Measurements of the carbon and oxygen fluxes in cosmic rays with the DAMPE experiment

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(On behalf of the DAMPE Collaboration)

Workshop on Diffuse Gamma Rays and Cosmic Ray Physics 2023

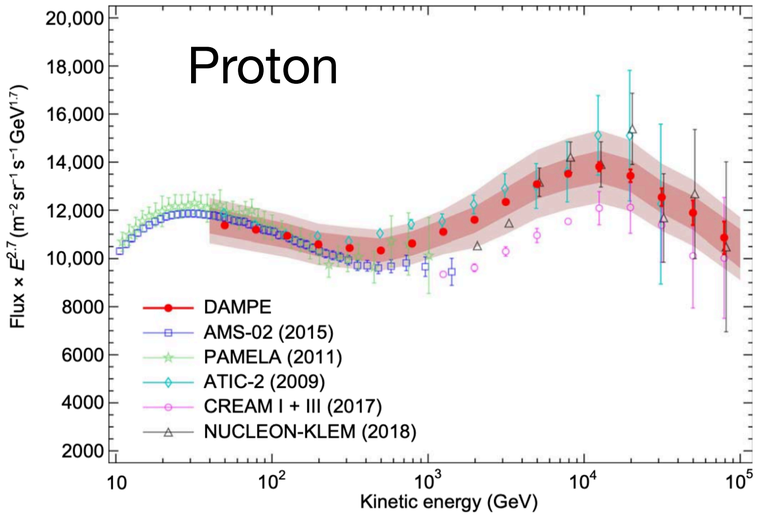
Hefei, Anhui, Oct 23th, 2023

Outline

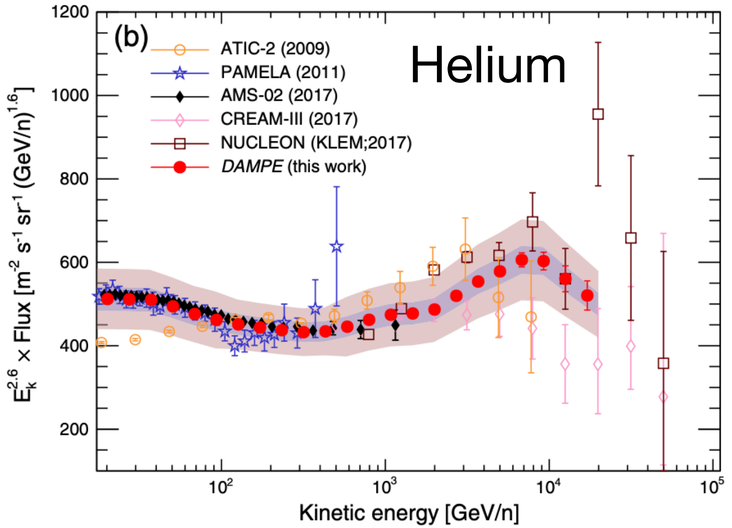
- Motivation
- DAMPE instrument
- Preliminary results: C & O fluxes
- C/O - BGO Cross Section Measurements
- Searching for Fractionally Charged Particle
- Summary

Motivation

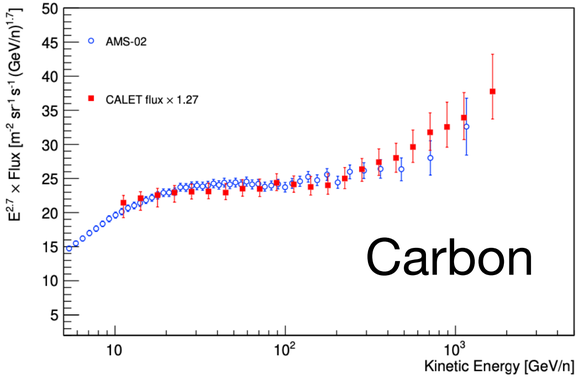
- The GCRs spectrum is expected to follow a power-law form below the “knee”
- Several experiments have observed changes in the power-law spectral indices γ
- DAMPE has the capability to extend the measurements of cosmic ray carbon and oxygen up to tens of TeV/n

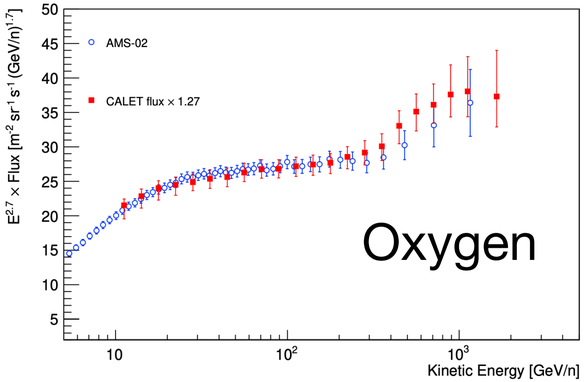


Sci. Adv. 5, eaax3793 (2019)



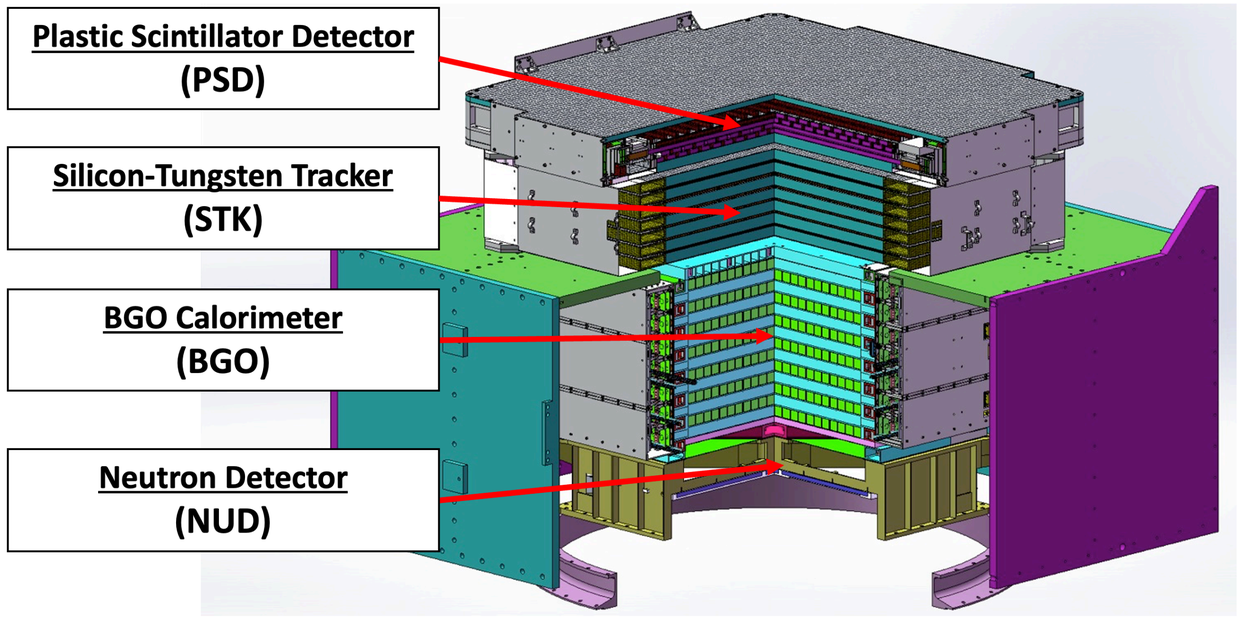
Phys. Rev. Lett. 126, 201102 (2021)





Phys. Rev. Lett. 125, 251102 (2020)

DArk Matter Particle Explorer



Main scientific goals:

- Origins and Propagations of Cosmic-Rays
- Dark Matter Indirected Detection
- High Energy Gamma-ray Astronomy

Orbit information:

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

DAMPE sub-detectors:

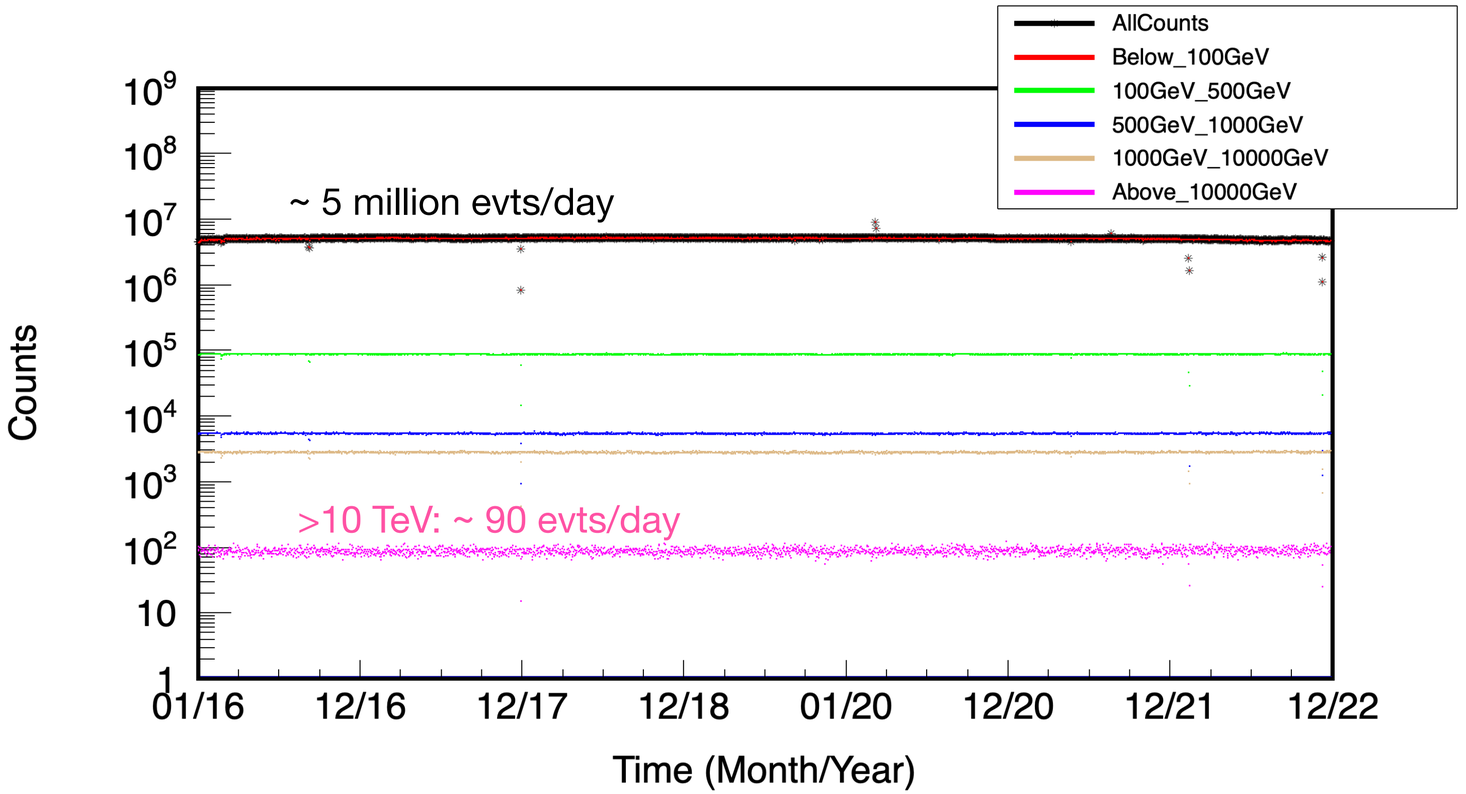
- Charge measurement (dE/dx in PSD, STK)
- Tracking and Gamma-ray converting (STK and BGO)
- Precise energy measurement (BGO)
- Electron-hadron separation (BGO and NUD)

Astropart.Phys. 95, 6 (2017)

Data Sample

Flight data:

- Jan. 1st, 2016 ~ Dec. 31st, 2022 (**7 years**)
- Live time: **1.68×10⁸s (76.10%)**
  - Dead time of the instrument is excluded
  - Data in SAA region is excluded
  - Data during Sep. 2017 Solar Flare (20170908~20170913) is excluded



Simulation data:

- Geant4.10.5.p02 (FTFP_BERT)

Selections

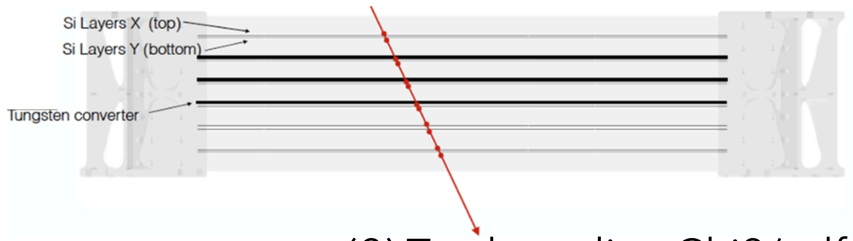
1. Pre-Selection:

- Pass high energy trigger (HET)
- Calorimeter energy: ≥ 60 GeV
- Calorimeter track reconstructed
- Reject events entering from the sides of detector

