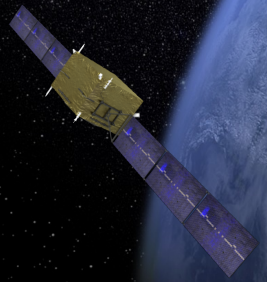
Measurement of Cosmic Ray spectra with the DAMPE space mission



Francesca Alemanno*
on behalf of the DAMPE collaboration

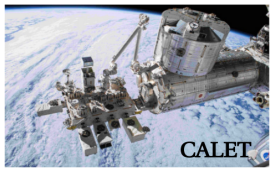
INFN-Lecce

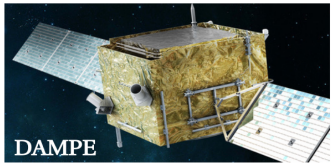
*email: francesca.alemanno@le.infn.it

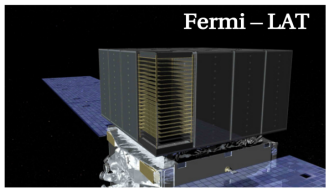
Cosmic Rays and Neutrinos in the Multi-Messenger Era,
APC Laboratory (Paris), 9-13/12/2024

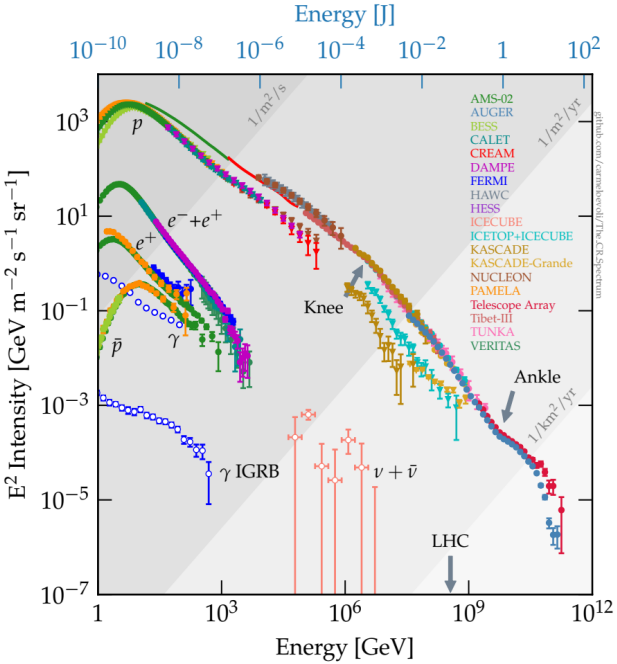
Study of CR spectra

Direct detection
up hundreds of TeV

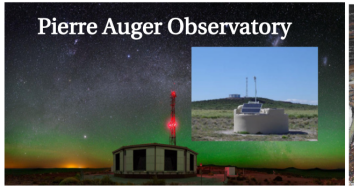


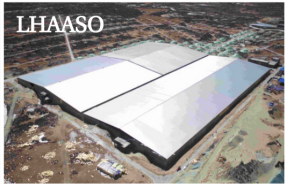






Indirect detection
up $\sim 10^{20}$ eV





Direct CR detection:

- **Precise measurement of particle energy and charge**
- **Covering the low-energy part of the spectrum**

Research Goals and Open Questions

- Precise measurements of **CR spectra** and **mass composition**
- Detection of **spectral structures** (hardenings/softenings)
- Understand CR **acceleration** and **propagation** mechanisms

Indirect CR detection:

- **Possibility to reach the highest energies**
- **Difficult to make composition studies with small systematics**

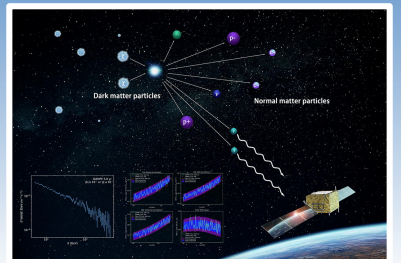
The DAMPE space mission

The **DA**rk **M**atter **P**article **E**xplorer (DAMPE) is a satellite-based experiment

DAMPE was successfully launched on **December 17th 2015** from the Jiuquan Satellite Launch Center

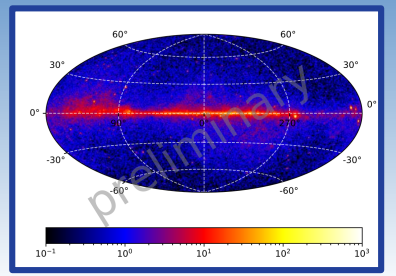
- ORBIT: Sun-synchronous
- ALTITUDE: 500 km
- INCLINATION: 97°
- PERIOD: 95 minutes

The DAMPE collaboration involves several institutes in China and Europe



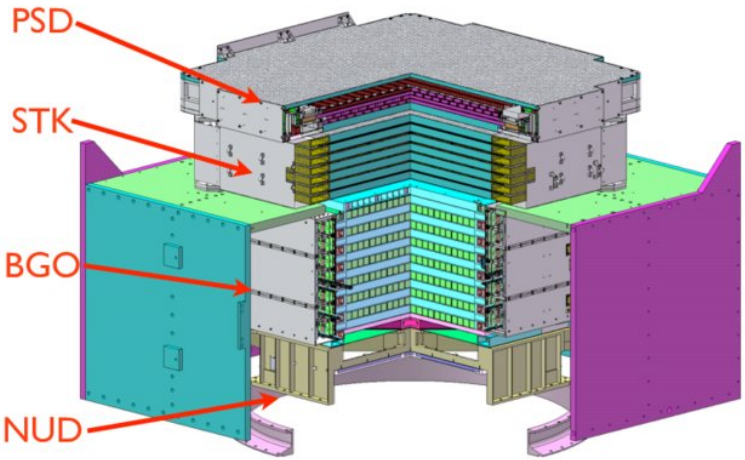
The main objectives of the DAMPE mission are:

- Study of galactic **cosmic-ray** physics
- **Dark matter** searches
- High-energy **gamma-ray** astronomy

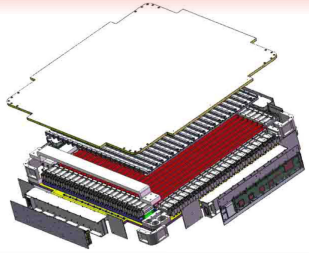


Detector structure

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

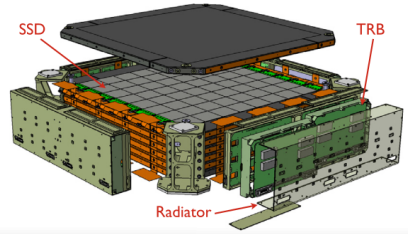


Plastic Scintillator Detector (PSD)



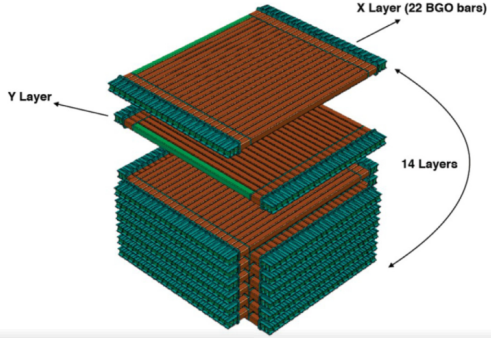
Charge measurement + identification of electrons and gamma-rays

Silicon-Tungsten tracKer (STK)



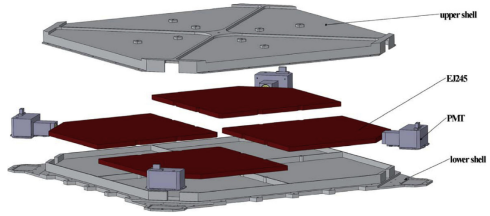
Silicon strips (precise tracking) + tungsten converter (pair production)

BGO Calorimeter (BGO)



Energy measurement + e/p separation

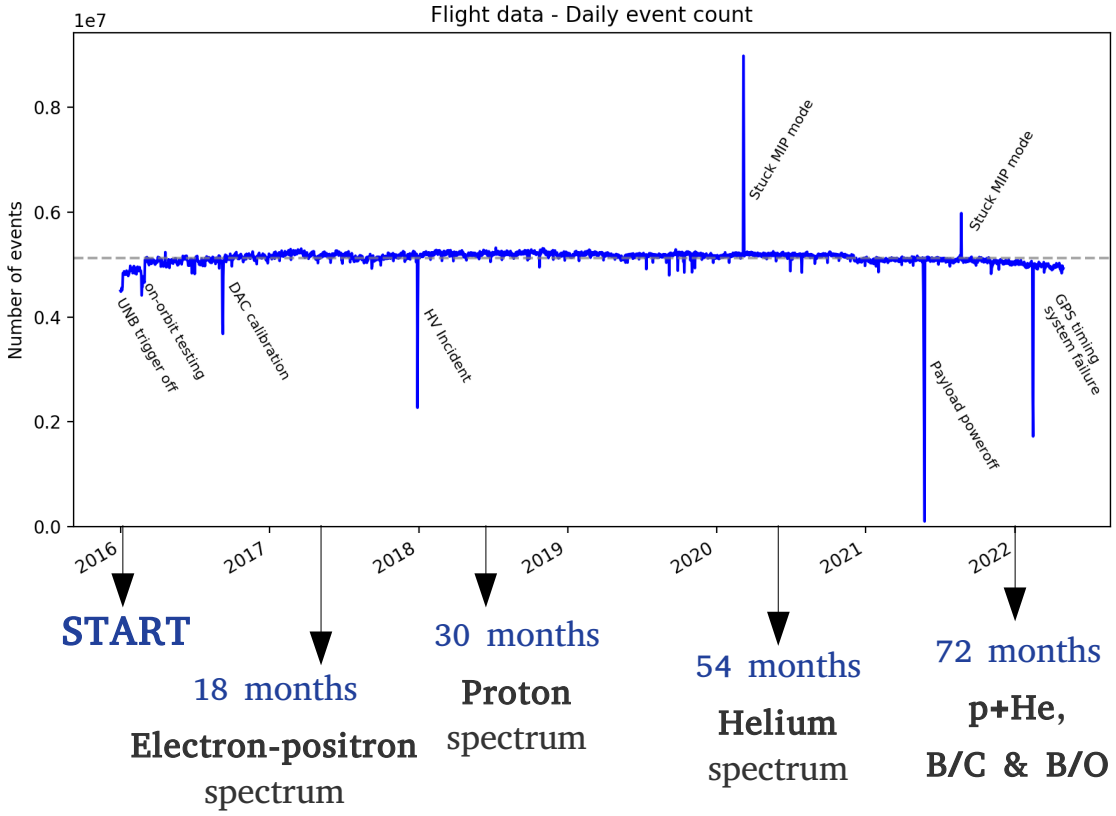
NeUtron Detector (NUD)

