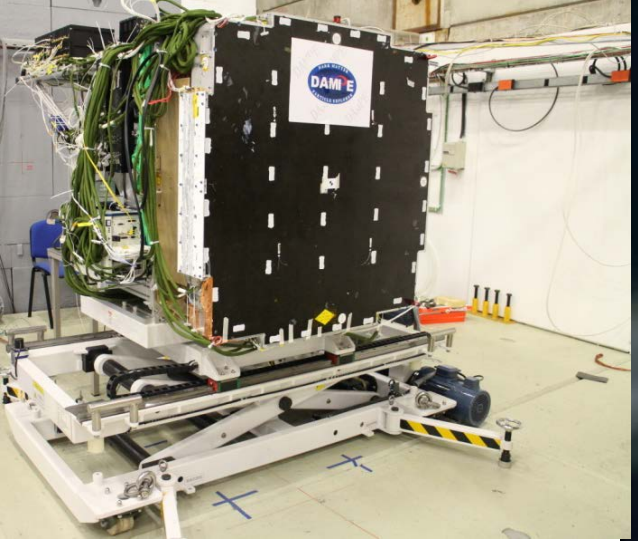


Results from the DAMPE space mission

Ivan DE MITRI

Gran Sasso Science Institute (GSSI)

& INFN Laboratori Nazionali del Gran Sasso

On behalf of the DAMPE collaboration

11th Cosmic Ray International Seminar, CRIS 2018

Portopalo di Capo Passero (Siracusa), June 18-22, 2018

The science goals

High energy particle detection in space

- Study of the cosmic electron and photon spectra
- Study of cosmic ray protons and nuclei: spectrum and composition
- High energy gamma ray astronomy
- Search for dark matter signatures in lepton spectra

Detection of
10 GeV - 10 TeV e/γ
50 GeV - 500 TeV protons and nuclei
with excellent energy resolution , tracking precision and particle identification capabilities

- Exotica and “unexpected” , e.g. GW e.m. counterpart in the FoV

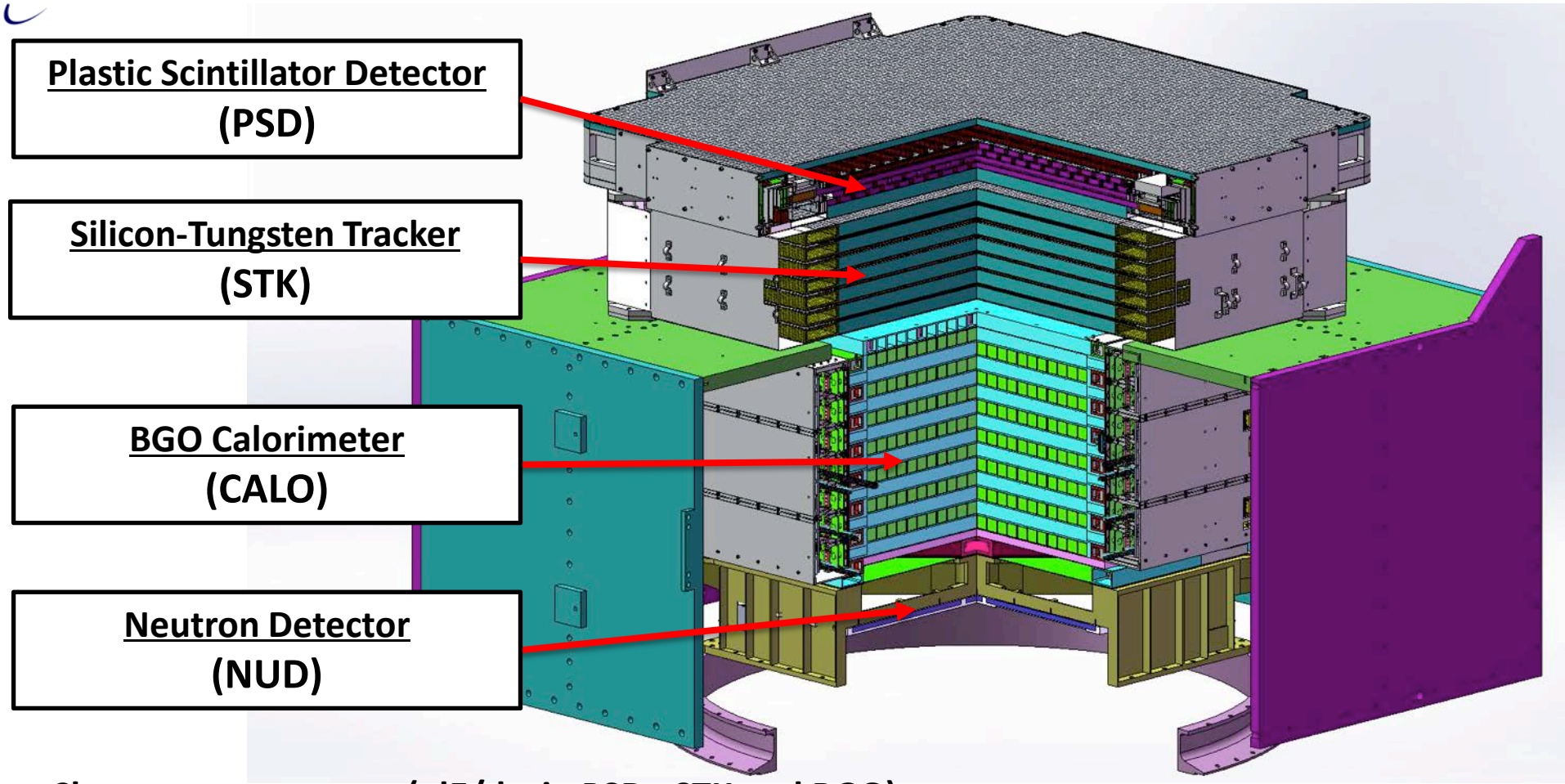
The collaboration

- **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

The detector

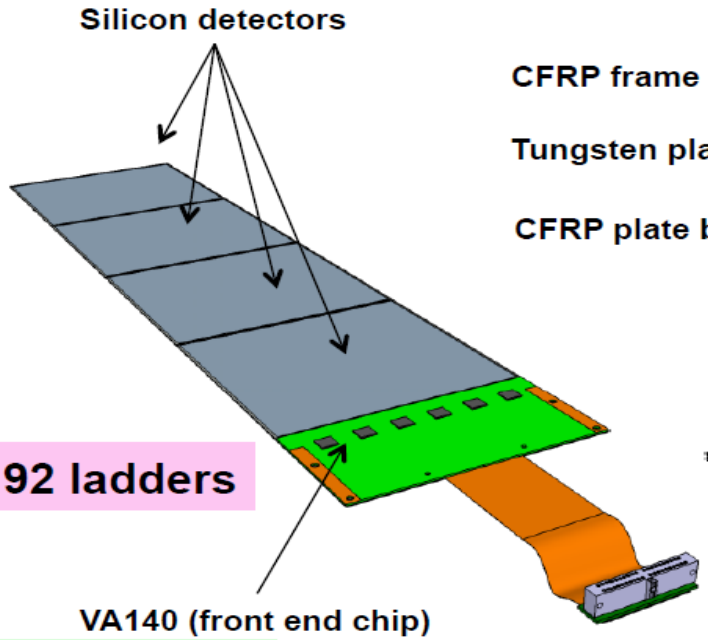


- **Charge measurement (dE/dx in PSD , STK and BGO)**
- **Tungsten converter (pair production)**
- **Precise tracking (silicon strips)**
- **Thick calorimeter (BGO bars)**
- **Hadron rejection (neutron detector)**

high energy
γ-ray, electron and cosmic ray
telescope

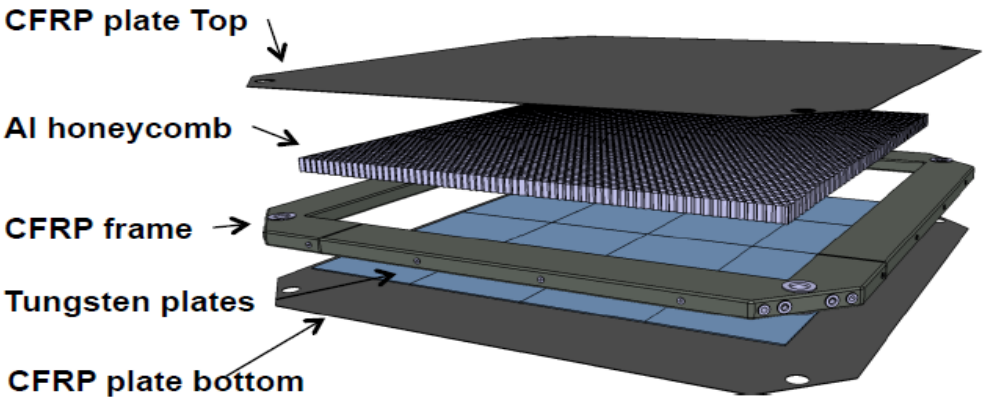
The Silicon TracKer (STK)

768 silicon sensors

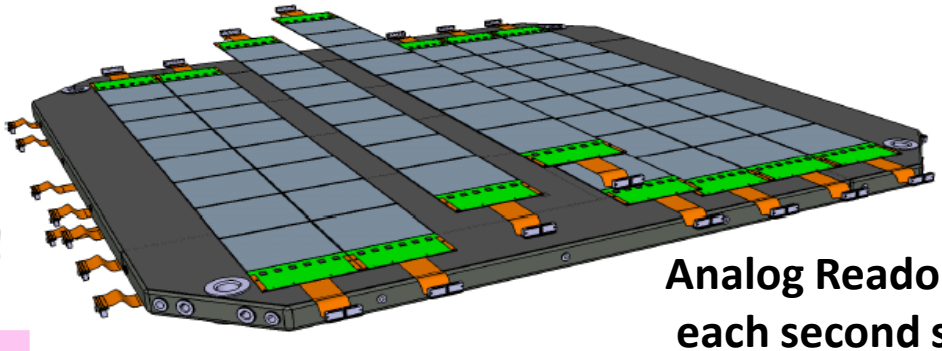


1152 ASICs

73728 channels



12 layers, 6-x and 6-y

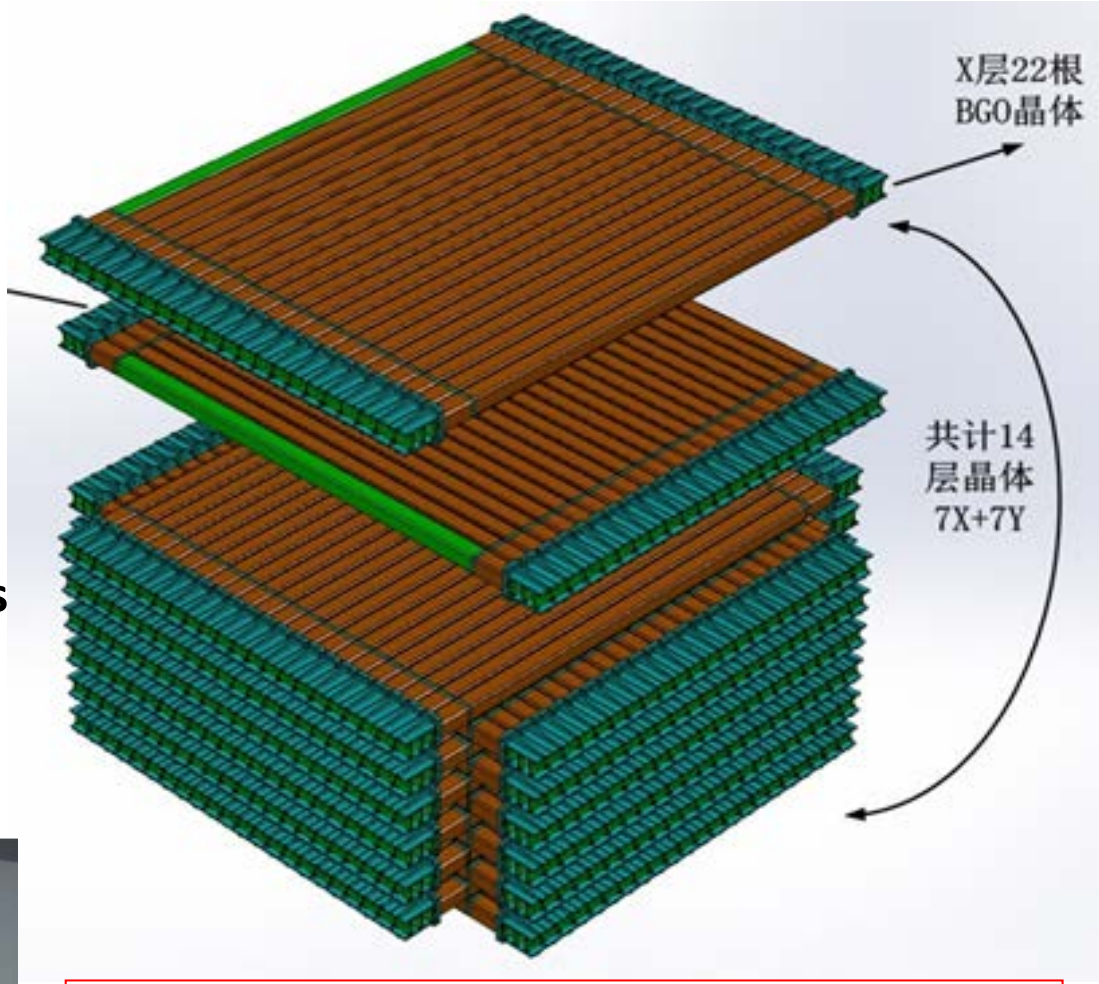


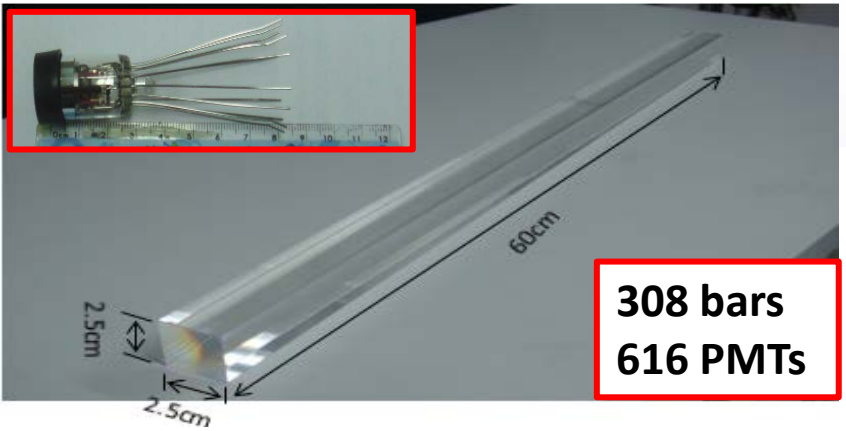
Analog Readout of each second strip:
384 channels / SSD- Ladder
Charge sharing

- 48 μm wide Si strips with 121 μm pitch
- (95 × 95 × 0.32 mm^3) Silicon Strip Detector (SSD)
- 768 strips in each SSD
- One ladder composed by 4 (SSD)
- 16 Ladders per layer (76 cm × 76 cm)
- 12 layers (6x + 6y)

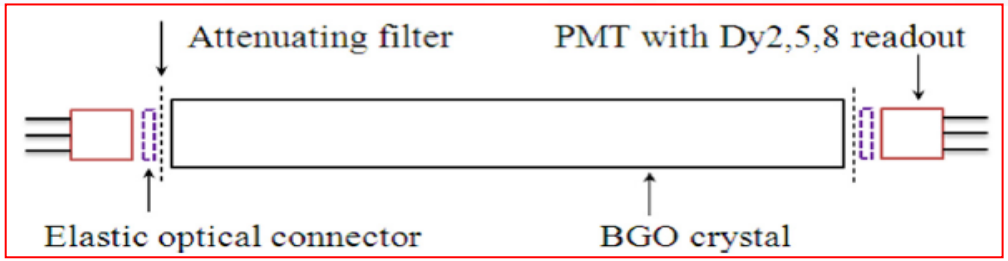
The CALOrimeter

- **14 layers of 22 BGO bars**
  - 2.5 × 2.5 × 60 cm^3 bars
  - 14 hodoscopic stacking alternating orthogonal layers
  - depth ~$32X_0$
- **Two PMTs coupled with each BGO crystal bar at the two ends**
- **Electronics boards attached to each side of module**

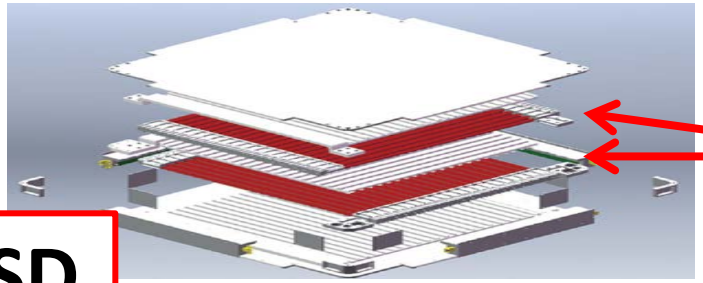




308 bars
616 PMTs

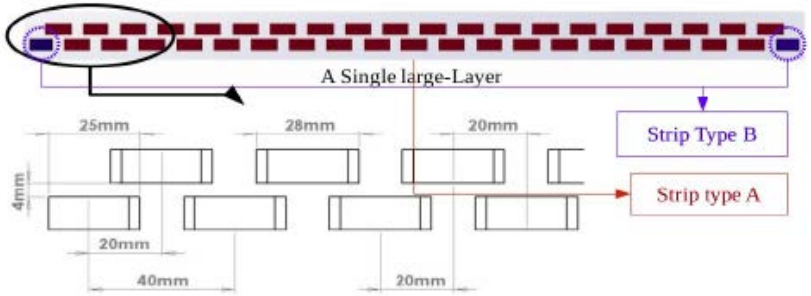


The Plastic Scintillator Detector and the NeUtron Detector

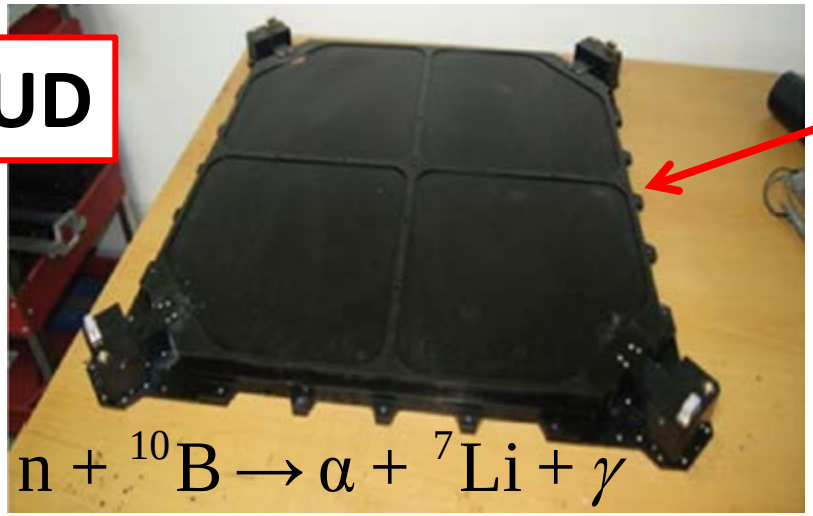


PSD

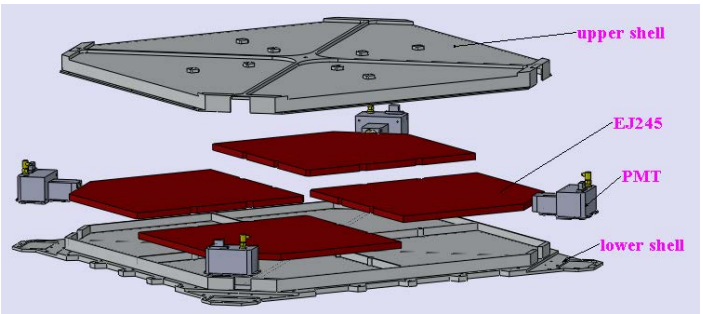
- 1.0 cm thick ,2.8cm wide and 82.0 cm long scintillator strips
- staggered by 0.8 cm in a layer
- 82 cm × 82 cm layers
- 2 layers (x and y)



NUD

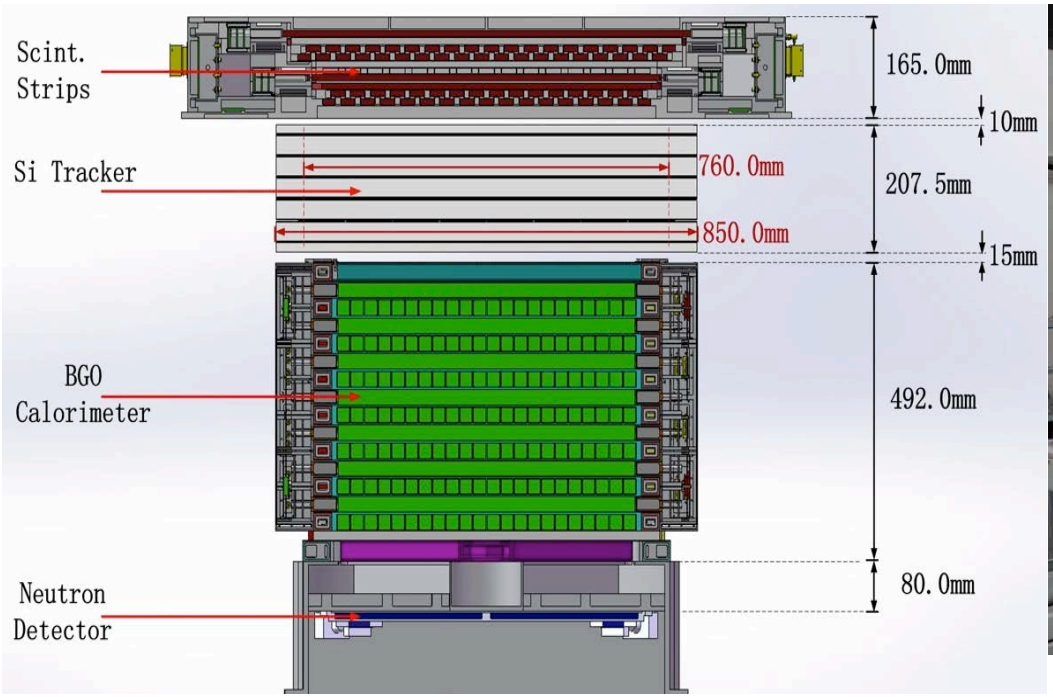


- 4 large area boron-doped plastic scintillators (30 cm × 30 cm × 1 cm)



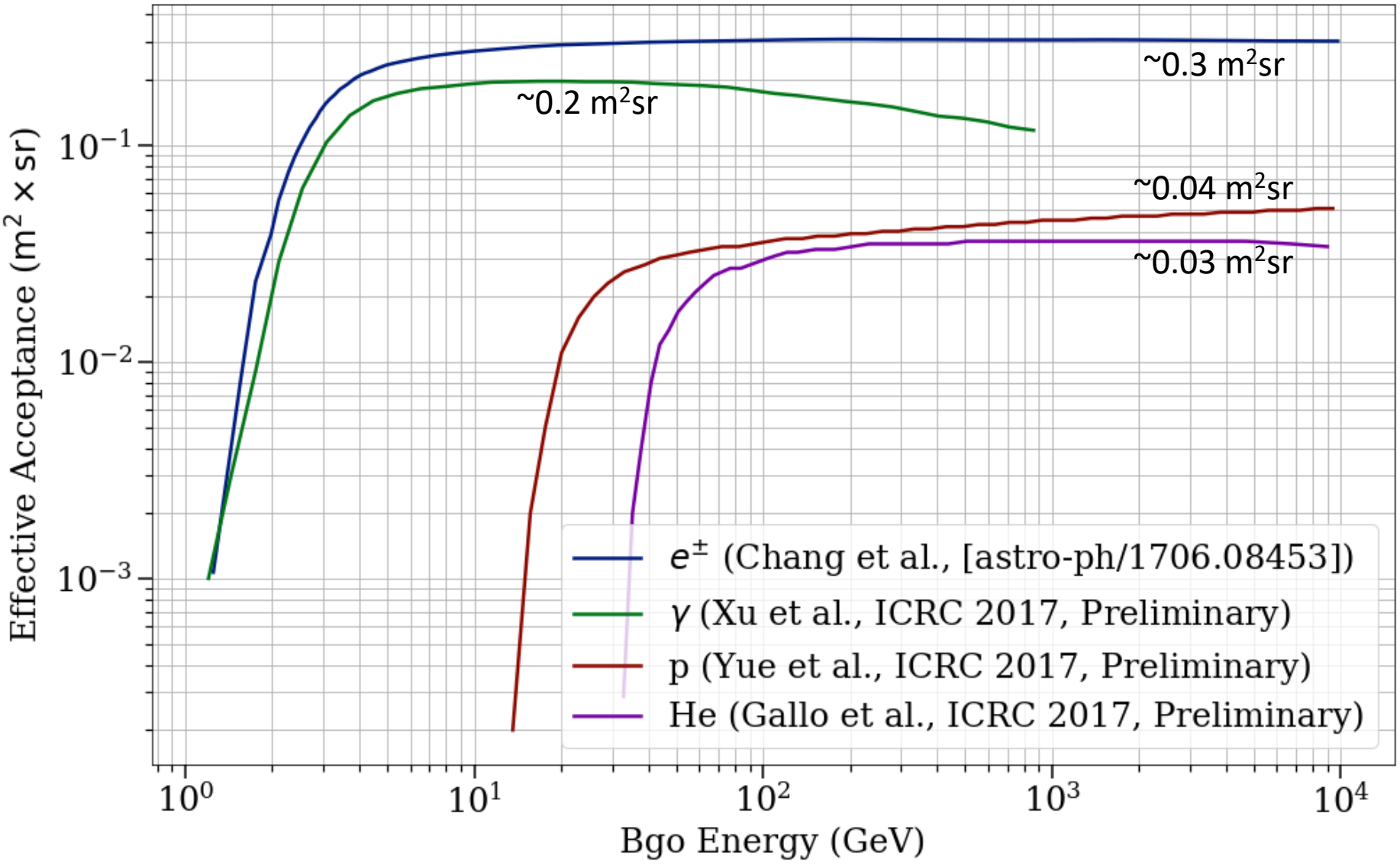
Comparison with AMS-02 and FERMI

	DAMPE	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	**1.2**	3	10
e/γ Angular res.@100 GeV (deg)	0.2	0.3	0.1
e/p discrimination	10^5-10^6	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	**32**	17	8.6
Geometrical accep. (m^2sr)	**0.3**	0.09	1

