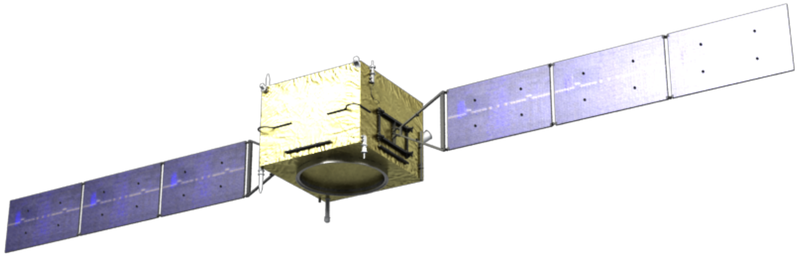


Measurements of primary cosmic ray spectra with DAMPE space mission

Yue, Chuan (岳川)

Purple Mountain Observatory, Chinese Academy of Sciences

on behalf of the DAMPE Collaboration

International Workshop on Cosmic Ray Direct Detection and Physics, 10th Anniversary of DAMPE

17 Dec. 2025, Nanjing

Outline

- DAMPE mission
- Cosmic-ray detection with DAMPE
- Primary CR spectral measurements
- Summary

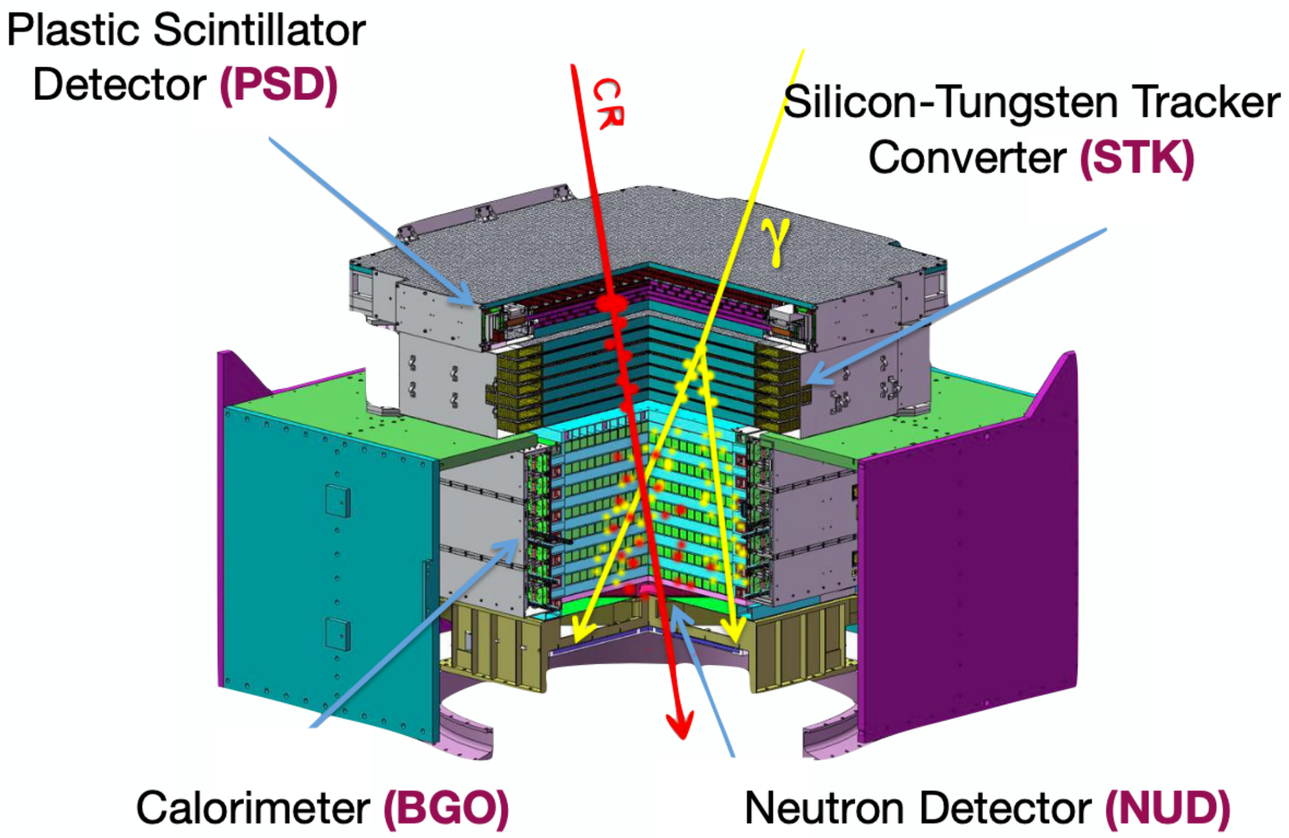
DAMPE collaboration

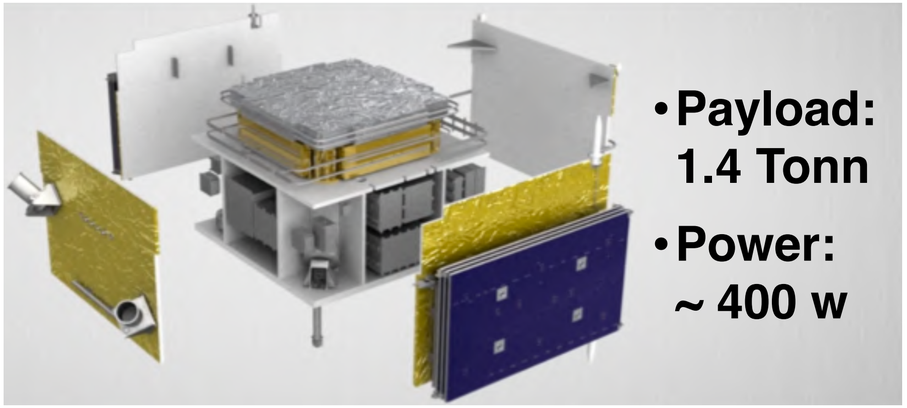
DAMPE ("Wukong" 悟空) is a satellite-borne particle detector proposed in the framework of the Strategic Pioneer Program on Space Science, promoted by the **Chinese Academy of Sciences (CAS)**

150+ members

- CHINA
  - Purple Mountain Observatory, CAS, Nanjing
  - Institute of High Energy Physics, CAS, Beijing
  - National Space Science Center, CAS, Beijing
  - University of Science and Technology of China, Hefei
  - Institute of Modern Physics, CAS, Lanzhou
- ITALY
  - INFN Perugia and University of Perugia
  - INFN Bari and University of Bari
  - INFN Lecce and University of Salento
  - INFN LNGS and Gran Sasso Science Institute
- SWITZERLAND
  - University of Geneva

DAMPE detector





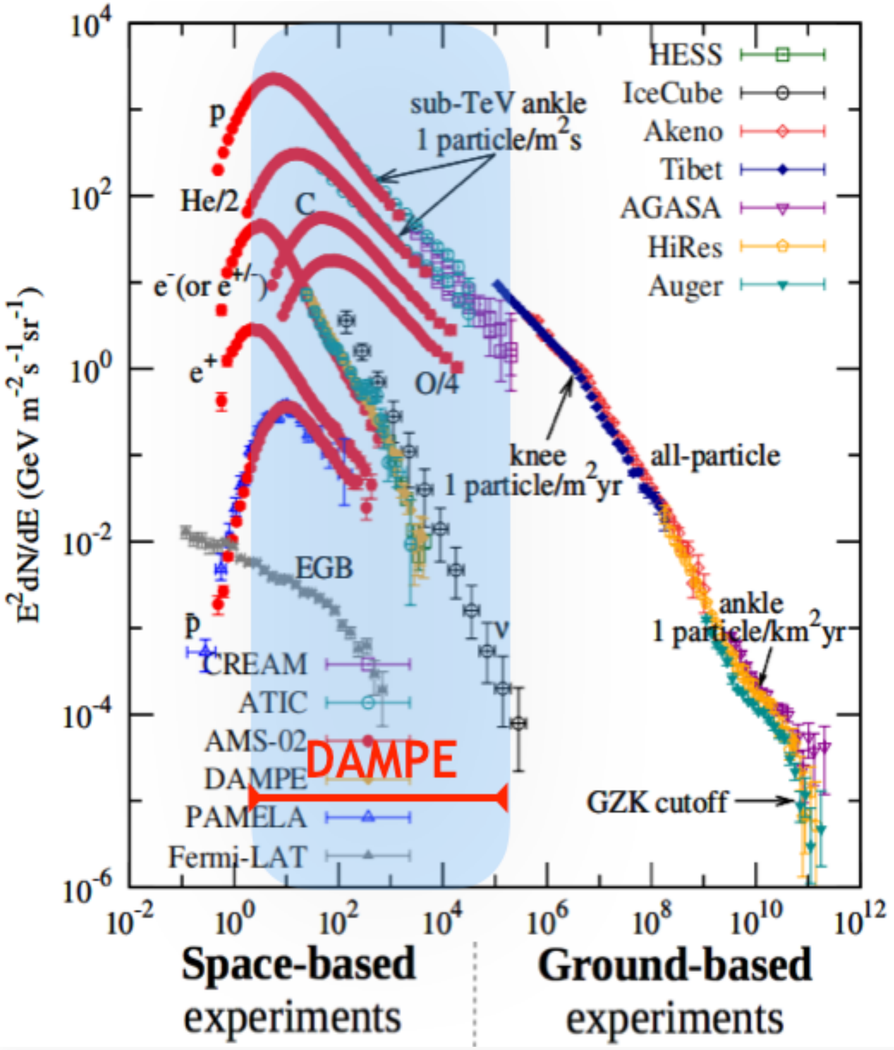
- **Payload: 1.4 Tonn**
- **Power: ~ 400 w**

