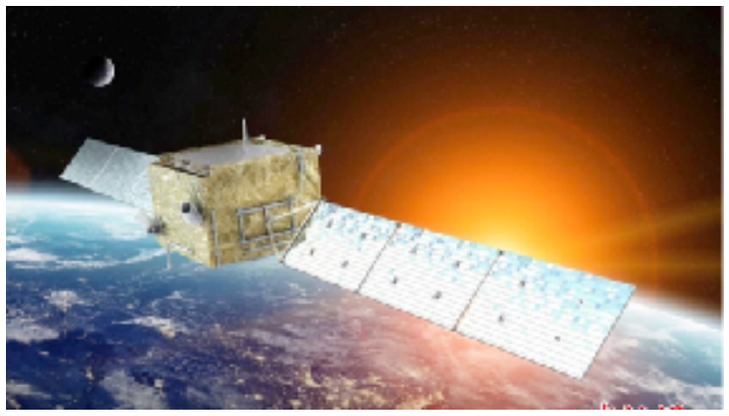
First results from the DAMPE mission

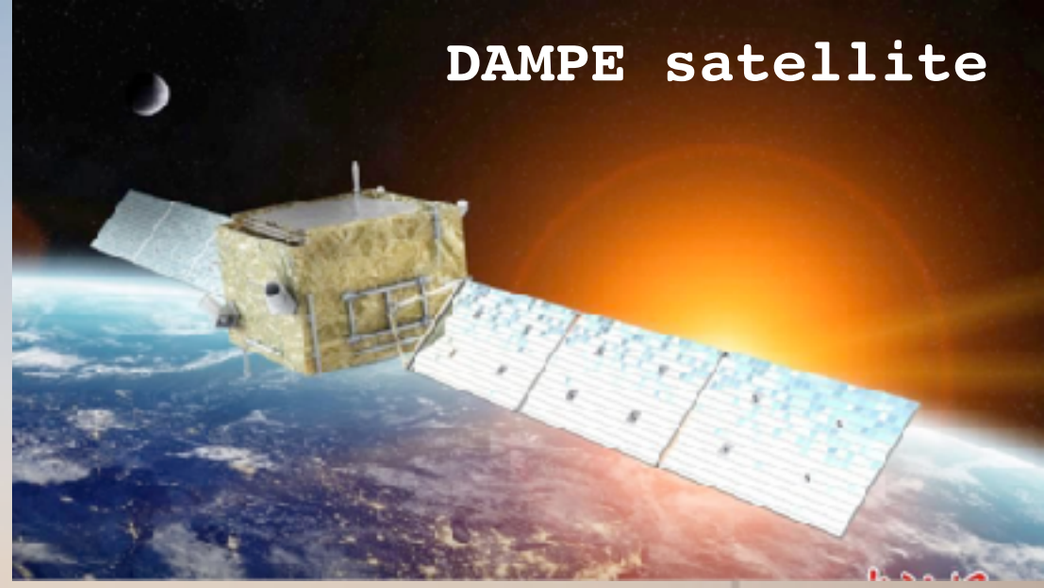
Andrii Tykhonov *(for the DAMPE collaboration)*

UNIVERSITÉ DE GENÈVE



DARK MATTER PARTICLE EXPLORER DAMPE

June 4, 2018



DArk Matter Particle Explorer (DAMPE)

Launched on Dec 17, 2015,
from the Jiuquan Satellite Launch Center,
Gobi desert, China.

Operates on a sun-synchronous
Sky-survey mode, permanently oriented to zenith

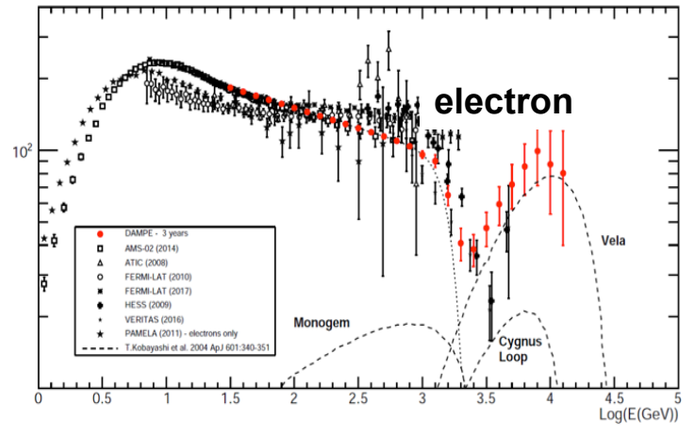
Scientific Goals

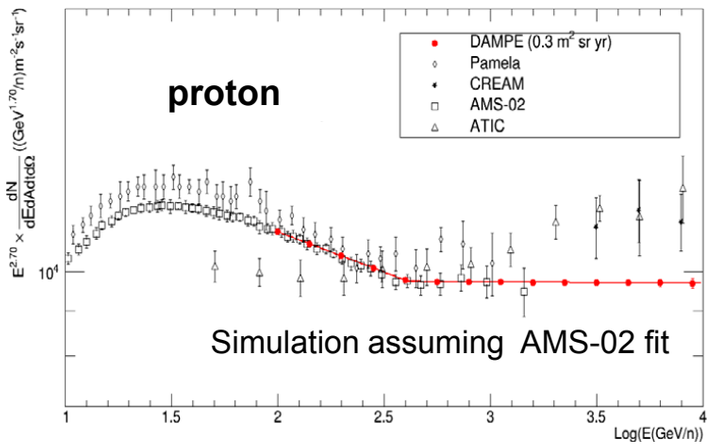
Detection of:

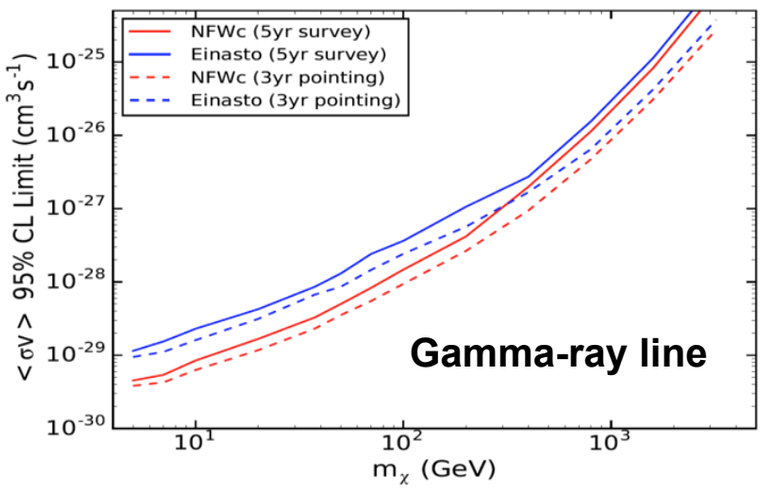
- e/γ @ 1GeV — 10 TeV
  (1% energy resolution)
- p/nuclei @ 50GeV — 500 TeV
- γ-rays

Excellent energy resolution (1% for 100 GeV electrons), direction and particle identification capabilities.

Search for Dark Matter annihilation/decay signatures.



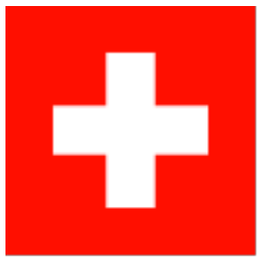




Collaboration

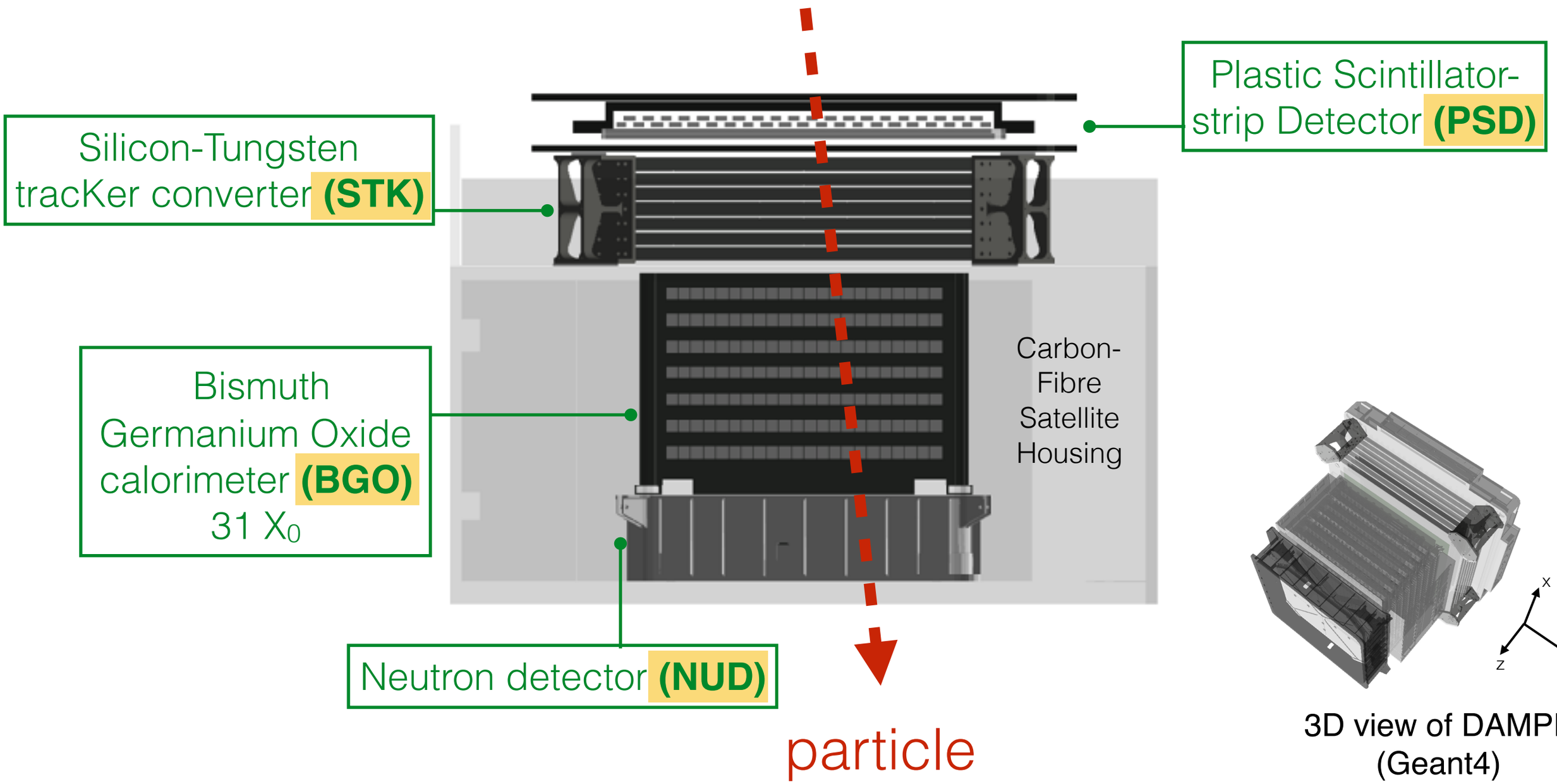
- **China**
  - Purple Mountain Observatory, CAS, Nanjing
  - University of Science and Technology of China, Hefei
  - Institute of High Energy Physics, CAS, Beijing
  - Institute of Modern Physics, CAS, Lanzhou
  - National Space Science Center, CAS, Beijing

- **Switzerland**
  - University of Geneva



- **Italy**
  - INFN Perugia and University of Perugia
  - INFN Bari and University of Bari
  - INFN-LNGS and Gran Sasso Science Institute
  - INFN Lecce and University of Salento

The detector

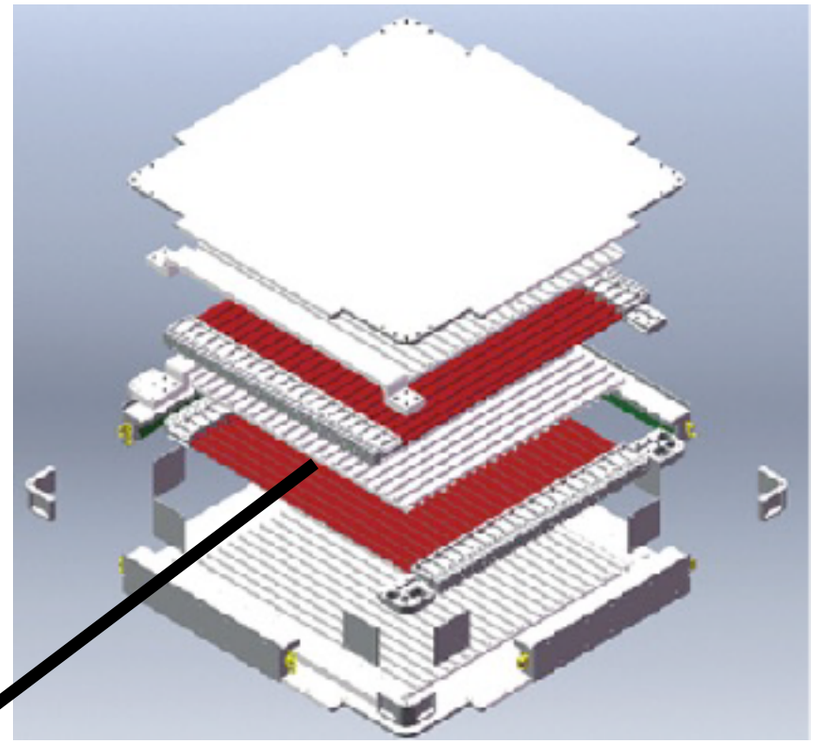


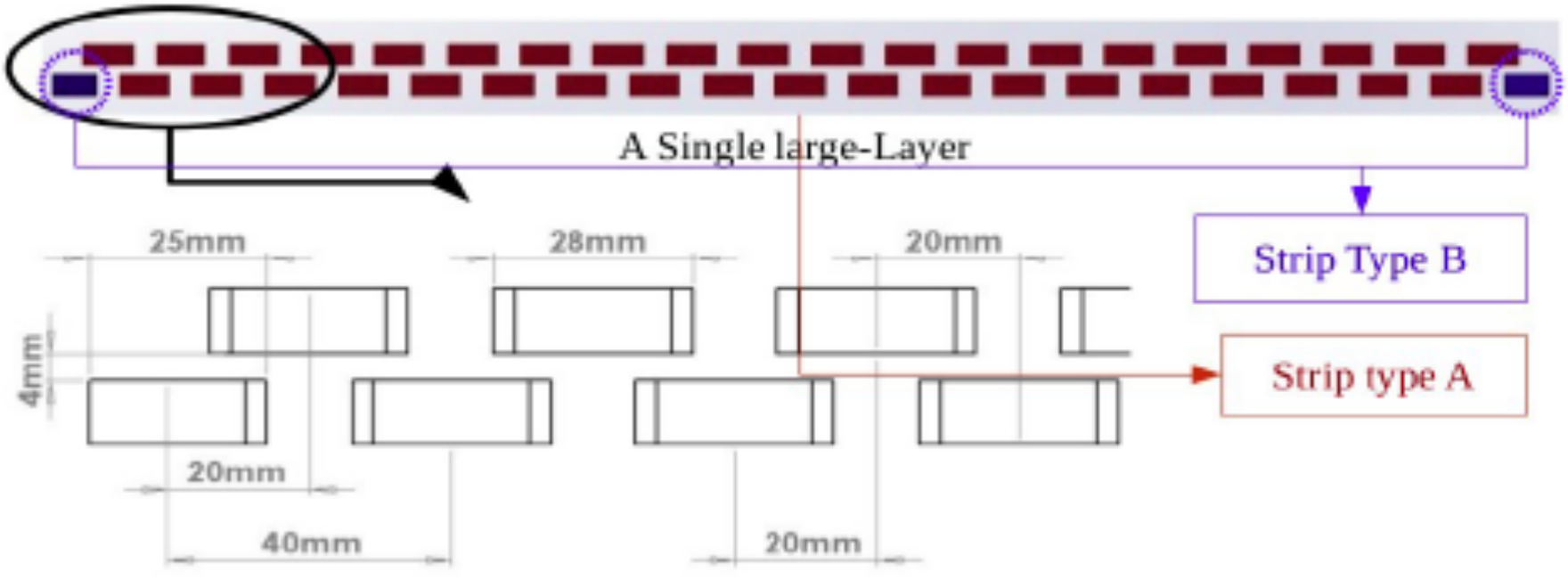
3D view of DAMPE (Geant4)

The detector

PSD

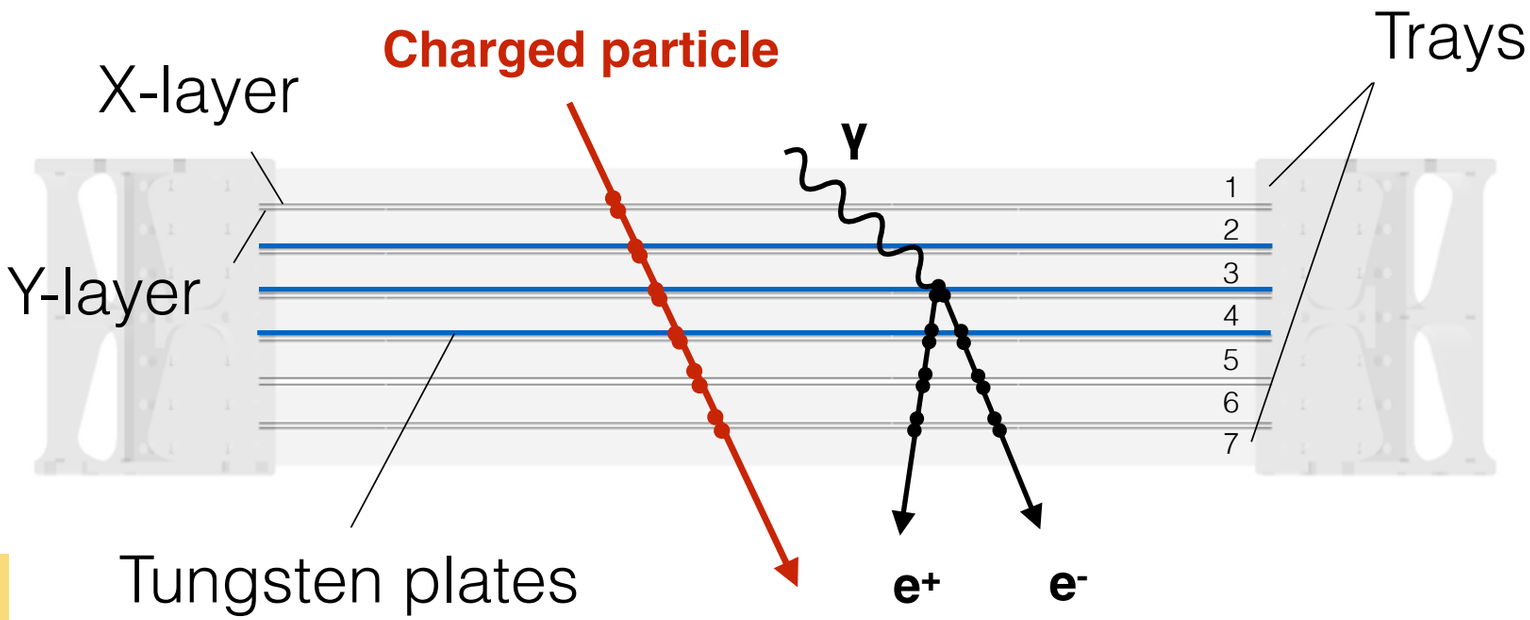
- 1 X double-layer and 1 Y double layer
- 82 x 82 cm layer dimension
- Scintillator bar dimension:
  1.0 (thick) x 2.8 (wide) x 82.0 (long) cm^3
- Bars staggered by 0.8 cm in a layer

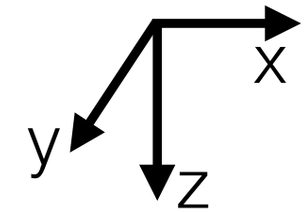




The detector

STK

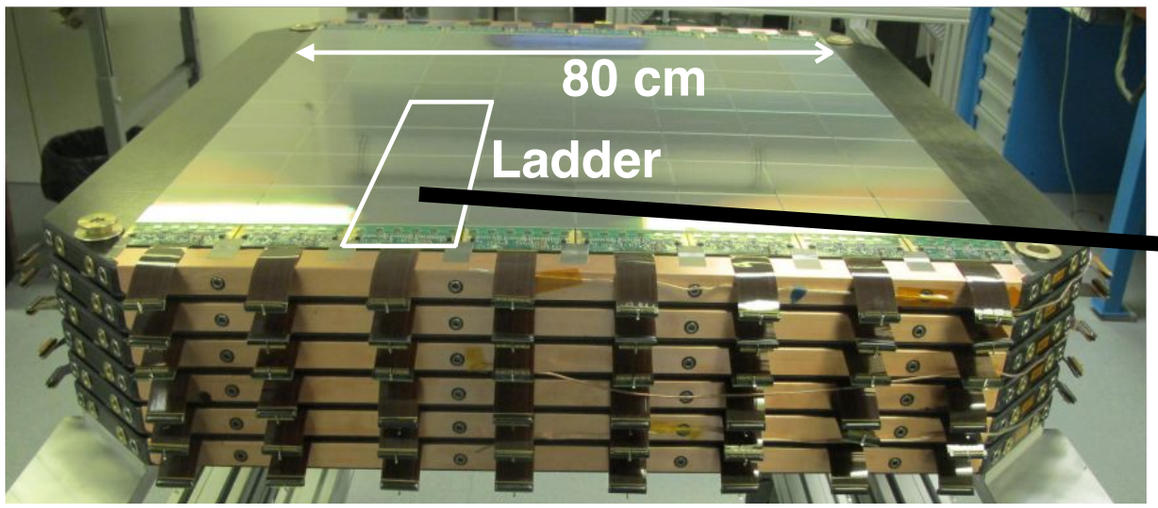




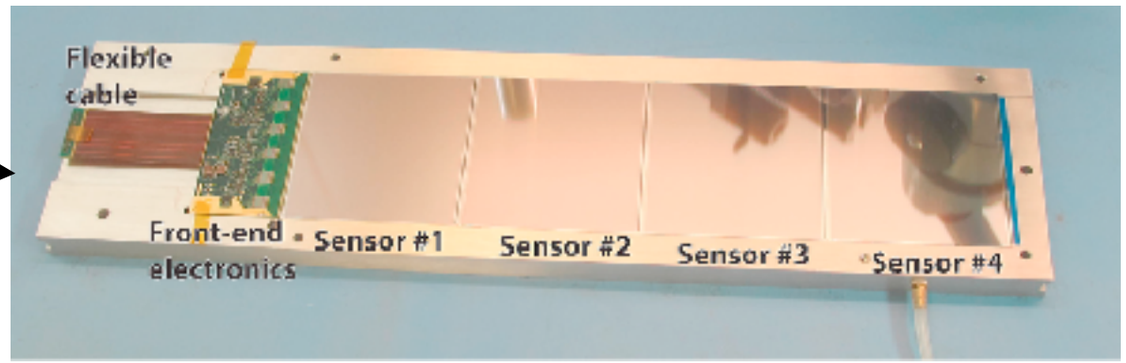
121 μm strip pitch

242 read-out pitch

6.6 m² of Si, 768 wafers



192 ladders in the STK

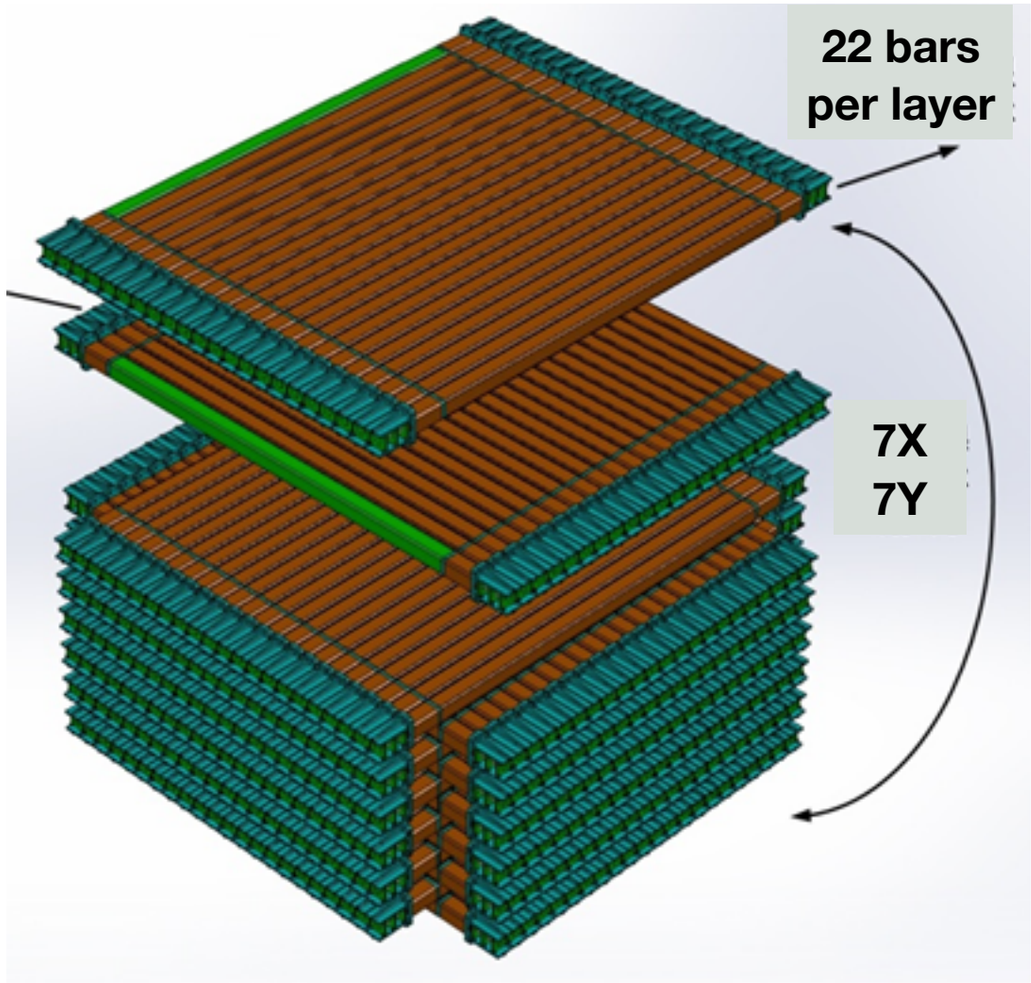


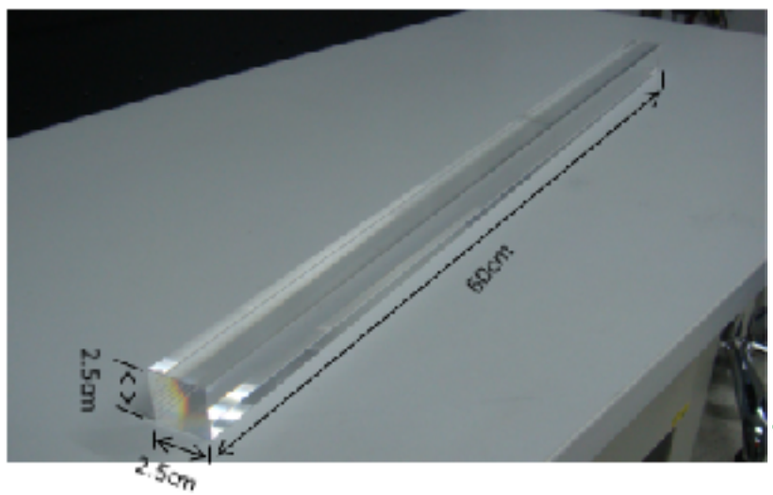
4 silicon sensors daisy chained via micro-bonds

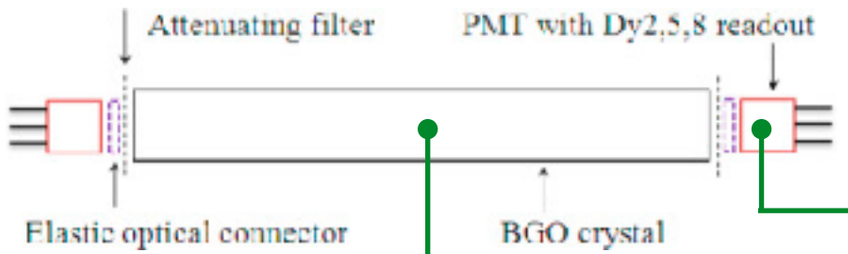
The detector

BGO

- 14 layers (7X and 7Y):
  - horoscopic arrangement, alternating X and Y layers
  - 22 bars per layer
  - Total 31 X_0
  - Bar dimension: 2.5 x 2.5 x 60 cm^3
  - Two PMTs coupled to each bar in two ends

