Measurement of Cosmic-ray secondary-to-primary ratios with CALET on the International Space Station

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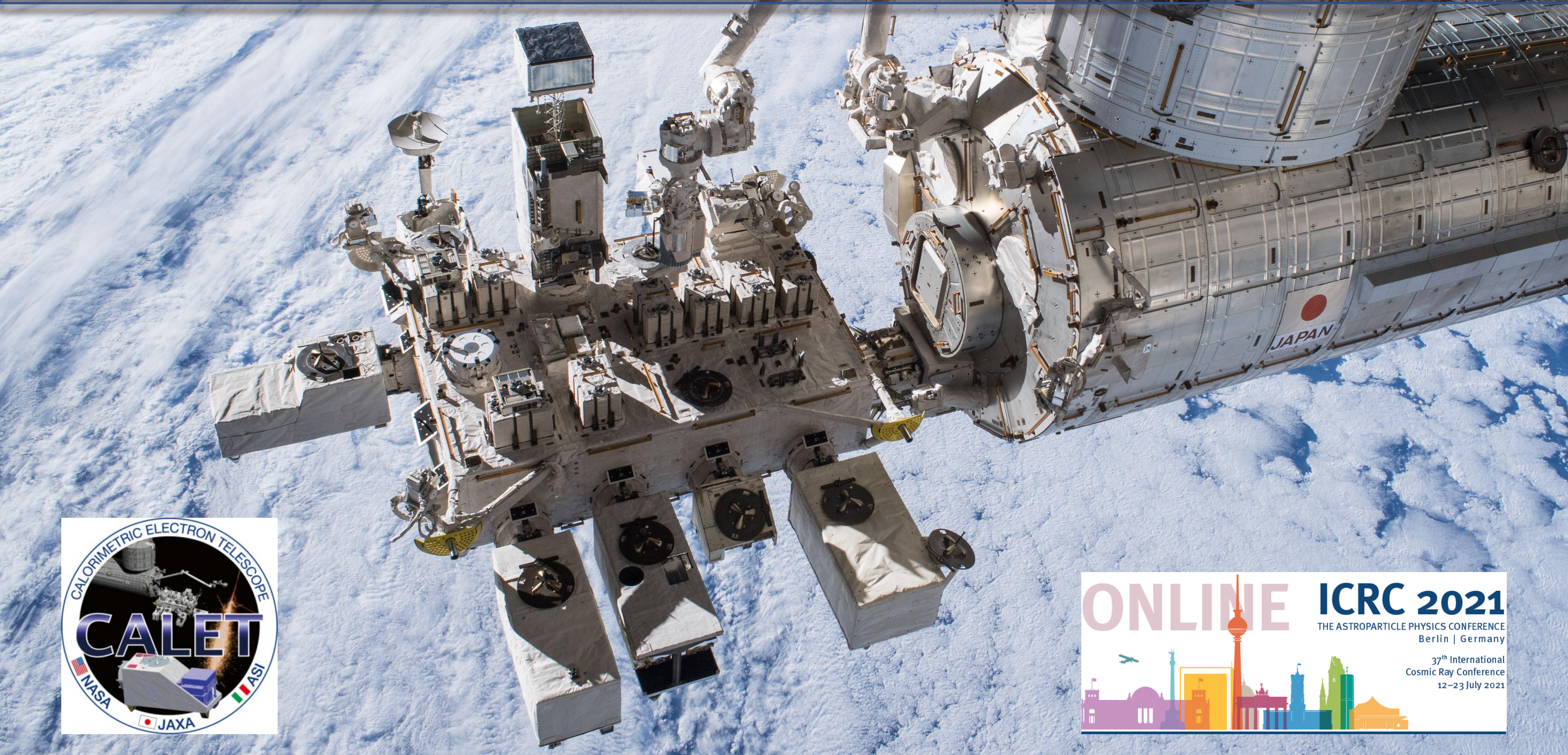

