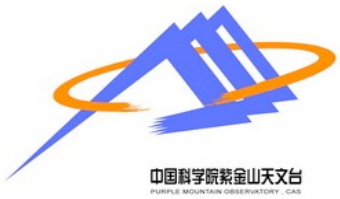


Recent Status and Results of the Dark Matter Particle Explorer

Li, Xiang (李翔)

Purple Mountain Observatory

(on behalf of the DAMPE collaboration)

July 12 - 23, 2021, Berlin, Germany (online)

The DAMPE 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

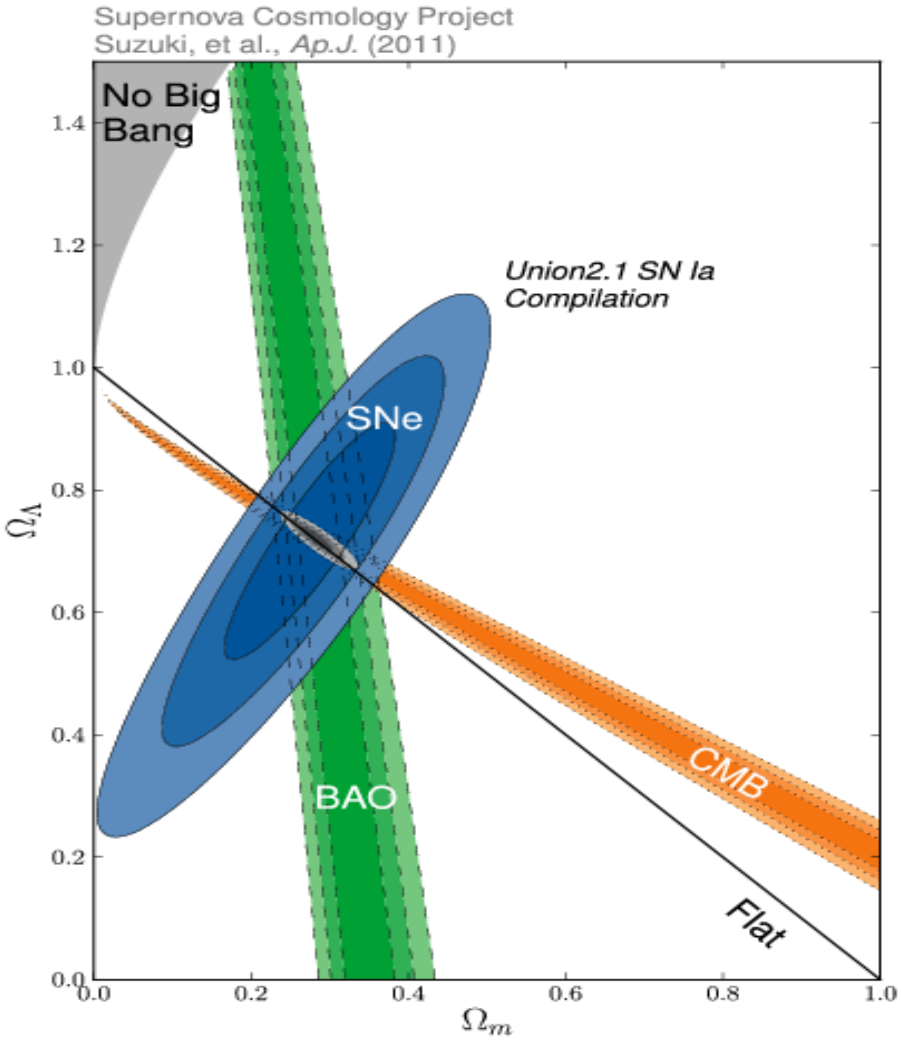
- ITALY
  - INFN Perugia and University of Perugia
  - INFN Bari and University of Bari
  - INFN Lecce and University of Salento
  - INFN LNGS and Gran Sasso Science Institute

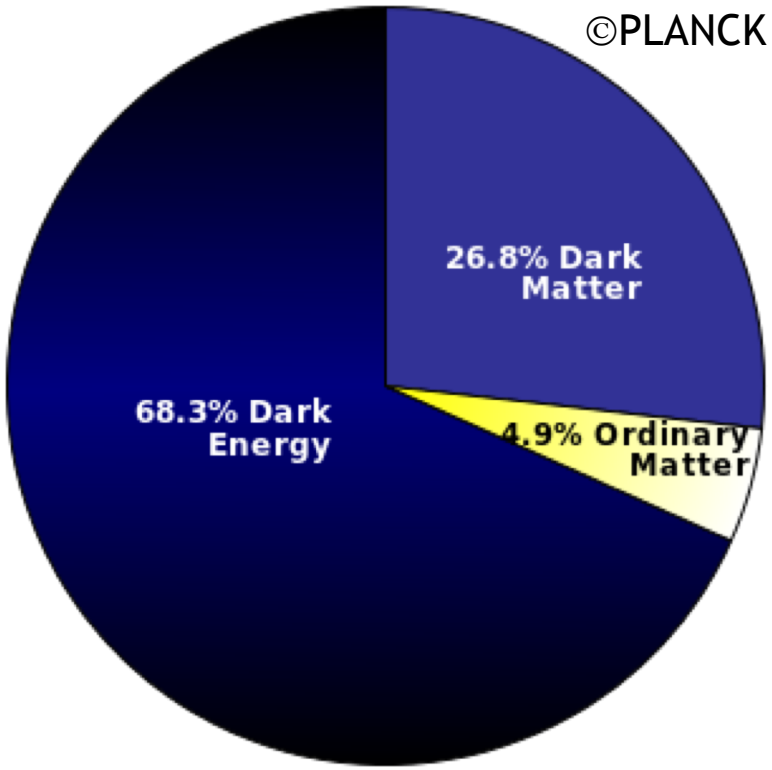
- SWITZERLAND
  - University of Geneva

Outline

- Introduction
- DAMPE mission
- On-orbit status
- Physical results
- Summary

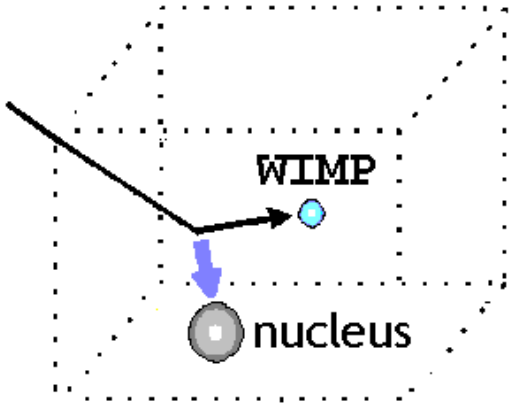
Composition of the Universe



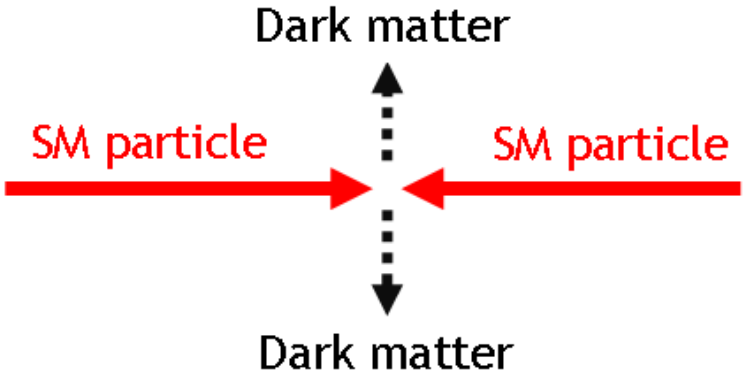


Detection of dark matter

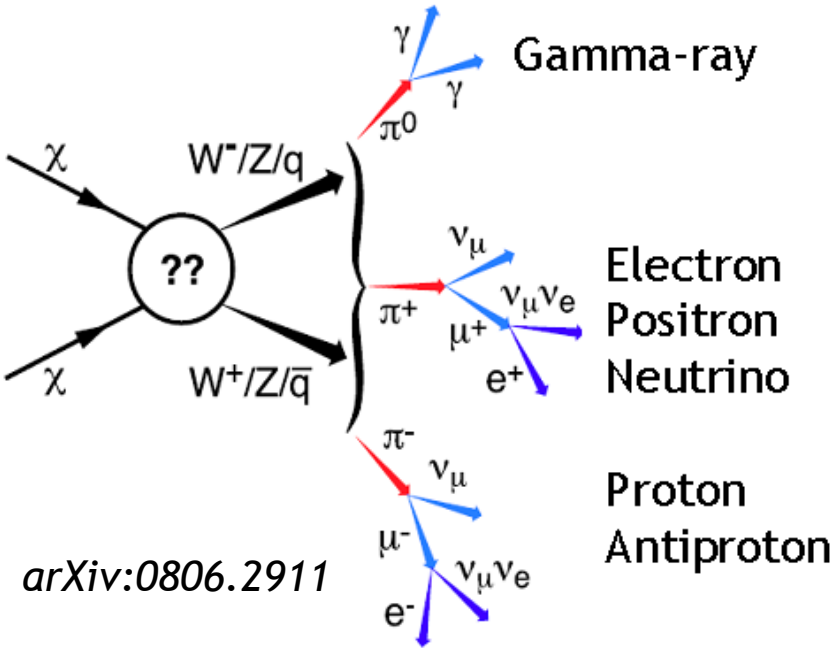
(a) Direct detection



(b) Collider detection

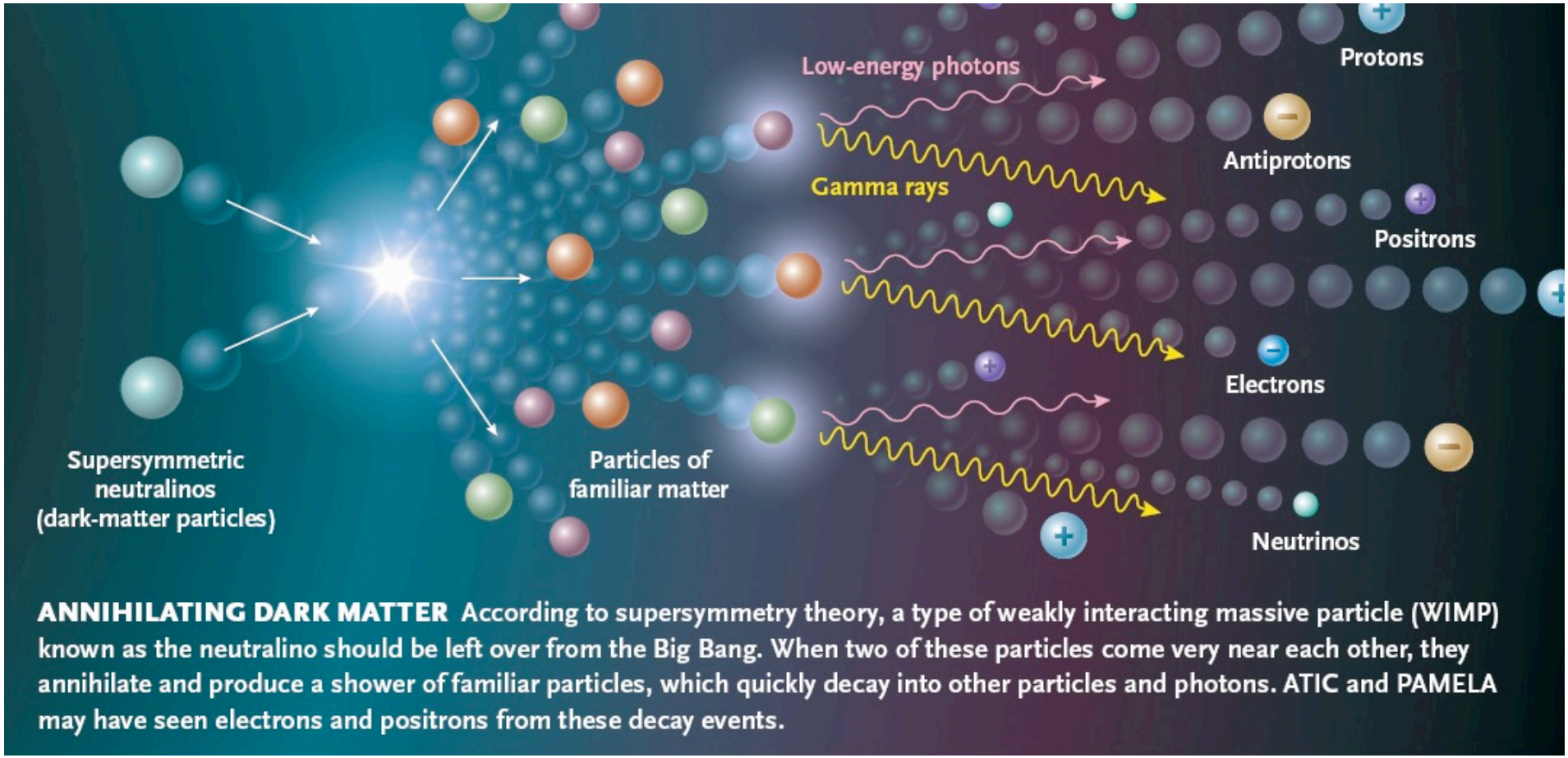


(c) Indirect detection



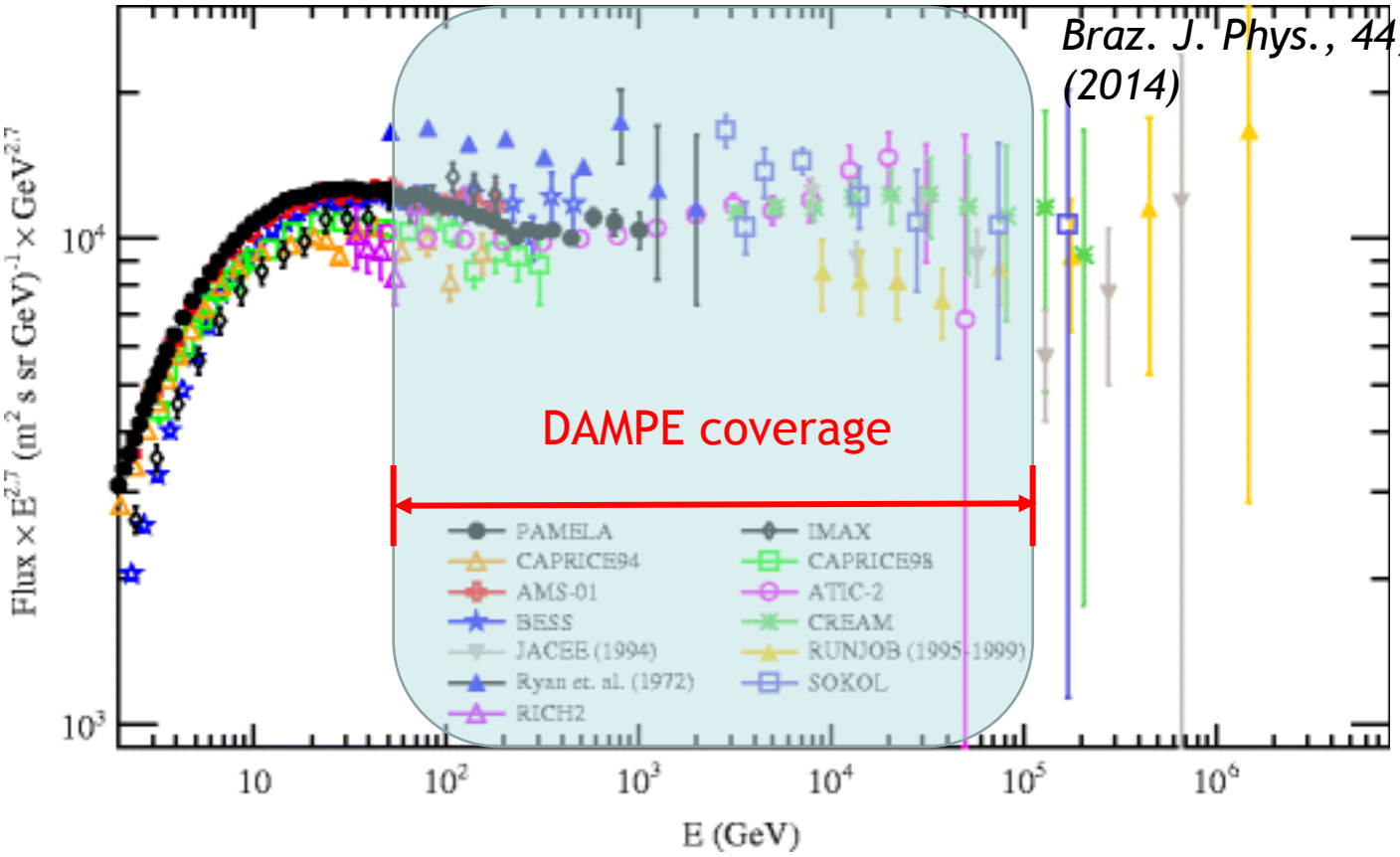
arXiv:0806.2911

Indirect detection



We need high energy resolution, high angular resolution, high statistics and low background cosmic ray electron/positron and gamma-ray experiments.

