Results from the DAMPE space mission

Ivan DE MITRI

Gran Sasso Science Institute (GSSI)

& INFN Laboratori Nazionali del Gran Sasso

on behalf of the DAMPE Collaboration

SuGAR MADISON 2024

SEARCHING FOR THE SOURCES OF GALACTIC COSMIC RAYS

OCTOBER 14-17

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

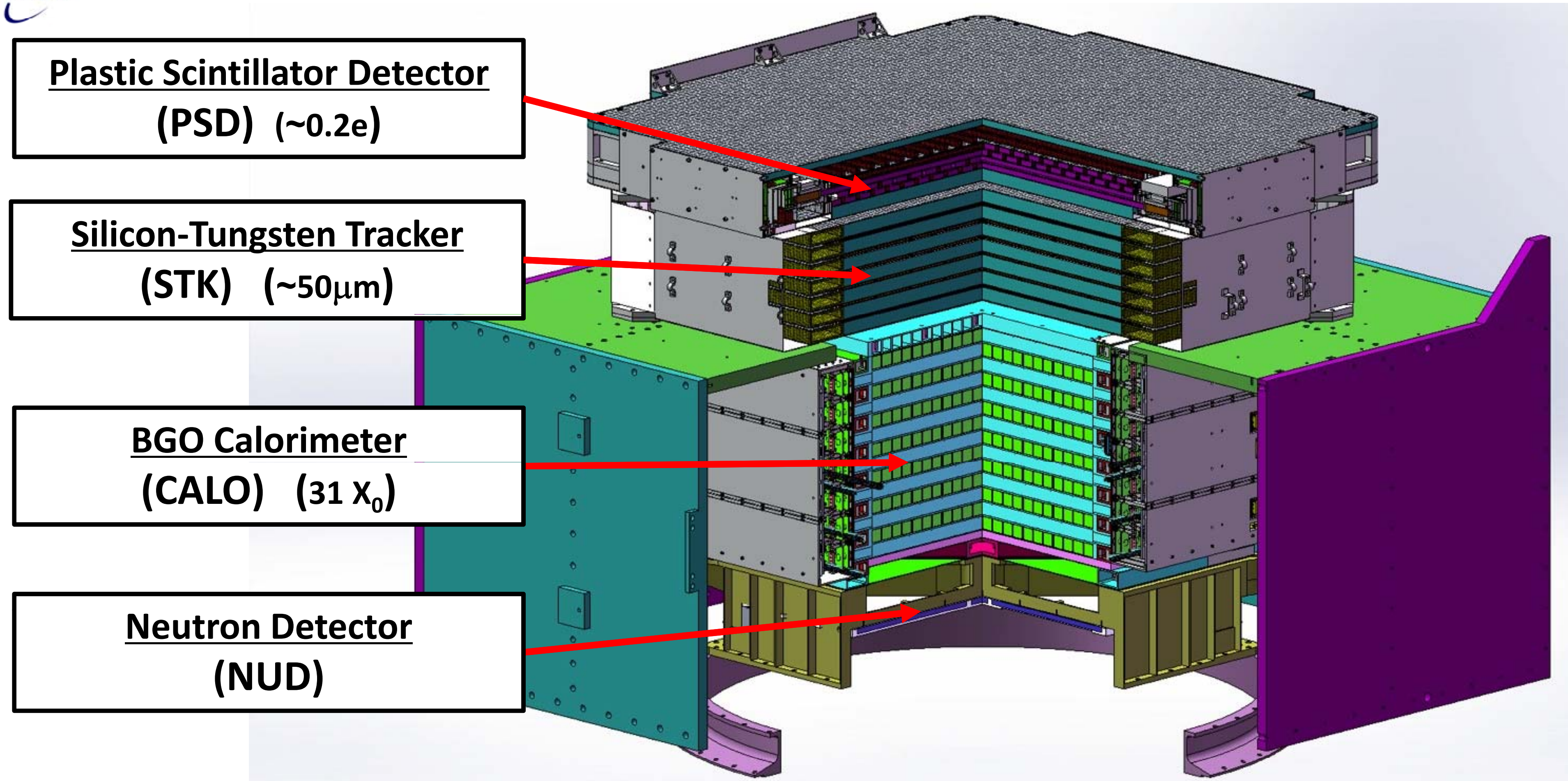
The collaboration

- **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**

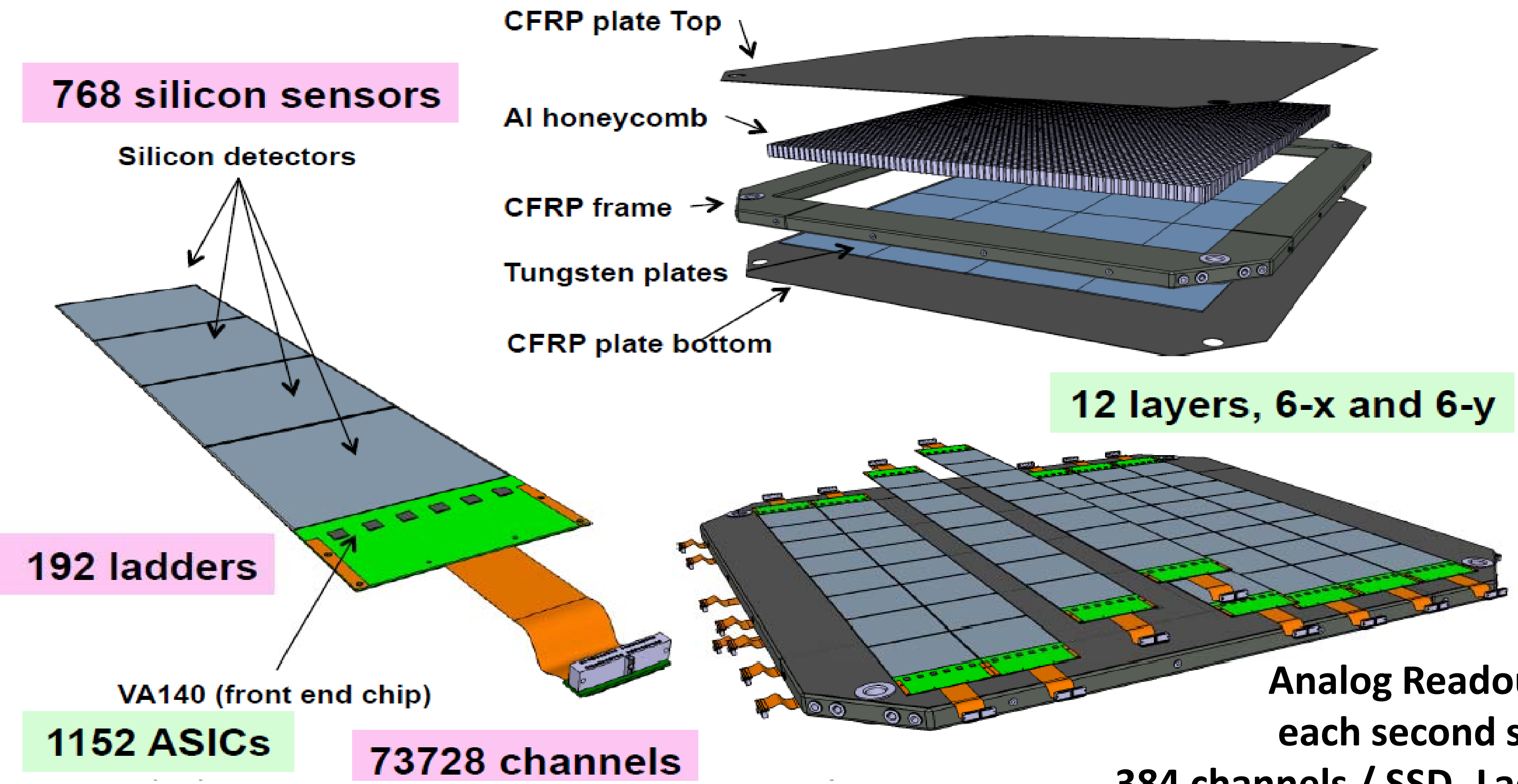
The detector



- 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 Silicon TracKer (STK)



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

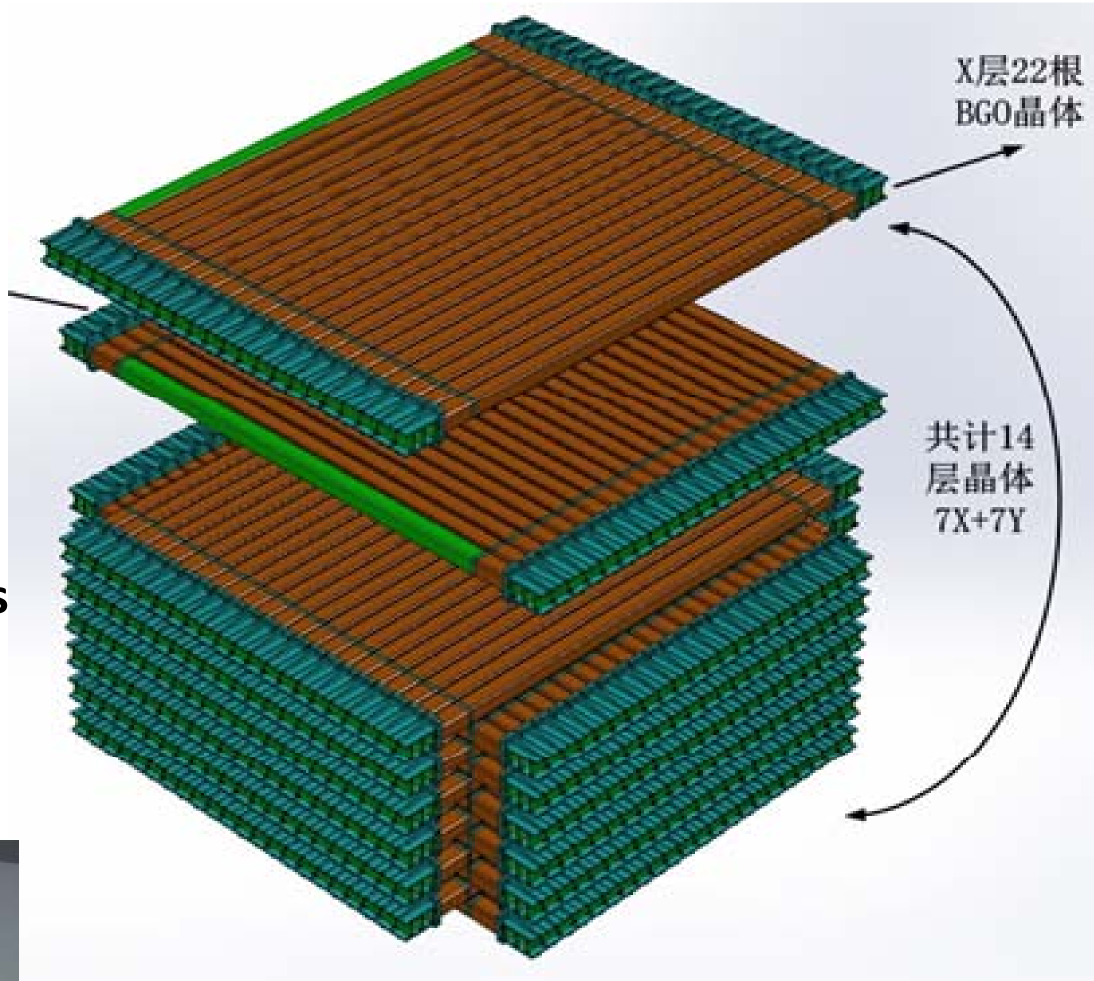
- **48 μm wide Si strips with 121 μm pitch**
- **(95 × 95 × 0.32 mm^3) Silicon Strip Detector (SSD)**
- **768 strips in each SSD**
- **One ladder composed by 4 (SSD)**
- **16 Ladders per layer (76 cm × 76 cm)**
- **12 layers (6x + 6y)**

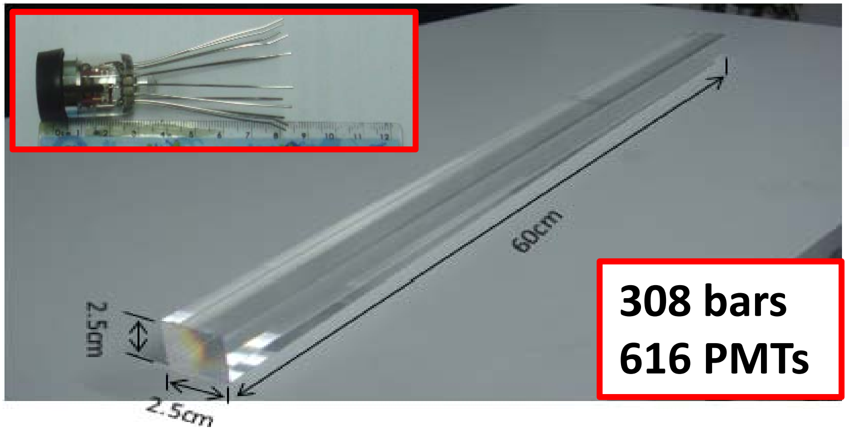
The CALOrimeter

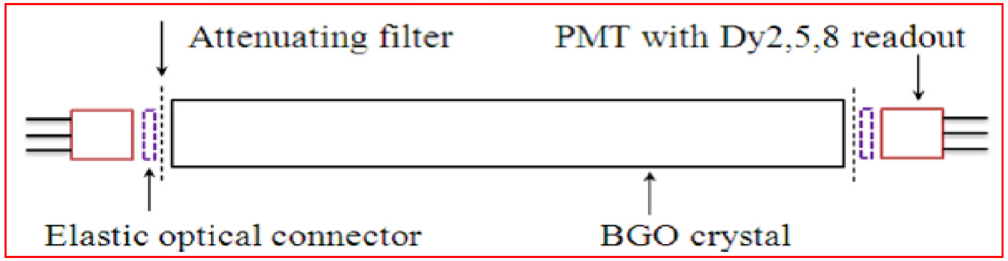
- **14 layers of 22 BGO bars**
  - 2.5×2.5×60 cm^3 bars
  - 14 hodoscopic stacking alternating orthogonal layers
  - depth ~$32X_0$

- **Two PMTs coupled with each BGO crystal bar at the two ends**

- **Electronics boards attached to each side of module**

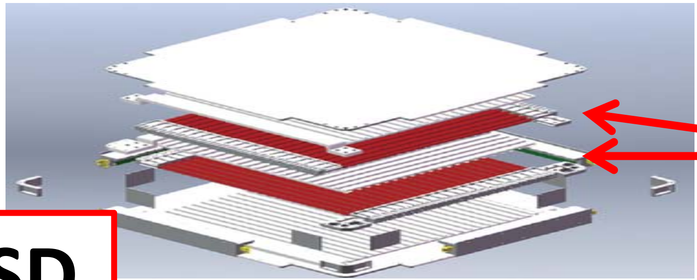




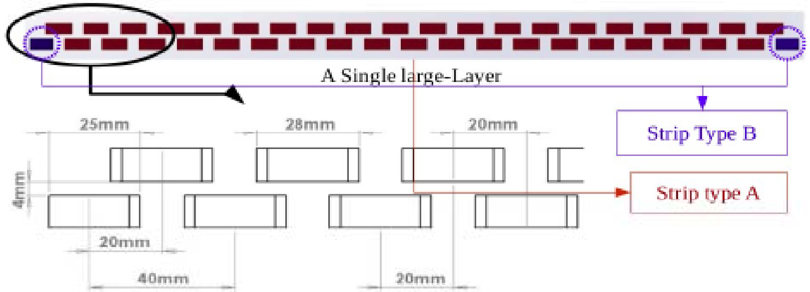


The Plastic Scintillator Detector and the NeUtron Detector

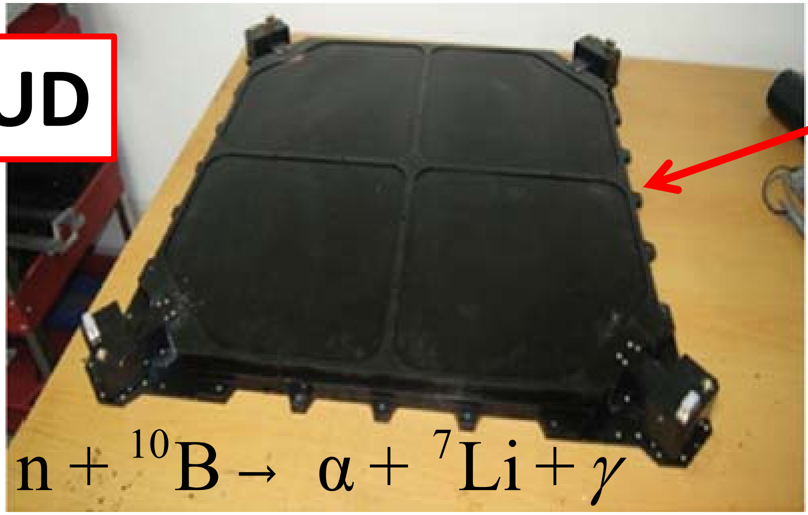
PSD



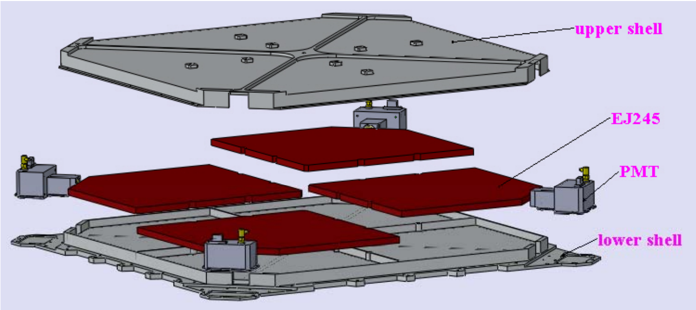
- 1.0 cm thick ,2.8cm wide and 82.0 cm long scintillator strips
- staggered by 0.8 cm in a layer
- 82 cm × 82 cm layers
- 2 layers (x and y)



NUD

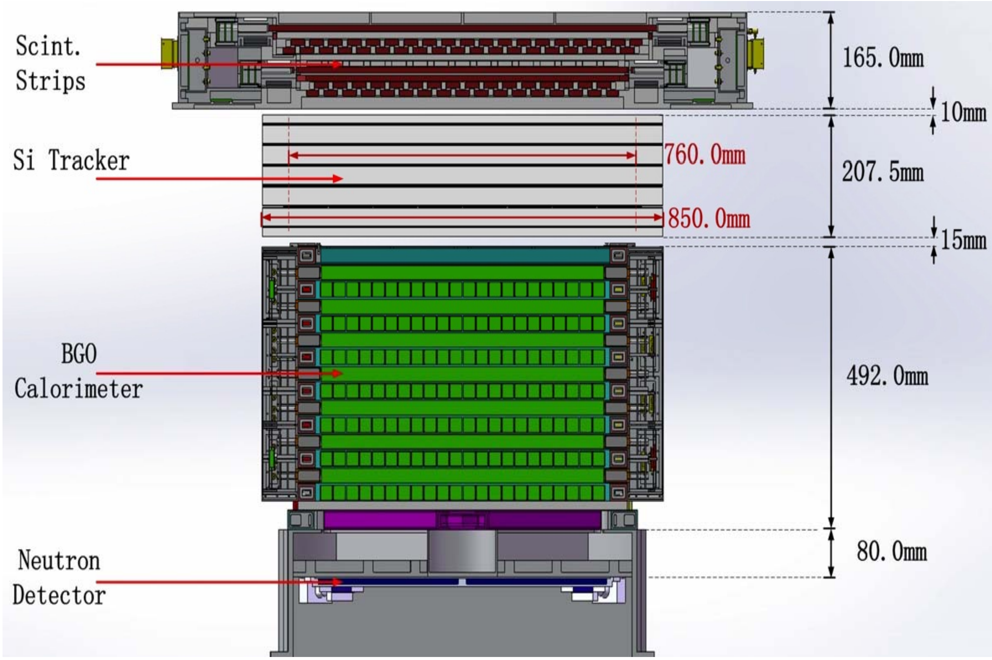


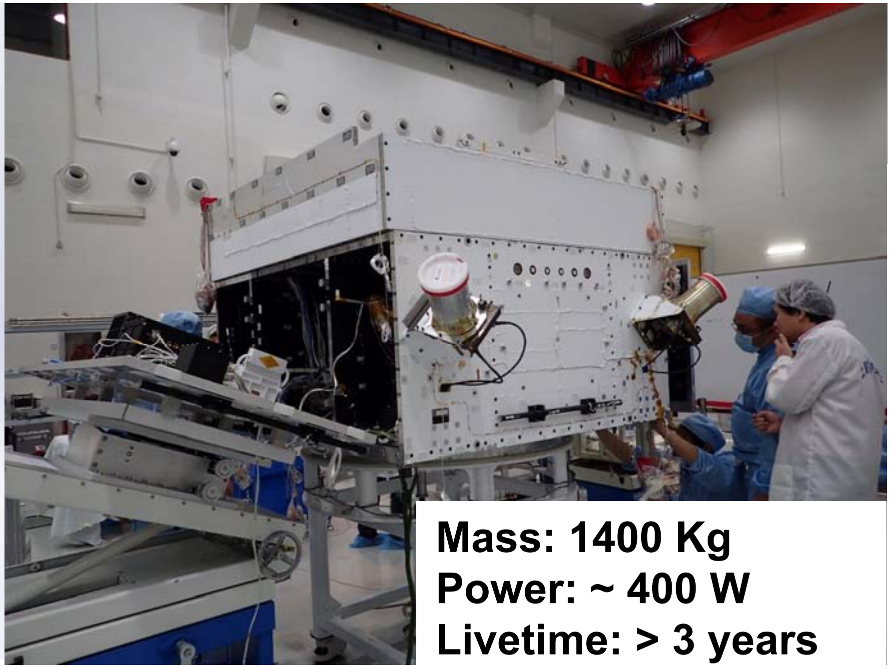
- 4 large area boron-doped plastic scintillators (30 cm × 30 cm × 1 cm)



Comparison with CALET, AMS and FERMI

	DAMPE	CALET	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	**1.2**	1.5 – 3.0	3	10
e/γ Angular res.@50 GeV (deg)	**0.2**	0.2	0.3	0.1
e/p discrimination	**10^5-10^6**	10^5	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	**32**	30	17	8.6
Geometrical accep. (m^2sr)	**0.3**	0.1	0.09	1





