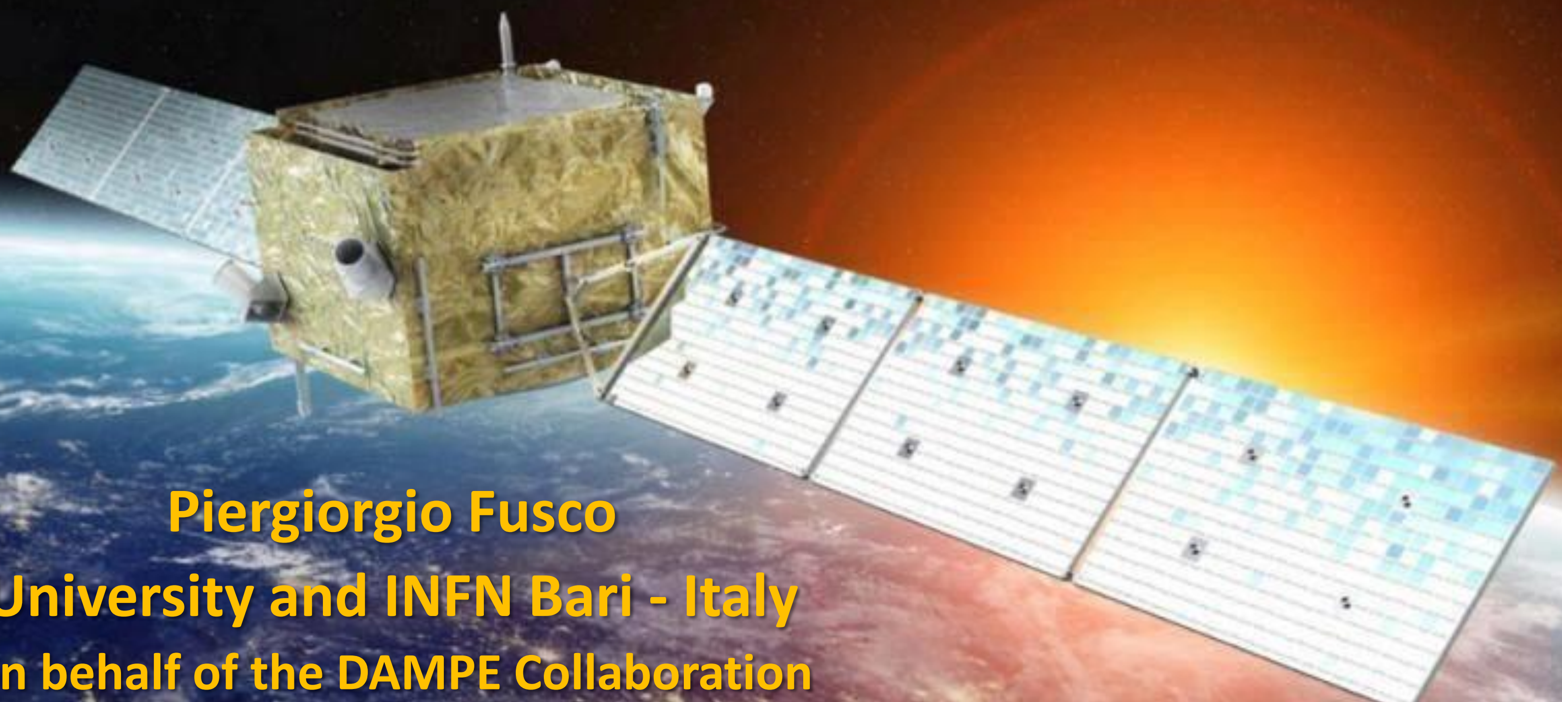
IV International Conference
on Particle Physics and Astrophysics

The DAMPE experiment
and its latest results



Piergiorgio Fusco
University and INFN Bari - Italy
on behalf of the DAMPE Collaboration

The DAMPE Collaboration

- CHINA
  - Purple Mountain Observatory, CAS, Nanjing, *Prof. Jin Chang*
  - 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

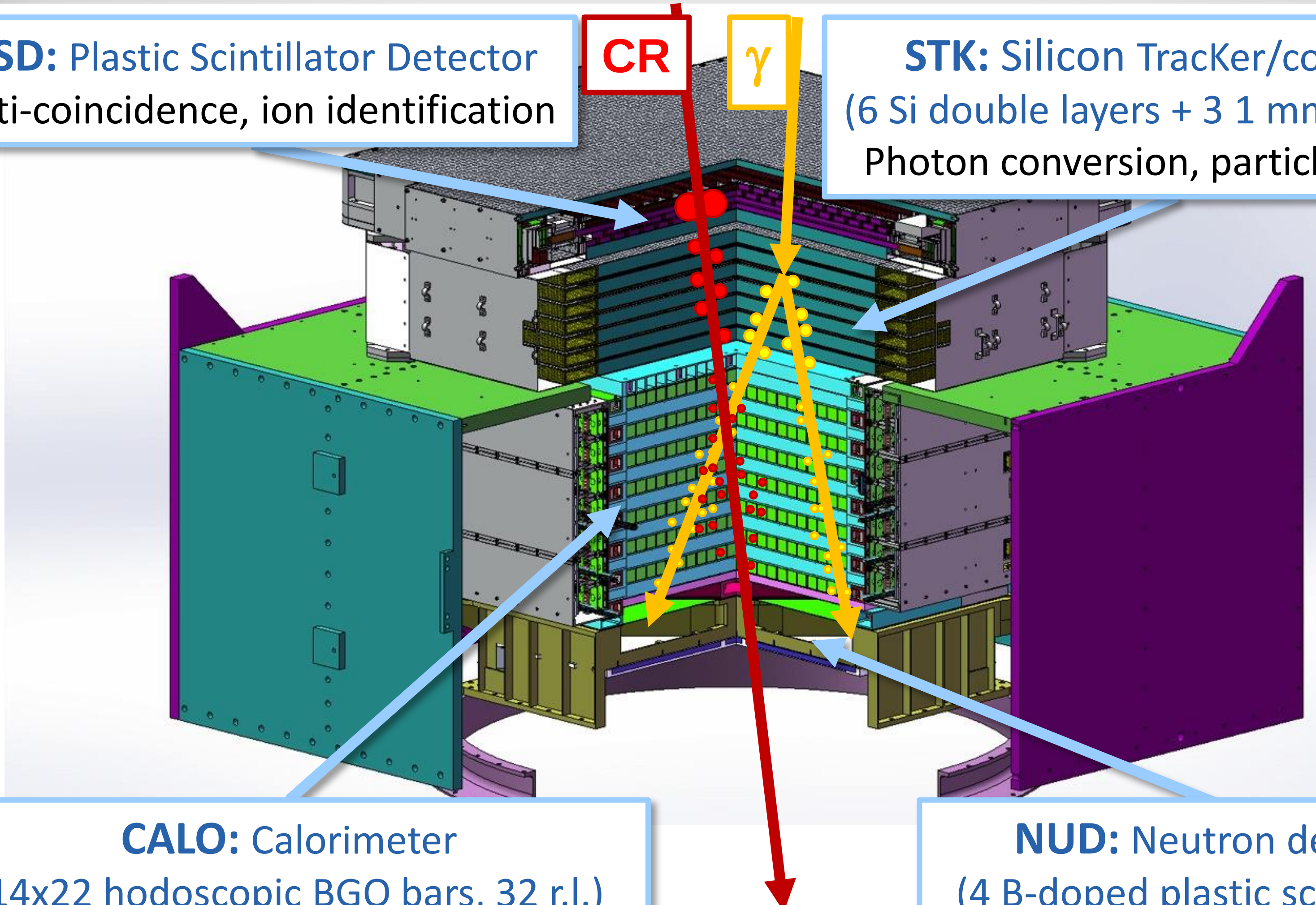
- ITALY
  - INFN Perugia and University of Perugia
  - INFN Bari and University of Bari
  - INFN Lecce and University of Salento

- SWITZERLAND
  - University of Geneva

Scientific goals

- DAMPE – DArk Matter Particle Explorer – is a **space particle detector** aimed to:
  - study **cosmic electrons** spectra
  - study **cosmic protons + nuclei** spectrum and composition
  - astronomy with high-energy cosmic **gamma-rays**
  - search for **dark matter** signatures in lepton spectra
  - search for **e.m. counterparts** of gravitational waves or neutrinos
  - quest for **exotic** particles and phenomena
- Excellent performance:
  - detection of 5 GeV – 10 TeV e/γ, 50 GeV – 100 TeV p and nuclei
  - energy resolution < 1.5% for 100 GeV e/γ, < 40% for 800 GeV p
  - angular resolution < 0.2° for 100 GeV γ
  - field of view ~1 sr

The DAMPE instrument



PSD: Plastic Scintillator Detector
Anti-coincidence, ion identification

STK: Silicon TracKer/converter
(6 Si double layers + 3 1 mm W plates)
Photon conversion, particle tracking

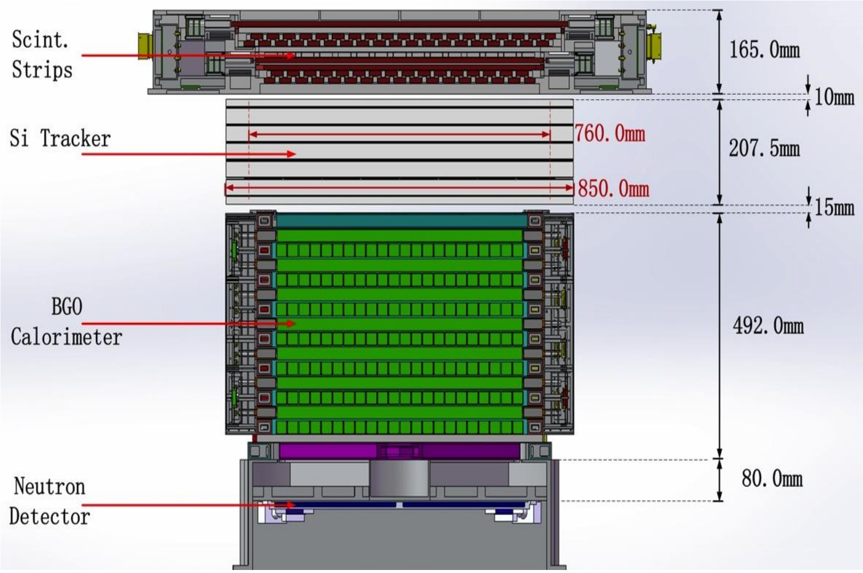
CALO: Calorimeter
(14x22 hodoscopic BGO bars, 32 r.l.)
Energy deposition and profile, trigger

NUD: Neutron detector
(4 B-doped plastic scintillators)
Neutron showers measurement

DAMPE, AMS-02, Fermi LAT

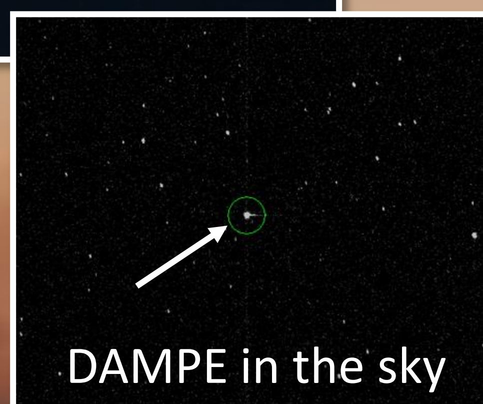
Performance	DAMPE	AMS-02	Fermi LAT
e/γ Energy resol. @100 GeV (%)	<1.5	3	10
e/γ Angular resol. @100 GeV (deg.)	<0.2	0.3	0.1
e/p discrimination	$>10^5$	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	32	17	8.6
Geometrical acceptance (m^2sr)	0.3	0.09	1

DAMPE facts
Mass: 1400 kg
Power consumption: 400 W
Readout channels: > 75k
Data transfer: 16 Gbyte/day
Lifetime: 5 years



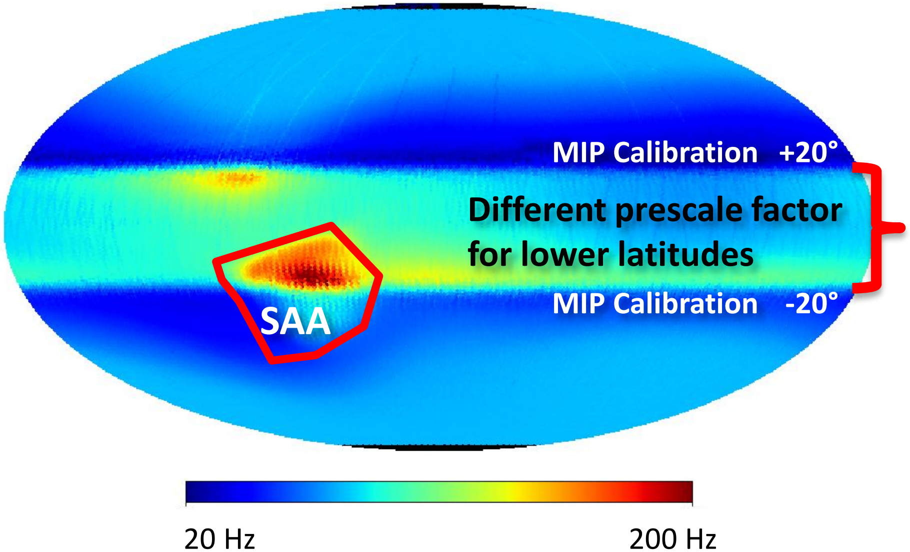
The launch

- **DAMPE was launched on Dec. 17th 2015**
  - **Launch site: Jiuquan Satellite Launch Center, Gobi desert, China**
  - **Orbit: 500 km altitude, Sun synchronous**