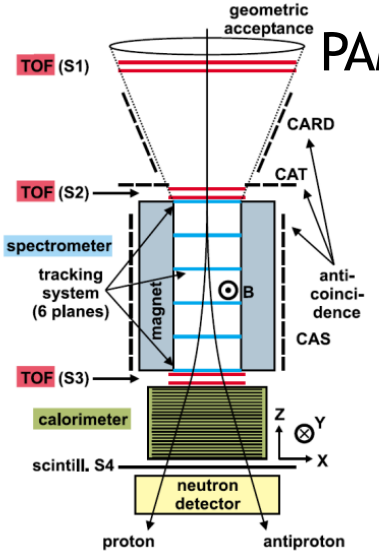
Cosmic rays

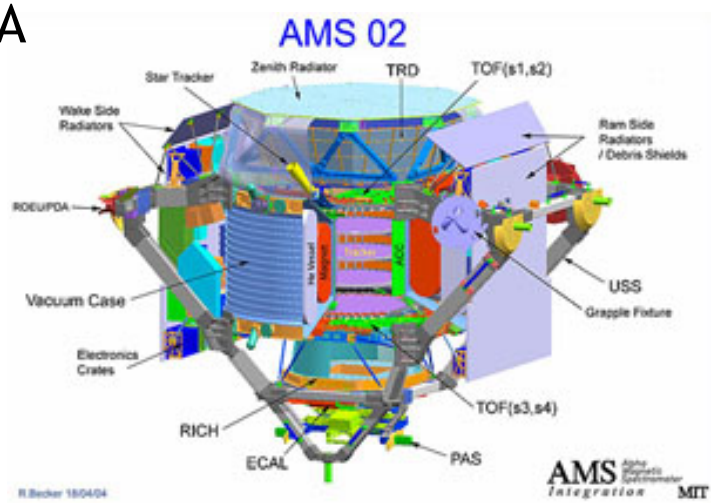


- Precision measurements of cosmic ray spectra: cosmic ray origin, acceleration, and propagation
- The spectra above TeV are not well measured due to limited statistics of direct detection experiments

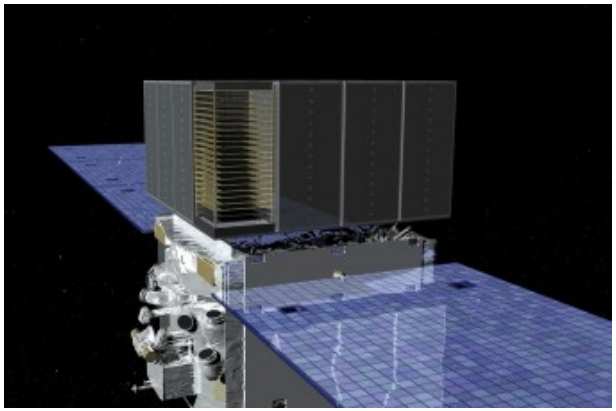
Recent space particle/γ detectors

PAMELA



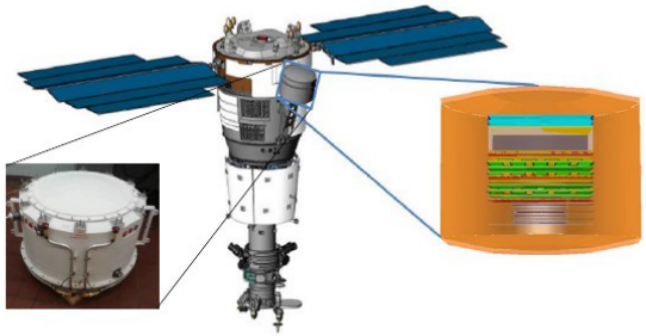


Fermi

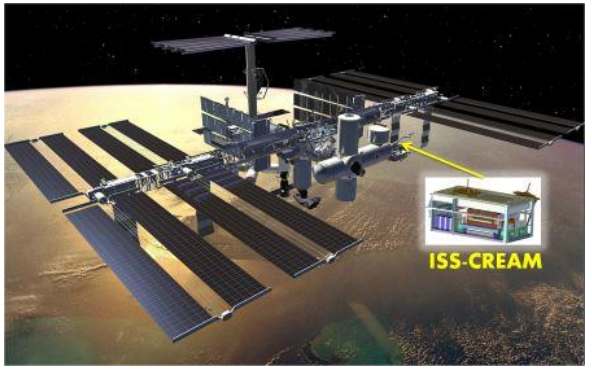


CALET

NUCLEON



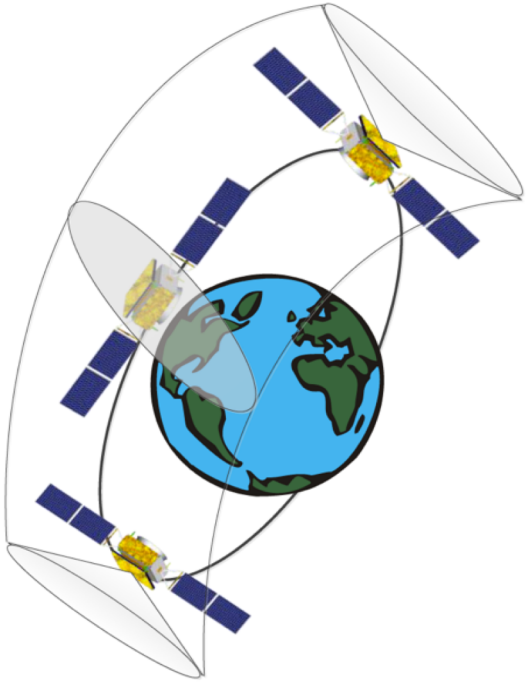
ISS-CREAM



DAMPE Mission

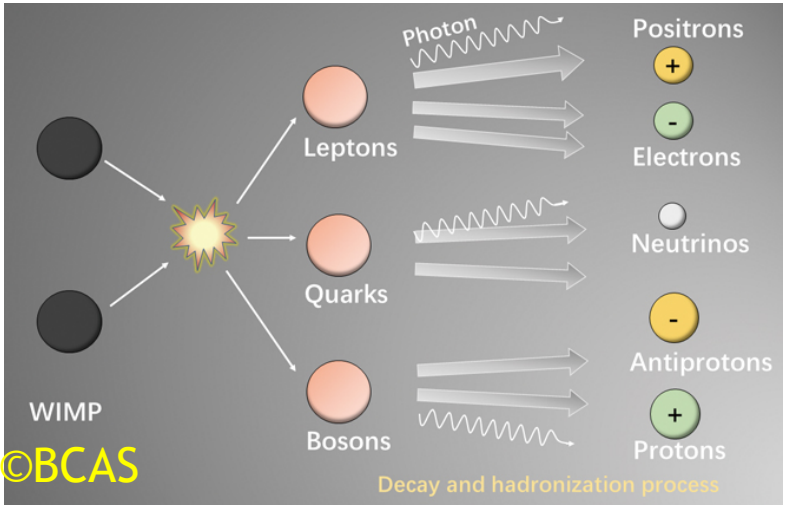
DAMPE mission

DAMPE ("Wukong") lanuched on Dec. 17, 2015



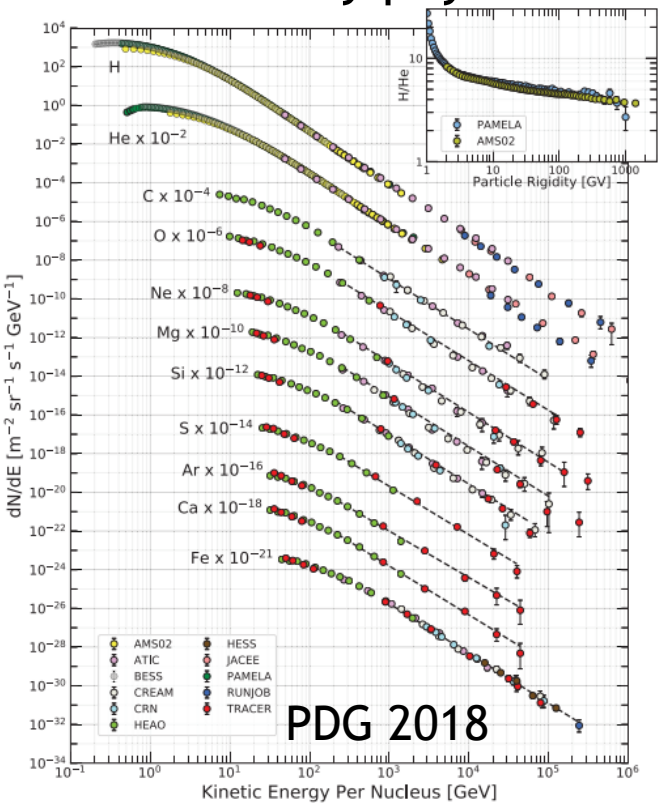
- Altitude: 500 km
- Inclination: 97.4°
- Period: 95 minutes
- Orbit: Sun-synchronous

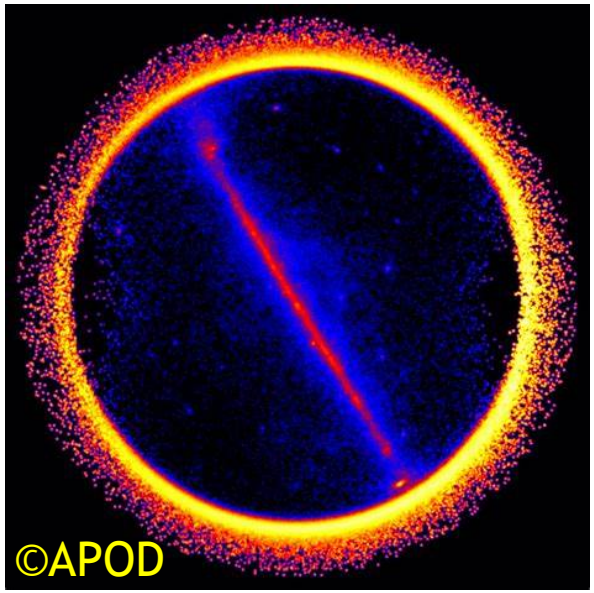
Scientific objectives



Indirect detection of dark matter

Cosmic ray physics

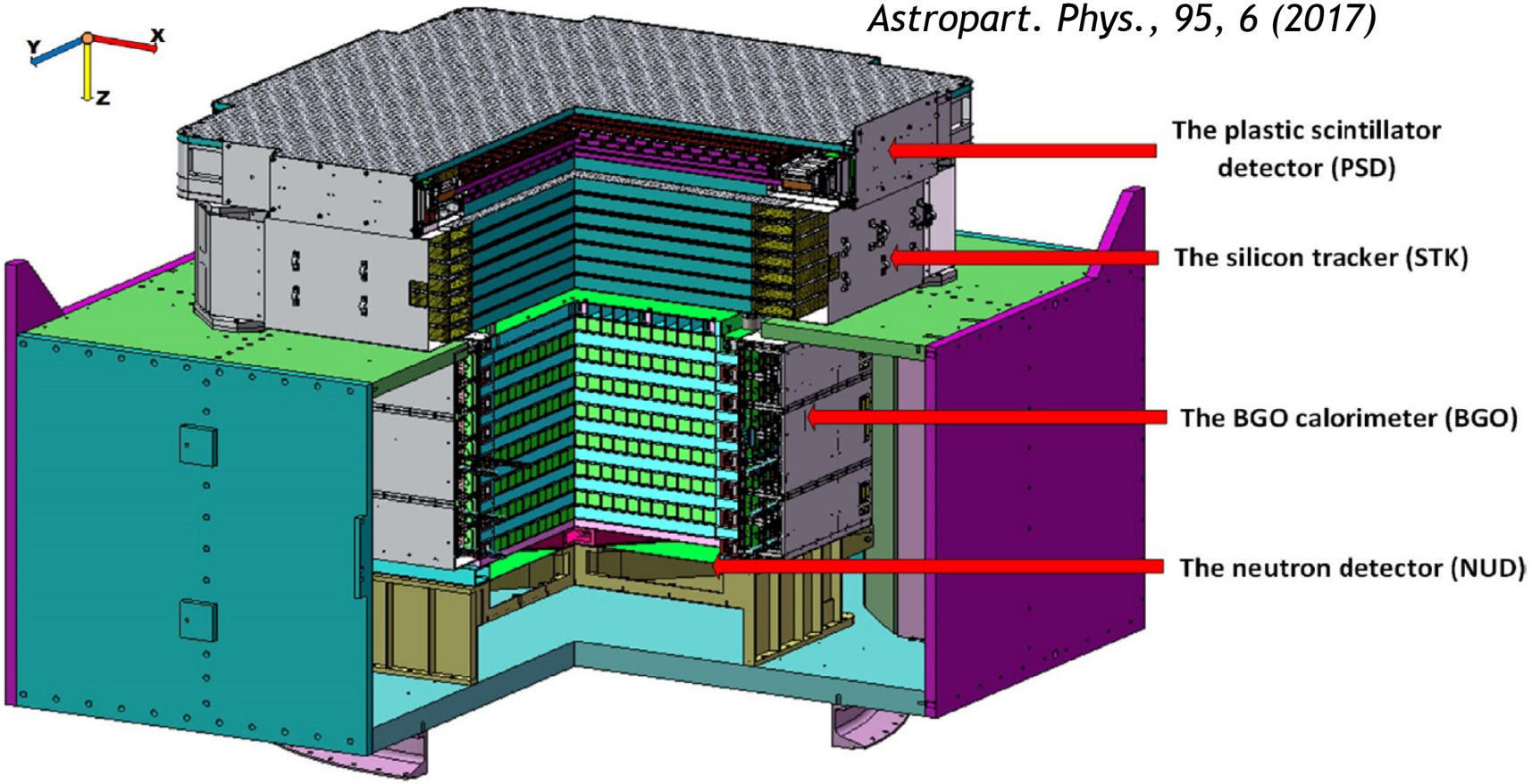




Gamma-ray astronomy

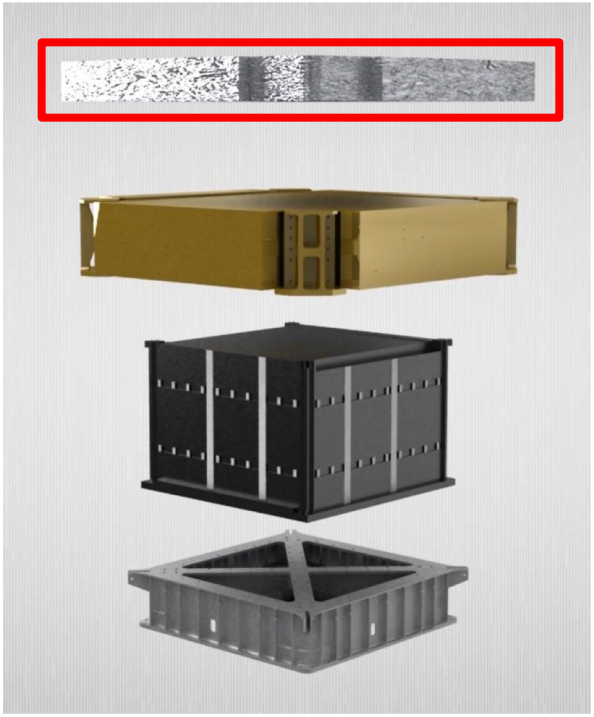
DAMPE instrument

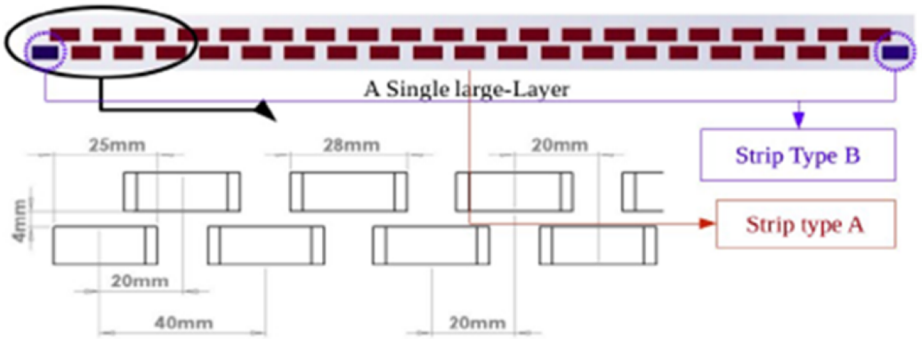
Astropart. Phys., 95, 6 (2017)



- PSD: charge measuresument via dE/dx and ACD for photons
- STK: track, charge, and photon converter
- BGO: energy measurement, particle (e-p) identification
- NUD: Particle identification

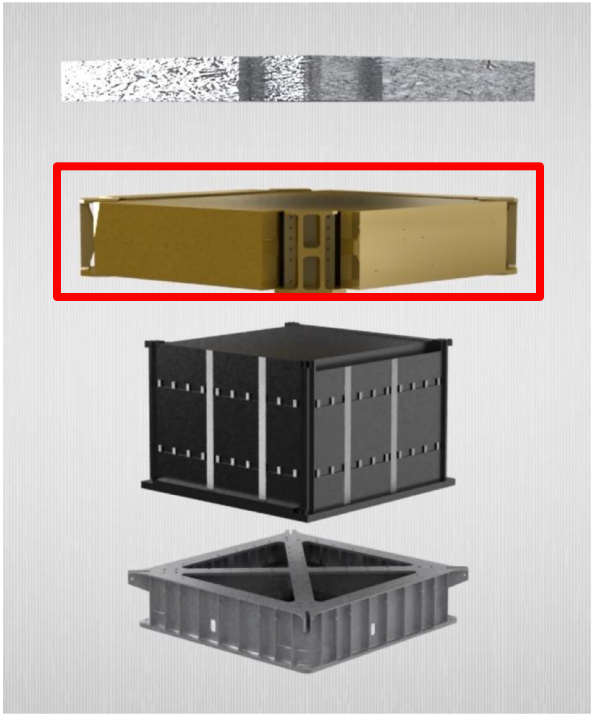
PSD charge detector

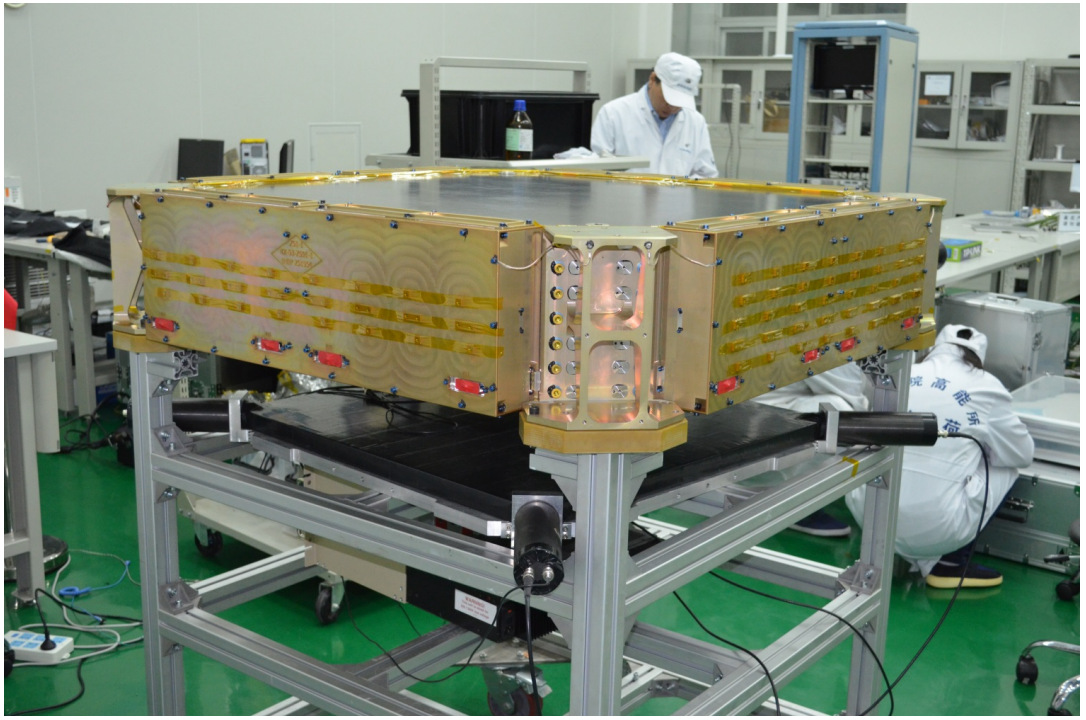




- 2 layers (x,y) of 88.4 cm × 2.8 cm × 1 cm
- Active area: 82 cm × 82 cm
- Weight : ~103 kg
- Power: ~ 8.5 W

Silicon tracker (STK)

