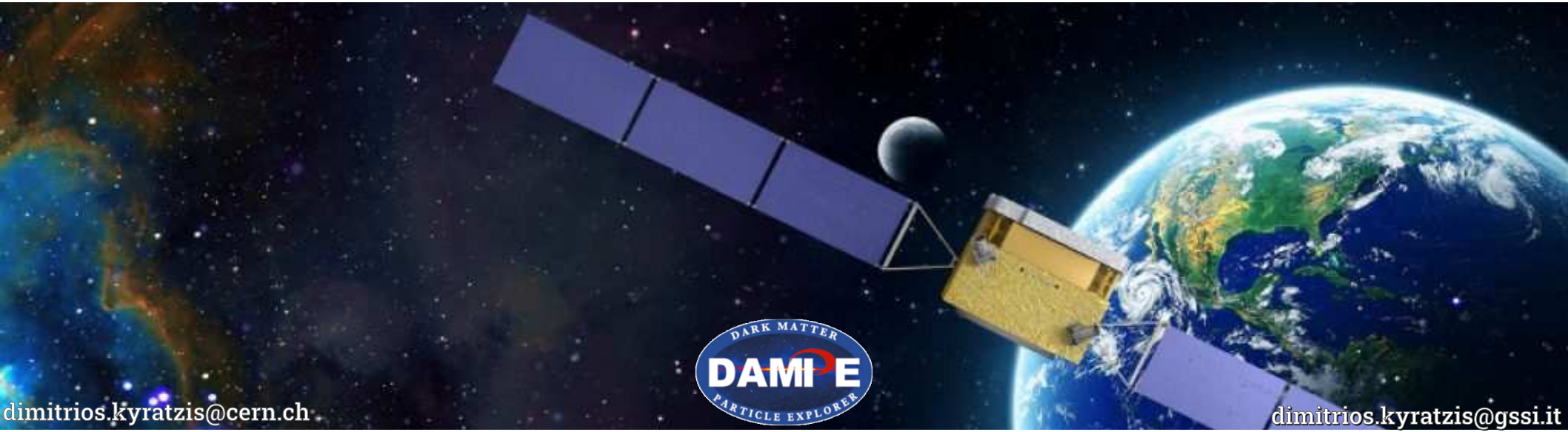


Latest Results on Cosmic Ray Carbon and Oxygen with the DAMPE space mission

Dimitrios Kyratzis

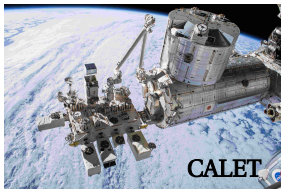
14/07/2024

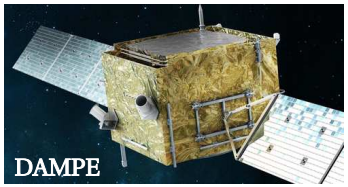
The Cosmic Ray Landscape

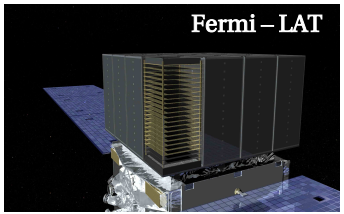
Energies achieved with **current space – borne** direct CR experiments (~ hundred TeV)

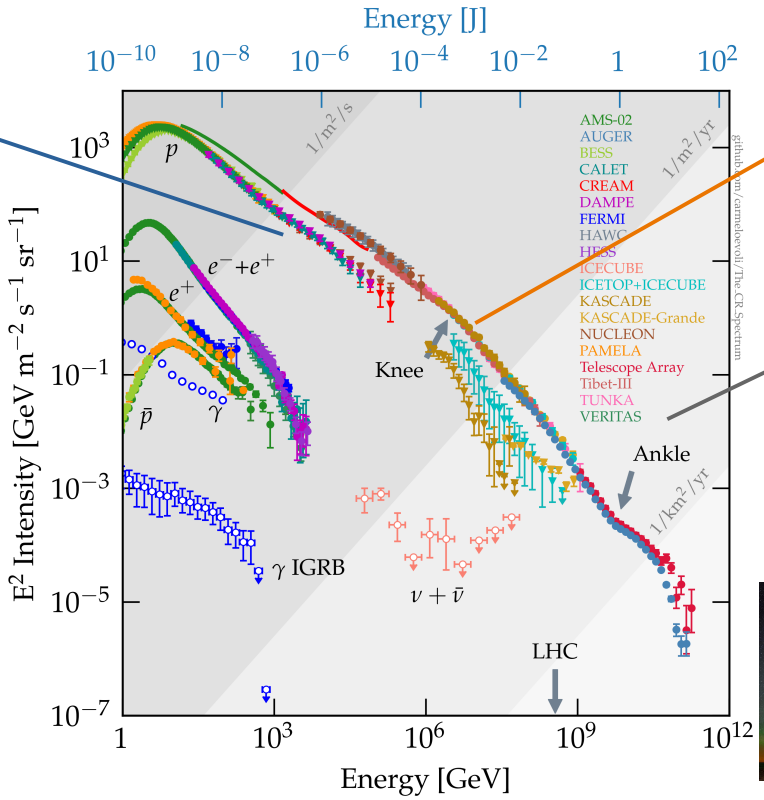
Maximal energies achieved with direct detection CR experiments (~ PeV)

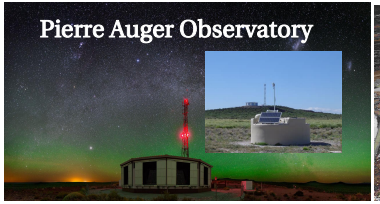
Region covered by **indirect CR experiments** (~ 10^{20} eV)

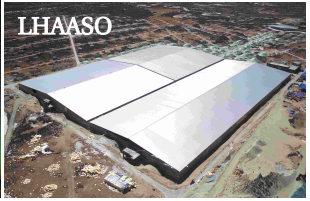












Research Goals & Open Questions

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

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

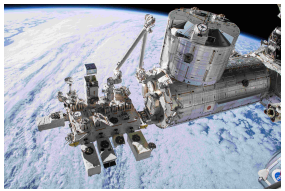
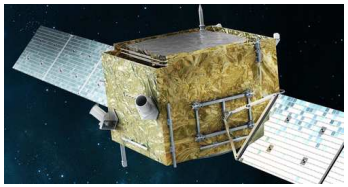
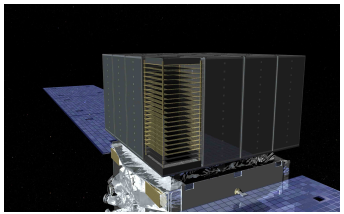
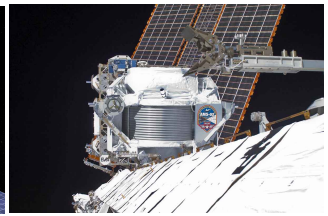
Understanding CR **acceleration & propagation** mechanisms

An analogy from Plato's Academy in Athens

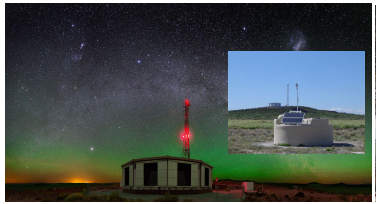
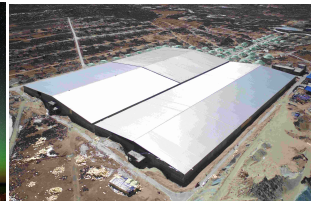
Raphael, *The School of Athens,* (1509-1510)

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

Space – borne experiments

Ground – based experiments

Direct CR experiments

Precise measurement of particle **charge + energy**

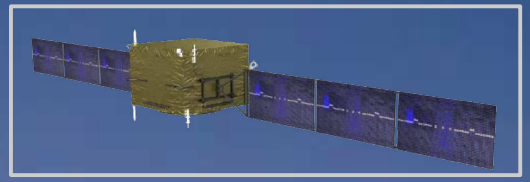
Small exposure for statistically meaningful measurements **above few tens of TeV/n**.

