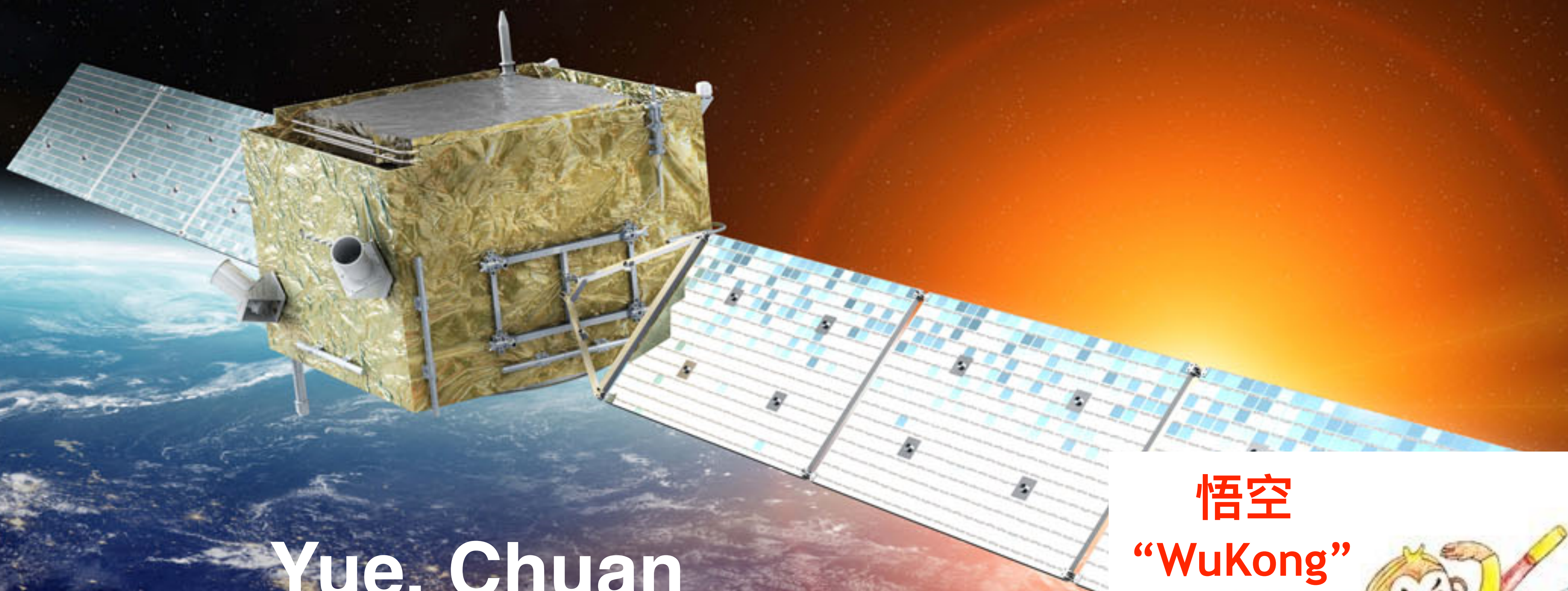
Measurement of Cosmic-ray Proton Spectrum with DAMPE Satellite



Yue, Chuan

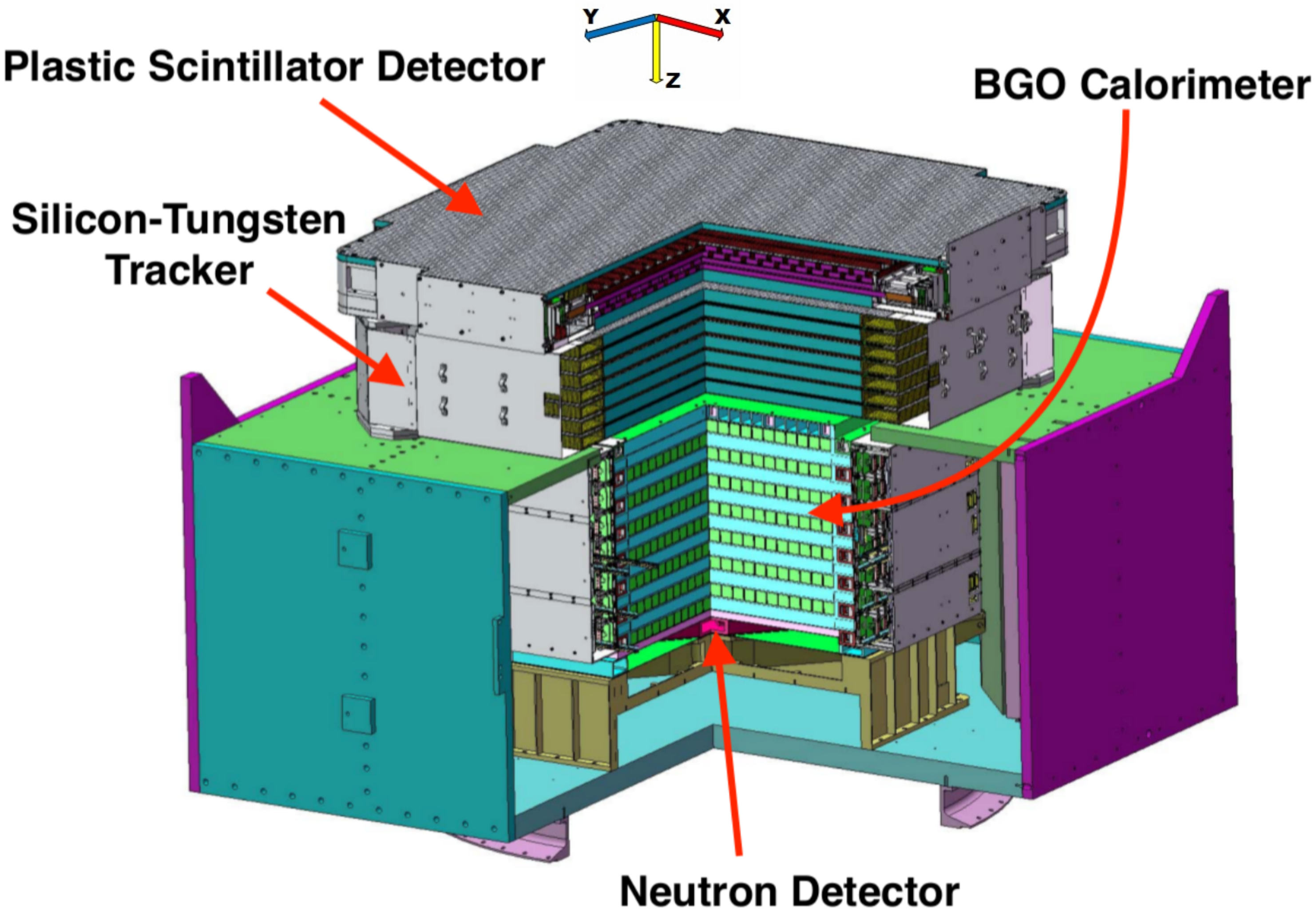
(on behalf of the DAMPE Collaboration)

The 10th International Workshop on
Air Shower Detection at High Altitudes

2020.01.09 Nanjing

悟空
“WuKong”

DAMPE Instrument



Orbit Information:

Sun-synchronous Orbit
Altitude: ~ 500 km
Inclination: ~ 97 deg
Launch Date: Dec.17th, 2015

Main Scientific Goals:

- Dark Matter Indirected Detection
- Cosmic-Ray Origin and Acceleration
- High Energy Gamma-ray Astronomy

- Charge measurement (dE/dx in PSD, STK)
- Gamma-ray converting and tracking (STK)
- Precise energy measurement (BGO ECAL)
- Hadron rejection (BGO and Neutron Detector)

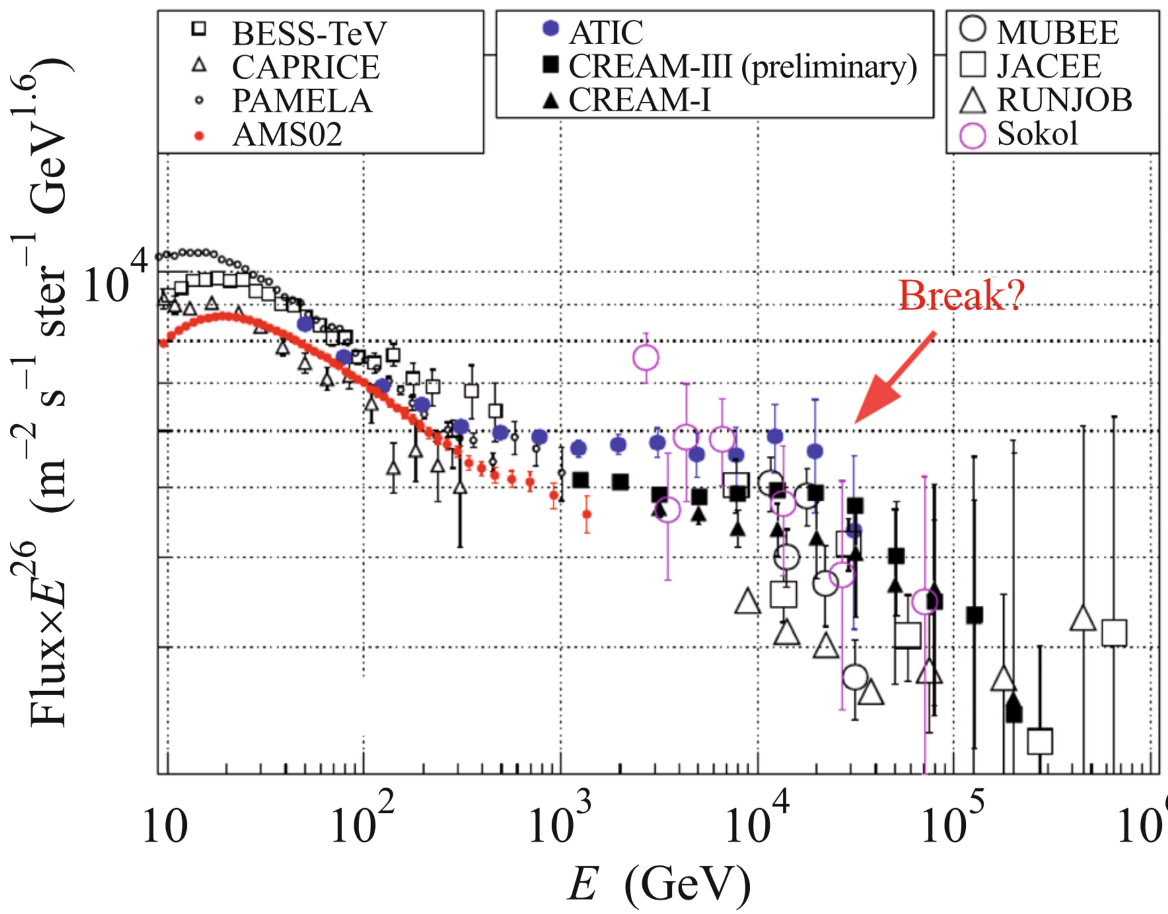
(Chang et al. Astropart.Phys. 2017, 95, 6-24)

Introduction

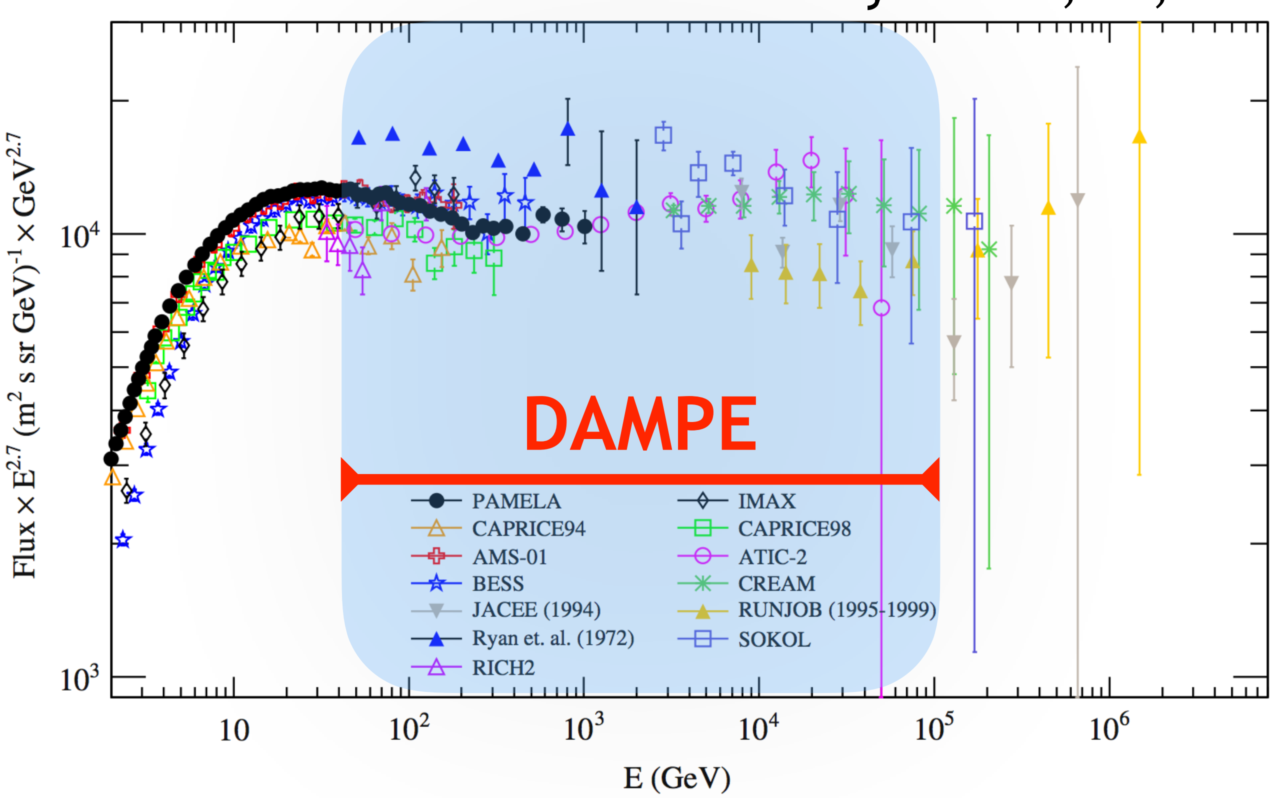
Proton spectrum has been measured with high precision up to TeV

Measurements in high energy range (TeV ~ PeV) have large uncertainties

E. Atkin et al., NUCLEON, 2018



Braz. J. Phys. 2014, 44, 441



Interesting Scientific Issues:

Proton Spectral Hardening at ~400 GeV

Other structures beyond TeV Range?

