Progresses of the Dark Matter Particle Explorer (DAMPE) experiment

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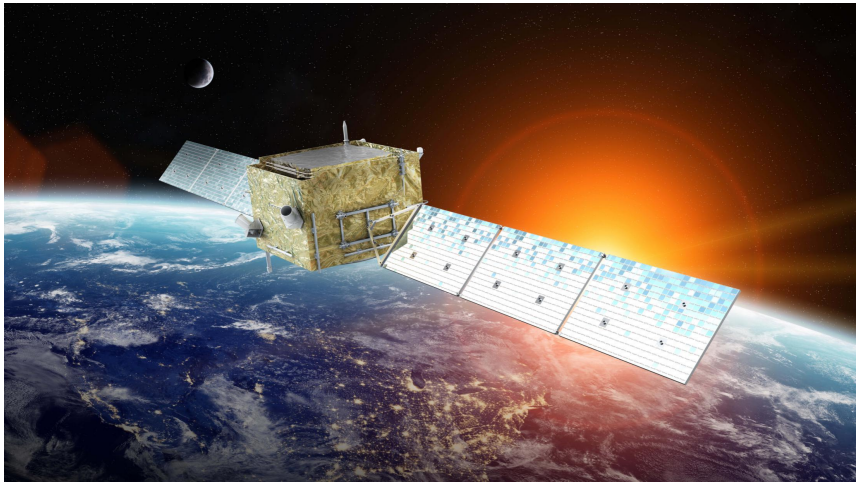
Purple Mountain Observatory

(on behalf of the DAMPE collaboration)

Jul. 24 - Aug.1, 2019, Madison, Wisconsin



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

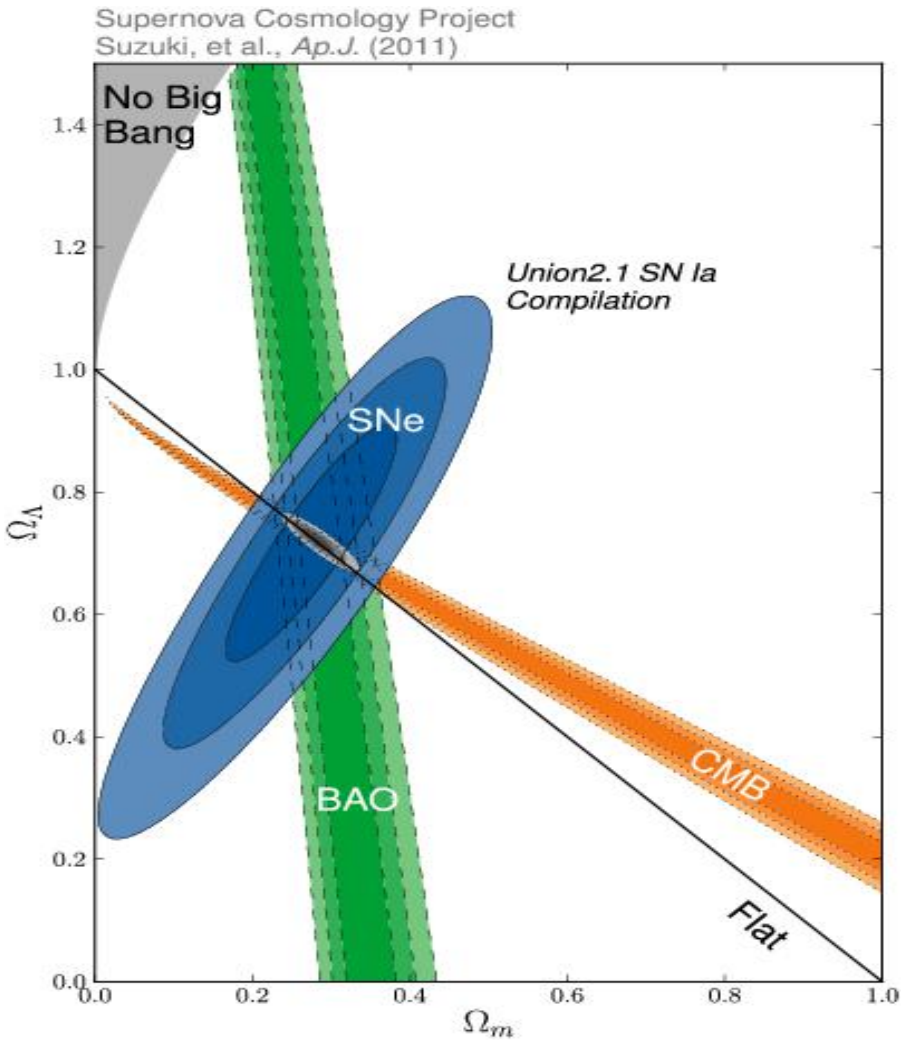
- ITALY
  - INFN Perugia and University of Perugia
  - INFN Bari and University of Bari
  - INFN Lecce and University of Salento
  - INFN LNGS and Gran Sasso Science Institute

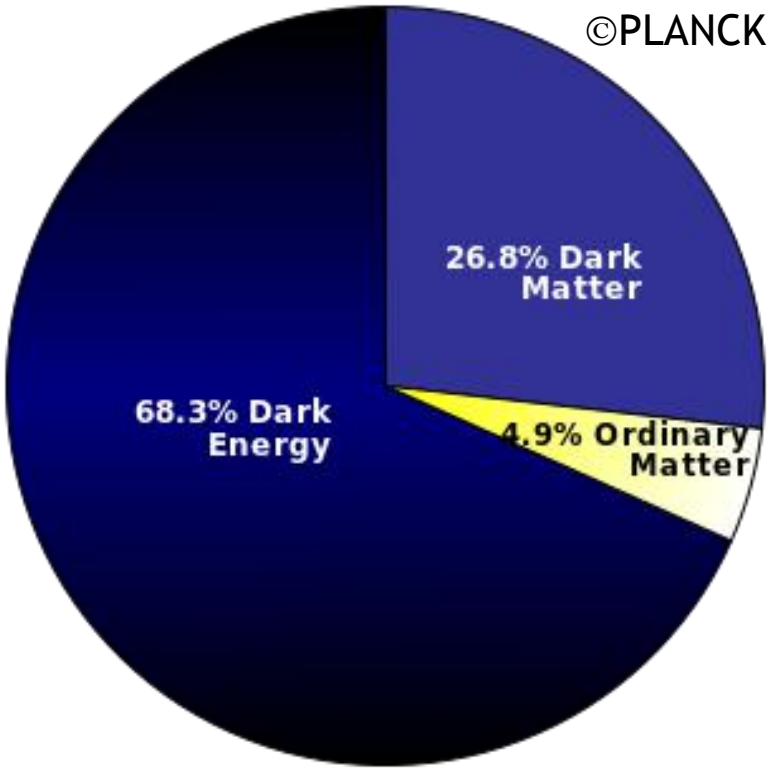
- SWITZERLAND
  - University of Geneva

Outline

- Introduction
- DAMPE instrument
- On-orbit performance
- Physical Results
- Summary

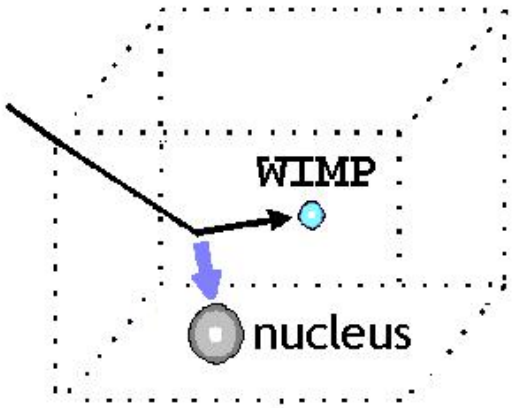
Composition of the Universe



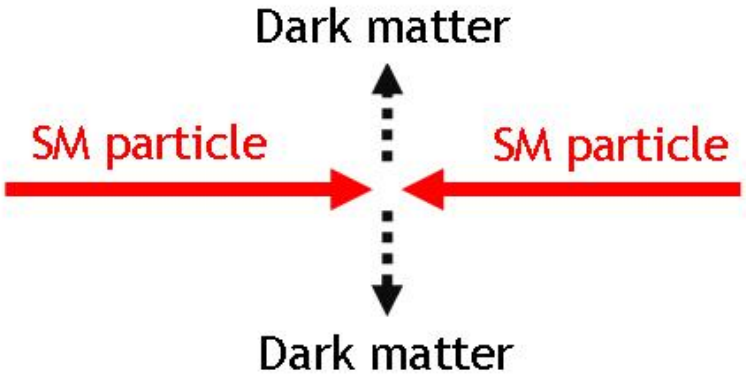


Detection of dark matter

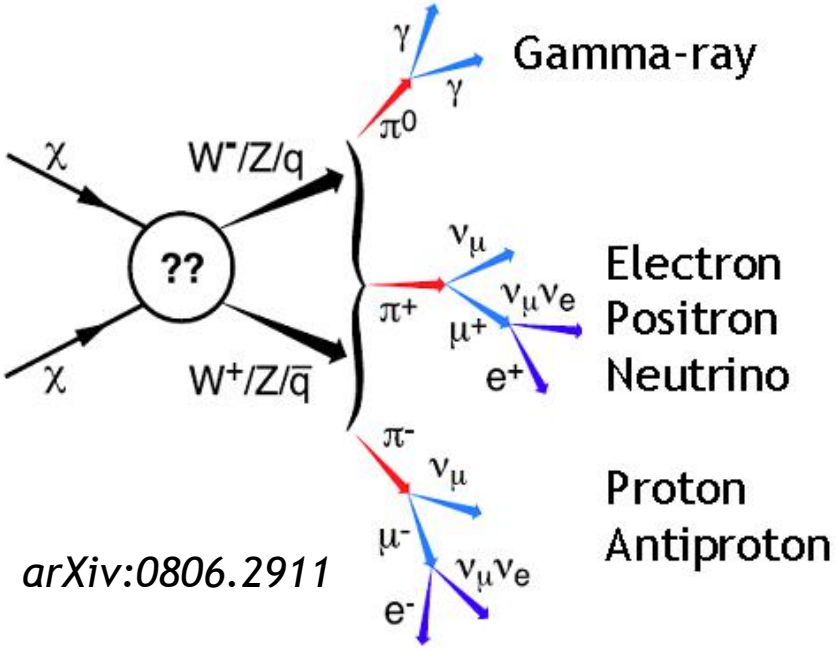
(a) Direct detection



(b) Collider detection

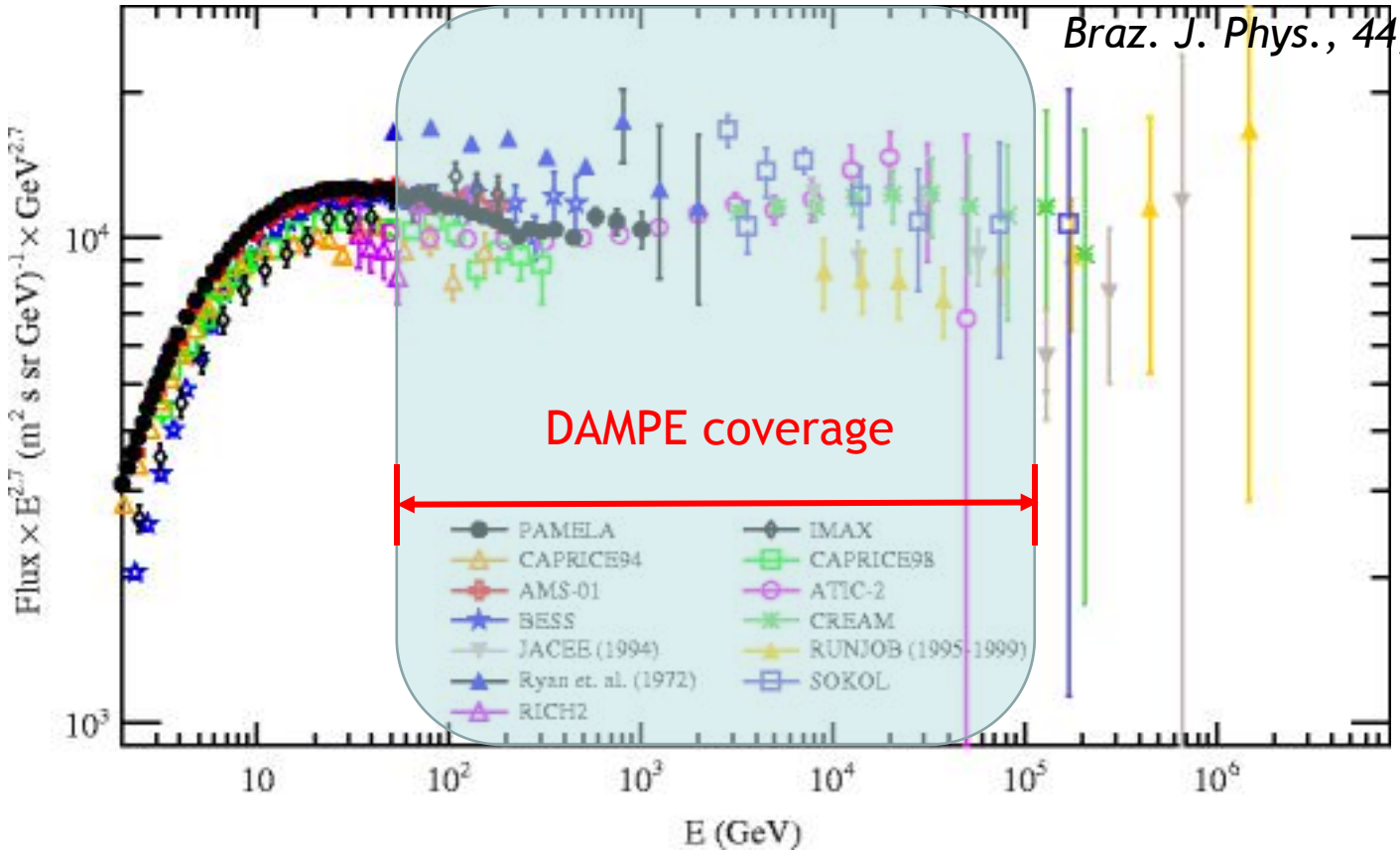


(c) Indirect detection



arXiv:0806.2911

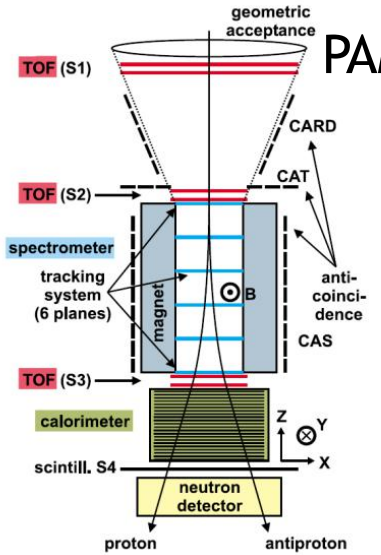
Cosmic rays

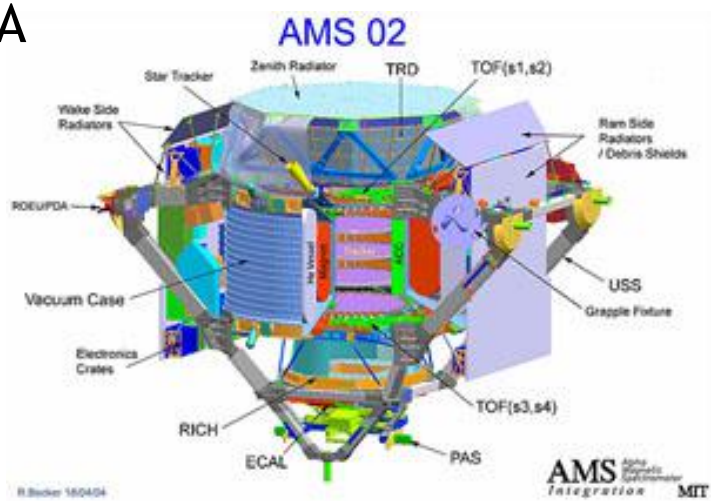


- Precision measurements of cosmic ray spectra: cosmic ray origin, acceleration, and propagation
- The spectra above TeV are not well measured due to limited statistics of direct detection experiments

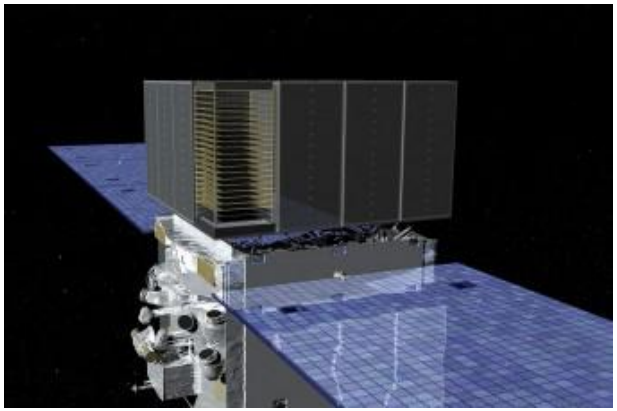
Recent space particle/γ detectors

PAMELA



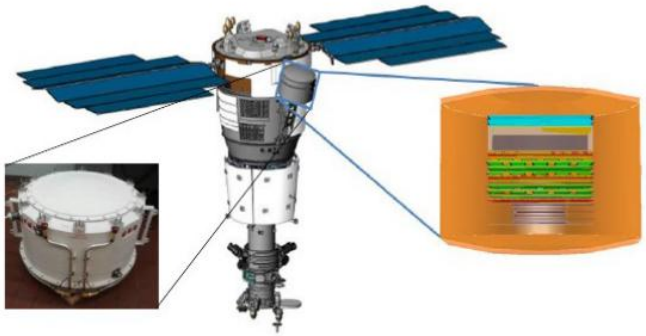


Fermi

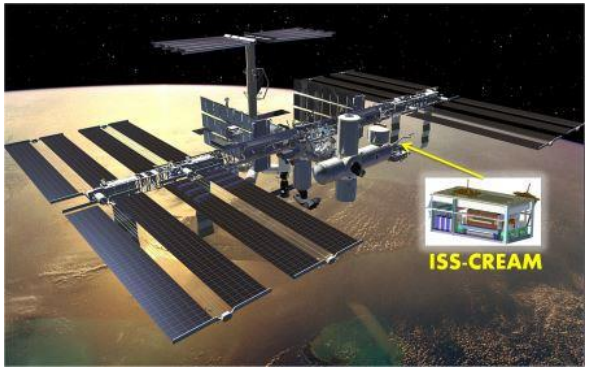


CALET

NUCLEON



ISS-CREAM



Dark Matter Particle Explorer (DAMPE)

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

Three major scientific goals

Cosmic ray physics

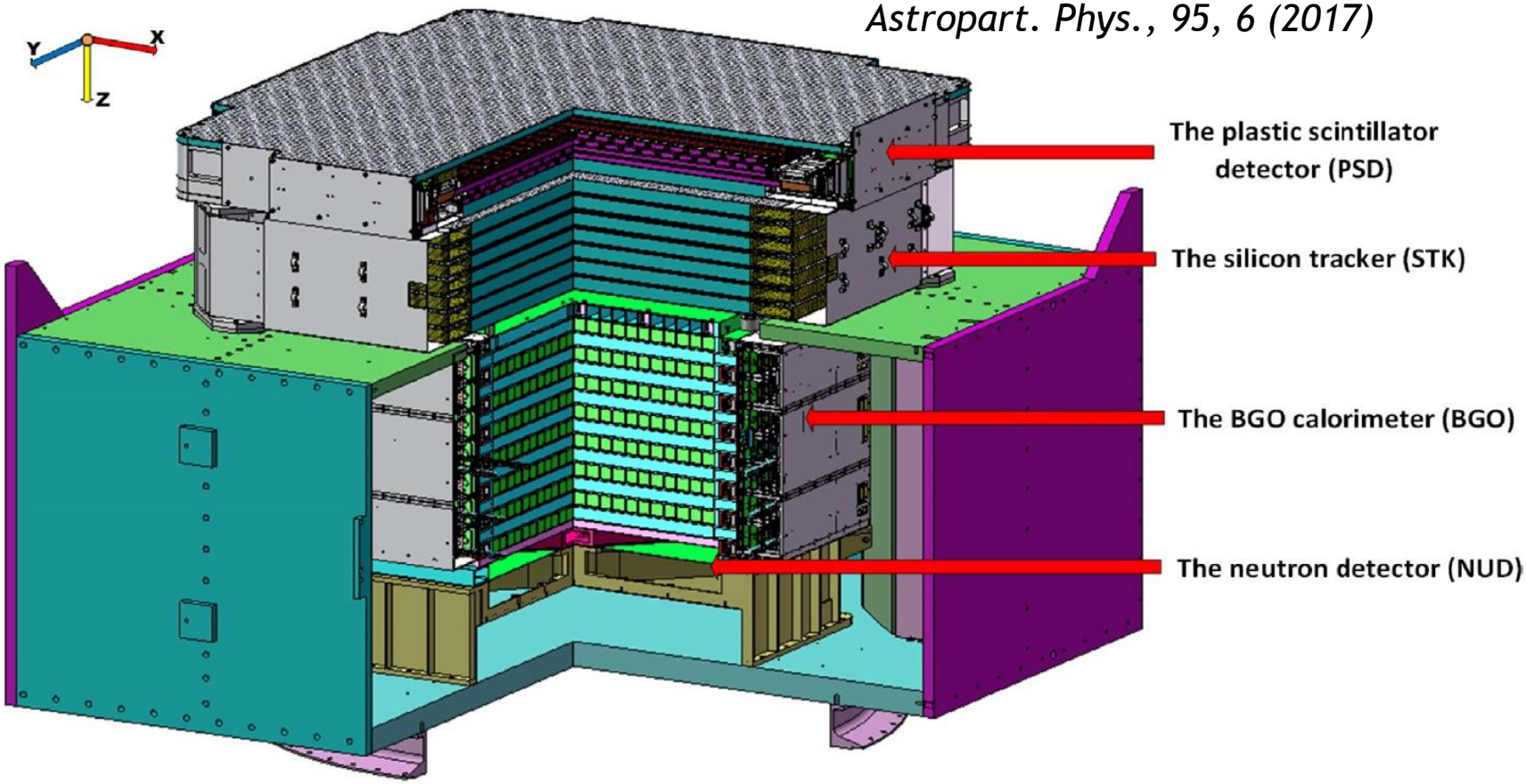
γ-ray astronomy

Dark matter indirect detection

DAMPE instrument

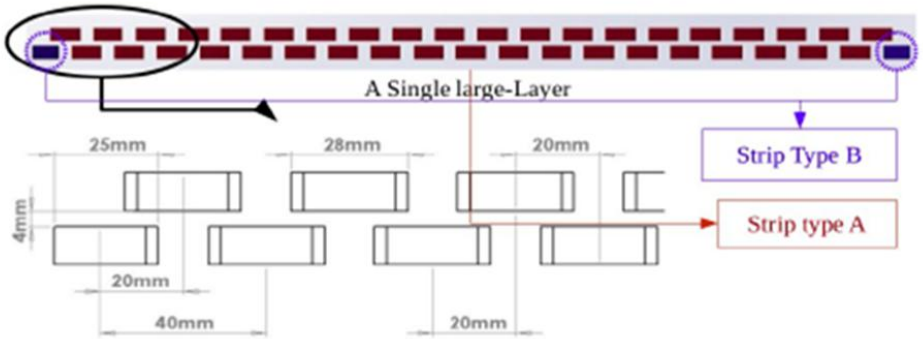
Instrument design

Astropart. Phys., 95, 6 (2017)



