Latest results from the DAMPE space mission

Elisabetta Casilli

On behalf of the DAMPE Collaboration

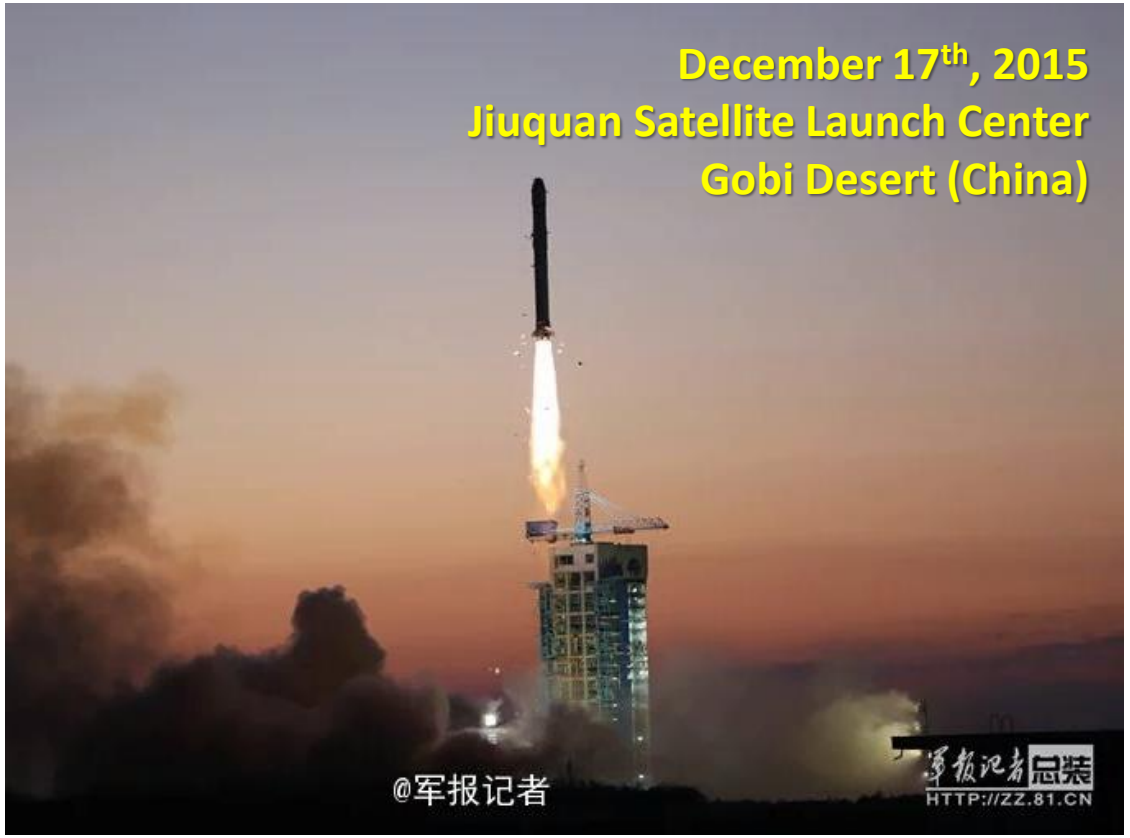
E-mail: elisabetta.casilli@le.infn.it

5th Gravi-Gamma-Nu Workshop

Bari, October 9-11, 2024

DAMPE space mission

The **DArk Matter Particle Explorer** (**DAMPE**) is a satellite-borne particle detector, included in the framework of the *Strategic Pioneer Program on Space Science* promoted by the Chinese Academy of Sciences.

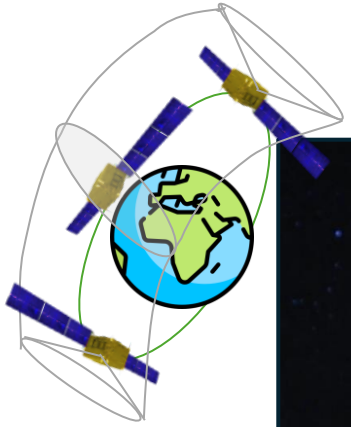


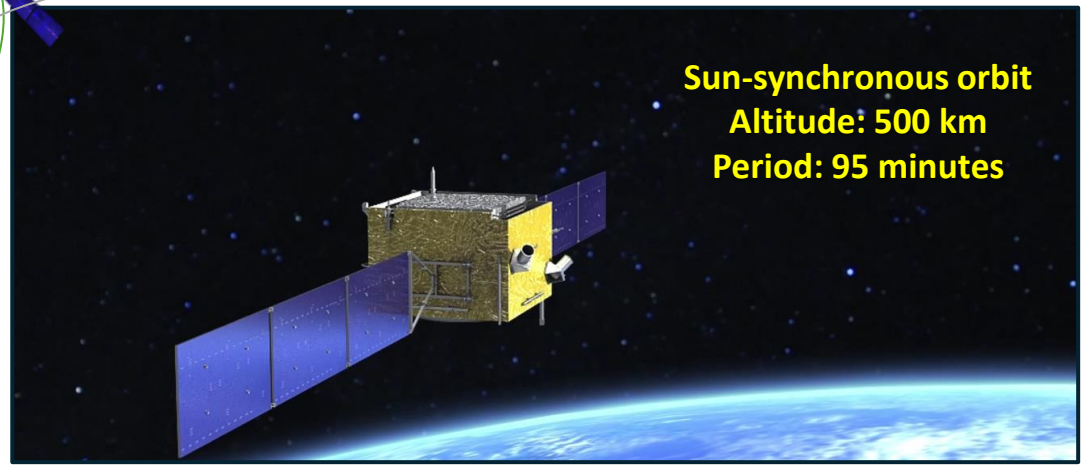
The DAMPE collaboration:

- Purple Mountain Observatory, Nanjing
- University of Science and Technology, Hefei
- Institute of High Energy Physics, Beijing
- National Space Science Center, Beijing
- Institute of Modern Physics, Lanzhou

- INFN Lecce & University of Salento
- INFN Bari & University of Bari
- INFN Perugia & University of Perugia
- INFN Laboratori Nazionali del Gran Sasso & Gran Sasso Science Institute, L'Aquila

- University of Geneva





DAMPE detector

PSD

- ❑ **Charge measurement (Z∝√E)**
- ❑ **γ-rays veto**
- 2 planes with double layer configuration
- 82 bars of plastic scintillator

STK

- ❑ **Track reconstruction**
- ❑ **Charge measurement (Z∝√ADC)**
- 6 planes with 2 single-sided silicon layers
- 3 tungsten layers (for γ conversion in e^+/e- pairs)
- Spatial resolution < 70 μm (θ_{inc} < 60°)
- Angular resolution ~ 0.2° for γ at 10 GeV

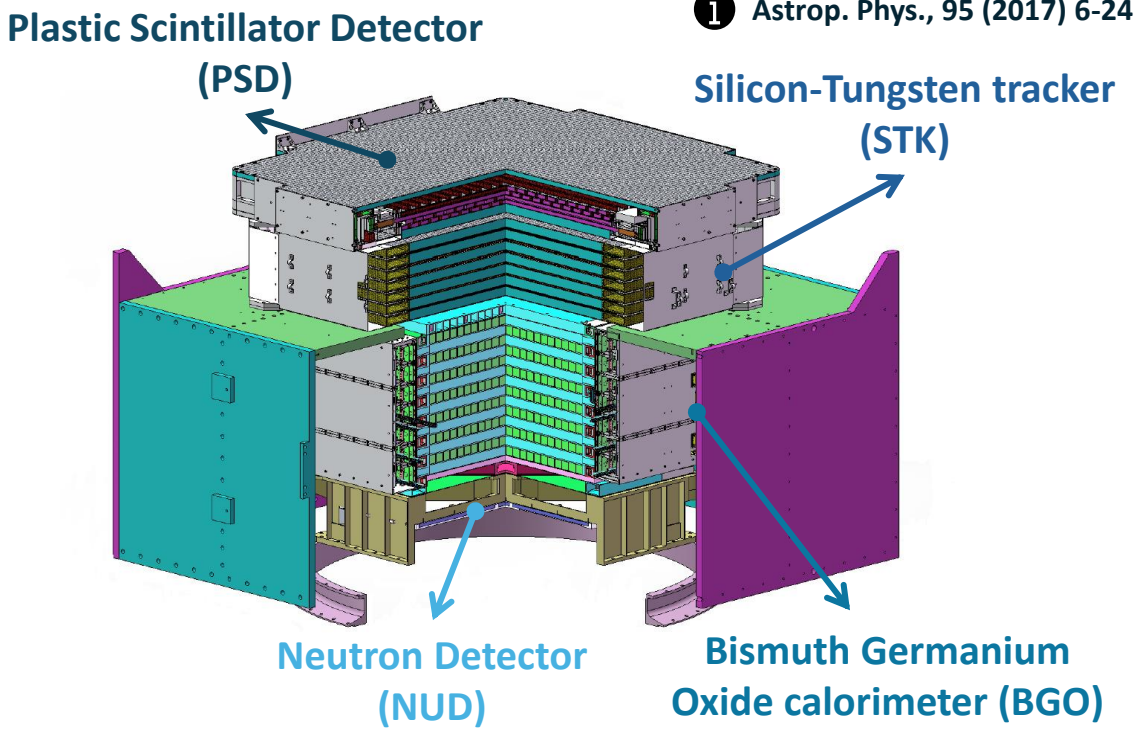
BGO

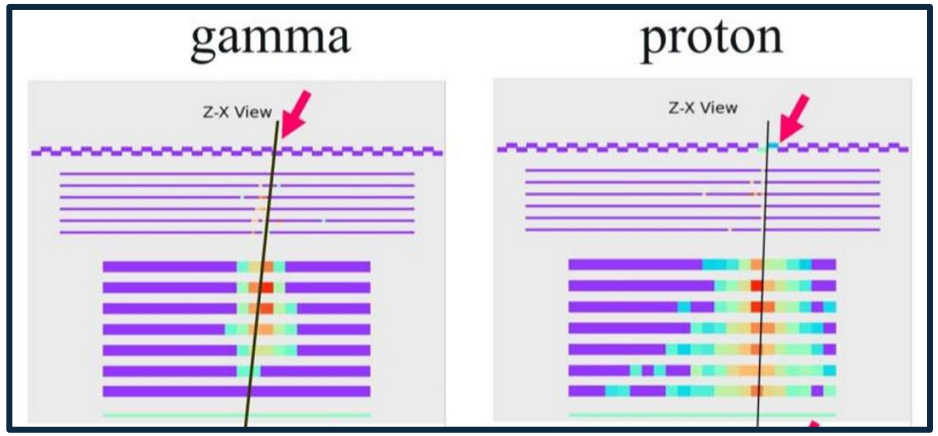
- ❑ **Energy measurement (E_{BGO})**
  - **e/gamma: 1 GeV – 10 TeV**
  - **p/nuclei: 20 GeV – 500 TeV**
- ❑ **e/p separation**
- 14 layers, each one with 22 bars of $Bi_3Ge_4O_{12}$
- A depth of ~ 32 X_0 (corresponding to ~ 1.6 λ_I)

NUD

- ❑ **Hadron/electromagnetic showers discrimination**
- A plan with 4 boron-doped plastic scintillator

