Main scientific results of the DAMPE mission

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(on behalf of DAMPE Collaboration)

The 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
  - INFN LNGS and Gran Sasso Science Institute

- **SWITZERLAND**
  - University of Geneva

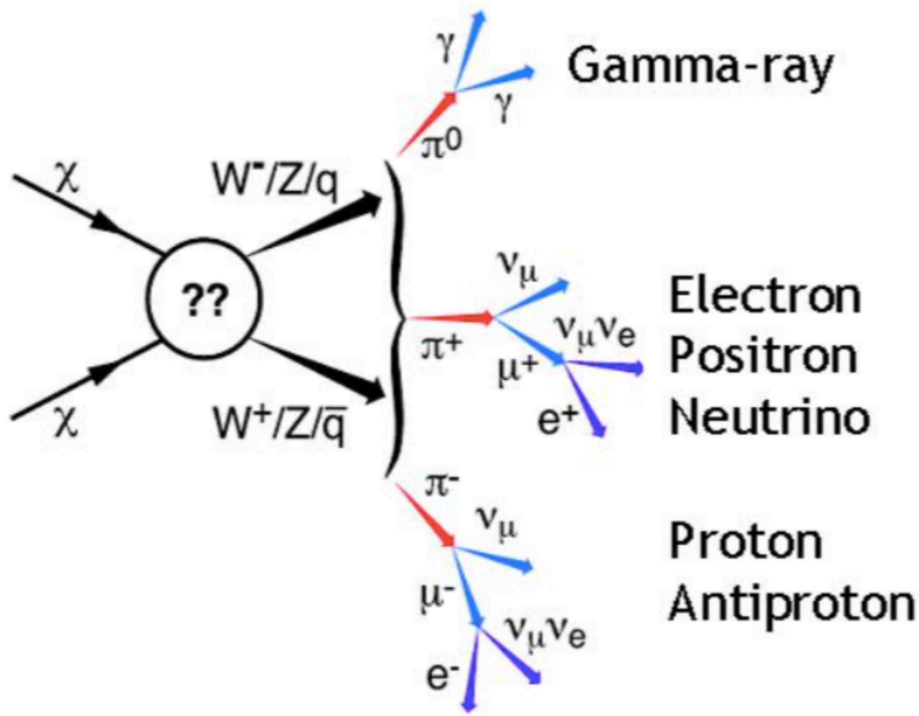
Outline

- Scientific goals
- Detector
- Beam test at CERN
- On-orbit perfomances
- First results
  - ✓ nuclei spectra (p, He …)
  - ✓ γ-astronomy
  - ✓ electron spectrum
- Conclusions

The physics goals

DArk Matter Particle Explorer

Possible indirect detection of Dark Matter



Main goal: search for Dark Matter signatures in cosmic charged and gamma rays

The physics goals

DArk Matter Particle Explorer

High energy particle detection in space

- Measurement of electron and photon spectra
- Study of protons and nuclei (spectra and composition)
- High energy gamma ray astronomy
- Search for dark-matter signatures in lepton spectra

Detection of

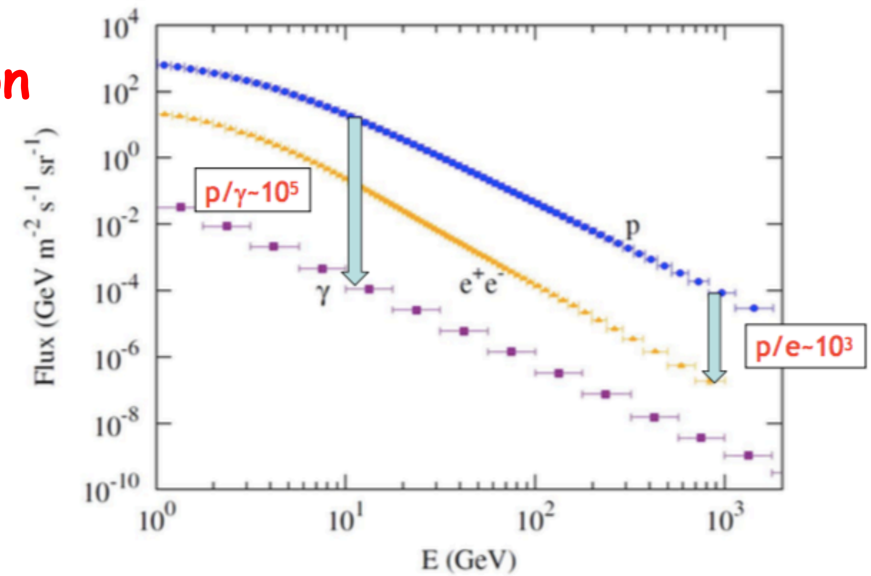
electrons and gammas (5 GeV - 10 TeV)
protons and nuclei (50 GeV - 100 TeV)

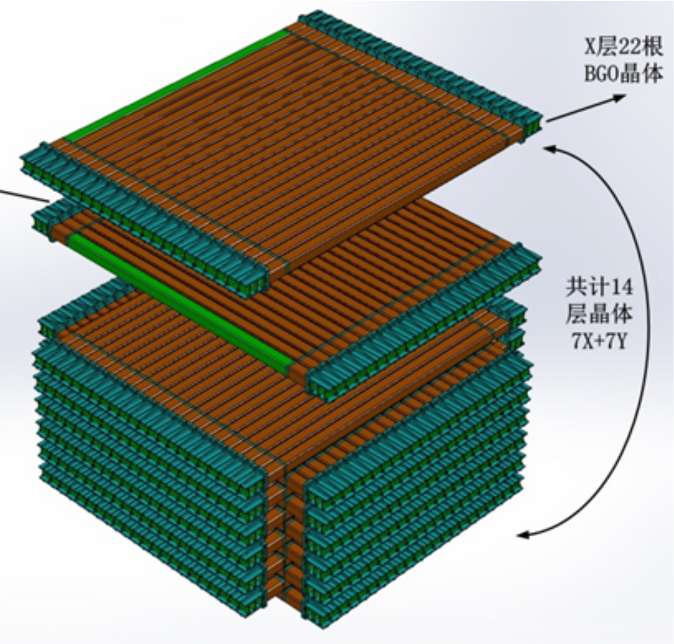
with excellent energy resolution, tracking precision and particle identification capabilities

Challenge detector features

Highly efficient particle-identification to remove proton background

1 electron / 10^3 protons
1 gamma / 10^5 protons

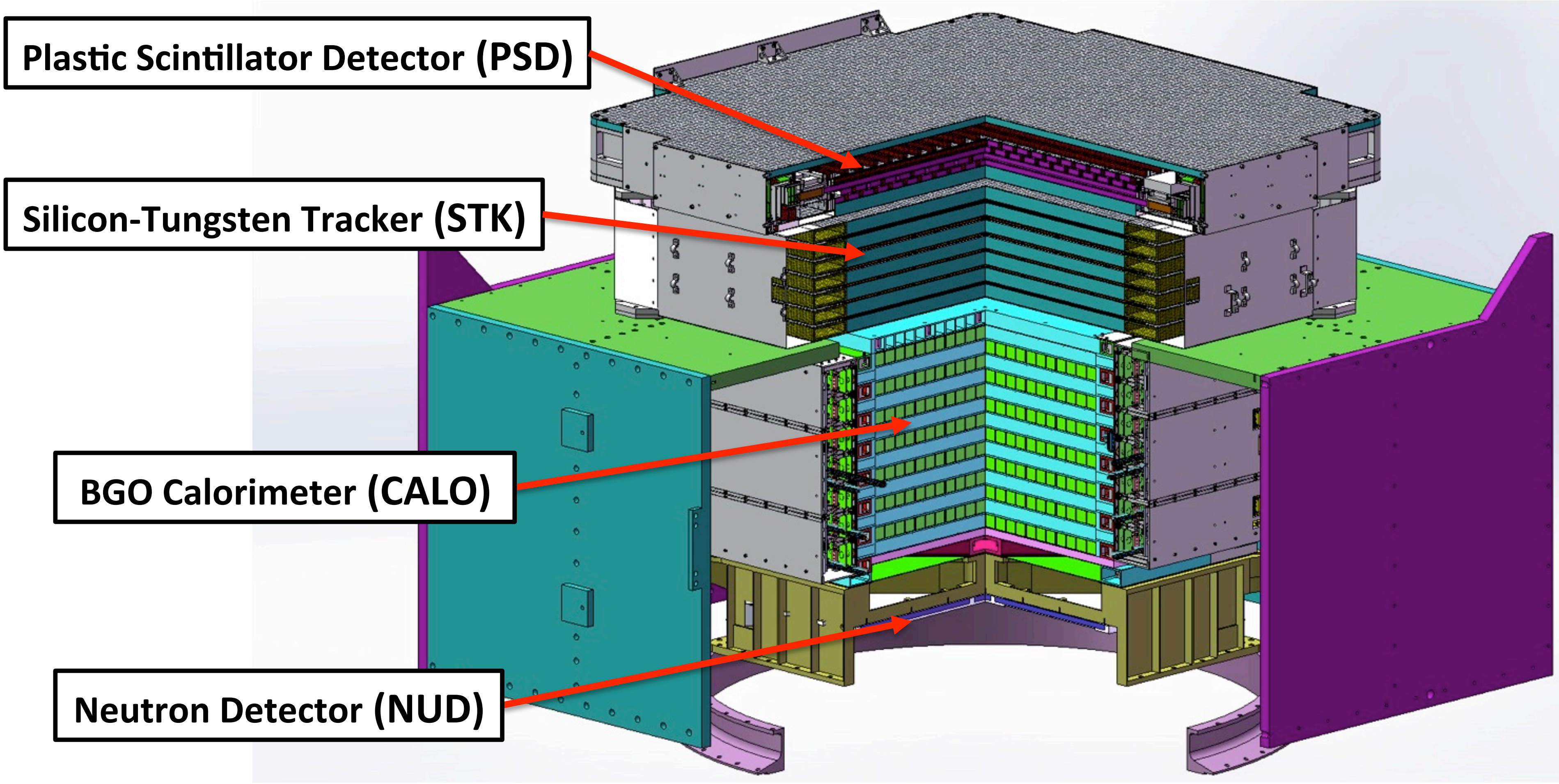




Detection of electrons and gamma-rays in the range GeV – tens TeV

Dynamical range of each calorimeter element must be MeV – TeV

The detector



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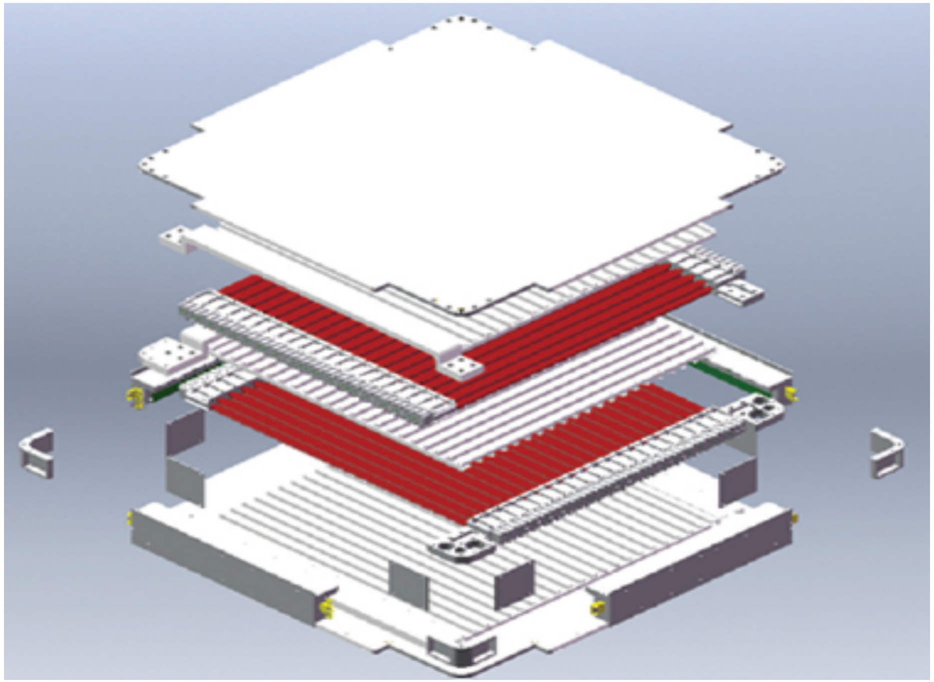
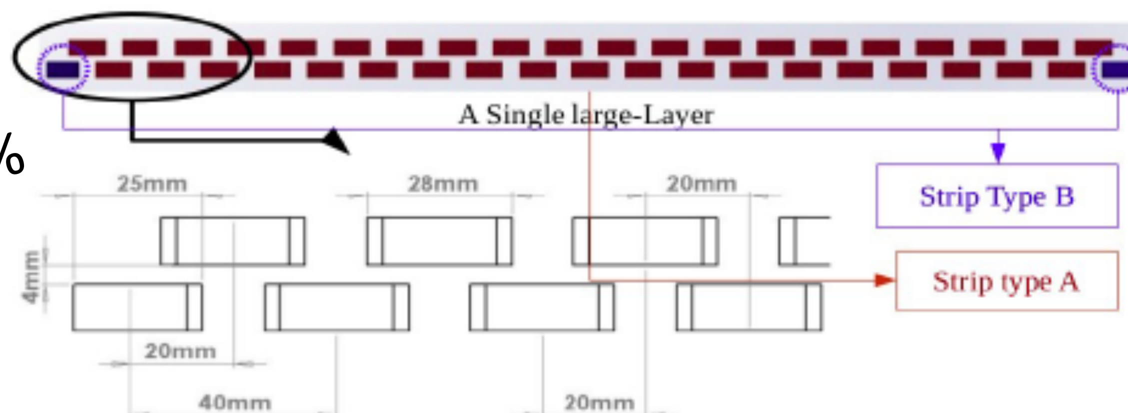
Plastic Scintillator Detector



- plastic scintillator strips ($2.8 \times 82 \times 1$ cm^3)
- staggered by 1.2 cm in a layer
- 82 cm × 82 cm layers
- 2 layers (x and y views)

Position resolution < 2 cm
Single layer efficiency > 95%

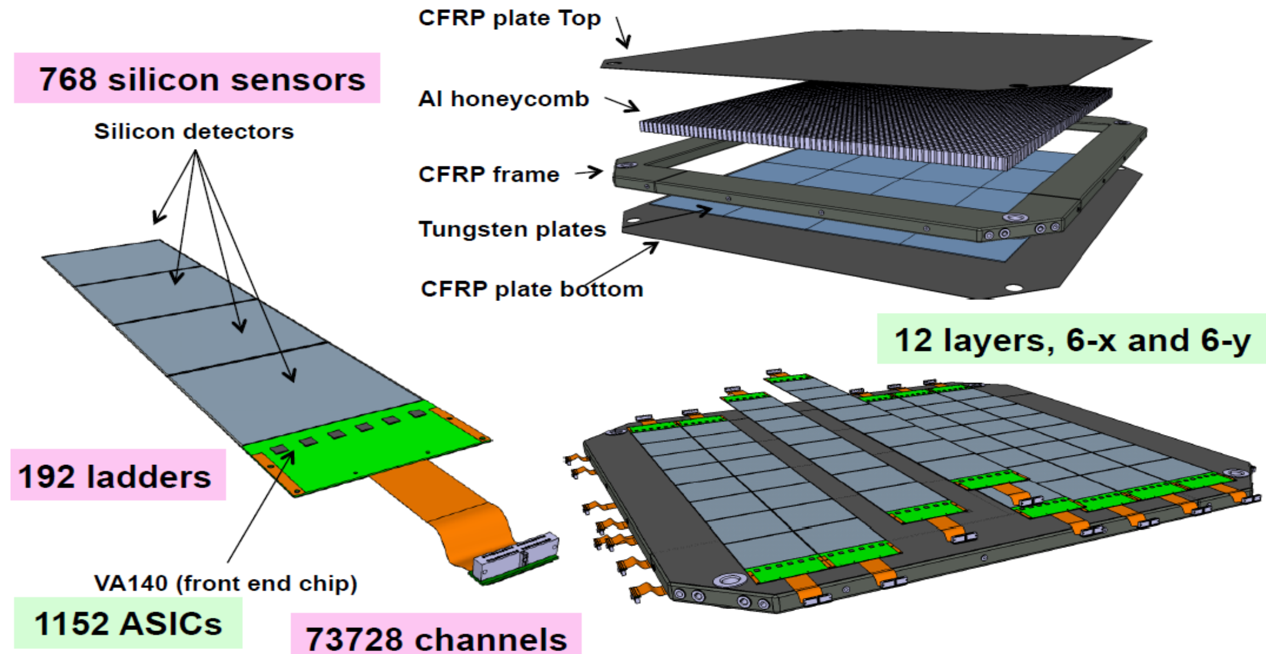


The Silicon Tracker

12 STK layers
(6 x-view, 6 y-view)

3 tungsten plates
as photon converter
in-between layer 1
and layer 4

Depth ~ 1 X_0



- 48 μm wide Si strips with 121 μm pitch
  - 768 strips = 1 Silicon Strip Detector (SSD)
    - 4 SSD = 1 ladder (380 mm × 95 mm × 0.32 mm)
      - 16 ladders = 1 layer (760 mm × 760 mm)

