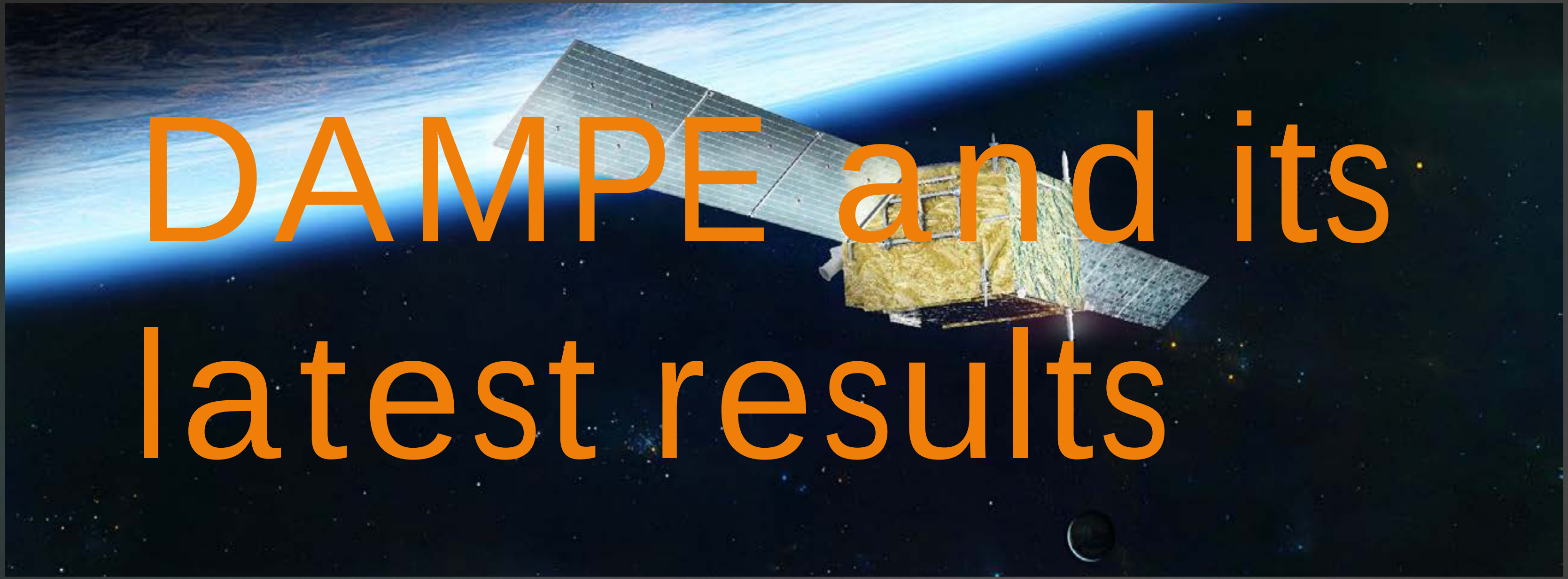
MG15 ROME 1-7 JULY 2018

DAMPE and its latest results



DARK MATTER DAMPE PARTICLE EXPLORER

暗物质粒子探测卫星

FABIO GARGANO – INFN BARI

ON BEHALF OF PROF.CHANG AND THE **DAMPE** COLLABORATION

INFN Istituto Nazionale di Fisica Nucleare

The collaboration

- **CHINA**
  - **Purple Mountain Observatory, CAS, Nanjing**
    - **PI *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**
  - **GSSI Gran Sasso Science Institute**

- **SWITZERLAND**
  - **University of Geneva**

Outline

- Scientific objectives
- Instrument and construction
- Beam Test
- On-orbit performance
- First Results
- Present status

The physics goals

- **High energy particle detection in space**
  - Study of the cosmic-ray **electron** and **positron**
  - Study of cosmic ray **protons** and **nuclei**:
    - spectrum and composition
  - High energy gamma-ray astronomy and **photon** spectra
  - Search for **dark matter** signatures in lepton and photon spectra
  - **Exotica** and "**unexpected**", e.g. GW e.m. counterpart in the FoV (1sr)

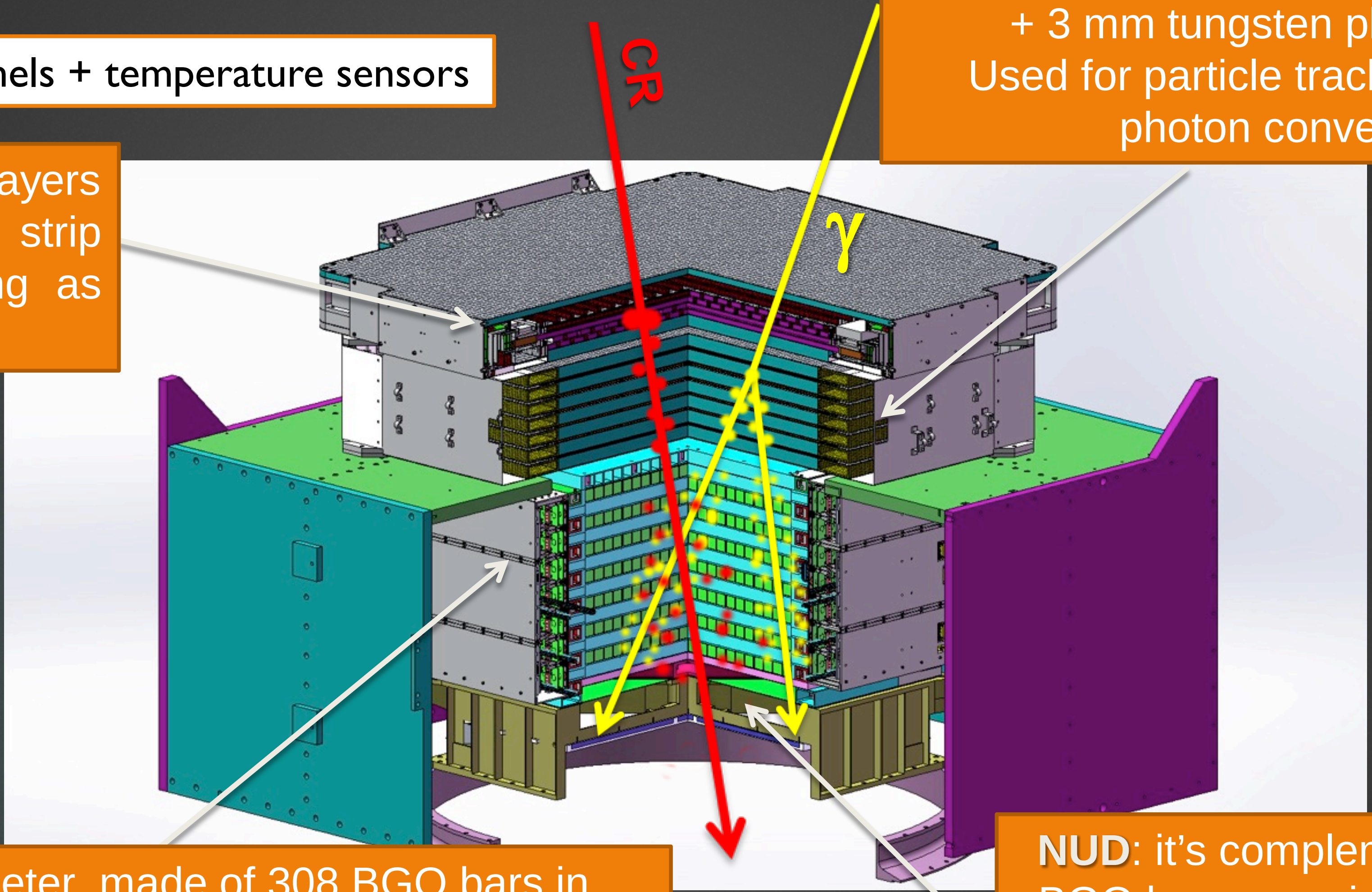
Detection of
5 GeV - 10 TeV e/γ
50 GeV - 100 TeV protons and nuclei
Excellent energy resolution
(<1.5%@100GeV e/γ; < 40% @800GeV p)
Very good angular resolution
(<0.2° @ 100GeV γ)

Instrument design

75k readout channels + temperature sensors

PSD: double layers of scintillating strip detector acting as ACD + PID

STK: 6 tracking double layers + 3 mm tungsten plates. Used for particle track and photon conversion



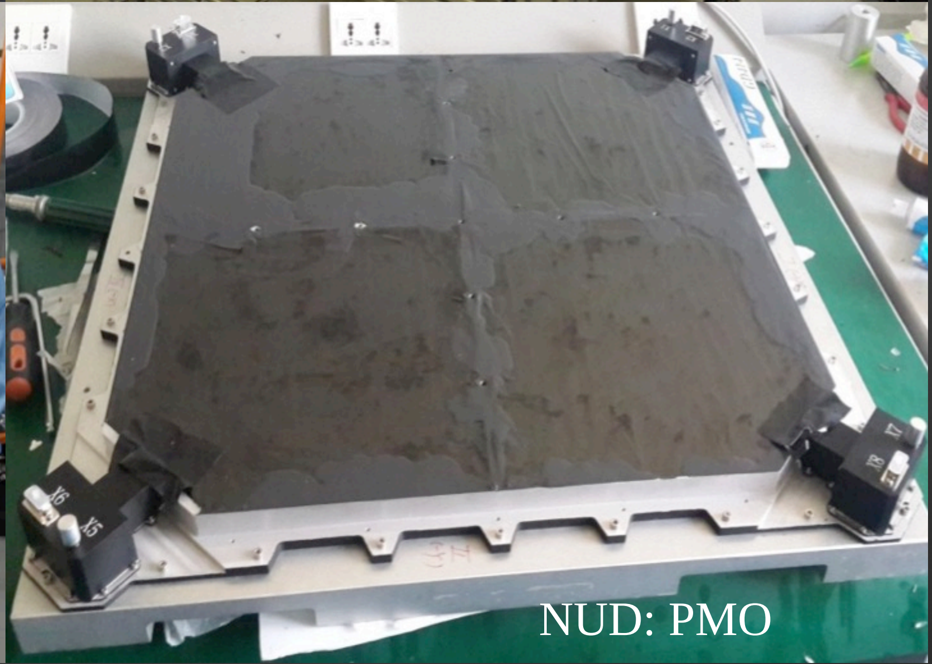
BGO: the calorimeter made of 308 BGO bars in hodoscopic arrangement (~32 radiation lengths). Performs both energy measurements and trigger

NUD: it's complementary to the BGO by measuring the thermal neutron shower activity. Made up of boron-doped plastic scintillators

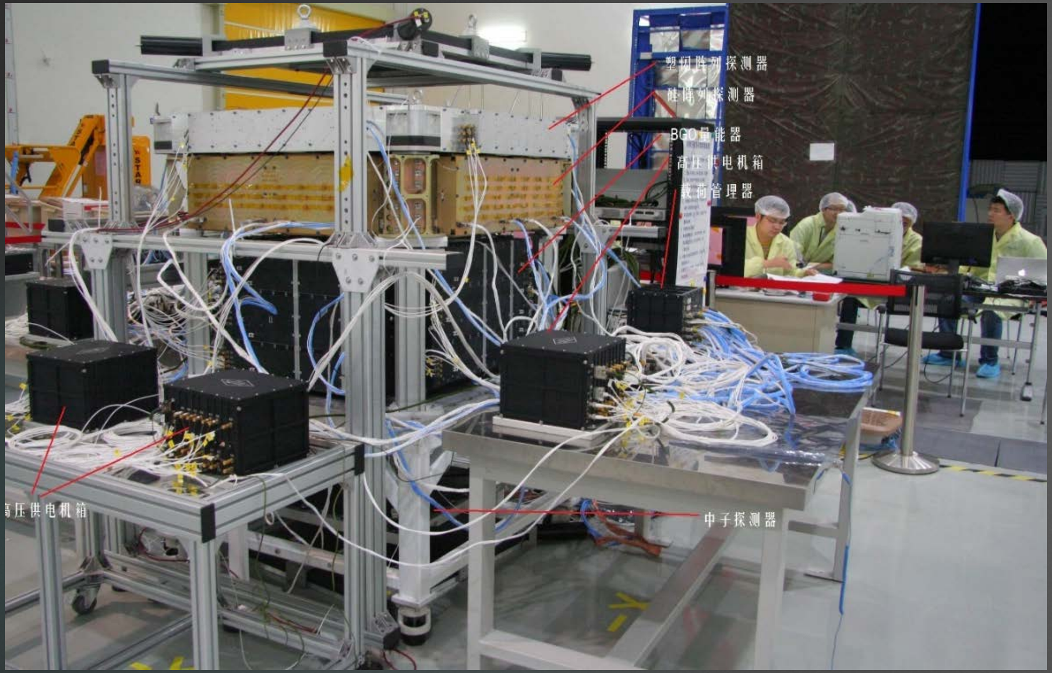

PSD: IMP
2015/08/01


STK: IHEP, UG, INFN Perugia

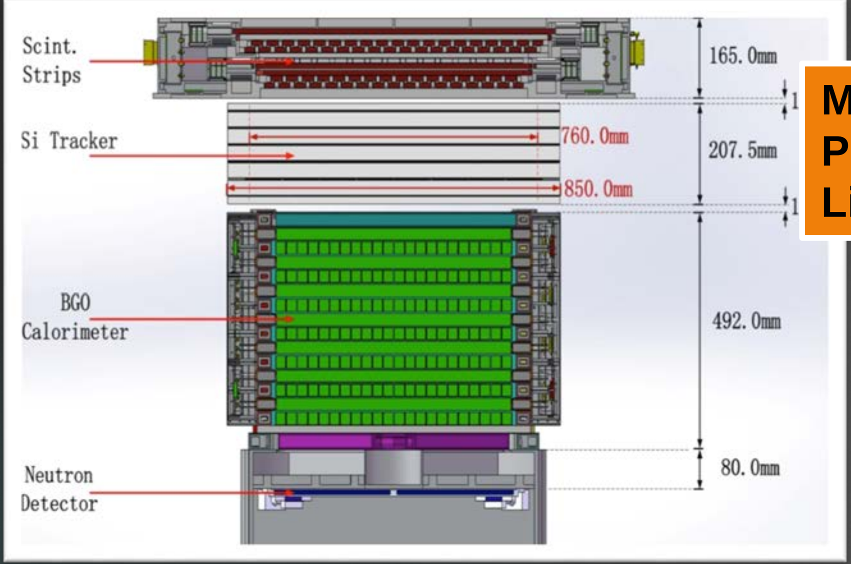

BGO: USTC & PMO


NUD: PMO

The detector during ground tests and integration



Comparison
DAMPE AMS-02 and FERMI



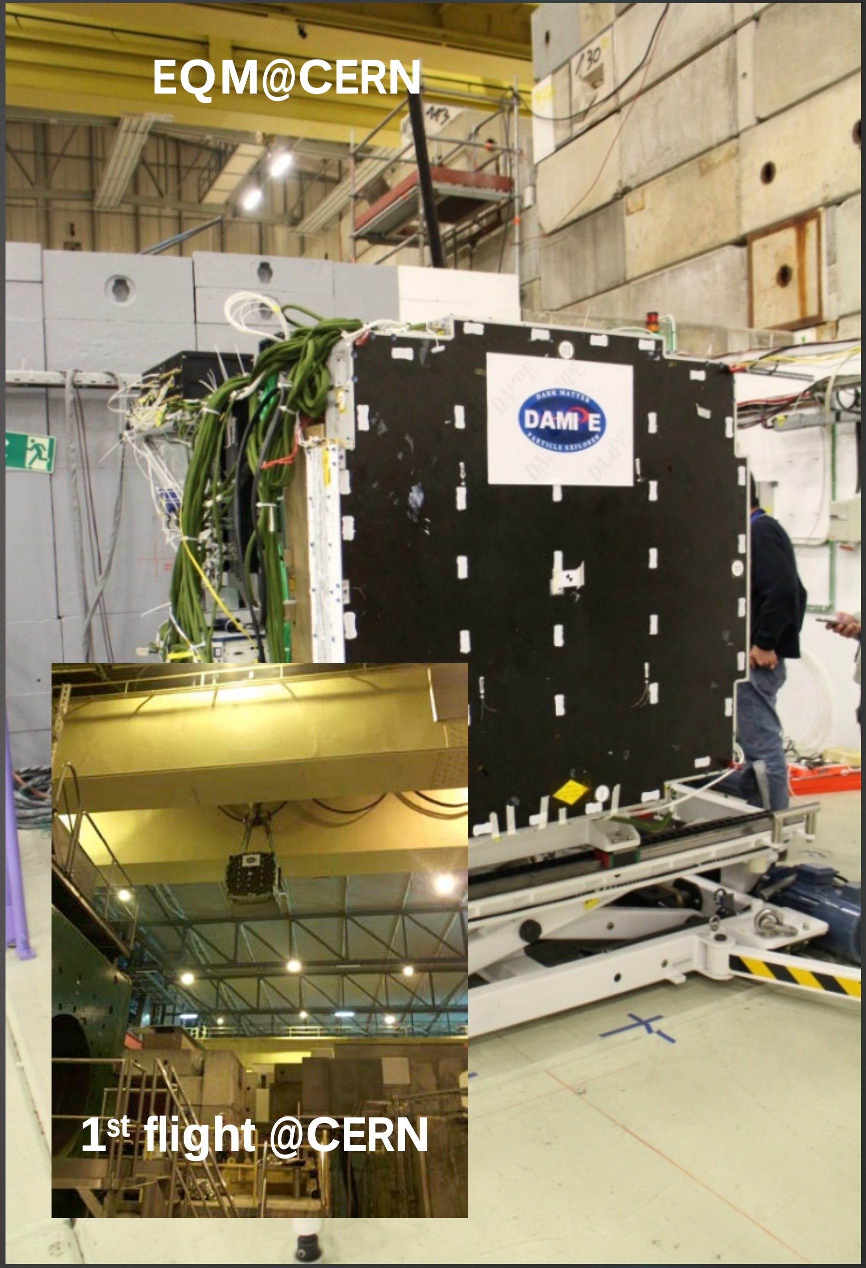
Mass: 1400 Kg
Power: ~ 400 W
Lifetime: > 3 years

	DAMPE	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	<1.5	3	10
e/γ Angular res.@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 accep. (m^2sr)	0.3	0.09	1

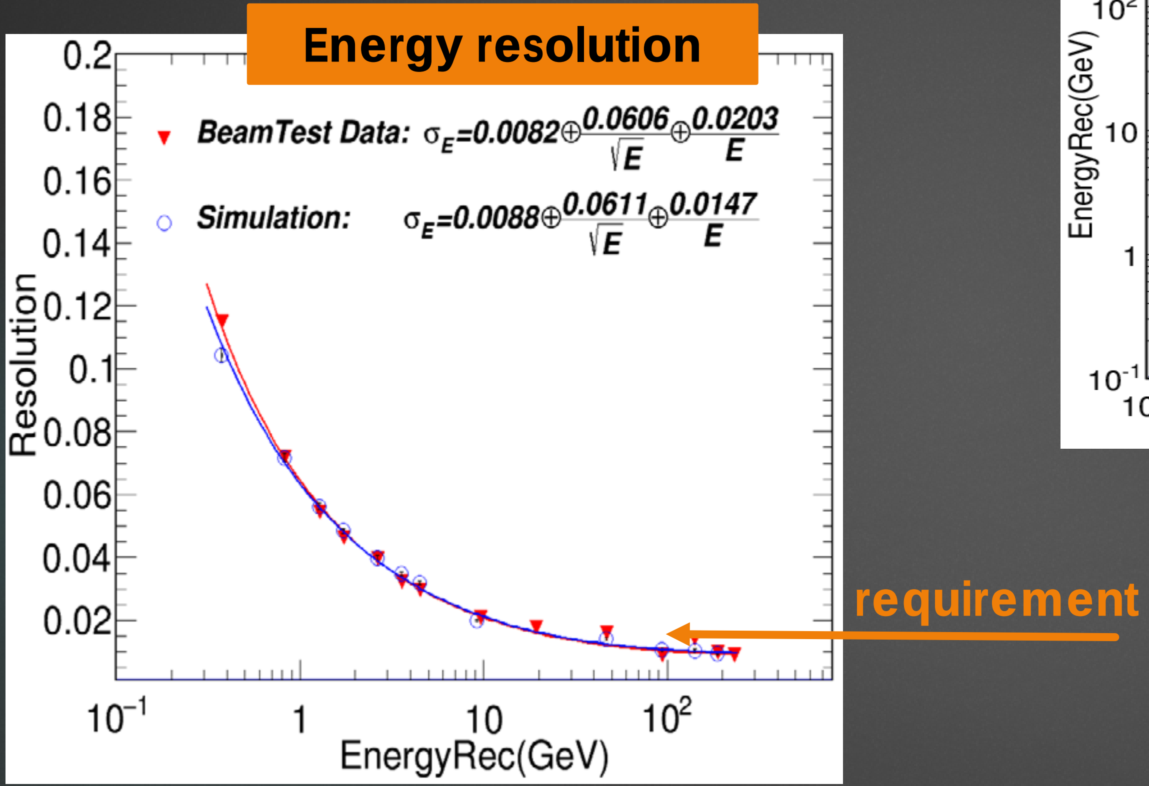
Beam Test

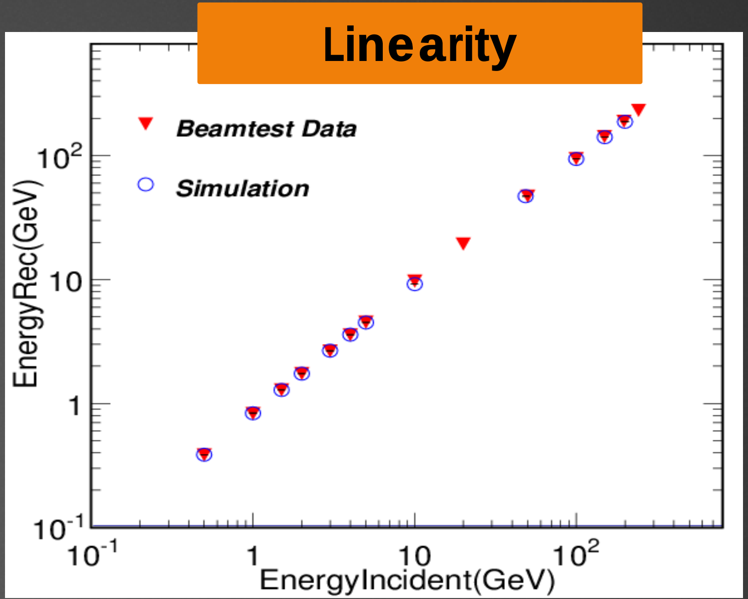
Beam test @ CERN

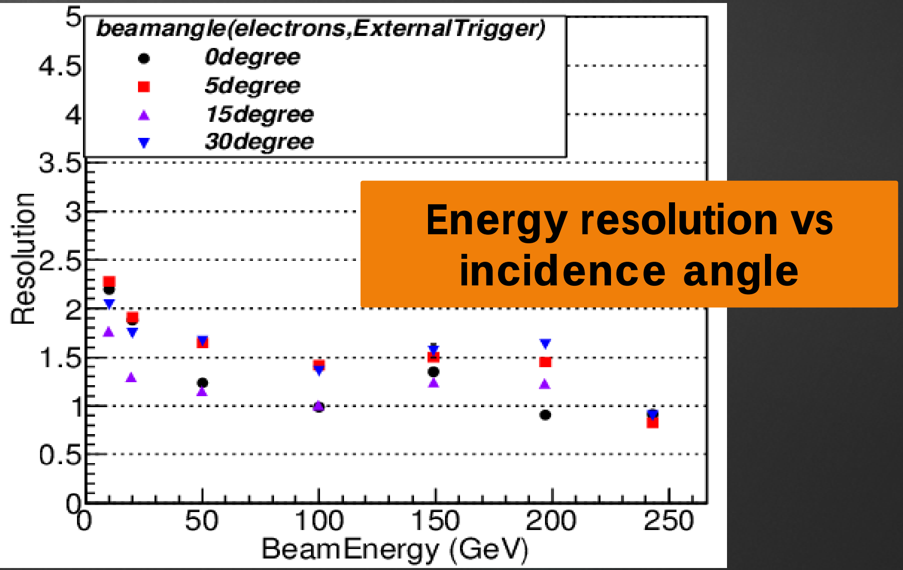
- 14days@PS, 29/10-11/11 2014
  - e @ 0.5GeV/c, 1GeV/c, 2GeV/c, 3GeV/c, 4GeV/c, 5GeV/c
  - p @ 3.5GeV/c, 4GeV/c, 5GeV/c, 6GeV/c, 8GeV/c, 10GeV/c
  - π-@ 3GeV/c, 10GeV/c
  - γ @ 0.5-3GeV/c
- 8days@SPS, 12/11-19/11 2014
  - e @ 5GeV/c, 10GeV/c, 20GeV/c, 50GeV/c, 100GeV/c, 150GeV/c, 200GeV/c, 250GeV/c
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



BGO Test beam results: electrons

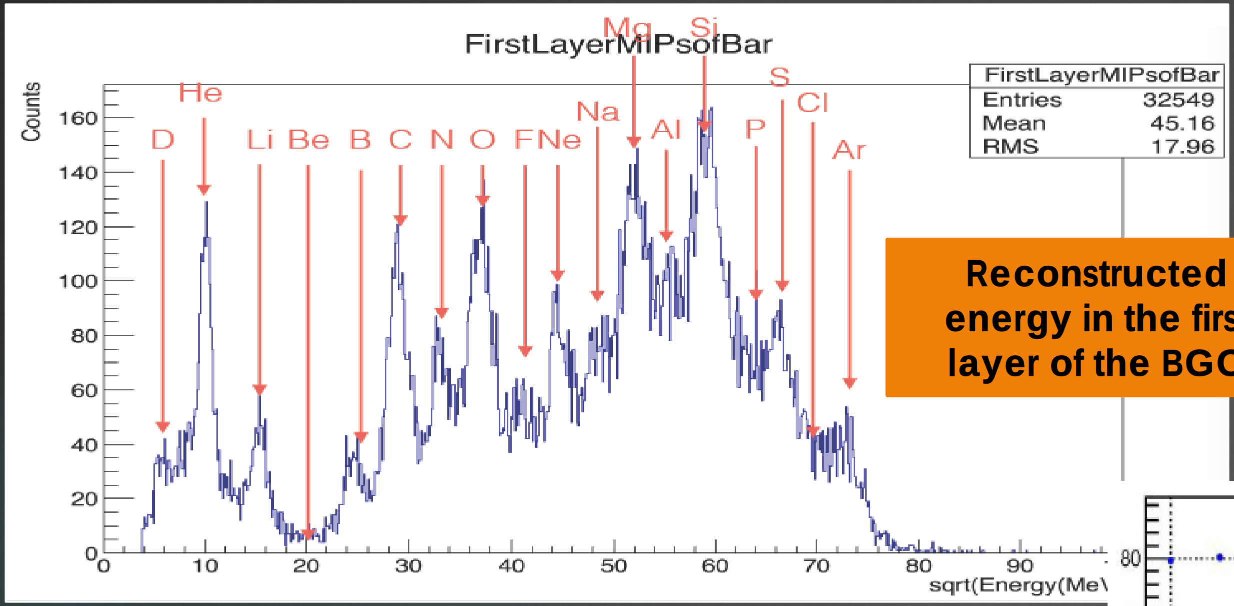






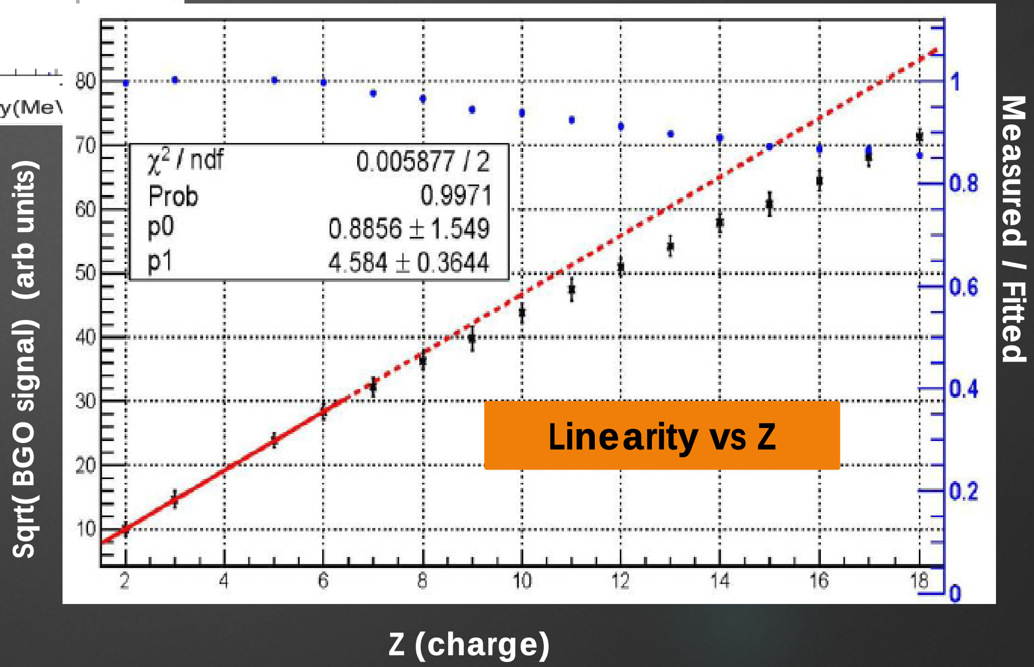
(Chang et al. Astropart.Phys. 95 (2017) 6–24)