2. Track reconstruction with STK

STK sub-detector

(1) Hits Number ≥ 3

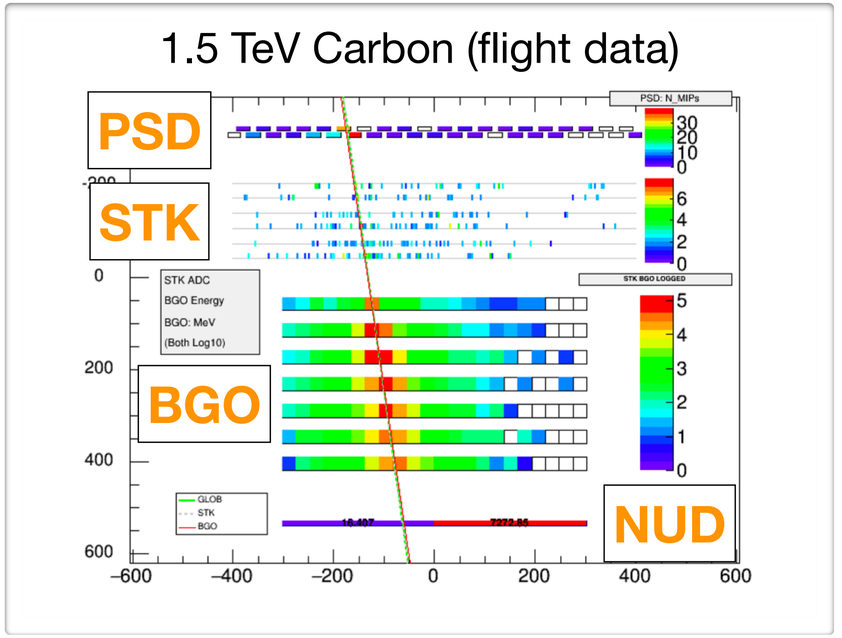


(2) Track quality: Chi2/ndf < 25

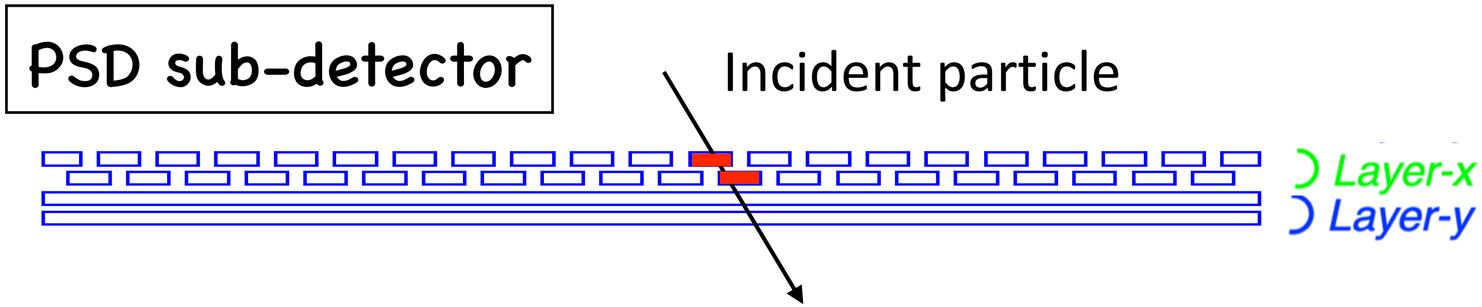
(3) Consistency in STK track and calorimeter track

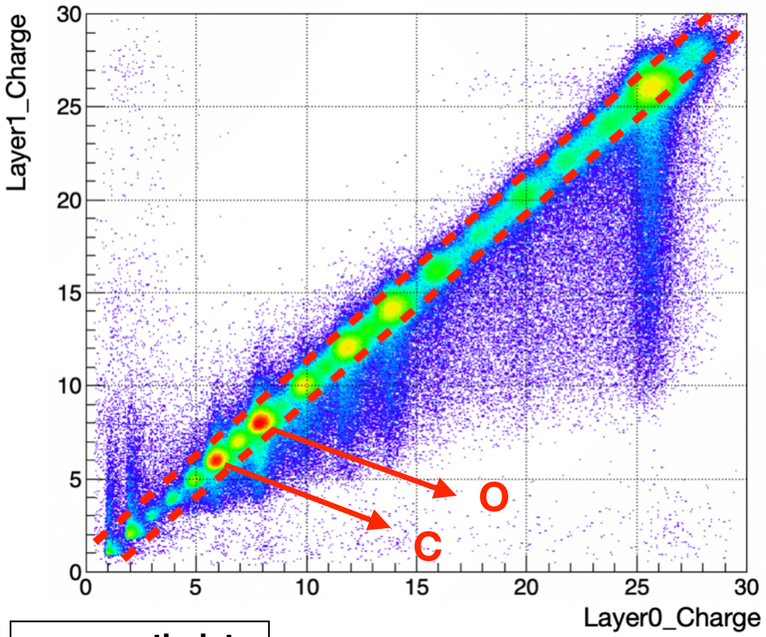
3. Fiducial Selection:

- The track has to be fully contained in (PSD + STK + BGO)
- Max energy bars are far away from the edge of the calorimeter



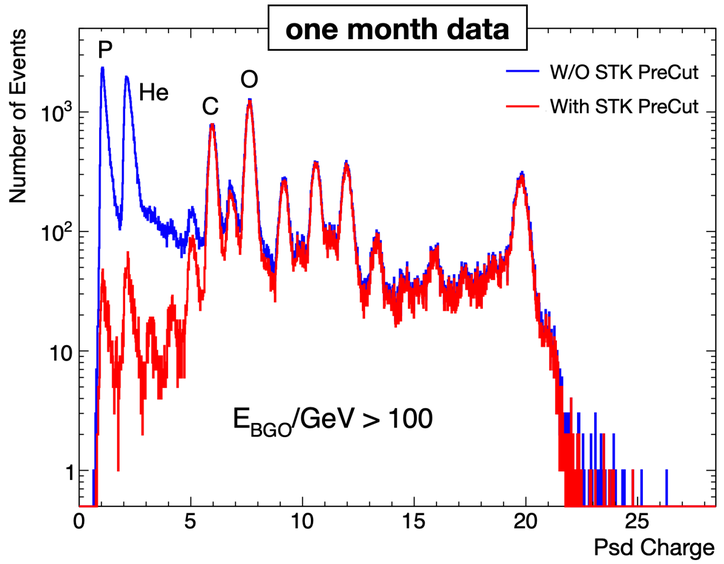
PreCuts for Charge Reconstruction





4. PSD PreCuts:

- Track pass through the max energy bar in PSD Layer X & Y
- Charge consistency: ($|Z_{Lx} - Z_{Ly}| < 1$)

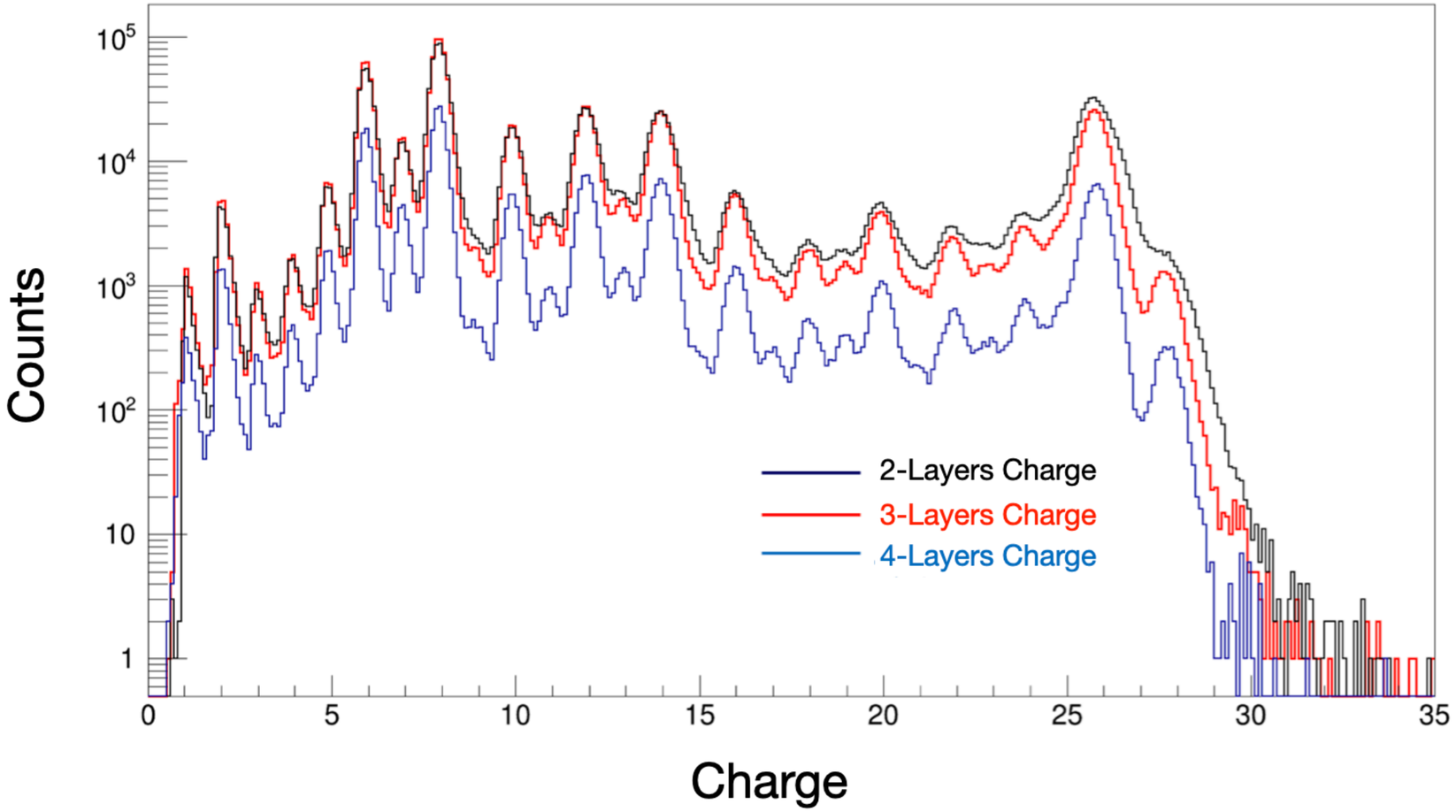


5. STK PreCut:

- Average signal of (STK_{L0}, STK_{L1}) > 500 ADC

Charge Reconstruction

- Using multi-layer charge reconstruction

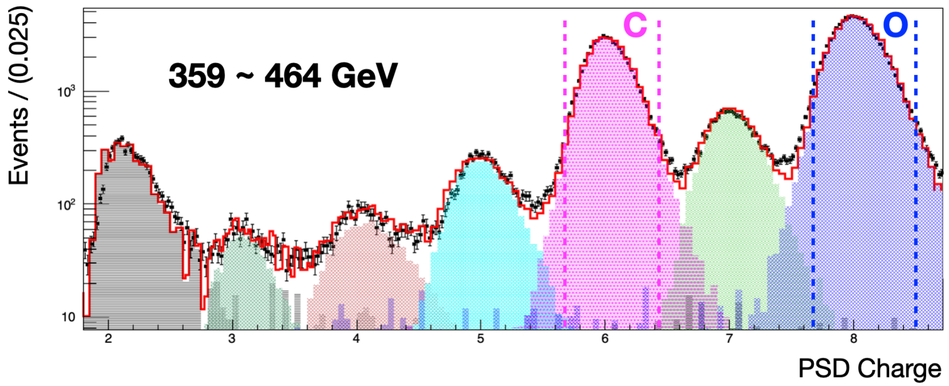


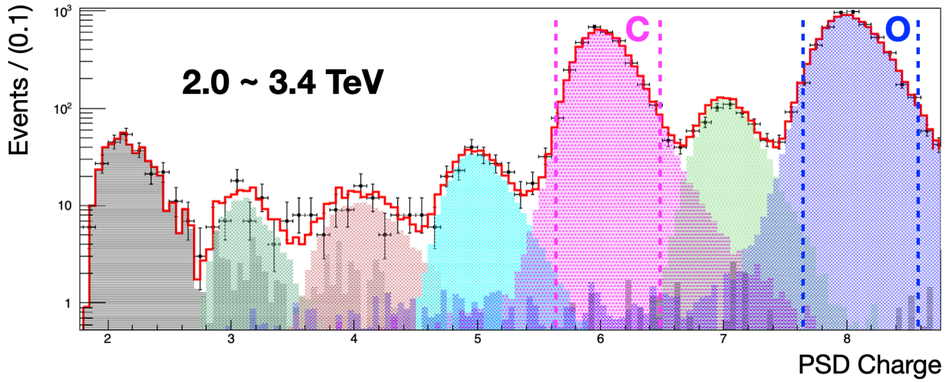
Charge Selection and Background Estimation

