Latest Results on Cosmic Ray Carbon and Oxygen with the DAMPE space mission

Dimitrios Kyratzis, C. Yue, Y. F. Wei

on behalf of the DAMPE collaboration
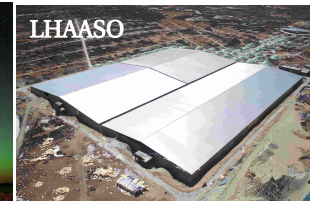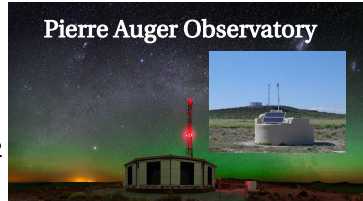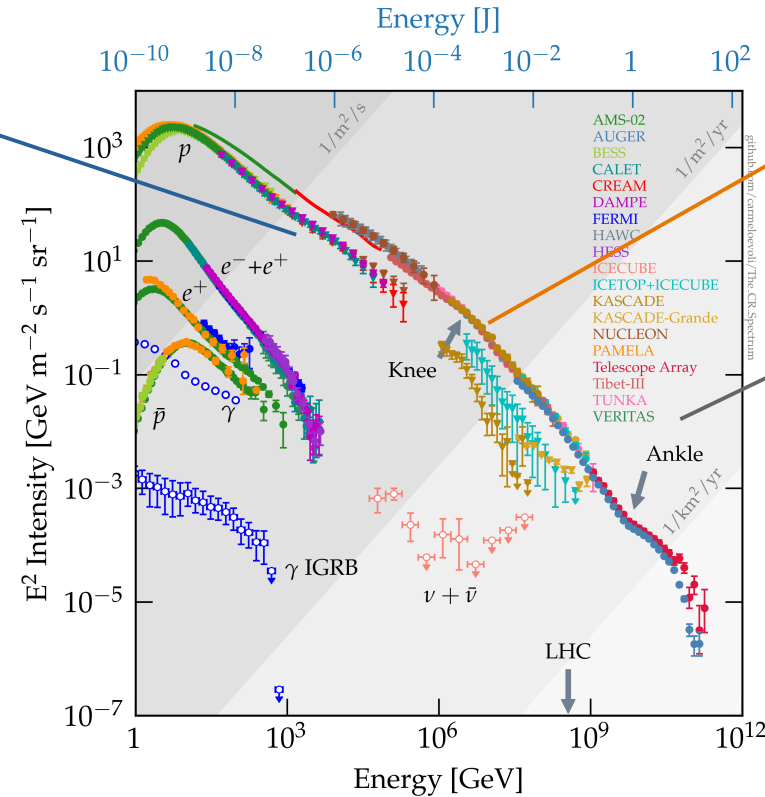
14/07/2024

The Cosmic Ray Landscape

Energies achieved with **current space – borne** direct CR experiments (~ hundred TeV)

Maximal energies achieved with direct detection CR experiments (~ PeV)

Region covered by **indirect CR experiments** (~ 10^{20} eV)

CALET

DAMPE

Fermi – LAT

AMS – 02

CTA North [future implementation]

Pierre Auger Observatory

LHAASO

Research Goals & Open Questions

Precise measurements of **CR spectra & mass composition**

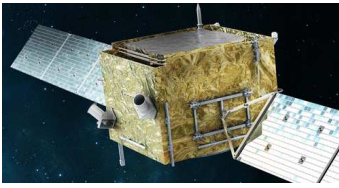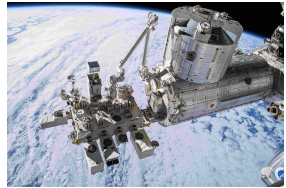Directly probing fine **spectral structures** (hardenings/softenings)

Understanding CR **acceleration & propagation** mechanisms

An analogy from Plato's Academy in Athens

Plato

Aristotle

COSPAR 2022
44th SCIENTIFIC ASSEMBLY
16-24 July 2022, Athens, Greece
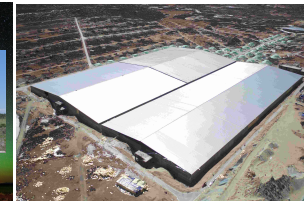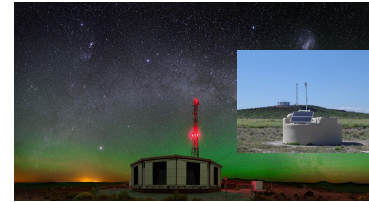aMUSEd by the Athenian URANIA

Space – borne experiments

Ground – based experiments

Raphael, *The School of Athens,* (1509-1510)

Direct CR experiments

Precise measurement of particle **charge + energy**

Small exposure for statistically meaningful measurements **above few tens of TeV/n.**

Indirect CR experiments

Huge achievable energies

Difficulty in making composition studies **with small systematics**

The Dark Matter Particle Explorer

Orbit: Sun – synchronous, 95 min

Altitude: 500 km (LEO)

Payload: 1300 kg

Launched on Dec 17th 2015

Jiuquan Satellite Launch Center
Gobi desert, China

The Collaboration
International synergy between Chinese,
Italian & Swiss institutes/universities.

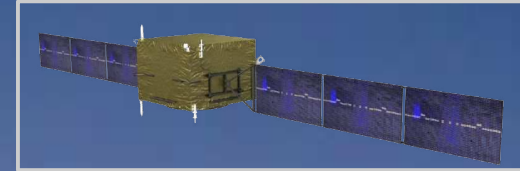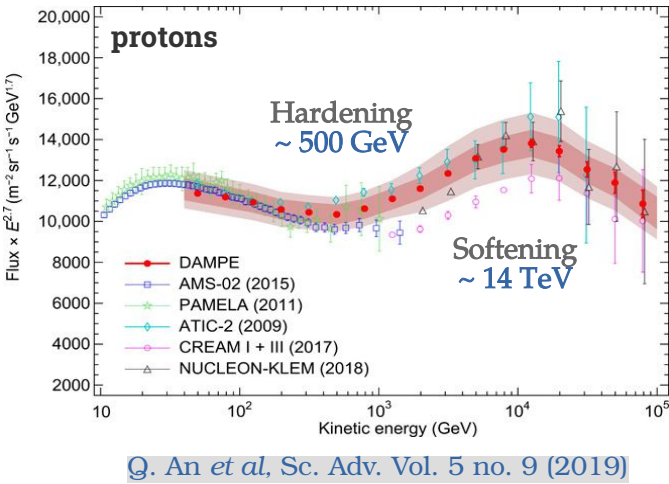## Main scientific objectives

