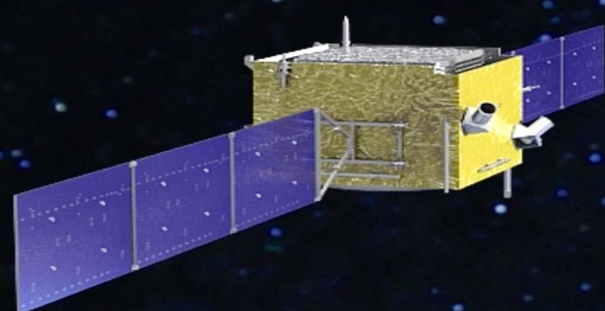
45th COSPAR Scientific Assembly
Busan, South Korea, 13-21 July 2024

Dark Matter Particle Explorer (DAMPE)
8 years in space

Fan, Yi-Zhong (范一中)
Purple Mountain Observatory, Chinese Academy of Sciences
on behalf of the DAMPE Collaboration



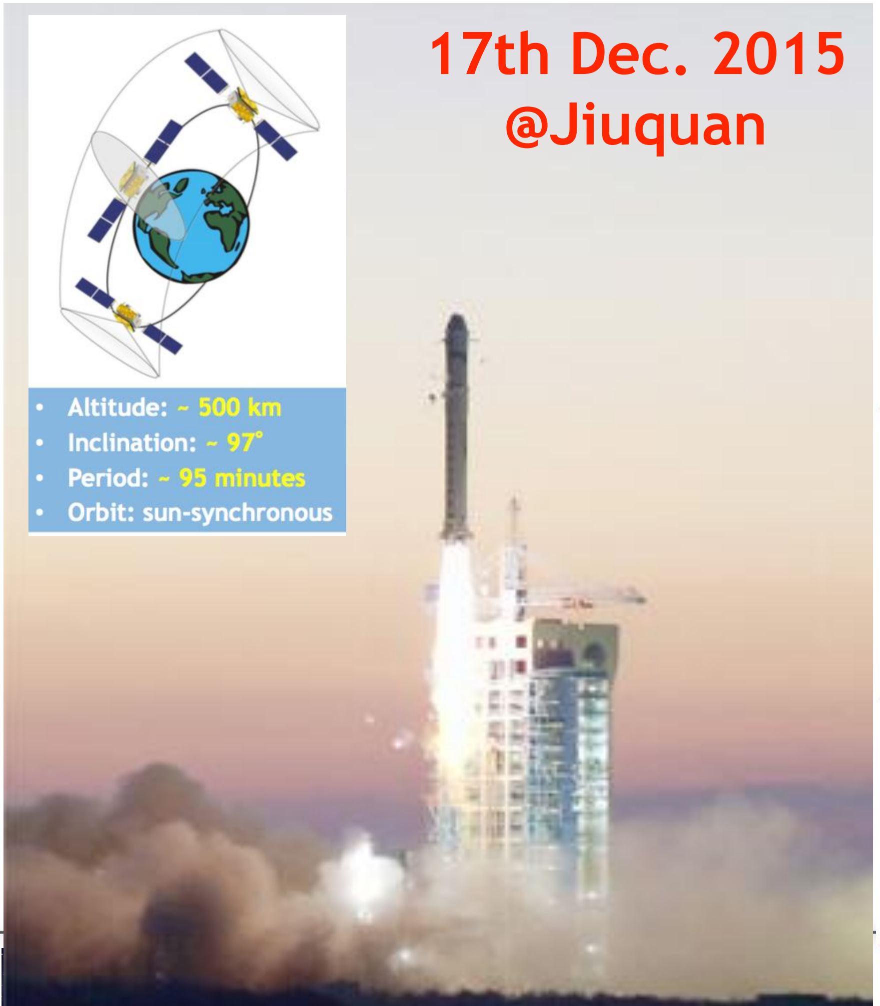
July 14th, 2024

Outline

- DAMPE mission
- Detector performance
- Latest physical results
- 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)**.

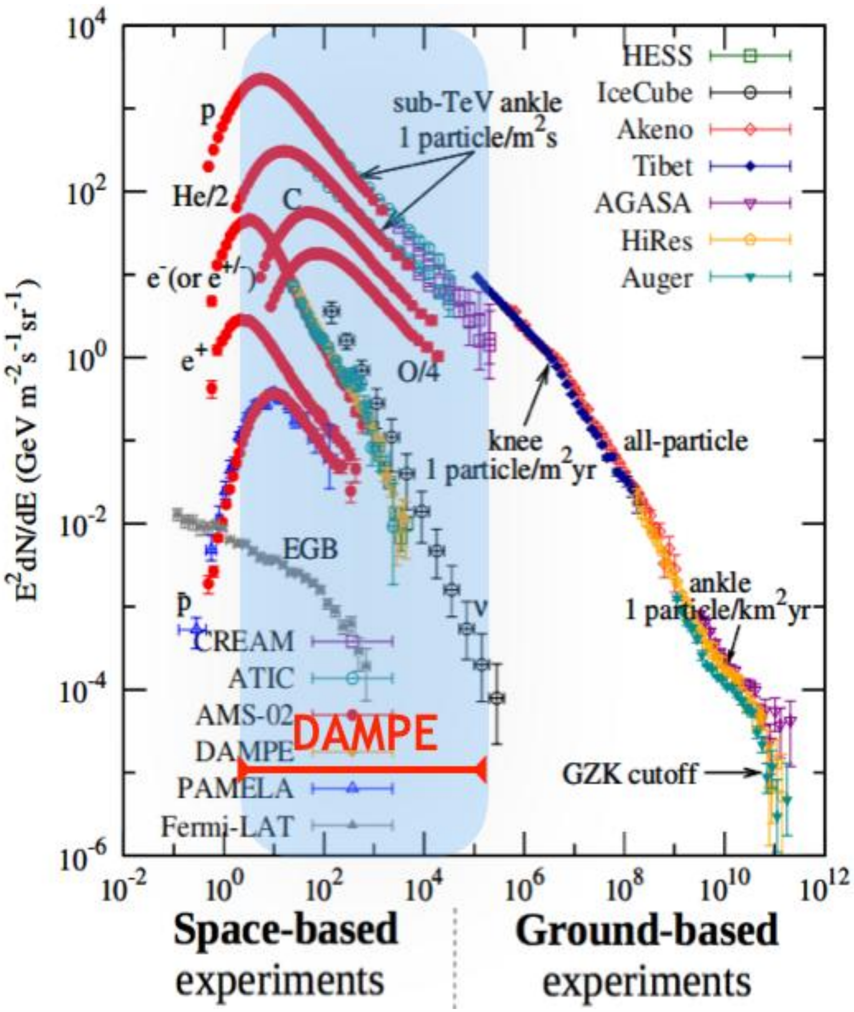


- Altitude: ~ 500 km
- Inclination: ~ 97°
- Period: ~ 95 minutes
- Orbit: sun-synchronous

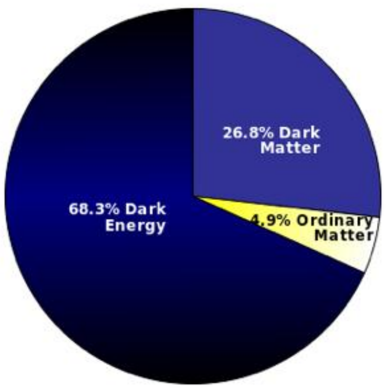
- CHINA
  - Purple Mountain Observatory, CAS, Nanjing
  - Institute of High Energy Physics, CAS, Beijing
  - National Space Science Center, CAS, Beijing
  - University of Science and Technology of China, Hefei
  - Institute of Modern Physics, CAS, Lanzhou
- ITALY
  - INFN Perugia and University of Perugia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

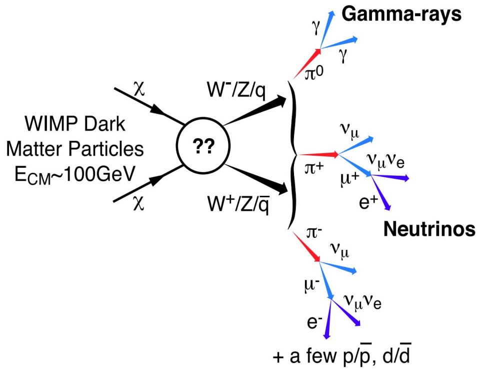
Scientific objects

Cosmic-ray detection

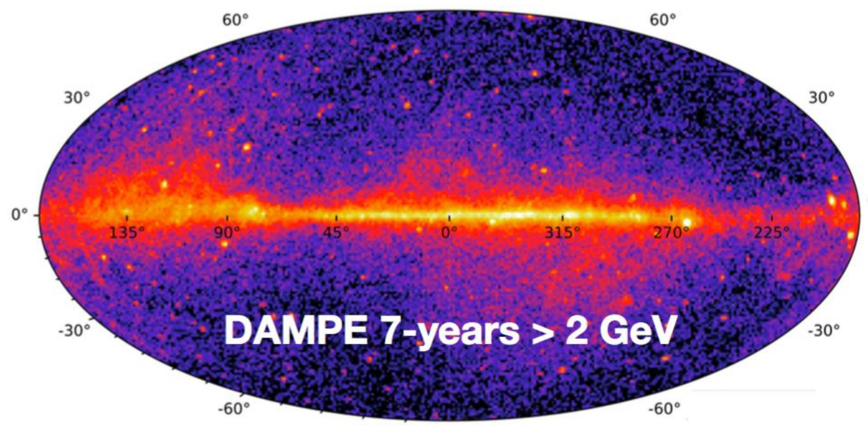


Indirect DM detection

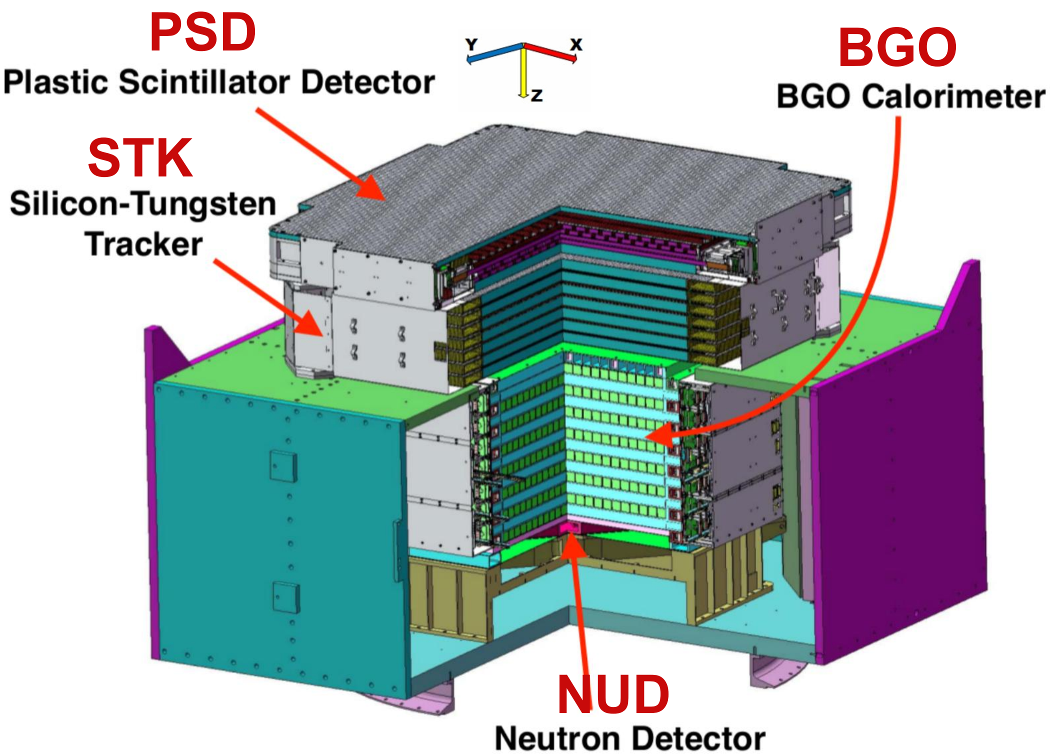




Gamma-ray astronomy



DAMPE detector



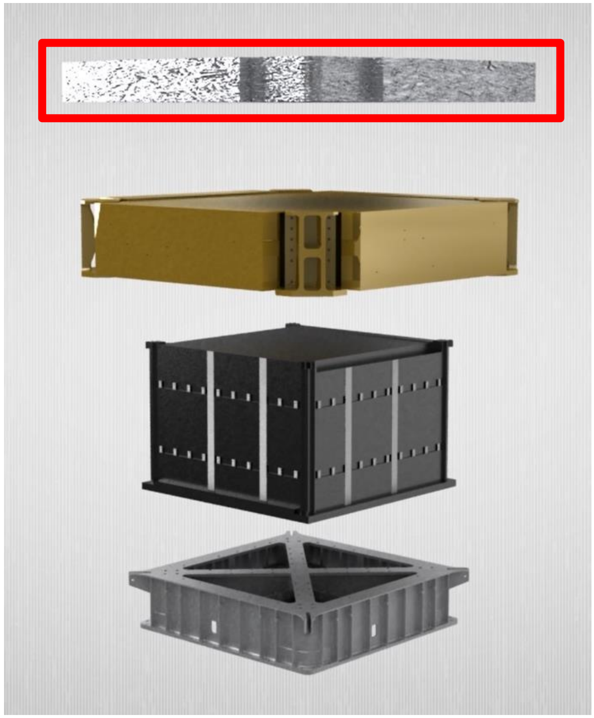
Parameter	Value
Energy range (e/γ)	5 GeV to 10 TeV
Energy resolution (e/γ)	1.5% at 800 GeV
Energy range (p/ion)	50 GeV to 500 TeV
Energy resolution (p)	40% at 800 GeV
Geometric factor (e)	0.3 m^2 sr above 30 GeV
Angular resolution (γ)	0.1 degree at 100 GeV
Field of view	1.0 sr

