Selected Results from DAMPE

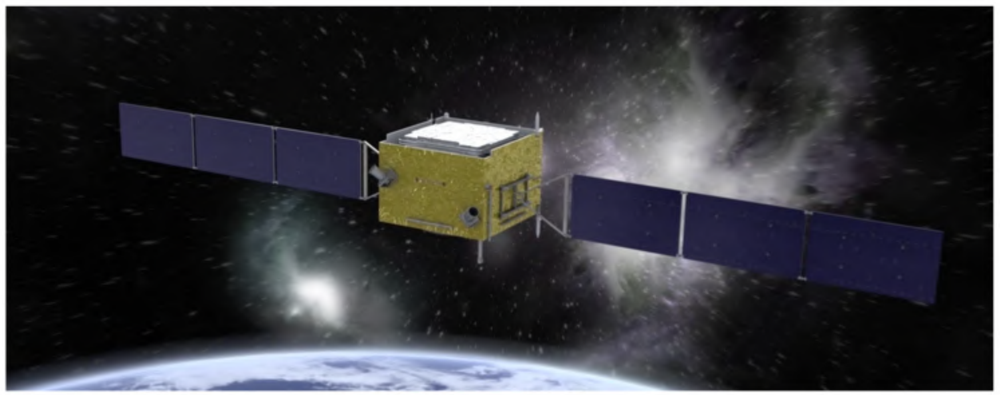
Andrii Tykhonov

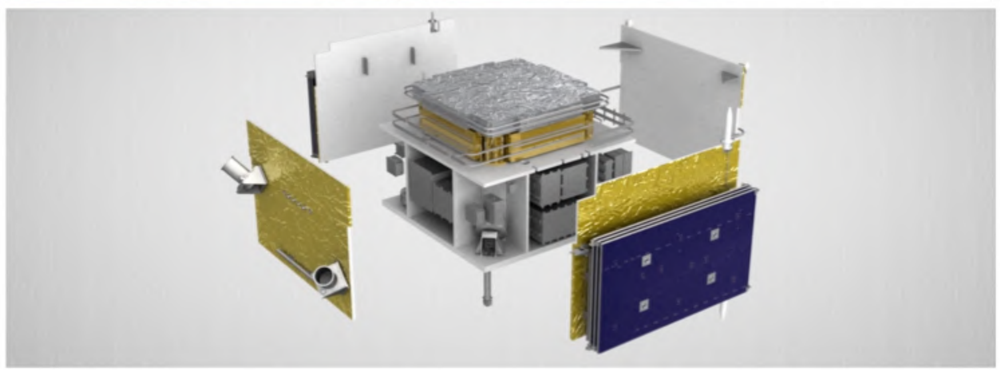
(for the DAMPE collaboration)

DArk Matter Particle Explorer (DAMPE)

- Launched in **Dec 2015**
- Orbit: sun-synchronous, **500 km**
- Period: **95 min**
- Payload: **1.4 Tonn**
- Power: ~ **400 W**
- Data: ~ **12 GByte / day**

Collaboration





DArk Matter Particle Explorer (DAMPE)

PSD

- Z identification up to *Zn* (Z=30)
- γ anti-coincidence signal

STK

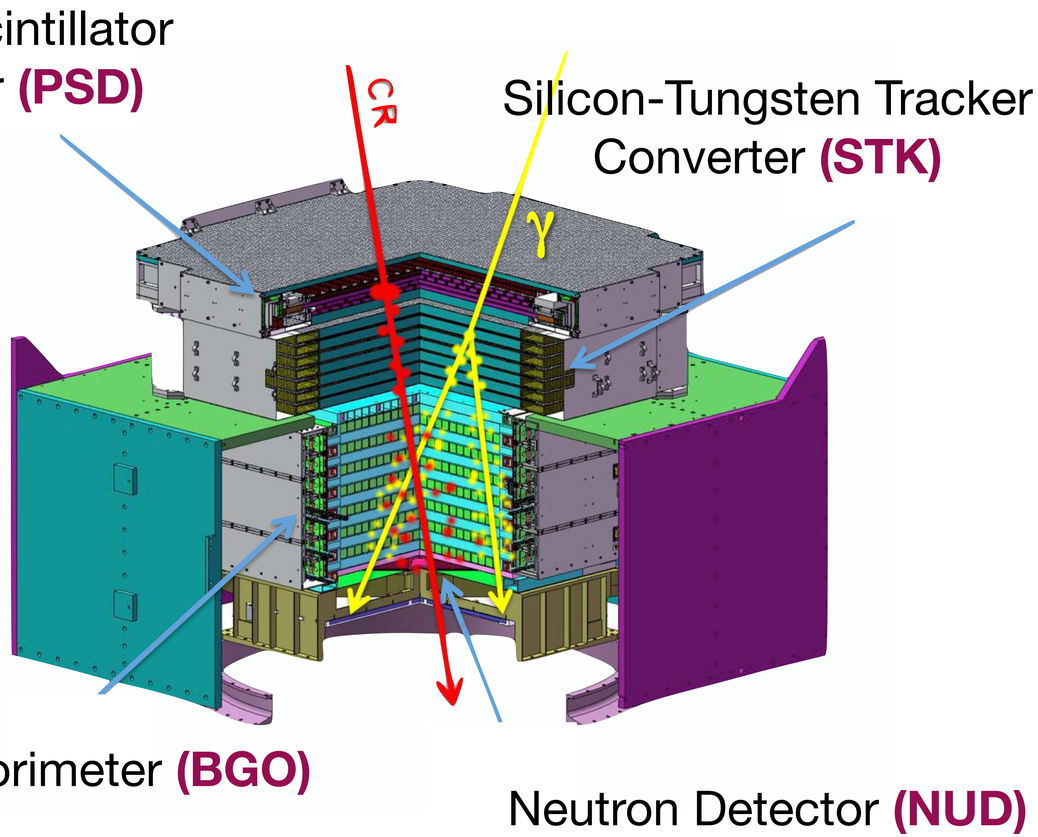
- Position solution **~50 micron**
- γ angular resolution **0.5°—0.1°** (GeV— TeV)
- Absolute Charge (Z) identification

BGO

- 31 X_0 — thickest in space
- e/γ detection up to **10 TeV**
- *p*/ions up to **50 GeV — PeV**