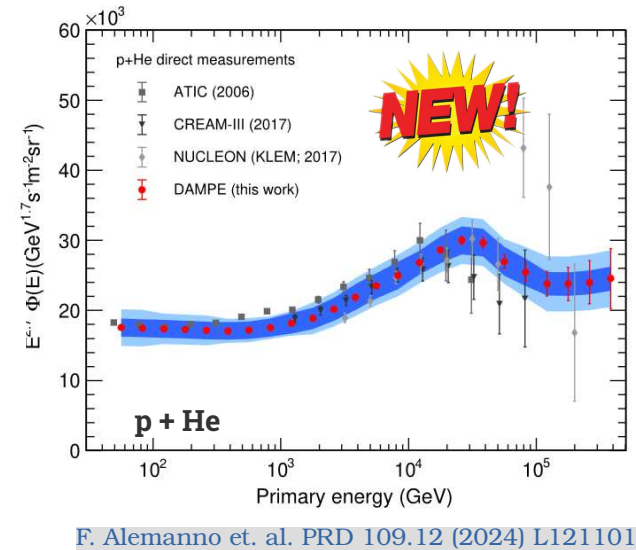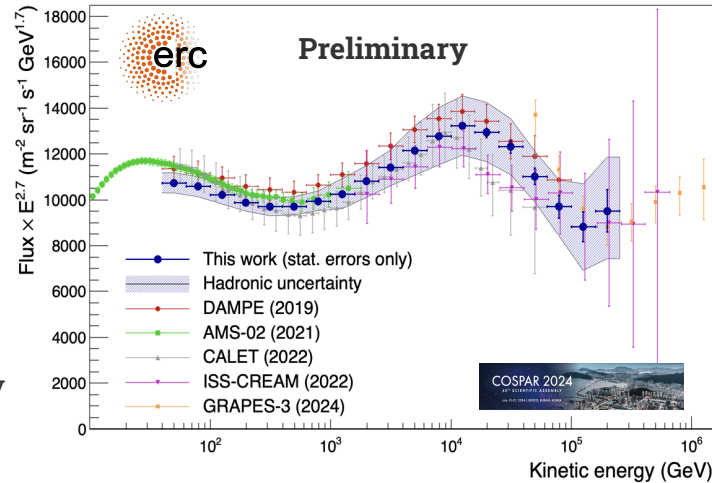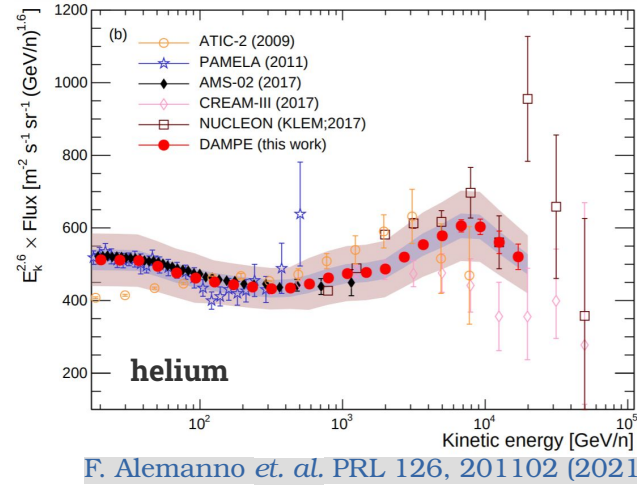**CRs:** All-electron, proton & nucleonic spectra w/ great precision

γ – rays: Insight on high-energy γ astronomy, transient studies, etc

DM: Indirect studies on possible DM candidates

DAMPE Collaboration, Astropart. Phys., 95, 6 [2017]

F. Alemanno *et. al.* PRL 126, 201102 (2021)

protons

Hardening
~ 500 GeV

Softening
~ 14 TeV

Q. An *et al*, Sc. Adv. Vol. 5 no. 9 (2019)

Latest proton spectrum presented by
A. Tykhonov [COSPAR 2024]

Preliminary

F. Alemanno et. al. PRD 109.12 (2024) L121101
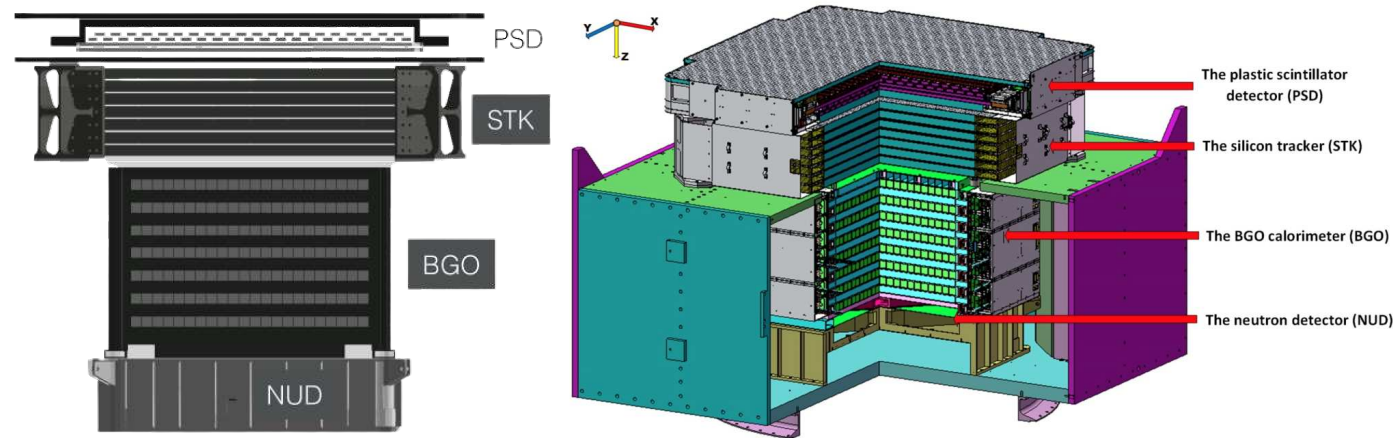
Main Features

Energy range (e/γ)	10 GeV - 10 TeV
Energy range (CRs)	50 GeV − 200 TeV
Energy resolution (e/γ)	< 1.5% @ 800 GeV
Energy resolution (p)	< 40% @ 800 GeV
Geometric Factor (e)	> 0.3 m^2sr @ 30 GeV
Calorimeter specs	32 X_0, 1.6 Λ_I
Field of View	~1.0 sr

PSD: **Anti − coincidence** detector for gammas and charge measurement

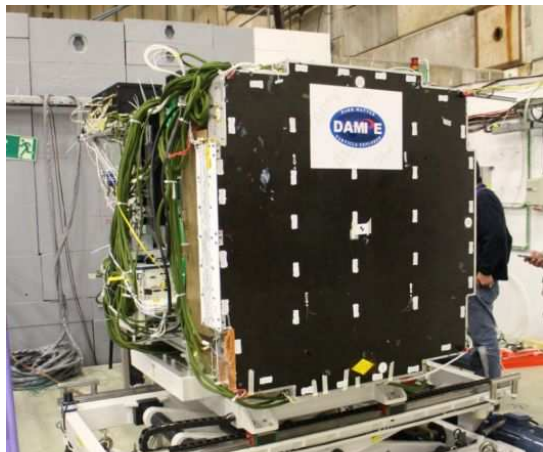**STK:** **Particle tracker**, photon converter & additional charge measurement