Charge reconstruction

$$PsdQ_{Comb} = \frac{\Sigma_0^k PsdQ_i}{k}$$

k is the number of sub-layers that reconstructed charge



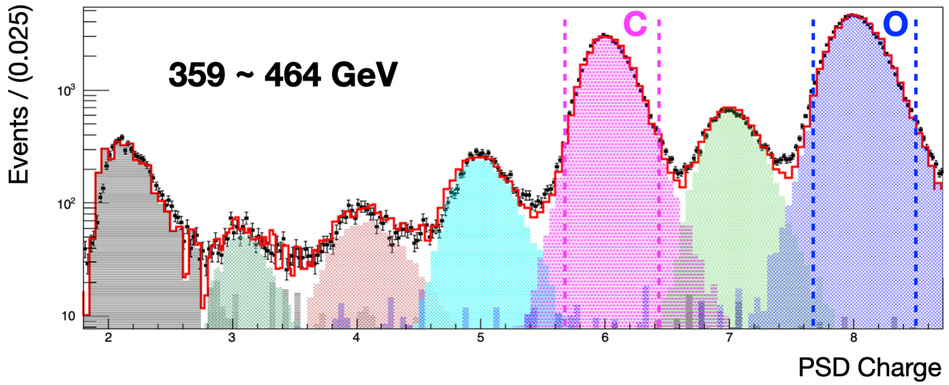


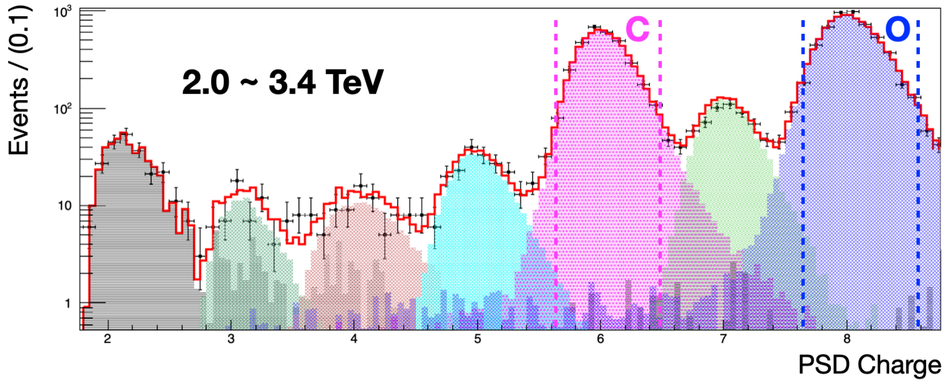
Charge Selection and Background Estimation

Charge selection windows:

$$[Peak_C - 2 * FWHM_C, Peak_C + 2.5 * FWHM_C]$$

$$[Peak_O - 2 * FWHM_O, Peak_O + 3 * FWHM_O]$$



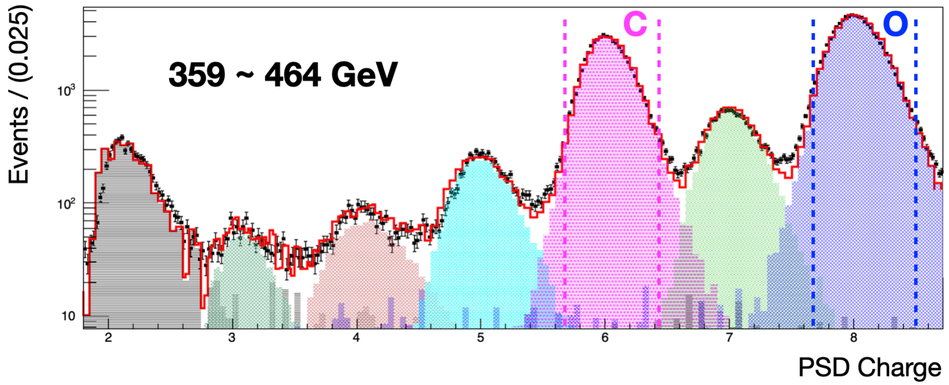


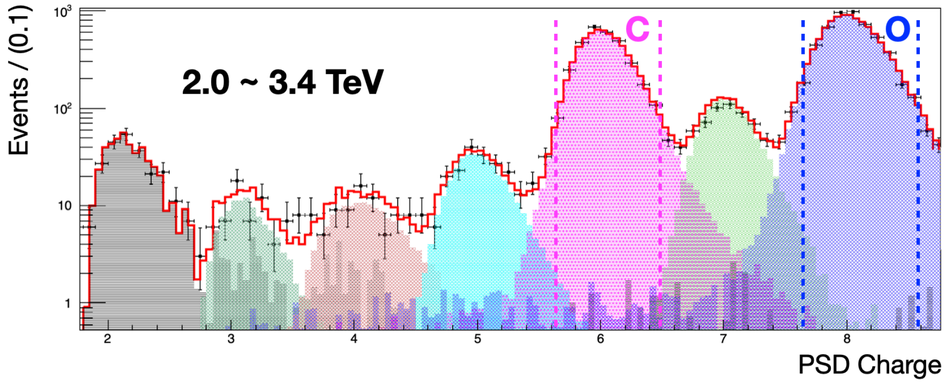
Charge Selection and Background Estimation

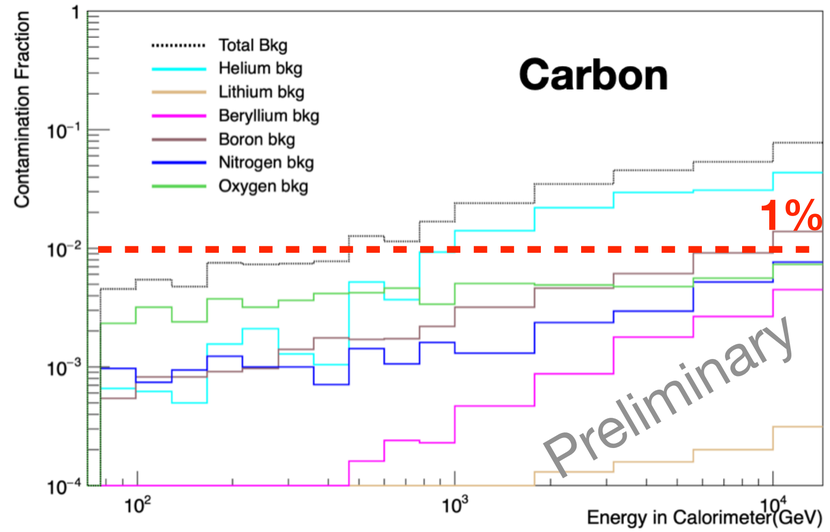
Charge selection windows:

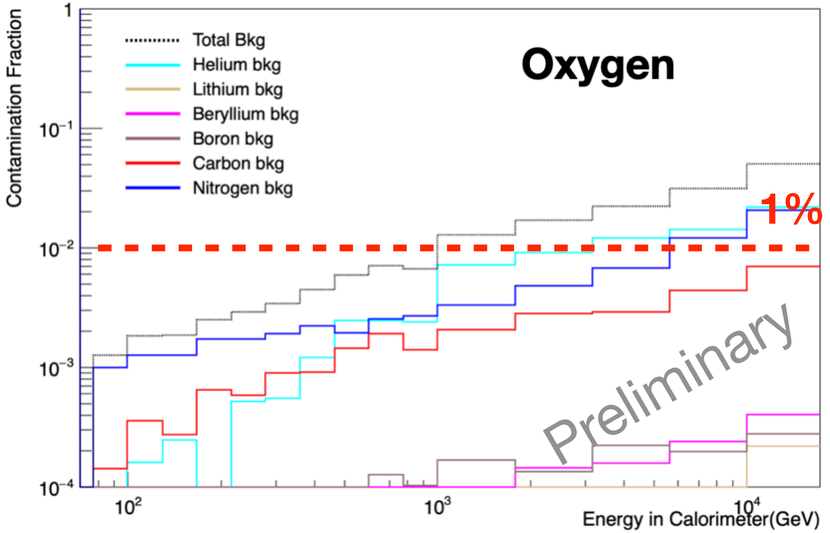
$$[Peak_C - 2 * FWHM_C, Peak_C + 2.5 * FWHM_C]$$

$$[Peak_O - 2 * FWHM_O, Peak_O + 3 * FWHM_O]$$

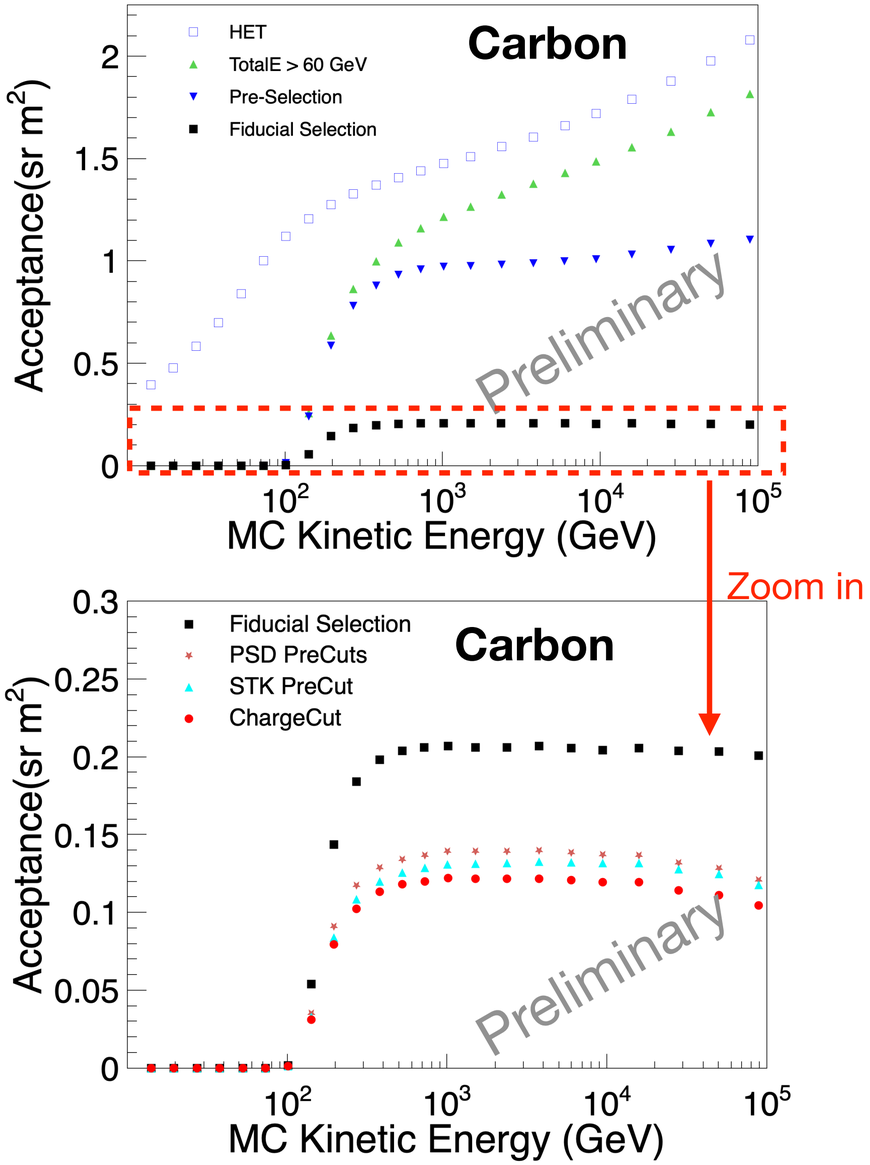






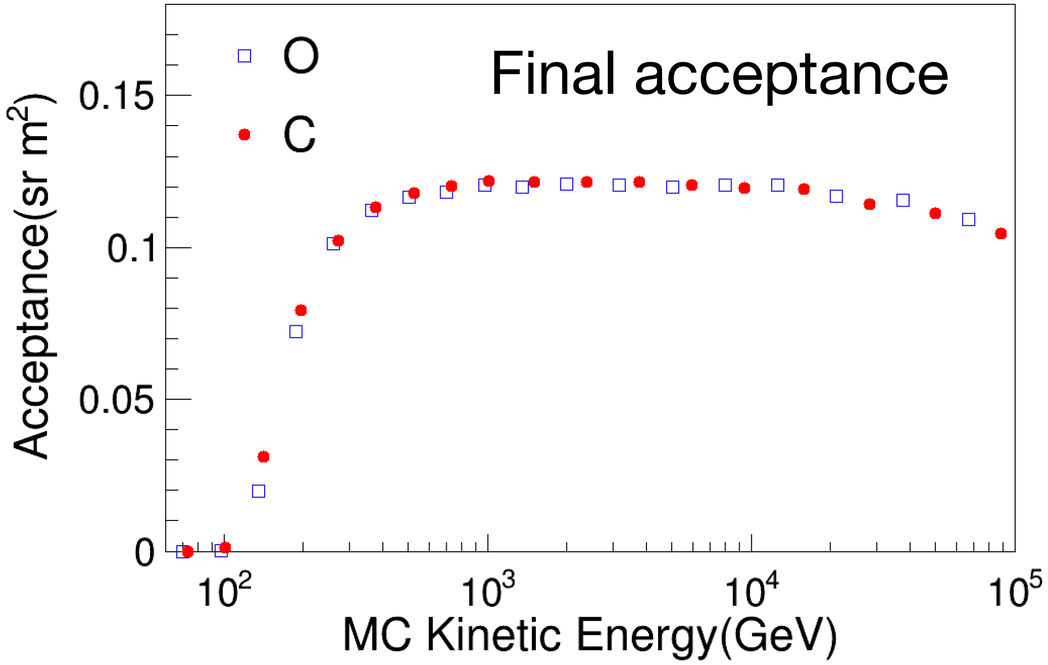


Effective Acceptance



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

- A_{gen} : the geometrical factor of the MC generation
- N_{gen} : the numbers of generated events
- N_{pass} : the numbers of events passing the selections

