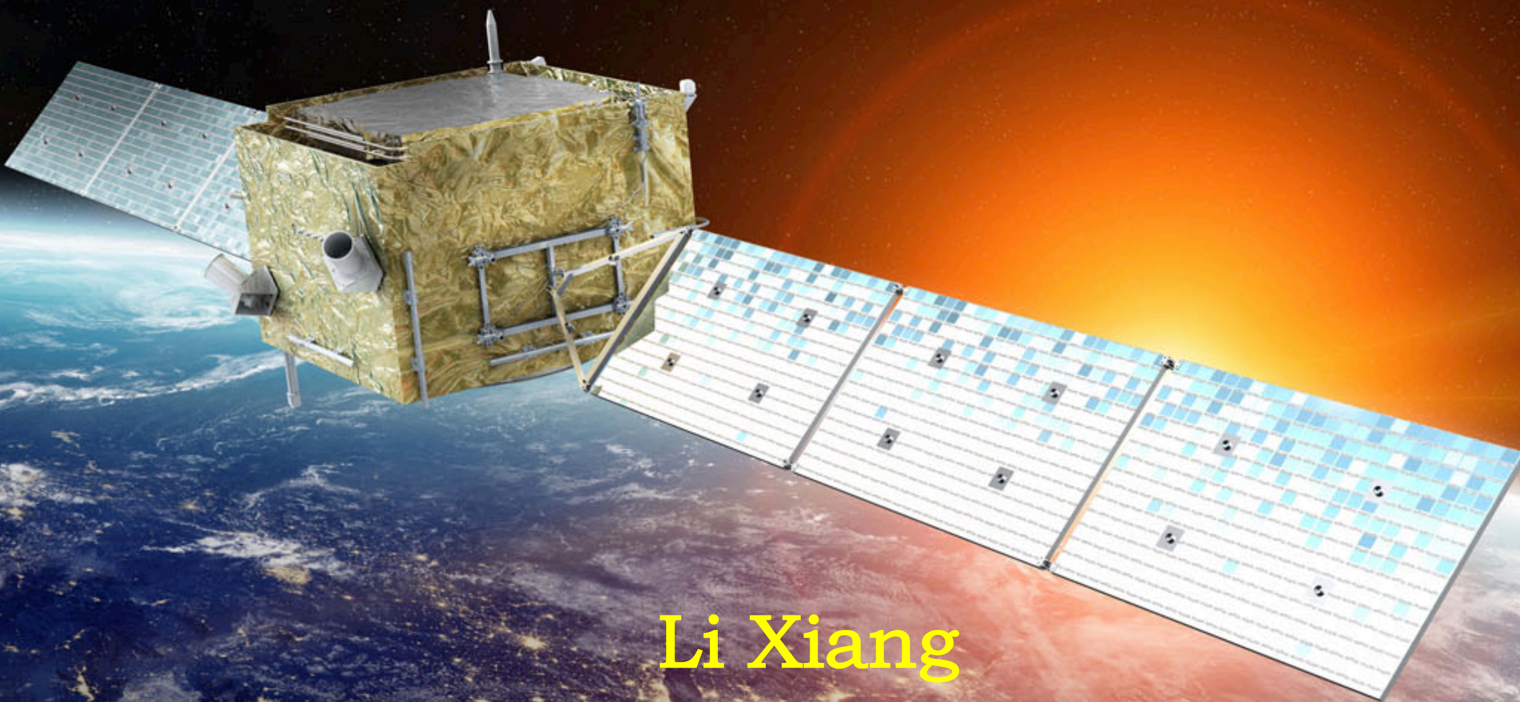
中国科学院暗物质与空间天文重点实验室

DSA Key Laboratory of Dark Matter and Space Astronomy, CAS

14th Dark Side of the Universe, Annecy, France, 25-29 June 2018

DAMPE Mission and Its First Results



Li Xiang

Purple Mountain Observatory, CAS

(on behalf of the DAMPE collaboration)

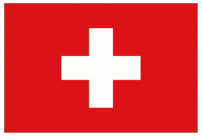
The collaboration

- **PI of DAMPE: Jin Chang from PMO**

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

- **ITALY**
  - INFN Perugia
  - INFN Bari
  - INFN Lecce

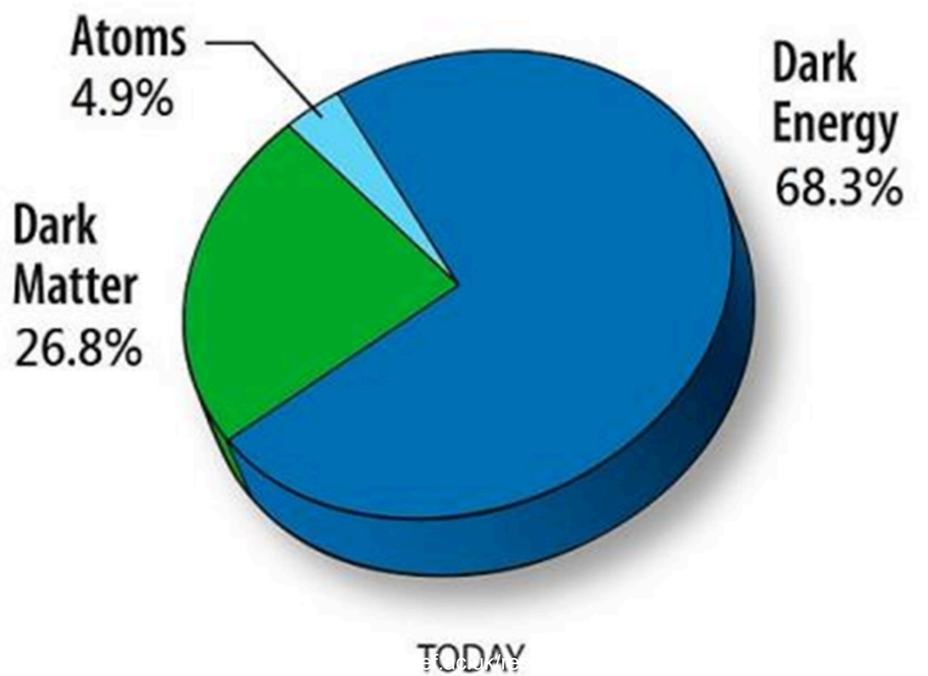
- **SWITZERLAND**
  - University of Geneva

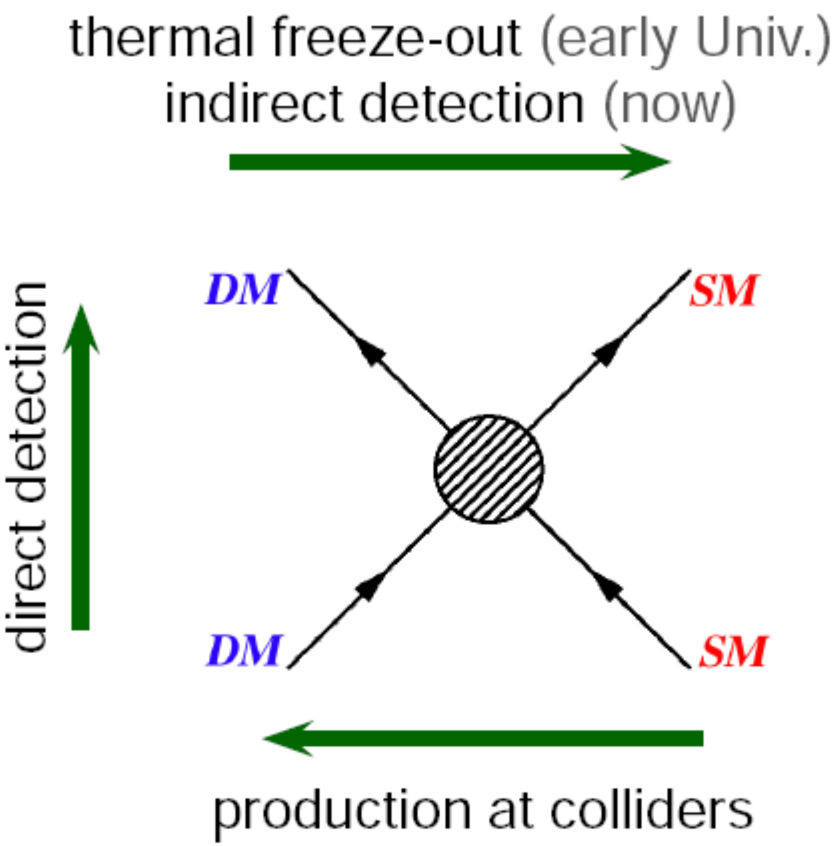


Outline

- Background
- DAMPE mission
  - Instrument
  - Beam Test
  - On-orbit performance
  - Present status
- First Results

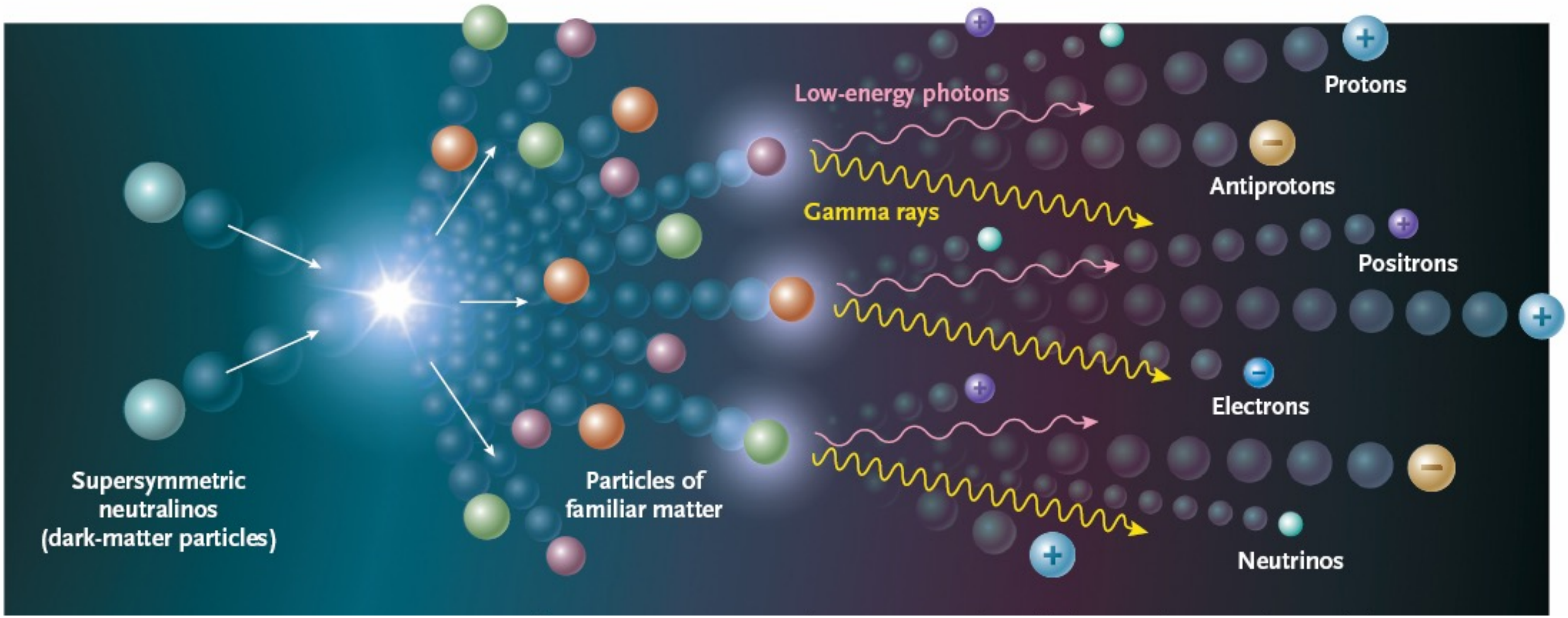
Dark matter





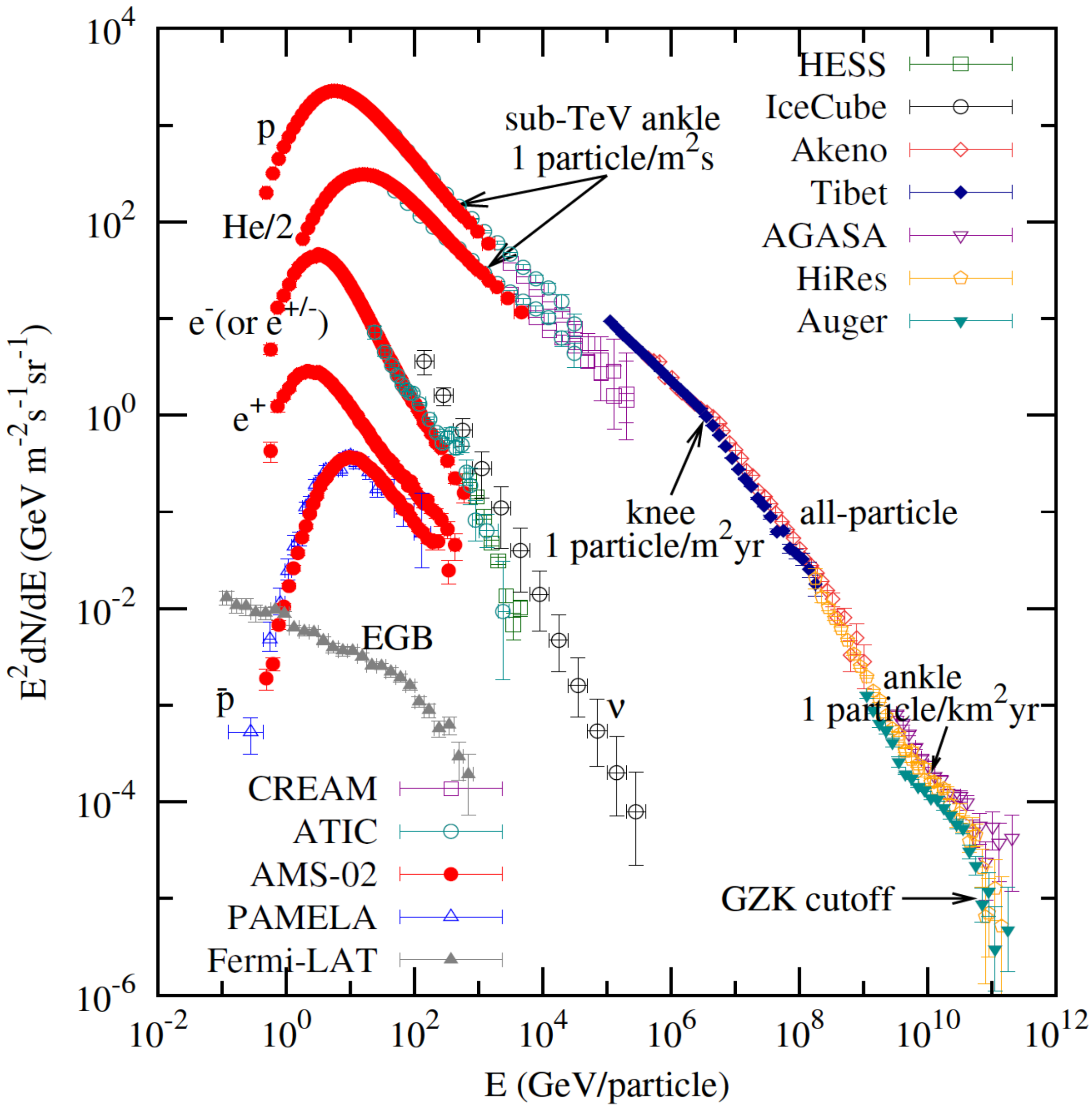
- **Compelling astrophysical evidence for dark matter**
- **New particle or modified gravity?**
- **Three detection methods**

Dark matter indirect detection



Dark matter particles may annihilate and then generate pairs of particles and anti-particles (gamma-rays, electrons/positrons, proton and antiprotons), see e.g., Bergström & Snellman 1988, Turner &Wilczek 1990

Dark matter indirect detection



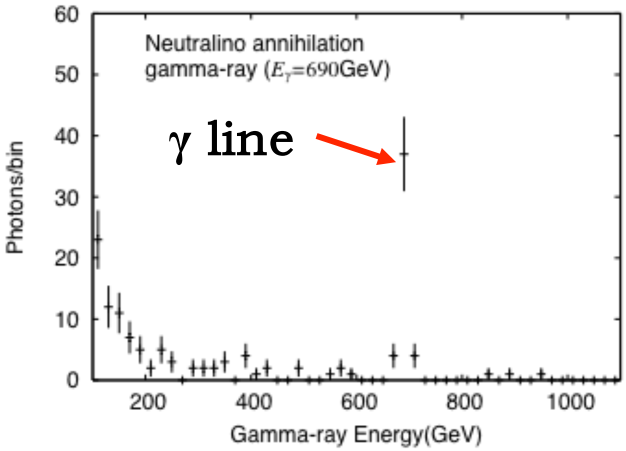
DM signal in anti-particles (AMS-02 like detectors): lower background

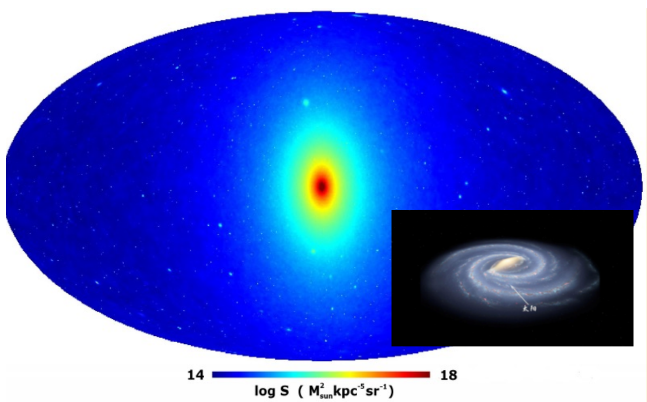
Electrons: relatively small contrast between the electron and positron flux

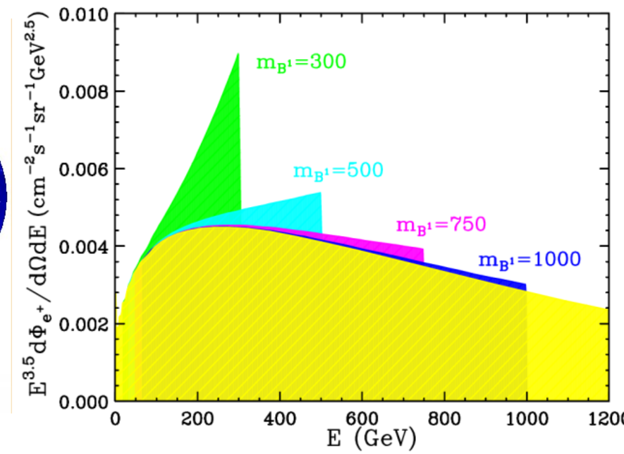
Gamma-rays and neutrinos: trace the source