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

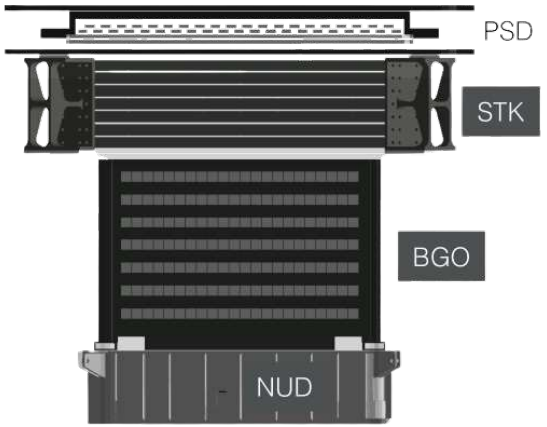
CRs: All-electron, proton & nucleonic spectra w/ great precision

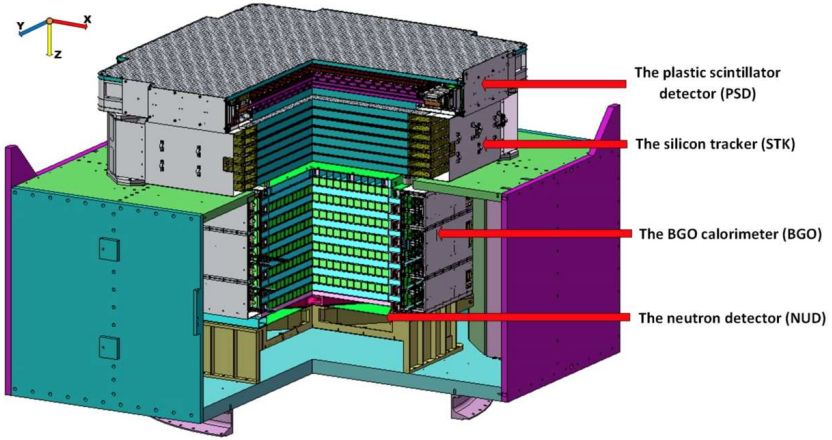
γ – rays: Insight on high-energy γ astronomy, transient studies, etc

DM: Indirect studies on possible DM candidates

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

Detector Description & Features





Main Features

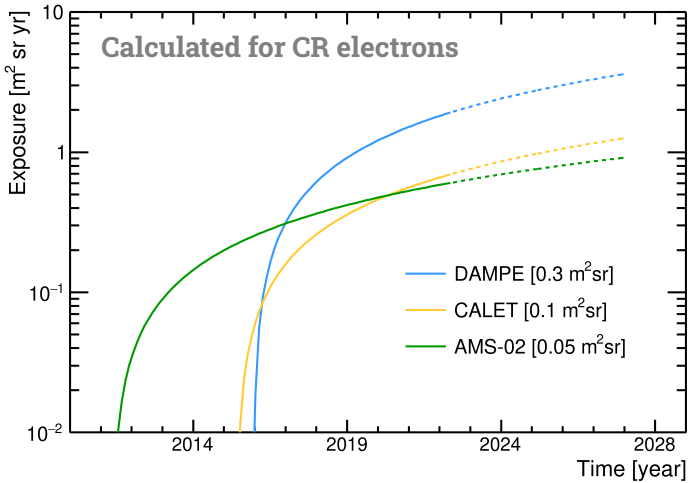
Energy range (e/γ)	10 GeV - 10 TeV
Energy range (CRs)	50 GeV – 200 TeV
Energy resolution (e/γ)	< 1.5% @ 800 GeV
Energy resolution (p)	< 40% @ 800 GeV
Geometric Factor (e)	> 0.3 m²sr @ 30 GeV
Calorimeter specs	32 X_0, 1.6 Λ_I
Field of View	~1.0 sr

PSD: Anti – coincidence detector for gammas and charge measurement

STK: Particle tracker, photon converter & additional charge measurement

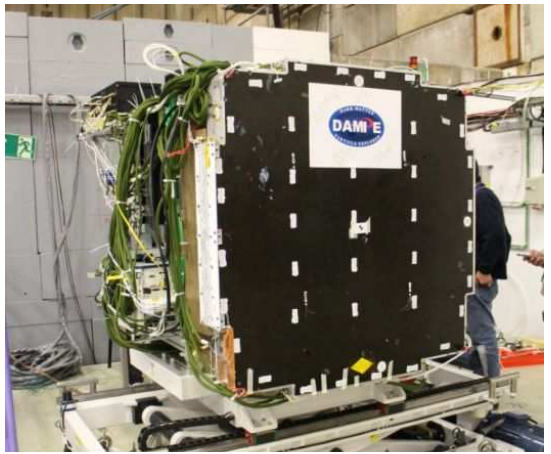
BGO: Energy measurement & particle identification via shower topology

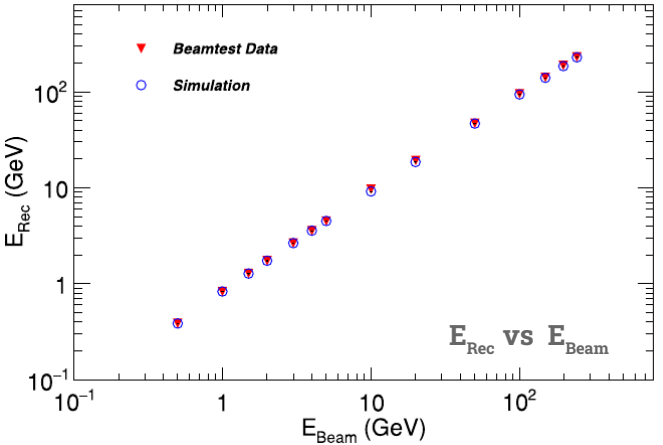
NUD: Further particle ID from electromagnetic & hadronic showers