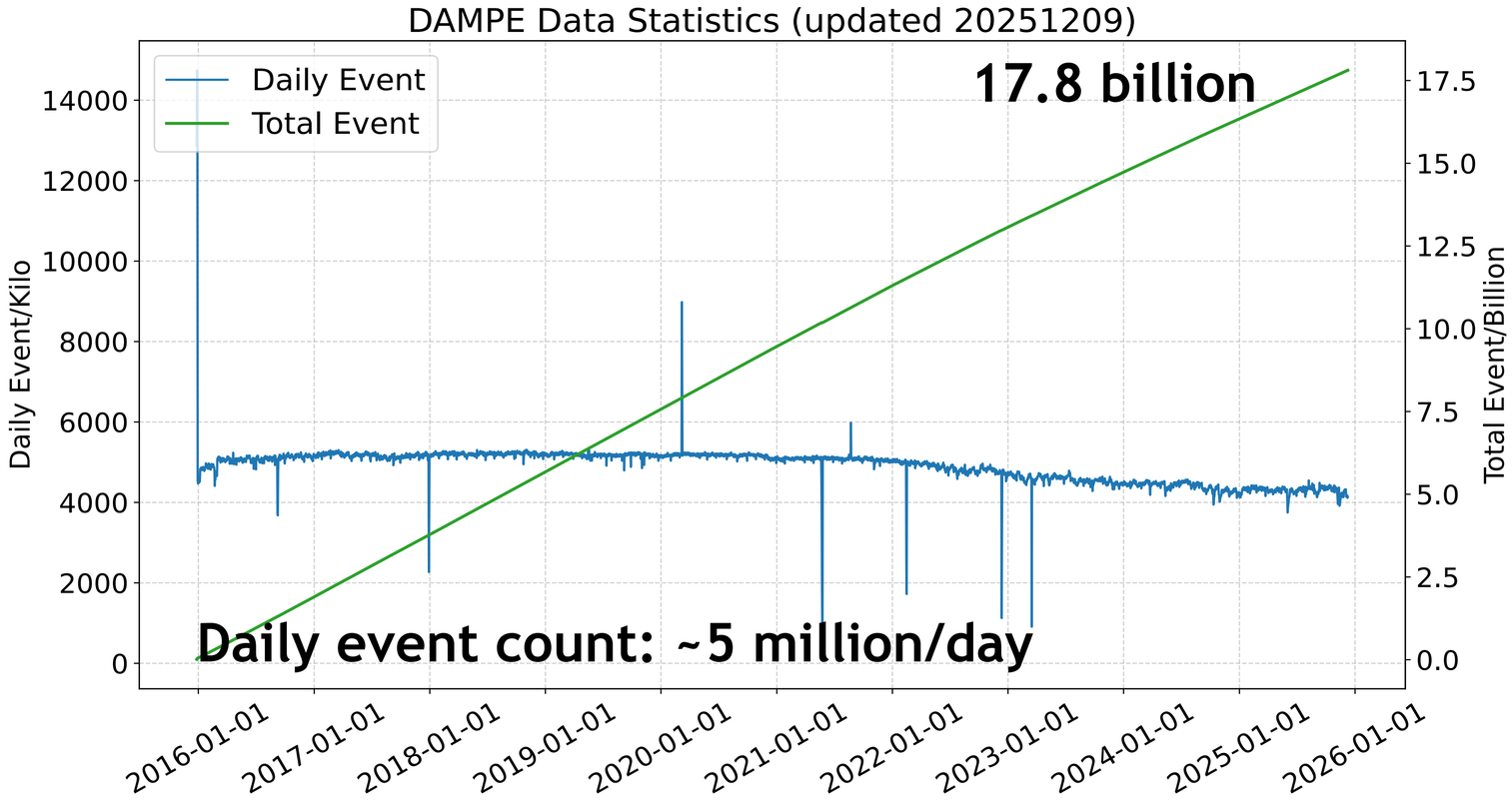
Parameter	Value
Energy range (e/γ)	5 GeV to 10 TeV
Energy resolution (e/γ)	1.5% at 800 GeV
Energy range (p/ion)	50 GeV to 500 TeV
Energy resolution (p)	40% at 800 GeV
Geometric factor (e)	0.3 m^2 sr above 30 GeV
Angular resolution (γ)	0.1 degree at 100 GeV
Field of view	1.0 sr

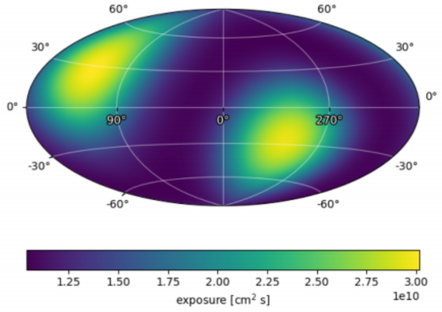
- **PSD: Charge measurement via dE/dx, ACD for photons**
- **STK: Track, charge, and photon converter**
- **BGO: Energy measurement, particle (e/p) identification**
- **NUD: Additional e/p identification in high energy range**

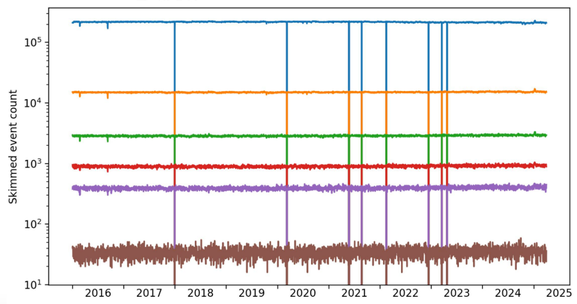
On-orbit operation of DAMPE

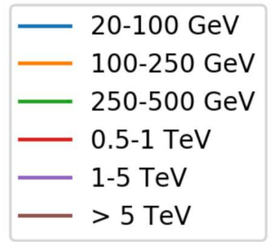
Cosmic-ray Detection





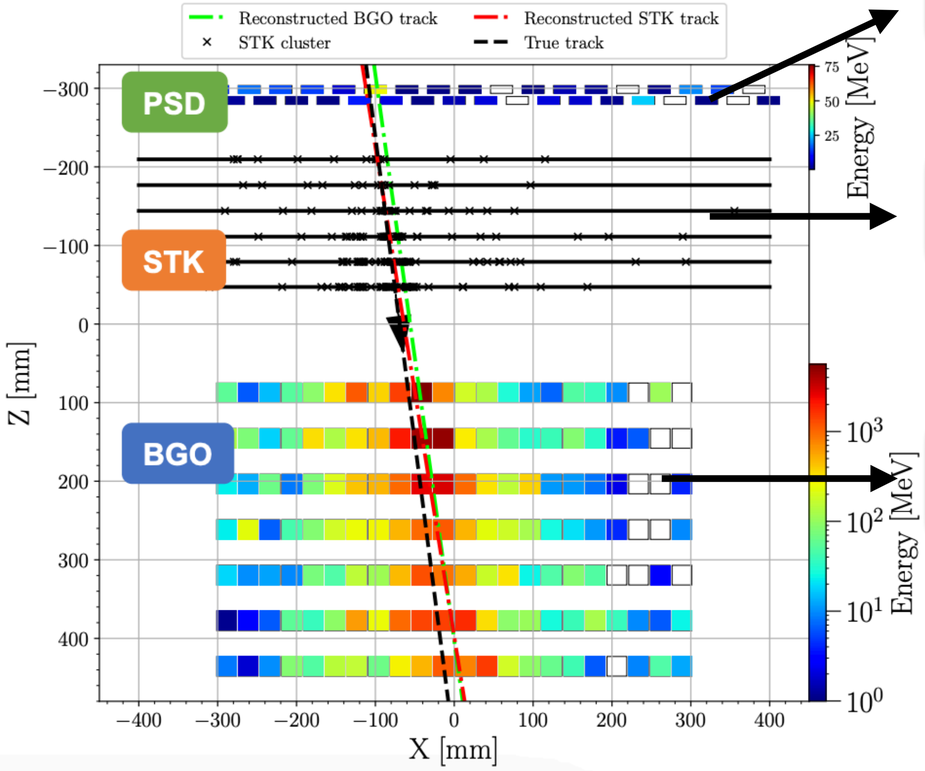






Shower detection

A shower event

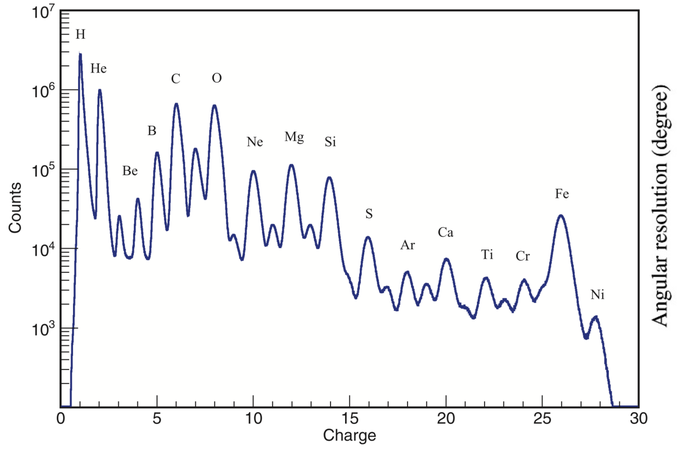


Charge Measurement

Track Measurement

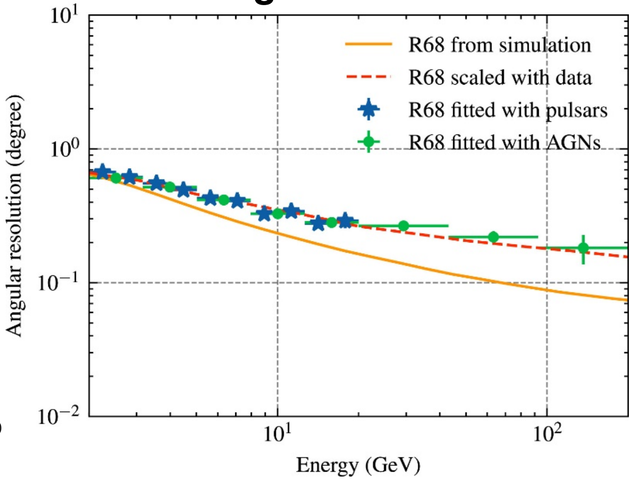
Energy Measurement

Charge distribution

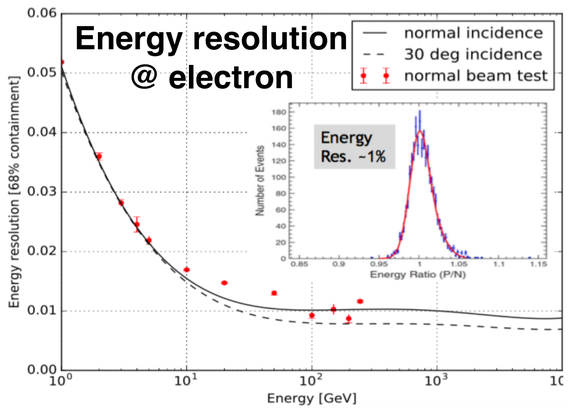


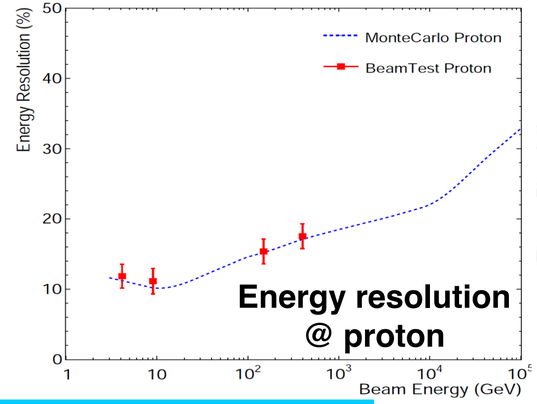
T. Dong et al., Astropart. Phys. 105 (2019)