BGO Test beam results: ions



Reconstructed energy in the first layer of the BGO

Beam: Ar @ 40 GeV/n

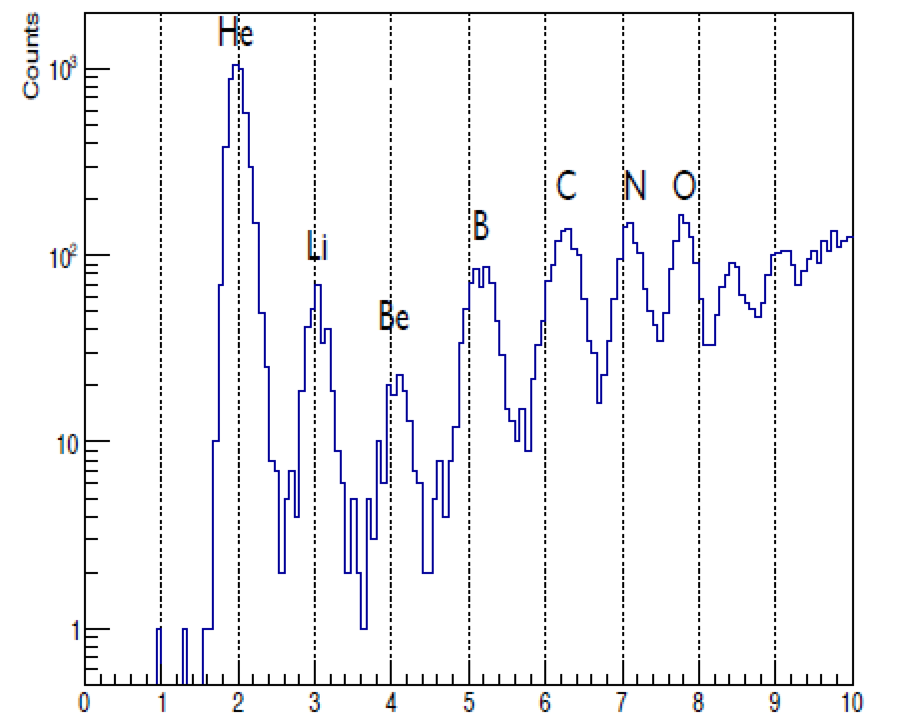


(Chang et al. Astropart.Phys. 95 (2017) 6–24)

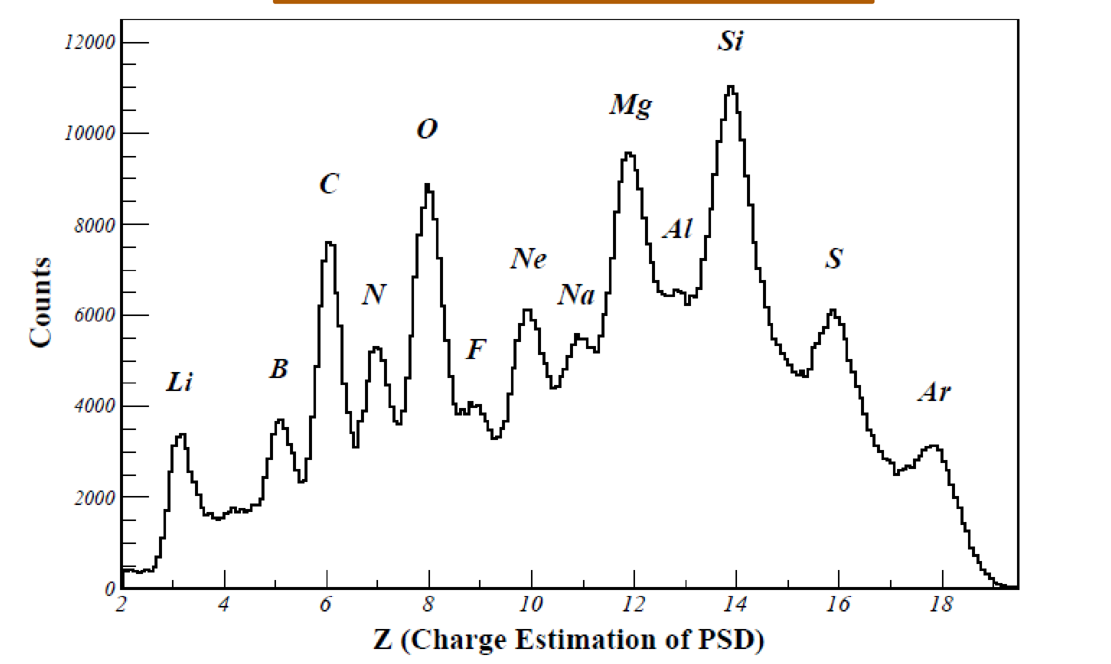
Protons and nuclei – Beam test

Identifying protons and nuclei with **PSD** and **STK**

Lead beam 40 GeV/n



Argon beam 40 GeV/n



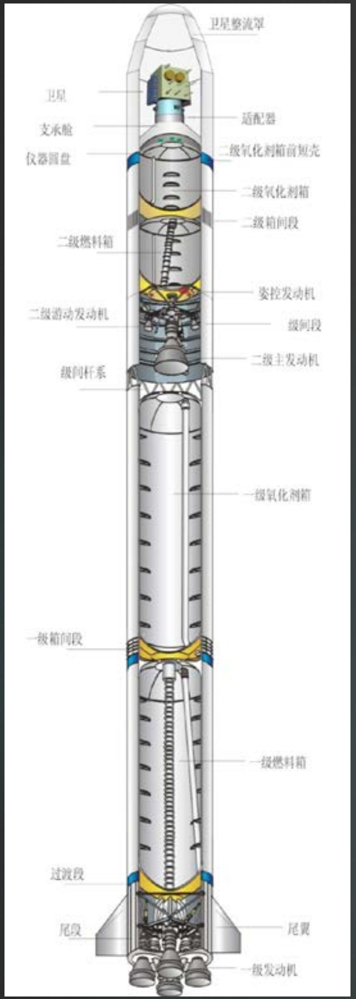
Charge measurement is done with **STK** up to Oxygen and with PSD from protons up to Iron

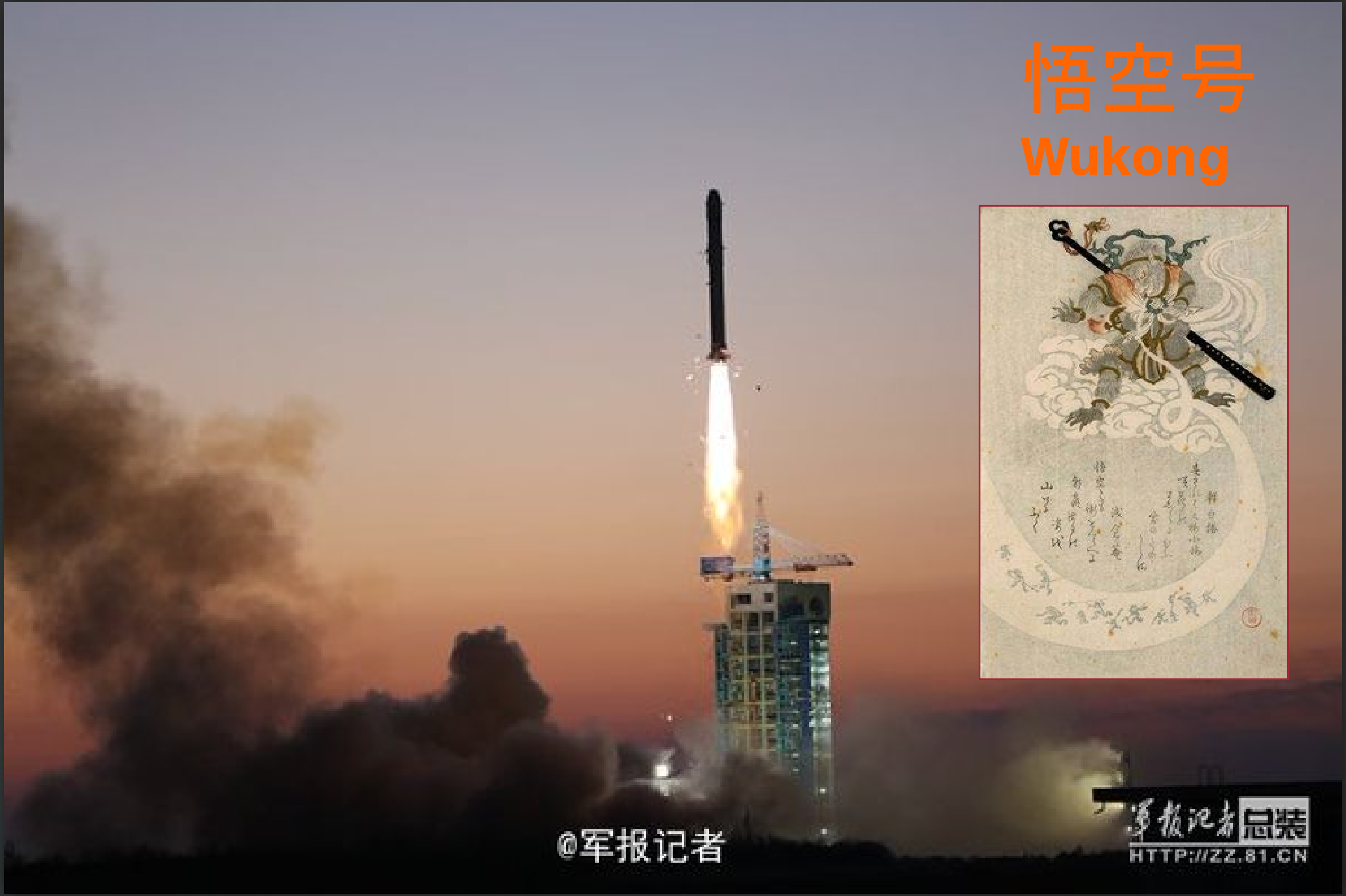
Charge resolution is Z dependent and ranges from 0.2 to 0.4

(Chang et al. Astropart.Phys. 95 (2017) 6–24)

Launch on 17th Dec. 2015

CZ-2D rocket



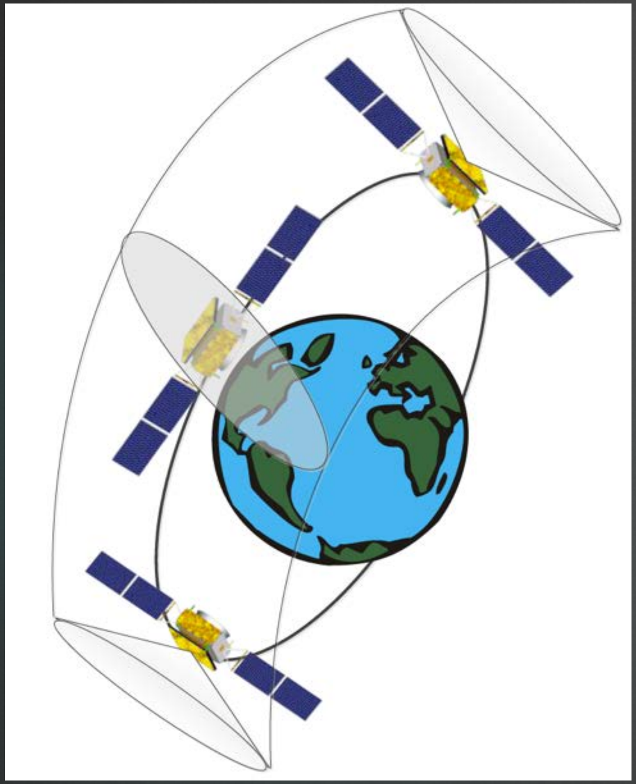


悟空号

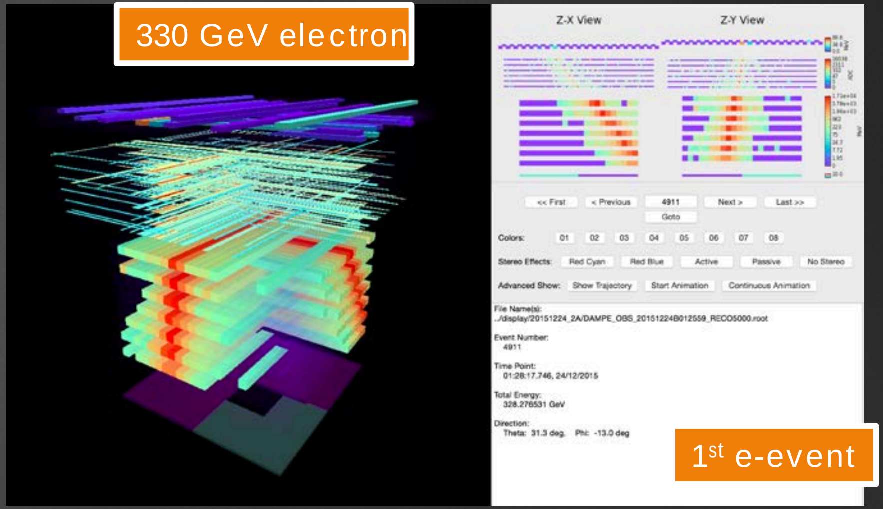
Wukong

Jiuquan Satellite Launch Center, Gobi desert

The orbit

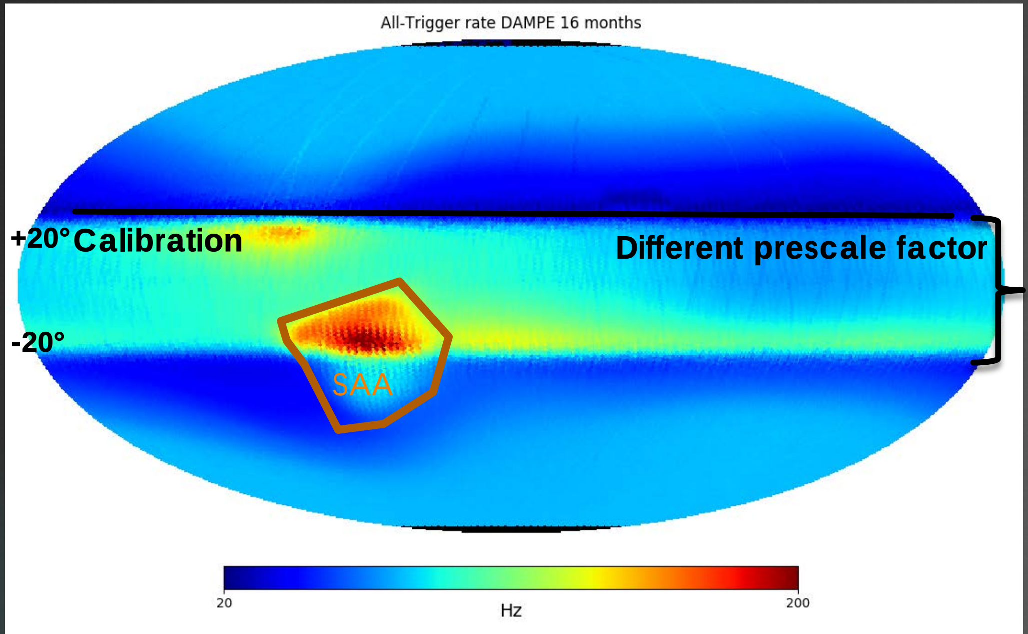


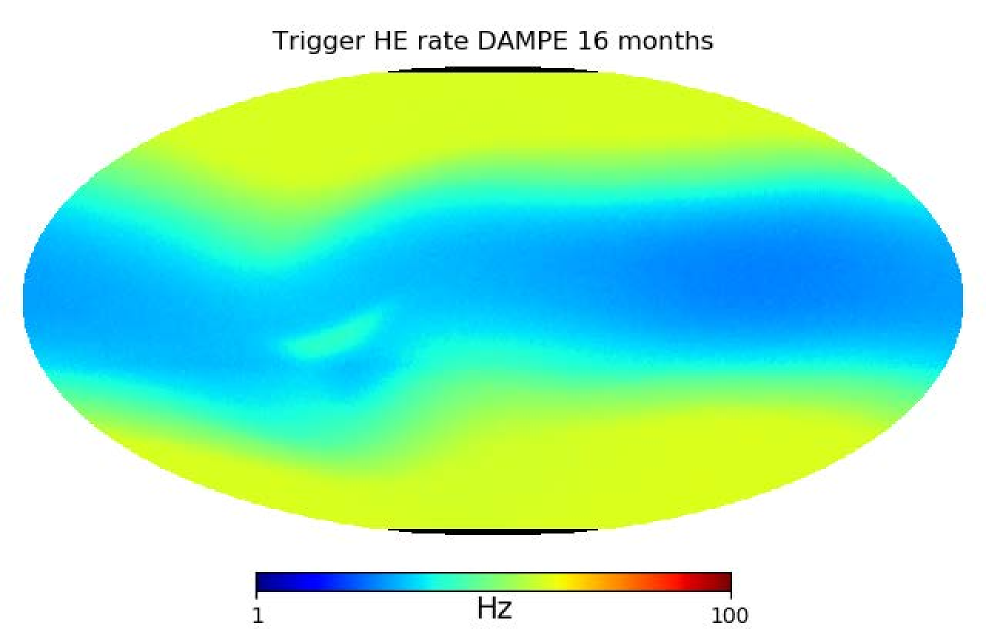
- **Altitude: 500 km**
- **Inclination: 97.4065°**
- **Period: 95 minutes**
- **Orbit: sun-synchronous**



- **Dec. 20: all detectors powered on, except the HV for PMTs**
- Dec. 24: HV on!
- Dec. 30: stable trigger condition

Trigger rate and data transfer

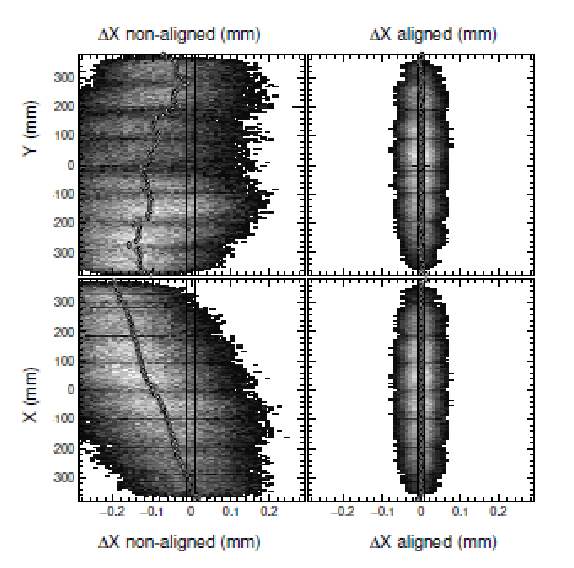




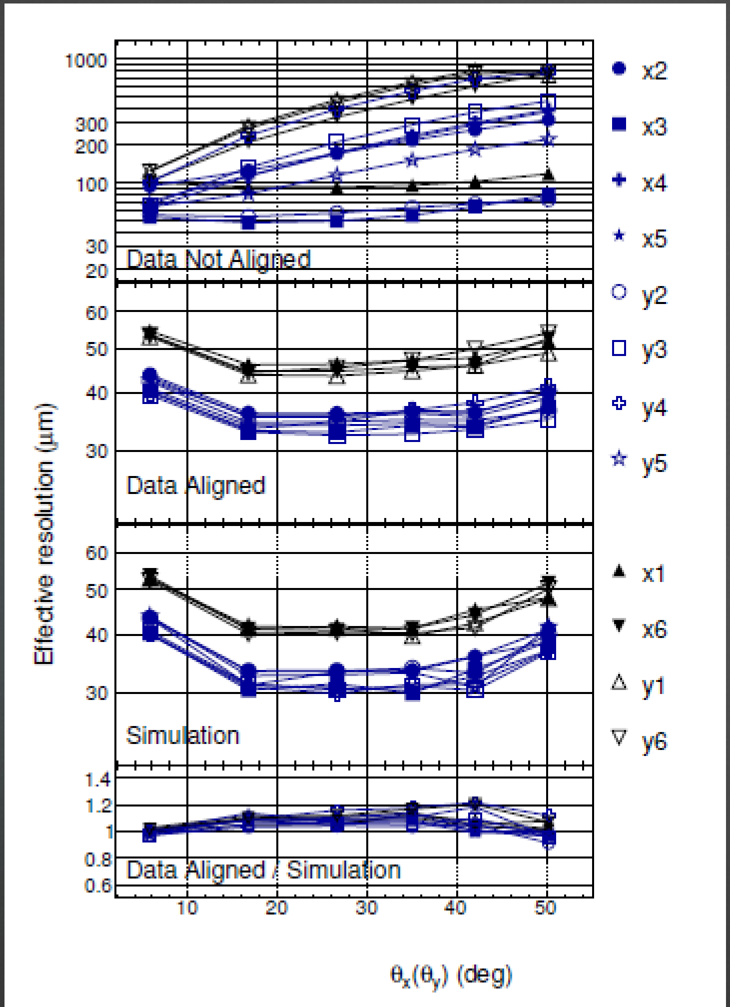
- Acquisition rate up to 200Hz (60 Hz for High Energy Trigger == main trigger for physics analysis)
- Data are collected 4 times per day, each time the DAMPE satellite is passing over Chinese ground stations
- 15 GB/day transmitted to ground
  - Raw Data (ROOT format 8GB) + Slow Control + Orbit Information
- 85 GB/day reconstructed data (ROOT format)
- **100 GB/day (35 TB/year) in total**

On-orbit performance

On orbit calibration



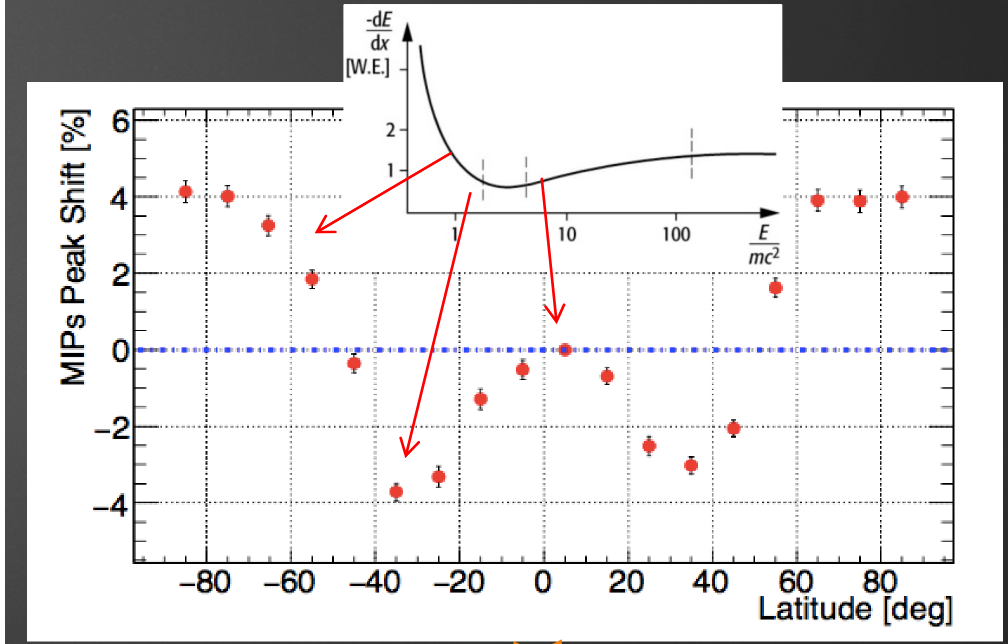
STK



On orbit STK alignment using "mips" (i.e. not showering particle).
The alignment (done every two weeks) allows us to achieve a spatial resolution better than 40μm on central STK planes

BGO

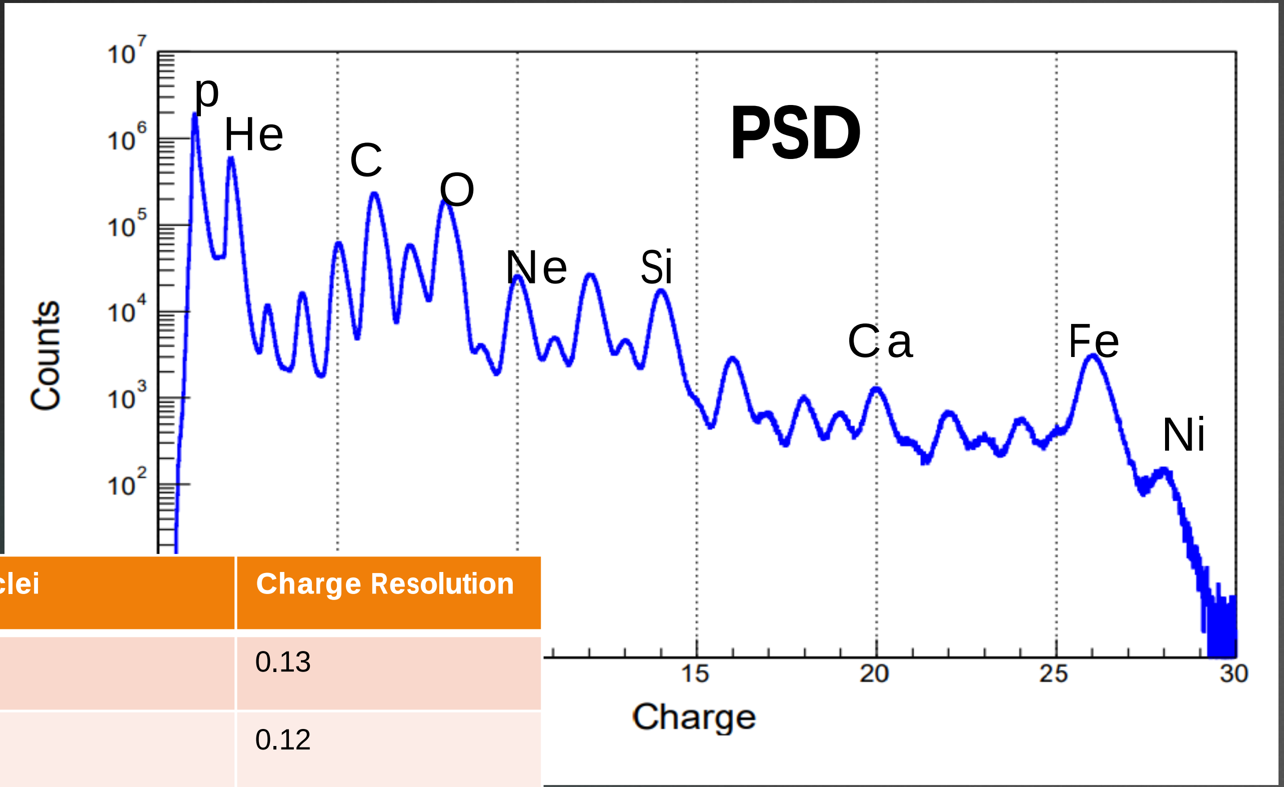
The "mip" (i.e. not showering particles) peak shift with latitude due to the geomagnetic cut-off.



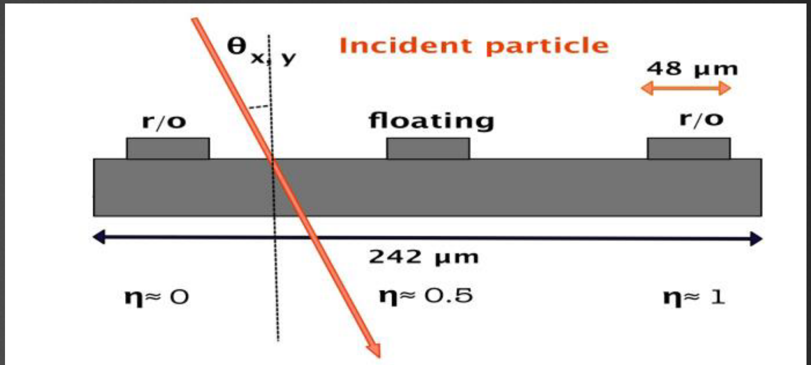
Vertical rigidity cut-off

A.Tykhonov et al. - NIMA - Volume 893, 43-56

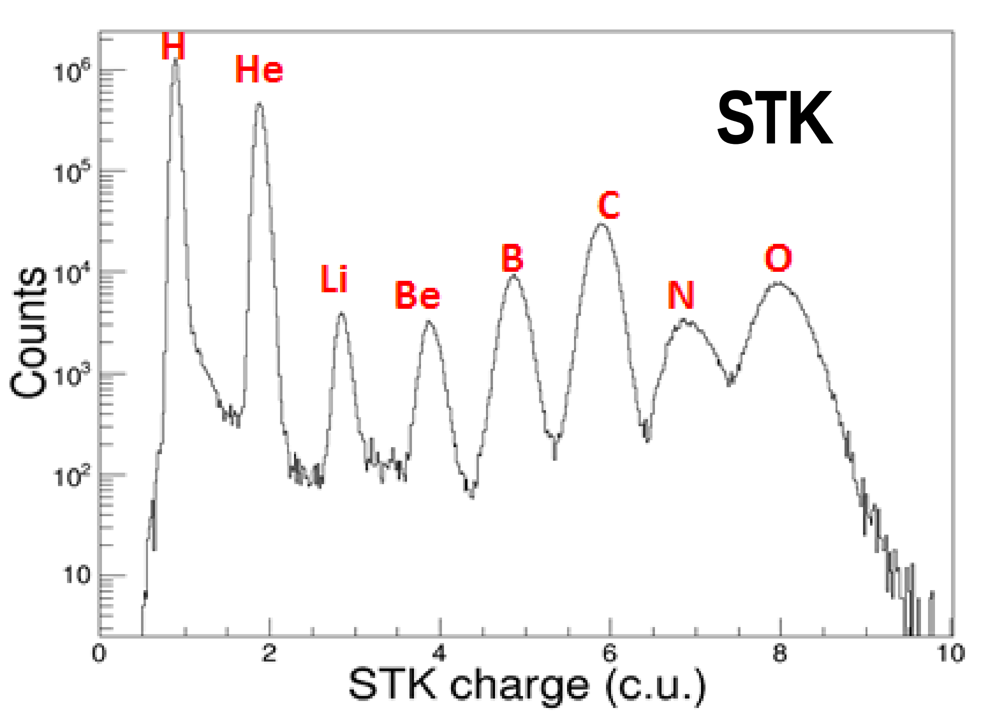
On orbit performance: PSD and STK



Nuclei	Charge Resolution
p	0.13
He	0.12
Li	0.14
Be	0.21
B	0.17
C	0.18
N	0.21
O	0.21
Fe	0.32