NUD

- Additional e/p rejection capability

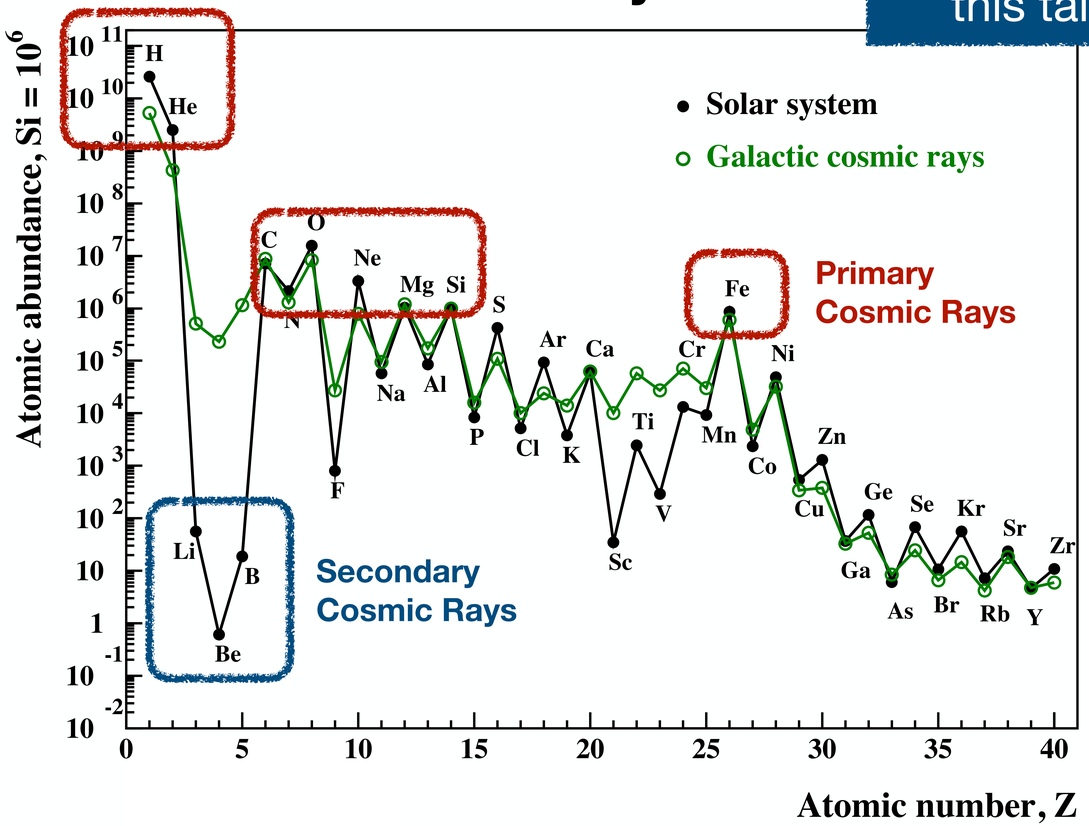


DAMPE collab., Astropart. Phys. 95 (2017) 6-24

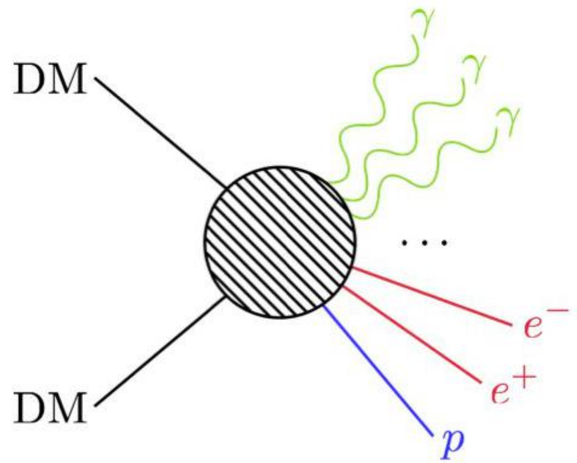
Scientific goals

Cosmic rays

Covered in this talk

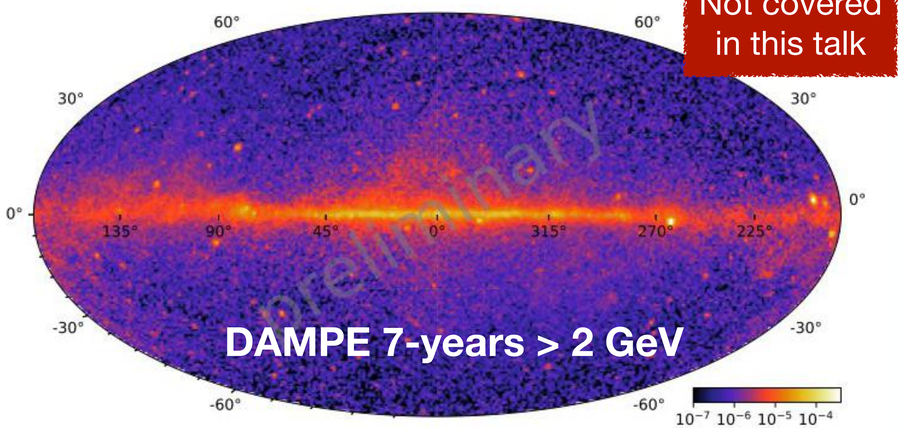


Indirect DM detection



γ-ray physics

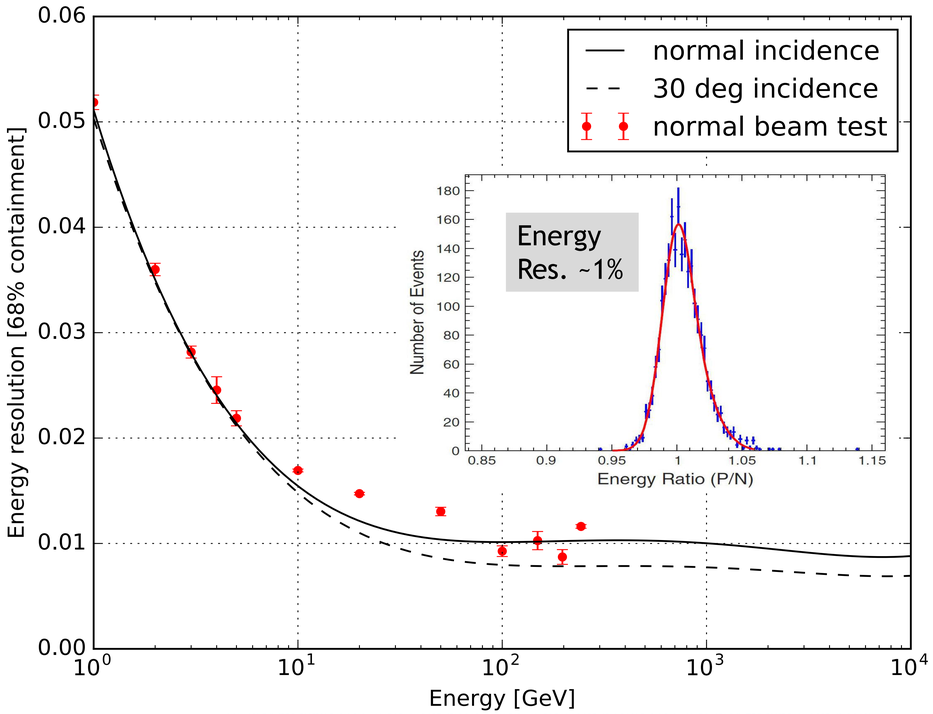
Not covered in this talk



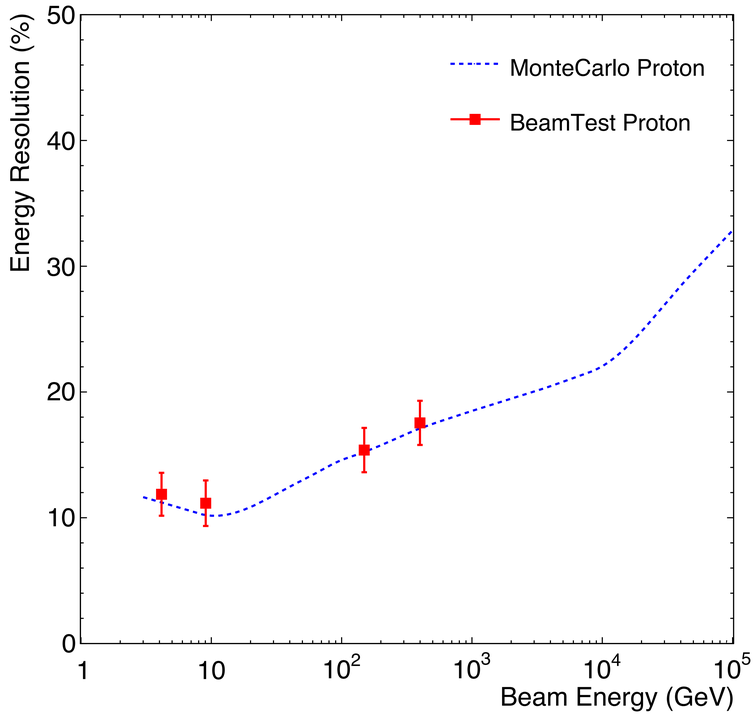
Energy calibration

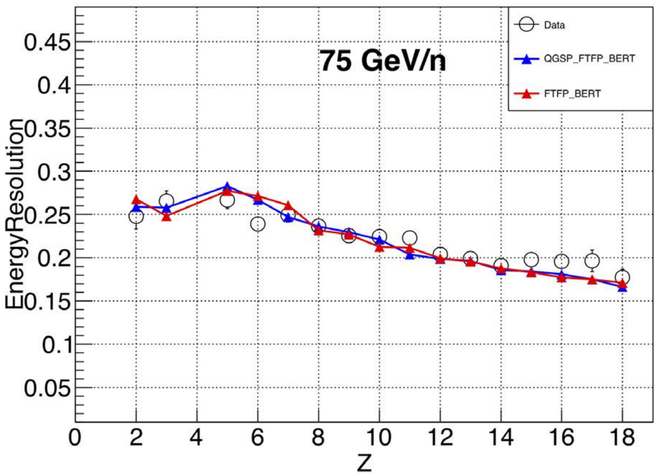
Beam tests at CERN PS & SPS

- Beams: e & p few GeV — 250 (400) GeV; Ions 40 GeV/n, 75 GeV/n.
- Energy resolution: **~1% (e/γ)** at >= 100 GeV, **20—30 % (p/ions)**



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



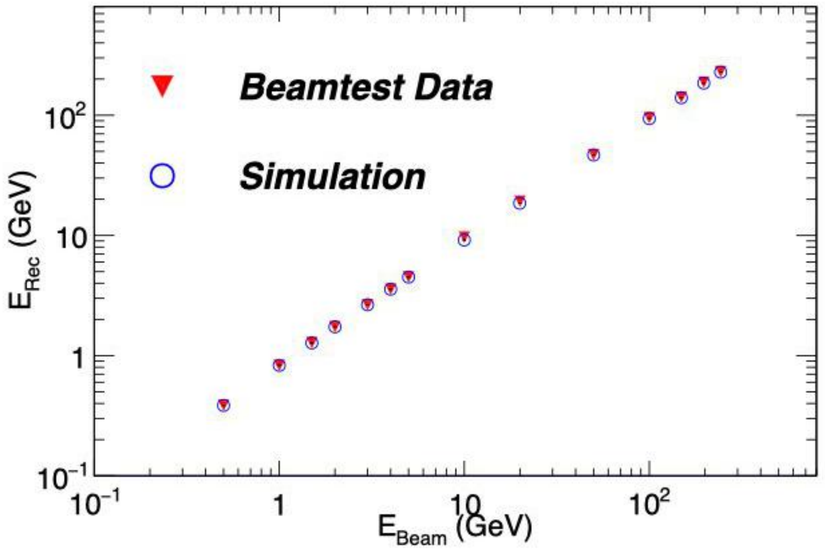


Y.-F. Wei et al. NIMA 922 (2019)

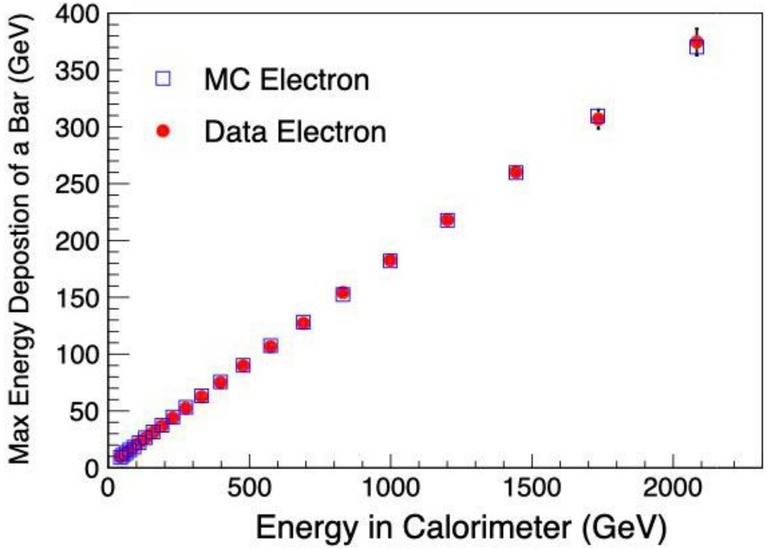
Energy scale and linearity

- Linearity verified up to 250 GeV with beam tests at CERN SPS
- On-orbit energy scale verified with geomagnetic cut-off: consistent within ~1.3%

Reconstructed VS beam energy

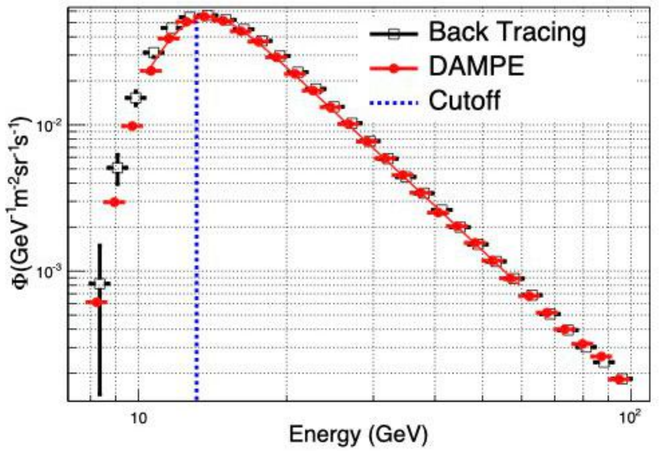


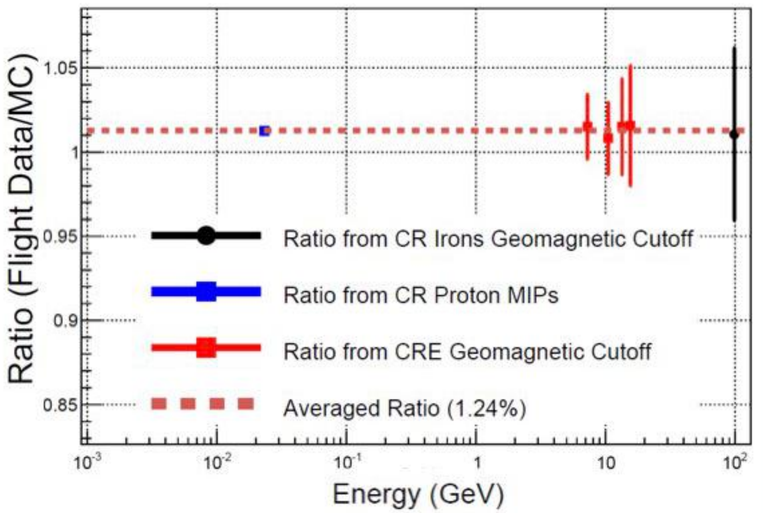
Max-bar VS Total energy



Z. Zhang el al. NIM A, 836 98-104 (2016),
C. Zhao NIM A 1029:166453 (2022),
J.-J. Zang et al. (2017), doi:10.22323/1.301.0197

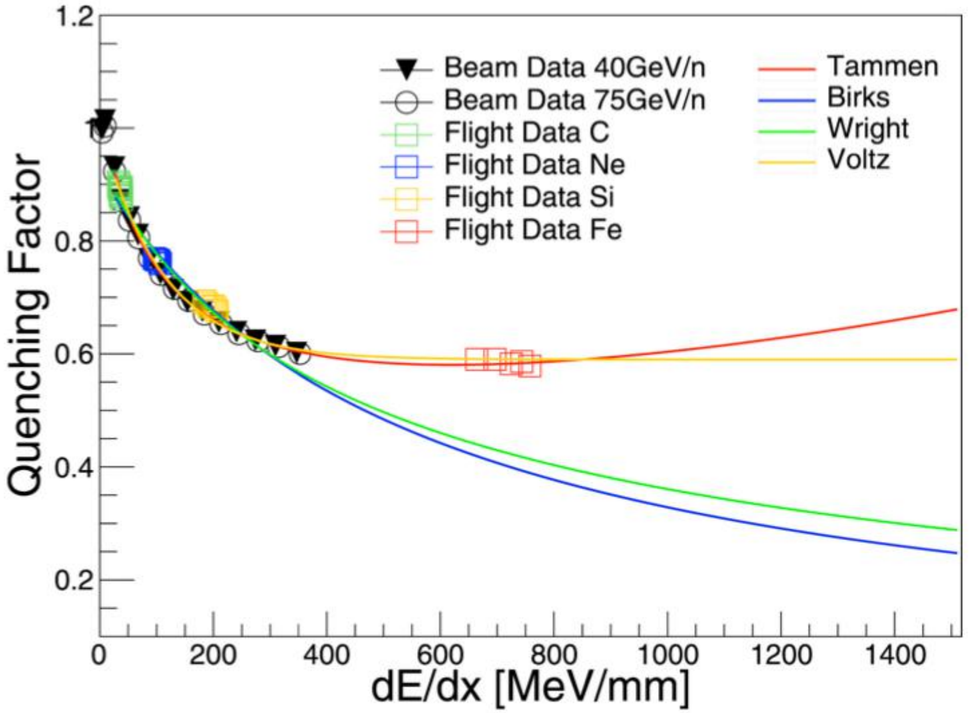
Geomagnetic cutoff for iron and electron in 4 latitude bins →



