Galactic Cosmic Ray Studies with the DAMPE space mission

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on behalf of the DAMPE Collaboration

Vulcano Workshop 2024
Frontier Objects in Astrophysics and Particle Physics
Ischia Island (Naples, Italy), May 26th to June 1st , 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

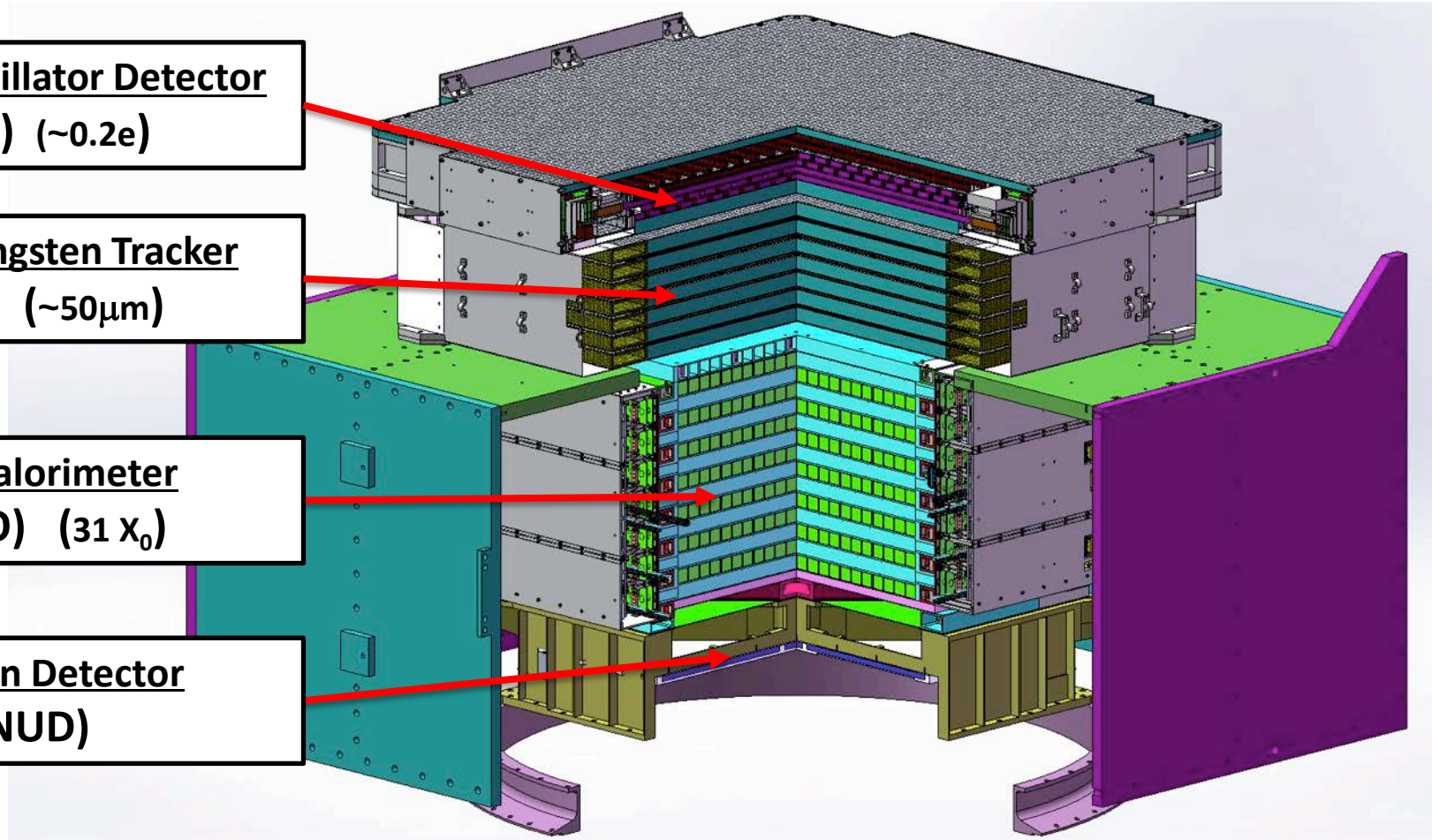
10 GeV - 10 TeV e/γ

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)**

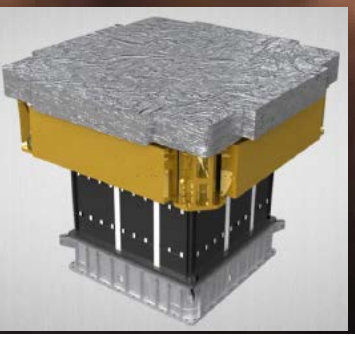
high energy
γ-ray, electron and cosmic ray
telescope

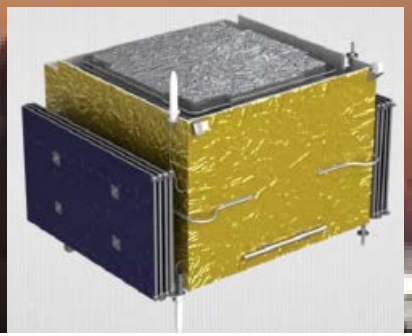
The launch: Dec 17th 2015, 0:12 UTC

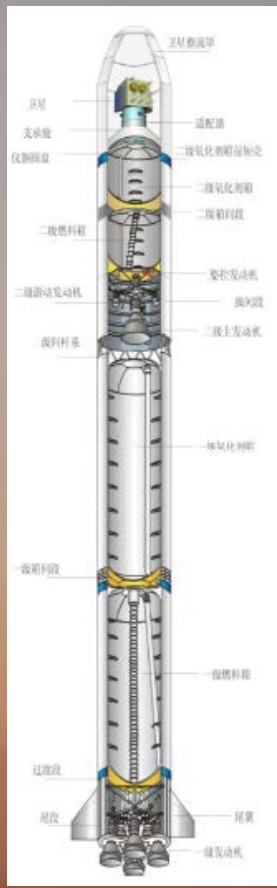
Jiuquan Satellite Launch Center
Gobi desert

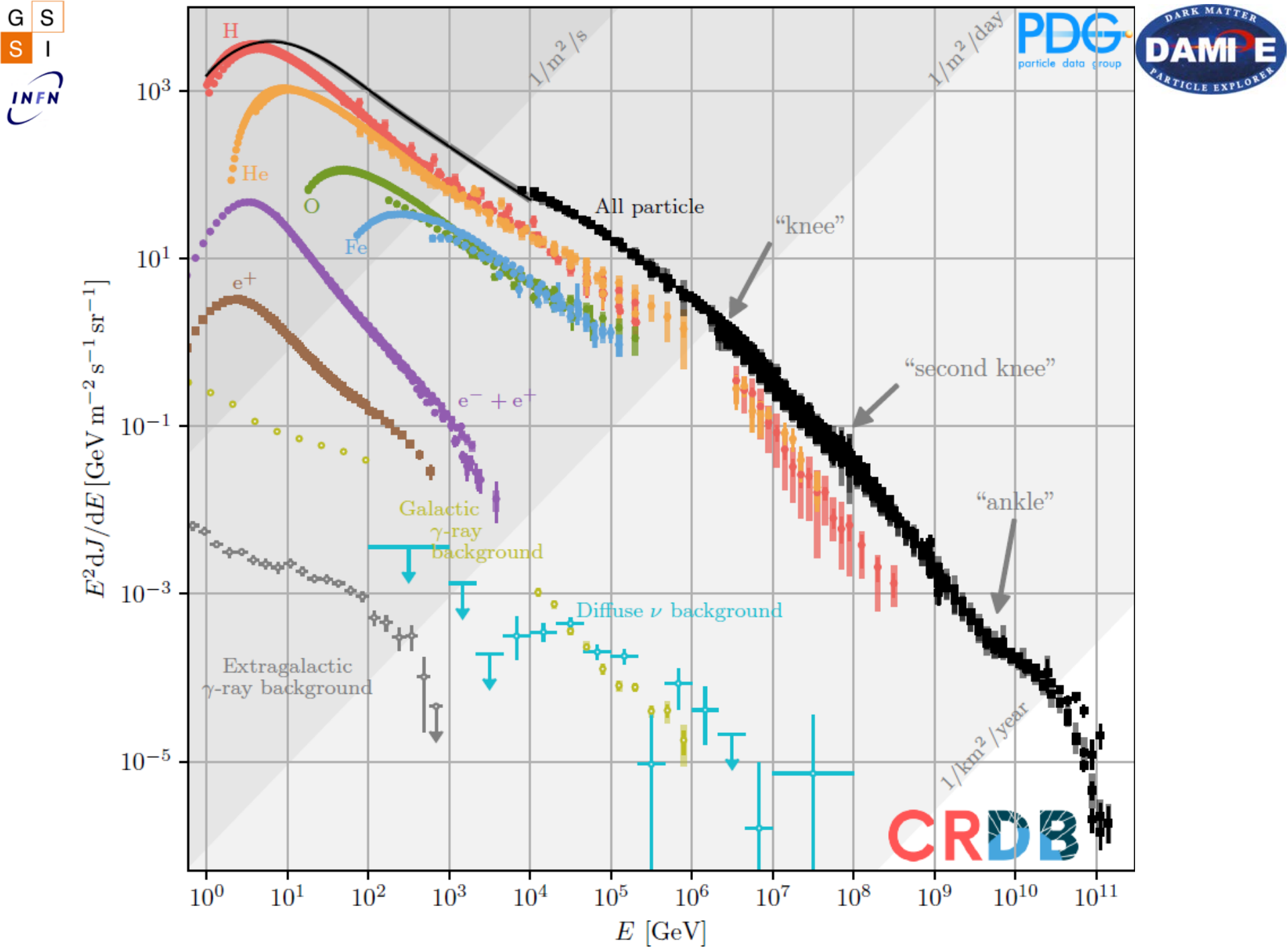
CZ-2D rocket

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








H
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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 PARTICLE EXPLORER DAMPE
CRDB
$E^2 dJ/dE$ [GeV m^{-2} s^{-1} sr^{-1}]
E [GeV]
10^3
10^1
10^{-1}
10^{-3}
10^{-5}
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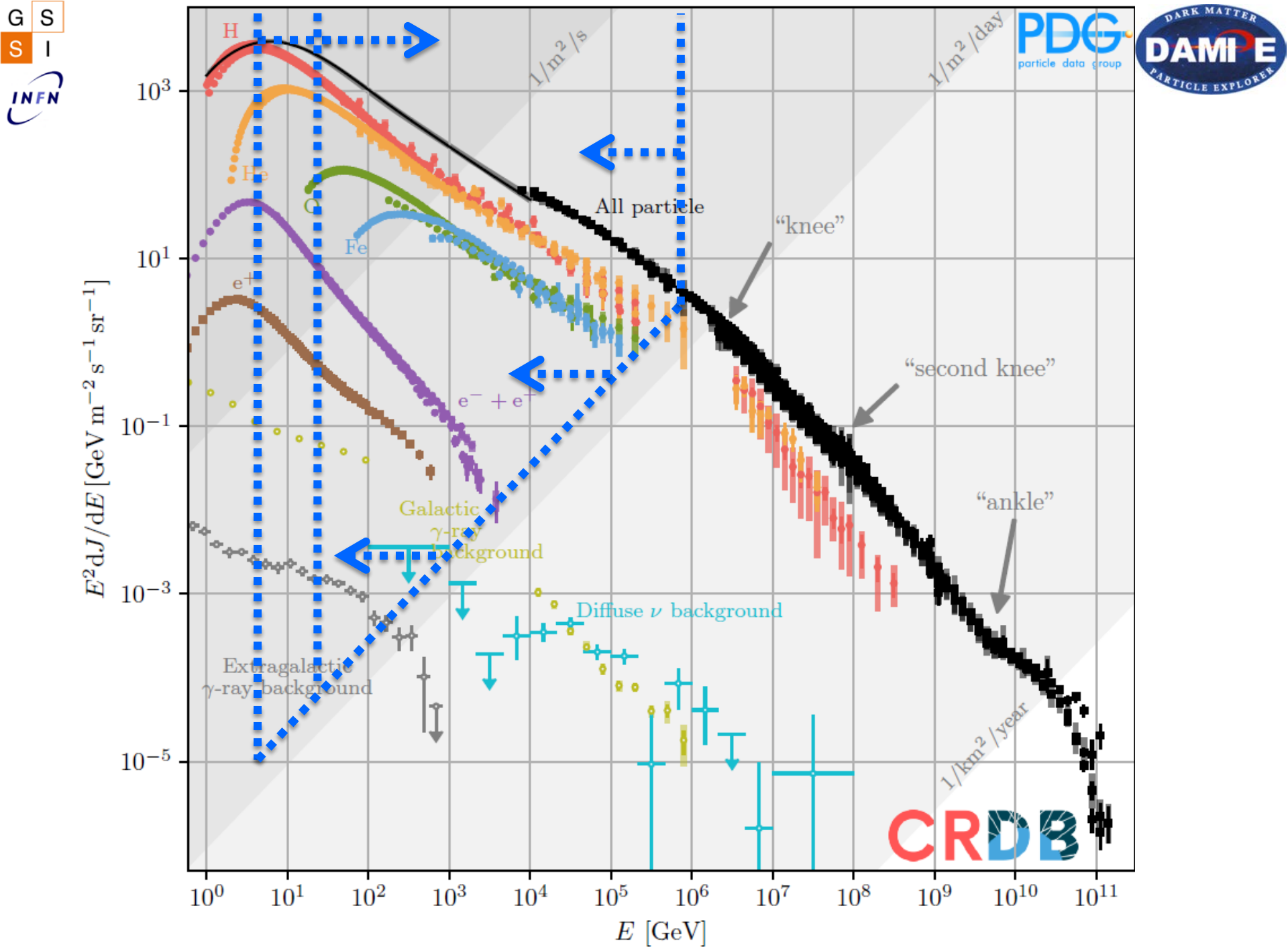
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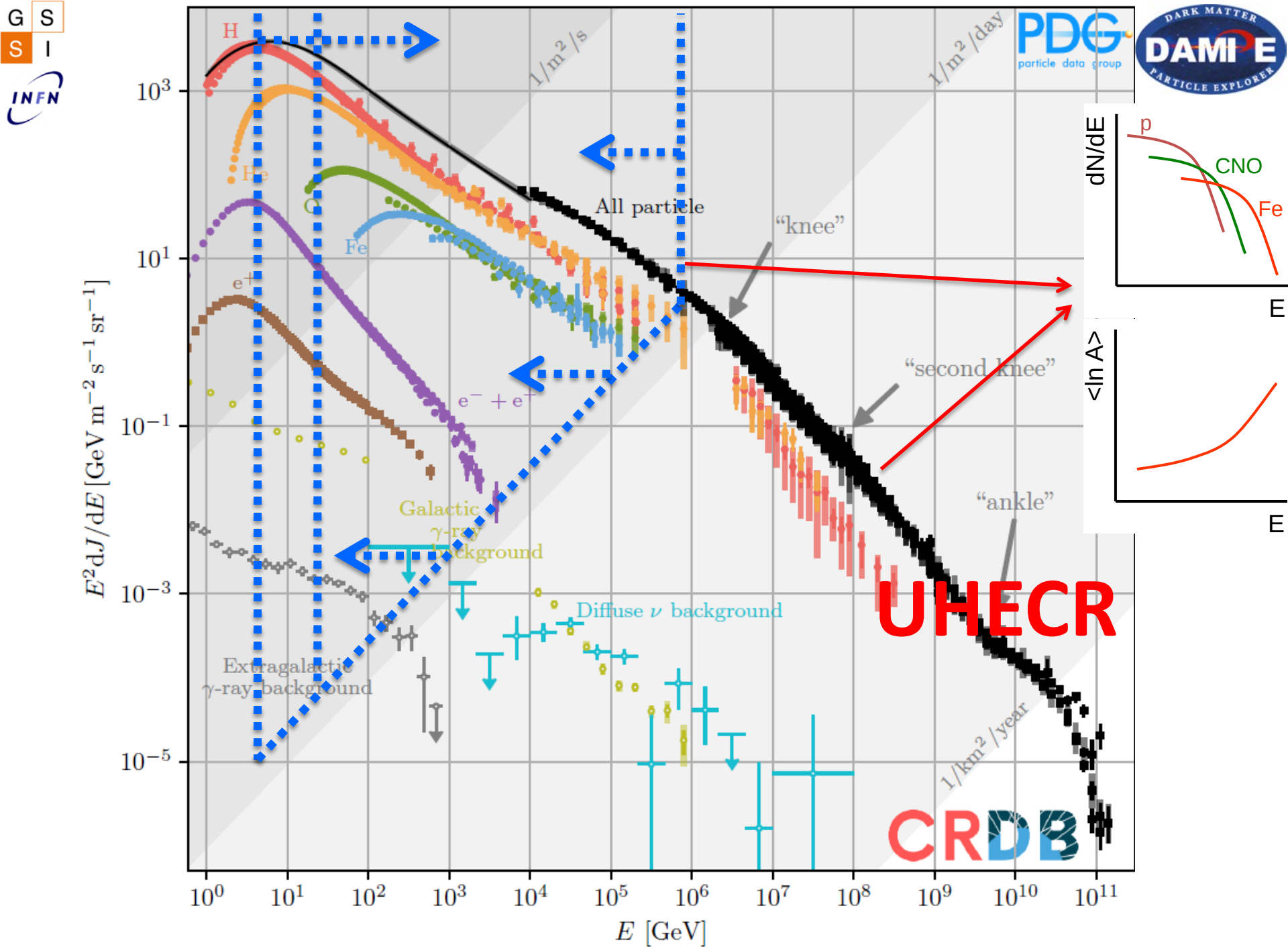
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$E^2 dJ/dE$ [GeV m^{-2} s^{-1} sr^{-1}]
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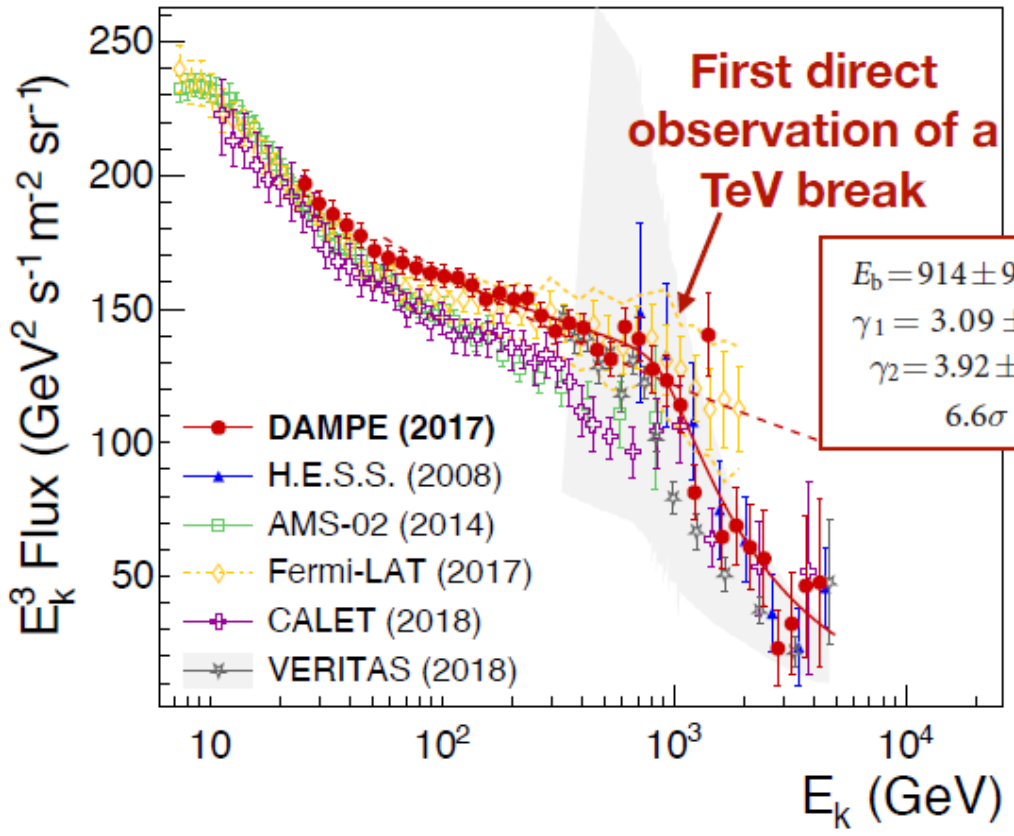
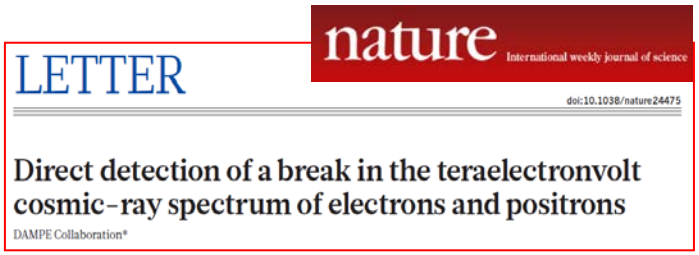
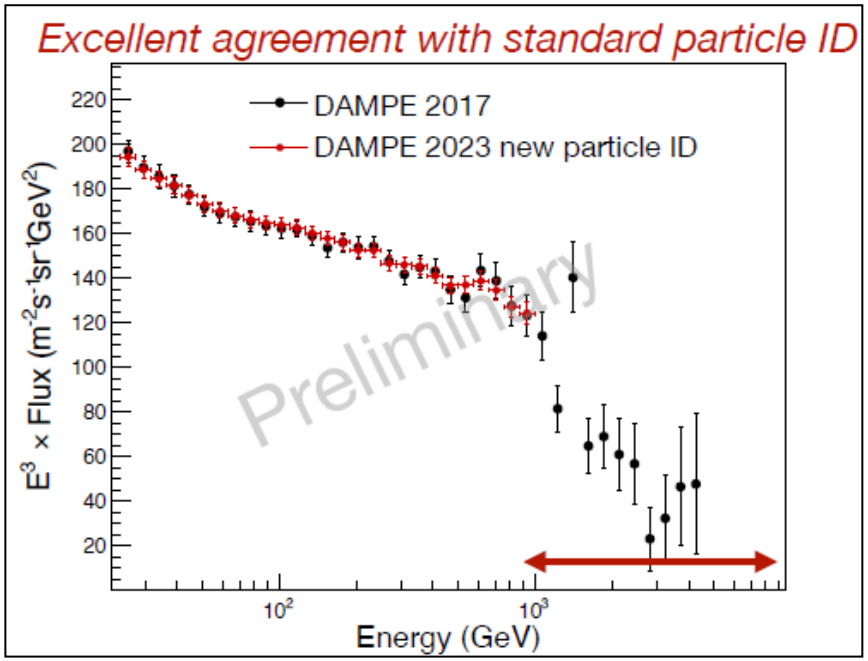
E