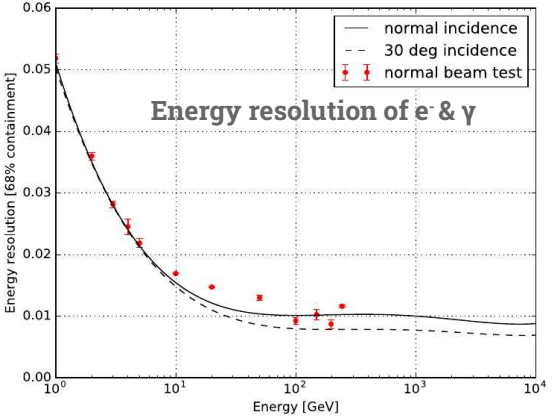


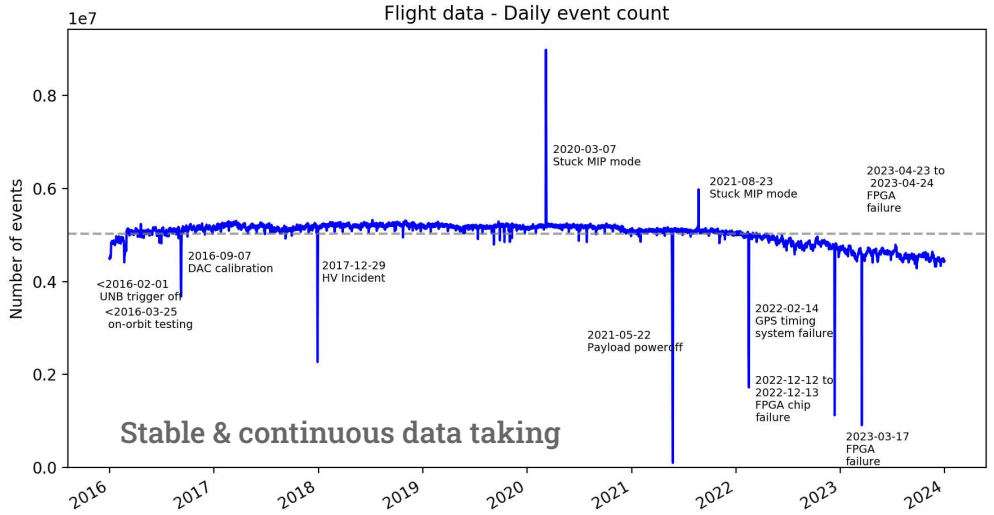
DAMPE features & performance validation

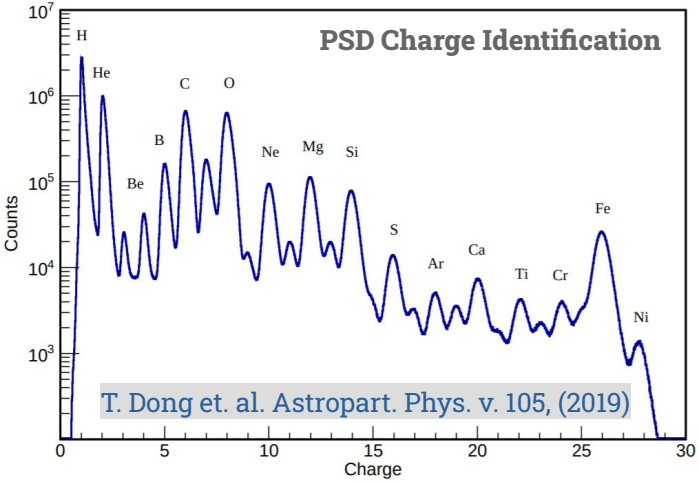
DAMPE @ CERN – SPS



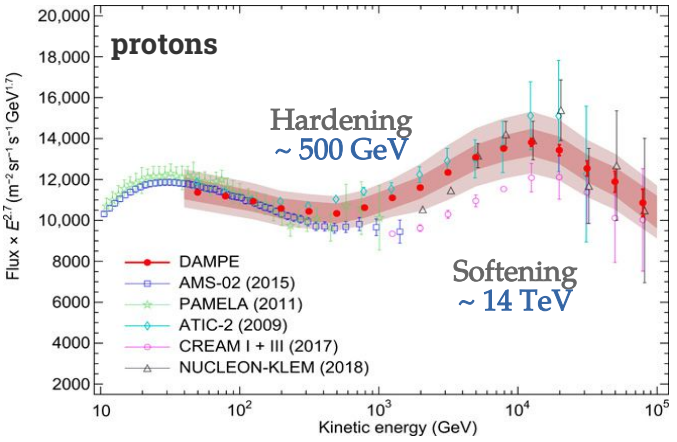




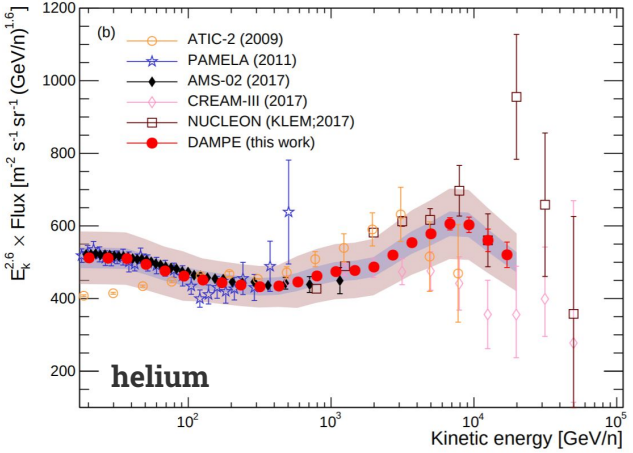




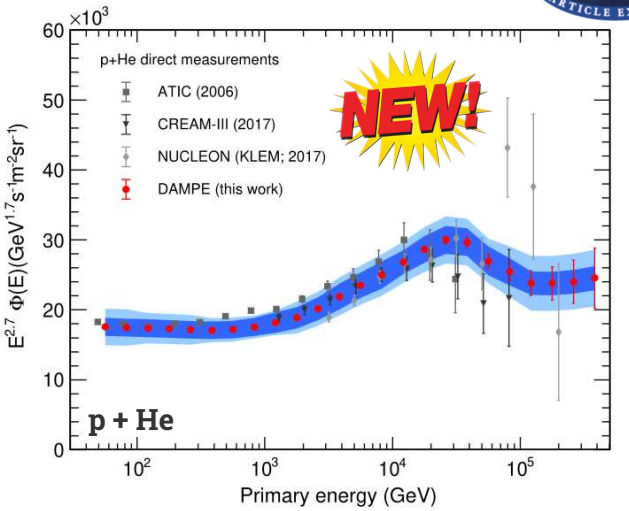
Primary CRs: Insightful results + Ongoing work



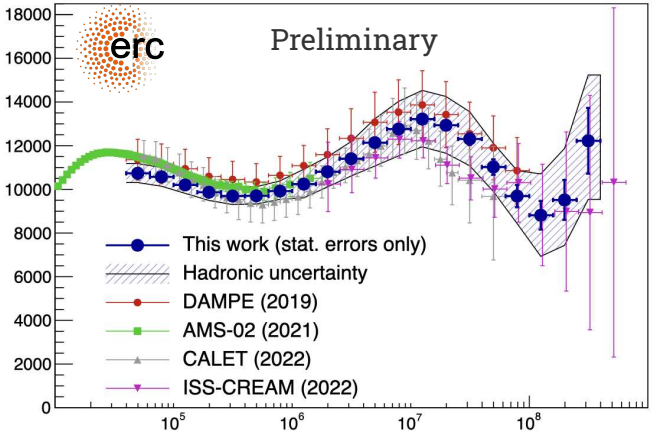
Q. An *et al*, Sc. Adv. Vol. 5 no. 9 (2019)



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

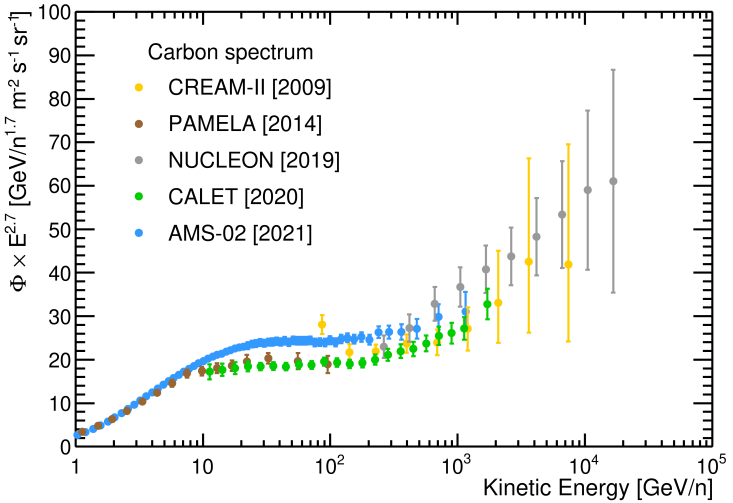


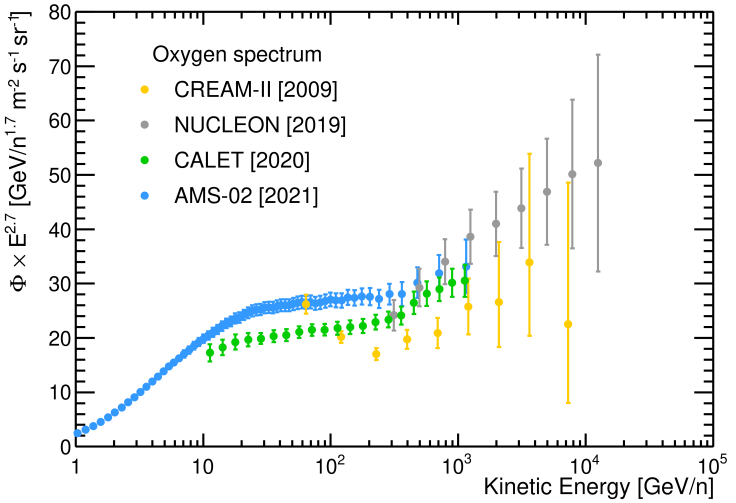
F. Alemanno et. al. PRD 109.12 (2024) L121101



