
# Studies of Medium and Heavy mass cosmic ray nuclei with the DAMPE space mission

**Dimitrios Kyratzis**

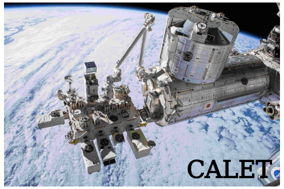
on behalf of the DAMPE collaboration

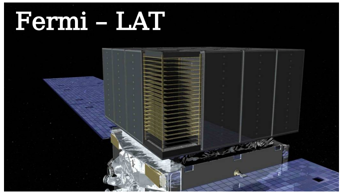
Gran Sasso Science Institute (GSSI) & INFN-LNGS

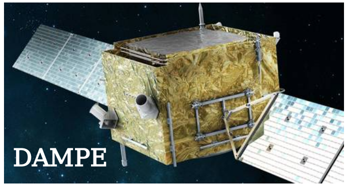
# Introduction: The Cosmic Ray Landscape

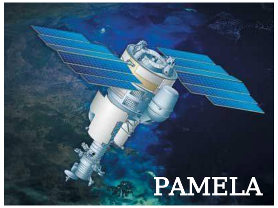


Energies achieved with current space – borne direct CR experiments (~ few hundred TeV)

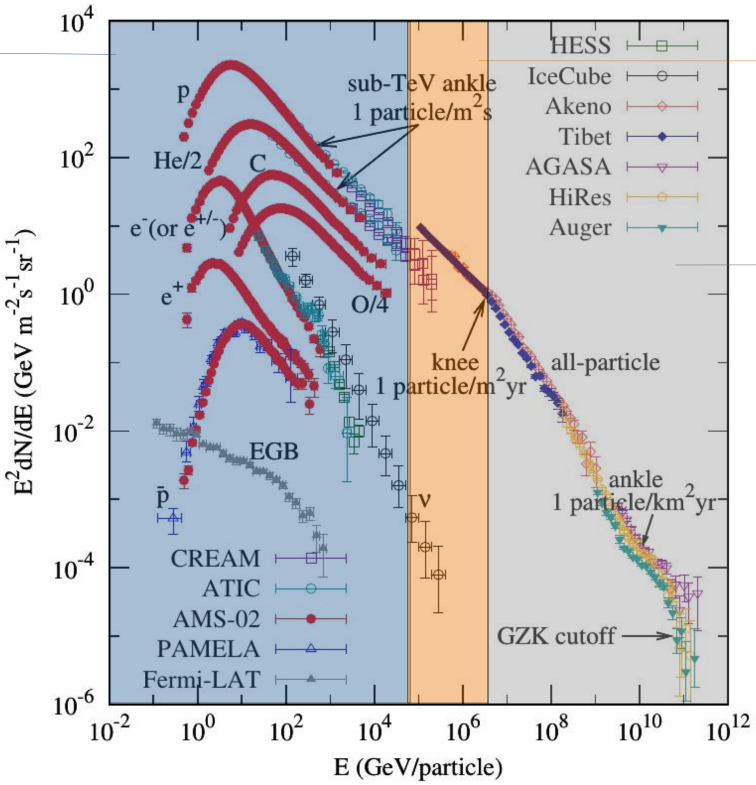


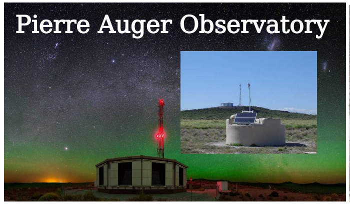



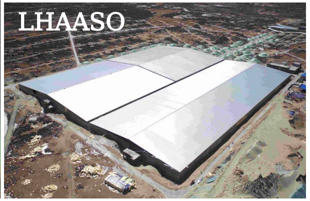





Maximal energies achieved with direct detection CR experiments (~ PeV energies)

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)

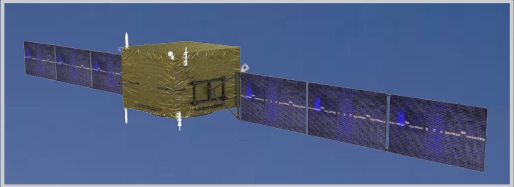
Understanding CR acceleration & propagation mechanisms

# The DAMPE space mission



DARK MATTER PARTICLE EXPLORER — DAMPE

**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

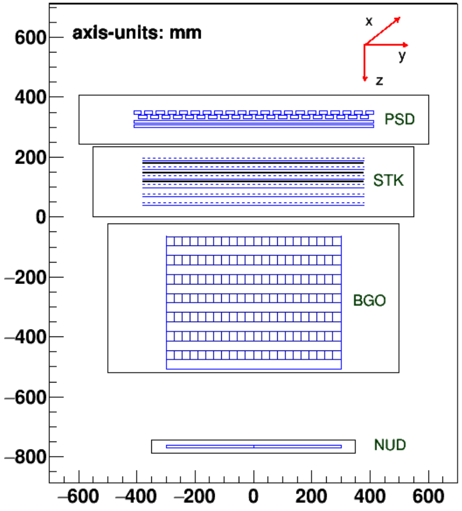
**γ – rays**: Insight on high-energy γ astronomy, transient studies, etc

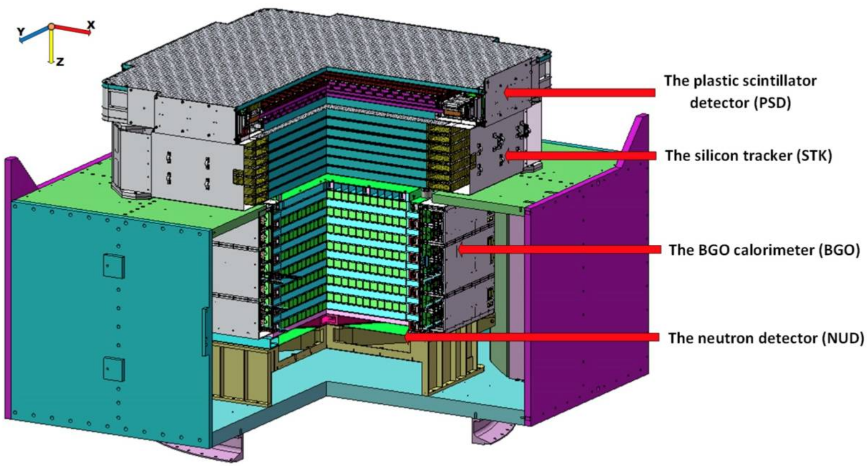
**DM**: Indirect studies on possible DM candidates