Angular resolution

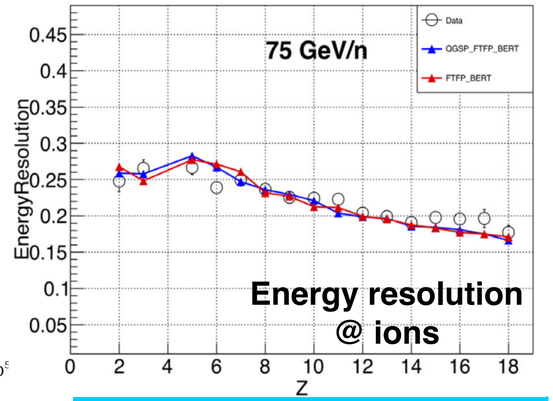


K. Duan et al., Astropart. Phys. 165 (2025)





J. Chang et al., Astropart. Phys. 95 (2017)



Y. Wei et al. NIMA 922 (2019)

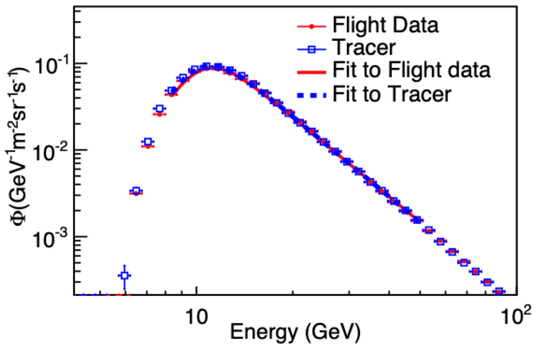
BGO Cal. depth:

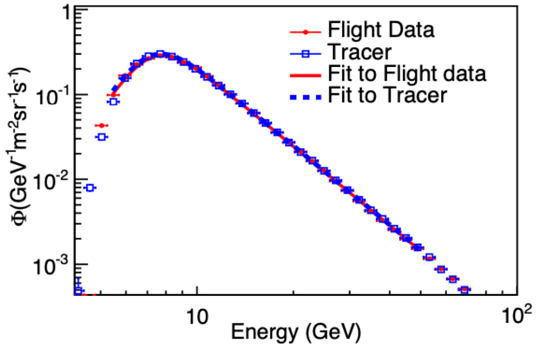
~ 32 X_0 (radiation length)

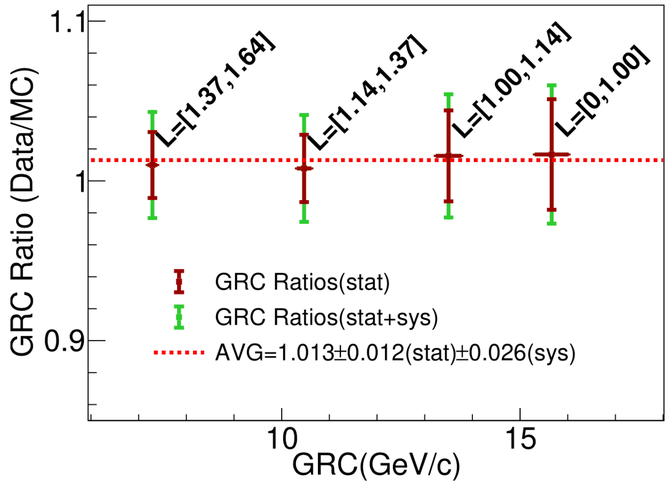
~ 1.6 λ (nuclear integration length)

Energy scale and linearity

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

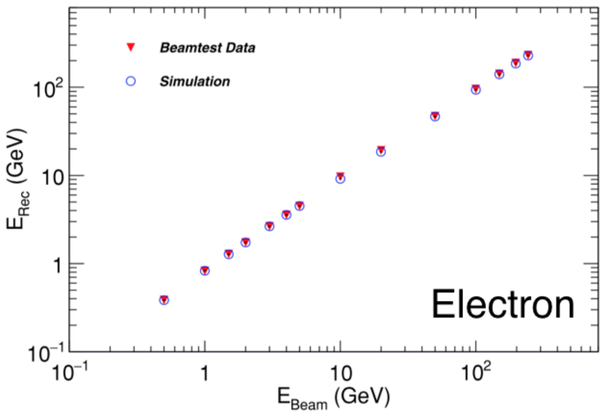


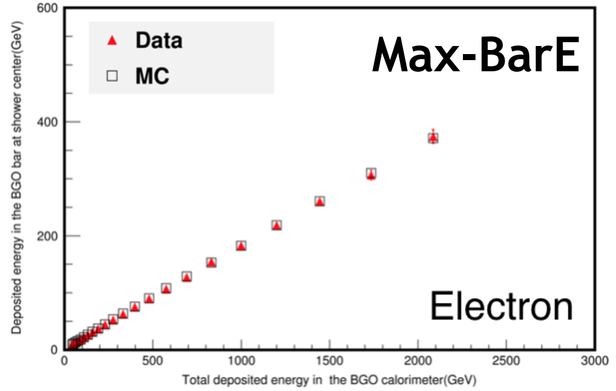


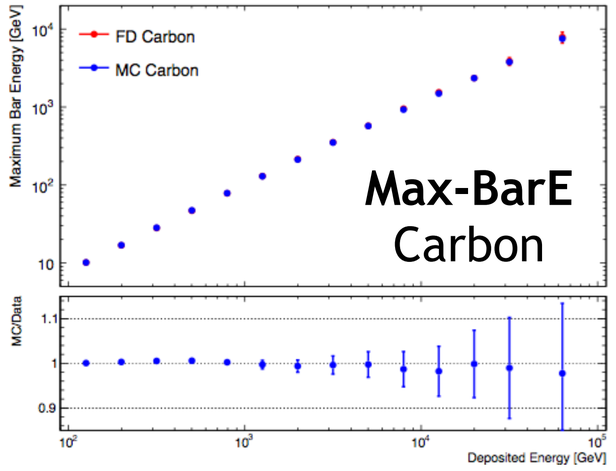


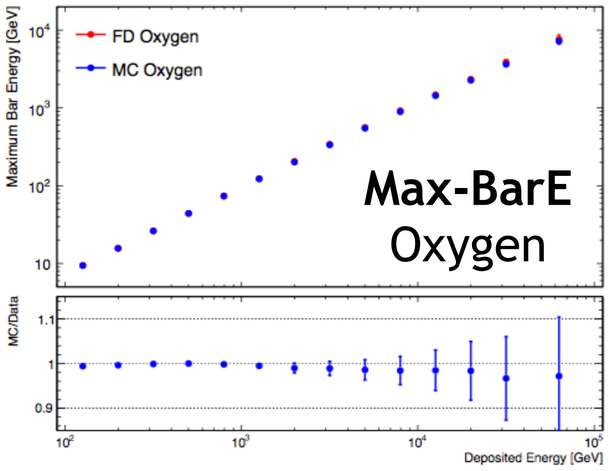
J. Zang et al. Astropart. Phys. 173 (2025)