Dark matter indirect detection

Possible DM signal in γ-rays and electrons



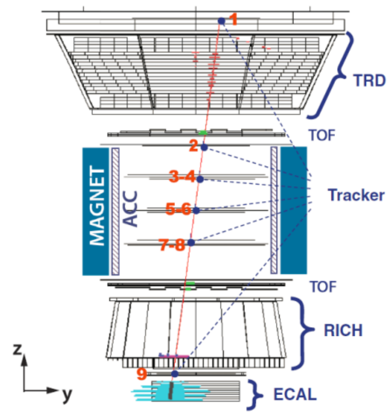


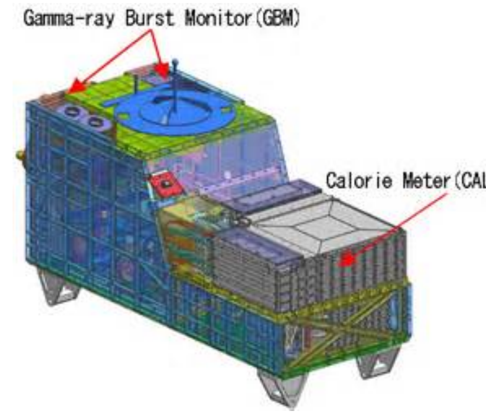


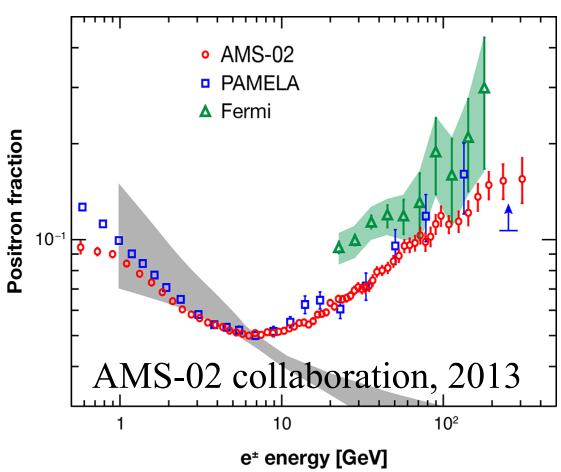
- The γ-ray line
- Continual γ-ray emission spatially correlated with the DM distribution
- Electrons with unusual spectrum

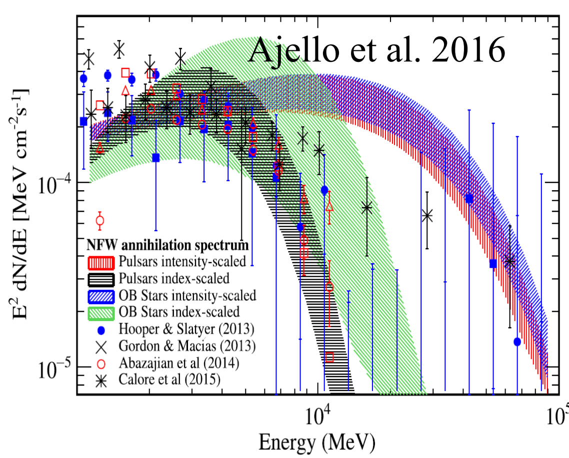
Dark matter indirect detection

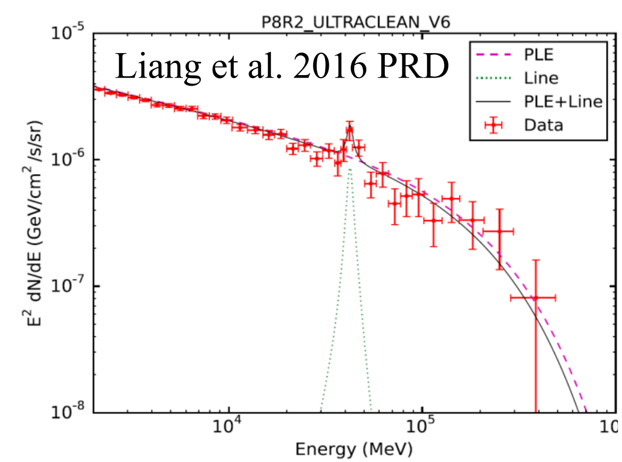
Some previous/current experiments and hints





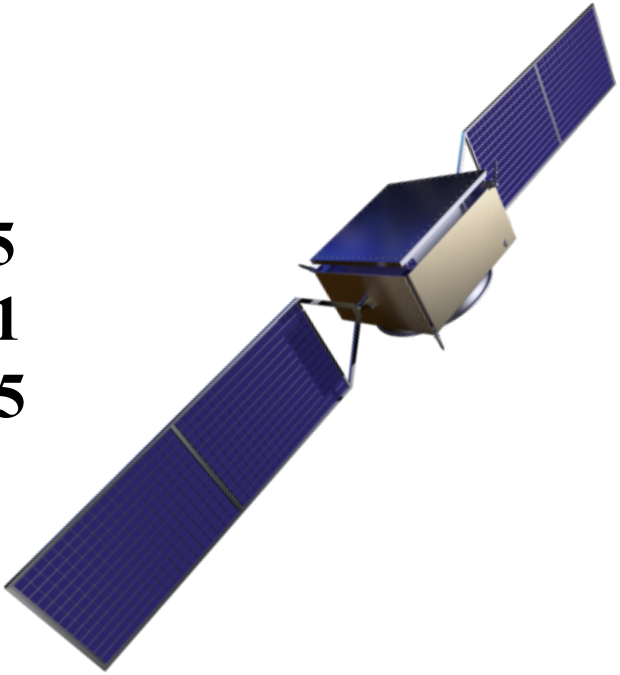






DArk Matter Particle Explorer

Proposed: 2005
Founded: 23 Dec. 2011
Launched: 17 Dec. 2015



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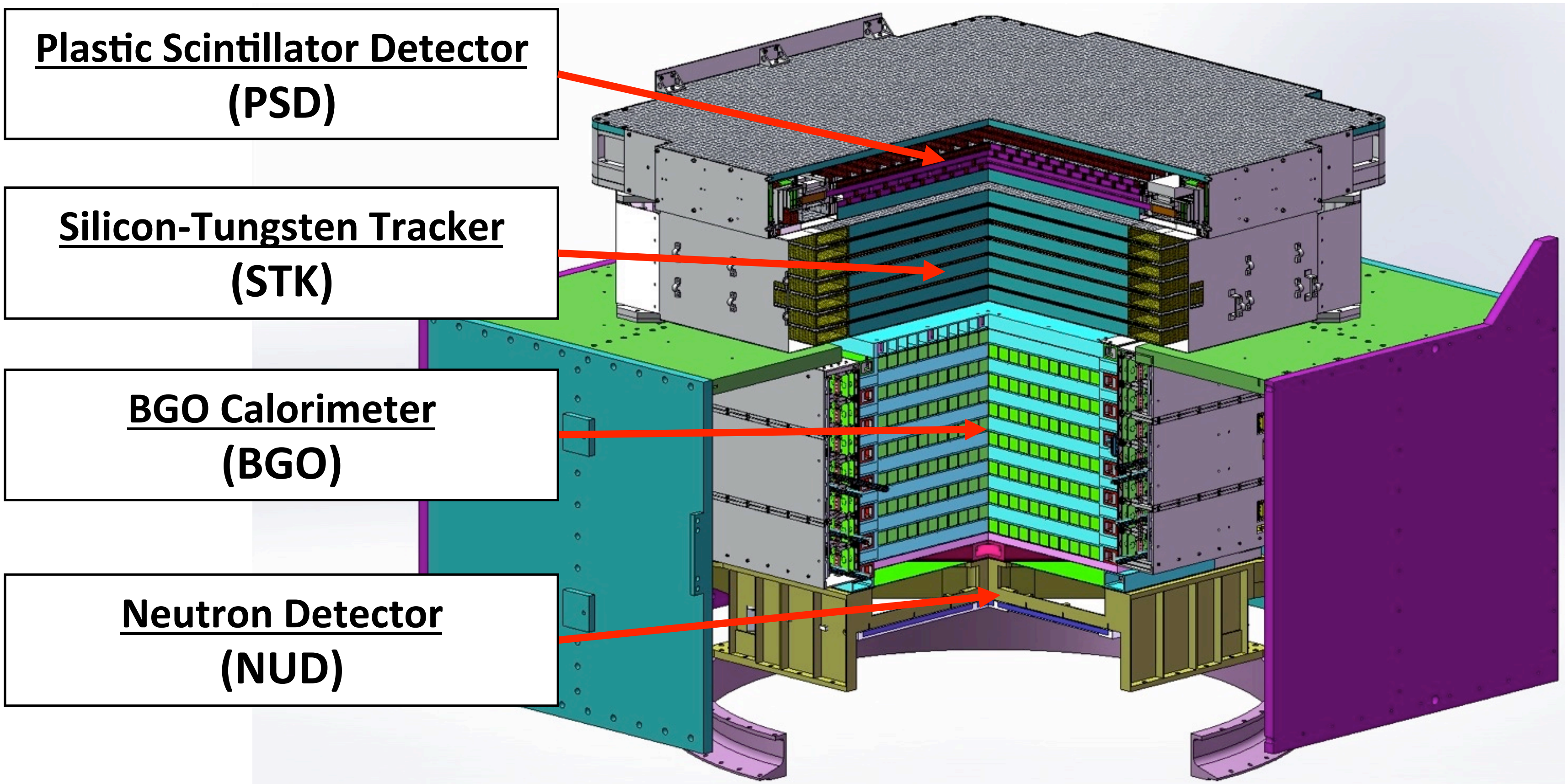
Wukong

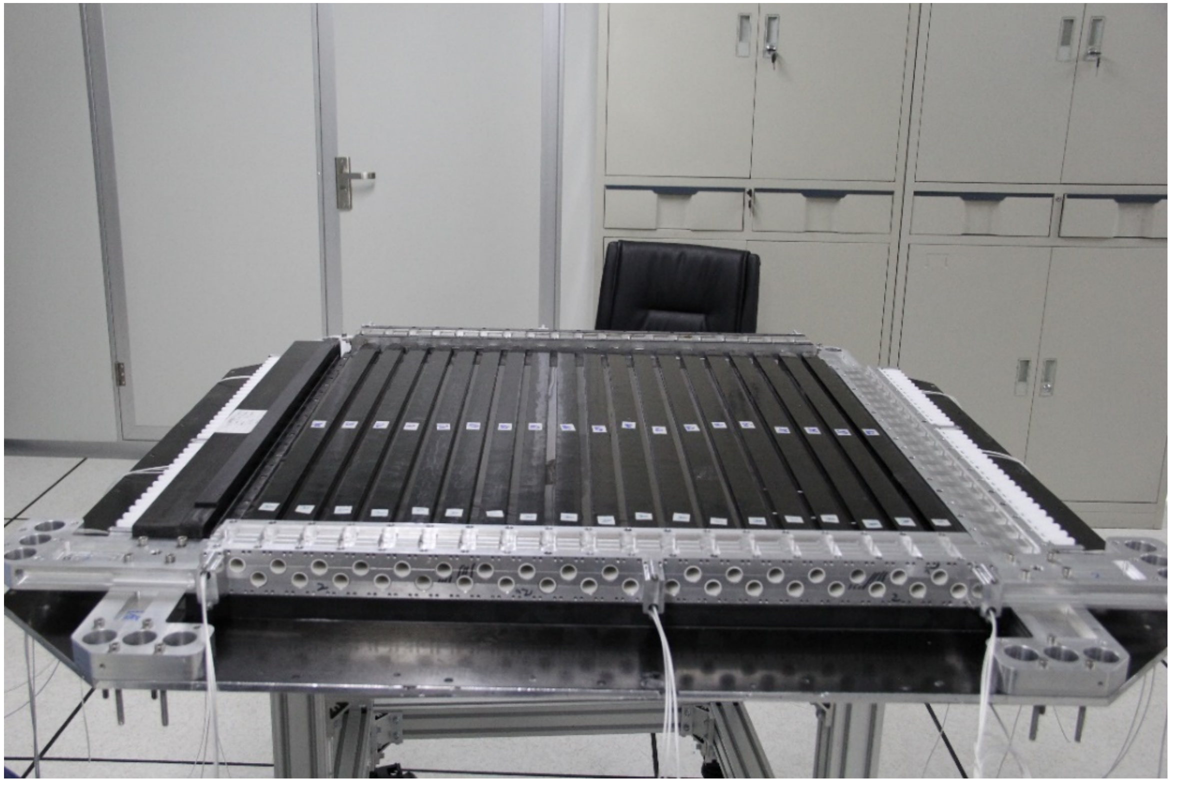
● Scientific objectives:
(a) Probing the nature of dark matter
(b) Understanding acceleration and propagation of cosmic rays
(c) Studying γ-ray emission from Galactic and extragalactic sources

The payload



- Charge measurement (dE/dx in PSD, STK and BGO)
- Pair production and tracking (STK and BGO)
- Precise energy measurement (BGO bars)
- Hadron rejection (BGO and neutron detector)

Instrument development: PSD

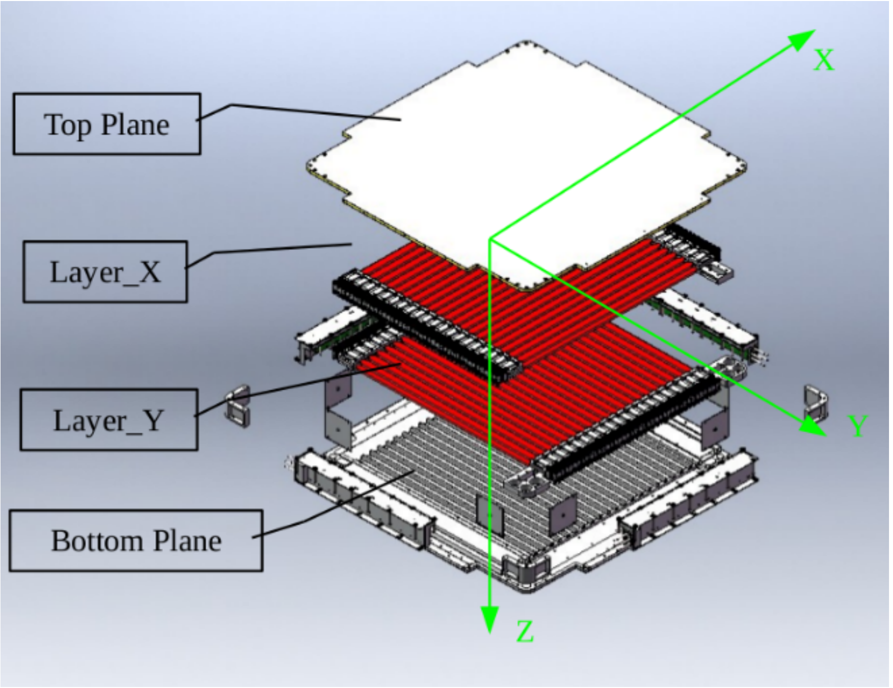


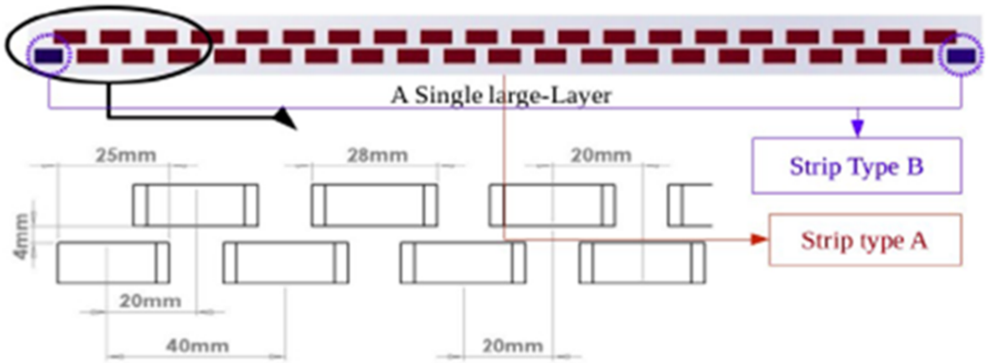
2 layers (x , y) of 1 cm thick strips,
41 stripes each layer
2.8 cm wide and 88.4 cm long
•Active area: 82 cm × 82 cm
•Weight : ~103 kg
•Power: ~ 8.5 W

Main purpose for PSD:
Charge particles rejection for gamma-ray
Charge measurement

(Yu et al. Astropart.Phys. 94 (2017) 1–10)

Instrument development: PSD



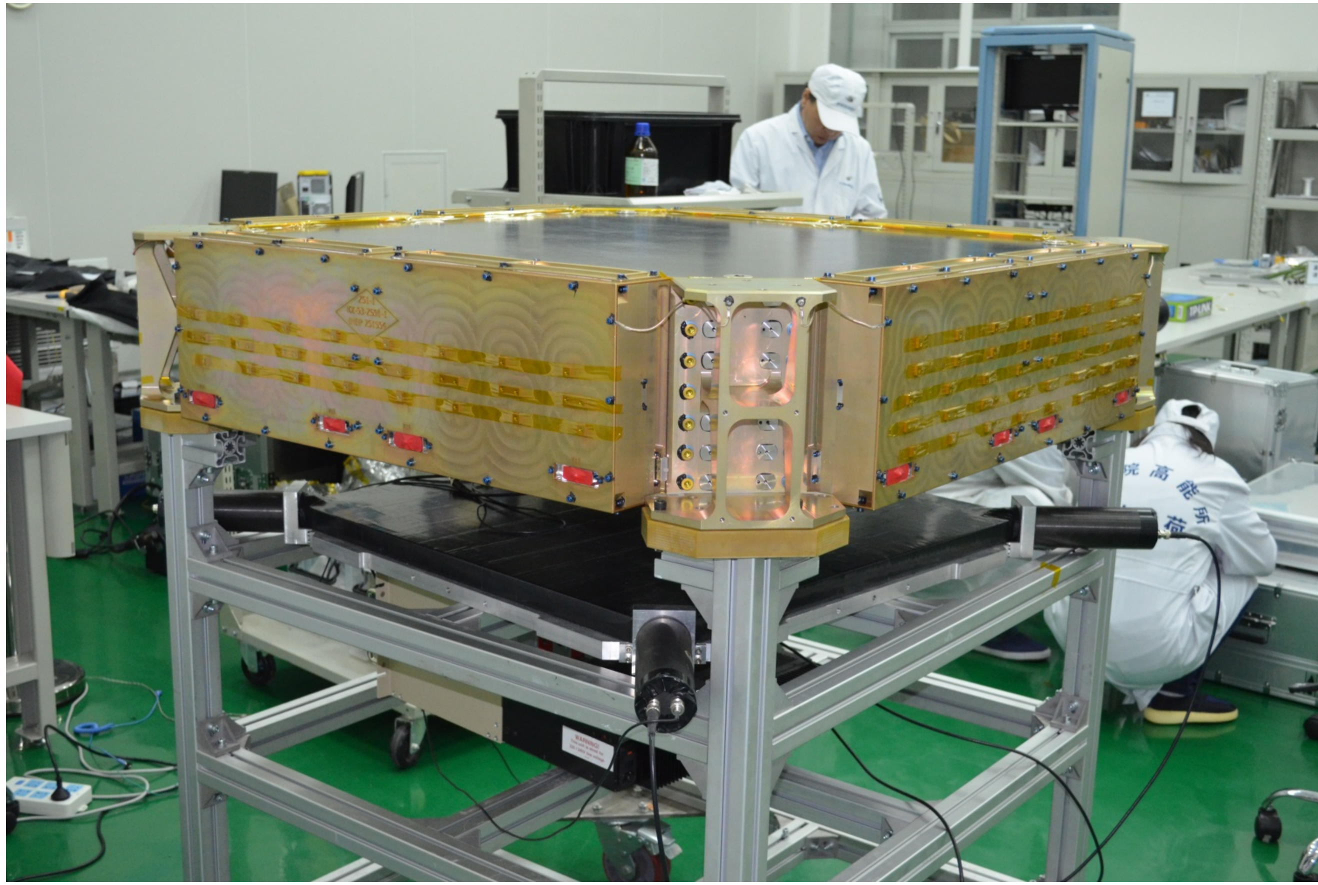


Readout both ends with PMT, each uses two dynode signals (factor ~ 40) to extend the dynamic range to cover Z = 1, 30

- Strip staggered by 0.8 cm
- No dead area
- Charge resolution: 0.12@Proton

(Yu et al. Astropart.Phys. 94 (2017) 1–10)

