Latest results of the Dark Matter Particle Explorer (DAMPE) experiment

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Purple Mountain Observatory

(on behalf of the DAMPE collaboration)

10th International Workshop on Air Shower Detection at High Altitudes

Nanjing, Jan. 7 - 10, 2020

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

Dark Matter Particle Explorer (DAMPE)

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

- Excellent energy resolution
- Excellent e-p separation

Three major scientific goals

Cosmic ray physics ⟵

⟶ γ-ray astronomy

⟱ Dark matter indirect detection

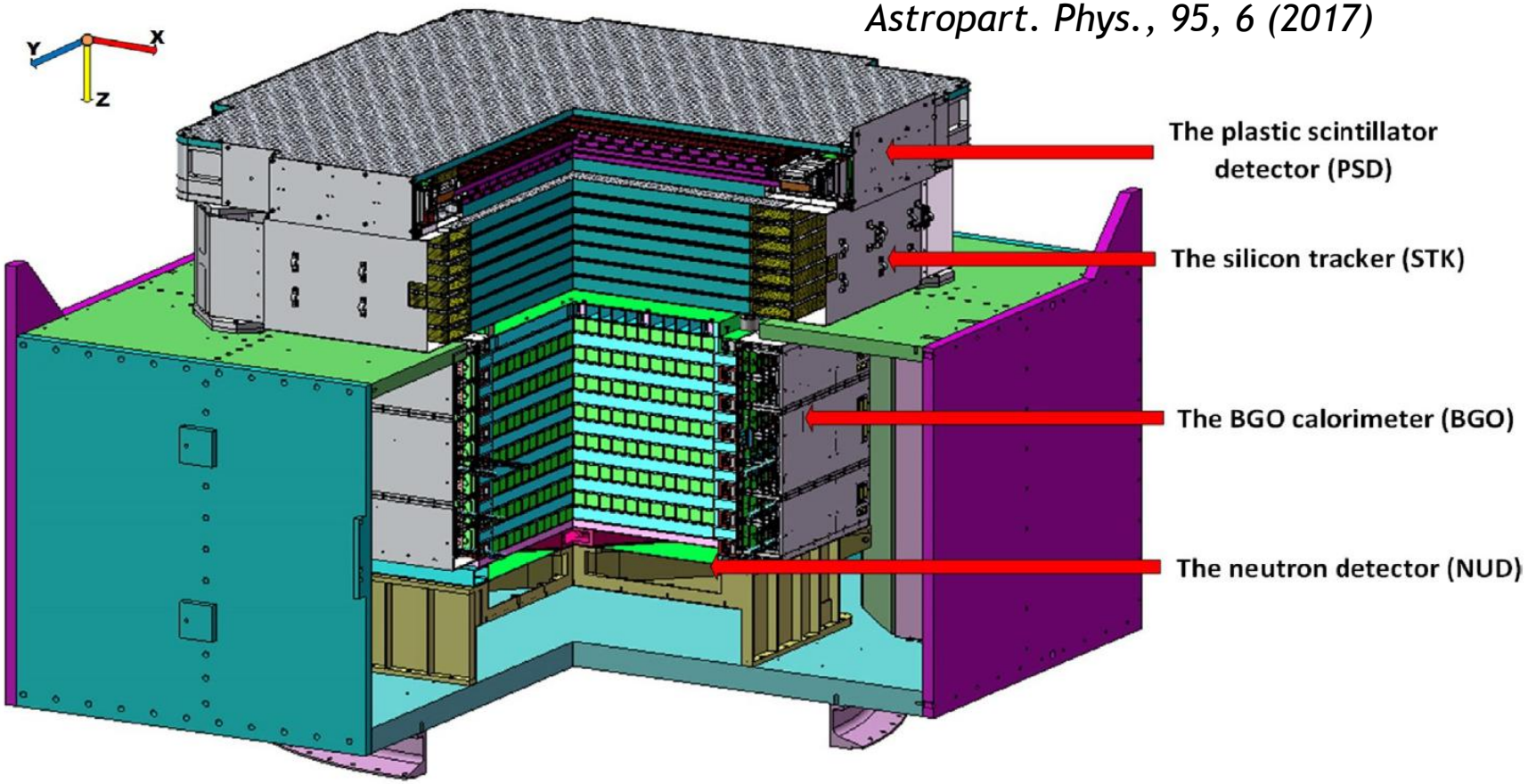
Outline

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

DAMPE instrument

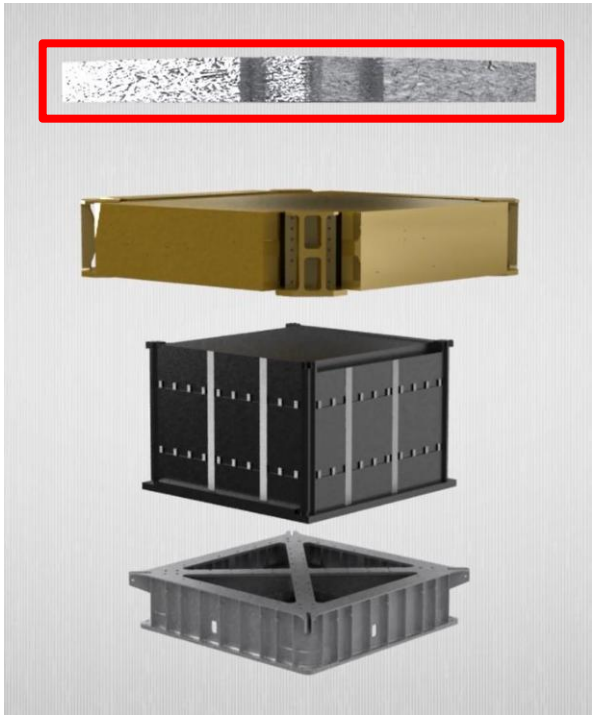
Instrument design

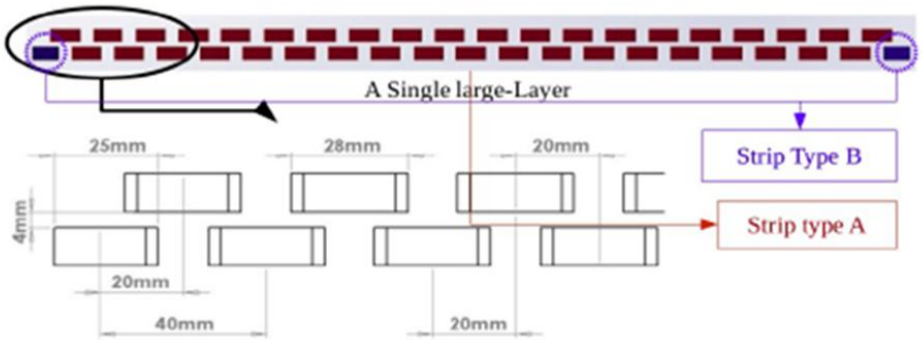
Astropart. Phys., 95, 6 (2017)



- 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

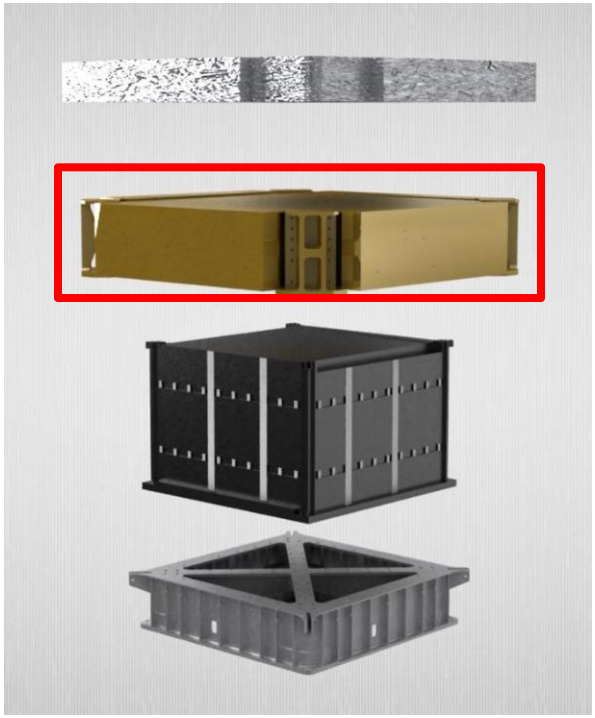
PSD charge detector

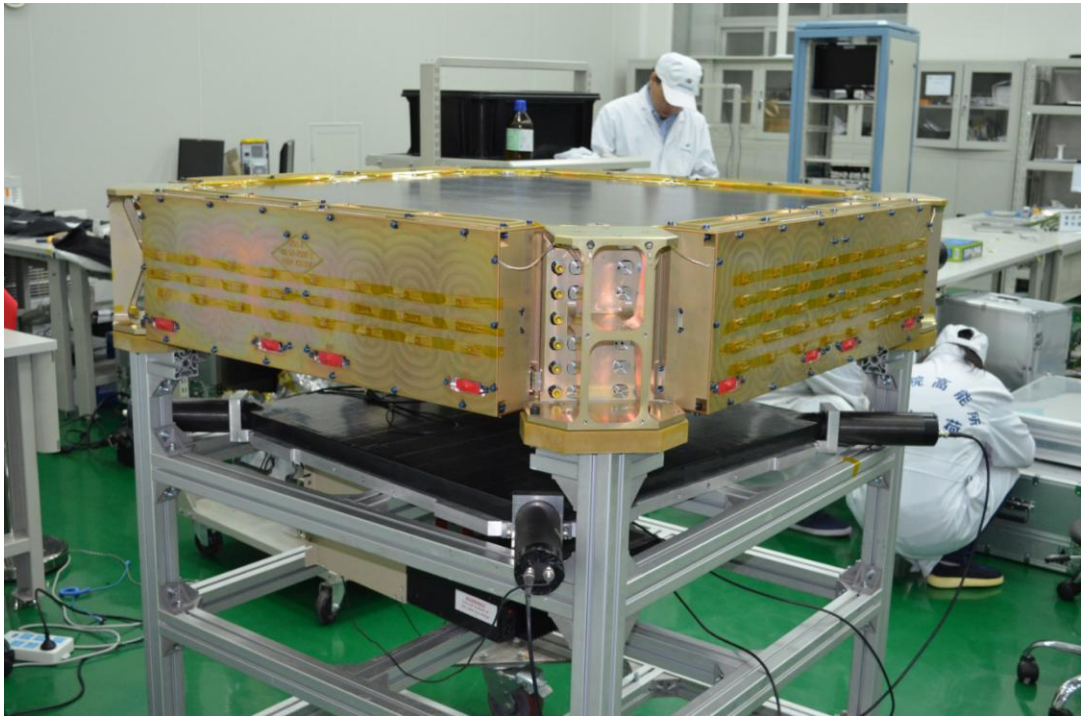




- 2 layers (x,y) of 88.4 cm × 2.8 cm × 1 cm
- Active area: 82 cm × 82 cm
- Weight : ~103 kg
- Power: ~ 8.5 W

Silicon tracker

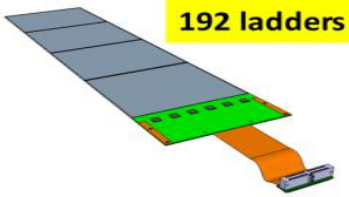


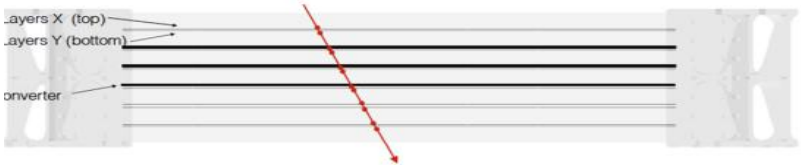


768 silicon sensors
95 x 95 x 0.32 mm³

1,152 ASICs

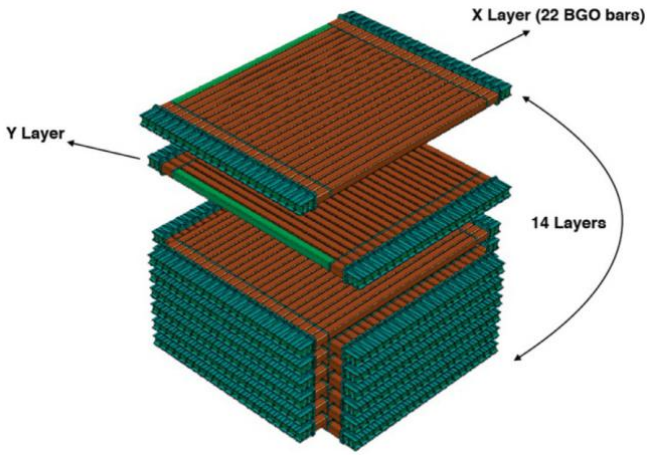
73,728 channels





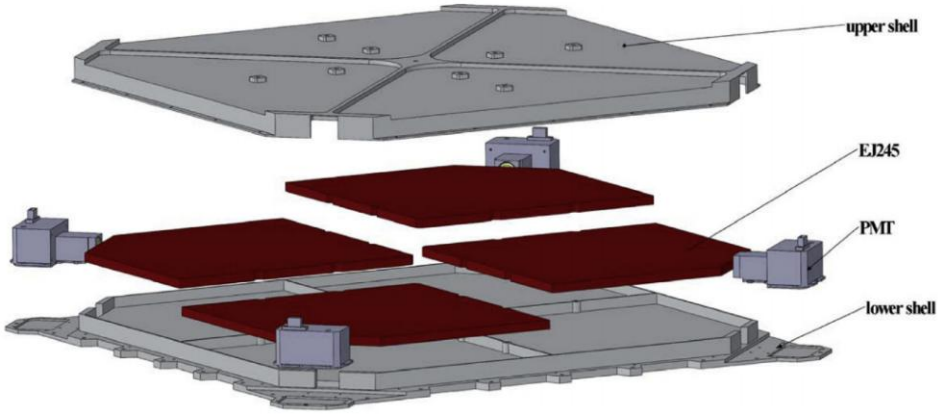
- Detection area: 76 cm x 76 cm
- Total weight: ~154 kg
- Total power consumption: ~ 82W
- Three 1 mm tungsten plates for photon conversion (0.86 X_0)

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

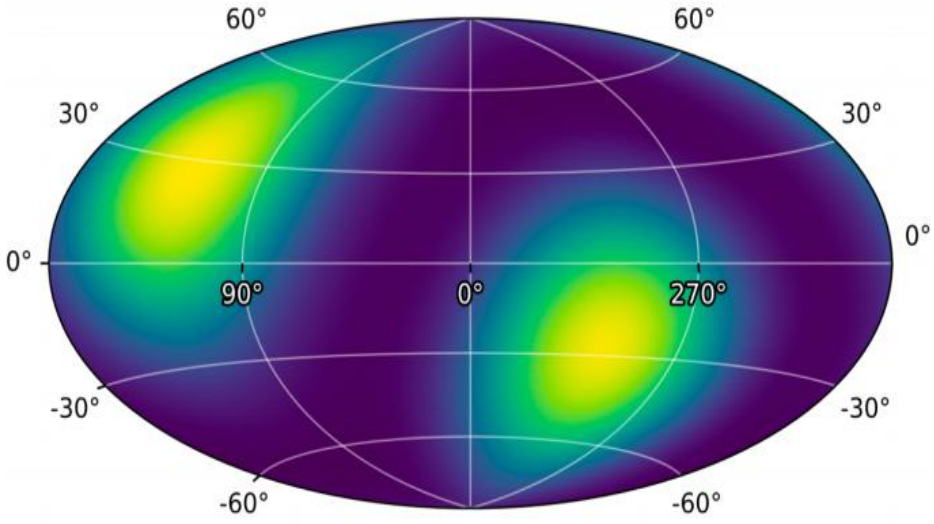


- $n + {}^{10}B \rightarrow \alpha + {}^{7}Li + \gamma$
- 4 plastic scintillators
- Active area: 60 cm x 60 cm
- Total weight: ~12 kg
- Total power: ~ 0.5 W