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

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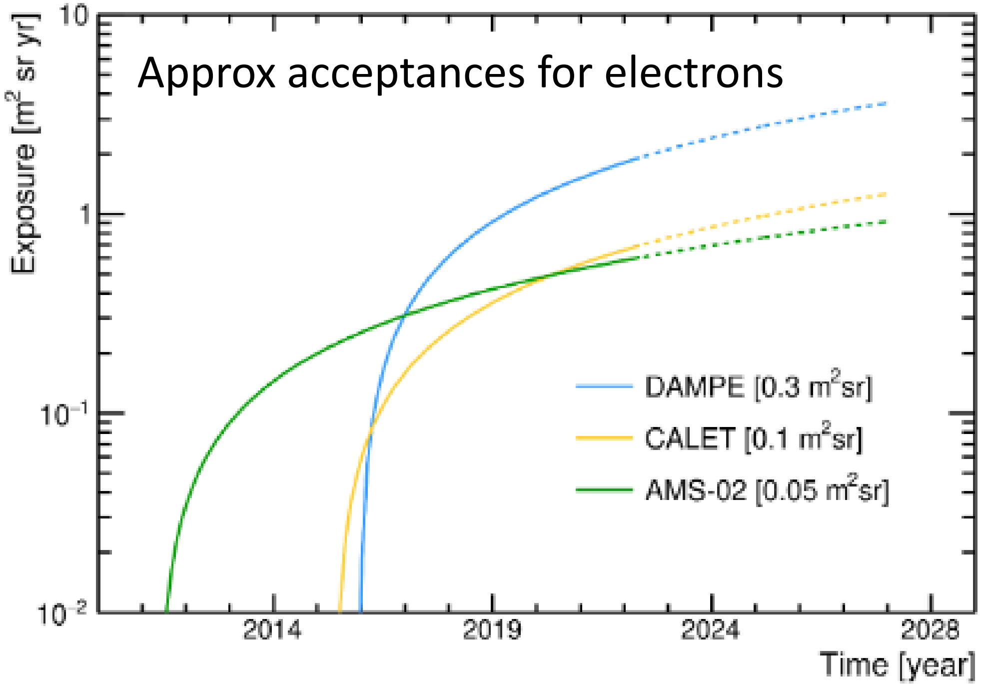

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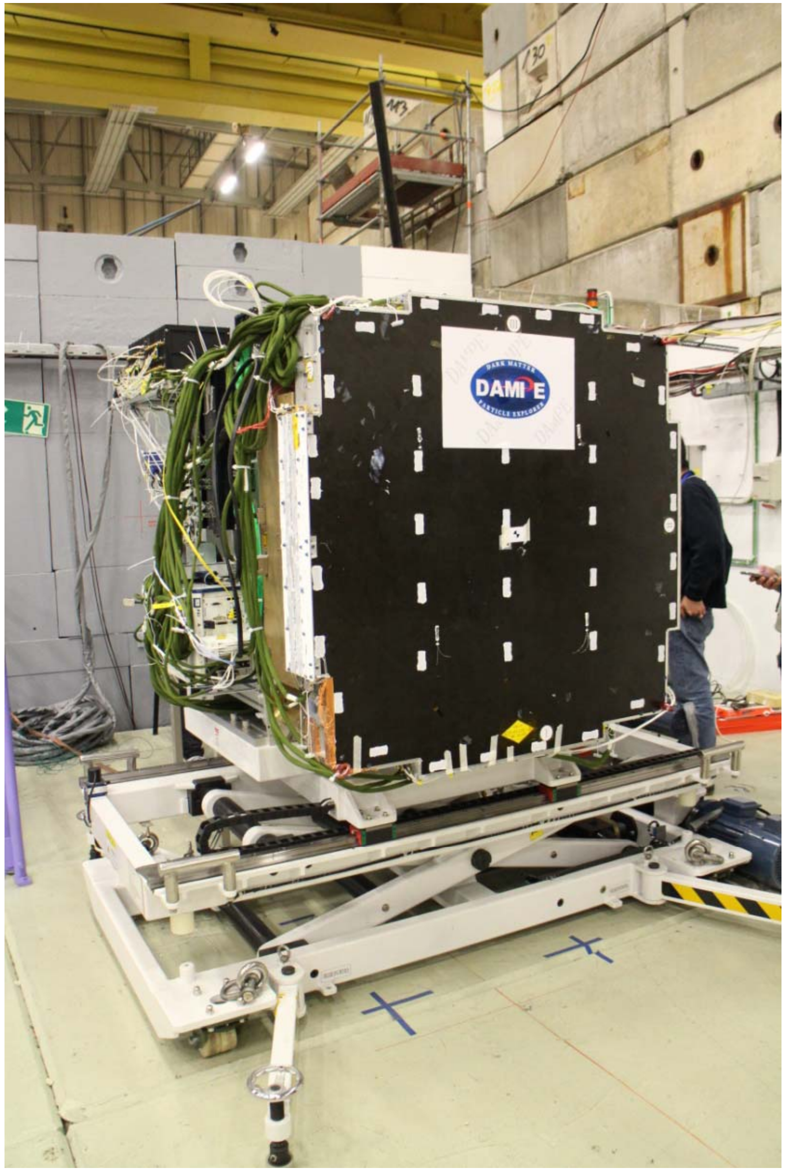
Test beam activity at CERN

- 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)

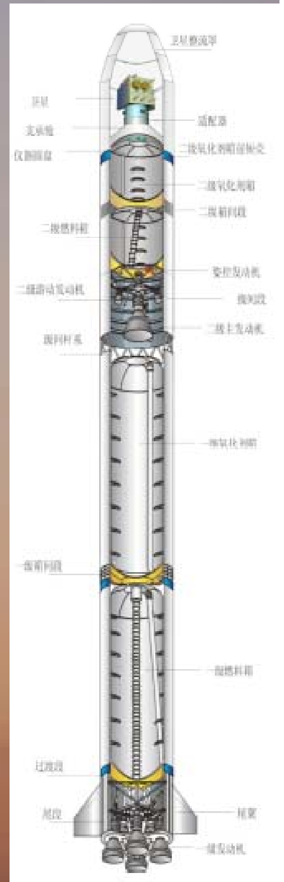


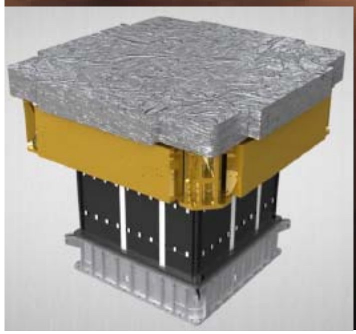
The launch: Dec 17th 2015, 0:12 UTC

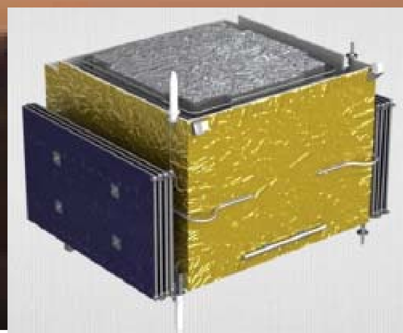
Jiuquan Satellite Launch Center
Gobi desert

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

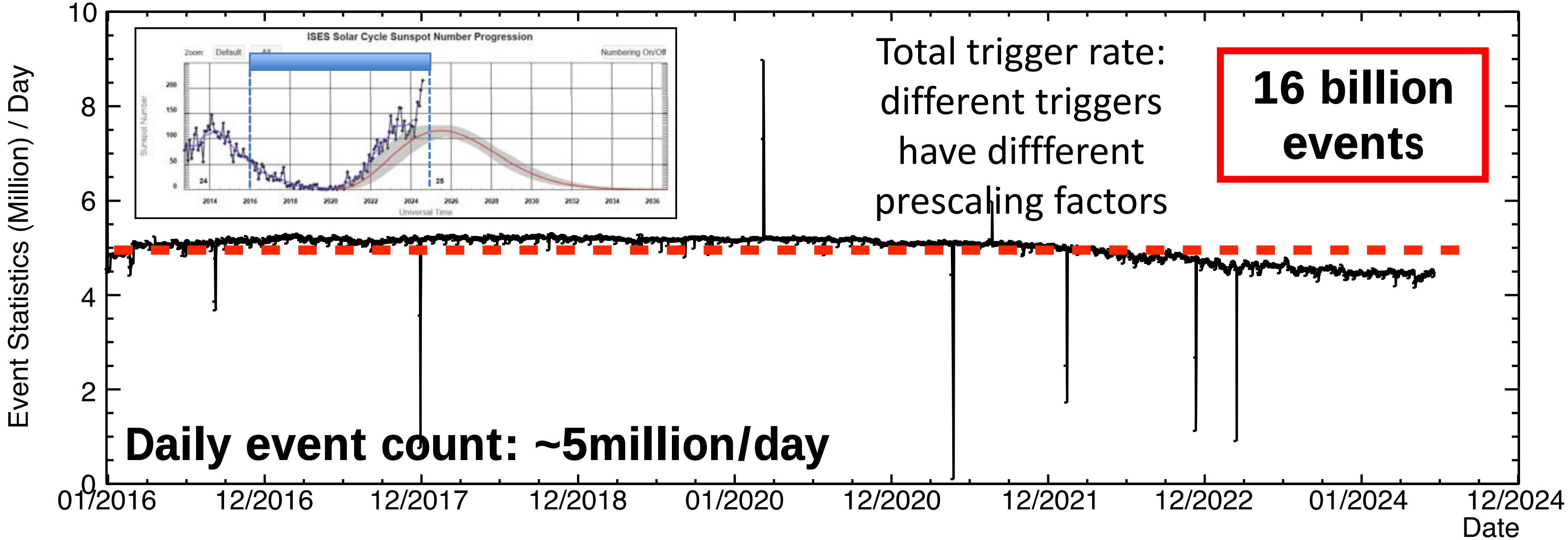




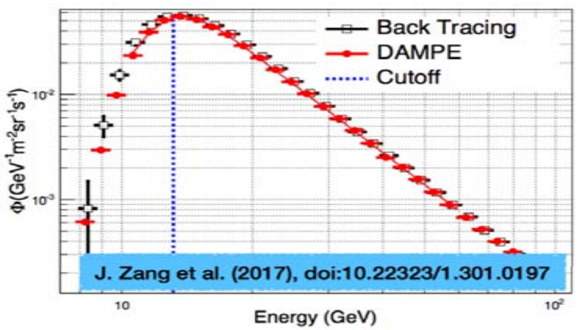


On orbit operation

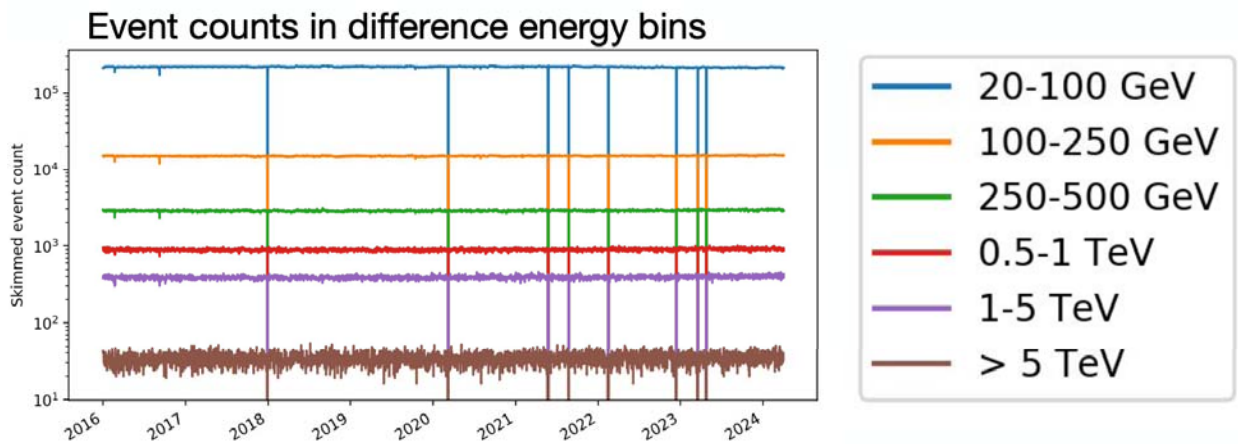
Smooth operation for 8.8 years since launch in Dec. 2015

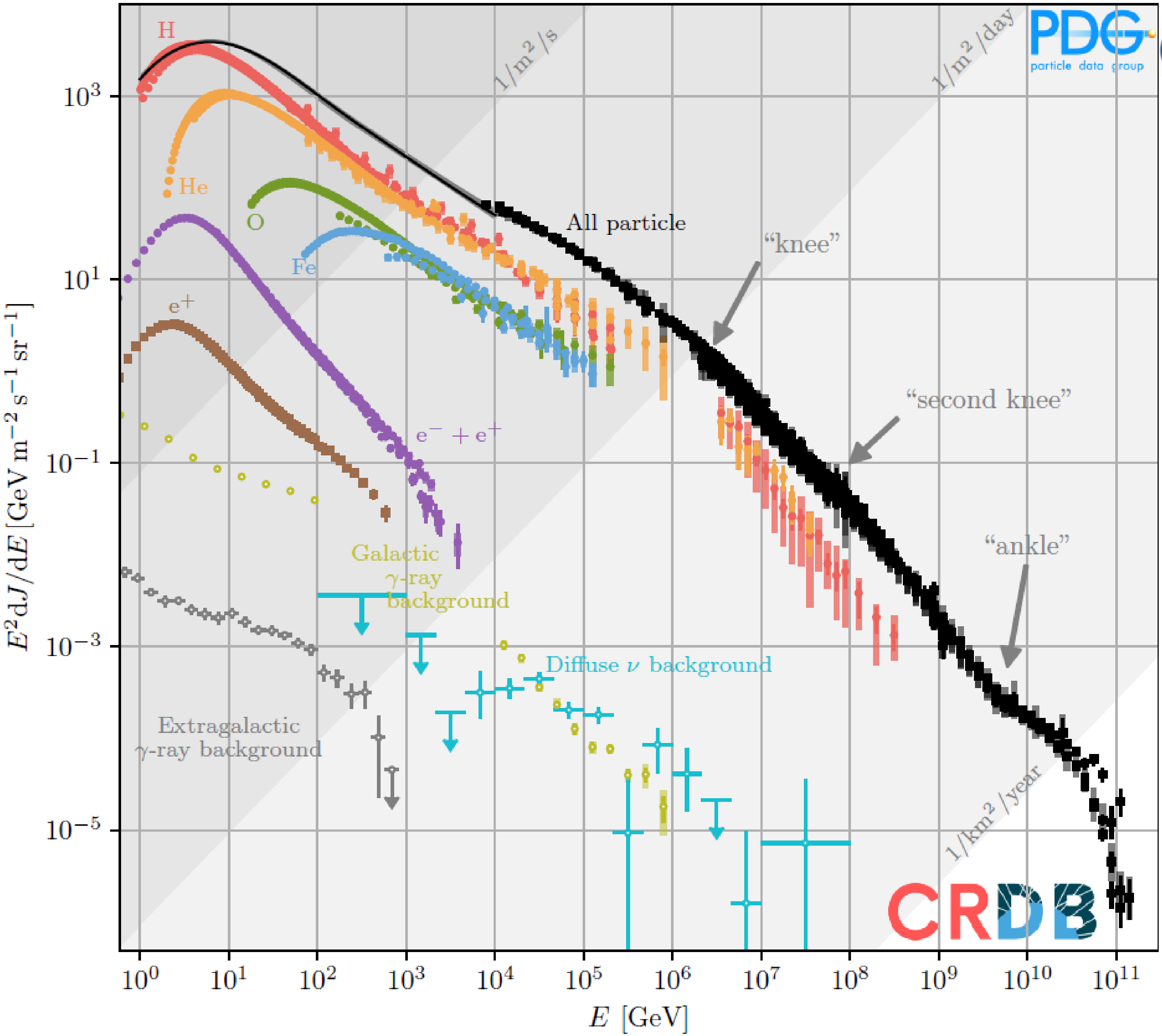


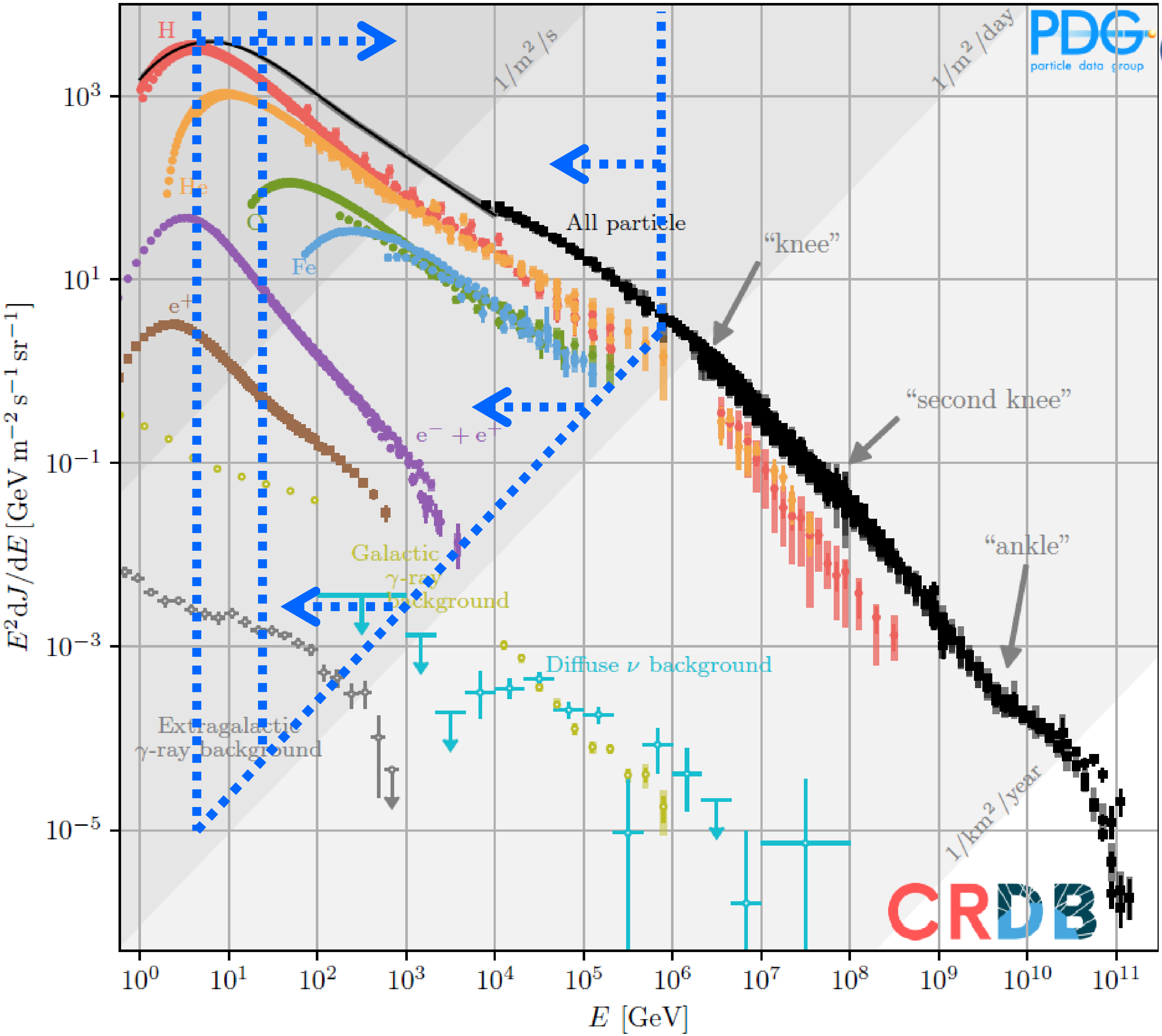
Energy scale calibration by using geomagnetic cutoff on electrons



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




H
He
O
Fe
e+
e− + e+
All particle
“knee”
“second knee”
“ankle”
1/m²/s
1/m²/day
1/km²/year
Galactic γ-ray background
Diffuse ν background
Extragalactic γ-ray background
E²dJ/dE [GeV m⁻² s⁻¹ sr⁻¹]
E [GeV]
PDG particle data group
DAMPE
CRDB



H
He
O
Fe
e+
e− + e+
All particle
“knee”
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1/m²/s
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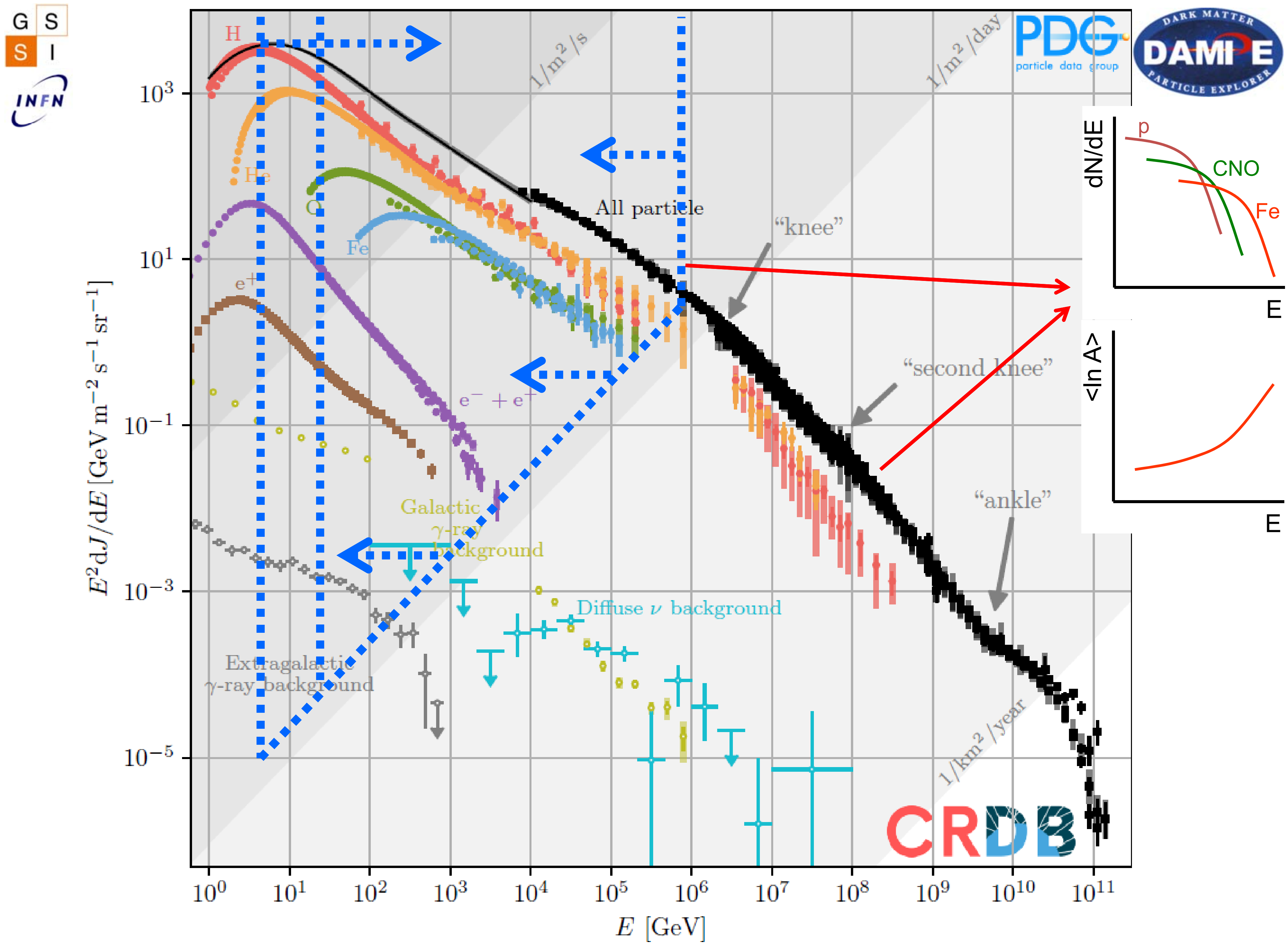
1/km²/year
Galactic γ-ray background
Diffuse ν background
Extragalactic γ-ray background
$E^2 \mathrm{d}J/\mathrm{d}E$ [GeV m^{-2} s^{-1} sr^{-1}]
E [GeV]