Astropart. Phys., 95, 6 [2017]

# Detector Description & Features






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

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

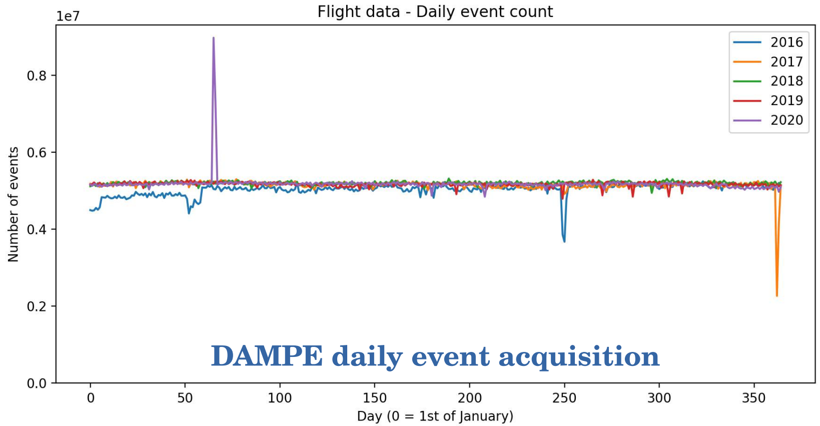
**BGO:** **Energy measurement** & particle identification via shower topology

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

## 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 $\Lambda_I$ |
| **Field of View** | ~1.0 sr |

# On – orbit status

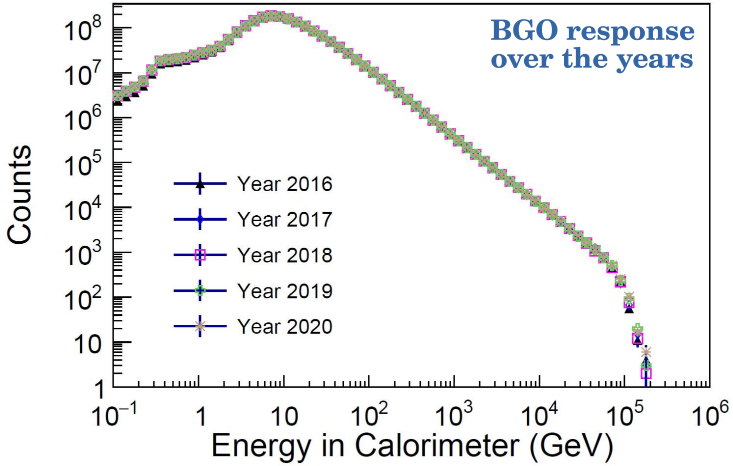


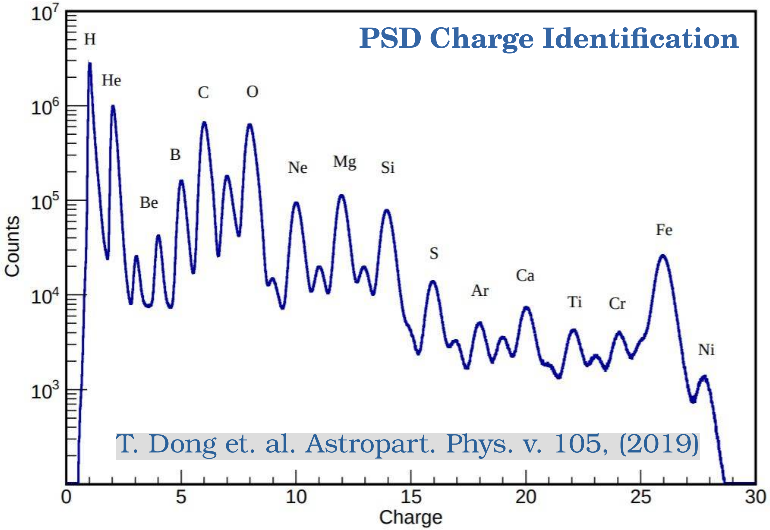

Excellent PSD charge & STK track resolutions

Stable BGO operation for more than 5 years of DAMPE live – time

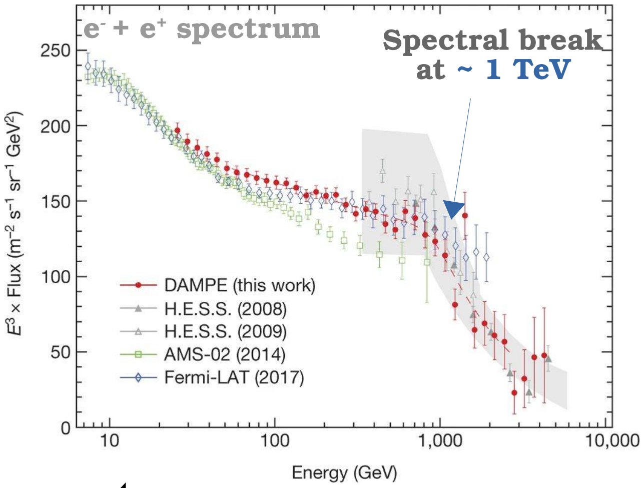
**...with more than 10 billion events collected**

