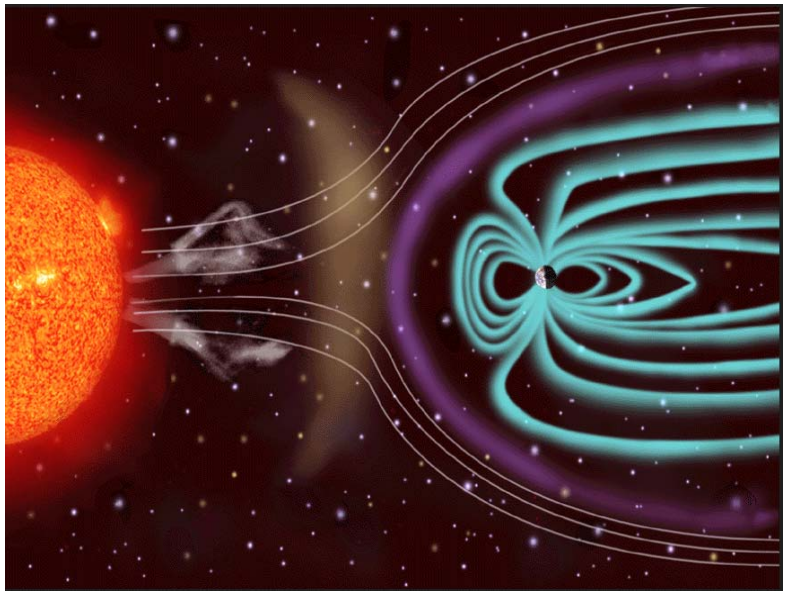
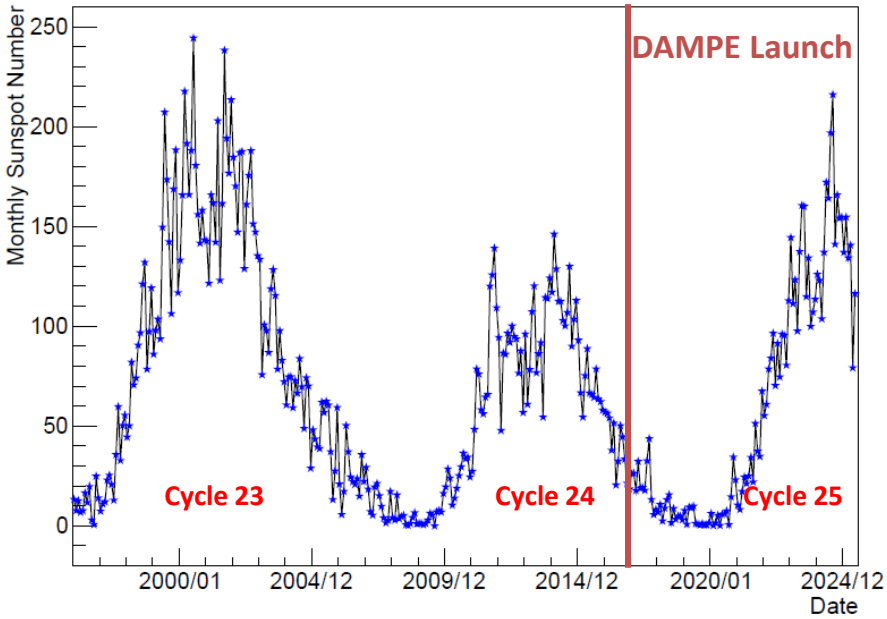
Solar Modulation of Primary Cosmic Ray Electron (Positron) Flux

Yang. Liu
PMO

Introduction



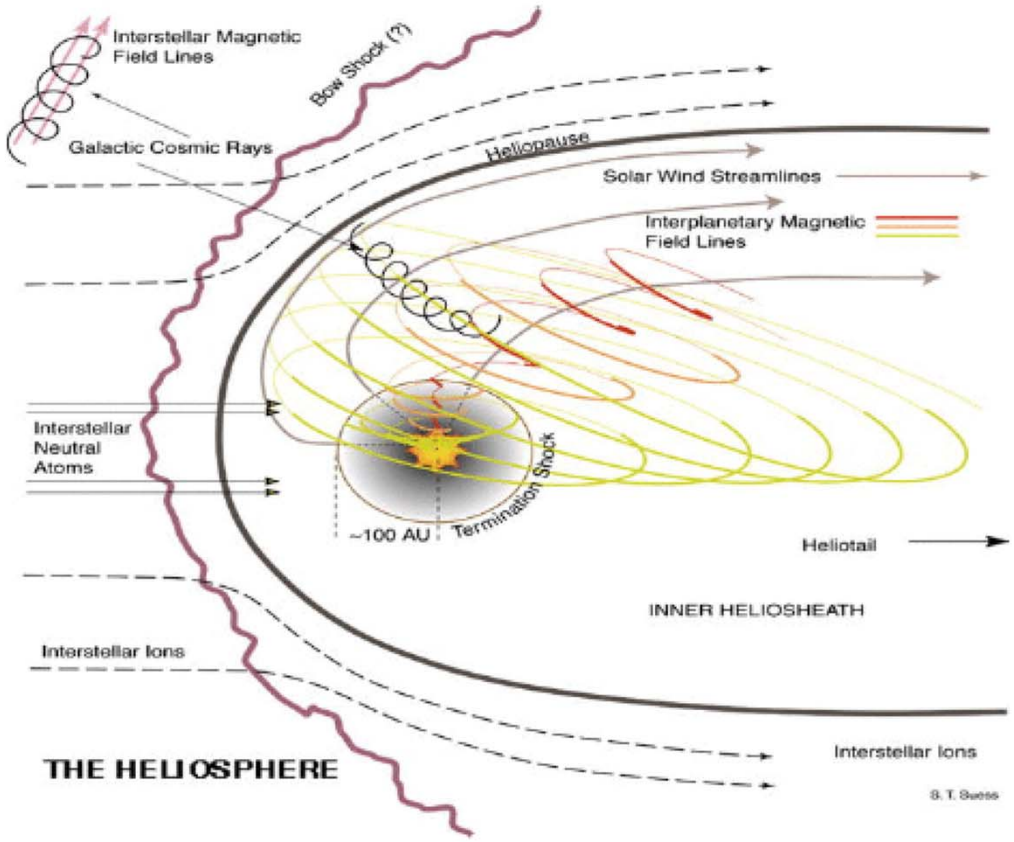


Monthly sunspot number

Source: WDC-SILSO, Royal Observatory of Belgium, Brussels,
DOI: https://doi.org/10.24414/qnza-ac80

- Cosmic Ray (CR) interacts with solar wind and the magnetic field accompanying, intensity changed
- Solar modulation observation help to understand the transportation process in heliosphere.

