Diverse properties of Forbush decreases of electrons and positrons revealed by the DAMPE

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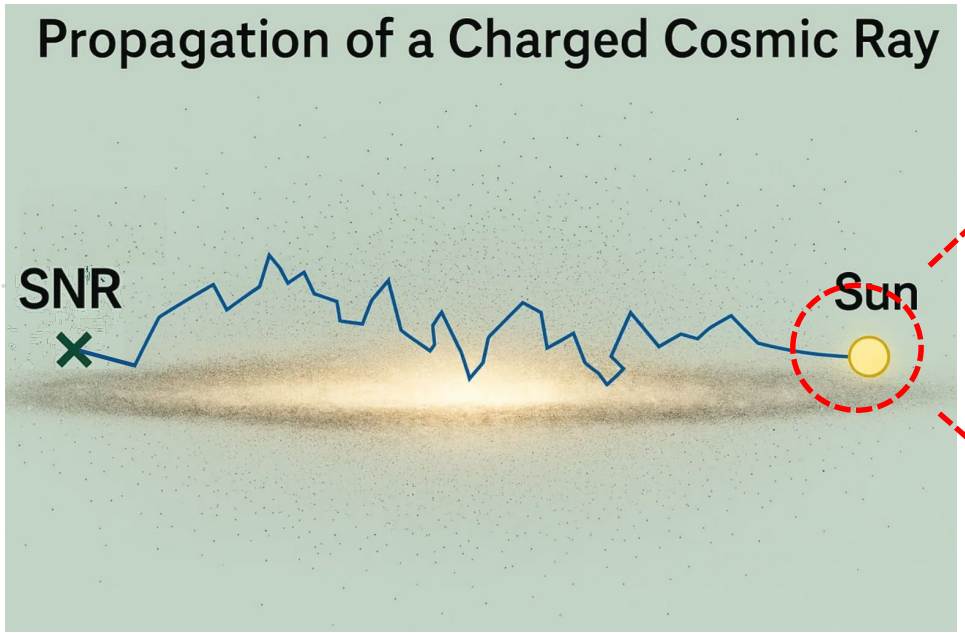
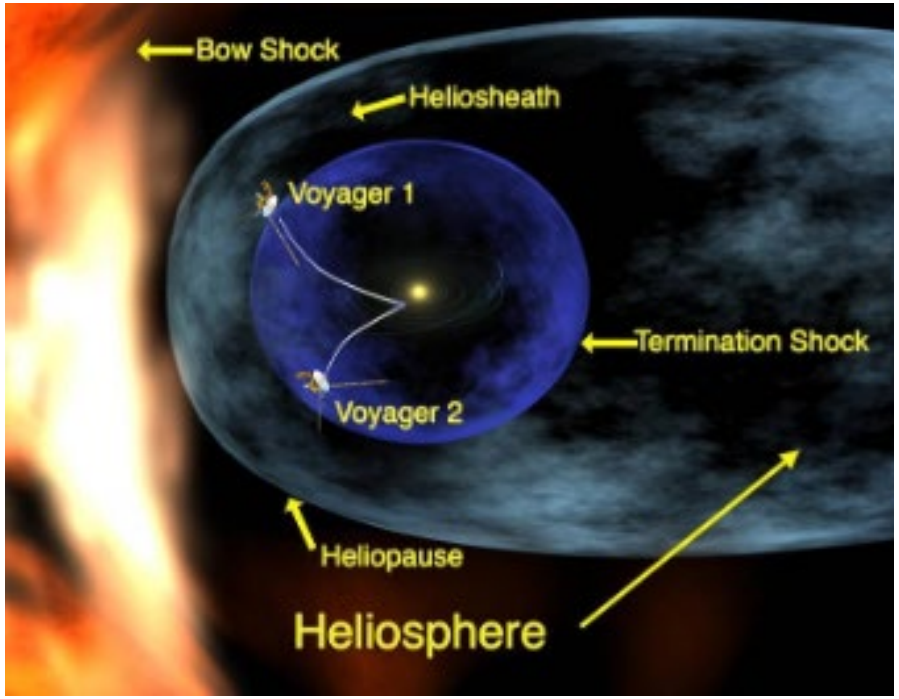
On behalf of the DAMPE Collaboration

