Measurements of galactic CR energy spectra with the DAMPE space mission

Ivan DE MITRI
Gran Sasso Science Institute (GSSI)
& INFN Laboratori Nazionali del Gran Sasso

The 27th European Cosmic Ray Symposium
ECRS 2022
July 25-29, 2022
Nijmegen, The Netherlands

DAMPE science goals

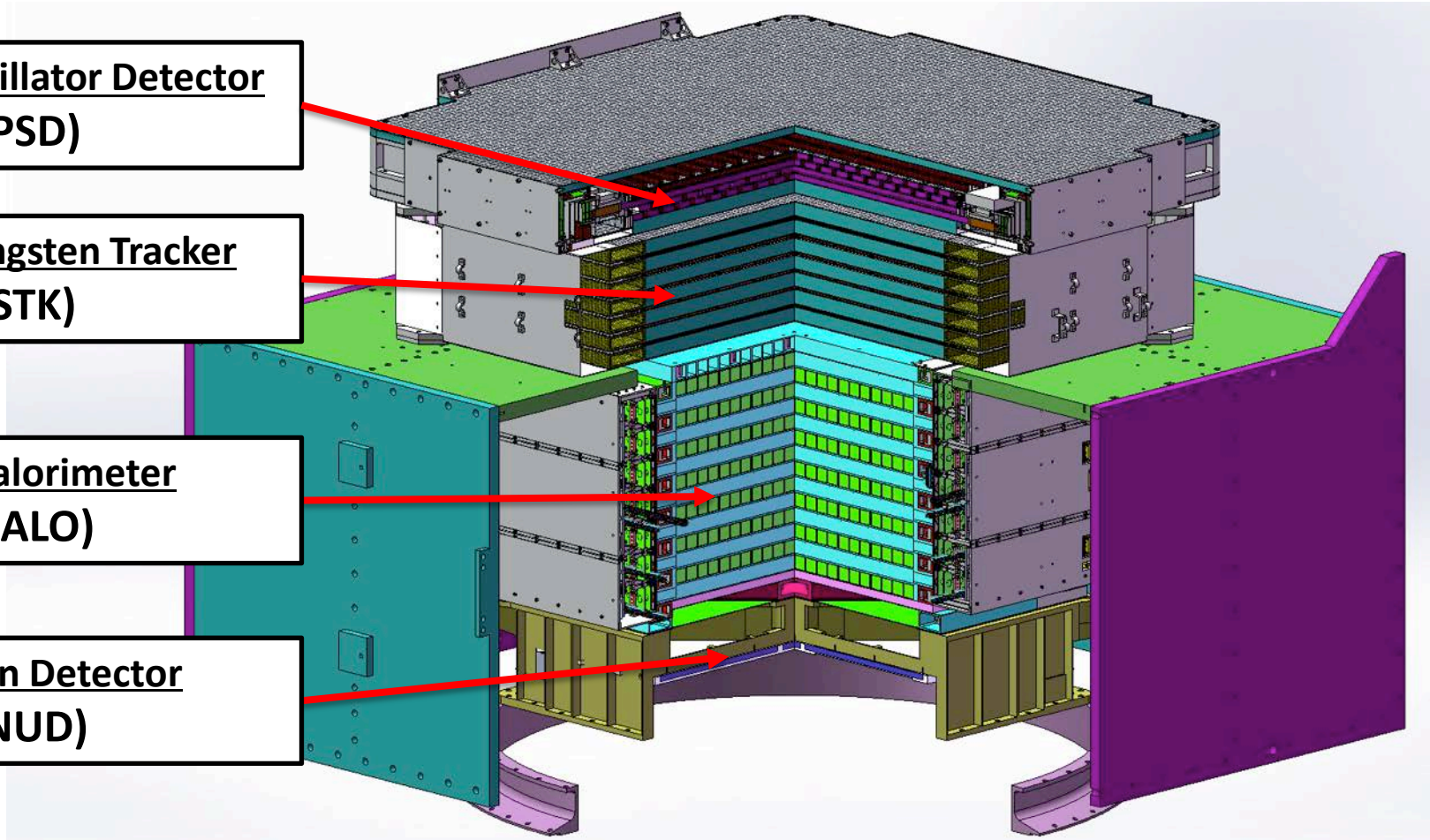
High energy particle detection in space

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

Detection of
10 GeV - 10 TeV e/γ
50 GeV - 200 TeV protons and nuclei
with excellent 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)**

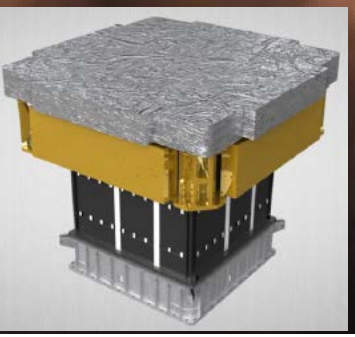
⇨ high energy γ-ray, electron and cosmic ray telescope

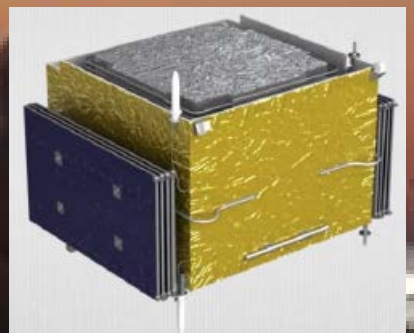
The launch: Dec 17th 2015, 0:12 UTC

Jiuquan Satellite Launch Center
Gobi desert

CZ-2D rocket

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

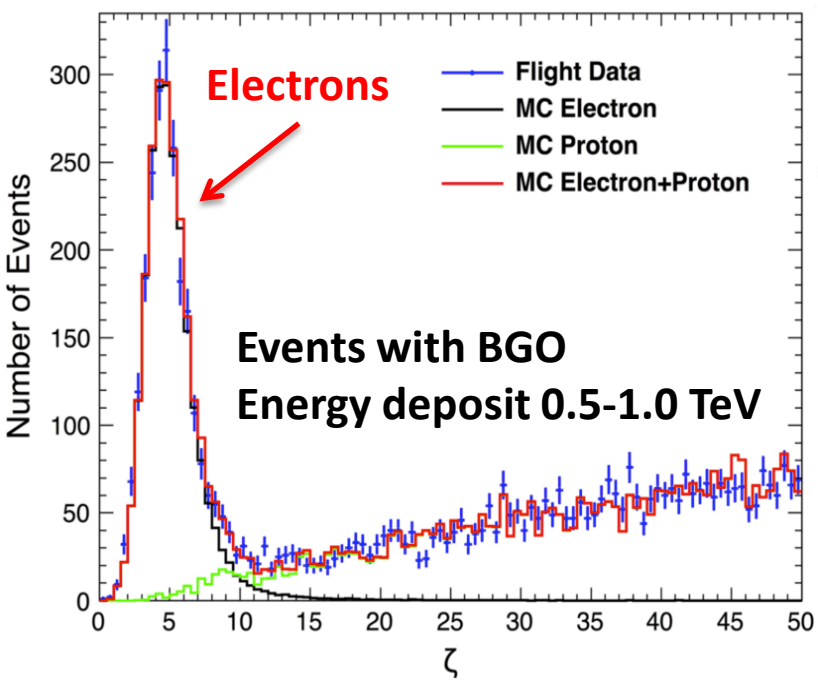


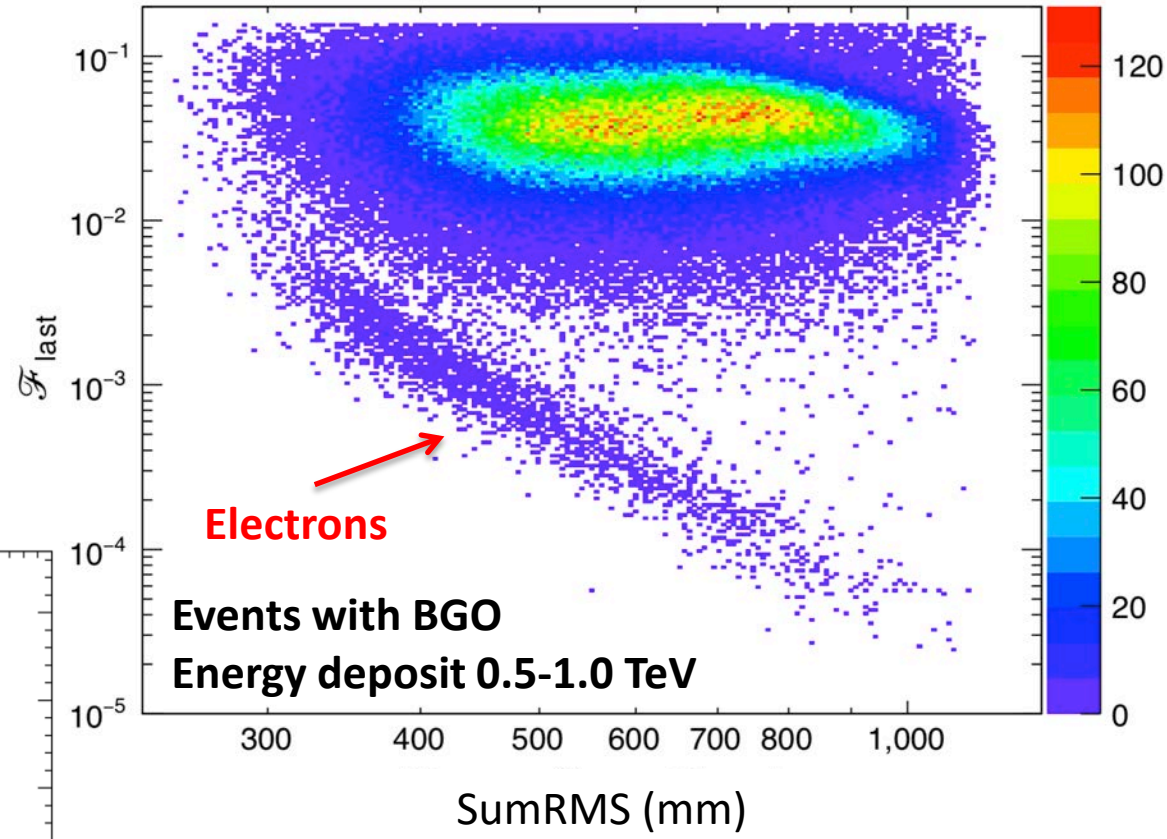


Electron IDentification

$\mathcal{F}_{\text{last}}$ = 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

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

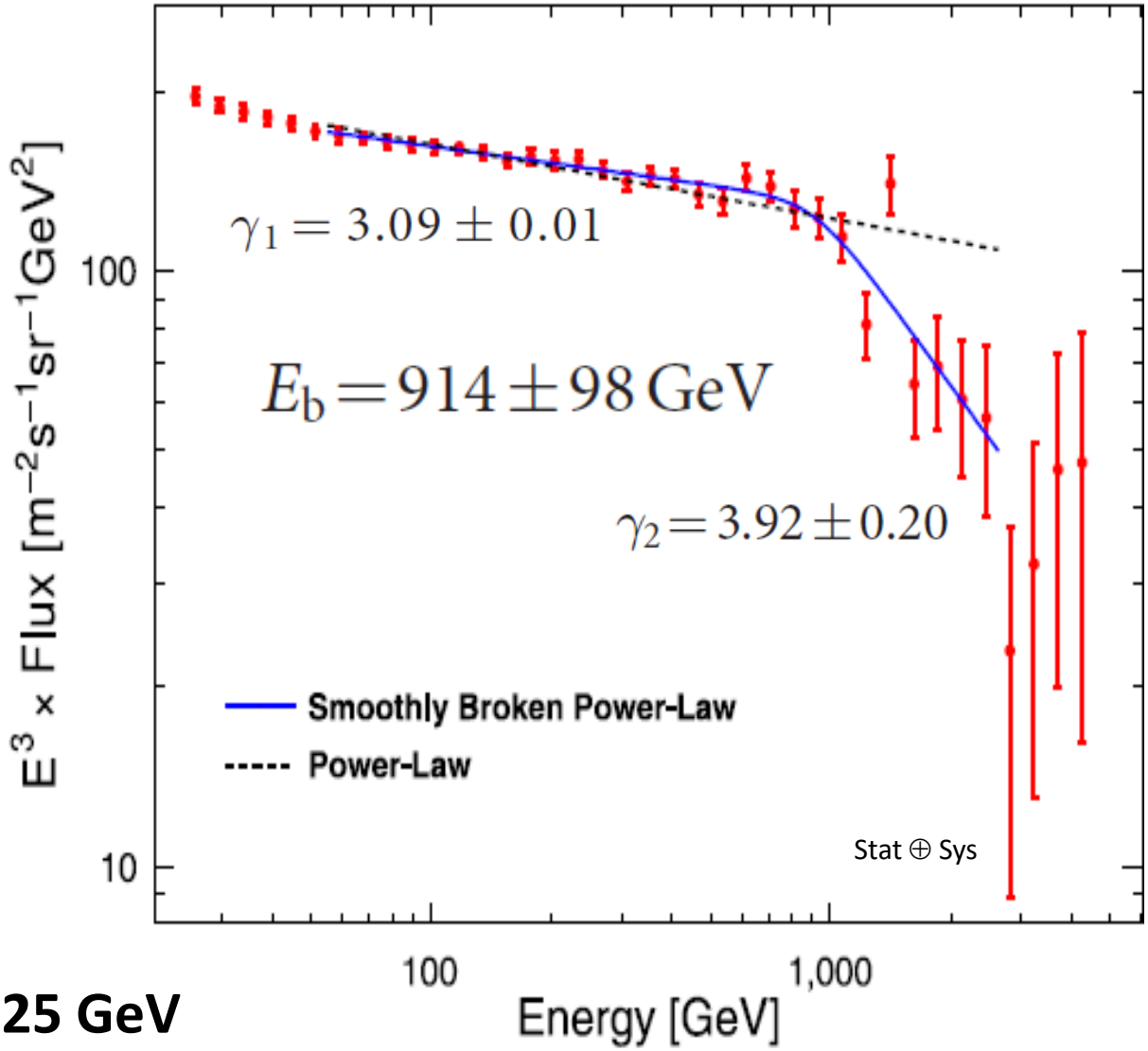
The DAMPE (e^++e^-) spectrum

LETTER nature International weekly journal of science doi:10.1038/nature24475

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

DAMPE Collaboration*

First Direct Evidence for a spectral break in the all-electron spectrum at 0.9 TeV



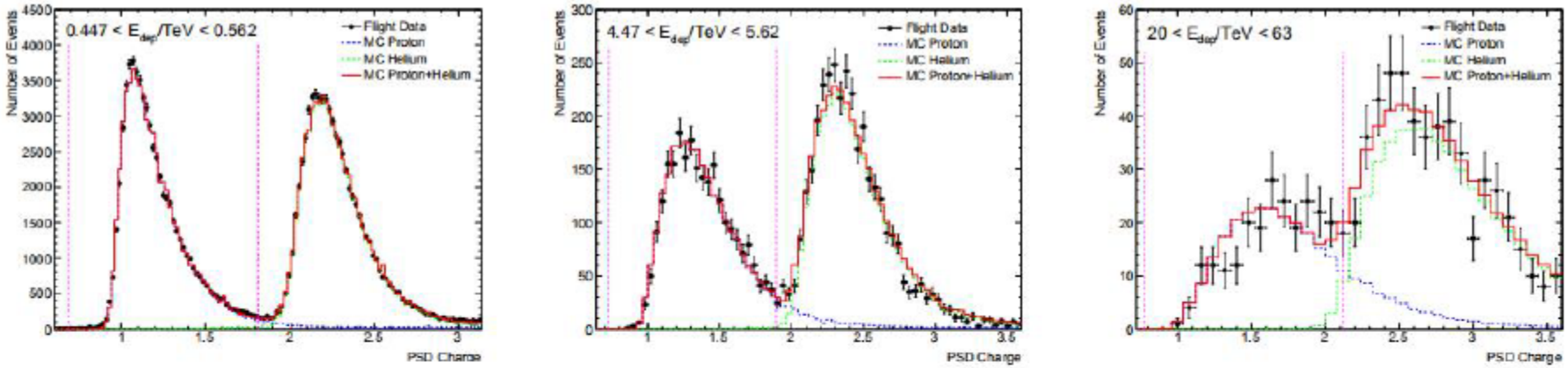
- 530 days
- 2.8 billions CR events
- 1.5 million CREs above 25 GeV

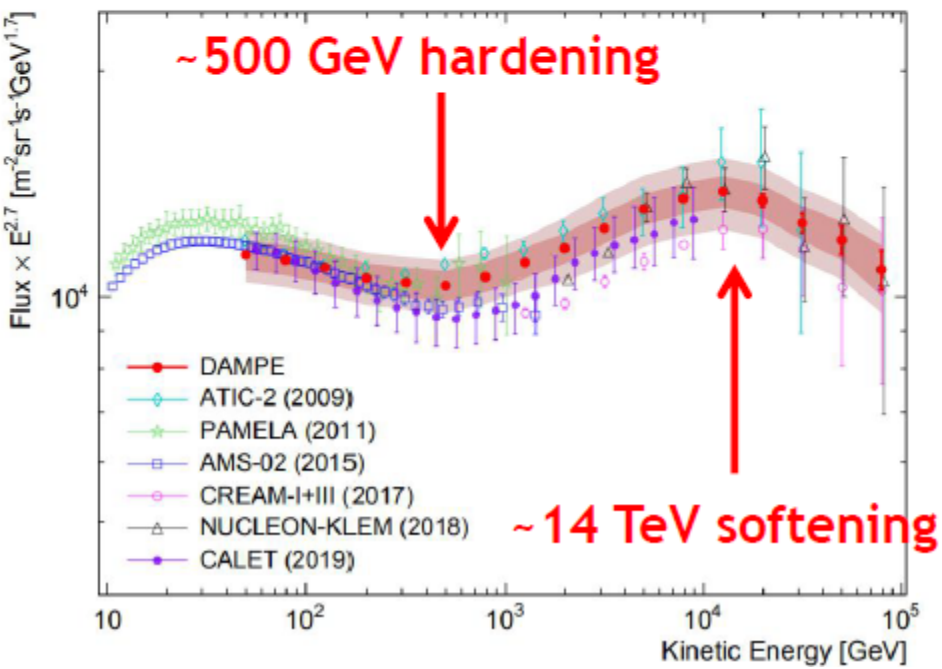
The DAMPE proton spectrum

SCIENCE ADVANCES | RESEARCH ARTICLE

PHYSICS

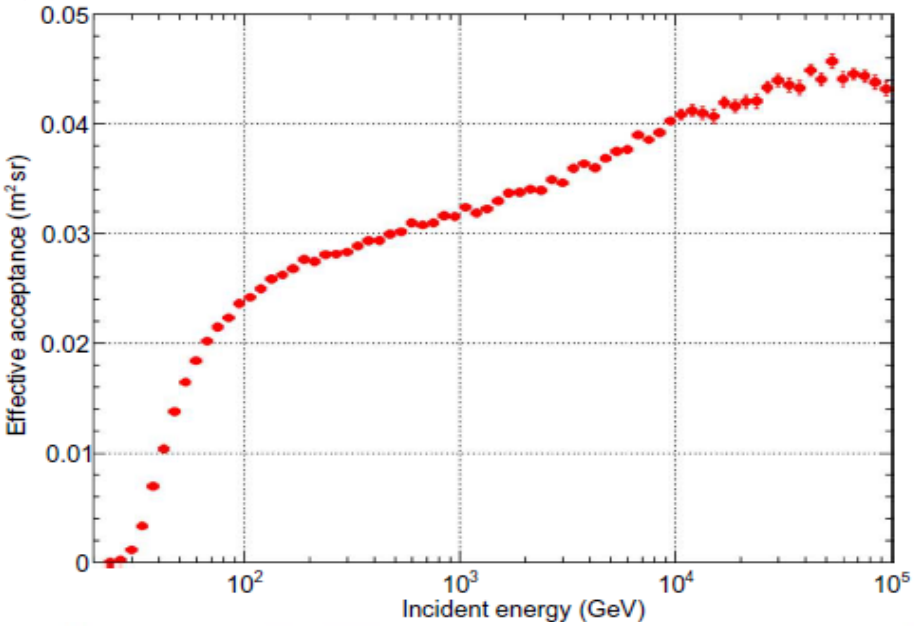
Measurement of the cosmic ray proton spectrum from 40 GeV to 100 TeV with the DAMPE satellite