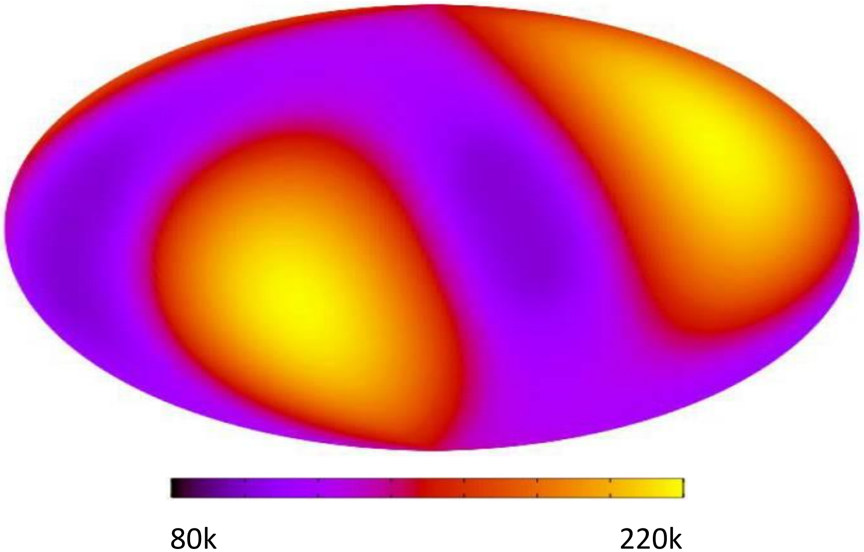


Trigger rate and data transfer

Total trigger rate



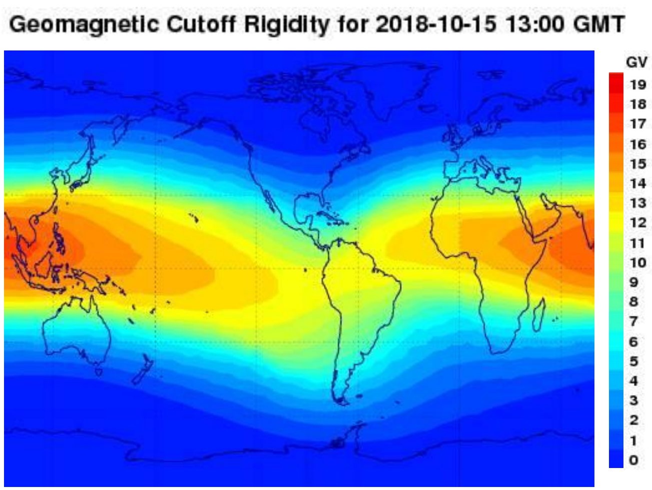
2.5 years exposure map

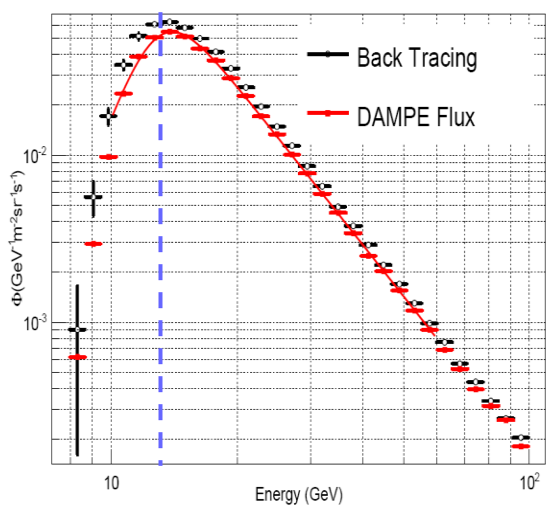


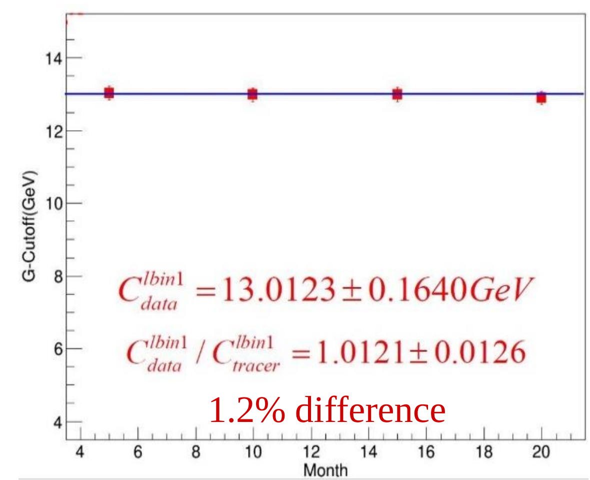
Acquisition rate	up to 200 Hz
High Energy (physics) trigger rate	up to 50 Hz
Raw data plus control data download	15 GB/day
Reconstructed data in ROOT format	85 GB/day
Total data per year	35 TB

Energy calibration

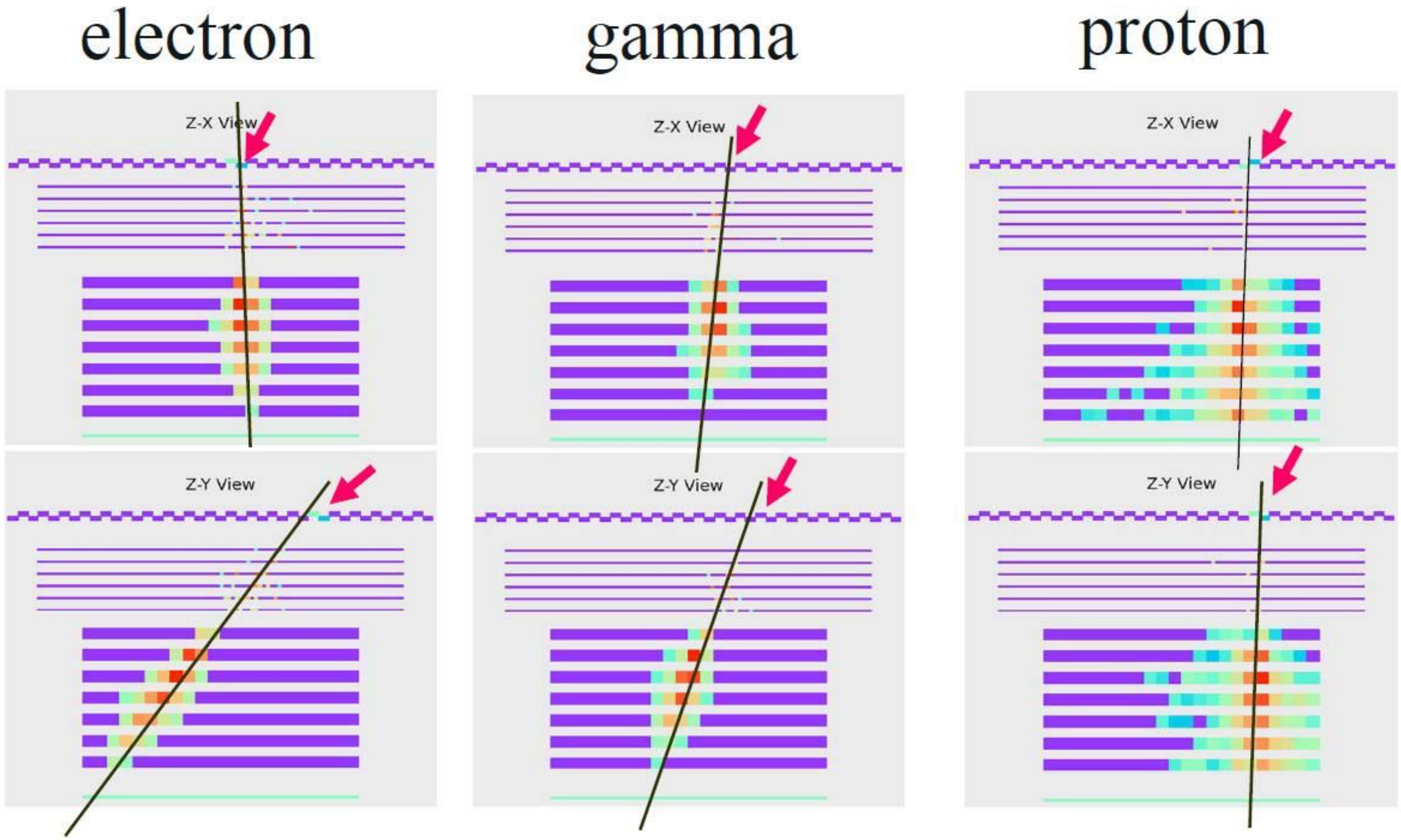
- The geomagnetic rigidity cut-off of cosmic-ray electrons (CRE) spectrum provides a reference for absolute energy calibration
  - low energy CRE flux is measured in the range 8 GeV < E < 100 GeV
  - flight data and Monte Carlo data (with back-tracing in Earth magnetic field model IGRF12) are compared
  - expected cut-off: 13.0 GeV; DAMPE measured cut-off 13.2 GeV
  - stable with time - slight decrease due to solar modulation of primary electrons





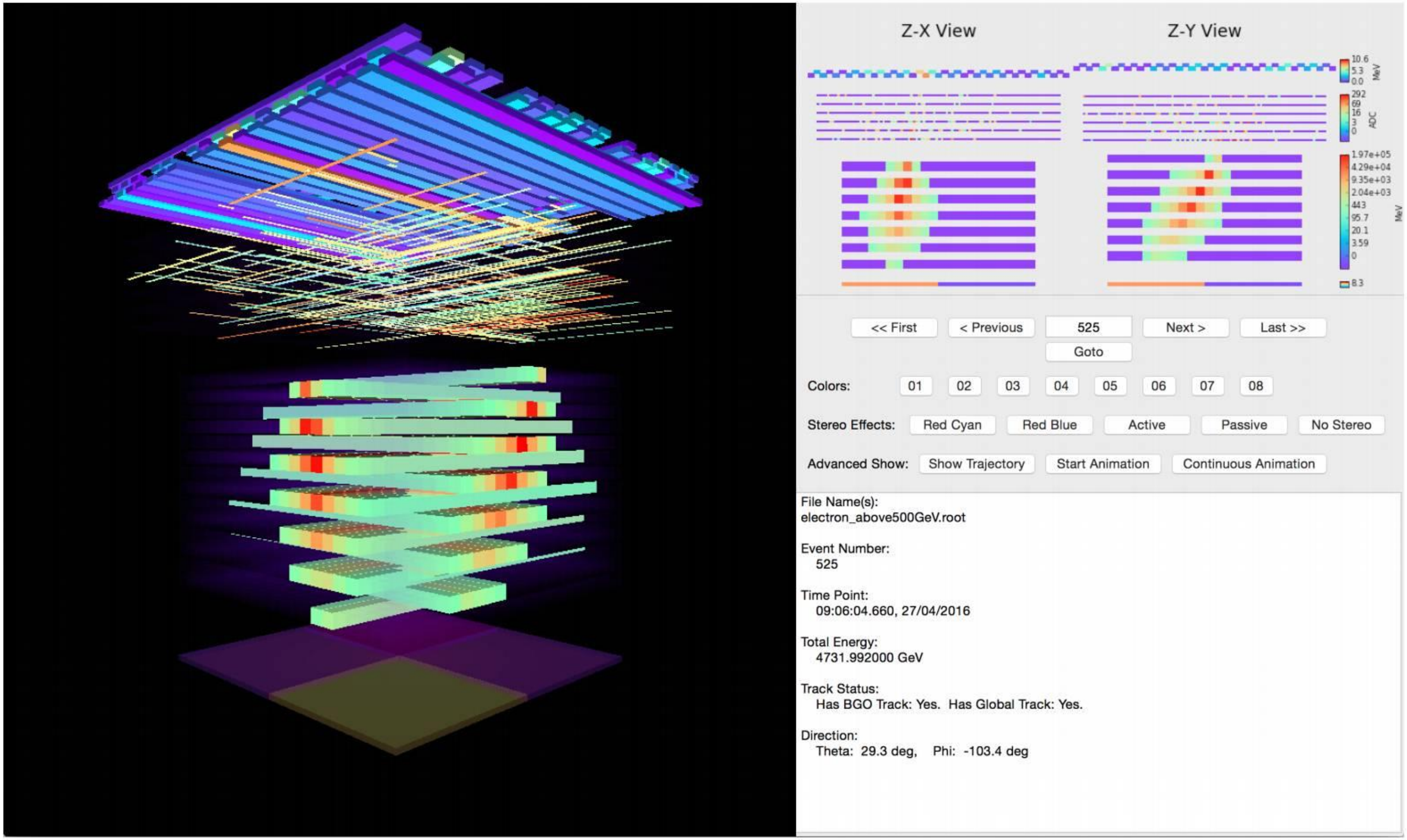


Particle identification



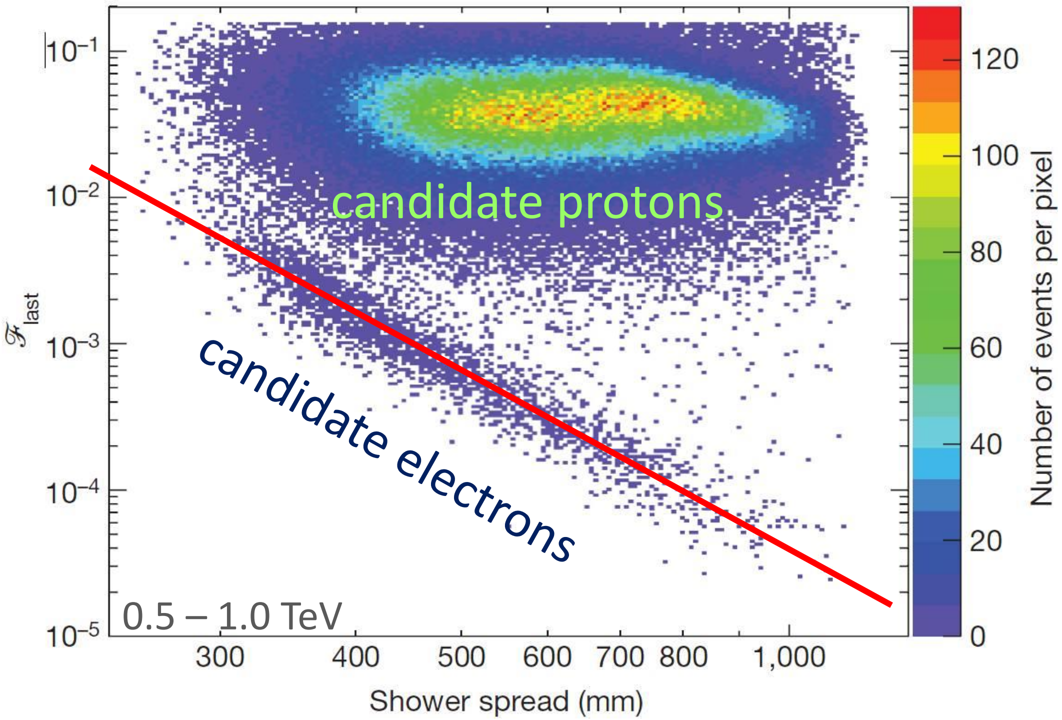
- Several different PID methods used (Shape parameters; Boosted Decision Trees; Random Forest + Convolutional Neural Network)