18 Dec 2025

BackGround



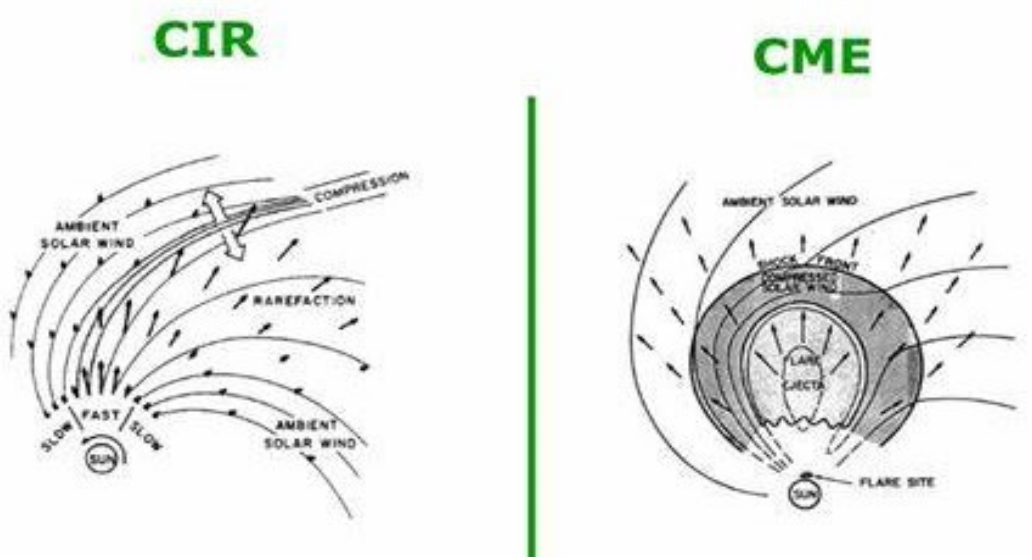
Credit: Sora

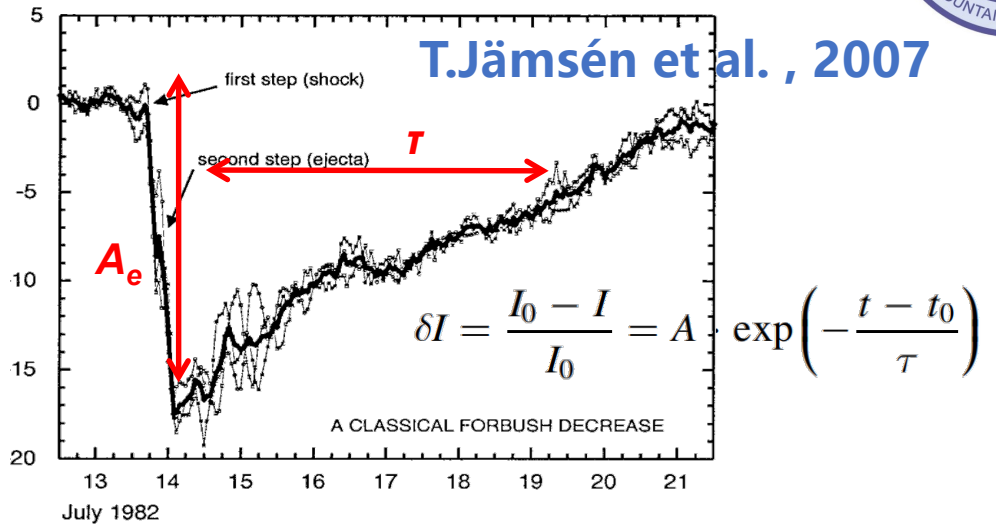


Credit: NASA

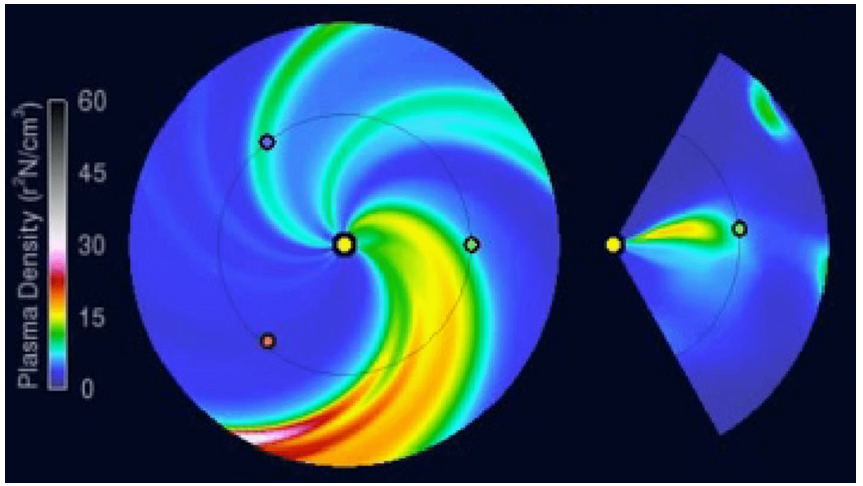
- Cosmic ray propogation: galatic propogation and solar modulations
- Structure of the heliospere： TS, HP and the BW

Introduction on FD (Forbush Decrease)



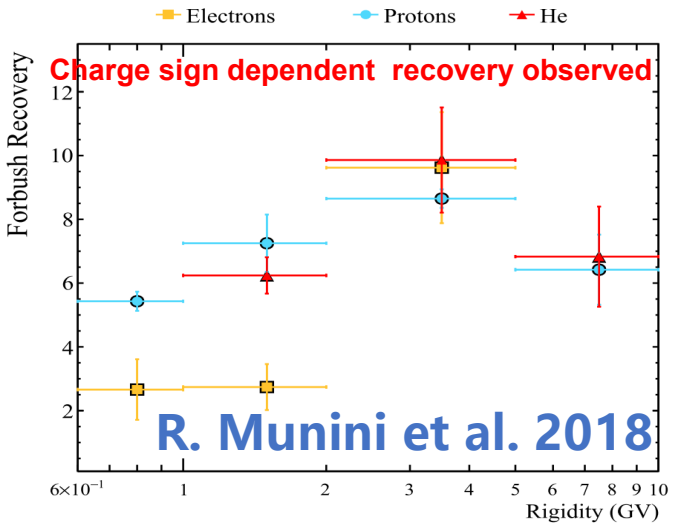


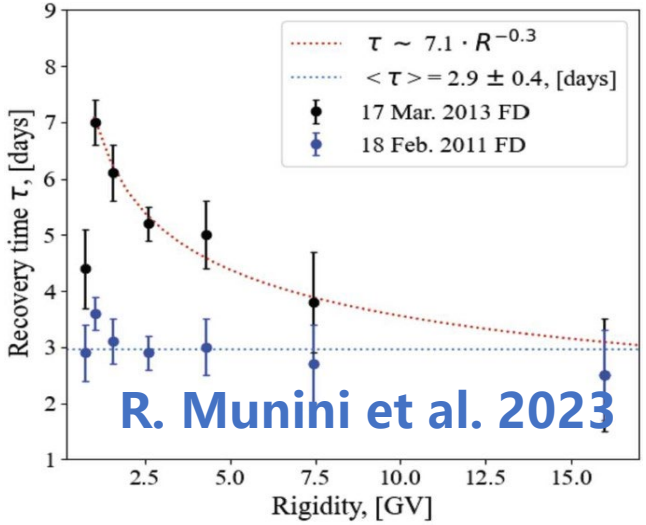
- Long/short period modulations
- Corotating Interaction Region (CIR) and Coronal Mass Ejection (CME) causes FD
- FD is a tool to diagnose the propagation of GCRs within heliosphere.

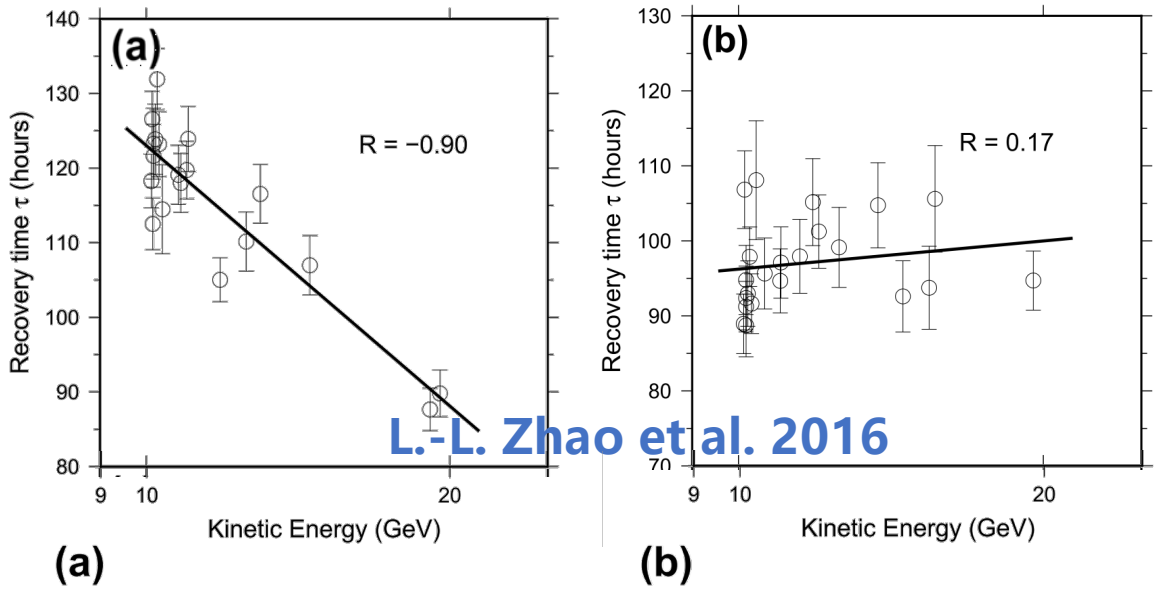


- **WSA 2017.09.08 (arrival) CME**

Introduction on FD







- PAMELA reports FD profiles for different particles(2018) and different FD recovery time profile (2023)
- Zhao et al. gives assumptions on energy dependence of the recovery time

