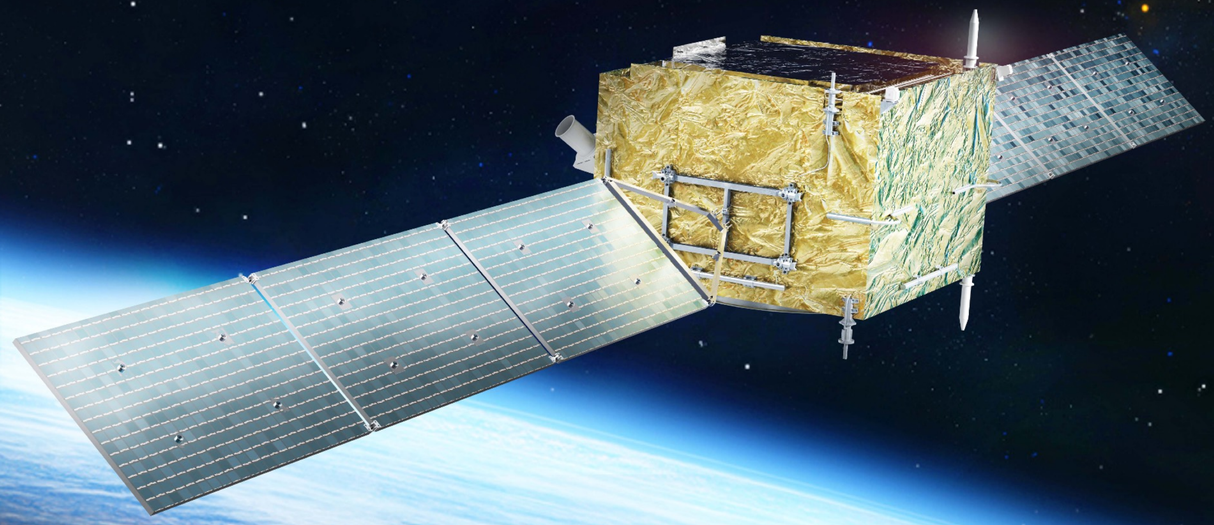
The latest results from the DAMPE space mission in more than 9 years

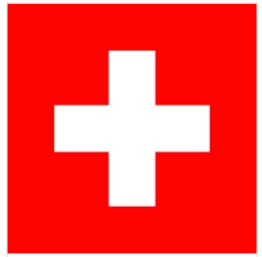


The 19th international conference on topics in astroparticle and Underground Physics, @ Xichang, China Aug.24-Aug.30 2025

Speaker: Pengxiong Ma, 马鹏雄
Purple mountain observatory, CAS, Nanjing, China
On bebalf of the DAMPE Collaboration.

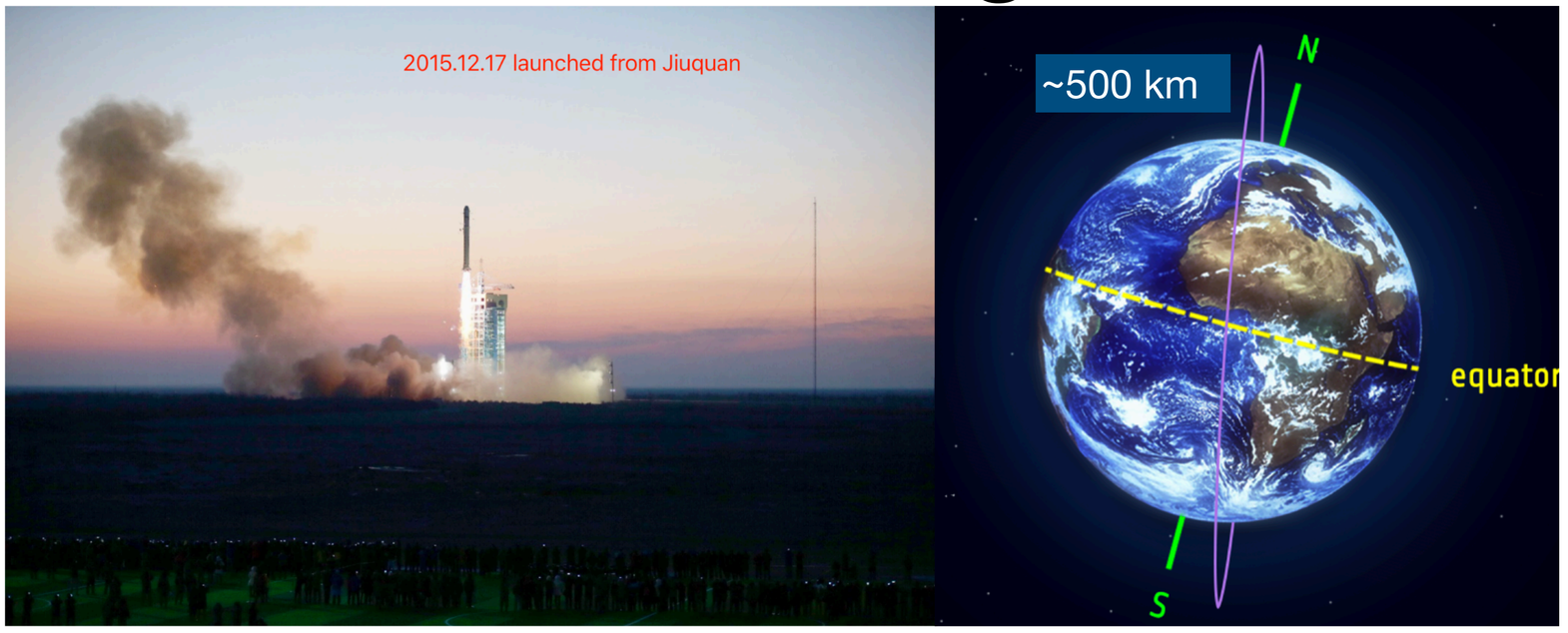
DAMPE collaboration

- China
  - **1.Purple mountain observatory, CAS, Nanjing.**
  - 2.University of Science and Technology of China, Hefei.
  - 3.Institute of Modern Physics, CAS, Lanzhou.
  - 4.Institute of High Energy Physics, CAS, Beijing.
  - 5.National Space Science Center, CAS, Beijing.
- Italy
  - 1.INFN Perugia and University of Perugia.
  - 2.INFN Bari and University of Bari.
  - 3.INFN-LNGS and Gran Sasso Science Institute.
  - 4.INFN Lecce and University of Salento.
- Switzerland
  - 1.University of Geneva.

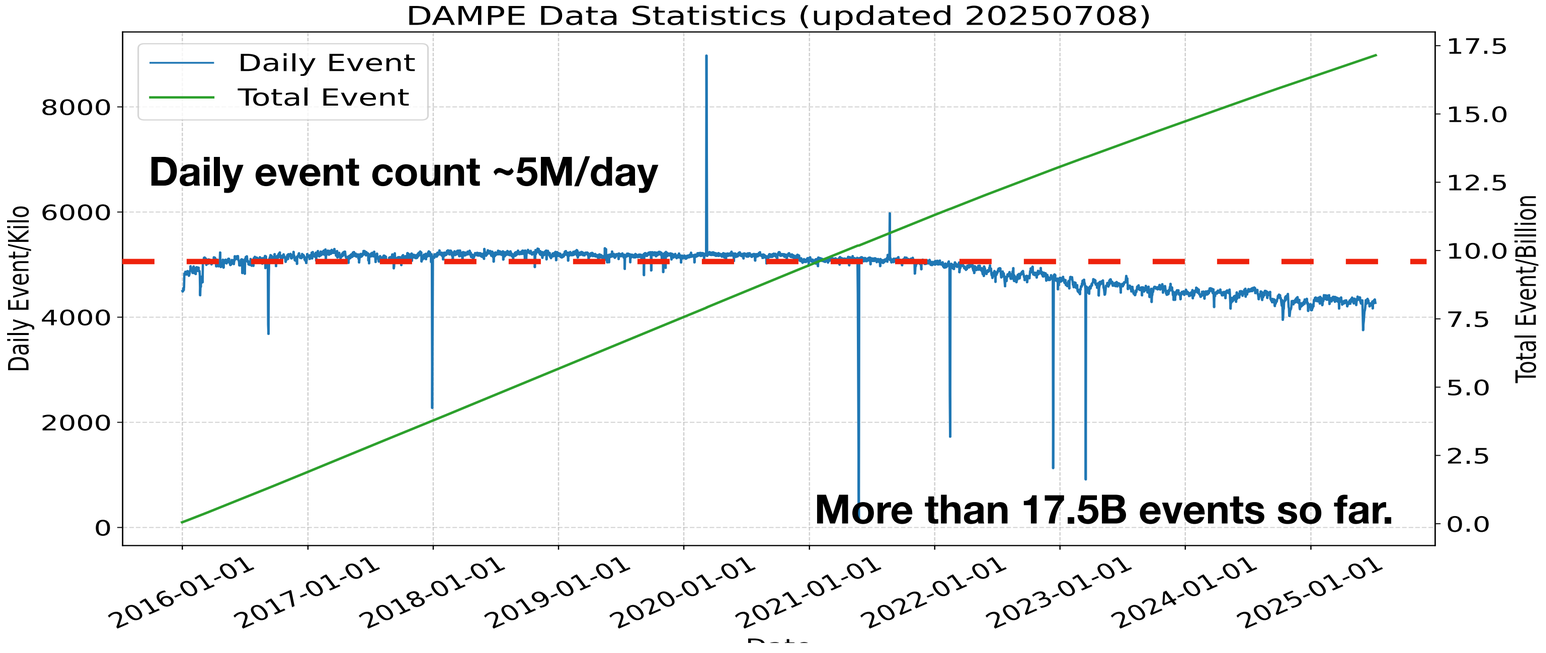


The launch: Dec 17th 2015 & long-term status

1. The first satellite dedicated to natural (astronomical) science from China.
2. “Launches the (new) era of Chinese space science”- <Nature>



- Expected lifetime: 3 years
- Raw data: 16GB per day.
- Orbit: sun-sync. ~500km, ~95minutes
- Smooth operation since launch for more than 9 years.



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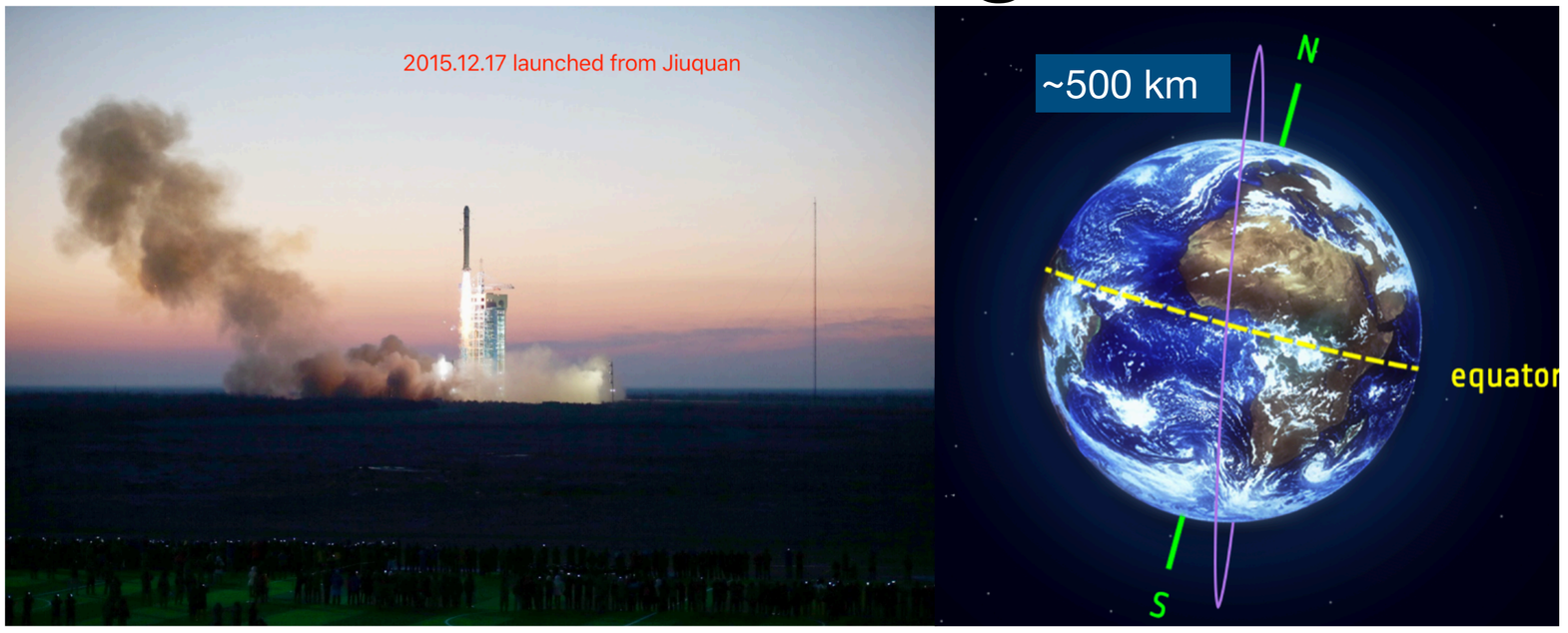

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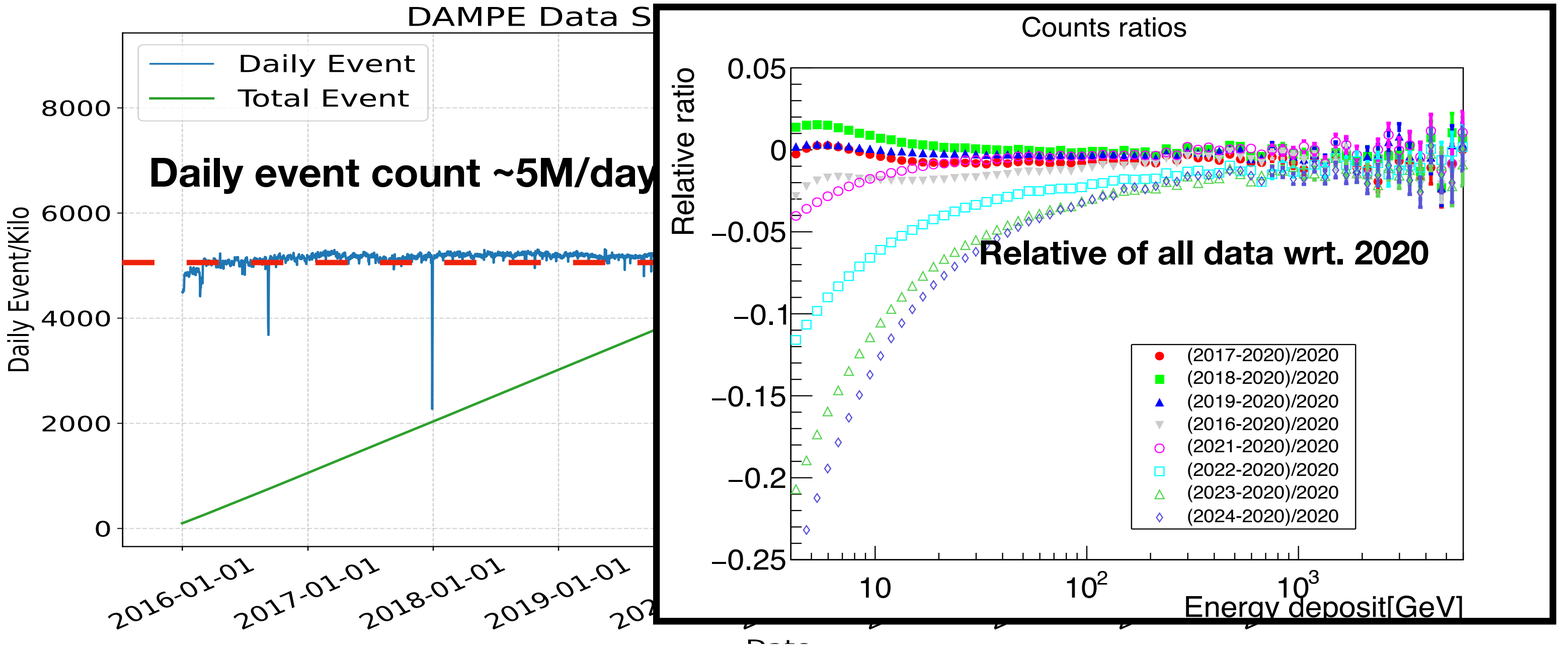
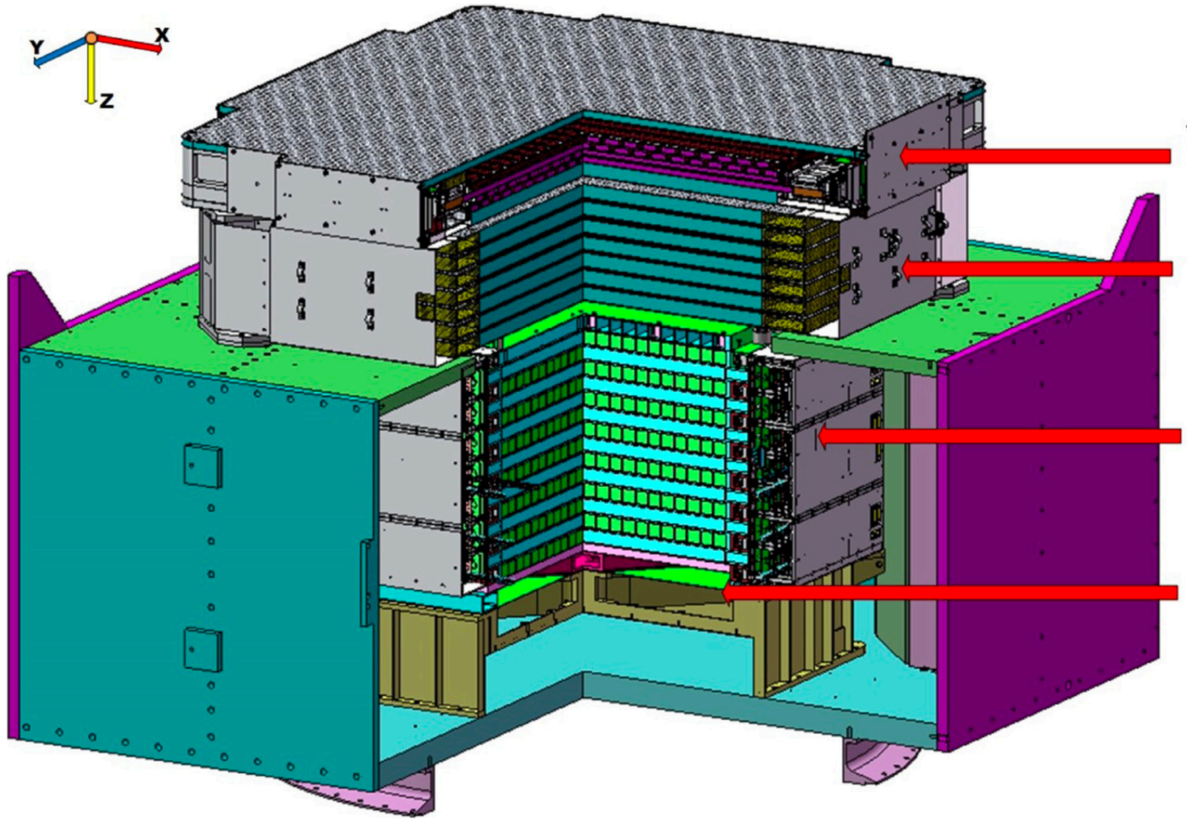