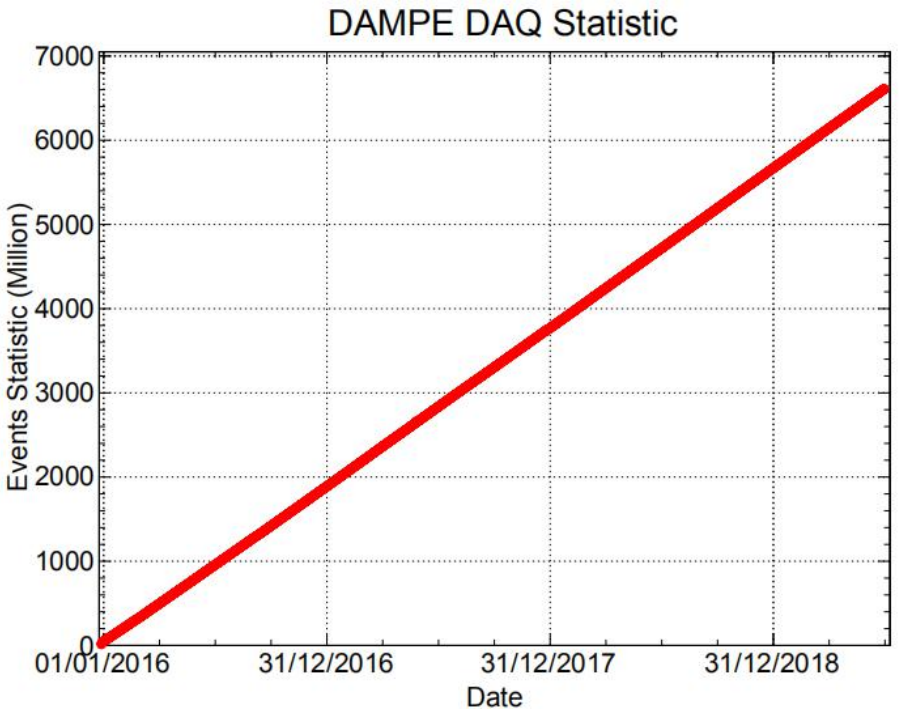
On-orbit performance

Observation overview

DAMPE 3.5 year counts map

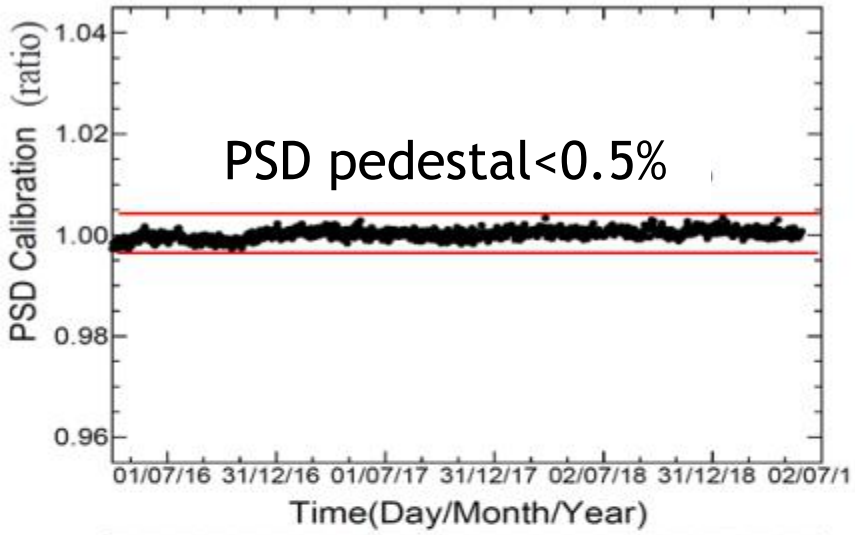


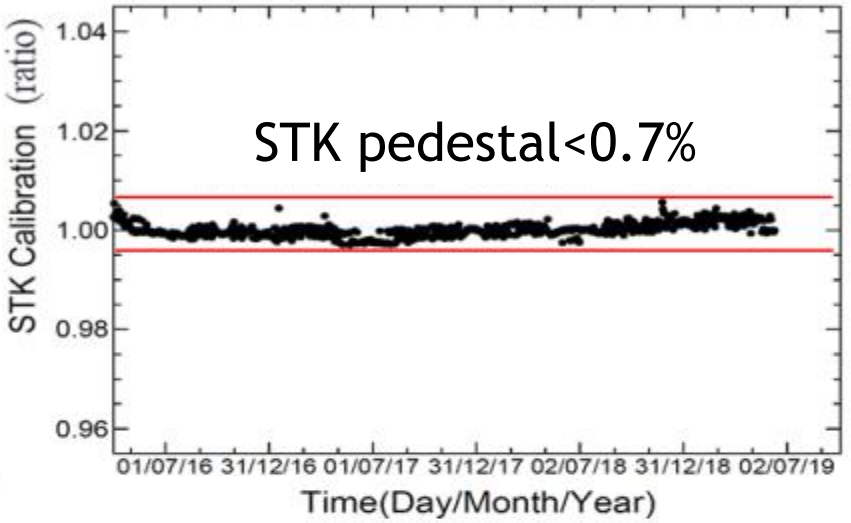
7 full scans of the sky

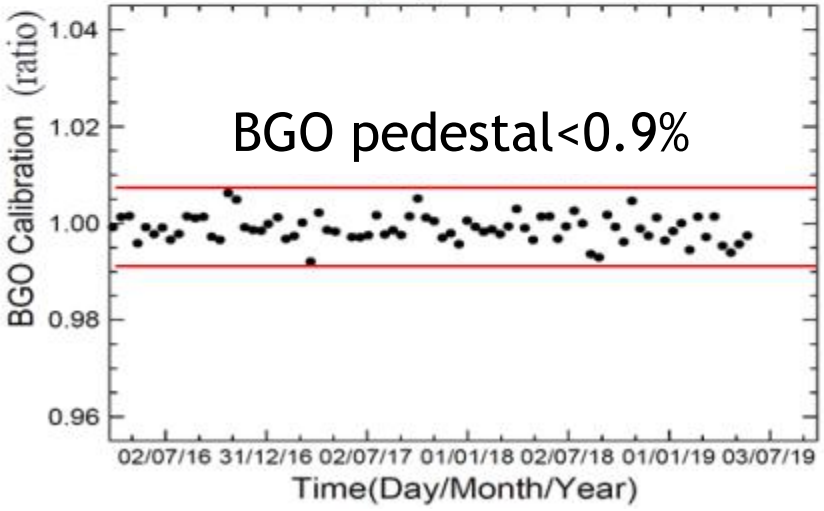


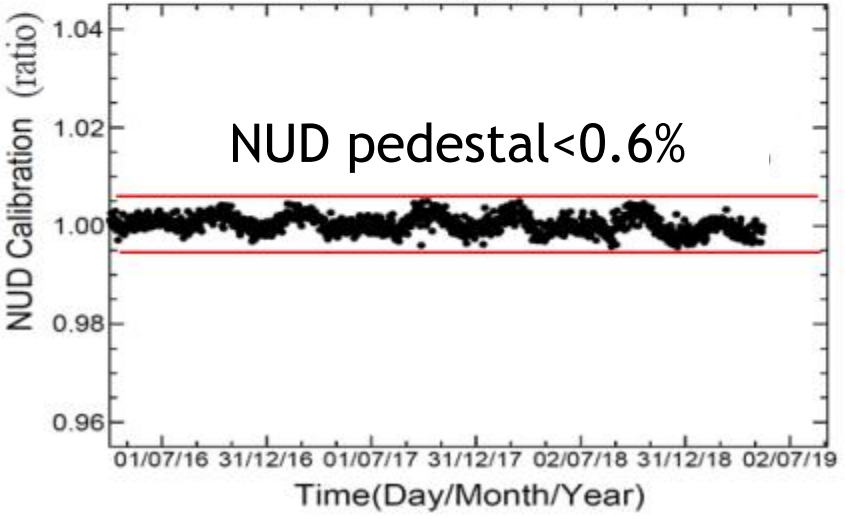
5M events/day
6.6 billion in total

Detector stability

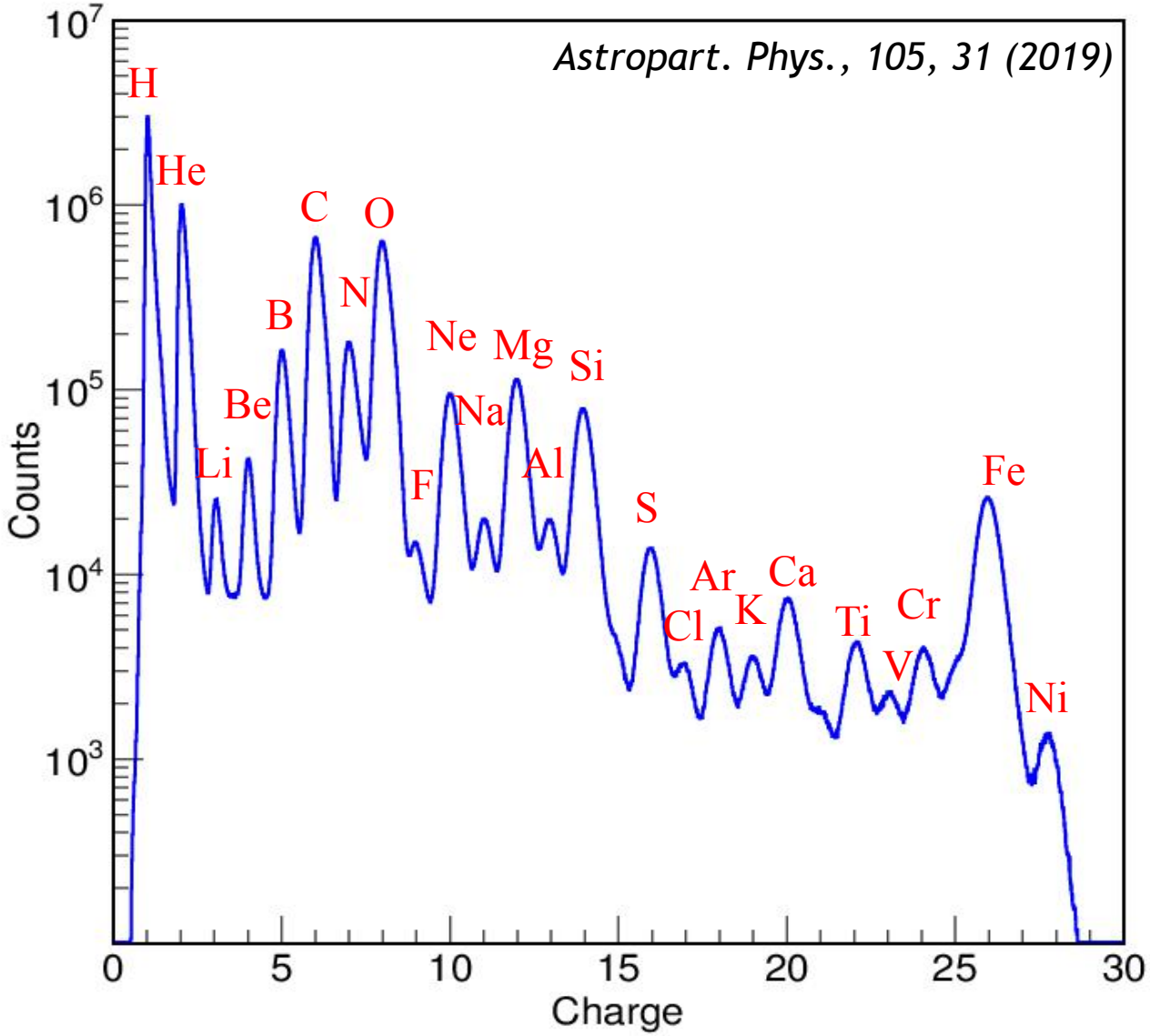






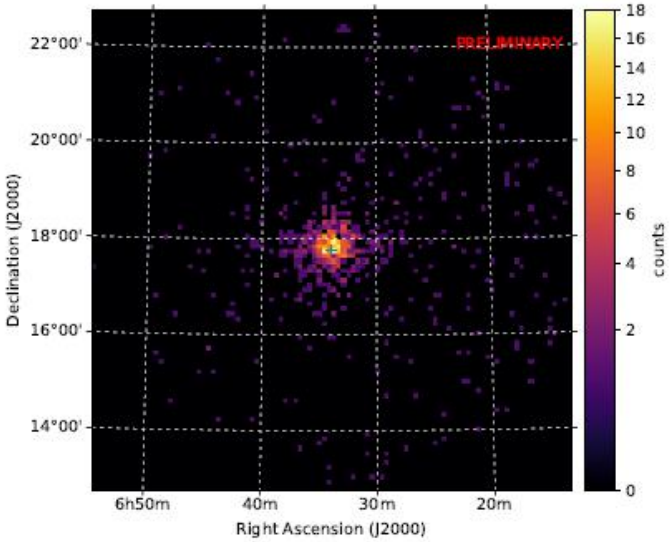


PSD charge measurement

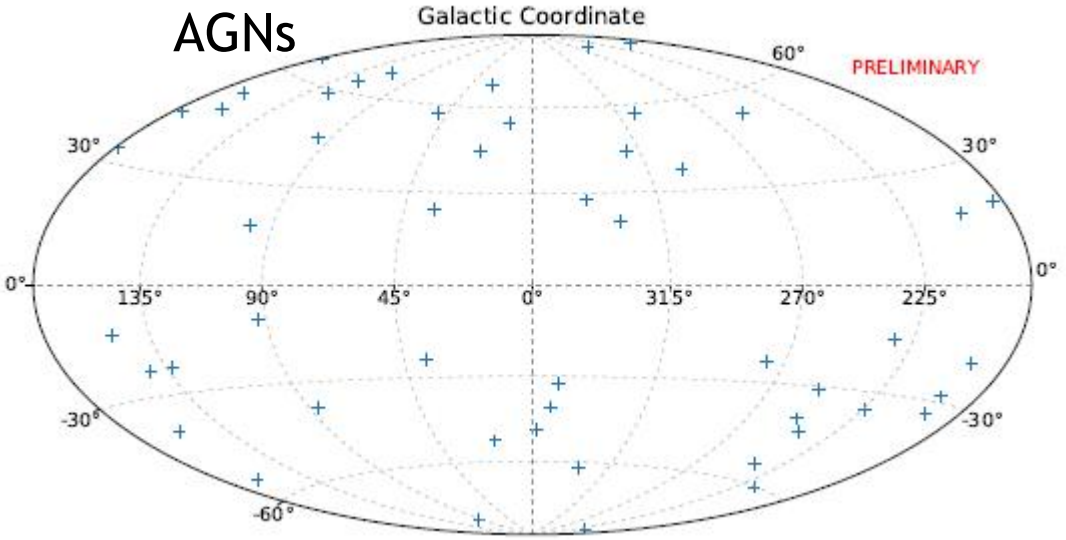


Species	Charge Res.
P	0.06
He	0.10
Li	0.14
Be	0.21
B	0.17
C	0.18
N	0.21
O	0.20

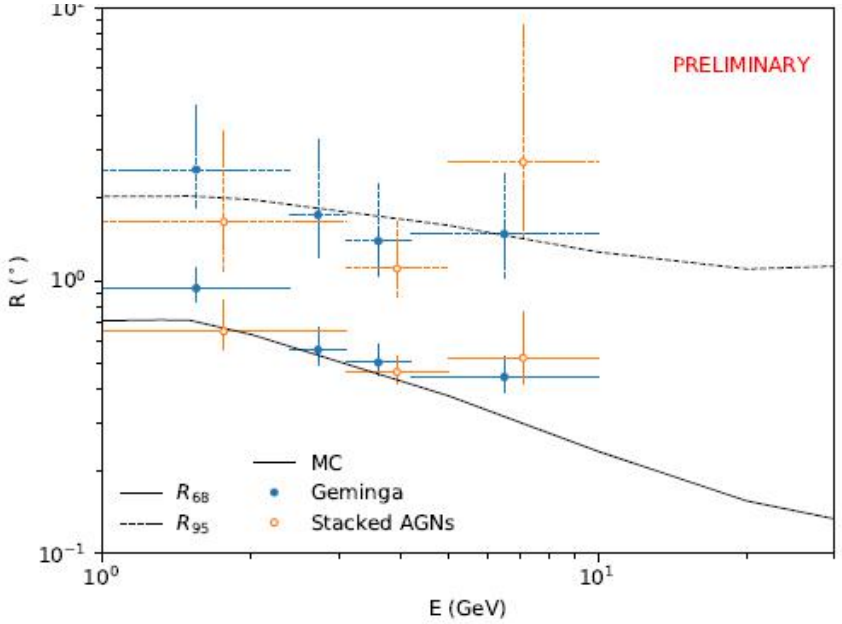
STK direction measurement



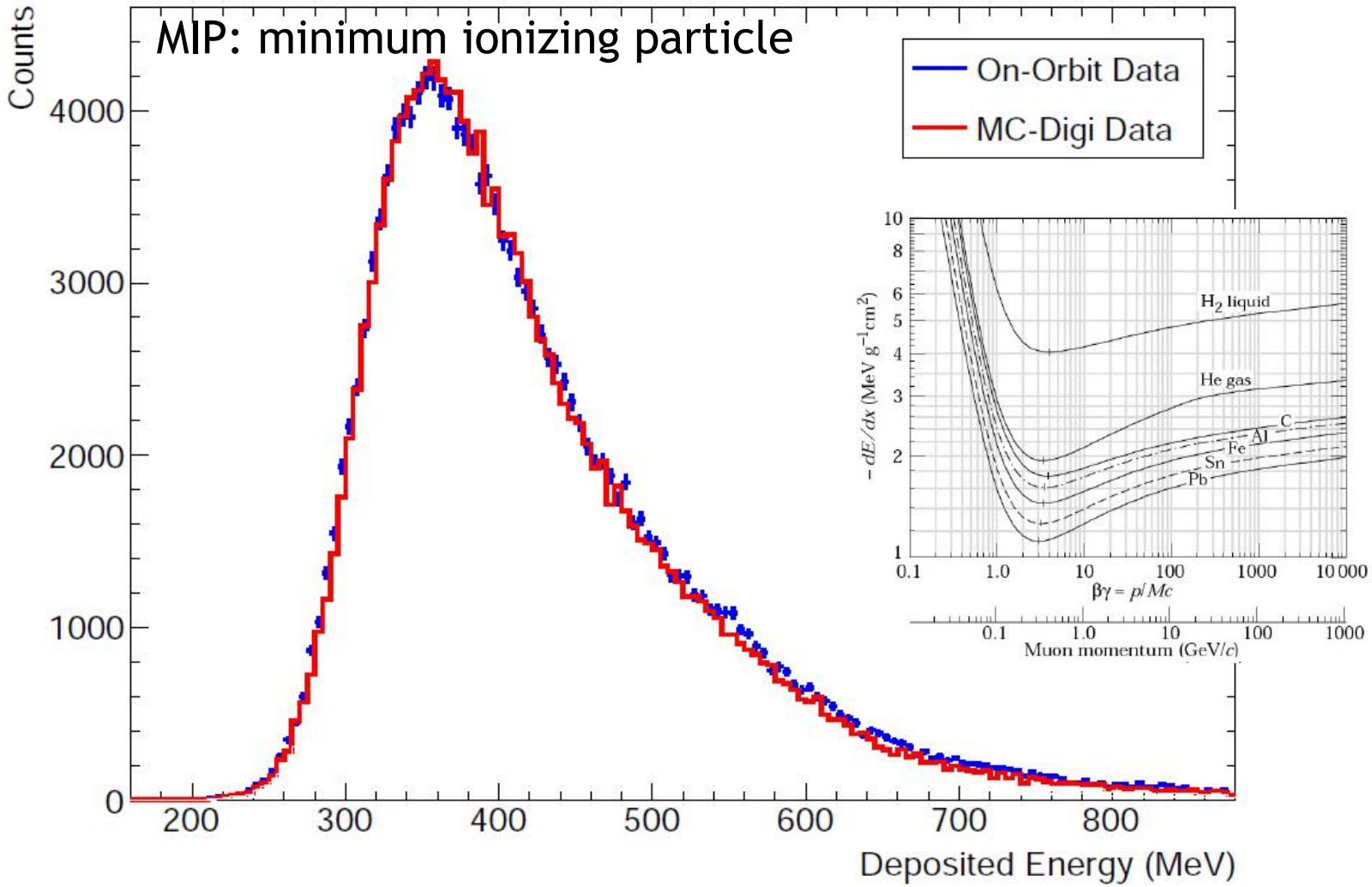
Geminga



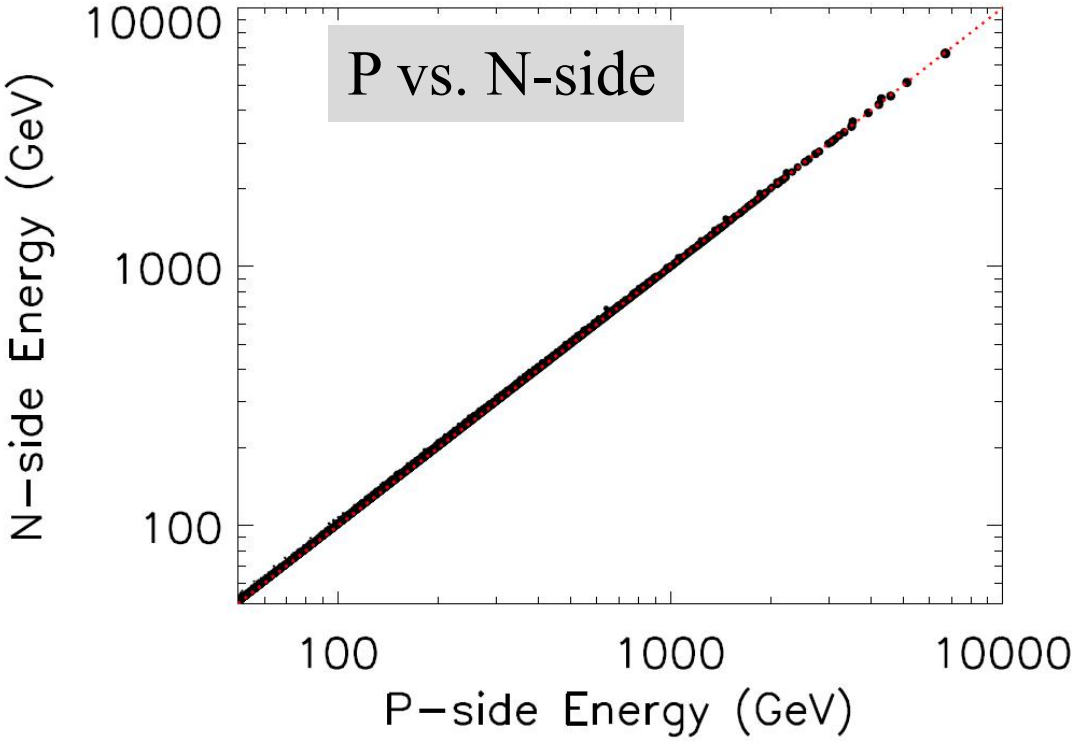
PSF calibrated with bright gamma-ray sources : ~0.5 degrees @ 5 GeV