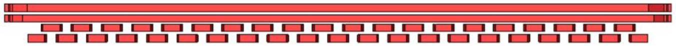
Weight: 1.4 tons in total
Power: ~400 W

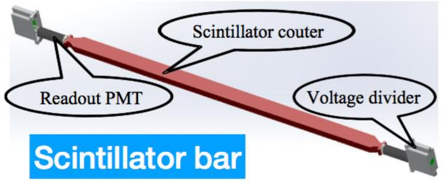
- PSD: Charge measurement via dE/dx and ACD for photons
- STK: Track, charge, and photon converter
- BGO: Energy measurement, particle (e/p) identification
- NUD: Additional e/p identification in high energy range

(Chang et al. Astropart.Phys. 2017, 95, 6-24)

Plastic Scintillator Detector (PSD)



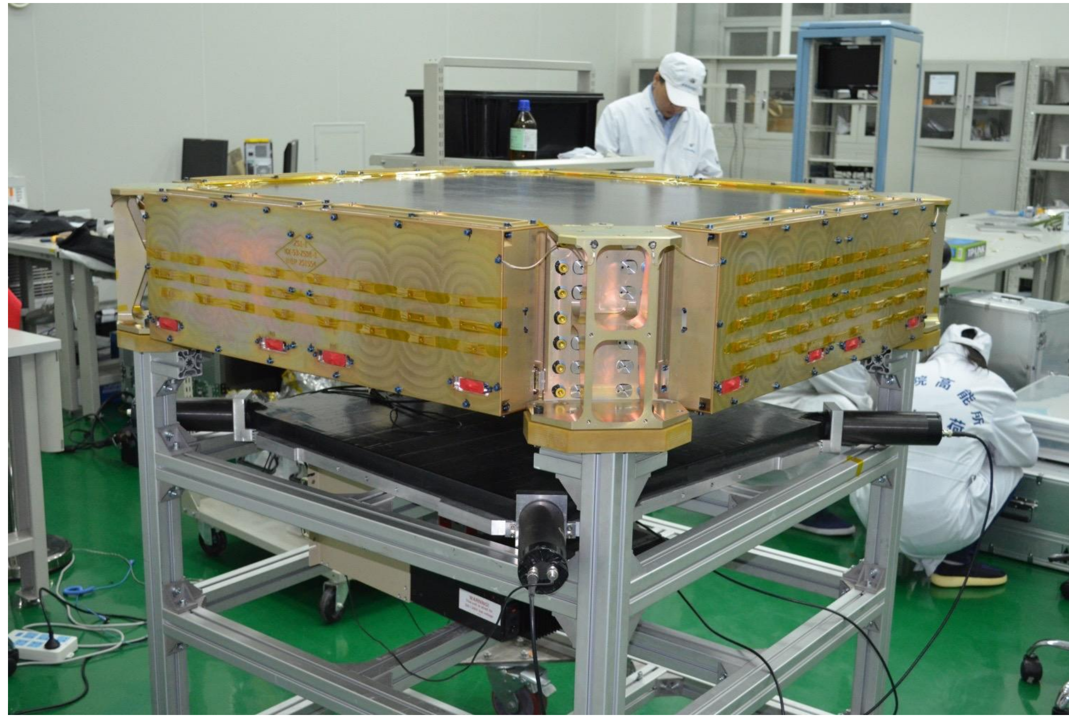


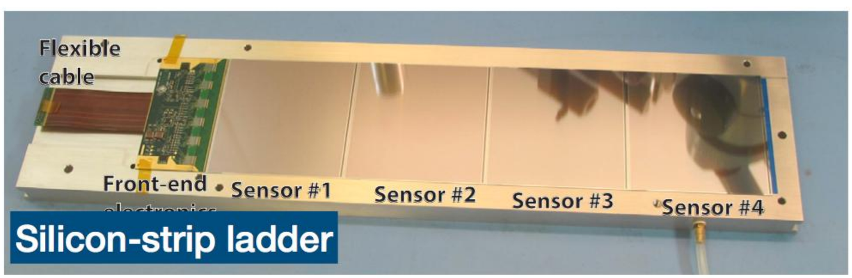


PSD

- 2 double-layers **(x,y)** of **88.4 × 2.8 × 1 cm³** bars
- Active area: **82 × 82 cm²**
- **Charge Measurement: Z = 1-28**
- **γ anti-coincidence**

Silicon-Tungsten Tracker (STK)

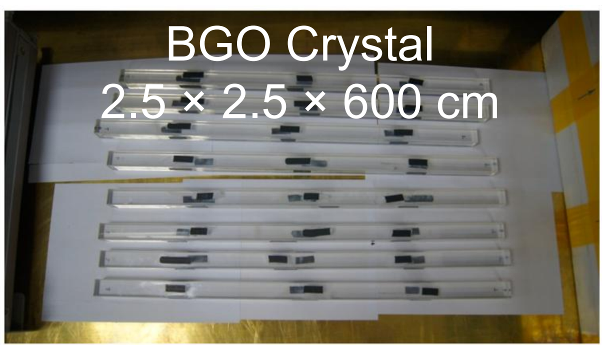


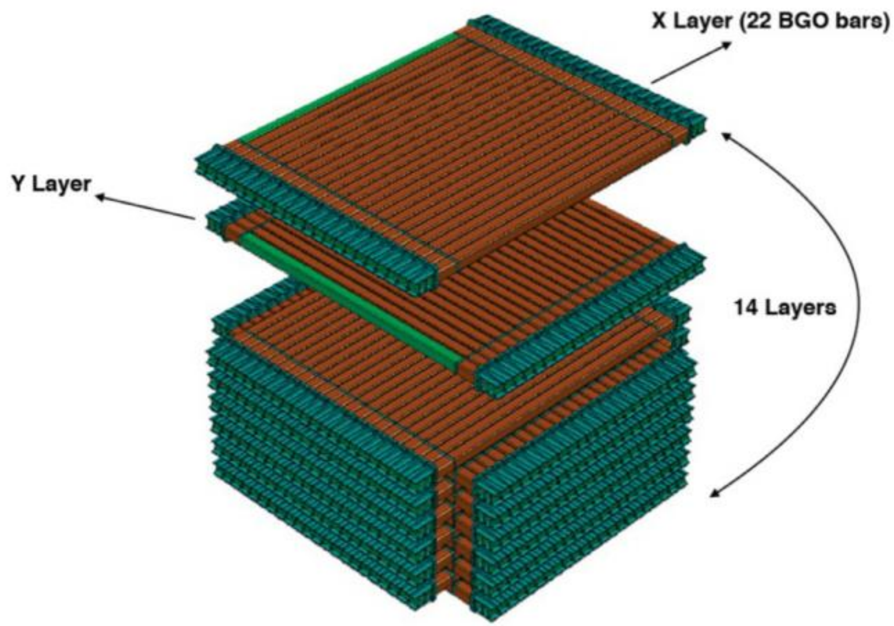


STK

- 6 double-layers **(x,y)**
- Active area: **76 × 76 cm²**
- 3 W layers for γ->e± conversion
- **Position resolution: ~50 μm**
- **γ angular resolution: 0.1°- 0.5°**

BGO Calorimeter

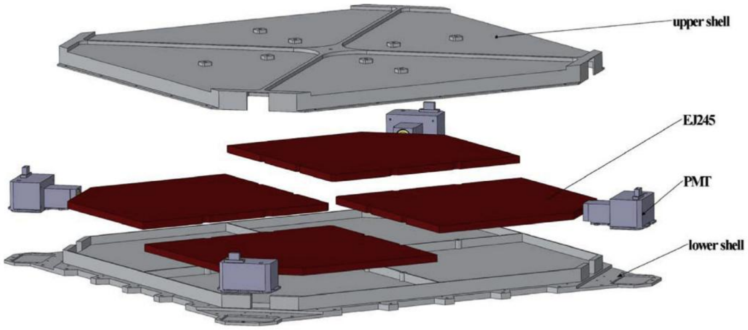




BGO

- 7 double-layers **(x,y)**, 308 BGO bars
- **31.5 X_0 - thickest in space**
- Active area: **60 × 60 cm²**
- **Energy resolution: 1% @ TeV (e/γ)**
- e/γ up to 10 TeV; p/ions up to sub-PeV

NeUtron Detector (NUD)

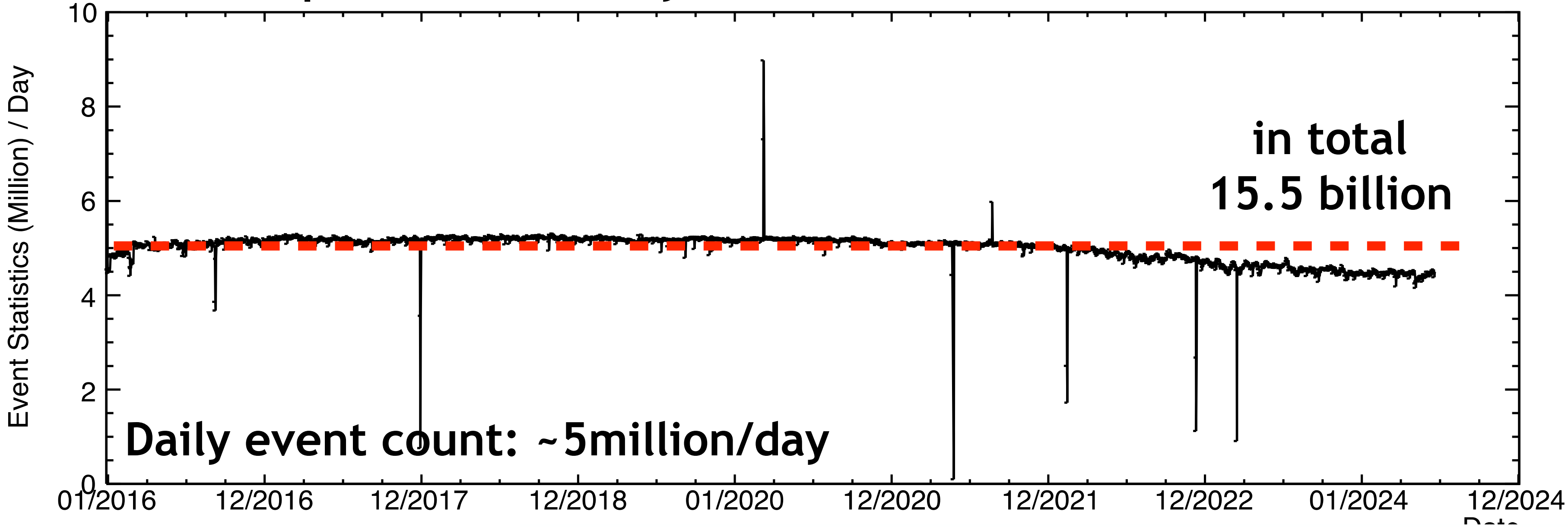


NUD

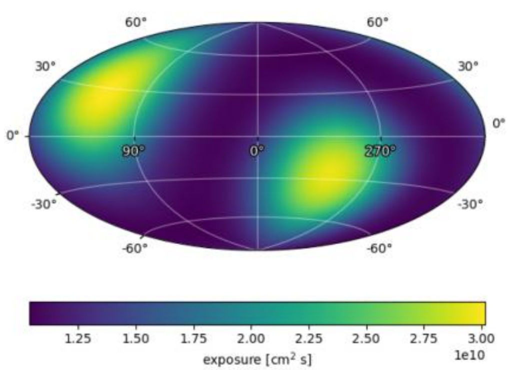
- 4 plastic scintillators (B)
- Active area: 60 cm x 60 cm
- Additional e/p separation
  $n + {}^{10}B \rightarrow \alpha + {}^{7}Li + \gamma$