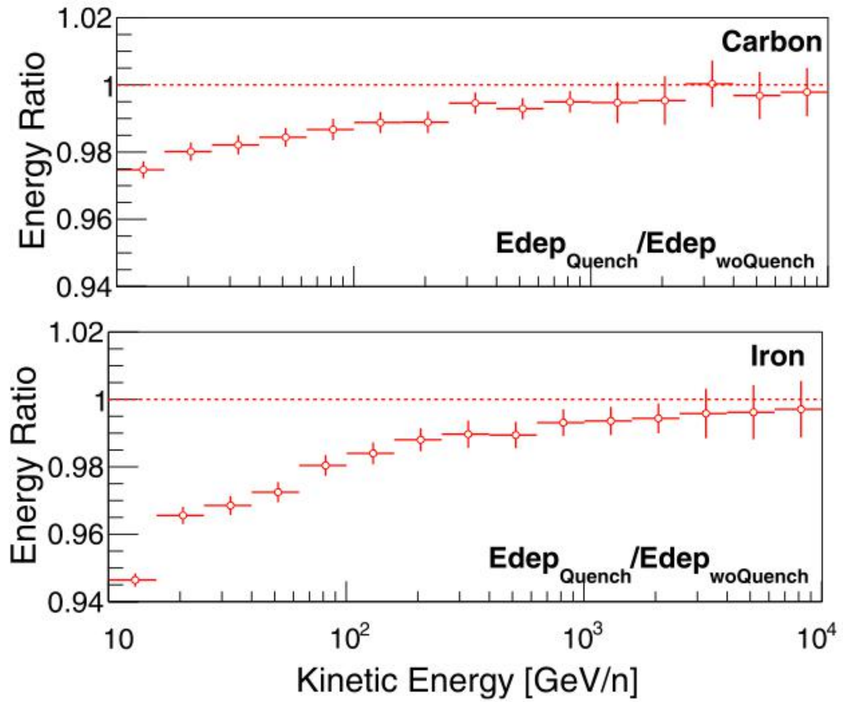


Energy quenching

- Quenching — nonlinear fluorescence response of BGO for large ionisation energy
- Derived from beam test and flight data, implemented in the detector response model



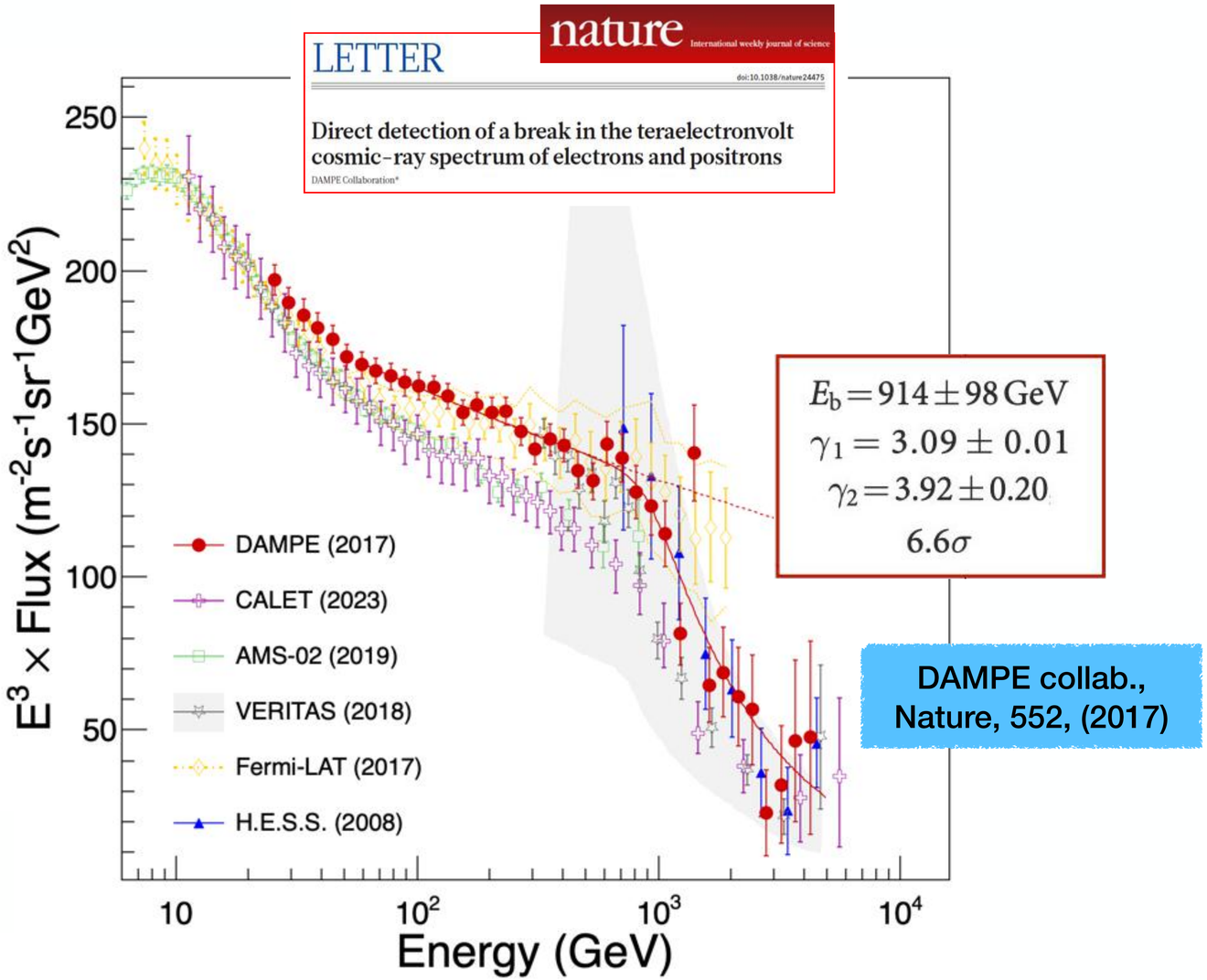
Z.-F. Chen et al. NIMA 1055 (2023), Y. Wei et al., Transac. Nucl. Sci. 67/6 (2020), NIMA 922 (2019)



- 10 GeV/n: **2.5% (5.7%)** for Carbon (Iron)
- 1 TeV/n: **~1%**

Results

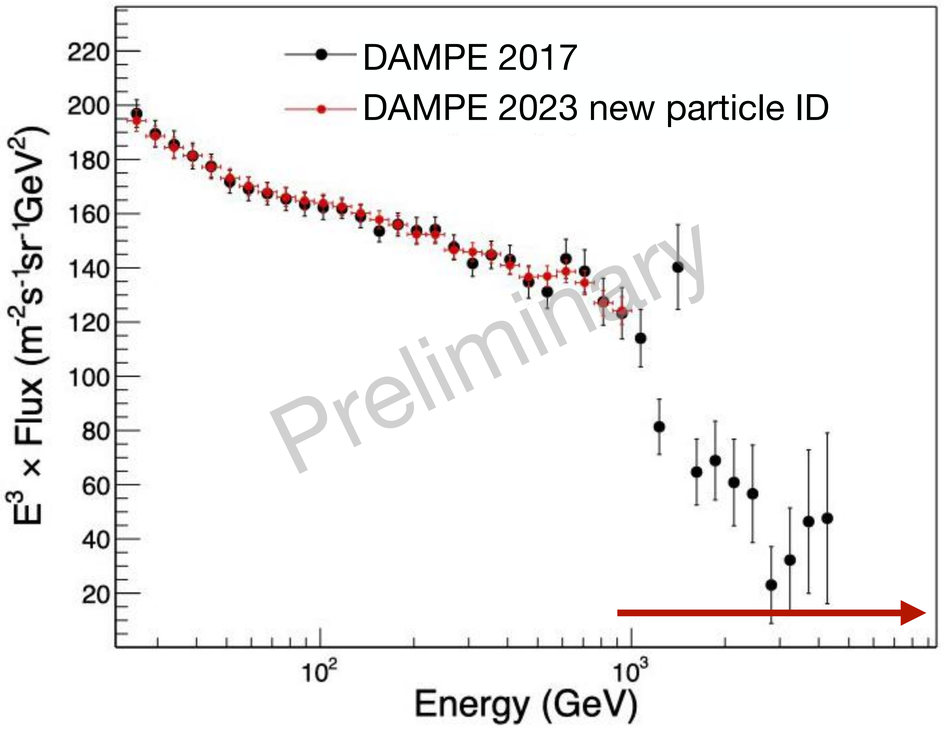
$e^+ + e^-$



DAMPE collab., Nature, 552, (2017)

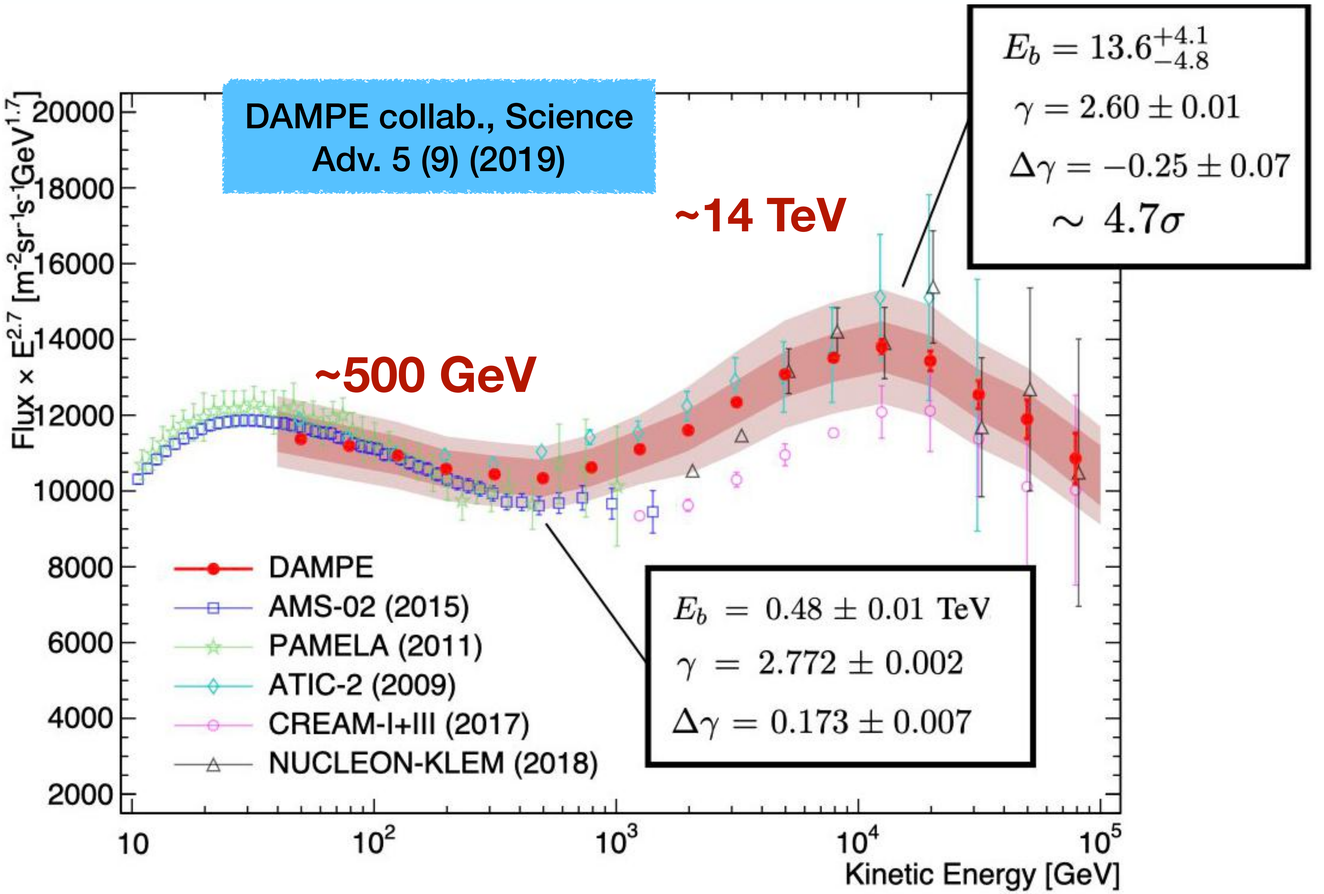
New e/p discrimination (Neural Networks) developed for higher energies → analysis ongoing