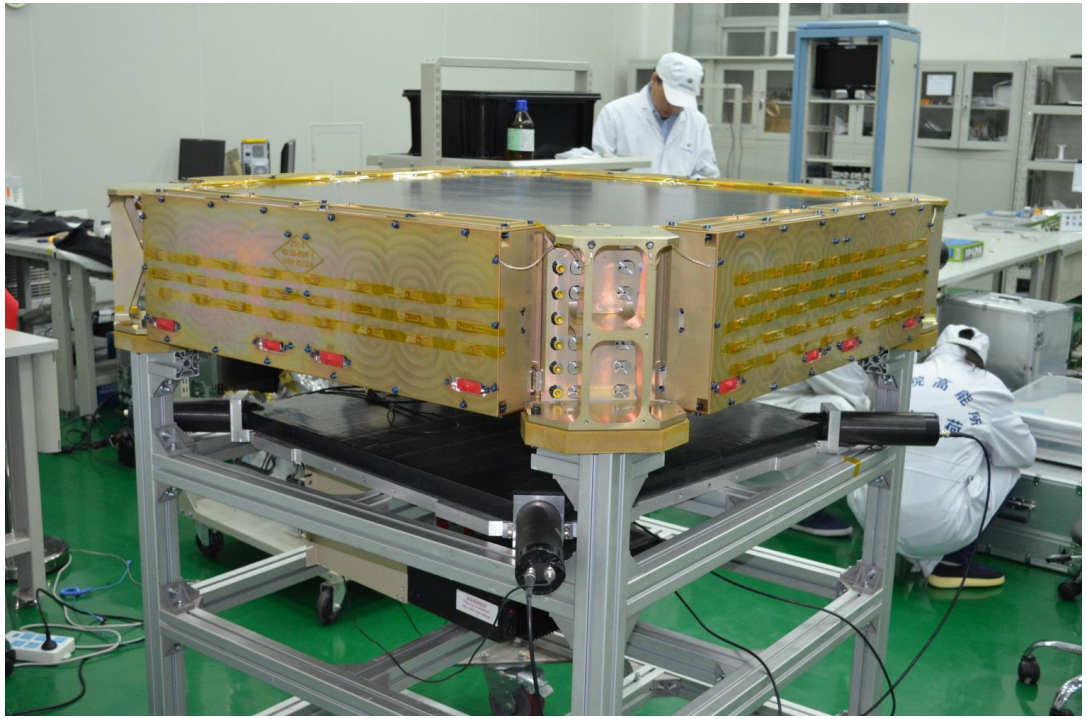
- PSD: charge measuresument via dE/dx and ACD for photons
- STK: track, charge, and photon converter
- BGO: energy measurement, particle (e-p) identification
- NUD: Particle identification

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

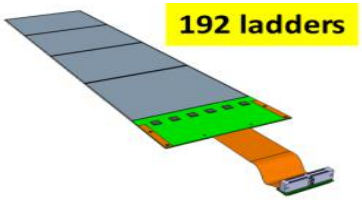
Silicon tracker

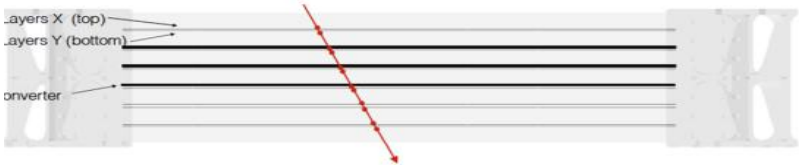


768 silicon sensors
95 x 95 x 0.32 mm³

1,152 ASICs

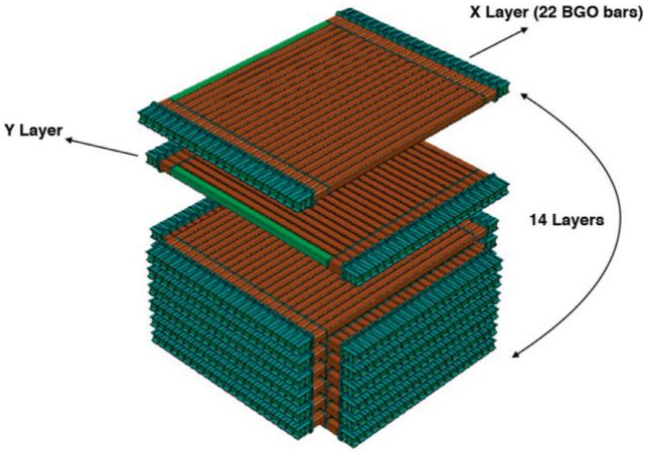
73,728 channels





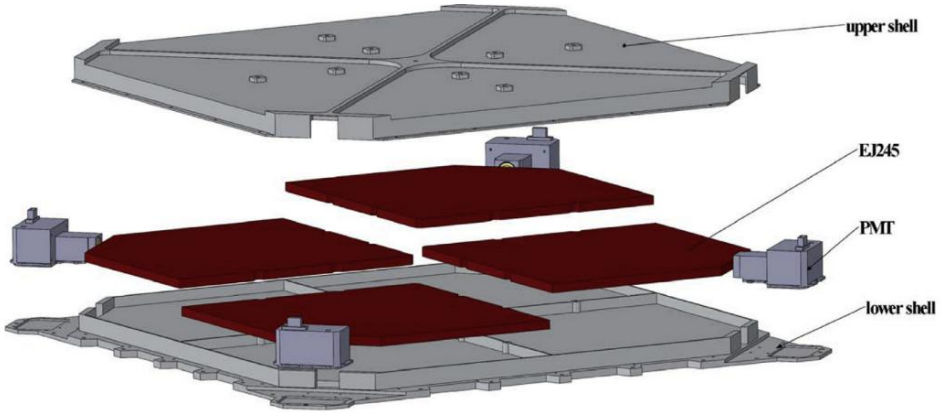
- Detection area: 76 cm x 76 cm
- Total weight: ~154 kg
- Total power consumption: ~ 82W
- Three 1 mm tungsten plates for photon conversion (0.86 X_0)

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

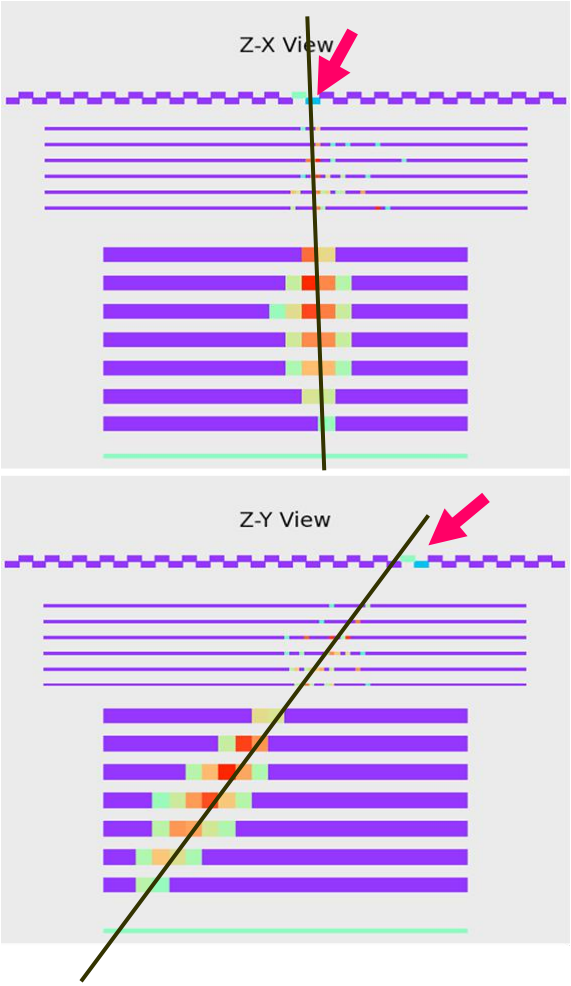
NUD neutron detector



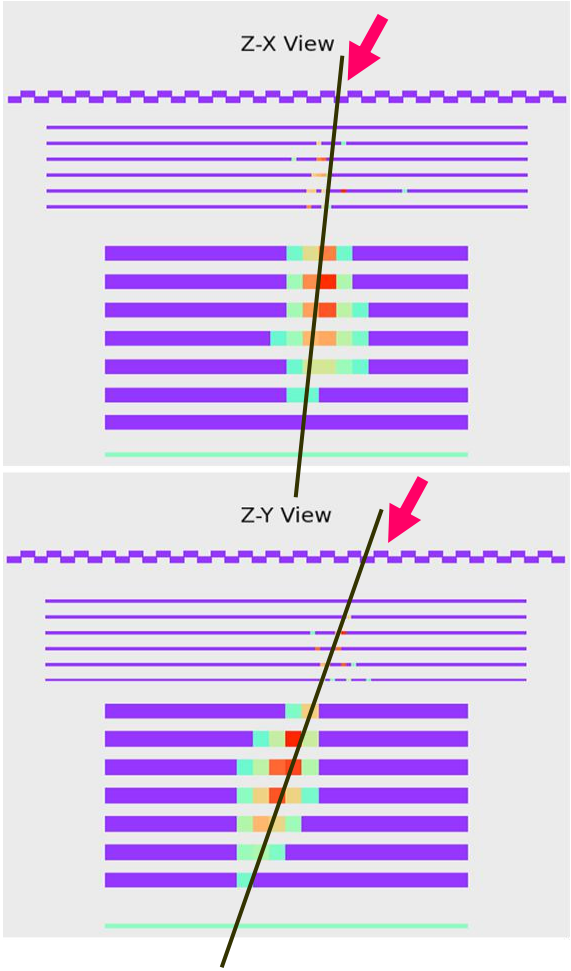
- $n + {}^{10}B \rightarrow \alpha + {}^{7}Li + \gamma$
- 4 plastic scintillators
- Active area: 60 cm x 60 cm
- Total weight: ~12 kg
- Total power: ~ 0.5 W

Particle identification

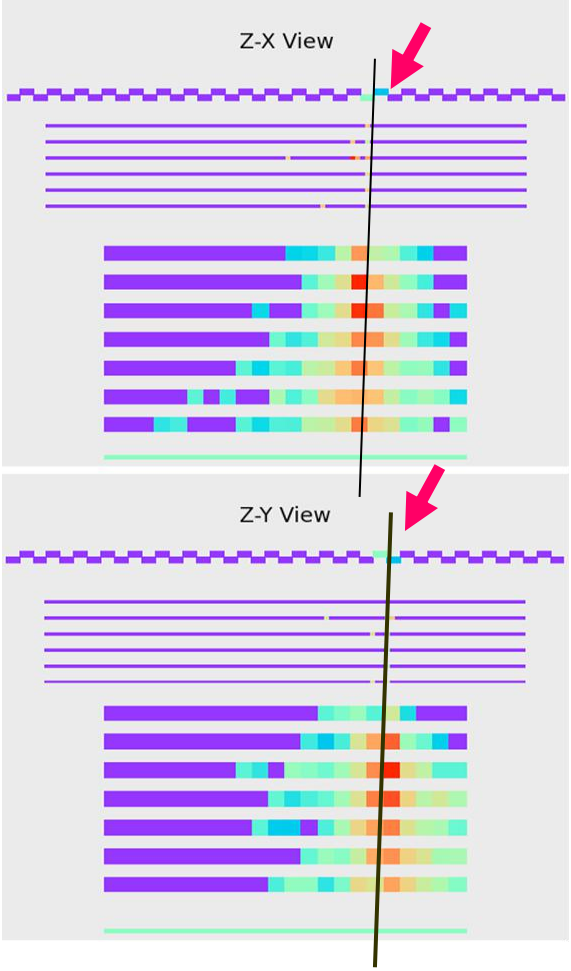
electron



gamma

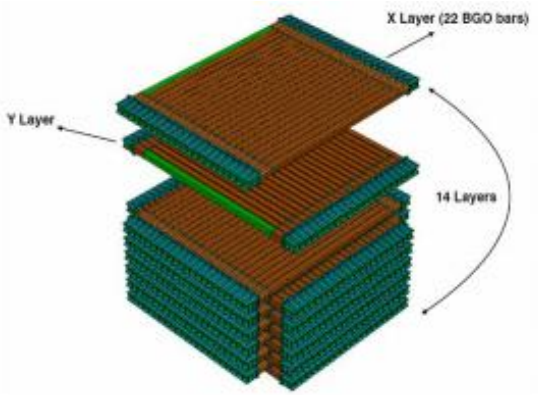


proton



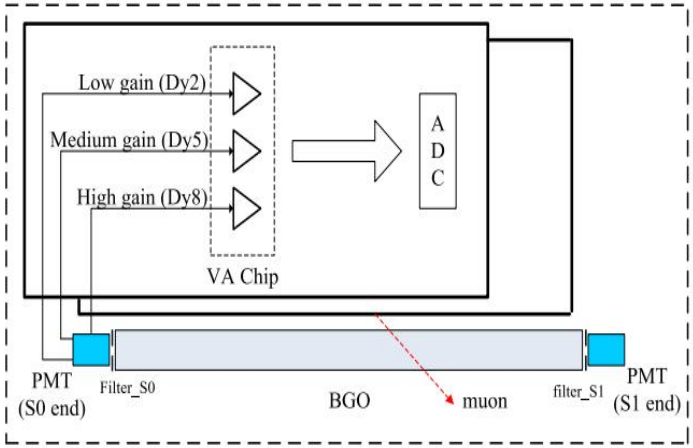
Energy measurement

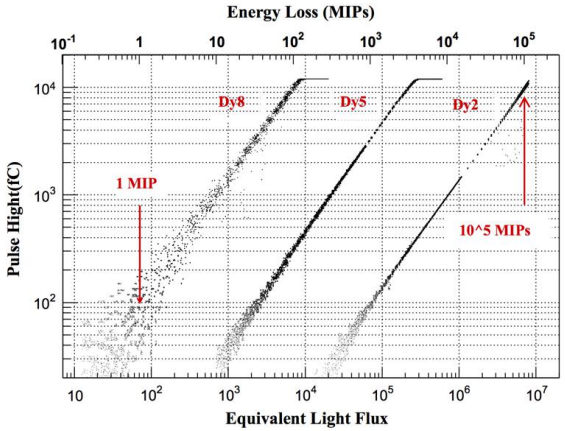
BGO calorimeter



308 BGO bars

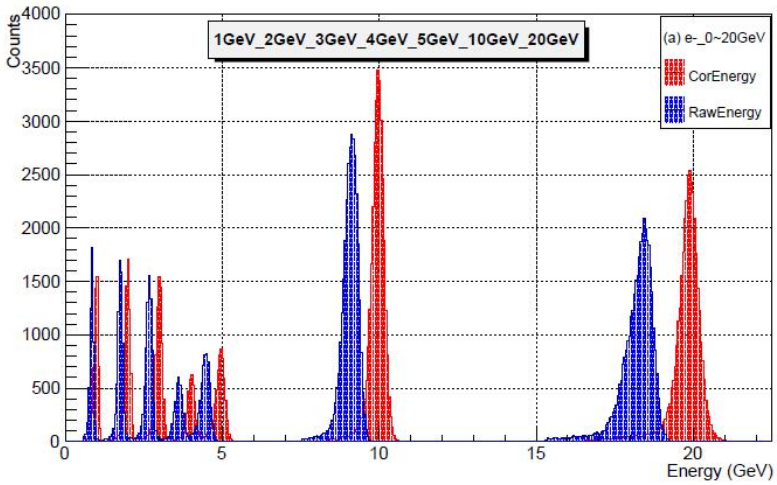
616 PMTs

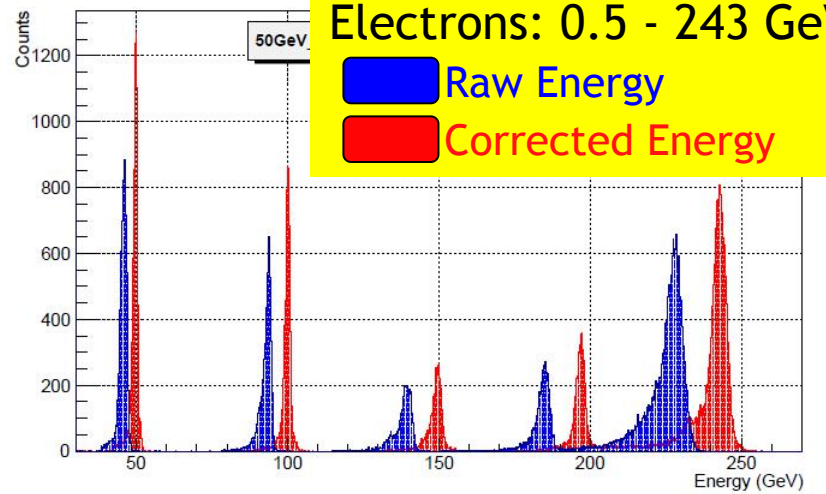




- Thick calorimeter (32 X_0): high-resolution
- Two-side readouts
- Three dynode outputs enable a $>10^6$ dynamic range

Test beam validation

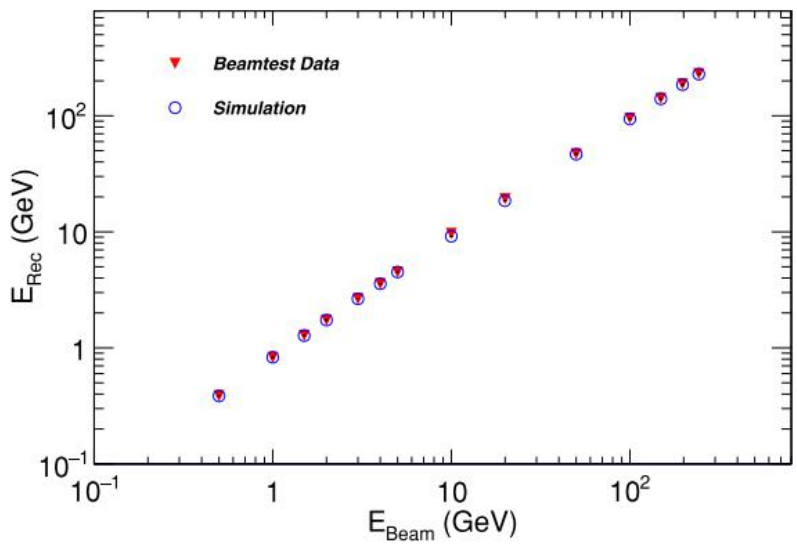


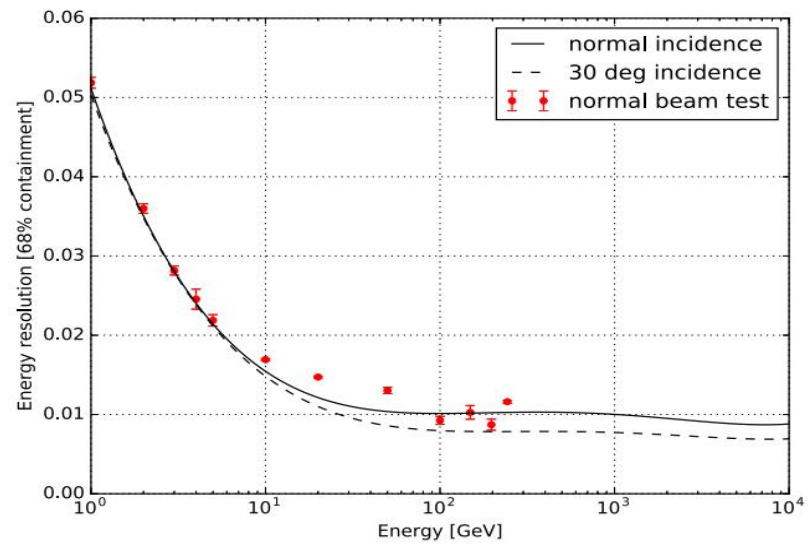


Electrons: 0.5 - 243 GeV

Raw Energy

Corrected Energy





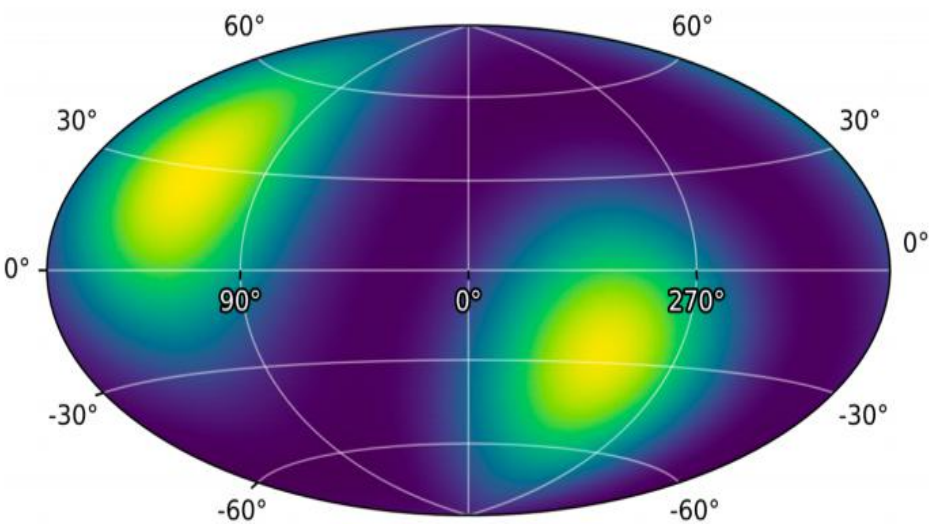
Astropart. Phys., 95, 6 (2017)