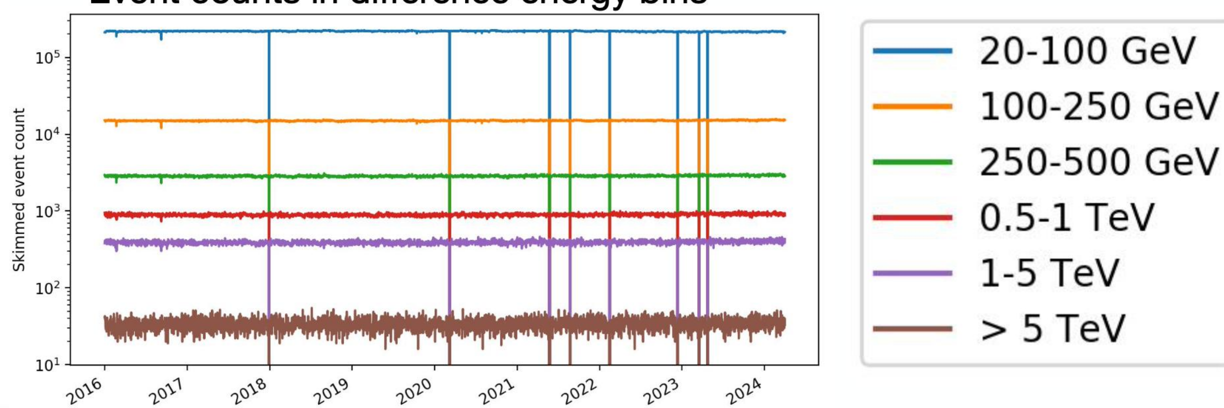
On-orbit operation

Smooth operation for 8.5 years since launch in Dec. 2017

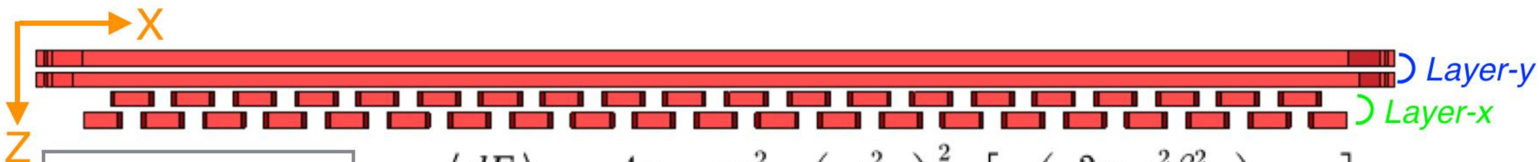


All sky exposure



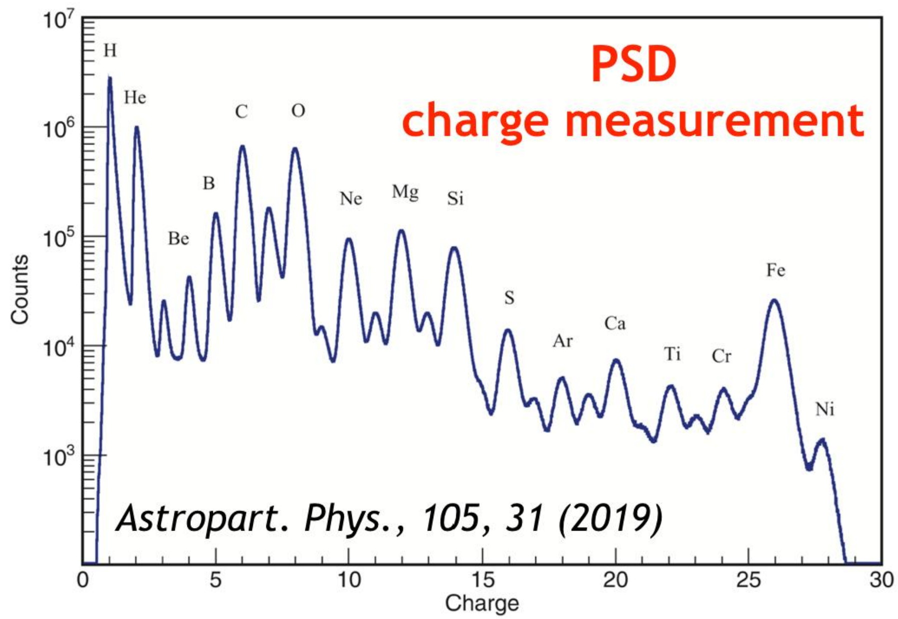


Charge measurement



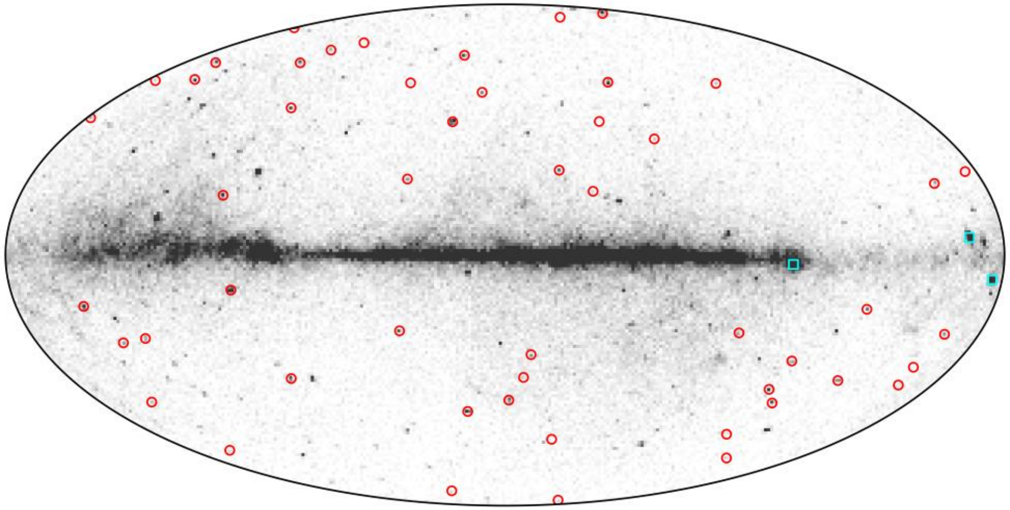
Bethe-Bloch

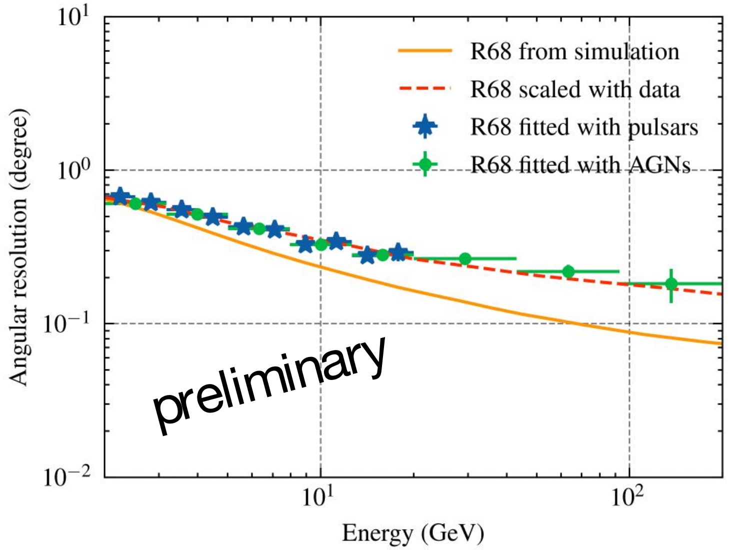
$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)}\right) - \beta^2\right]$$



Element	σ_Z	Element	σ_Z	Element	σ_Z	Element	σ_Z
Li	0.14	C	0.18	Ne	0.21	S	0.25
Be	0.21	N	0.21	Mg	0.22	Ca	0.29
B	0.17	O	0.20	Si	0.25	Fe	0.30

Angular calibration



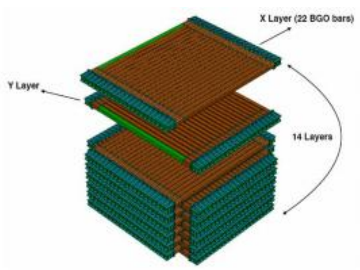


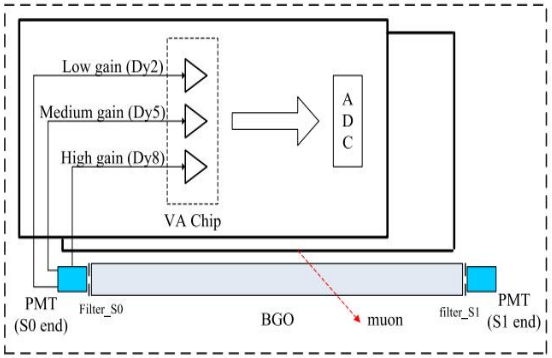
- The Point-Spread Function (PSF) is calibrated with photons from pulsars and stacked AGNs
- Angular resolution — **0.3 degrees @ 10 GeV**

See talk by K.K. Duan

Energy calibration

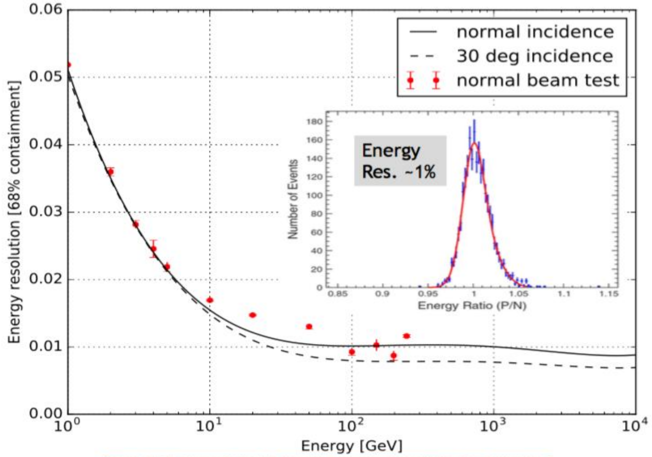
BGO calorimeter | 308 BGO bars | 616 PMTs



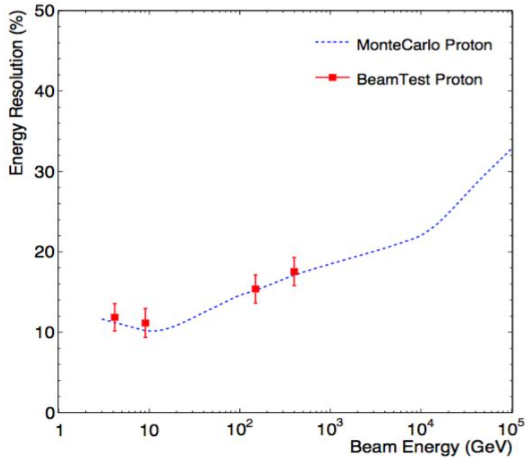


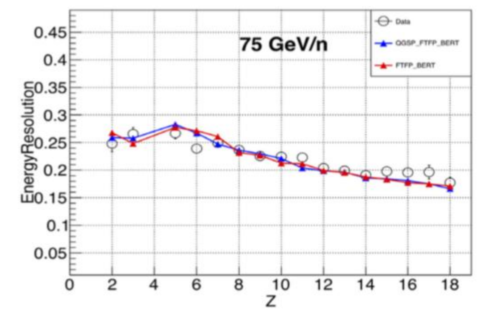
Beam tests at CERN PS & SPS

- Electrons (protons): few GeV — 250 (400) GeV, ions: 40 GeV/n, 75 GeV/n
- Energy resolution: ~1% (e/γ) at 100 GeV and above, 20%—30% for protons/ions



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





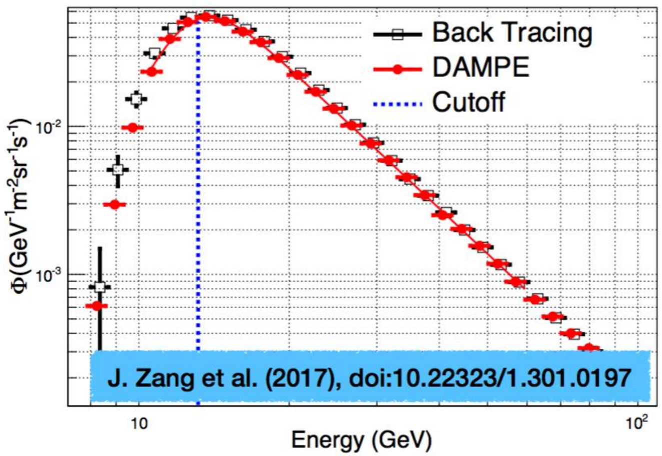
Y. Wei et al. NIMA 922 (2019)

Energy calibration

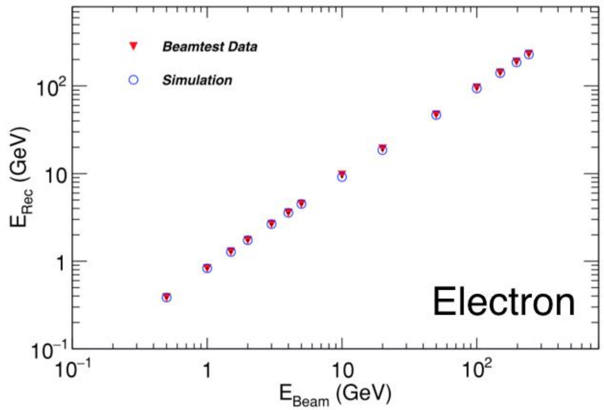
- On-orbit energy scale verified with **geomagnetic cut-off**
- Good linearity to ~2.5 (100) TeV with electron (nuclei) events

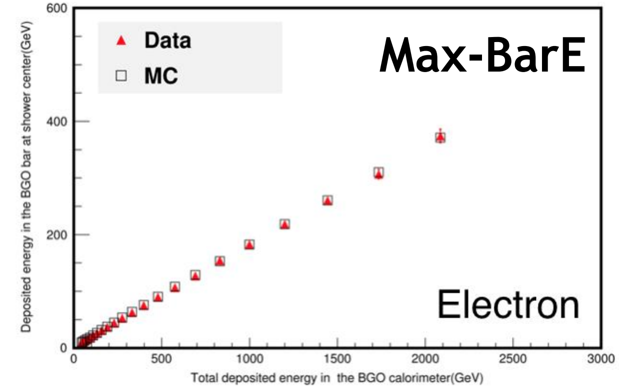
C. Zhao et al. NIMA 1092, 166453 (2022)