Parker Spiral in Heliosphere



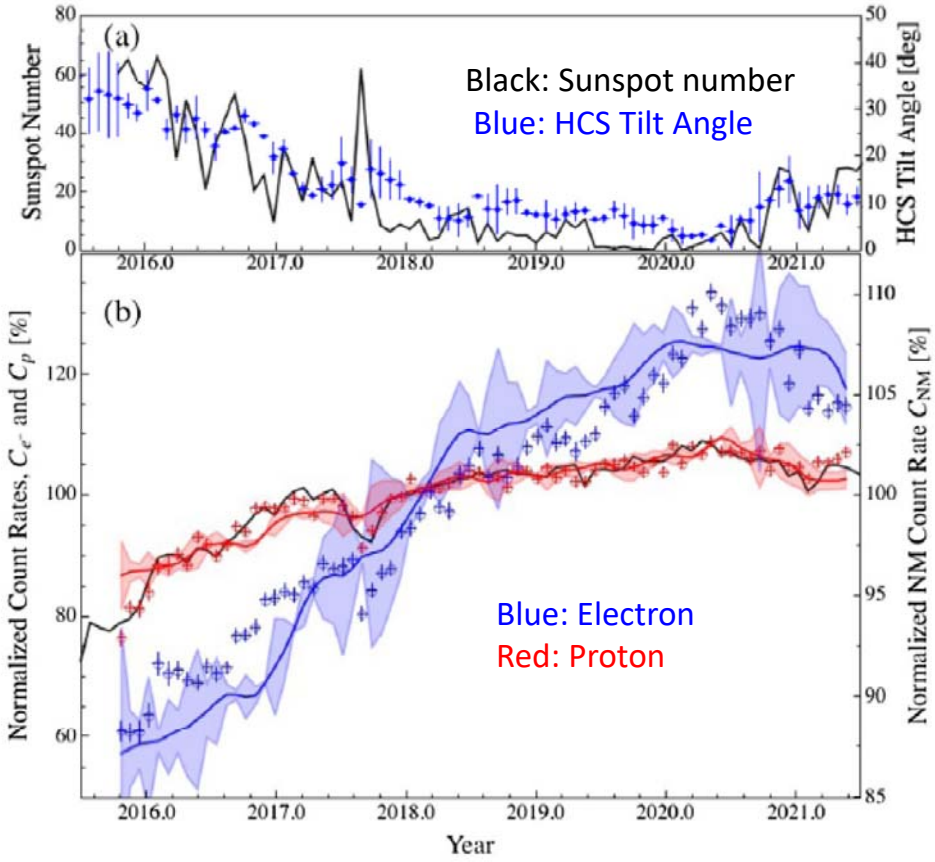
Parker Equation

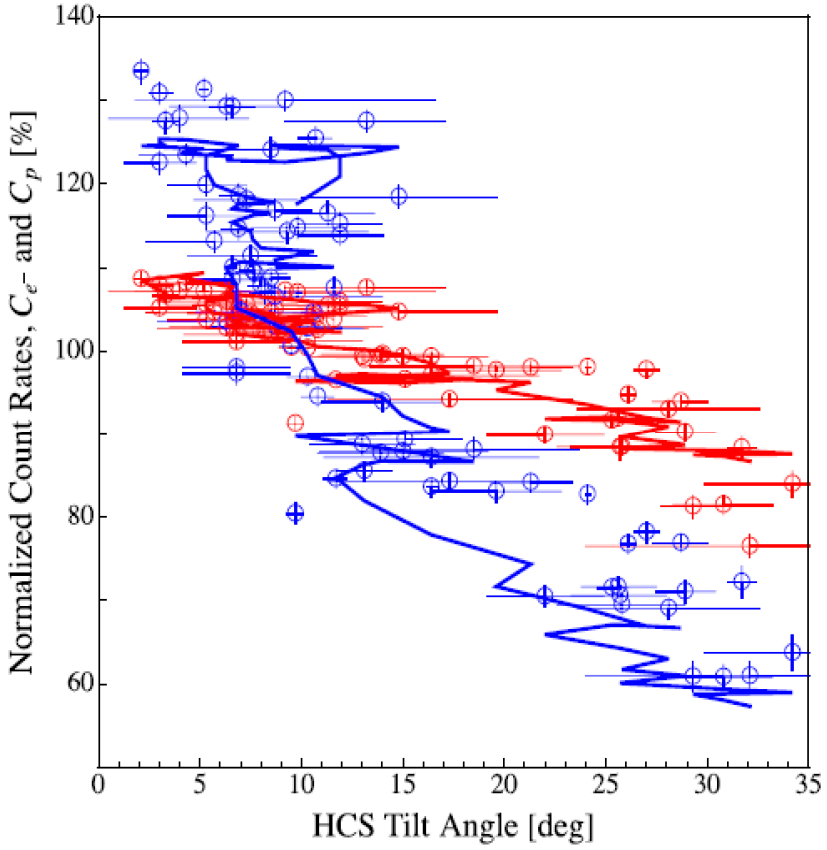
$$\underbrace{\frac{\partial f}{\partial t}}_{a} = -(\underbrace{\mathbf{V}_{sw}}_{b} + \underbrace{\langle \mathbf{v}_d \rangle}_{c}) \cdot \nabla f + \underbrace{\nabla \cdot (\mathbf{K}_s \cdot \nabla f)}_{d} + \underbrace{\frac{1}{3}(\nabla \cdot \mathbf{V}_{sw}) \frac{\partial f}{\partial \ln p}}_{e} + \underbrace{Q}_{f}$$

$$f(\mathbf{r}, p, t) = \frac{J(\mathbf{r}, p, t)}{p^2}$$

b: outward convection, Vsw: velosity of solar wind
c: drift , Vd drift velosity
d: diffusion, Ks: diffusion tensor
e: adiabatic energy process
f: additional source of electron in heliosphere

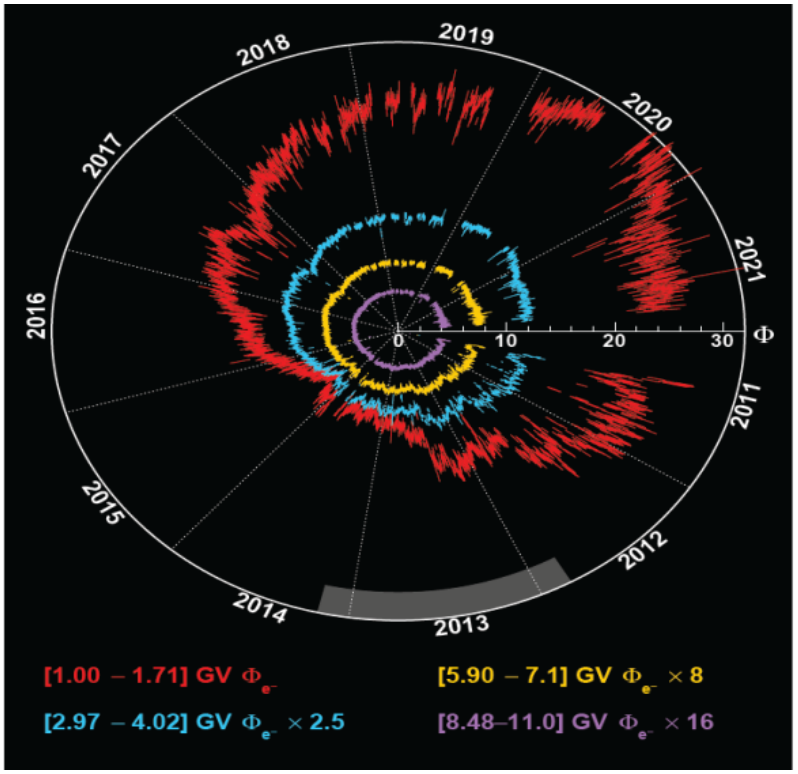
Previous Results from other Collaboration