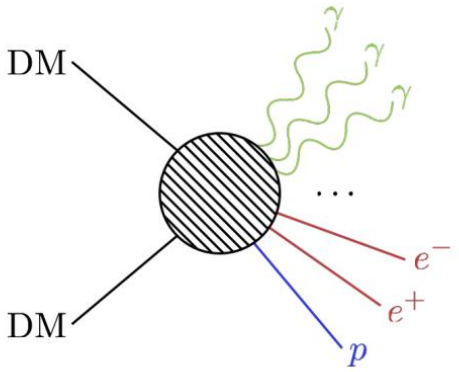
Astrop. Phys., 95 (2017) 6-24





Scientific goals

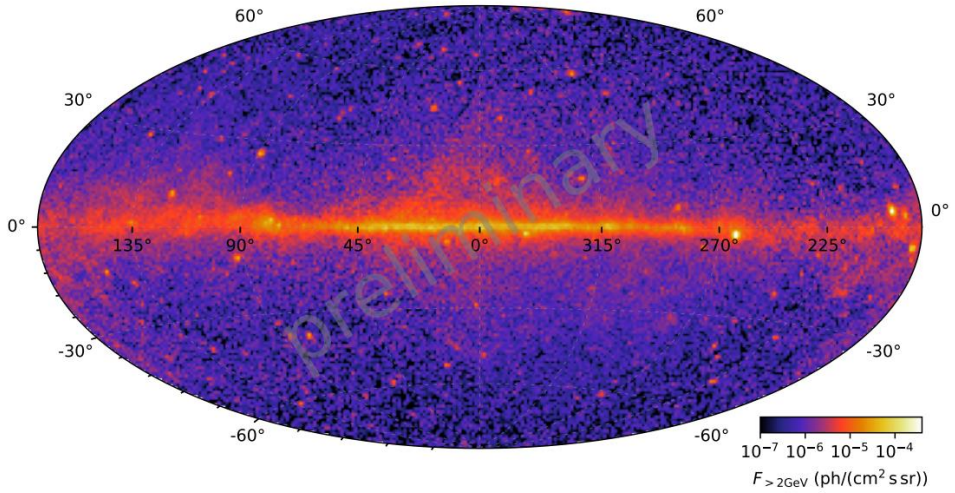
Indirect Dark Matter (DM) search



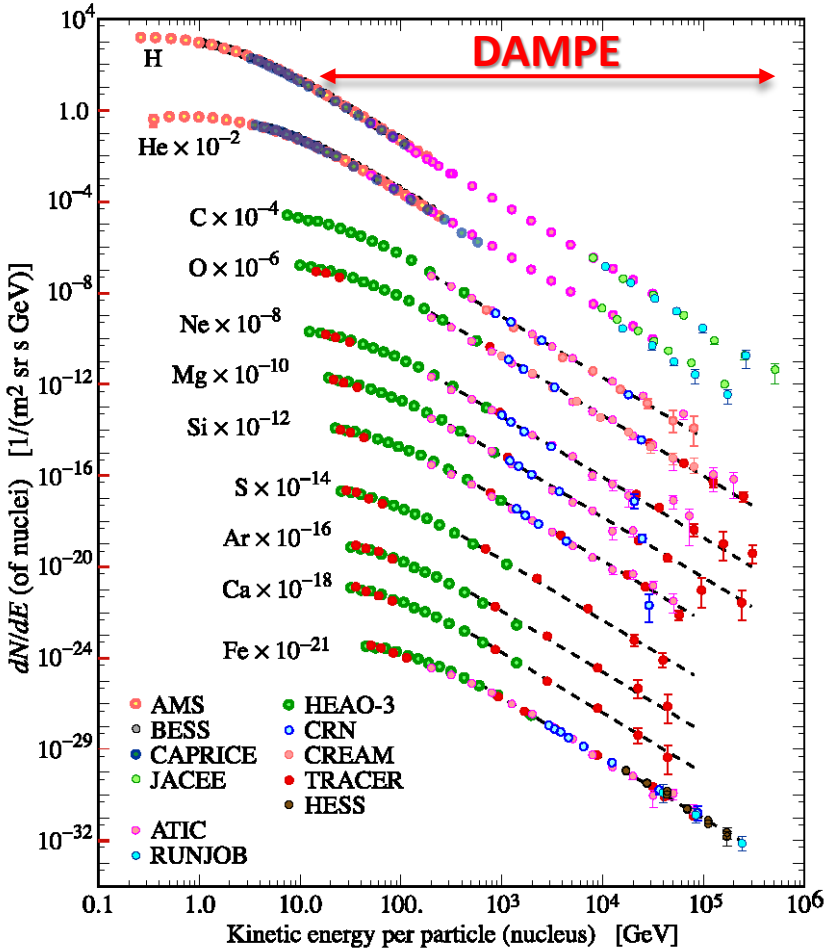
WIMP hypothesis

$$E_\gamma = m_\chi \left(1 - \frac{m_X^2}{4m_\chi^2}\right)$$

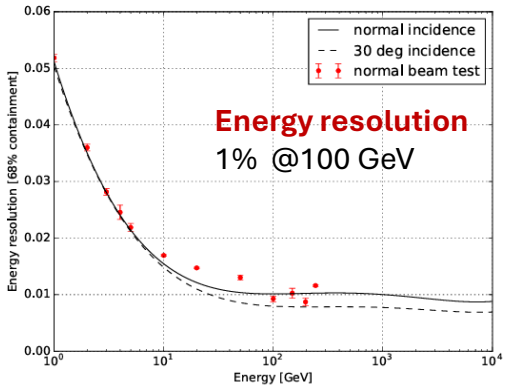
Gamma-ray astronomy

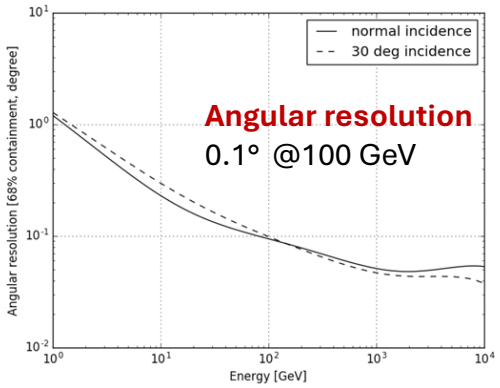


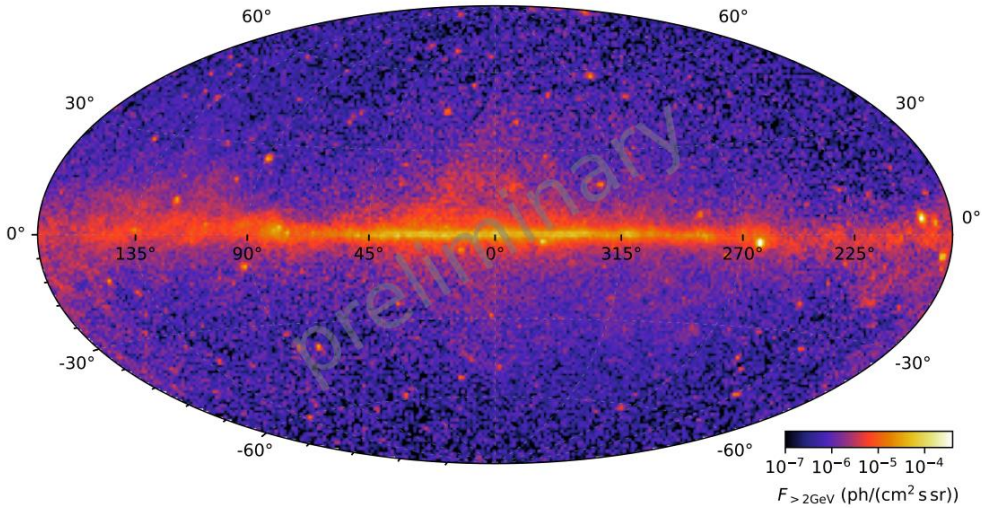
Cosmic-ray (CR) direct detection



Results: Gamma-ray sky

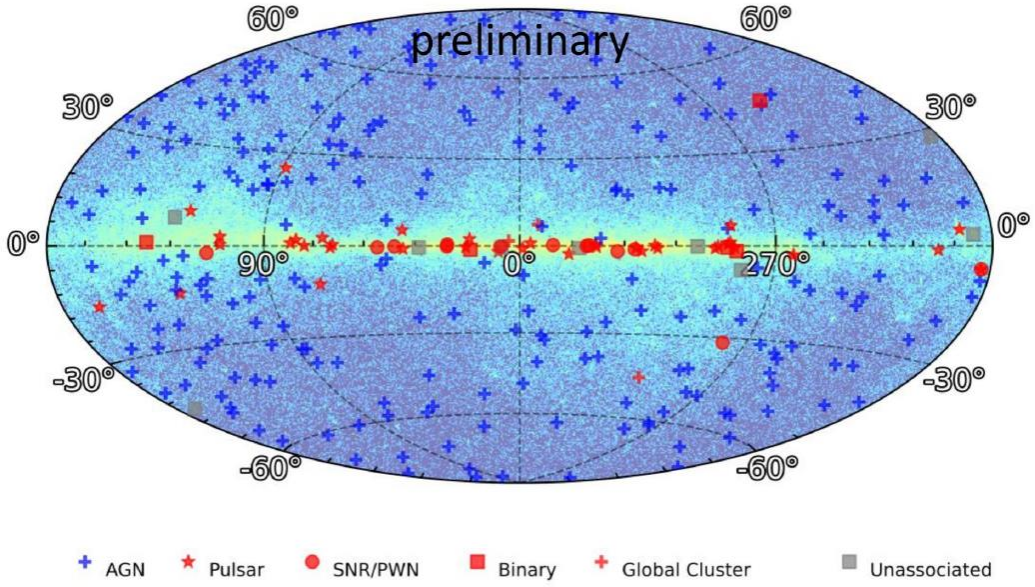






- 8 years of operations:
  - Over 0.3 M photons above 2 GeV
  - 192 M seconds live-time

- More than 300 point sources detected and studied in 7.5 years

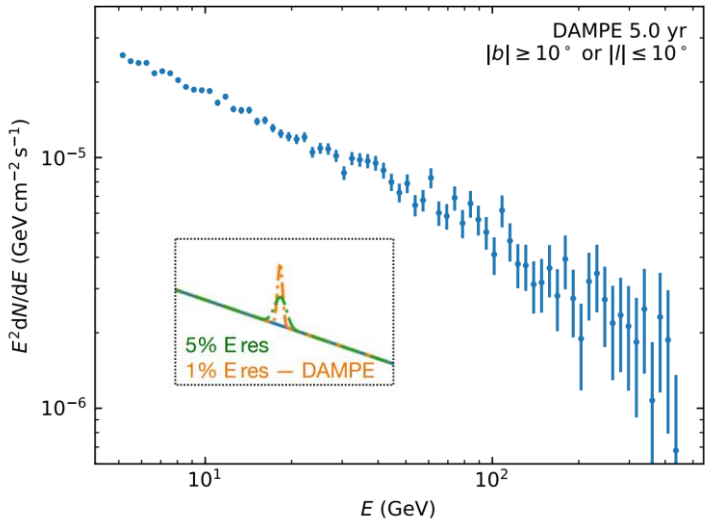


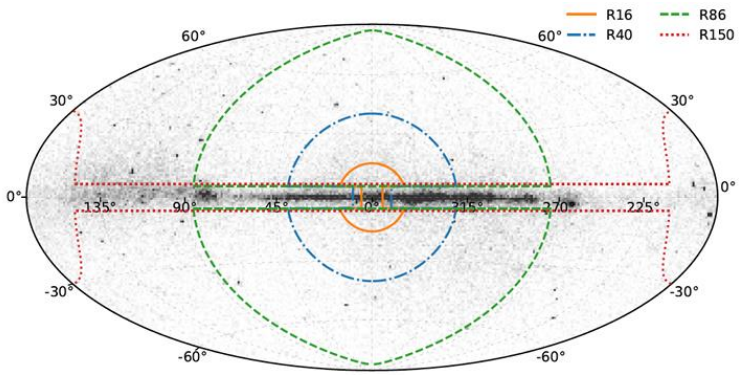
AGN	Pulsar	SNR/PWN	Binary	Global cluster	Un-associated	Total
241	62	14	5	4	10	**336**

Sources associated with the Fermi-LAT 4FGL-DR3 catalog

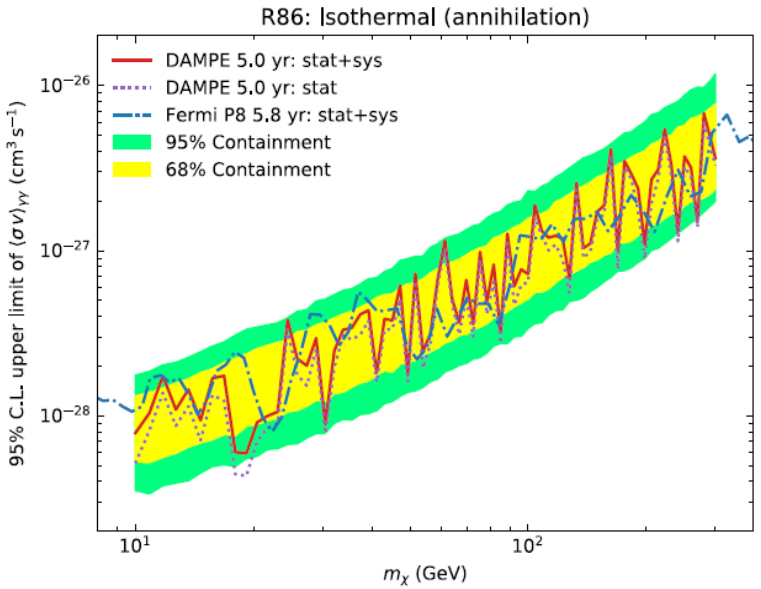
Presented by K.K. Duan @COSPAR 2024

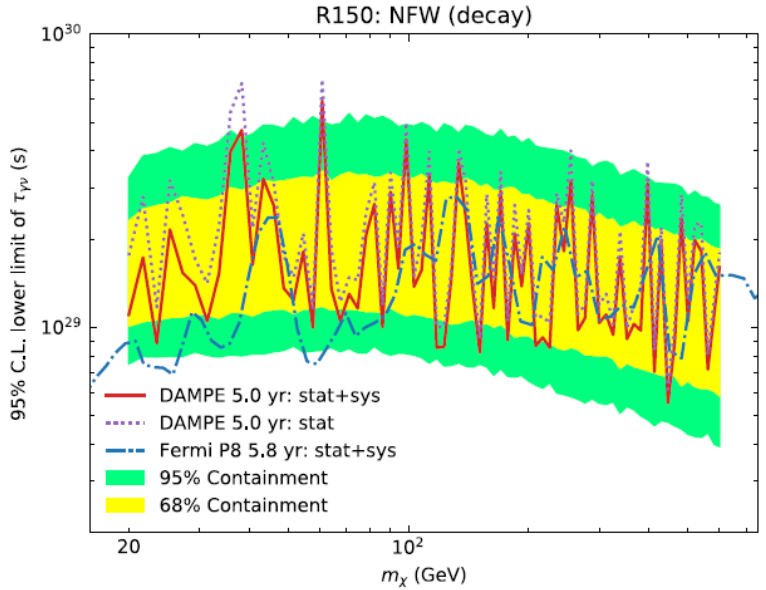
Results: Gamma-ray lines





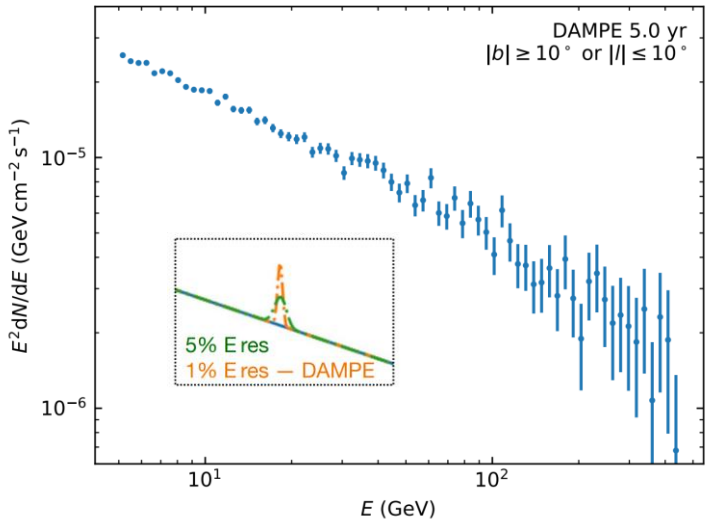
- Gamma-ray lines are considered the “smoking gun” signal for DM indirect detection.
- DAMPE’s excellent energy resolution (~1%) makes it ideal for gamma-ray line searching.
- A search was conducted in 5 years of data, covering the energy range from 5 to 450 GeV.
- No significant signal (>3σ) was found, leading to new constraints on DM.