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

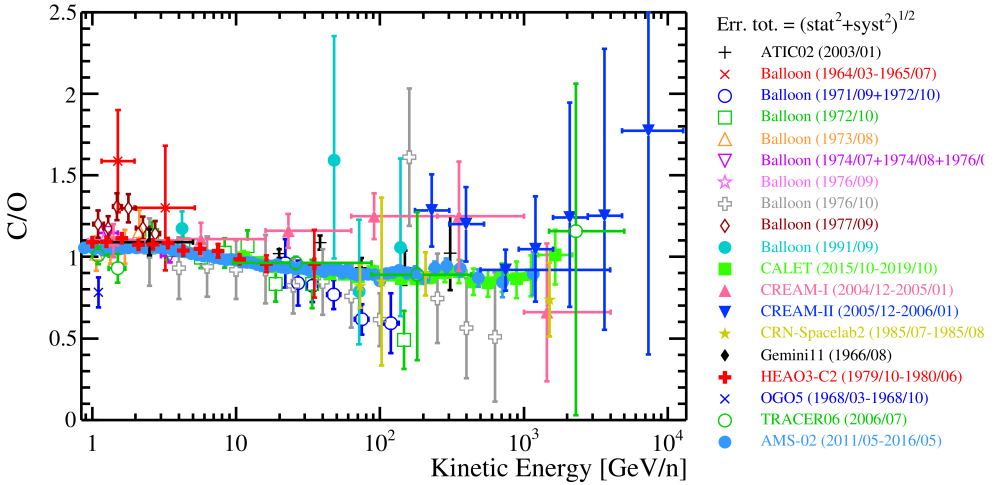
Primary CRs: Motivation on Carbon and Oxygen





Individual C & O spectra

Interesting 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

C & O analyses: Candidate event selections

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

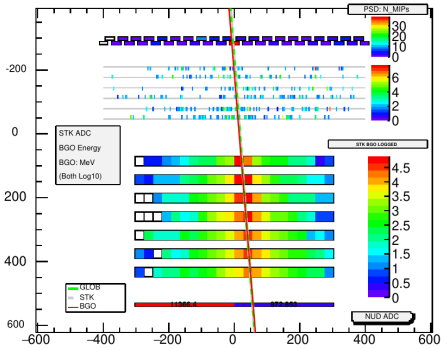
PSD Fiducial cut:

Track projection on first PSD layer < 400 mm

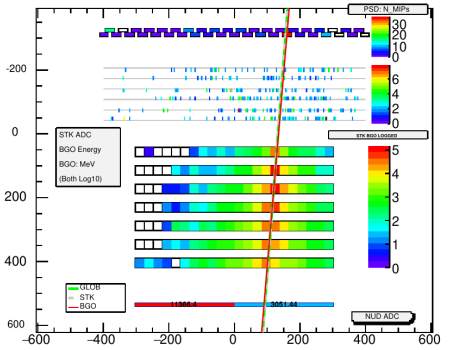
PSD – STK match:

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

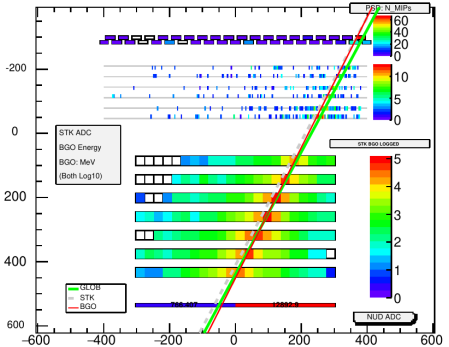
Carbon – XZ view



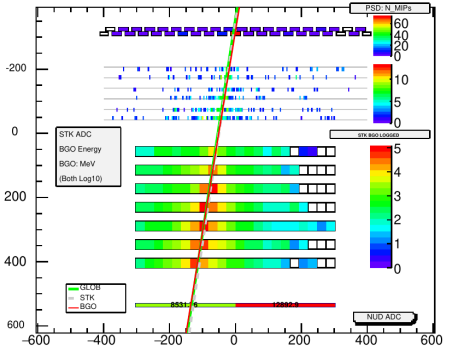
Carbon – YZ view



Flight data event displays @ 1.4 TeV



Oxygen – XZ view



Oxygen – YZ view

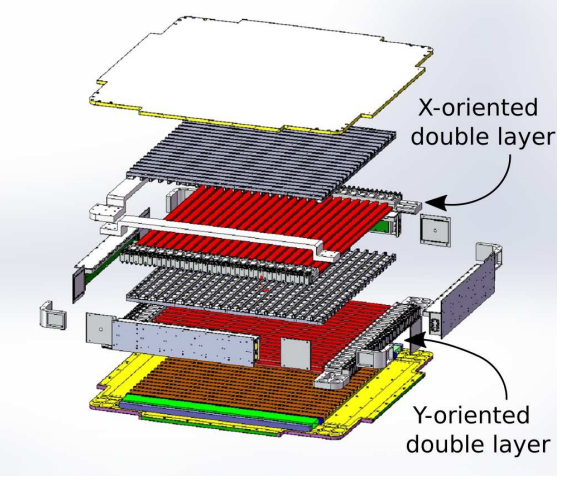
Event selection in PSD and STK subdetectors

Progressing PSD charge selection:

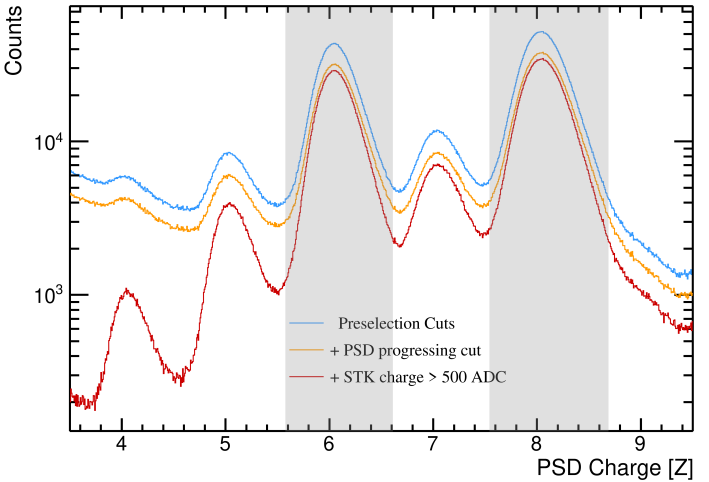
$$Q^{PSD} = \frac{\sum_i Q_i^{PSD}}{N_{Layers}}$$