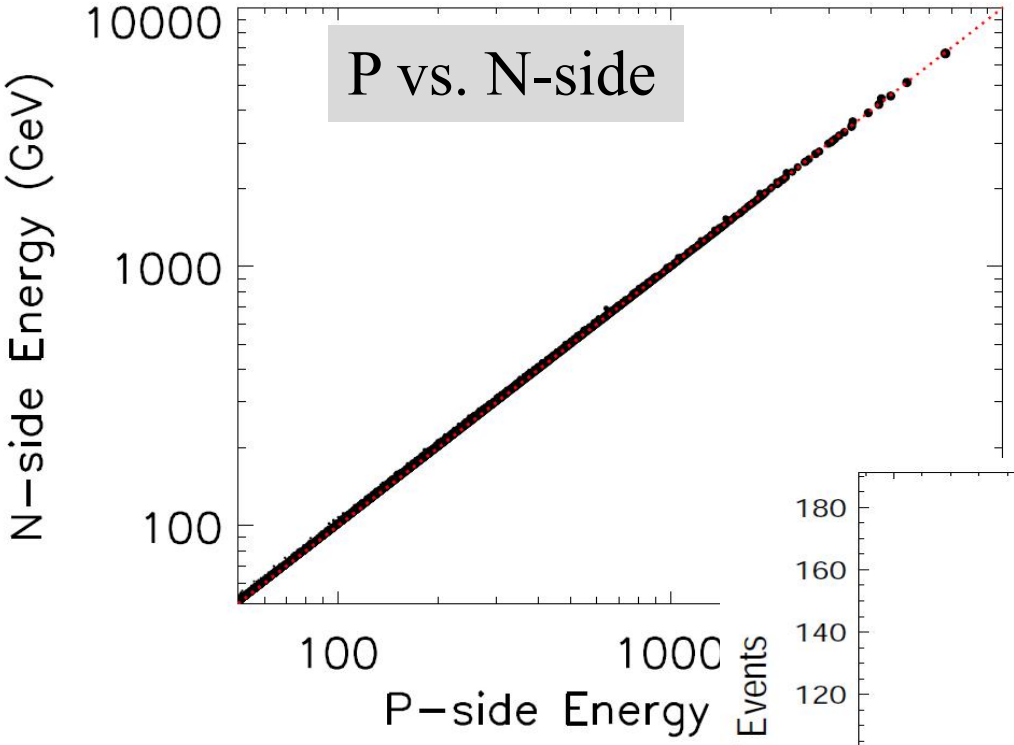
BGO energy calibration

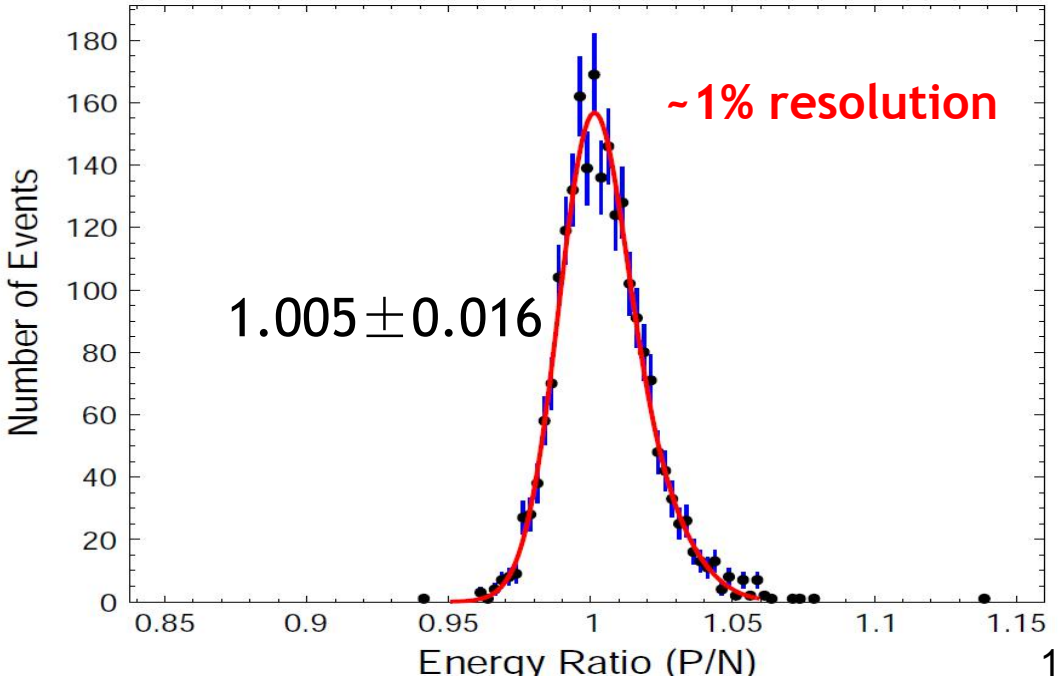


BGO energy linearity



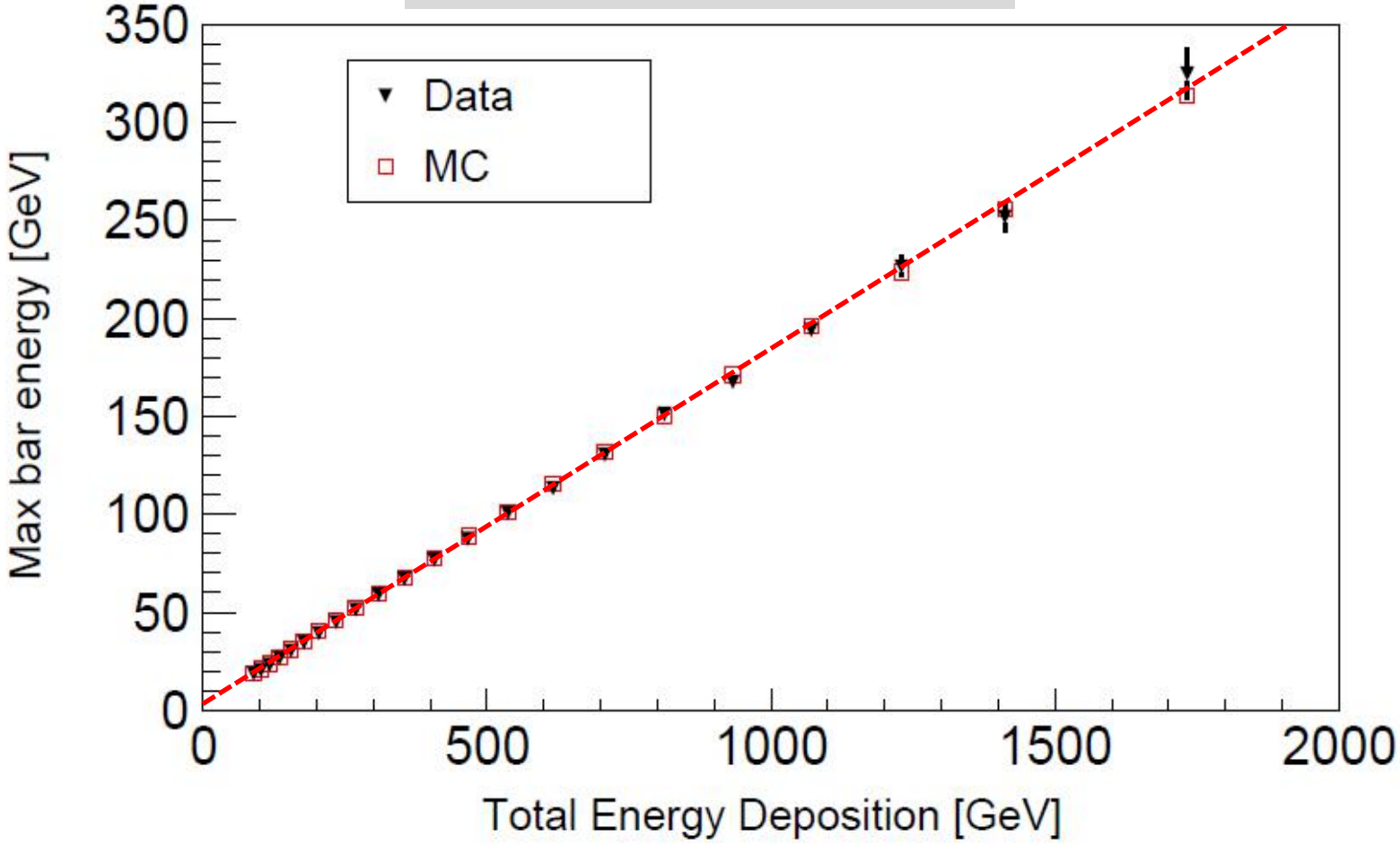
BGO energy linearity





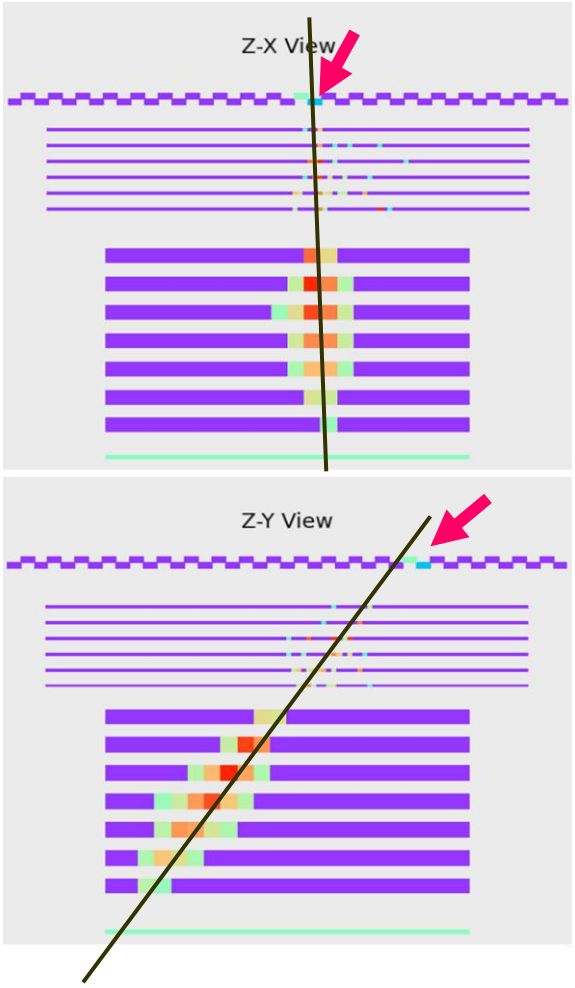
BGO energy linearity

Total vs. Max bar energy

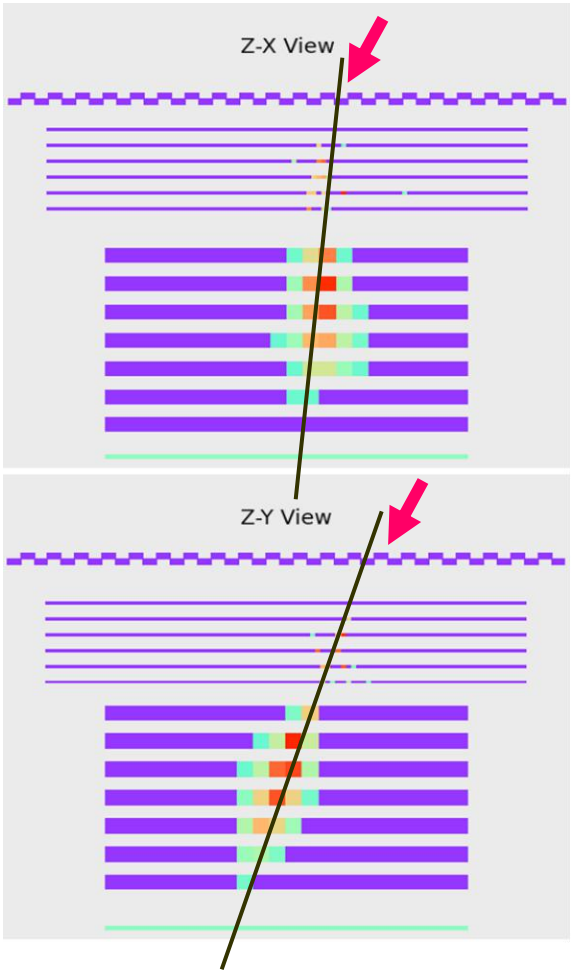


Particle identification

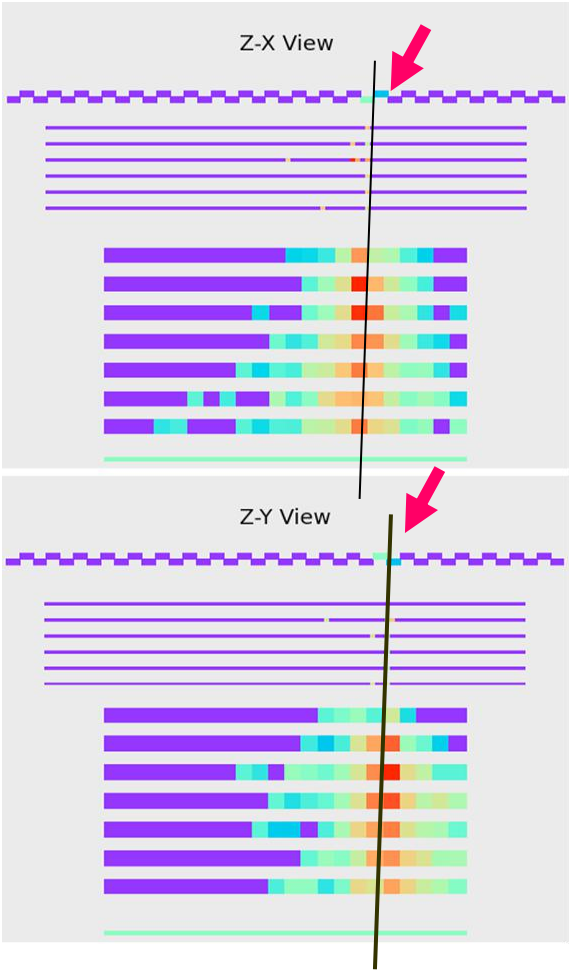
electron



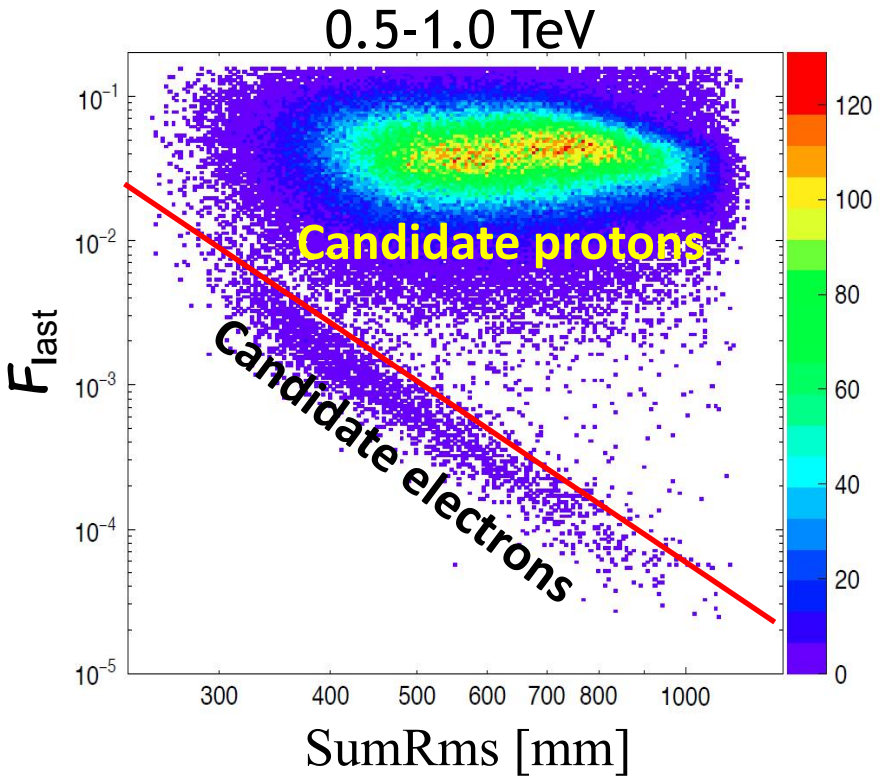
gamma

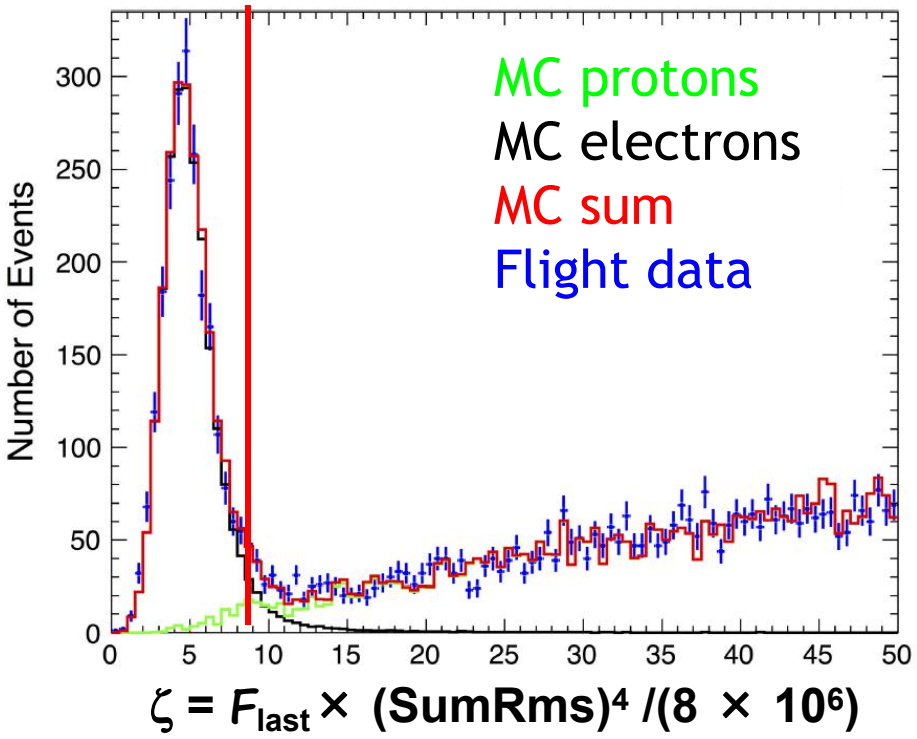


proton



e/p separation



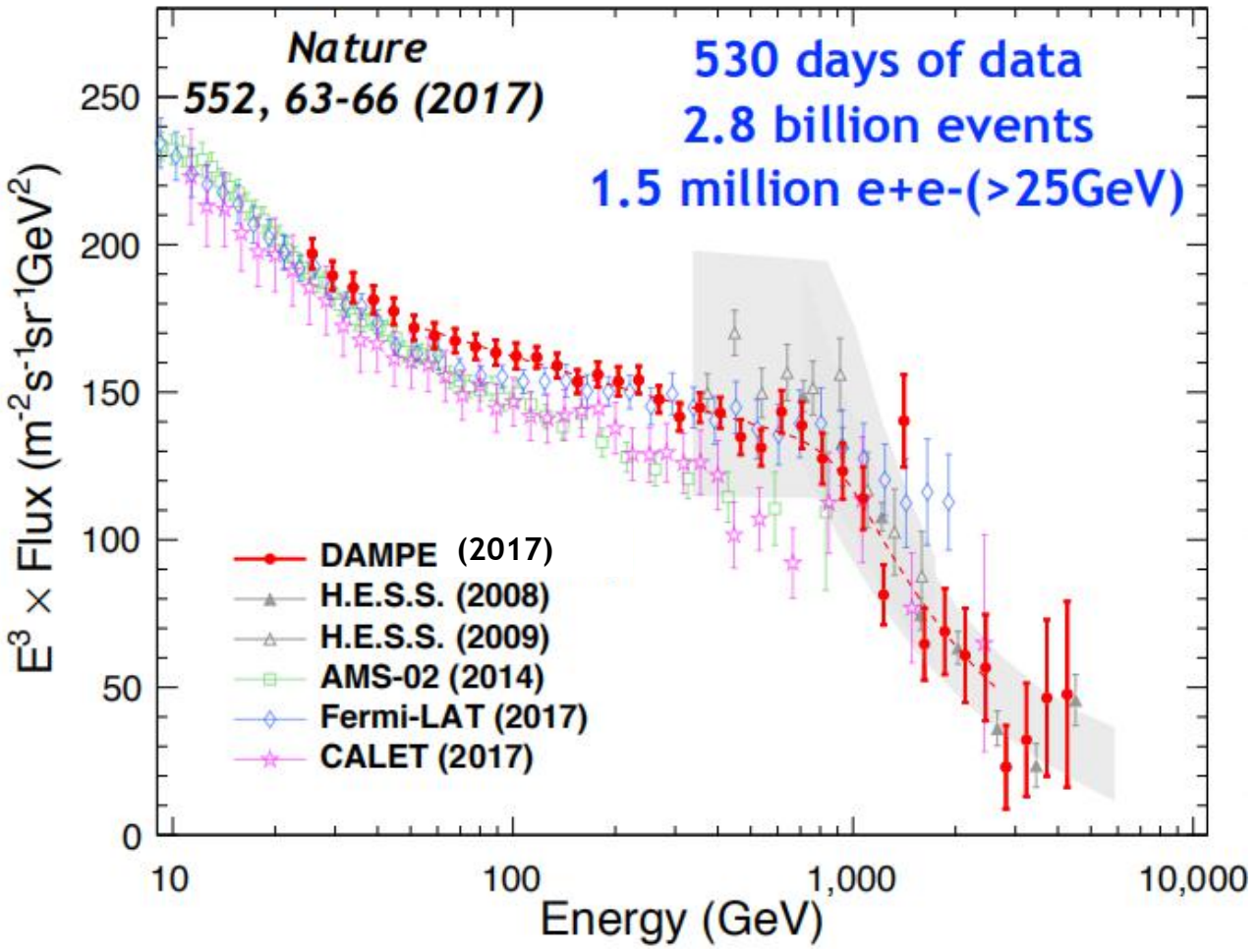


- We use the lateral (SumRMS) and longitudinal (energy ratio in last layer) developments of the showers to discriminate electrons from protons
- For 90% electron efficiency, proton background is ~2% @ TeV, ~5% @ 2 TeV, ~10% @ 5 TeV

Nature, 552, 63 (2017)