On-orbit performance

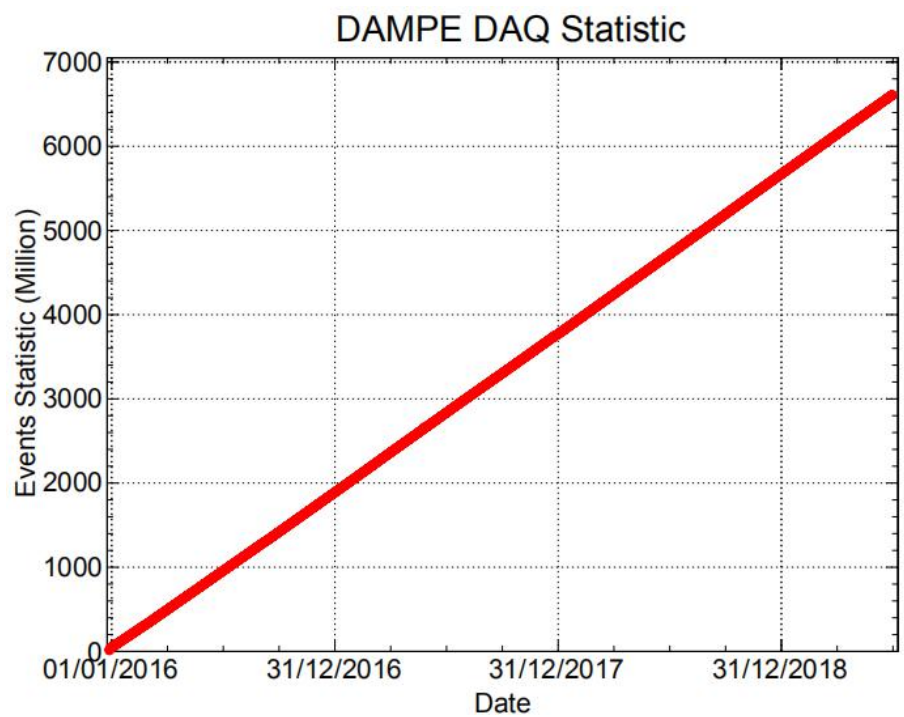
See Y. L. Zhang CRD7e

Observation overview

DAMPE 3.5 year counts map

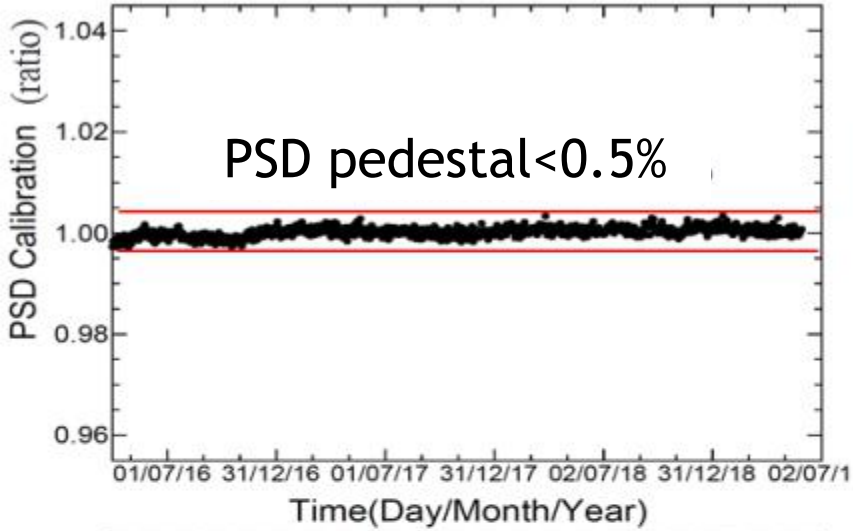


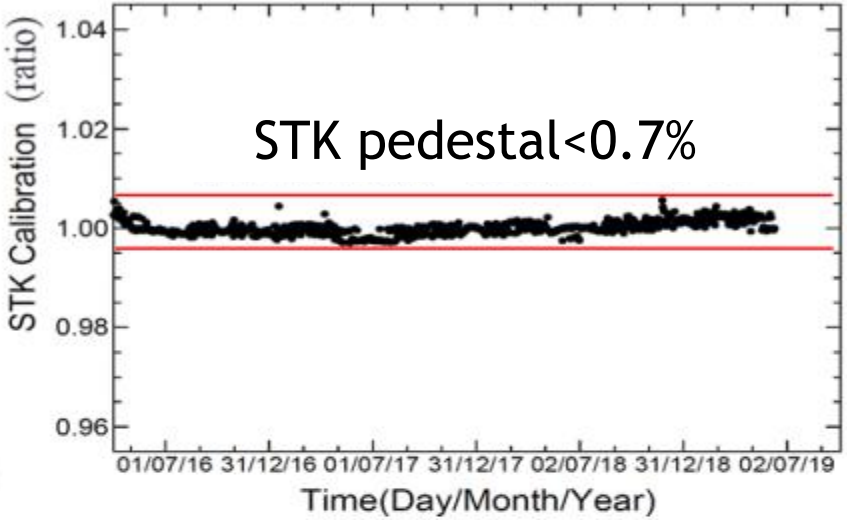
7 full scans of the sky

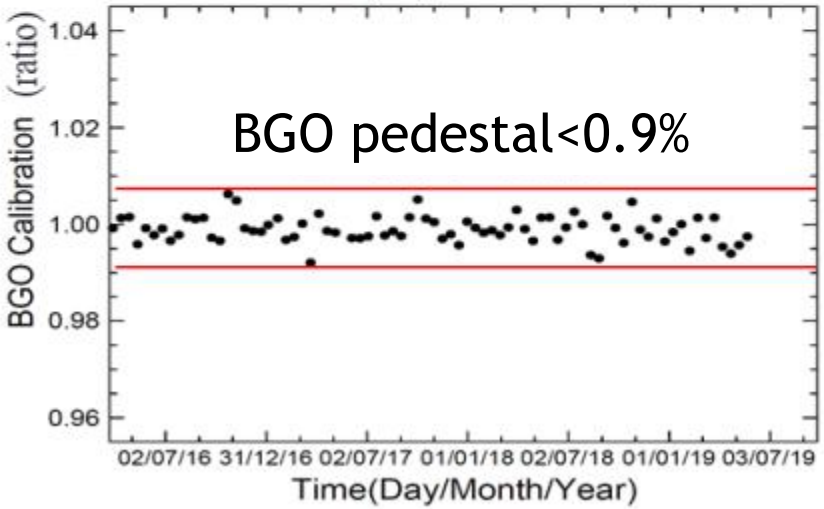


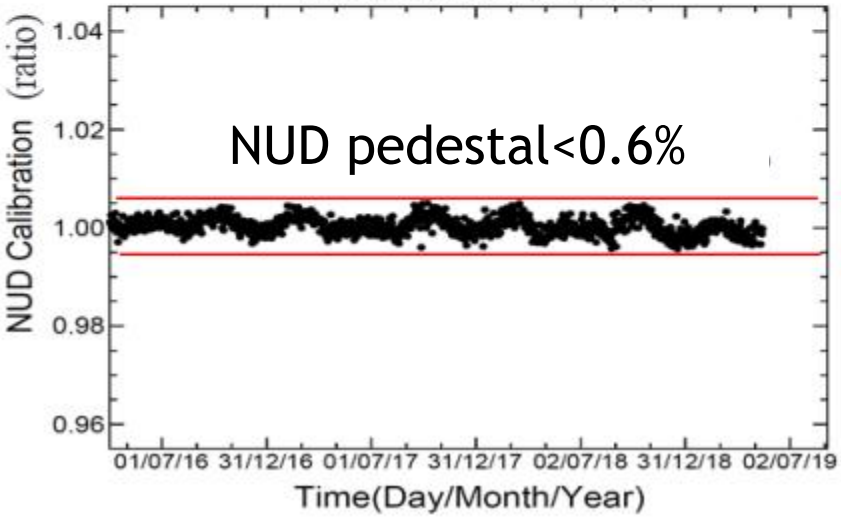
5M events/day
6.6 billion in total

Detector stability

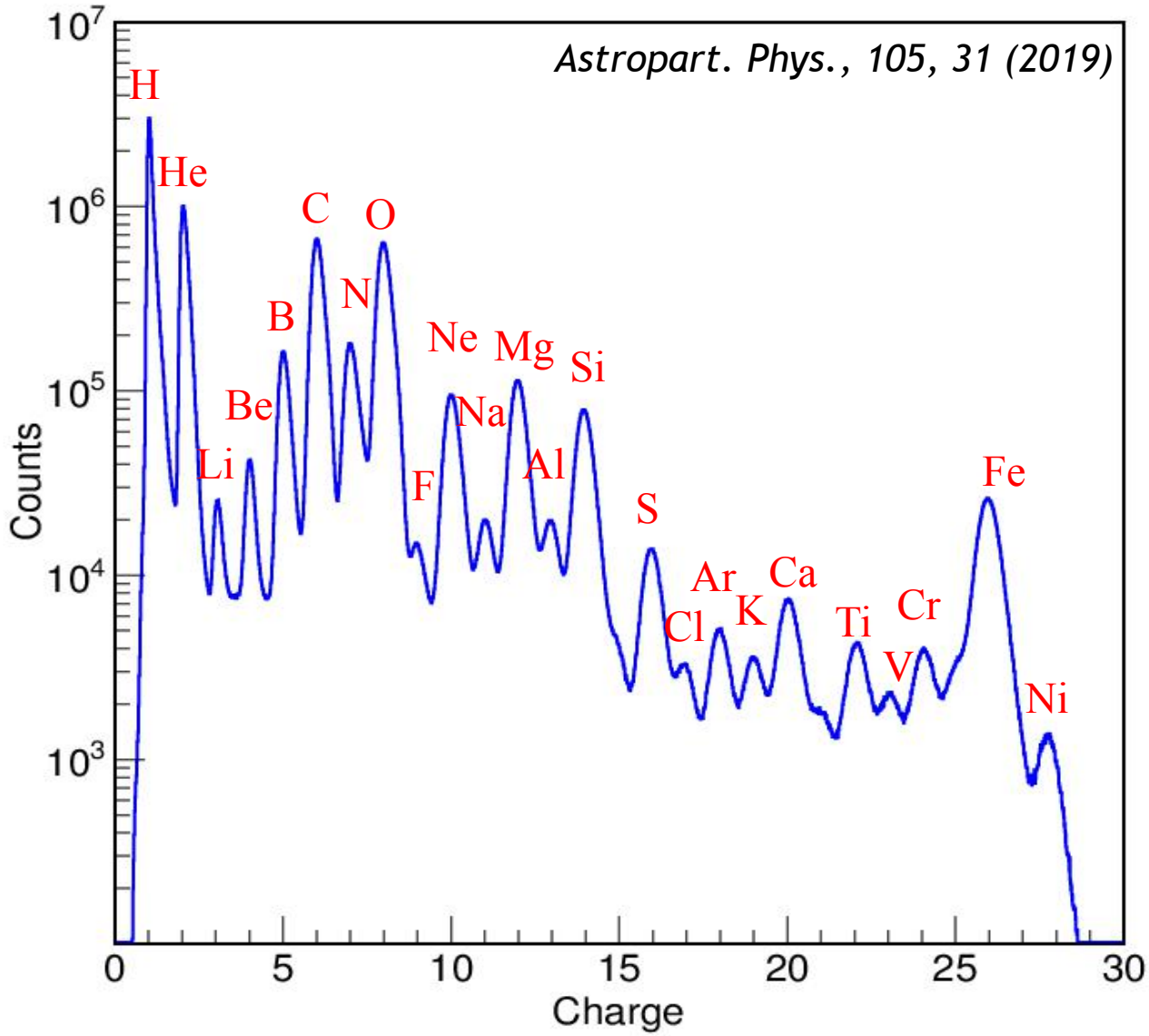






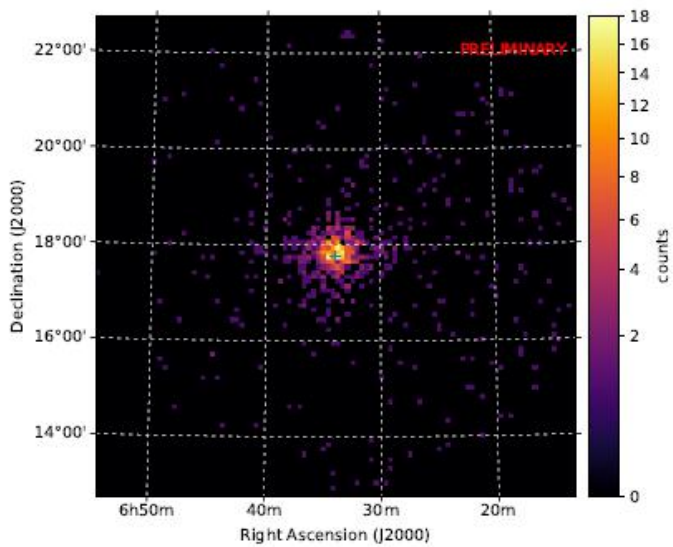


PSD charge measurement



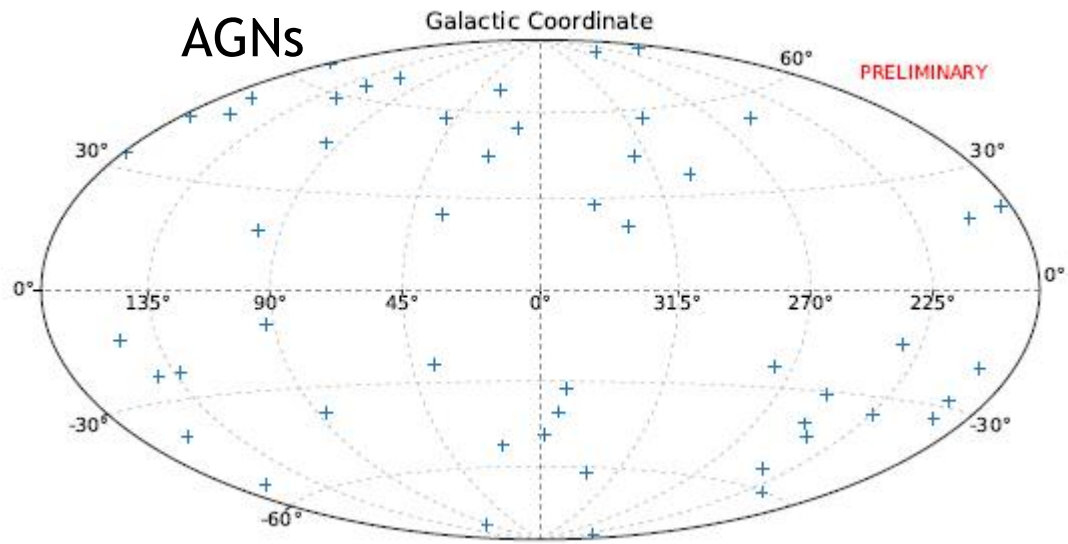
Species	Charge Res.
P	0.06
He	0.10
Li	0.14
Be	0.21
B	0.17
C	0.18
N	0.21
O	0.20

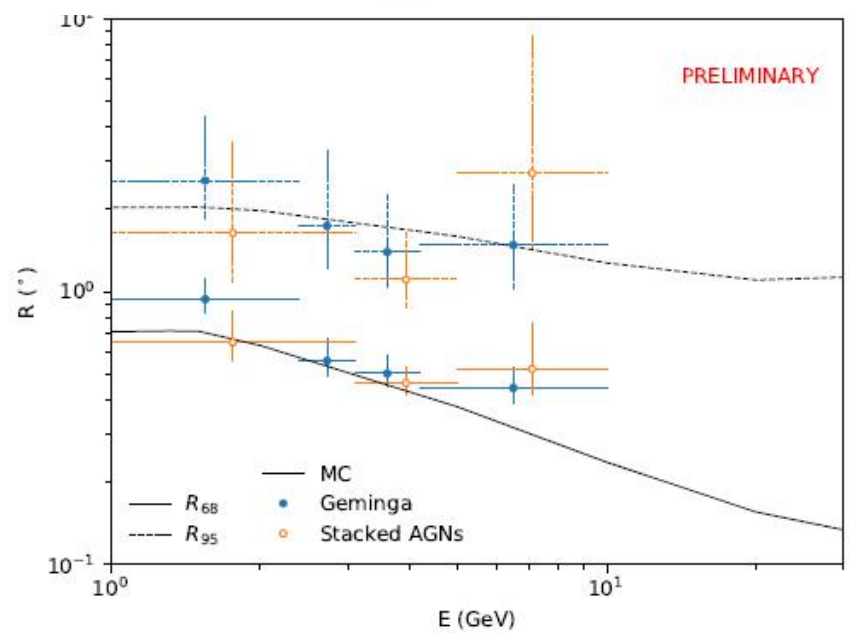
STK direction measurement



Geminga

AGNs

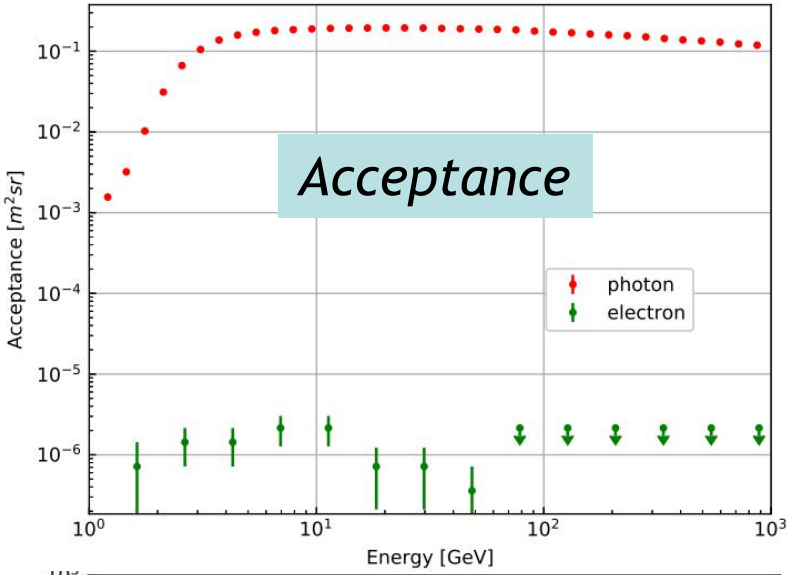




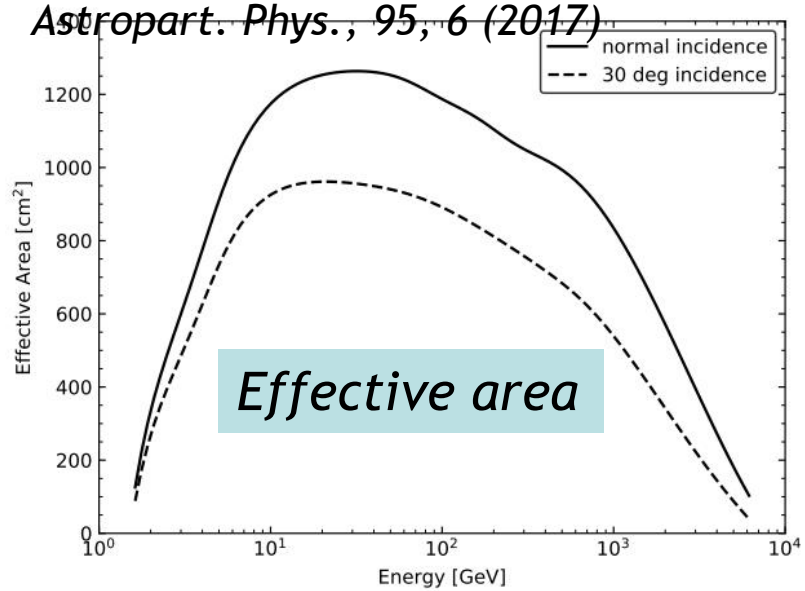
PSF calibrated with bright gamma-ray sources : ~0.5 degrees @ 5 GeV

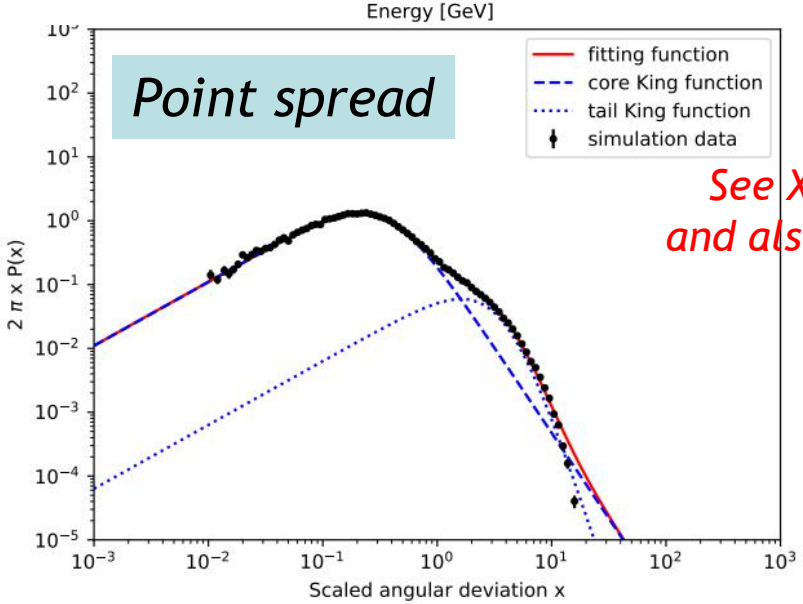
DAMPE IRFs for γ-rays

Res. Astron. Astrophys., 18, 027 (2018)

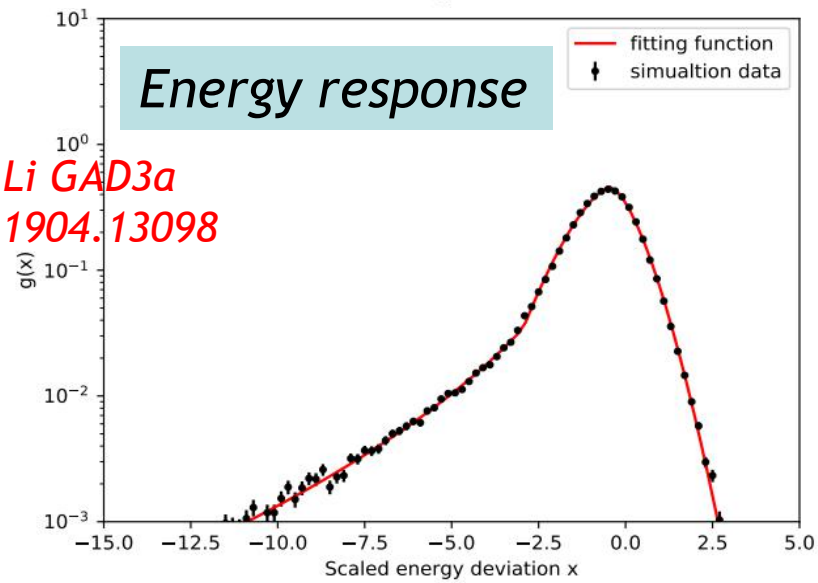


Astropart. Phys., 95, 6 (2017)