On-orbit Data Sample

Data Sample:

30 months

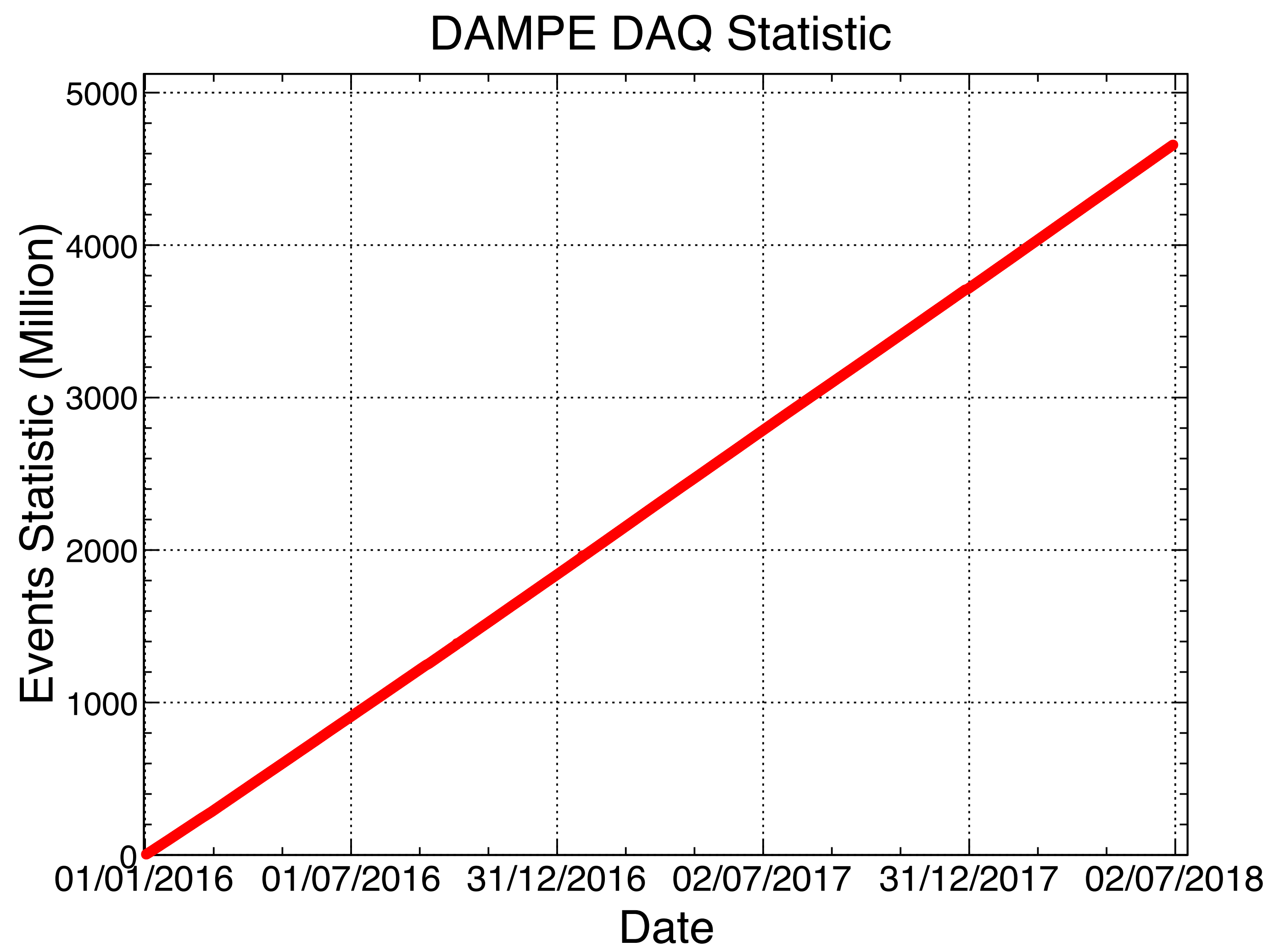
2016/01/01-2018/06/30

Total Events:

4.68 Billion Events

Live Time:

75.73%



Dead Time: Instrument Recovery, On-orbit Calibration, etc

Data in SAA region are excluded

Data during Sep2017 Solar Flare (20170908~20170913) are excluded

Proton Selections

Pre-selections

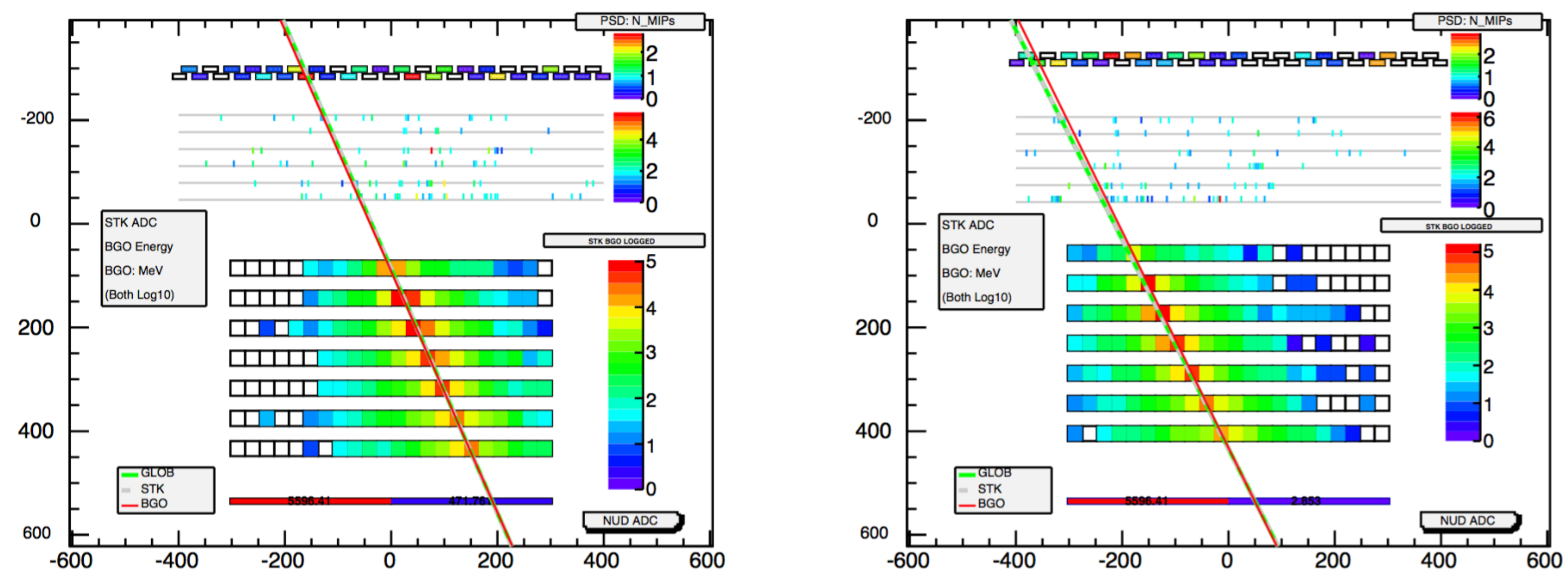
- **Cut 0:** BgoEnergy > 20 GeV
- **Cut 1:** HE-Trigger
- **Cut 2:** STK Track
- **Cut 3:** Track-PSD Match
- **Cut 4:** Track-BGO Match
- **Cut 5:** PSD pre-selection
- **Cut 6:** BGO pre-selection

Particle Identification

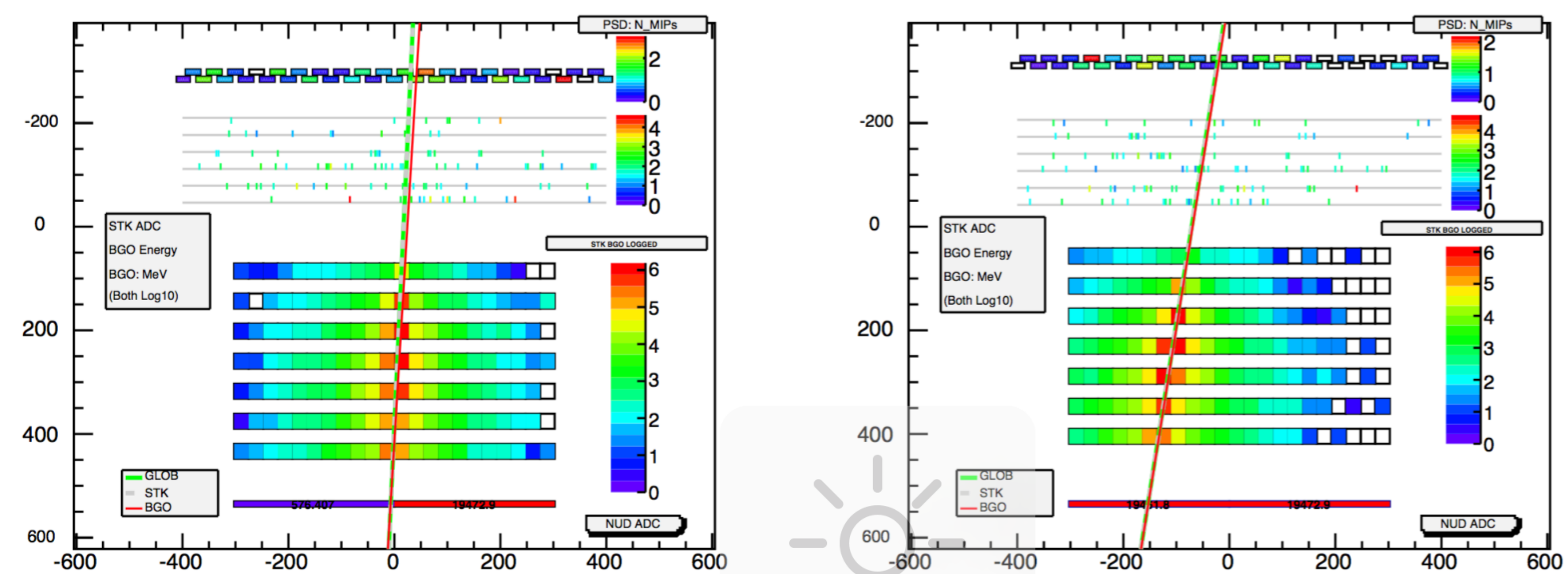
Cut 7: e/p Separation

Cut 8: Charge Selection

Flight-Data Proton (BGO-Energy: 1.2 TeV)



Flight-Data Proton (BGO-Energy: 12.1 TeV)



HE-Trigger Efficiency

- ☐ Unbias Trigger (G0)
- ☐ MIPs Trigger (G1&G2)
- ☑ High Energy Trigger (G3)
- ☐ Low Energy Trigger (G4)

G3 Trigger Efficiency:

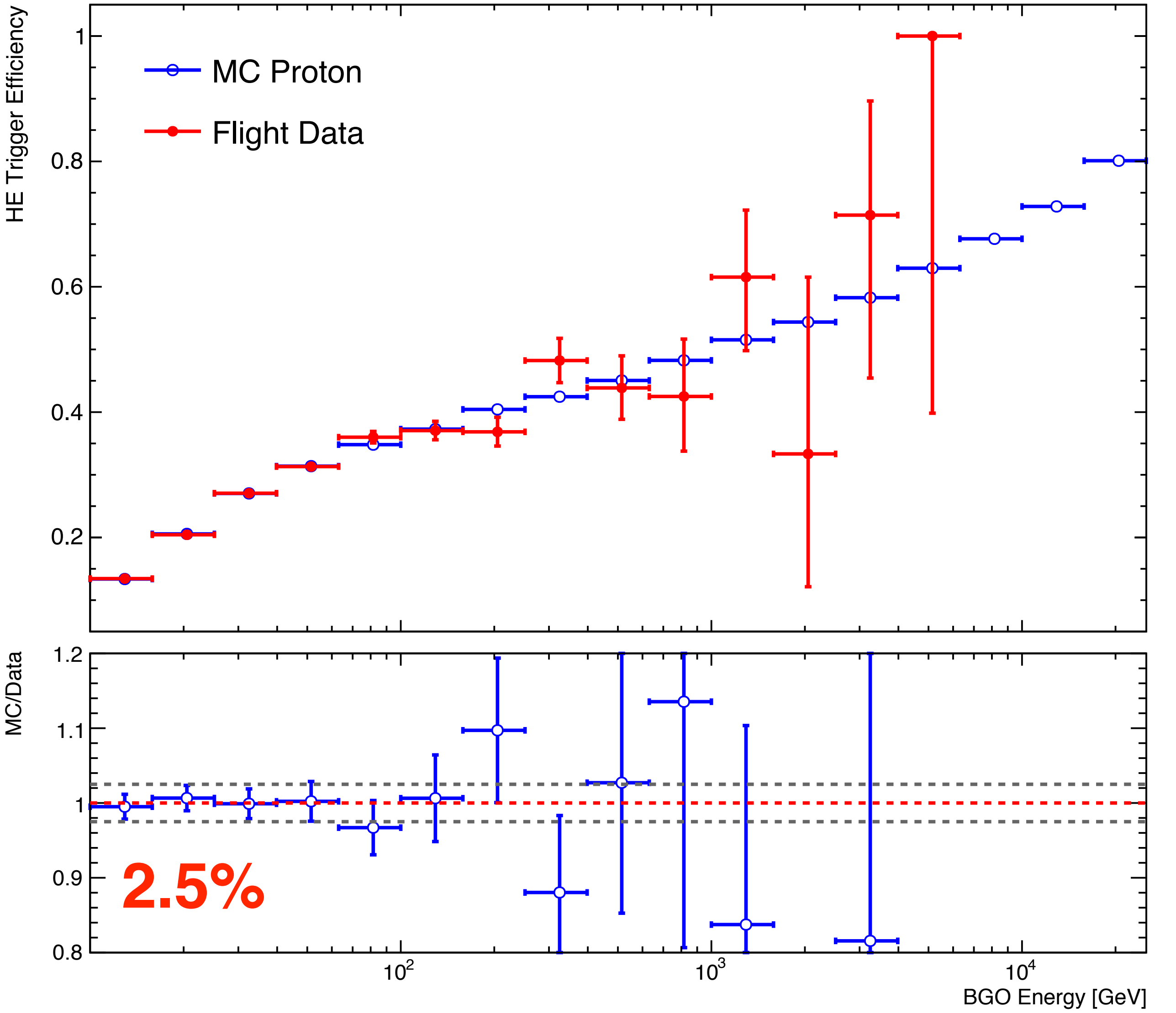
$$\varepsilon_{\text{trigger}} = \frac{N_{\text{he}|\text{unb}}}{N_{\text{unb}}}$$

Uncertainty mainly comes from the threshold calibration and the limited statistics of unbias trigger events

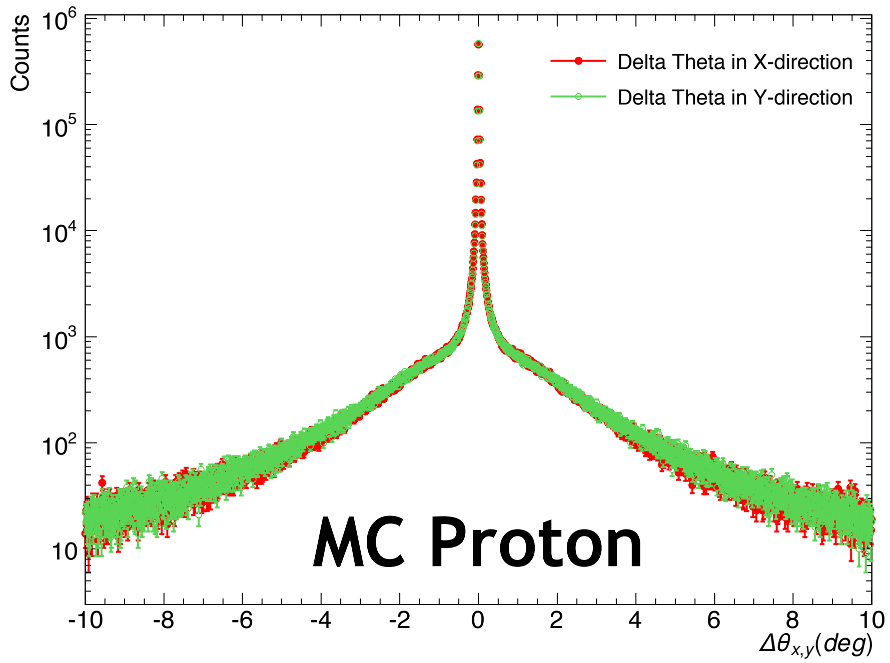
(unbias trigger pre-scaled by 1/512 at low latitudes <20deg and 1/2048 at high latitudes)