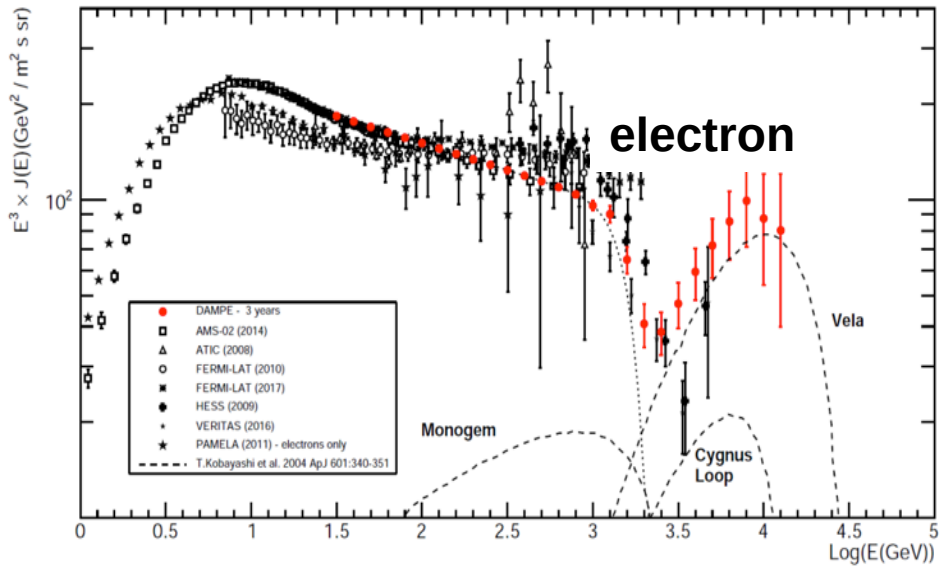


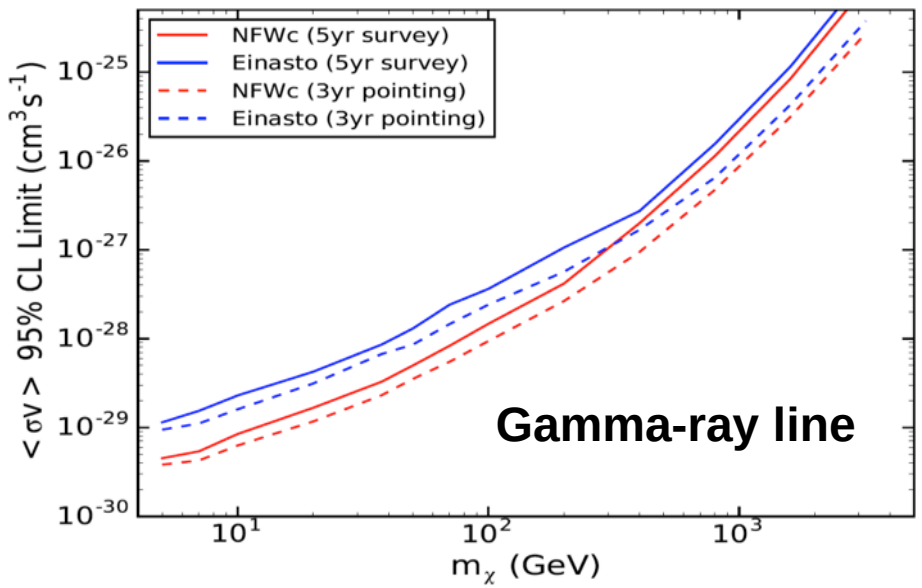
Mass: 1400 Kg
Power: ~ 400 W
Livetime: > 3 years

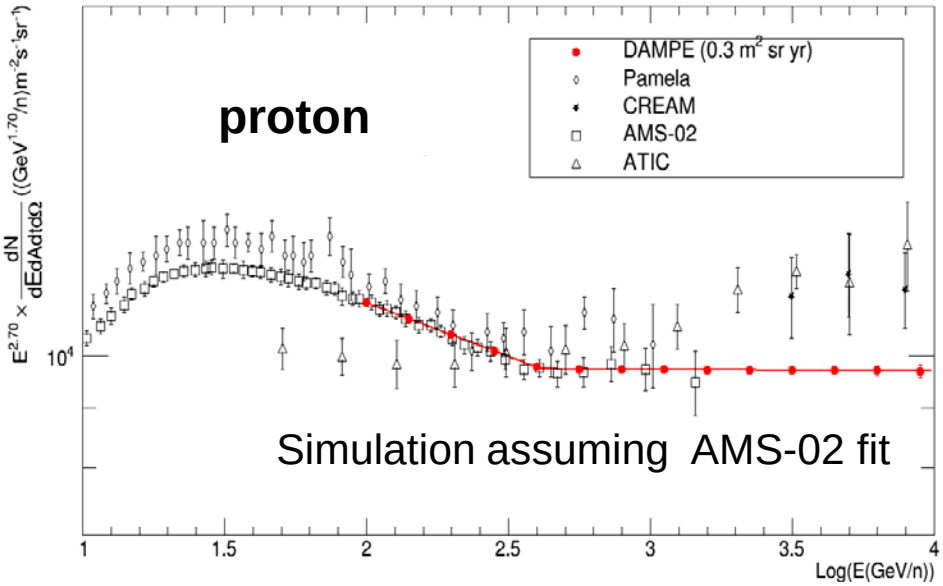
Acceptance estimates

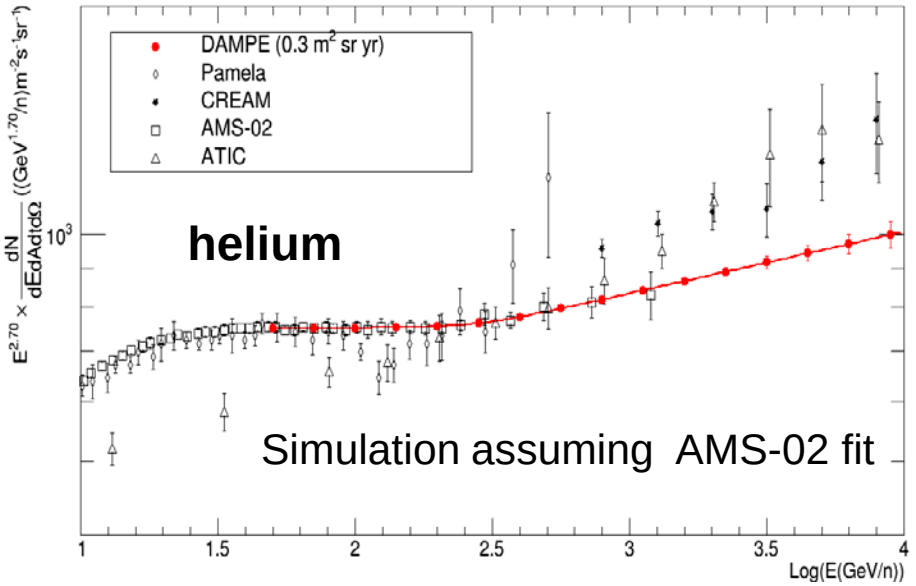


Expected performances



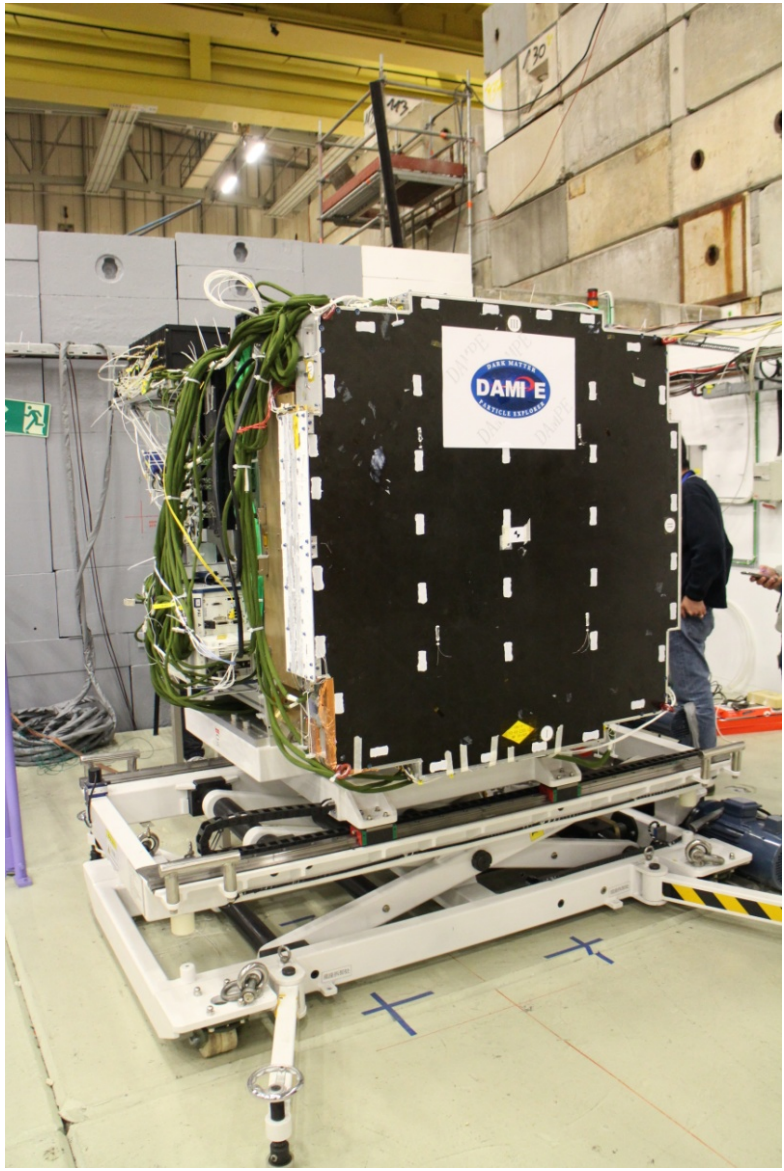






Test beam activity at CERN

- 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
  - Fragments：66.67-88.89-166.67GeV/c
  - Argon：30A- 40A- 75AGeV/c
  - Proton：30GeV/c，40GeV/c
- 21days@SPS，10/6-1/7 2015
  - Primary Proton: 400GeV/c
  - Electrons @ 20, 100, 150 GeV/c
  - γ @ 50, 75 , 150 GeV/c
  - μ @ 150 GeV /c
  - π+ @10, 20, 50, 100 GeV/c
- 10days@SPS, 11/11-20/11 2015
  - -- Pb 30AGeV/c (and fragments) (HERD)
- 6days@SPS, 20/11-25/11 2015
  - -- Pb 030 AGeV/c (and fragments)

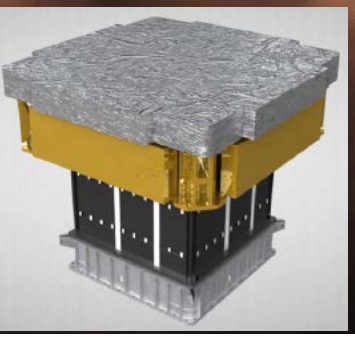


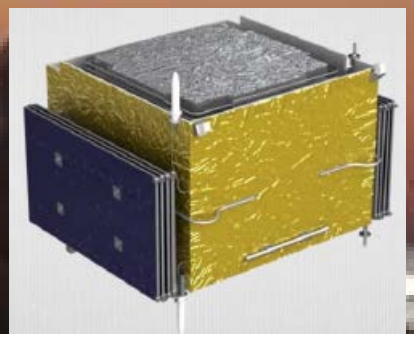
The launch: Dec 17th 2015, 0:12 UTC

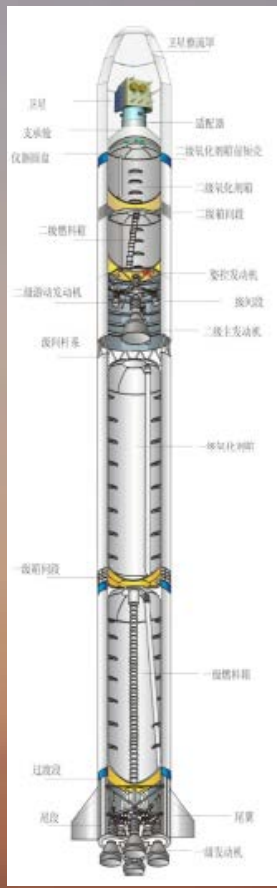
Jiuquan Satellite Launch Center
Gobi desert

CZ-2D rocket

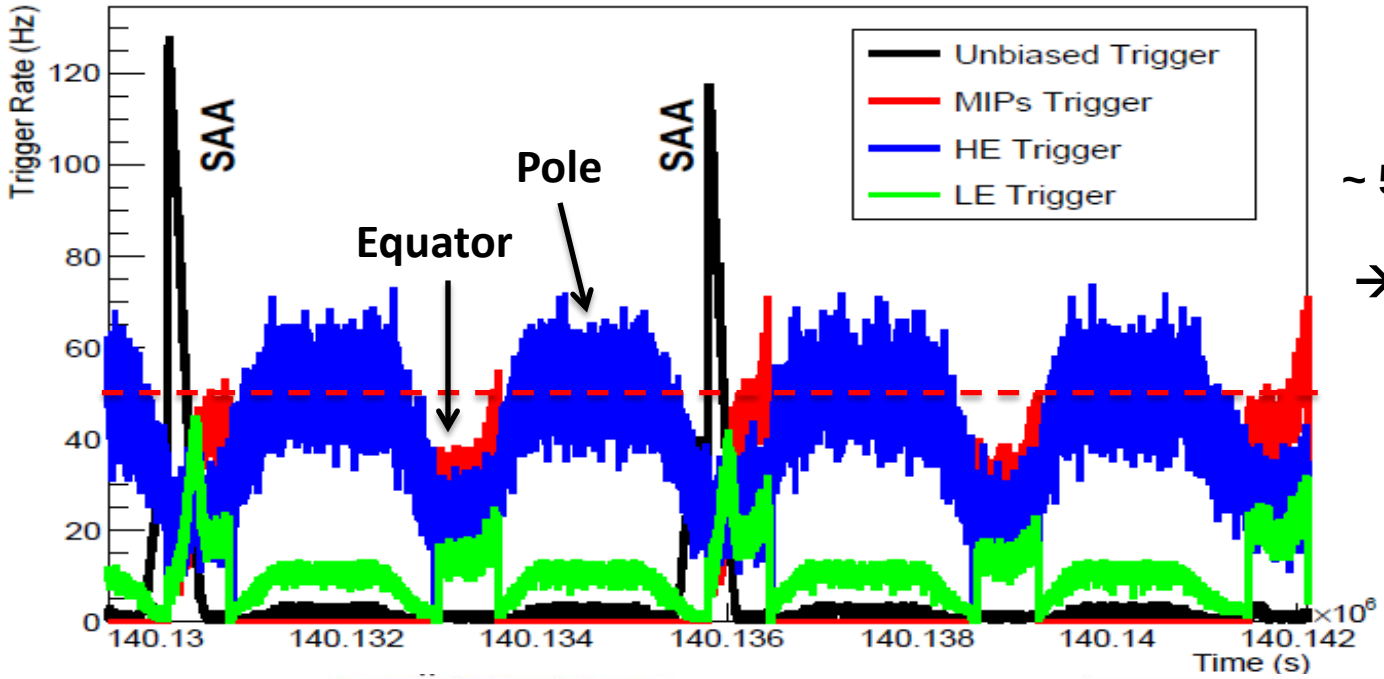
Mass: 1850 kg (scientific payload 1400 kg)
Power : 640 W (scientific payolad 400 W)
Orbit: sun syncronous
Altitude: 500km
Inclination: 97.41°
Period: 95 minutes
Downlink: 16 GB / day
Lifetime: > 3 years