H
He
O
Fe
e+
e− + e+
All particle
"knee"
"second knee"
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1/m²/s
1/m²/day
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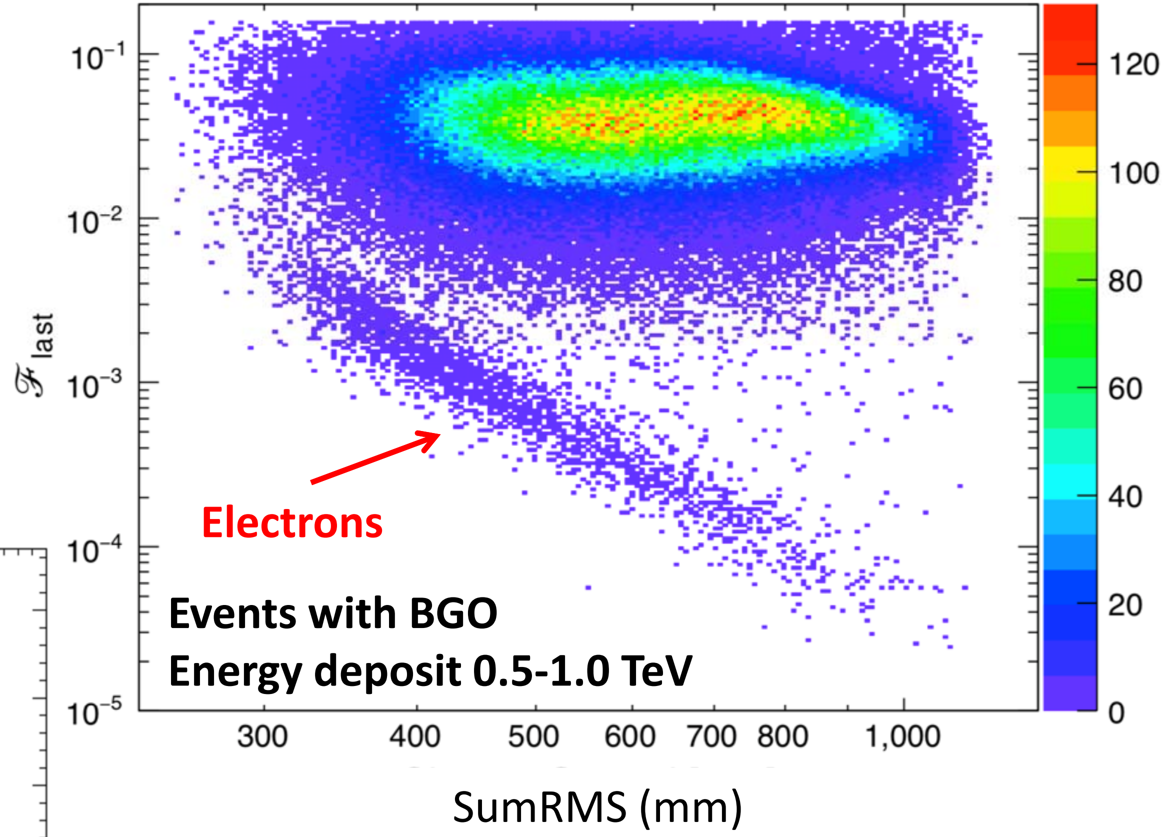
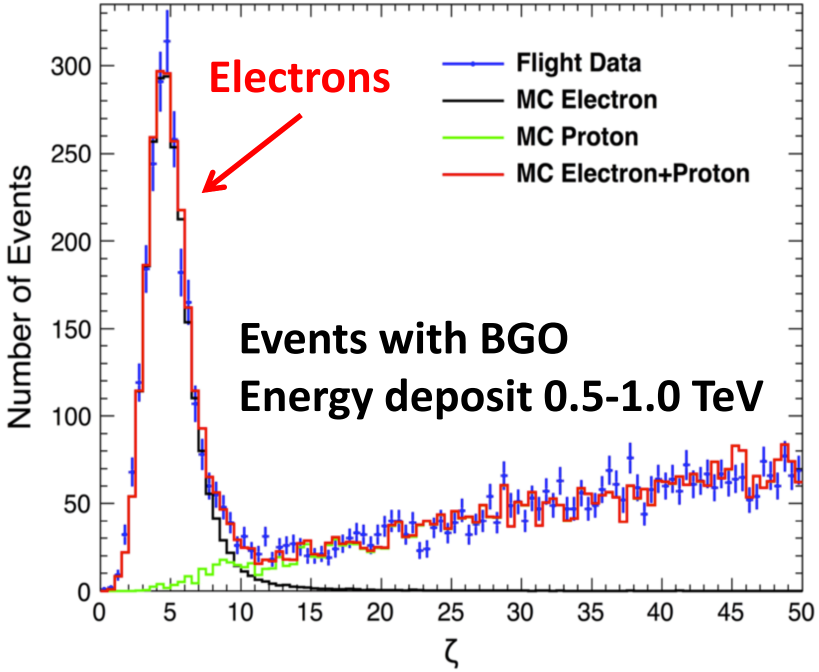
Galactic γ-ray background
Diffuse ν background
Extragalactic γ-ray background
E²dJ/dE [GeV m⁻² s⁻¹ sr⁻¹]
E [GeV]
dN/dE
p
CNO
Fe
E
<ln A>
E
PDG particle data group
DAMPE DARK MATTER PARTICLE EXPLORER
CRDB
GSSI
INFN

Electron IDentification

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

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

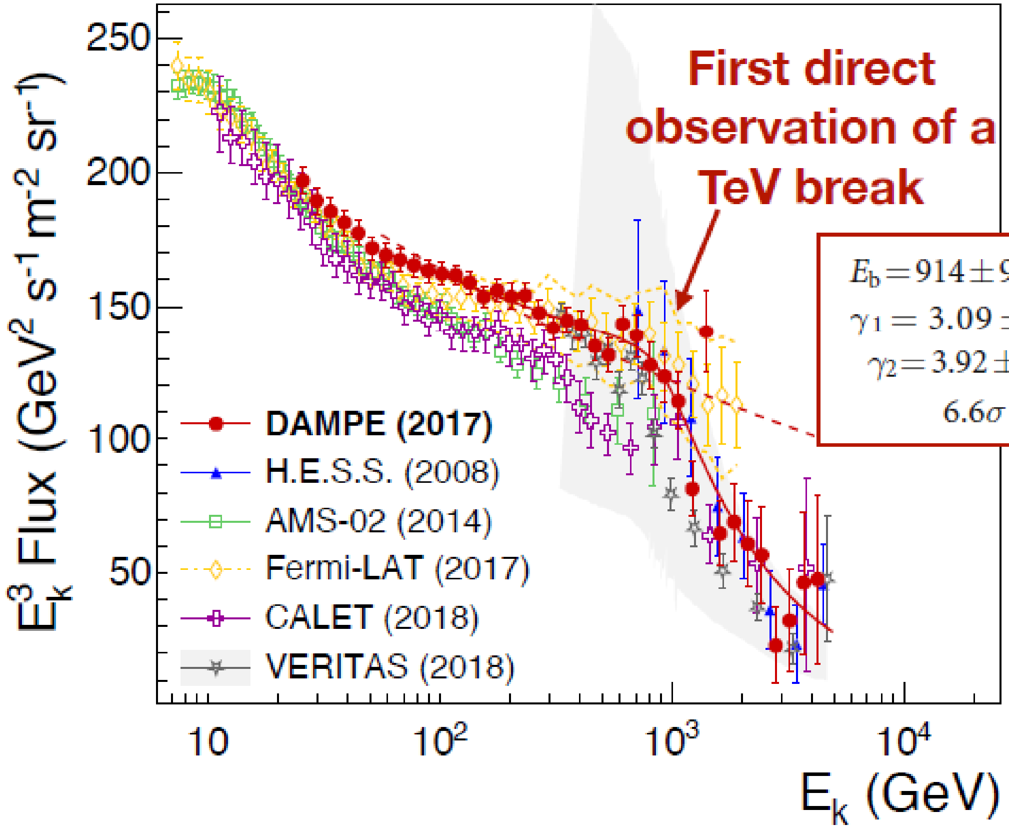




SumRMS = Sum of single layer RMS values

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

The DAMPE ($e^{+}+e^{-}$) spectrum



$E_b = 914 \pm 98$ GeV
$\gamma_1 = 3.09 \pm 0.01$
$\gamma_2 = 3.92 \pm 0.20$
6.6σ

nature International weekly journal of science

LETTER

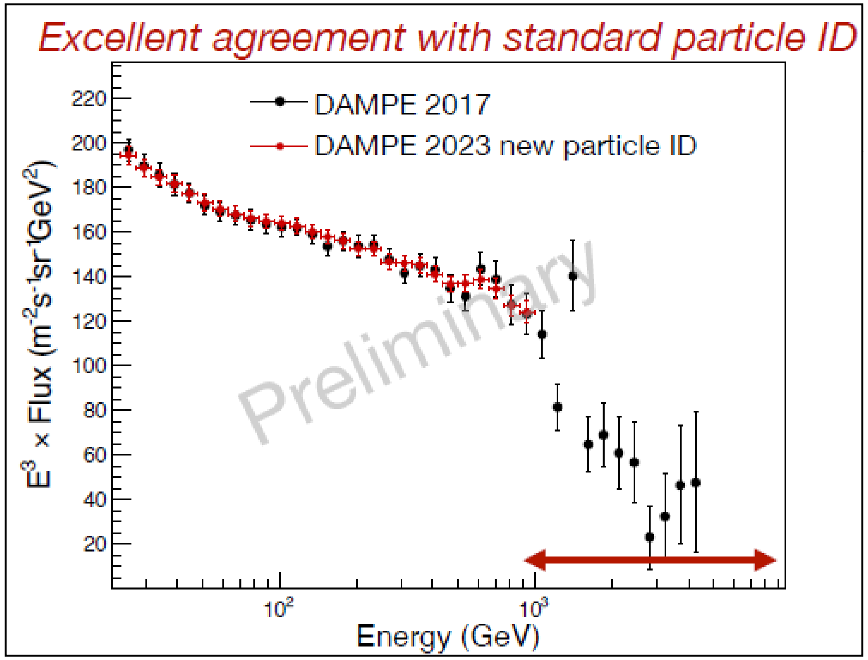
doi:10.1038/nature24475

Direct detection of a break in the teraelectronvolt cosmic-ray spectrum of electrons and positrons

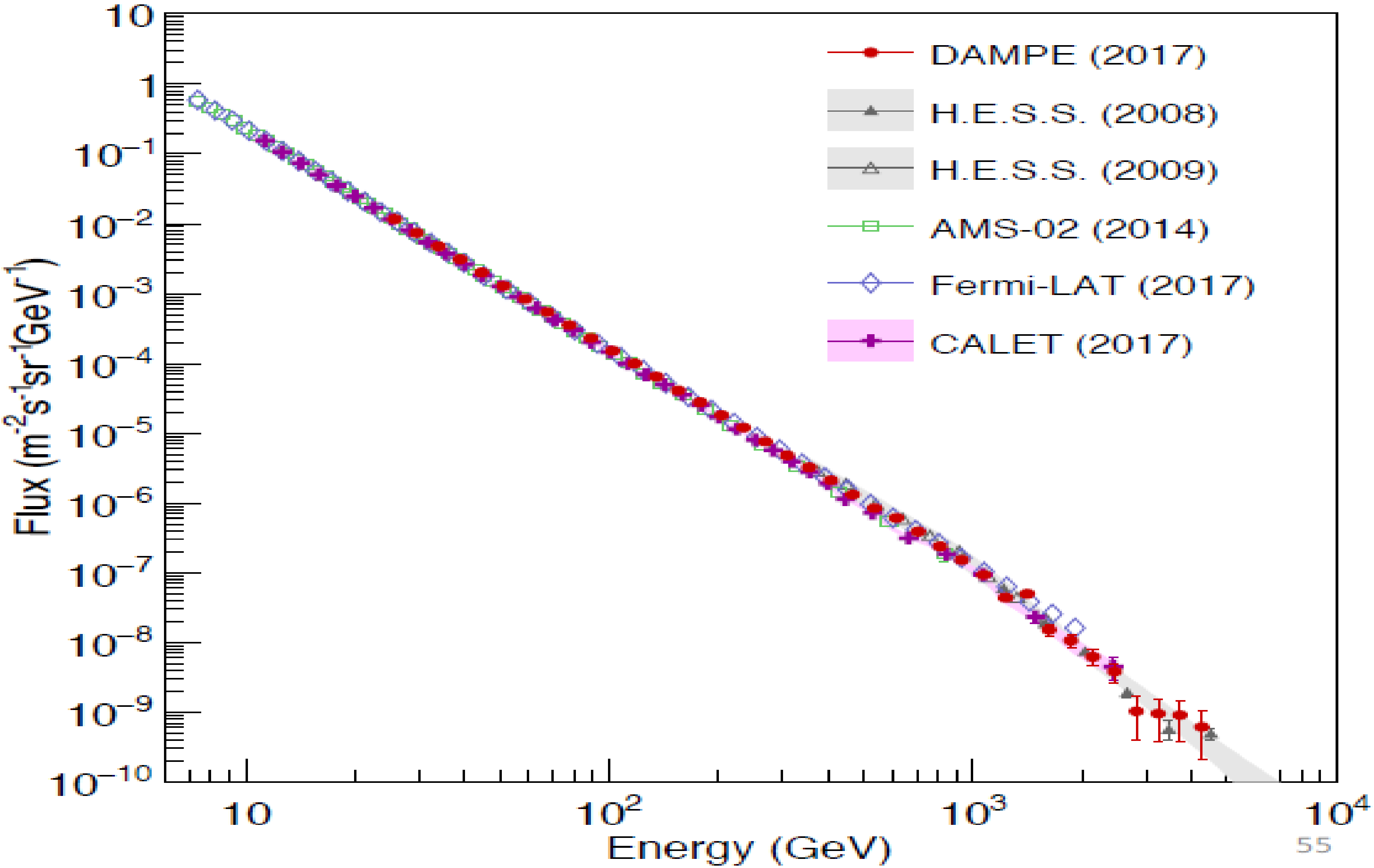
DAMPE Collaboration*

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

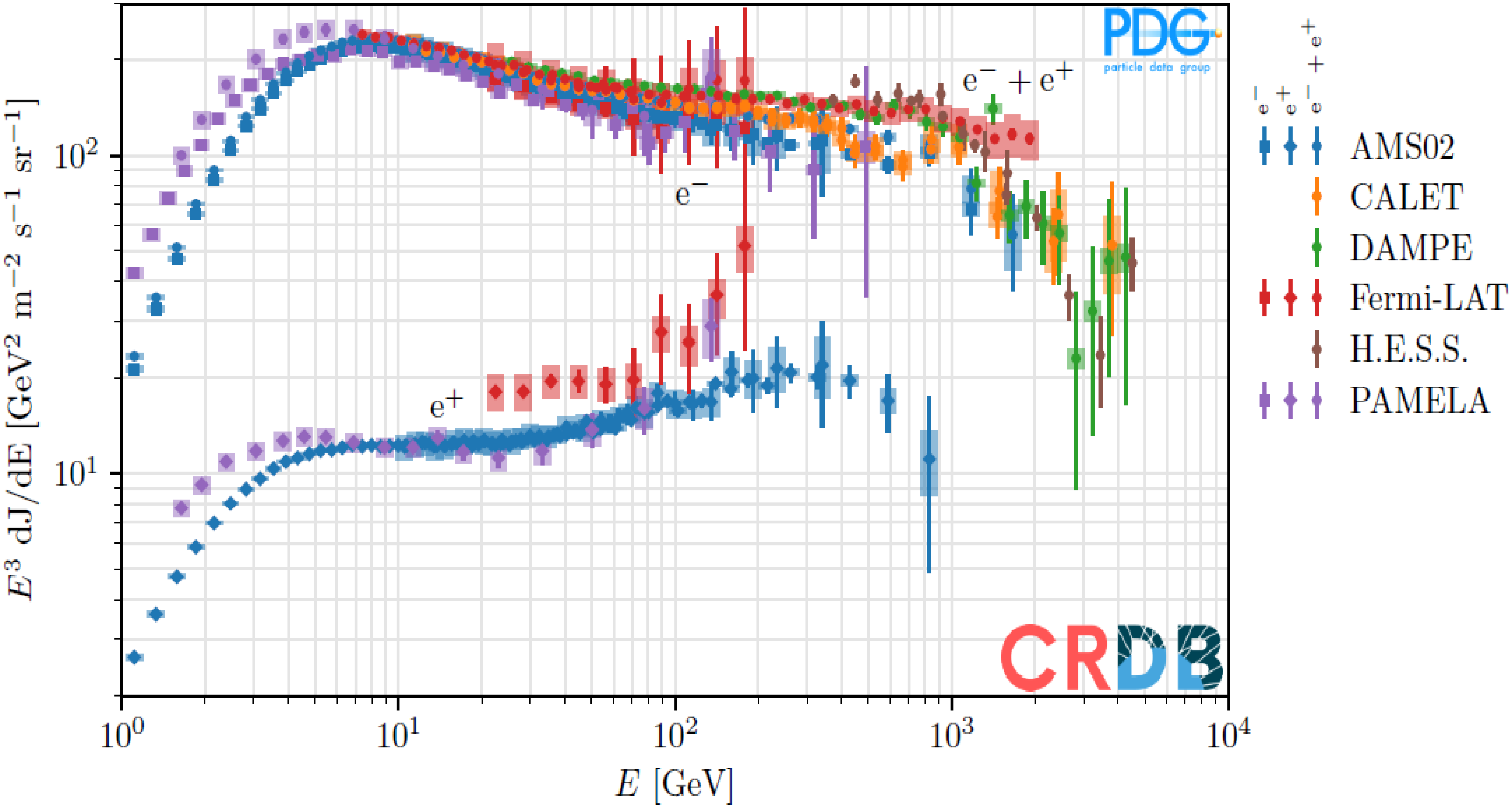
New analyses (ML, ..) ongoing



(The power of powers….)



“electron” spectra



At the TeV scale:

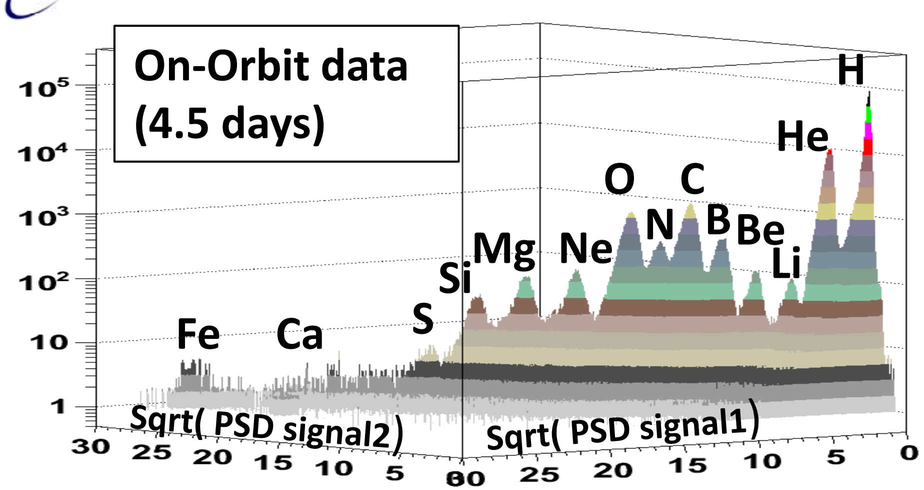
- diffusion-loss length is approx 300pc
- confinement time is approx 100 kyr

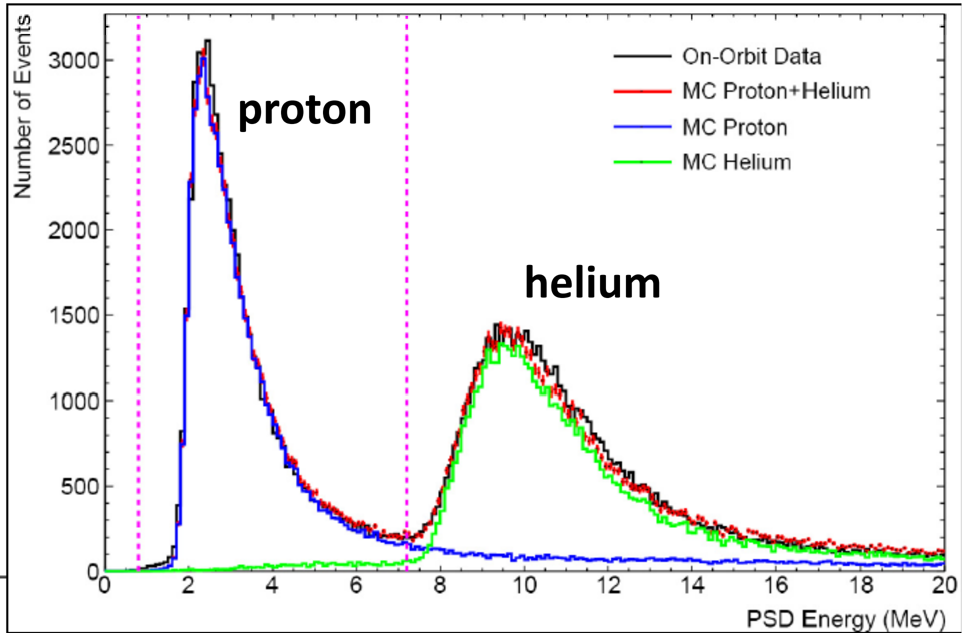
→ The spectra at high energies are dominated by **close and young cosmic ray sources**

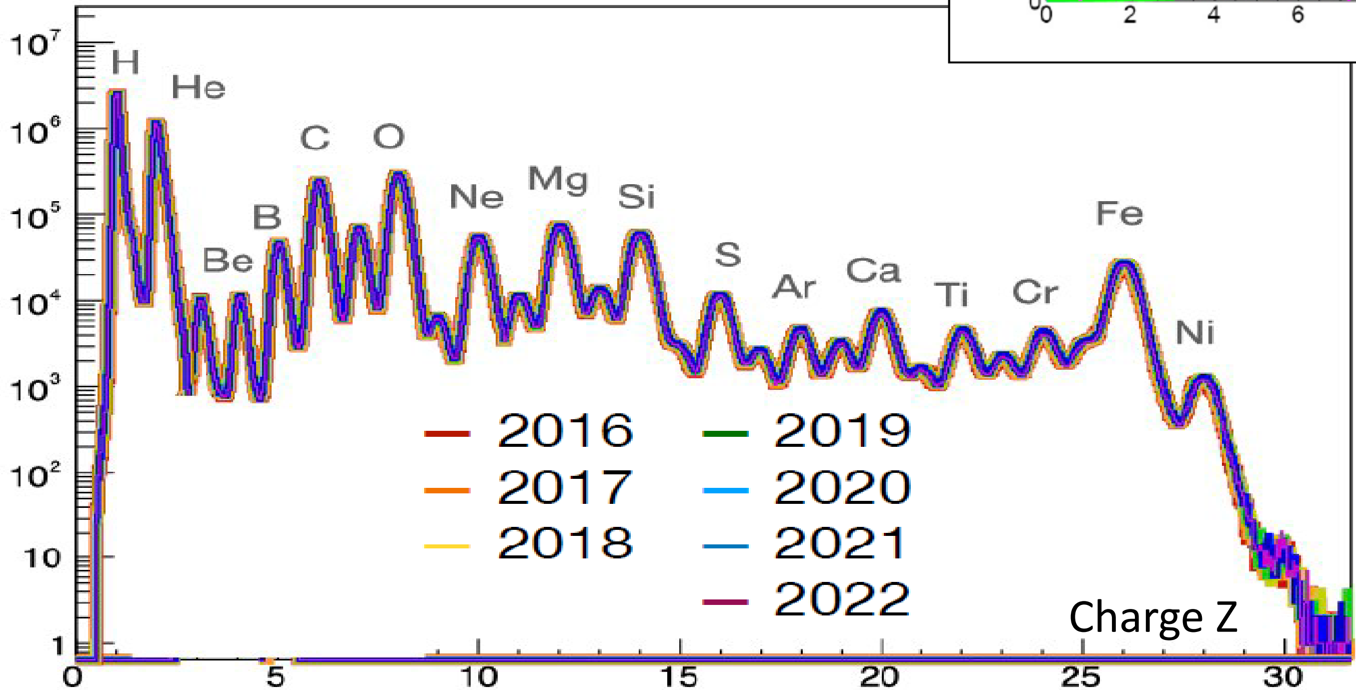
→ Bumps might appear in the spectra above few TeV due to local sources

→ Possible anisotropies

Nuclei ID with PSD







Excellent charge reconstruction up to Nickel and beyond.