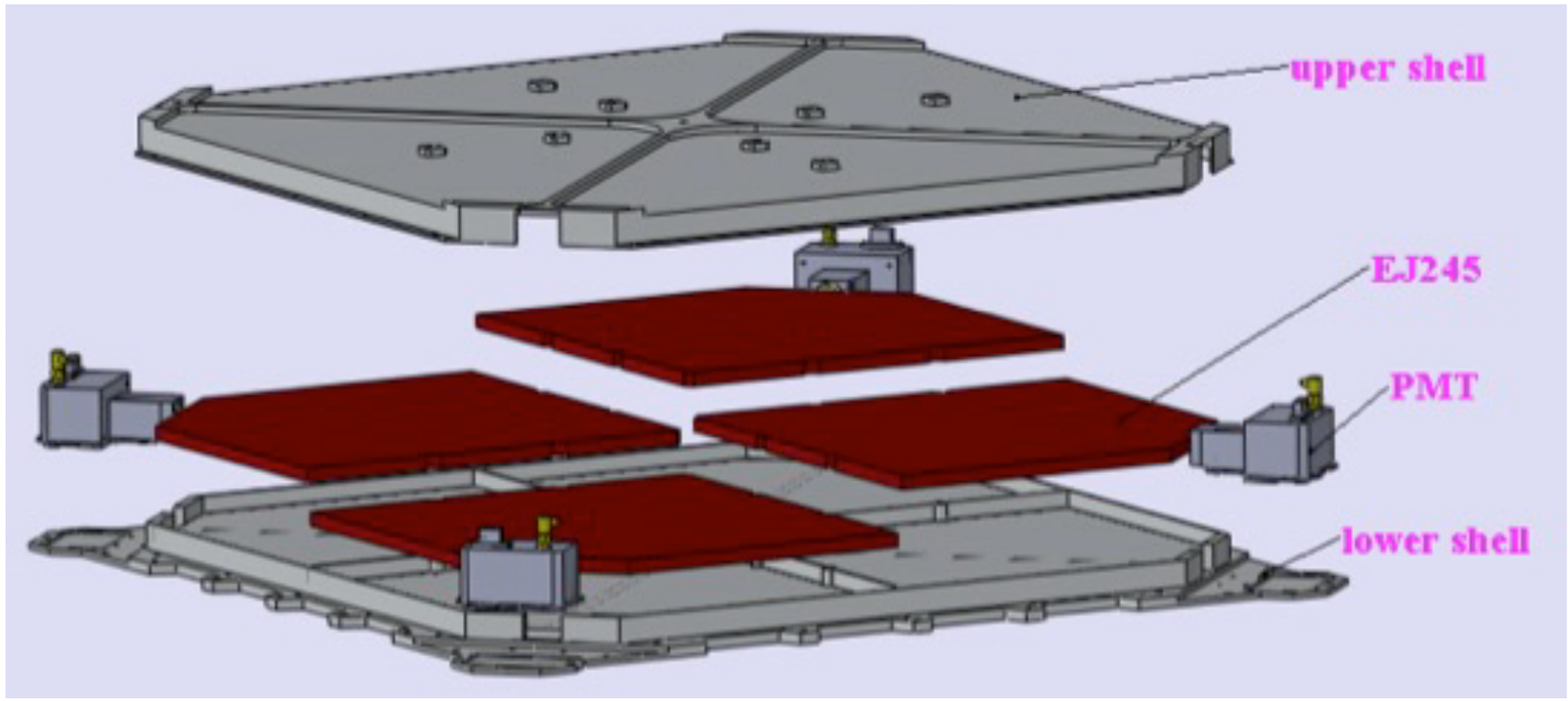






The detector

NUD

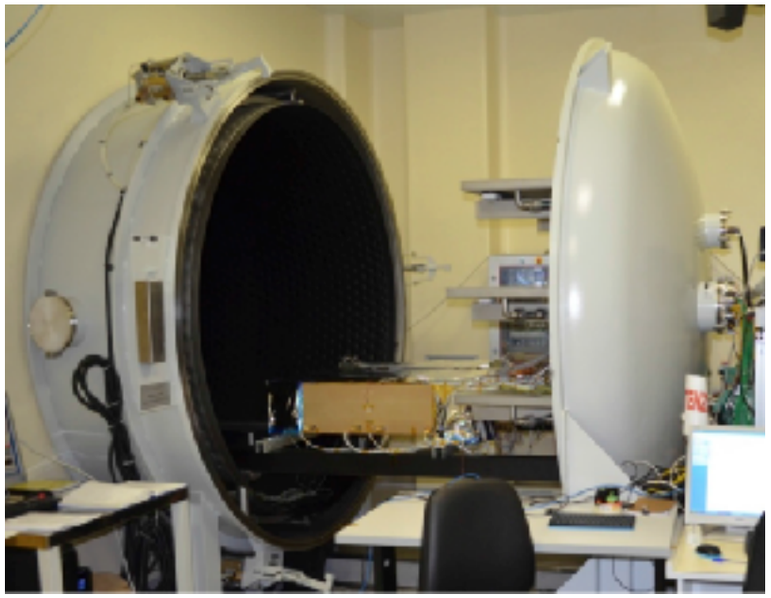


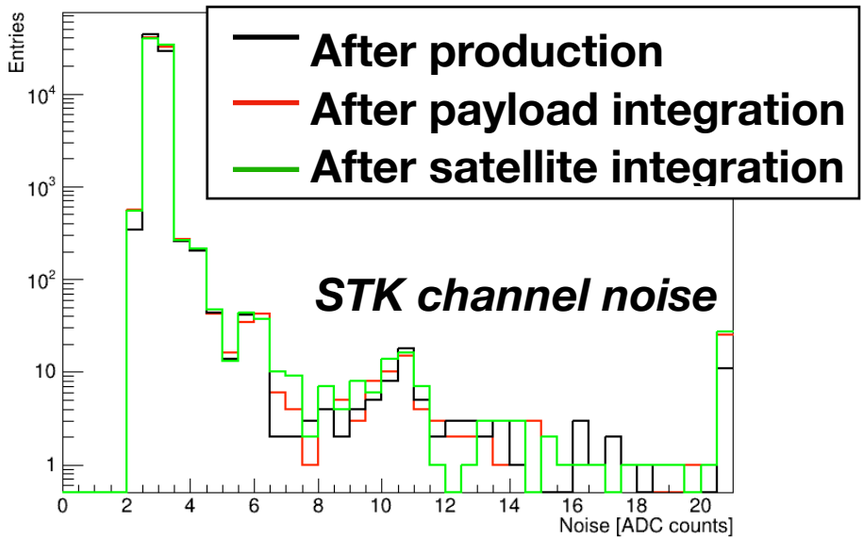
- 4 large-area boron doped plastic scintillators
- 30 x 30 x 1 cm^3 scintillator dimension

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

On-ground tests

Thermal cycling





Vibration & Acceleration & Shock

STK cosmics (April 2015)

On-ground tests

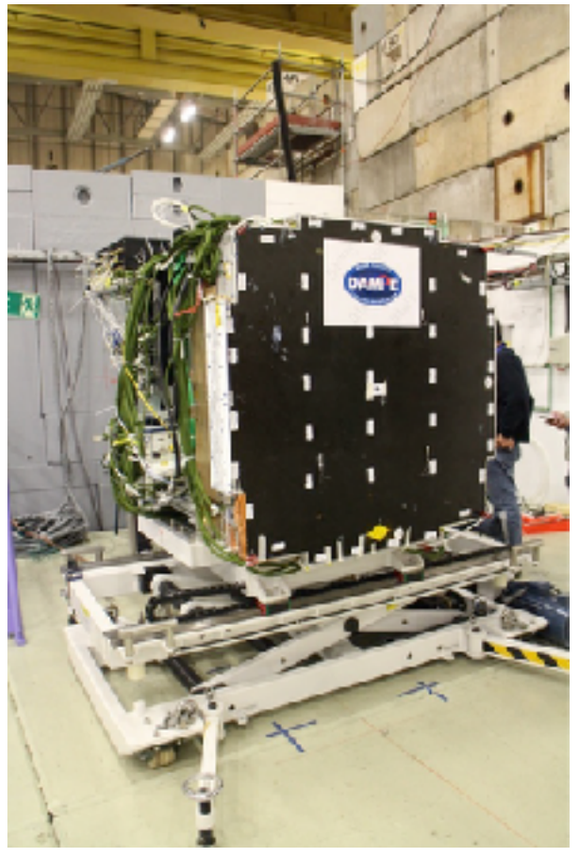
DAMPE beam-tests @ CERN

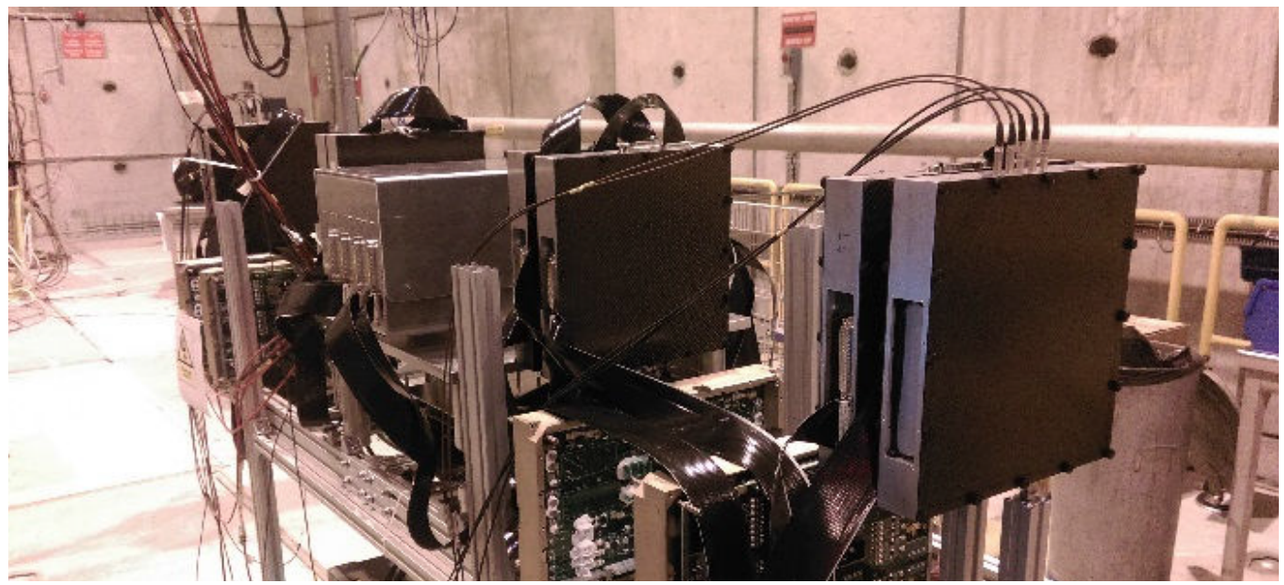
PS & SPS, Oct-Nov 2014
— e/p/γ/π/μ

SPS, Mar 2015
— Ions, p

SPS, Jun 2015
— e/p/γ/π/μ

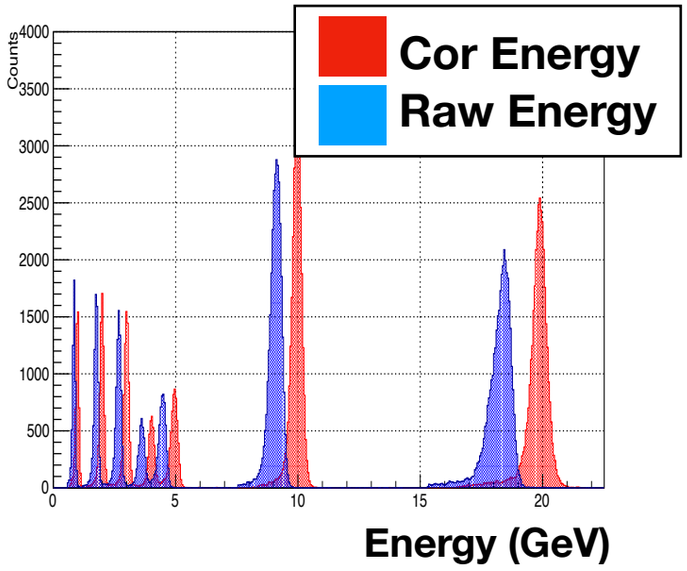
SPS, Nov 2016
— Ions (STK ladder tests)

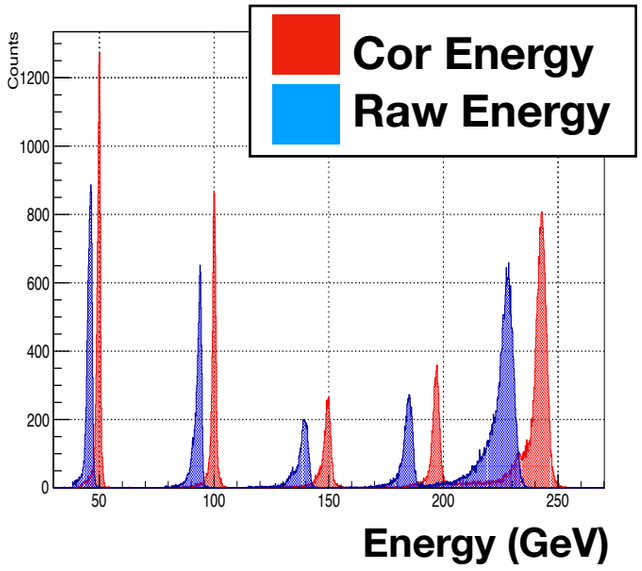


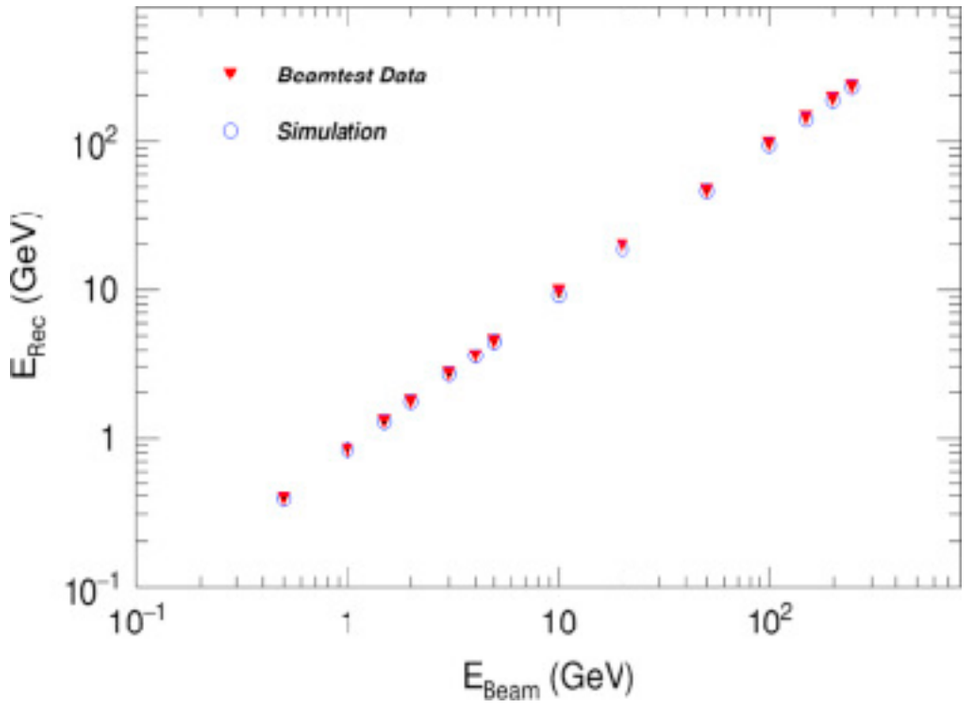


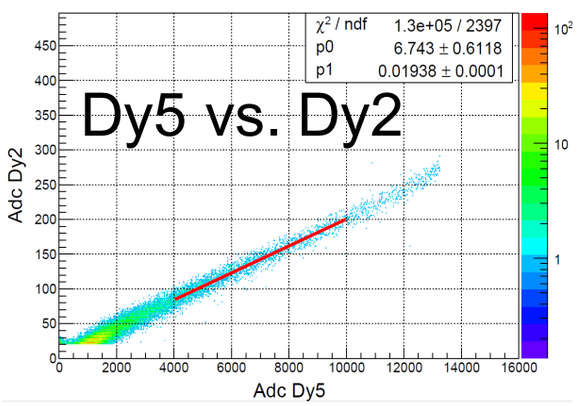
On-ground tests

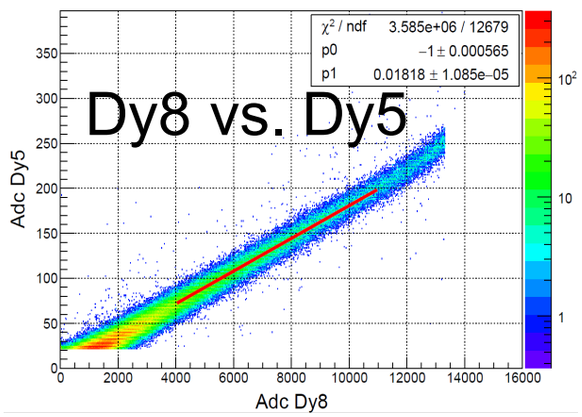
BGO energy resolution: electrons

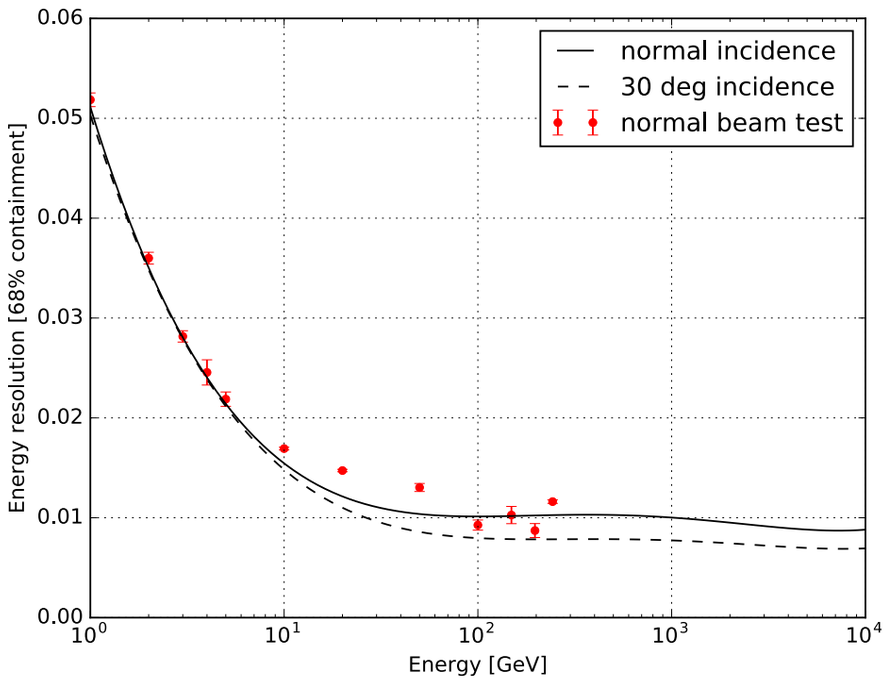








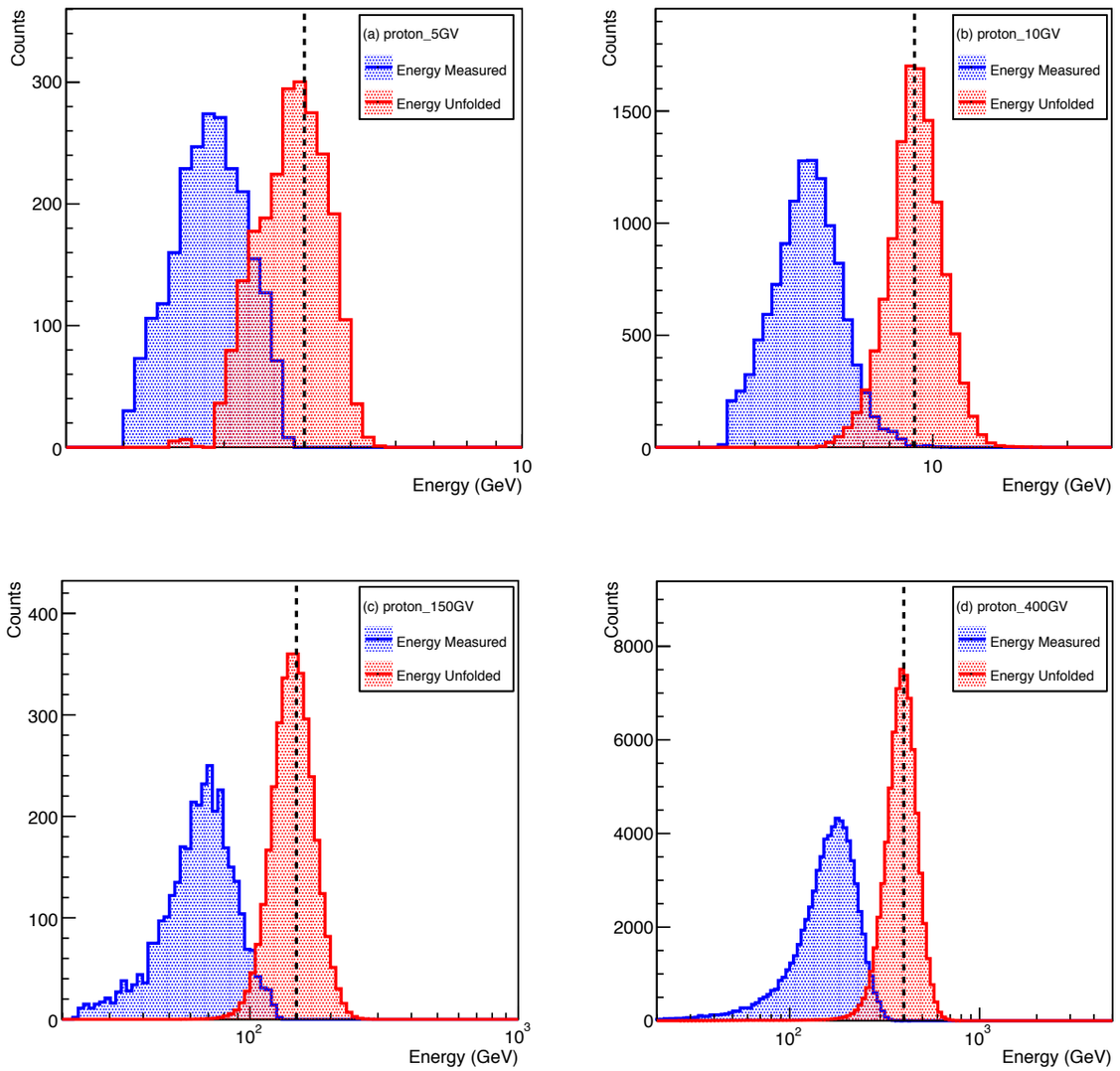


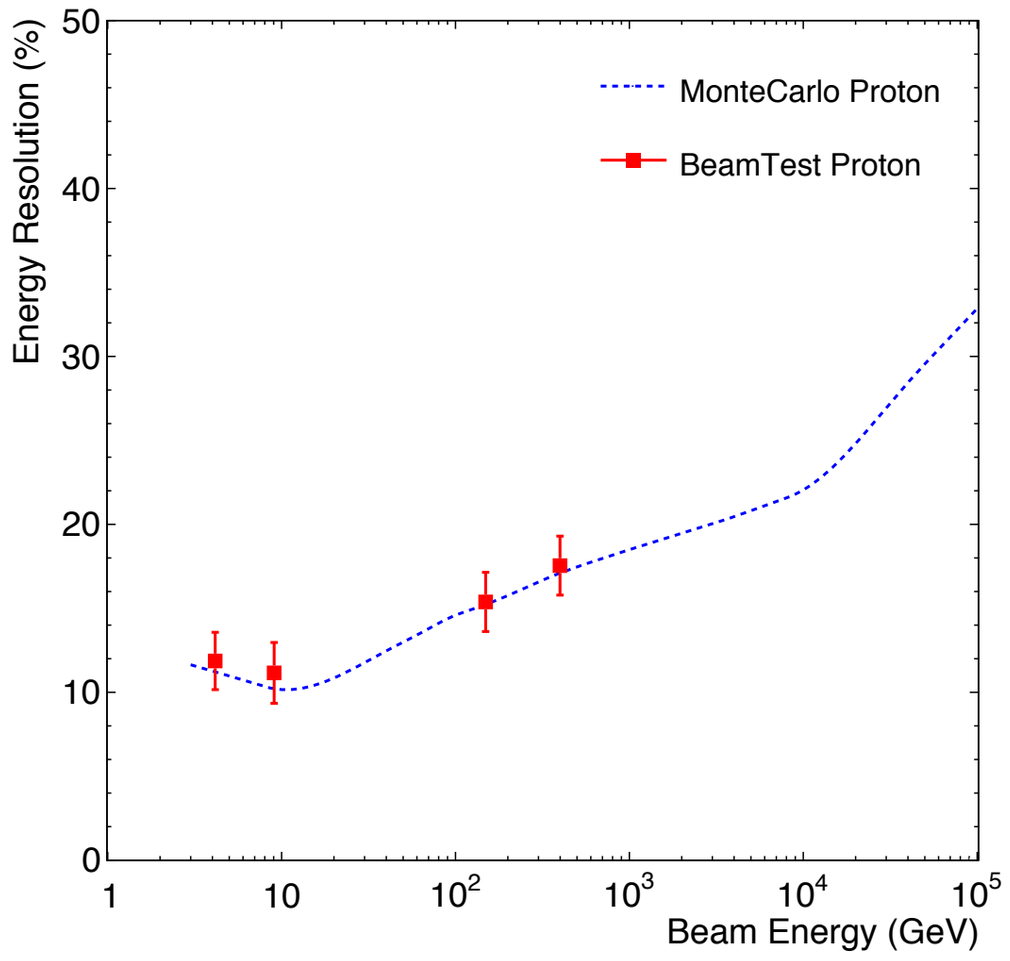


[10.1016/j.nima.2016.08.015](https://doi.org/10.1016/j.nima.2016.08.015)

