



Latest results on medium mass cosmic ray nuclei with the DAMPE space mission

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on behalf of the DAMPE collaboration

Gran Sasso Science Institute (GSSI) & INFN-LNGS

Overview

Introduction

The DAMPE space mission & status

CR results thus far & medium mass nuclei motivation

Secondary CRs: Li, Be, B

Primary CRs: C, N, O & C/O

Secondary-over-primary ratios: B/C & B/O

Summary & Upcoming work

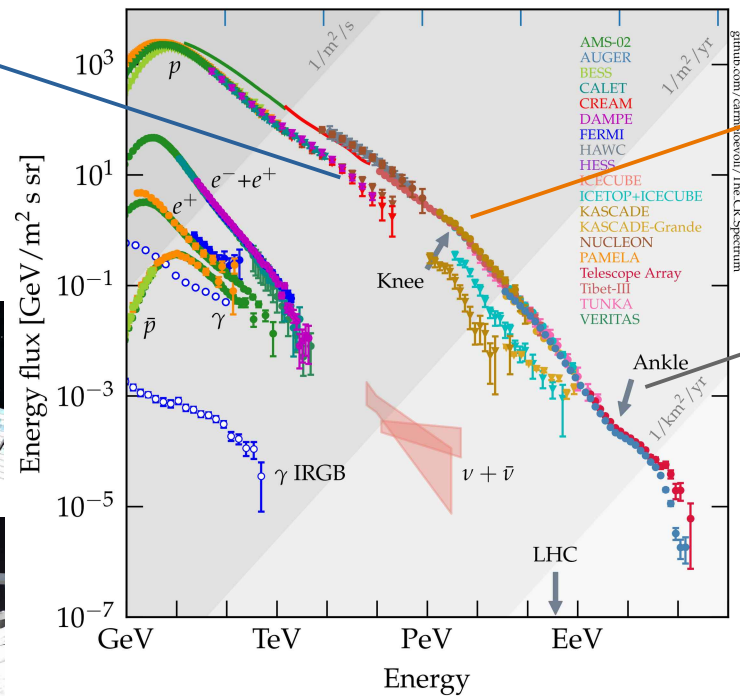


The Cosmic Ray Landscape

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

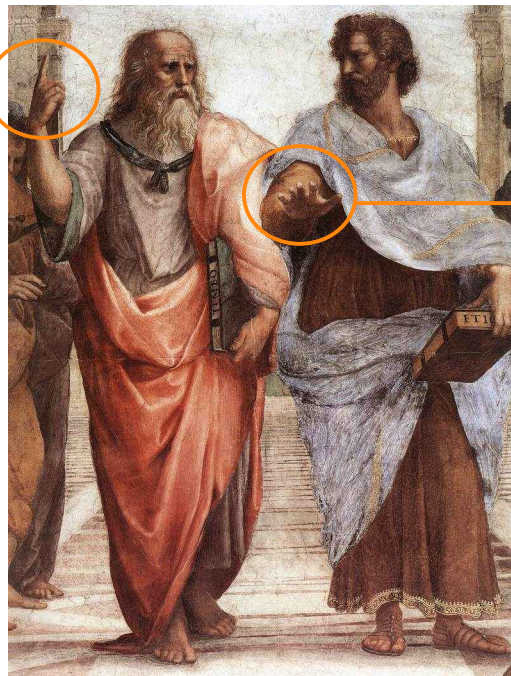
An analogy from Plato's Academy in Athens

Space – borne experiments

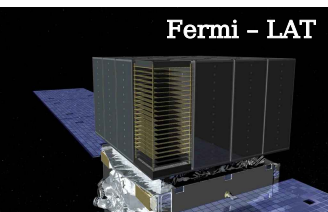
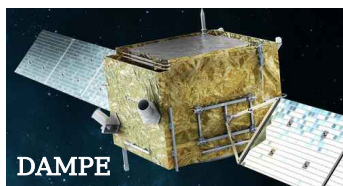
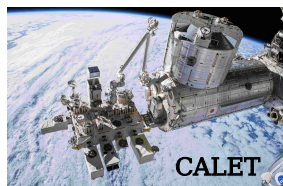
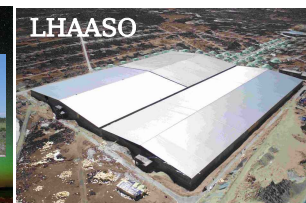
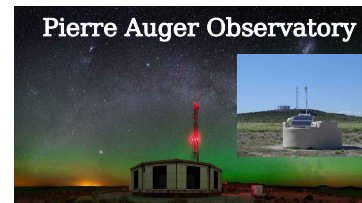
Ground – based experiments

Plato

Aristotle



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



Direct CR experiments

Precise measurement of particle charge and energy
Small exposure to provide statistically meaningful measurements above few tens of TeV.

Indirect CR experiments

Huge achievable energies
Difficulty in making composition studies with small systematics



Orbit: Sun – synchronous, 95 min

Altitude: 500 km (LEO)

Payload: 1300 kg

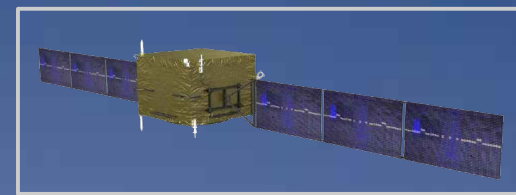
Main scientific objectives

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

Astropart. Phys., 95, 6 [2017]



Launched on Dec 17th 2015

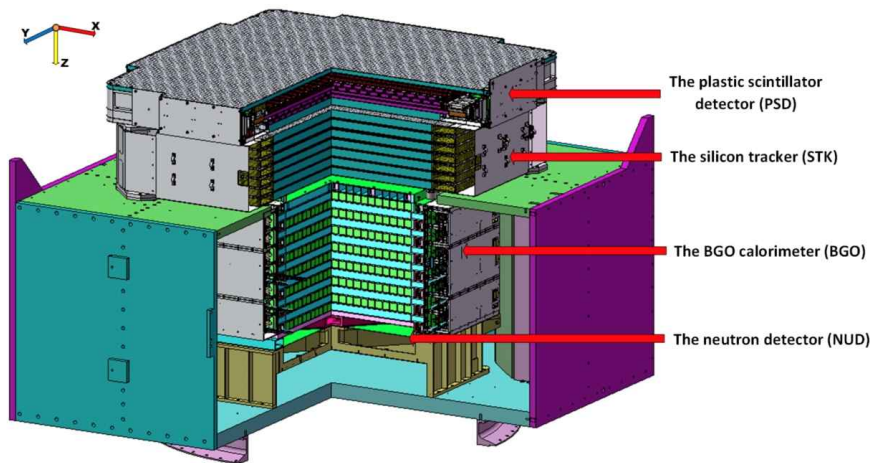
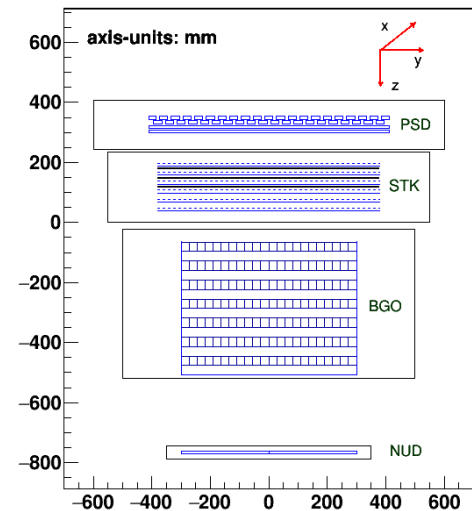
Jiuquan Satellite Launch Center
Gobi desert, China