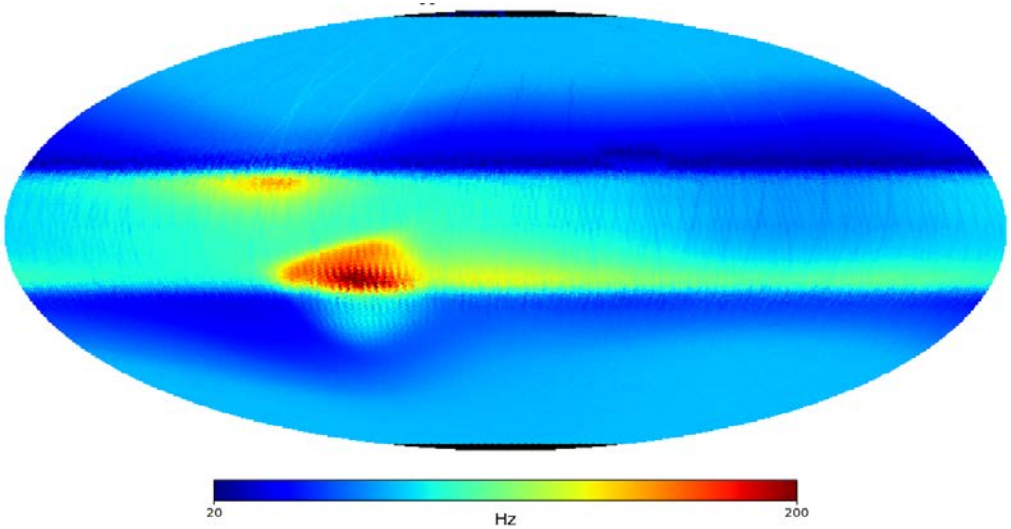


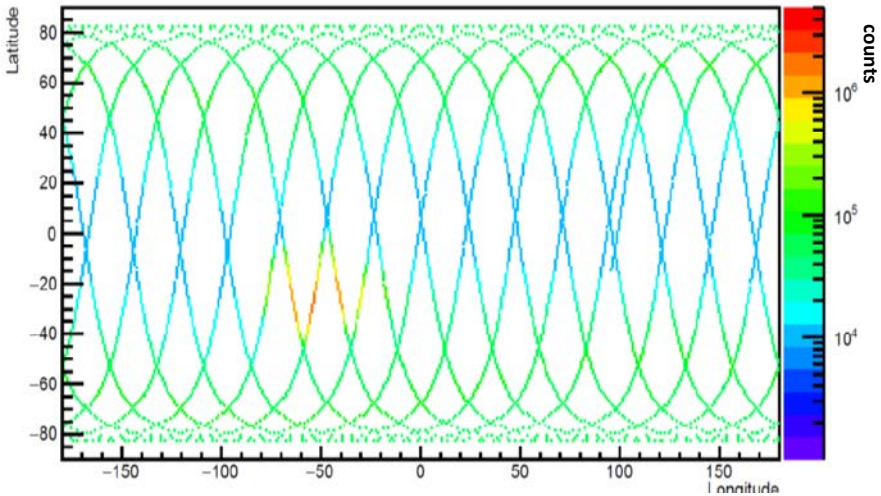
Trigger rate in orbit



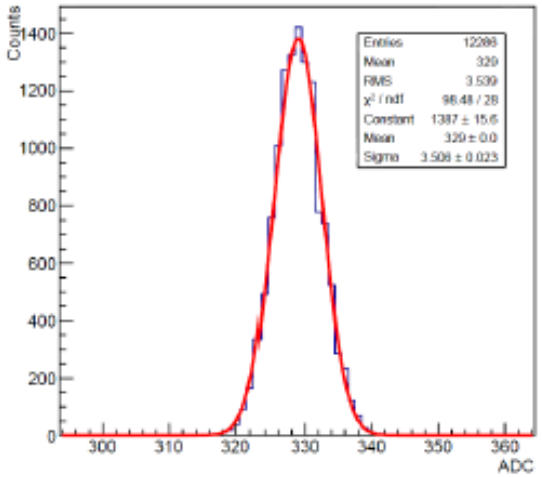
~ 50 Hz average trigger rate

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

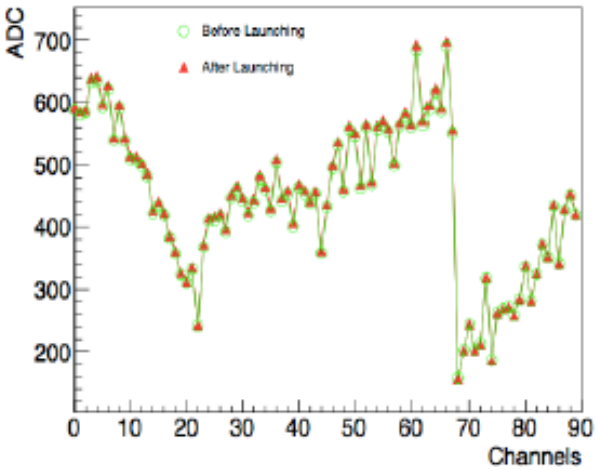




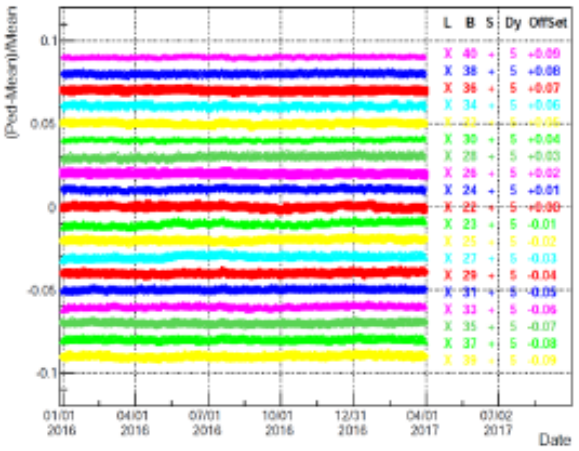
On orbit performance: PSD



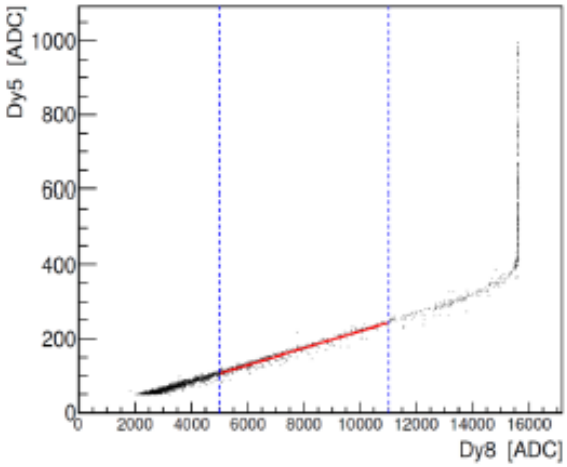
Pedestal distribution



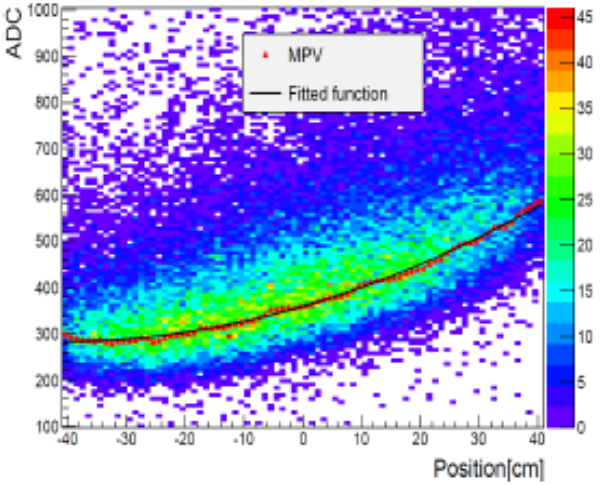
Pedestal comparison



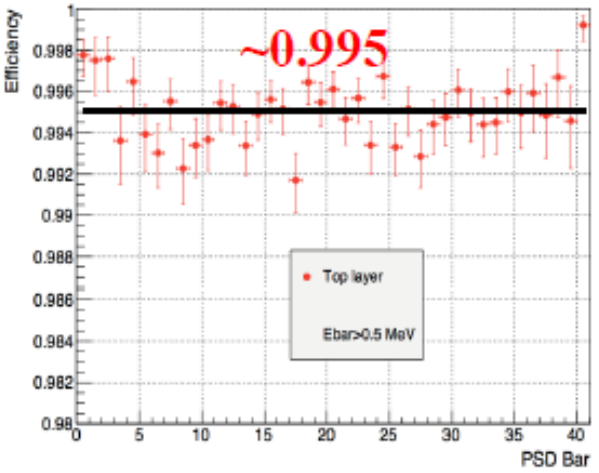
Pedestal variation



Dynode 5 and 8 correlation

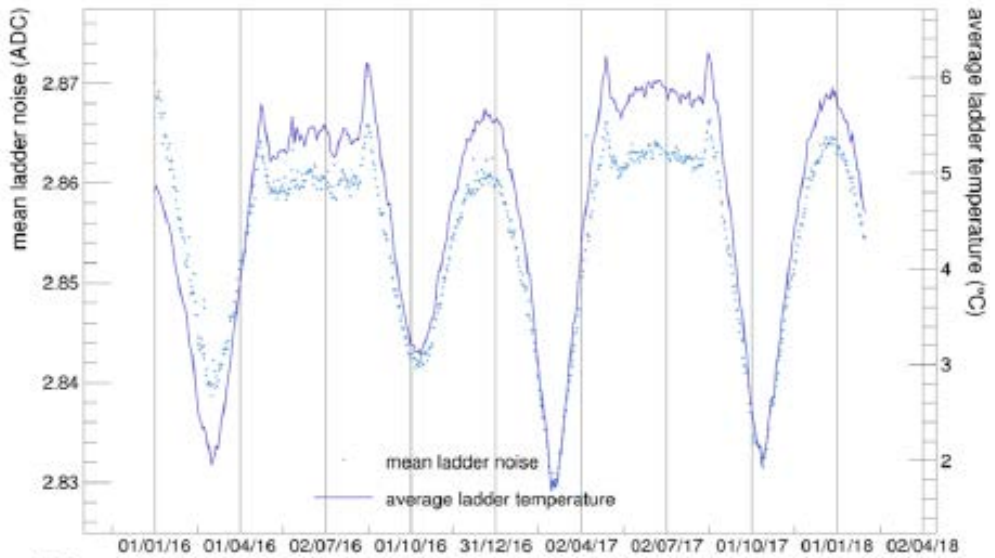


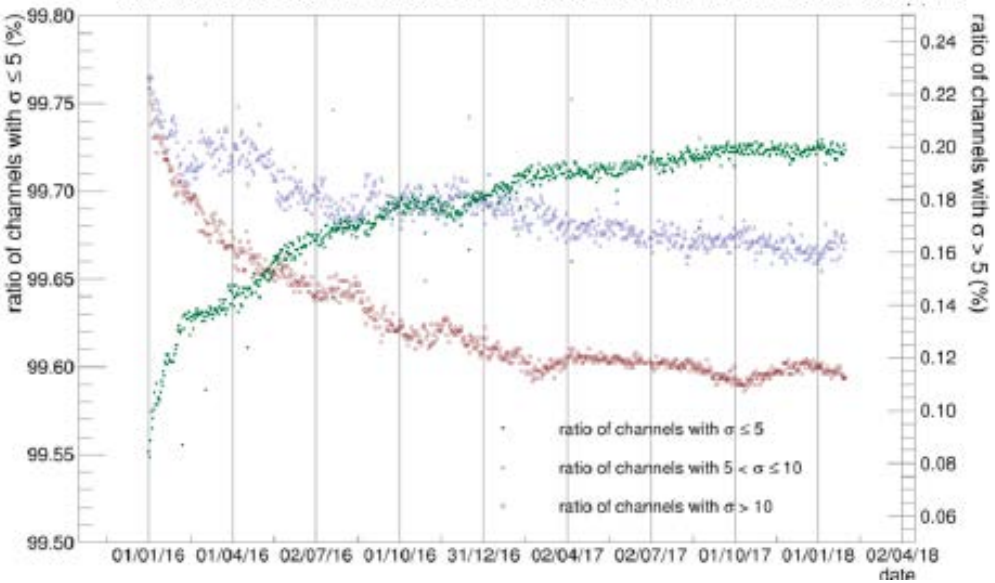
Light attenuation calibration

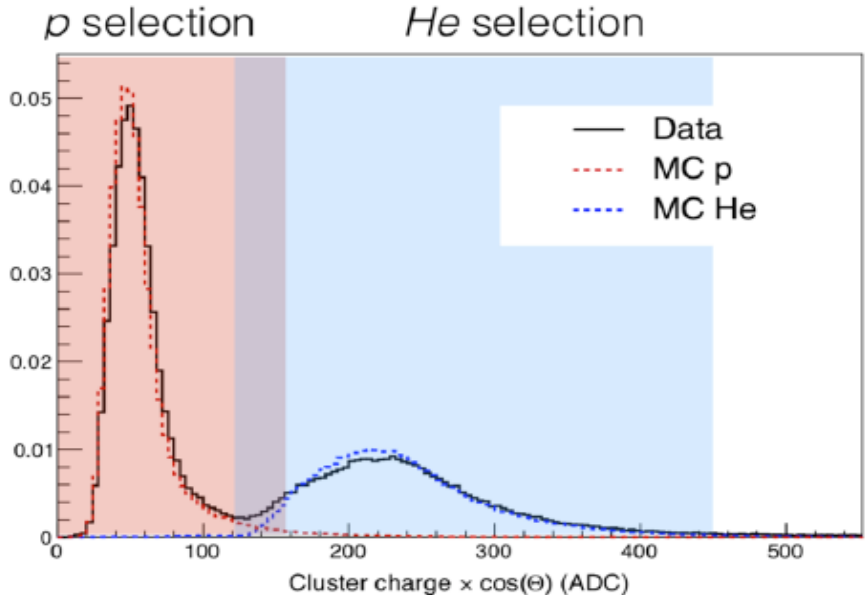


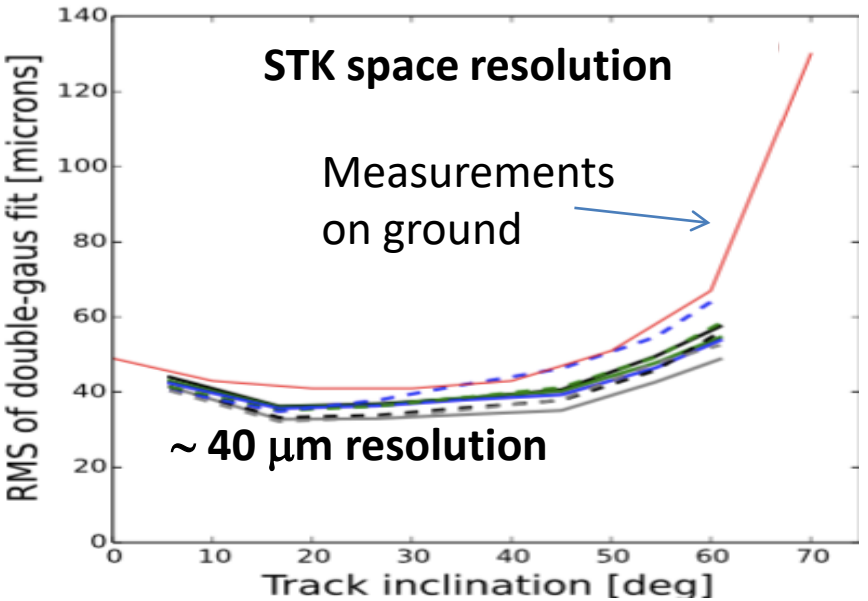
Single layer efficiency

On orbit performance: STK

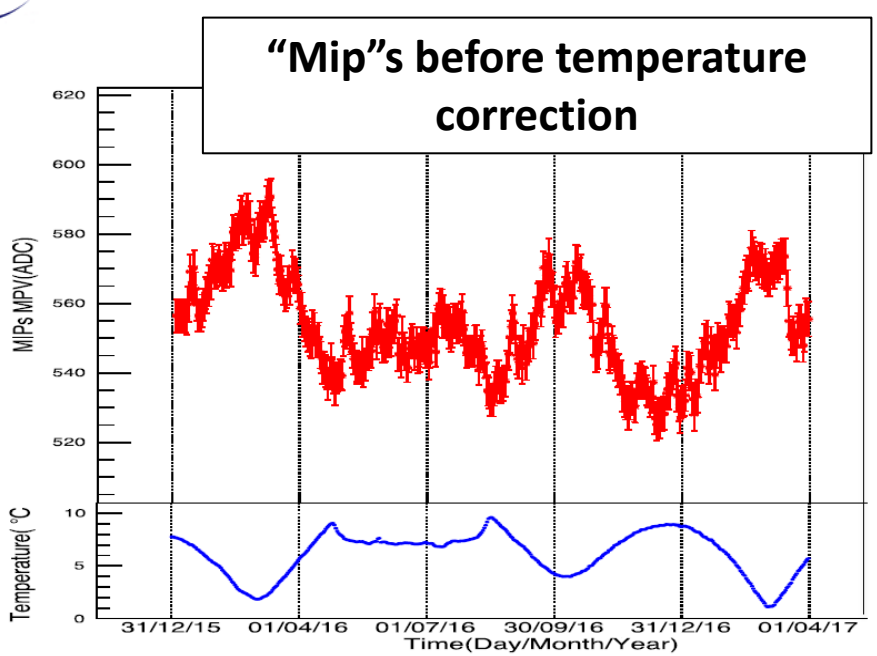


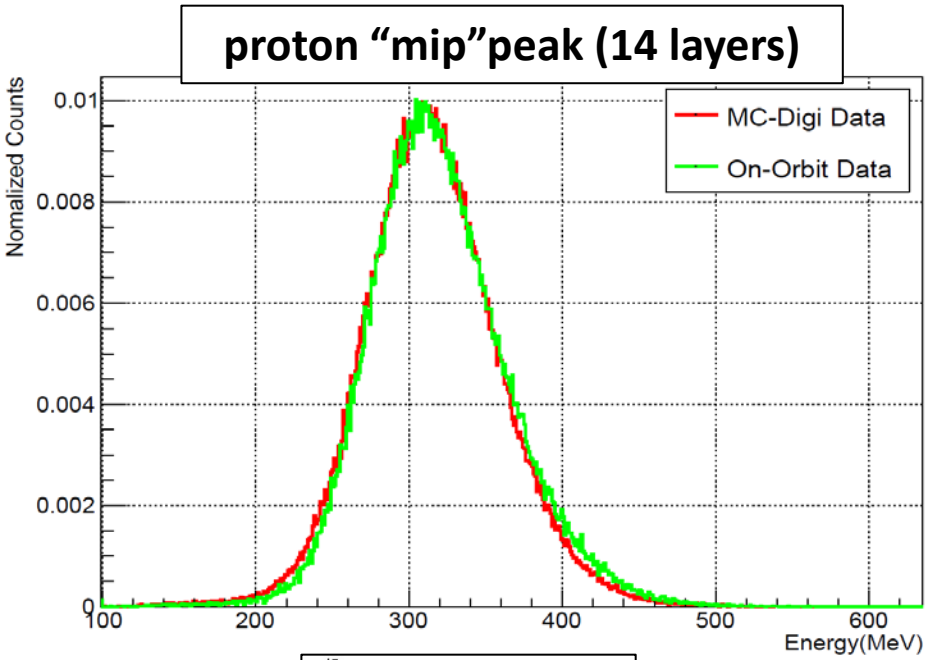


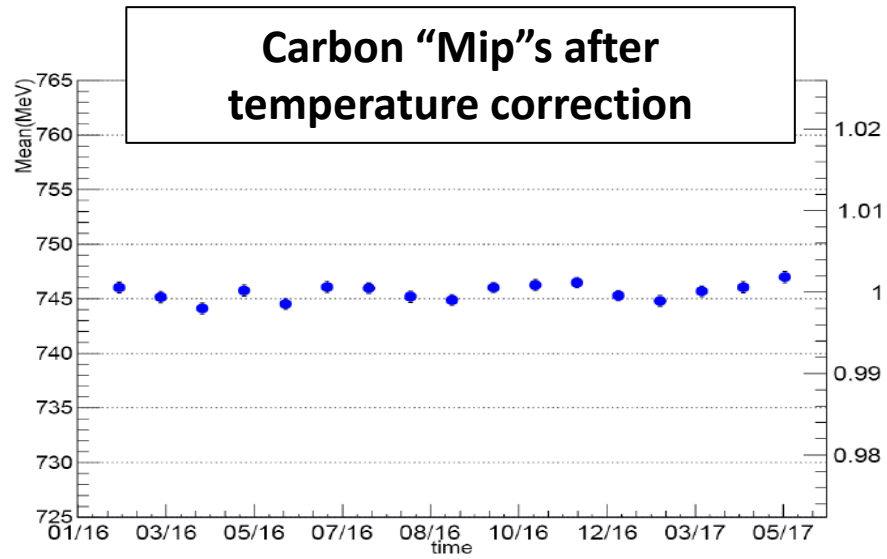


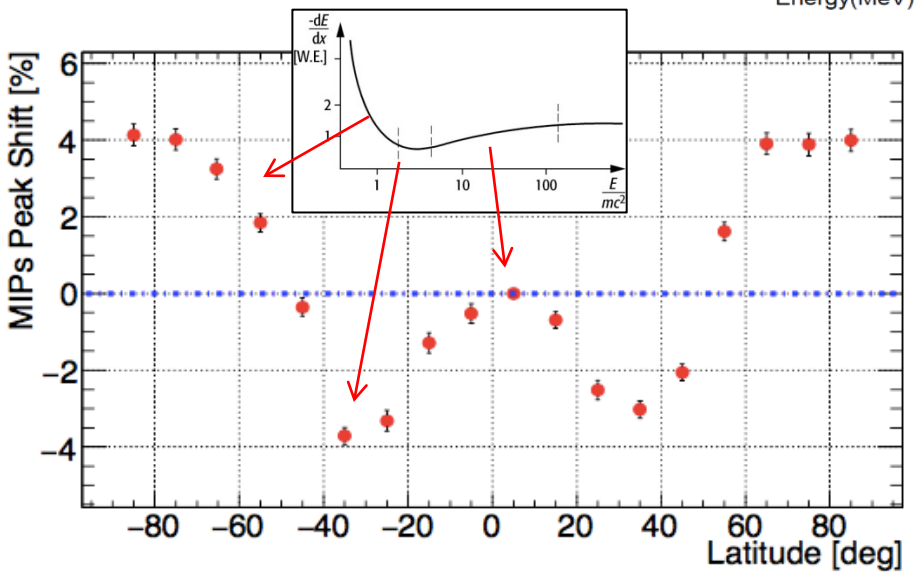


On orbit performance: BGO







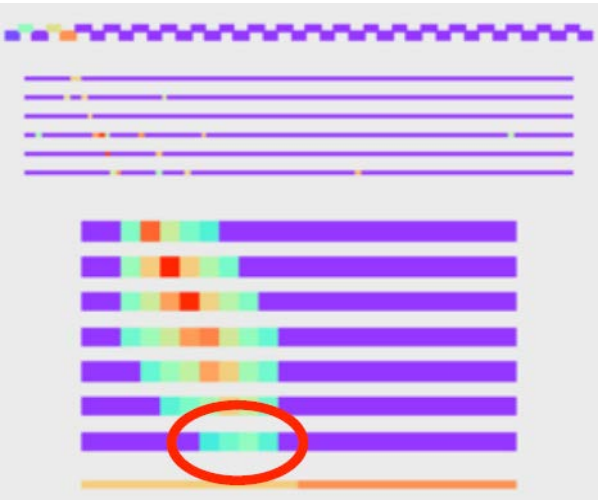


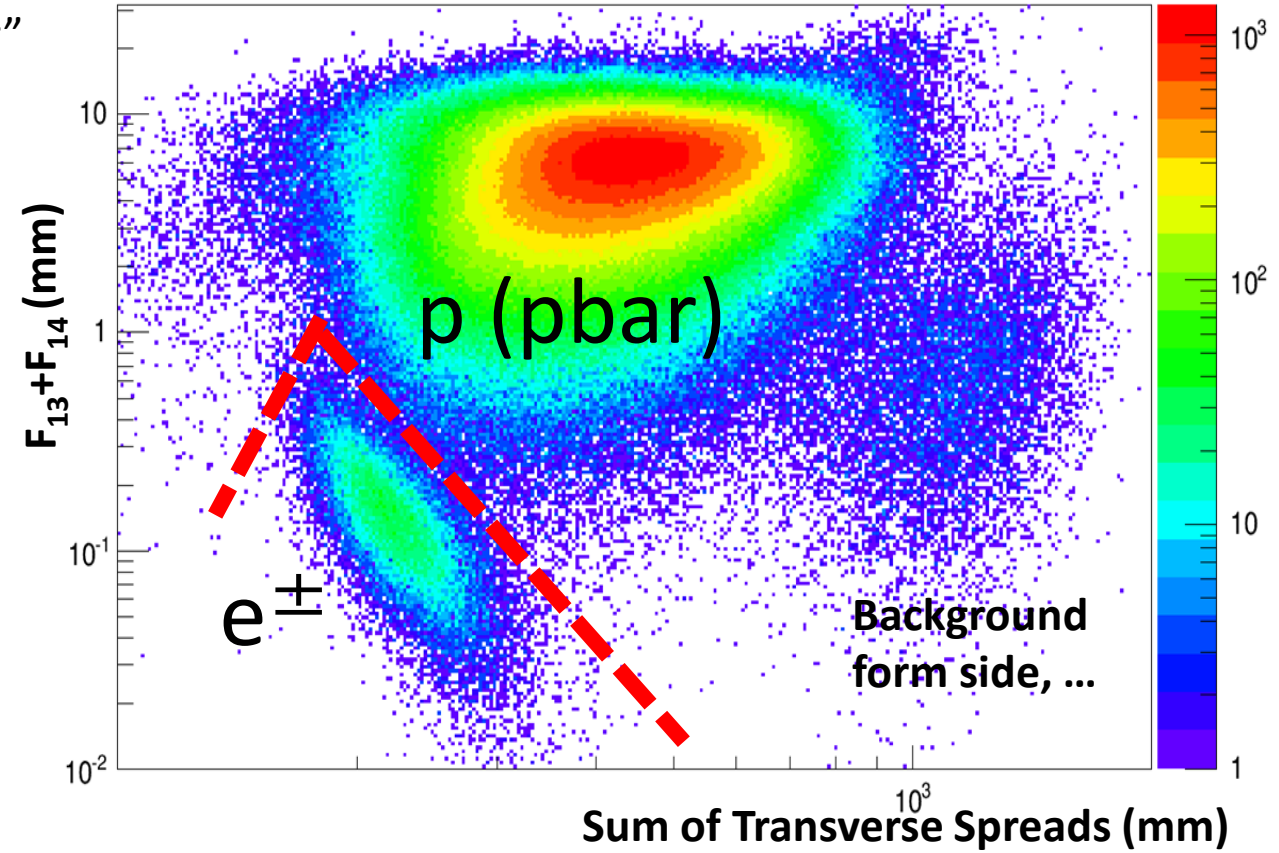
Study of the shower topology

One possible "shape parameter"