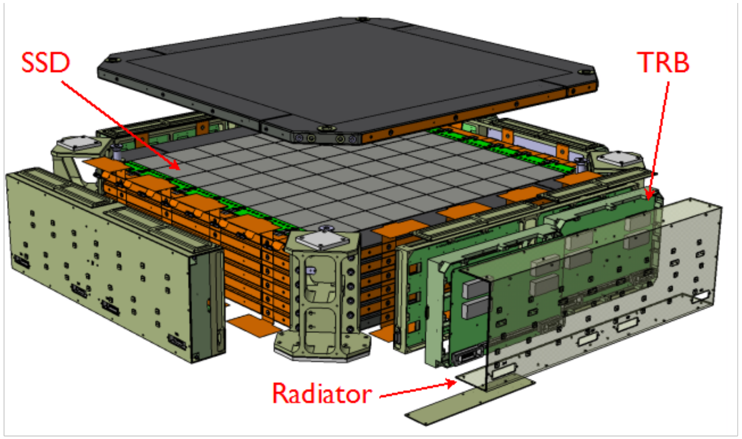
Instrument development: STK



- Envelop Size: 1.12m x 1.12m x 25.2 cm
- Total weight: ~154 Kg
- Power : ~ 82W
- Detection area: 76 cm x 76 cm

STK :
Direction
Charge measurement

Instrument development: STK

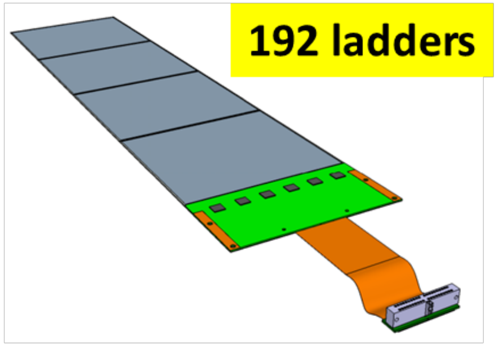


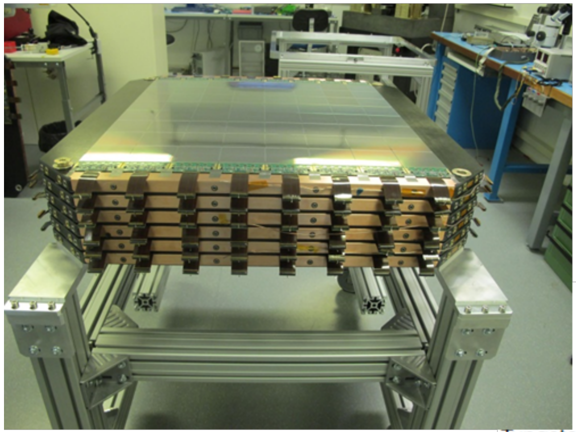
- 12 layers (6x, 6y) of single-sided Si strip detector mounted on 7 support trays
- Tungsten plates (1mm thick) integrated in trays 2, 3, 4 (from the top)
  - Total 0.85 X_0 for photon conversion

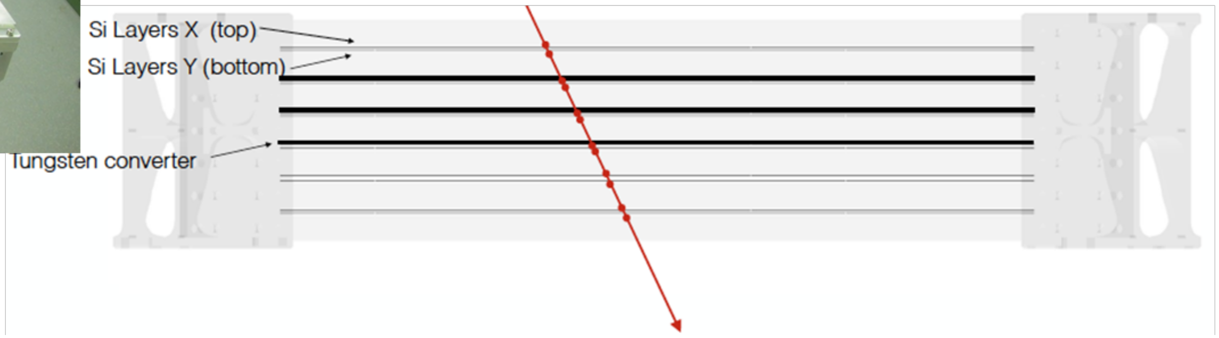
768 silicon sensors
95 x 95 x 0.32 mm^3

1,152 ASICs

73,728 channels





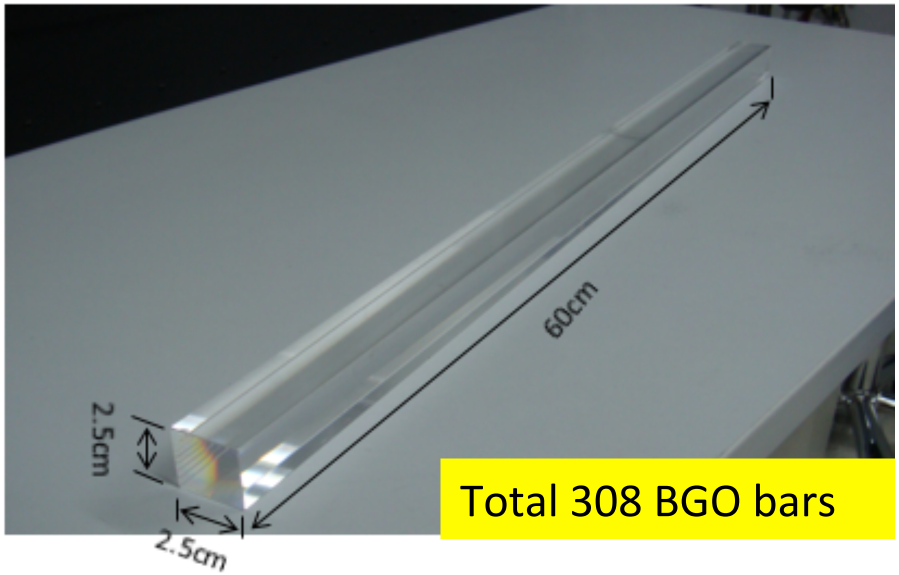


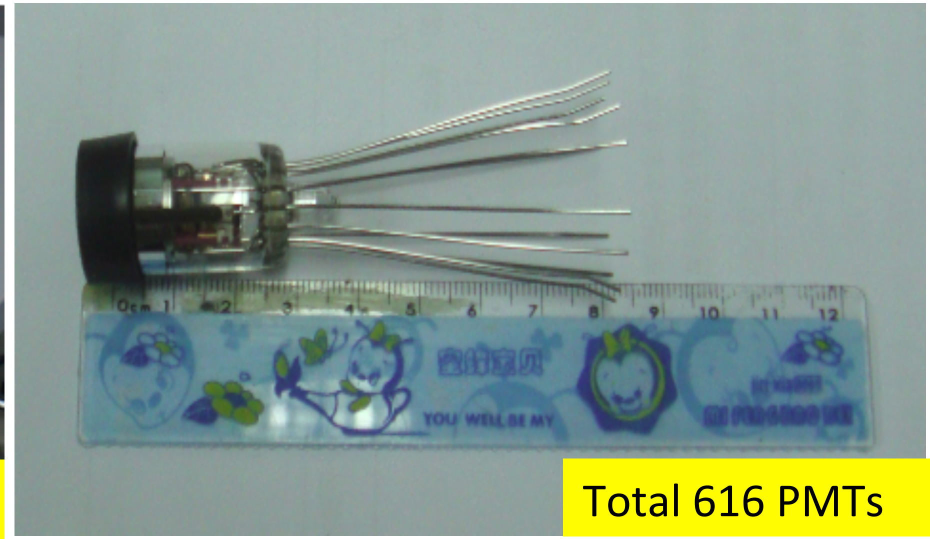
Instrument development: BGO

- Outer envelop: 1 m x 1 m x 50 cm
- Detection area: 60 cm x 60 cm
- Total weight: ~1052 Kg
- Total power consumption: ~ 41.6 W

BGO:
Energy deposition
Imaging the 3D shower development
Providing the trigger for DAQ

Instrument development: BGO





- 14 layers of BGO Calorimeter
  - 7x & 7Y stacking alternating orthogonal
  - 22 BGO bars in each layer

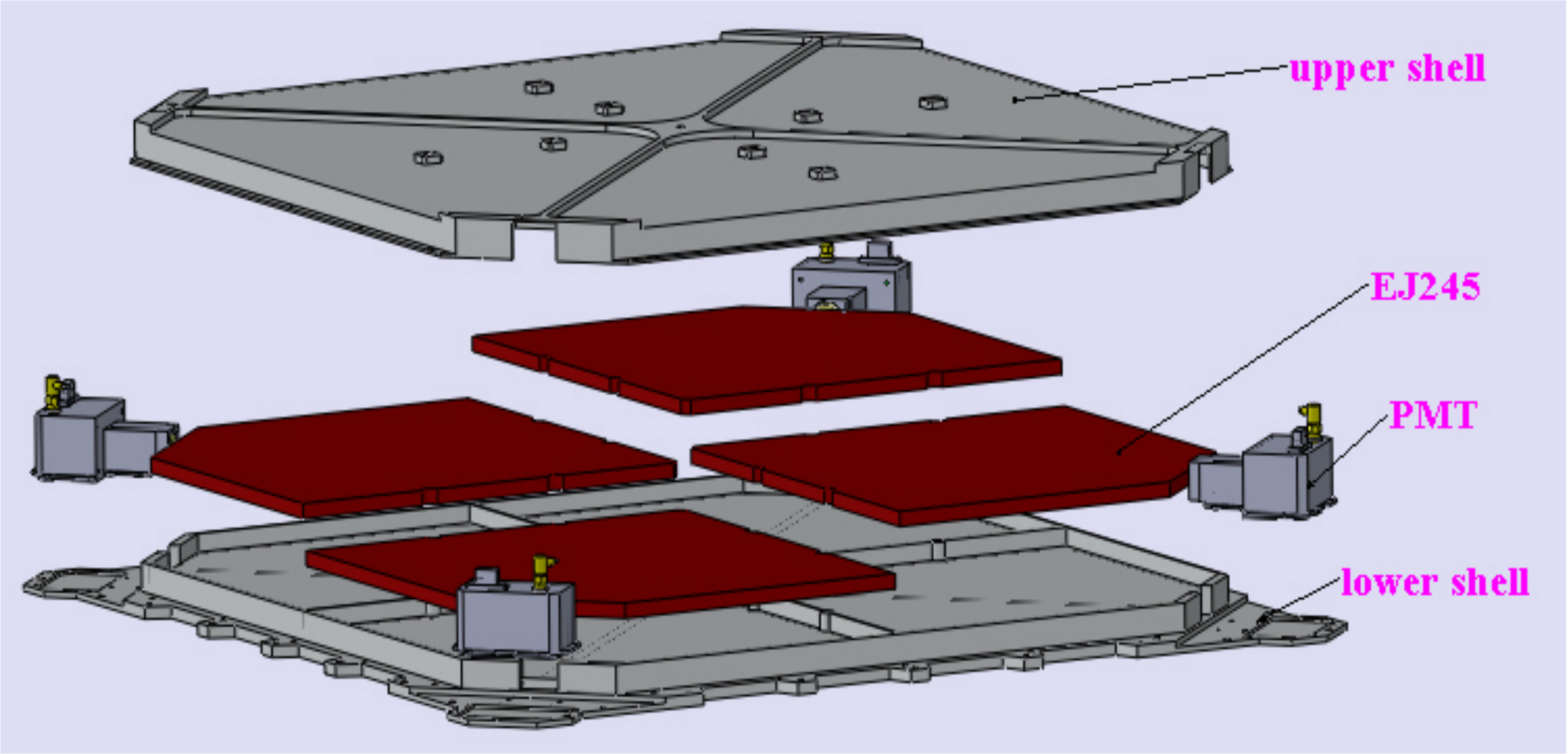
    each bar: 2.5 cm×2.5 cm×60 cm
  - r.l: ~$32X_0$, NIL: 1.6
- 2 PMTs coupled with each bar in two ends
- 3 readouts from each PMT (Dy2,Dy5,Dy8)
- Electronics boards attached to each side

Instrument development: NUD

- 4 plastic Scintillators (^{10}B)
- Active area: 61cm×61cm
- Energy range: 2-60 MeV for single detector
- Energy resolution: ≤10% at 30 MeV
- Power: 0.5 W
- Mass: 12 Kg