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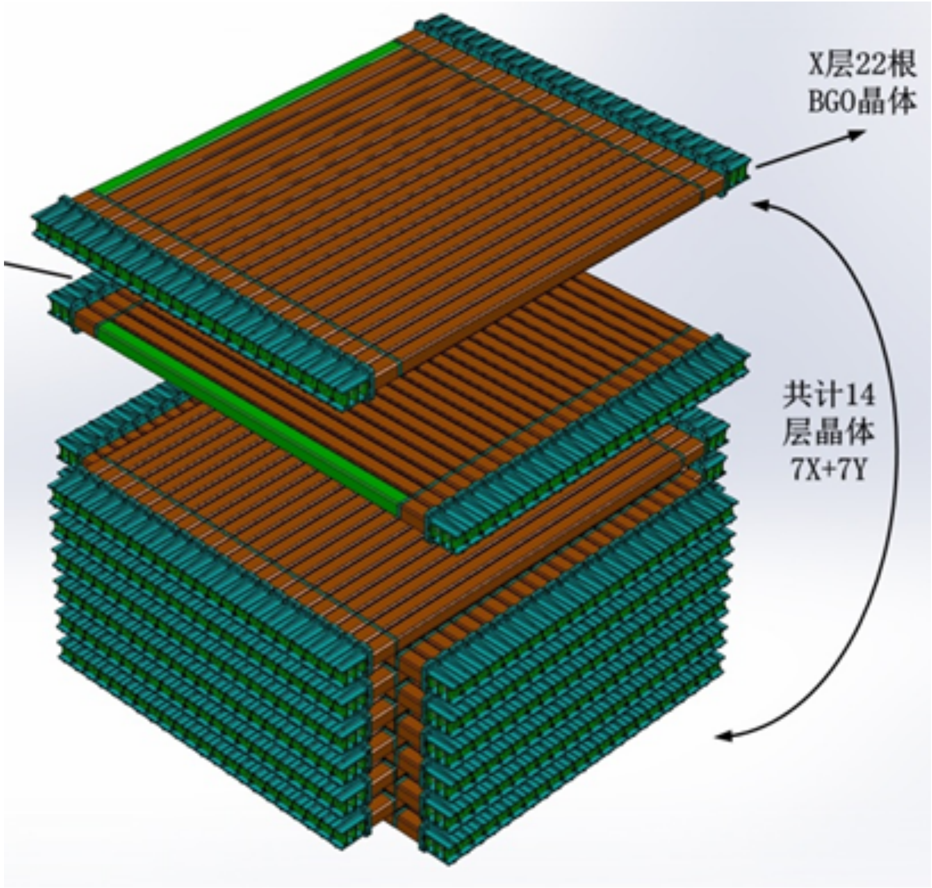
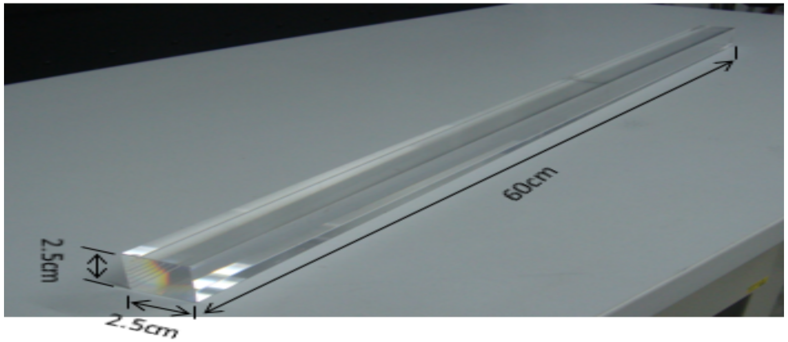
Analog Readout of each second strip (384 channels / ladder)

The BGO CALOrimeter

Hodoscopic stacking of 14 alternate orthogonal layers

Depth ~32 X_0





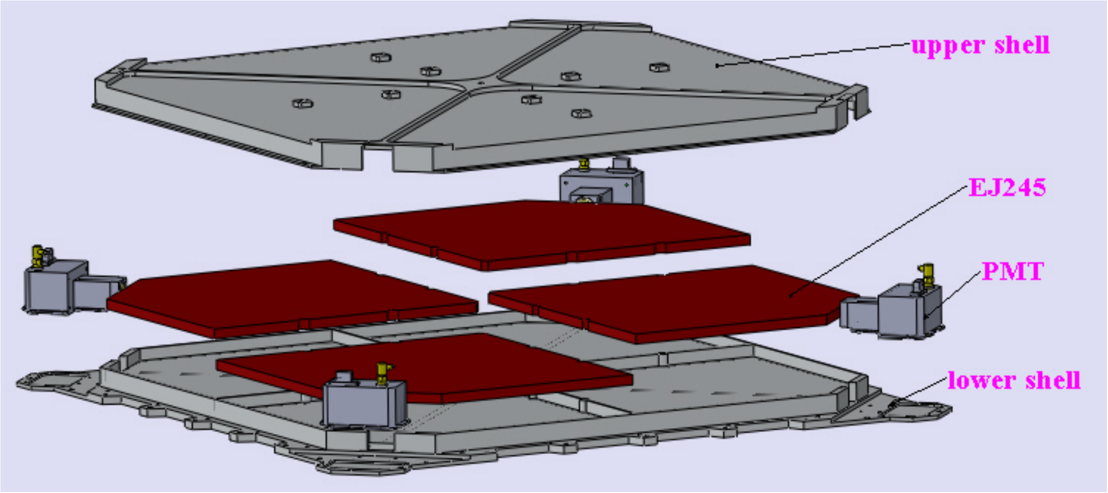
- BGO bar (2.5 × 2.5 × 60 cm^3)
- 22 BGO bars in each layer

- PMTs coupled with each BGO crystal bar in two ends
- Front-end electronics on each side of the module

NeUtron Detector

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

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



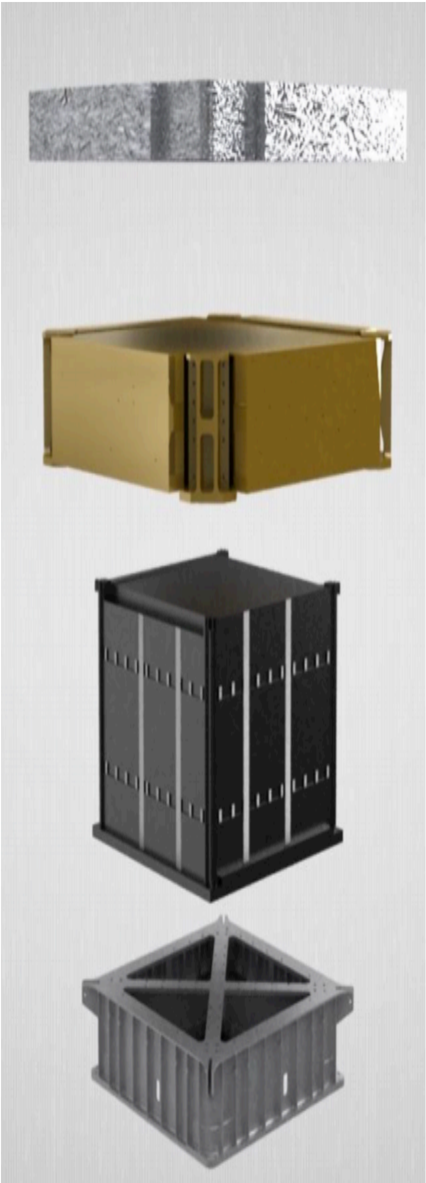
Summary of sub-detectors

PSD - Charge measurement ($Z \propto \sqrt{dE/dx}$)
- Z-range = 1-28, using two dynodes
- Veto for gammas

STK - Precise tracking
  spatial resolution <80 μm (incidence < 60°)
  angular resolution ~0.2° (γ at 10 GeV)
- Tungsten converter for pair production
- Charge measurement ($Z \propto \sqrt{ADC}$)

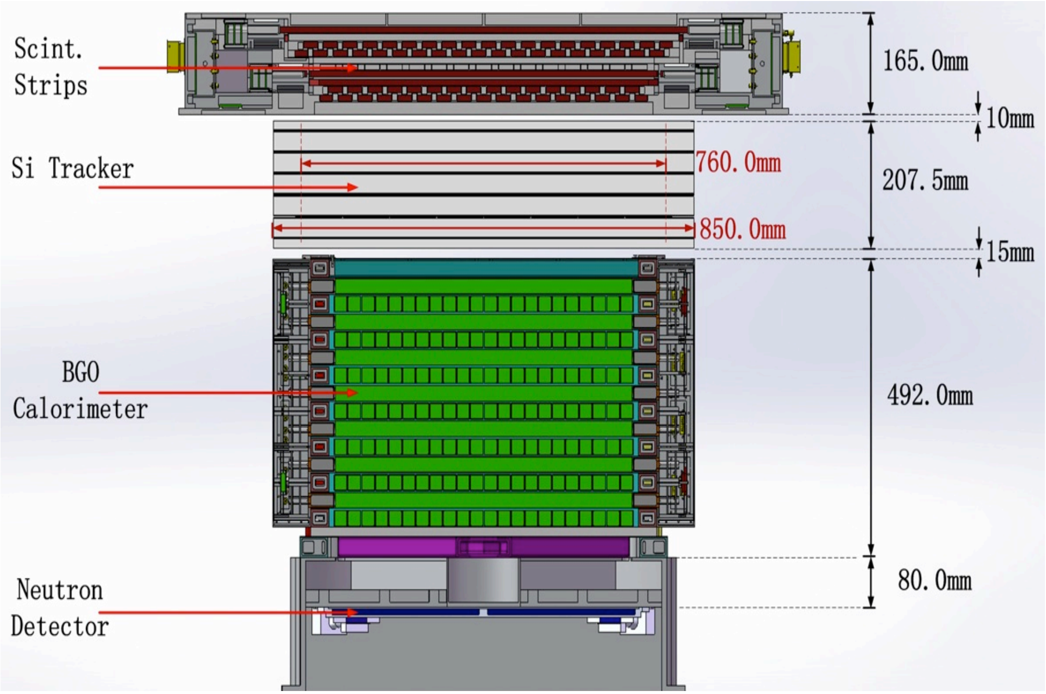
CALO - Thickness ~ 32 X_0
- Energy measurement using two dynodes
  5 GeV – 10 TeV for electrons and γ
  50 GeV – 200 TeV for nuclei
- Charge measurement for MIPs

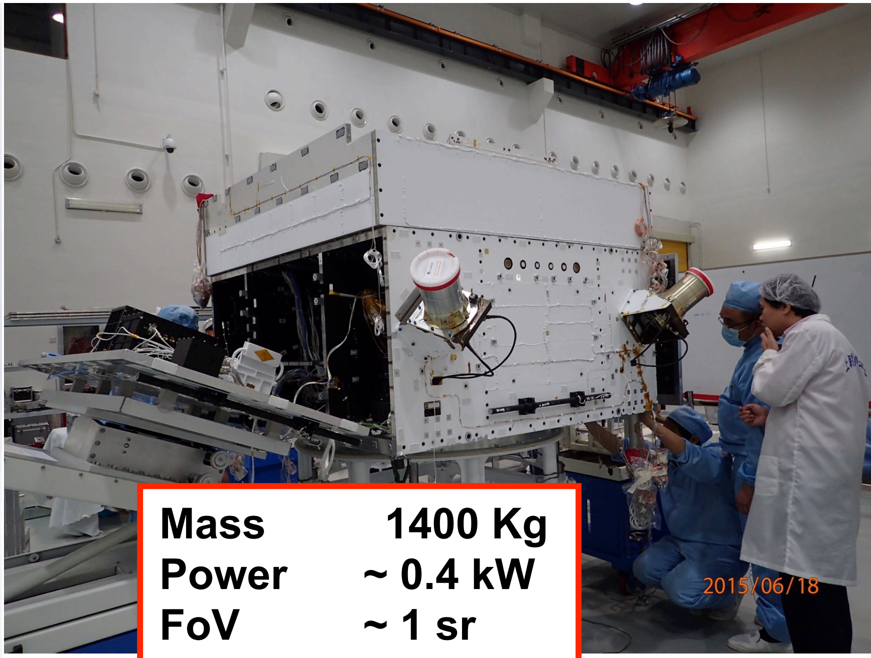
NUD - Hadron rejection looking for delayed (~2 μs) coincidence of neutrons



Comparison with other detectors

	DAMPE	AMS-02	Fermi LAT
e/γ energy res.@100 GeV (%)	**1.5**	3	10
e/γ angular res.@100 GeV (°)	**0.1**	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^2 sr)	**0.29**	0.09	1

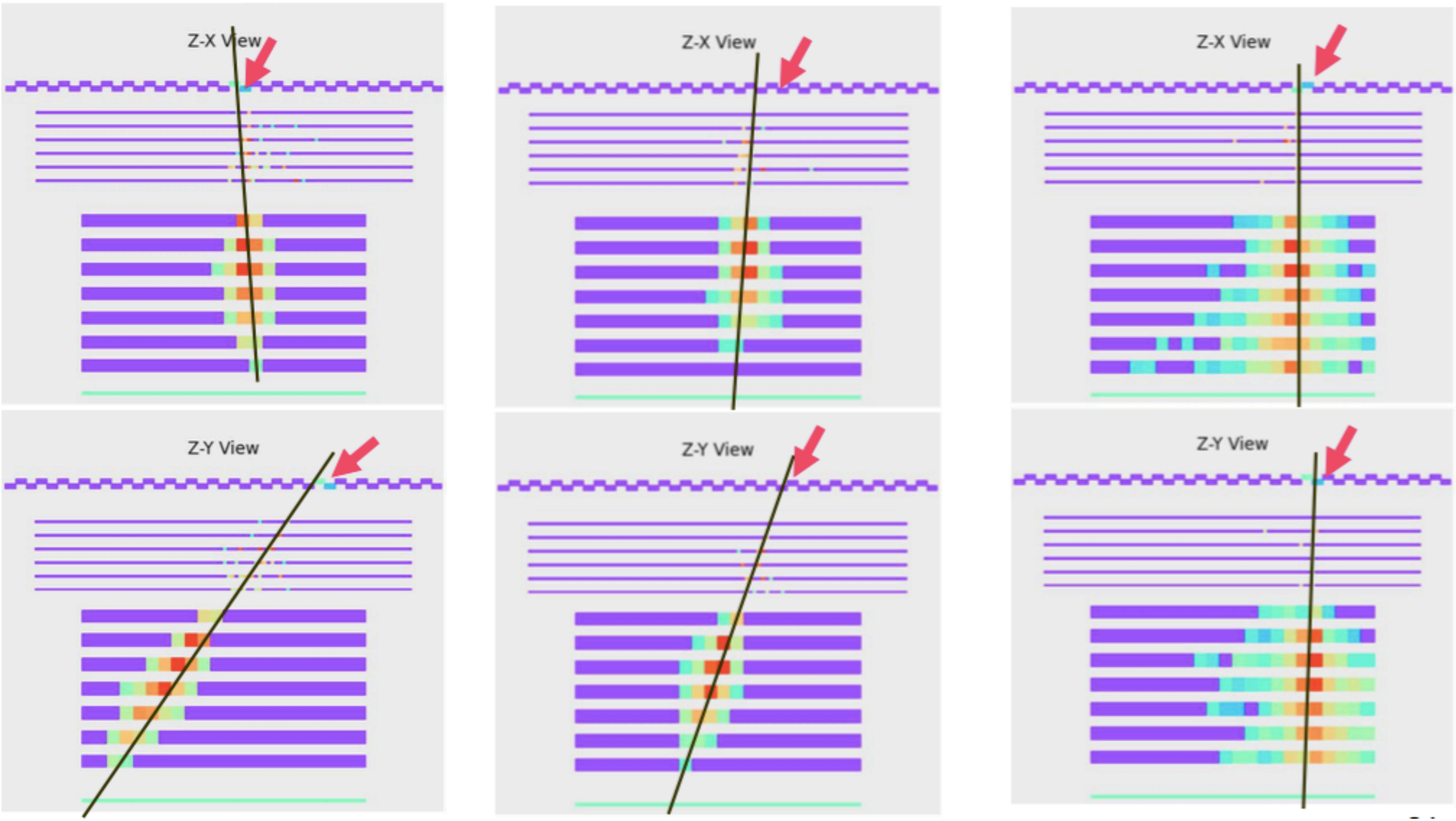




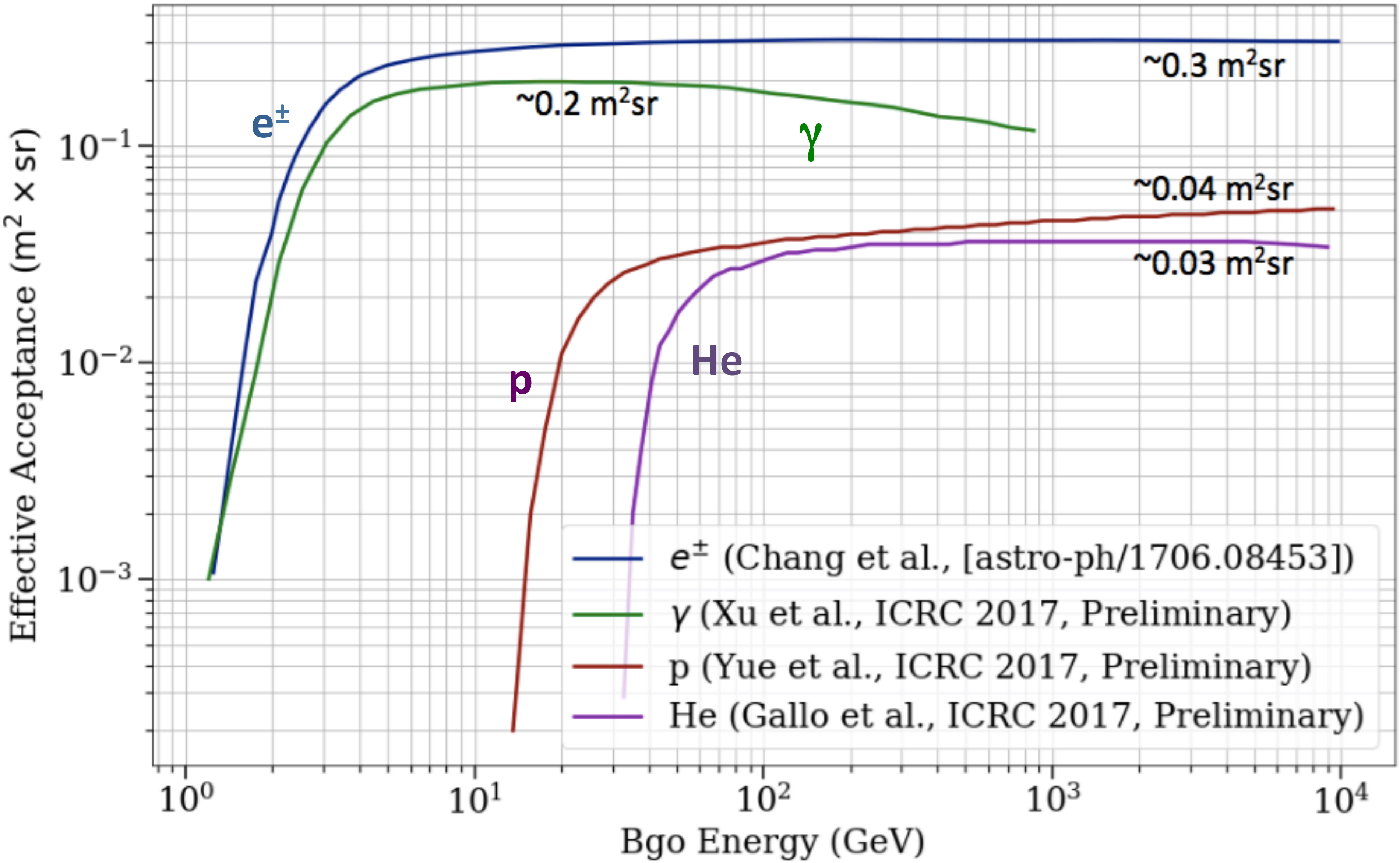
Mass	**1400 Kg**
Power	**~ 0.4 kW**
FoV	**~ 1 sr**
Livetime	**> 3 years**

