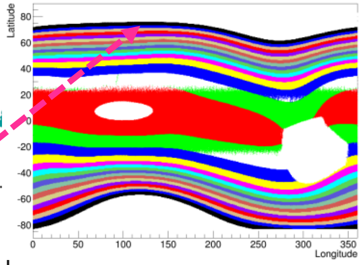


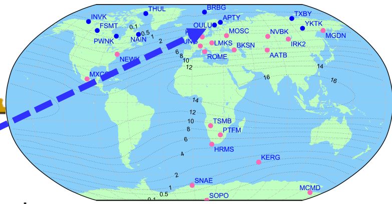
- **DAMPE recorded Trigger T0 counting every 4s.**
- **T0 trigger is a low threshold hit signal measuring the overall intensity of all species of GCRs above 100 MeV**

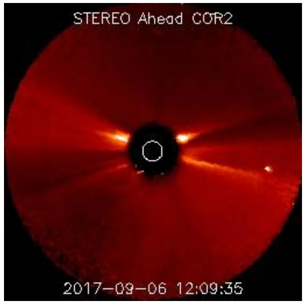
The T0 trigger makes DAMPE a GCR intensity monitor like NMs

DAMPE ---- GCR intensity monitor









A weak SEP event has been revealed through the T0 counting rate, while no unambiguous signal is shown by ground-based NMs.

CRE Data sample selection

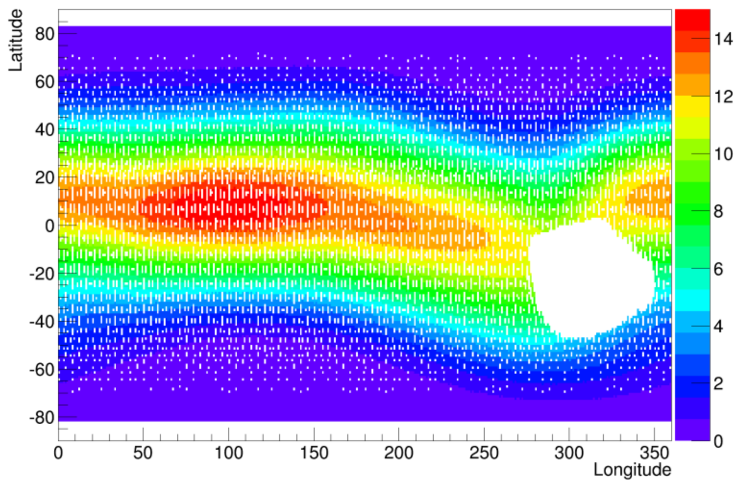
CRE preselection

Selection Cuts:

1. **Shower Max not Edge**
2. **Photon track without PSD veto**
3. **Track cross PSD & PSD charge cut**
4. **Corrected energy > 1.2*Vertical rigidity cutoff**

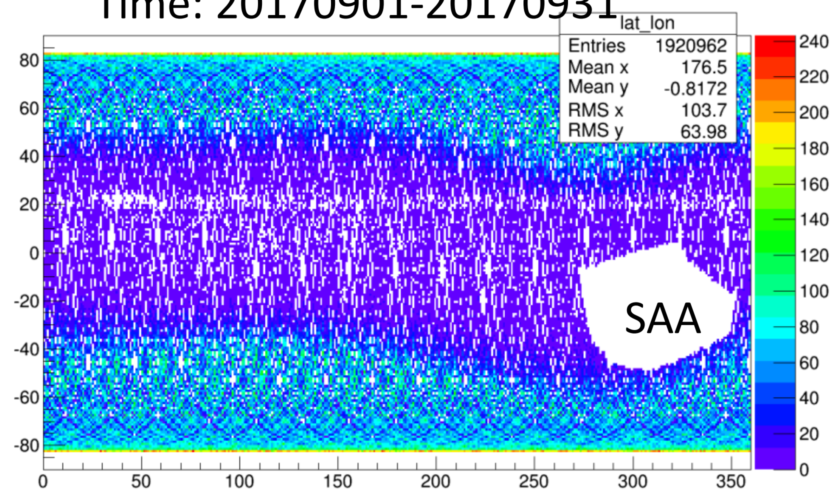
Trigger Logic:

5. ***HET***



Vertical Rigidity Cutoff in DAMPE orbit

Time: 20170901-20170931

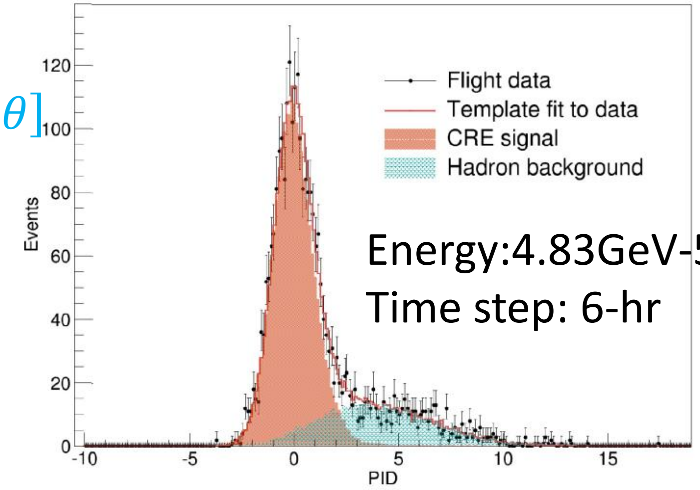


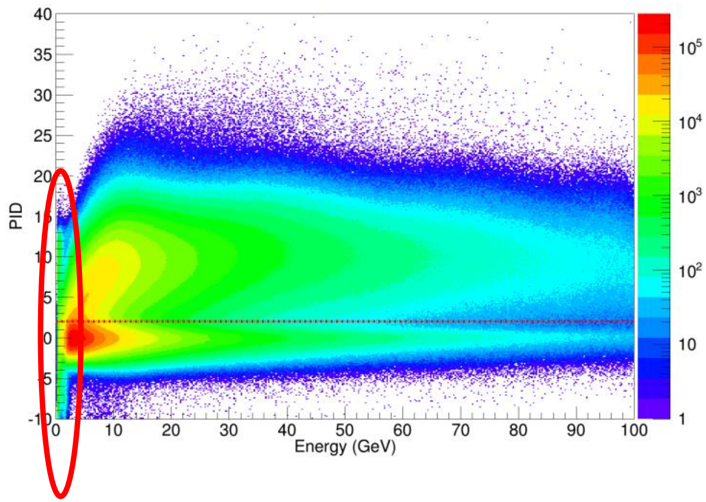
Data sample geography longitude & latitude