$$n + {}^{10}B \longrightarrow \alpha + {}^{7}Li + \gamma$$

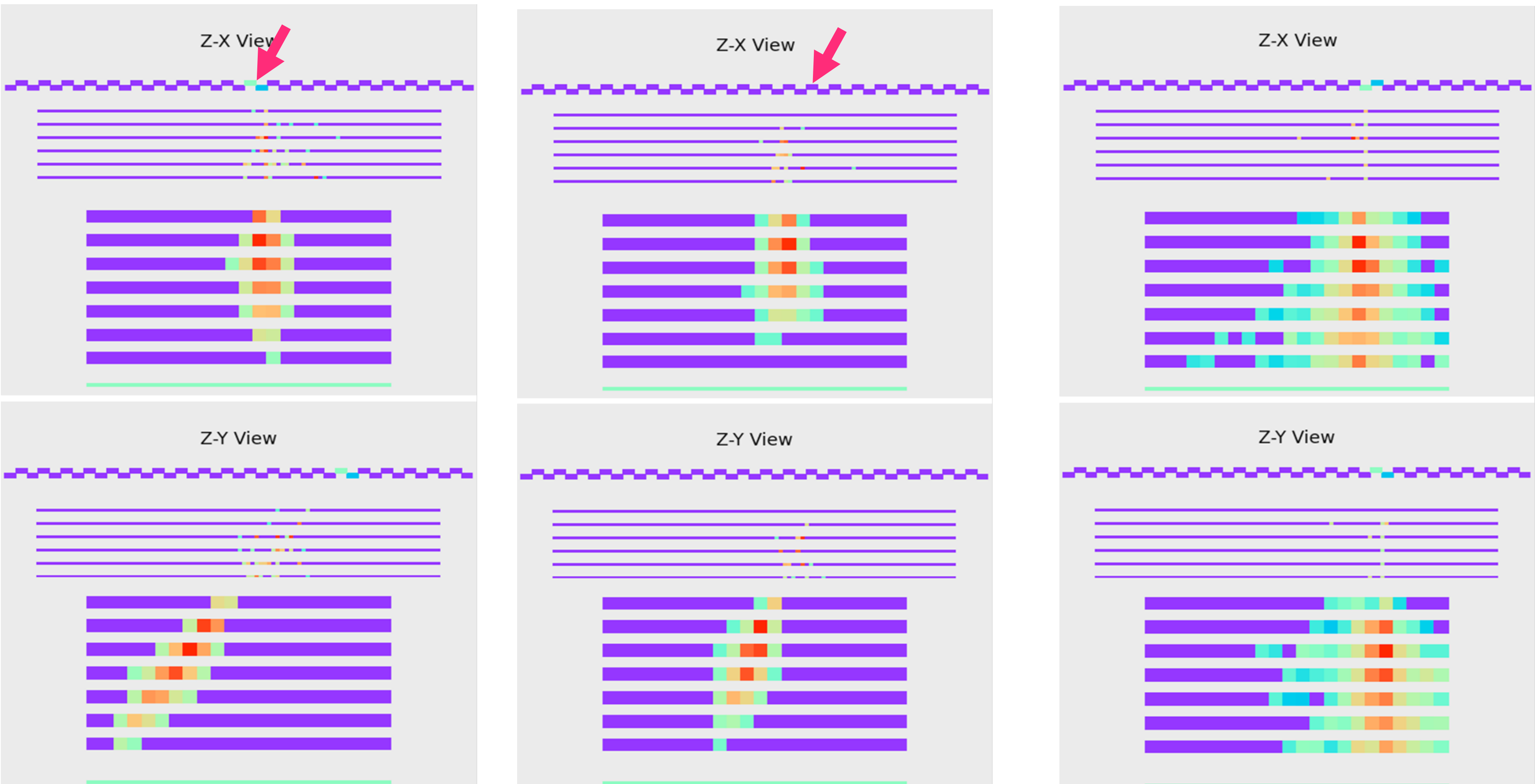
Instrument development: NUD



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

Signals for different particles

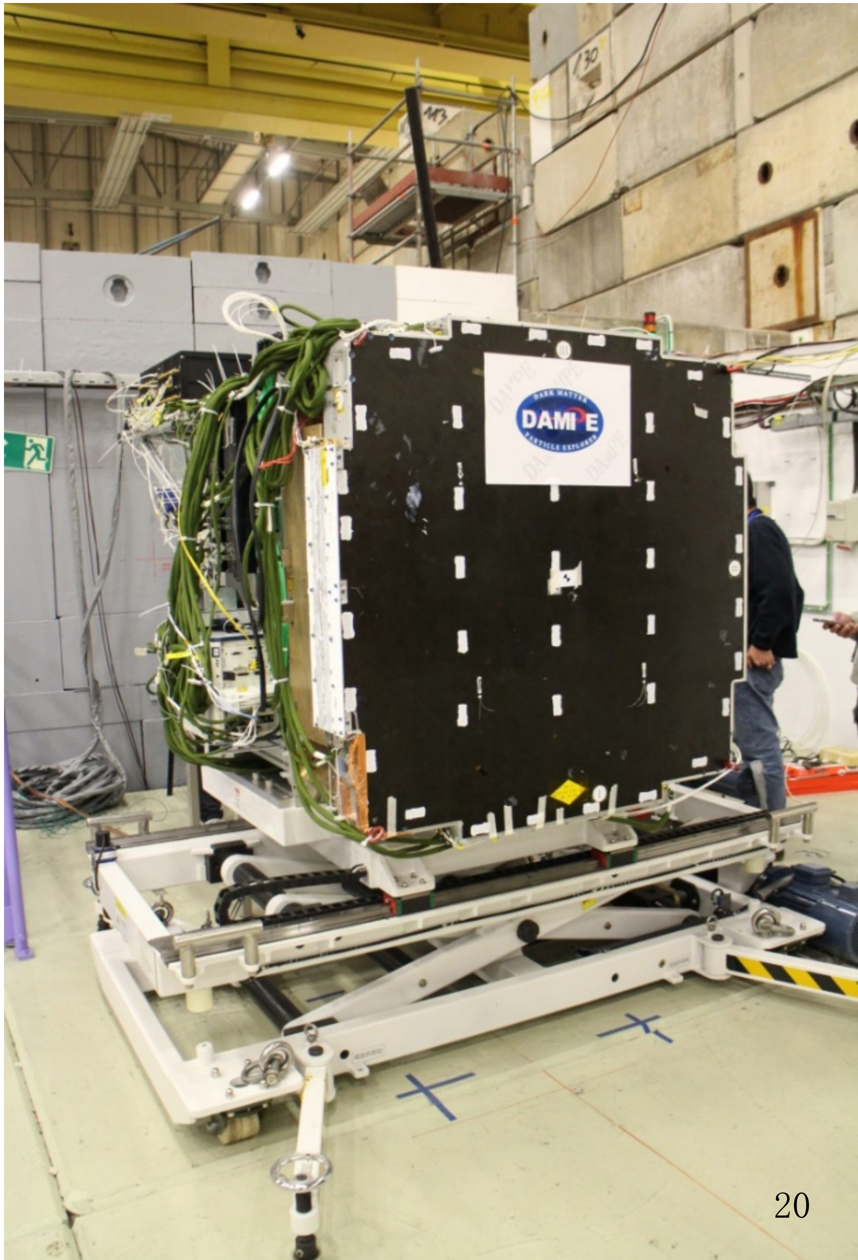
electron gamma proton



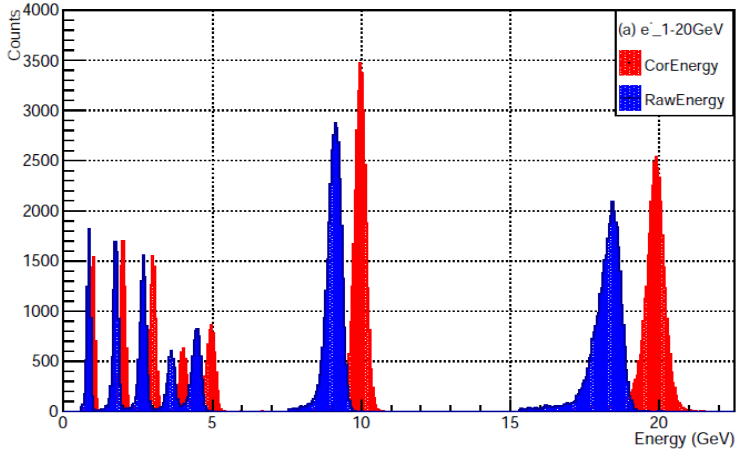
Beam test @ CERN

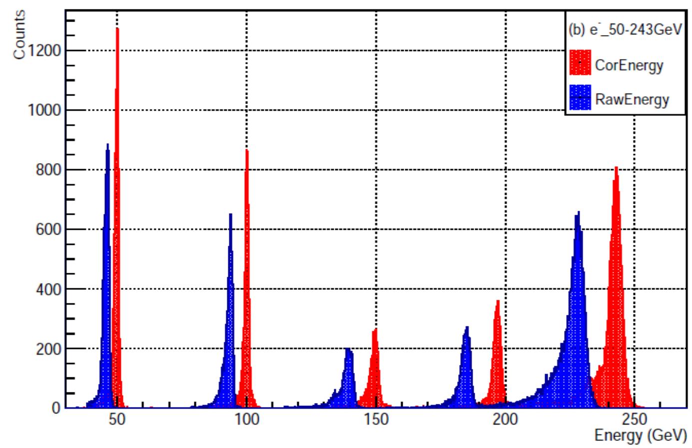
- 14 days@PS， 29/10-11/11 2014
  - e @ 0.5GeV/c, 1GeV/c, 2GeV/c, 3GeV/c, 4GeV/c, 5GeV/c
  - p @ 3.5GeV/c, 4GeV/c, 5GeV/c, 6GeV/c, 8GeV/c, 10GeV/c
  - π-@ 3GeV/c, 10GeV/c
  - γ @ 0.5-3GeV/c
- 8 days@SPS， 12/11-19/11 2014
  - e @ 5GeV/c, 10GeV/c, 20GeV/c, 50GeV/c, 100GeV/c, 150GeV/c, 200GeV/c, 250GeV/c
  - p @ 400GeV/c (SPS primary beam)
  - γ @ 3-20GeV/c
  - μ @ 150GeV/c,
- 17 days@SPS， 16/3-1/4 2015
  - Fragments： 66.67-88.89-166.67GeV/c
  - Argon： 30A- 40A- 75AGeV/c
  - Proton： 30GeV/c， 40GeV/c
- 21 days@SPS， 10/6-1/7 2015
  - Primary Proton: 400GeV/c
  - Electrons @ 20, 100, 150 GeV/c
  - g @ 50, 75 , 150 GeV/c
  - m @ 150 GeV /c
  - p+ @10, 20, 50, 100 GeV/c
- 6 days@SPS, 20/11-25/11 2015

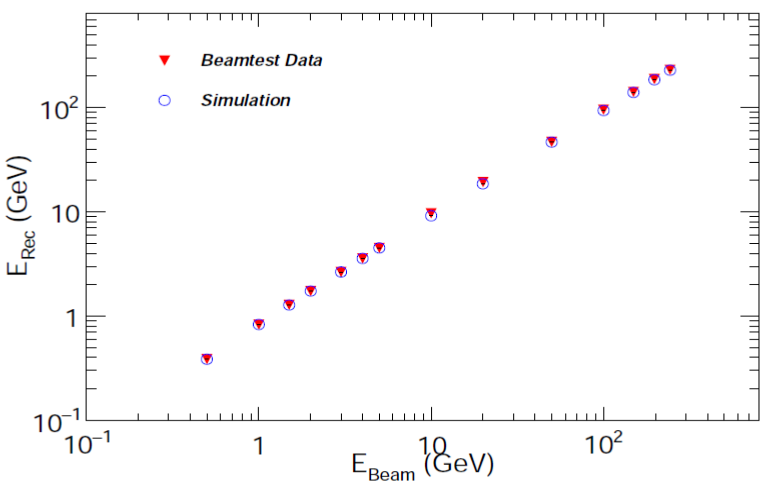
  -- Pb 030 AGeV/c (and fragments)



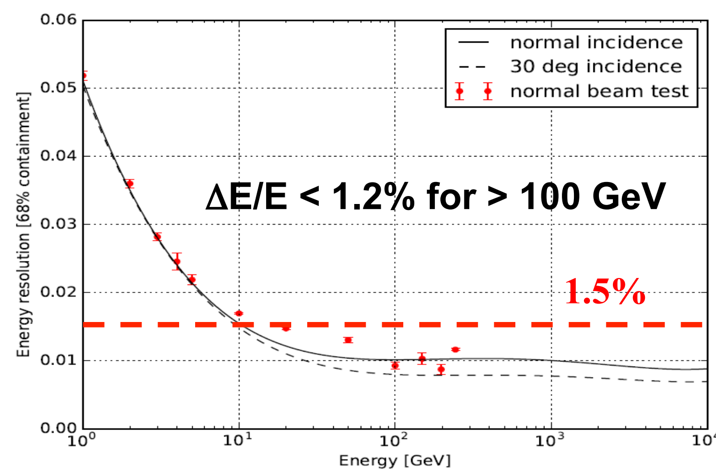
Beam test @ CERN







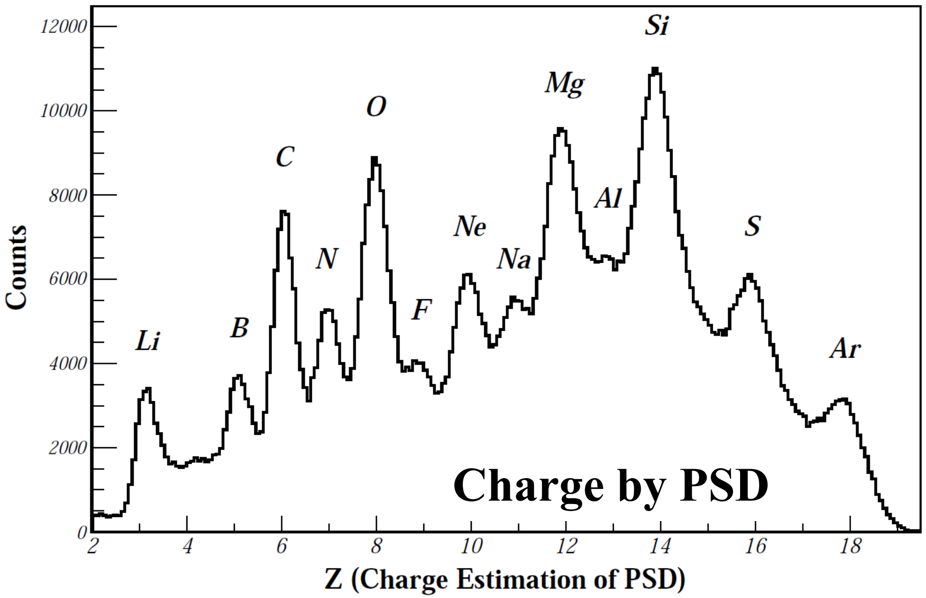
Energy linearity of electrons

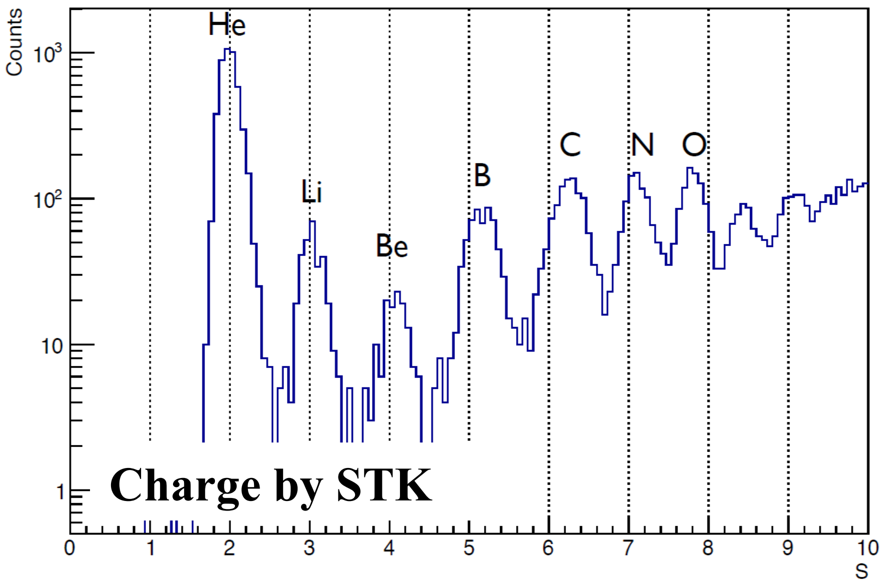


Energy resolution of electrons

(Chang et al. [DAMPE collaboration] 2017 Astropart. Phys.)

Beam test @ CERN





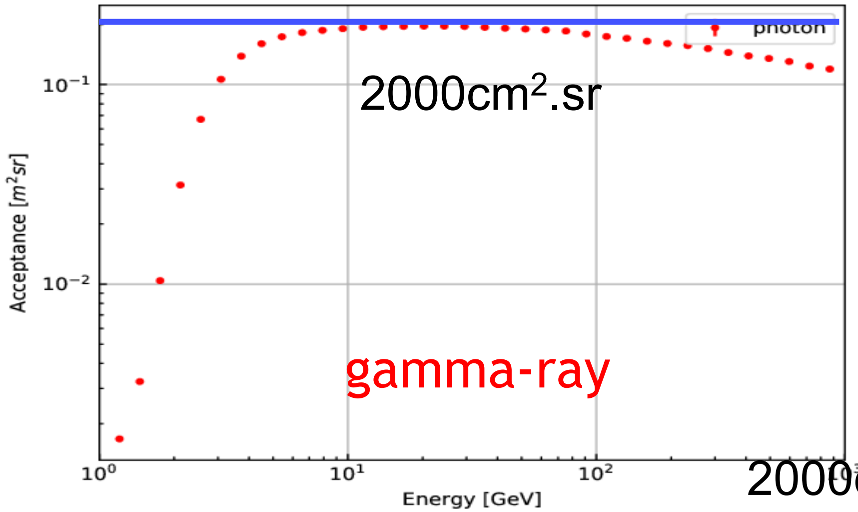
(Chang et al. [DAMPE collaboration] 2017 Astropart. Phys.)

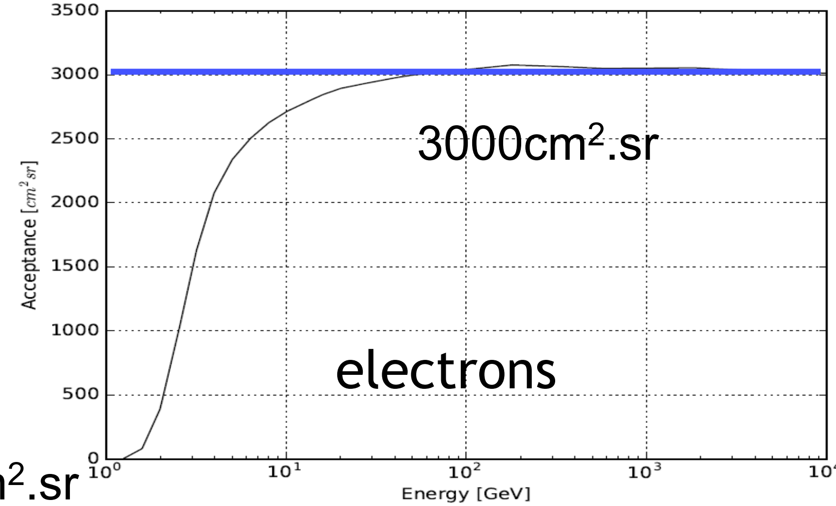
Expected performance

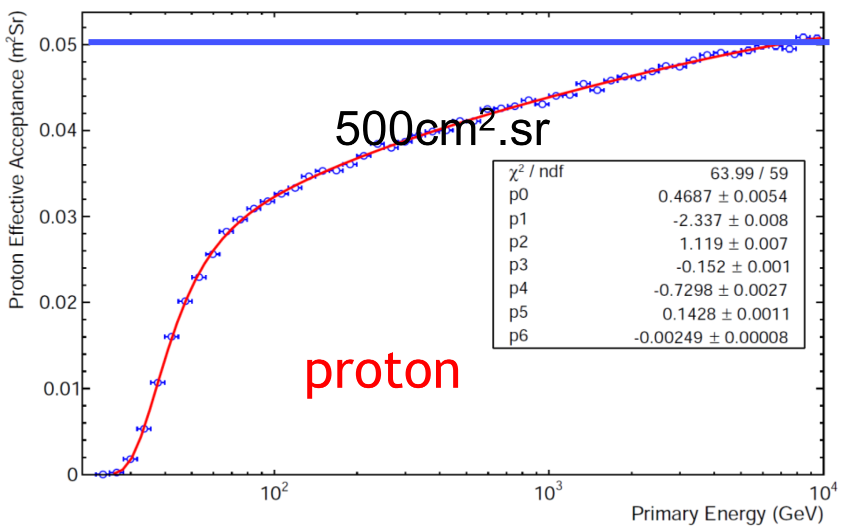
Parameter	Value
Energy range of gamma-rays/electrons	5 GeV to 10 TeV
Energy resolution(electron and gamma)	1.5% at 800 GeV
Energy range of protons/heavy nuclei	50 GeV to 500 TeV
Energy resolution of protons	40% at 800 GeV
Eff. area at normal incidence (gamma)	1100 cm^2 at 100 GeV
Geometric factor for electrons	0.3 m^2 sr above 30 GeV
Photon angular resolution	0.1 degree at 100 GeV
Field of View	1.0 sr

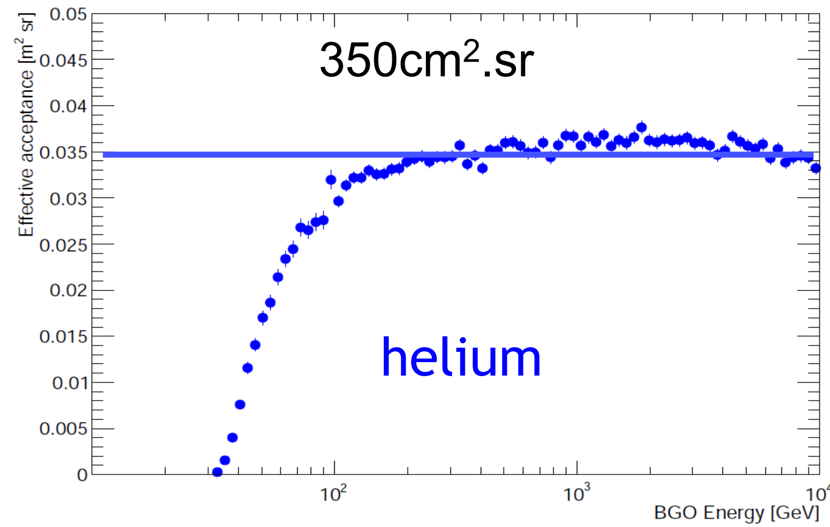
(Chang et al. [DAMPE collaboration] 2017 Astropart. Phys.)

Expected performance(eff. area)





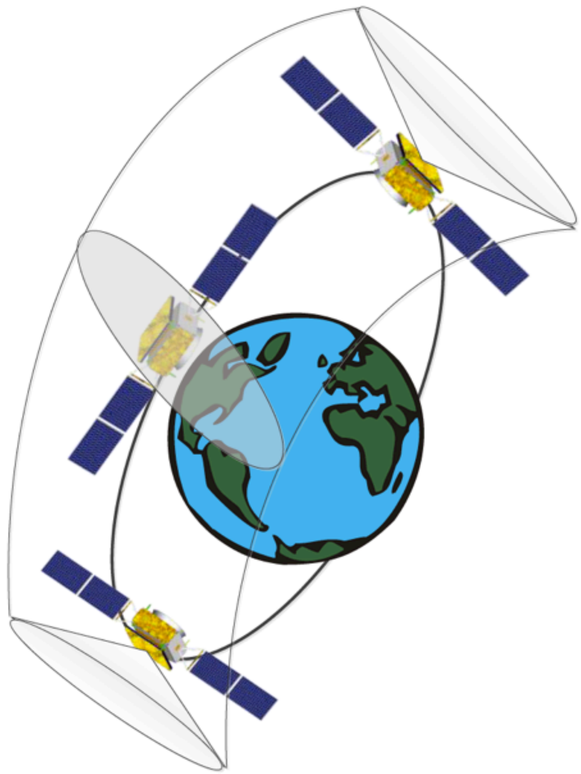


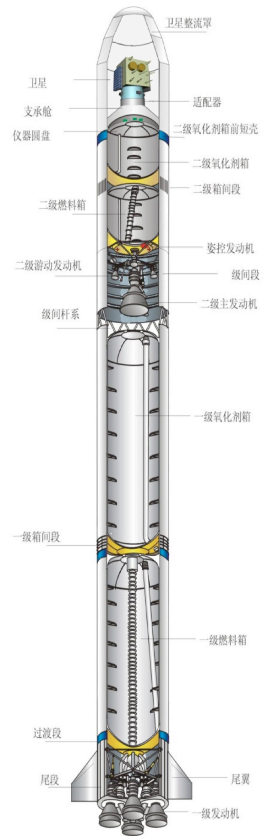


Launch of DAMPE

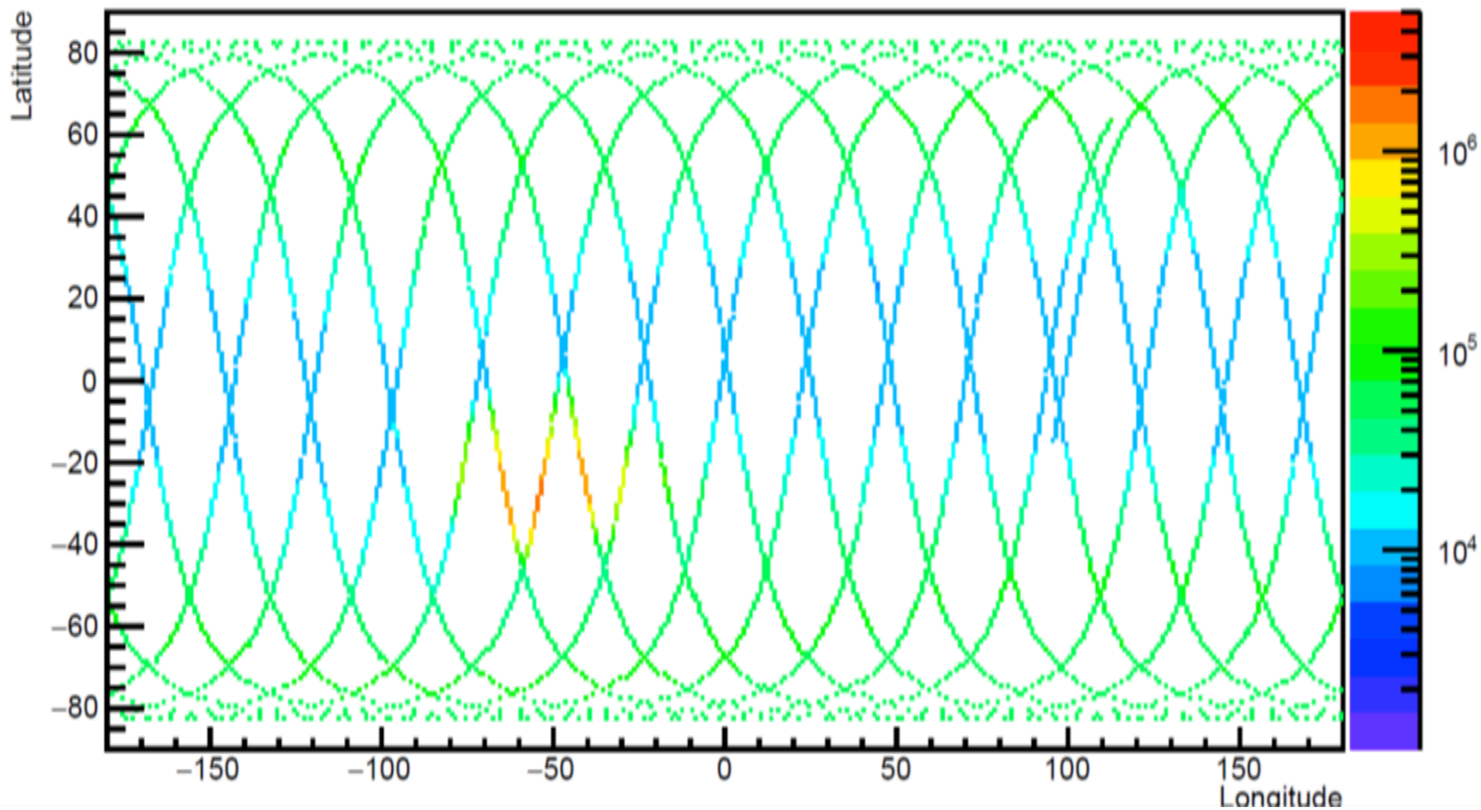
- Launch: December 17th 2015, CZ-2D rocket
  - Total weight ~1850 kg, power consumption ~640 W
    - Scientific payload ~1400 kg, ~400 W
  - Lifetime > 3 year