The Collaboration

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



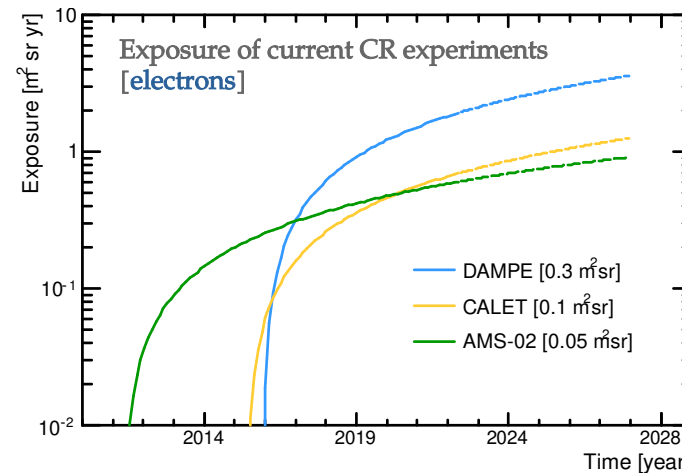
Detector Description & Features



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 m ² sr @ 30 GeV
Calorimeter specs	32 X_0 , 1.6 Λ_I
Field of View	~1.0 sr

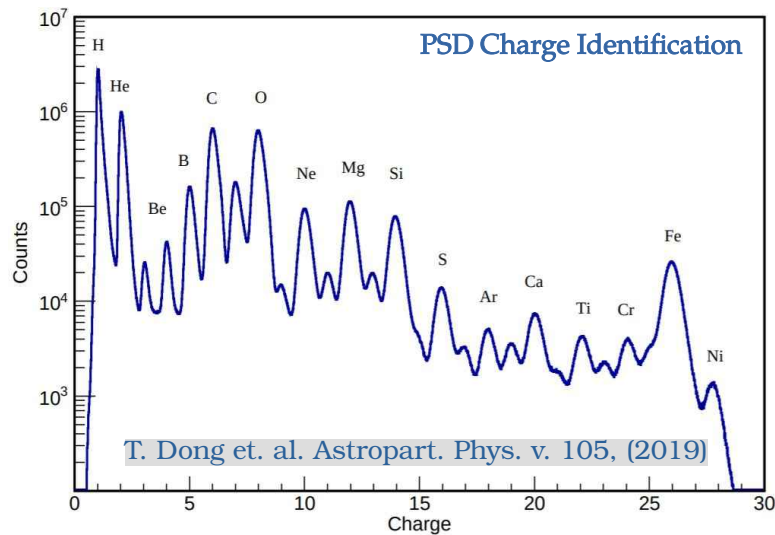
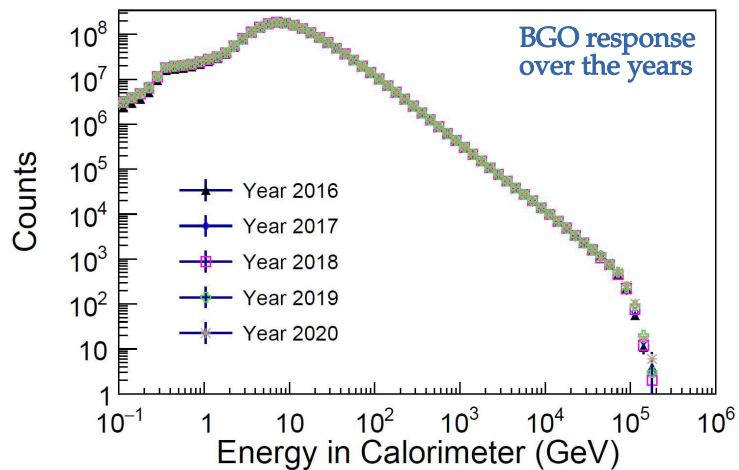
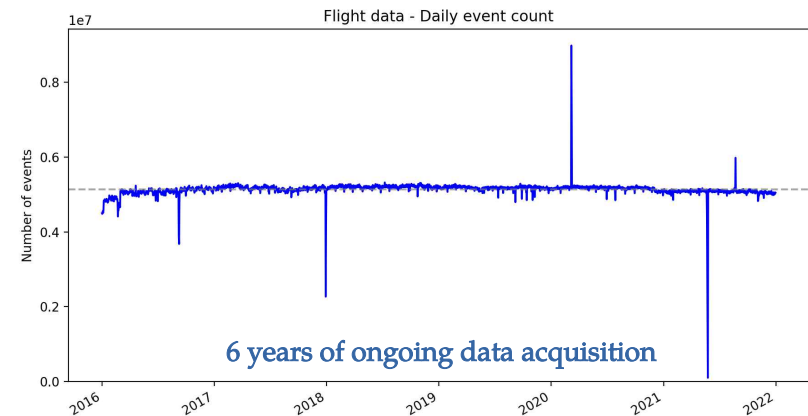
- PSD:** Anti – coincidence detector for gammas and charge measurement
- STK:** Particle tracker, photon converter & additional charge measurement
- BGO:** Energy measurement & particle identification via shower topology
- NUD:** Further particle ID from electromagnetic & hadronic showers