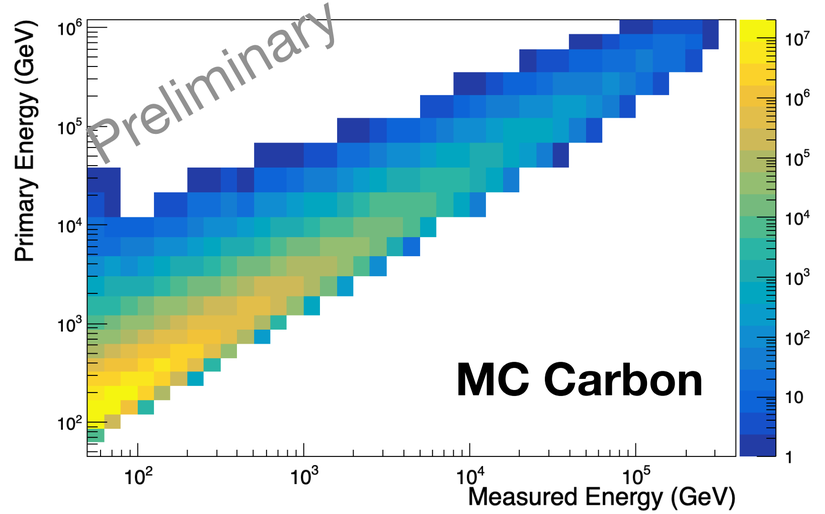


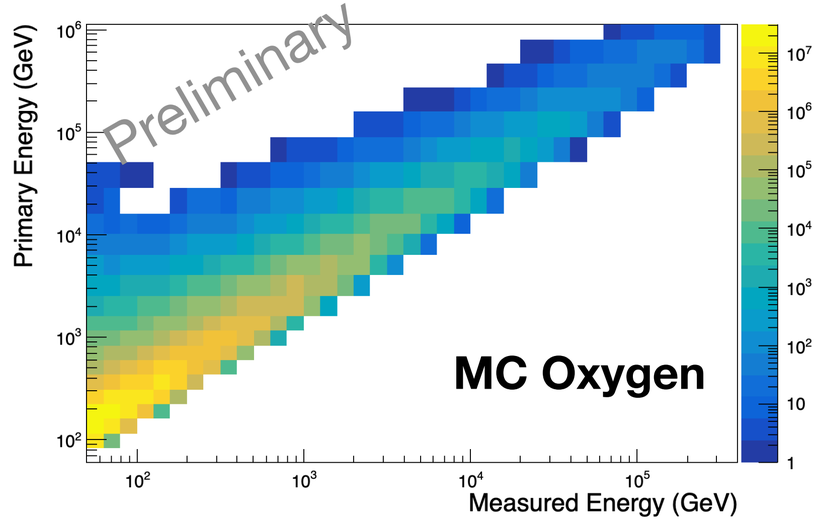
Energy Unfolding

- Convert the measured energy spectrum to the primary energy spectrum

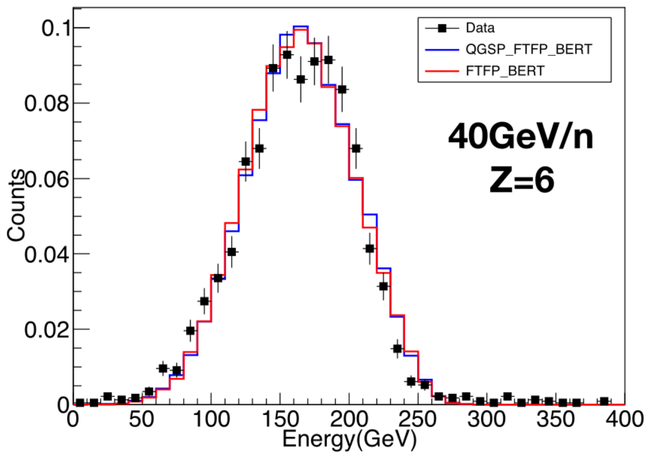
$$N_{Prim,i} = \Sigma M_{ij} N_{Meas,j}$$

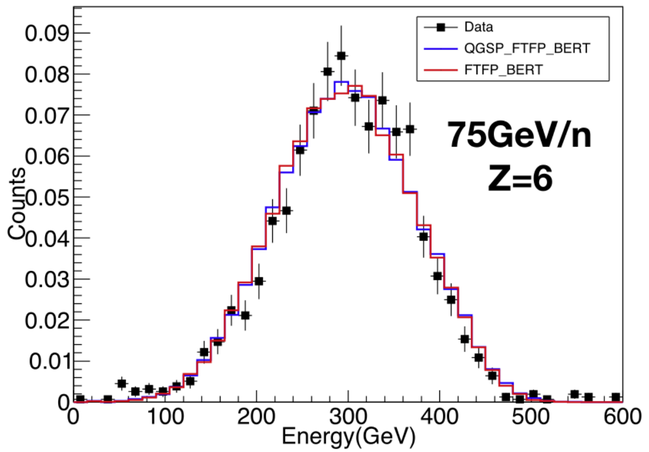
  - M_{ij} : Energy response matrix
  - $N_{Meas,i}$: Measured event number
  - $N_{Prim,i}$: Primary (unfolded) event number





- G4 FTFP_BERT model is validated with beam test below 1 TeV
- Deviation of Mean value < 2%

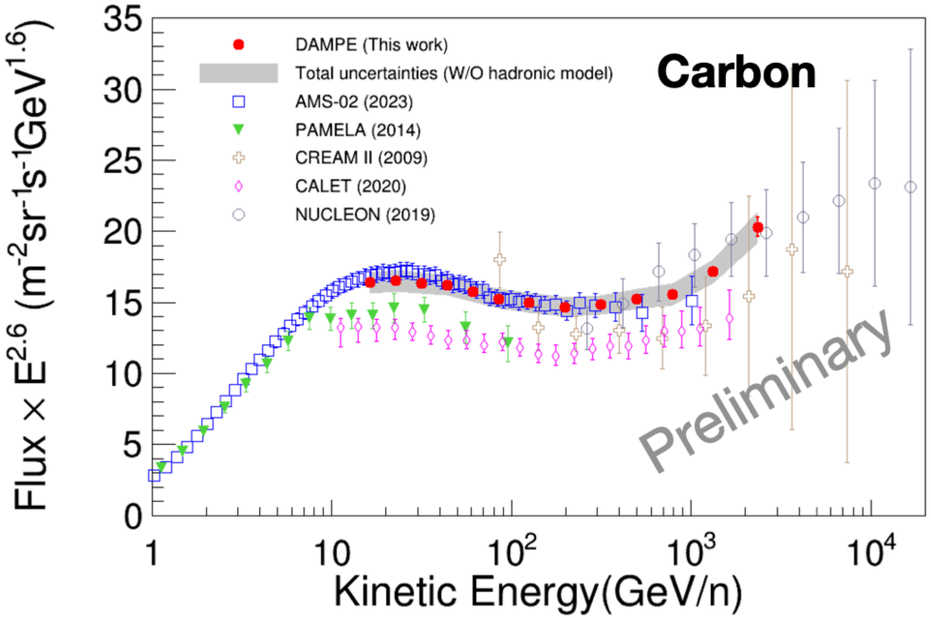


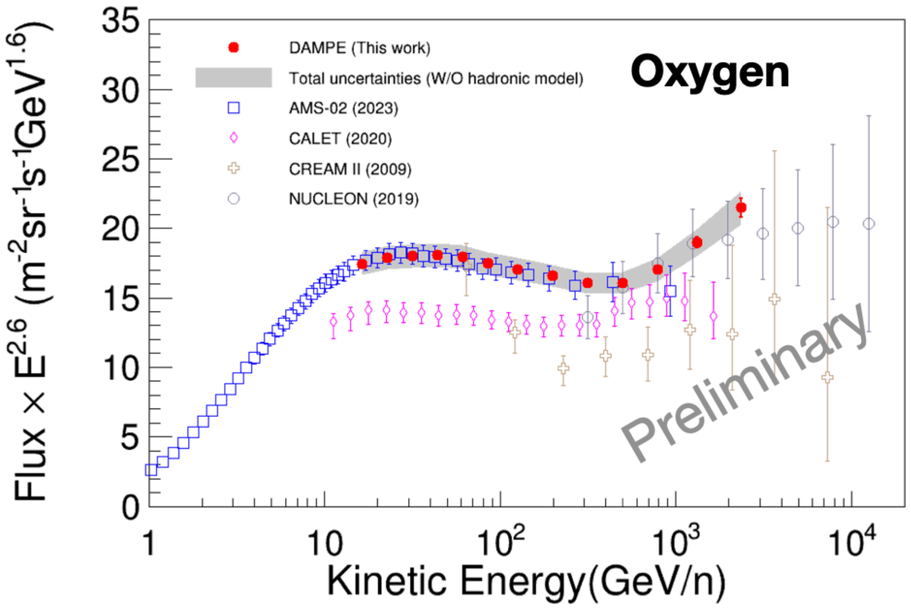


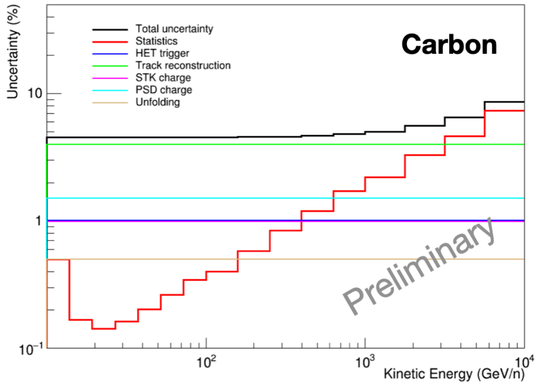
- BGO quenching effect is yet to be applied to the MC data

C & O Fluxes (13 GeV/n ~ 3.1 TeV/n)

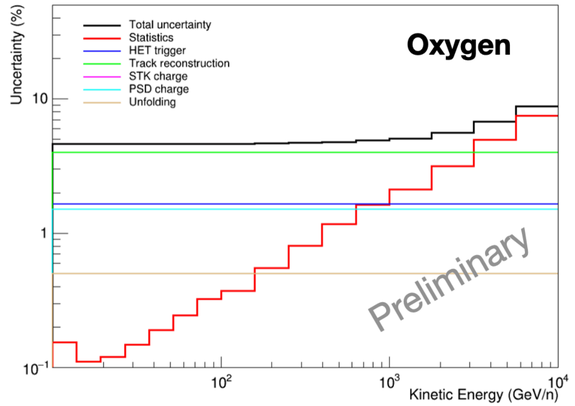
- Flux in i-th energy bin: $\Phi(E_i, E_i + \Delta E_i) = \dfrac{\Delta N_i}{\Delta E_i \; A_{\mathrm{eff},i} \; \Delta T}$







- **Uncertainties from hadronic models** are not included
- Expected to be 10% ~ 15% at various energies



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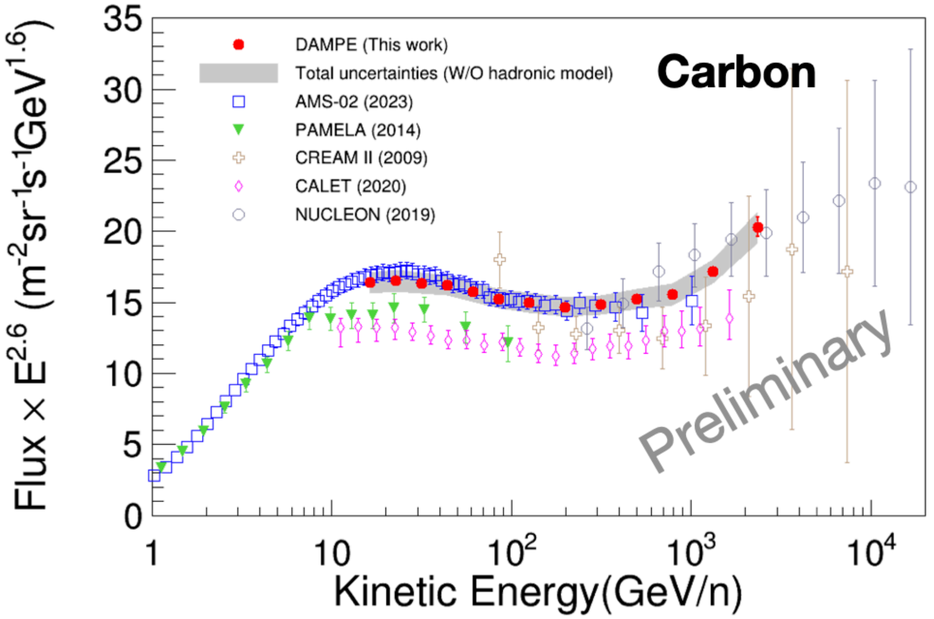