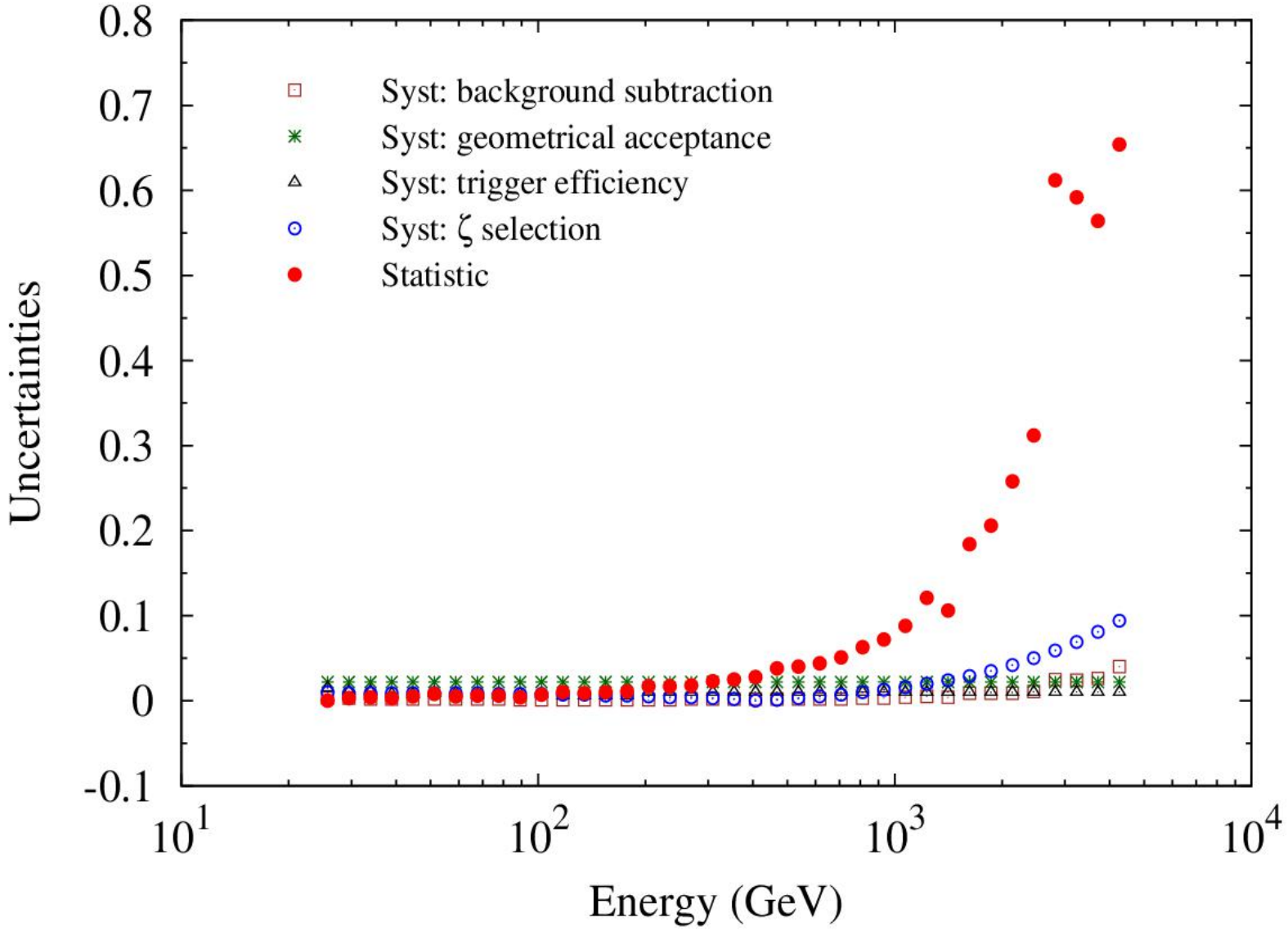
Physical results

Total $e^+ + e^-$ spectrum



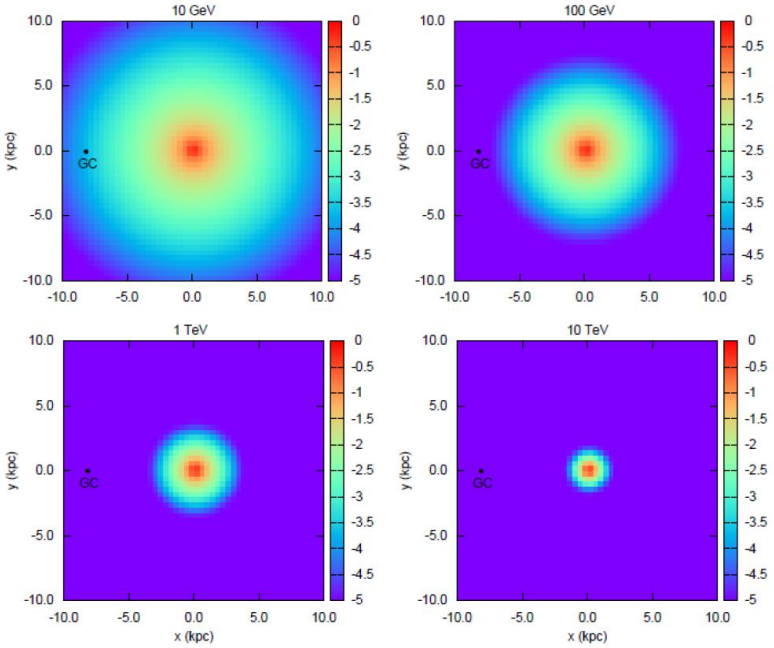
- Three different PID methods give very consistent results on event-by-event level
- Direct detection of a spectral break at ~1 TeV with 6.6σ confidence level
- Analysis with new data is on-going

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

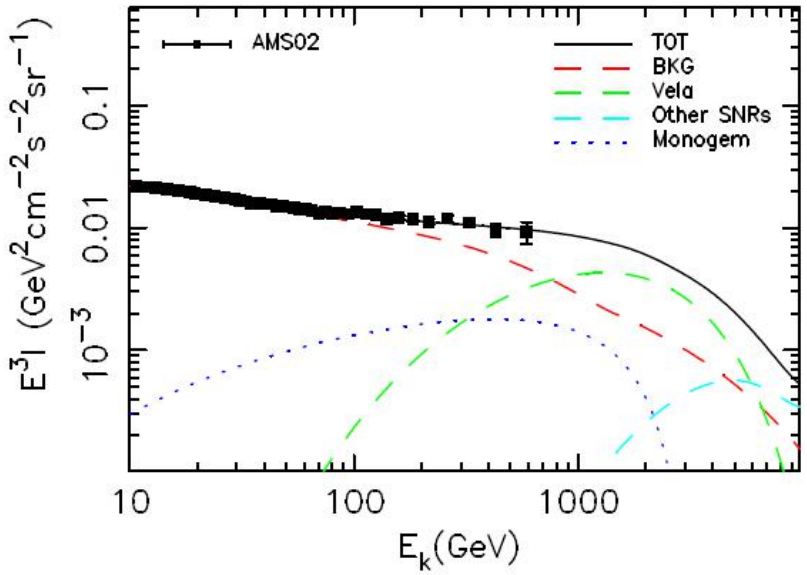


Implication of the spectral softening: discreteness of source distributions?

- 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)

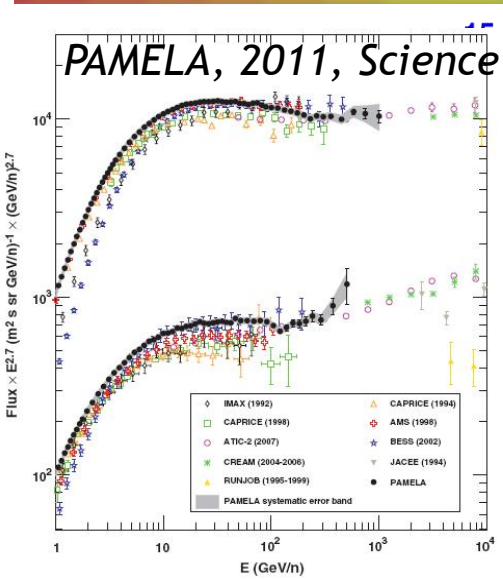


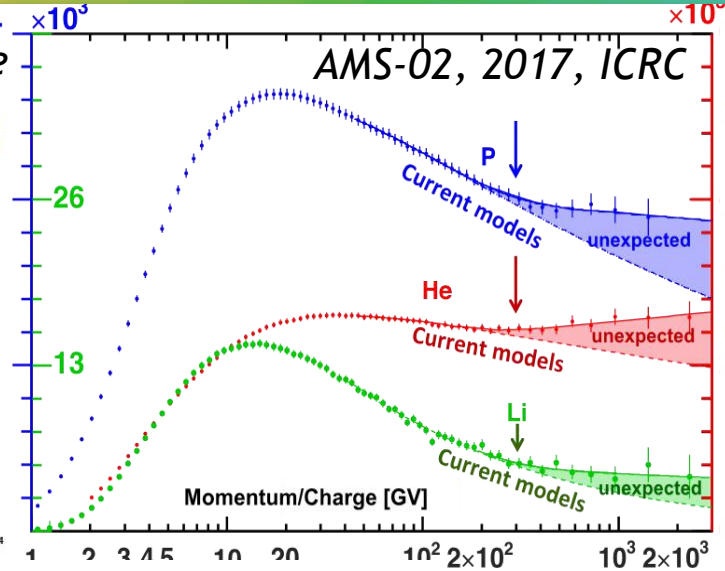
Astrophys. J., 836, 172 (2017)

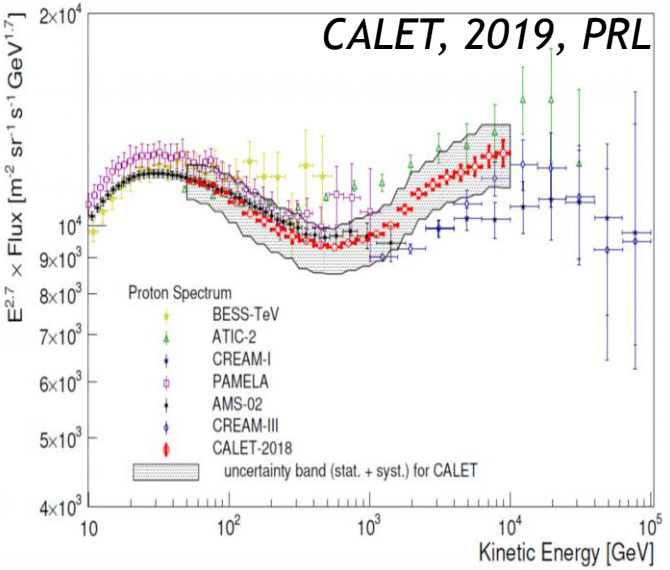


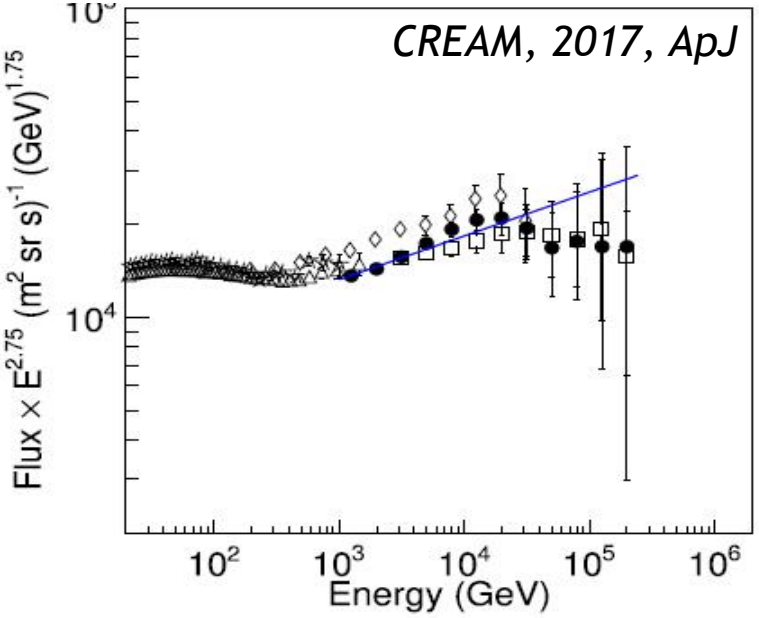
Fang et al. (2017)
Di Mauro et al. (2017)
Manconi et al. (2019)...

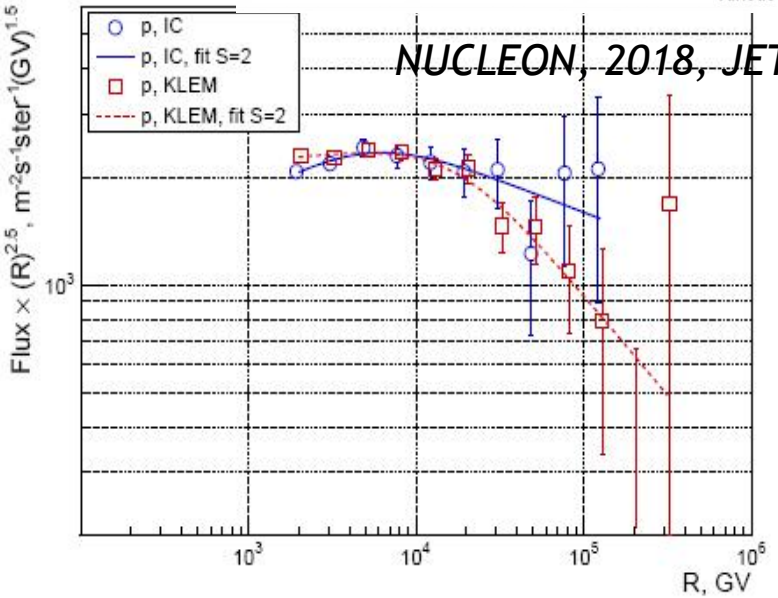
Spectral structures of nuclei



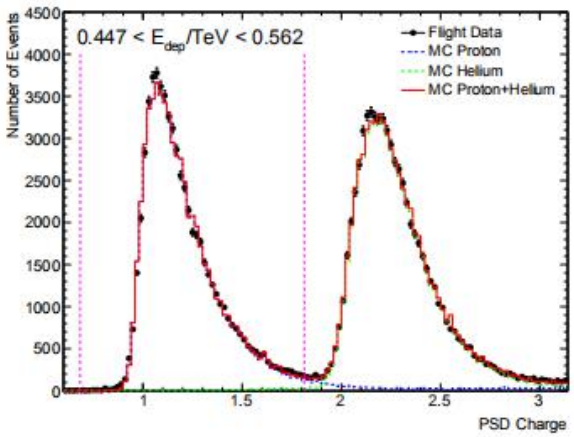


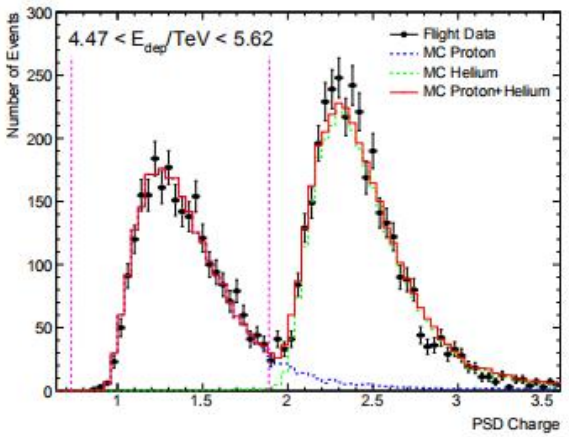


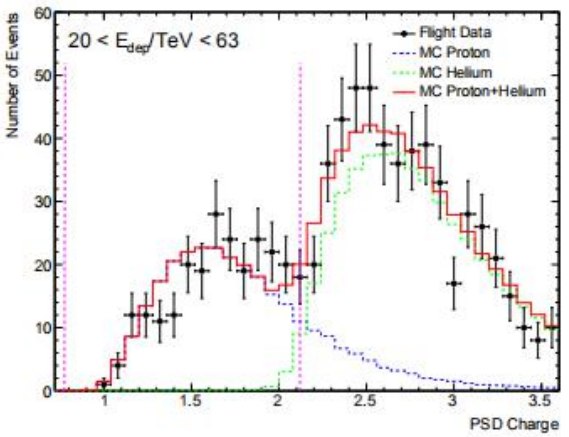




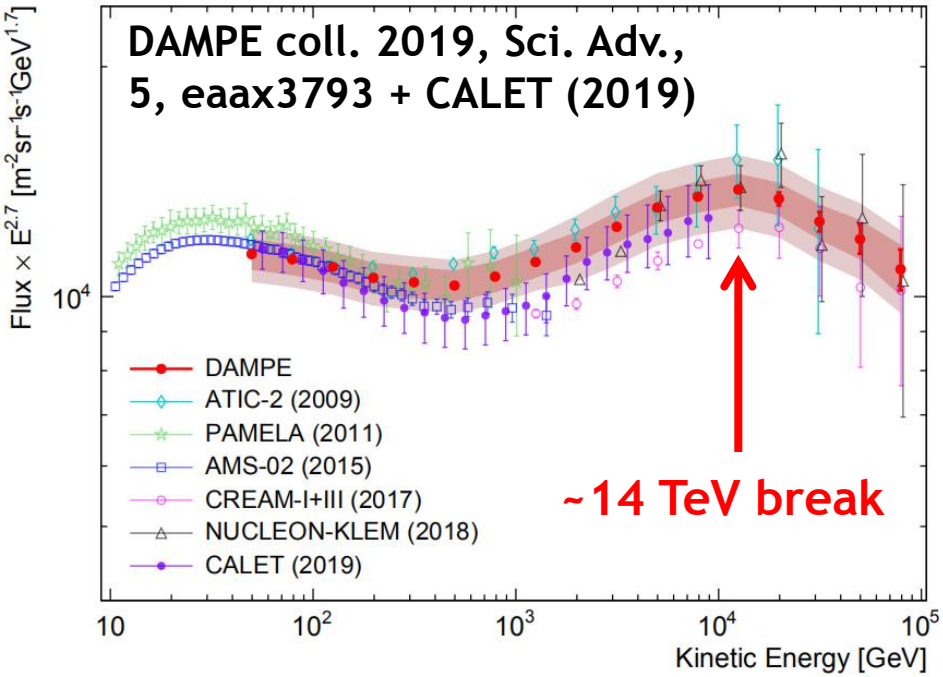
DAMPE proton spectrum





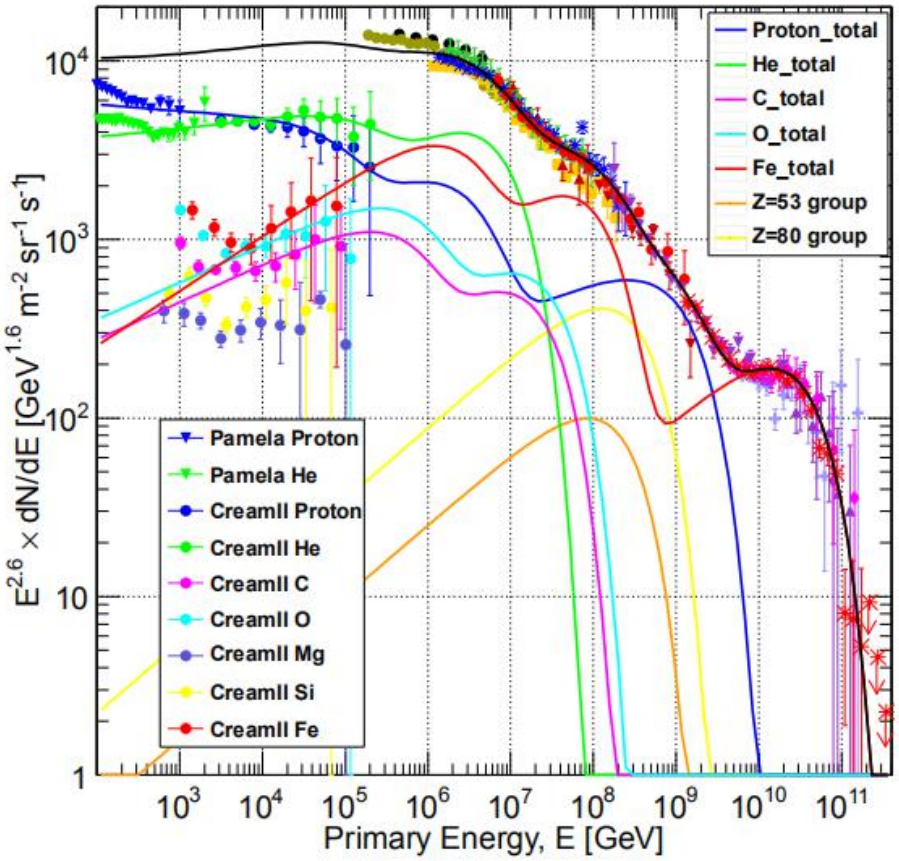


- Confirms the hundreds GeV hardening
- Detecting a softening at ~14 TeV with high significance

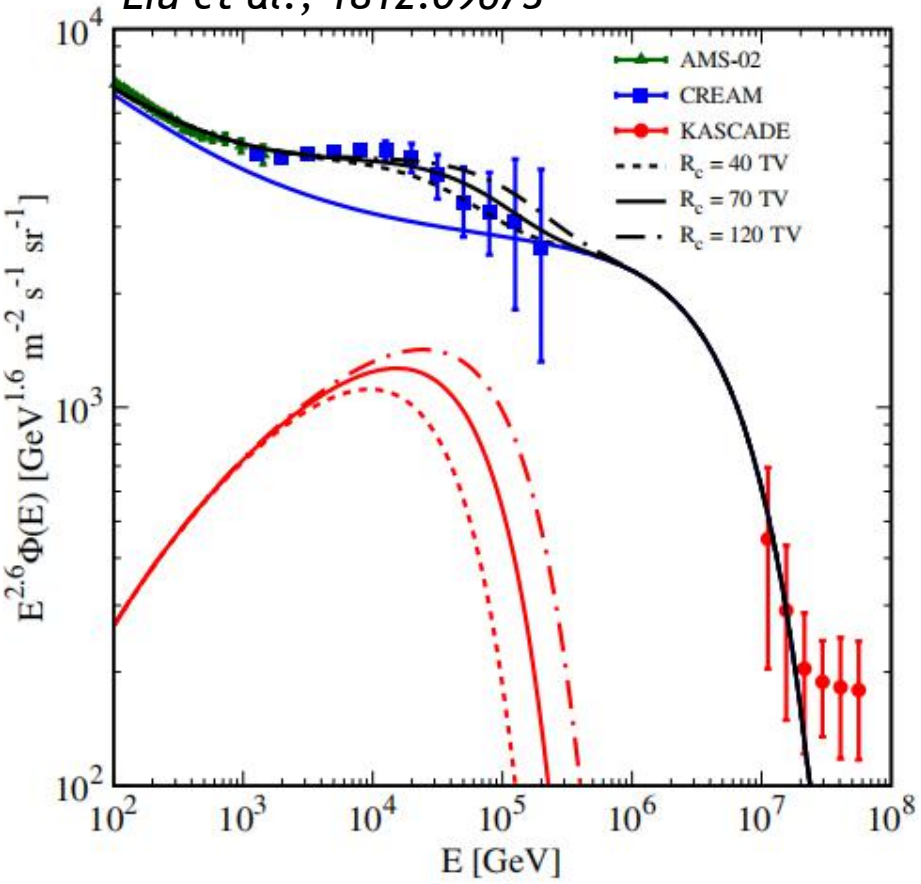


Implications: source population(?) Nearby source(?)

