COSPAR 2024
45th Scientific Assembly
July 13-21 2024, BEXCO, Busan, Korea

Direct Measurement of the Cosmic-Ray Iron Spectrum with the Dark Matter Particle Explorer

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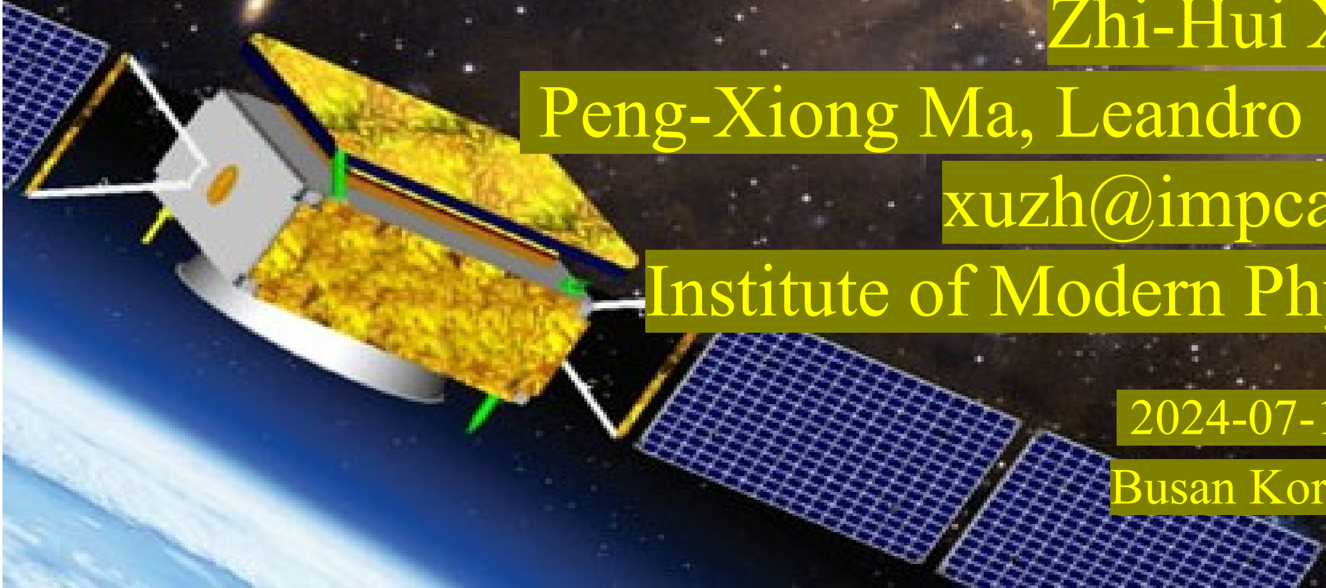


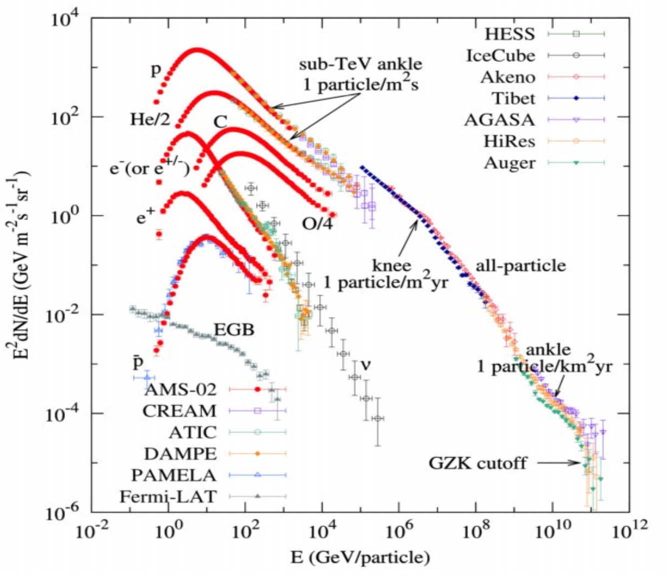
2024-07-14
Busan Korea

Outline

- **Cosmic Ray**
- **Dark Matter Particle Explorer (DAMPE)**
- **Data Used**
- **Preselection**
- **Particle Identify**
- **Spectrum reconstruction**
- **Efficiency calibration and Error analysis**
- **Summary**