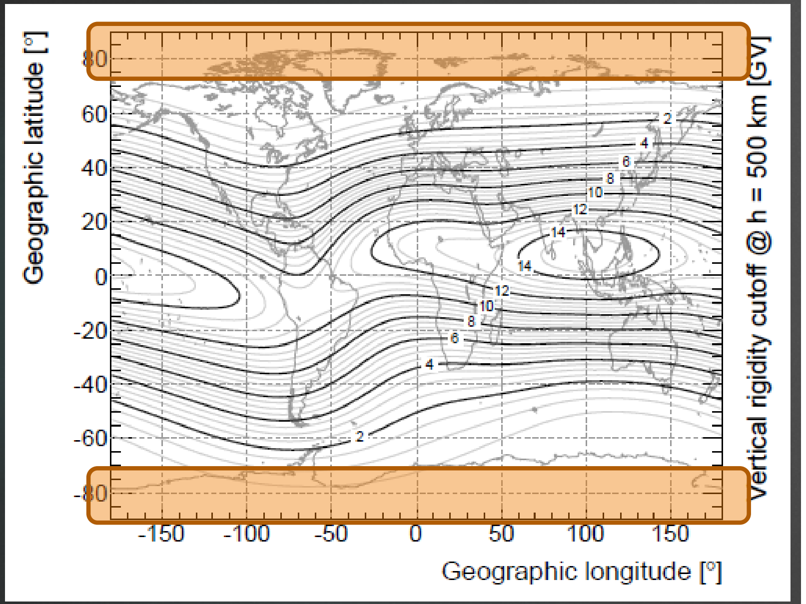


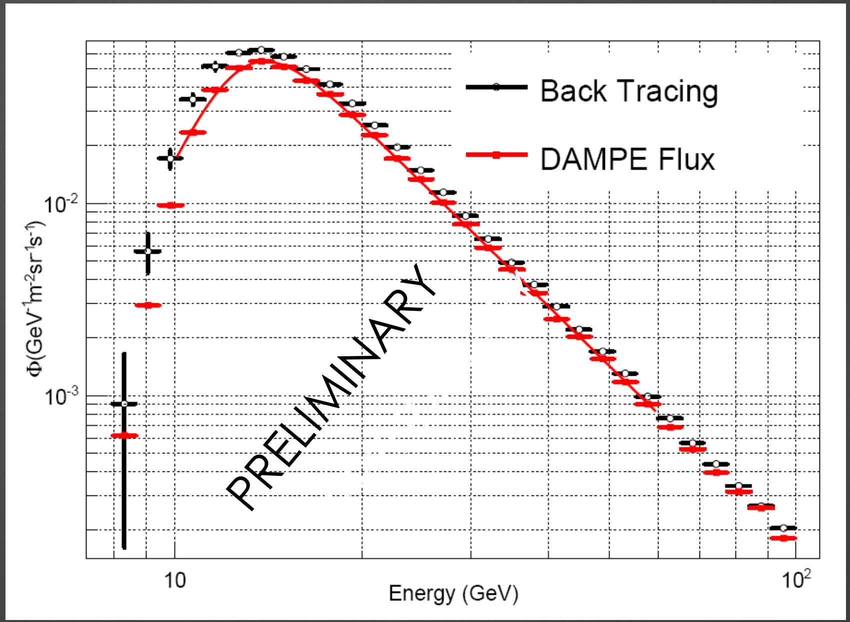
Correction for hit position and angle



On orbit performance: BGO absolute energy calibration

- Geomagnetic cut-off on cosmic ray electron spectrum provides a good spectral feature for absolute energy calibration
- Measure the low energy CRE flux with 1<L<1.14 in the energy range 8GeV < E < 100GeV
- We made a direct comparison between flight data and MC (with back tracing in Earth magnetic field – IGRF12)





Exp. Cut-off 13.038 GeV
Meas. Cut-off 13.201 GeV

By comparing geomagnetic cut-off on cosmic ray electron and positron fluxes measured from data and MC back tracing, we found DAMPE's absolute energy scale differ from expected by 1.25%

First Results

The global shower shape variable ζ

Lateral shower shape

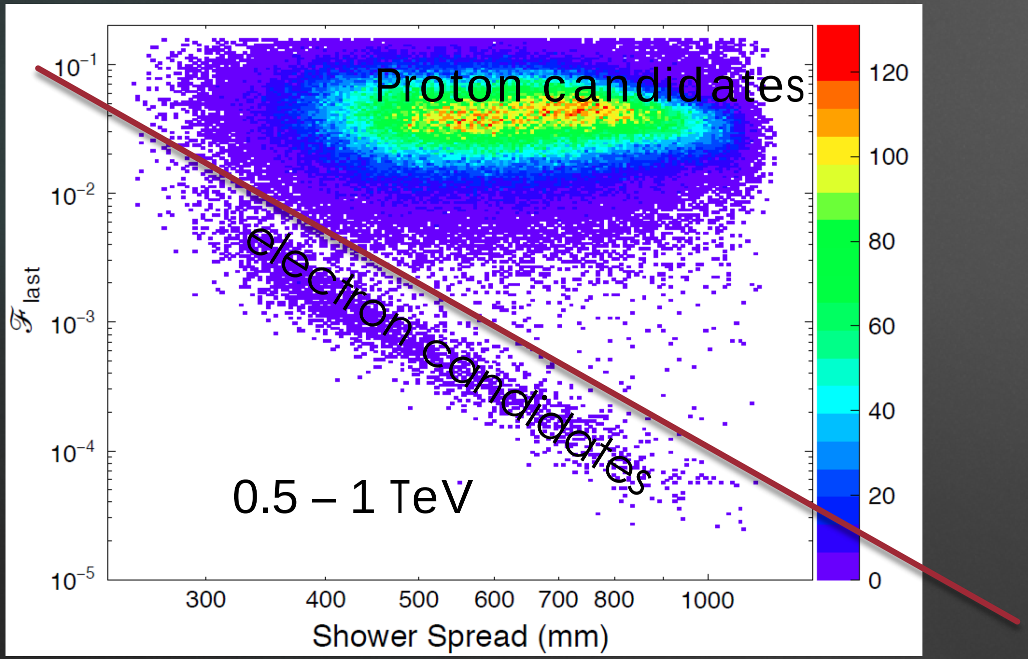
sumRms = sum of the shower width of all 14BGO layers

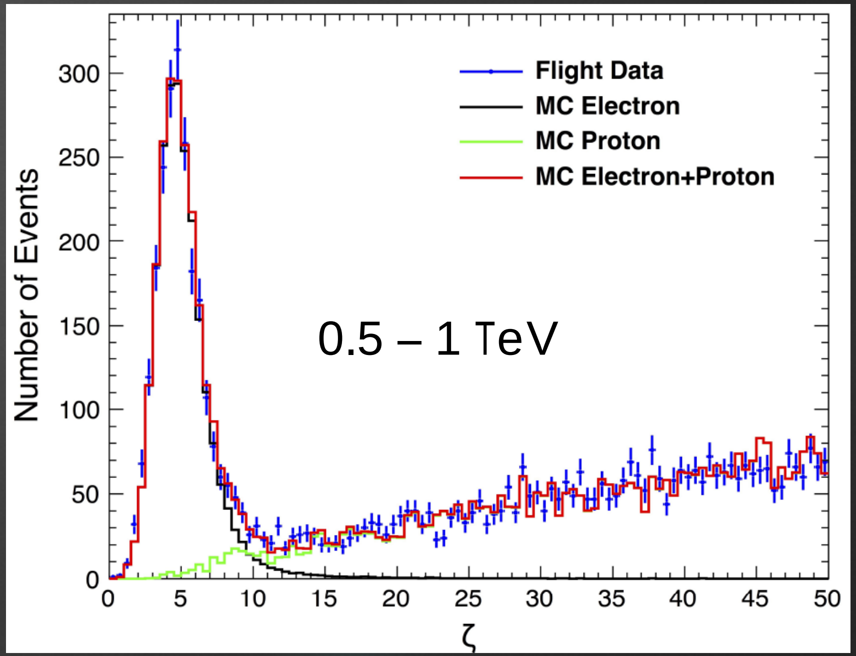
Longitudinal shower shape

F_{last} **= ratio of the last layer energy to the total BGO energy**

$$\zeta = \mathcal{F}_{\text{last}} \times (\Sigma_i RMS_i/\text{mm})^4/(8 \times 10^6)$$

> 90% detection efficiency with proton contamination 2 % @ < 1 TeV

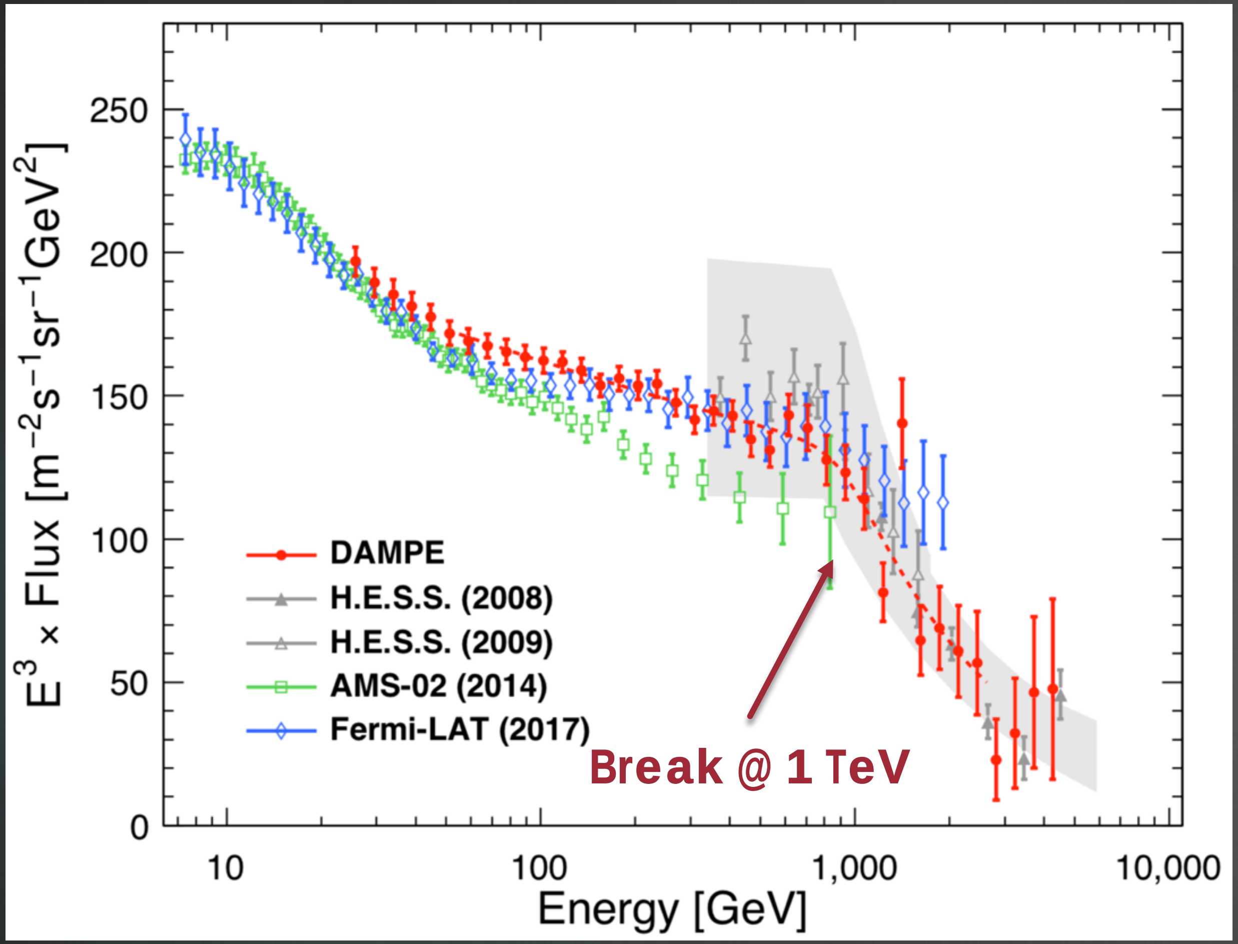




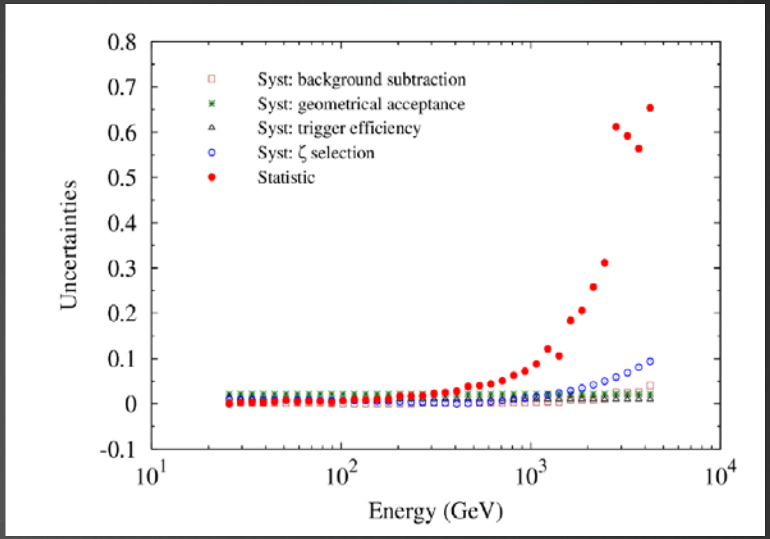
e^+e^- spectrum

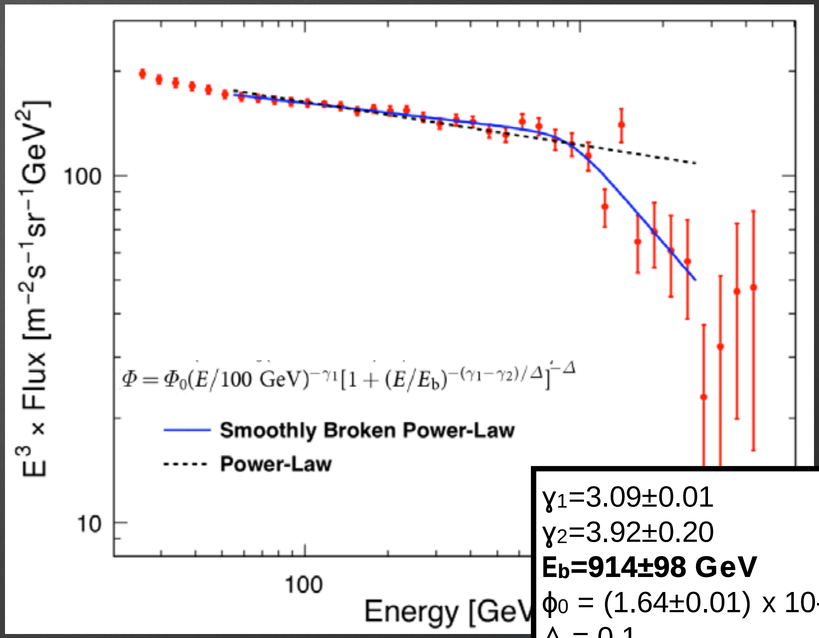
- 530 days of data
- 1.5million electrons between 25GeV and 4.6 TeV have been selected
- 3 independent analyses have been performed, using different PID(e-p separation) methods
  - Shower shape (ζ method): combine lateral and longitudinal shower shape variables to one parameter ζ
  - Principal component analysis
  - Boosted Decision Tree
- An event by event(>100GeV) comparison among different methods gives very consistent results

e^+e^- spectrum



Systematic and statistic errors



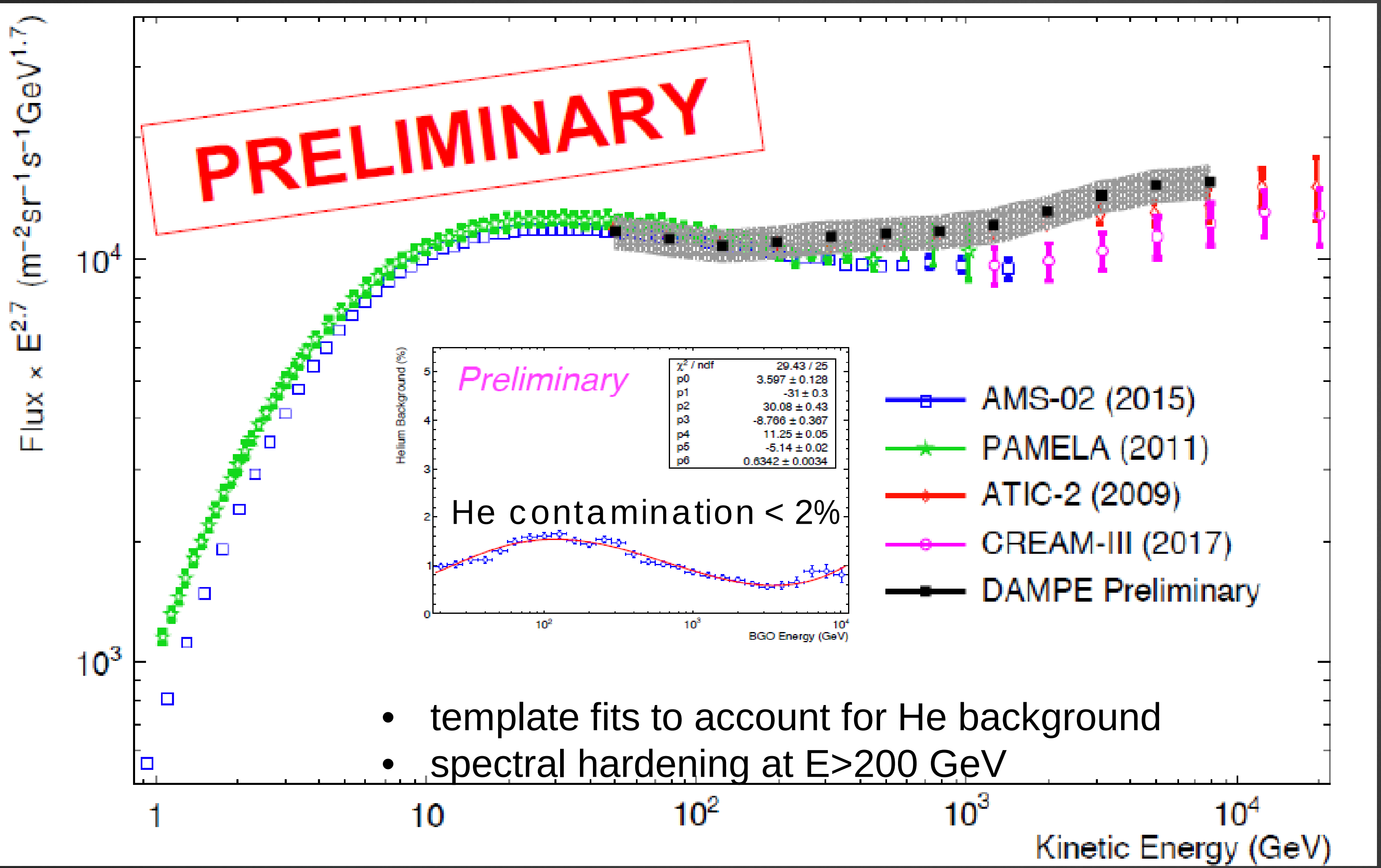


γ_1=3.09±0.01
γ_2=3.92±0.20
E_b=914±98 GeV
ϕ_0 = (1.64±0.01) x 10-4 m^{-2}s^{-1}sr^{-1}GeV^{-1}
Δ = 0.1
χ2/NdF = 23.3/18 (6.6σ preference over PL)

(Ambrosi et al. Nat. 552 (2017) 63-66 + CALET result)

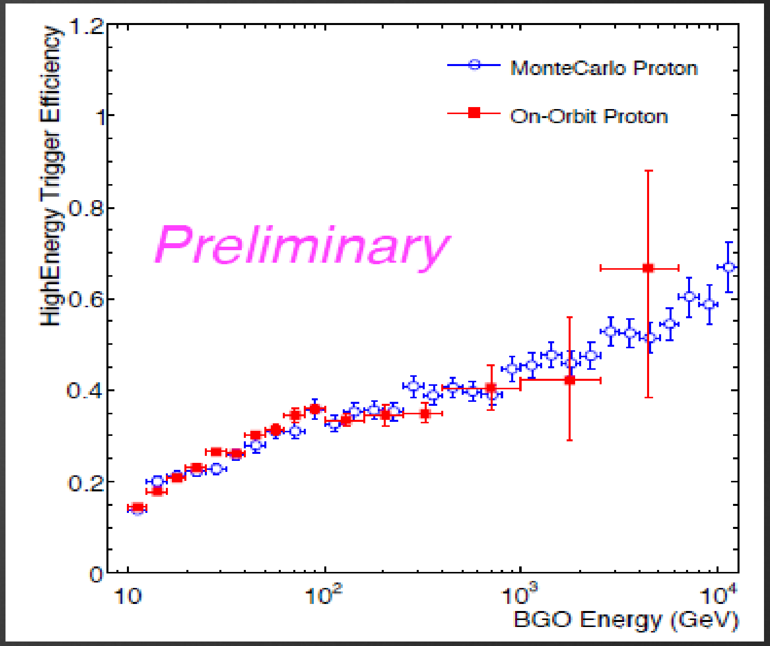
Proton spectrum

(three independent analyses ongoing)



- template fits to account for He background
- spectral hardening at E>200 GeV

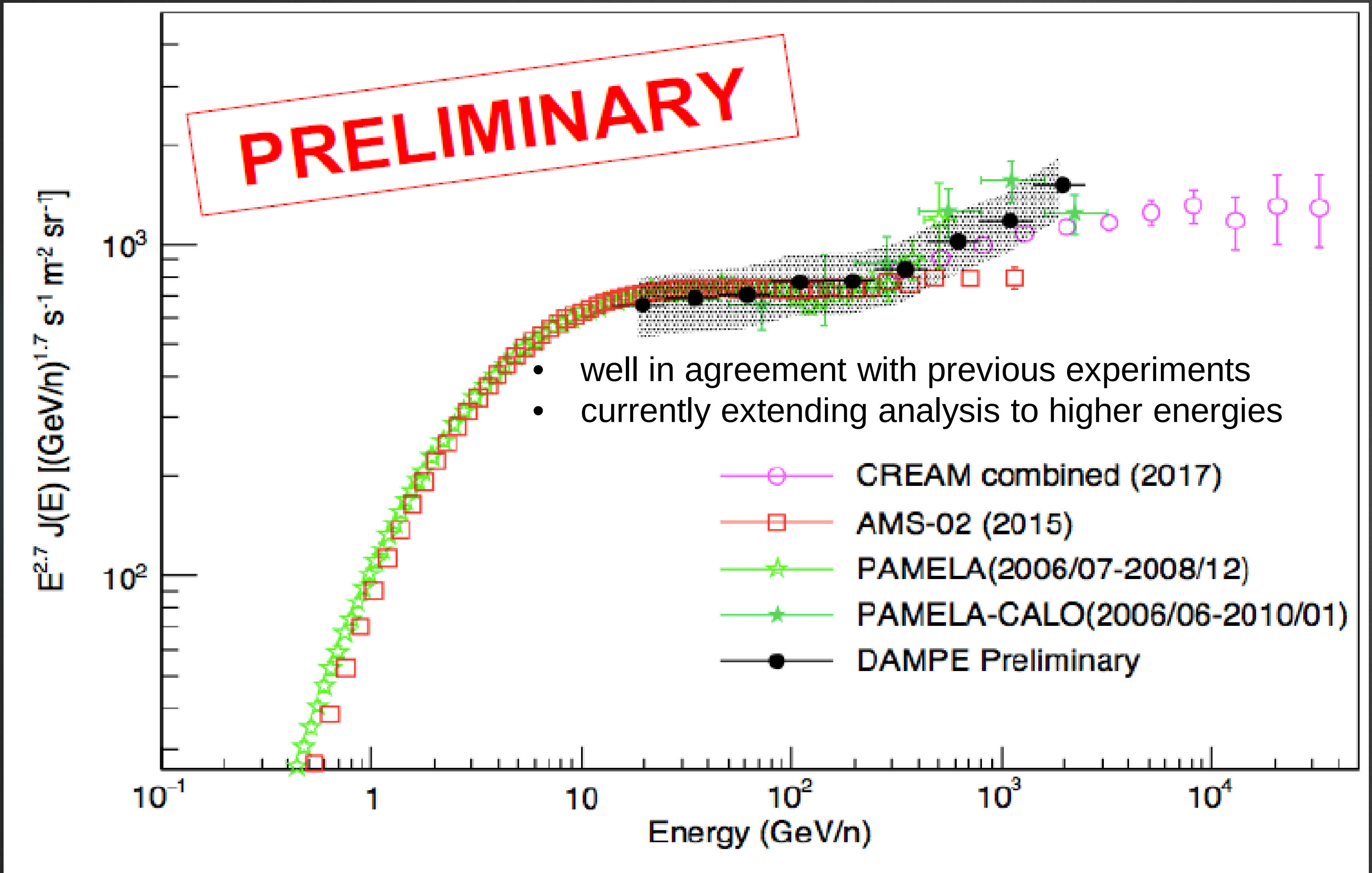
Data set
Jan 1, 2016 – May 31, 2017
2.6 Billon events



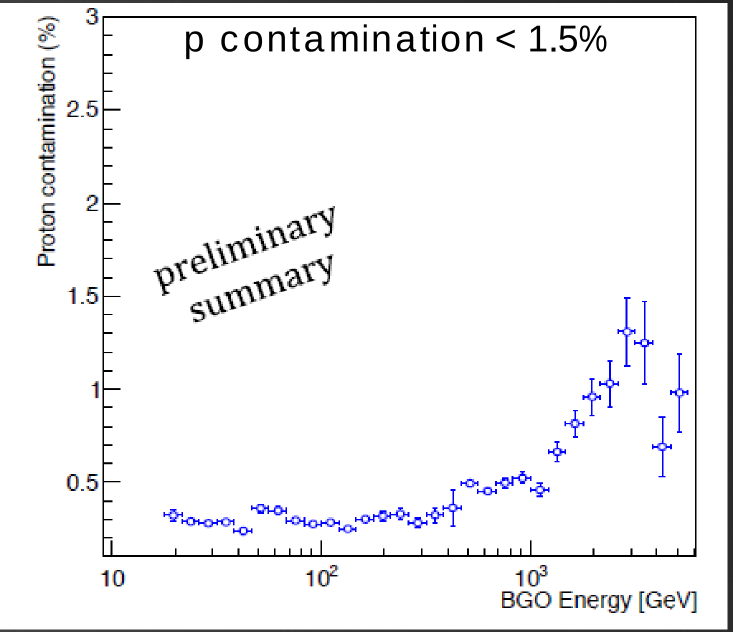
Helium spectrum

(three independent analyses ongoing)

Data set
Jan 1, 2016 – May 31, 2017
2.6 Billon events

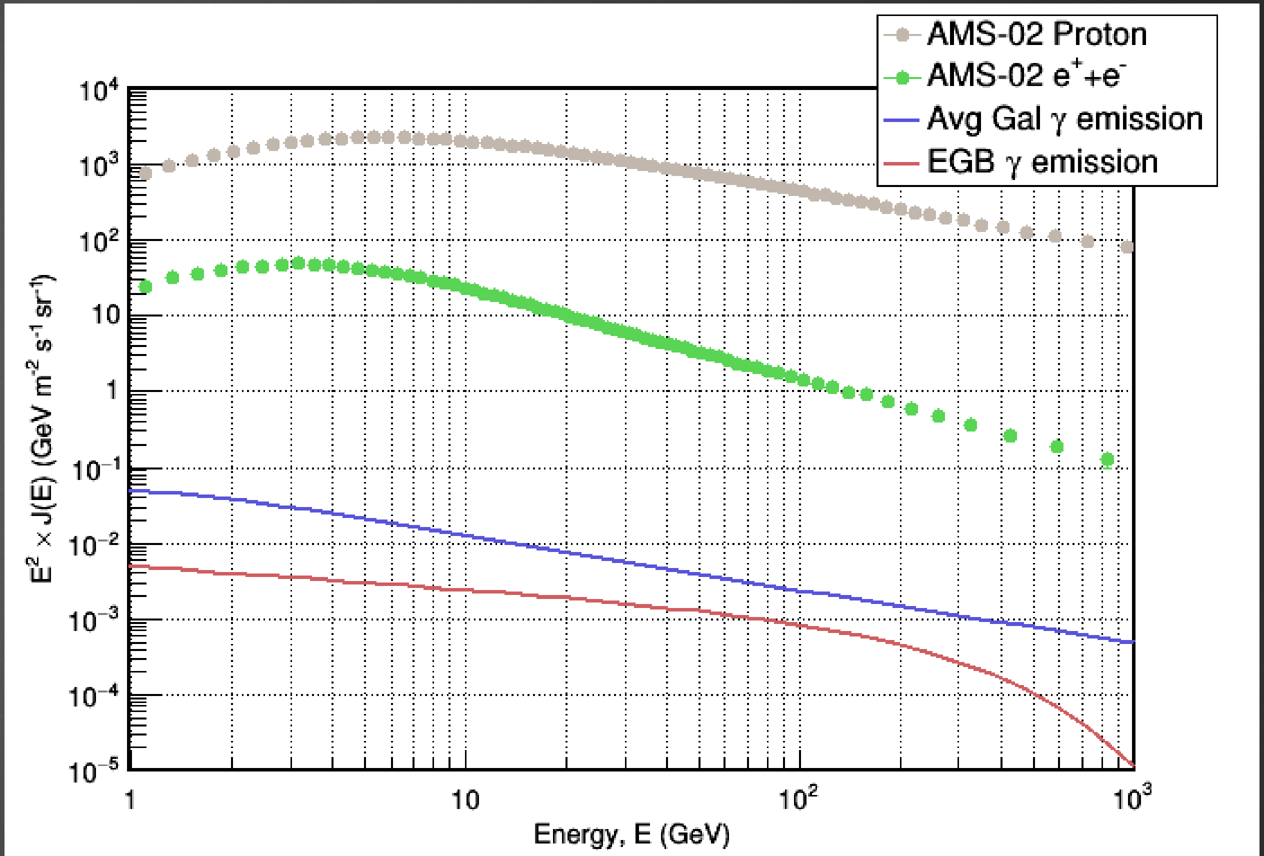


- well in agreement with previous experiments
- currently extending analysis to higher energies



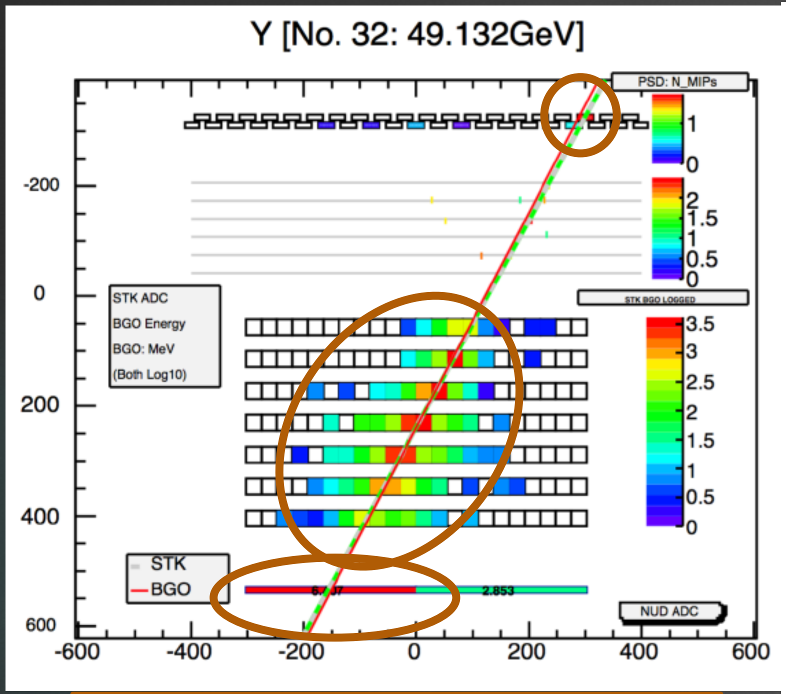
Photons: Selection

- The main background sources are protons and electrons
  - Protons: 10^5 @ E > 100GeV
  - Electrons: 10^3 @ E > 100GeV
- Protons
  - Are mainly rejected using the shower profile and the onboard trigger
- Electrons
  - Are mainly rejected using the PSD and 1st layer of STK
  - Main problem is back scattering at high energy