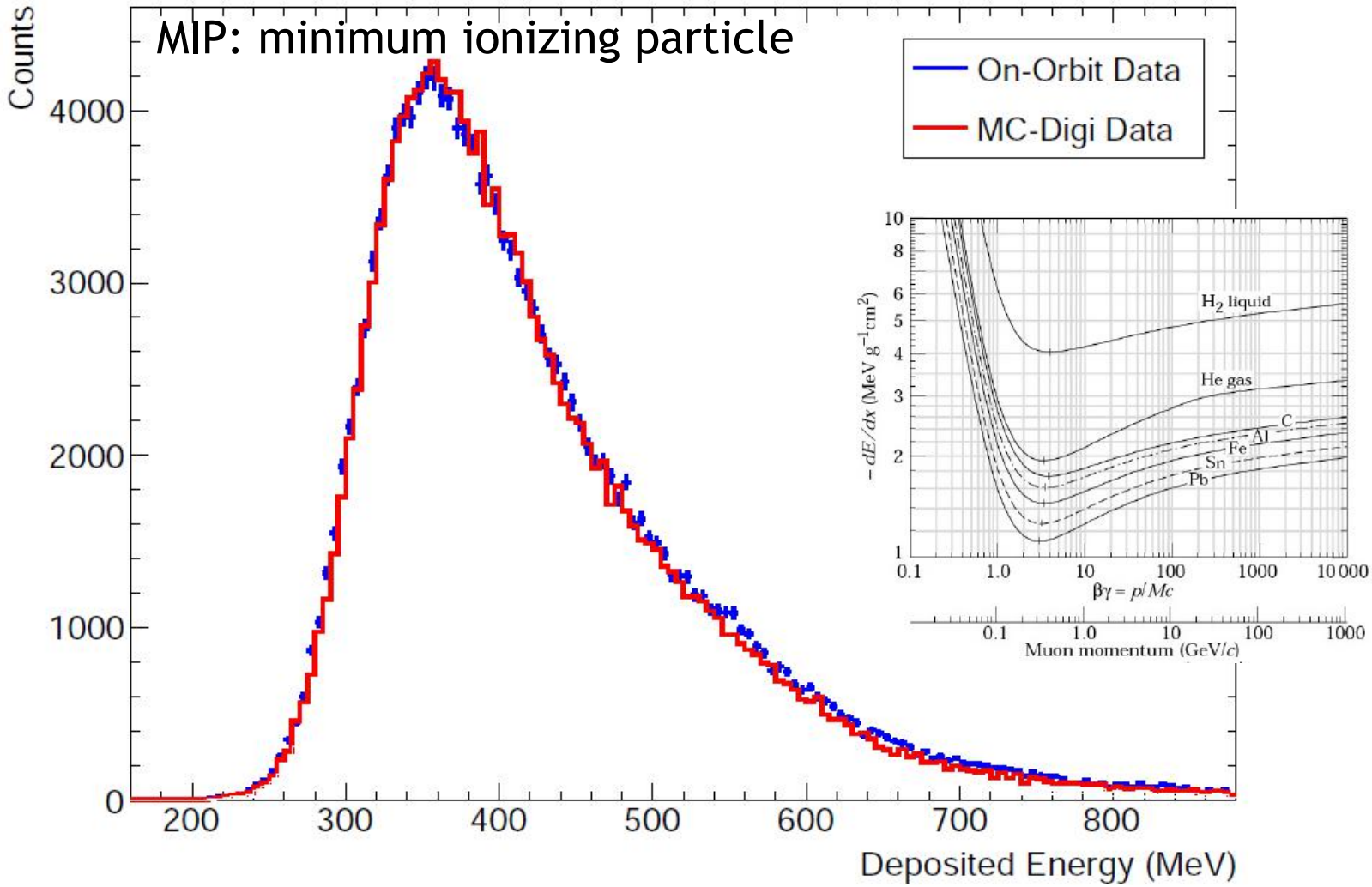




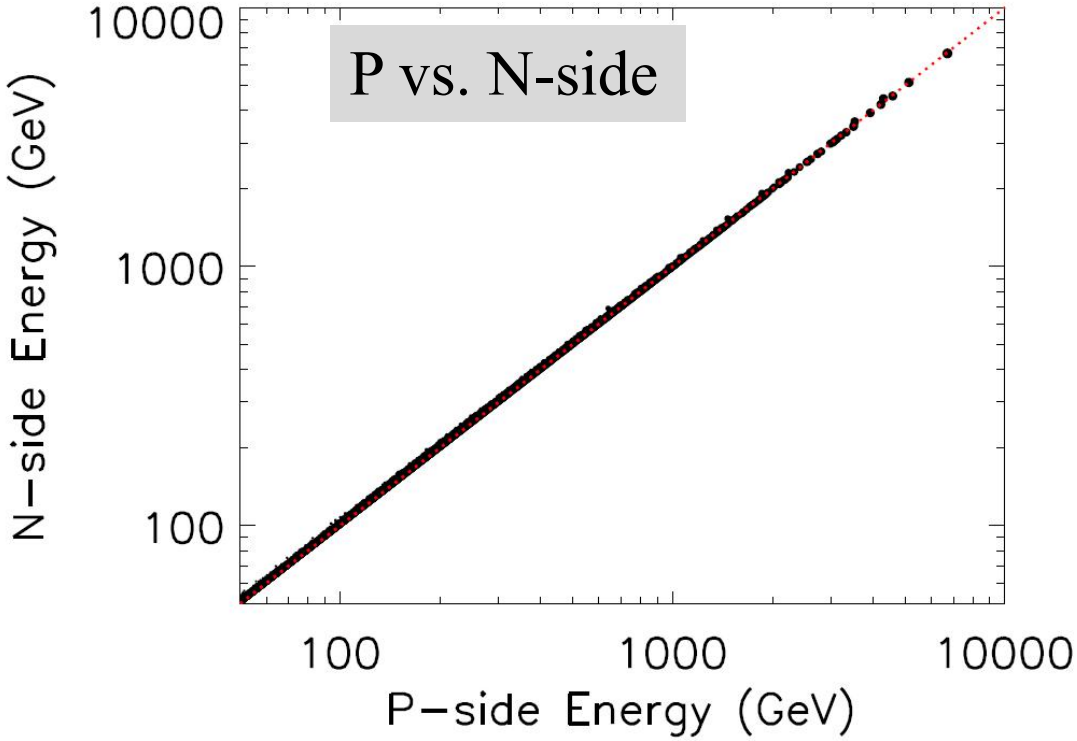
See X. Li GAD3a
and also 1904.13098



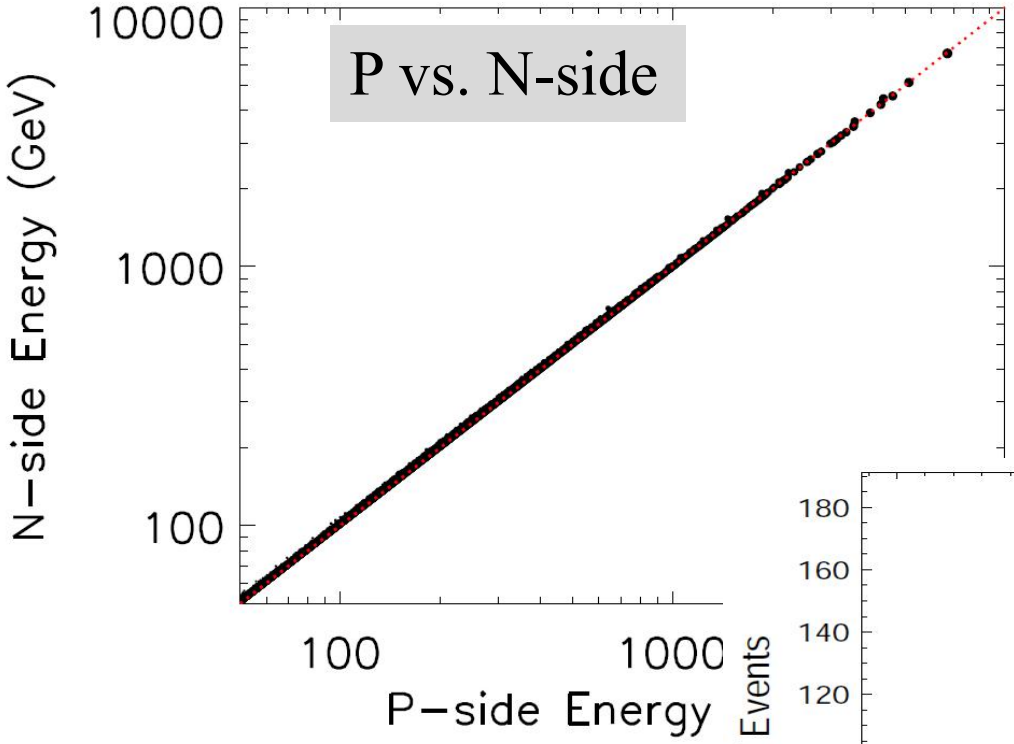
BGO energy calibration

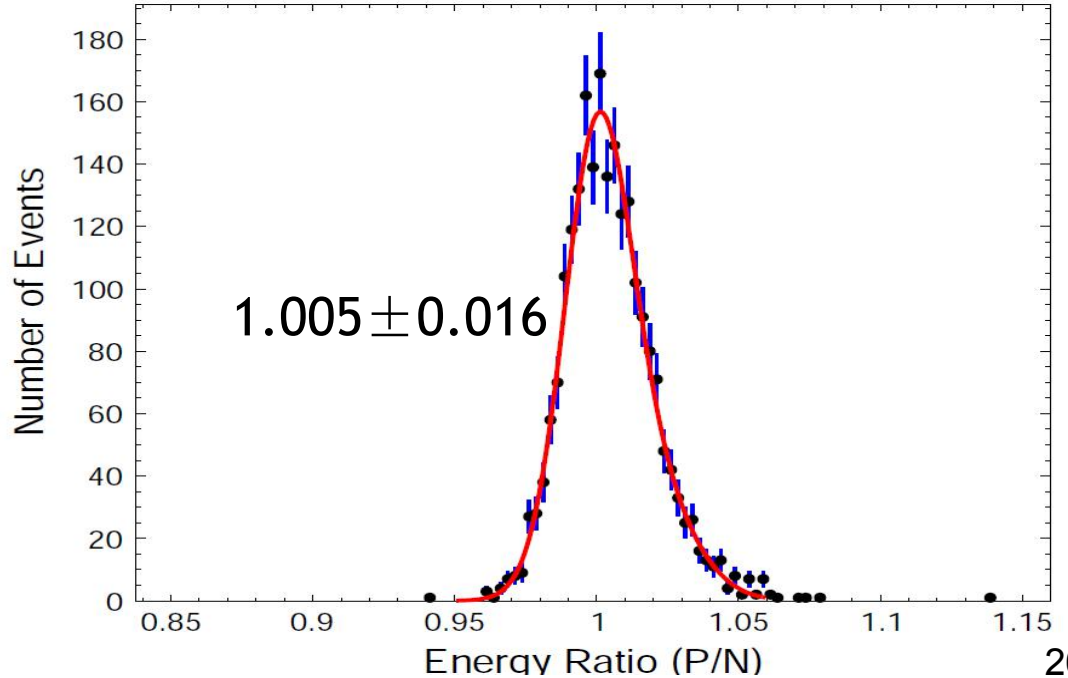


BGO energy linearity



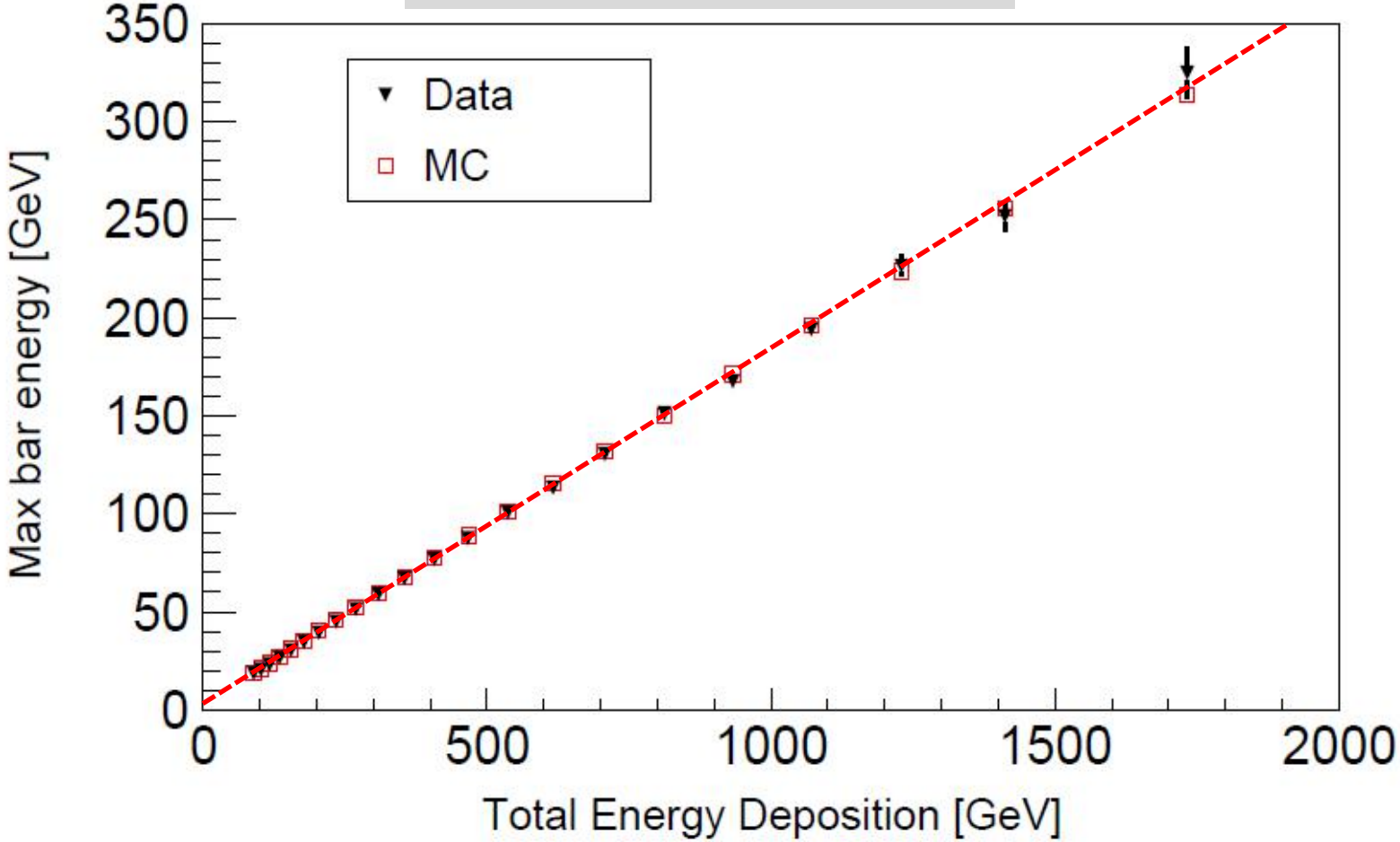
BGO energy linearity



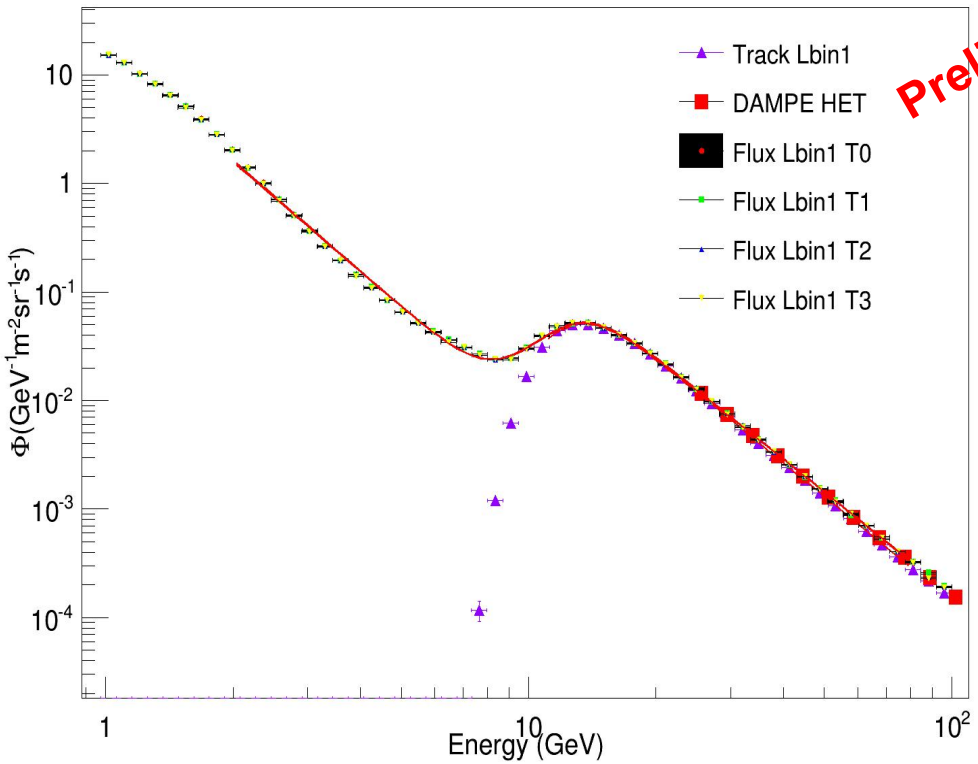


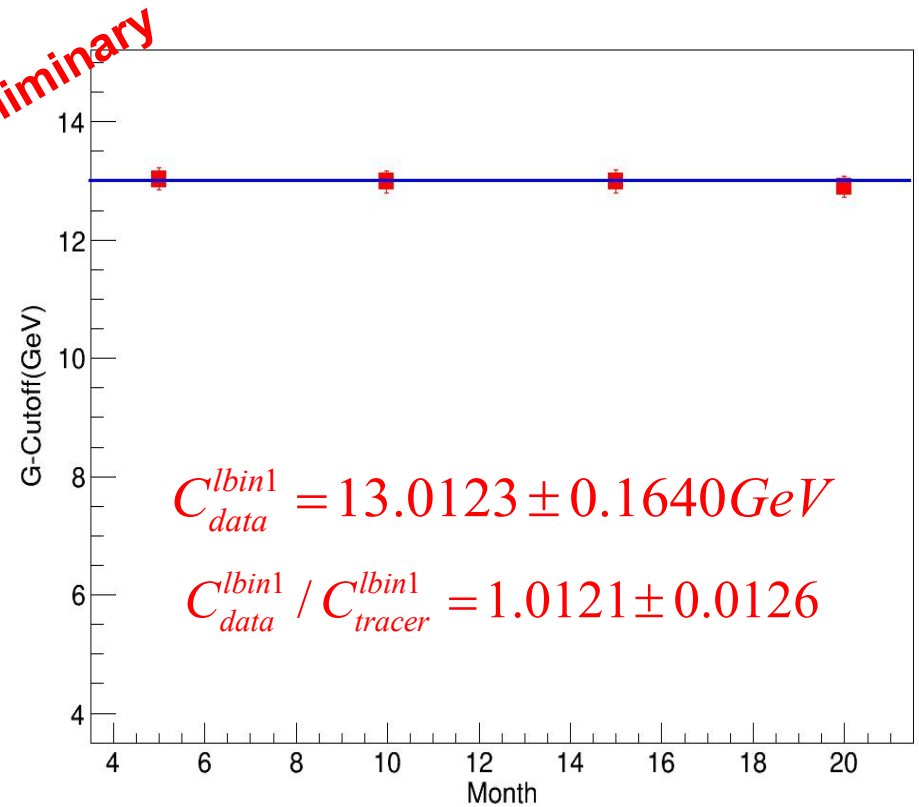
BGO energy linearity

Total vs. Max bar energy



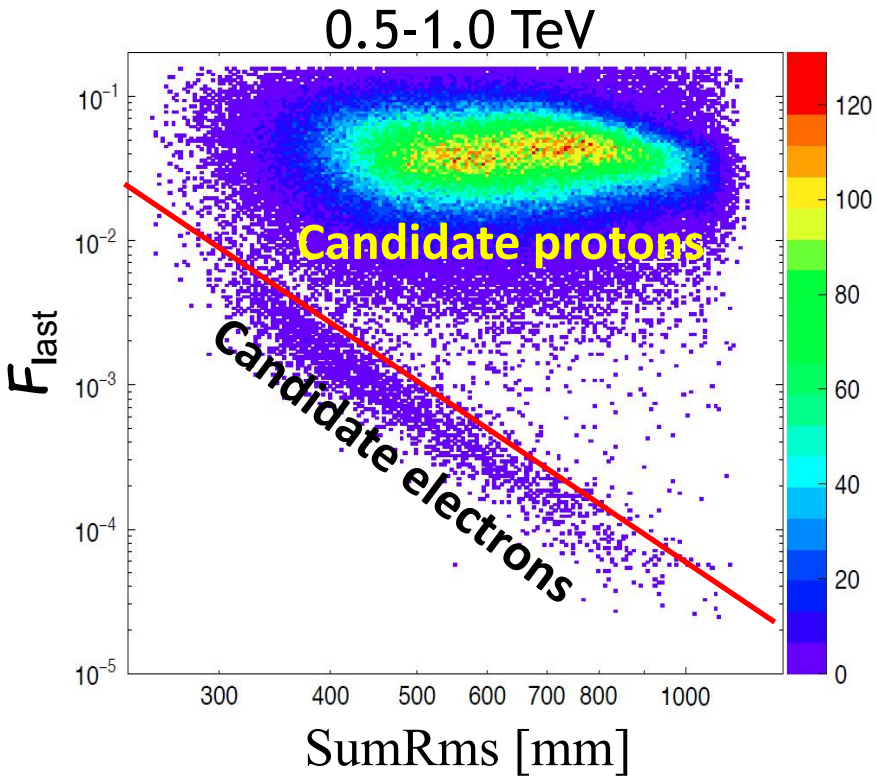
Absolute energy scale

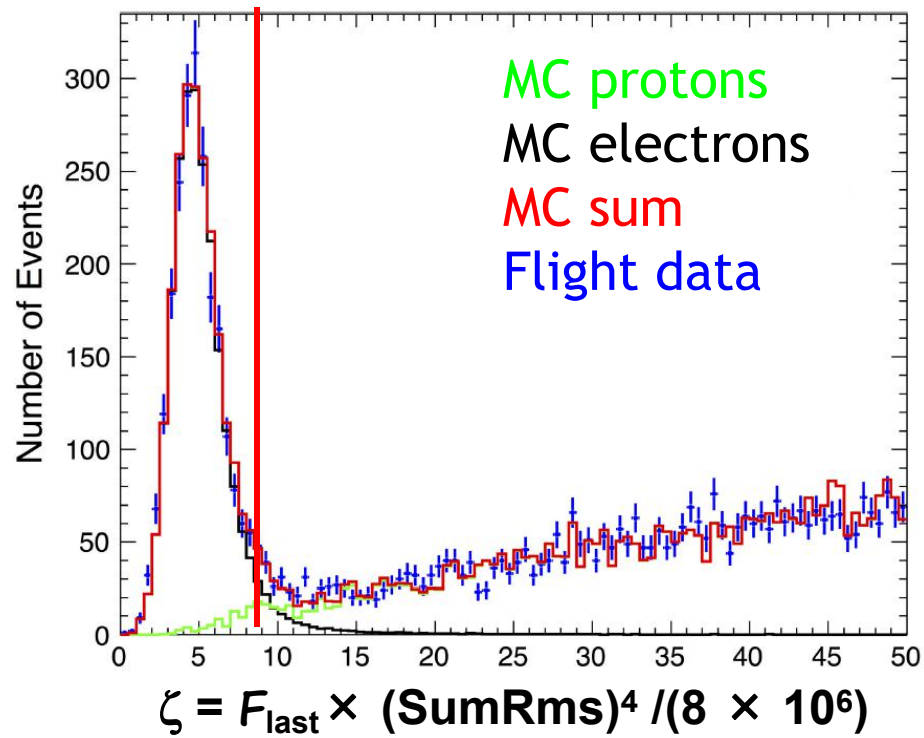




- An energy scale higher by (1.2+/-1.3)% from the geomagnetic cutoff
- Cutoff energy is stable with time (a slight decrease due to solar modulation)