The DAMPE (e^++e^-) spectrum



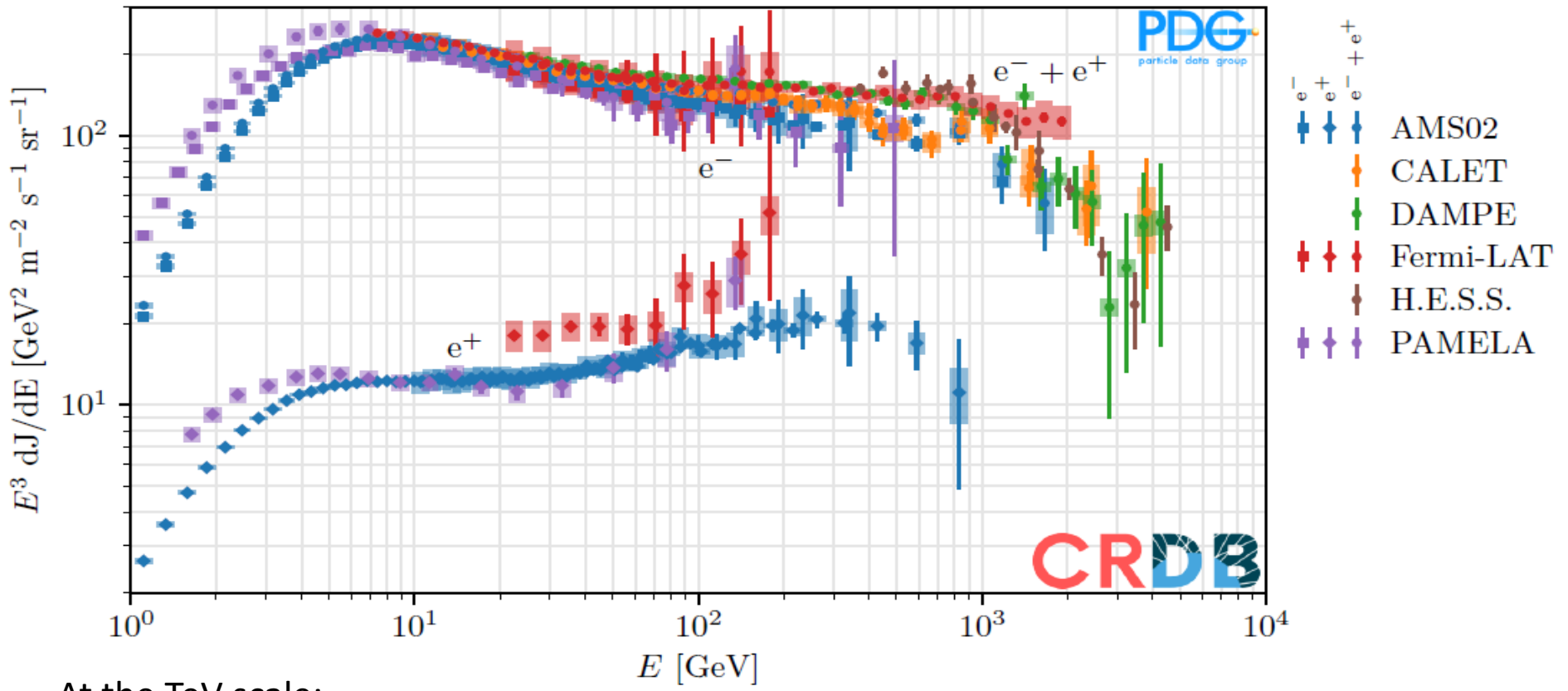


- **530 days**
- **2.8 billions CR events**
- **1.5 million CREs above 25 GeV**



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

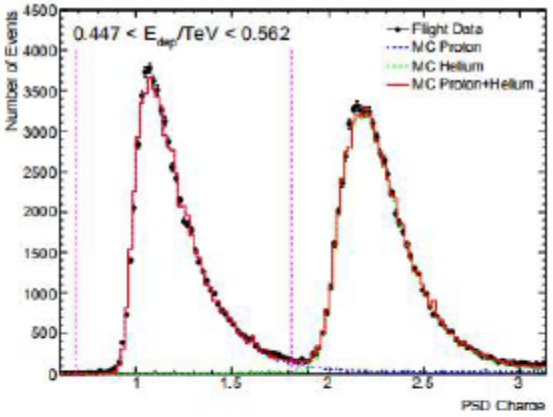
→ Possible anisotropies

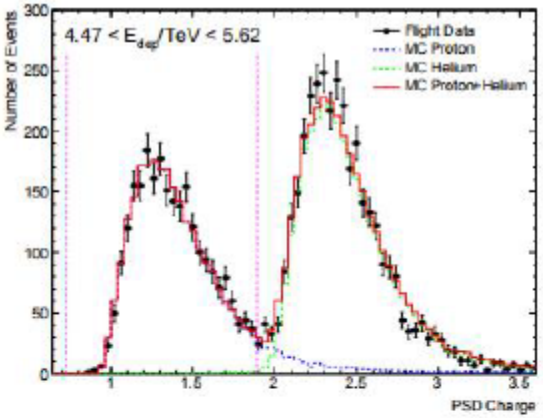
The DAMPE proton spectrum

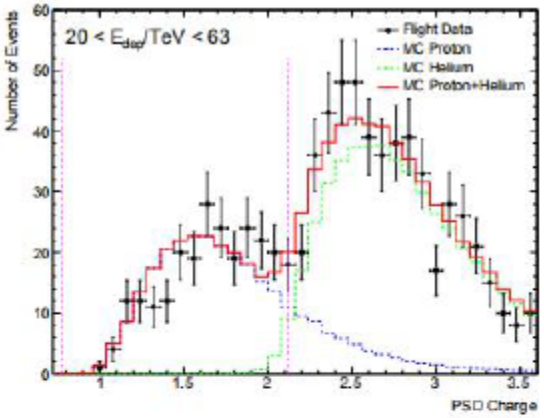
SCIENCE ADVANCES | RESEARCH ARTICLE

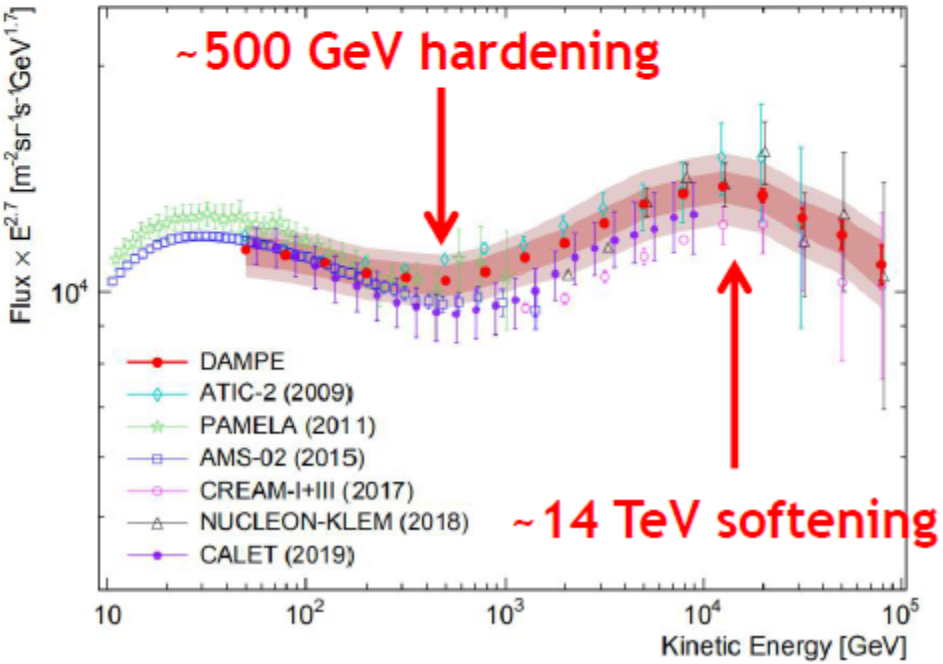
PHYSICS

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









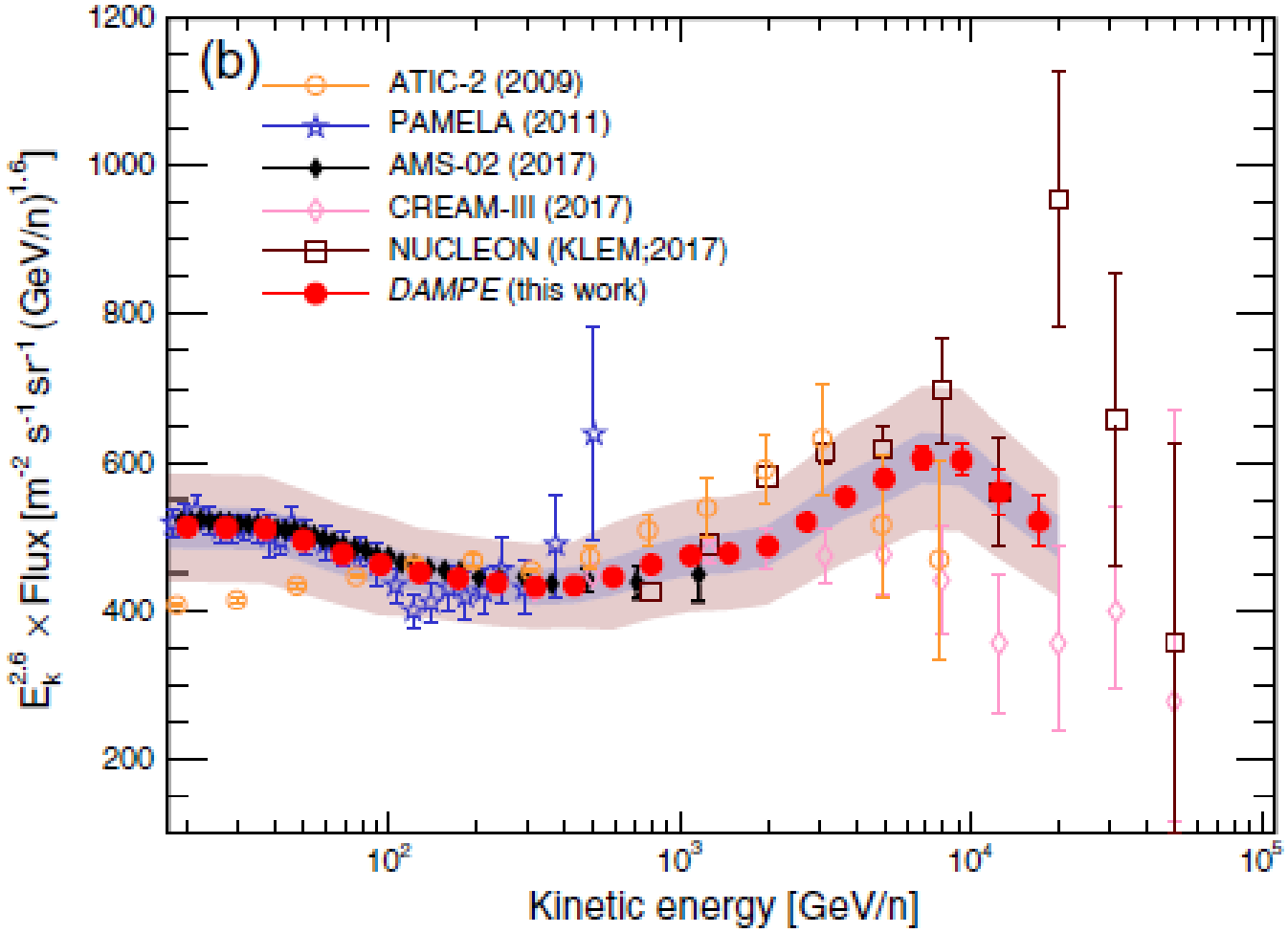
- Confirms the hundreds of GeV hardening
- Detecting a softening at ~14 TeV with high significance