DAMPE

DArk Matter Particle Explorer



The plastic scintillator detector (PSD) — Charge, veto for gamma ray; 2x41

The silicon tracker (STK) — Direction, charge; 12 layers

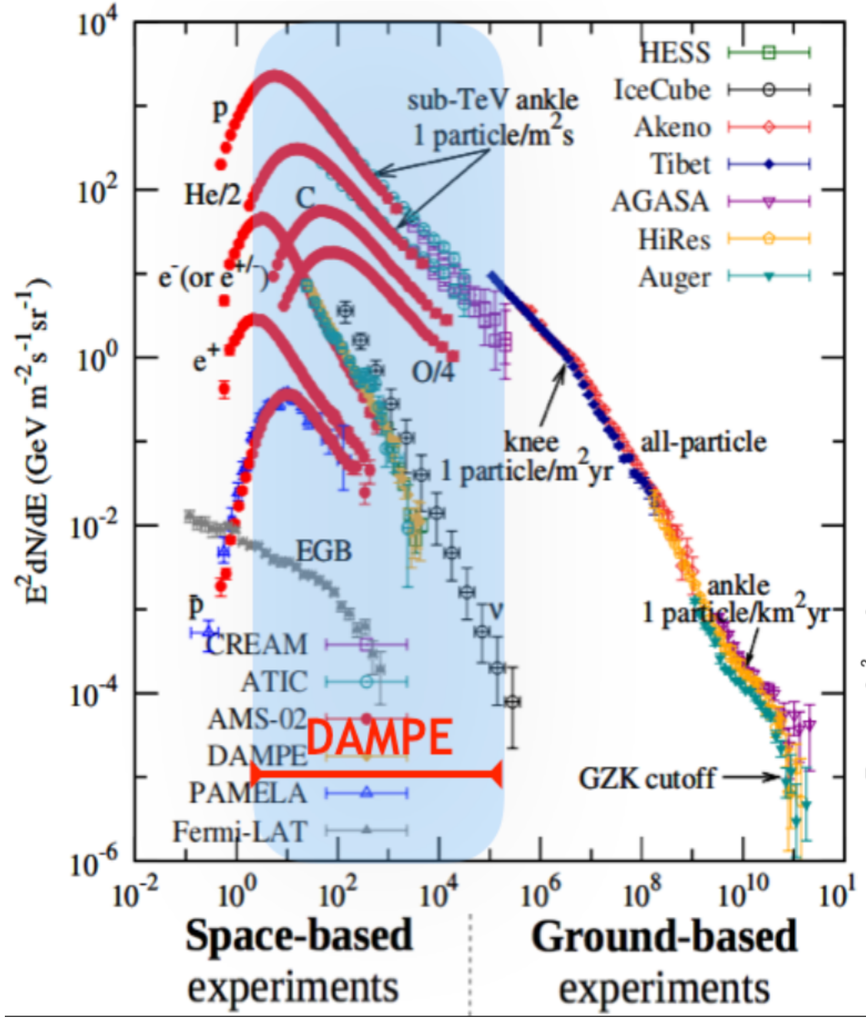
The BGO calorimeter (BGO) — Energy, direction, charge; 14x22 crystals

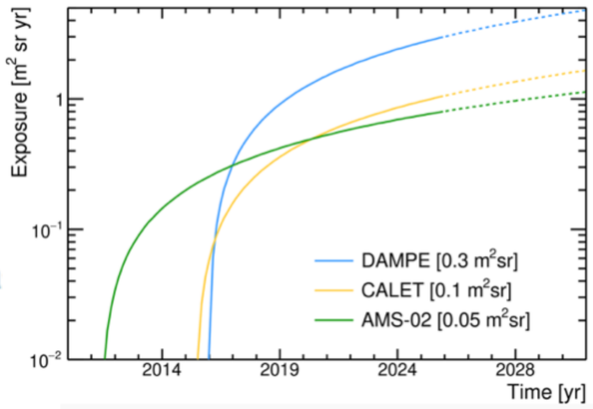
The neutron detector (NUD) — Proton electron seperation; 4 blocks

Four sub-detectors, 1.4 tons in total. 32 radiation length & 1.6 nuclear interaction length

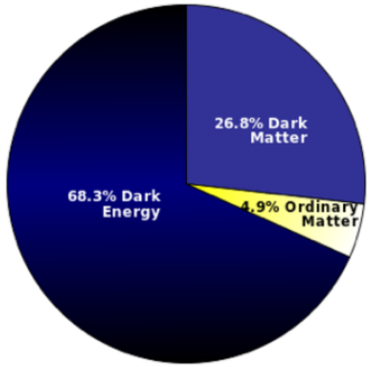
DAMPE's main sience

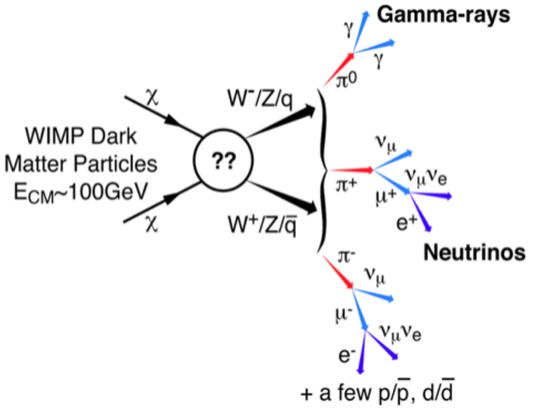
Cosmic-ray physics

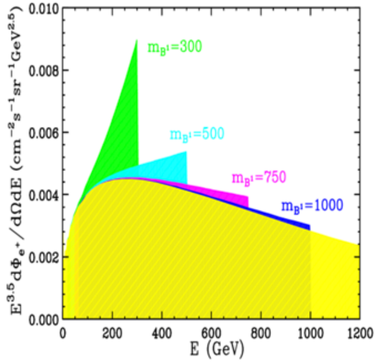




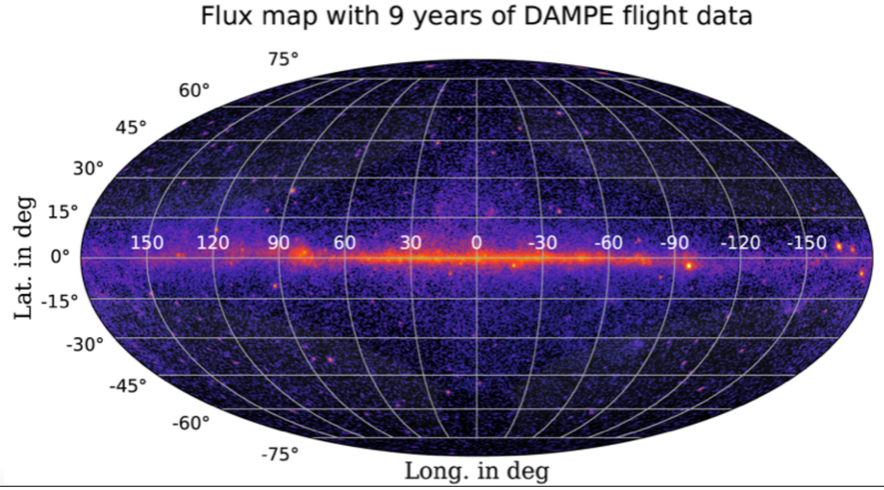
Indirect DM detection





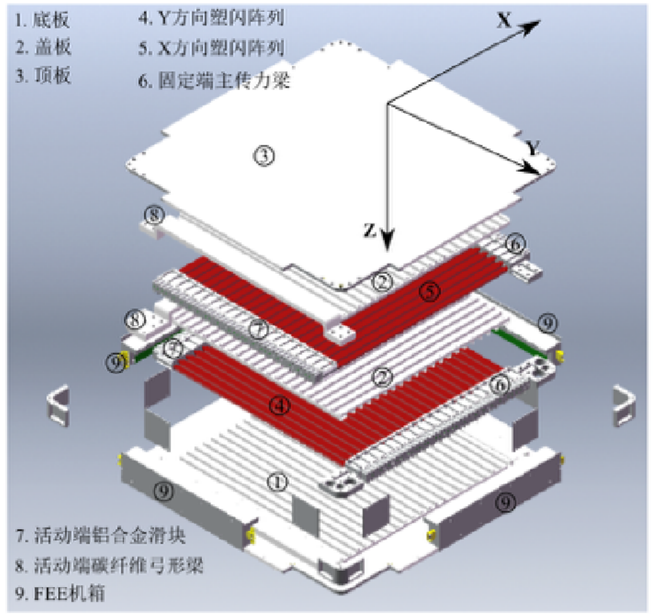


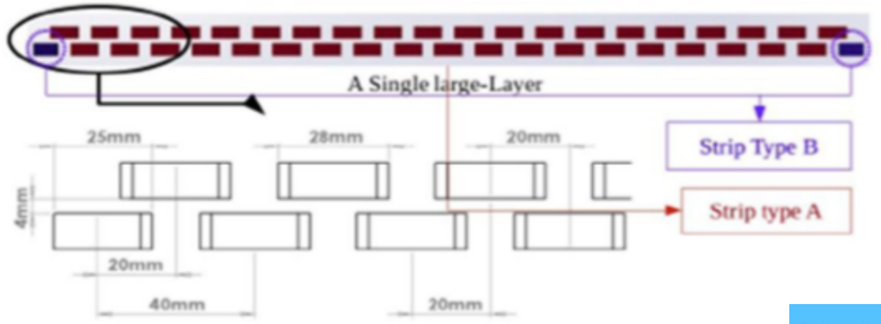
Gamma-ray astronomy



Adapted from Chuan Yue's slides on ICRC2025

Plastic scintillator detector



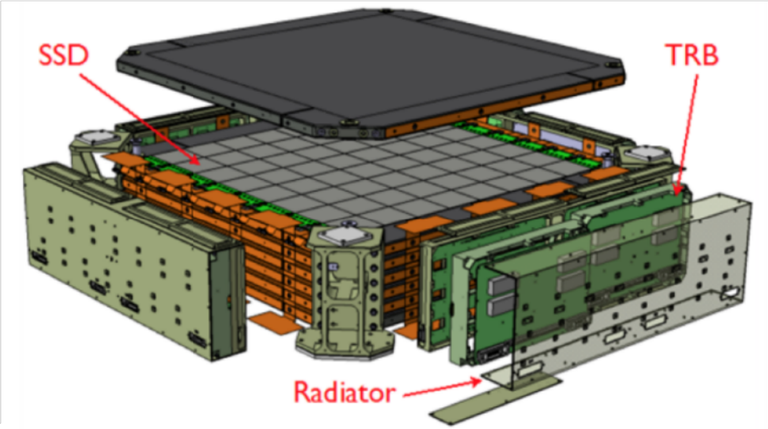


- 2 layers (x,y) of 88.4 cm × 2.8 cm × 1 cm
- Active area: 82 cm × 82 cm
- Weight : ~103 kg
- Power: ~ 8.5 W

Y. Yu et al., Astropart. Phys. 94 (2017)

100% effective area; high detection efficiency.

Silicon (tungsten) track detector

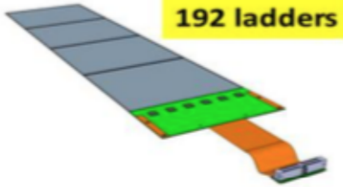


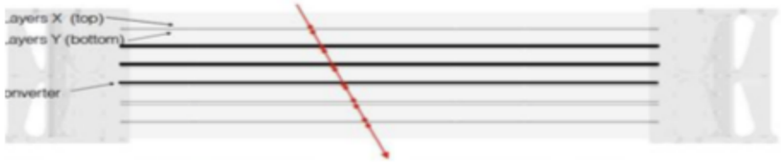
768 silicon sensors
95 x 95 x 0.32 mm³

192 ladders

1,152 ASICs

73,728 channels



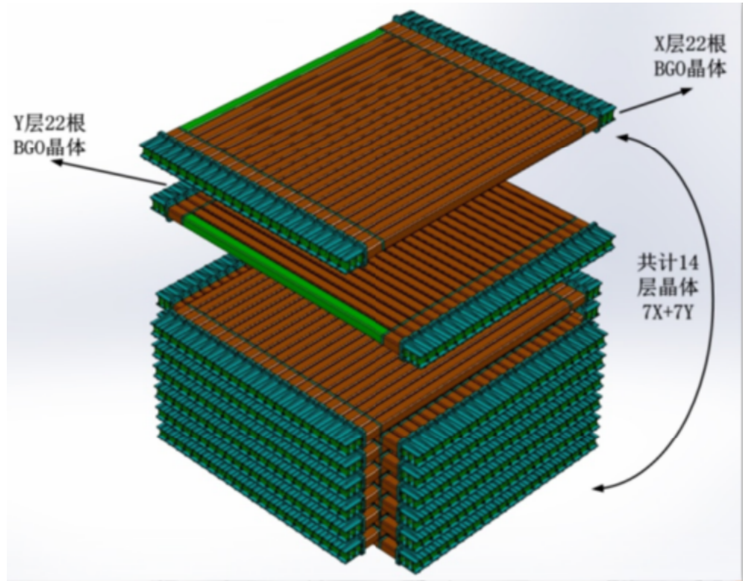


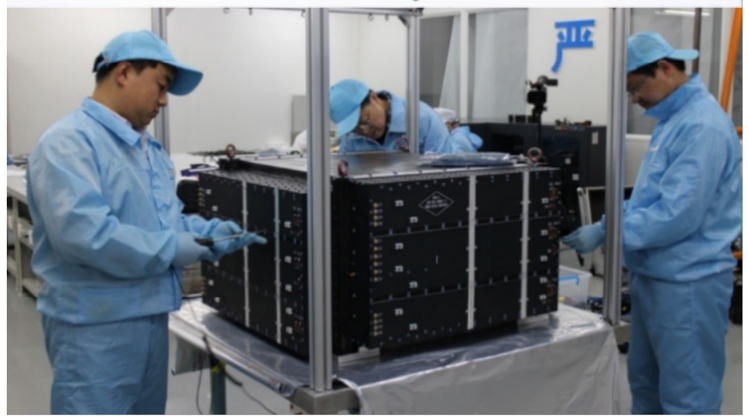
- Detection area: 76 cm x 76 cm
- Total weight: ~154 kg
- Total power consumption: ~ 82W
- Three 1 mm tungsten plates for photon conversion (0.86 X_0)

P. Azzarello et al. NIMA 831 (2016)

Total area is ~ 7 sqm; angular resolution ~ 0.1 degree

The BGO Colorimeter





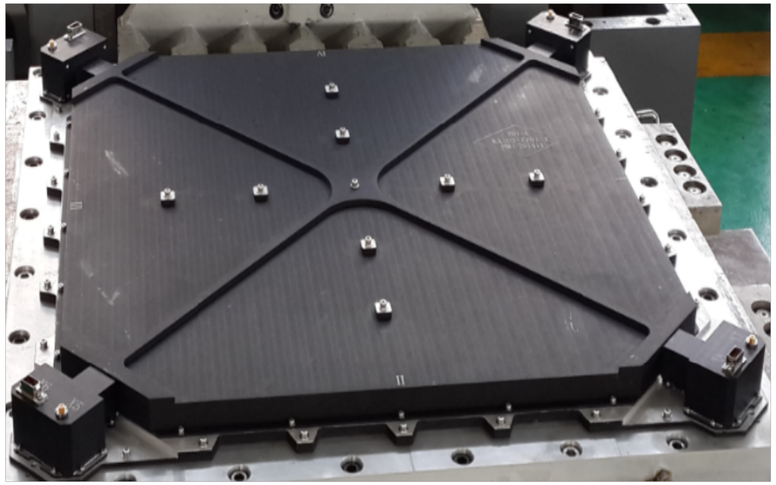
Parameter	Value
Active area	60 cm × 60 cm (on-axis)
Depth (radiation lengths)	32
Sampling	≥ 90%
Longitudinal segmentation	14 layers (≃ 2.3 rad. lengths each)
Lateral segmentation	∼1 Molière radius

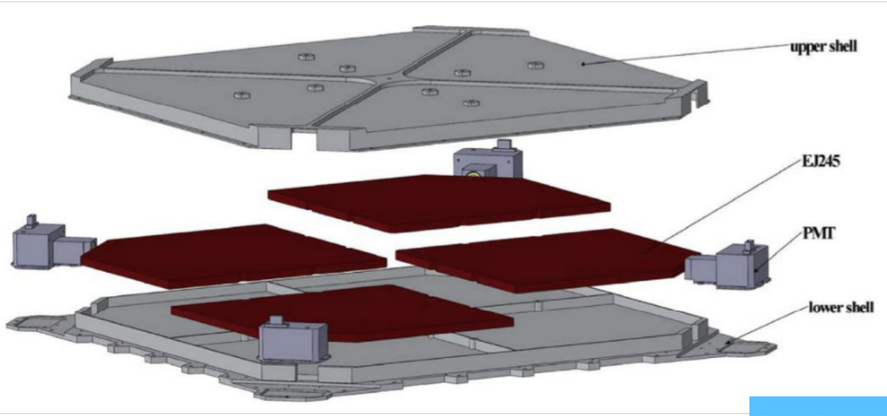
- Total weight: ~1052 kg
- Total power: ~42 W

Z. Zhang et al. NIMA 780 (2015)

Excellent energy resolution for electron/positron above ~10s GeV;
Excellent ability of separation between proton and electron(positron).

The Neutron detector





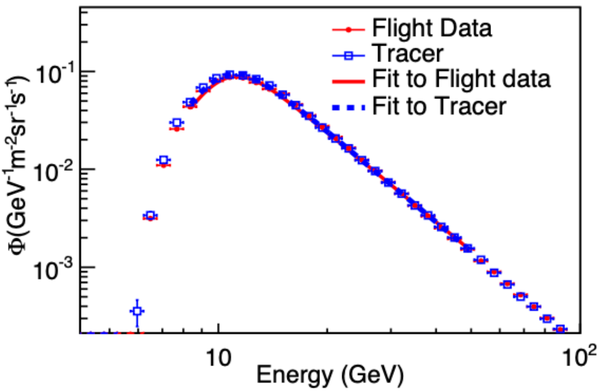
- $n + {}^{10}B \rightarrow \alpha + {}^{7}Li + \gamma$
- 4 plastic scintillators
- Active area: 60 cm x 60 cm
- Total weight: ~12 kg
- Total power: ~ 0.5 W

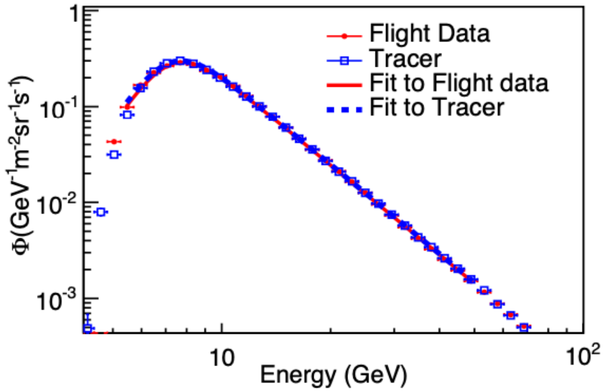
Y. Huang et al. Res. Astron. Astrophys. 20 (2020)

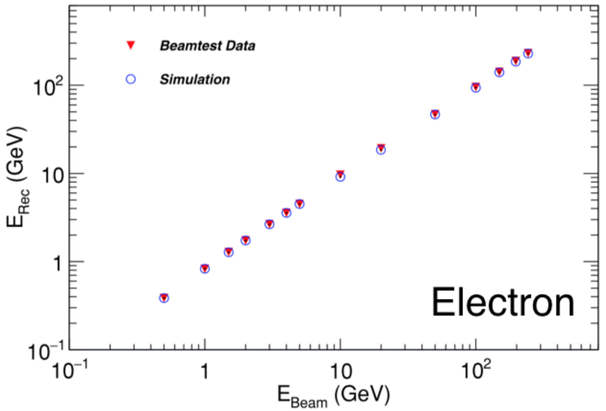
Enhancement of the ability for separation between p/e at high energy.