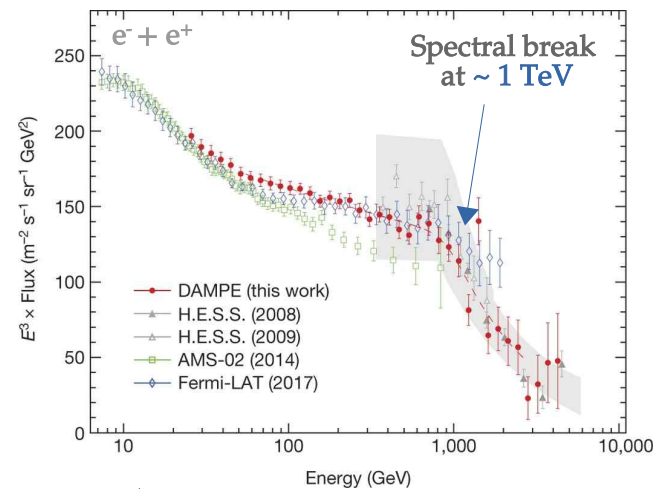


Excellent PSD charge & STK track resolutions
Stable BGO operation for more than 5 years of DAMPE live – time

...with more than 10 billion events collected

Stable & continuous data taking from Dec 2015 up to now



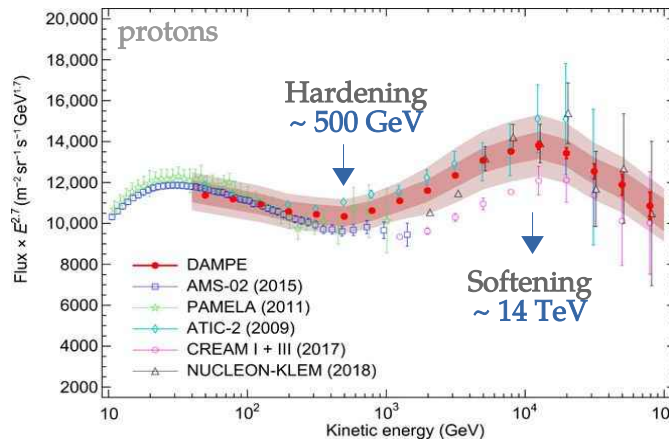


nature

Ambrosi *et al.* Nature vol 552, (2017)

Direct detection of a spectral break at $\sim 1 \text{ TeV}$ in the all – electron spectrum

- **Sample:** 530 days of data
- **Measurement range:** 25 GeV – 4.6 TeV

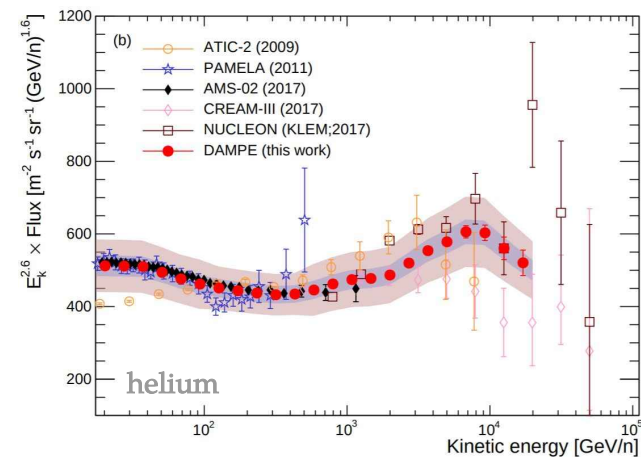


ScienceAdvances

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

Confirming spectral hardening around 500 GeV + revealing a novel softening at $\sim 14 \text{ TeV}$

- **Sample:** 30 months of data
- **Measurement range:** 40 GeV – 100 TeV



PHYSICAL REVIEW LETTERS

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

Confirming spectral hardening around 1 TeV + revealing a novel softening at $\sim 34 \text{ TeV}$

- **Sample:** 54 months of data
- **Measurement range:** 70 GeV – 80 TeV

Medium mass CR nuclei: Motivation

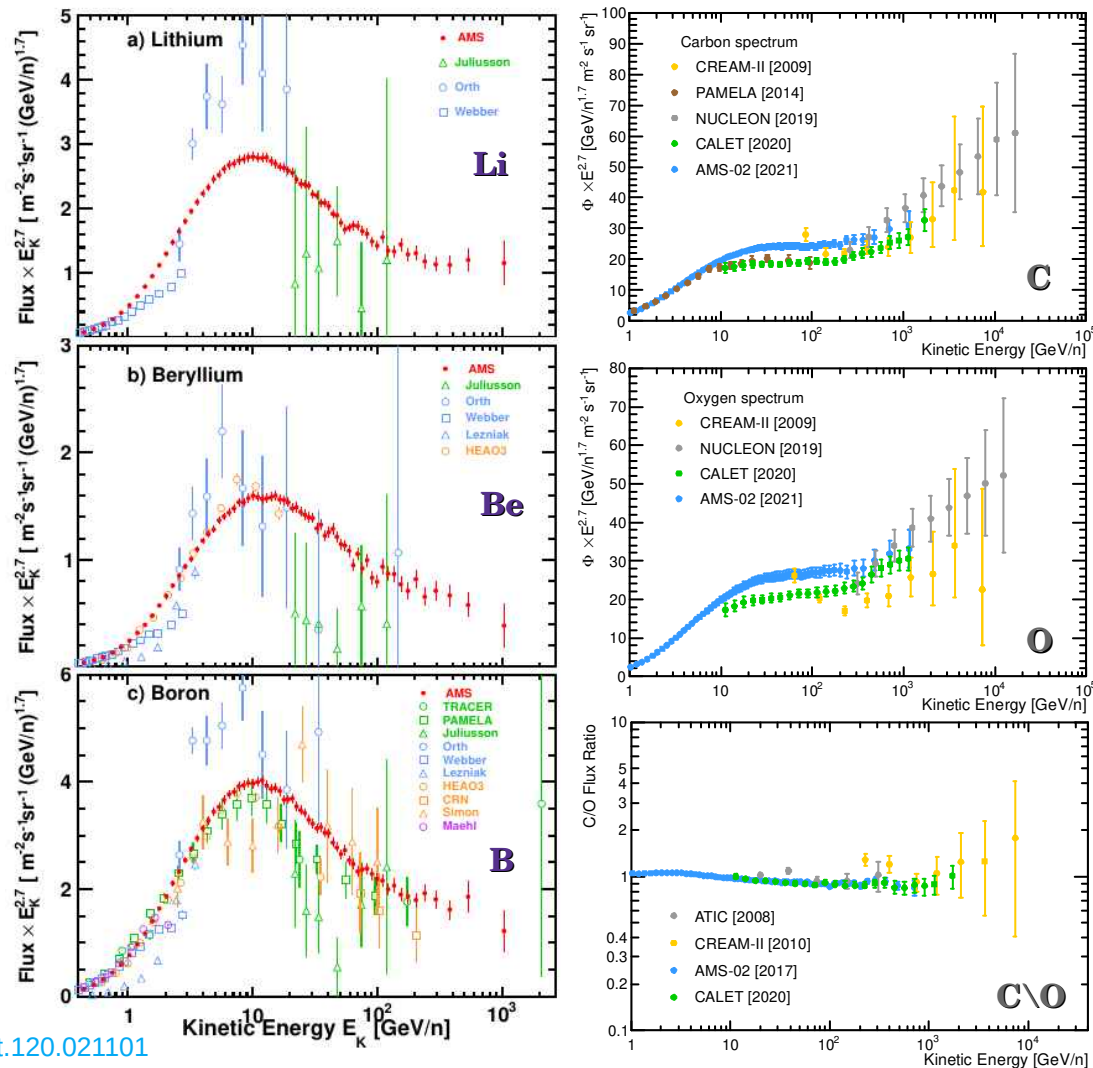
Li, Be, B:

Secondaries produced
by heavier primaries

C & O:

Most abundant primaries
after He

+Important insight on B/C & B/O
...more on the following



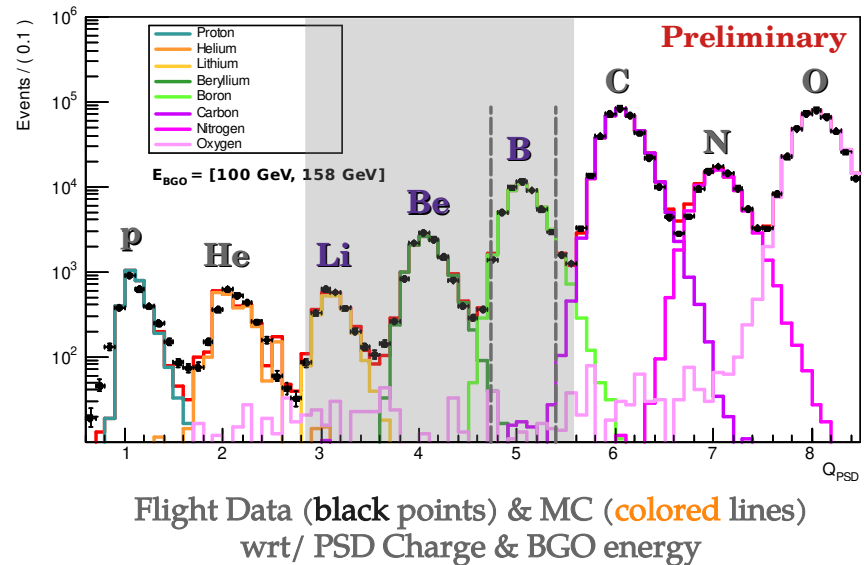
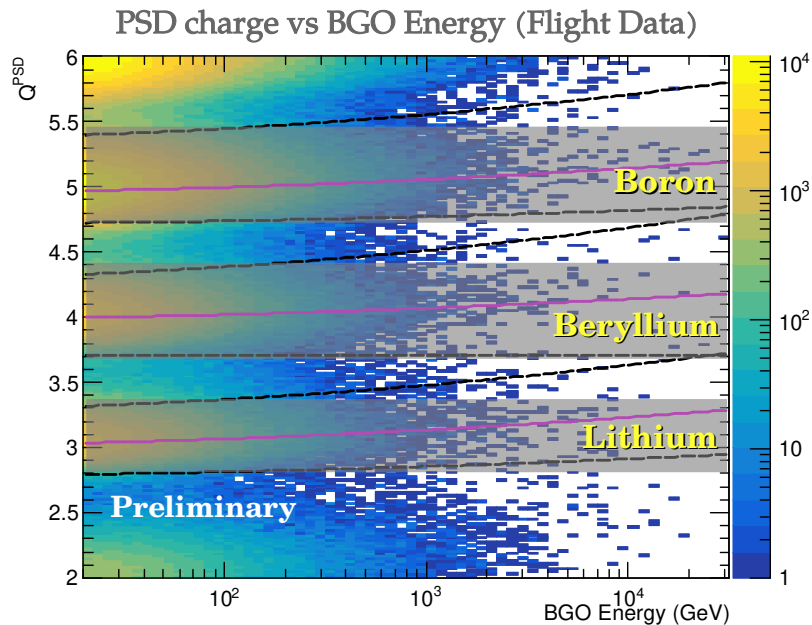
What's needed?

Extension in the multi-TeV region
w/ great precision

Insight on discrepancies between
experiments

Current work focusing on **Lithium, Beryllium & Boron**

DAMPE measurement range
[~10 GeV/n – few TeV/n]



Insightful results to be extracted from the ongoing analysis

- Individual fluxes
- Flux ratios (i.e., Be/B)

Selection Cuts

Exclusion of SAA flight data

$$E_{\text{BGO}} > 100 \text{ GeV}$$

High Energy Trigger (HET) activation

BGO pre-selections:

Reconstructed track contained in first & last (of first 3) BGO layers

Shower maximum not in the BGO border

Removal of side entering events

Rejection of shower vectors failing reconstruction

BGO – STK match:

$$\chi^2 < 25 \text{ \& } \Delta(\theta_{\text{track}} - \theta_{\text{BGO}}) < 25^\circ$$

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

Same track ID for XZ and YZ

PSD fiducial cut:

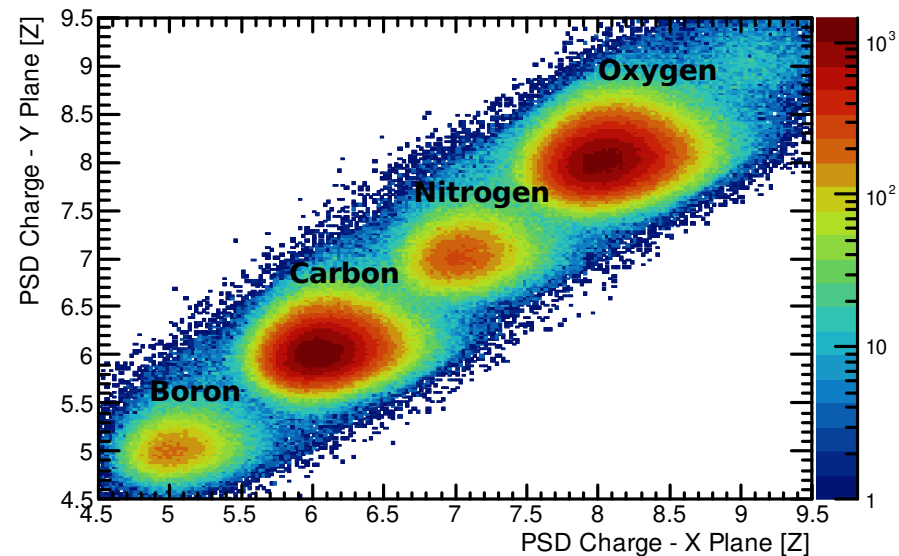
Track projection on first PSD layer < 400 mm

