Galactic Cosmic Ray spectral measurements with the DAMPE space mission

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on behalf of the DAMPE Collaboration

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Frascati, September 23-27, 2024

DAMPE science goals

High energy particle detection in space

- Study of the cosmic electron spectrum
- Study of cosmic ray protons and nuclei
- High energy gamma ray astronomy
- Search for dark matter signatures in e/γ spectra

Detection of

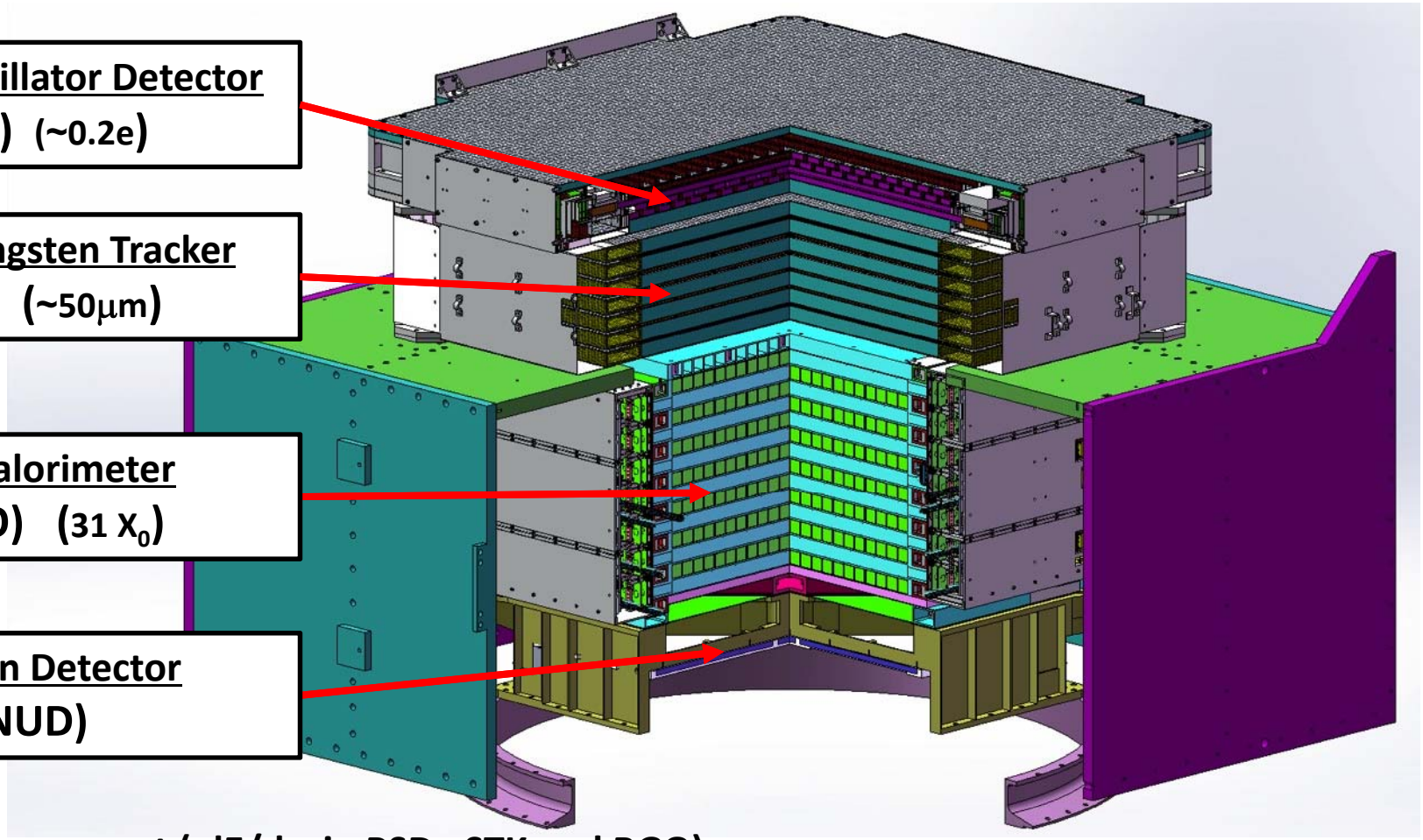
10 GeV - 10 TeV e/γ

50 GeV – 0.5 PeV protons and nuclei

with excellent (e.m.) energy resolution , tracking precision and particle identification capabilities

- Exotica and “unexpected” , e.g. GW e.m. counterpart in the FoV

The detector

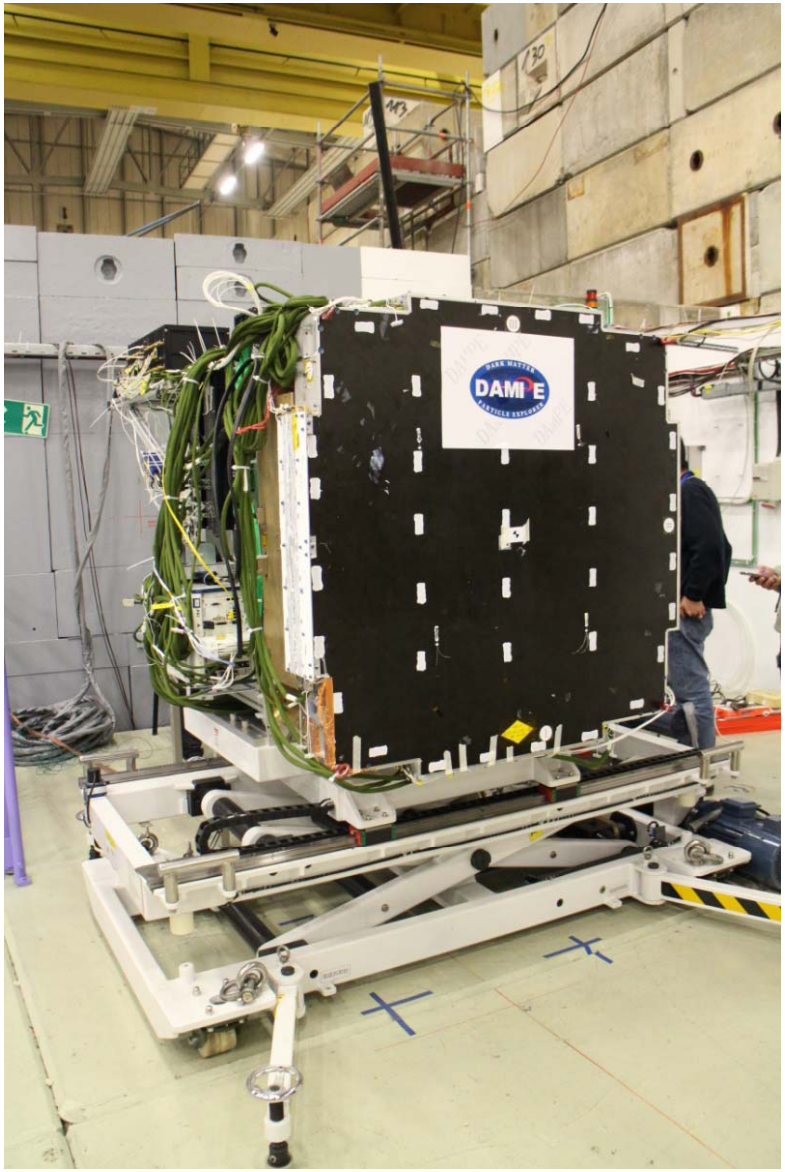


- **Charge measurement (dE/dx in PSD , STK and BGO)**
- **Tungsten converter (pair production)**
- **Precise tracking (silicon strips)**
- **Thick calorimeter (BGO bars)**
- **Hadron rejection (neutron detector)**

high energy
γ-ray, electron and cosmic ray
telescope

Test beam activity at CERN

- 14days@PS，29/10-11/11 2014
  - e @ 0.5GeV/c, 1GeV/c, 2GeV/c, 3GeV/c, 4GeV/c, 5GeV/c
  - p @ 3.5GeV/c, 4GeV/c, 5GeV/c, 6GeV/c, 8GeV/c, 10GeV/c
  - π-@ 3GeV/c, 10GeV/c
  - γ @ 0.5-3GeV/c
- 8days@SPS，12/11-19/11 2014
  - e @ 5GeV/c, 10GeV/c, 20GeV/c, 50GeV/c, 100GeV/c, 150GeV/c, 200GeV/c, 250GeV/c
  - p @ 400GeV/c (SPS primary beam)
  - γ @ 3-20GeV/c
  - μ @ 150GeV/c,
- 17days@SPS，16/3-1/4 2015
  - Fragments：66.67-88.89-166.67GeV/c
  - Argon：30A- 40A- 75AGeV/c
  - Proton：30GeV/c，40GeV/c
- 21days@SPS，10/6-1/7 2015
  - Primary Proton: 400GeV/c
  - Electrons @ 20, 100, 150 GeV/c
  - γ @ 50, 75 , 150 GeV/c
  - μ @ 150 GeV /c
  - π+ @10, 20, 50, 100 GeV/c
- 10days@SPS, 11/11-20/11 2015
  - -- Pb 30AGeV/c (and fragments) (HERD)
- 6days@SPS, 20/11-25/11 2015
  - -- Pb 030 AGeV/c (and fragments)

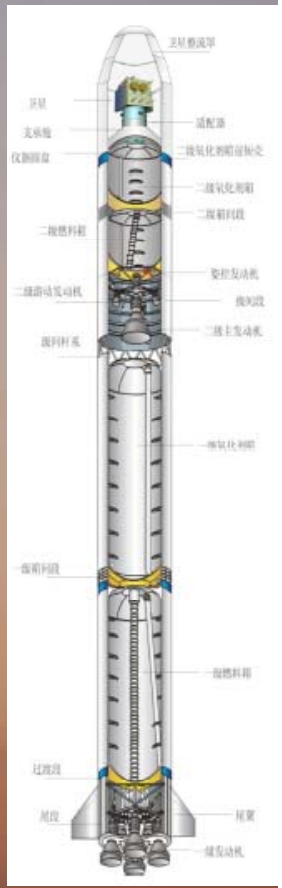


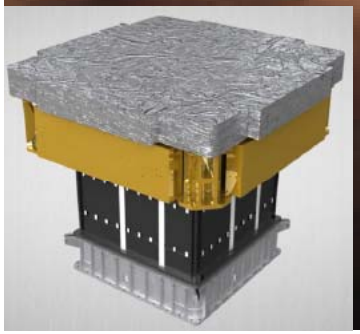
The launch: Dec 17th 2015, 0:12 UTC

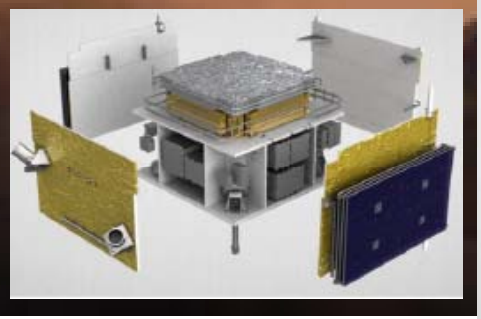
Jiuquan Satellite Launch Center
Gobi desert

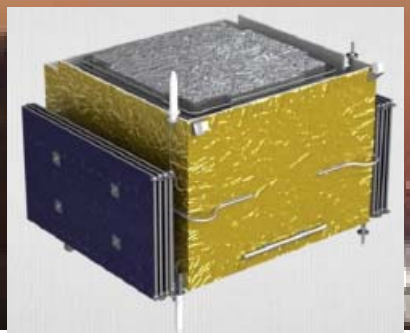
CZ-2D rocket

Mass: 1850 kg (scientific payload 1400 kg)
Power : 640 W (scientific payload 400 W)
Orbit: sun syncronous
Altitude: 500km
Inclination: 97.41°
Period: 95 minutes
Downlink: 16 GB / day
Lifetime: > 3 years



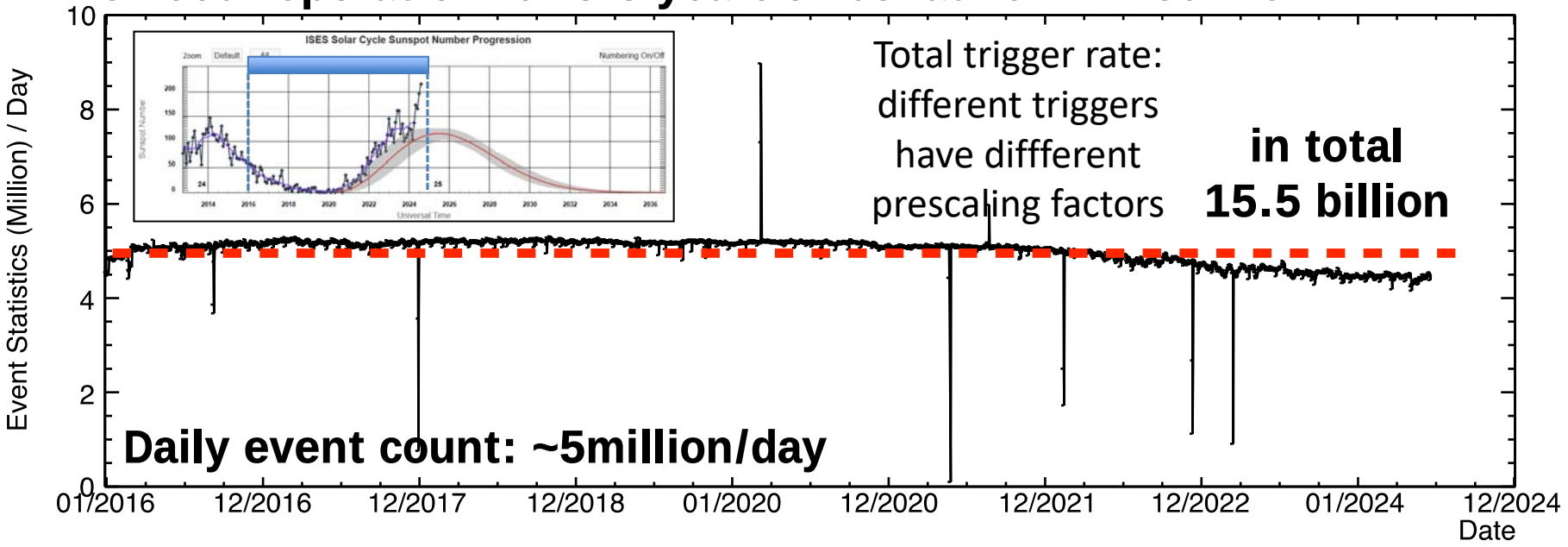




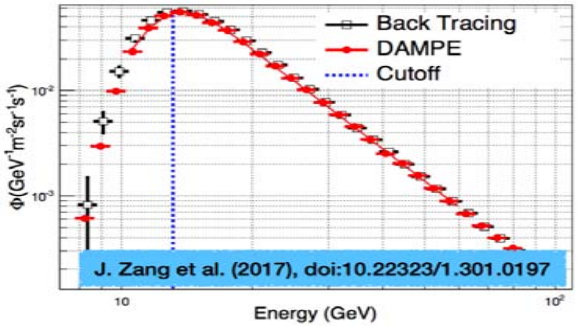


On orbit operation

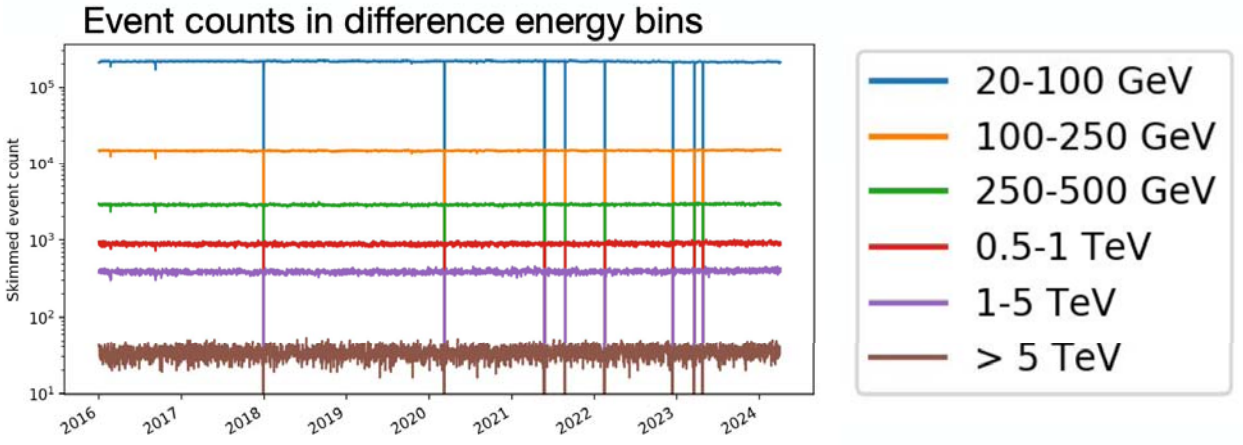
Smooth operation for 8.5 years since launch in Dec. 2017