Continuous calibration and monitoring of light yield, attenuation and alignement.

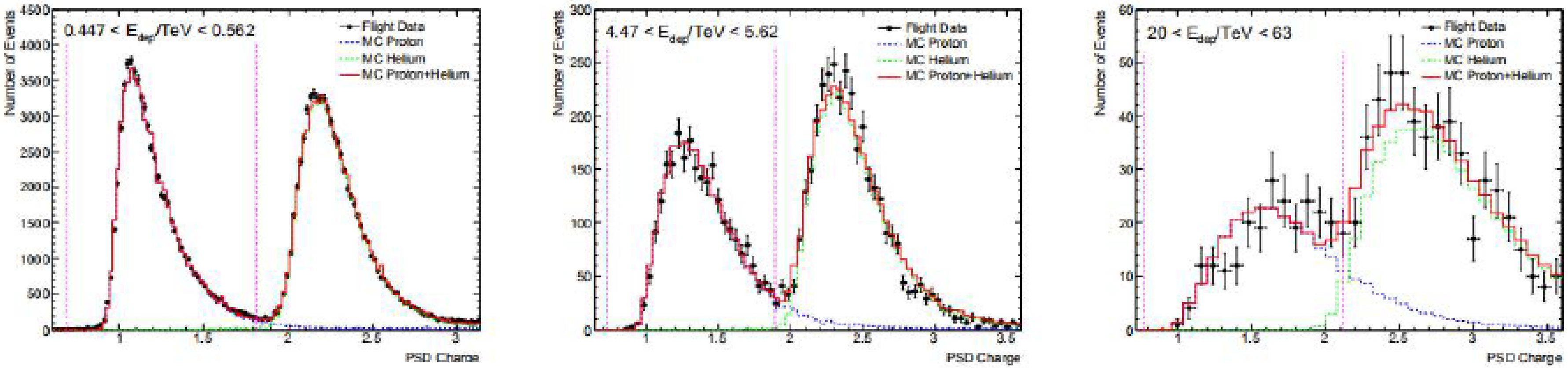
Charge measurement also given by STK and (with lower precision) by the BGO bars

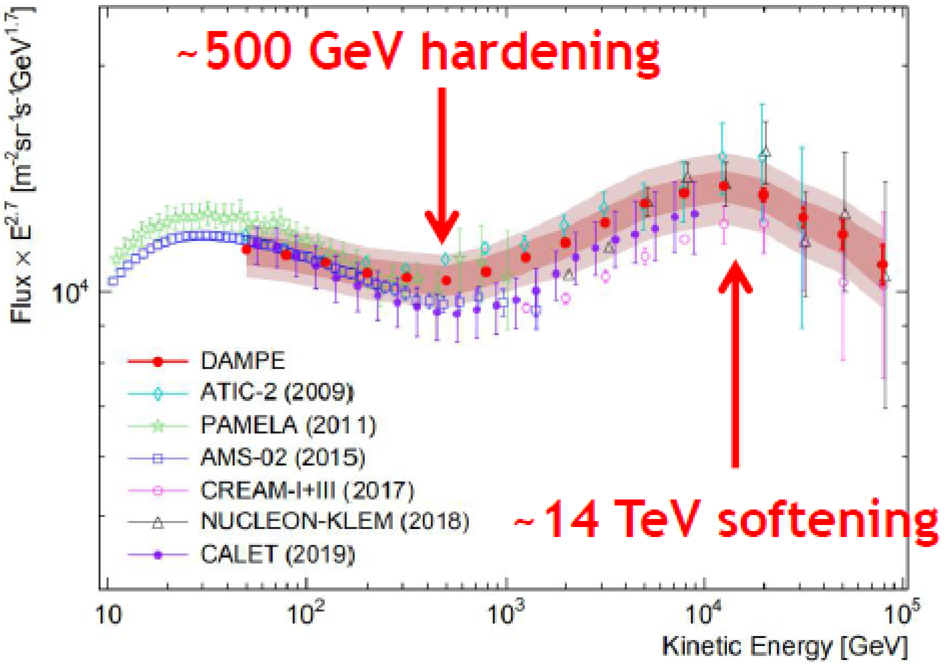
The DAMPE proton spectrum

SCIENCE ADVANCES | RESEARCH ARTICLE

PHYSICS

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





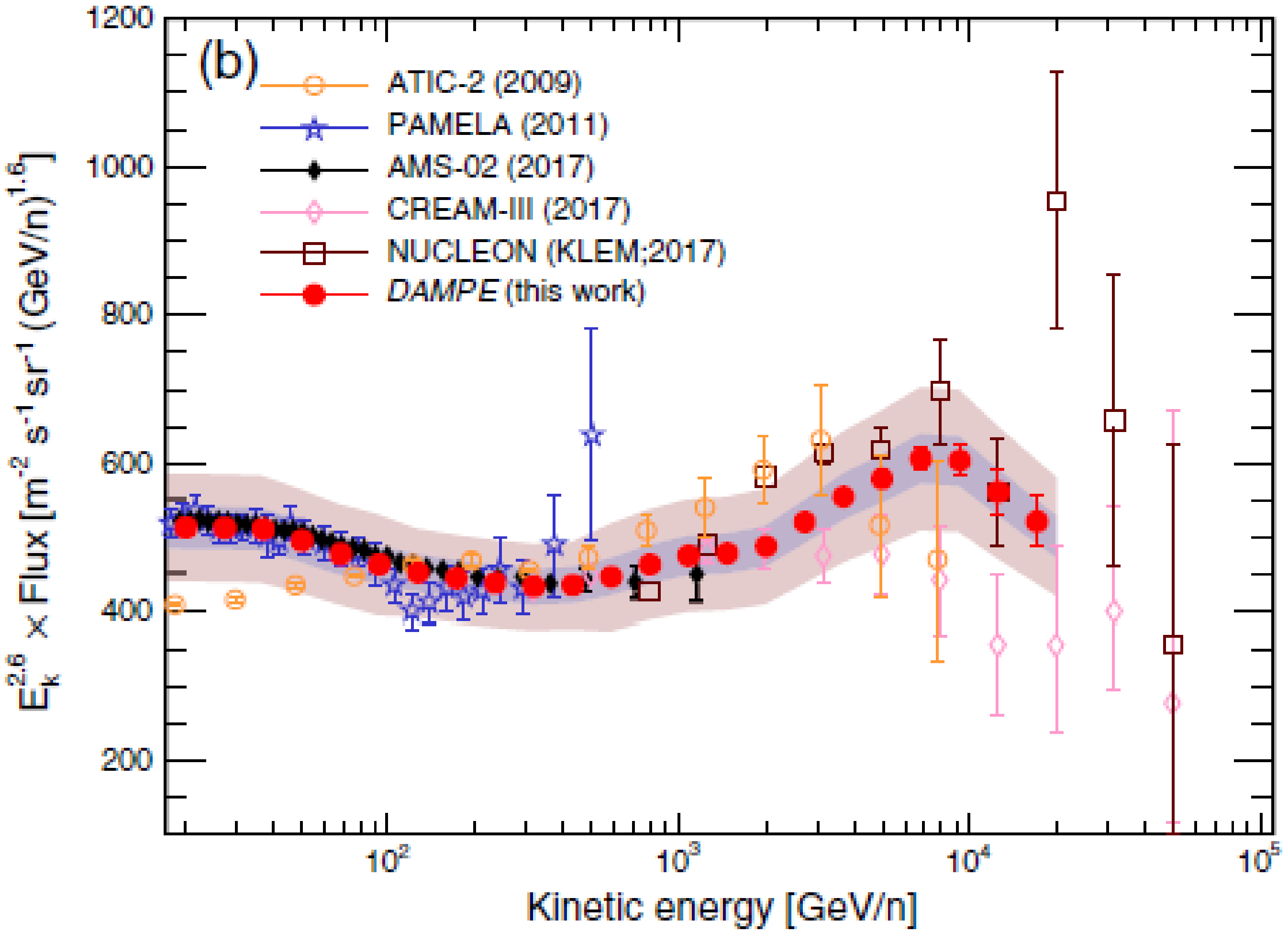
- Confirms the hundreds of GeV hardening
- Detecting a softening at ~14 TeV with high significance

The DAMPE helium spectrum

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

Editors' Suggestion | Featured in Physics

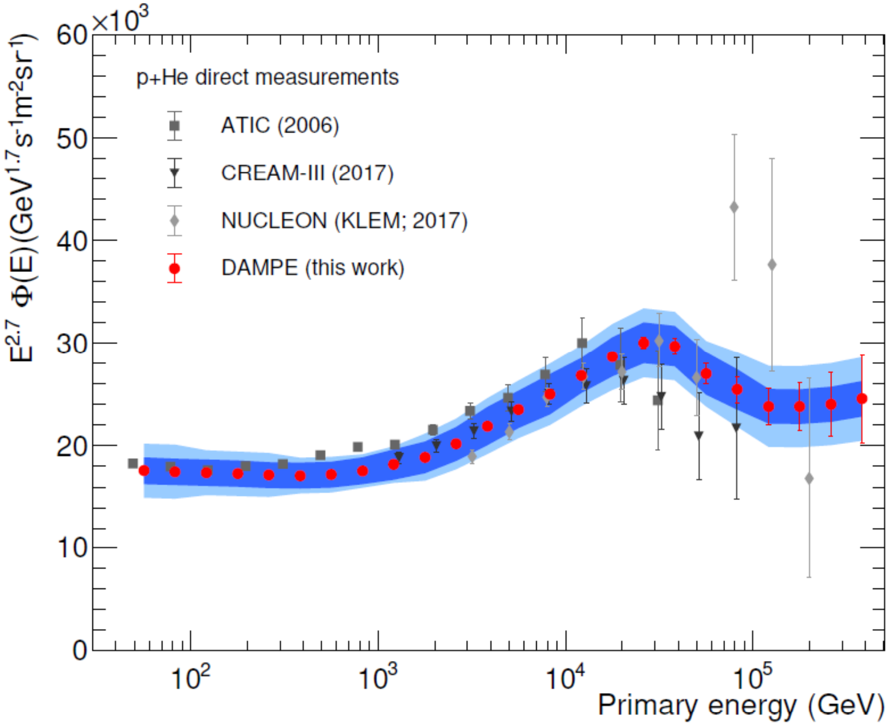
Measurement of the Cosmic Ray Helium Energy Spectrum from 70 GeV to 80 TeV with the DAMPE Space Mission

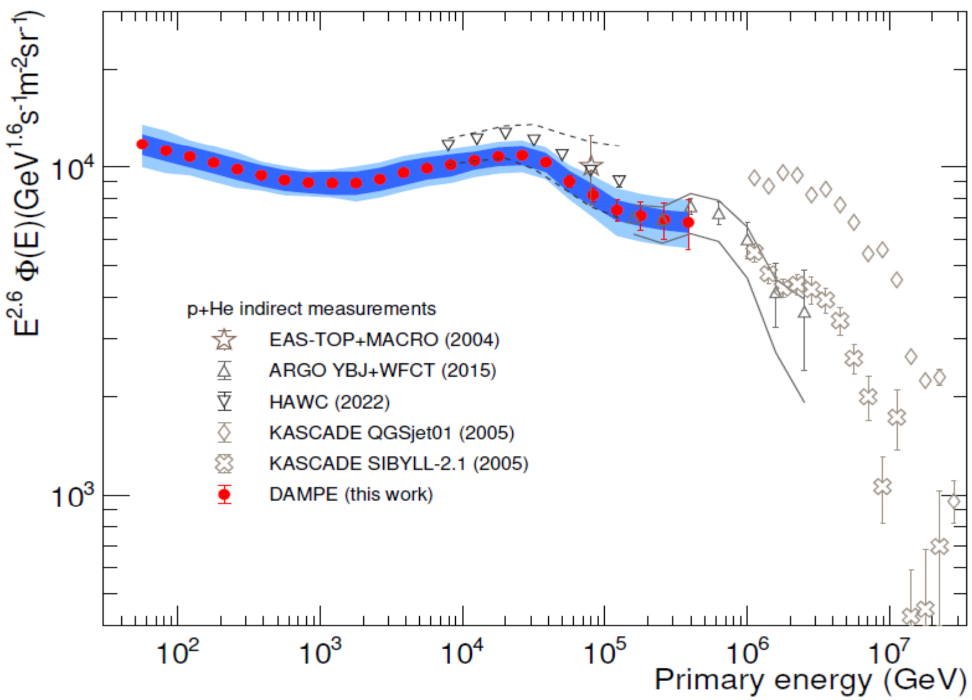


First clear evidence for a softening at about 34 TeV

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

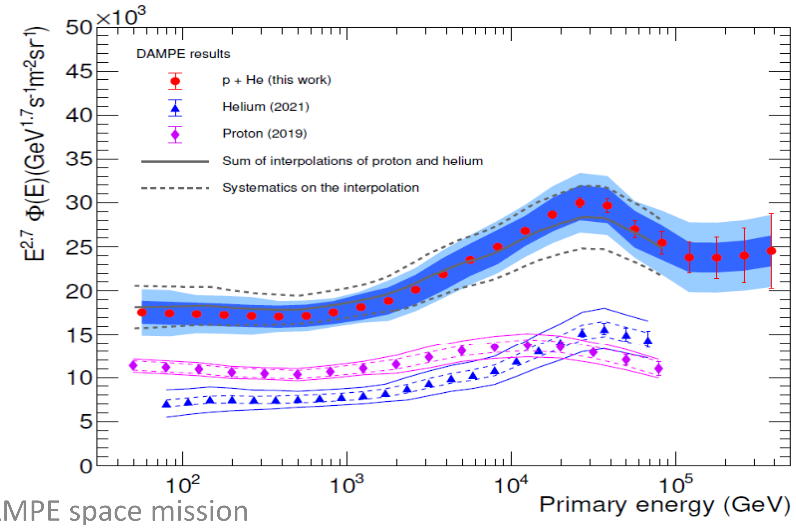
The p+He spectrum (up to 0.5 PeV)



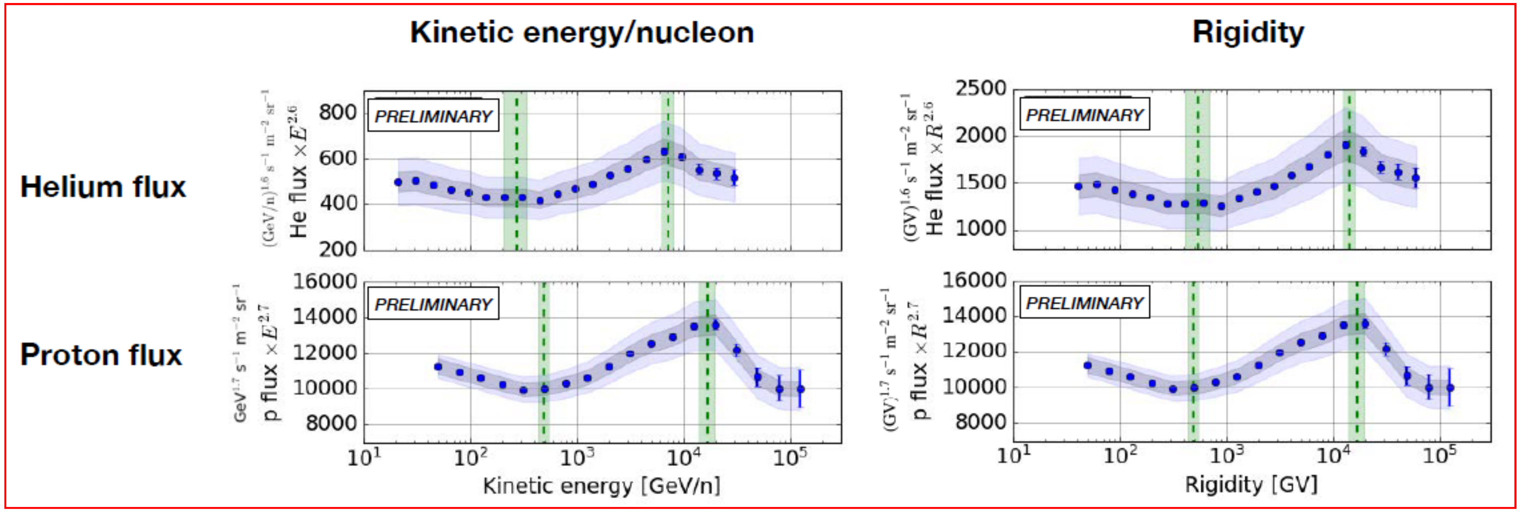


- Confirmation of the softening at 15TV
- Hint for a hardening above 100 TeV
- bridge with indirect measurements

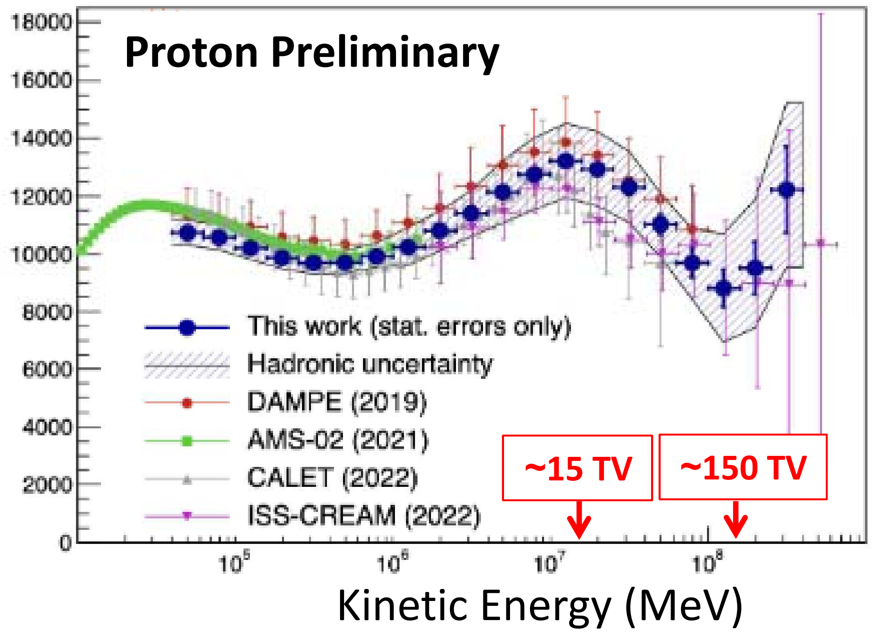
(Phys. Rev. D June 2024)