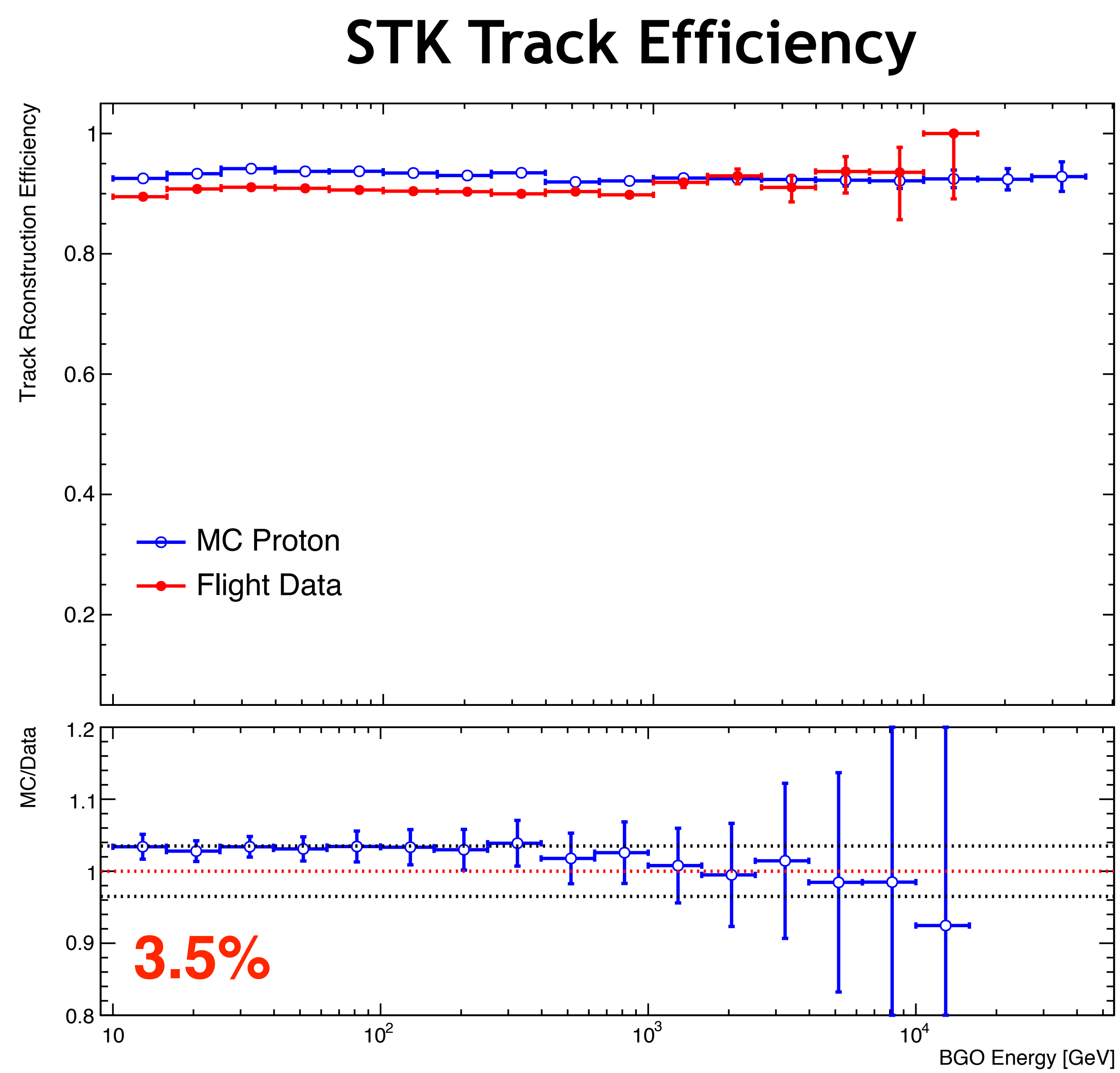
Efficiency Validation ("N-1"):

High-Energy (G3) trigger efficiency can be obtained by applying all other proton selections ("N-1") to unbias (G0) sample



STK Track Efficiency





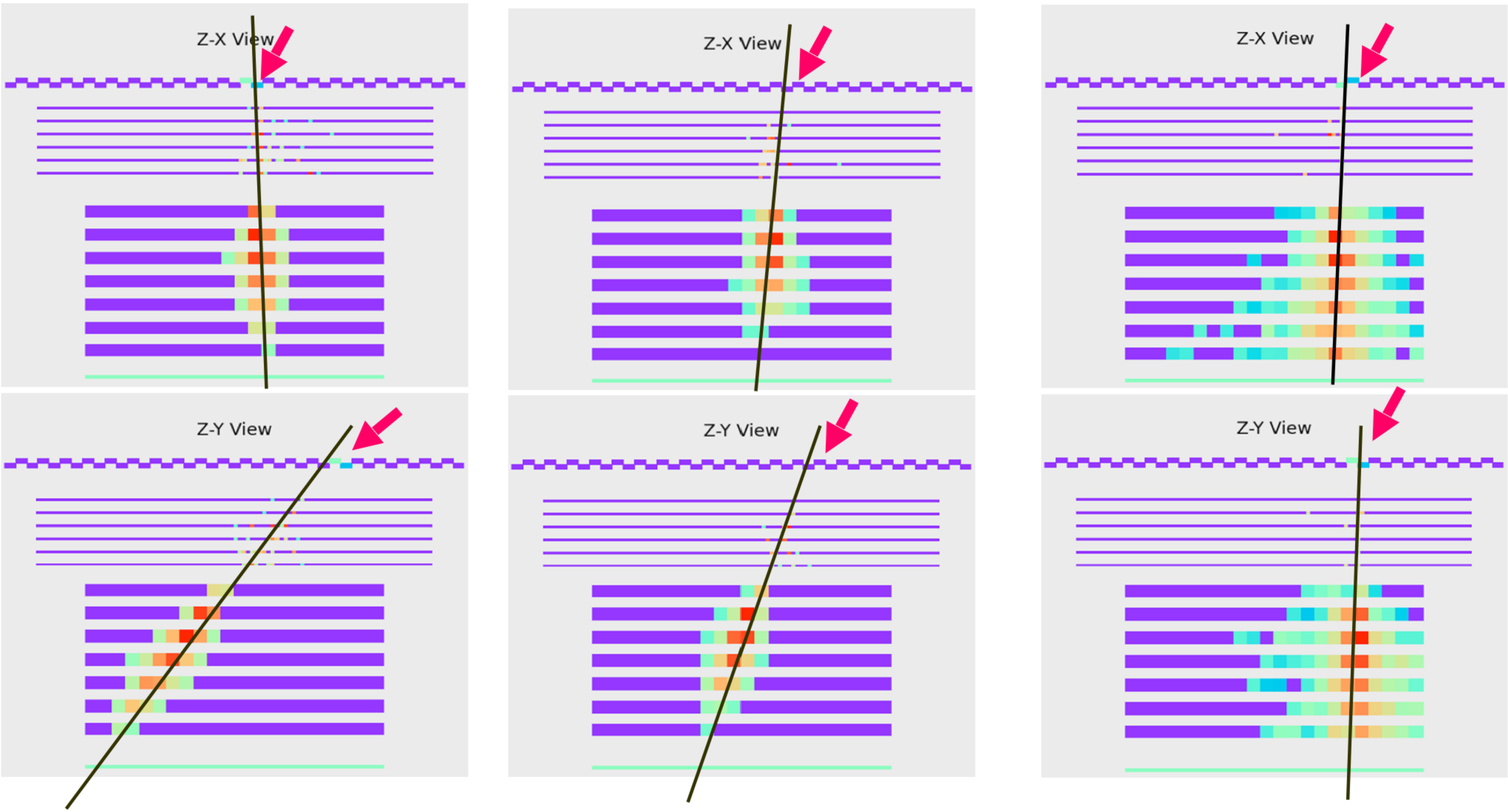
STK track Efficiency Validation

Selecting a "pure" proton sample by applying BGO shower-axis based proton selections ("N-1") to estimate STK track reconstruction efficiency

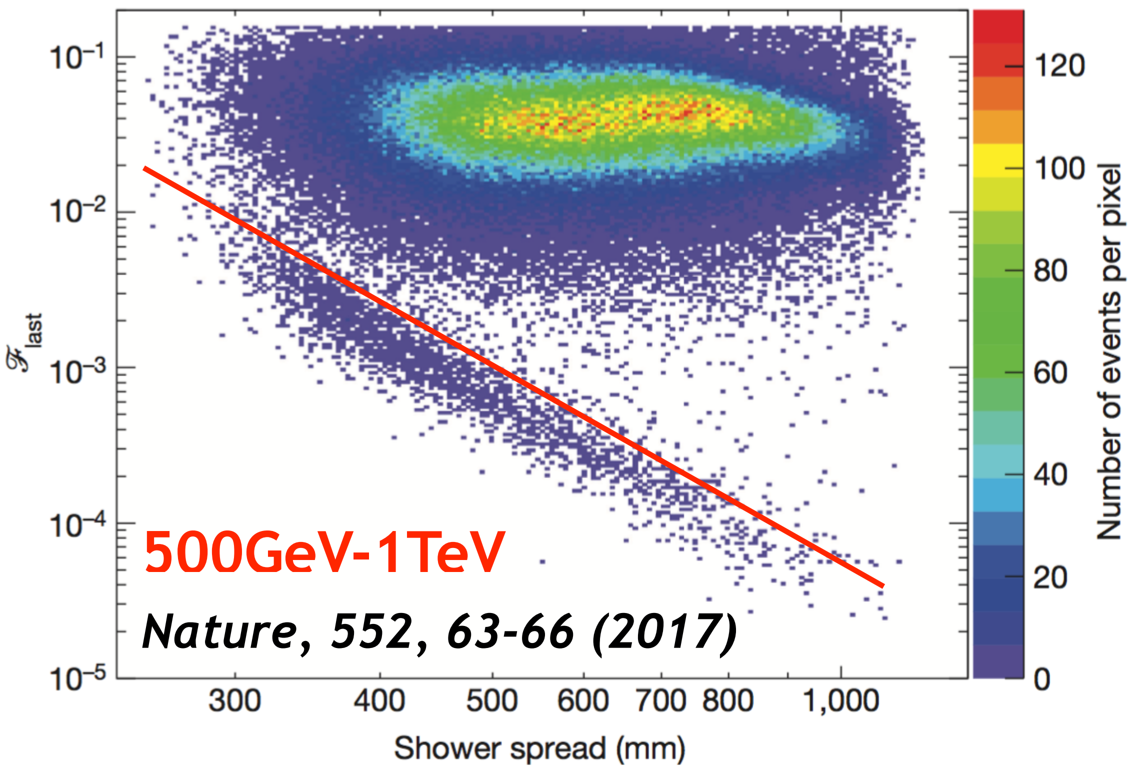
$$\varepsilon_{track} = \frac{N_{track|BGOtrack}}{N_{BGOtrack}}$$

Particle Identification

e±　　　γ-ray　　　proton



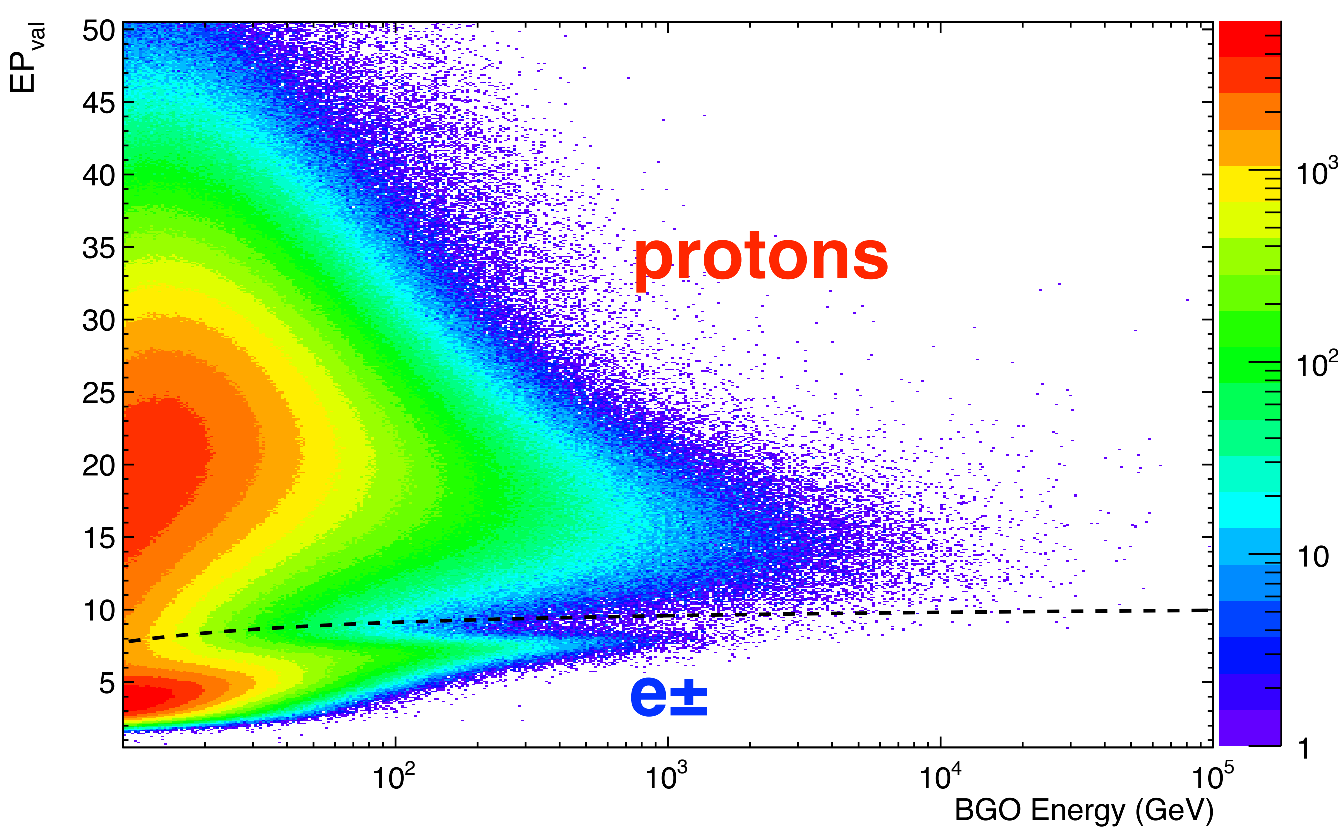
“e/p” seperation

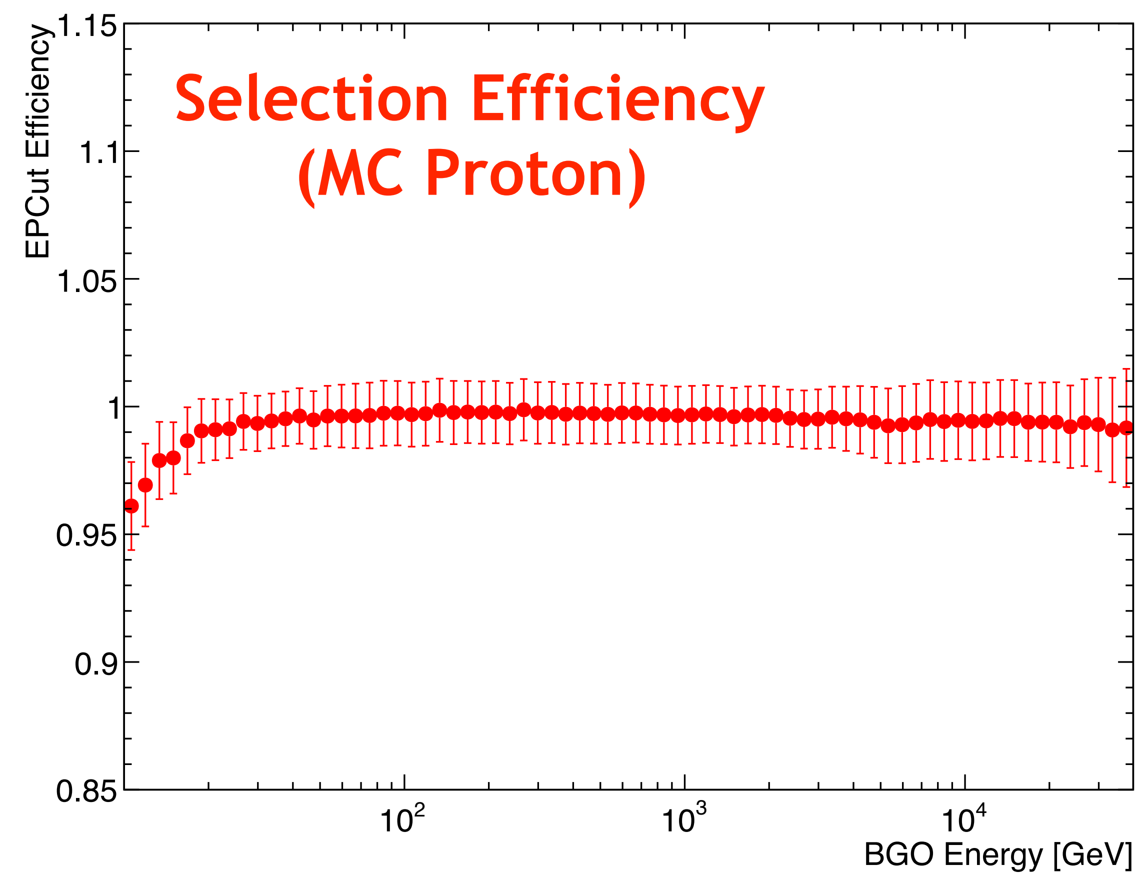


Shower Development:

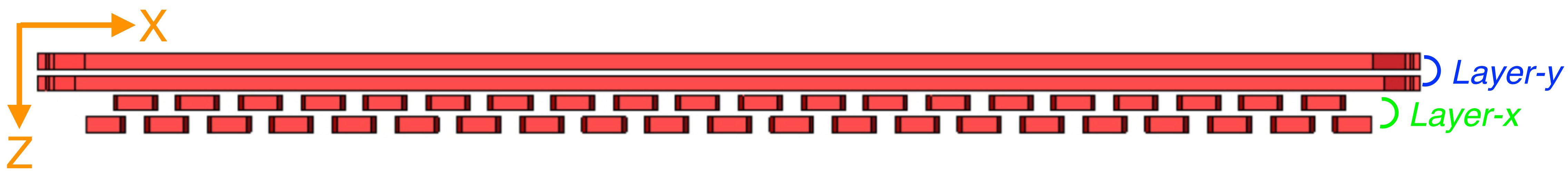
$$EP_{val} = \frac{\sum_{i=1}^{\mathcal{L}} RMS_i}{\mathcal{L}} \times \mathcal{F}_{last}$$

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





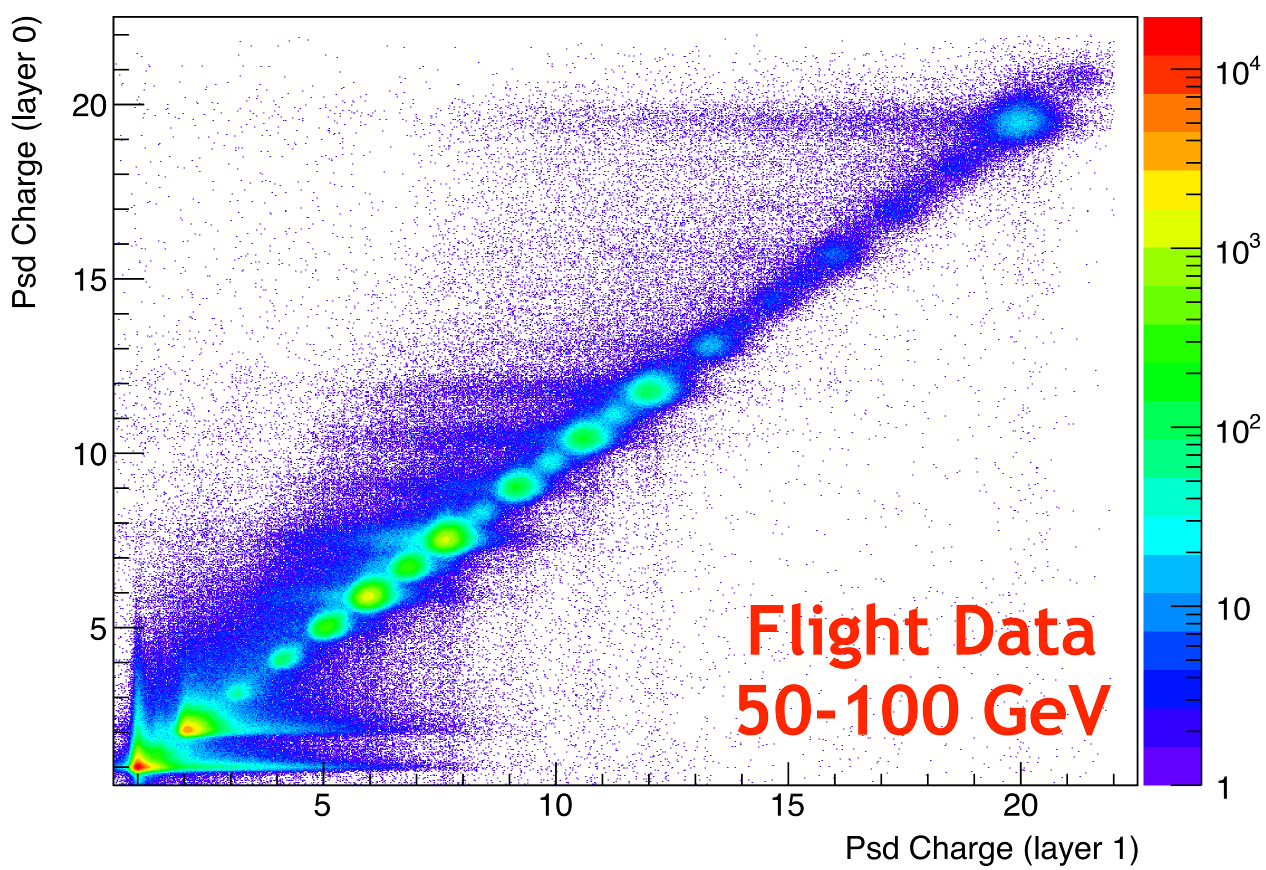
Charge selection

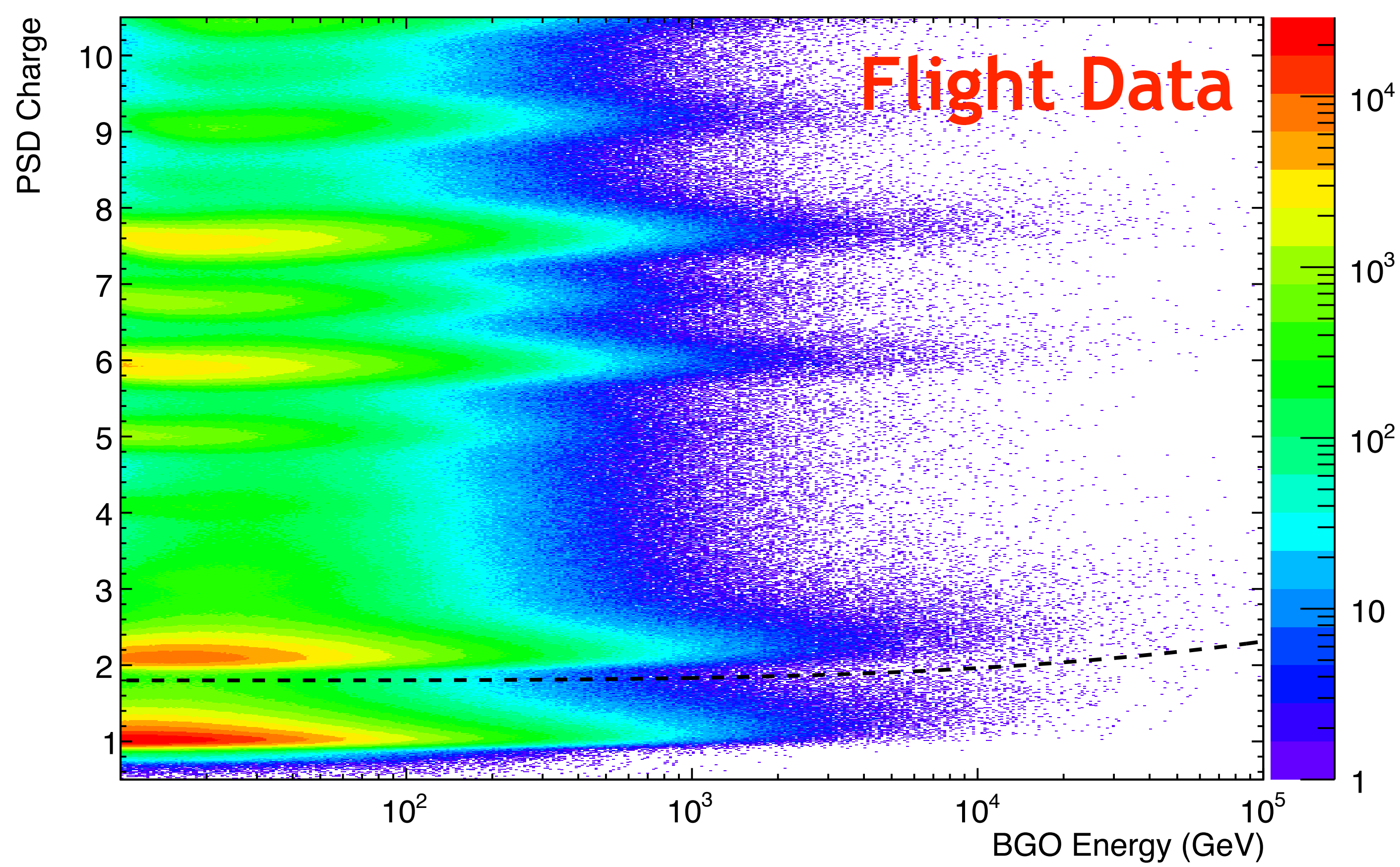


Bethe-Bloch

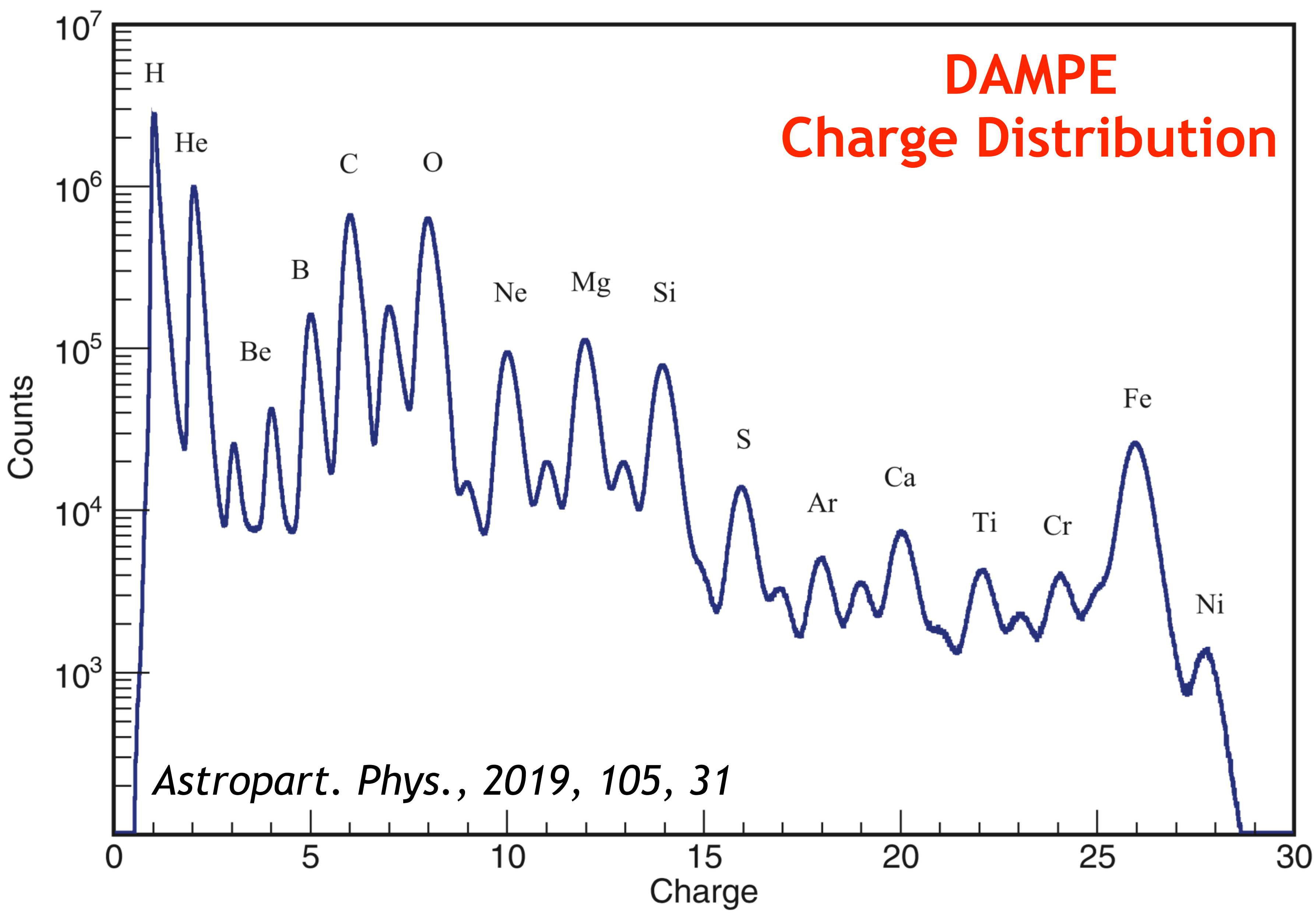
$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)}\right) - \beta^2\right]$$

$$Z_y = \sqrt{PsdE_y/MipE} \quad Z_x = \sqrt{PsdE_x/MipE} \quad Z_{PSD} = (Z_y + Z_x)/2$$