C. Zhao et al. NIMA 1092 (2022)



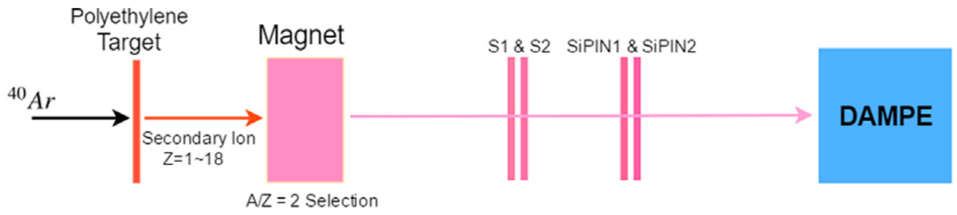


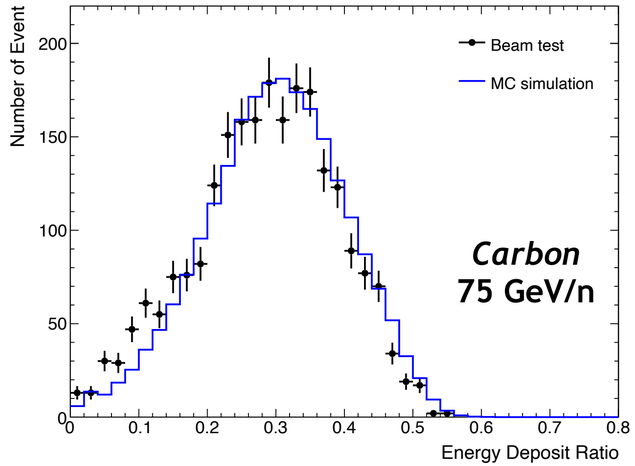


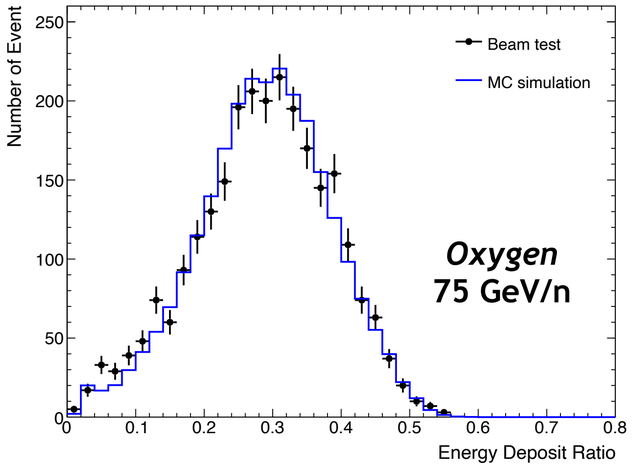


Energy response for nuclei

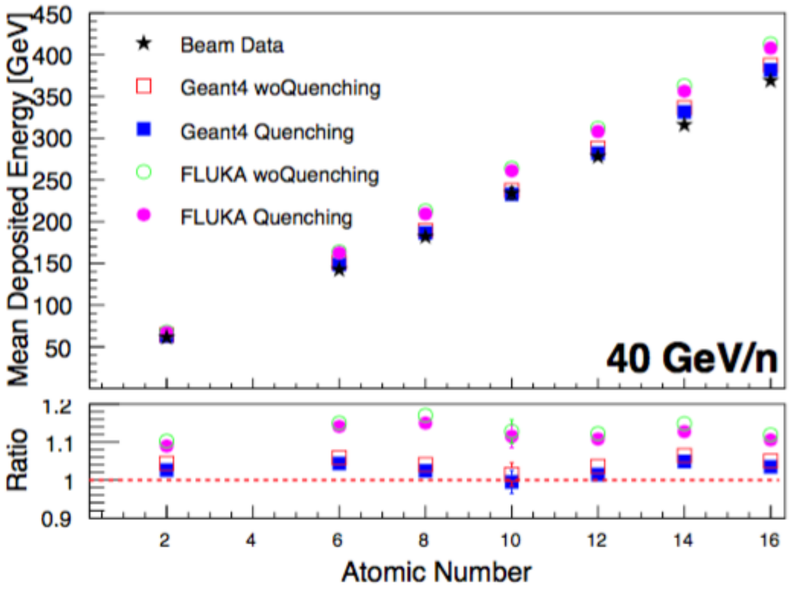
Ion Beam Test @ CERN

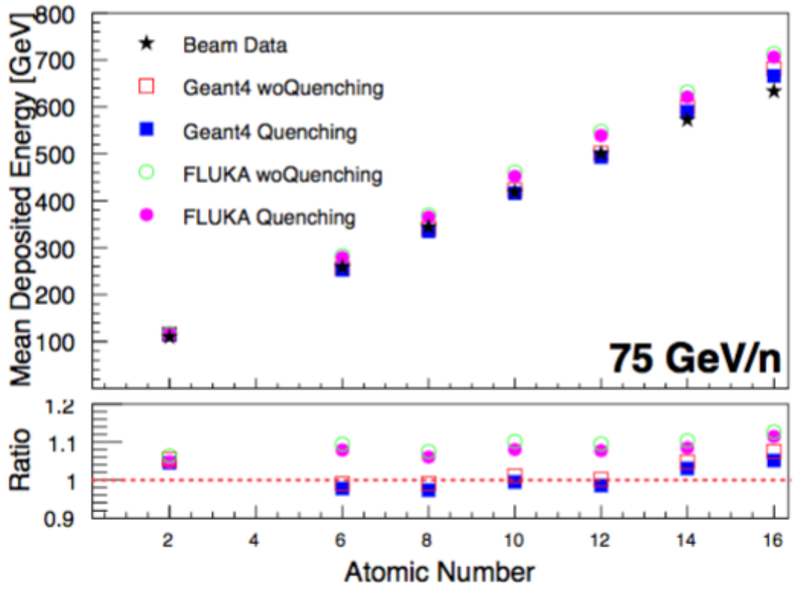




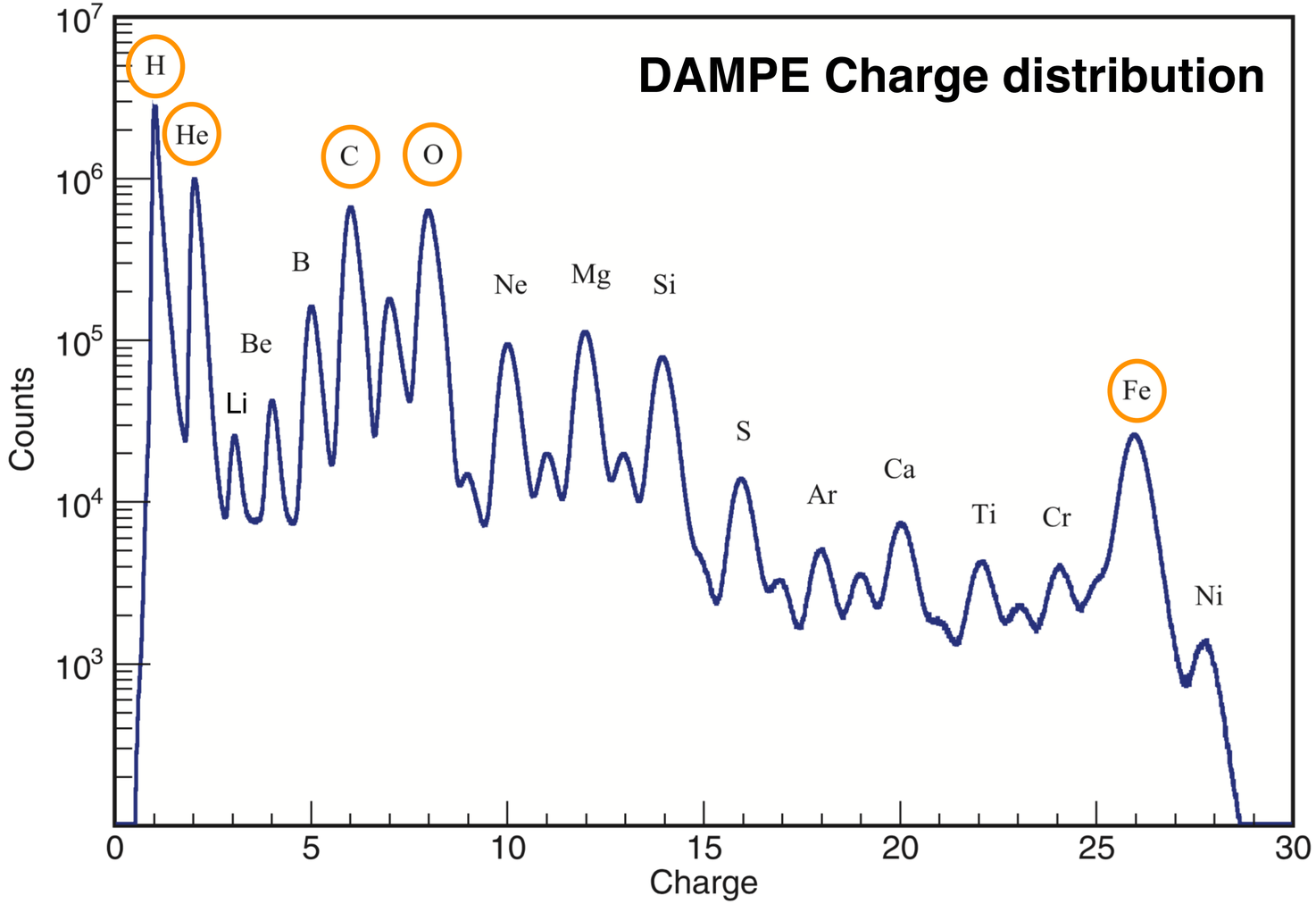


Different MC simulations (GEANT4, FLUKA) are validated with ion beam test data at CERN (p, He, …, Ar)





CR nulcei

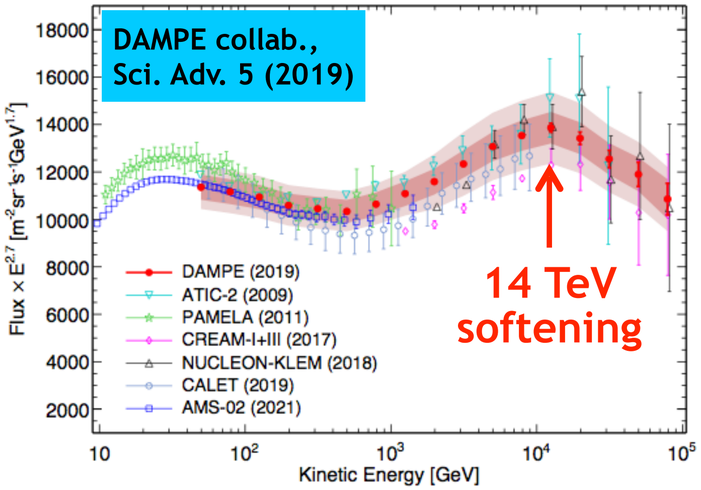


Primary CRs:
CR origin / acceleration
- p, He, C, O, Fe, …

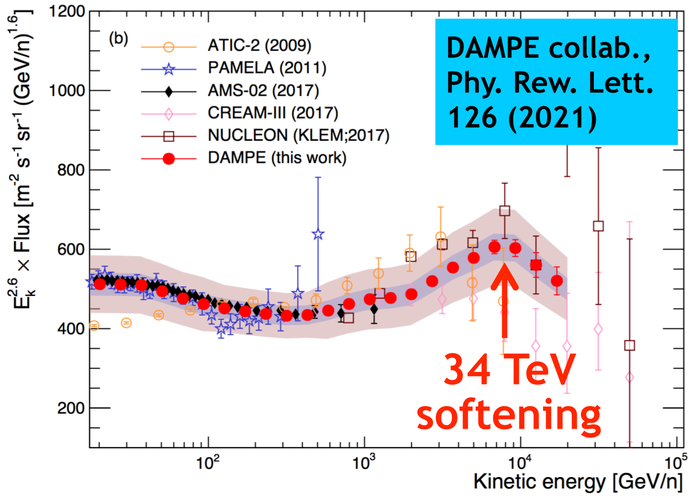
Secondary CRs:
CR propagation
- Li, Be, B, …