BGO: **Energy measurement** & particle identification via shower topology

NUD: **Further particle ID** from electromagnetic & hadronic showers

Calculated for CR electrons
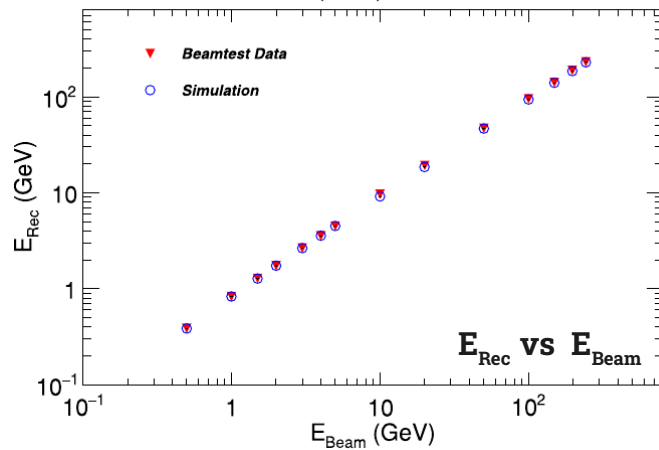
DAMPE [0.3 m^2sr]
CALET [0.1 m^2sr]
AMS-02 [0.05 m^2sr]
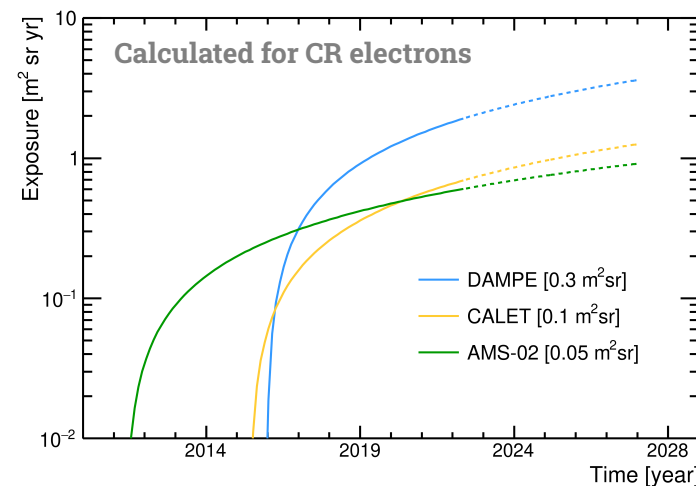
DAMPE features & performance validation

DAMPE @ CERN – SPS

C. Zhao et al., NIM A (2022)

- ▼ *Beamtest Data*
- ○ *Simulation*

E_{Rec} **vs** E_{Beam}

DAMPE Collaboration, Astropart. Phys., 95, 6 [2017]

Energy resolution e^- & γ

- normal incidence
- 30 deg incidence
- normal beam test

Flight data - Daily event count

C & O analysis: 8 yrs of DAMPE flight data

2020-03-07
Stuck MIP mode

2021-08-23
Stuck MIP mode

2023-04-23 to
2023-04-24
FPGA failure

2016-09-07
DAC calibration

2017-12-29
HV Incident

<2016-02-01
UNB trigger off
<2016-03-25
on-orbit testing

2021-05-22
Payload poweroff

2022-02-14
GPS timing
system failure

2022-12-12 to
2022-12-13
FPGA chip
failure

2023-03-17
FPGA
failure

Stable & continuous data taking

PSD Charge Identification

H, He, Be, B, C, O, Ne, Mg, Si, S, Ar, Ca, Ti, Cr, Fe, Ni

T. Dong et. al. Astropart. Phys. v. 105, (2019)

Individual C & O spectra

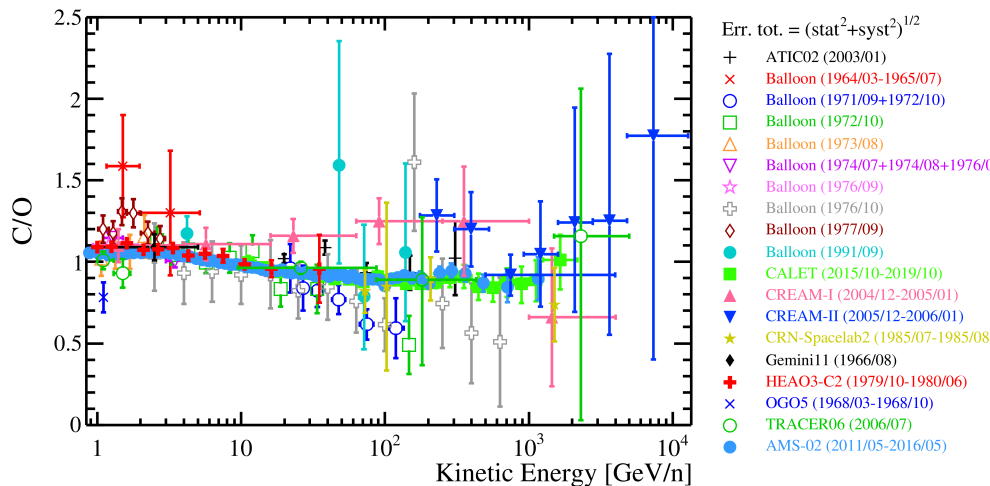Hardening features
at ~ hundred **GeV/n**
+
Possible new findings
at ~ **TeV/n**
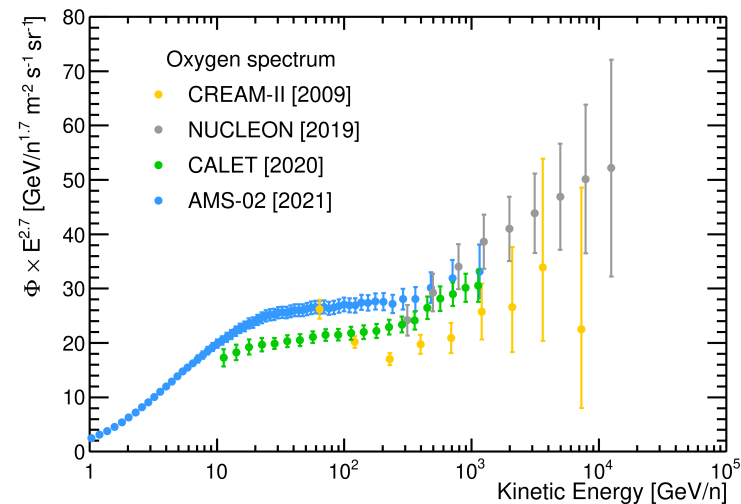
What's needed?