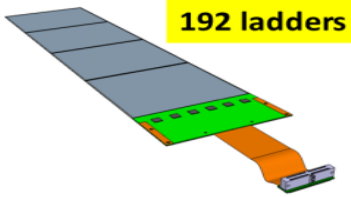


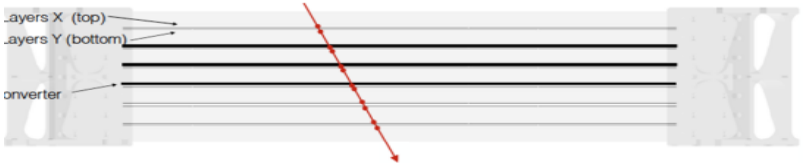


768 silicon sensors
95 x 95 x 0.32 mm³

1,152 ASICs

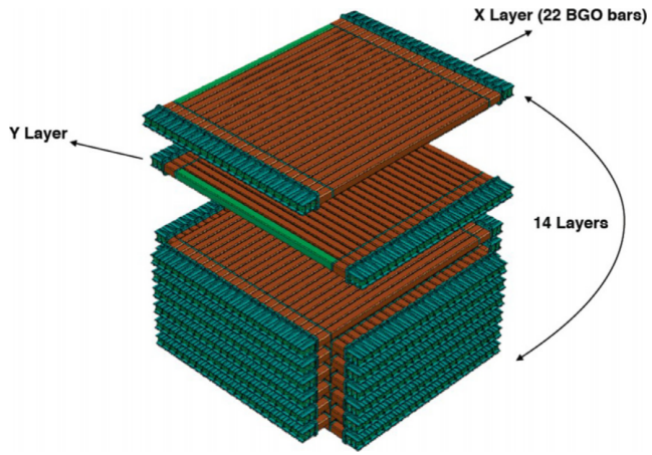
73,728 channels





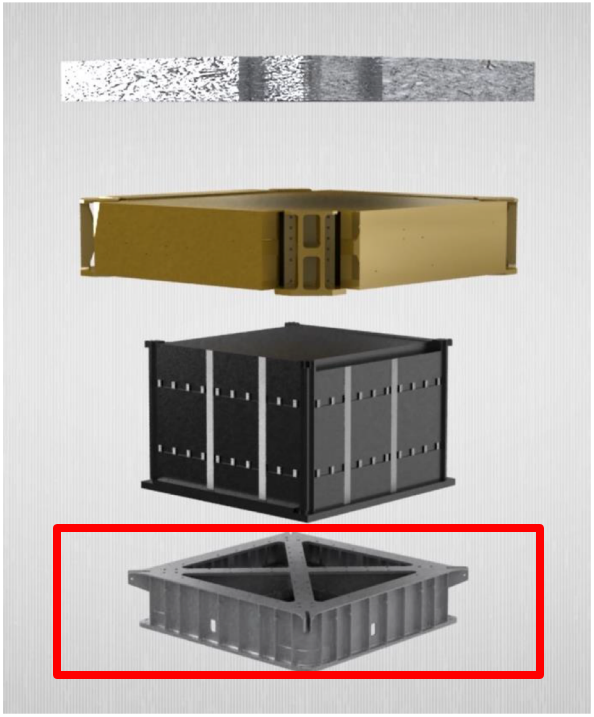
- Detection area: 76 cm x 76 cm
- Total weight: ~154 kg
- Total power consumption: ~ 82W
- Three 1 mm tungsten plates for photon conversion (0.86 X_0)

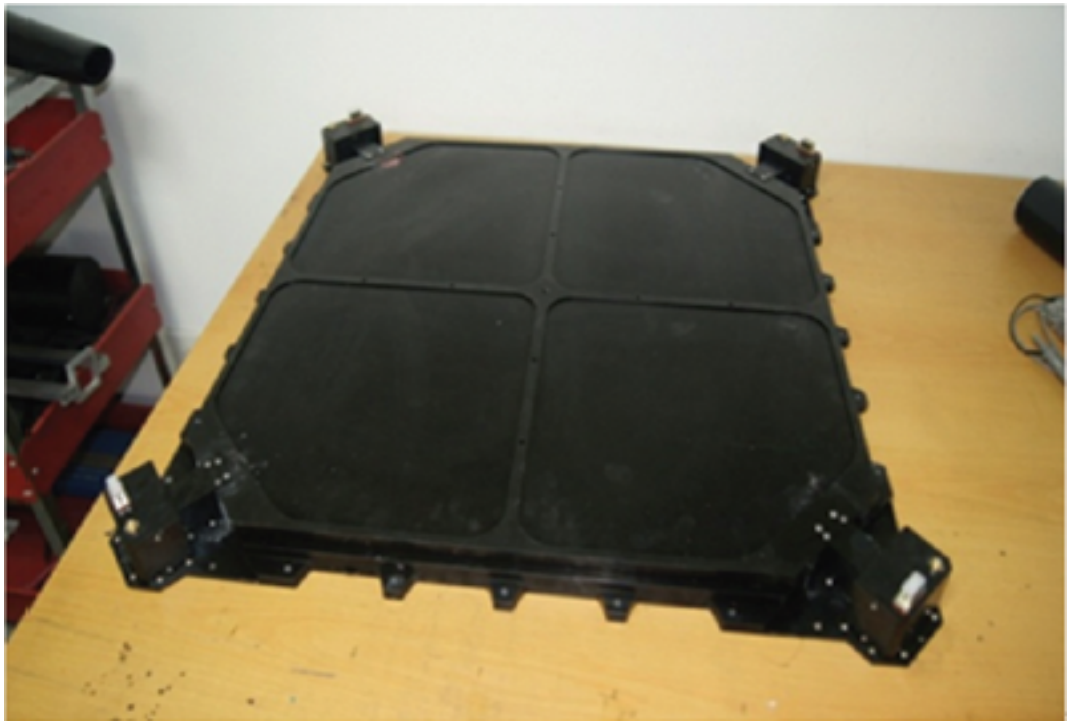
BGO calorimeter

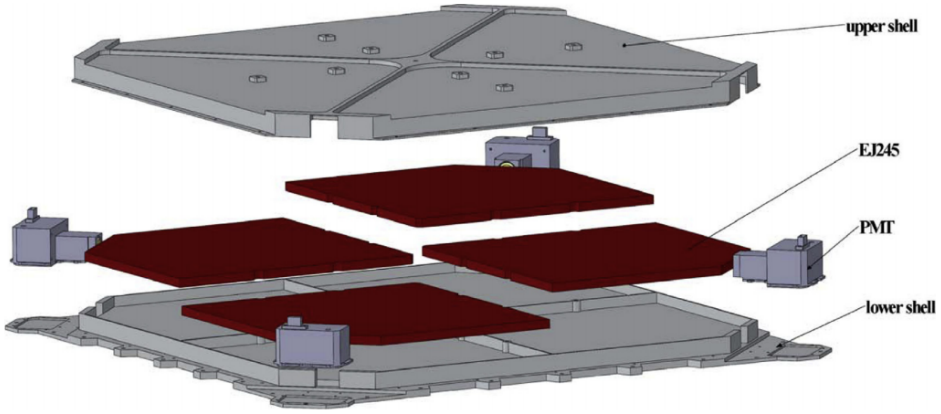


- Outer envelop: 100 cm x 100 cm x 50 cm
- Detection area: 60 cm x 60 cm
- Total weight: ~1052 kg
- Total power consumption: ~ 41.6 W

NUD neutron detector



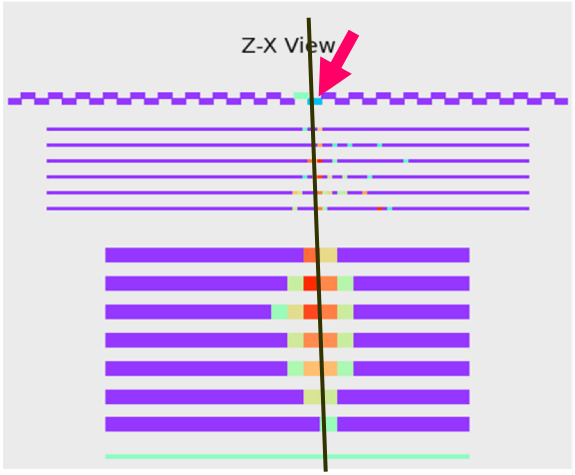




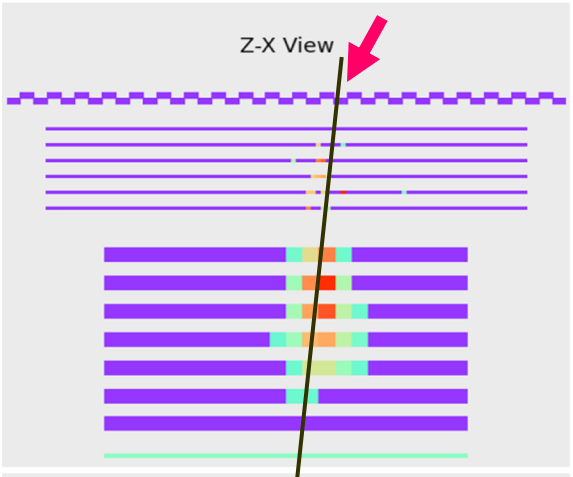
- $n + {}^{10}B \rightarrow \alpha + {}^{7}Li + \gamma$
- 4 plastic scintillators
- Active area: 60 cm x 60 cm
- Total weight: ~12 kg
- Total power: ~ 0.5 W

Particle identification

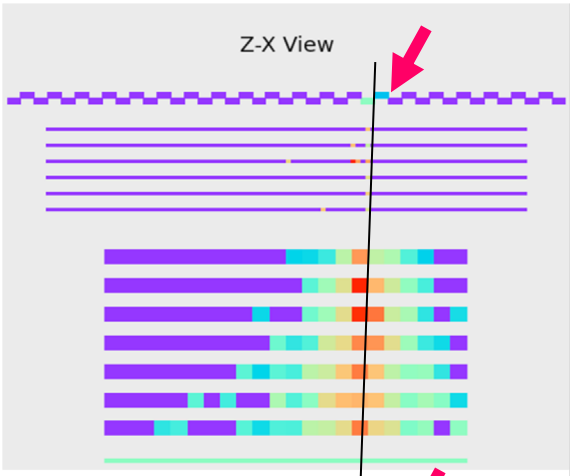
electron



gamma



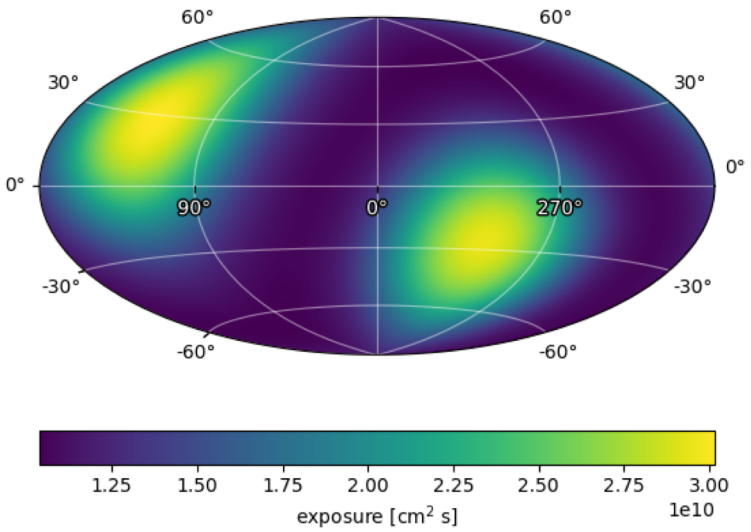
proton



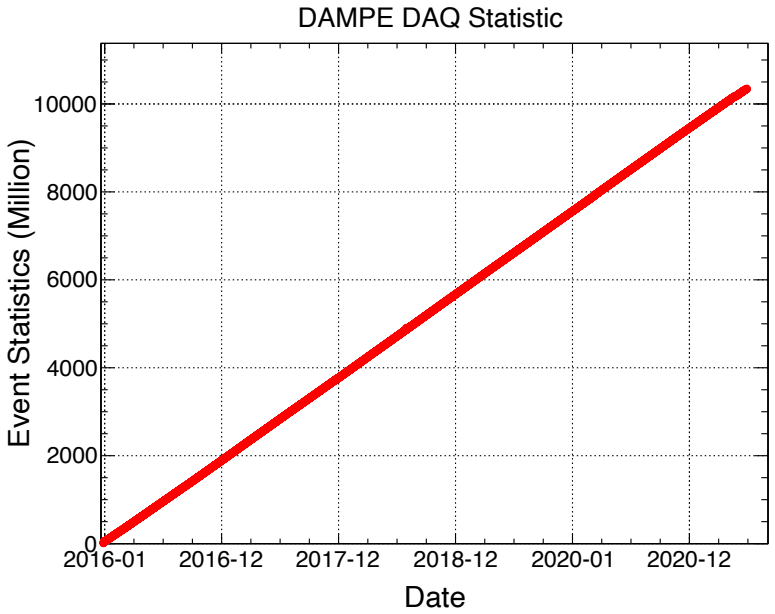
On-orbit Status

Status

DAMPE 5.5 year exposure map

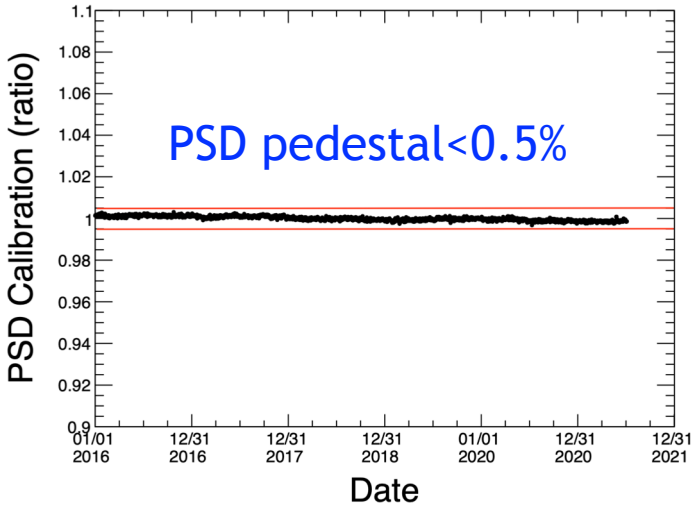


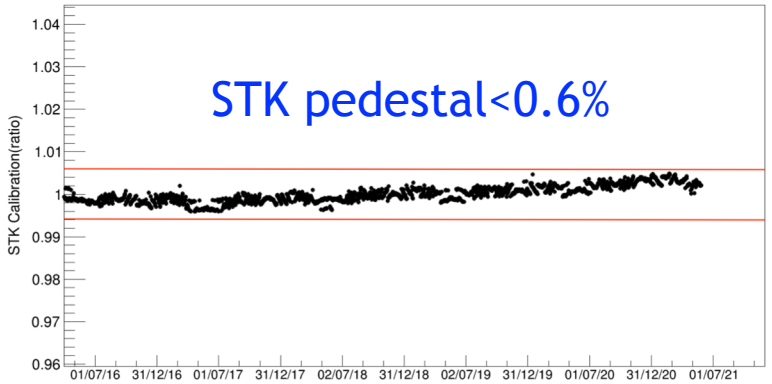
>10 billion events

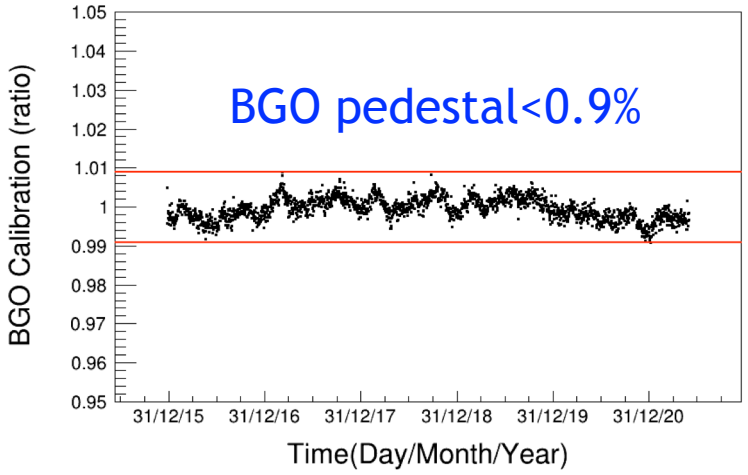


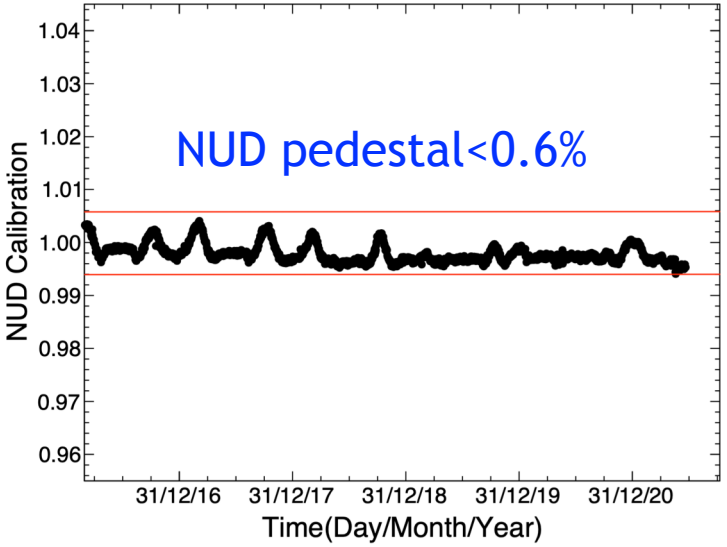
Since the launch on Dec. 17, 2015, DAMPE has operated on-orbit for 5.5 years, surveyed the sky for 11 times, and recorded more than 10 billion events