CR p+He spectrum

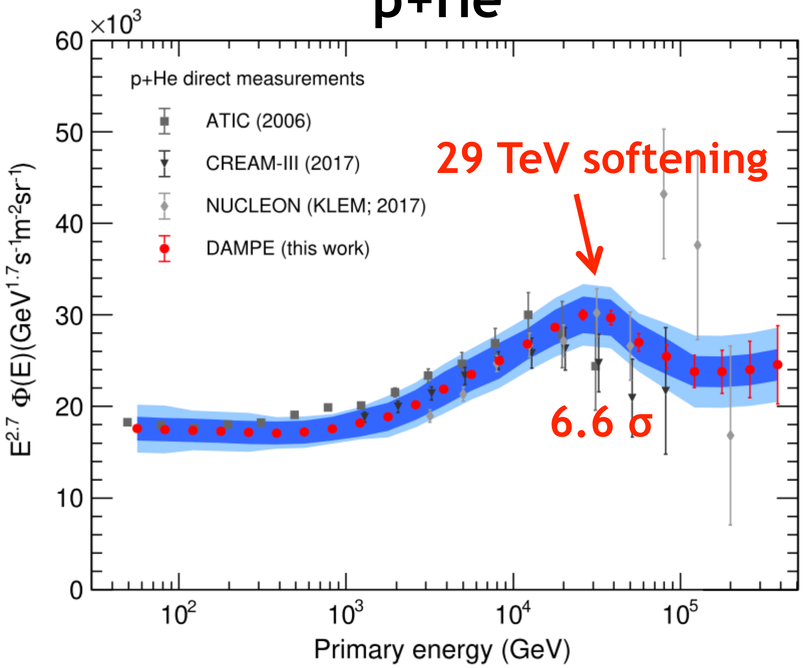
Proton



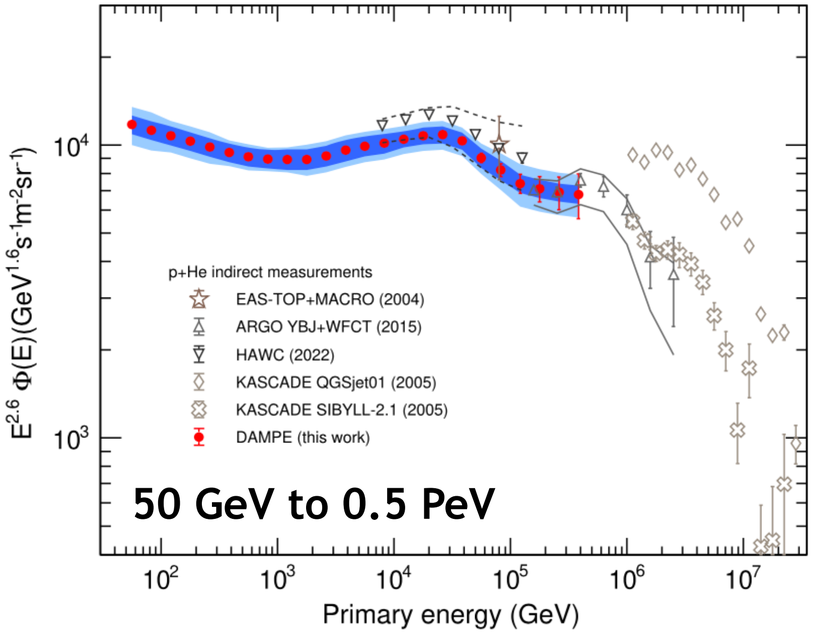
Helium



p+He



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



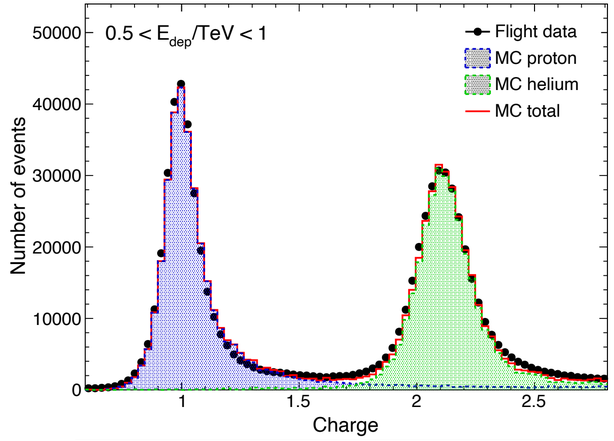
	Proton	Helium	Proton+Helium
E_b (TeV)	$13.6^{+4.1}_{-4.8}$	$34.4^{+6.7+11.6}_{-9.8-0.0}$	$28.8^{+6.2+2.9}_{-4.4-0.0}$
γ	2.60 ± 0.01	$2.41^{+0.02+0.02}_{-0.02-0.00}$	$2.51^{+0.021+0.01}_{-0.024-0.00}$
$\Delta\gamma$	-0.25 ± 0.07	$-0.51^{+0.18+0.01}_{-0.20-0.00}$	$0.43^{+0.066+0.066}_{-0.057-0.00}$

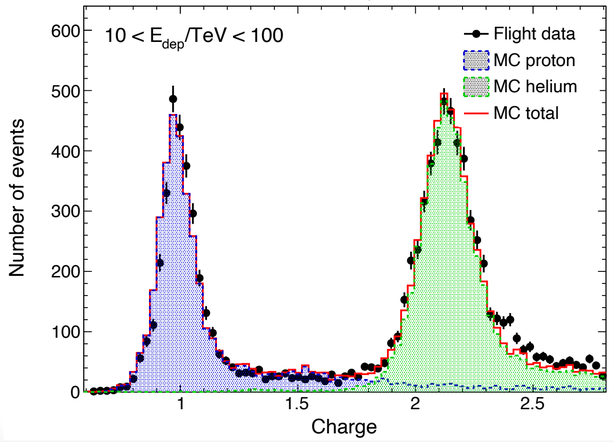
- **Link between space- and ground- based CR measurements**
- **Observation of the softening at 29 TeV and a hardening hit at ~150 TeV**

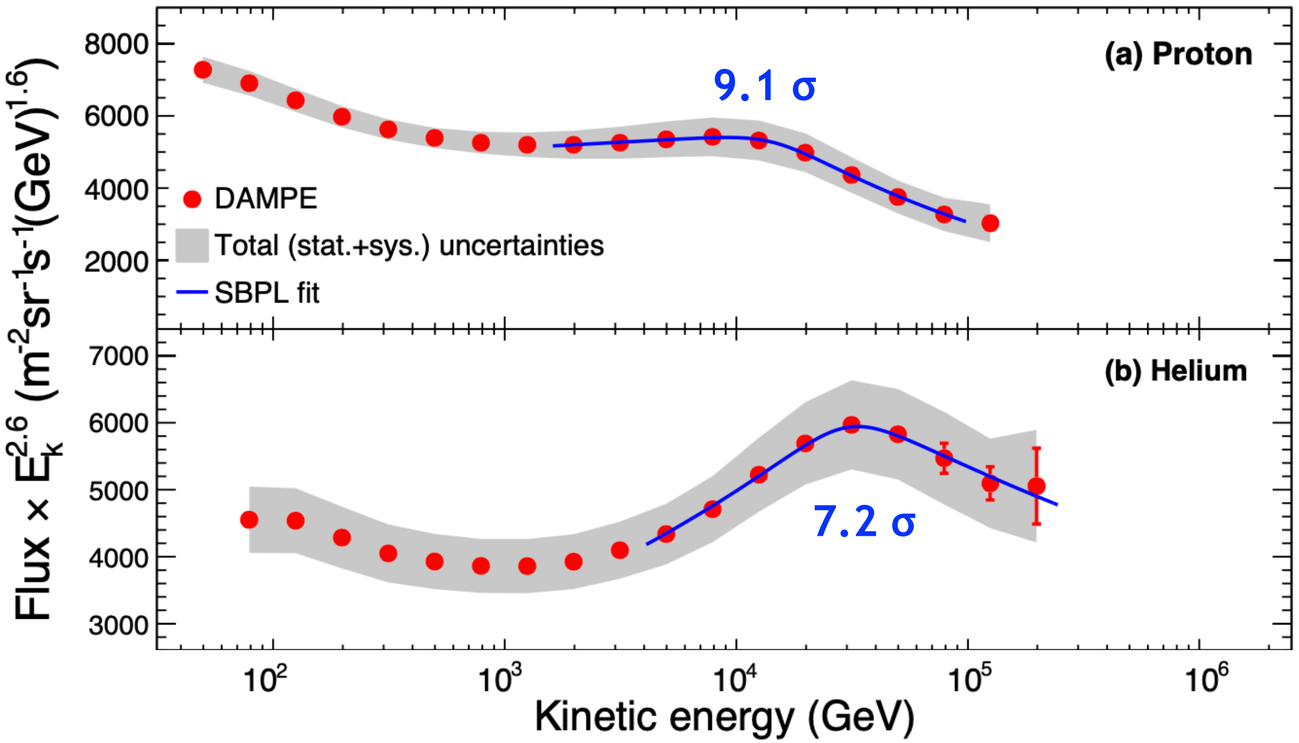
Primary cosmic-ray: p, He

Advanced analysis in high energies:

1. New ML track reconstruction & New charge identification : STK + PSD
2. Quenching correction, cross-section correction and new saturation correction up to PeV







$$\Phi_{\mathrm{SBPL}}(E) = \Phi_0 \cdot \left(\frac{E}{10^3\ \mathrm{GeV}}\right)^{-\gamma} \left[1 + \left(\frac{E}{E_{\mathrm{br}}}\right)^{s}\right]^{\frac{\Delta\gamma}{s}}$$

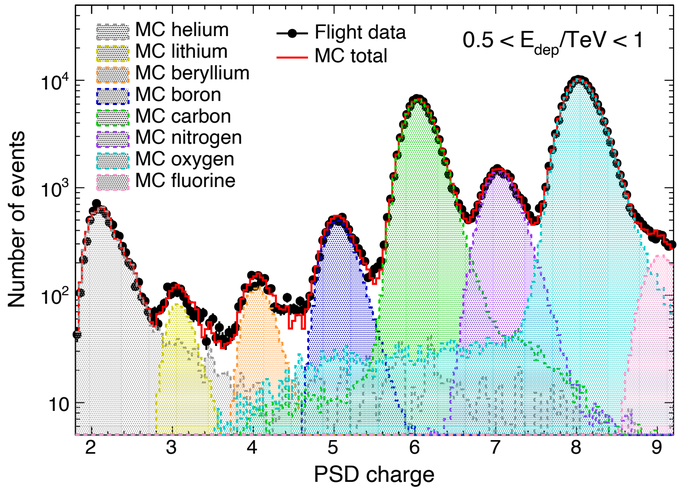
Particle	Proton	Helium
Fit energy range	1.58 - 100 TeV	3.98 - 250 TeV
Nuisance parameters	3	3
Φ_0 (10^{-5} GeV^{-1} m^{-2} s^{-1} sr^{-1})	8.08 ± 0.48	5.03 ± 0.35
E_{br} (TeV)	14.6 ± 1.3	30.6 ± 4.4
γ	2.57 ± 0.01	2.40 ± 0.01
$\Delta\gamma$	-0.34 ± 0.05	-0.32 ± 0.07
s	5 (fixed)	5 (fixed)

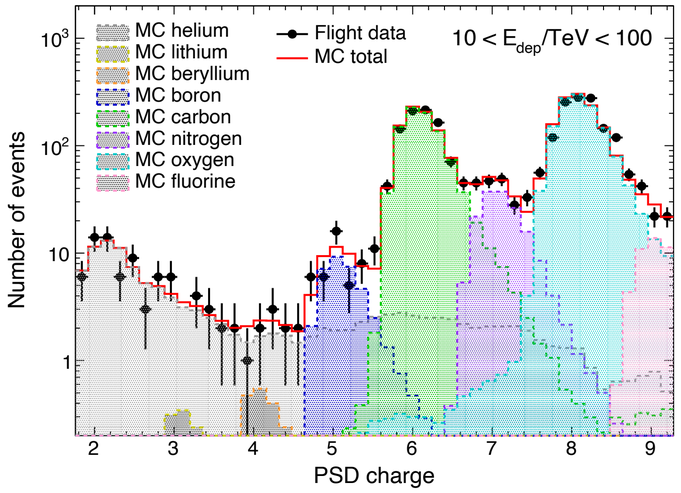
◉ **Latest results based on 9 years' DAMPE data**