Cosmic Ray

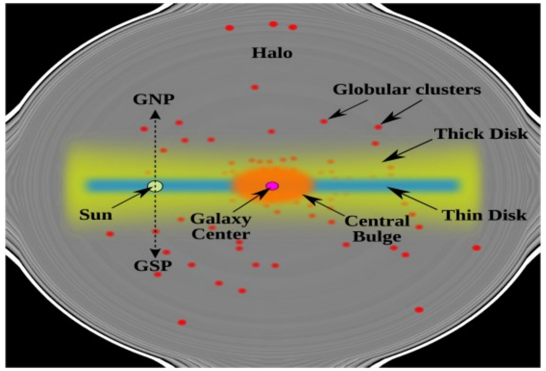
DOI: 10.1088/1674-1137/ac3faa



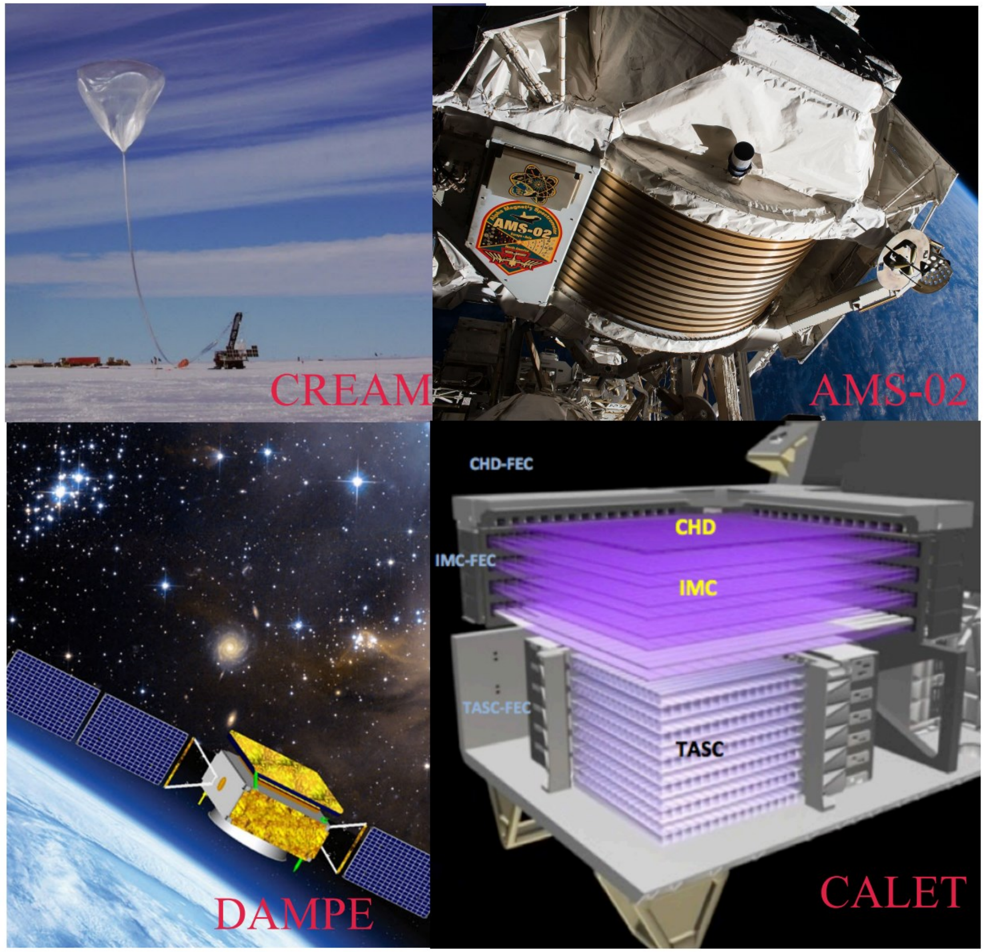
cosmic ray spectrum

- Knee (10^6 GeV/n), Ankle (10^9 GeV/n), GZK cutoff (5×10^{10} GeV/n)
- Spans 12 orders of magnitude in energy. Spans 32 orders of magnitude in flux

~10% of SN explosion energy is sufficient to meet cosmic ray acceleration power: $10^{41}\ erg\ s^{-1}$