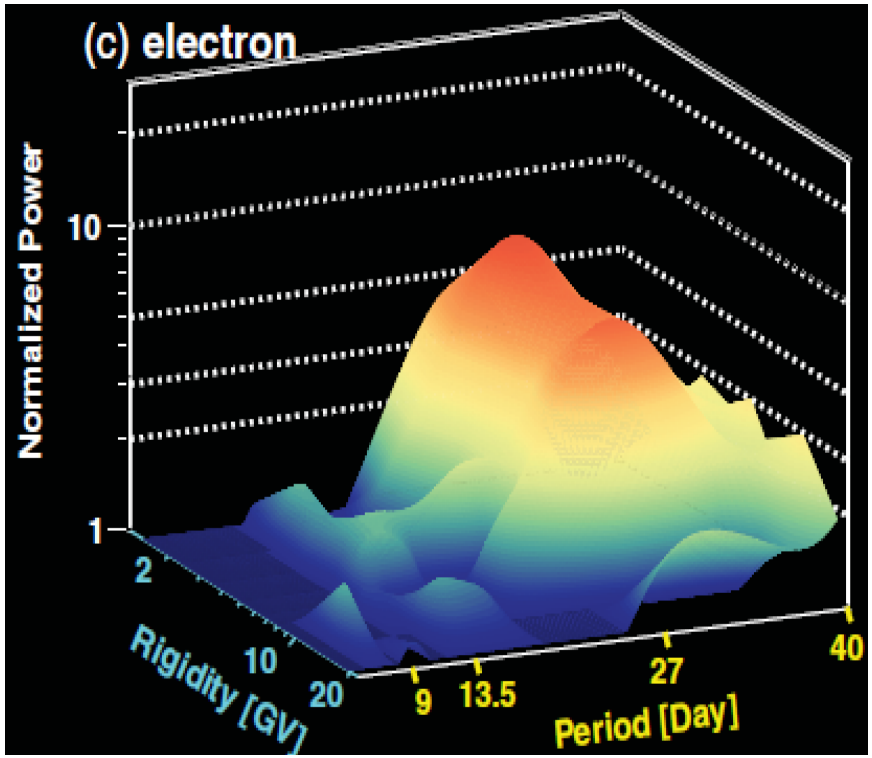


CALET Collaboration PRL. 130.211001

Previous Results from other Collaboration



AMS-02, PRL. 130. 161001



First half of 2017

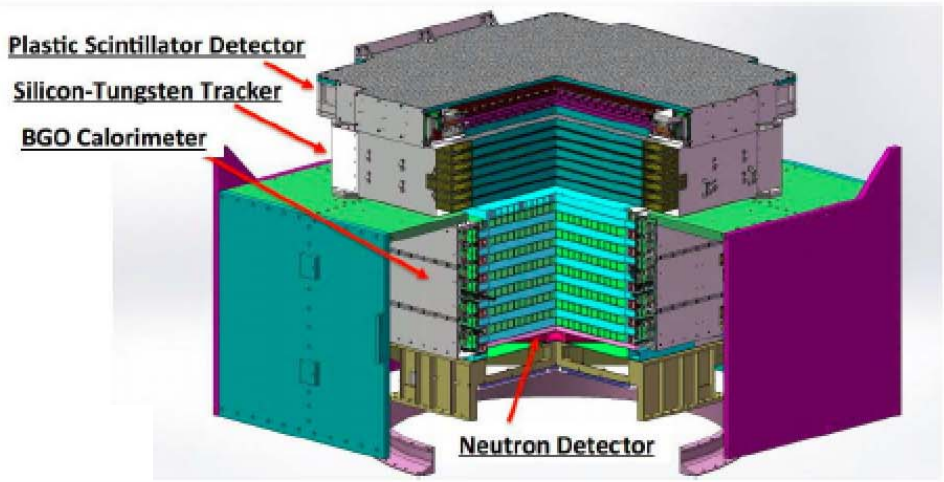
The DAMPE Detector

Motivation:

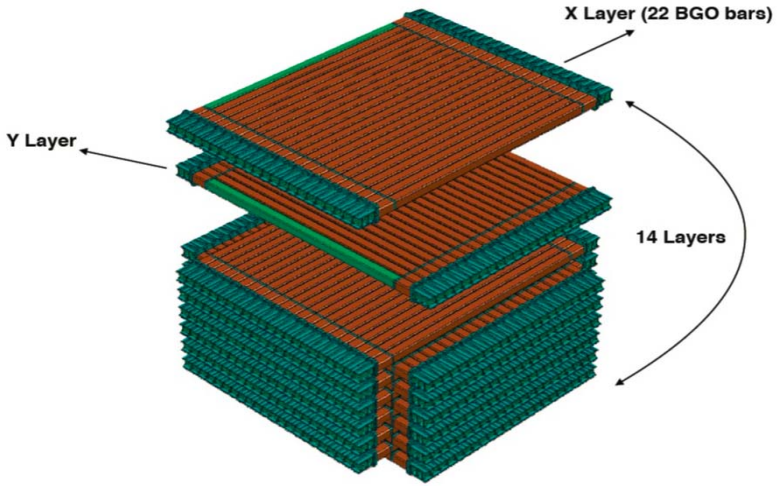
electron, proton, nuclei spectra measurement
indirect search of Dark Matter
Galaxy gamma ray source

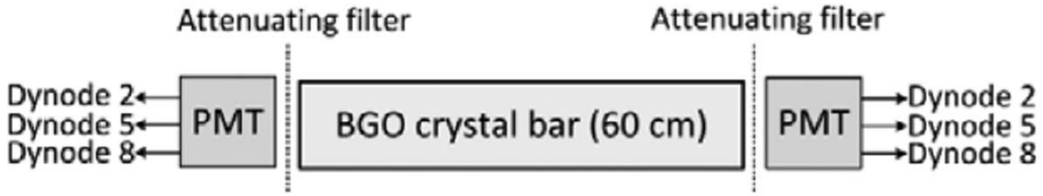
Launch time : 2015.12.17
Altitude: 500 km
Orbit type: solar-synchronous
Orbit period: ~95 min

PSD: Charge measurement, Anti-coincidence
STK: Track reconstruction, Charge measurement
BGO: Energy measurement, E-p separation, Trigger
NUD: E-p separation



DAMPE Trigger System





14 Layer, 22 BGO/layer
2 side, 3 dynodes readout;
Top 4 and Bottom 4 layers, 5, 8 dynode for trigger

DAMPE uses an energy trigger system employing the hit information in BGO calorimeter

Trigger Type	Logic	Energy Threshold	Pre-scale factor
HE	L1_P_dy5	~10 MIPs	1
	& L2_P_dy5	~10 MIPs	
	& L3_P_dy5	~10 MIPs	
	& L4_N_dy8	~2 MIPs	