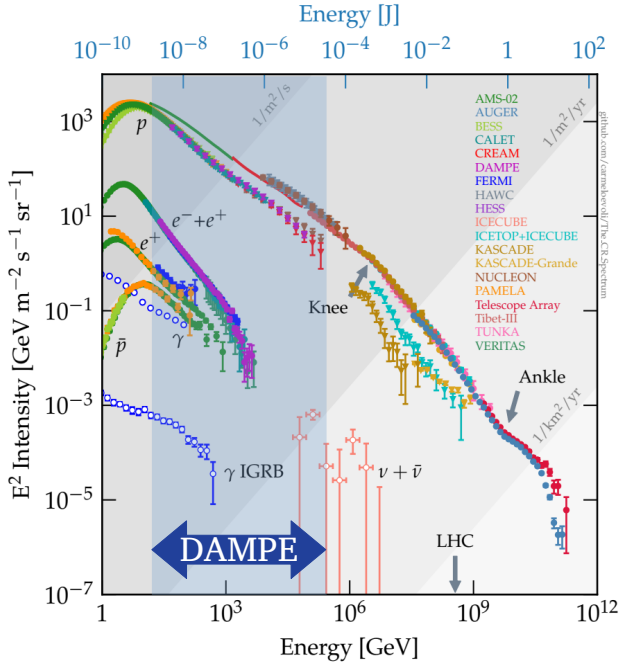


Additional hadrons rejection

CR data collected

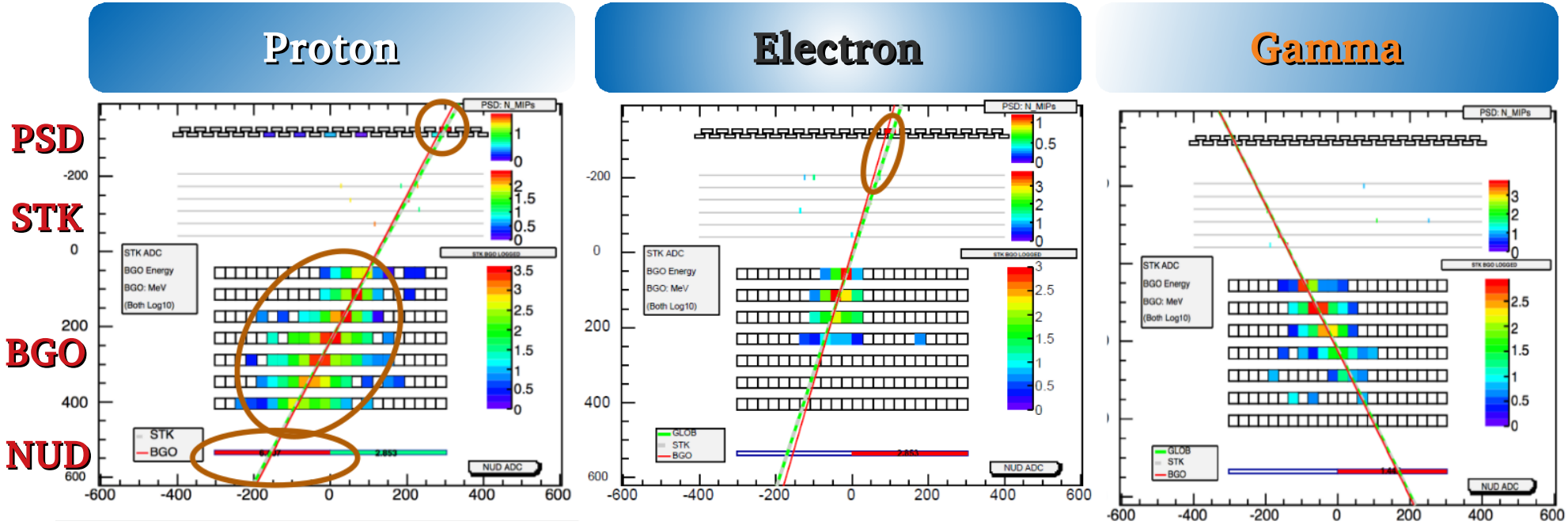
DAMPE collects ~5 million CR events per day





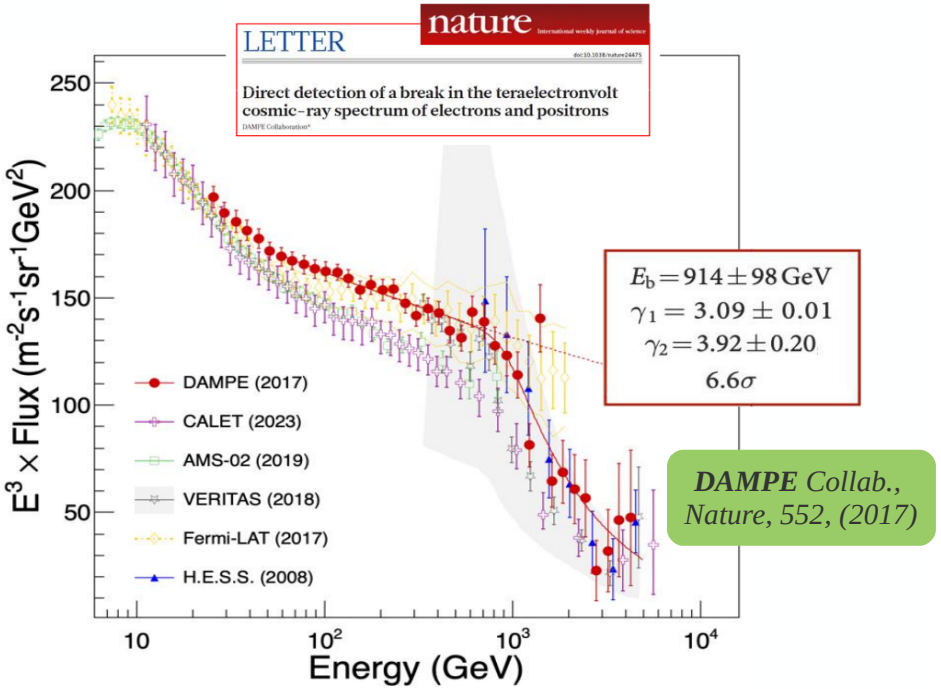
Energy range:
5 GeV – 10 TeV e/γ
50 GeV – 0.5 PeV protons and nuclei

Particle selection and identification



Plots from F. Gargano @MG15 ROME 2018

Electron-positron spectrum

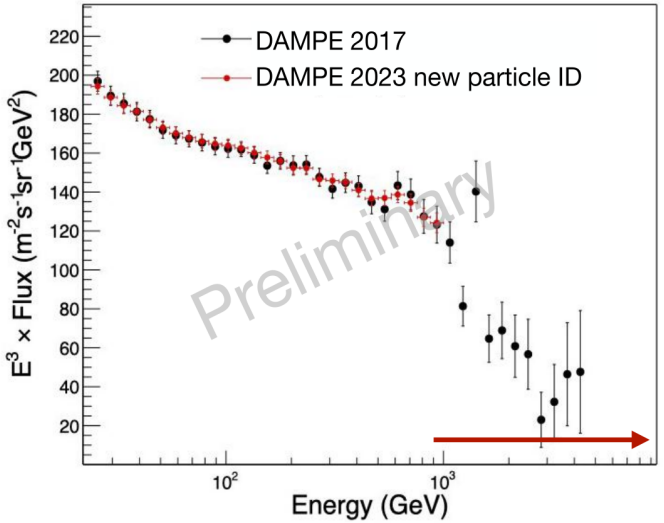


***DAMPE** Collab., Nature, 552, (2017)*

EVIDENCE OF A BREAK AT ~ 0.9 TeV with 6.6 σ significance

New e/p discrimination (Neural Networks) developed for higher energies → analysis ongoing

***D. Droz** et al, JINST, (2021)*



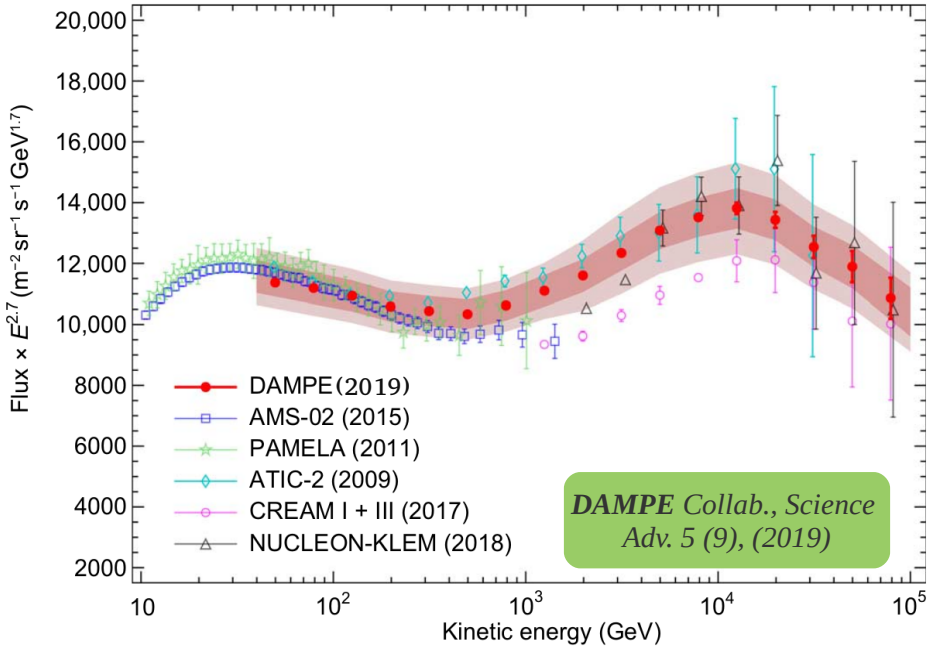
Excellent agreement with standard particle ID