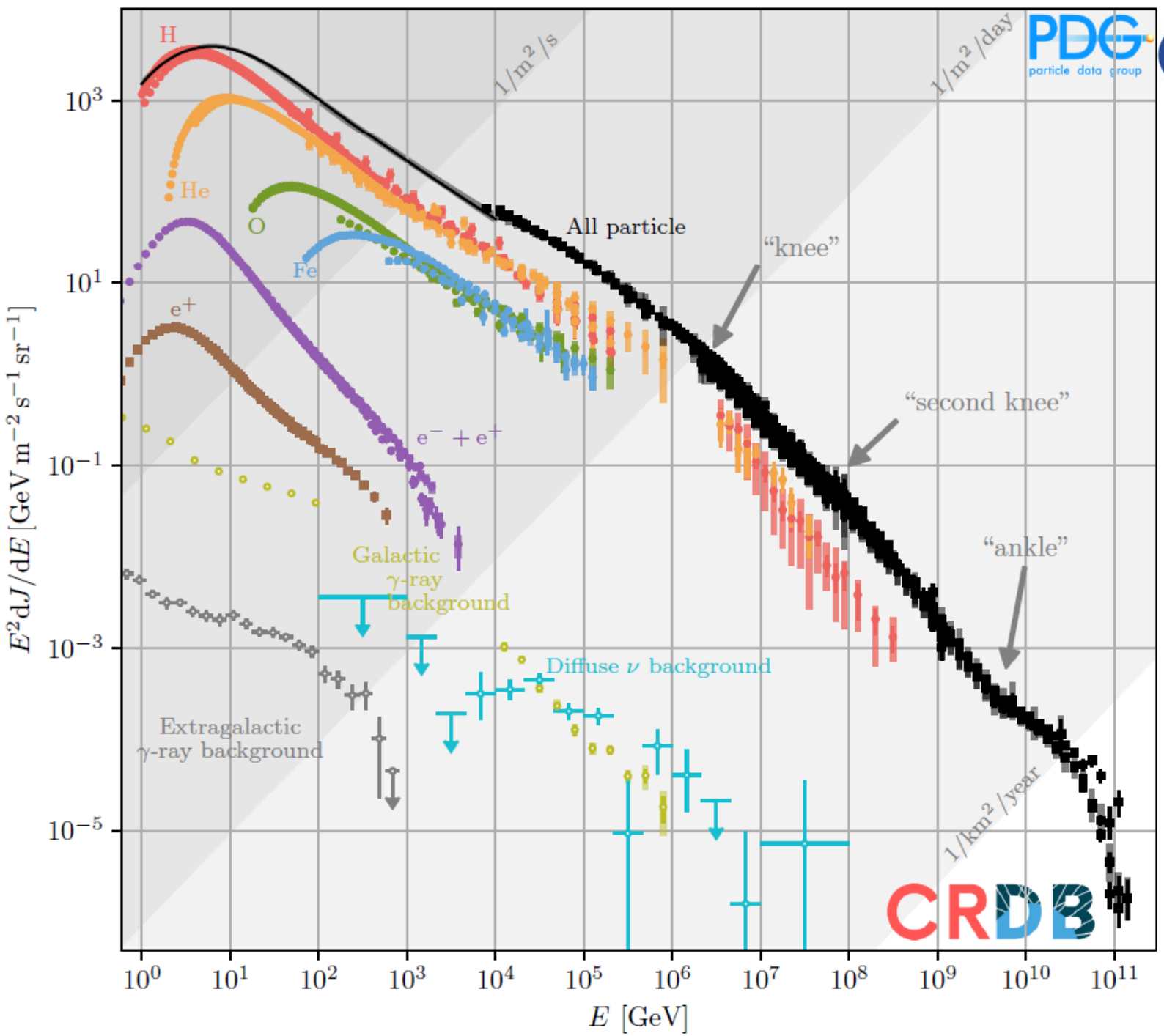


Energy scale calibration by using geomagnetic cutoff on electrons



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




H
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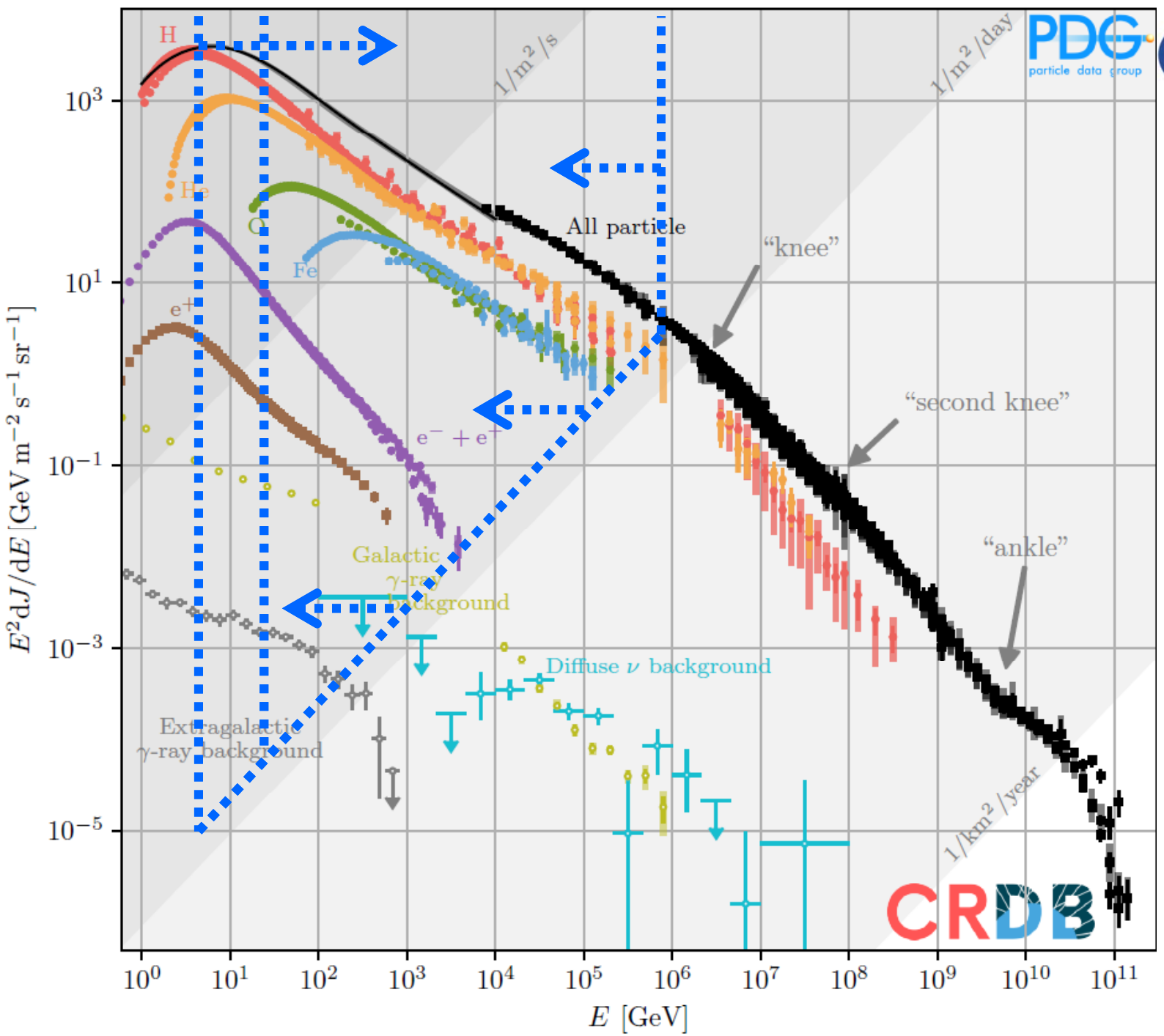
e+
e− + e+
All particle
"knee"
"second knee"
"ankle"
Galactic γ-ray background
Diffuse ν background
Extragalactic γ-ray background
1/m² /s
1/m² /day
1/km² /year
PDG particle data group
DARK MATTER DAMPE PARTICLE EXPLORER
CRDB
$E^2 dJ/dE$ [GeV m^{-2} s^{-1} sr^{-1}]
E [GeV]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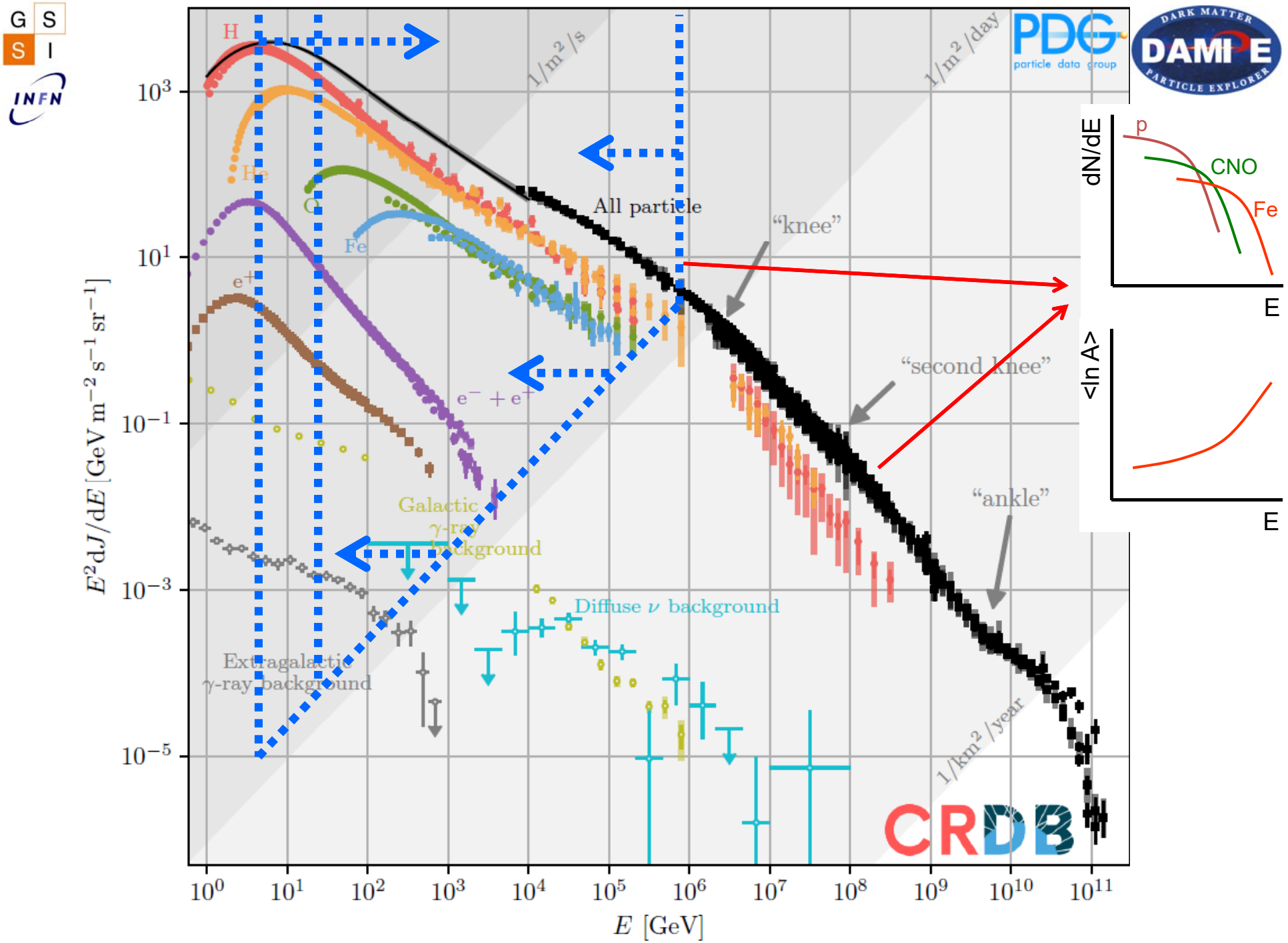
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E [GeV]
PDG particle data group
DAMPE DARK MATTER PARTICLE EXPLORER
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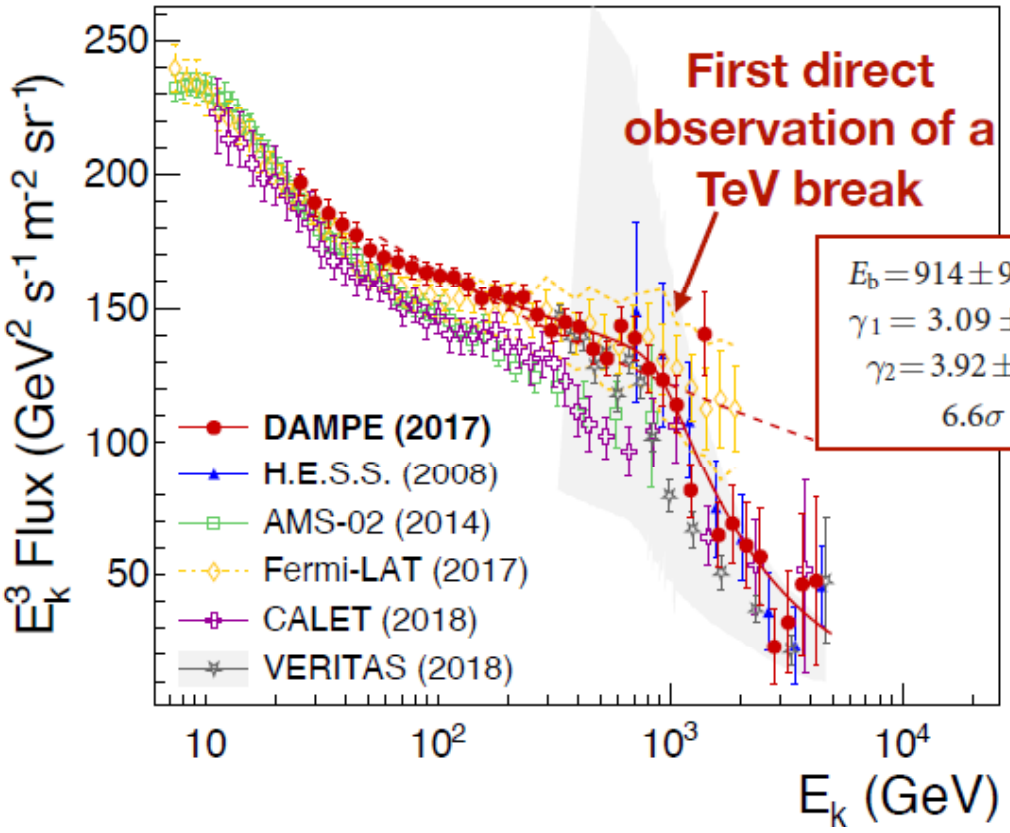
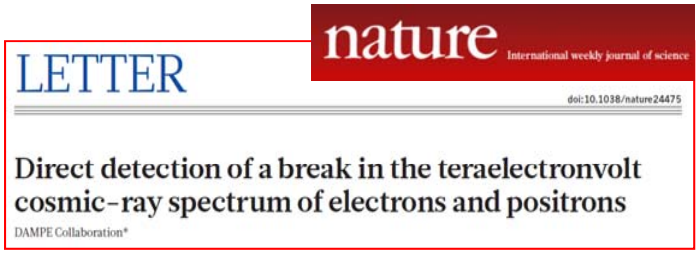
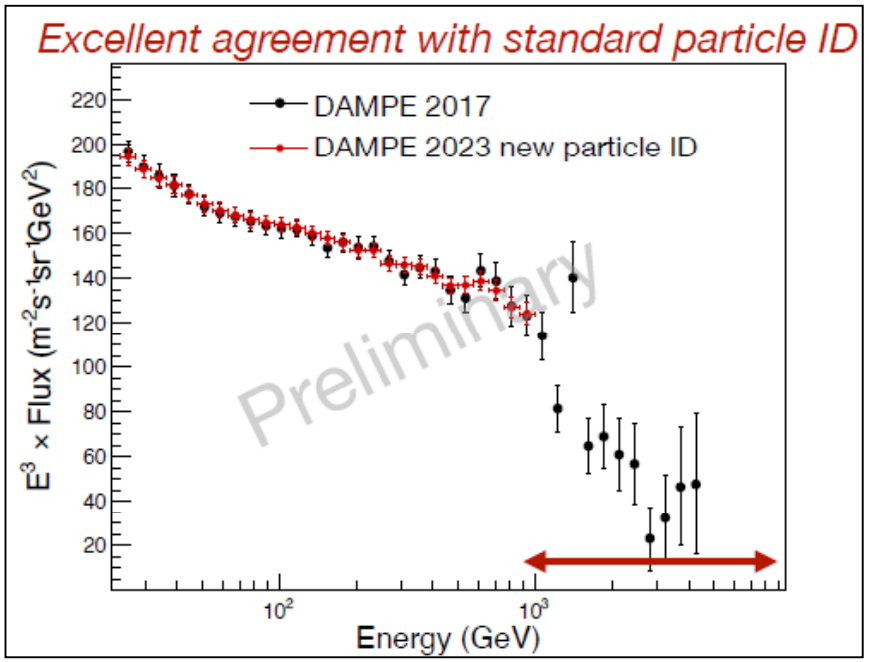
The DAMPE (e^++e^-) spectrum



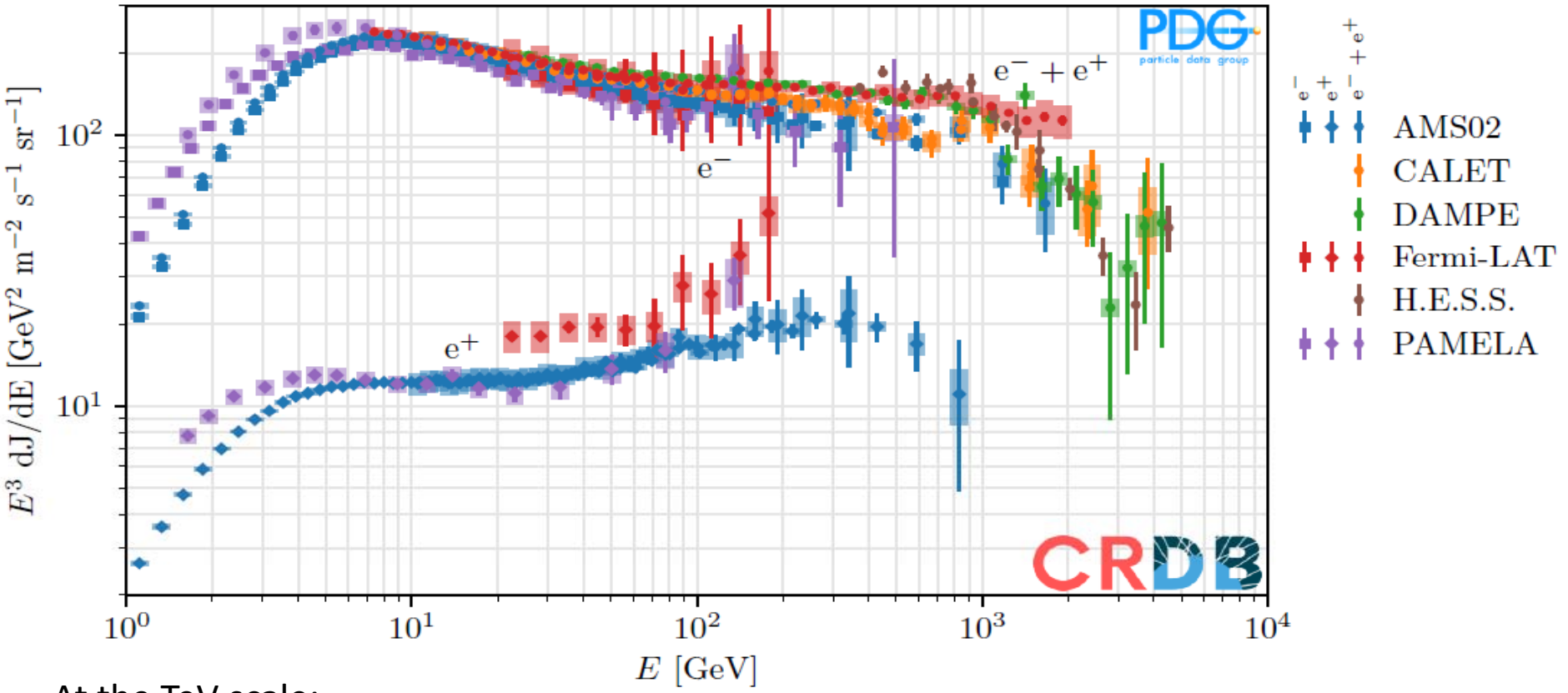


- **530 days**
- **2.8 billions CR events**
- **1.5 million CREs above 25 GeV**

New analyses (NN, NL, ..) ongoing



“electron” spectra



At the TeV scale:

- diffusion-loss length is approx 300pc
- confinement time is approx 100 kyr

→ The spectra at high energies are dominated by **close and young cosmic ray sources**

→ Bumps might appear in the spectra above few TeV due to local sources

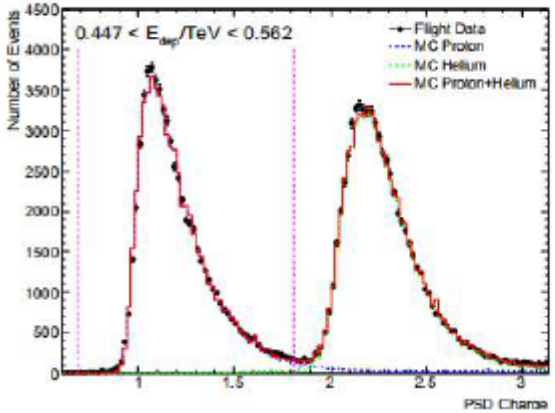
→ Possible anisotropies

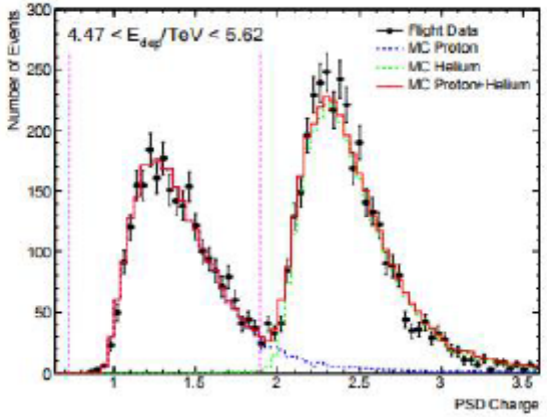
The DAMPE proton spectrum

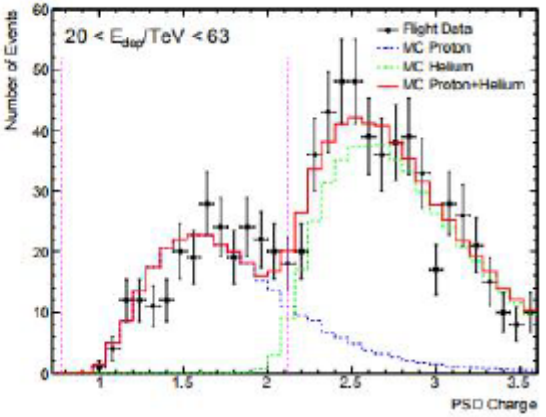
SCIENCE ADVANCES | RESEARCH ARTICLE

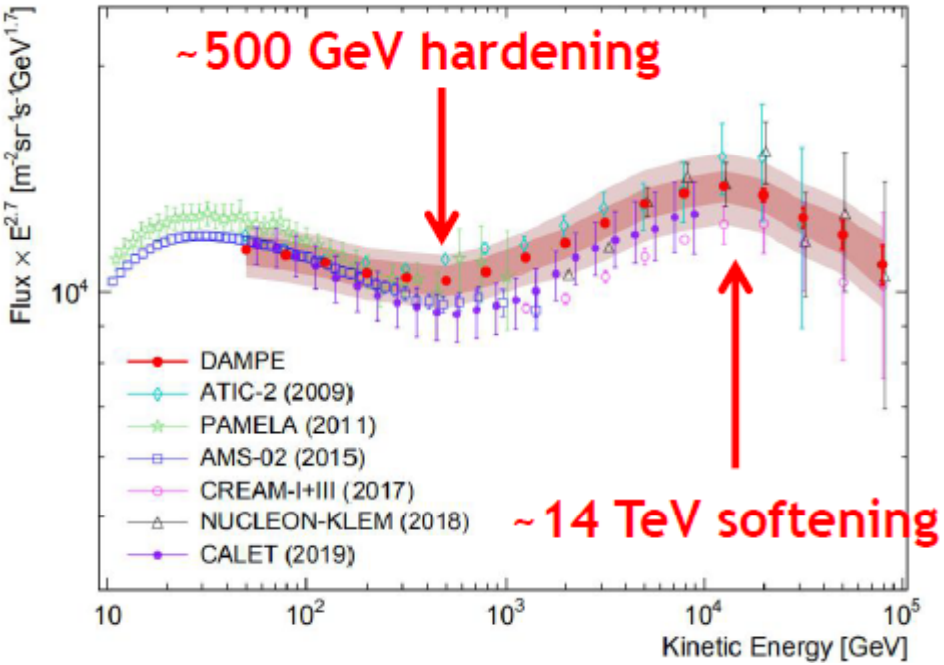
PHYSICS

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









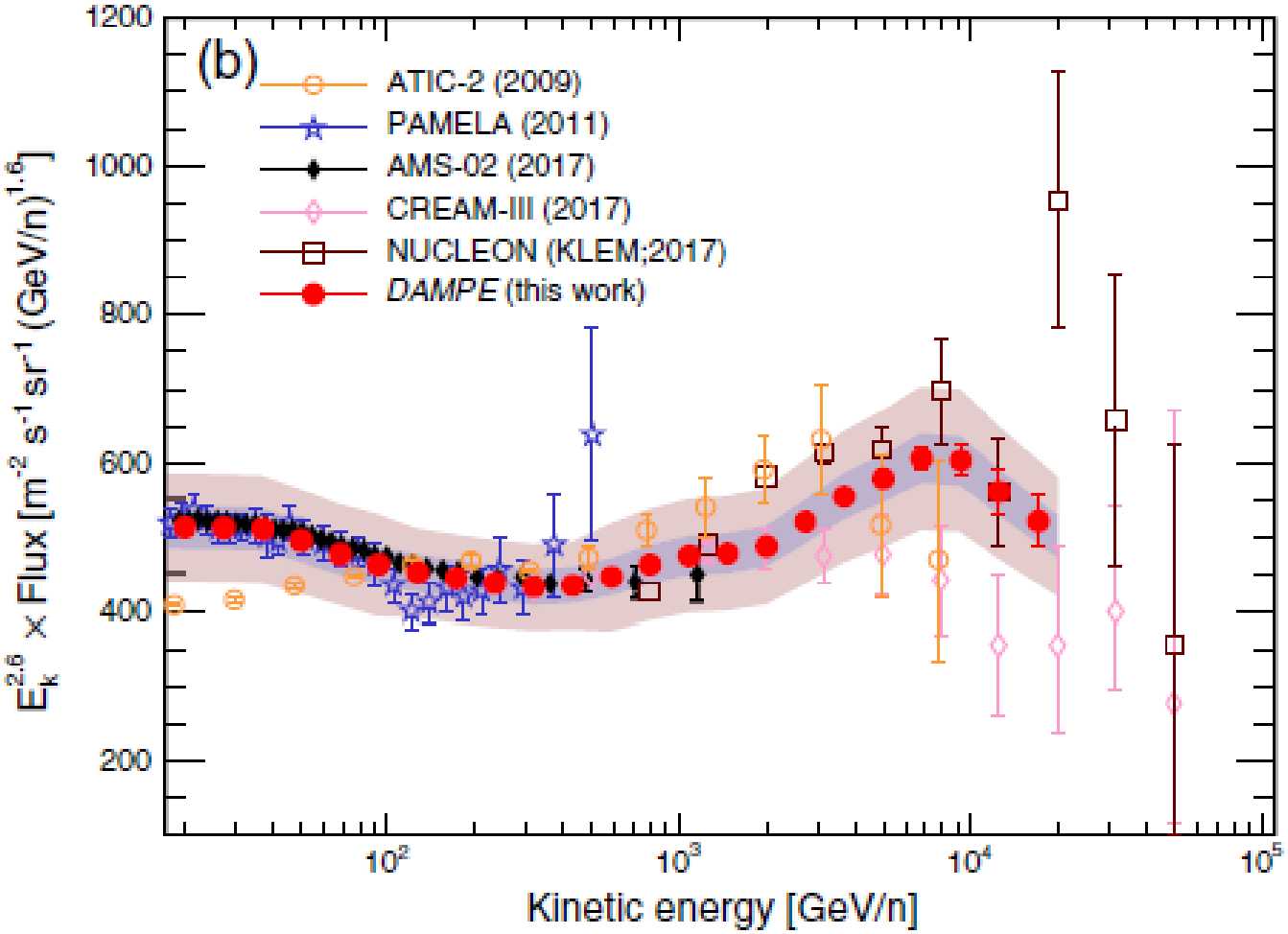
- Confirms the hundreds of GeV hardening
- Detecting a softening at ~14 TeV with high significance

The DAMPE helium spectrum

PHYSICAL REVIEW LETTERS **126,** 201102 (2021)

Editors' Suggestion | Featured in Physics

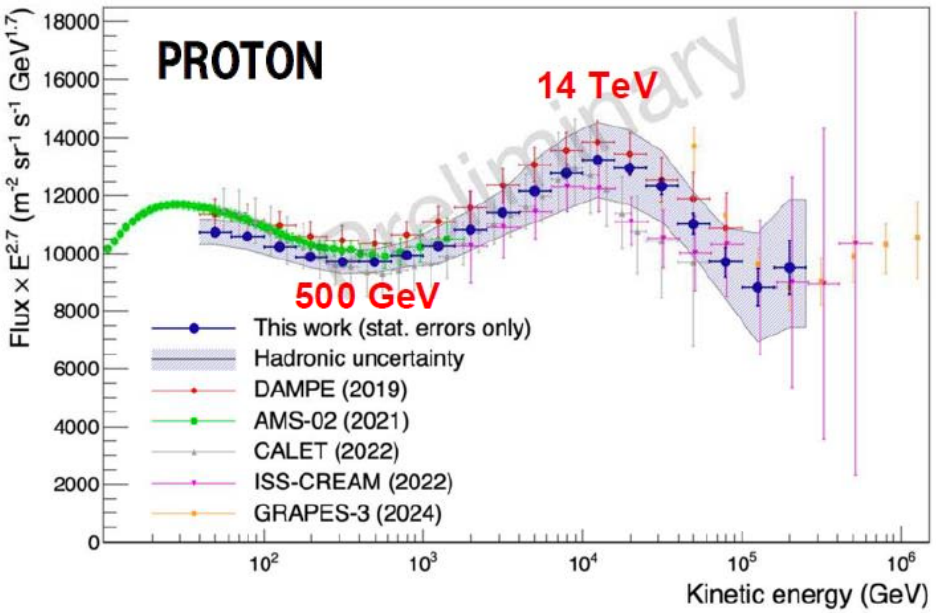
Measurement of the Cosmic Ray Helium Energy Spectrum from 70 GeV to 80 TeV with the DAMPE Space Mission

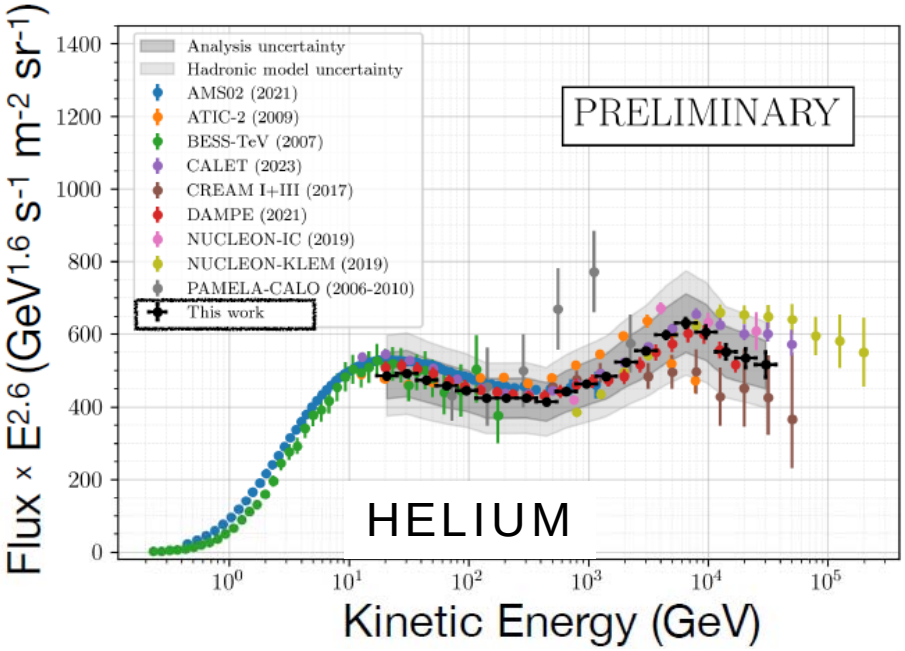


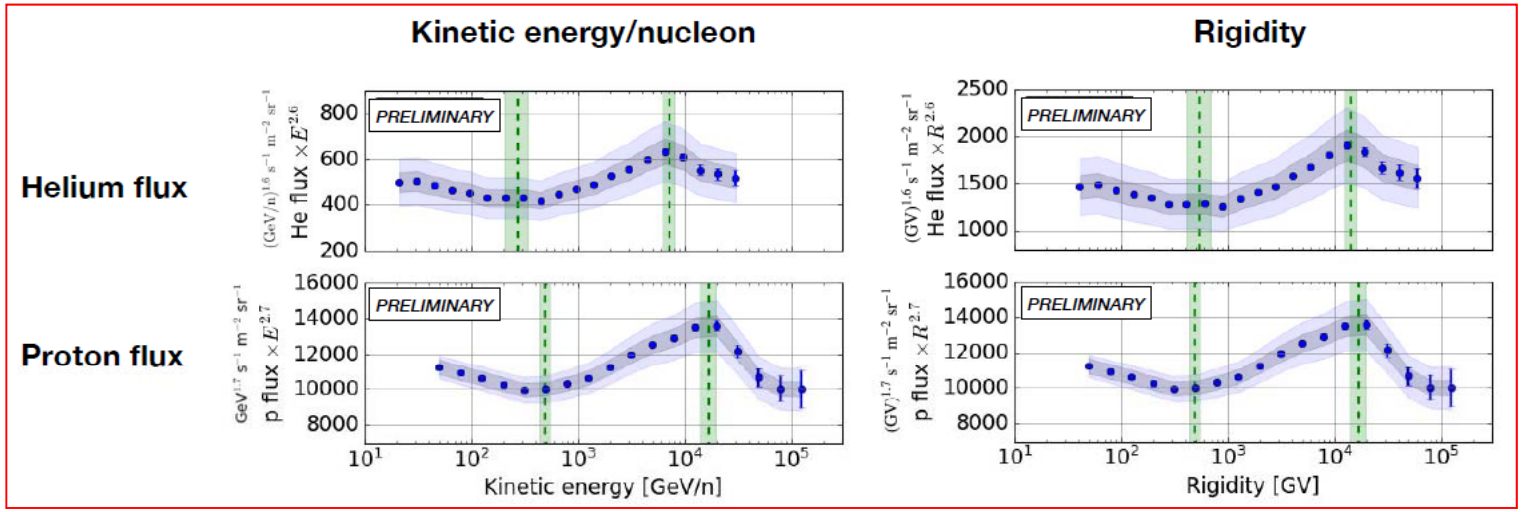
First clear evidence for a softening at about 34 TeV