**Extension in multi-TeV/n
w/ great precision**
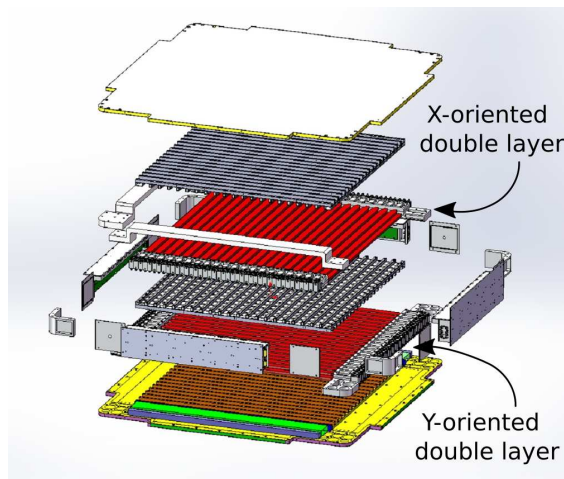
**Understand discrepancies
between experiments**

Analysis Selections

Exclusion of SAA flight data

Energy deposited in BGO: $E_{BGO} > 70$ GeV

High Energy Trigger (HET) activation

$E_{BGO,0} + E_{BGO,1} < E_{BGO,2} + E_{BGO,3}$

$E_{maxLayer}/E_{BGO} < 0.35$

8 years of DAMPE data

BGO – STK match:

STK track based on ML techniques

XZ and YZ projections on top of STK < 200 mm & BGO < 60 mm

Same track ID for XZ and YZ views

BGO Fiducial cut:

In Z = [46, 448] mm and in XY = 280 mm

PSD Fiducial cut:

Track projection on first PSD layer < 400 mm

PSD – STK match:

Selecting bar crossed by STK both in XZ & YZ, from PSD bars
within: PSD_YZ_Top = -324.7 mm PSD_XZ_Top = -298.5 mm

Carbon – XZ view

Carbon – YZ view

Flight data event displays @ 1.4 TeV

Oxygen – XZ view

Oxygen – YZ view

Multiple DAMPE groups involved in the analysis

Progressing PSD charge selection:
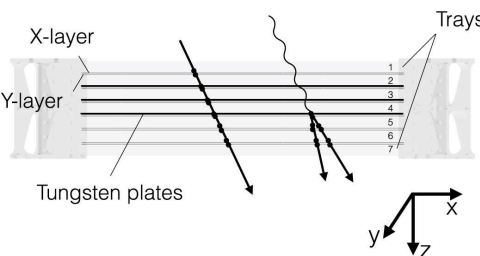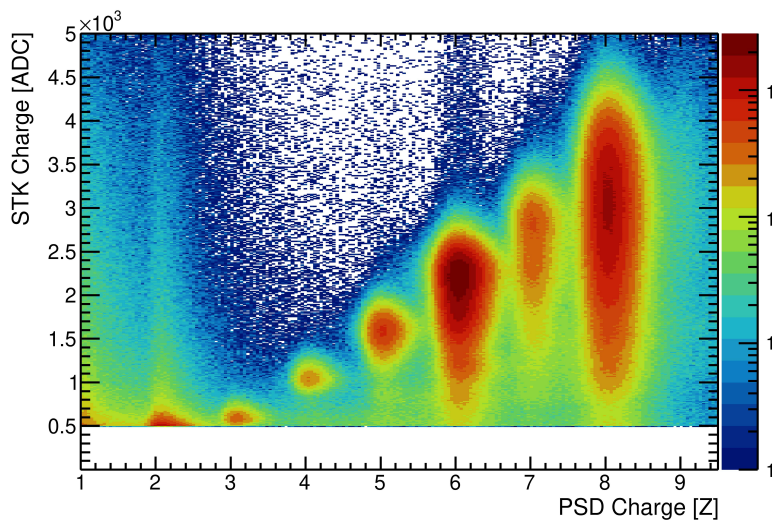
$$Q^{PSD} = \frac{\sum_i Q_i^{PSD}}{N_{Layers}}$$

i = index of consecutive layers
with non-zero charge, while satisfying:

$$\left| Q_i^{PSD} - Q_{i+1}^{PSD} \right| < 2$$

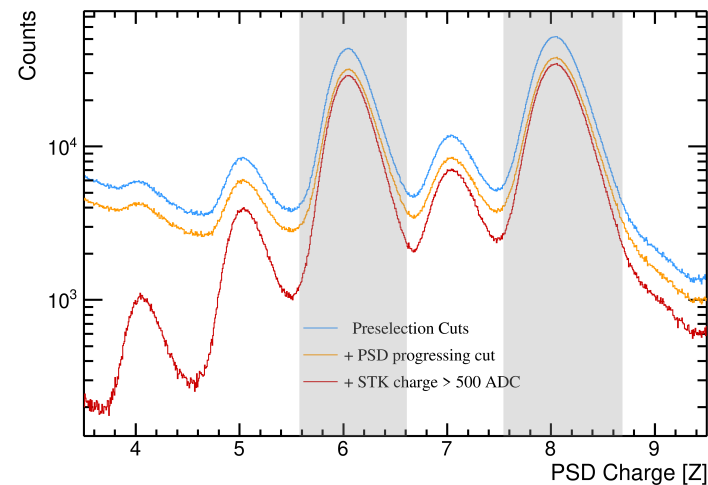X-oriented double layer

Y-oriented double layer

Selection cut sequence

- Preselection Cuts
- + PSD progressing cut
- + STK charge > 500 ADC

Maximizing C & O sample purity

15-20% increased acceptance
with ML tracking techniques

erc

A. Tykhonov, et al. Astroparticle Physics, 146 (2023) 102795

Taking into account the FIRST STK plane

Trays

X-layer

Y-layer

Tungsten plates

$$Q^{STK} = \frac{\sum_j Q_j^{STK}}{N_{Layers}} > 500 \; ADC$$
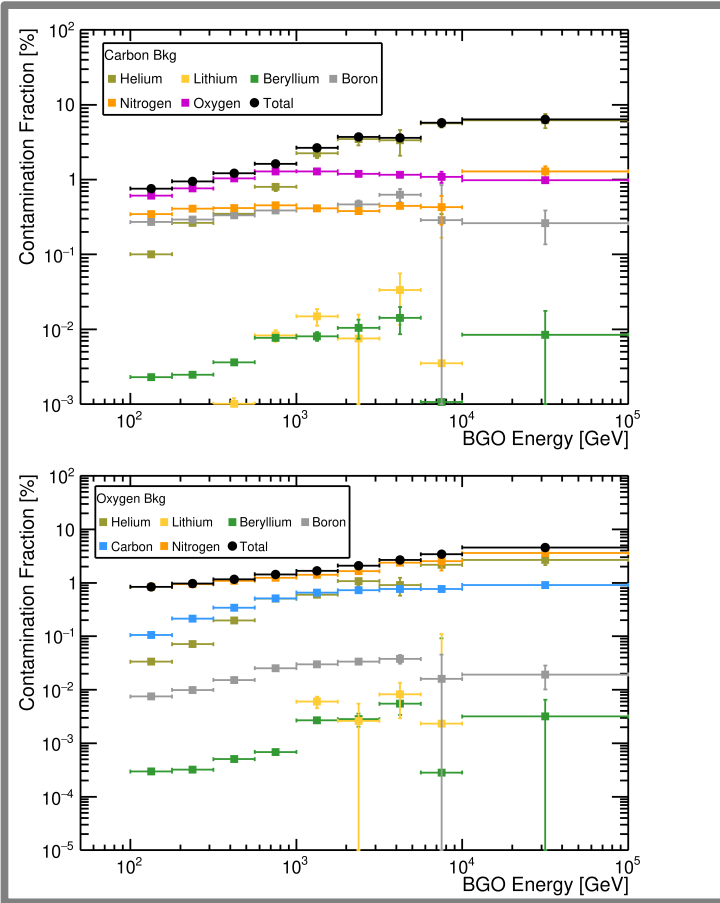
Data vs MC | Template fits