The DAMPE helium spectrum

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

Editors' Suggestion | Featured in Physics

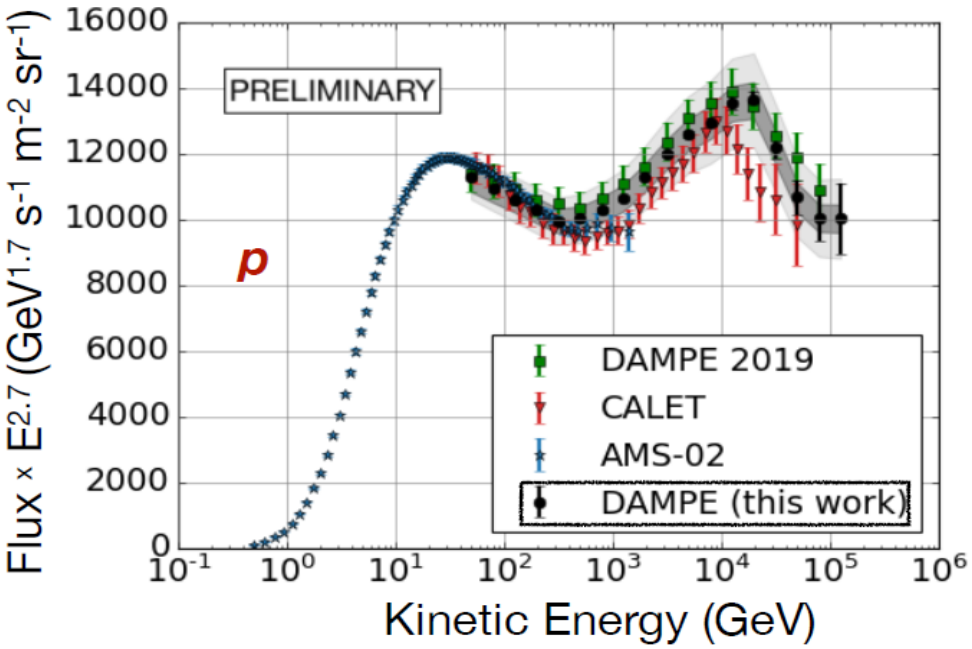
Measurement of the Cosmic Ray Helium Energy Spectrum from 70 GeV to 80 TeV with the DAMPE Space Mission

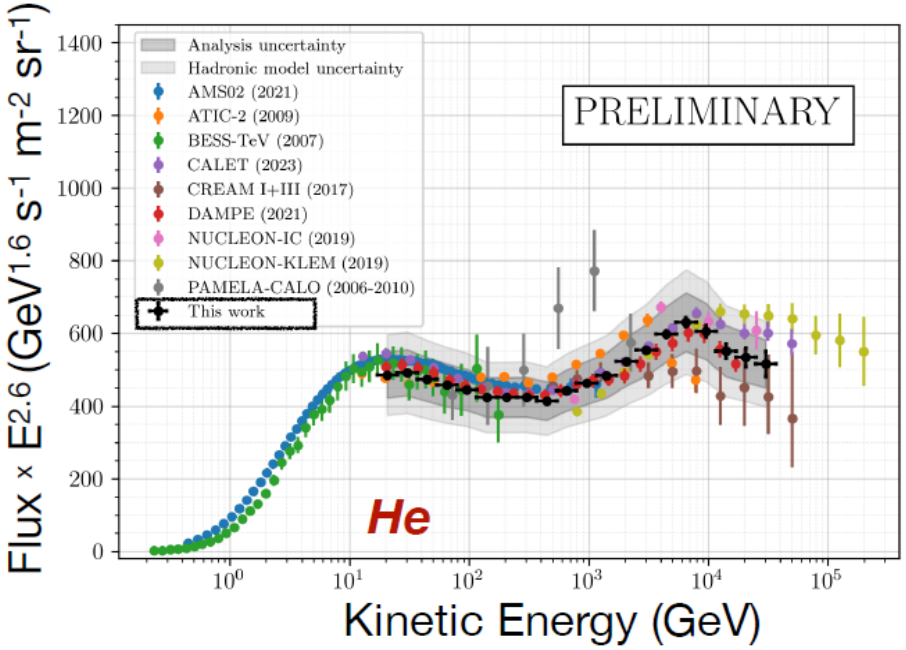


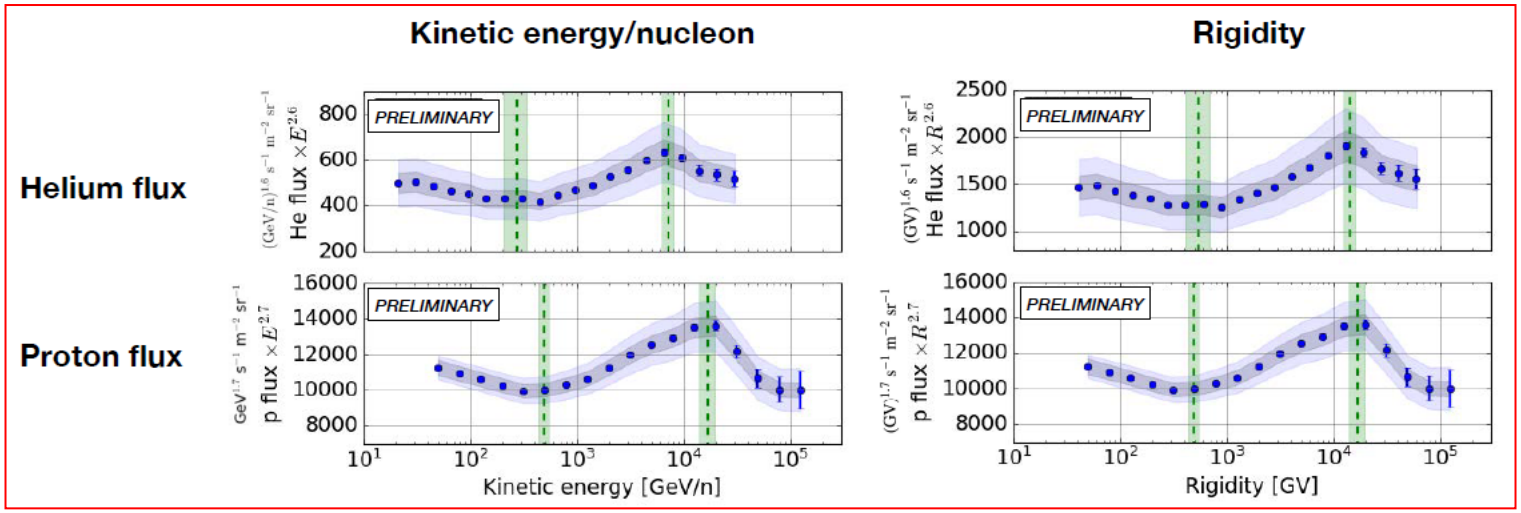
First clear evidence for a softening at about 34 TeV

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

p and He spectra: updates

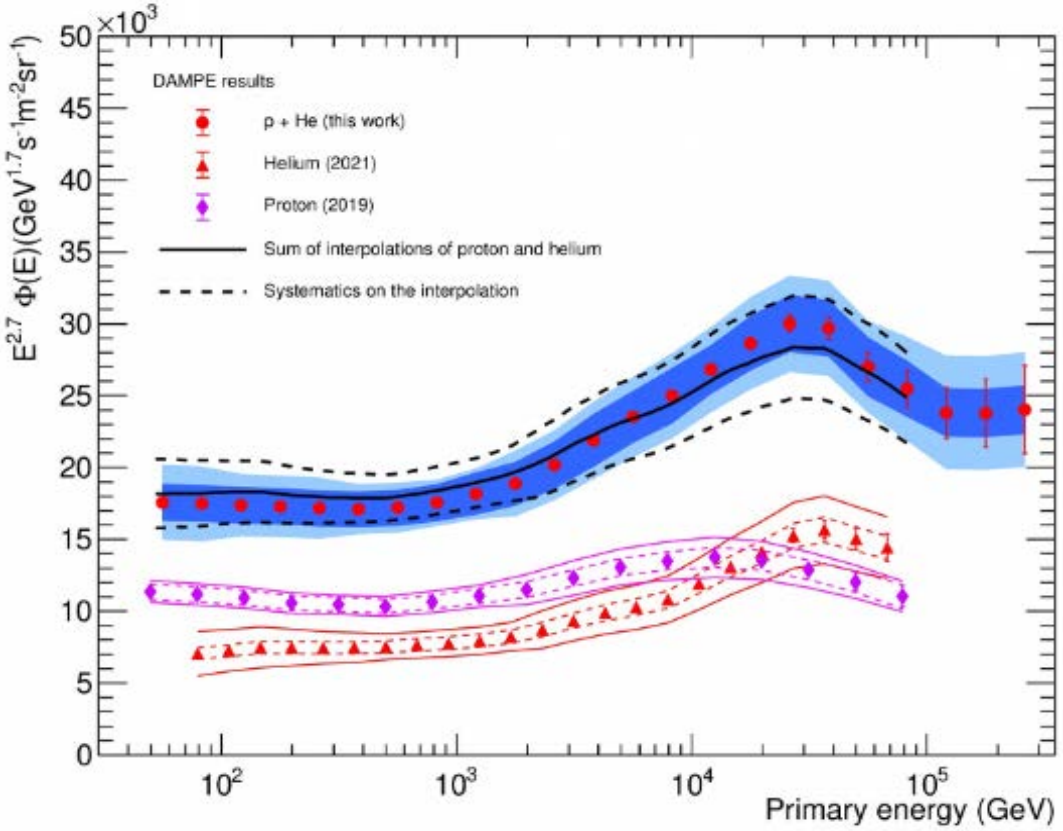


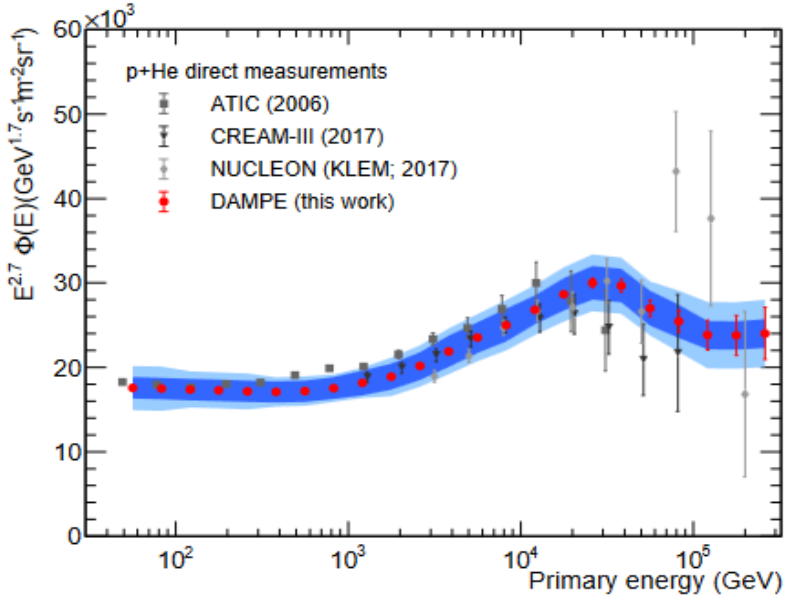


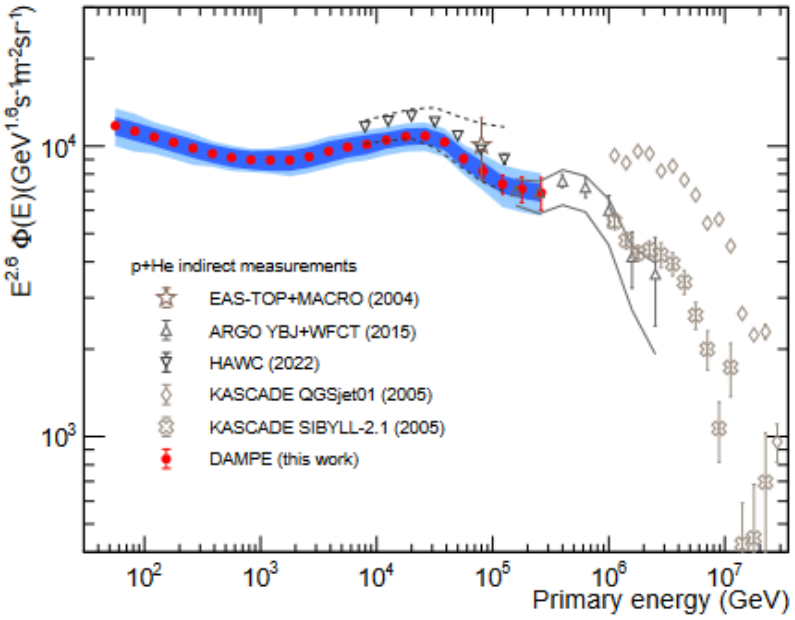


A rigidity dependence of both hardnening and softening is favoured by data

The p+He spectrum

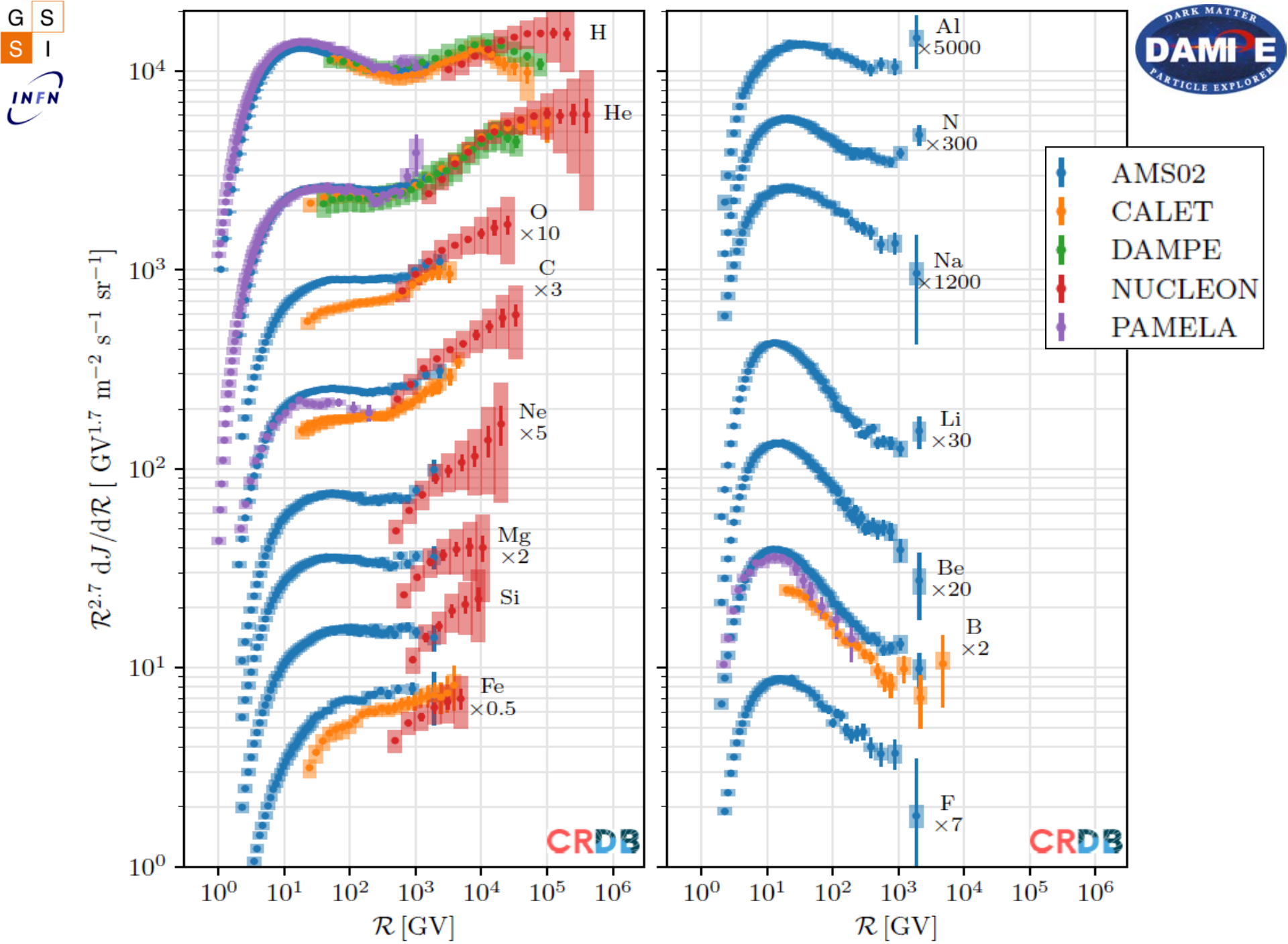






- Confirmation of the softening at 15TV
- Hint for a hardening above 100 TeV
- bridge with indirect measurements