Topology of different events in DAMPE

Electron (e.m. shower) — **Gamma-ray (no PSD signal, e.m. shower)** — **Proton (hadronic shower)**



Estimate of the acceptances



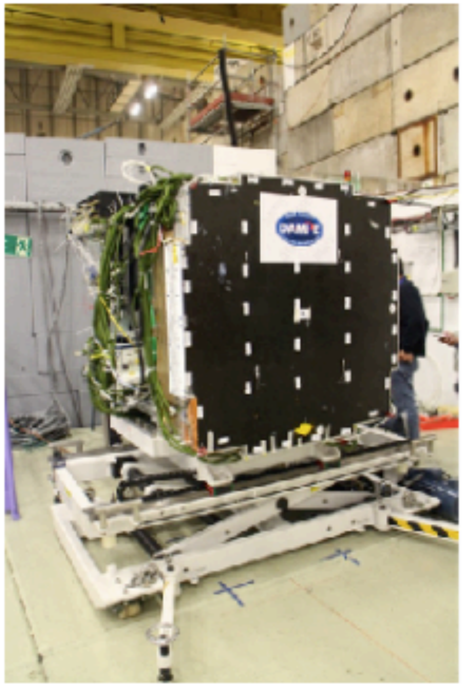
Beam test at CERN

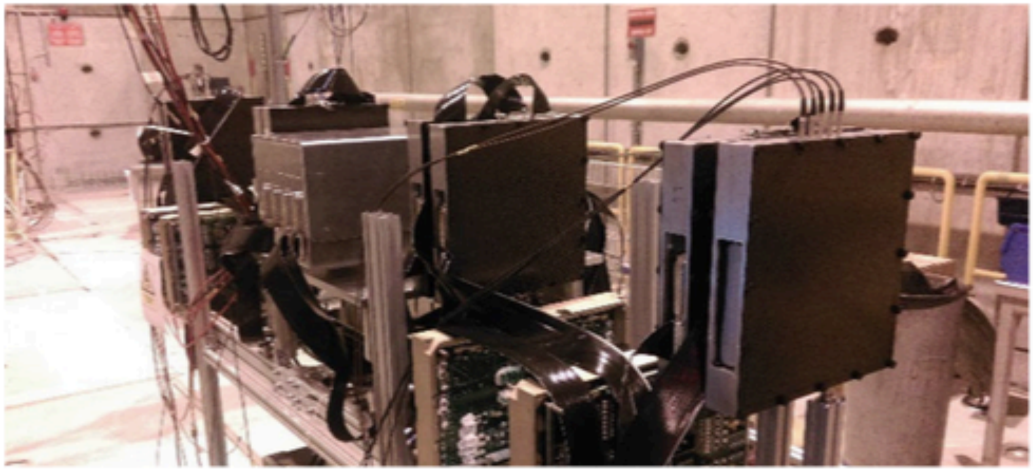
2014 - PS & SPS

- electrons
- protons
- pions
- gamma
- muons

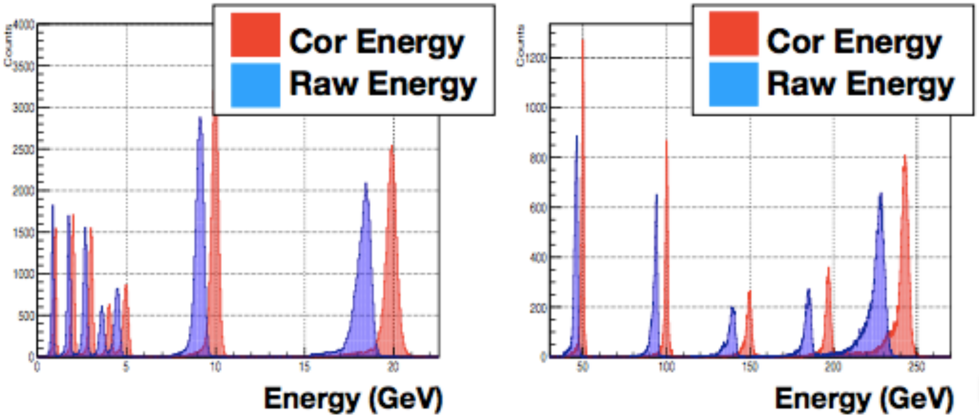
2015 - SPS

- argon (and fragments)
- lead (and fragments)
- electrons
- protons
- pions
- gamma
- muons

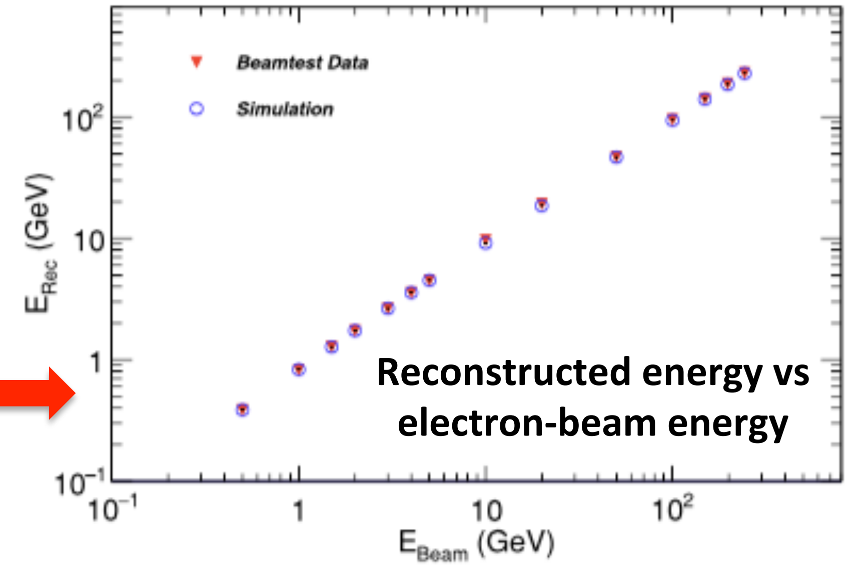




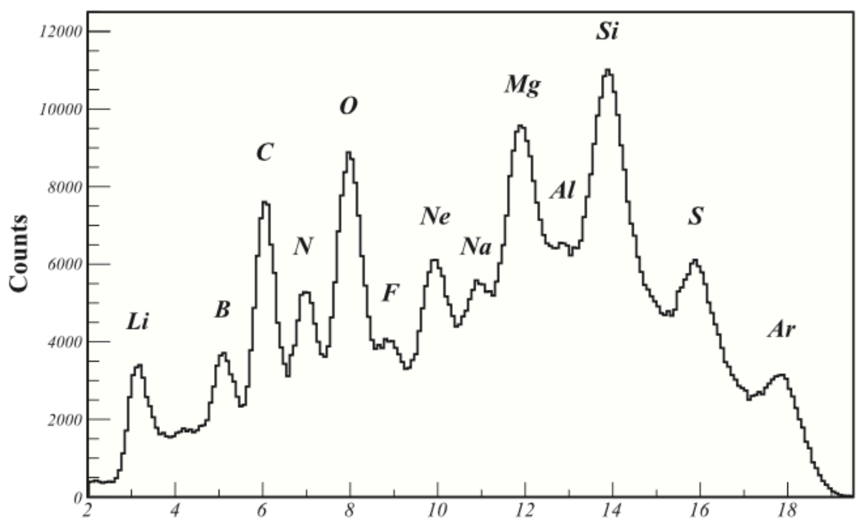
Some results of the beam test



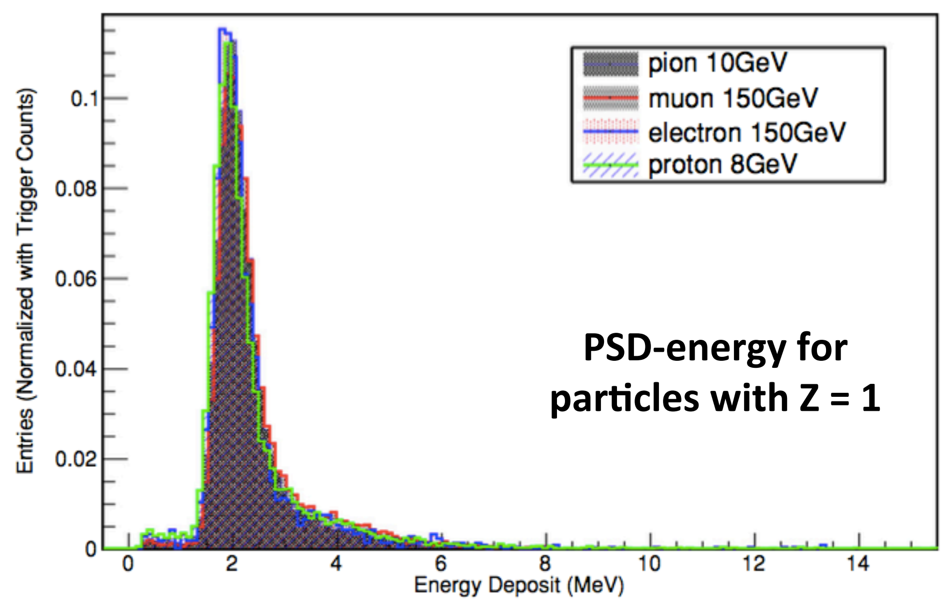
Electron BGO-energy before and after correction (resolution 0.8% for 100-GeV electrons)



Reconstructed energy vs electron-beam energy

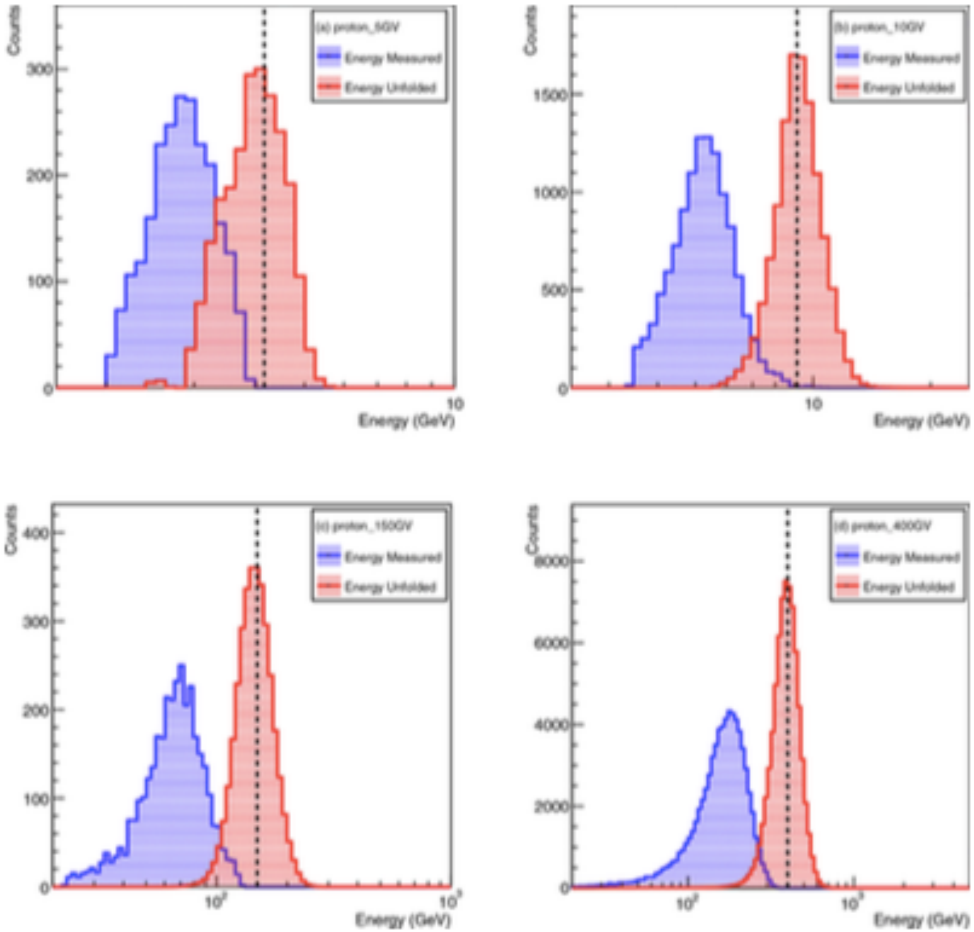


Ar-beam on PSD: Charge spectrum of fragments (Helium peak removed)

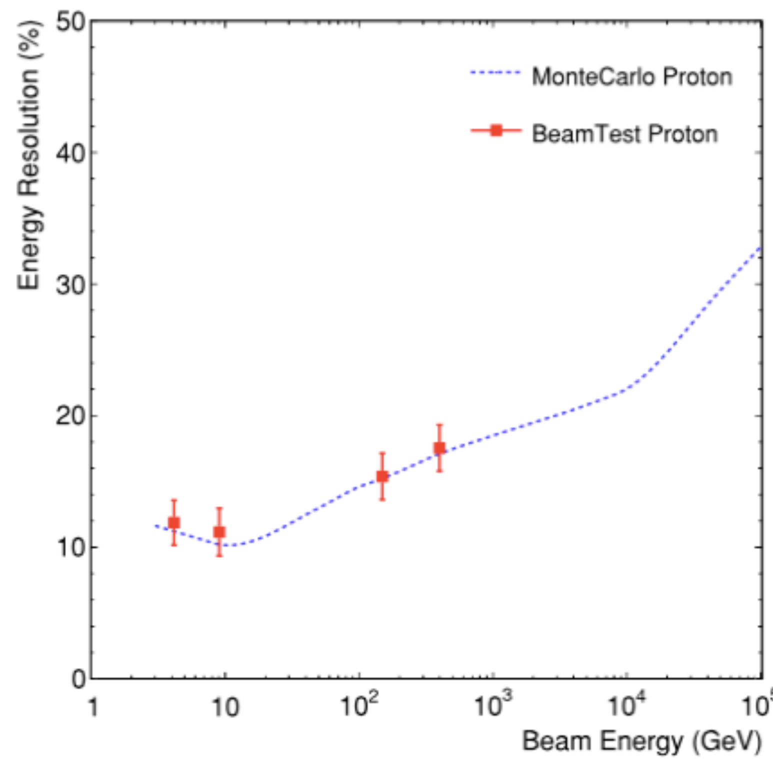


PSD-energy for particles with Z = 1

Other results of the beam test



BGO-deposited energy (blue) and unfolded ones (red) for different proton beams (5, 10, 150, 400 GeV/c)



Energy resolution for protons (simulation and beam-test data)

The launch: Dec 17th 2015, 0:12 UTC

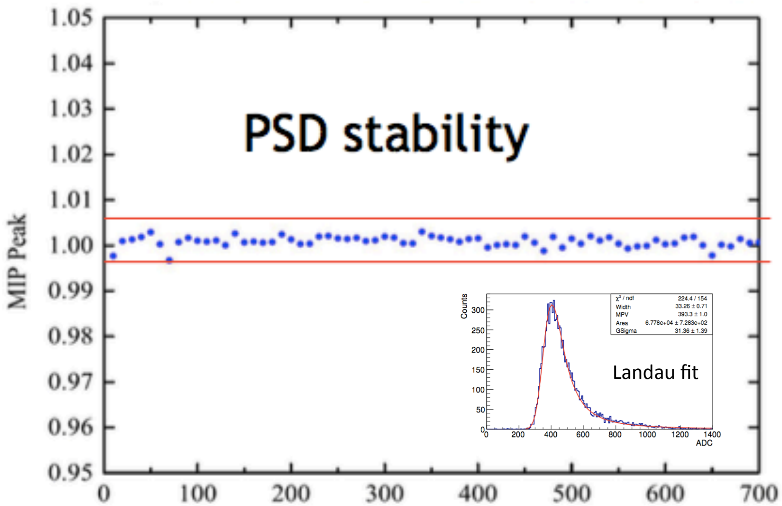
Jiuquan Satellite Launch Center
Gobi desert, China

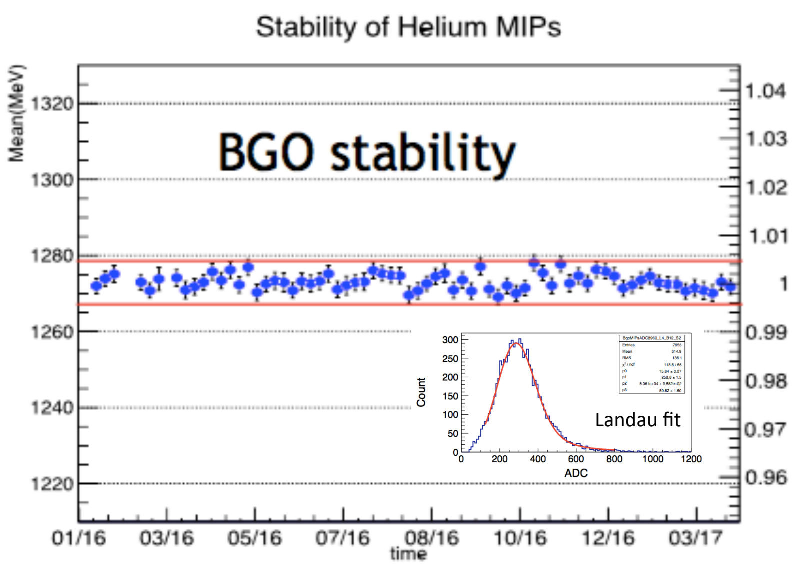
Orbit: Sun-syncronous
Altitude: 500 km
Period: 1.5 hours