**Stable & continuous data taking from Dec 2015 up to now**



# DAMPE CRs: Insightful results so far

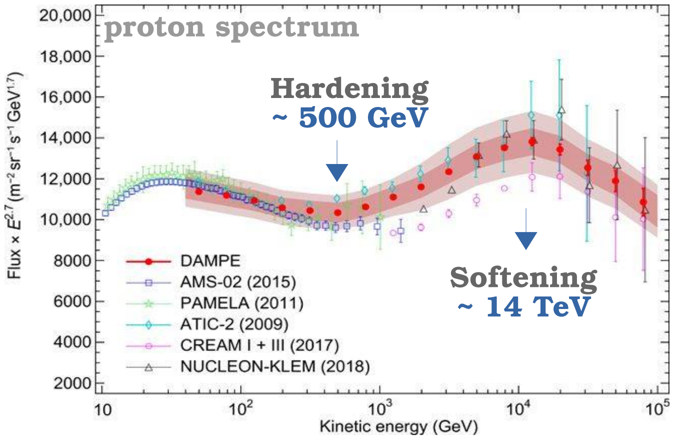



nature

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

**Direct detection of a spectral break at ~ 1 TeV in the all – electron spectrum**

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

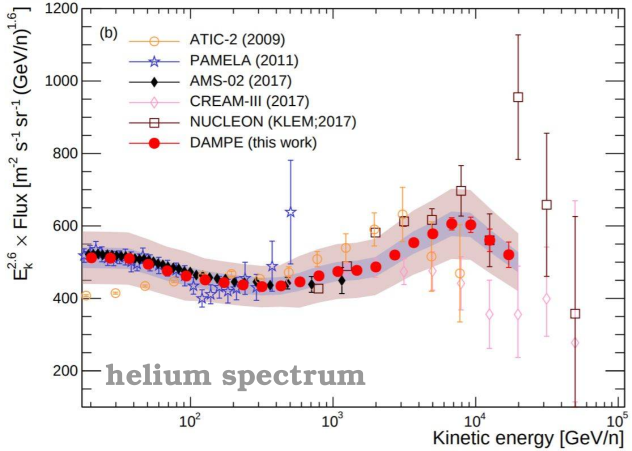



ScienceAdvances

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

**Confirming spectral hardening around 500 GeV + revealing a novel softening at ~ 14 TeV**

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




PHYSICAL REVIEW LETTERS

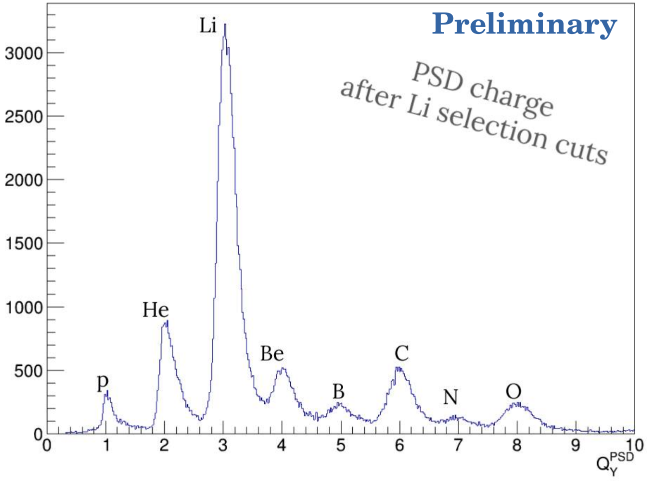
Alemanno *et. al.* PRL 126, 201102 (2021)

**Confirming spectral hardening around 1 TeV + revealing a novel softening at ~ 34 TeV**

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

# Secondary CRs: Li, Be, B

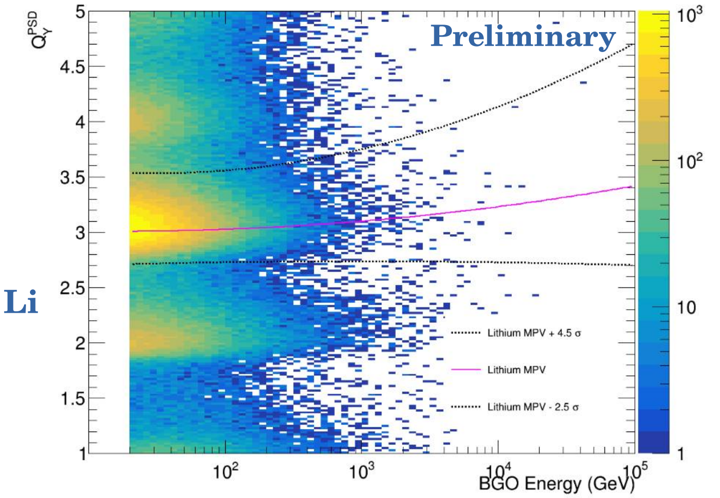





**Current work focusing on Lithium**

Specific selections to reduce background from: He, C, N, O

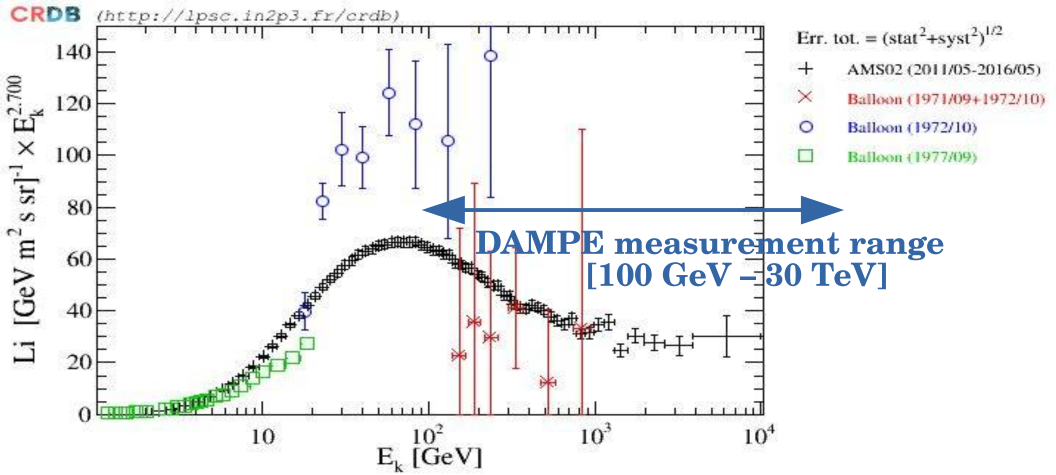
Thus clearly revealing the contribution of Li