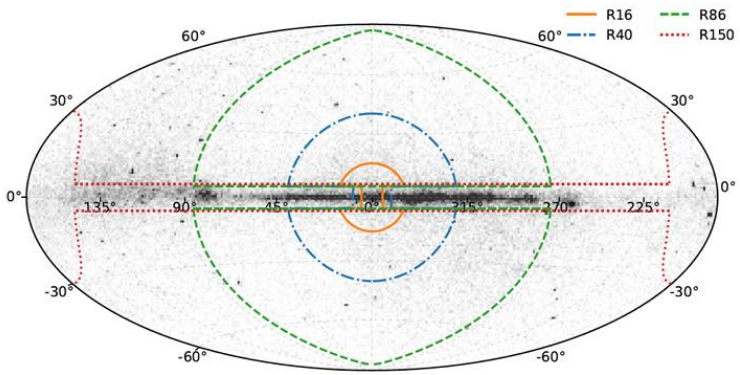




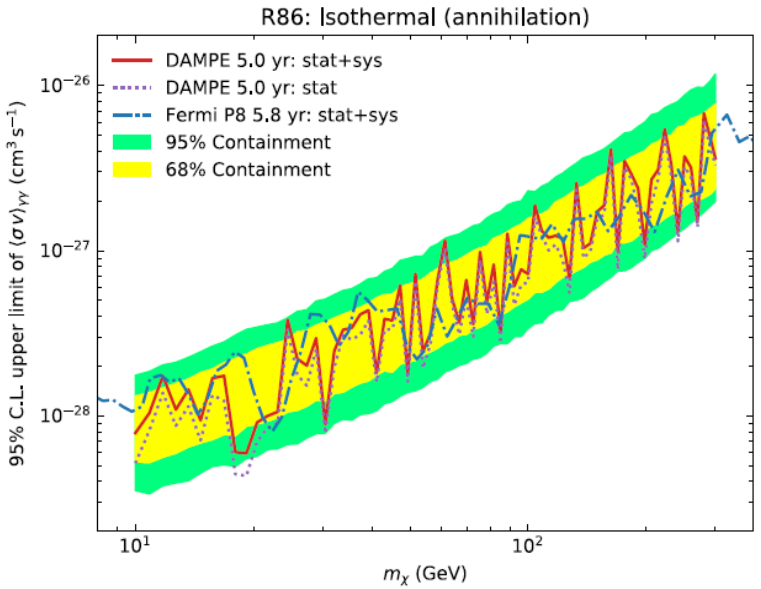
ℹ **DAMPE Collaboration, Sci. Bull. 67, 679-684 (2022)**

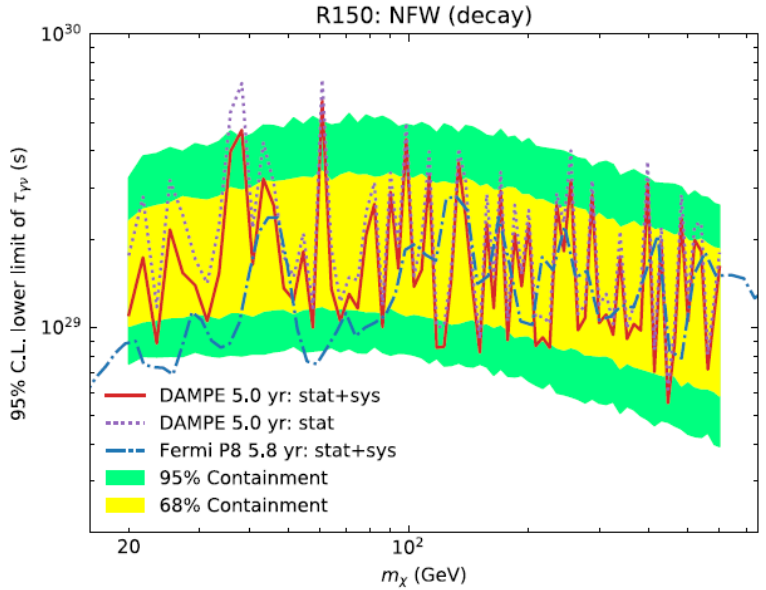
Results: Gamma-ray lines





- Gamma-ray lines are considered the “smoking gun” signal for DM indirect detection.
- DAMPE’s excellent energy resolution (~1%) makes it ideal for gamma-ray line searching.
- **<u>More data is currently being analyzed, and different analyses are ongoing…</u>**

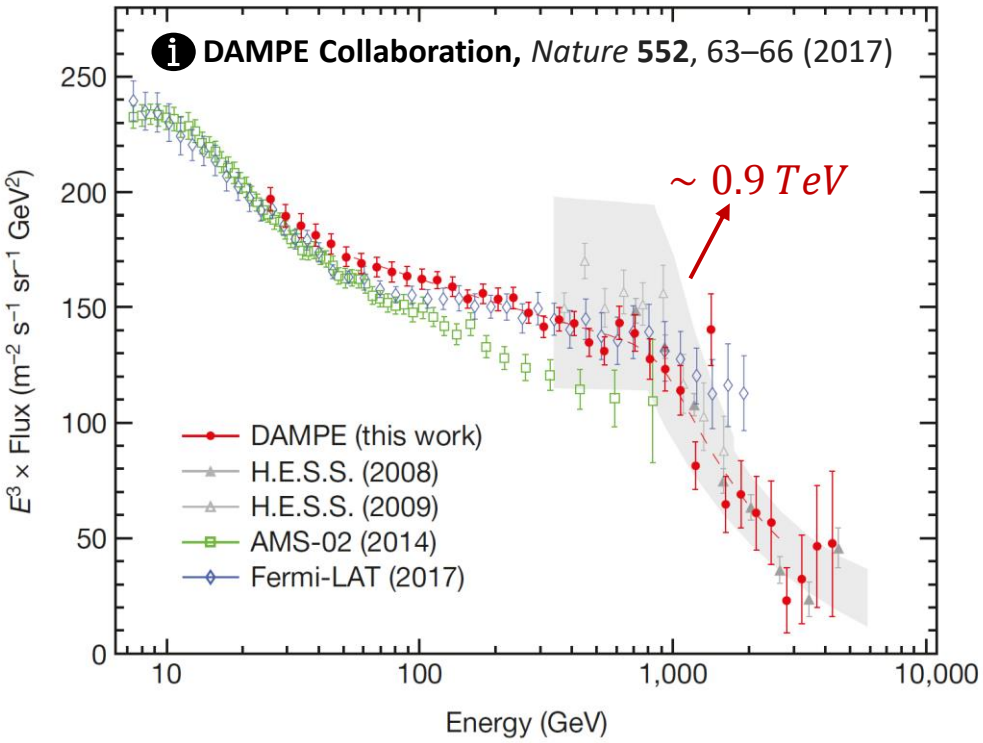




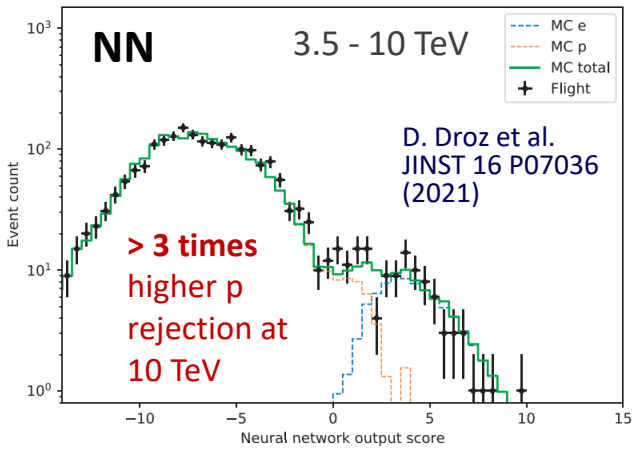
ℹ **DAMPE Collaboration, Sci. Bull. 67, 679-684 (2022)**

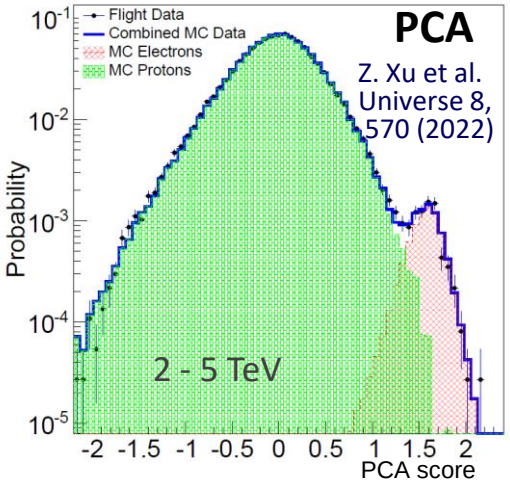
Results: e^-/e^+

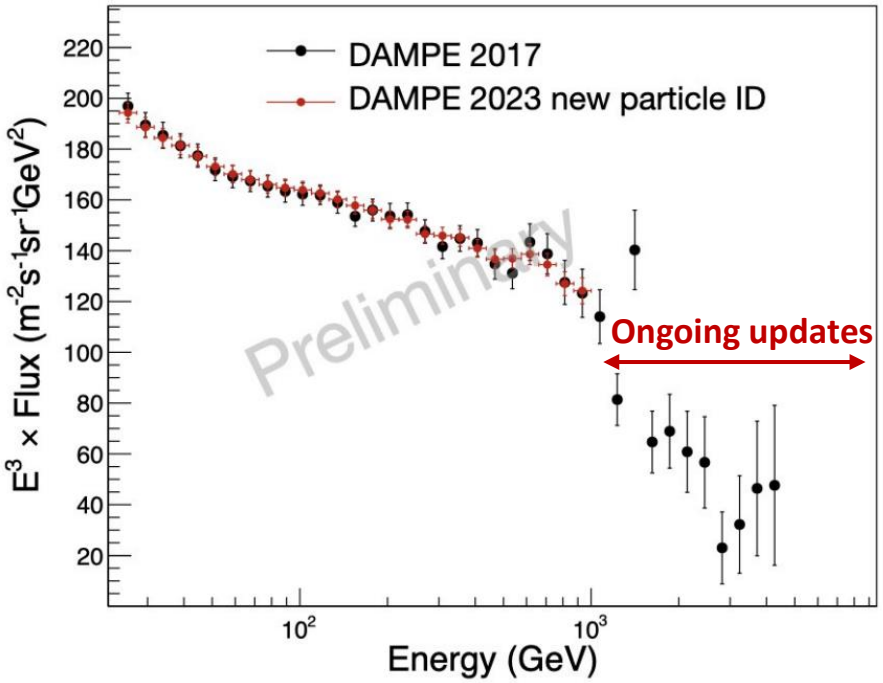
First direct observation of a TeV break



- Measurement of the spectrum in the range 25 GeV – 4.6 TeV
- 1.5 years of data
- Proton contamination lower than 3% @1 TeV