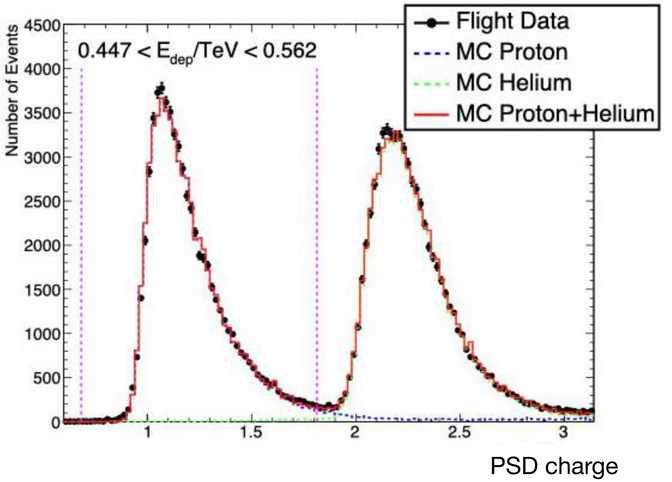
D. Droz et. al. JINST (2021)

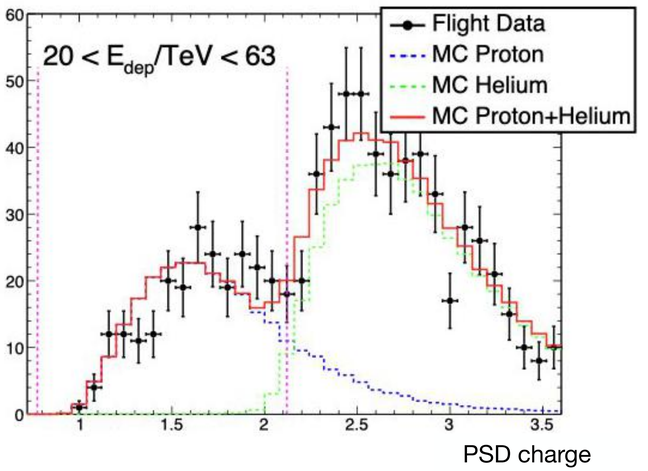


Excellent agreement with standard particle ID

p

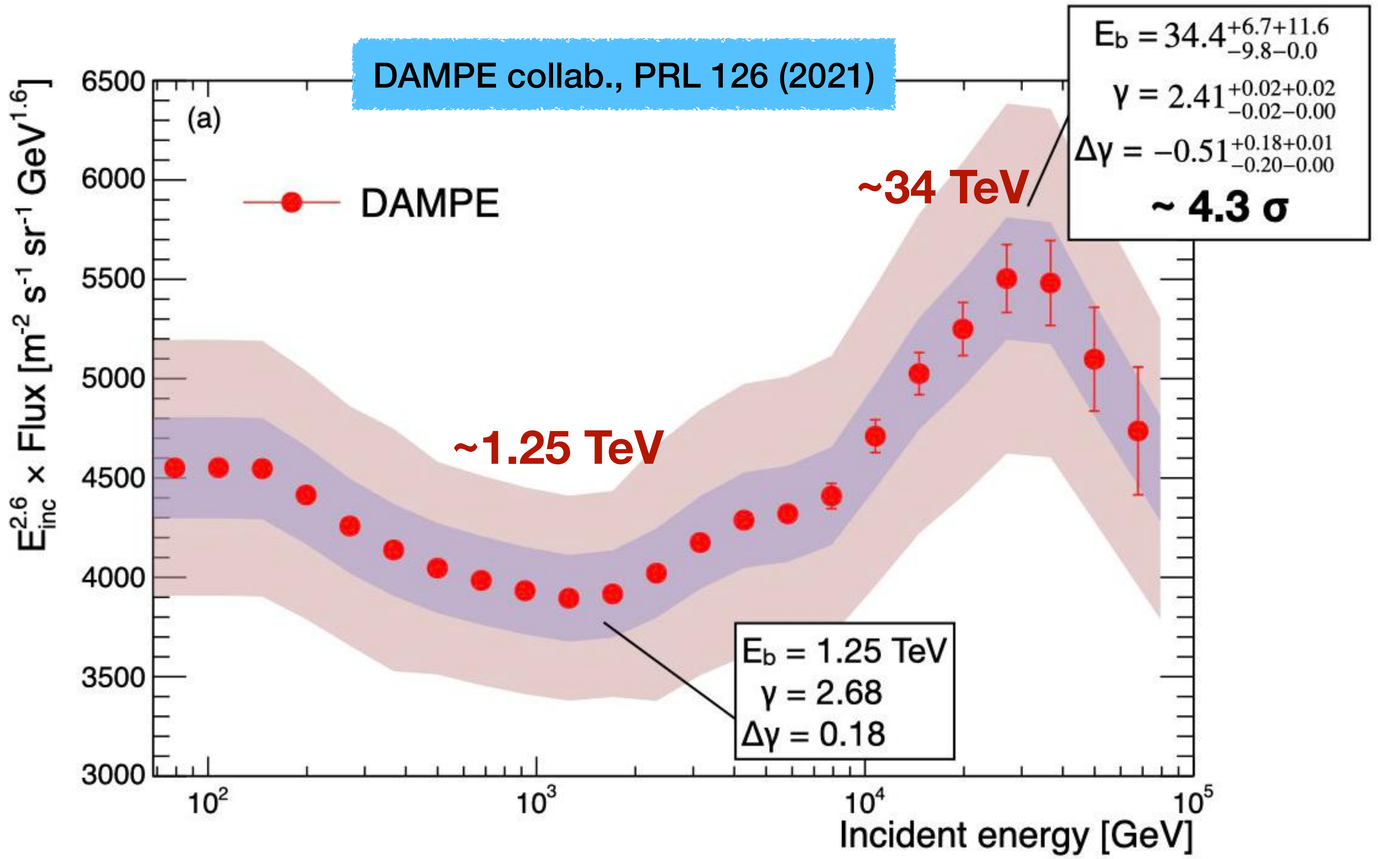


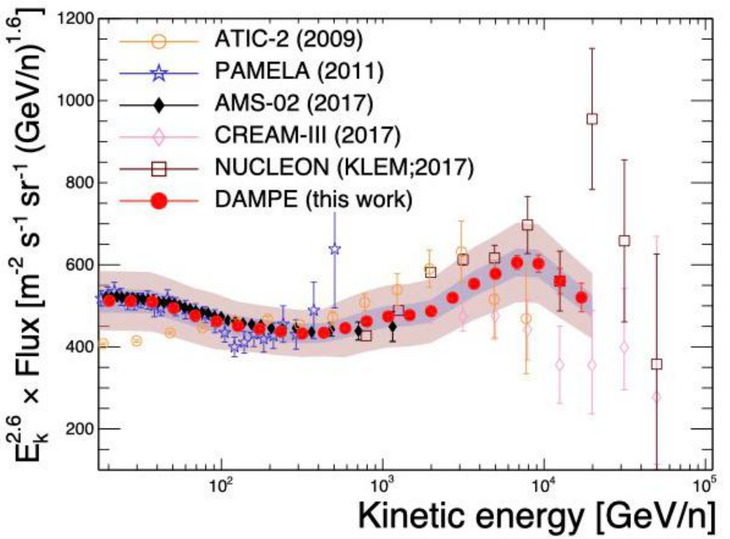


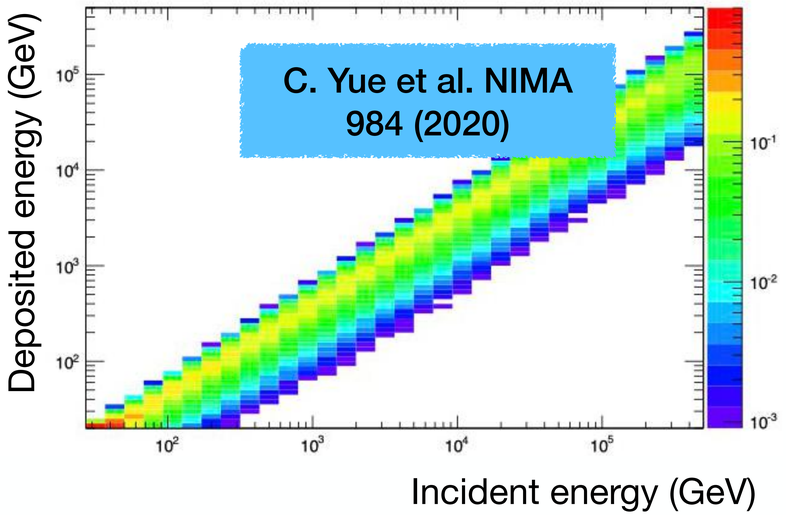


- Confirms hardening at ~ 500 GeV
- Detection of softening at ~14 TeV

He

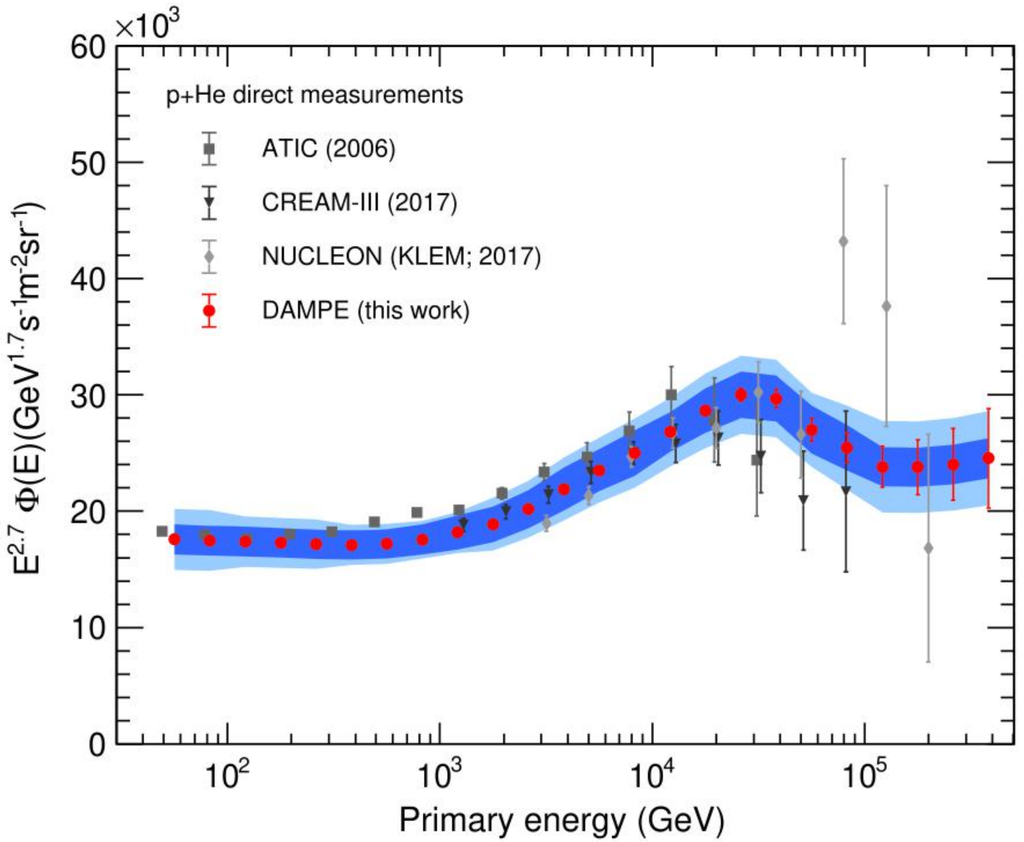




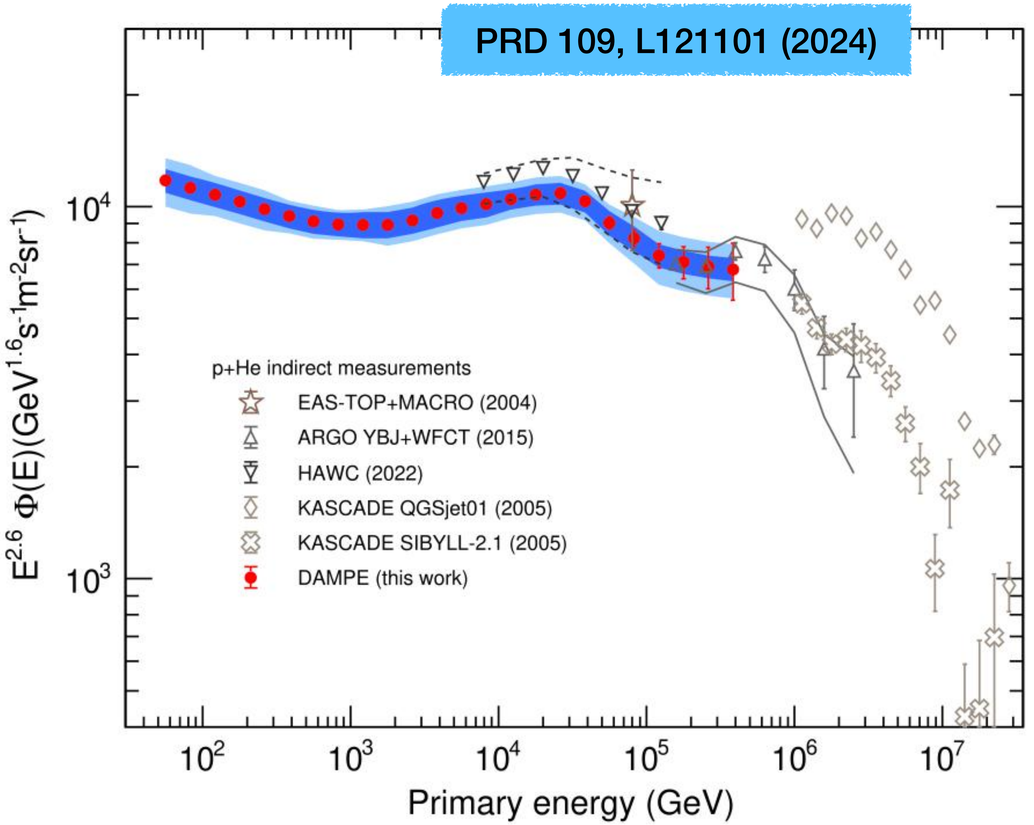


- Detection of softening at ~34 TeV