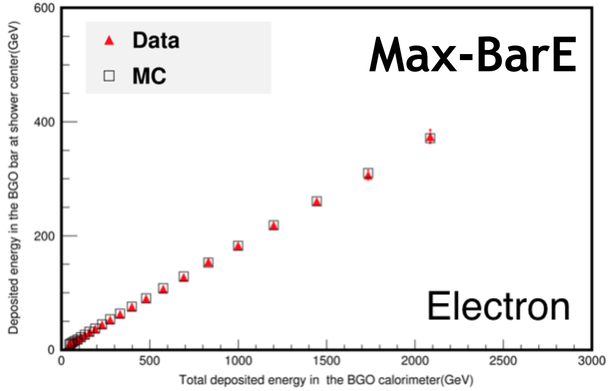
Energy scale and linearity

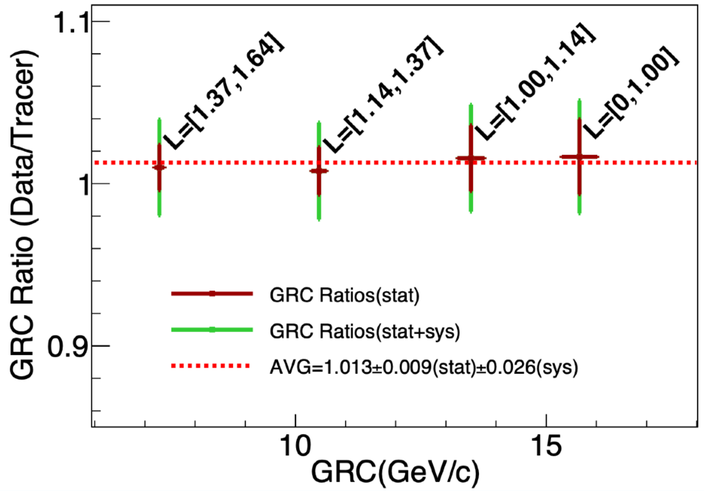
- On-orbit energy scale verified with **geomagnetic cut-off of CR e±**
- Good linearity up to ~2.5 (100) TeV with electron (nuclei) events

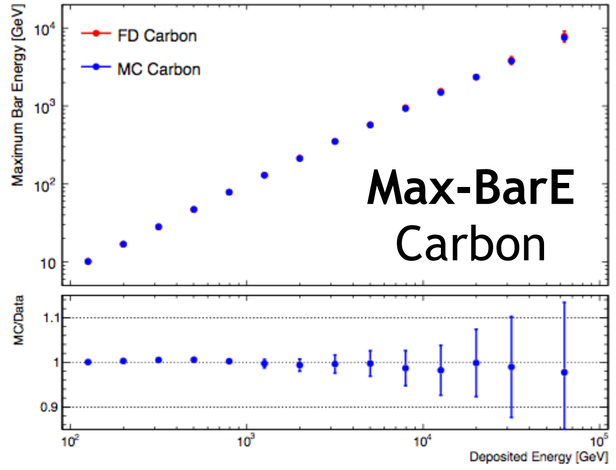


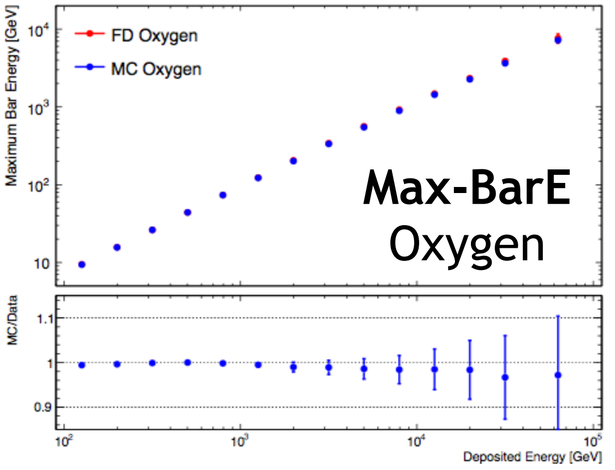












J. Zang et al. (2025) Astropart. Phys. 177, 103149 (2025)

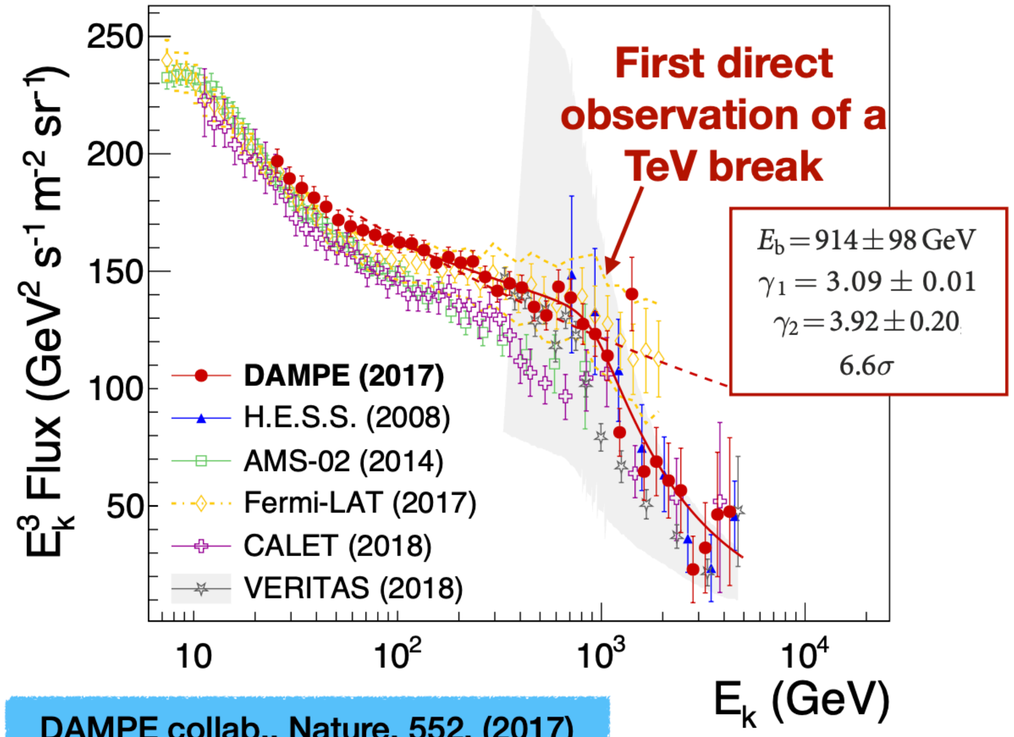
C. Zhao et al. NIMA 1092 (2022)

Results

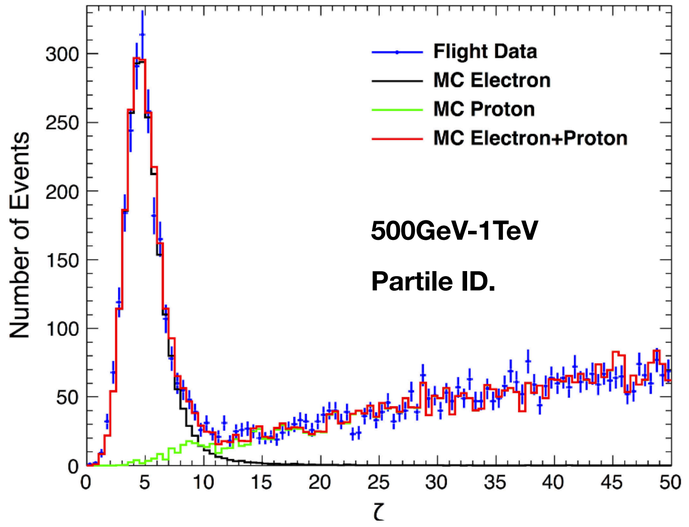
electron+positron spectrum

- Excellent ability of particle identification.
- Excellent energy resolution.

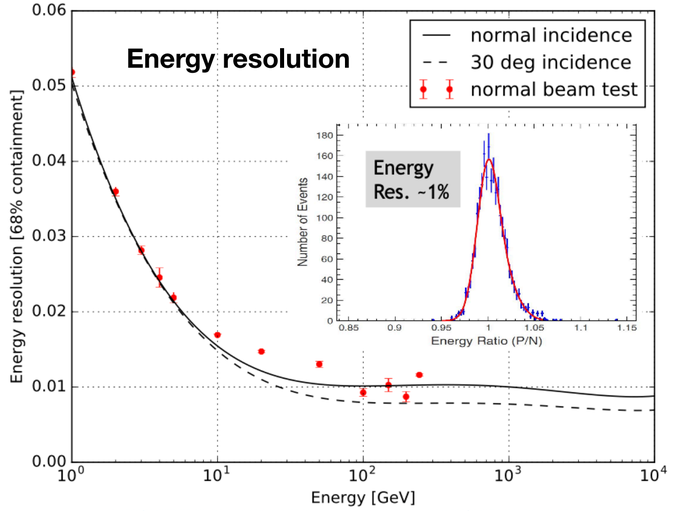
$e^- + e^+$ spectrum:



DAMPE collab., Nature, 552, (2017)



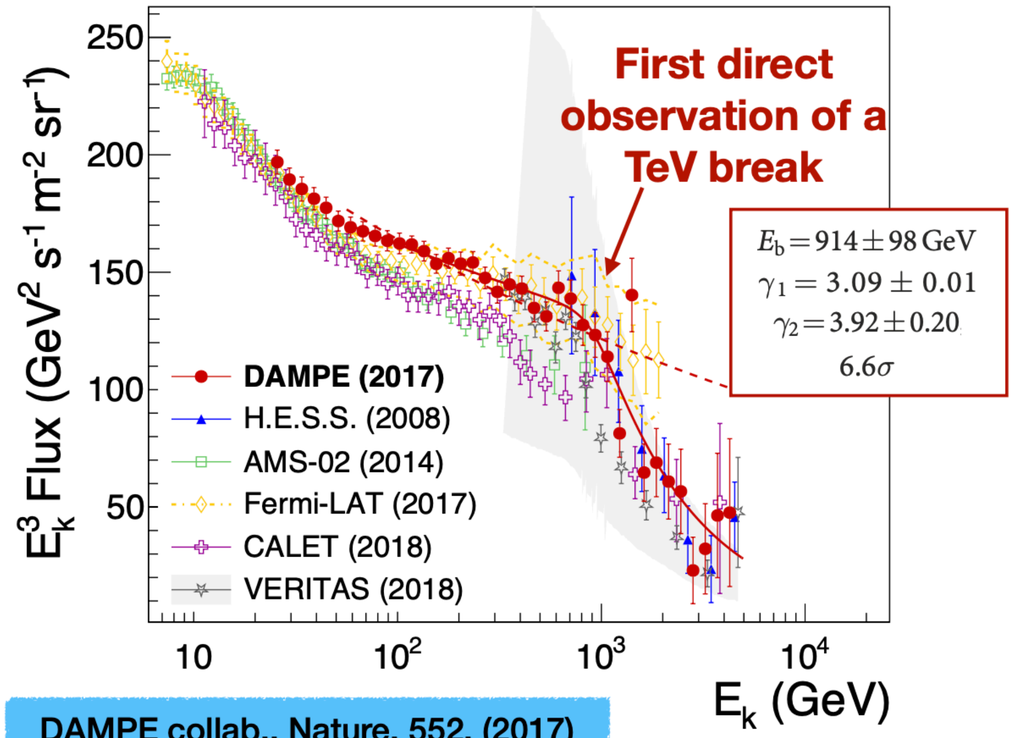
$$\zeta = \mathcal{F}_{\text{last}} \times (\Sigma_i \text{RMS}_i/\text{mm})^4/(8 \times 10^6)$$



DAMPE collab., Astropart. Phys. 95 (2017) 6-24

electron+positron spectrum

$e^- + e^+$ spectrum:

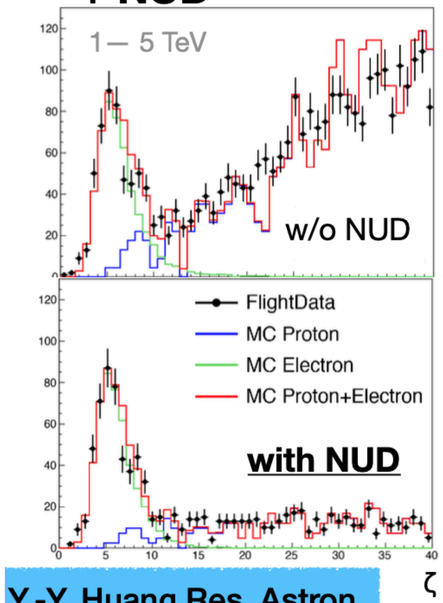


DAMPE collab., Nature, 552, (2017)

Work in process:

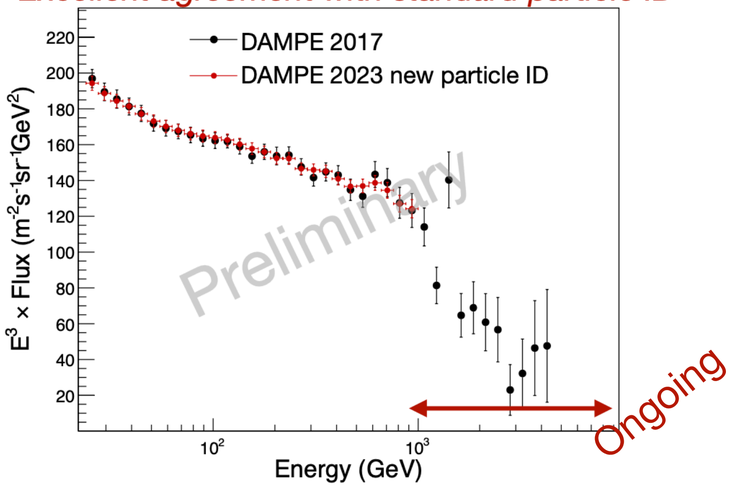
1. Deep and long-term detector calibration.
2. New particle ID for high energies:
   Neural Networks (NN), Principal Component Analysis (PCA),
   Application of Neutron Detector (NUD)
3. Non-fiducial event selection and reconstruction

+ NUD



Y.-Y. Huang Res. Astron. Astrophys. (2020)

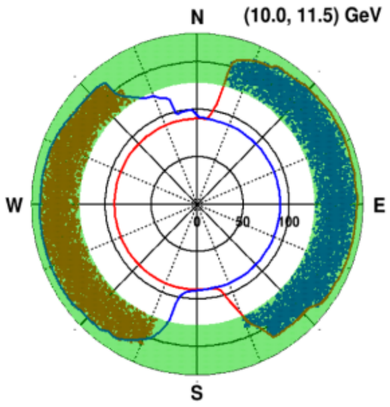
Excellent agreement with standard particle ID

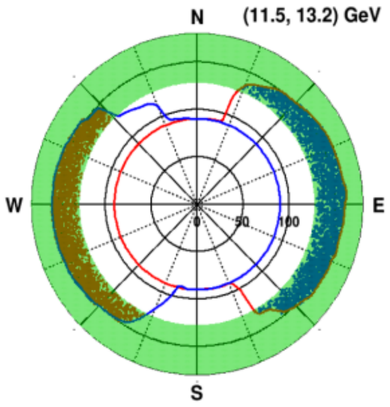


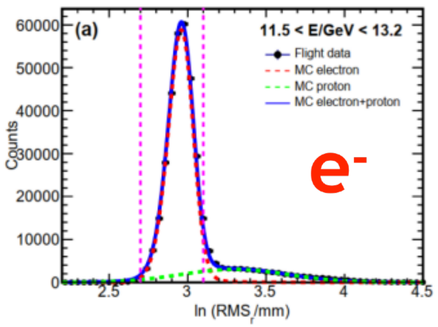
analysis up to ~15 TeV is in progress

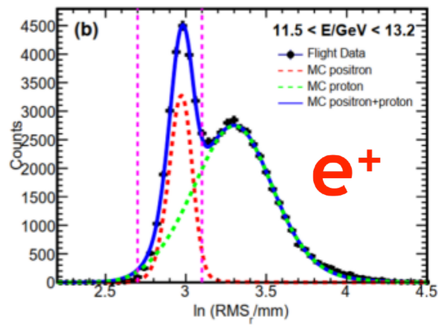
e^+/e^- spectrum towards low energy

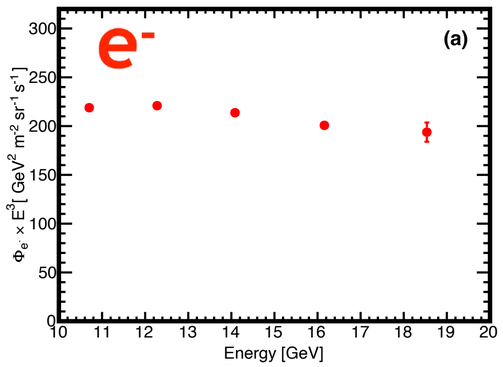
◉CR e^+/e^- **discrimination** based on the **East-West effect** in the Geomagnetic field