PSD – STK match

Selecting bar crossed by STK both in XZ & YZ, from PSD bars

STK cut:

Accept events impinging on the first STK layer with > 900 ADC



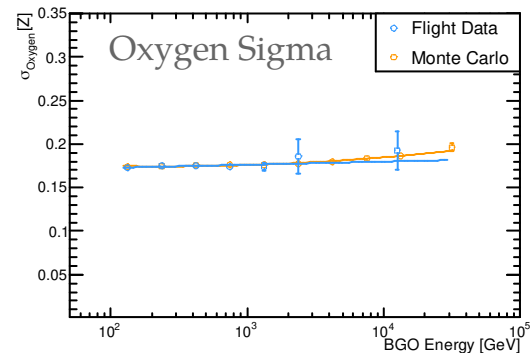
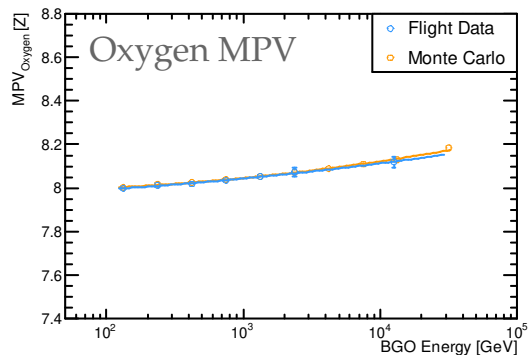
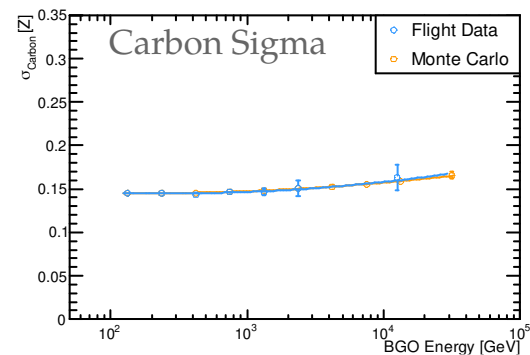
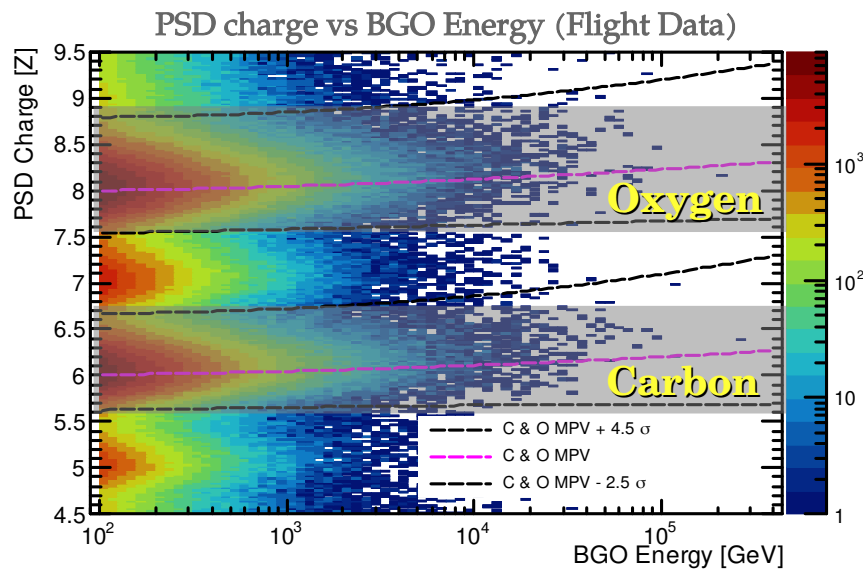
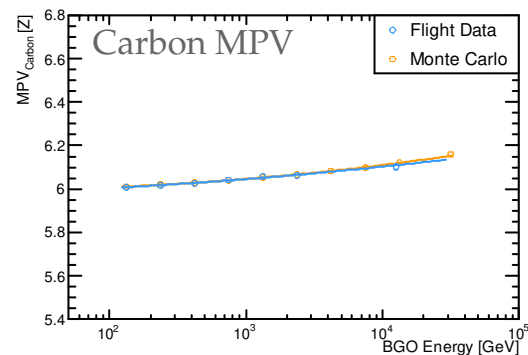
$$PSD_Q = \frac{isY_0 + isY_1 + isX_0 + isX_1}{N_{\text{layersTriggered}}} \quad \&\& \quad \text{Only for adjacent PSD layers} \quad -1 < PSD_Q^i - PSD_Q^{i+1} < 1$$

**Great increase in statistics coupled
w/ significant
contamination reduction**

Selecting pure C & O samples

Fitting each contribution with a Landau + Gaussian function (LanGaus)

Thus accurately defining the charge selection for C & O

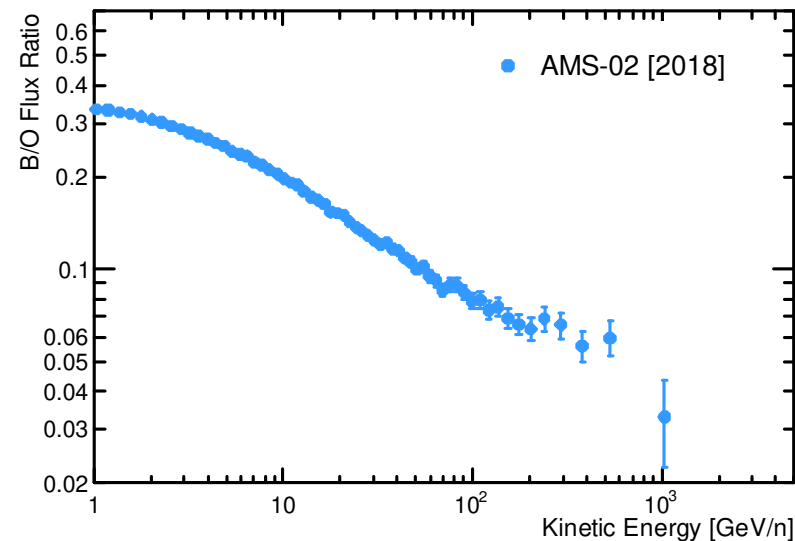
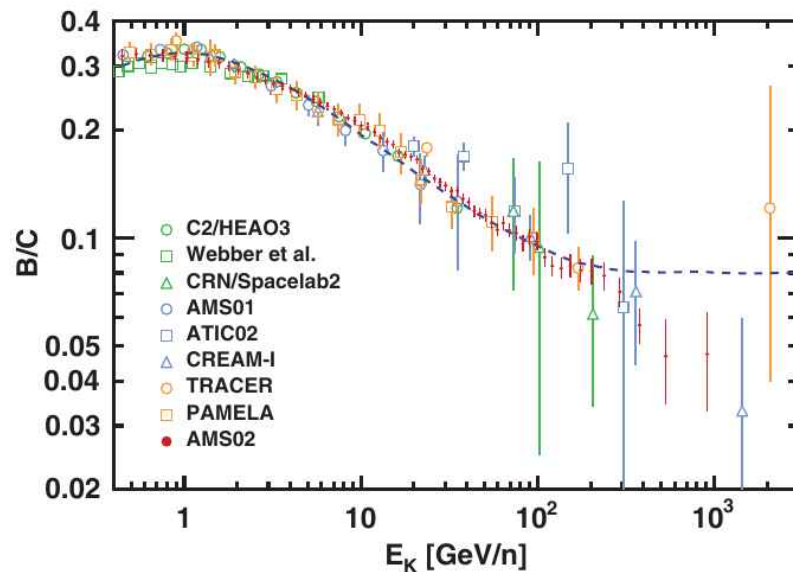