- *p* and *He* results: Z-dependent CR softening favored (A-dependence cannot be excluded)

p + He

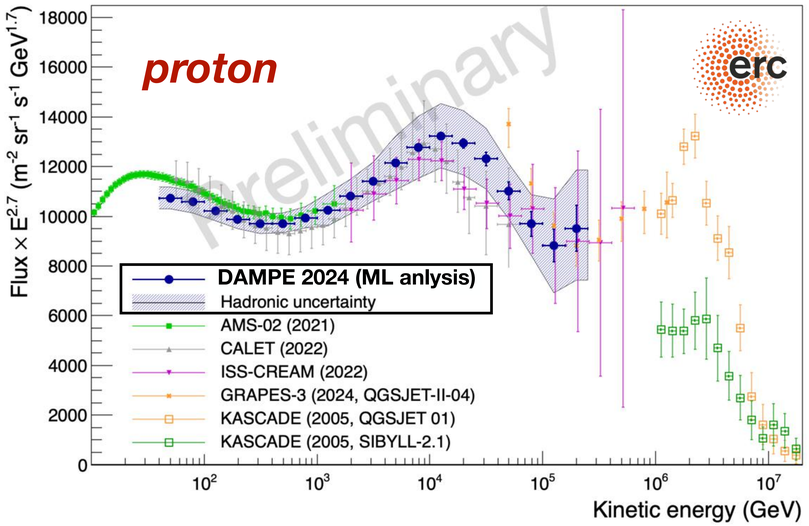


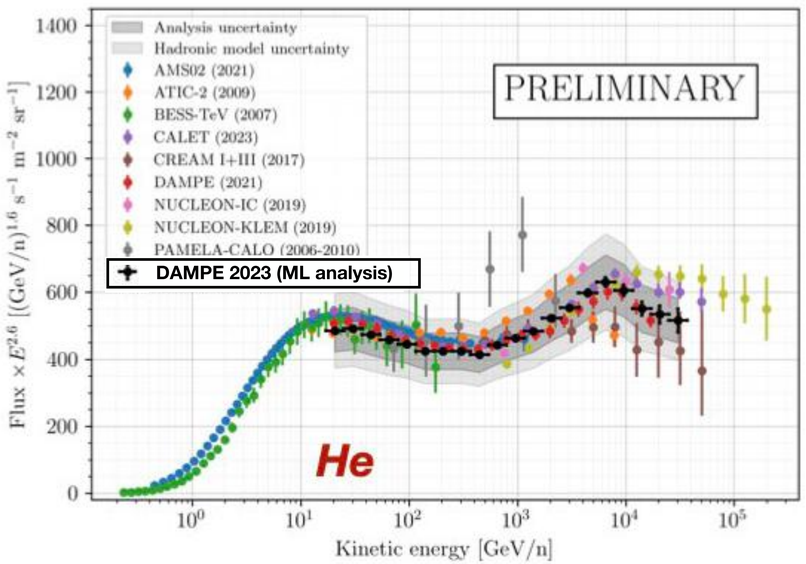
PRD 109, L121101 (2024)



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

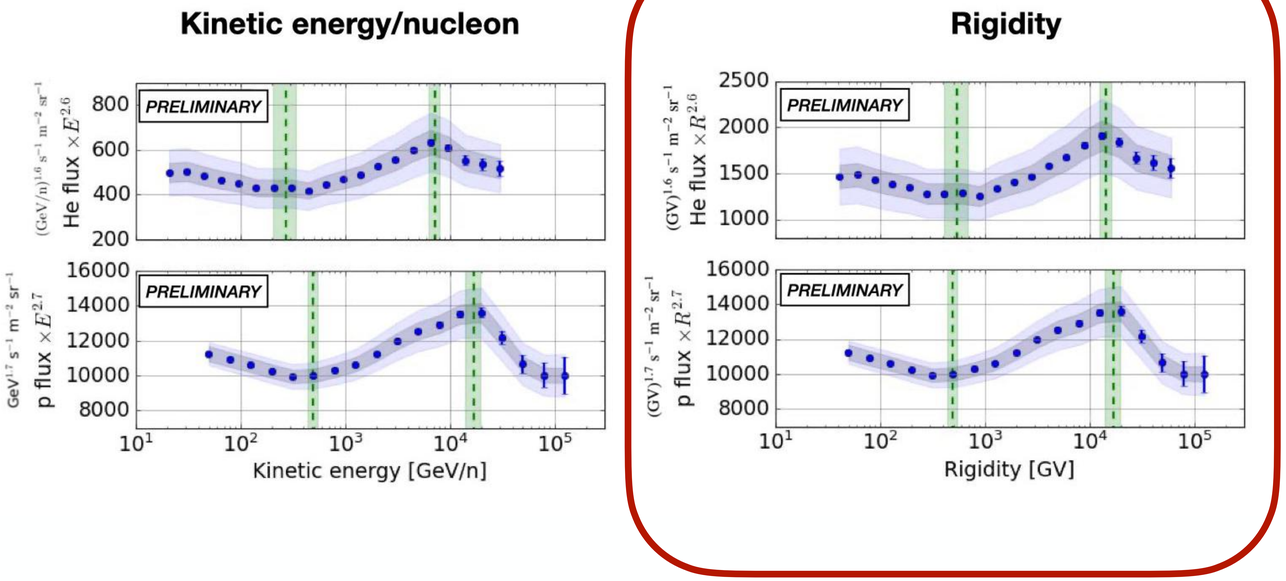
p, He - new results





Helium flux
(2023)

Proton flux
(2023)



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**

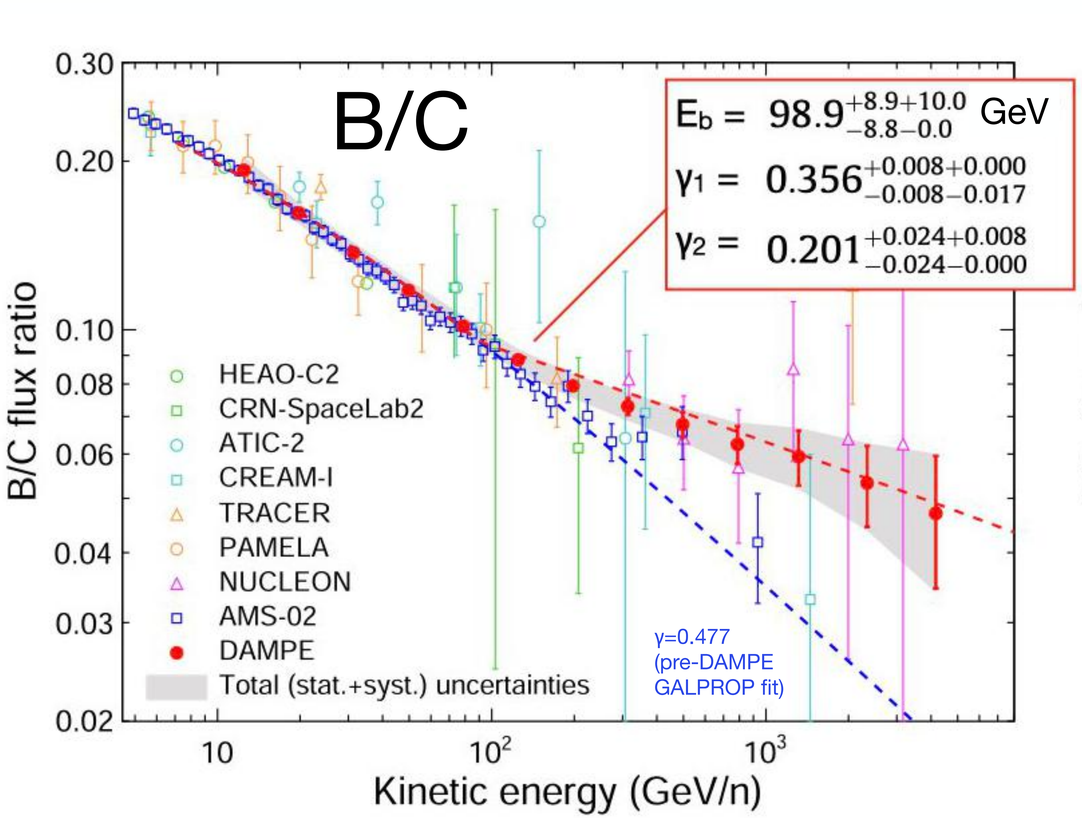
A. Tykhonov et al. Astropart. Phys. (2023)