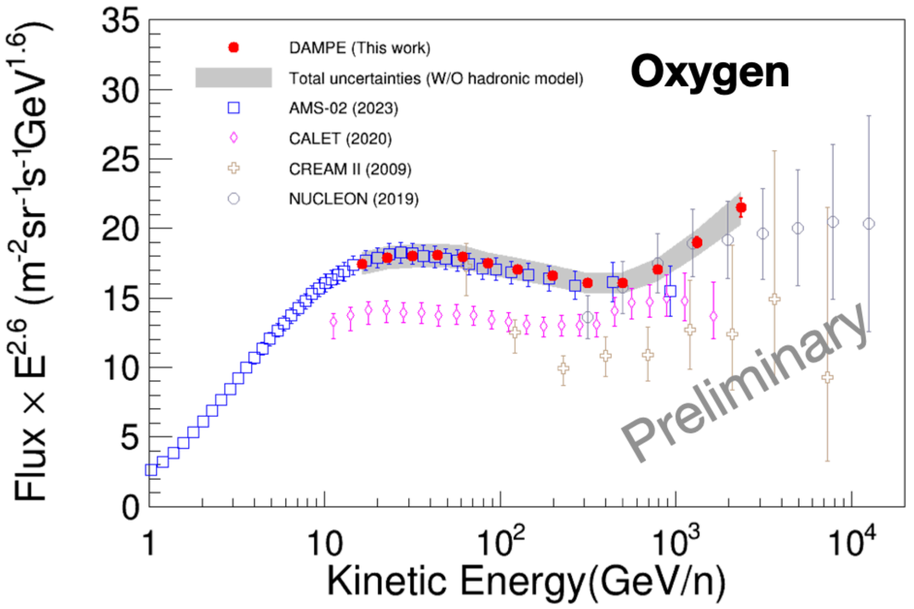

- Confirm the **hardening structure** at several hundred GeV/n observed by previous experiments

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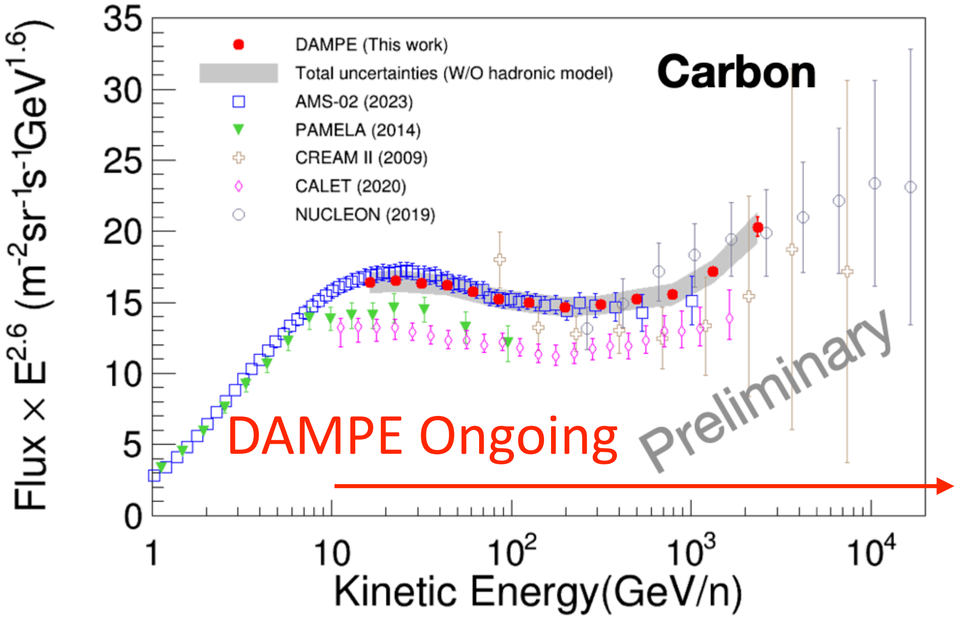
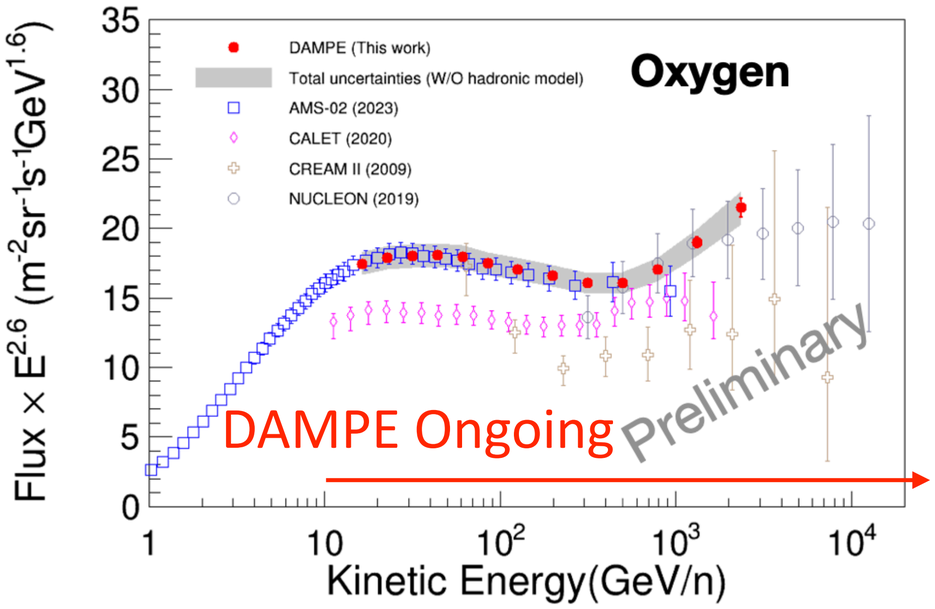
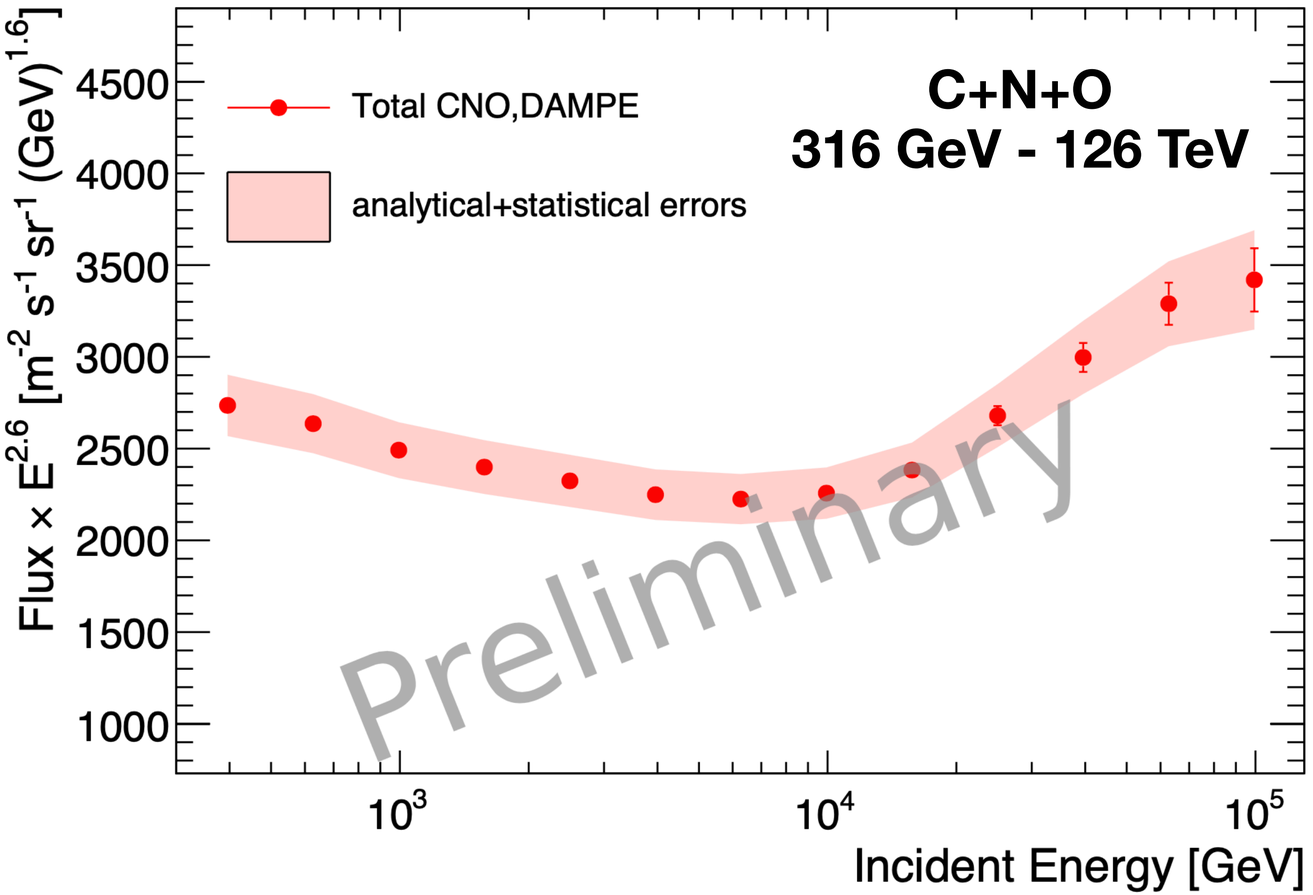




- Confirm the **hardening structure** at several hundred GeV/n observed by previous experiments
- DAMPE is expected to extend the measurements up to **tens of TeV/n**

CNO Group Measurement

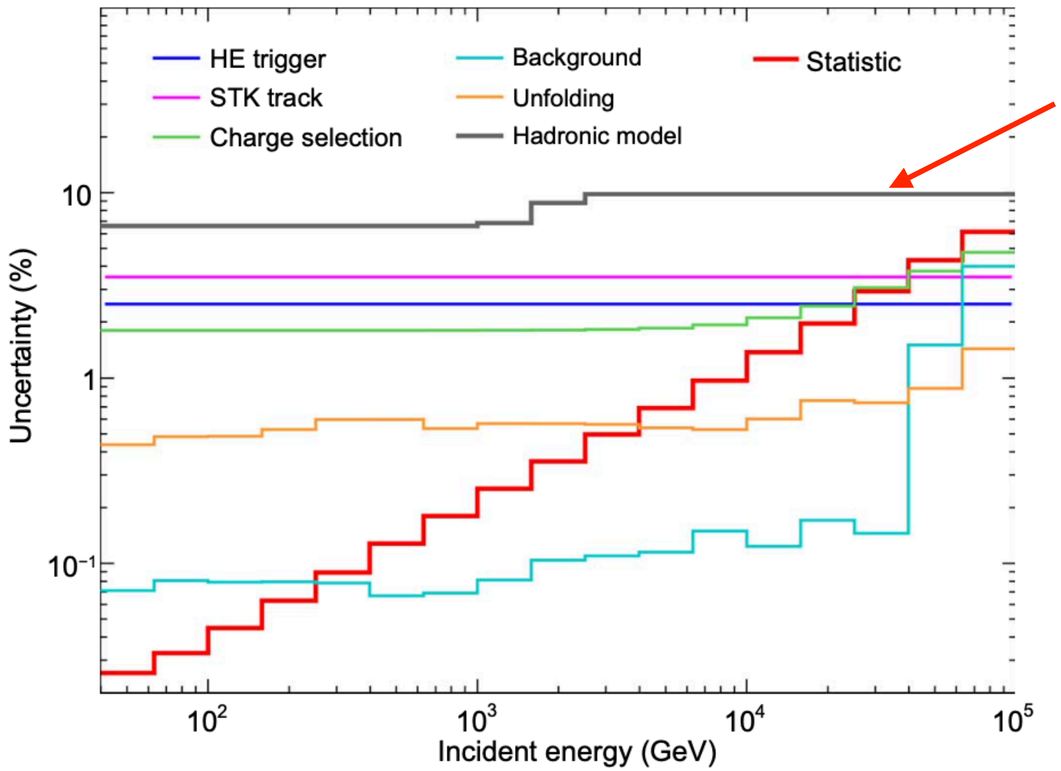
- The spectral measurement of the **carbon-nitrogen-oxygen** combined group with DAMPE