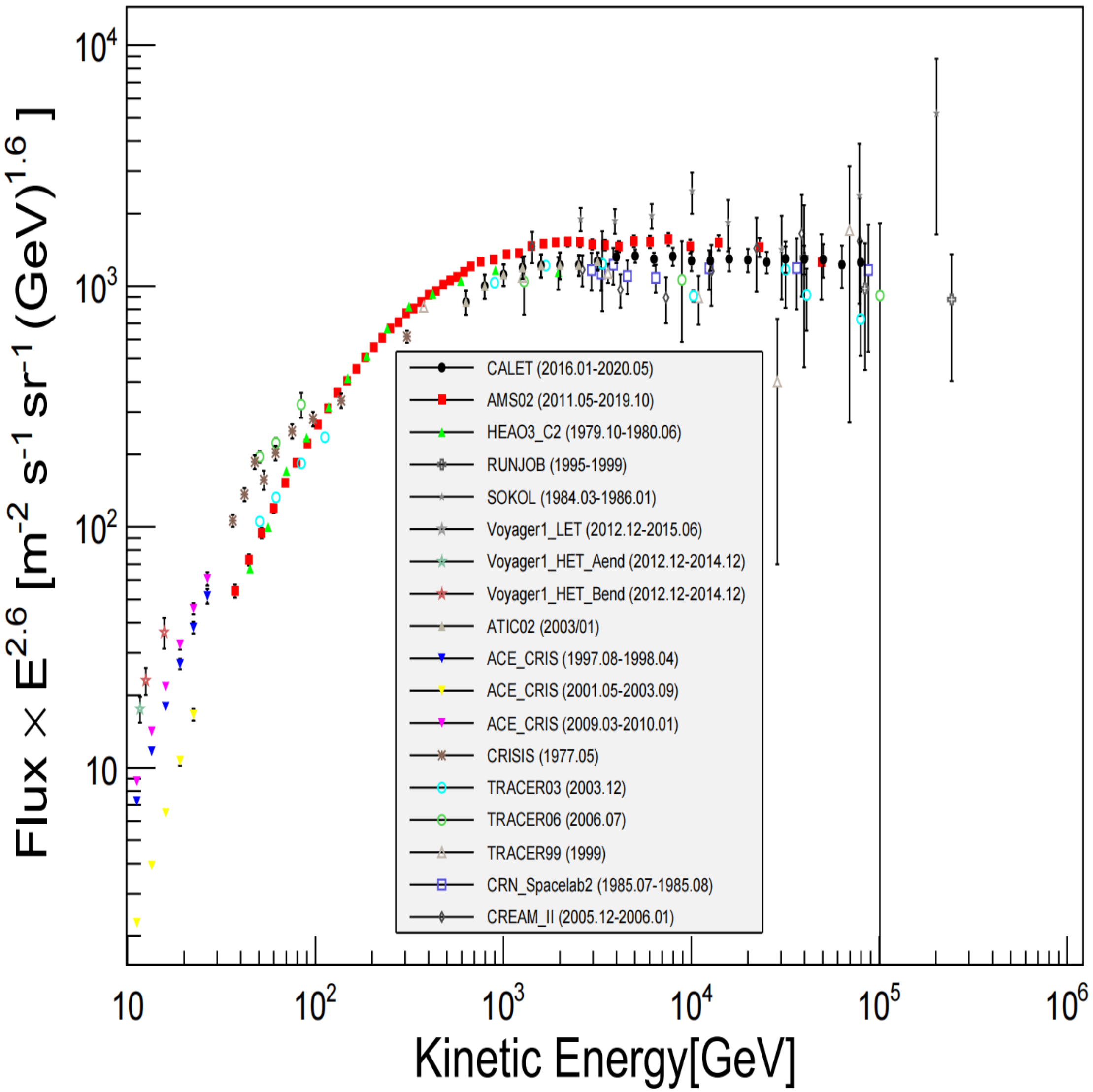


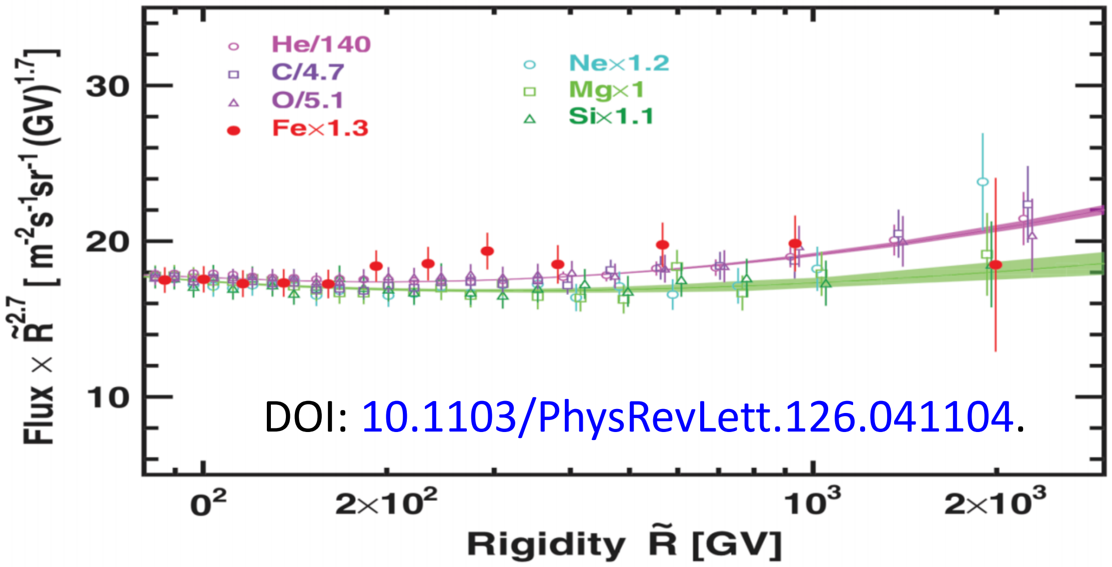
Cosmic ray propagation in galaxy



Cosmic ray detection

Iron Spectrum



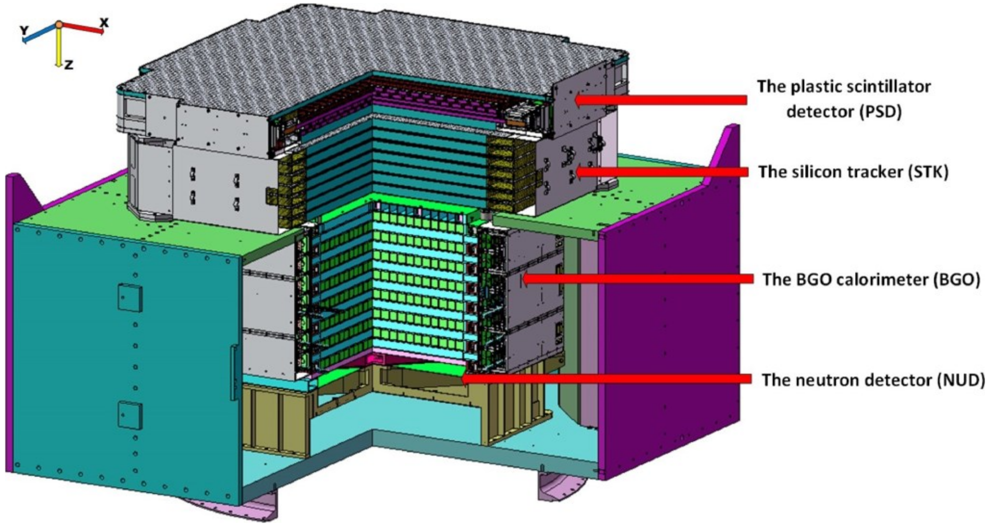


DOI: 10.1103/PhysRevLett.126.041104.

Normalization energy spectrum of primary nuclei

- The overall energy spectrum of CALET is about 20% lower than AMS-02.
- ATIC (FLUKA), CALET(EPICS-DPMJET-III, FLUKA)

Dark Matter Particle Explorer



China`s first space observatory

Lunch time: 2015.12.17

Solar synchronous orbit

Orbit altitude : 500 km

Orbital period : 95 min

DAMPE Main mission

- Dark Matter indirect detection
- Cosmic ray physics
- Gamma ray astronomy
- New physics

DAMPE Collaboration

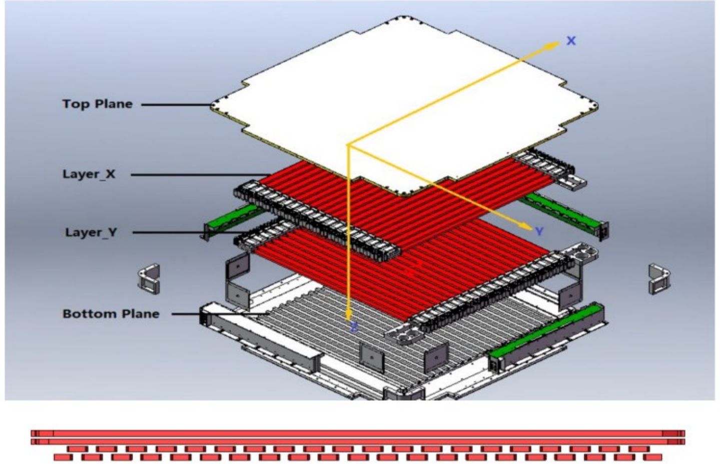
Purple Mountain Observatory, National Space Science Center, Inst. High Energy Physics, Inst. Modern Physics, University of Science and Technology