Suggesting a Z dependent softening energy (~ 14 TeV for protons)

p and He spectra: updates

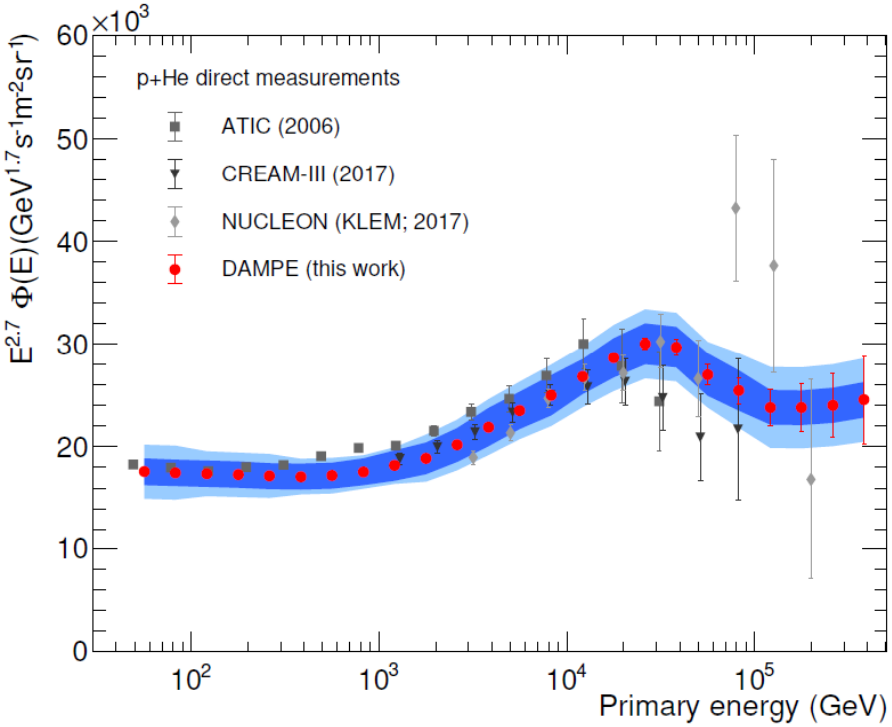


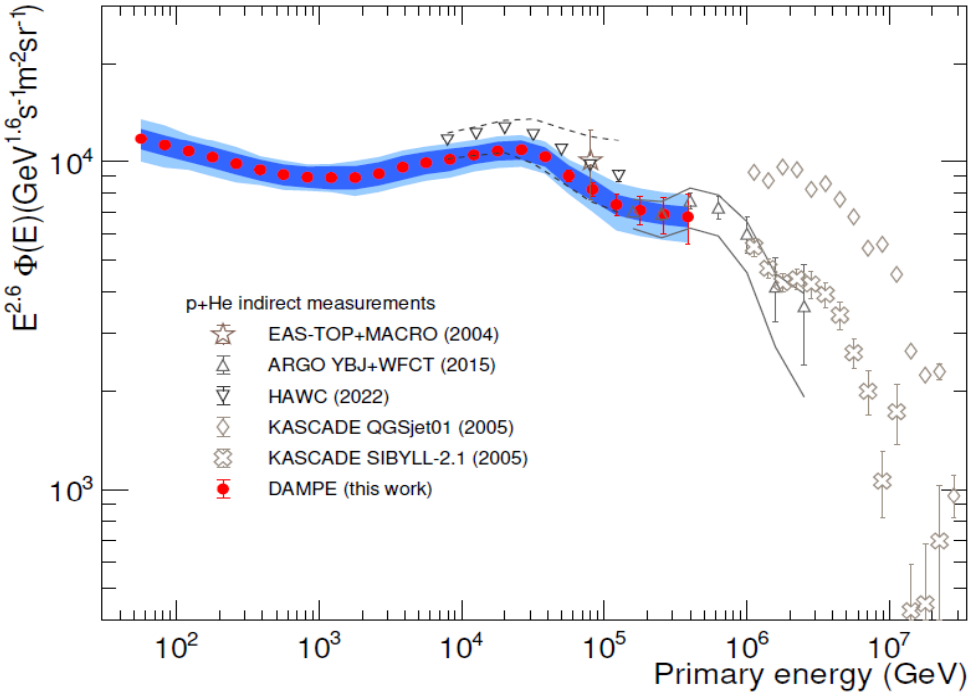




A rigidity dependence of both hardnening and softening is favoured by data

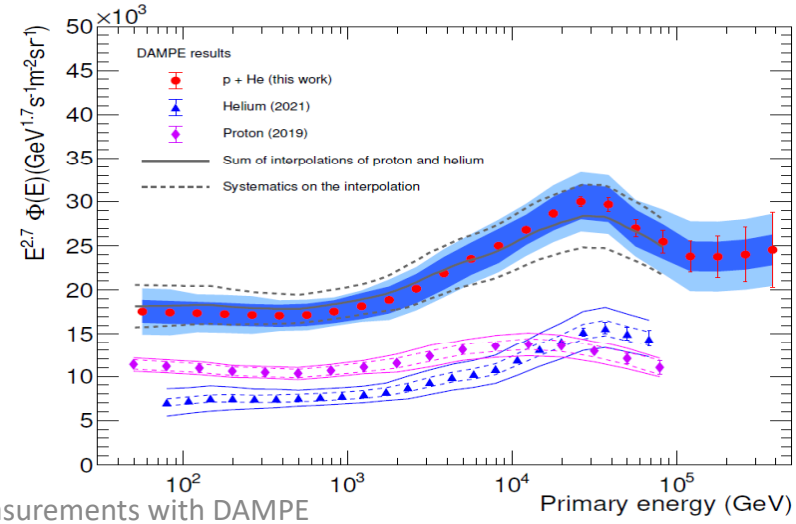
The p+He spectrum (up to 0.5 PeV)

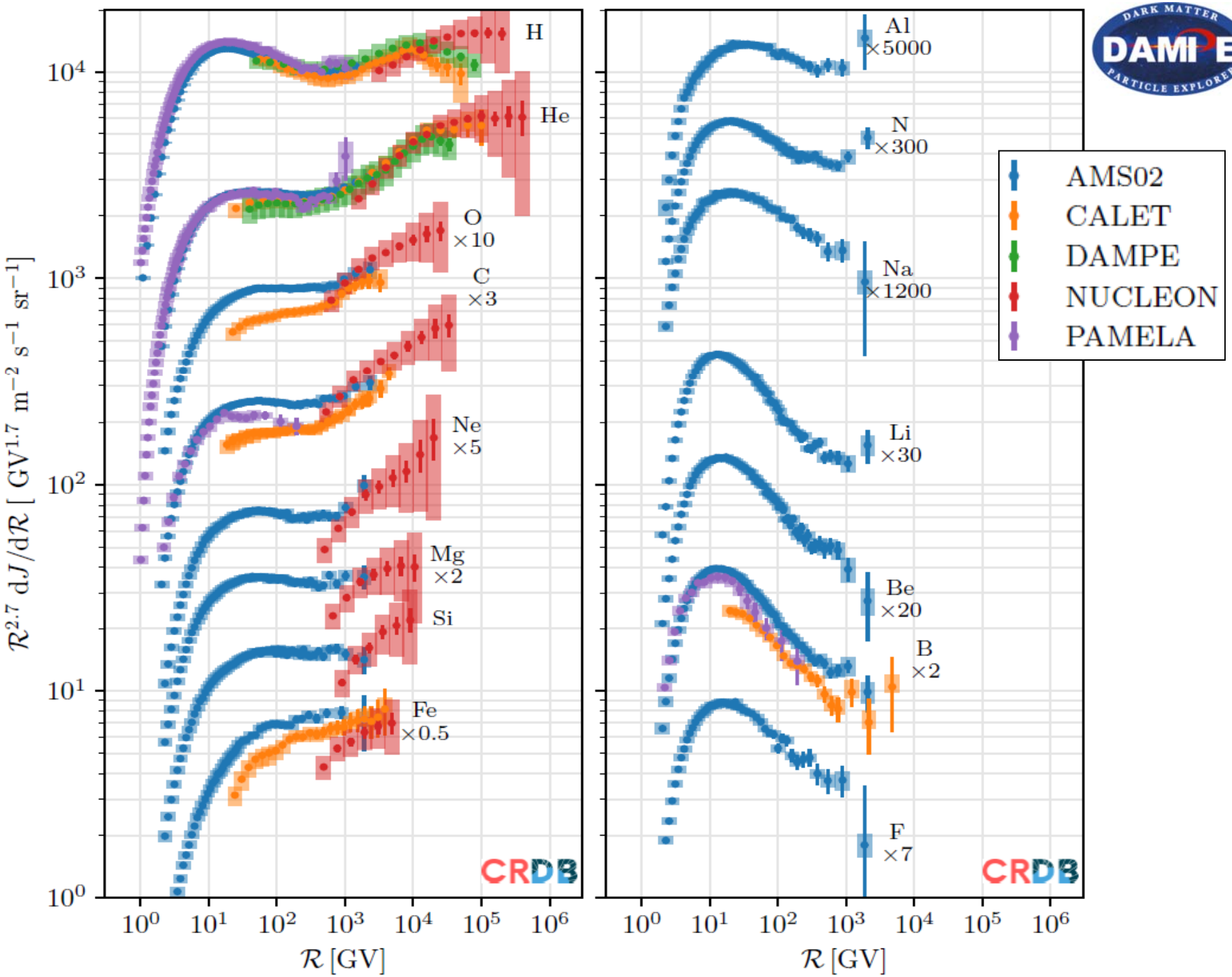




- Confirmation of the softening at 15TV
- Hint for a hardening above 100 TeV
- bridge with indirect measurements

(Phys. Rev. D June 2024)

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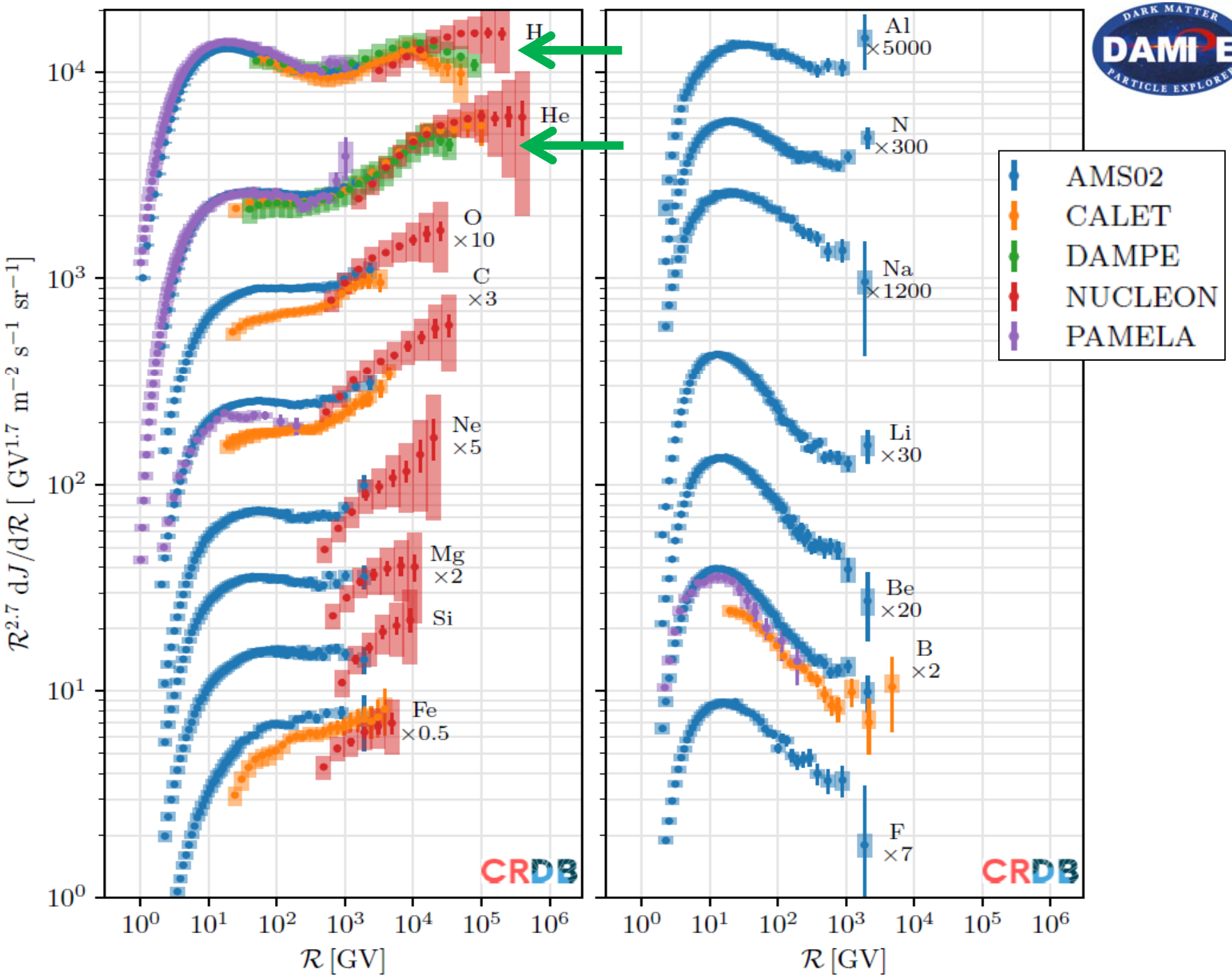
DAMPE
NUCLEON
PAMELA
CRDB
CRDB
$\mathcal{R}^{2.7}\,\mathrm{d}J/\mathrm{d}\mathcal{R}$ [$\mathrm{GV}^{1.7}\ \mathrm{m}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$]
$\mathcal{R}$ [GV]
$\mathcal{R}$ [GV]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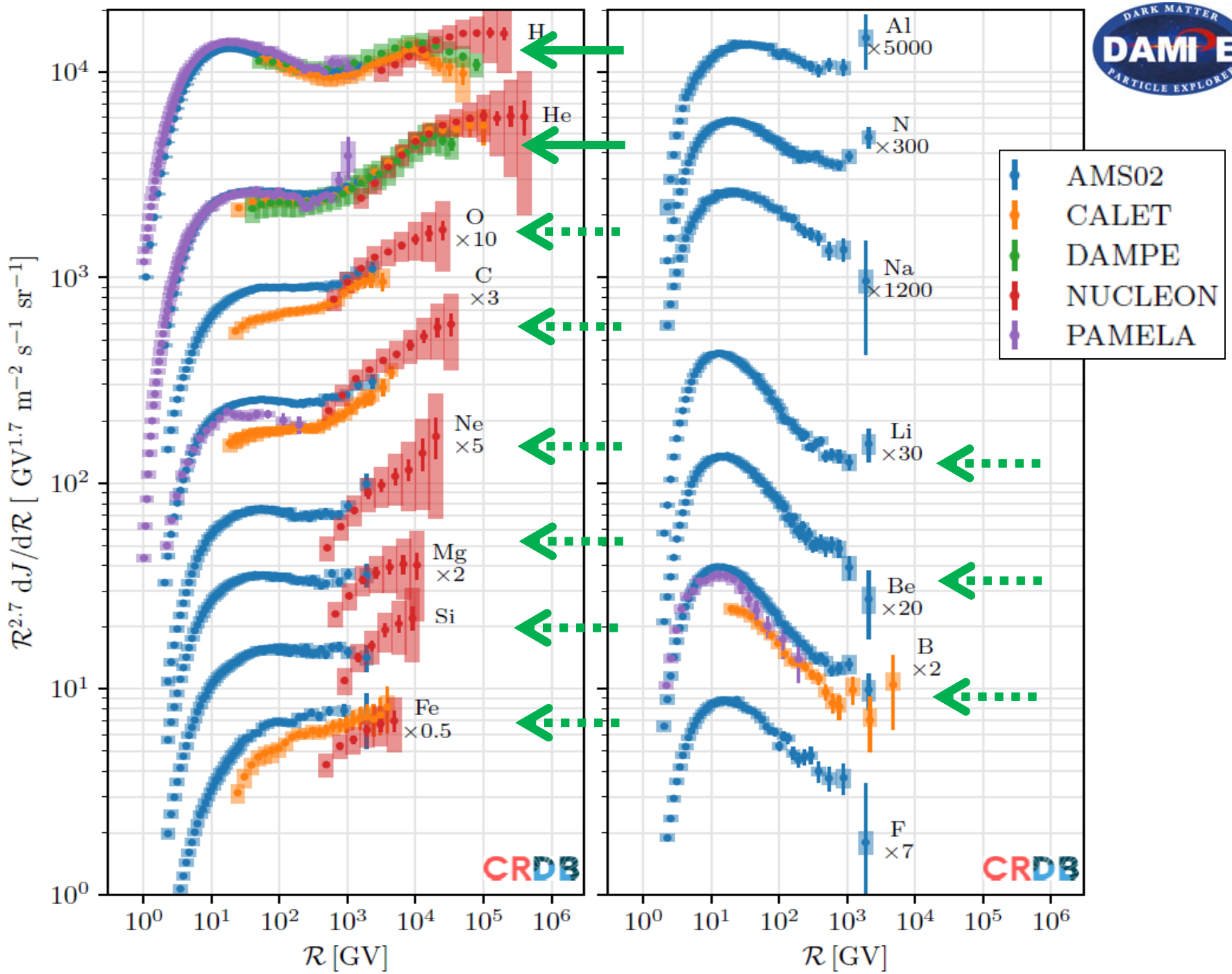
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$\mathcal{R}^{2.7}\,\mathrm{d}J/\mathrm{d}\mathcal{R}$ [$\mathrm{GV}^{1.7}\ \mathrm{m}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$]
$\mathcal{R}$ [GV]
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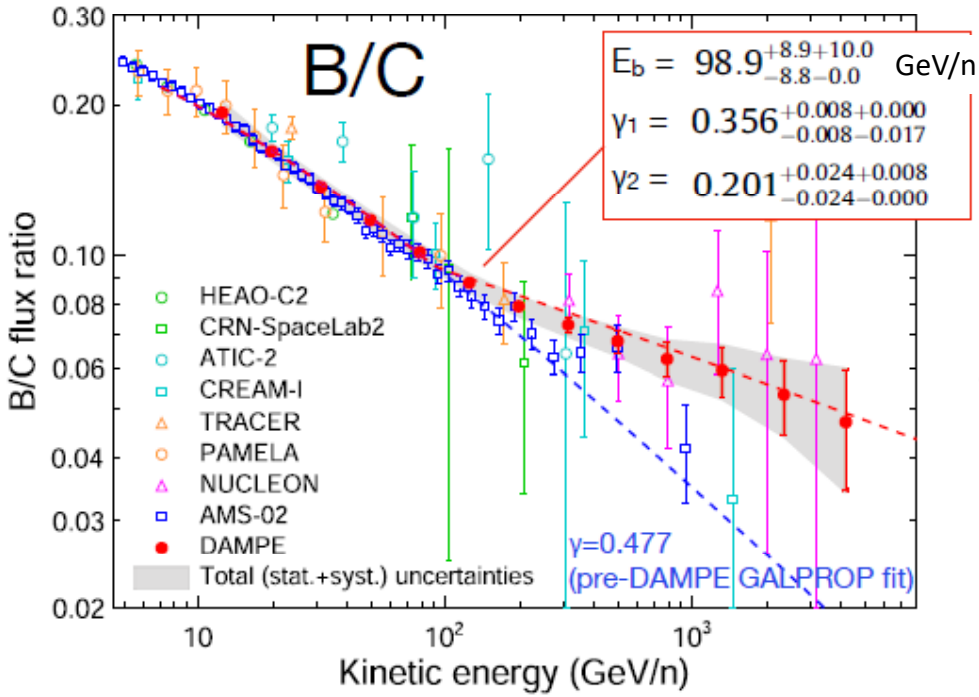
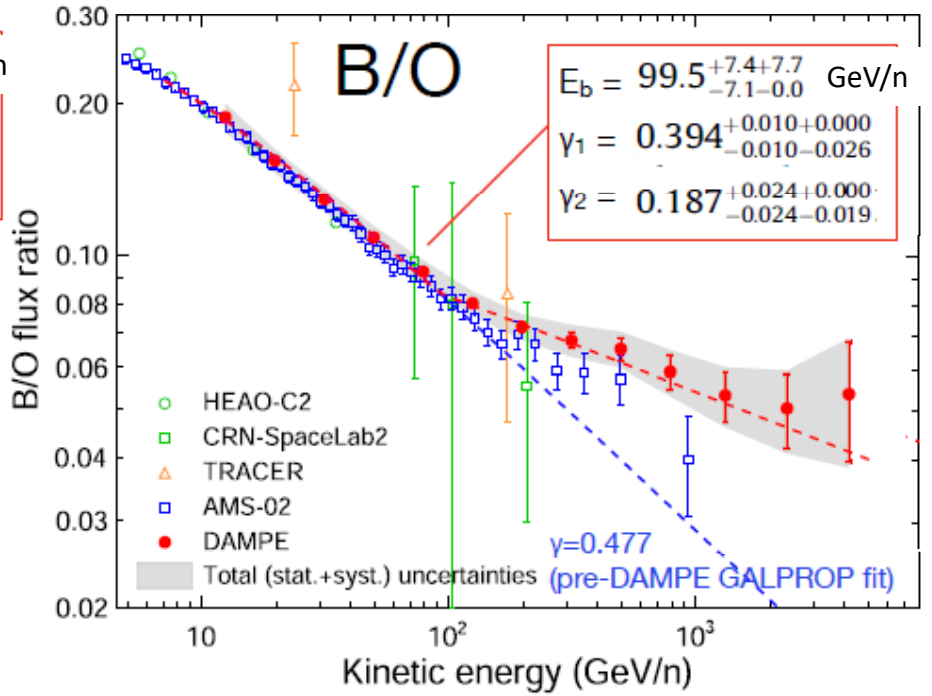
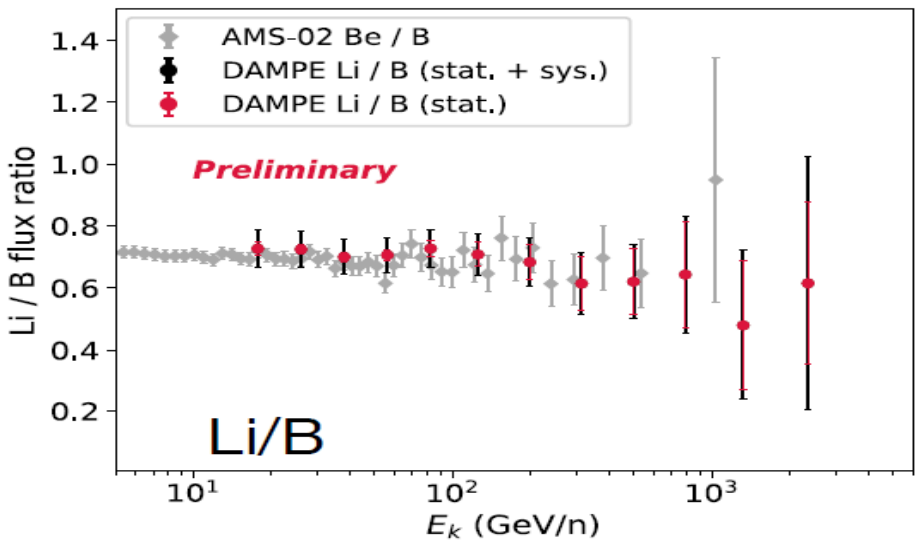
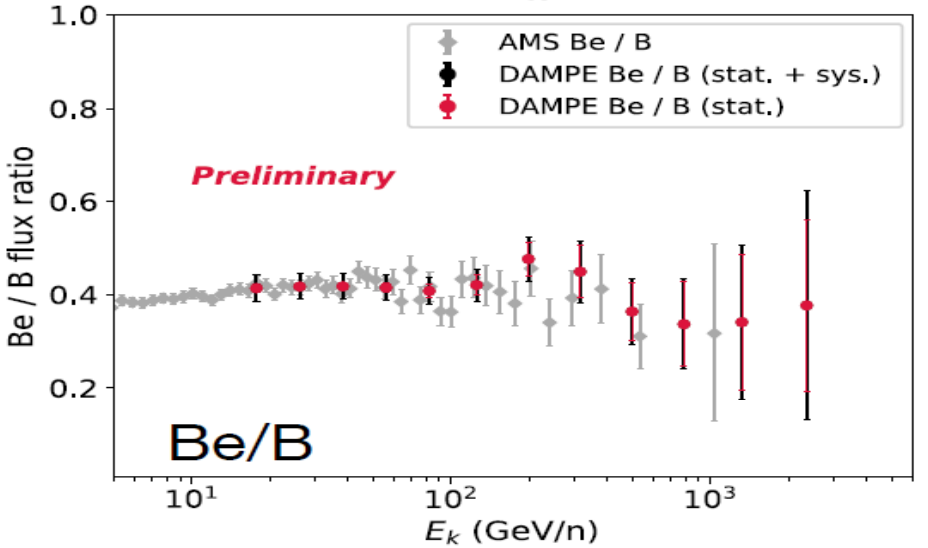
Flux ratios