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CALET
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THE ASTROPARTICLE PHYSICS CONFERENCE
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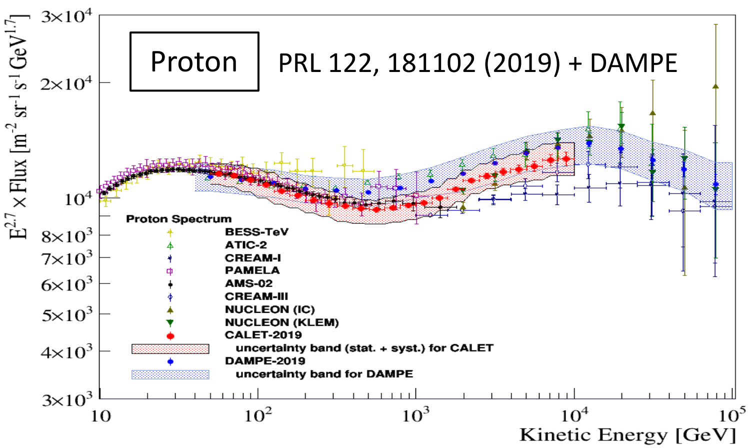
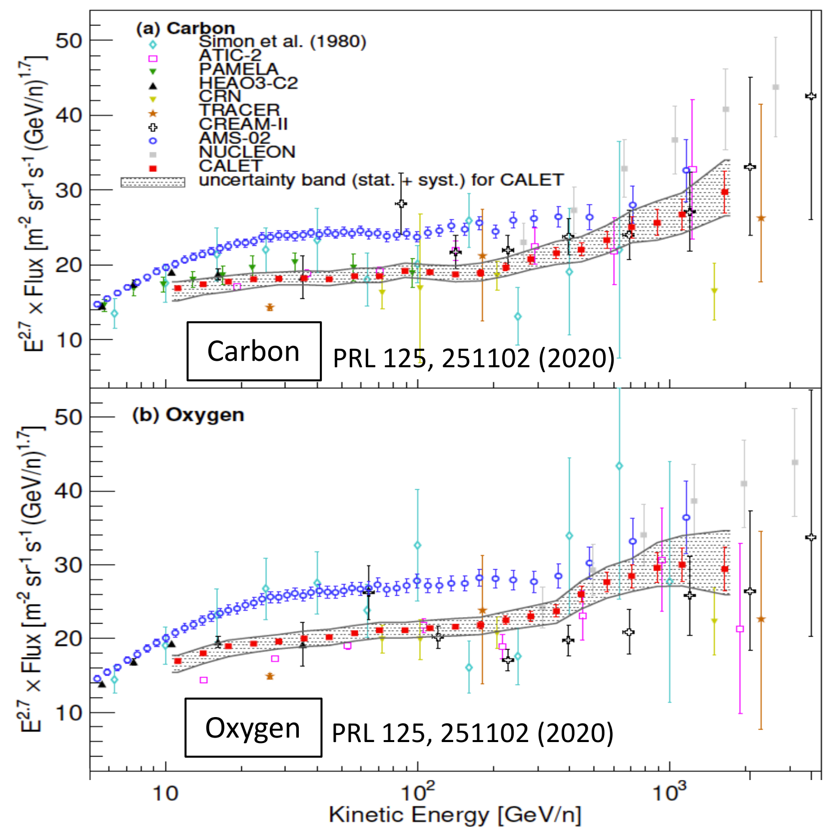
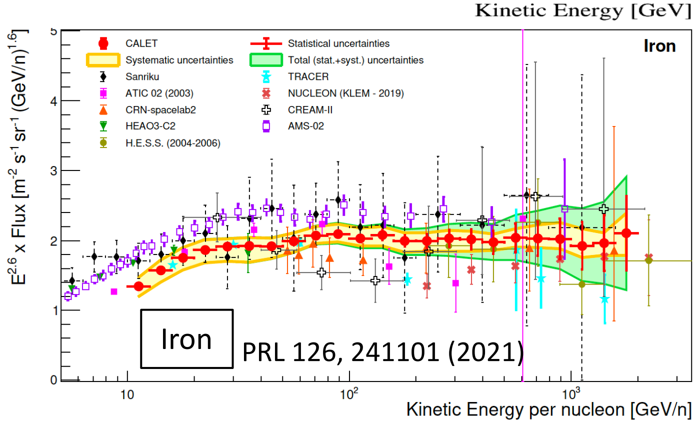
Nuclei observations with CALET