Gaisser et al. (2013)

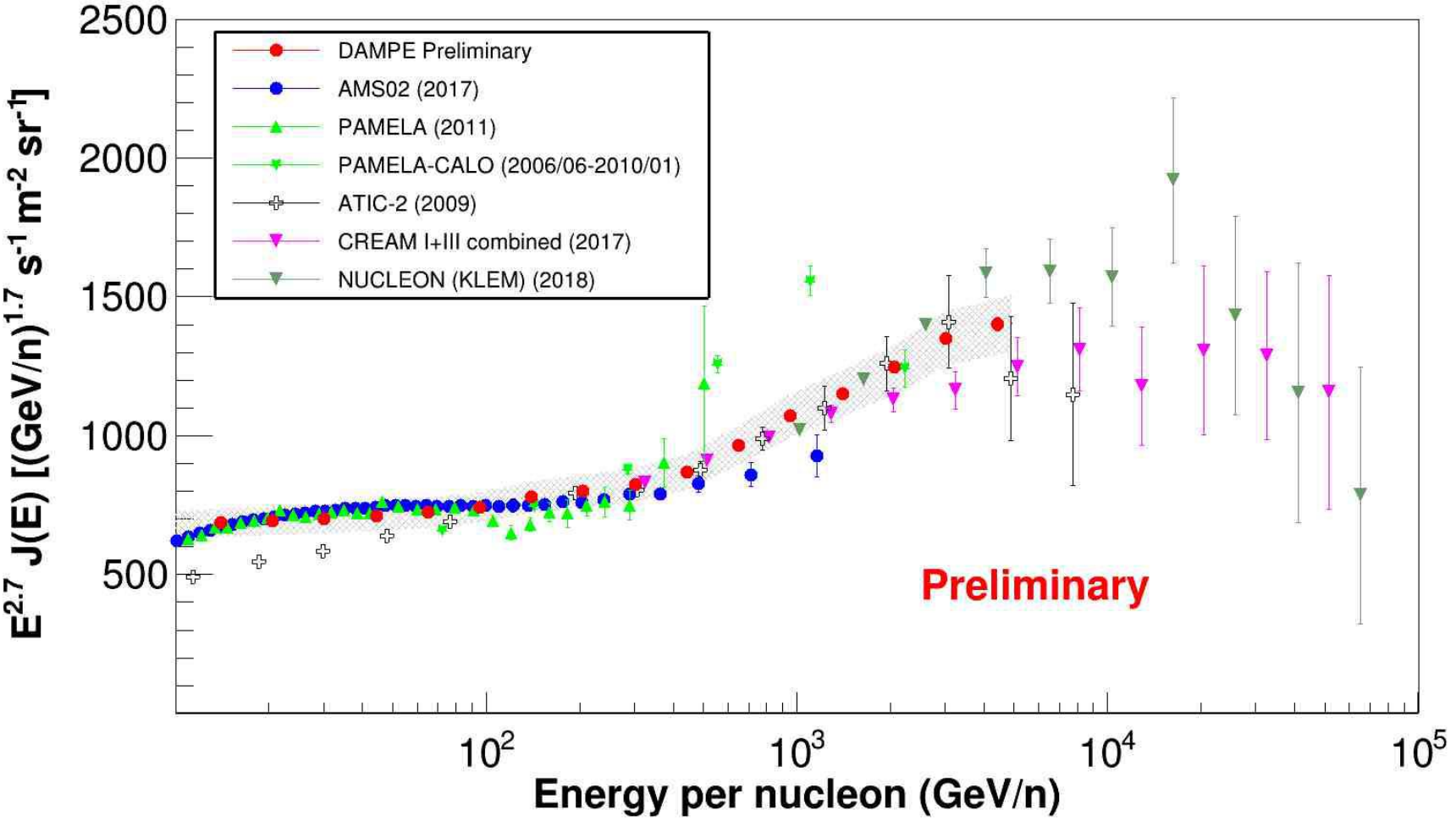


Liu et al., 1812.09673

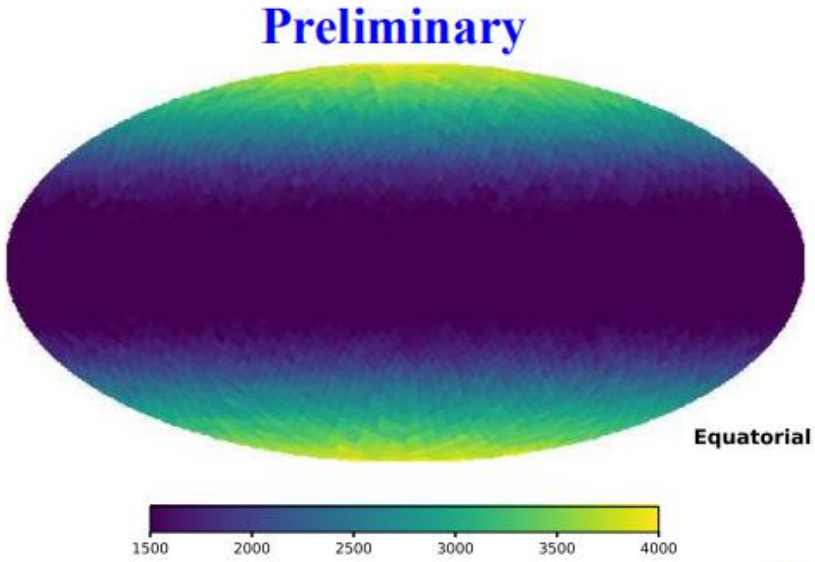


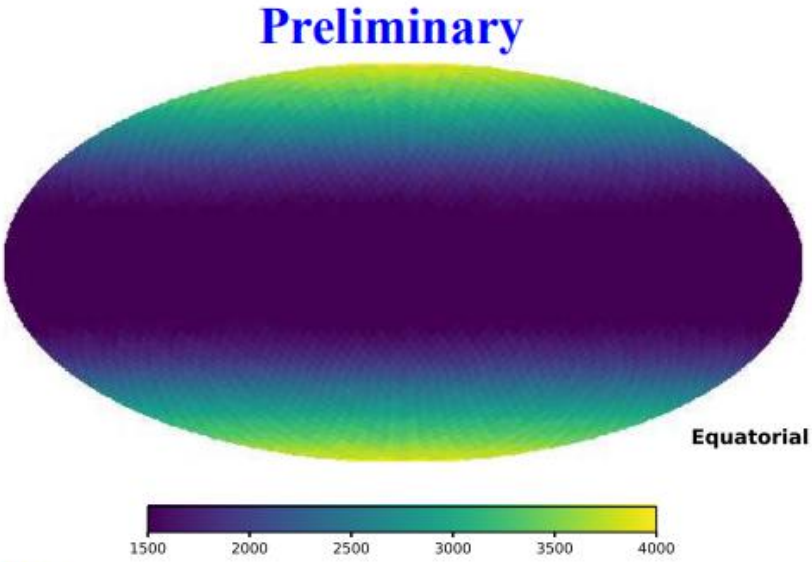
See Dr. C. Yue's talk tomorrow

DAMPE helium spectrum

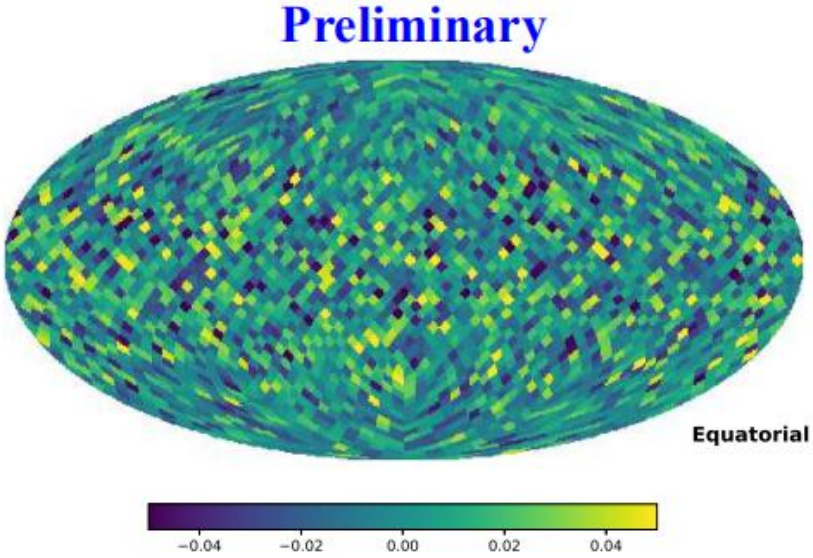


Cosmic ray anisotropies

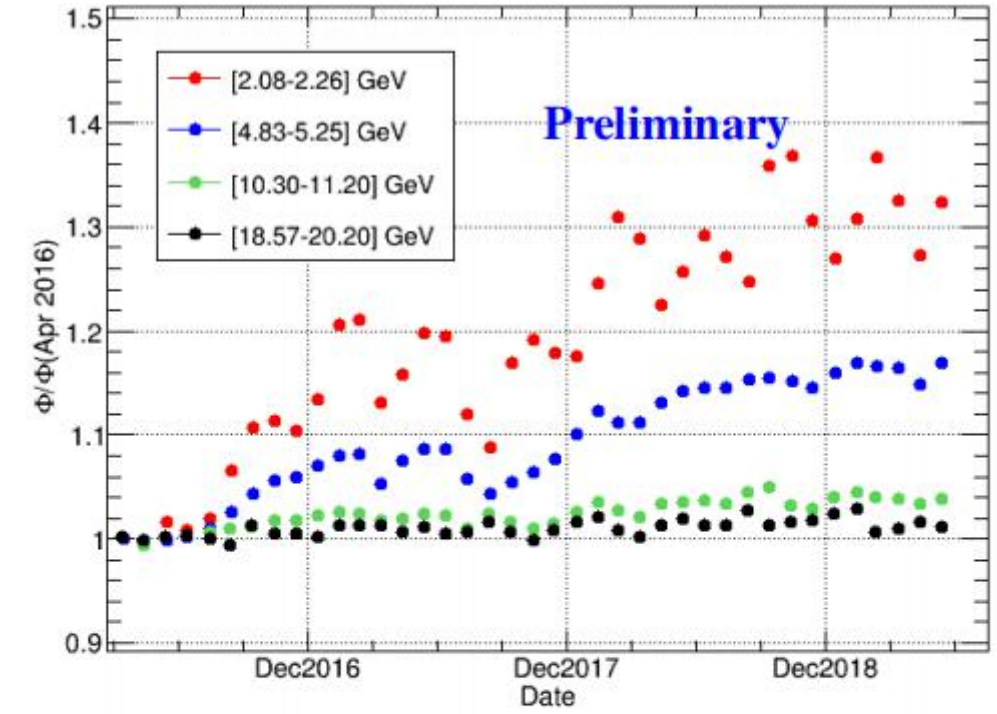


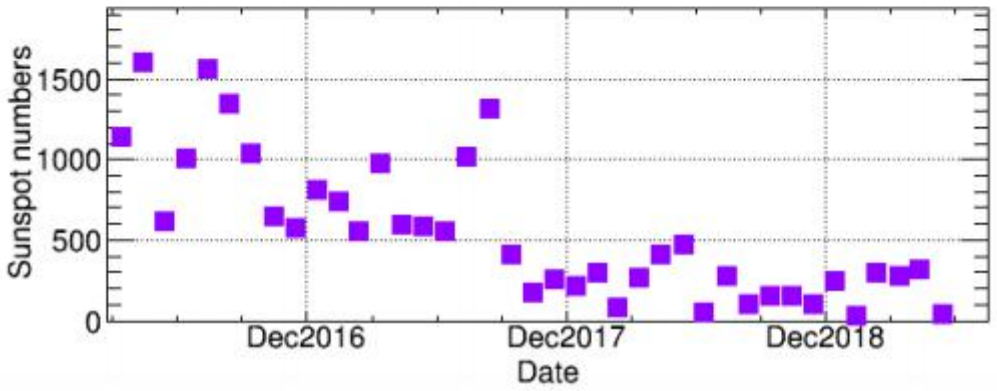


95% UL of dipole amplitude for 1-yr data (>~300 GeV): 6.7×10^{-3}



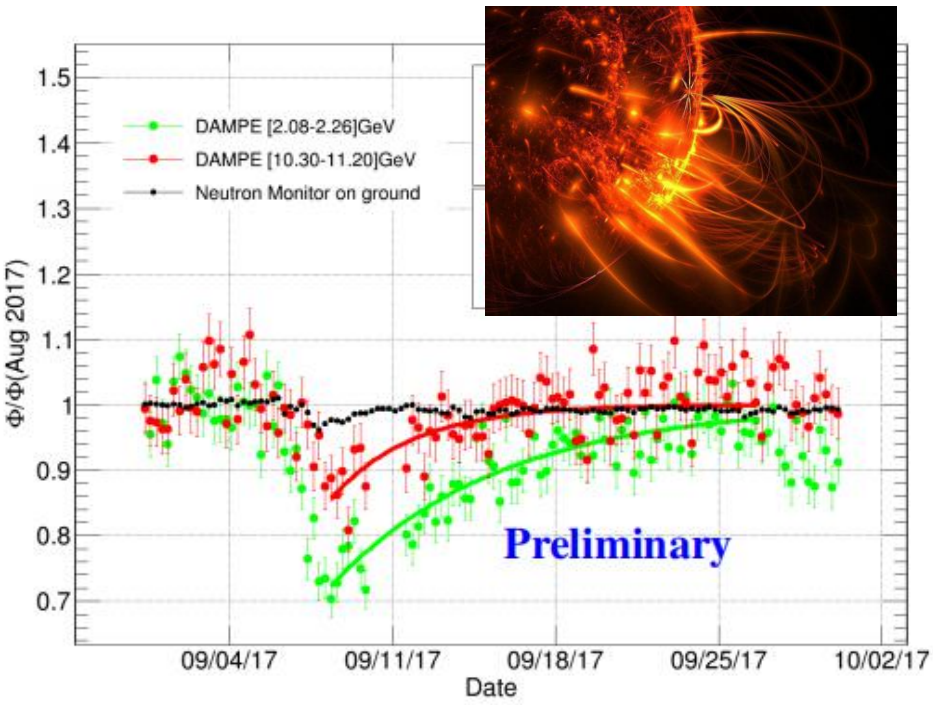
Solar modulation of $e^+ + e^-$

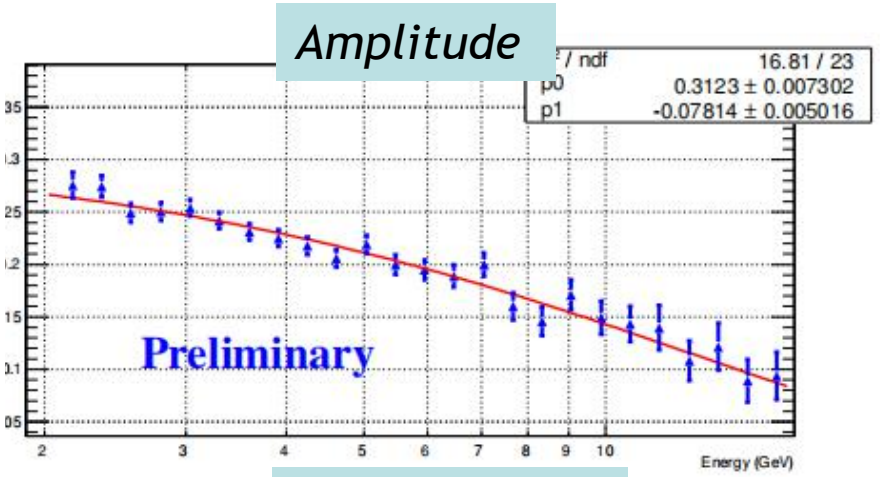


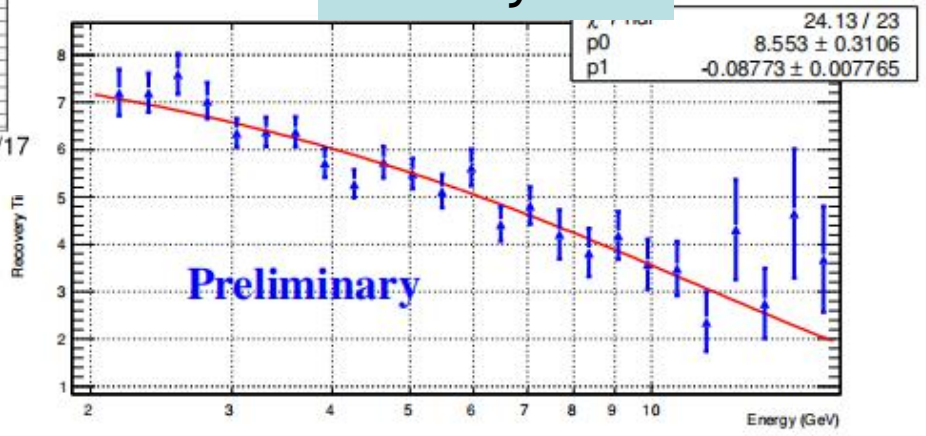


- Anti-correlation with sunspot numbers
- Monthly variation may be related to occasional solar activities
- Possible time delay between sunspot numbers and CR modulation

Electron Forbush decrease



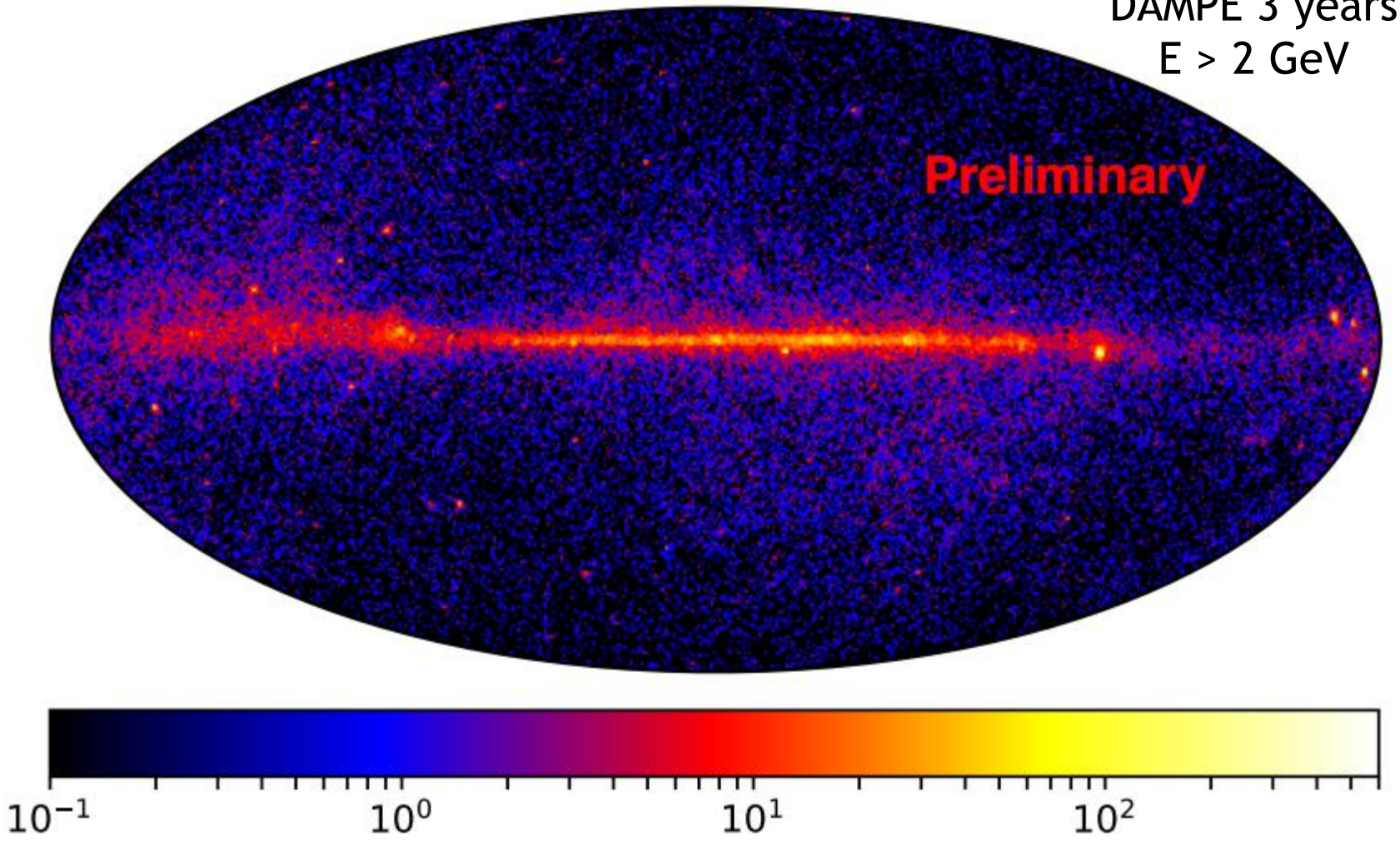




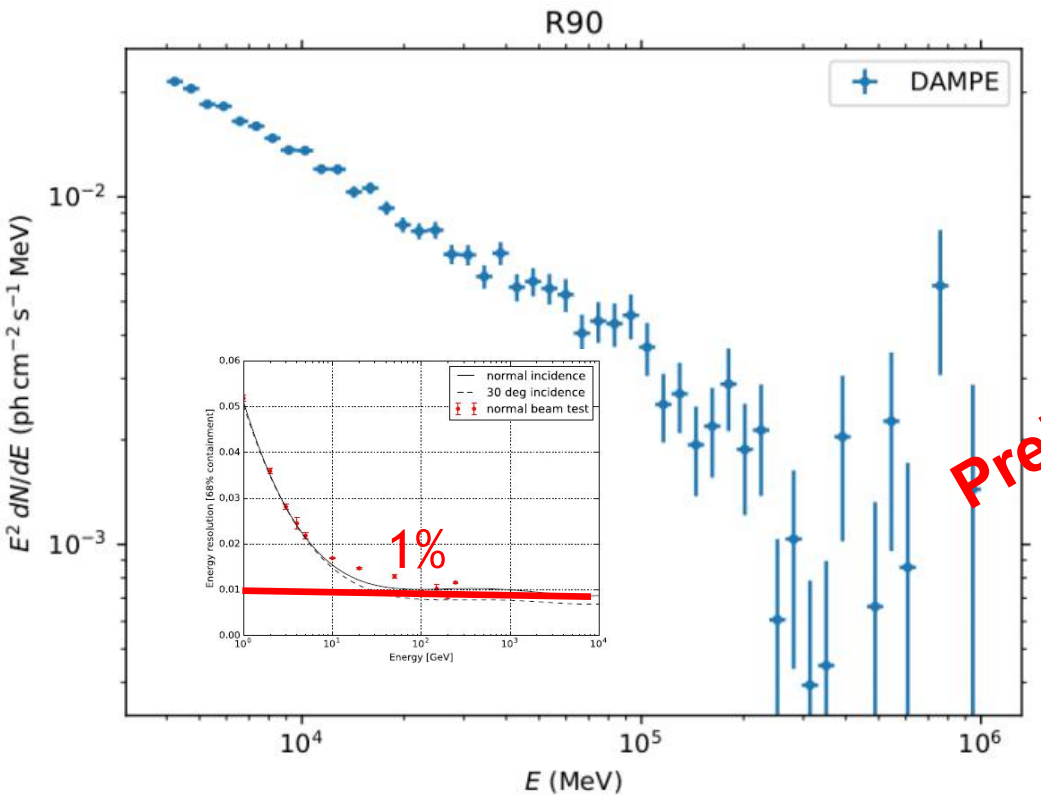
- Clear flux decreases after 2017/09/07 flare
- Decreasing behavior of recovery time versus energy