The logic and threshold of DAMPE HE trigger

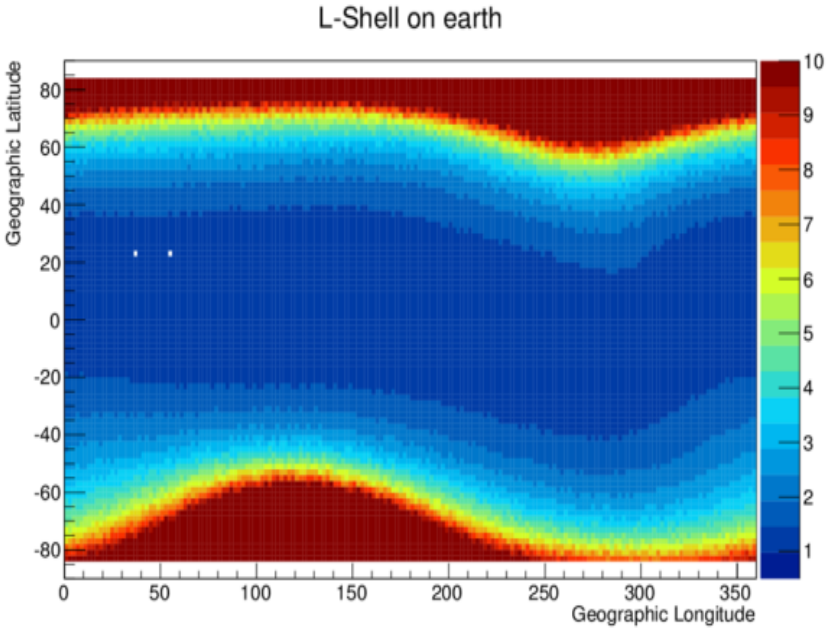
Primary Electron Flux Calculation

$$\Phi(E) = \frac{N}{G\varepsilon \times T \times \Delta E}$$

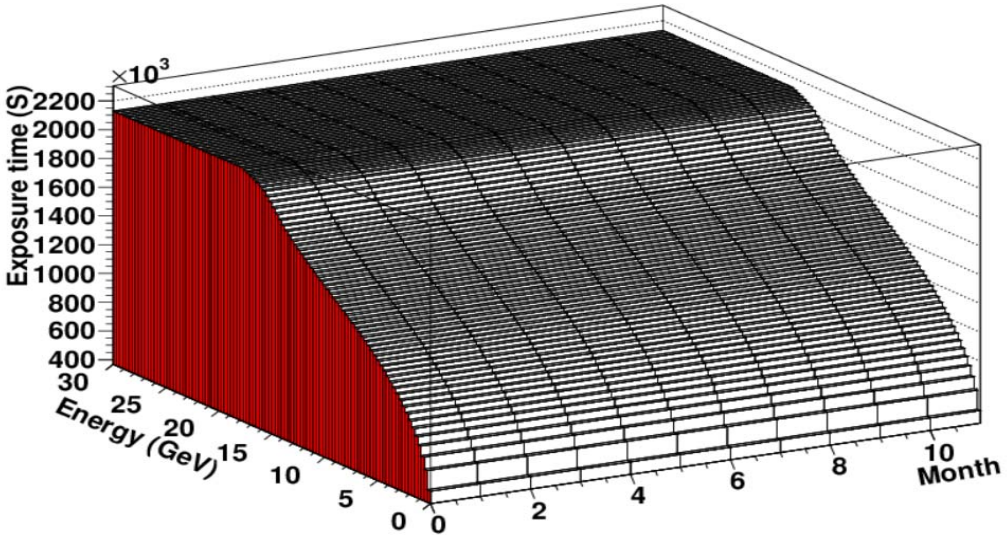
N: number of events selected
G: Geometric factor
ε : Select efficiency
ΔE : Energy bin width
T : Exposure time

Long term calibration and correction applied to the detector

Exposure Time



McIlwain parameter in DAMPE orbit



Exposure time for different energy

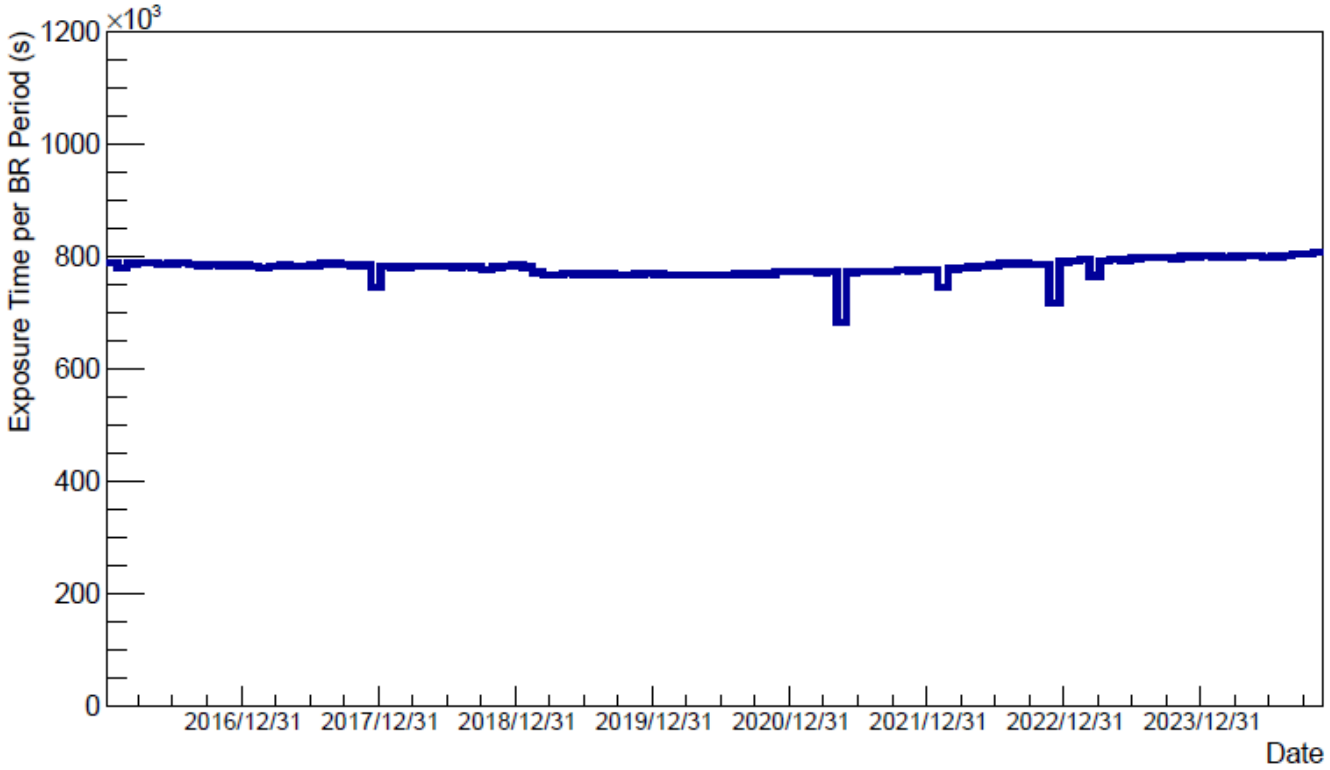
Vertical cutoff: $R_{\perp} = 14.5 / L^2$, L: McIlwain parameter

Remove secondary CR by require:

$\rho > 1.2\ R_{\perp}$: Particle with rigidity 1.2 times larger than local cut-off rigidity