- CALET measures energy spectra of nuclei from proton to Iron
  - Energy spectra of proton, C and O indicate the spectral hardening at a few 100 GeV/n, while less in iron spectrum.
  - Measurement of secondary CRs can constrain the theoretical models

<u>➡ Boron spectrum and B/C ratio will be presented in this presentation</u>



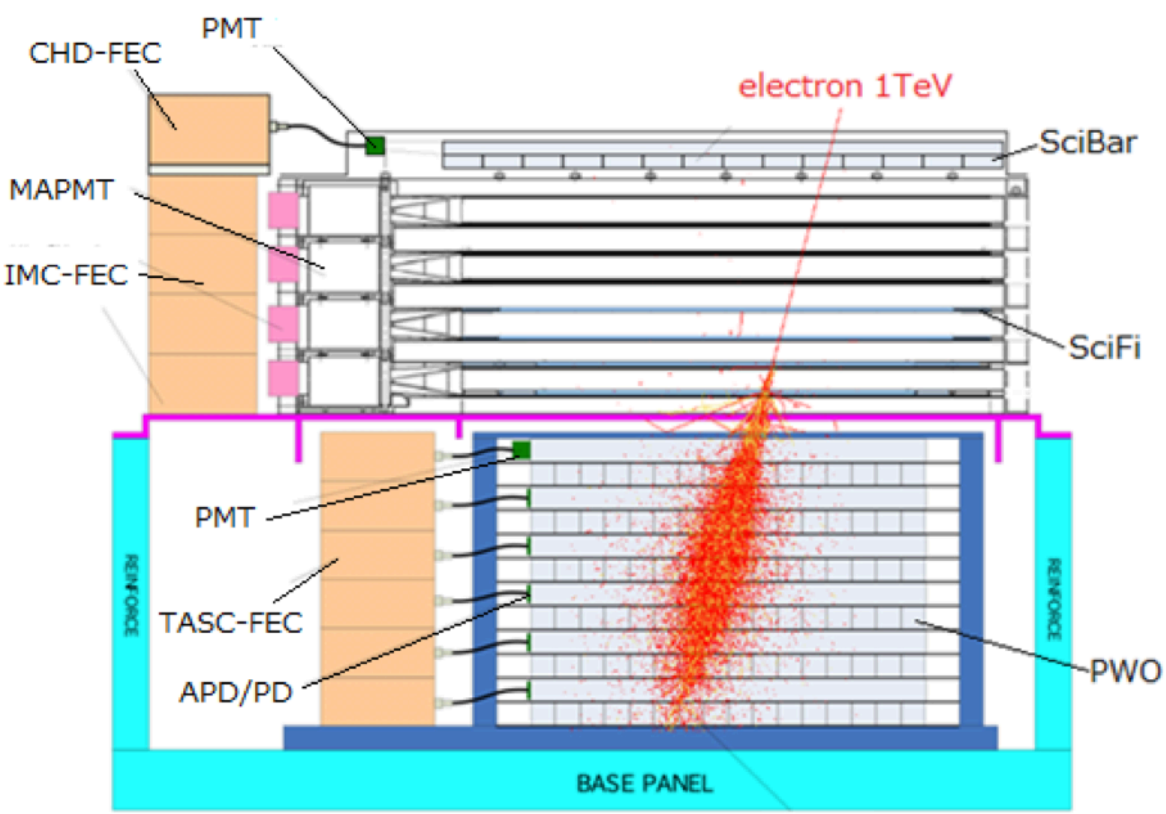




Instrument of CALET

A 30-radiation length deep calorimeter designed to detect electrons and gammas to 20 TeV and cosmic rays up to 1 PeV

Since the start of operation on the ISS in October 2015,
CALET has been accumulating scientific data without any major interruption



CHD: Charge Detector

Charge measurements (Z=1-40)

- Plastic scintillator paddles 14 x (X, Y)