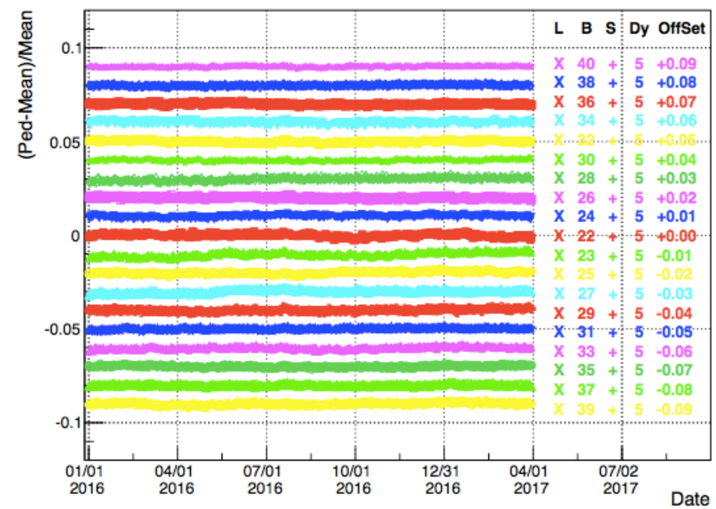
Dec 24th, 2015: HV on

On-orbit performances

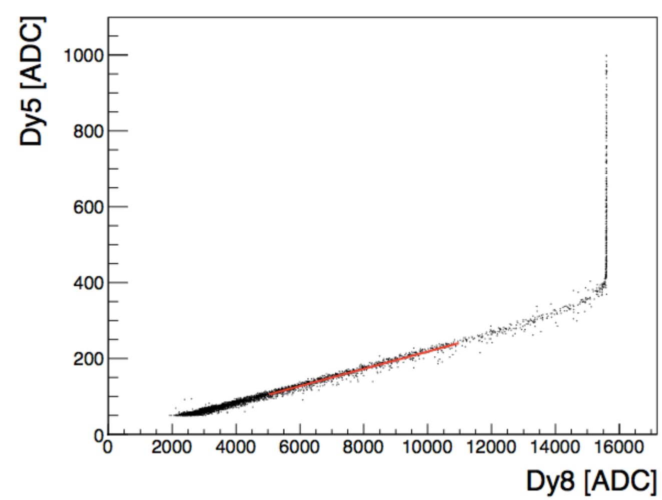
Average trigger rate: ~ 50 Hz
100 GB/day on ground (about 5 M events)







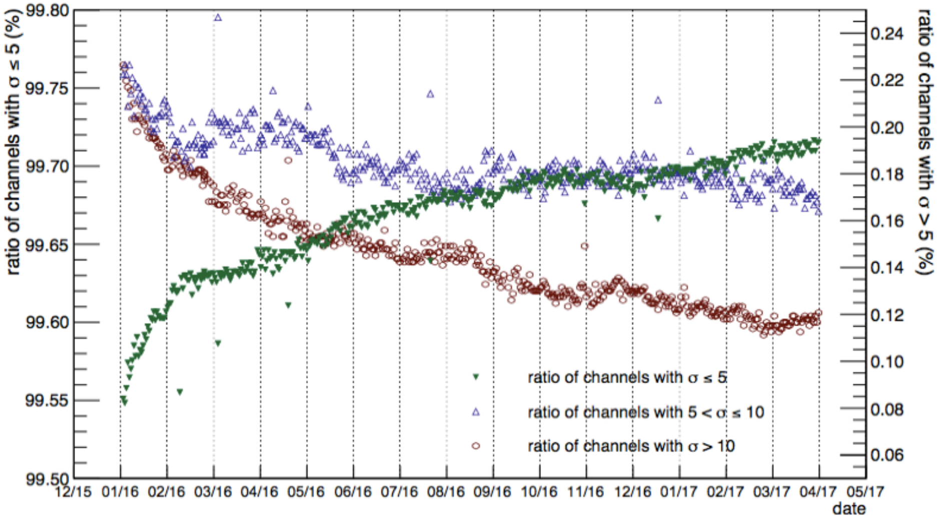
PSD-pedestals are very stable

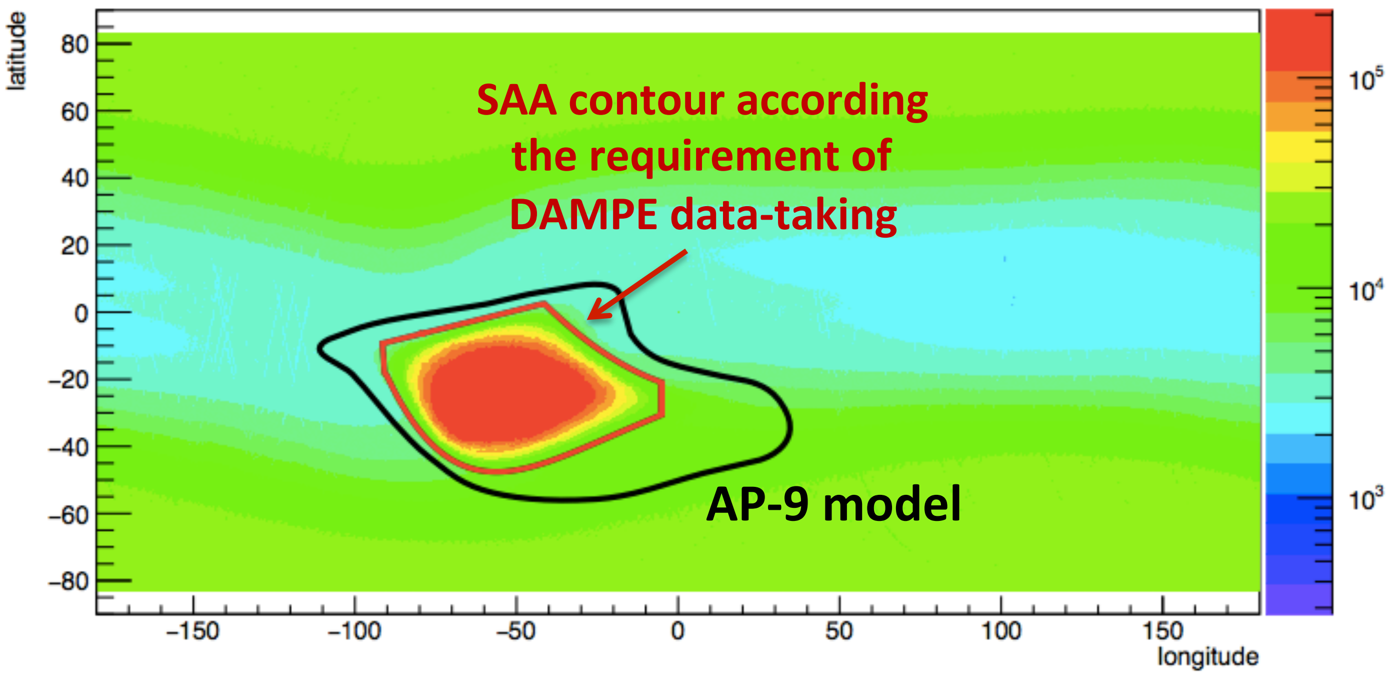


Two dynodes to cover a wide range

On-orbit performances

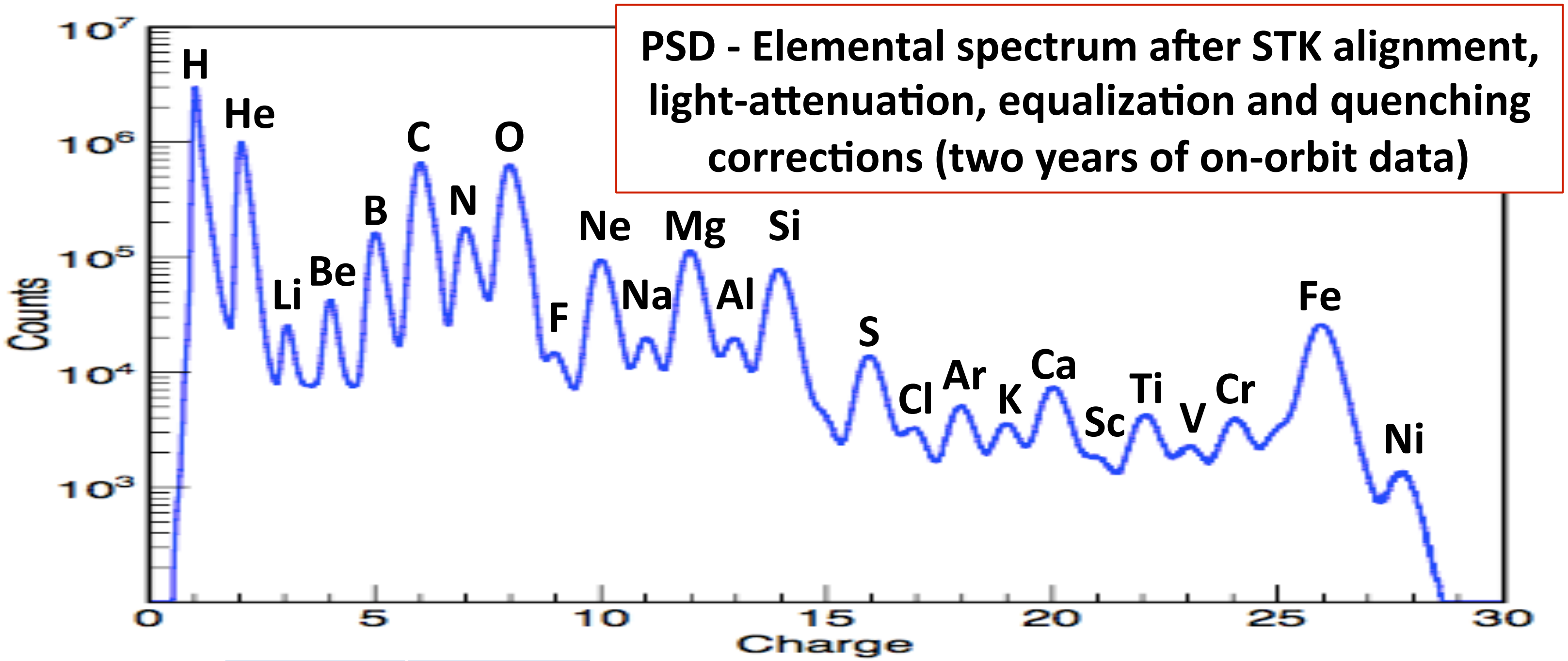
The percentage of noisy STK-channels is very low (< 0.5 %) and decreases with time





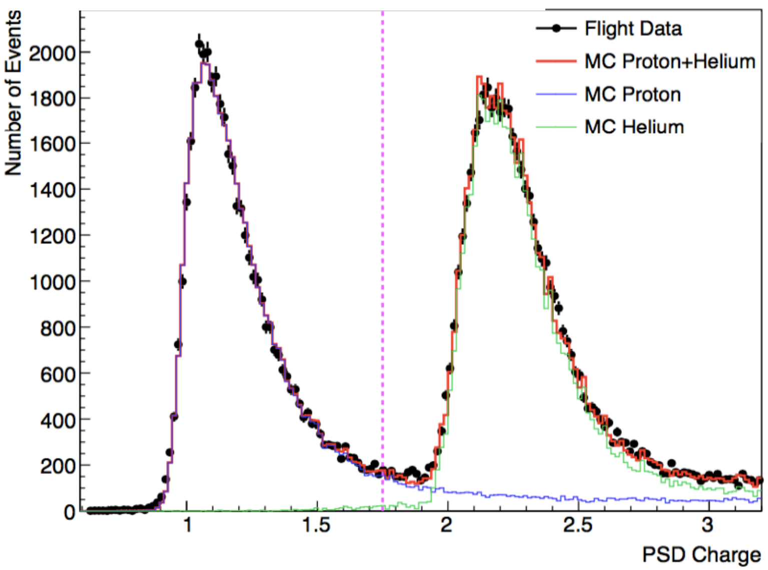
South Atlantic Anomaly (SAA)

Nuclei (Z=1-26 and more)



Element	σ_Z
p	0.07
He	0.12
Li	0.14
Be	0.21
B	0.17
C	0.18
N	0.21
O	0.21

Template fit for protons and Helium



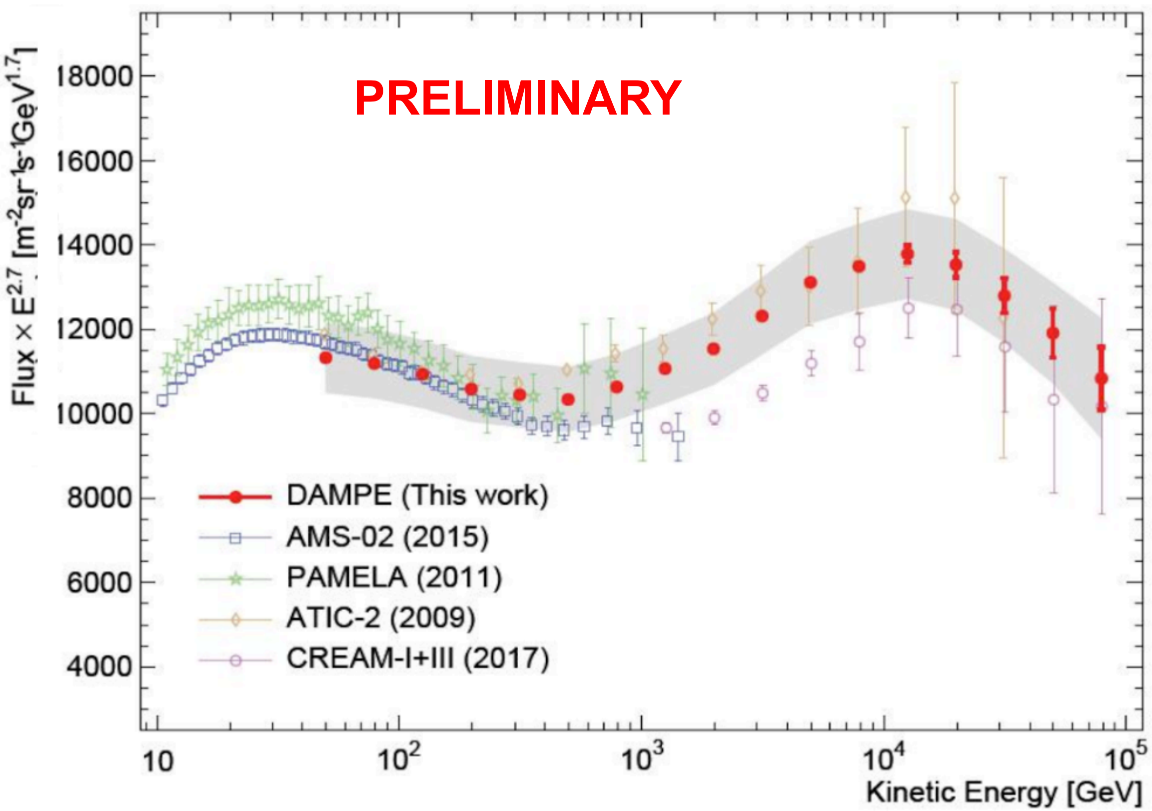
Proton flux

The gray band represents
the systematic uncertainties

2 years of data
(2016 + 2017)

Spectral hardening
at ~200 GeV

Exponential cutoff
at ~80 TeV



See talk by A. De Benedittis
September 5, RICAP ID = 124

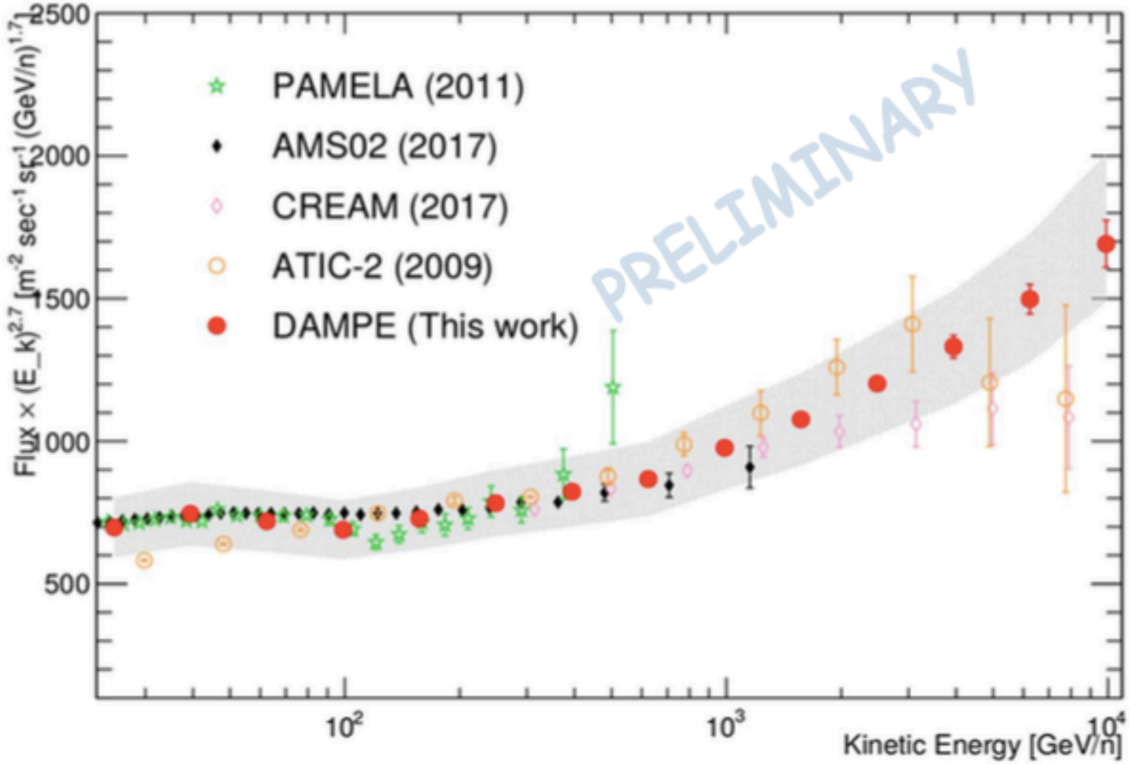
Helium flux

2 years of data (2016 + 2017)