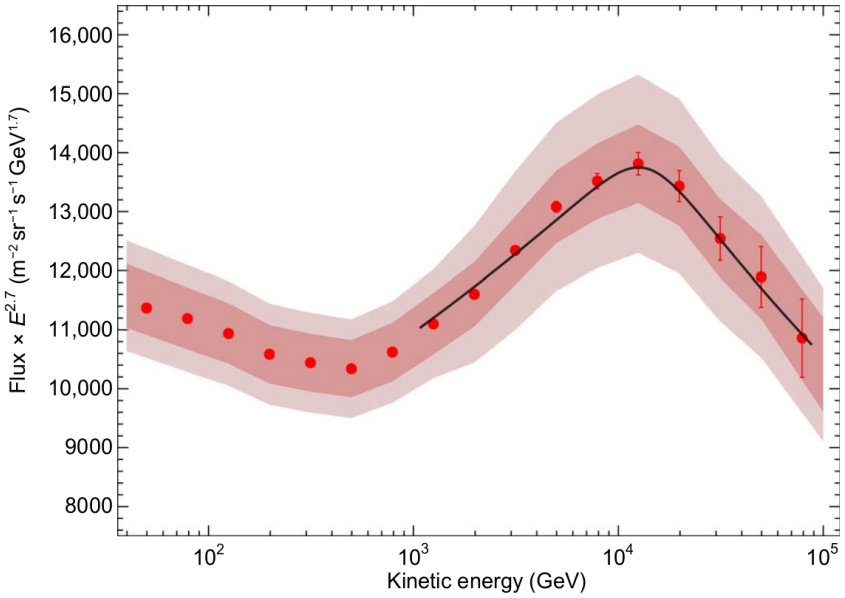
Proton spectrum

SCIENCE ADVANCES | RESEARCH ARTICLE

PHYSICS

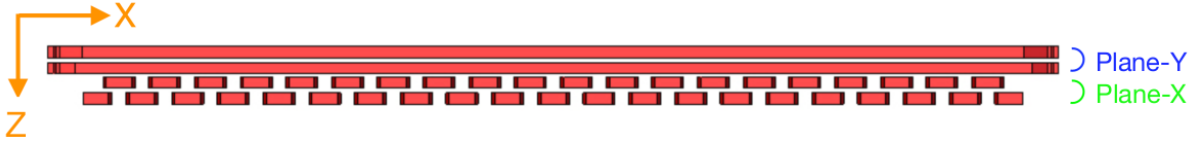
Measurement of the cosmic ray proton spectrum from 40 GeV to 100 TeV with the DAMPE satellite

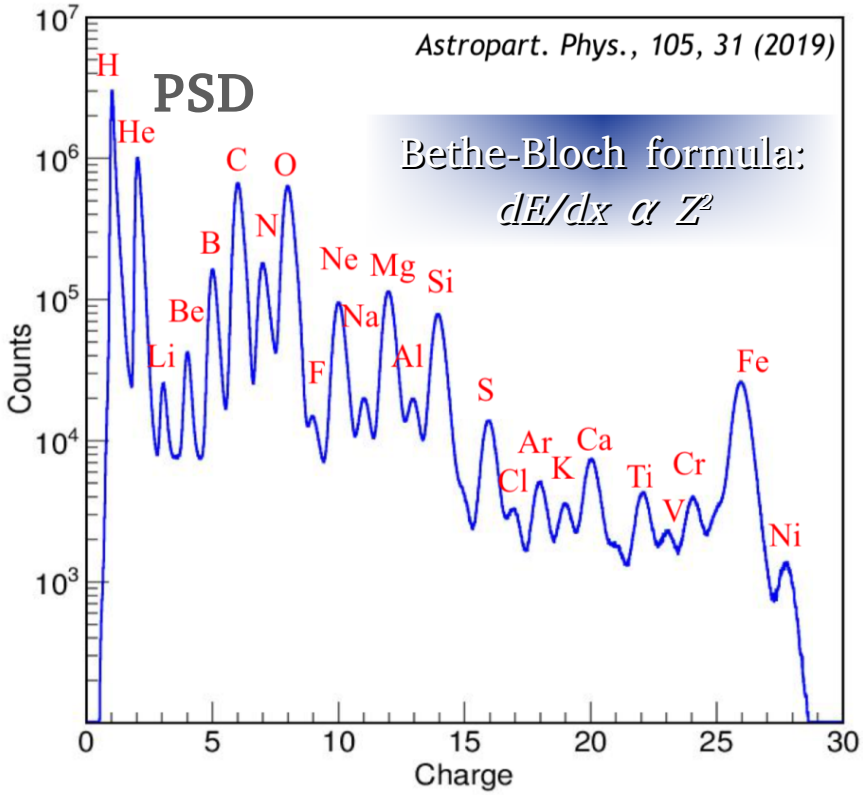




- Confirmation of a **hardening** structure at 480±10 GeV
- Detection of a **softening** at $13.6^{+4.1}_{-4.8}$ TeV with significance of ~4.7σ

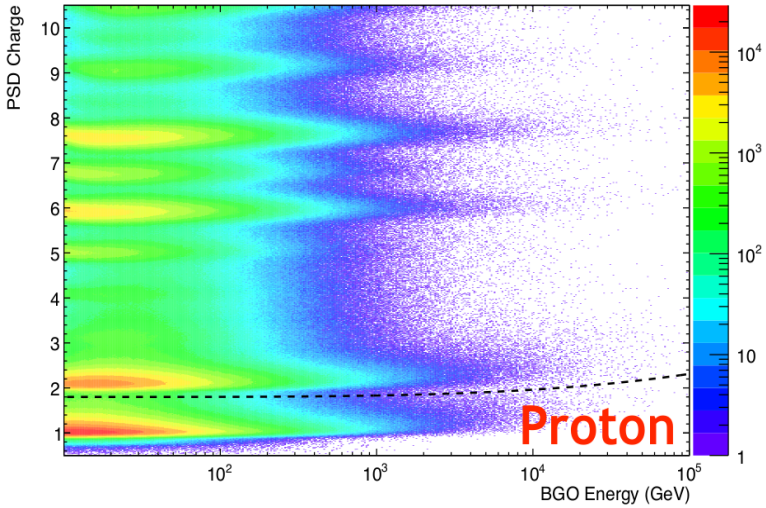
Identification of nuclei



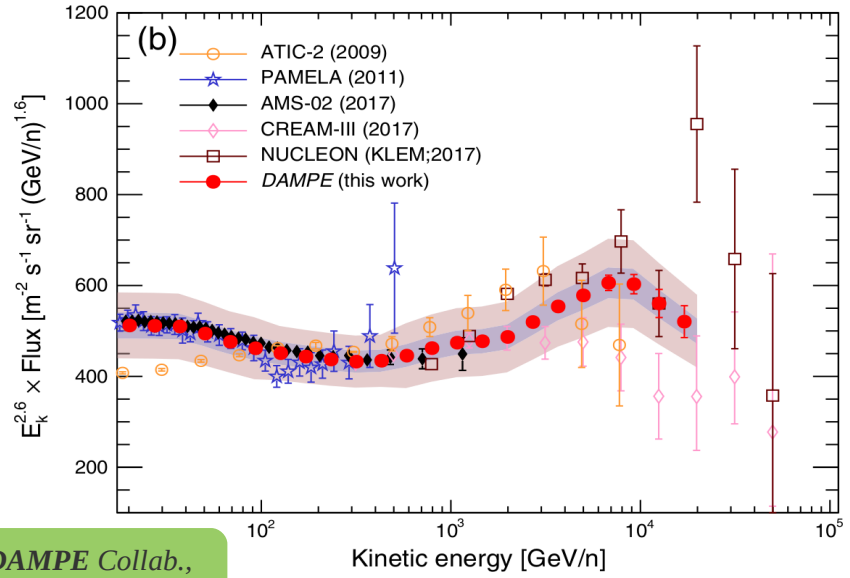


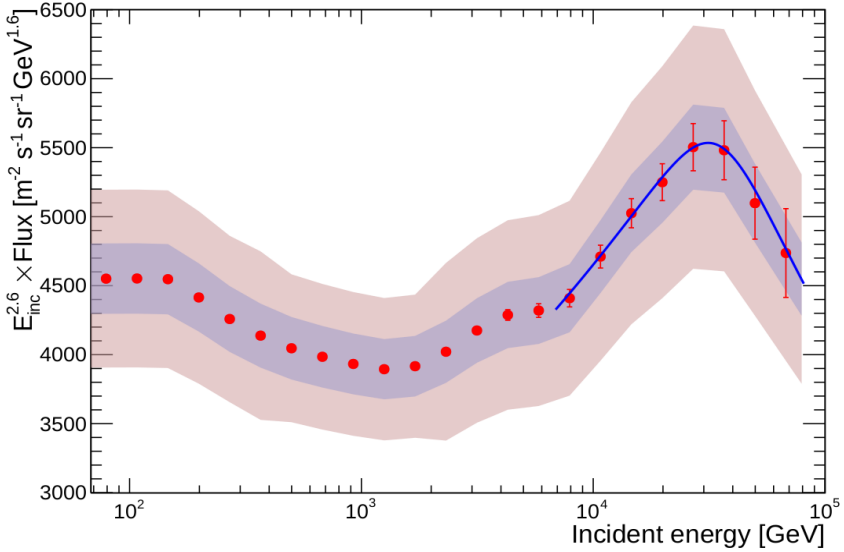
Nuclei	Charge Resolution
p	0.13
He	0.12
Li	0.14
Be	0.21
B	0.17
C	0.18
N	0.21
O	0.21
Fe	0.32