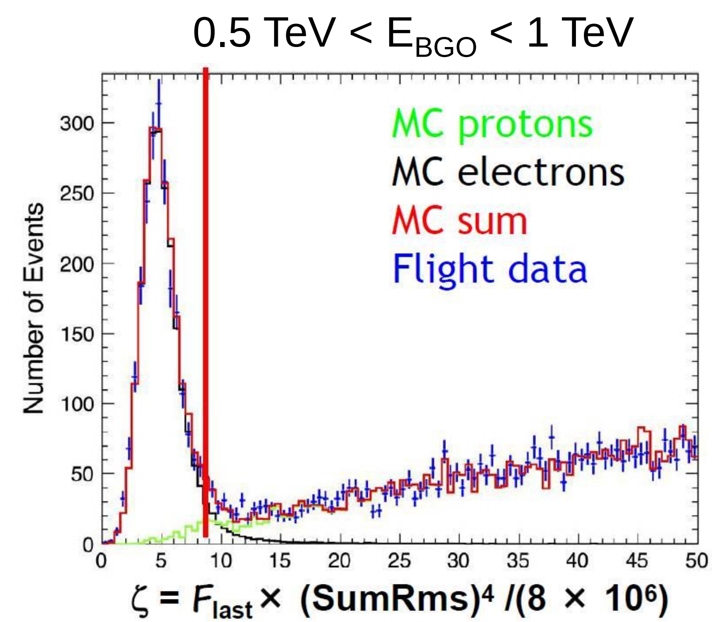
An electron candidate (~5 TeV)



Electron/proton separation

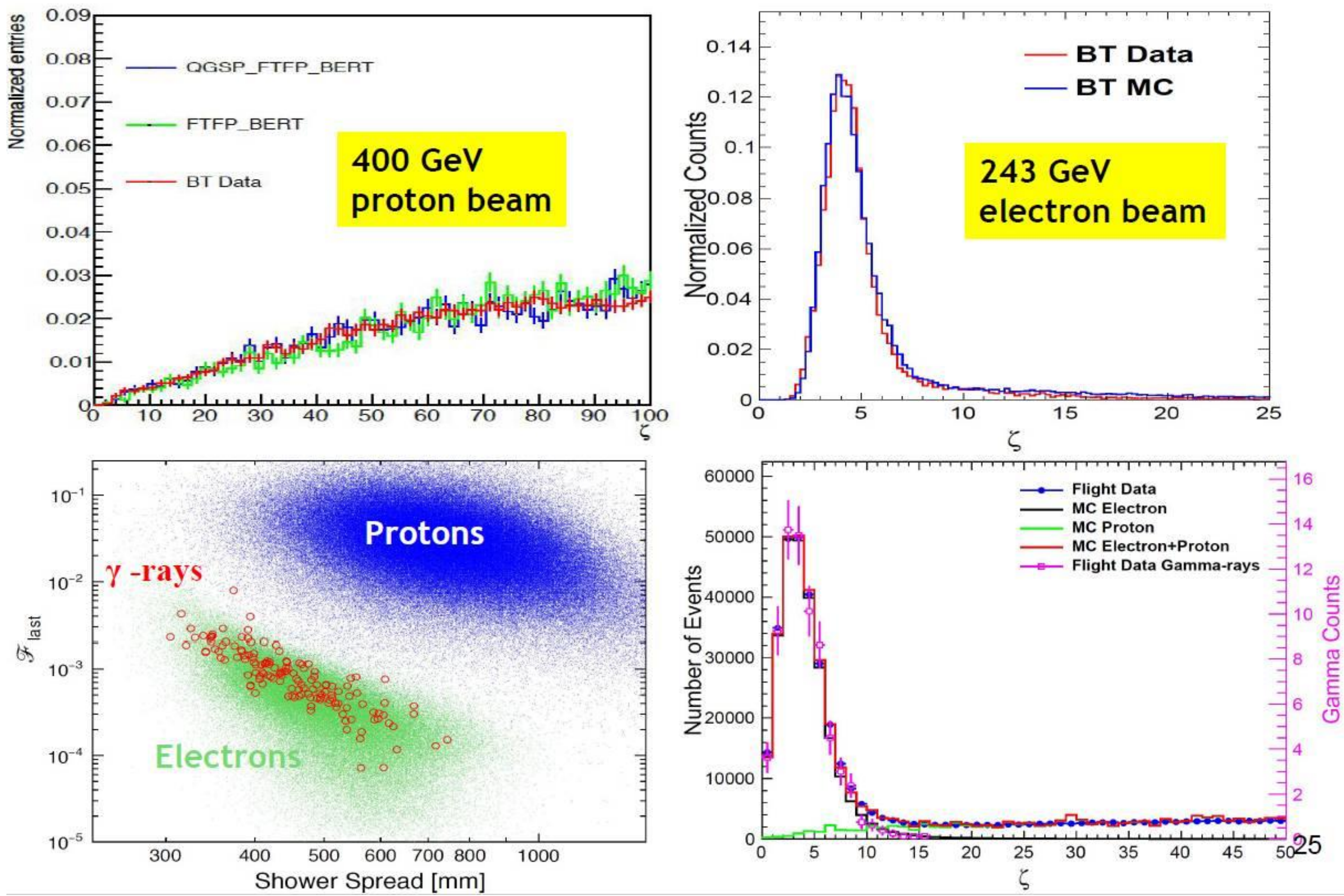
- The "ζ shower parameter" was computed from the lateral shower development in BGO plus the energy deposition in the last layer
  - the cut $\zeta > 8.5$ was adopted to discriminate e^- (and e^+) from p
  - for 90% $e^\pm$ efficiency, p background ~2% @ 1 TeV, ~5% @ 2 TeV, ~10% @ 5 TeV





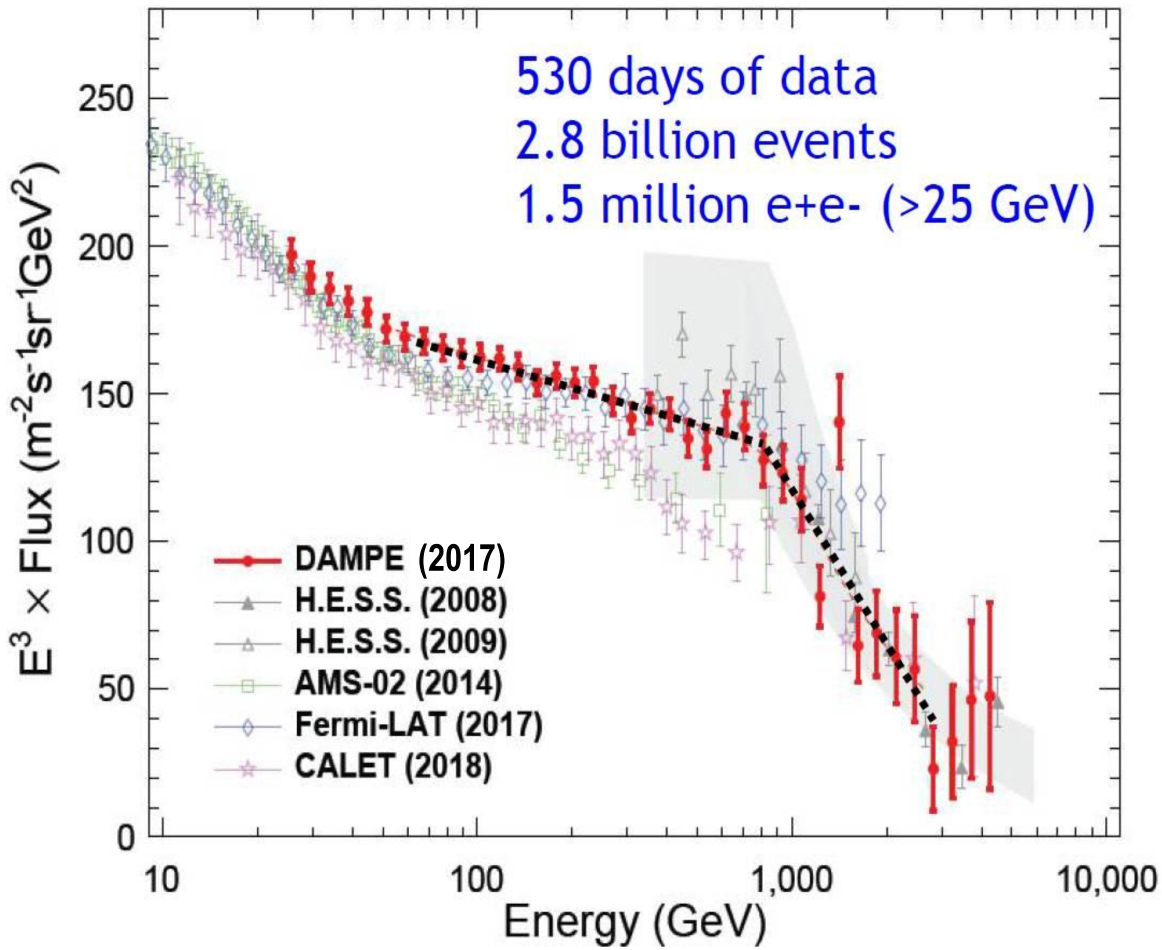
Validation of ζ parameter

- The ζ parameter was validated with beam tests and with photons
  - Different PID methods give consistent results



$e^+ + e^-$ spectrum

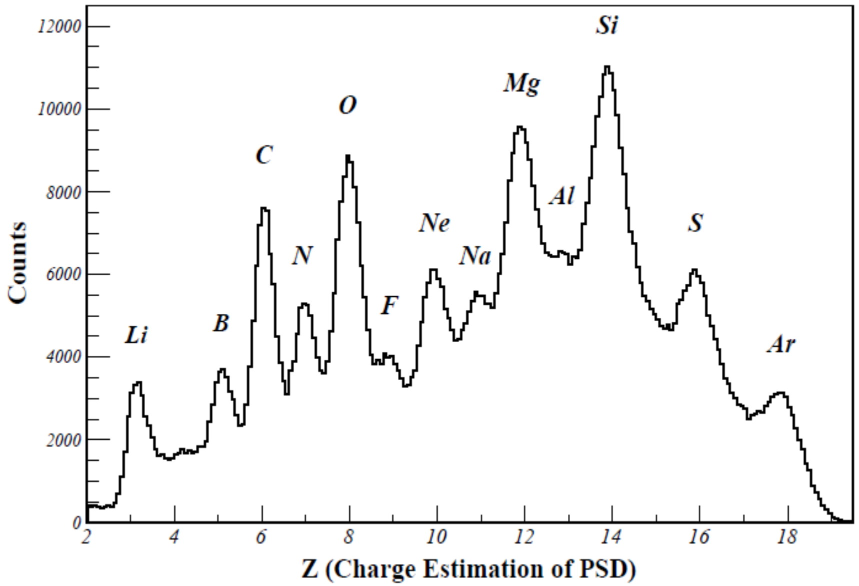
- Cosmic-rays electrons and positrons from 20 GeV to ~5 TeV [Nature 552, 64 (2017)]
- Direct detection of a spectral break at 0.9 TeV (6.6 σ c.l.)
- A smoothly broken power law fits data ($\gamma = 3.1 \rightarrow 3.9$)
- Next step: search for structures and anisotropies (nearby sources, pulsars, DM?)