- Altitude: 500 km
- Inclination: 97.4065°
- Period: 95 minutes
- Orbit: sun-synchronous
- 16 GB/day downlink





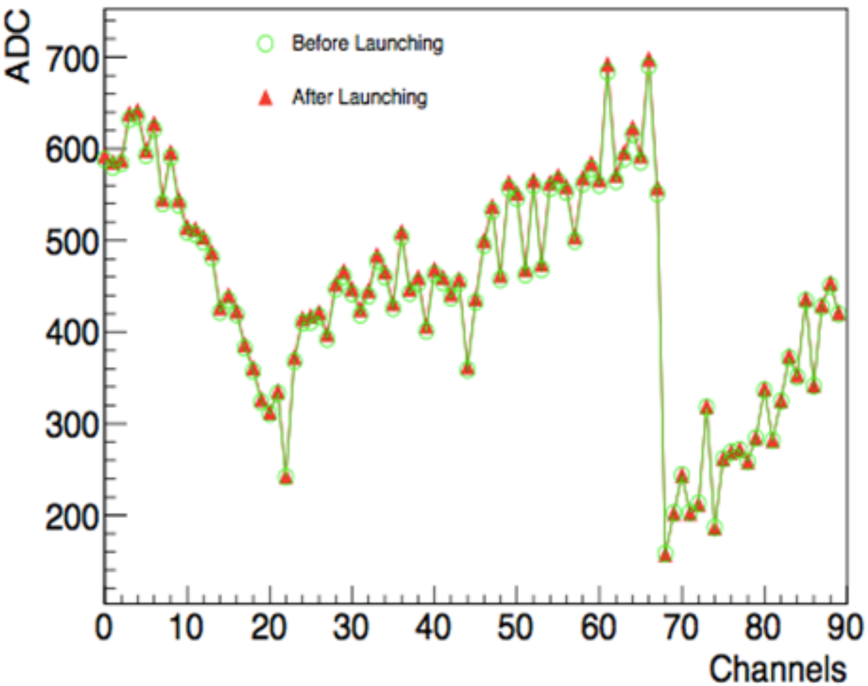
On-orbit trigger rate

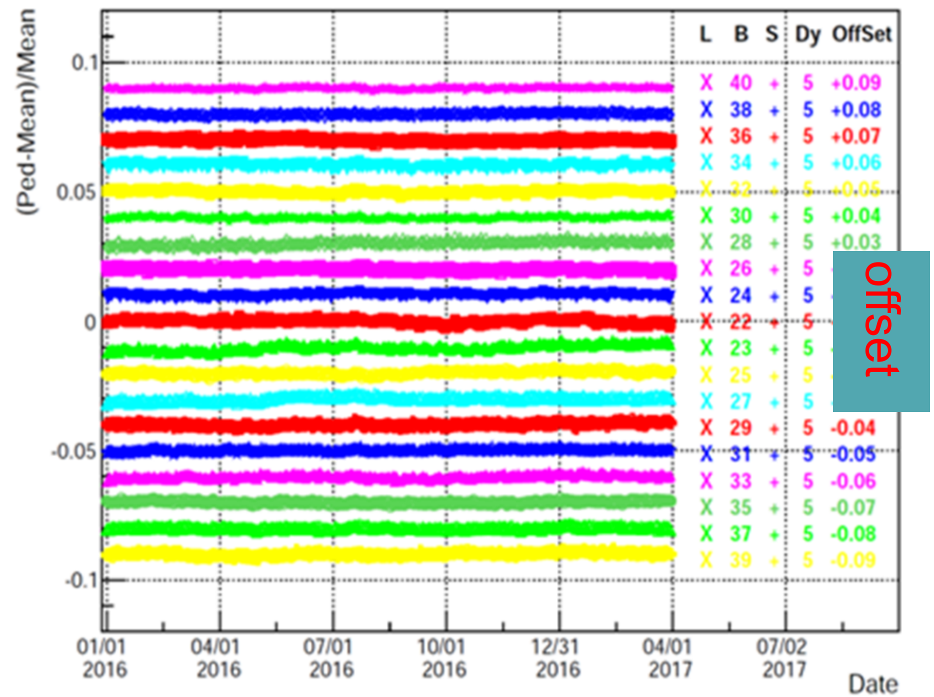


~60 Hz average trigger rate

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

PSD on-orbit calibration



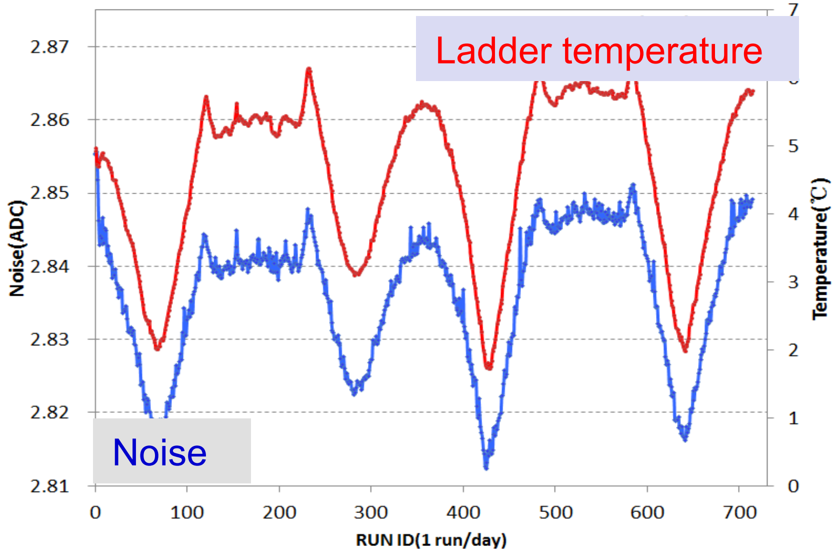


Each channel before/after the launch has been checked

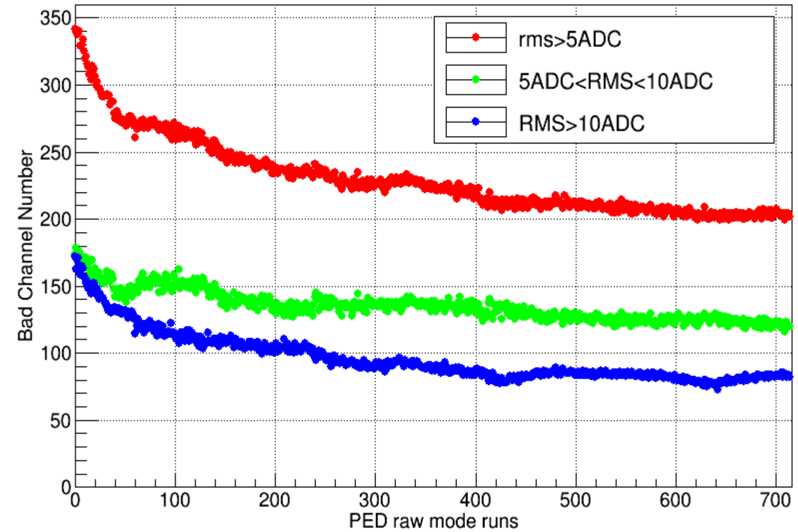
(Zhang et al. PoS (ICRC2017) 168)

On-orbit STK noise: very stable

Average noise 2.81-2.85 ADC



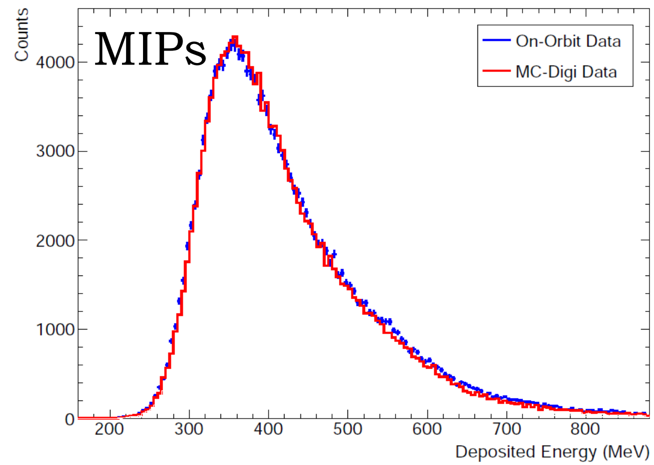
Number of noisy channels <0.3%

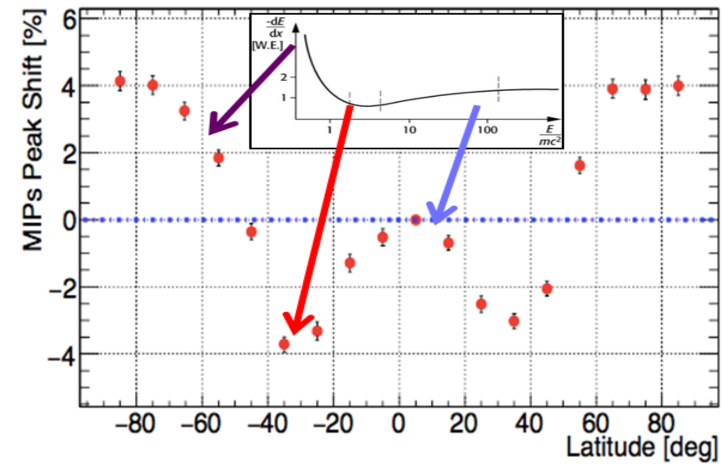


Two years since launch

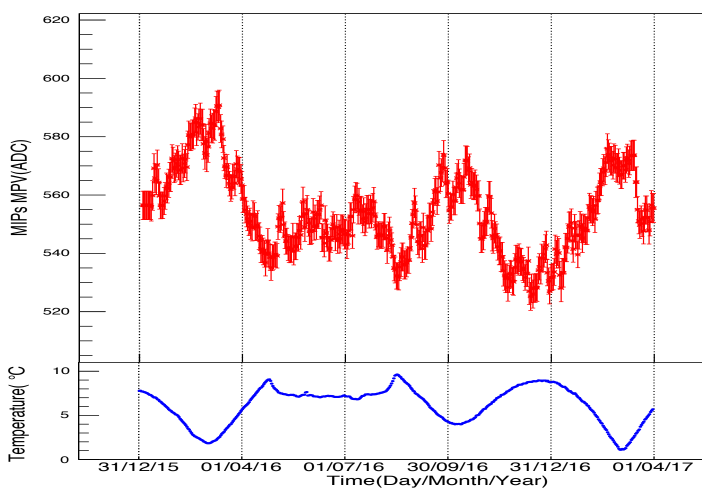
- **Bulk of noise correlated with temperature**
  - **Very small temperature coefficient**
    - **~0.01 ADC per 2 °C**
- **Noisy channels stabilized to lower noise values**
  - **very small temperature effect**

BGO on-orbit calibration: MIPs

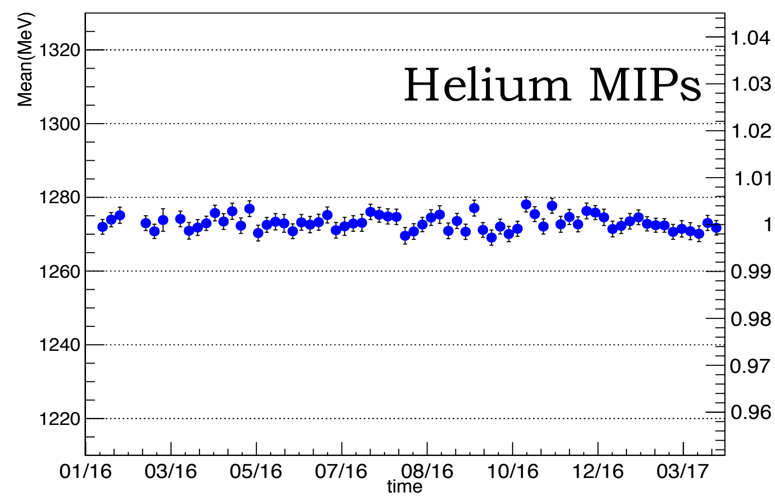




Before temperature correction

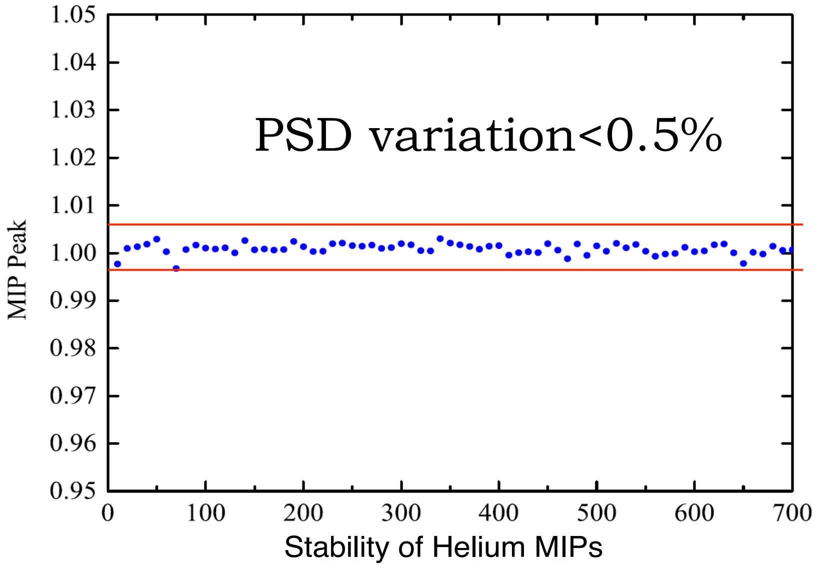


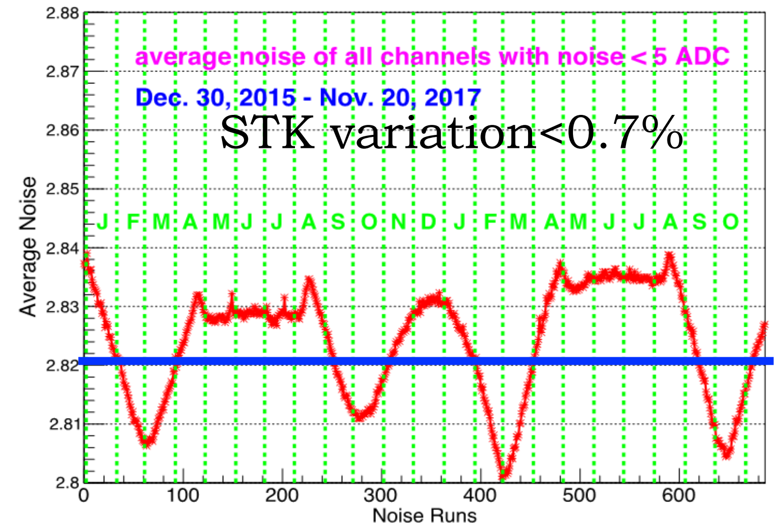
After temperature correction

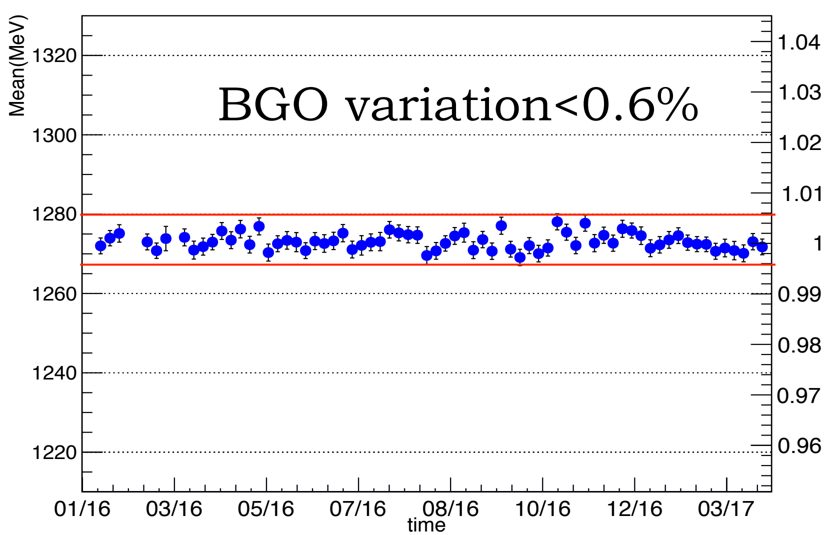


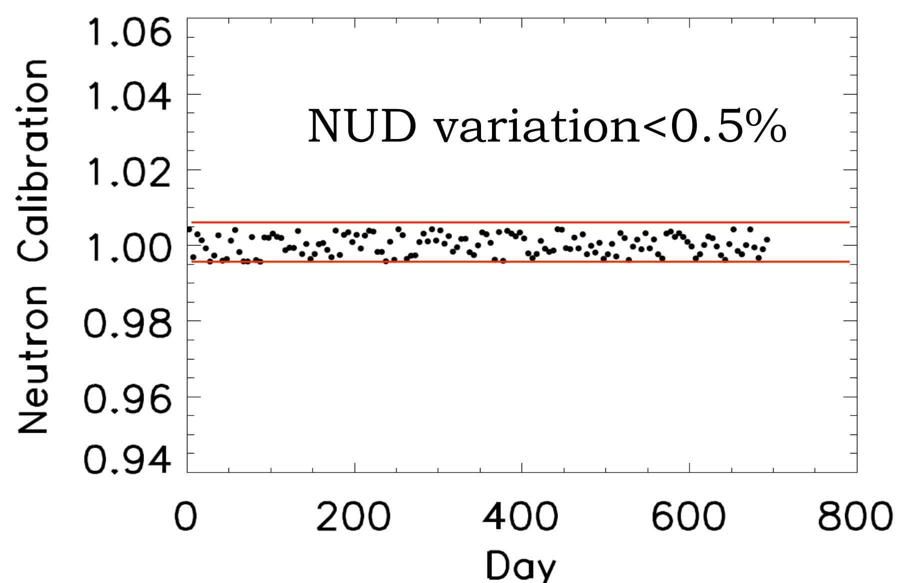
(DAMPE collaboration. 2018, to be submitted to Astropart. Phys.)