B/C and B/O
DAMPE Coll. Science Bull. 67 (2022) 21

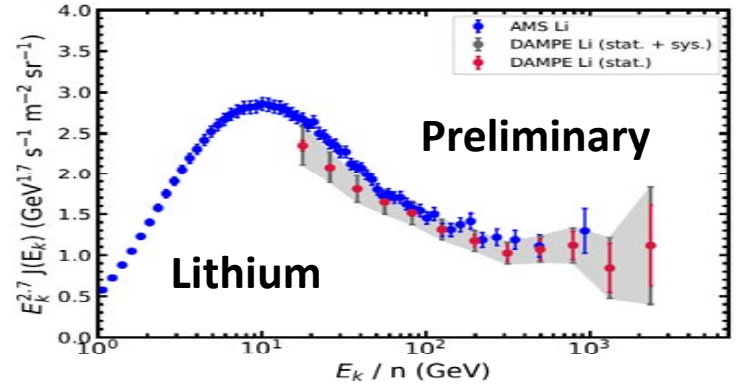


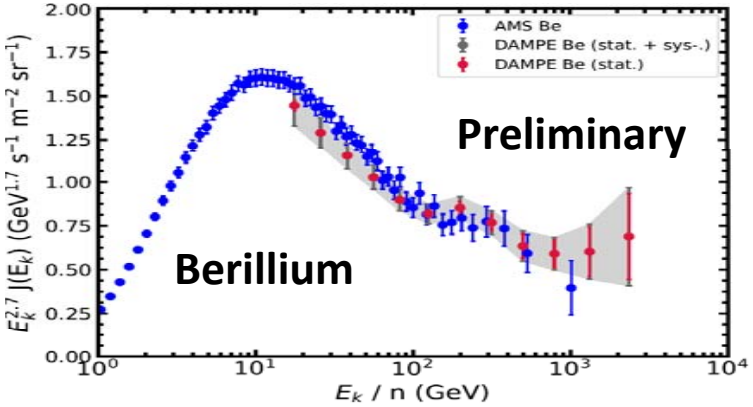


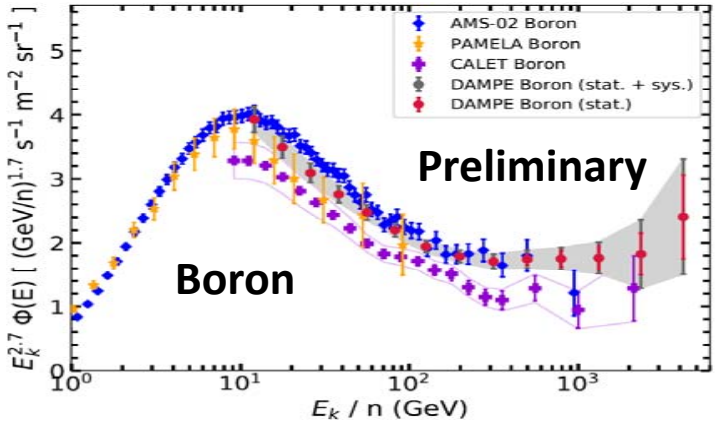


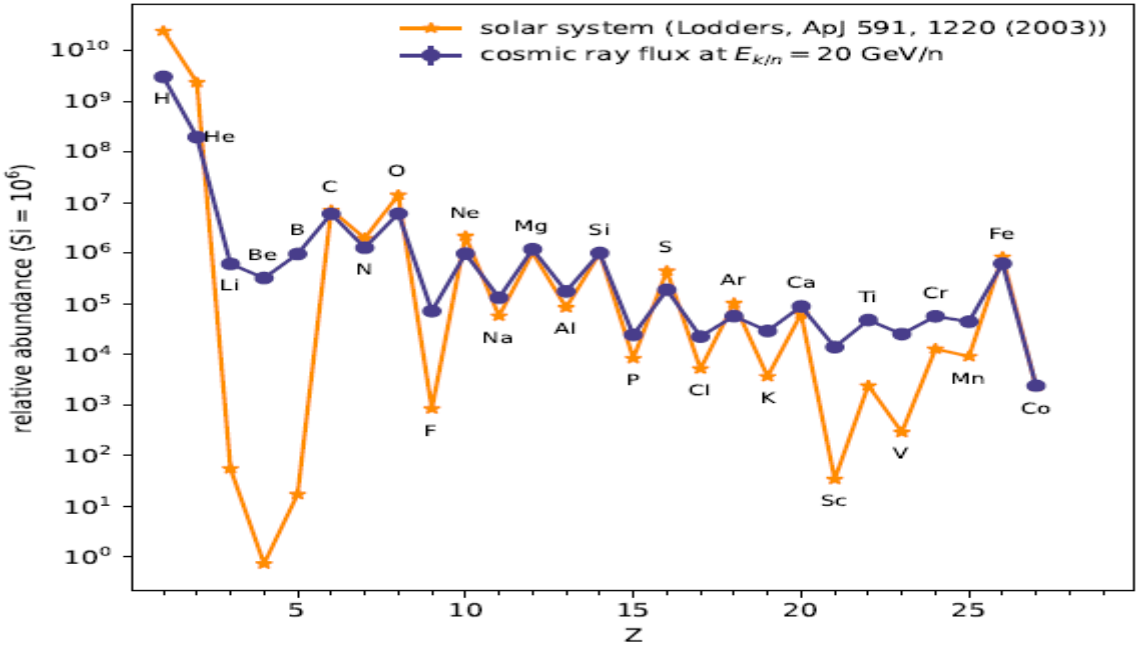


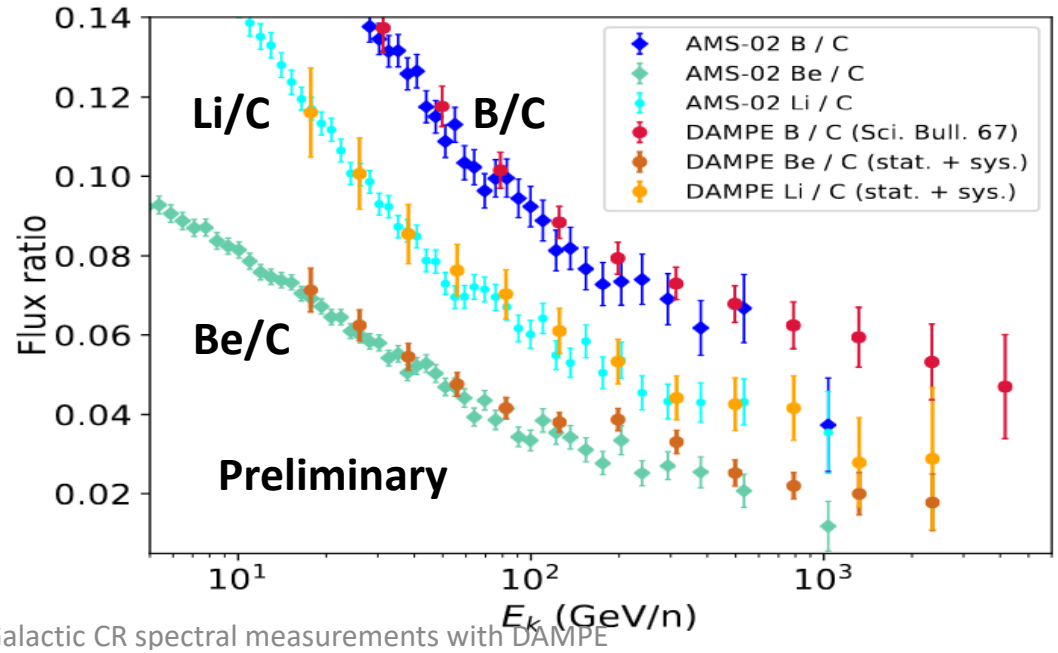
Secondaries: Li, Be and B





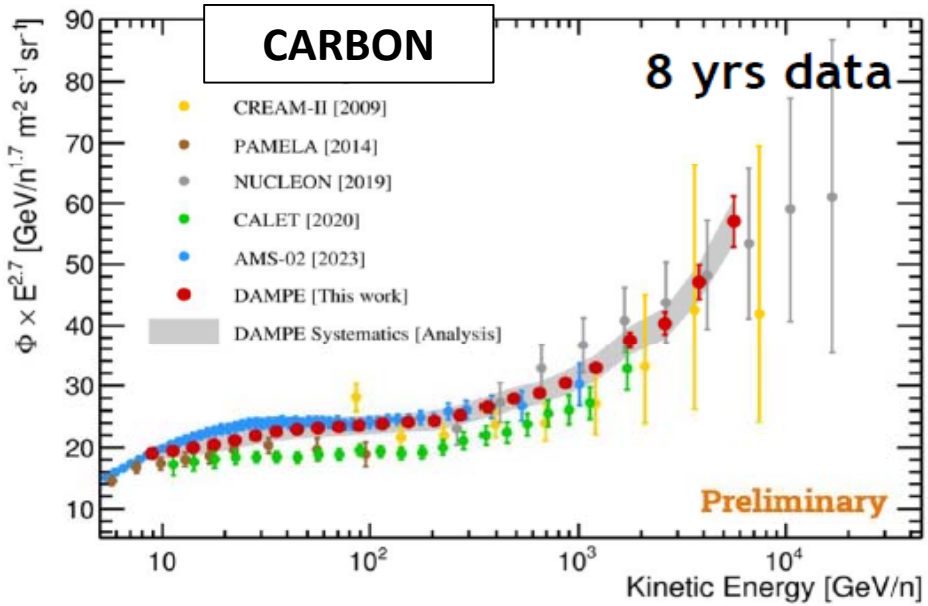


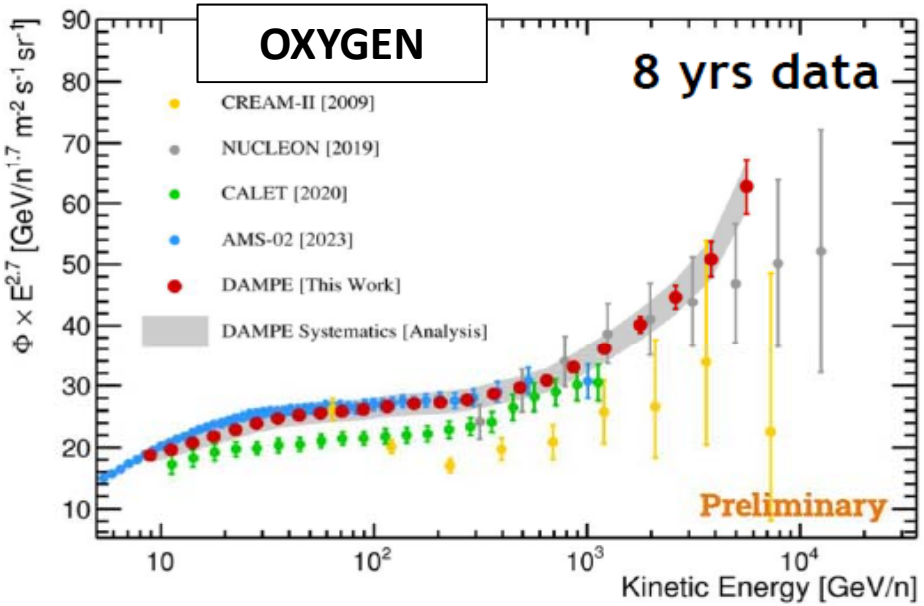


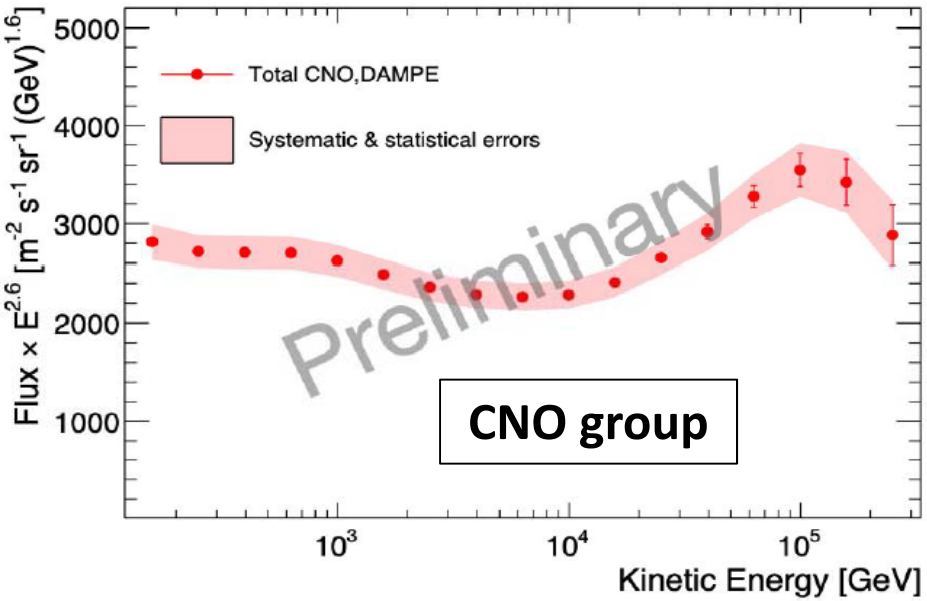


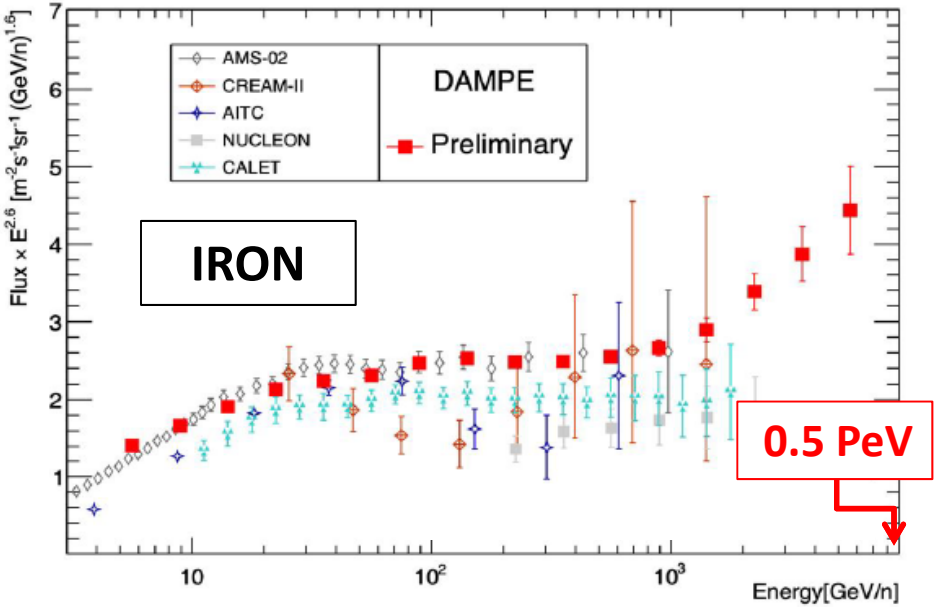
Heavier elements…

Several analyses are in progress towards the highest energies (~0.8 PeV for Fe)