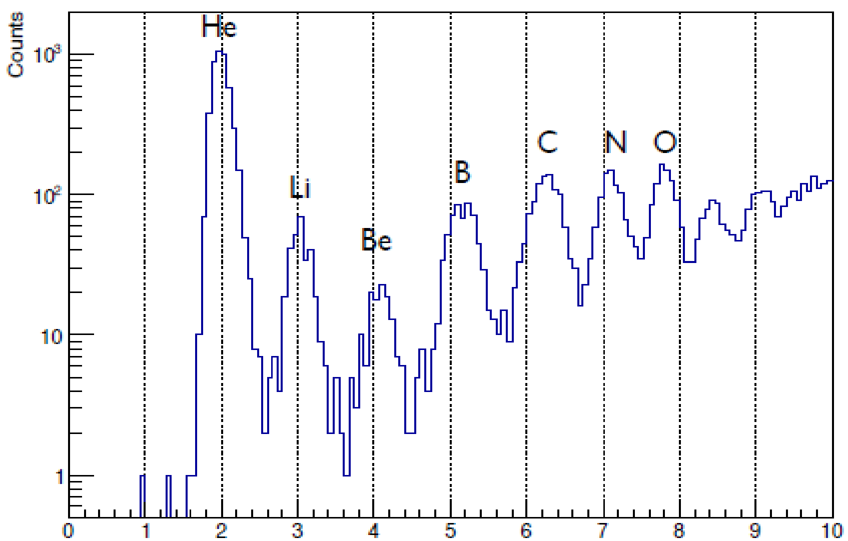
Protons and nuclei: beam tests

- Identifying protons and nuclei with PSD and STK
  - charge measurement tested with ion beam tests at CERN
  - PSD: up to Argon; STK: up to Oxygen
  - charge resolution is dependent on Z and ranges from 0.2 to 0.4
  - more details in Astropart. Phys. 95, 6 (2017)

PSD – Argon beam 40 GeV/n



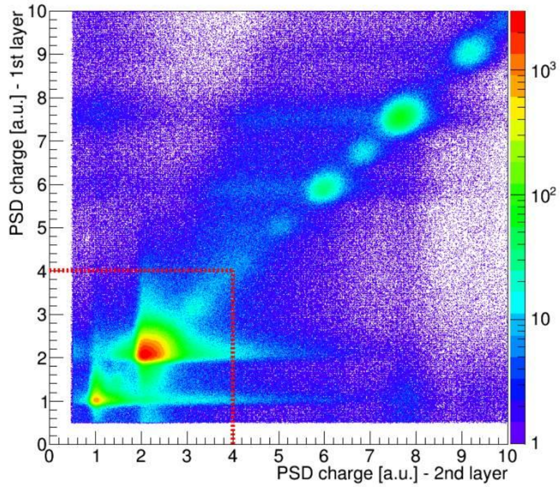
STK – Lead beam 40 GeV/n



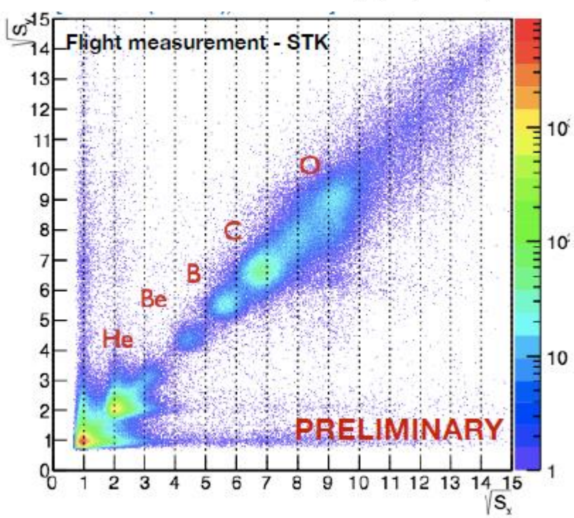
Protons and nuclei: flight data

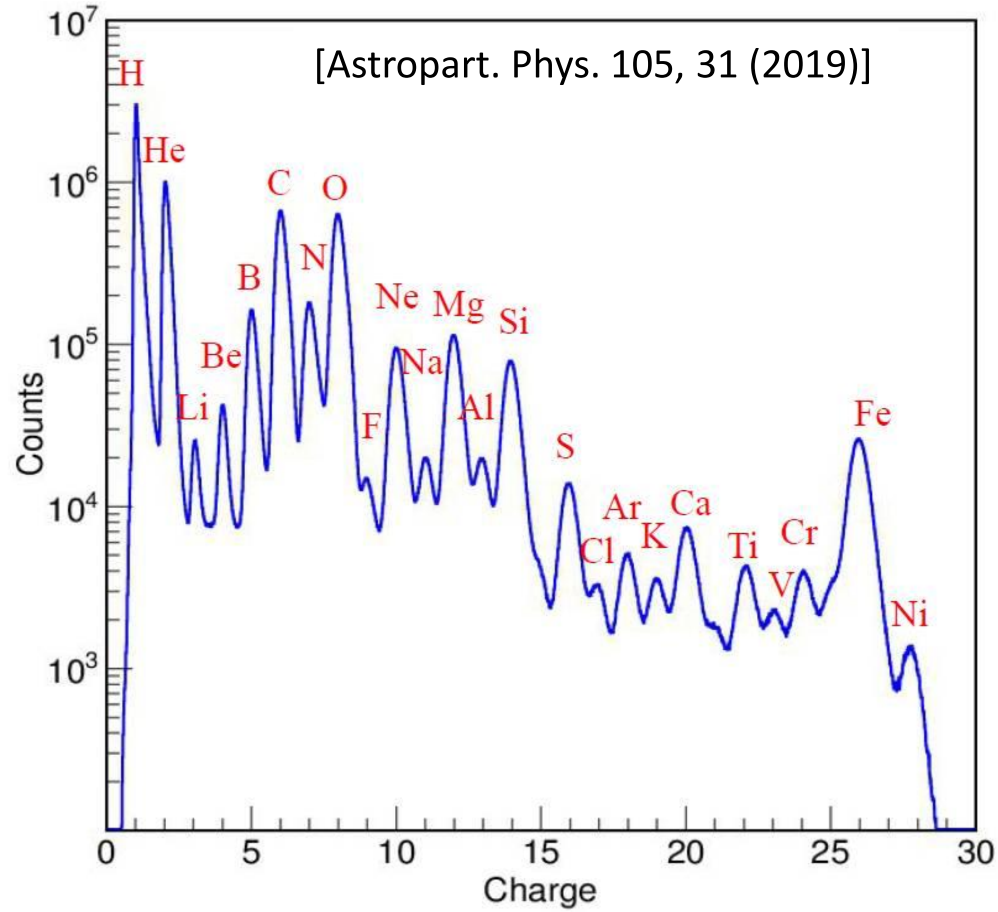
- Identifying protons and nuclei with PSD and STK

PSD

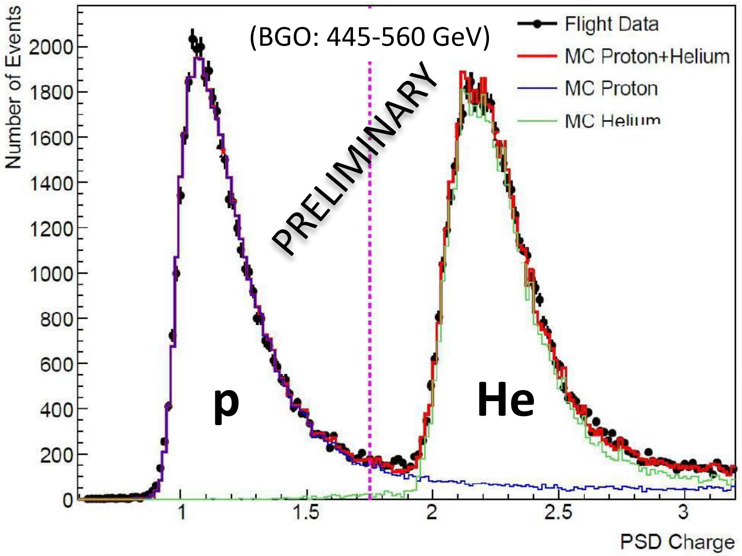


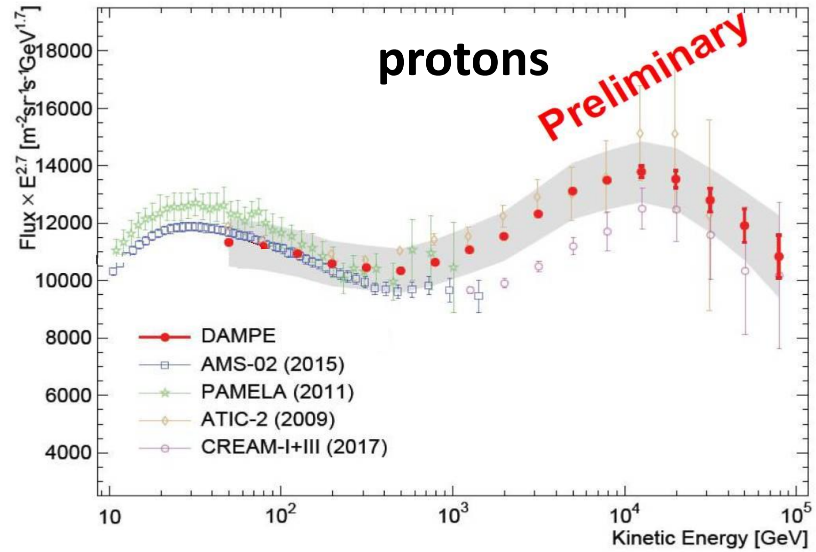
STK



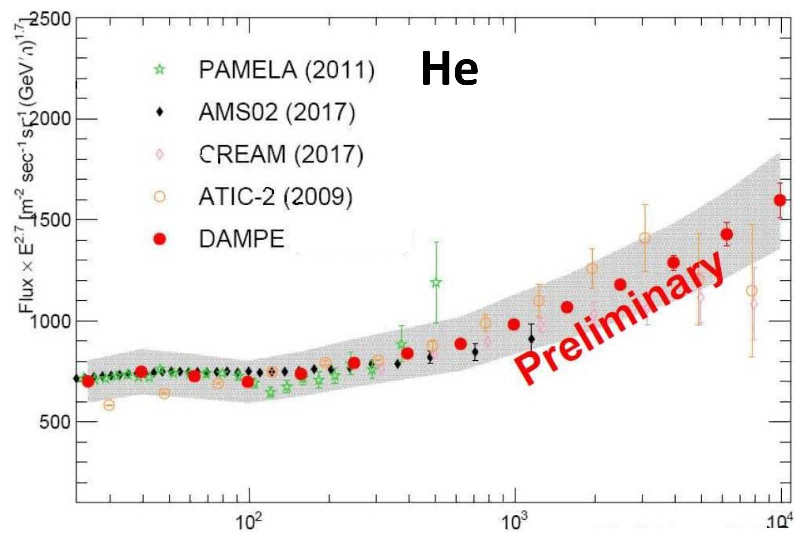


Protons and Helium spectra



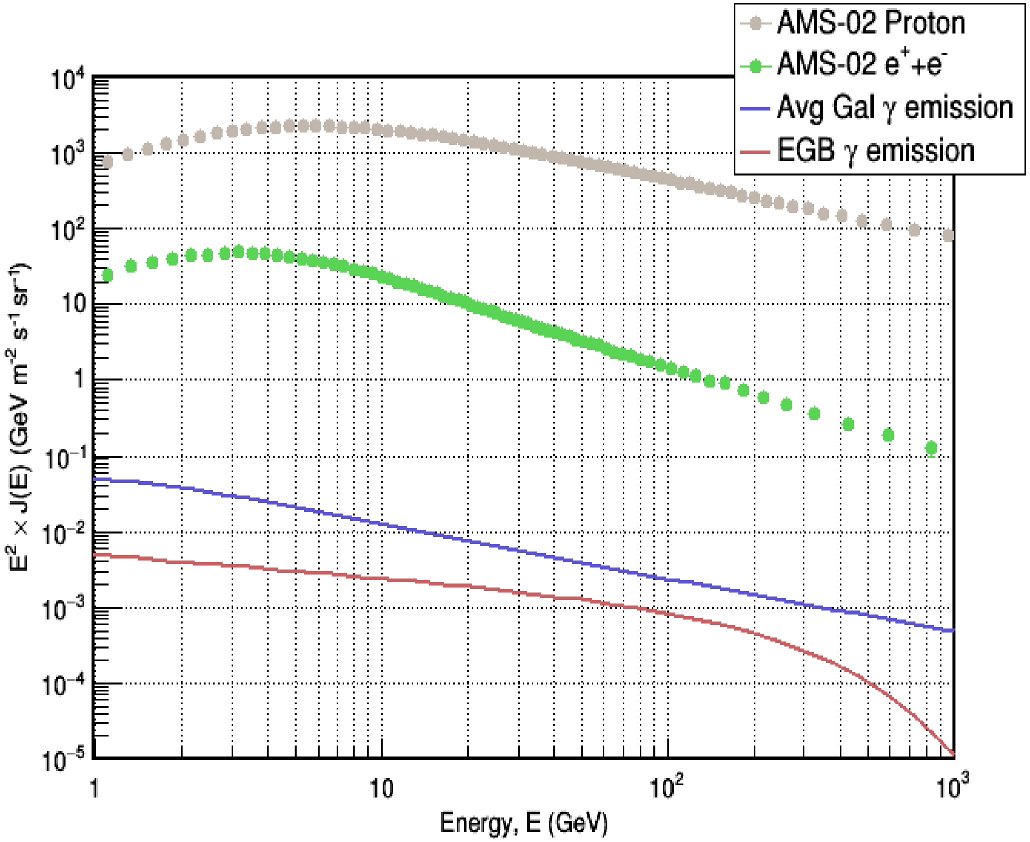


- Agreement with other experiments
- Protons: hardening at E > 300 GeV, softening at E > 10 TeV
- Helium: hardening at 200 GeV
- Analysis is being extended to higher energies