Hadronic Cross Section Measurement

- **Main source** of systematic uncertainty: hadronic model
- What depend on the hadronic model?
  - Energy response matrix
  - Trigger efficiency
  - Selection efficiency
  - …

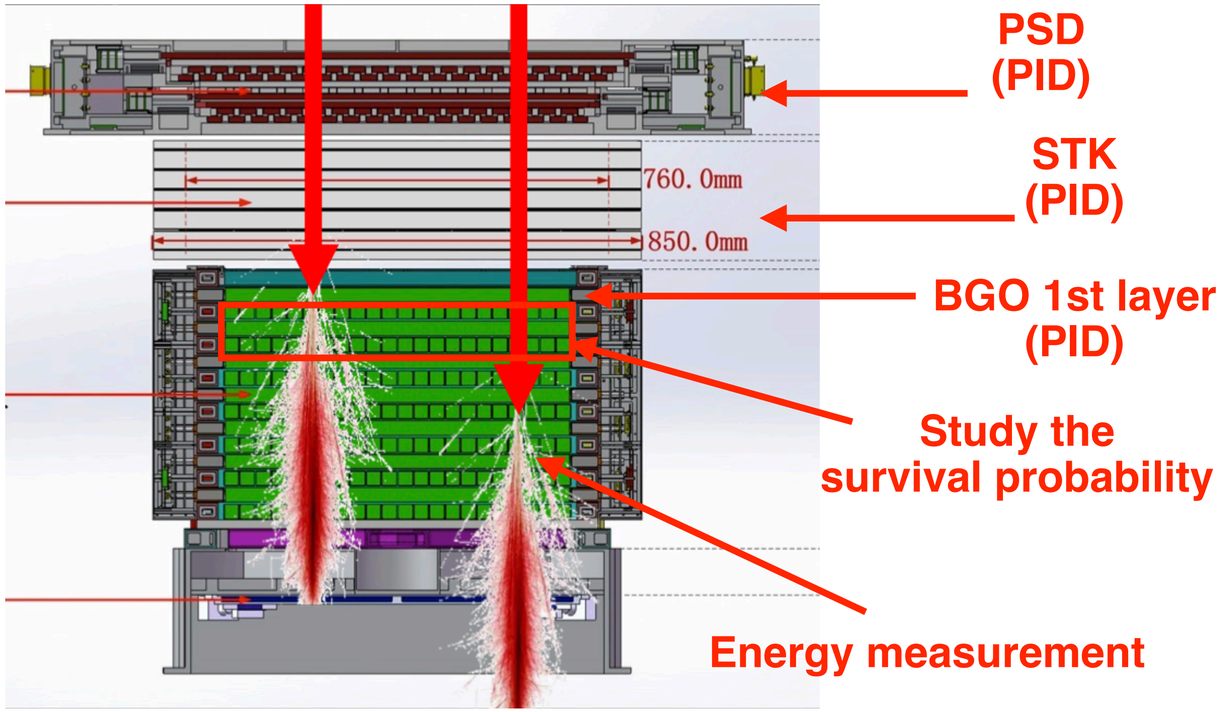
DAMPE Proton's uncertainties,
Sci. Adv. 5, eaax3793 (2019)



Hadronic Cross Section Measurement

- A detailed study regarding the hadronic model is needed
- We proposed a method to validate the MC hadronic cross section using DAMPE's flight data

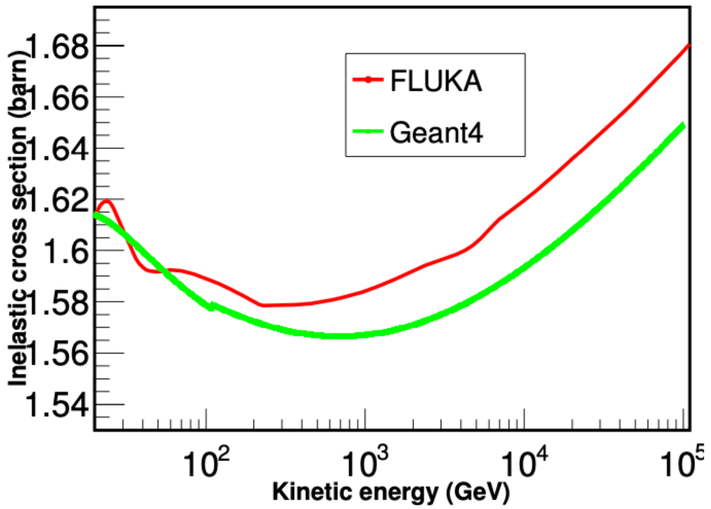
$$\varepsilon^{sur} = \frac{N_{out}}{N_{in}} = exp(-n \cdot l \cdot \sigma_{had})$$