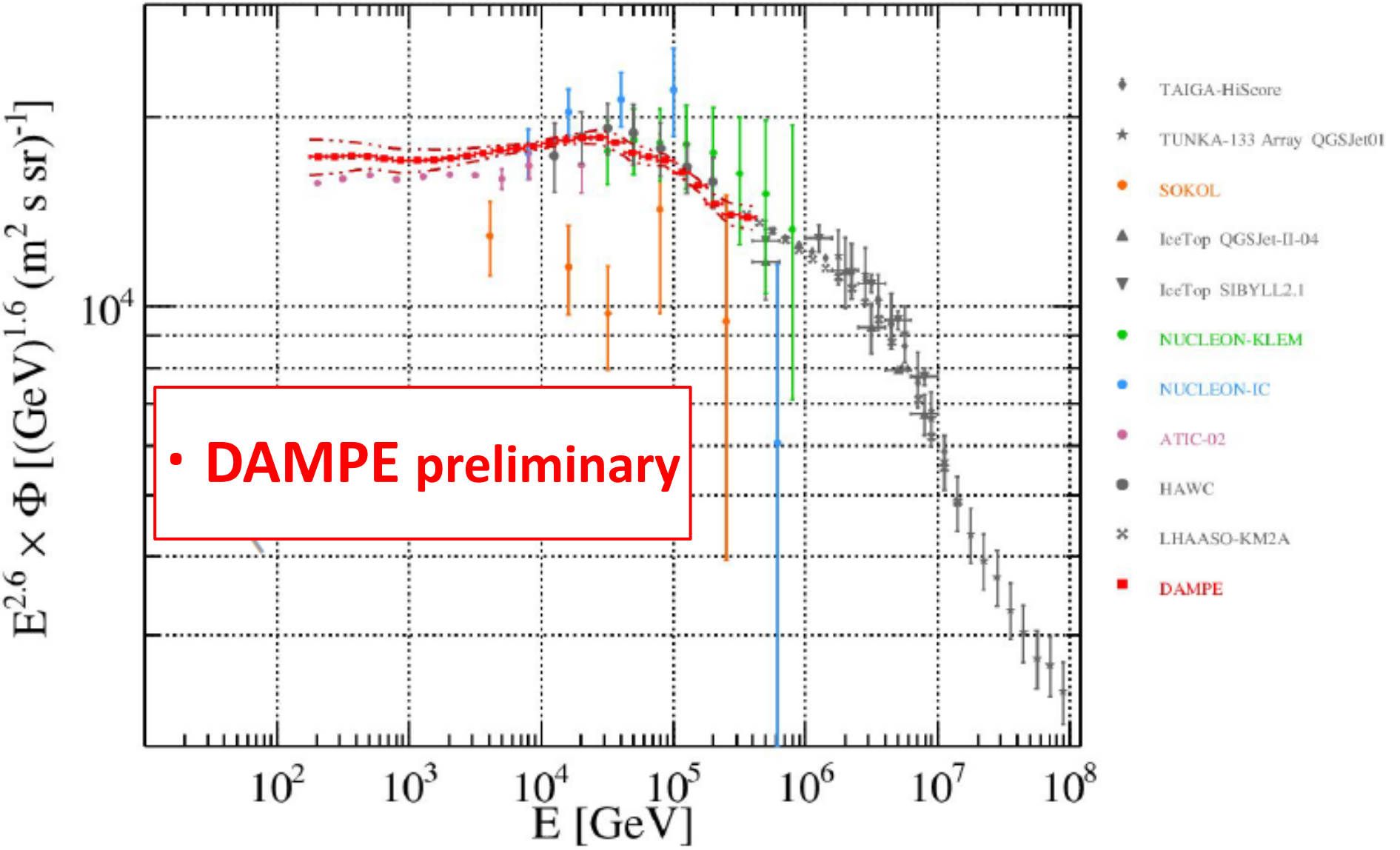




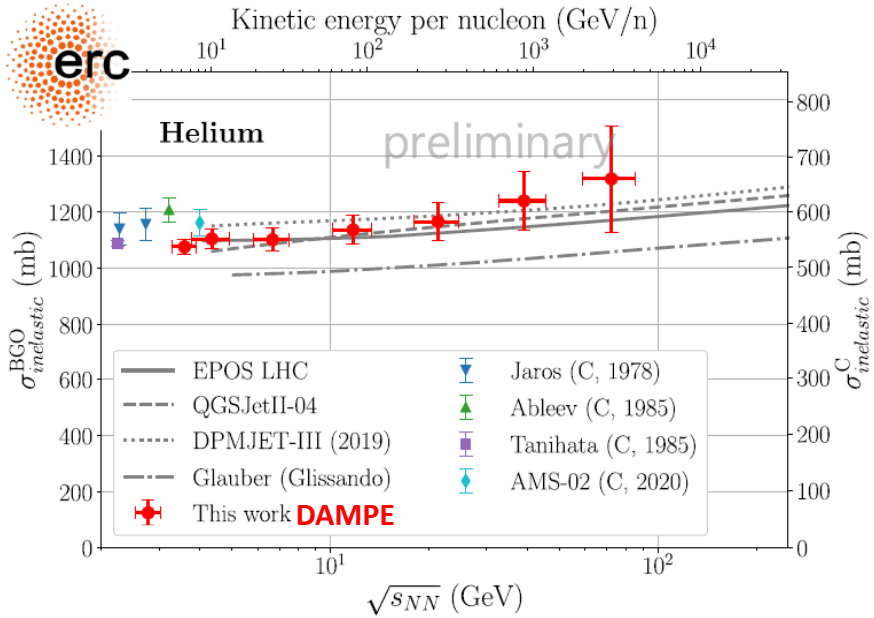


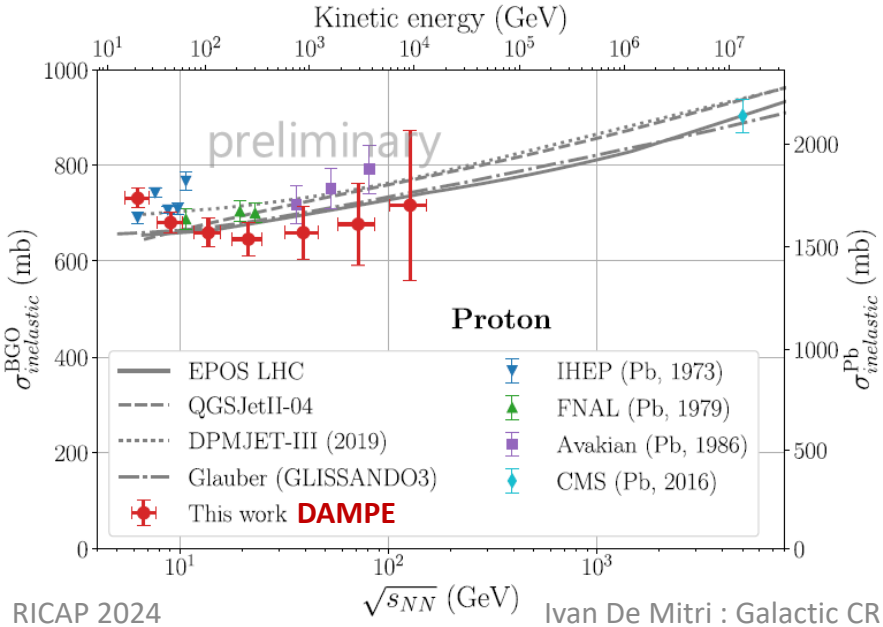
The all-particle spectrum

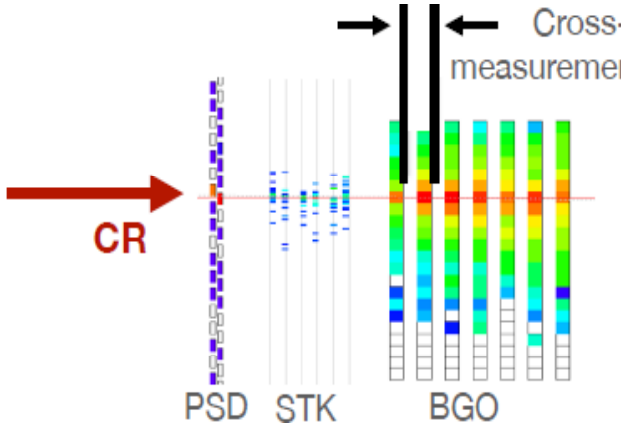
A single measurement across almost 4 orders of magnitude

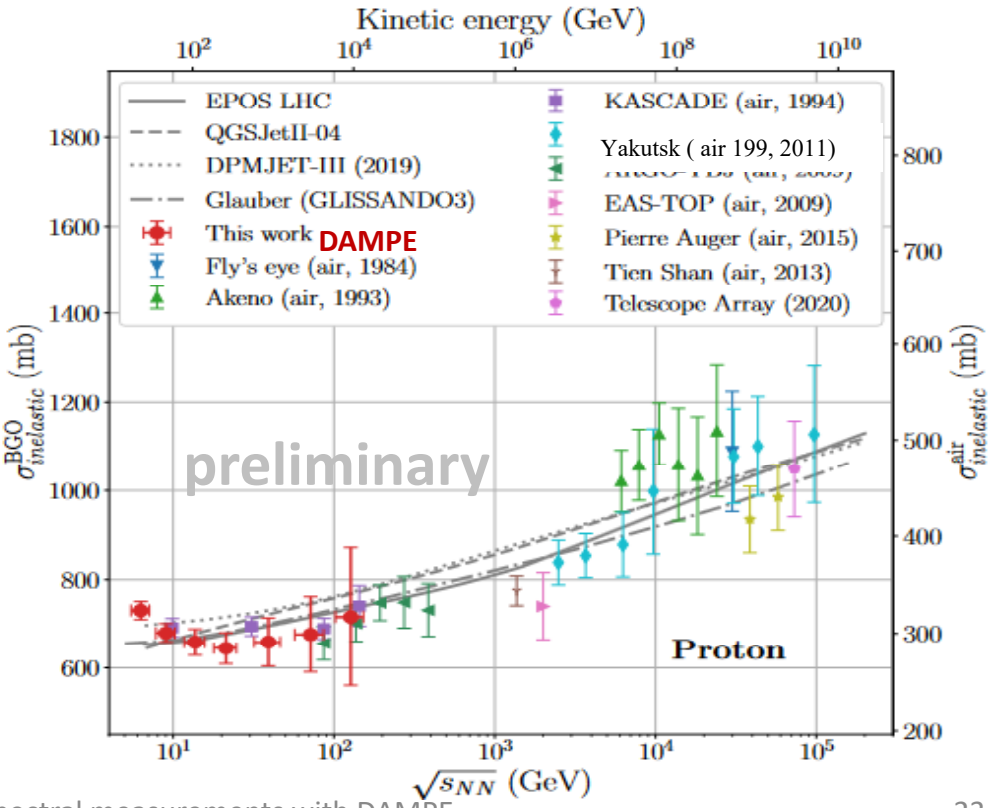


Hadronic cross section measurements









Summary

The detector

- Large geometric factor instrument (0.3 m^2 sr for p and nuclei)
- Precision Si-W tracker (50μm , 0.2°)
- Thick calorimeter (31 X_0 , σ_E/E better than 1% above 50 GeV for e/γ , ~35% for hadrons)
- "Multiple" charge measurements (0.2-0.3 e resolution)
- e/p rejection power > 10^5 (topology alone, plus neutron detector)

Launch and performances

- Succesfull launch on Dec 17th, 2015
- On orbit operation steady and with high efficiencies (50 Hz, more than 13 billion events)
- Absolute energy calibration by using the geomagnetic cut-off (+1.25% at 13 GeV)
- Absolute pointing cross check by use of the photon map (PSF = 0.3° for 10GeV photons)

Science:

- Evidence for a cutoff at ~1 TeV in the all electron spectrum
- Evidence for a softening in the proton spectrum at ~ 14 TeV
- Evidence for a softening in the helium spectrum at ~ 34 TeV (suggest Z dependence)
- Measurement of p+He confirms the softening and suggest a hardening around 100TeV
- Break in secondary to primary ratios (B/C and B/O) at 100 GeV/n
- Undergoing spectral measurements of heavier nuclei (C, N, O Fe, …) and light secondaries (Li, Be, B)
- Preliminary studies of gamma ray sources (250 sources, Fermi bubble, …)
- Detected new features in Forbush decrease
- Upper limits for dark matter signatures, fractionally charged particles, …

More Stuff

The collaboration

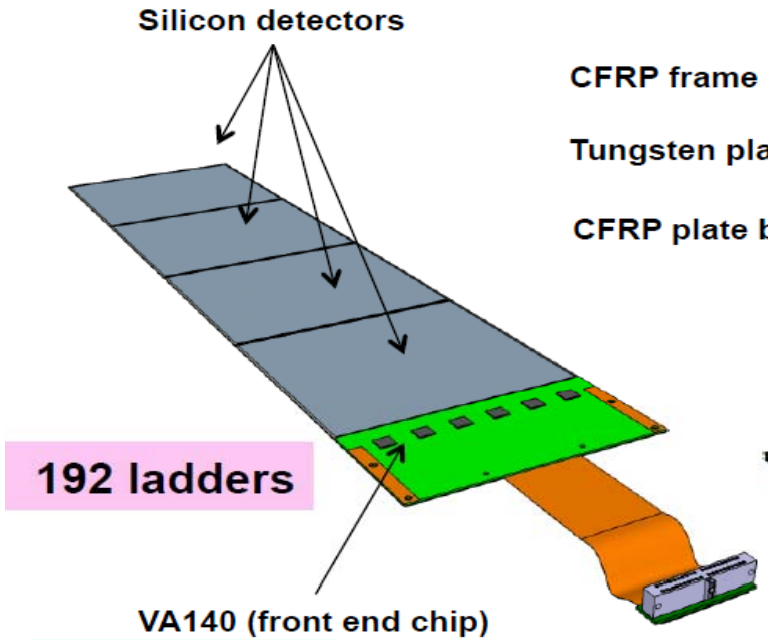
- **CHINA**
  - Purple Mountain Observatory, CAS, Nanjing
  - Institute of High Energy Physics, CAS, Beijing
  - National Space Science Center, CAS, Beijing
  - University of Science and Technology of China, Hefei
  - Institute of Modern Physics, CAS, Lanzhou

- **ITALY**
  - INFN Bari and University of Bari
  - INFN Lecce and University of Salento
  - INFN LNGS and Gran Sasso Science Institute
  - INFN Perugia and University of Perugia

- **SWITZERLAND**
  - University of Geneva

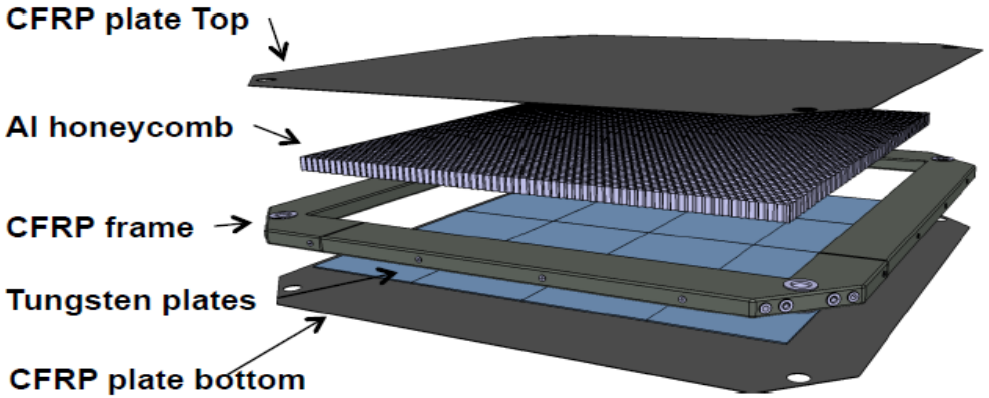
The Silicon TracKer (STK)