Both GEANT4 and FLUKA simulations were tested w/ DAMPE software

Flight & simulated data of He, Li, Be, B, C, N and O used towards the contamination estimation
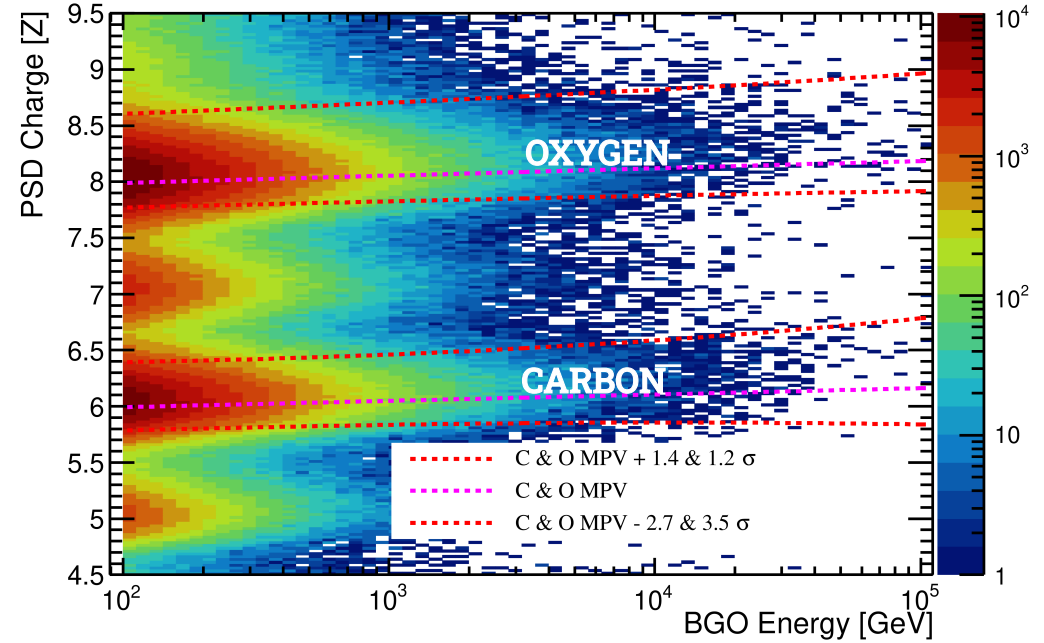

Good agreement between Flight data and Monte Carlo

<BGO Energy>
@ 237 GeV

<BGO Energy>
@ 2.3 TeV
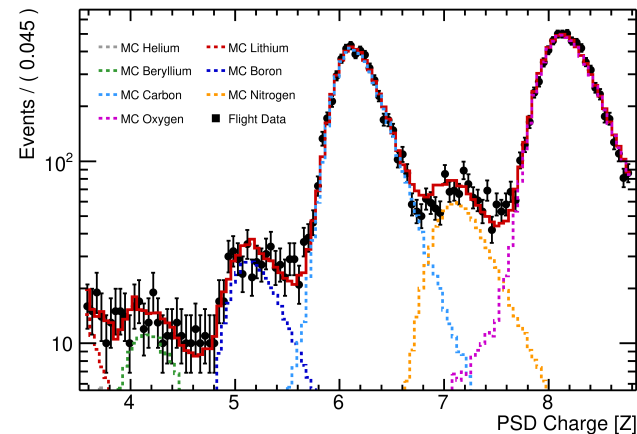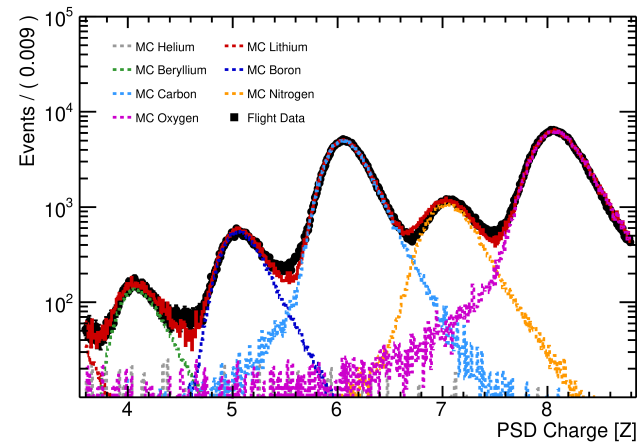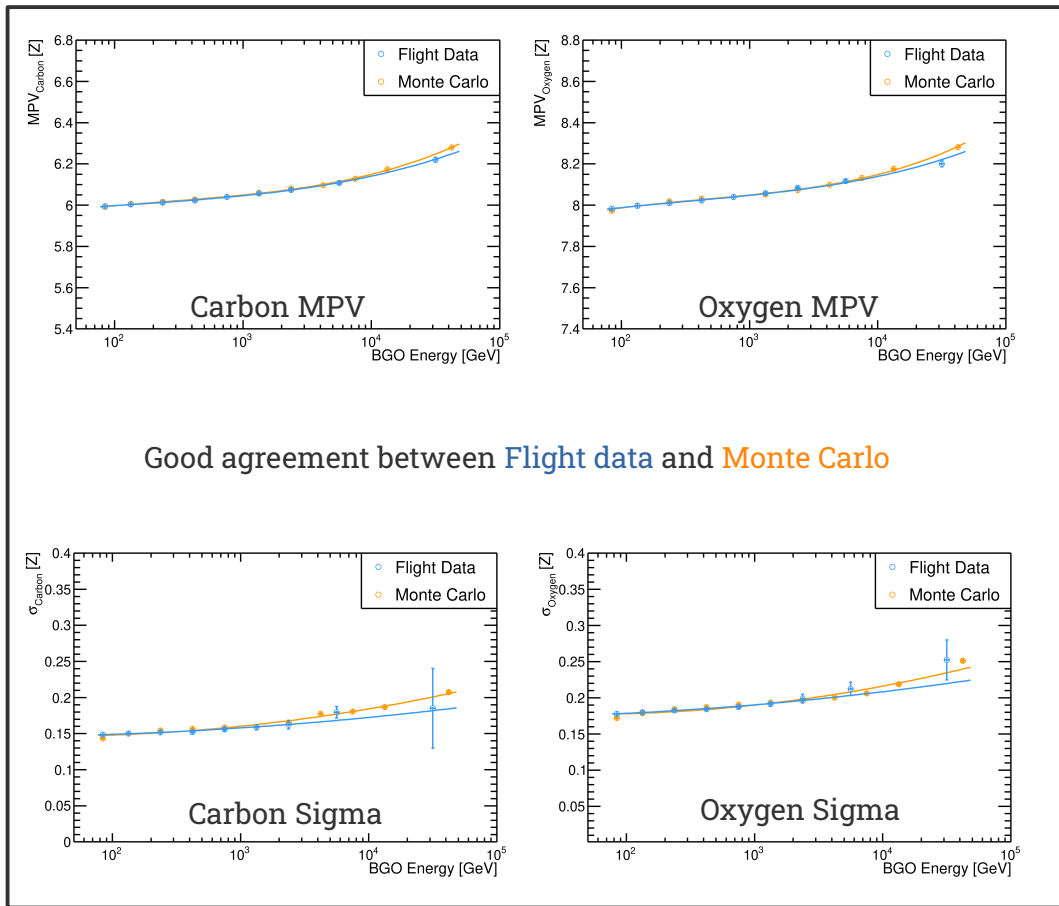
Final charge selection