SAA , dead time of DAQ, calibration time excluded

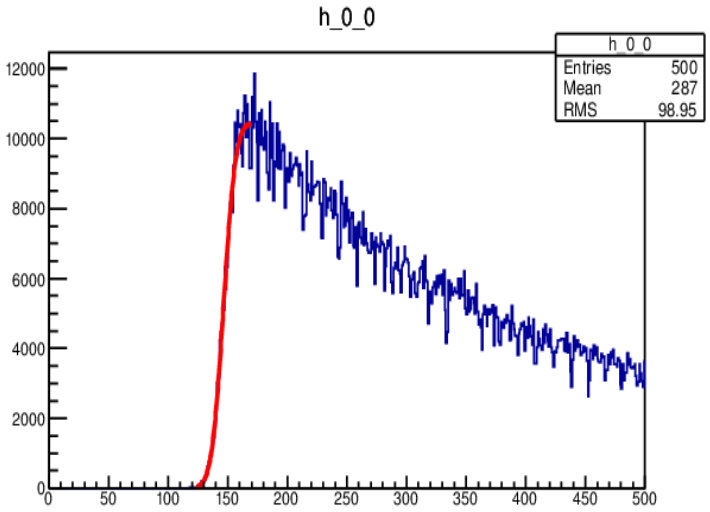
Exposure Time Variation



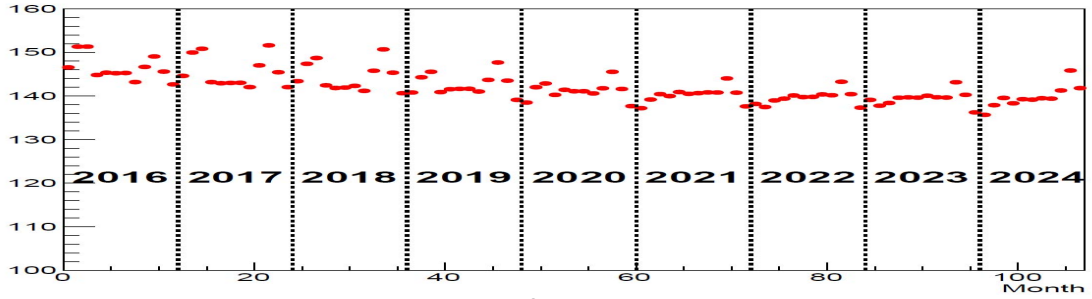
Integrated exposure time of 3-4 GeV electrons in Bartels rotation period (27 days)

From 2016.1 to 2024.11. totally 120 Bartels rotation periods
The detector works continuously except for some maintenance time

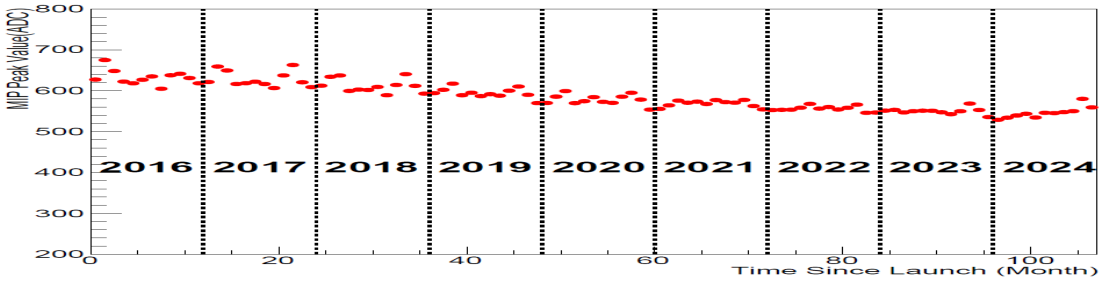
Trigger Efficiency



Trigger threshold calibration



Long term variation of trigger threshold, unit: ADC

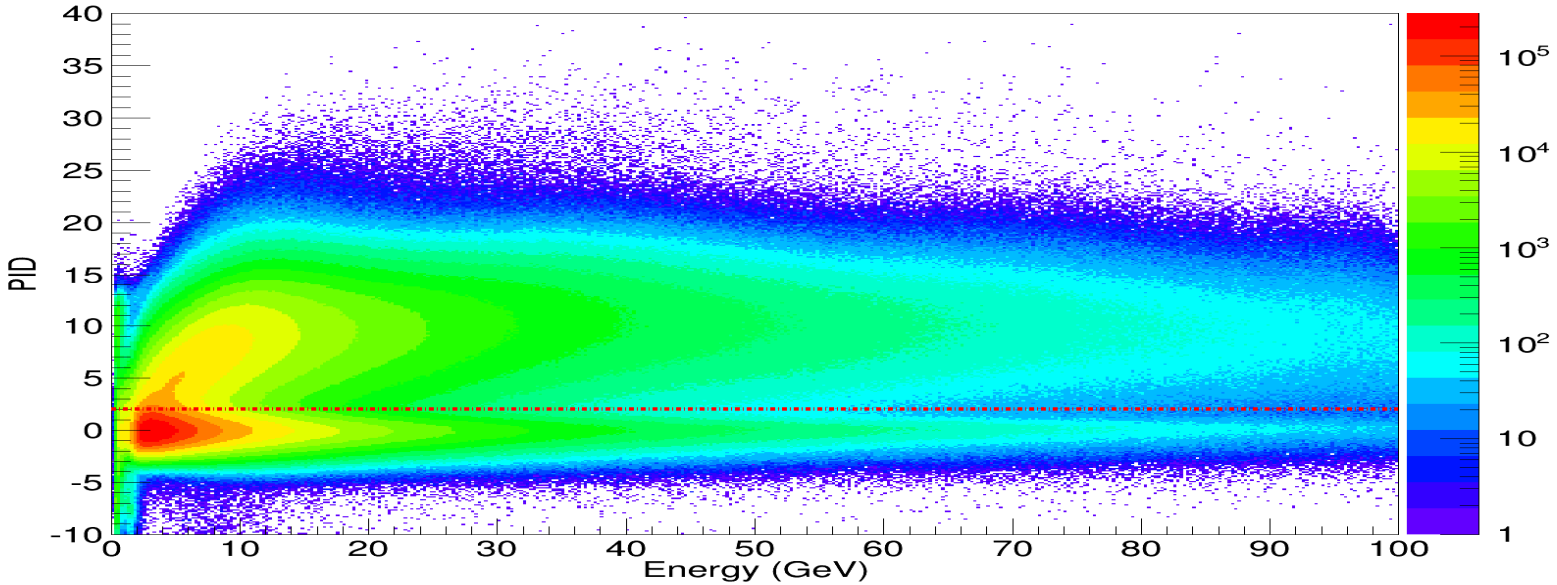


MIPs peak position, unit (ADC)

W.Li et,al, NIM. A 1069(2024) 169815

Trigger Threshold precisely calibrated every day since launch
Trigger Efficiency calculated using MC events and calibrated parameter
Trigger Efficiency keeps on a stable level with little correction.