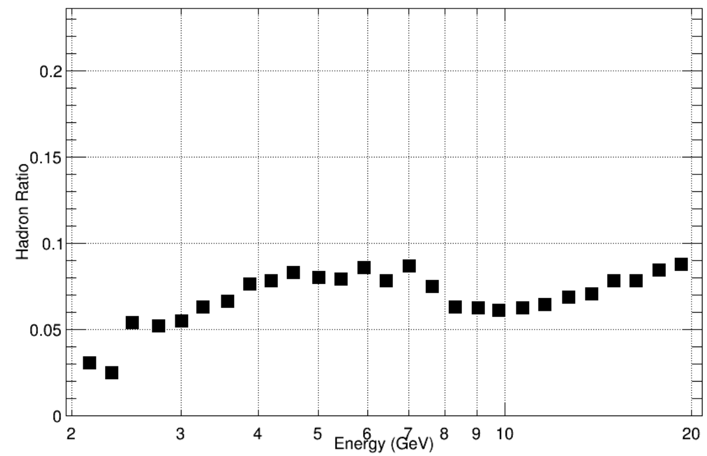
Particle Identification

$$PID = F(E)[\log(rmsr)\sin\theta + \log(rmsl)\cos\theta]$$

$F(E)$: energy decorrelation function
$rmsr$: lateral RMS
$rmsl$: longitudinal RMS





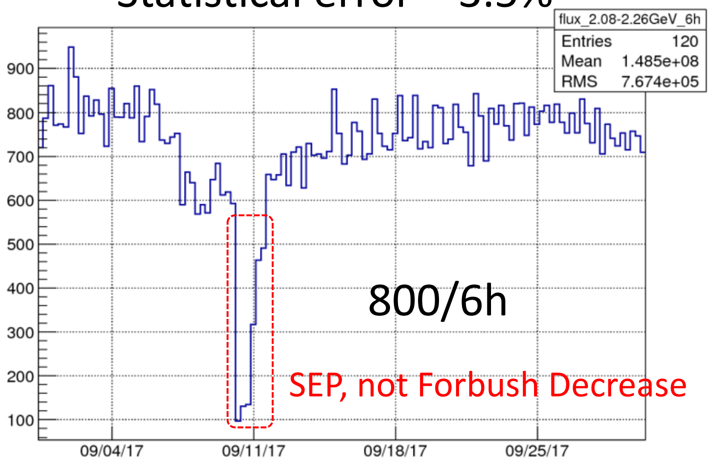


Below 2GeV, too weak PID capability.

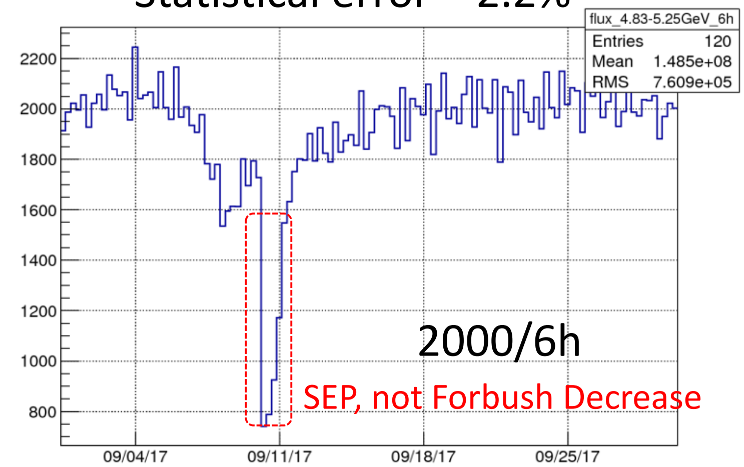
Background contamination < 9%

CRE candidates in 4 typical energy bins

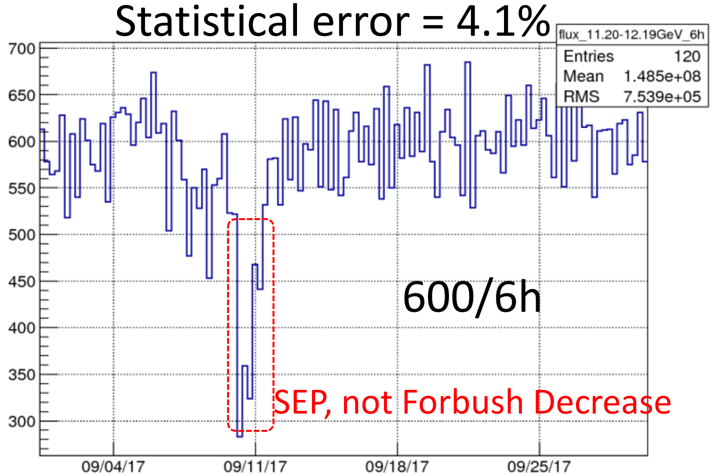
Statistical error = 3.5%



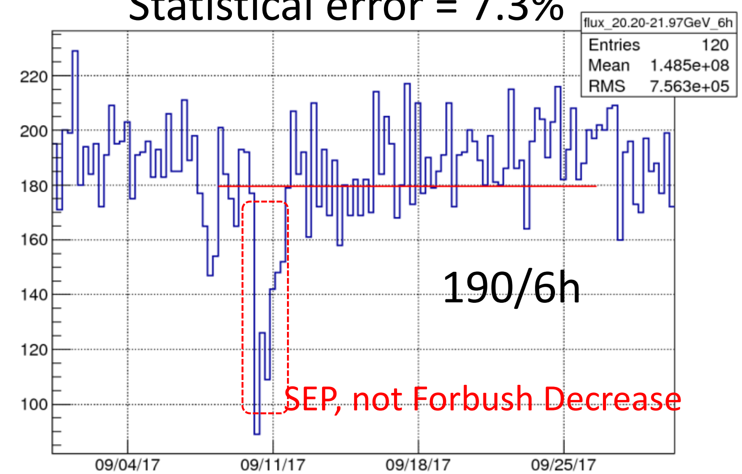
Statistical error = 2.2%



Statistical error = 4.1%



Statistical error = 7.3%



From 2GeV to 20GeV, CRE candidates are divided into 27 energy bins

Time profile of the flux of CMEs from 2GeV to 20GeV

Electron candidates

Background ratio

$$\frac{d\emptyset(t)}{dE} = \frac{N(t)\cdot\left(1-\sigma(t)\right)}{A\cdot\eta_{pre}(t)\cdot\eta_{trg}(t)\cdot T_{tbin}^{Ebin}(t)\cdot\Delta E}$$