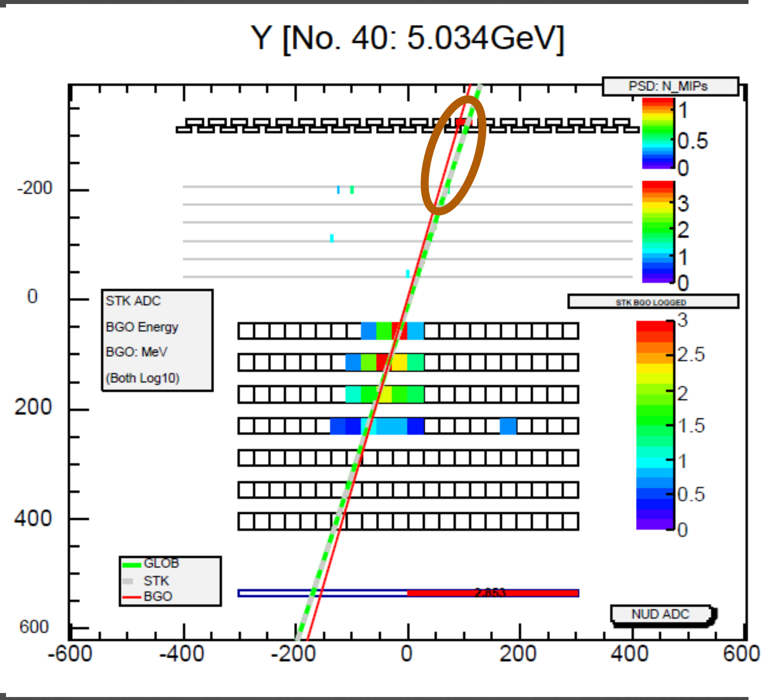


Photons: Selection

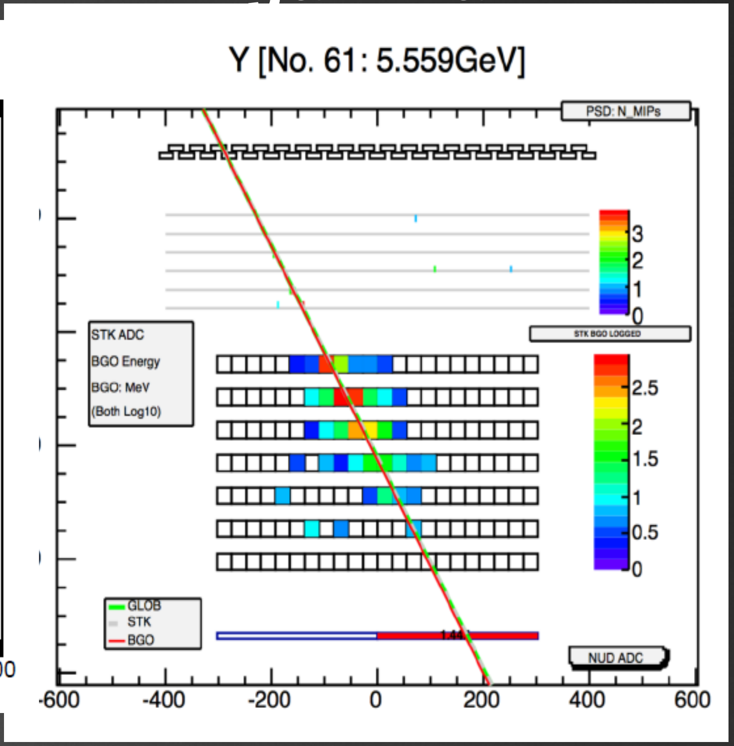
proton



electron



gamma



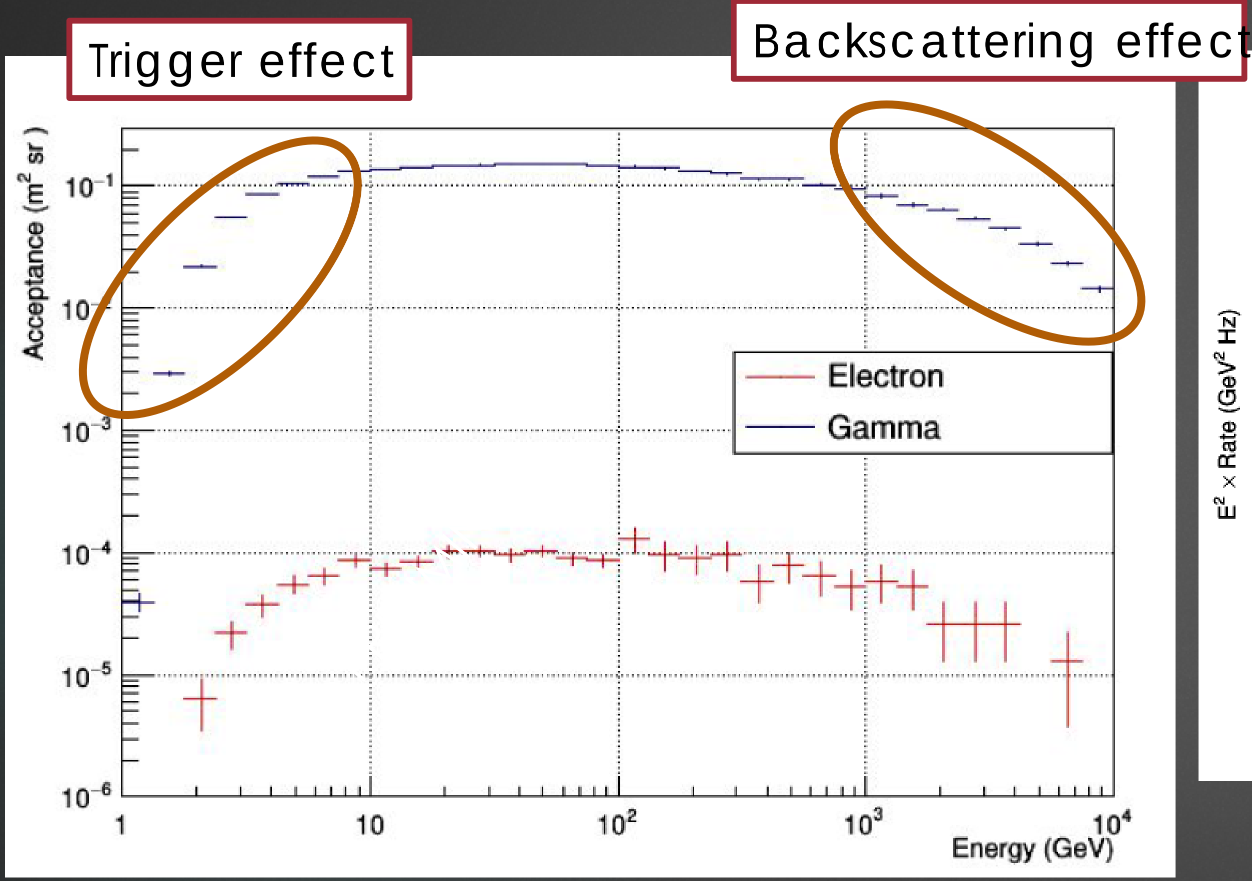
PSD, BGO shower profile and NUD allow to reach a rejection **> 10^7** for hadrons

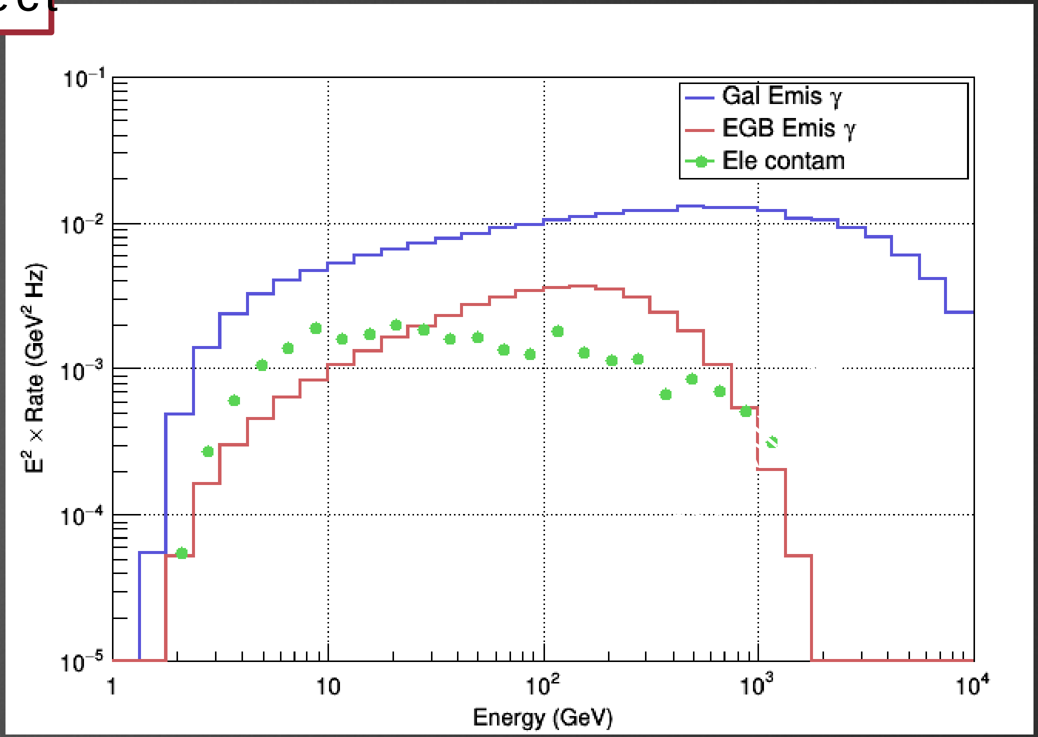
PSD and STK allow to reach a rejection of **10^3** for electrons

Random **F**orest + **C**onvolutional **N**eural **N**etwork are used for PID

Photons: Selection

- Acceptance after the selection criteria applied to reject protons and electrons



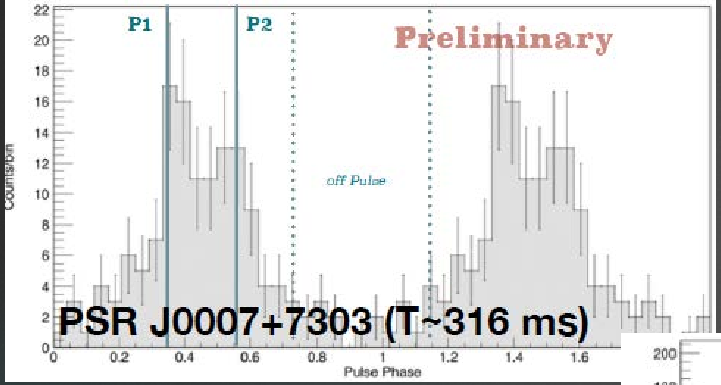


Expected rate w/ selection criteria applied

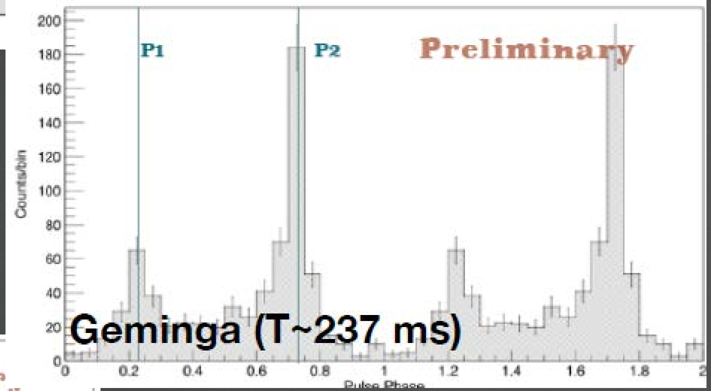
Other PID algorithms are under study to reduce electron contamination at a level below the Extra Galactic Background emission

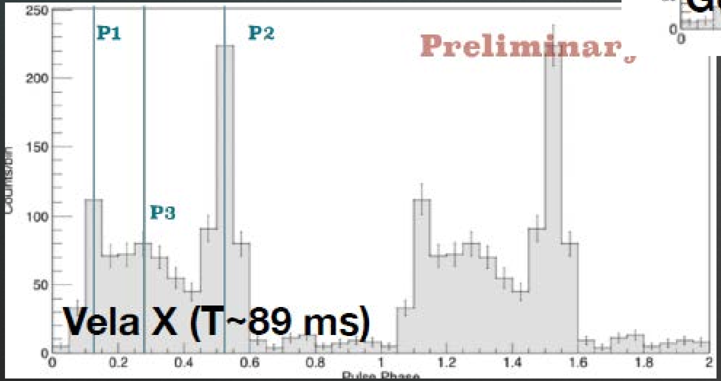
Photons: First results on timing

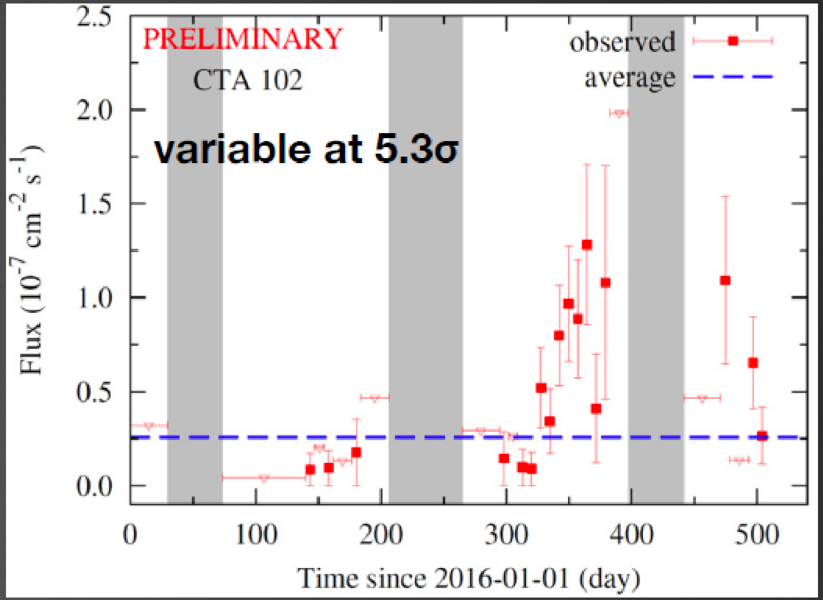
Pulsars and variability



Very good agreement with Fermi and Agile data







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

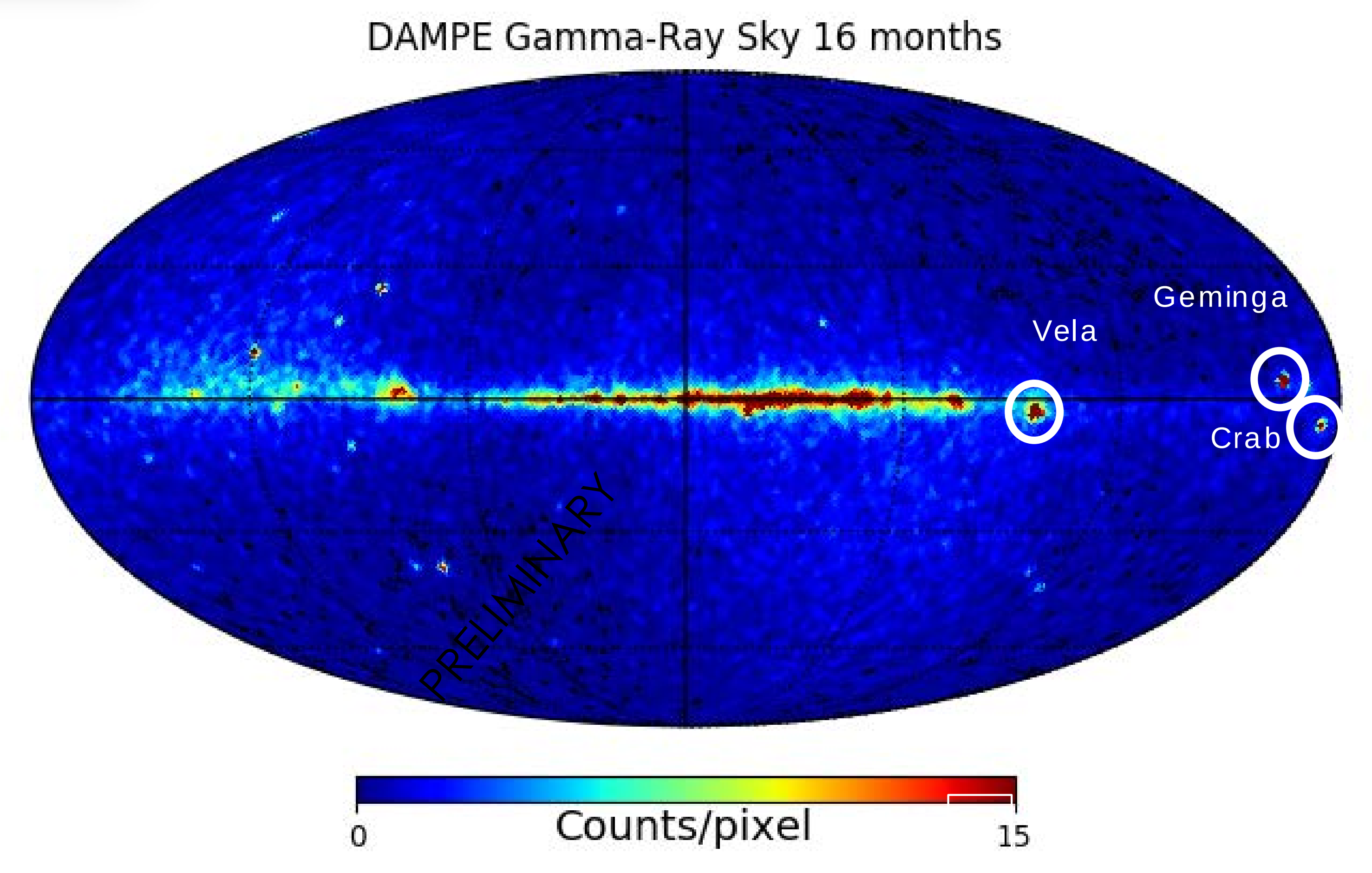
Credential Certification: Zun-Lei Xu (xuzl@pmo.ac.cn)

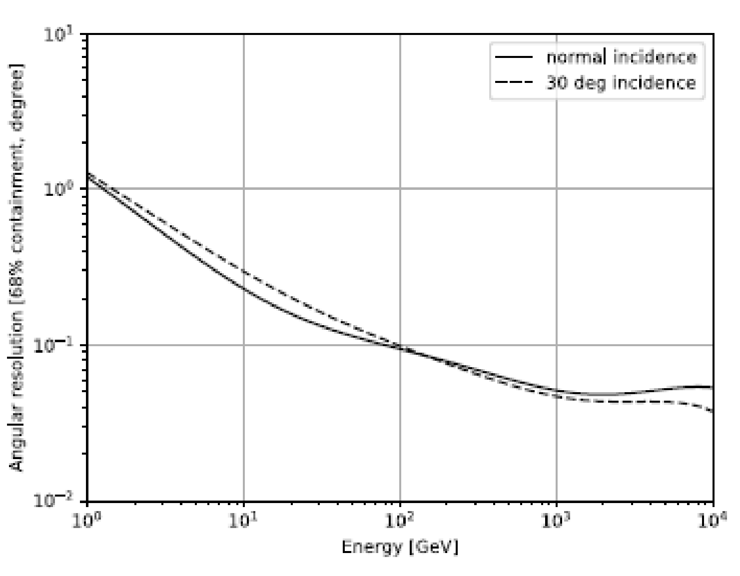
Subjects: Gamma Ray, >GeV, AGN, Blazar, Quasar

Referred to by ATel #: 9924, 10007, 10292

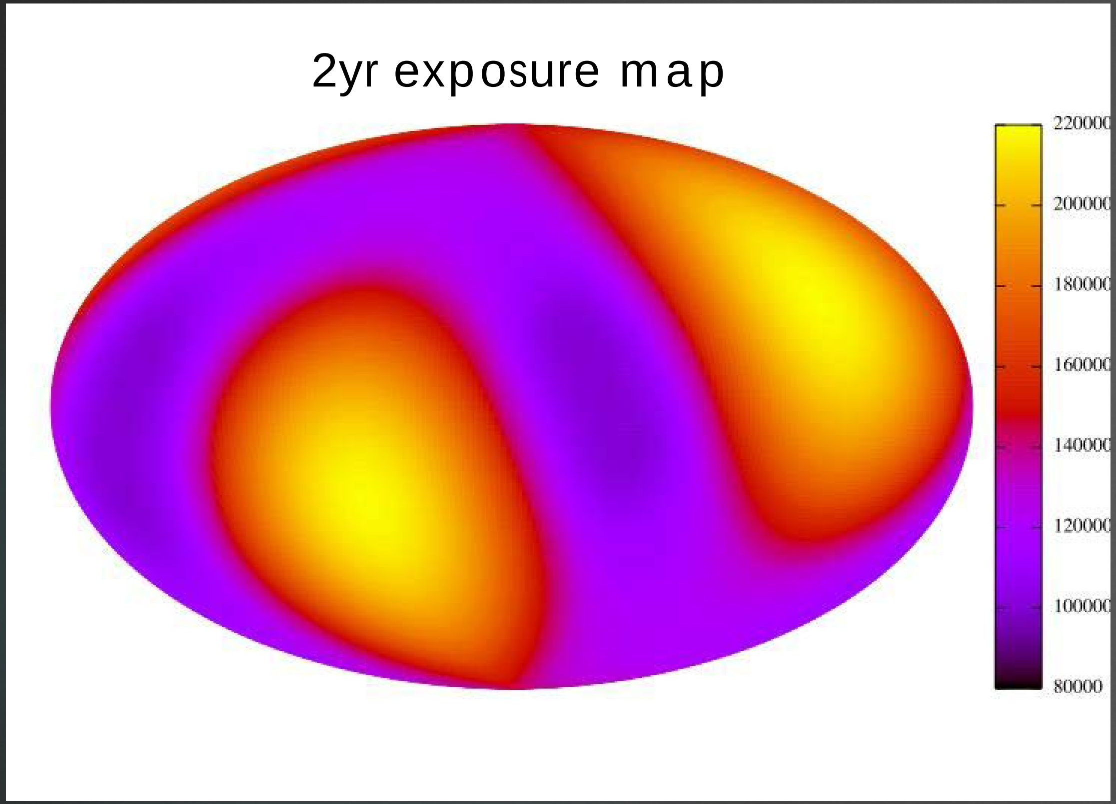
DAMPE Counts map

E > 1GeV
16 months

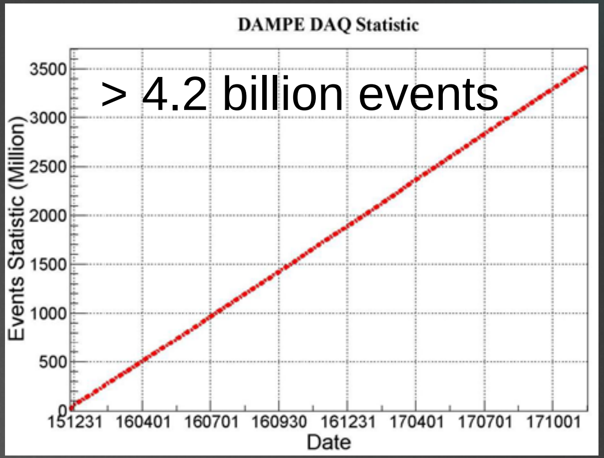


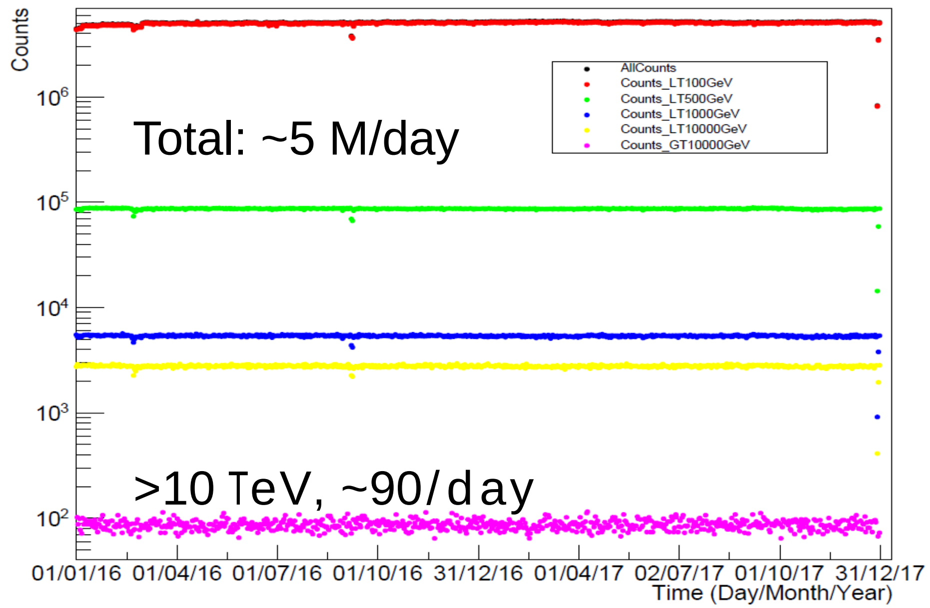


Present status



4 full sky surveys in 2 years





Very stable count rate in the last 2 years

Conclusion

- The detector performance in flight are excellent
- The understanding of the detector behavior and calibration (alignments, gains, charge ID etc) is improving with the consequent improvements in reconstruction and simulation software
- The electron + positron spectrum at TeV energies has been precisely measured
  - A clear spectral break has been directly measured at ~1TeV
- Nuclei measurements are ongoing
- Photon detection capability is demonstrated but more statistics to profit the excellent energy resolution at high energy is needed
- **Detector calibration with particle beams at CERN was fundamental to the success of DAMPE**

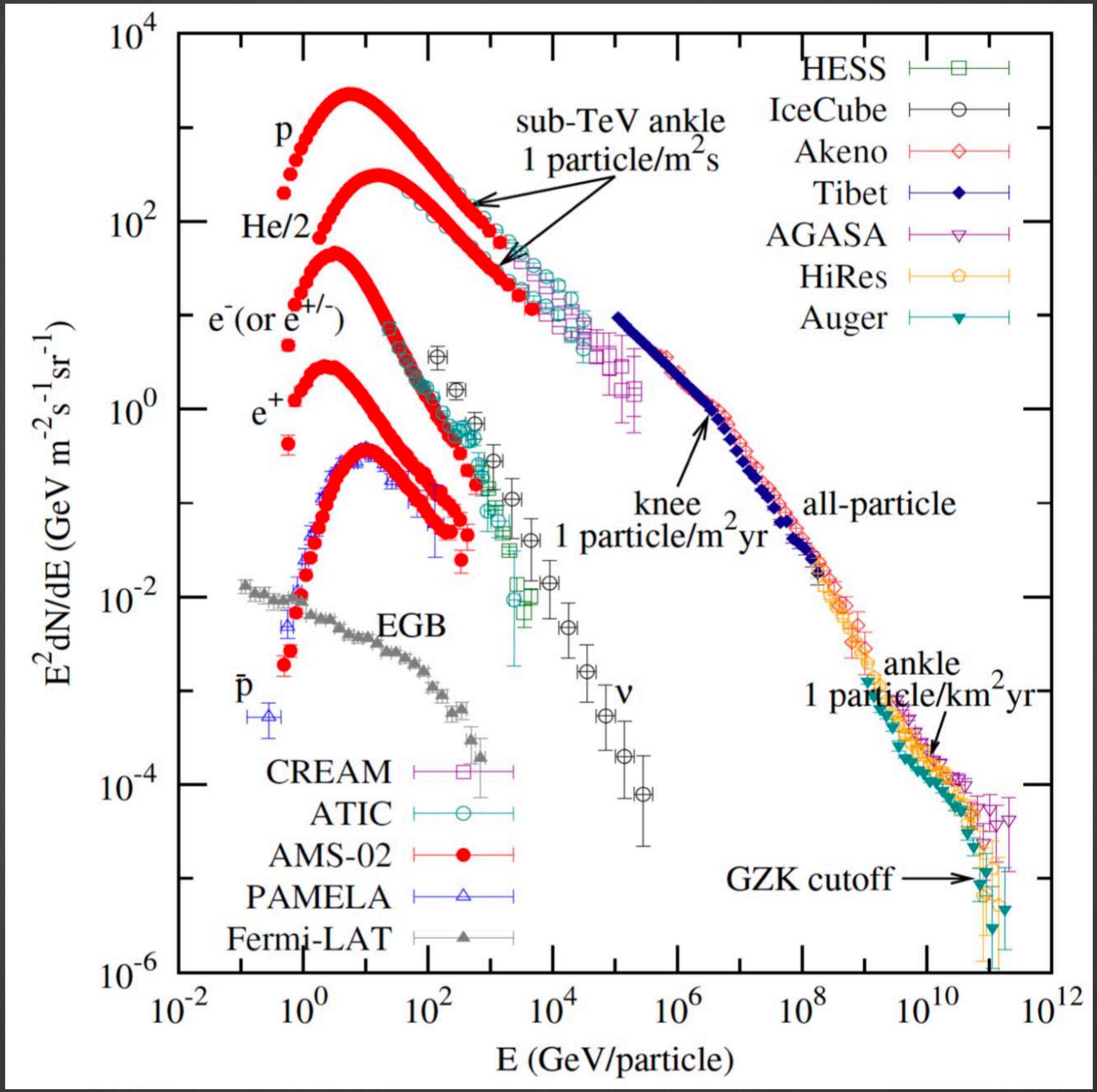
2016

2017

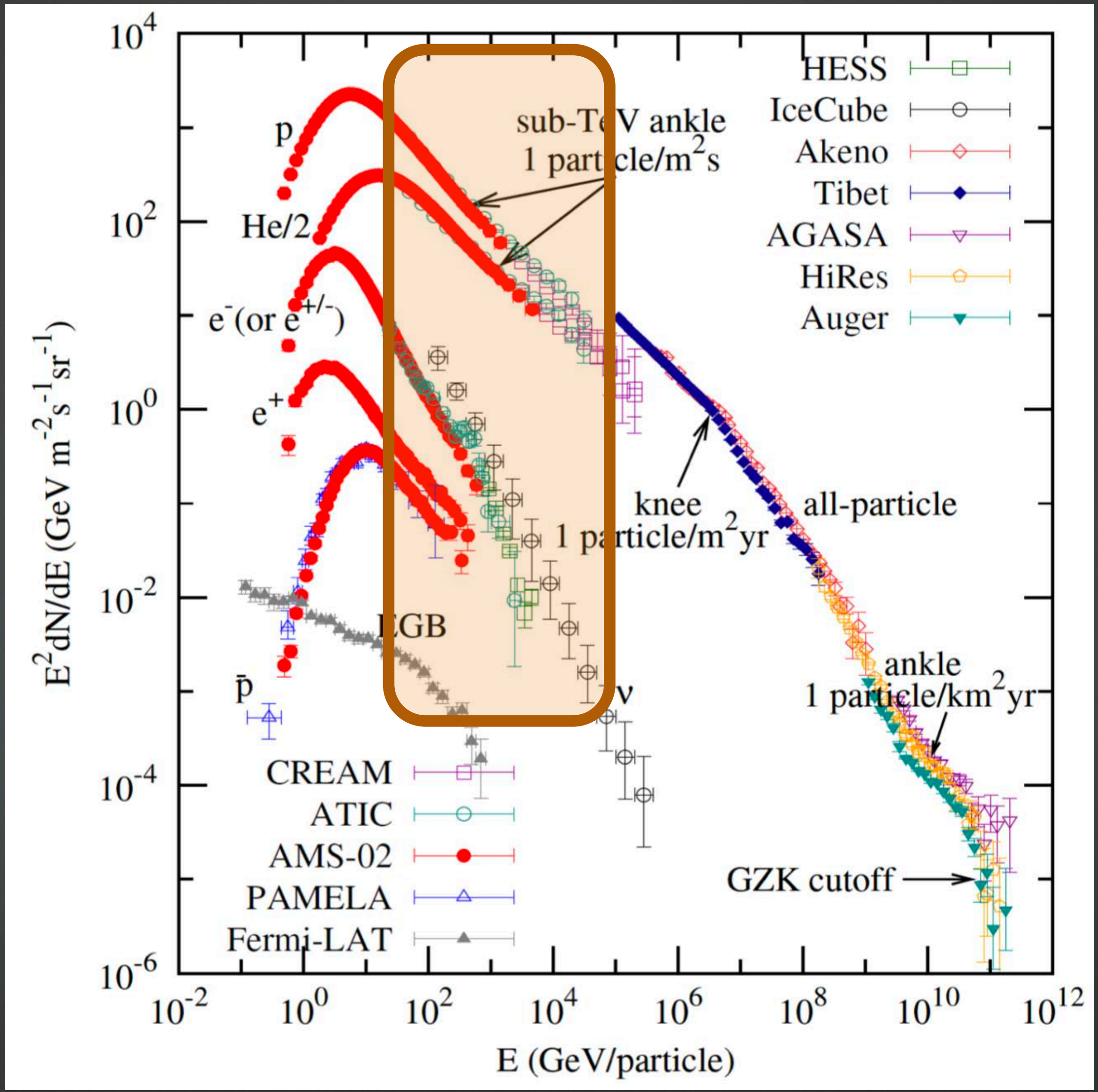
Thanks for your attention!