Charge measurement also performed by STK and (with lower precision) by BGO bars



Helium spectrum

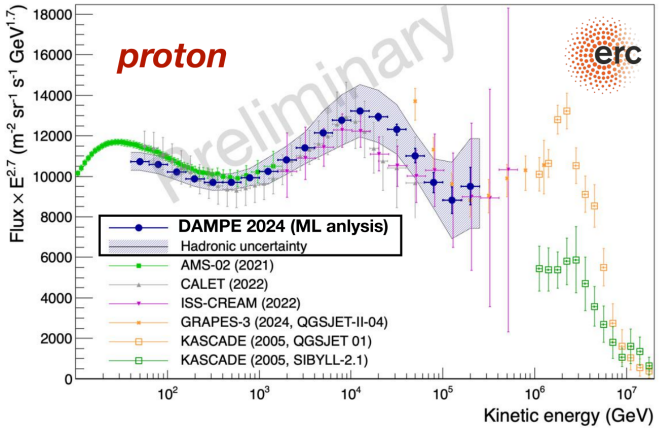


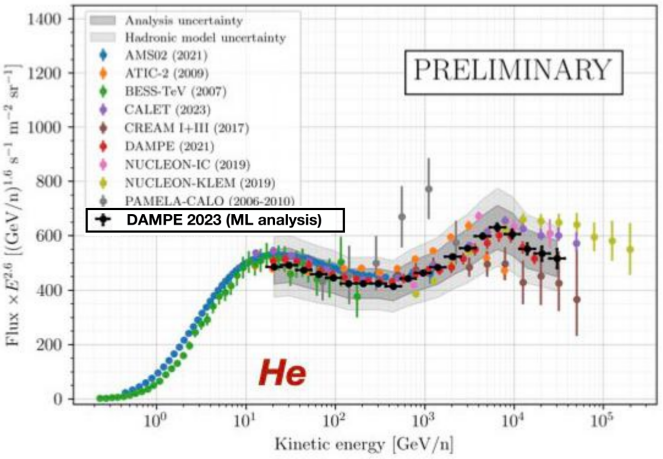


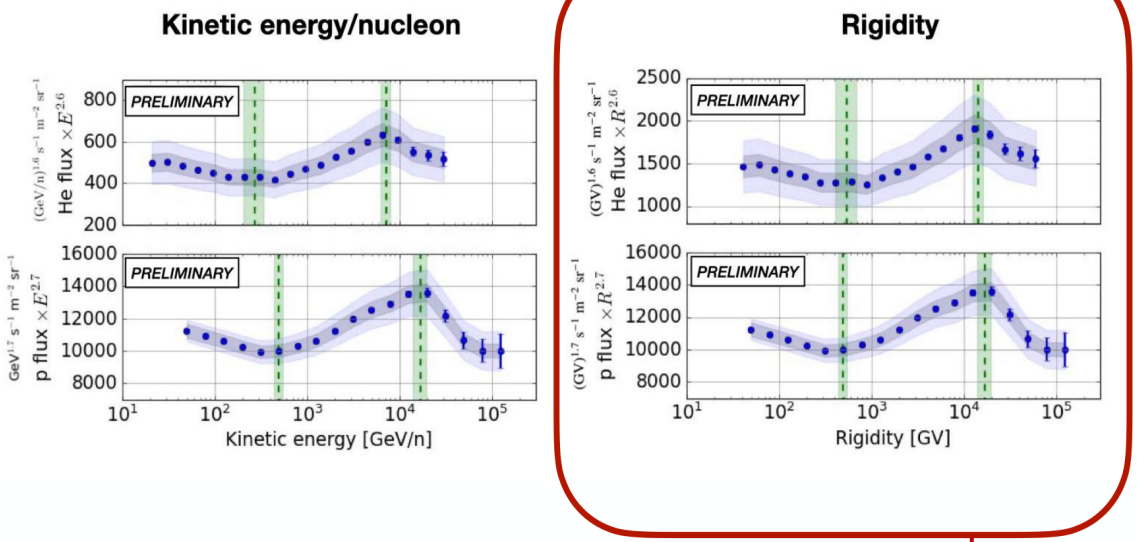
***DAMPE** Collab., PRL 126, (2021)*

- First detection of a **softening** at 34.4$^{+6.7}_{-9.8}$ TeV with significance of ~4.3 σ
- Suggesting a **charge dependent** feature

p and He – updates







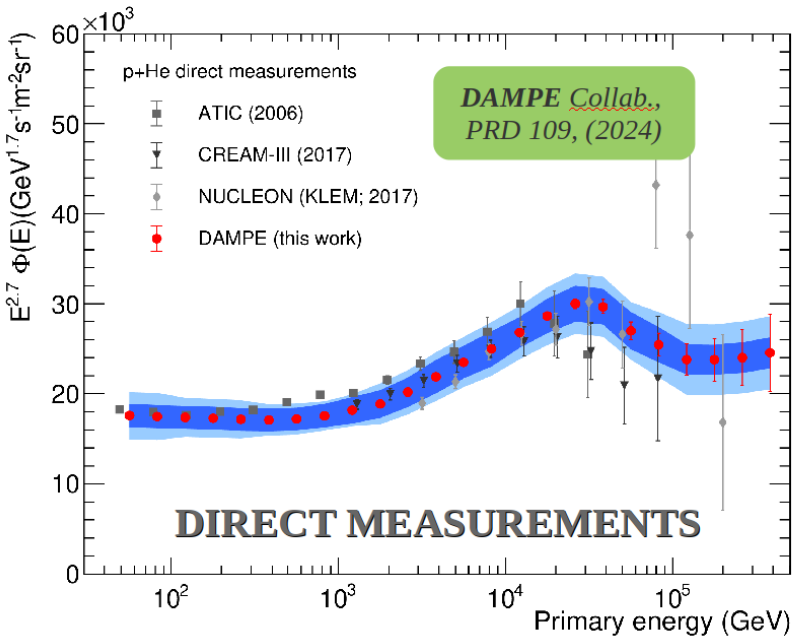
ML-based analysis

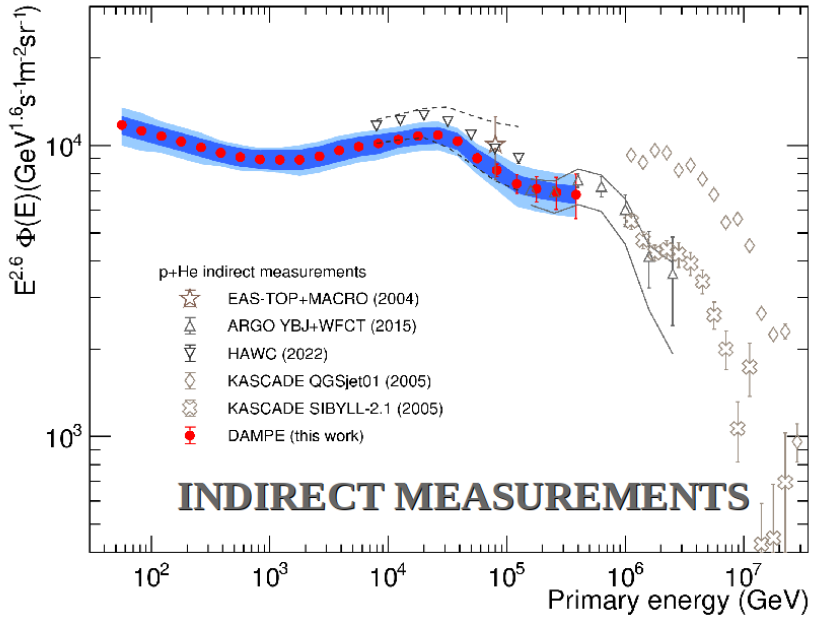
- Proton spectrum extended from 100 TeV to 250 TeV
- Helium spectrum extended from 80 TeV to 120 TeV
- p & He hardening/softening : **charge (rigidity) dependence favored**

A. Tykhonov et al. Astropart. Phys. (2023)

A. Ruina et al. pos.sissa.it/444/170/ (2023)

p+He spectrum

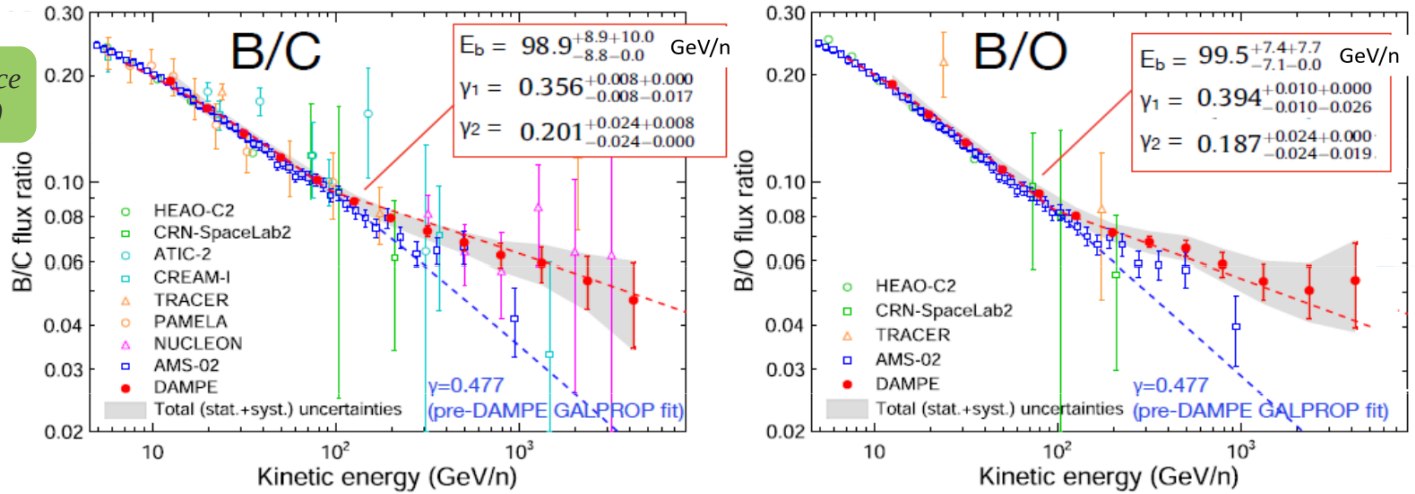




- General agreement with DAMPE proton and helium independent analyses
- Evidence of the combined proton and helium softening at 28.8±4.5 TeV with 6.6 σ significance
- Extension to high energy (~0.5 PeV) and comparison with ground-based experiments
- Hint of new spectral hardening at ~150 TeV

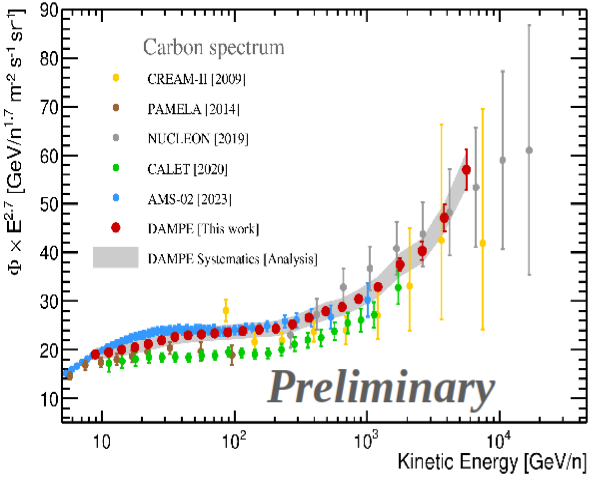
B/C & B/O

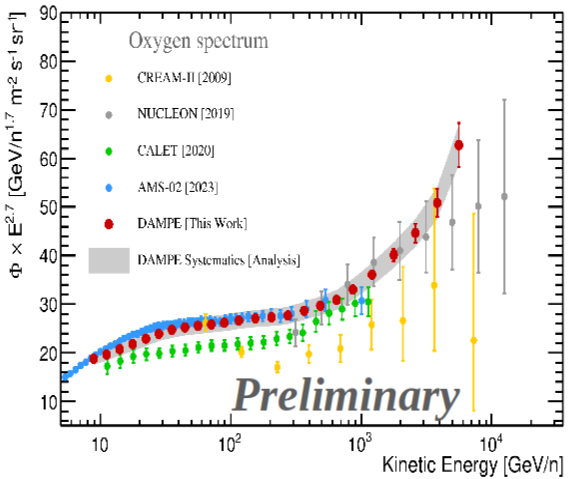
***DAMPE** Collab., Science Bulletin 67, 21 (2022)*