Contamination fractions

$$MPV - 1.4\,\sigma < \text{PSD Charge}_{Carbon} < MPV + 2.7\,\sigma$$

$$MPV - 1.2\,\sigma < \text{PSD Charge}_{Oxygen} < MPV + 3.5\,\sigma$$

**From the background contamination estimation
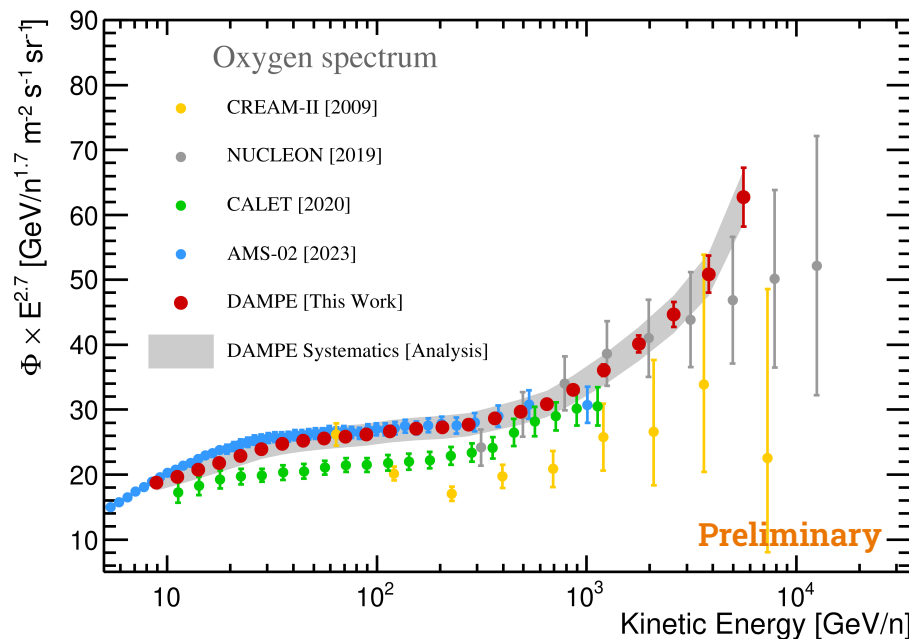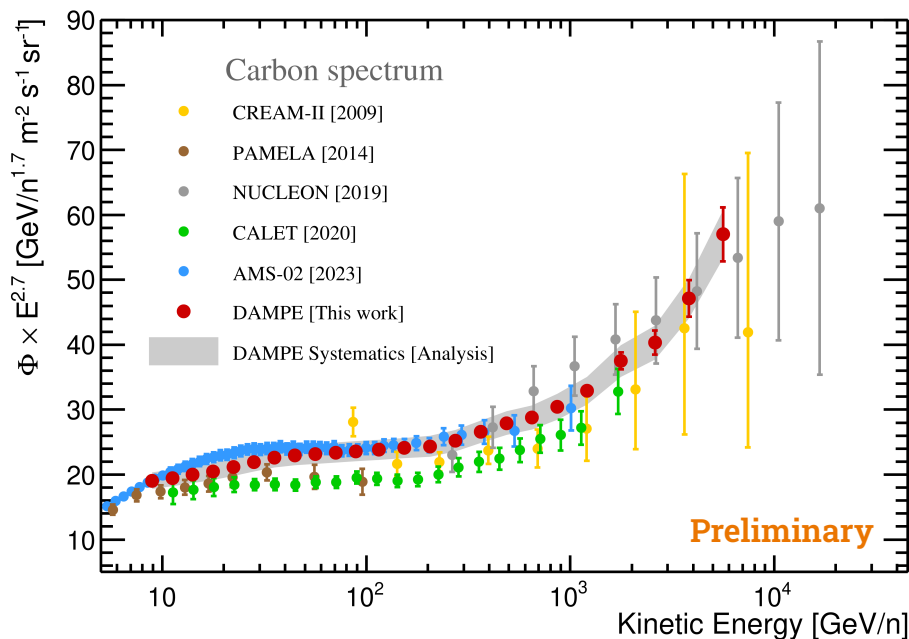the upper/lower charge limits are defined**

Preliminary Carbon and Oxygen Spectra

$$\Delta\Phi\left(E_i, E_i + \Delta E_i\right) = \frac{\Delta N_i}{\Delta E_i \, A_{eff,i} \Delta T}$$

8 yrs of data + Systematic uncertainties [analysis]

Good agreement among different DAMPE groups

Carbon spectrum
- CREAM-II [2009]
- PAMELA [2014]
- NUCLEON [2019]
- CALET [2020]
- AMS-02 [2023]
- DAMPE [This work]
- DAMPE Systematics [Analysis]

Preliminary

Oxygen spectrum
- CREAM-II [2009]
- NUCLEON [2019]
- CALET [2020]
- AMS-02 [2023]
- DAMPE [This Work]
- DAMPE Systematics [Analysis]

Preliminary

Spectral feature(s):
   Hardening @ 300 GeV/n
   Multi-TeV/n energies? ...stay tuned

Consistent overall trend w/ other experiments

Similar behavior to previously published DAMPE results (on p & He)