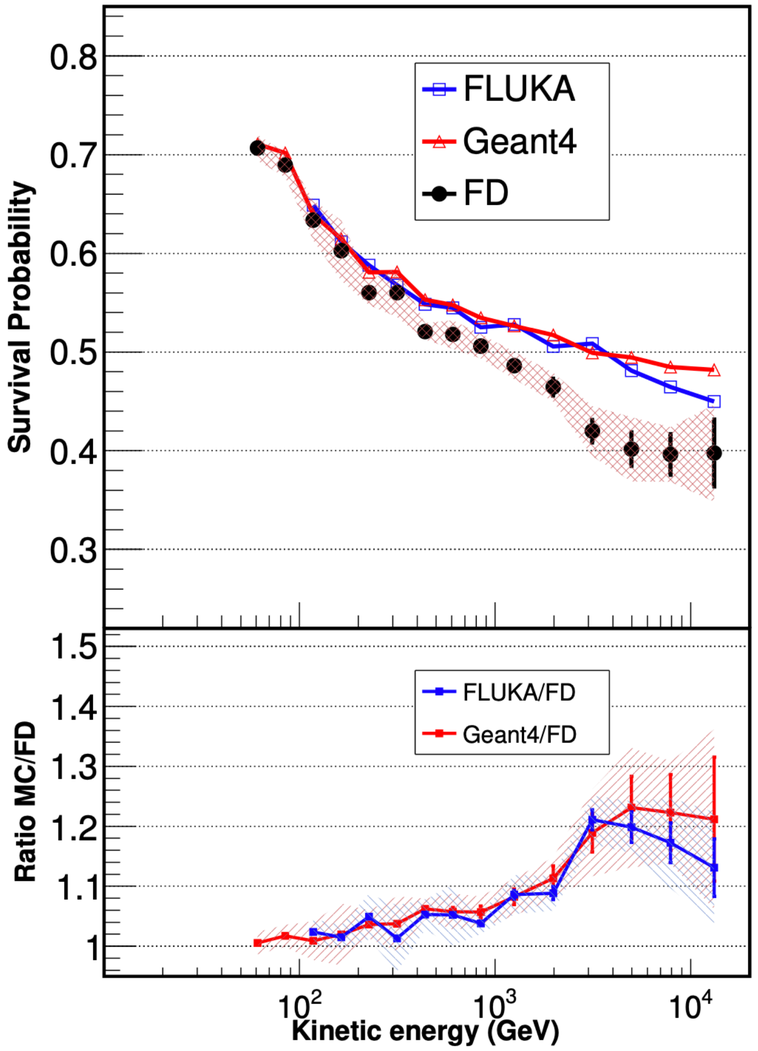
Hadronic Cross Section Measurement

Carbon

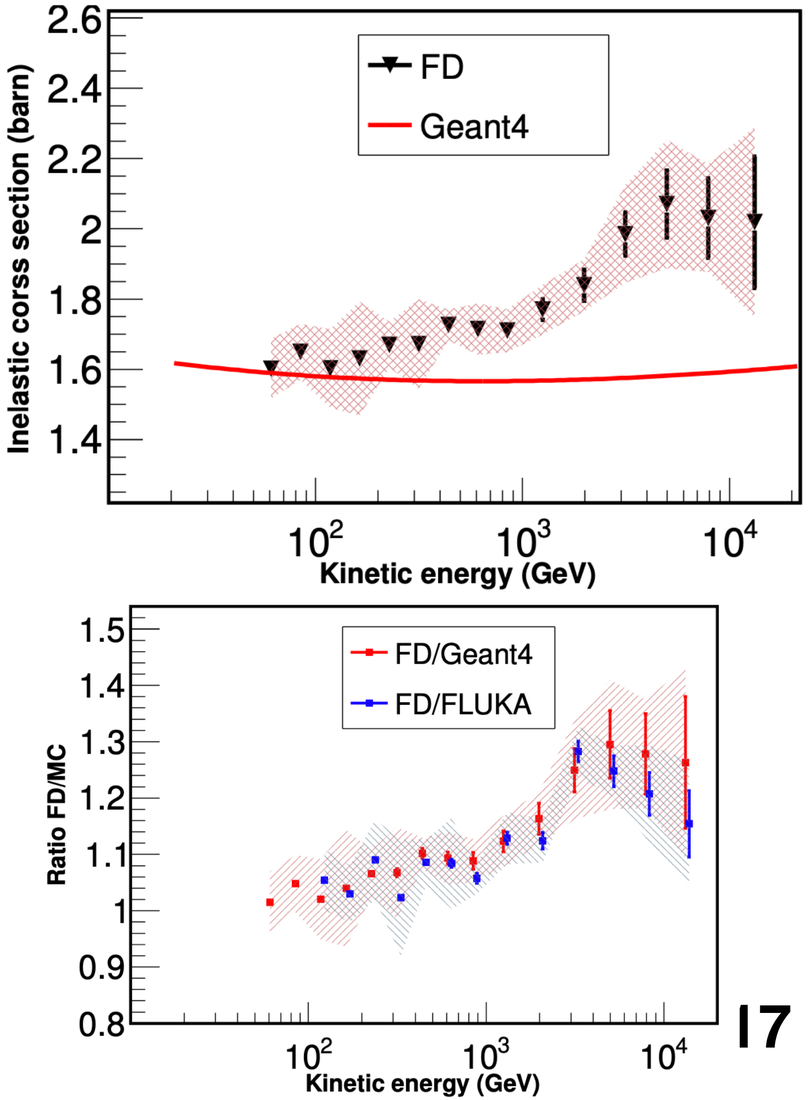
Cross section in MC



Survival probability



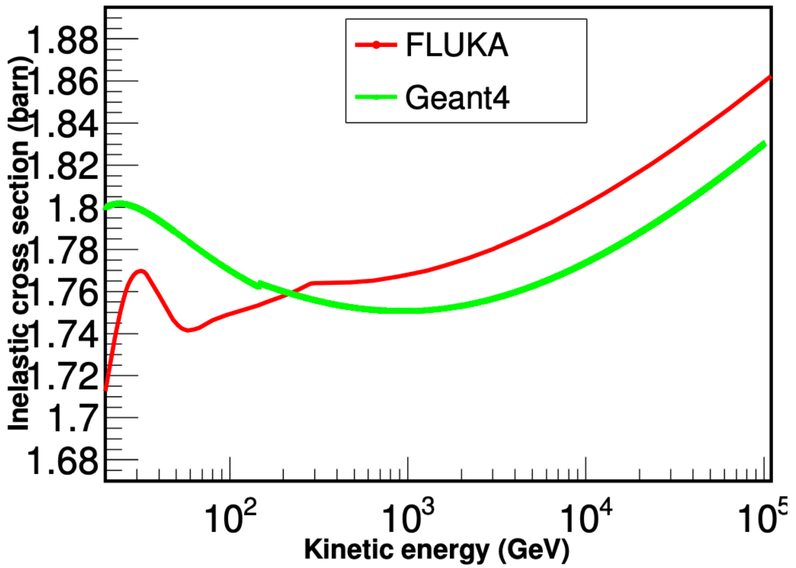
Cross section in Data



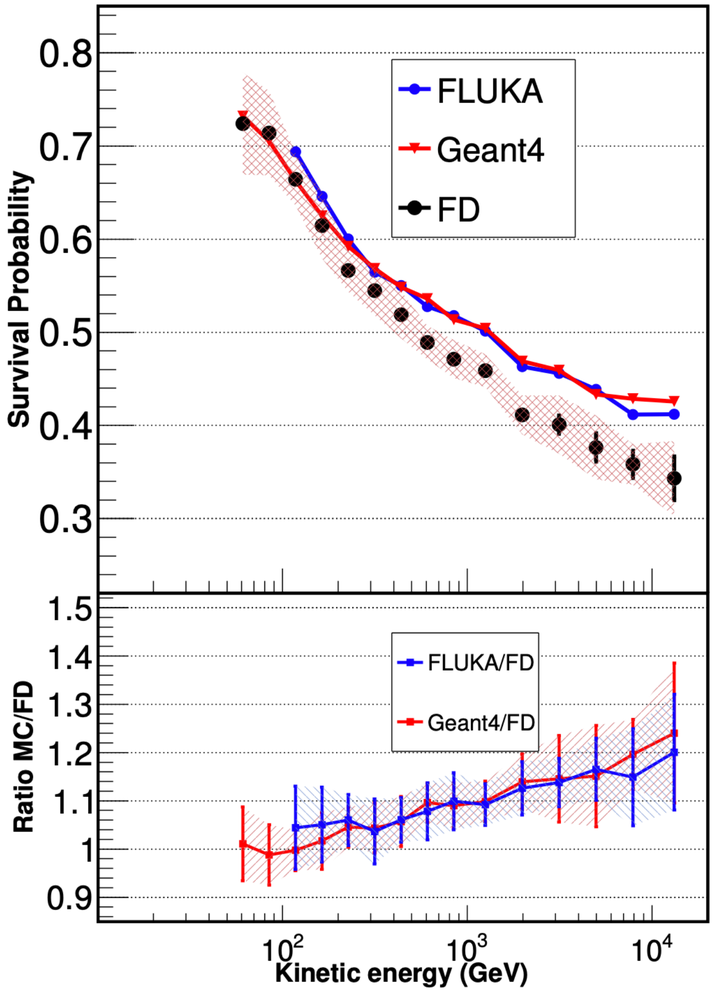
Hadronic Cross Section Measurement

Oxygen

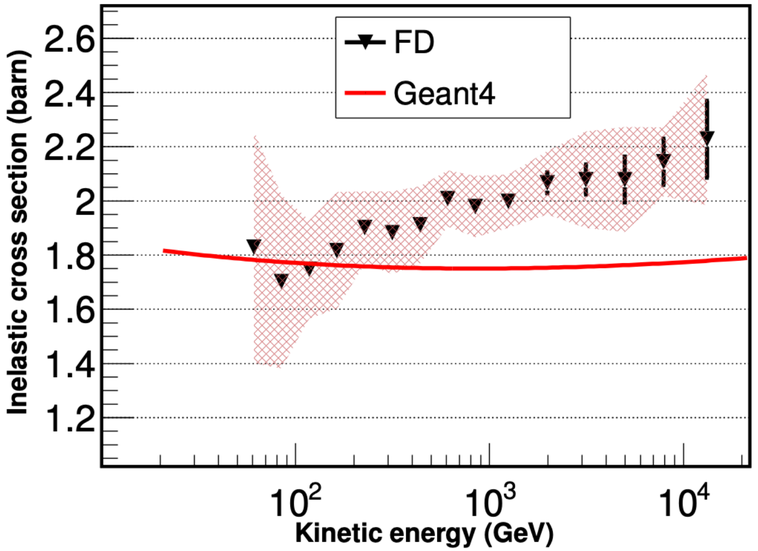
Cross section in MC

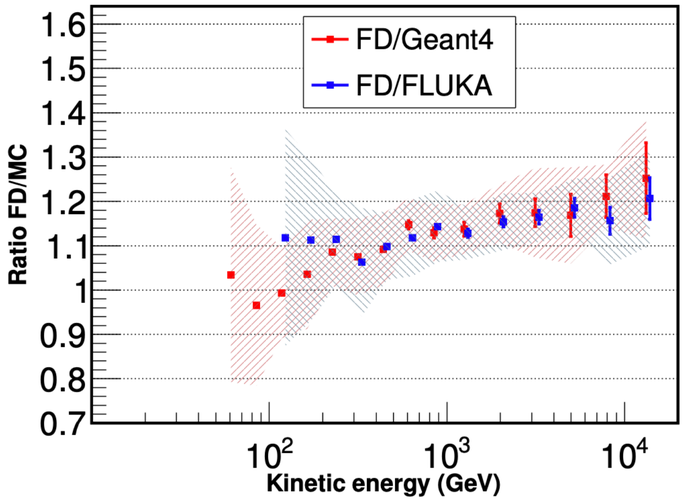


Survival probability



Cross section in Data





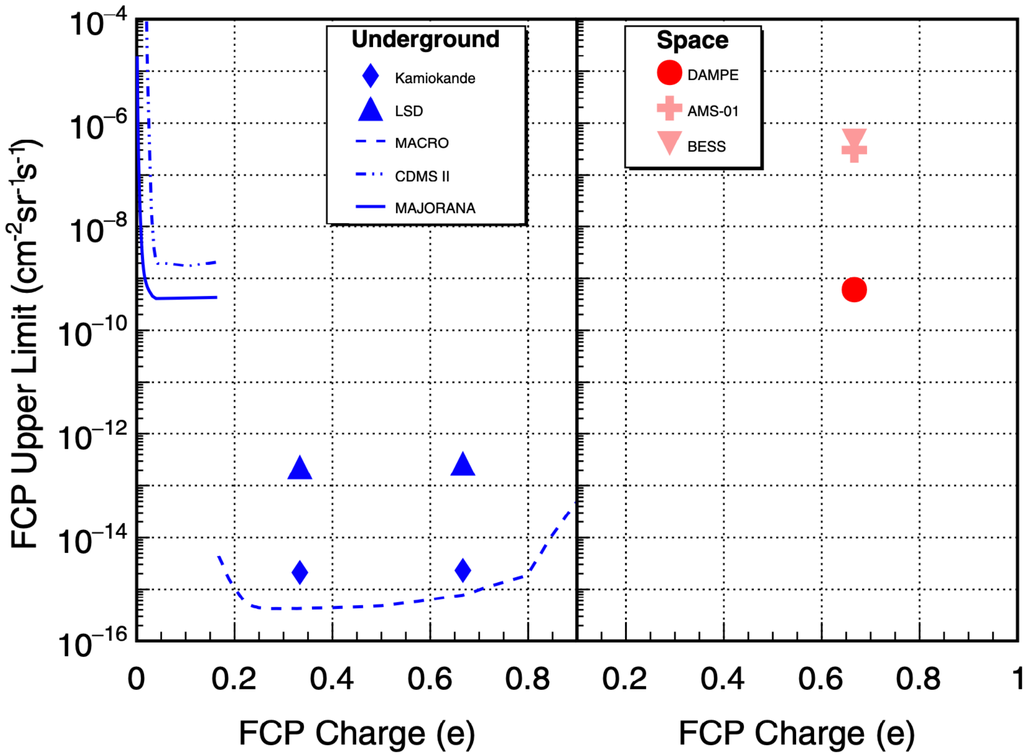
Searching for FCP in Cosmic Rays

- We search for 2/3e FCP with DAMPE experiment
- Space experiments can detect FCPs with energy as low as a few GeV
- No FCP signals are observed and a flux upper limit of $\Phi < 6.2 \times 10^{-10}\mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{s}^{-1}$ is established at the 90% C.L..

TABLE I. The comparison between DAMPE and other similar types experiments.

Experiments	Geometric acceptance(cm^{-2} sr)	Exposure time (s)	Upper limit (cm^{-2} sr^{-1} s^{-1})
AMS-01	3000	3.6×10^4	3.0×10^{-7} (95% CL)
BESS	1500	3.2×10^5	4.5×10^{-7} (90% CL)
DAMPE	3000	2.3×10^7	6.2×10^{-10} (90% CL)

$$\Phi < 6.2 \times 10^{-10}\mathrm{cm}^{-2}\,\mathrm{sr}^{-1}\,\mathrm{s}^{-1}$$



Phys. Rev. D 106, 063026 (2022)

Summary

- Seven years of DAMPE data are analyzed for the Carbon and Oxygen fluxes
- The preliminary results of Carbon and Oxygen fluxes from 13 GeV/n to 3.1 TeV/n is reported
- The DAMPE results confirm the spectral hardening at several hundred GeV/n found in previous experiments
- More studies are in processing, DAMPE's measurements will be extended up to tens of TeV/n in the near future.

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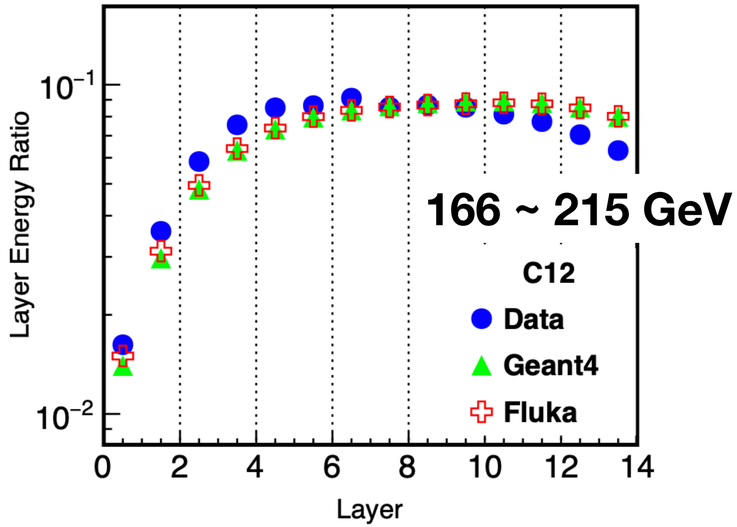
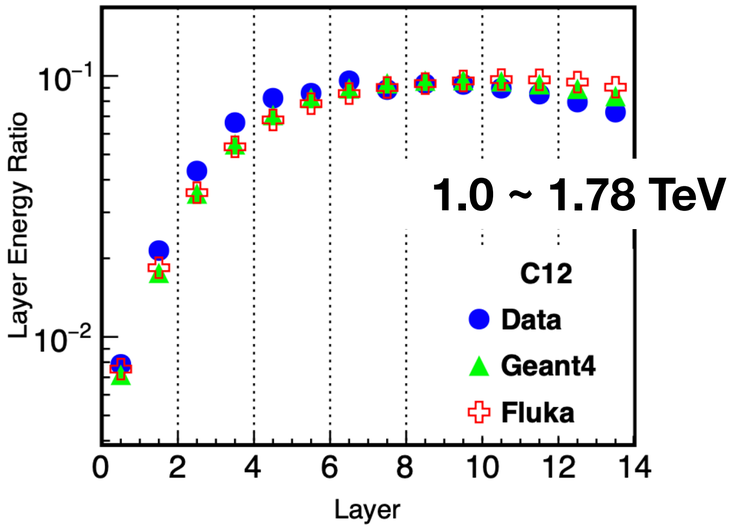
Thank you !