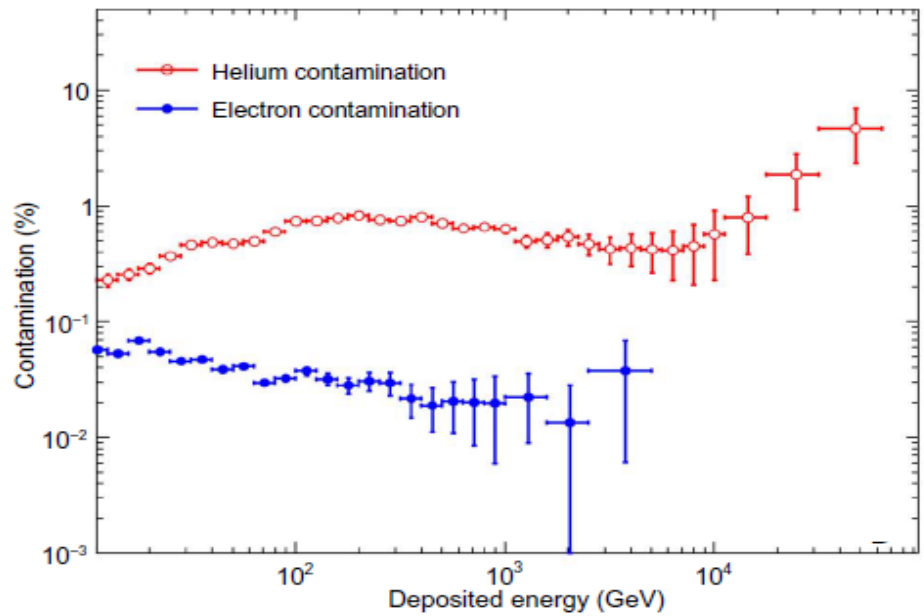


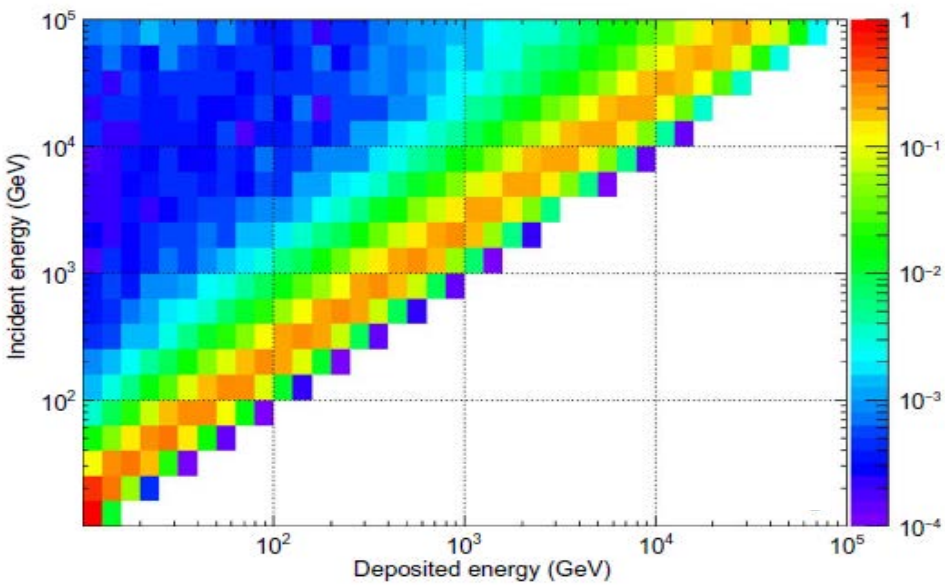


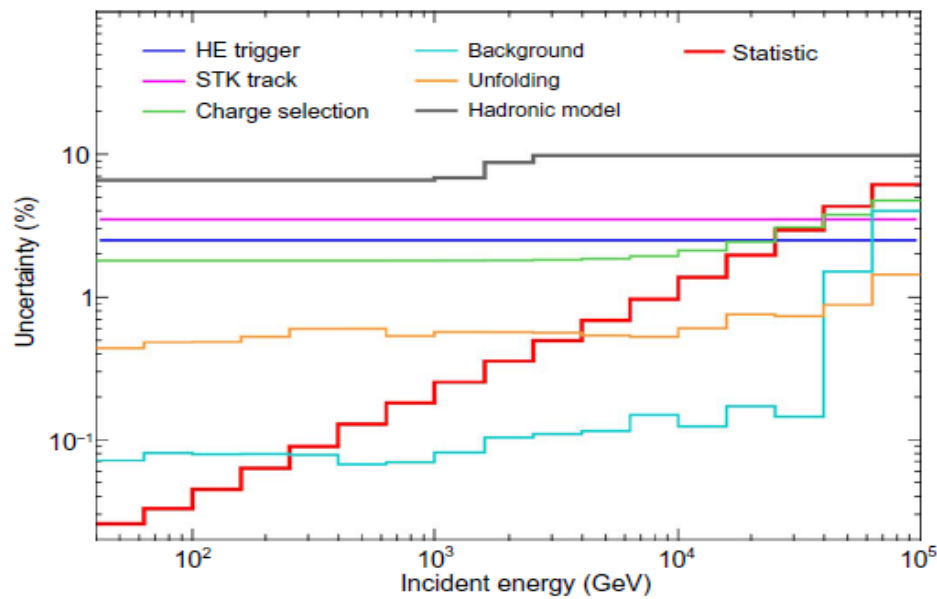
- Confirms the hundreds of GeV hardening
- Detecting a softening at ~14 TeV with high significance

The DAMPE proton spectrum

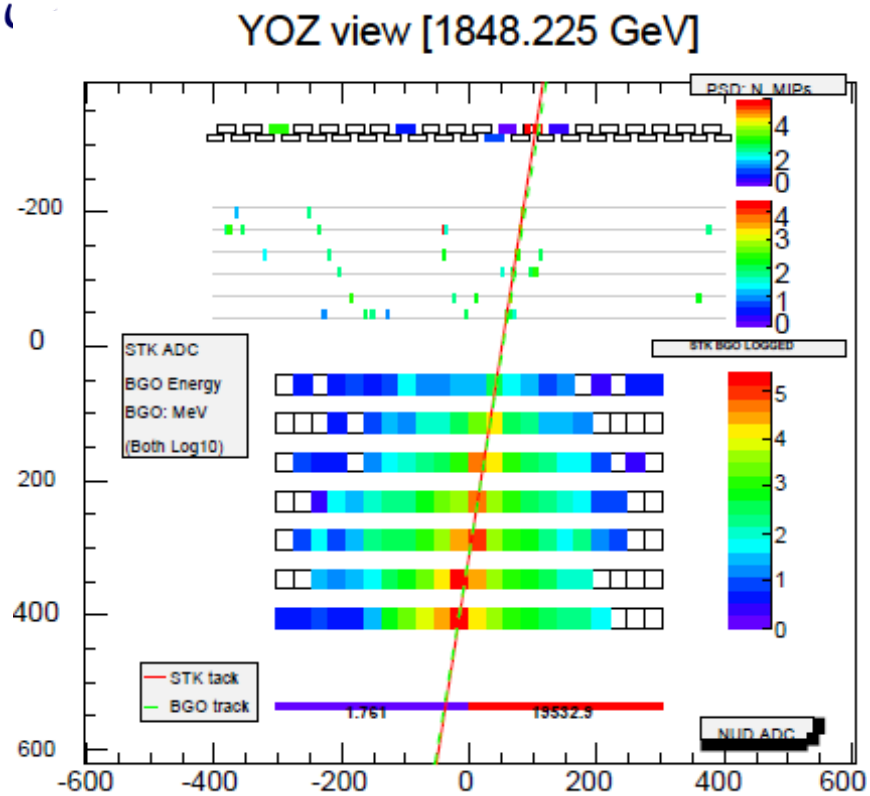


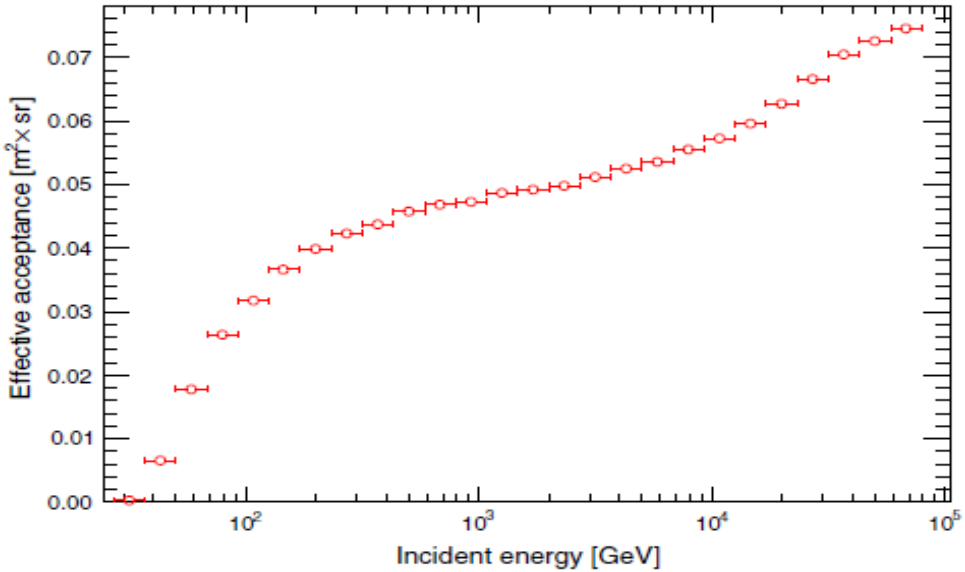


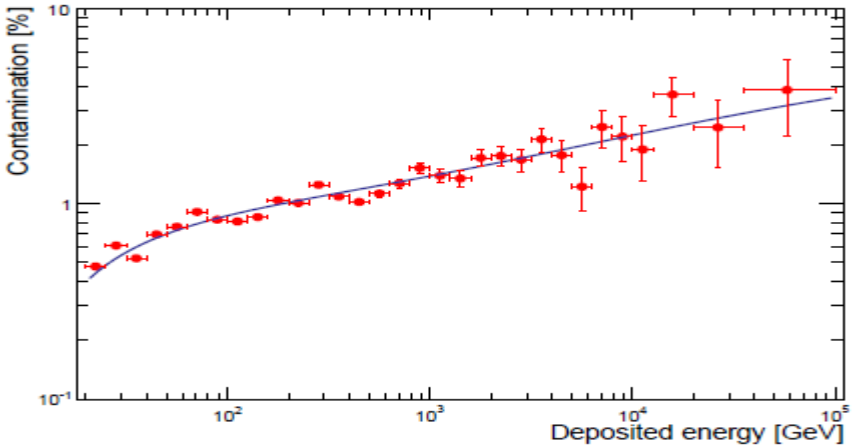


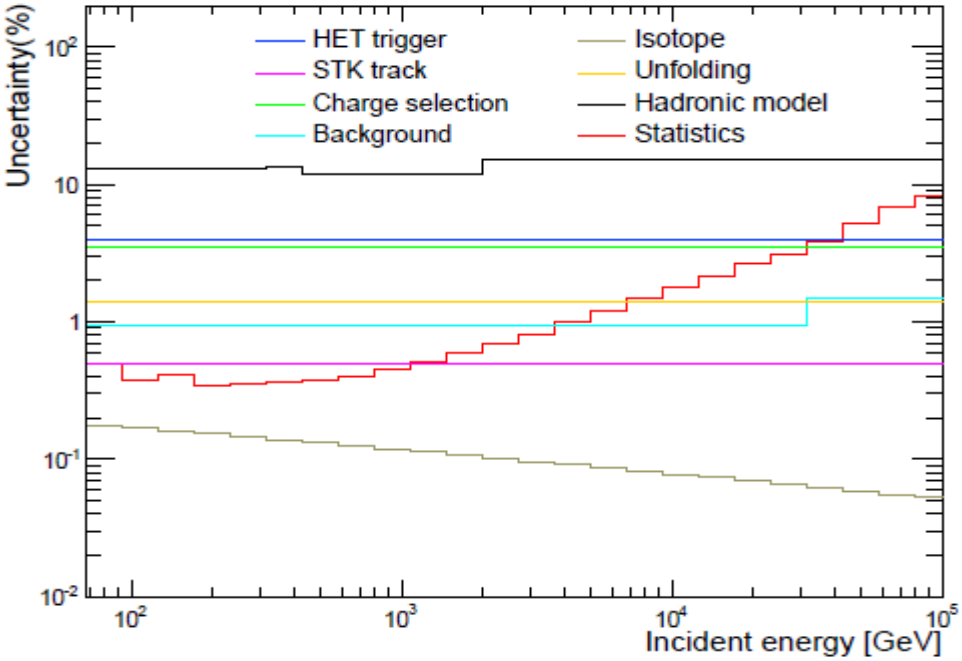


The DAMPE helium spectrum







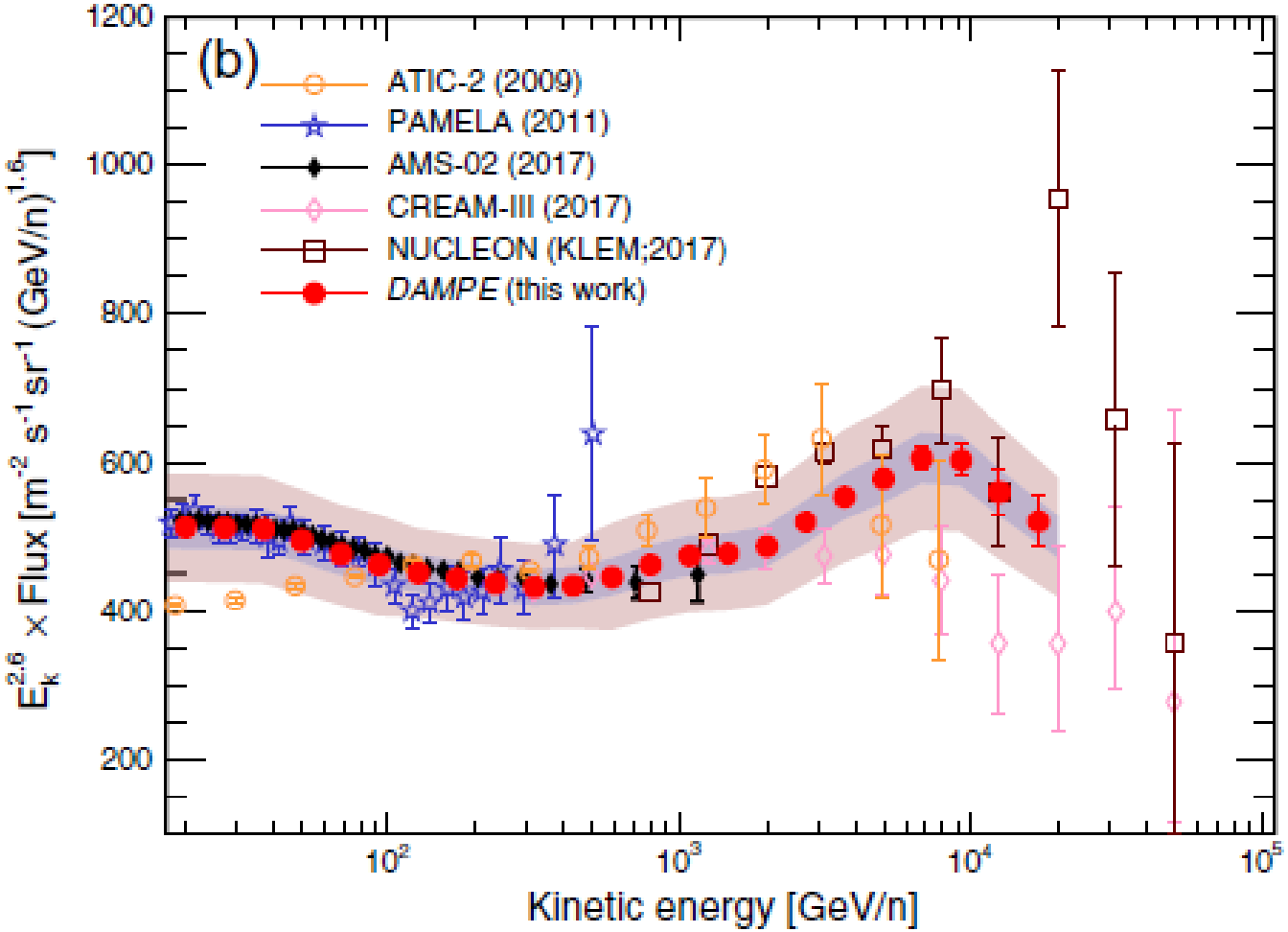


The DAMPE helium spectrum

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

Editors' Suggestion | Featured in Physics

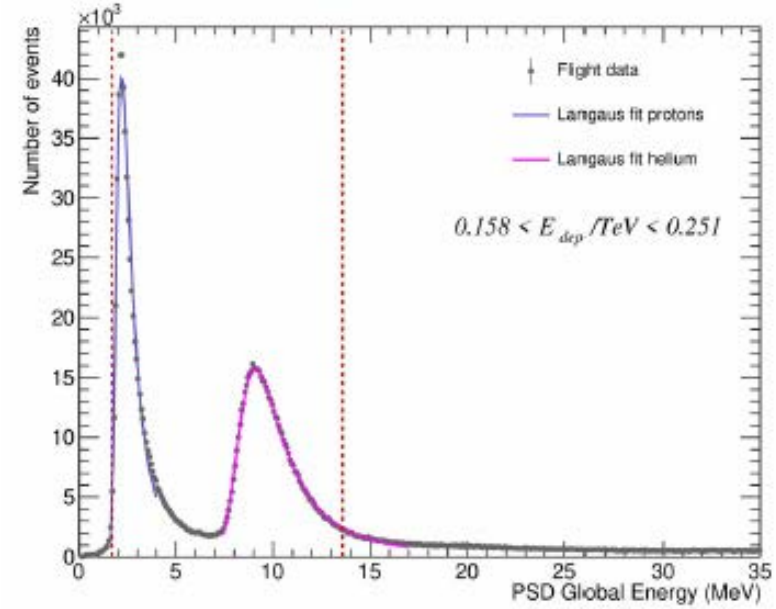
Measurement of the Cosmic Ray Helium Energy Spectrum from 70 GeV to 80 TeV with the DAMPE Space Mission