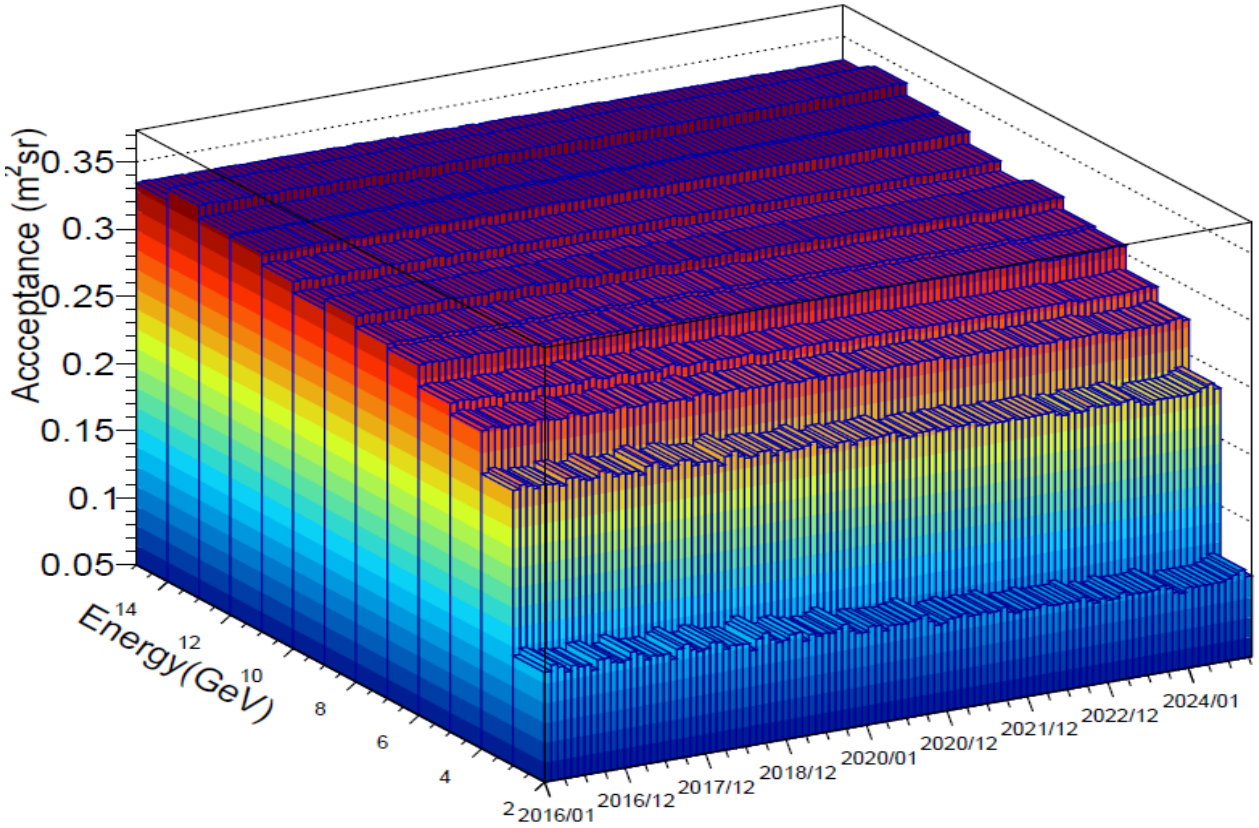
Event Selection



$$\mathrm{PID}=\mathrm{F}(\mathrm{E})\left[\log(\mathrm{rmsr})\sin(\theta)+\log(rmsl)\cos(\theta)\right]$$

Track and its extend line should penetrate the detector, not on edge.
Using calorimeter shower shape parameter to separate leptons from protons.
Using energy deposit in PSD to identify charge number.

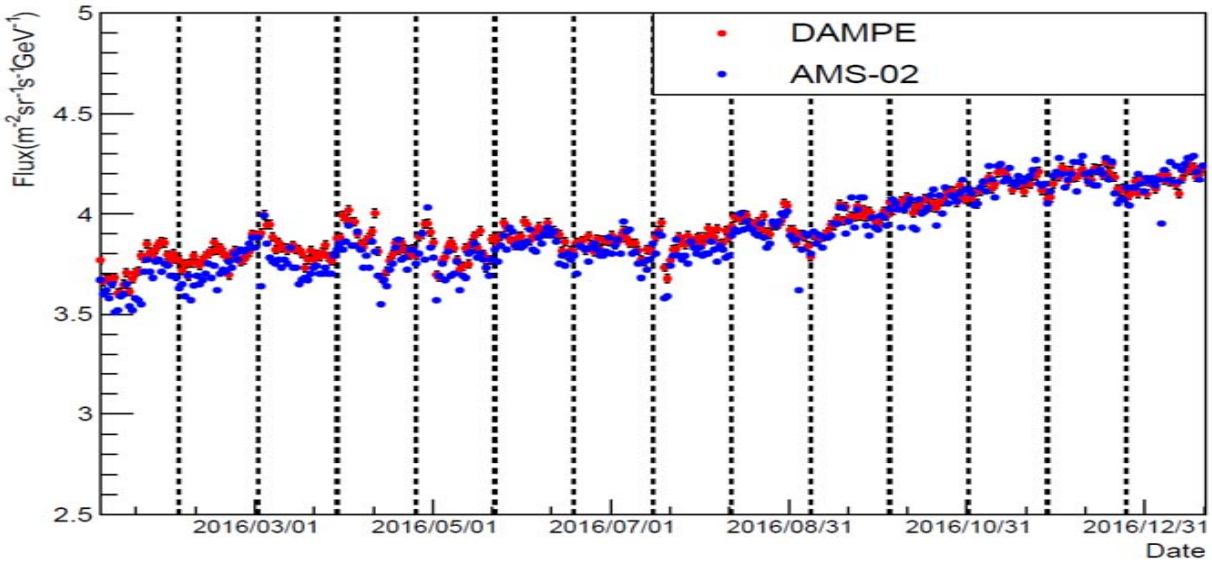
Detector Acceptance



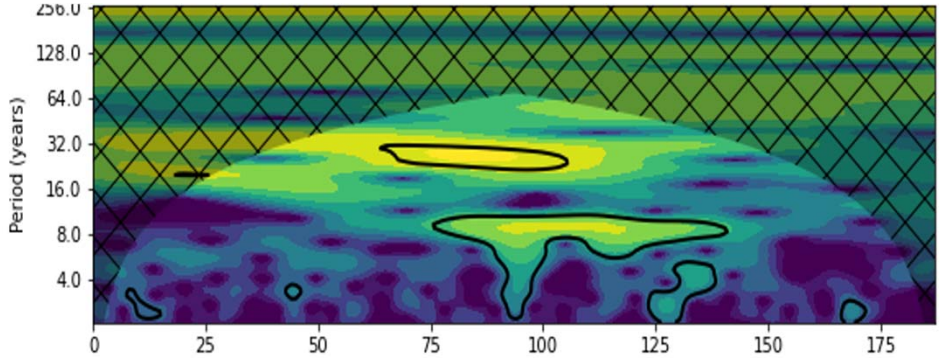
Acceptance: product of the geometry factor and selection efficiency
Acceptance keeps stable for 9 year's operation

Evolution of Daily Electron Flux in 2016

AMS-02 result (PRL. 130. 161001)