Detector stability



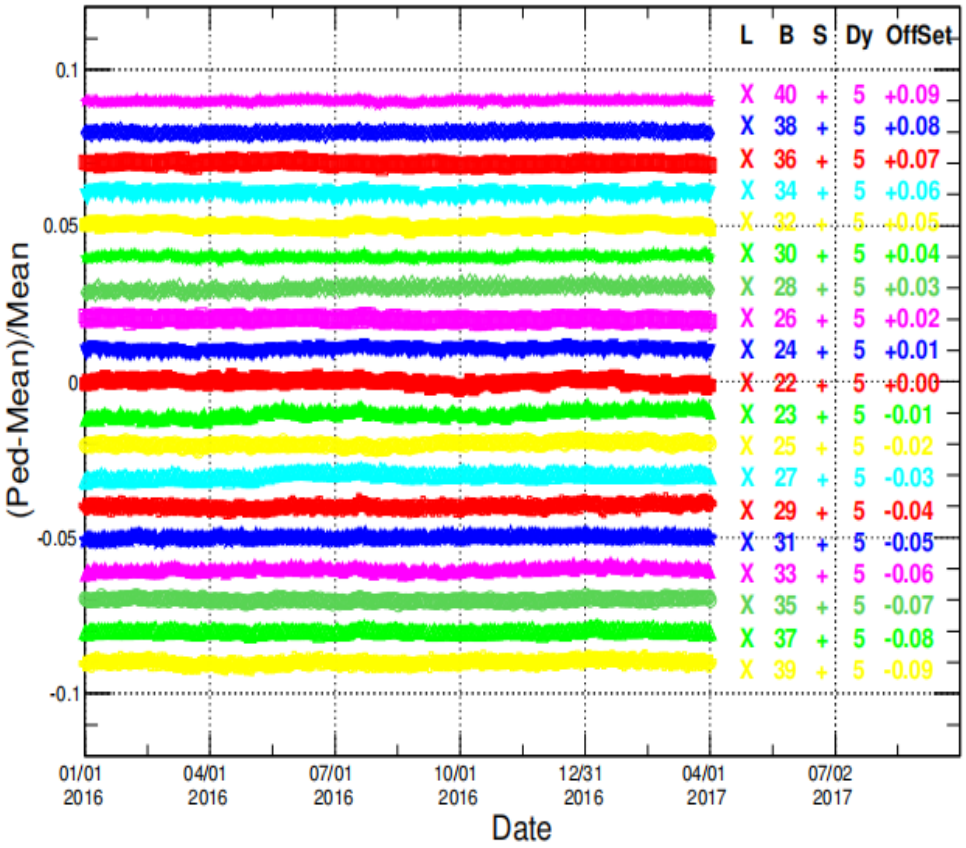






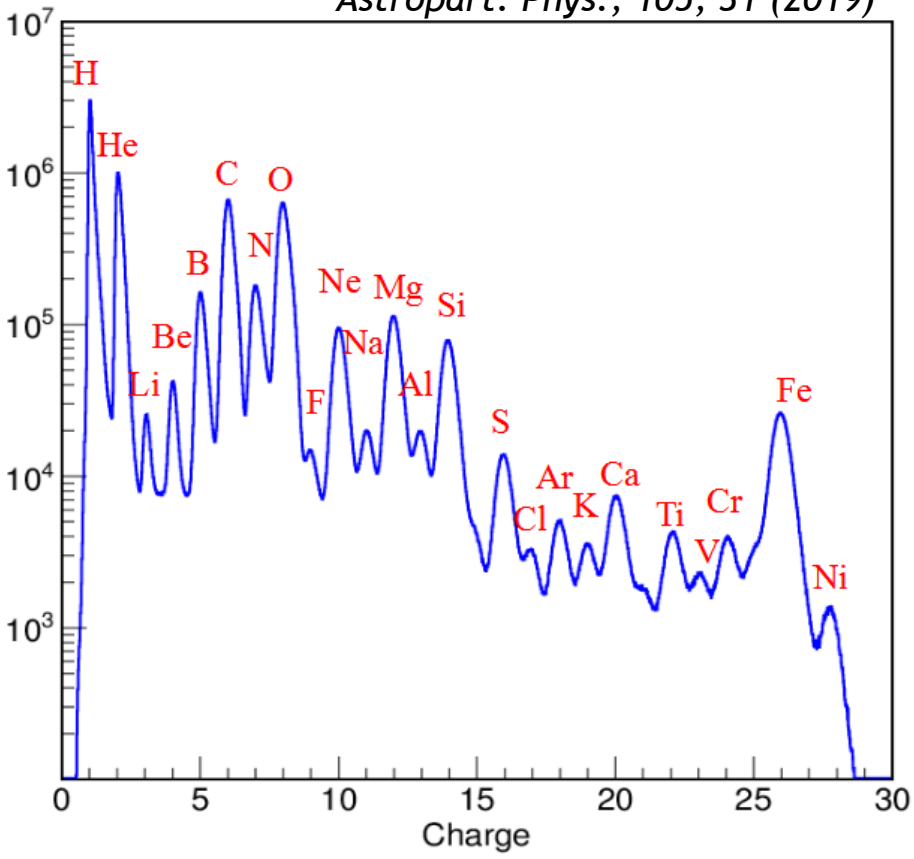
Status: charge

Res. Astron. Astrophys., 19, 47 (2019)



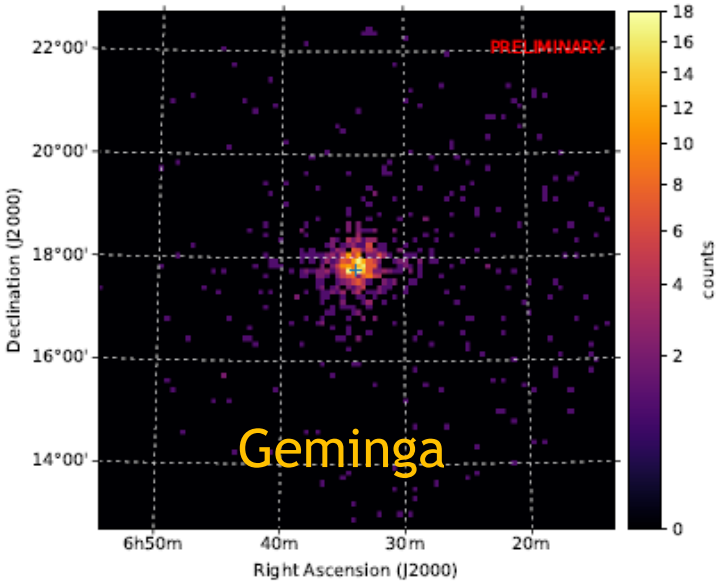
Pedstal stability

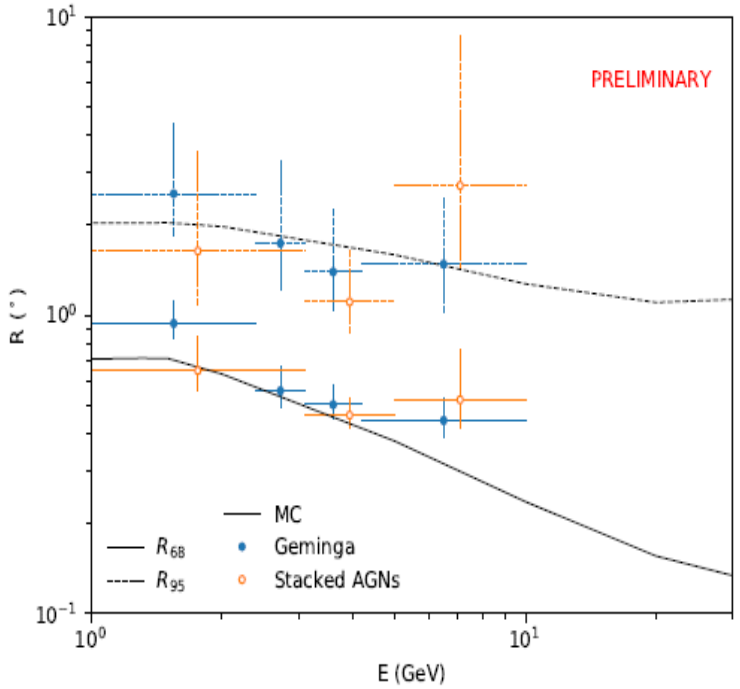
Astropart. Phys., 105, 31 (2019)

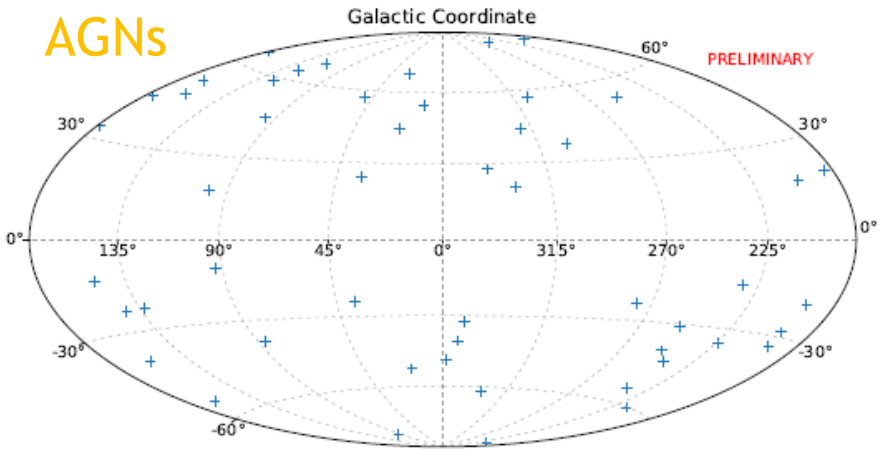


Charge measurements

Status: direction

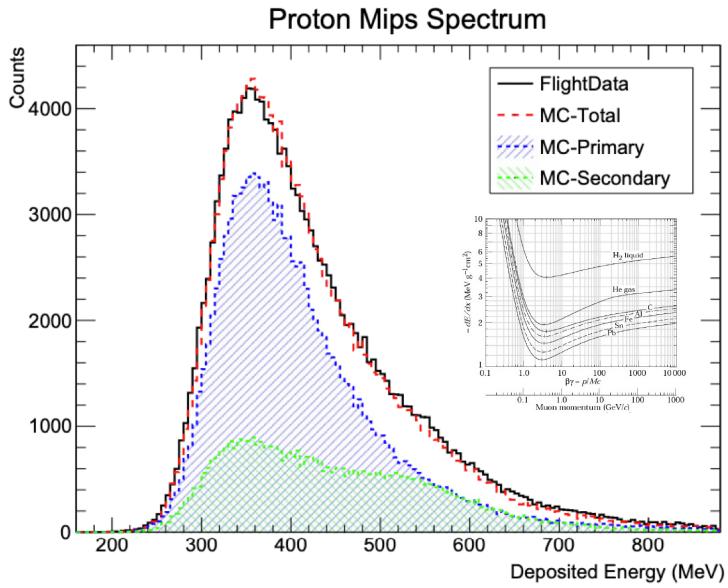




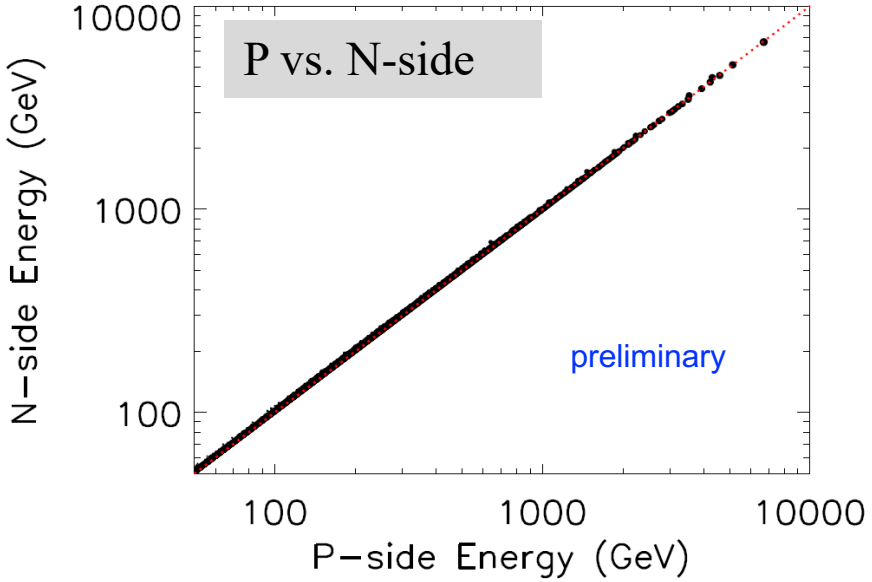


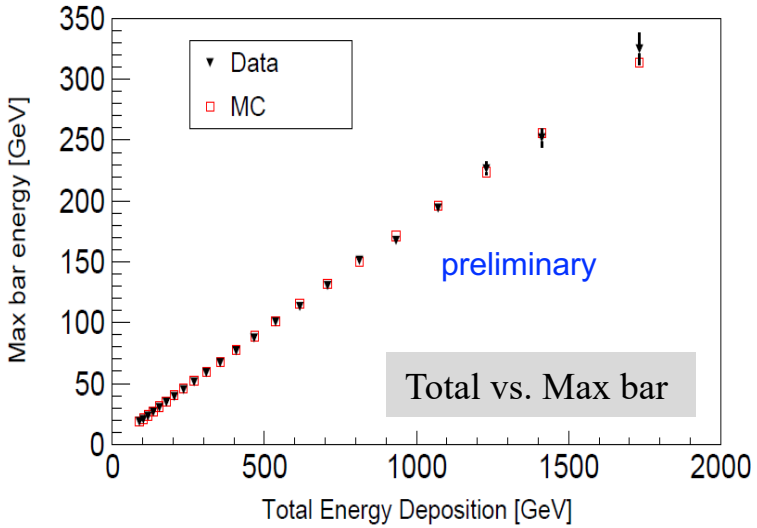
Angular resolution calibrated with photons from pulsars and stacked AGNs gives ~0.5 degrees @ 5 GeV

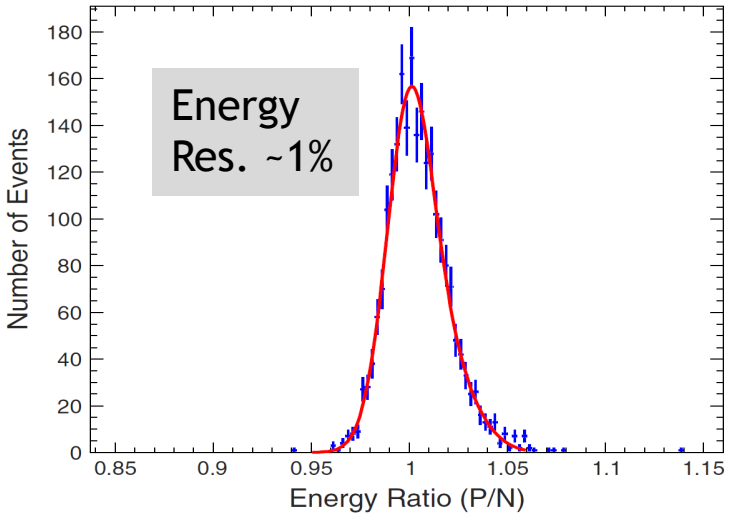
Status: energy



NIMA, 856, 11 (2017)

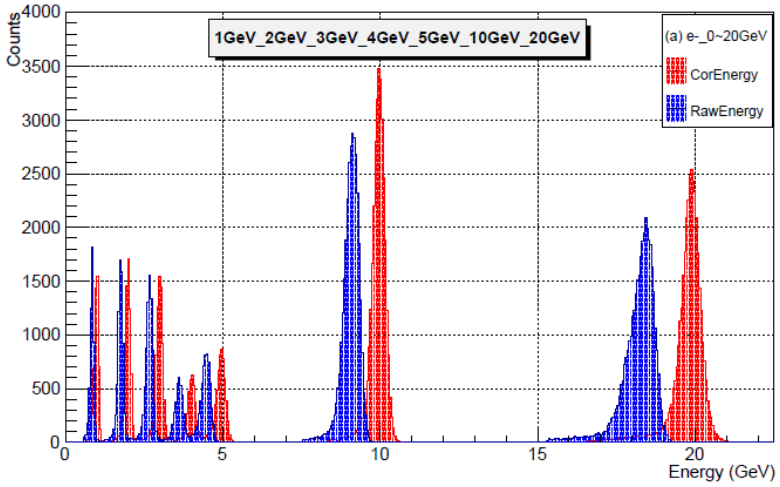


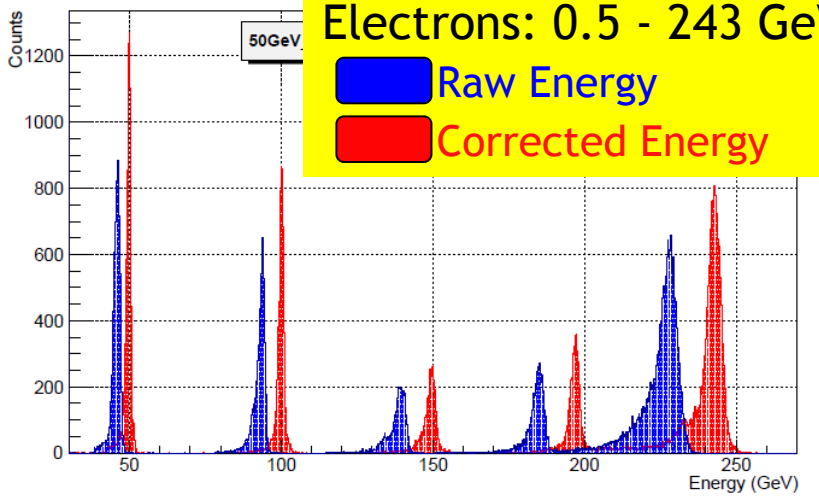




Nature, 552, 63 (2017)