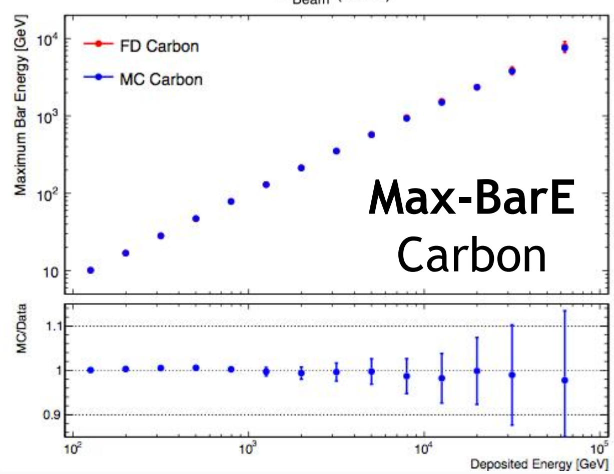
cosmic-ray electron
geomagnetic cut-off

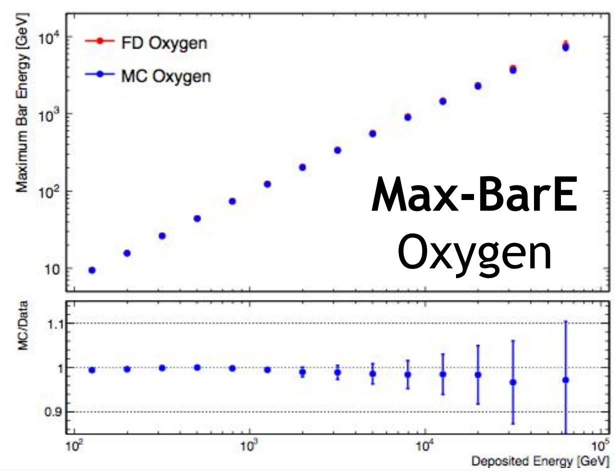


E scale in flight: **+ 1.25%** ± 1.75%(stat) ± 1.34%(sys)





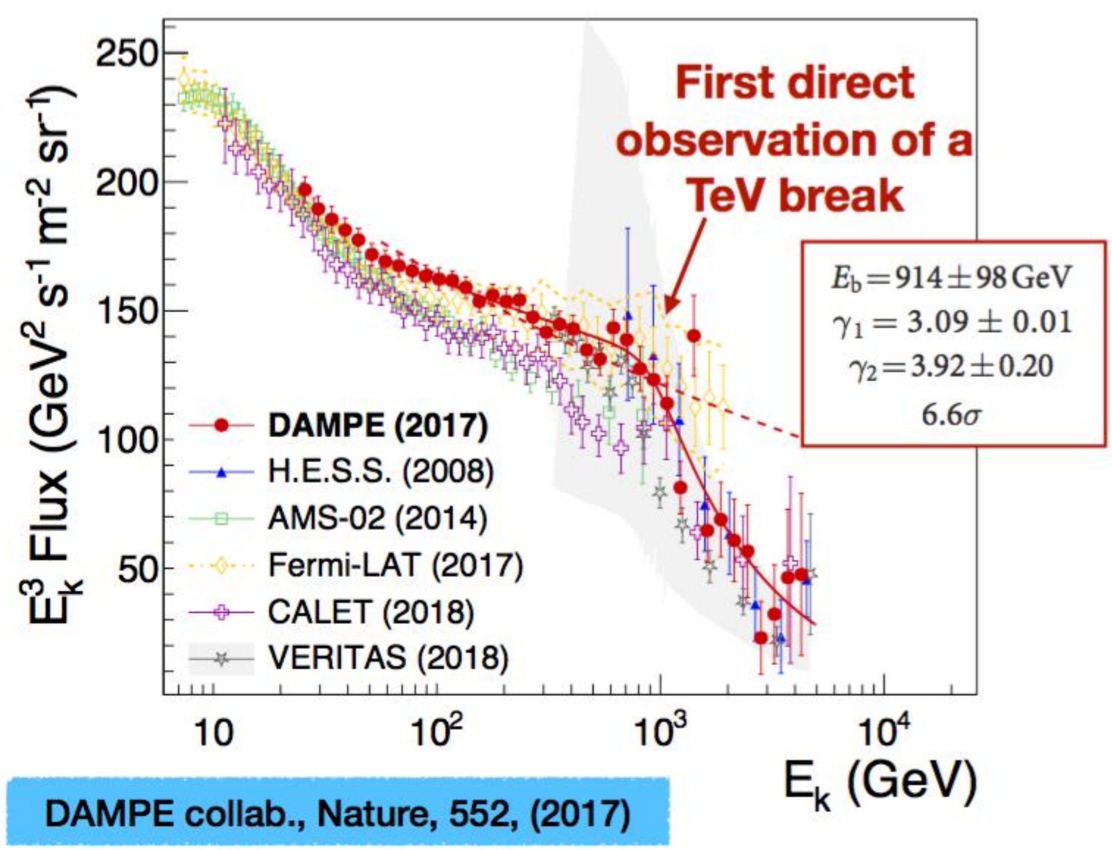


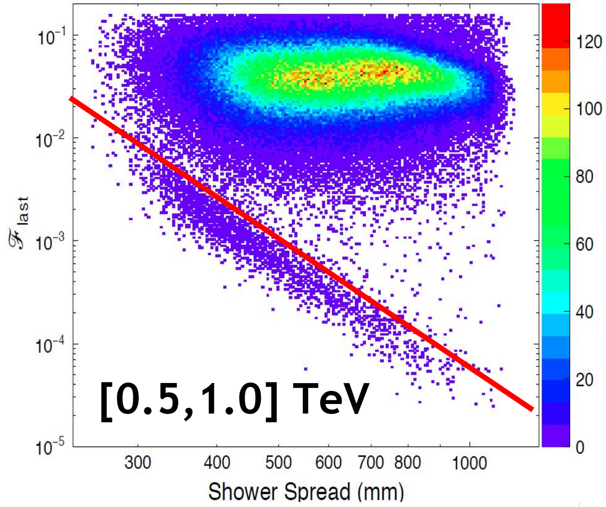


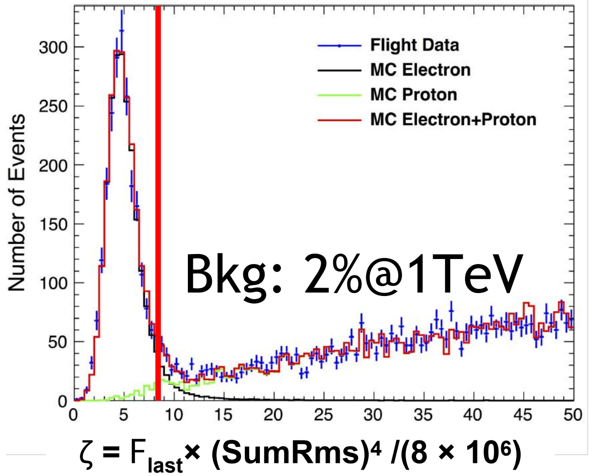
Physical results

$e^{+}+e^{-}$ spectrum

$e^{-} + e^{+}$ spectrum:







- **Excellent energy resolution** and **powerful e/p identification**

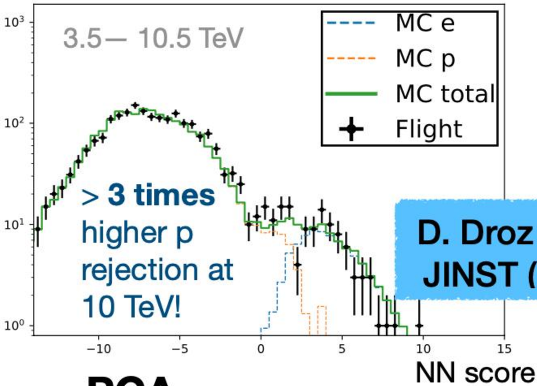
$e^{+}+e^{-}$ spectrum (in process)

Work in process:

1. **Deep and long-term detector calibration.**
2. **New particle ID for high energies:**

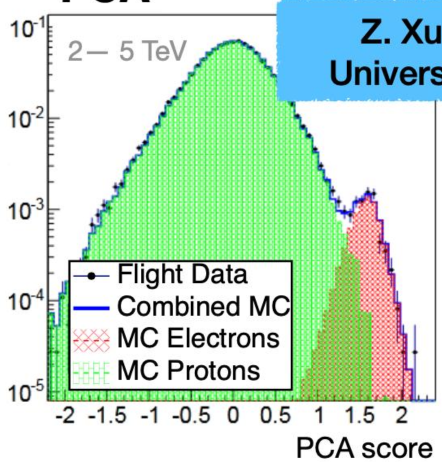
Neural Networks (NN), Principal Component Analysis (PCA), Application of Neutron Detector (NUD)

NN



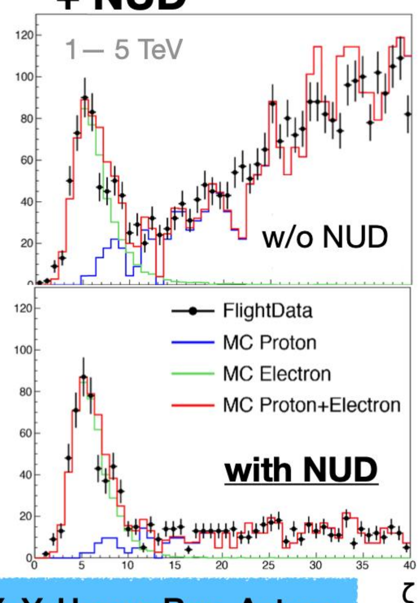
D. Droz et. al. JINST (2021)

PCA



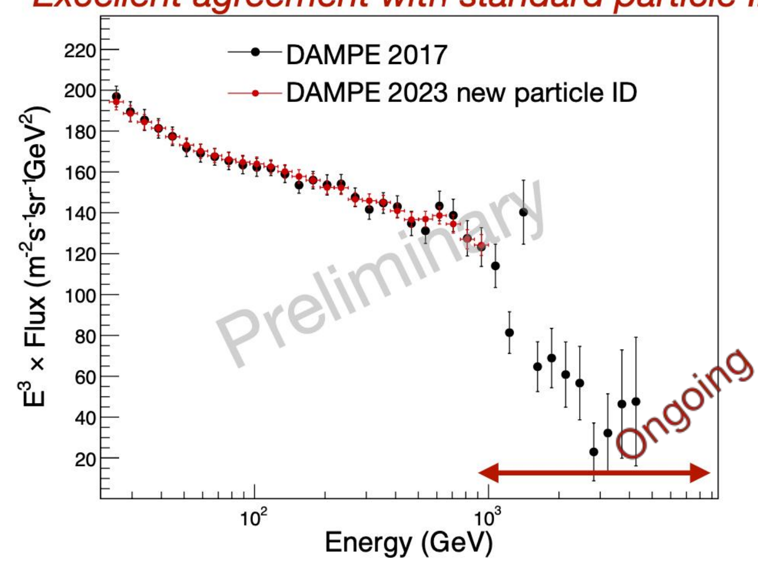
Z. Xu et. al. Universe (2022)

+ NUD



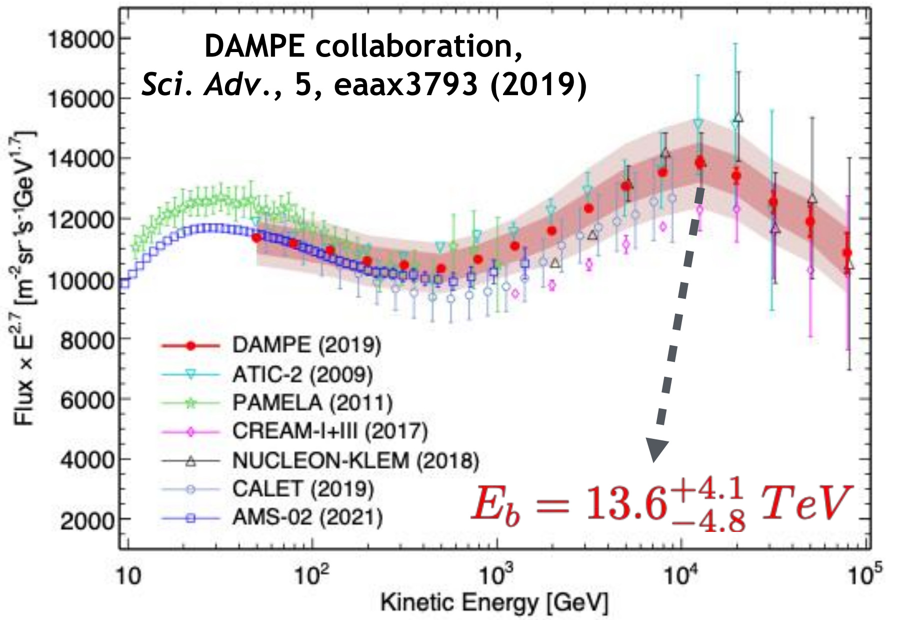
Y.-Y. Huang Res. Astron. Astrophys. (2020)