Geometry Acceptance

HET trigger efficiency

Width of E bin

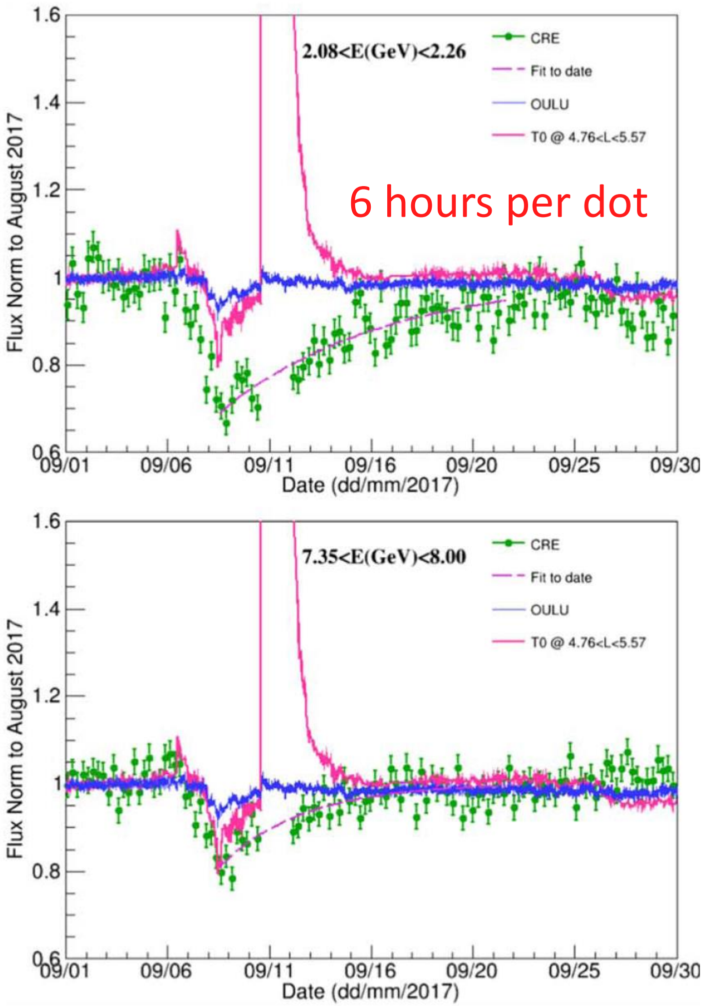
Preselection efficiency

Exposure time

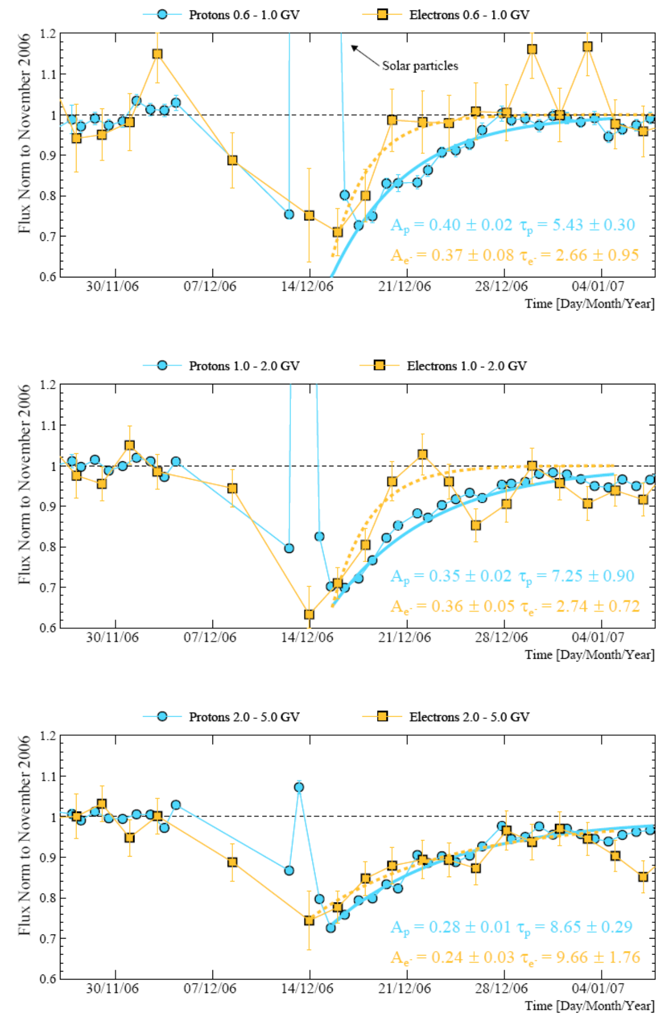
Key of the measurement : **Stability of**

1. Exposure time
2. Background contamination ratio
3. Preselection efficiency (mainly tracking efficiency)
4. HET trigger efficiency