Geneva University

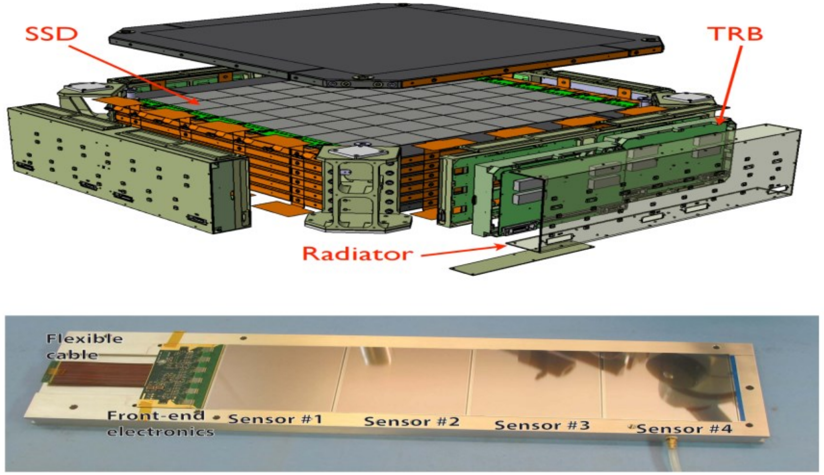
Bari, Lecce, Perugia (Universities and INFN)

Parameter	Value
Energy range of gamma-rays/electrons	5 GeV to 10 TeV
Energy resolution(electron and gamma)	1.5% at 800 GeV
Energy range of protons/heavy nuclei	50 GeV to 500 TeV
Energy resolution of protons	40% at 800 GeV
Eff. area at normal incidence (gamma)	1100 cm^2 at 100 GeV
Geometric factor for electrons	0.3 m^2 sr above 30 GeV
Photon angular resolution	0.1 degree at 100 GeV
Field of View	1.0 sr

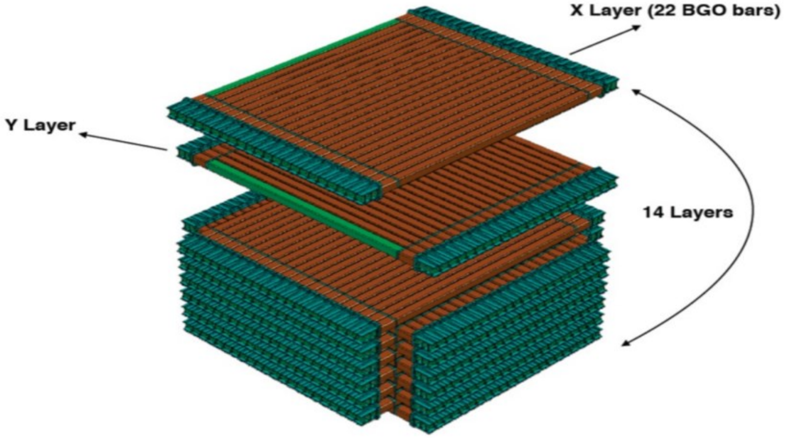
DAMPE instrument



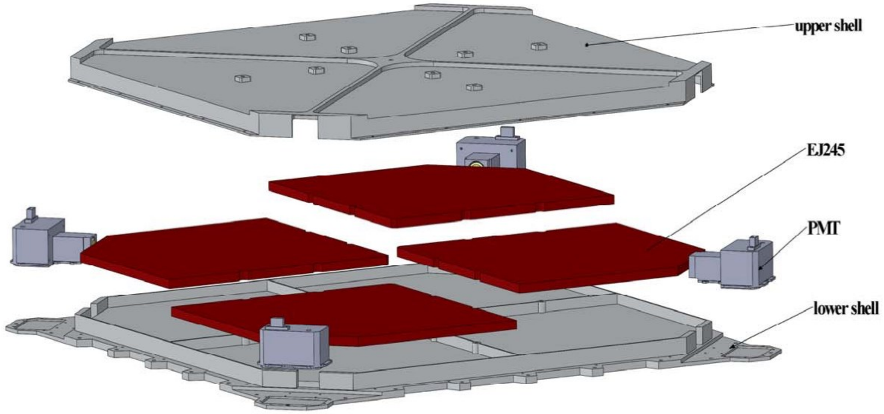
PSD: Charge, Photon Anti-Coincidence



STK :charge, track



BGO: Energy, Track, Trigger System



NUD Enhancing the Distinction Between Hadronic and Electromagnetic Showers

Pre-Selection

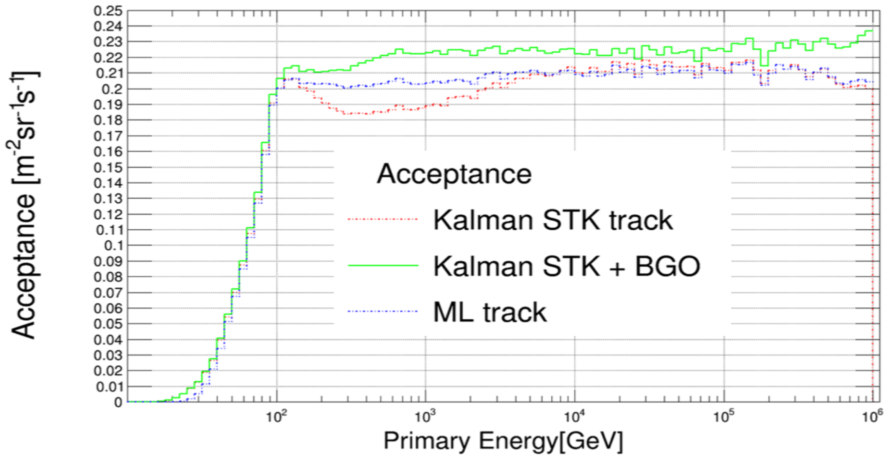
- $E_{dep} > 10$ GeV
- Has STK or BGO track
- STK track selection; (if there is no STK track, use BGO track instead)
  a) $chi^2/ndf < 50$ & Angle to BGO track < 15°
  b) Match with MGO shower
  c) Selected the track with max Energy deposition in STK detector
  d) Max $E_{Ratio} < 0.35$ & Track Pass PSD top and BGO buttle