Analogous interval selection for both C & O nuclei
+ novel STK track selection procedure via ML algorithms

B/C & B/O: Motivation

B/C – Customarily used to probe CR propagation in the Interstellar Medium

B/O – Even greater probe of CR propagation in the ISM



Insightful results by a multitude of experiments
precise results in the TeV/n region needed

Understanding the CR propagation mechanism (and more...)

Secondary nuclei (Li, Be, B) produced via spallation
from interactions of heavier nuclei (C, N, O)
w/ Interstellar Medium (ISM)

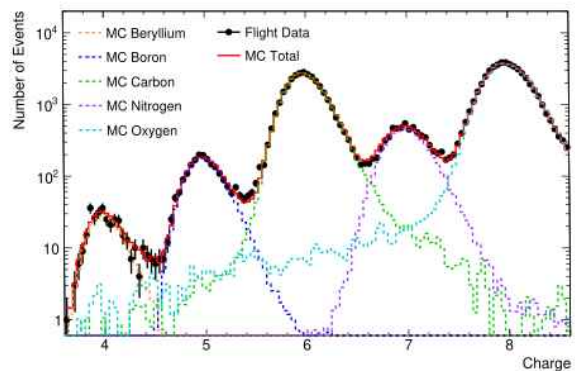


Secondary – to – primary ratios
provide crucial information on the
CR propagation mechanism

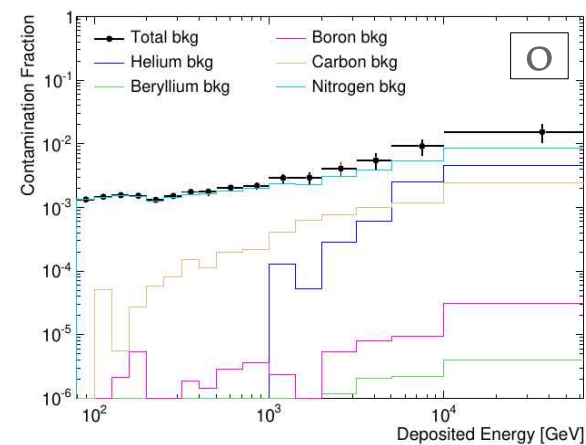
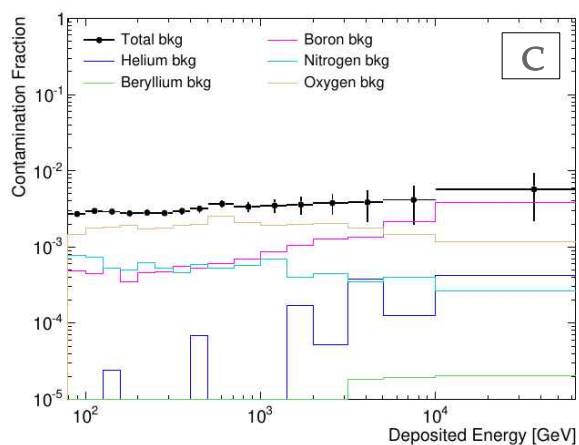
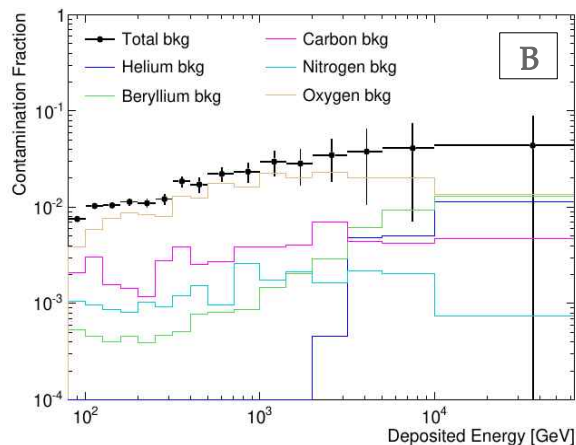
B, C & O: Sample Contamination