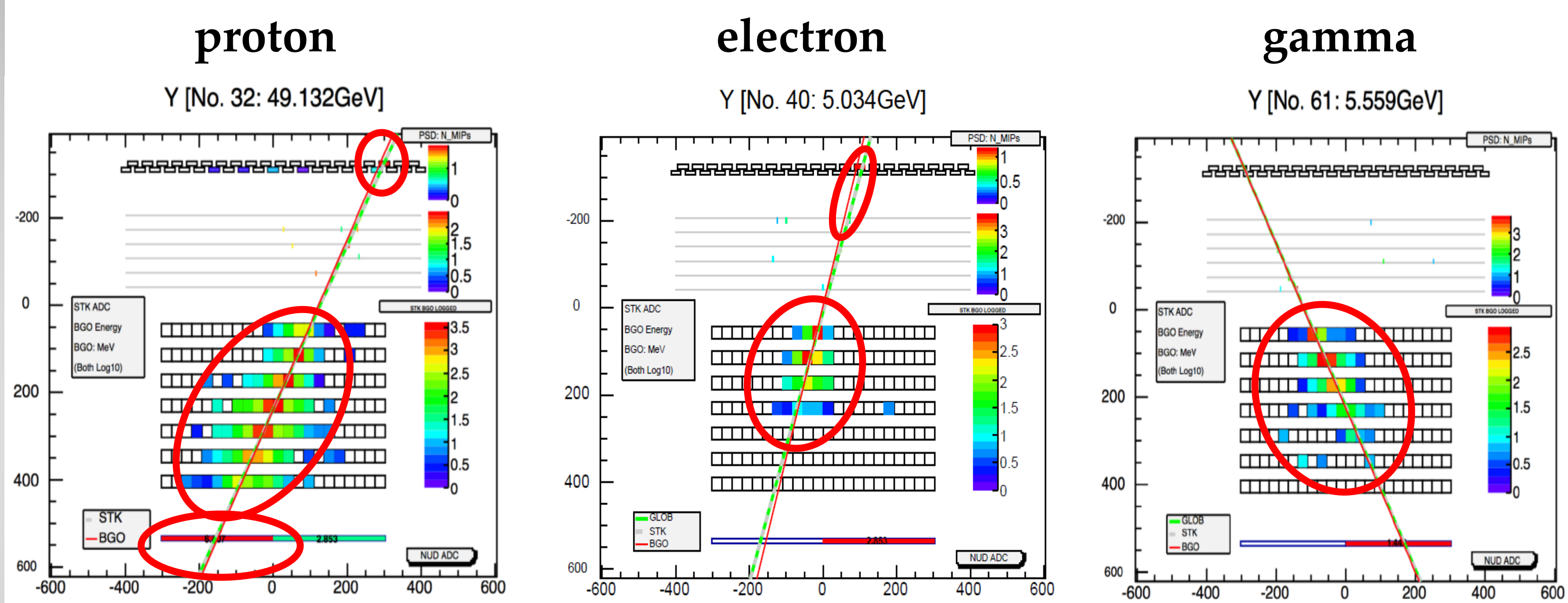


Photons: background

- Charged particles are a massive background for photons
- Protons vs γ:
  - 10^5 factor @ E > 100 GeV
  - mainly rejected using the shower profile and the onboard trigger
- Electrons vs γ:
  - 10^3 factor @ E > 100 GeV
  - mainly rejected using the PSD and the 1st layer of STK
  - key problem is the back scattering at high energy



Photons: selection



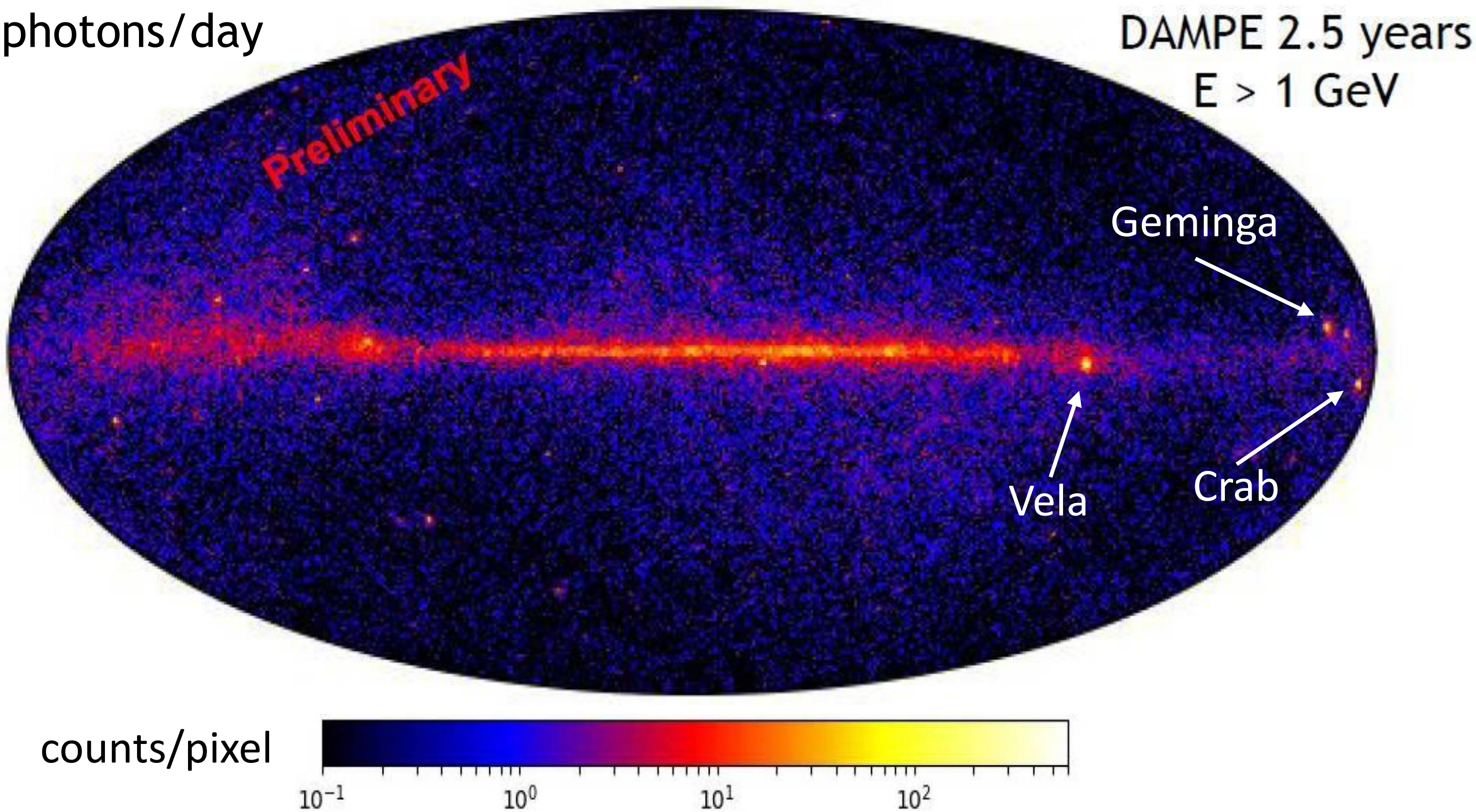
PSD + BGO profile + NUD : rejection > 10^7 for hadrons

PSD + STK : rejection up to 10^3 for electrons

- Event topology
- Random Forest + Convolutional Neural Networks

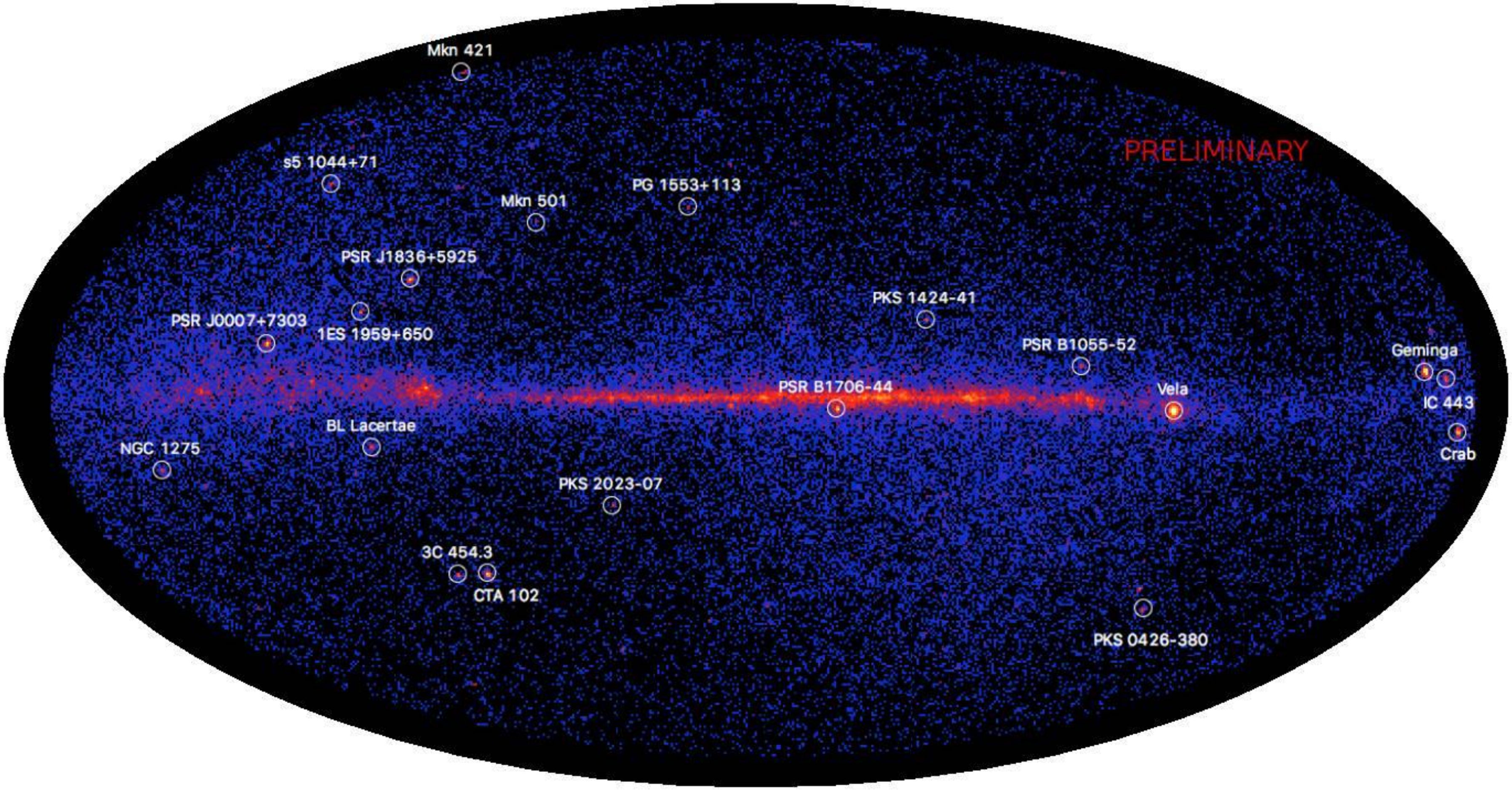
Photons: counts maps

~150 photons/day



Angular resolution: ~1° @ 1 GeV, ~0.1° @ 100 GeV, ~0.05° @ 1 TeV

The DAMPE gamma-ray sky

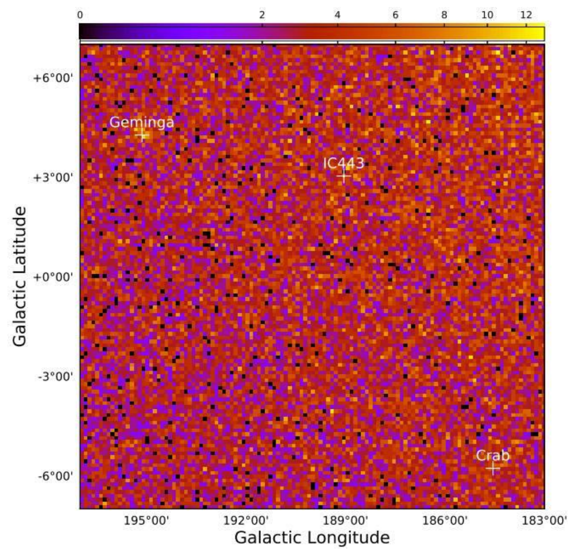


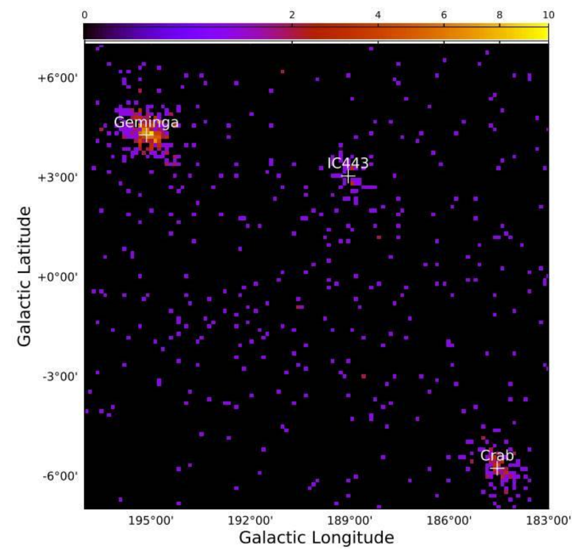
DAMPE gamma-ray sky and major gamma-ray sources