768 silicon sensors

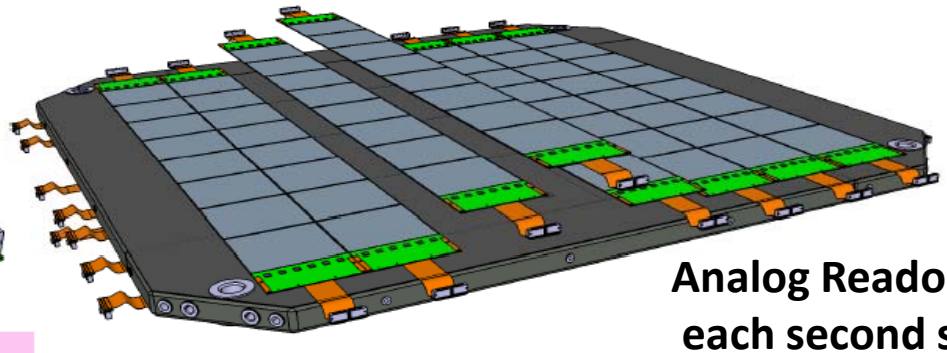


1152 ASICs

73728 channels

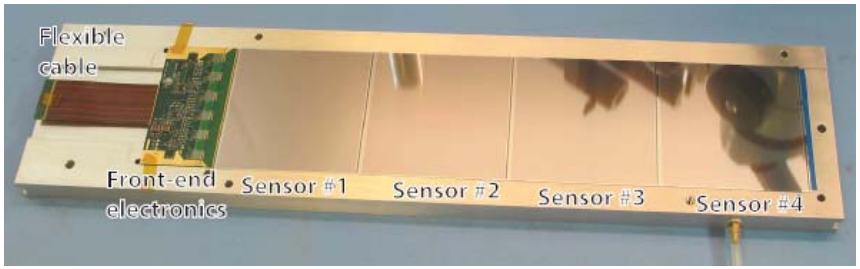


12 layers, 6-x and 6-y



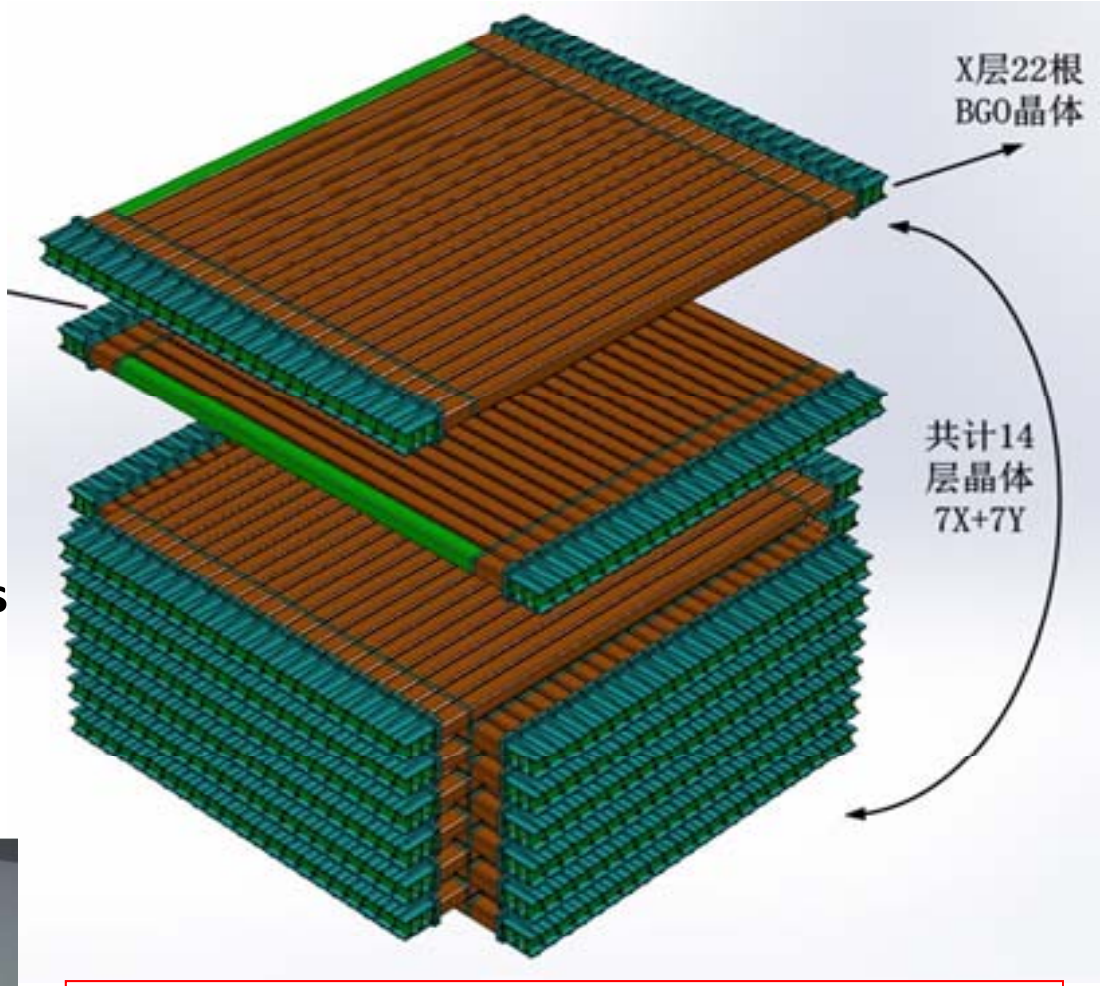
Analog Readout of each second strip:
384 channels / SSD- Ladder
Charge sharing

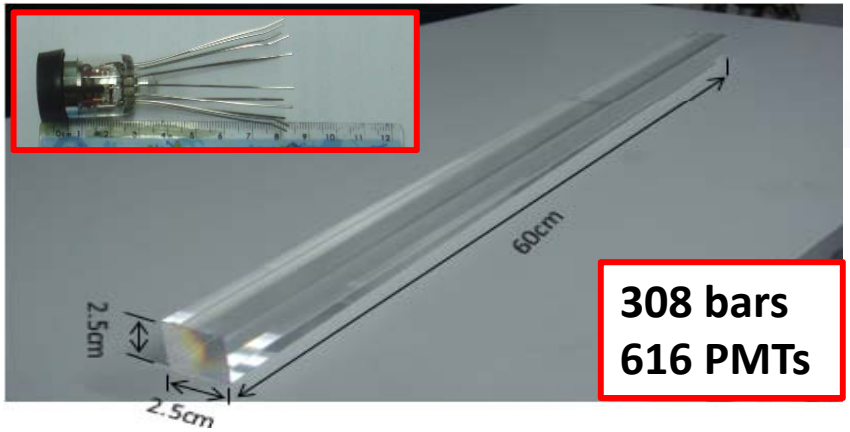
- 48 μm wide Si strips with 121 μm pitch
- (95 × 95 × 0.32 mm^3) Silicon Strip Detector (SSD)
- 768 strips in each SSD
- One ladder composed by 4 (SSD)
- 16 Ladders per layer (76 cm × 76 cm)
- 12 layers (6x + 6y)



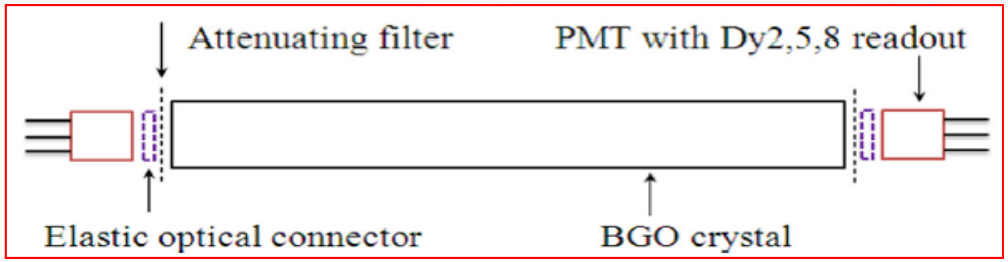
The CALOrimeter

- **14 layers of 22 BGO bars**
  - 2.5×2.5×60 cm^3 bars
  - 14 hodoscopic stacking alternating orthogonal layers
  - depth ~32X_0
- **Two PMTs coupled with each BGO crystal bar at the two ends**
- **Electronics boards attached to each side of module**

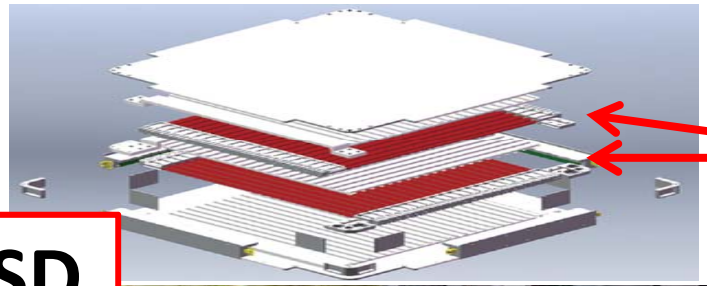




308 bars
616 PMTs

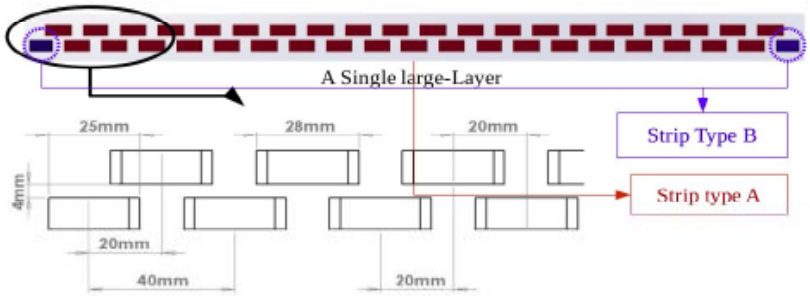


The Plastic Scintillator Detector and the NeUtron Detector

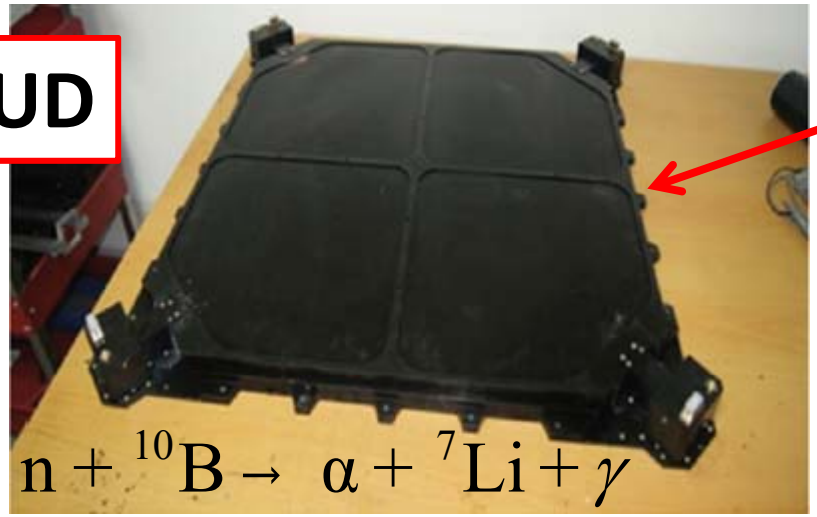


PSD

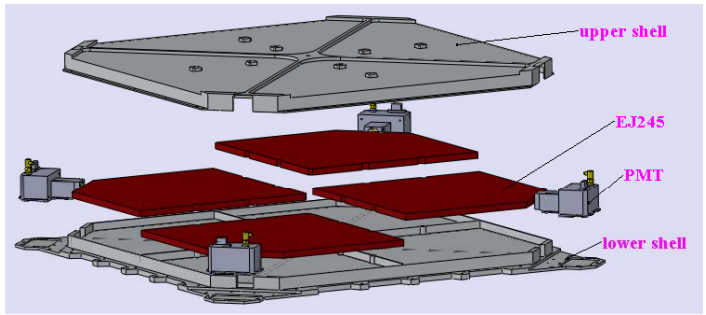
- 1.0 cm thick ,2.8cm wide and 82.0 cm long scintillator strips
- staggered by 0.8 cm in a layer
- 82 cm × 82 cm layers
- 2 layers (x and y)



NUD

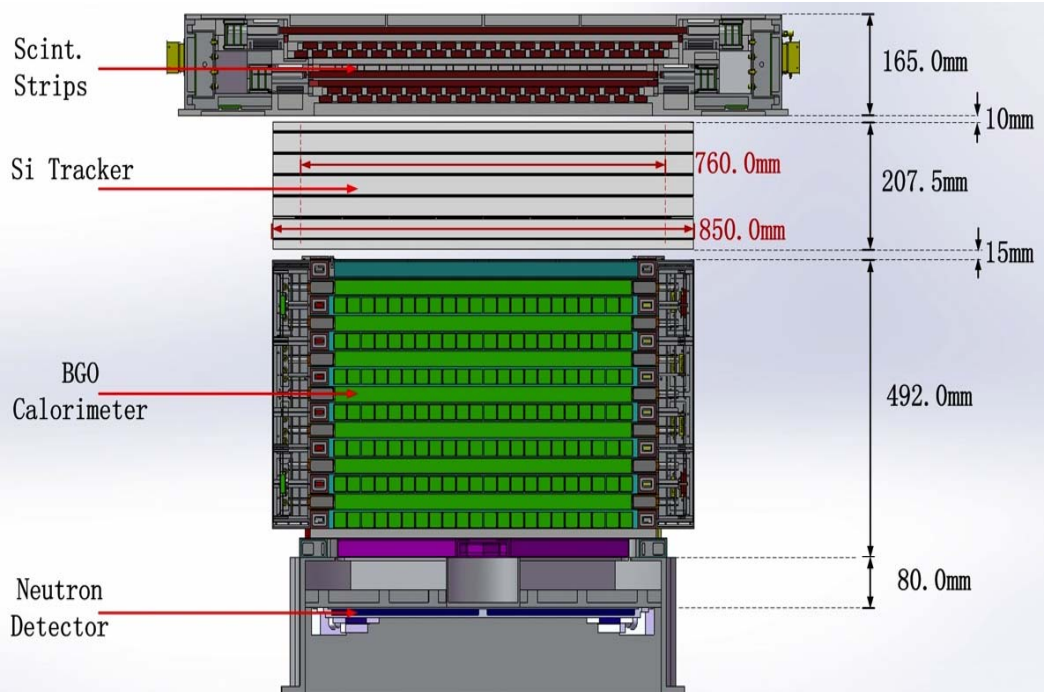


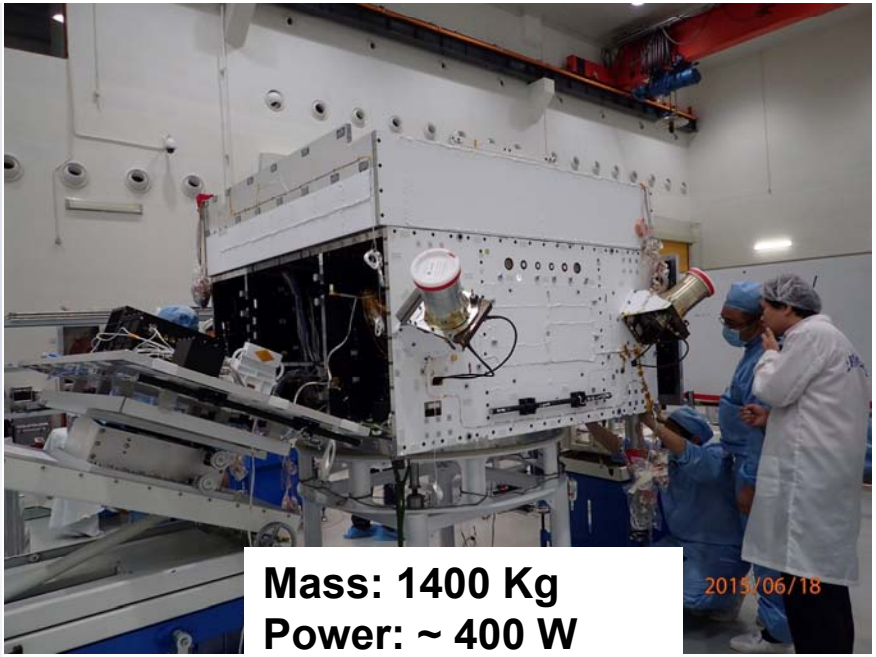
- 4 large area boron-doped plastic scintillators (30 cm × 30 cm × 1 cm)



Comparison with AMS-02 and FERMI

	DAMPE	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	**1.2**	3	10
e/γ Angular res.@100 GeV (deg)	0.2	0.3	0.1
e/p discrimination	10^5-10^6	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	**32**	17	8.6
Geometrical accep. (m^2sr)	**0.3**	0.09	1