Test beam validation of energy measurement

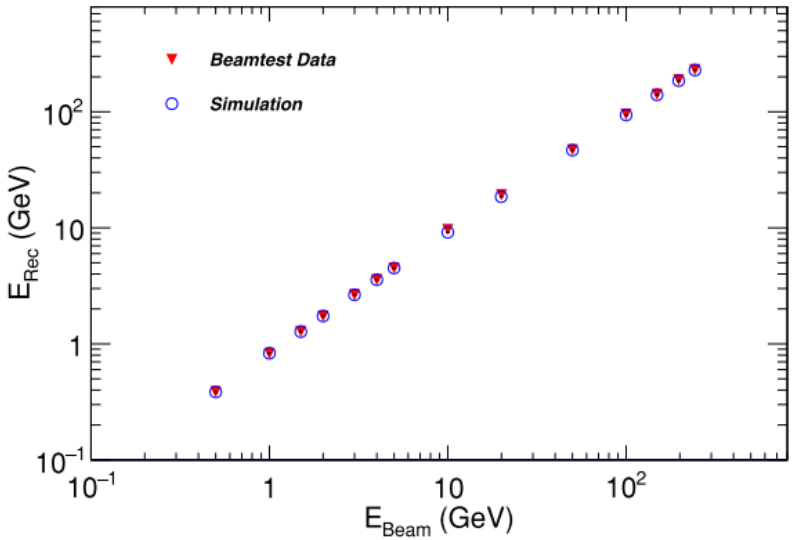


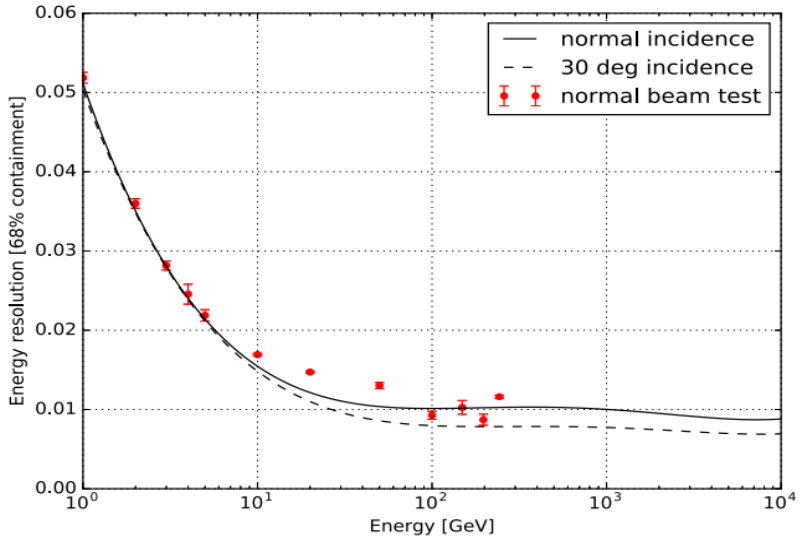


Electrons: 0.5 - 243 GeV

Raw Energy

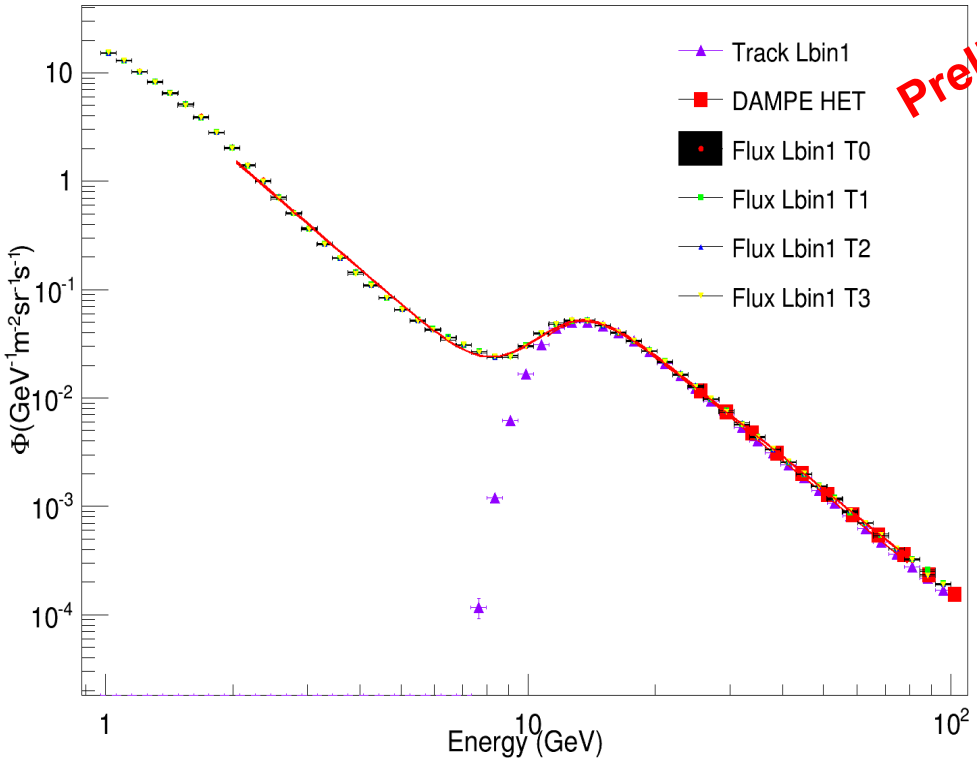
Corrected Energy

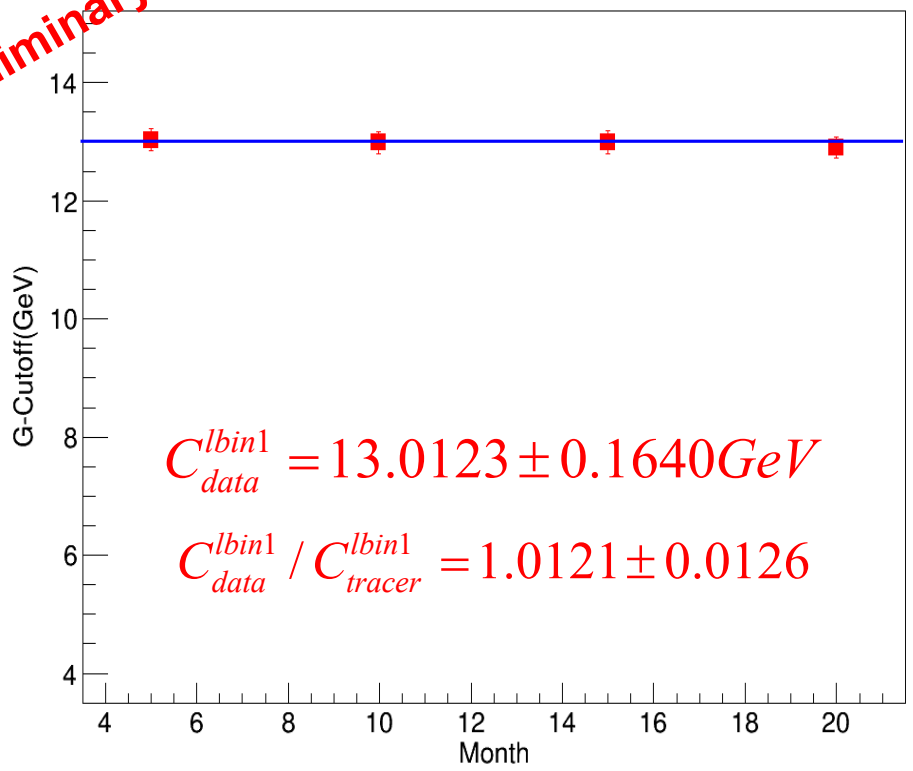




Astropart. Phys., 95, 6 (2017)

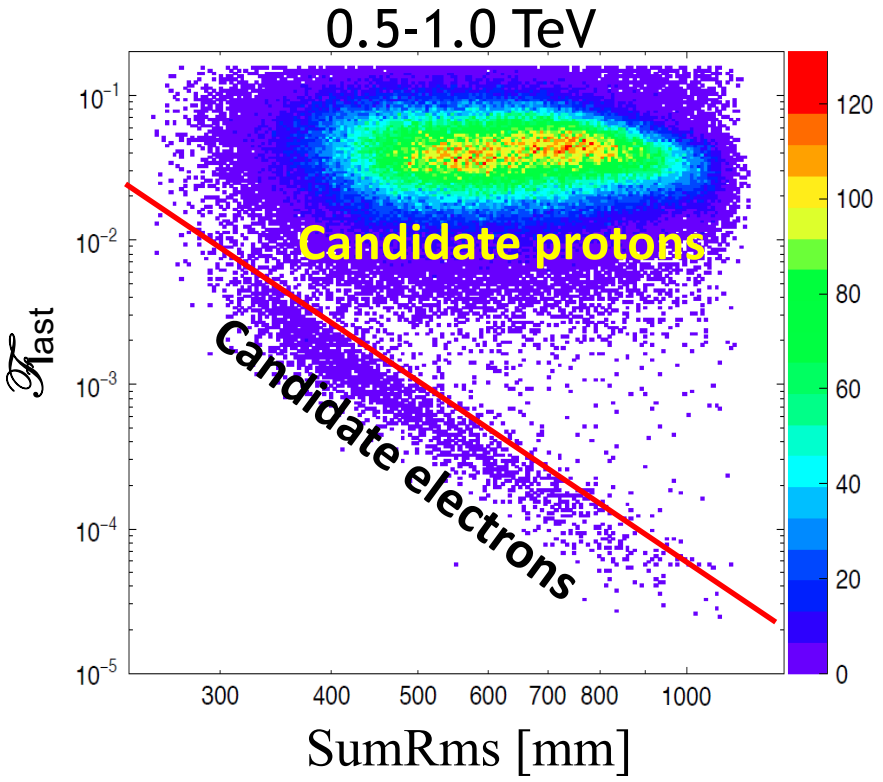
Absolute energy scale

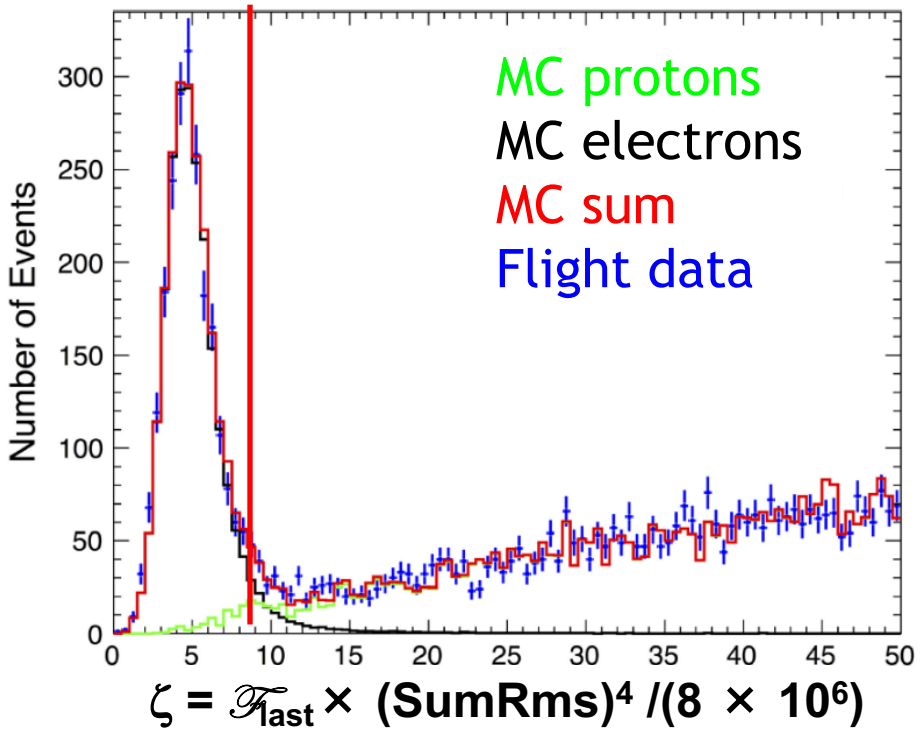




- An energy scale higher by (1.2+/-1.3)% from the geomagnetic cutoff
- Cutoff energy is stable with time (a slight decrease due to solar modulation)

Performance: particle ID

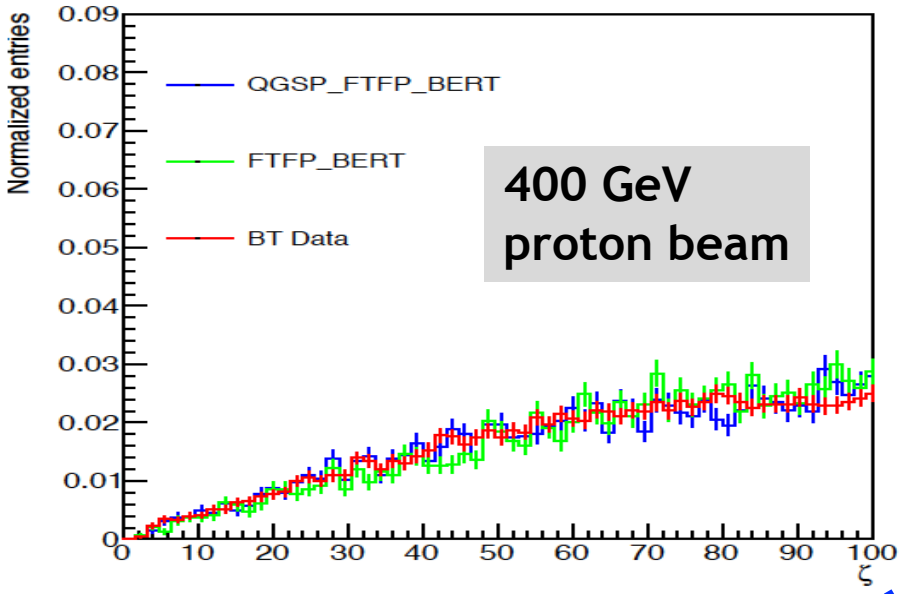


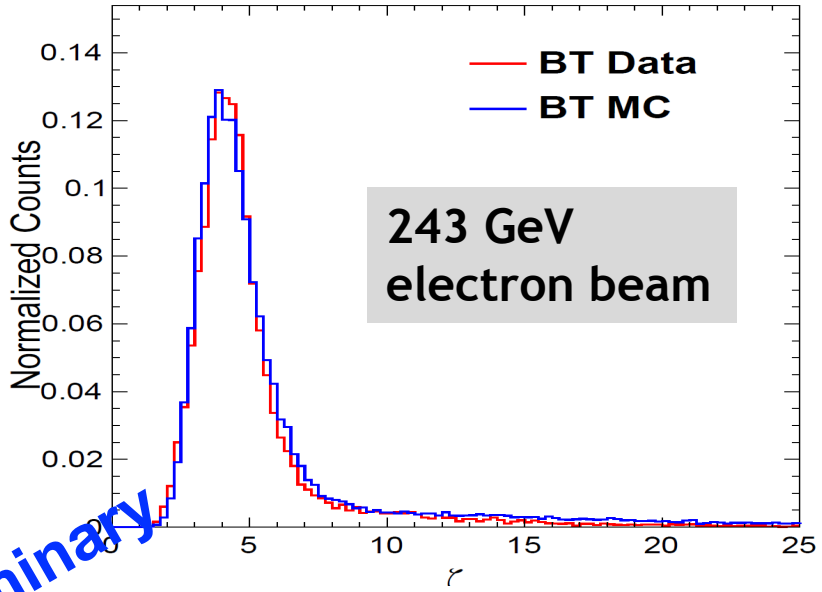


- DAMPE uses lateral (SumRMS) and longitudinal (energy ratio in last layer) developments of showers to discriminate electrons from protons
- For 90% electron efficiency, proton background is ~2% @ TeV, ~5% @ 2 TeV, ~10% @ 5 TeV

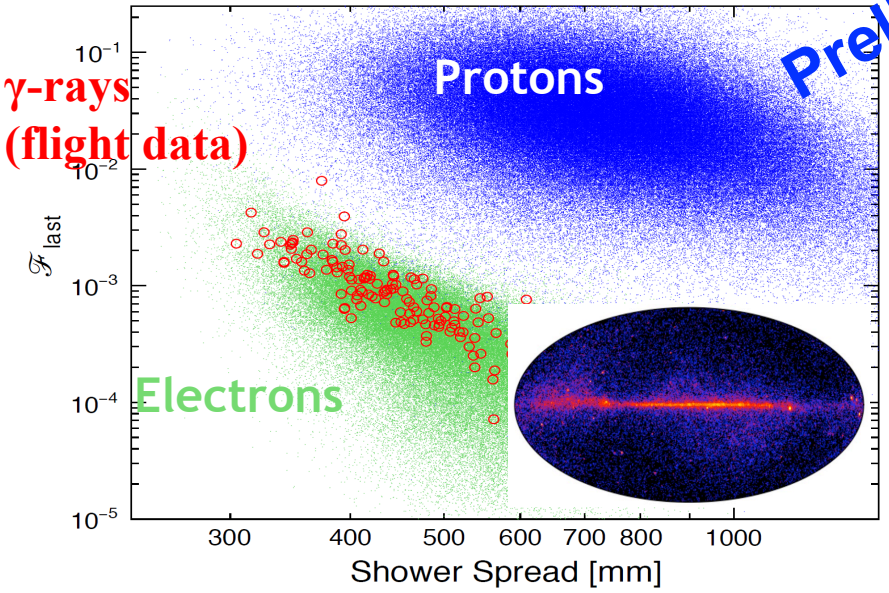
Nature, 552, 63 (2017)