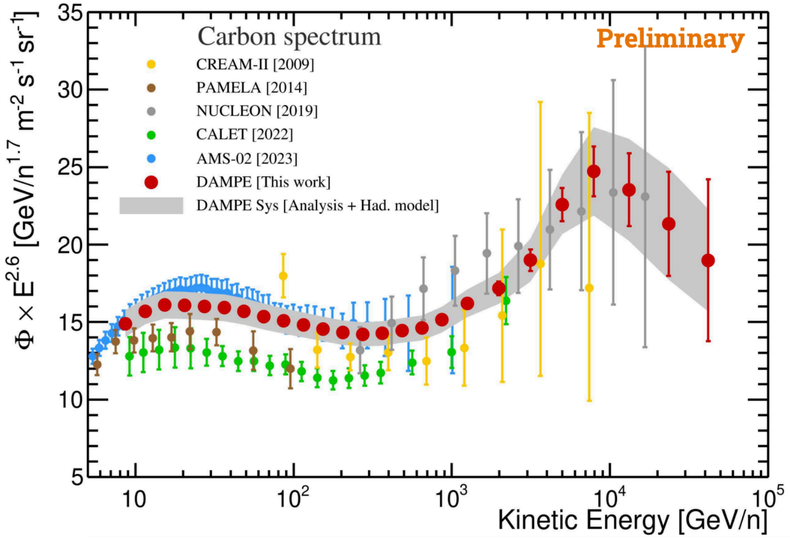
see Talk by A. Tykhonoy

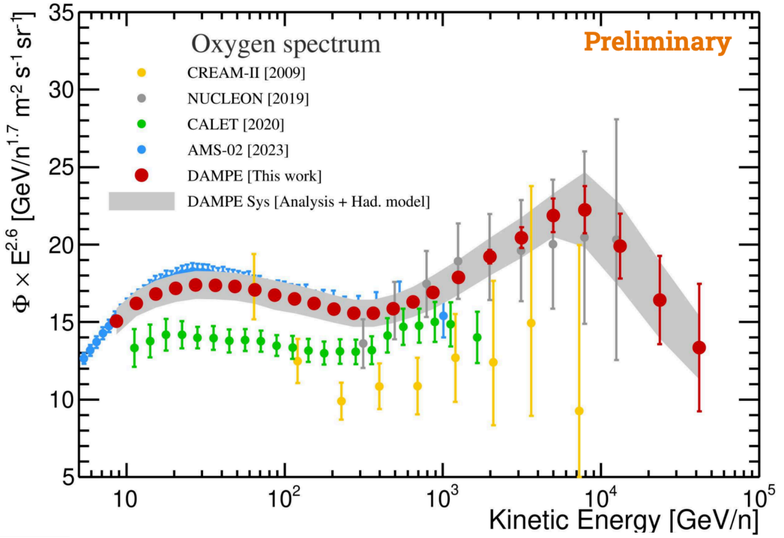
Primary cosmic-ray: C, O

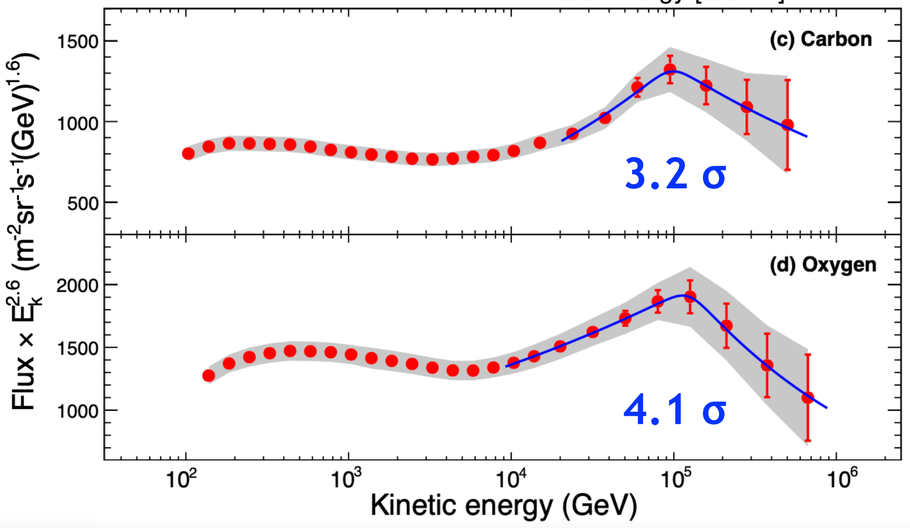
- **Latest results based on 9 years' DAMPE data**











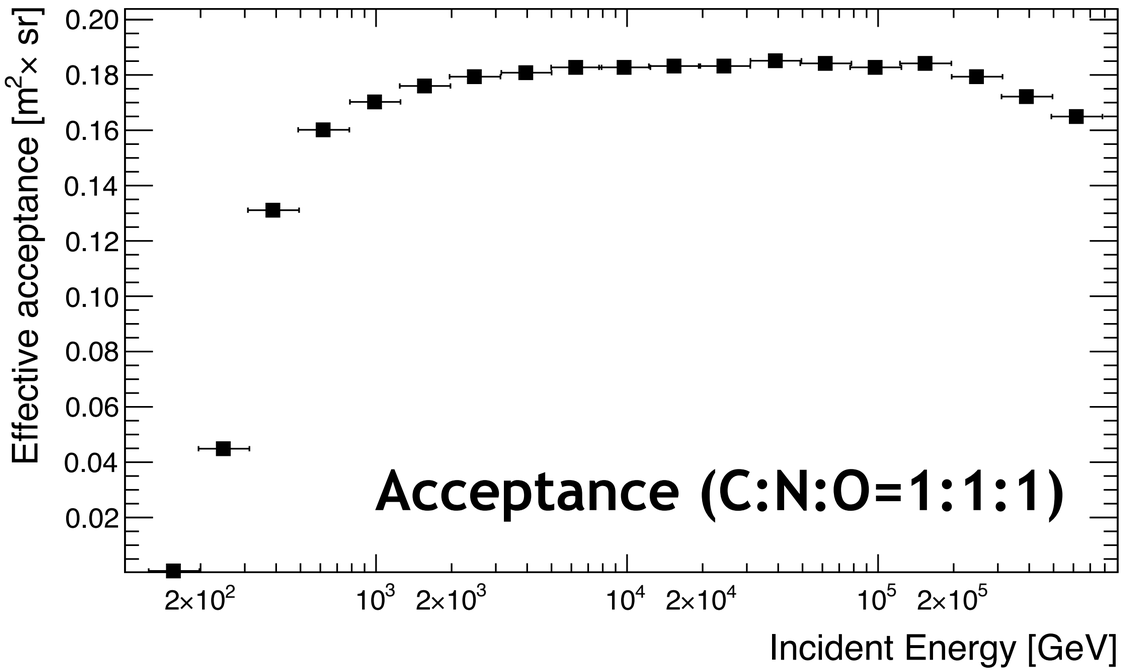
$$\Phi_{\mathrm{SBPL}}(E) = \Phi_0 \cdot \left(\frac{E}{10^3\ \mathrm{GeV}}\right)^{-\gamma} \left[1 + \left(\frac{E}{E_{\mathrm{br}}}\right)^{s}\right]^{\frac{\Delta\gamma}{s}}$$

Particle	Carbon	Oxygen
Fit energy range	19.0 - 675 TeV	9.0 - 900 TeV
Nuisance parameters	2	3
Φ_0 (10^{-5} GeV^{-1} m^{-2} s^{-1} sr^{-1})	0.60 ± 0.12	1.54 ± 0.16
E_{br} (TeV)	96.5 ± 33.5	123 ± 38
γ	2.32 ± 0.06	2.45 ± 0.03
$\Delta\gamma$	-0.49 ± 0.17	-0.48 ± 0.18
s	10 (fixed)	10 (fixed)