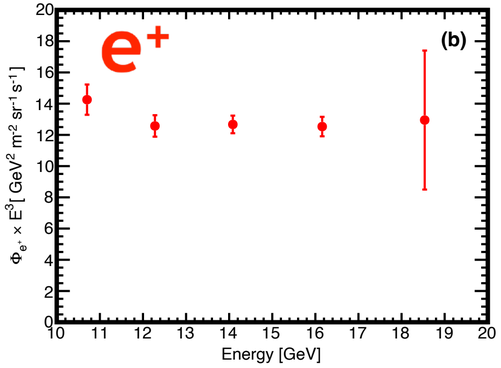


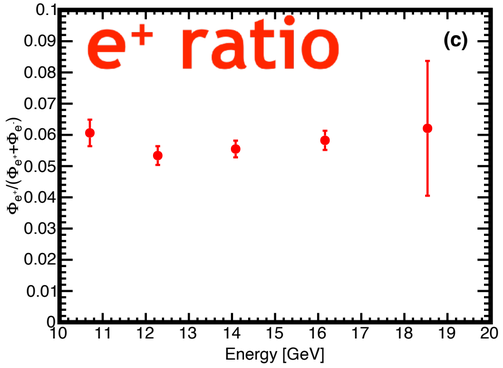


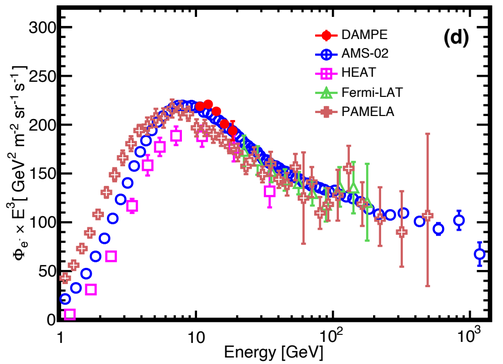


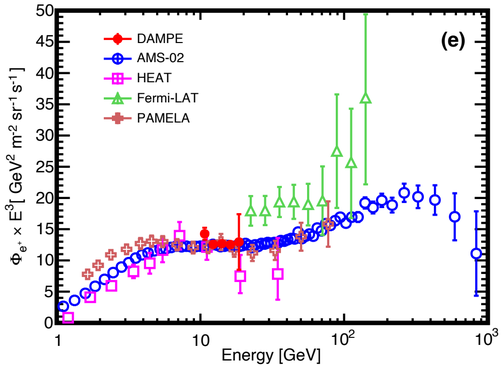


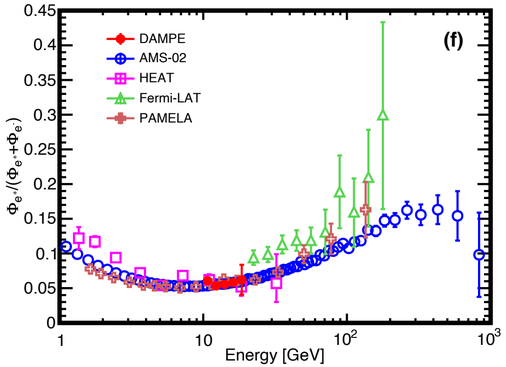








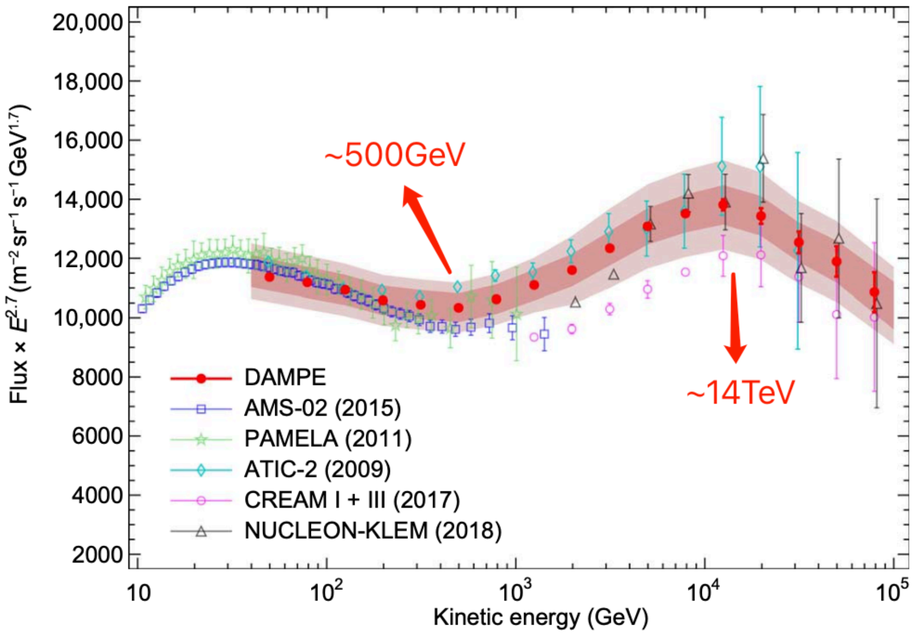




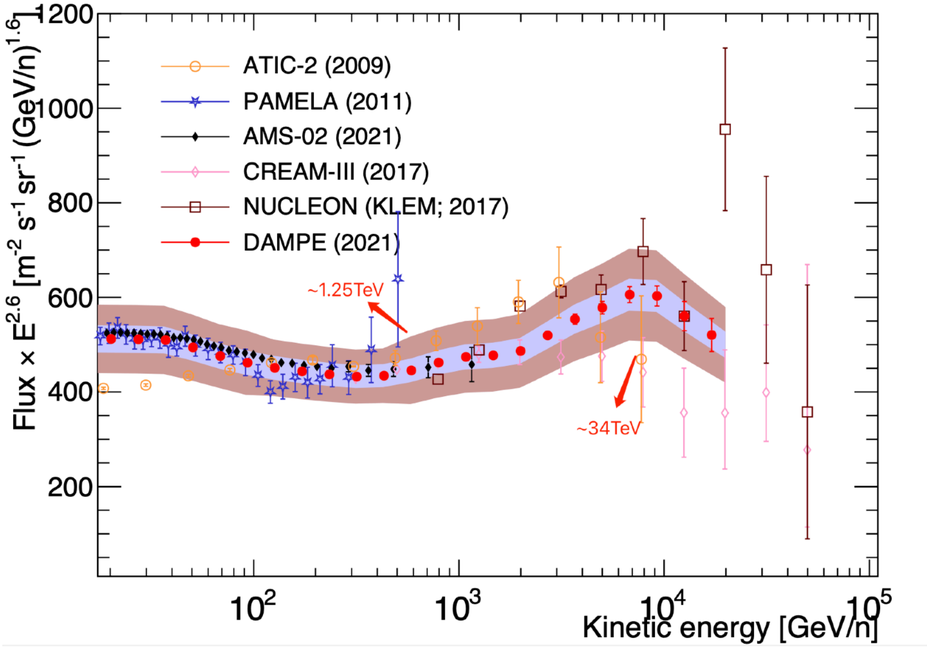
DAMPE Collab., et al. CPC accepted, 2025

◉ **DAMPE measurements from 10 to 20 GeV are consistent with the previous results of AMS-02 and PAMELA**

Proton,Helium

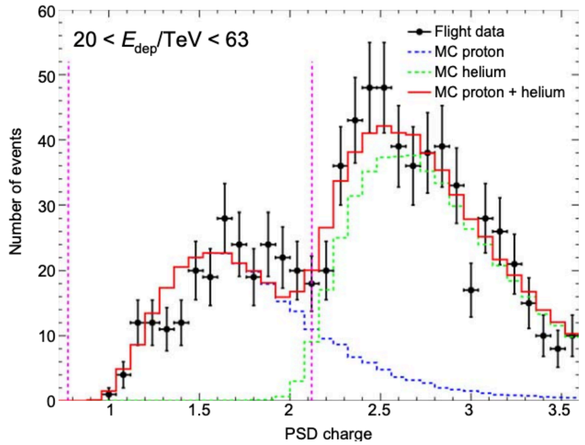


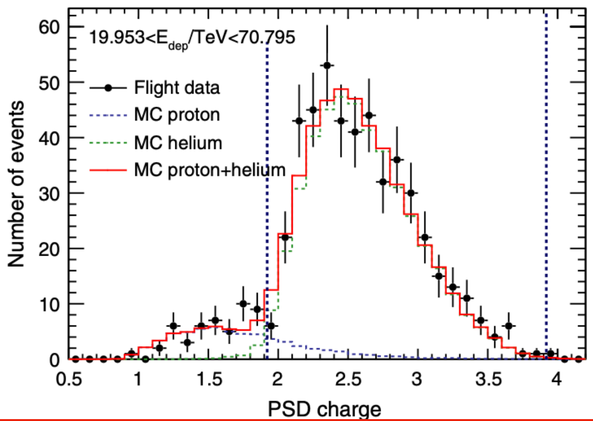
DAMPE Collab., et al. Sci. Adv. 2019;5 eaax3793



DAMPE Collab., et al. PRL 126, 201102 (2021).

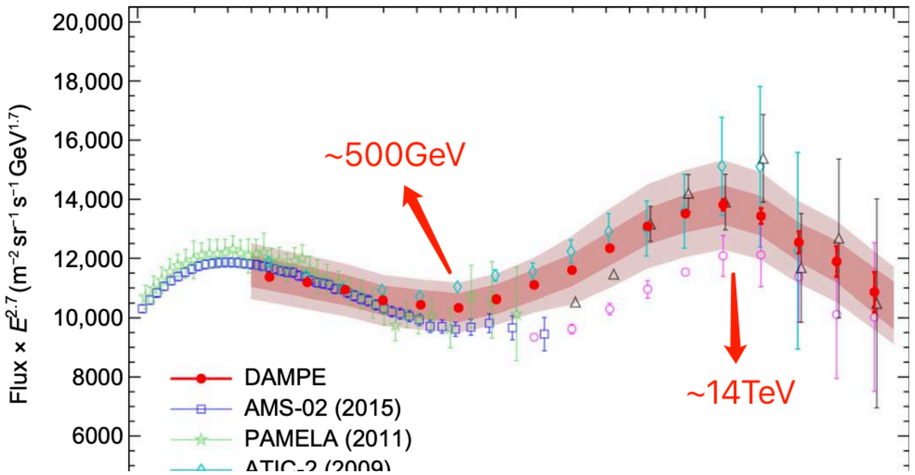
1. **Large acceptance.**
2. **Good charge identification.**

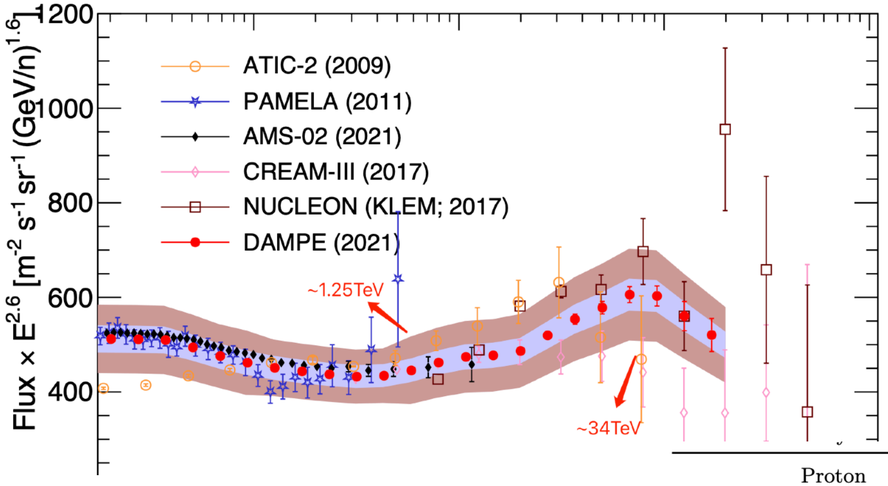




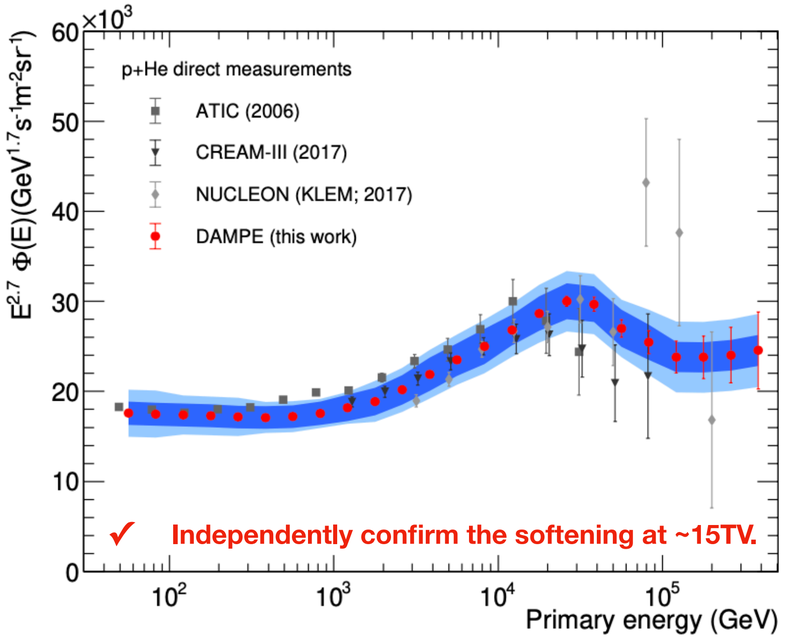
Please refer to Wei's slides for detailed analysis for nuclei spectrum

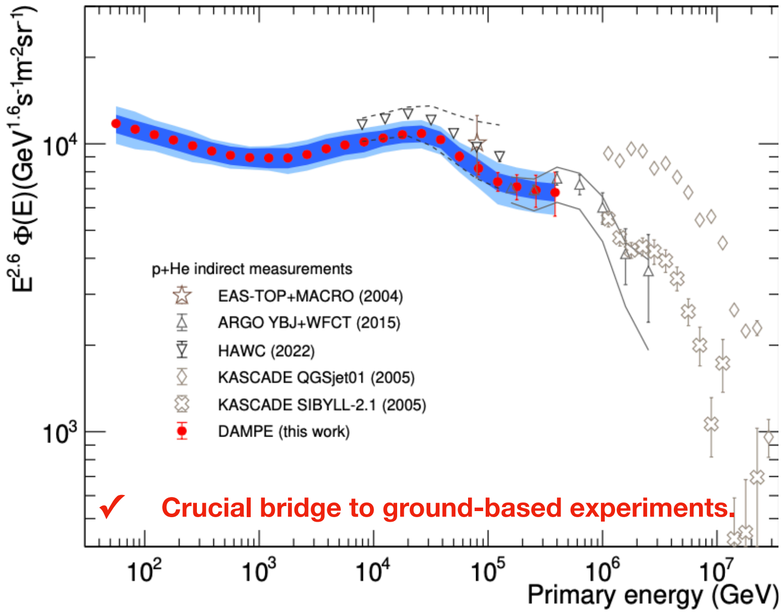
Proton,Helium, P+He

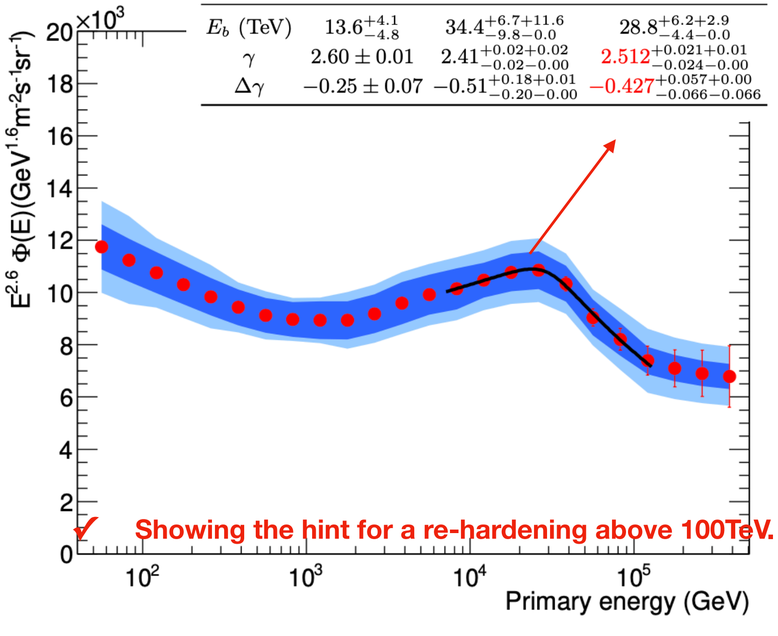




	Proton	Helium	Proton+Helium
E_b (TeV)	$13.6^{+4.1}_{-4.8}$	$34.4^{+6.7+11.6}_{-9.8-0.0}$	$28.8^{+6.2+2.9}_{-4.4-0.0}$
γ	2.60 ± 0.01	$2.41^{+0.02+0.02}_{-0.02-0.00}$	$2.512^{+0.021+0.01}_{-0.024-0.00}$
$\Delta\gamma$	-0.25 ± 0.07	$-0.51^{+0.18+0.01}_{-0.20-0.00}$	$-0.427^{+0.057+0.00}_{-0.066-0.066}$



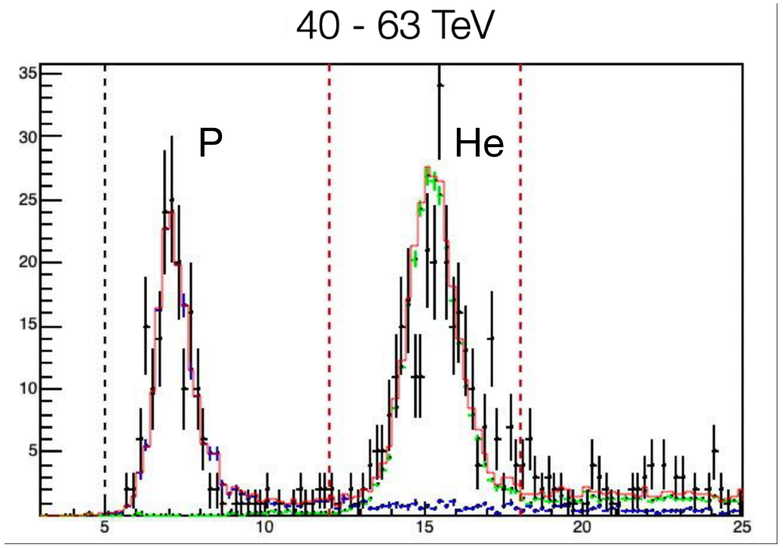


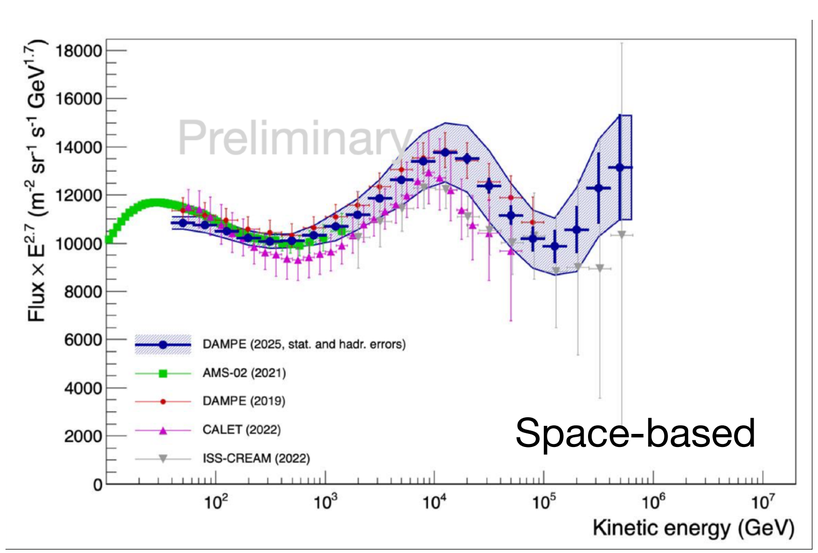


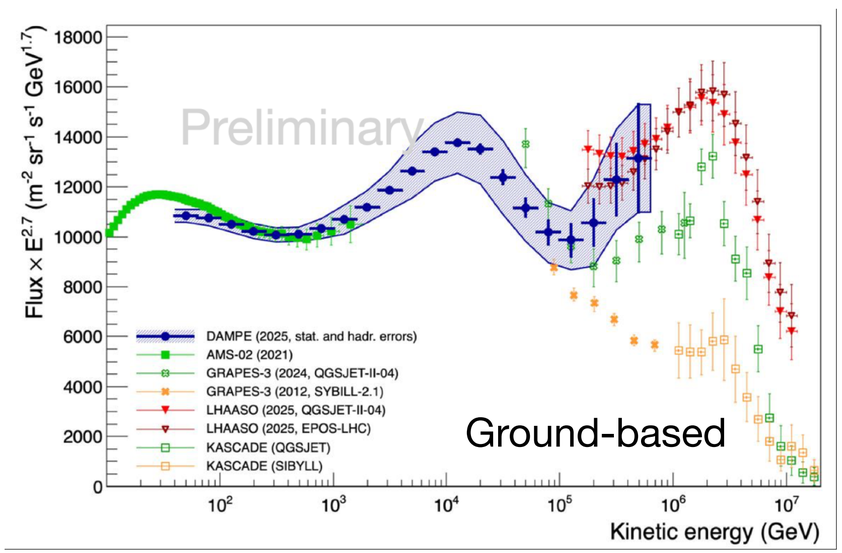
DAMPE collab., Phy. Rew.D 109, L121101 (2024)

Proton toward PeV (new updates)

1. Much more deepening understanding for the detectors and more statistics at higher energies.
2. New data processing approaches employed, i.e. ML tracking and Particle ID.
3. Updates and new approaches on detector calibration. Saturation.