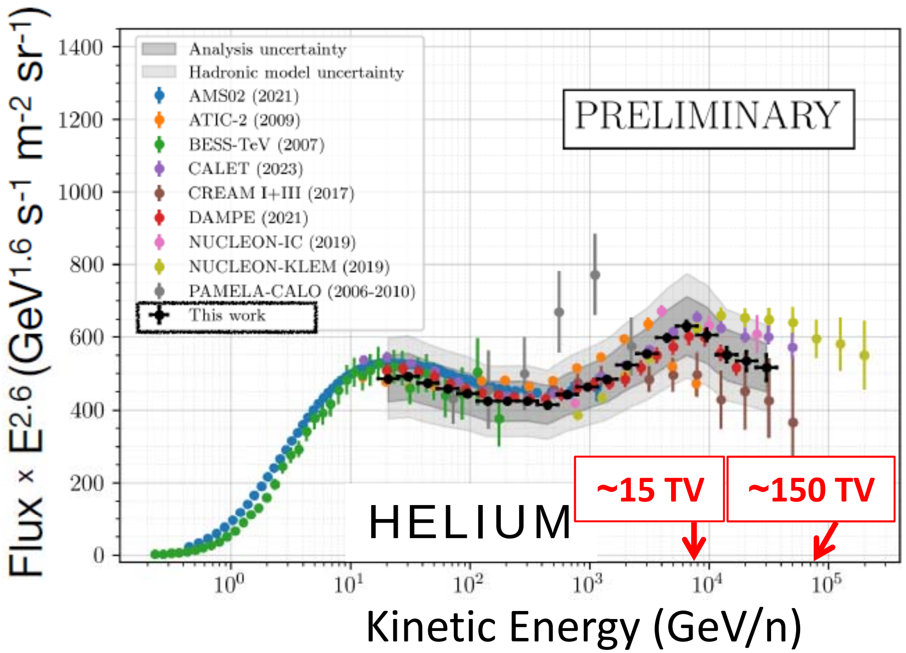


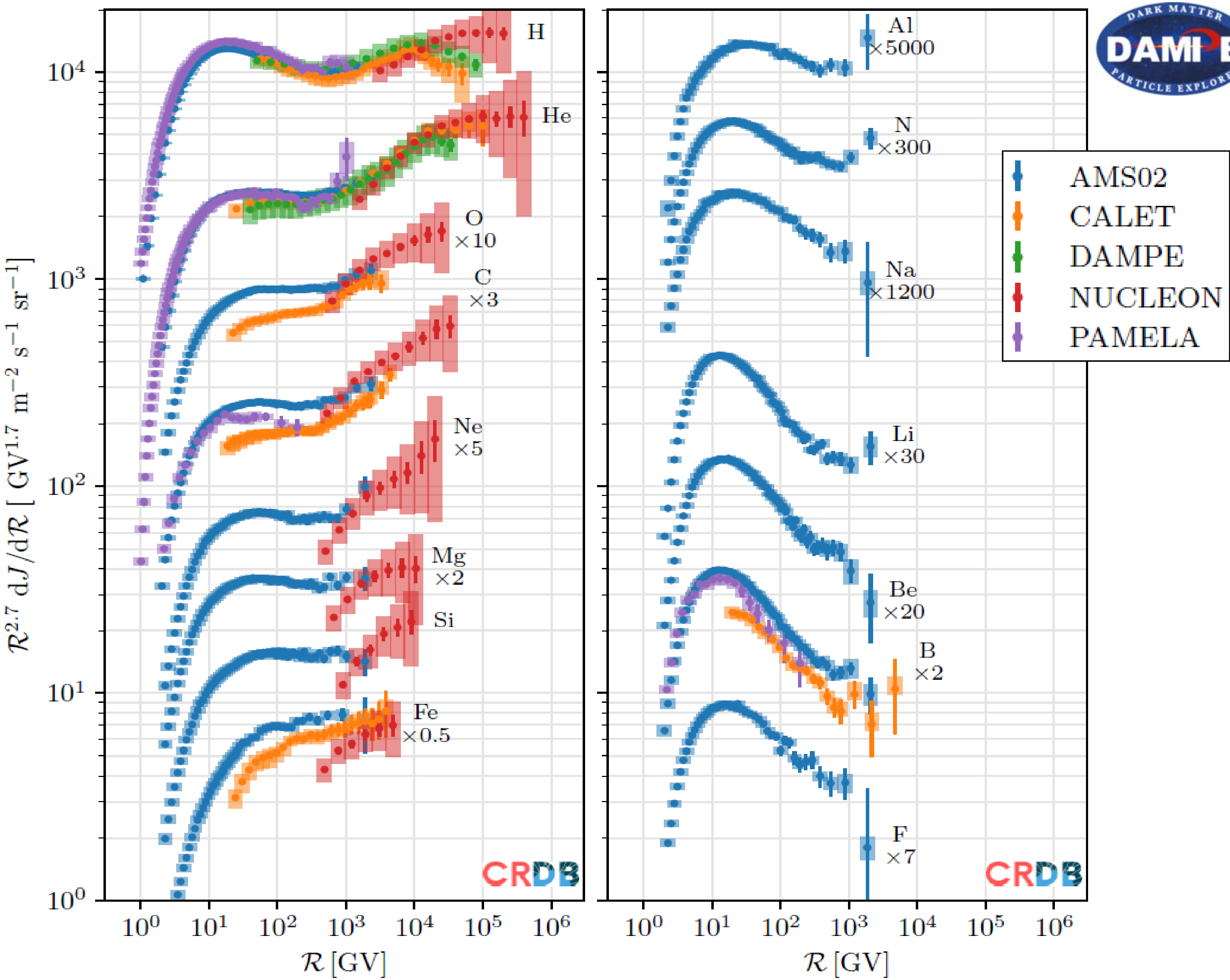
p and He: comparison and updates



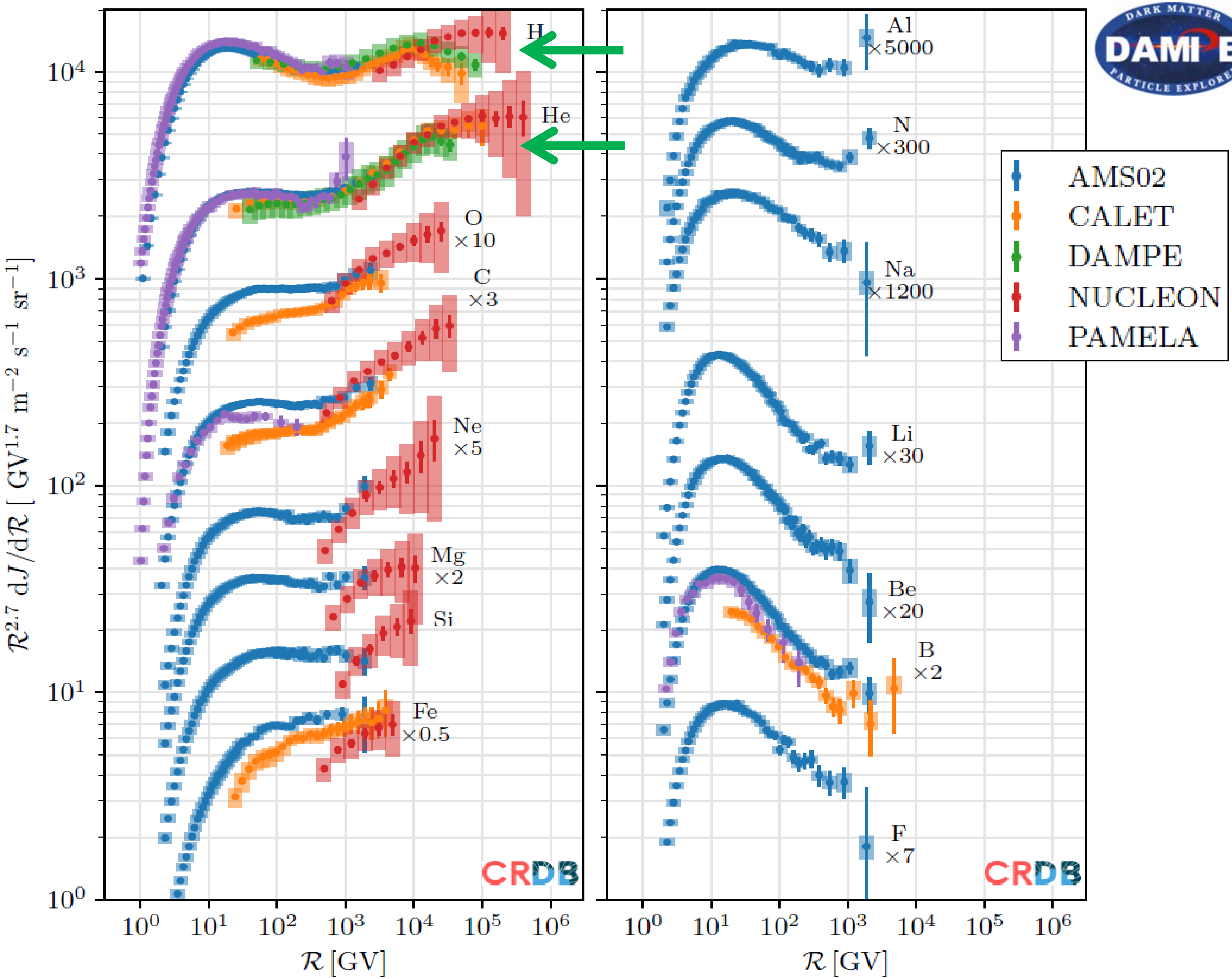
A rigidity dependence of both hardnening and softening is favoured by data







H
He
O ×10
C ×3
Ne ×5
Mg ×2
Si
Fe ×0.5
Al ×5000
N ×300
Na ×1200
Li ×30
Be ×20
B ×2
F ×7
AMS02
CALET
DAMPE
NUCLEON
PAMELA
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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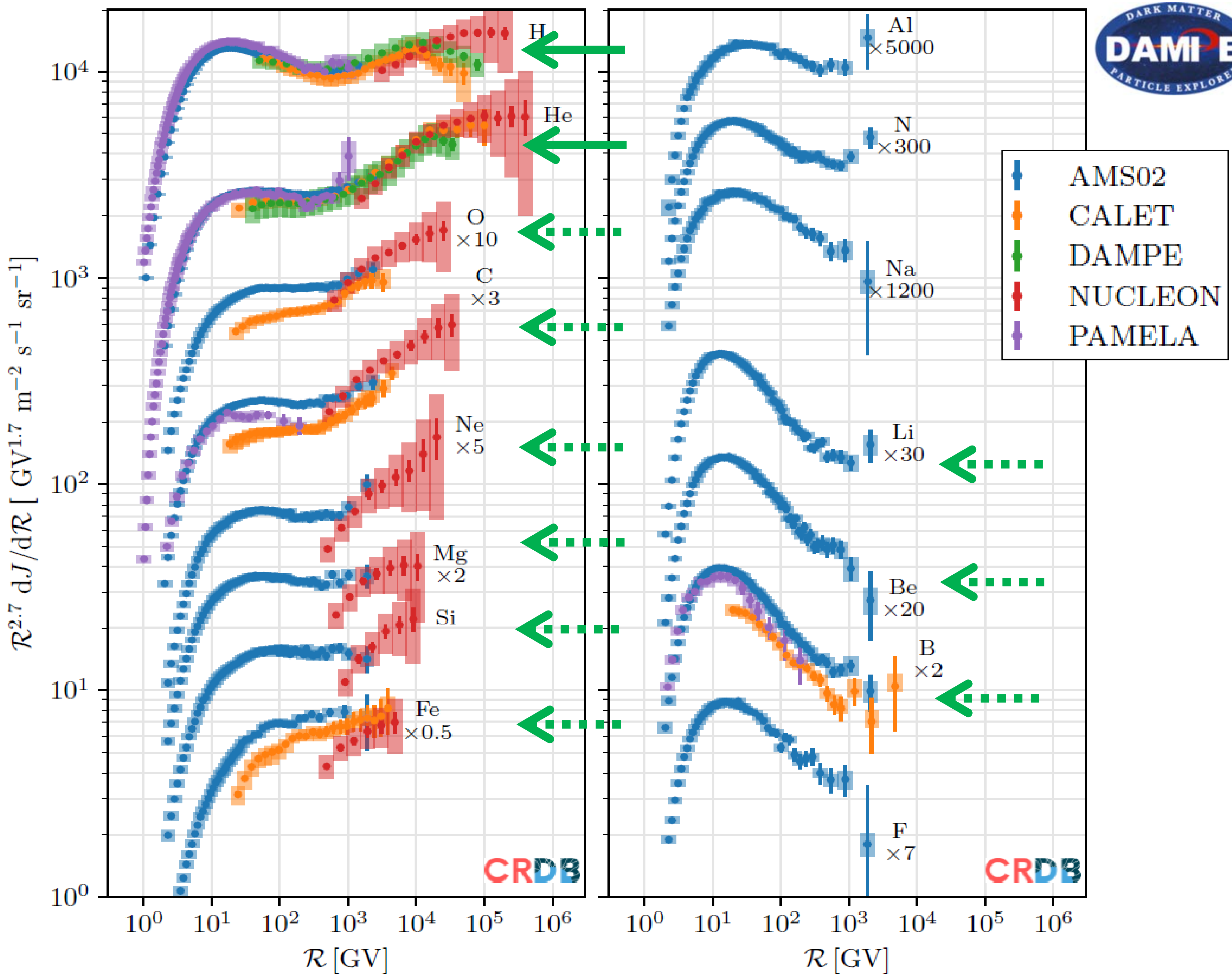
$\mathcal{R}$ [GV]
CRDB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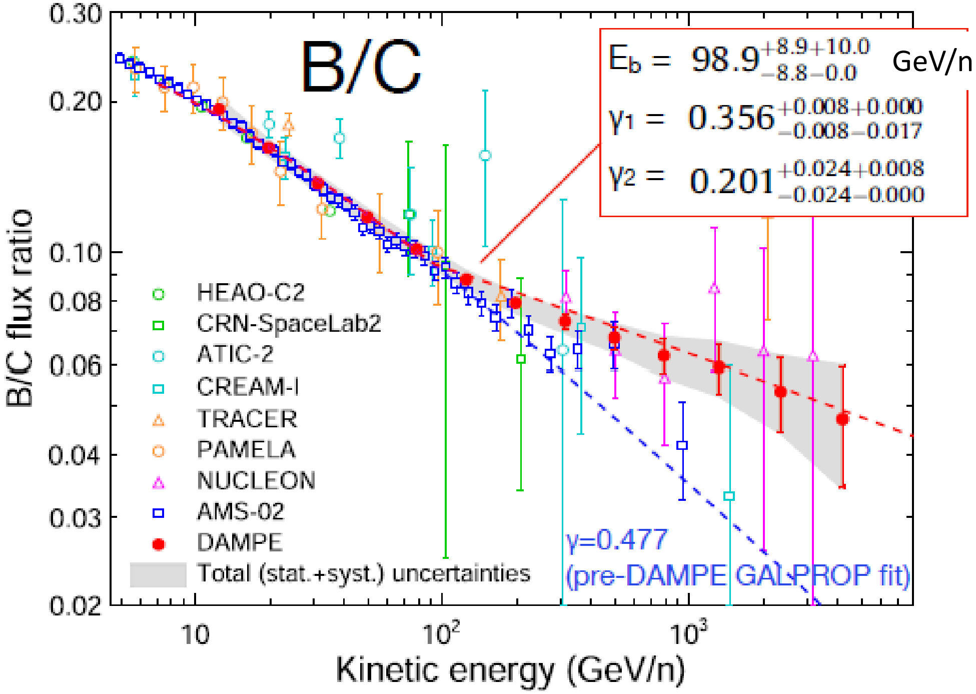
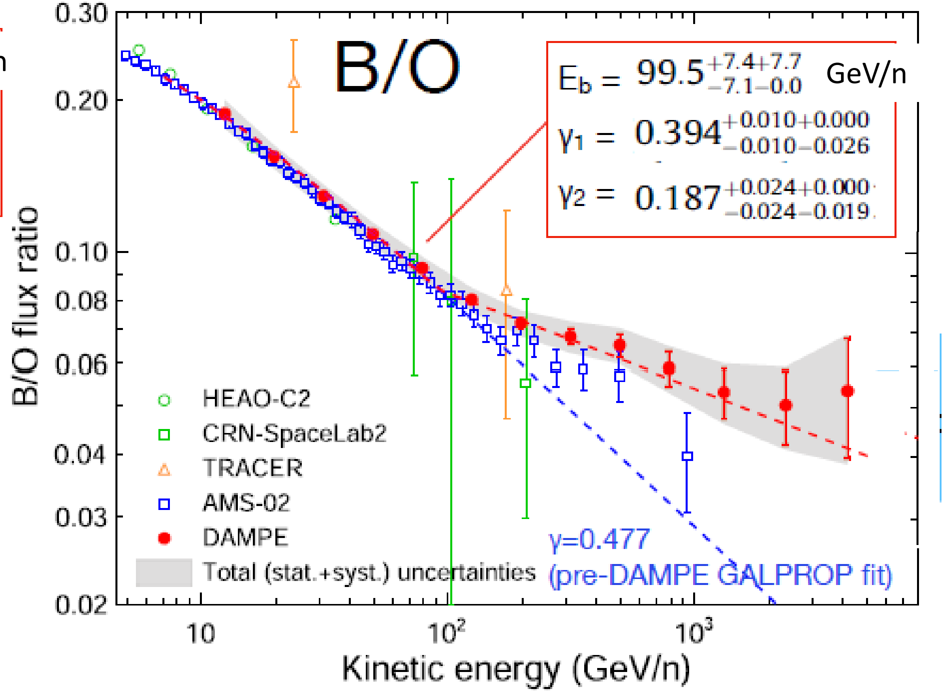
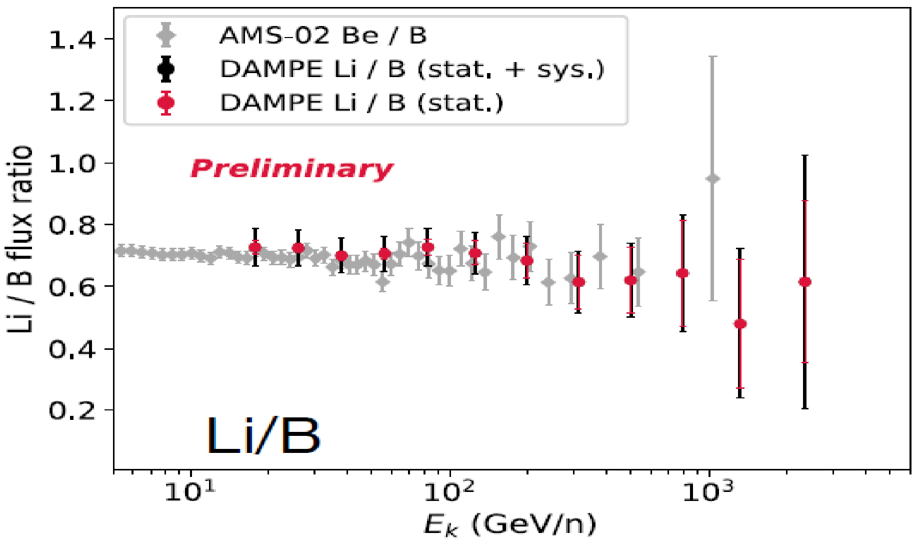
NUCLEON
PAMELA
$\mathcal{R}^{2.7}$ dJ/d$\mathcal{R}$ [GV$^{1.7}$ m^{-2} s^{-1} sr^{-1}]
$\mathcal{R}$ [GV]
CRDB