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

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

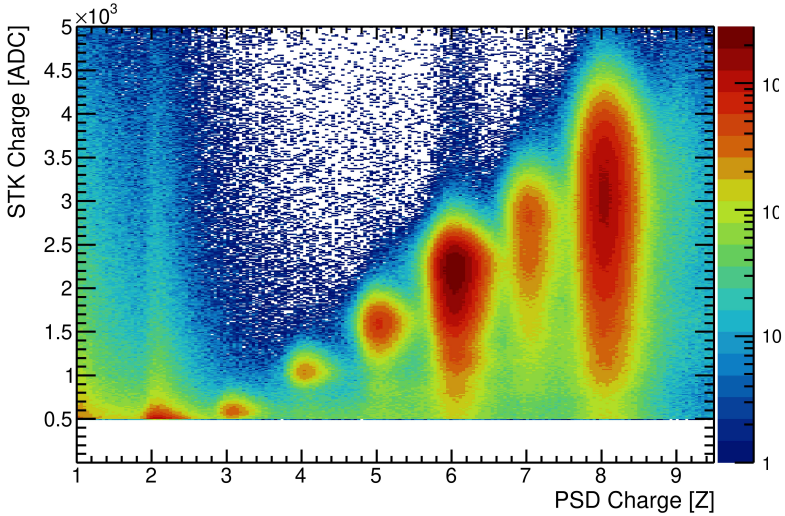


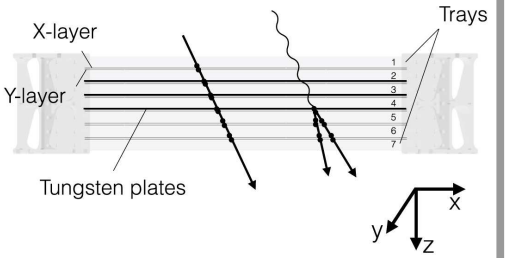
Selection cut sequence



Maximizing C & O sample purity

Taking into account the FIRST STK plane





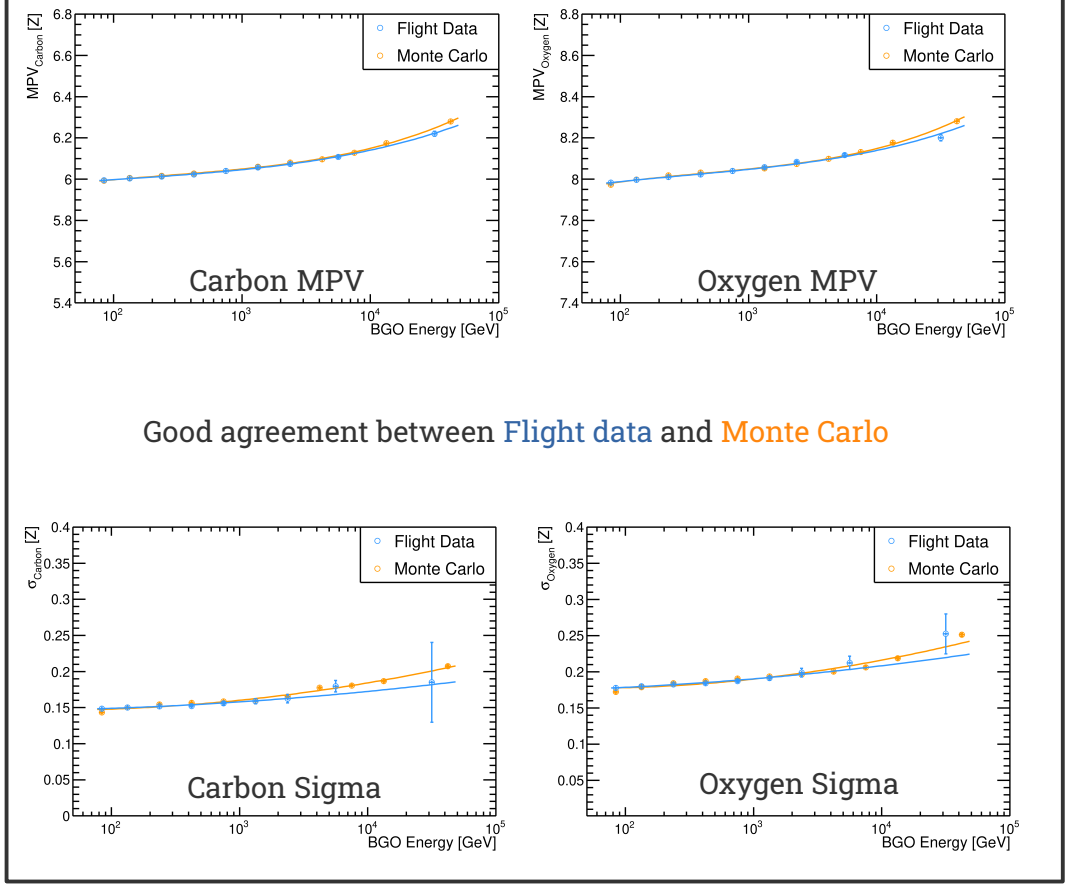
$$Q^{STK} = \frac{\sum_j Q_j^{STK}}{N_{Layers}} > 500 \text{ ADC}$$

15-20% increased acceptance
with ML tracking techniques

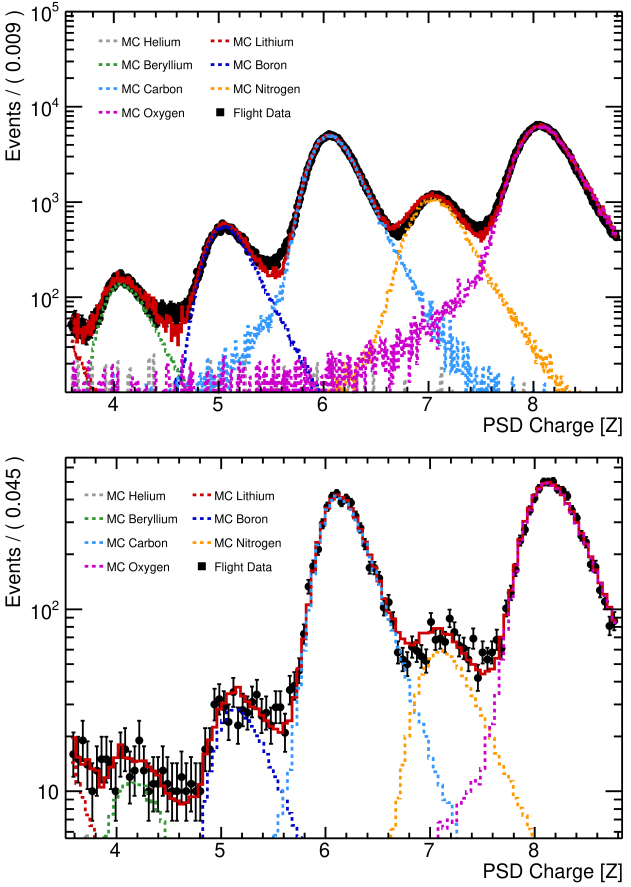
A. Tykhonov, et al. Astroparticle Physics, 146 (2023) 102795