**Towards Li spectral measurement**

## Ongoing & upcoming work

- Acceptance validation
- Estimation of background & systematics
- Similar techniques adopted for Be & B



# Primary CRs: C & O nuclei

## Selection Cuts

**Exclusion of SAA flight data**

**$E_{BGO}$ > 100 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:**

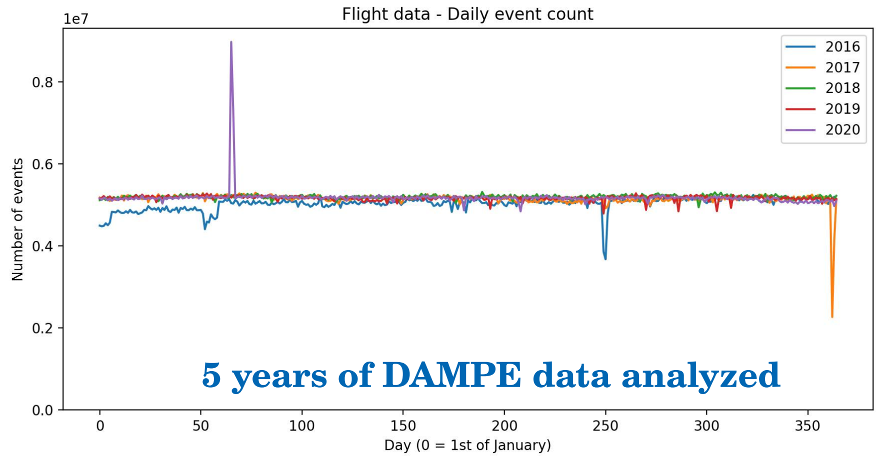
**$\chi^2 < 25$, & $\Delta(\theta_{track} - \theta_{BGO}) < 25^0$**
**XZ and YZ projections on top of STK < 200 mm & BGO < 60 mm**
**Same track ID for XZ and YZ**

**PSD fiducial cut:**

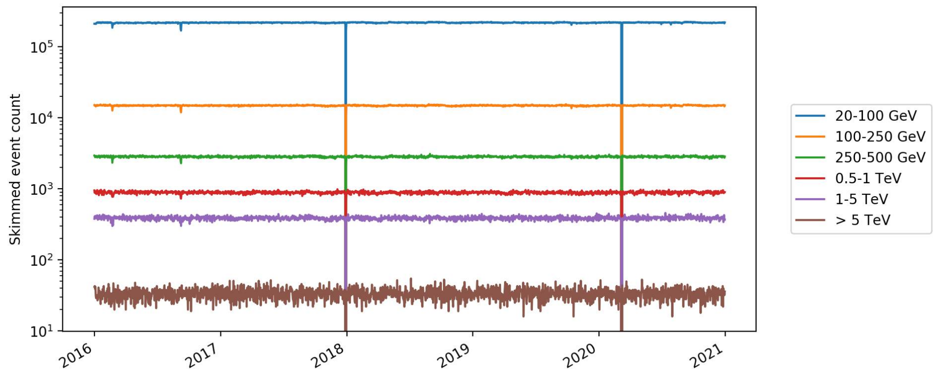
**Track projection on first PSD layer < 400 mm**

**PSD – STK match**

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



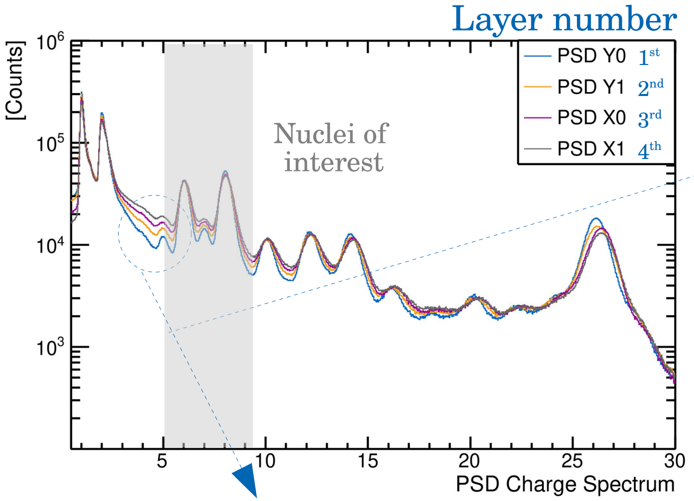

BGO preselections used to alleviate file size & eliminate unwanted events

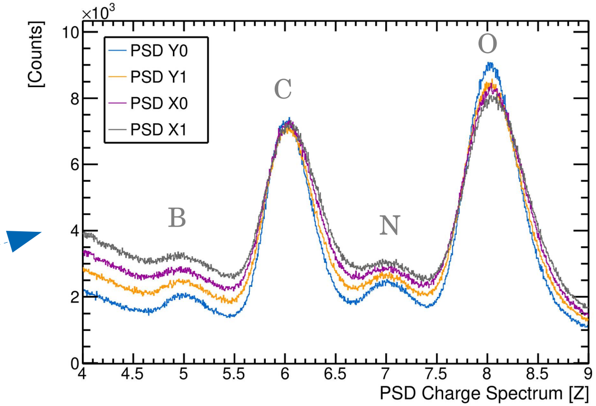


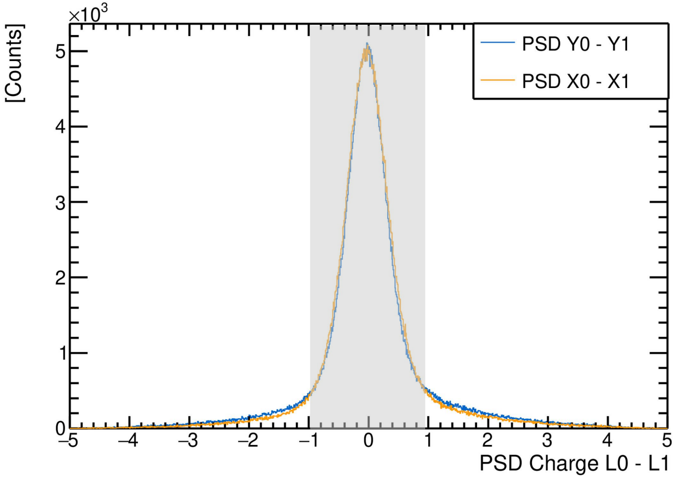
# PSD Charge Spectrum [Flight Data]