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

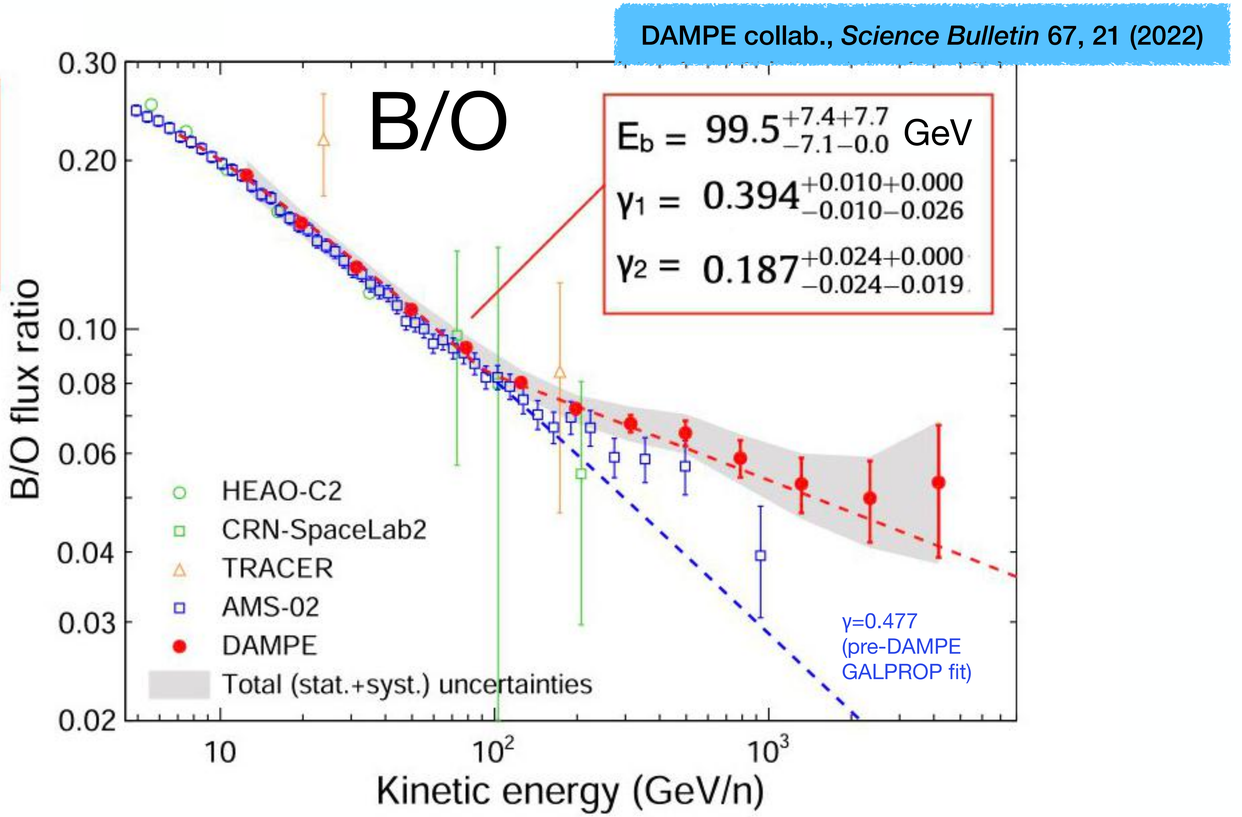
B/C, B/O

- **Detection of spectral hardening at ~ 100 GeV/n**
  Indication of change of the CR diffusion coefficient?

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

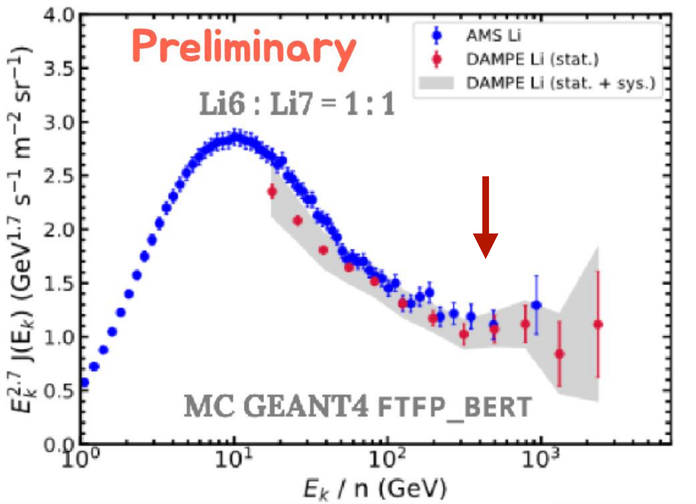


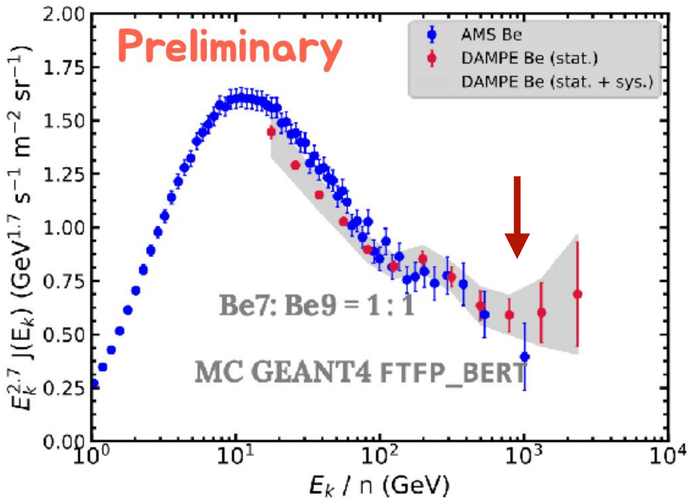
Significance ~ **5.6σ** (GEANT), 4.4σ (FLUKA)

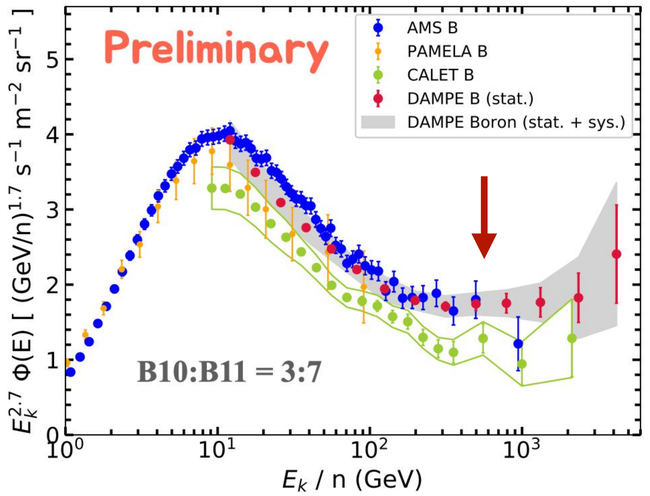


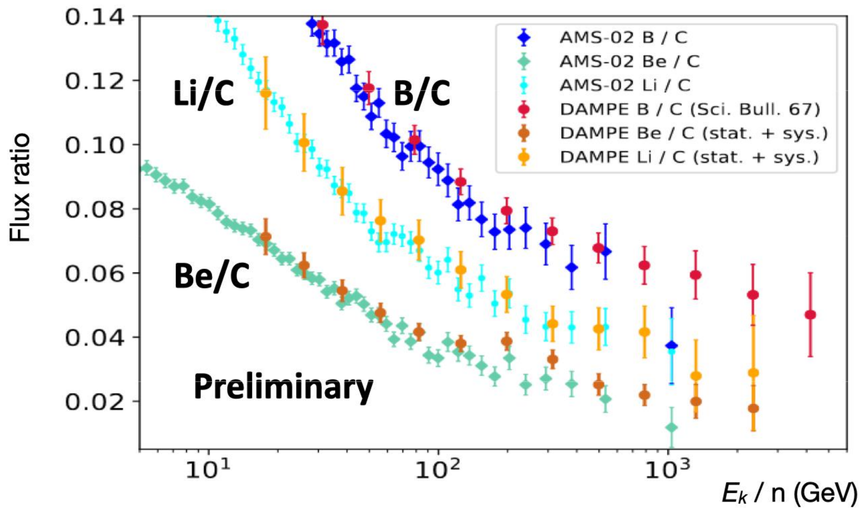
Significance ~ **6.9σ** (both GEANT and FLUKA)

Secondaries: Li, Be, B



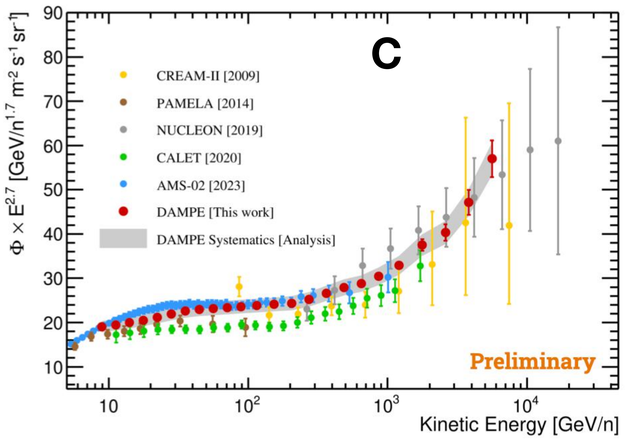


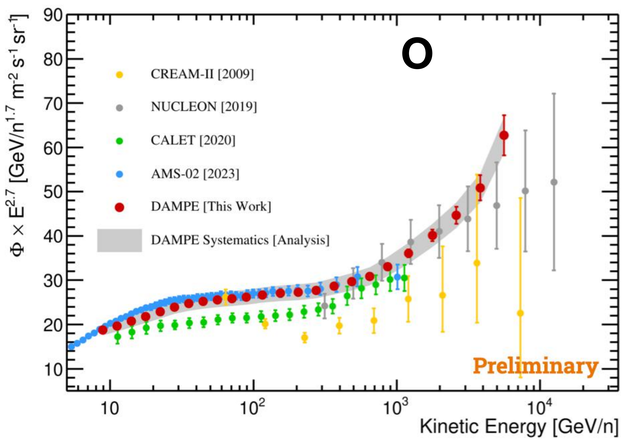


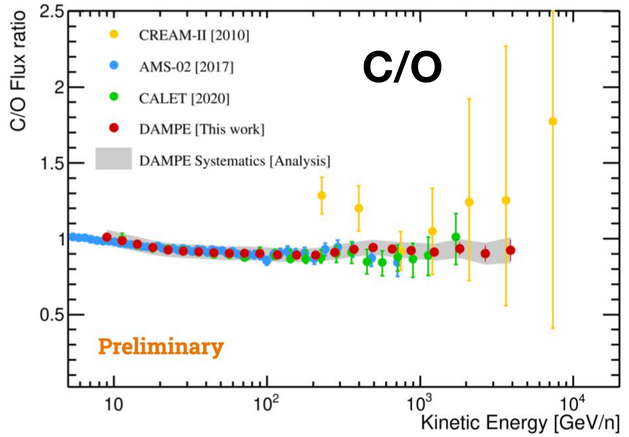


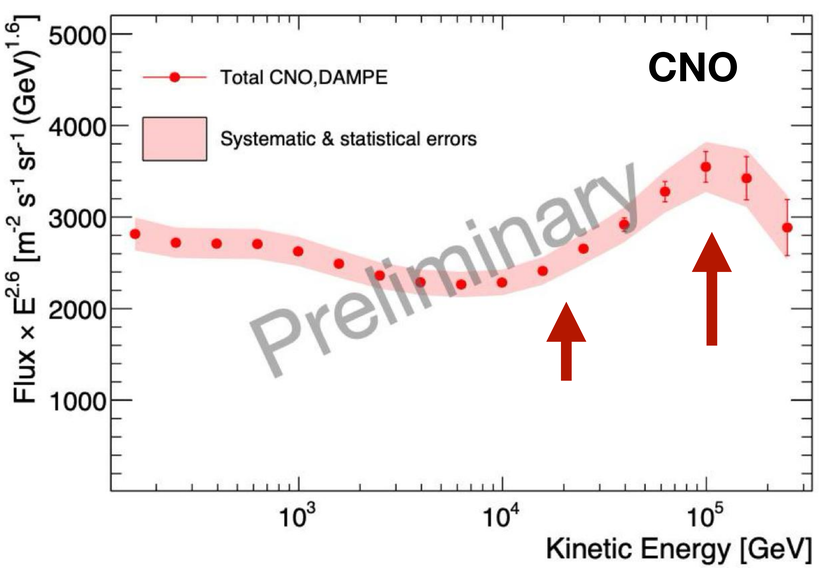
- Spectral hardening confirmed in secondaries
- Consistent break in all secondary-to-primary ratios