Backup

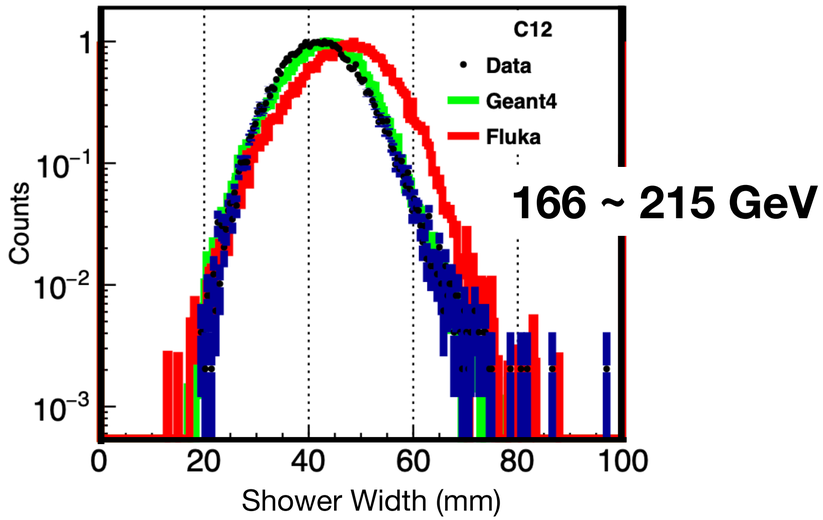
Validation of Energy Response

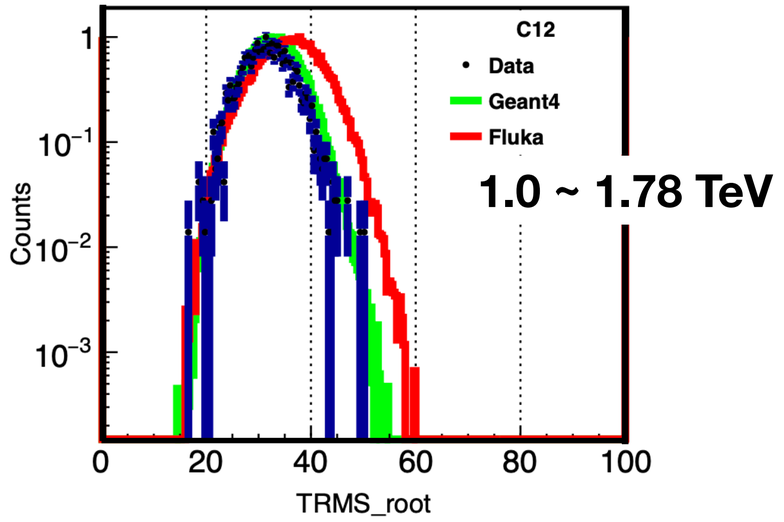
- Longitudinal shower profile





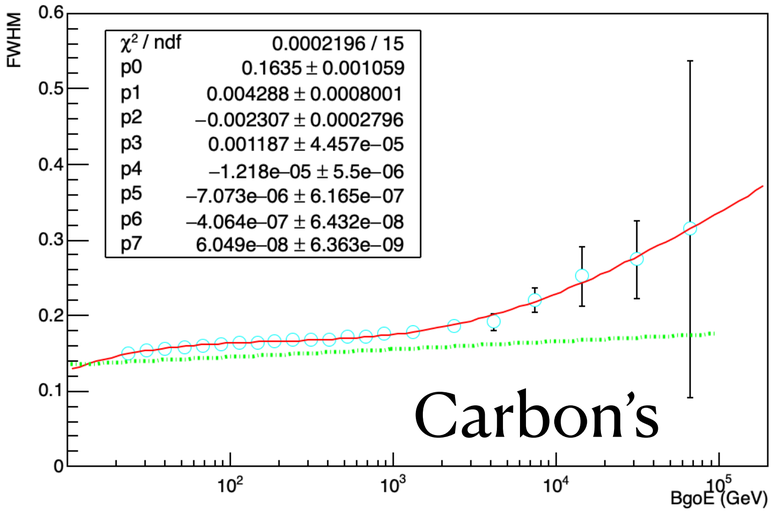
- Shower lateral width

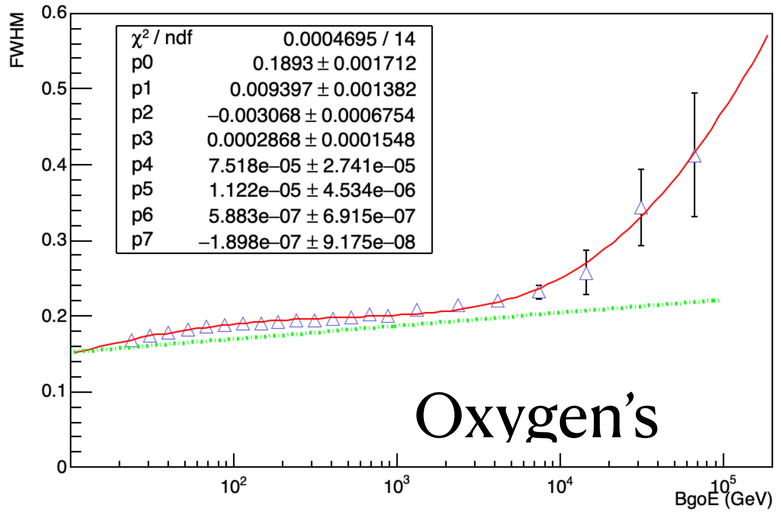




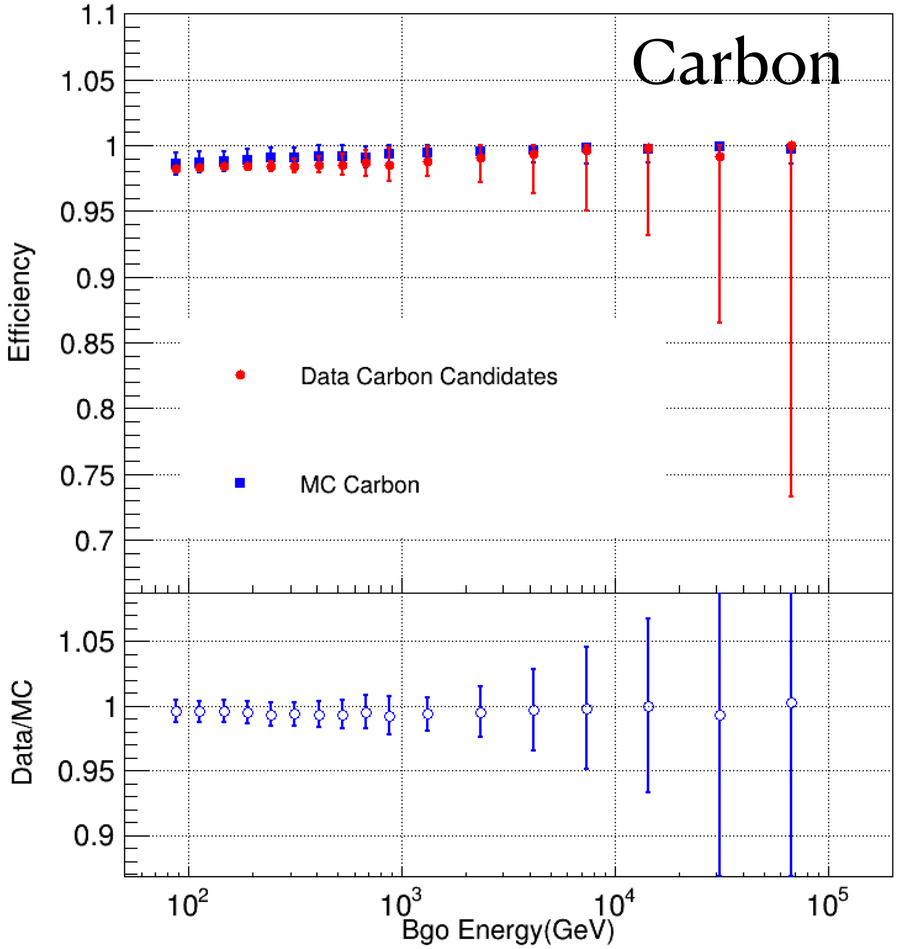
Charge Selection

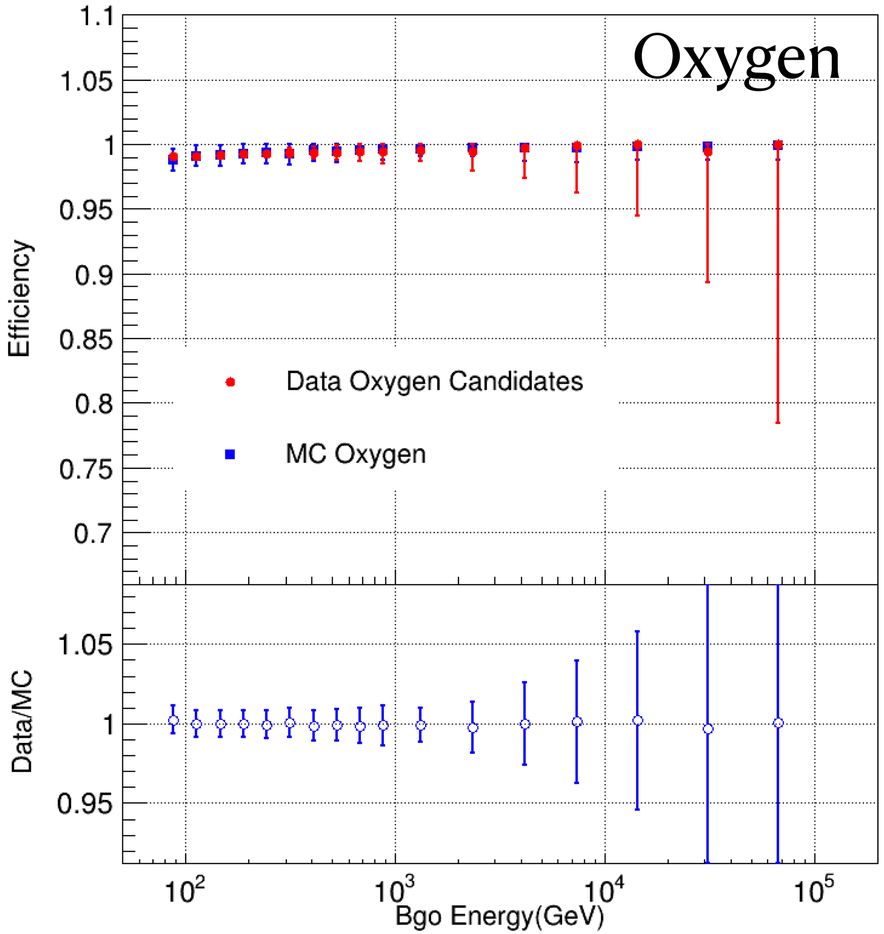
- Energy dependent charge cuts are applied for Carbon and Oxygen:
  - C: (6 - 2*FWHM, 6 + 2.5*FWHM)
  - O: (8 - 2*FWHM, 8 + 3.0*FWHM)





STK Pre Cut

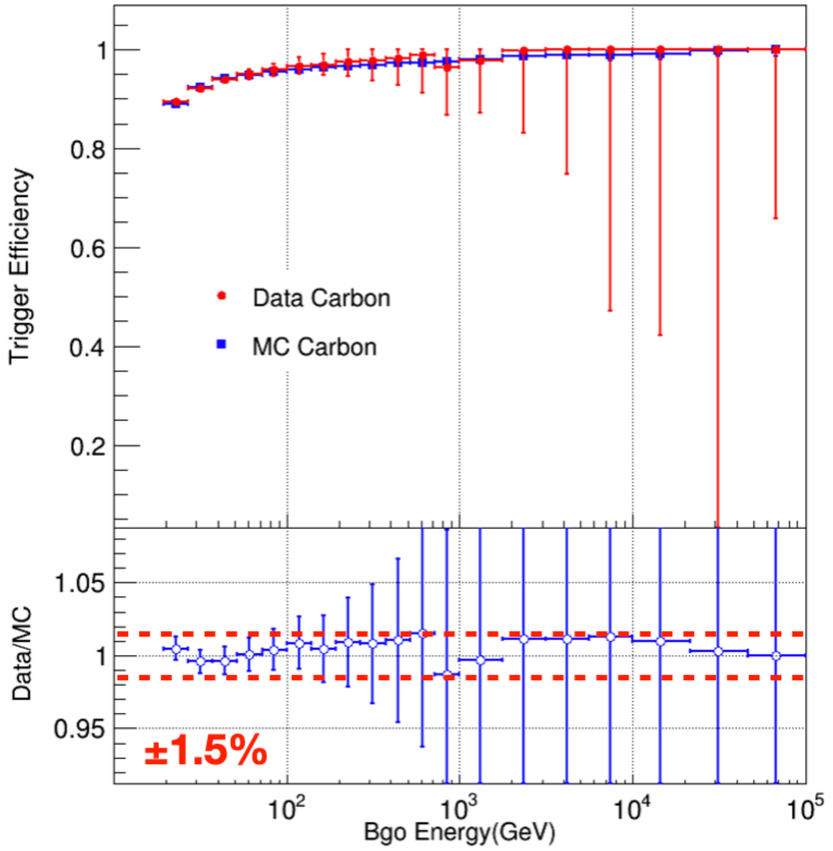

Carbon
Efficiency
Data Carbon Candidates
MC Carbon
Data/MC
Bgo Energy(GeV)


Oxygen
Efficiency
Data Oxygen Candidates
MC Oxygen
Data/MC
Bgo Energy(GeV)

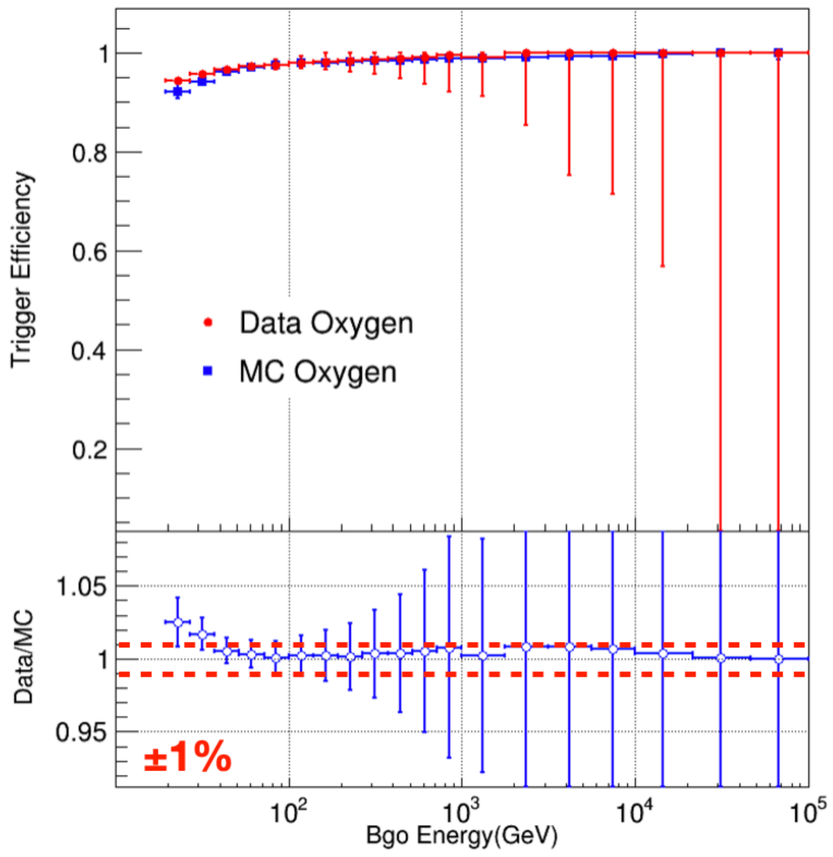
G3 Trigger Efficiency

$$\varepsilon_{trigger} = \frac{N_{G3\ G4}}{N_{G4}}$$

Carbon



Oxygen



Searching for FCP in Cosmic Rays