Accepted by PRD (→ 0.5 PeV)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CRDB
$\mathcal{R}^{2.7}\, dJ/d\mathcal{R}$ [GV$^{1.7}$ m^{-2} s^{-1} sr^{-1}]
$\mathcal{R}$ [GV]
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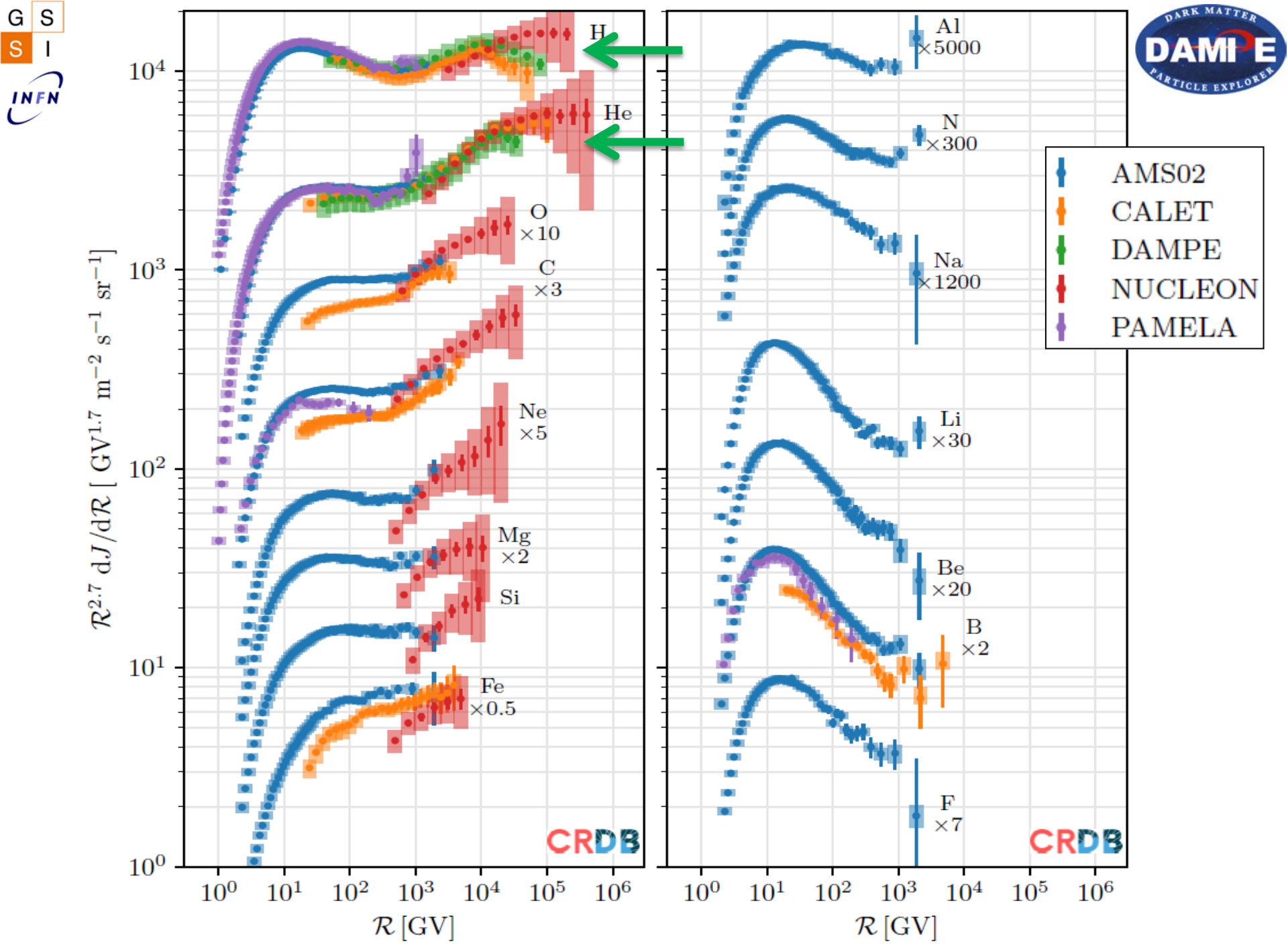
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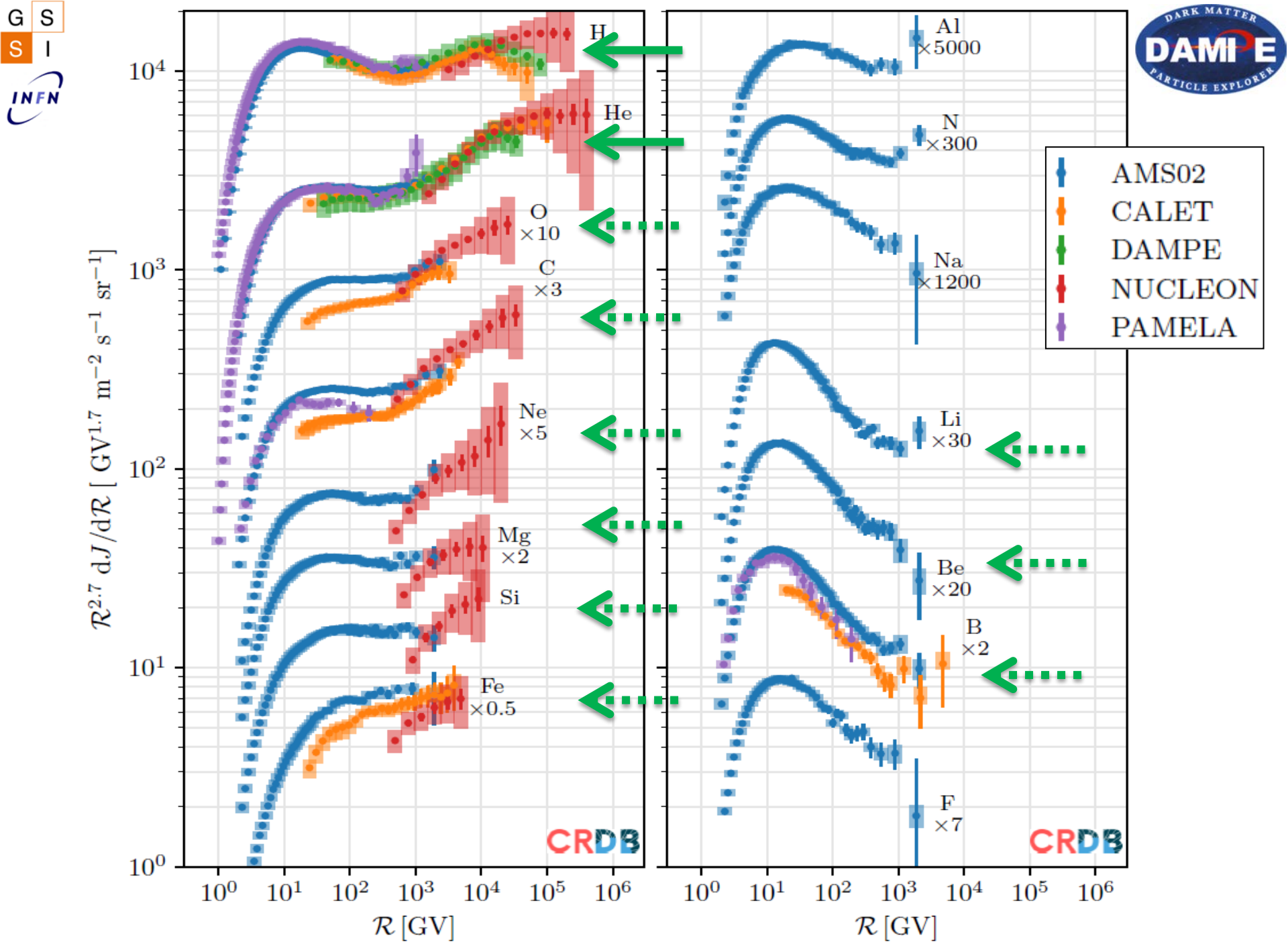
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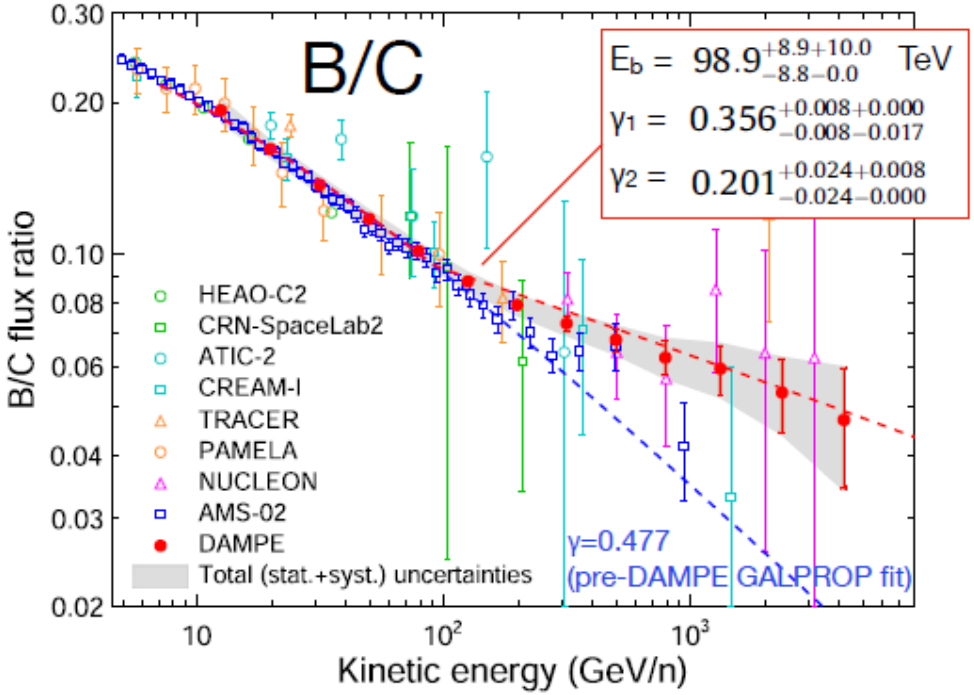
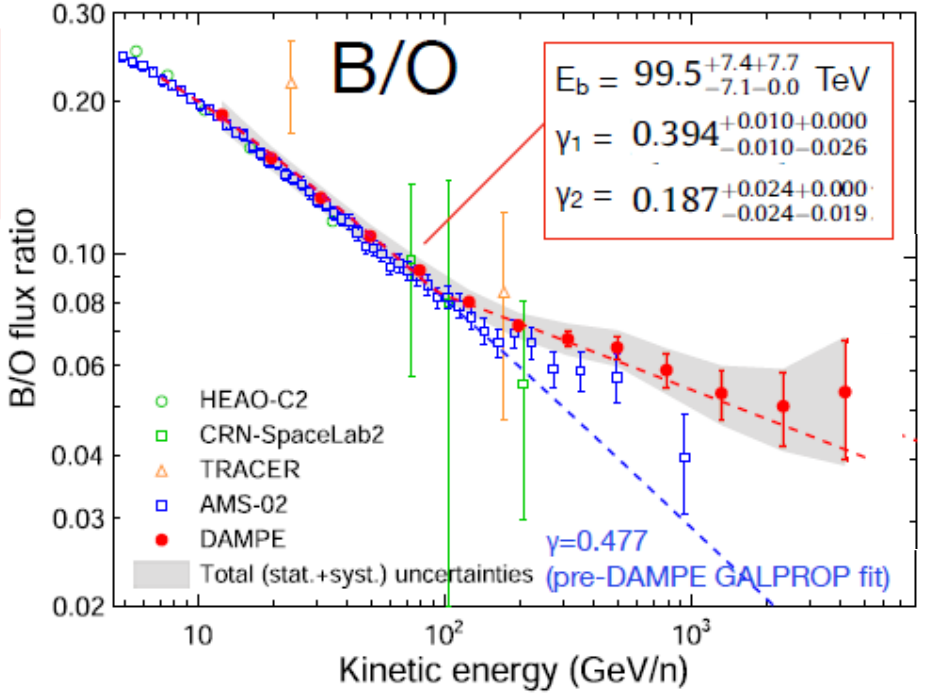
$\mathcal{R}^{2.7}\,\mathrm{d}J/\mathrm{d}\mathcal{R}$ [$\mathrm{GV}^{1.7}\ \mathrm{m}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$]
$\mathcal{R}$ [GV]
$\mathcal{R}$ [GV]