On-ground tests

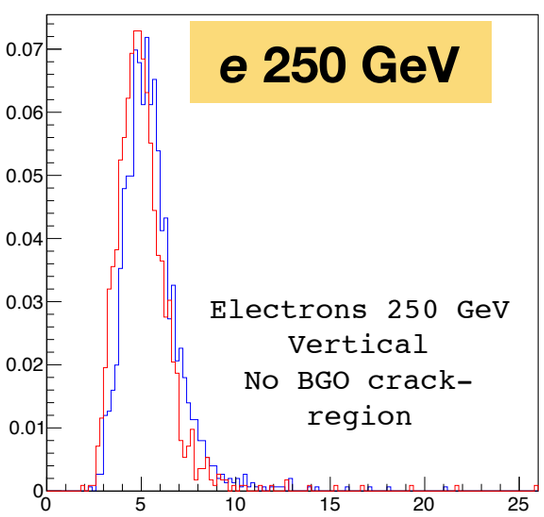
BGO energy resolution: protons

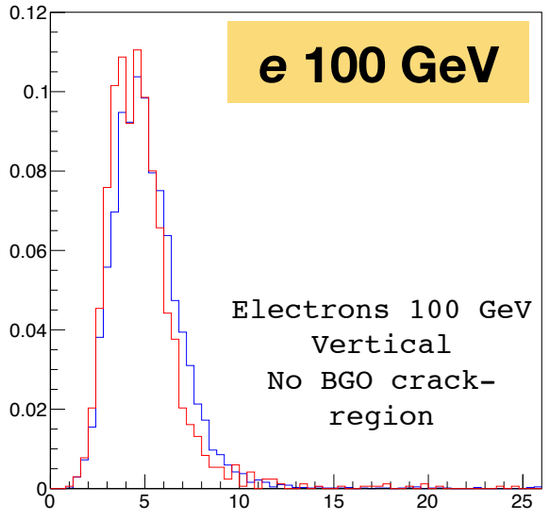


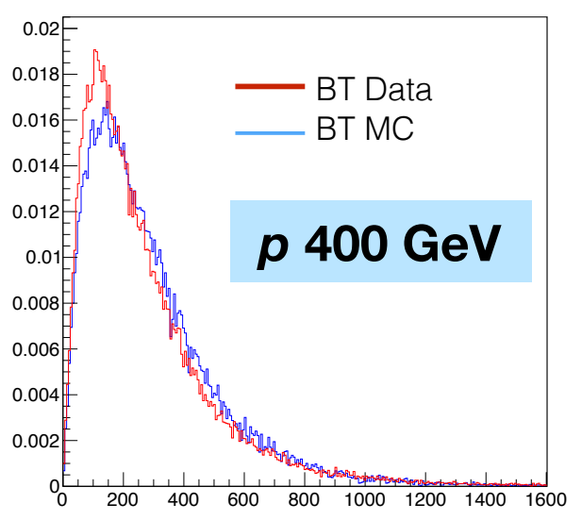


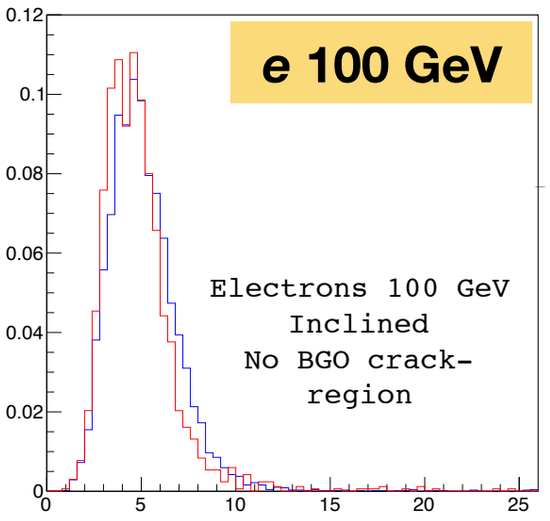
On-ground tests

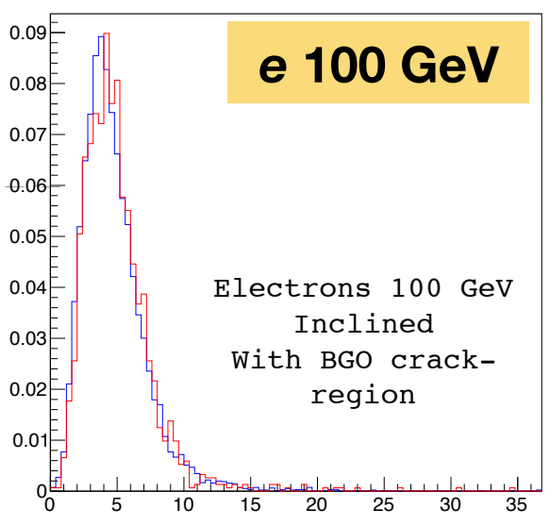
BGO energy resolution: e/p separation

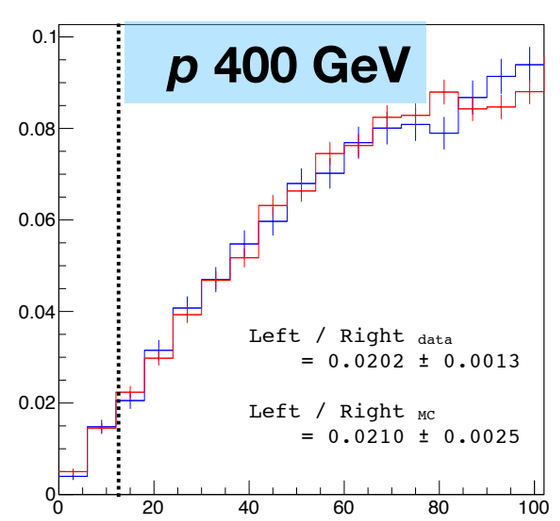








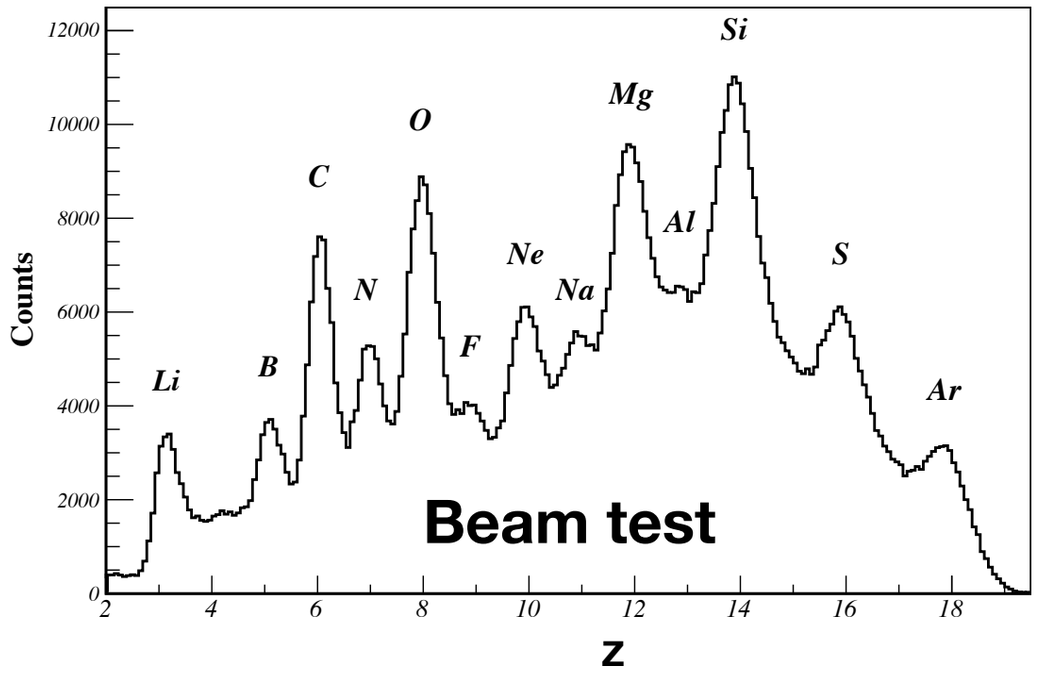




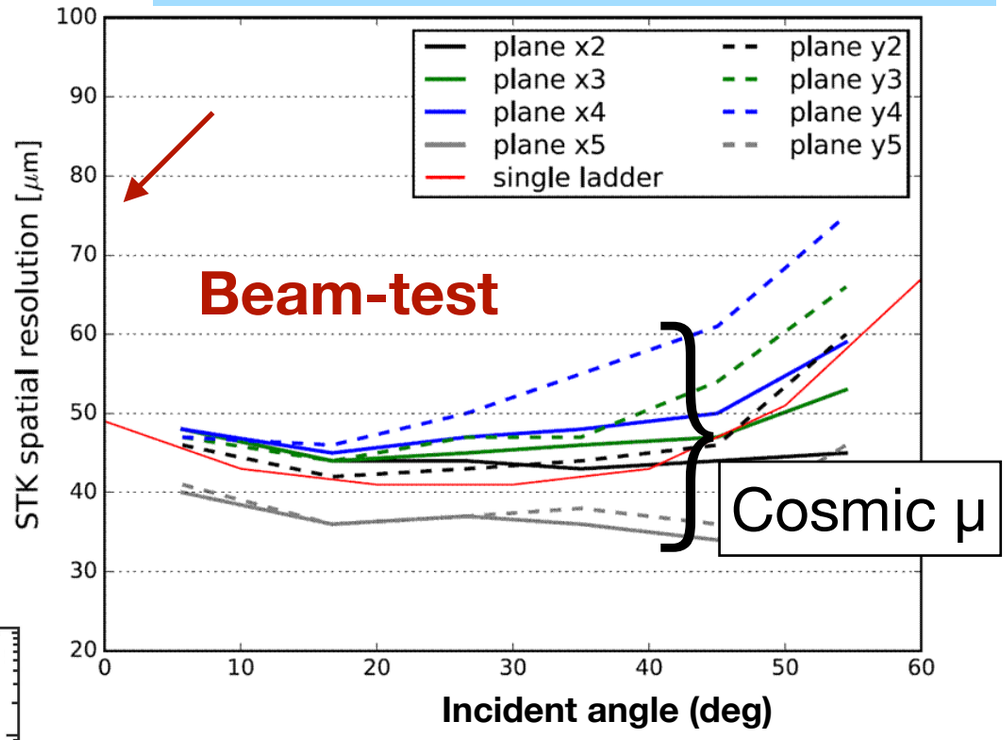
e/p discriminator

On-ground tests

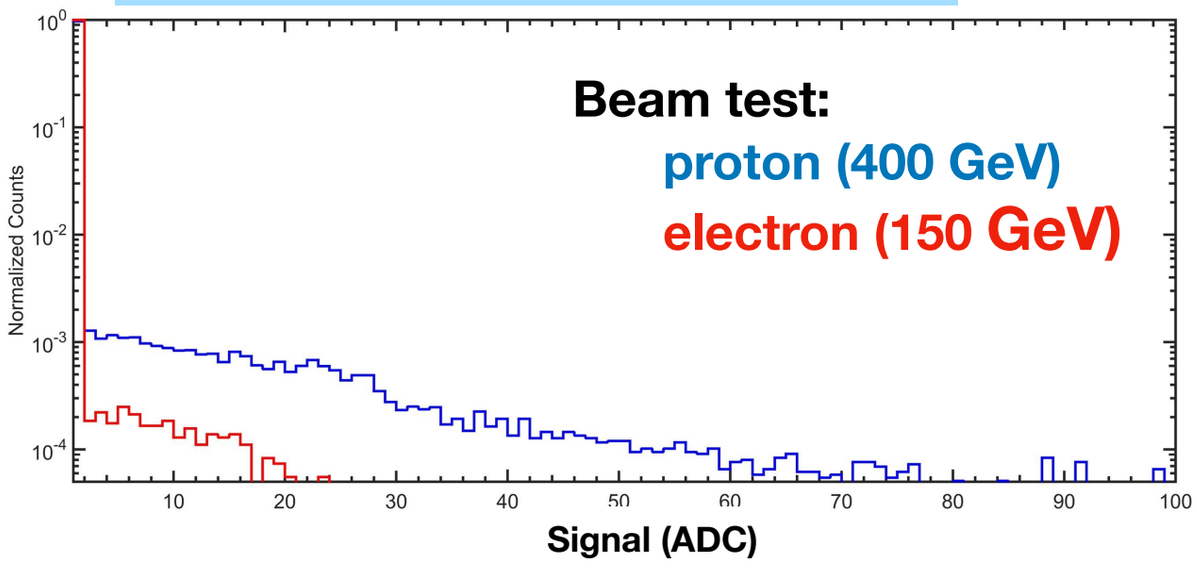
PSD charge reconstruction



STK position resolution

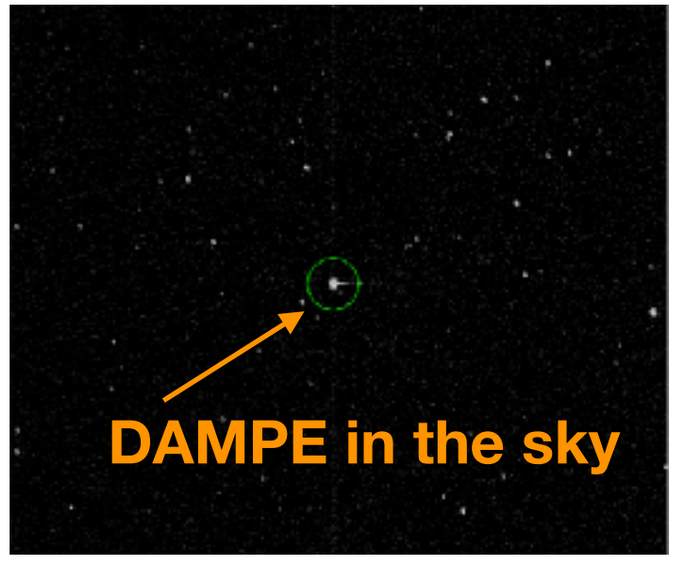


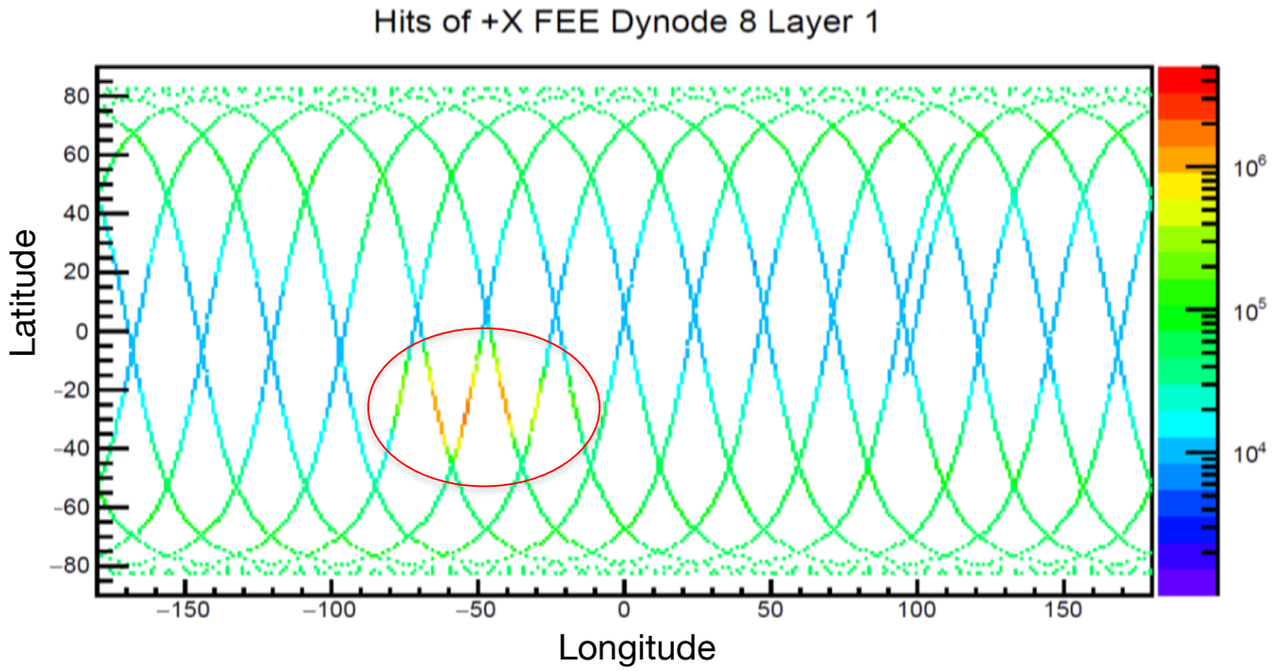
NUD e/p separation

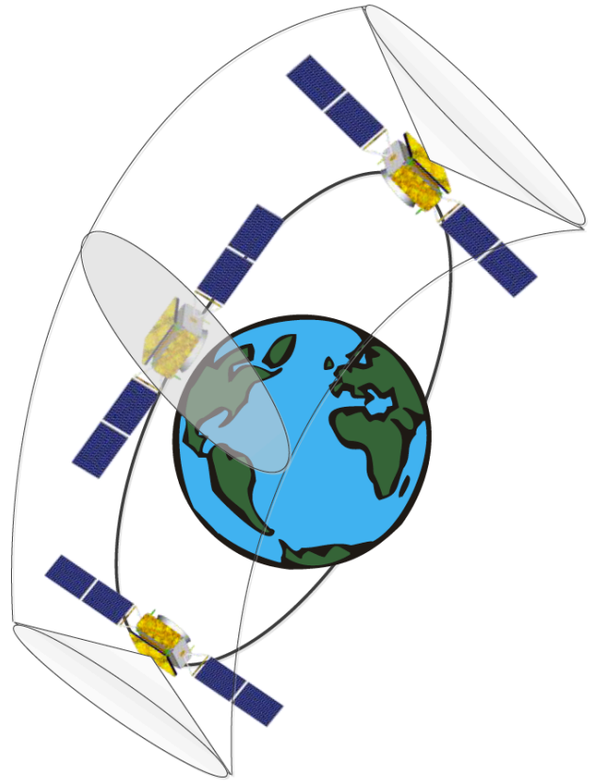


10.1016/j.astropartphys.2017.08.005

In-flight operation





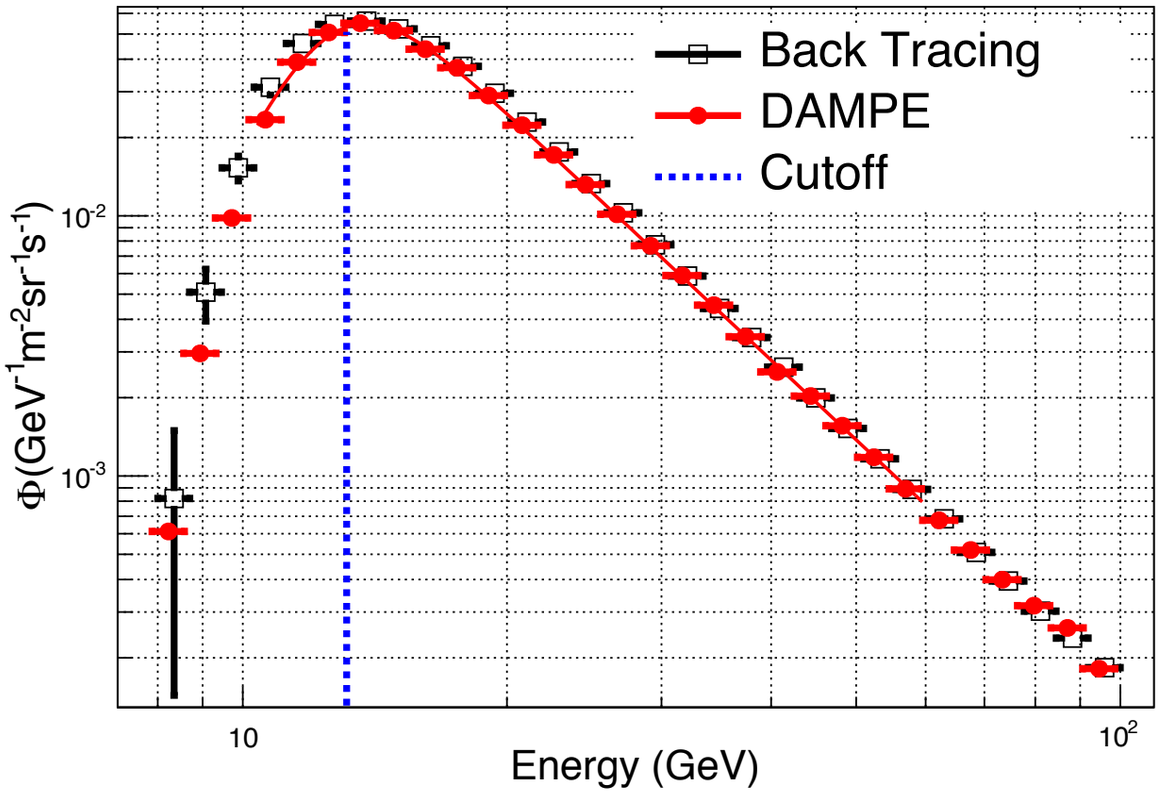


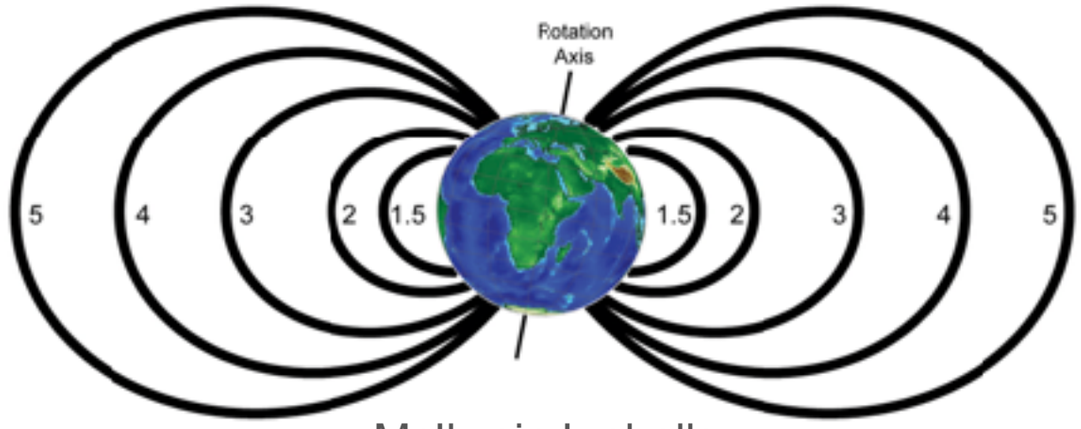
15 orbits and 5M events per day

In-flight operation

BGO energy scale

https://pos.sissa.it/301/197/pdf





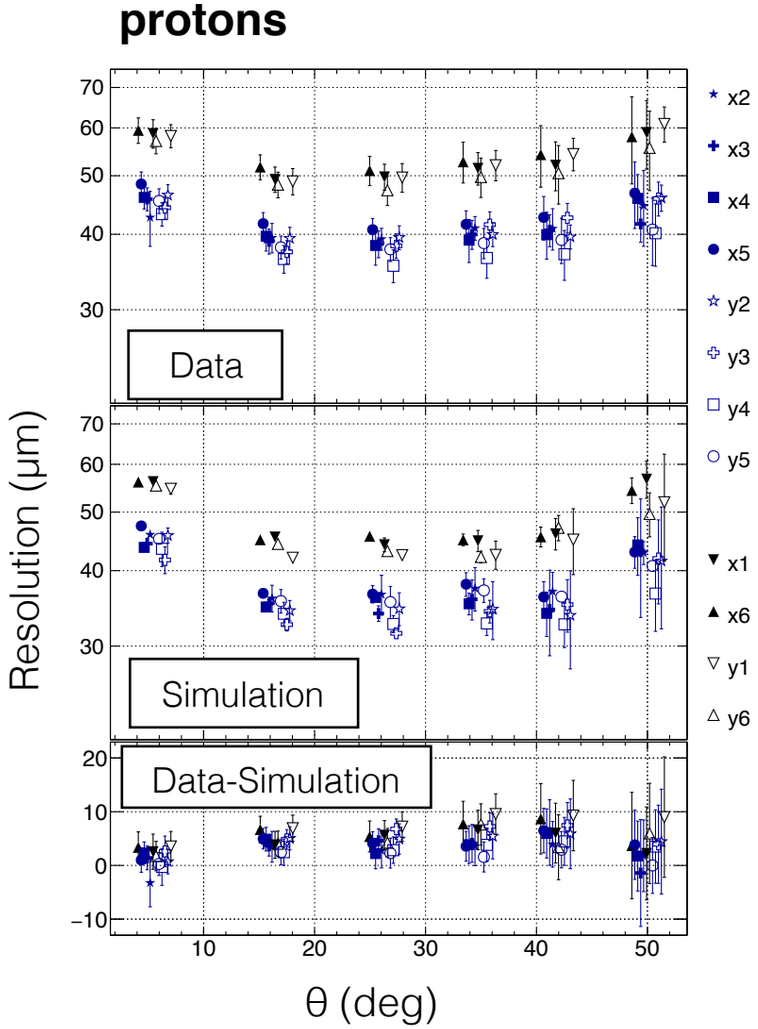
McIlwain L-shells

- Cosmic rays bent by geomagnetic field:
  - cutoff for $e^+ + e^-$ at about 10GeV
  - calculated using the IGRF-12 model
  - allows to estimate absolute energy scale

Energy scale correction @13 GeV = **1.25% ± 1.75% (stat) ± 1.34% (syst)**

In-flight operation

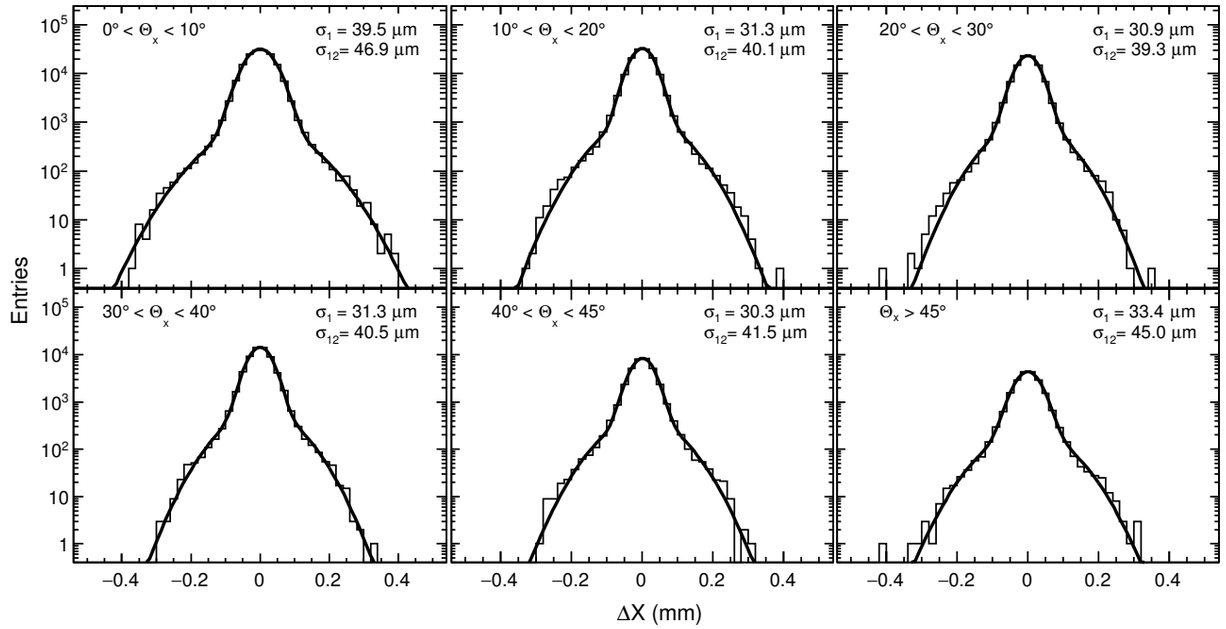
STK alignment and position resolution



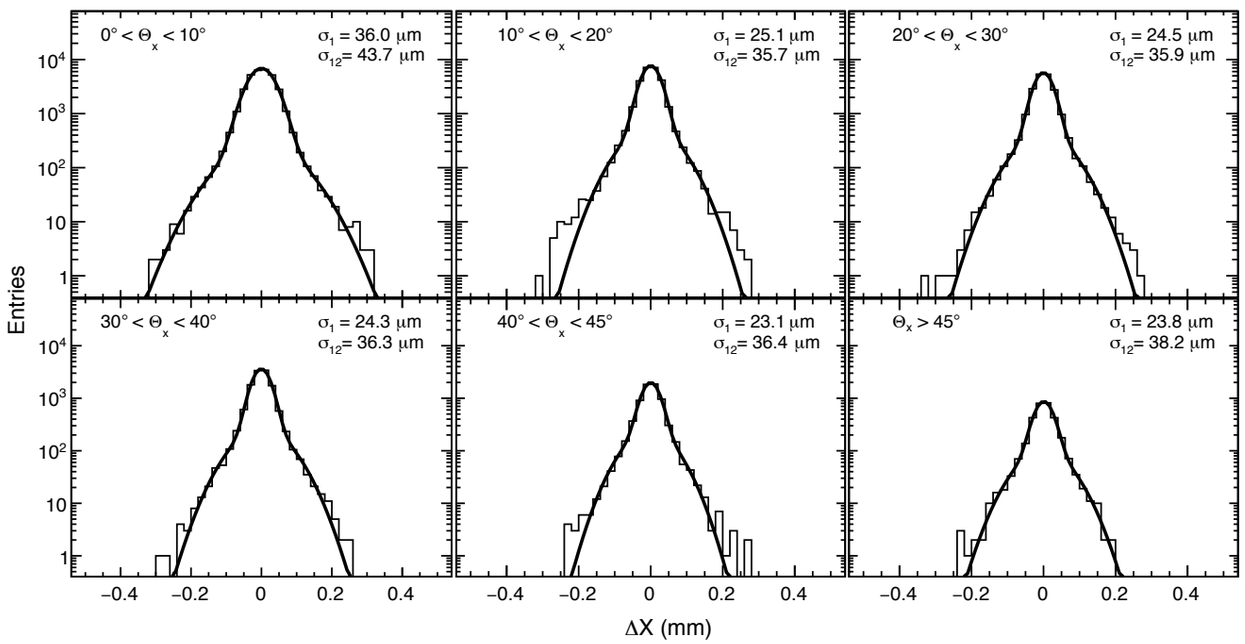
STK alignment is performed by optimising the track-hit residuals

10.1016/j.nima.2018.02.105

p resolution: **~ 41 μm** (intermediate angles)



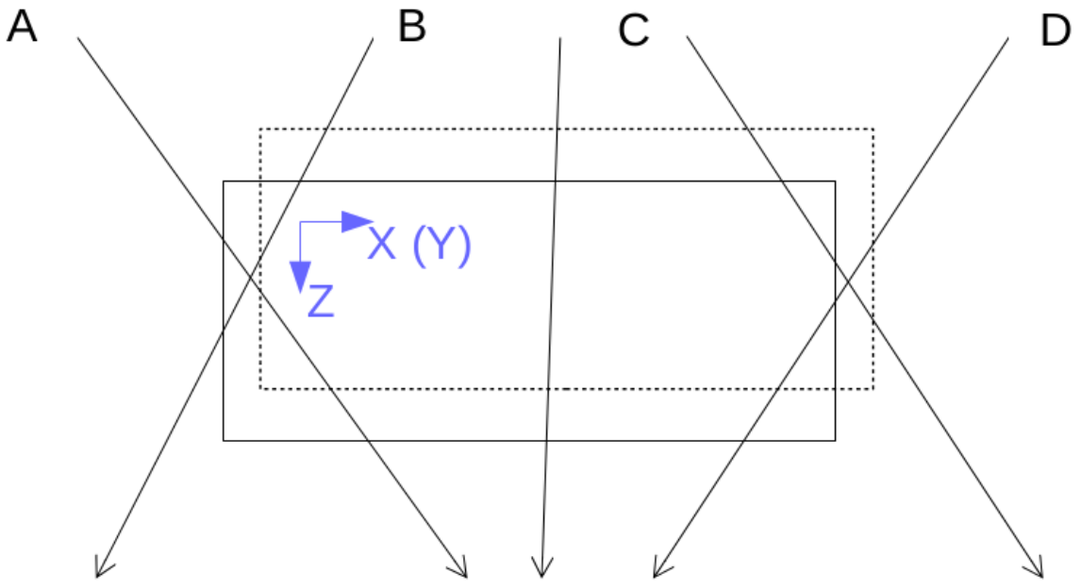
He resolution: **~ 36 μm** (intermediate angles)