Excellent agreement with standard particle ID

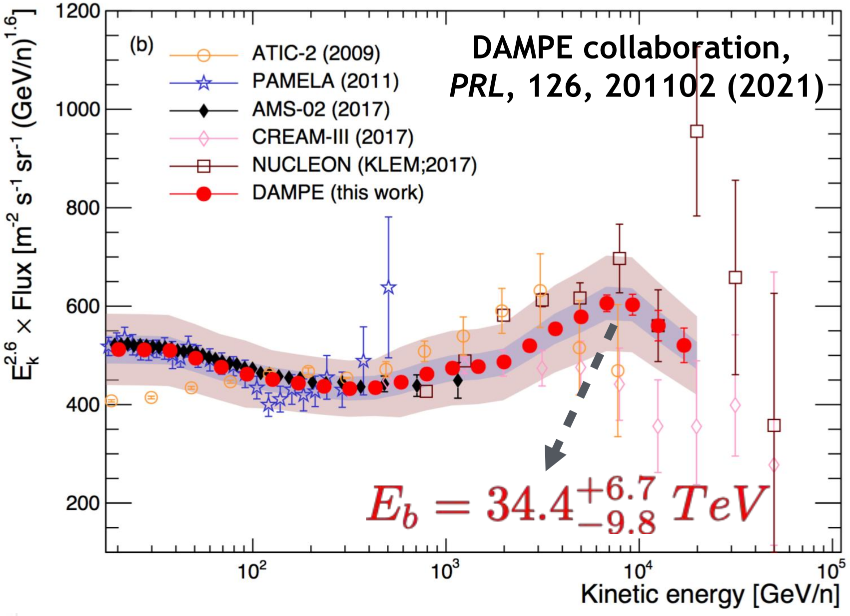


proton, Helium

CR Proton



CR Helium

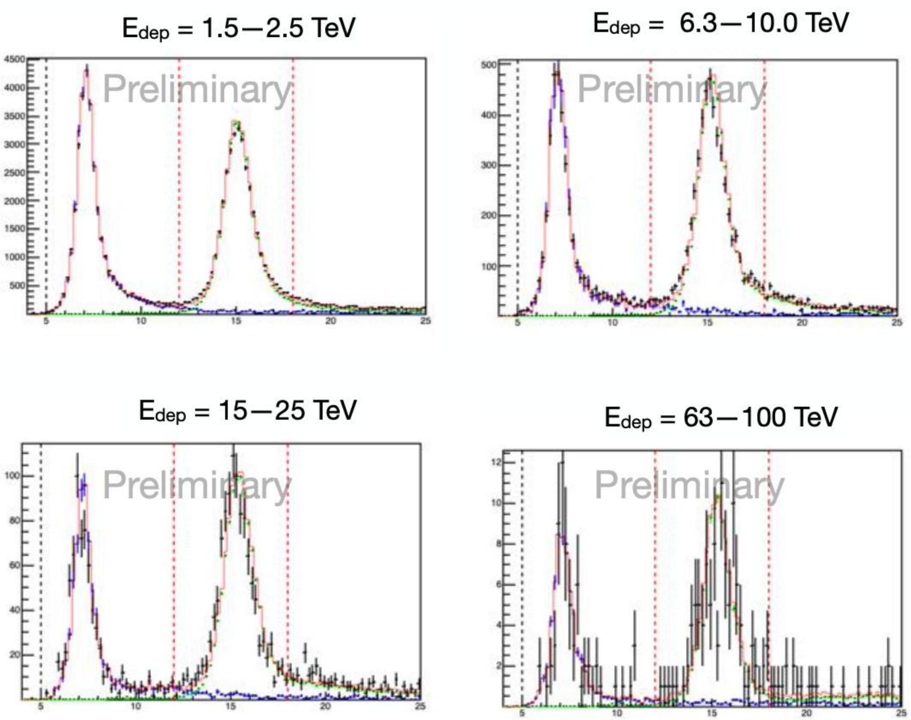


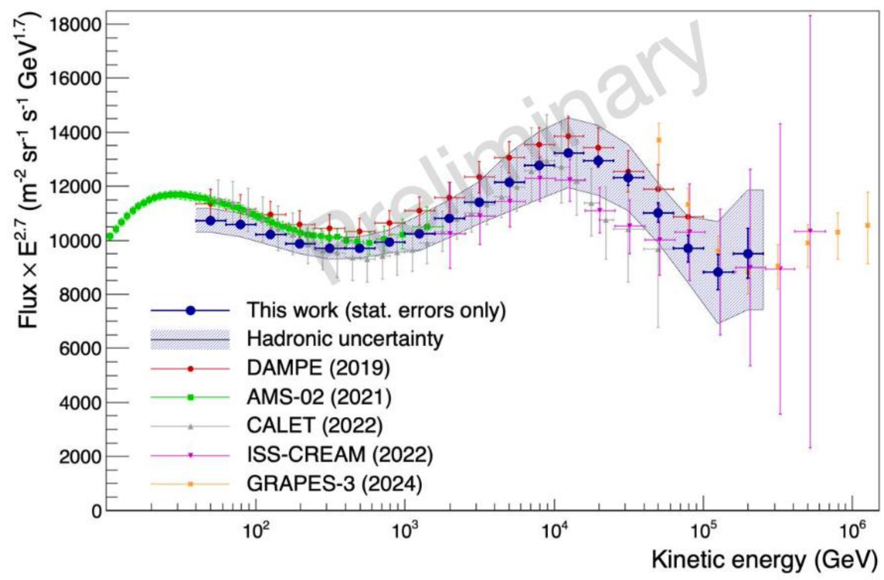
- The spectra of CR proton and helium measured by DAMPE show a very similar softening feature at tens of TeVs.
- The softening energies are well consistent with a dependence on particle charge, although a dependence on particle mass can not be ruled out yet.
- The results implicate a Z-dependent spectral break (e.g. "knee") in CR nuclei, which is likely an imprint of a nearby cosmic ray source.

proton, Helium (new updates)

<u>Work in process:</u>

Updates and new approaches on detector calibration.
New track & charge reconstruction with ML method.





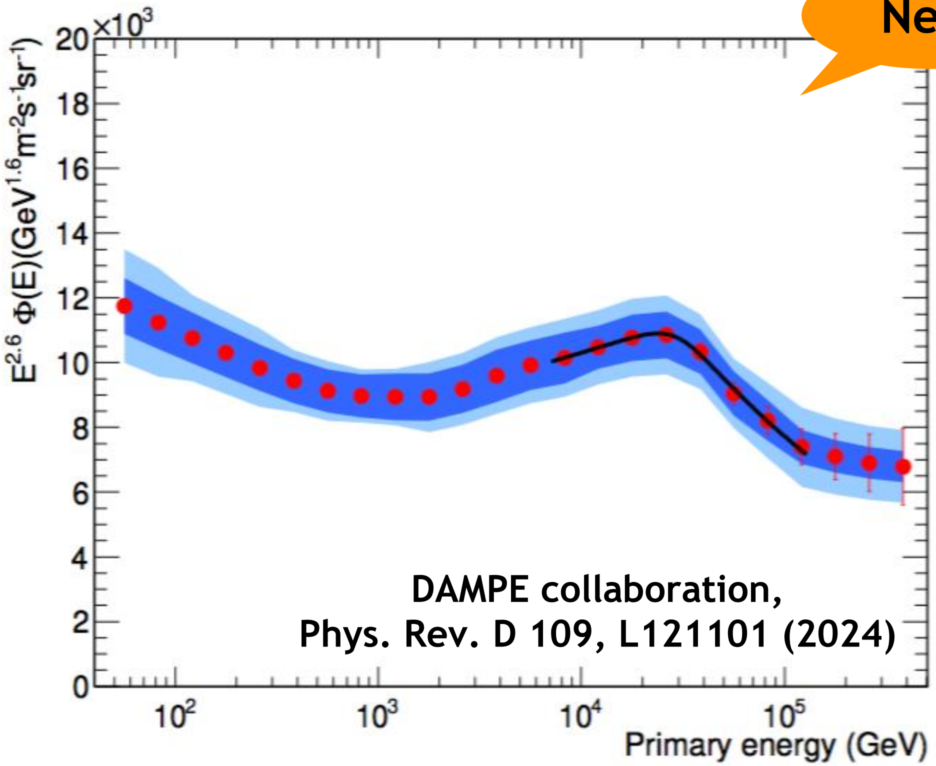
See talk by A. Tykhonov

proton+Helium (new)

Independent analysis of p+He spectrum in the collaboration

Very low contamination + Very large statistics => High upper limit of measurement

New



DAMPE collaboration,
Phys. Rev. D 109, L121101 (2024)

Smoothly-broken power-law model (SBPL)

$$\Phi(E) = \Phi_0 \left(\frac{E}{TeV}\right)^{-\gamma} \left[1 + \left(\frac{E}{E_b}\right)^{1/w}\right]^{-\Delta\gamma \cdot w}$$

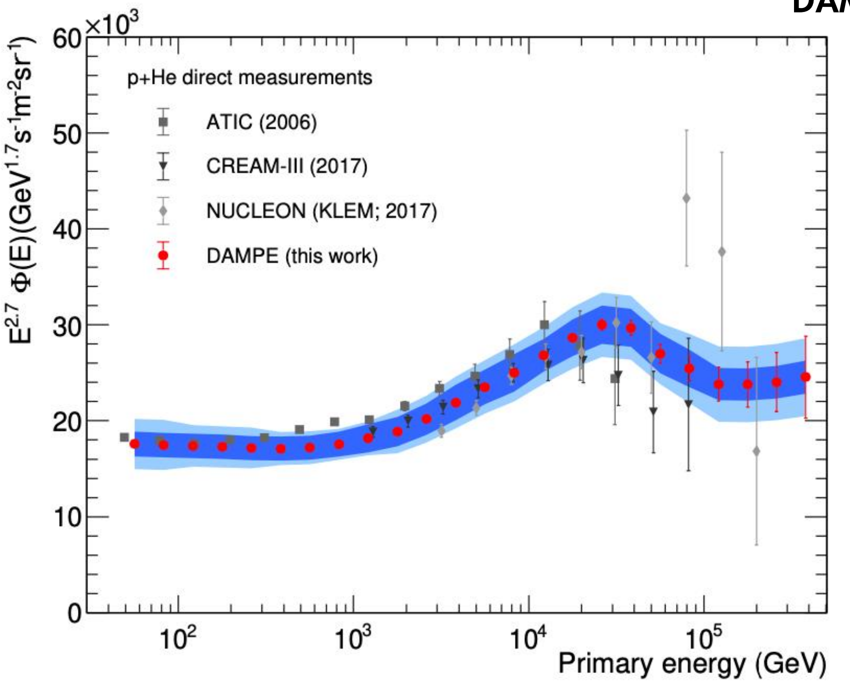
	Proton	Helium	Proton+Helium
E_b (TeV)	$13.6^{+4.1}_{-4.8}$	$34.4^{+6.7+11.6}_{-9.8-0.0}$	$28.8^{+6.2+2.9}_{-4.4-0.0}$
γ	2.60 ± 0.01	$2.41^{+0.02+0.02}_{-0.02-0.00}$	$2.51^{+0.021+0.01}_{-0.024-0.00}$
$\Delta\gamma$	-0.25 ± 0.07	$-0.51^{+0.18+0.01}_{-0.20-0.00}$	$0.43^{+0.066+0.066}_{-0.057-0.00}$

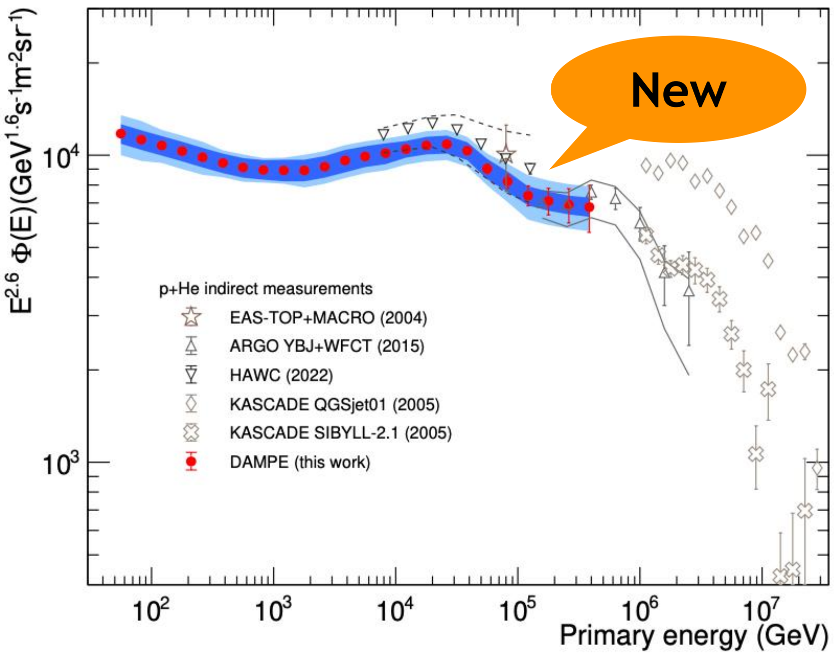
SBPL model favored on the PL model with a significance of 6.6σ

proton+Helium (new)

Independent analysis of p+He spectrum in the collaboration

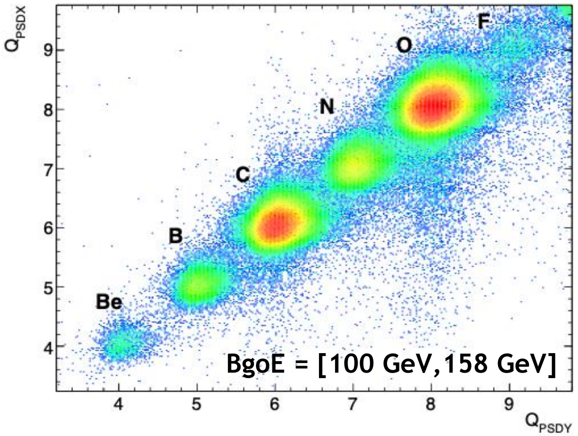
DAMPE collaboration, Phys. Rev. D 109, L121101 (2024)