$$F_i = Spread_i \times \frac{E_i}{E_{tot}}$$

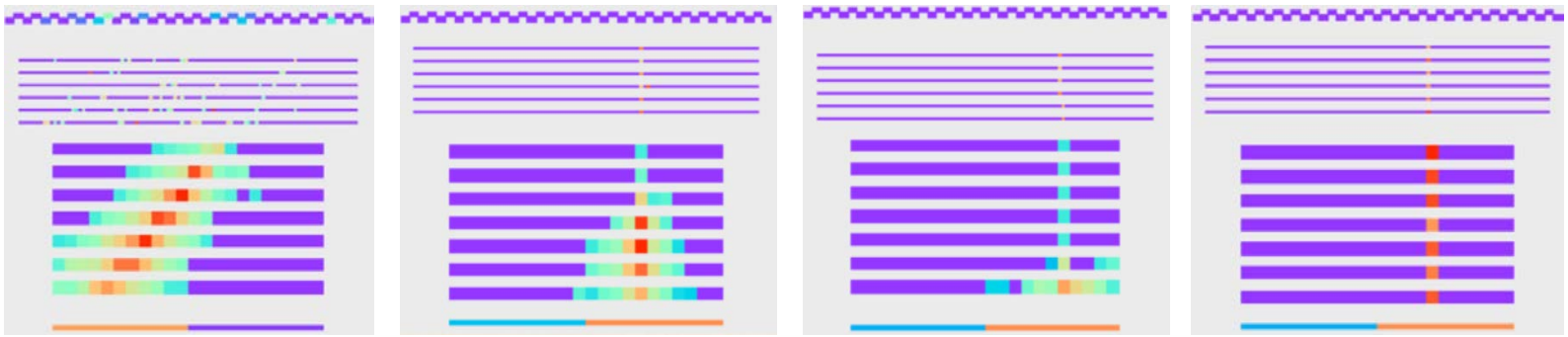
Rejection power > 10^5





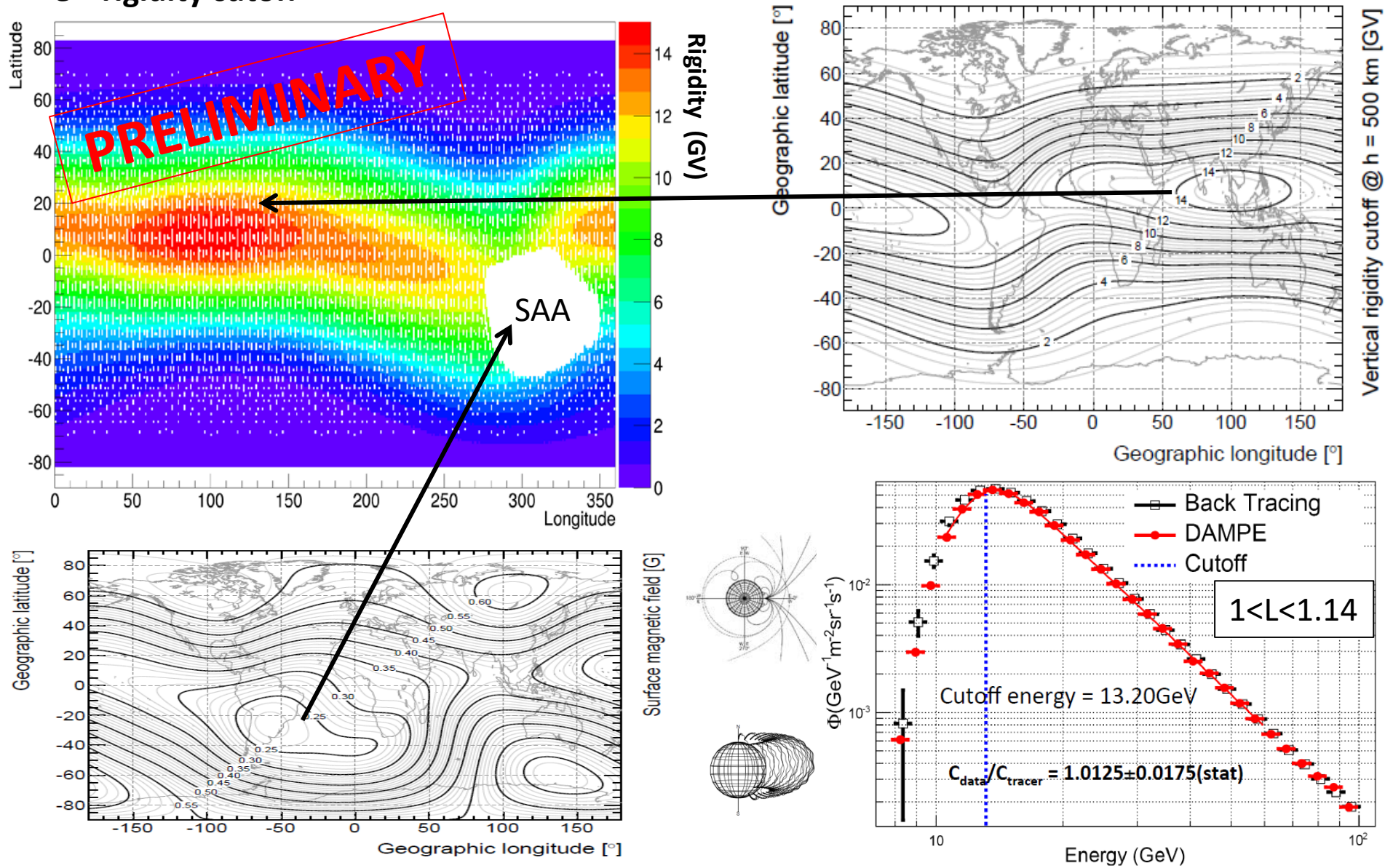
Electrons and positrons

Protons and nuclei

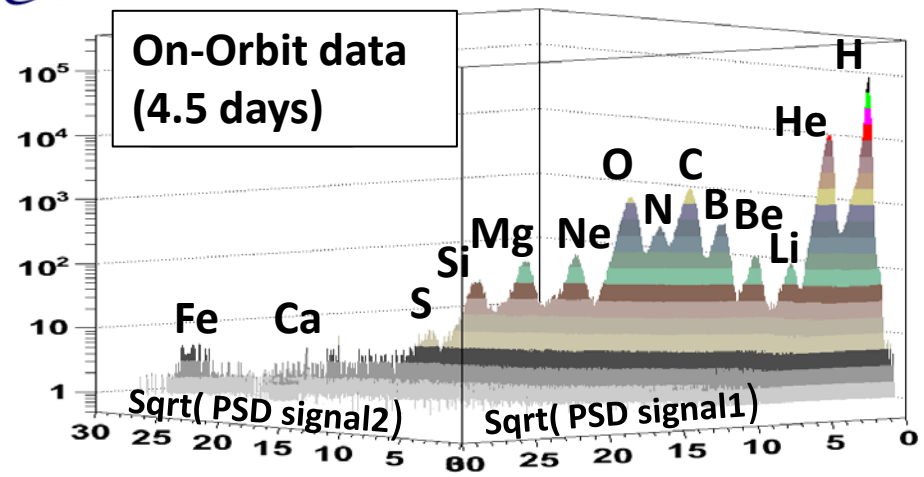


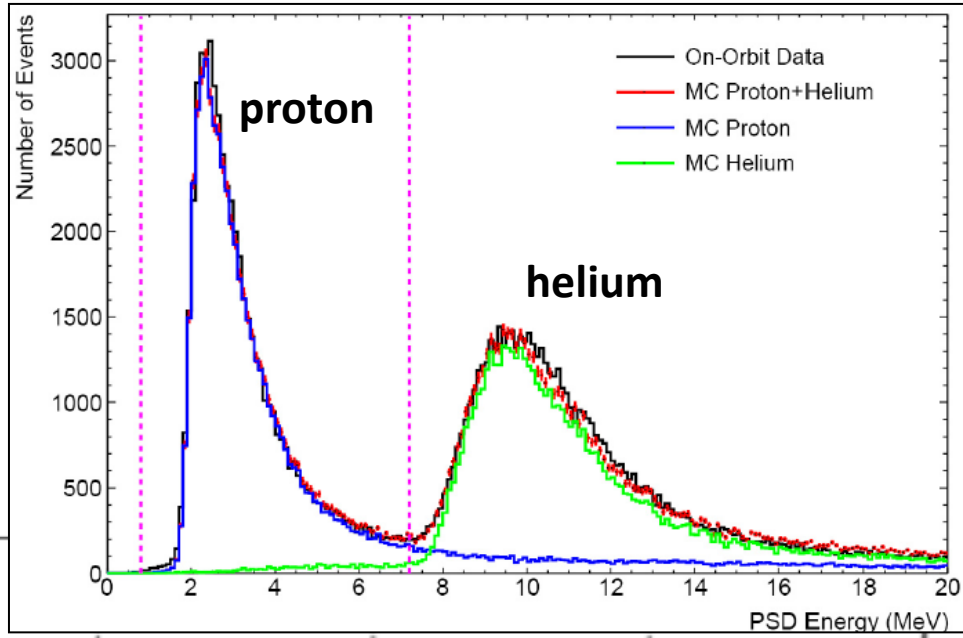
On-orbit energy scale calibration

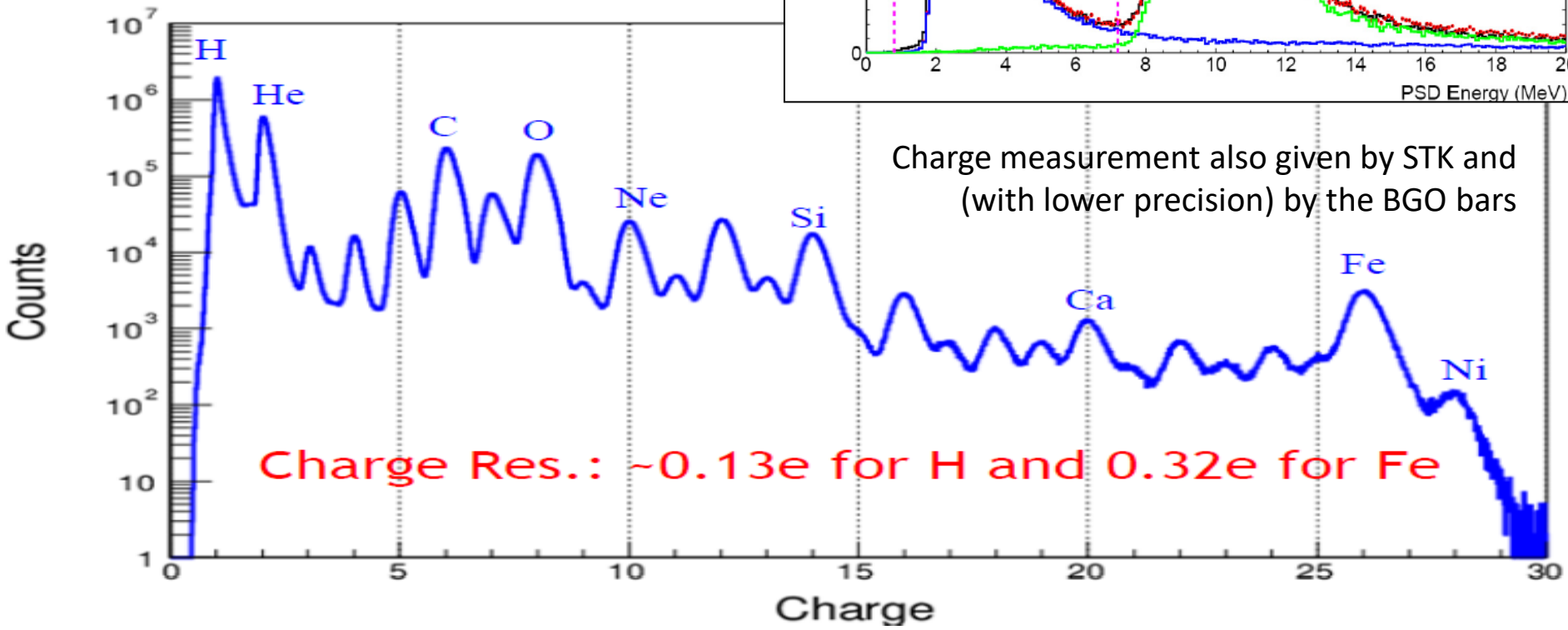
$e^{\pm}$ rigidity cutoff



Nuclei ID with PSD

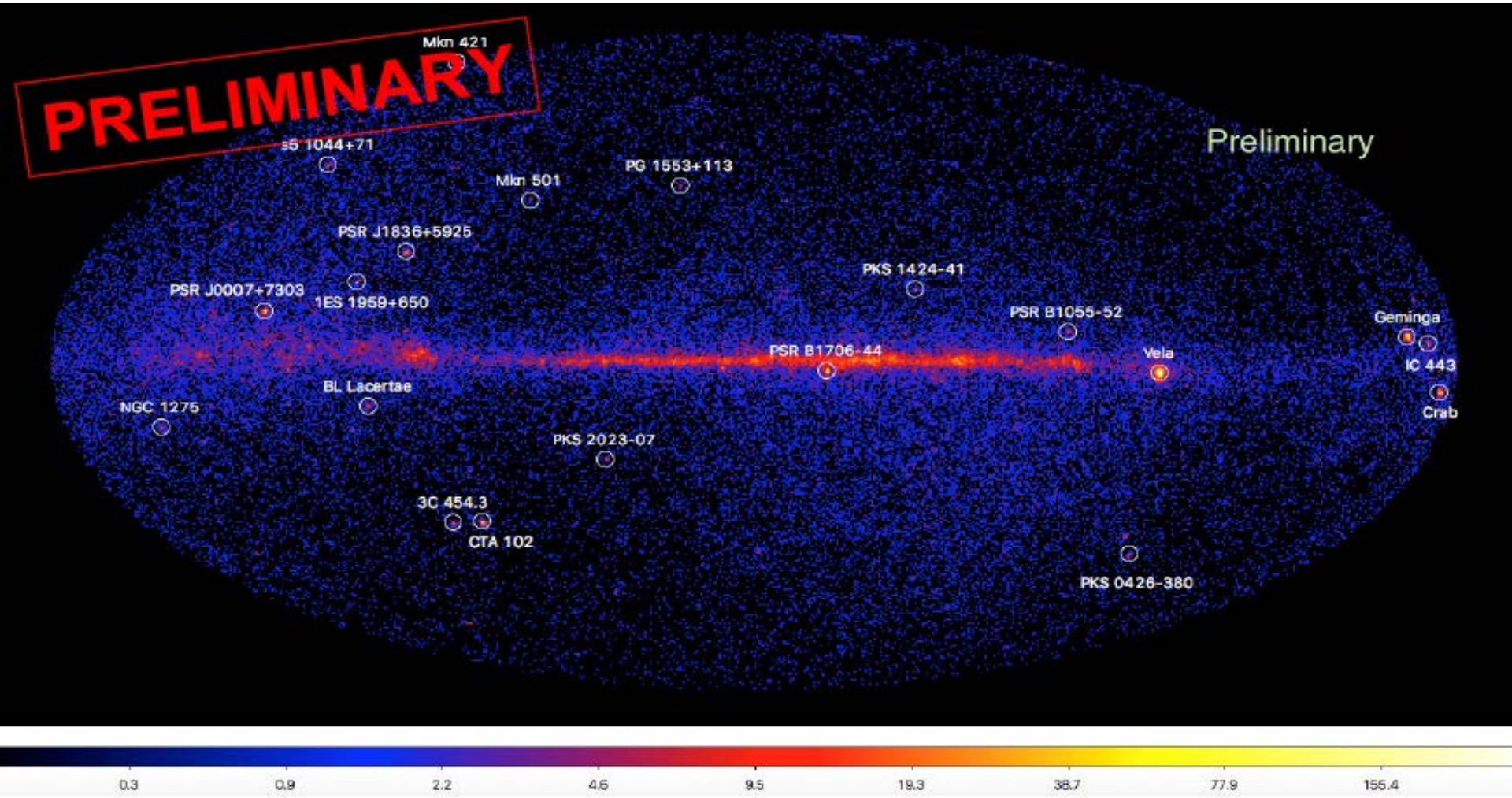






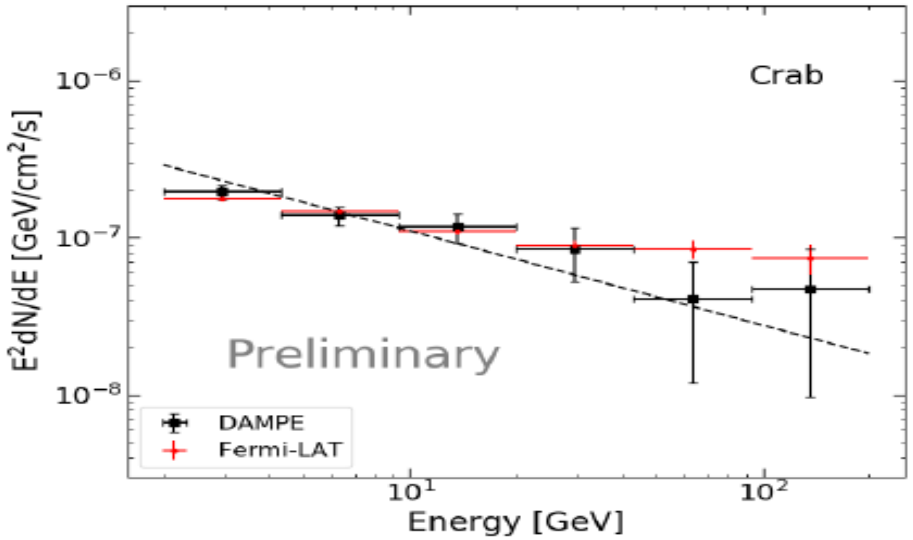
Charge measurement also given by STK and (with lower precision) by the BGO bars

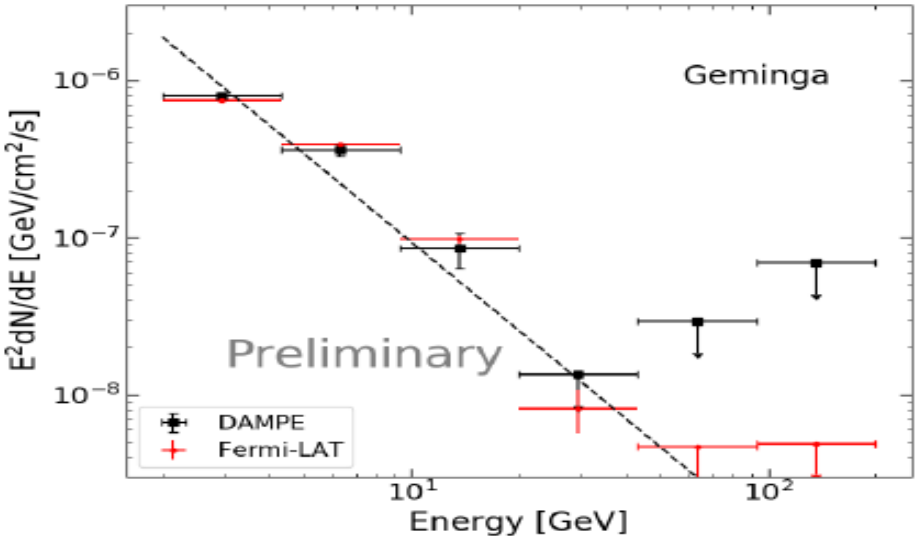
The gamma ray sky

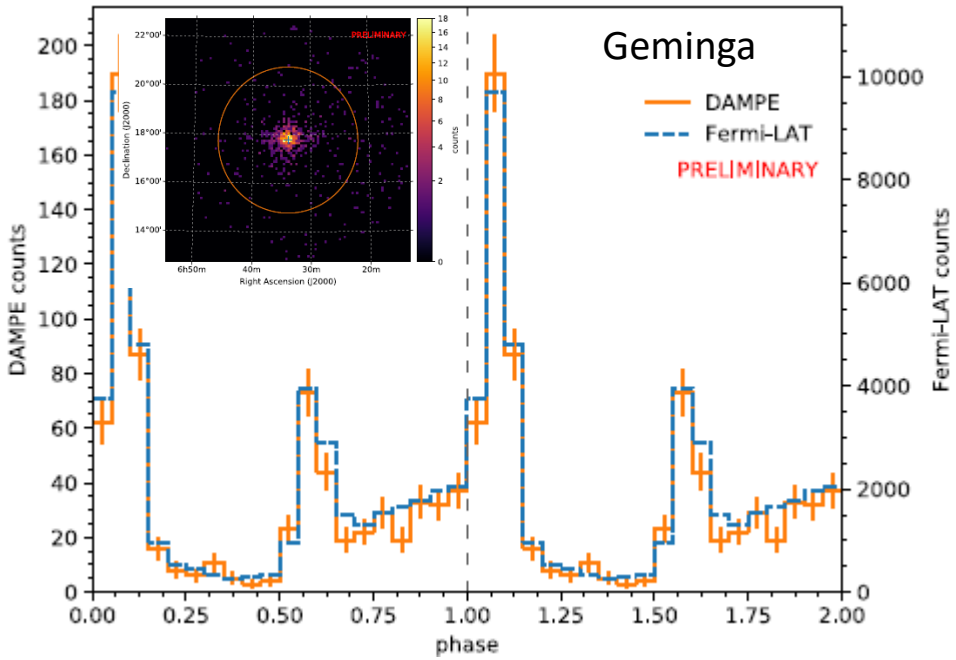


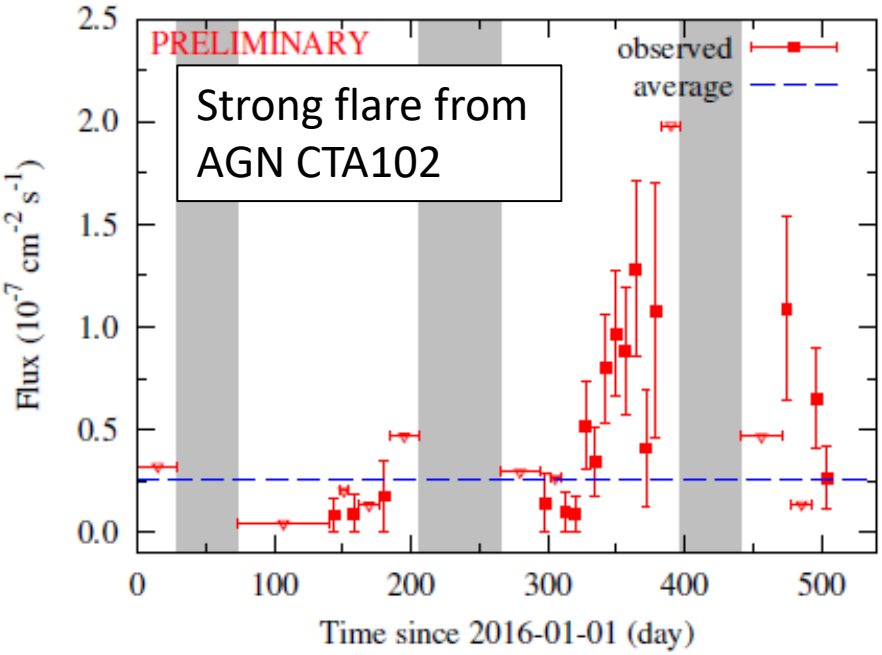
510 days counts map. Mollweide projection, 0.5° ×0.5° pixels
E> 2GeV 90000 events O(20) sources detected

Some gamma ray observations





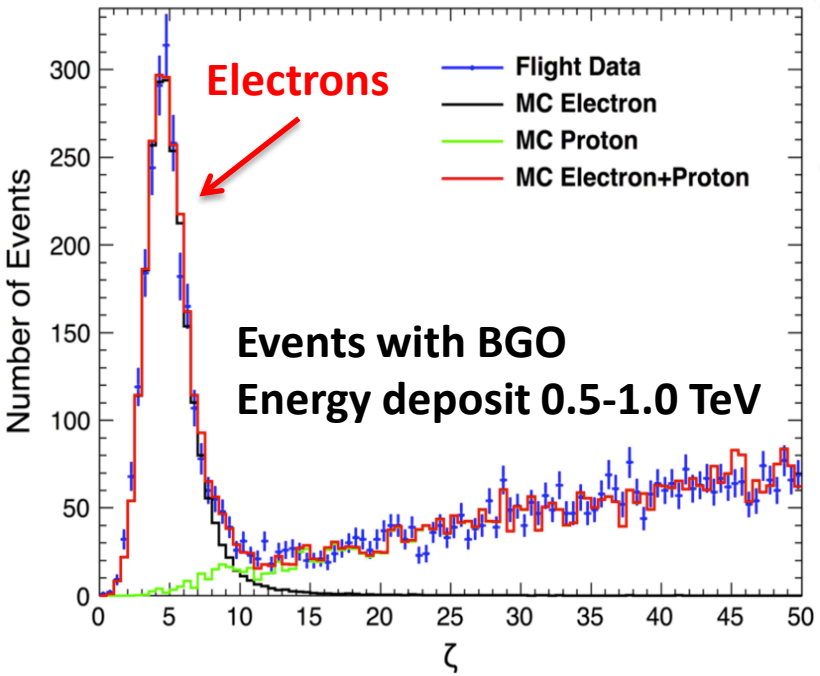


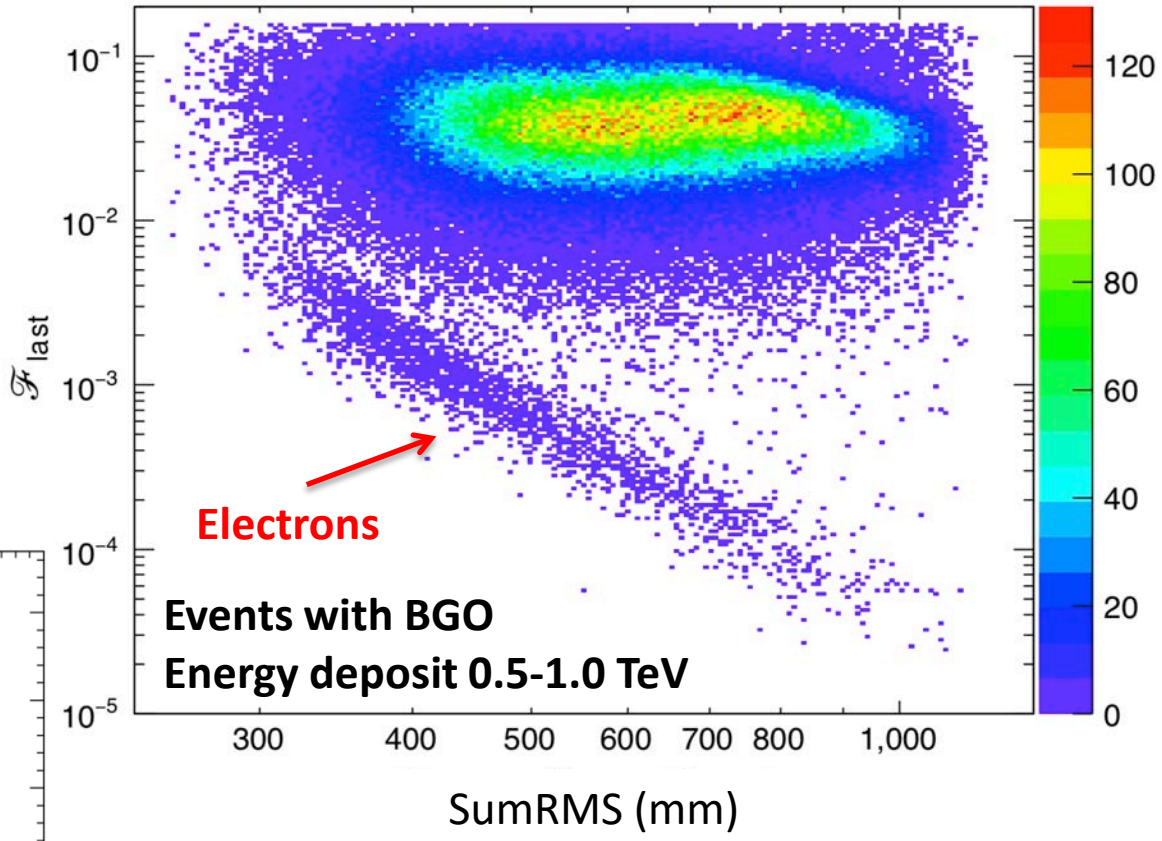


Electron IDentification

$\mathcal{F}_{\text{last}}$ = fraction of energy deposit in the last BGO layer with hits

$$RMS_i = \sqrt{\frac{\sum_j (x_{j,i} - x_{c,i})^2 E_{j,i}}{\sum_j E_{j,i}}}$$





SumRMS = Sum of single layer RMS values

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

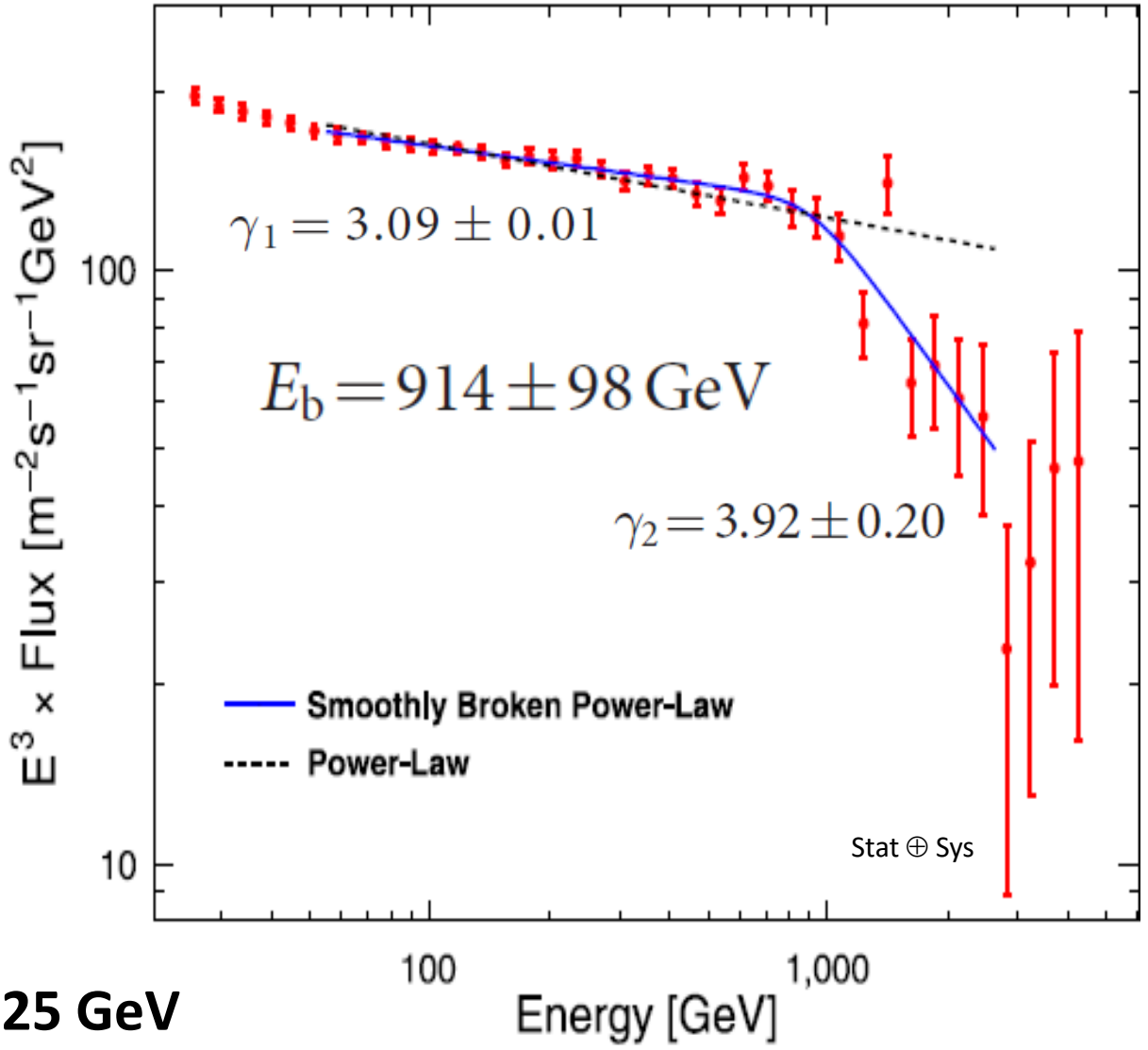
The DAMPE (e^++e^-) spectrum

LETTER nature International weekly journal of science :10.1038/nature24475

Direct detection of a break in the teraelectronvolt cosmic-ray spectrum of electrons and positrons

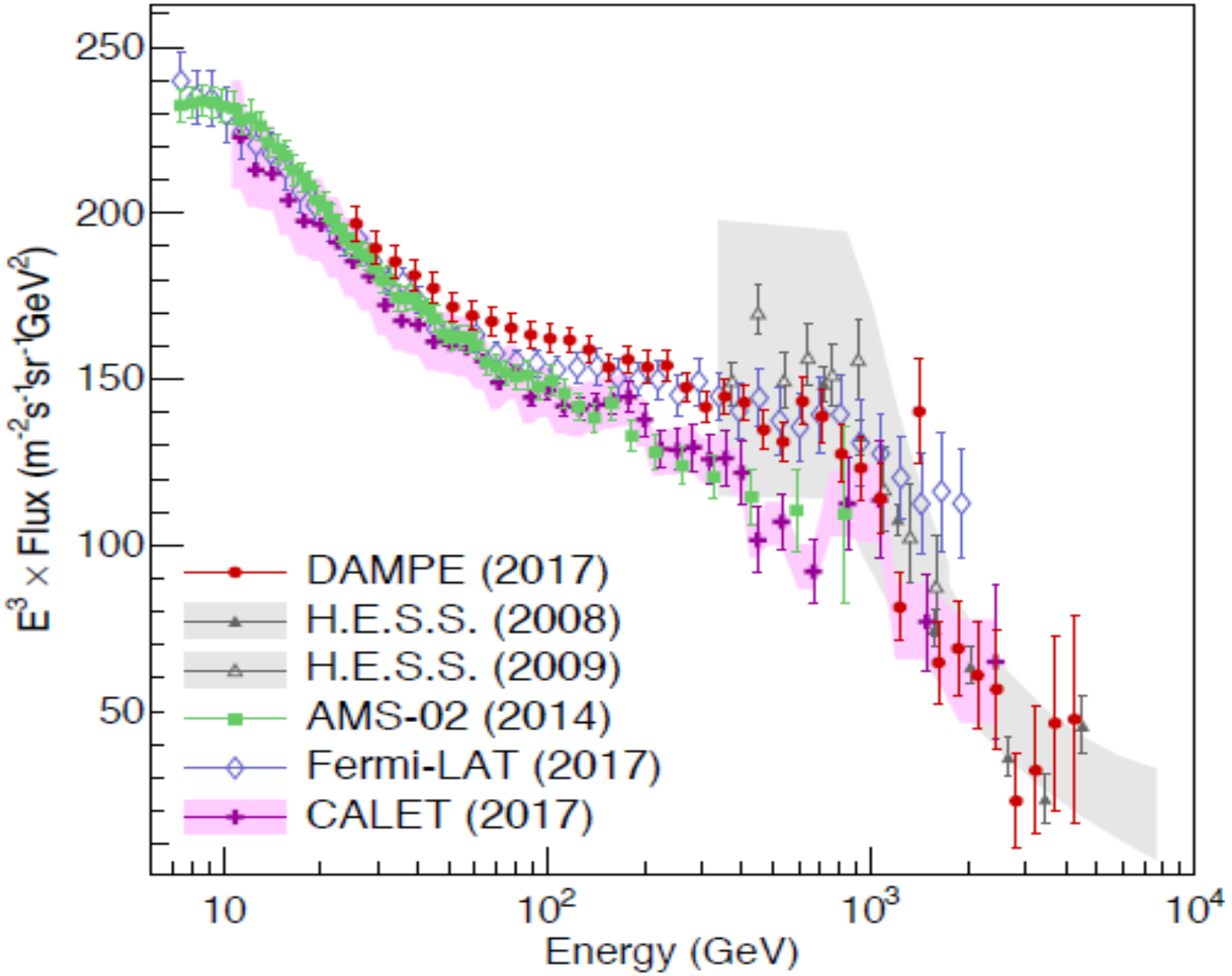
DAMPE Collaboration*

First Direct Evidence for a spectral break in the all-electron spectrum at 0.9 TeV

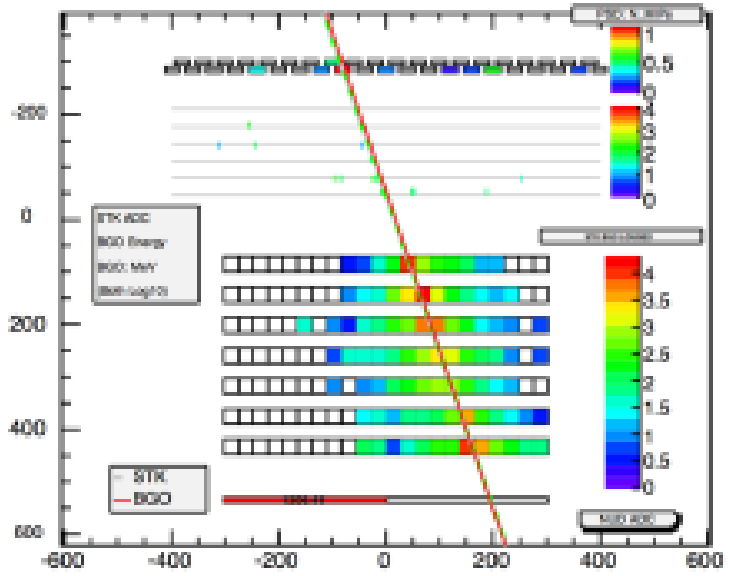


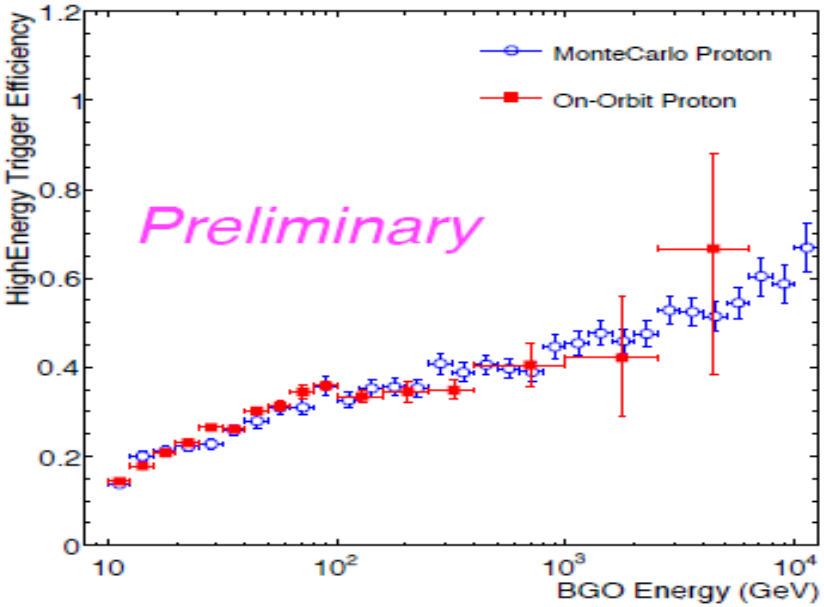
- 530 days
- 2.8 billions CR events
- 1.5 million CREs above 25 GeV