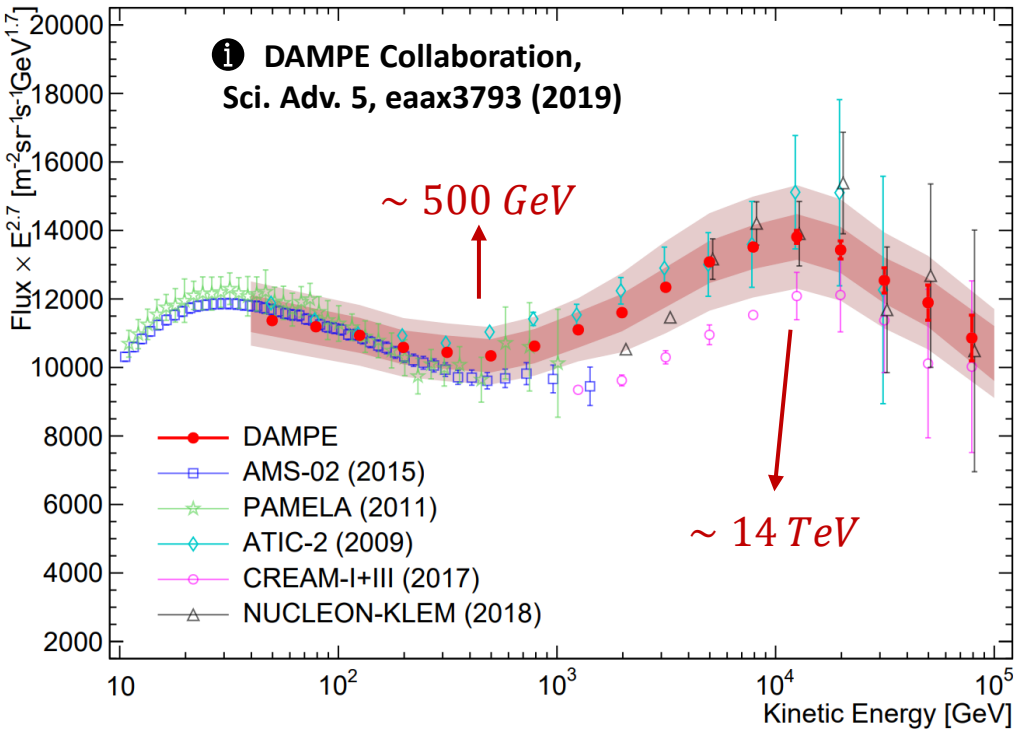




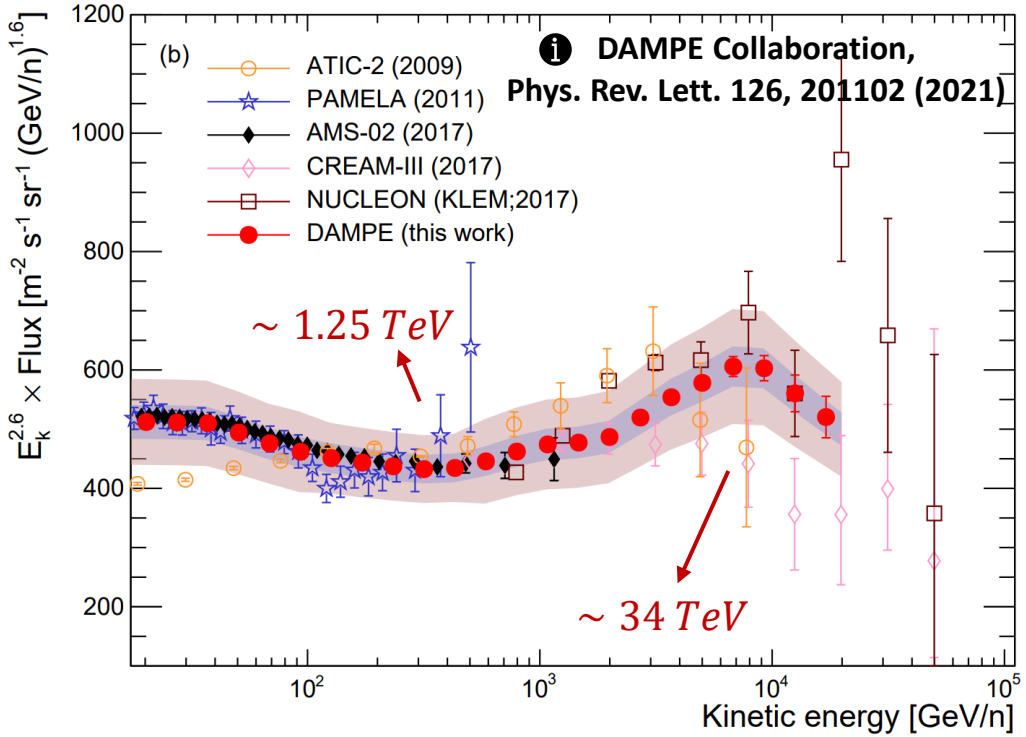


Results: p and He

CR proton spectrum

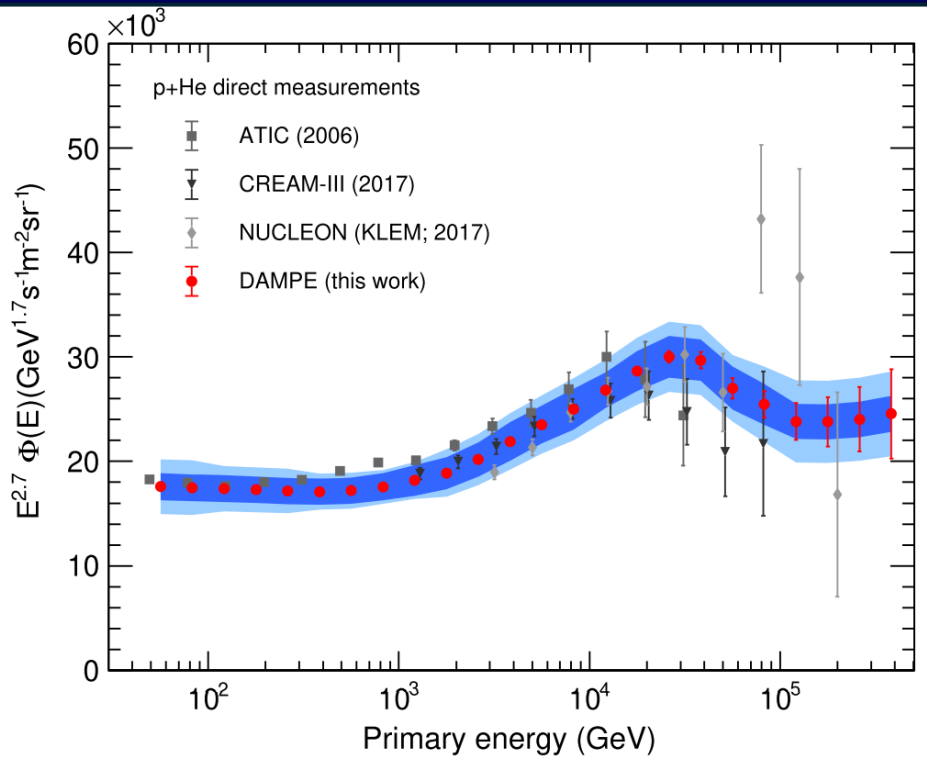


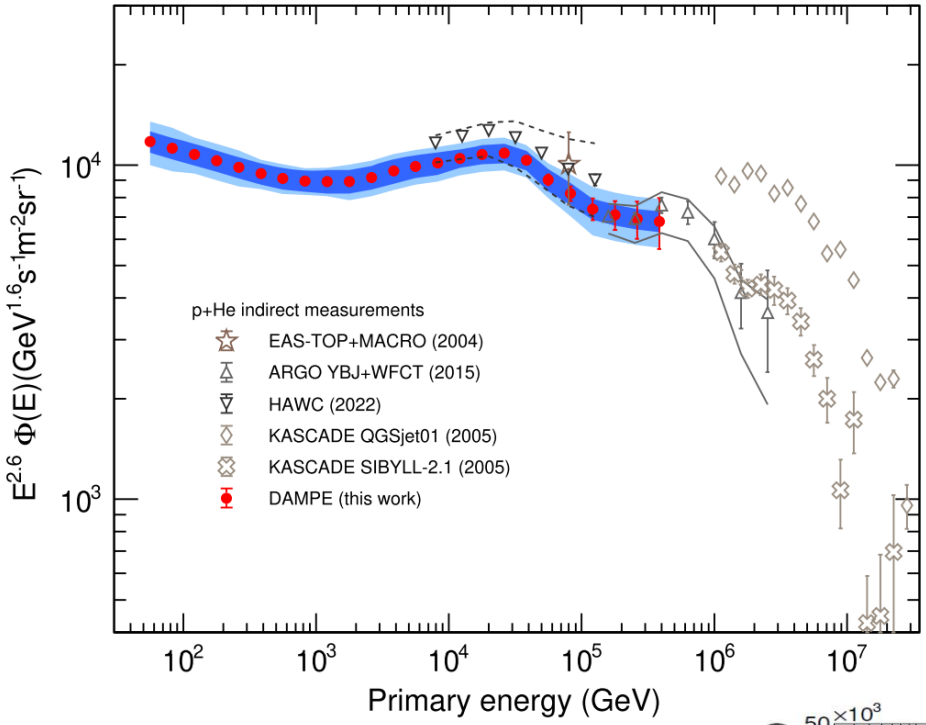
CR helium spectrum

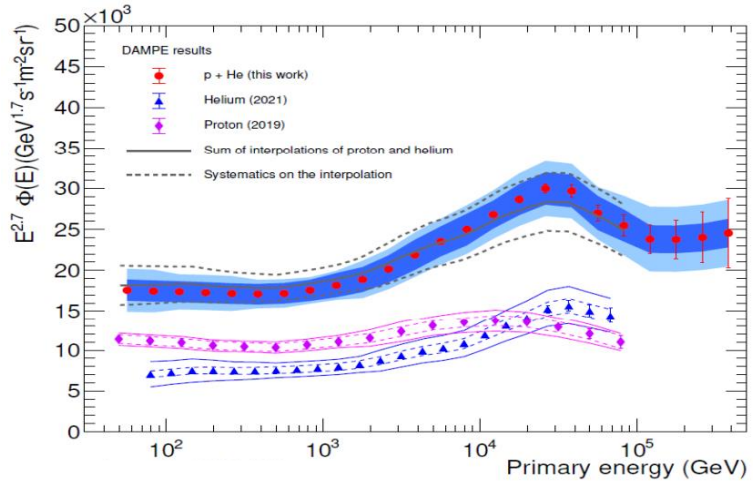


- CR proton and He spectra confirm the hardening at hundreds of GeV/n and show a similar softening feature, suggesting a **Z-dependent spectral break around 15 TV**
- **New updates ongoing… (with Machine Learning techniques)**

Results: p+He





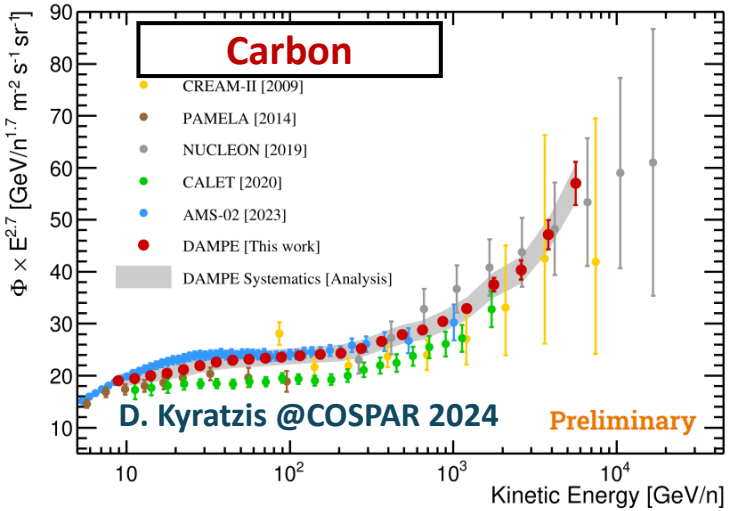


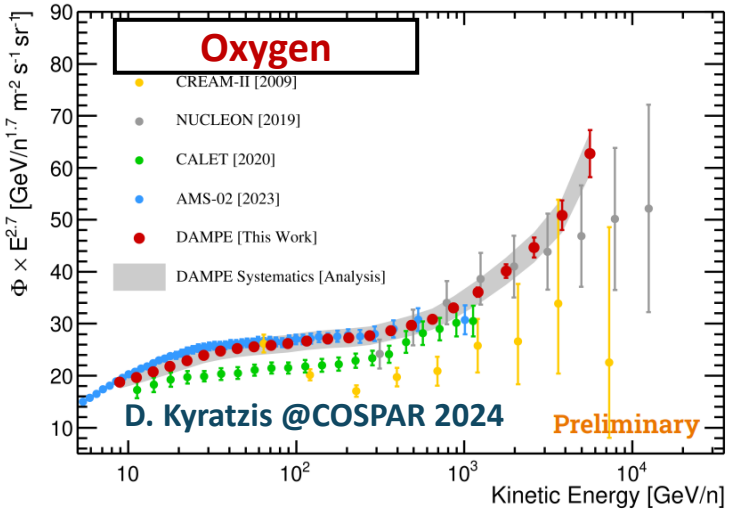
- **Confirmation of the softening at ~15 TV** (suggesting Z-dependence)
- Link between direct and indirect CR measurements
- Hint of spectral hardening above 100 TeV

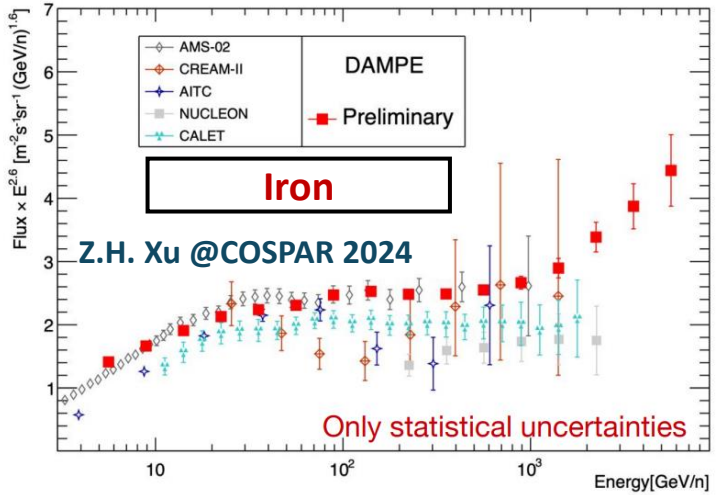
DAMPE Collaboration, Phys. Rev. D 109, L121101 (2024)

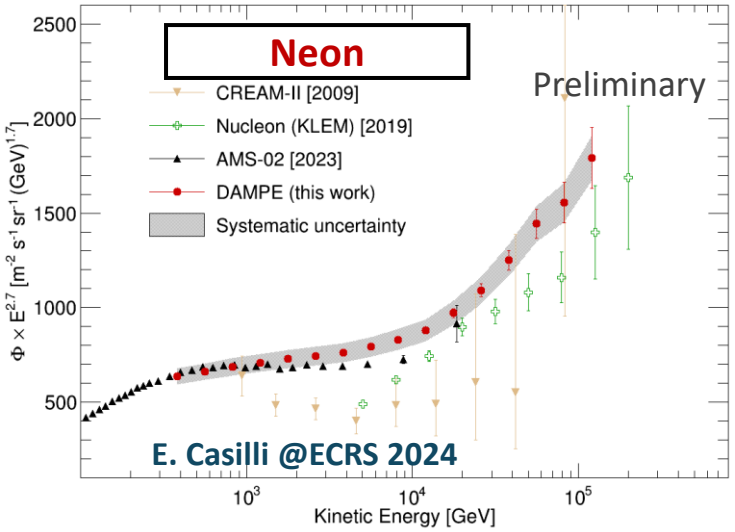
Results: heavier nuclei

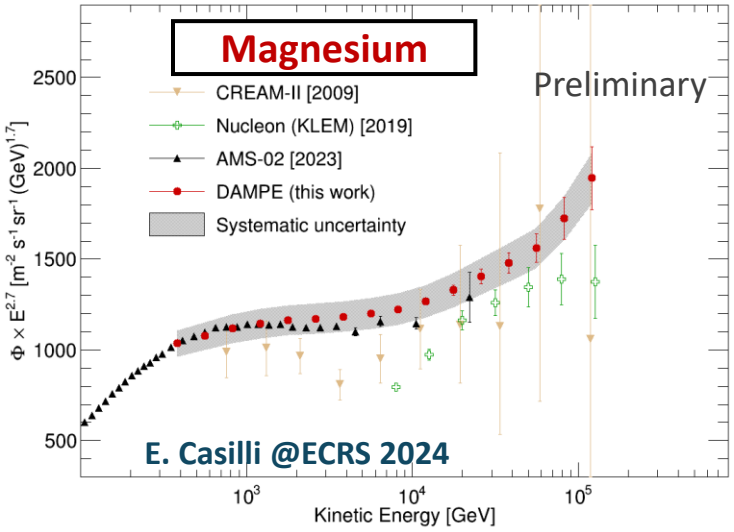
- Several analyses are in progress toward the highest energies (~0.8 PeV for Fe)
- Confirmation of the spectral hardening at several hundreds of GeV/n