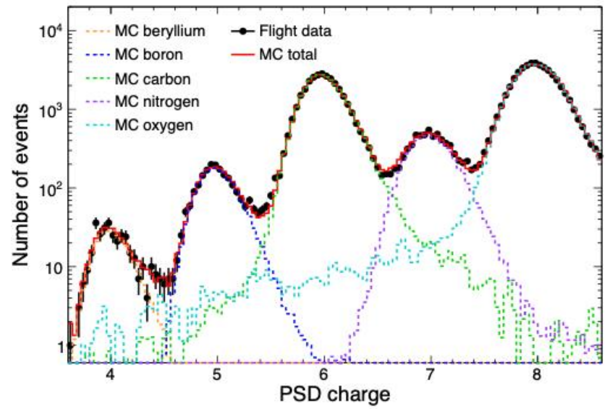


- Link between direct/indirect CR measurements
- **Hint of new spectral hardening at ~150 TeV**

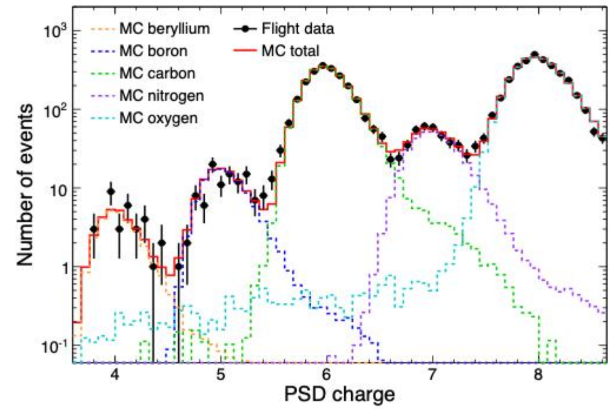
Carbon and Oxygen

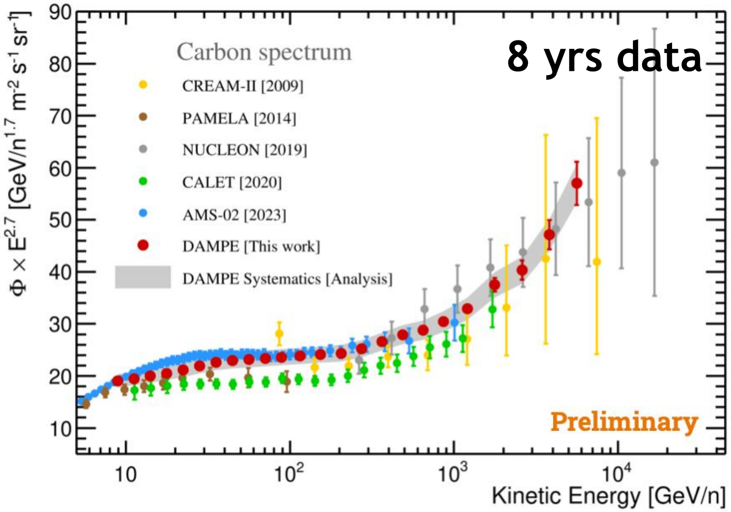


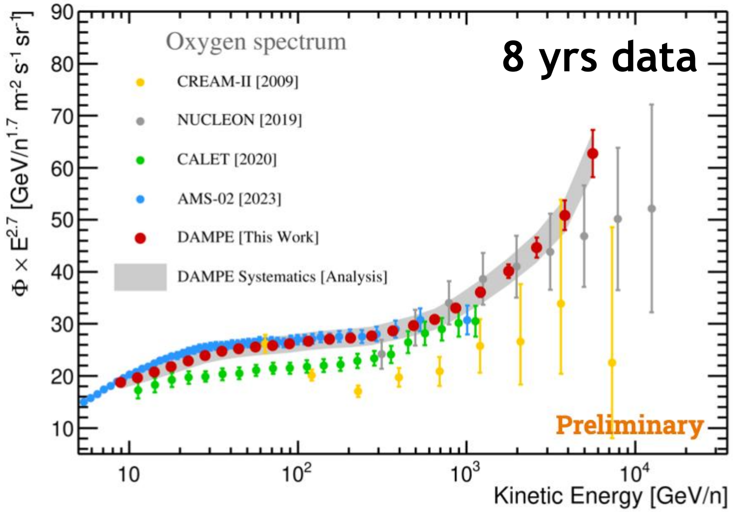
0.63-2 TeV



3.16-10 TeV





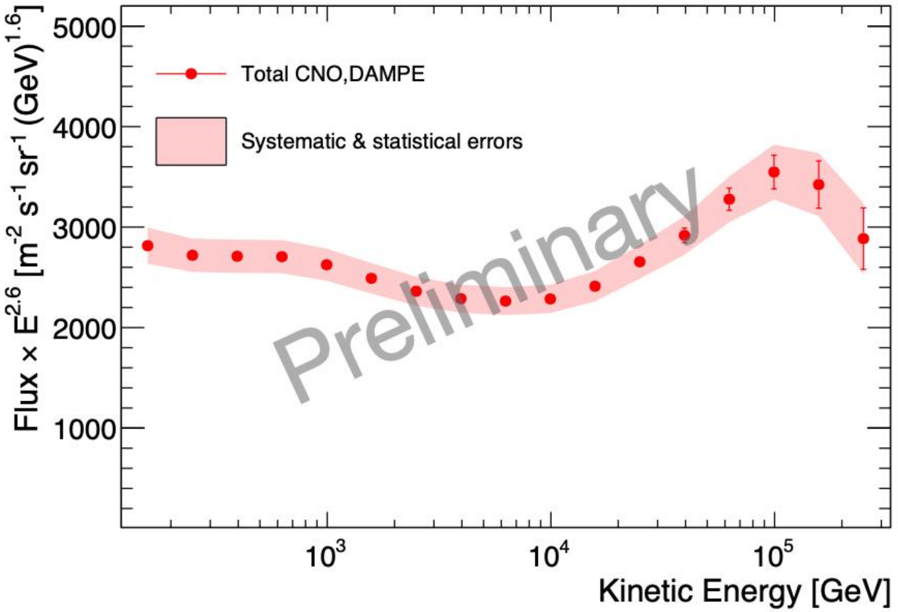


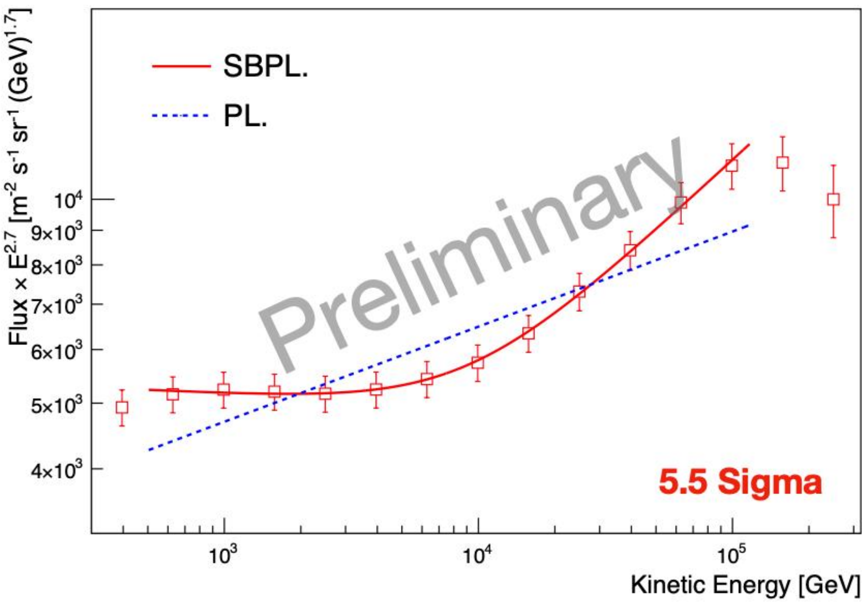
See talk by D. Kyratzis

- **Preliminary DAMPE measurements confirm the hardening structure at several hundreds of GeV/n observed by previous experiments.**

CNO group

The spectrum of CNO group in cosmic rays

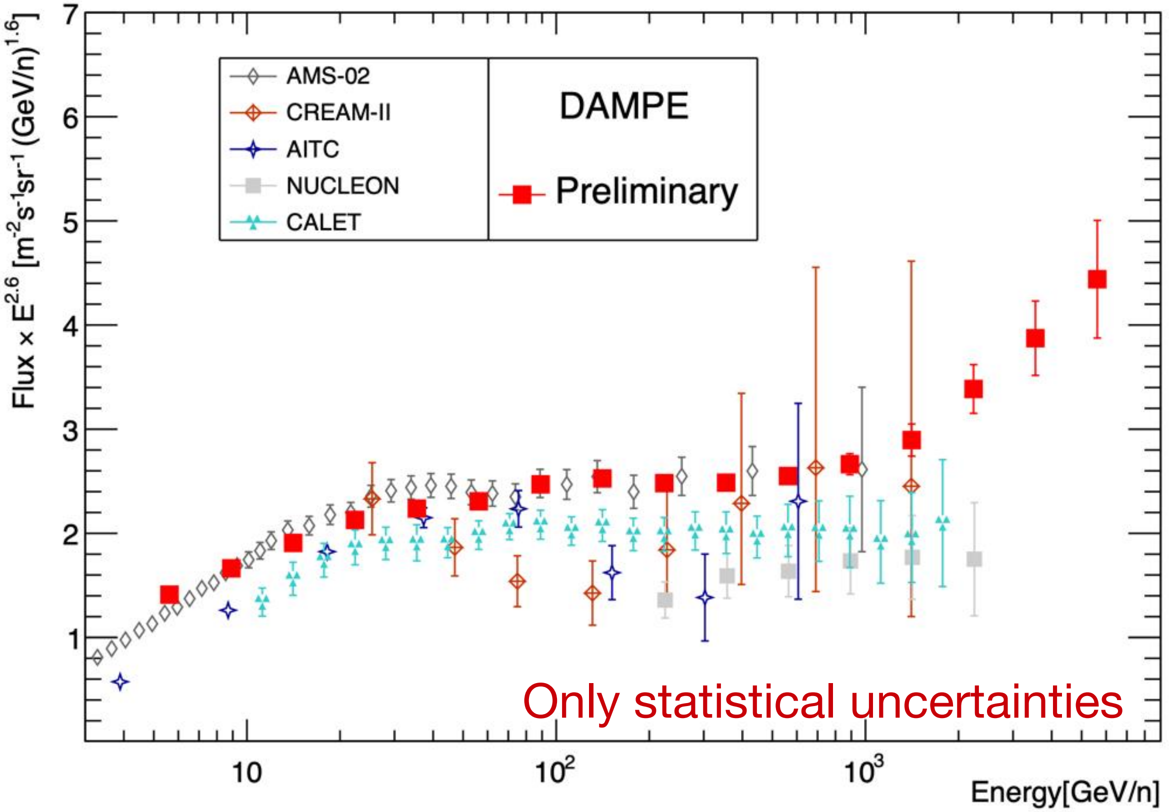




See talk by P.X. Ma

- **The spectrum of CNO group can be measured up to 500 TeV**
- **A spectral hardening at ~9 TeV with 5.5 sigma of CL. is observed.**

Iron

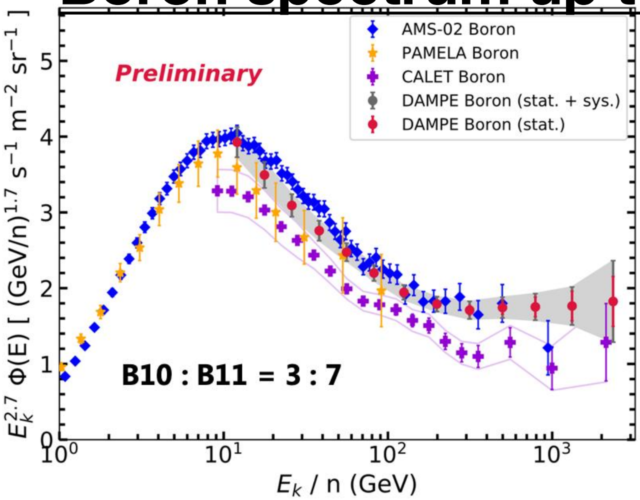


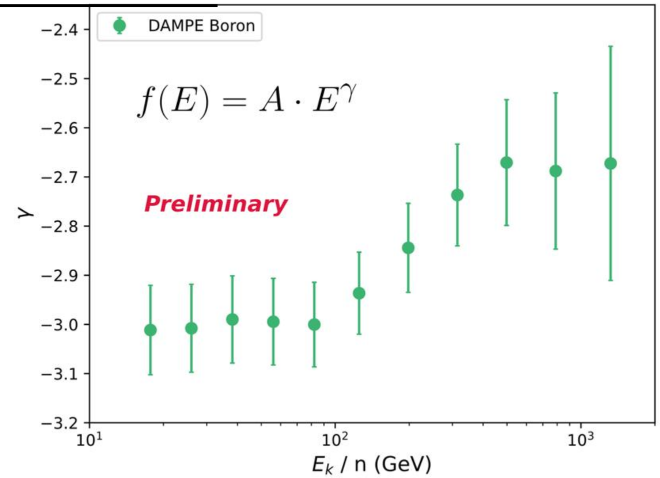
- Preliminary iron spectrum up to 10 TeV/n shows **a significant hardening around 1 TeV/n**. Evaluation of systematics is in progress …