Satbility of on-orbit performance









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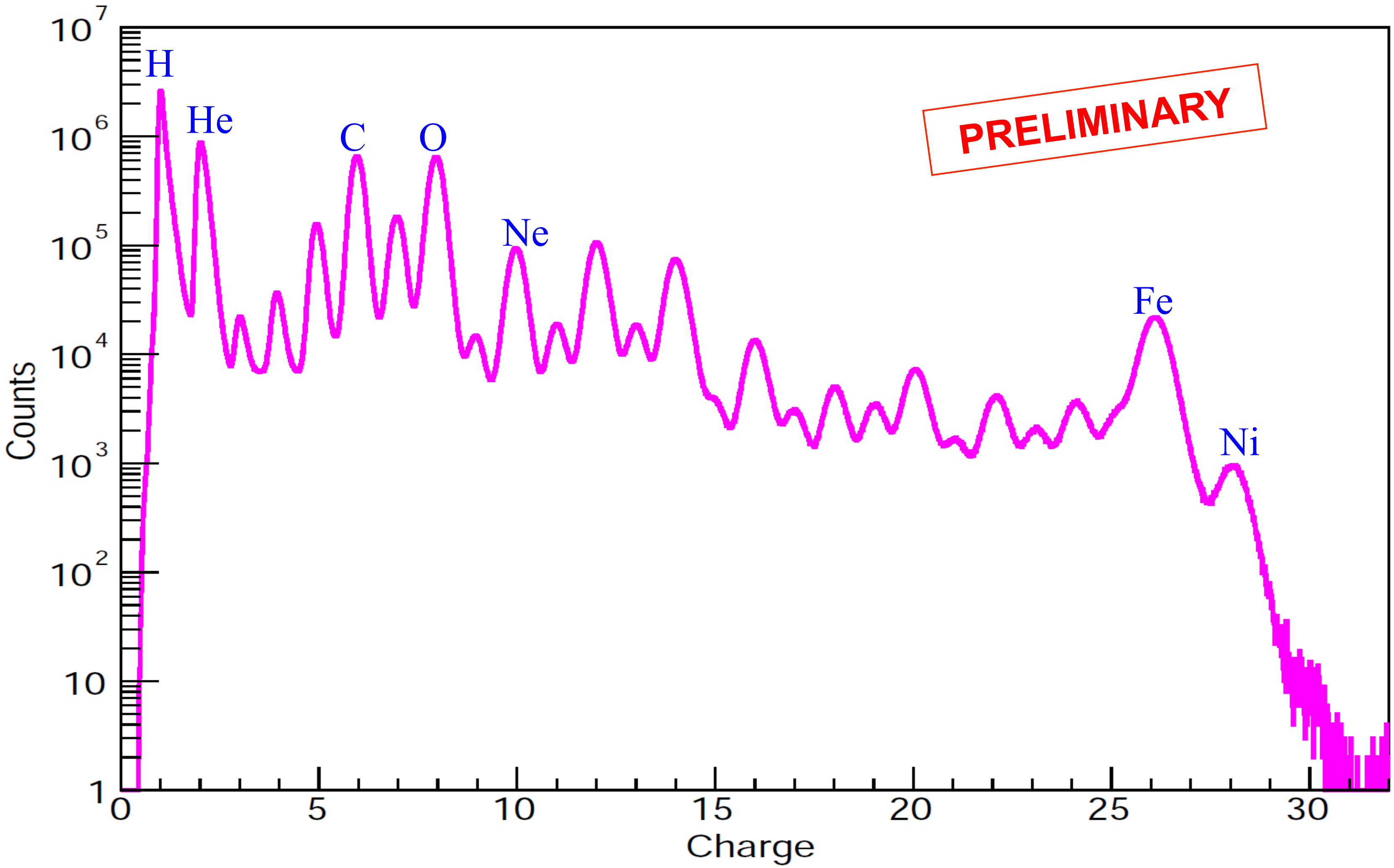
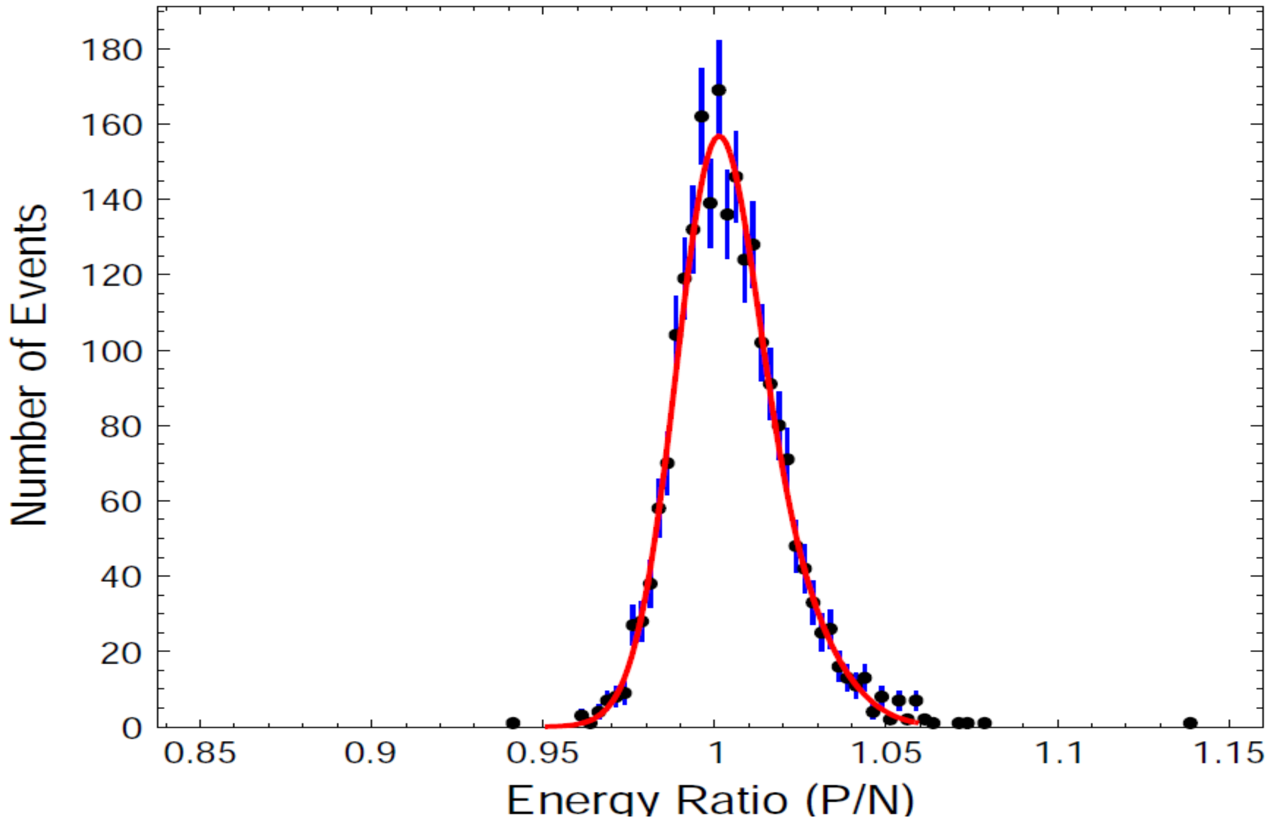
On-orbit performance: Charge measurement by PSD



(H, Fe)=(0.12, 0.28)e

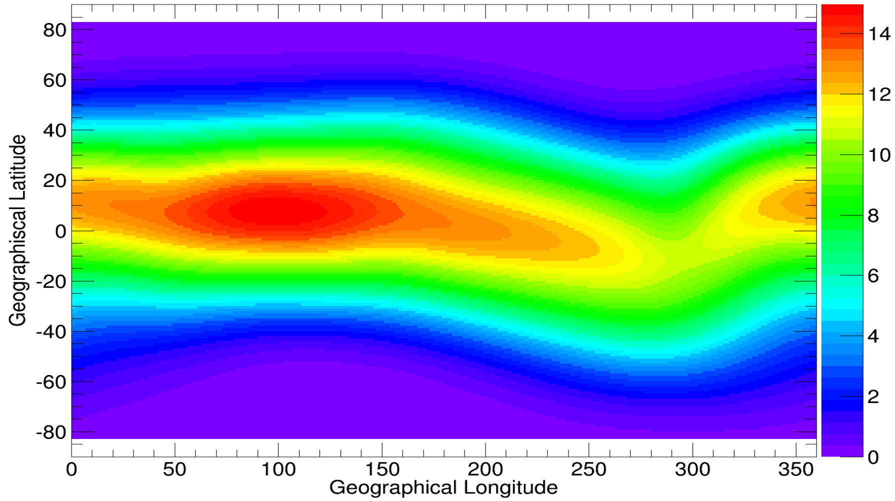
On-orbit performance: energy measurement by BGO



The ratio of the energies reconstructed with positive and negative side readout data of BGO crystals, for CRE candidates with deposit energy of 0.5-1.0 TeV

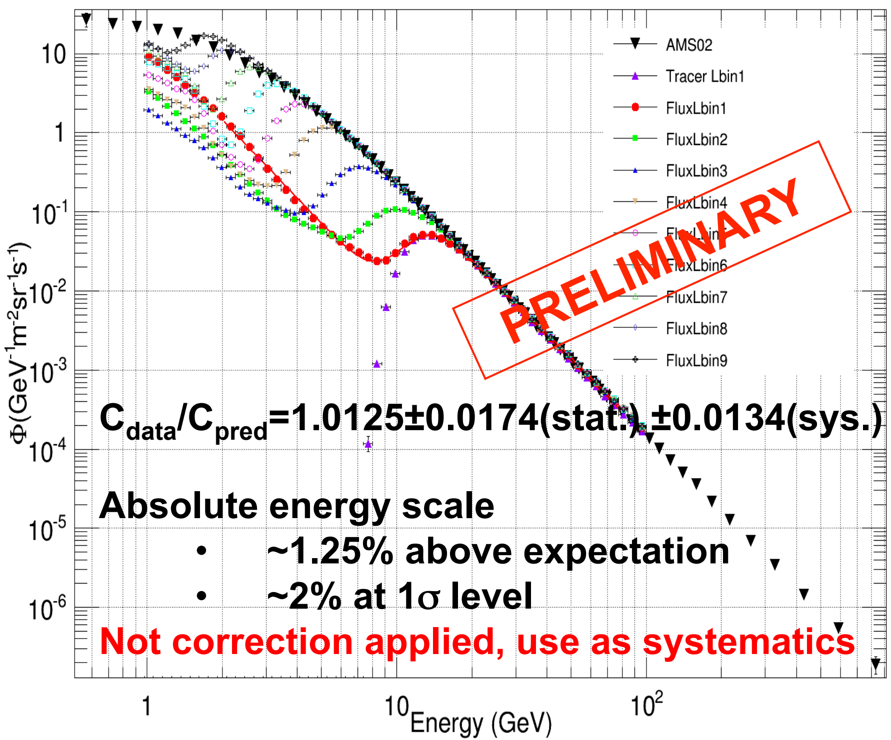
(DAMPE collaboration. 2017, Nature, 552, 63)

Absolute energy scale



Overall energy scale can be checked with geomagnetic cut-off effects

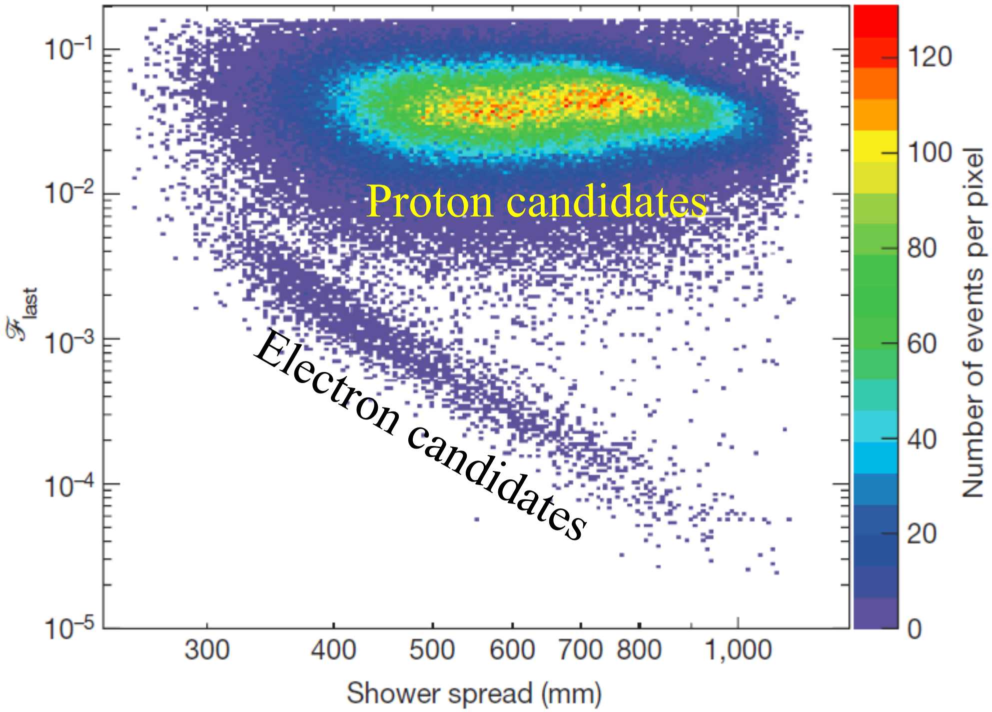
Charge particles detected in a geomagnetic zone have specific cut-off in the flux (deflection by the magnetic shield)

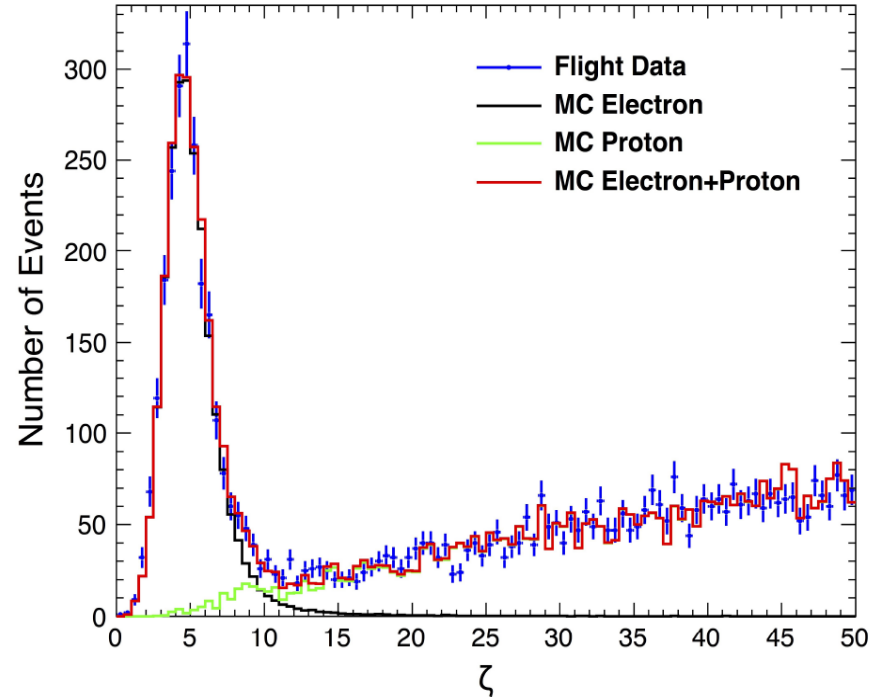


Use L in 1 – 1.14, cut-off ~ 13 GeV Measured cut-off compared to MC simulation with IGRF-12 model and back-tracing code (International Geomagnetic Reference Field)

Cut-off : 13.20 GeV (data) vs. 13.04 GeV (IGRF)

On-orbit performance: e/p separation

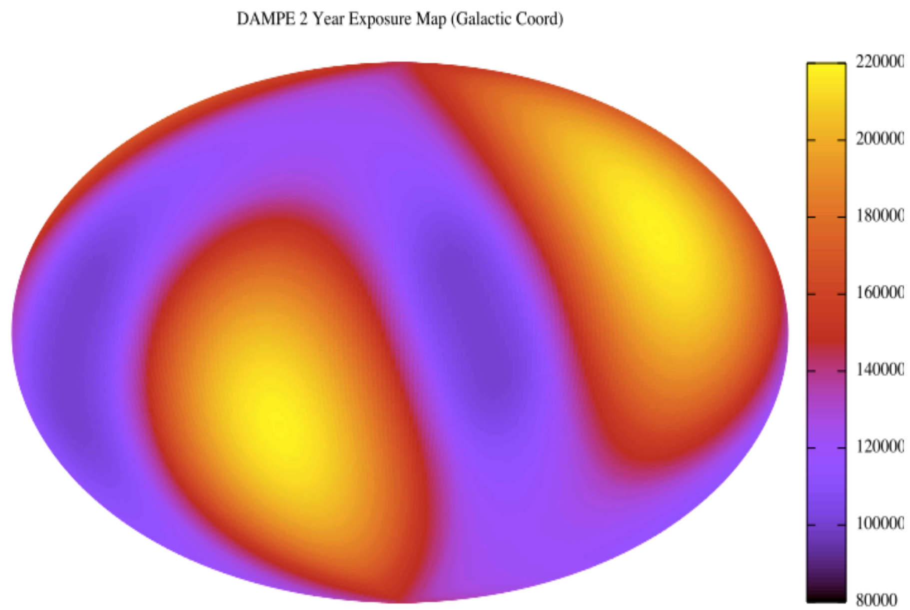


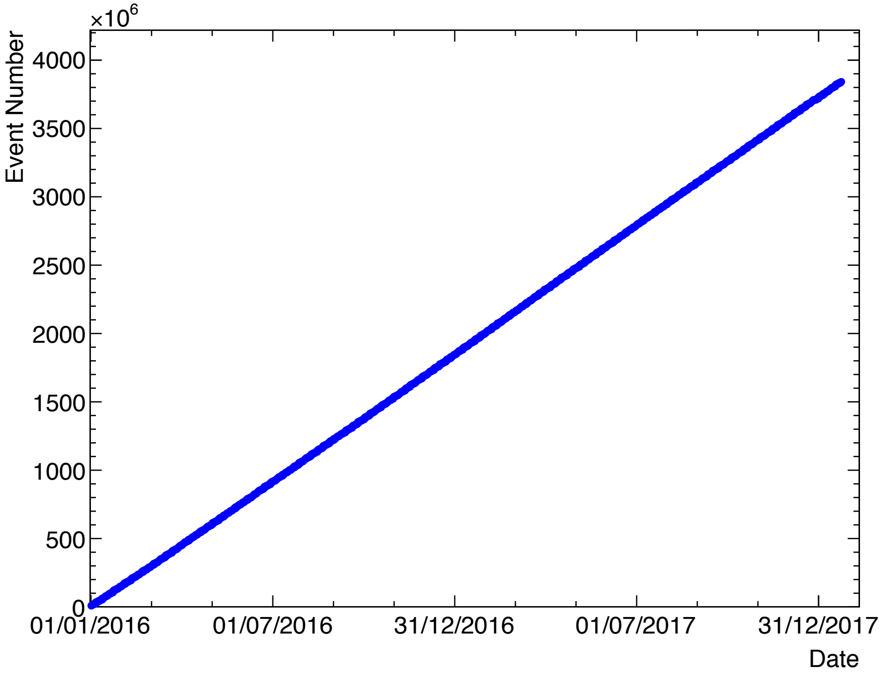


For events with deposit energy of 0.5-1.0 TeV; the proton contamination fraction is found to be <3% below 1TeV and <6% in the energy range of 1-2 TeV.