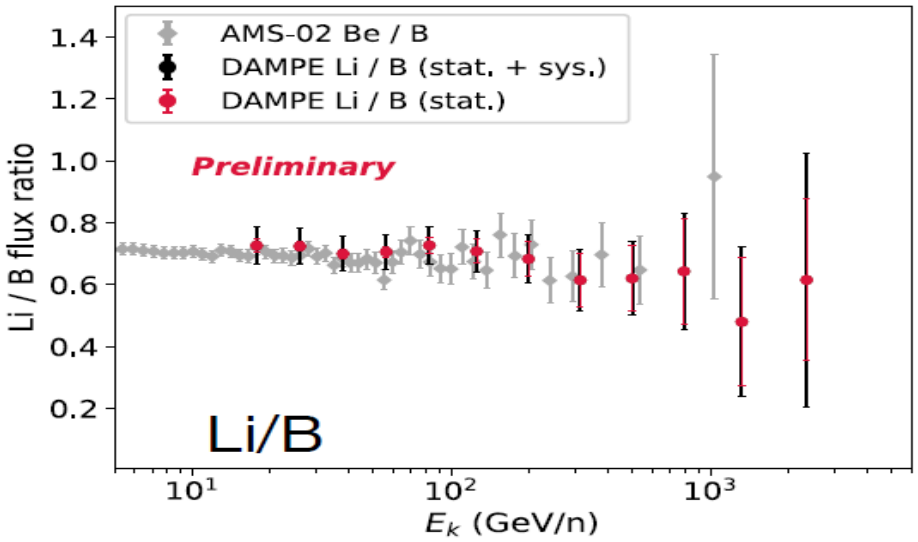
Flux ratios

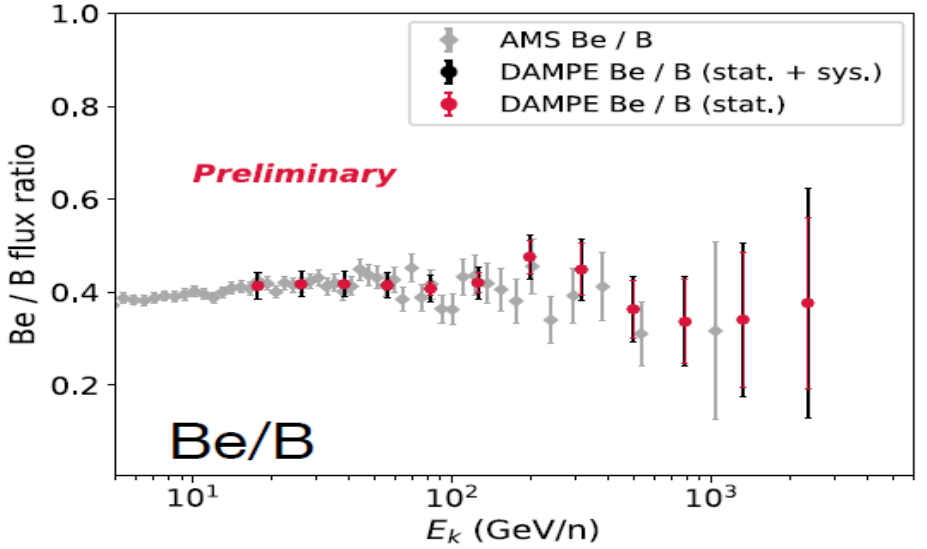
B/C and B/O

DAMPE Coll. Science Bull. 67 (2022) 21

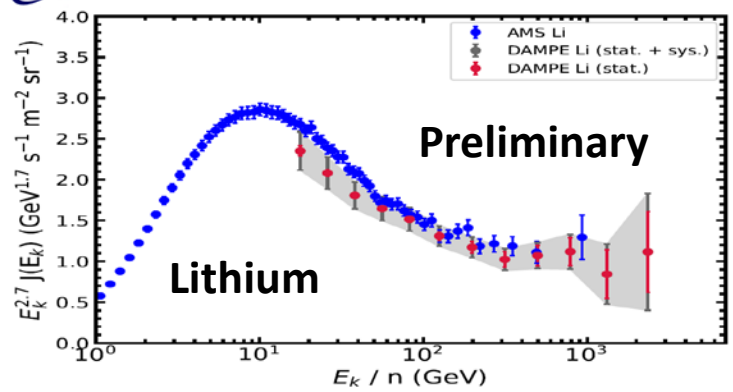


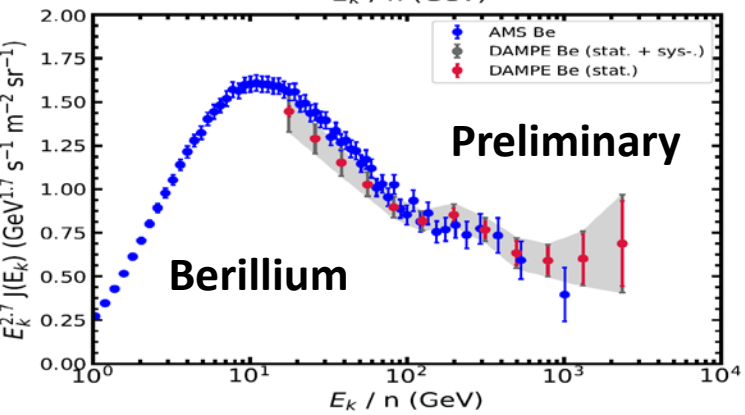


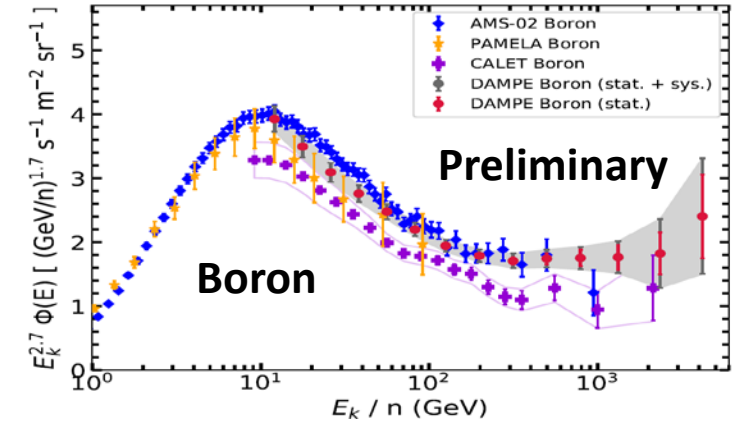


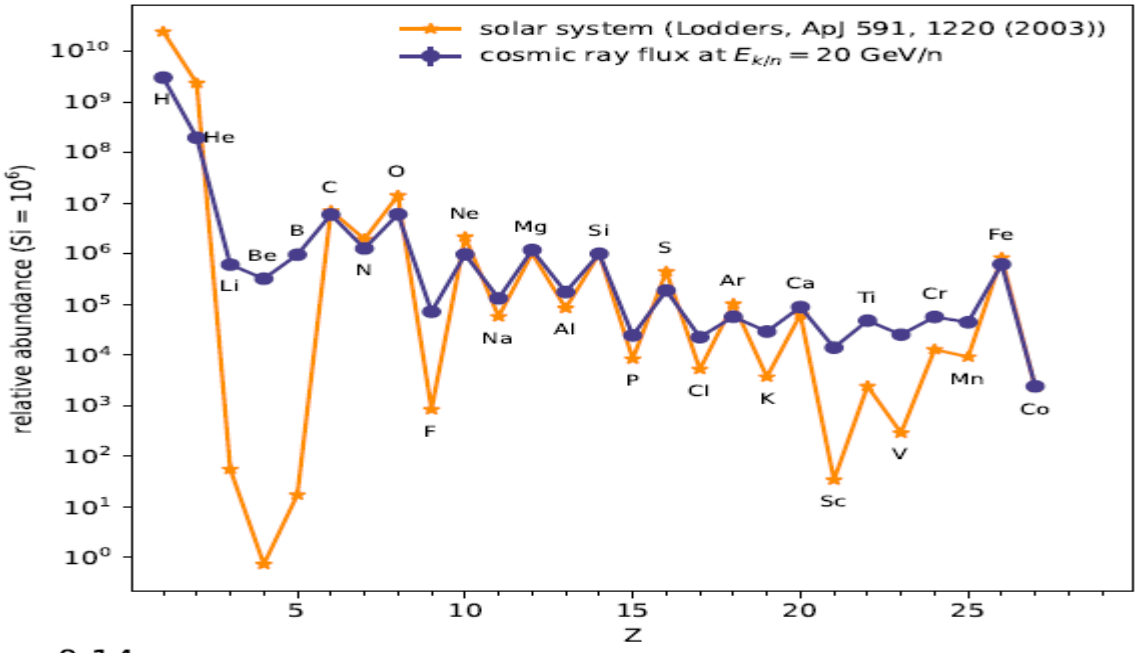


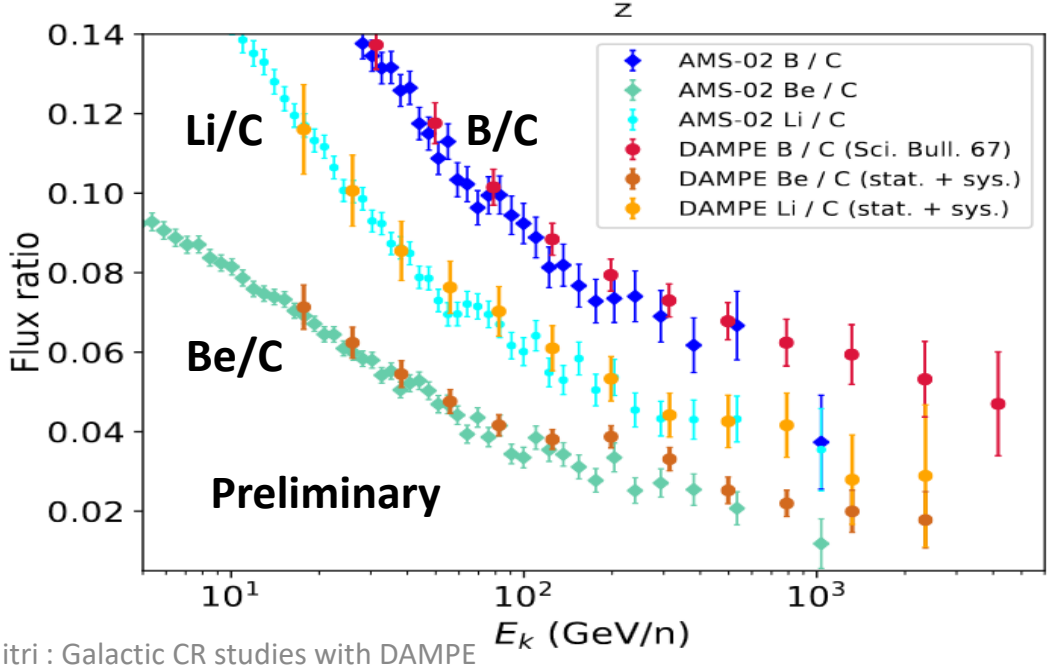
Secondaries: Li, Be and B



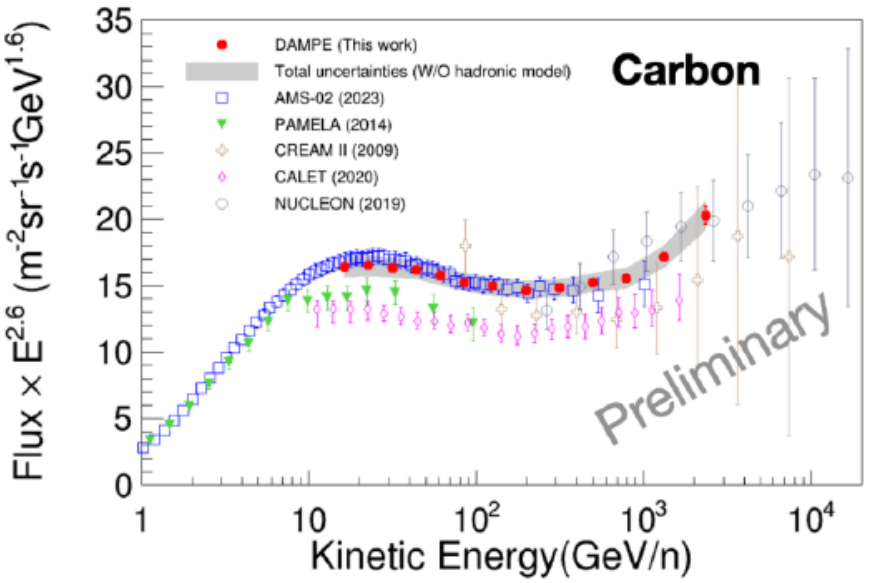


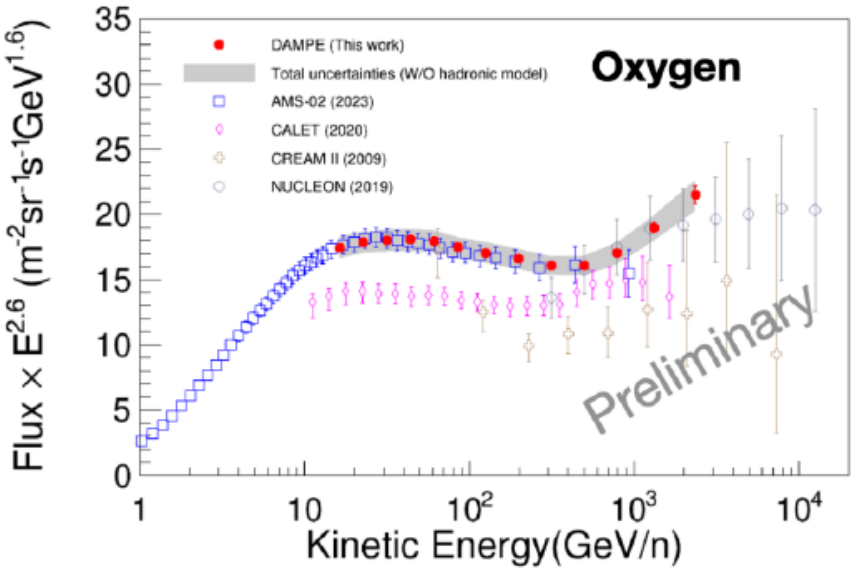


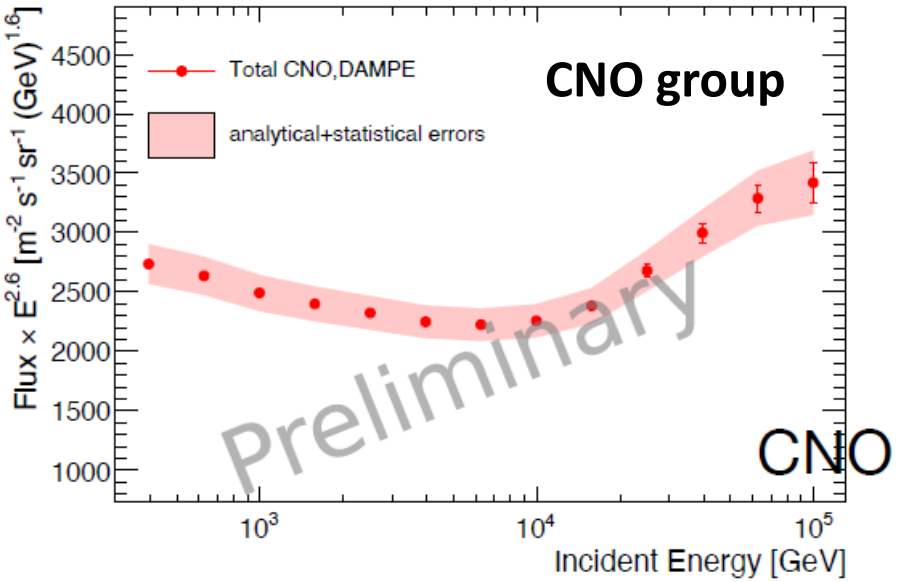


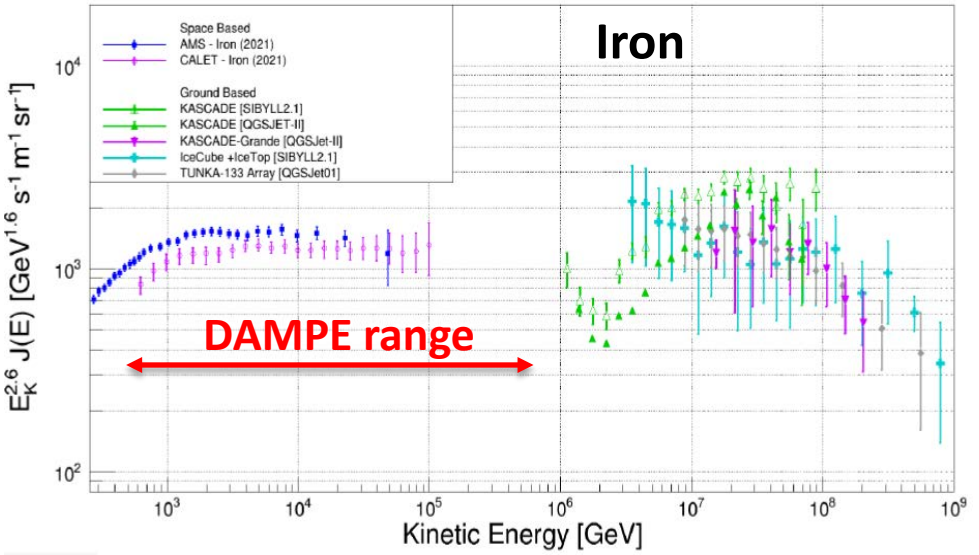


Heavier elements…

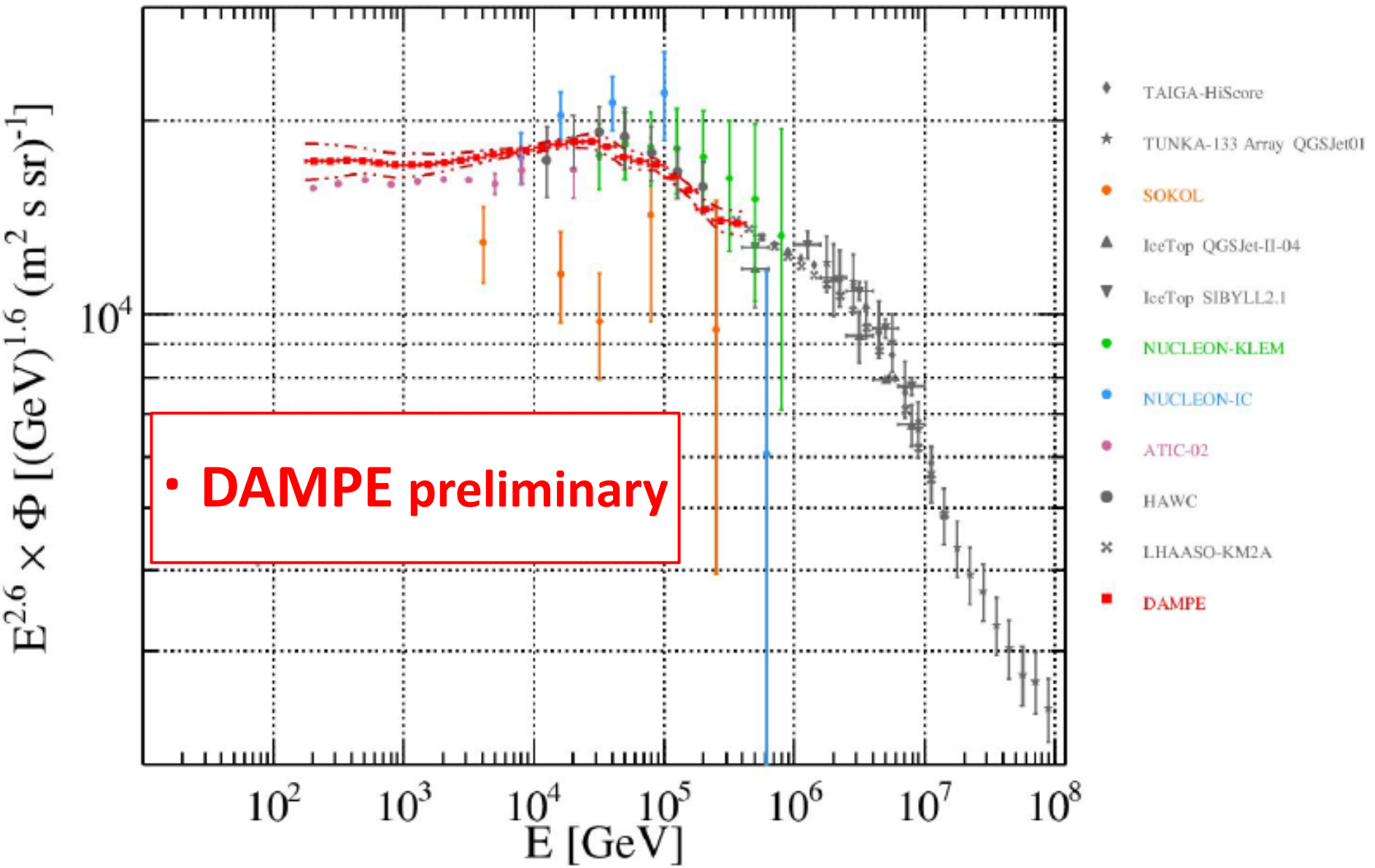






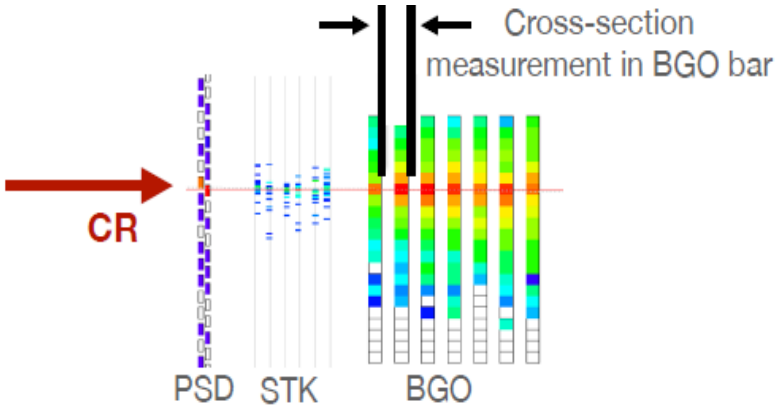


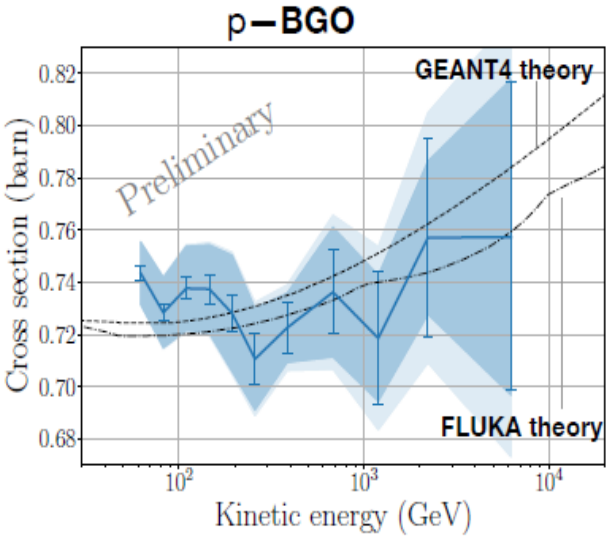
The all-particle spectrum

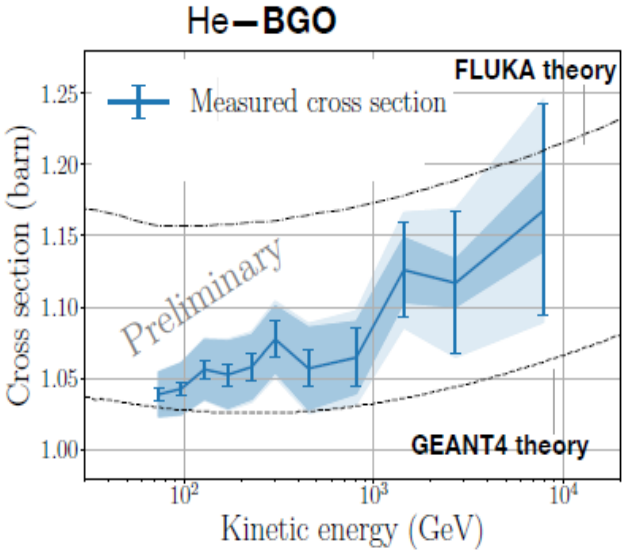


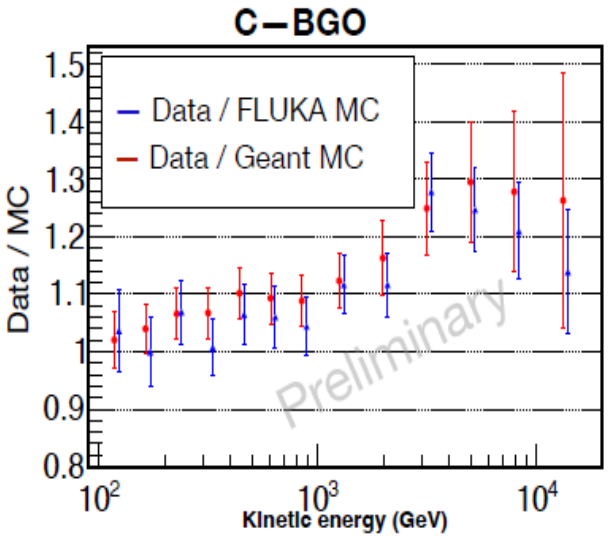
Hadronic interaction studies

- Good segmentation of BGO calorimeter allows to use DAMPE for cross-section measurements:
  - p, He
  - C, O