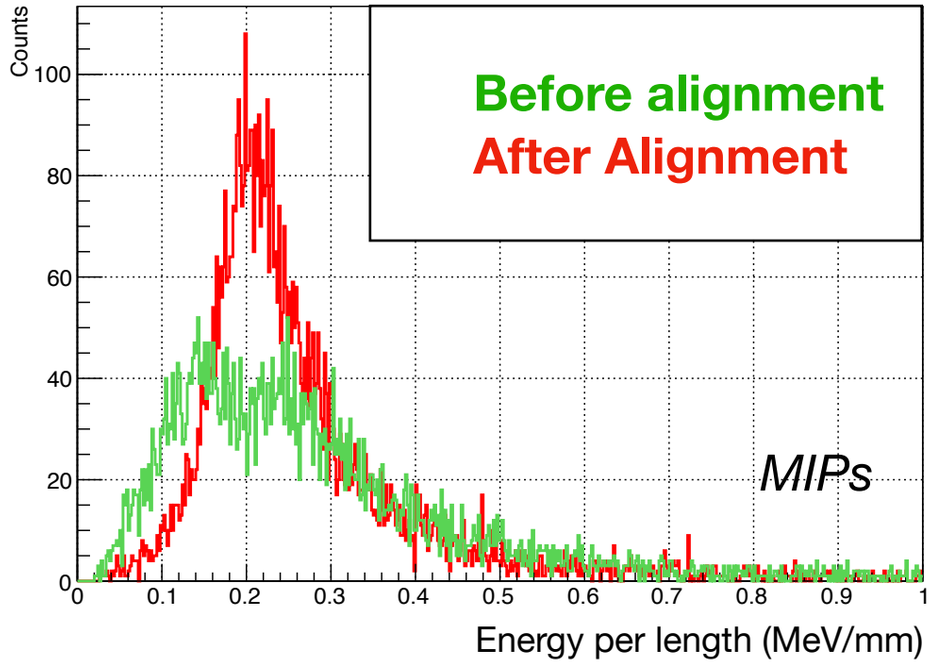


In-flight operation

PSD alignment and charge resolution

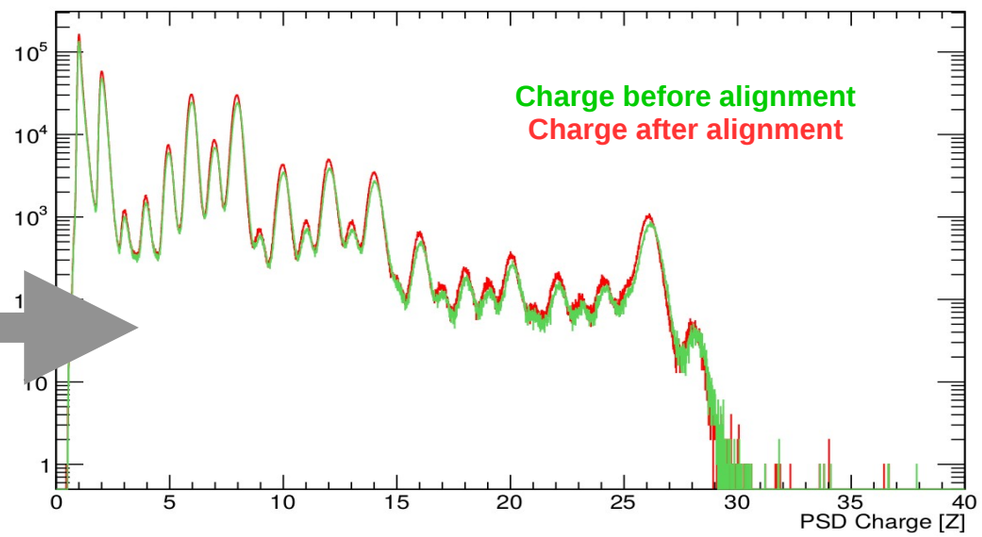
PSD alignment is performed by optimising particle path length in a PSD bars





Charge resolution before and after the alignment, and the relative improvement:

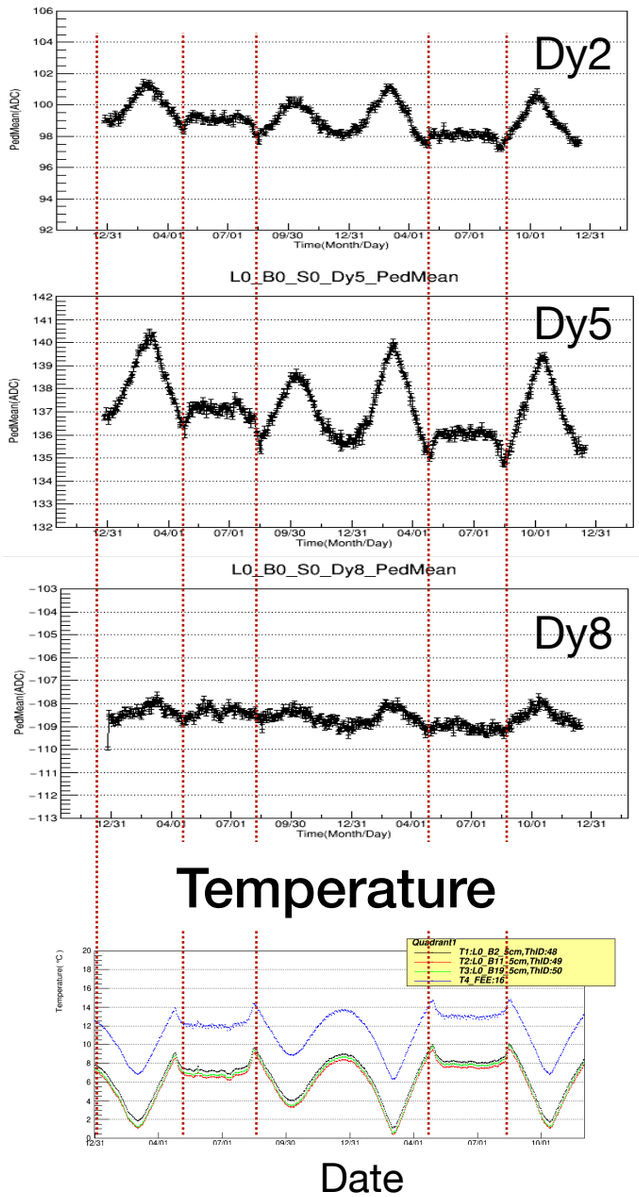
H	He	Li	Be	B	C	N	O	Ne	Mg	Si
0.037	0.056	0.126	0.124	0.138	0.156	0.193	0.202	0.239	0.254	0.286
0.035	0.051	0.119	0.119	0.131	0.149	0.188	0.193	0.229	0.240	0.274
5.4%	8.9%	5.5%	4.0%	5.1%	4.5%	2.6%	4.5%	4.2%	5.5%	4.2%



In-flight operation

BGO & PSD signal stability

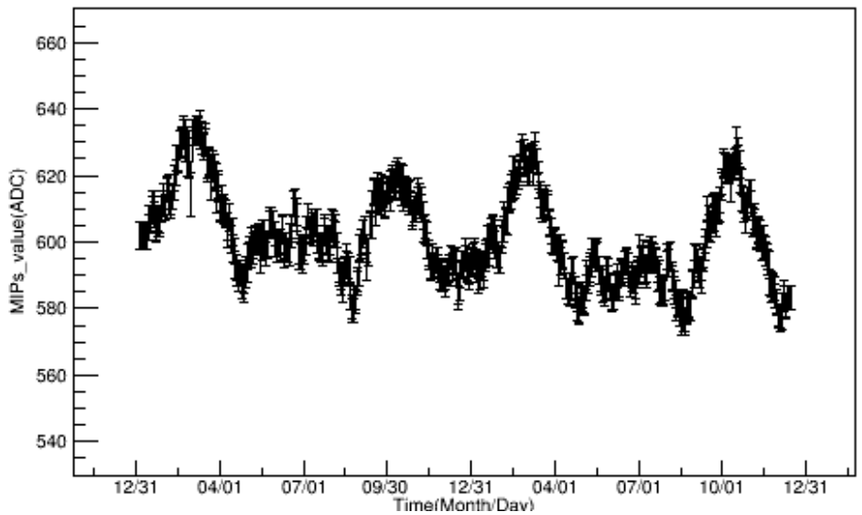
BGO pedestals



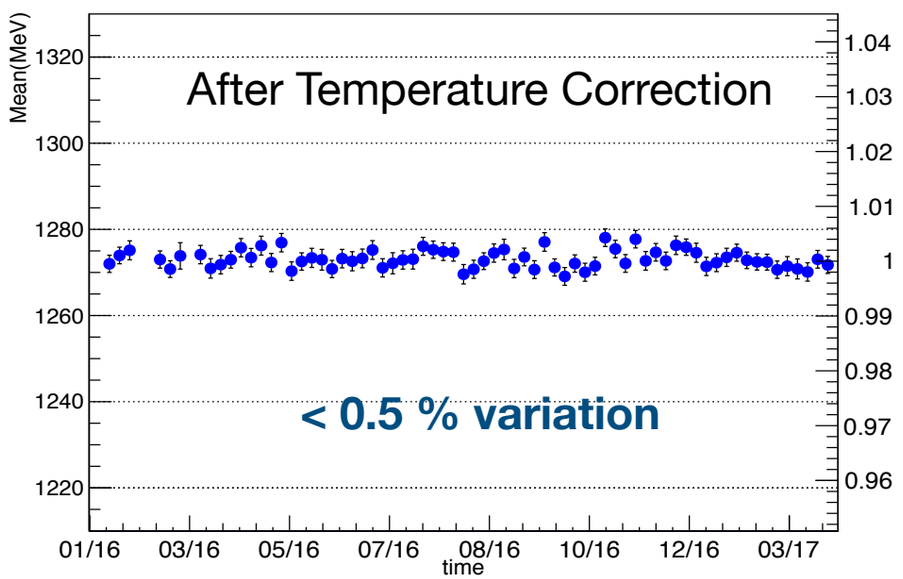
Temperature

Date

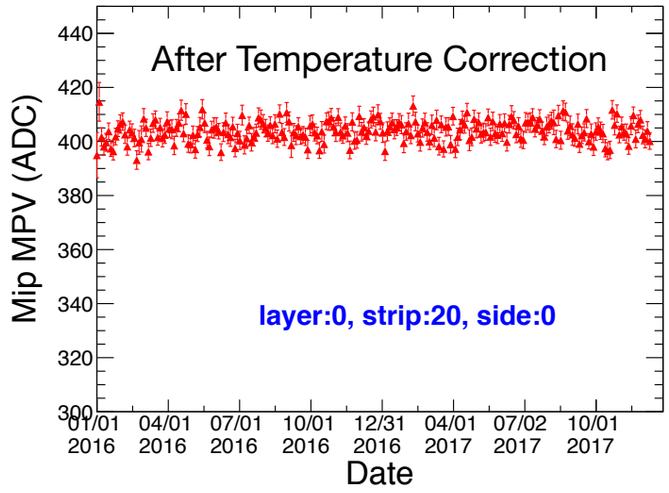
MIP value (BGO)

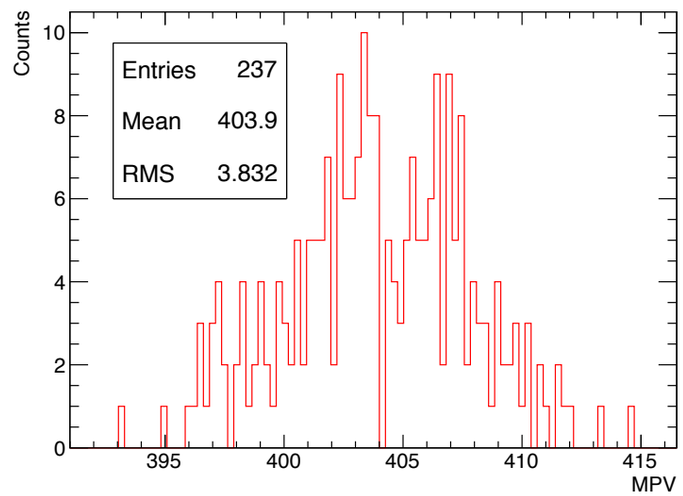


Stability of Helium MIPs



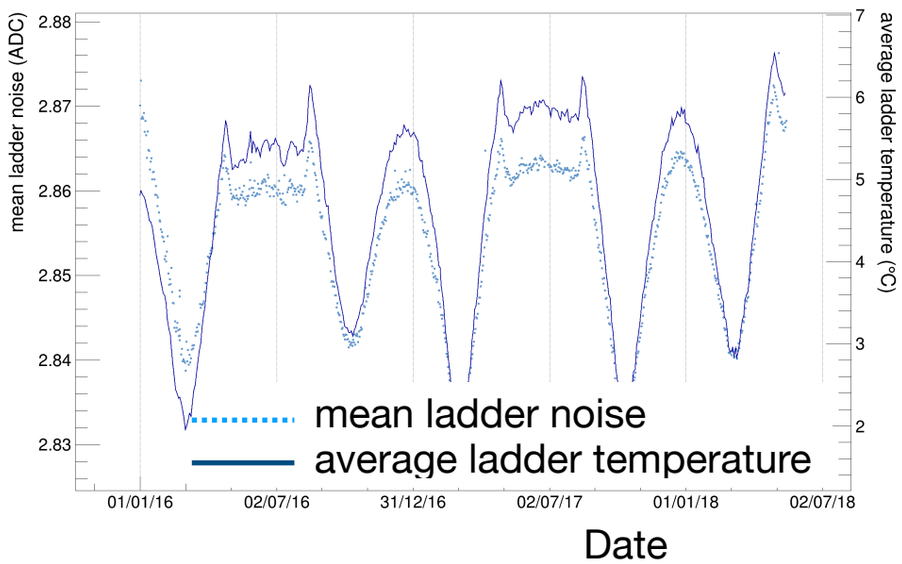
MIP value (PSD)

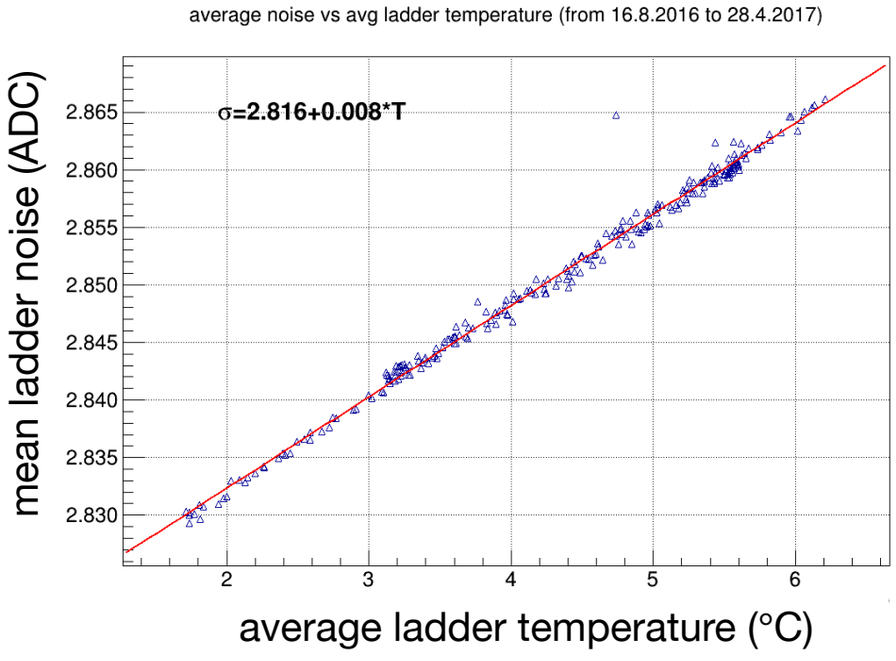


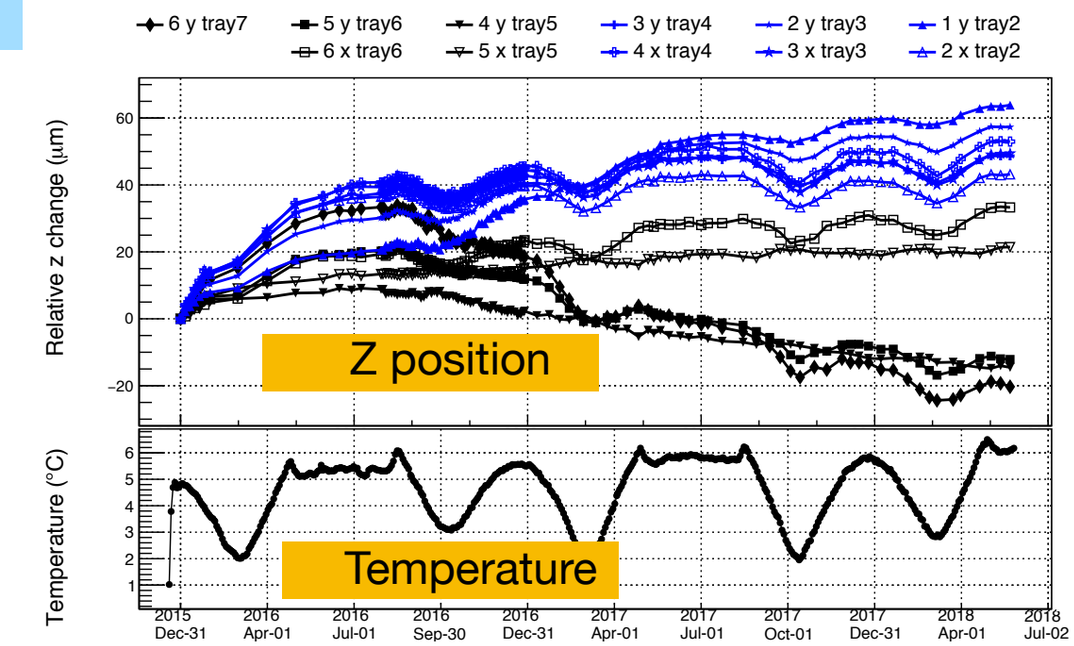


In-flight operation

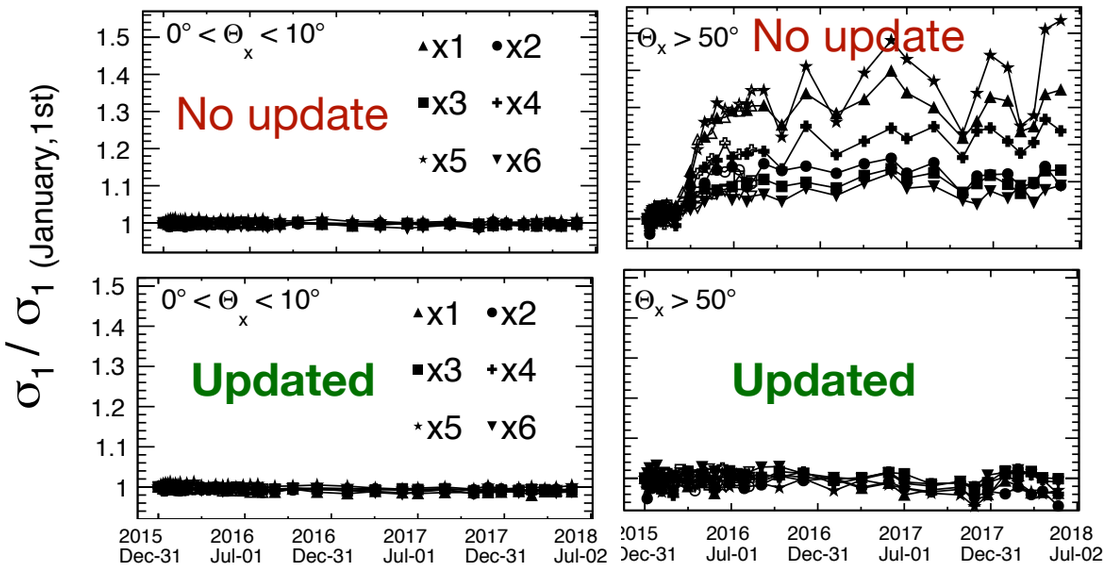
STK Noise and Alignment stability





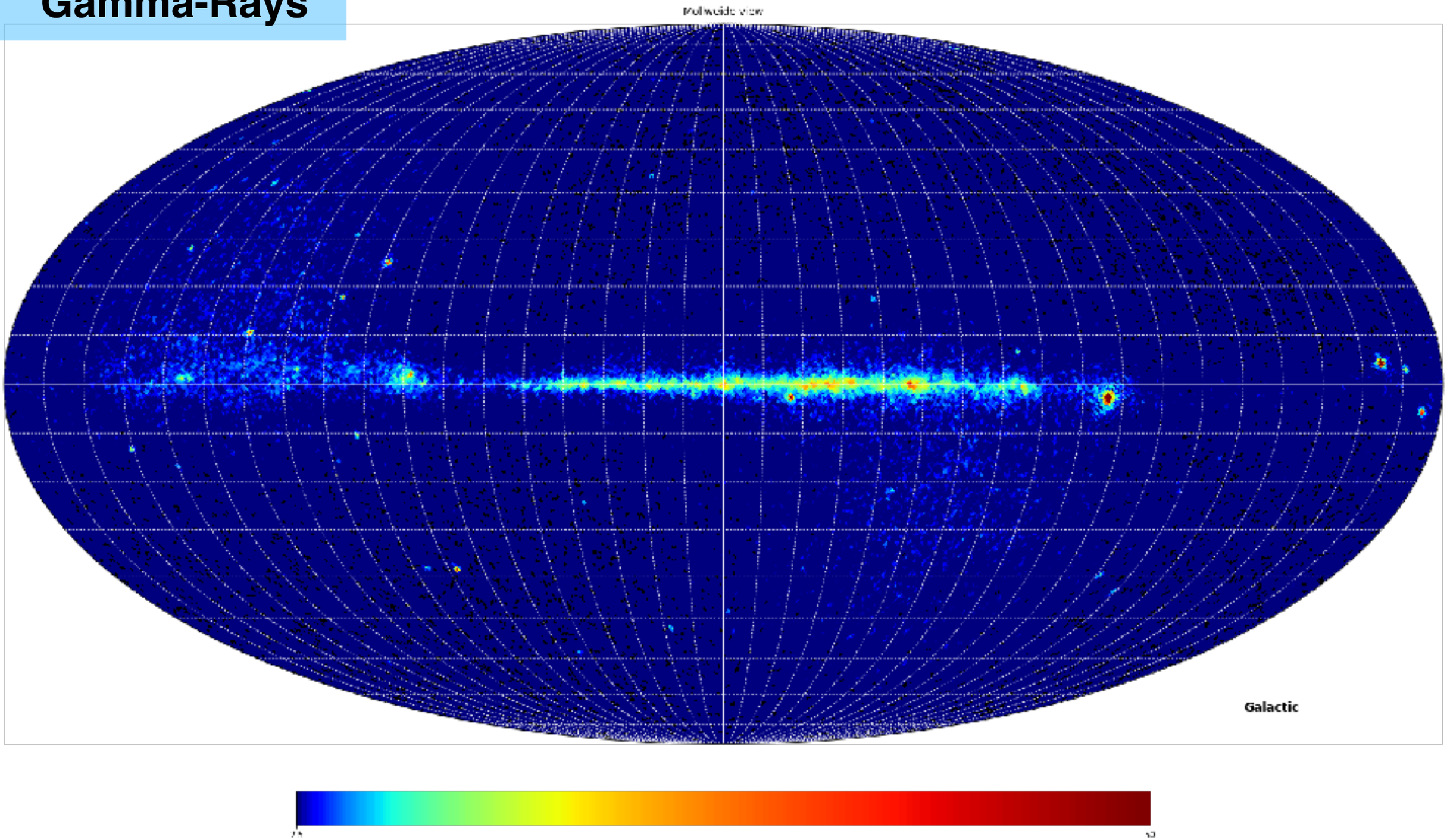


Effect of regular STK alignment update:



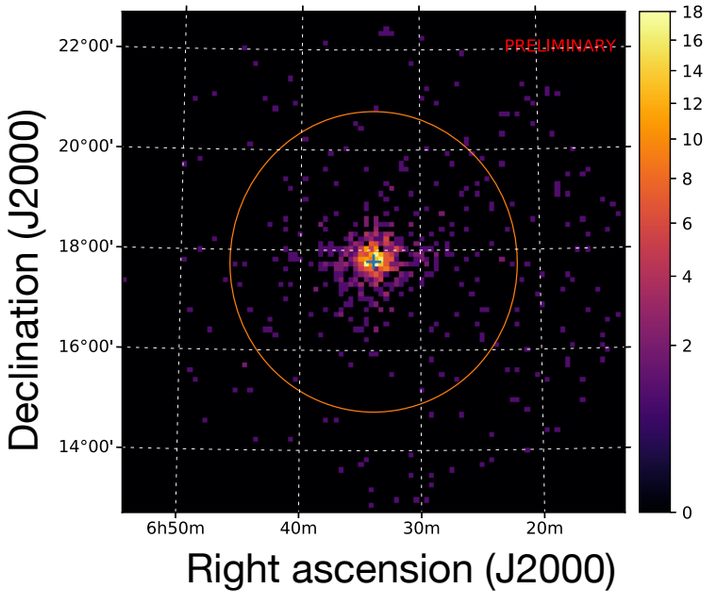
First results

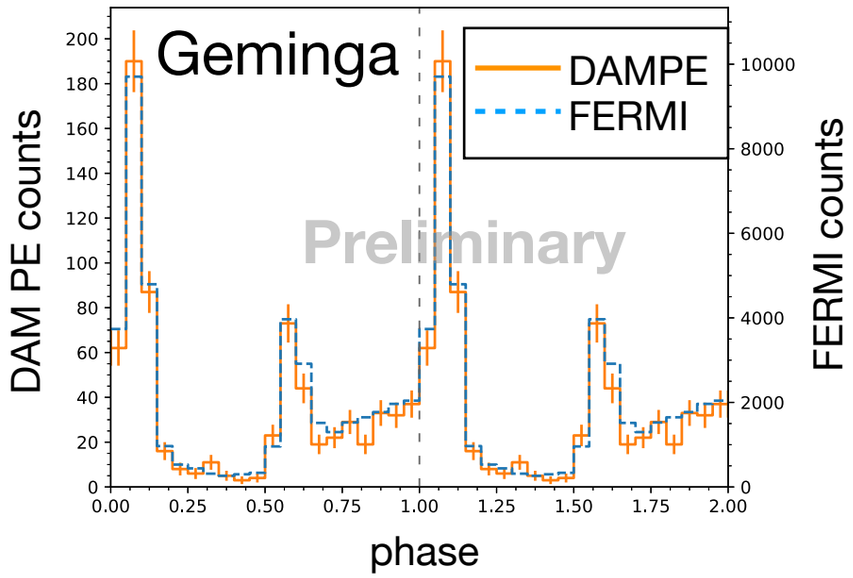
Gamma-Rays

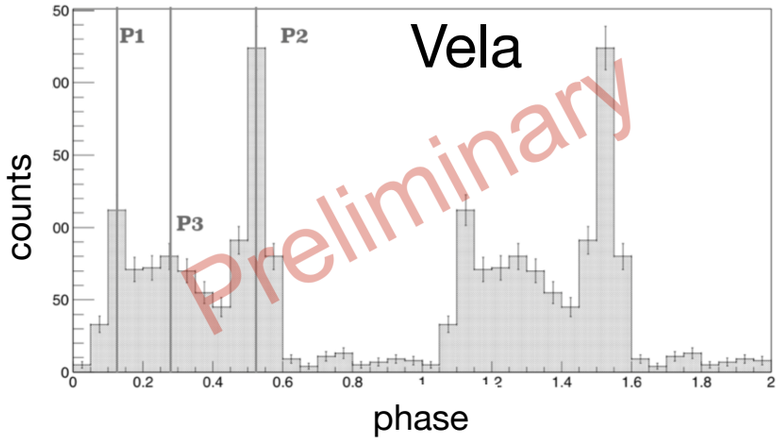


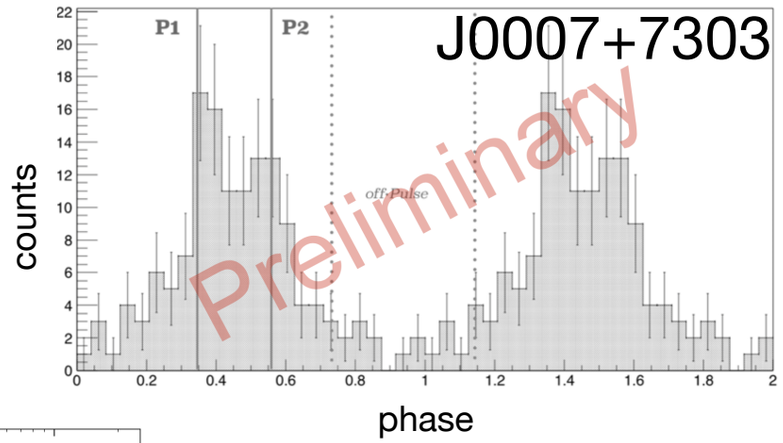
First results

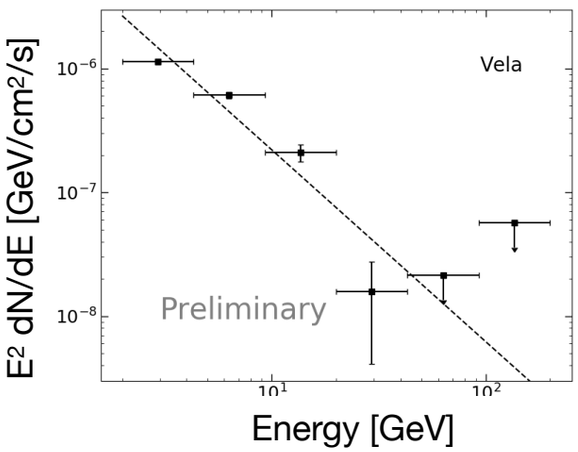
Gamma-Rays: Pulsars

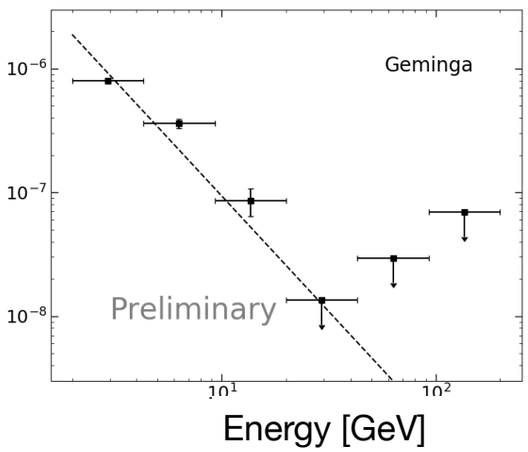


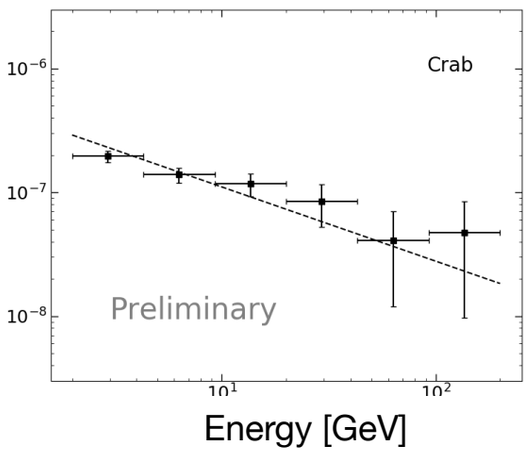










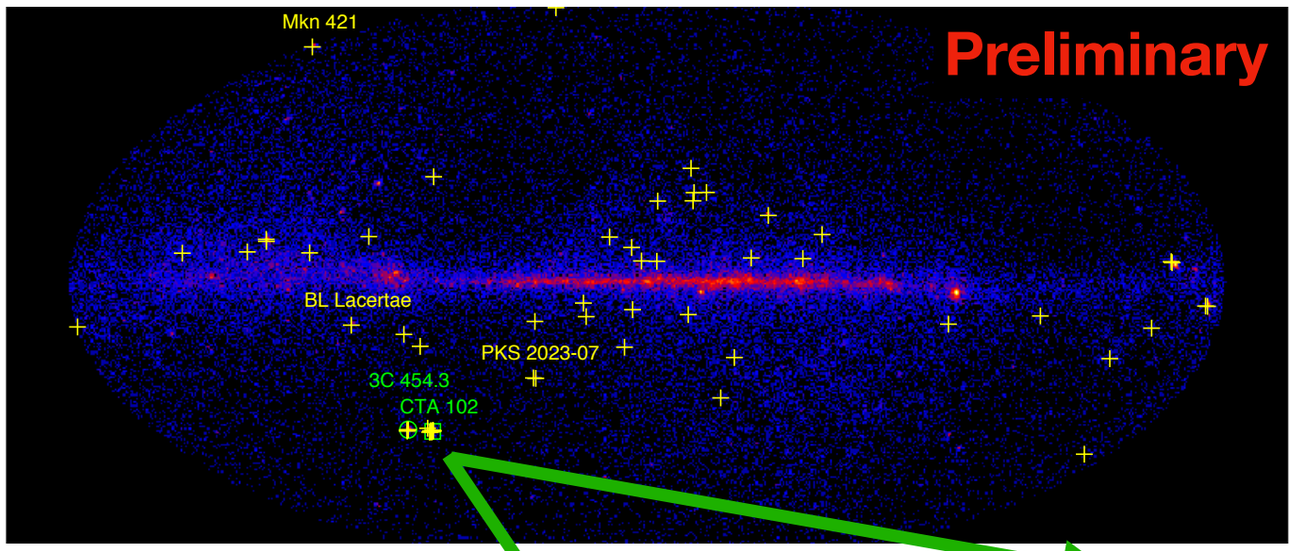


https://pos.sissa.it/301/709/pdf
https://pos.sissa.it/301/616/pdf

An excellent instrument for the identification and analysis of pulsars in an energy 1-100 GeV!

First results

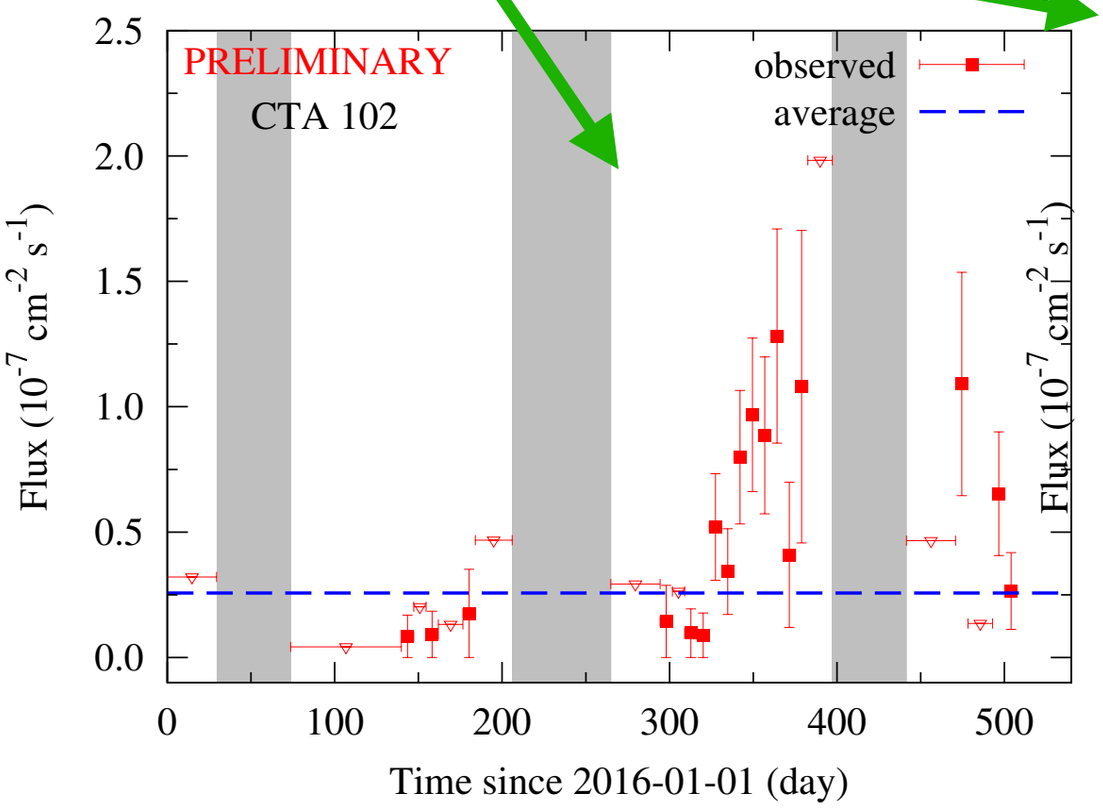
Gamma-Rays: Variable Sources

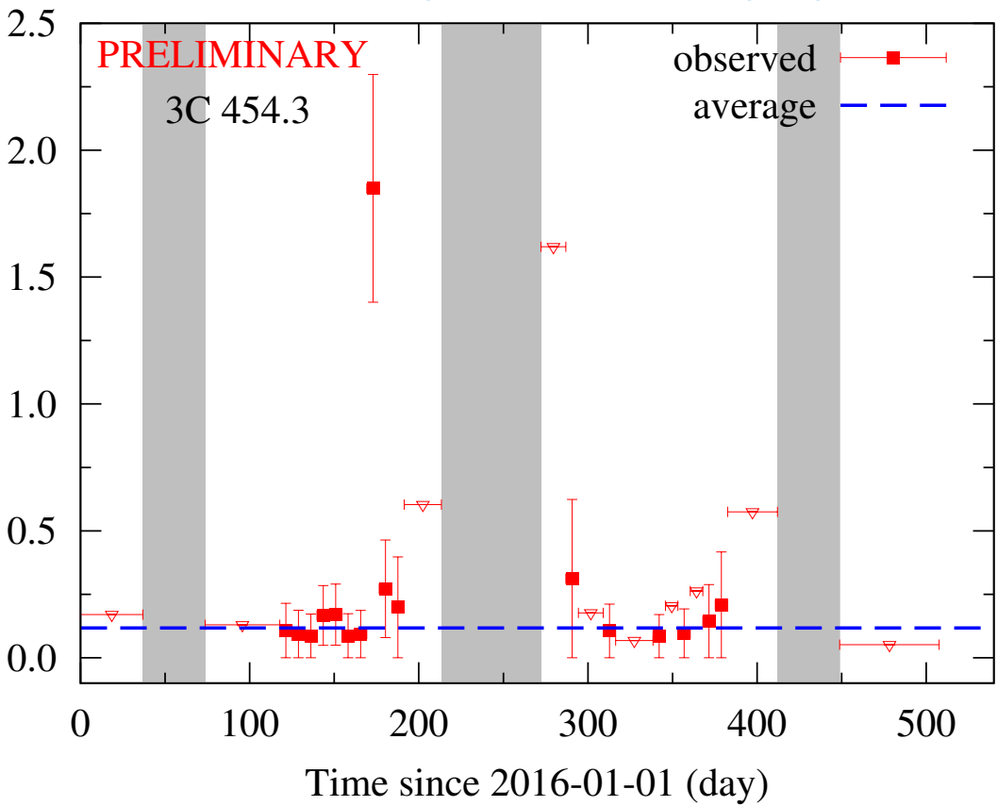


Two AGNs, CTA 102 and 3C 454.3 are found to be significantly variable at time scales longer than one week.

Photon clusterings: 63 photon pairs, one photon triple, and one quadruple ($\Delta T < 1500s$ and $\Delta\Theta < 1°$)

Astronomy telegram: astronomerstelegram.org/?read=9901
For details: pos.sissa.it/301/617/pdf, pos.sissa.it/301/616/pdf

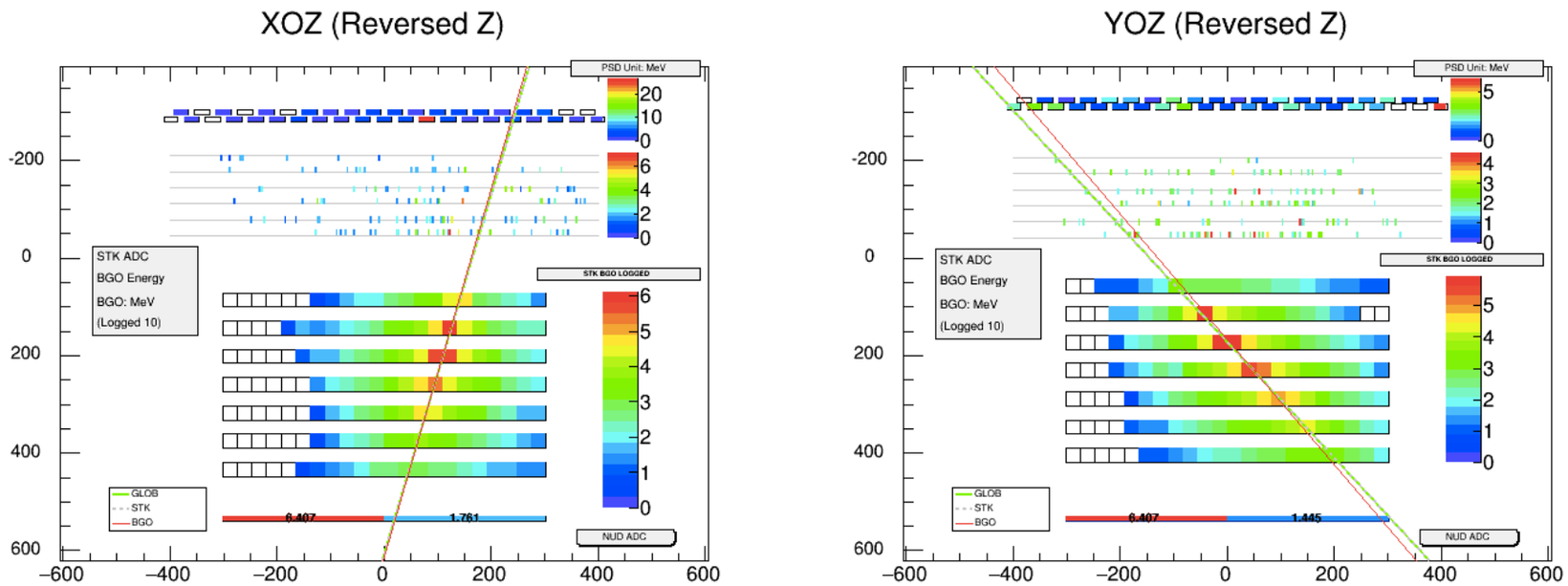




First results

Electrons: e/p discrimination

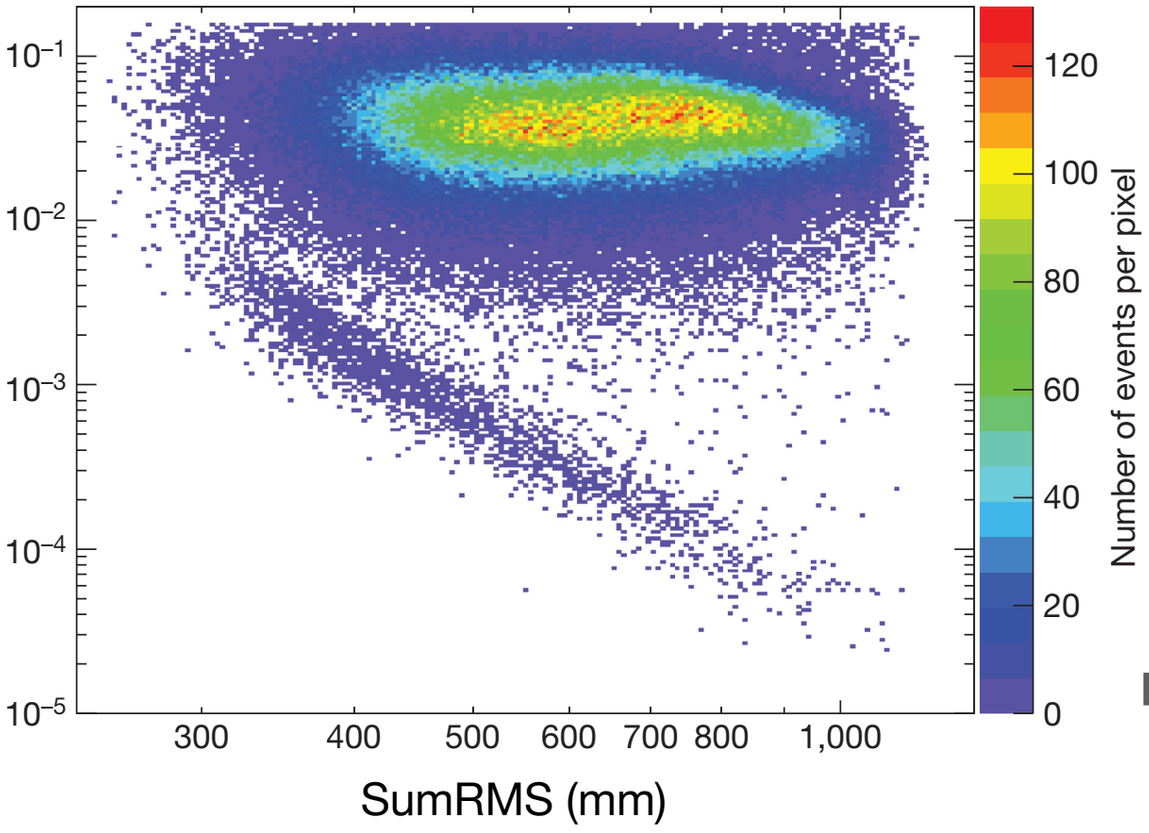
- Electron showers are narrow and short
  - **Longitudinal shower shape**
    SumRMS - sum of shower RMS in 14 layers of BGO
  - **Lateral shower shape**
    $\mathcal{F}_{last}$ —fraction of total shower energy in the last shower layer.

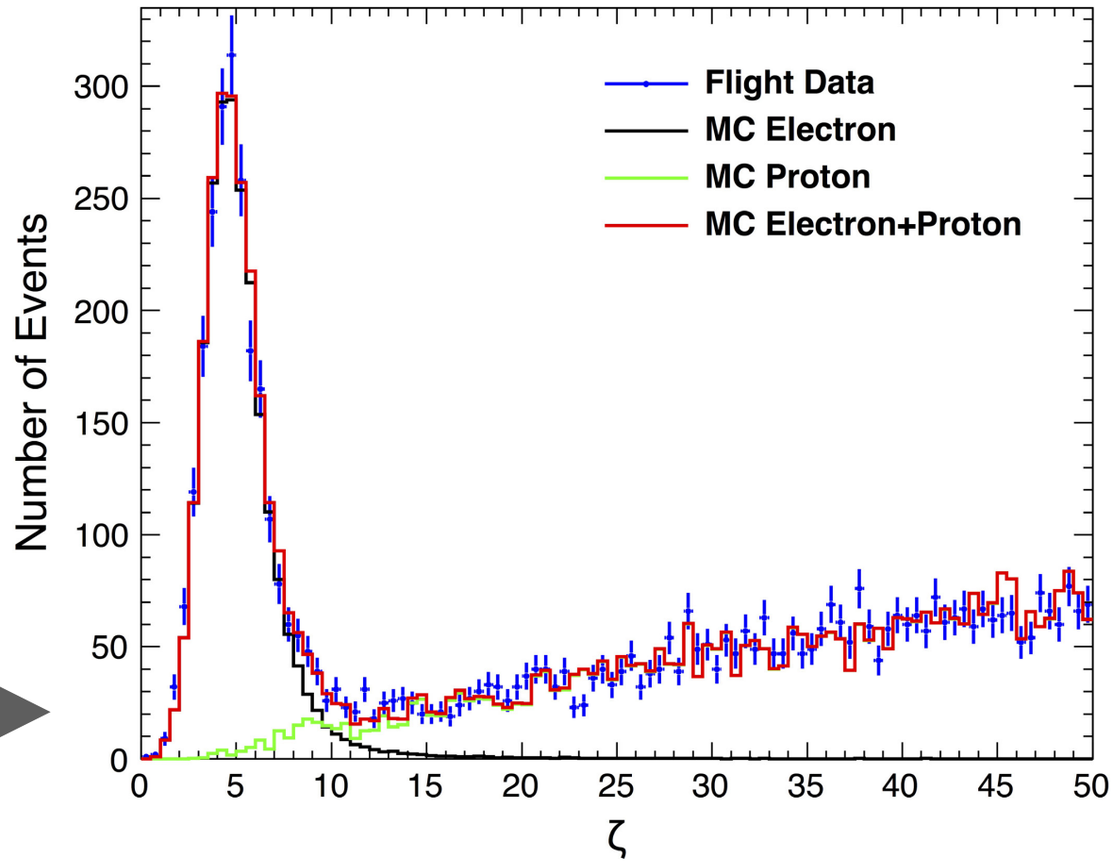


5.6 TeV electron candidate

First results

Electrons: e/p discrimination



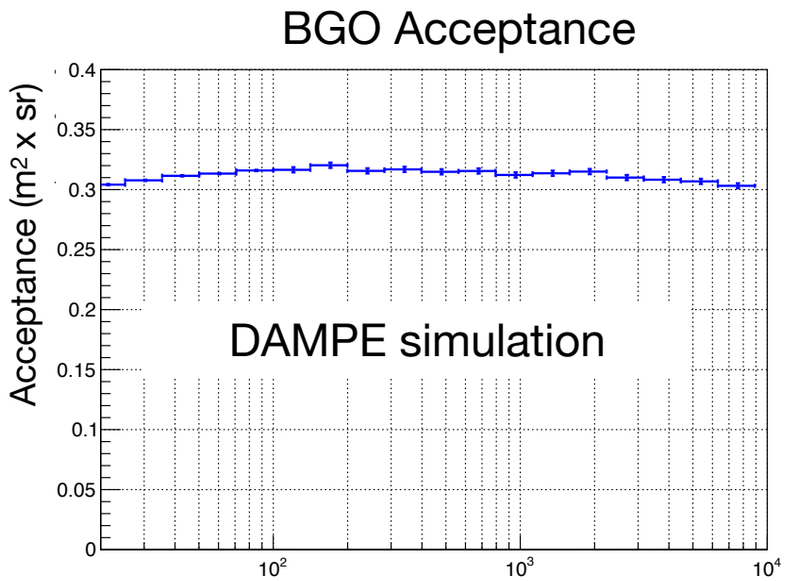


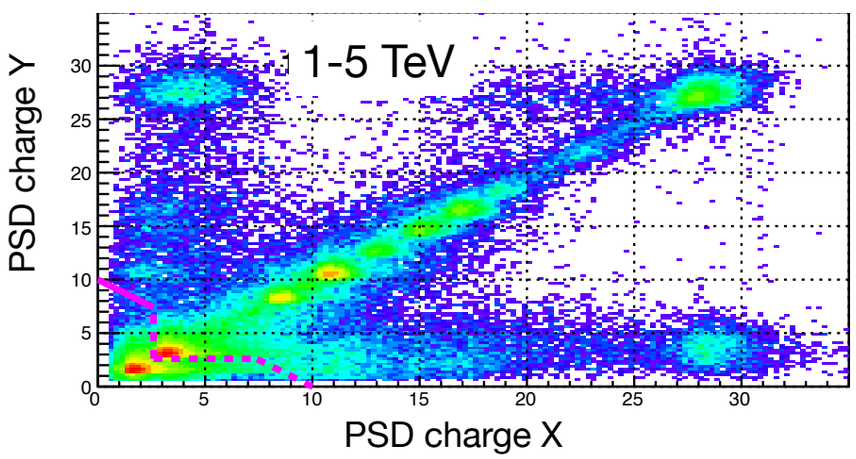
$$\zeta = \mathcal{F}_{last} \times [\text{SumRMS} / \text{mm}]^4 / (8 \times 10^6)$$

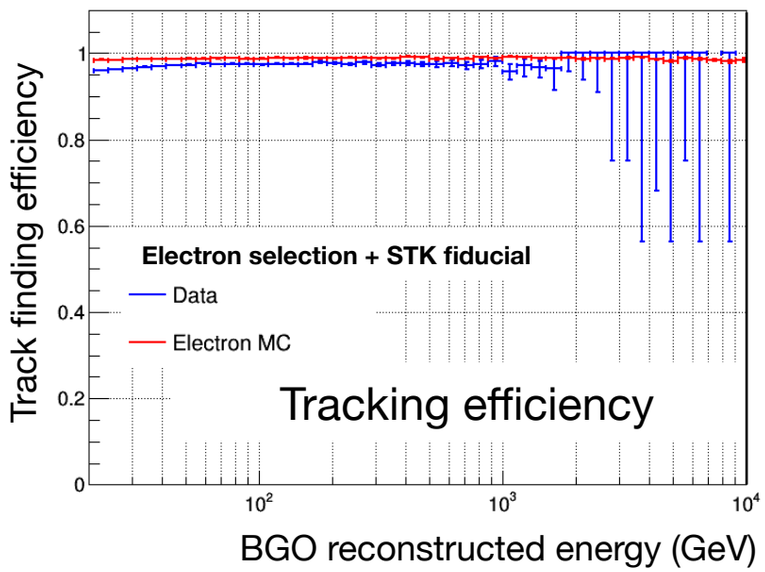
First results

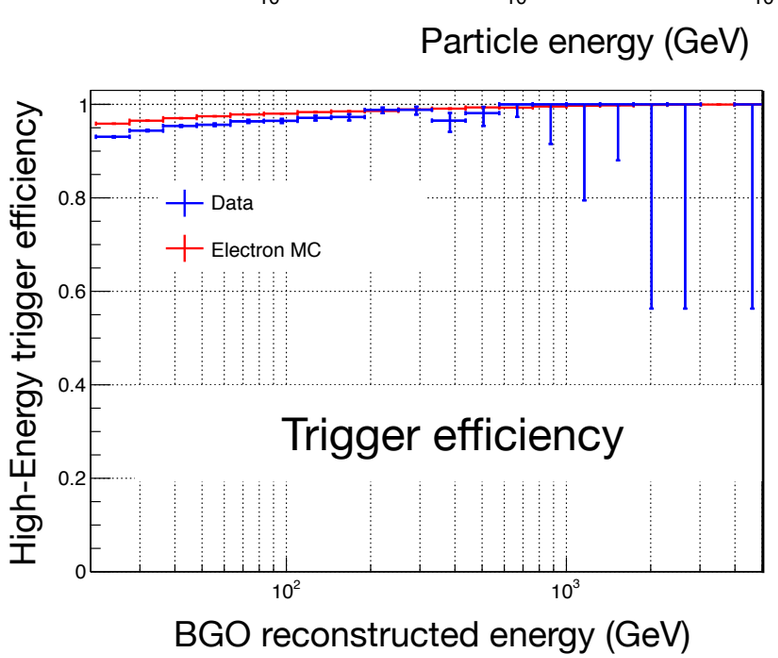
Electrons: selection

- High-Energy Trigger
- Pre-selection (clean-up)
- Fiducial volume
- Heavy nuclei removal
  - STK & PSD charge in track-matched sample
  - First 2 layer of BGO for BGO-only events
- ζ signal extraction





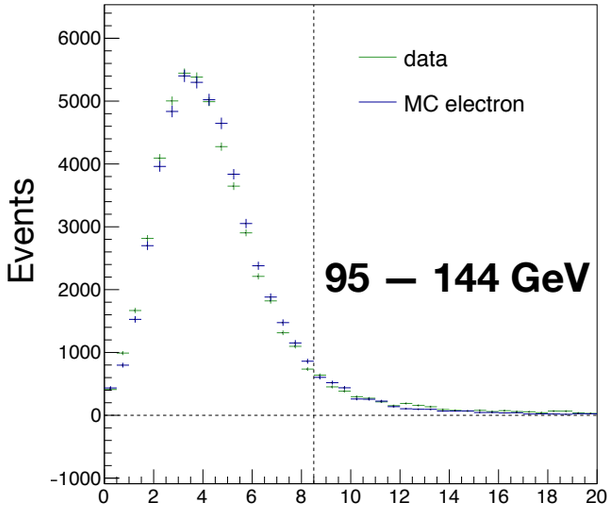


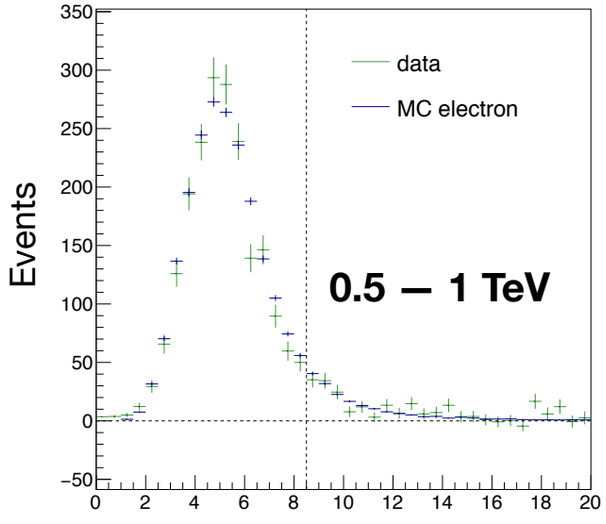


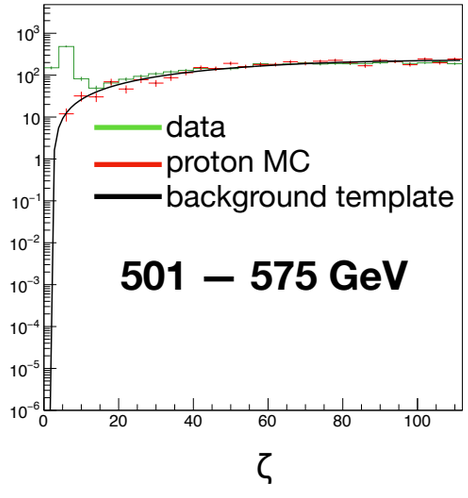
Very high trigger and selection efficiency, good data-MC agreement!