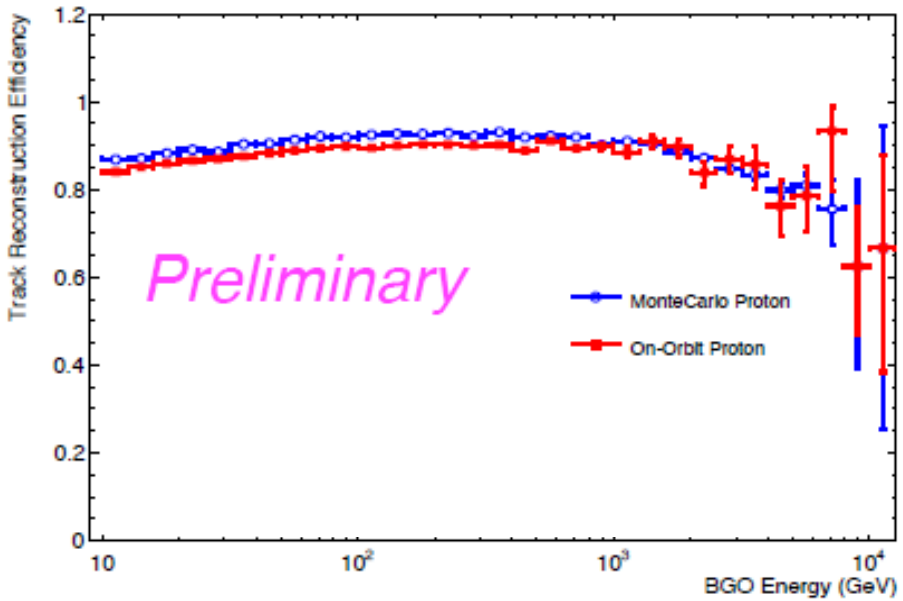
The all-electron spectrum

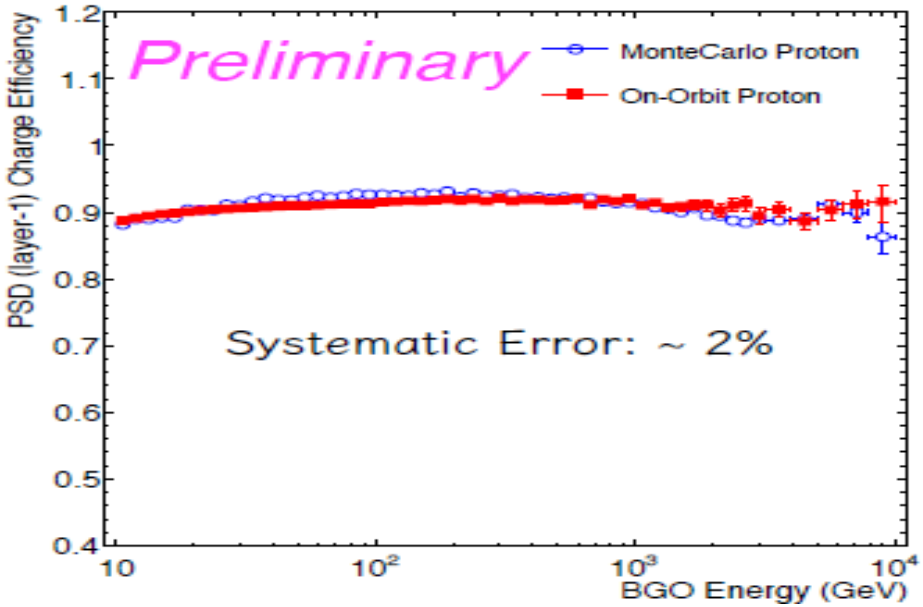


Proton flux measurement

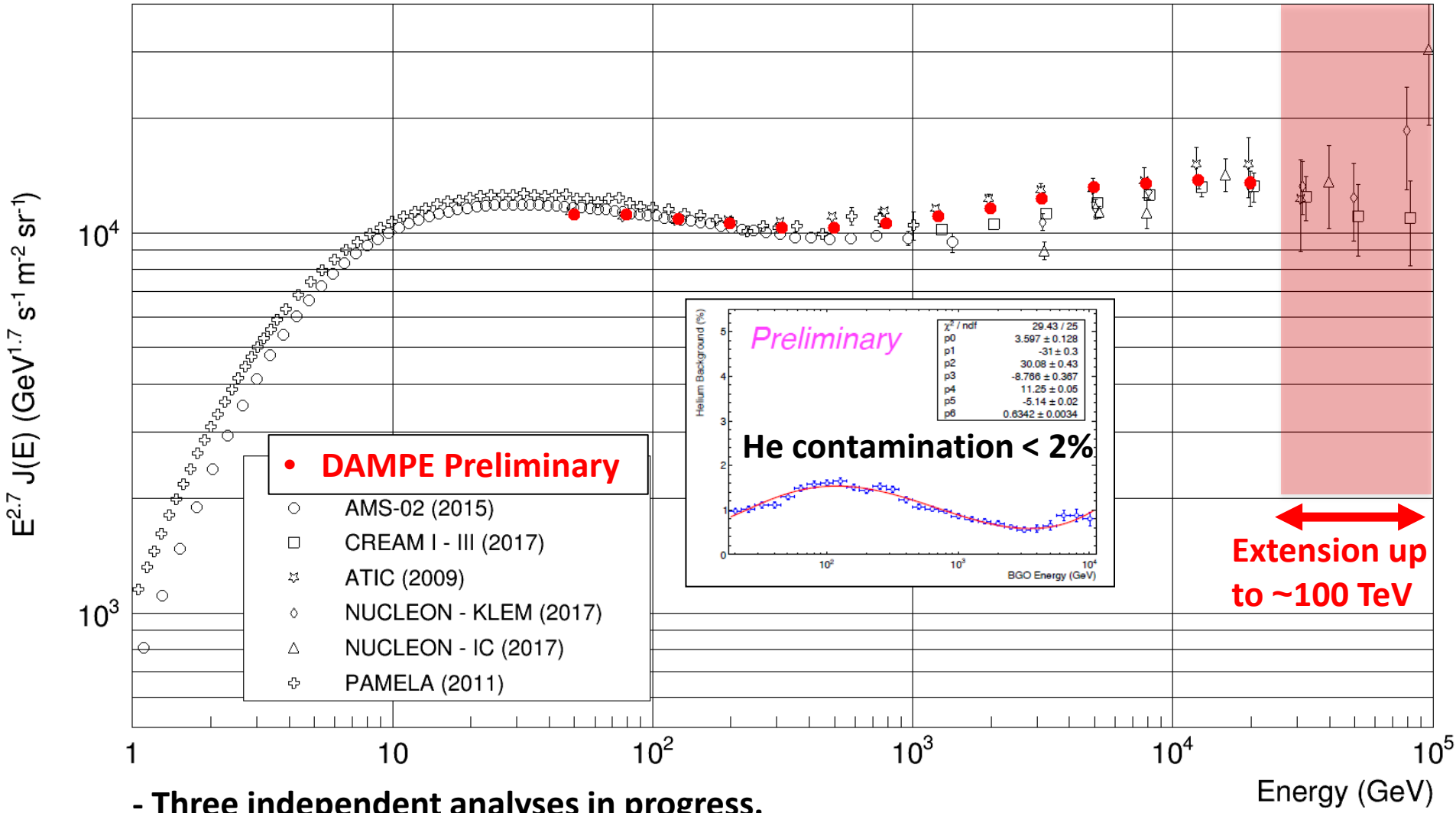






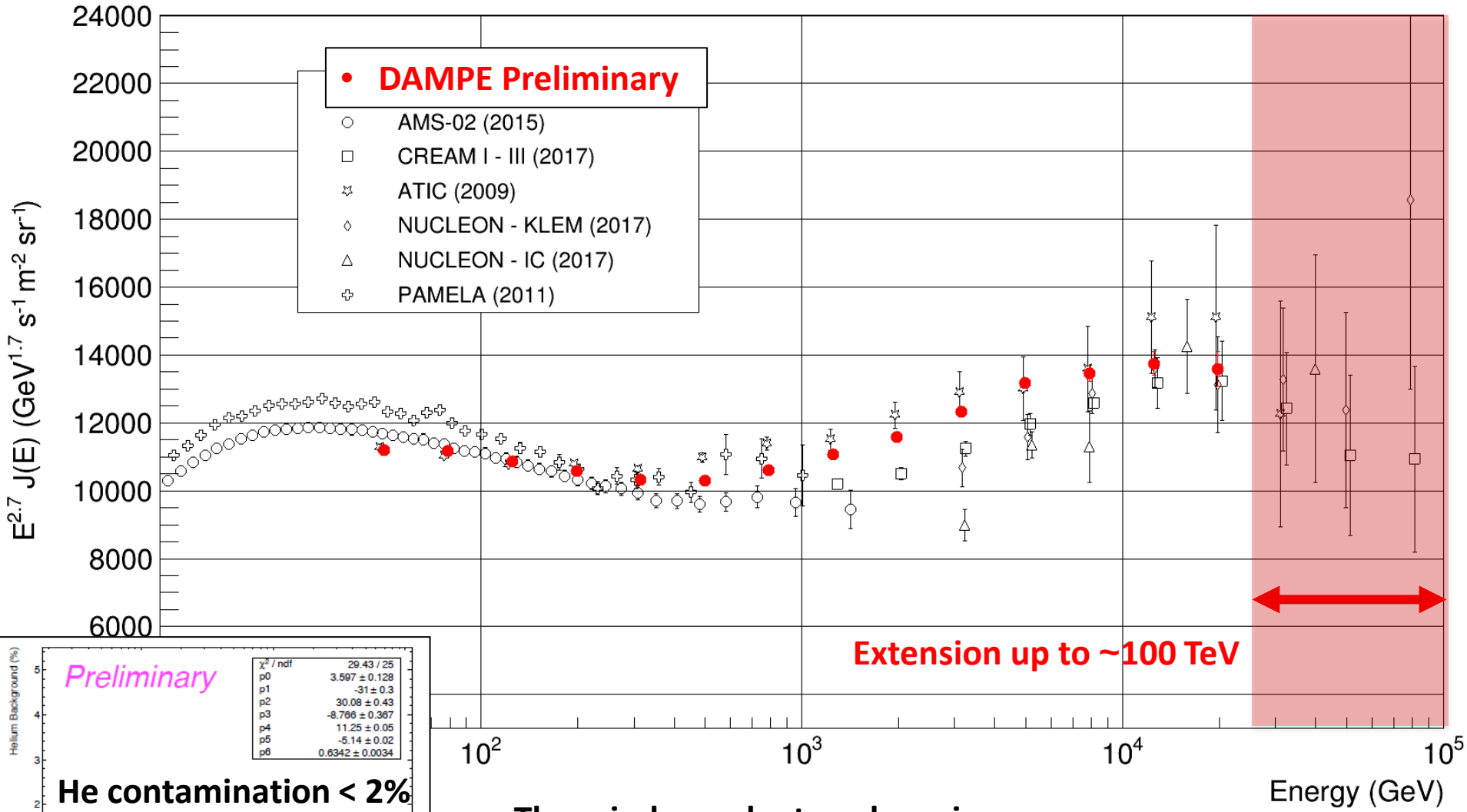


Proton flux measurement



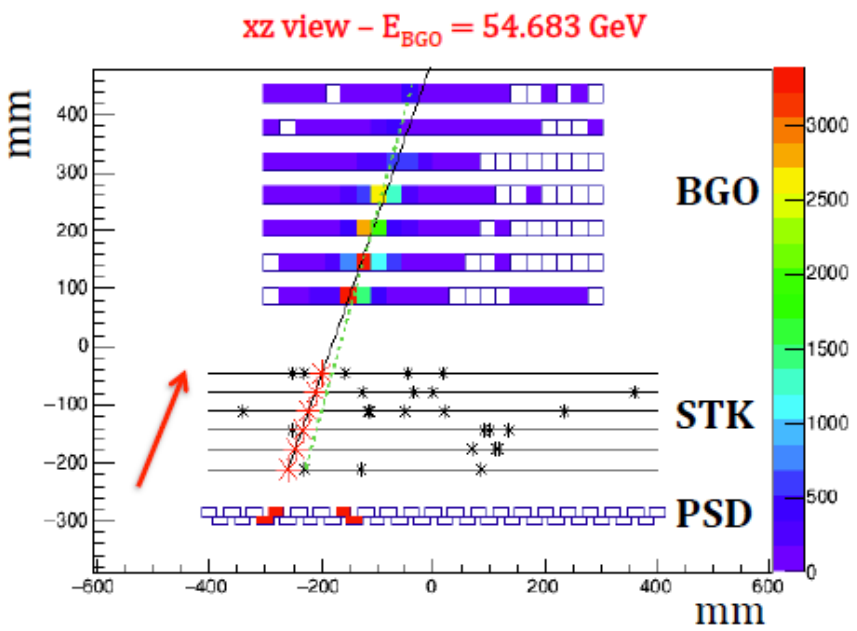
- Three independent analyses in progress.
- Systematic uncertainties not shown.

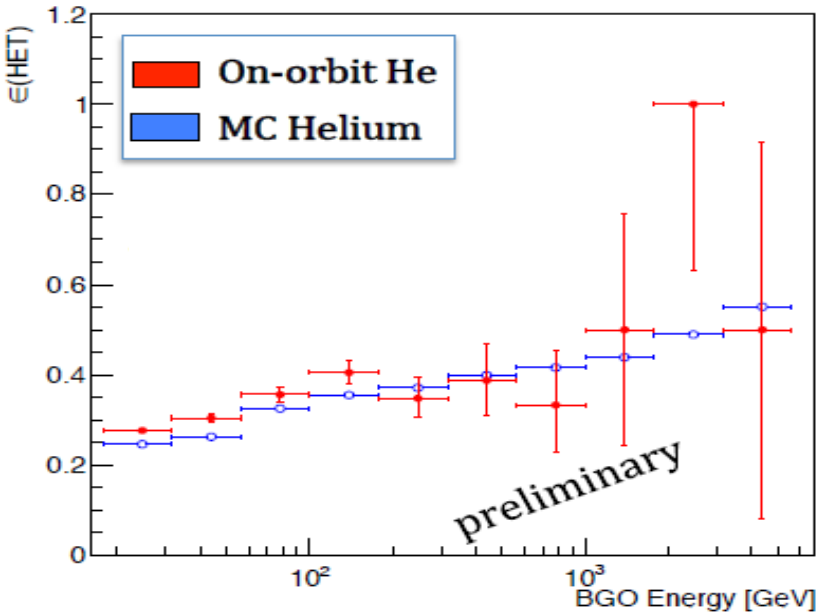
Proton flux measurement

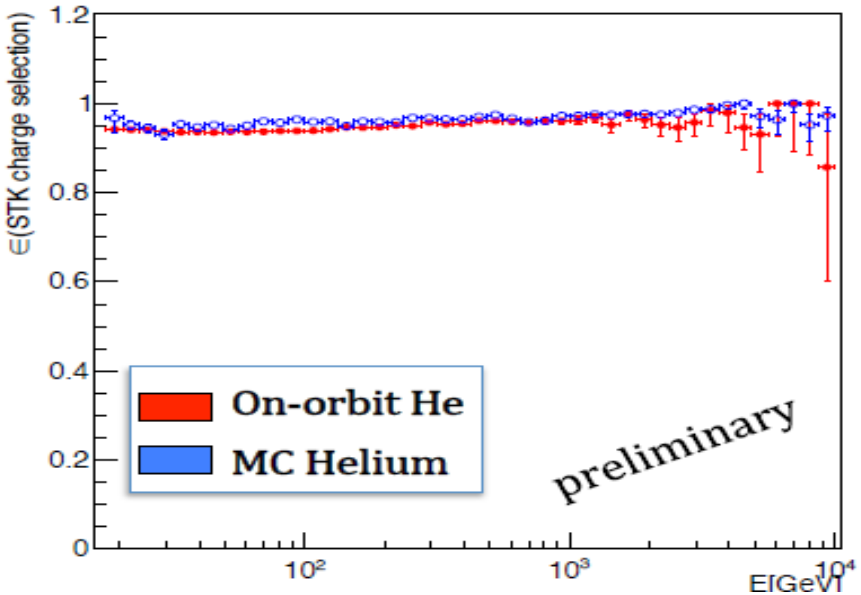


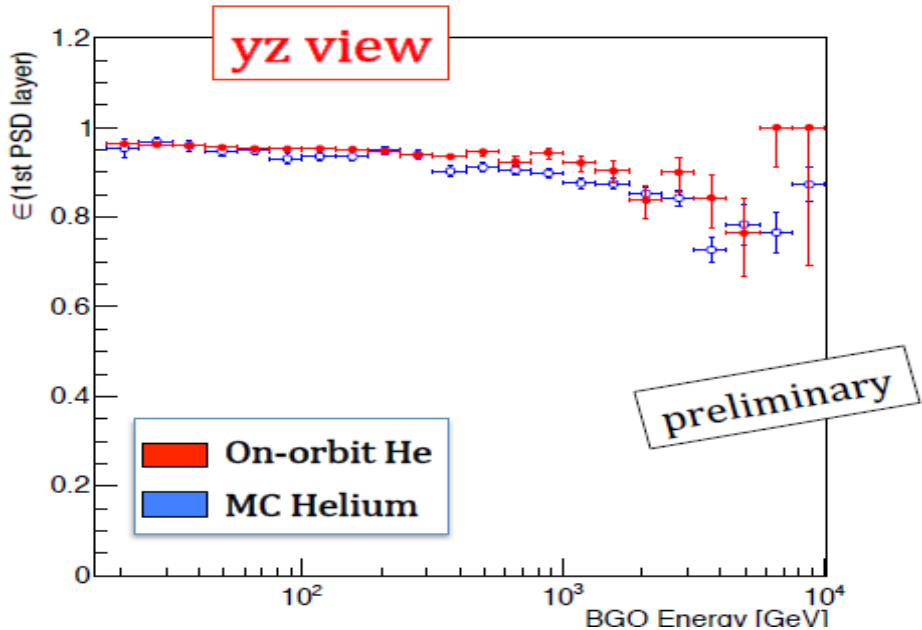
- Three independent analyses in progress.
- Systematic uncertainties not shown.

He flux measurement

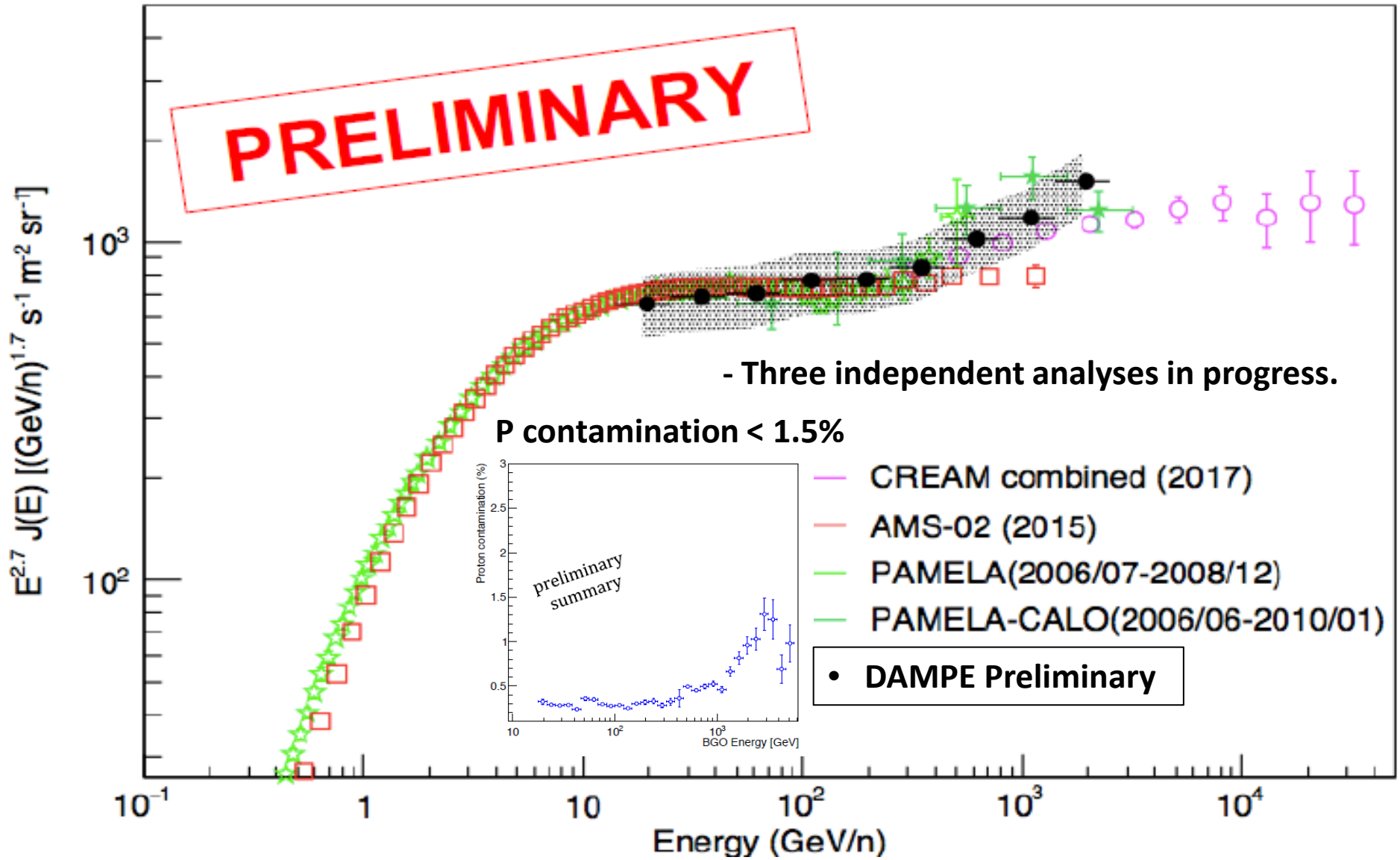








He flux measurement



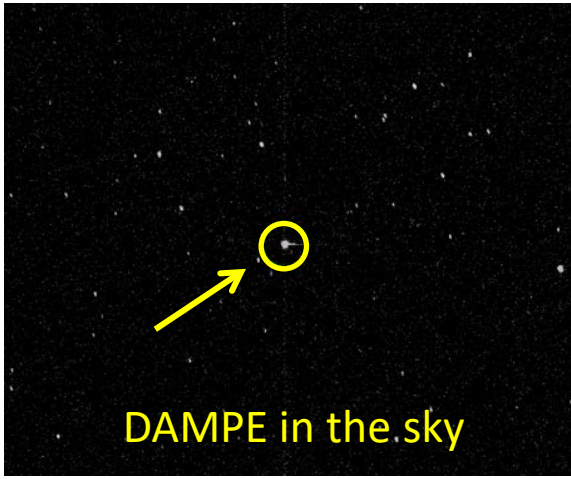
Summary

The detector

- Large geometric factor instrument (0.3 m^2 sr for p and nuclei)
- Precision Si-W tracker (40μm , 0.2°)
- Thick calorimeter (32 X_0 , σ_E/E better than 1% above 50 GeV for e/γ , ~35% for hadrons)
- "Mutiple" charge measurements (0.2-0.3 e resolution)
- e/p rejection power > 10^5 (topology alone, plus neutron detector)

Launch and performances

- Succesfull launch on dec 17, 2015
- On orbit operation steady and with high efficiencies
- Absolute energy calibration by using the geomagnetic cut-off
- Absolute pointing cross check by use of the photon map



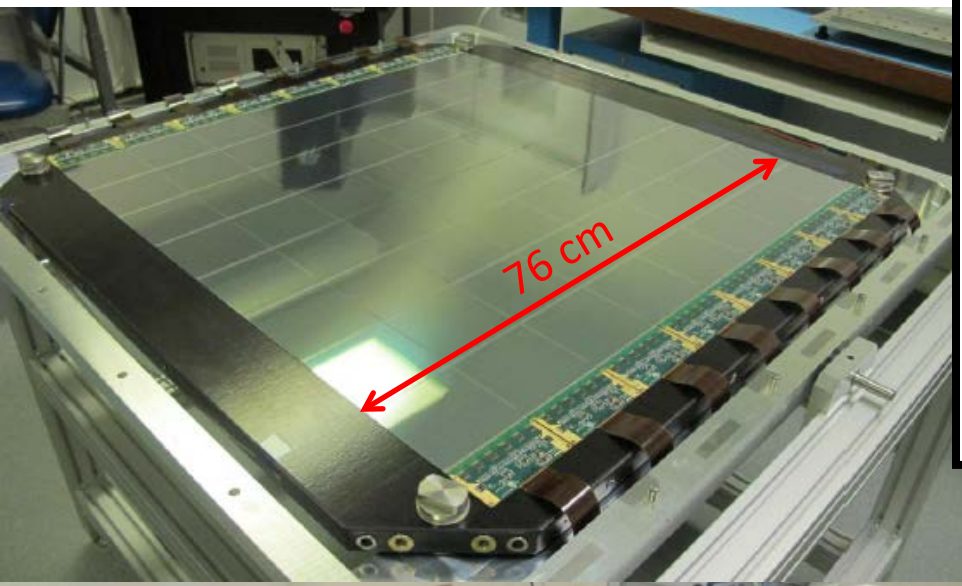
Physics: first results and goals

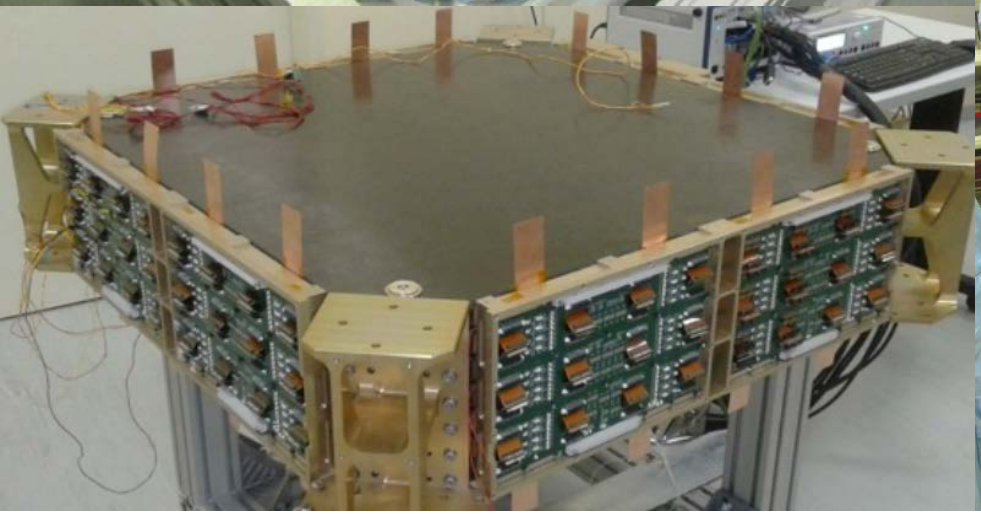
- Study of the **cosmic electron and photon spectra**
- Study of electron anisotropy and nearby sources contribution
- Study of **cosmic ray protons and nuclei**: spectrum and composition
- Precise measurement of CR discrepant hardenings and spectral indexes
- High energy **gamma ray astronomy**
- Search for dark matter signatures in lepton spectra
- The "unexpected": GW electromagnetic follow up in FoV