Overall template fits for B, C & O

- Dashed lines: MC samples
- Points: Flight Data



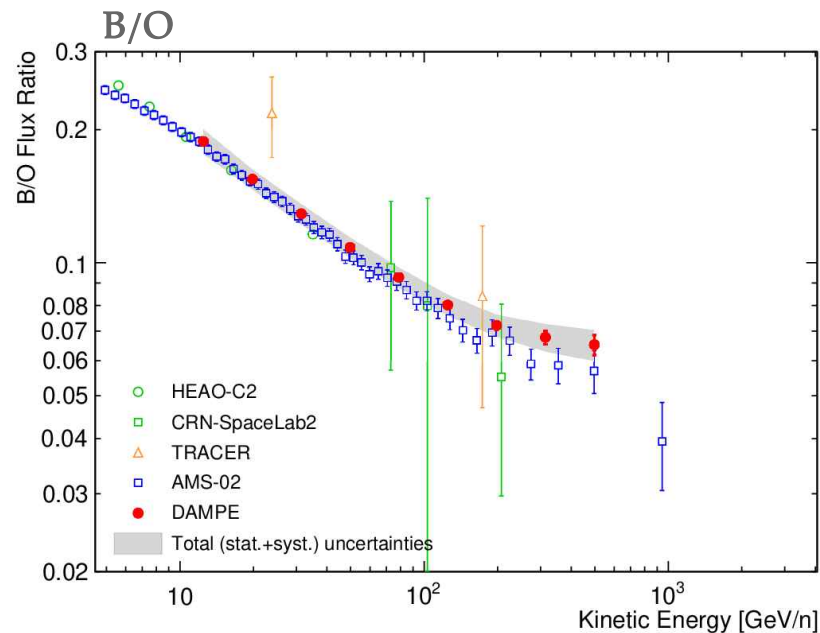
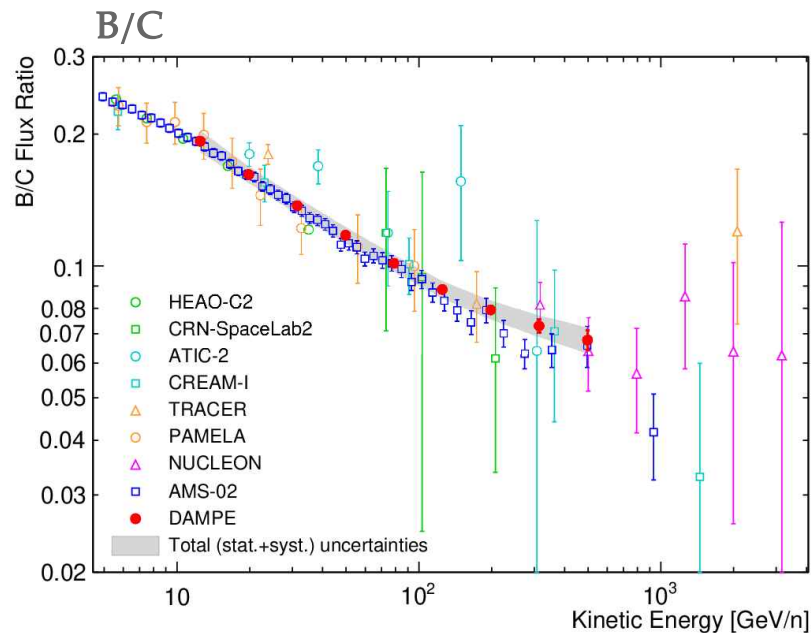
Good agreement
between FD & MC



Very limited contamination for **C & O** (~1%)
Low contamination for **B** (<5%)

B/C & B/O flux ratios

Taking into account **ongoing** works from B, C and O fluxes



Overall agreement with AMS-02 + **new** measurements (TBA) in the TeV/n region

...soon to be published

Current study concerning the spectral measurements of medium mass CR nuclei

DAMPE shows great capabilities of precisely measuring such nuclei in the multi-TeV/n region

Ongoing works on Li, Be, B, C, N, O with 6 years of DAMPE data,
w/ great insight on the B/C and B/O flux ratios

Good agreement with current experiments on B/C and B/O flux ratios

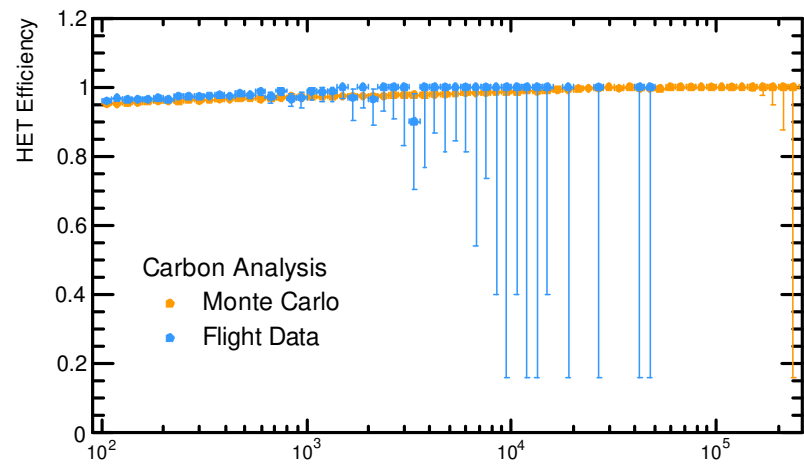
Ongoing work

Additional corrections/optimizations

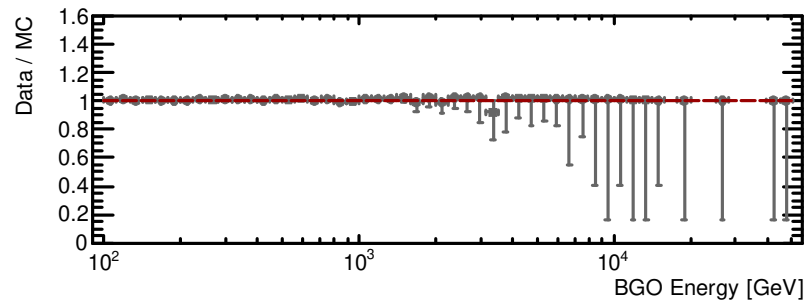
Extension to higher energies for all nucleonic spectra

Finalizing contamination & systematics' studies

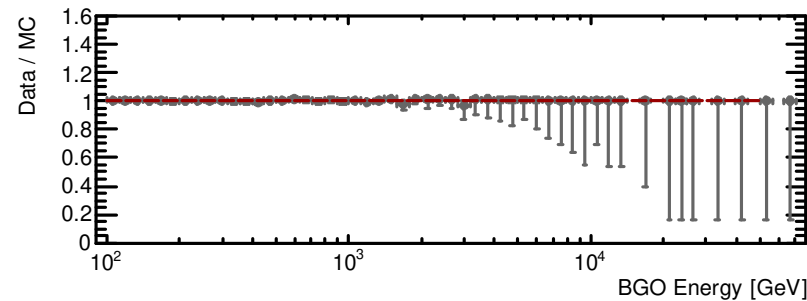
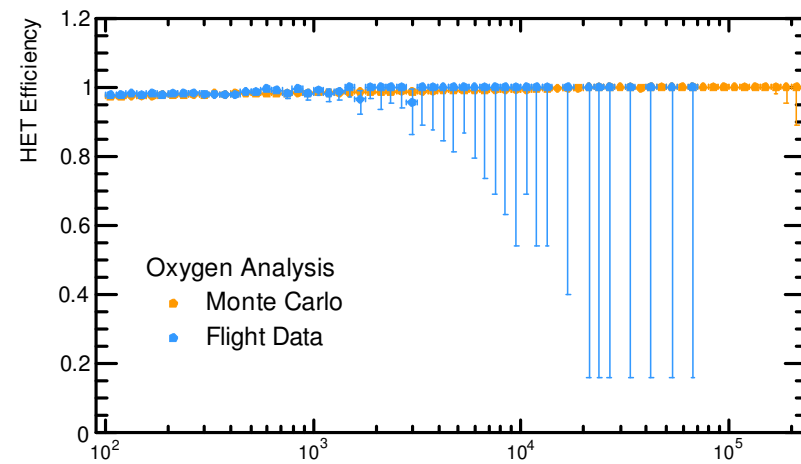
Additional Info