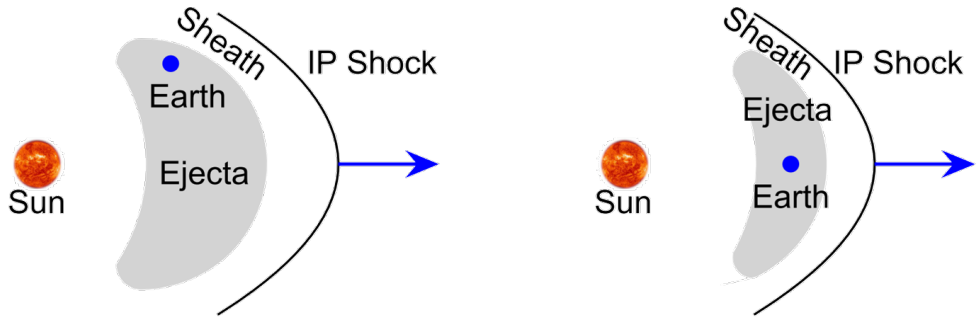
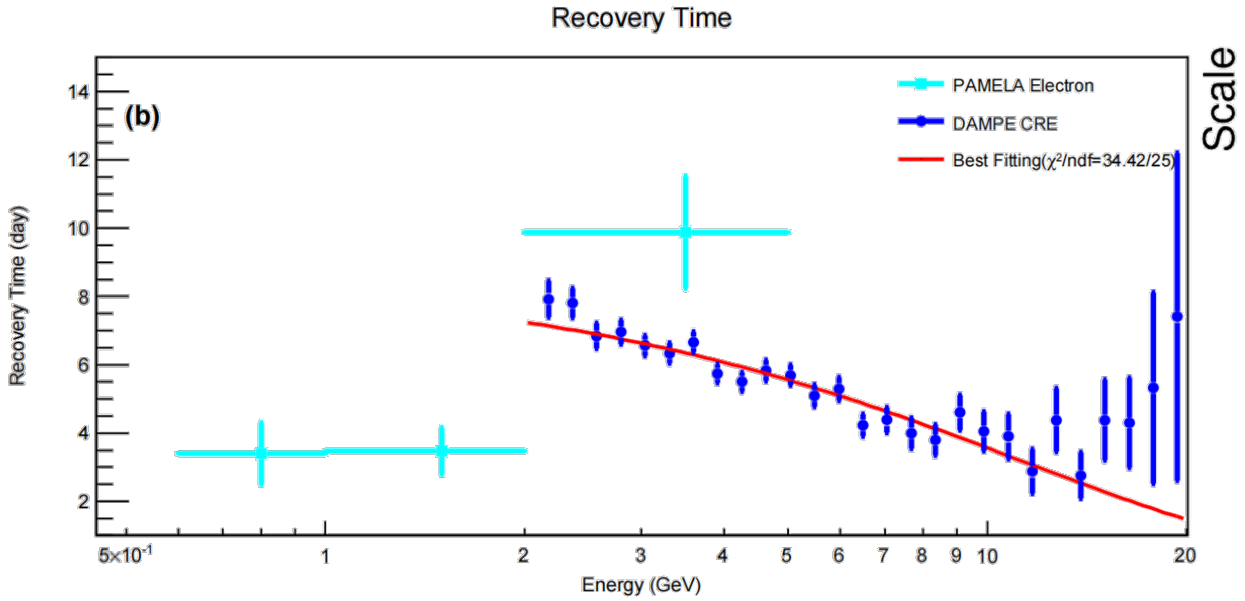
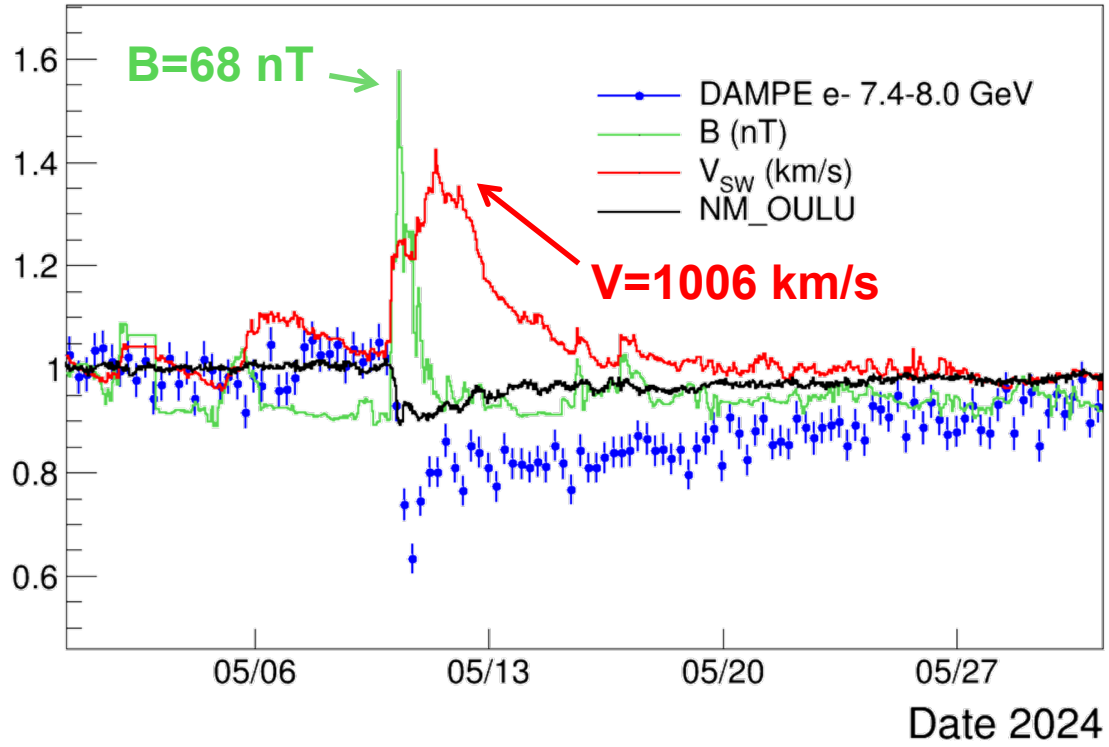


Figure 9. Schematic diagram (not to scale) explaining (a) Event 1 and (b) Event 2.