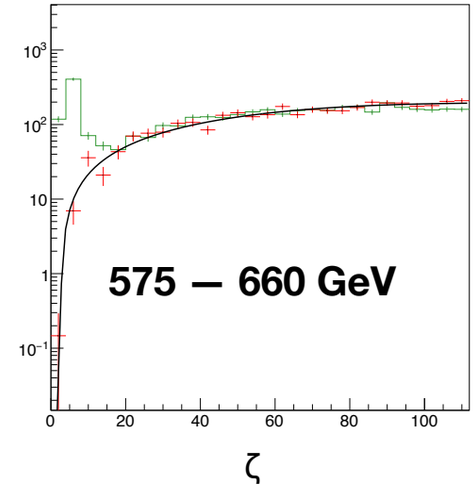
First results

Electrons: background and signal efficiency

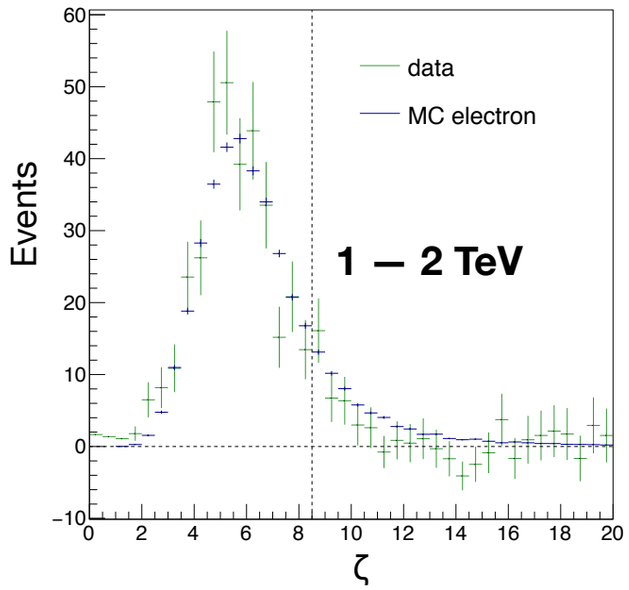


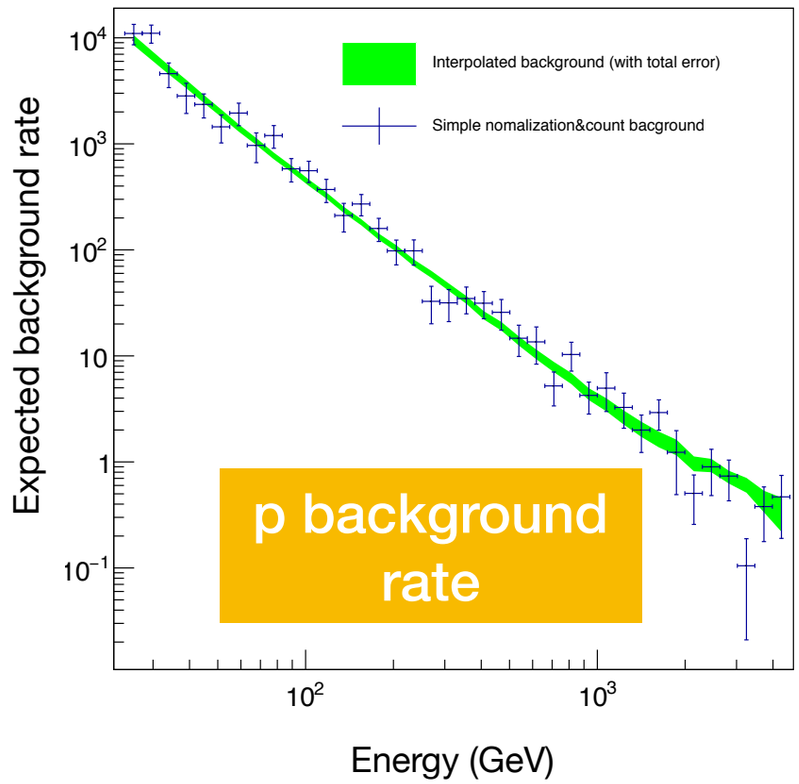






electrons

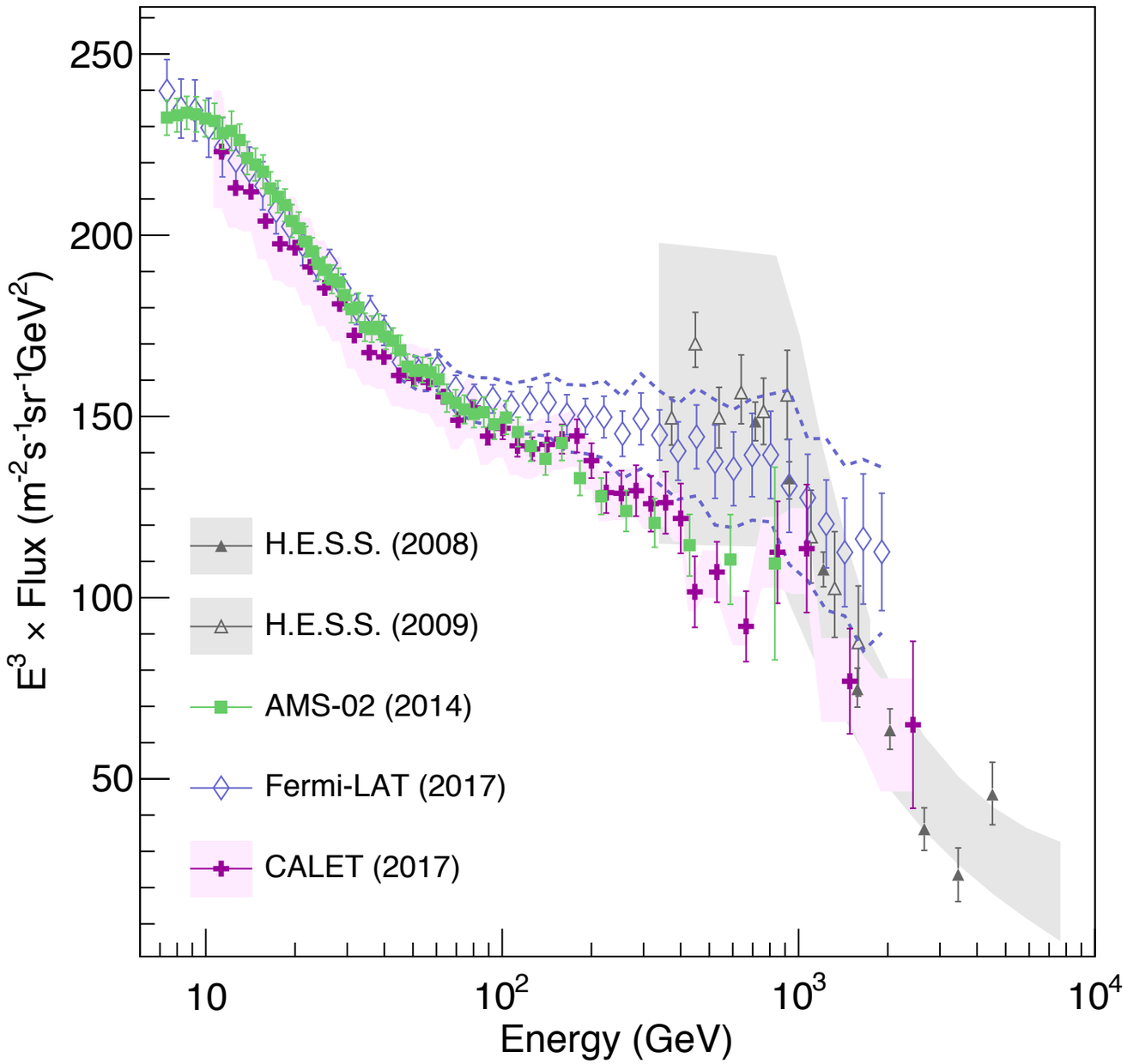




Semi-analytic background templates obtained from the Simulation. Good data-MC agreement of ζ both for electrons and protons.

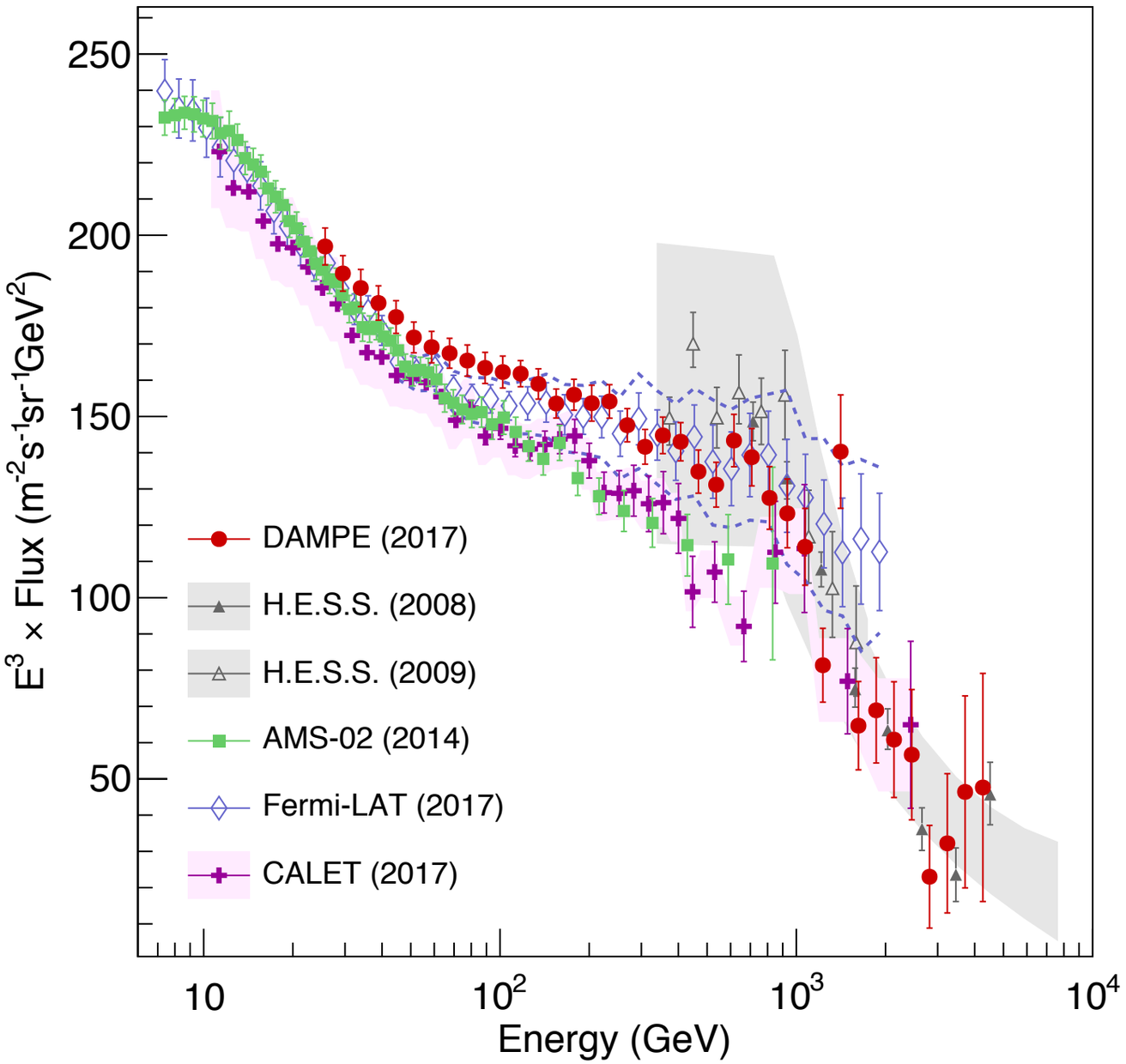
First results

Electrons: flux



First results

Electrons: flux

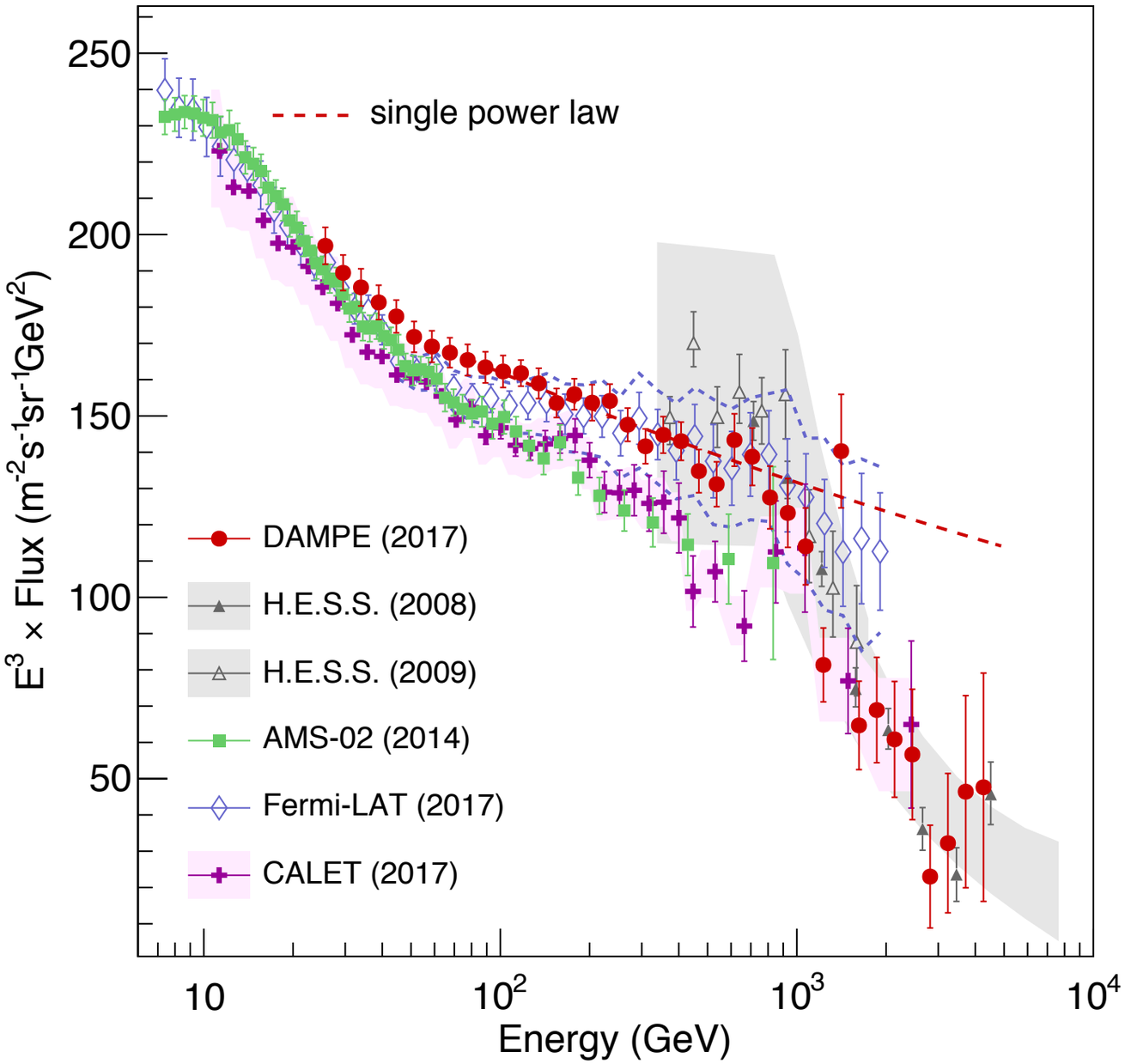


https://www.nature.com/articles/nature24475

First results

Electrons: flux & single power law fit

$\Phi = (1.64 \pm 0.01) \times 10^{-4} \, (E/100\mathrm{GeV})^{-3.13 \pm 0.01}$

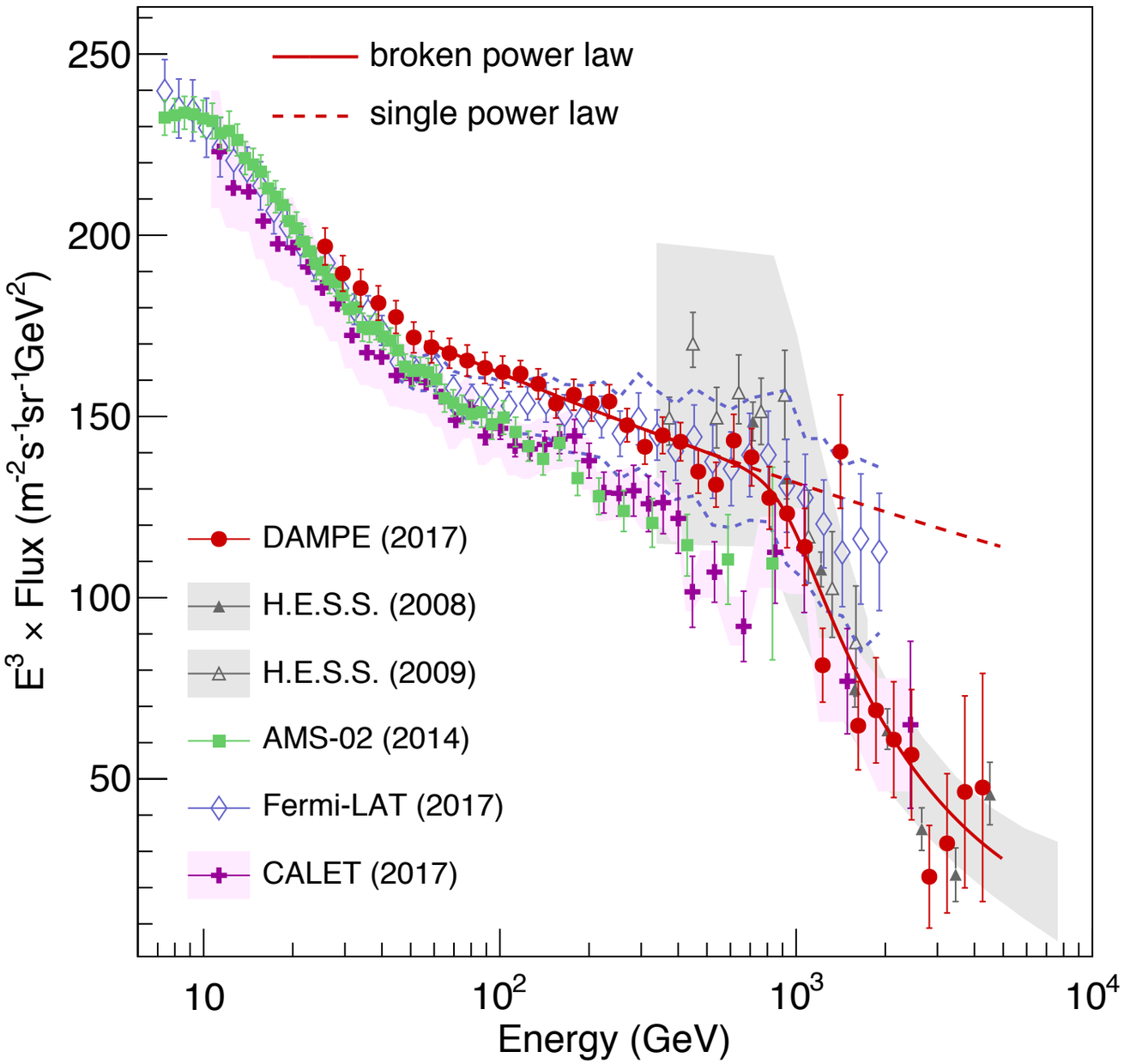


https://www.nature.com/articles/nature24475

First results

Electrons: flux & smoothly broken power law fit

$$\Phi=(1.62 \pm 0.01) \times 10^{-4} \, (E/100\mathrm{GeV})^{-3.09\pm0.01} \, [1+ (E/(914 \pm 98 \ \mathrm{GeV}))^{-(3.09 - 3.92 \pm 0.01 \pm 0.20)/\Delta} \,]^{-\Delta}$$



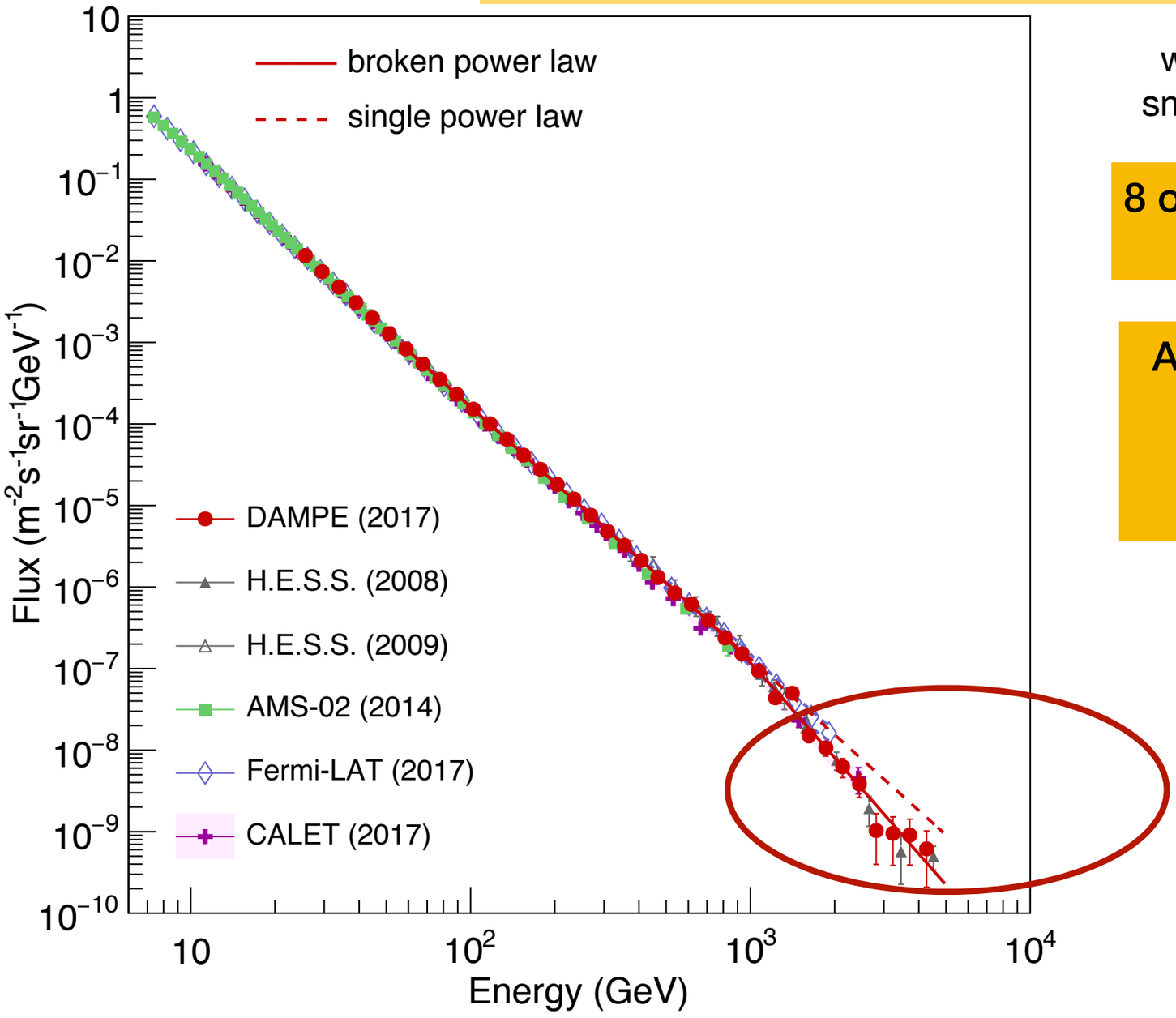
where Δ=0.1 — fixed smoothness parameter

https://www.nature.com/articles/nature24475

First results

Electrons: flux & smoothly broken power law fit

$$\Phi=(1.62 \pm 0.01) \times 10^{-4} \, (E/100\mathrm{GeV})^{-3.09\pm0.01} \, [1+ (E/(914 \pm 98 \ \mathrm{GeV}))^{-(3.09 - 3.92 \pm 0.01 \pm 0.20)/\Delta} \,]^{-\Delta}$$



where Δ=0.1 — fixed smoothness parameter

8 orders of magnitude span!

At highest energies, uncertainties are dominated by statistics.

https://www.nature.com/articles/nature24475

First results

Electrons: flux & smoothly broken power law fit

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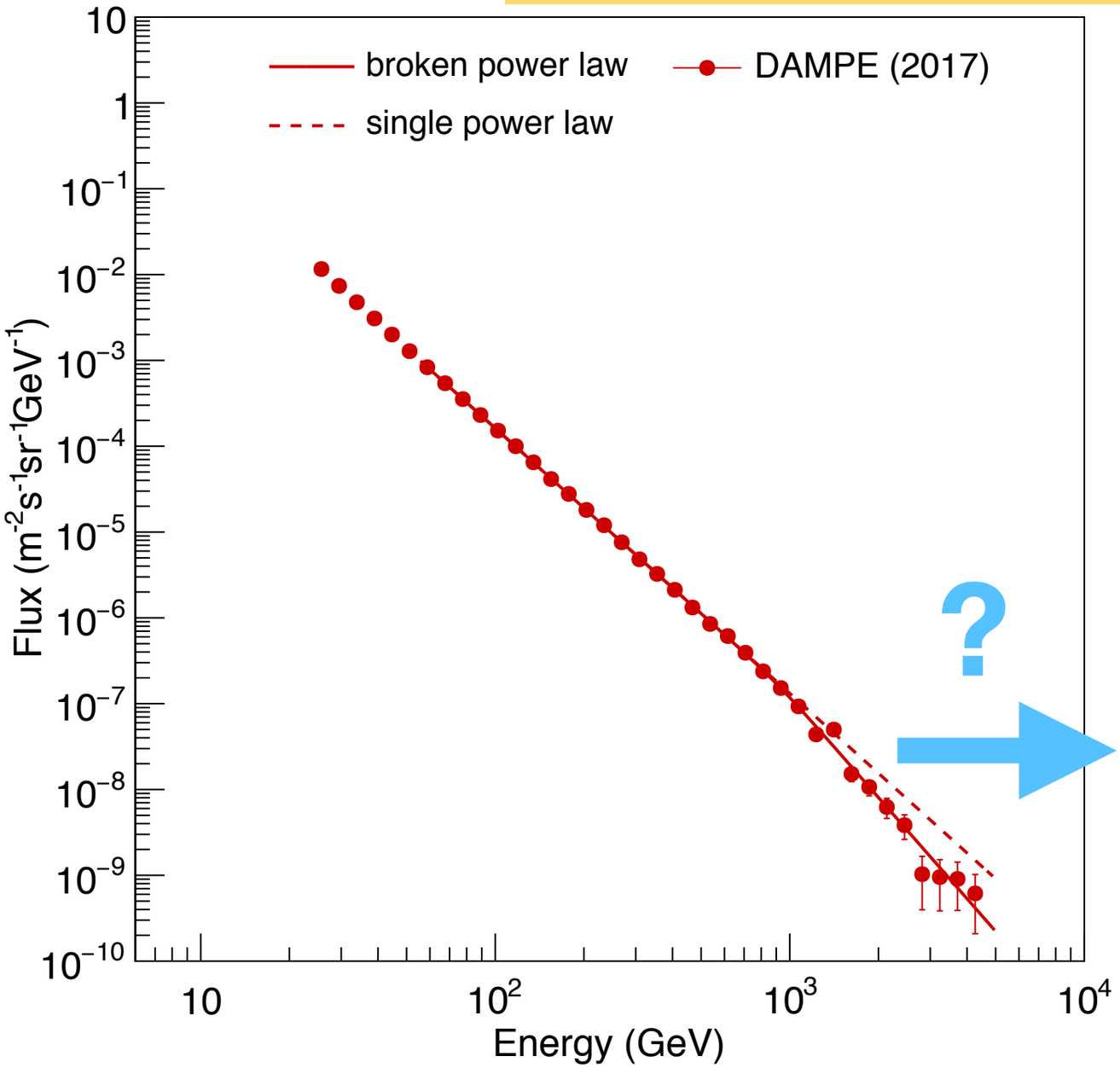


where Δ=0.1 — fixed smoothness parameter

8 orders of magnitude span!

At highest energies, uncertainties are dominated by statistics.