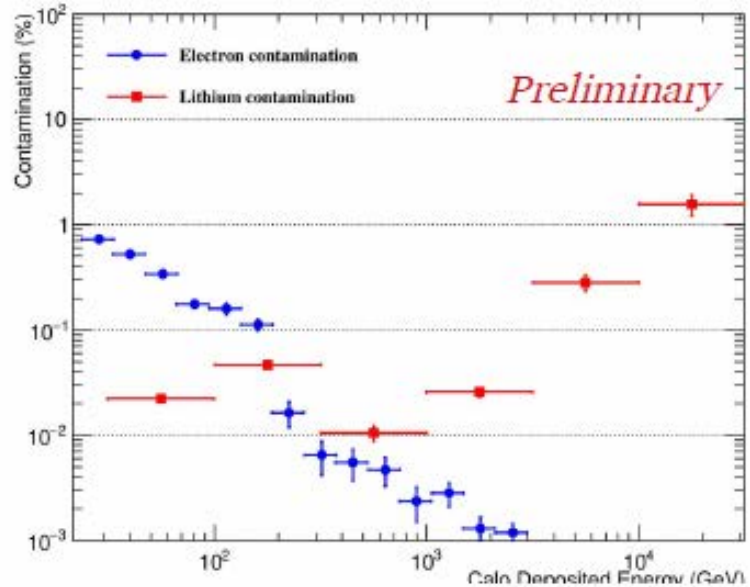


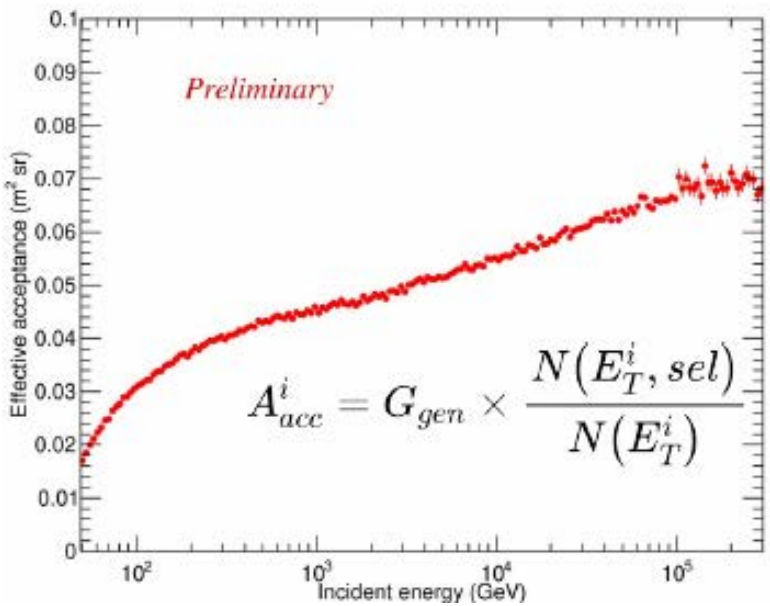
First clear evidence for a softening at about 34 TeV

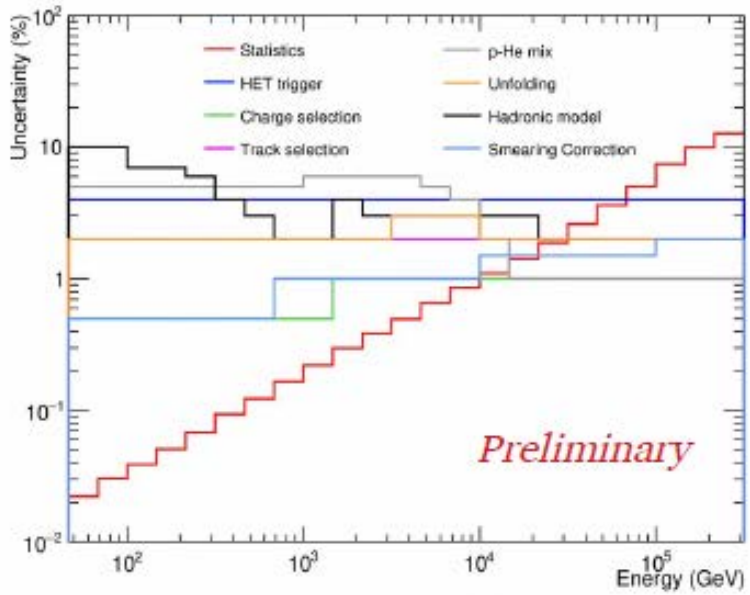
Suggesting a Z dependent softening energy (~ 14 TeV for protons)

The DAMPE p+He spectrum

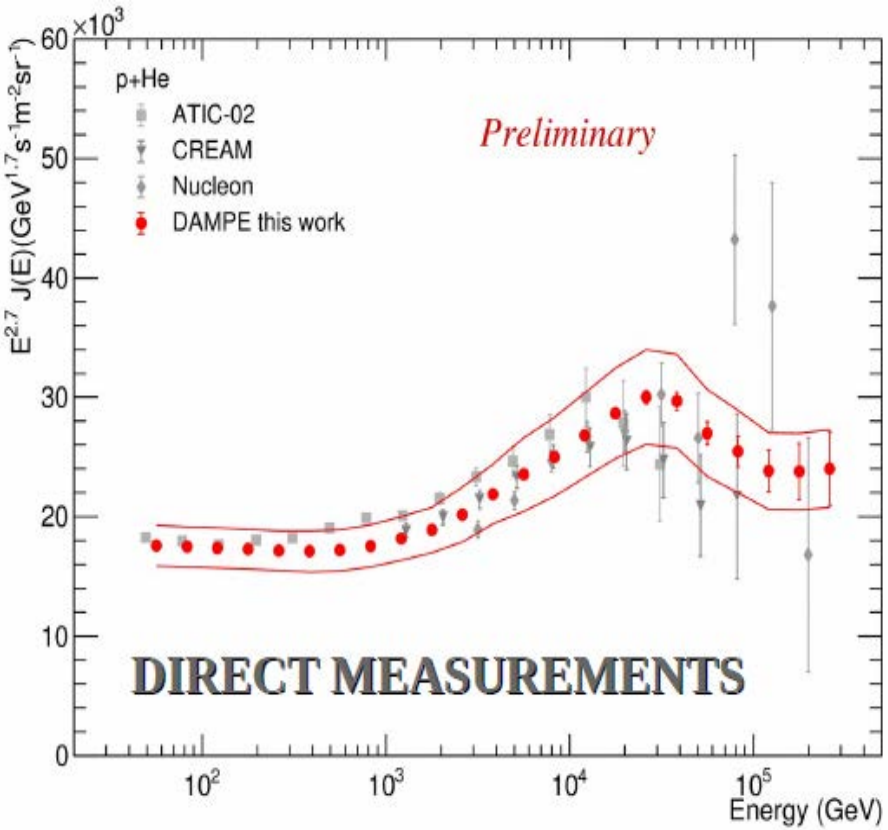


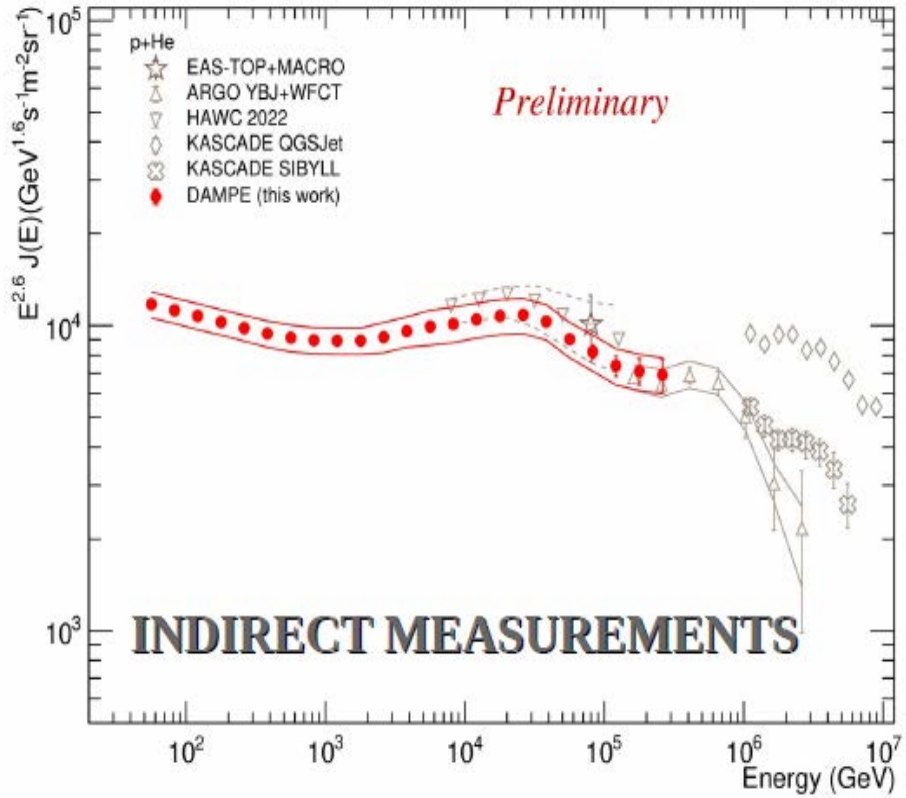






The DAMPE p+He spectrum

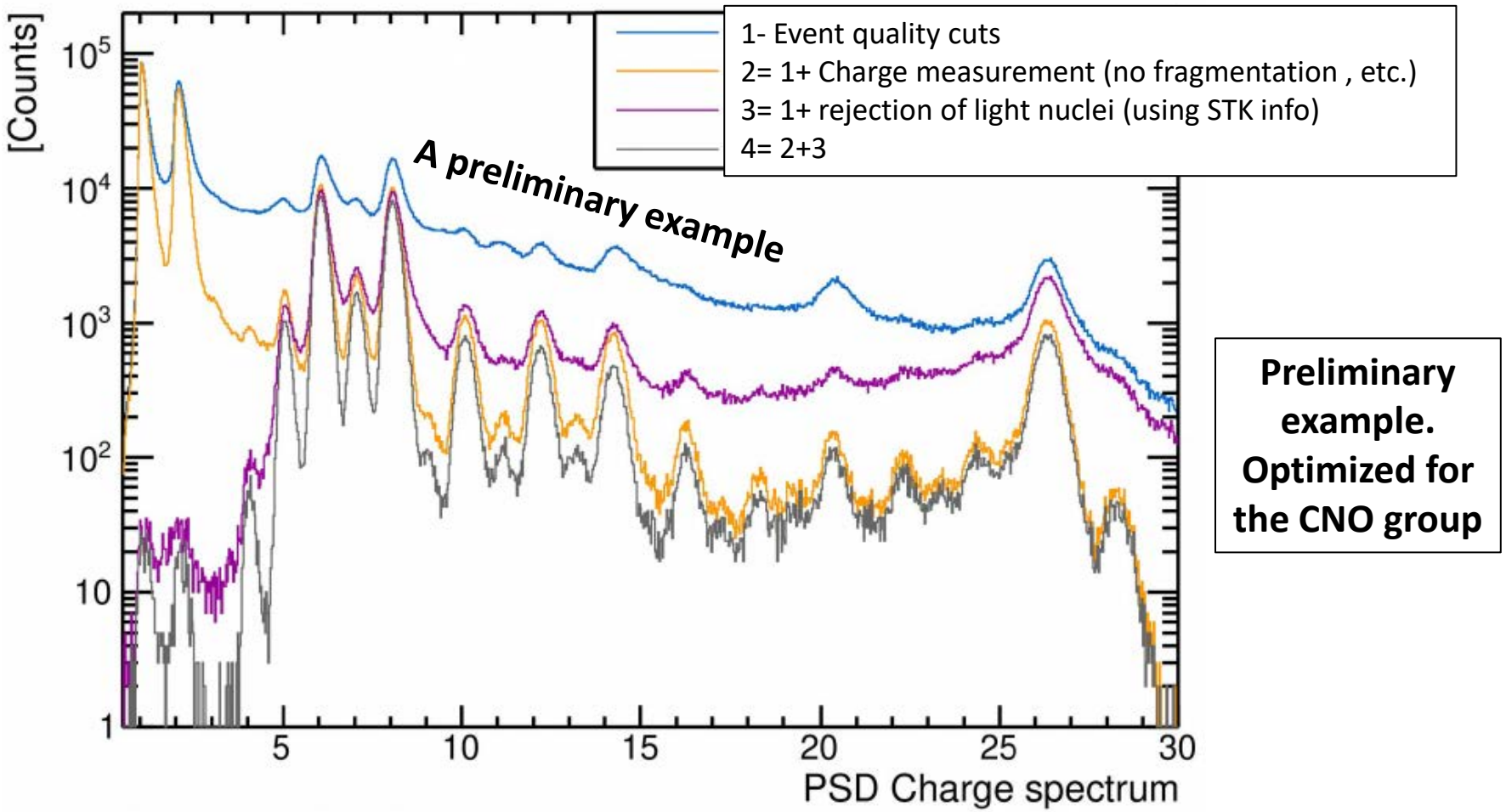




- ✓ Confirmation of the softening
  (at about 25 TeV due to the combination of p and He spectra)
- ✓ Extension to 300 TeV
- ✓ Overlapping with indirect measurements

DAMPE: heavier nuclei

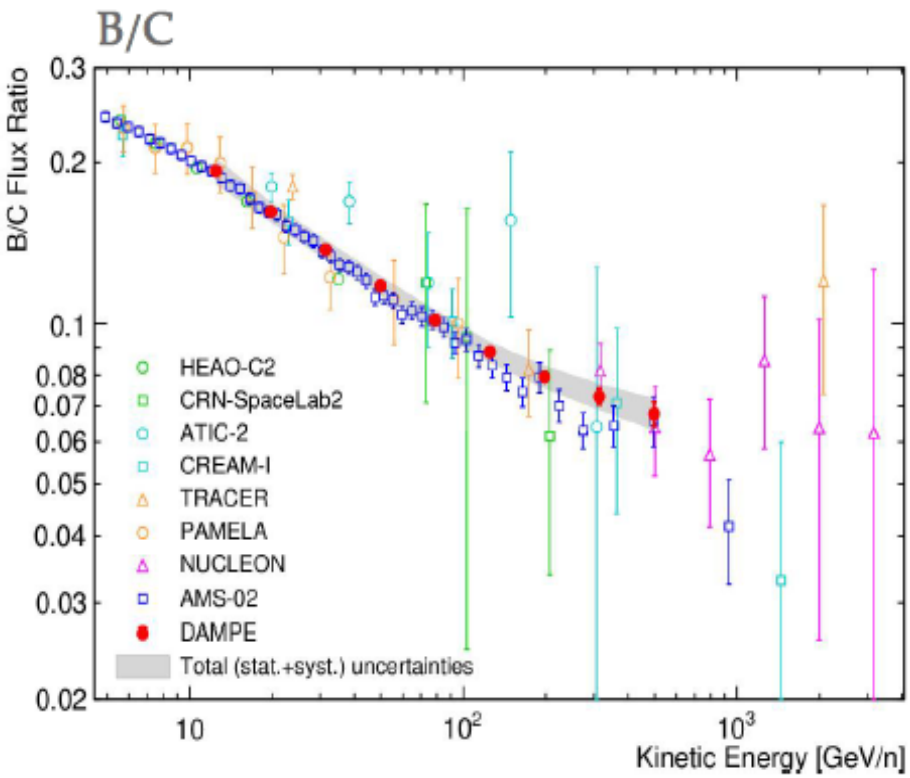
Several independent analyses are ongoing from Li up to Iron
Different selection criteria to reject other nuclei and avoid charge misidentification
Different approaches to limit and better evaluate the systematics.

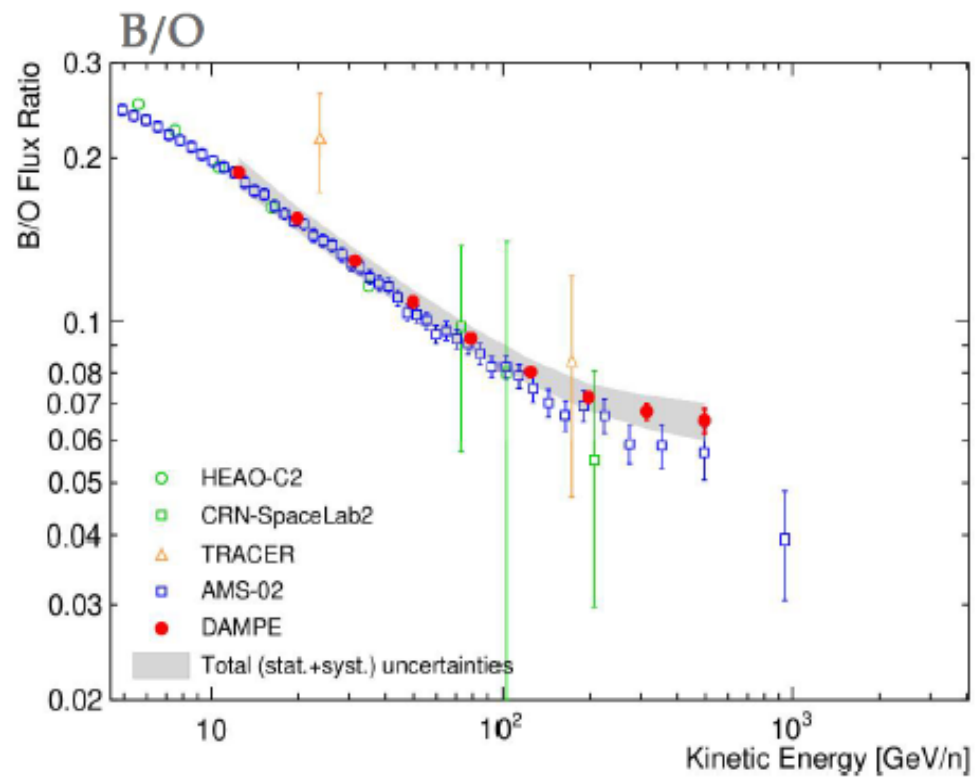


Secondary-to-primary ratios

As a further cross check, several secondary-to-primary ratios are being measured with different analysis approaches

Preliminary results for B/C and B/O. Extension to few TeV/n in progress.