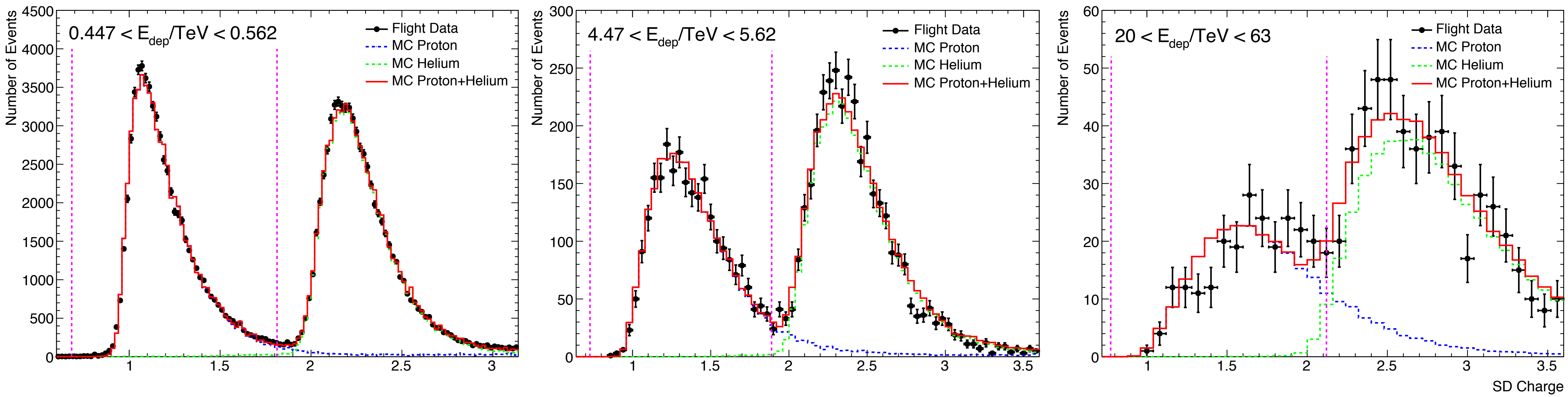


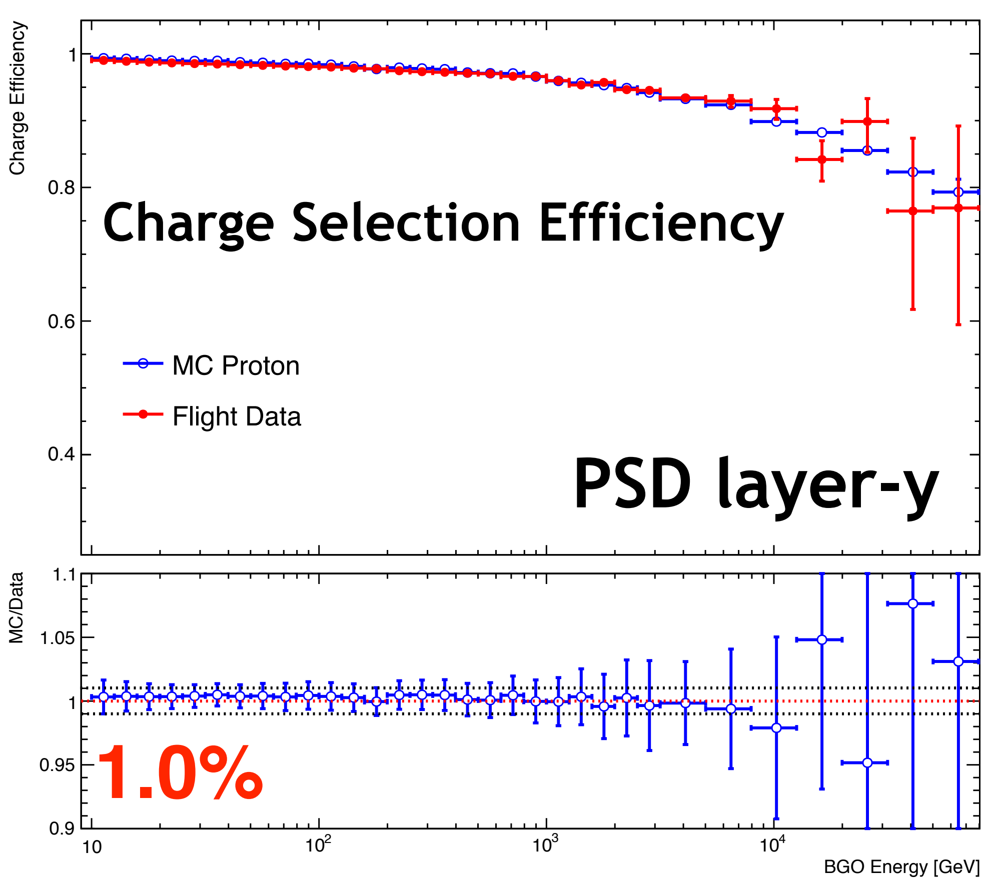
Charge selection

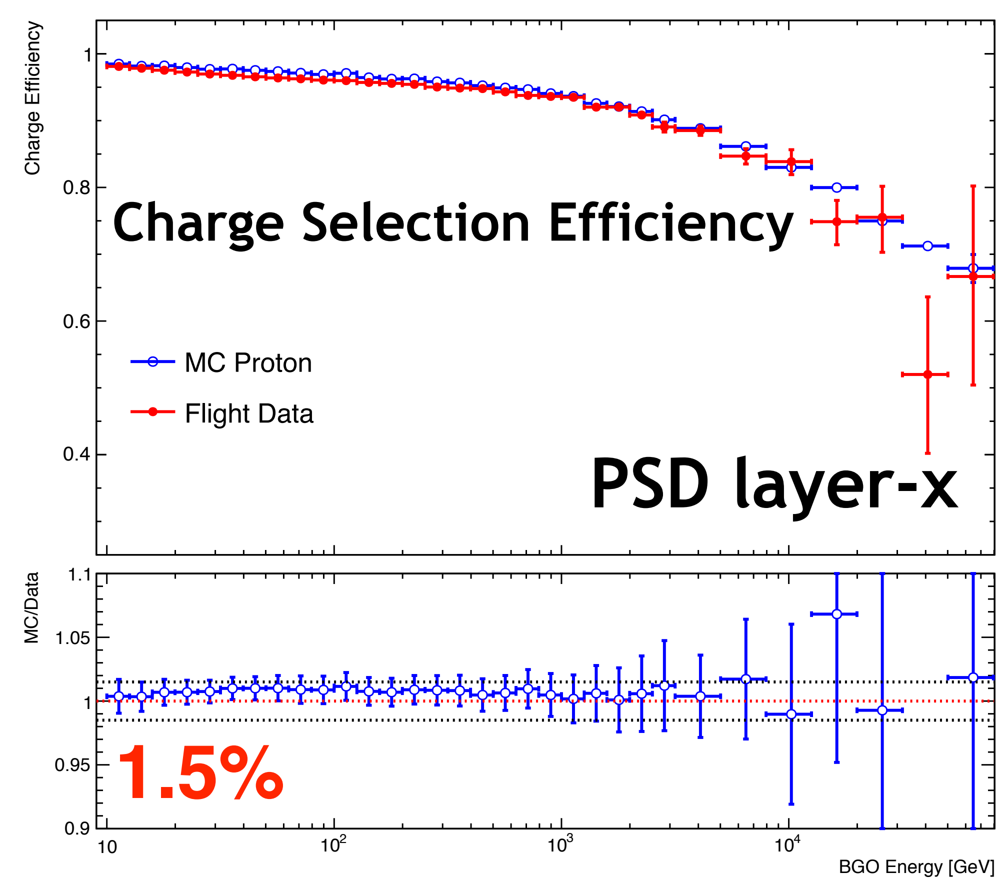


Element	σ_Z	Element	σ_Z	Element	σ_Z	Element	σ_Z
Li	0.14	C	0.18	Ne	0.21	S	0.25
Be	0.21	N	0.21	Mg	0.22	Ca	0.29
B	0.17	O	0.20	Si	0.25	Fe	0.30

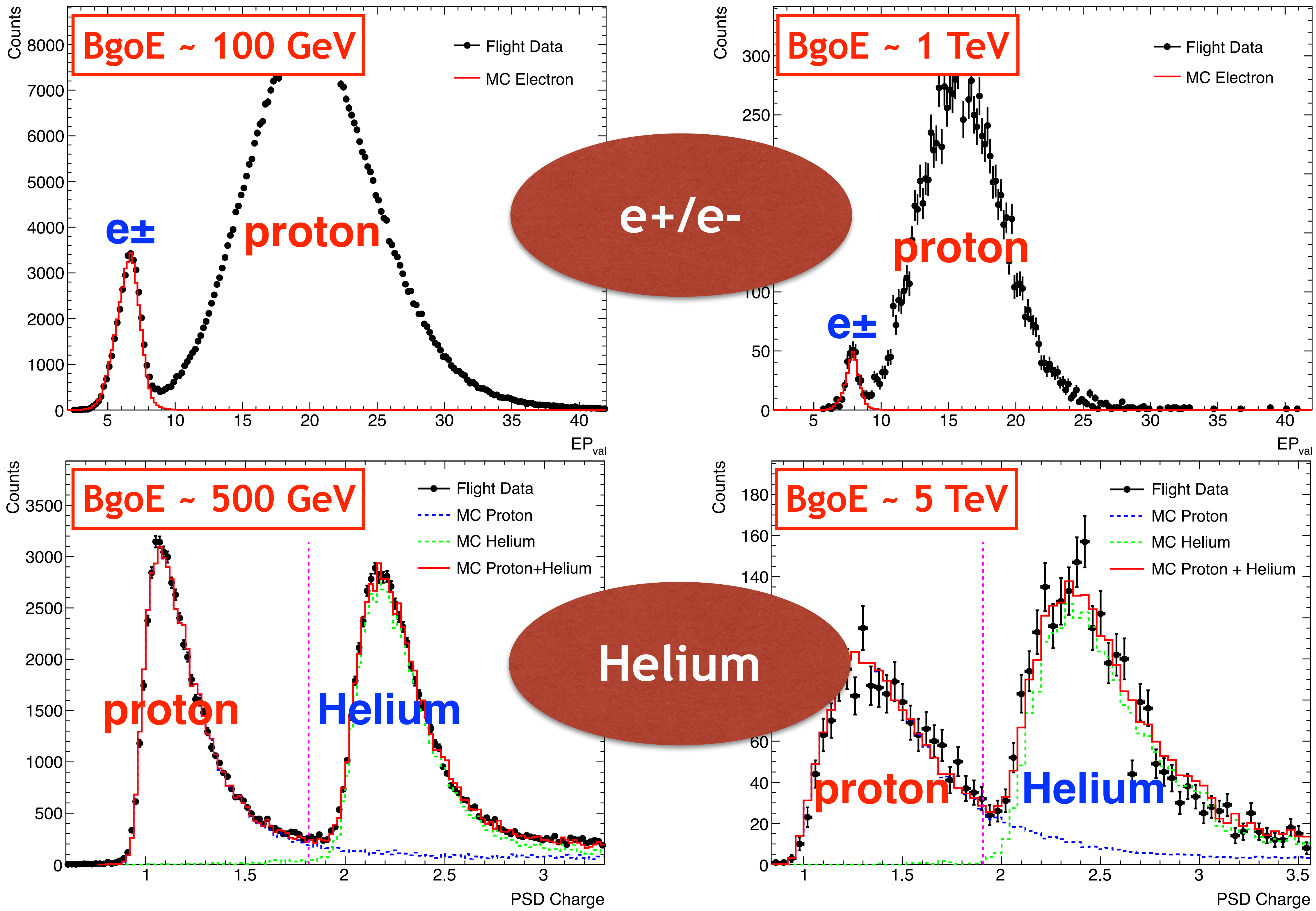
Charge selection



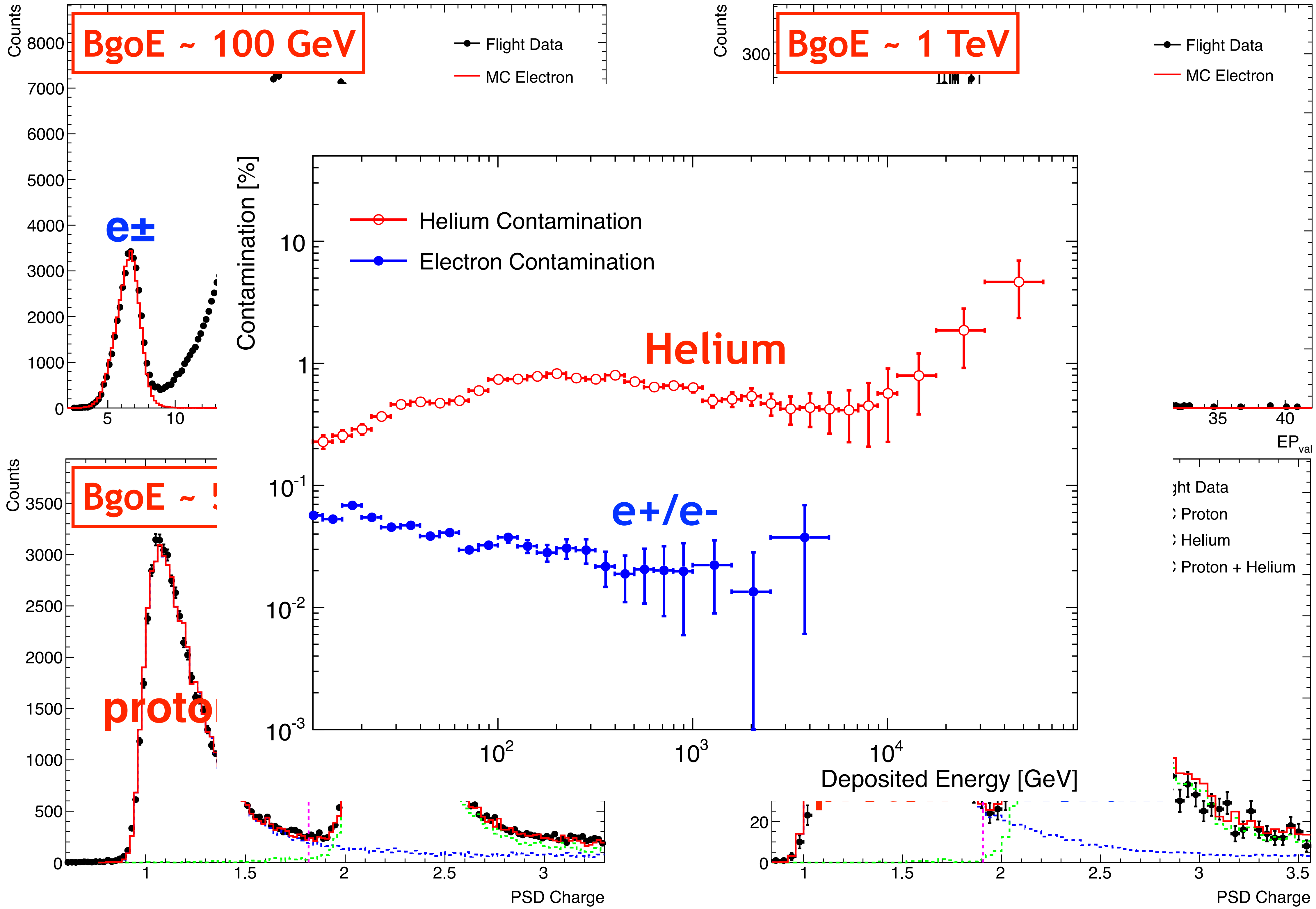




Background


BgoE ~ 100 GeV
Flight Data
MC Electron
e±
proton
Counts
EP$_{val}$
e+/e-
BgoE ~ 1 TeV
Flight Data
MC Electron
proton
e±
Counts
EP$_{val}$
BgoE ~ 500 GeV
Flight Data
MC Proton
MC Helium
MC Proton+Helium
proton
Helium
Counts
PSD Charge
Helium
BgoE ~ 5 TeV
Flight Data
MC Proton
MC Helium
MC Proton + Helium
proton
Helium
Counts
PSD Charge

Background



BgoE ~ 100 GeV
Flight Data
MC Electron
e±
BgoE ~ 1 TeV
Flight Data
MC Electron
EP$_{val}$
BgoE ~ !
proto
PSD Charge
Helium Contamination
Electron Contamination
Contamination [%]
Helium
e+/e-
Deposited Energy [GeV]
ght Data
Proton
Helium
Proton + Helium
PSD Charge
Counts

Energy Unfolding

Iterative Bayesian Unfolding Method
[Giulio D'Agostini, NIM A362(1995), 487]

$$N_i = \sum_{j=1}^{n} \alpha_{ij} M_j (1 - \beta_j)$$

$$\alpha_{ij} = \frac{P(E_{d,j}|E_{0,i})\hat{N}_i}{\epsilon_i \sum_{i=1}^{n} P(E_{d,j}|E_{0,i})\hat{N}_i}$$