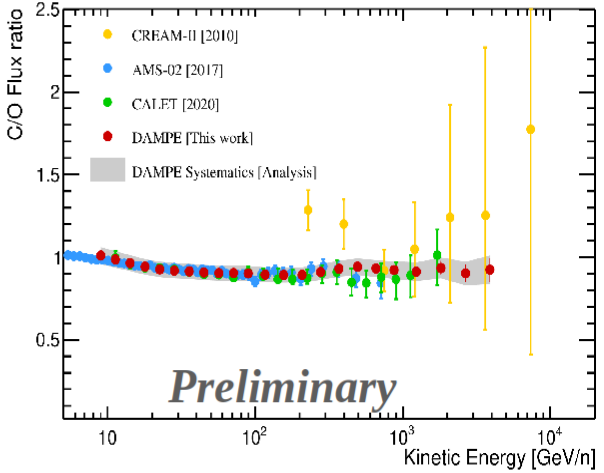


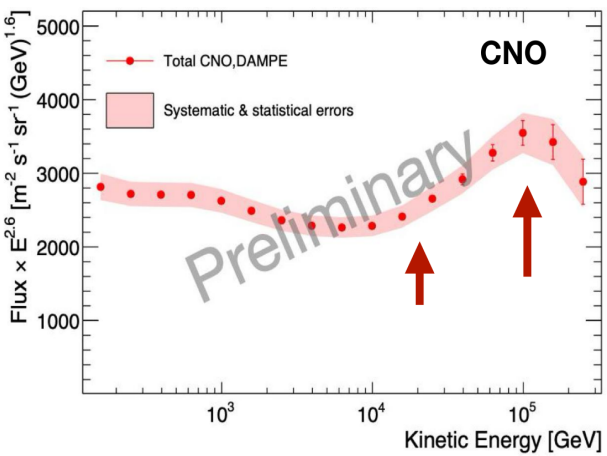
- Detection of a spectral hardening at ~ 100 GeV/n
  → Indication of change in the CR diffusion coefficient?
- Significance ~5.6 σ in B/C
- Significance ~6.9 σ in B/O

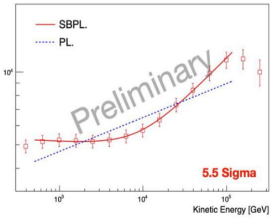
C, N, O

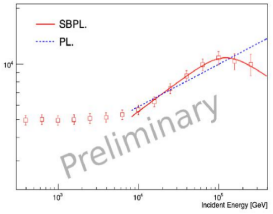






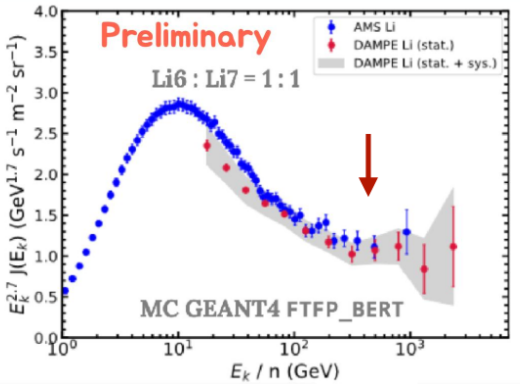


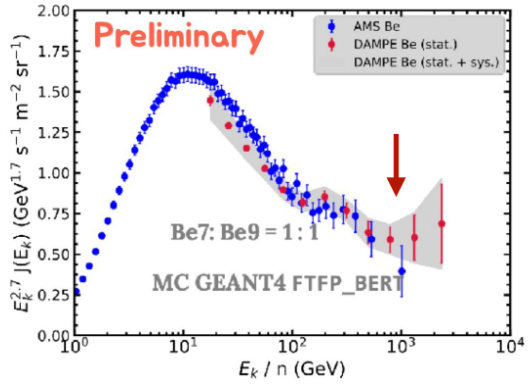


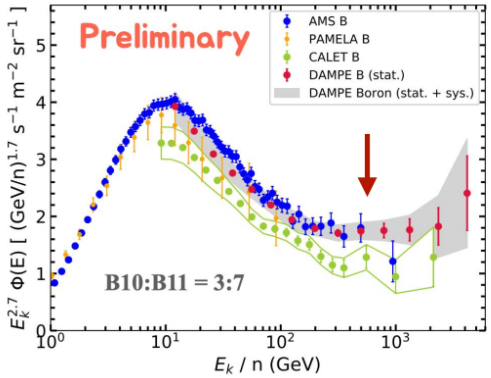


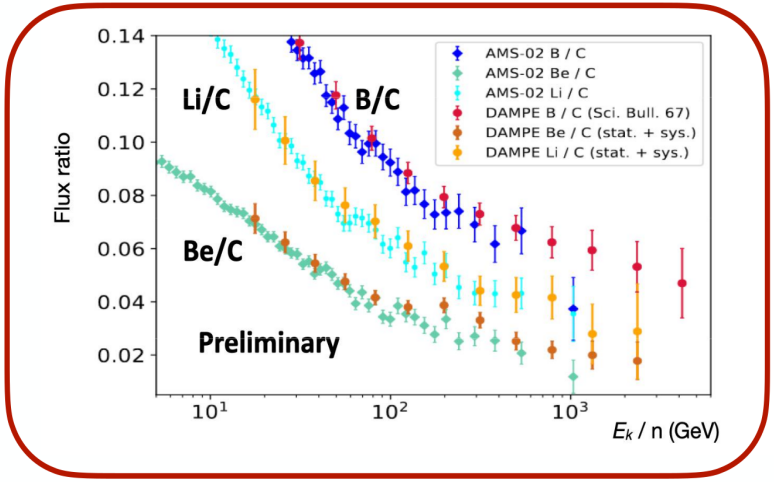
- **C, O: hardening at hundreds of GeV/n**
- **No structure in C/O**
- **CNO: softening at ~ 10 TeV/n**

Secondaries: Li, Be, B



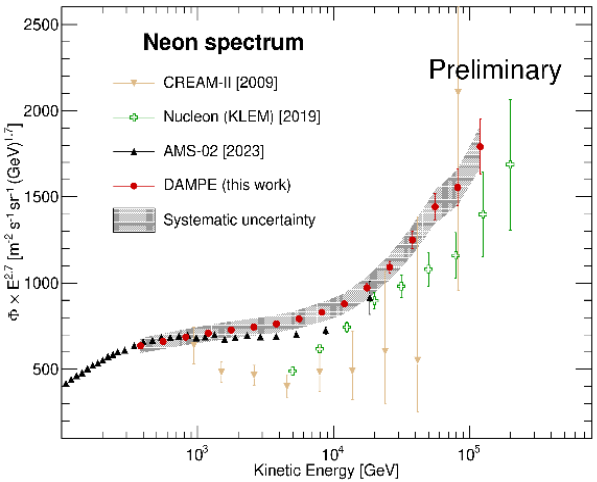


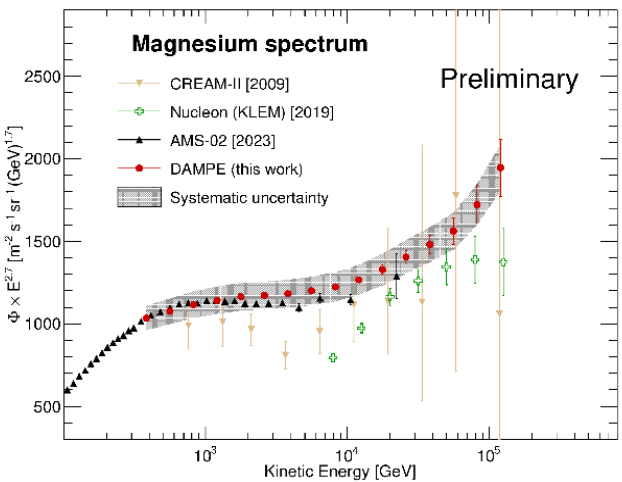


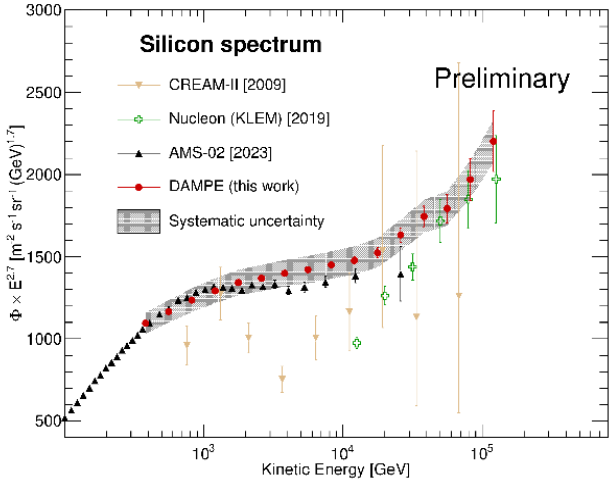


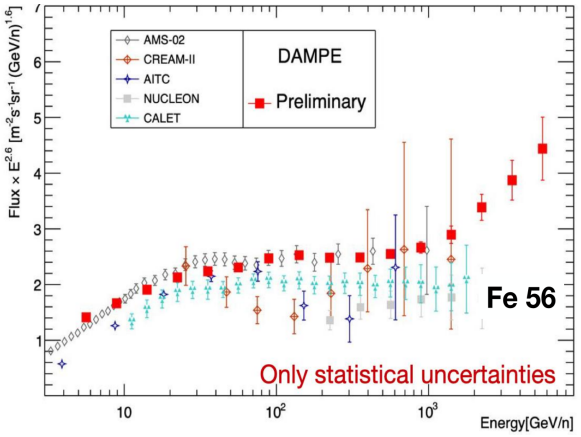
- Spectral hardening confirmed in secondaries
- Consistent break in all secondary-to-primary ratios