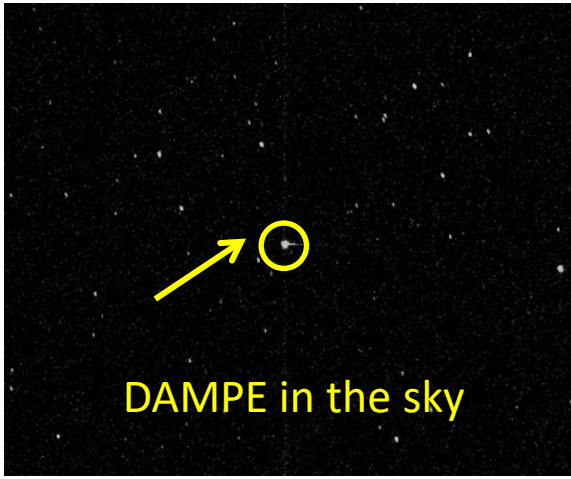
DAMPE Summary

The detector

- Large geometric factor instrument (0.3 m^2 sr for p and nuclei)
- Precision Si-W tracker (40μm , 0.2°)
- Thick calorimeter (32 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 extend till 300 TeV
- 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,…)
- Be ready for the "unexpected": GW electromagnetic follow up in FoV, ……

More Stuff

The collaboration

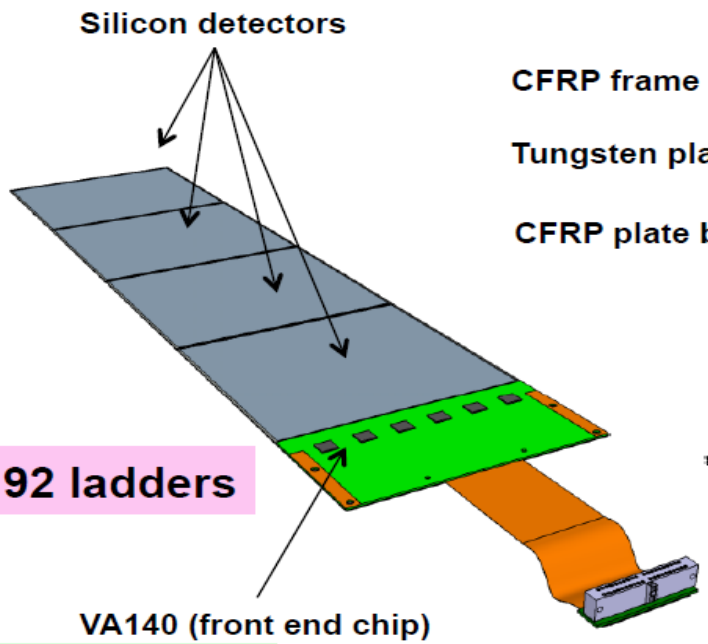
- **CHINA**
  - Purple Mountain Observatory, CAS, Nanjing
  - Institute of High Energy Physics, CAS, Beijing
  - National Space Science Center, CAS, Beijing
  - University of Science and Technology of China, Hefei
  - Institute of Modern Physics, CAS, Lanzhou

- **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)

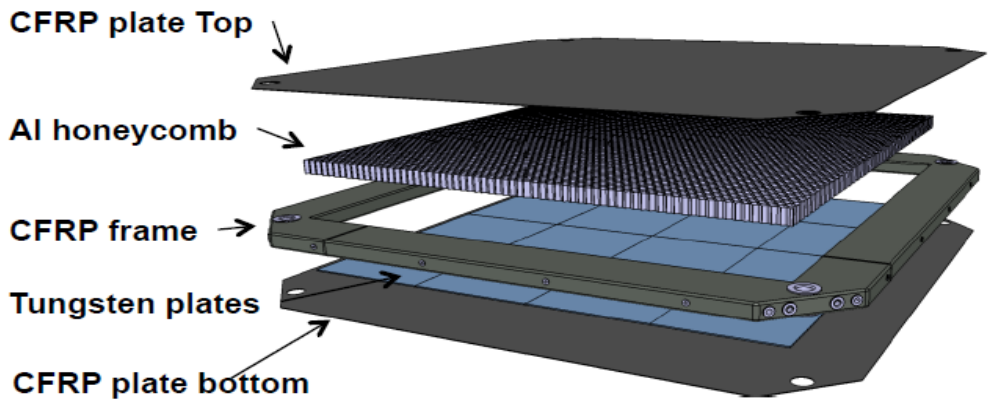
768 silicon sensors



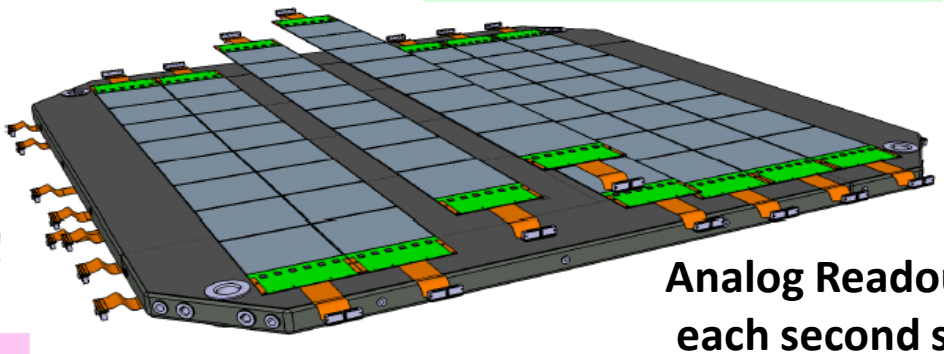
192 ladders

1152 ASICs

73728 channels

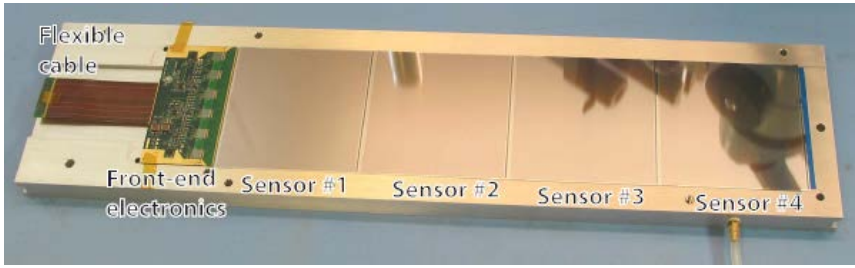


12 layers, 6-x and 6-y



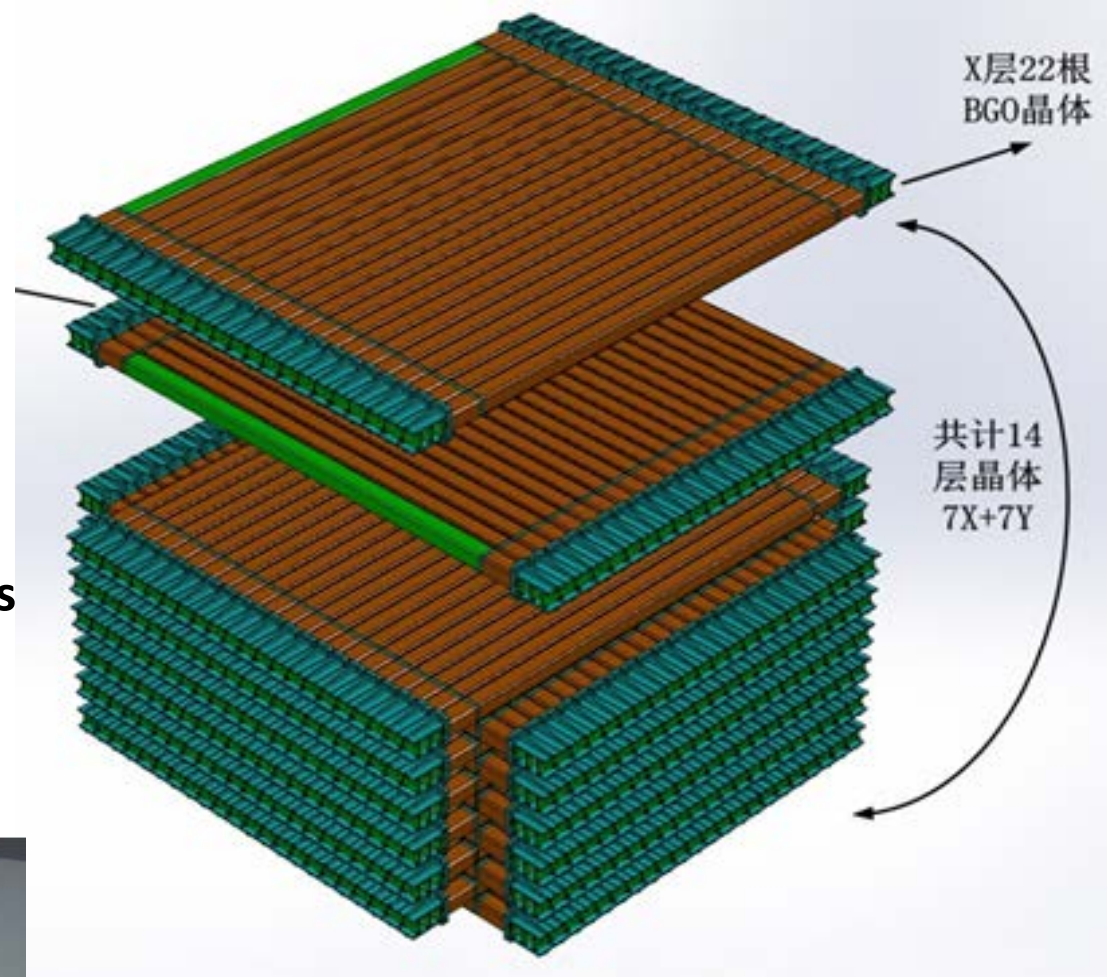
Analog Readout of each second strip:
384 channels / SSD- Ladder
Charge sharing

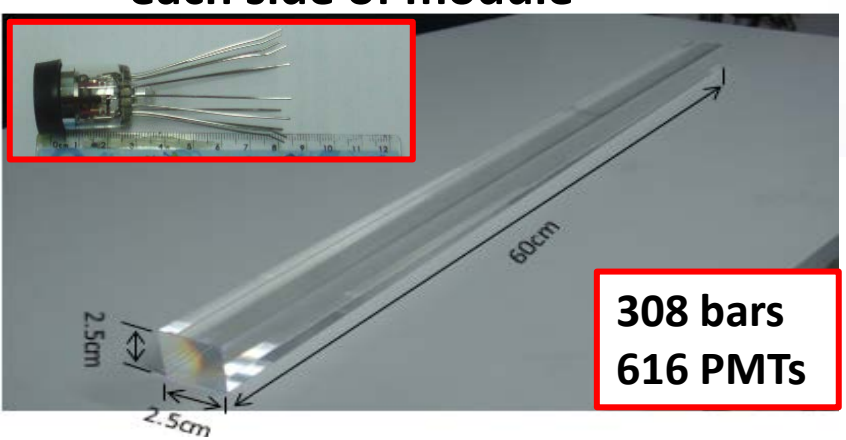
- 48 μm wide Si strips with 121 μm pitch
- (95 × 95 × 0.32 mm³) Silicon Strip Detector (SSD)
- 768 strips in each SSD
- One ladder composed by 4 (SSD)
- 16 Ladders per layer (76 cm × 76 cm)
- 12 layers (6x + 6y)



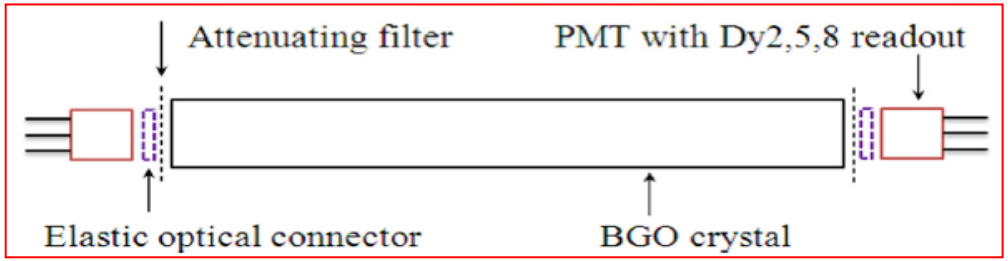
The CALOrimeter

- **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**

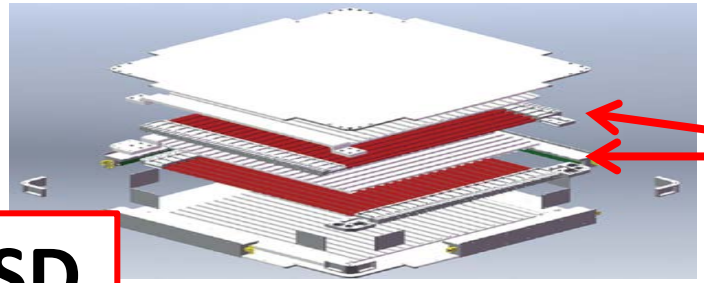




308 bars
616 PMTs

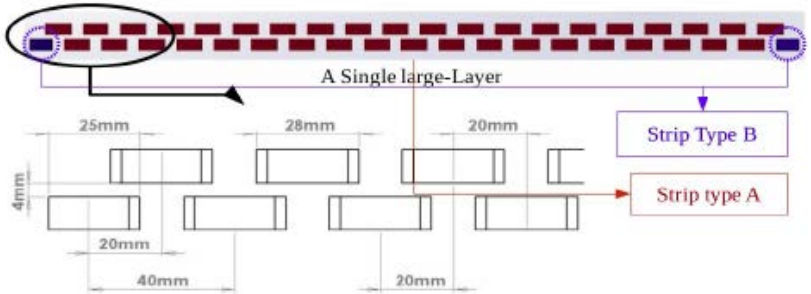


The Plastic Scintillator Detector and the NeUtron Detector

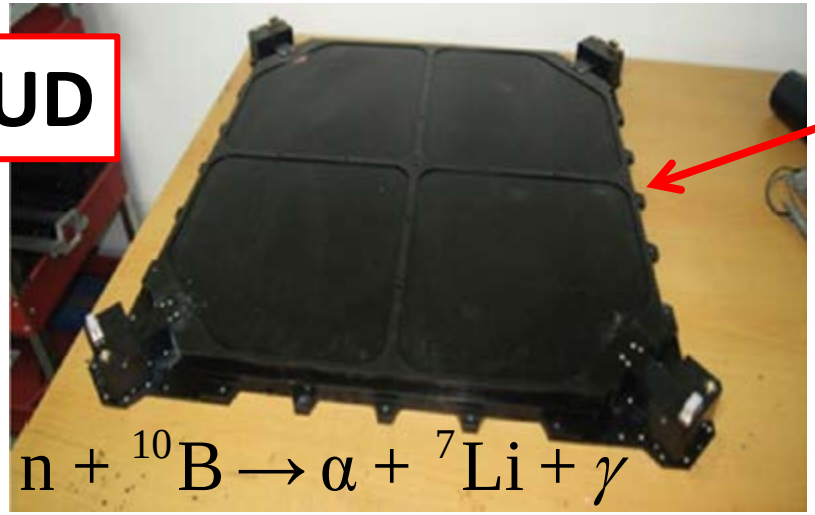


PSD

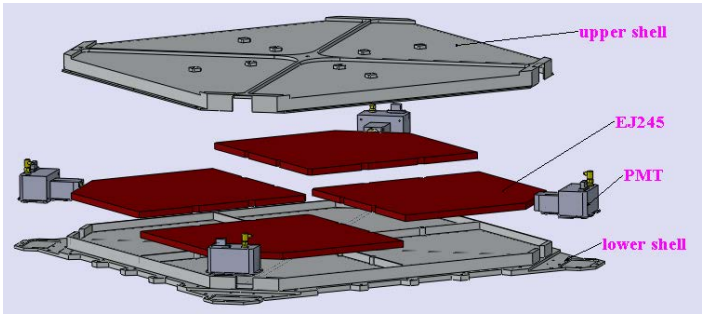
- 1.0 cm thick ,2.8cm wide and 82.0 cm long scintillator strips
- staggered by 0.8 cm in a layer
- 82 cm × 82 cm layers
- 2 layers (x and y)



NUD

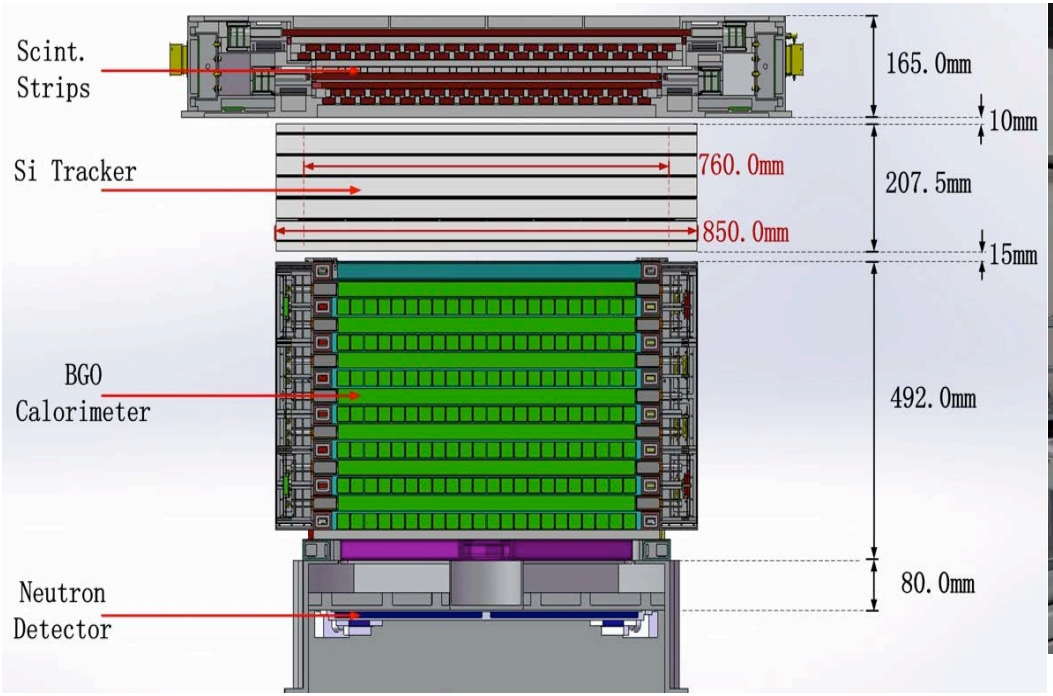


- 4 large area boron-doped plastic scintillators (30 cm × 30 cm × 1 cm)