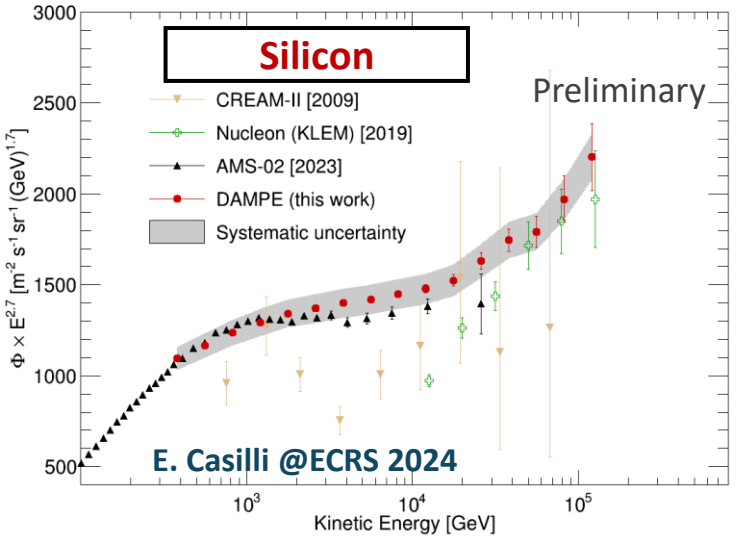






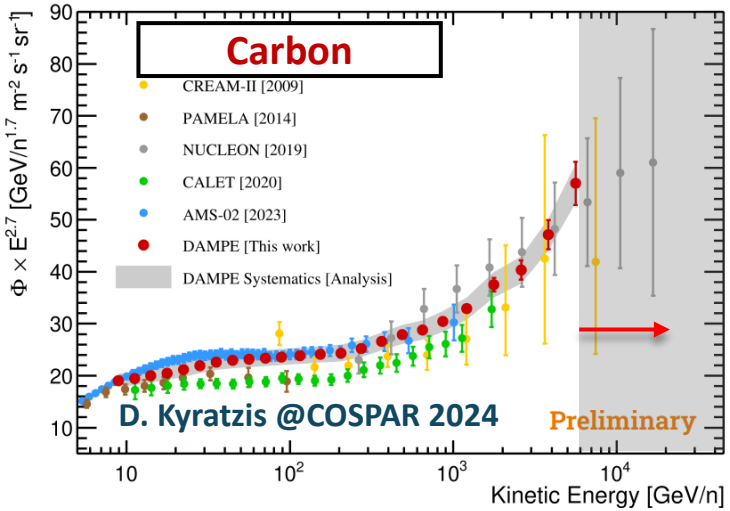


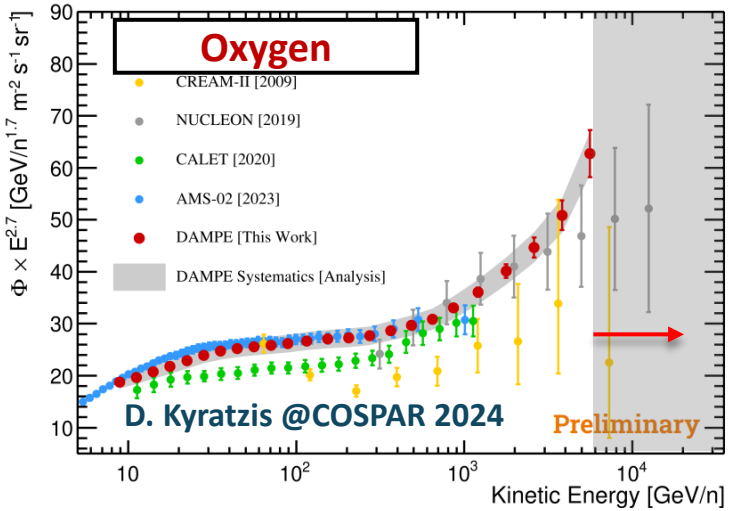


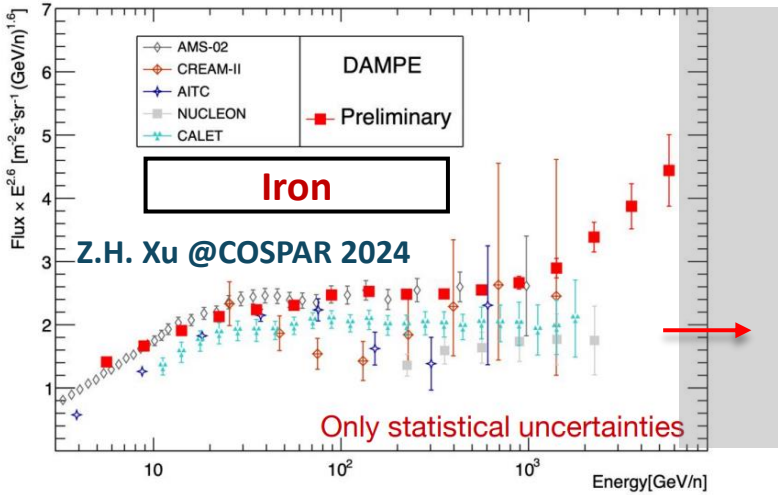


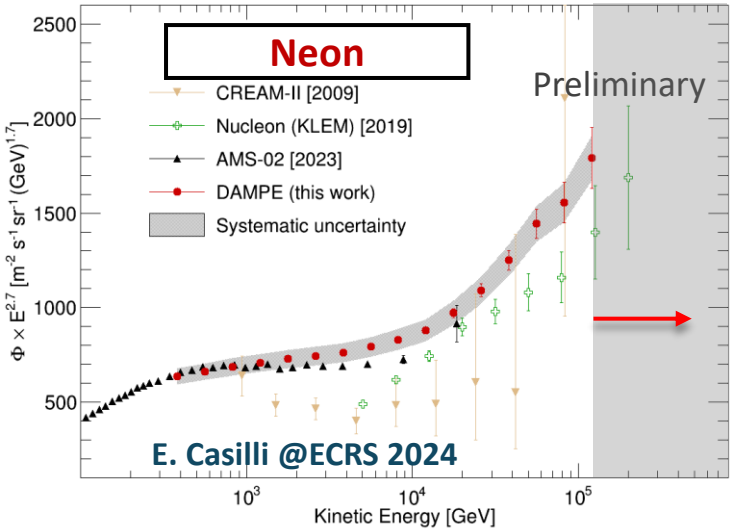
Results: heavier nuclei

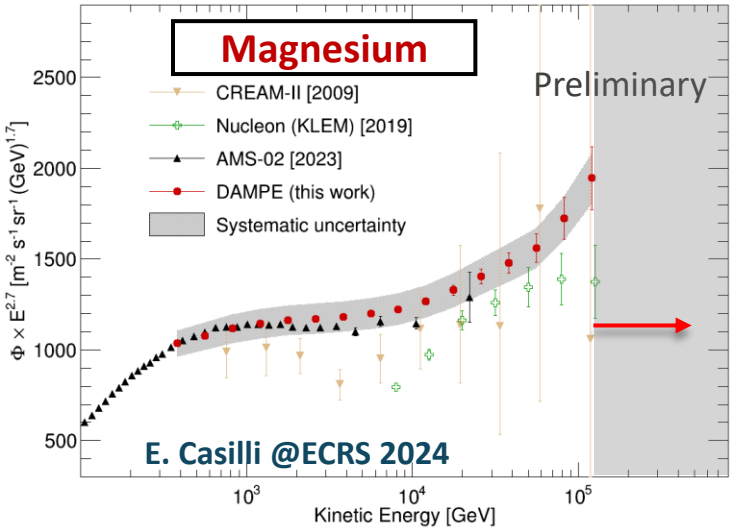
- Several analyses are in progress toward the highest energies (~0.8 PeV for Fe)
- Confirmation of the spectral hardening at several hundreds of GeV/n

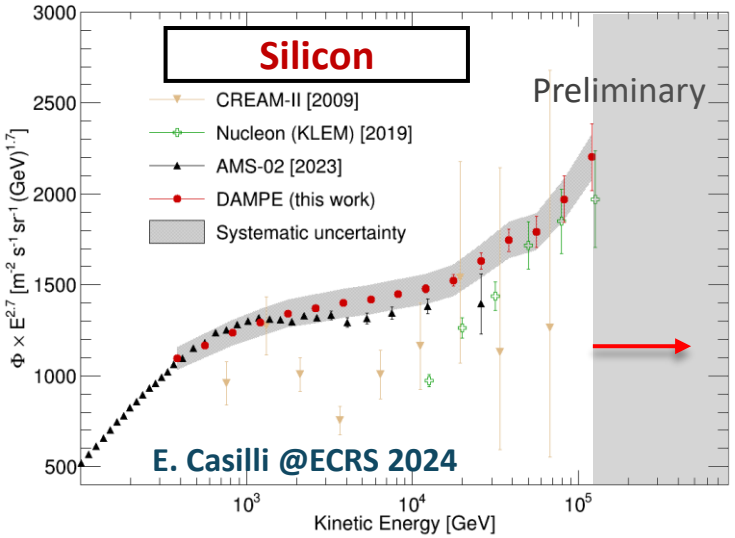






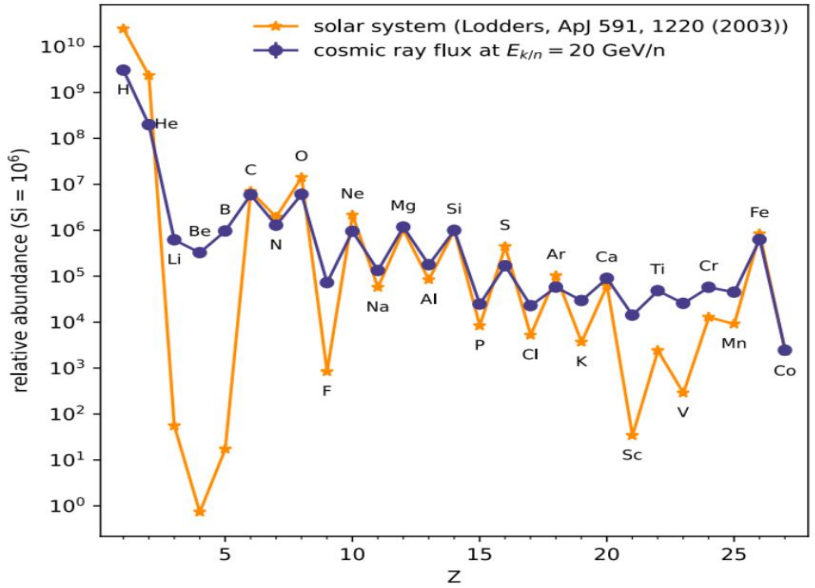


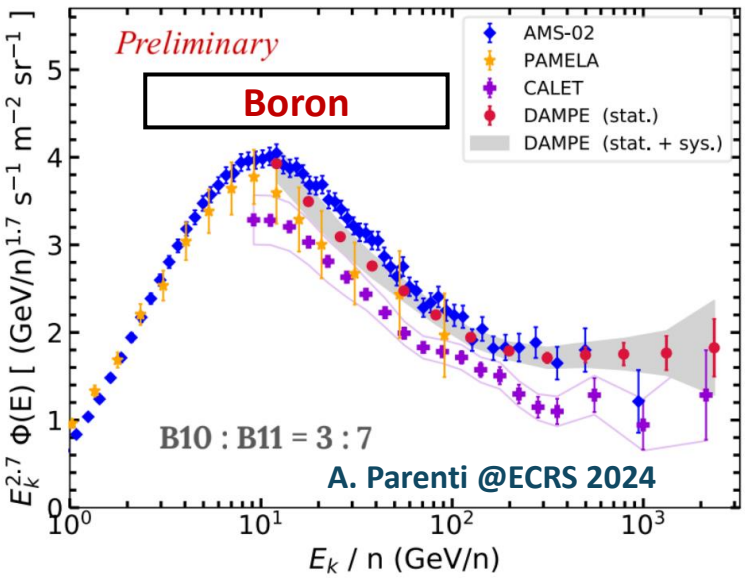


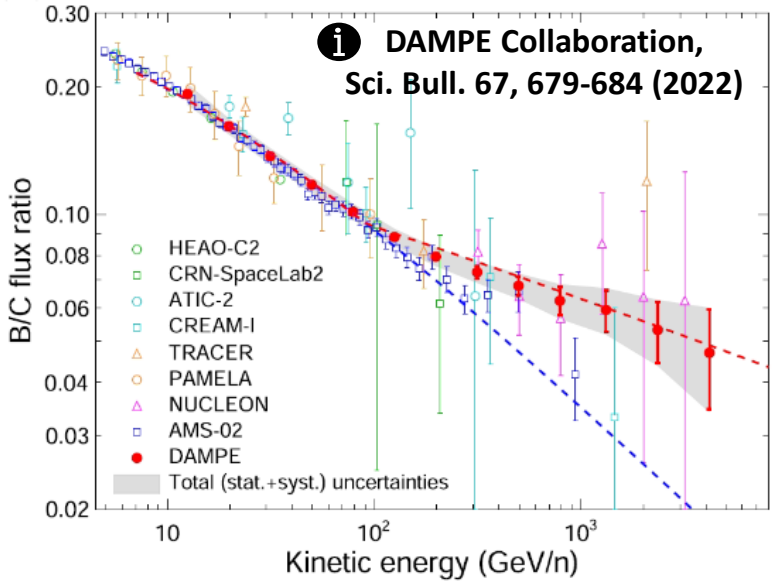


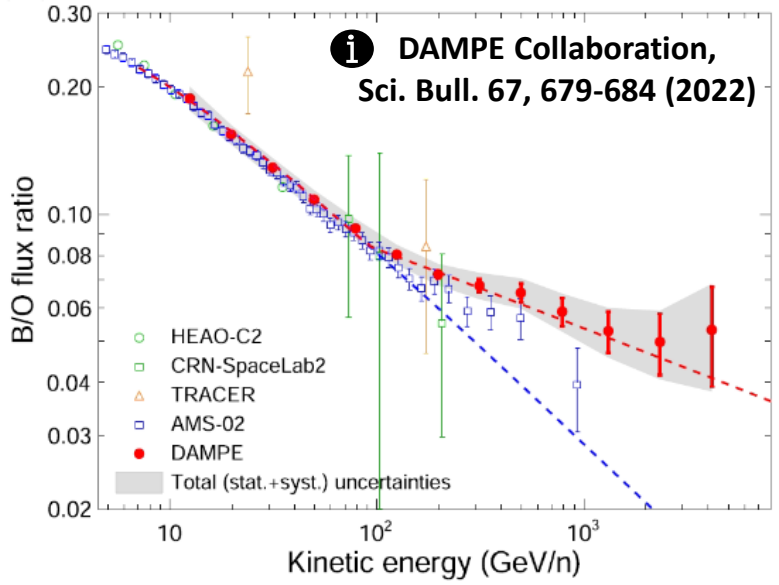
Results: flux ratios

- Secondary CRs (such as B) are produced by **spallation** with the Interstellar Medium (mainly from C and O).
- Measuring the secondary fluxes provides insight into CR propagation mechanisms.
- **Detection of hardening ~100 GeV/n in B flux and B/C and B/O flux ratios**.
- Propagation-related origin of this spectral feature.









Conclusions

- **DAMPE mission:**
  - Operating smoothly since December 2015, with excellent on-orbit performance and large acceptance.
  - Strong potential to extend measurements beyond 100 TeV for CR measurements.