Unit size: 32mm x 10 mm x 450 mm

ΔZ/Z = 0.15 for C, 0.30 for Fe

IMC: Imaging Calorimeter

Arrival direction, Particle ID

- Scintillating fiber belts 448 x 16 layers

Unit size: 1 mm^2 x 448 mm

- Tungsten plates 7 layers

3 X_0 (=0.2 X_0 x 5 + 1.0 X_0x 2)

ΔX at CHD = 200μm, ΔZ/Z = 0.20 for C

TASC: Total Absorption Calorimeter

Energy measurement, Particle ID

- PWO logs 16 x 12 layers

Unit size: 19 mm x 20 mm x 326 mm

27 X_0 for electrons

1.2 interaction length for protons

Dynamic range ; 1 – 10^6 MIP (1GeV – 1PeV)

Data analysis

Analyzed Flight Data

1,815 days (Oct. 13, 2015 – Sep. 30, 2020)

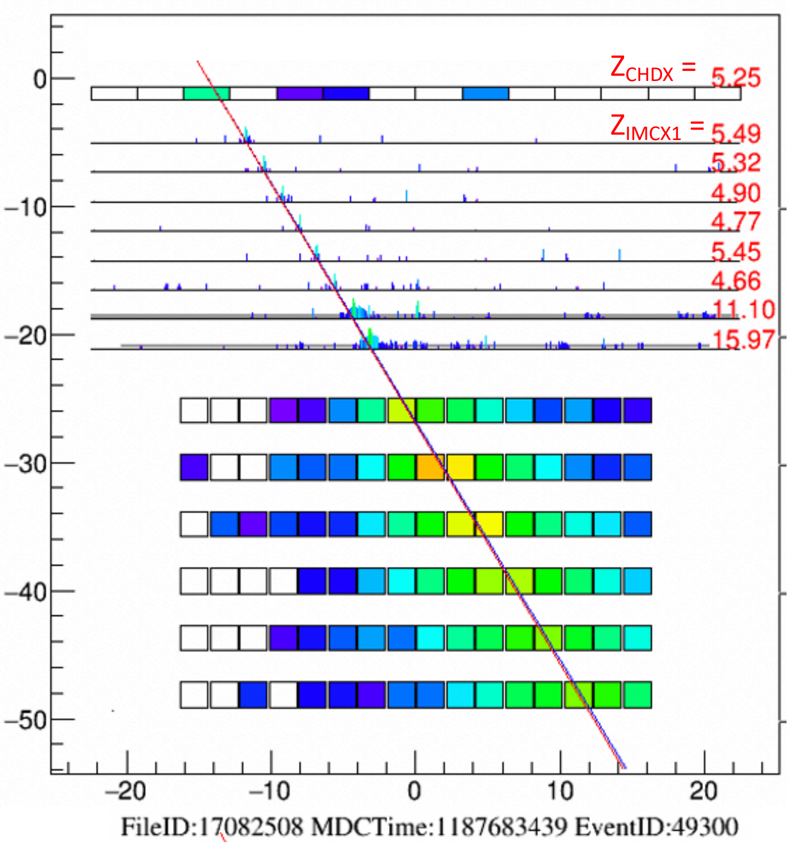
T_{live}=3.69 x 10^4 hours

Analysis procedure

- Field of view cut
  - Remove shielded region by ISS structures
- High energy trigger + offline shower trigger
  - E>10GeV
- Tracking with IMC
- Acceptance cut
  - CHD, TASC top and bottom layers
- Charge identification
  - Charge consistency among CHD and IMC layer
  - Track width selection
- Estimate efficiency and background
- Apply energy unfolding
- Calculate flux and the ratio

An example of Boron candidate (X-Z view)

E_{TASC} = 475.8 GeV



Event selection

Major possible background source is events interacting in CHD or upper surface materials