Preliminary C/O Flux Ratio

$$R_i = \frac{\Phi_i^C}{\Phi_i^O} = \frac{N_i^C}{N_i^O} \left(\frac{\varepsilon_i^C}{\varepsilon_i^O}\right)^{-1}$$
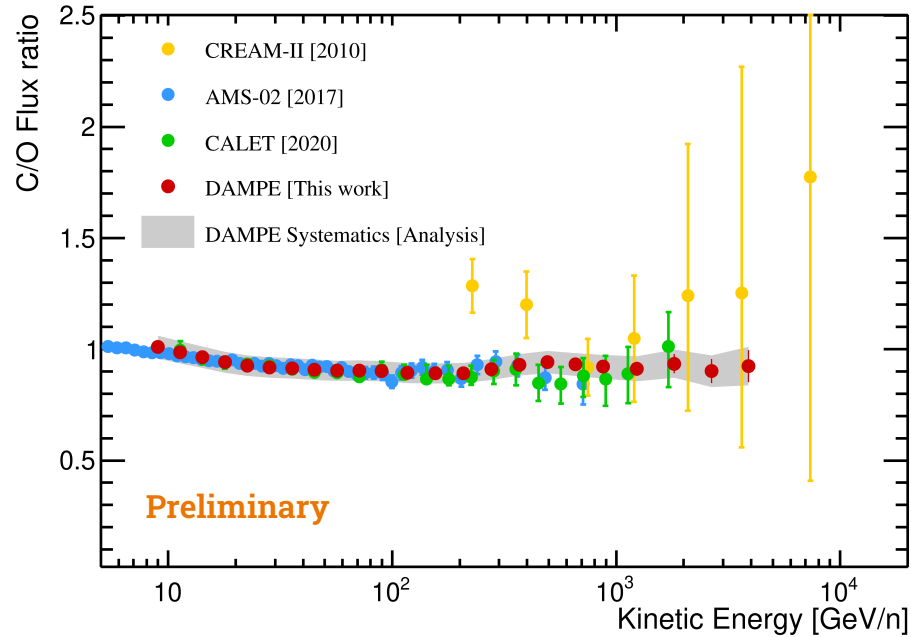
8 yrs of data
+ Systematic uncertainties [analysis]

Consistency between experiments

+ Extension into the multi-TeV/n region

Conclusions

Recent advancements towards the **Cosmic Carbon and Oxygen fluxes** and their respective flux ratio (C/O) with **8 years of DAMPE flight data**

Consistent spectral shapes between current experiments
Good agreement with AMS-02 data up to the TeV/n range
Confirming the **hardening** feature at **~ 300 GeV/n**

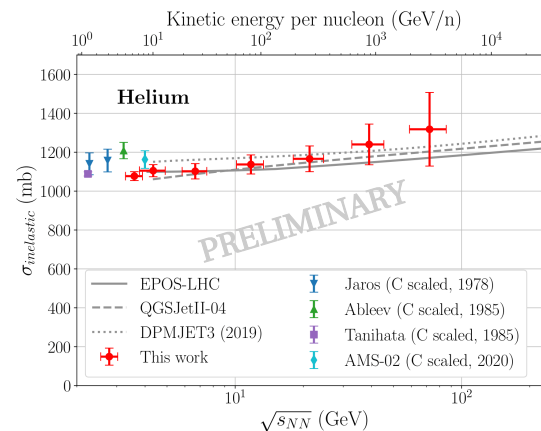**Extending precise C & O (+ C/O) measurements well into the multi-TeV/n region**
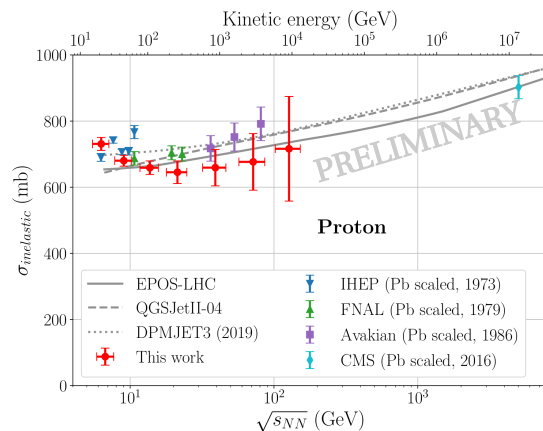
New DAMPE results aim to unveil intricate spectral aspects at even higher energies
...stay tuned

More info

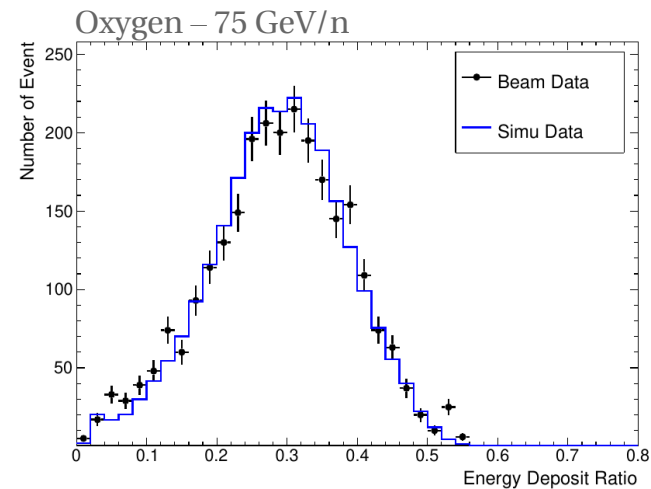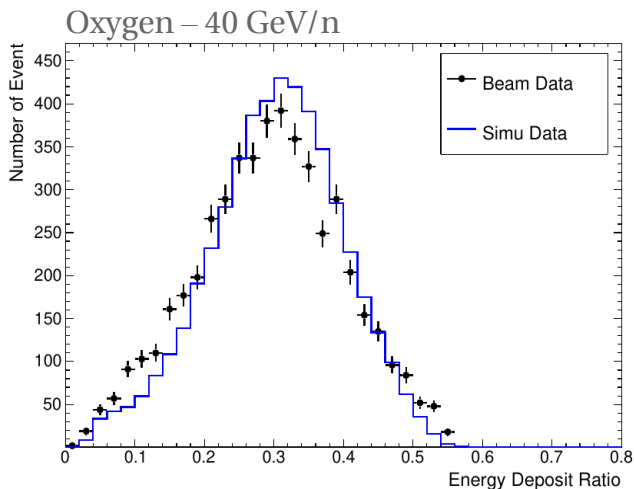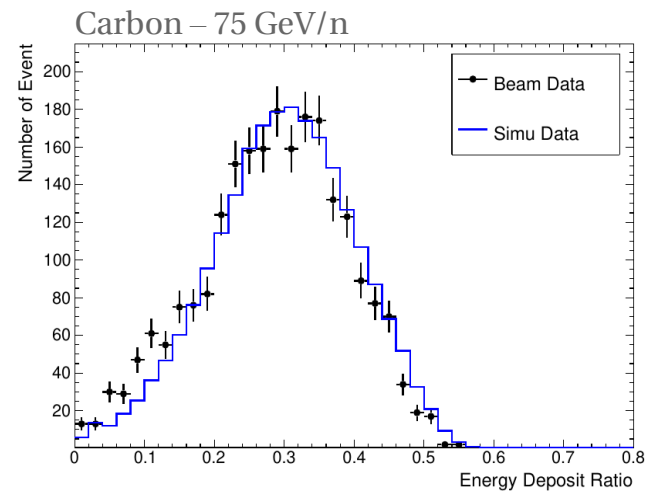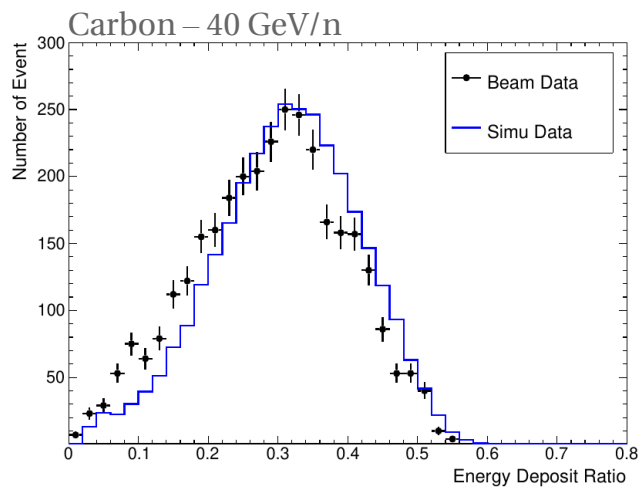# Ongoing work: Cross section studies