Comparison with AMS-02 and FERMI

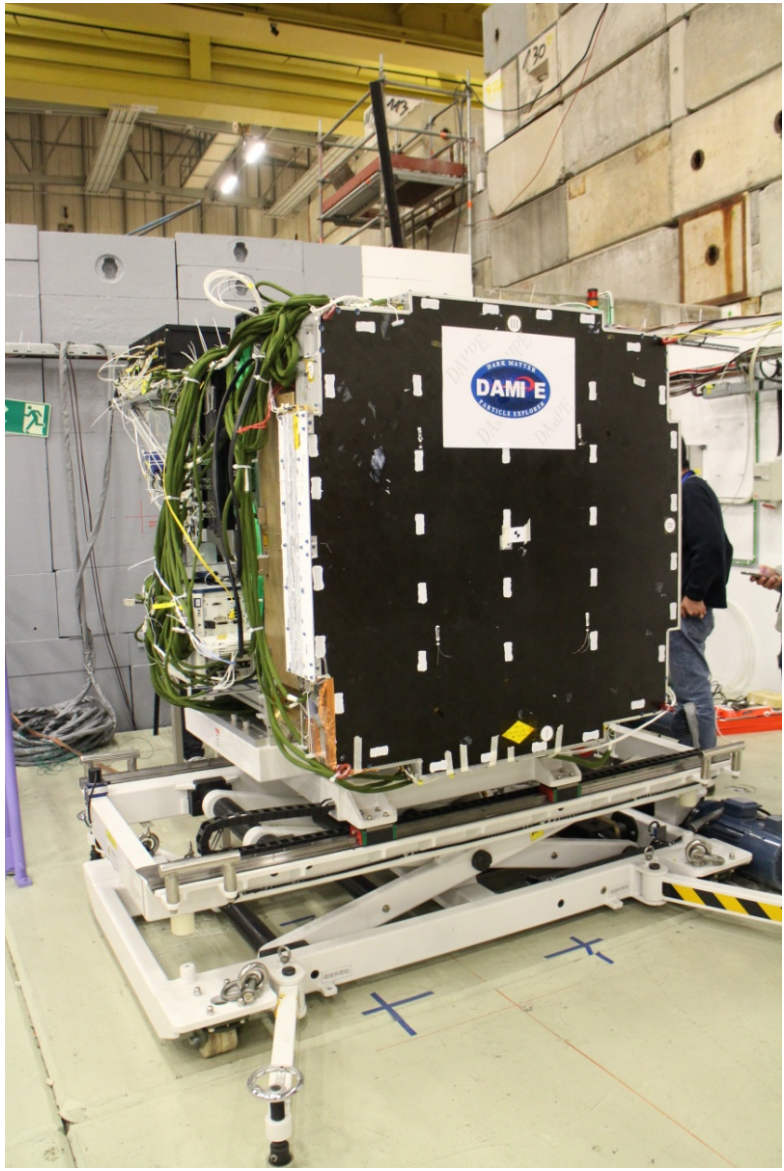
	DAMPE	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	**1.2**	3	10
e/γ Angular res.@100 GeV (deg)	0.2	0.3	0.1
e/p discrimination	10^5-10^6	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	**32**	17	8.6
Geometrical accep. (m^2sr)	**0.3**	0.09	1



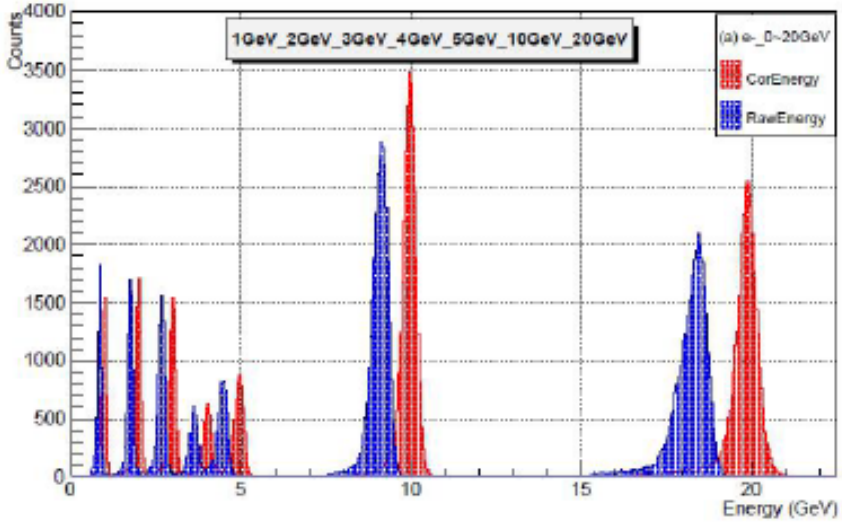
Mass: 1400 Kg
Power: ~ 400 W
Livetime: > 3 years

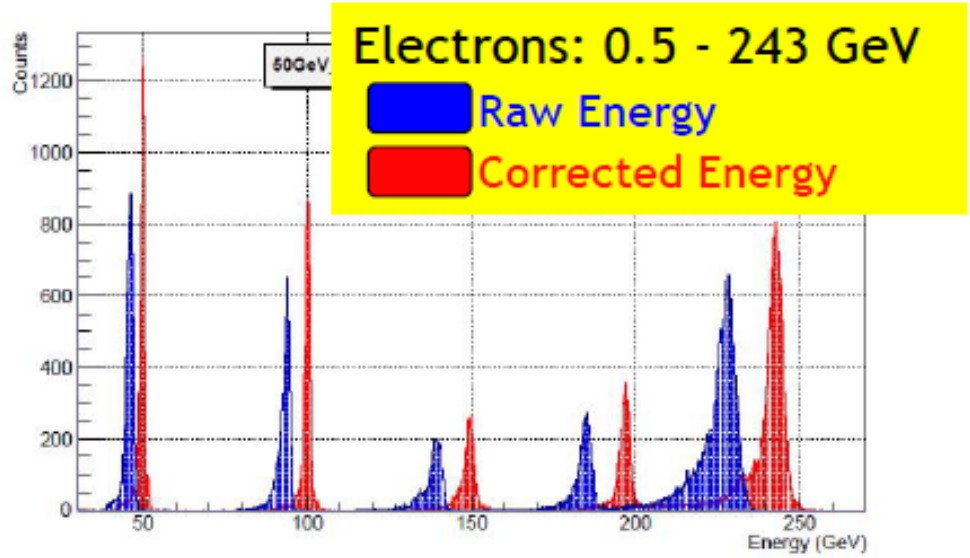
Test beam activity at CERN

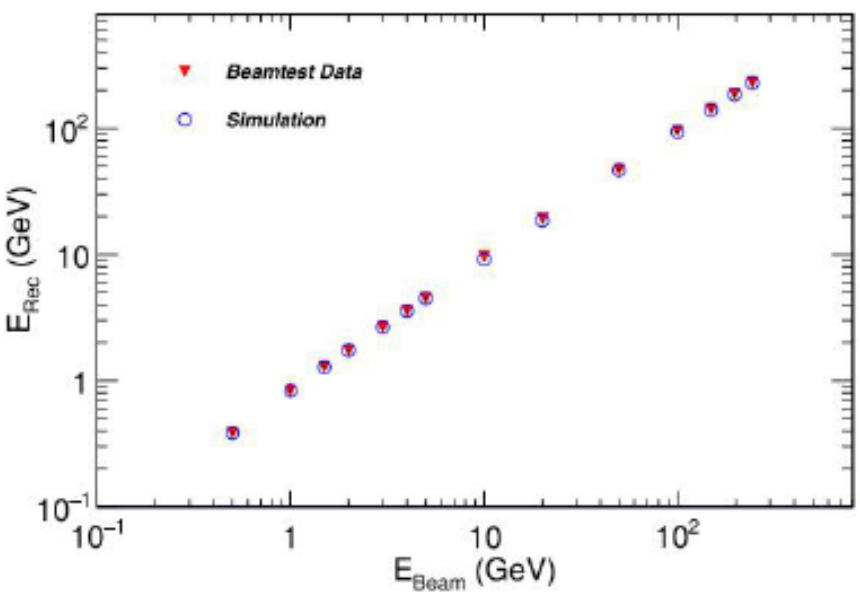
- 14days@PS，29/10-11/11 2014
  - e @ 0.5GeV/c, 1GeV/c, 2GeV/c, 3GeV/c, 4GeV/c, 5GeV/c
  - p @ 3.5GeV/c, 4GeV/c, 5GeV/c, 6GeV/c, 8GeV/c, 10GeV/c
  - π-@ 3GeV/c, 10GeV/c
  - γ @ 0.5-3GeV/c
- 8days@SPS，12/11-19/11 2014
  - e @ 5GeV/c, 10GeV/c, 20GeV/c, 50GeV/c, 100GeV/c, 150GeV/c, 200GeV/c, 250GeV/c
  - 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)