γ-ray skymap

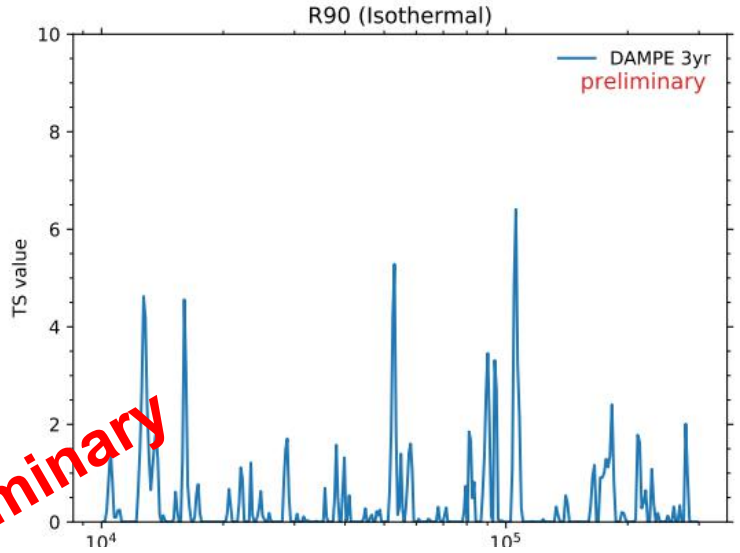
DAMPE 3 years
E > 2 GeV

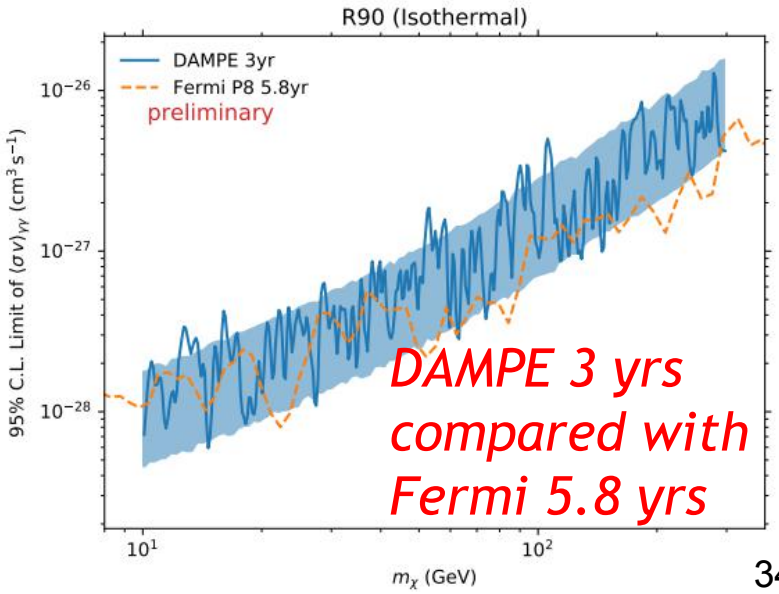


γ-ray line searches

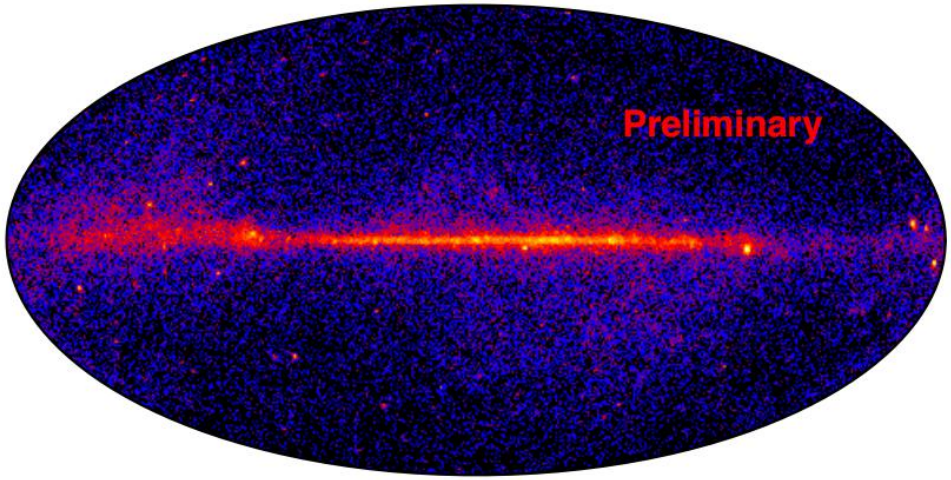


Preliminary





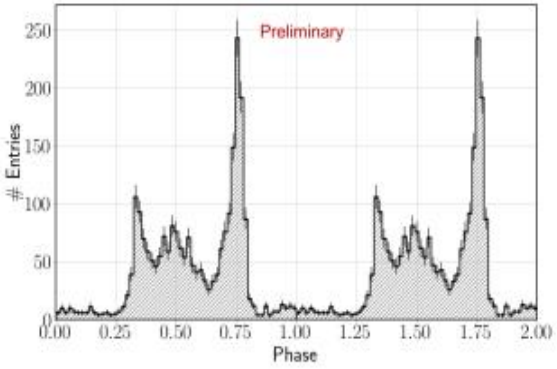
γ-ray point sources



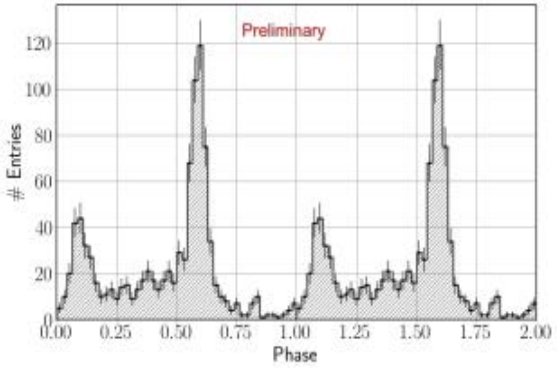
Source Type	Number
AGN	121
Pulsar	32
SNR/PWN	8
Binary	3
Globular cluster	1
Unassociated	6
Total	171

Source Name	3FGL Name	Type	RA (°)	DEC (°)	Flux[a] (10^{-8} ph/cm^2/s)	Spectral Index	TS Value
s5 1044+71	3FGL J1048.4+7144	FSRQ	162.12	71.74	1.102 ± 0.186	3.05 ± 0.31	196
3C 454.3	3FGL J2254.0+1608	FSRQ	343.50	16.15	4.563 ± 0.603	3.61 ± 0.32	385
CTA 102	3FGL J2232.5+1143	FSRQ	338.14	11.72	11.008 ± 0.885	2.65 ± 0.12	1330
Vela	3FGL J0835.3-4510	Pulsar	128.84	-45.18	52.630 ± 1.520	3.55 ± 0.07	7195
Geminga	3FGL J0633.9+1746	Pulsar	98.48	17.77	33.058 ± 1.385	3.87 ± 0.11	4565
Crab	3FGL J0534.5+2201	Pulsar	83.64	22.02	9.086 ± 0.707	2.60 ± 0.12	1067
Mkn501	3FGL J1653.9+3945	BL Lac	253.48	39.75	0.414 ± 0.134	2.00 ± 0.36	44
Mkn421	3FGL J1104.4+3812	BL Lac	166.12	38.21	2.165 ± 0.317	2.04 ± 0.17	331
IC443	3FGL J0617.2+2234e	SNR	94.31	22.58	3.659 ± 0.517	2.76 ± 0.23	211
PSR J1836+5925	3FGL J1836.2+5925	Pulsar	279.06	59.43	4.419 ± 0.354	3.88 ± 0.22	993
PSR J0007+7303	3FGL J0007.0+7302	Pulsar	1.77	73.05	3.459 ± 0.305	3.00 ± 0.17	716
PSR B1706-44	3FGL J1709.7-4429	Pulsar	257.43	-44.49	8.246 ± 0.652	3.13 ± 0.16	729

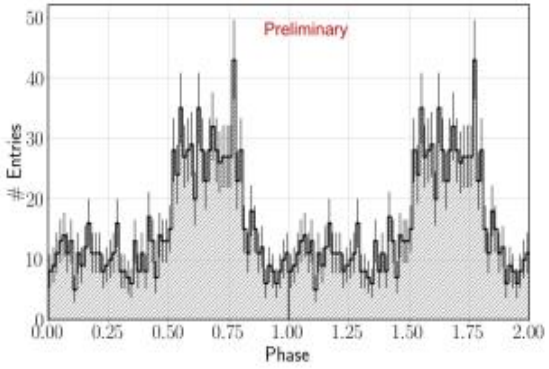
γ-ray pulsars



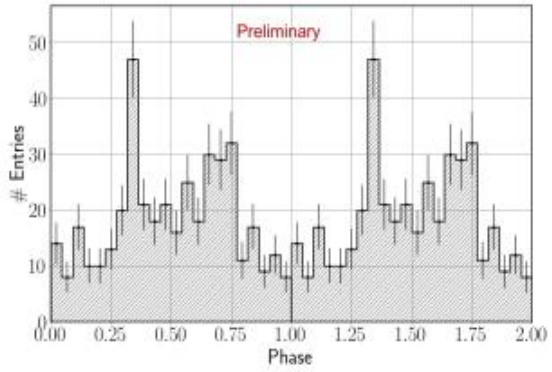
(a) Vela



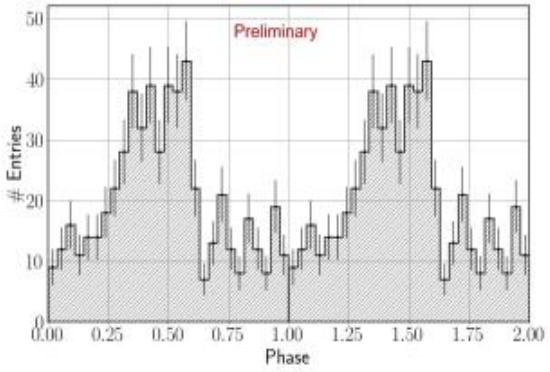
(b) Geminga



(c) J1709-4229

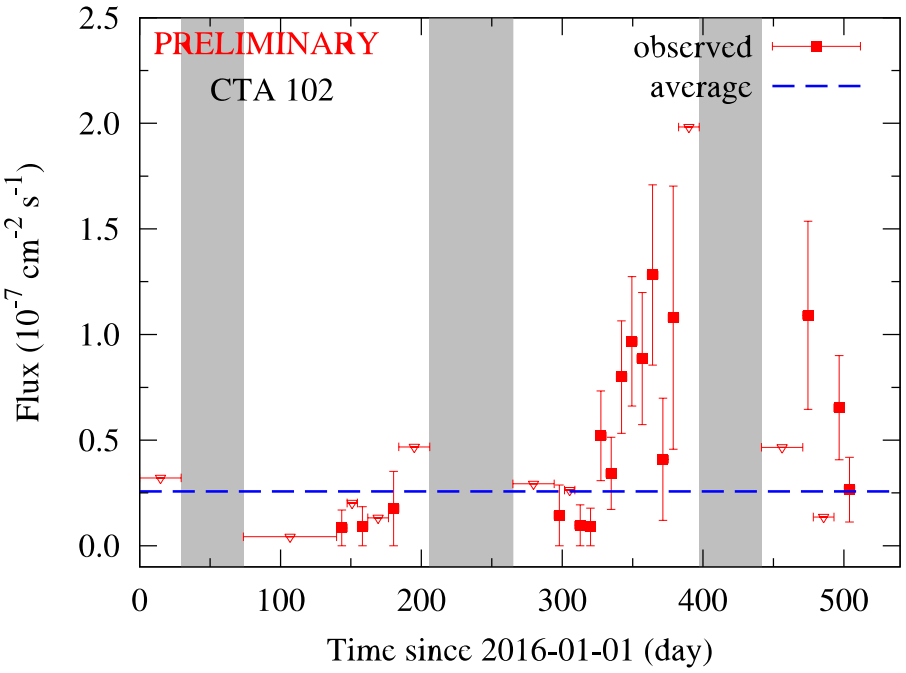


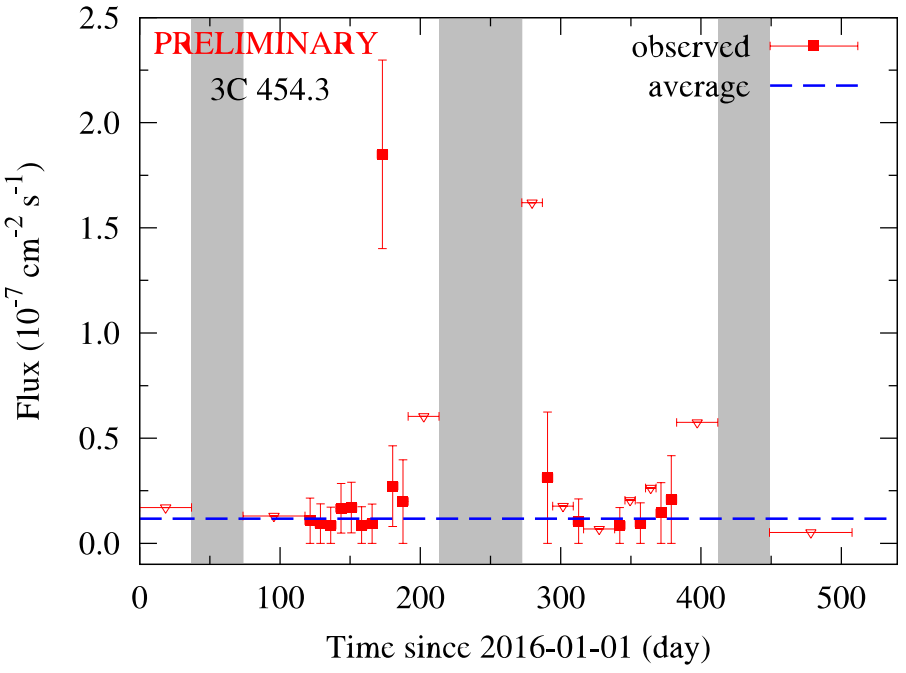
(d) Crab



(e) J0007+7303

AGNs/Multi-messengers

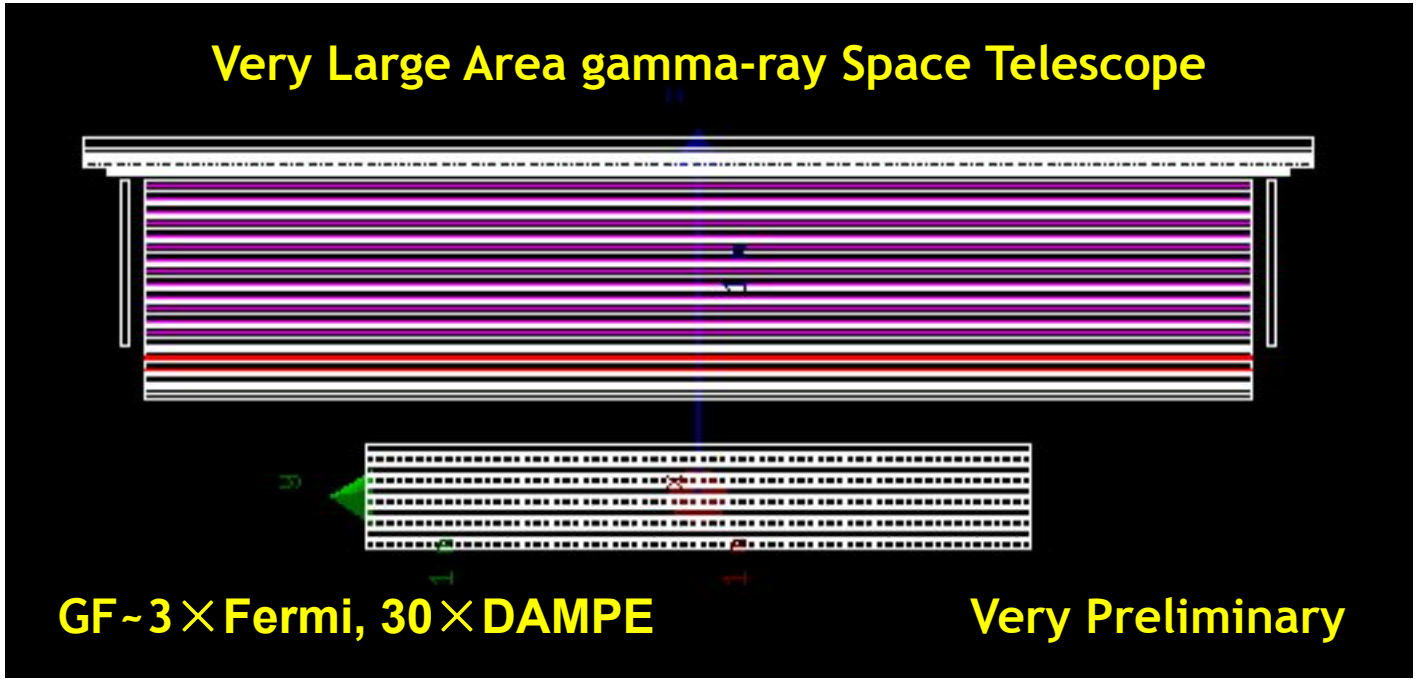




- DAMPE detected outbursts of several AGNs
- Consistent with multi-wavelength observations

(Yuan et al. PoS (ICRC2017) 617)

VLAST



DAMPE: thick, high-resolution, high-background-rejection

VLAST: thin, large, wide

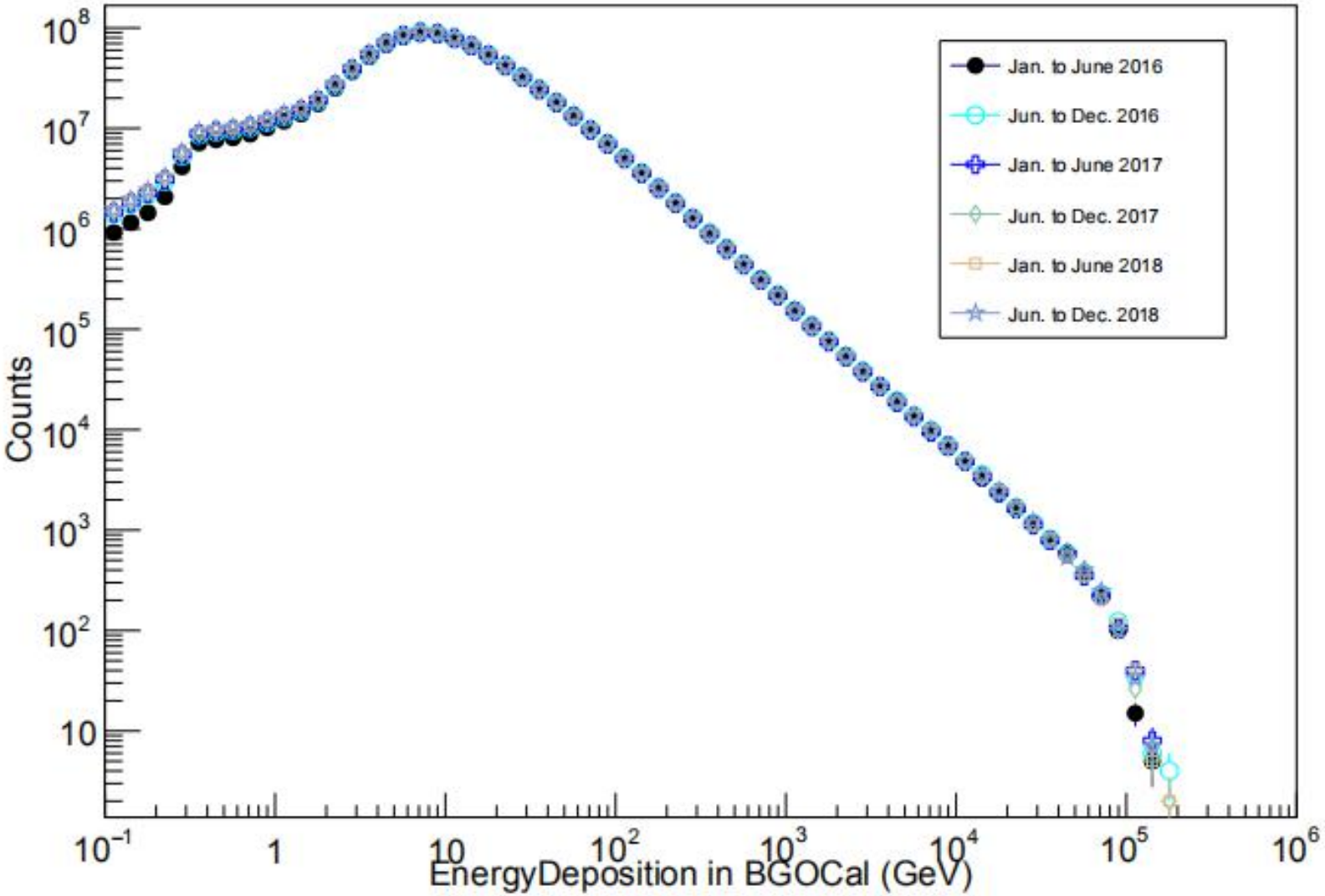
Summary

- DAMPE detector is working extremely stably for nearly 4 years 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
- Precise measurements of proton spectrum from 40 GeV to 100 TeV have been obtained, revealing interesting softening features at ~10 TeV
- Various kinds of gamma-ray sources have been detected. DAMPE is expected to play an important role in the multi-messenger campaign!
- More results are coming

Thank You!