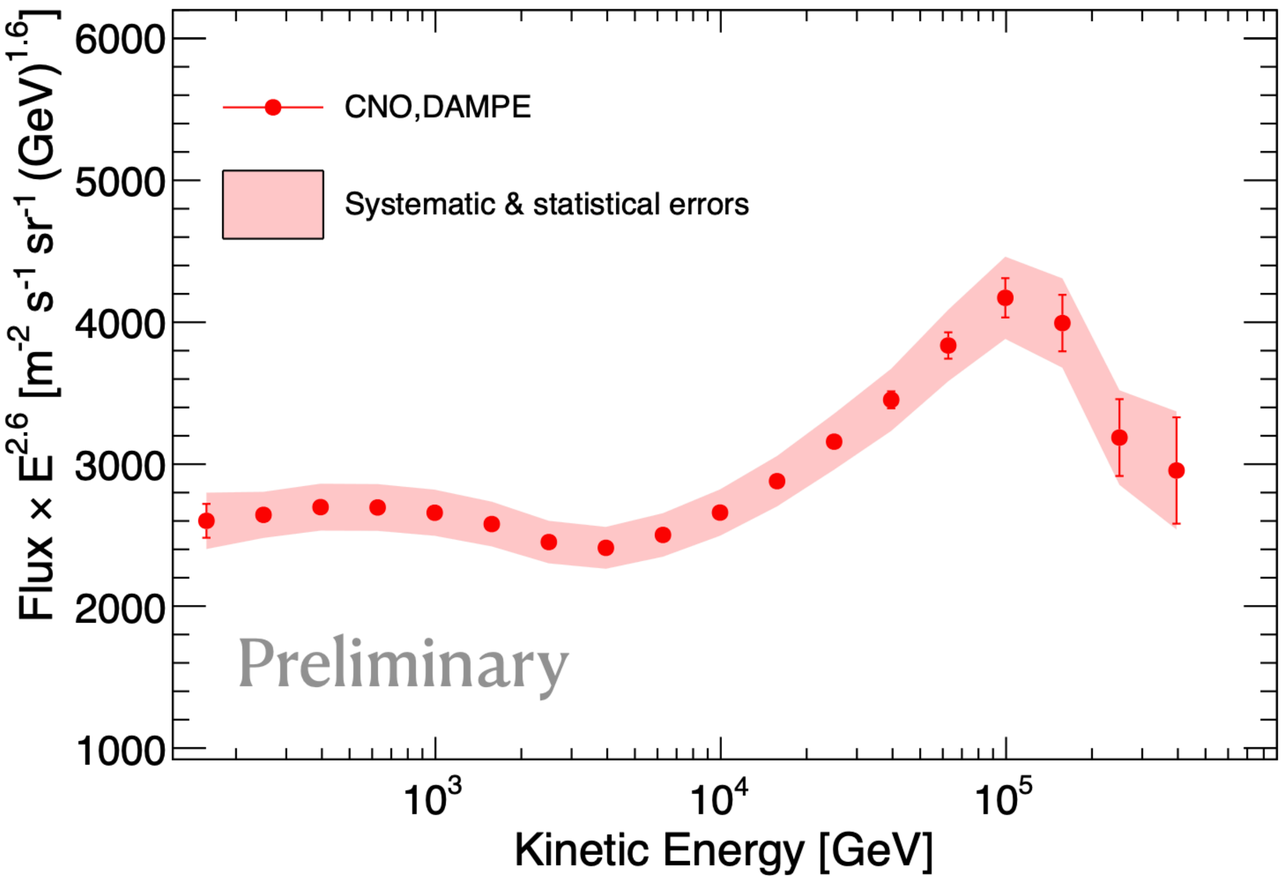
CR CNO group

- Take CNO as a group

  Larger acceptance & upper energy limit



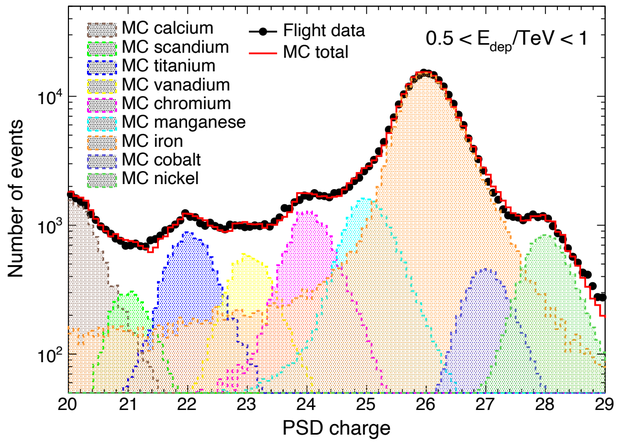
CNO spectrum

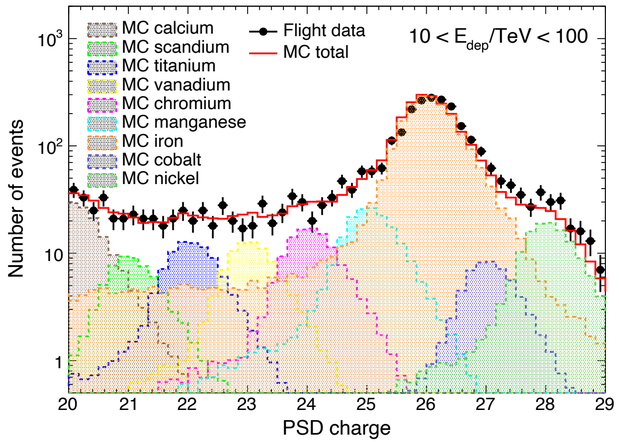


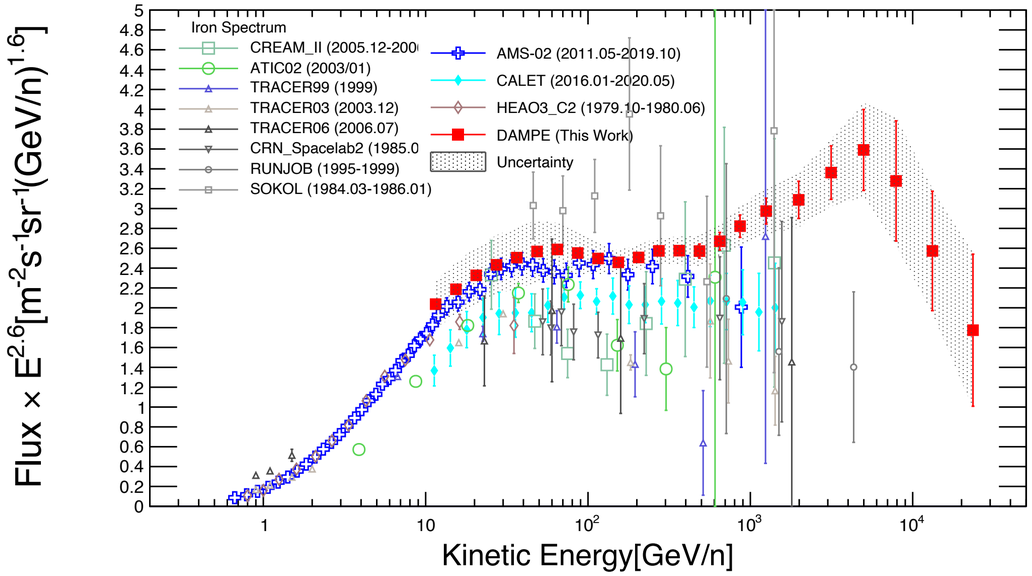
- **With much more event statistics, the stat. errors are better controlled.**
- **A spectral softening at ~110 TeV with > 5 sigma of CL. is observed (preliminary).**

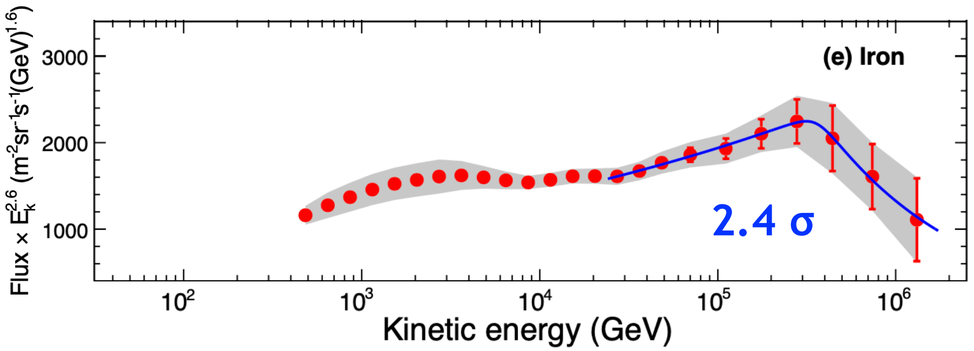
Primary cosmic-ray: Fe

- **Latest results based on 9 years' DAMPE data**









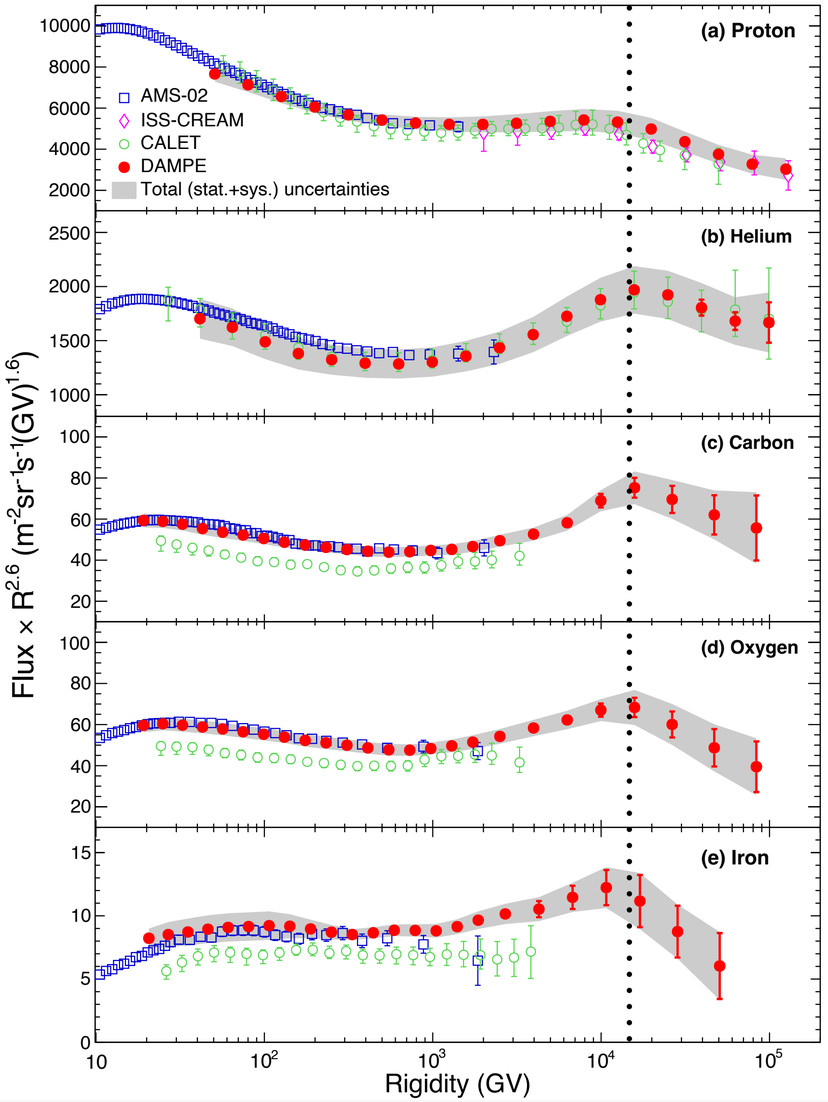
$$\Phi_{\mathrm{SBPL}}(E) = \Phi_0 \cdot \left(\frac{E}{10^3\ \mathrm{GeV}}\right)^{-\gamma} \left[1 + \left(\frac{E}{E_{\mathrm{br}}}\right)^{s}\right]^{\frac{\Delta\gamma}{s}}$$

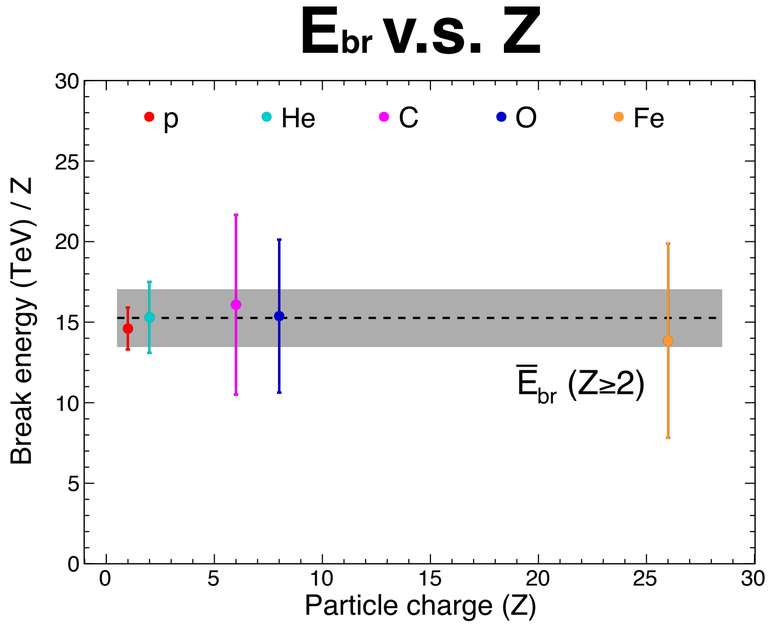
Particle	Carbon	Oxygen	Iron
Fit energy range	19.0 - 675 TeV	9.0 - 900 TeV	236 - 1771 TeV
Nuisance parameters	2	3	3
Φ_0 (10^{-5} GeV^{-1} m^{-2} s^{-1} sr^{-1})	0.60 ± 0.12	1.54 ± 0.16	1.50 ± 0.47
E_{br} (TeV)	96.5 ± 33.5	123 ± 38	360 ± 157
γ	2.32 ± 0.06	2.45 ± 0.03	2.46 ± 0.05
$\Delta\gamma$	-0.49 ± 0.17	-0.48 ± 0.18	-0.69 ± 0.41
s	10 (fixed)	10 (fixed)	10 (fixed)