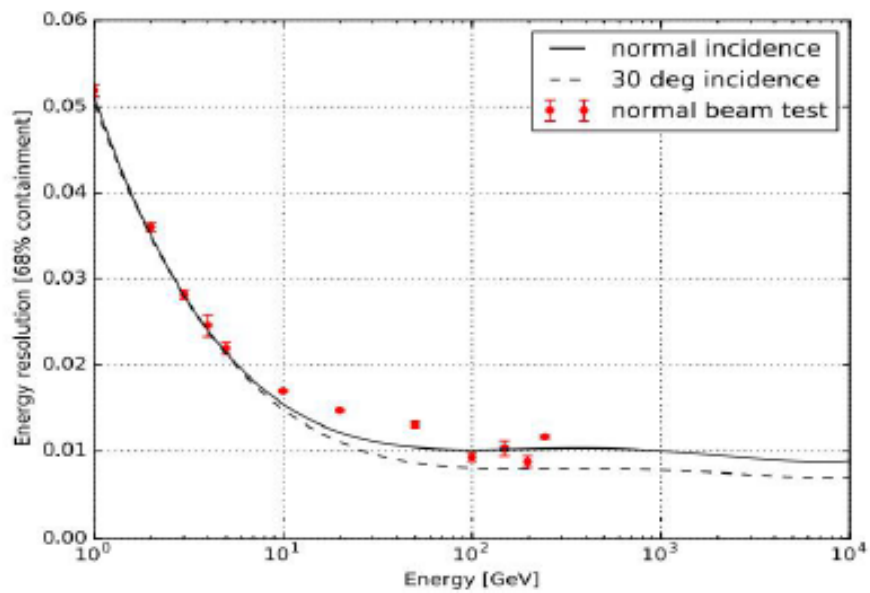


Test beam activity at CERN

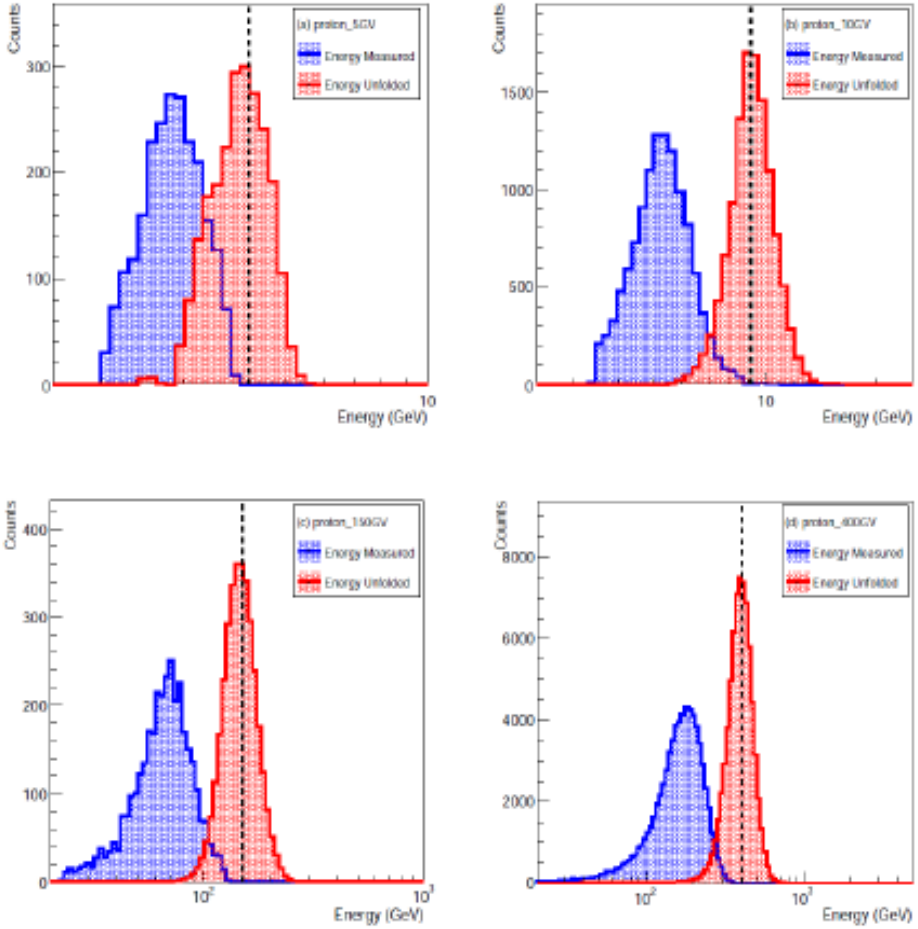


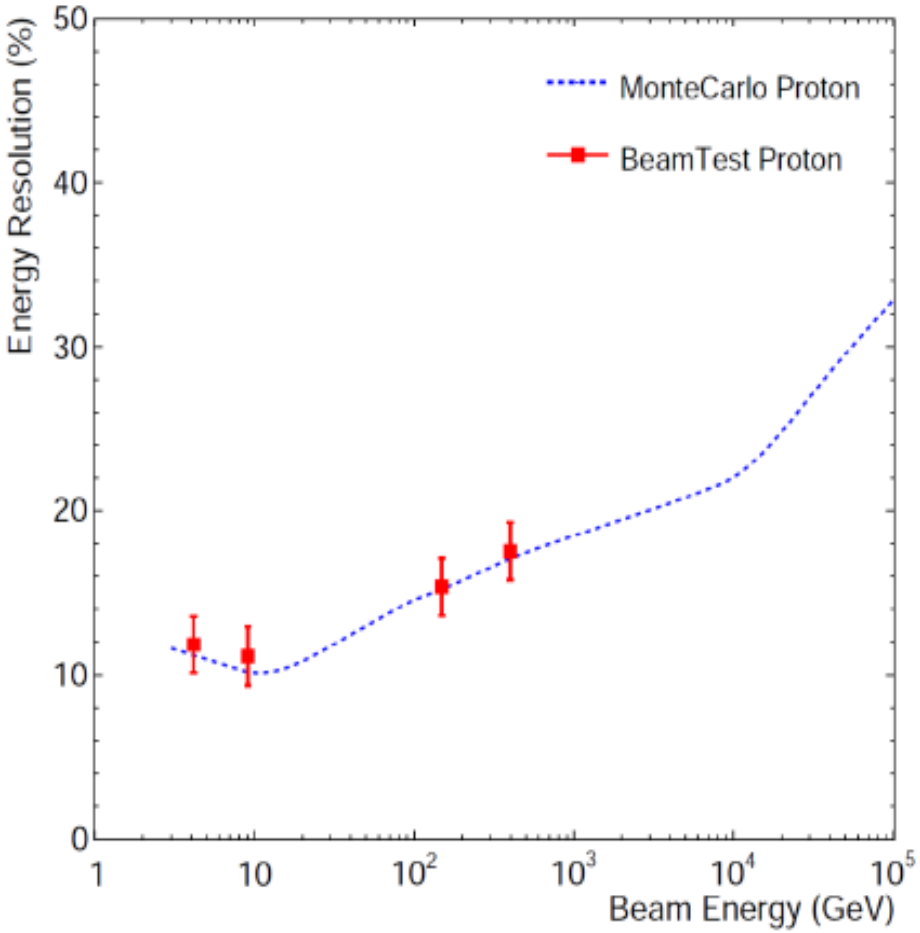




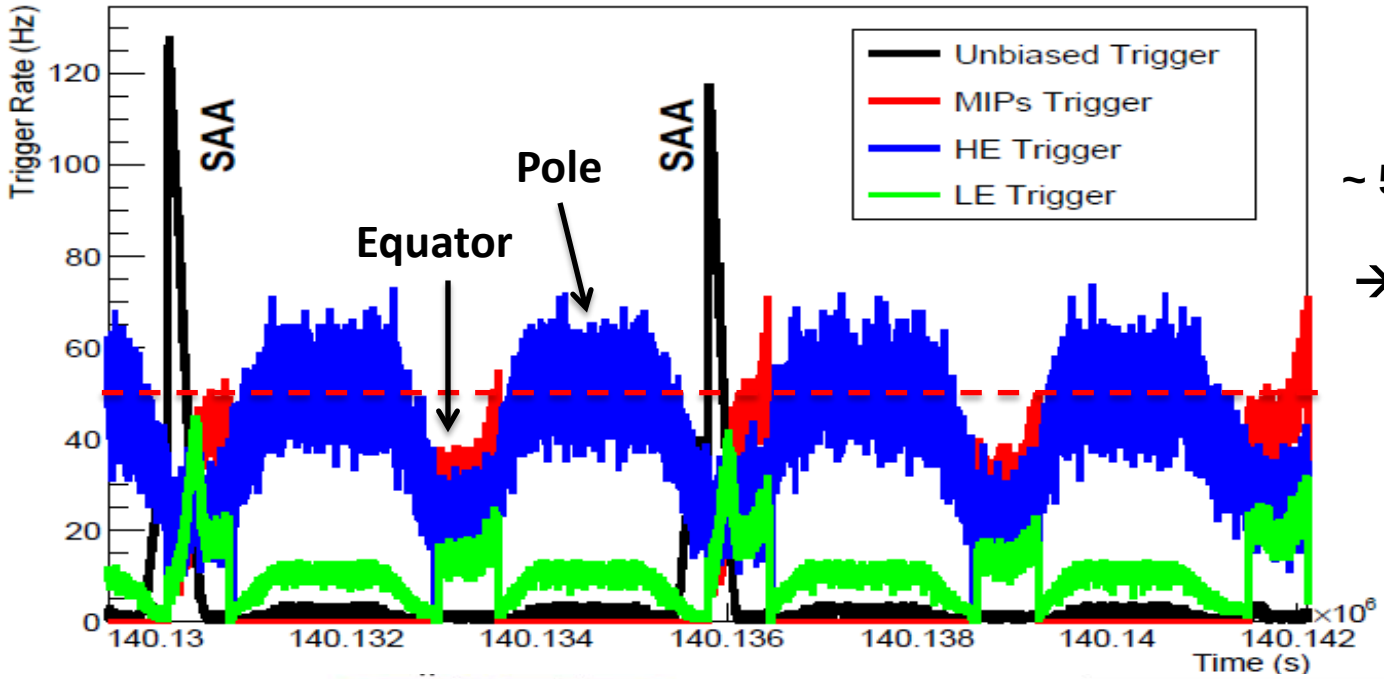


Test beam activity at CERN: protons



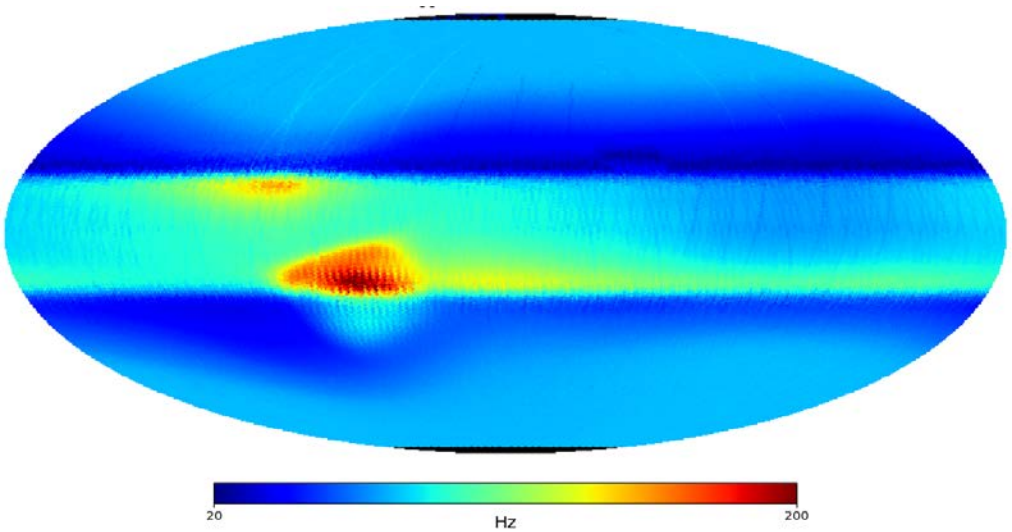


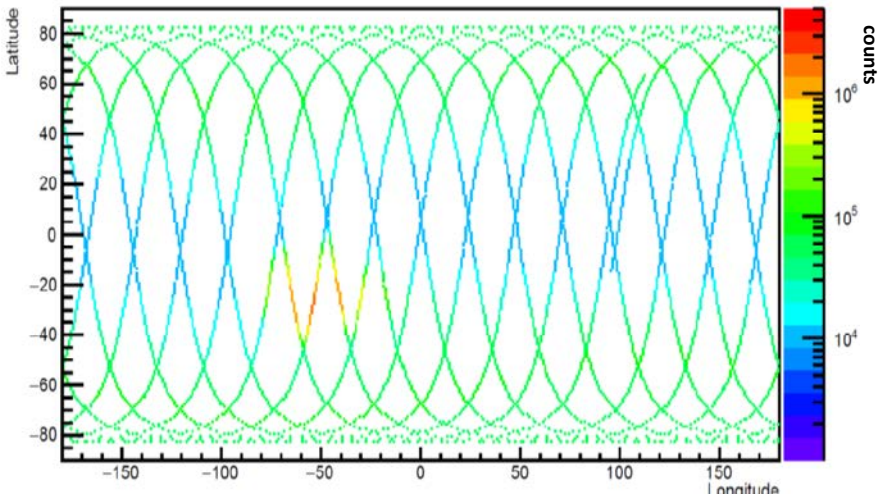
Trigger rate in orbit



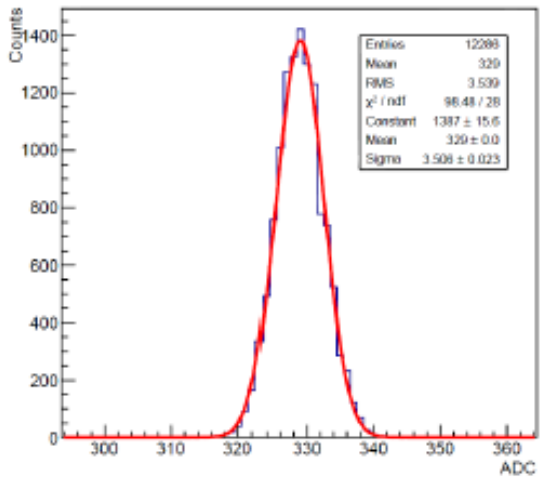
~ 50 Hz average trigger rate

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

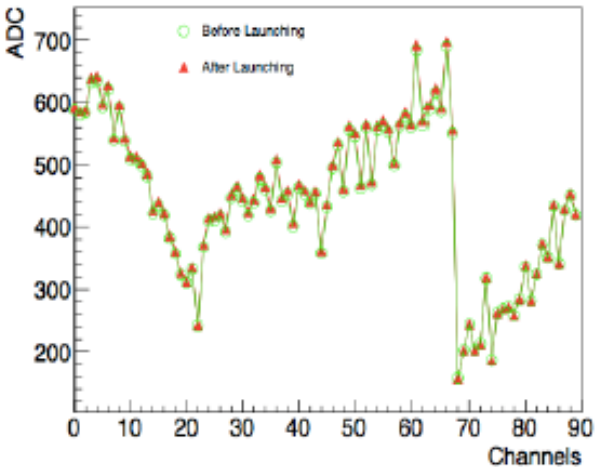




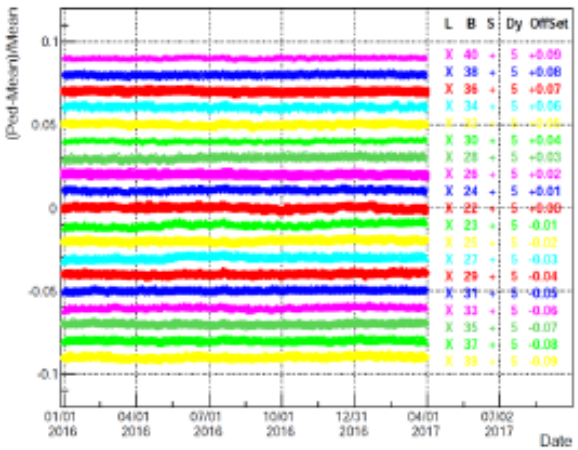
On orbit performance: PSD



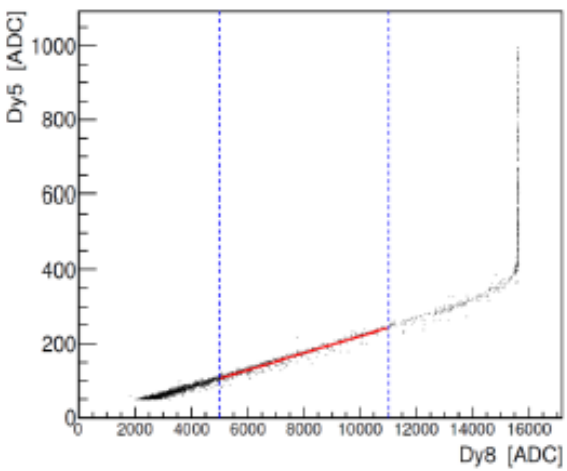
Pedestal distribution



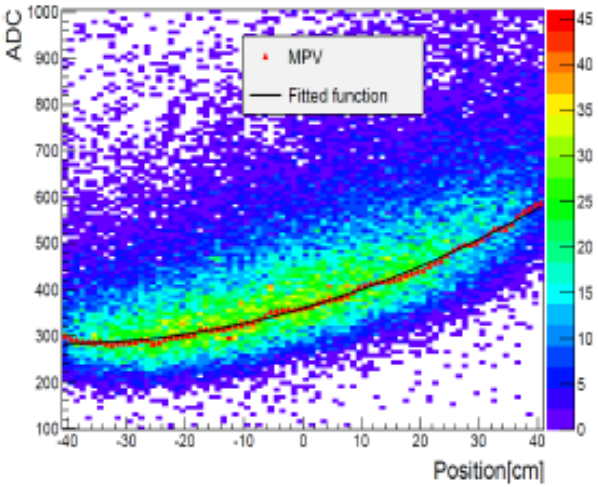