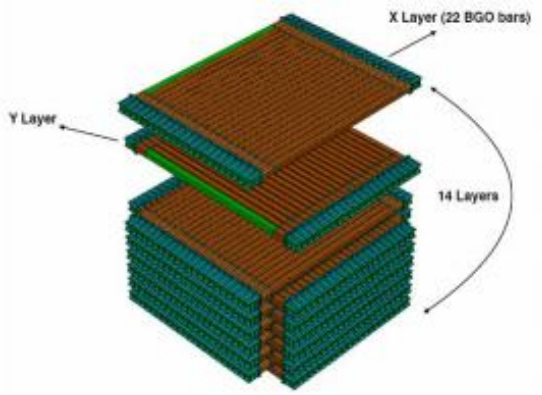
Backup

Raw count spectra



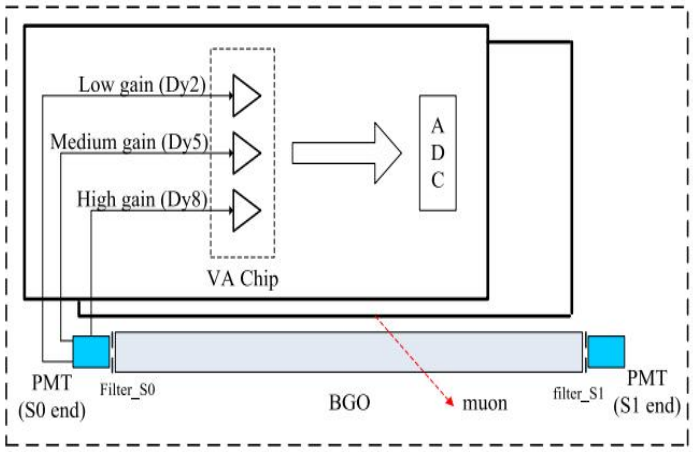
Energy measurement

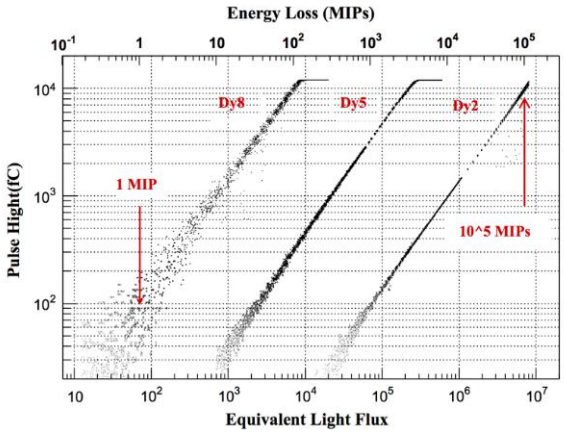
BGO calorimeter



308 BGO bars

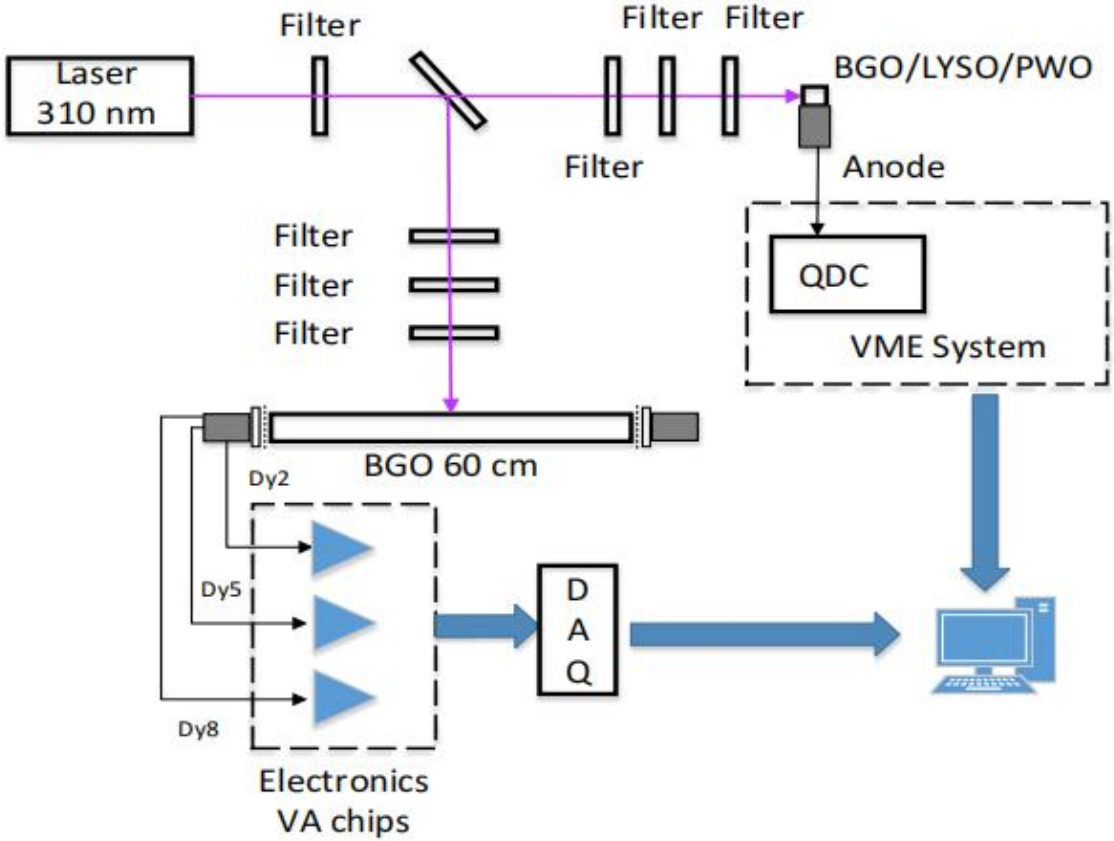
616 PMTs

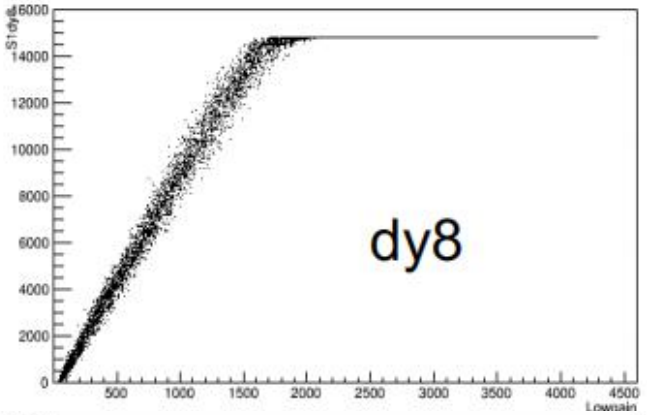


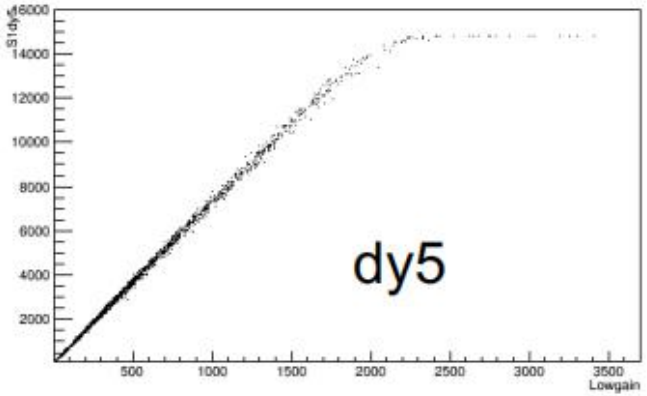


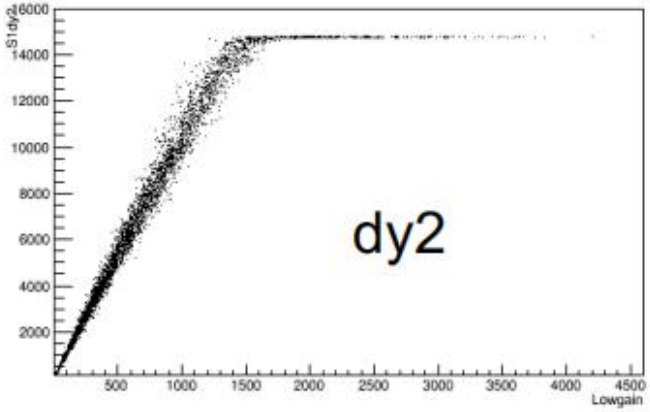
- Thick calorimeter (32 X_0): high-resolution
- Two-side readouts
- Three dynode outputs enable a >10^6 dynamic range

Laser experiment

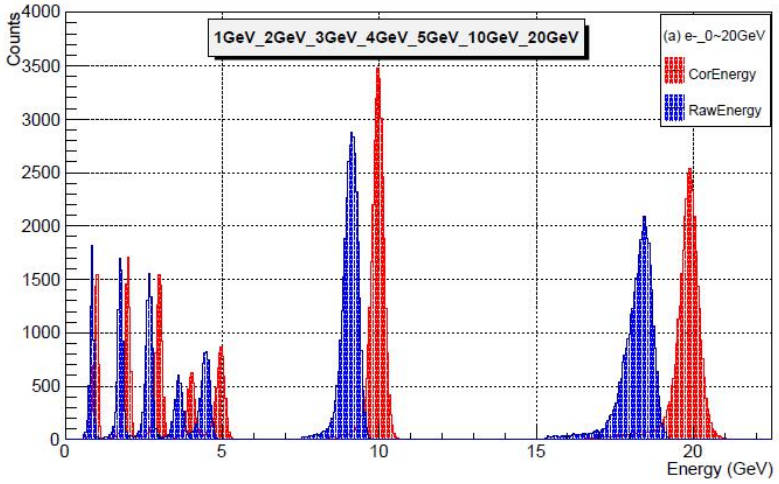


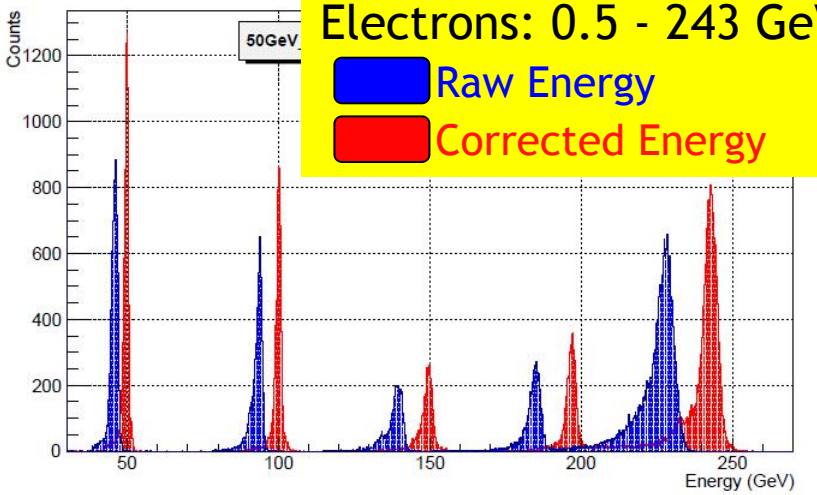






Test beam validation

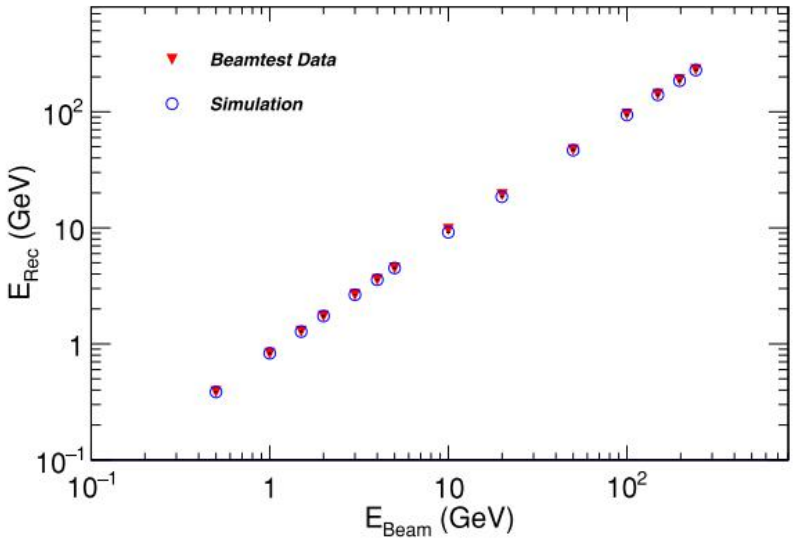


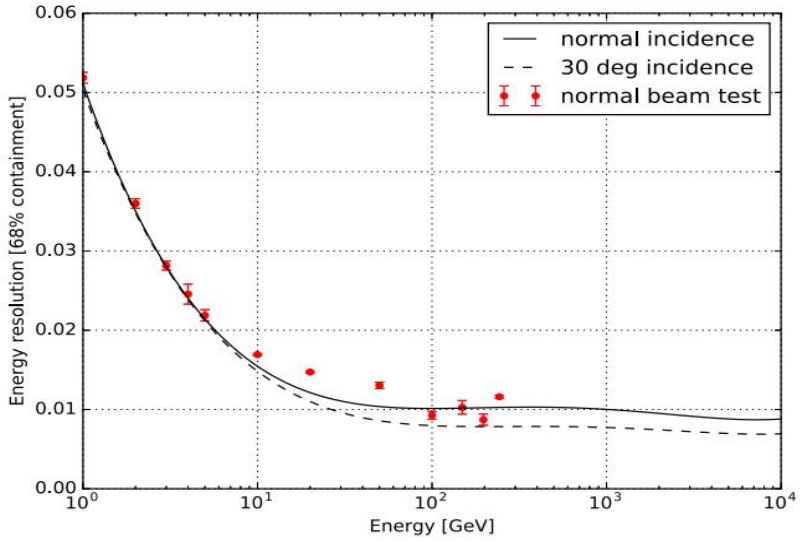


Electrons: 0.5 - 243 GeV

Raw Energy

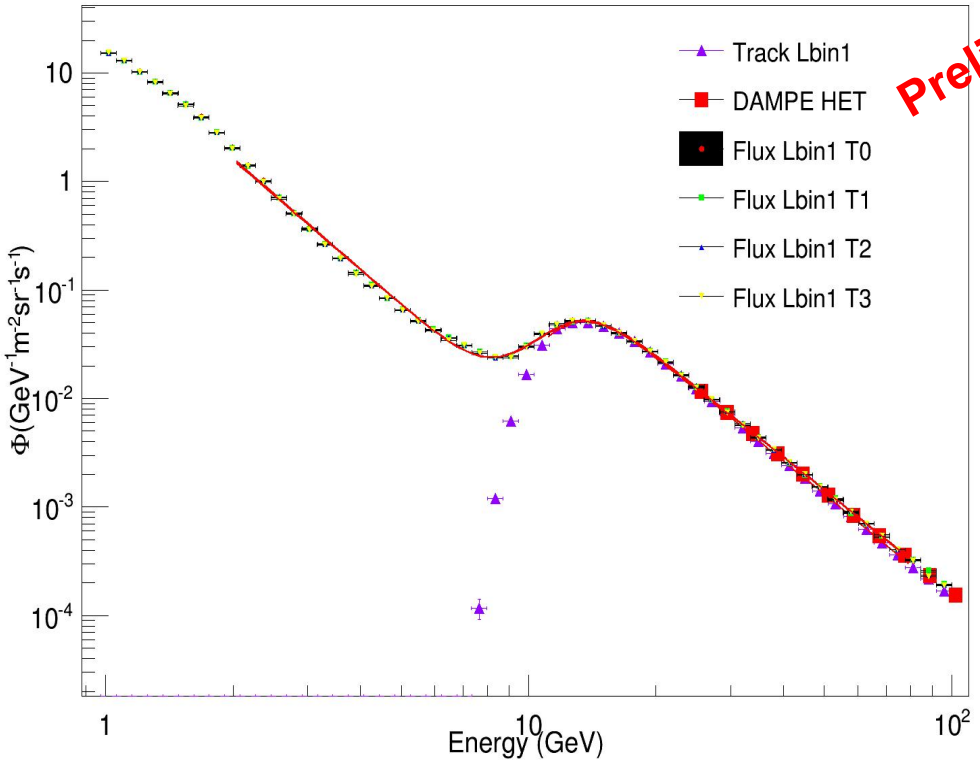
Corrected Energy



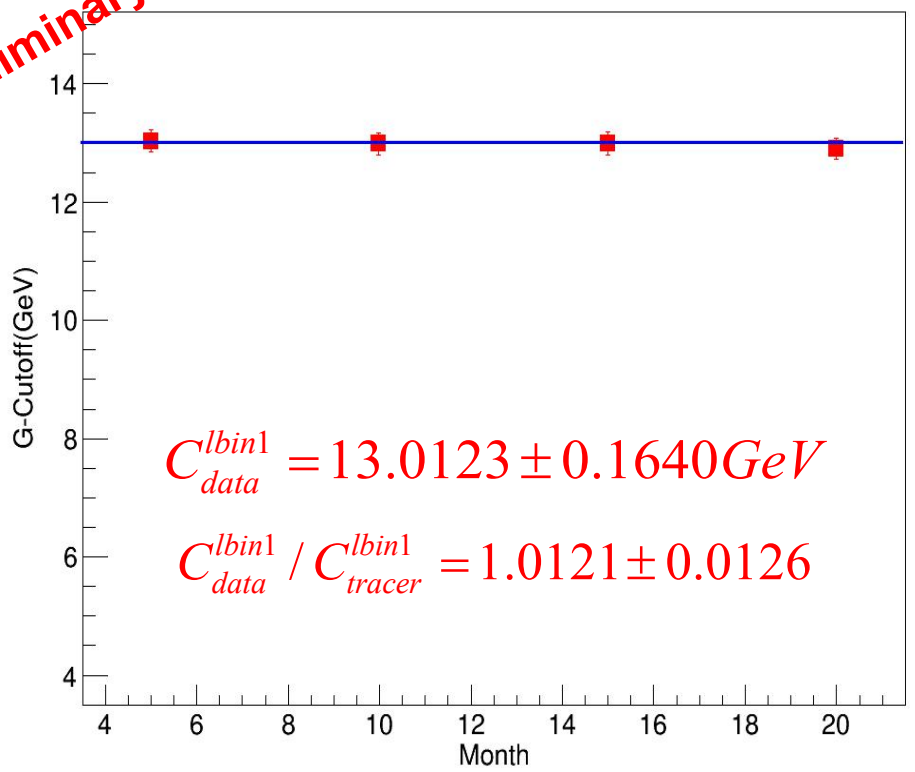


Astropart. Phys., 95, 6 (2017)