ML track

- PSD selection

  ① PASS two layer PSD, $Q_0 > 10$ & $Q_1 < 10$

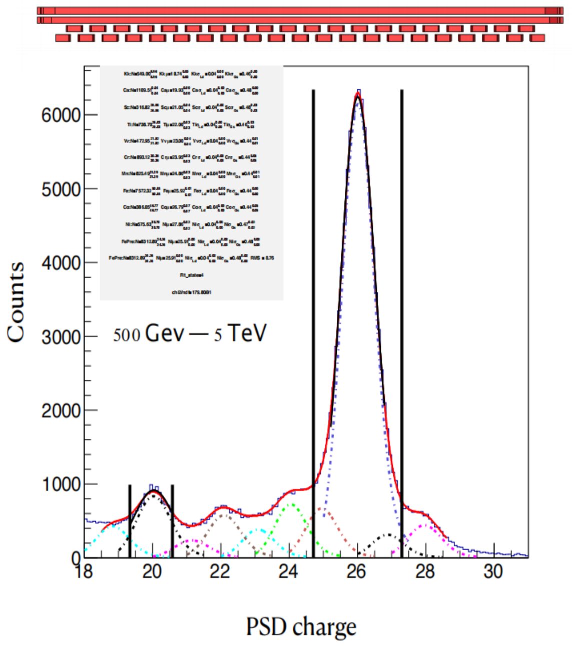
  ② $$Q_i = \begin{cases} \frac{(q_{i1}+q_{i2})}{2}, & for\ \frac{|q_{i1}-q_{i2}|}{Max\{q_{i1},q_{i2}\}} < 0.1 \\ Max\{q_{i1}, q_{i2}\}, & for\ \frac{|q_{i1}-q_{i2}|}{Max\{q_{i1},q_{i2}\}} > 0.1 \end{cases}, \quad i = 0 \text{ or } 1$$



- HET

Charge reconstruction

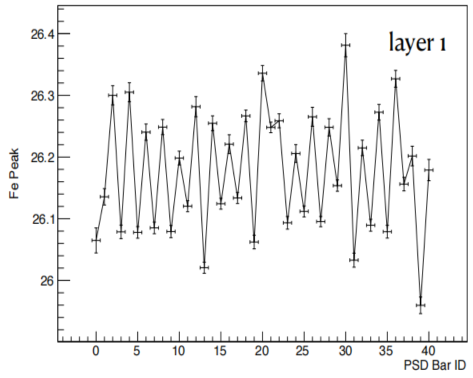
Charge Readout Correction

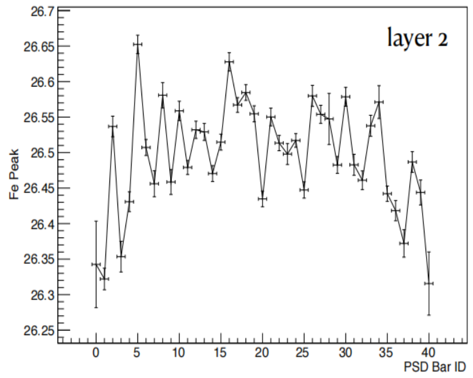


Charge Readout Offset: $\delta_i = Fe\_P_i - 26$。

Correction for Each PSD Bar:

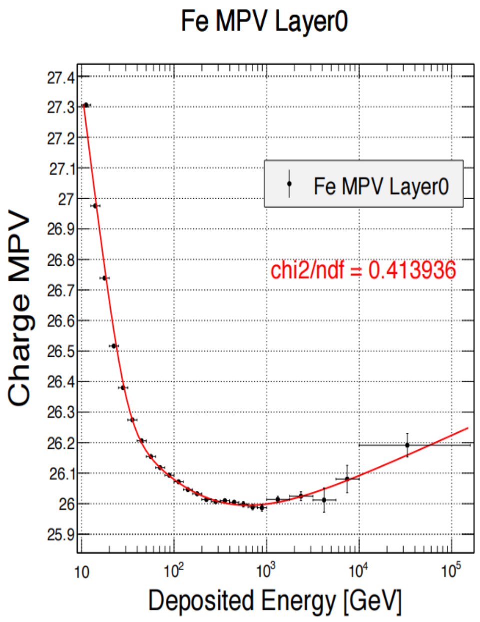
$$C_i' = C_i - \delta i, \quad i = 0, \cdots, 81,$$