Spectral hardening at ~100 GeV/nucleon

Systematics due to energy and interaction model to be estimated

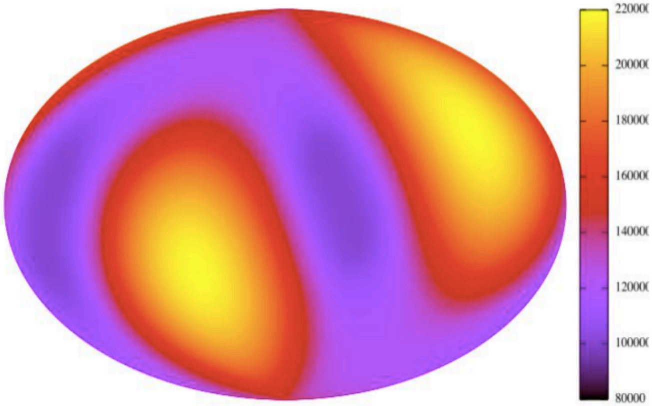
Measurement will be extended up to 50 TeV/nucleon



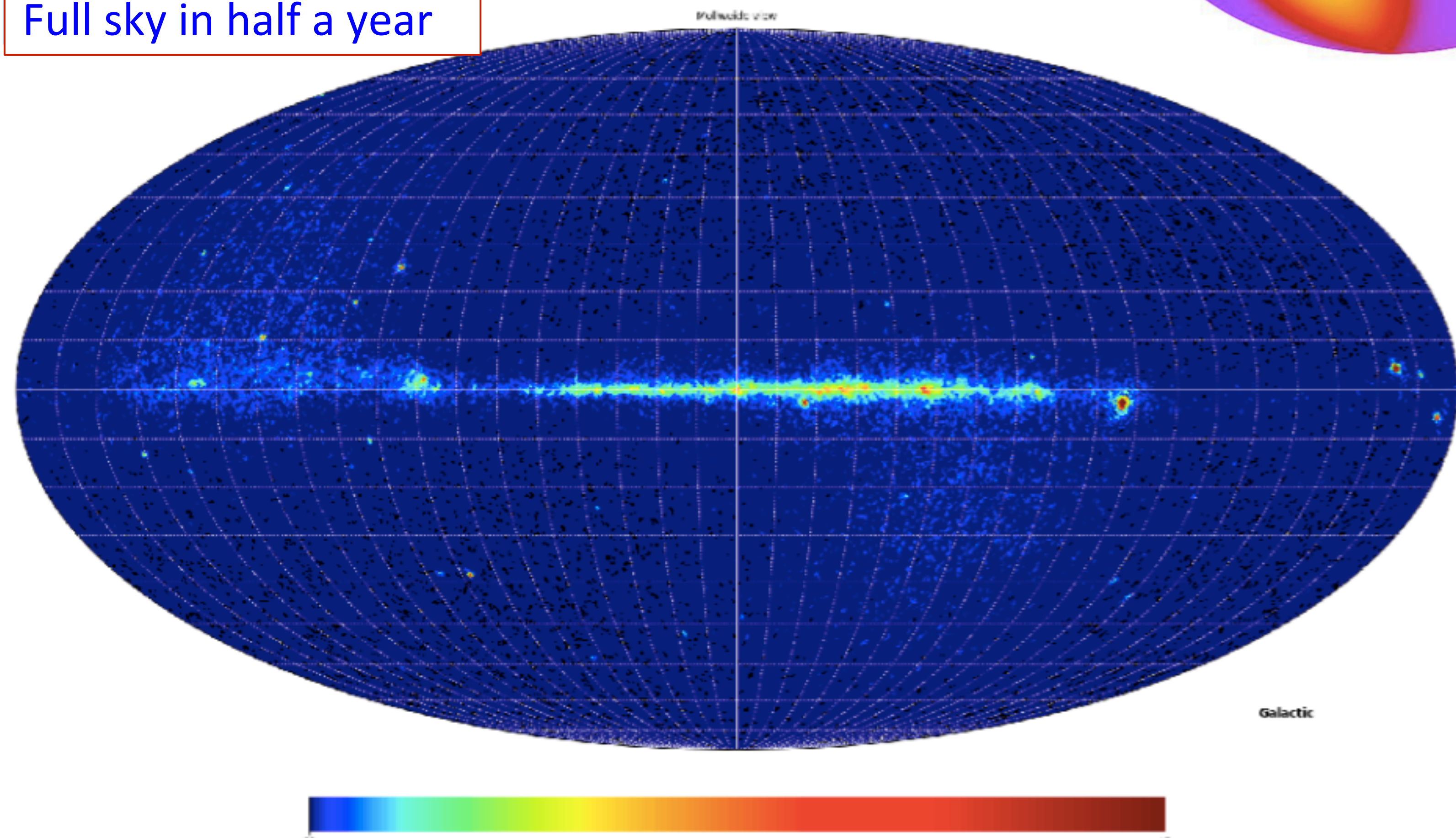
See talk by M. Di Santo
September 5, RICAP ID = 123

Gamma sky

2-years exposure map (galactic coor.s)



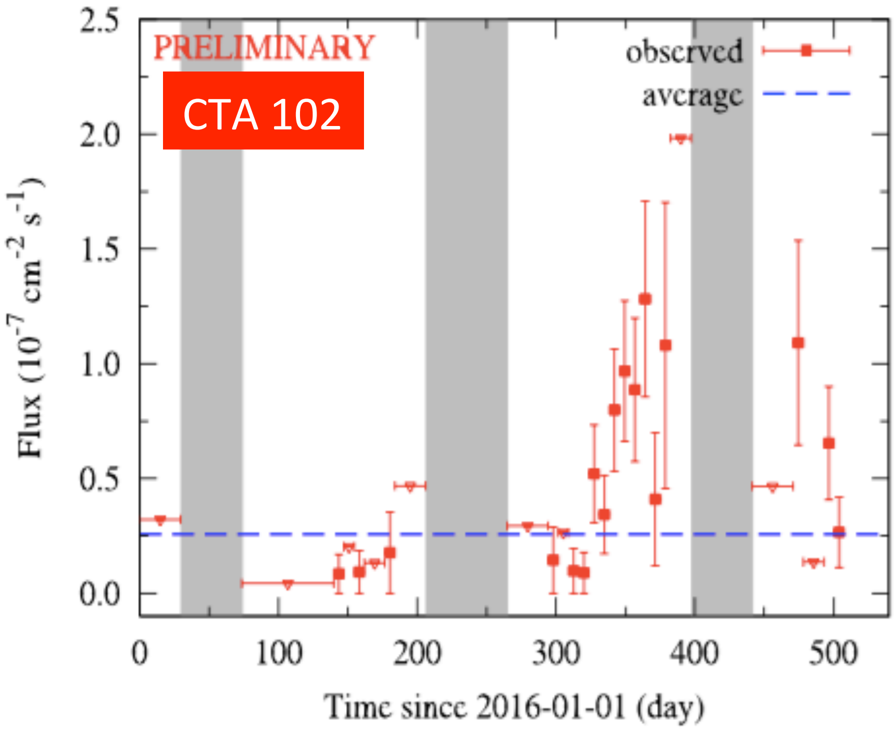
$\sigma_\theta \approx 0.2°$ @ 30 GeV
Full sky in half a year



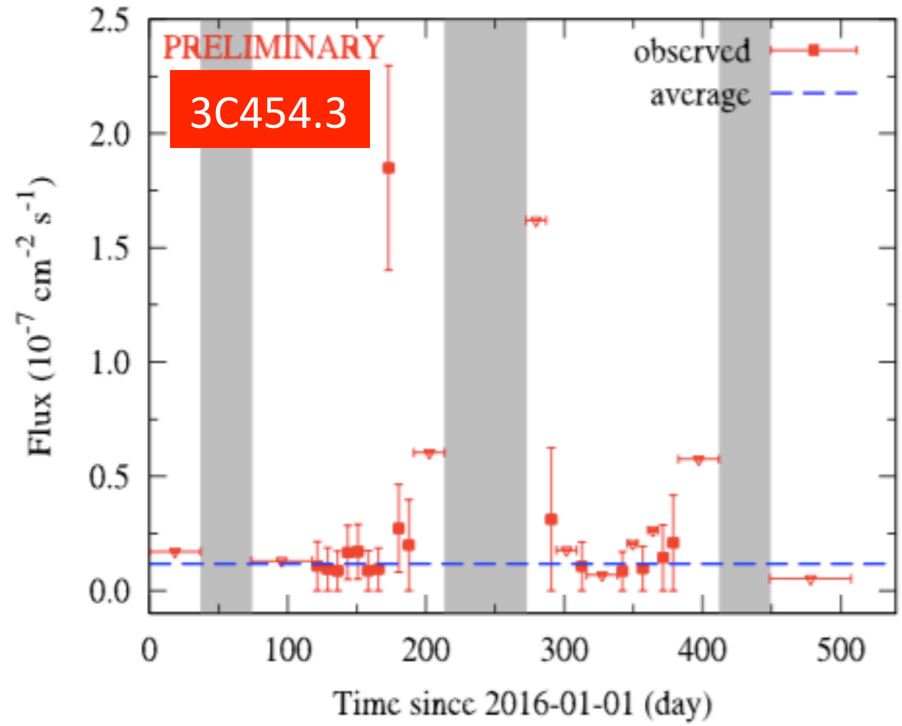
Variable Gamma Sources

E_γ > 2 GeV

Search for variable source in bins of 3×10^{-4} sr
Weekly light curve for each angular bin



Flare in November-December 2016



Flare in June 2016

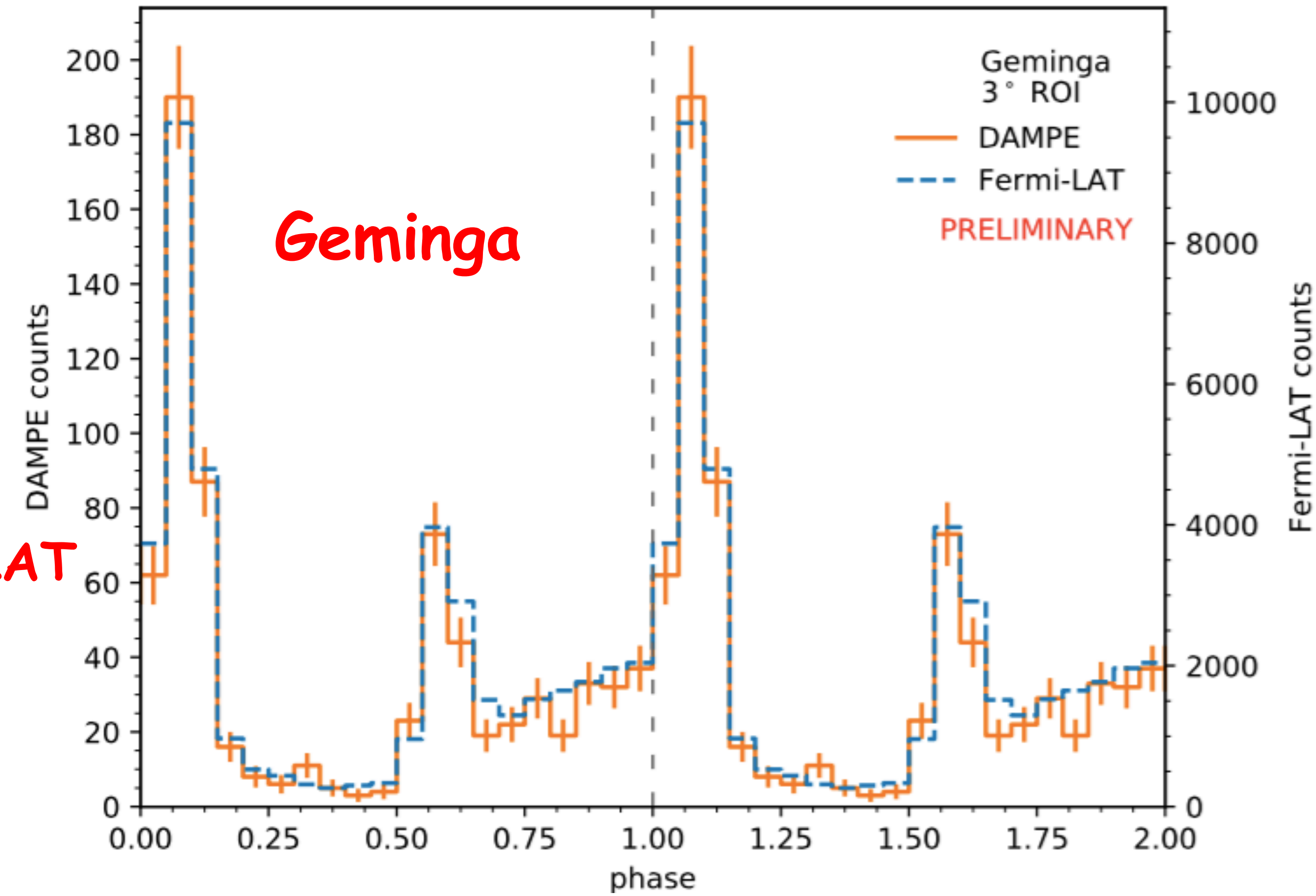
Results consistent with other observations (Agile, Fermi-LAT)

Pulsar periodicity

$1 < E_\gamma < 50$ GeV

RoI 3°

Agreement with Egret and Fermi-LAT results

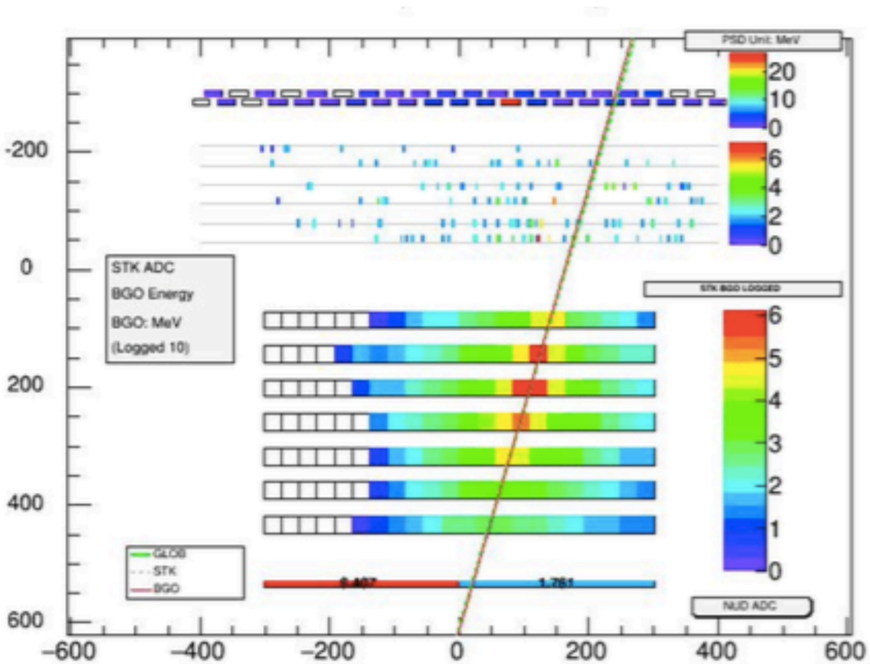


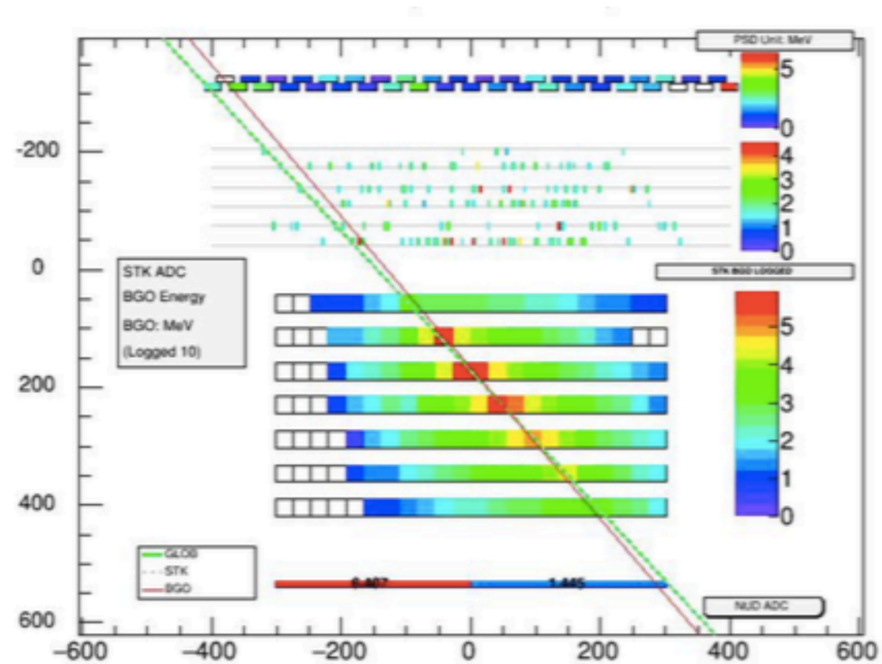
Detected periodical signal from other pulsars (Vela, PSR J0007+7303 …)