Ne, Mg, Si, Fe



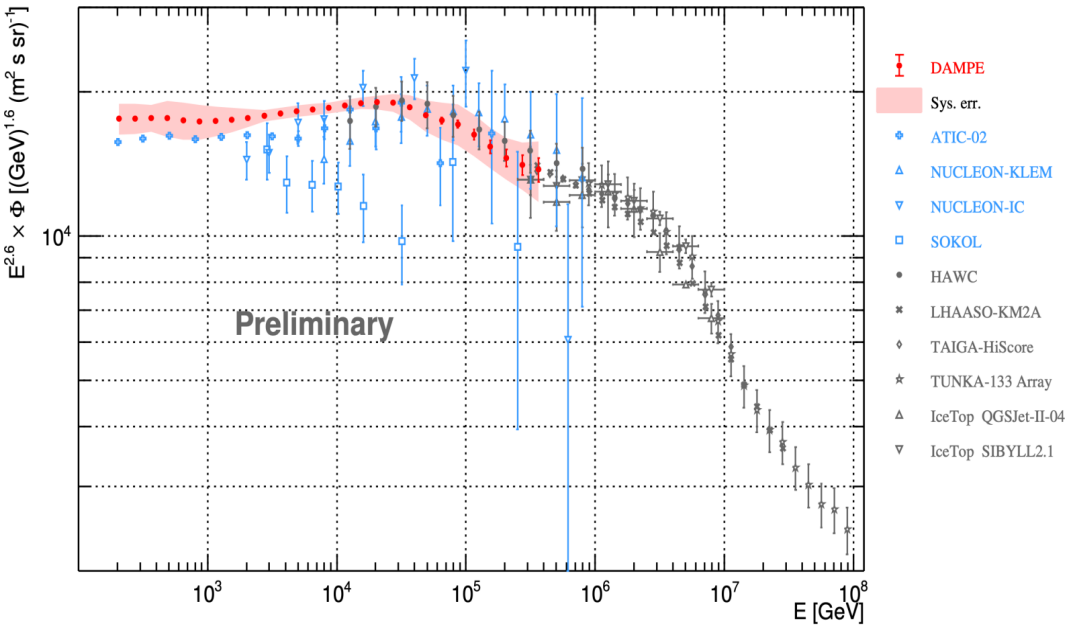






- **Hardening** confirmed in heavy elements
- Systematics evaluation in progress

All particle



Measurement over ~ 4 energy decades

Composition-weighted:

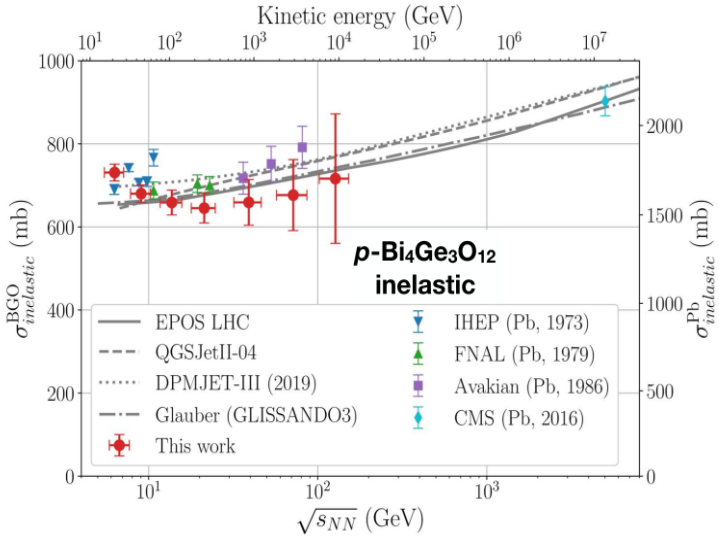
- Instrument acceptance
- Energy response matrix

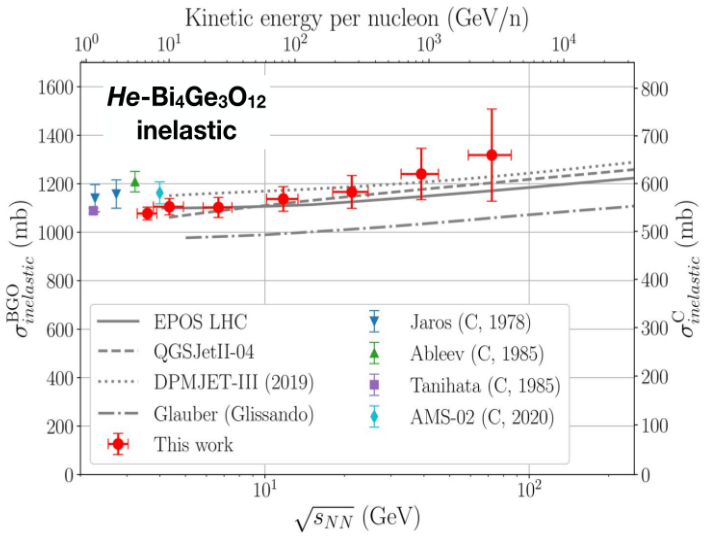
Different composition models considered:

- Recchia-Gabici (RG)
- Hoerandel (poly-gonato)
- HAWC model
- Zatsepin-Sokolskaya (ZS)

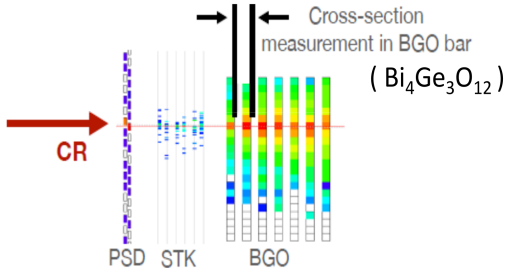
Systematics evaluation in progress

Hadronic cross sections





***DAMPE** Collab., arXiv:2408.17224v1*



Cross section measurement in 2 decades of energy (center-of-mass)
p-BGO compared with p-Pb at colliders: ~67% of BGO is bismuth
He-BGO first probe of helium-ion cross sections up to ~100 GeV

82	83
Pb	Bi

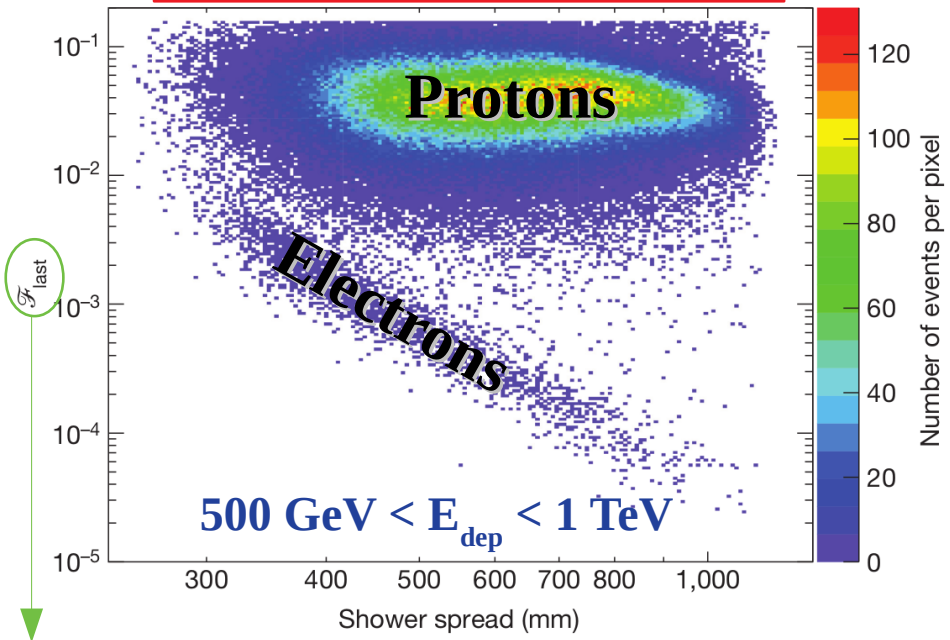
Summary

- The DArk Matter Particle Explorer, was launched in December 2015 and it is smoothly taking data since then
  - Direct detection of a **break** at ~1 TeV in the **electrons and positrons** spectrum
  - Detection of a **softening** at ~14 TeV in the **proton** spectrum
- First detection of a **softening** in the **helium** spectrum at ~34 TeV, suggesting a Z dependence
- Measurement of the **p+He** spectrum showing the hint of a second **hardening** above 100 TeV, while connecting **space-based** and **ground-based** experiments
  - **B/C** and **B/O** flux ratios show a **break** at ~ 100 GeV/n
- Ongoing works on both primaries (**C, O, Ne, Mg, Si, Fe**) and secondaries (**Li, Be, B**) showing the presence of a **hardening**
  - First probe of **inelastic cross section** up to 10 TeV


BACKUP

Electron IDentification

Discrimination between electrons and protons in the BGO

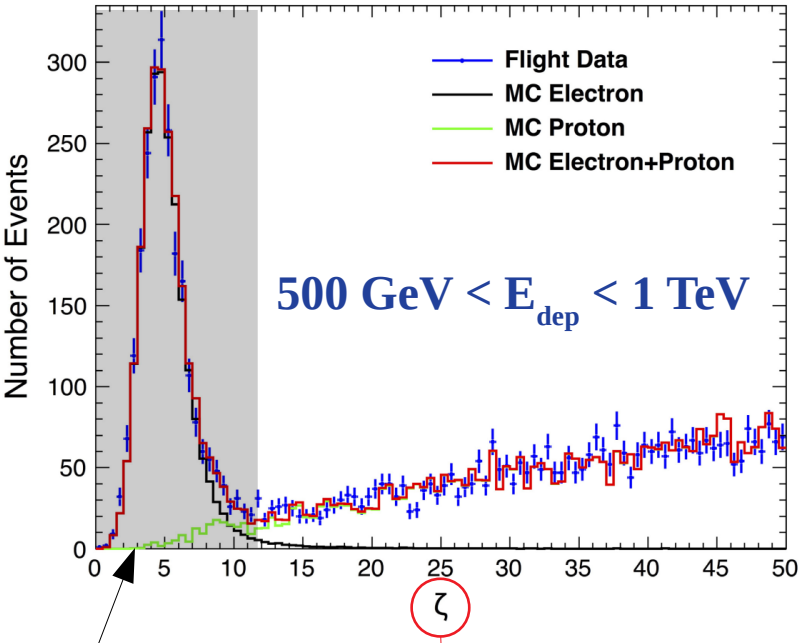


Ratio of energy deposited in the last BGO layer to the total energy deposited in the BGO calorimeter