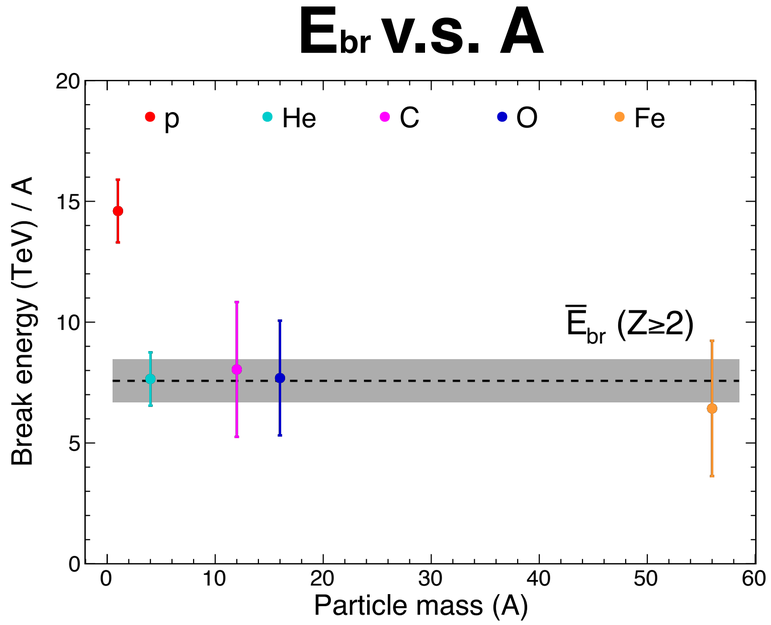
see Talk by Z.H. Xu

Universal softening at 15 GV

DAMPE collab., arXiv:2511.05409 (2025)





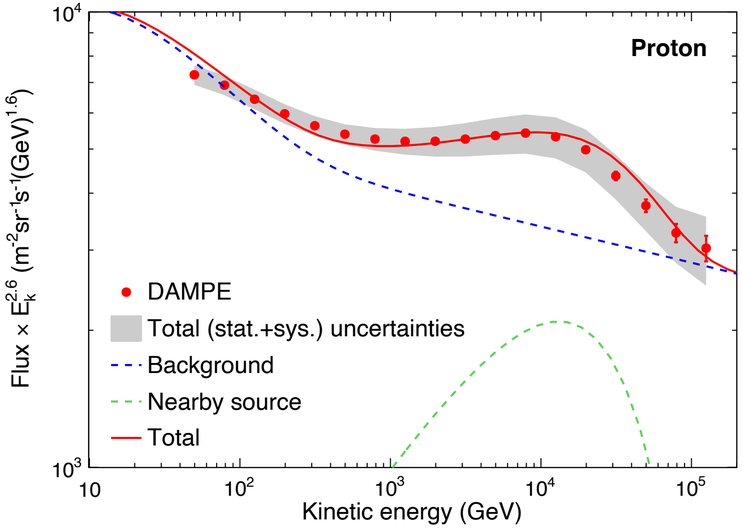


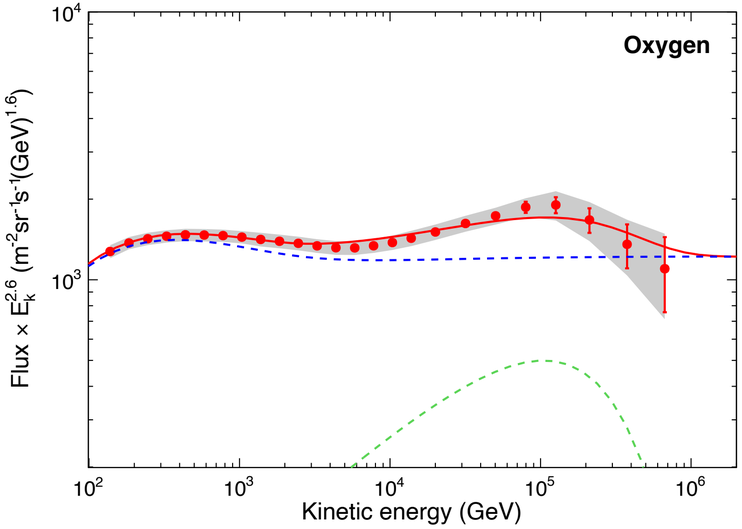
- **A universal softening feature in five primary CR spectra at a unified rigidity (E_{br} ~ 15 GV) is detected for the first time, providing observational verification of the charge-dependent energy limit of cosmic ray acceleration**
- **The mass(A) dependence of the softening energies can be excluded at a confidence level of > 99.999% (4.4 σ)**

Nearby source model

- Two components model: Background + Nearby source

CR Spectra

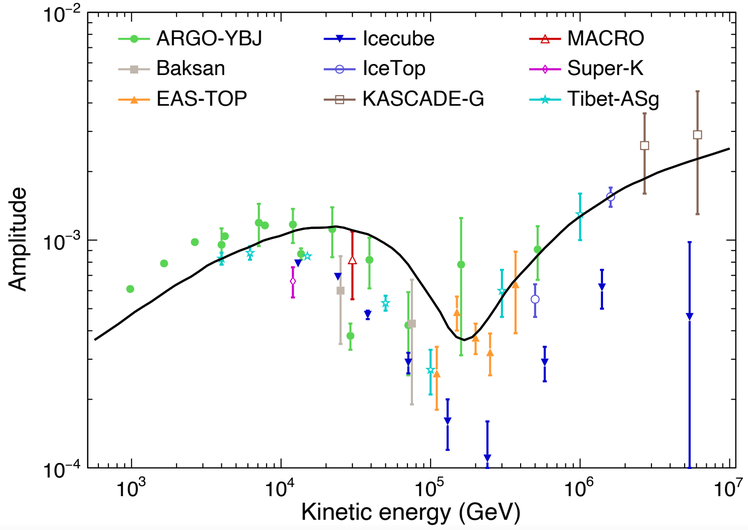


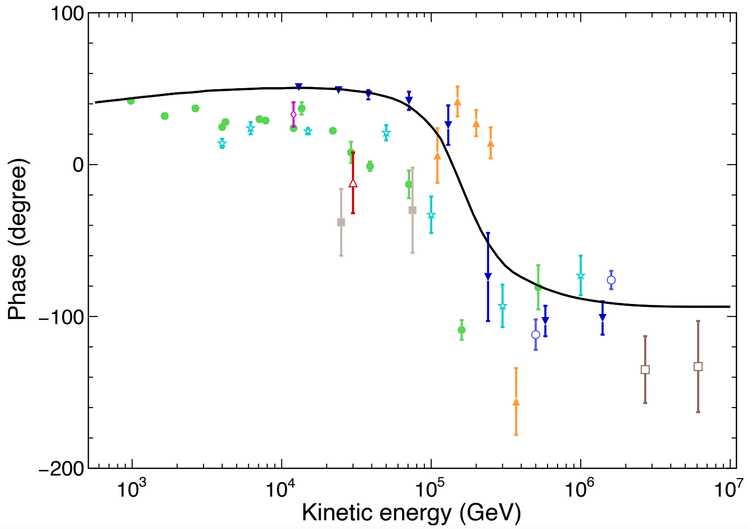


Nearby source:
Geminga-like
250 pc, 3.4×10^5 yr

$$q_{\rm src} \propto (R/{\rm GV})^{-\beta} \exp(-R/R_c)$$

CR Anisotropy

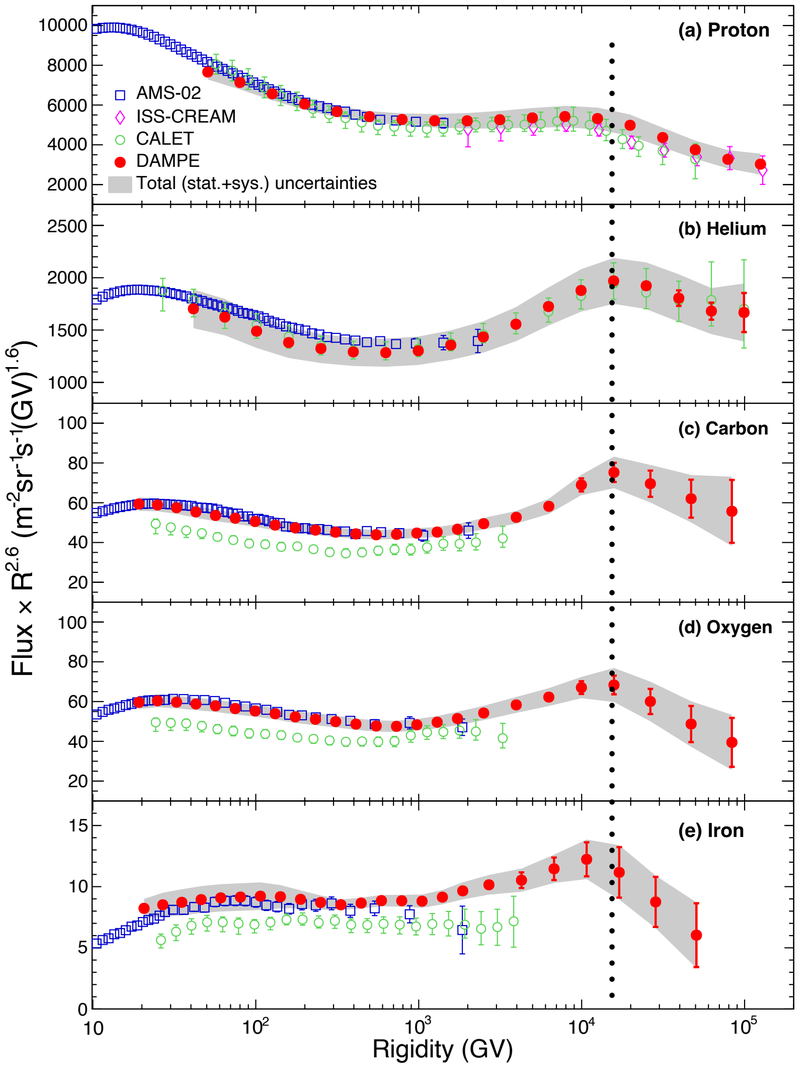




Simultaneously explain the CR spectral bumps and the large-scale CR anisotropies.

Summary

- DAMPE has operated smoothly or-orbit for 10 years, all the four sub-detectors keep in good status.
- A universal softening feature in five primary CR spectra (p, He, C, O, Fe) at a unified rigidity (E_{br} ~ 15 GV) is detected for the first time in space.
- The results providing observational verification of the charge-dependent energy limit of cosmic ray acceleration
- The mass(A) dependence of the softening energies can be excluded at a confidence level of > 99.999% (4.4 σ)
- A nearby source model can simultaneously the spectral features and the large-scale CR anisotropy.
- More spectral measurements of Ne, Mg, Si, …, from DAMPE may enhance the discovery of the universal softening ~ 15 TV



Thank You!

arXiv: 2511.05409