Backup

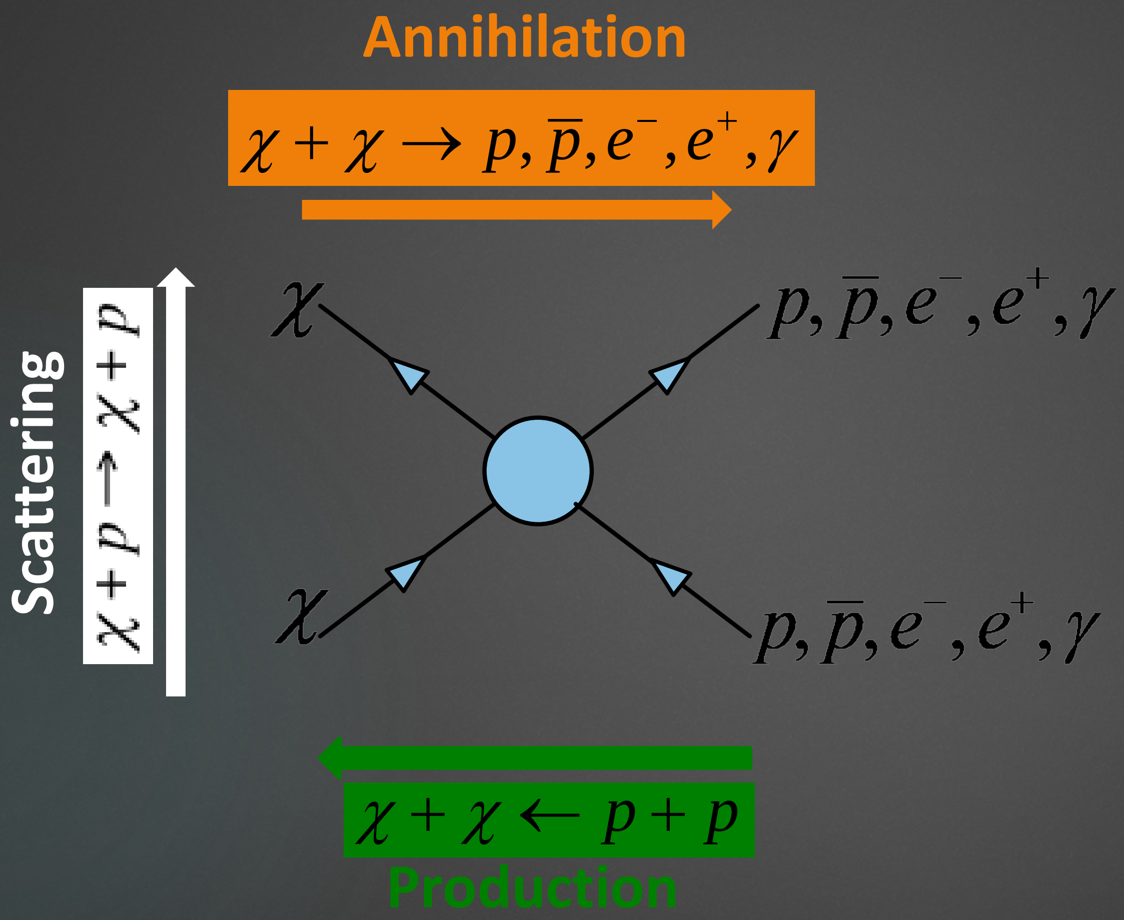
All particle spectrum



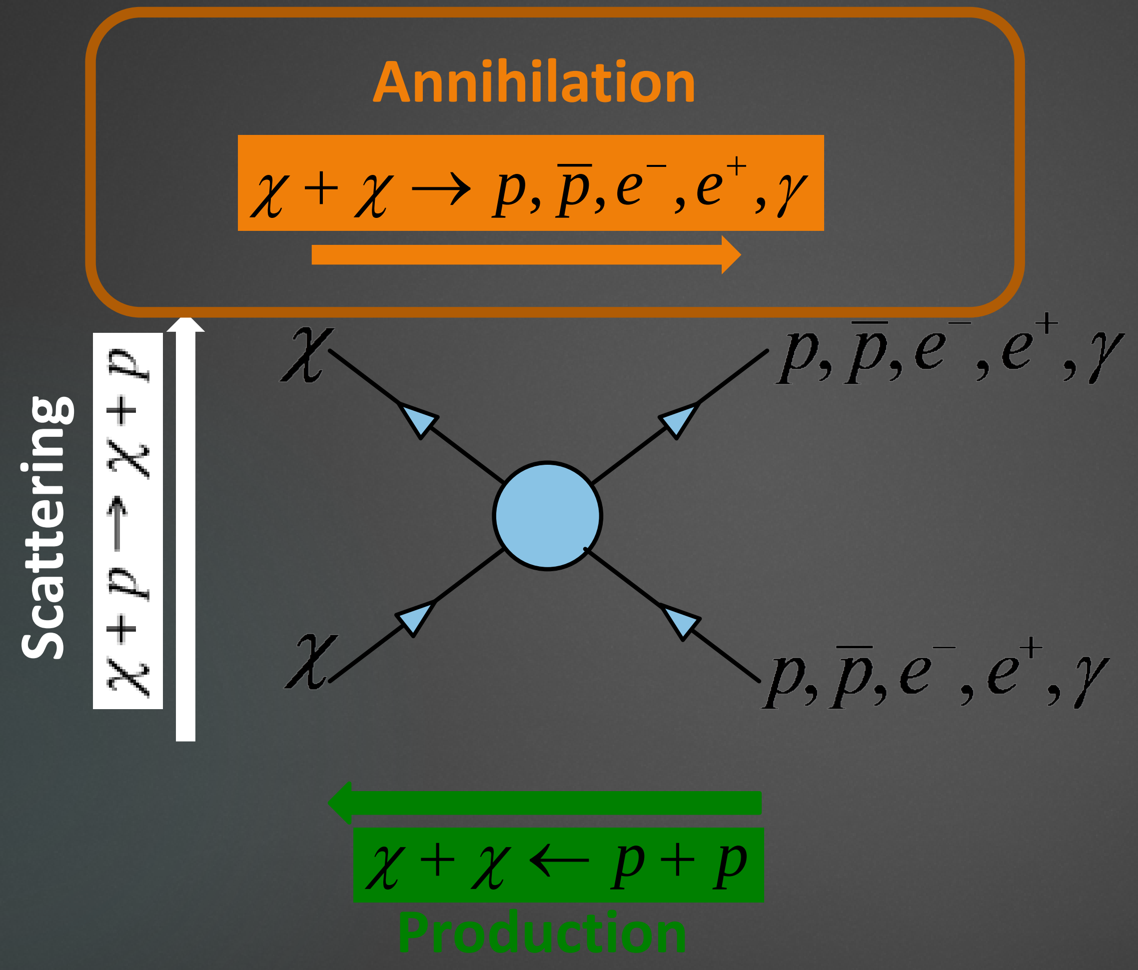
All particle spectrum



The quest for dark matter

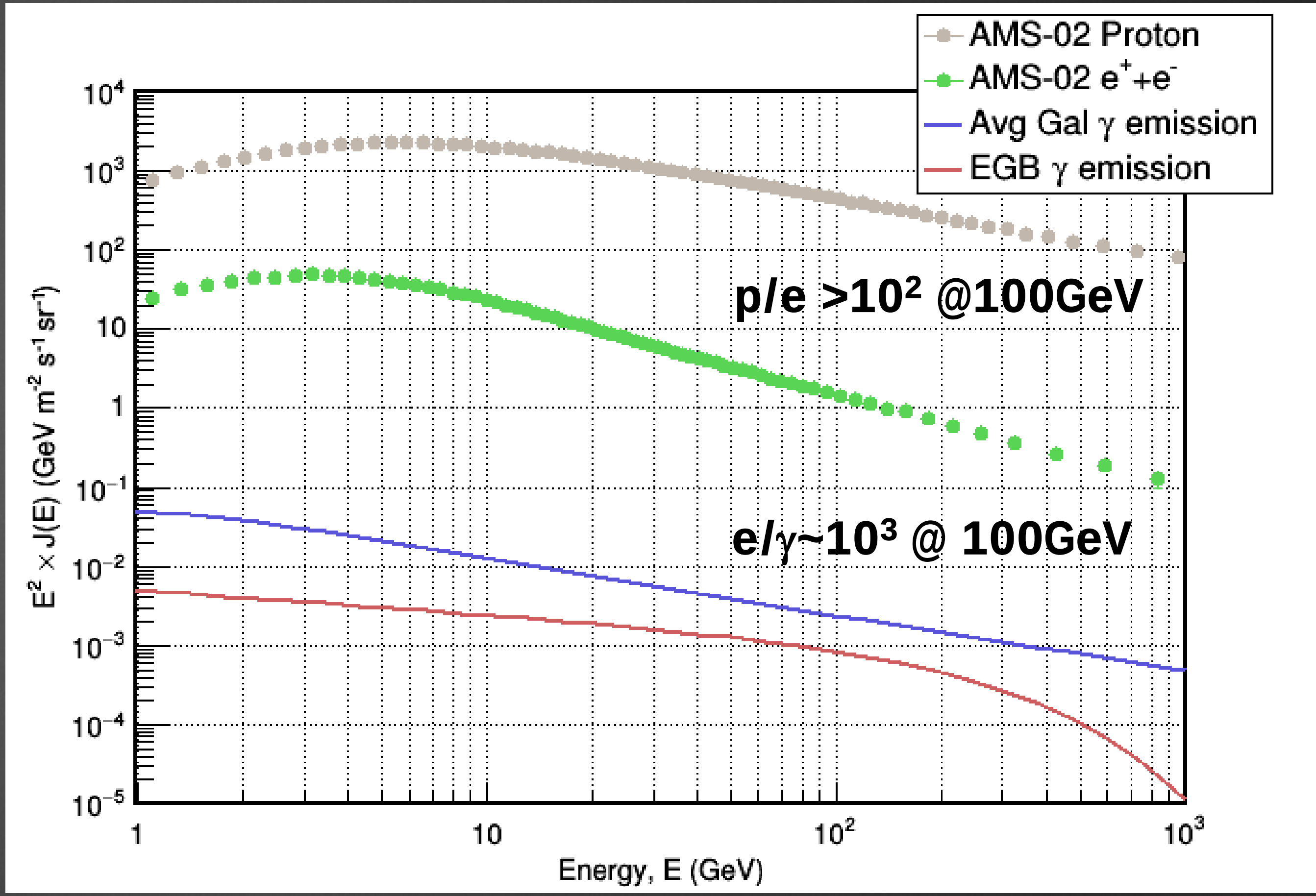


The quest for dark matter



Challenges

- Particle identification
  - A very high rejection power is needed
- Dynamical Range
  - Requirement for calorimeter elements: MeV to TeV
  - Electron & gamma-ray: GeV to few TeV

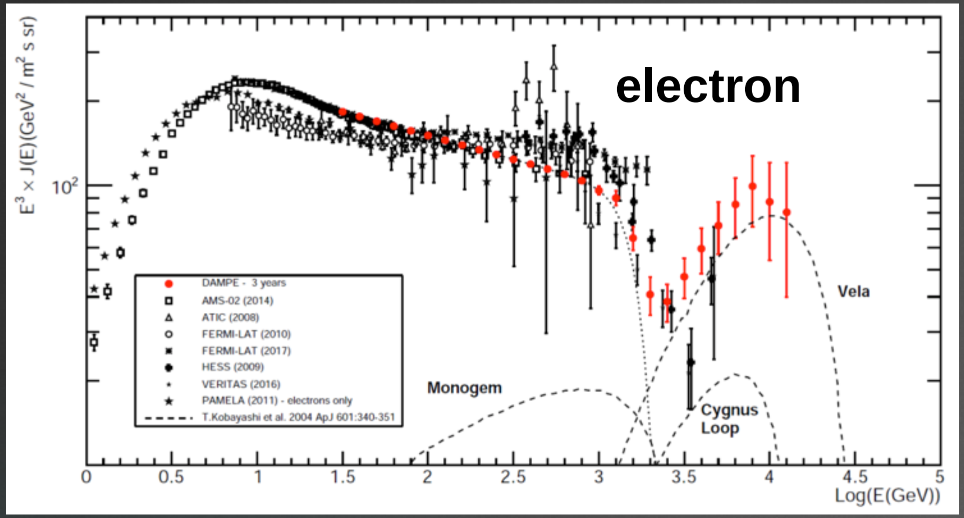


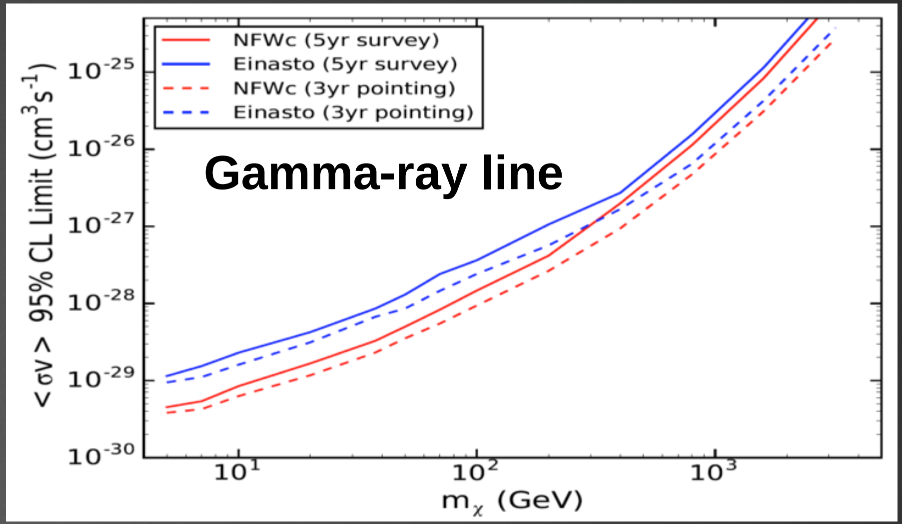
Expected performance

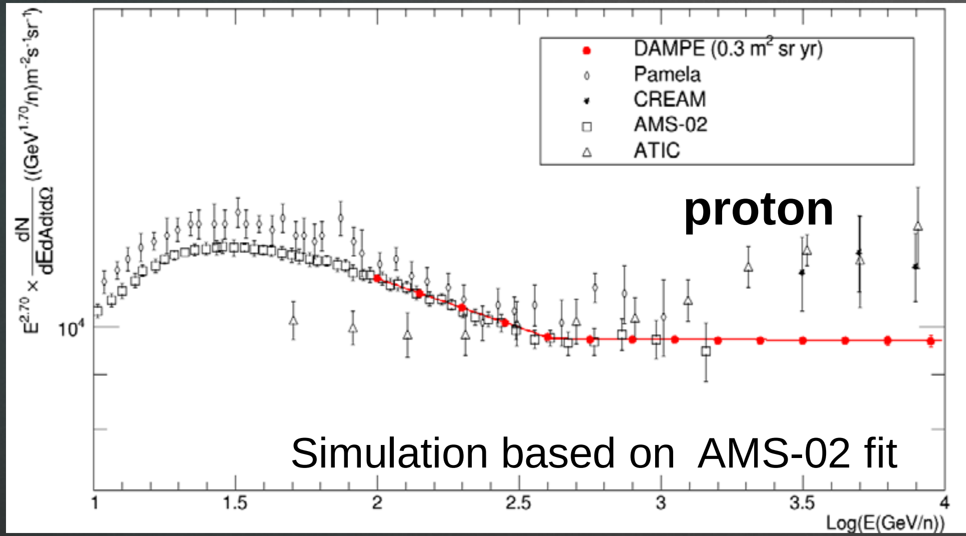
Parameter	Value
Energy range of gamma rays/electrons	5GeV to 10 TeV
Energy resolution (e and γ)	1.5% at 800 GeV
Energy range of protons/heavy nuclei	50 GeV to 500 TeV
Energy resolution of protons	40% at 800 GeV
Eff. area at normal incidence (γ-rays)	1100 cm^2 at 100 GeV
Geometric factor for electrons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

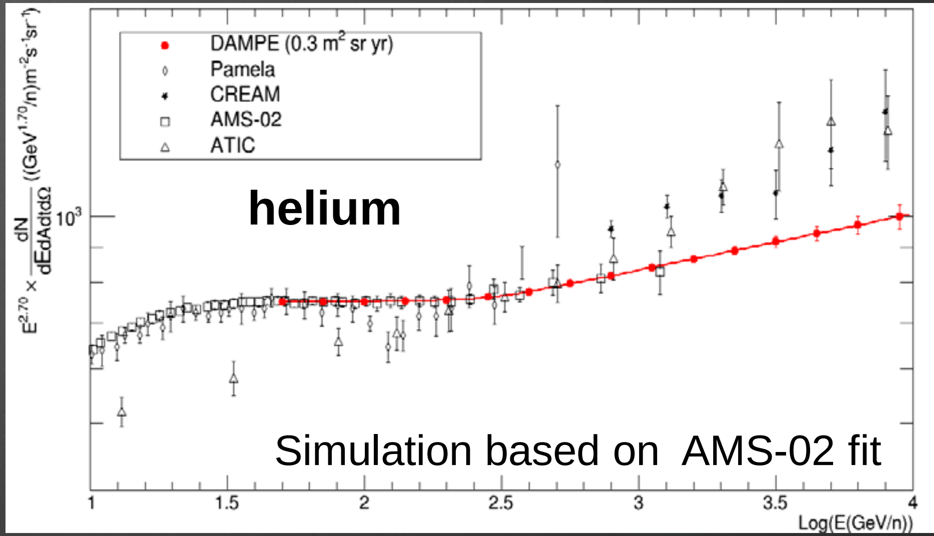
Astroparticle Physics 95 (2017) 6

Expected performance in 5 years

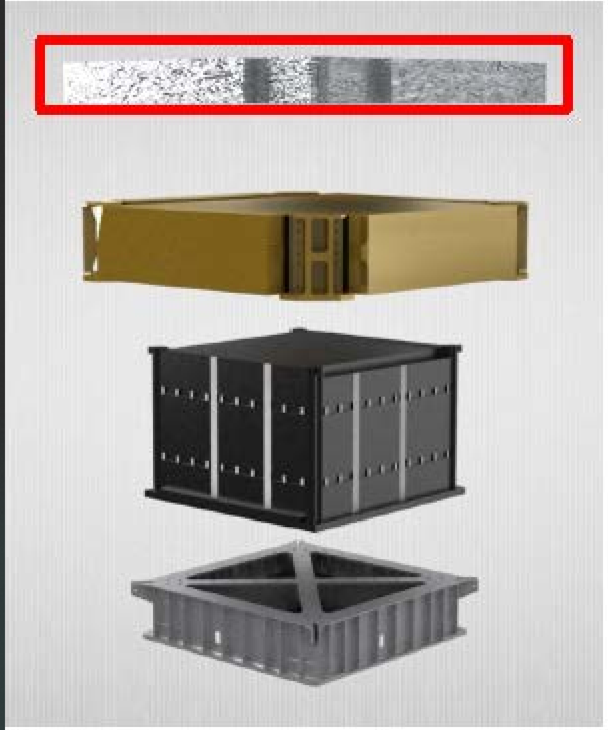








Instrument development: PSD



2 layers (x , y) of 1 cm thick strips, 2.8 cm wide and 88.4 cm long

- Active area: 82 cm × 82 cm
- Weight : ~103 kg
- Power: ~ 8.5 W

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

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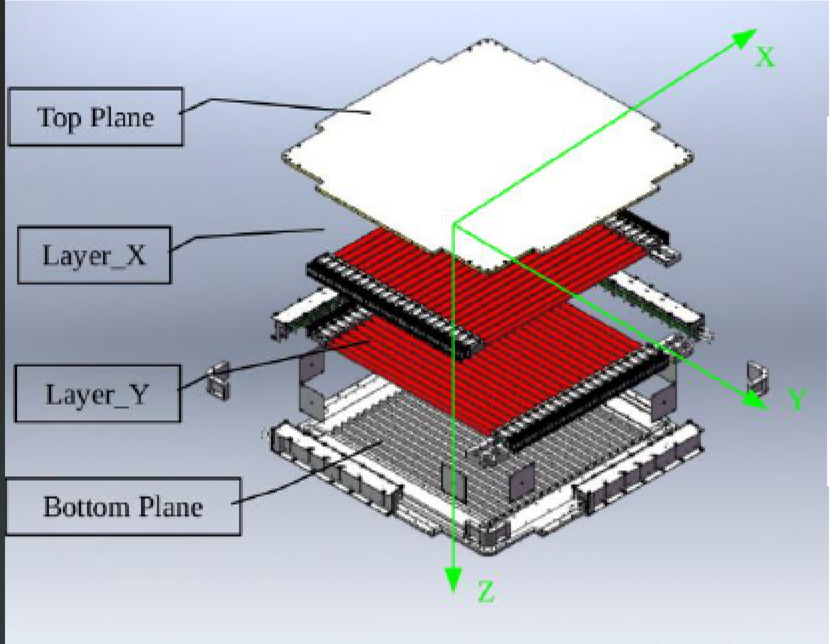
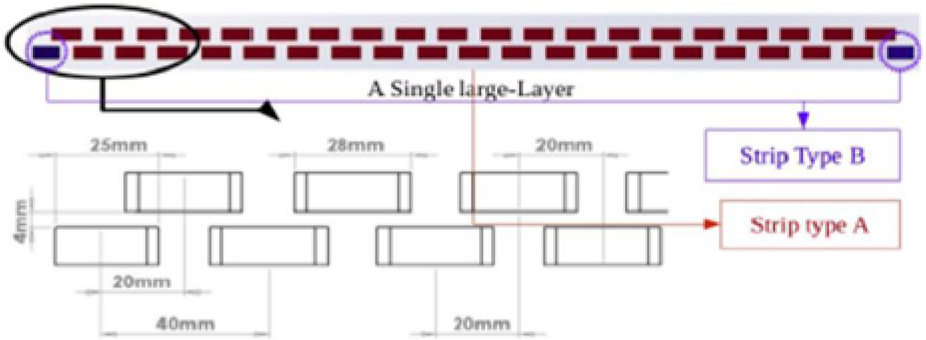
Instrument development: PSD





- Strip staggered by 0.8 cm
- 41 modules each layer
- Charge resolution: 0.07@Proton

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

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

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Instrument development: STK

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

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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

Instrument development: BGO

- 14 layers of 22 BGO crystals
  - Dimension of BGO bar:
    2.5 cm × 2.5 cm × 60 cm
  - Hodoscopic stacking alternating orthogonal layers
  - r.l: ~$32X_0$, NIL: 1.6
- 2 PMTs coupled with each BGO bar in two ends
- Electronics boards attached to each side

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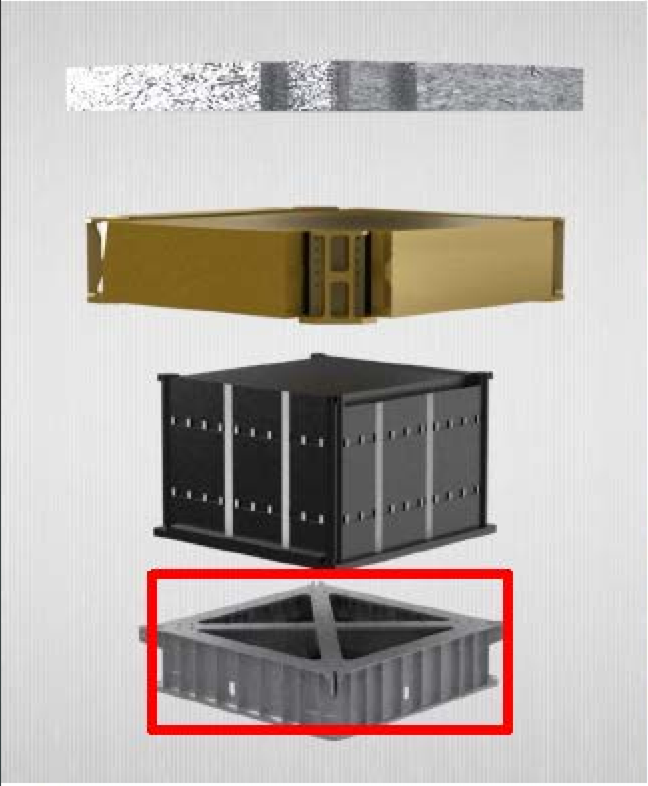
Instrument development: NUD



- 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

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

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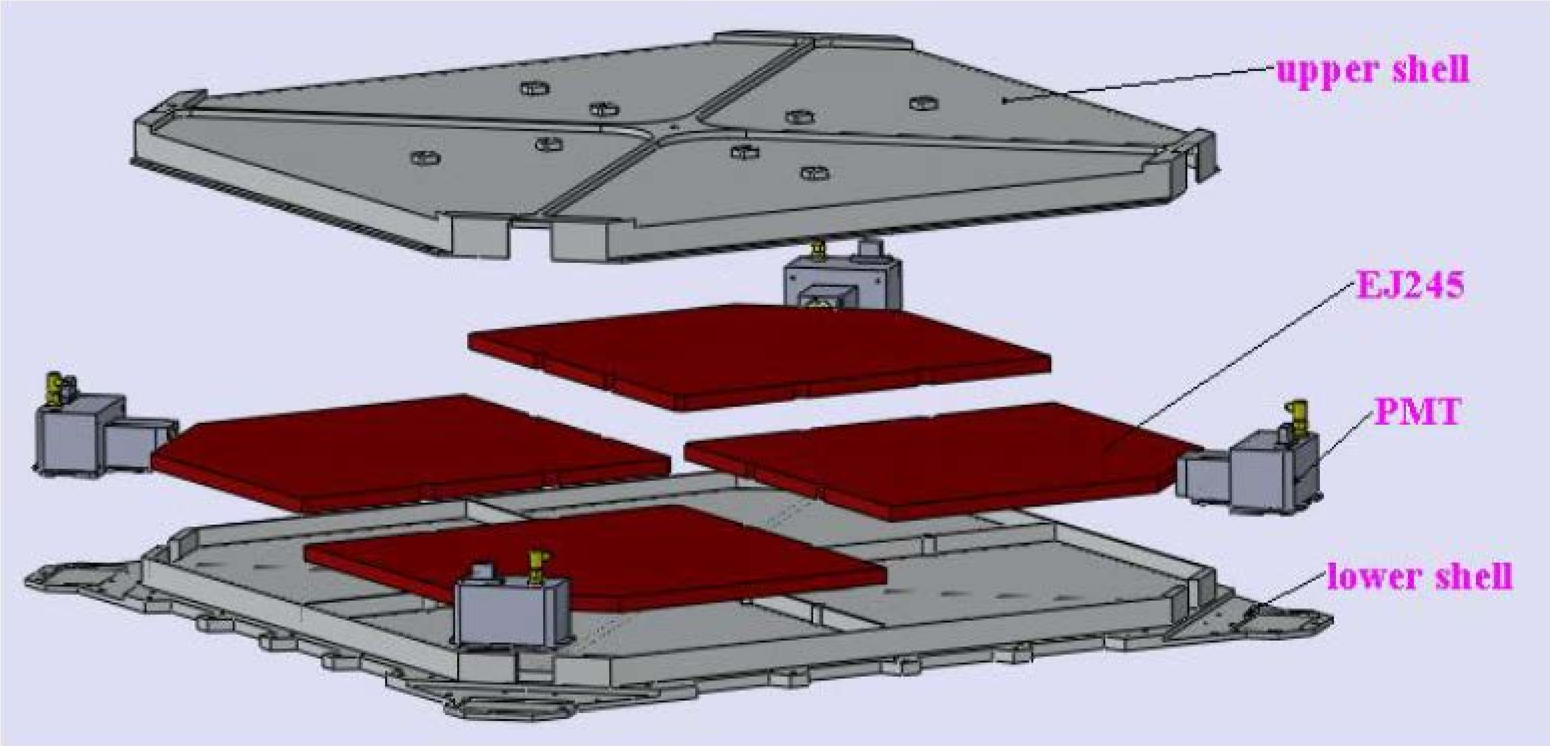
Instrument development: NUD