Time profiles of Relative CRE fluxes in 2 typical energy bins

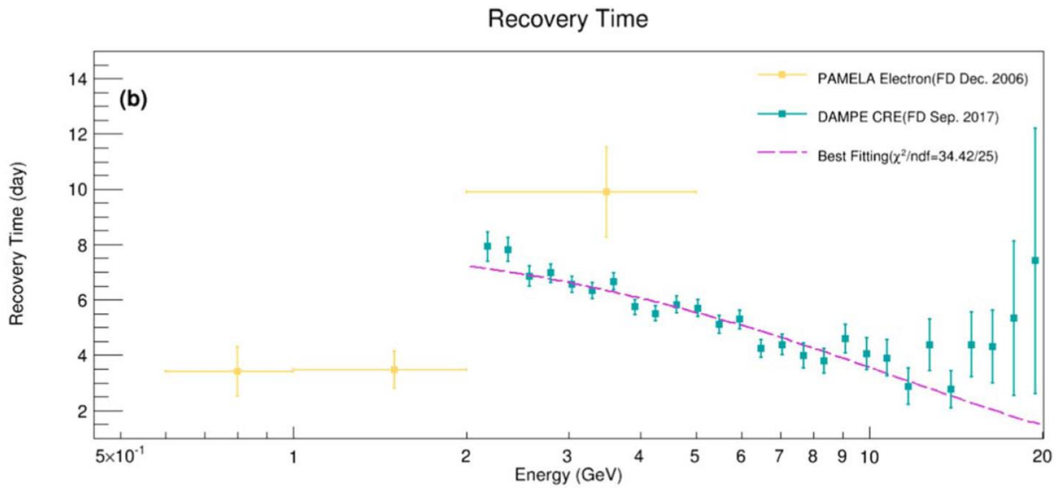


DAMPE



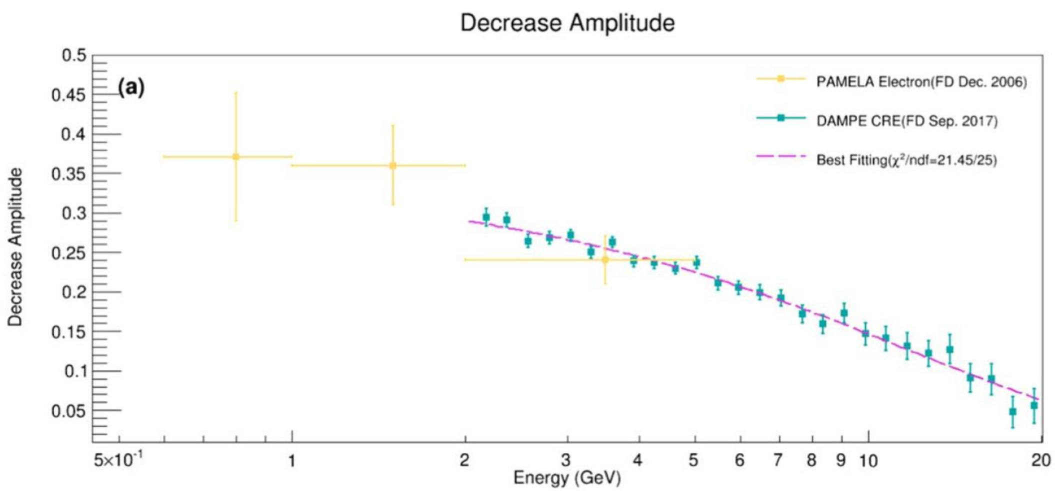
PAMELA

Decrease Amplitude and Recovery time versus Energy for CME

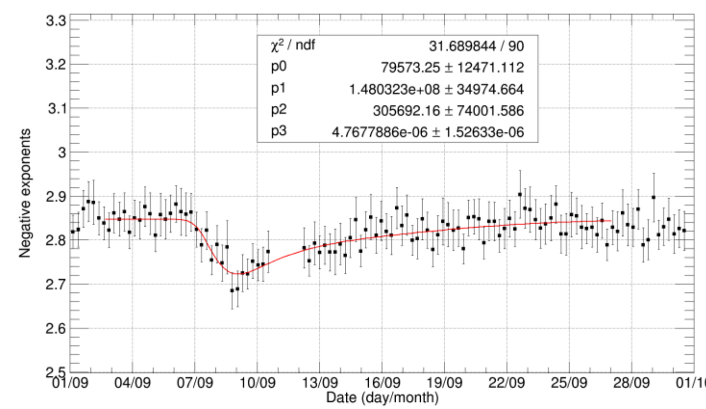


$\chi^2/ndf = 34.42/25$

Above 10GeV, constant?



Spectral index of 4GeV-20GeV



The Astrophysical Journal, 827:13 (10pp), 2016 August 10

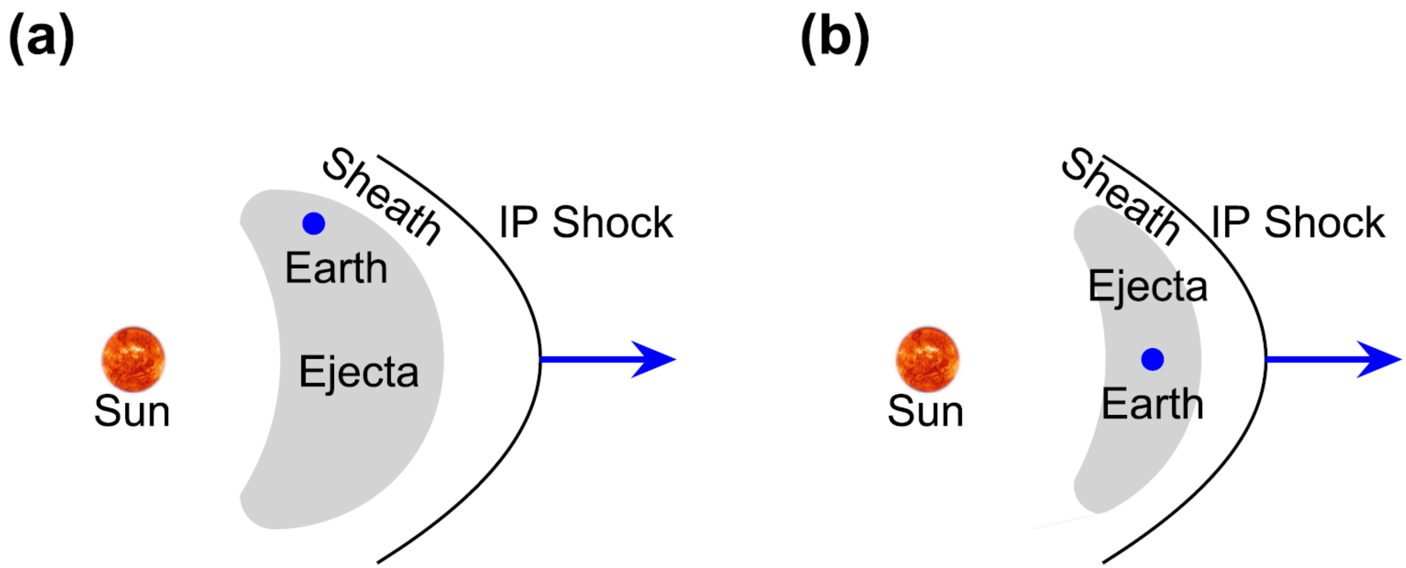
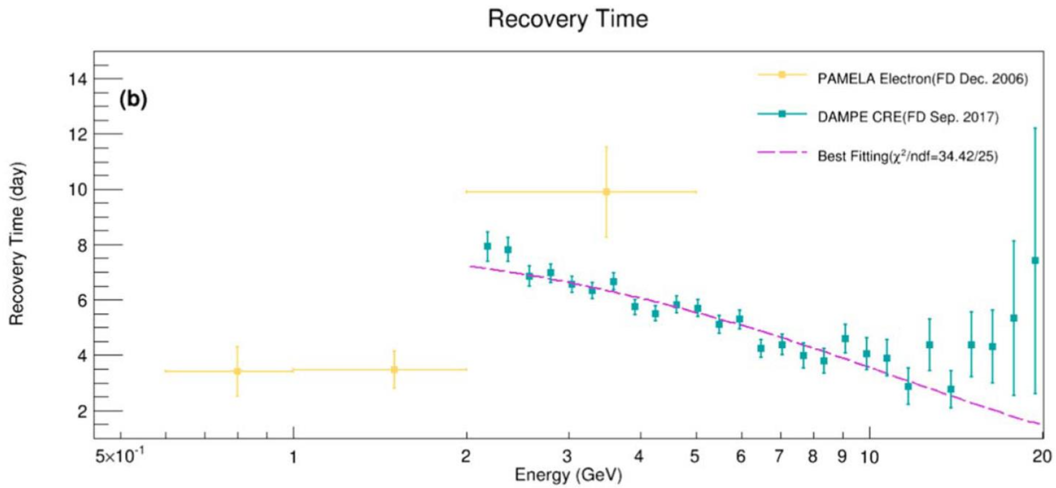
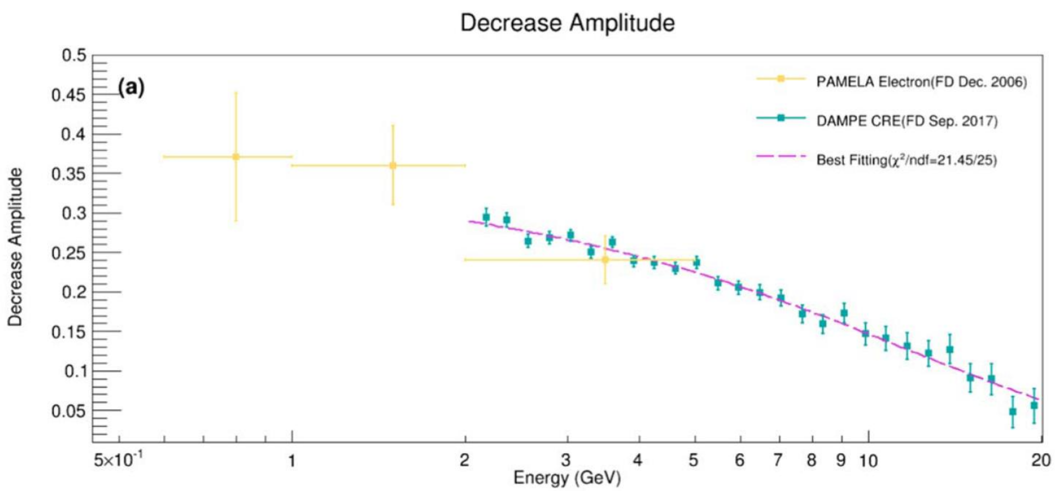


Figure 9. Schematic diagram (not to scale) explaining (a) Event 1 and (b) Event 2.