Electron+positron identification

Selected events with $Z_{PSD} = 1$

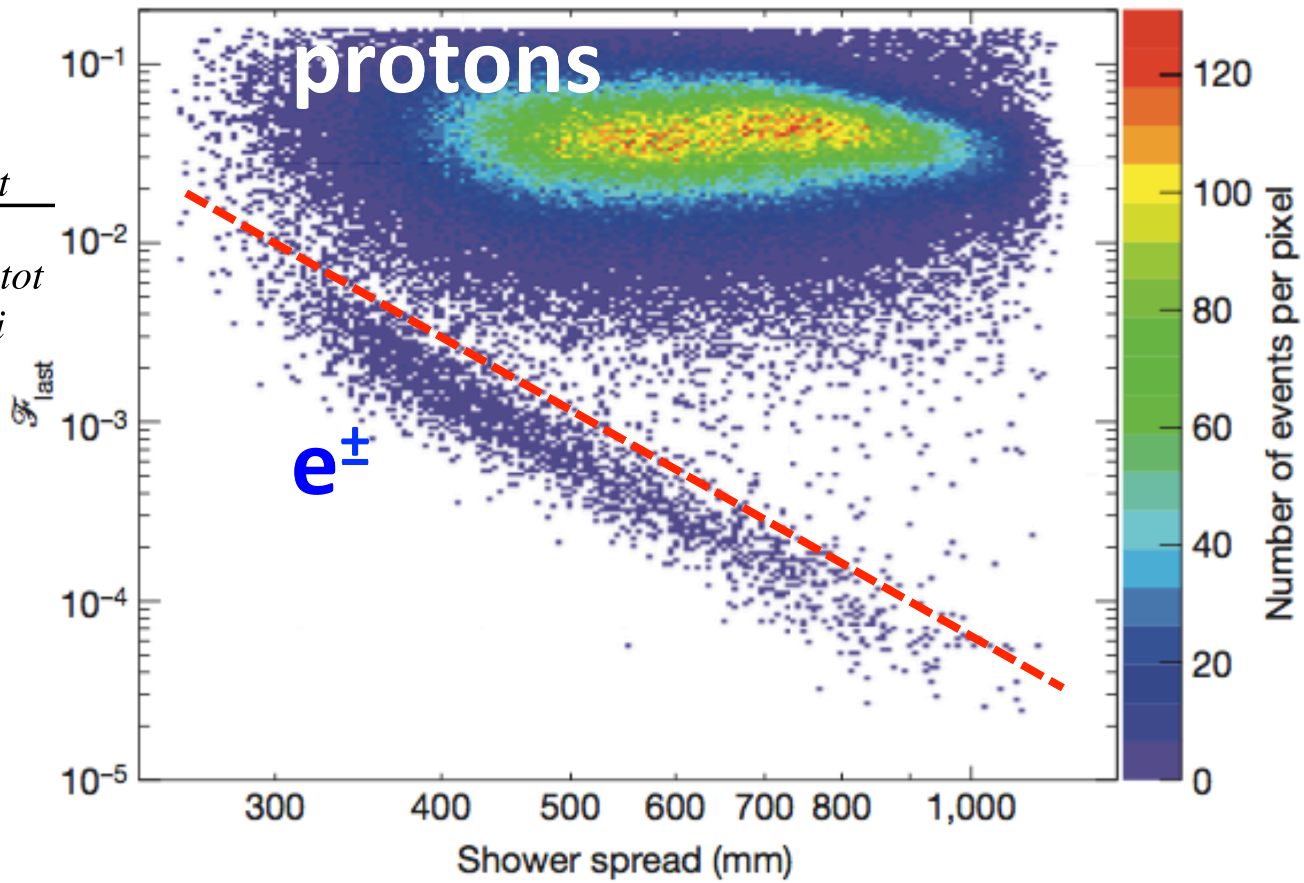
Exploiting the imaging CALO-features





BGO imaging to separate electrons and hadrons

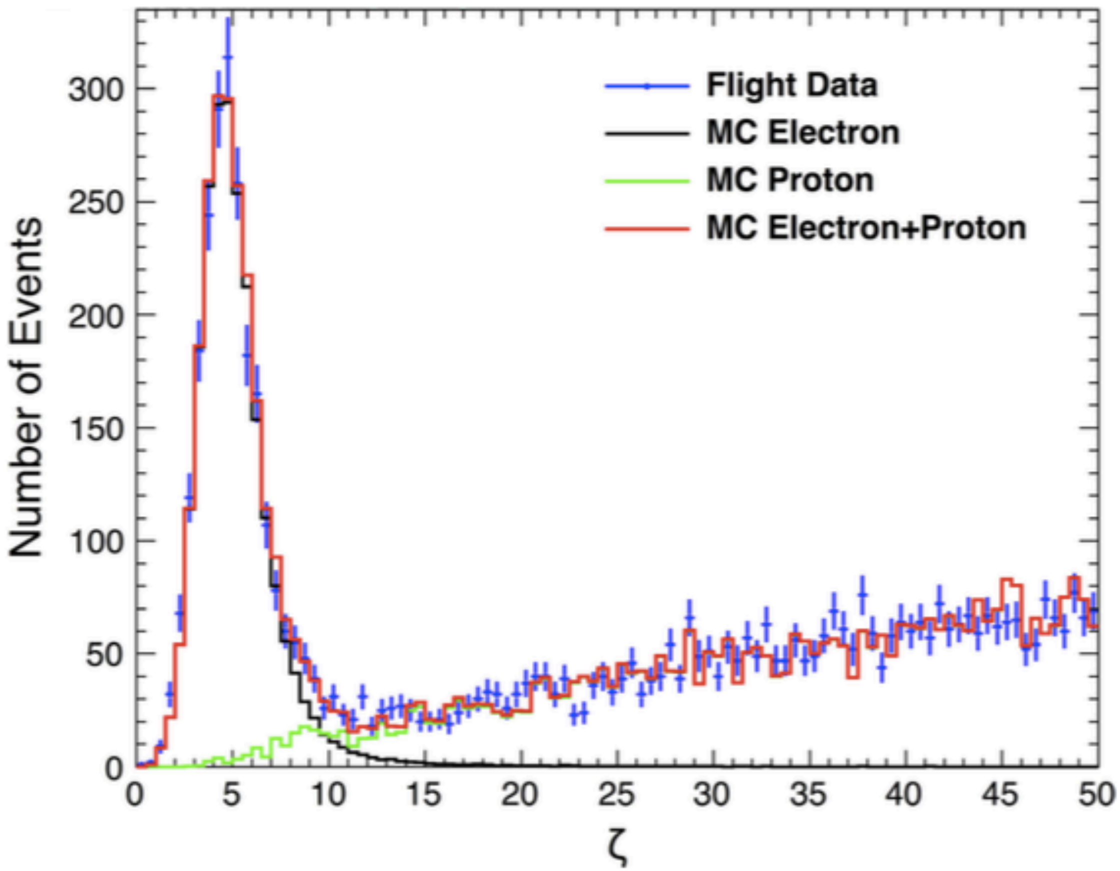
$$F_{last} = \frac{E_{last}^{tot}}{\sum_{i=1}^{14} E_i^{tot}}$$



$$spread = \sum_{i=1}^{14} RMS_i = \sum_{i=1}^{14} \sqrt{\frac{\sum (x_{ij} - x_{iC})^2 E_{ij}}{E_i^{tot}}}$$

nature
International journal of science
552 (2017)63-66

BGO imaging to separate electrons and hadrons



Electron and positron selection

Estimate of proton pollution

$$\varsigma = F_{last} \frac{(spread / mm)^4}{8 \times 10^6} < 8.5$$

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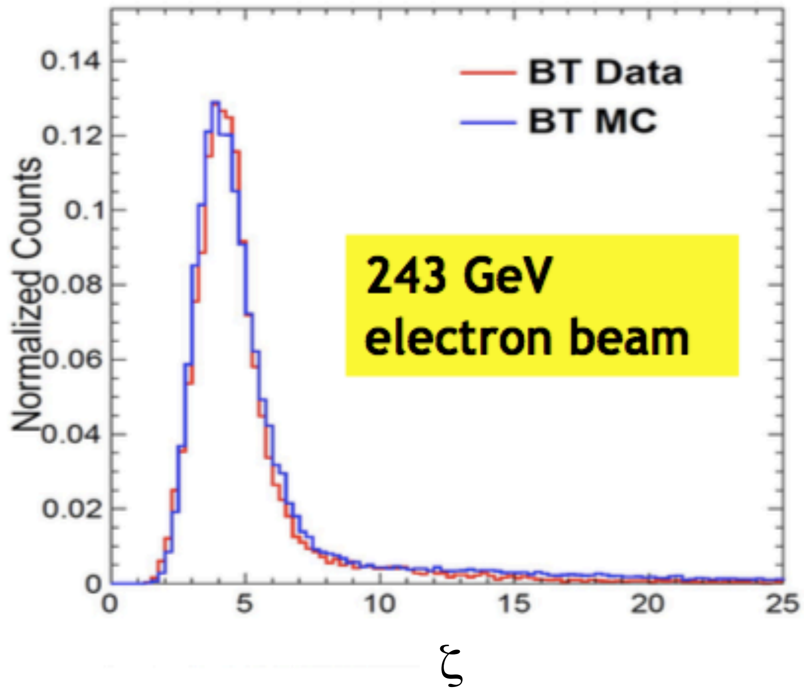
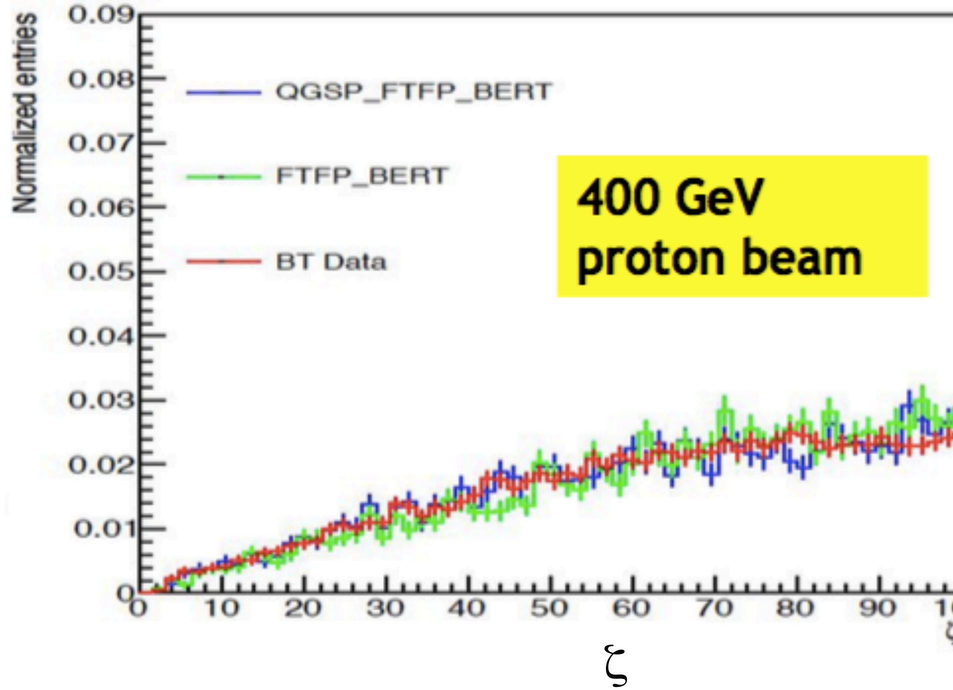
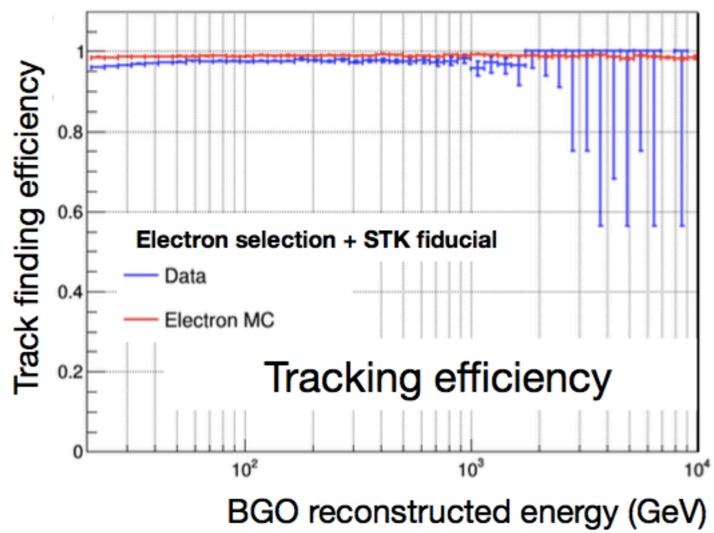
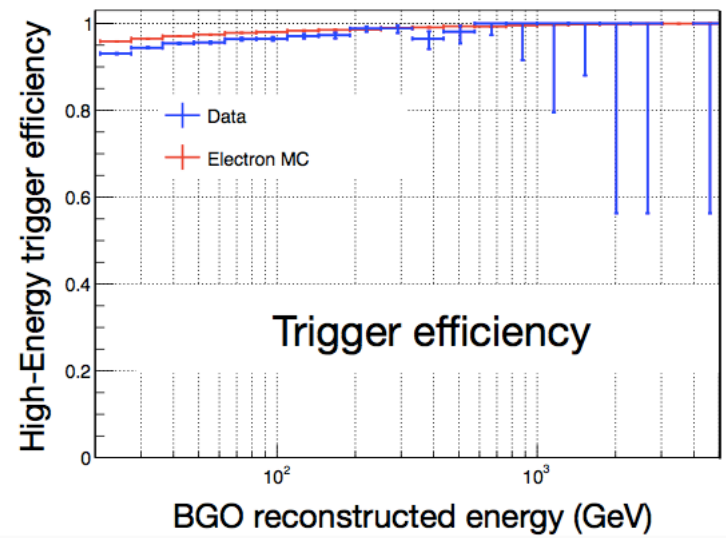
Validation of parameter ζ with beam-test data



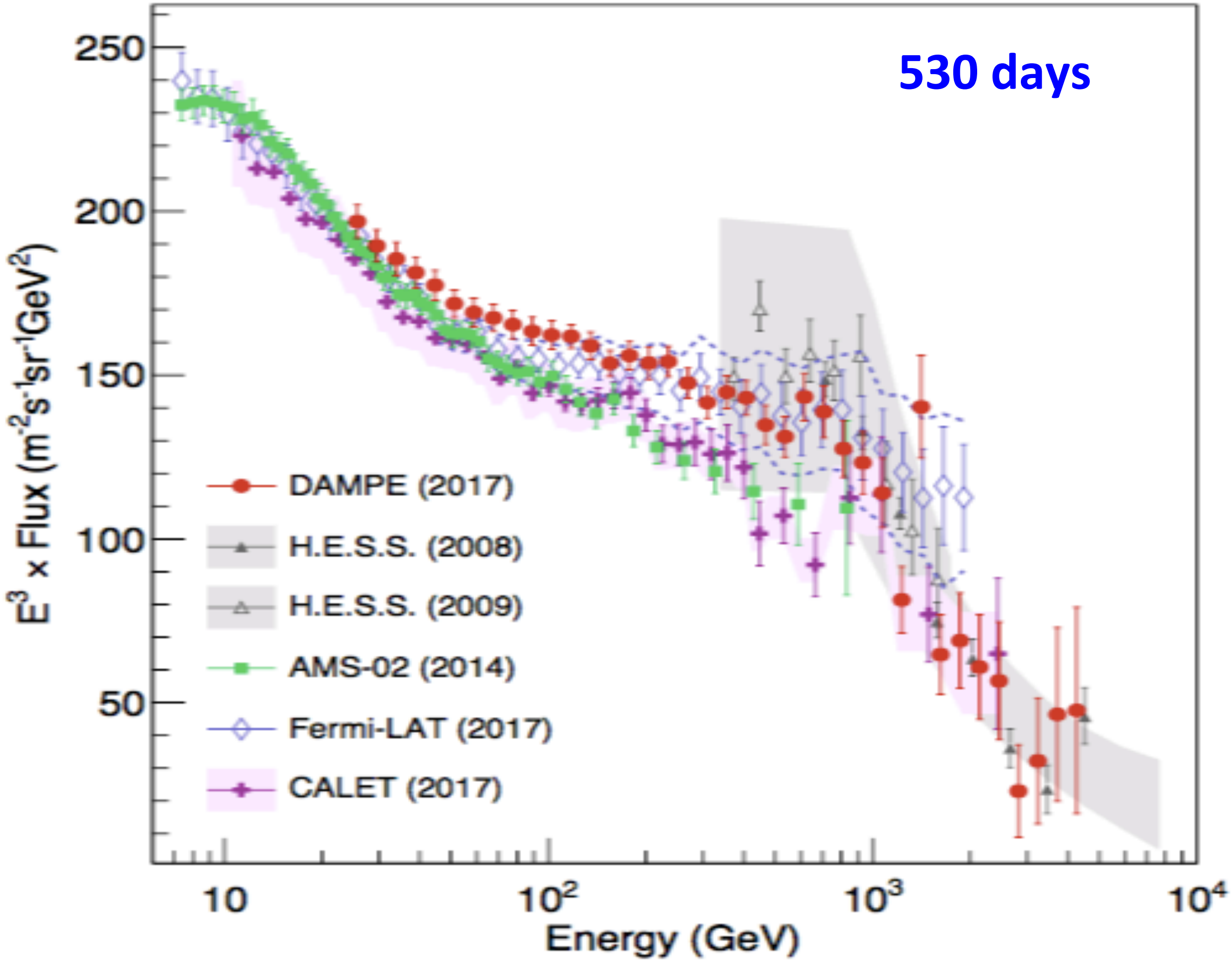


Tracking and trigger efficiencies agree with simulation





Electron+positron spectrum



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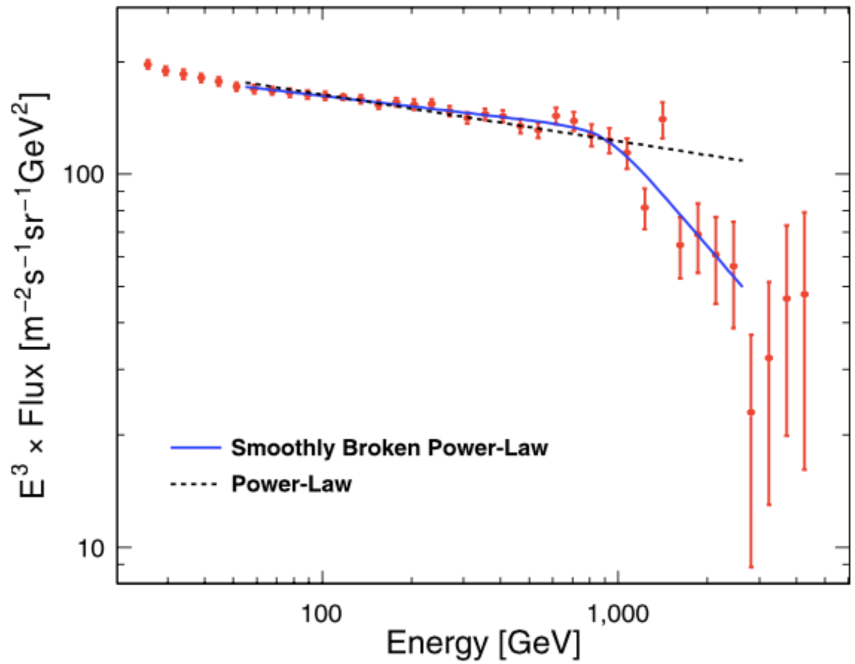
Energy range:
25 GeV – 4.6 TeV

Energy resolution <1.2%
for E>100 GeV

Uncertainties mainly due to the statistics at high energy
Significant improvements are expected with more data-taking
(edge-like feature as a signal of dark-matter or nearby pulsars ?)