e/p separation

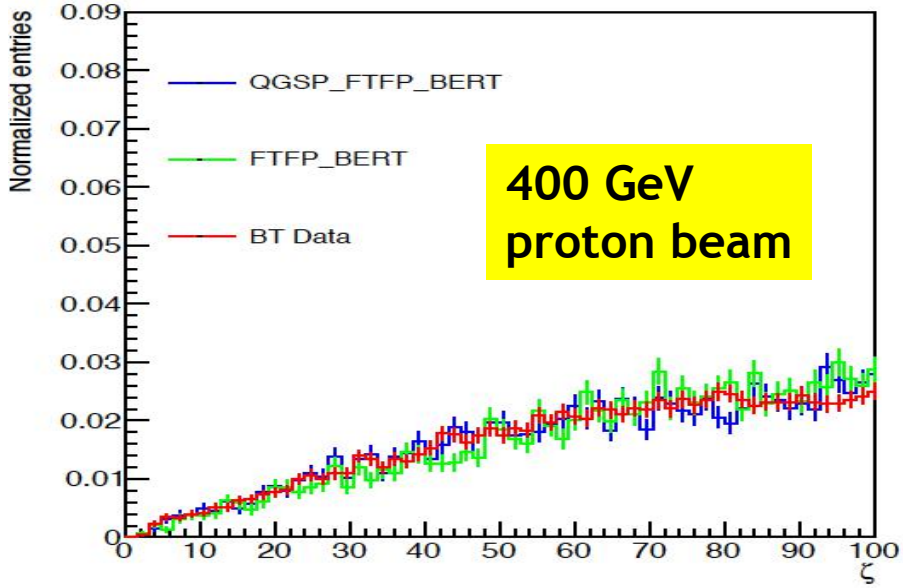


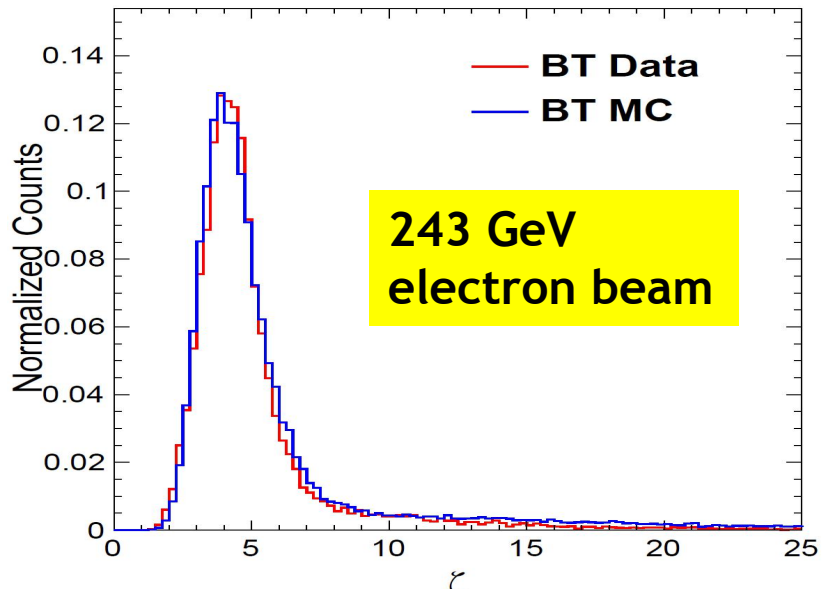


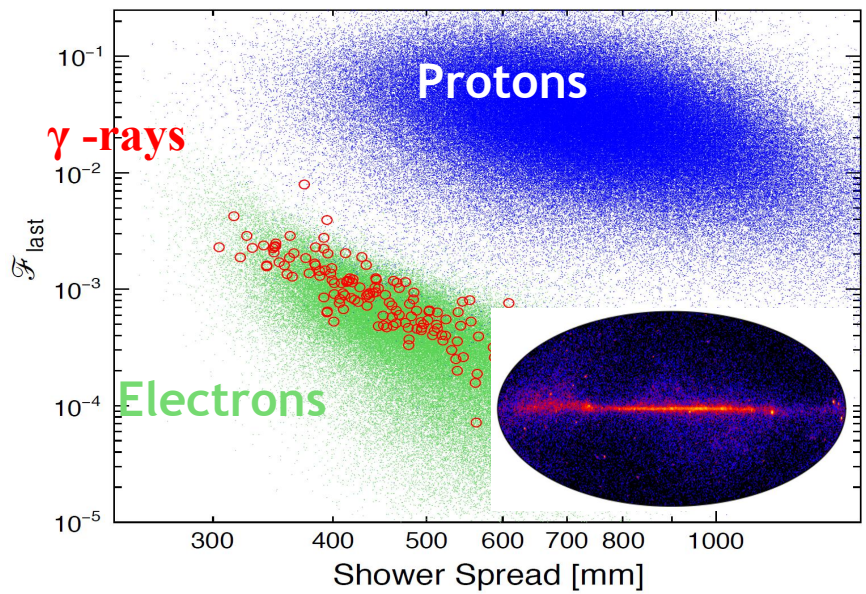
- We use the lateral (SumRMS) and longitudinal (energy ratio in last layer) developments of the showers to discriminate electrons from protons
- For 90% electron efficiency, proton background is ~2% @ TeV, ~5% @ 2 TeV, ~10% @ 5 TeV

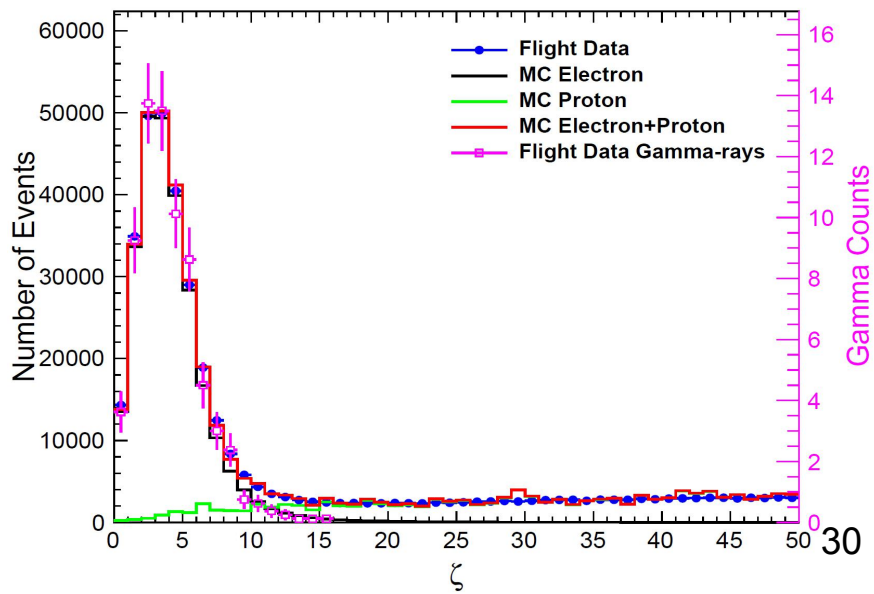
Nature, 552, 63 (2017)

Validation of e/p separation



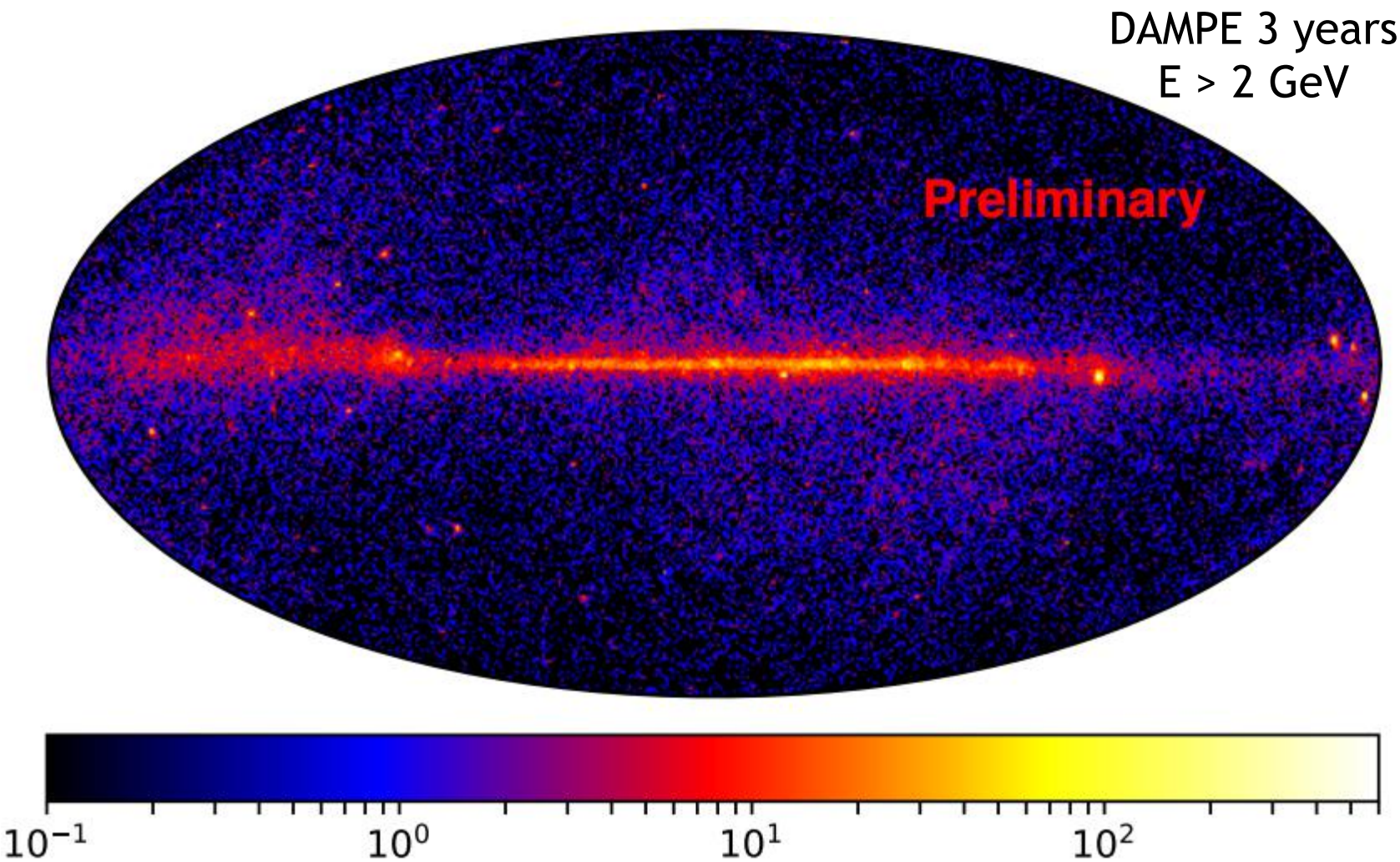




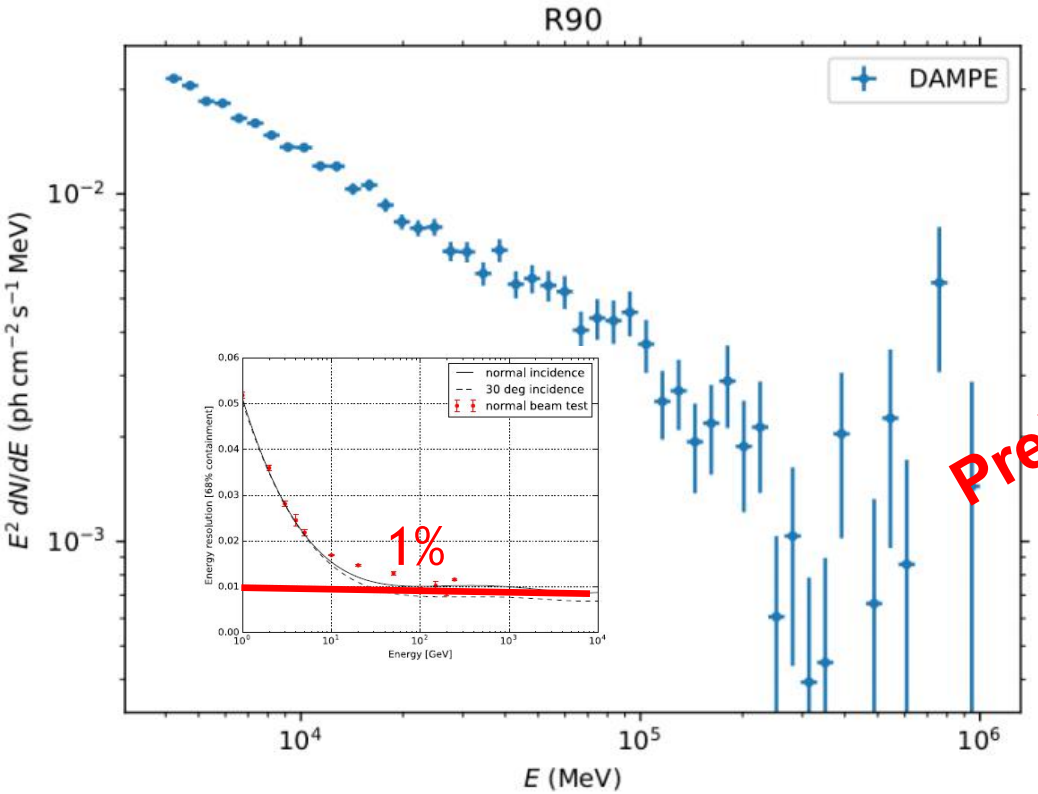


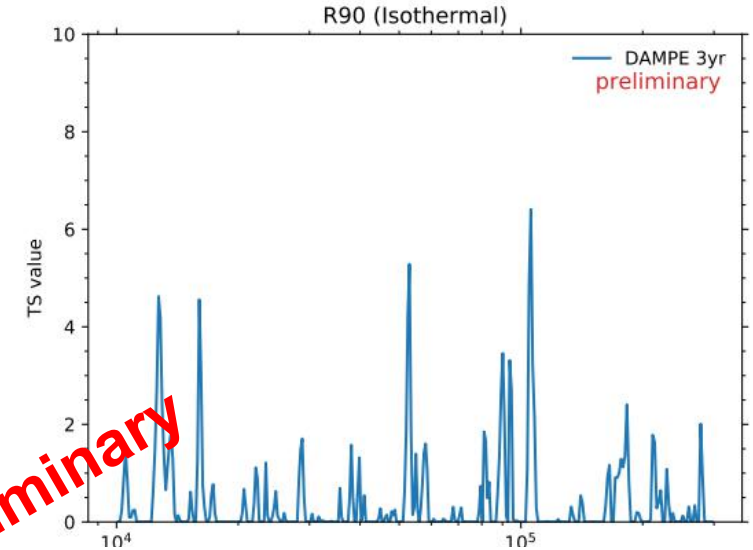
Physical results

γ-ray skymap

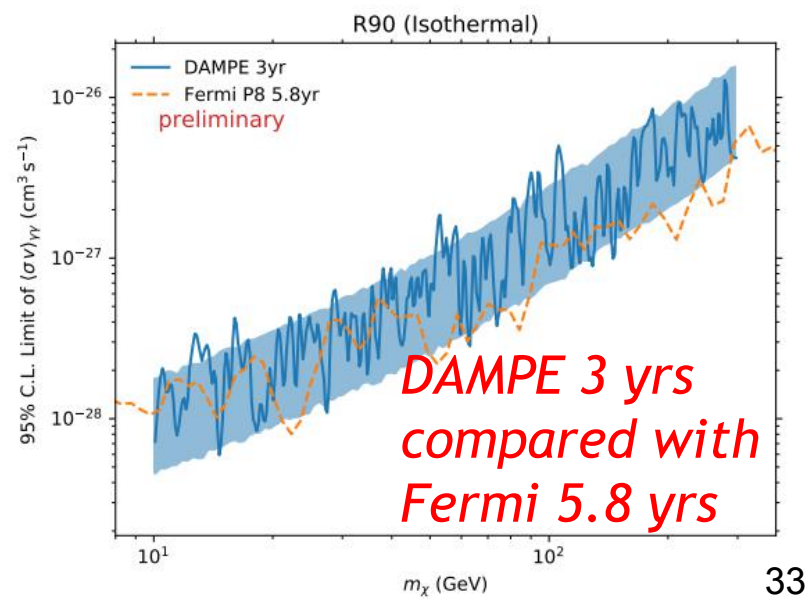


γ-ray line searches





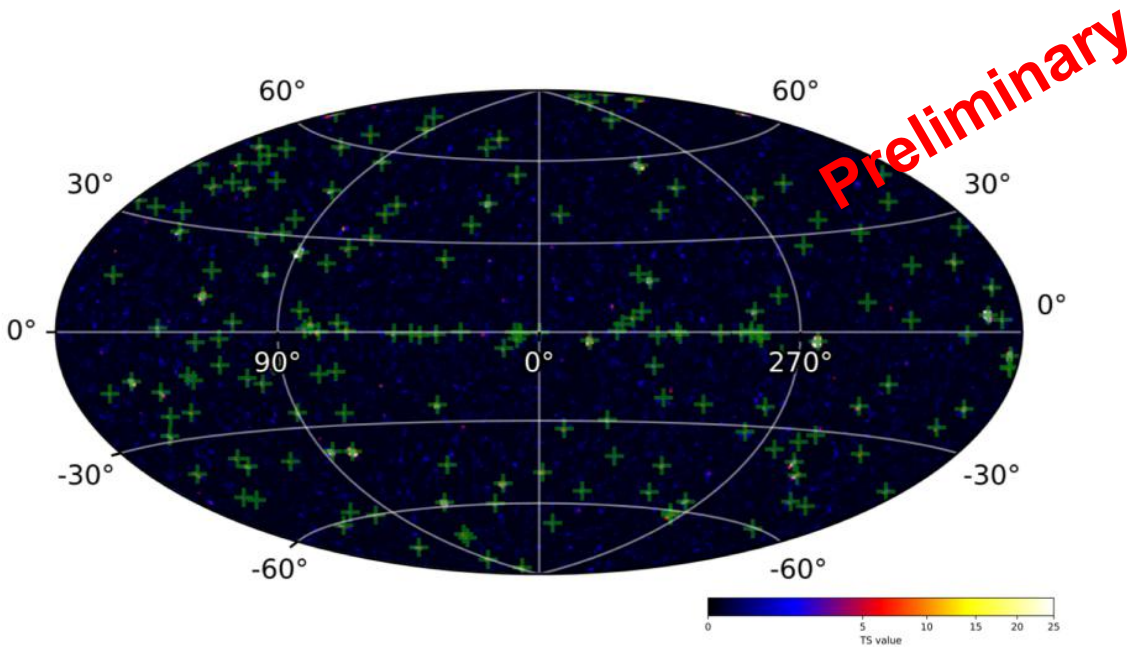
Preliminary



See Z. Q. Shen PS1-256

DAMPE 3 yrs compared with Fermi 5.8 yrs

γ-ray point sources

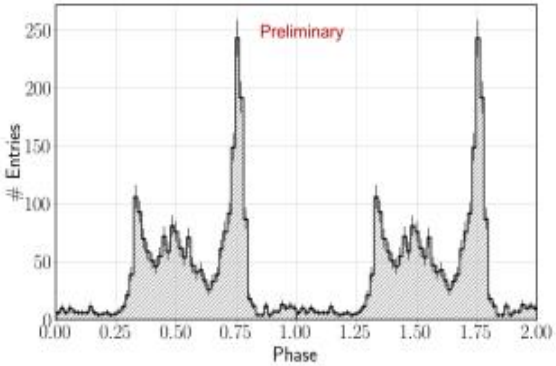


Source Type	Number
AGN	100
Pulsar	27
SNR / PWN	9
Binary	2
Globular cluster	1
Unassociated	4
Total	143

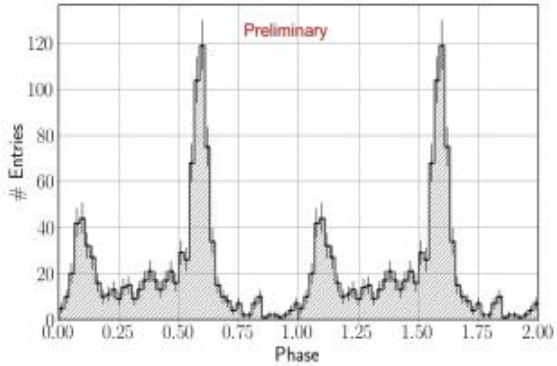
- 143 sources with TS > 20
- Most are AGNs and pulsars