Absolute energy scale

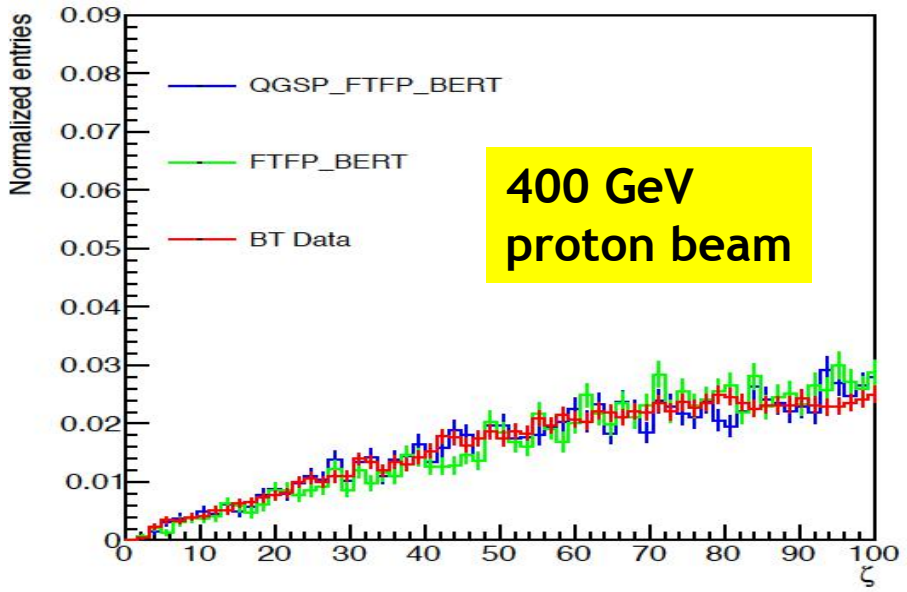


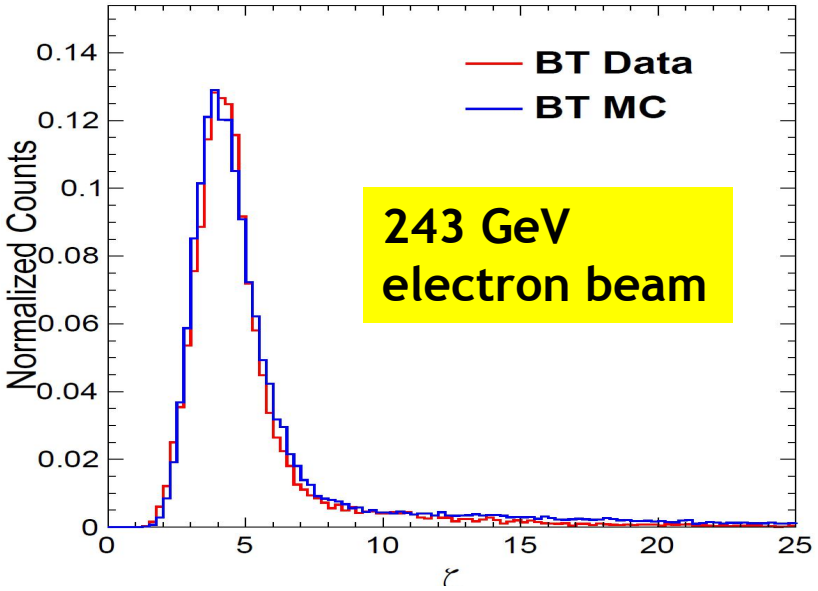
Preliminary

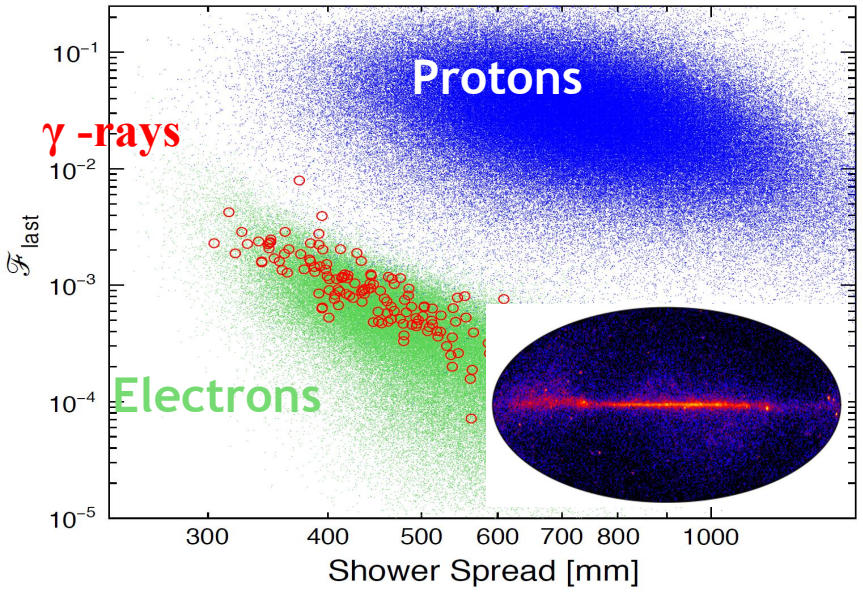


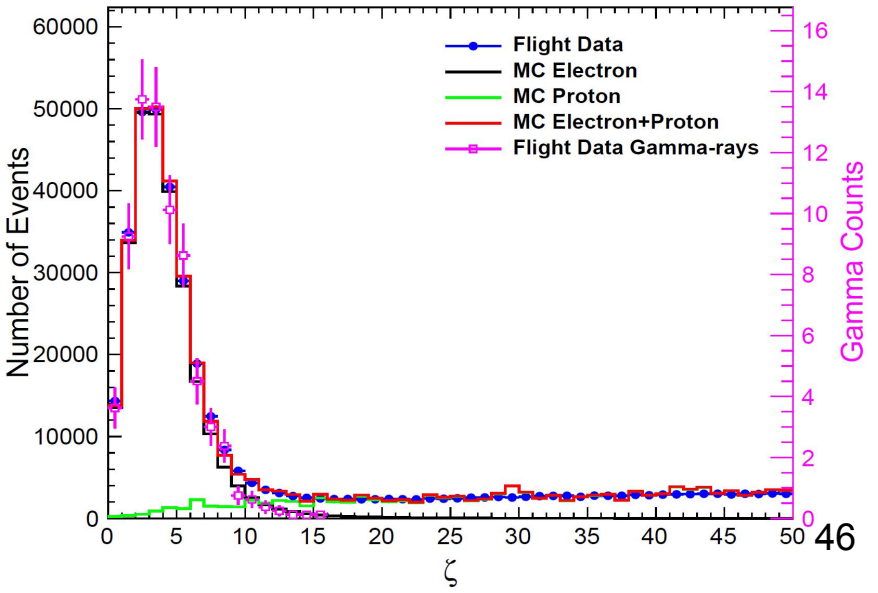
- An energy scale higher by (1.2+/-1.3)% from the geomagnetic cutoff
- Cutoff energy is stable with time (a slight decrease due to solar modulation)

Validation of e/p separation

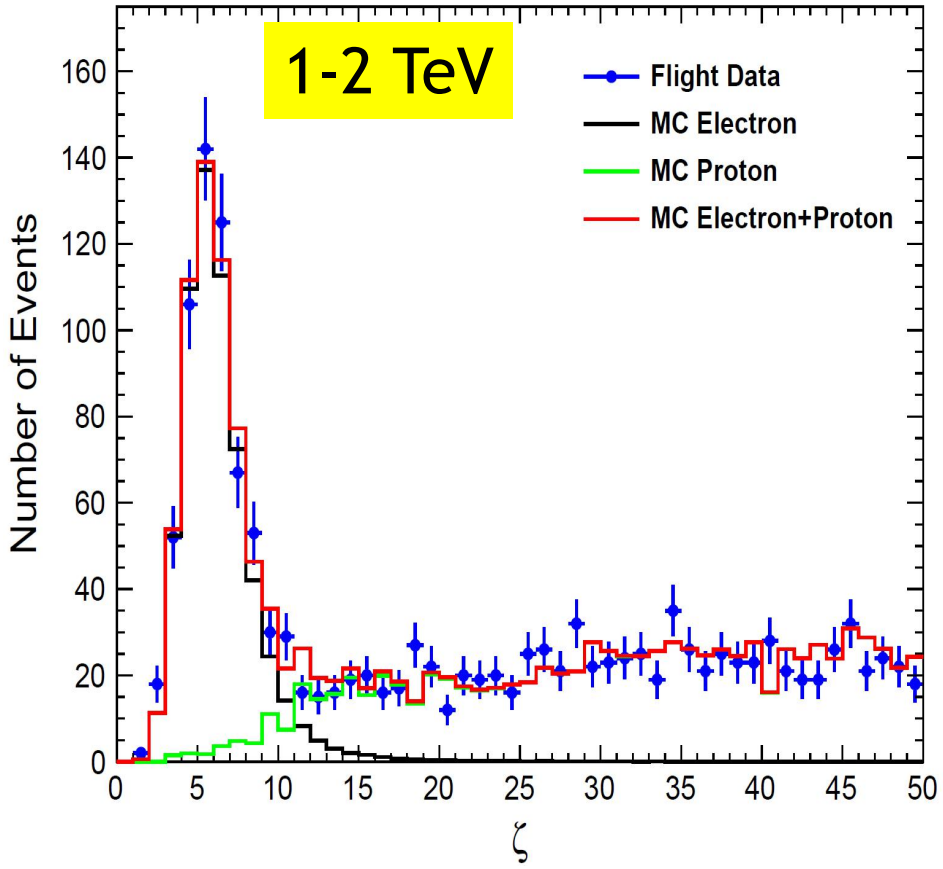


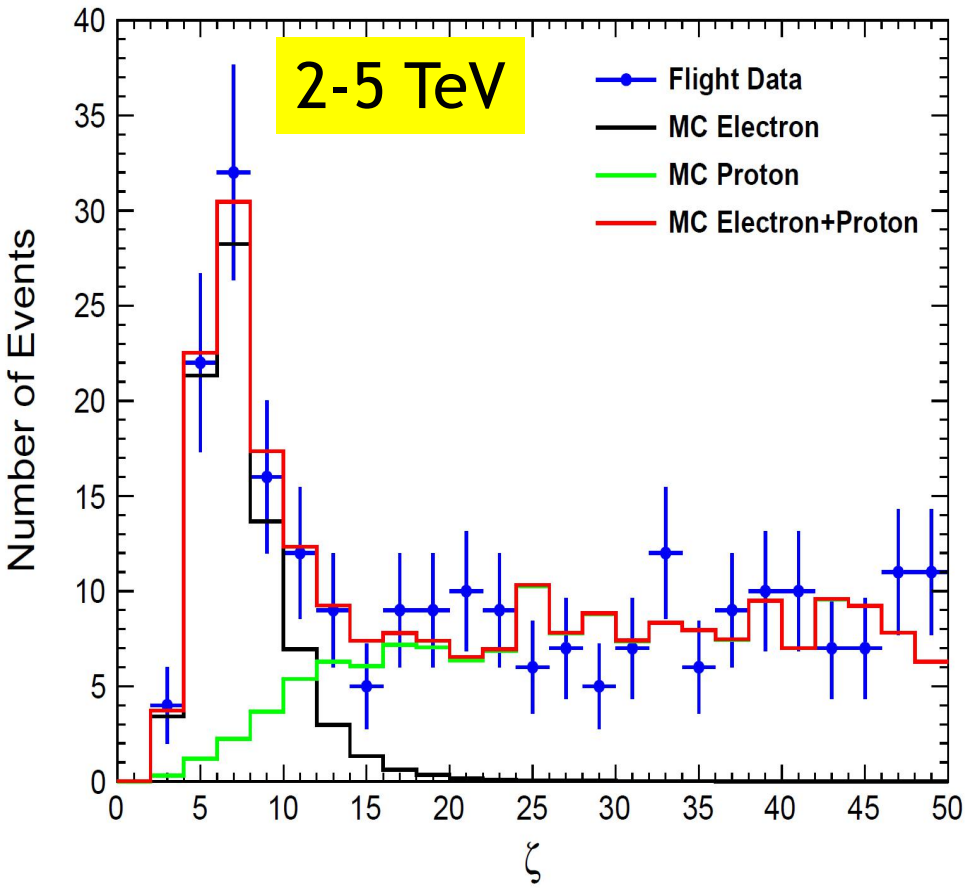






e/p separation at higher energies

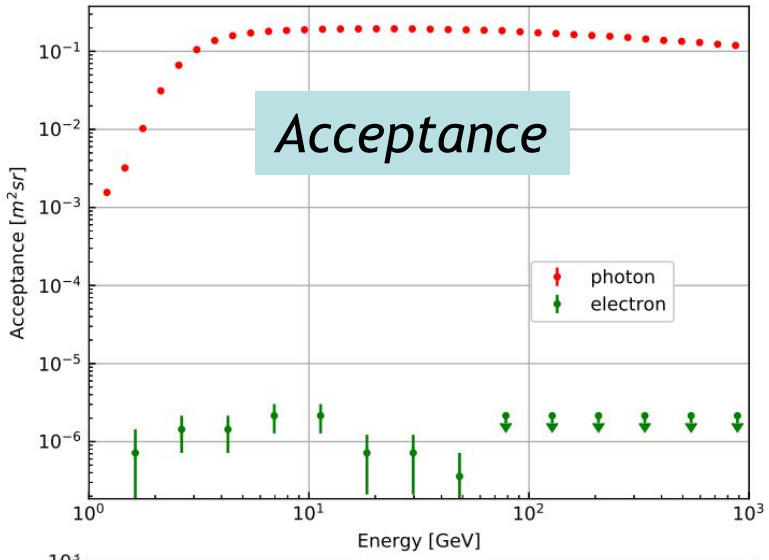


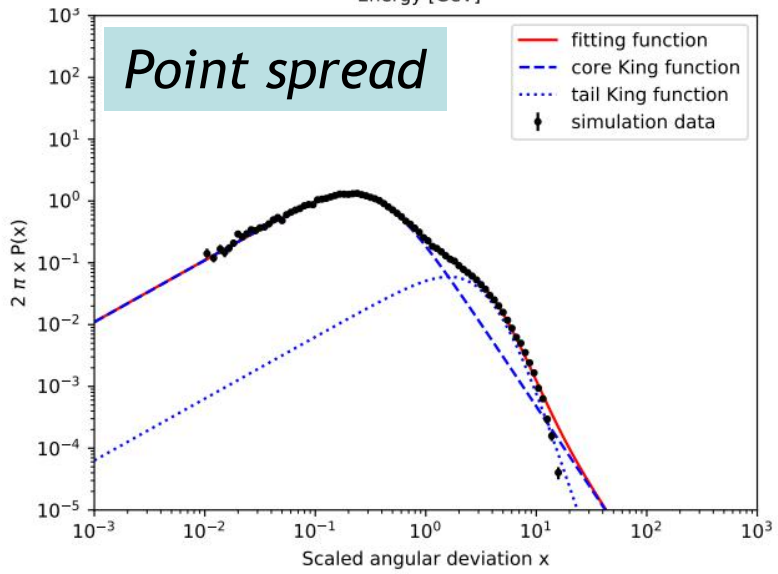


For 90% electron efficiency, proton background is ~2% @ TeV, ~5% @ 2 TeV, ~10% @ 5 TeV.

DAMPE IRFs for γ-rays

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





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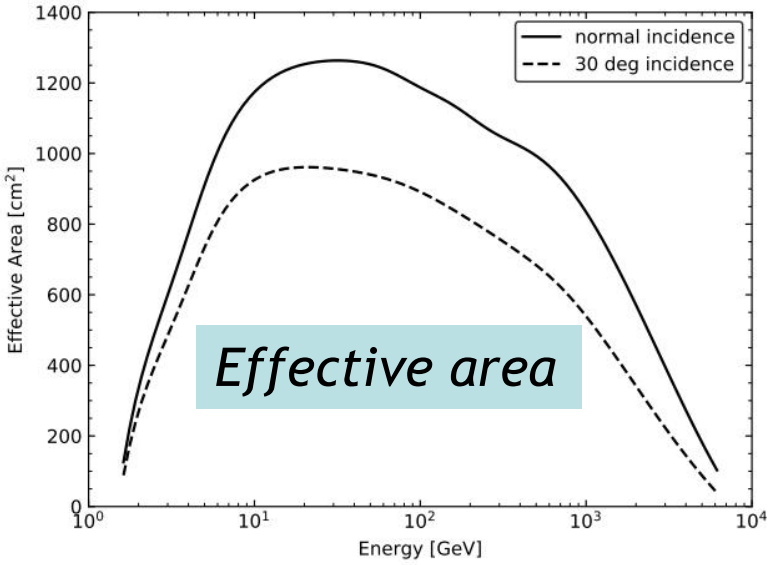
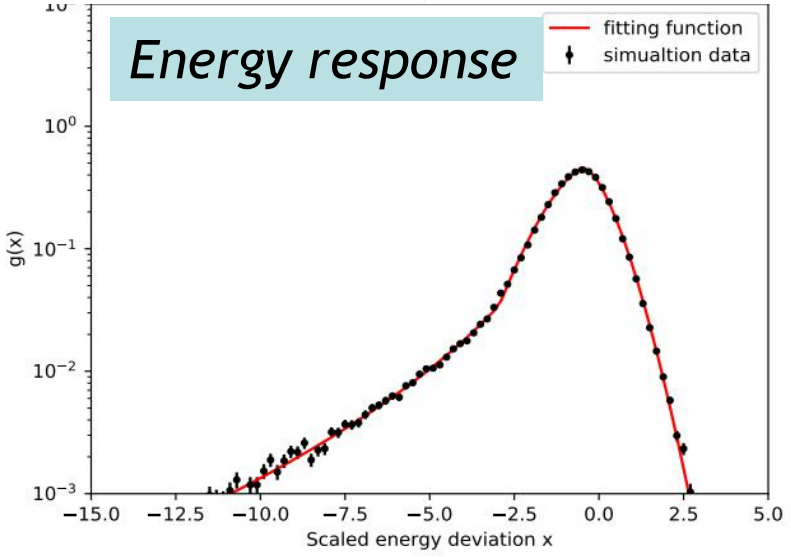
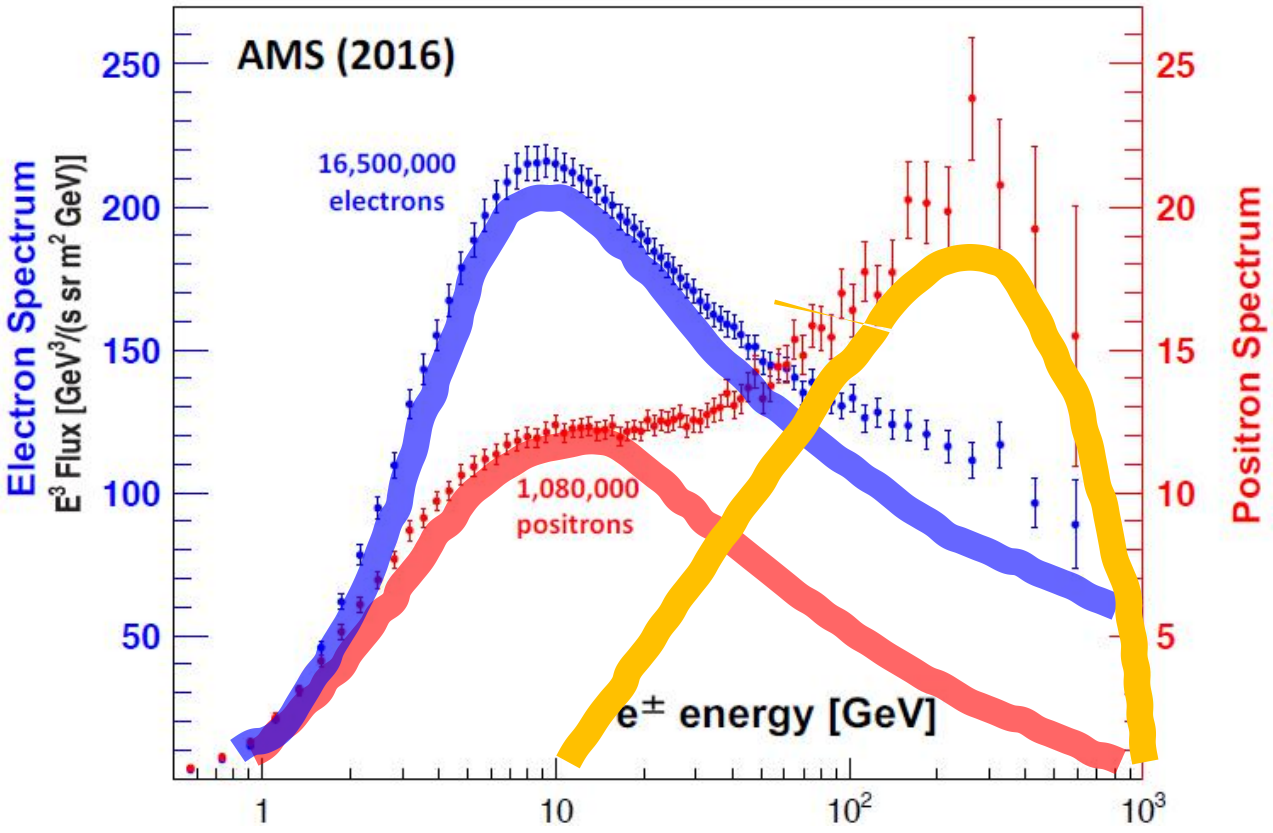




Three-component e^+e^- model



- 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, ...)