Introduction on FD



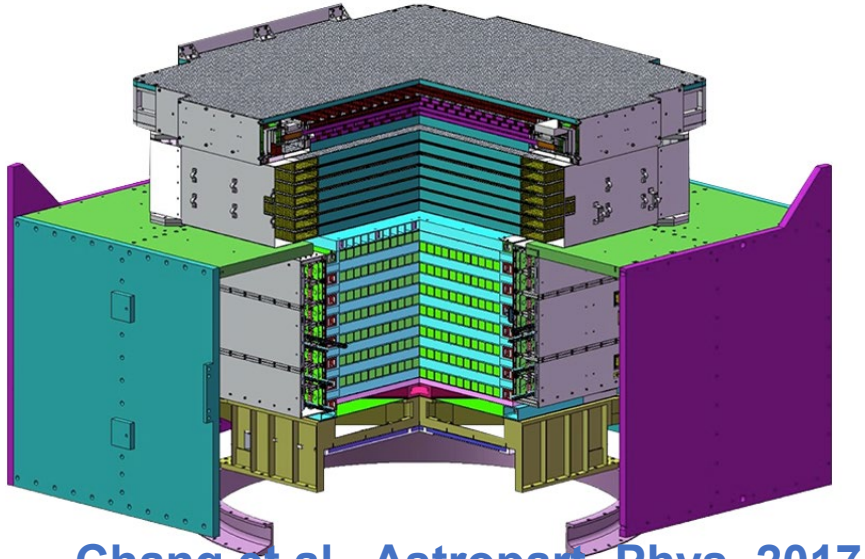
DAMPE collaboration, 2021, ApJL



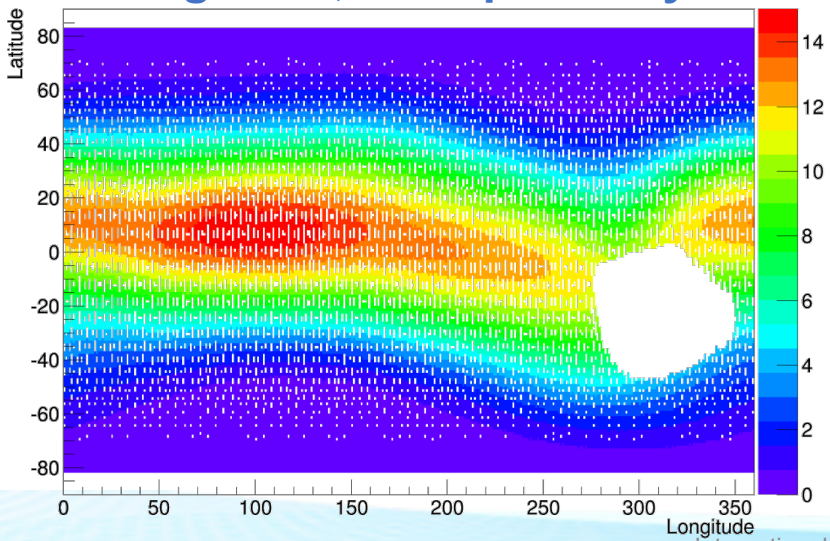
- Data analysis methods of this work is based on the 2021 paper
- Strong energy-correlated recovery time

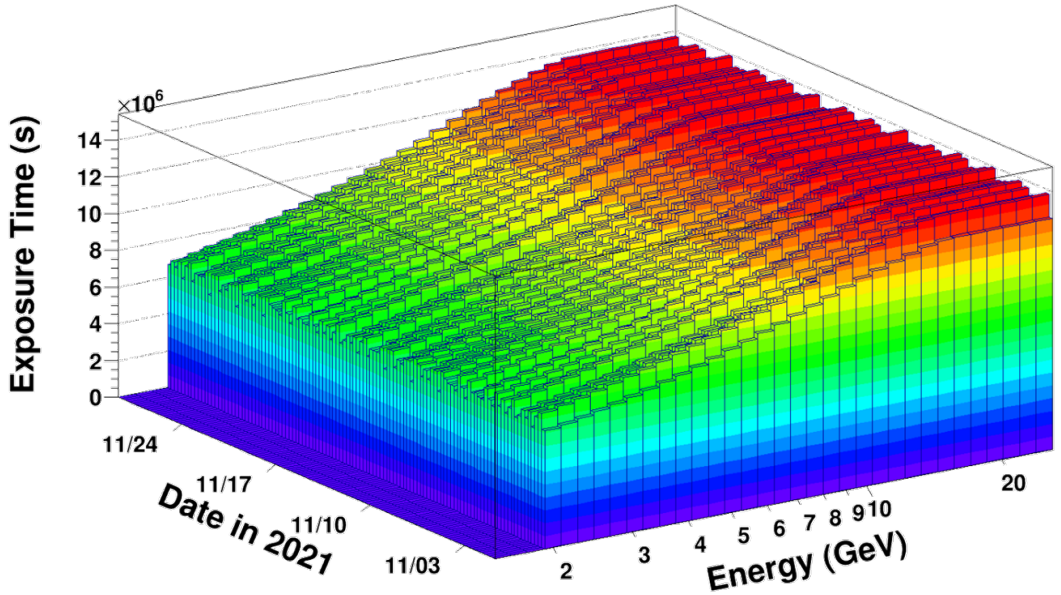
- Event search: NMs , DAMPE-T0, OMNIweb
- Time range: 2016.01-2024.05, 8 FDs in total confirmed