See X. Li GAD3a

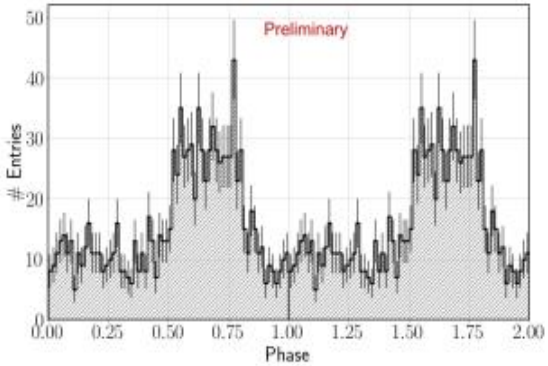
γ-ray pulsars



(a) Vela

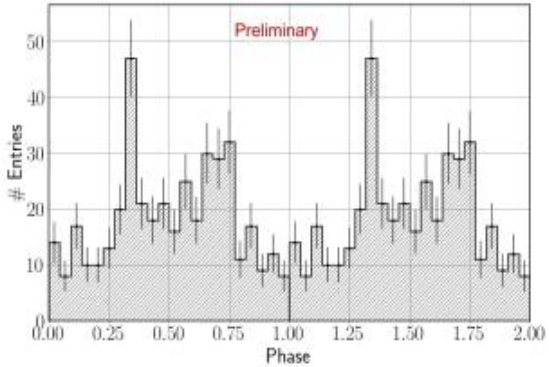


(b) Geminga

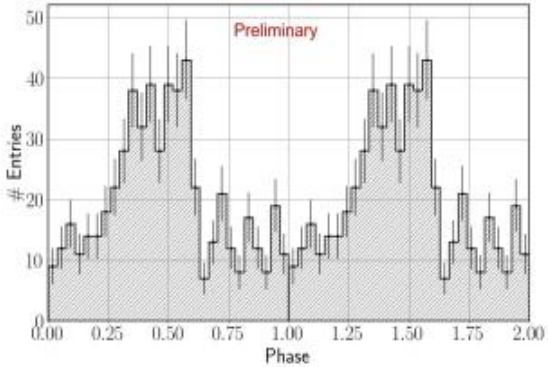


(c) J1709-4229

See M. Munoz GAD2d

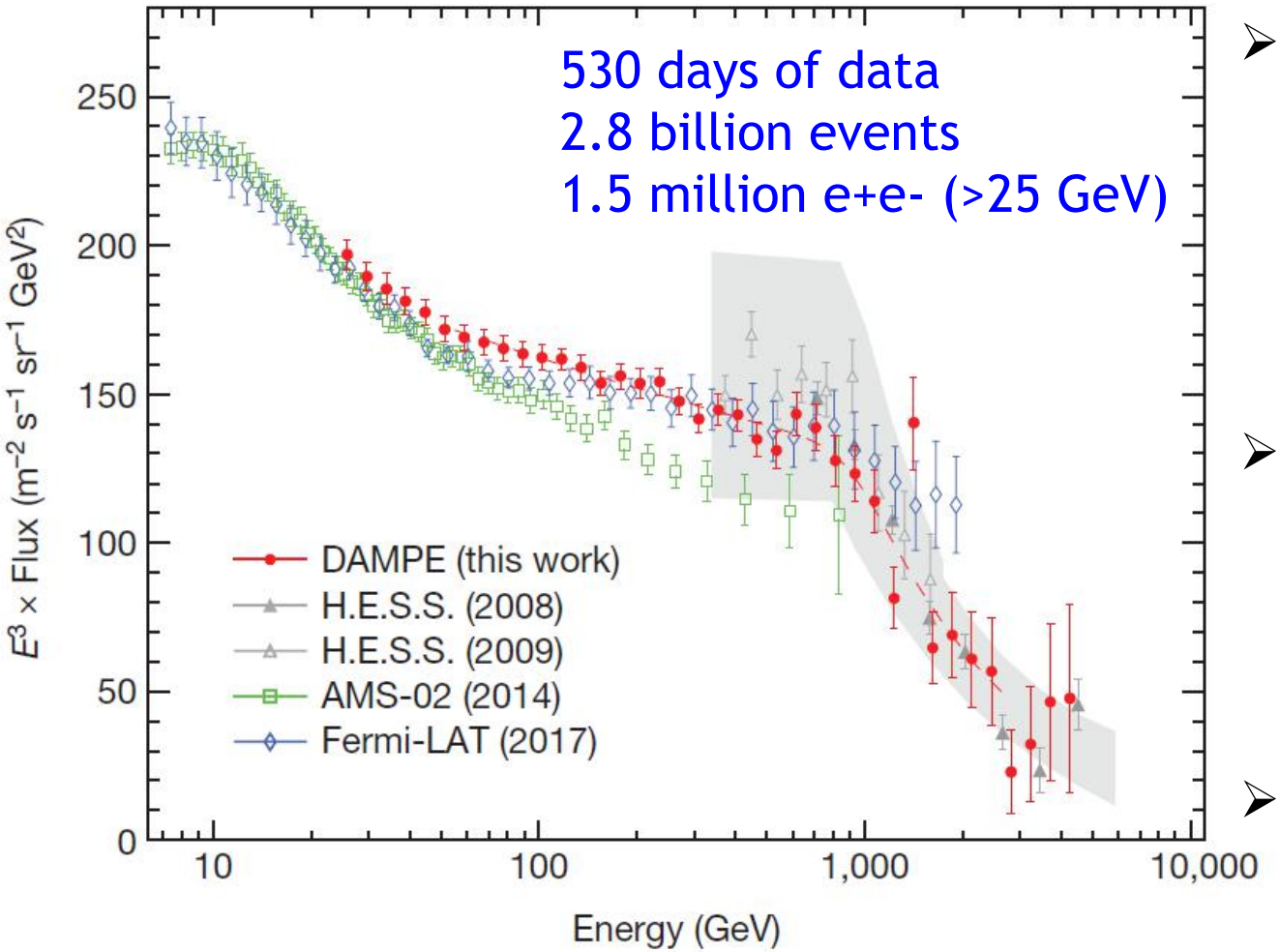


(d) Crab



(e) J0007+7303

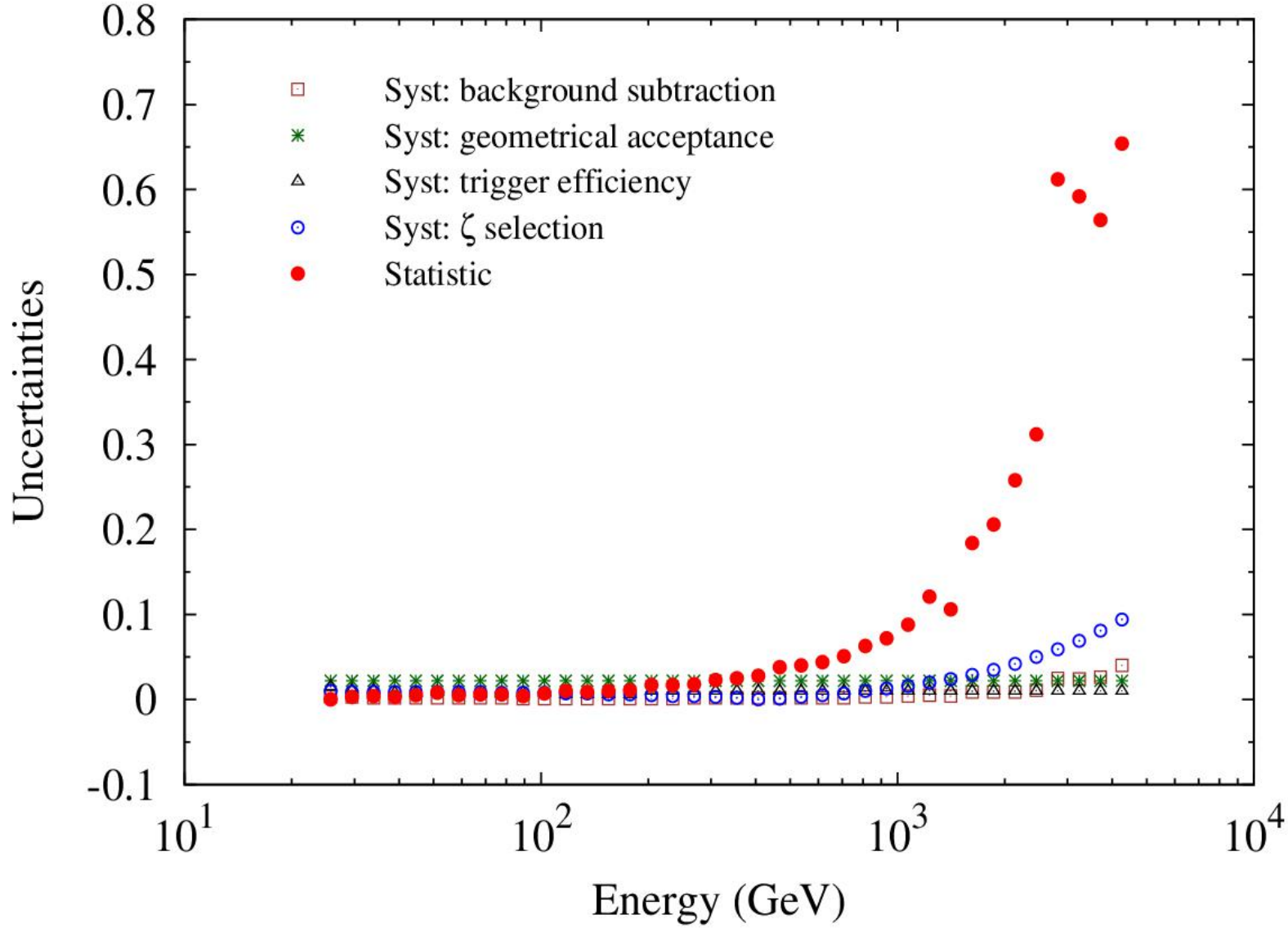
Total e^++e^- spectrum



- 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

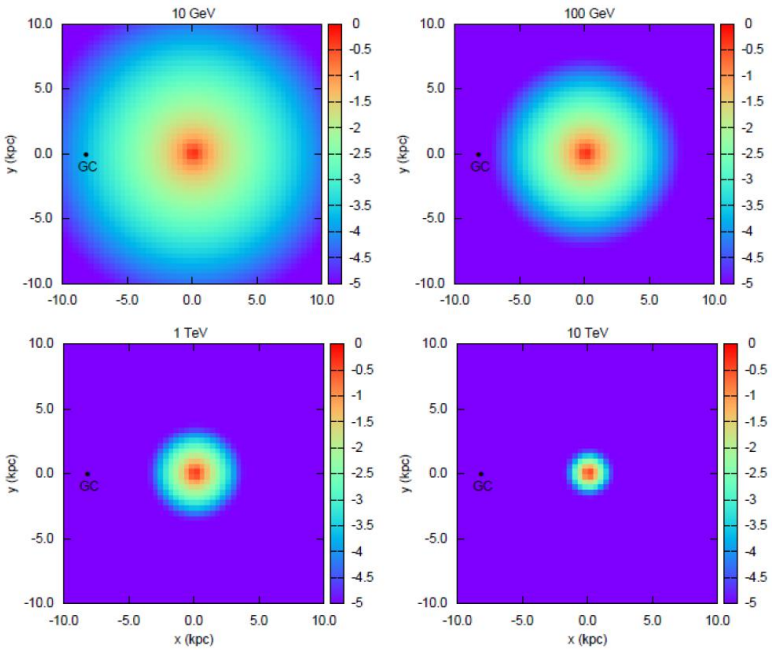
Nature, 552, 63 (2017)

Errors of e^++e^- spectrum

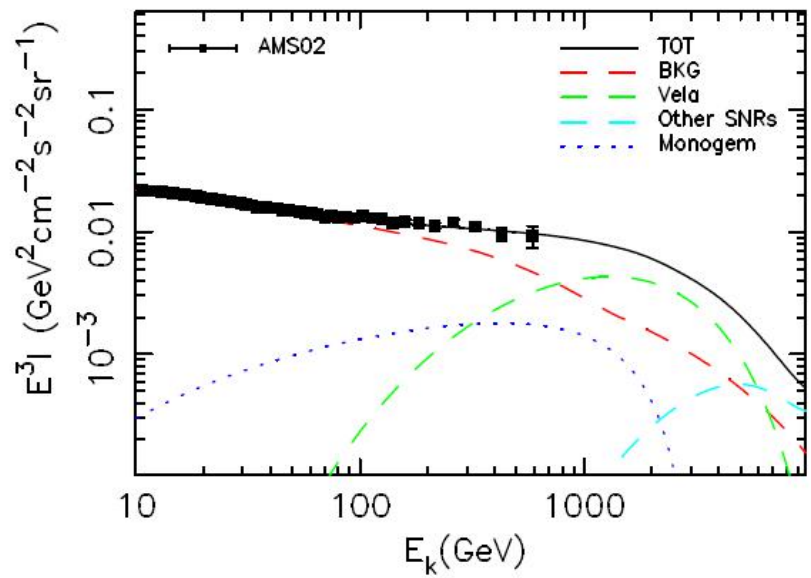


Implication of the spectral softening: discreteness of source distributions?

- 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)

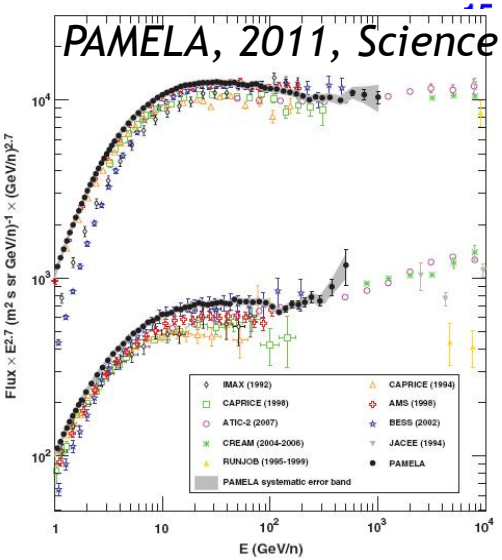


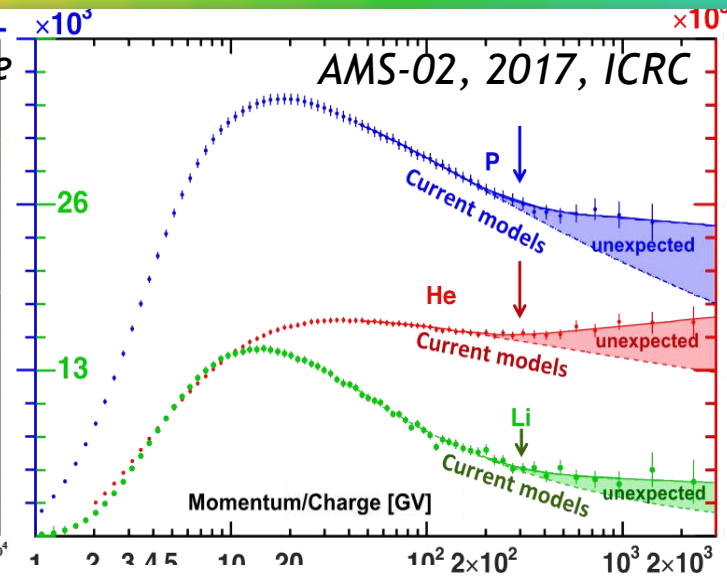
Astrophys. J., 836, 172 (2017)

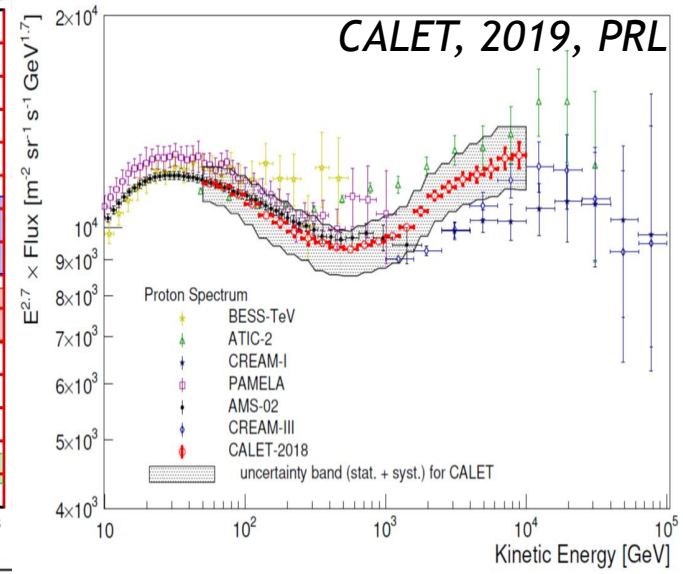


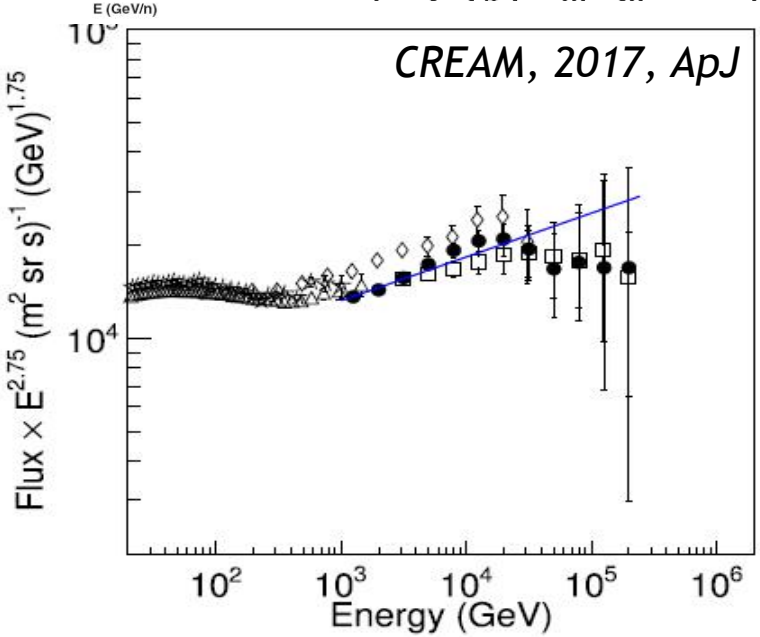
Fang et al. (2017)
Di Mauro et al. (2017)
Manconi et al. (2019)...