$\Sigma_i RMS_i$

Sum of the energy-weighted shower dispersion of each layer

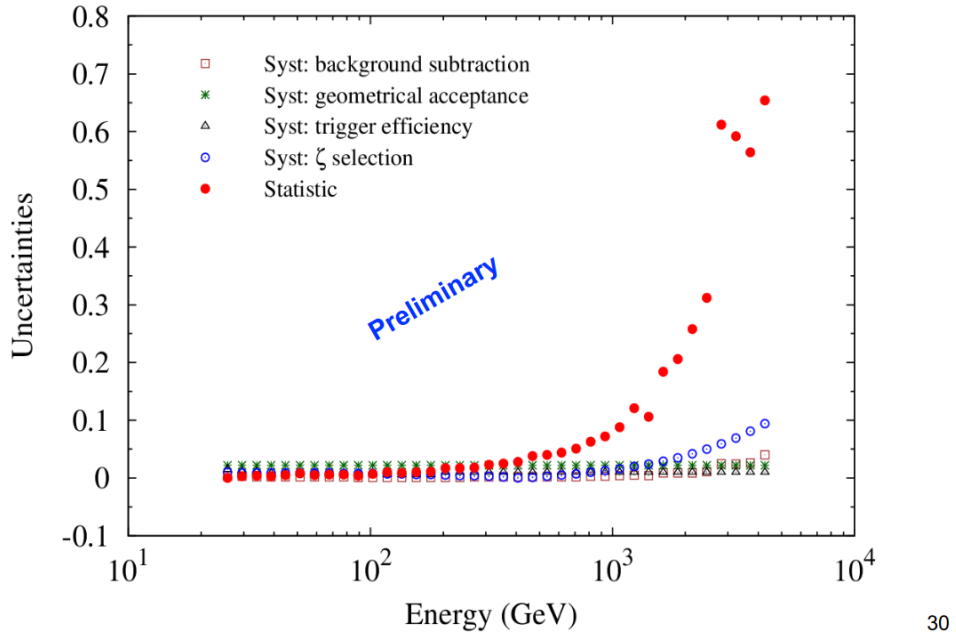
Comparison of flight data and MC simulations of the ζ distributions



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

All-electron spectrum

Errors of $e^+ + e^-$ spectrum

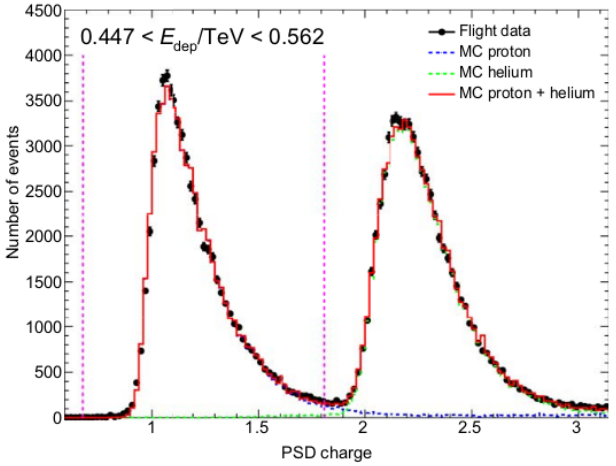


30

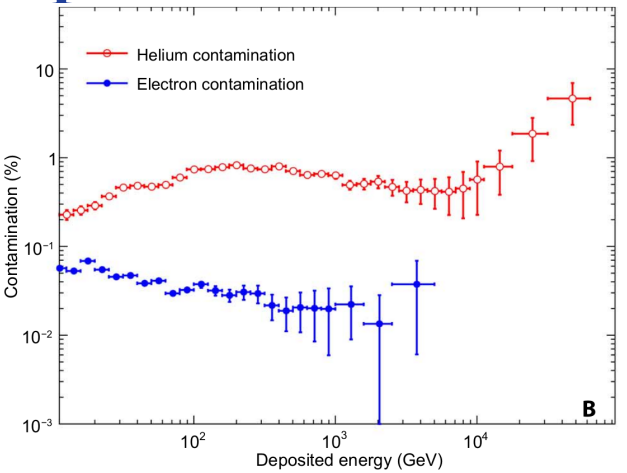
SLIDES TAKEN FROM ICRC 2021 – *Li Xiang* for DAMPE

Proton spectrum

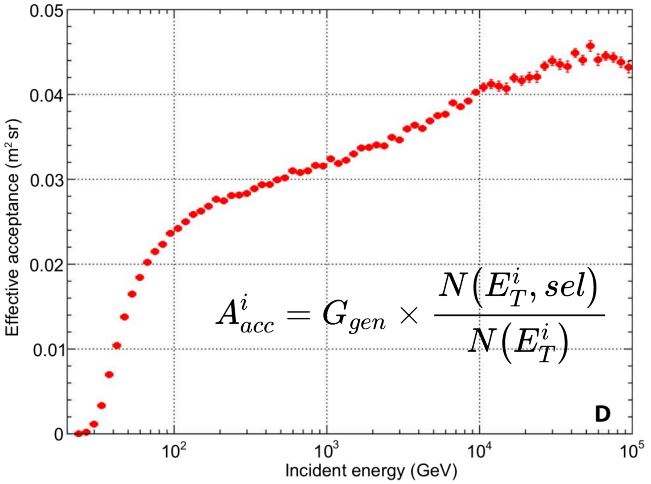
Charge selection



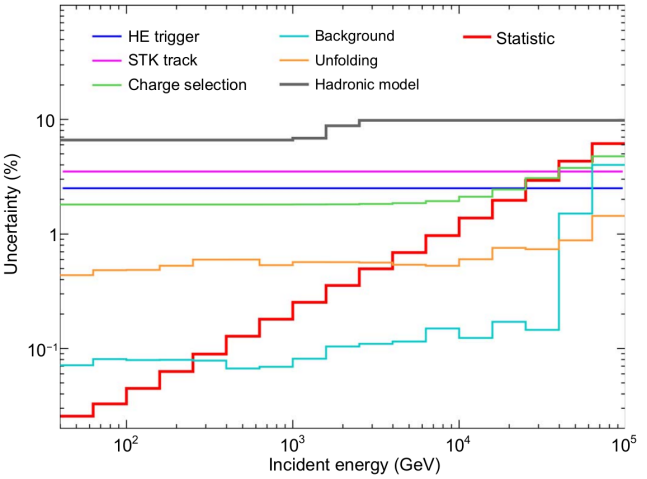
Contamination



Acceptance



Uncertainty



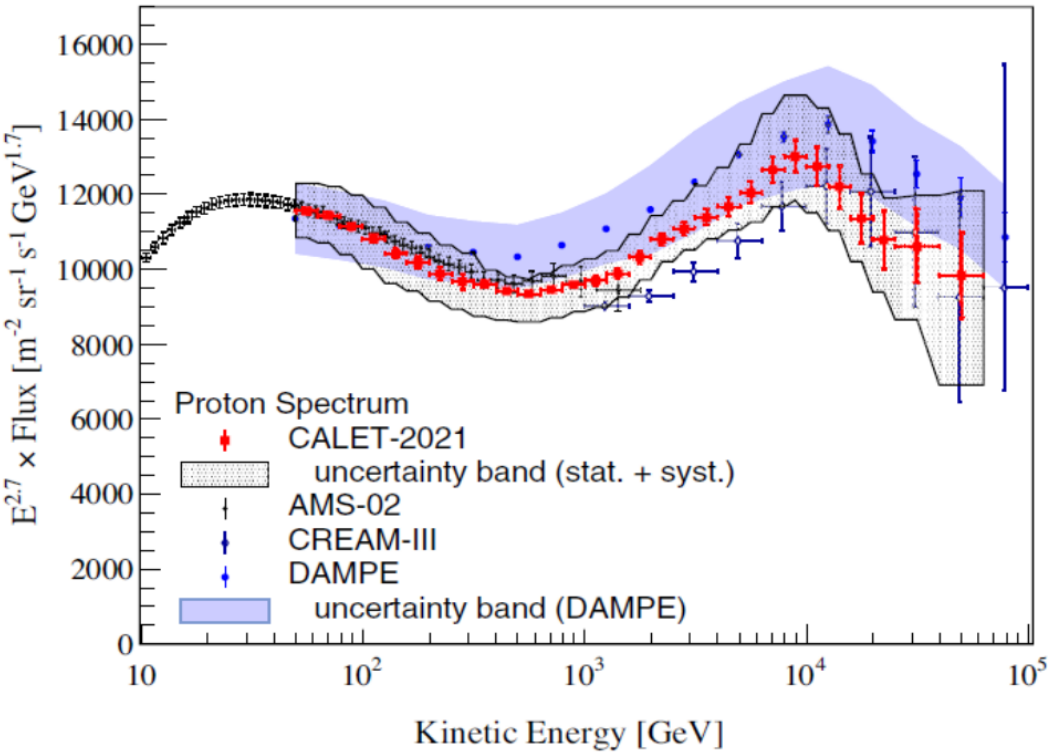
Proton spectrum

PHYSICAL REVIEW LETTERS **129,** 101102 (2022)