See talk by Z.H. Xu

Secondries (Li, Be, B)

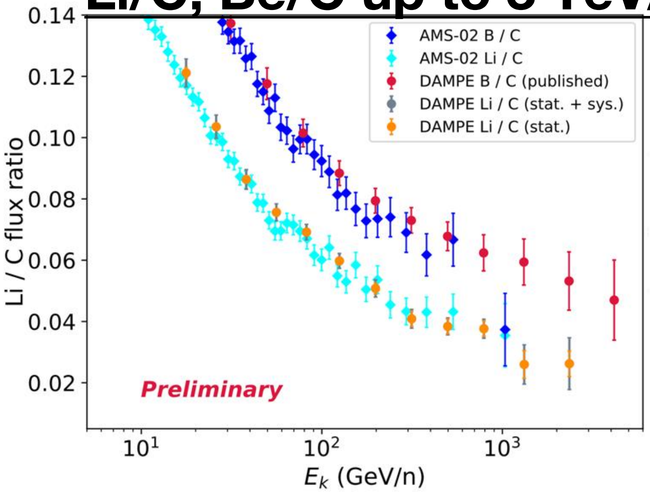
Boron spectrum up to 3TeV/n

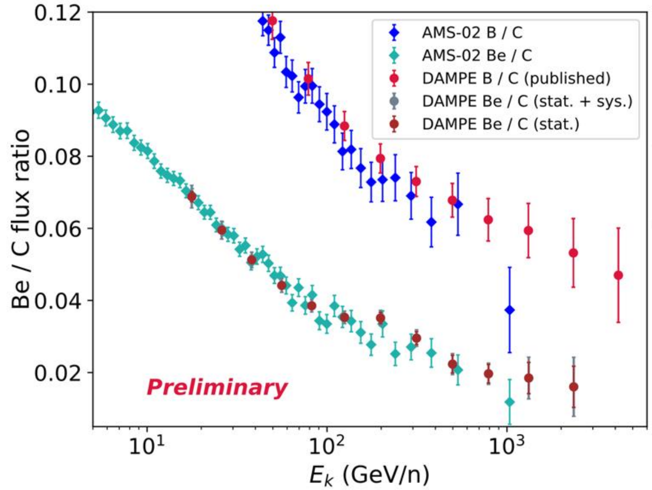




- Spectral hardening: from -3.0 to -2.7 at a few hundreds of GeV/n

Li/C, Be/C up to 3 TeV/n

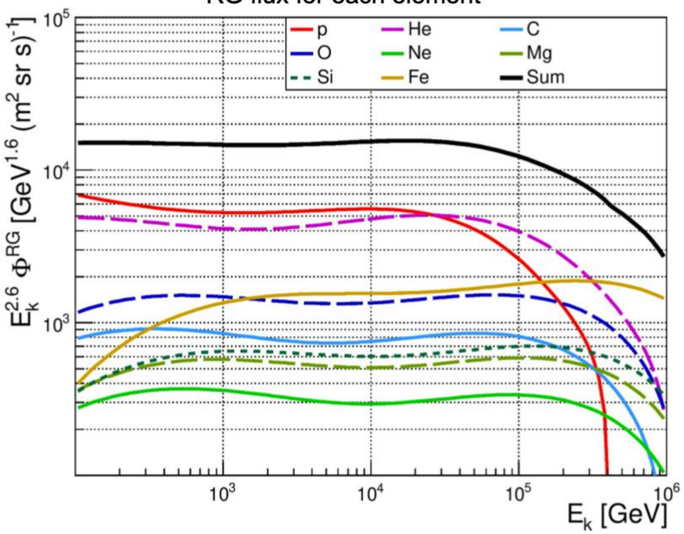


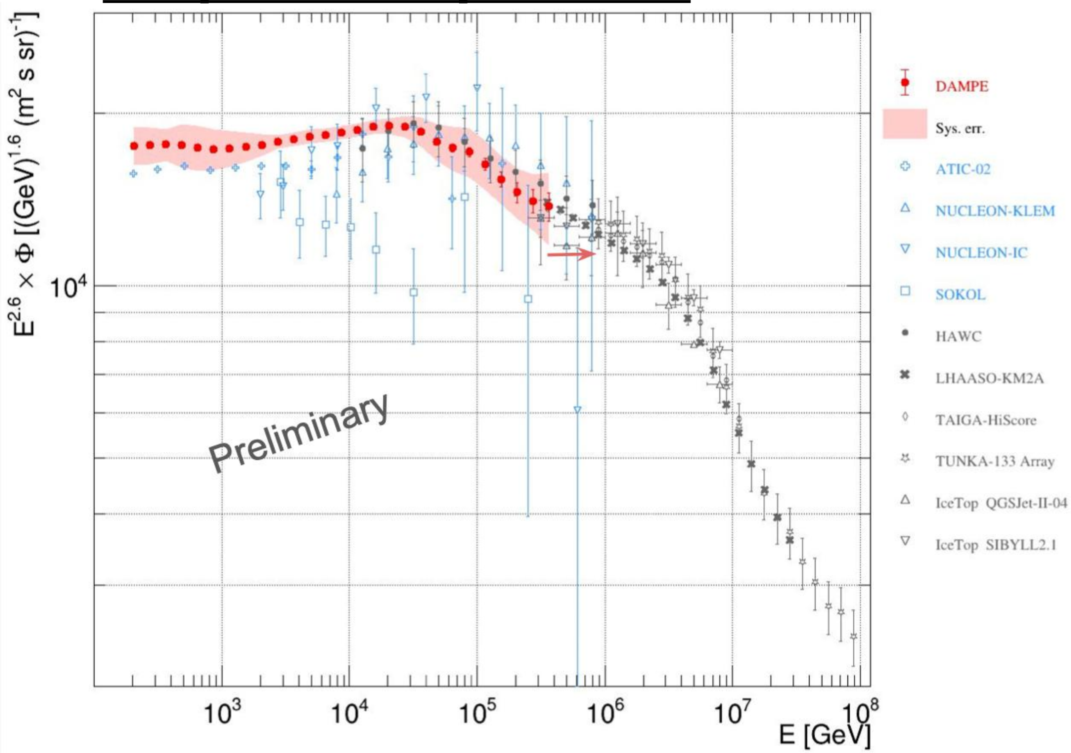


- Hints of hardening at ~100 GeV/n in **Li/C and Be/C, similar as B/C and B/O**

See talk by Z.F Chen

All particle





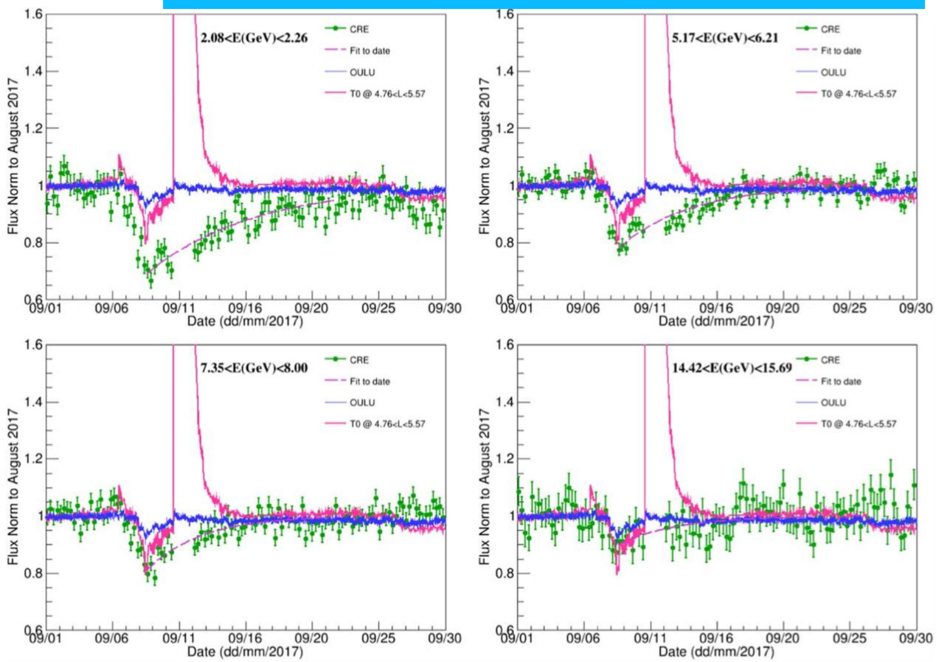
- **Different composition models are evaluated and applied in the analysis.**
- **Preliminary all-particle spectrum shows a “knee” feature at tens of TeV, most probably due to the softening of different components.**

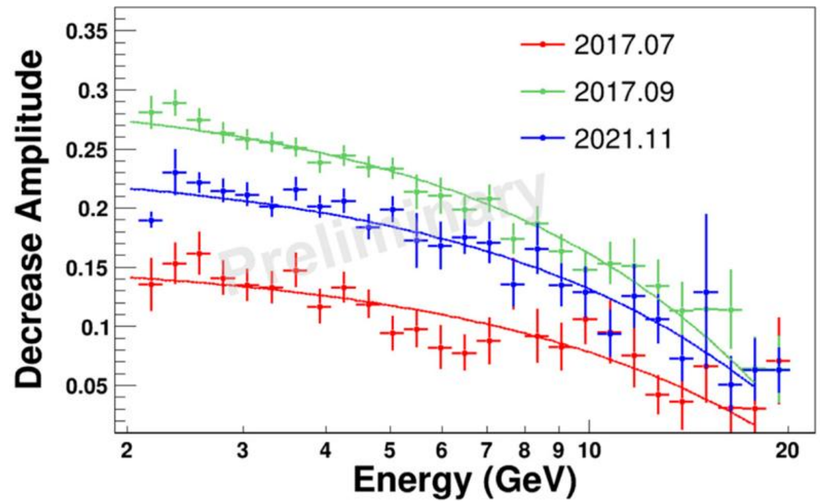
See talk by I. Cagnoli

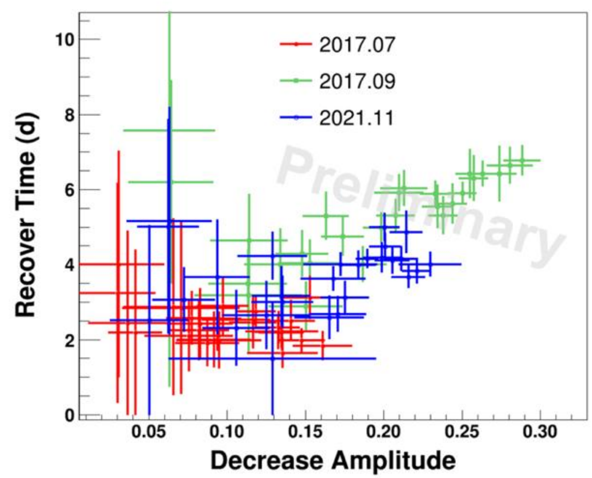
Heliosphere physics

- **Forbush Decrease (FD)** — A rapid decrease in CR intensity following a CME
- Large acceptance and polar orbit of DAMPE— allows precise FD measurement

DAMPE collaboration, ApJL. 920 L43 (2021)