**PSD charge spectrum for Flight Data after all implemented corrections**



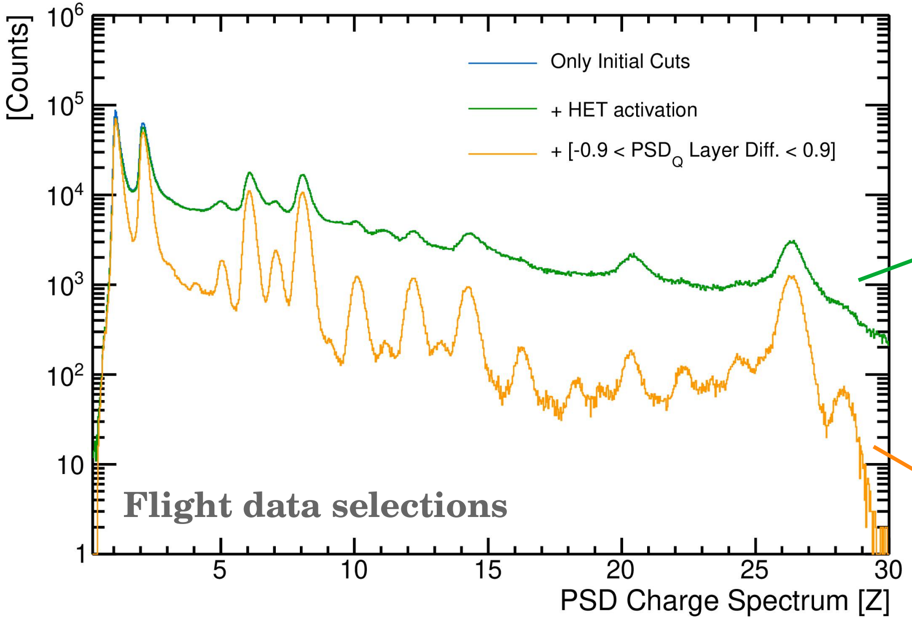

Increase of background contamination (from He, fragmentation of CNO, Fe) as nuclei propagate further inside the PSD layers.

A pure sample is achieved by subtracting Layers 0 from 1 in the same plane (Y/X) + fitting each contribution to obtain the limits