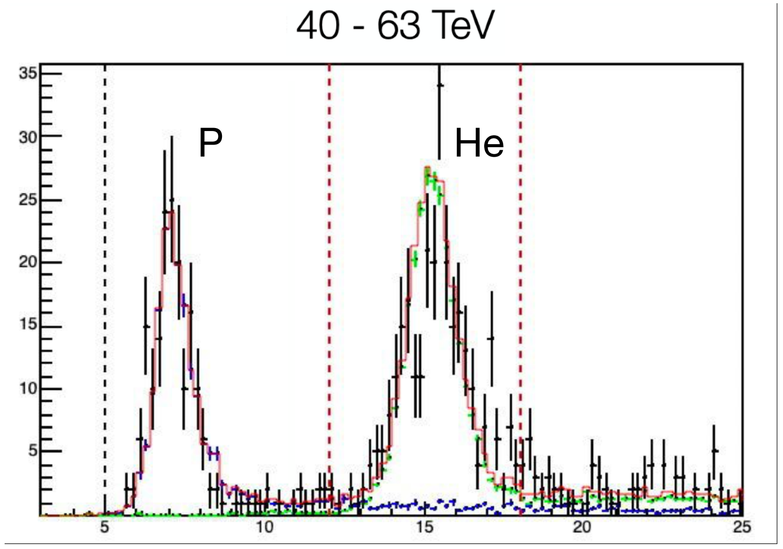


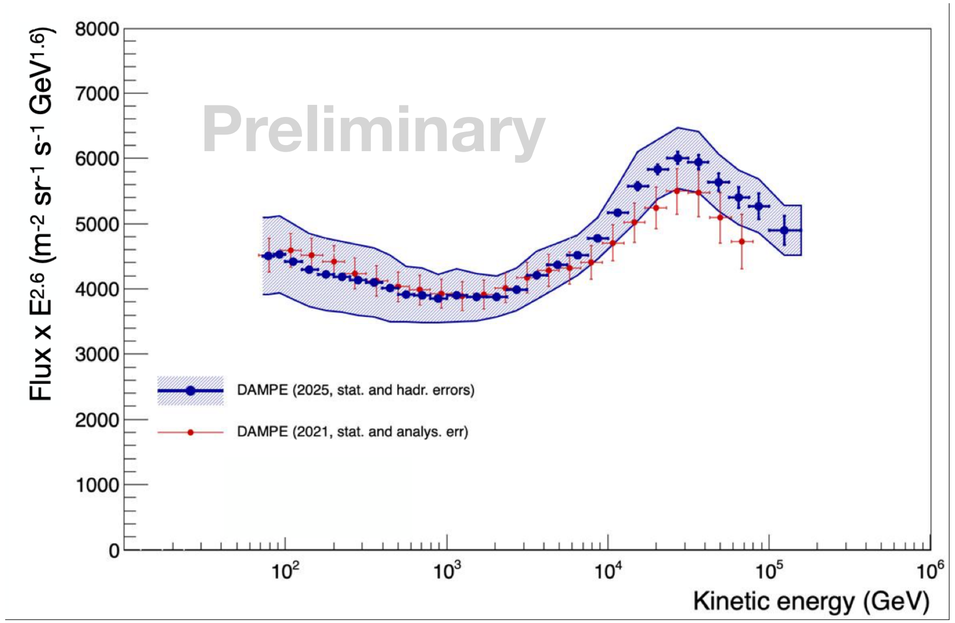
✓ Very consistent with published results.

✓ Direct comparable with ground-based experiments.

Helium (new updates)

1. Much more deepening understanding for the detectors and more statistics at higher energies.
2. New data processing approaches employed, i.e. ML tracking and Particle ID.
3. Updates and new approaches on detector calibration. Saturation.

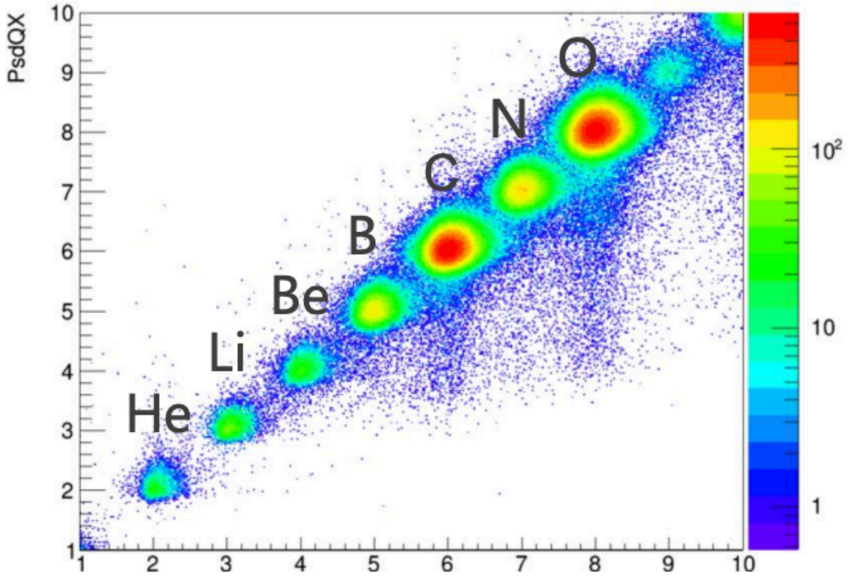


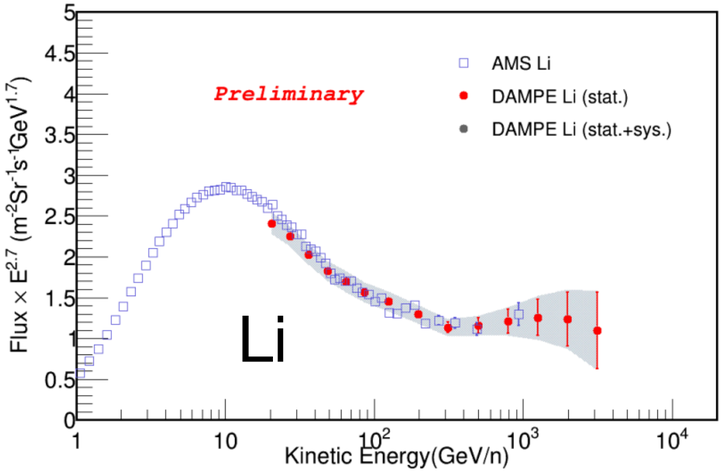


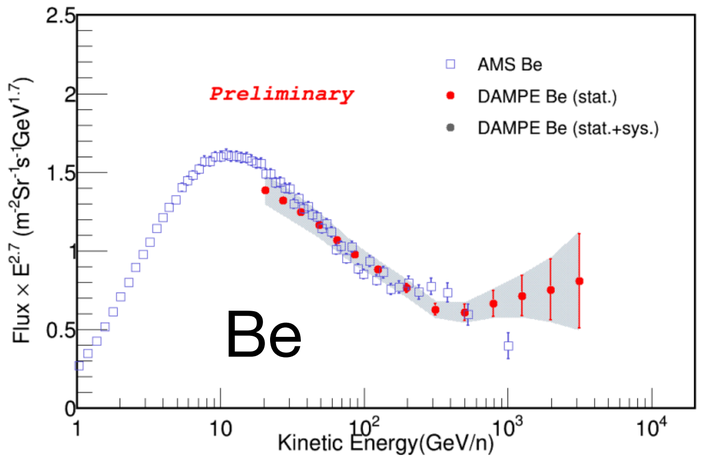
✓ Very consistent with published results.

Estimation of systematics in process

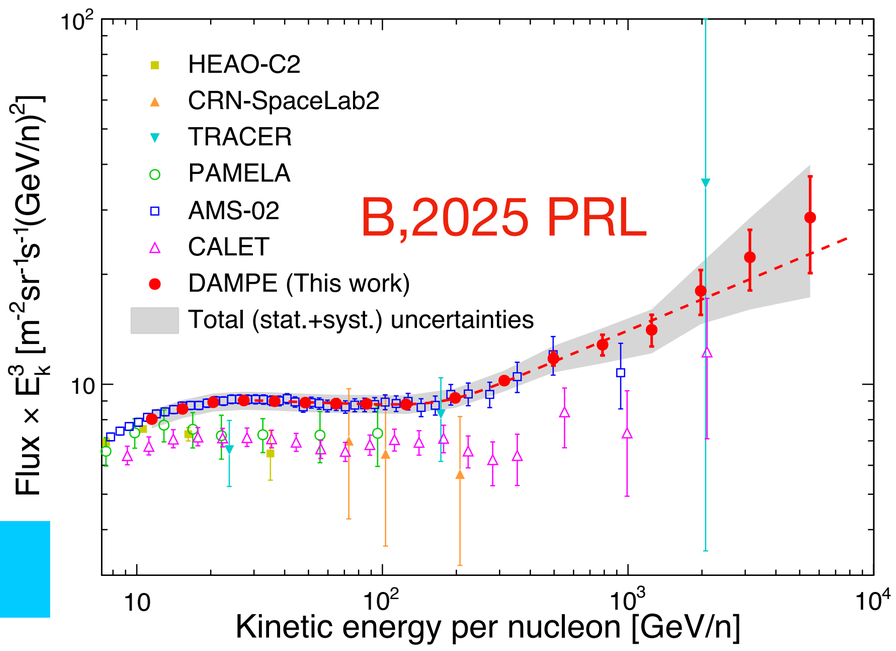
Li, Be and B

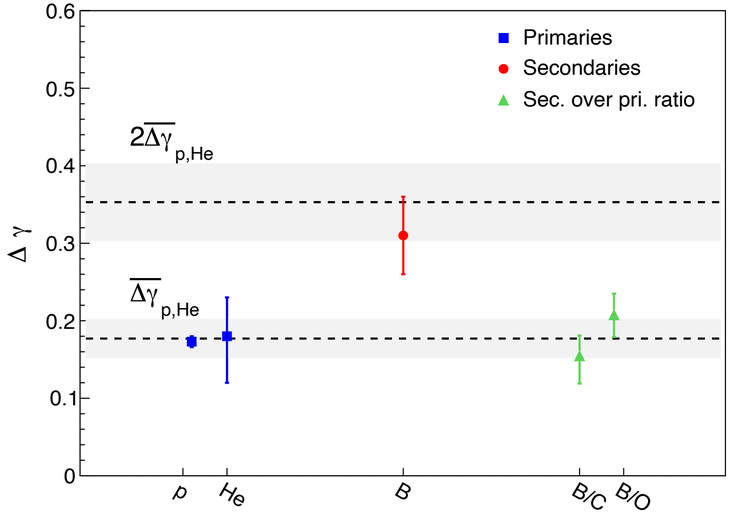






- ✓ Light attenuation correction
- ✓ Light saturation correction
- ✓ Charge energy-Independence
- ✓ MC charge smearing correction





DAMPE collab., Phy. Rew. Lett. 134, 191001 (2025) Brono spectrum

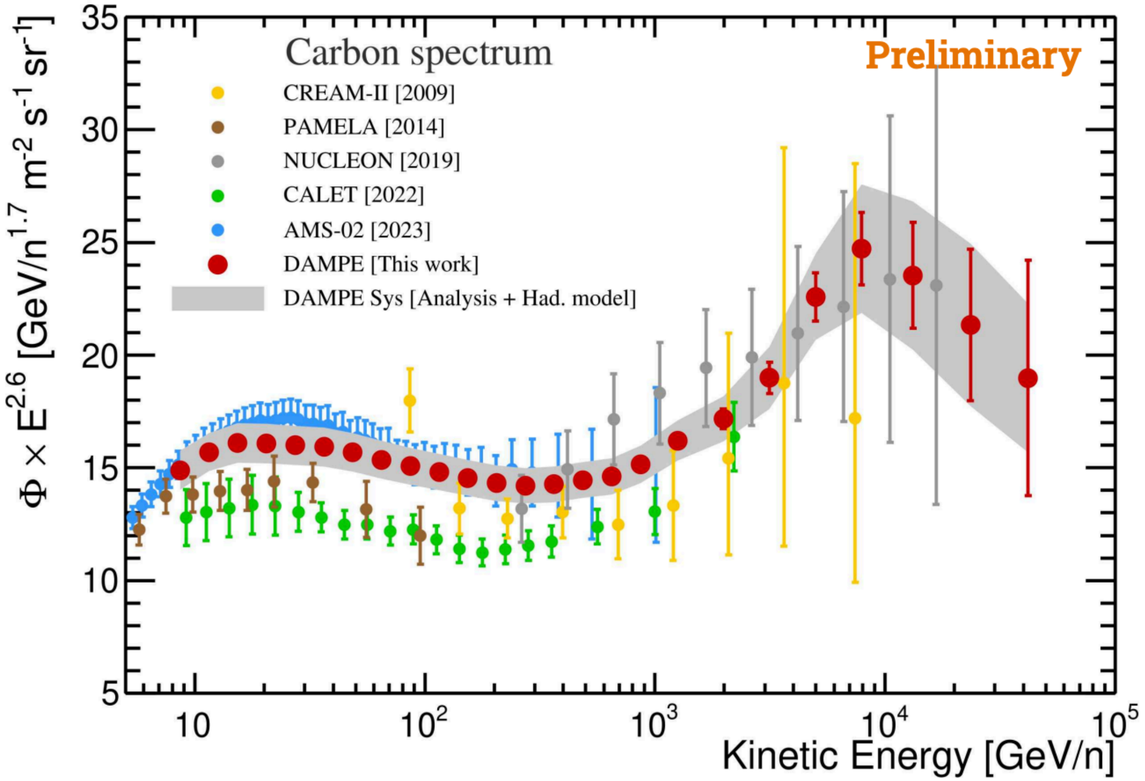
- ✓ A spectral hardening at ~ 200 GeV/n with sigma of CL. is observed
- ✓ △γ is about twice vs. p & He, consistent with propagation model.

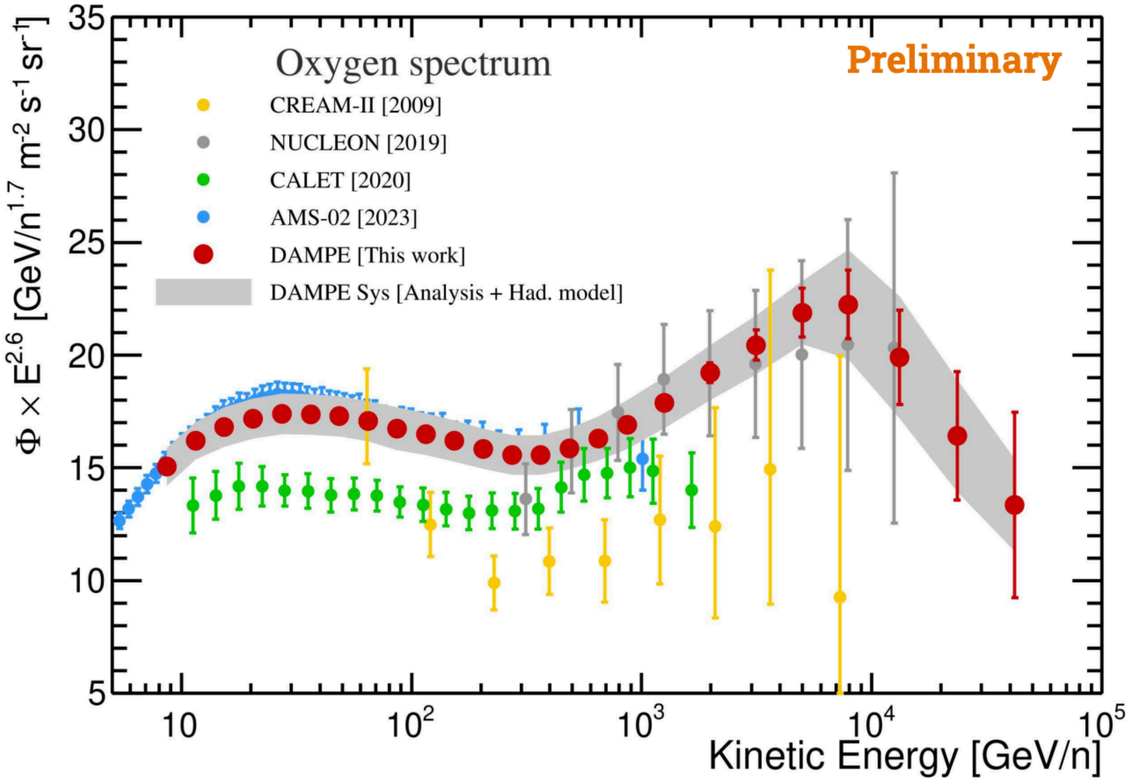
C and O

$$\Delta\Phi\left(E_i, E_i+\Delta E_i\right)=\frac{\Delta \mathrm{N_i}}{\Delta \mathrm{E_i}\ \mathrm{A_{eff},}_i \Delta \mathrm{T}}$$

9 years of Flight Data

Good agreement among DAMPE analyses groups

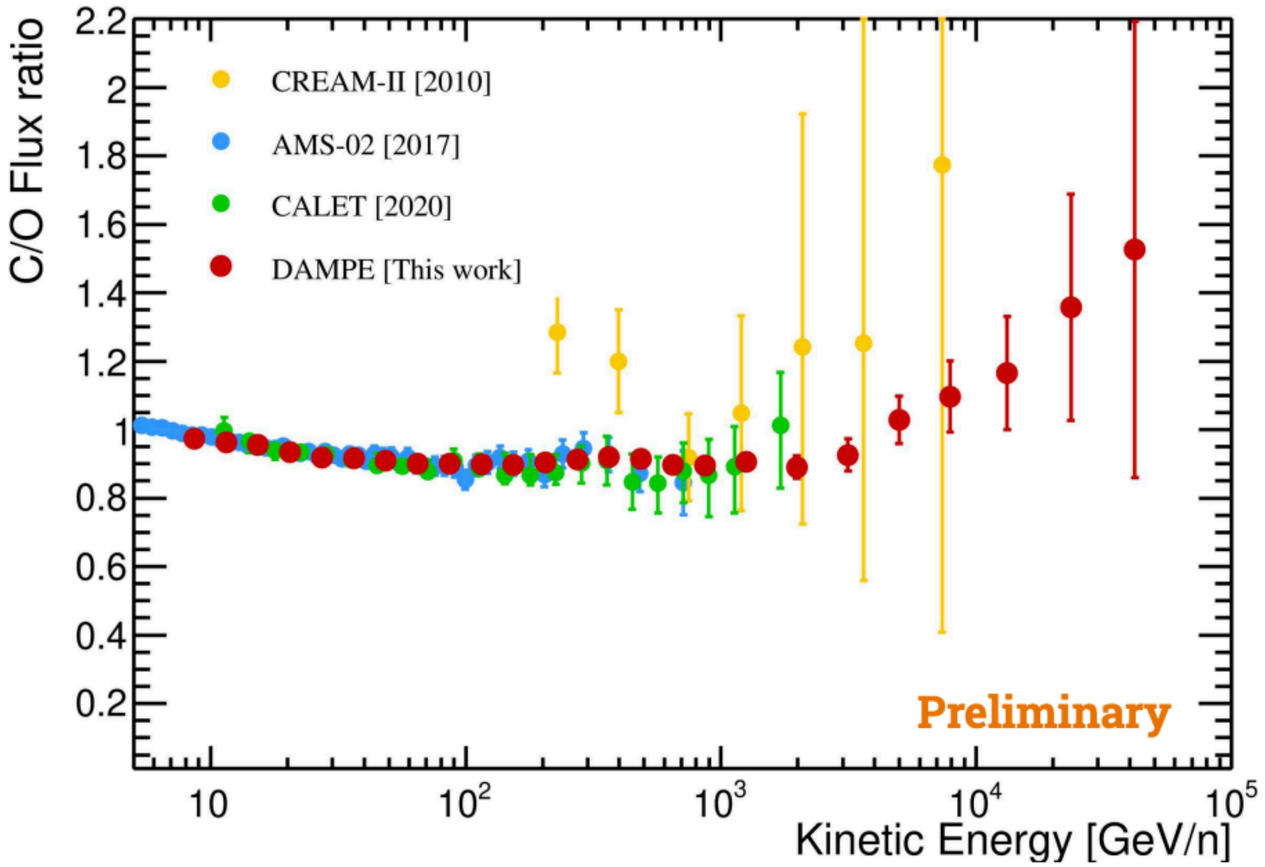




- ✓ **Extend to above 10 TeV/n with sufficient statistics in space**
- ✓ **Confirm the hardening at ~ 300 GeV/n and unveil the novel a softening at ~ 7.5 GeV/n (15 TV)**

Adapted from Chuan Yue's slides on ICRC2025

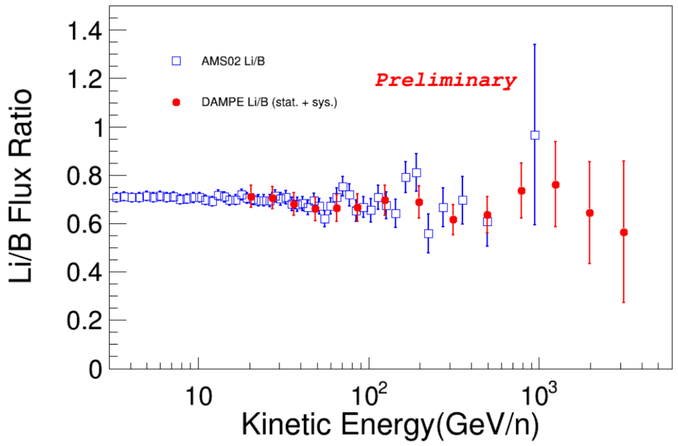
C/O ratio



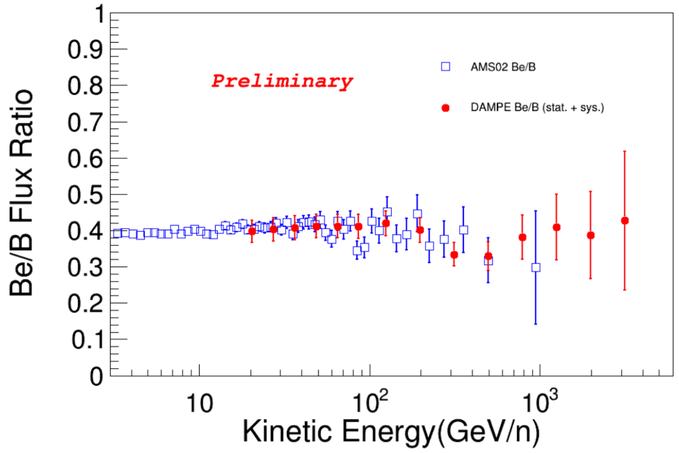
✓ **Hardening above a few TeV/n observed.**