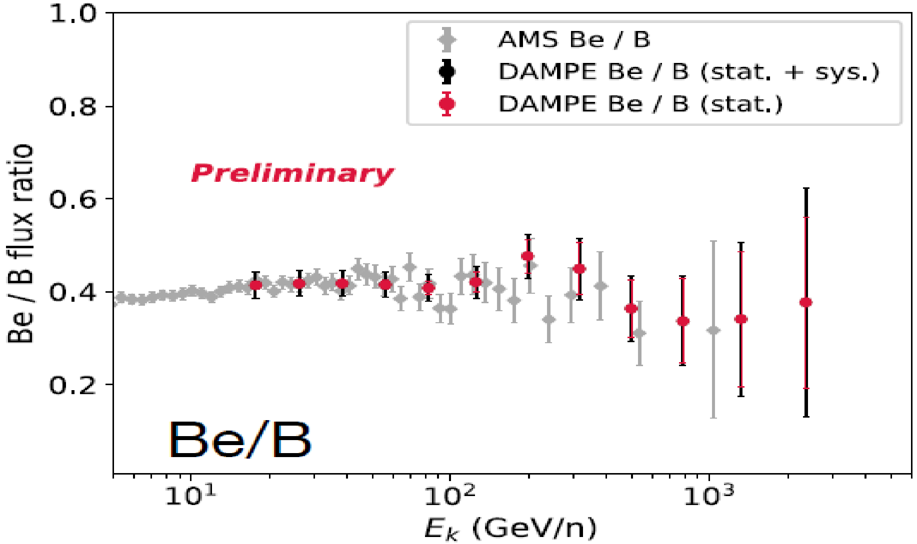
Flux ratios

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

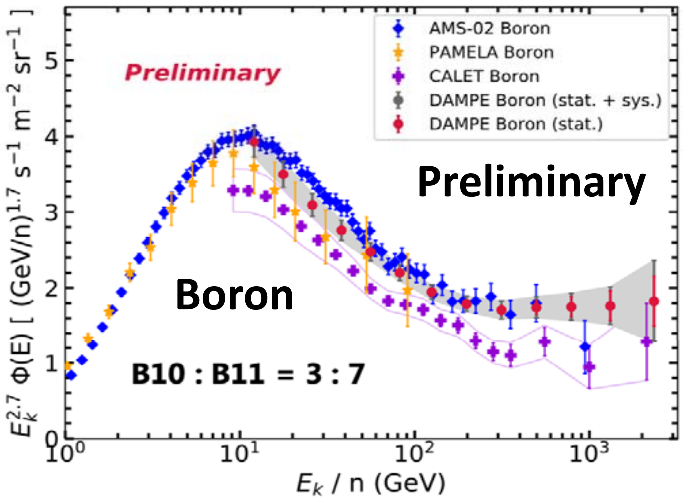


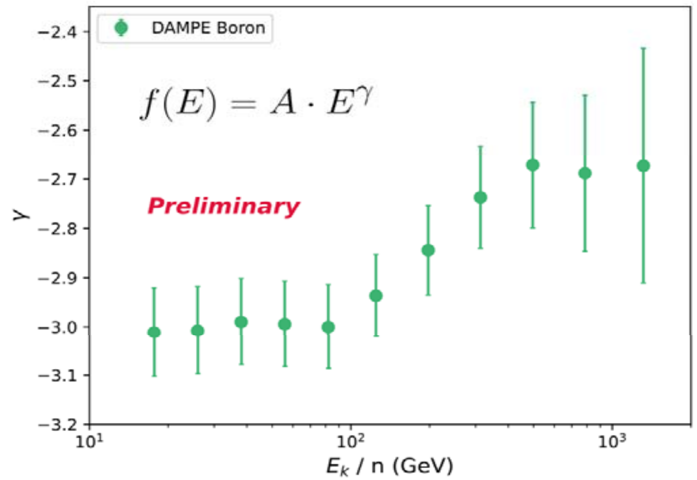




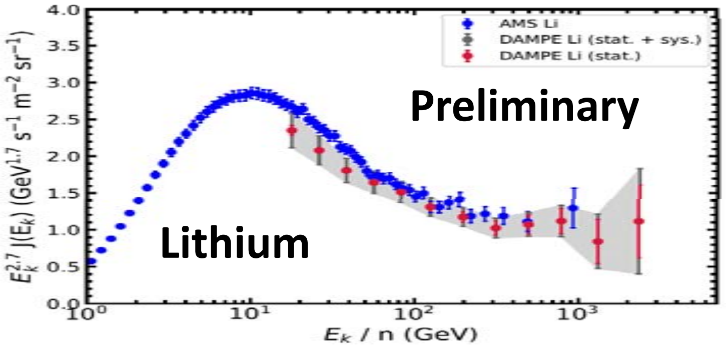


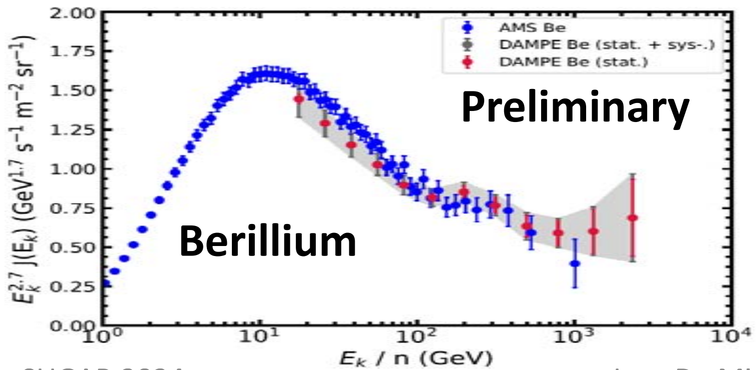
Secondaries: Li, Be and B

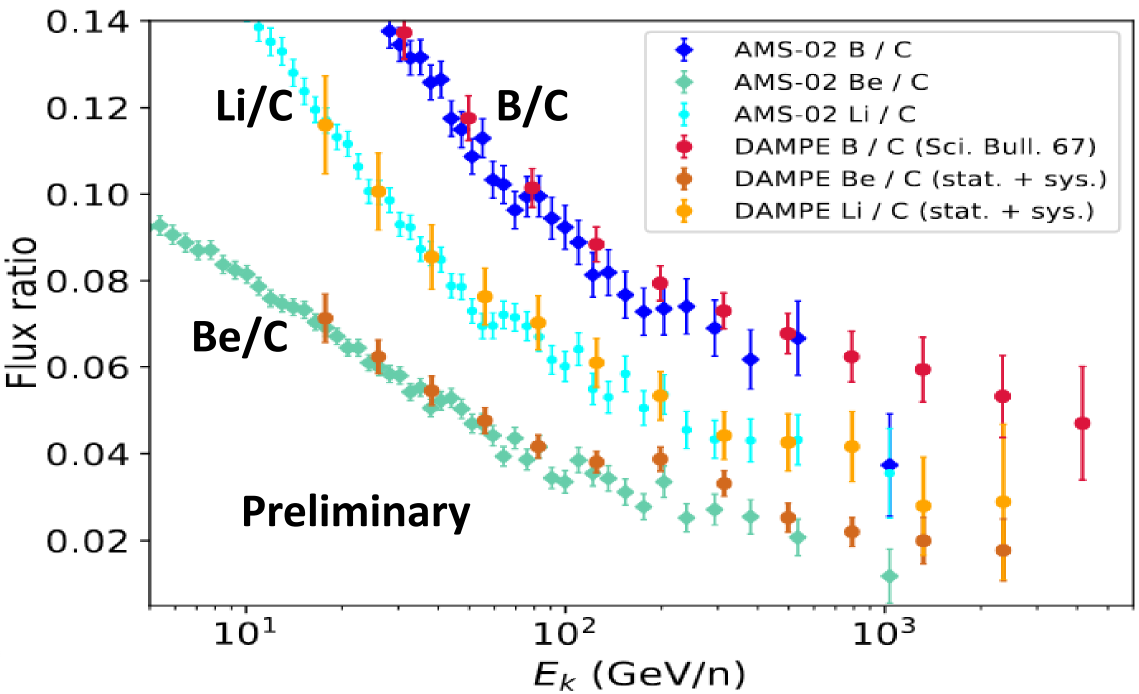




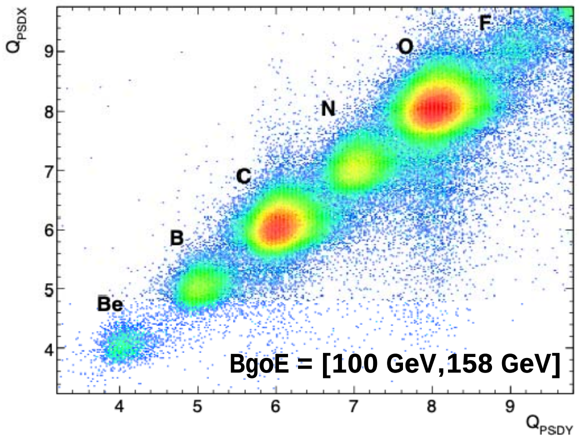
Clear hardenings at few hundreds GeV/n

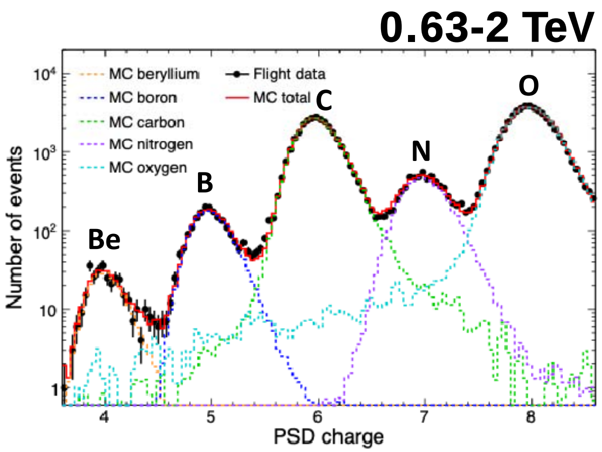


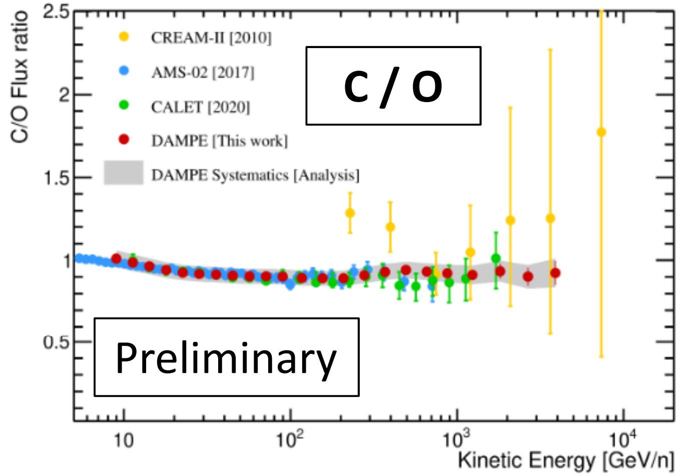


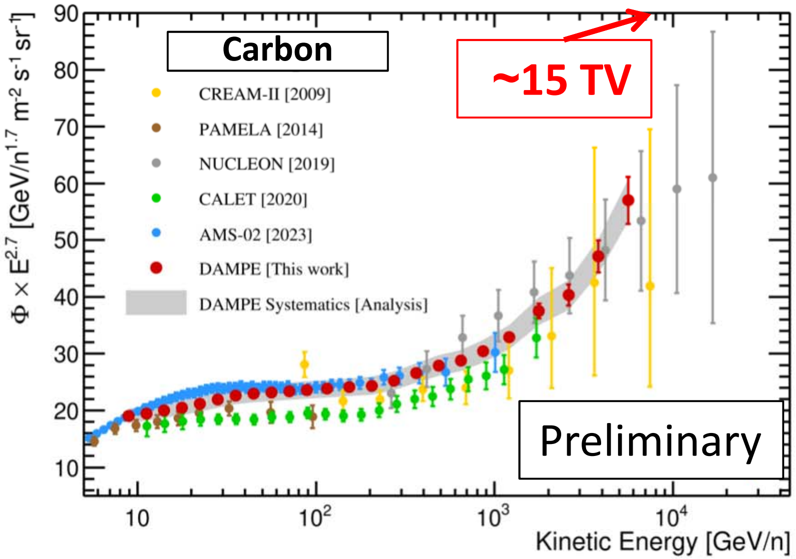


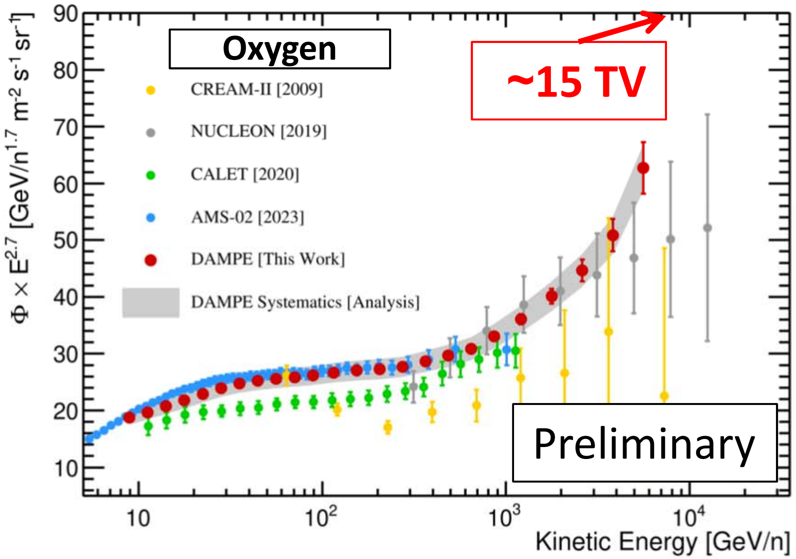
Carbon and Oxygen







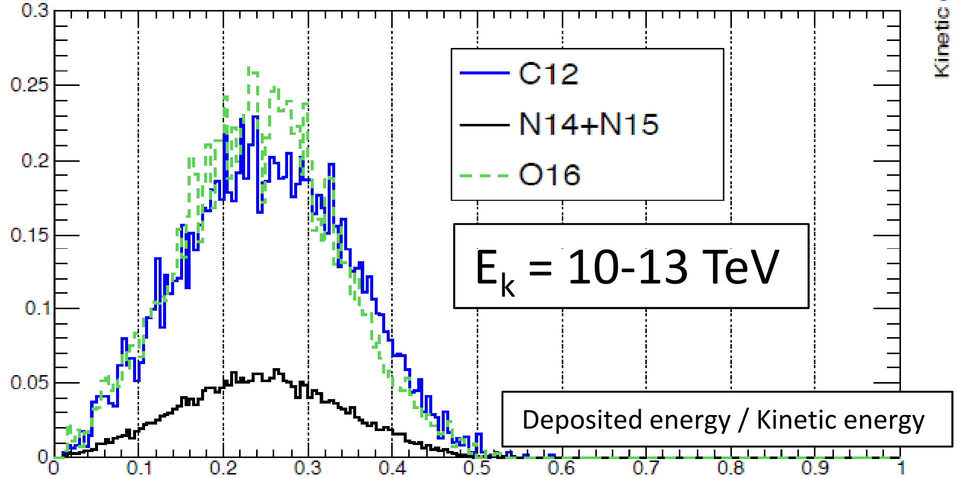


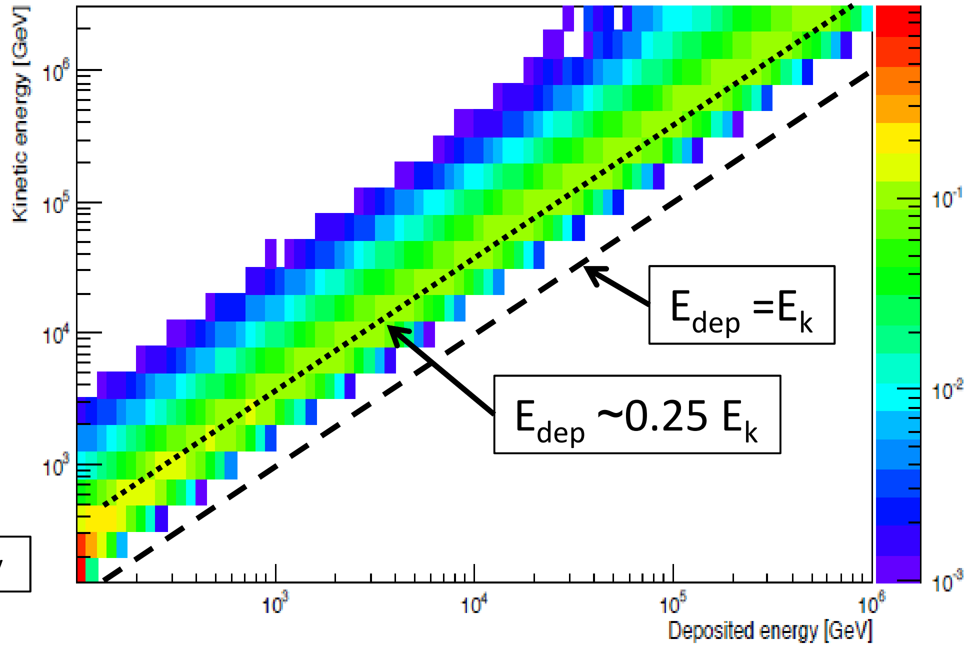


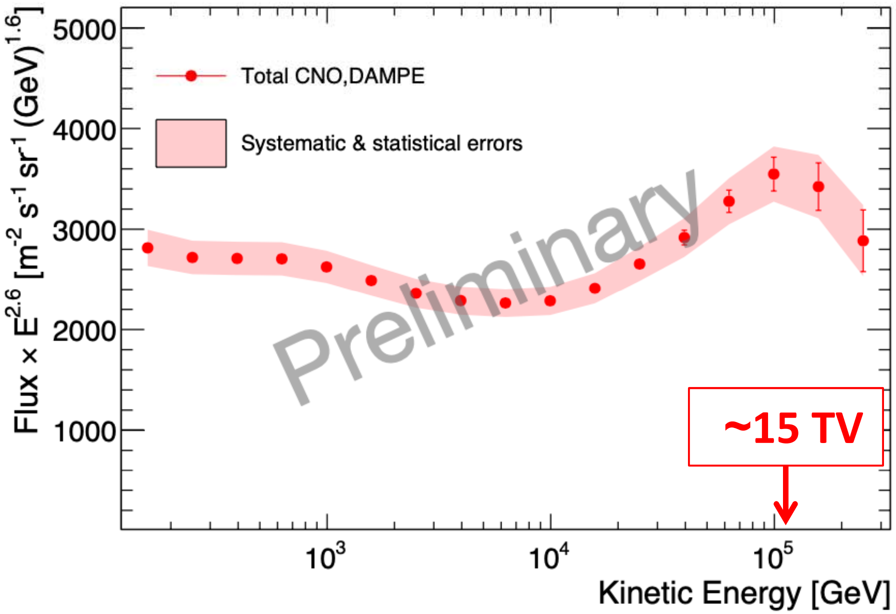
Preliminary DAMPE results do confirm the hardening and improve the precision at high energies. Work in progress for the extension up to hundreds TeV

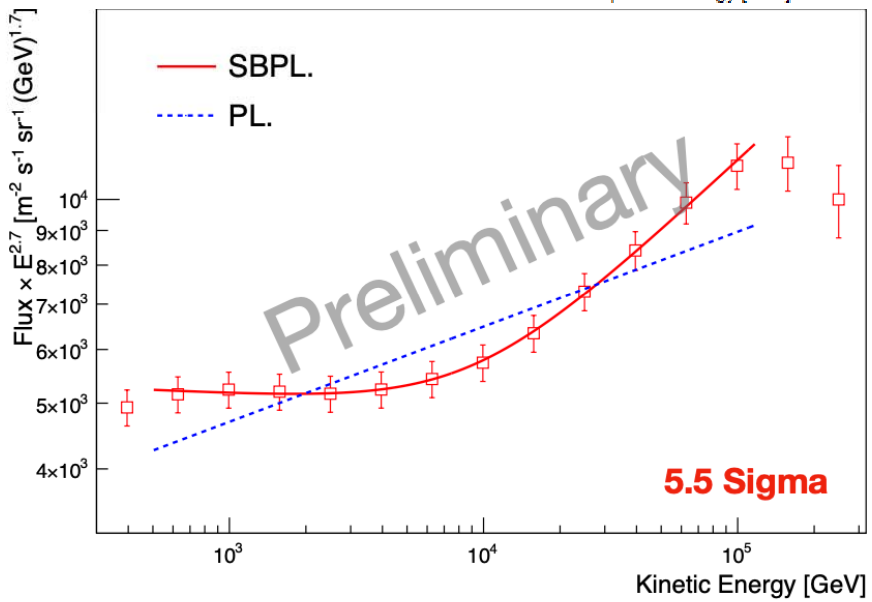
The CNO group

- Confirmation of the spectral hardening
- Hint for a softening at about 15 TV

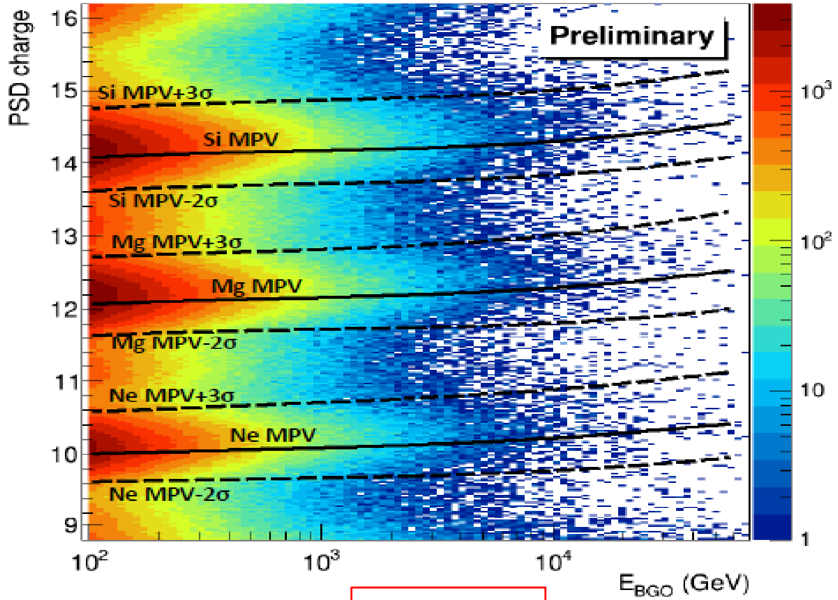




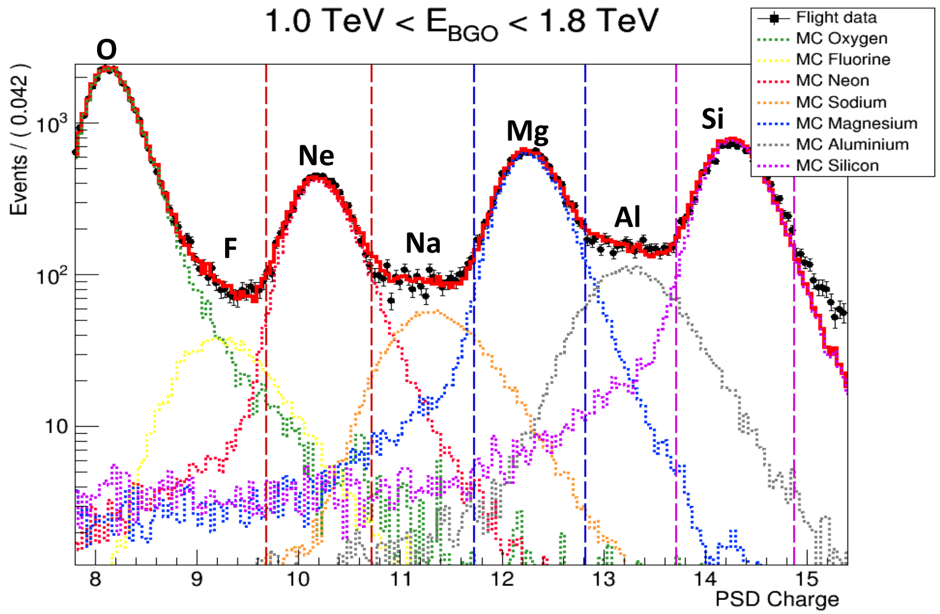




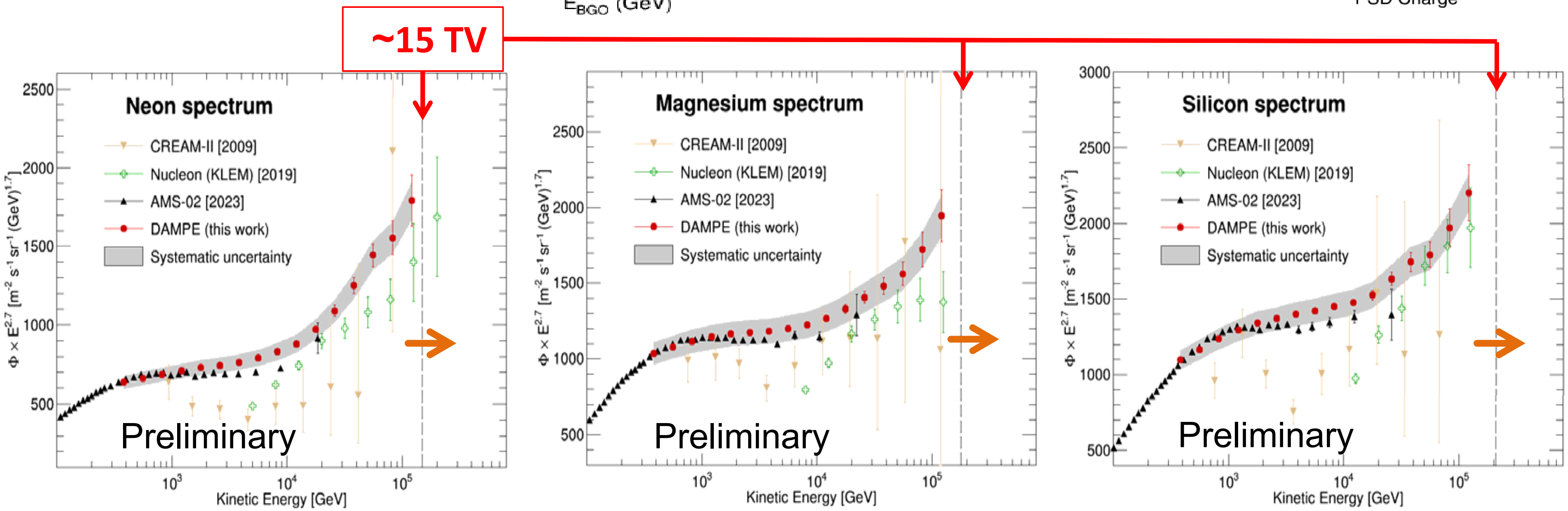
Ne , Mg and Si



Preliminary
Si MPV+3σ
Si MPV
Si MPV-2σ
Mg MPV+3σ
Mg MPV
Mg MPV-2σ
Ne MPV+3σ
Ne MPV
Ne MPV-2σ
PSD charge
E_{BGO} (GeV)