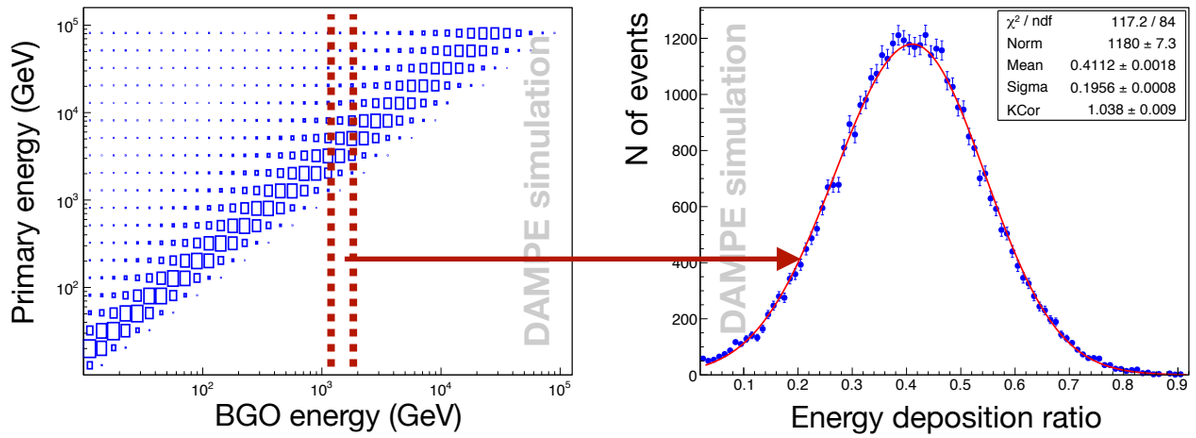
Further statistics will allow to test possible **edge-like features** at 10 TeV and higher.

https://www.nature.com/articles/nature24475

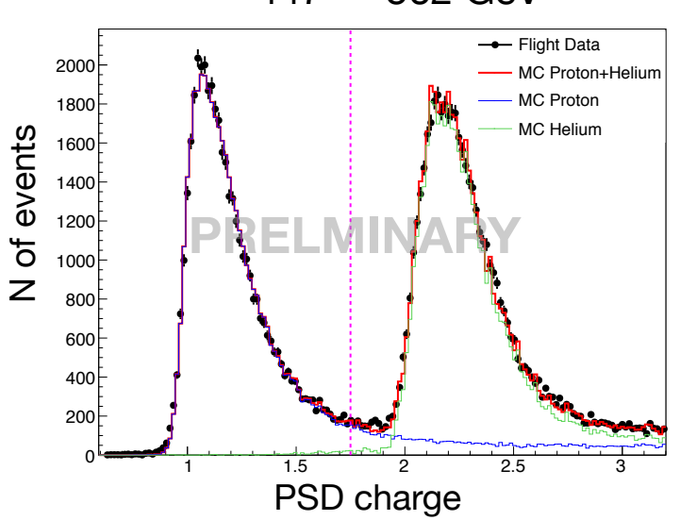
First results

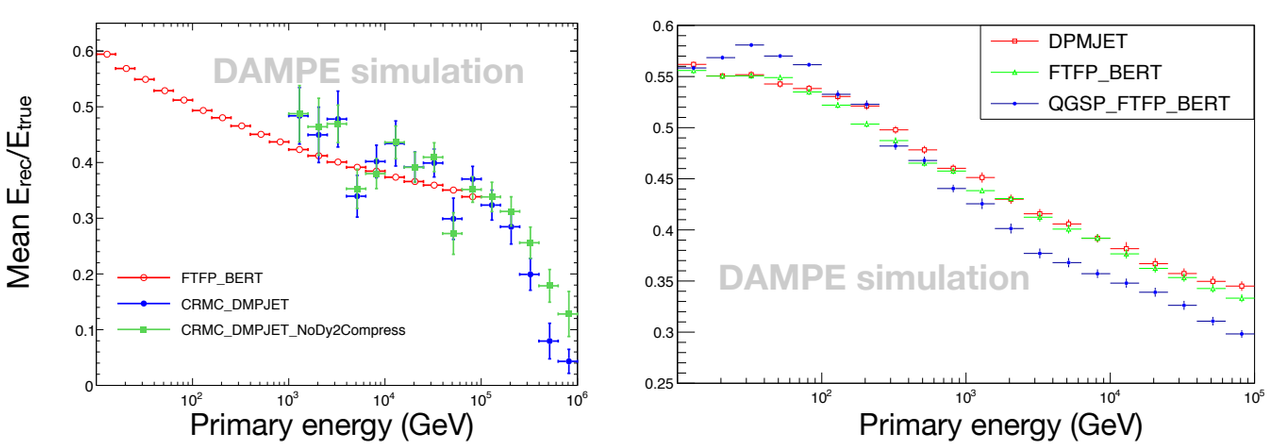
CR protons: selection & energy measurement

- High-Energy Trigger
- Pre-selection (clean-up)
- Track selection (STK)
- Charge selection (PSD)



447 — 562 GeV



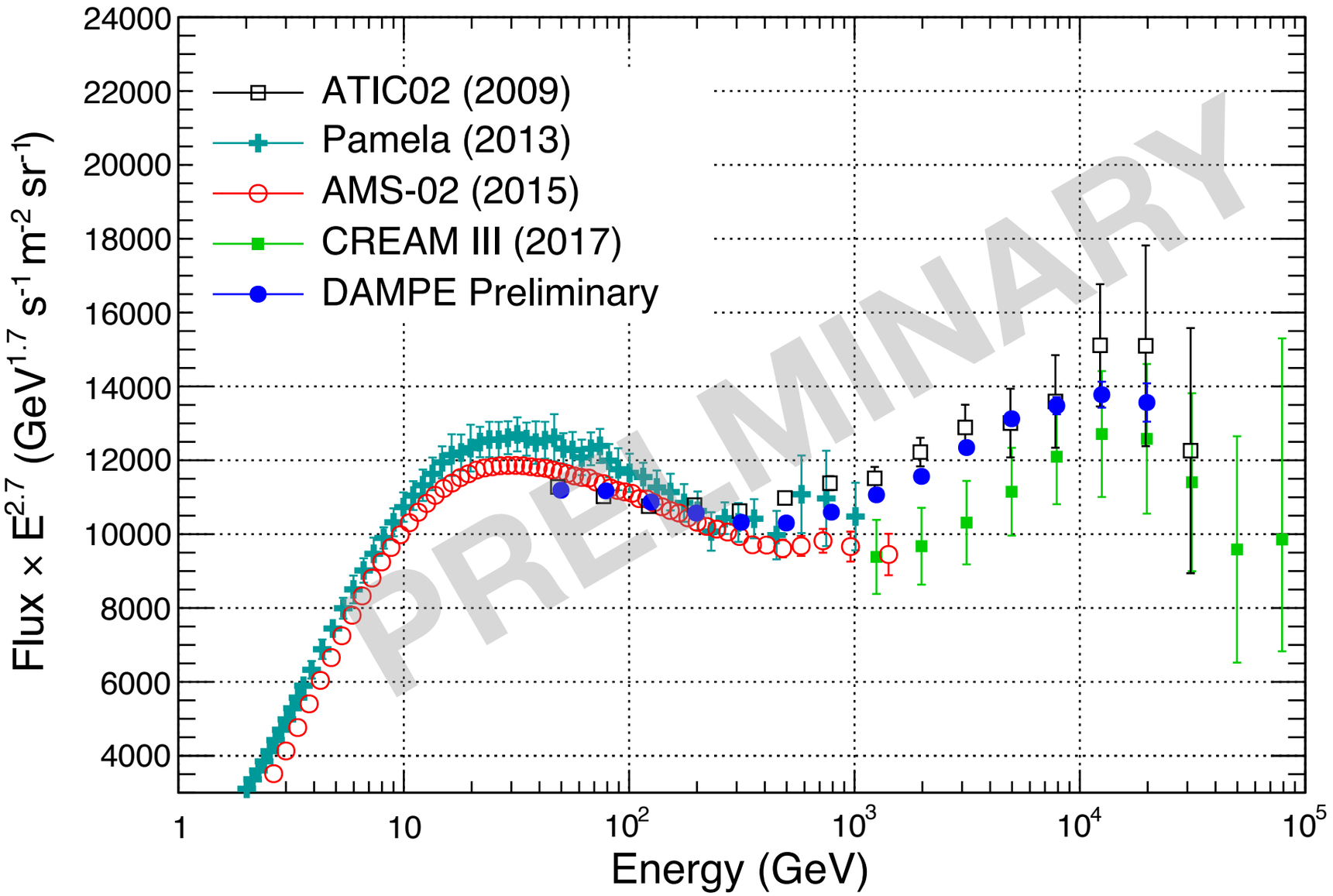


DPMJET and FTFP hadronic models are consistent between each other

About 1.6 nuclear length in the calorimeter → a deconvolution of measured energy into primary is applied

First results

CR protons

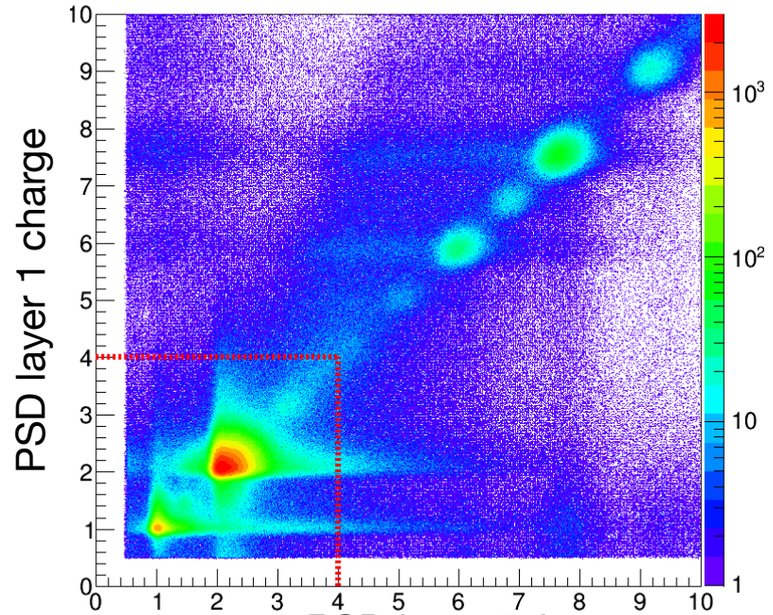


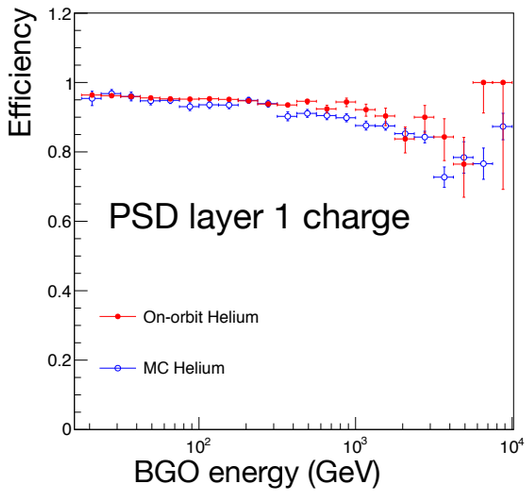
First results

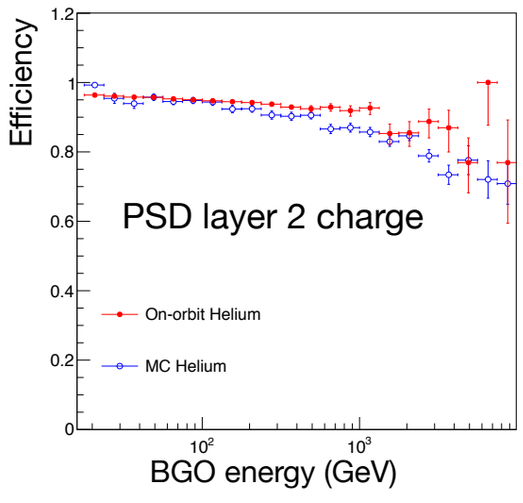
CR helium

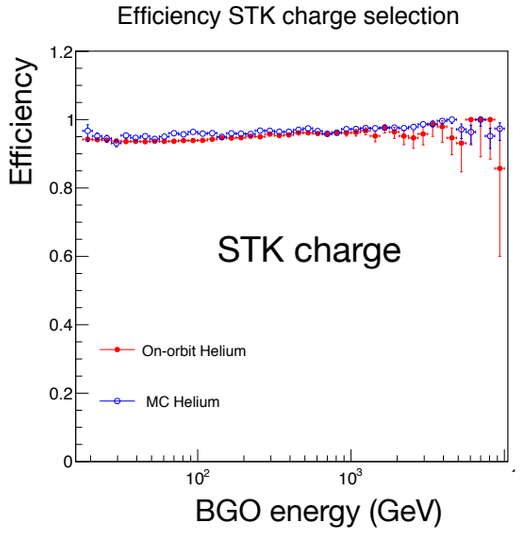
Selection

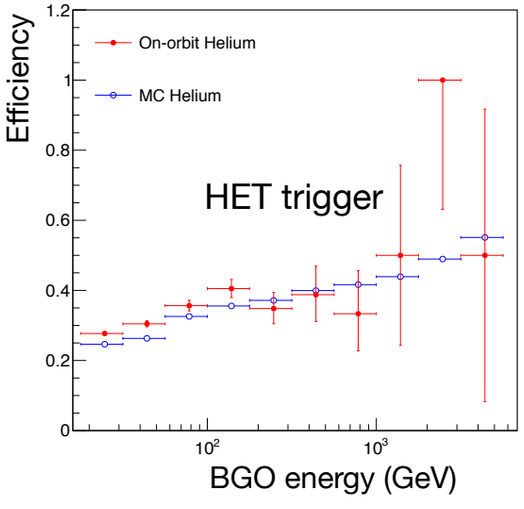
- High-Energy Trigger
- BGO fiducial
- Shower shape
  - longitudinal and lateral to exclude side entering events
- Charge selection (PSD+STK)







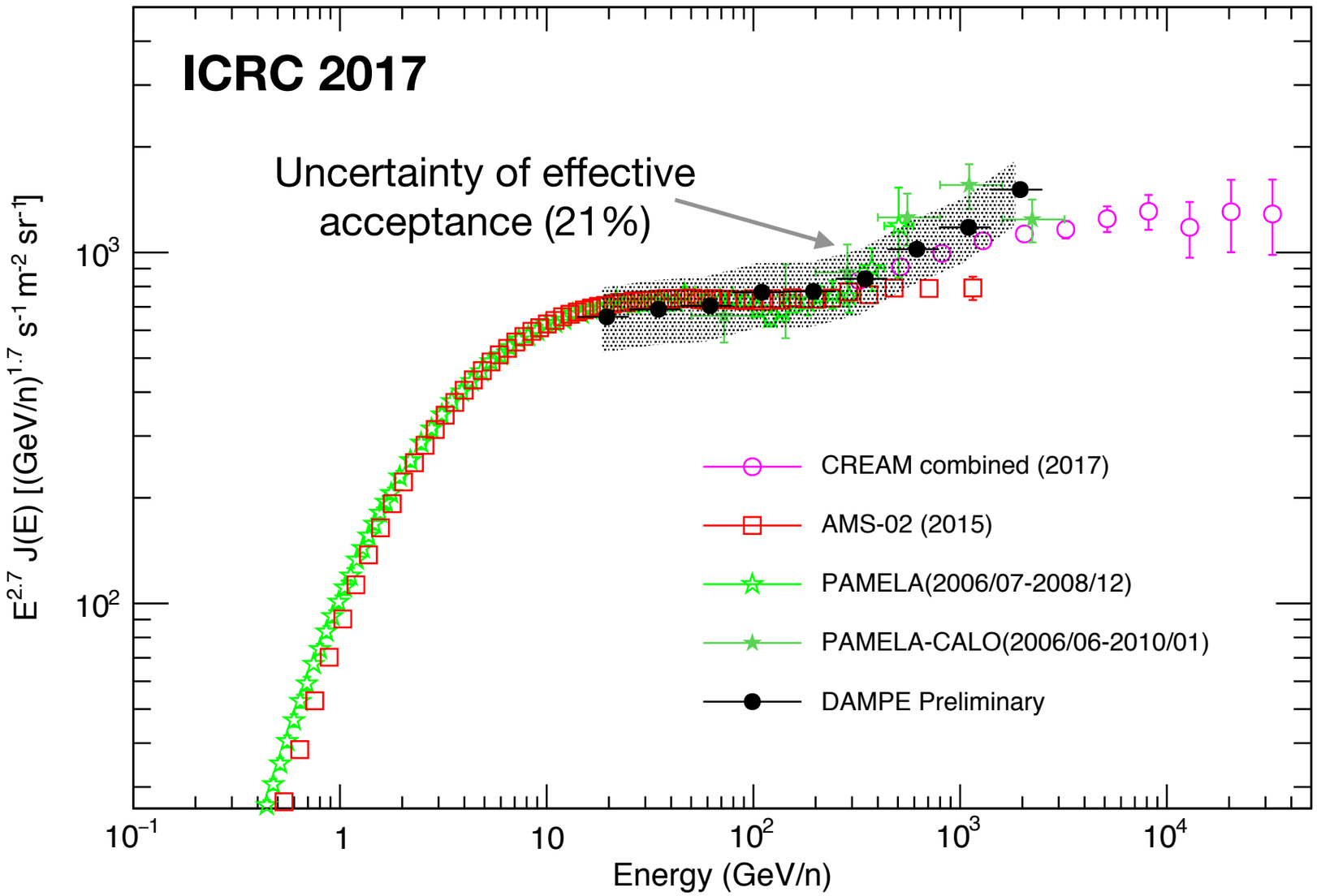




https://pos.sissa.it/301/169/pdf

First results

CR helium



https://pos.sissa.it/301/169/pdf

Uncertainty on the unfolding method is not taken into account as well as the energy resolution for Helium.

Conclusions

- DAMPE detector works extremely well since launch in December 2015.
- Electron + positron flux measured with very high precision:
    - A clear spectral break directly observed at ~ 1 TeV.
- Cosmic-ray nuclei measurements (proton and helium) coming soon.
- Photon detection capabilities demonstrated.
    - More statistics needed to profit from the excellent energy resolution.

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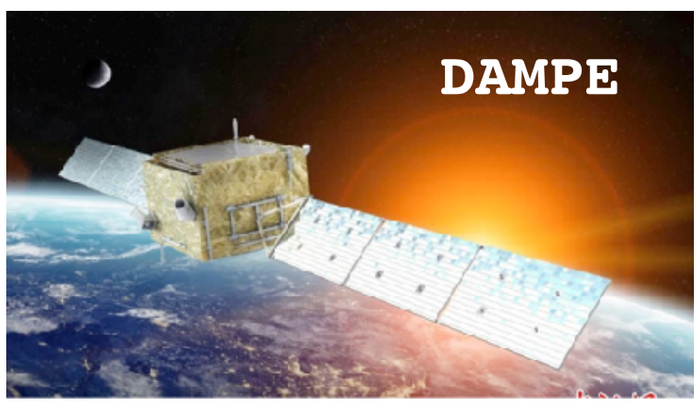
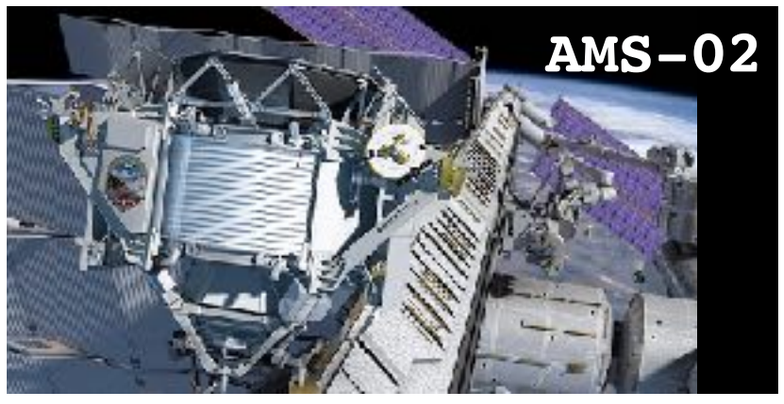
Thank You!

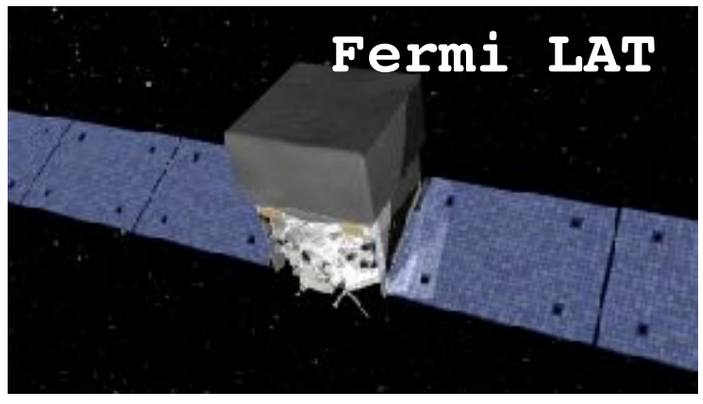
Something more

Comparison with AMS-02 and FERMI

	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 accep. (m^2sr)	**0.29**	0.09	1



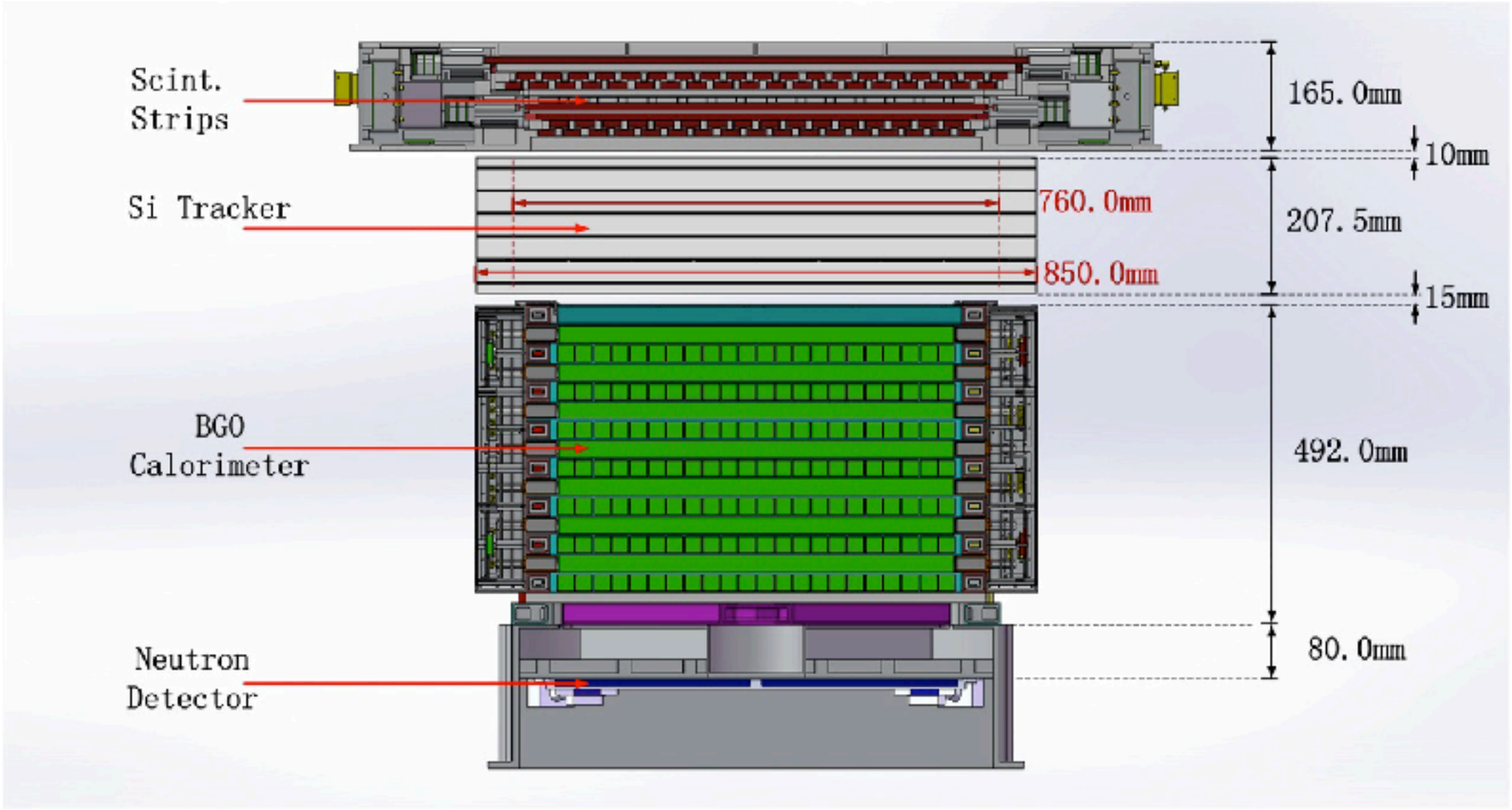




Boresight alignment

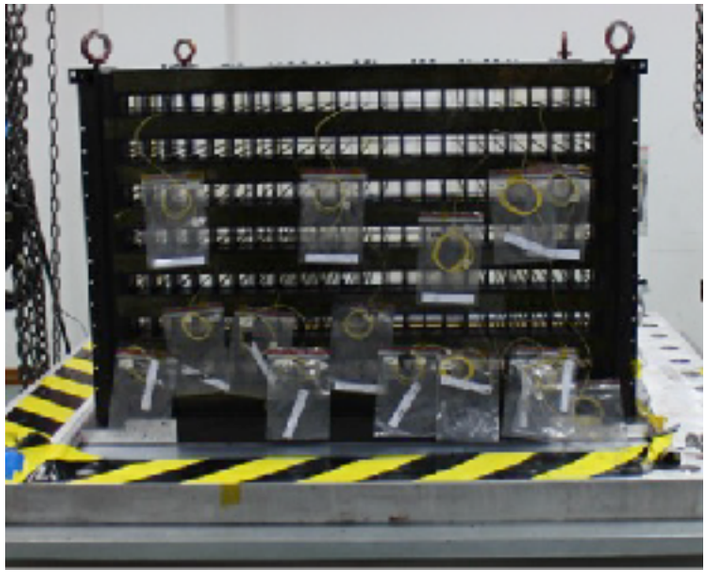
Source Name	Photon Number	θ_X (degree)	θ_Y (degree)	$\theta_Z(degree)$
Vela	1438	0.13±0.01	0.02±0.01	-0.14±0.02
Geminga	446	0.13±0.02	-0.02±0.02	-0.14±0.02
Crab	265	0.11±0.02	-0.03±0.03	-0.15±0.03

The DAMPE detector



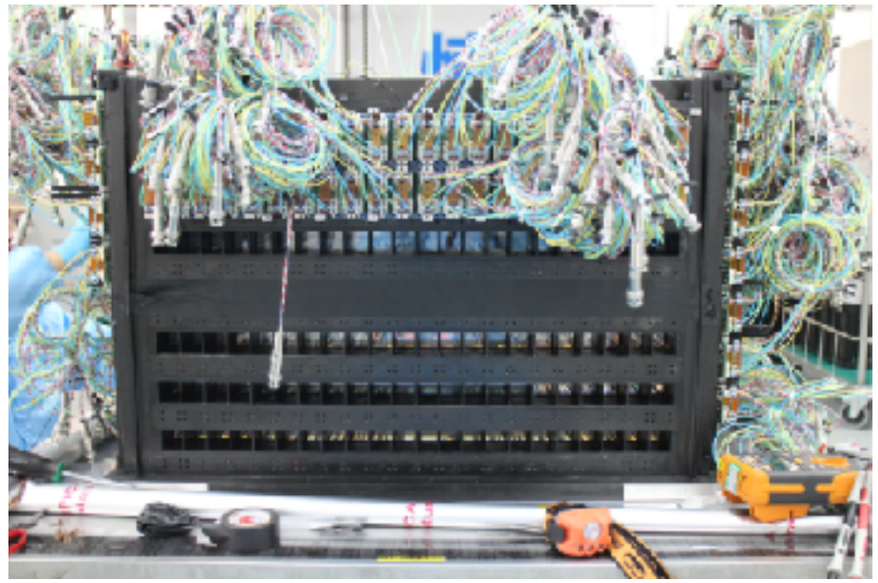
Mass: 1400 Kg
Power: 400 W
Data: 13 GB/day
Lifetime: 5 years