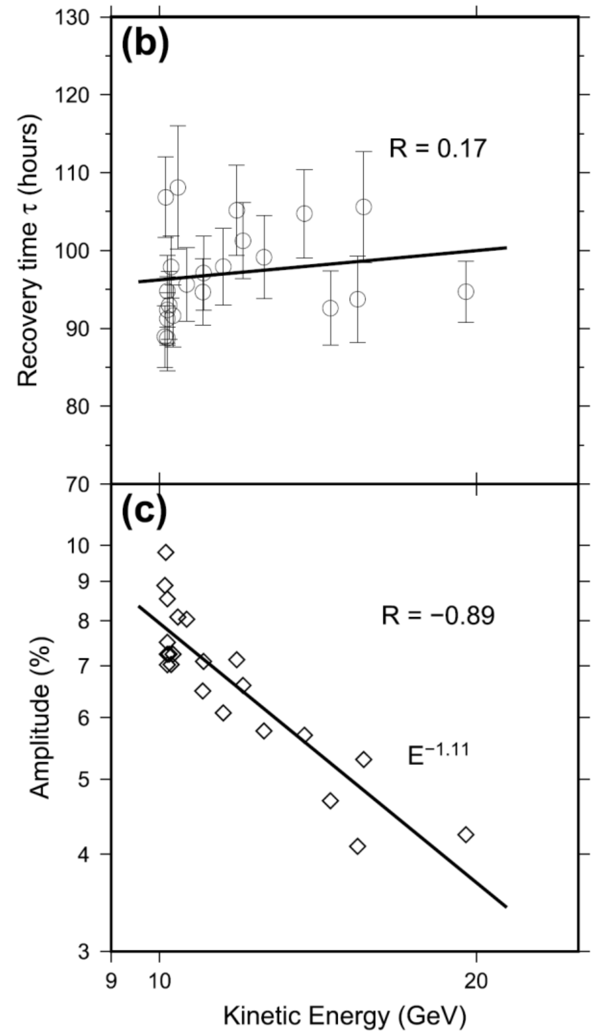
The recovery time of Event 1 is strongly dependent on the median energy
Conversely, the recovery time of Event 2 remains almost constant (~95 hr) over the studied energy range.

Decrease Amplitude and Recovery time versus Energy for CME





Neutron Monitor



Summary

- we give a detailed study of the FDs of CREs associated with the CME occurred in September, 2017
- T0 counting rate revealed two SEP events, while no unambiguous signal is shown by ground-based NM for the weak one.
- high-precision time evolutions of CRE fluxes with a 6-hour time resolution have been obtained, both FD amplitude and recovery time decrease with energy
- Combining with PAMELA results, recovery time of all species of particles show an increase below a few GeV and a decrease at higher energies
- above $\sim$ 10 GeV, the recovery time may become constant, a more complete modeling of the recovery time versus the energies is necessary.

BACKUP

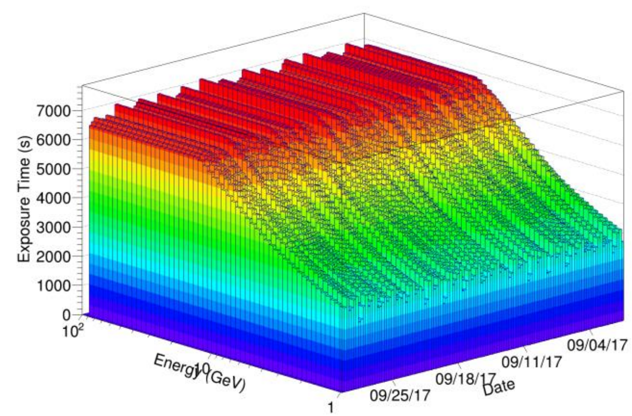
Exposure Time in *energy bins* × *time bins*

Live Time in 1 second T_{1s}

$$T_{1s} = \sum_{i=0}^{N_{trg}} \Delta T_i - T_{dead}\,, T_{dead} = T_b * N_{trg} + T_a * N_{T_0} * (1 - T_b * N_{trg})/(1 - T_c * N_{trg})$$

- T_{1s} : live time in 1 second
- ΔT_i : time interval for event i
- T_{dead}: total dead time
- T_b: dead time from effective trigger =3.0725ms
- N_{trg}: recorded events in 1s
- T_a: dead time from T0 trigger = 1us
- N_{T_0}: T0 trigger counts in 1s

Exposure Time $T_{tbin}^{Ebin} = \sum T_{1s}$



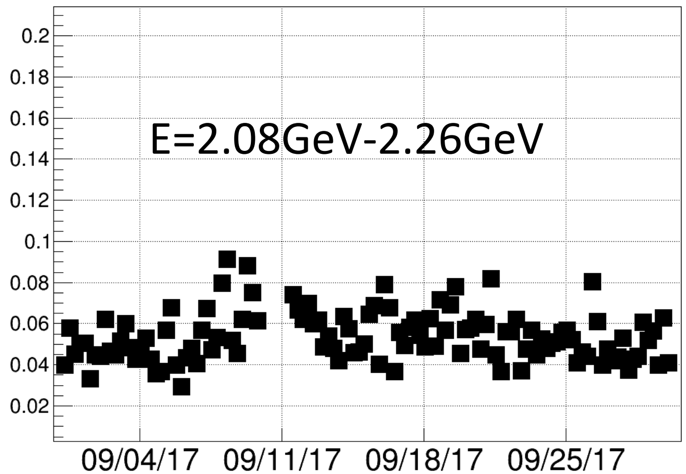
Stability of Background Ratio

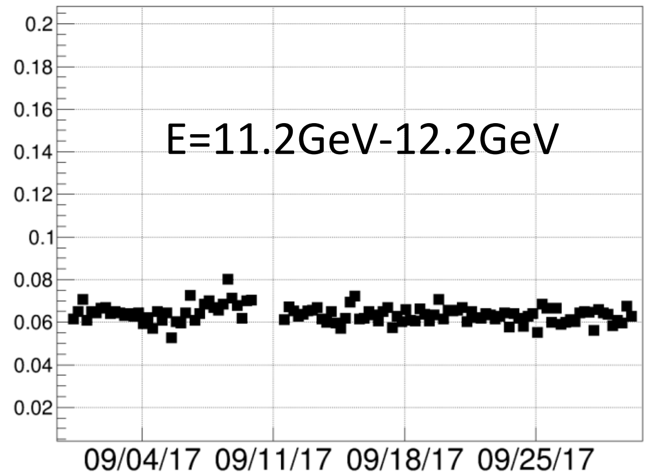
Background Ratio with same **rigidity** is stable, but not for same **energy**.