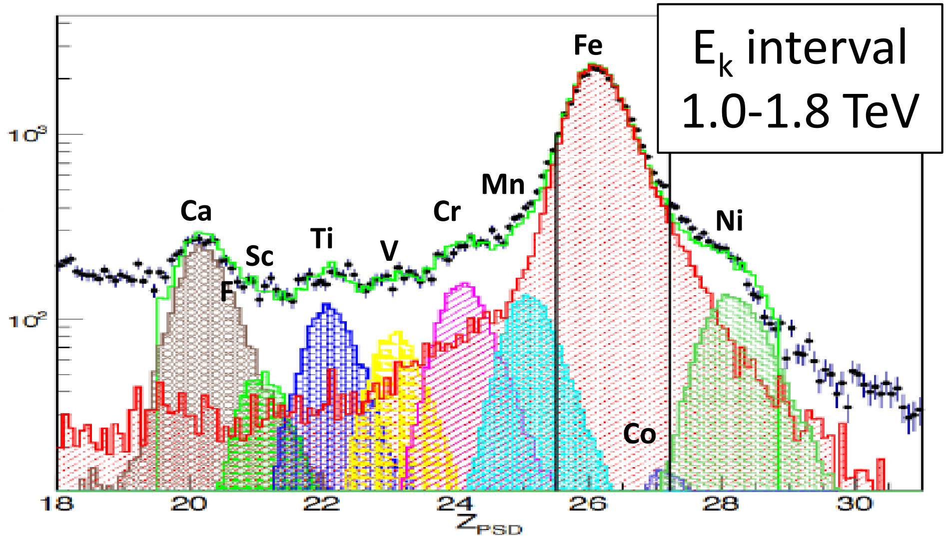


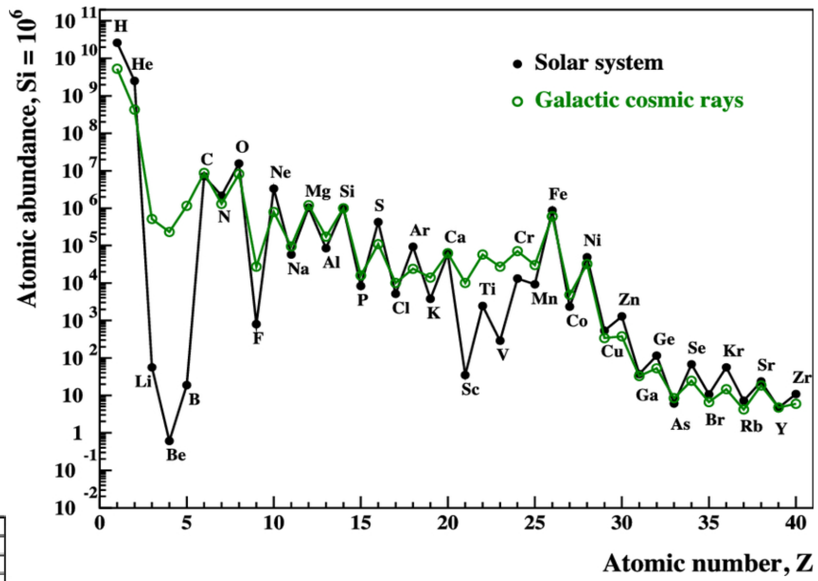
1.0 TeV < E_{BGO} < 1.8 TeV
Flight data
MC Oxygen
MC Fluorine
MC Neon
MC Sodium
MC Magnesium
MC Aluminium
MC Silicon
O
F
Ne
Na
Mg
Al
Si
Events / (0.042)
PSD Charge

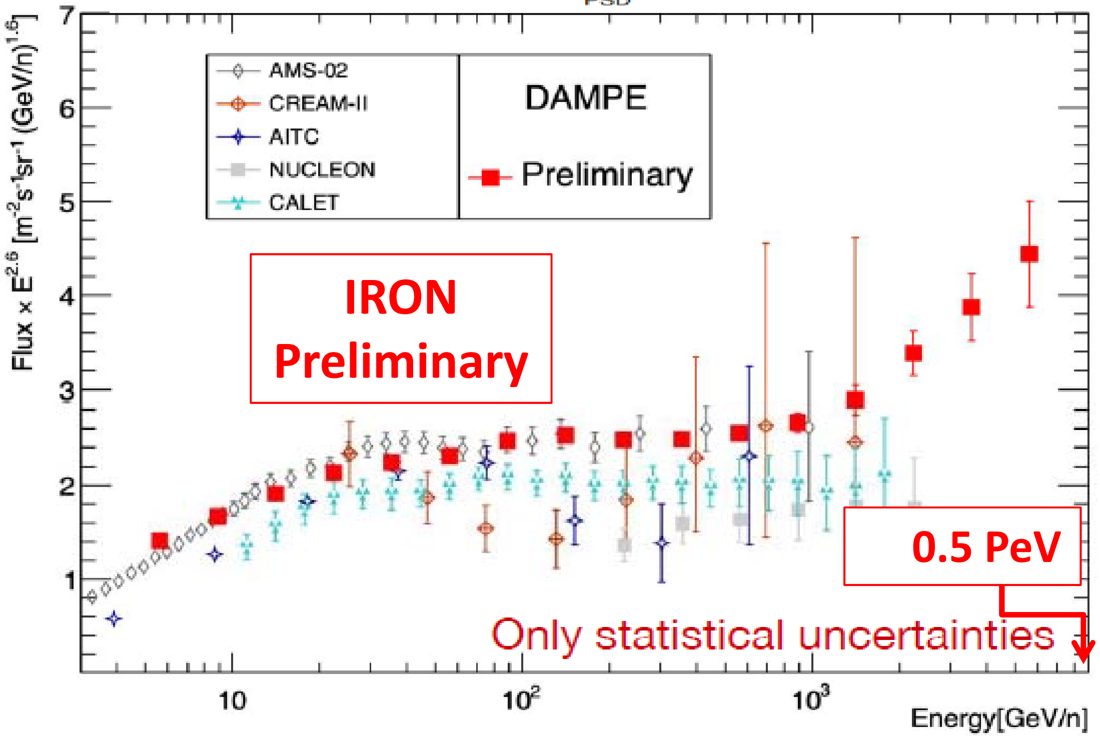


~15 TV
Neon spectrum
Magnesium spectrum
Silicon spectrum
CREAM-II [2009]
Nucleon (KLEM) [2019]
AMS-02 [2023]
DAMPE (this work)
Systematic uncertainty
Preliminary
$\Phi \times E^{2.7}$ [m^{-2} s^{-1} sr^{-1} $(GeV)^{1.7}$]
Kinetic Energy [GeV]

The Iron spectrum



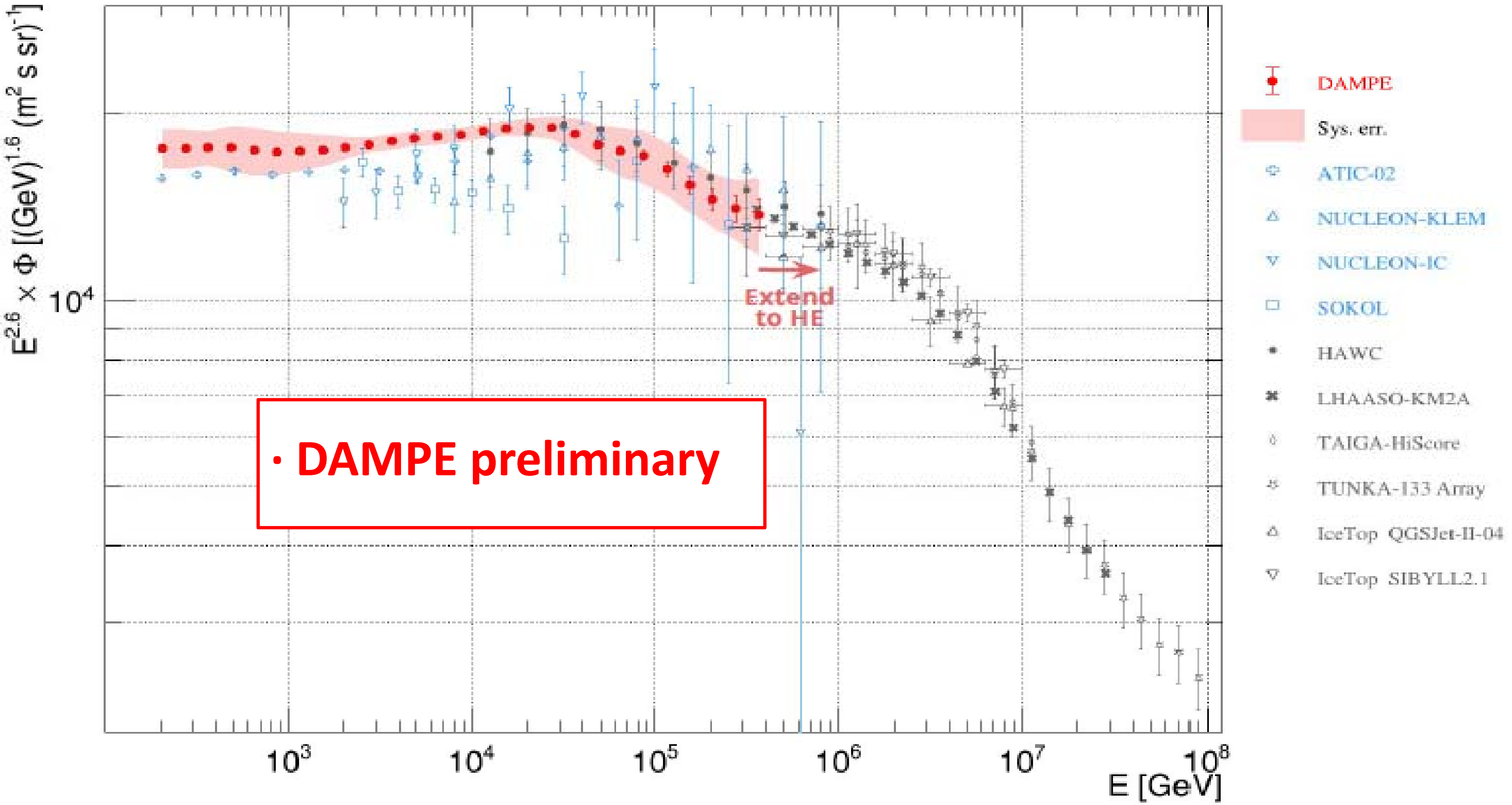




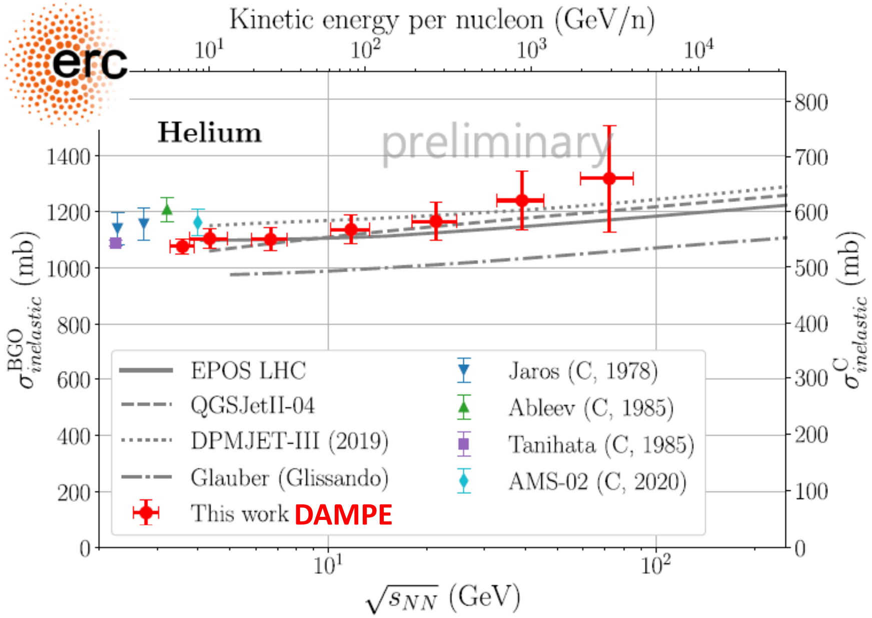
- Small background nuclei
- Special care to fragmentation
- Systematics under evaluation
- **Hardening at hundreds GeV / n**
- **Extension to higher energies in progress**

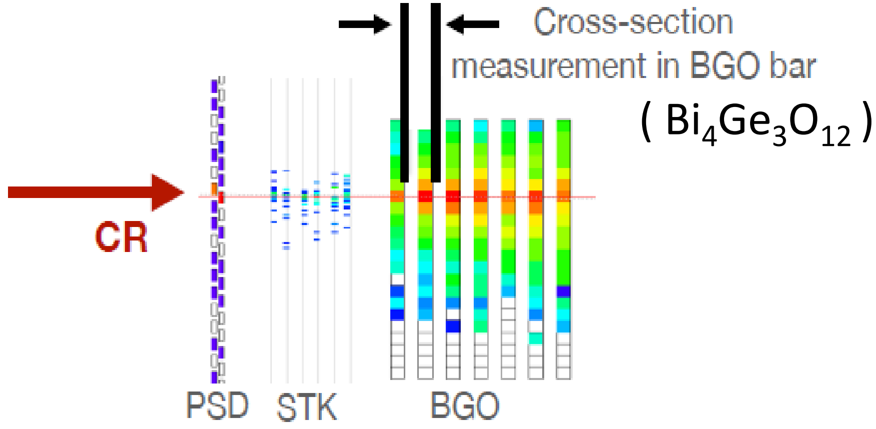
The all-particle spectrum

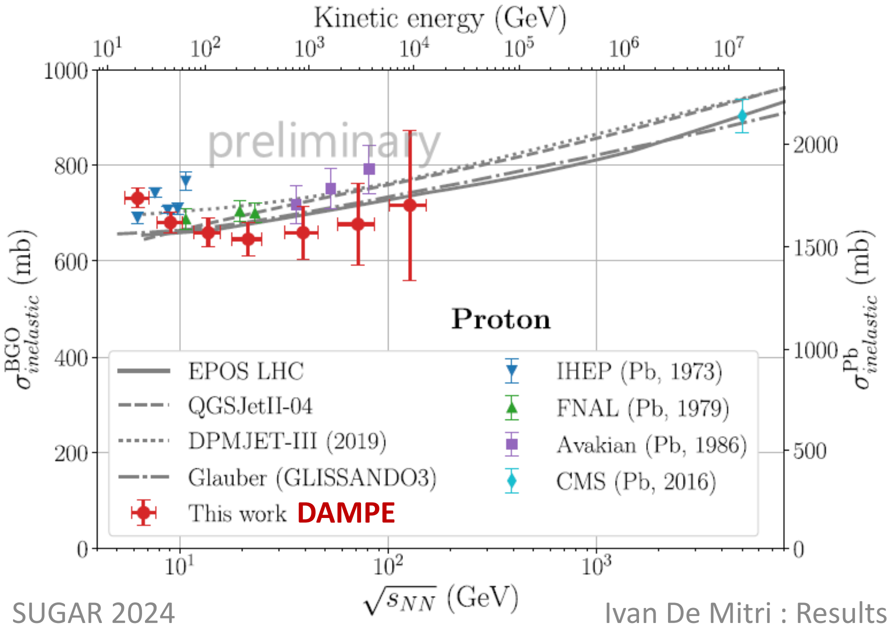
- A **single measurement across almost 4 orders of magnitude**
- Not the sum of single spectra but independent analysis slecting all nuclei
- Small (composition) model dependence, within the quoted systematics

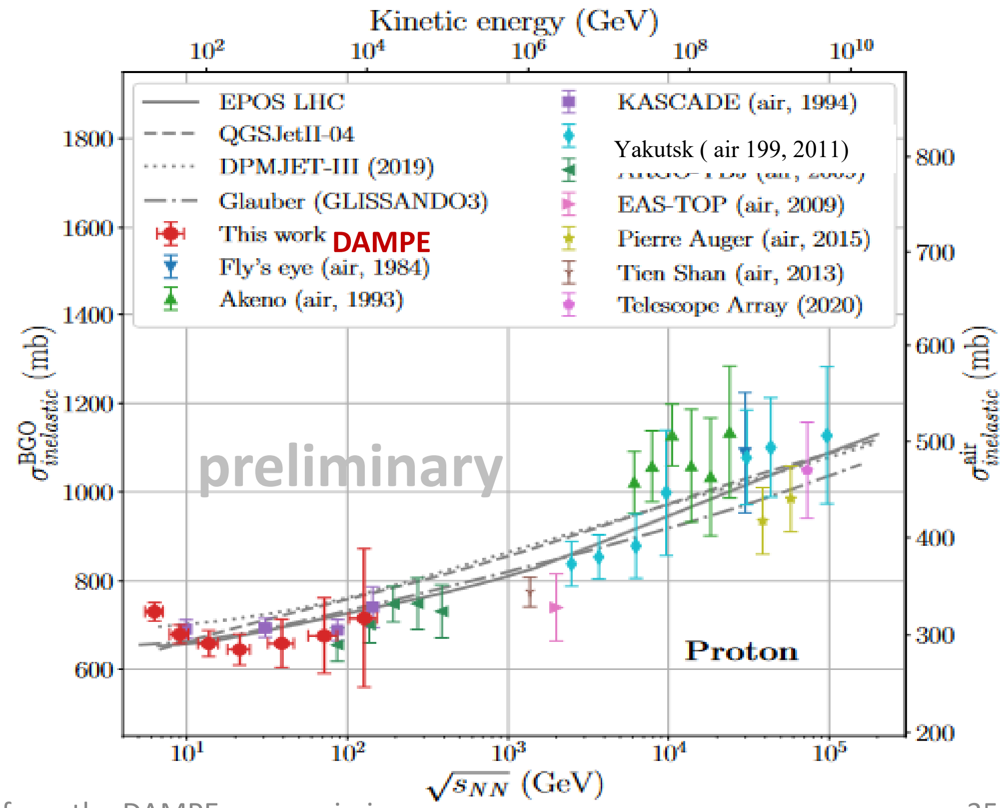


Hadronic cross section measurements



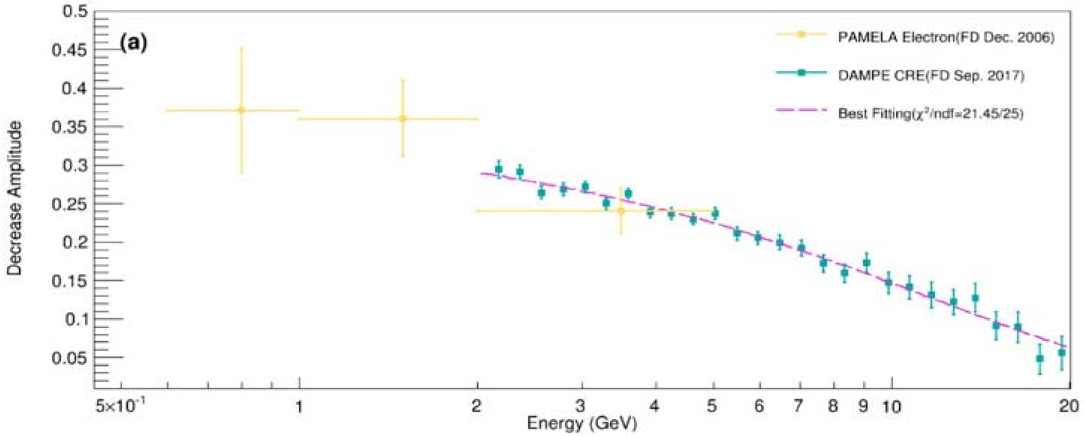


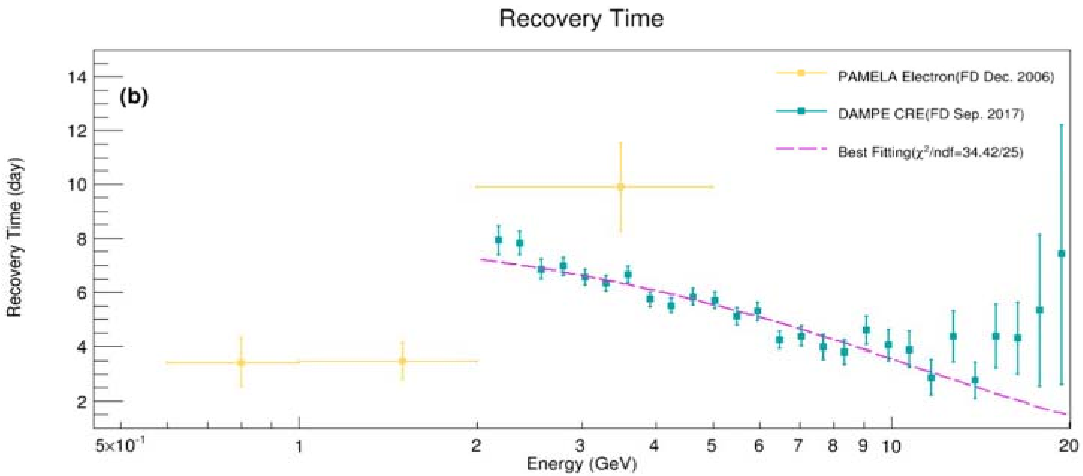


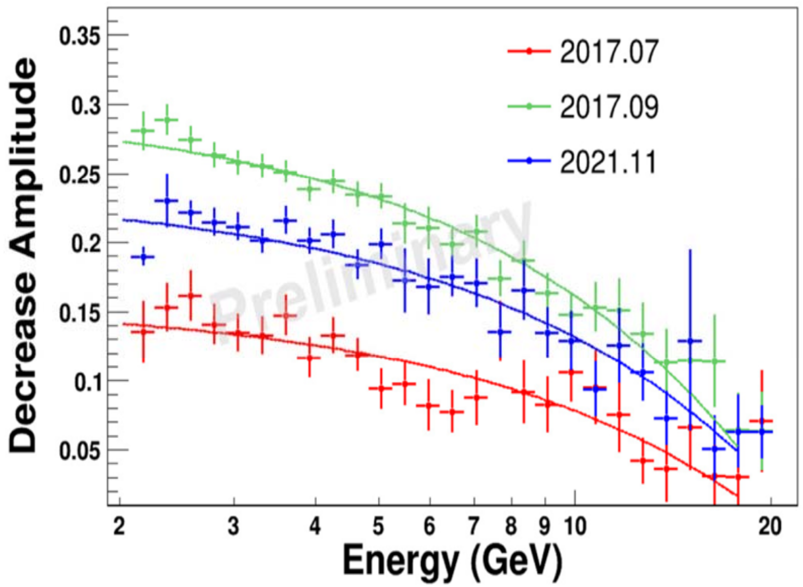


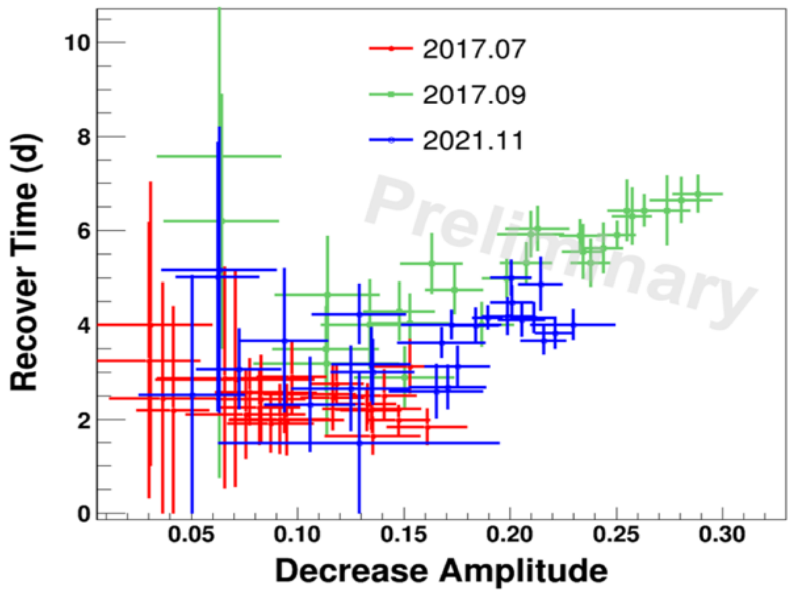
Forbush decrease in $e^{-}+e^{+}$

- Flux decrease due to solar activity (CMEs, etc.)
- Use the DAMPE excellent energy resolution for $e^{\pm}$
- Interesting correlations among recovery times and energies