(DAMPE collaboration. 2017, Nature, 552, 63)

Summary of two years' data



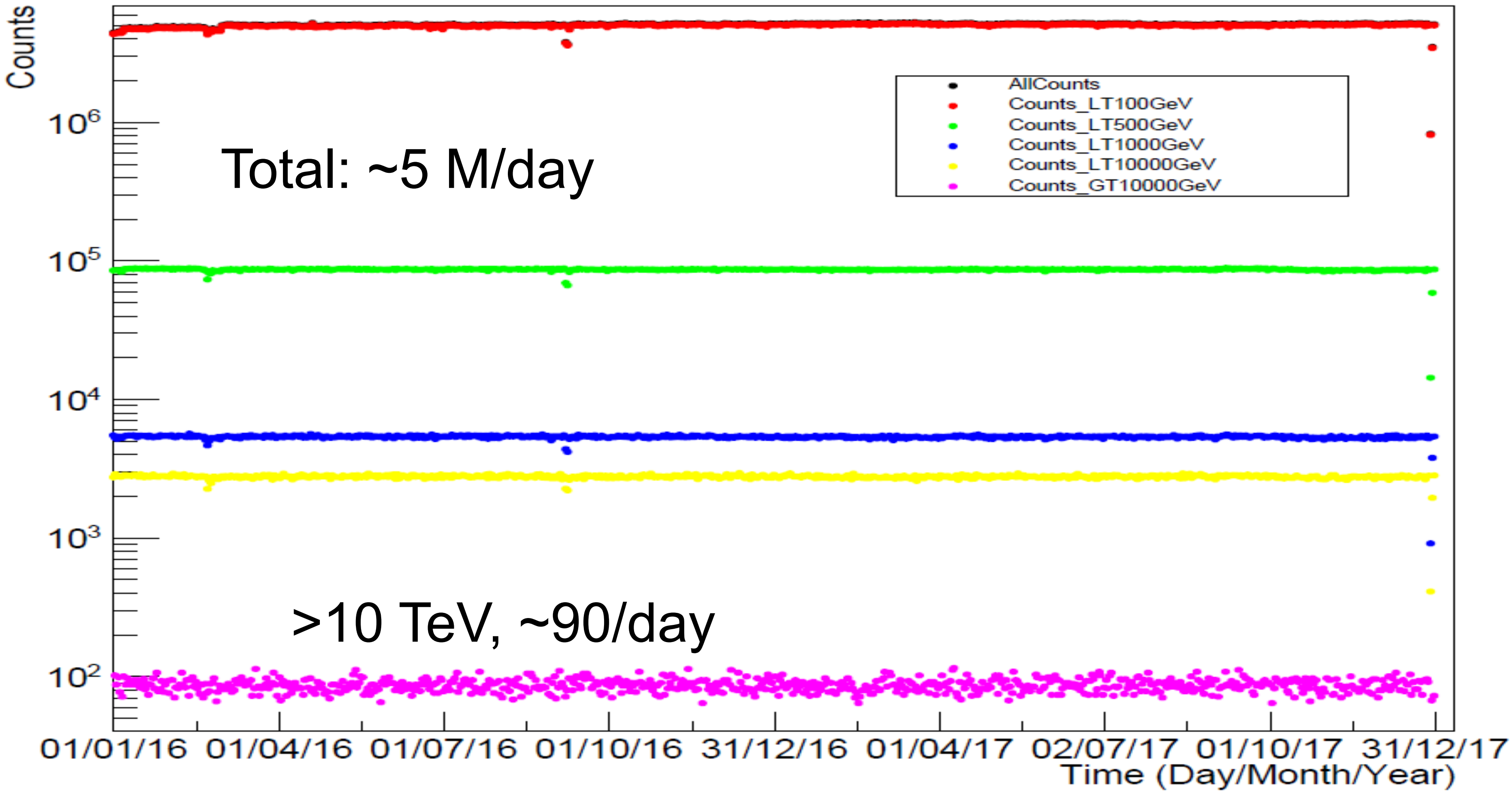


Full sky survey: 4 times

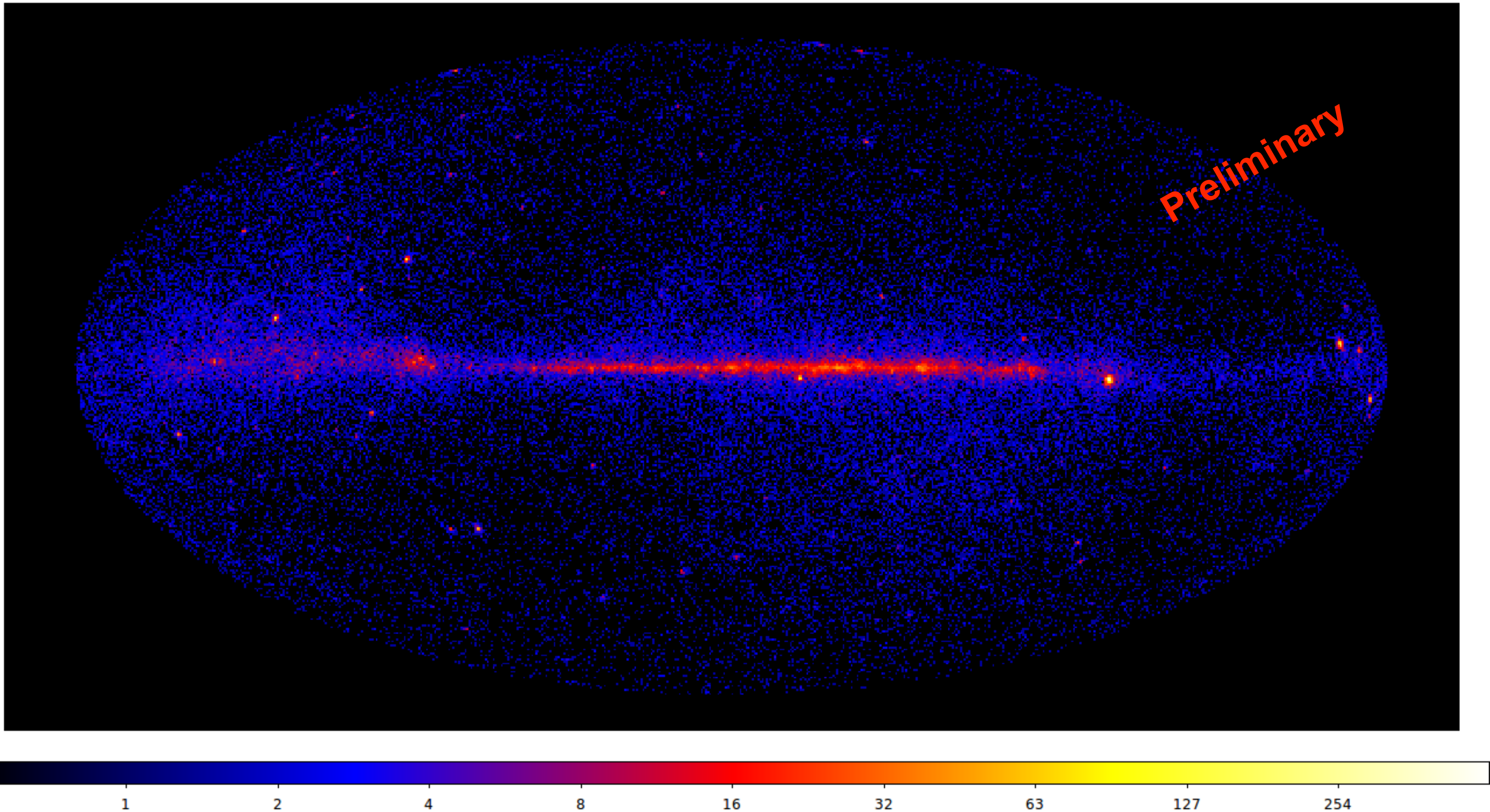
3.7 billion CRs (~5 million/day)

up to the end of 2017

Two-year on-orbit count rate

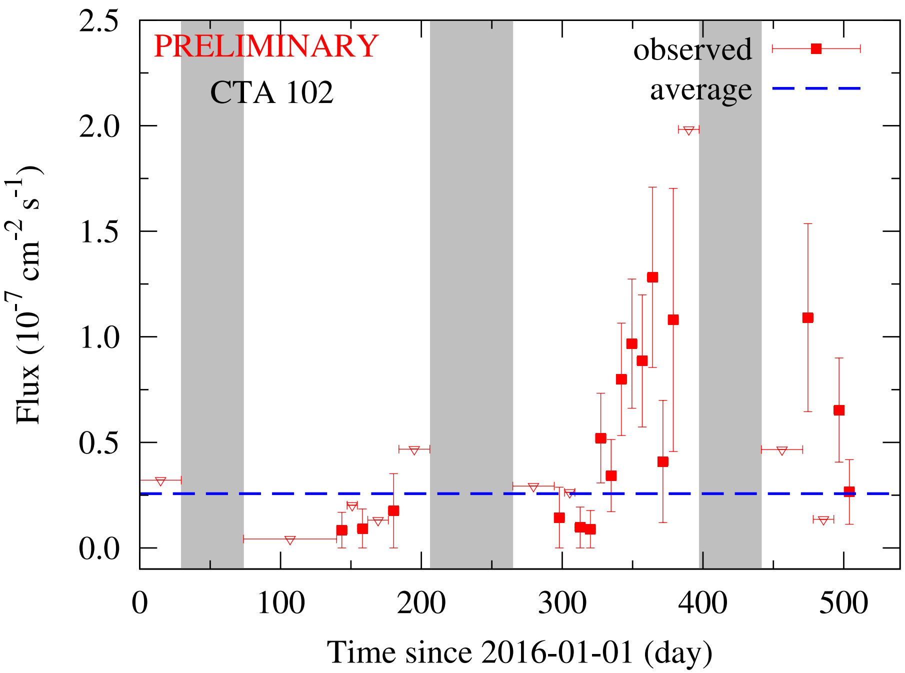


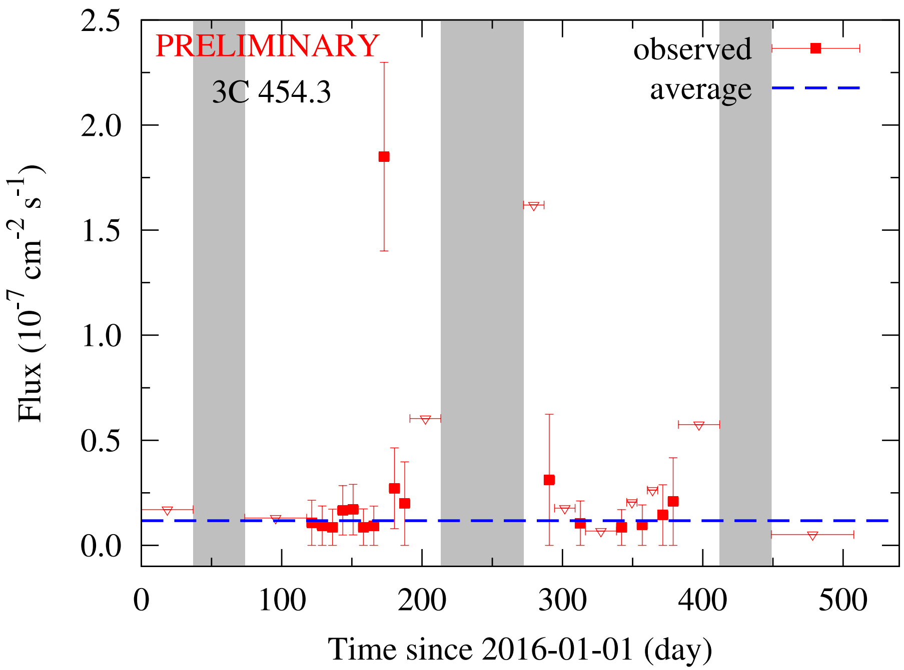
First results: gamma-ray sky map



(Lei et al. PoS (ICRC2017) 616)

First results: variable AGNs

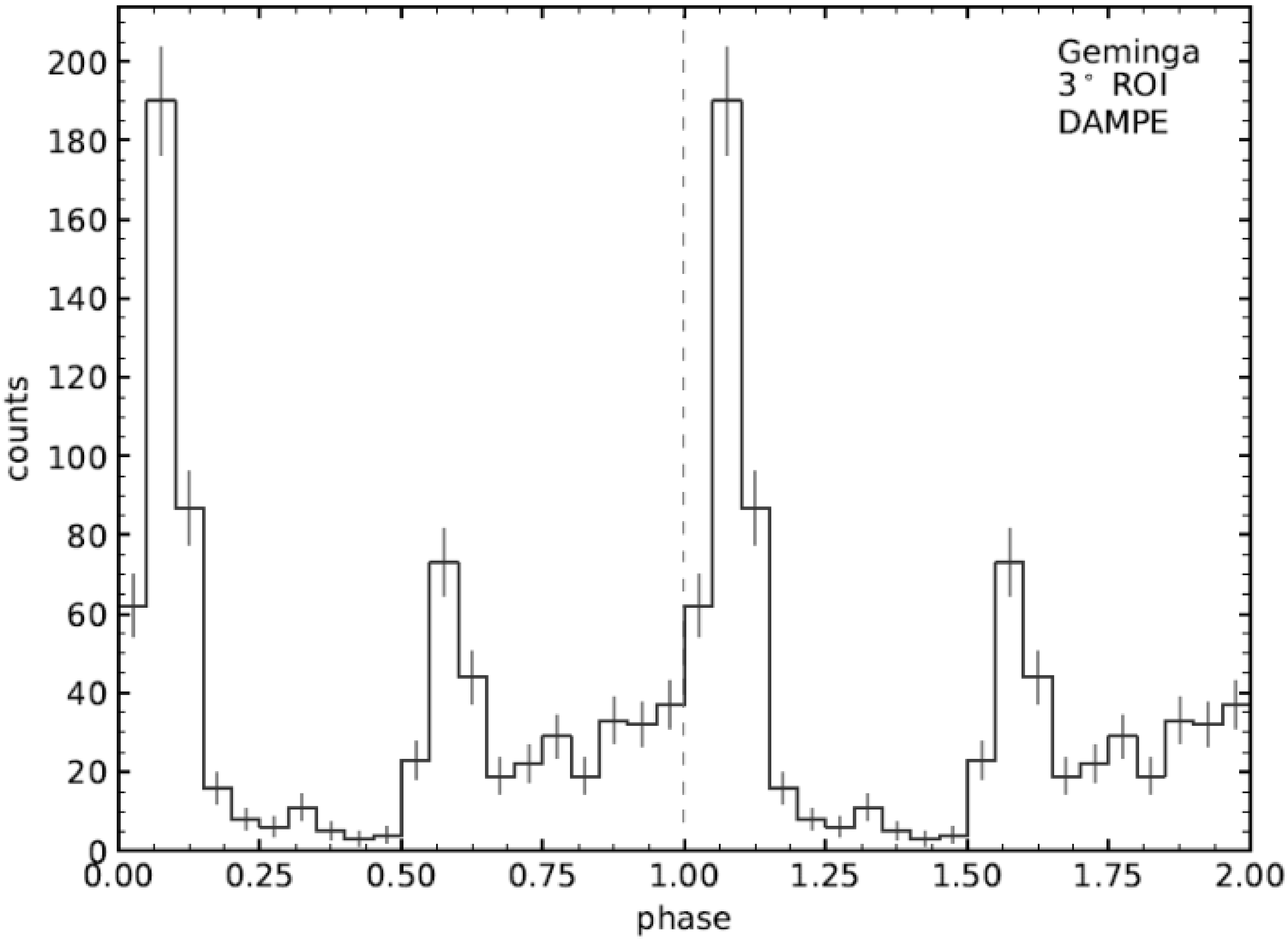




- DAMPE detected outbursts of CTA 102 and 3C 454.3
- Consistent with multi-wavelength observations

(Yuan et al. PoS (ICRC2017) 617)

First results: Geminga pulsar



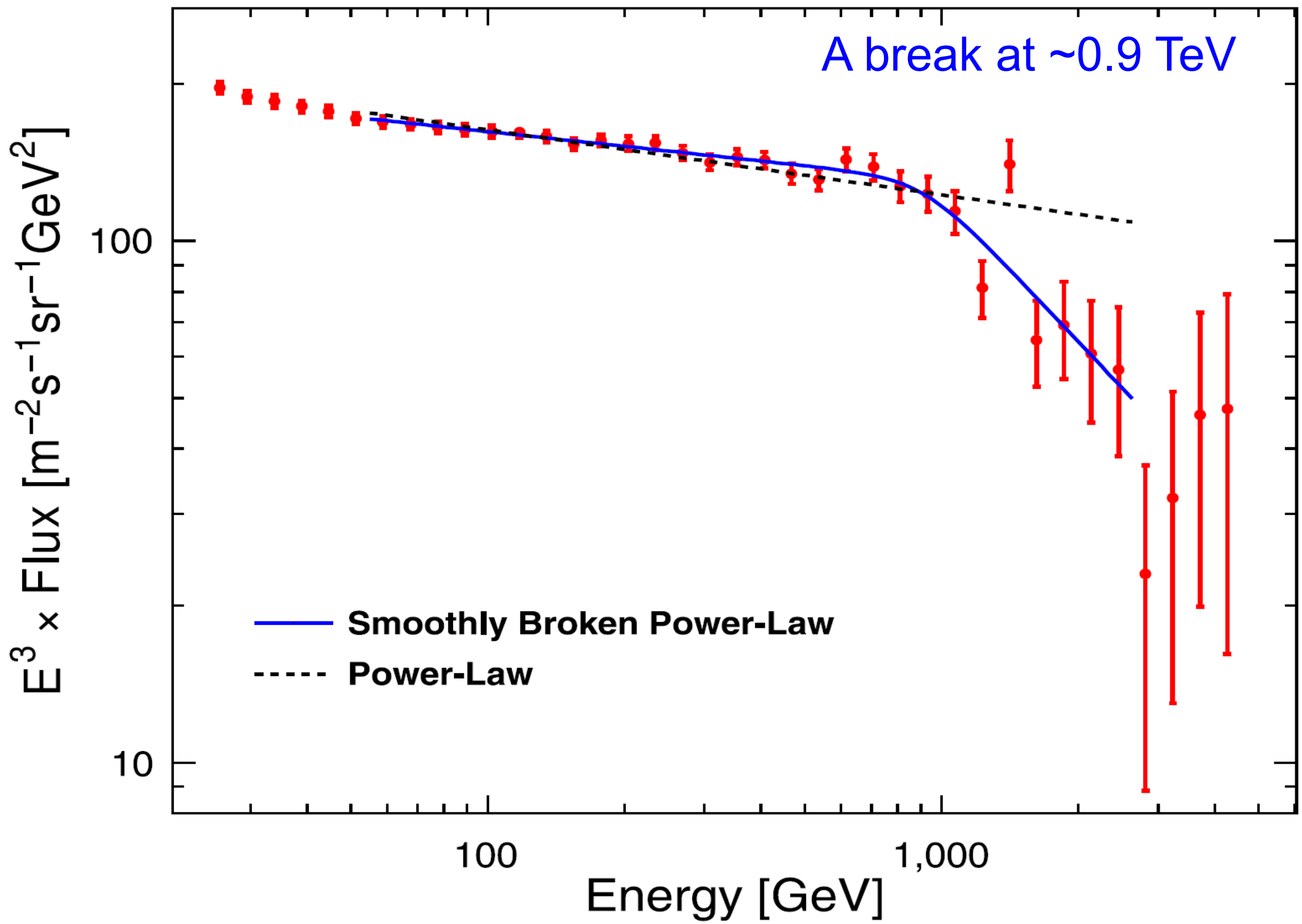
(Xu et al. Res. Astron. Astrophys. 18 (2018) 27)