- **Scientific results:**
  - Preliminary studies on 336 gamma-ray sources.
  - Upper limits for DM signatures (published results and ongoing analyses).
  - Evidence of softening in the p and He CR spectra around ~14 TV, suggesting Z-dependence.
  - p+He measurements confirm the softening and suggest a hardening above 100 TeV.
  - Ongoing measurements of heavier nuclei (C, O, Ne, Mg, Si, Fe) and light secondaries (Li, Be, B)
  - Observation of hardening around 100 GeV/n in B/C and B/O flux ratio.
  - Ongoing studies for Li/C, Be/C.
  - …
  - **Further analyses in progress**

Conclusions

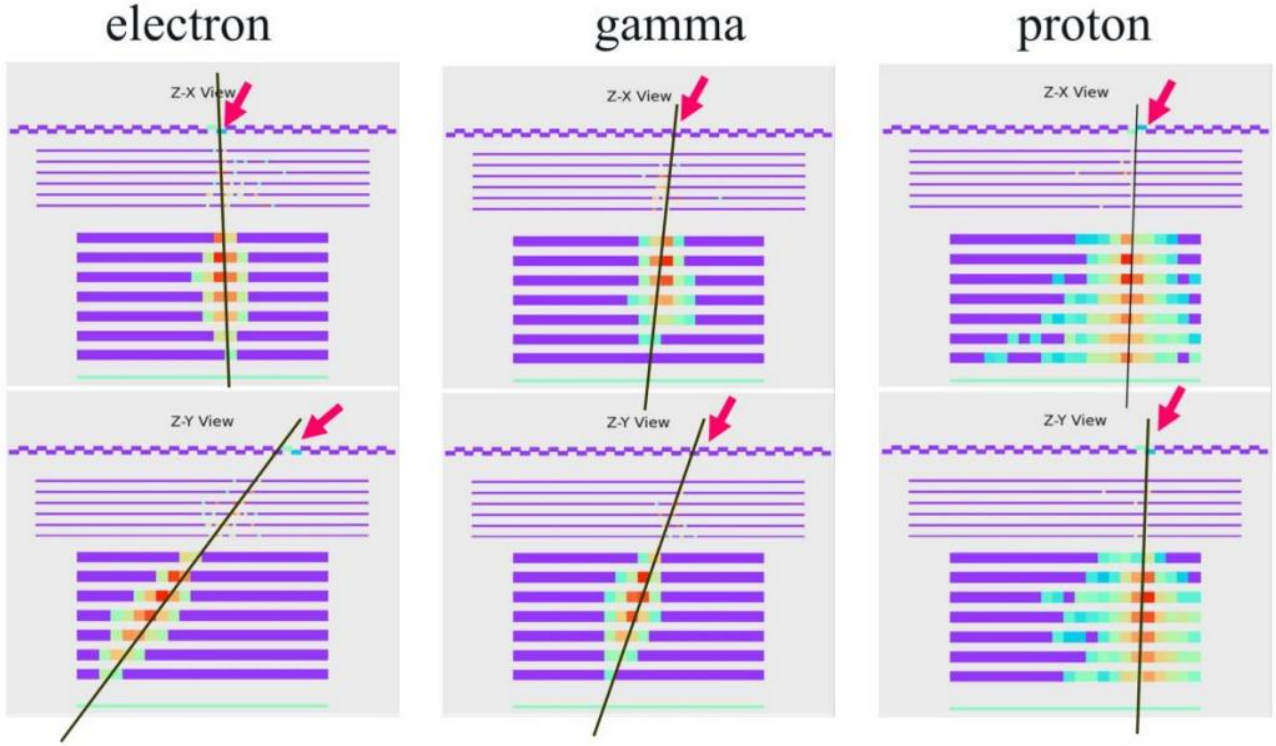
- **DAMPE mission:**
  - Operating smoothly since December 2015, with excellent on-orbit performance and large acceptance.
  - Strong potential to extend measurements beyond 100 TeV for CR measurements.

- **Scientific results:**
  - Preliminary studies on 336 gamma-ray sources.
  - Upper limits for DM signatures (published results and ongoing analyses).
  - Evidence of softening in the p and He CR spectra around ~14 TV, suggesting Z-dependence.
  - p+He measurements confirm the softening and suggest a hardening above 100 TeV.
  - Ongoing measurements of heavier nuclei (C, O, Ne, Mg, Si, Fe) and light secondaries (Li, Be, B)
  - Observation of hardening around 100 GeV/n in B/C and B/O flux ratio.
  - Ongoing studies for Li/C, Be/C.
  - …
  - **Further analyses in progress**

Thank you!

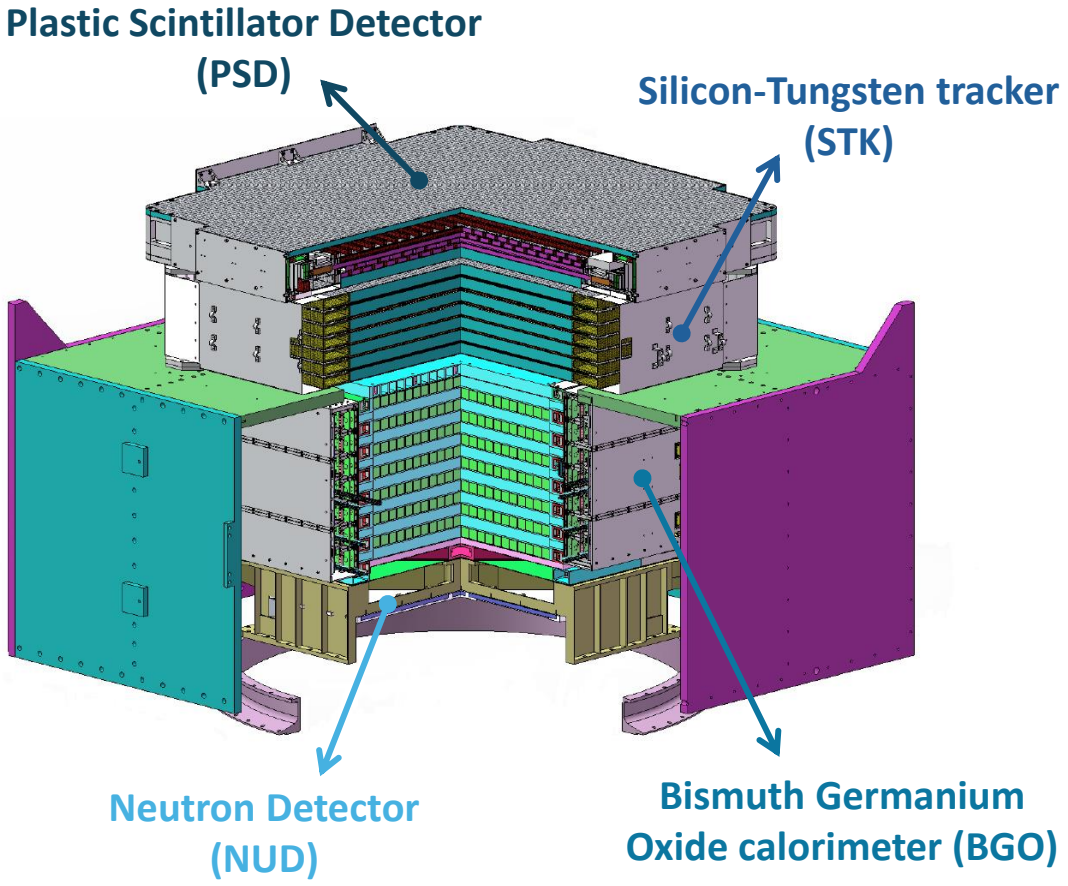

DAMPE
Backup

DAMPE detector

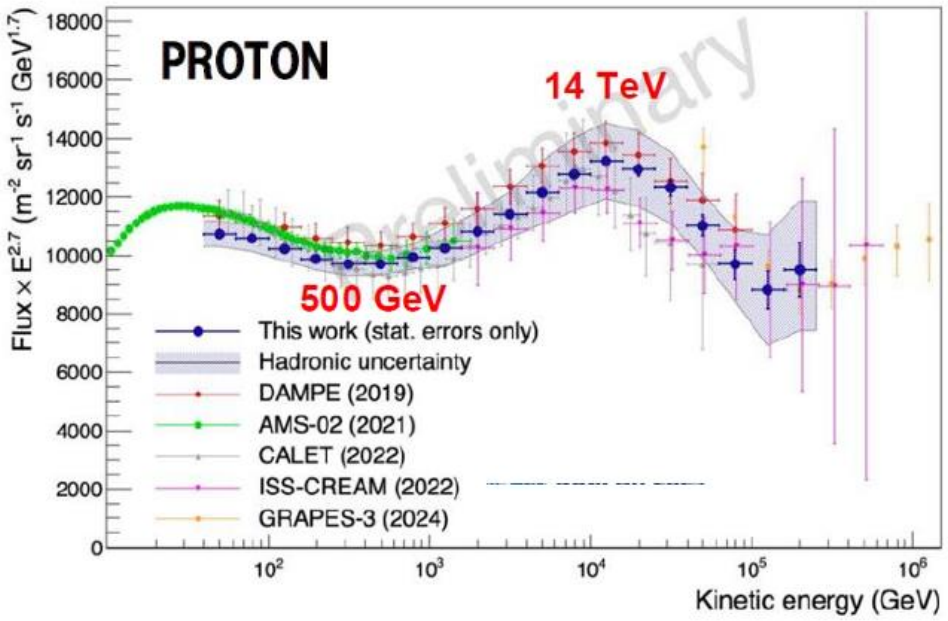


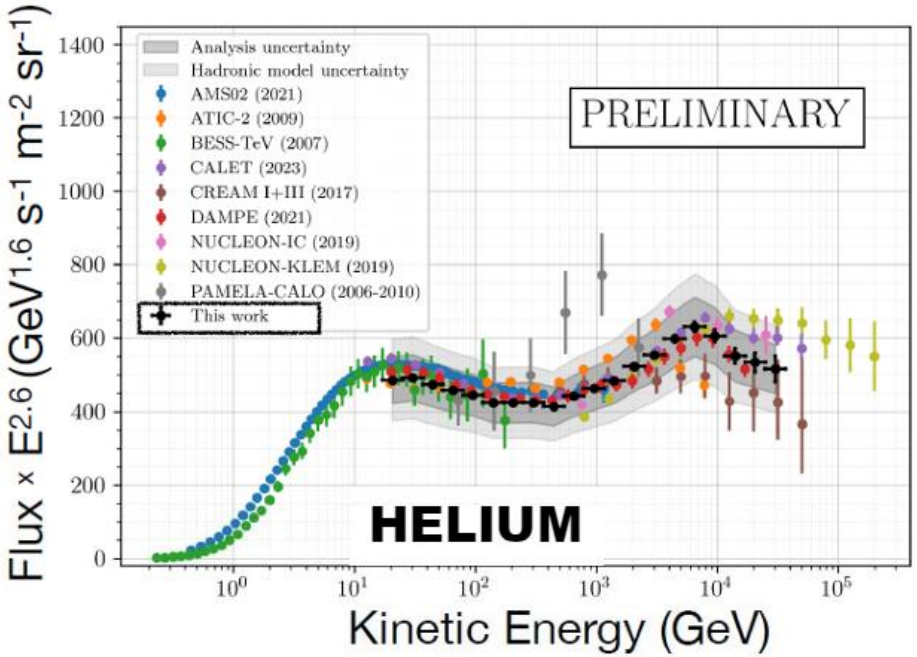
Parameter	Value
Energy resolution (e/γ)	1% @ 100 GeV
Energy resolution (p/nuclei)	30-40%
Geometric factor	0.3 m^2sr above 30 GeV
Field of view	1.0 sr

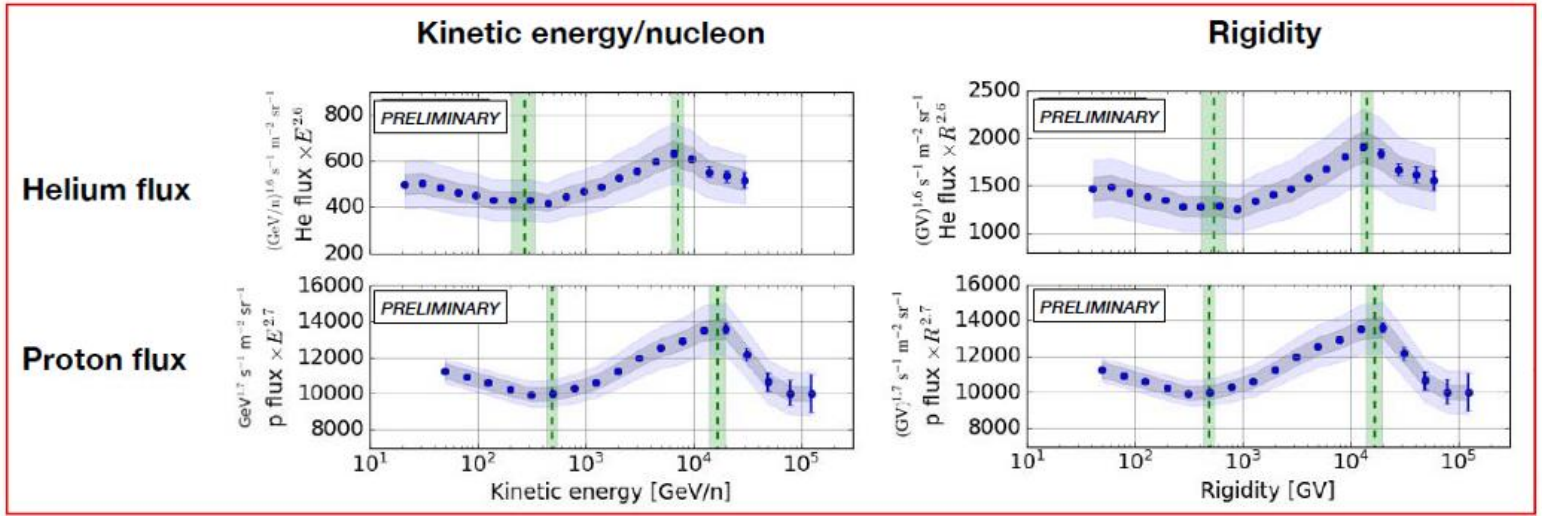
Astrop. Phys., 95 (2017) 6-24



Results: p and He (updates)