FD analysis: DAMPE observations



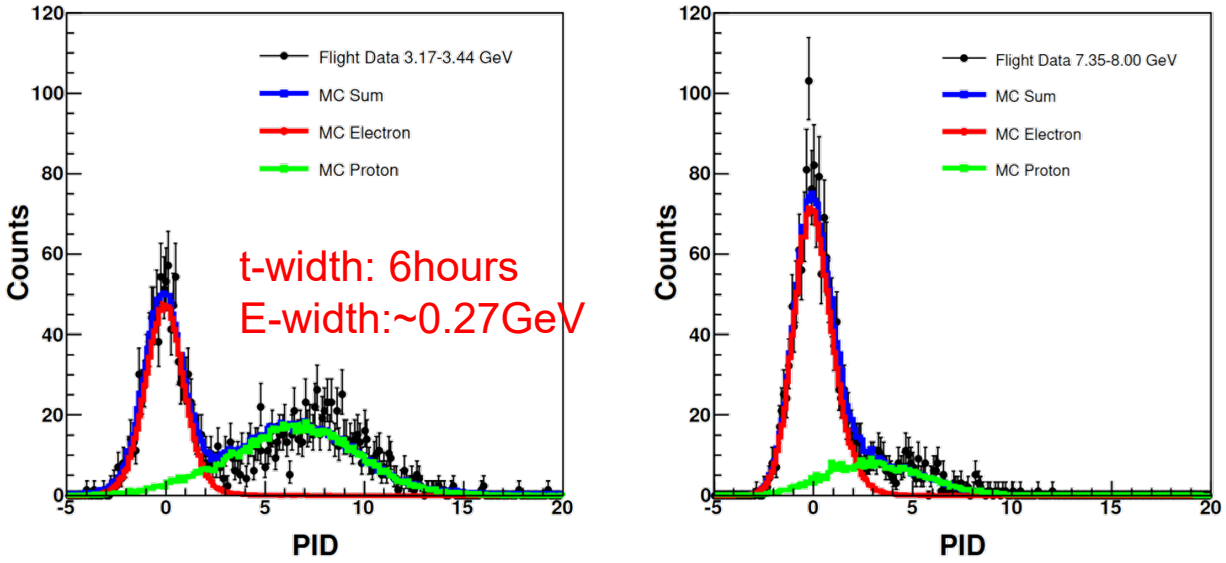
Chang et al., Astropart. Phys. 2017





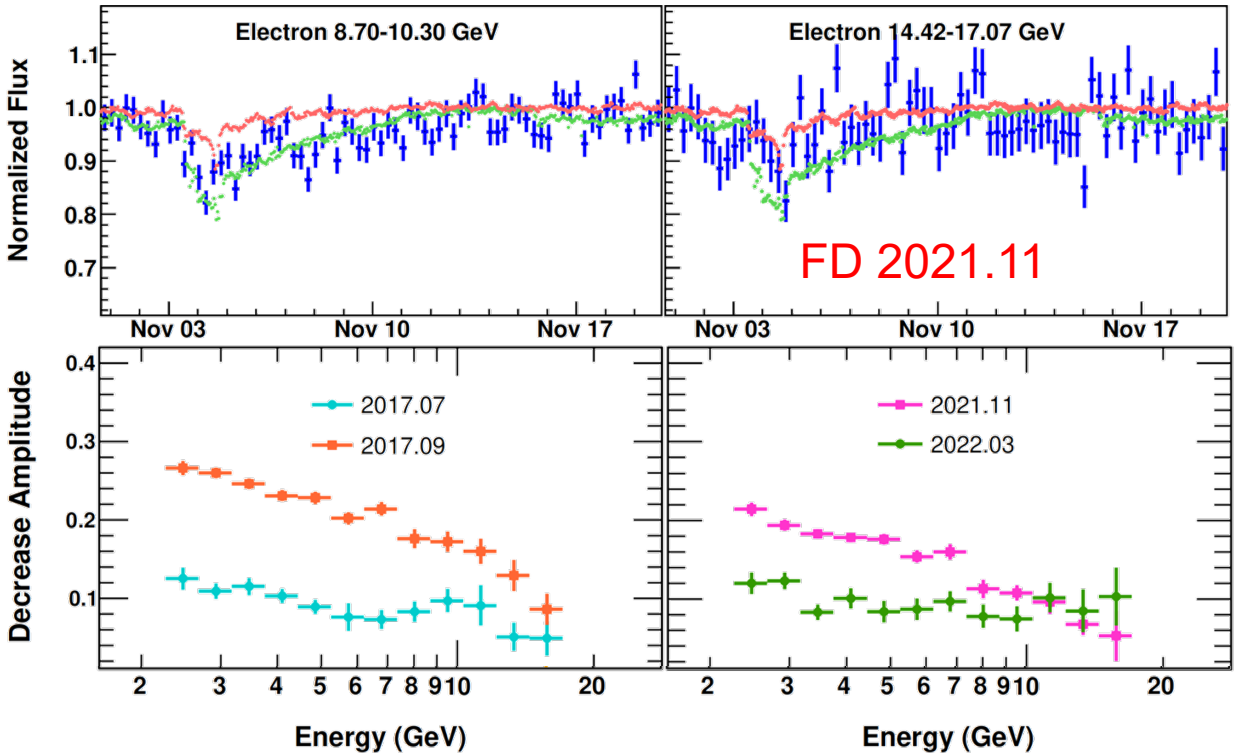
- VRC of DAMPE satellite orbit (GV)
- Dead time from T0 ,DAQ & Trigger
- Divider 8 and 64 are separately calculated
- T0 & 2A satisfication

FD analysis: DAMPE observations



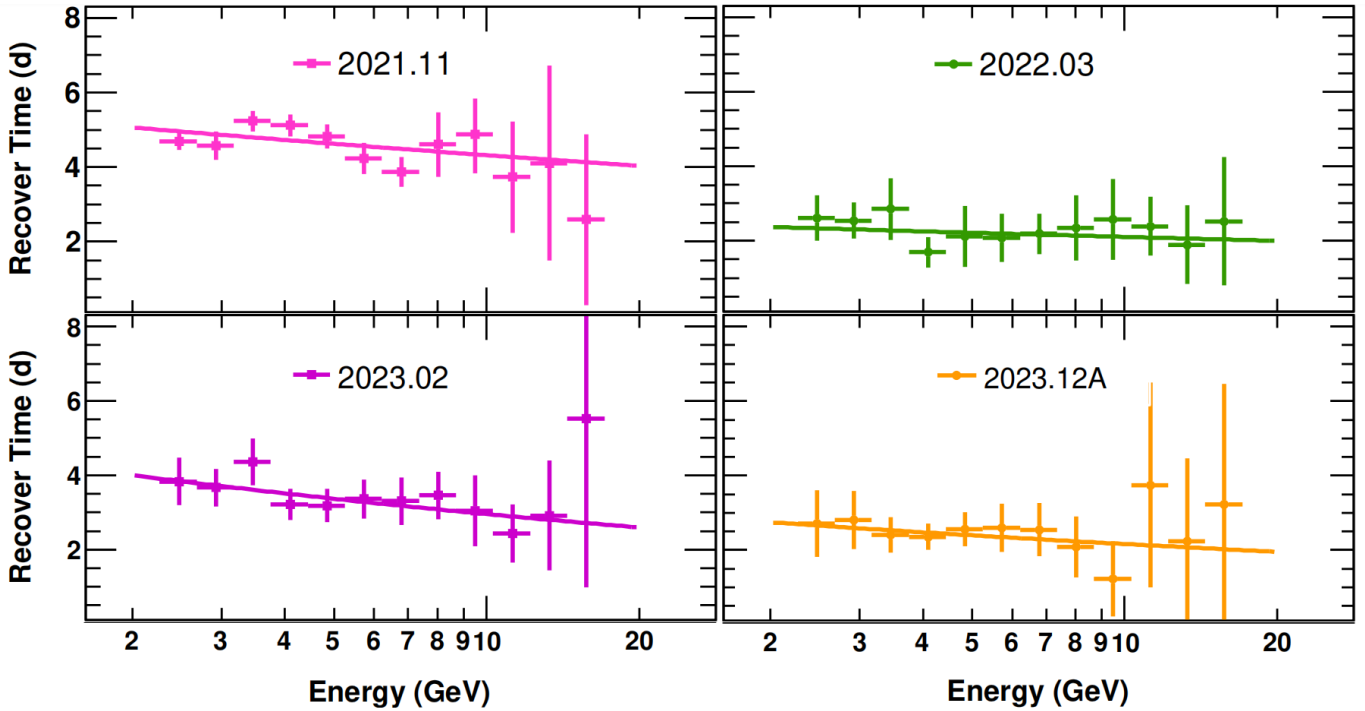
$$\mathrm{PID}=\mathrm{F}(\mathrm{E})\left[\log(\mathrm{rmsr})\sin(\theta)+\log(rmsl)\cos(\theta)\right]$$

- Shower Max not Edge
- Fiducial: Track within top 4 layers
- Track cross PSD & PSD charge cut
- E> 1.2*Vertical rigidity cutoff