- **Charge consistency**

  with each CHD and upper 4 IMC layers

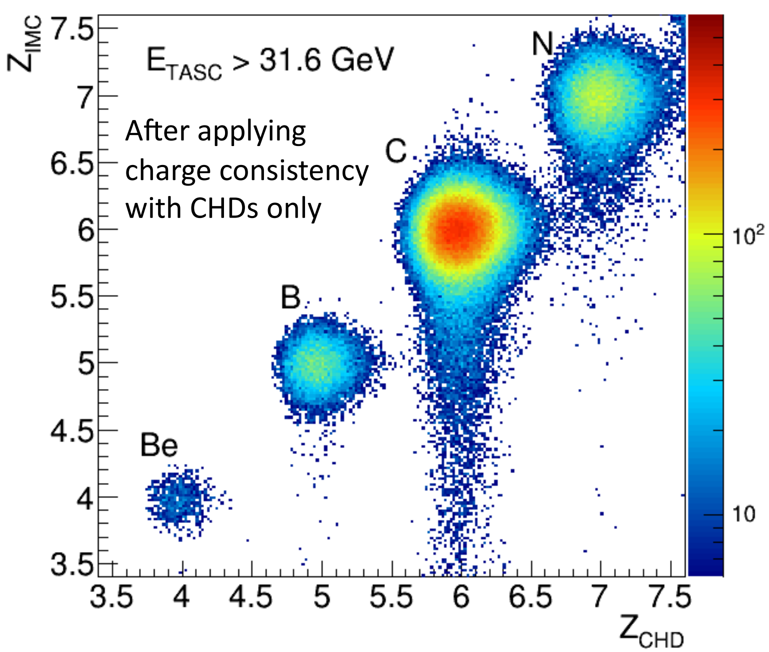
  - $1/1.10 < Z_{CHDY}/Z_{CHDX} < 1.10$
  - $1/1.15 < Z_{CHD}/Z_{IMC} < 1.15$
  - $|Z_{IMC12} - Z_{IMC34}| < 1$
  - $|(Z_{IMC12} + Z_{IMC34})/2 - Z_{CHD}| < 1$

- **Track width**

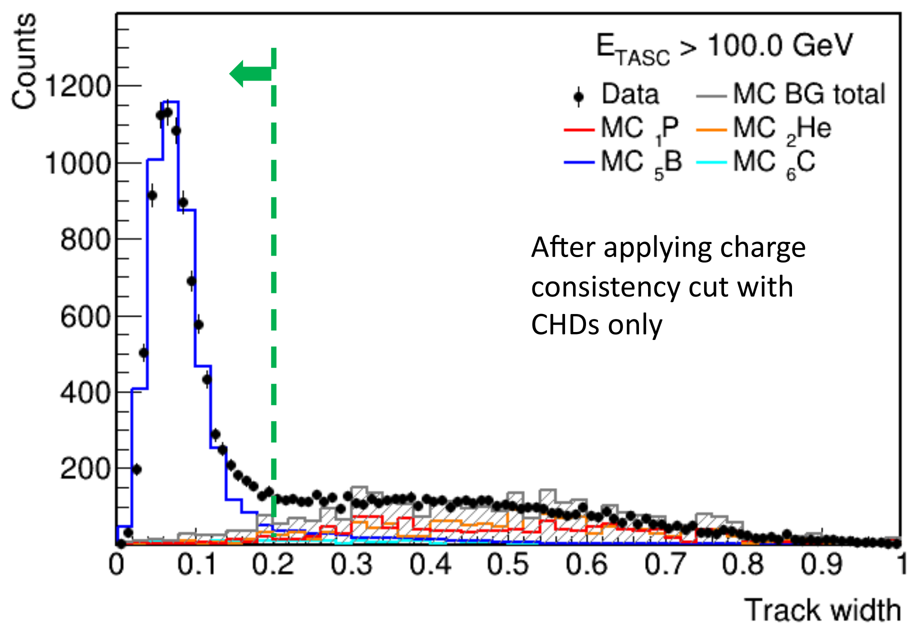
  Track width of the backgrounds spread wider

$$B_{\mathrm{IMCi}} = (\underbrace{\sum_{j=-k}^{k} N_{\mathrm{IMCi,j}}}_{\text{Sum of 7 SciFis}} - \underbrace{\sum_{j=-1}^{1} N_{\mathrm{IMCi,j}}}_{\text{Sum of 3 SciFis}})\frac{1}{Z^2_{\mathrm{IMCi}}}$$