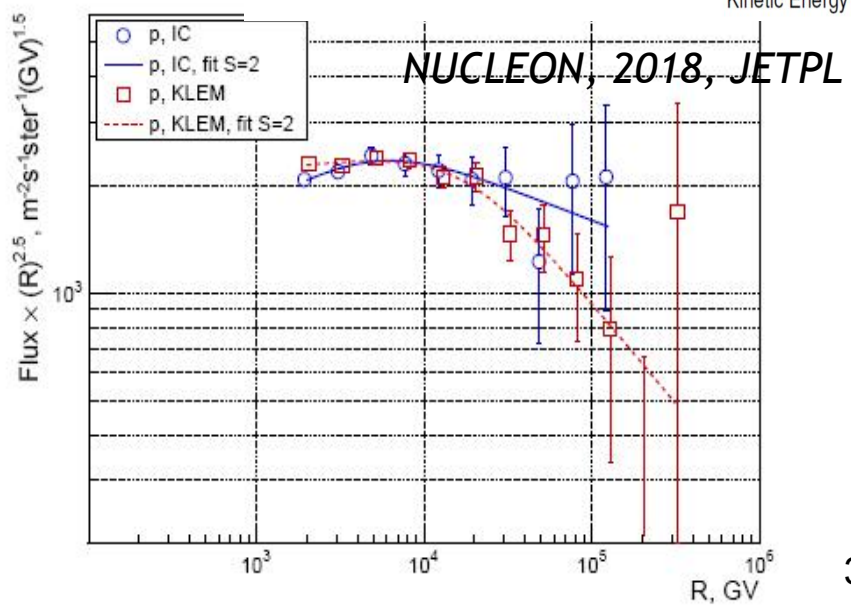
Spectral structures of nuclei



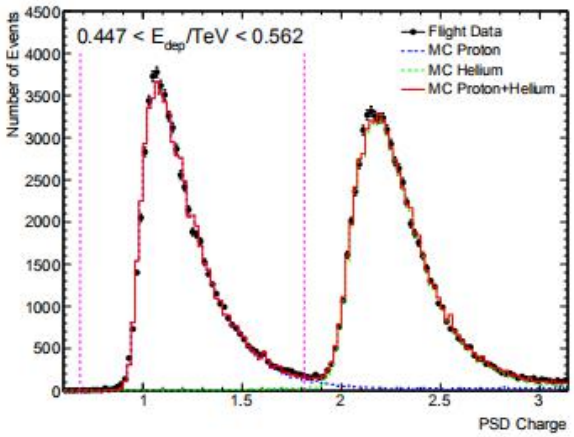


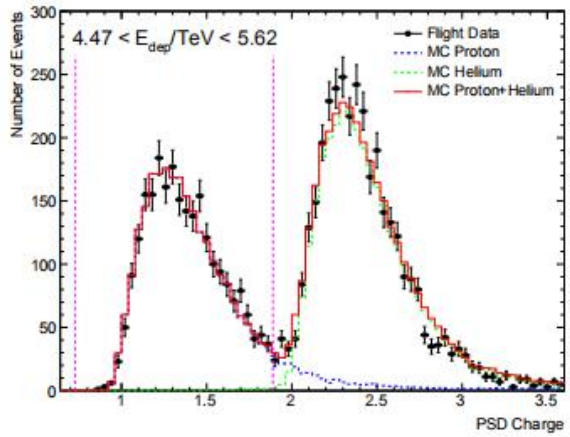


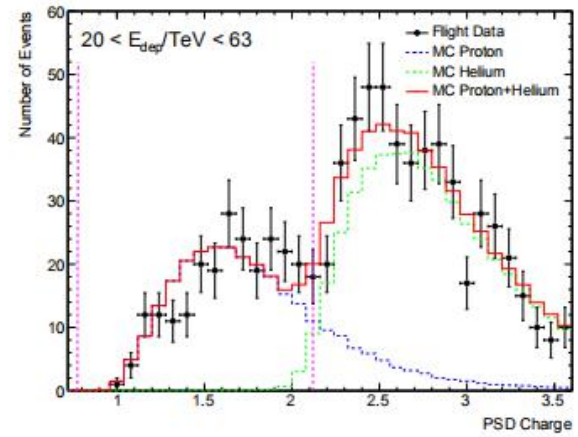




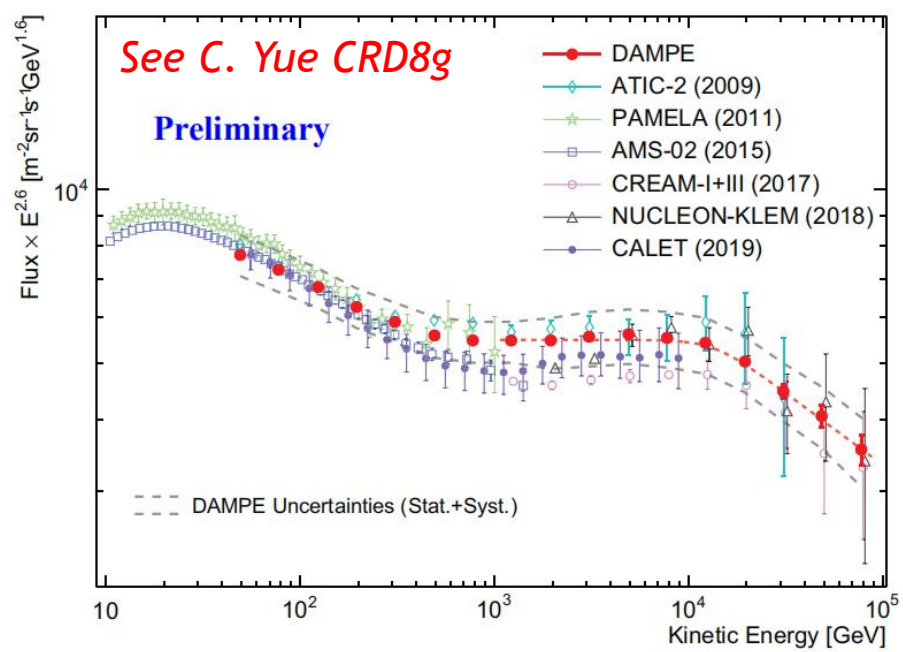
DAMPE proton spectrum





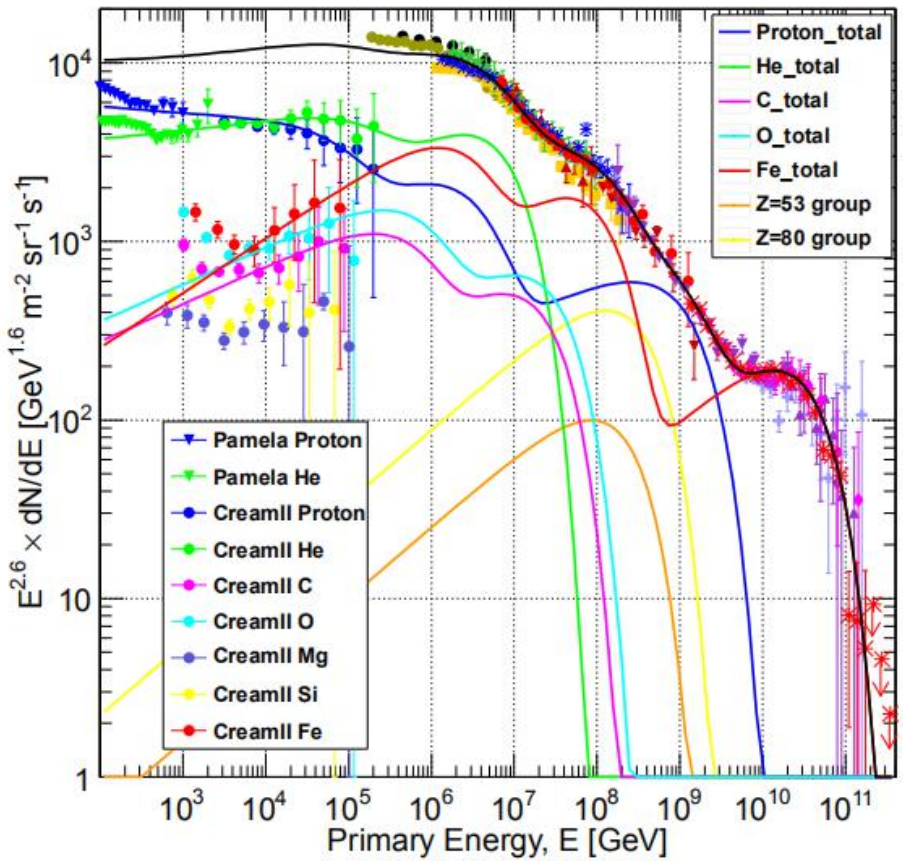


- Confirms the hundreds GeV hardening
- Detecting a softening at ~13 TeV with high significance

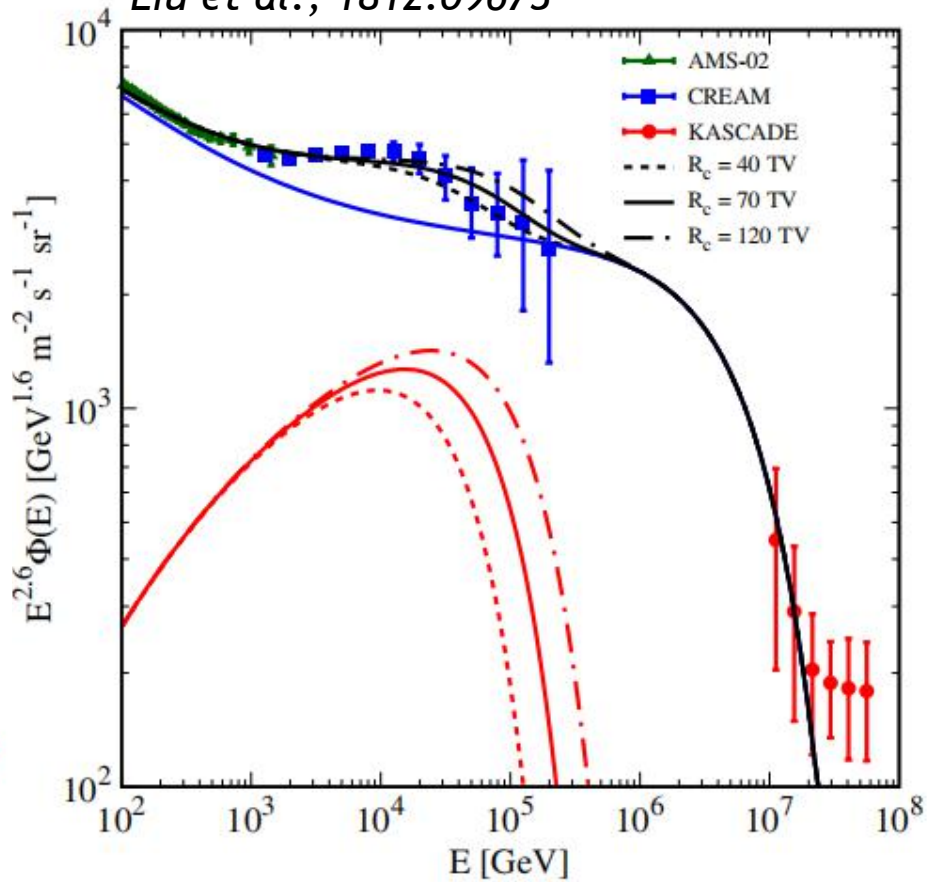


Implications: source population(?) Nearby source(?)

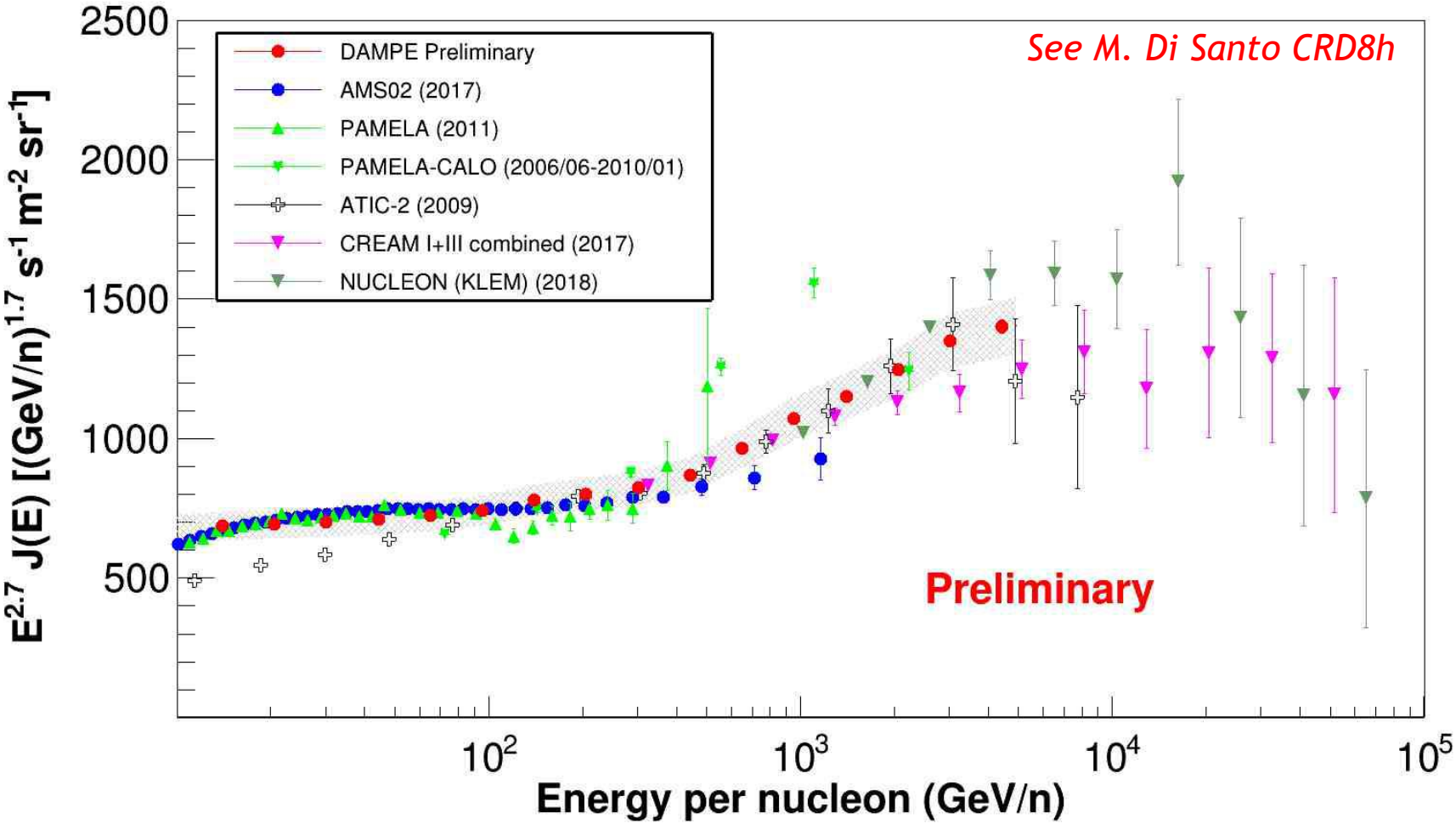
Gaisser et al. (2013)



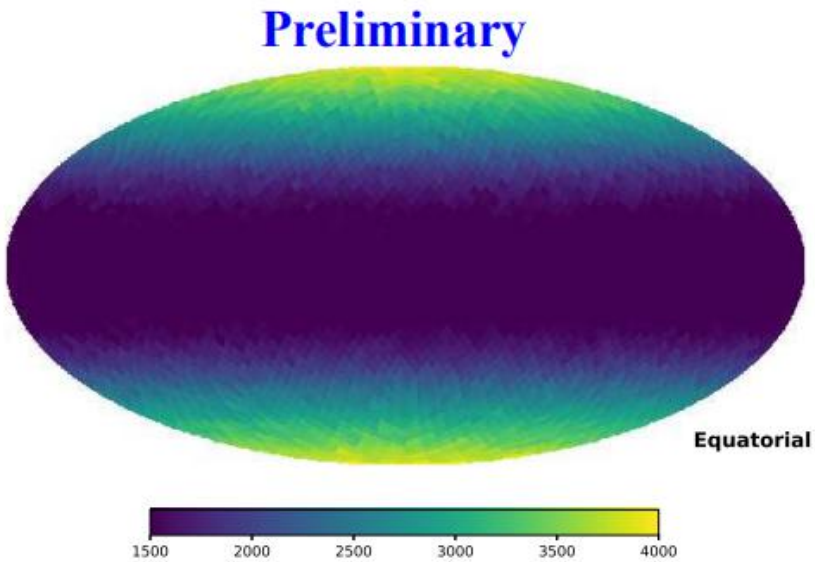
Liu et al., 1812.09673

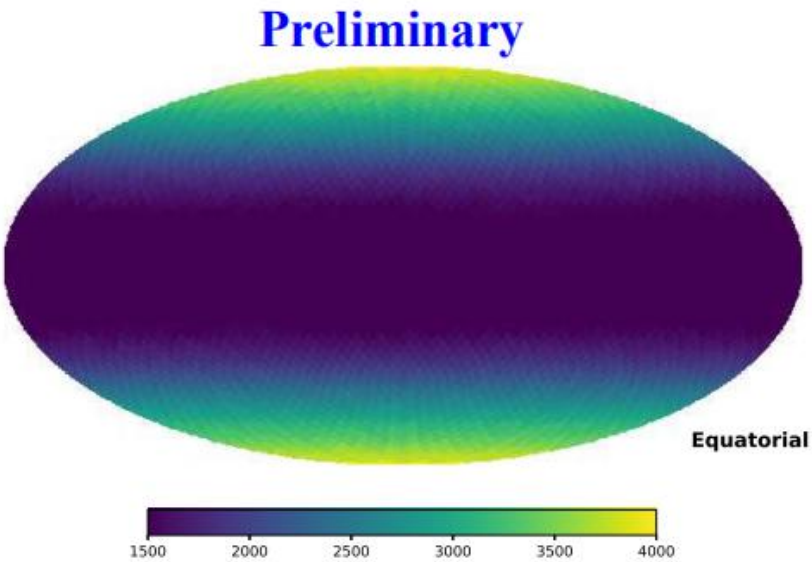


DAMPE helium spectrum

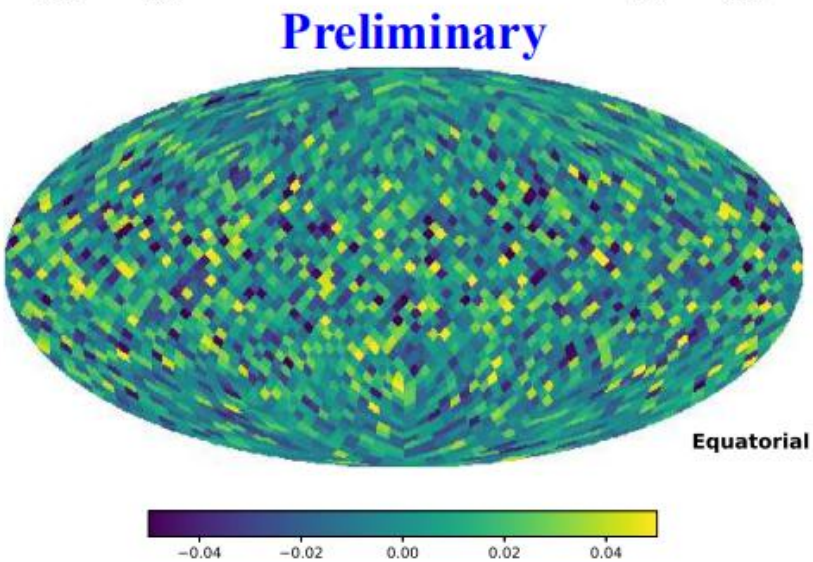


Cosmic ray anisotropies



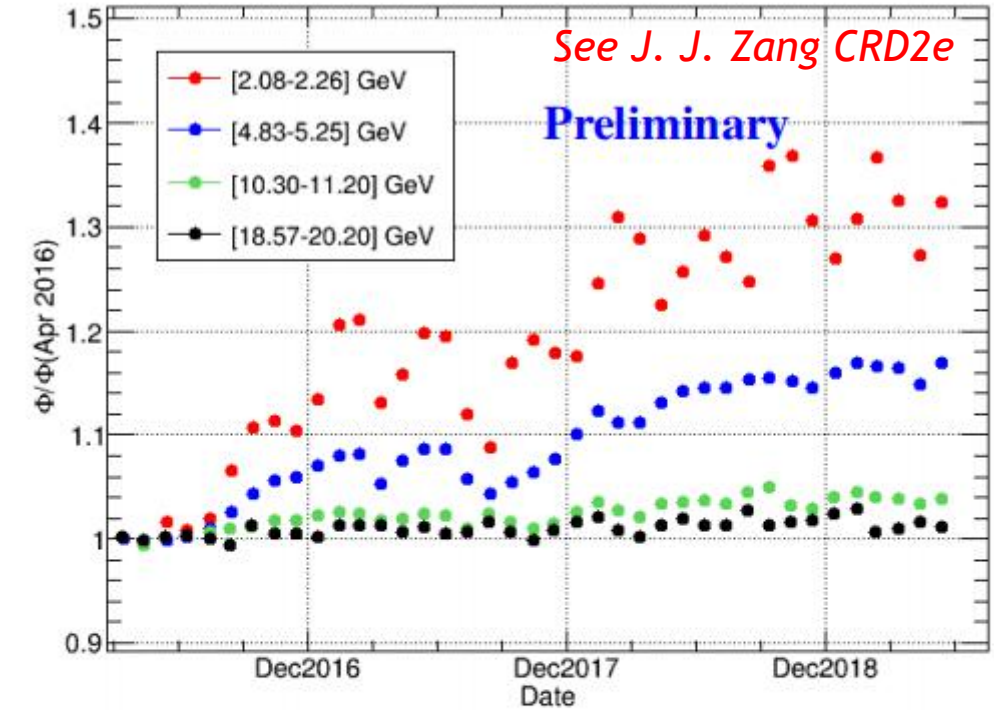


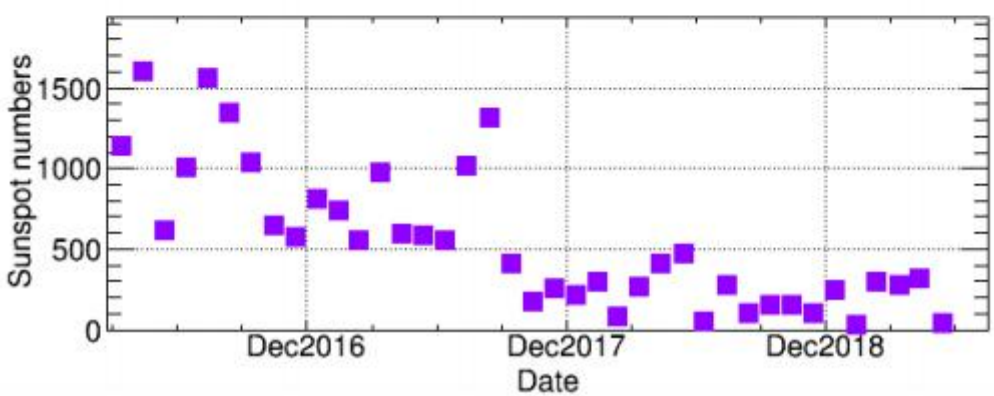
95% UL of dipole amplitude for 1-yr data (>~300 GeV): 6.7×10^{-3}



See M. Munoz CRD4e

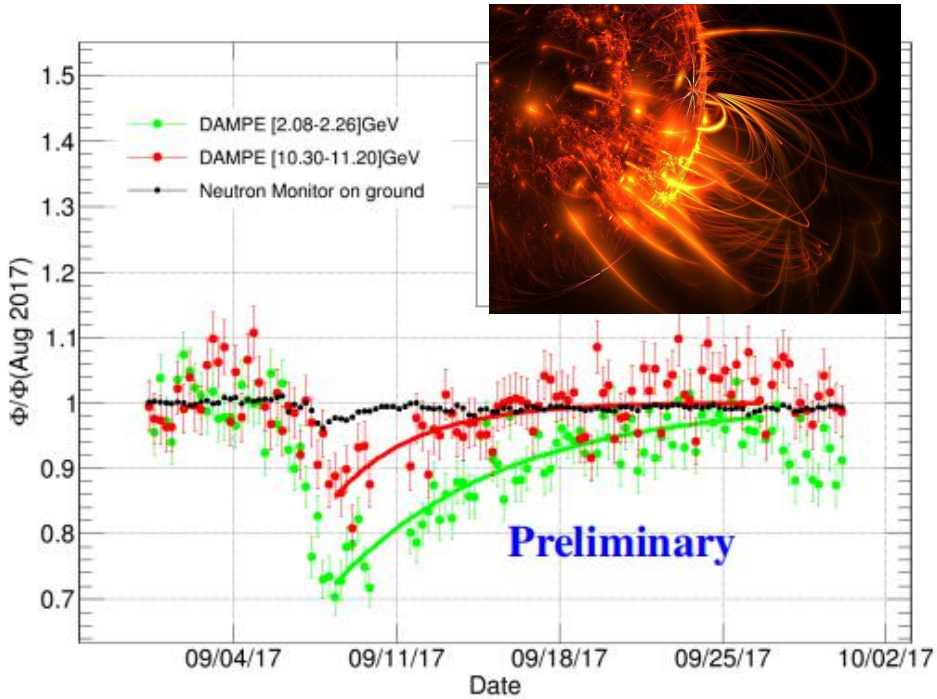
Solar modulation of $e^+ + e^-$

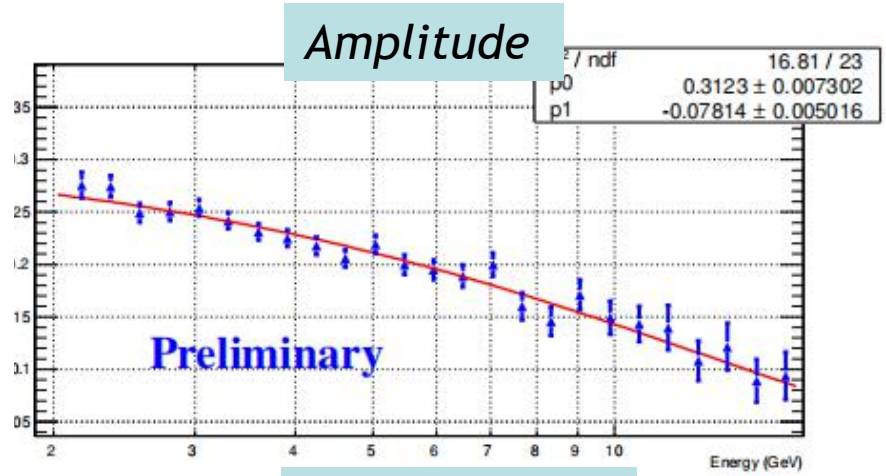


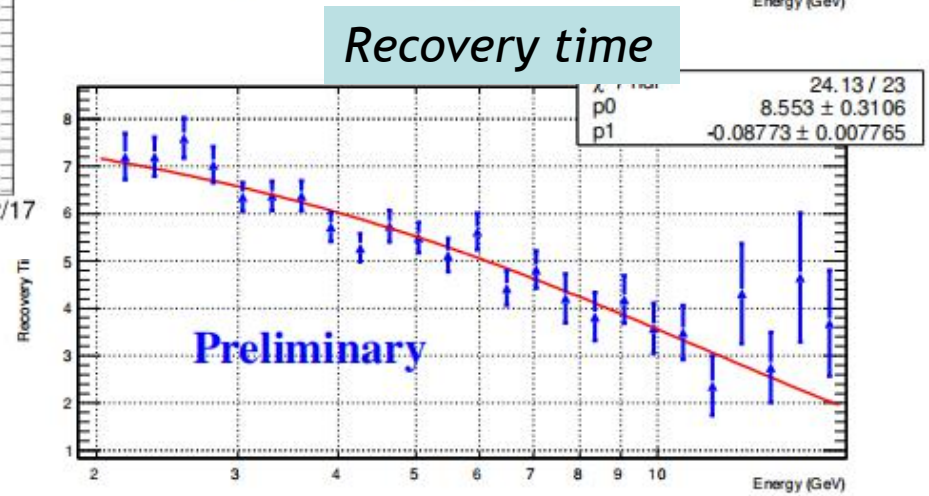


- Anti-correlation with sunspot numbers
- Monthly variation may be related to occasional solar activities
- Possible time delay between sunspot numbers and CR modulation