**This specific selection cut ensures a pure sample in BCNO & is universally applied throughout the analysis**

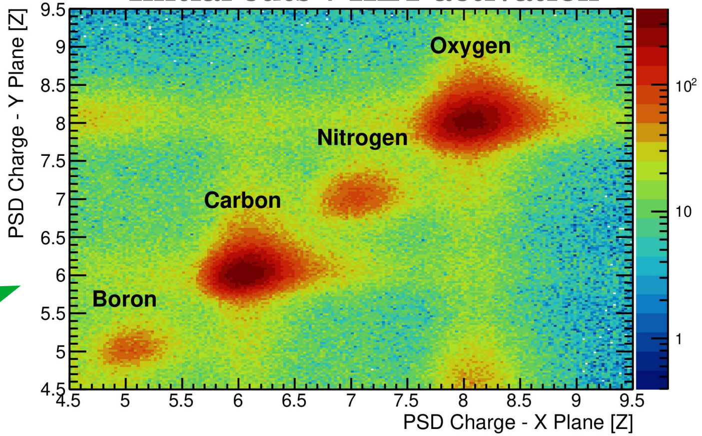
# PSD Charge Spectra

**Application of the aforementioned cut both in Flight & MC data**

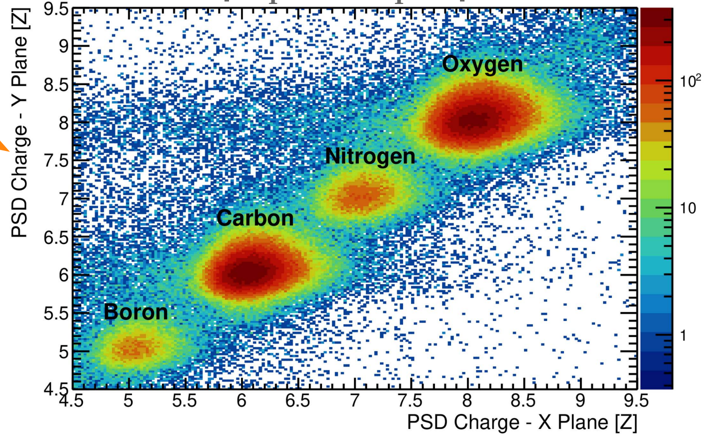



**Dramatic decrease in background contamination + increase in peak resolution**

**Initial cuts + HET activation**




**$+|Q_Y^{PSD} - Q_Y^{PSD}| < 0.9$**

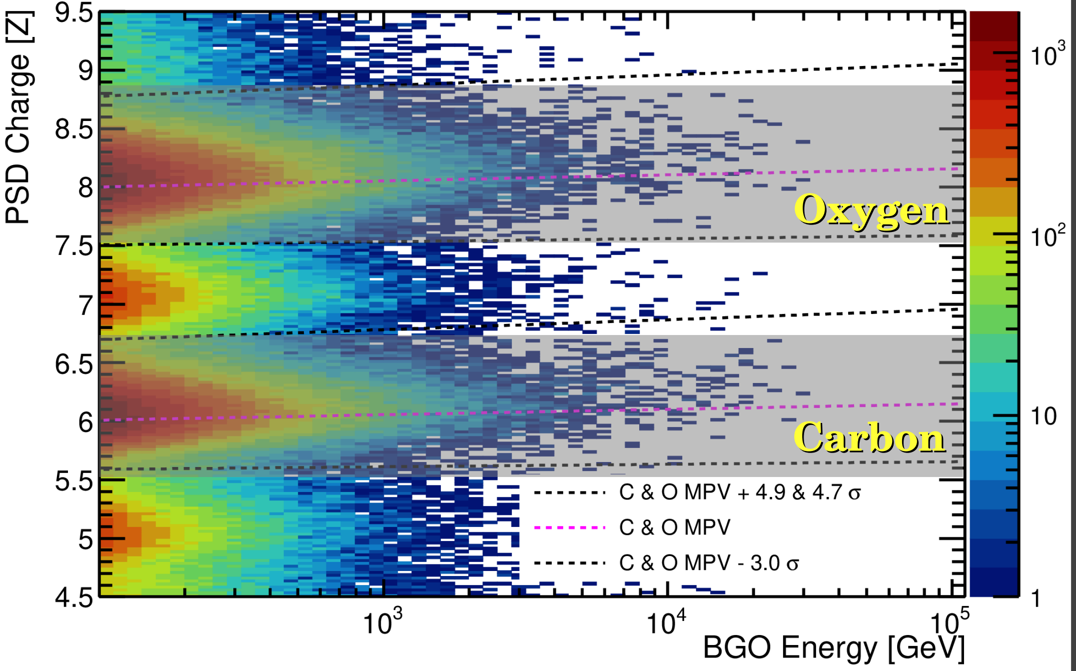


# Charge Selection [FD] & Future prospects

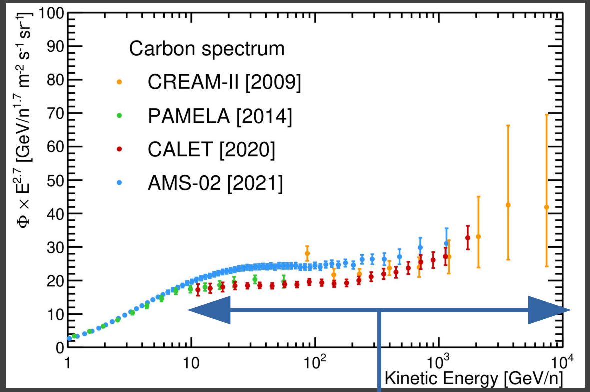


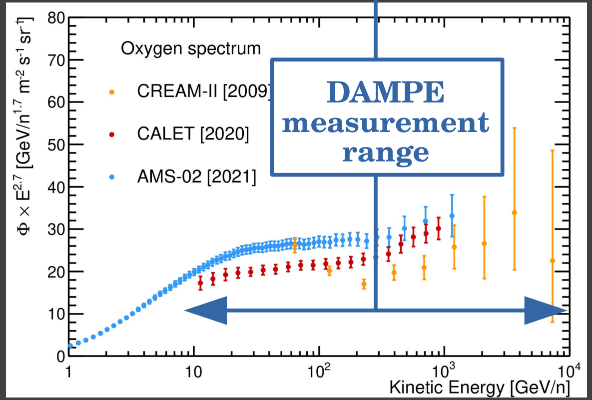
## Flight Data

**C & O selections following the charge smearing procedure**




**Analogous interval selections for C & O nuclei**




**Ongoing & upcoming efforts foresee**
**background & systematics' evaluation**
**+extension to higher energies ( ~ TeV/n)**

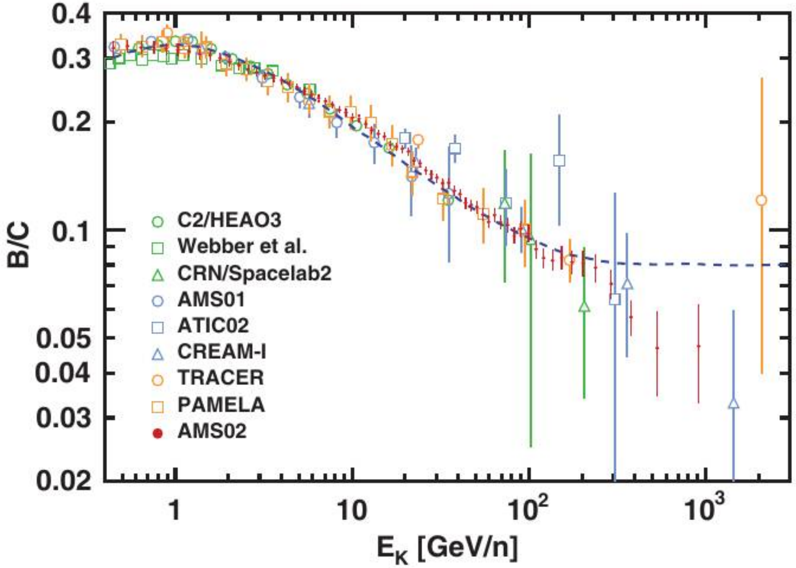
# CR Flux Ratios: B/C



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

Insightful results obtained by a multitude of experiments

M. Aguilar *et al.* (AMS), Phys. Rev. Lett. 117, (2016), 231102




...although precise results in the TeV/n region are needed

**Understanding the CR propagation mechanism** (and more…)

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

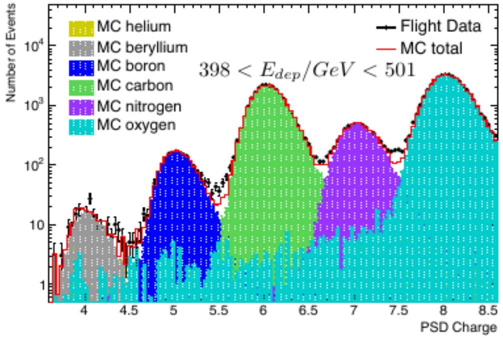
→

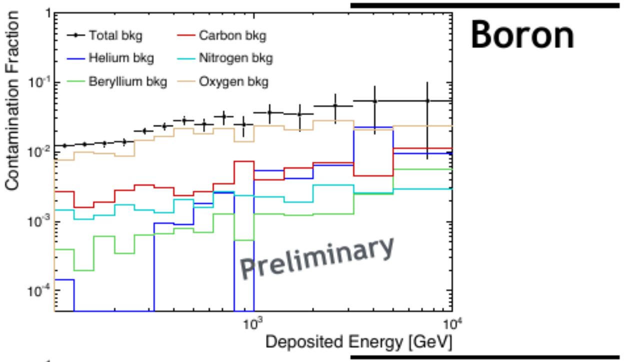
**Secondary – to – primary** ratios provide crucial information on the **CR propagation mechanism**