Wavelet analysis applied to find the possible variation period



2016.1-2016.7

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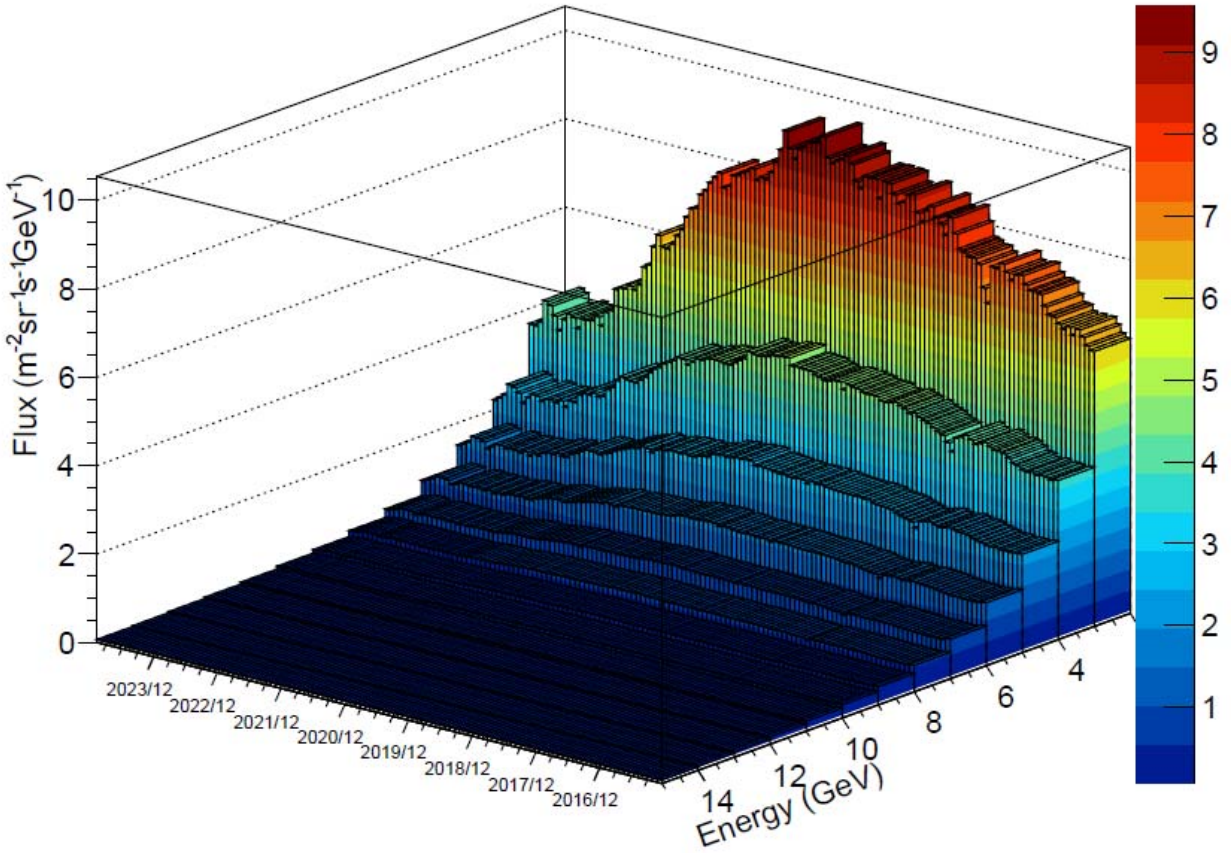
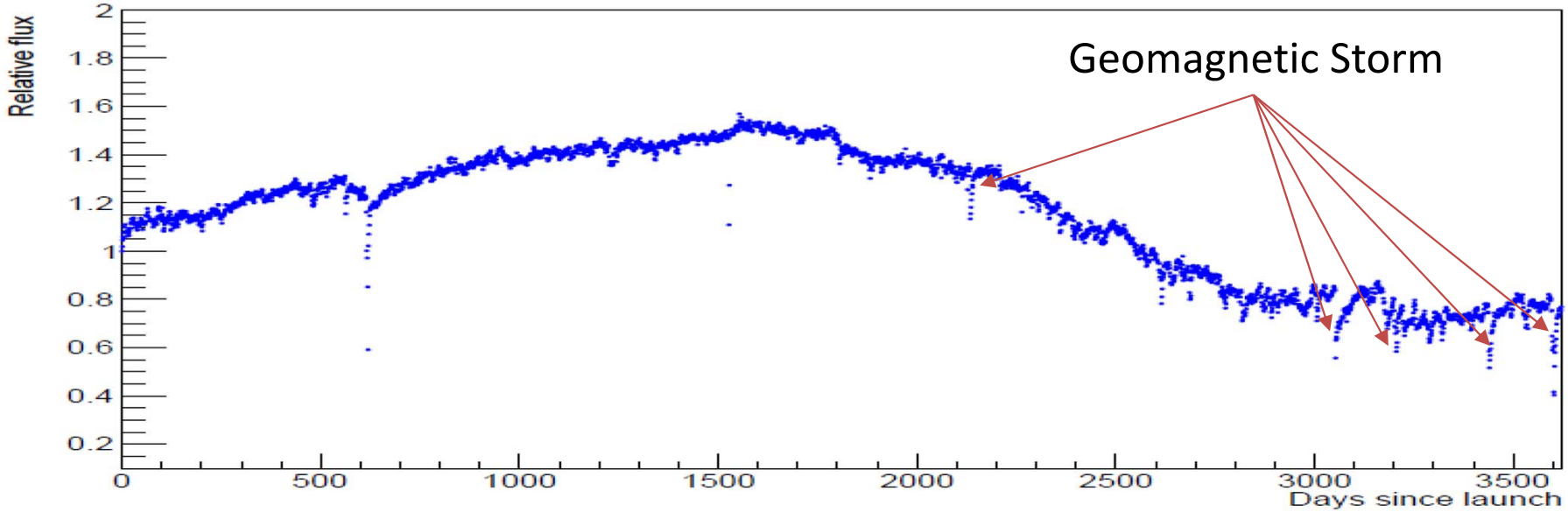
Evolution of Electron Flux in 9 years

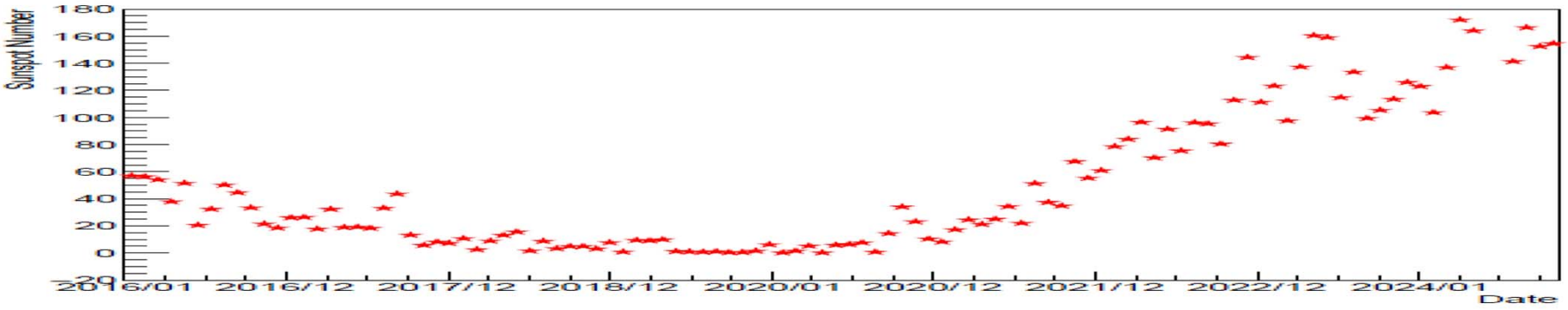


Primary CR electron (positron) flux in 2-15 GeV, from Jan, 2016 to Nov, 2024

Electron Flux and the Solar Activity



Relative CR electron (positron) flux 2016-2025 (3-4 GeV)