Photons: pulsars

- Algorithms to resolve gamma-rays from charged cosmic rays

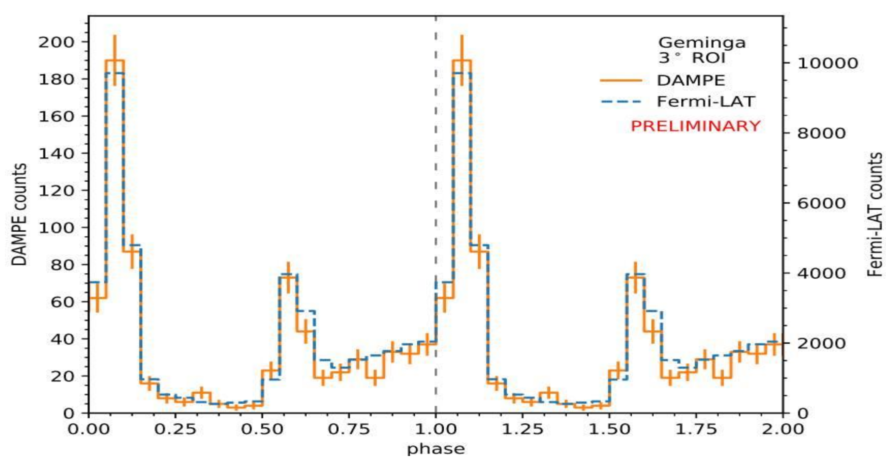
[Res. Astron. Astrophys. 18, 27 (2018)]





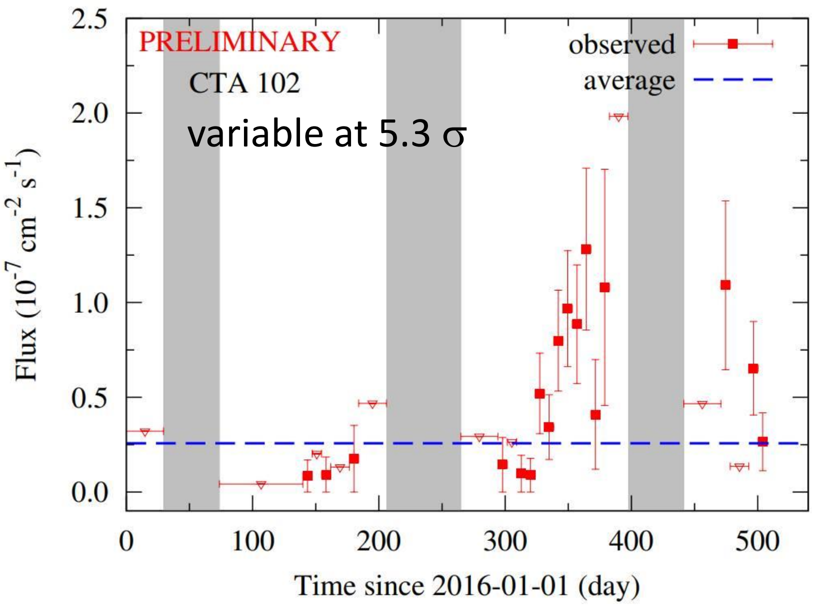
- Geminga, IC443 and Crab pulsars

- Geminga pulsar phase profile (T ~237 ms)



Photons: blazars variability

- DAMPE detection of gamma-ray variability of some blazars:
  - CTA 102
  - 3C 454.3
  - 3C 279
  - …

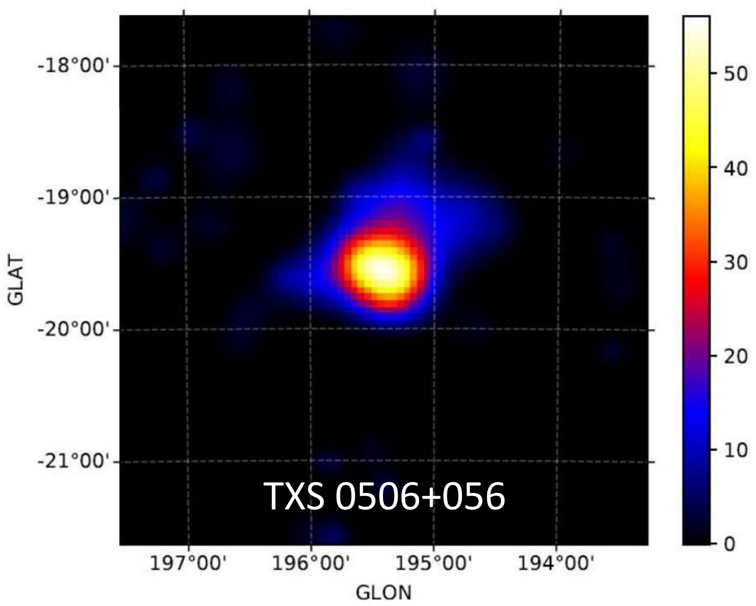


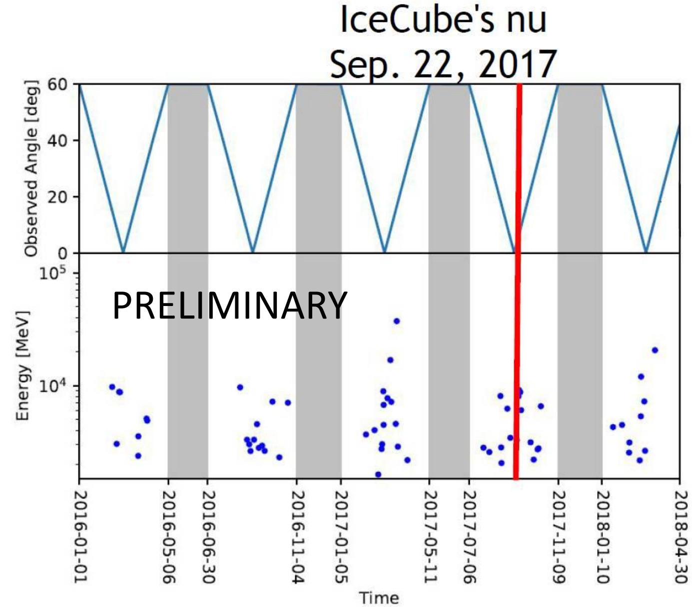
DAMPE detection of variable GeV gamma-ray emission from blazar CTA 102

ATel #9901; *Zun-Lei Xu (PMO), Micaela Caragiulo (Bari), Jin Chang (PMO), Kai-Kai Duan (PMO), Yi-Zhong Fan (PMO), Fabio Gargano (Bari), Shi-Jun Lei (PMO), Xiang Li (PMO), Yun-Feng Liang (PMO), M. Nicola Mazziotta (Bari), Zhao-Qiang Shen (PMO), Meng Su (HKU/PMO), Andrii Tykhonov (Geneva), Qiang Yuan (PMO), Stephan Zimmer (Geneva), on behalf of the DAMPE collaboration, and Bin Li (PMO) and Hai-Bin Zhao (PMO) on behalf of the CNEOST group.*
on ***27 Dec 2016; 01:02 UT***
Credential Certification: Zun-Lei Xu (xuzl@pmo.ac.cn)

Participation to multi-messenger searches

- DAMPE participates to multi-messenger search of γ counterparts
- Detection of gamma-ray source TXS 0506+056 (possibly associated with the neutrino event IceCube-170922A)
  - no clear variability detected due to limited statistics
  - ongoing monitoring of the source





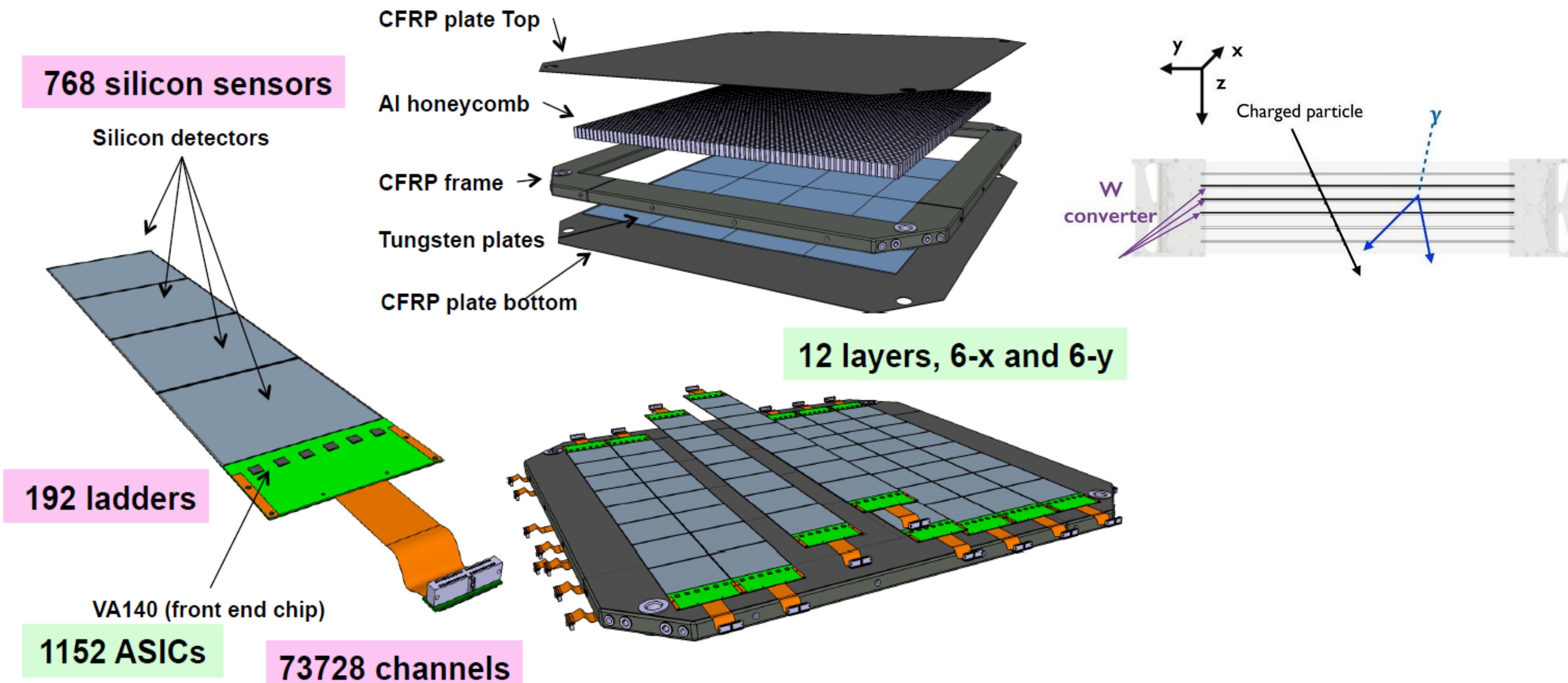
Summary

- DAMPE is working extremely well since ~3 years
- $e^{-}+e^{+}$ spectrum precisely measured up to TeV energies
  - a clear spectral break has been directly measured at ~1 TeV
  - improved precision of the $e^{-}+e^{+}$ spectrum behavior and structures may shed light on nearby sources, anisotropies, DM
- Proton, Helium and nuclei measurements are ongoing
- Photon detection capability assessed
  - accumulating more statistics to profit the excellent energy resolution at high energy

Thank you

Backup

The Silicon TracKer (STK)



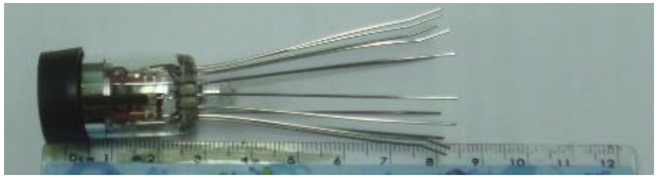
- 48 μm wide Si strips - 121 μm pitch
- 95×95×0.32 mm^3 Silicon Strip Detectors (SSD) - 768 strips
- 1 ladder composed by 4 SSDs
- 16 ladders per layer (76×76 cm^2)
- 12 layers (6x + 6y)

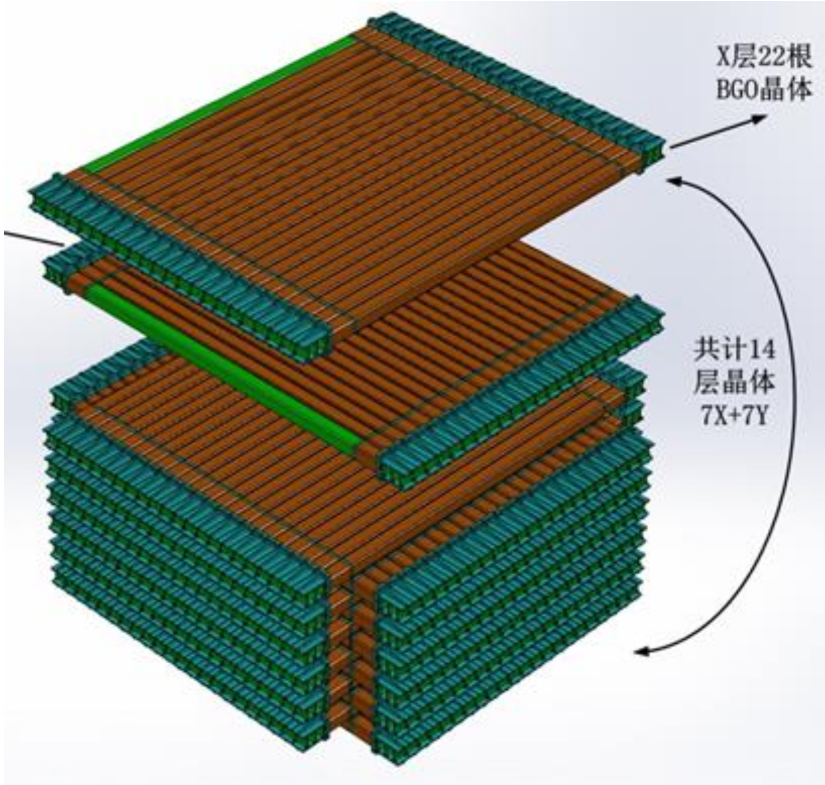
Analog Readout of each second strip:
384 channels / SSD- Ladder
Charge sharing