Flux ratio

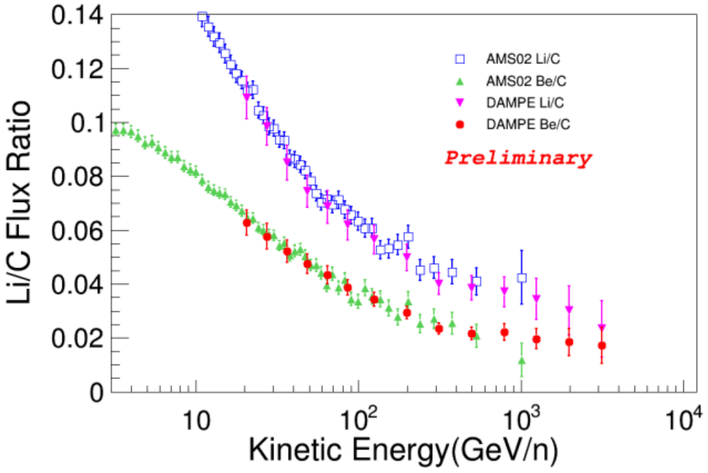
Li/B



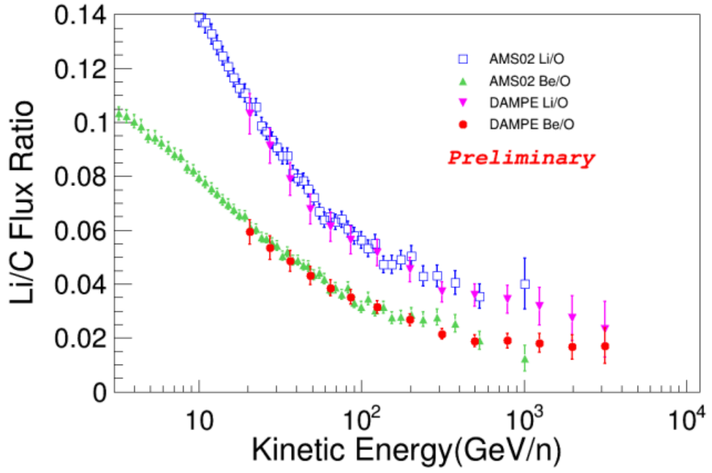
Be/B

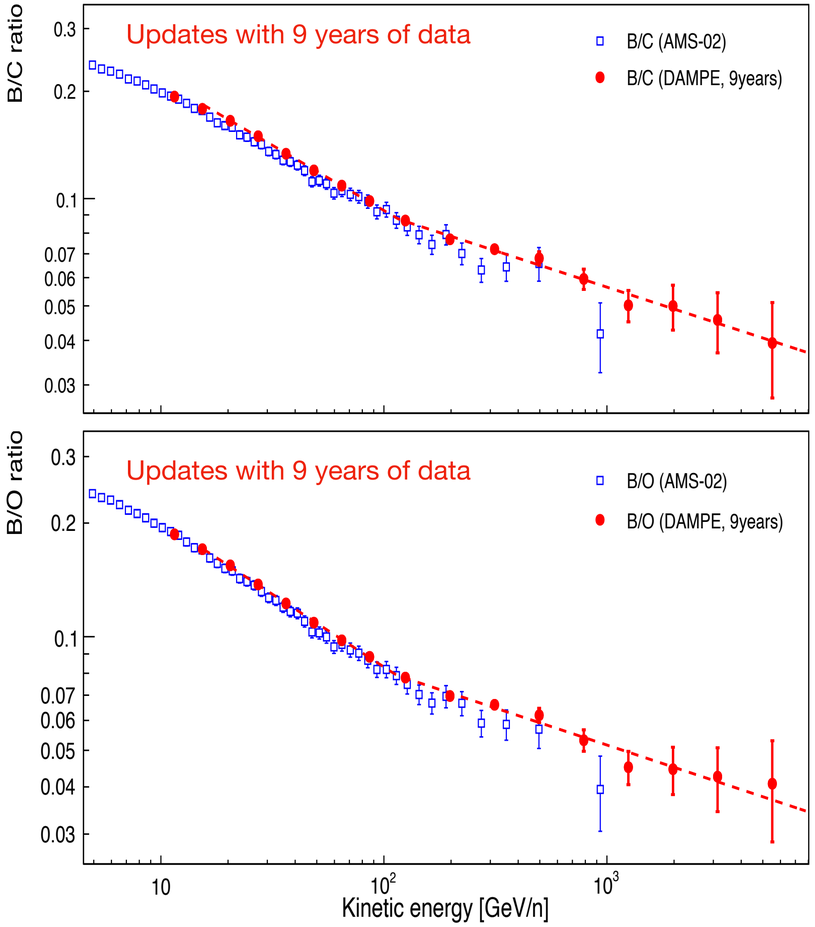


Li(Be)/C



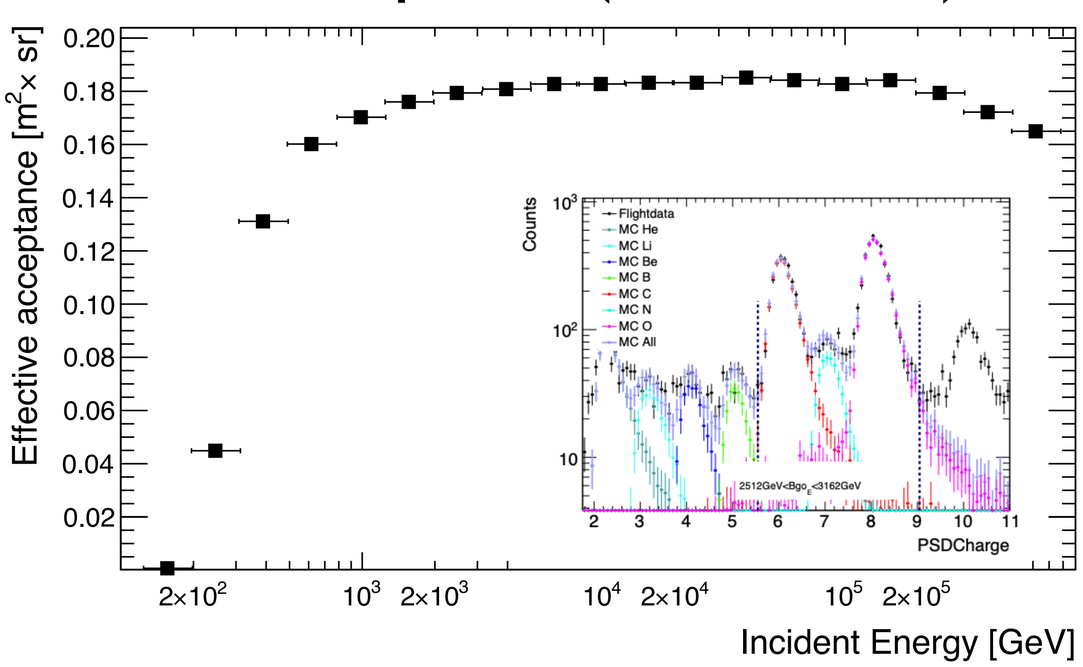
Li(Be)/O

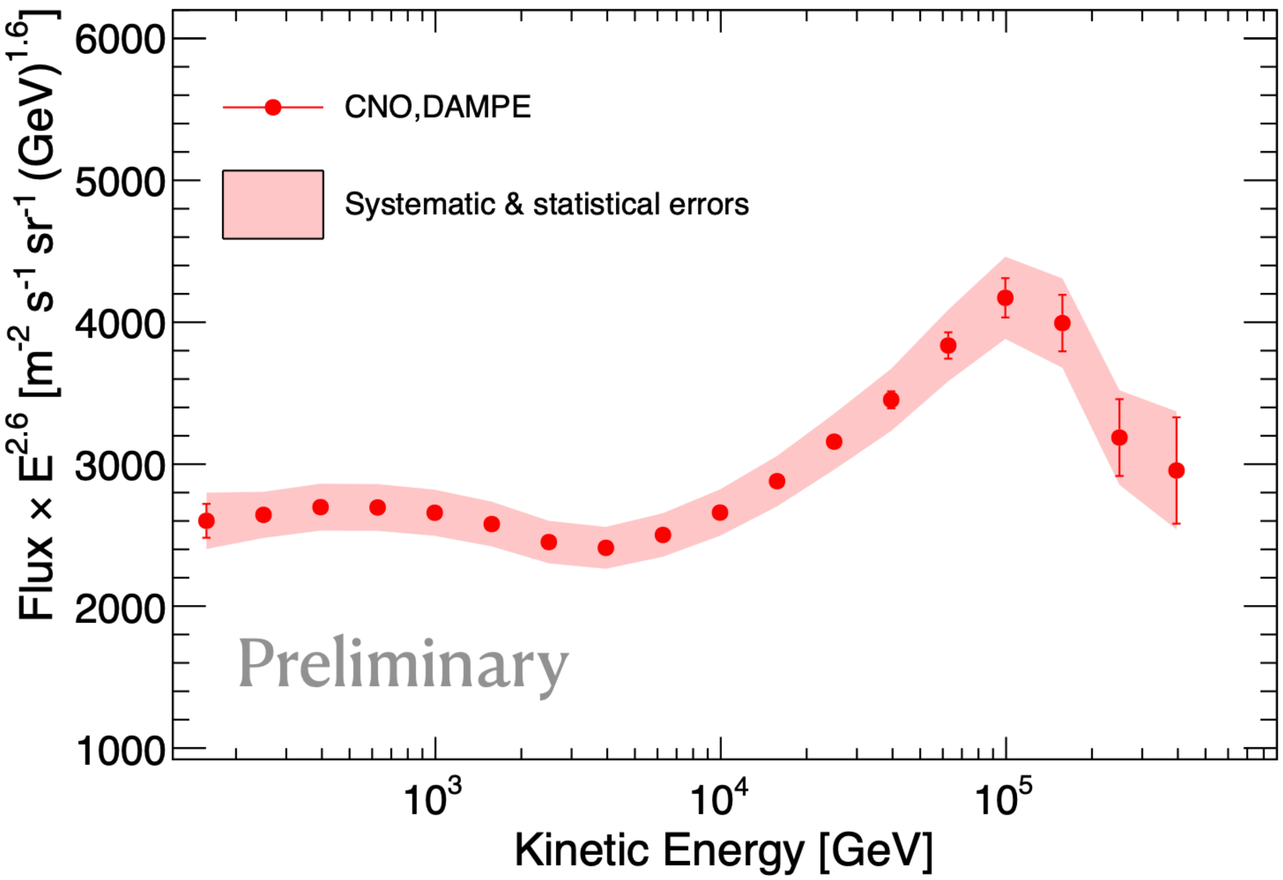




DAMPE Collaboration, Science Bulletin 67 (2022) 2162–2166

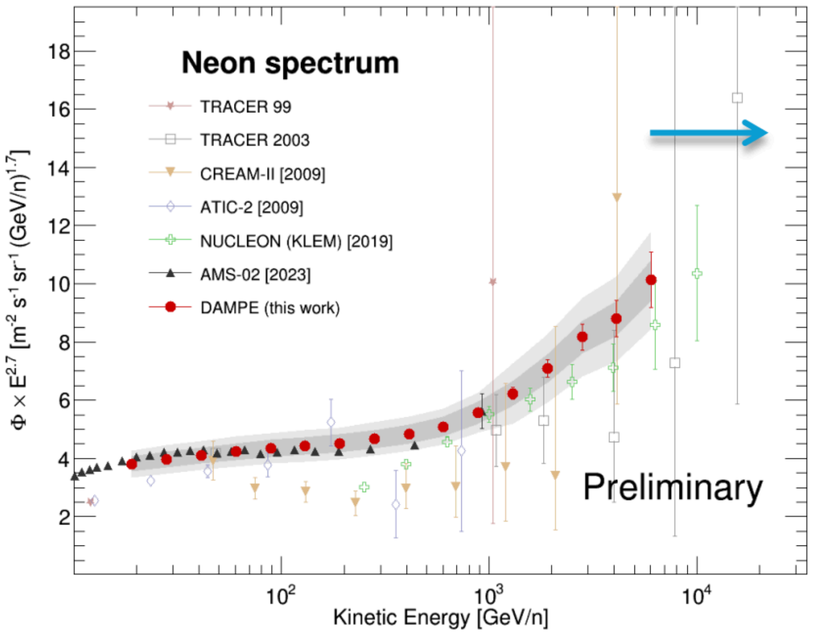
CNO flux

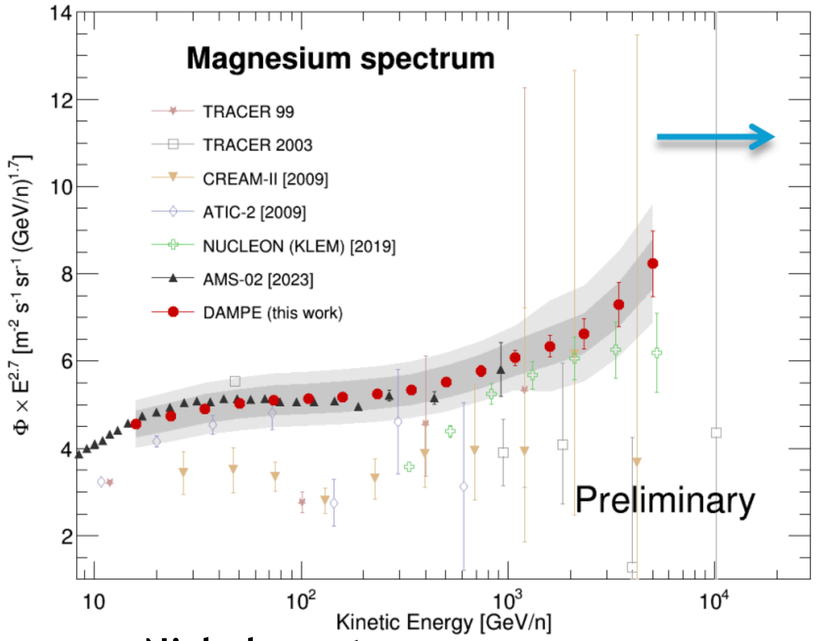


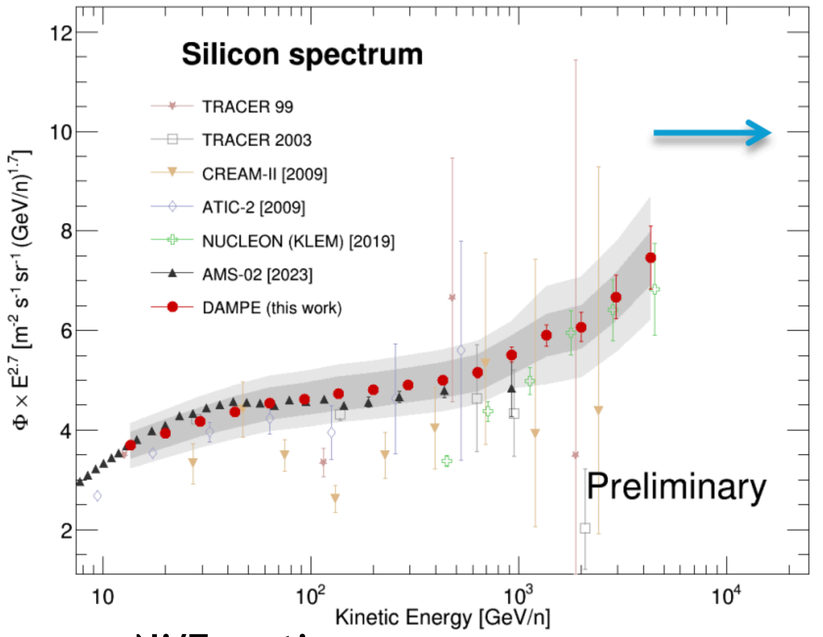


- The spectrum of CNO group is measured up to 500 TeV
- A spectral hardening at ~9 TeV with > 6 sigma of CL. is observed.