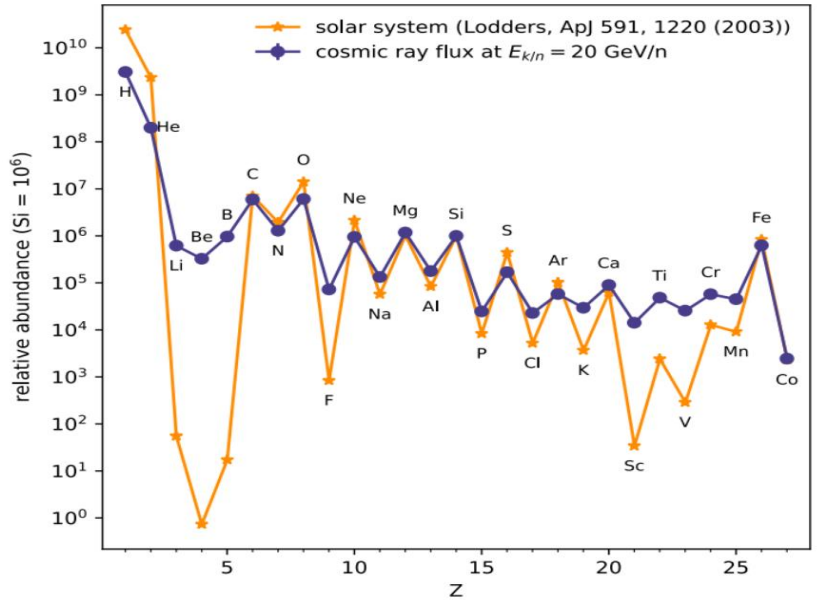


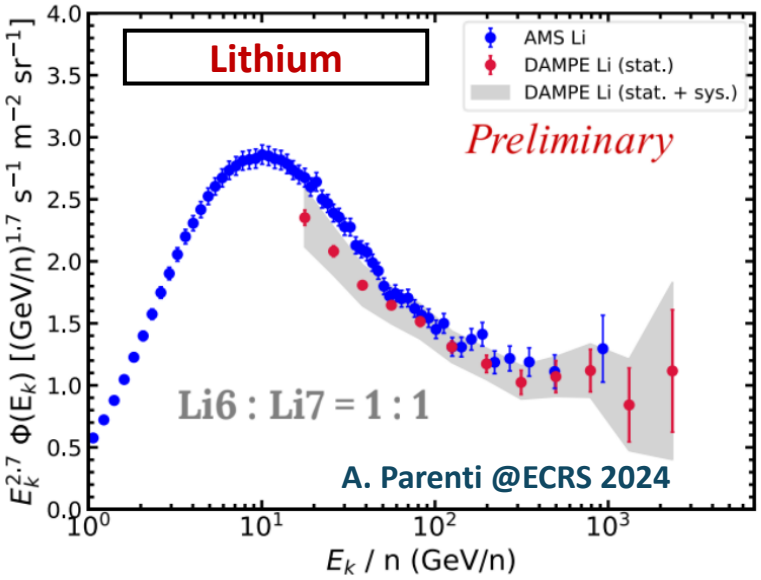
A rigidity dependence of both hardnening and softening is favoured by data

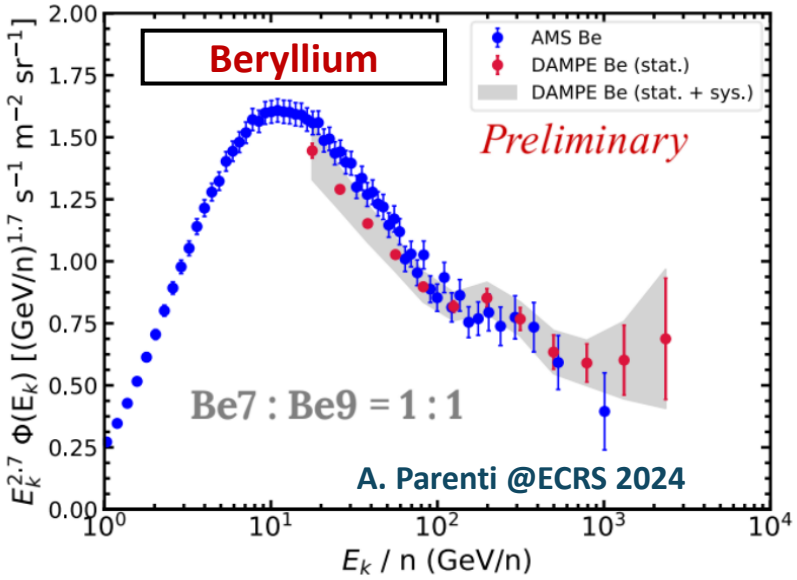
Results: Li, Be, B

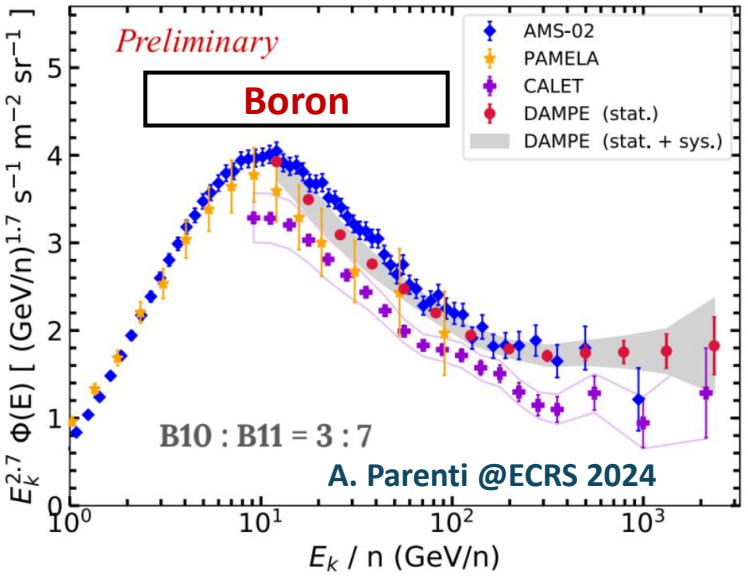
- Li, Be and B are produced by **CR spallation** with the Interstellar Medium (mainly from C and O)
- Measuring the secondary fluxes provides insight into CR propagation mechanisms.

- **Detection of hardening** ~100 GeV/n in B flux
- Strong hints of hardening in Li and Be fluxes

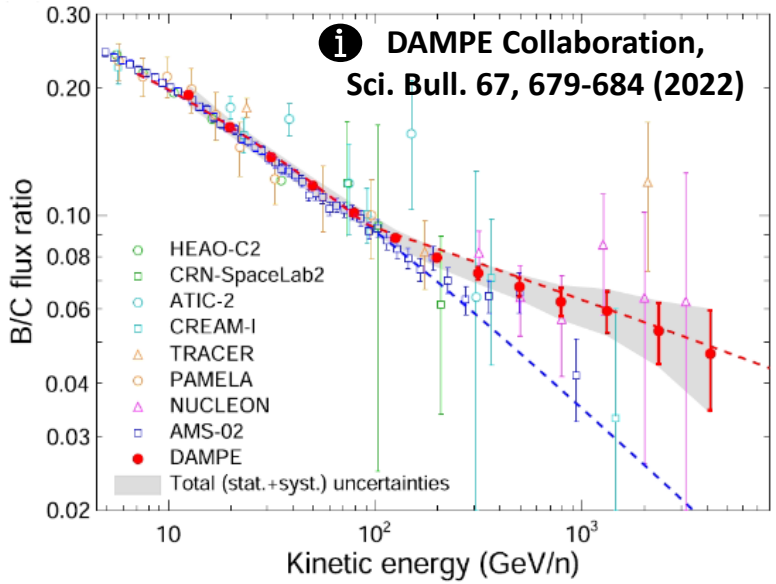


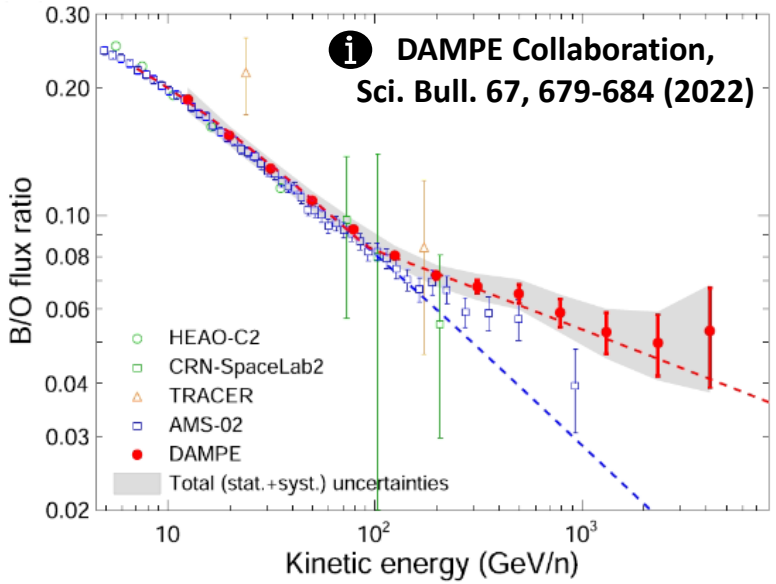


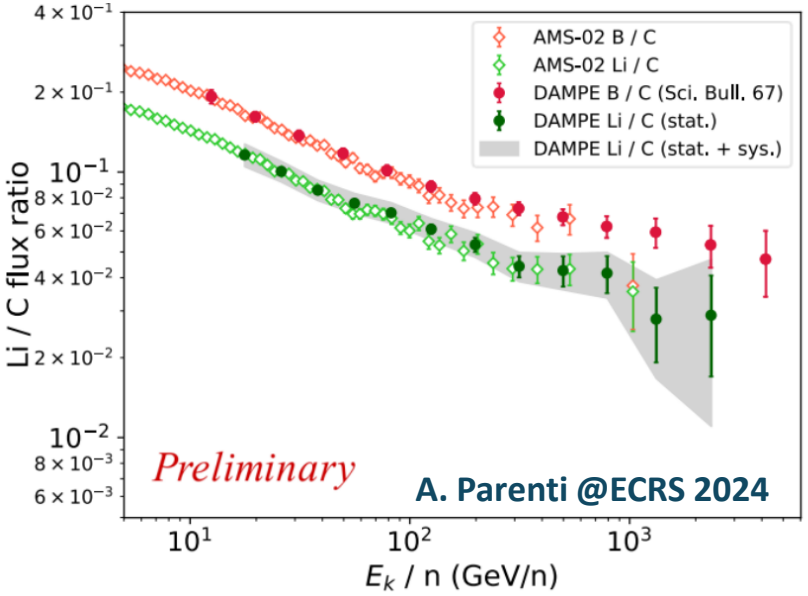


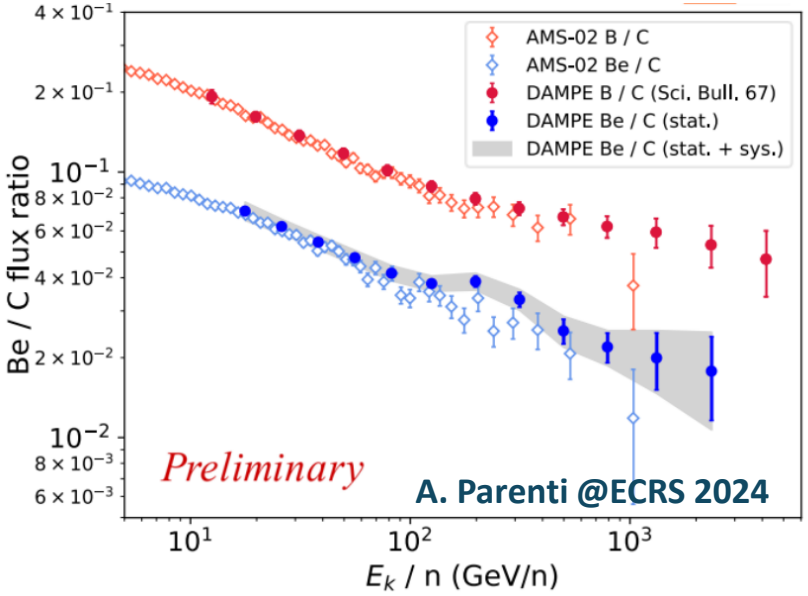


Results: flux ratios





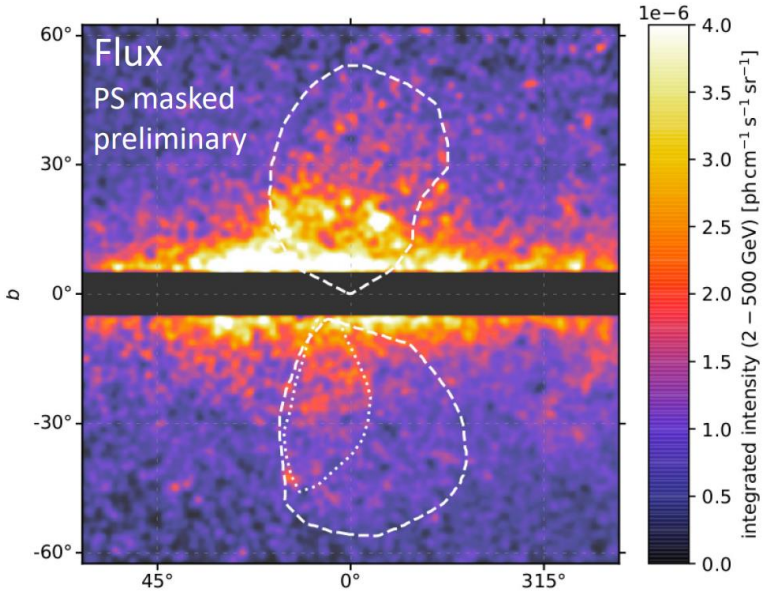


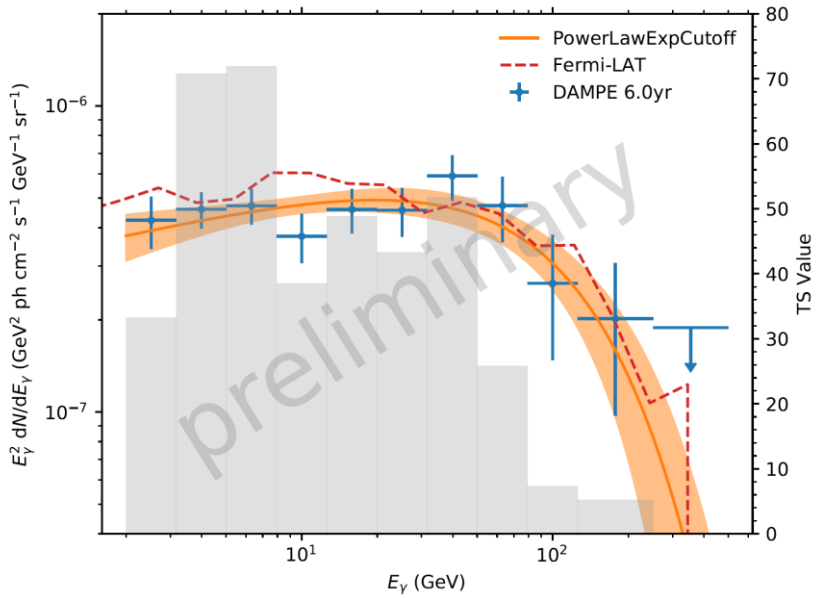


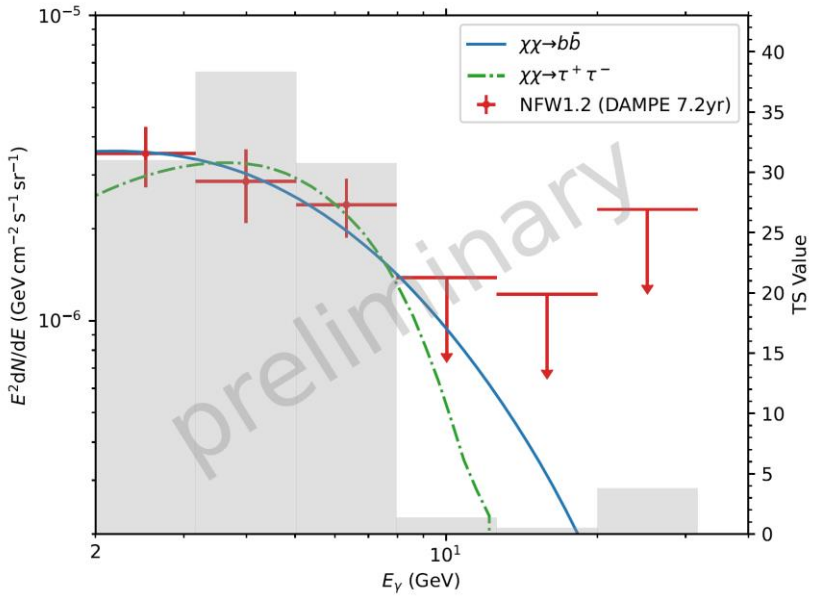
- Detection of **spectral hardening** at ~100 GeV/n in **B/C and B/O flux ratios**.
- **Hints of hardening** in Li/C and Be/C flux ratios at 100 GeV/n.
- Propagation-related origin of this spectral feature.