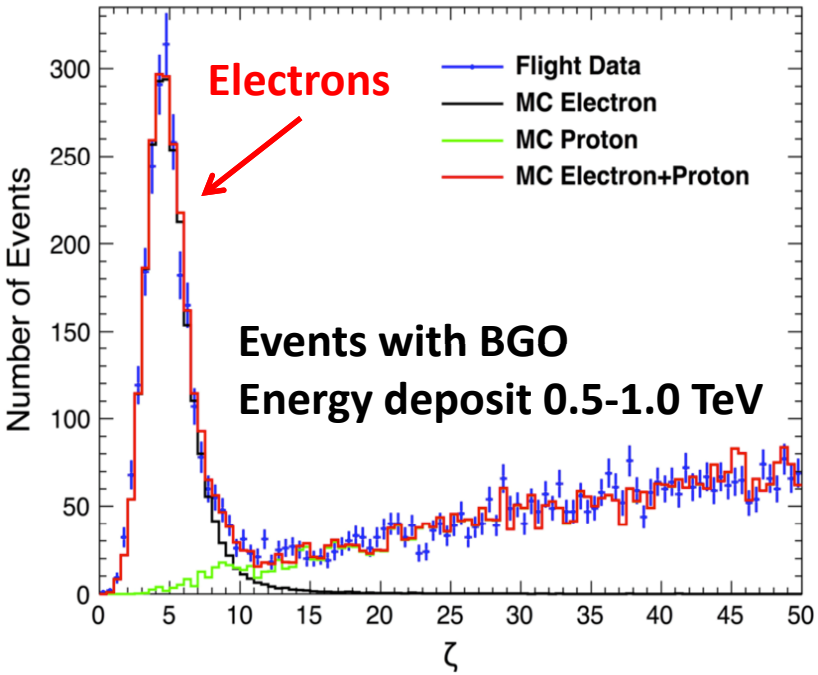


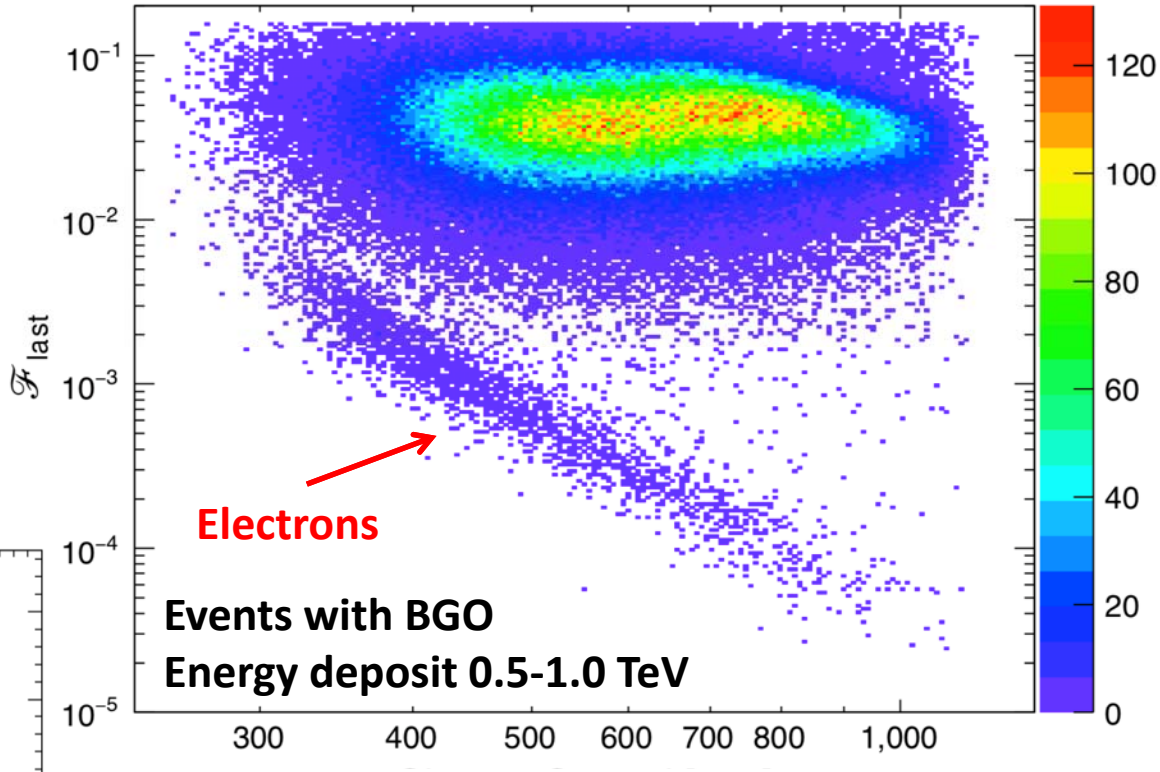
Mass: 1400 Kg
Power: ~ 400 W
Livetime: > 3 years

Electron IDentification

$\mathcal{F}_{\text{last}}$ = fraction of energy deposit in the last BGO layer with hits

$$RMS_i = \sqrt{\frac{\sum_j (x_{j,i} - x_{c,i})^2 E_{j,i}}{\sum_j E_{j,i}}}$$

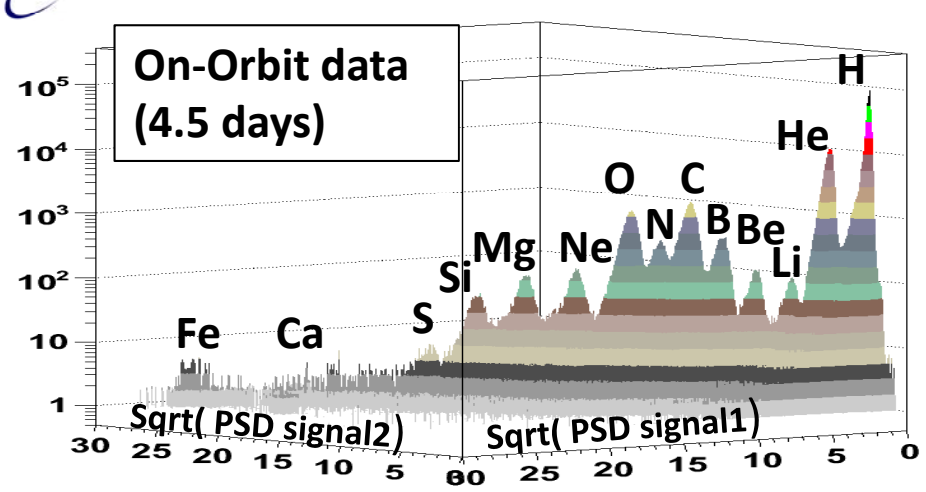


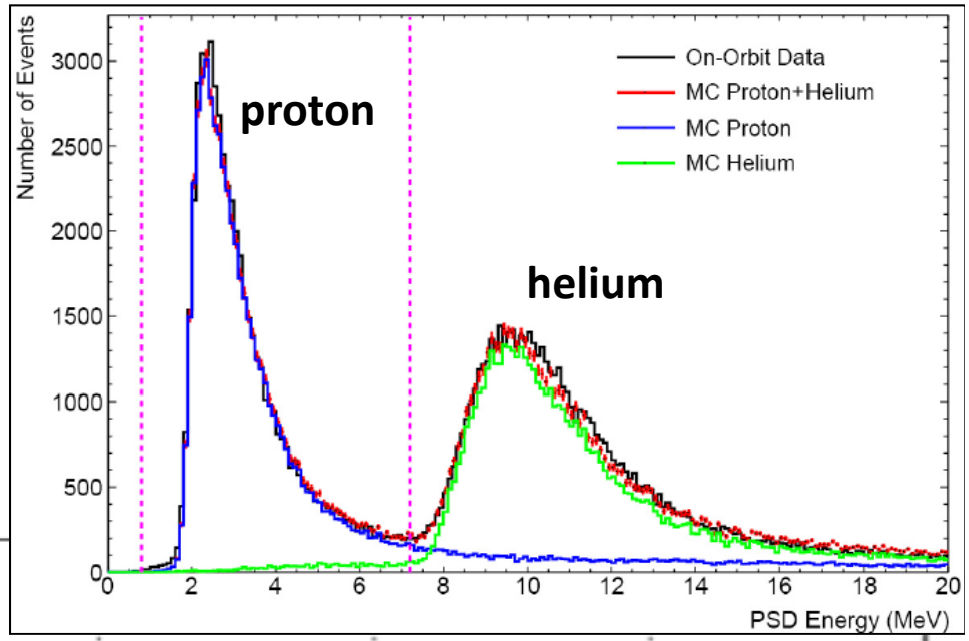


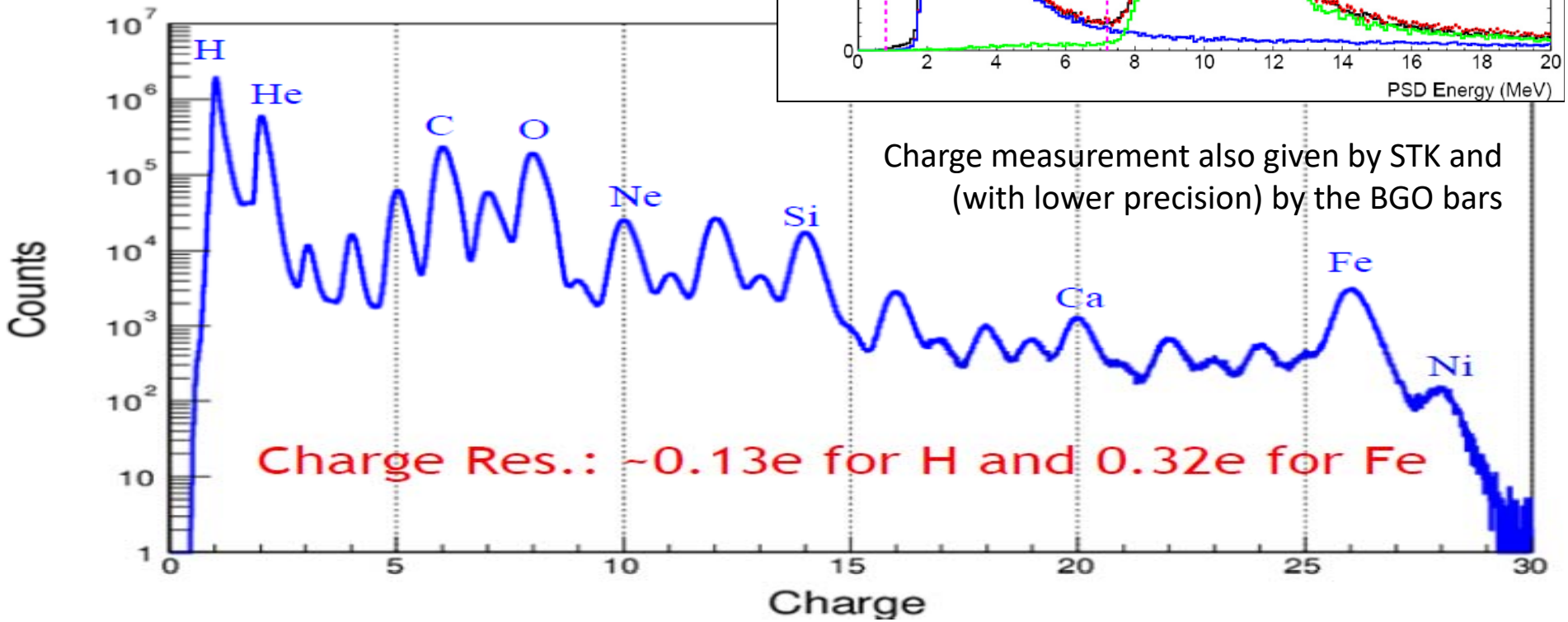
SumRMS = Sum of single layer RMS values

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

Nuclei ID with PSD



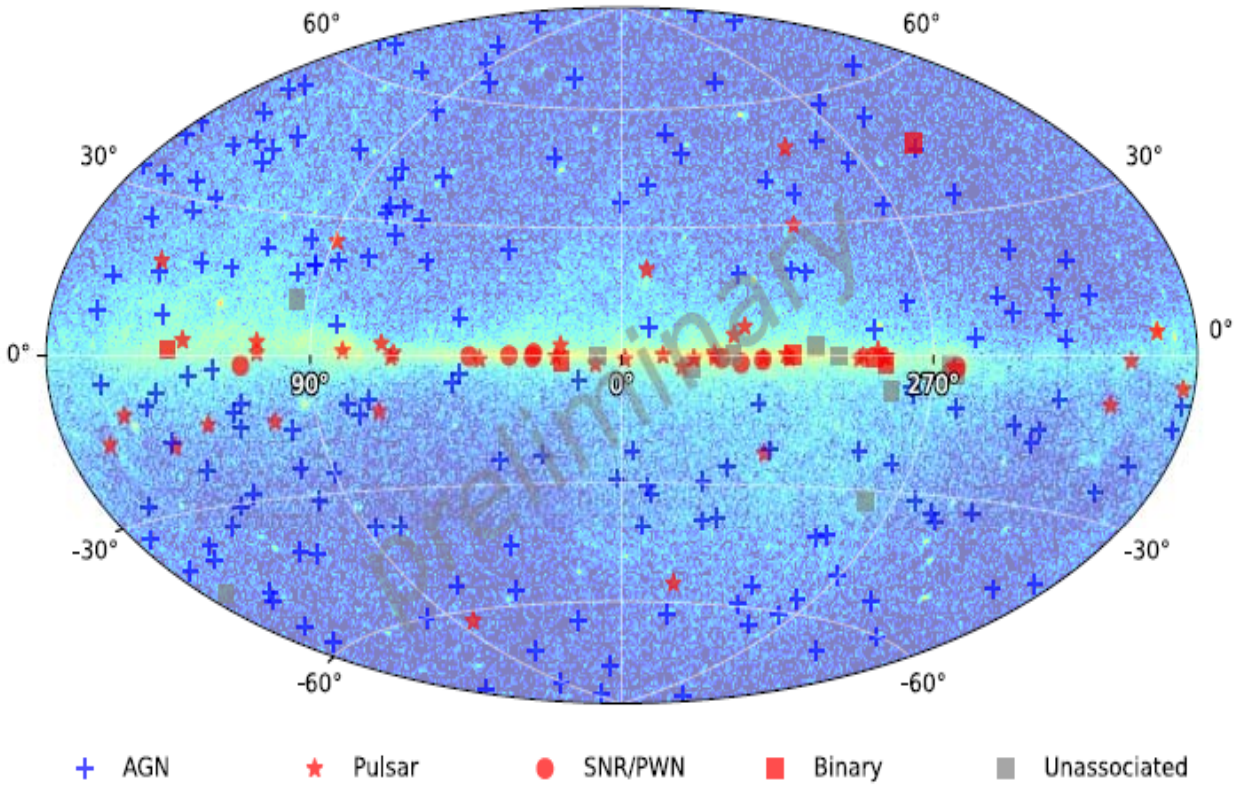




Charge measurement also given by STK and (with lower precision) by the BGO bars

The DAMPE gamma-ray sky

~250 point sources detected and studied

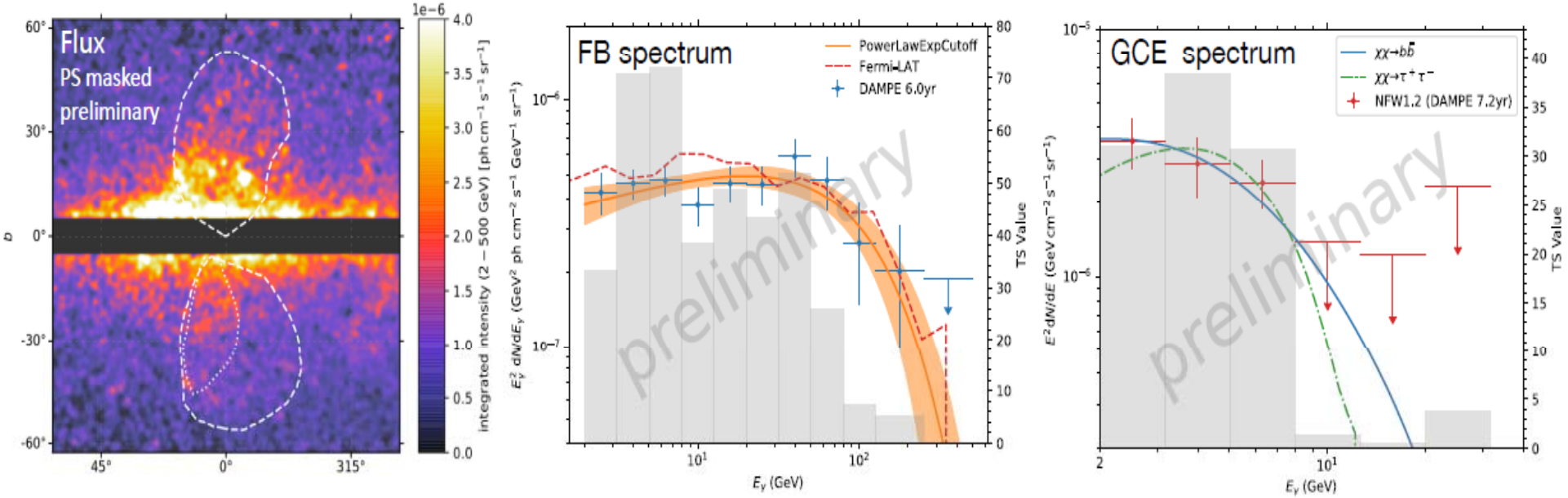


Source Type	Number
AGN	175
Pulsar	46
SNR/PWN	10
Binary	6
Unassociated	11
Total	248

14 times full-sky coverage in 7 years, ~ 300'000 photons total

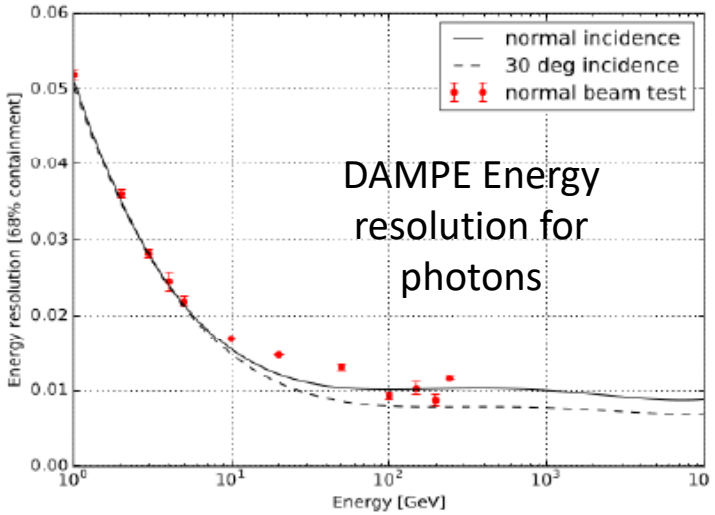
γ-rays: large scale structures

Fermi Bubbles (FB) — diffuse structures discovered by FERMI LAT, associated with Galactic Centre (DAMPE FB detection at ~17.8σ)



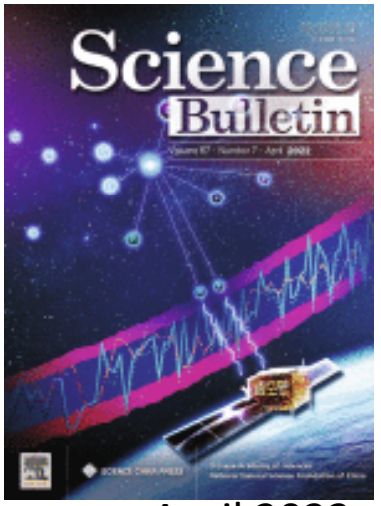
- FB: 6-year spectrum well consistent with FERMI, curved at 3.7σ, weak excess in the Cocoon (~3.3σ)
- **Galactic Center Excess (GCE)** detected at ~7.9σ, with 7.2 years of DAMPE data

Indirect Dark Matter search



Search for gamma ray lines from neutralino annihilation or decay

Very high sensitivity due to:
-Effective area
-Energy resolution



April 2022