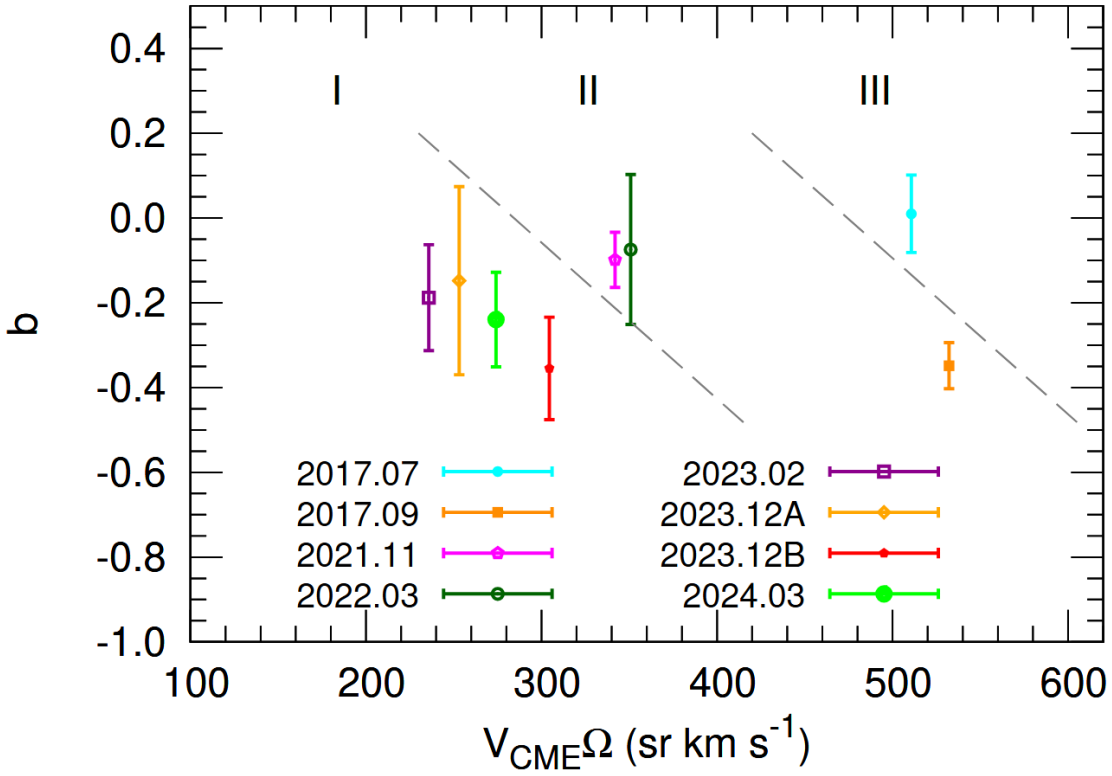
- Rebin in energy dimension after the template fit
- The decrease amplitude shows energy-dependent property.

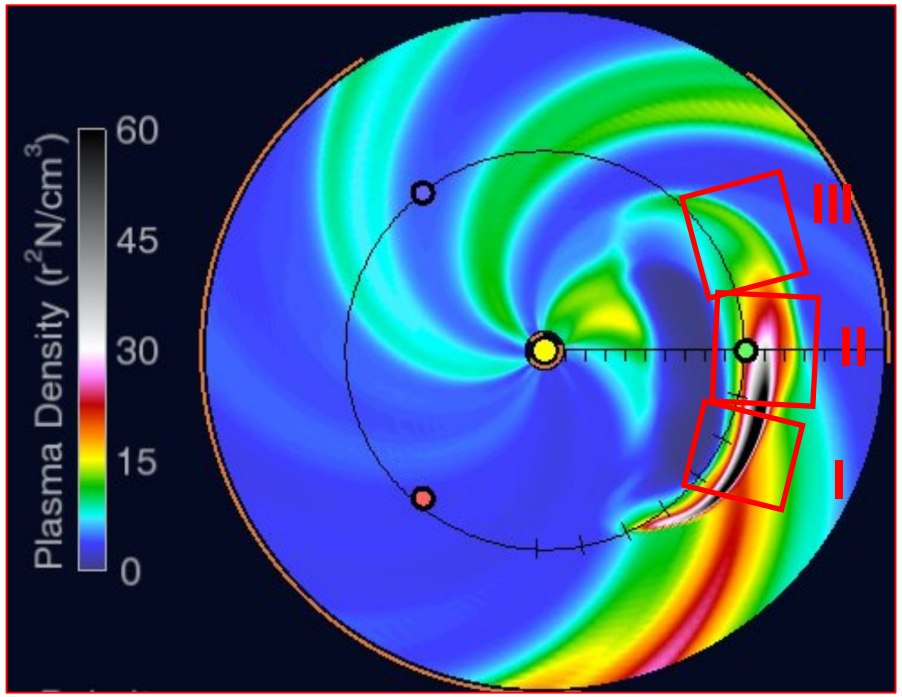
FD analysis: DAMPE observations



- **Recovery time:** $\tau = a \cdot E^b$
- **Energy range: 2.2 GeV - 17 GeV to lower the statistic errors**

FD analysis: DAMPE observations





Credit: WSA_ENLIL, 2017-09FD

- The FDs are divided into head-on(I) events, glancing(II) events, and edge-on(III) events

FD analysis: simulations

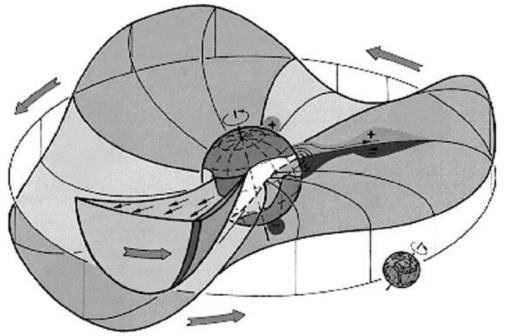
A. Stochastic Differential Equation (SDE)

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

Advection Drift Diffusion Adiabatic Energy loss

B. Heliospheric Current Sheet (HCS)

$$\boldsymbol{B}(r,\theta) = \frac{A}{r^2}\left(\hat{e_r} - \frac{r\Omega \sin\theta}{V_{\rm sw}}\hat{e_\phi}\right)[1 - 2H(\theta - \theta_{\rm cs})],$$

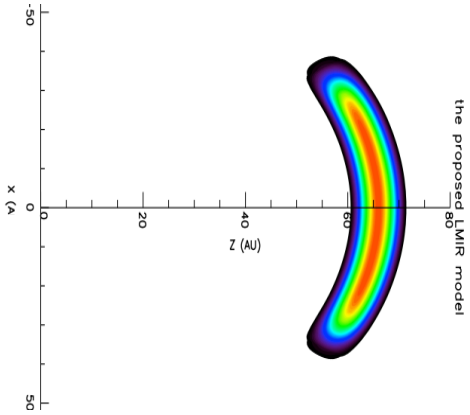


C.Propagating Diffusion Barriers (PDB)

$$\kappa'_{\parallel,\perp,T} = \frac{\kappa_{\parallel,\perp,T}}{[1 + \rho h(\theta) f(r) g(\phi)]}.$$