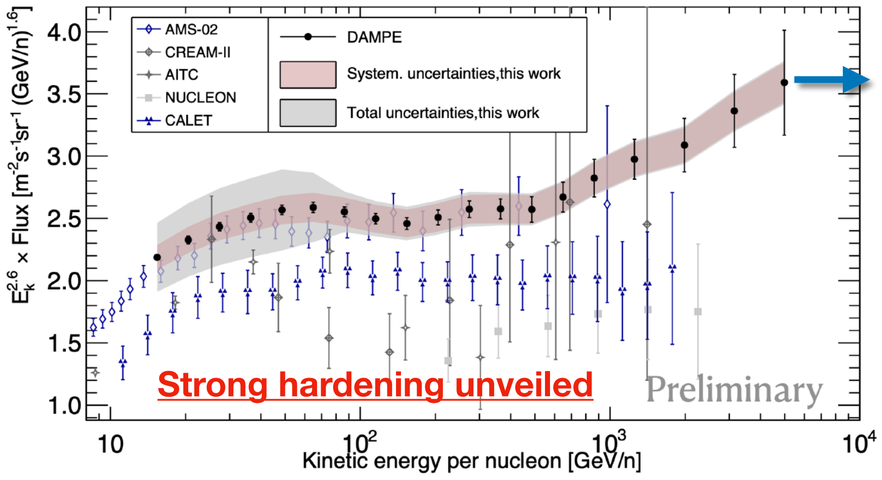
Much heavy nuclei's flux



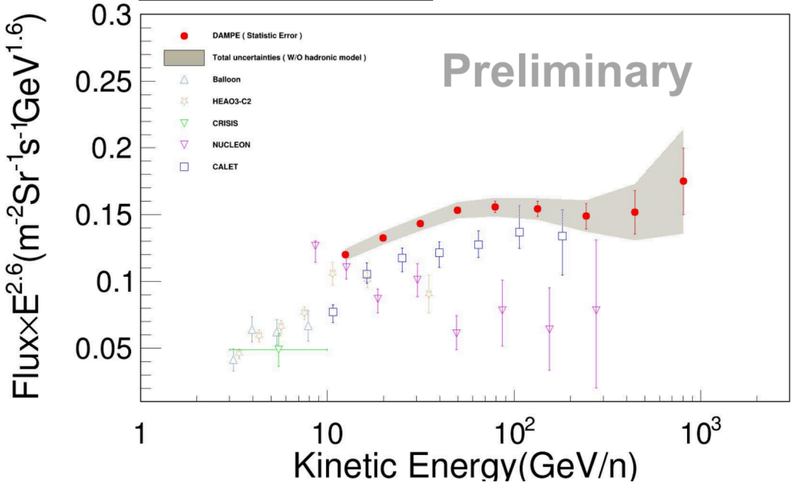




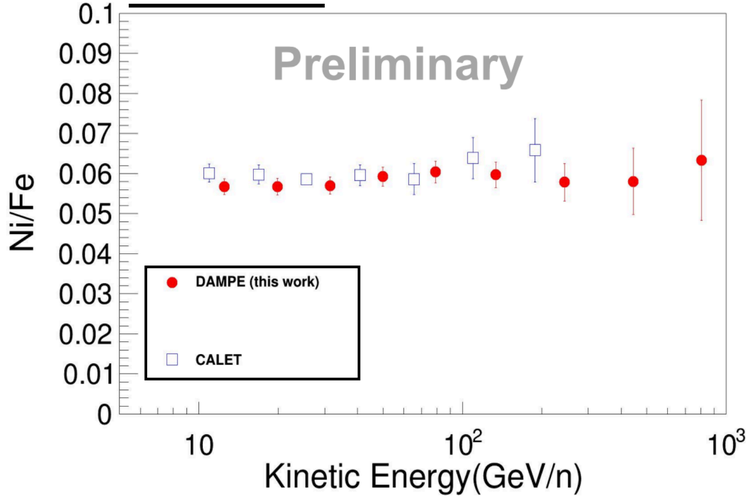
Iron spectrum



Nickel spectrum



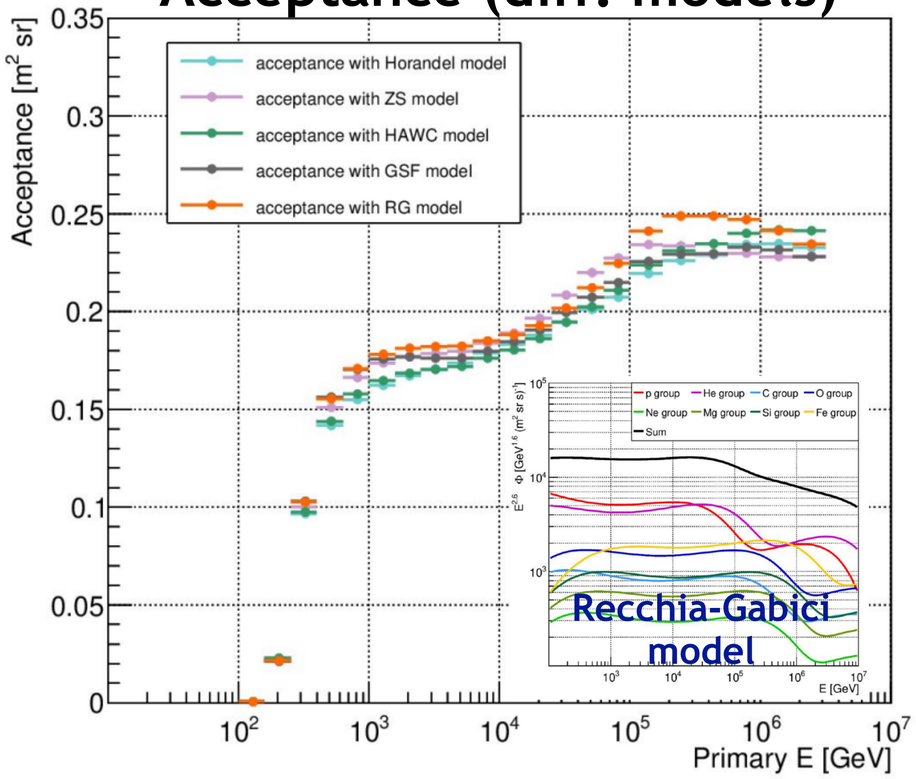
Ni/Fe ratio



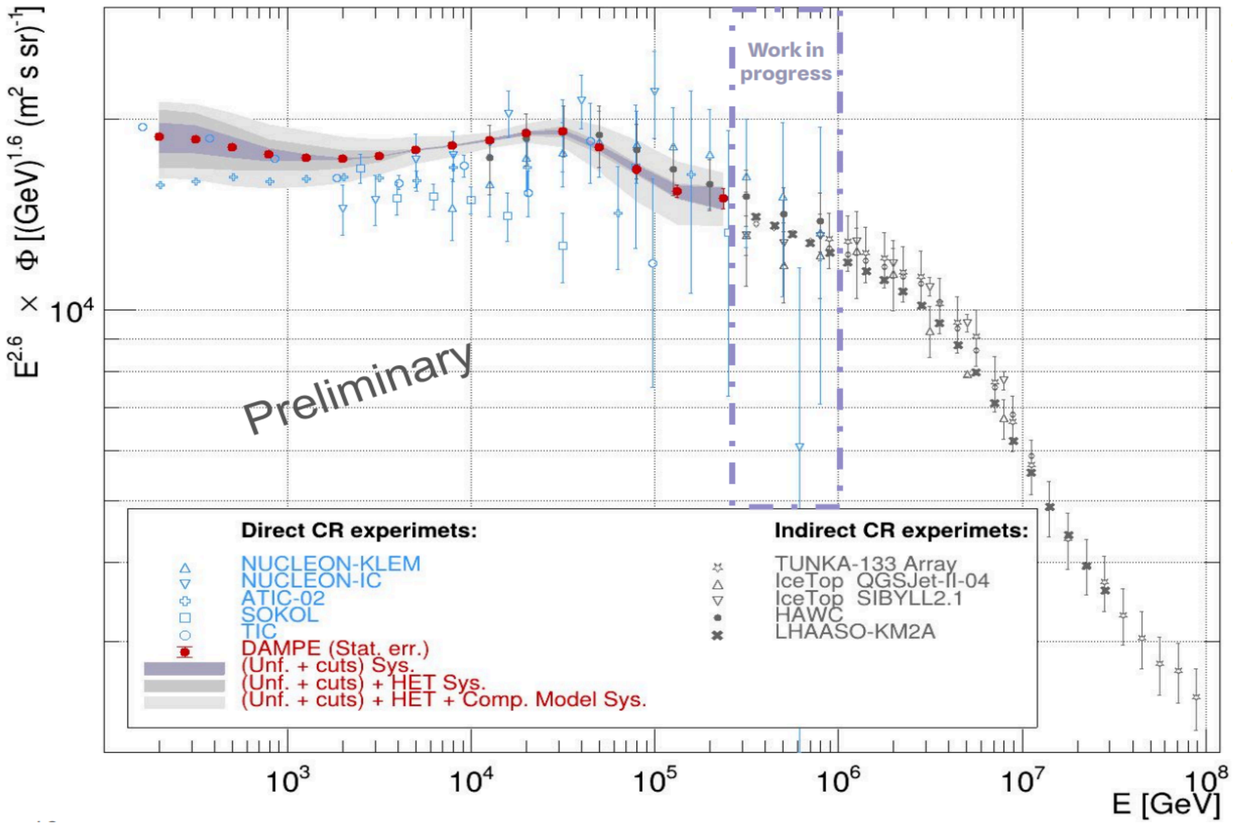
◉ **Confirm the hardening, analyses for >10 TeV/n below nickel are in progress**

All-particle spectrum

Acceptance (diff. models)



All-particle spectrum



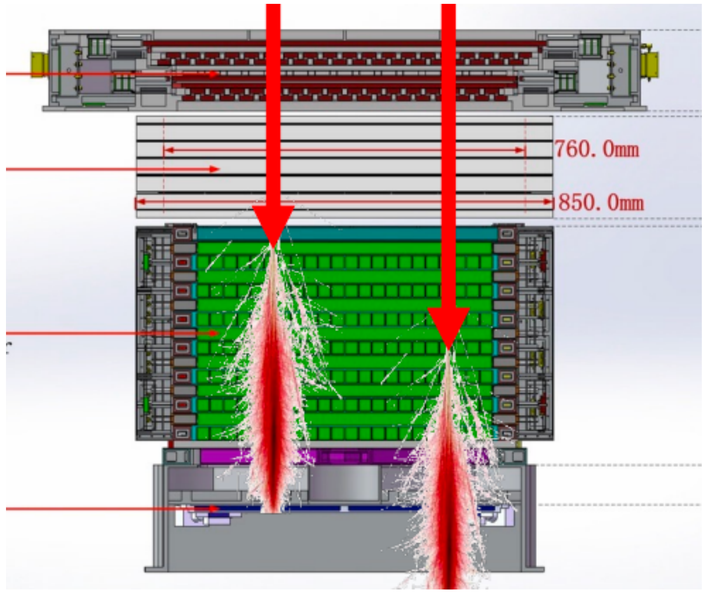
- Different composition models are evaluated and applied in the analysis.
- Preliminary all-particle spectrum show a clear “knee” feature at tens of TeV, most probably due to the softening of different components (p,He dominant).

Cross-section: p,He vs. BGO

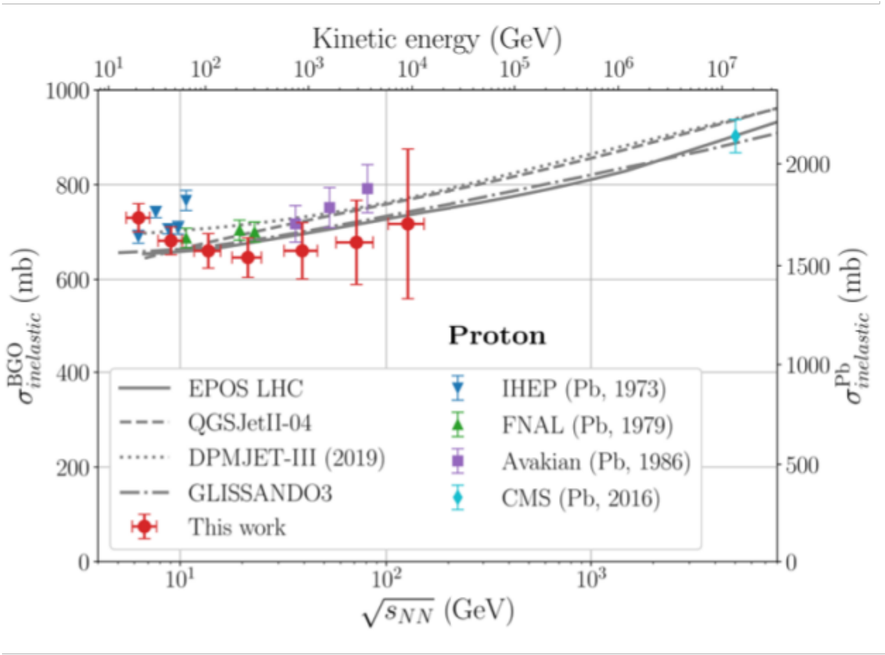
A beam-target experiment

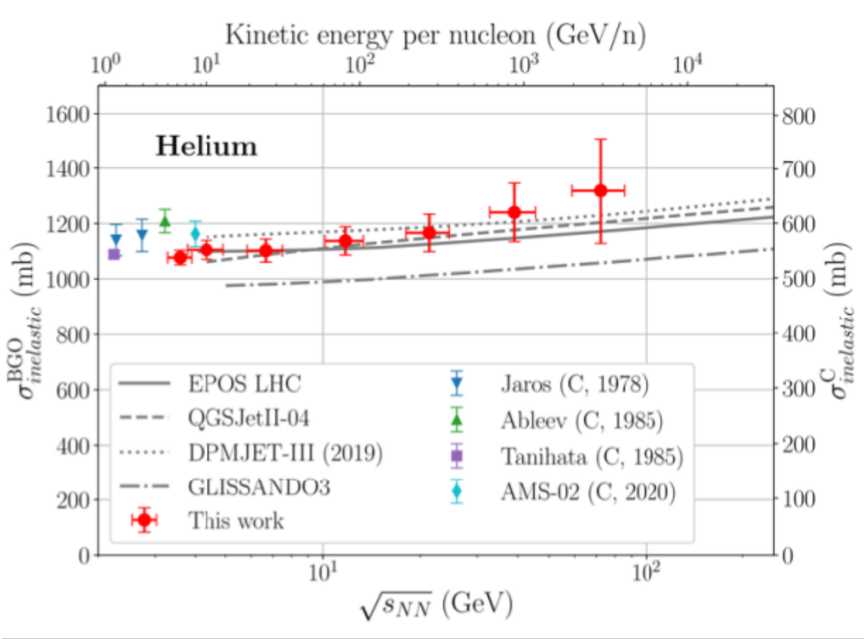
Beam: CR particles

Target: BGO ($Bi_4Ge_4O_{12}$)



DAMPE collab., Phy. Rew. D 111, 012002 (2025)





Survive possibility → Hadronic cross-section

$$\alpha_i = \frac{N_i}{\sum_{j=2}^{10} N_j}$$

$$\sigma_{true}(E) = (1+\kappa)\cdot\sigma_{MC}(E)$$

- **Inelastic cross-section of p/He vs. BGO up to 10 TeV**
- **Effective validation for the hadronic models above TeV**

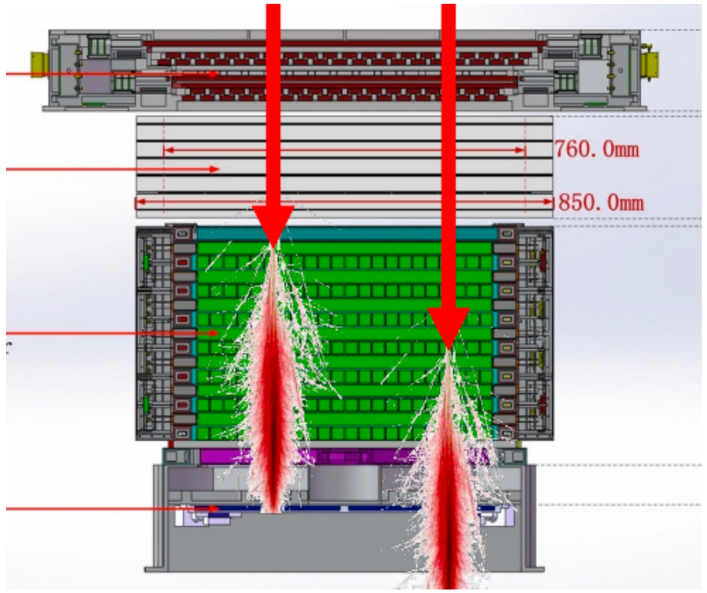
Adapted from Chuan Yue's slides on ICRC2025

Cross-section: C,O vs. BGO

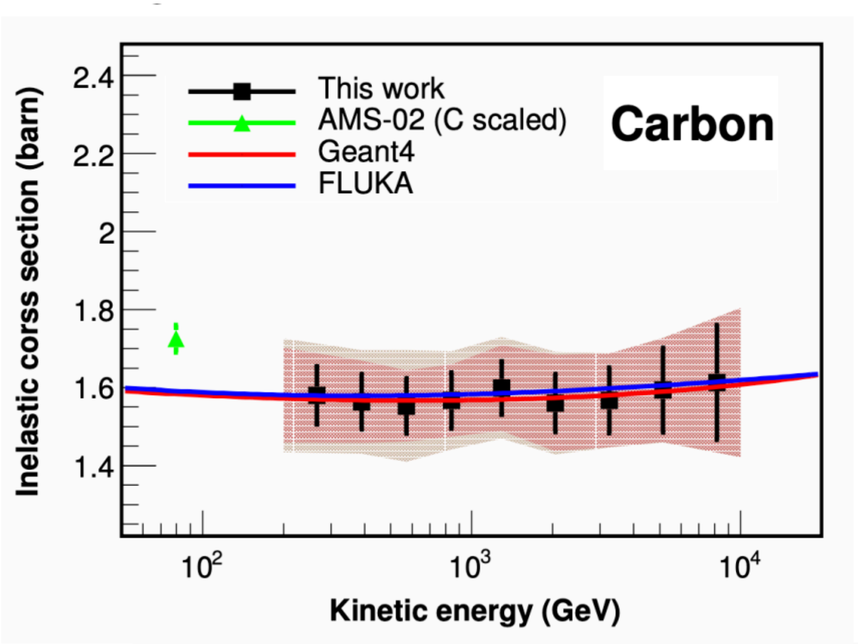
A beam-target experiment

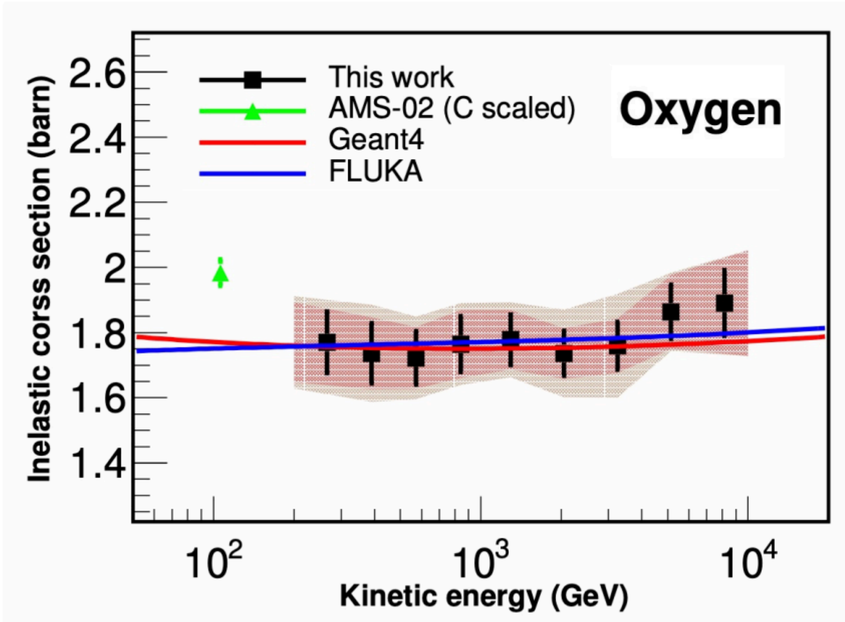
Beam: CR particles

Target: BGO ($Bi_4Ge_4O_{12}$)



DAMPE collab., Phy. Rew. D in print (2025)





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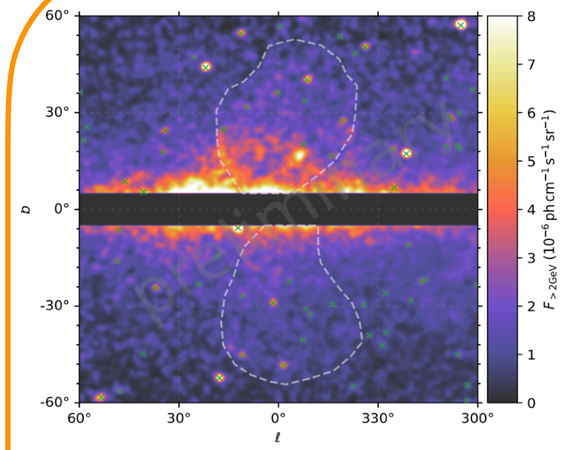
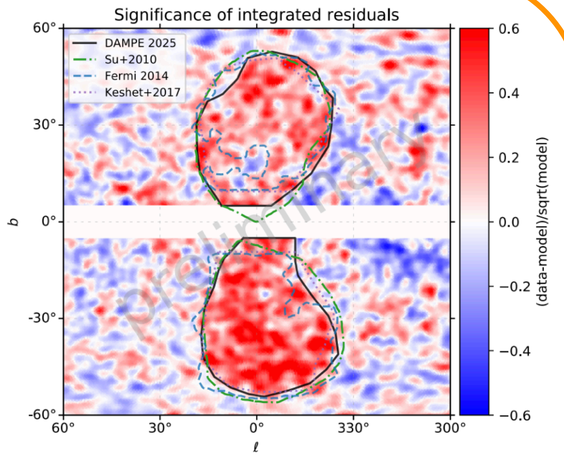
- **Inelastic cross-section of C/O vs. BGO up to 10 TeV**
- **Effective validation for the hadronic models above TeV**

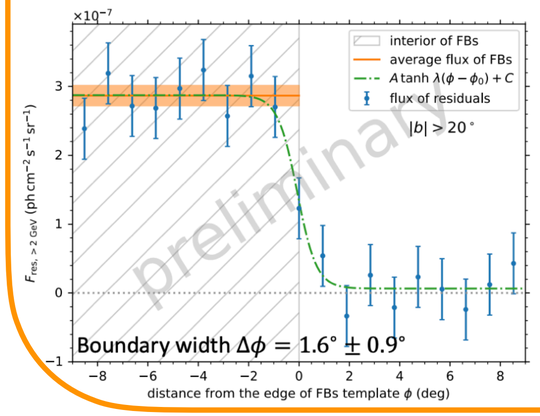
Adapted from Chuan Yue's slides on ICRC2025