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)
- "Mutiple" 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 17, 2015
- On orbit operation steady and with high efficiencies
- Absolute energy calibration by using the geomagnetic cut-off
- Absolute pointing cross check by use of the photon map

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
- Undergoing spectral measurements of heavier nuclei and secondary-to-primary ratios
- …..
- Preliminary studies of gamma ray sources (250 sources, Fermi bubble, …)
- Detected new features in Forbush decrease
- Search for dark matter signatures (upper limits from gamma line searches,…)

More Stuff

The collaboration

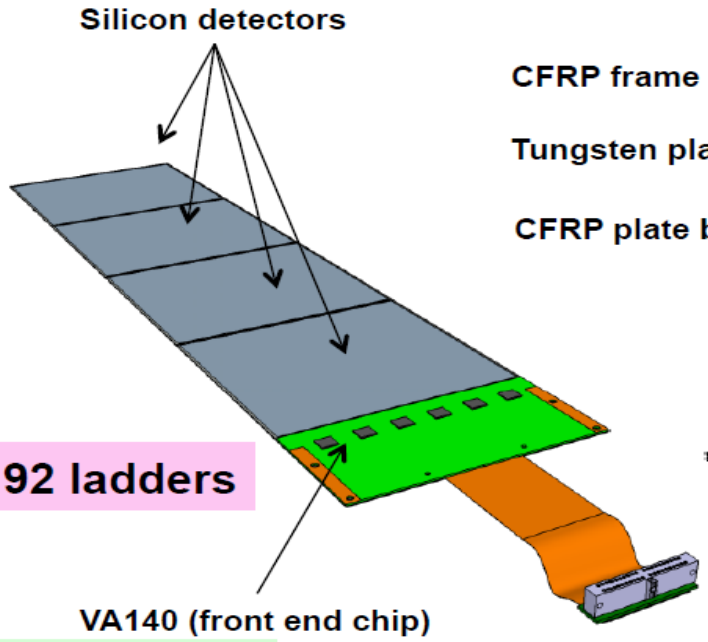
- **CHINA**
  - Purple Mountain Observatory, CAS, Nanjing
  - Institute of High Energy Physics, CAS, Beijing
  - National Space Science Center, CAS, Beijing
  - University of Science and Technology of China, Hefei
  - Institute of Modern Physics, CAS, Lanzhou

- **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

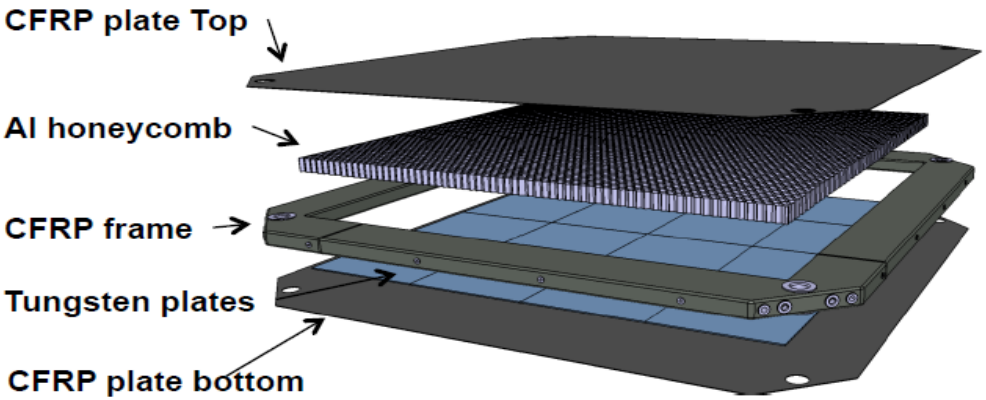
The Silicon TracKer (STK)

768 silicon sensors

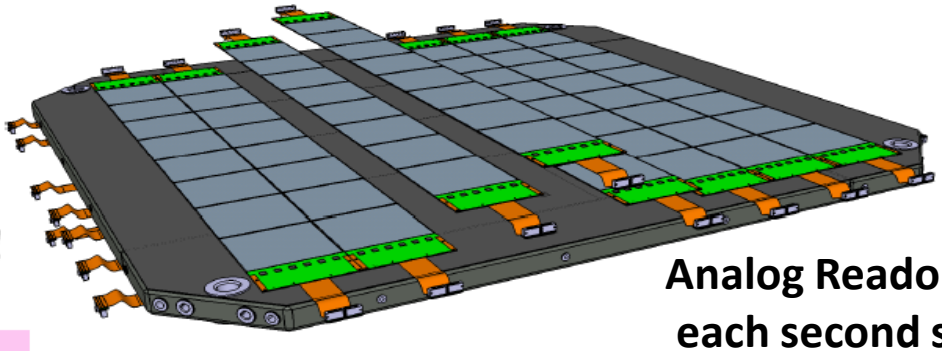


1152 ASICs

73728 channels

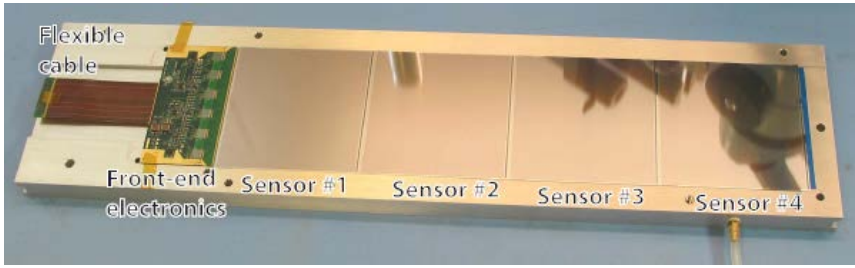


12 layers, 6-x and 6-y



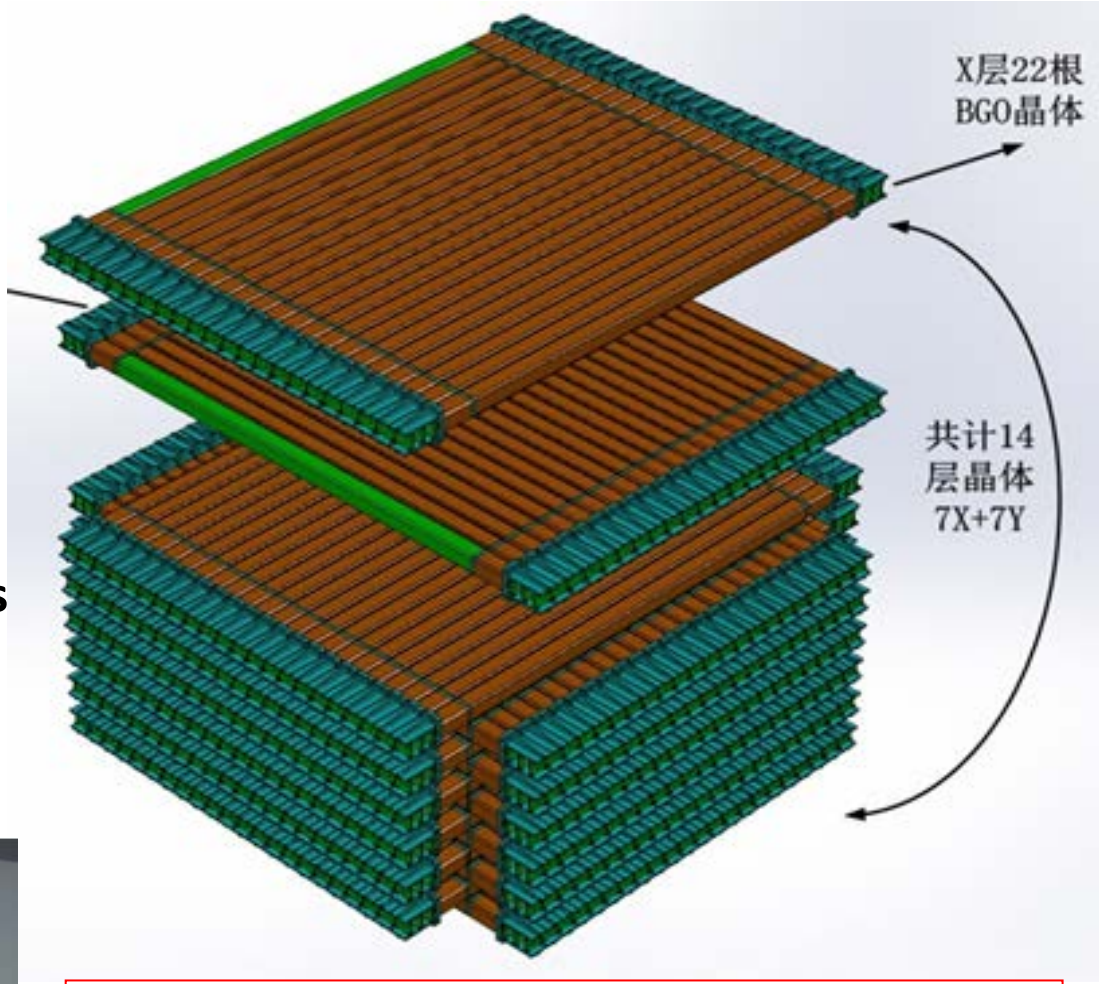
Analog Readout of each second strip:
384 channels / SSD- Ladder
Charge sharing

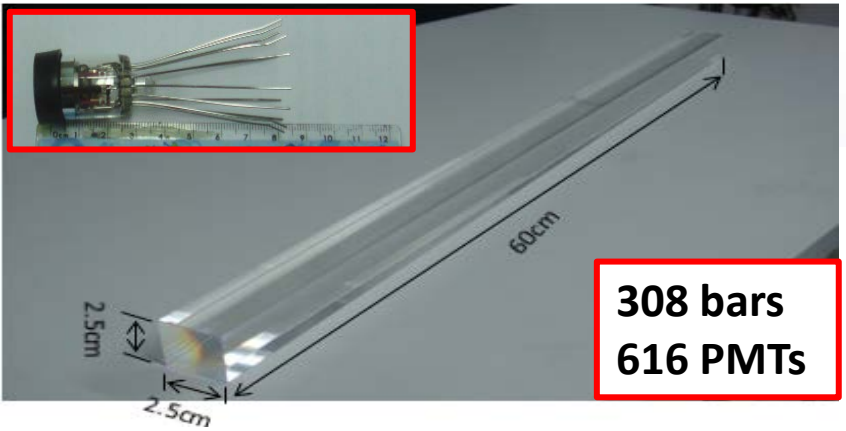
- 48 μm wide Si strips with 121 μm pitch
- (95 × 95 × 0.32 mm^3) Silicon Strip Detector (SSD)
- 768 strips in each SSD
- One ladder composed by 4 (SSD)
- 16 Ladders per layer (76 cm × 76 cm)
- 12 layers (6x + 6y)



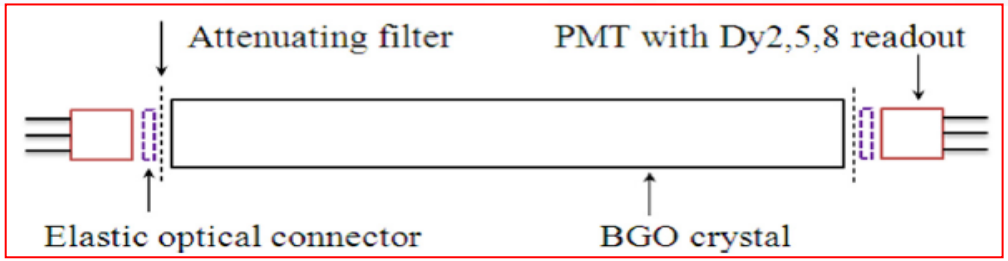
The CALOrimeter

- **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**

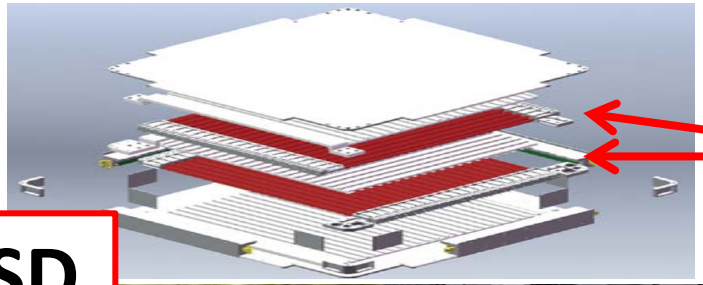




308 bars
616 PMTs

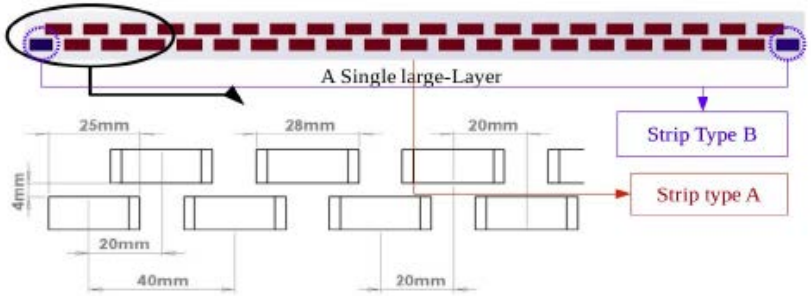


The Plastic Scintillator Detector and the NeUtron Detector

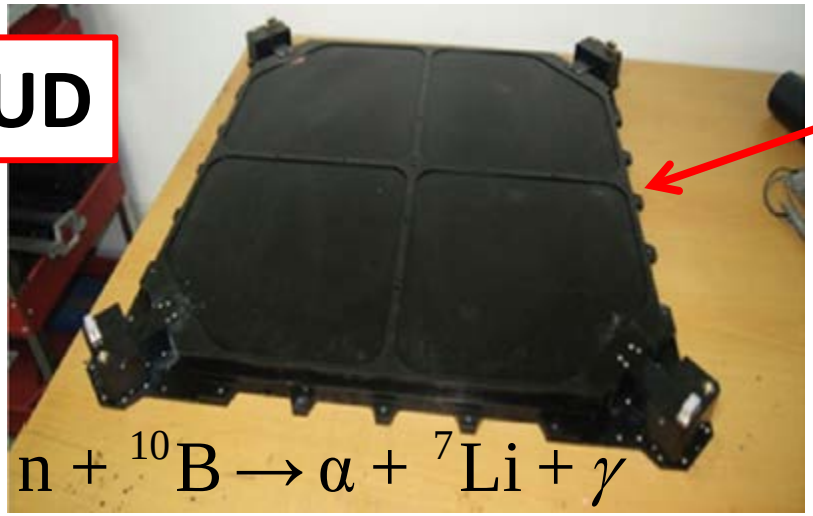


PSD

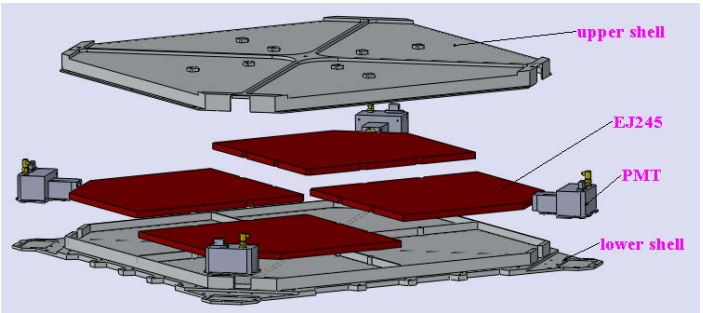
- 1.0 cm thick ,2.8cm wide and 82.0 cm long scintillator strips
- staggered by 0.8 cm in a layer
- 82 cm × 82 cm layers
- 2 layers (x and y)



NUD

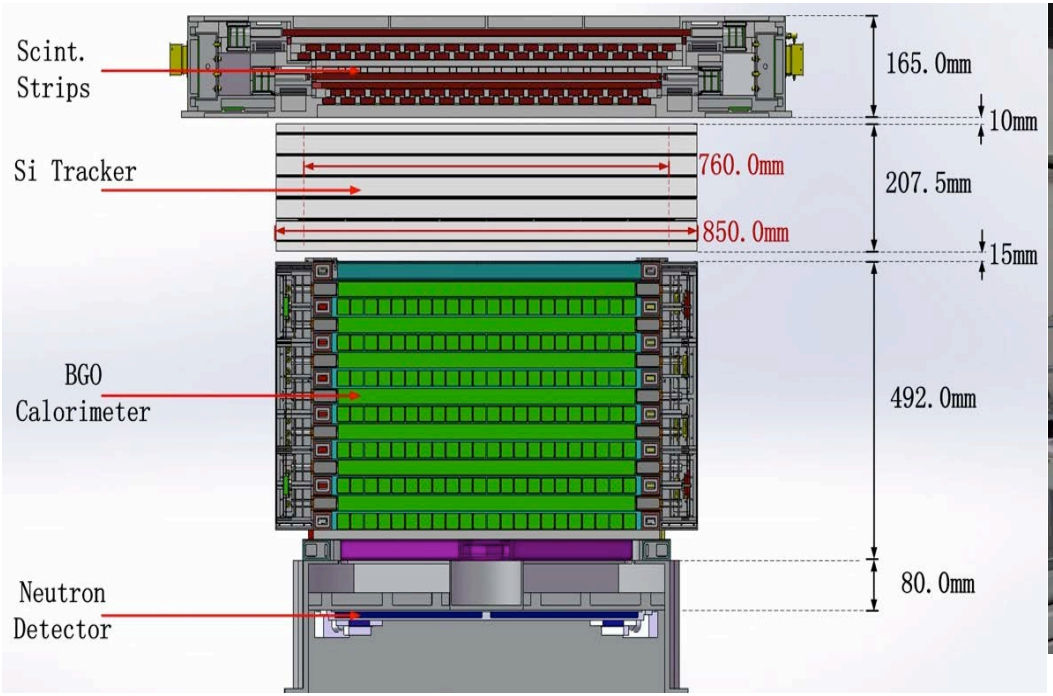


- 4 large area boron-doped plastic scintillators (30 cm × 30 cm × 1 cm)