The CALOrimeter

- 14 alternate orthogonal layers,each of 22 BGO bars
  - Total 308 bars
  - Dimensions of a bar: $2.5 \times 2.5 \times 60\ cm^3$
  - Total depth ~32 X_0, ~1.6 λ

- One PMT at each BGO bar end
  - Two PMTs per bar, total 616 PMTs

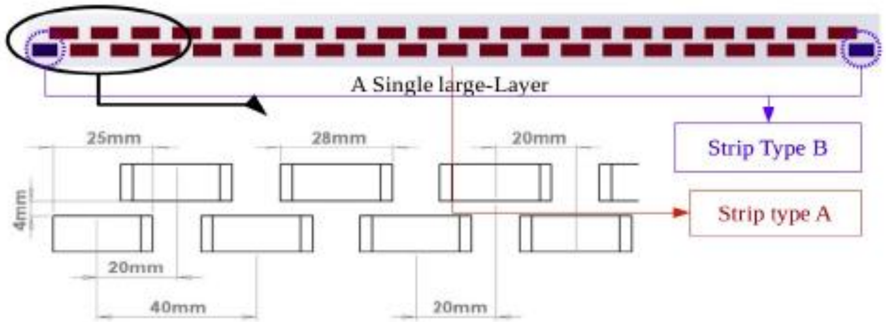




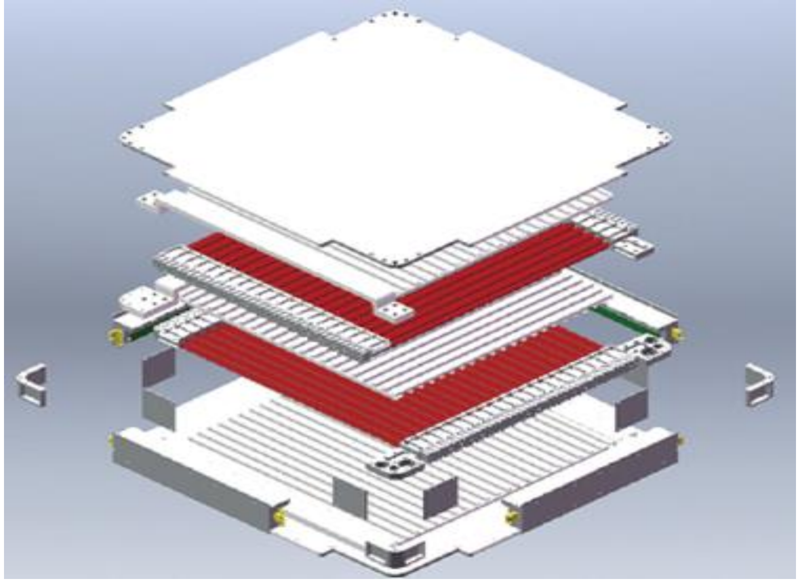
- Electronics boards attached to each side of the module
- Deposited energy ranges: 2 MeV – 2 TeV and 10 MeV – 5 TeV

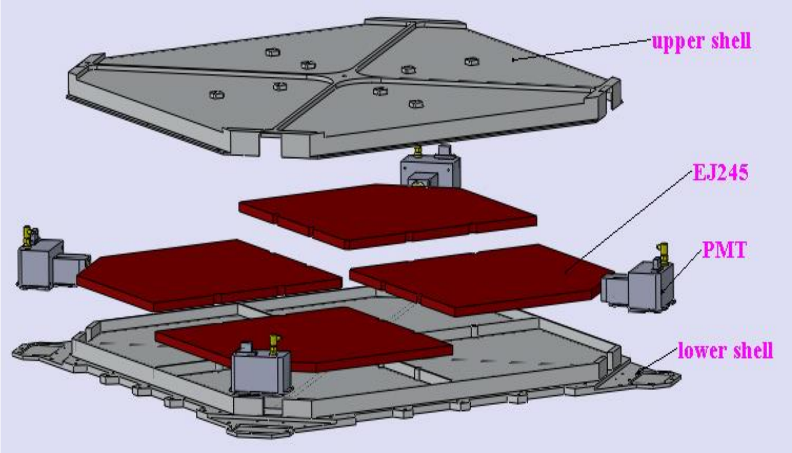
The PSD and the NUD

- PSD
  - 2 layers (*x* and *y*), each is 82×82 cm^2
  - 88×2.8×1 cm^3 scintillator bars
  - Staggered by 0.8 cm in each layer



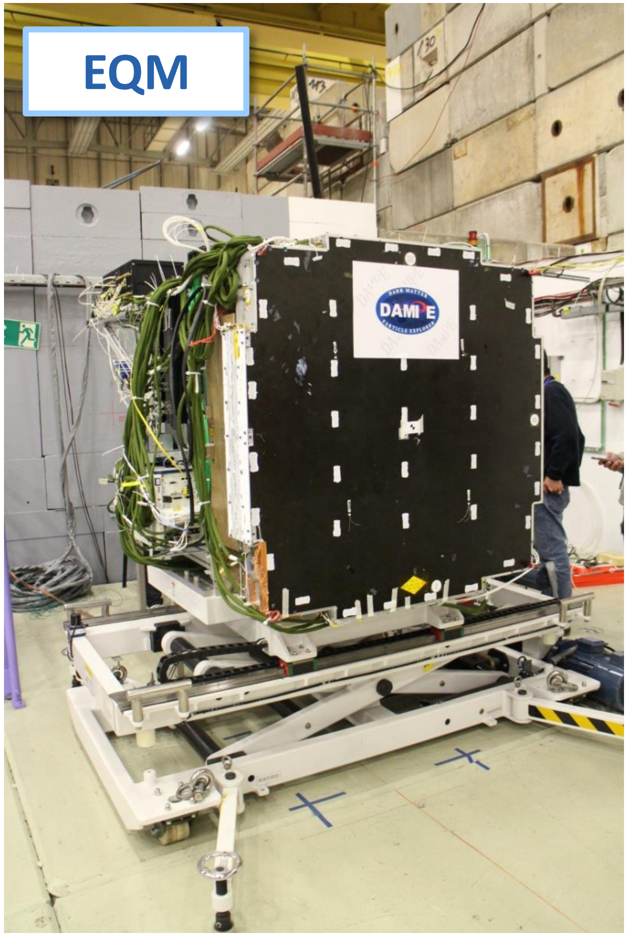
- NUD
  - 4 large area boron-doped plastic scintillators, 30×30×1 cm^3 each
  - Wrapped in Al for photon reflection





Beam tests at CERN

- 14 days @ PS, 29/10-11/11 2014
  - e @ 0.5, 1, 2, 3, 4, 5 GeV/c
  - p @ 3.5, 4, 5, 6, 8, 10 GeV/c
  - π^- @ 3, 10 G.eV/c
  - γ @ 0.5-3 GeV/c
- 8 days @ SPS, 12/11-19/11 2014
  - e @ 5, 10, 20, 50, 100, 150, 200, 250 GeV/c
  - p @ 400 GeV/c (SPS primary beam)
  - γ @ 3-20 GeV/c
  - μ @ 150 GeV/c,
- 17 days @ SPS, 16/03-10/04 2015
  - Fragments @ 66.67, 88.89, 166.67 GeV/c
  - Argon @ 30A, 40A, 75A GeV/c
  - p @ 30, 40 GeV/c
- 21 days @ SPS, 10/06-01/07 2015
  - p @ 400 GeV/c (SPS primary beam)
  - e @ 20, 100, 150 GeV/c
  - γ @ 50, 75 , 150 GeV/c
  - μ @ 150 GeV /c
  - π^+ @ 10, 20, 50, 100 GeV/c
- 6 days @ SPS, 20/11-25/11 2015
  - Pb @ 30A GeV/c (and fragments)

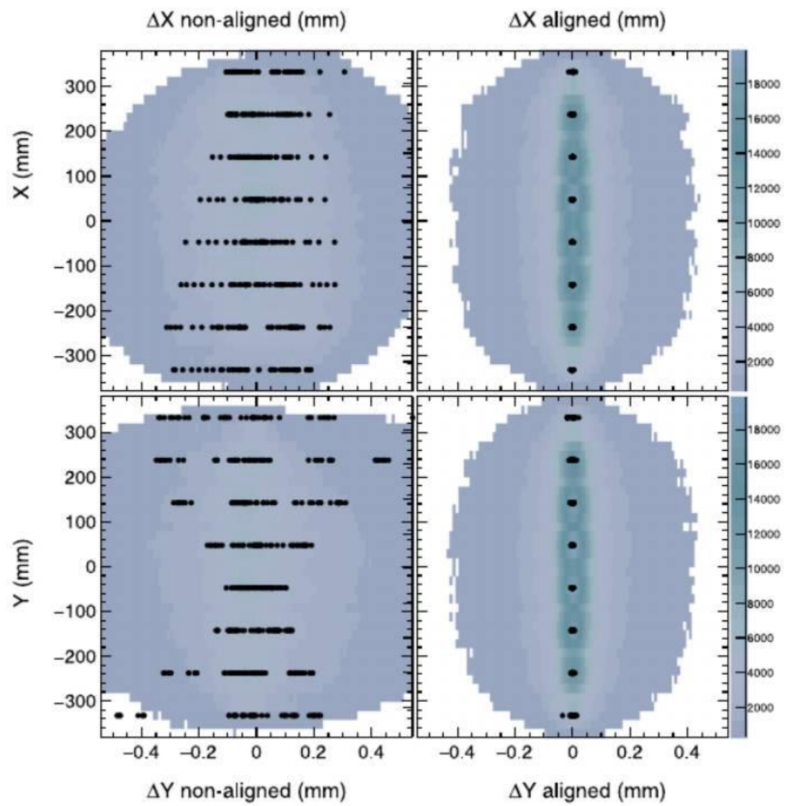


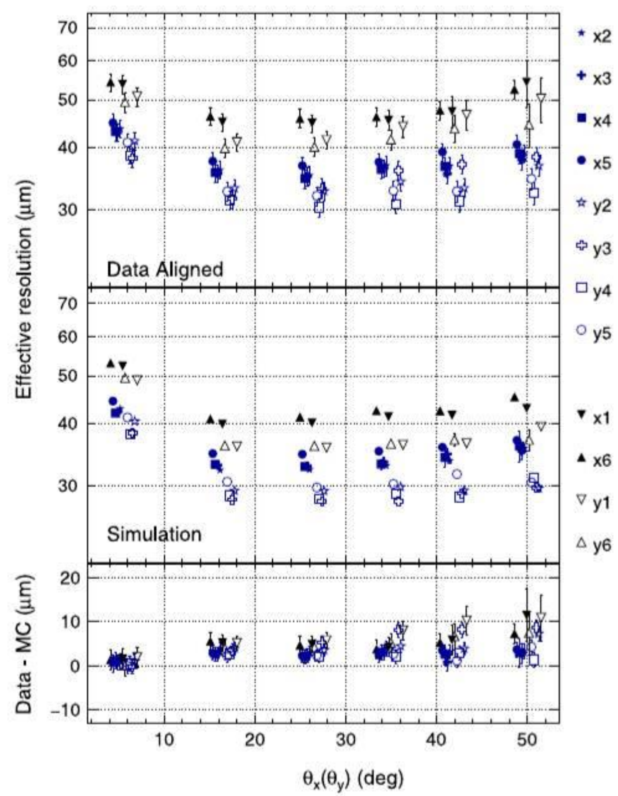
The DAMPE triggers

Trigger Type	Logic	Energy Threshold	Pre-scale factor
HE	L1_P_dy5	~10 MIPs	1
	& L2_P_dy5	~10 MIPs	
	& L3_P_dy5	~10 MIPs	
	& L4_N_dy8	~2 MIPs	
MIPs (Type I)	L3_P_dy8	~0.4 MIPs	4 (low latitude(±20°))
	& L11_P_dy8	~0.4 MIPs	
	& L13_P_dy8	~0.4 MIPs	Turn Off (other region)
MIPs (Type II)	L4_P_dy8	~0.4 MIPs	4 (low latitude(±20°))
	& L12_P_dy8	~0.4 MIPs	
	& L14_P_dy8	~0.4 MIPs	Turn Off (other region)
LE	L1_N_dy8	~0.4 MIPs	
	& L2_N_dy8	~0.4 MIPs	8 (low latitude(±20°))
	& L3_N_dy8	~2 MIPs	
	& L4_N_dy8	~2 MIPs	64 (other region)
Unbiased	(L1_P_dy8 & L1_N_dy8)	~0.4 MIPs ~0.4 MIPs	512 (low latitude(±20°))
	| (L2_P_dy8 & L2_N_dy8)	~0.4 MIPs ~0.4 MIPs	2048 (other region)