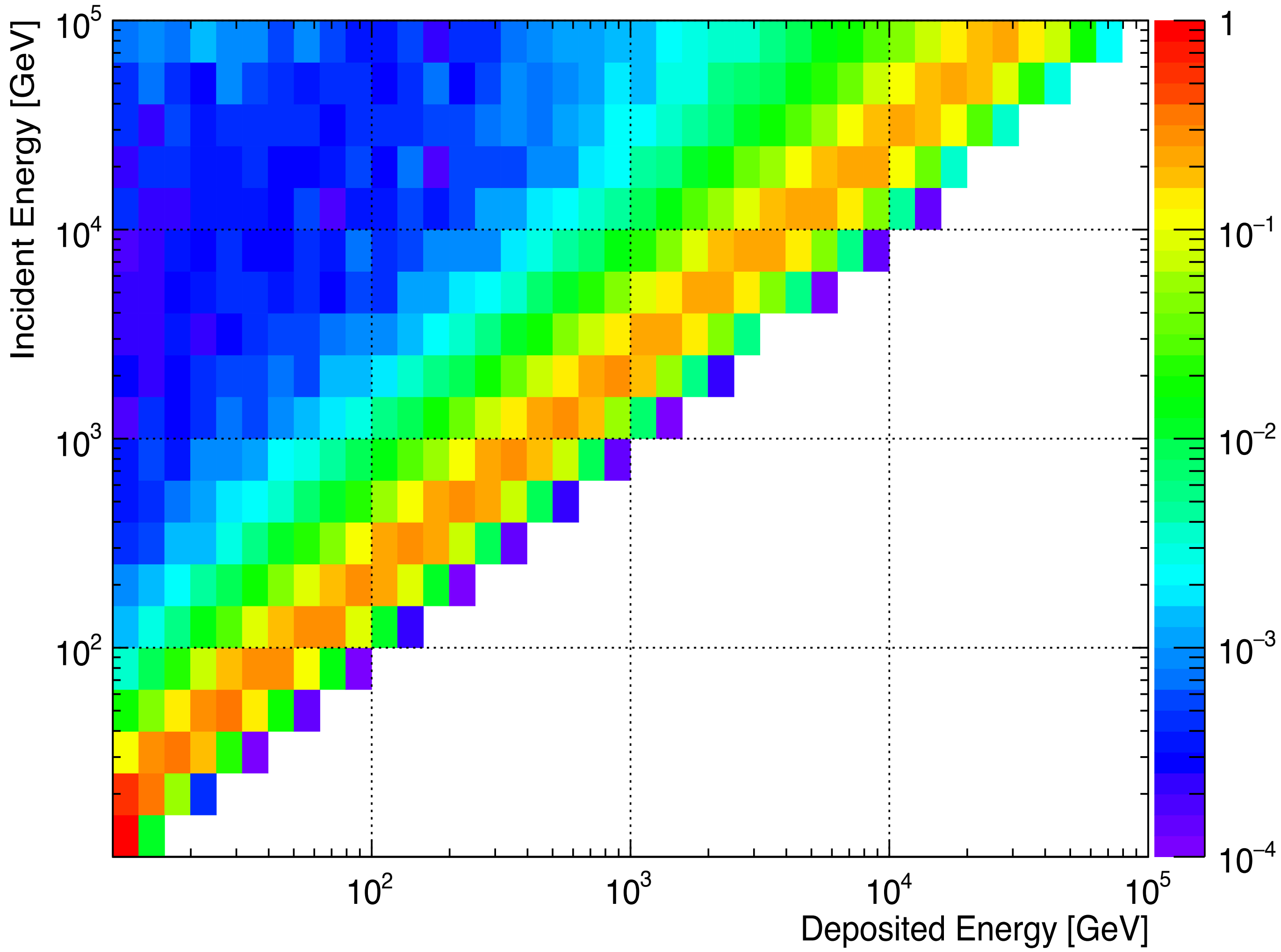
N_i : **Unfolded event number**

M_j: **Measured event number**

β_j : **Background**

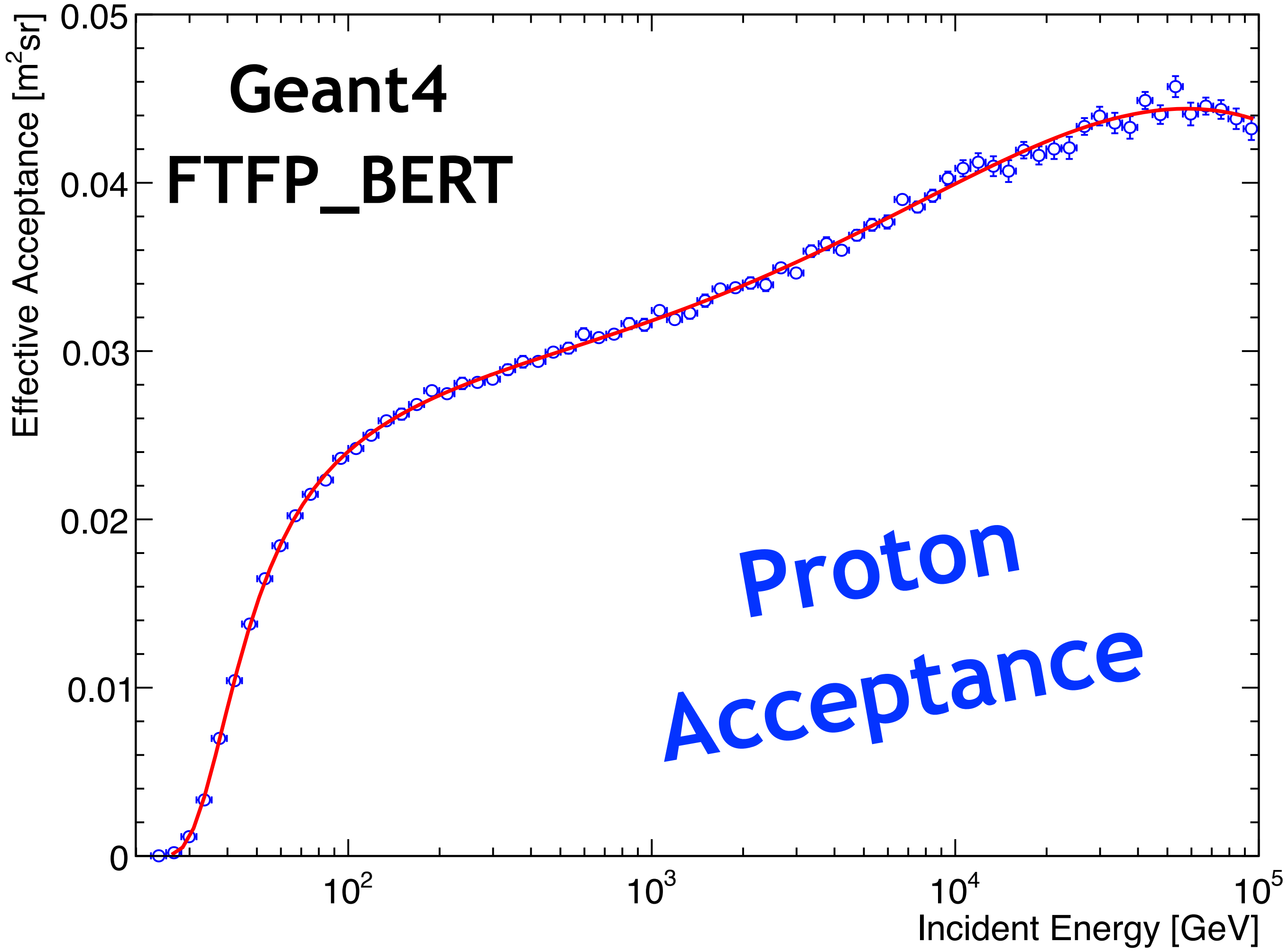
$P(E_{d,j}|E_{0,i})$: **Response Matrix (MC)**

$\hat{N}_i$: **Prior ($E^{-2.7}$)**



Effective Acceptance

$$Flux(E) = \frac{N_{obs}(E)}{T_{\exp}(E) A_{eff}(E) dE}$$



$$A_{\mathrm{eff},i} = A_{\mathrm{gen}} \times \frac{N_{\mathrm{pass},i}}{N_{\mathrm{gen},i}}$$

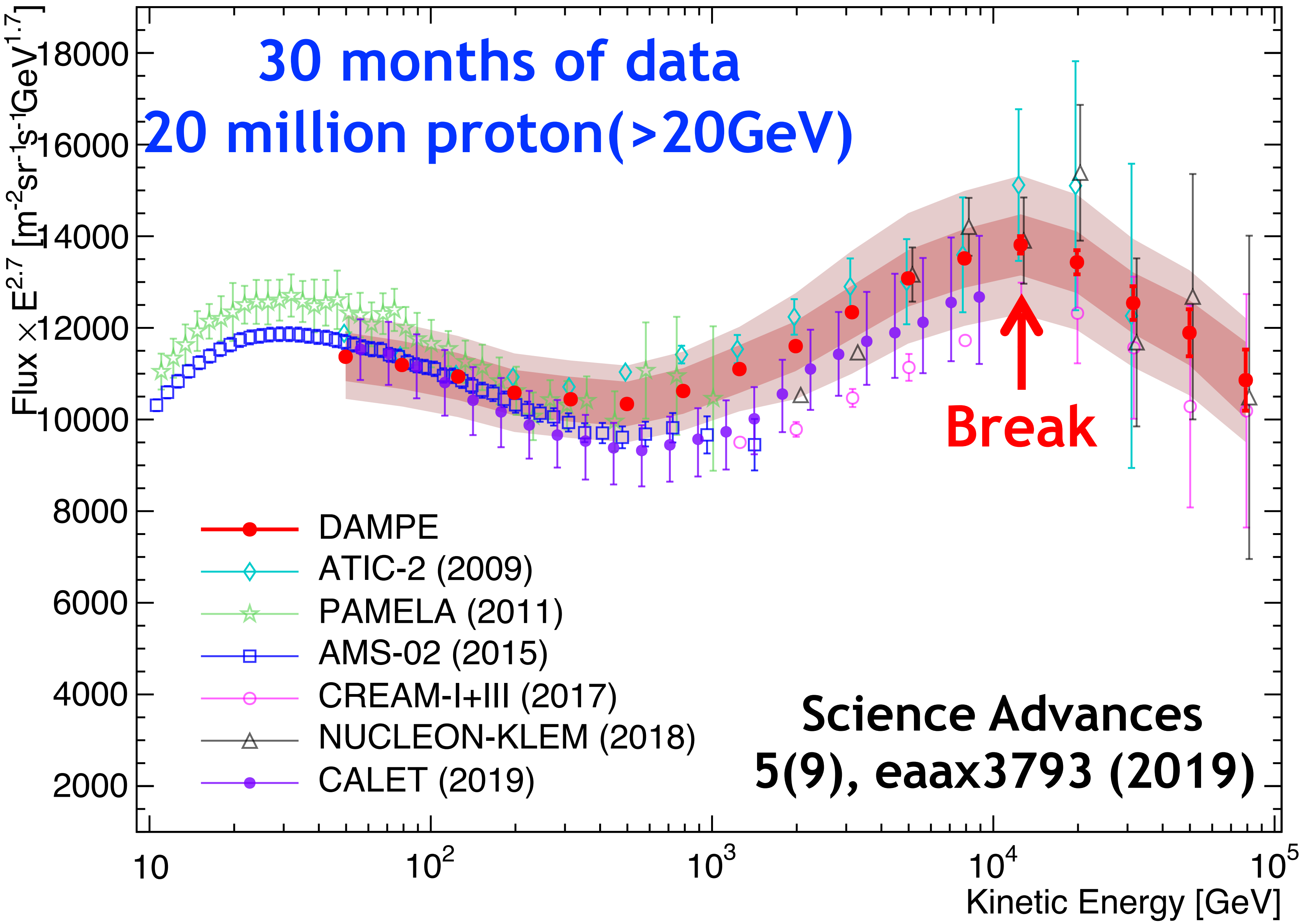
$$\sigma_{\mathrm{sel}} = \sqrt{\sigma^2_{\mathrm{trigger}} + \sigma^2_{\mathrm{track}} + \sigma^2_{\mathrm{charge}}} \approx 4.7\%$$