Comparison with AMS-02 and FERMI

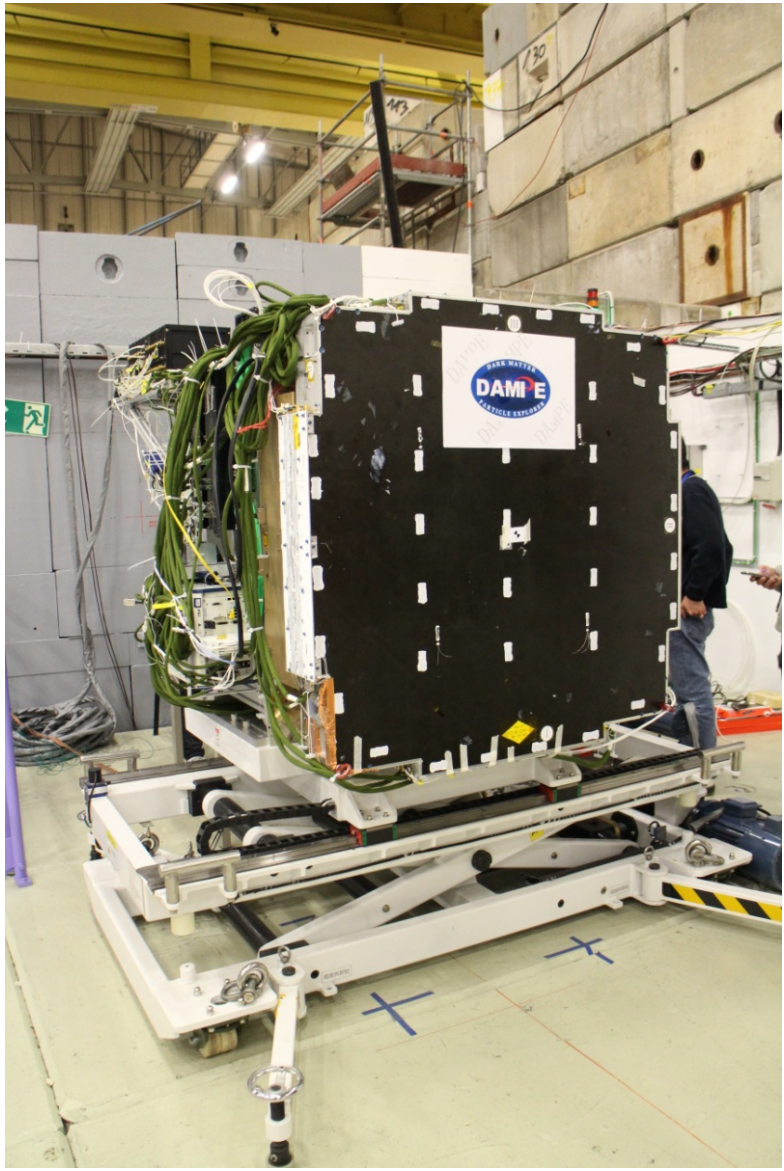
	DAMPE	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	**1.2**	3	10
e/γ Angular res.@100 GeV (deg)	0.2	0.3	0.1
e/p discrimination	10^5-10^6	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	**32**	17	8.6
Geometrical accep. (m^2sr)	**0.3**	0.09	1



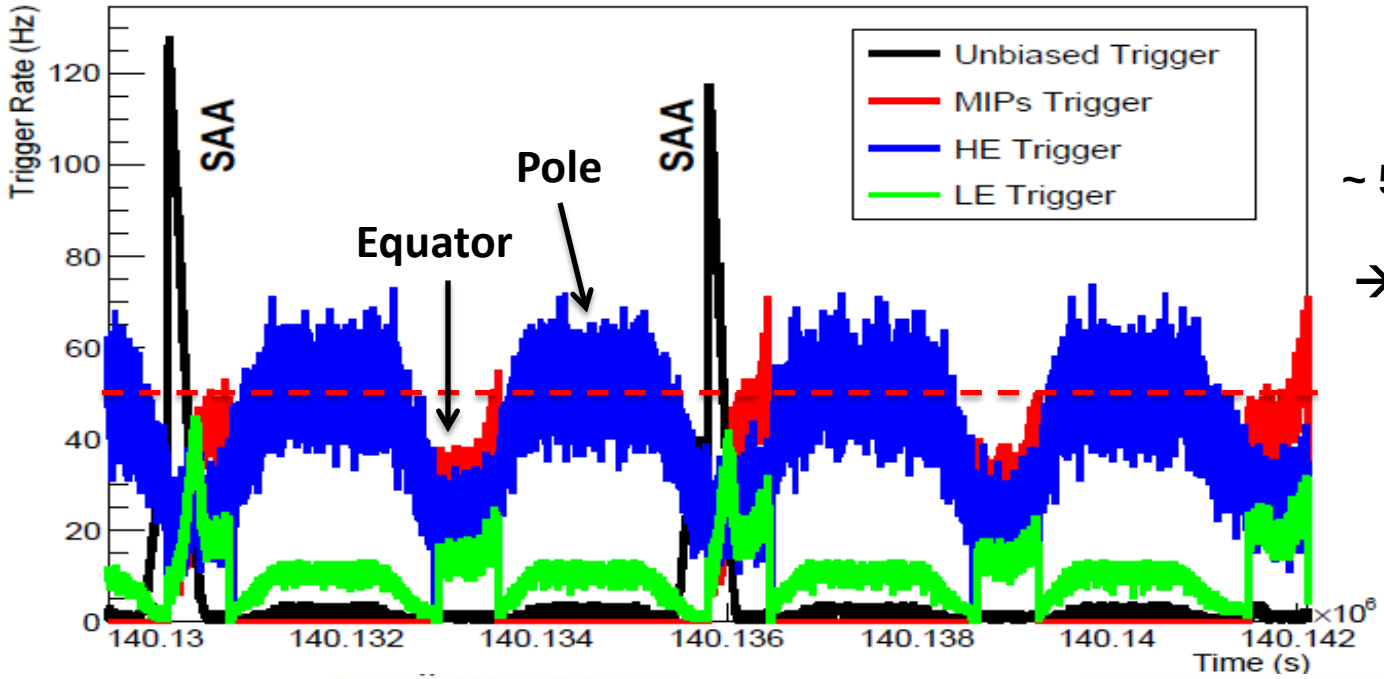
Mass: 1400 Kg
Power: ~ 400 W
Livetime: > 3 years

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)

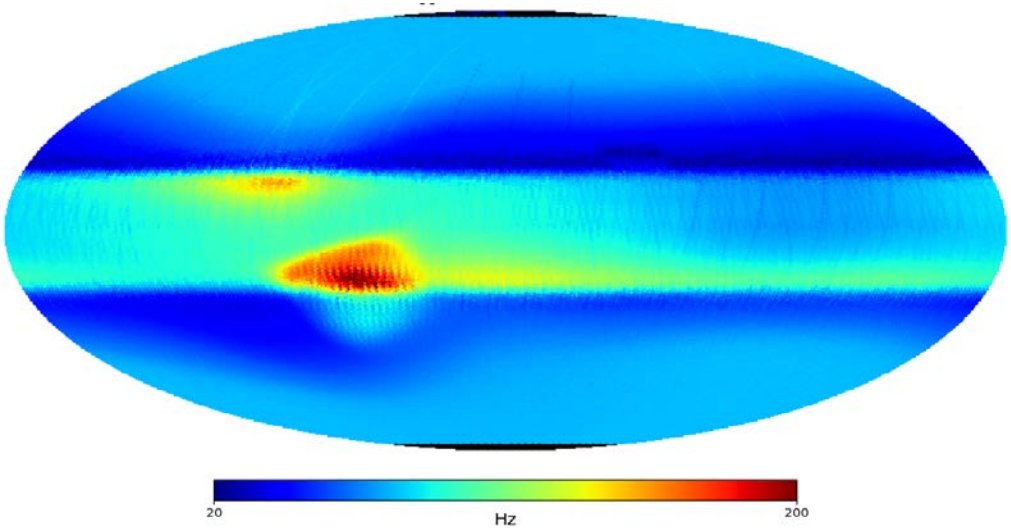


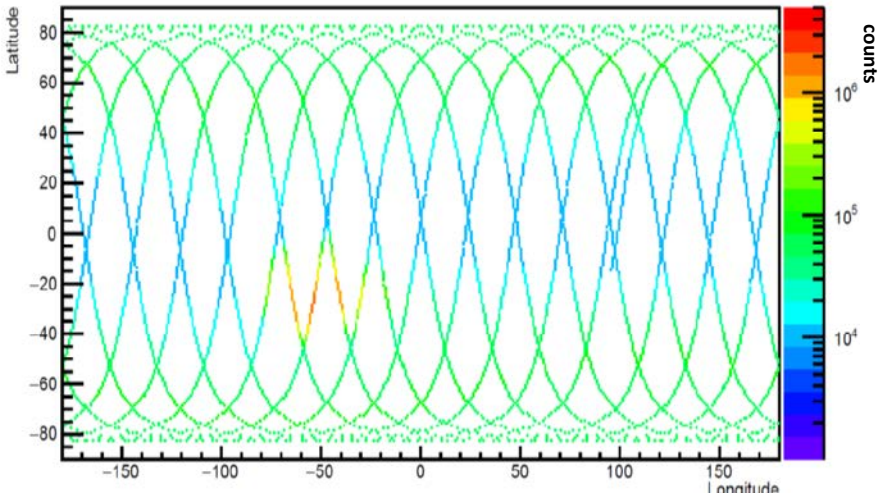
Trigger rate in orbit



~ 50 Hz average trigger rate

→100GB/day on ground (about 5 M events)