<1% discrepancy
between FD & MC

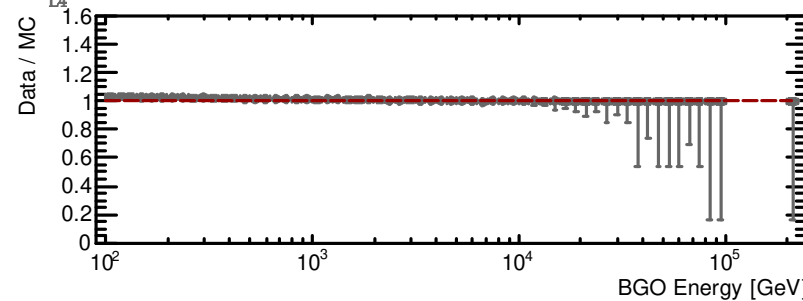
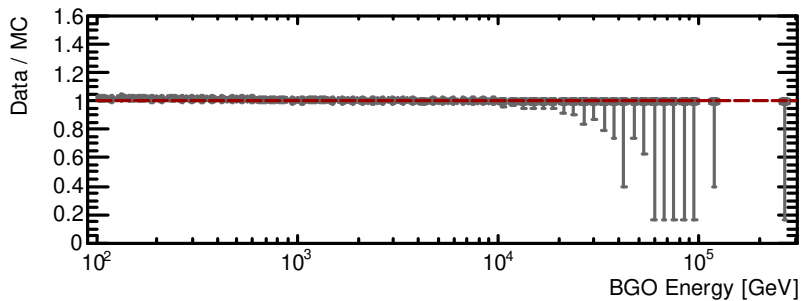
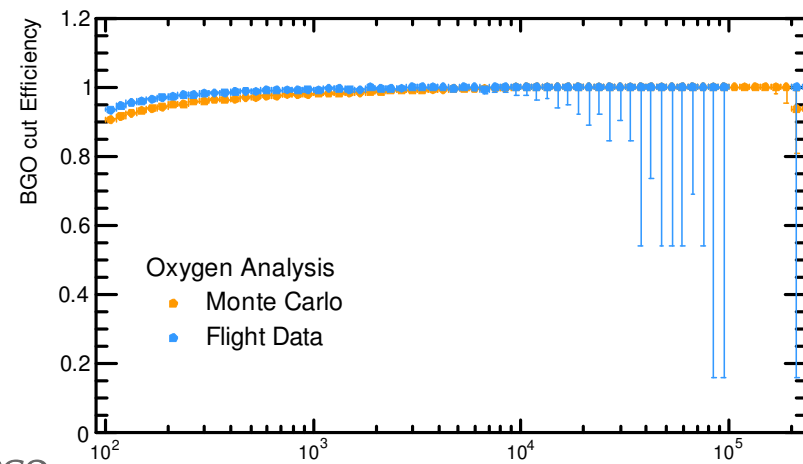
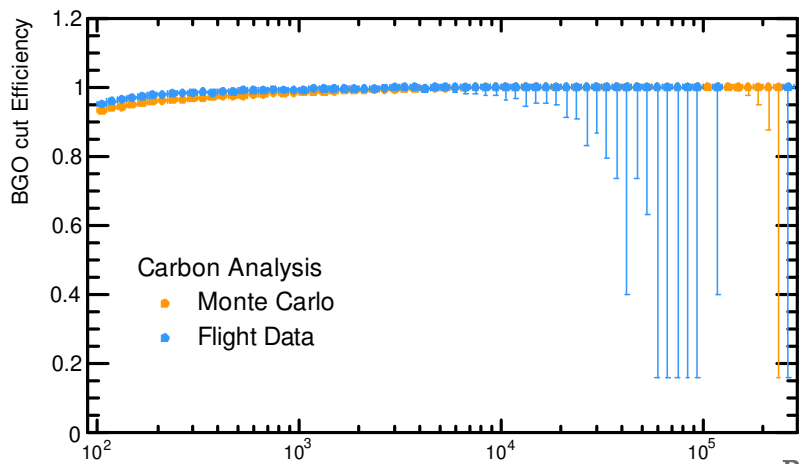


Carbon



Oxygen

$$\epsilon_{HET} = \frac{N_{HET|LET} | N_{PSD_{cut}} | N_{STK_{cut}}}{N_{LET} | N_{PSD_{cut}} | N_{STK_{cut}}}$$



Carbon

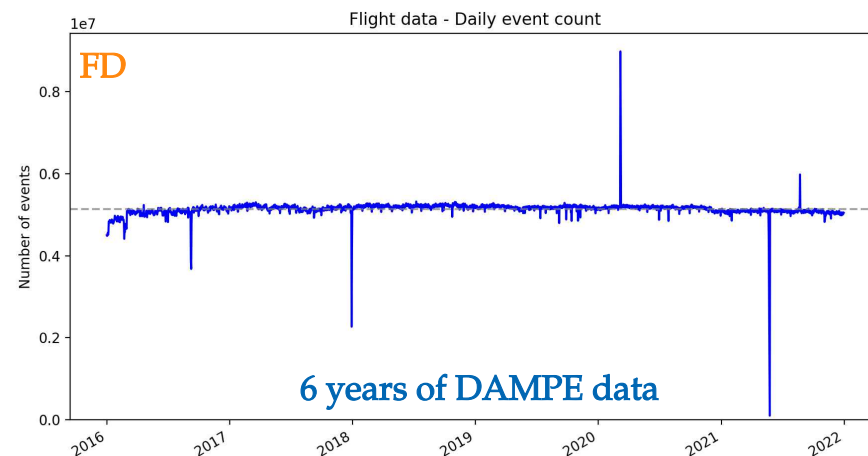
Oxygen

$$\epsilon_{BGO_{L1+L2 < L3+L4}} = \frac{N_{HET} | N_{PSD_{cut}} | N_{STK_{First Layer}} | N_{BGO_{L1+L2 < L3+L4}}}{N_{HET} | N_{PSD_{cut}} | N_{STK_{First Layer}}}$$

MC used in this work

Energy Range	^{12}C [M]
100 GeV – 1 TeV	100.15
1 – 10 TeV	106.97
10 – 100 TeV	109.88
100 – 500 TeV	7.676

Energy Range	^{16}O [M]
100 GeV – 1 TeV	100.37
1 – 10 TeV	101.21
10 – 100 TeV	116.53
100 – 500 TeV	8.358



BGO preselections used to alleviate file size & eliminate unwanted events