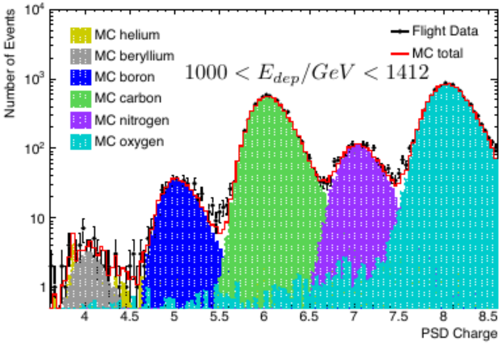
# CR Flux Ratios: B/C

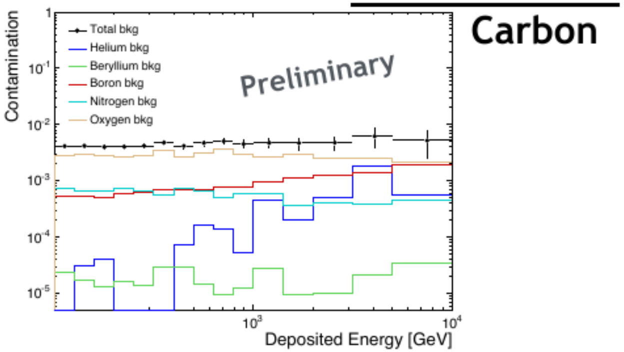


**5 years of DAMPE data used in the measurement of secondary-over-primary ratios**

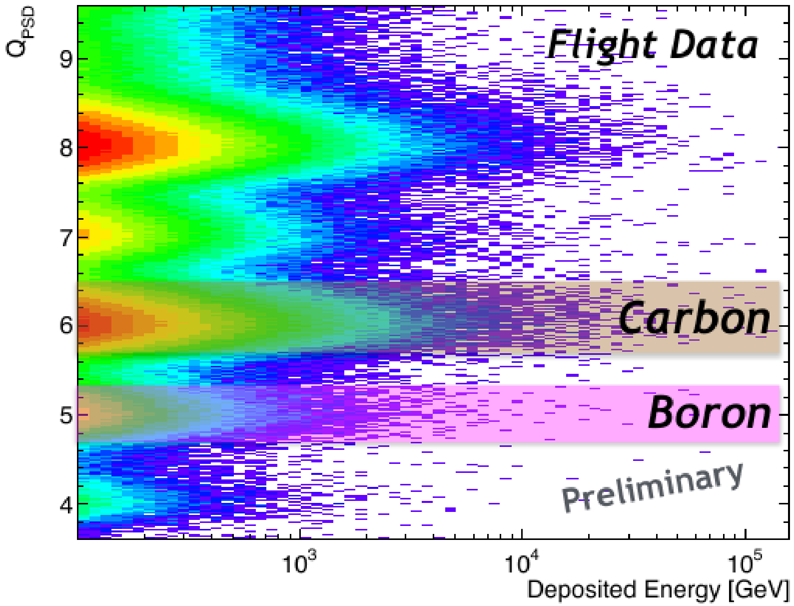



C. Yue *et. al.* PoS, ICRC 2021, 126



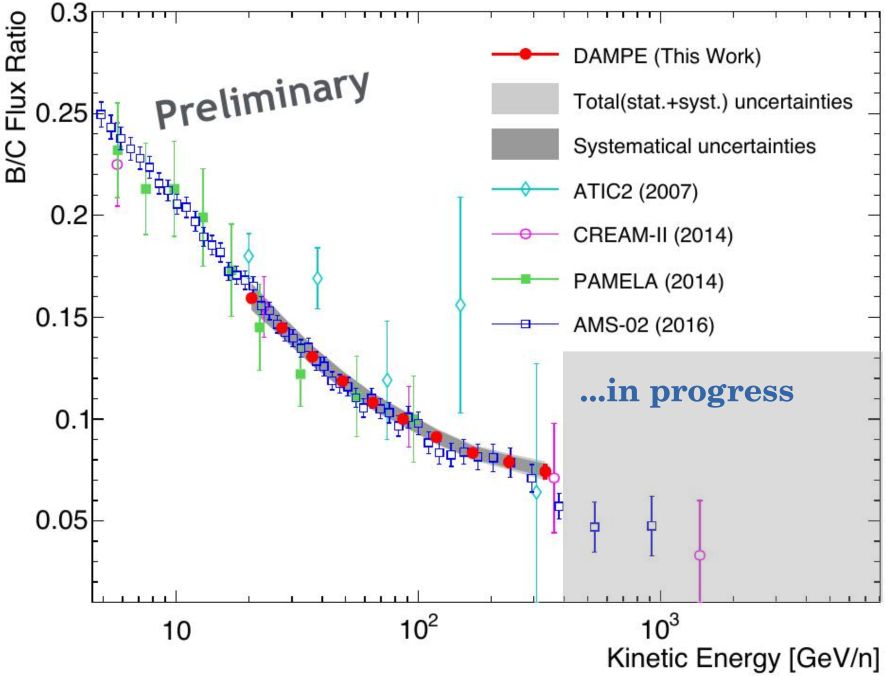

**Charge selection**

**Contamination estimation for Boron & Carbon nuclei**

# CR Flux Ratios: B/C

**Preliminary results for B/C in the range of 20 – 400 GeV/n**

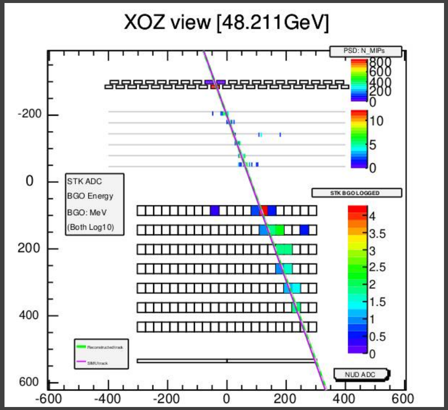
C. Yue *et. al.* PoS, ICRC 2021, 126

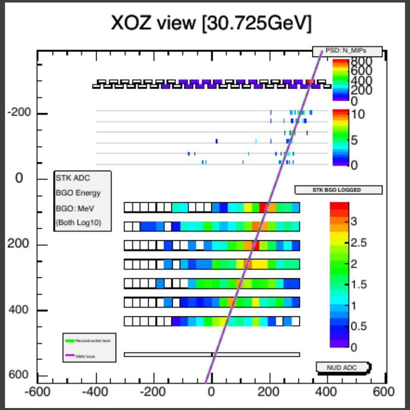



**Consistent results w/ AMS & PAMELA within the systematics**

**B/C analysis up to few TeV/n is ongoing**

Z. Xu *et. al.* PoS, ICRC 2021, 115




## Iron Fragmentation

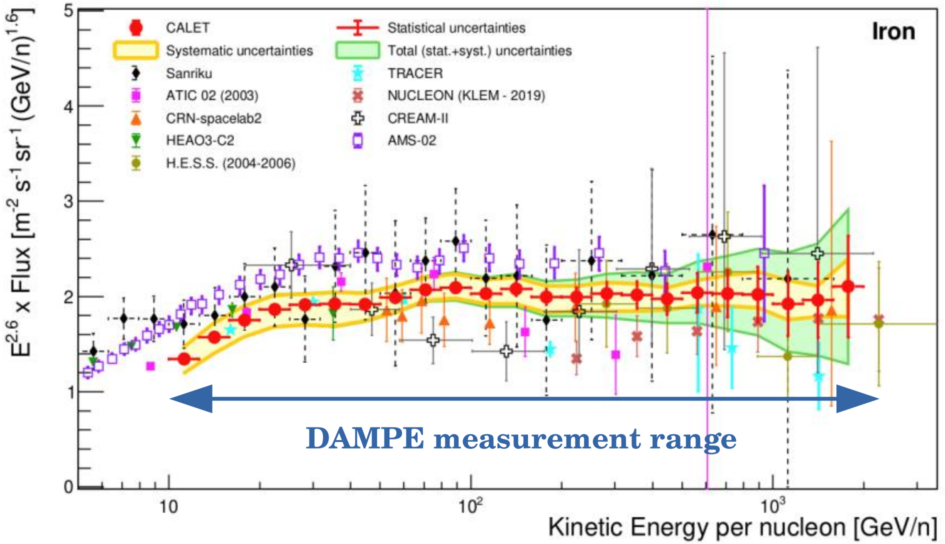
Large percentage fragmenting in PSD or STK

**Common issue in all analyses involving such heavy nuclei**

Nuclear fragmentation taking place inside the BGO will result in a cleaner track (left) when compared to events fragmenting inside the STK (right)