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

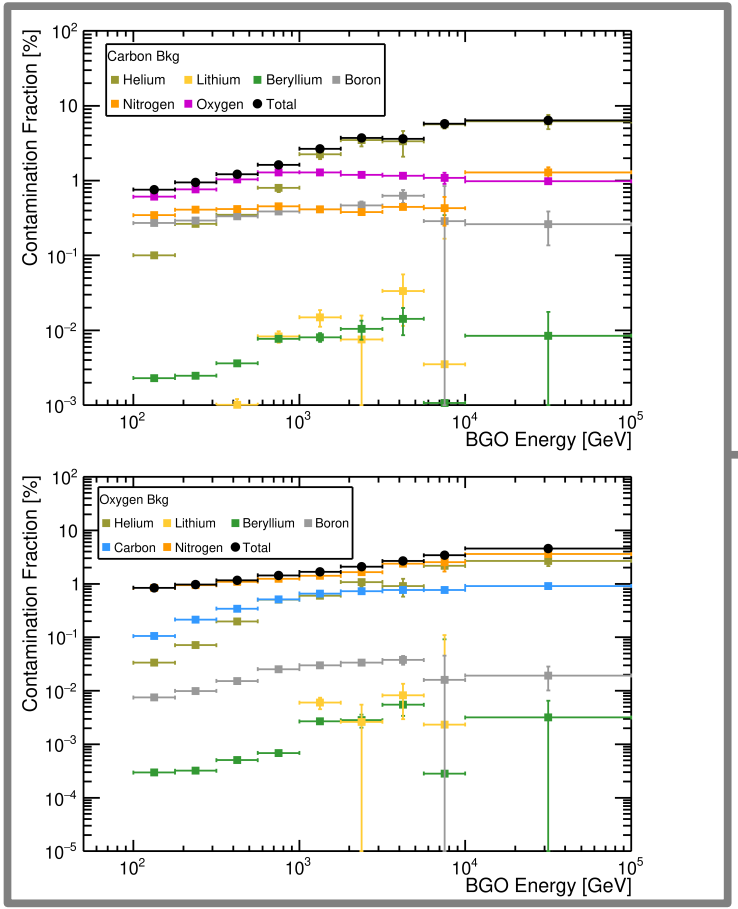


<BGO Energy> @ 237 GeV

<BGO Energy> @ 2.3 TeV

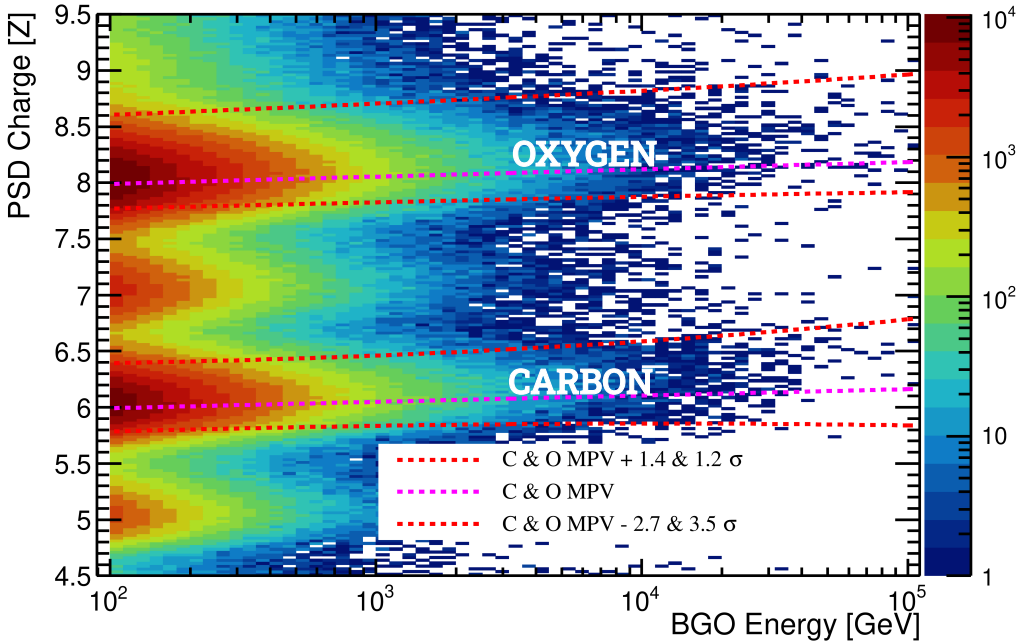
Final charge selection

Contamination fractions



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

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

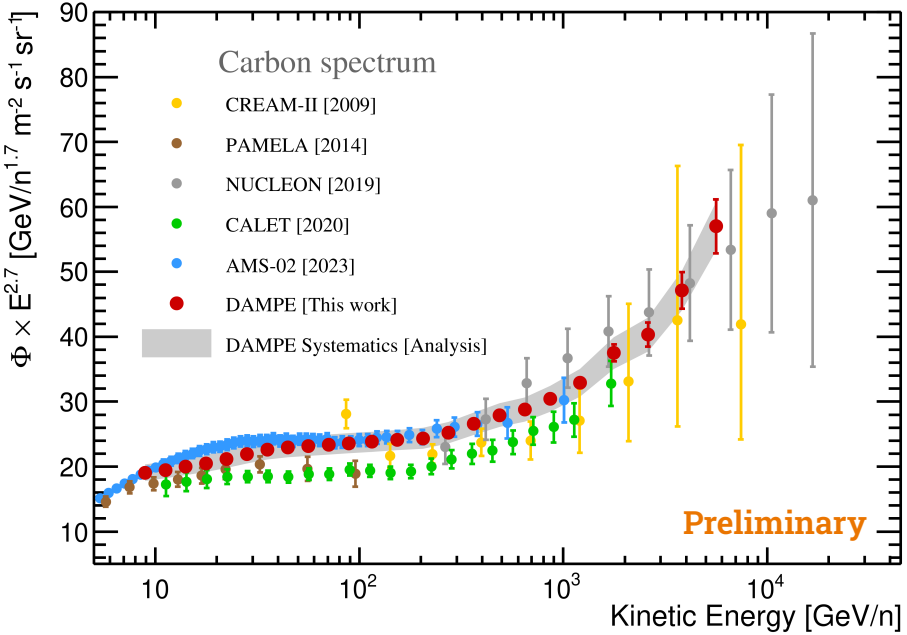


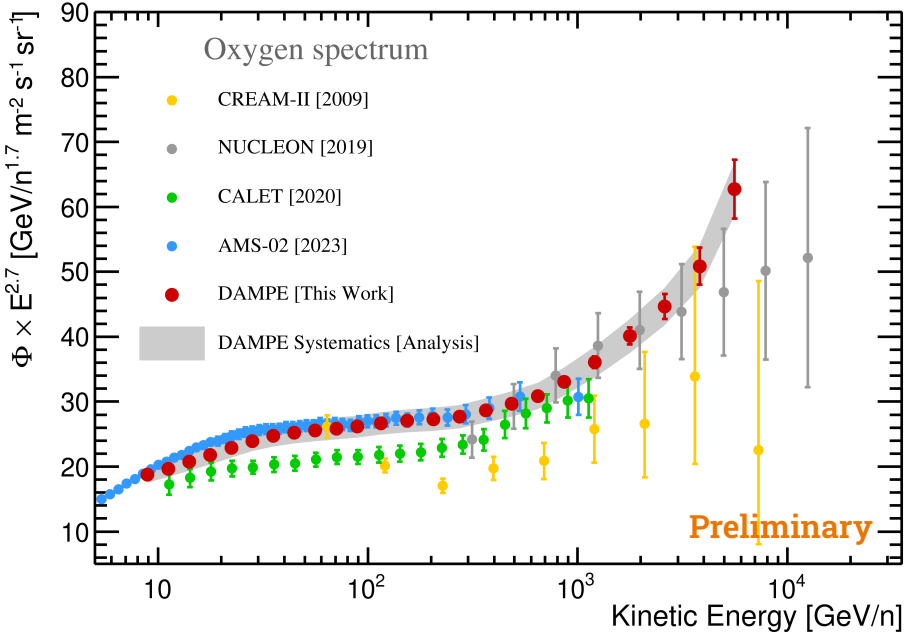
From the background contamination estimation the upper/lower charge limits are defined

Preliminary Carbon and Oxygen Spectra

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

8 yrs of data + Systematic uncertainties [analysis]





Spectral feature(s):

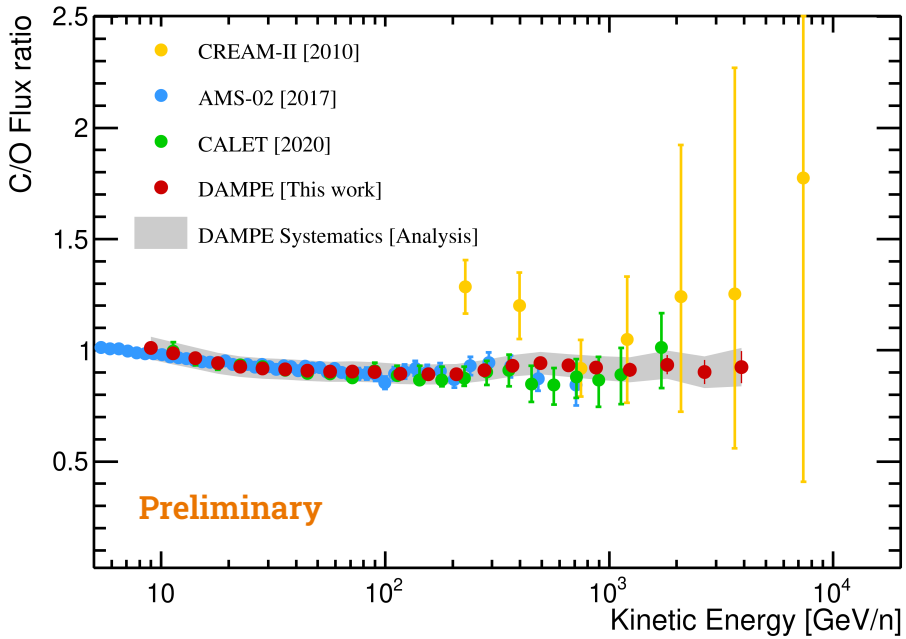
- **Hardening @ 300 GeV/n**
- **Multi-TeV/n energies? …stay tuned**