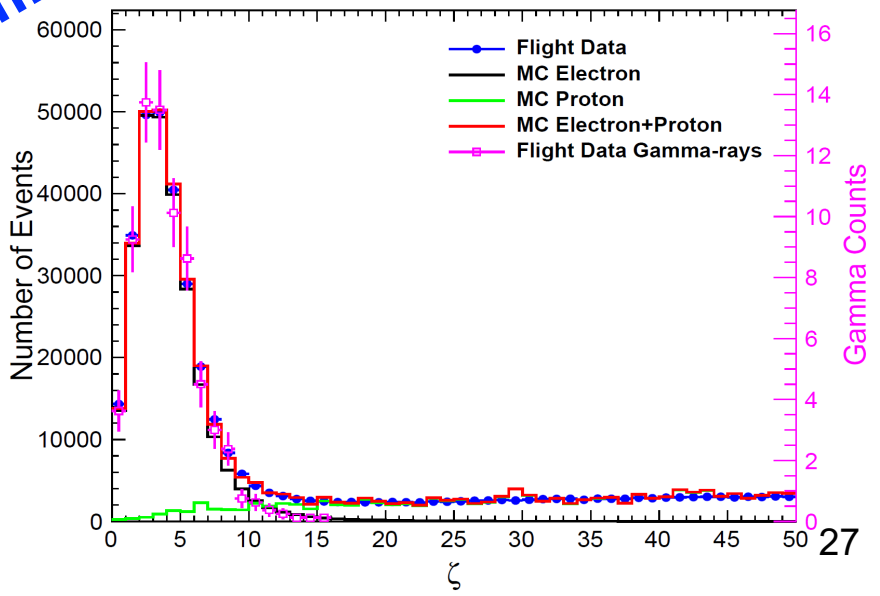
Validation of particle ID





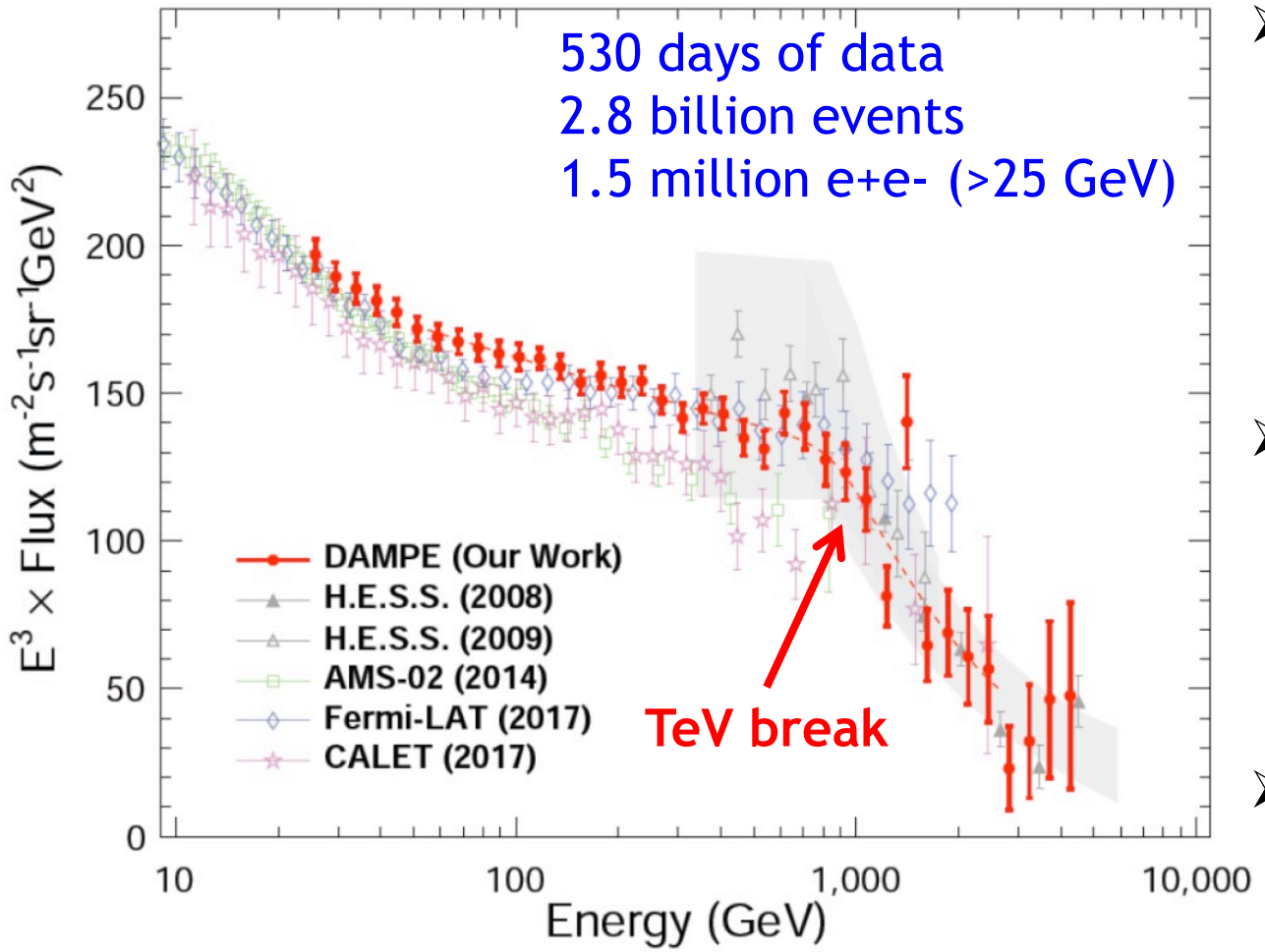
Preliminary





Physical Results

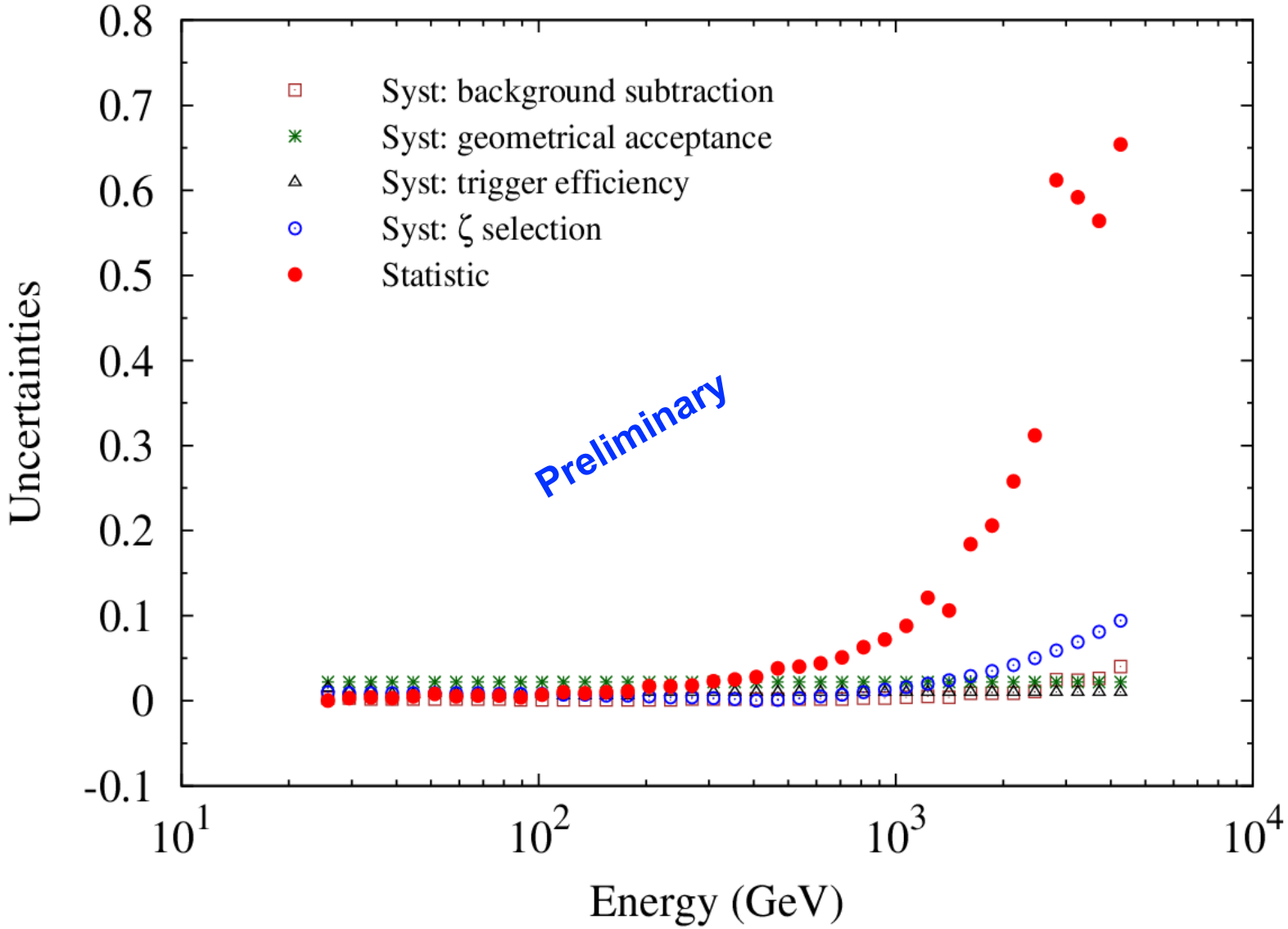
Results: $e^+ + e^-$ spectrum



- Three different PID methods give very consistent results on event-by-event level
- Direct detection of a spectral break at ~1 TeV with 6.6σ confidence level
- Analysis with new data is on-going

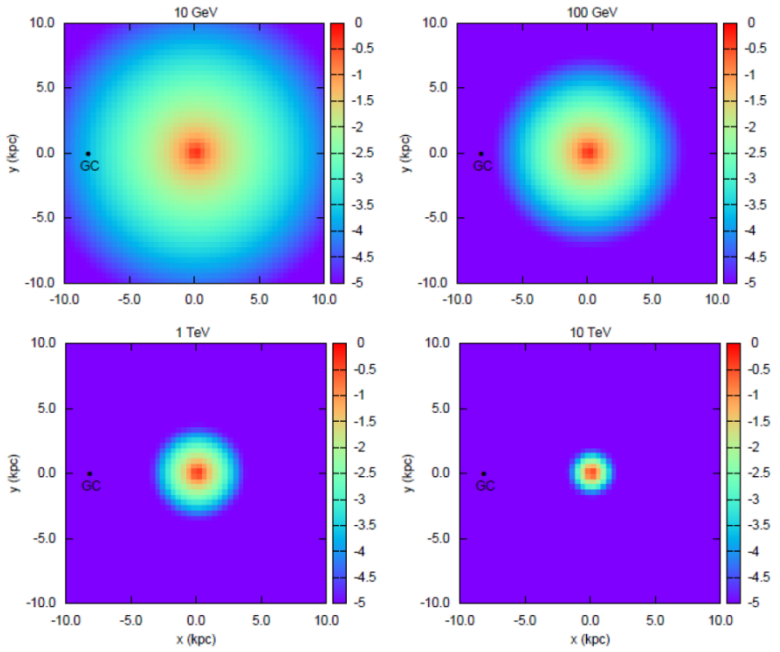
Nature, 552, 63 (2017)

Errors of $e^+ + e^-$ spectrum

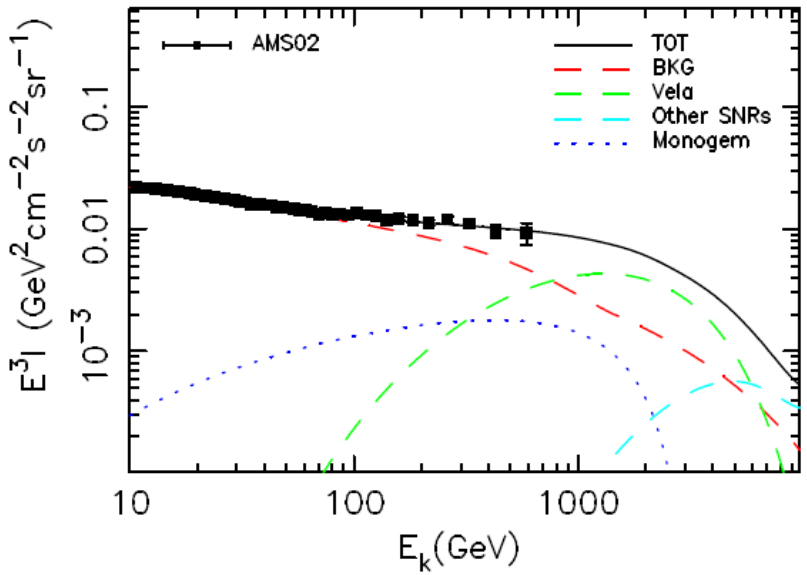


Implication of the spectral softening: discreteness of source distributions?

- Cooling time of TeV electrons ~ Myr, effective propagation range ~ kpc
- Assuming a total SN rate of 0.01 per year, the total number of SNRs within the effective volume and cooling time is O(10)



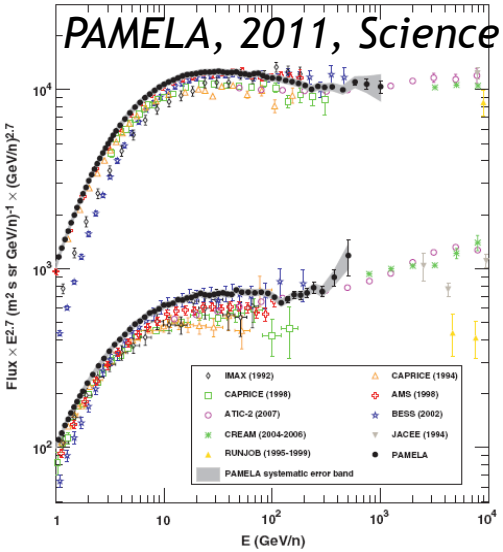
Astrophys. J., 836, 172 (2017)



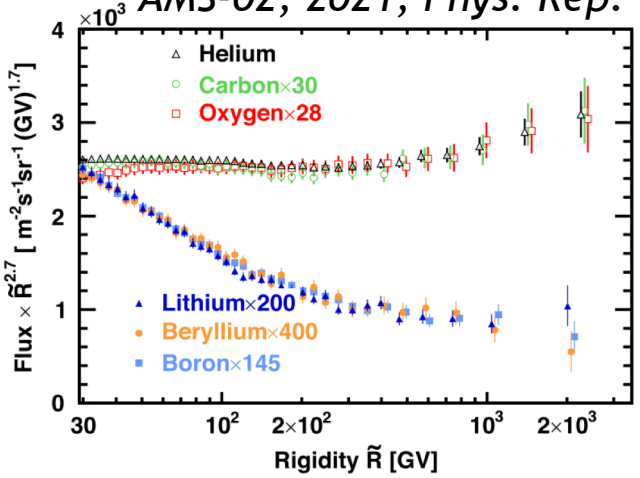
Fang et al. (2017)
Di Mauro et al. (2017)
Manconi et al. (2019)
.....

Spectral structures of nuclei

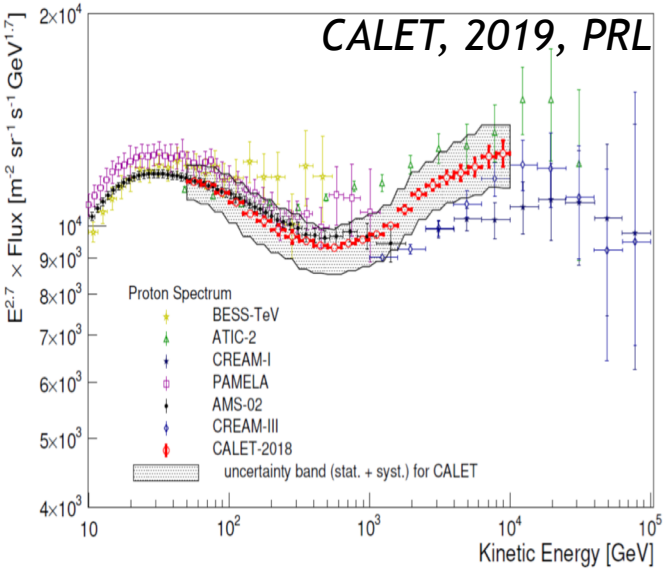
PAMELA, 2011, Science



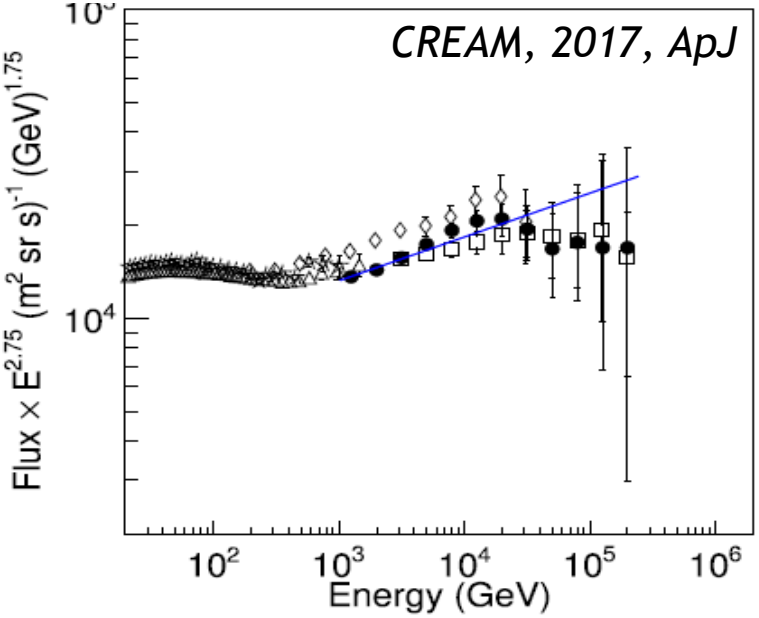
AMS-02, 2021, Phys. Rep.



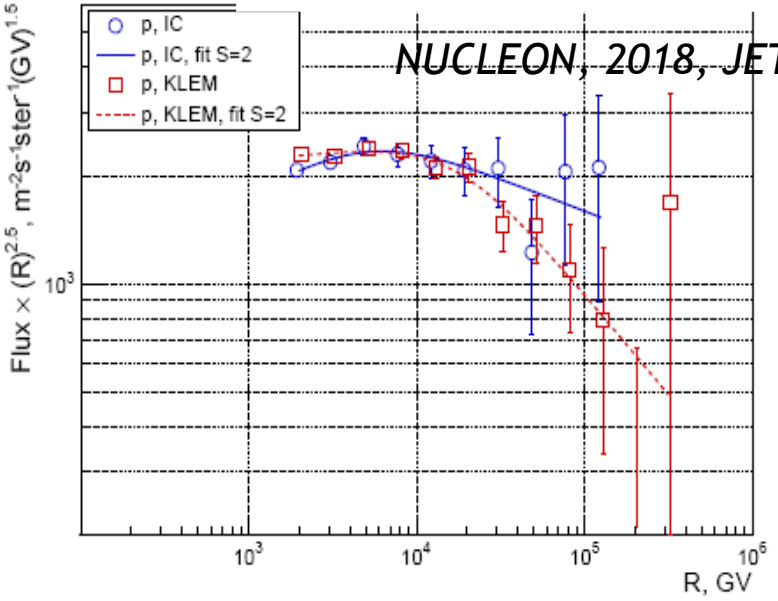
CALET, 2019, PRL



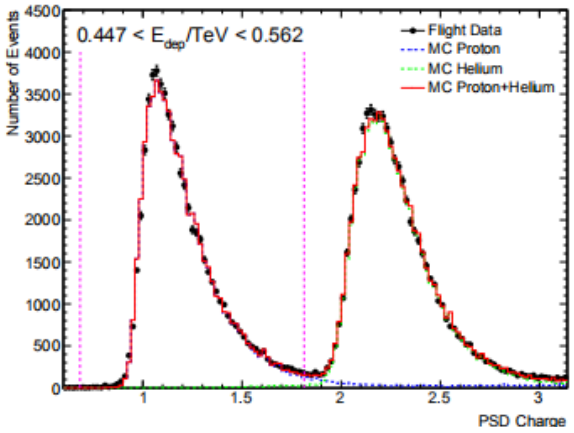
CREAM, 2017, ApJ

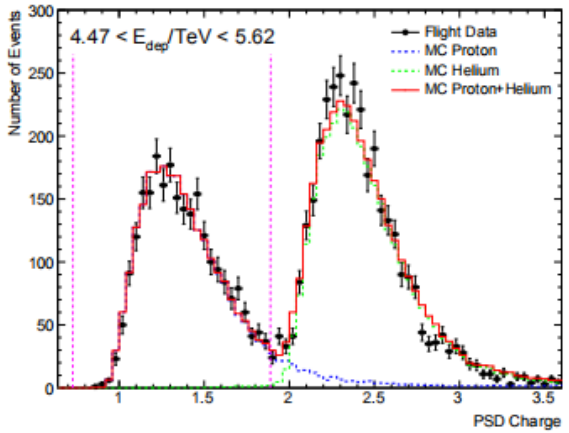


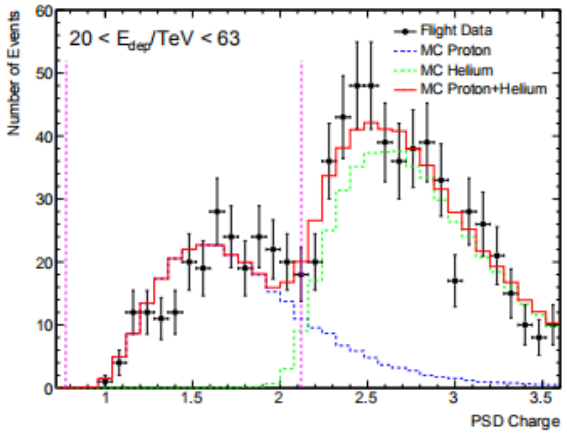
NUCLEON, 2018, JETPL

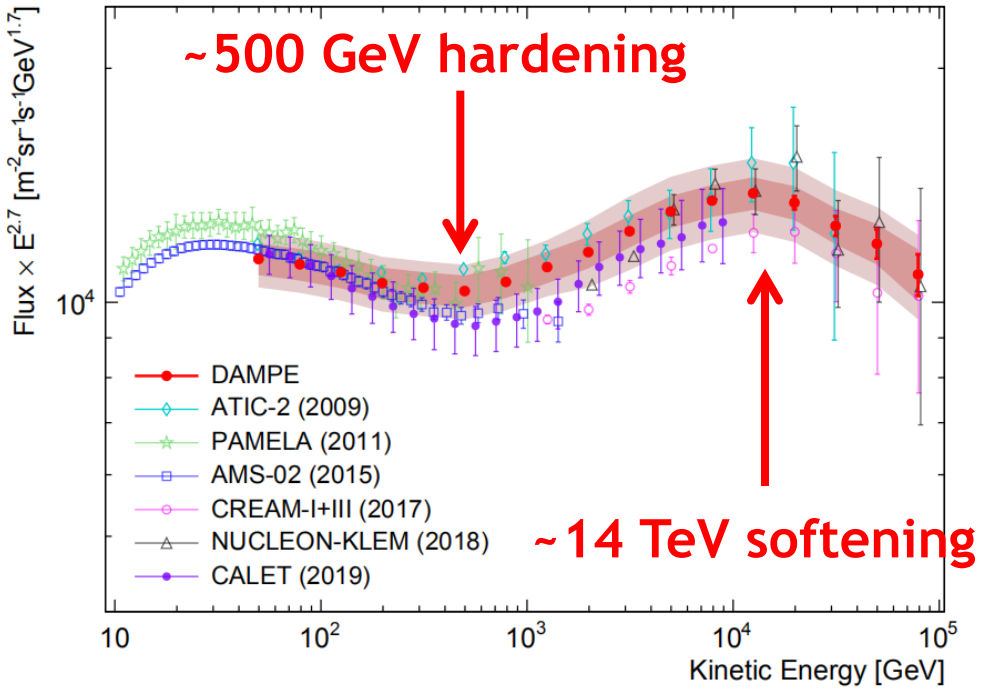


Results: proton spectrum





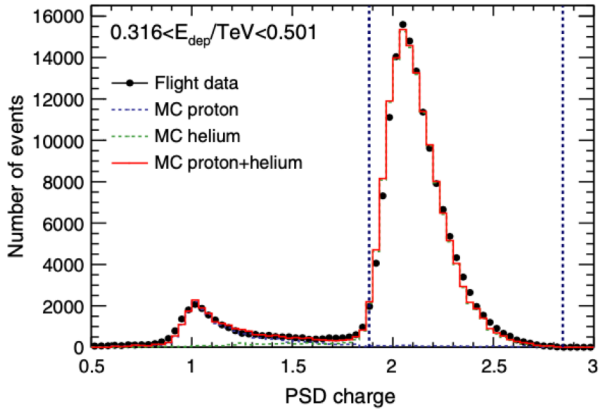


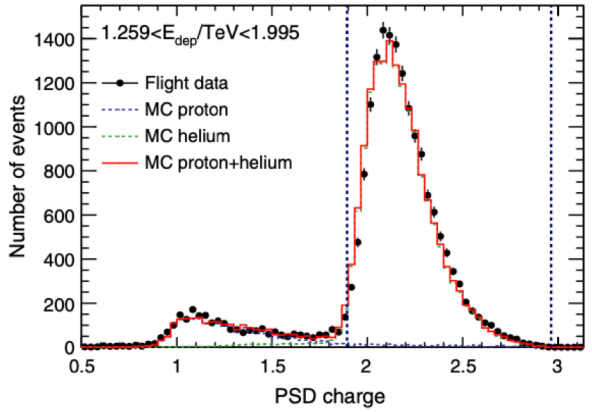


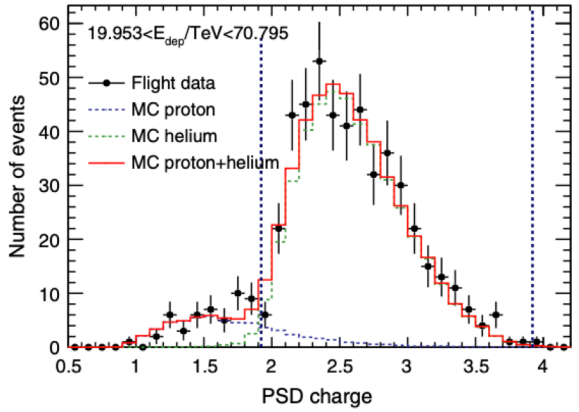
- Confirms the hundreds of GeV hardening
- Detecting a softening at ~14 TeV with high significance