Electron Forbush decrease







- Clear flux decreases after 2017/09/07 flare
- Decreasing behavior of recovery time versus energy

See J. J. Zang CRD2e

DAMPE contributions at ICRC2019

- H16: Progresses of the Dark Matter Particle Explorer
- CRD2e: Observation of time evolution of cosmic ray electron and positron flux with Dark Matter Particle Explorer
- CRD4e: Anisotropy Searches with DAMPE
- CRD7b: Elemental analysis of Cosmic Ray flux with DAMPE
- CRD7e: The Status of DAMPE Satellite in Space
- CRD8g: Measurement of cosmic ray proton spectrum with the Dark Matter Particle Explorer
- CRD8h: Helium spectrum in the cosmic rays measured by the DAMPE detector
- GAD3a: Recent Gamma ray Results from DAMPE
- GAD2d: Gamma ray Pulsars with DAMPE

- PS1-2: Checking the Reconstructed Energy of the DAMPE Experiment with Geomagnetic Cutoff CR-Nuclei
- PS1-5: Charge Measurement of Cosmic Ray Nuclei with DAMPE - Tiekuang Dong
- PS1-6: Neural Networks for Electron Identification with DAMPE
- PS1-7: TeV—PeV hadronic simulations with DAMPE
- PS1-17: First Look on Fractional Charged Particles in Space Based on DAMPE Orbit Data
- PS1-19: A Method of Alignment for Plastic Scintillator Detector of DAMPE

DAMPE contributions at ICRC2019

- PS1-36: Measurement of the Cosmic-ray Proton + Helium Spectrum with DAMPE
- PS1-37: Hadronic cross section validation in the DAMPE experiment
- PS1-42: The selection and energy validation of heavy ions based on DAMPE orbit data
- PS1-44: Ultra-heavy cosmic rays measurements with DAMPE
- PS1-248: Boresight Alignment with DAMPE
- PS1-256: Search for a gamma-ray line feature with DAMPE

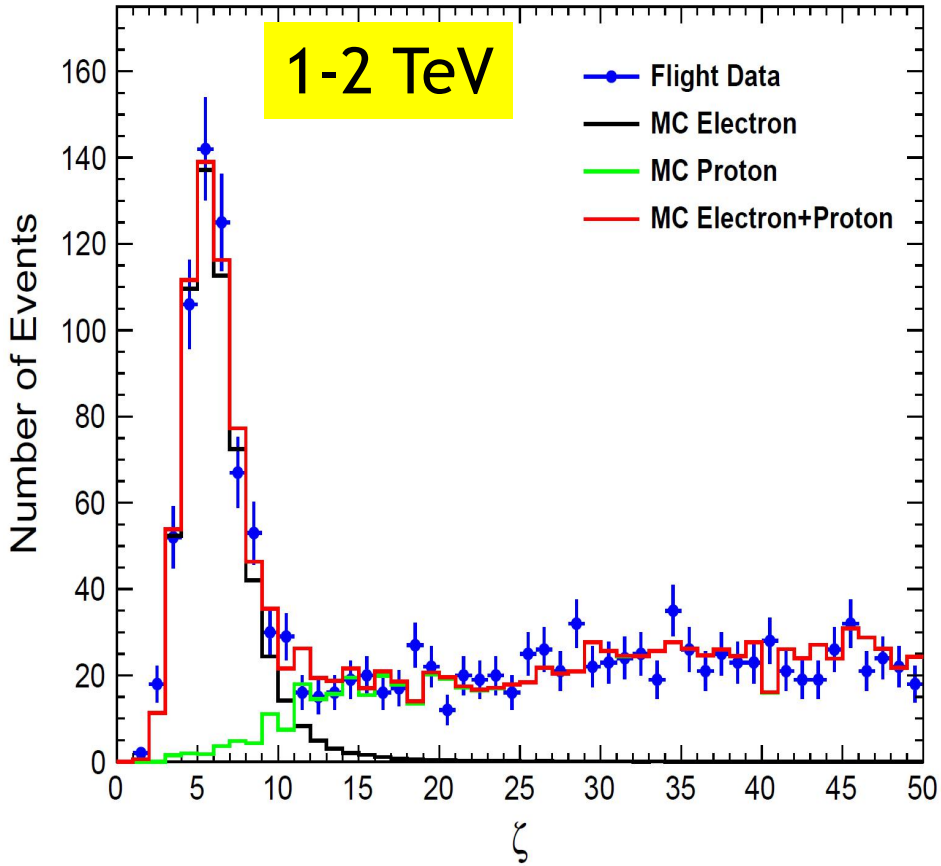
Summary

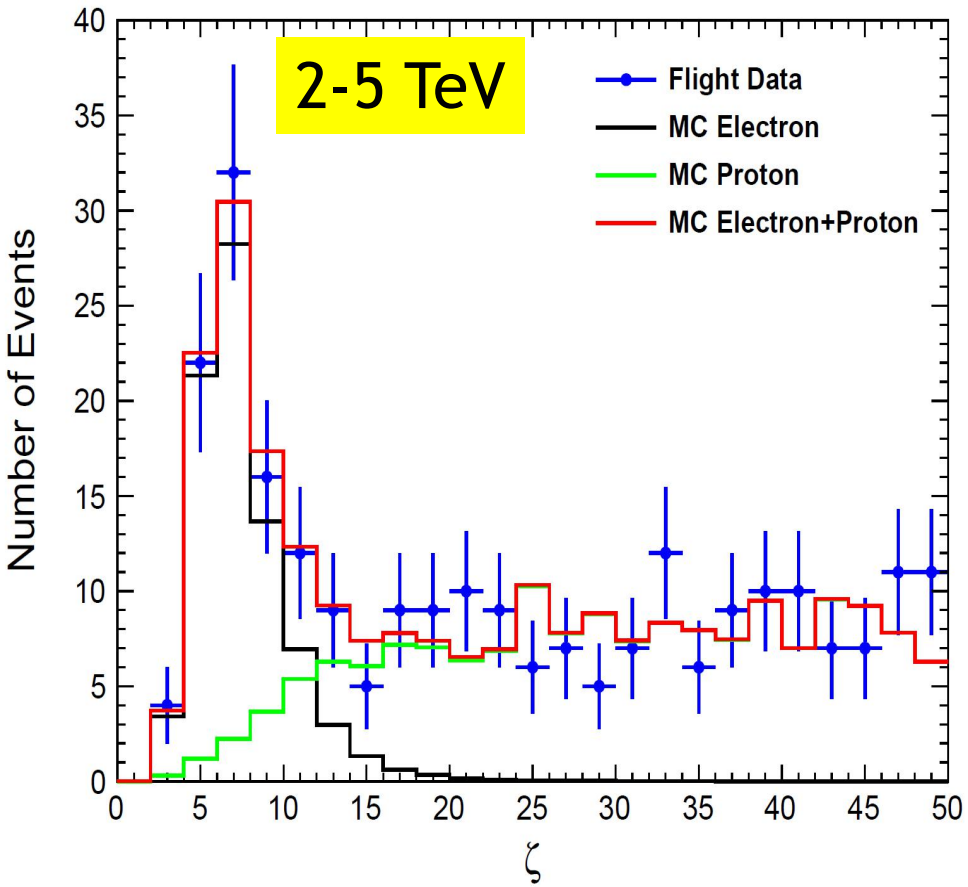
- DAMPE detector is working extremely well since launch
- Very precise measurements of the e^++e^- spectrum from 25 GeV to 4.6 TeV have been obtained, showing a spectral break at ~TeV energies and possible new spectral features
- Precise measurements of proton spectrum from 40 GeV to 100 TeV have been obtained, revealing interesting softening features at ~10 TeV
- More results are coming

Thank You!

Backup

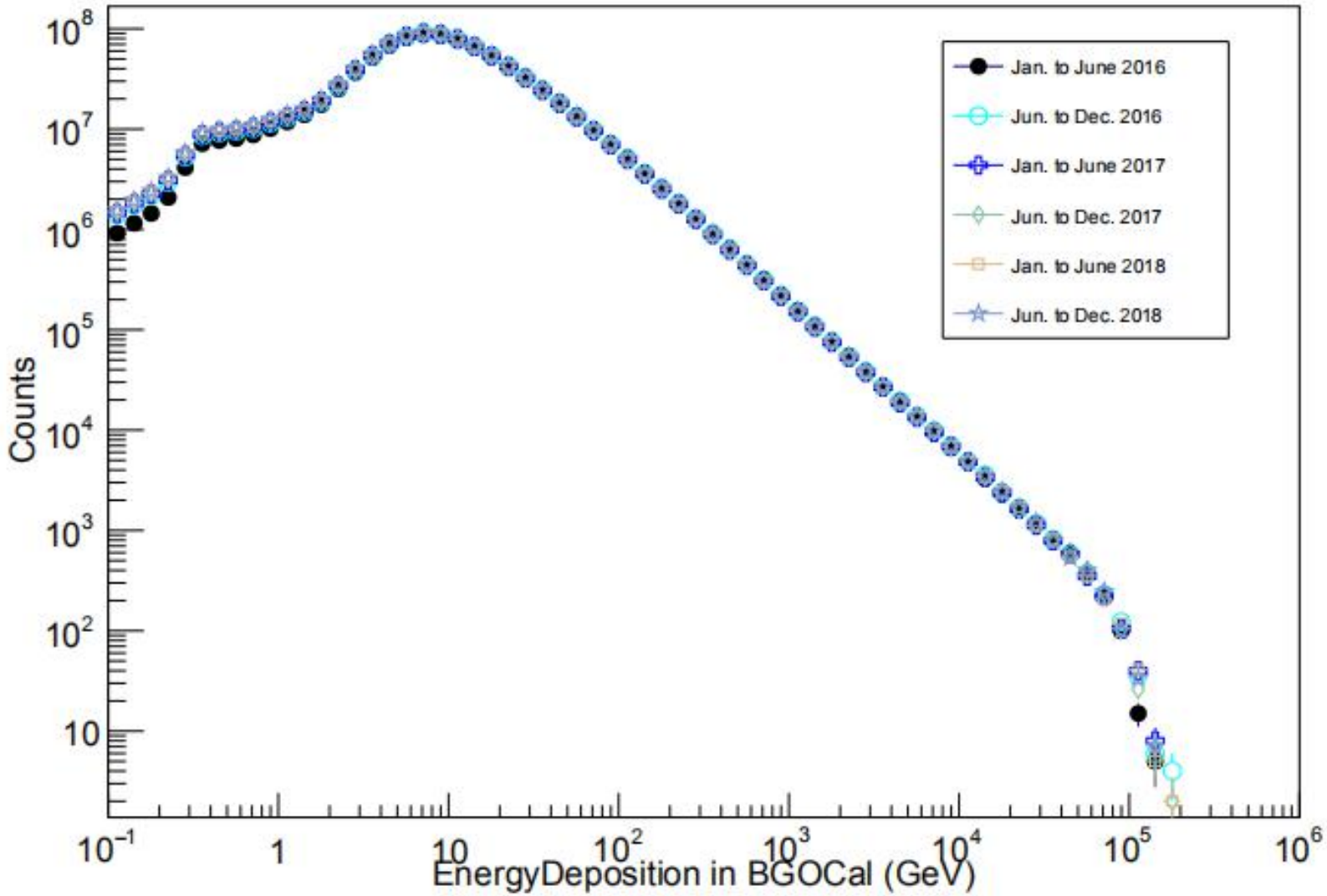
e/p separation at higher energies



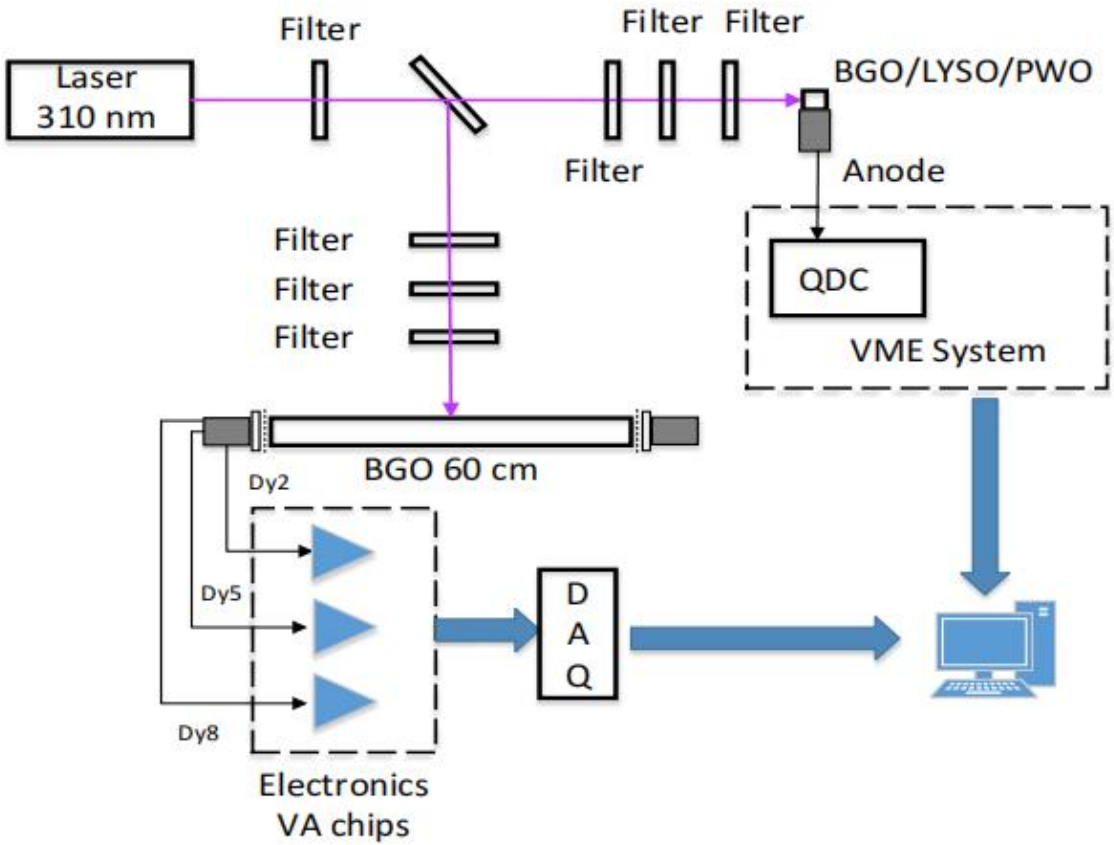


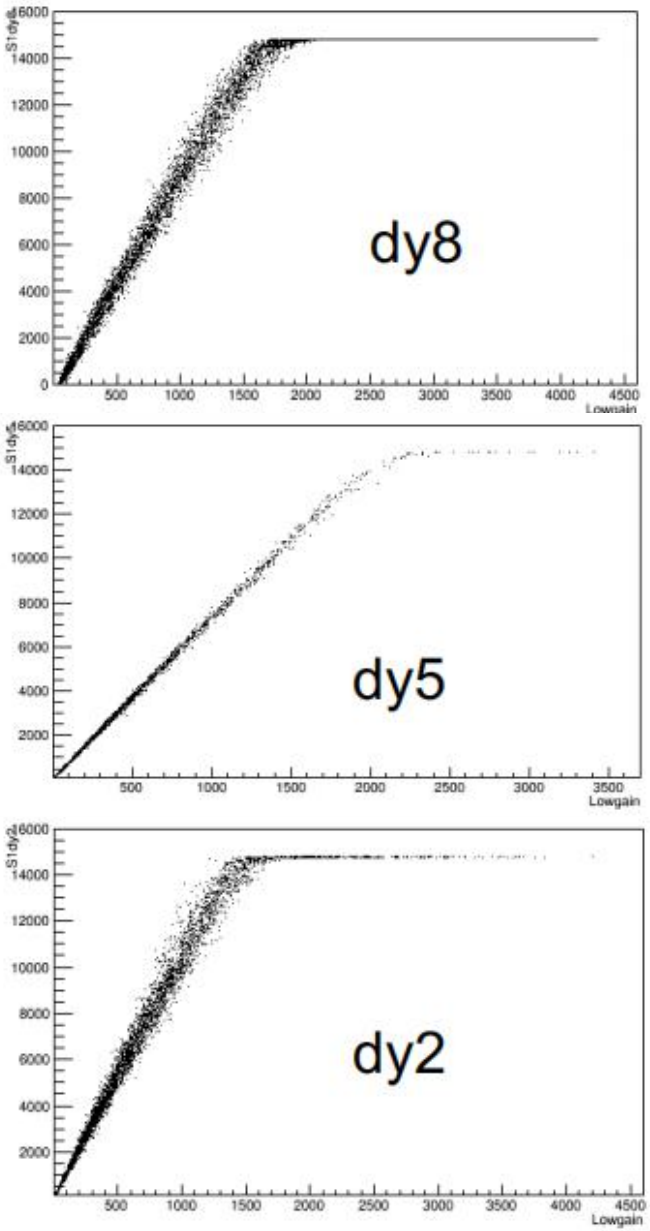
For 90% electron efficiency, proton background is ~2% @ TeV, ~5% @ 2 TeV, ~10% @ 5 TeV.

Raw count spectra

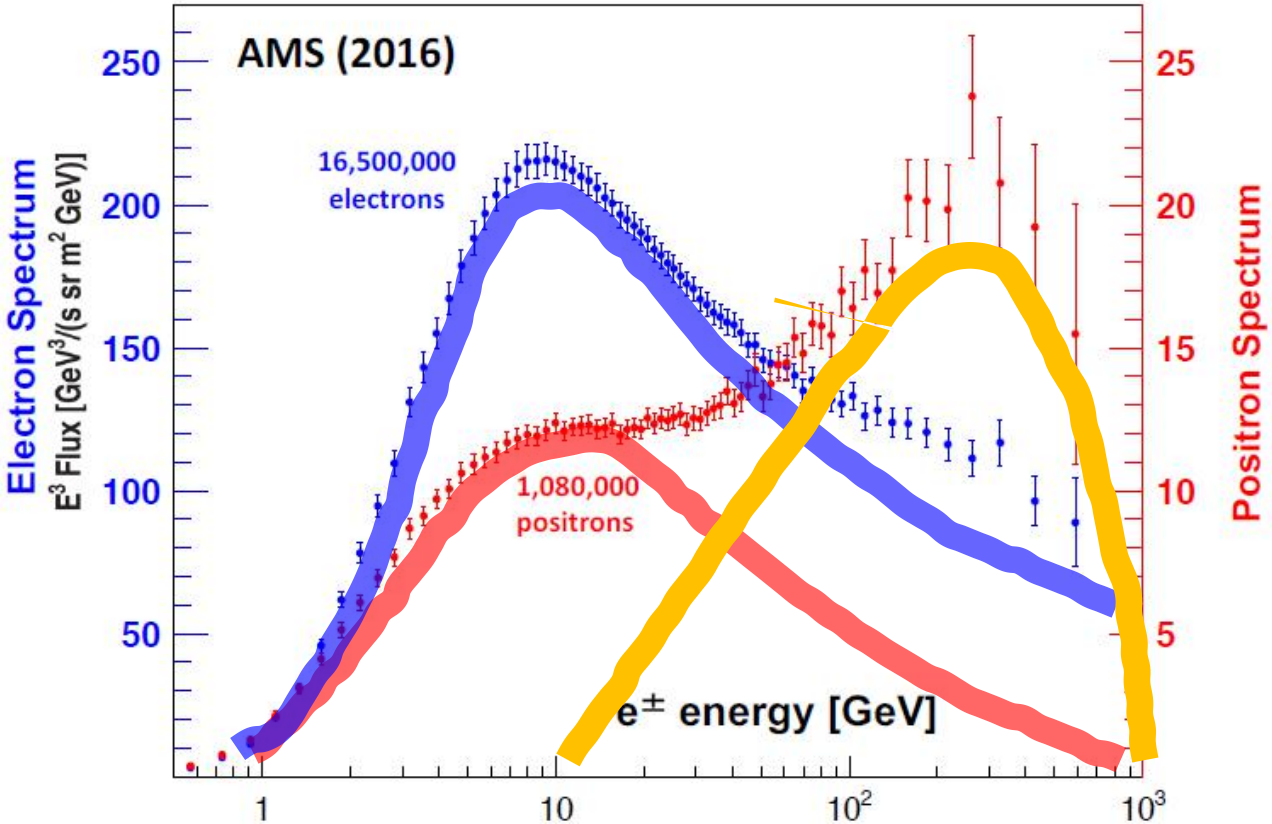


Laser experiment





Three-component e^+e^- model



- Primary e- accelerated together with ions (in e.g., supernova remnants)
- Secondary e- and e+ from hadronic interaction of cosmic ray nuclei
- Additional e- and e+ from extra sources (e.g., pulsars, ...)