→ **Consistent overall trend w/ other experiments**

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

Preliminary C/O Flux Ratio

$$R_i = \frac{\Phi_i^{\mathrm{C}}}{\Phi_i^{\mathrm{O}}} = \frac{N_i^{\mathrm{C}}}{N_i^{\mathrm{O}}} \left(\frac{\varepsilon_i^{\mathrm{C}}}{\varepsilon_i^{\mathrm{O}}}\right)^{-1}$$

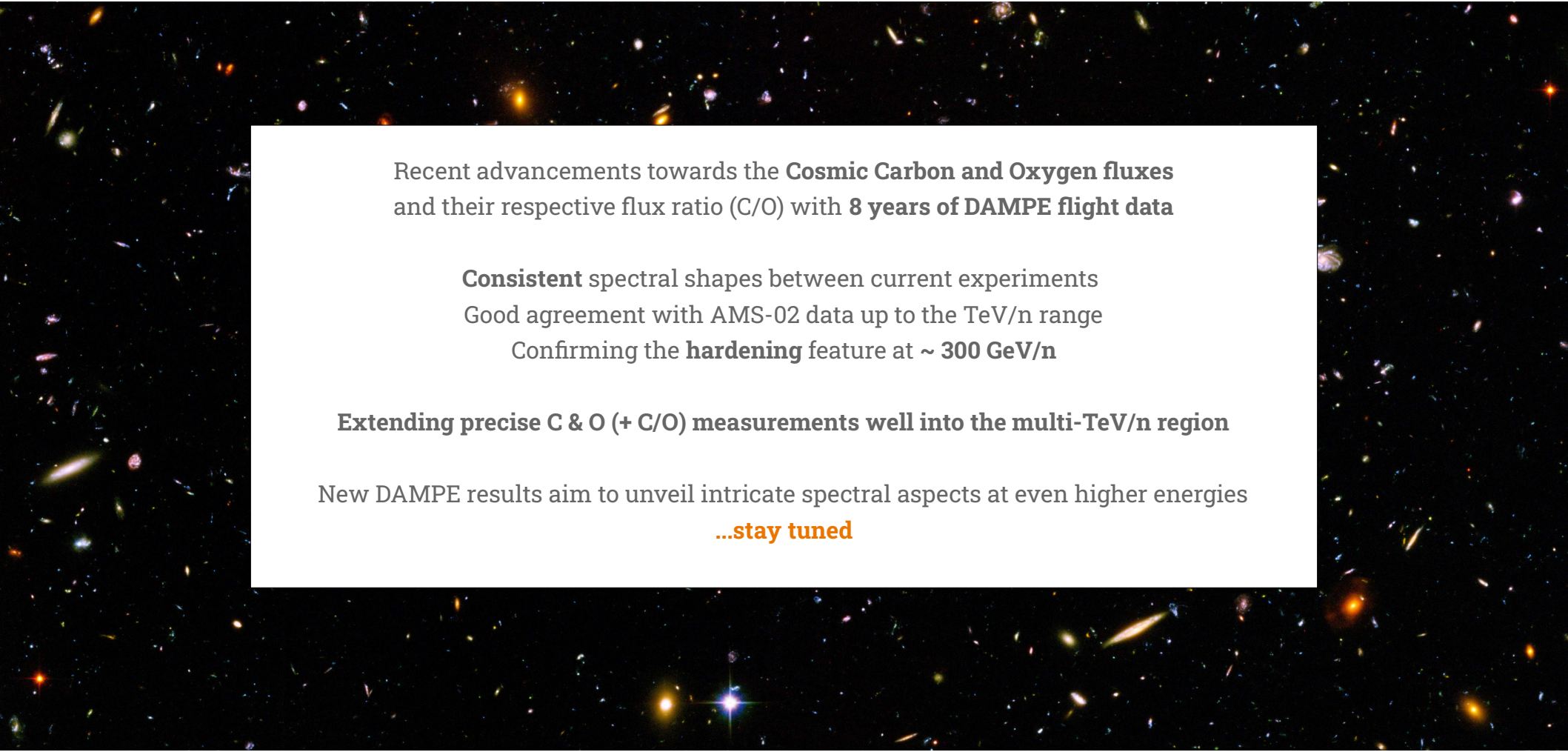


8 yrs of data
+ Systematic uncertainties [analysis]

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

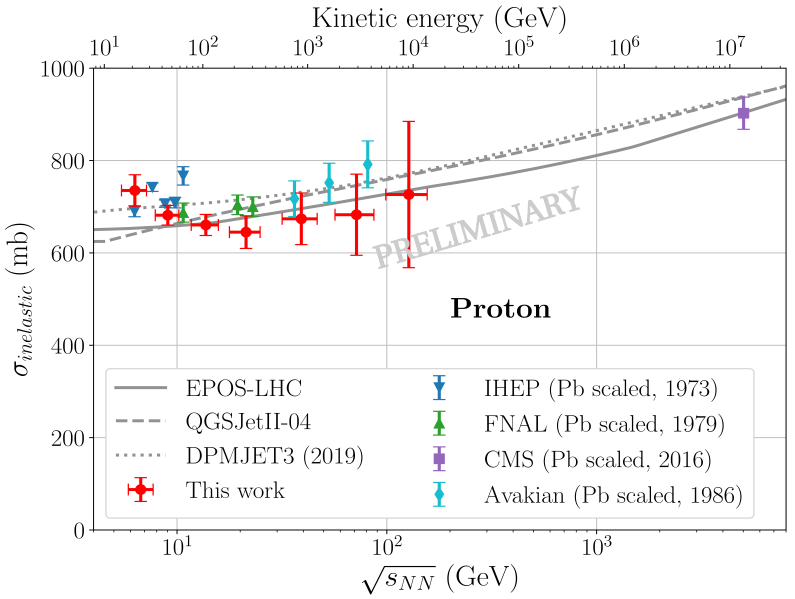
New DAMPE results aim to unveil intricate spectral aspects at even higher energies
...stay tuned

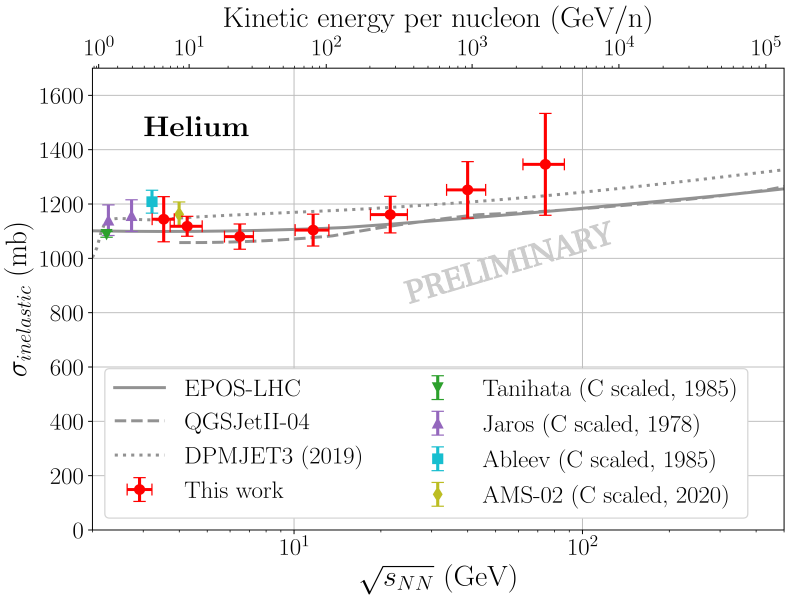
More info

Ongoing work: Cross section studies

Measuring the inelastic hadronic cross sections of protons and helium nuclei on BGO