HE Tigger: ~2.5%

Track Reconstruction: ~3.5%

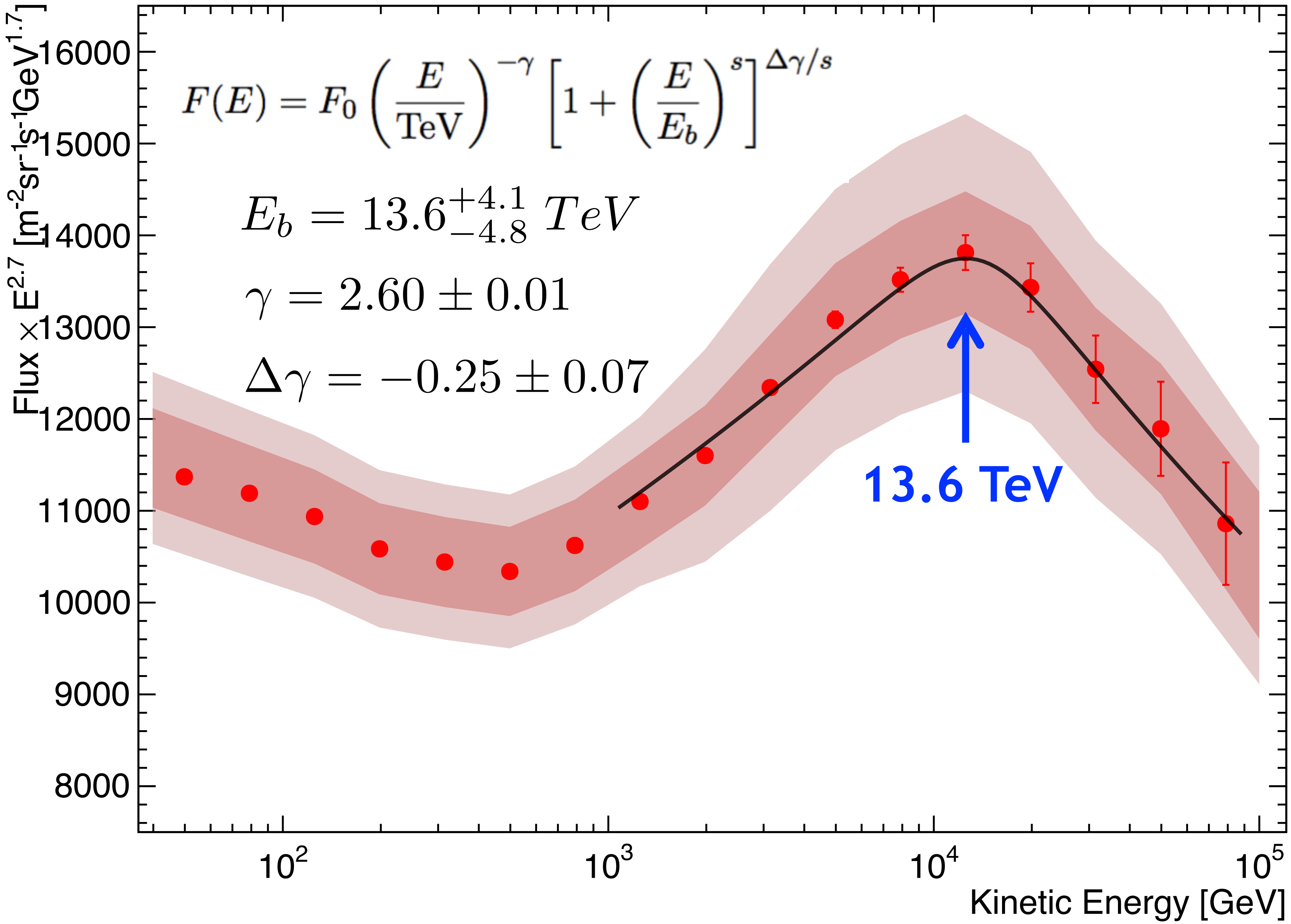
Charge Identification: ~1.8%

Proton Spectrum



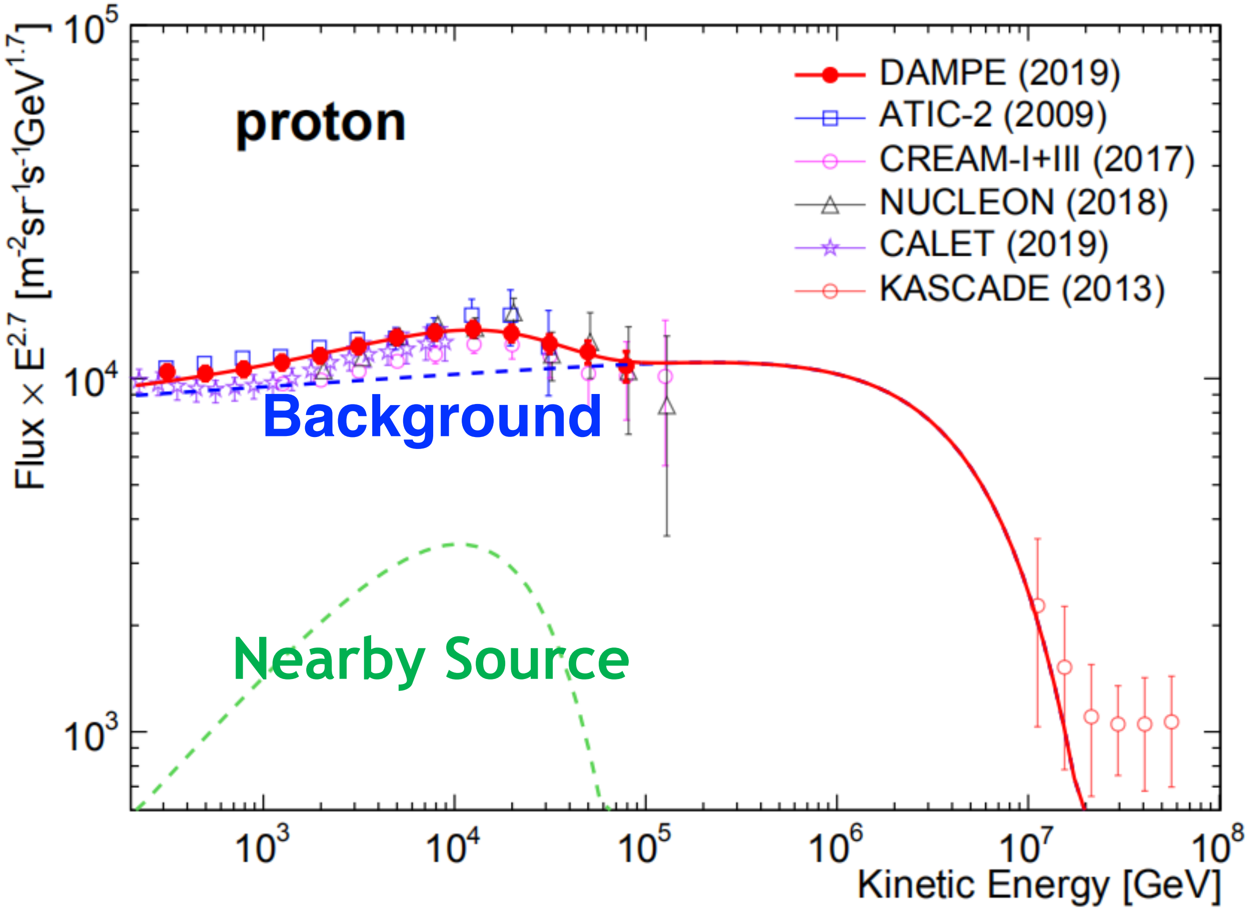
The DAMPE measurement confirms the spectral hardening at a few hundreds of GeVs found by previous experiments, and more importantly, it reveals a steepening feature at ~13.6 TeV.

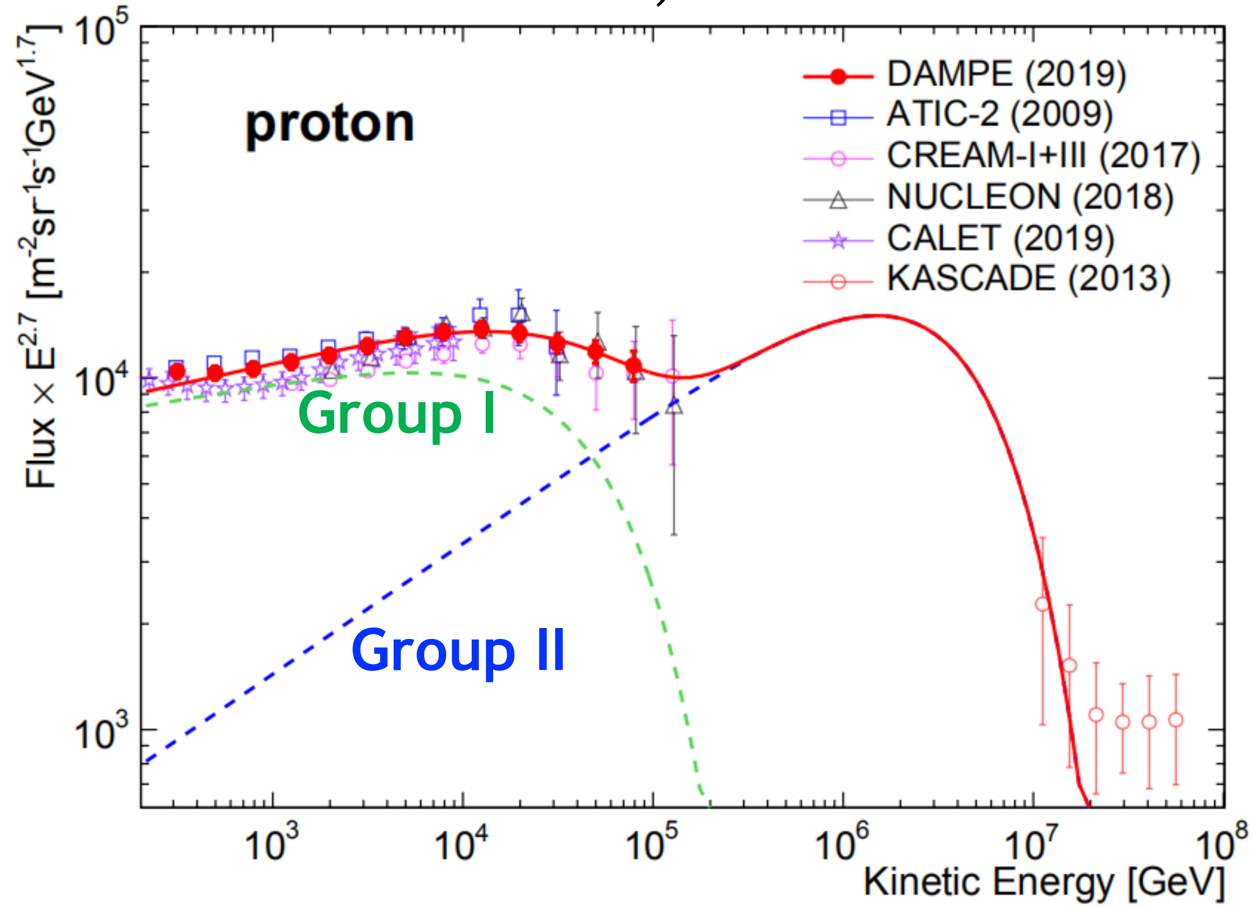
Proton Spectrum



Possible Implications

Yue et al., arXiv: 1909.12857





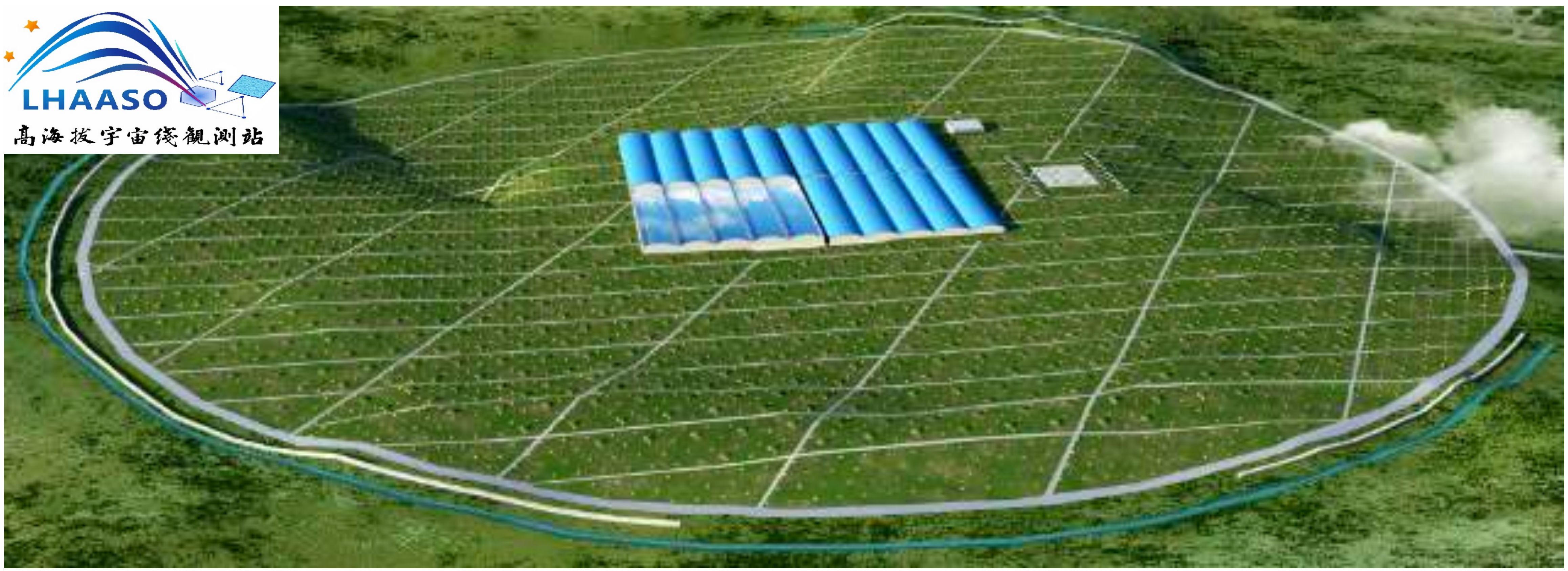
- **This spectral feature may be a signature by nearby source (Liu et al., 2019), and the break energy would be related to the upper limit of acceleration capability.**
- **Alternatively, this feature can also be well explained by the multi-component sources model (Zatsepin and Sokolskaya, 2006).**
- **The measurement of proton “knee” from LHAASO would be very essential for further study.**

Conclusions

- Since launch on Dec. 17th, 2015, DAMPE("Wukong") has been operated stably for four years
- Thirty months of on-orbit data with a live time fraction of 75.73% are analysed for CR proton spectrum
- For the first time in space, DAMPE measures the CR proton spectrum in a wide energy range from 40GeV to 100TeV with a single experiment
- The DAMPE measurement confirms the spectral hardening around 400GeV and reveals a steepening feature at ~13.6TeV
- More results of nuclei spectra from DAMPE are forthcoming, and we would like to see if the steepening is an universal feature for all nuclei with Z-dependence or A-dependence

It is our time!

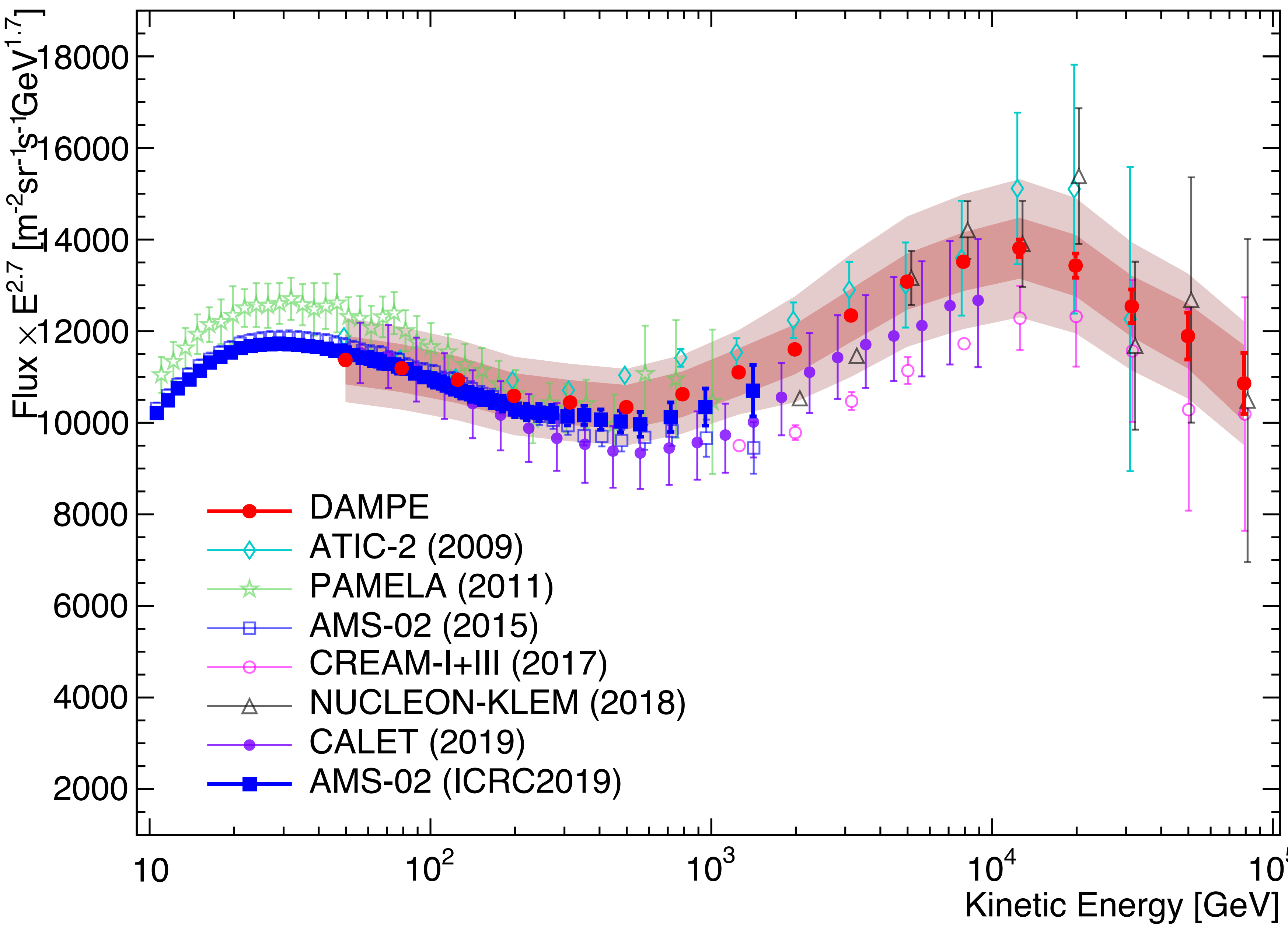
+



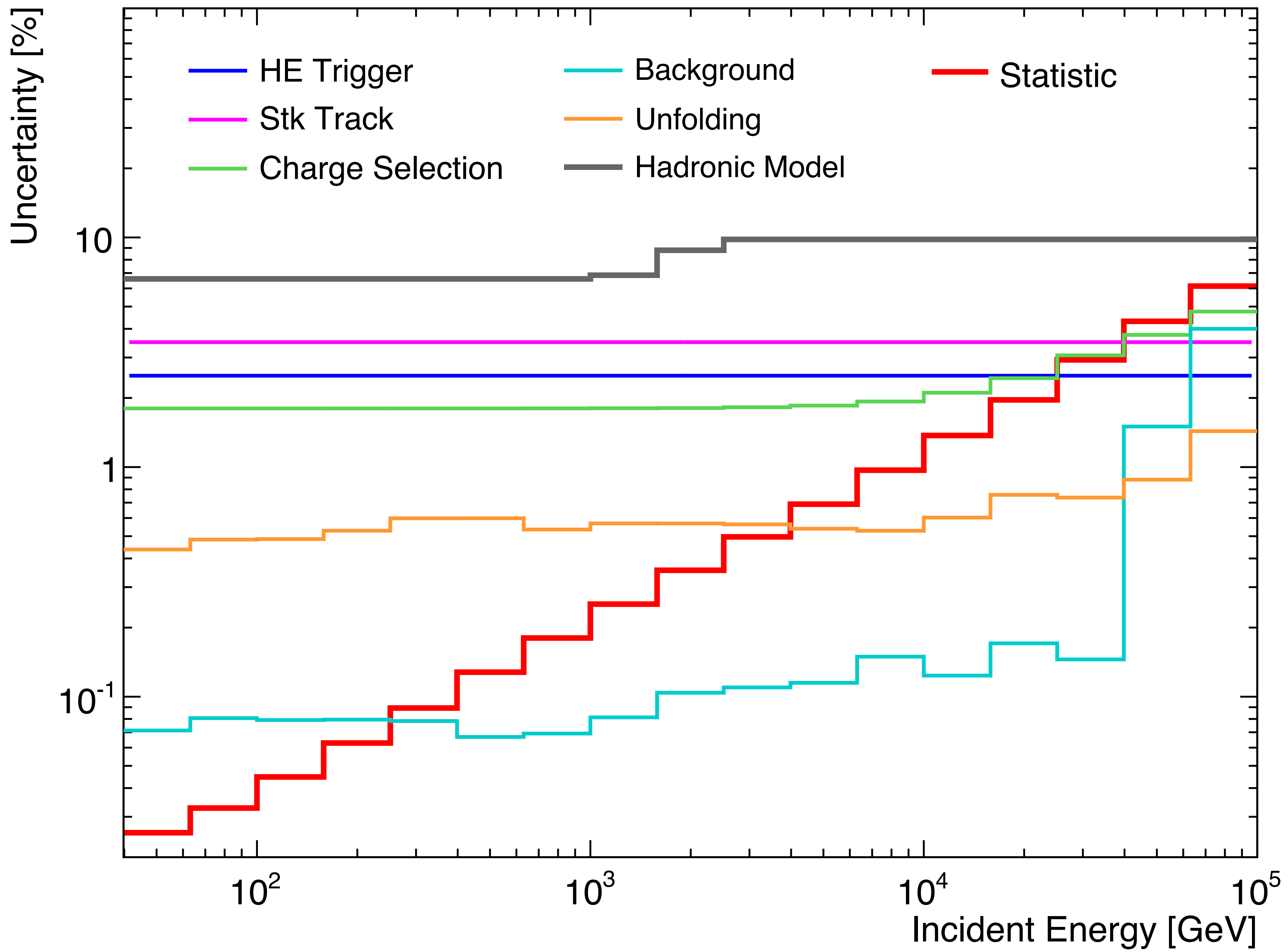
Thanks for your attention!