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

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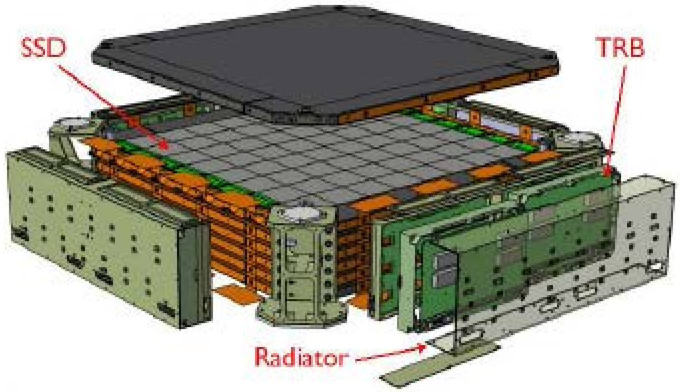
Instrument development: STK

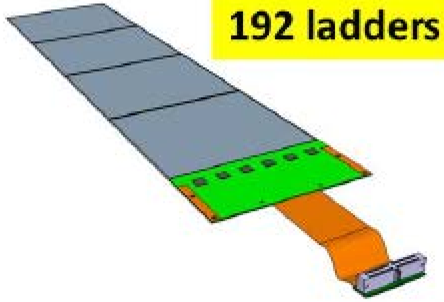


- 12 layers (6x, 6y) of single-sided Si strip detector mounted on 7 support trays
- Tungsten plates (1mm thick) integrated in trays 2, 3, 4 (from the top)
  - Total 0.85 X_0 for photon conversion

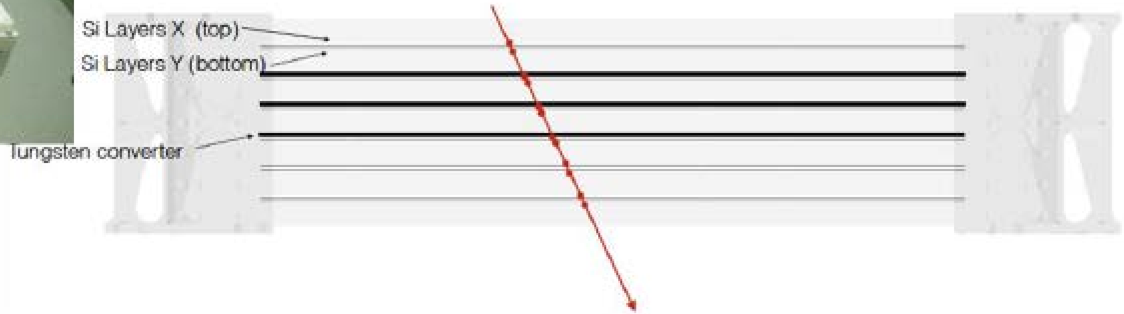
768 silicon sensors
95 x 95 x 0.32 mm^3

1,152 ASICs

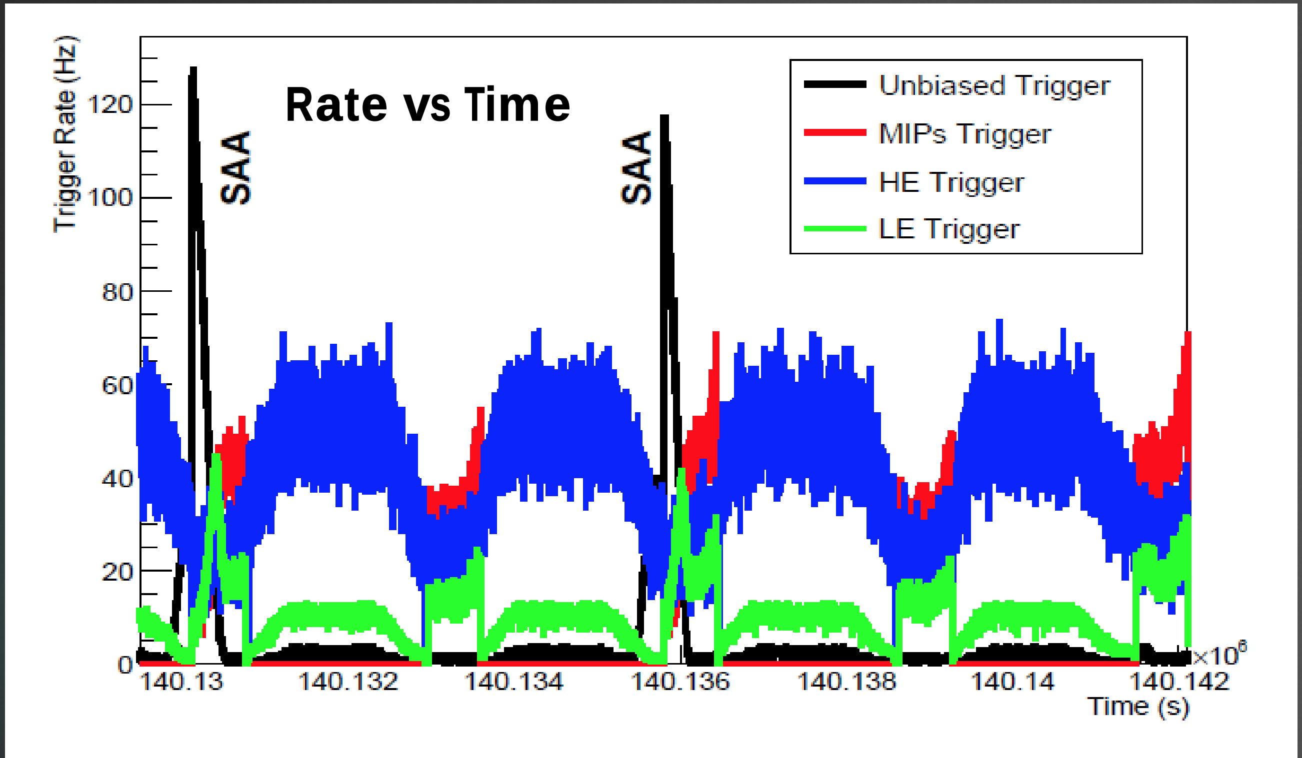
73,728 channels

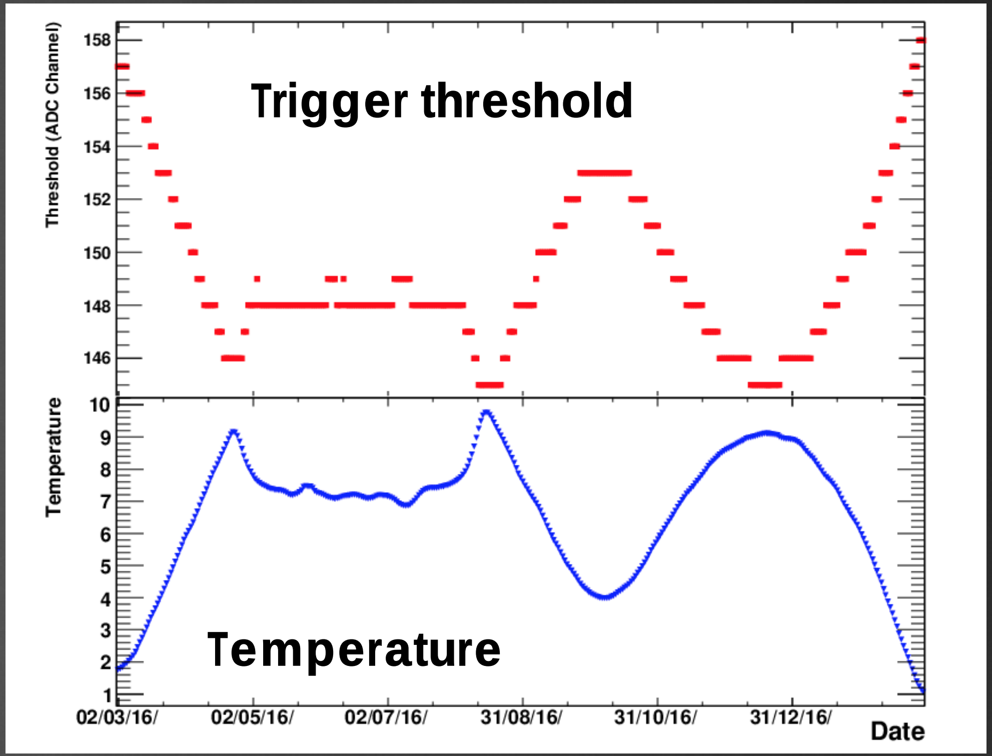


192 ladders



Trigger rate

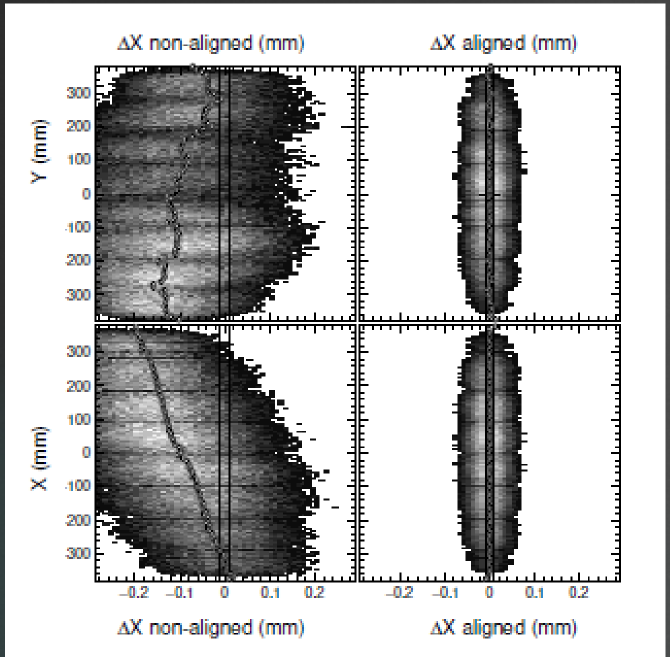


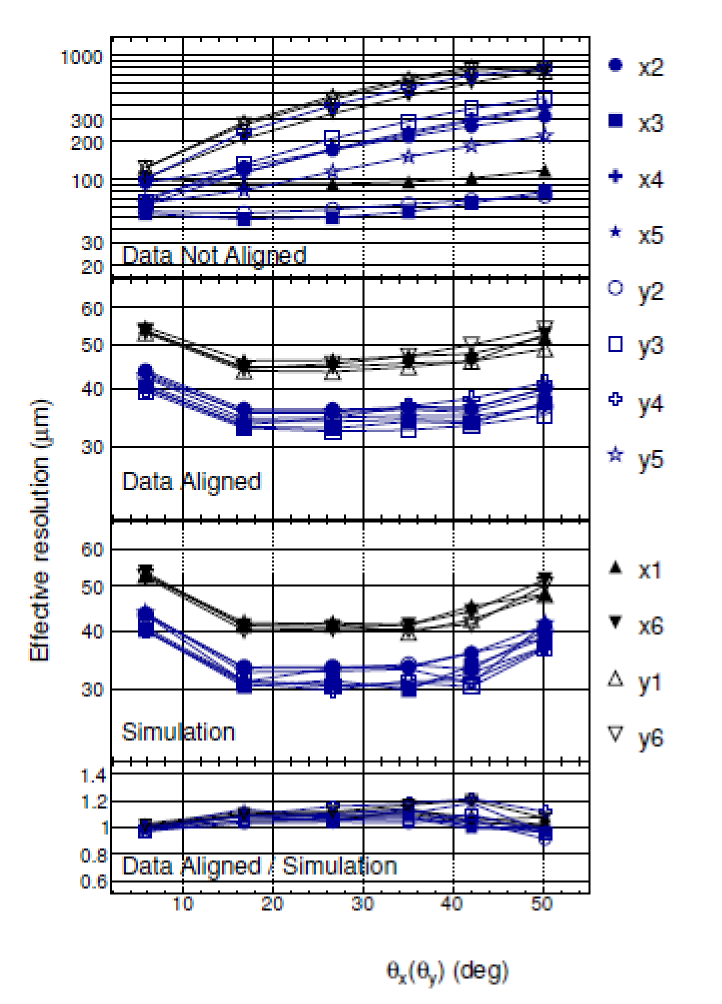


- HET trigger rate 20 – 60 Hz
- Events in South Atlantic Anomaly are not used for analysis

- variation with temperature
- ~13 ACD (0.04 MIP) in full temperature range

On orbit calibration: STK

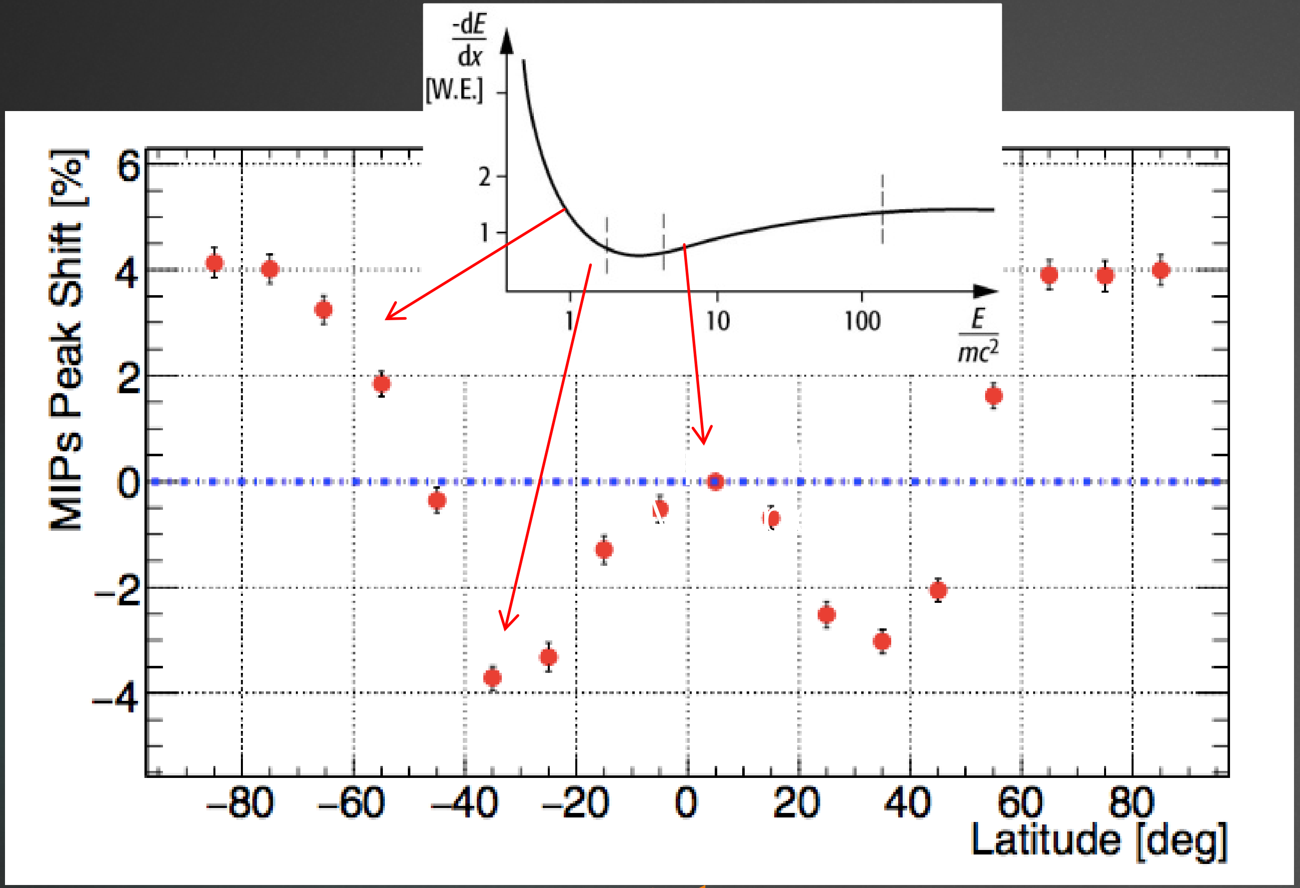




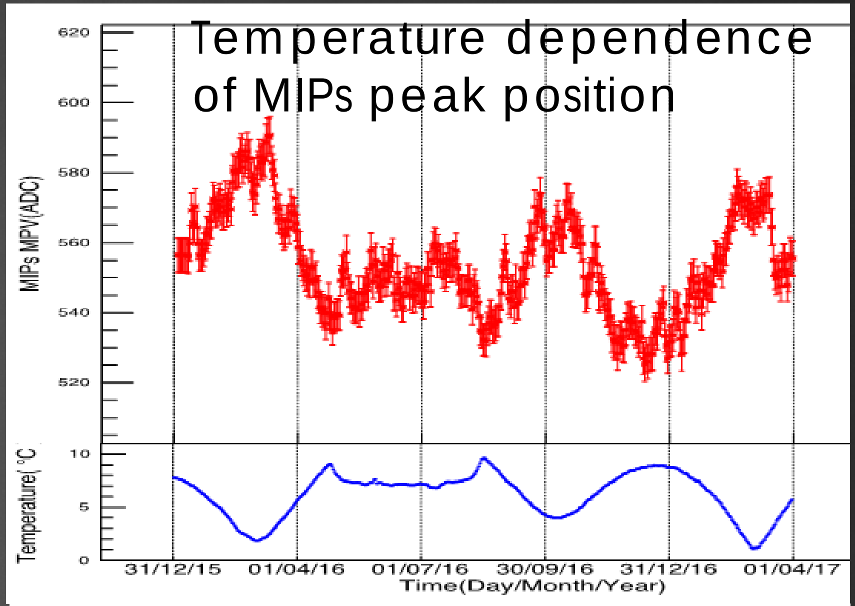
- On orbit STK alignment using "mips" (i.e. not showering particles).
- The alignment (done every two weeks) allows us to achieve a spatial resolution better than 40μm on central STK planes

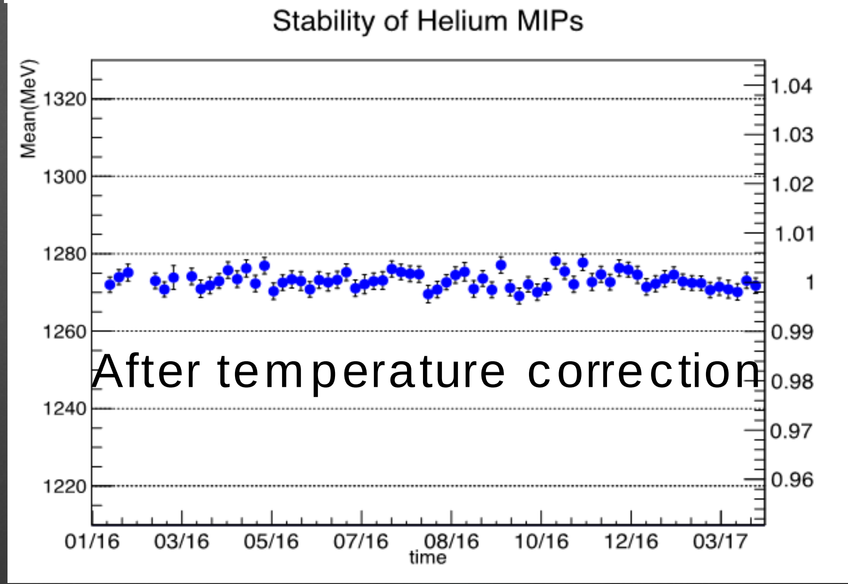
A.Tykhonov et al. - NIMA - Volume 893, 43-56

On orbit calibration: BGO



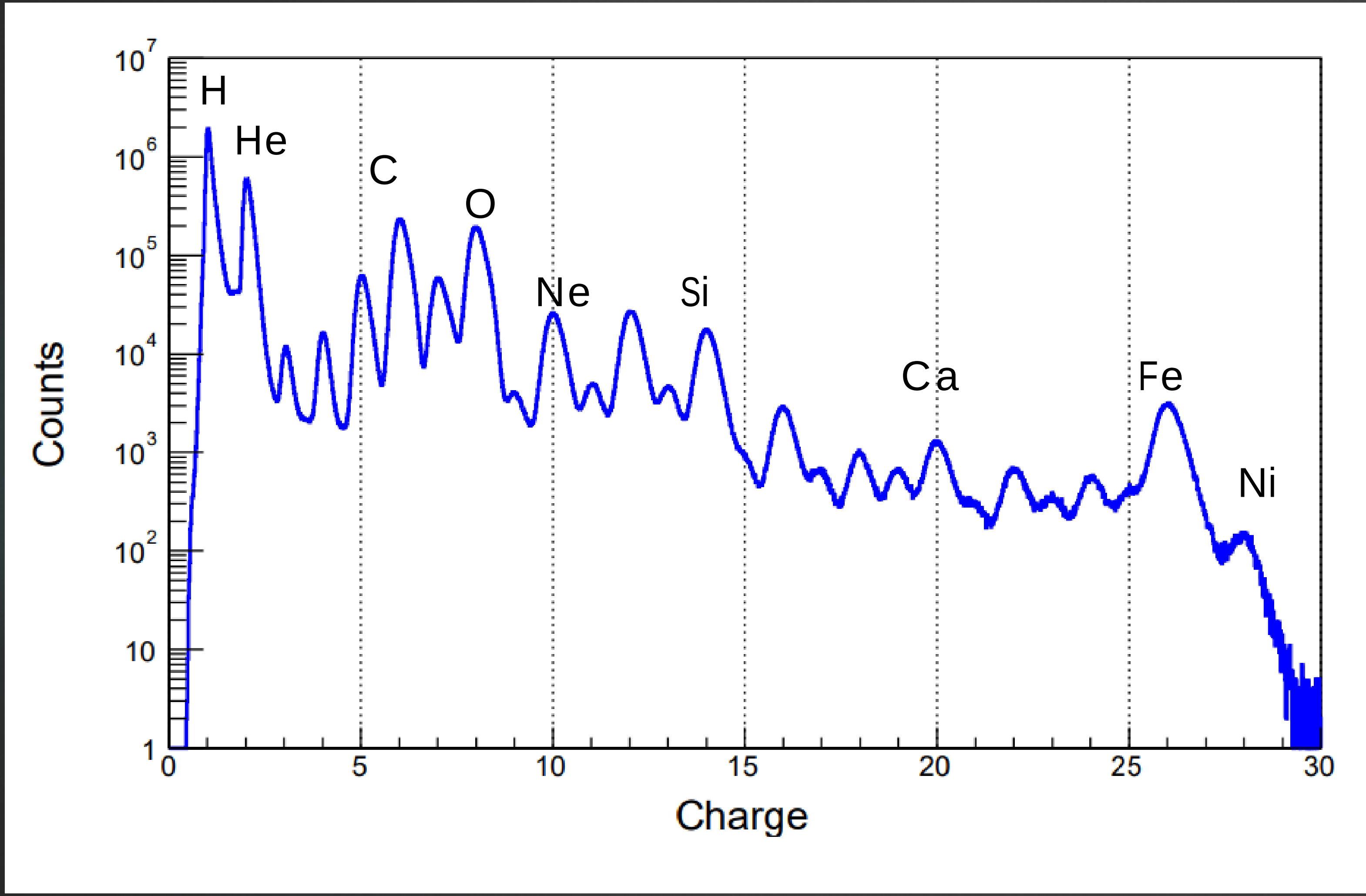
Vertical rigidity cut-off





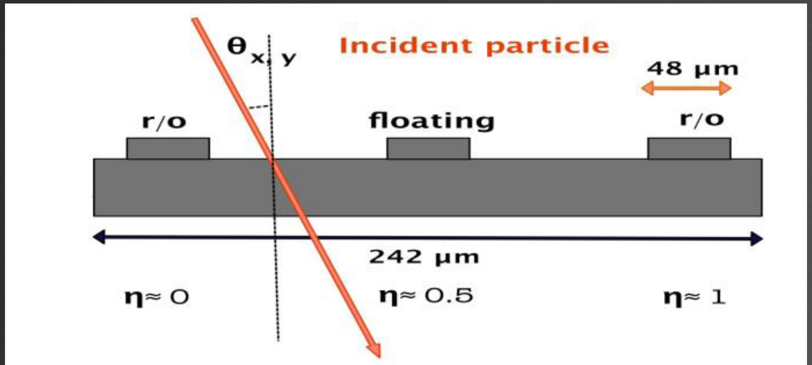
- The “mip” (i.e. not showering particles) peak changes with latitude due to the geomagnetic cut-off.

On orbit performance: PSD

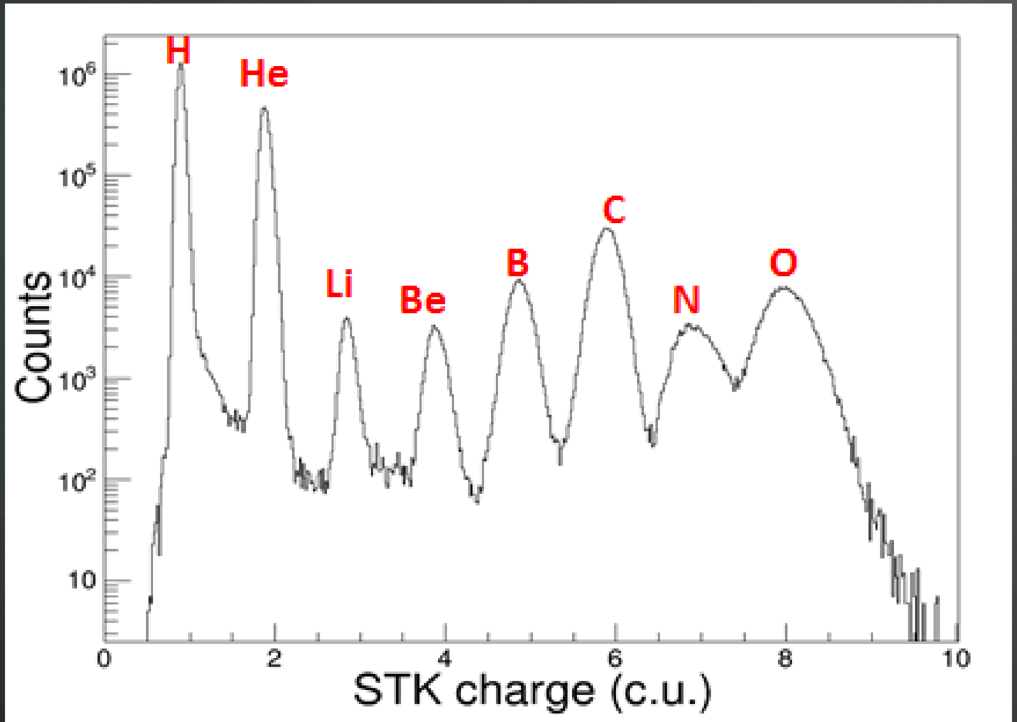


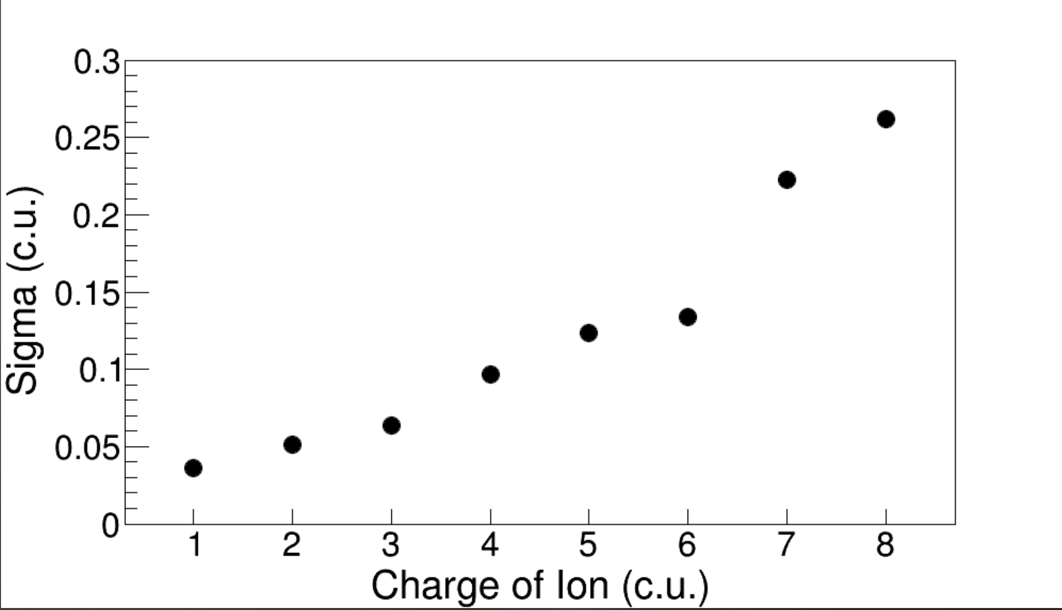
Nuclei	Charge Resolution
p	0.13
He	0.12
Li	0.14
Be	0.21
B	0.17
C	0.18
N	0.21
O	0.21
Fe	0.32