P. Coppin et al., in preparation, (2024)

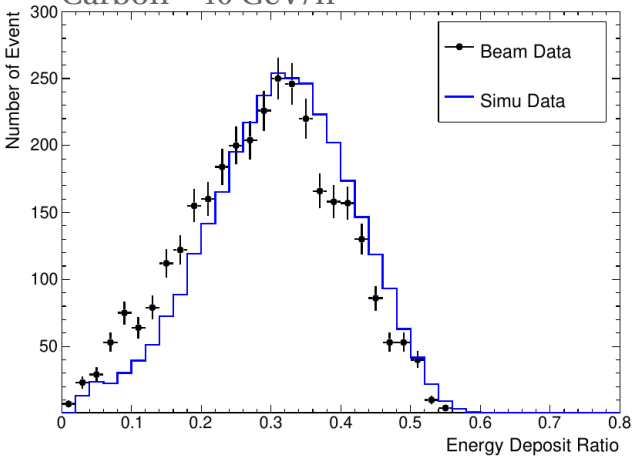




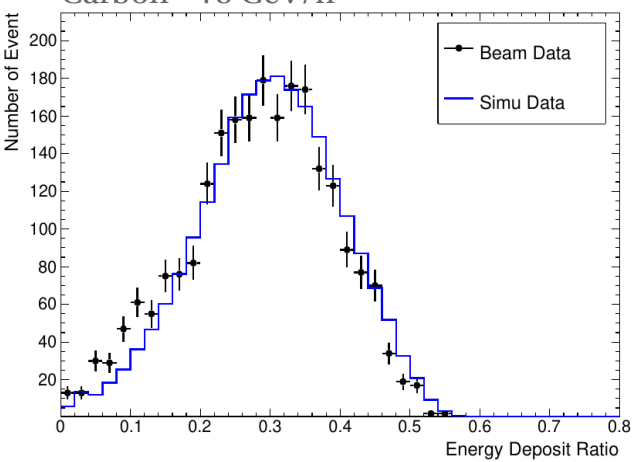
Sample	E (GeV)	σ (mb)
Proton	$31.4 - 359$	660 ± 1 (stat) ± 43 (sys)
Helium	$9.5 - 119$	1079 ± 1 (stat) ± 44 (sys)

Hadronic model – Test beam data

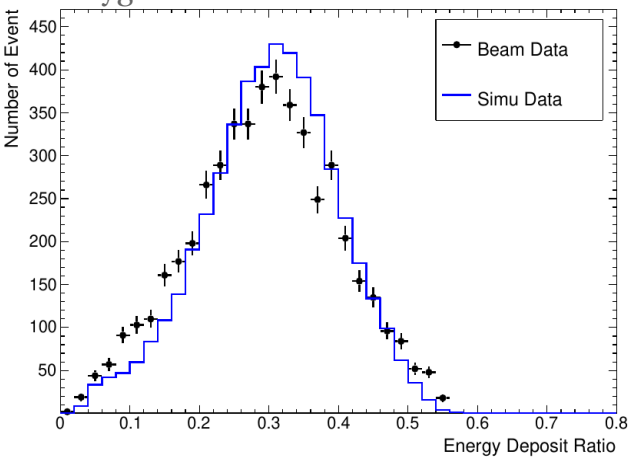
Carbon – 40 GeV/n



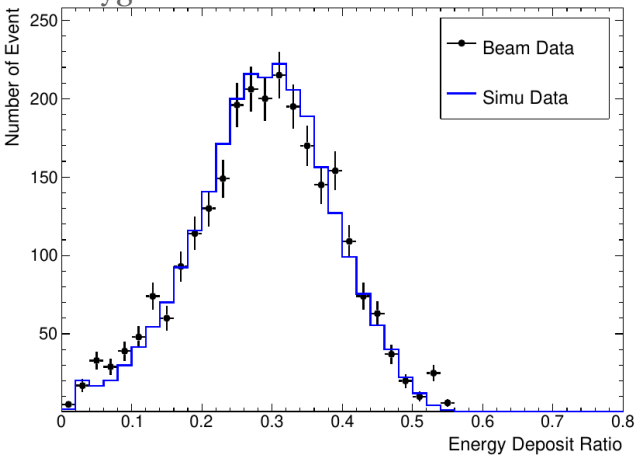
Carbon – 75 GeV/n



Oxygen – 40 GeV/n

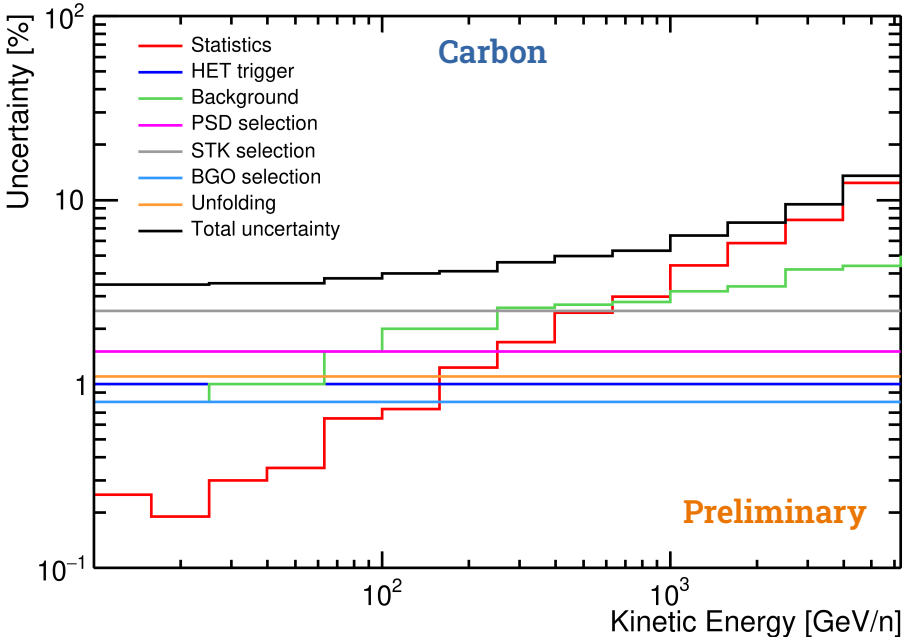


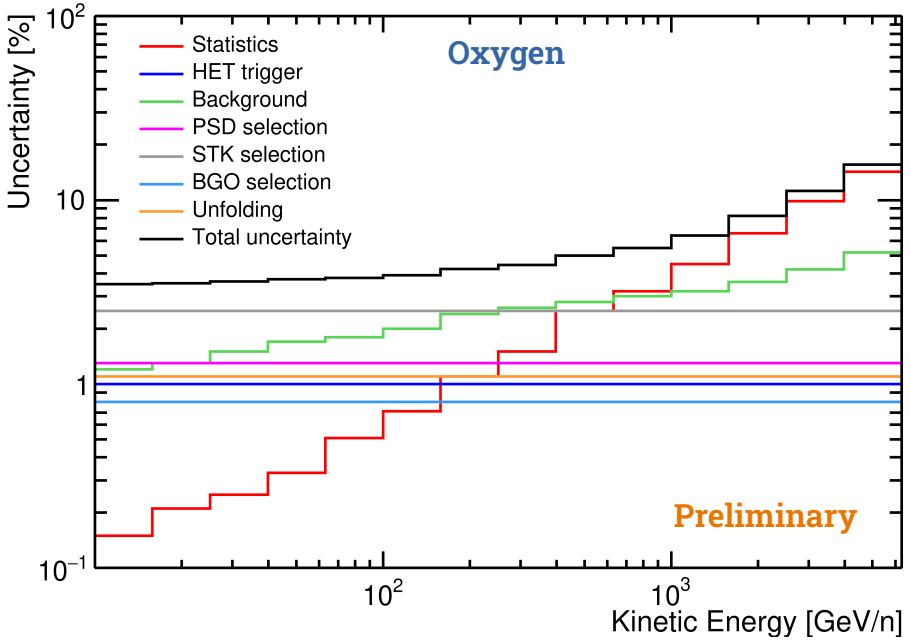
Oxygen – 75 GeV/n



Carbon and Oxygen Systematics

Statistical + Systematic uncertainties [analysis]





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