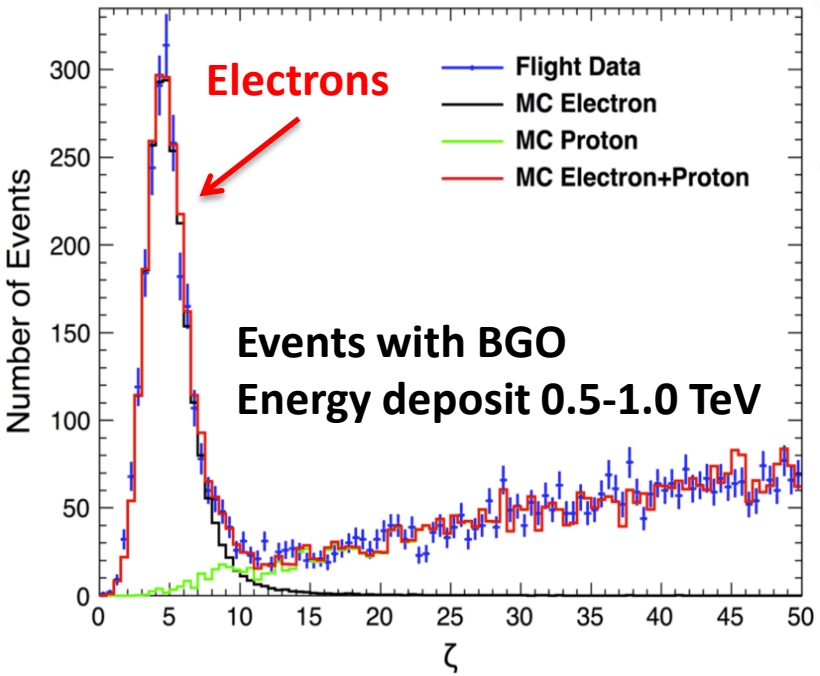


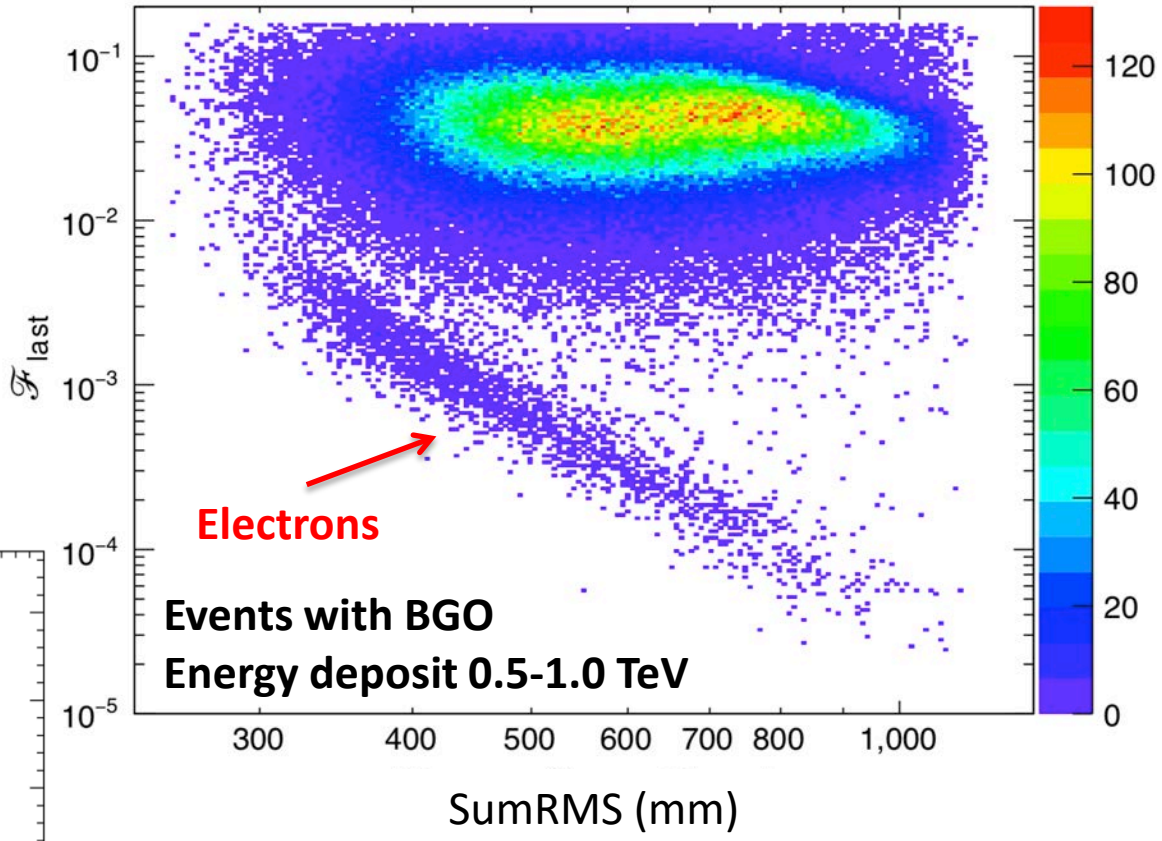


Electron IDentification

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

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

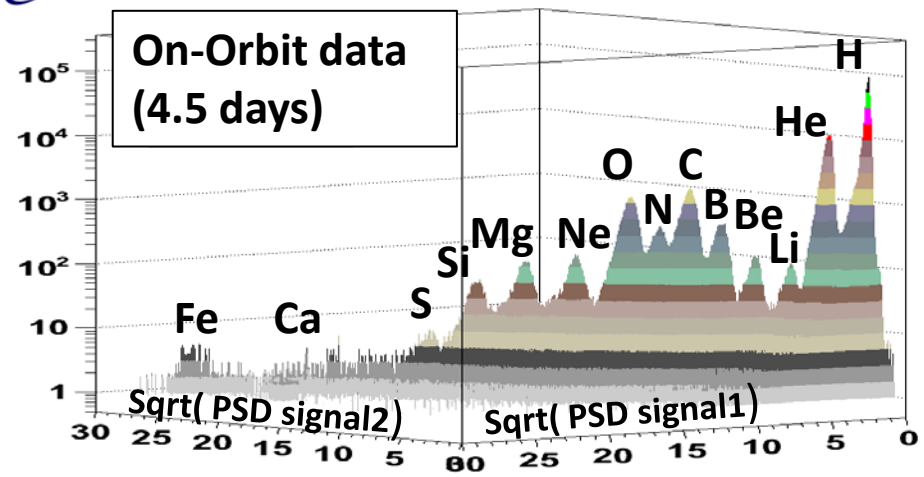


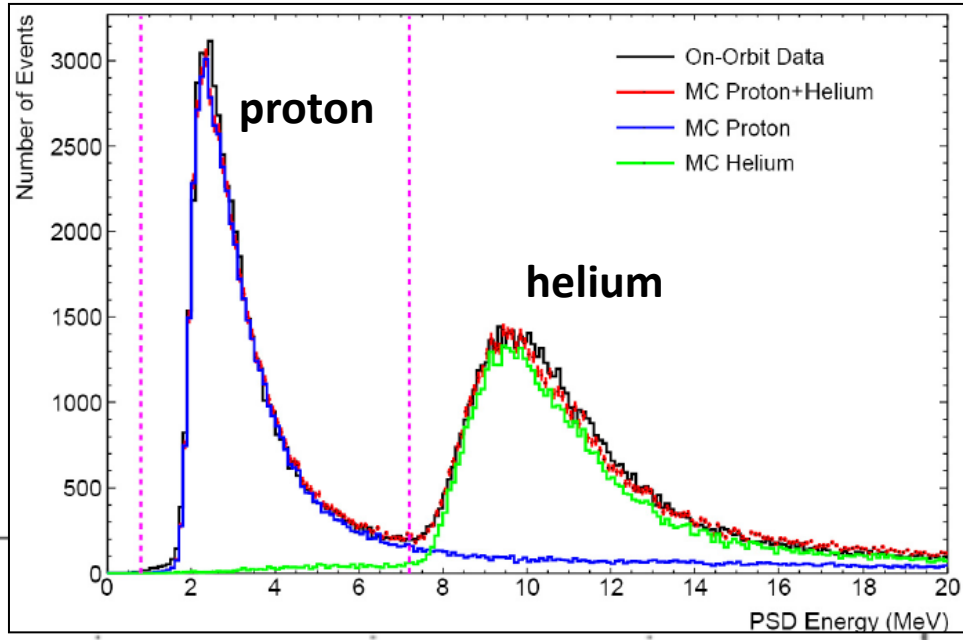


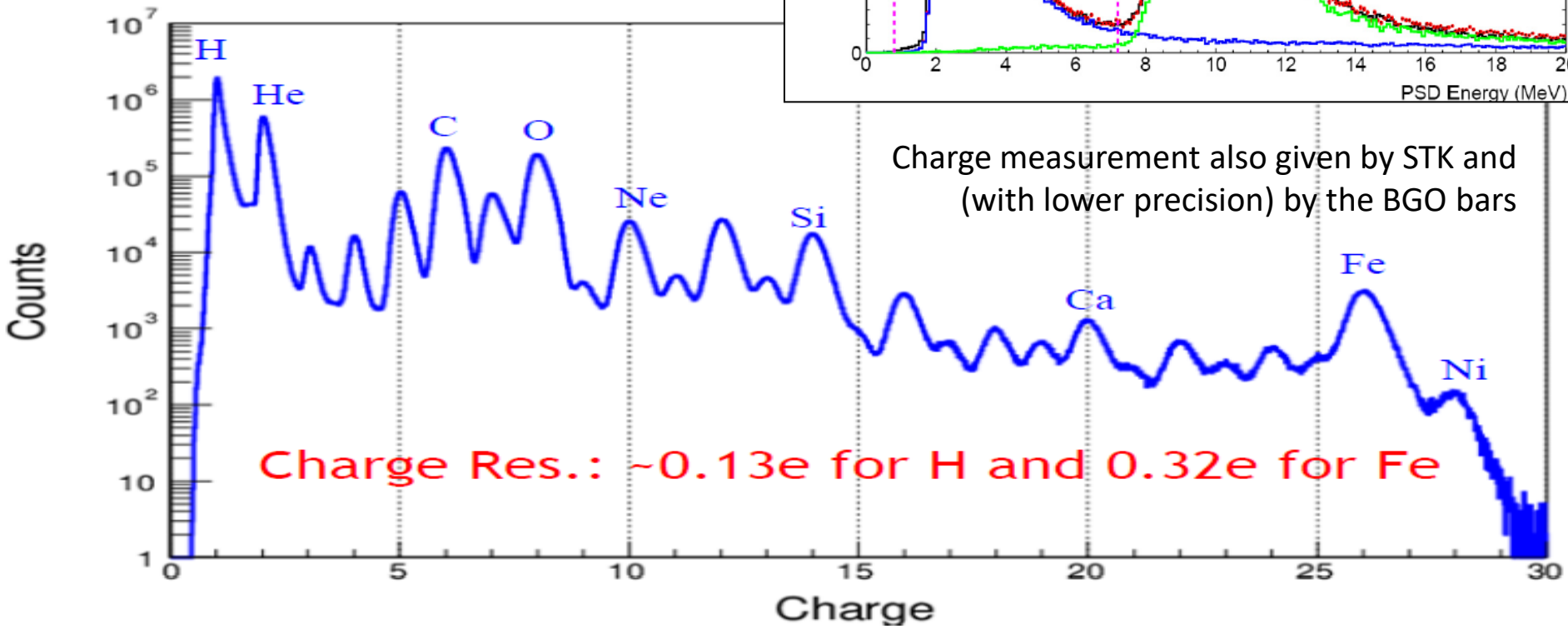
SumRMS = Sum of single layer RMS values

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

Nuclei ID with PSD



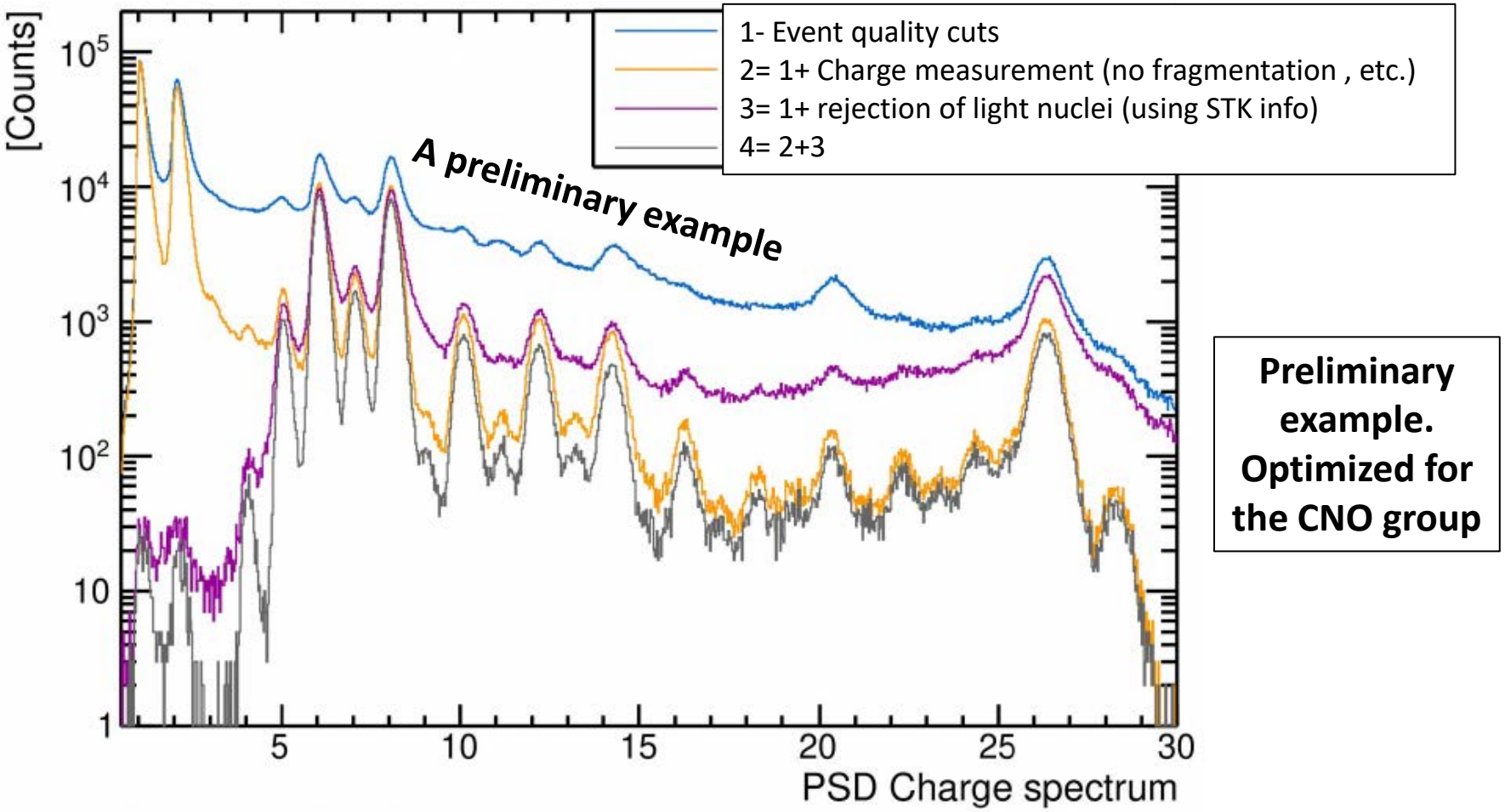




Charge measurement also given by STK and (with lower precision) by the BGO bars

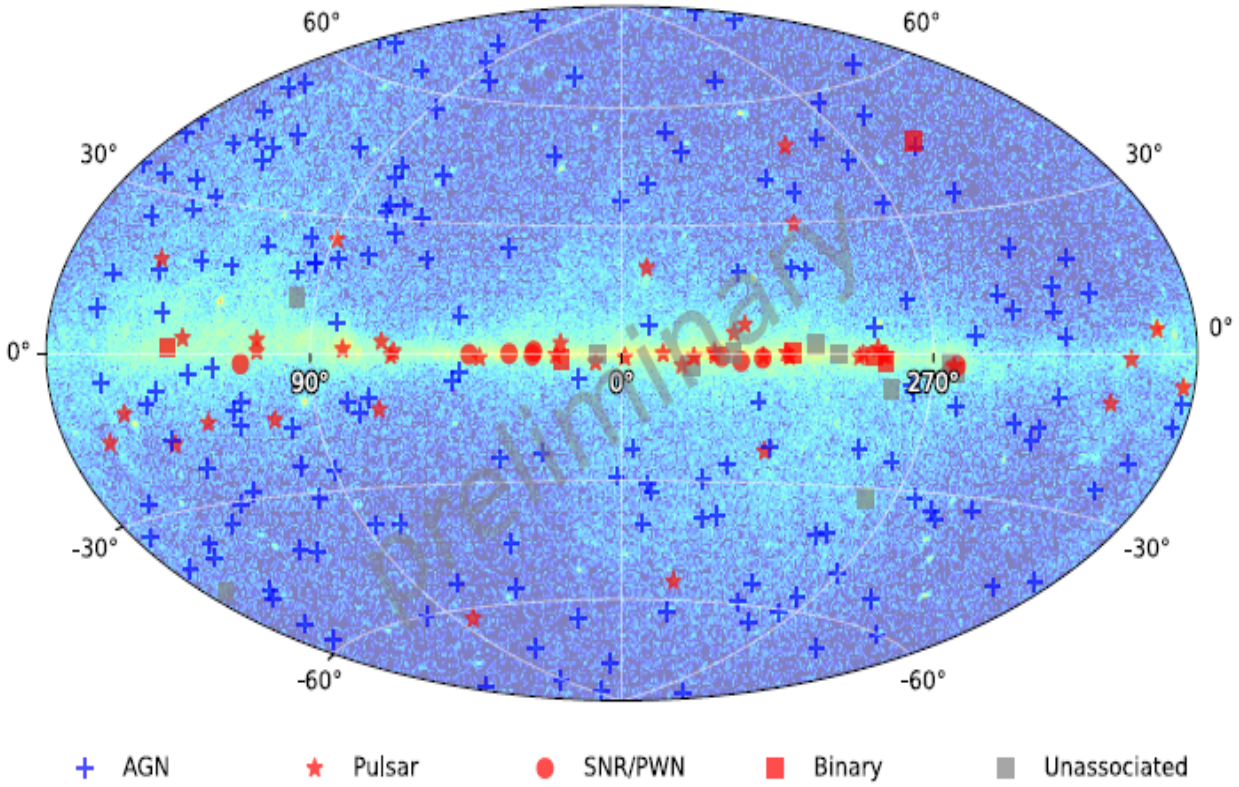
DAMPE: heavier nuclei

Several independent analyses are ongoing from Li up to Iron
Different selection criteria to reject other nuclei and avoid charge misidentification
Different approaches to limit and better evaluate the systematics.



The DAMPE gamma-ray sky

~250 point sources detected and studied

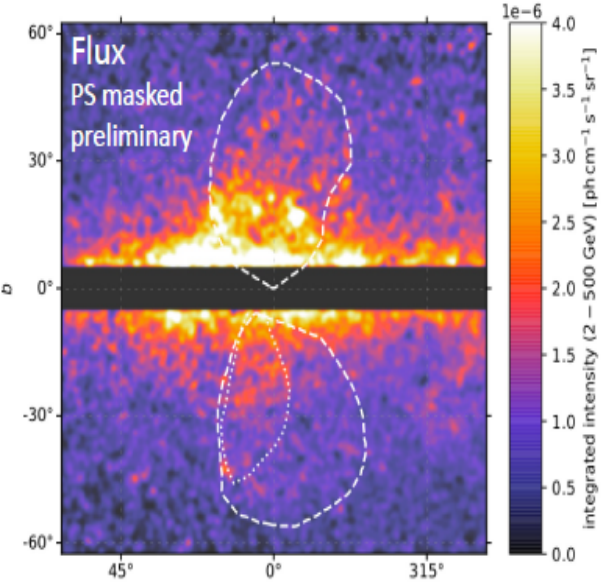


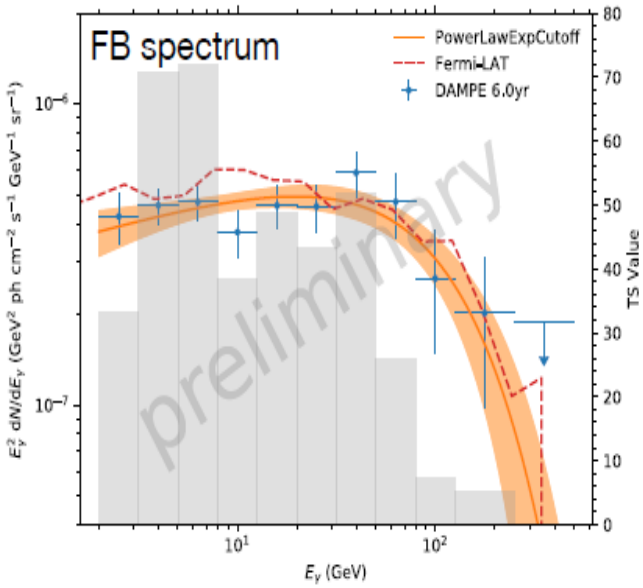
Source Type	Number
AGN	175
Pulsar	46
SNR/PWN	10
Binary	6
Unassociated	11
Total	248

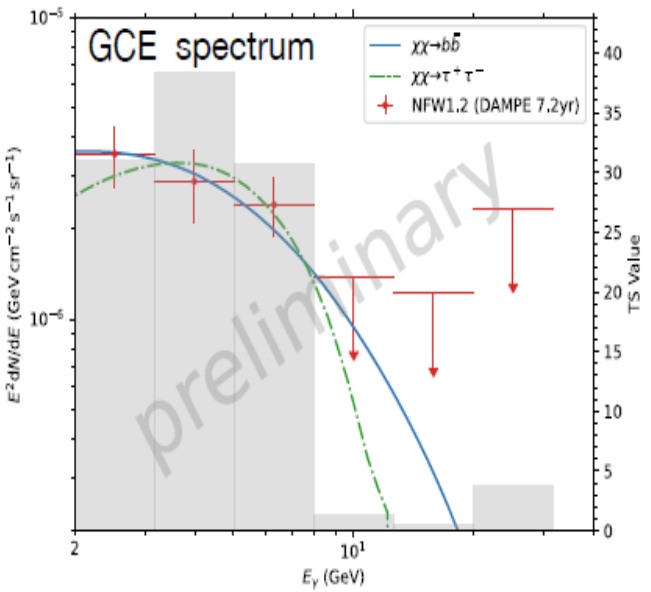
14 times full-sky coverage in 7 years, ~ 300'000 photons total

γ-rays: large scale structures

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

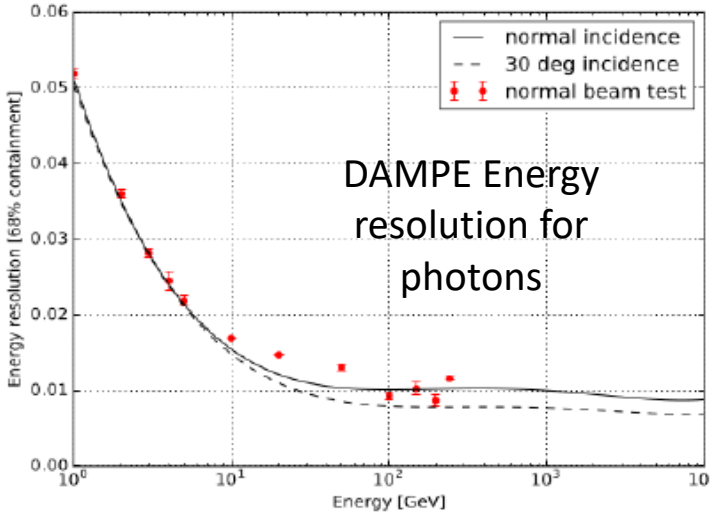






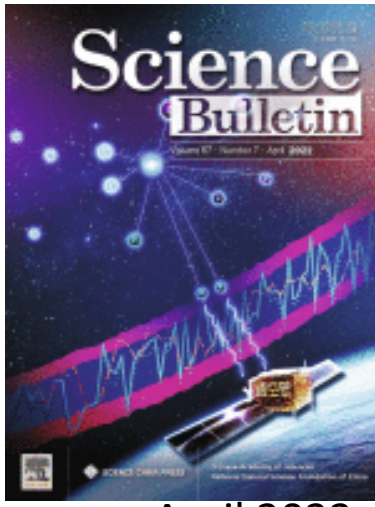
- FB: 6-year spectrum well consistent with FERMI, curved at 3.7σ, weak excess in the Cocoon (~3.3σ)
- **Galactic Center Excess (GCE)** detected at ~7.9σ, with 7.2 years of DAMPE data

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