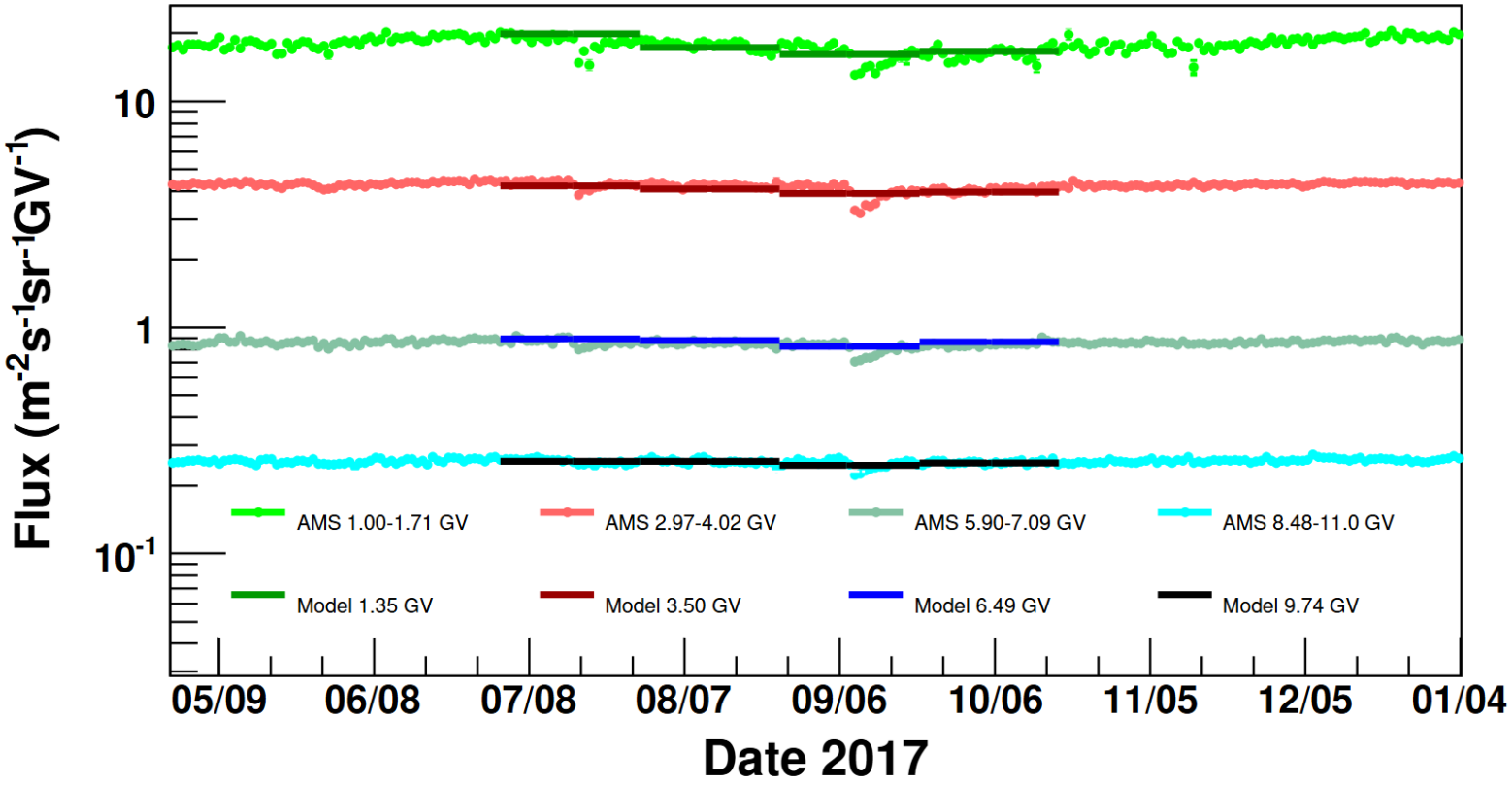
$$\begin{cases} h(\theta) = e^{-\left(\frac{\theta-\pi/2}{\theta_{\rm br}}\right)^{10}}, \\ g(\phi) = e^{-\left(\frac{\phi}{\phi_{\rm br}}\right)^{10}}. \end{cases}$$

$$f(r) = \begin{cases} 1 - \frac{r - r_{\rm cen}}{r_a} & \text{if } r_{\rm cen} < r < r_{\rm sh} \\ \frac{r - r_{\rm end}}{r_b} & \text{if } r_{\rm end} < r \leqslant r_{\rm cen}, \end{cases}$$



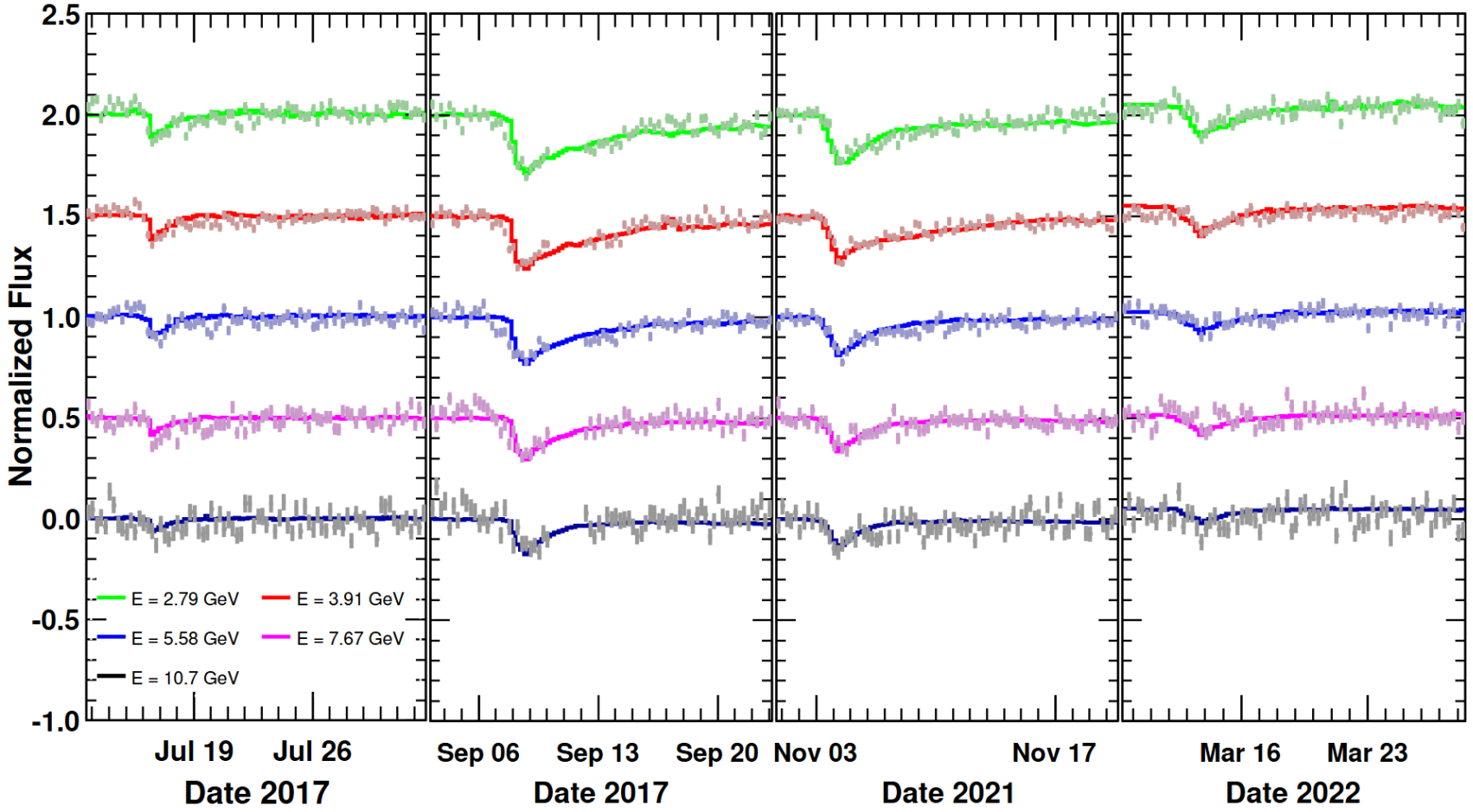
- Numerical simulation of CRs
- Code from Luo et al. 2017 ,ApJ