First results: $e^{+} + e^{-}$

- Using 530 days of data, 1.5 million electrons between 25 GeV and 4.6 TeV have been selected
- 3 independent analyses have been performed, using different PID (e-p separation) methods
  - Shower shape (ζ method): combine lateral and longitudinal shower shape variables to one parameter ζ
  - Principal component analysis
  - boosted decision tree

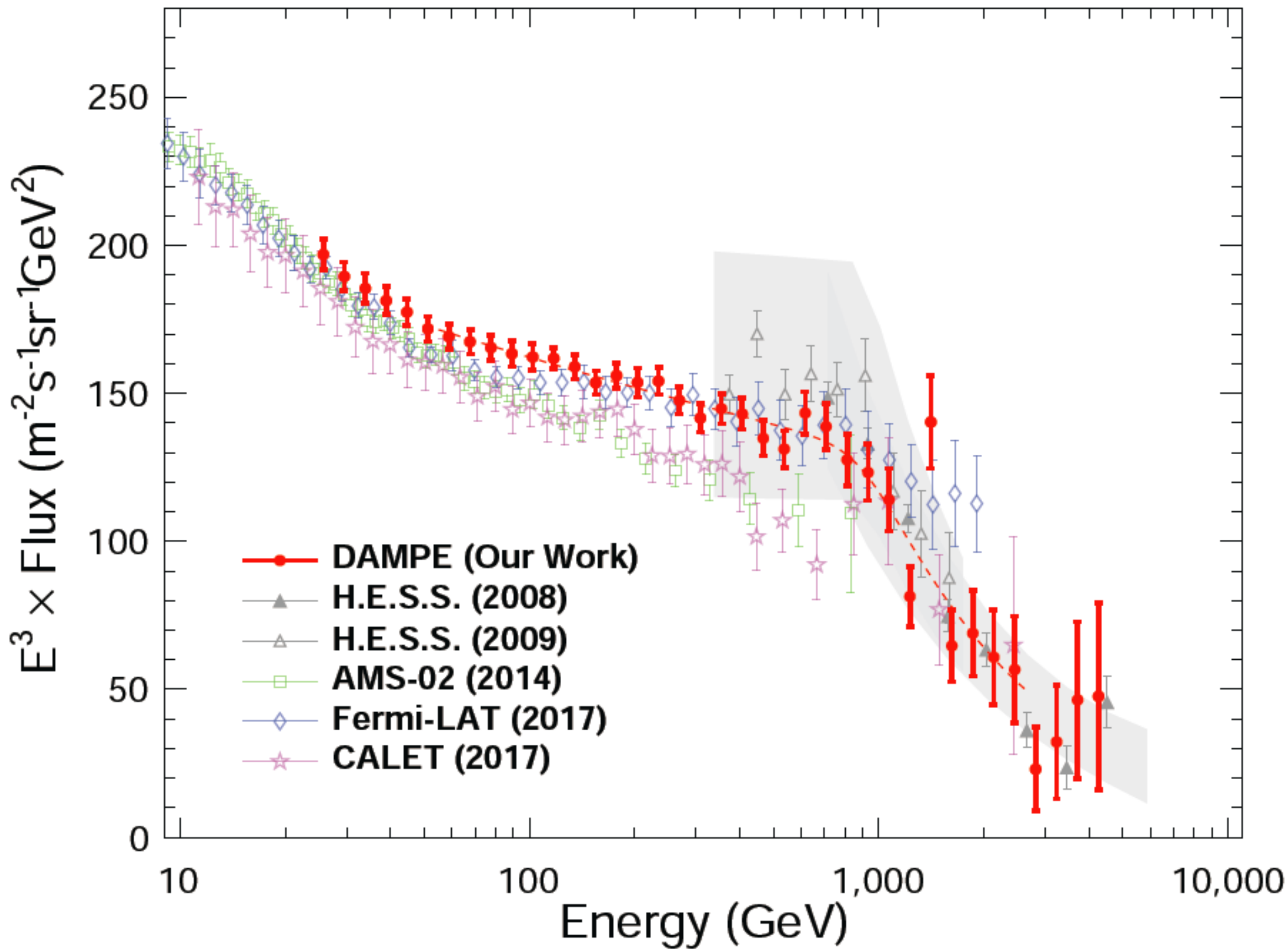
- An event-by-event (>100 GeV) comparison among different methods gives very consistent results

First results: CRE spectrum



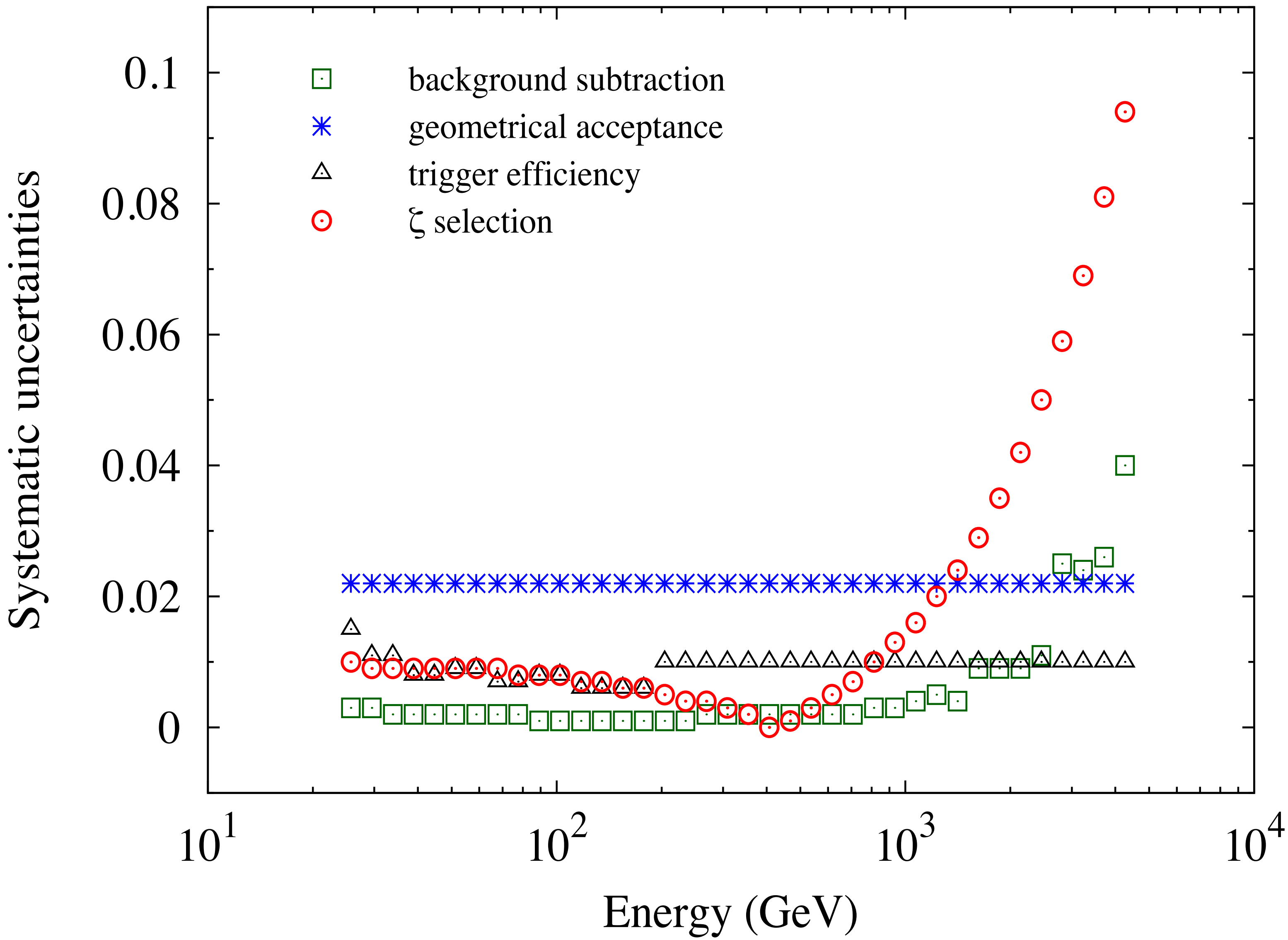
(DAMPE collaboration, 2017, Nature, 552, 63)

Some high energy CRE spectra

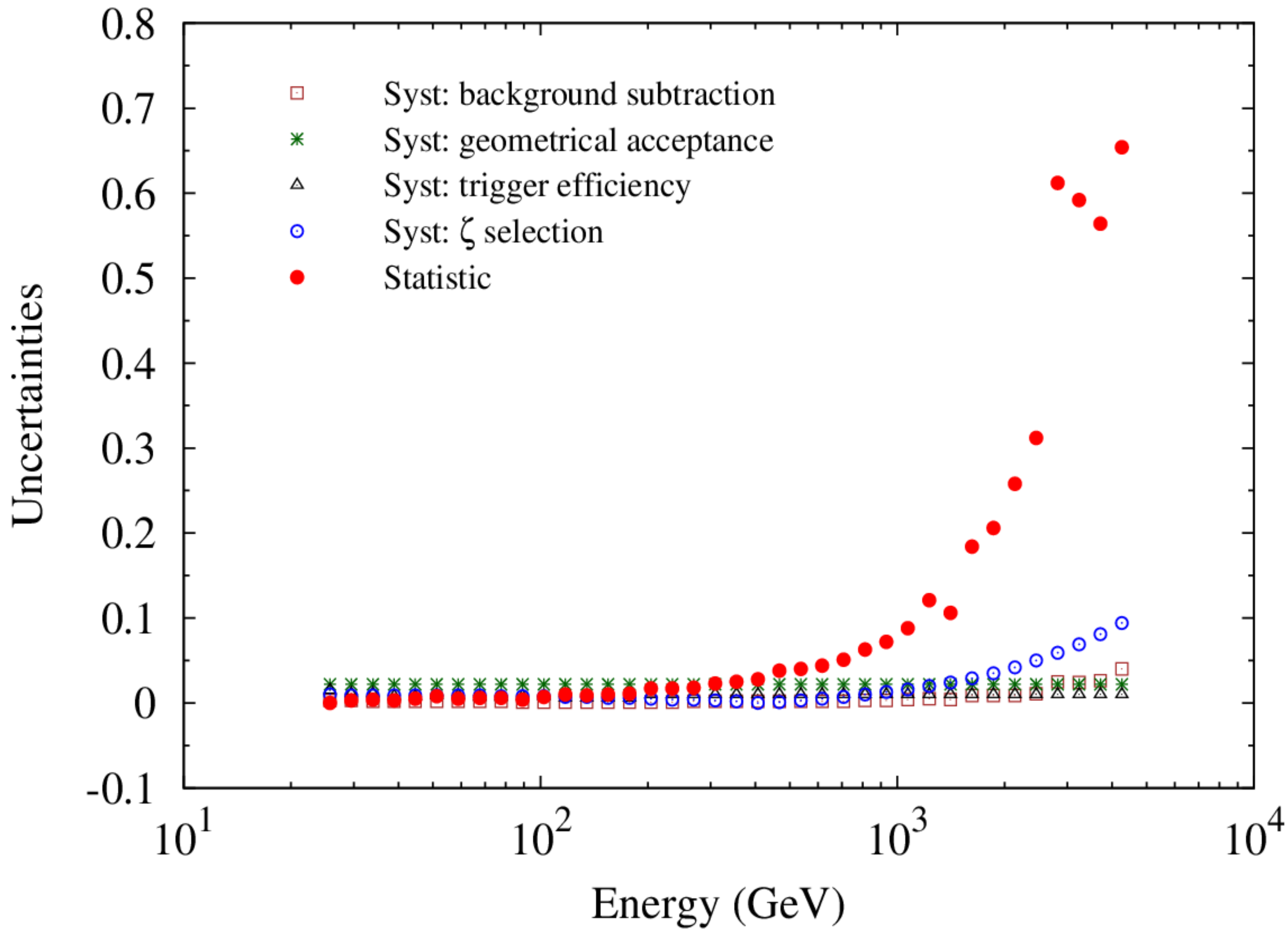


Error bars: systematic and statistical uncertainties added in quadrature for direct measurements. For H.E.S.S the grey band represents its systematic errors apart from the approximately 15% energy scale uncertainty.

Systematic errors



Systematic and statistical errors



Summary

- DAMPE detector was Succesfully launched on Dec 17, 2015
- Working extremely well since launched more than 2 years ago
- The electron + positron spectrum at TeV energies has been precisely measured → **as anticipated!**
  - A clear spectral break has been directly measured at ~ 1 TeV
- More results will be released in the future

Some members and partners

Thank you for your attention!

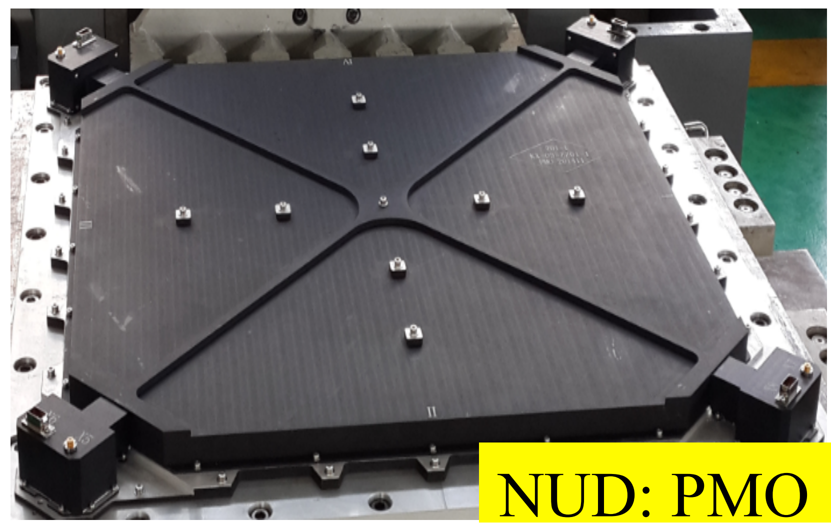
Back up

Flight Model: four sub-detectors

PSD: IMP

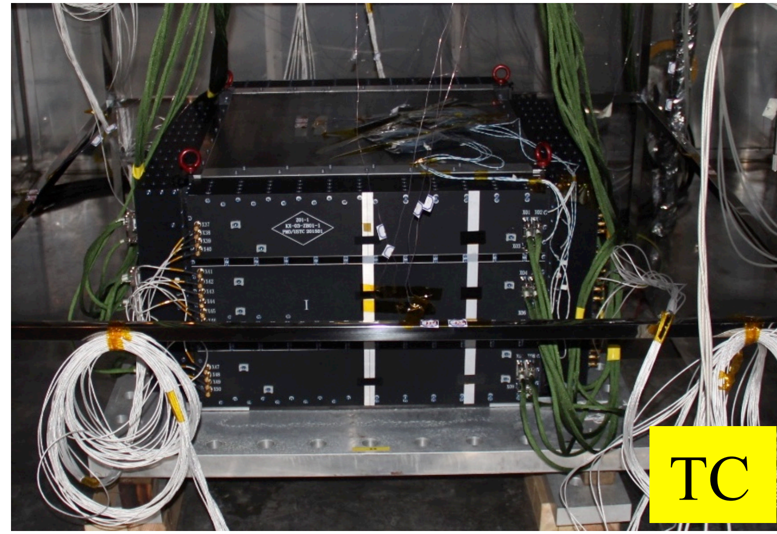
STK: IHEP, UG, INFN Perugia

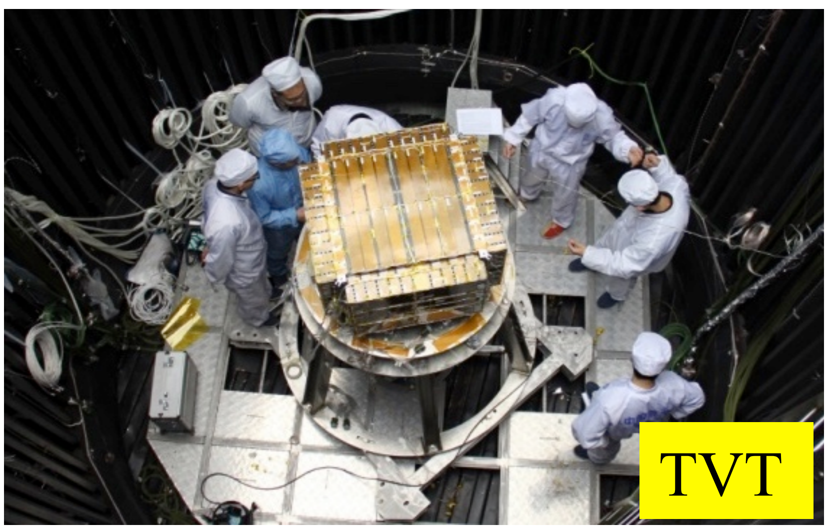
BGO: USTC & PMO

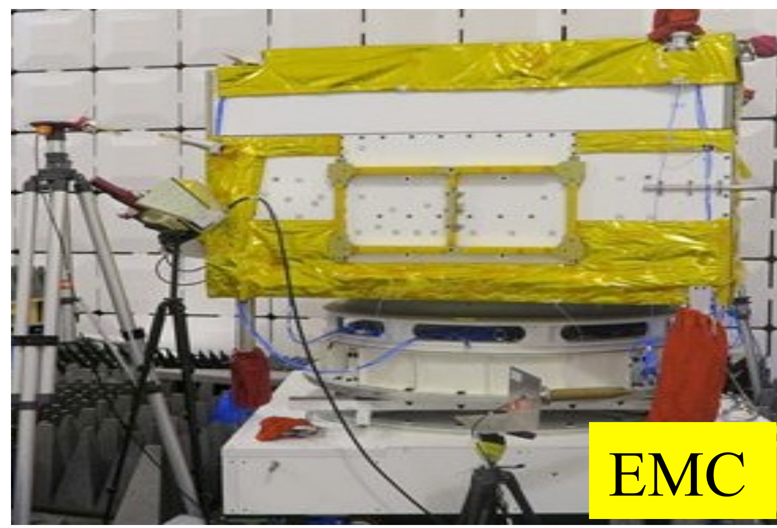


NUD: PMO

Flight model: environmental tests







METHODS

Discrimination between electrons and protons. The method of electron selection in this work relies on the differences in the development of showers initiated by protons and electrons[23,31,32]. The procedure is as follows. First, we search for events passing through the entire BGO calorimeter. We select events with hit positions from −28.5 cm to 28.5 cm for the top layer and −28 cm to 28 cm for the bottom layer (each BGO bar lies between −30 cm and 30 cm). Second, we calculate the shower spread, expressed by the energy-weighted root-mean-square value of hit positions in the calorimeter. The root-mean-square value of the ith layer is calculated as:

$$\mathrm{RMS}_i = \sqrt{\frac{\sum_j (x_{j,i} - x_{\mathrm{c},i})^2 E_{j,i}}{\sum_j E_{j,i}}} \quad (1)$$

where $x_{j,i}$ and $E_{j,i}$ are the coordinates and deposited energy of the jth bar in the ith layer, and $x_{\mathrm{c},i}$ is the coordinate of the shower centre of the ith layer. Figure 1 shows the deposited energy fraction in the last BGO layer ($\mathcal{F}_{\mathrm{last}}$) versus the total root-mean-square value of all 14 BGO layers (that is, $\sum_i \mathrm{RMS}_i$). We can see that electrons are well separated from protons. Note that in Fig. 1 and Extended Data Fig. 1, heavy ions have already been effectively removed by selection through the plastic scintillator detector, on the basis of the charge measurement.

For a better evaluation of the electron/proton discrimination capabilities, we introduce a dimensionless variable, ζ, defined as

$$\zeta = \mathcal{F}_{\mathrm{last}} \times (\Sigma_i \mathrm{RMS}_i/\mathrm{mm})^4/(8\times 10^6) \quad (2)$$