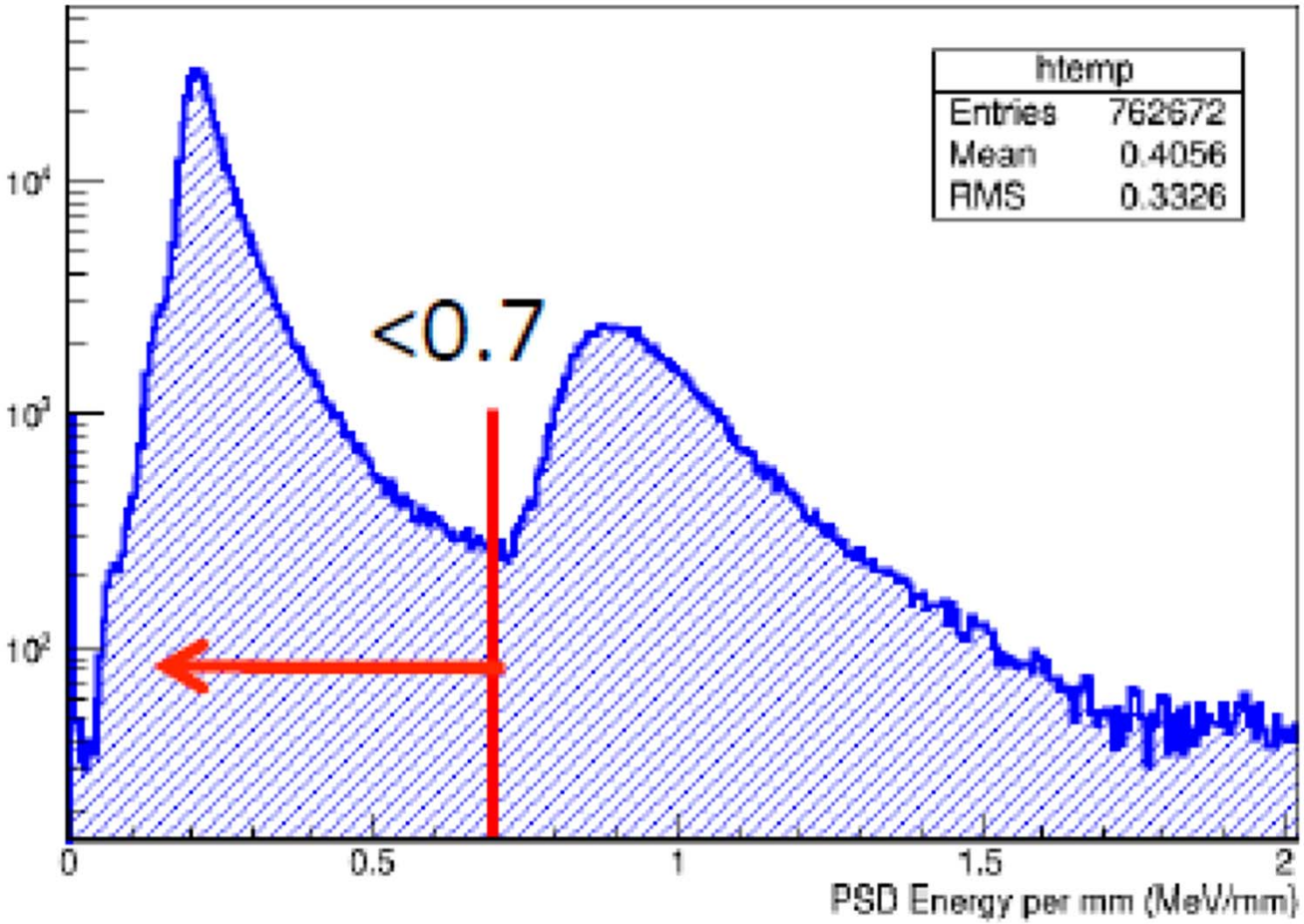
Monthly sunspot number

Source: WDC-SILSO, Royal Observatory of Belgium, Brussels,
DOI: https://doi.org/10.24414/qnza-ac80

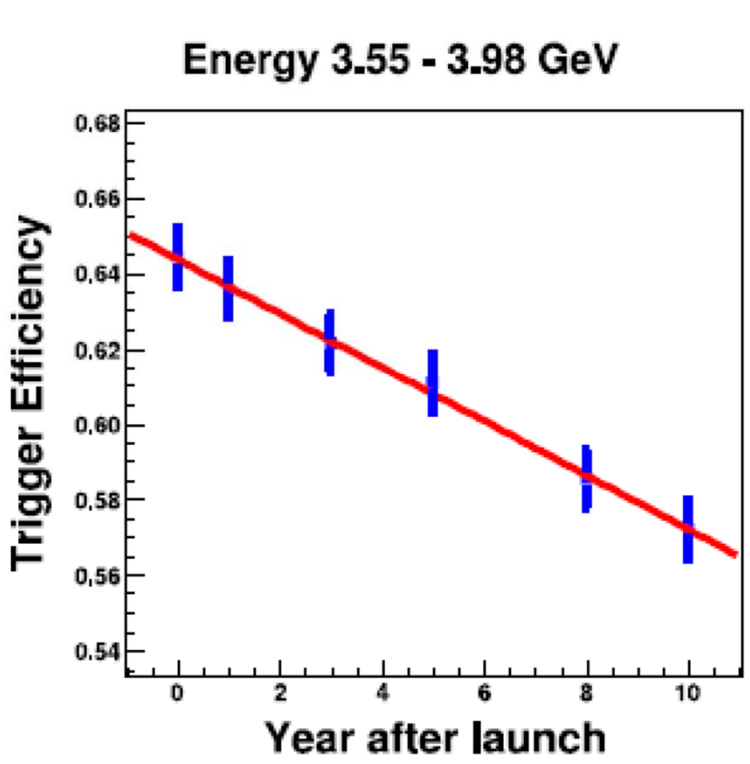
Summary

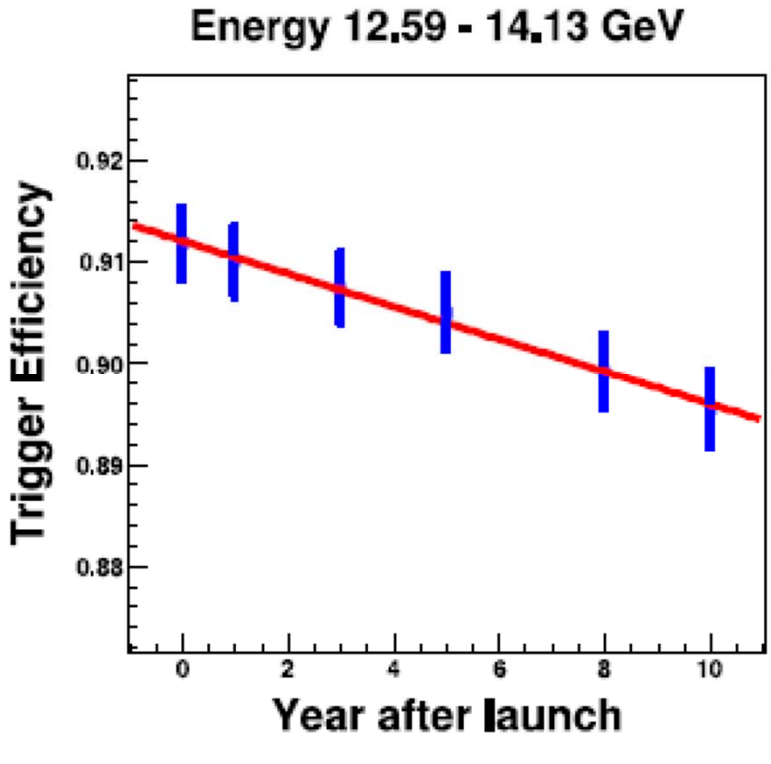
- The DAMPE detector operates in good state since launch, the trigger efficiency keeps in a stable level.
- The primary CR electron (positron) measurement result shows a time structure of 27-day, which is related to the rotation of sun.
- The measured flux shows an anti-correlation with sunspot number, verifying the flux is modulated by solar activity.

Back up



Energy deposit per pathlength in PSD


Energy 3.55 - 3.98 GeV
Trigger Efficiency
0.68
0.66
0.64
0.62
0.60
0.58
0.56
0.54
0
2
4
6
8
10
Year after launch


Energy 12.59 - 14.13 GeV
Trigger Efficiency
0.92
0.91
0.90
0.89
0.88
0
2
4
6
8
10
Year after launch