- GCR modulated by interplanetary magnetic field

  $When\ E \rightarrow m_p, E \neq R, m_p\ is\ proton\ mass$ $\quad E^2 = p^2c^2 + m_p^2c^4$

- The composition of GCR with same energy varies with geomagnetic field
- e/p ratio variation $\Longrightarrow$ background ratio variation



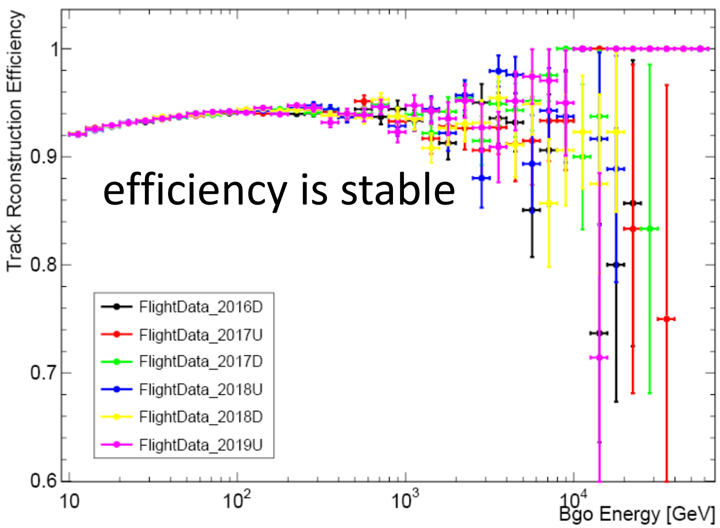


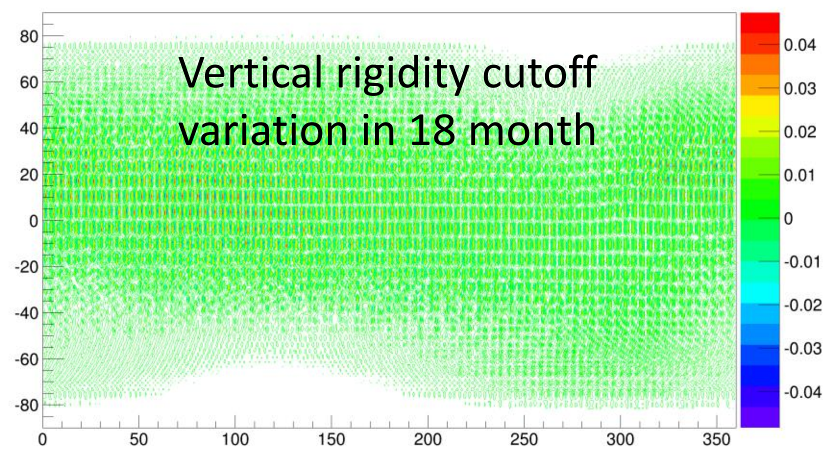
Finally, background ratio is estimated in each time bin and each energy bin.

Stability of preselection efficiency

Selection Cuts：

1. **Shower Max not Edge (shower shape morphology, no short term variation)**
2. **Photon track without PSD veto (may change)**
3. **Track cross PSD & PSD charge cut (if tracking efficiency change, then change)**
4. **Corrected energy > 1.2*Vertical rigidity cutoff (depend on cutoff)**





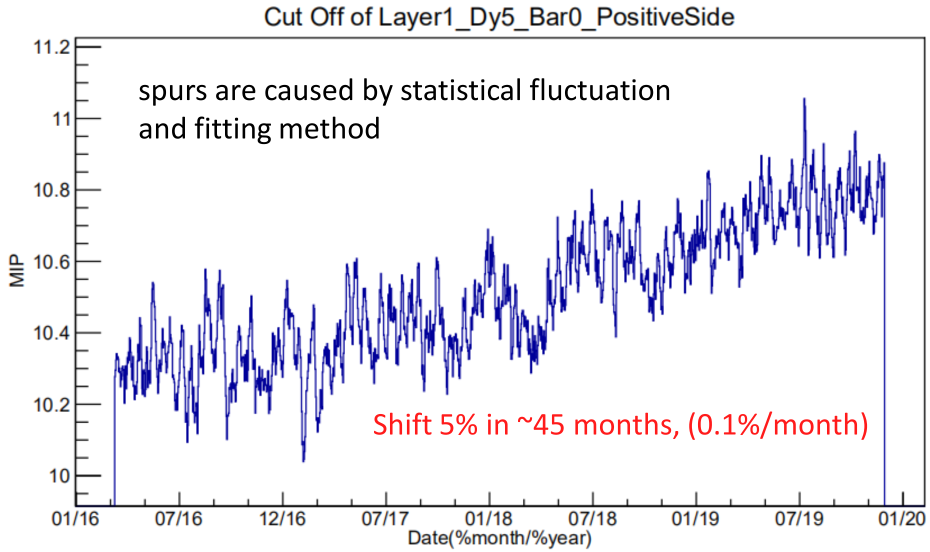
- Limited by low statistic of electron, tracking efficiency evaluated by proton.
- we only care relative variation (not absolute value).
- It’s safe to believe electron has same level of efficiency variation with that of proton

18 months Δ ~ 1% (max~4%)
Within 1 month Δ<<1%

Stability of HET trigger efficiency

Trigger threshold is main reason of variation of trigger efficiency.

A typical channel's threshold



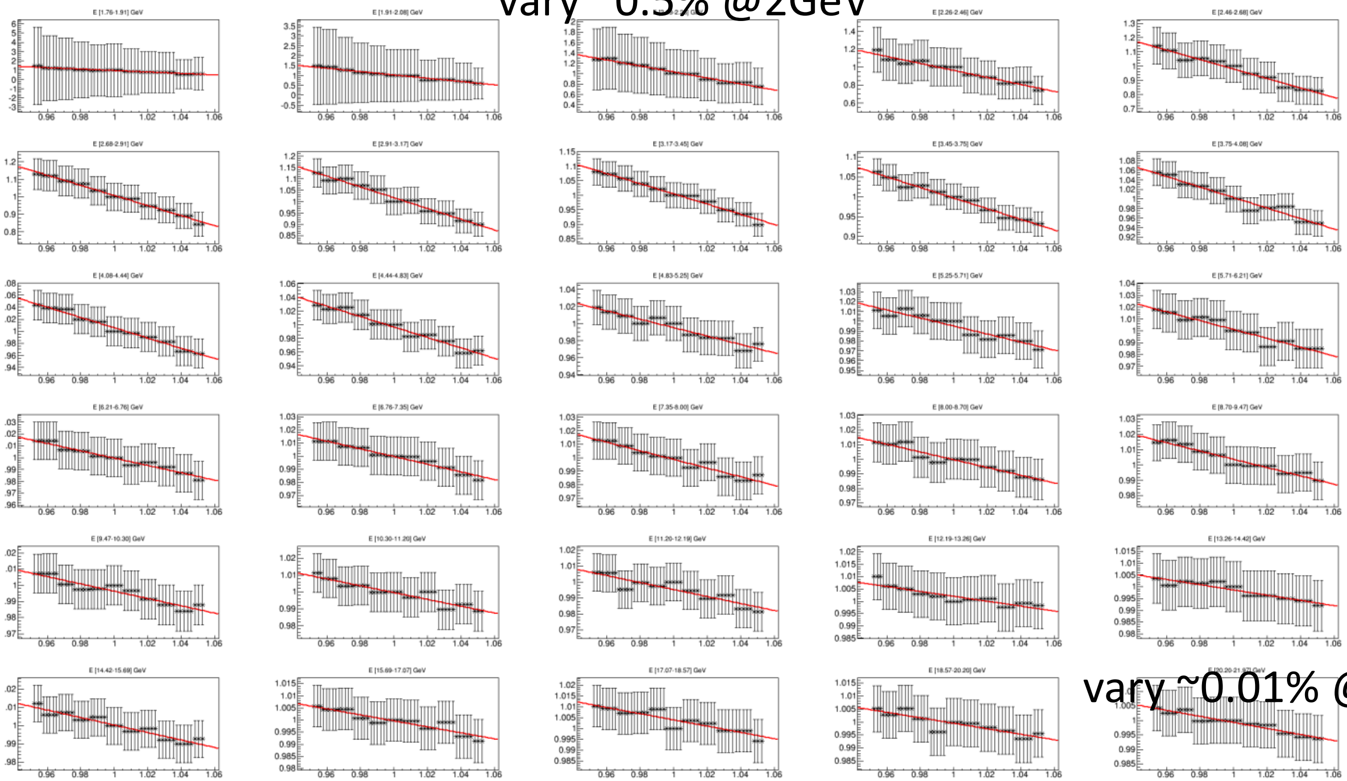
Reason: Light yield, PMT gain factor, electronics aging and etc.