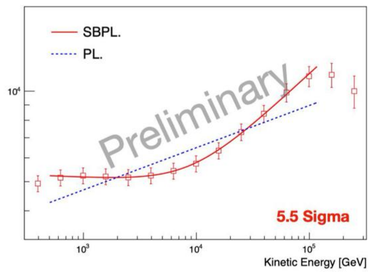
C, N, O

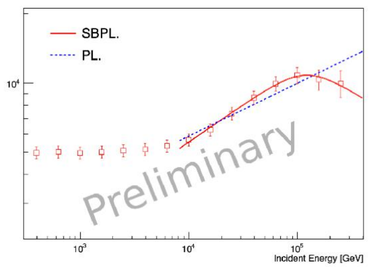






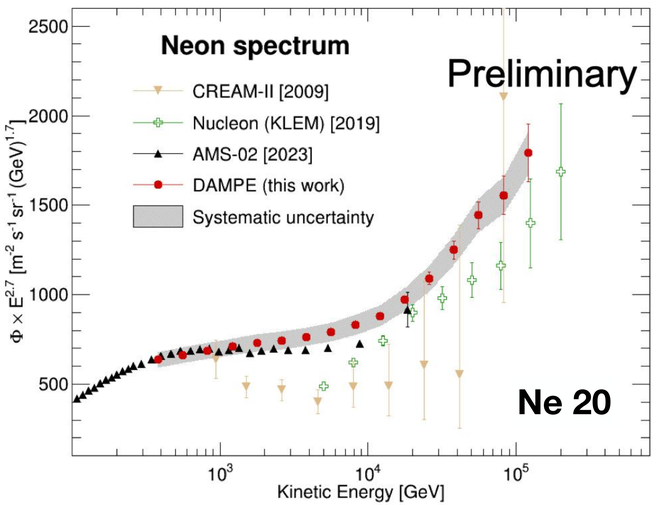


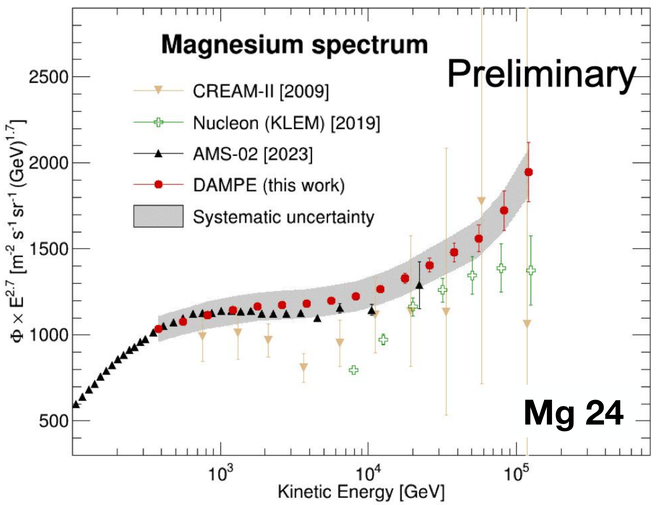


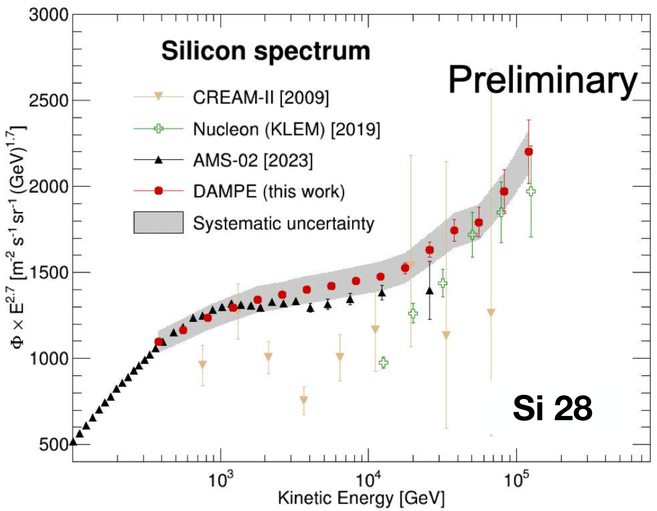


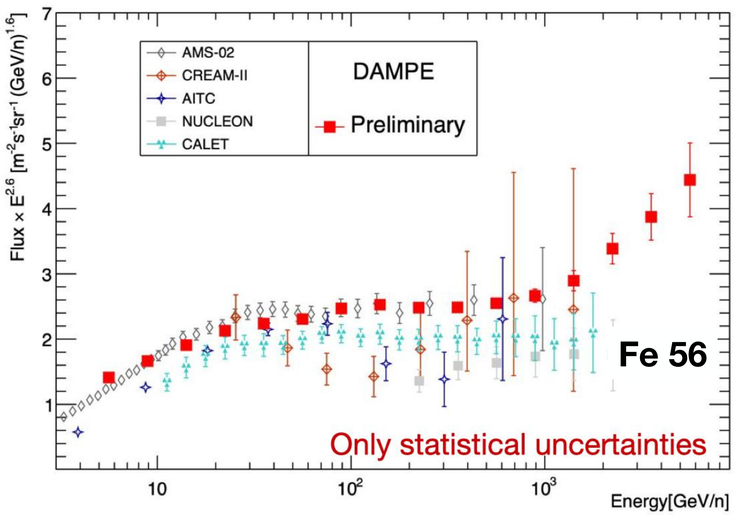
- C,O: **hardening** structure at several hundred GeV/n
- No structure in C/O ratio
- CNO: **softening** at ~10 TeV/n (similar to *p* and *He*)

Ne, Mg, Si, Fe



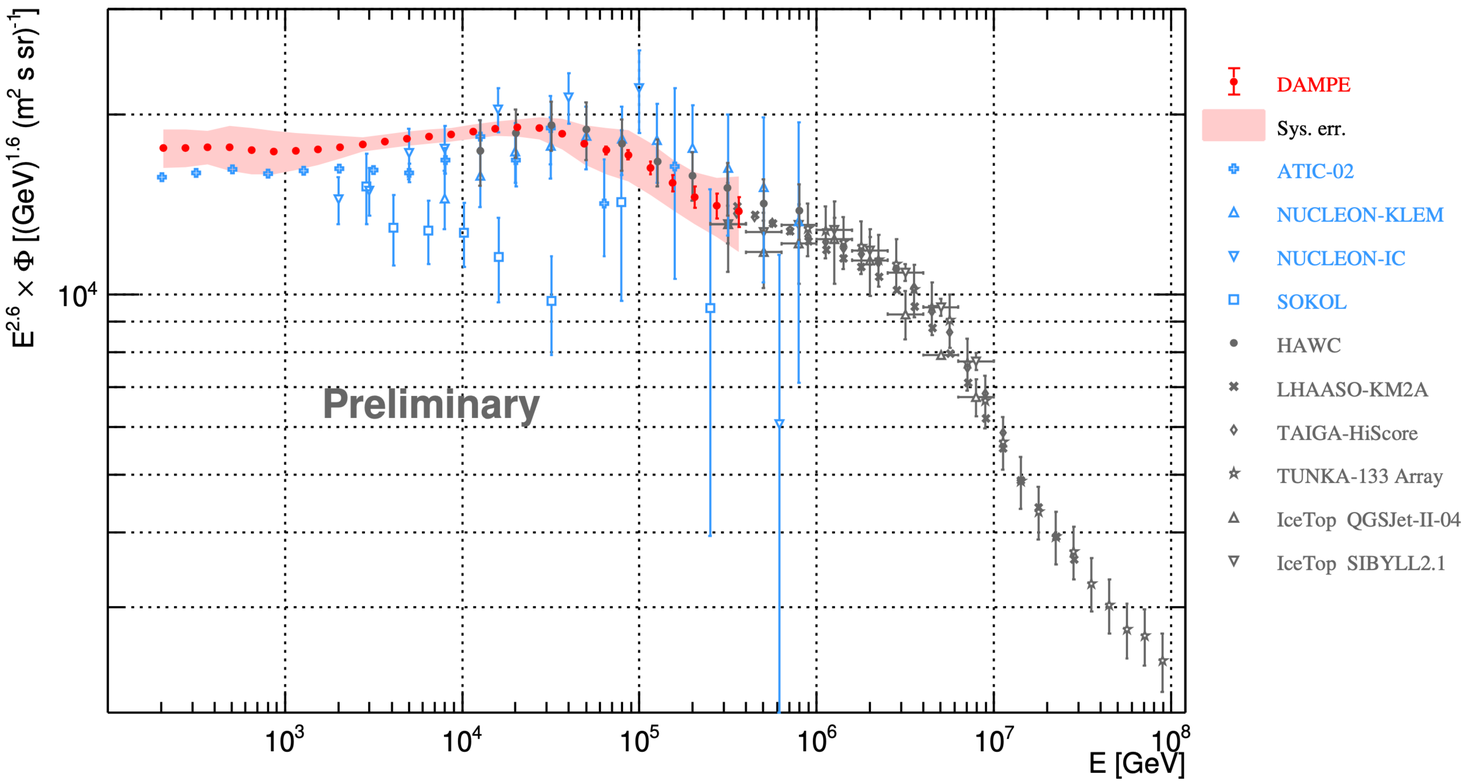






- **Confirmation of hardening in heavier elements**
- Analyses based on ML particle reconstruction (similar to p, He, C,O)
- Studies of systematics in process, including hadronic uncertainty