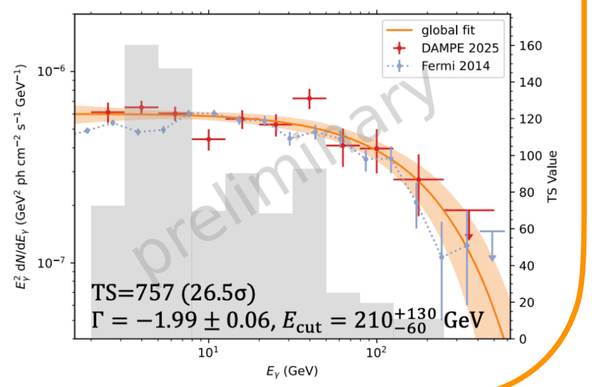
Fermi bubbles, Galatic Center Excess

Fermi-Bubbles (FB)

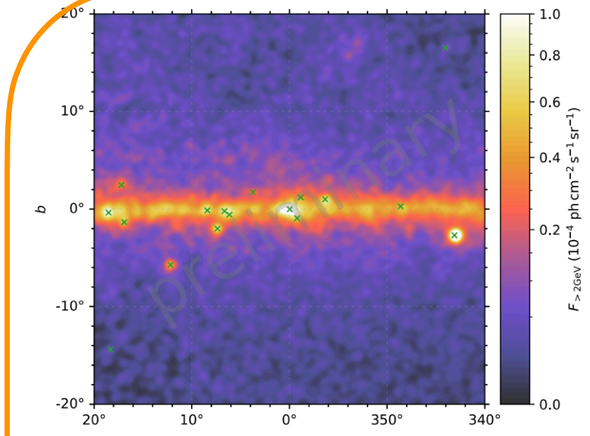


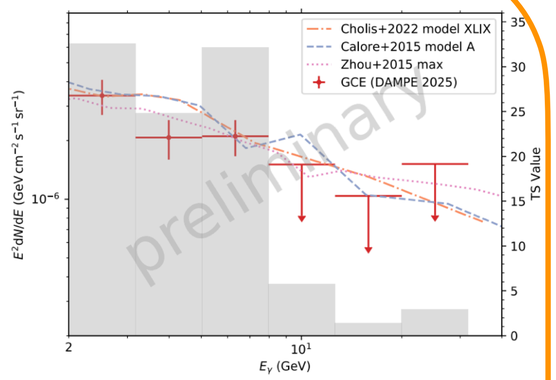


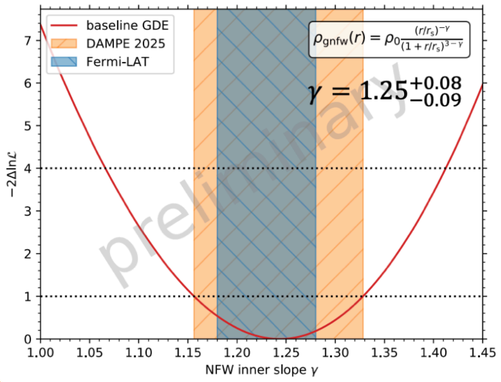


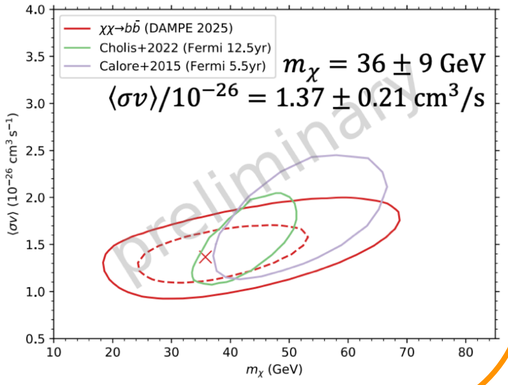


Galatic Center Excess (GCE)









◉ **FB: TS=757 (26.5σ for 11 dof)**

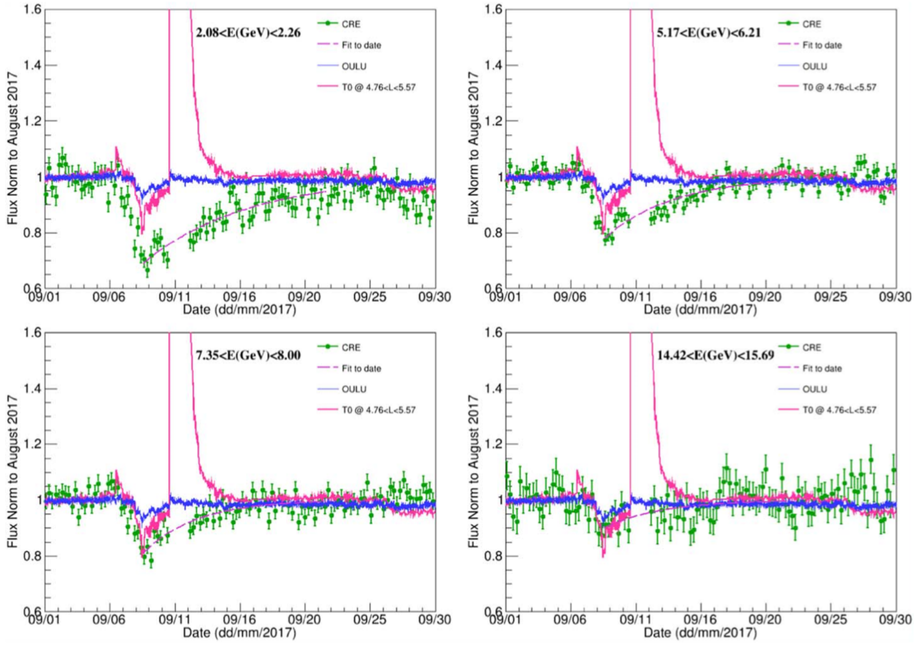
◉ **GCE: TS=72.8 (7.4σ for 6 dof)**

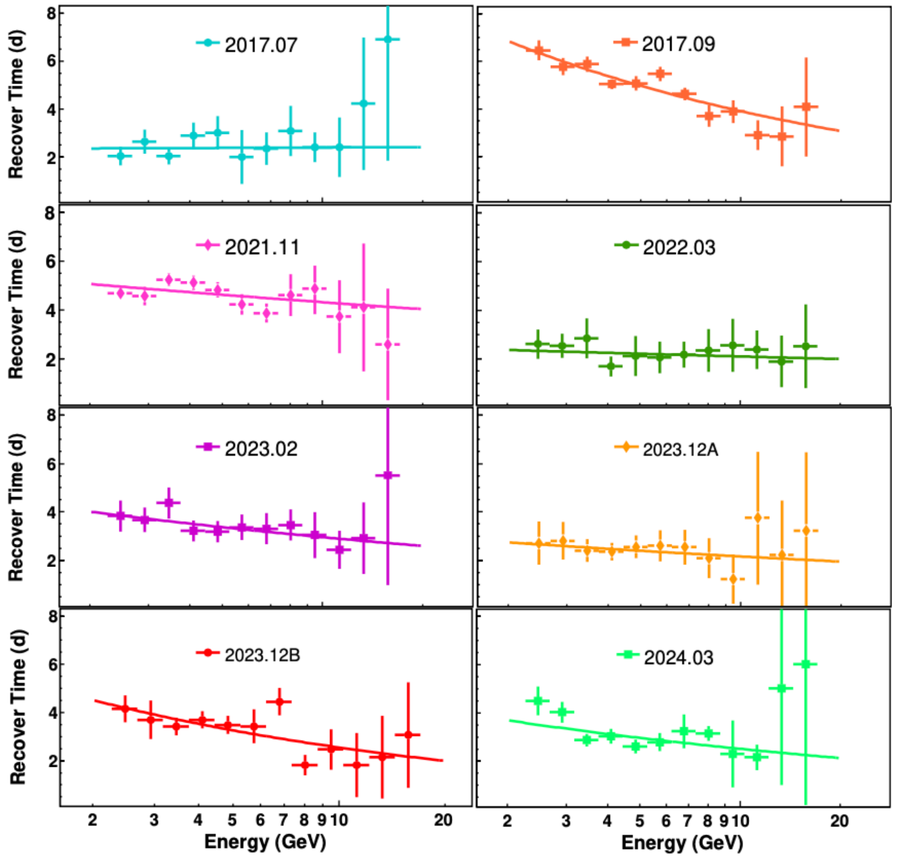
✓First independent observations in space outside the Fermi mission.

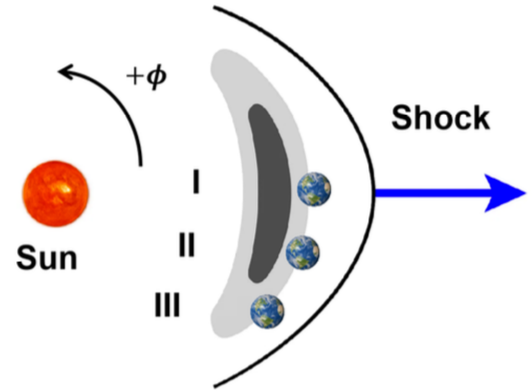
Heliosphere physics:Forbush decrease

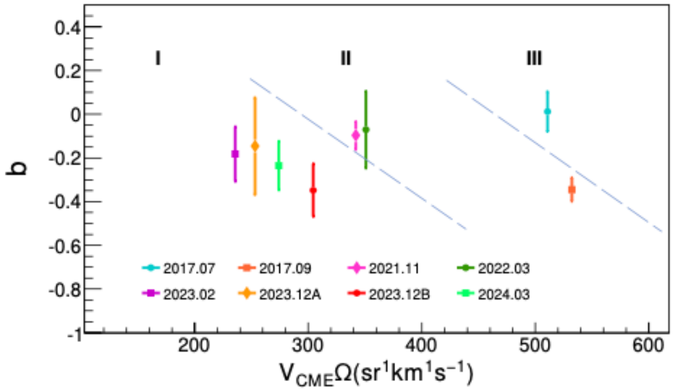
- **Forbush Decrease (FD)** — CR follow-up of explosive solar activity, e.g. CME
- Large acceptance and polar orbit of DAMPE— allows precise FD measurement

DAMPE collaboration, ApJL. 920 L43 (2021)









More events observed.

New FD features for the relation: **recovery time** vs. **decrease amplitude —> diverse properties of FDs**

Summary

- **DAMPE mission**
  - **1.DAMPE has been operating smoothly since Dec. 2015, for over 9 years.**
  - **2.Largest acceptance in space and good performance.**
  - **3. Potential for extension above 100TeV.**
  - **4.Stable operation to collect much more data.**
- **Sciences**
  - **1.Direction observation of break at TeV in $e^{\pm}$ spectrum.**
  - **2.P&He show the softening around ~15TV.**
  - **3.P+He confirms the softening and shows the hint above 100TeV.**
  - **4.C,O and CNO confirm the hardening at hundreds of GV, suggesting a Z-dependent softening.**
  - **5.B/C,B/O show the significant hardening above 100TeV/n, challenging the conventional models.**
  - **6. Secondary elements, Li,Be,B confirm the hardening around hundreds of GV.**
  - **7. Preliminary iron spectrum shows the hardening around 1TeV/n for the first time.**
  - **8. Confirm the FB. and GCE as a independent measurement.**
  - **9. Heliosphere physics in terms of low energy electron measurements, unique point of view.**
  - **10. Gamma ray catalog, gamma ray line searching, fractional charge particle search in space. (Not included in this talk.)**

Published

Summary

- **DAMPE mission**

  1.DAMPE has been operating smoothly since Dec. 2015, for over 9 years.

  2.Largest acceptance in space and good performance.

  3. Potential for extension above 100TeV.

  4.Stable operation to collect much more data.

- **Sciences**

  1.Direction observation of break at TeV in $e^{\pm}$ spectrum.

  2.P&He show the softening around ~15TV.

  3.P+He confirms the softening and shows the hint above 100TeV.

  Published

  4.C,O and CNO confirm the hardening at hundreds of GV, suggesting a Z-dependent softening.

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  9. Heliosphere physics in terms of low energy electron measurements, unique point of view.

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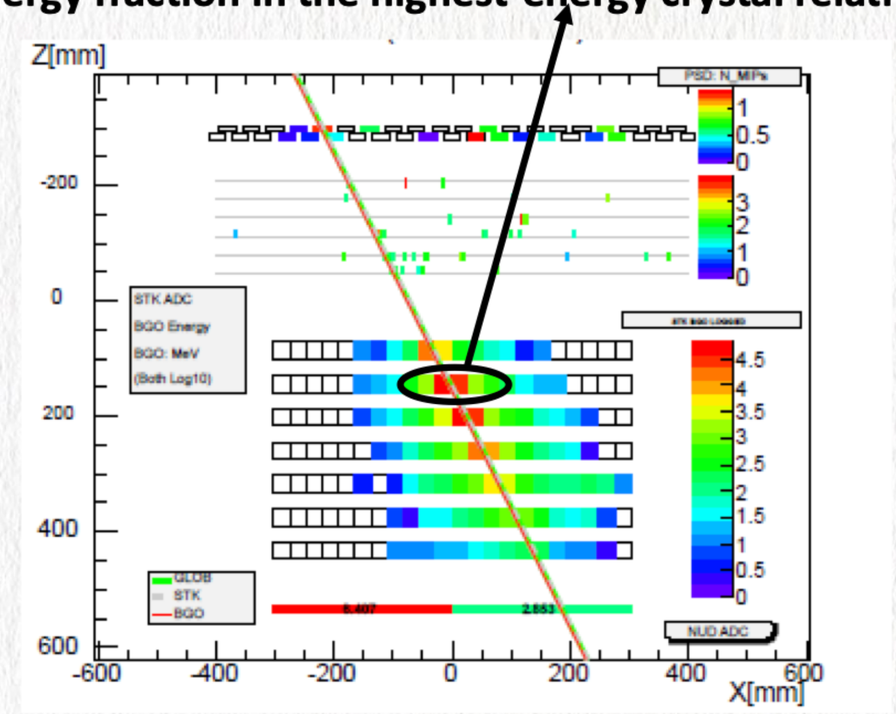
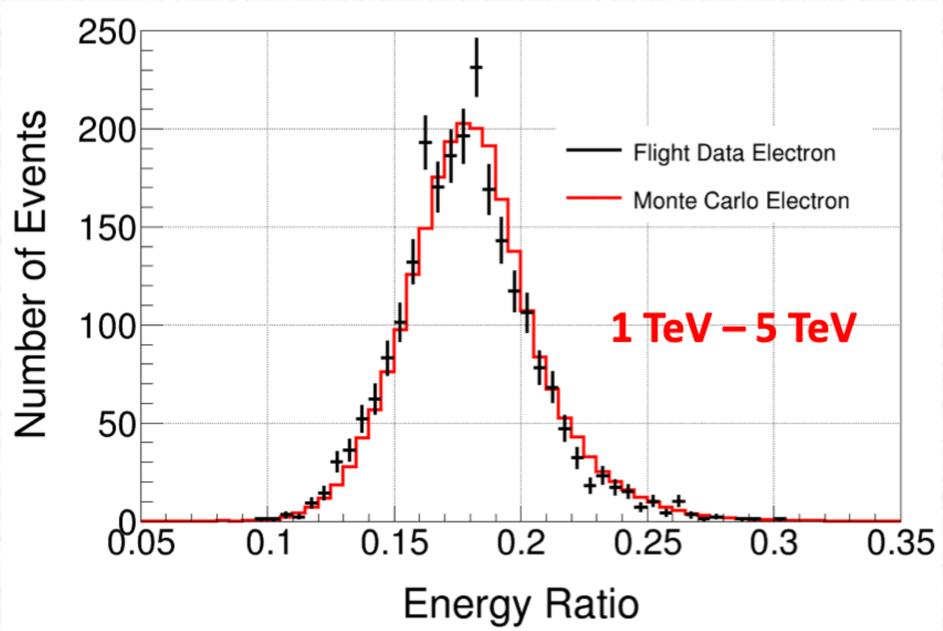
Thank you!

Backup

Energy fraction in shower maximum crystal

Energy fraction in the highest-energy crystal relative to total deposited energy in the BGO calorimeter





- High sensitivity to calorimeter status
- Validation of energy calibration via data–MC consistency

Adapted from Cong Zhao's slides on ICRC2025

On-orbit calibration of BGO Calorimeter

MeV scale

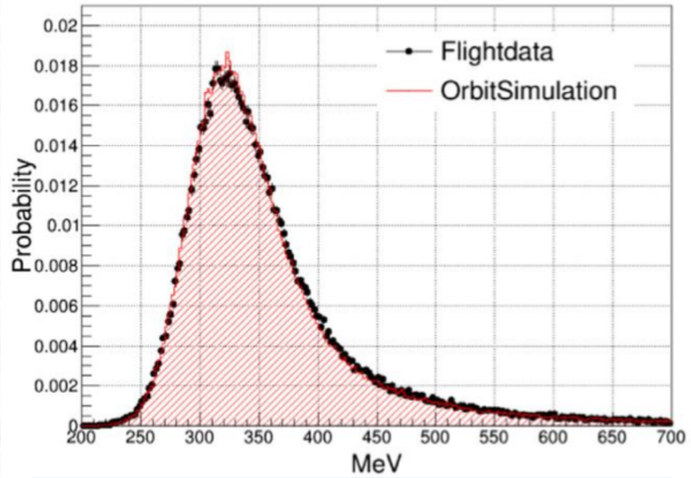
MIP signals precisely calibrate each individual detector unit

GeV scale

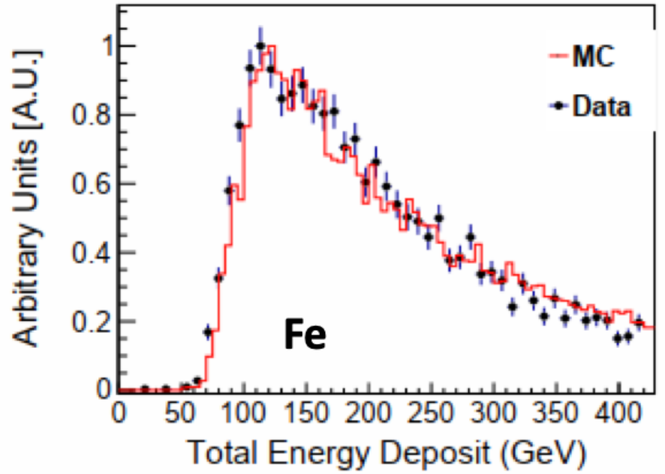
Geomagnetic cutoff of heavy nuclei serves as an absolute energy scale reference for higher energy

TeV scale

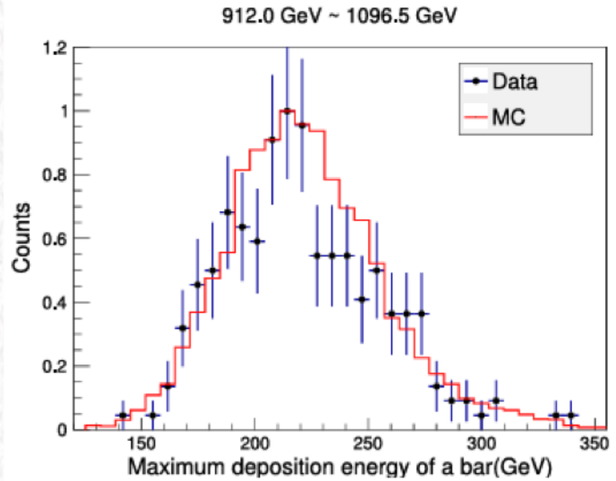
TeV electron shower cores verify detector performance and response



S. C. Wen et al., NIMA 1028 (2022)



H. T. Dai et al, IEEE 67.6 (2020)



C. Zhao et al, NIMA 1029 (2022)

Energy calibration covers a wide dynamic range from MeV to TeV

Adapted from Cong Zhao's slides on ICRC2025