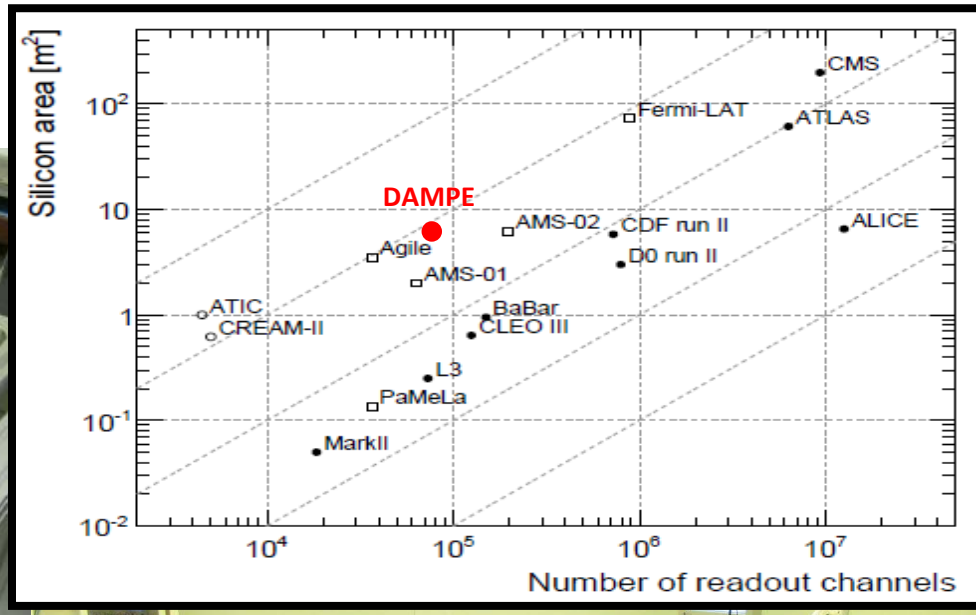
More Stuff

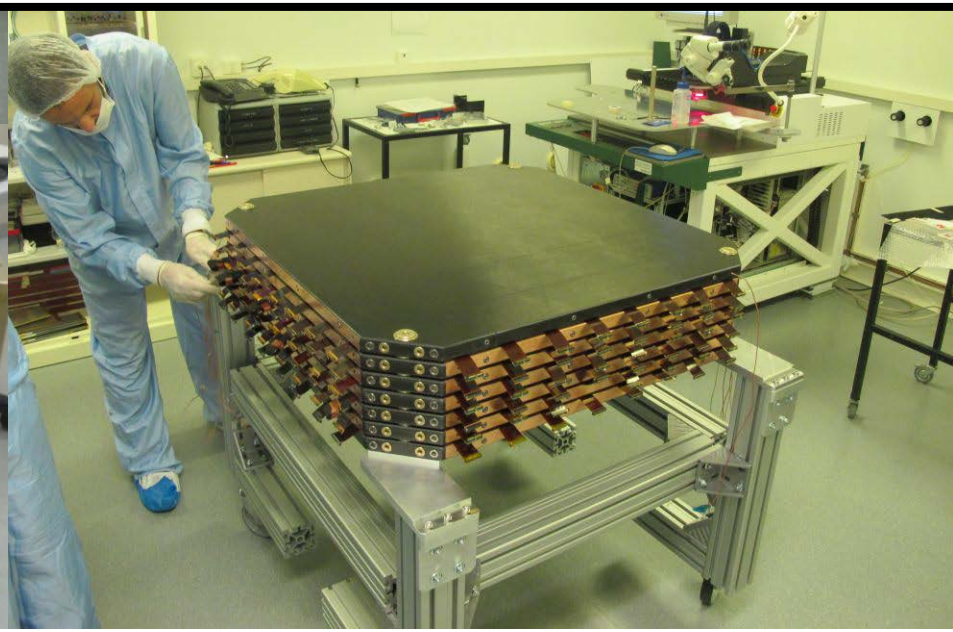
The Silicon TracKer (STK) - 2

Power consumption: 83 W **Mass: 155 kg**

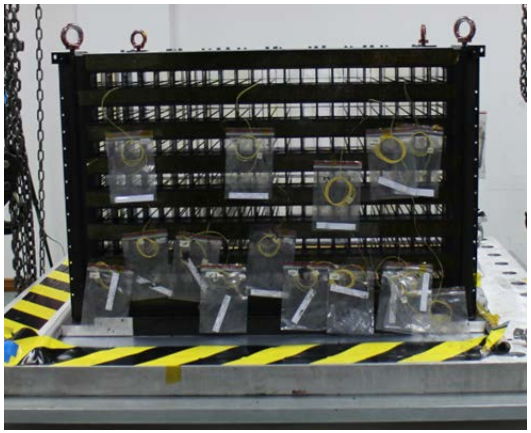






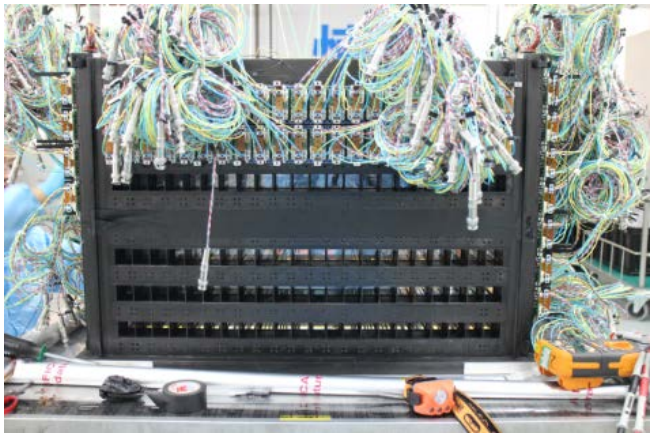


The CALOrimeter -2

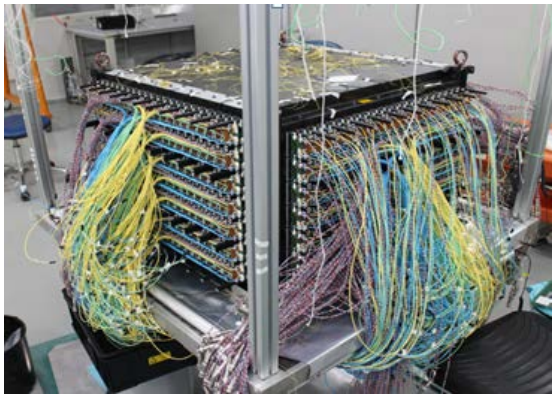


Carbon Fiber Structure

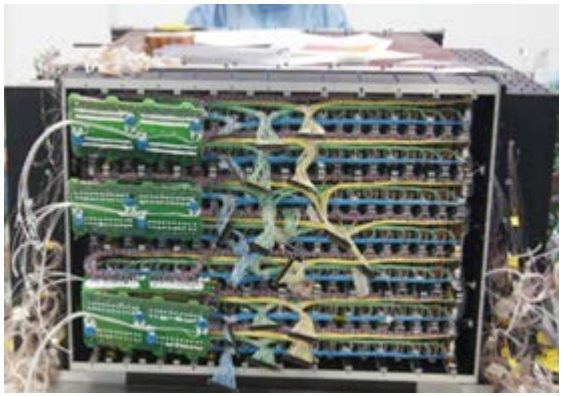
BGO crystal installation



PMT installation



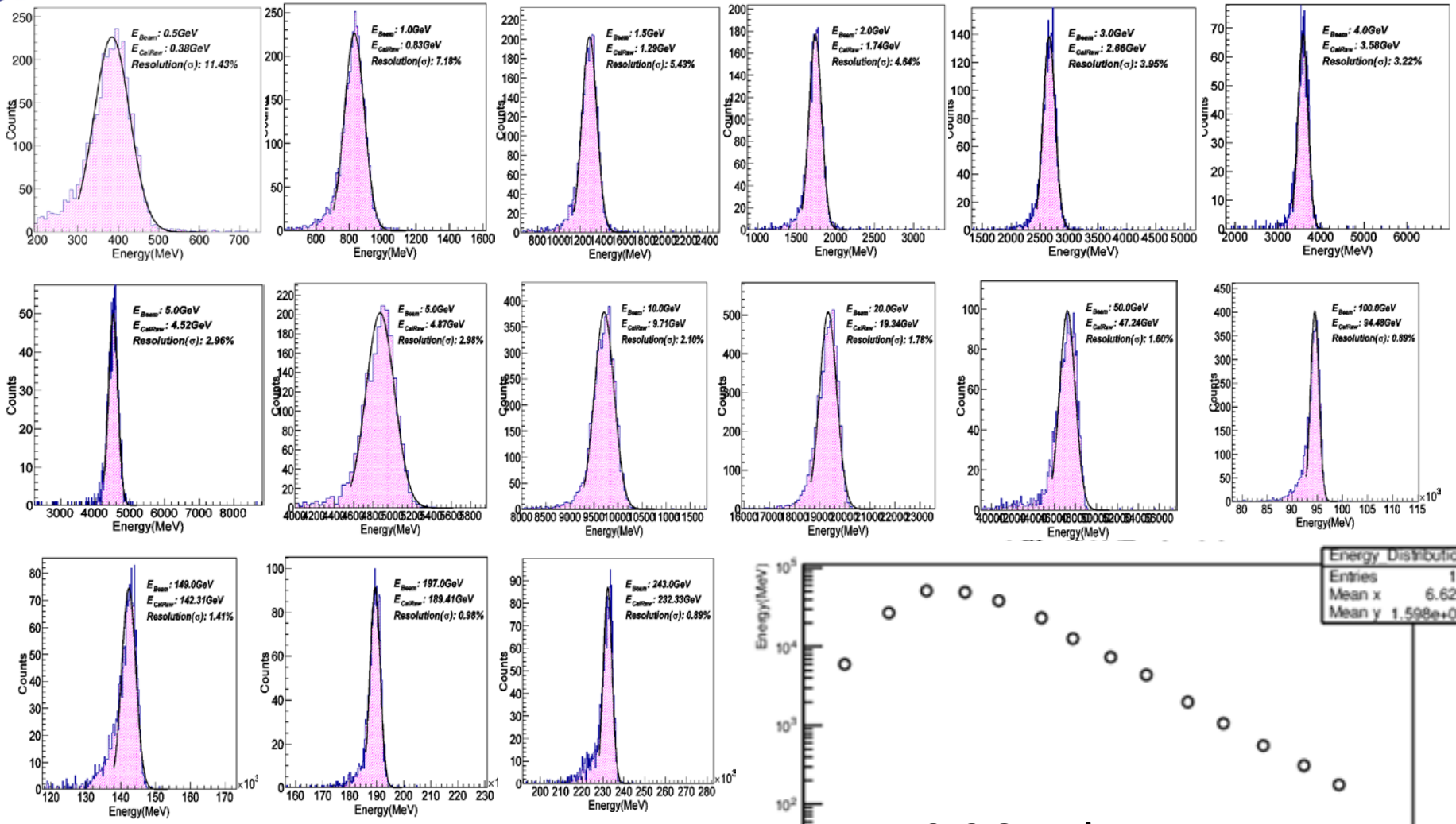
Cable arranging



Cable connector

BGO Cal

Test beam activity at CERN: electrons



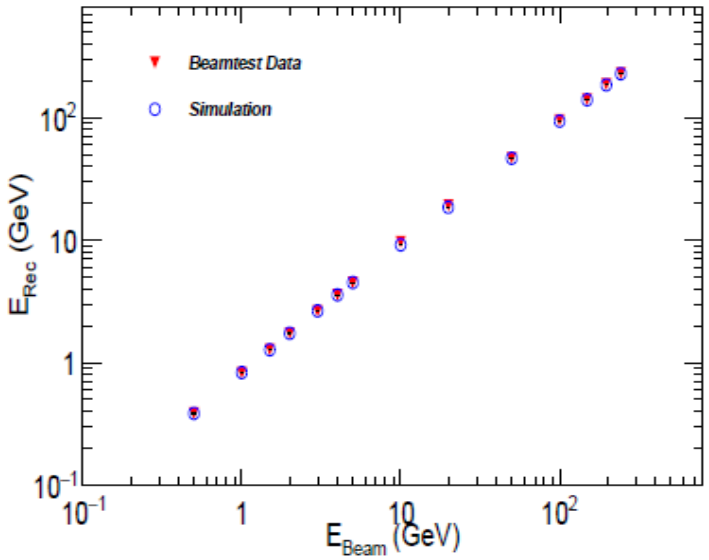
A 243 GeV Electron Longitudinal profile

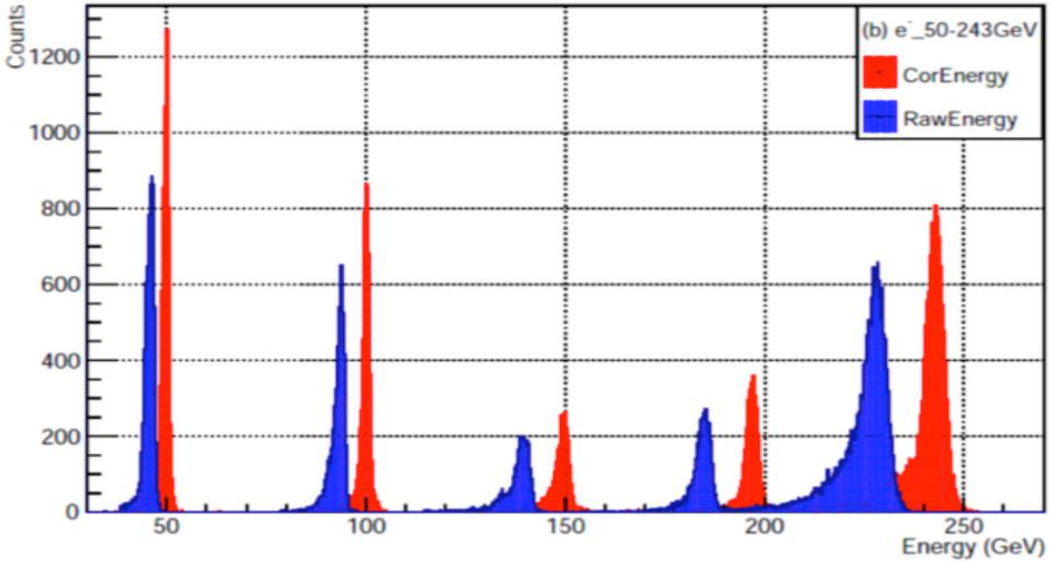
Electrons

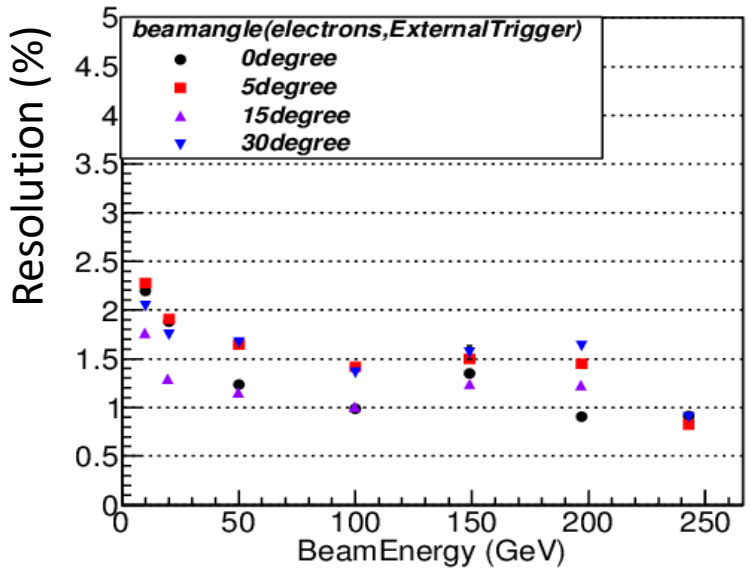
0.5, 1, 1.5, 2, 3, 4, 5 GeV @ PS

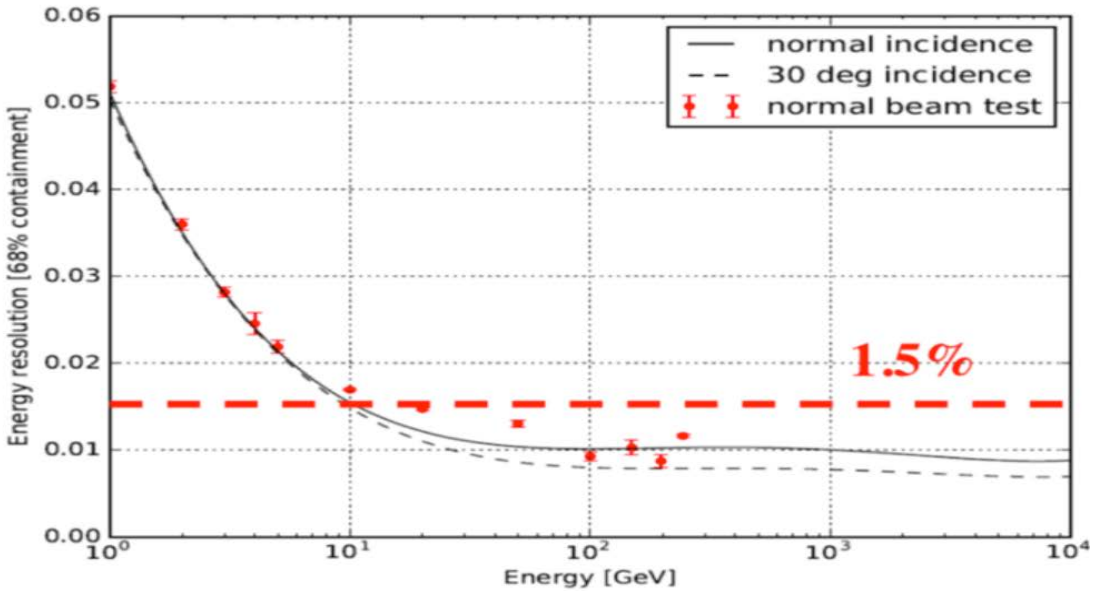
5, 10, 20, 50, 100, 149, 197, 243 GeV @ SPS