Z_{IMC} vs Z_{CHD} of flight data



Track width distribution

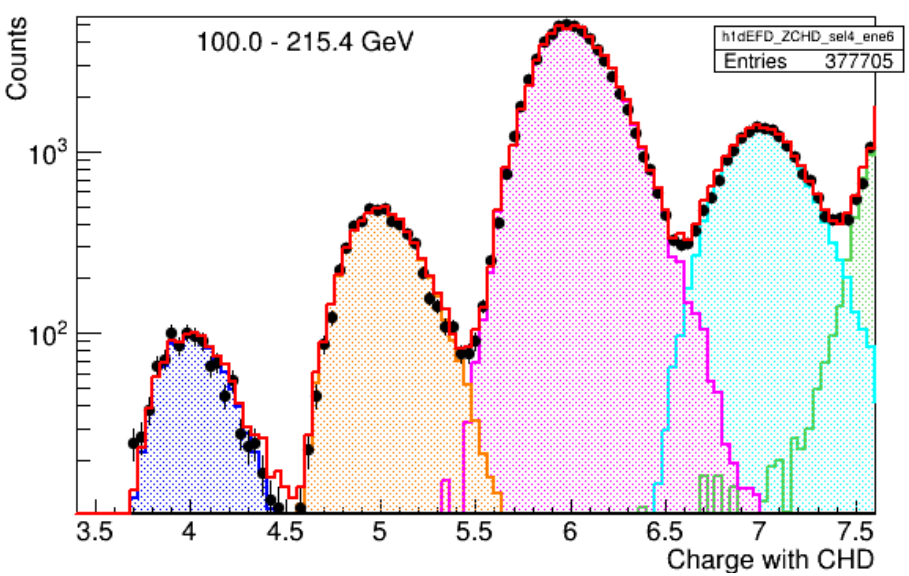


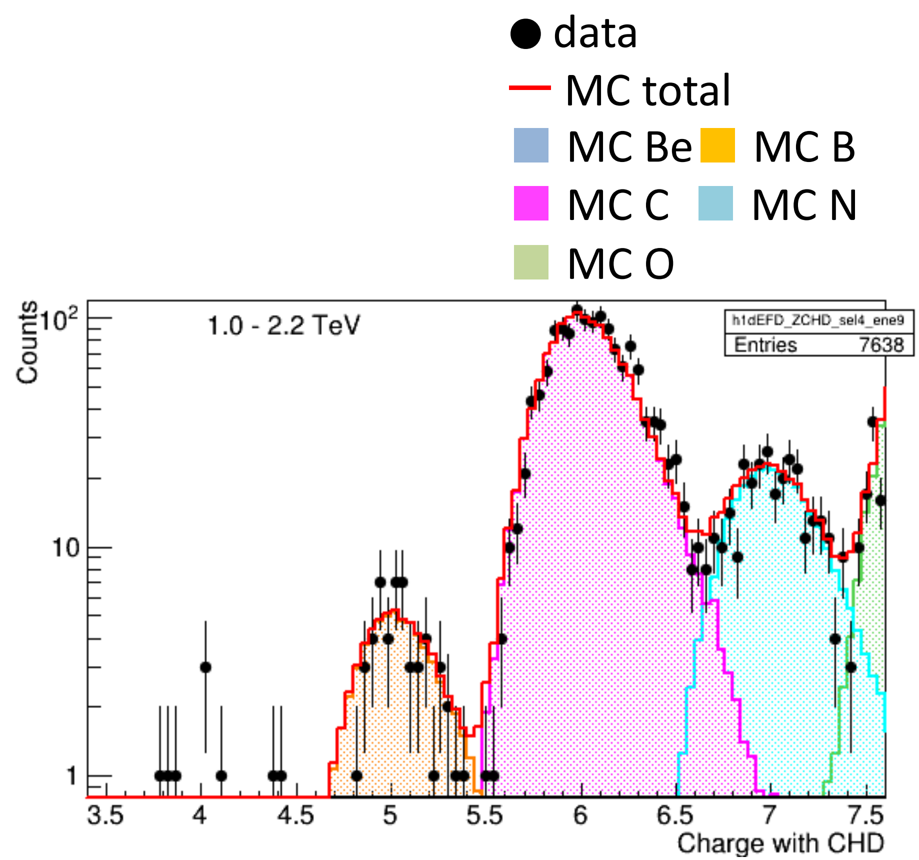
Charge distributions with MC

MC data

- EPICS v9.22, Cosmos8.02, DPMJET-III
- proton – Ni in 1 GeV – 1 PeV

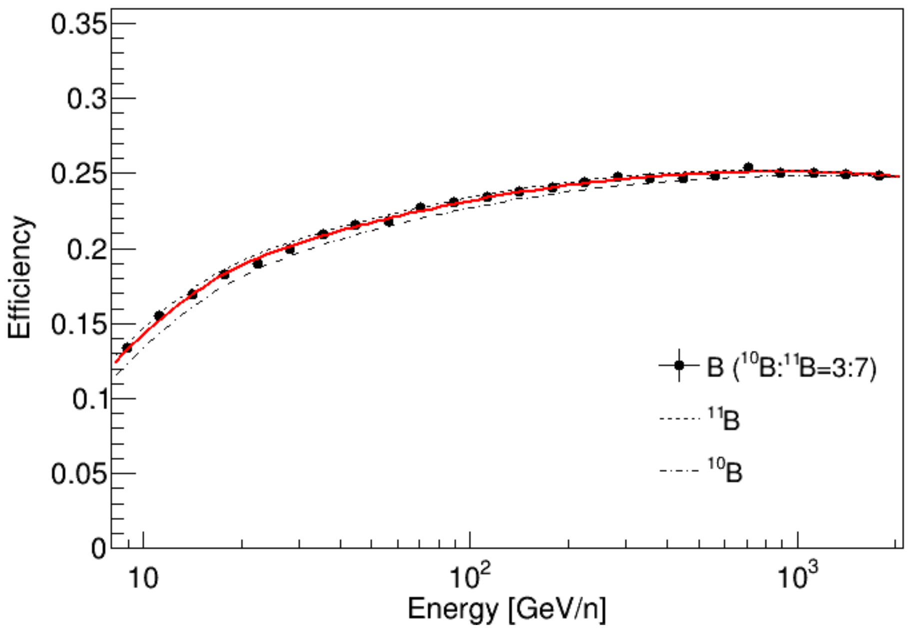
Digitization of signals in simulation are modelled and tuned by beam test results and flight data; quenching of light yield, noise and saturation.