On orbit performance: STK



STK Charge sharing reconstruction: Correction for hit position and angle





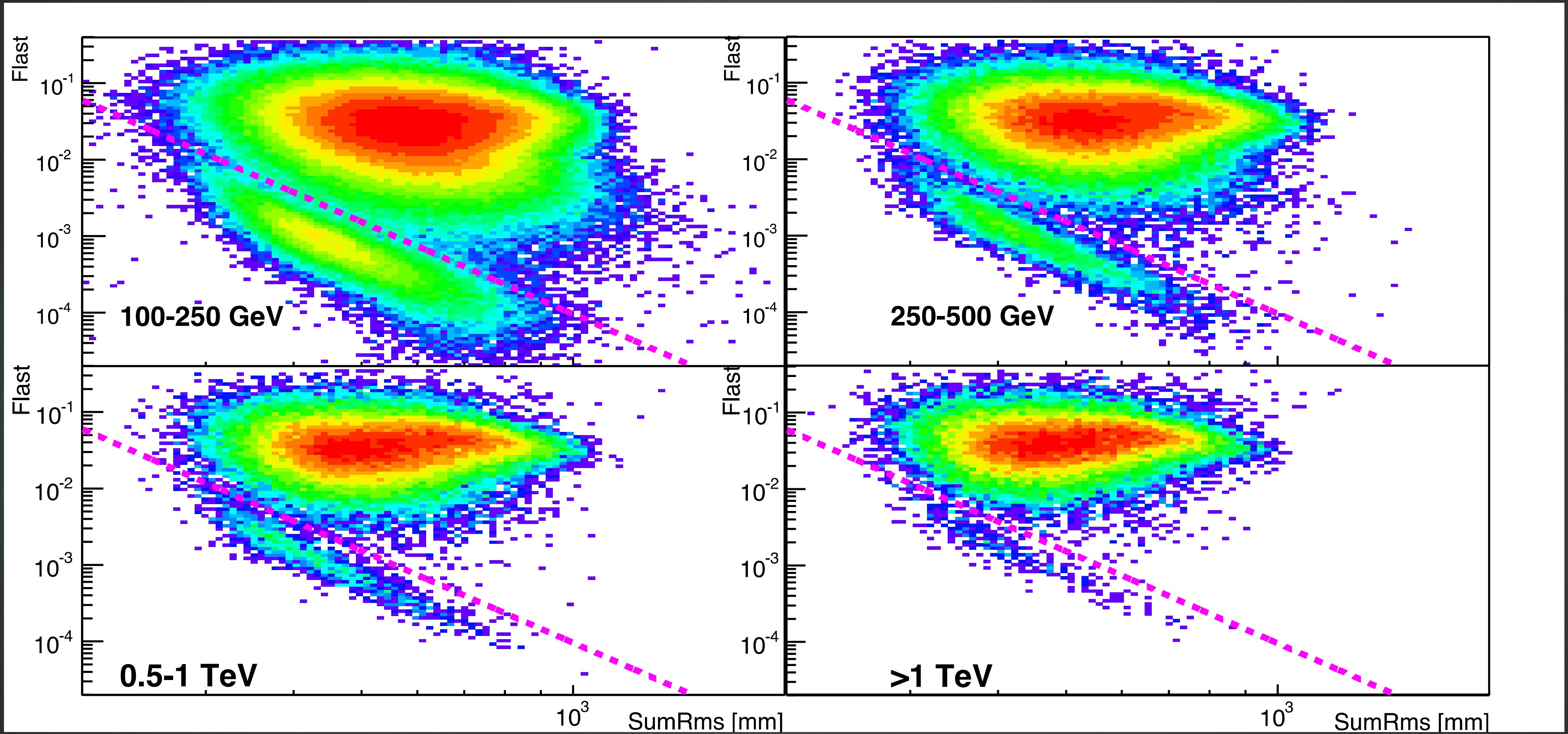
The global shower shape variable ζ

Electrons have narrower and short showers

- Lateral shower shape
  - **sumRms = sum of the shower width of all 14BGO layers**
- Longitudinal shower shape
  - F_{last} **= ratio of the last layer energy to the total BGO energy**

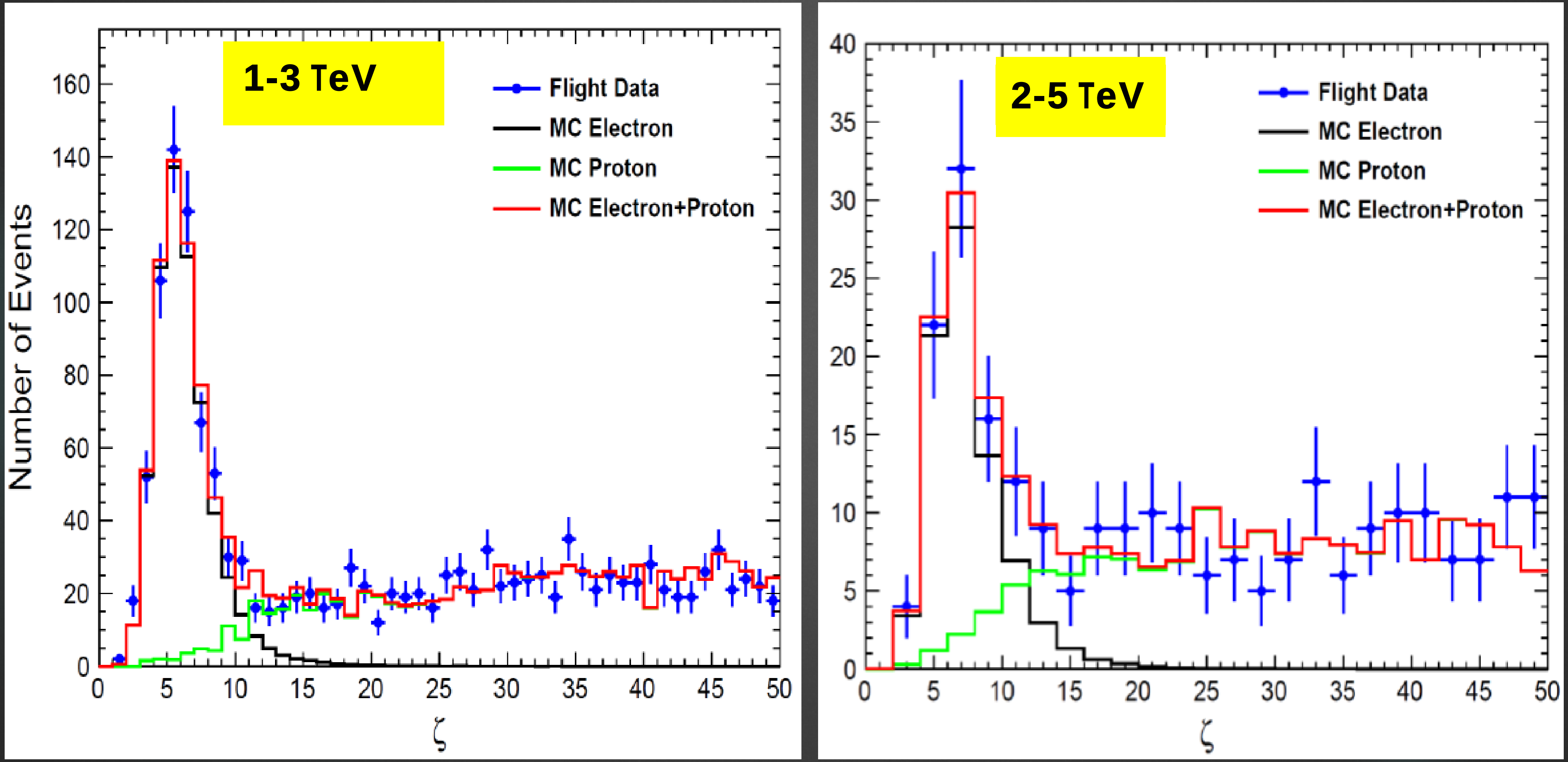
$e^{\pm}$ $p\bar{p}$

Electron identification

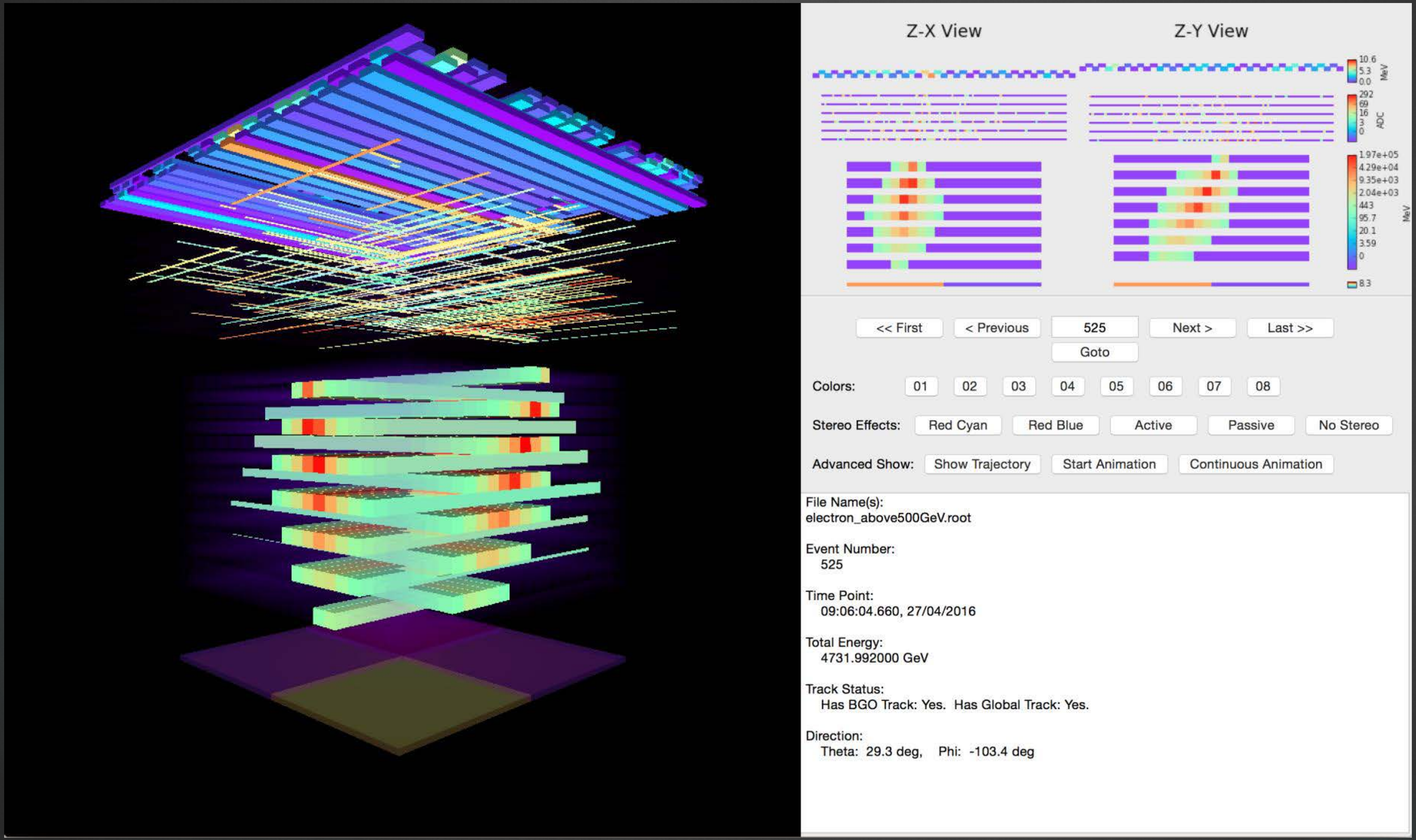


The global shower shape variable ζ

> > 90% detection efficiency with proton contamination 5% (2TeV) and 10 % (> 5 TeV)

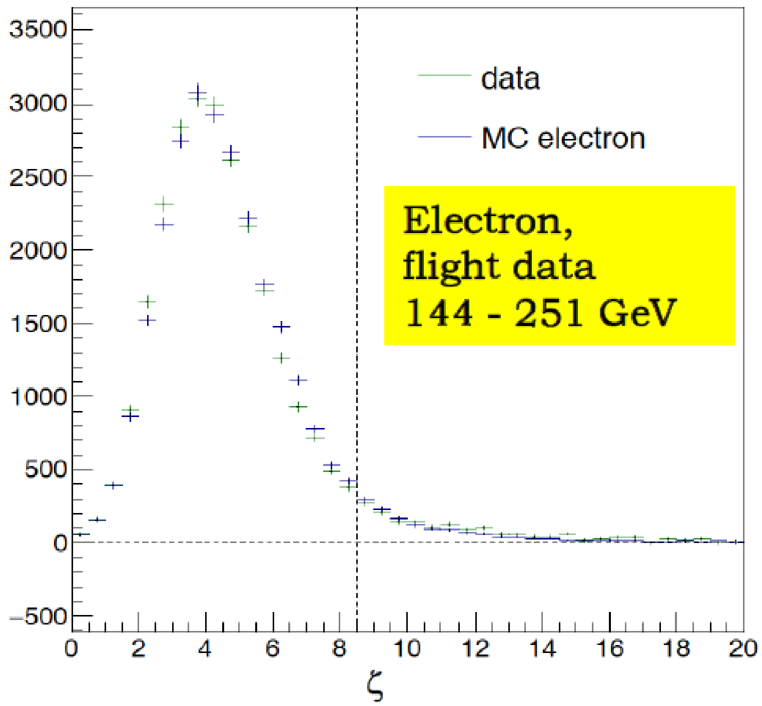


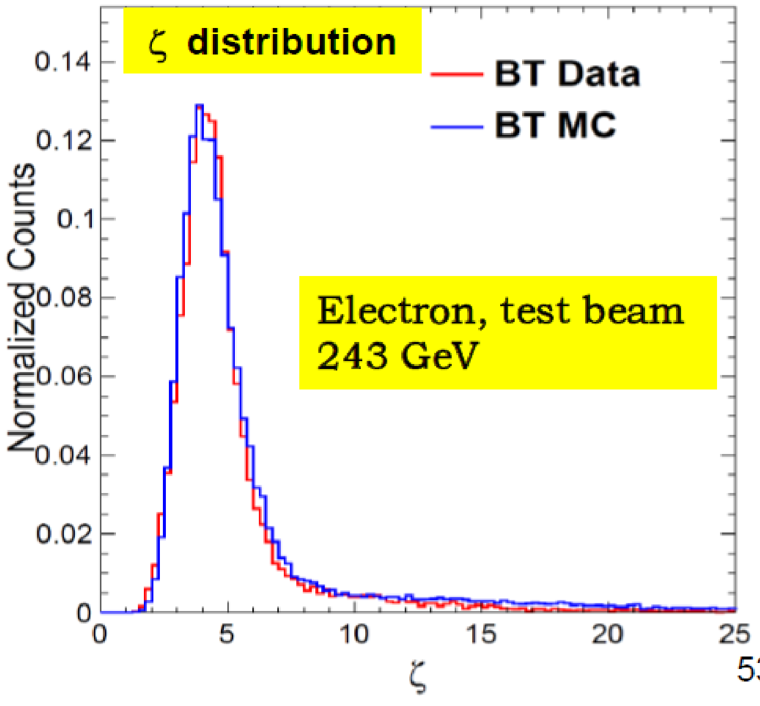
5 TeV Electron



Validation of the electron ζ distribution

- Compare the z distribution of electron MC to data after subtracting the proton background
  - Very good agreement in general
  - Small energy-dependent difference : -1.9% at 25 GeV to 8.4% at 2 TeV
    - Confirmed with 243 GeV electron CERN test beam data
  - **MC efficiency is corrected for this difference**
    - Half of the difference is taken as systematics





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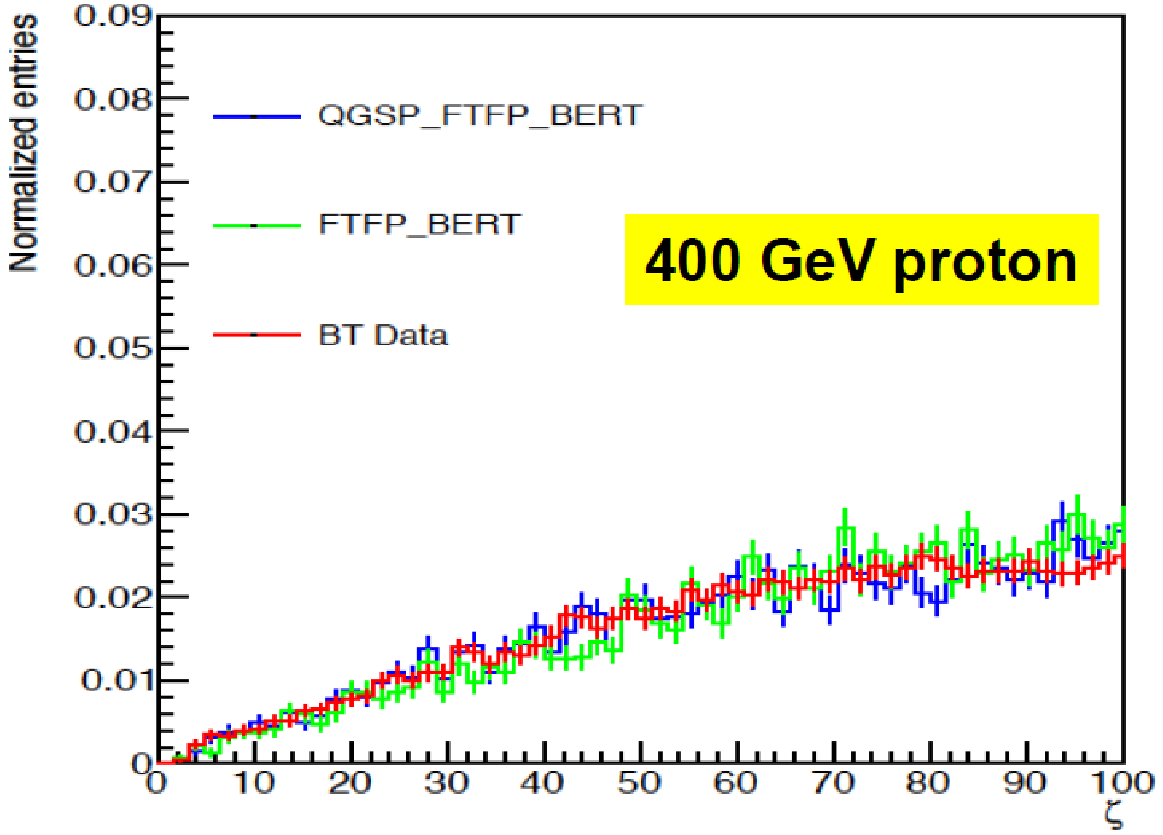
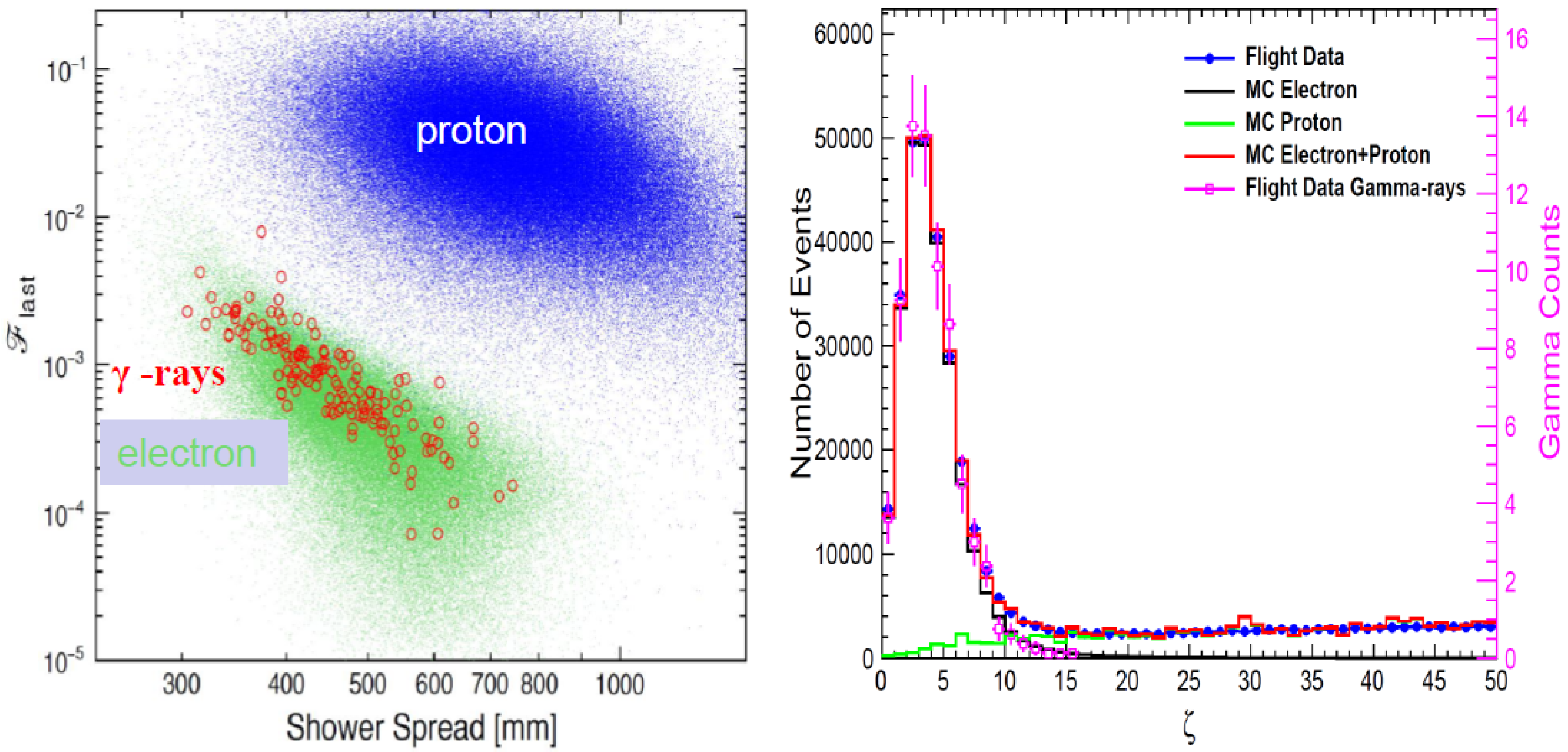
Validation of the proton ζ distribution

- Validation with 400 GeV protons data taken at the CERN SPS
  - Two MC hadronic models are compared: QGSP and FTFP
  - Data-MC have good agreement (within statistics)
  - Two hadronic models have similar distributions



Validating e/p separation with γ-rays



Comparison of the flight data and the Monte Carlo simulations for deposit energies 50-100 GeV.

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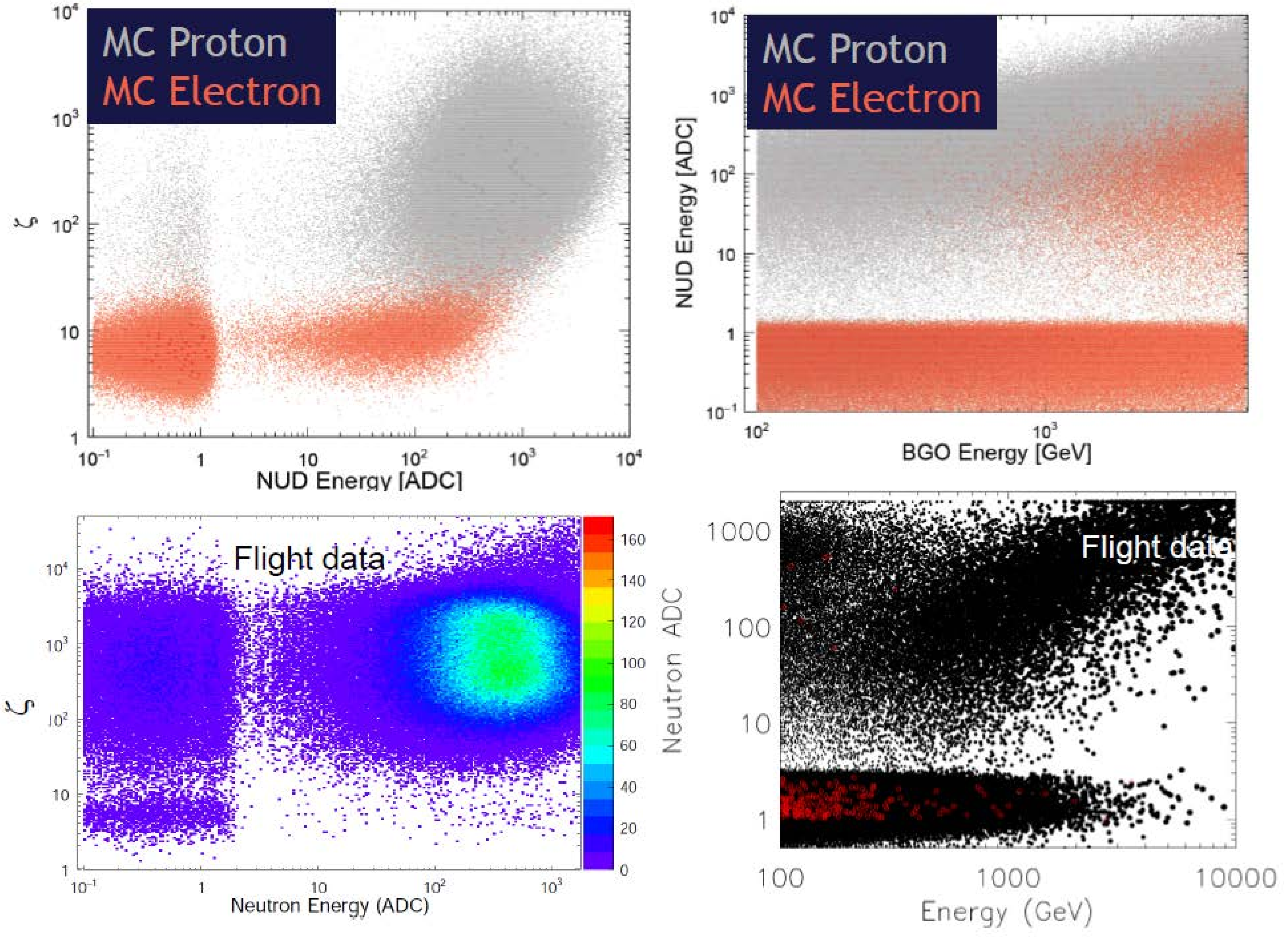
NUD performance on e/p separation



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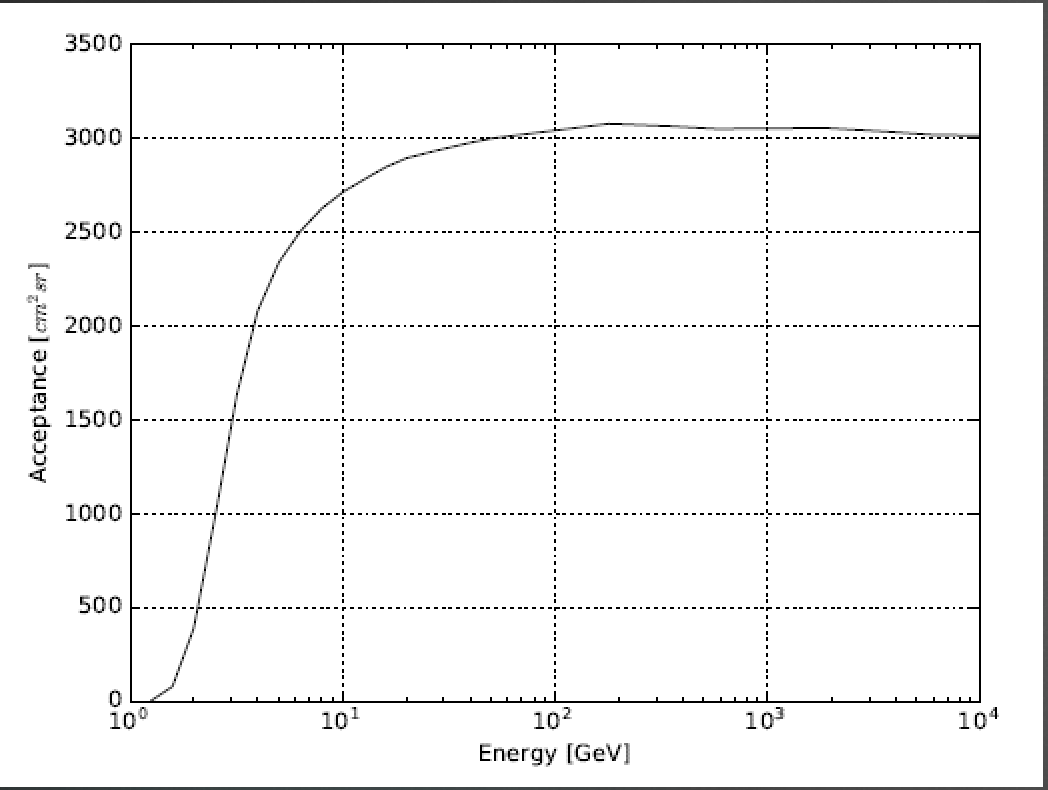
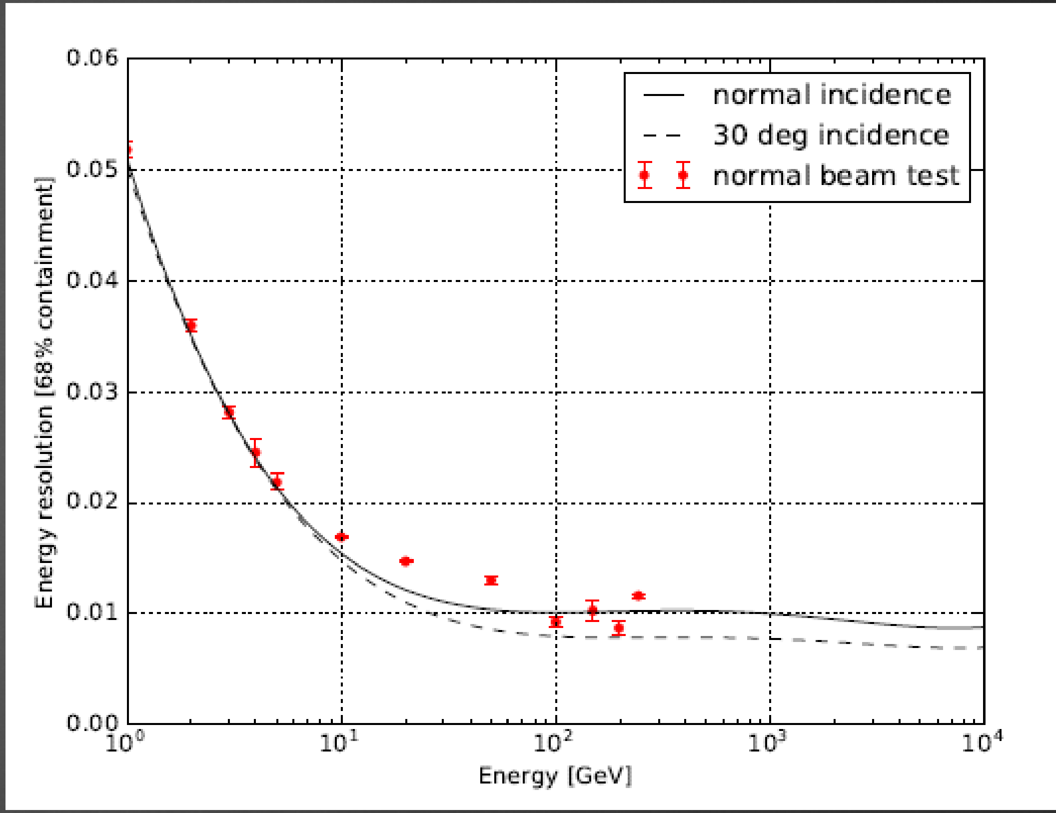
Electrons: performances