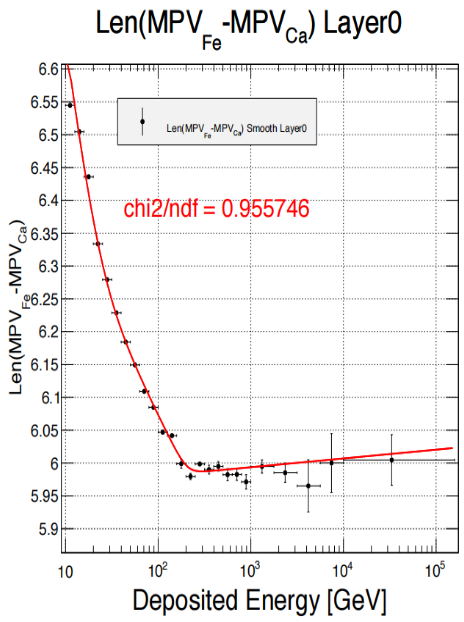




Charge Peak Values Fitted with Different PSD Bars

Charge Vary with Energy



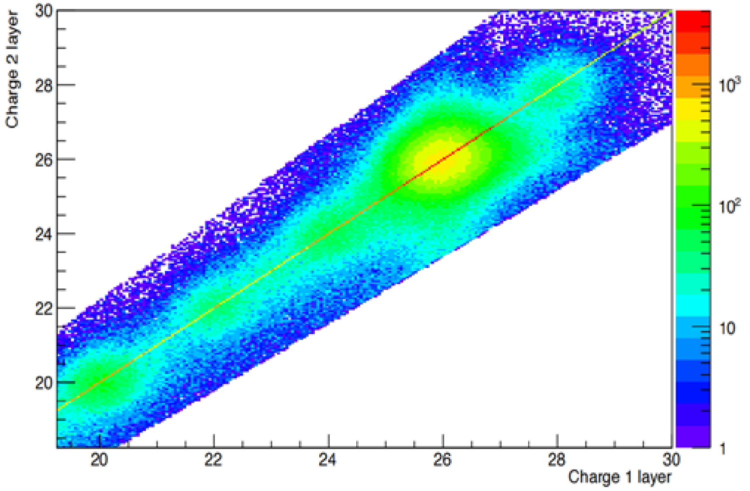


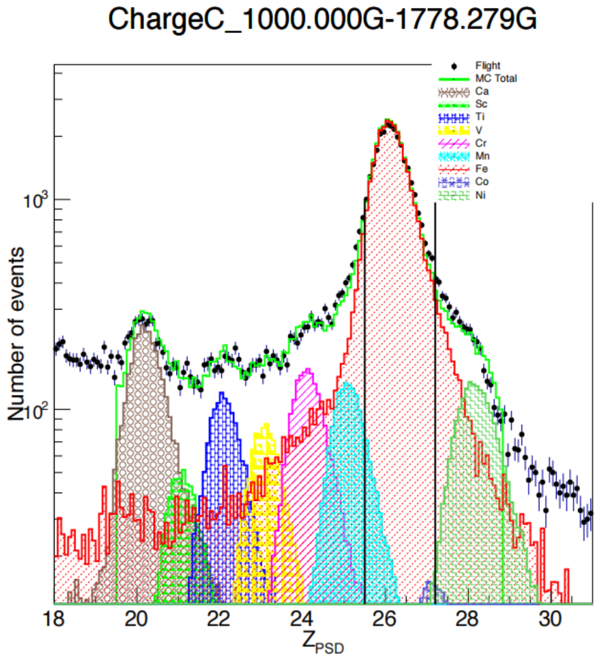
$$C'' = (C_i' - Fe\_P_i) \times 6/(Fe\_P_i \; - \; Ca\_P_i) + 26, \quad i = 0, \; \ldots, \; 3.$$

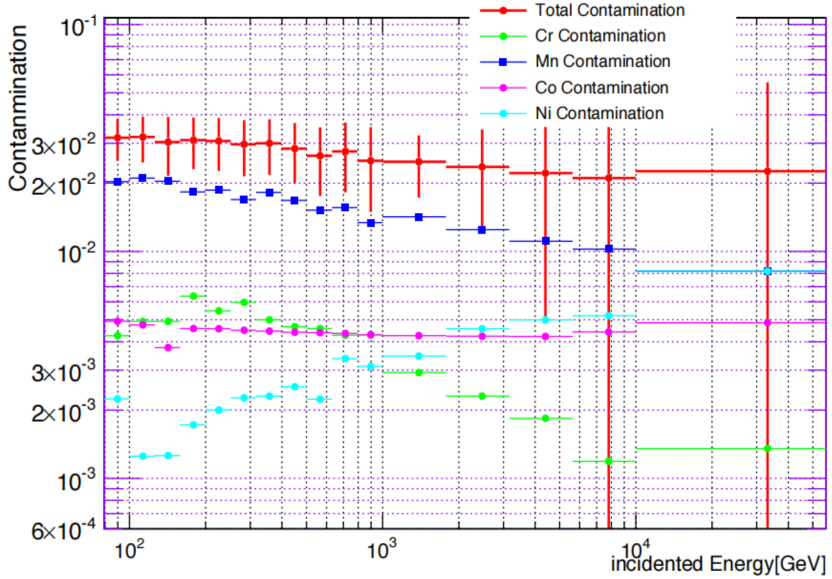
Enhance Charge resolution and evaluate of contamination

Particle Identify

Templet Fit and contamination evaluate







Template Fit(1TeV-1.78TeV)

Contamination < 3.2%in all range

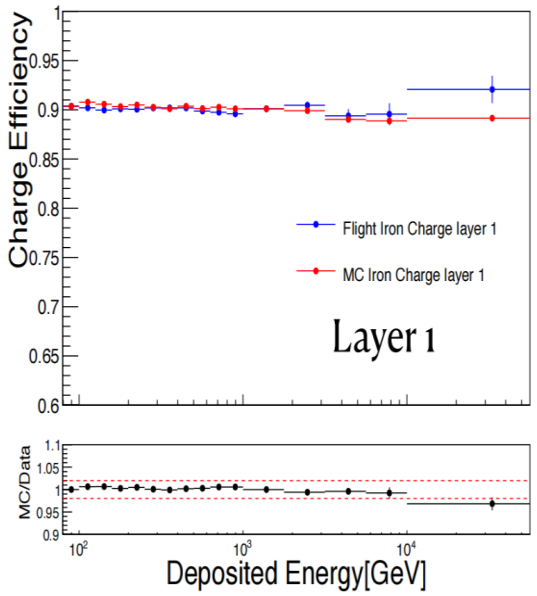
- If $\left(\frac{|C_0'' - C_1''|}{max\{C_0'', C_1''\}} < 0.1\right)$:

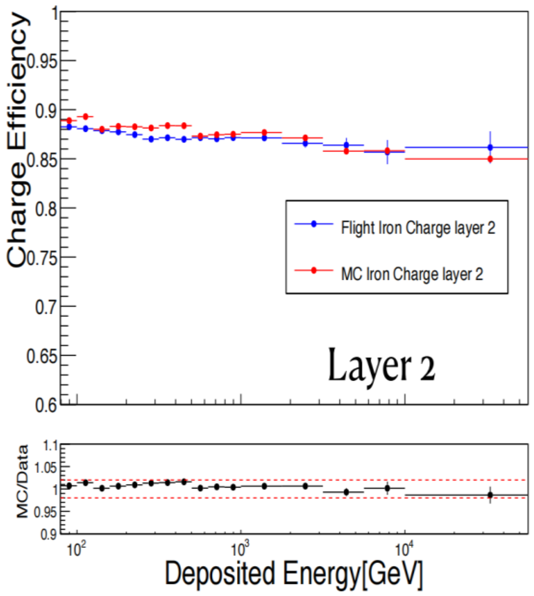
$$C = \frac{C_0'' + C_1''}{2}$$

- else: $C = max\{C_0'' + C_1''\}$

- Select Charge Range : 25.5 – 27.2
- Contamination of Fe main from Mn.
- All Contamination lower than 3.2%