Electron+positron spectrum



Smootly Broken Power-Law is favorite

$$\Phi = \Phi_0 \left(E / 100\ GeV \right)^{-\gamma_1} \left[1 + \left(E / E_B \right)^{-(\gamma_1 - \gamma_2)/\Delta} \right]^{-\Delta}$$

$\Delta = 0.1$
$\gamma_1 = 3.09 \pm 0.01$
$\gamma_2 = 3.92 \pm 0.20$
$E_B = (914 \pm 98)$ GeV

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Summary

DAMPE detector works extremely well since its launch more than 2.5 years ago.

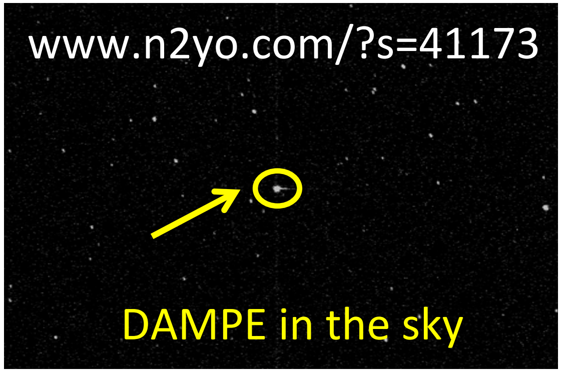
We expect DAMPE will "live" for a period longer than 3 years (third DAMPE birthday : December 17, 2018)

Nuclei analyses are going on successfully.
Proton and helium spectra coming soon.

Photon detection capability is confirmed. More statistics shall allow to exploit the excellent energy resolution at high energy.

Positron+electron flux has been measured with high precision and low background in TeV energy range.

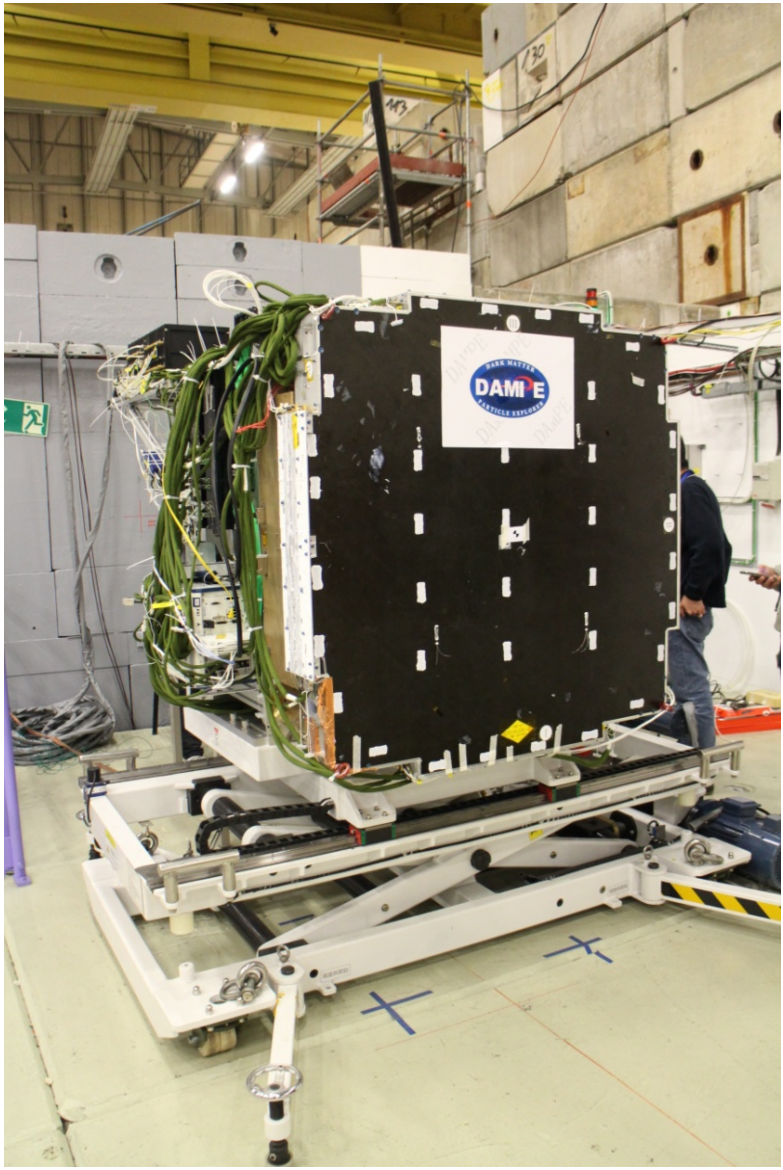
A clear spectral break has been directly detected at ~1 TeV. Dark-matter signature ? Nearby pulsar ? Other ? New data from DAMPE can help to solve the puzzle.



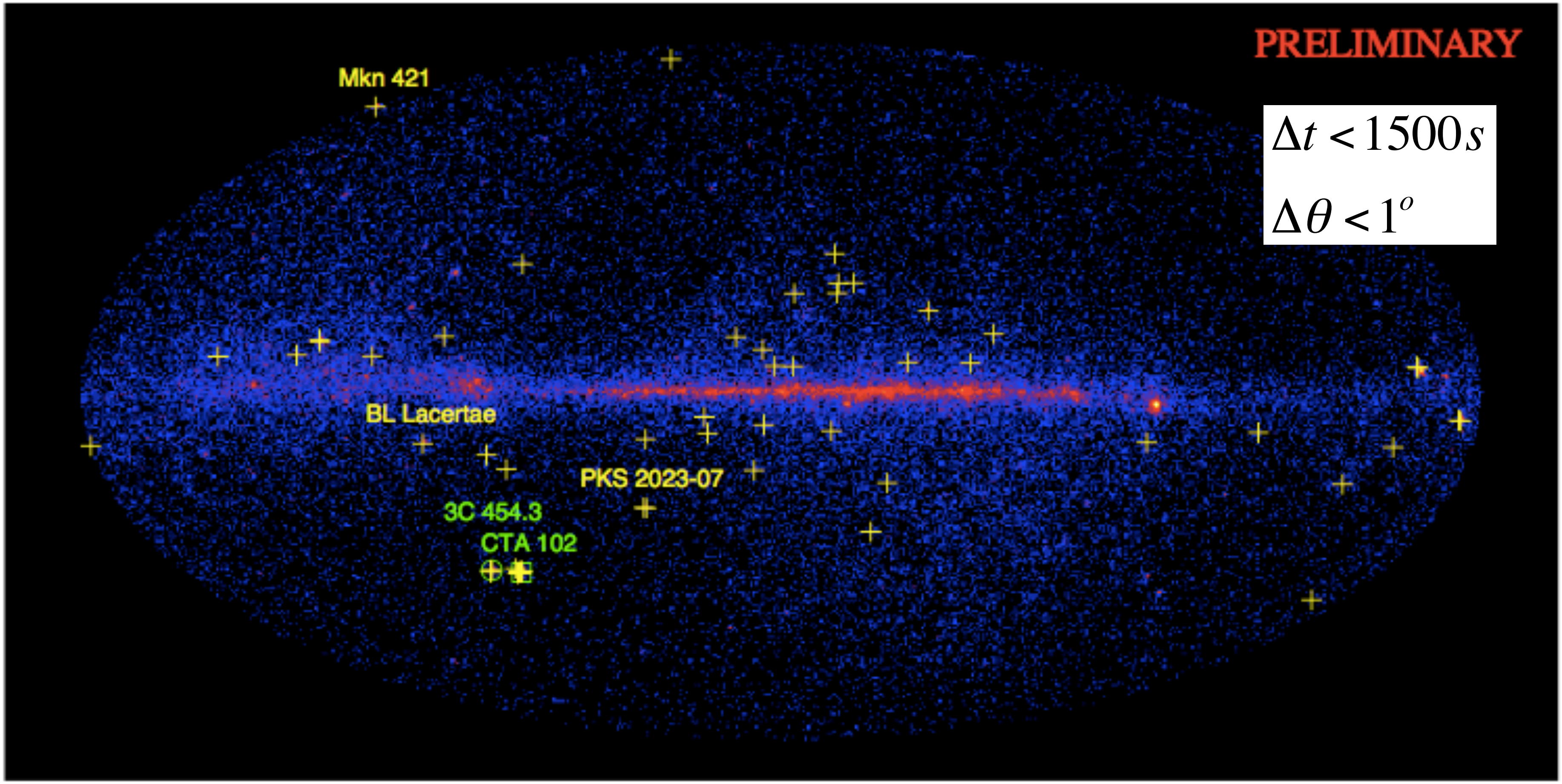
Backup slides

Test beam at CERN

- 14 days@PS, October 29 – November 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 GeV/c
  - γ @ 0.5-3 GeV/c
- 8 days@SPS, November 12 – 19, 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, March 16 – April 1 2015
  - Argon (and fragments): 30 – 40 – 75 A GeV/c
  - Protons: 30, 40 GeV/c
- 21 days@SPS, June 10 – July 1 2015
  - p @ 400 GeV/c
  - 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, November 20-25 2015
  - Pb (and fragments): 30 A GeV/c



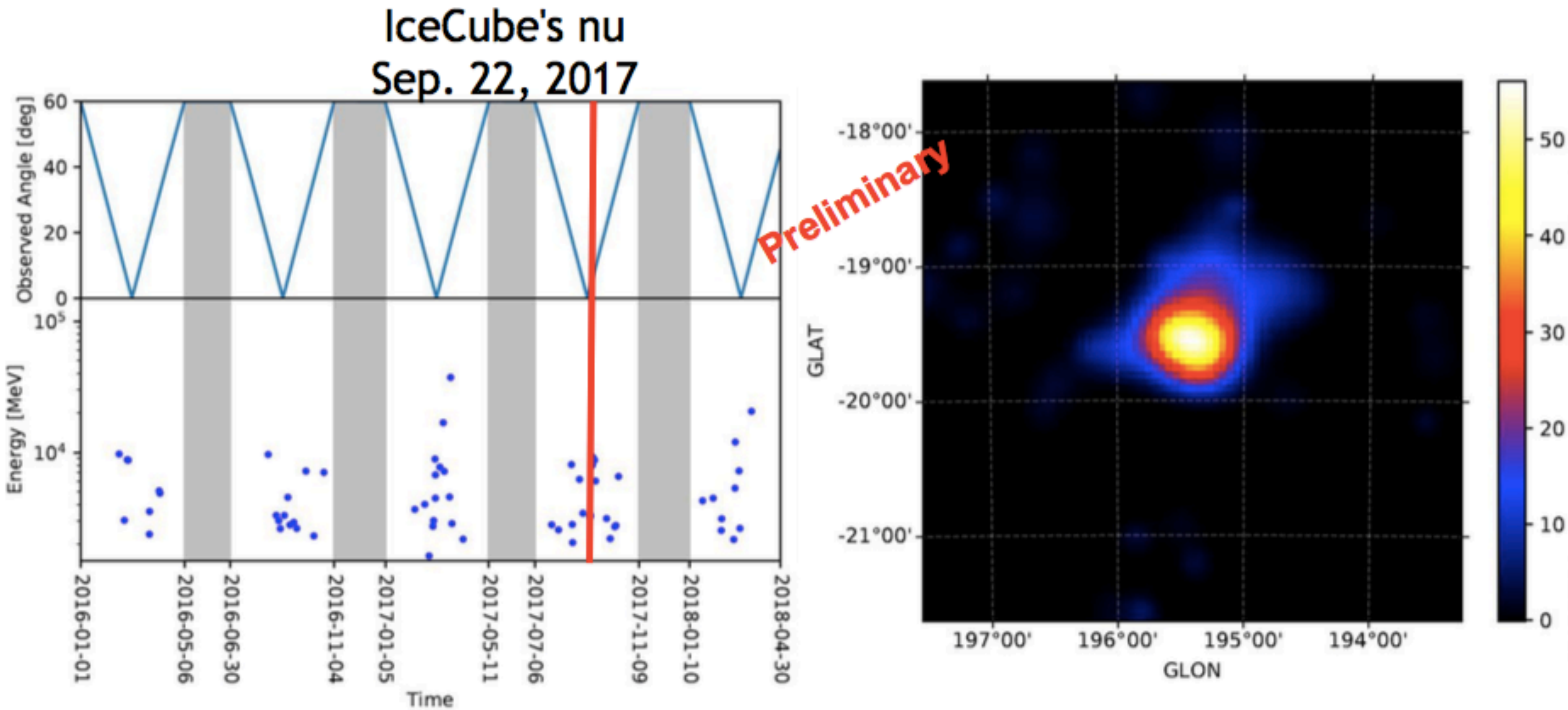
Photon clustering



$$\Delta t < 1500\,s$$
$$\Delta\theta < 1^o$$

Figure 3: Skymap of DAMPE photon counts overlaid with the coordinates of photon clusterings. Crosses are for photon pairs, the circle is for the triple, and the box is for the quadruple.

Observations of neutrino event candidate TXS 0506+056

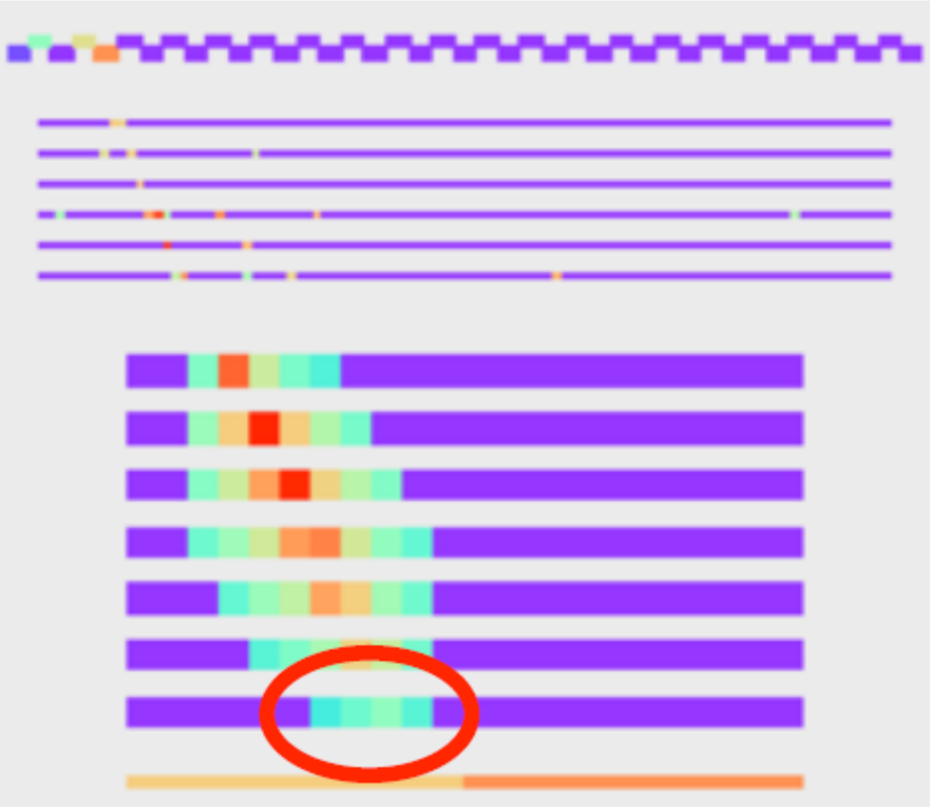


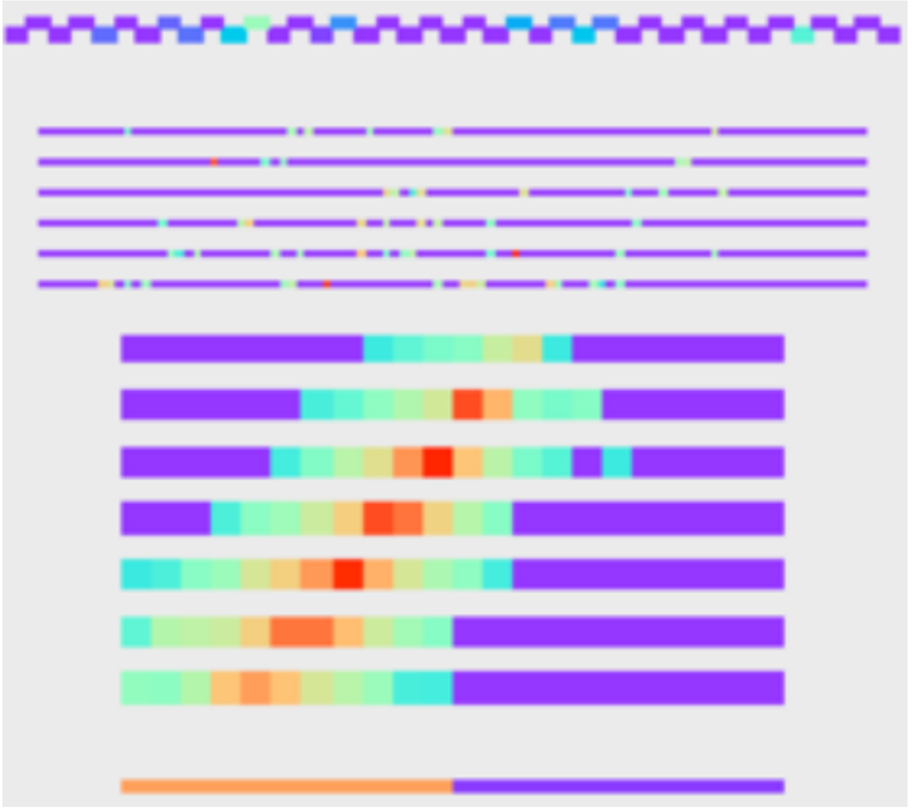
- DAMPE has detected the gamma-ray source TXS 0506+056 which is possibly associated with a neutrino event
- No clear variabilities are revealed due to limited statistics