Acceptance for electrons and positrons



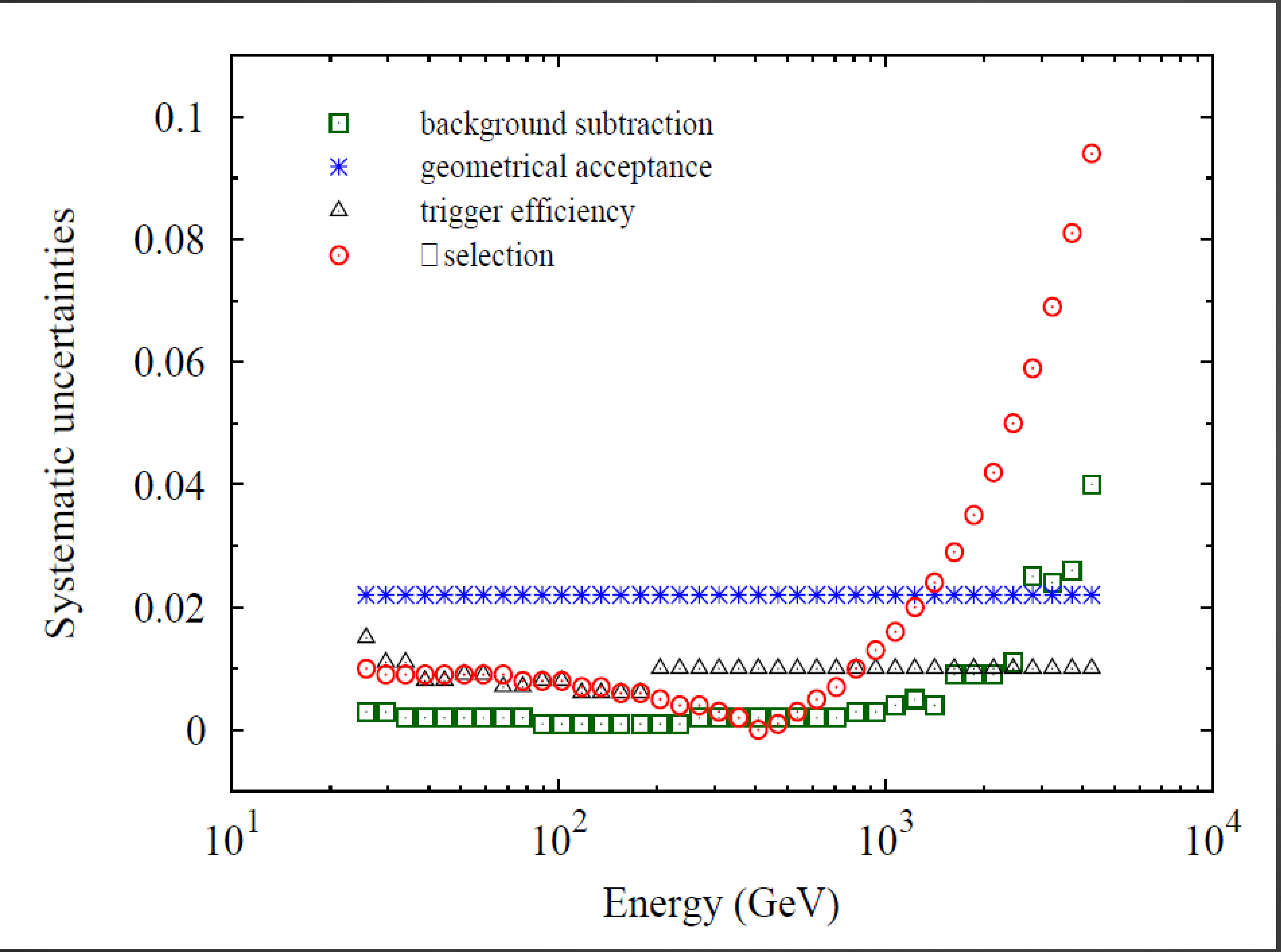
0.3m^2 sr for E > 100GeV

Energy resolution for E.M. showers

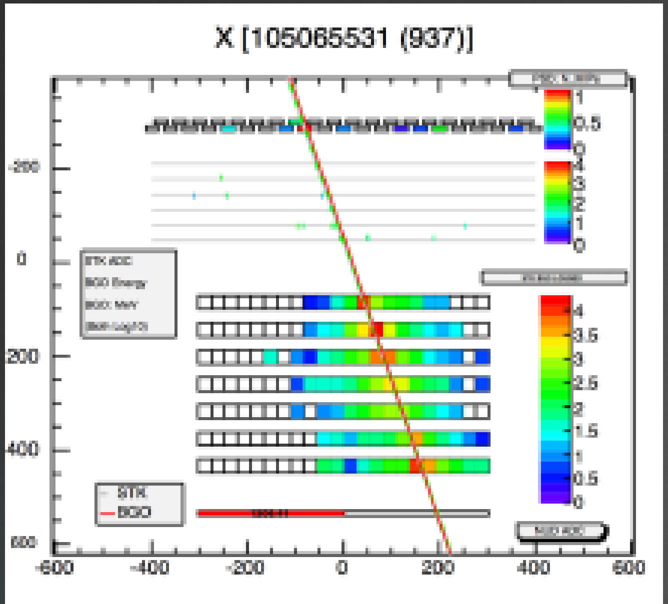


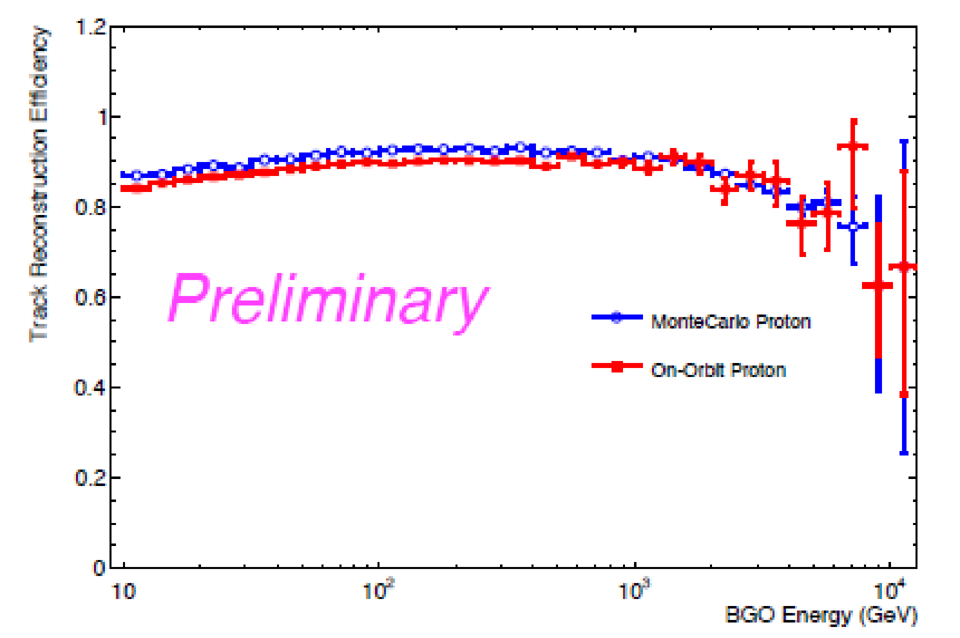
1% for E > 100GeV

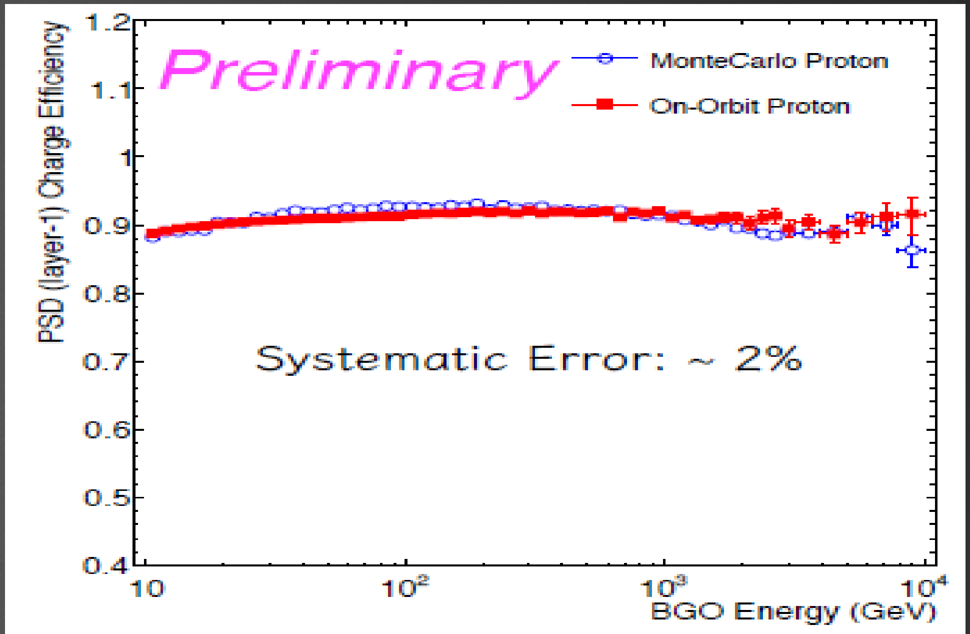
All e: Systematic errors



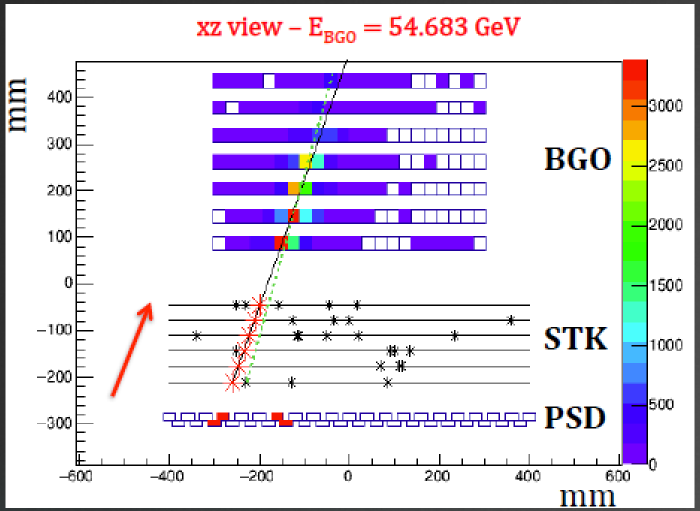
Proton analysis

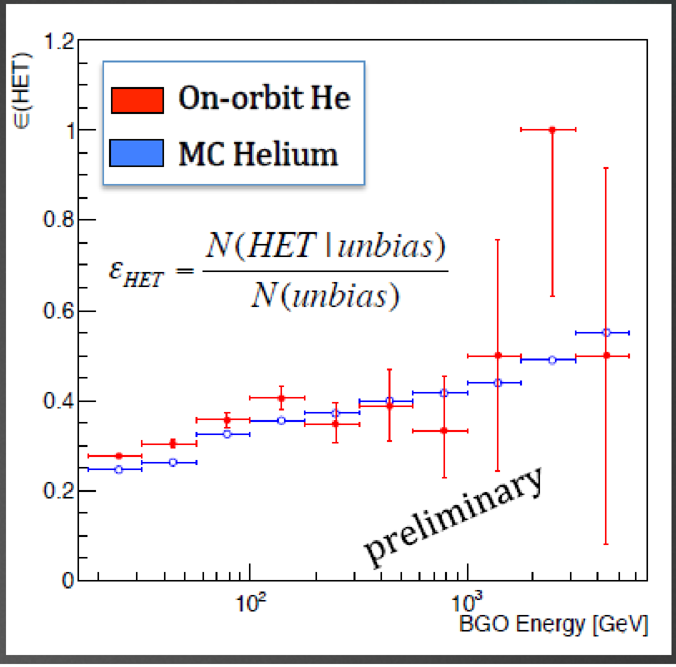


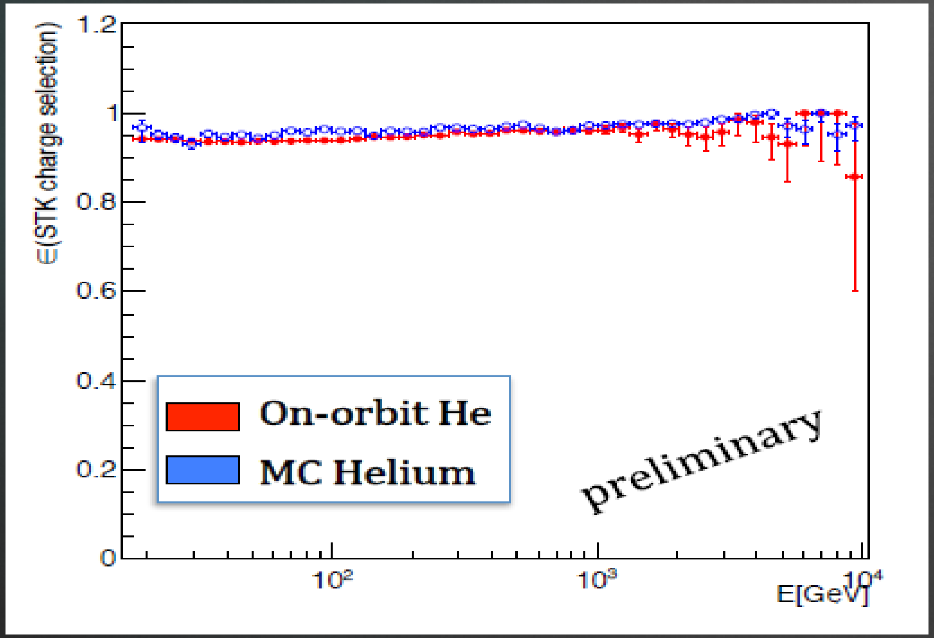


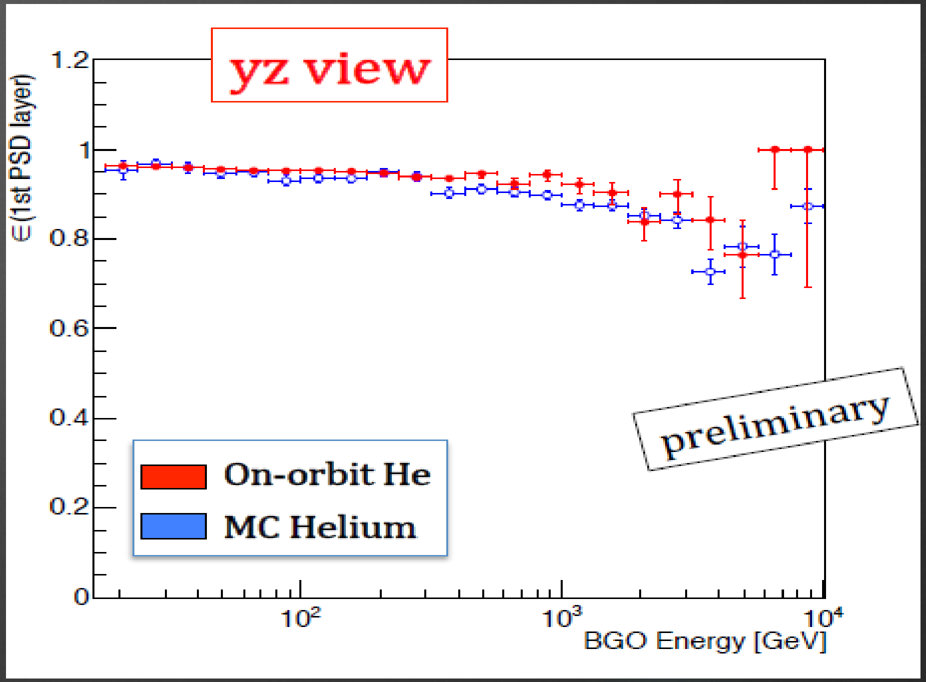


Helium analysis



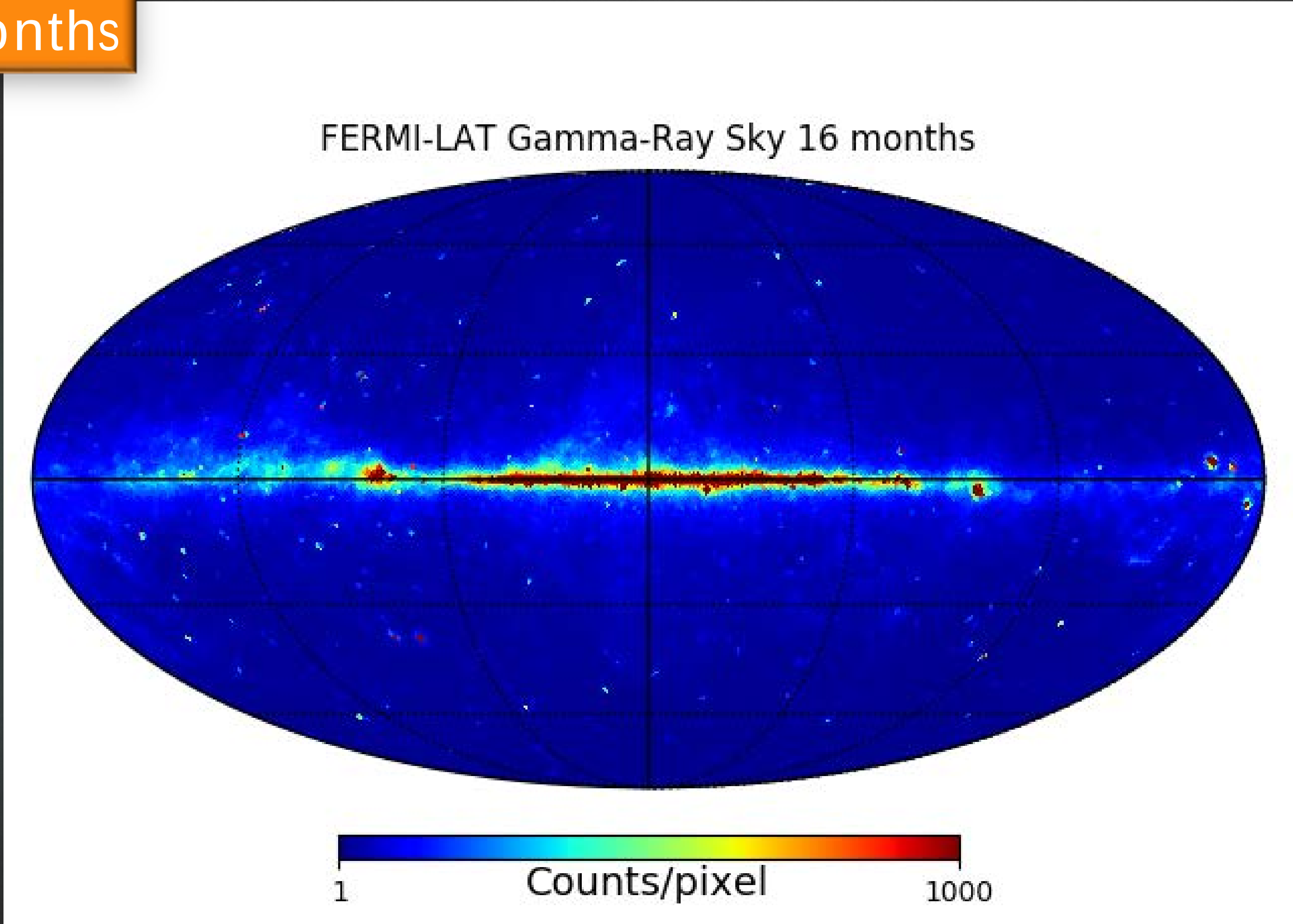


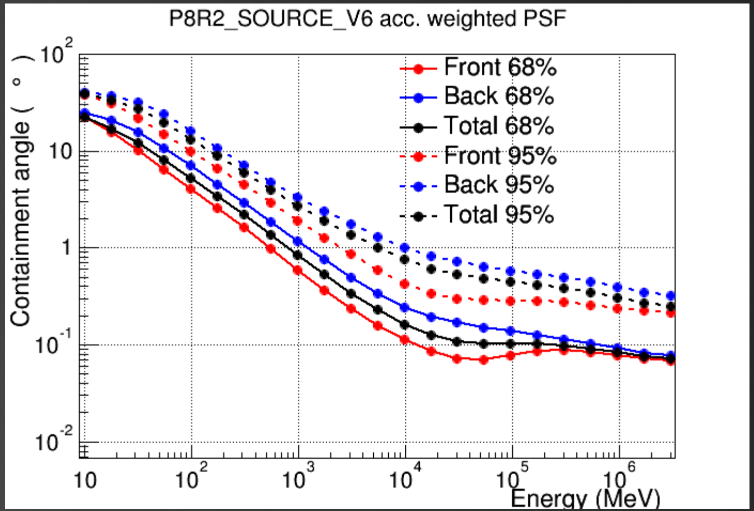




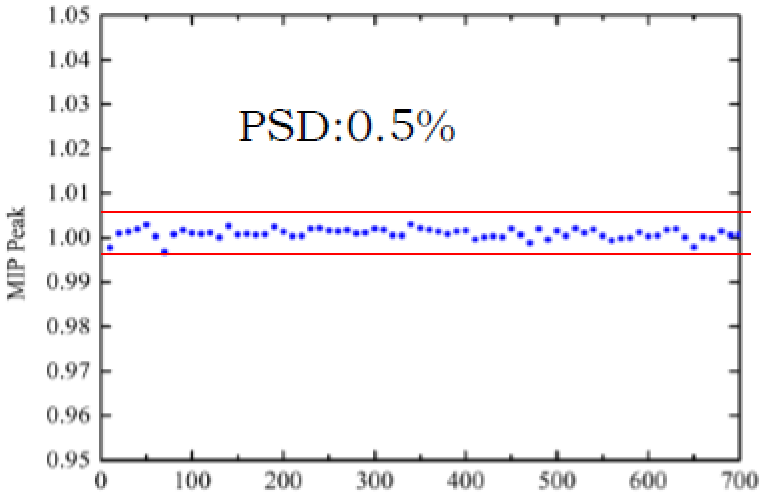
FERMI Counts map

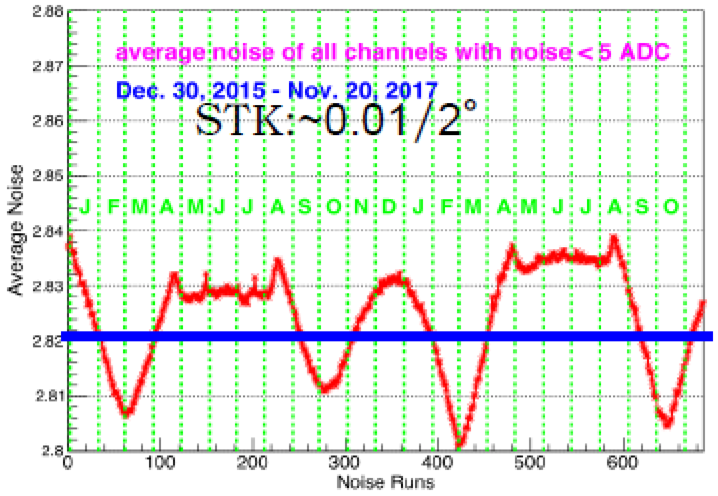
E > 1GeV
16 months



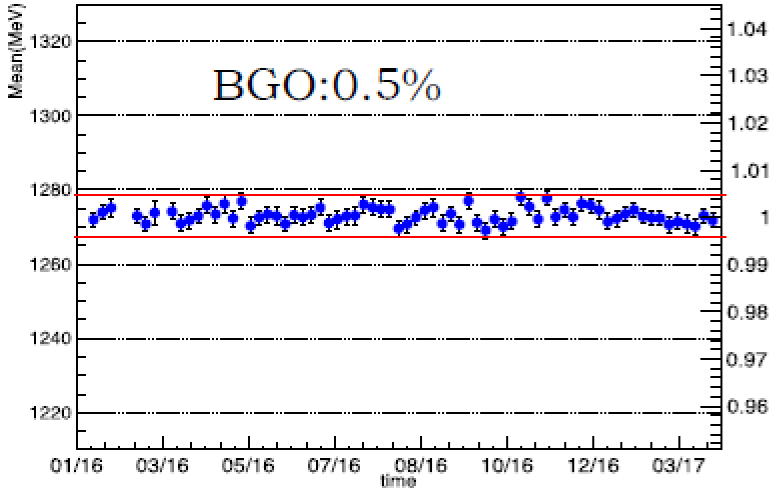


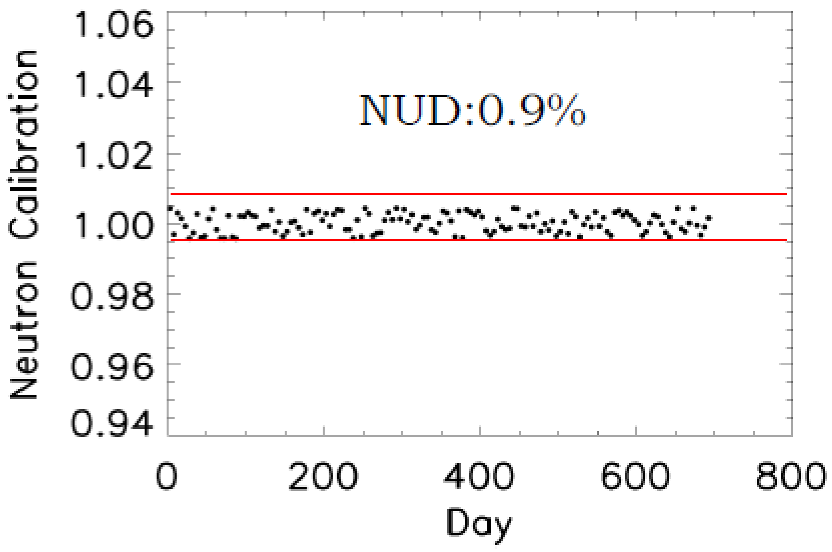
Detector status



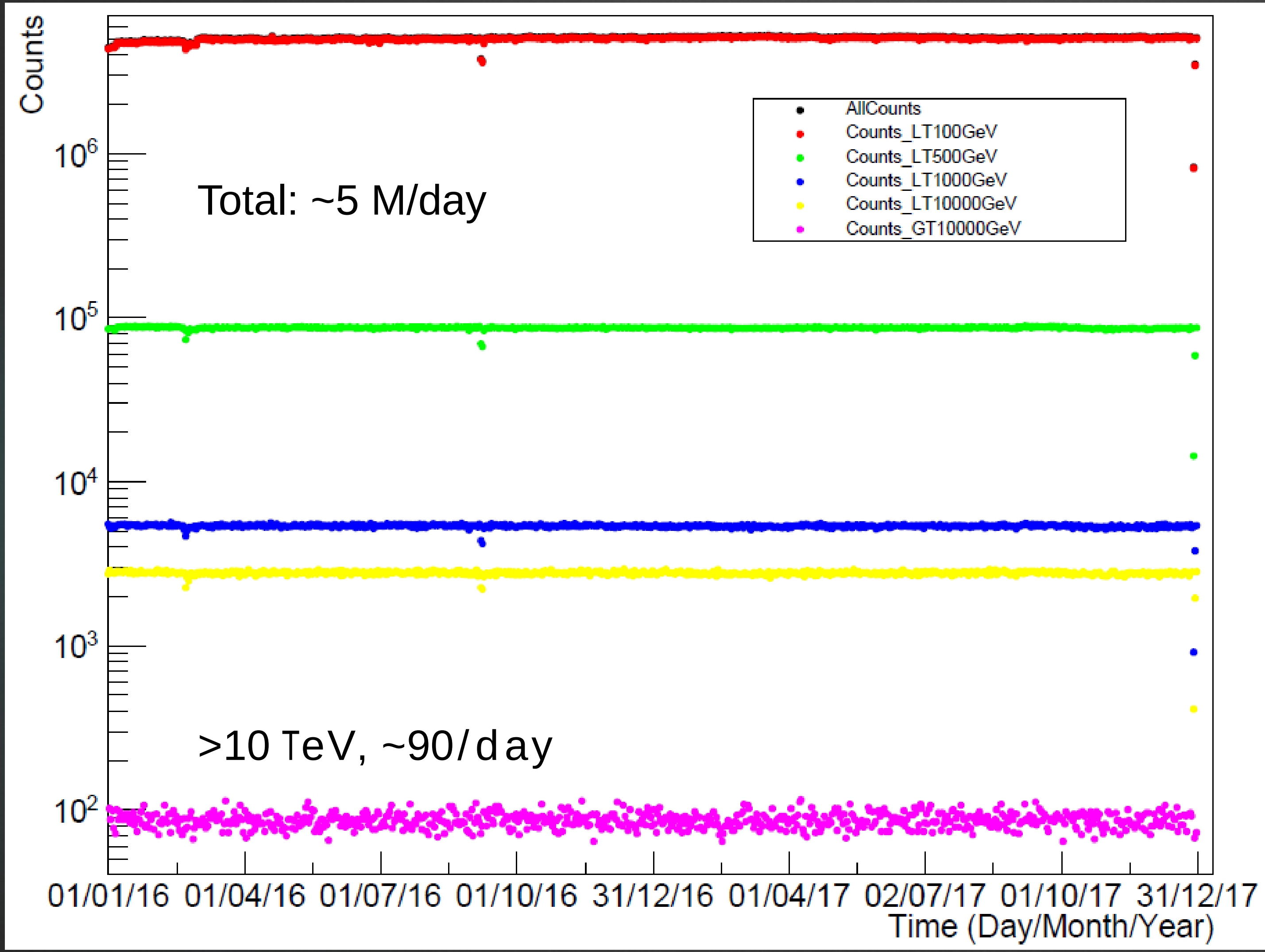


Stability of Helium MIPs





Count rate



Very stable count rate in the last 2 years