BackUp

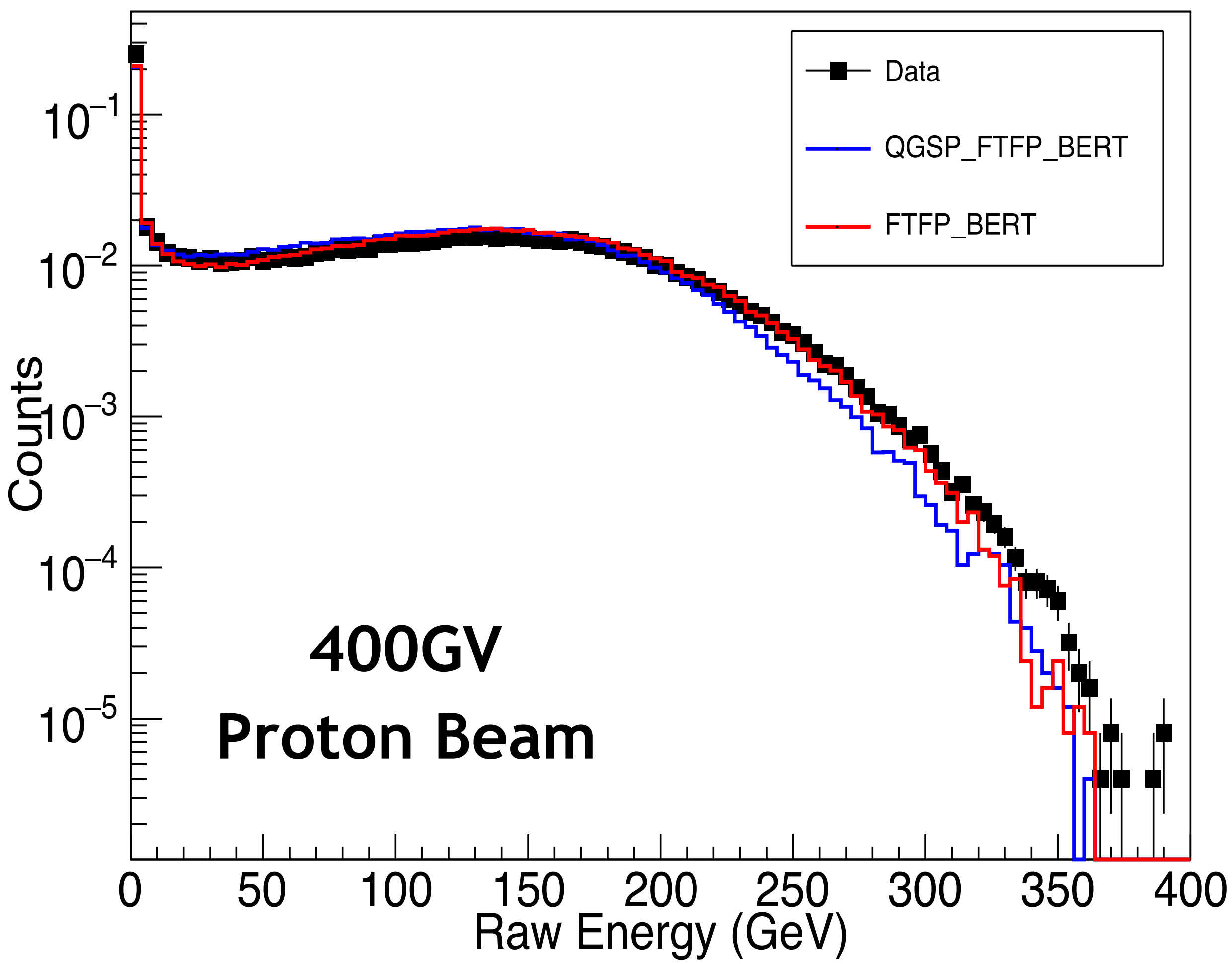
Updated AMS-02 Result (ICRC2019)

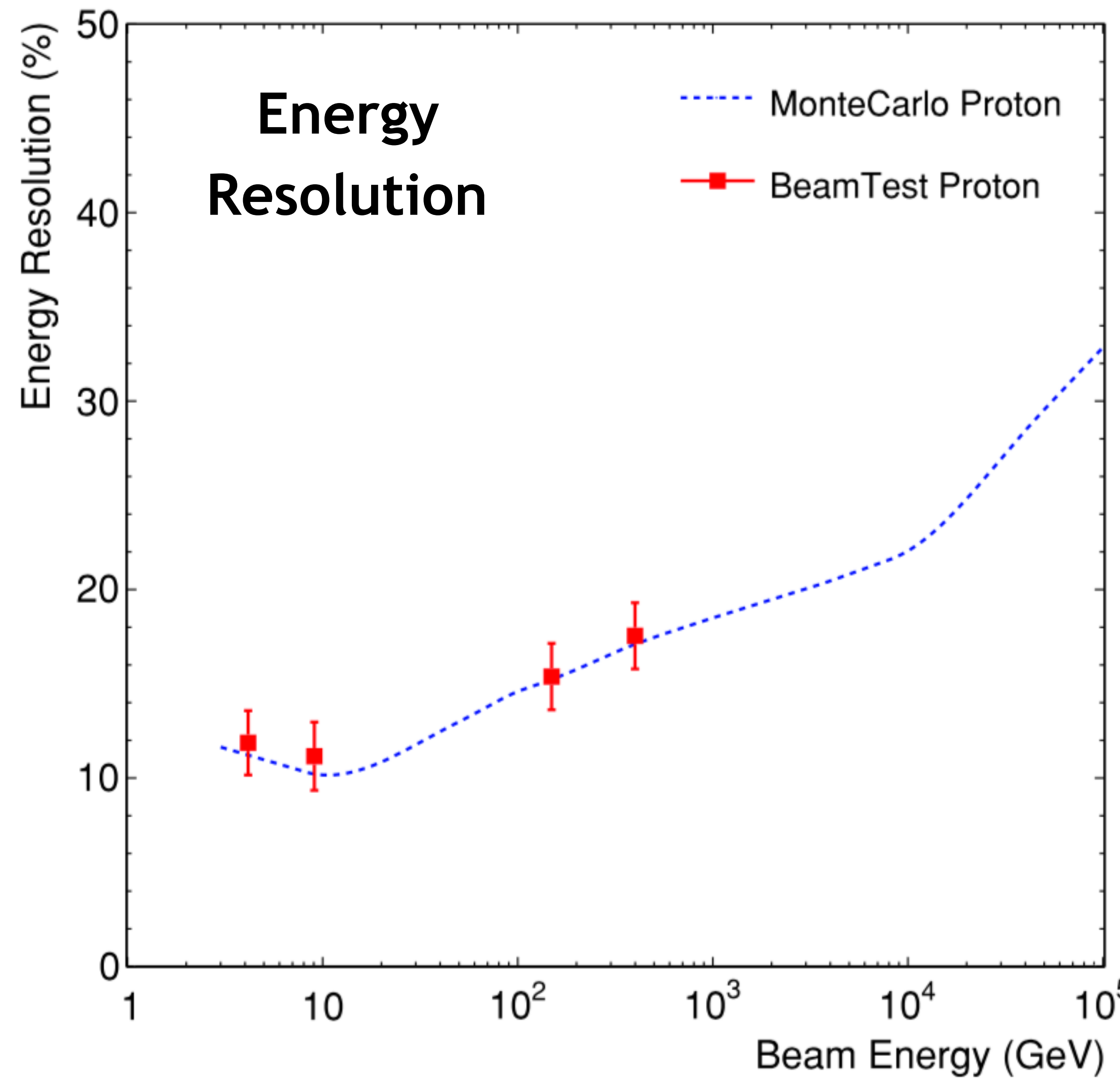


Uncertainties



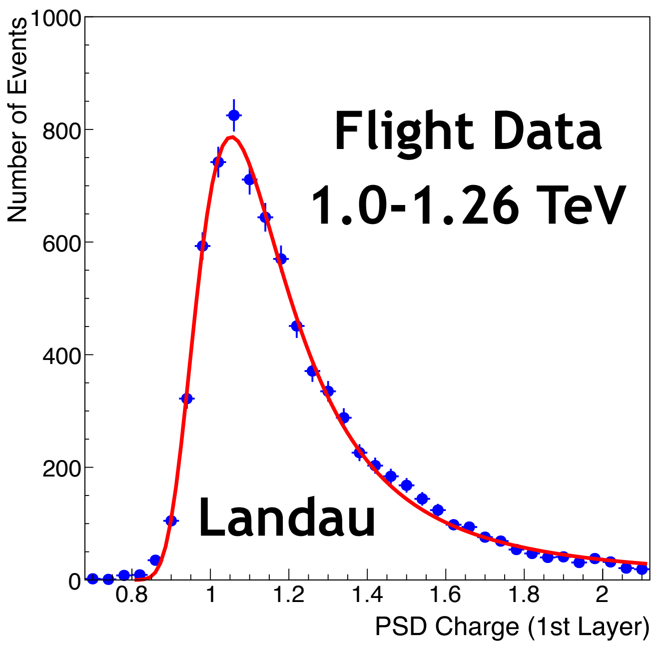
Energy Resolution

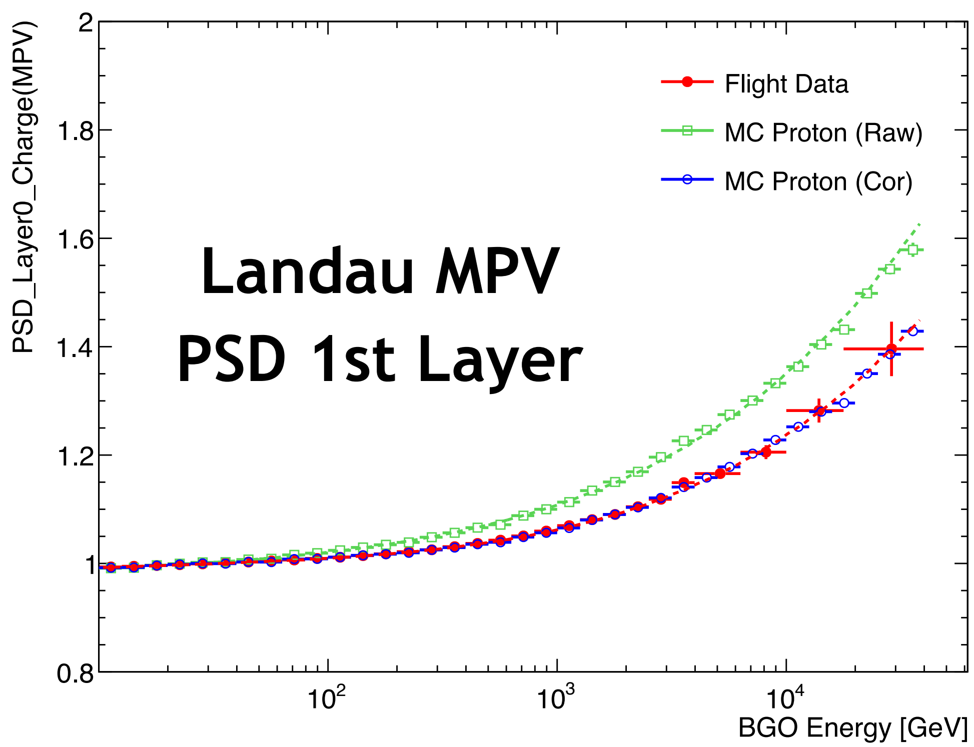


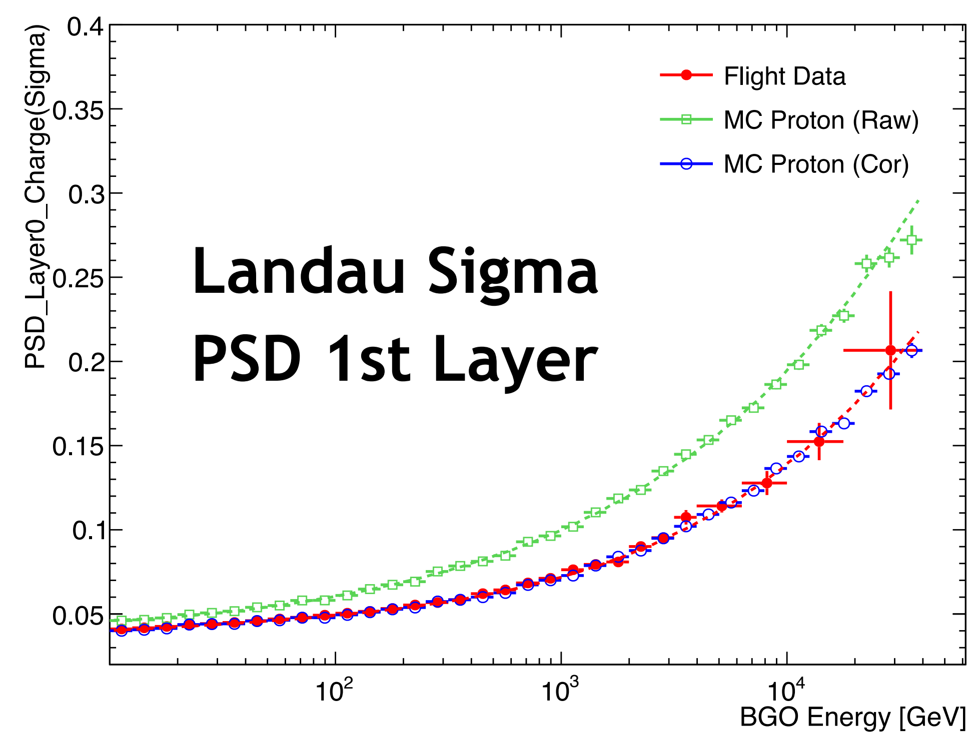


PSD Charge Correction

The charge measurements of the MC simulations show an energy-dependent difference from that of the flight data due primarily to the back-scattering secondaries.







An energy-dependent charge correction is applied for the MC data to mitigate the back-scattering effect and achieve a good agreement with the flight data.

$$Charge_{MC,cor} = (Charge_{MC} - f_{MPV,MC}(E_{BGO}))\frac{f_{\sigma,Data}(E_{BGO})}{f_{\sigma,MC}(E_{BGO})} + f_{MPV,Data}(E_{BGO})$$