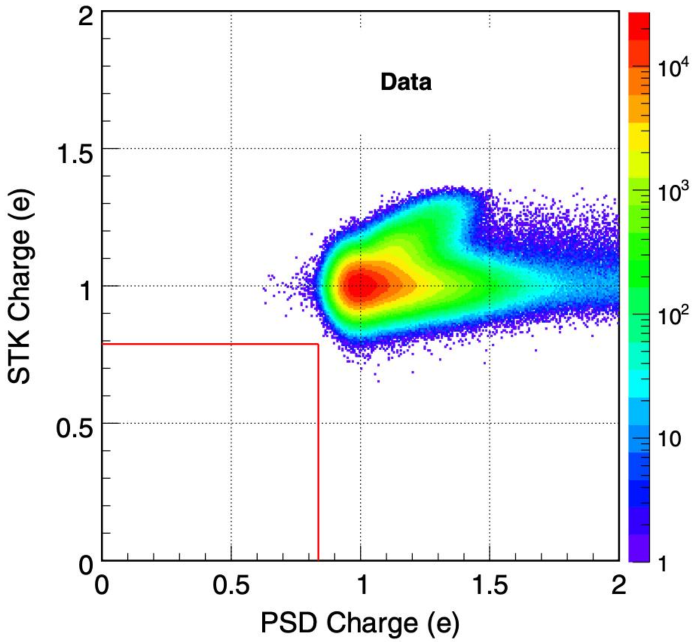


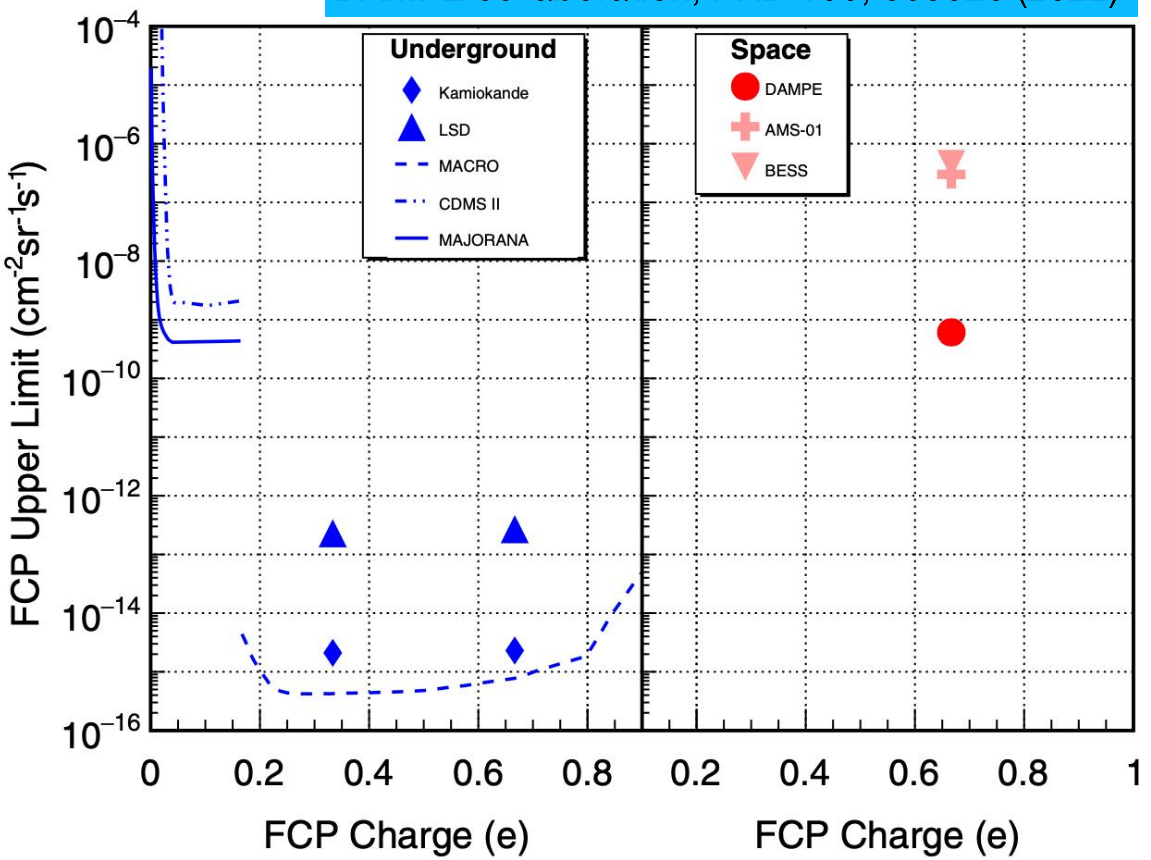
New FD features observed for the relation: **recovery time** v.s. **decrease amplitude**

Fractional Charged Particles (FCP)

- FCP search in space
  — beyond Standard Model

DAMPE collaboration, PRD 106, 063026 (2022)

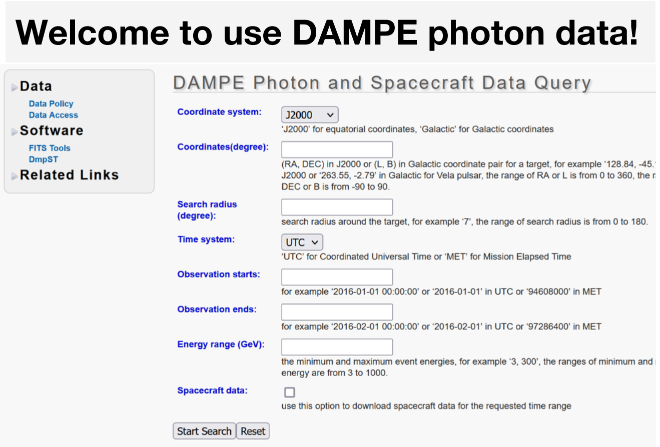




DAMPE provides the most stringent constrains on the FCP flux upper limit in space at a few GeV. <u>note: Ground-based results — above hundreds GeV</u>

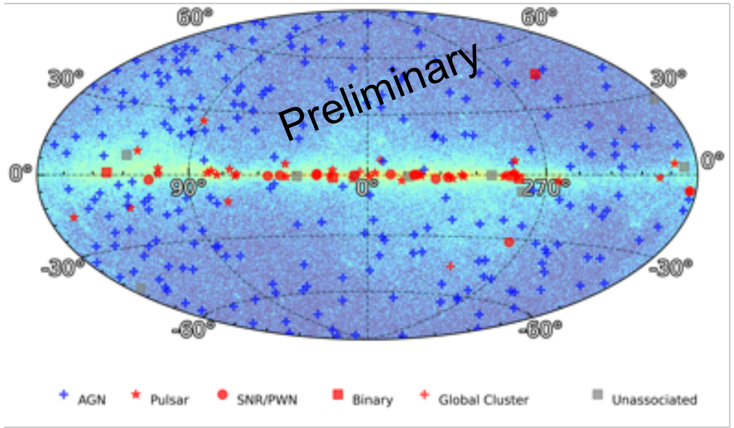
Gamma-ray astronomy

Welcome to use DAMPE photon data!



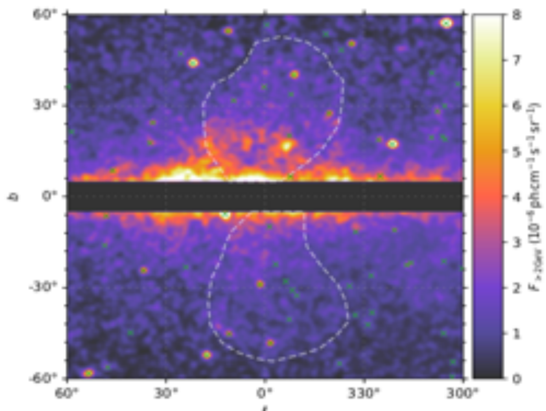
https://dampe.nssdc.ac.cn/dampe/dataquerysc.php
http://dgdb.pmo.ac.cn/dampe/

Point source catalog

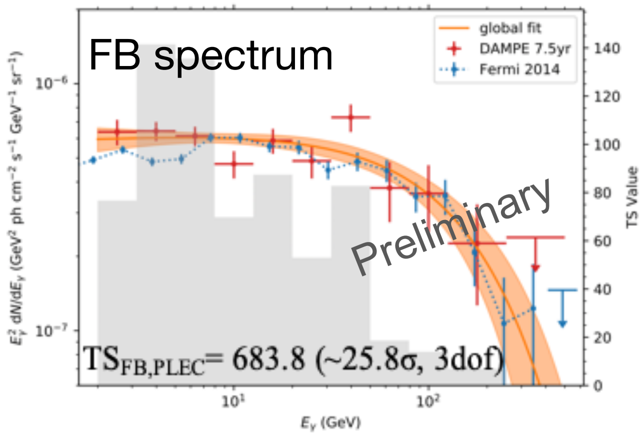


Source type	number
AGN	241
Pulsar	62
SNR/PWN	14
Binary	5
Global cluster	4
Unassociated	10
Total	336

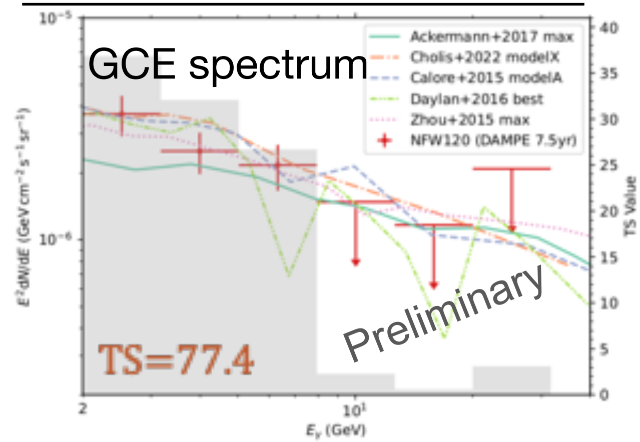
Fermi Bubbles



Flux map



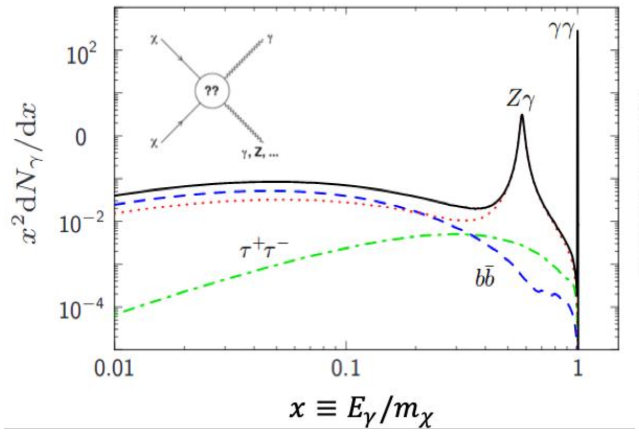
Galatic Center Excess

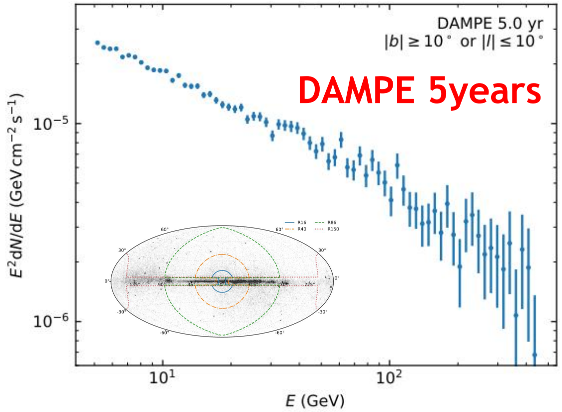


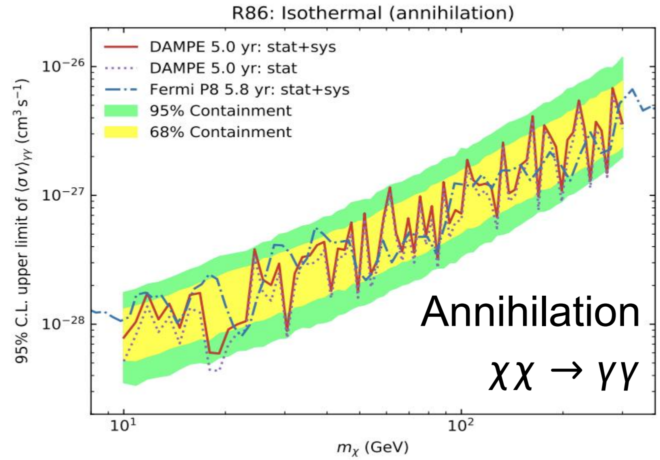
See talk by K.K Duan

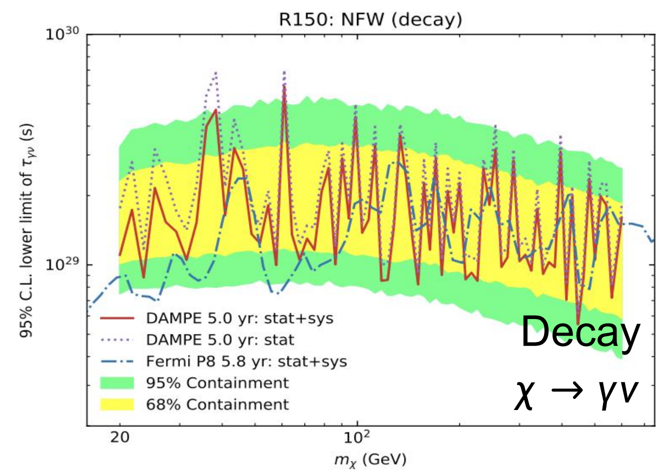
Gamma-ray line search

DAMPE collaboration & Y.F Liang, Science Bulletin, 67, 679 (2022)









- Gamma-ray line is the "smoking gun" signal for dark matter indirect search.
- The energy resolution of DAMPE is excellent for searching gamma-ray lines.
- We searched for the lines with 5 years data beween 5 and 450 GeV. No significant line signals are detected.
- More data is currently being analyzed.

See talk by K.K Duan

Summary

DAMPE mission

- Smooth on-orbit operation for 8.5 years
- Excellent performance and stability
- Unique for TeV-PeV Cosmic Ray detection in space

Physical programs

- $e^{+}+e^{-}$ — direct observation of TeV-break
- p & He — universal softening at 15 TV and approaching the PeV frontier
- B/C & B/O ratio — observation of 100 GeV break
- C, O, Fe — observation of hardening at hundreds of GeV/n
- Li, Be, B and more — in progress ...
- Heliophysics — FD observations with CRE flux
- γ-ray sky, Fermi Bubbles, GCE, DM search, …

Summary

DAMPE talks in COSPAR2024

- **A. Tykhonov** CR proton flux towards PeV energies with DAMPE
- **Z.F. Chen** Spectral Analysis of Lithium, Beryllium and Boron Nuclides with DAMPE
- **D. Kyratzis** Latest Results on Cosmic Ray Carbon and Oxygen with the DAMPE space mission
- **P.X. Ma** Combined analysis of CNO group with DAMPE
- **Z.H. Xu** Direct Measurement of the Cosmic-Ray Iron Spectrum with the Dark Matter Particle Explorer
- **I. Cagnoli** Measurement of the all-particle energy spectrum with the DAMPE mission
- **K.K. Duan** Recent Gamma-ray Results from DAMPE

Thank You!