All-particle



Measurement over ~ 4 energy decades

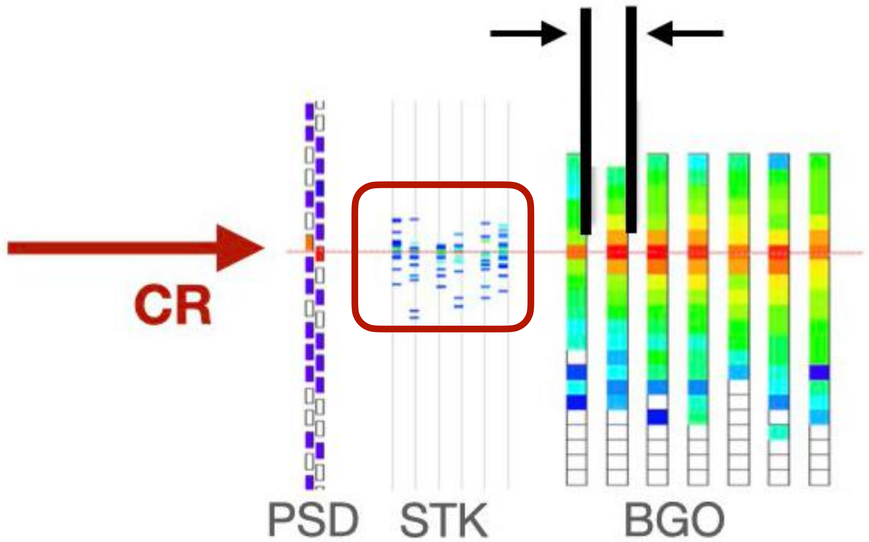
- Composition-weighted:
  - Instrument acceptance
  - Energy response matrix
- Different composition models considered:
  - Recchia-Gabici (RG)
  - Hoerandel (poly-gonato)
  - HAWC model
  - Zatsepin-Sokolskaya (ZS)

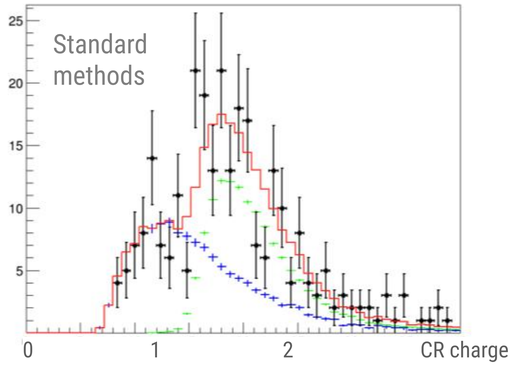
Hadronic cross sections

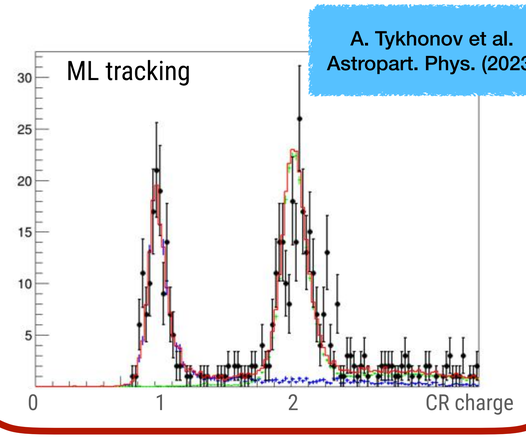
ML based tracking enables **clean and unbiased particle identification** — critical for *proton* and *helium* **cross section measurement** with DAMPE:

Funded by the European Union
European Research Council

Cross section measurement in $Bi_4Ge_3O_{12}$

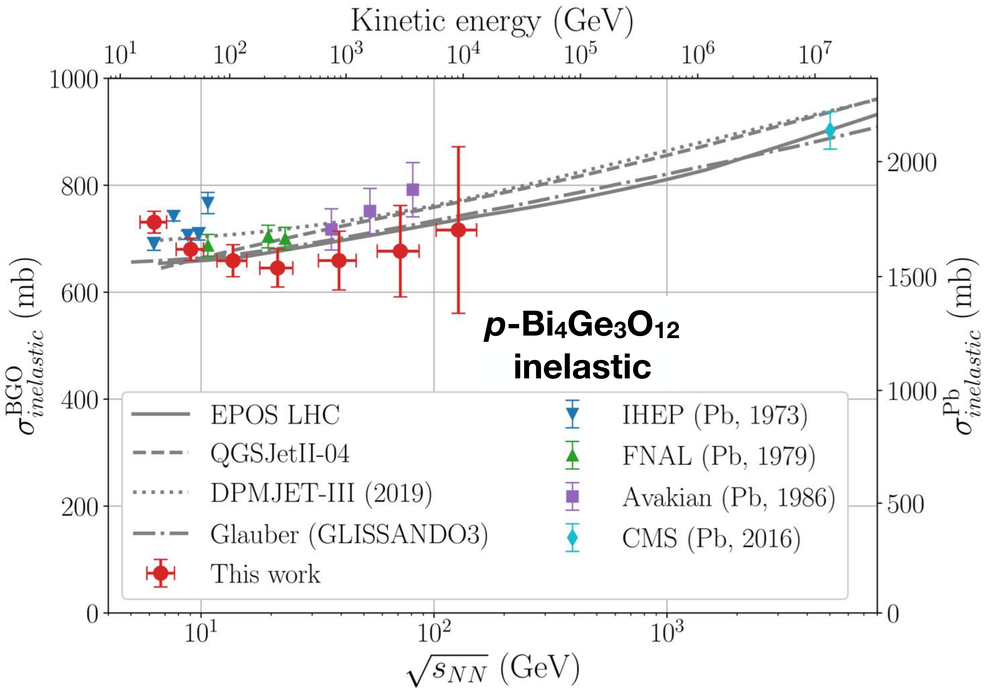


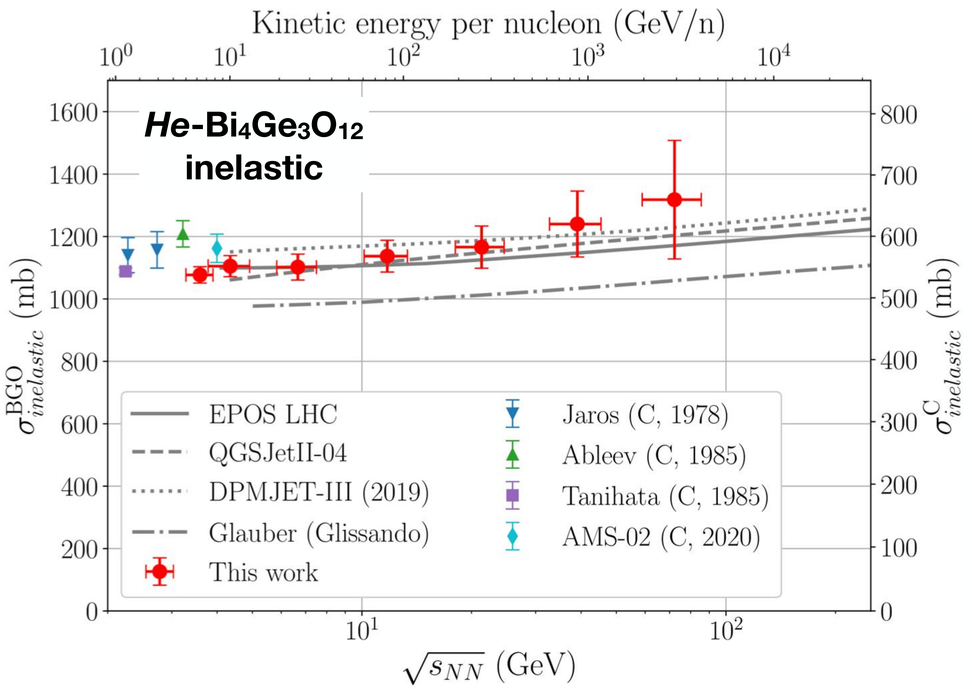




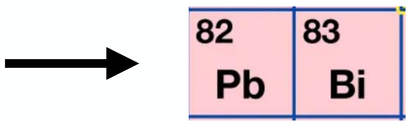
Universe as a particle machine

Hadronic cross sections



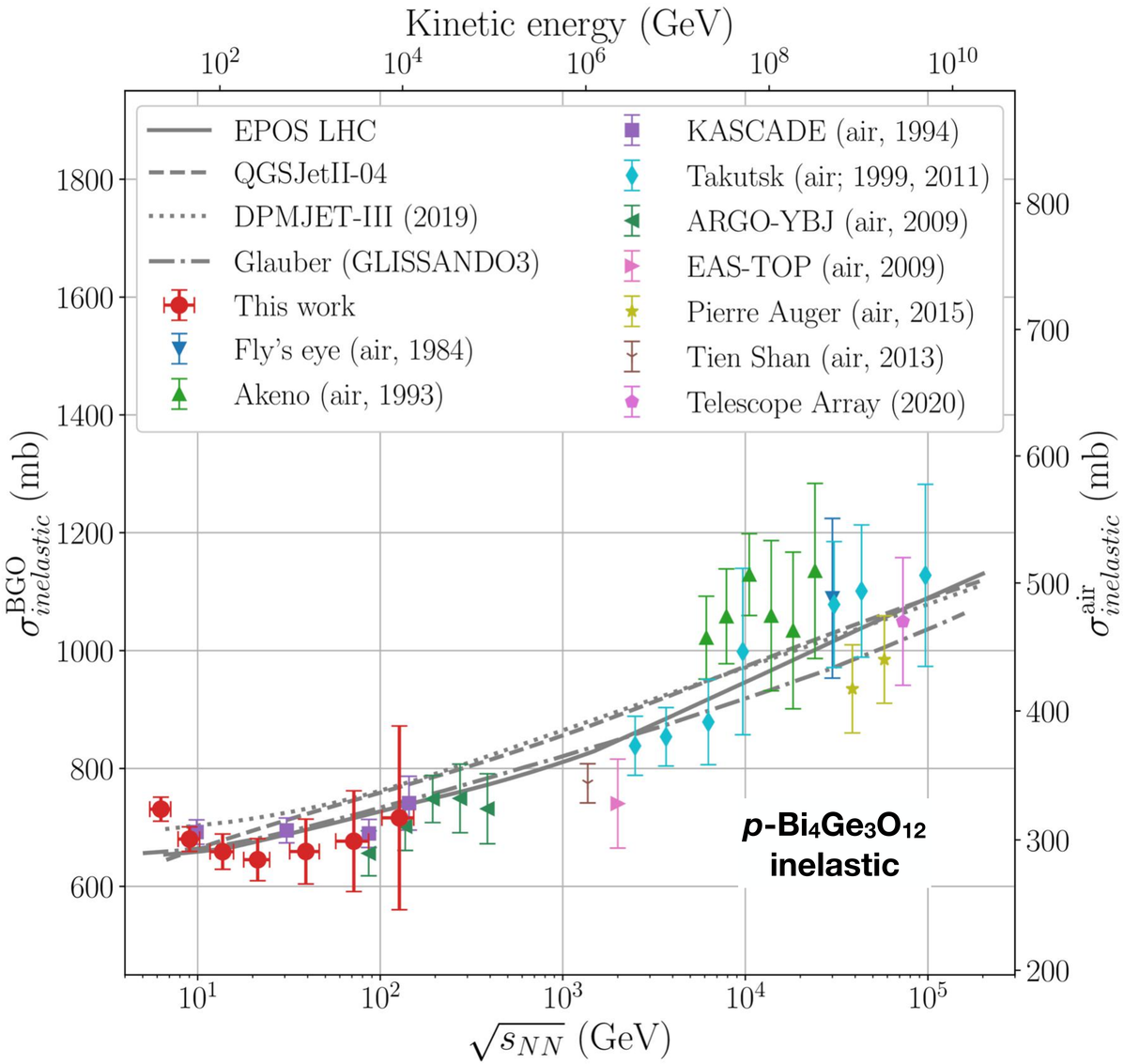


- Probe of cross section in 2 decades of energy (in center-of-mass system)
- **p-BGO** synergetic with collider **p-Pb** measurements:
  ~ 67% of BGO is bismuth → cross section scaling uncertainty < 1%
- **He-BGO** — first probe of helium-ion cross sections up to $\sqrt{s}$ ~ 100 GeV



arXiv:2408.17224v1

Hadronic cross sections



See talk of
Paul Coppin!

arXiv:2408.17224v1

Conclusions

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- In-flight operation 2015 — now
- Excellent performance & stability
- Unique for multi-TeV Cosmic Rays (CR)

Physics Program

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- *p & He* — approaching the PeV frontier
- B/C & B/O — observation of ~100 GeV/n break
- Observation of hardening in secondaries (*Li, Be, B)*
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To be continued ….

Thank You!