Pedestal comparison



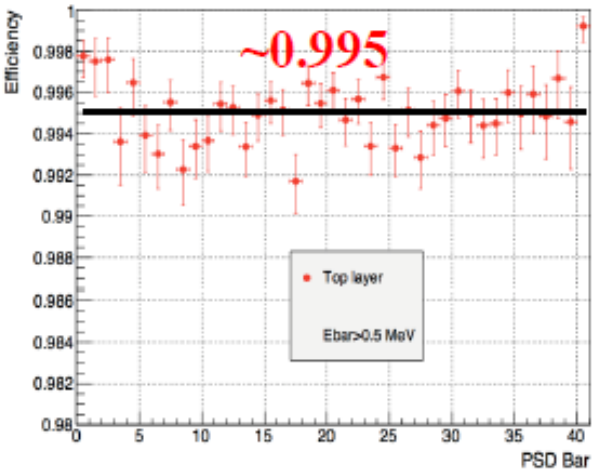
Pedestal variation



Dynode 5 and 8 correlation

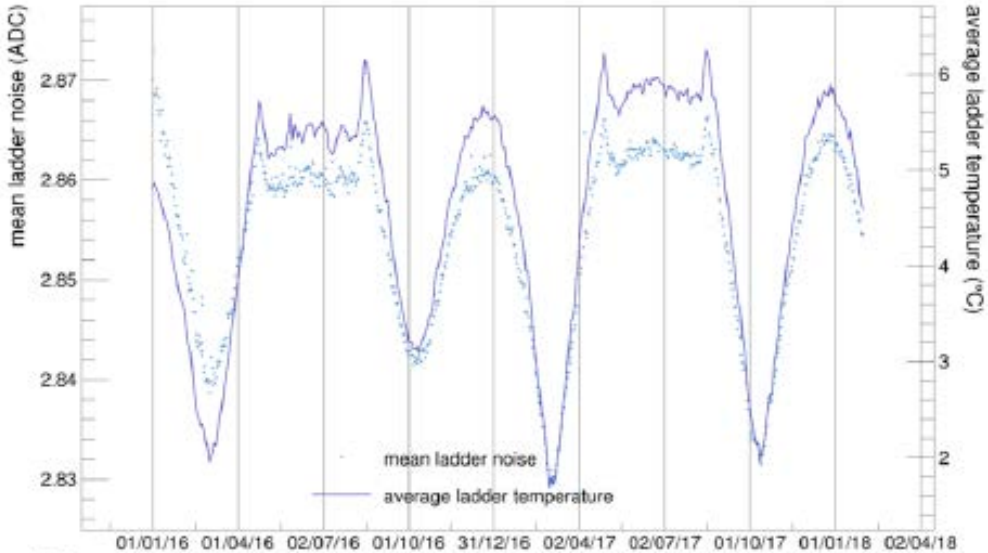


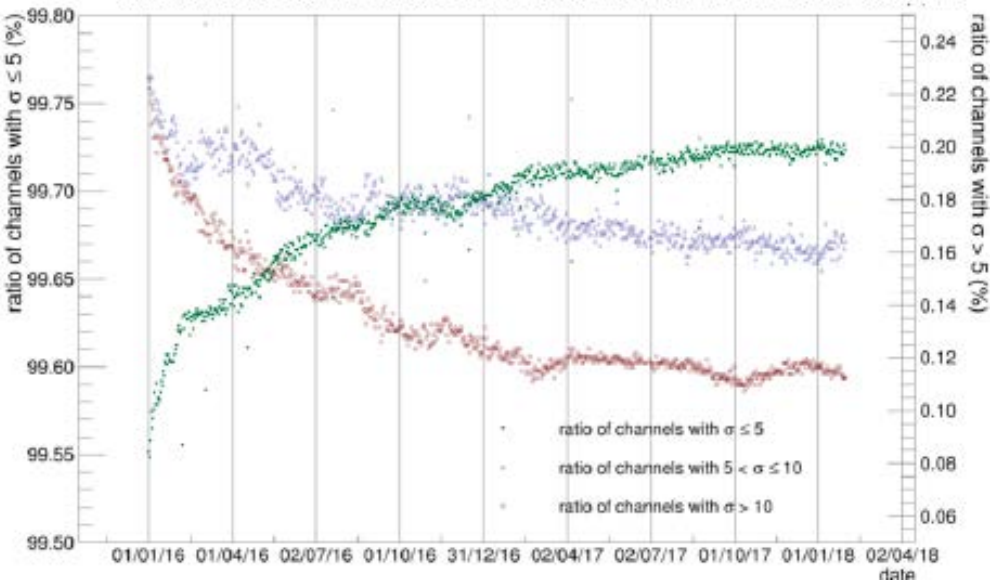
Light attenuation calibration

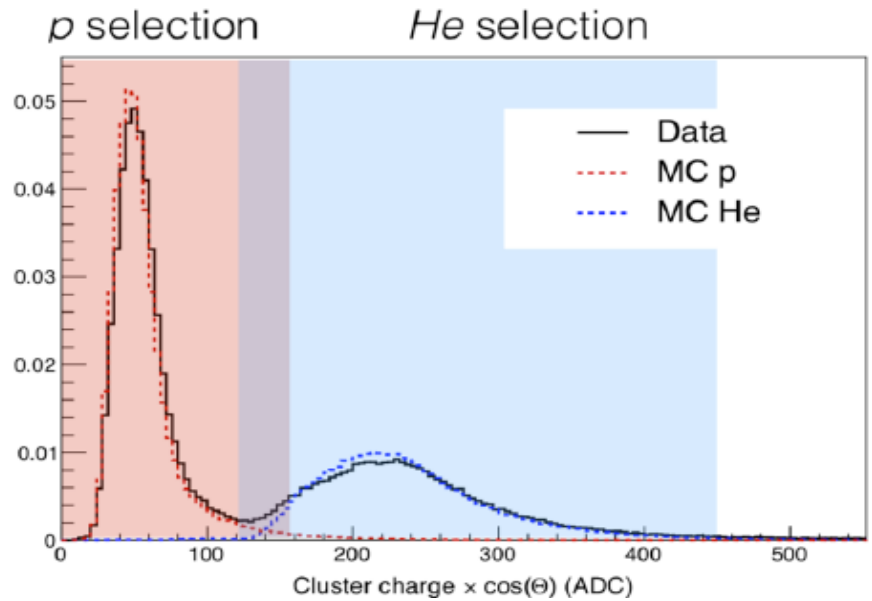


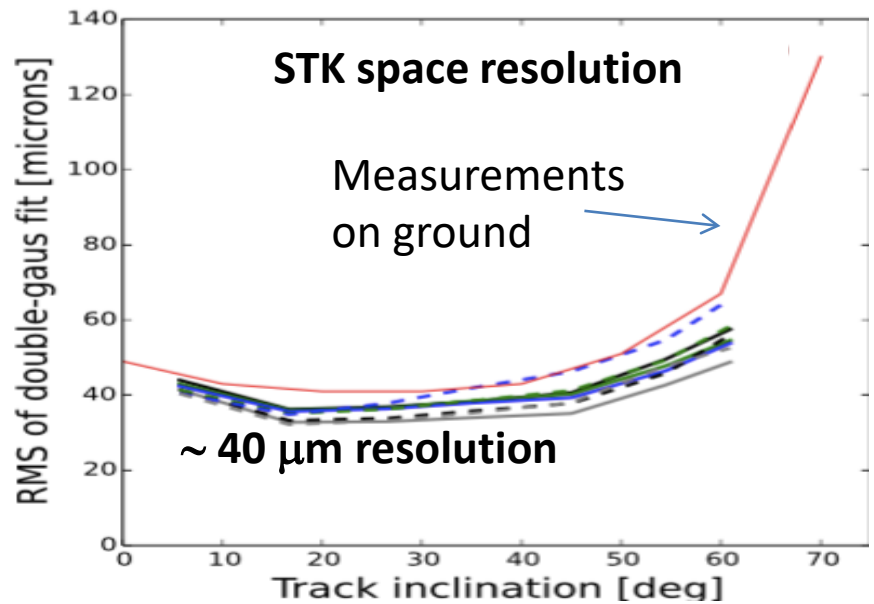
Single layer efficiency

On orbit performance: STK

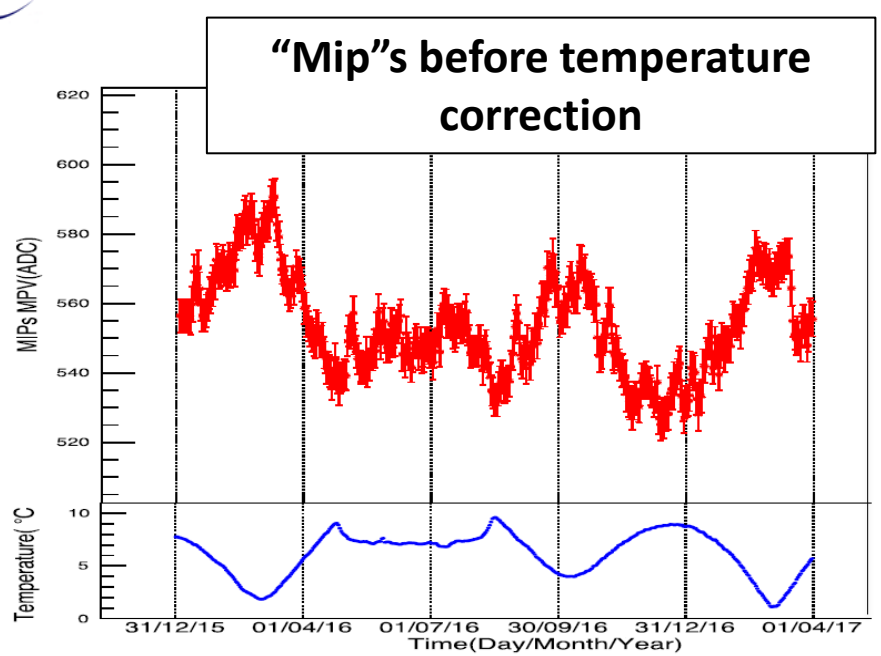


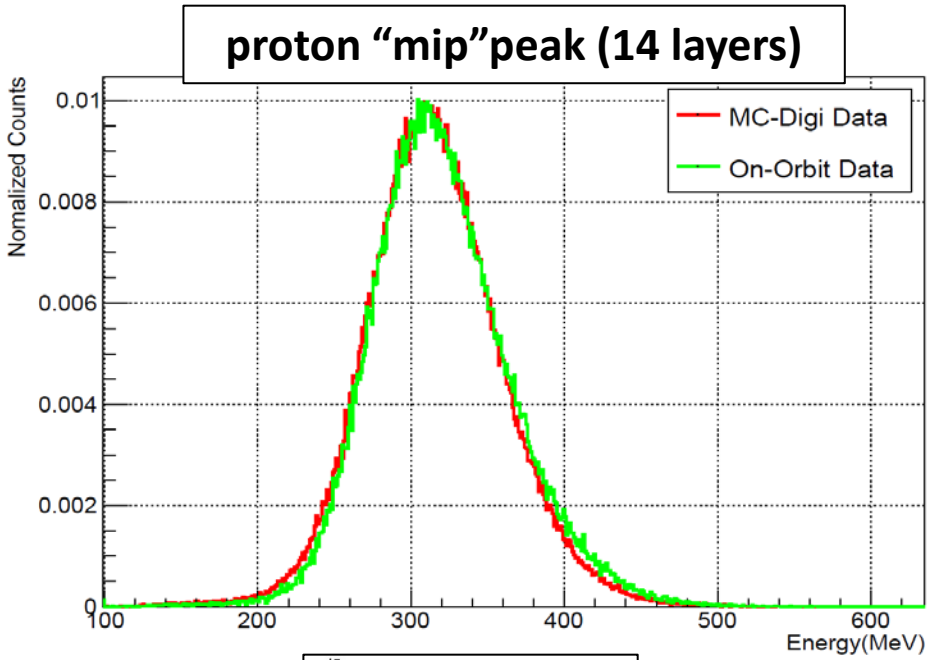


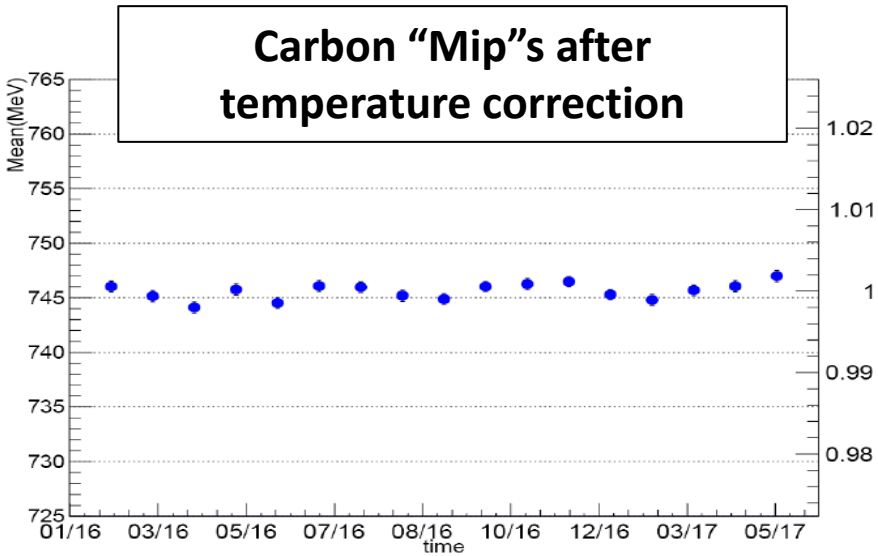


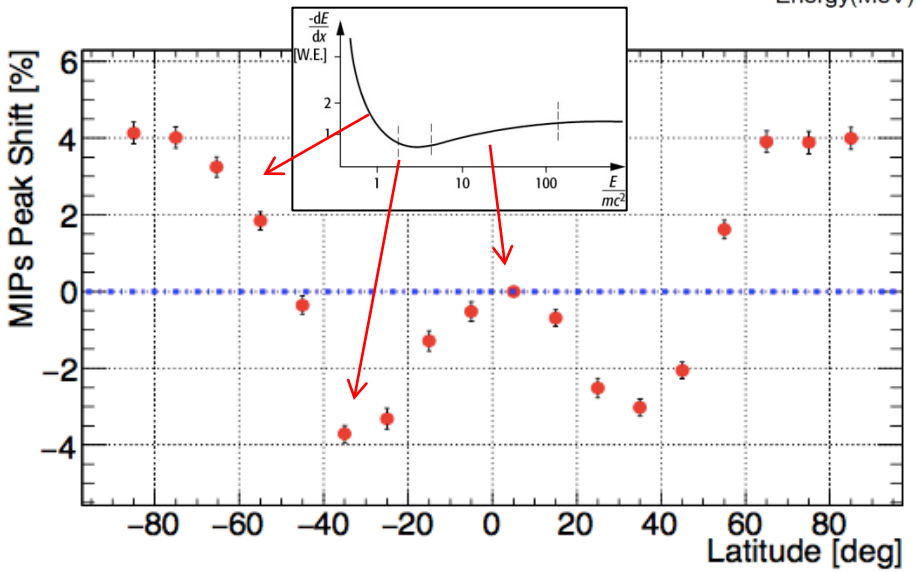


On orbit performance: BGO







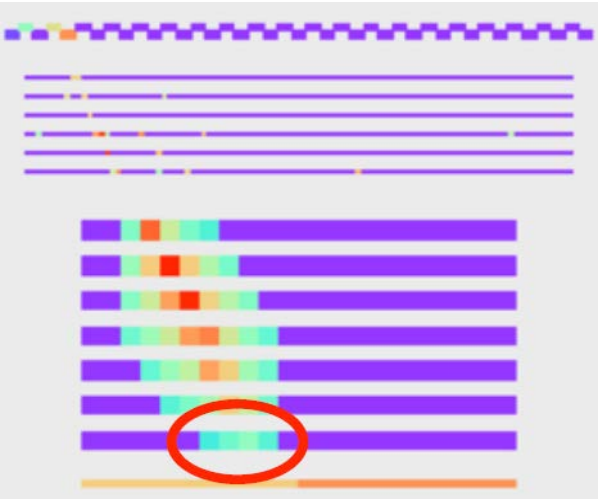


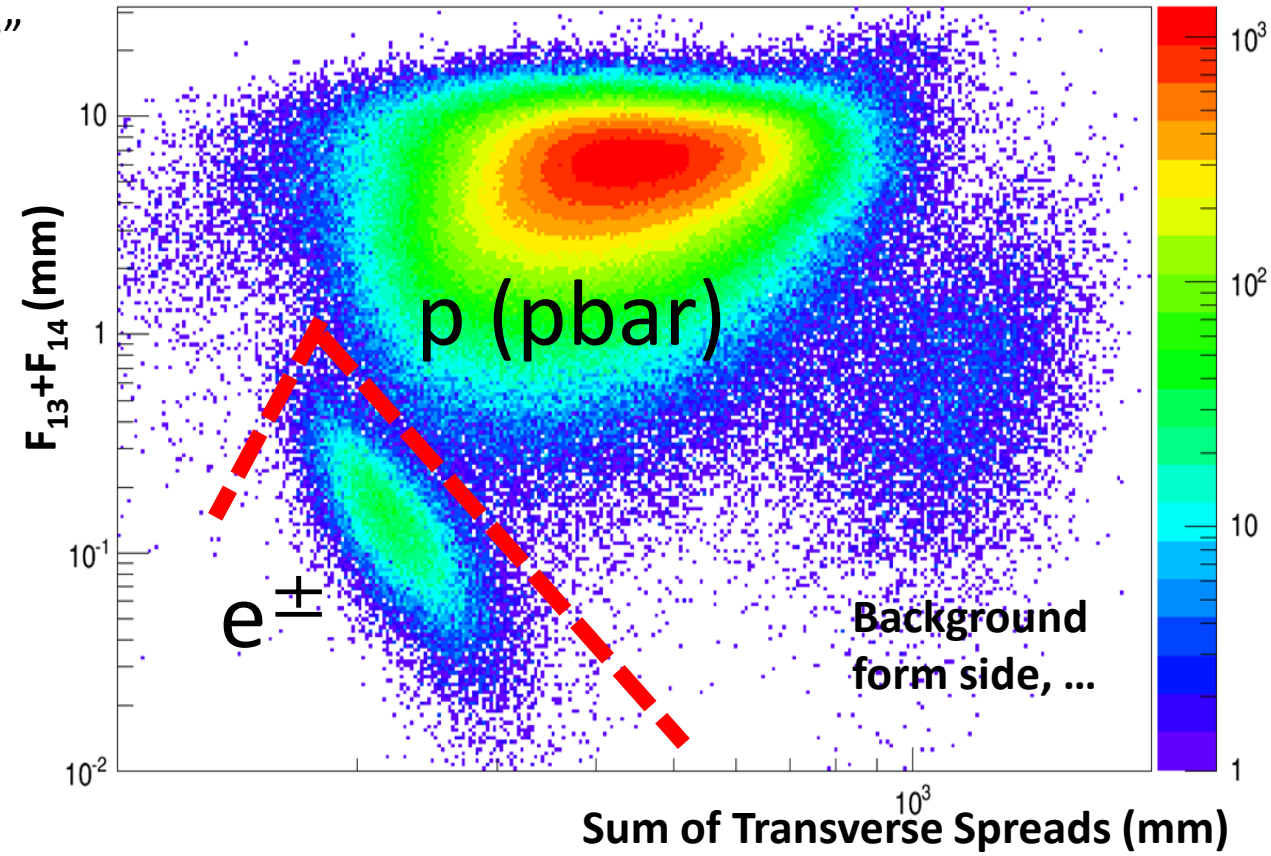
Study of the shower topology

One possible "shape parameter"