Stability of HET trigger efficiency

Shift a bias on deposited energy, simulate threshold shift, study efficiency variation

$$\eta(E,\Delta T)/\eta_{ref} = P_0\text{-}P_1 * \left(\mathrm{ADC}_{\mathrm{thresh}}/\mathrm{ADC}_{\mathrm{thresh}_{ref}}\right)$$

vary ~0.5% @2GeV

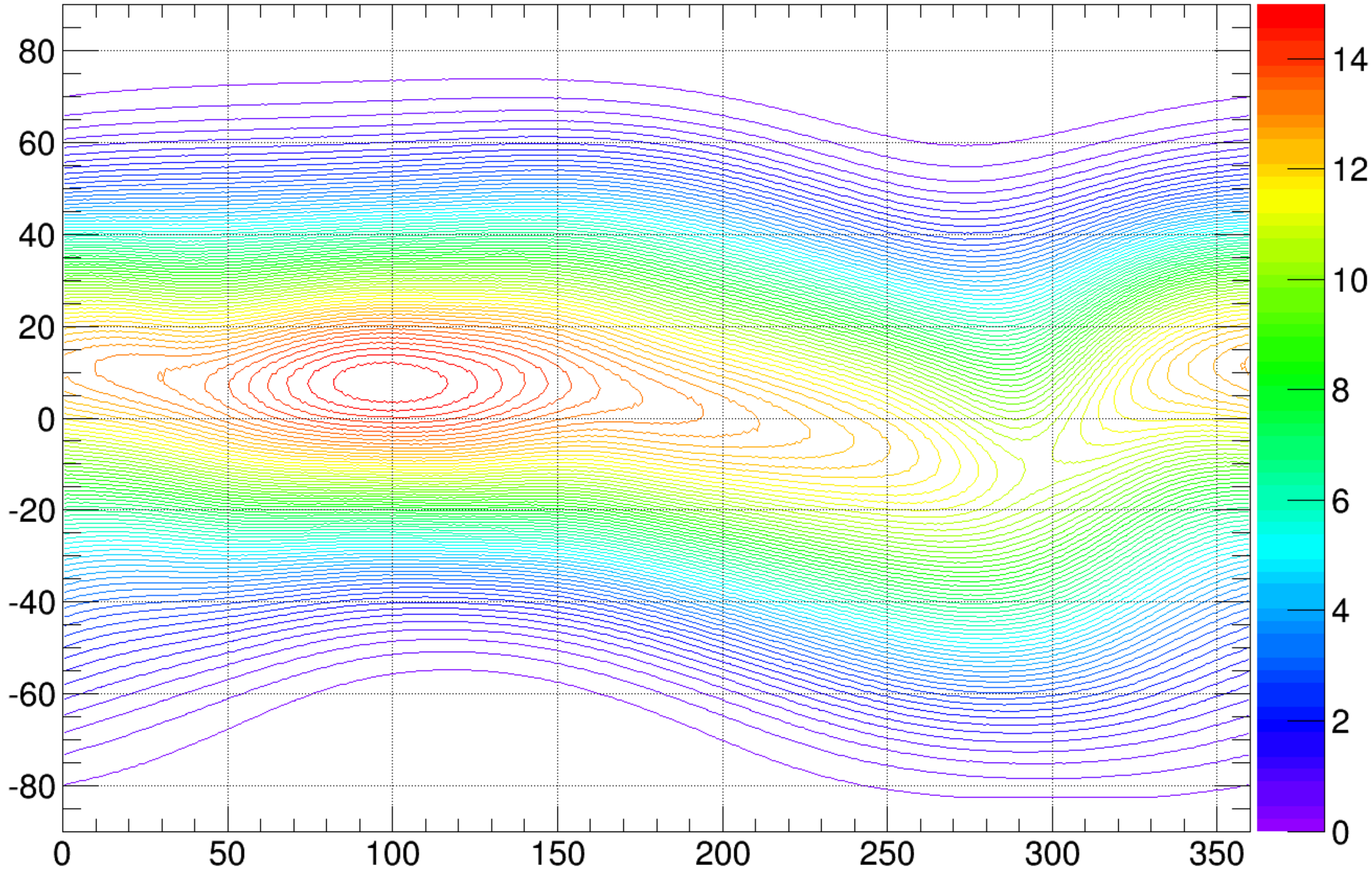


vary ~0.01% @20GeV

Correlation between threshold and trigger efficiency from 2GeV to 20GeV

Conclusion:

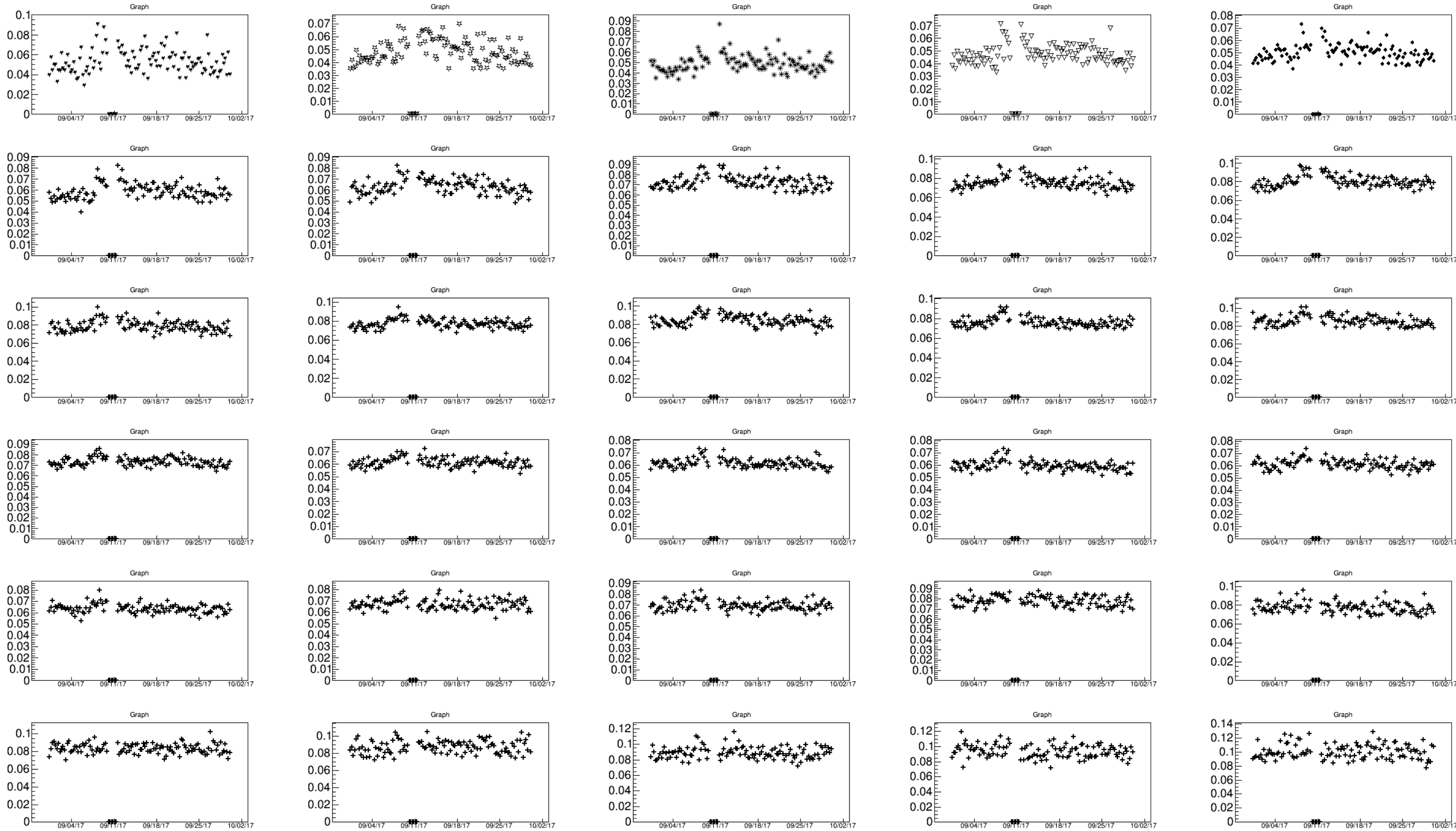
Comparing with 2%~8% statistical error, HET trigger efficiency is stable within 1 month



80
60
40
20
0
-20
-40
-60
-80
0
50
100
150
200
250
300
350
14
12
10
8
6
4
2
0

本底污染绝对变化

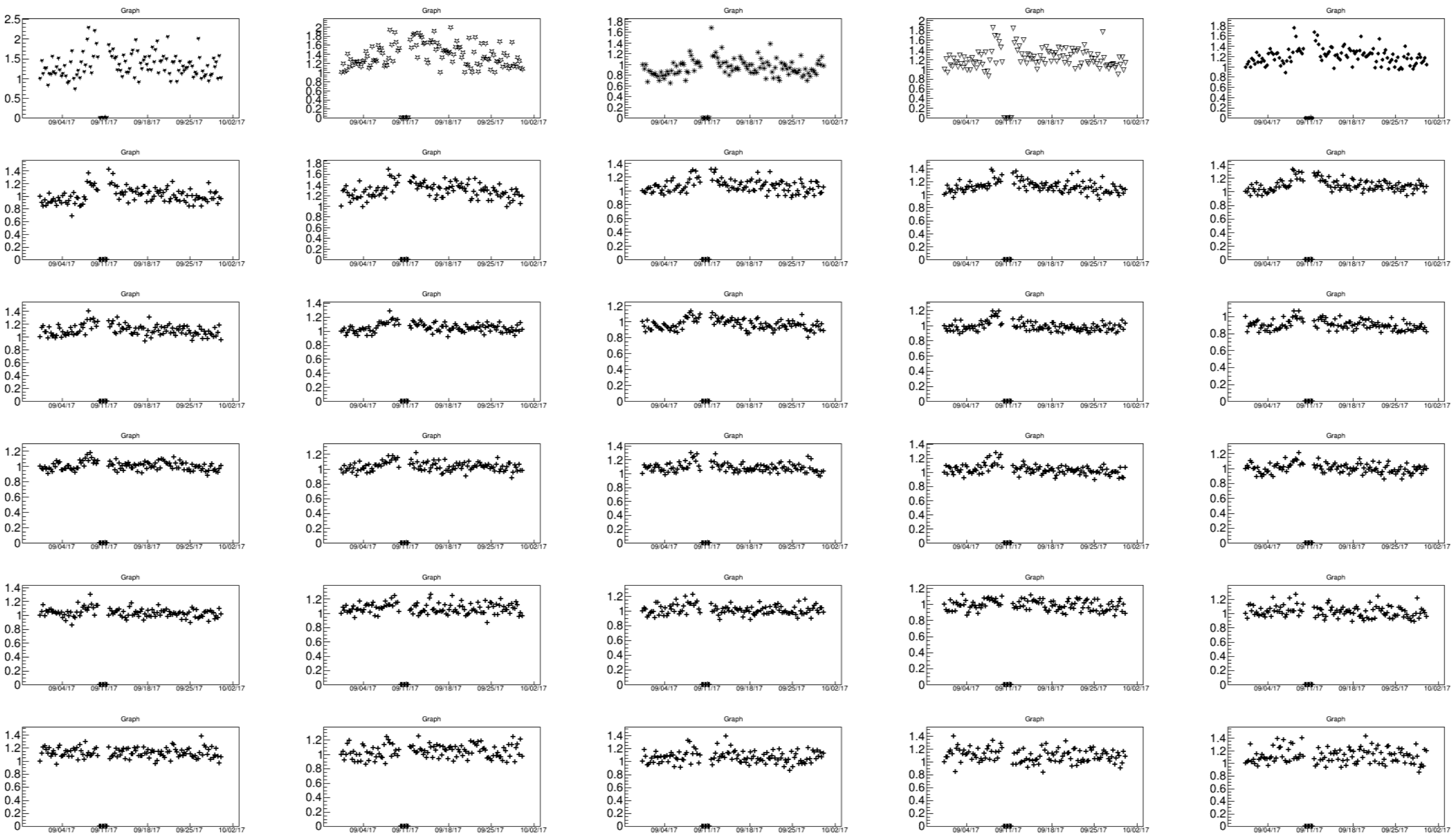
2GeV



27GeV

本底污染相对变化

2GeV



27GeV