Efficiency Calibration



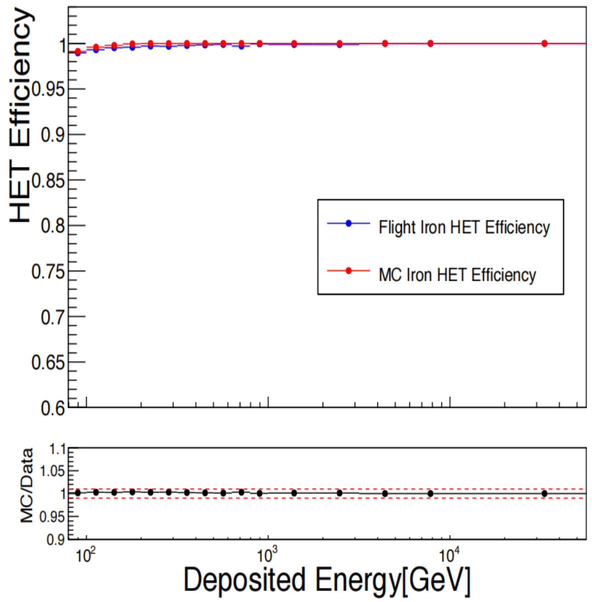


$$\varepsilon_{PSD1} = \frac{N_{PSD1|PSD2}}{N_{PSD2}}$$

$$\varepsilon_{PSD2} = \frac{N_{PSD2|PSD1}}{N_{PSD1}}$$

$$MC/Data < 2\% \,(Energy < 10TeV)$$

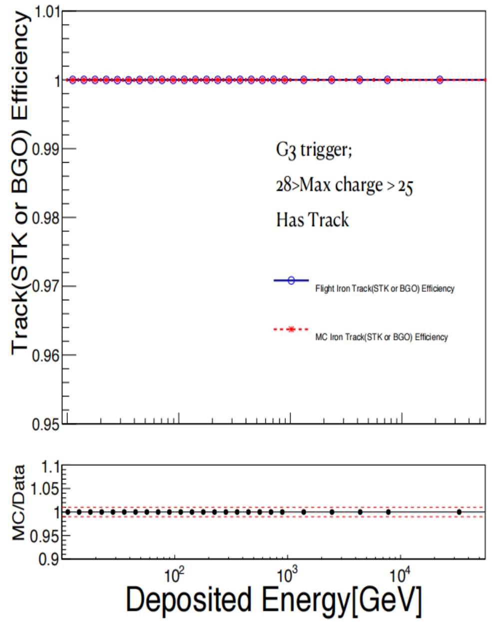
PSD charge Efficiency



$$MC/Data < 0.3\%$$

$$\varepsilon_{HET} = \frac{N_{HET|UNBT}}{N_{UNBT}}$$

HET Efficiency

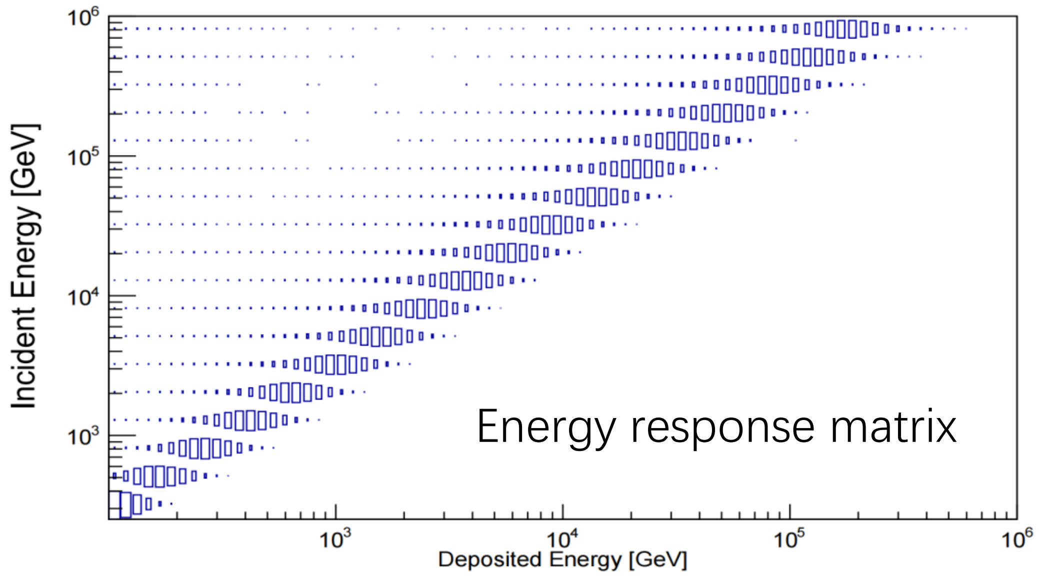


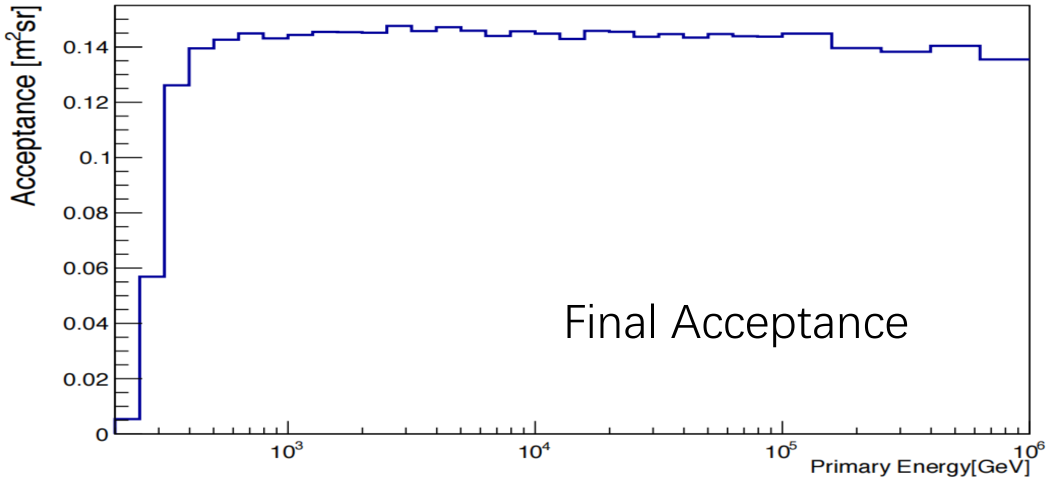
MC/Data<0.01%

$$Track\ Efficiency = \frac{Track(STK\ or\ BGO)}{Max\ Charge}$$

Track Efficiency

Spectrum reconstruction





Primary Energy C_i with Events $n(C_i)$, Deposited Energy E_j with events $n(E_j)$.

$$n(C_i) = \sum_{j=1}^{n_E} M_{ij} n(E_j),$$

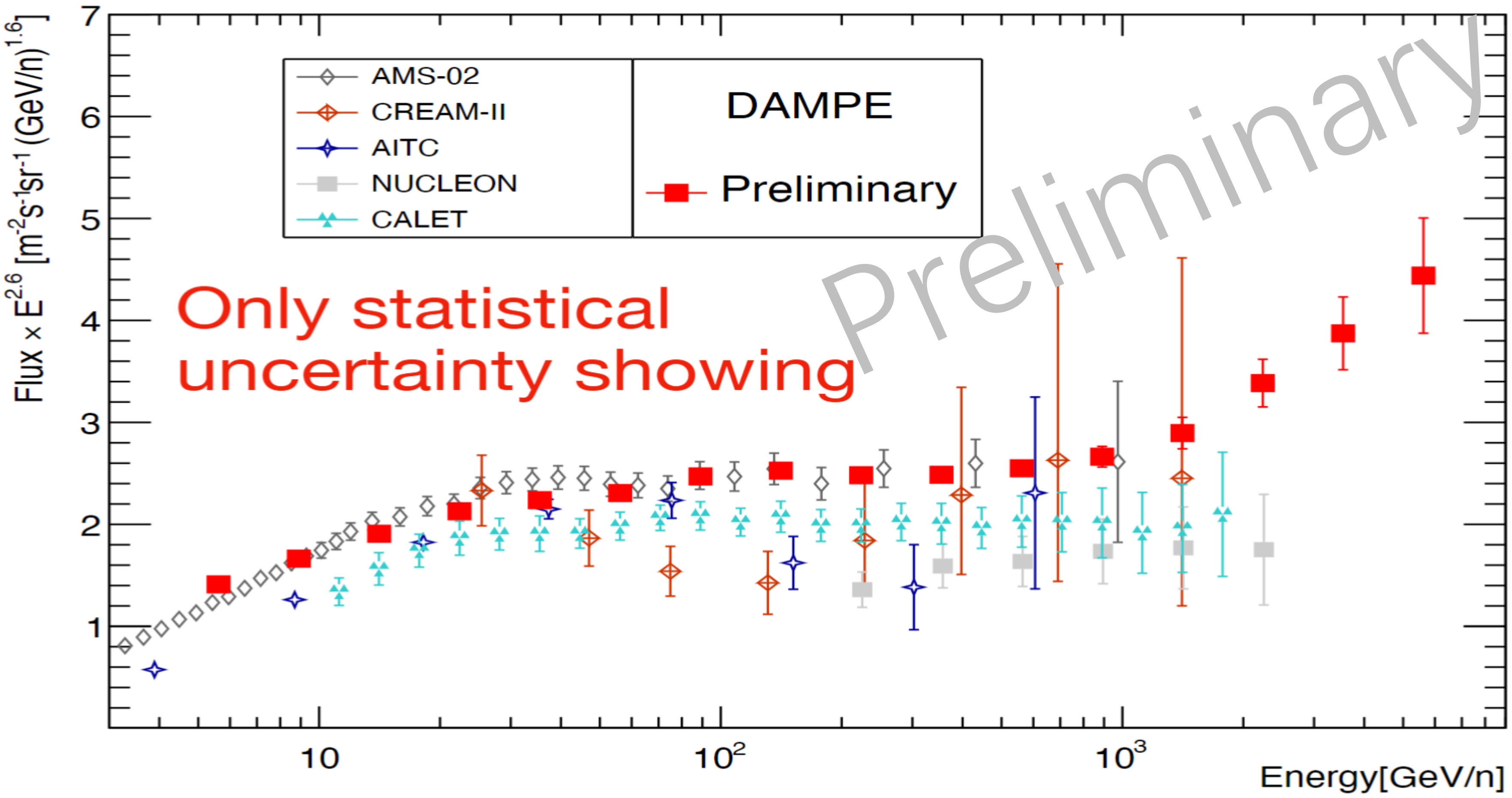
$$M_{ij} = \frac{P(E_j|C_i) n_0(C_i)}{\epsilon_i \sum_{l=1}^{n_C} P(E_j|C_l) n_0(C_l)}$$

Where $P(E_j|C_i)$ is the response matrix.

Final Spectrum

$$\Phi(E_i, E_i + \Delta E_i) = \frac{N_{inc,i}}{\Delta E_i A_{eff,i} \Delta t},$$

DAMPE Iron Spectrum



Four independent analyses reached the same conclusion:
DAMPE observed a hardening of the iron spectrum above TeV/n.

Summary

- DAMPE has been in orbit for nearly eight years, and the detector is currently operating well.
- DAMPE exhibits excellent charge resolution, allowing for precise identification and accurate energy spectrum measurements of iron nuclei particles.
- Preliminary analysis has yielded the iron spectrum up to 10 TeV/n, and observed a hardening above TeV/n. With further refinement and in-depth analysis, it is anticipated that the energy spectrum measurements can be extended to several hundred TeV.

Thank you for your attention