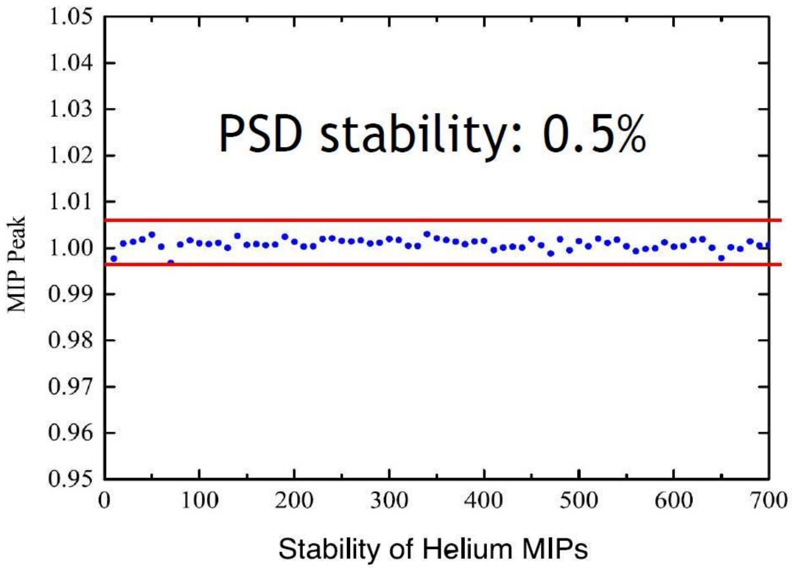
STK alignment

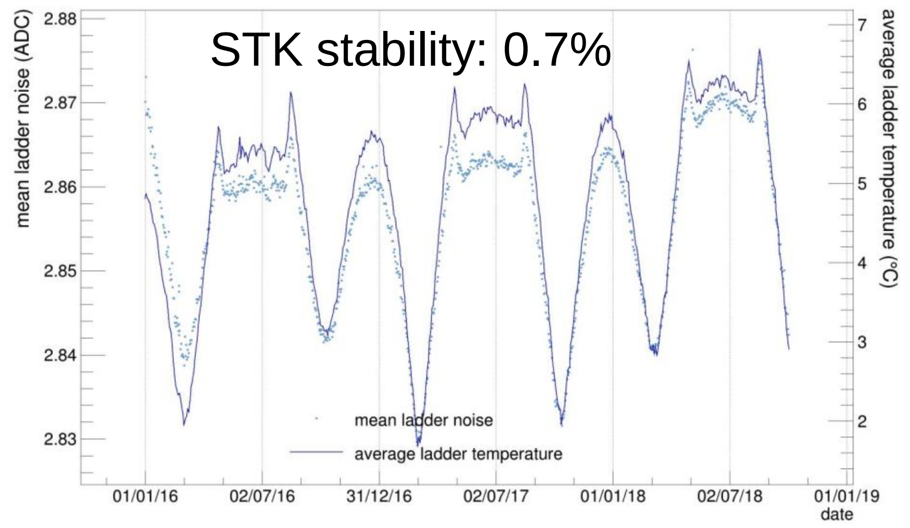
- STK alignment is performed once every two weeks
  - MIPs (non-showering particles) are used to correct the alignment
  - a spatial resolution < 40 μm on central STK planes is achieved

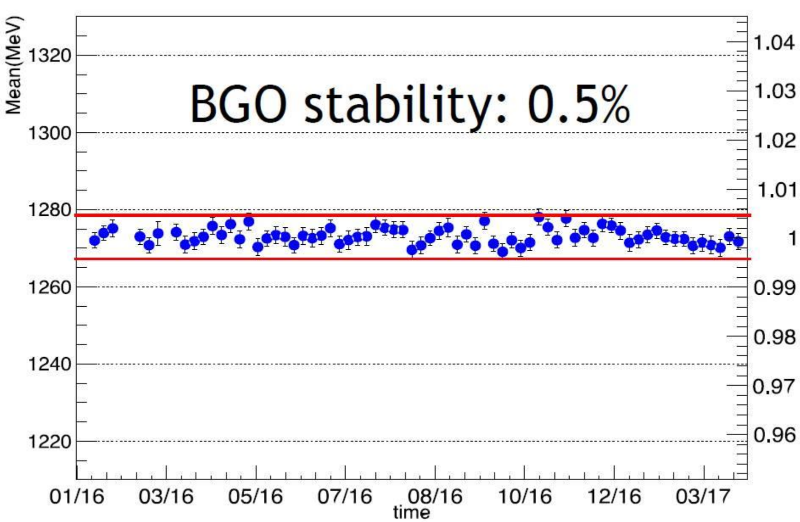


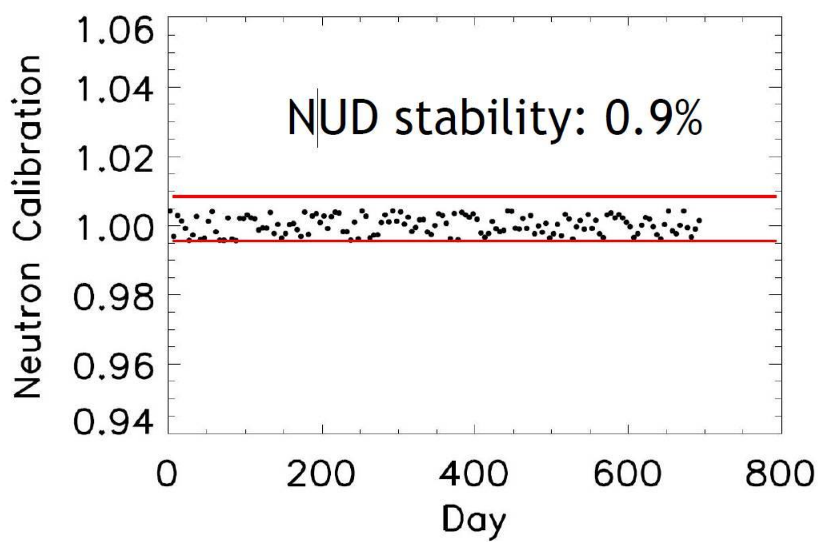


Stability of detectors



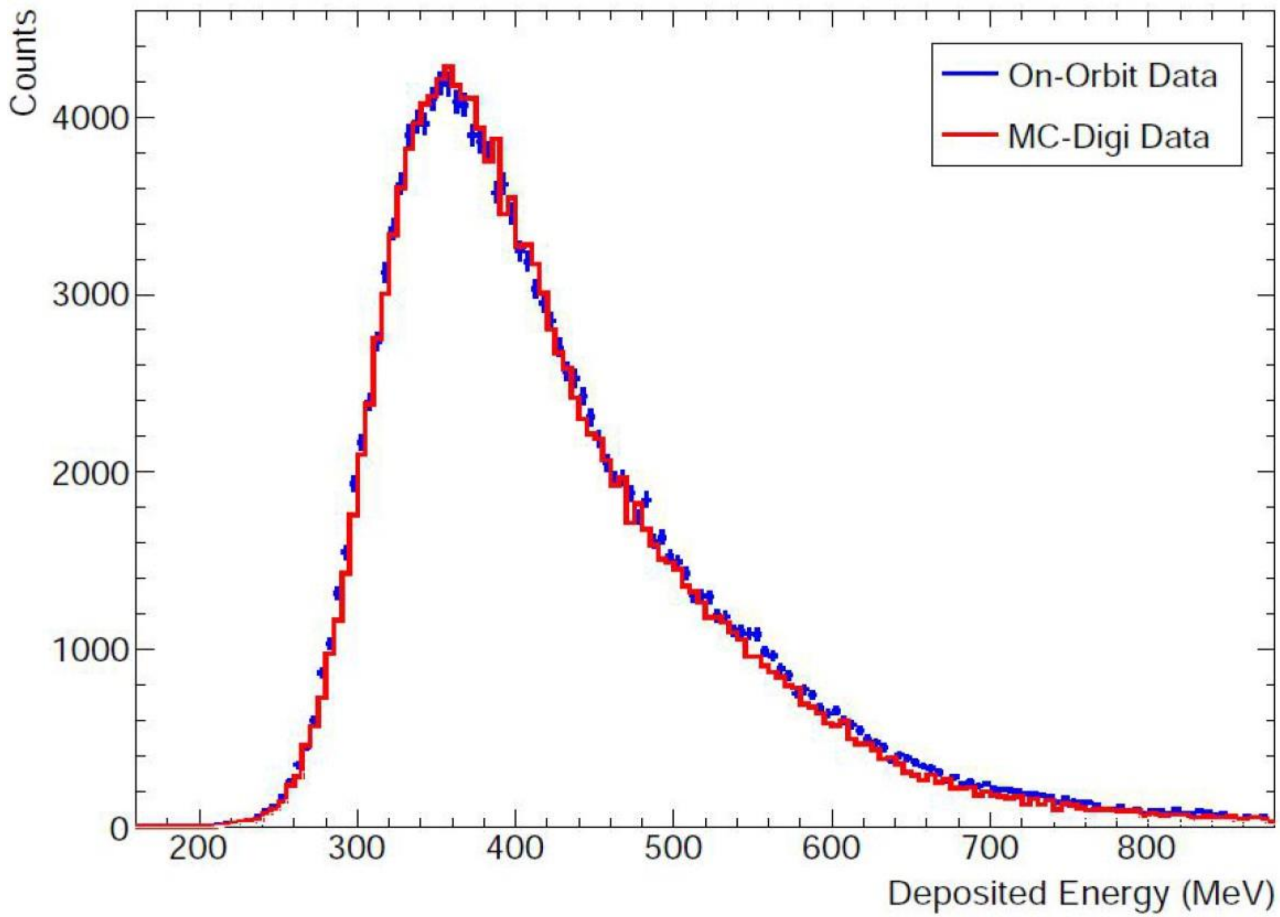






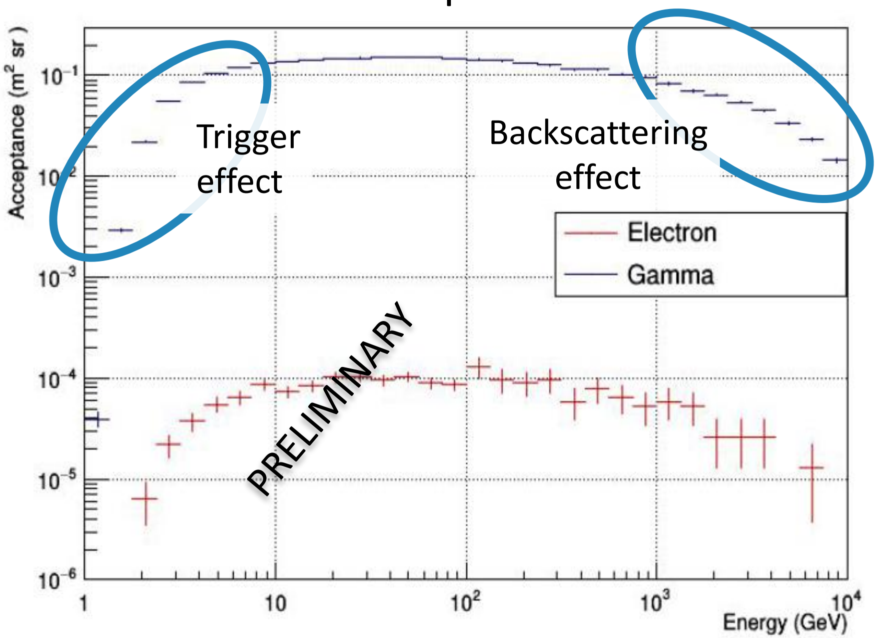
MIP calibration

- Energy calibration with MIPs

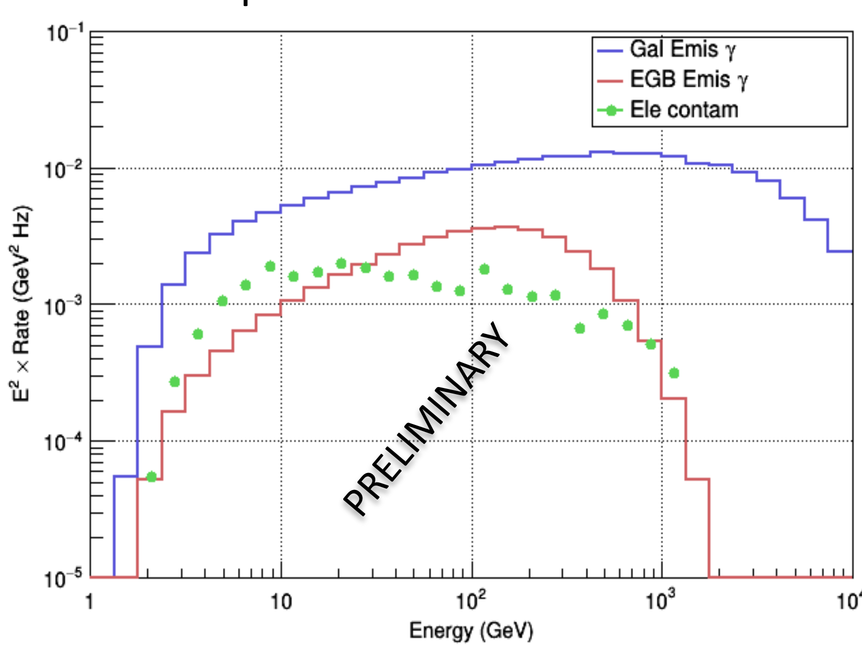


Photons: acceptance and rates

Acceptance



Expected rate after selection



- Selection based on Convolutional Neural Networks + Random Forest
- Other PID algorithms are under study to decrease the contamination from electrons at a level below the Extra Galactic Background emission