Editors' Suggestion

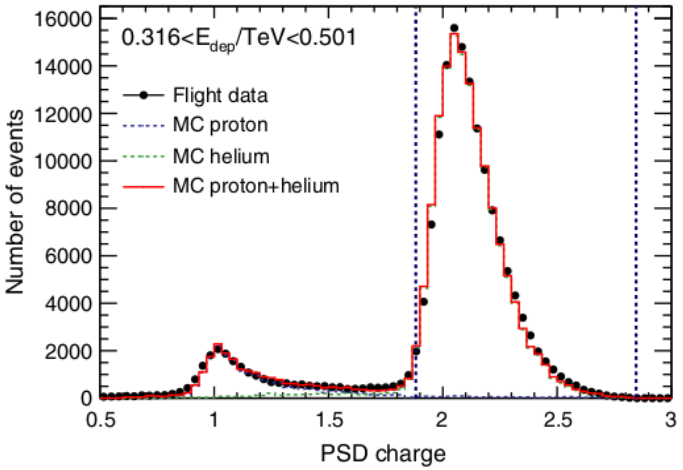
September 1, 2022

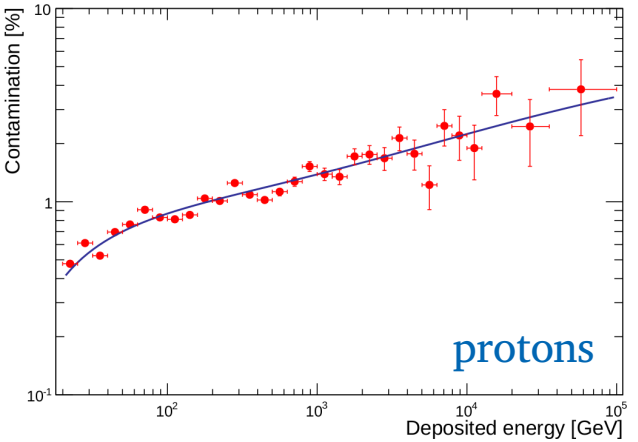
Observation of Spectral Structures in the Flux of Cosmic-Ray Protons from 50 GeV to 60 TeV with the Calorimetric Electron Telescope on the International Space Station



Helium spectrum

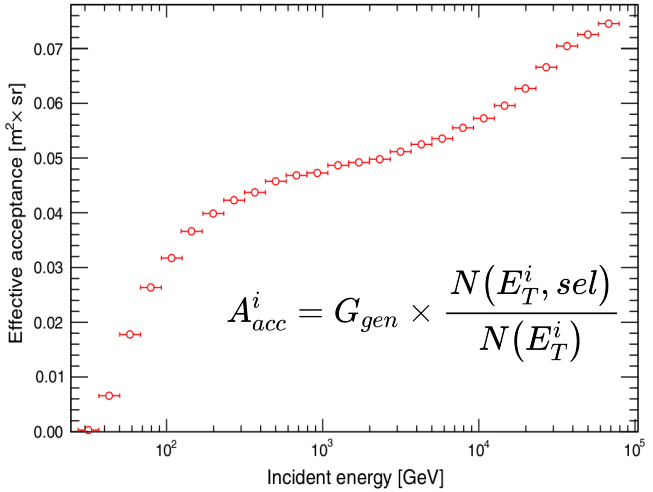
Charge selection

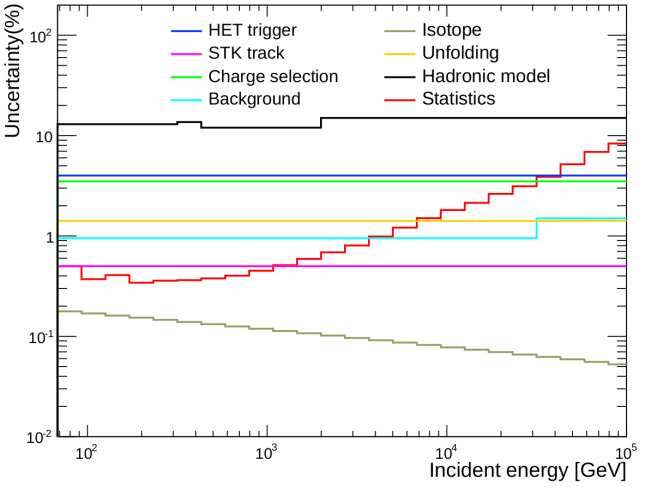




Contamination

Acceptance

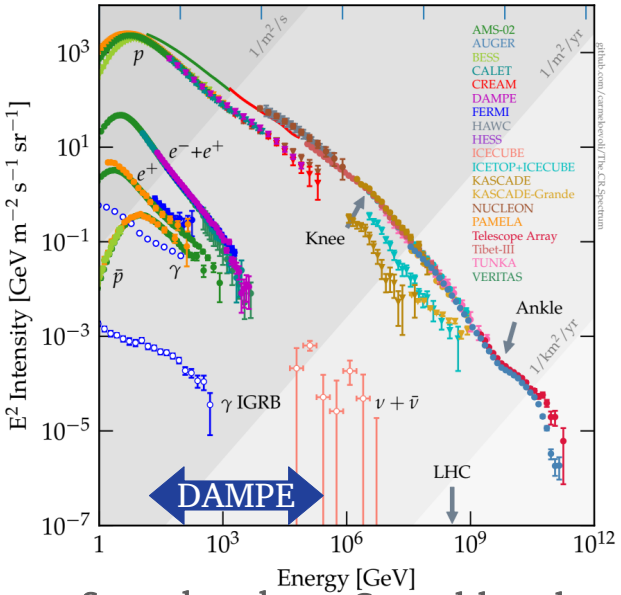




Uncertainty

Study of light (p+He) CR component: motivations

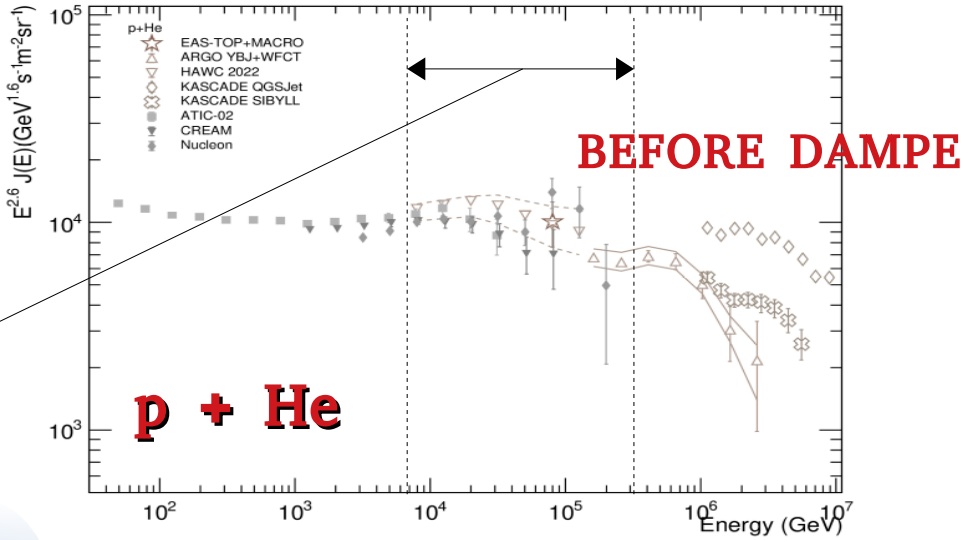
Measuring light elements in space (i.e. proton + helium spectrum) gives the **possibility to compare results between direct and indirect experiments**



Space-based experiments (direct measurements)

Ground-based experiments (indirect measurements)

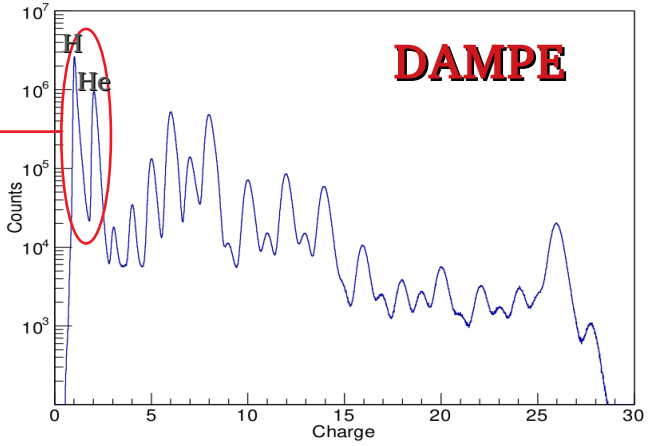
In this energy region direct and indirect spectra can be compared



Proton and Helium are well separated from other peaks

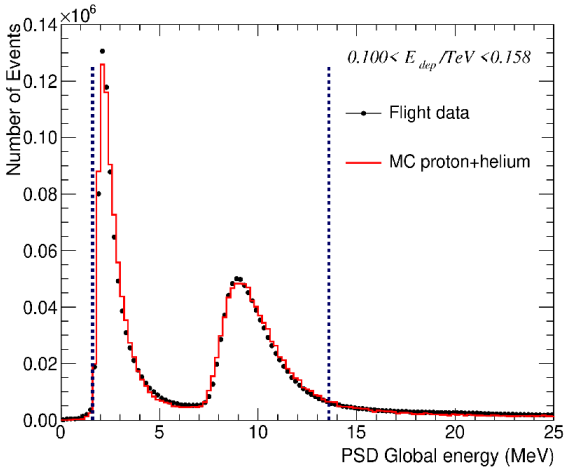
VERY LOW CONTAMINATION (less than 0.1%)

Looser cuts
Possibility to go to higher energy

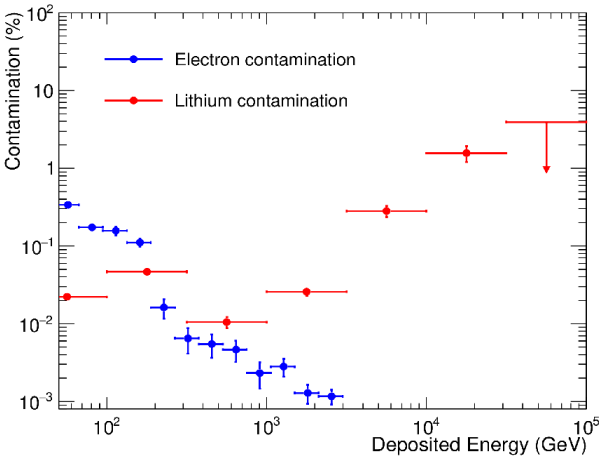


p+He spectrum

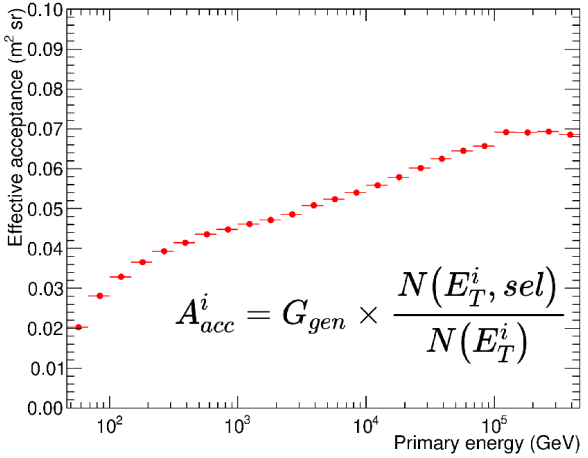
Charge selection



Contamination



Acceptance



Uncertainty