Test beam activity at CERN: electrons

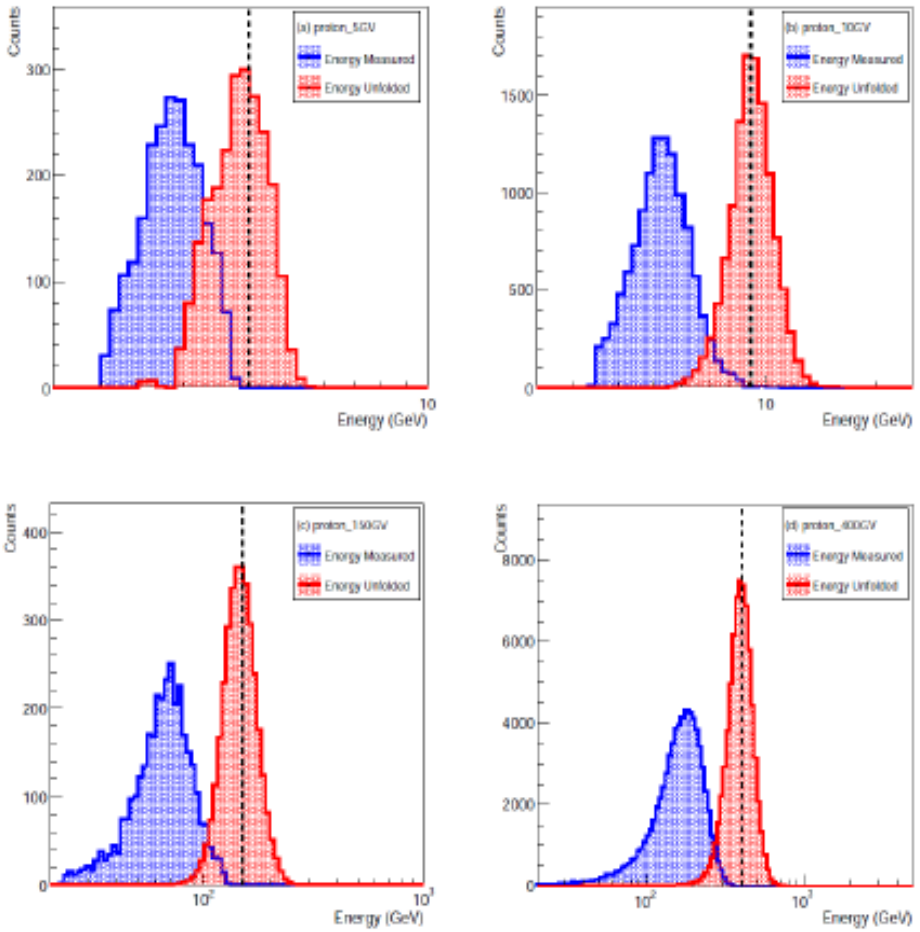


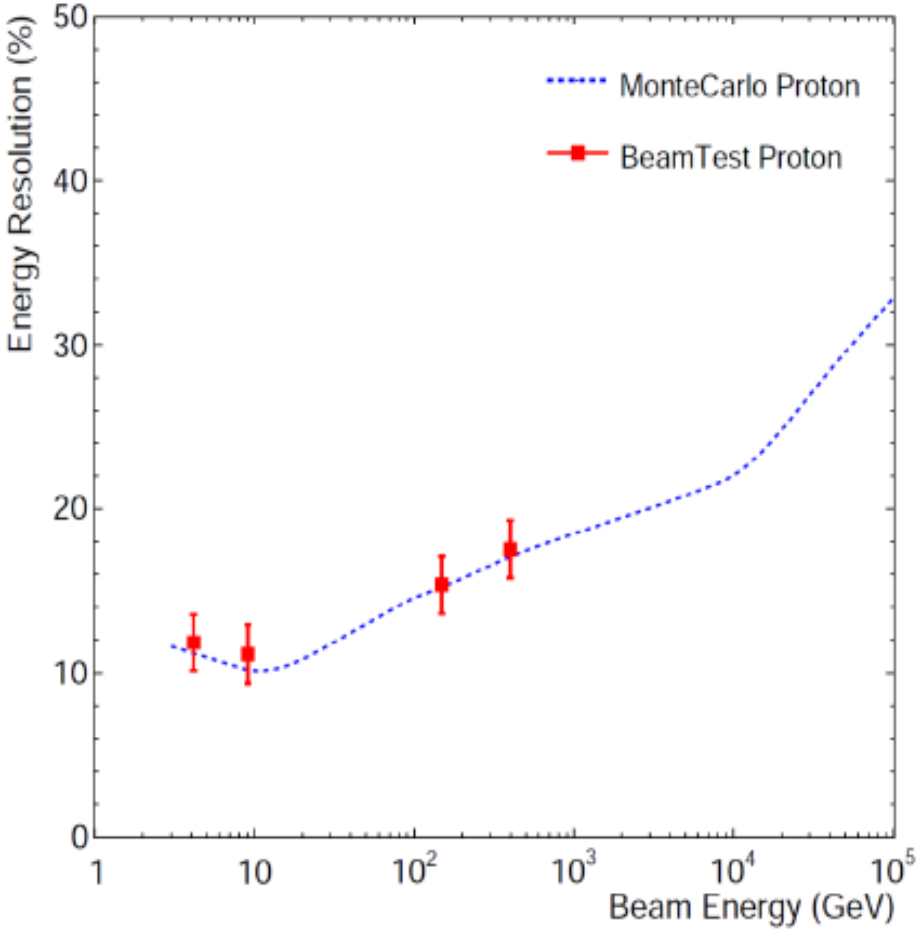




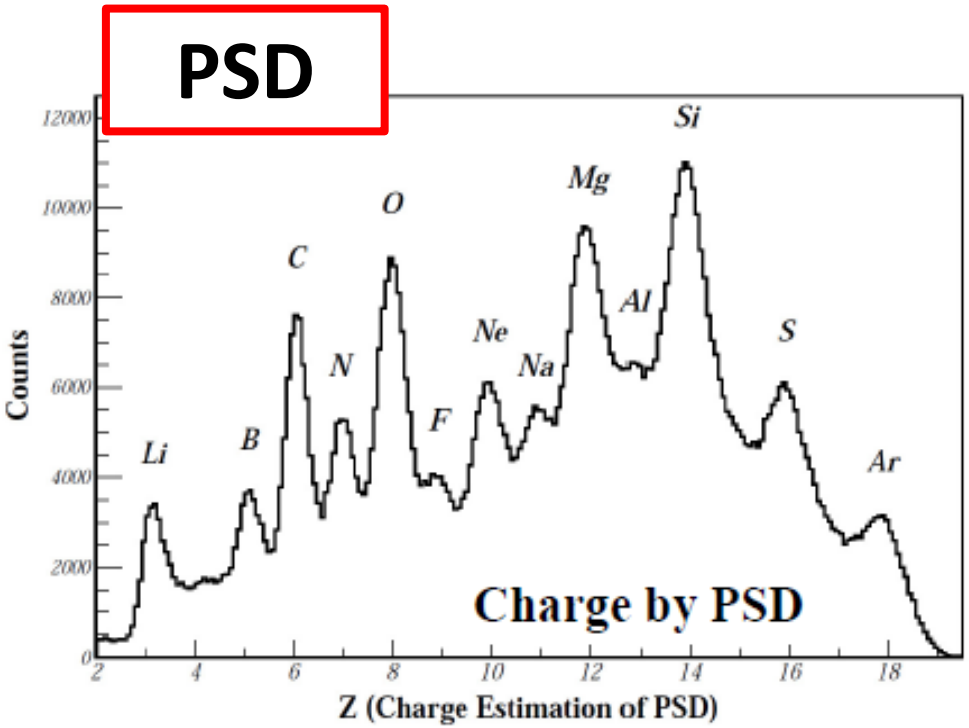


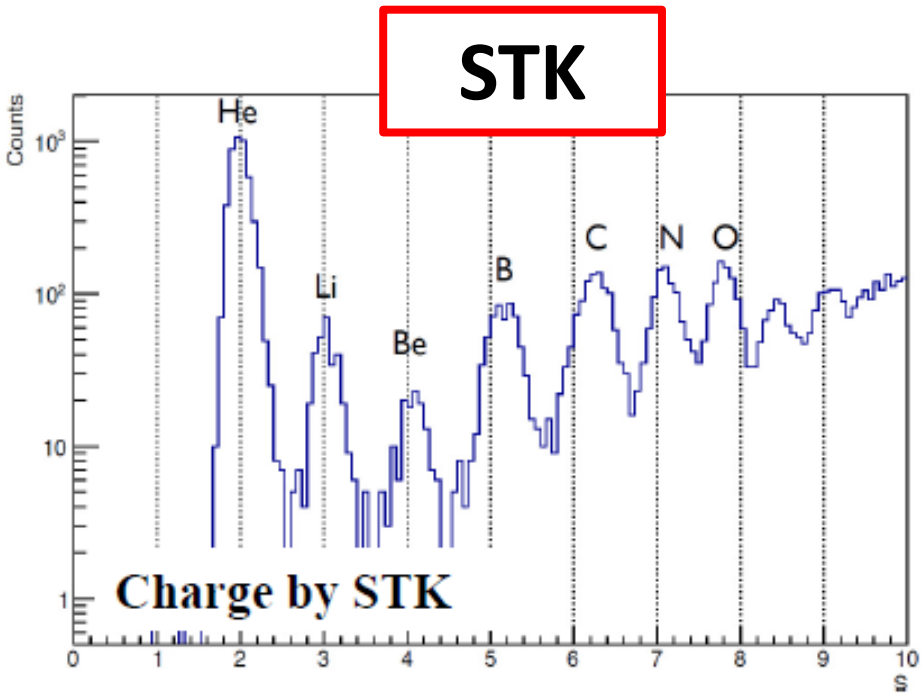
Test beam activity at CERN: protons





Test beam activity at CERN: ions

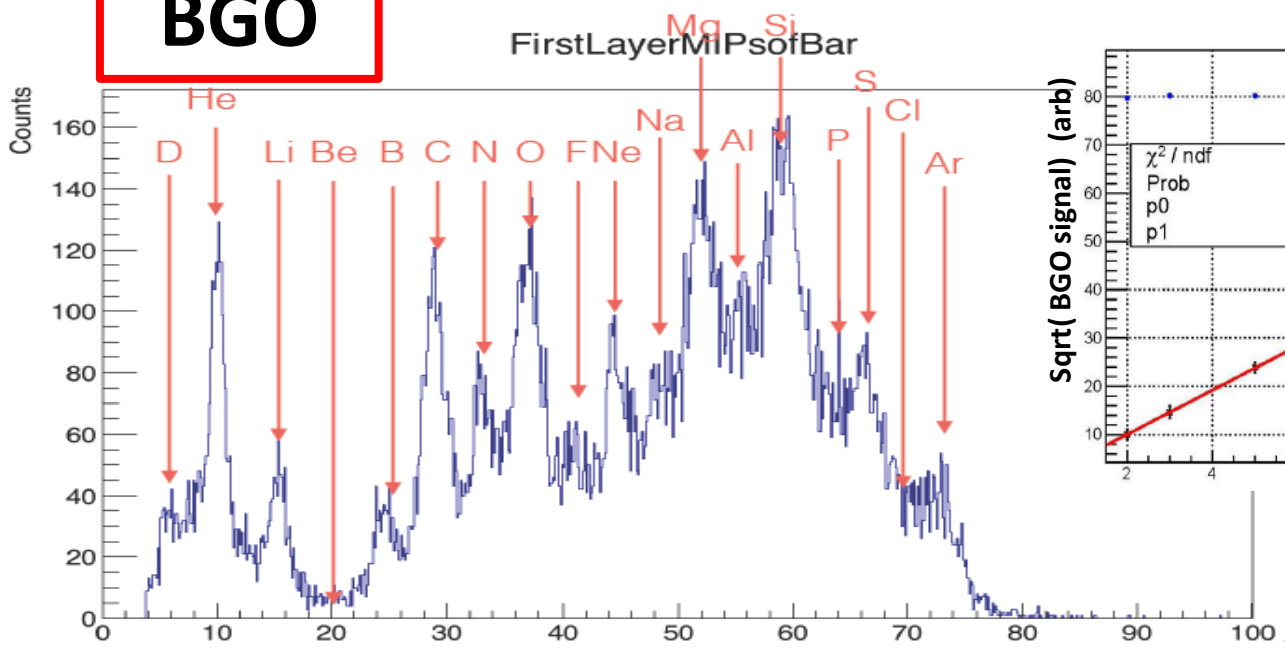


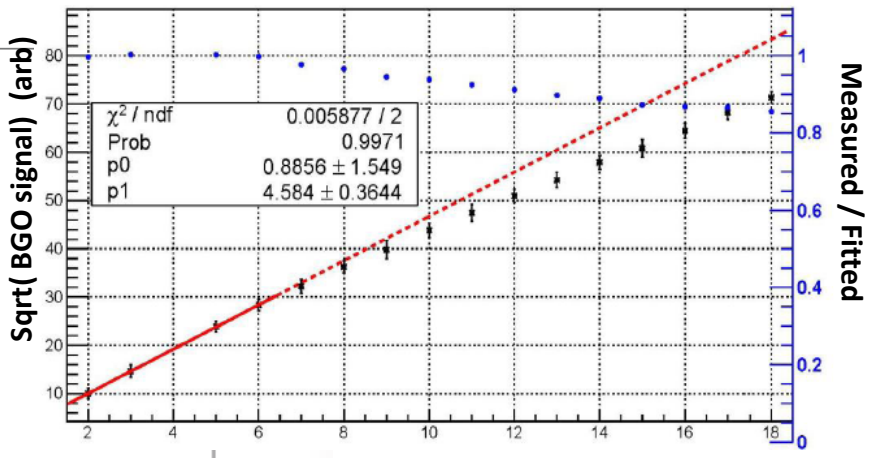


The identification of nuclei is made by using the PSD signal.
Complementary information can be given by the BGO calorimeter and the STK