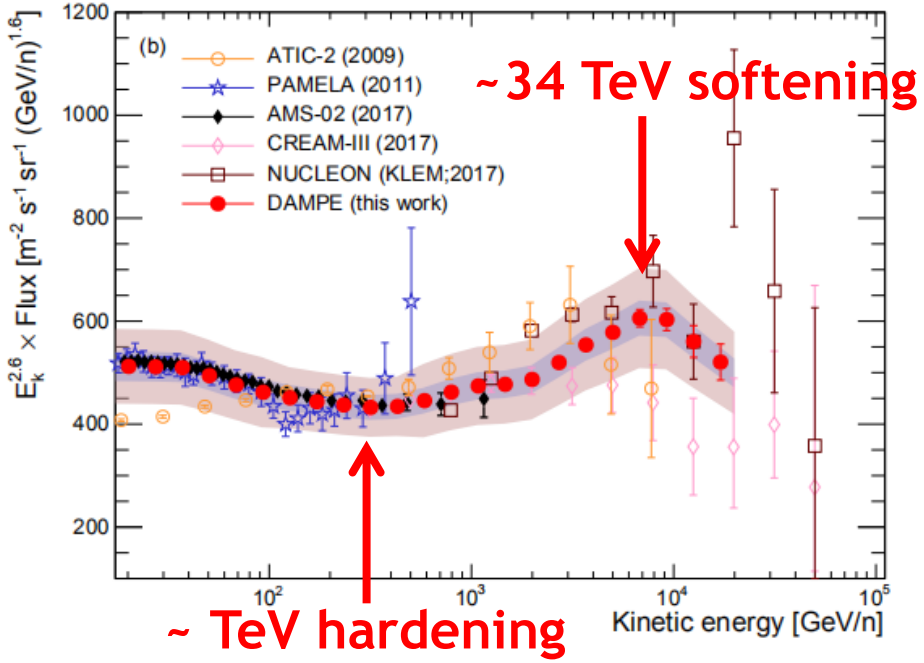
Science Advances, 5, eaax3793 (2019)

Results: helium spectrum







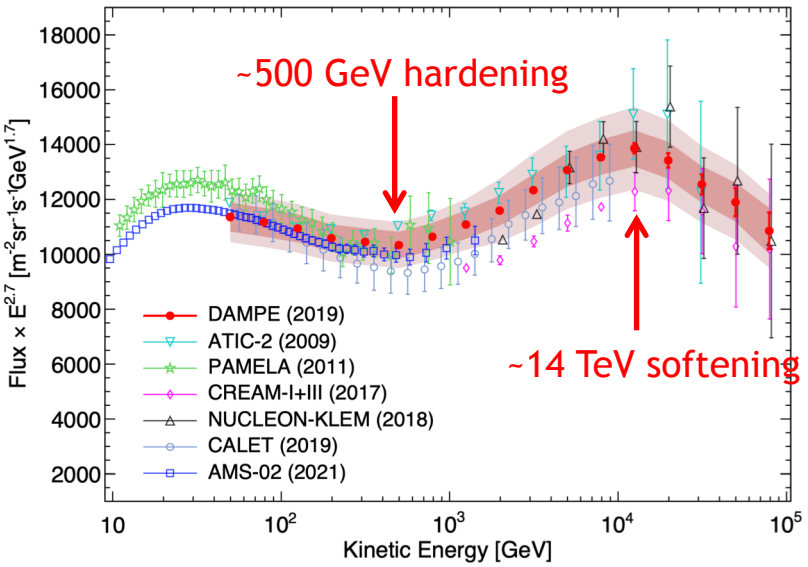


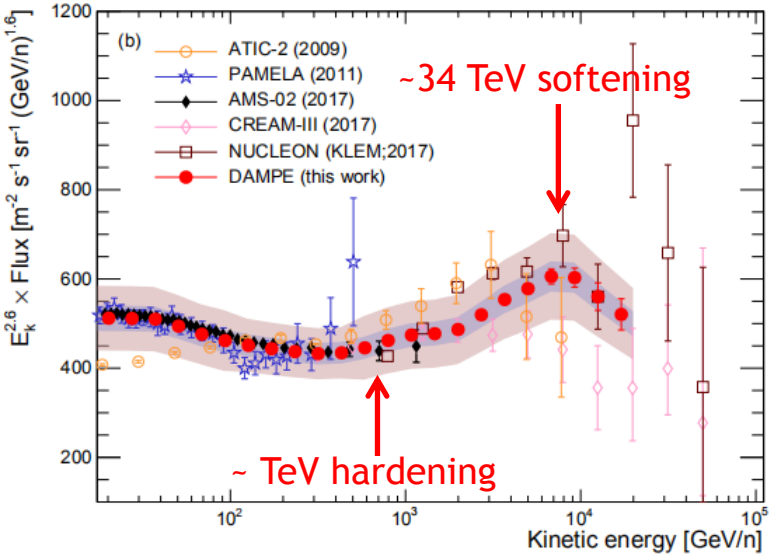
- Confirms the ~TeV hardening
- Detecting a softening at ~34 TeV with high significance

See talk #895

Phys. Rev. Lett., 126, 201102.(2021)

Softening: proton vs helium

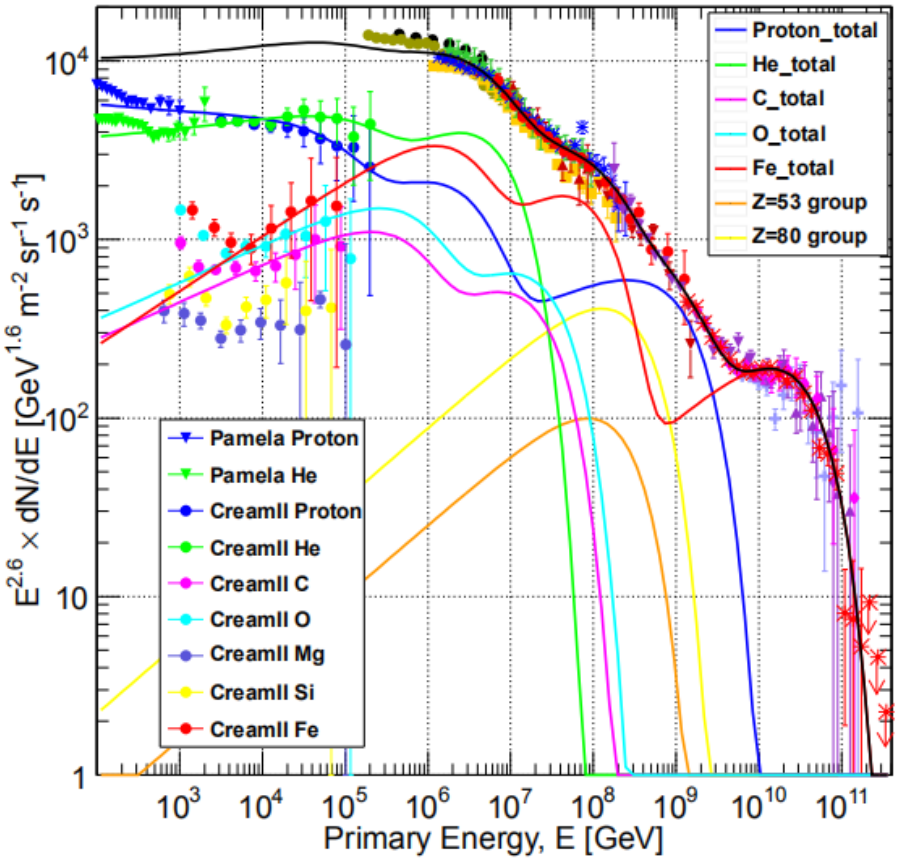




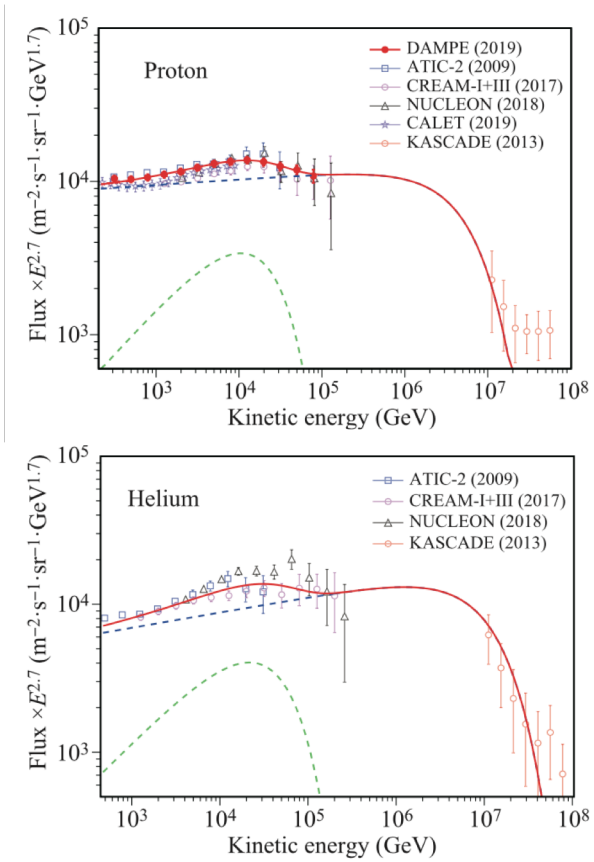
- Proton: A softening at $14^{+4.1}_{-4.8}$ TeV
- Helium: A softening at $34^{+6.7}_{-9.8}$ TeV
- A Z-dependent softening point

Implications: source population(?) Nearby source(?)

Gaisser et al. (2013)

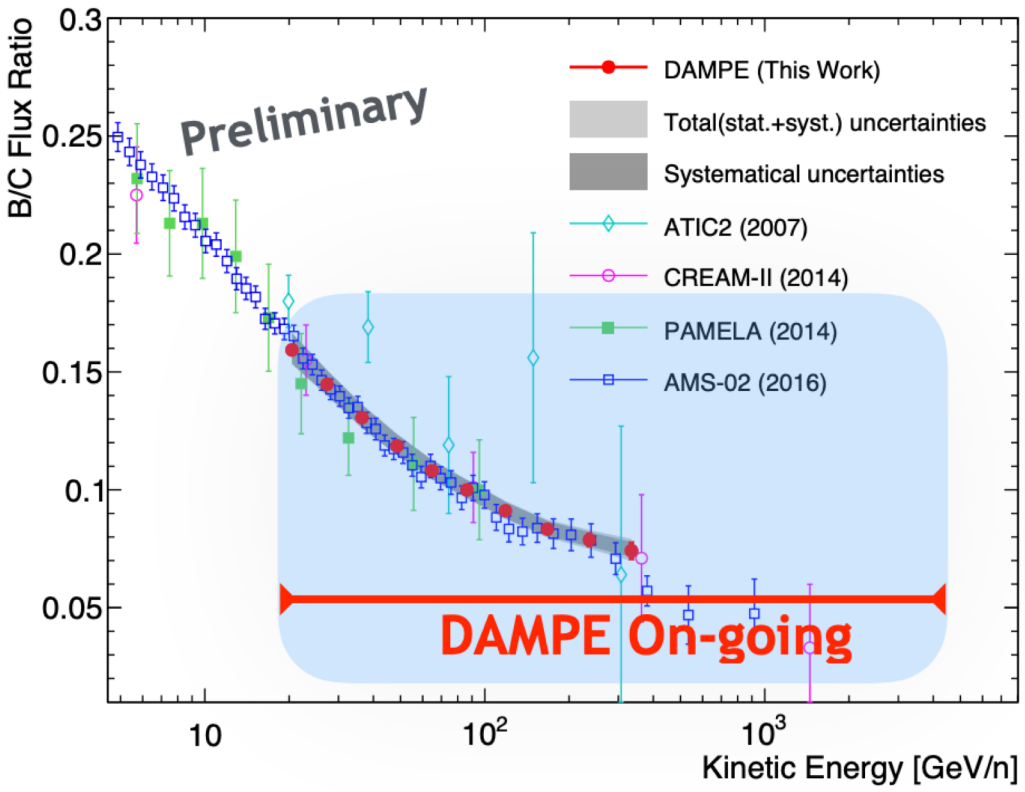


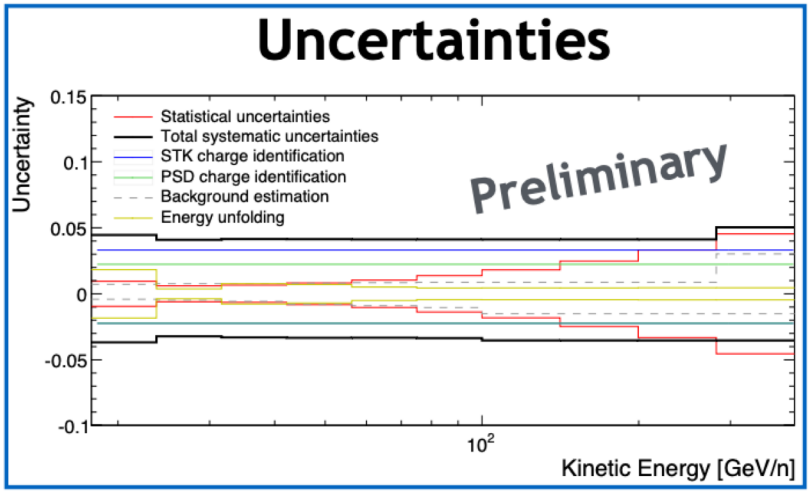
Yue et al. (2020)



Liu et al., 1812.09673
Malkov et al., 2105.04630
.....