**Ongoing work on Fe analysis with 5 years of DAMPE data**

O. Adriani *et al.* (CALET), Phys. Rev. Lett. 126, (2021), 241101



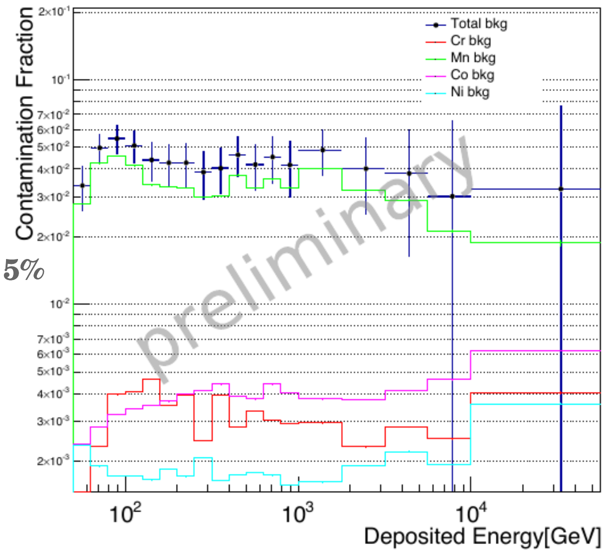

**DAMPE results should assist in understanding spectral differences**

# Primary CRs: Fe

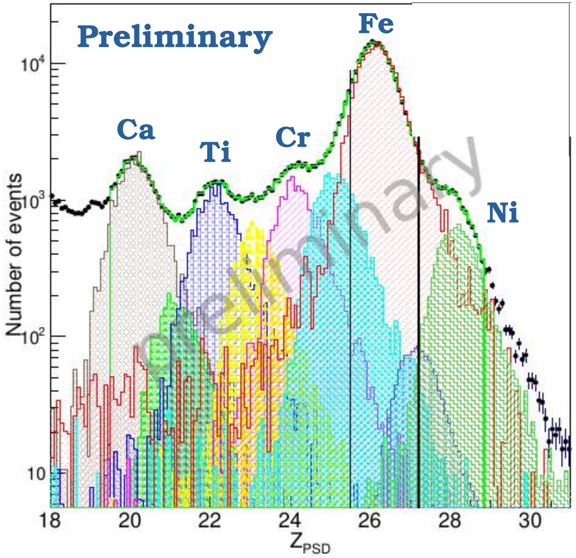
**Ongoing work on Fe analysis with 5 years of DAMPE data**

Z. Xu *et. al.* PoS, ICRC 2021, 115

**Contamination < 5%**




**158 < $E_{DEP}$ / GeV < 200**




**Rigorous efforts in:**

evaluating systematics,

optimizing selection cuts,

understanding nuclear fragmentation effects

extension of measurements in the multi-TeV region

# Summary

## DArk Matter Particle Explorer (DAMPE)

- In – orbit since 2015
- Stable data taking with excellent performance
- Unique instrument in probing Galactic Cosmic Rays

## Scientific results & ongoing work

- Insight on ongoing CR analyses regarding medium & heavy mass nuclei
- All analyses performed include 5 years of DAMPE flight data
- Updated works on Li, B/C, C, O & Fe
- Extension of previous measurements to higher energies with great precision