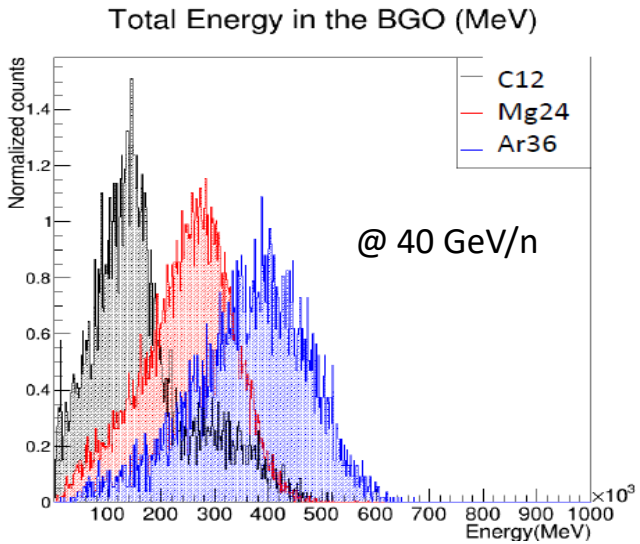
Test beam activity at CERN: ions

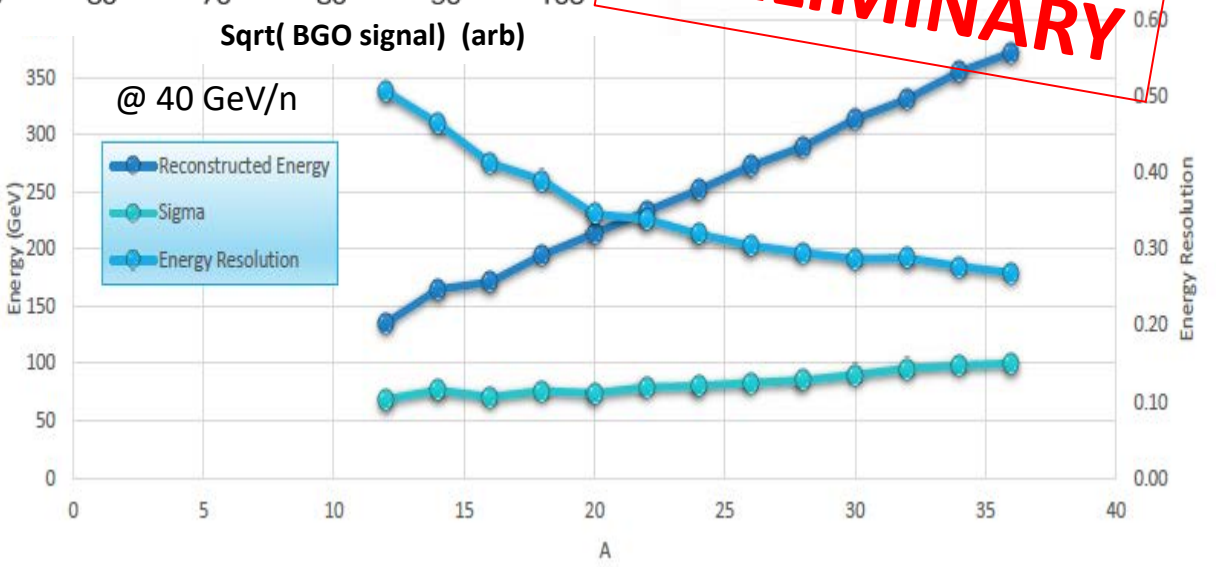
BGO





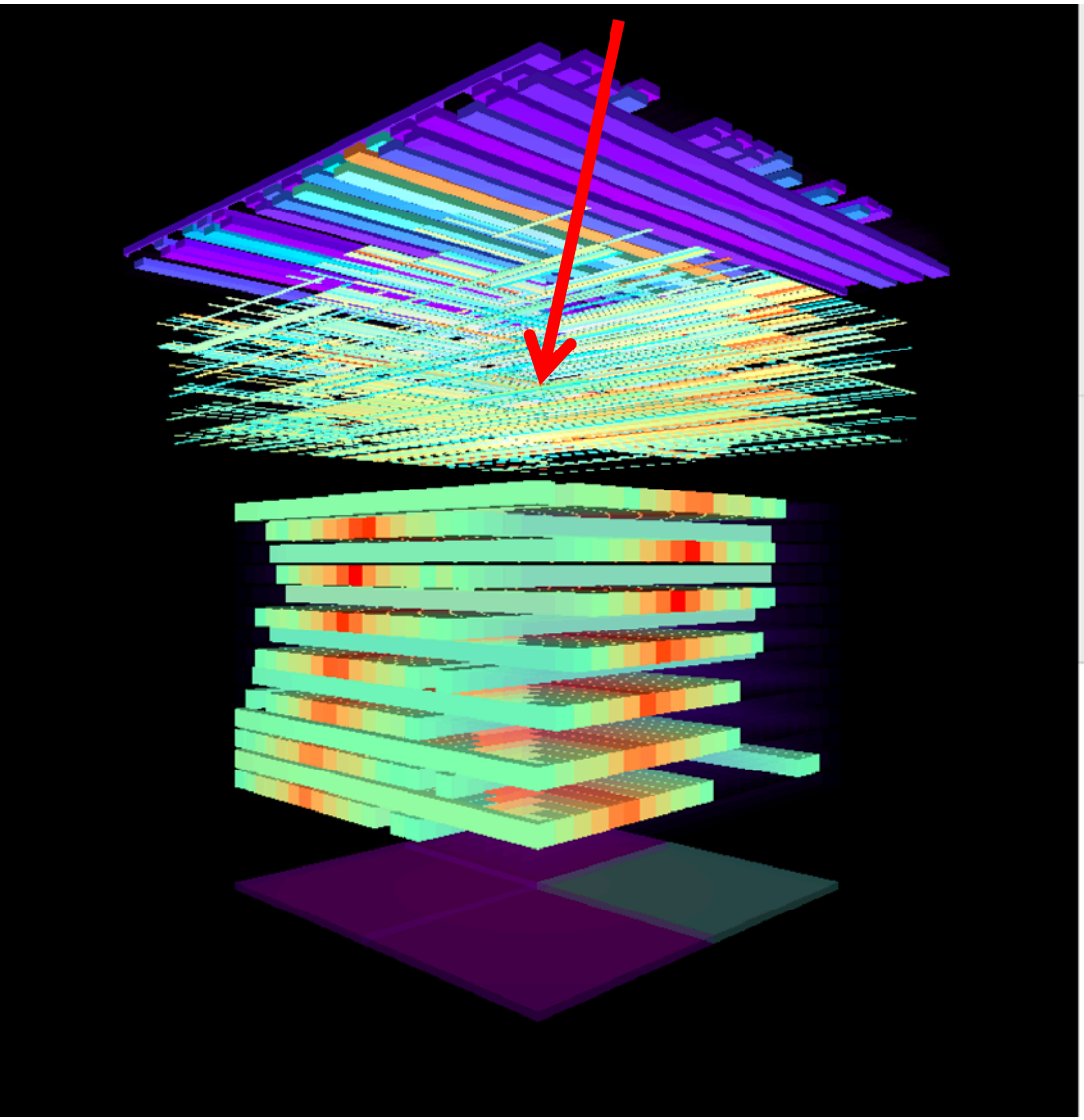
PRELIMINARY

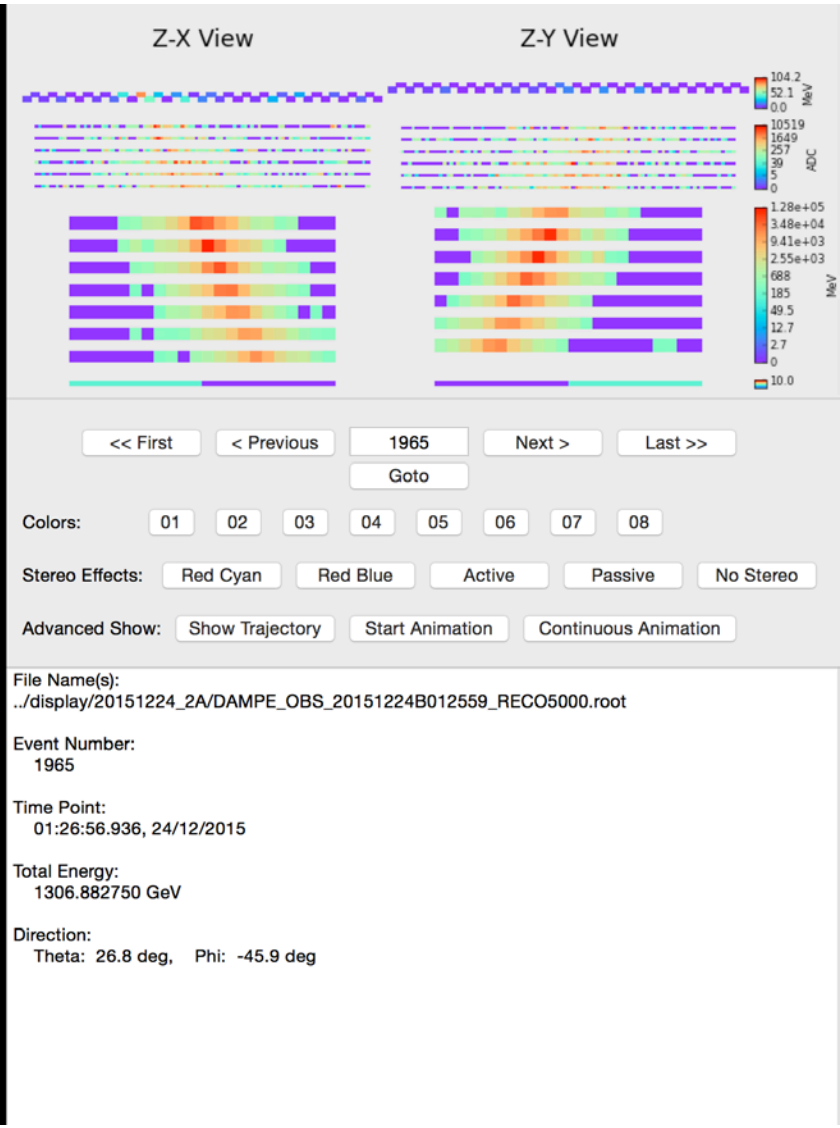




Dec 24th 2015: HV on

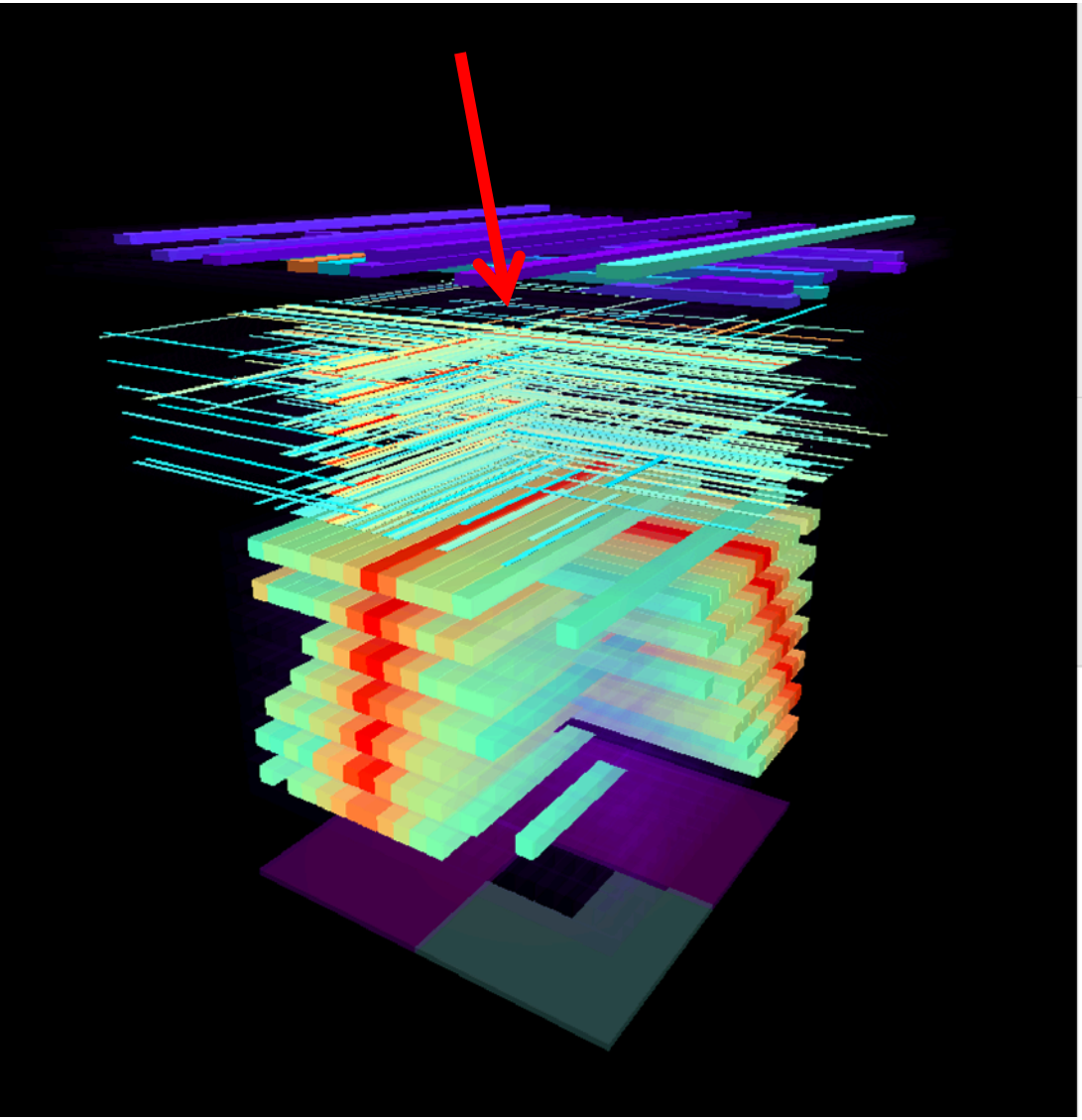
1.3 TeV carbon candidate

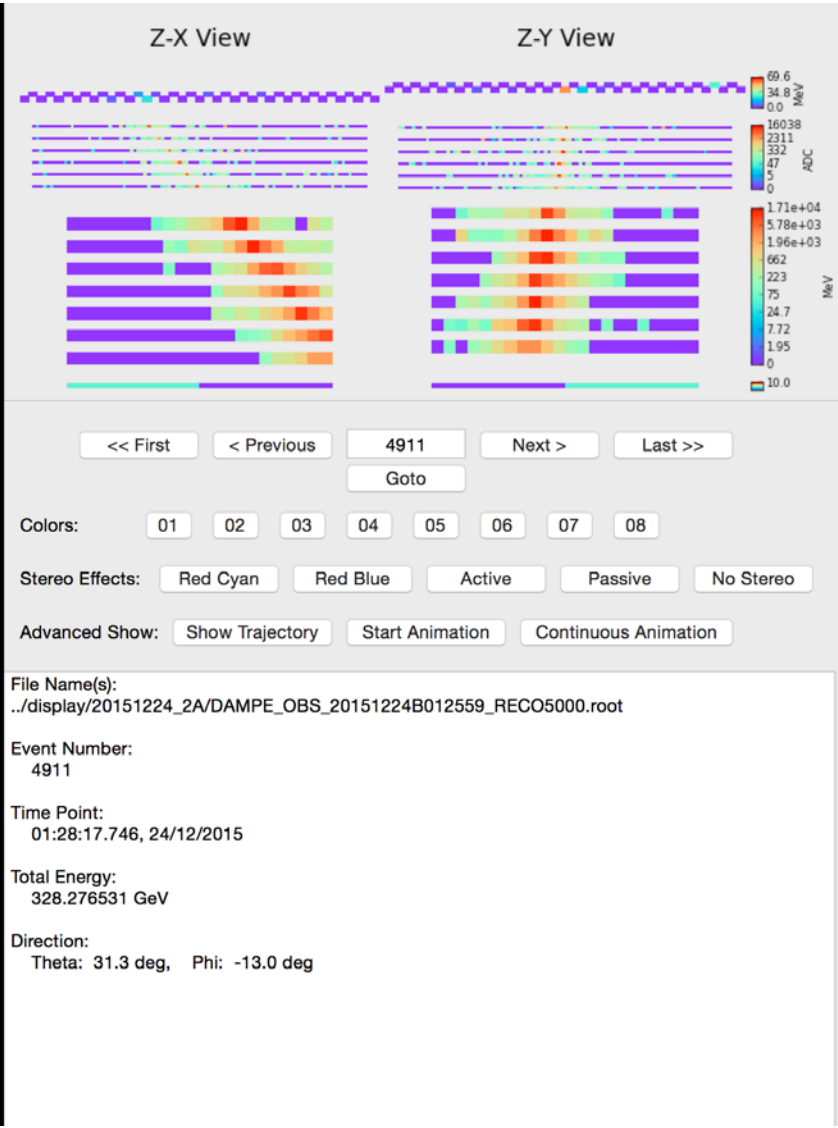




Dec 24th 2015: HV on

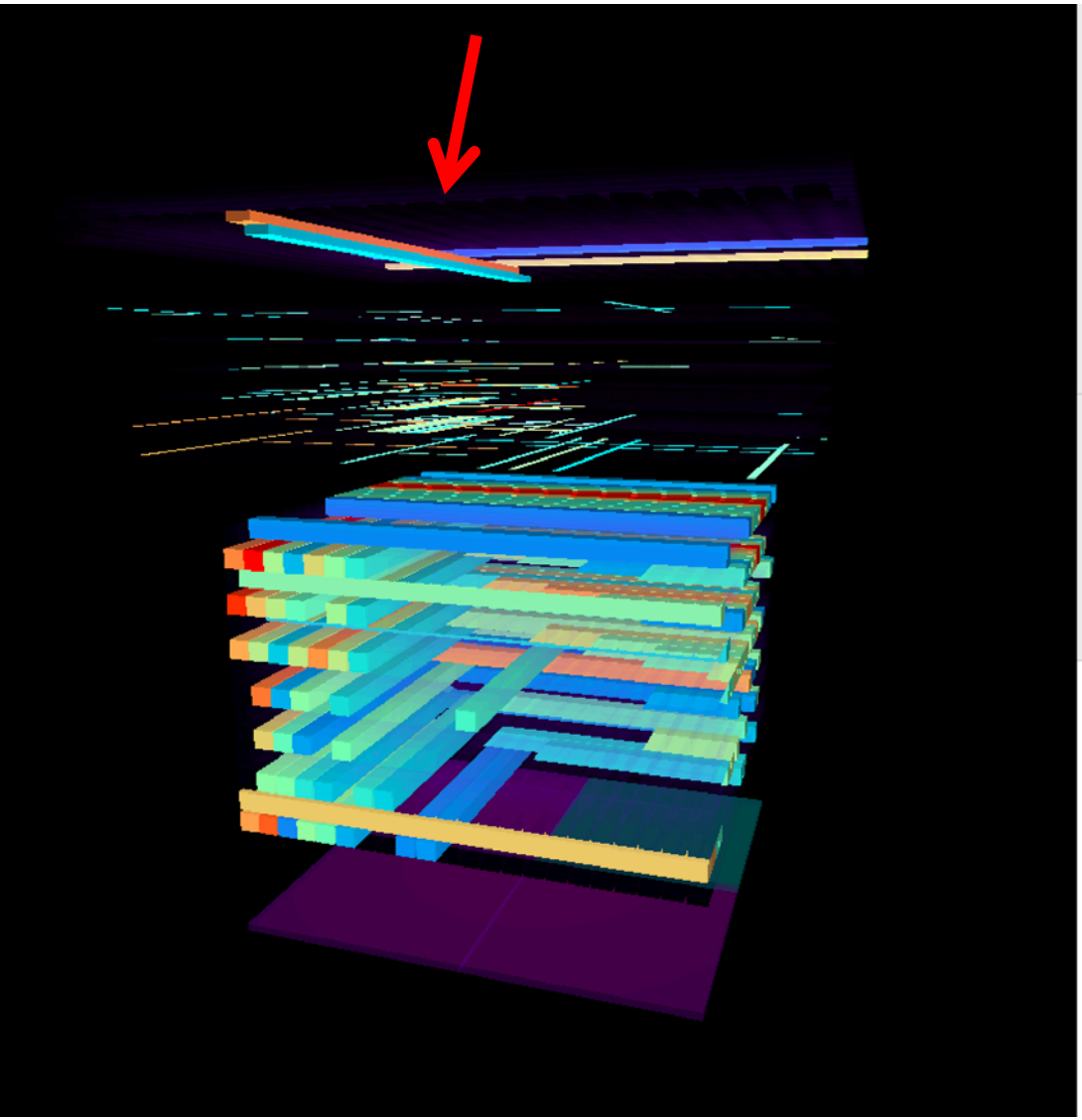
330 GeV electron candidate

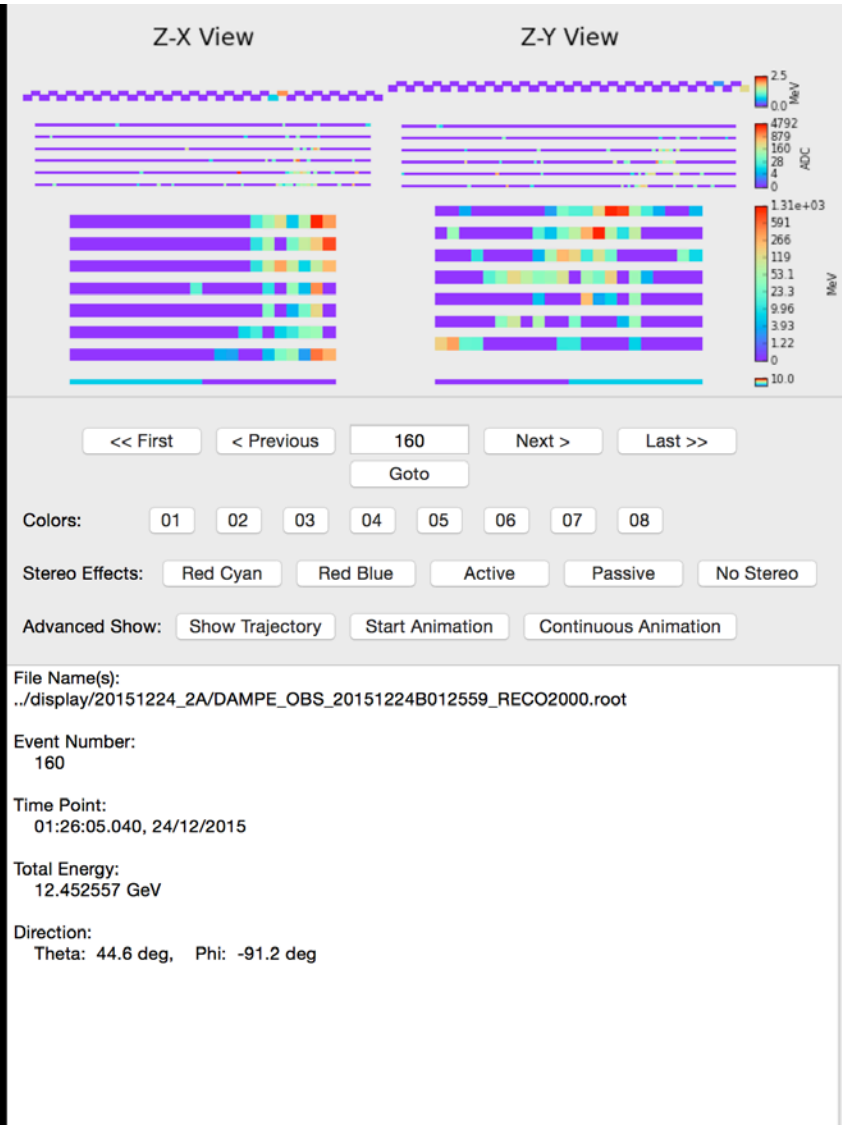




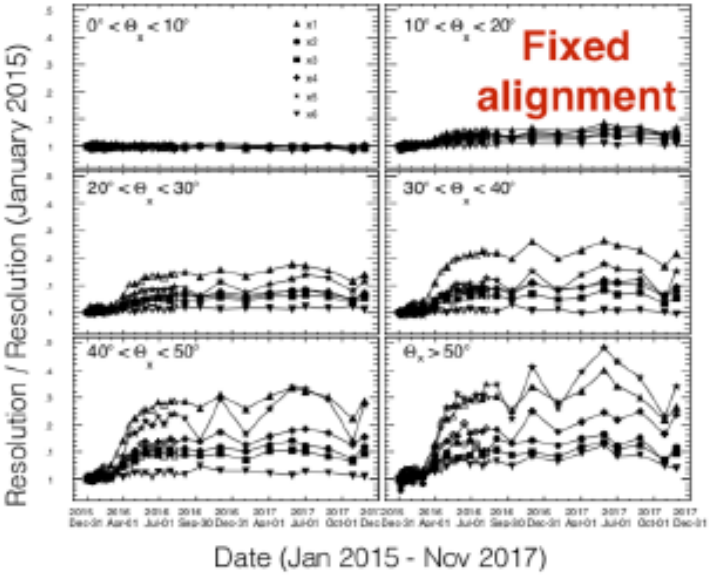
Dec 24th 2015: HV on

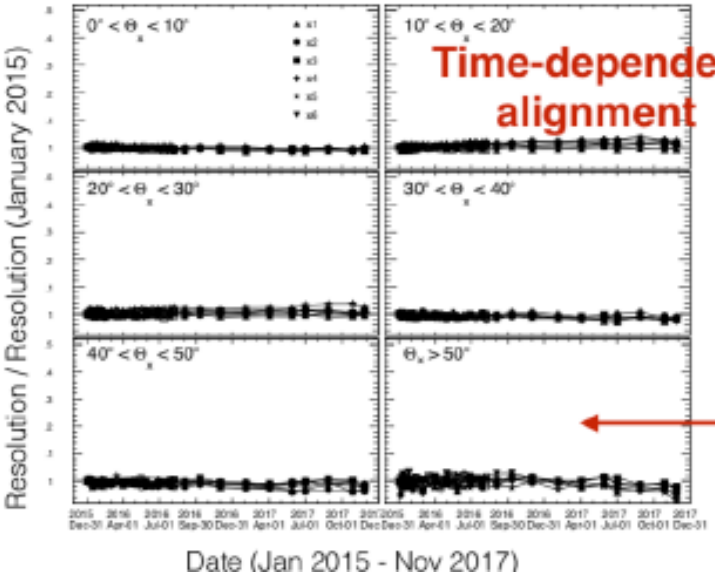
12 GeV proton candidate



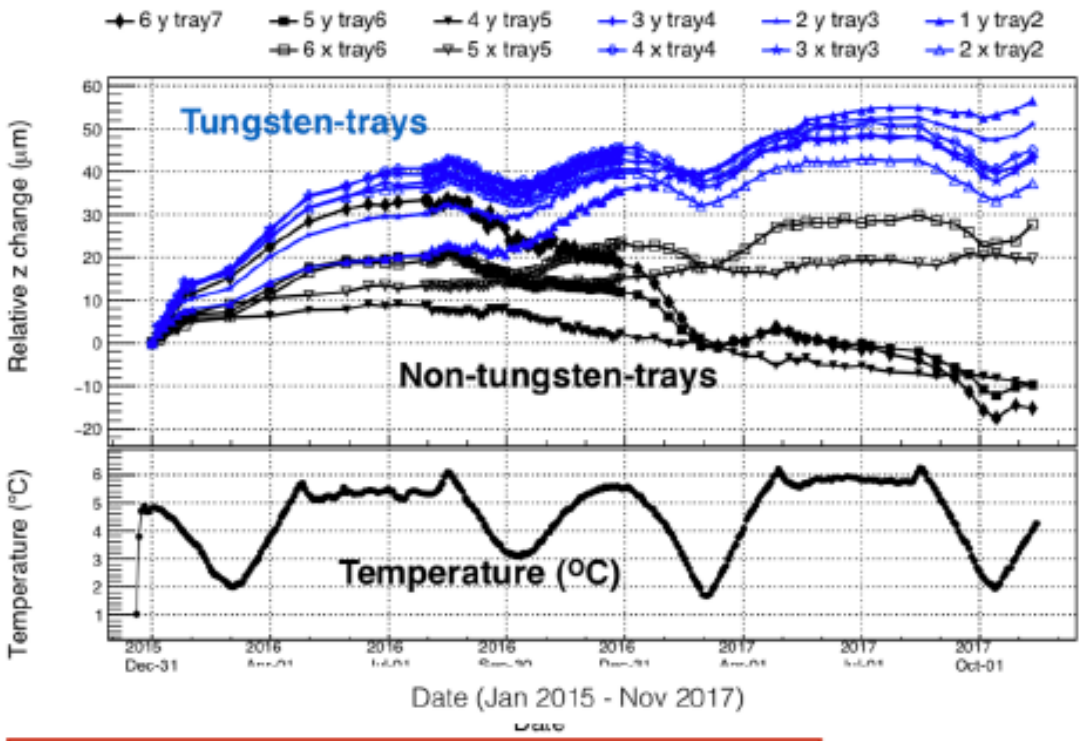


STK on orbit alignment



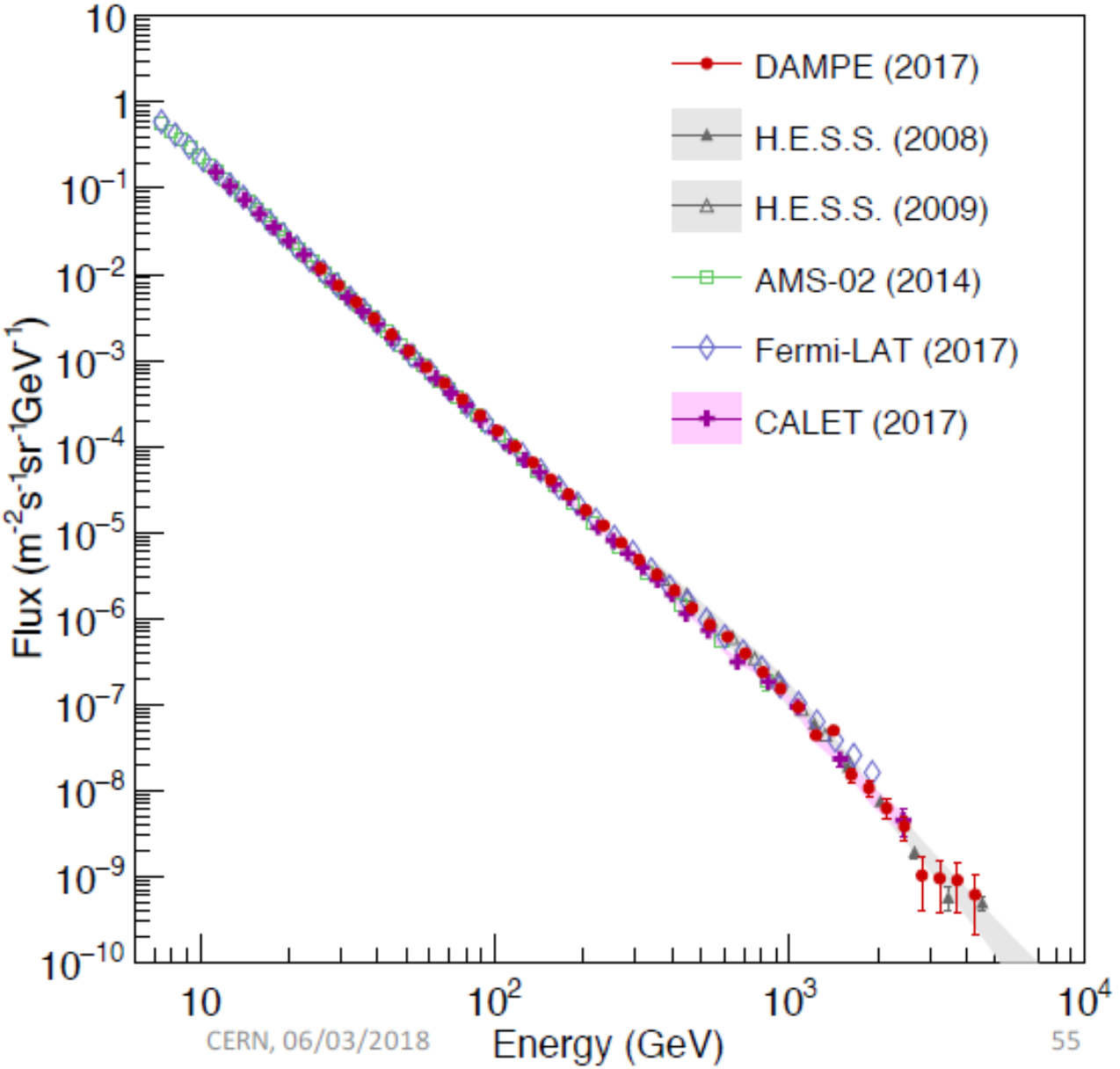


Re-alignment is performed on-orbit twice per month



< 4% (< 2 μm) variation of the position resolution

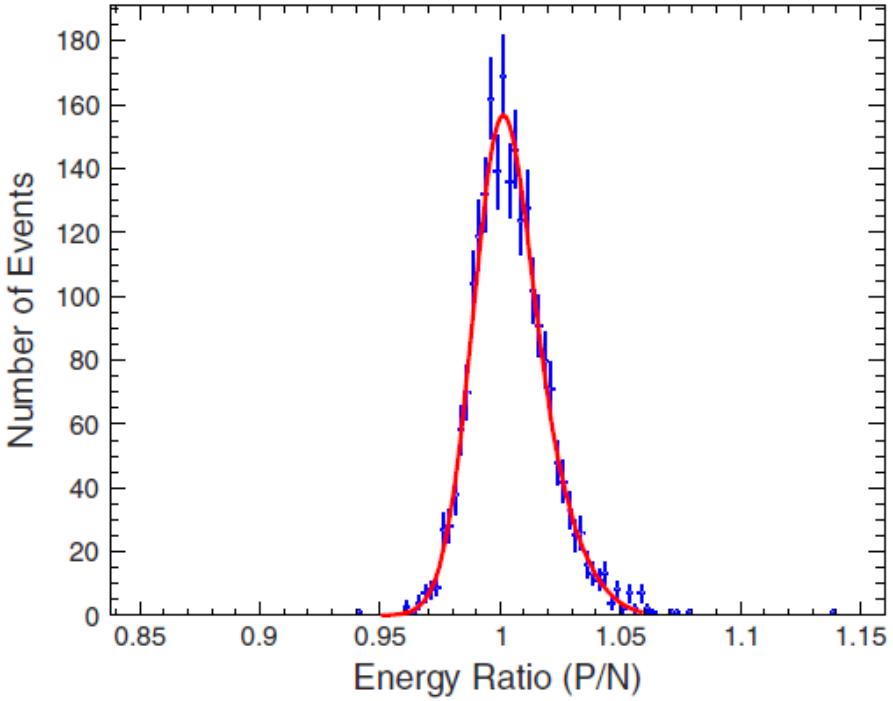
The all-electron flux



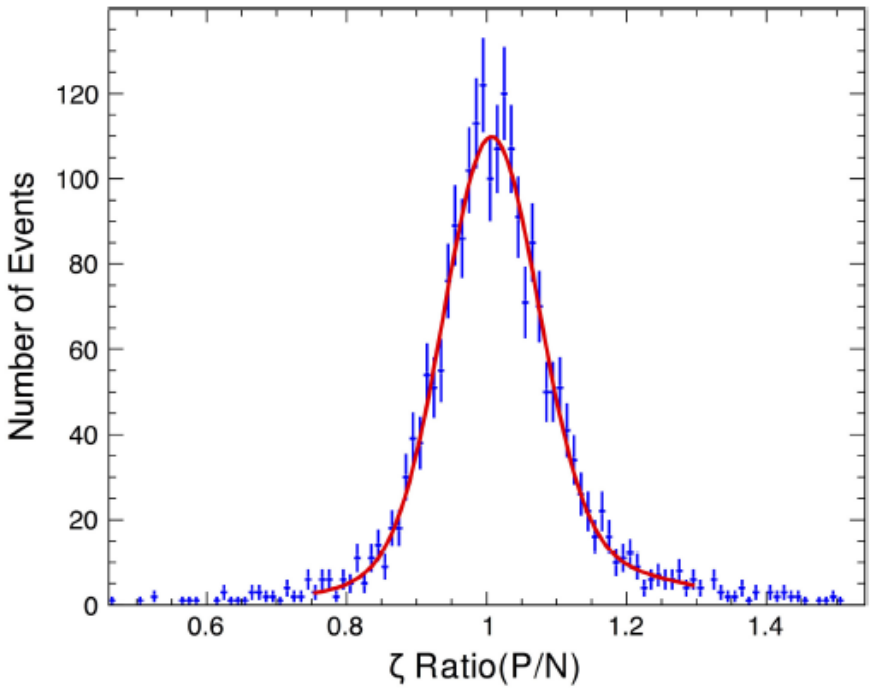
CERN, 06/03/2018

55

Electro analysis: cross checks

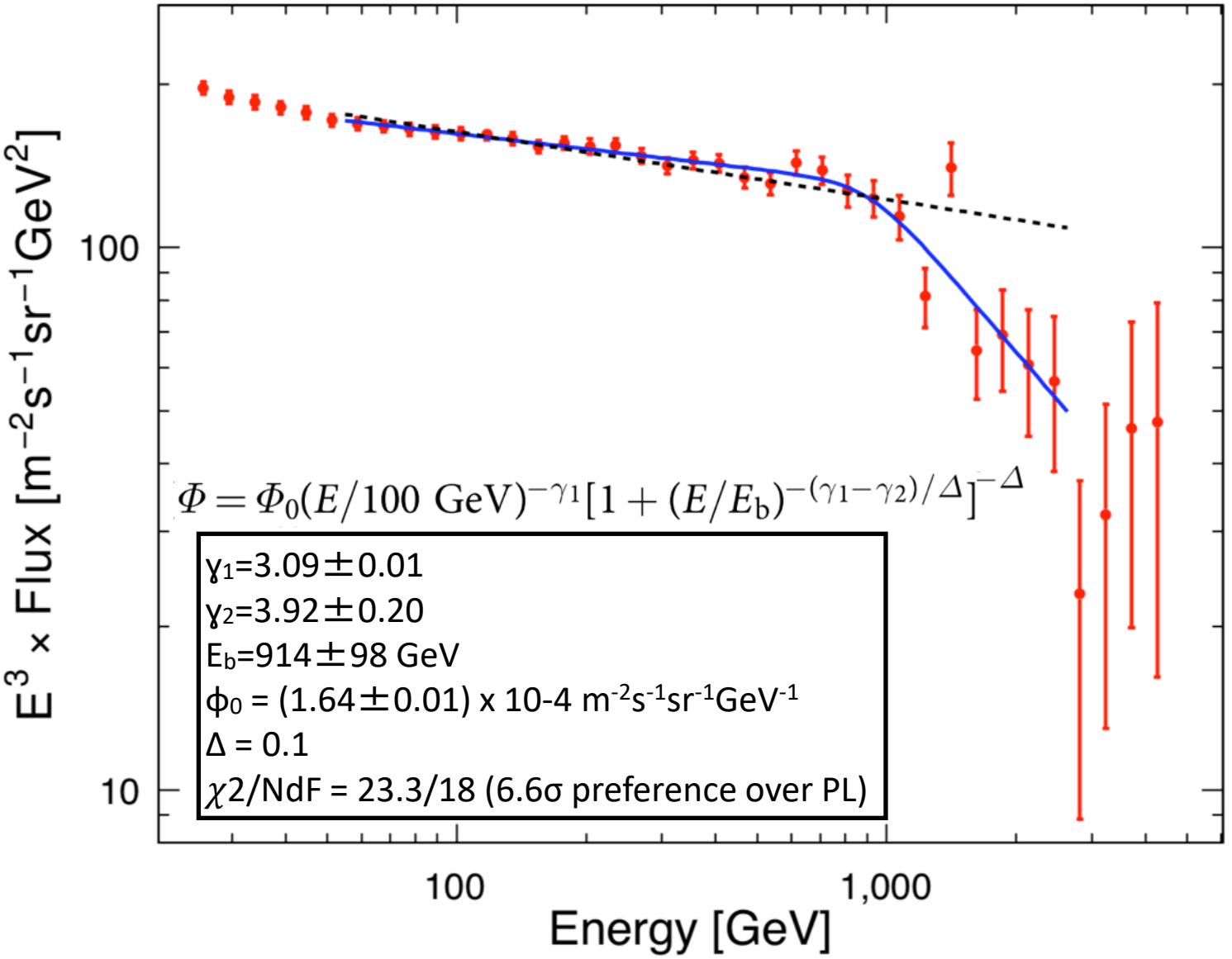


Extended Data Figure 3 | Ratios of the energies reconstructed with the *P*- and *N*-side readout data. All events have deposited energies between 500 GeV and 1 TeV in the BGO calorimeter. The error bars ($\pm 1\sigma$) represent statistical uncertainties. The red line represents a Gaussian fit to the data, with a mean of 1.005 ± 0.005 and a σ of 0.016 ± 0.001.



Extended Data Figure 2 | Ratios of the ζ values calculated from the *P*- and *N*-side readout data. The events have deposited energies between 500 GeV and 1 TeV in the BGO calorimeter. The error bars ($\pm 1\sigma$) represent statistical uncertainties. The red line represents a Gaussian fit to the data points. The mean of the ratios is 1.015 ± 0.002 and σ is 0.110 ± 0.005.

The all-electron flux



The all-electron flux

Table 1 | The CRE flux (in units of $m^{-2}\,s^{-1}\,sr^{-1}\,GeV^{-1}$) with 1σ 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±0.00±0.03)×10^{-2}
27.5–31.6	29.5±0.4	0.259±0.007	279,458	(2.5±0.3)%	(7.38±0.02±0.19)×10^{-3}
31.6–36.3	33.9±0.4	0.261±0.007	208,809	(2.4±0.2)%	(4.76±0.02±0.13)×10^{-3}
36.3–41.7	38.9±0.5	0.264±0.007	156,489	(2.4±0.2)%	(3.08±0.01±0.08)×10^{-3}
41.7–47.9	44.6±0.6	0.266±0.007	117,246	(2.3±0.2)%	(2.00±0.01±0.05)×10^{-3}
47.9–55.0	51.2±0.6	0.269±0.007	87,259	(2.3±0.2)%	(1.28±0.01±0.03)×10^{-3}
55.0–63.1	58.8±0.7	0.272±0.007	65,860	(2.2±0.2)%	(8.32±0.04±0.21)×10^{-4}
63.1–72.4	67.6±0.8	0.275±0.007	49,600	(2.1±0.2)%	(5.42±0.03±0.13)×10^{-4}
72.4–83.2	77.6±1.0	0.277±0.007	37,522	(2.1±0.2)%	(3.54±0.02±0.09)×10^{-4}
83.2–95.5	89.1±1.1	0.279±0.007	28,325	(2.1±0.1)%	(2.31±0.01±0.06)×10^{-4}
95.5–109.7	102.2±1.3	0.283±0.007	21,644	(2.0±0.1)%	(1.52±0.01±0.04)×10^{-4}
109.7–125.9	117.4±1.5	0.282±0.007	16,319	(2.0±0.1)%	(1.00±0.01±0.02)×10^{-4}
125.9–144.5	134.8±1.7	0.286±0.007	12,337	(2.0±0.1)%	(6.49±0.06±0.16)×10^{-5}
144.5–166.0	154.8±1.9	0.287±0.007	9,079	(2.0±0.1)%	(4.14±0.04±0.10)×10^{-5}
166.0–190.6	177.7±2.2	0.288±0.007	7,007	(1.9±0.1)%	(2.78±0.03±0.07)×10^{-5}
190.6–218.8	204.0±2.6	0.288±0.007	5,256	(2.0±0.1)%	(1.81±0.03±0.05)×10^{-5}
218.8–251.2	234.2±2.9	0.290±0.007	4,002	(1.9±0.1)%	(1.20±0.02±0.03)×10^{-5}
251.2–288.4	268.9±3.4	0.291±0.007	2,926	(2.0±0.2)%	(7.59±0.14±0.19)×10^{-6}
288.4–331.1	308.8±3.9	0.291±0.007	2,136	(2.1±0.2)%	(4.81±0.11±0.12)×10^{-6}
331.1–380.2	354.5±4.4	0.290±0.007	1,648	(2.1±0.2)%	(3.25±0.08±0.08)×10^{-6}
380.2–436.5	407.1±5.1	0.292±0.007	1,240	(2.0±0.2)%	(2.12±0.06±0.05)×10^{-6}
436.5–501.2	467.4±5.8	0.291±0.007	889	(2.2±0.2)%	(1.32±0.05±0.03)×10^{-6}
501.2–575.4	536.6±6.7	0.289±0.007	650	(2.2±0.2)%	(8.49±0.34±0.21)×10^{-7}
575.4–660.7	616.1±7.7	0.288±0.007	536	(2.0±0.2)%	(6.13±0.27±0.15)×10^{-7}
660.7–758.6	707.4±8.8	0.285±0.007	390	(2.0±0.2)%	(3.92±0.20±0.10)×10^{-7}
758.6–871.0	812.2±10.2	0.284±0.007	271	(2.3±0.3)%	(2.38±0.15±0.06)×10^{-7}
871.0–1,000.0	932.5±11.7	0.278±0.008	195	(2.3±0.3)%	(1.52±0.11±0.04)×10^{-7}
1,000.0–1,148.2	1,070.7±13.4	0.276±0.008	136	(2.6±0.4)%	(9.29±0.82±0.27)×10^{-8}
1,148.2–1,318.3	1,229.3±15.4	0.274±0.009	74	(3.6±0.5)%	(4.38±0.53±0.14)×10^{-8}
1,318.3–1,513.6	1,411.4±17.6	0.267±0.009	93	(2.2±0.4)%	(4.99±0.53±0.17)×10^{-8}
1,513.6–1,737.8	1,620.5±20.3	0.263±0.010	33	(5.0±0.9)%	(1.52±0.28±0.06)×10^{-8}
1,737.8–1,995.3	1,860.6±23.3	0.255±0.011	26	(5.4±0.9)%	(1.07±0.22±0.05)×10^{-8}
1,995.3–2,290.9	2,136.3±26.7	0.249±0.012	17	(5.8±0.9)%	(6.24±1.61±0.30)×10^{-9}
2,290.9–2,630.3	2,452.8±30.7	0.243±0.014	12	(7.9±1.1)%	(3.84±1.20±0.21)×10^{-9}
2,630.3–3,019.9	2,816.1±35.2	0.233±0.015	4	(18.2±2.5)%	(1.03±0.63±0.07)×10^{-9}
3,019.9–3,467.4	3,233.4±40.4	0.227±0.017	4	(15.4±2.4)%	(9.53±5.64±0.70)×10^{-10}
3,467.4–3,981.1	3,712.4±46.4	0.218±0.018	4	(11.2±2.6)%	(9.07±5.12±0.77)×10^{-10}
3,981.1–4,570.9	4,262.4±53.3	0.210±0.020	3	(11.4±4.0)%	(6.15±4.02±0.60)×10^{-10}

$\langle E\rangle$ is the representative value of the energy in the bin, calculated in the same way as in ref. 14.

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