FD analysis: simulations

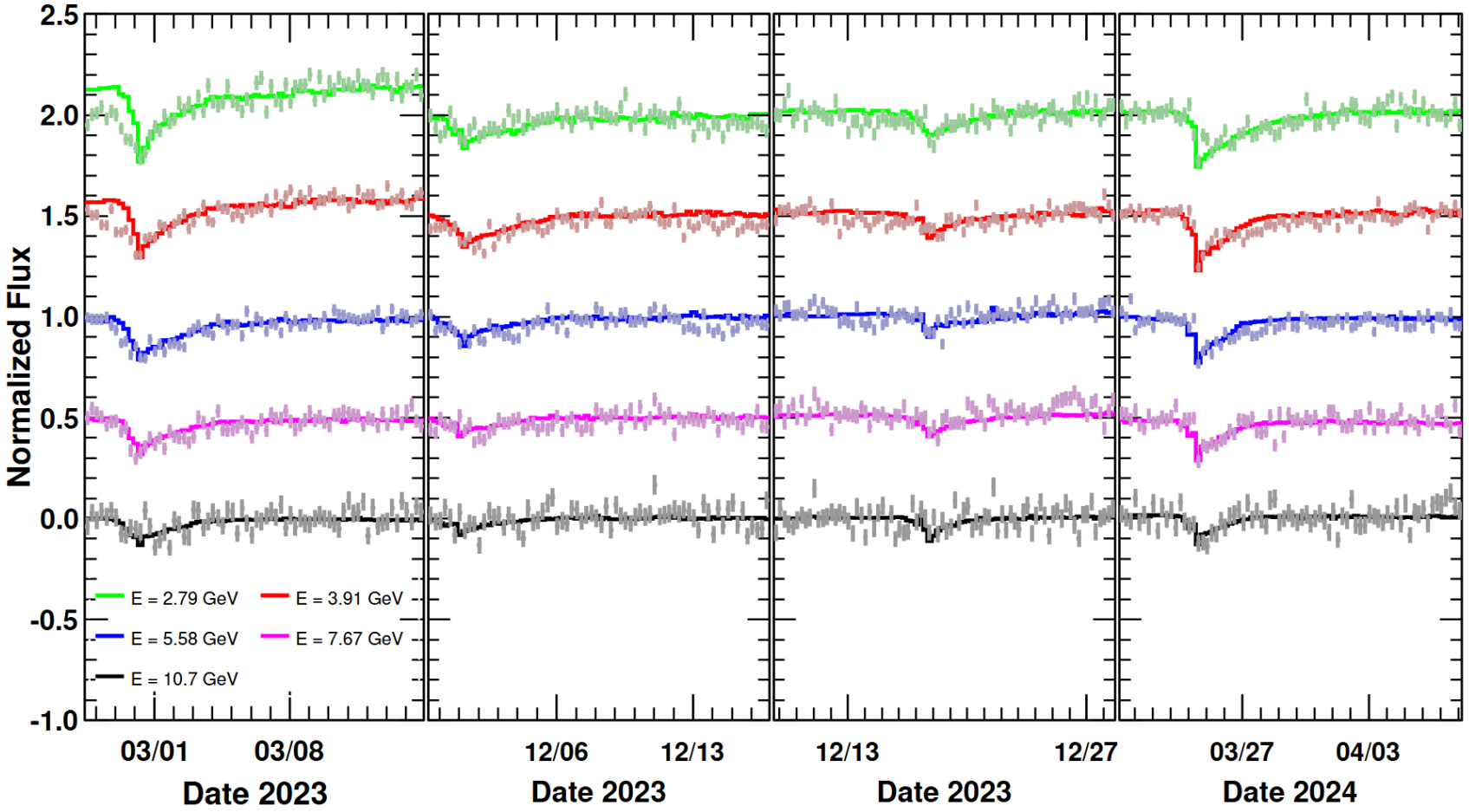


- The FD is short-period solar modulation based on the long-period modulation
- Long-period modulation : extract from AMS-02 electron daily flux

FD analysis:Simulations

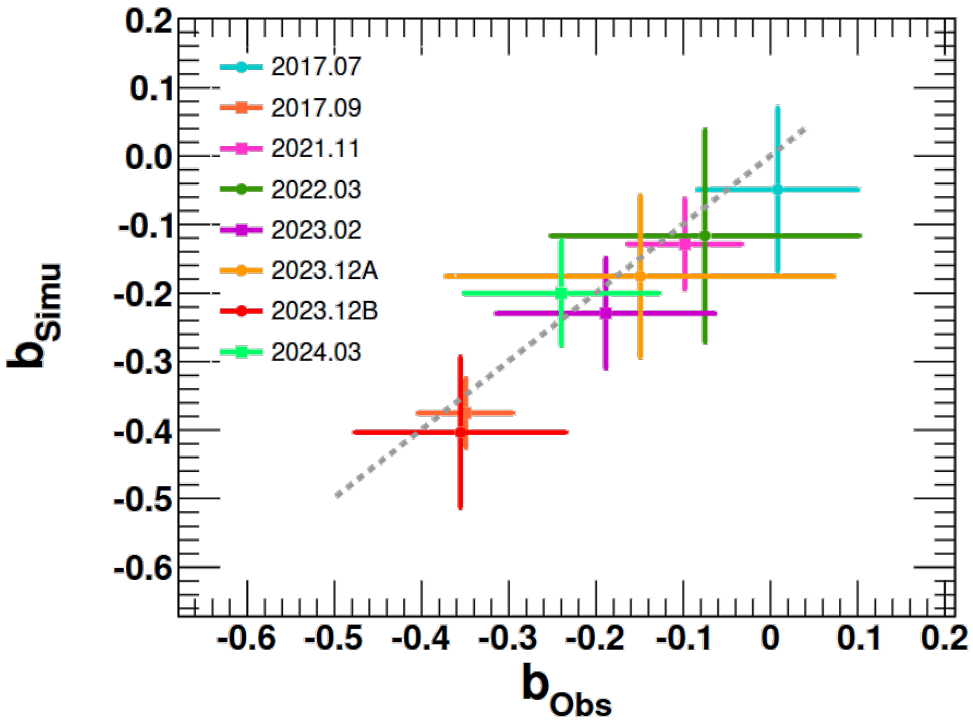


FD analysis:Simulations



FD analysis: simulations

DAMPE CRE Observations				CME Parameters	
Time (UTC)	A_e^{max}	τ	b	V_{ord} (km s^{-1})	$\Theta(^\circ)$
2017-07-17 04:30	0.125	2.03	0.010	1199	57
2017-09-08 13:30	0.266	6.46	−0.348	1611	48
2021-11-04 21:30	0.214	4.69	−0.099	1397	41
2022-03-14 19:30	0.123	2.61	−0.074	983	50
2023-02-28 14:30	0.244	3.83	−0.187	1237	36
2023-12-01 18:30	0.137	2.71	−0.148	944	43
2023-12-17 22:30	0.154	4.15	−0.355	921	48
2024-03-24 22:30	0.254	4.49	−0.239	1438	36



- FD parameters from NASA, CME catalog and WSA-ENLIL model
- Comparison of FD recovry time profile and the SDE simulations

Summary

- DAMPE observations of FDs from 2016 to 2024, eight FDs are analyzed
- FDs recover time shows strong energy dependence for large CME events ($V_{Ord}\Omega$)
- The relative positions influences the dependence (blue dashed line)
- The simulation confirm the observations