Results: Fermi Bubbles, Galactic Center

Fermi Bubbles (FB) – diffuse structures discovered by Fermi-LAT, associated with Galactic Center (DAMPE FB detection at ~17.8σ)



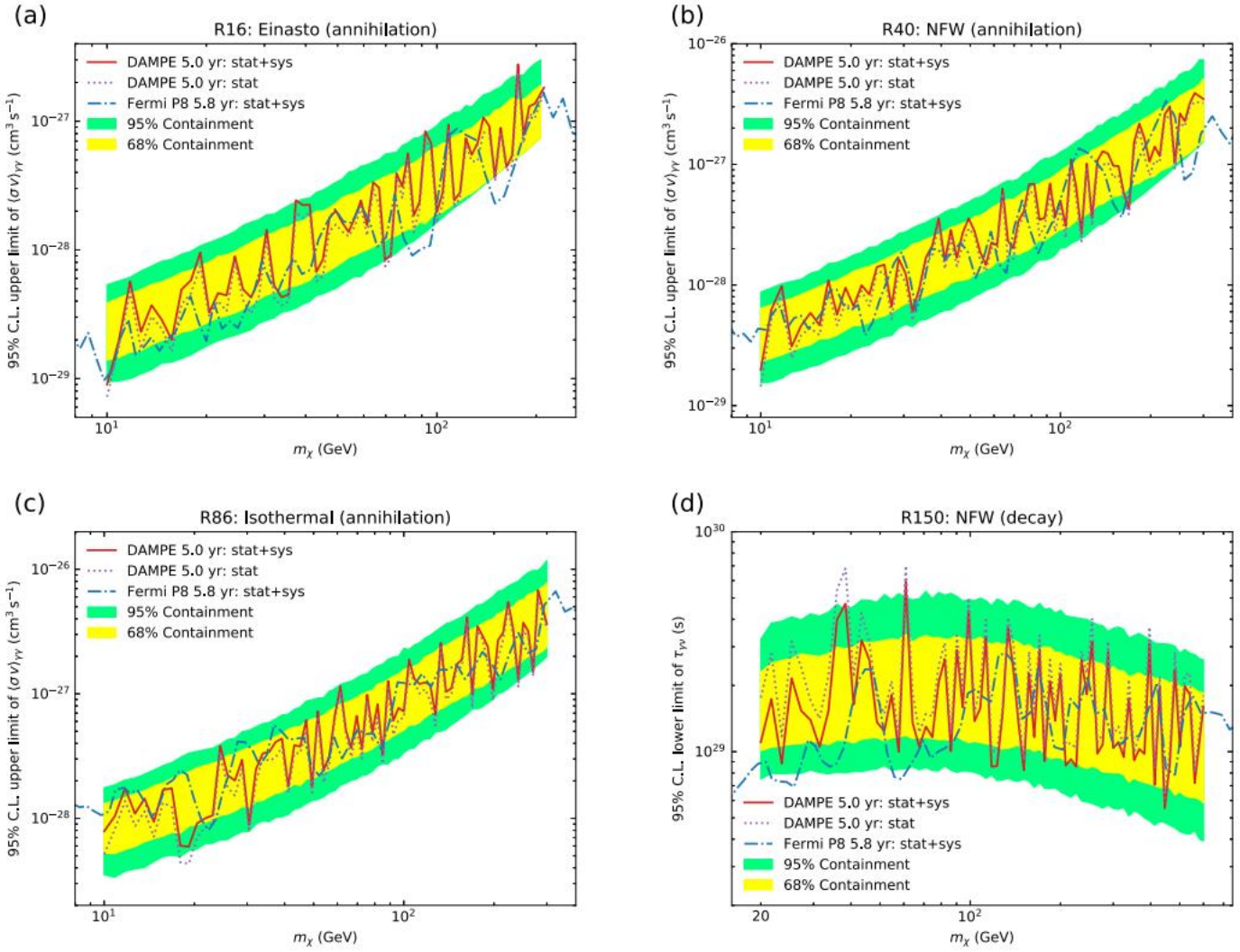




- FB: 6-year spectrum well consistent with FERMI, curved at 3.7σ, weak excess in the Cocoon (~3.3σ)
- Galactic Center Excess (GCE) detected at ~7.9σ, with 7.2 years of DAMPE data

Gamma-ray lines – TS

We increase (decrease) the cross section (lifetime) from its best-fit value until the log-likelihood changes by 1.35 to achieve the constraints.

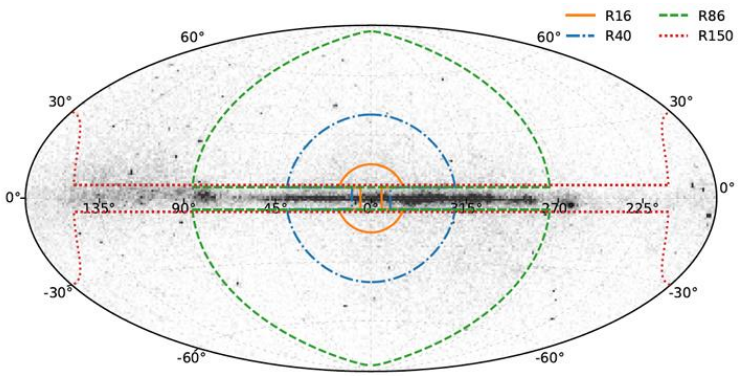


68% (95%) containment obtained from 1000 simulations of background emission

Systematic uncertainties:

- Uncertainties about the conversion from the signal counts to the fluxes ($\leq$ 6%)
- Uncertainties that could affect the expected signal counts ($\sim$ 9%)
- Uncertainties that could mask or produce line-like structures ($\leq$ 2%)

Results: Gamma-ray lines



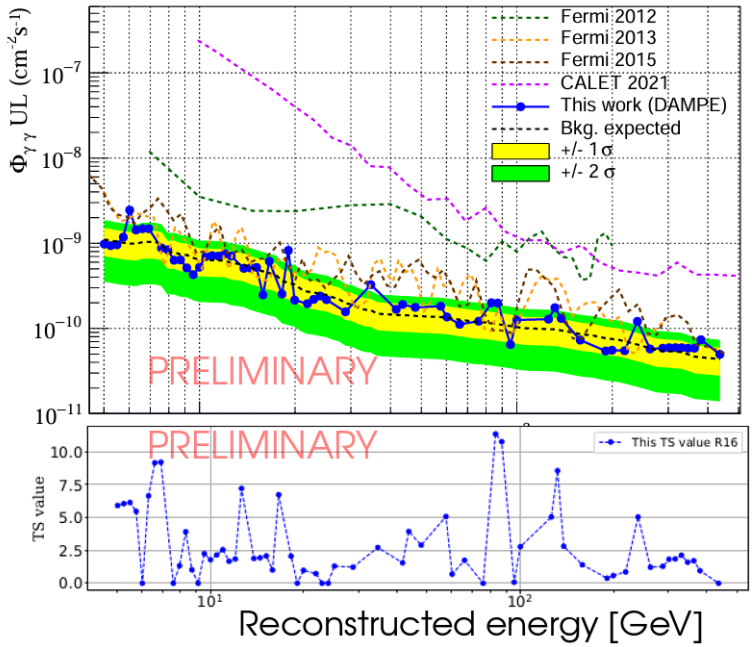
- Gamma-ray lines are considered the “smoking gun” signal for DM indirect detection.
- DAMPE’s excellent energy resolution (~1%) makes it ideal for gamma-ray line searching.

8 years of flight data

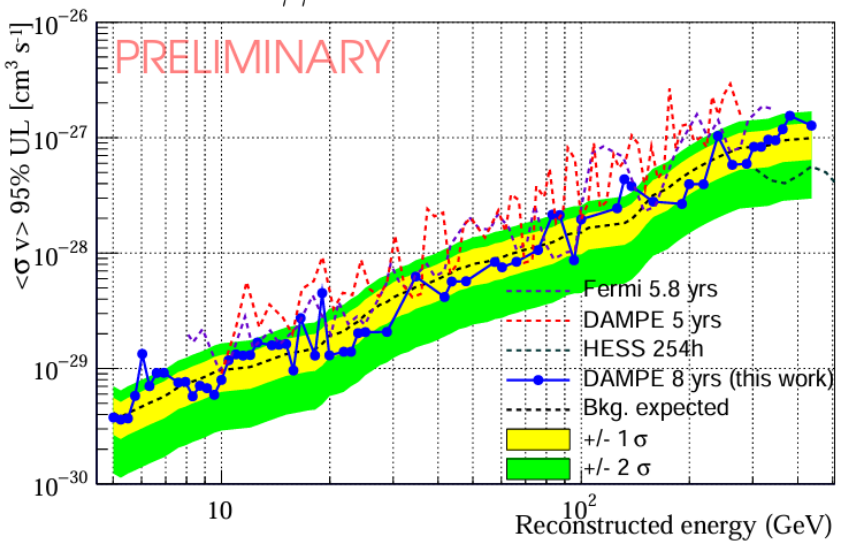
- **CNN developed for γ/p separation**
- **BDT developed for γ/e separation**

Stronger upper limits than those obtained before by Fermi-LAT and DAMPE in most of the energy range

DM annihilation flux UL R16



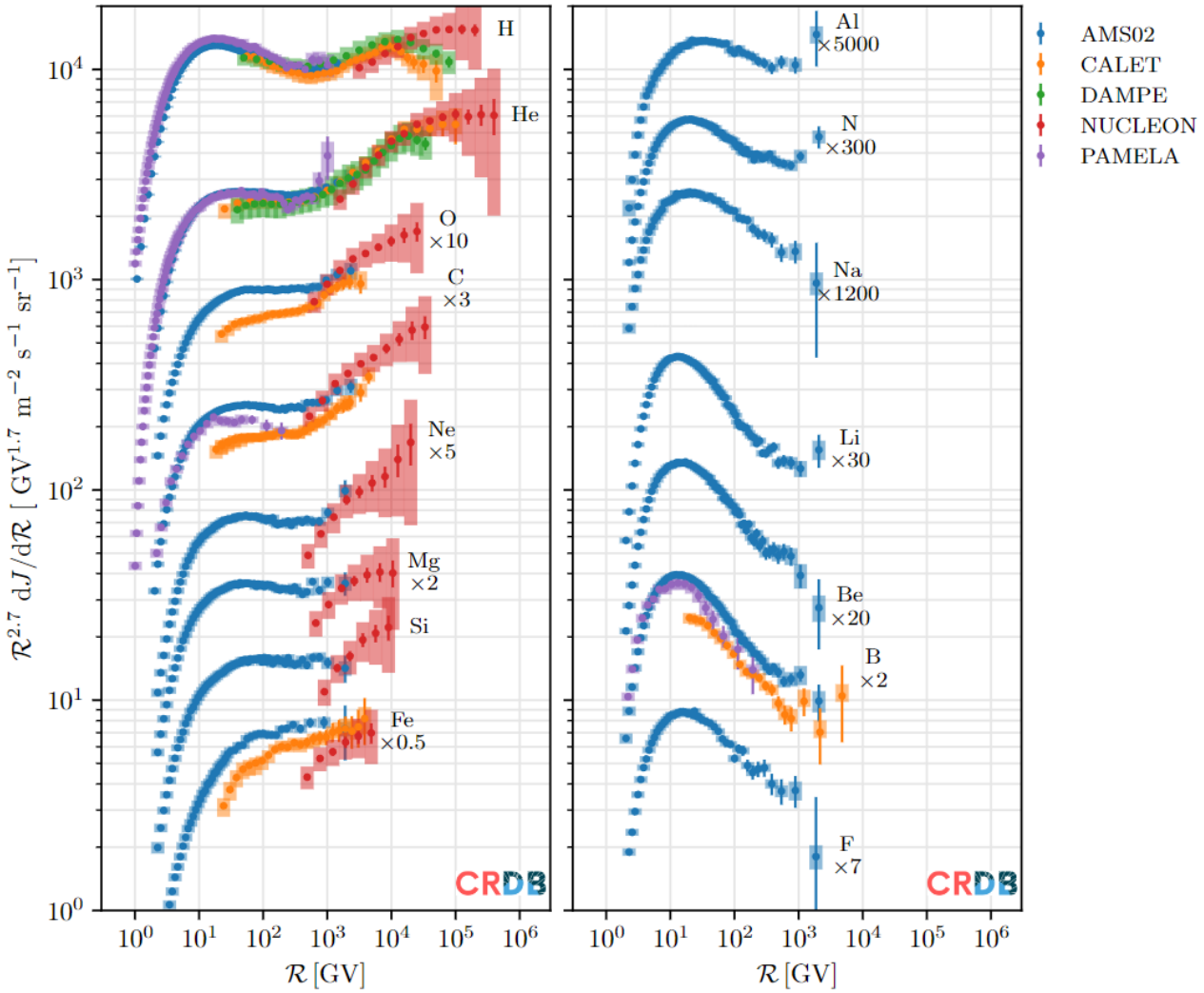
$\langle \sigma v \rangle_{\gamma\gamma}$ annihilation UL: R16



Presented by J. Frieden @RICAP 2024

Results

Cosmic-ray (CR) direct detection



- A **spectral hardening** is visible for all nuclei.
  - Hardening is stronger in secondary CRs, likely linked to **propagation / diffusion effect.**
- **Spectral softening** for p and He has been observed by different experiments
  - **Possible imprint of a nearby source?**
- **Z-dependence or A-dependence?**