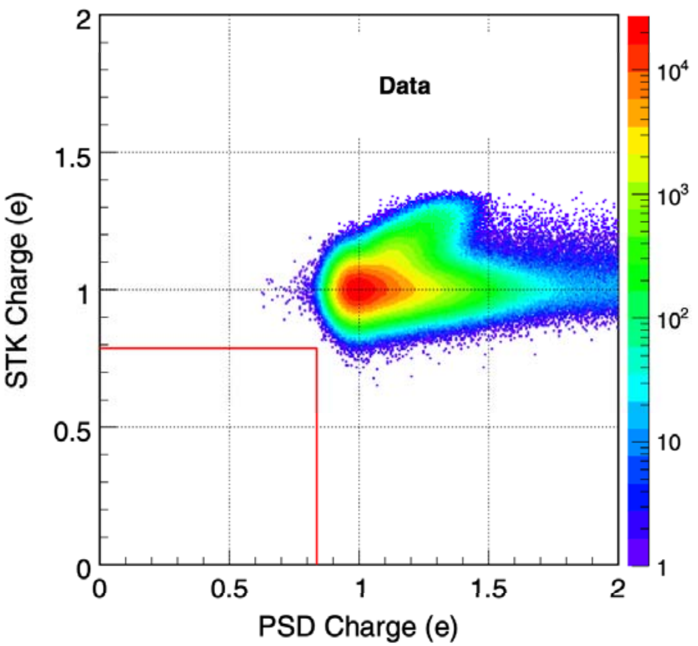


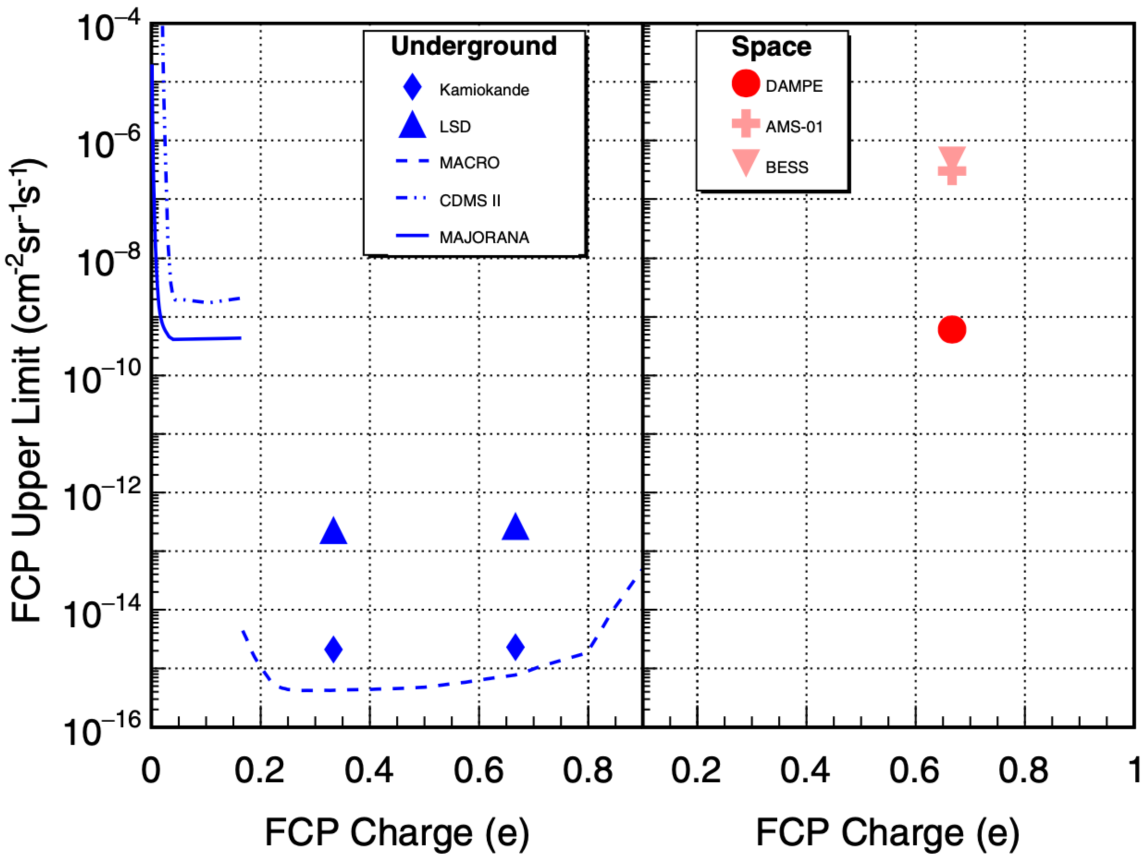


Fractionally charged particles

- Beyond the Standard Model prediction
- Strongest upper limits from underground experiment (e.g. MACRO) but **above hundreds TeV**
- **Space based searches applies to kinetic energies above few GeV**

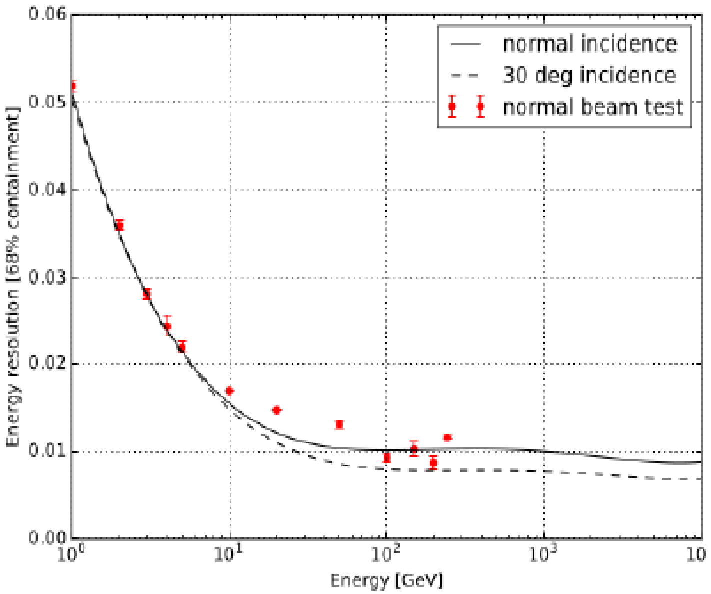
Look for dE/dX below the mip level in both PSD and STK

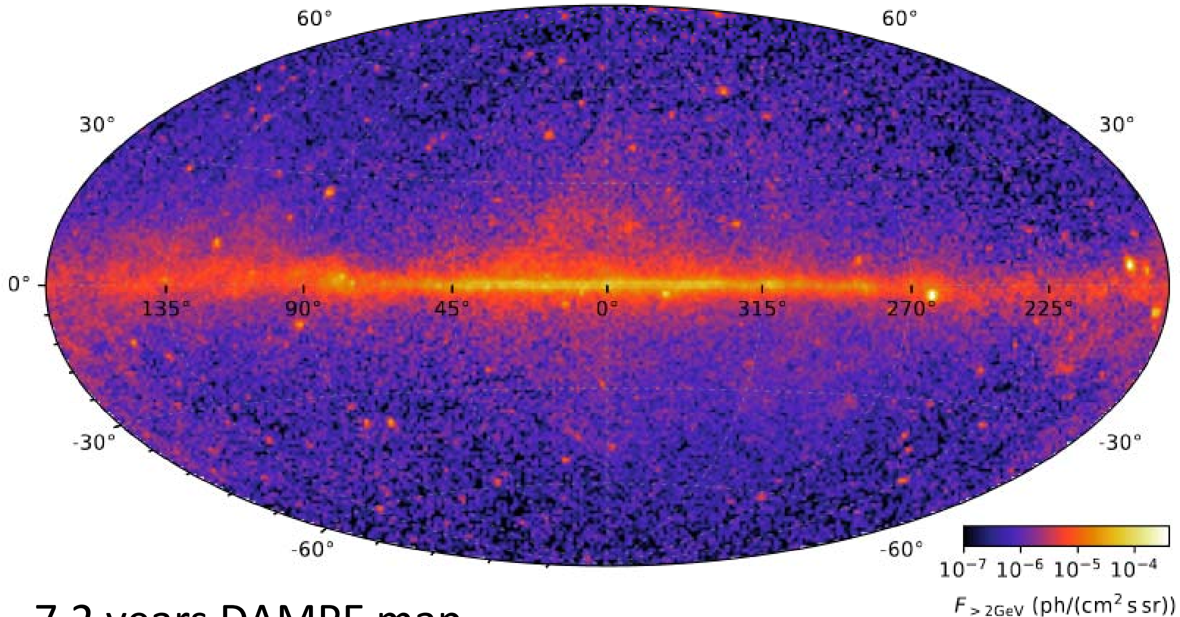




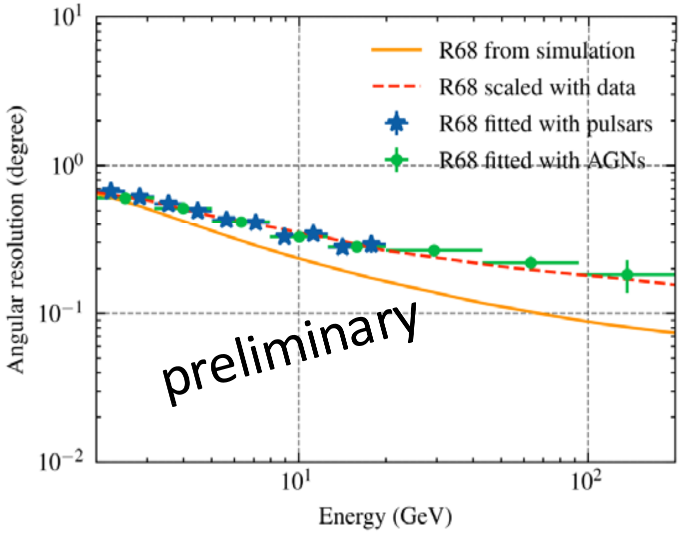
Photon detection with DAMPE

- Energy resolution: better than 1.5% above 10GeV
- Angular resolution: better than 0.3° above 10GeV
- Effective area ~0.1 m^2 between few GeV and few TeV
- The energy resolution has been checked at beams
- The Point Spread Function (PSF) has been calibrated with photons from 52 AGNs and 3 pulsars
- About 2 sky surveys/year



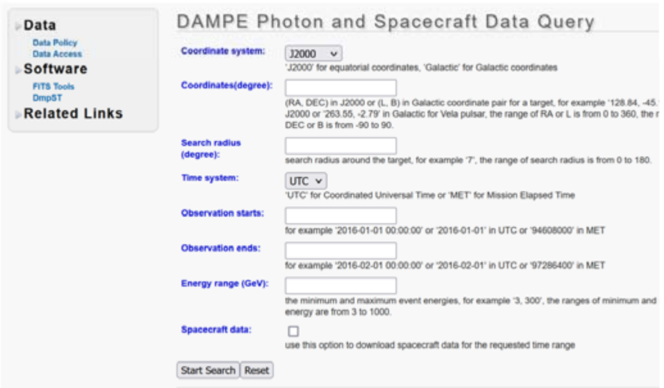


7.2 years DAMPE map
($4 \cdot 10^4$ events/year above 2GeV)

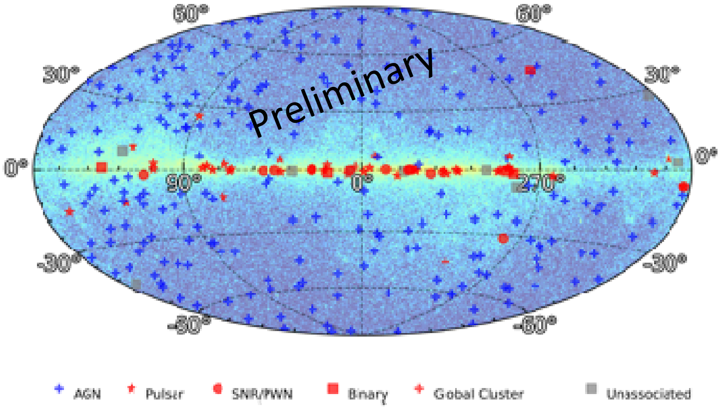


Gamma ray astronomy

Welcome to use DAMPE photon data !



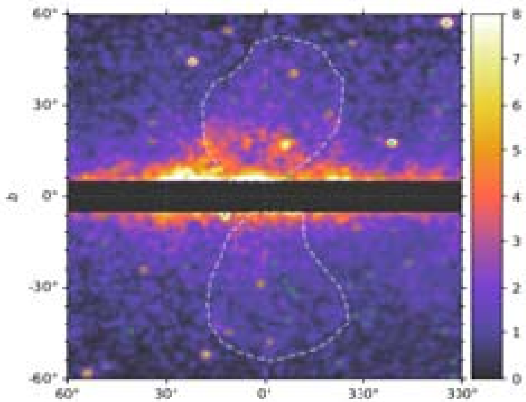
https://dampe.nssdc.ac.cn/dampe/dataquerysc.php
http://dgdb.pmo.ac.cn/dampe/



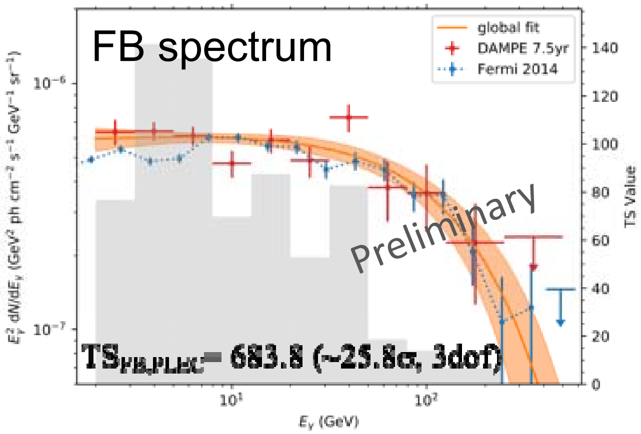
Point source catalog

Source type	number
AGN	241
Pulsar	62
SNR/PWN	14
Binary	5
Global cluster	4
Unassociated	10
Total	336

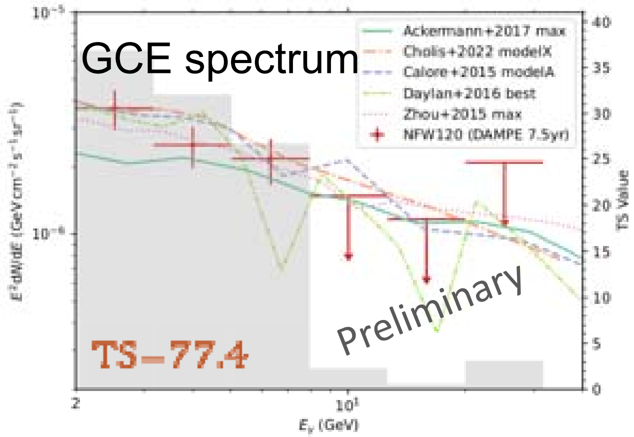
Fermi Bubbles



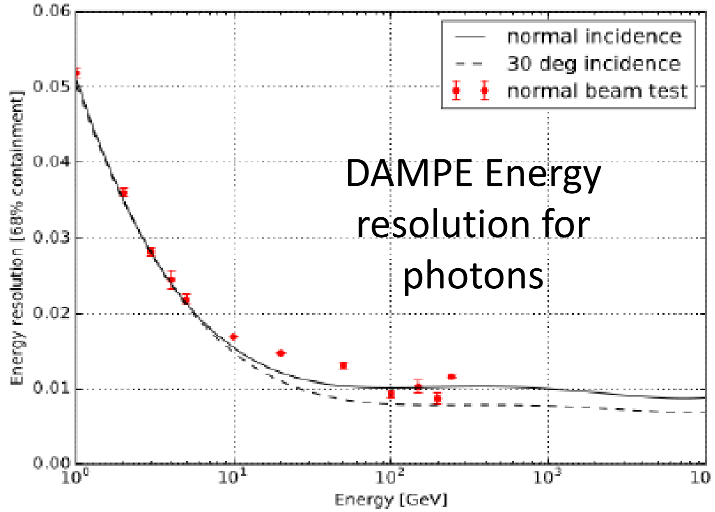
Flux map



Galactic Center Excess

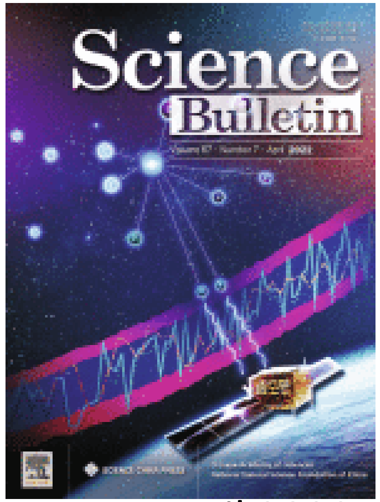


Indirect Dark Matter search

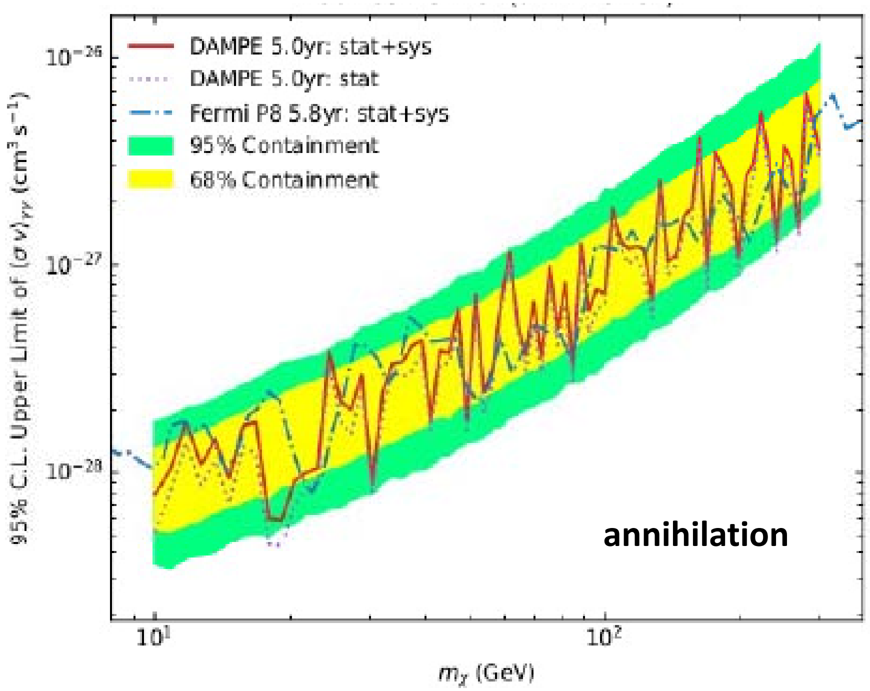


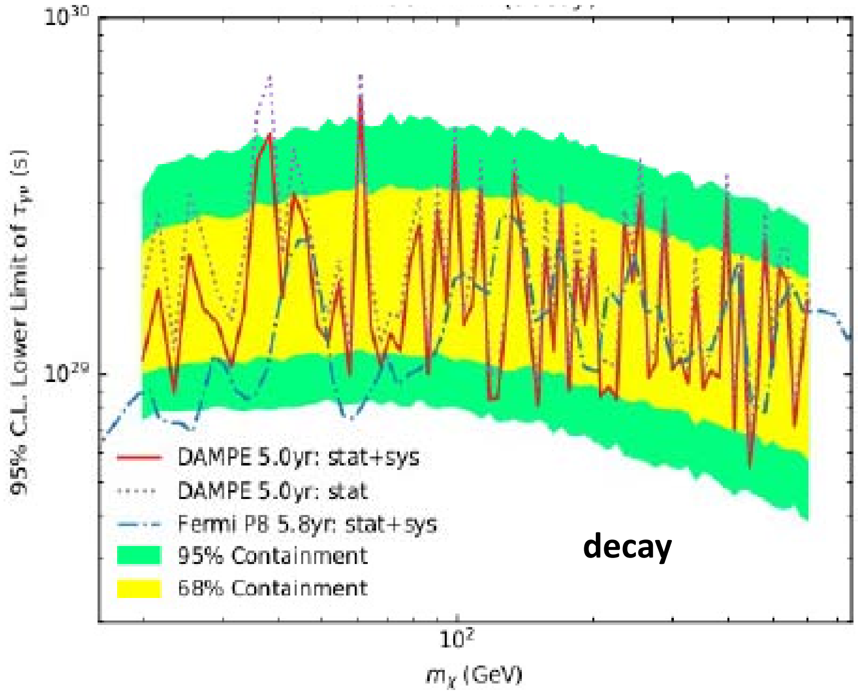
Search for gamma ray lines from neutralino annihilation or decay

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



April 2022





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
- Preliminary spectral measurements of heavier nuclei (C, N, O Fe, …) and light secondaries (Li, Be, B)
- Studies of gamma ray sources (>300 sources, Fermi bubble, …)
- Detected new features in Forbush decrease
- Upper limits for dark matter signatures, fractionally charged particles, …