Electron+positron identification

Selected events with $Z_{PSD} = 1$

Exploiting the imaging CALO-features

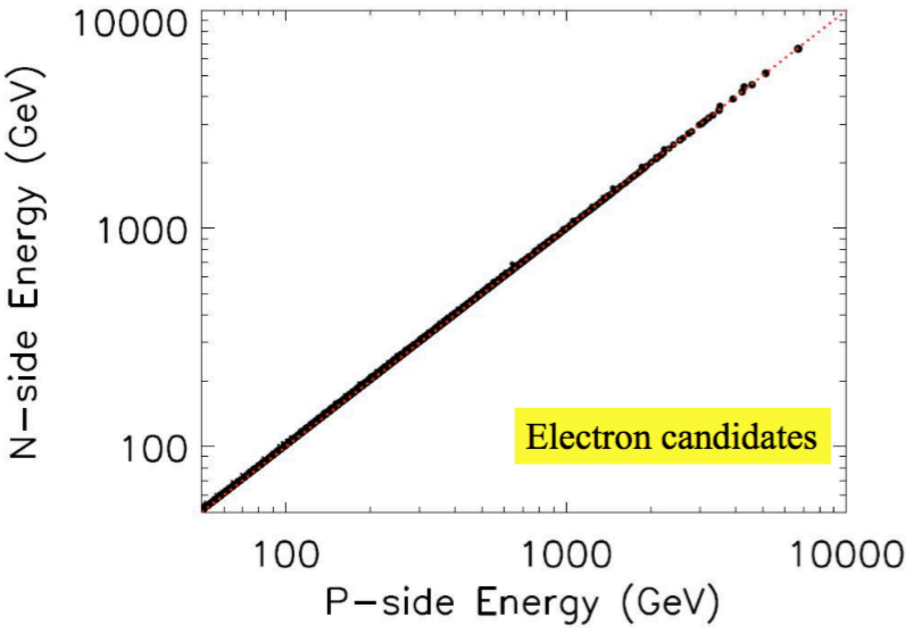


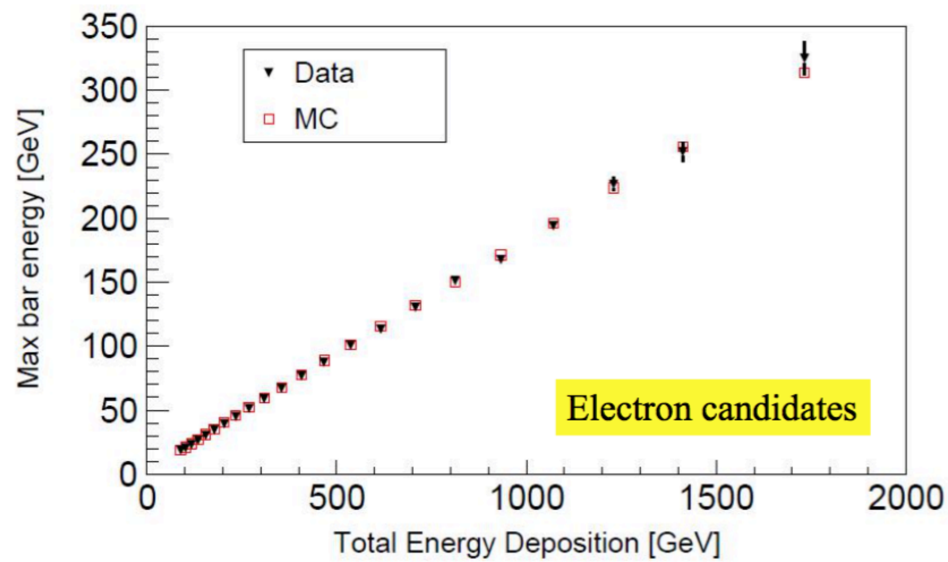


Exponential cutoff

$$\Phi(E) = \Phi_0 \left(\frac{E}{TeV}\right)^{-\gamma} exp\left(-\frac{E}{E_{cut}}\right)$$

Electron-like events
Energy measurement





Neutron detector performances

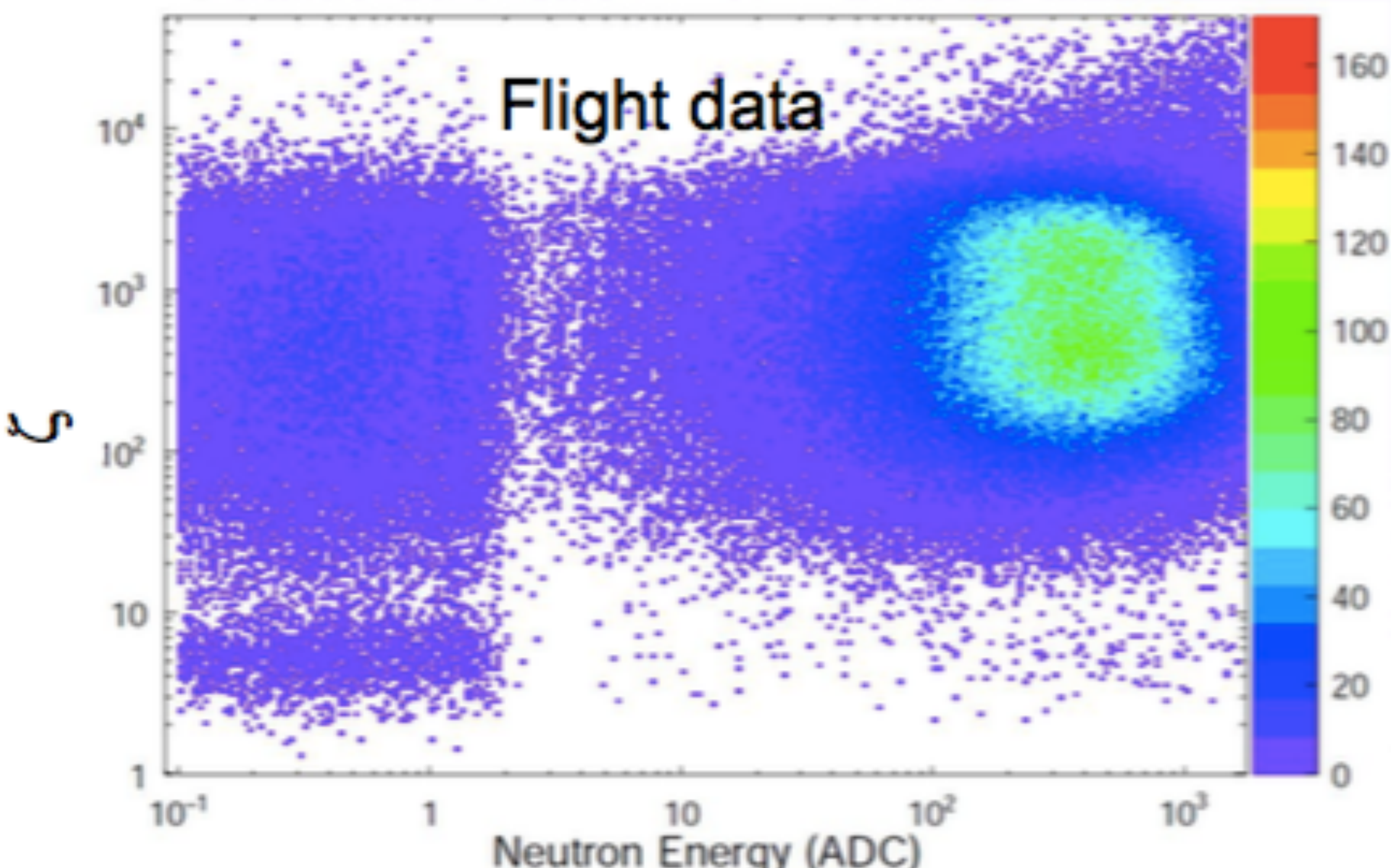
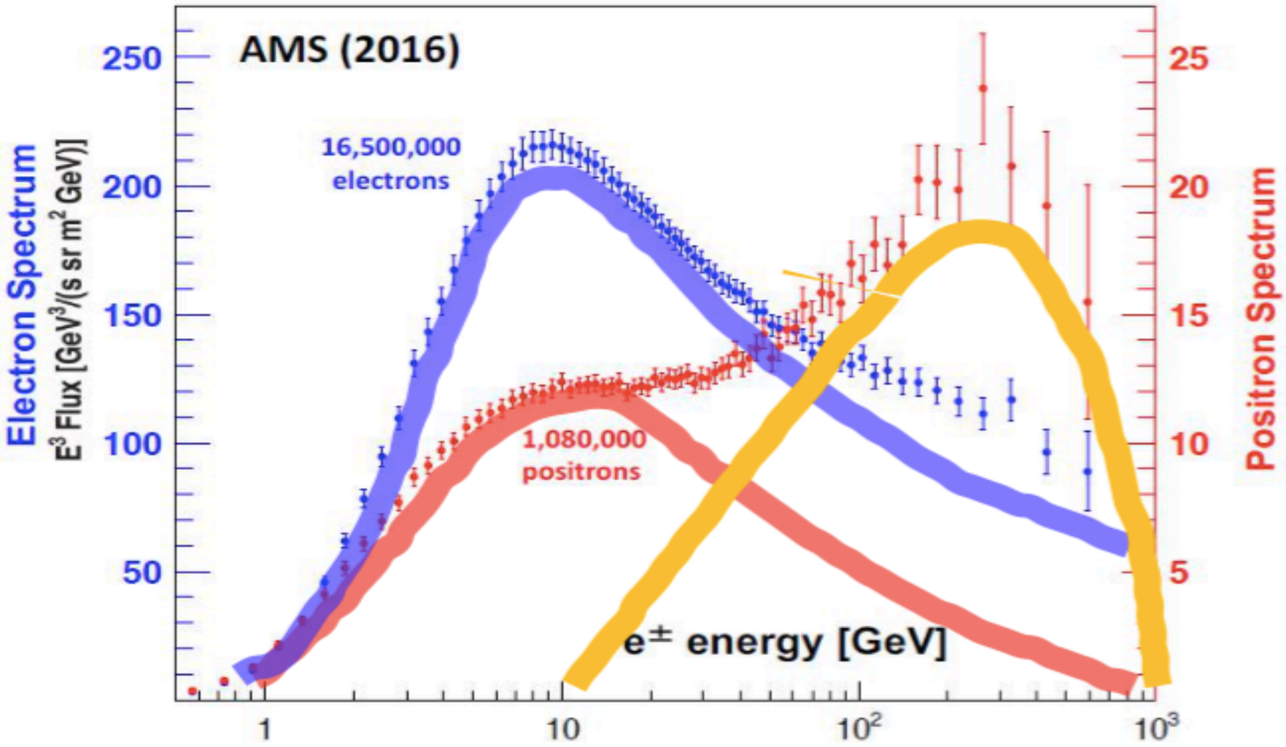


Table 1 | The CRE flux (in units of $m^{-2}\,s^{-1}\,sr^{-1}\,GeV^{-1}$) with 1$\sigma$ statistical and systematic errors

Energy range (GeV)	$\langle E \rangle$ (GeV)	Acceptance ($m^2 \times sr$)	Counts	Background fraction	$\Phi(e^+ + e^-) \pm \sigma_{stat} \pm \sigma_{sys}$
24.0–27.5	25.7±0.3	0.256±0.007	377,469	(2.6±0.3)%	$(1.16\pm0.00\pm0.03)\times10^{-2}$
27.5–31.6	29.5±0.4	0.259±0.007	279,458	(2.5±0.3)%	$(7.38\pm0.02\pm0.19)\times10^{-3}$
31.6–36.3	33.9±0.4	0.261±0.007	208,809	(2.4±0.2)%	$(4.76\pm0.02\pm0.13)\times10^{-3}$
36.3–41.7	38.9±0.5	0.264±0.007	156,489	(2.4±0.2)%	$(3.08\pm0.01\pm0.08)\times10^{-3}$
41.7–47.9	44.6±0.6	0.266±0.007	117,246	(2.3±0.2)%	$(2.00\pm0.01\pm0.05)\times10^{-3}$
47.9–55.0	51.2±0.6	0.269±0.007	87,259	(2.3±0.2)%	$(1.28\pm0.01\pm0.03)\times10^{-3}$
55.0–63.1	58.8±0.7	0.272±0.007	65,860	(2.2±0.2)%	$(8.32\pm0.04\pm0.21)\times10^{-4}$
63.1–72.4	67.6±0.8	0.275±0.007	49,600	(2.1±0.2)%	$(5.42\pm0.03\pm0.13)\times10^{-4}$
72.4–83.2	77.6±1.0	0.277±0.007	37,522	(2.1±0.2)%	$(3.54\pm0.02\pm0.09)\times10^{-4}$
83.2–95.5	89.1±1.1	0.279±0.007	28,325	(2.1±0.1)%	$(2.31\pm0.01\pm0.06)\times10^{-4}$
95.5–109.7	102.2±1.3	0.283±0.007	21,644	(2.0±0.1)%	$(1.52\pm0.01\pm0.04)\times10^{-4}$
109.7–125.9	117.4±1.5	0.282±0.007	16,319	(2.0±0.1)%	$(1.00\pm0.01\pm0.02)\times10^{-4}$
125.9–144.5	134.8±1.7	0.286±0.007	12,337	(2.0±0.1)%	$(6.49\pm0.06\pm0.16)\times10^{-5}$
144.5–166.0	154.8±1.9	0.287±0.007	9,079	(2.0±0.1)%	$(4.14\pm0.04\pm0.10)\times10^{-5}$
166.0–190.6	177.7±2.2	0.288±0.007	7,007	(1.9±0.1)%	$(2.78\pm0.03\pm0.07)\times10^{-5}$
190.6–218.8	204.0±2.6	0.288±0.007	5,256	(2.0±0.1)%	$(1.81\pm0.03\pm0.05)\times10^{-5}$
218.8–251.2	234.2±2.9	0.290±0.007	4,002	(1.9±0.1)%	$(1.20\pm0.02\pm0.03)\times10^{-5}$
251.2–288.4	268.9±3.4	0.291±0.007	2,926	(2.0±0.2)%	$(7.59\pm0.14\pm0.19)\times10^{-6}$
288.4–331.1	308.8±3.9	0.291±0.007	2,136	(2.1±0.2)%	$(4.81\pm0.11\pm0.12)\times10^{-6}$
331.1–380.2	354.5±4.4	0.290±0.007	1,648	(2.1±0.2)%	$(3.25\pm0.08\pm0.08)\times10^{-6}$
380.2–436.5	407.1±5.1	0.292±0.007	1,240	(2.0±0.2)%	$(2.12\pm0.06\pm0.05)\times10^{-6}$
436.5–501.2	467.4±5.8	0.291±0.007	889	(2.2±0.2)%	$(1.32\pm0.05\pm0.03)\times10^{-6}$
501.2–575.4	536.6±6.7	0.289±0.007	650	(2.2±0.2)%	$(8.49\pm0.34\pm0.21)\times10^{-7}$
575.4–660.7	616.1±7.7	0.288±0.007	536	(2.0±0.2)%	$(6.13\pm0.27\pm0.15)\times10^{-7}$
660.7–758.6	707.4±8.8	0.285±0.007	390	(2.0±0.2)%	$(3.92\pm0.20\pm0.10)\times10^{-7}$
758.6–871.0	812.2±10.2	0.284±0.007	271	(2.3±0.3)%	$(2.38\pm0.15\pm0.06)\times10^{-7}$
871.0–1,000.0	932.5±11.7	0.278±0.008	195	(2.3±0.3)%	$(1.52\pm0.11\pm0.04)\times10^{-7}$
1,000.0–1,148.2	1,070.7±13.4	0.276±0.008	136	(2.6±0.4)%	$(9.29\pm0.82\pm0.27)\times10^{-8}$
1,148.2–1,318.3	1,229.3±15.4	0.274±0.009	74	(3.6±0.5)%	$(4.38\pm0.53\pm0.14)\times10^{-8}$
1,318.3–1,513.6	1,411.4±17.6	0.267±0.009	93	(2.2±0.4)%	$(4.99\pm0.53\pm0.17)\times10^{-8}$
1,513.6–1,737.8	1,620.5±20.3	0.263±0.010	33	(5.0±0.9)%	$(1.52\pm0.28\pm0.06)\times10^{-8}$
1,737.8–1,995.3	1,860.6±23.3	0.255±0.011	26	(5.4±0.9)%	$(1.07\pm0.22\pm0.05)\times10^{-8}$
1,995.3–2,290.9	2,136.3±26.7	0.249±0.012	17	(5.8±0.9)%	$(6.24\pm1.61\pm0.30)\times10^{-9}$
2,290.9–2,630.3	2,452.8±30.7	0.243±0.014	12	(7.9±1.1)%	$(3.84\pm1.20\pm0.21)\times10^{-9}$
2,630.3–3,019.9	2,816.1±35.2	0.233±0.015	4	(18.2±2.5)%	$(1.03\pm0.63\pm0.07)\times10^{-9}$
3,019.9–3,467.4	3,233.4±40.4	0.227±0.017	4	(15.4±2.4)%	$(9.53\pm5.64\pm0.70)\times10^{-10}$
3,467.4–3,981.1	3,712.4±46.4	0.218±0.018	4	(11.2±2.6)%	$(9.07\pm5.12\pm0.77)\times10^{-10}$
3,981.1–4,570.9	4,262.4±53.3	0.210±0.020	3	(11.4±4.0)%	$(6.15\pm4.02\pm0.60)\times10^{-10}$

3-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, ...)