$$F_i = Spread_i \times \frac{E_i}{E_{tot}}$$

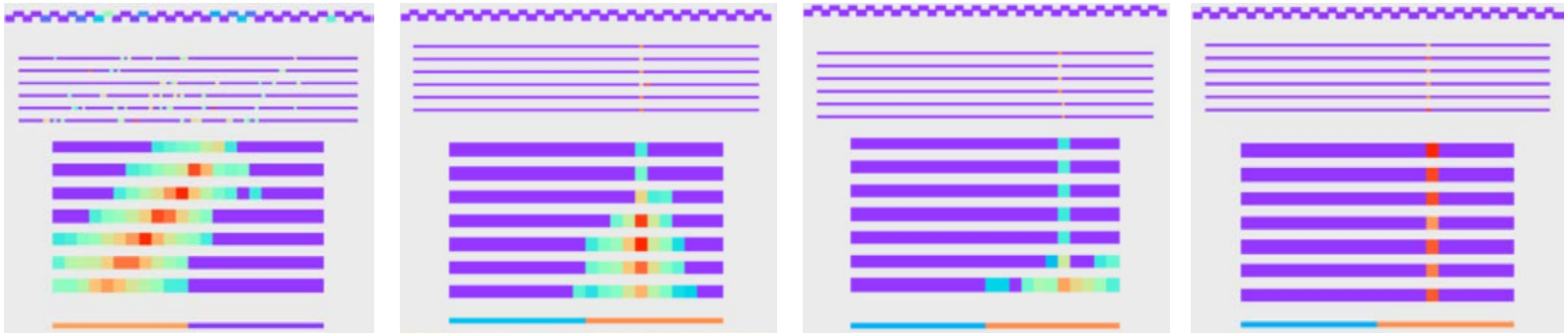
Rejection power > 10^5





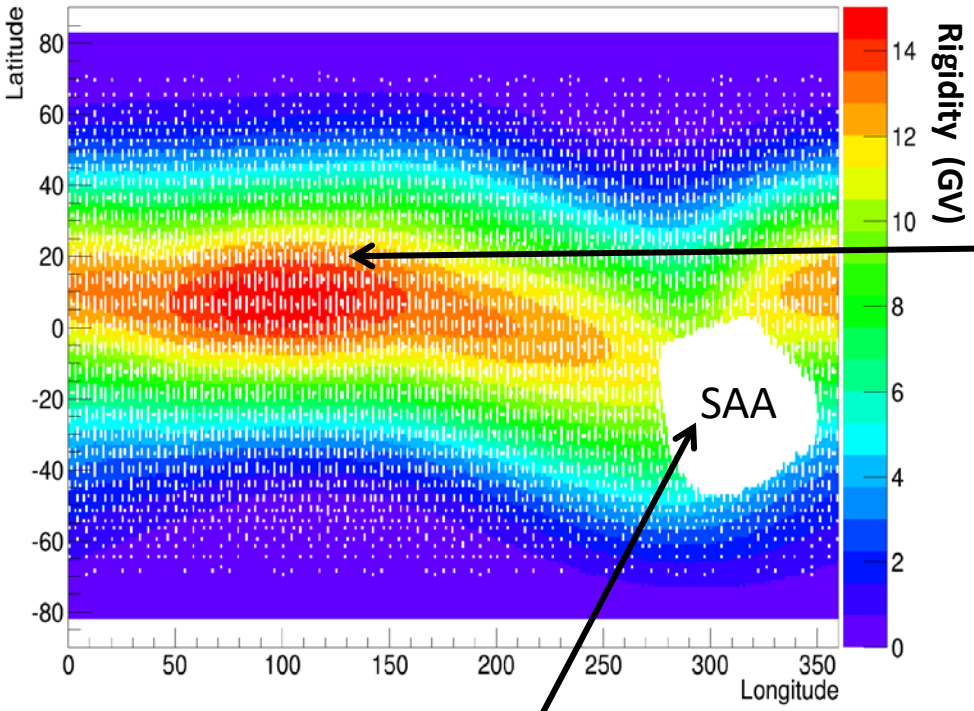
Electrons and positrons

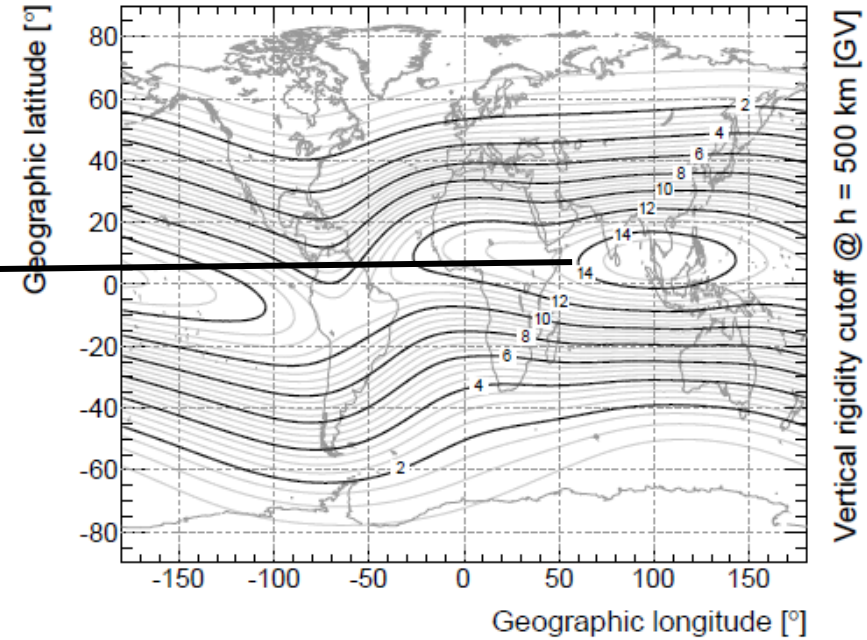
Protons and nuclei

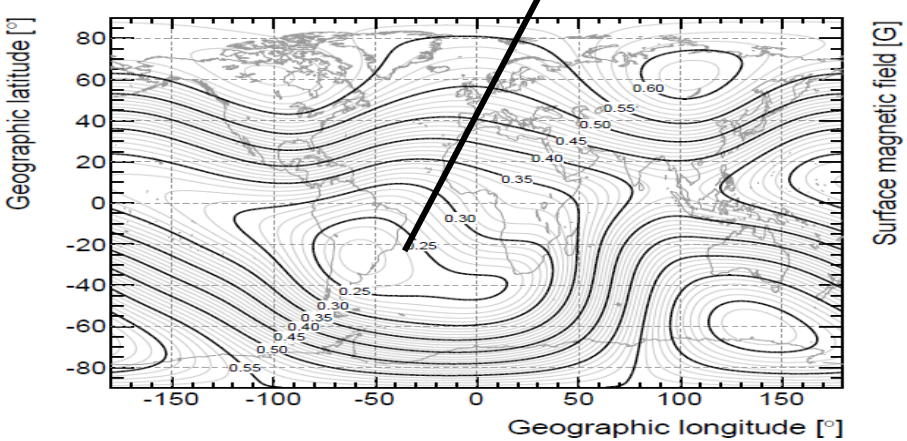


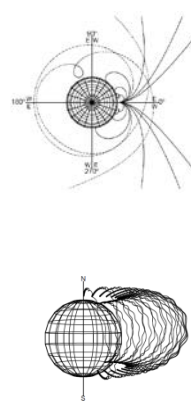
On-orbit energy scale calibration

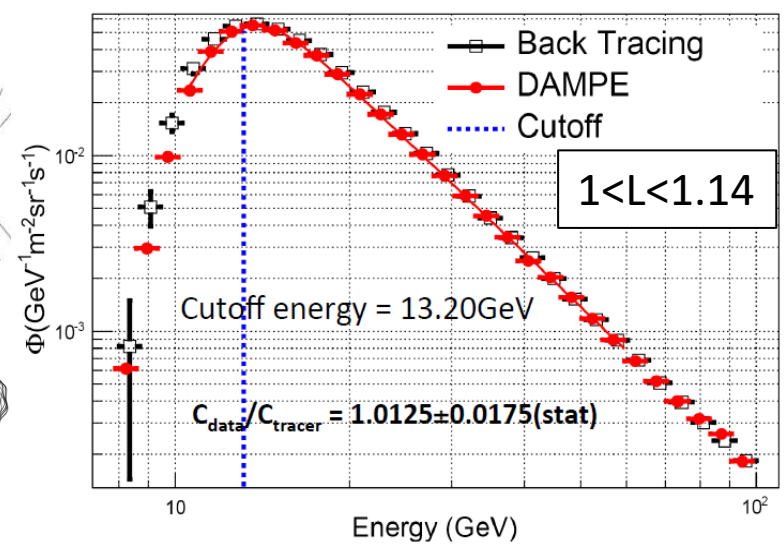
$e^{\pm}$ rigidity cutoff



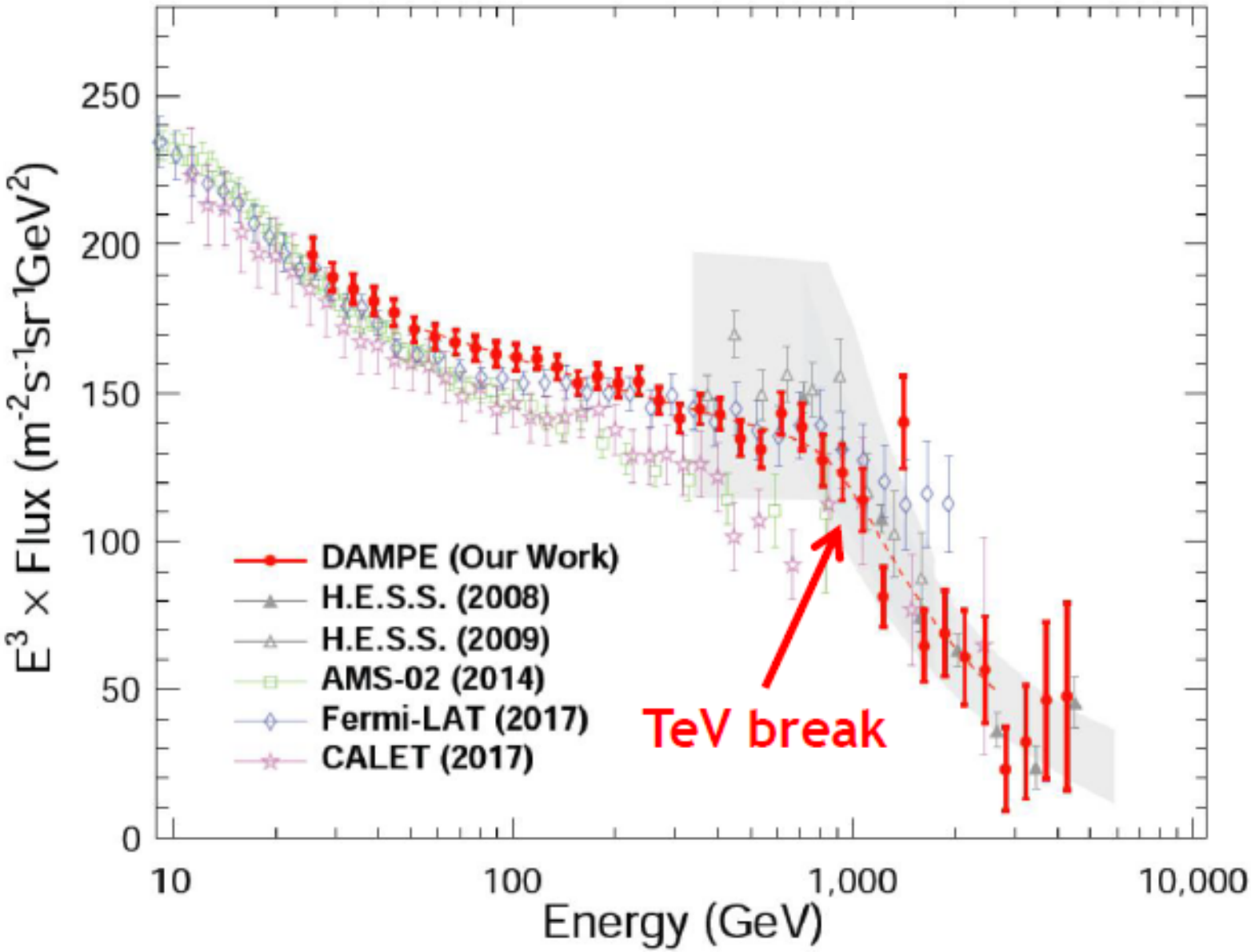




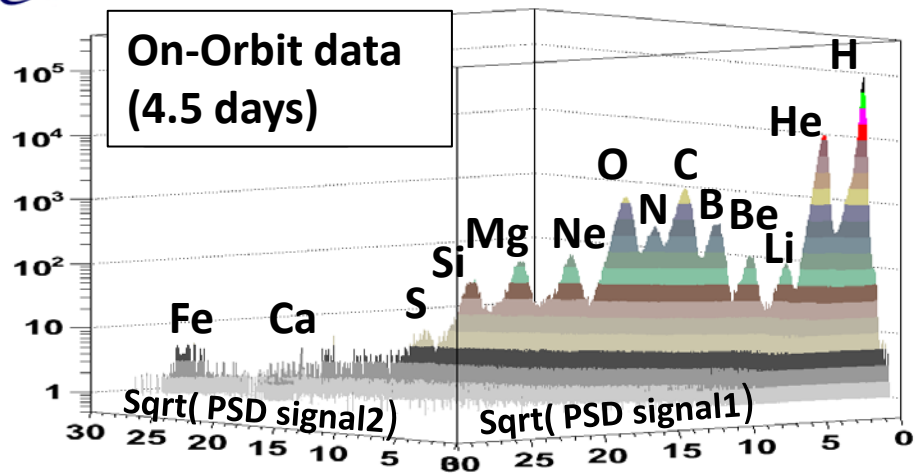


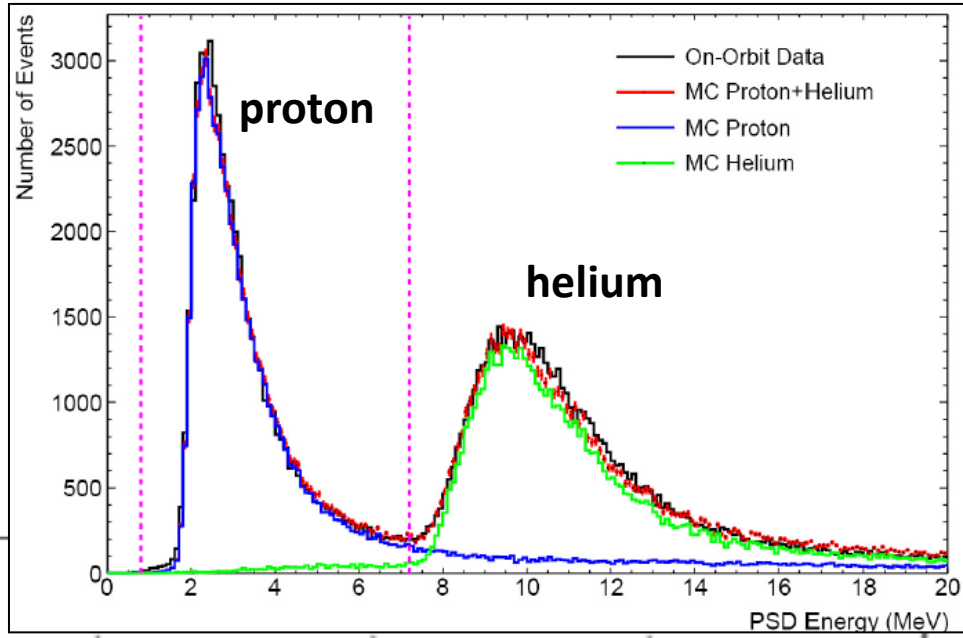


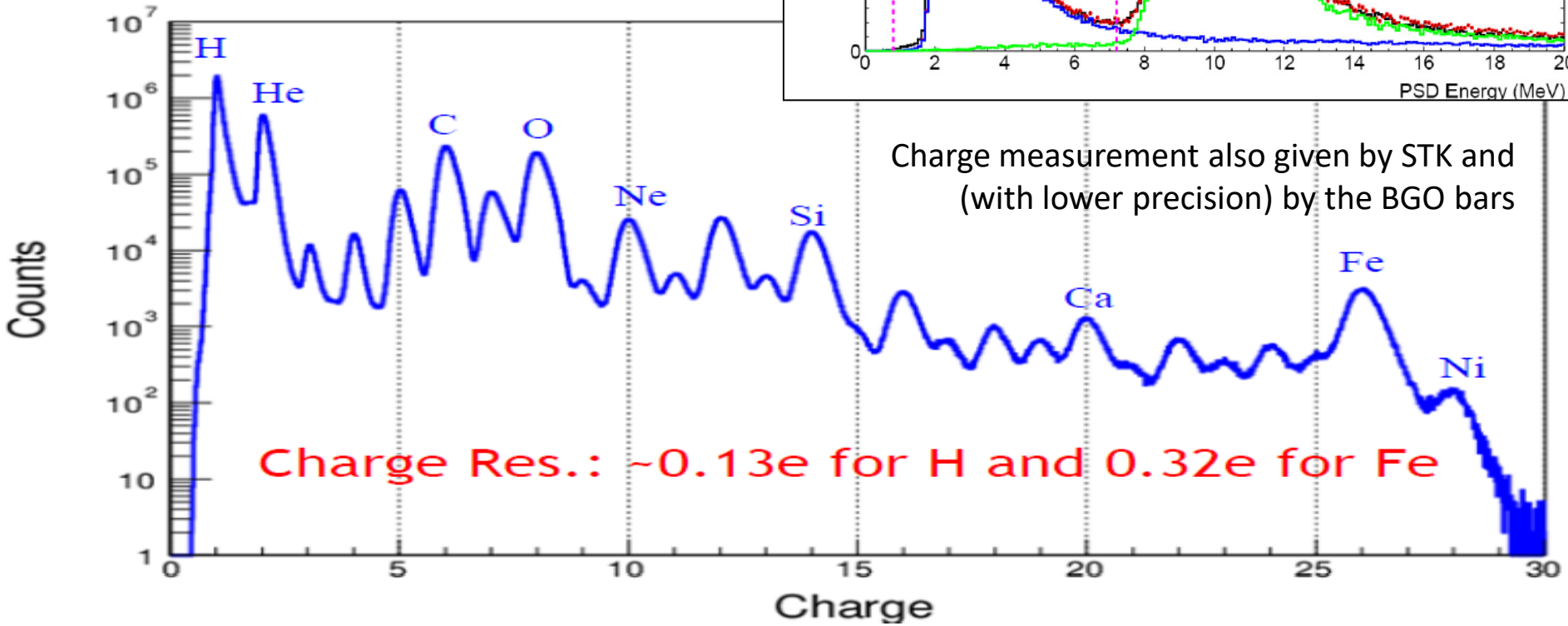
The all-electron spectrum



Nuclei ID with PSD

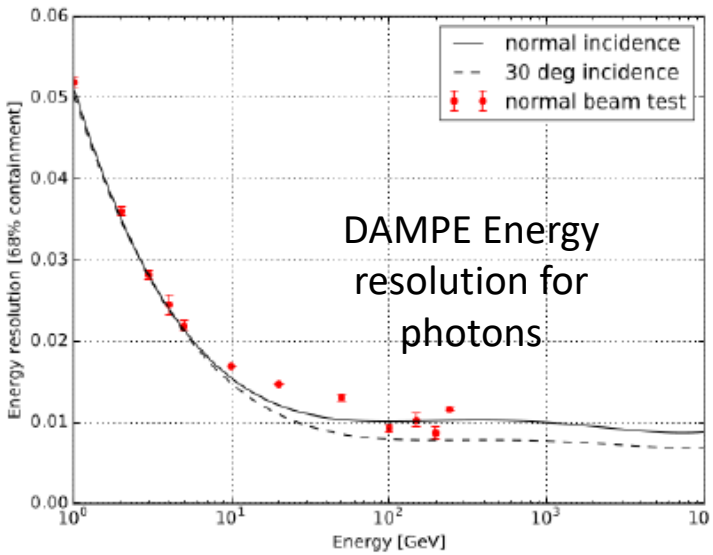






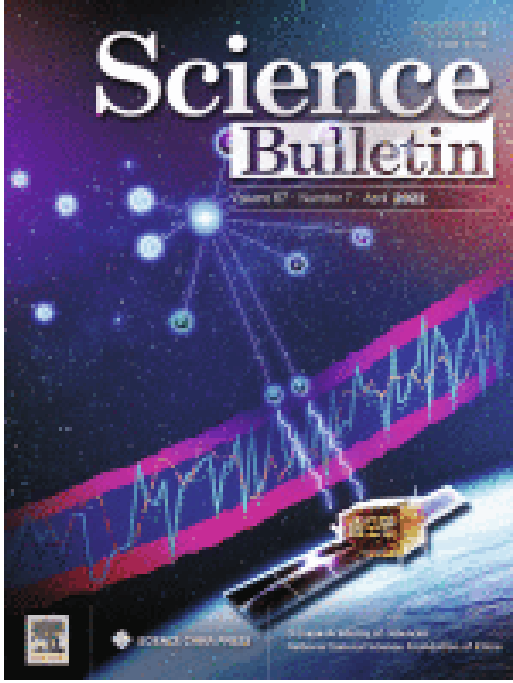
Charge measurement also given by STK and (with lower precision) by the BGO bars

DAMPE: indirect DM searches

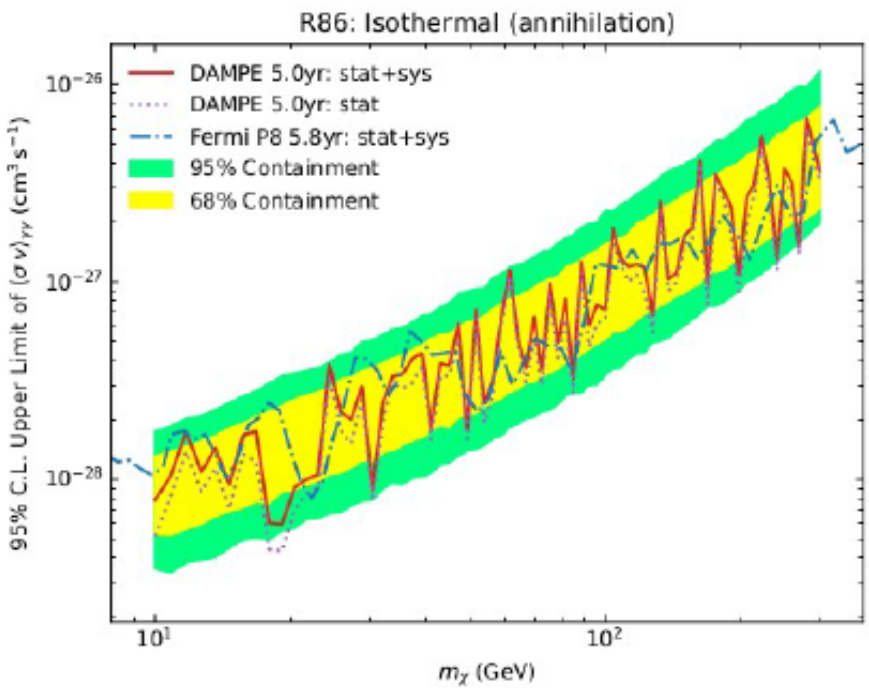


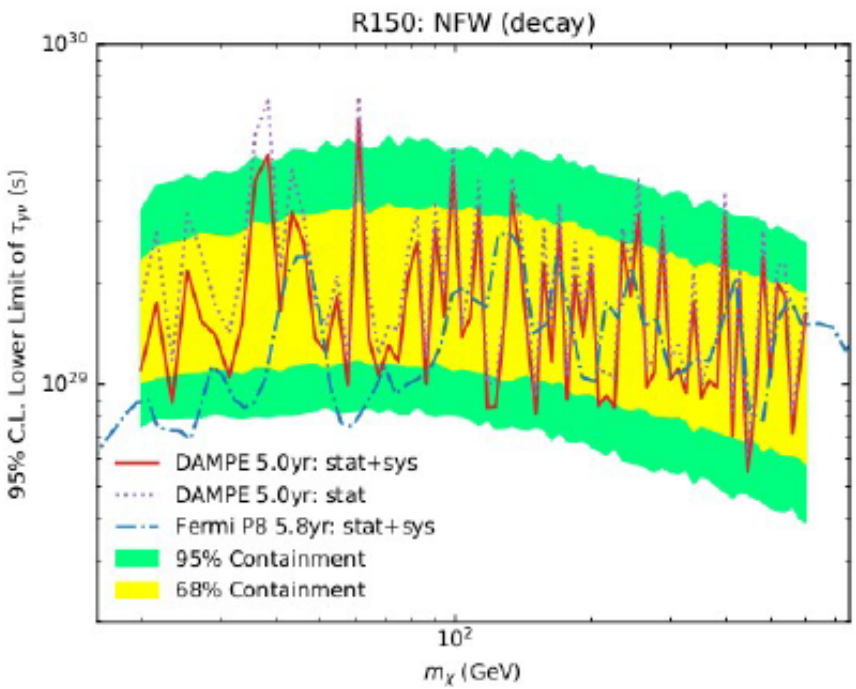
Search for gamma ray lines from neutralino annihilation or decay

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



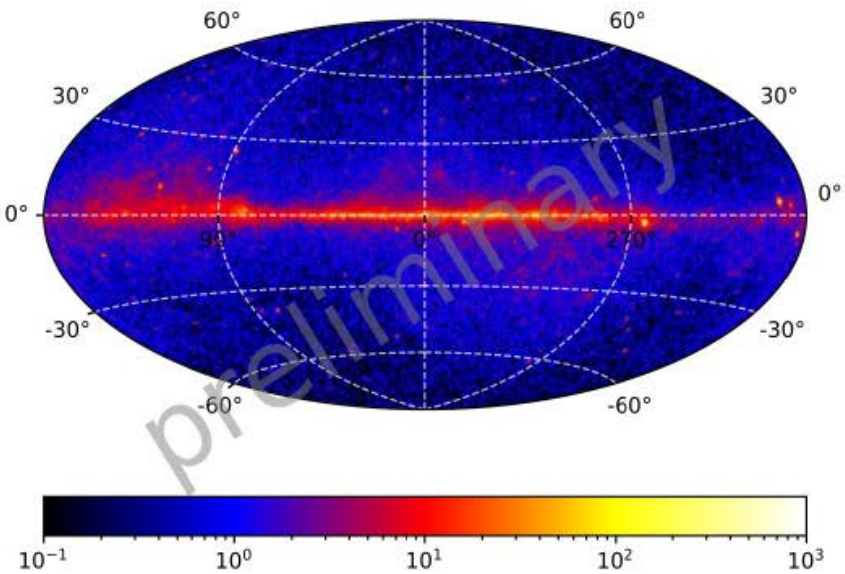
April 2022



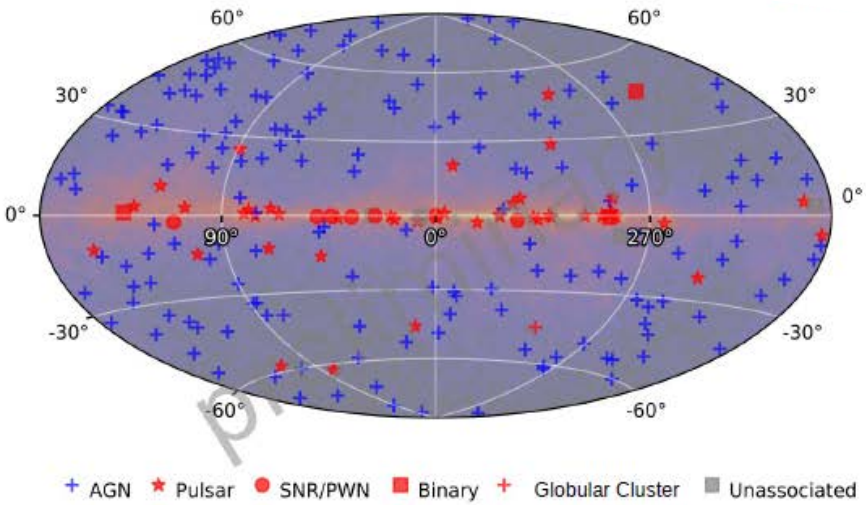


DAMPE: the gamma-ray sky

5-years gamma-ray data



120 M seconds livetime and
more than 220'000 photons above 2 GeV



AGN	Pulsar	SNR and/or PWN	Binary	Globular Cluster	Unassociated	Total
163	44	7	3	1	4	222

Associated with the 4FGL