BGO calorimeter

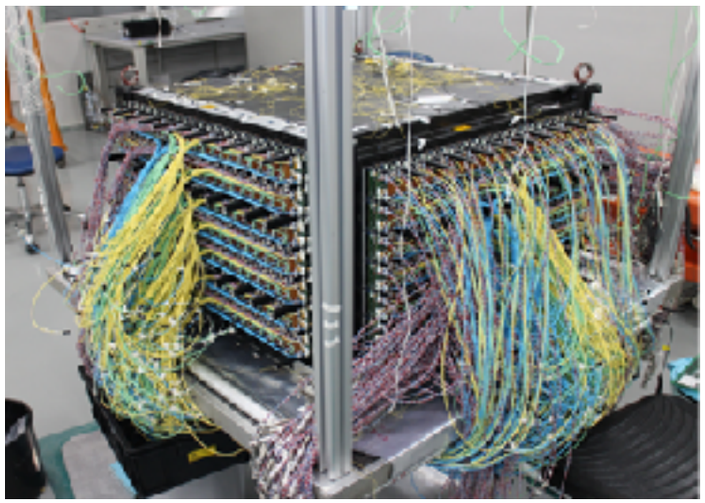


Carbon Fiber Structure

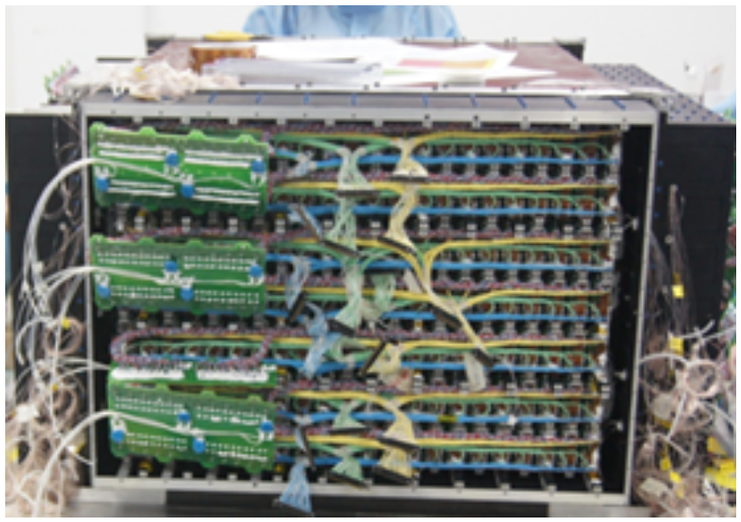
BGO crystal installation



PMT installation



Cable arranging

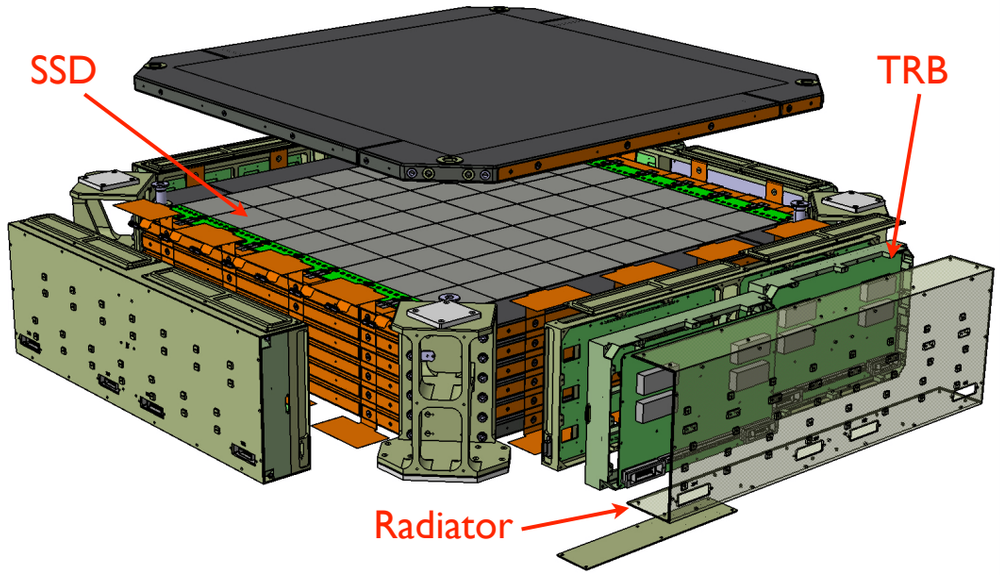


Cable connectors

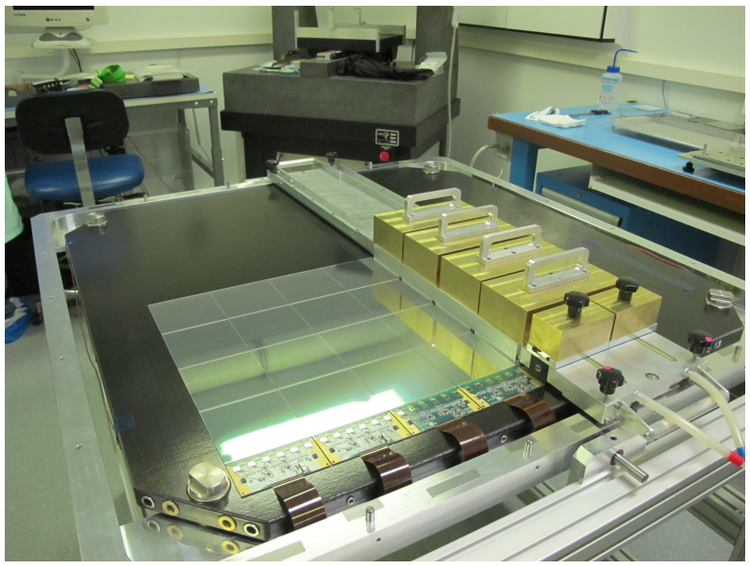
BGO calorimeter

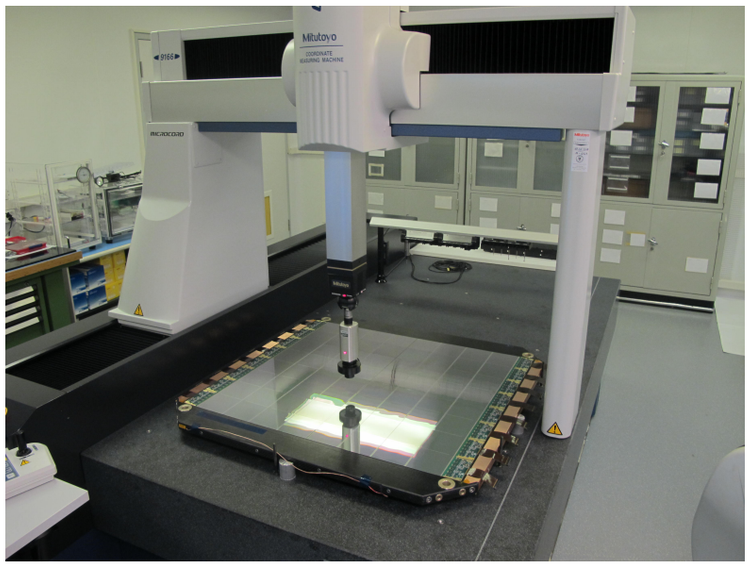
Silicon TracKer (STK)

Assembly jig for mounting ladders on the trays, O(100) μm precision

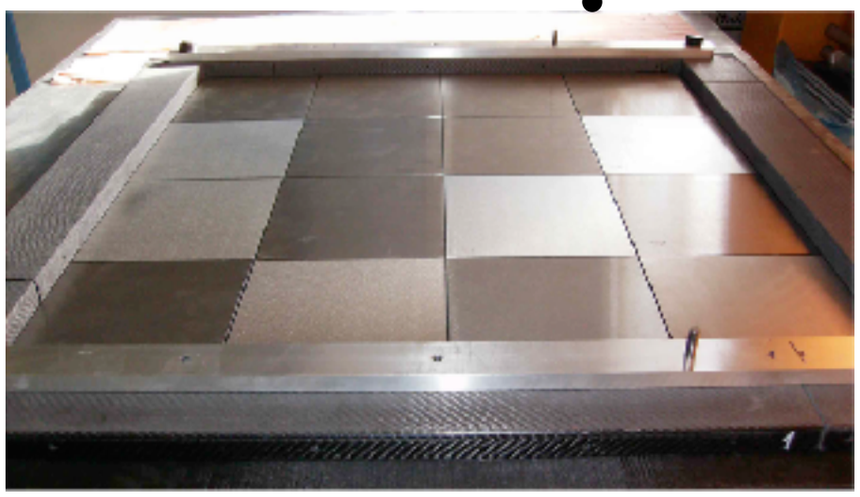


Tungsten converter plates (16 per tray)





The trays' metrology procedure



DAMPE EQM beam tests @ CERN: ions

Beam Test Setup

- Primary ion: ^{40}Ar
- Secondary ions: Z=2-18, A/Z=2
- Energy: 40 GeV/nucleon, 75 GeV/nucleon
- PID for secondary ions with dE/dx detectors on beam line:

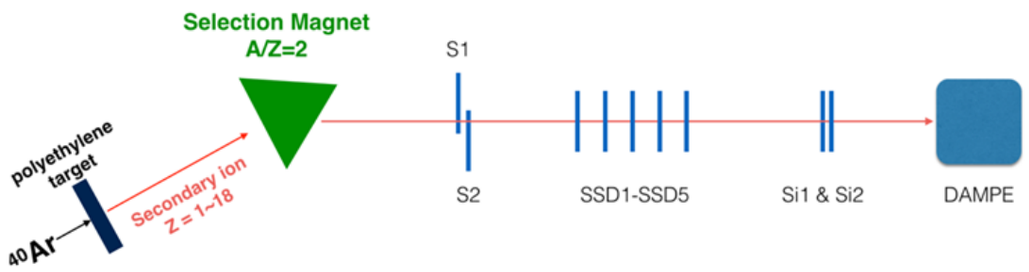


Fig1. Beam line

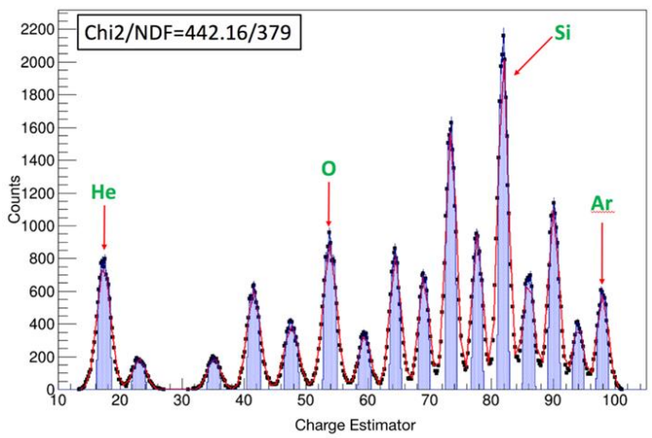
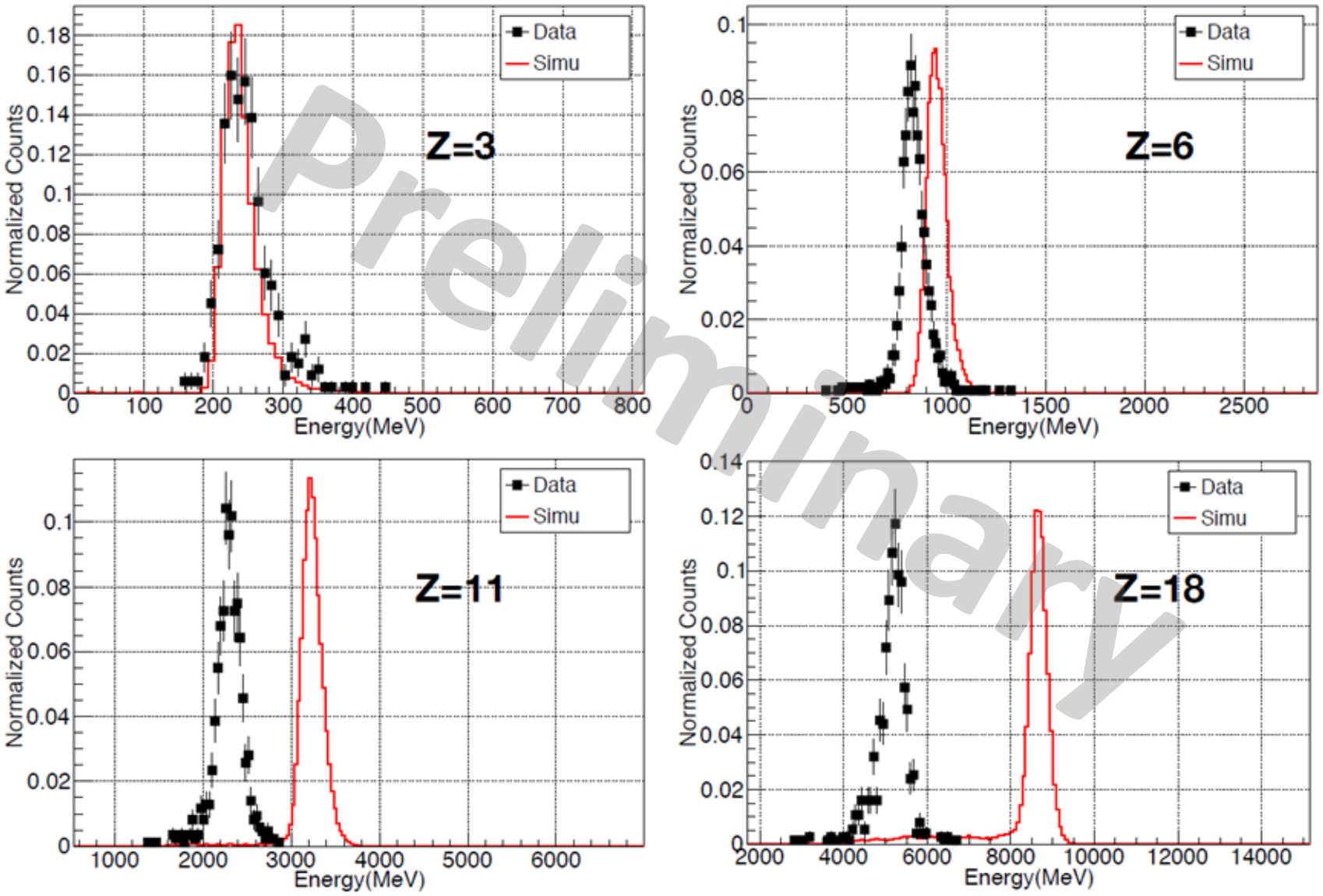


Fig2. PID for secondary ions

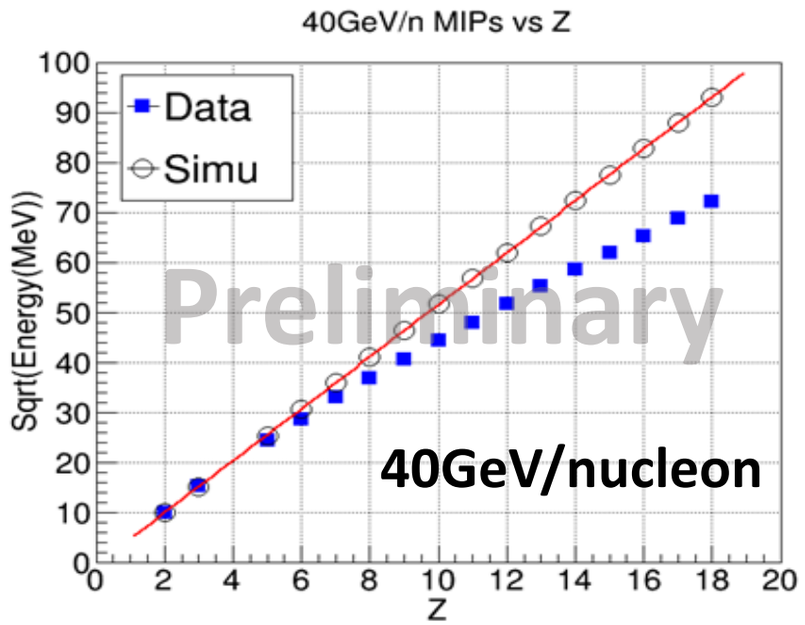
DAMPE EQM beam tests @ CERN: ions

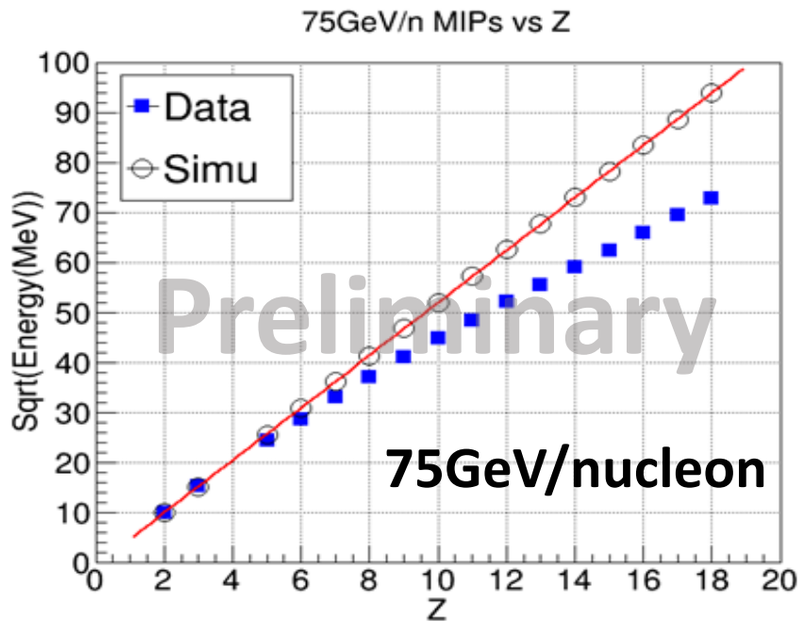
MIPs spectrum in the BGO crystal (40 GeV/nucleon)



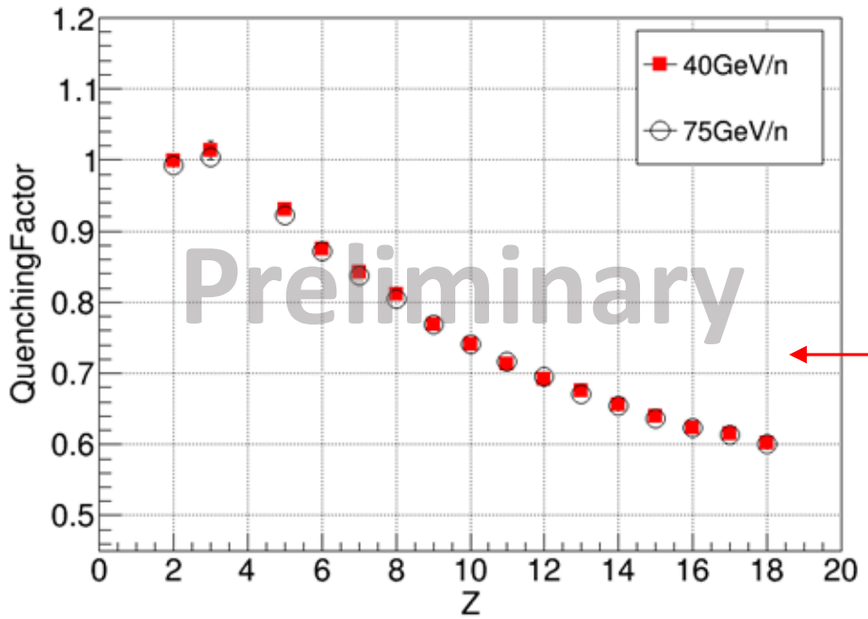
DAMPE EQM beam tests @ CERN: ions

Quenching effect of BGO



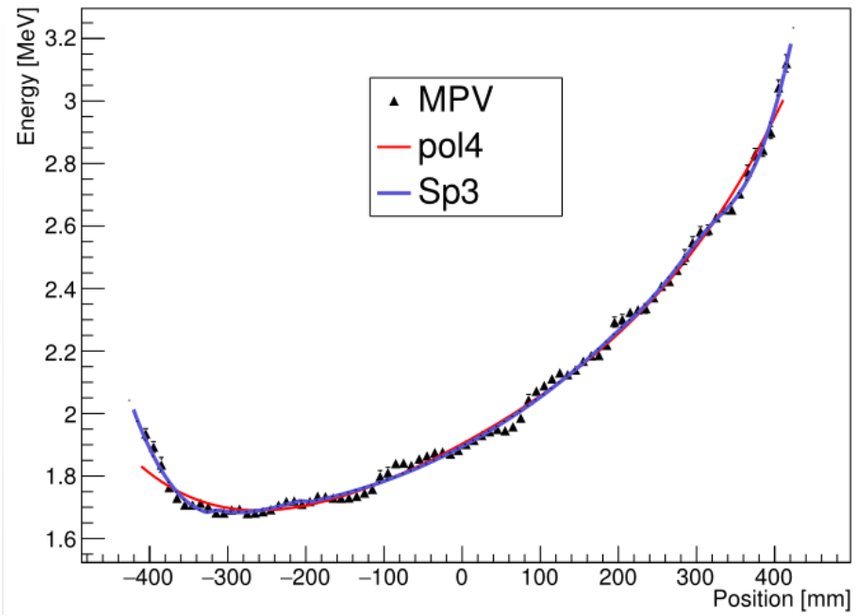


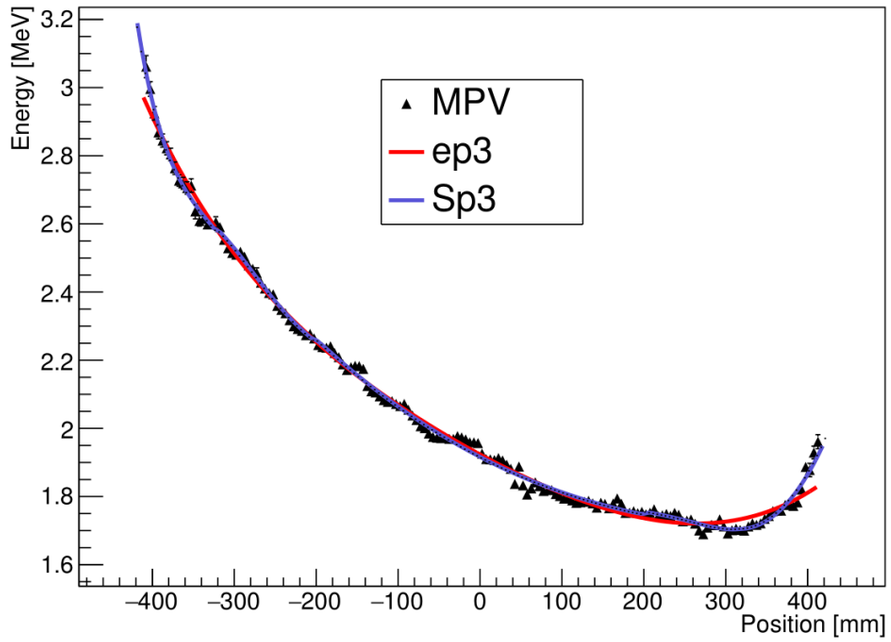
Sqrt(MIPs Peak Energy) vs atomic number

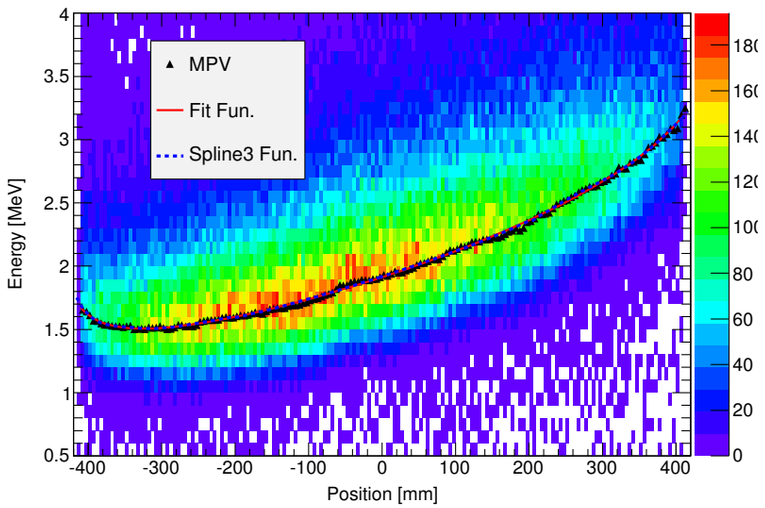


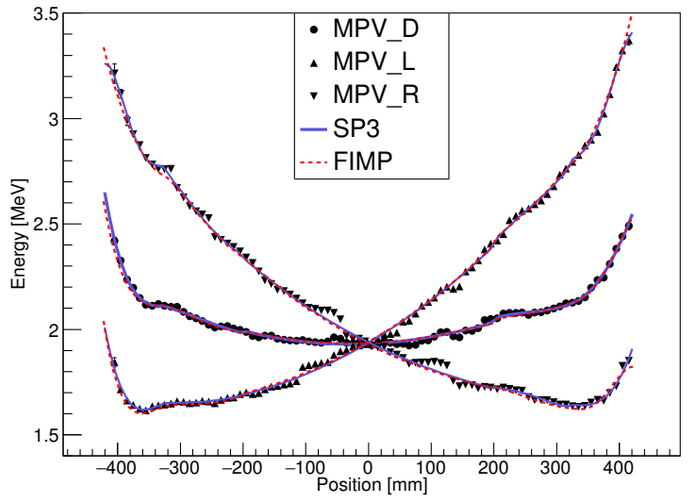
$$QuenchingFactor = \frac{MIPsEnergy\_Data}{MIPsEnergy\_Simu}$$

PSD charge attenuation

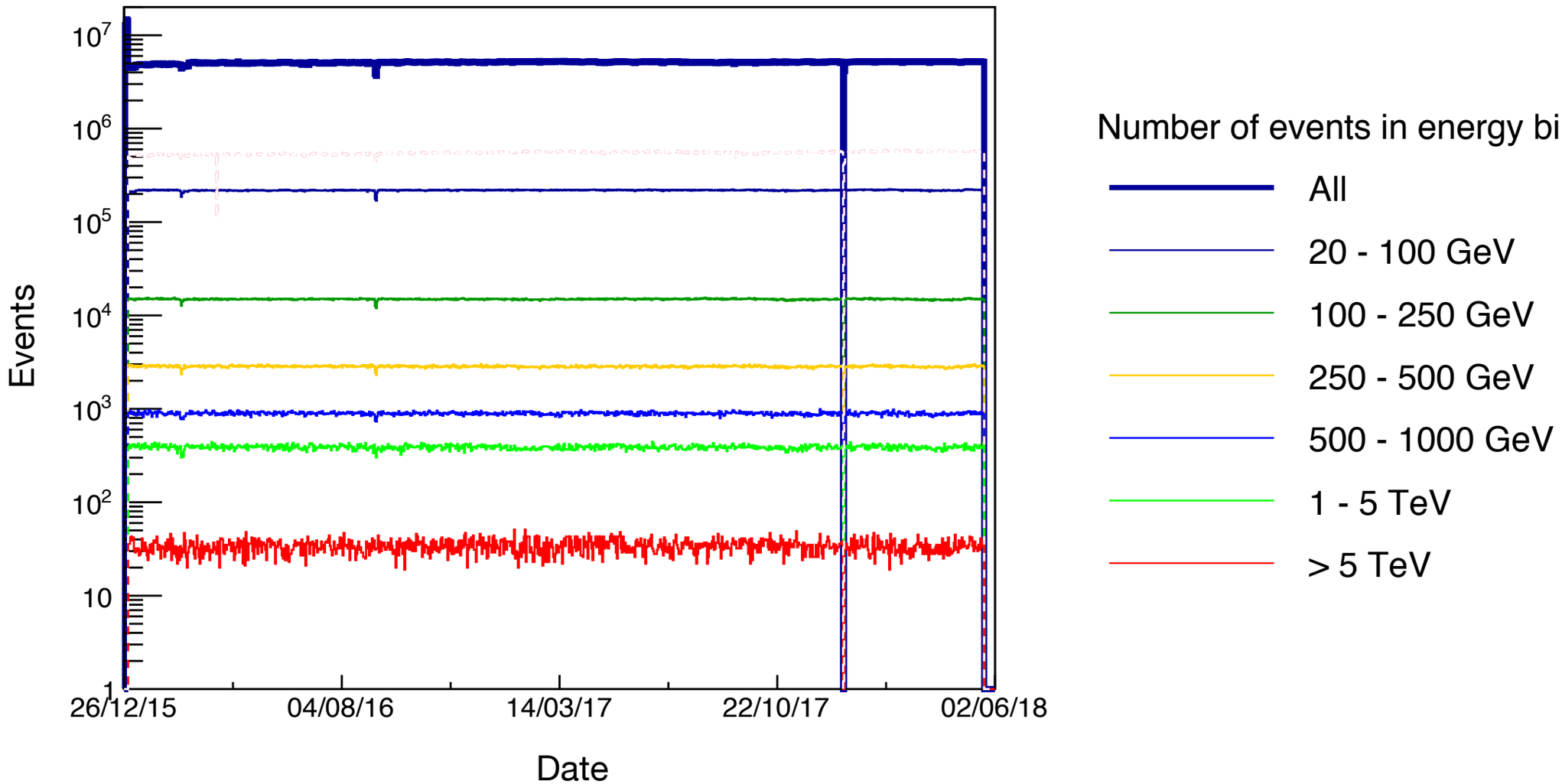








Event rate


Events
10^7
10^6
10^5
10^4
10^3
10^2
10
1
26/12/15
04/08/16
14/03/17
22/10/17
02/06/18
Date
Number of events in energy bins per day
All
20 - 100 GeV
100 - 250 GeV
250 - 500 GeV
500 - 1000 GeV
1 - 5 TeV
> 5 TeV