Results: B/C flux ratio

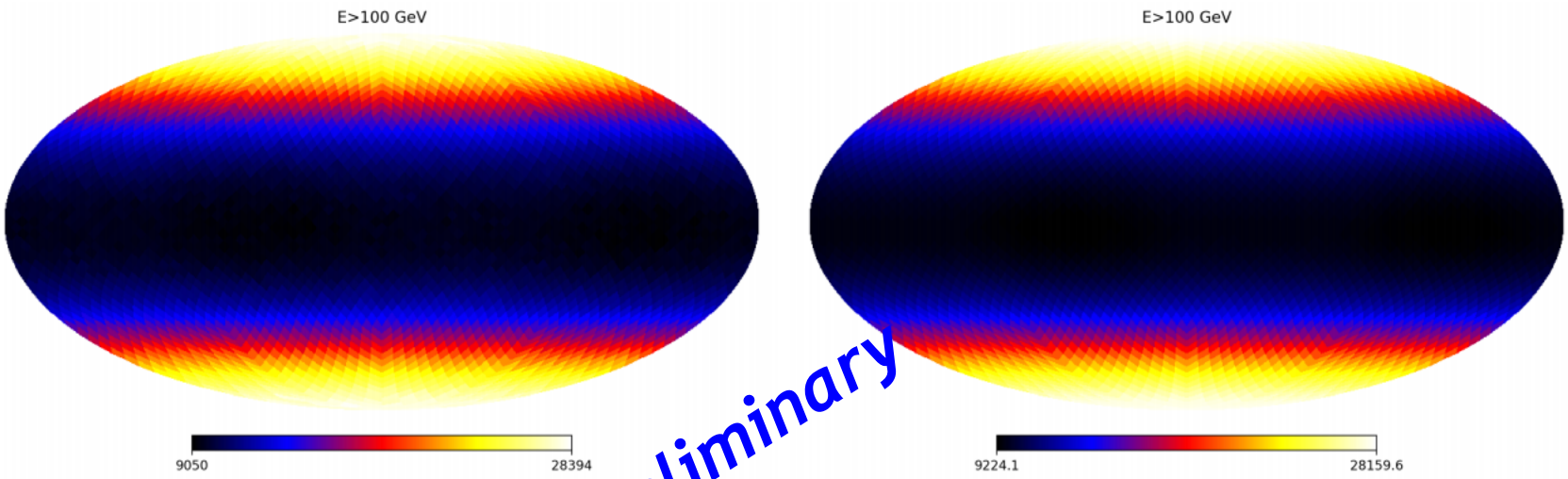




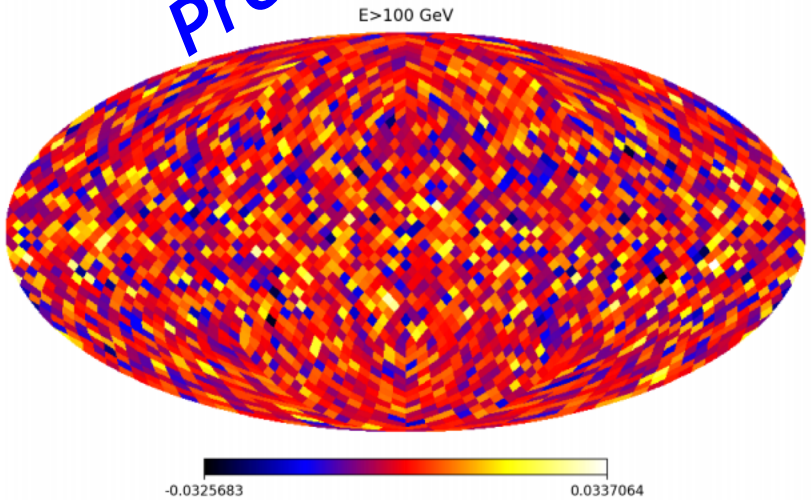
- Preliminary result of B/C flux ratio from 20GeV/n to 400GeV/n has been obtained.
- DAMPE measurement is well consistent with PAMELA and AMS-02 within uncertainties

See talk #1089

Results: cosmic ray anisotropies



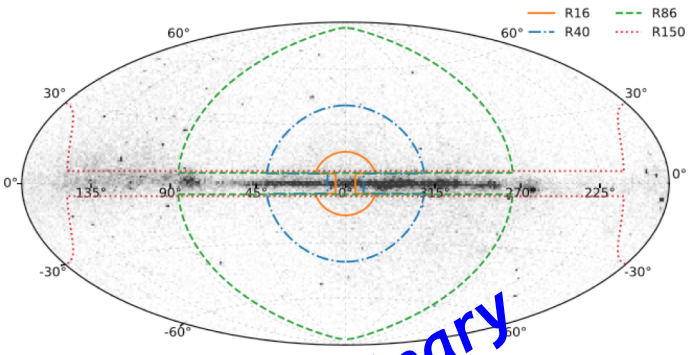
Preliminary

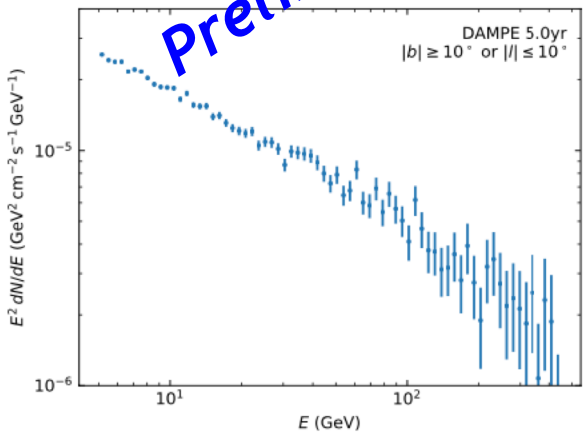


95% UL of dipole amplitude for 5-yr data (>~100 GeV): 1.2×10^{-3}

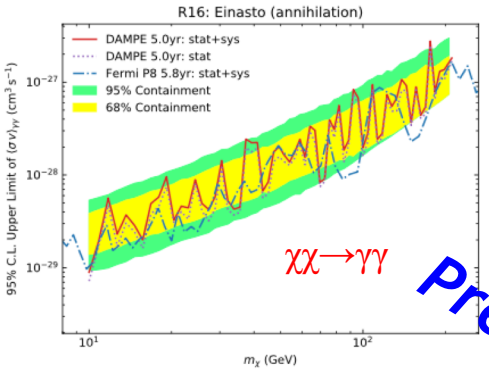
See poster #1087

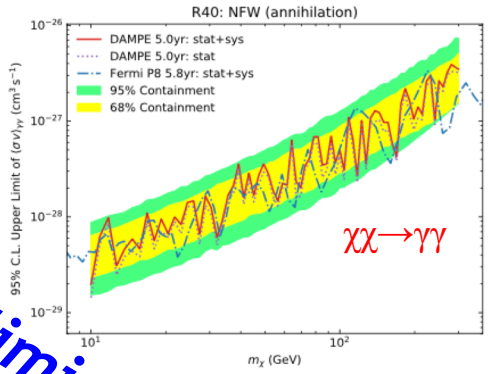
Results: γ-ray line searches



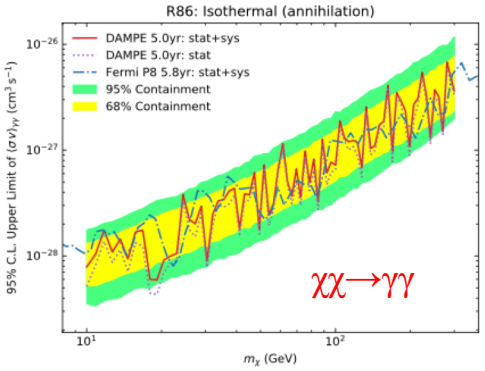


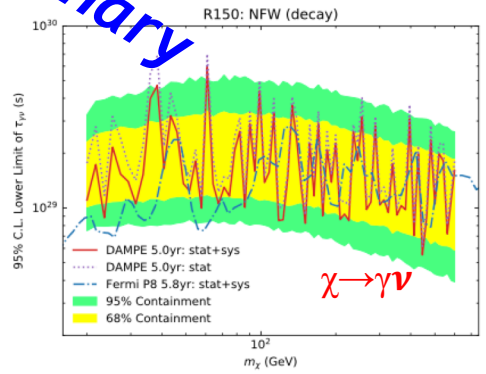
Preliminary





Preliminary

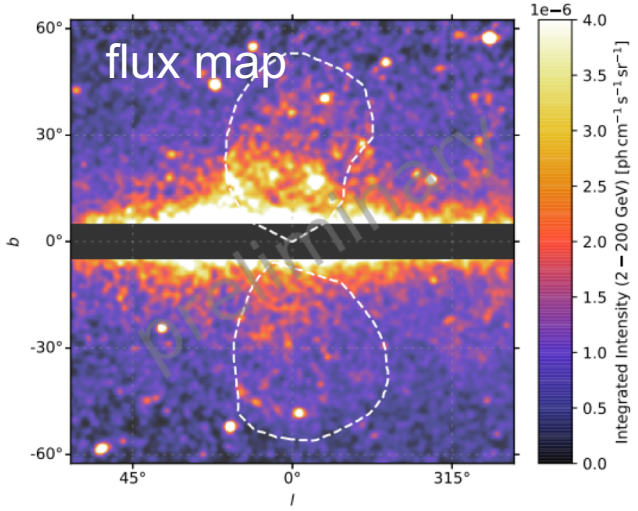


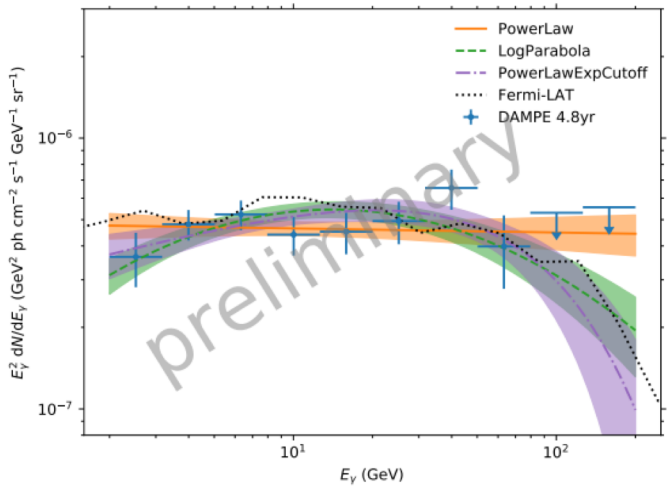


See talk #891

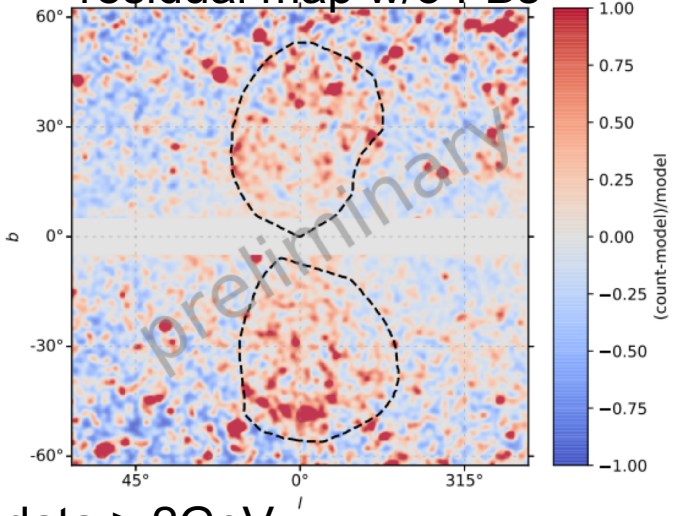
Obtain the most stringent upper limits on dark matter annihilation cross section or decay lifetime

Results: Fermi bubbles

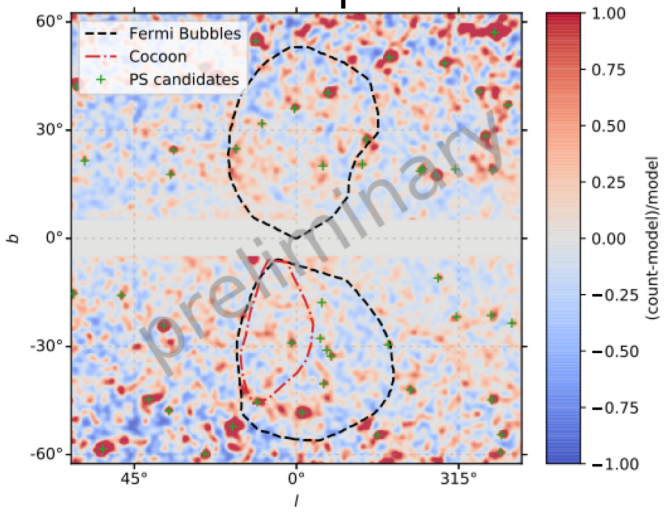




residual map w/o FBs



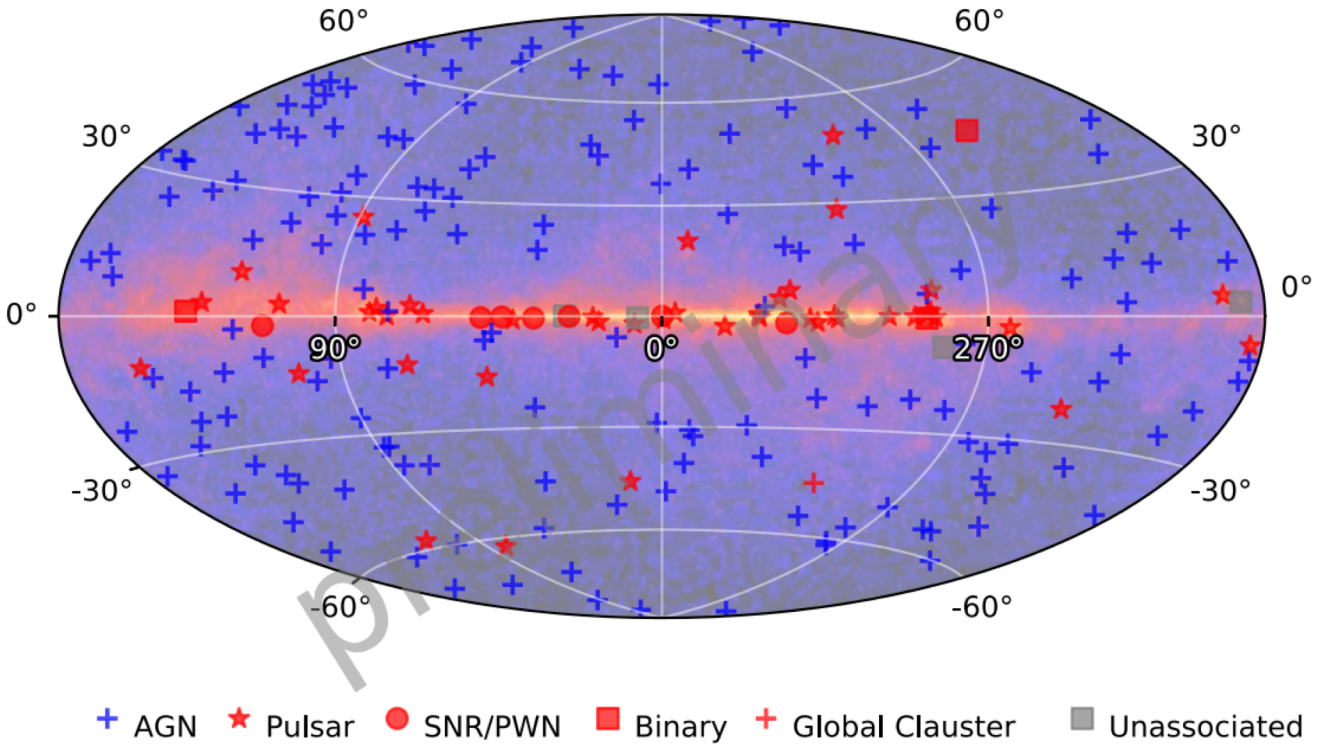
residual map w/ FBs



4.8-yr data > 2GeV

See poster #1101

Results: γ-ray catalog

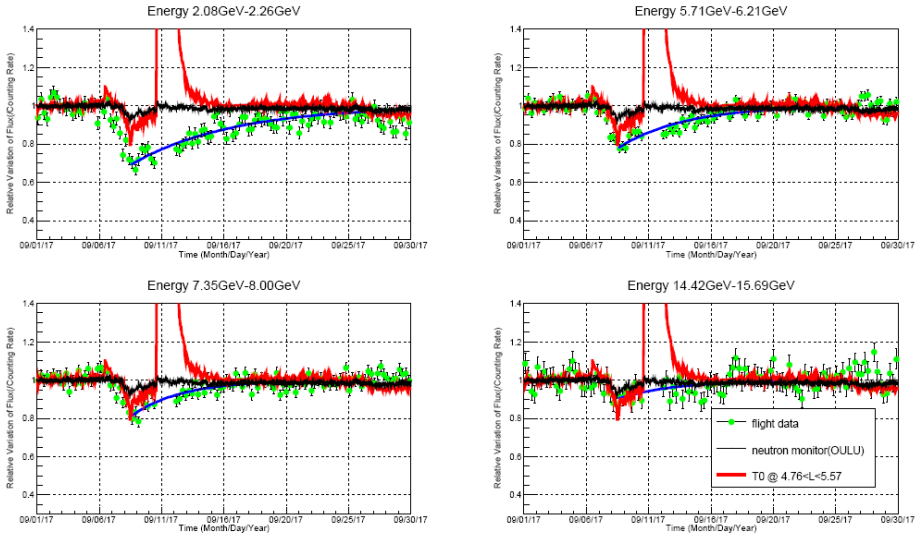


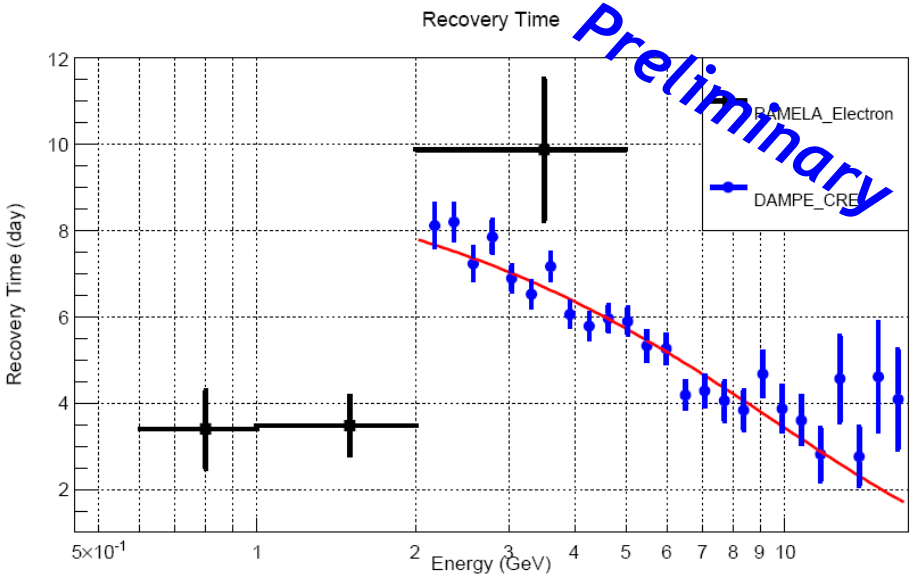
AGN	Pulsar	SNR and/or PWN	Binary	Globular Cluster	Unassociated	Total
163	44	7	3	1	4	222

5-yr data > 2GeV

See poster #875

Results: Forbush decrease





- DAMPE observed the Forbush decrease (FD) of cosmic ray e+e- with high precision
- Reveal new features of the recovery time

DAMPE contributions at ICRC2021

Highlight

#1175: Recent status and results of the Dark Matter Particle Explorer

Oral talks

#891: Search for gamma-ray lines in the Galaxy with DAMPE

#895: Cosmic ray helium spectrum measured by the DAMPE experiment

#903: Direct Measurement of the Cosmic-Ray Iron Spectrum with the Dark Matter Particle Explorer

#970: Measurement of the light component (p+He) energy spectrum with the DAMPE space mission

#1089: Measurement of the Boron to Carbon Flux Ratio in Cosmic Rays with the DAMPE Experiment

#1136: Measurement of carbon and oxygen fluxes in cosmic rays with the DAMPE experiment

Posters

#855: Charge measurement of cosmic rays by Plastic Scintillator Detector of DAMPE

#875: Observations of gamma-ray sources with DAMPE

#982: Machine learning methods for helium flux analysis with DAMPE experiment

#1087: Studies of cosmic ray anisotropies with DAMPE

#1101: Analyzing the Fermi Bubbles with DAMPE

#1125: On-orbit performance of the DAMPE BGO calorimeter

#1127: Simulation of the DAMPE detector

#1150: Charge Loss Correction in the Silicon-Tungsten Tracker-Converter for Proton-Helium Charge Identification in the DAMPE Detector

#1156: Searching for fractionally charged particles based on DAMPE

#1184: Performance of the DAMPE silicon-tungsten tracker during the first 5 years of in-orbit operation

Summary

- DAMPE detector works smoothly for five years, opening a new window to look at the high-energy Universe above TeV
- Precise measurements of the e^++e^- spectrum show a break at ~TeV energies
- Precise measurements of proton (helium) spectra reveal interesting softening features at ~14 (34) TeV
- Stringent upper limits on dark matter annihilation/decay into monochromatic γ-rays have been obtained
- More results about cosmic ray nuclei and γ-rays are coming

Summary

- DAMPE detector works smoothly for five years, opening a new window to look at the high-energy Universe above TeV
- Precise measurements of the $e^+ + e^-$ spectrum show a break at ~TeV energies
- Precise measurements of proton (helium) spectra reveal interesting softening features at ~14 (34) TeV
- Stringent upper limits on dark matter annihilation/decay into monochromatic γ-rays have been obtained
- More results about cosmic ray nuclei and γ-rays are coming

Thank You!