Measuring the inelastic hadronic cross sections of p, He, C, O
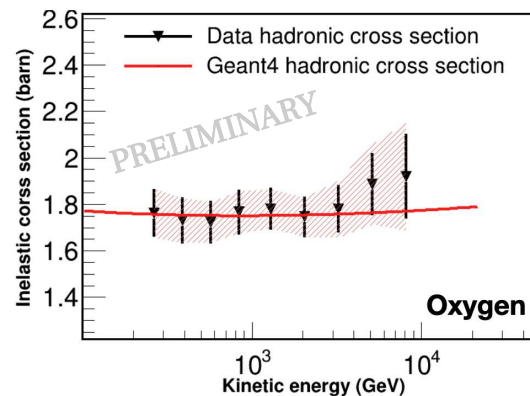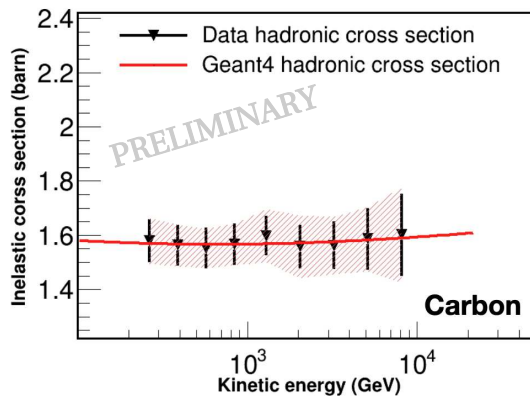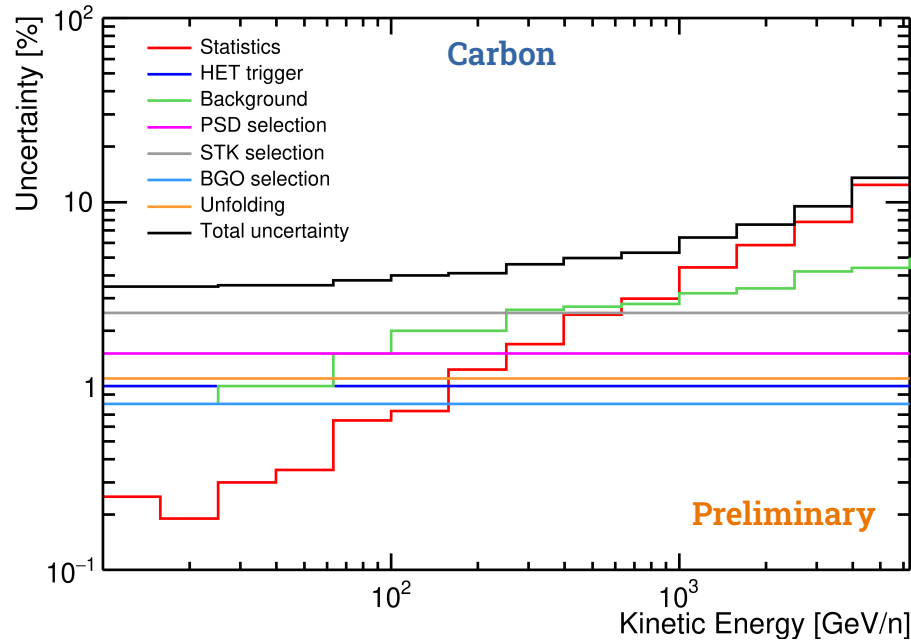
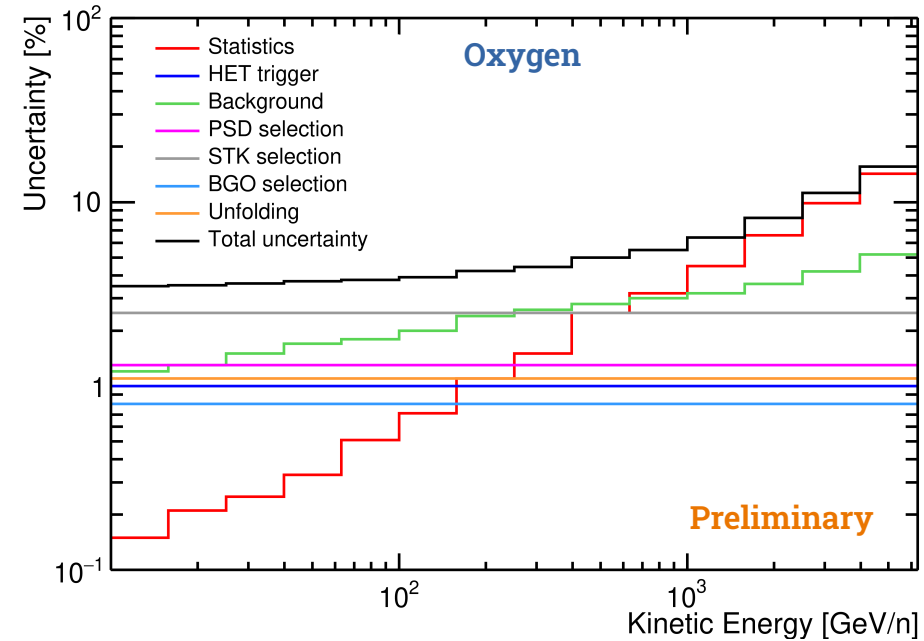# Hadronic model – Test beam data

Carbon and Oxygen Systematics

Statistical + Systematic uncertainties [analysis]

- Statistical
- HET trigger
- Background
- Unfolding
- PSD, STK, BGO selections
- Total uncertainty