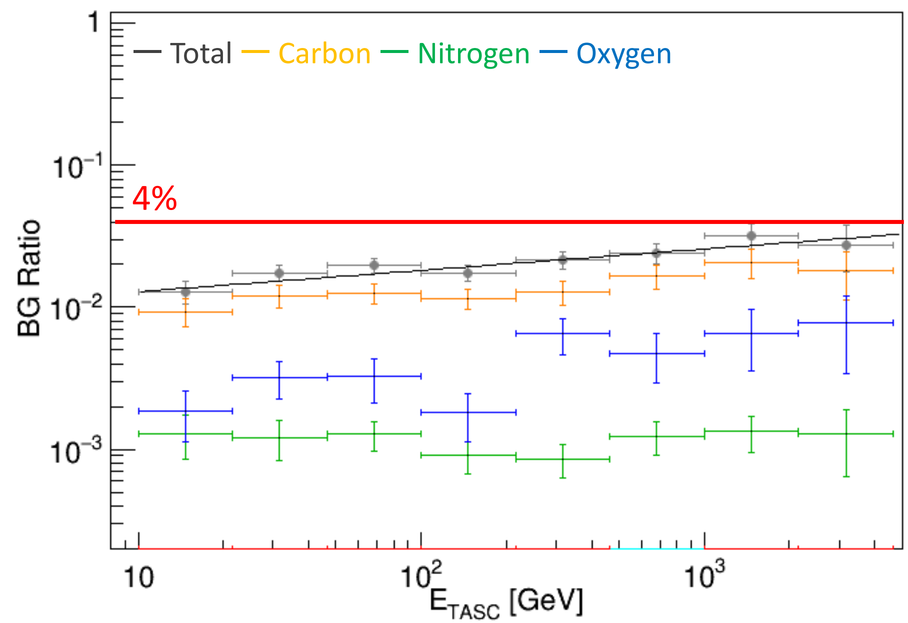


Efficiency and background for Boron

Efficiency



Background



Efficiency is evaluated by MC simulations

- Isotope abundance ratio is assumed as ^{10}B : ^{11}B = 30 : 70
- The difference of the efficiency between pure ^{10}B and ^{11}B is 1%

Background is evaluated by MC simulations

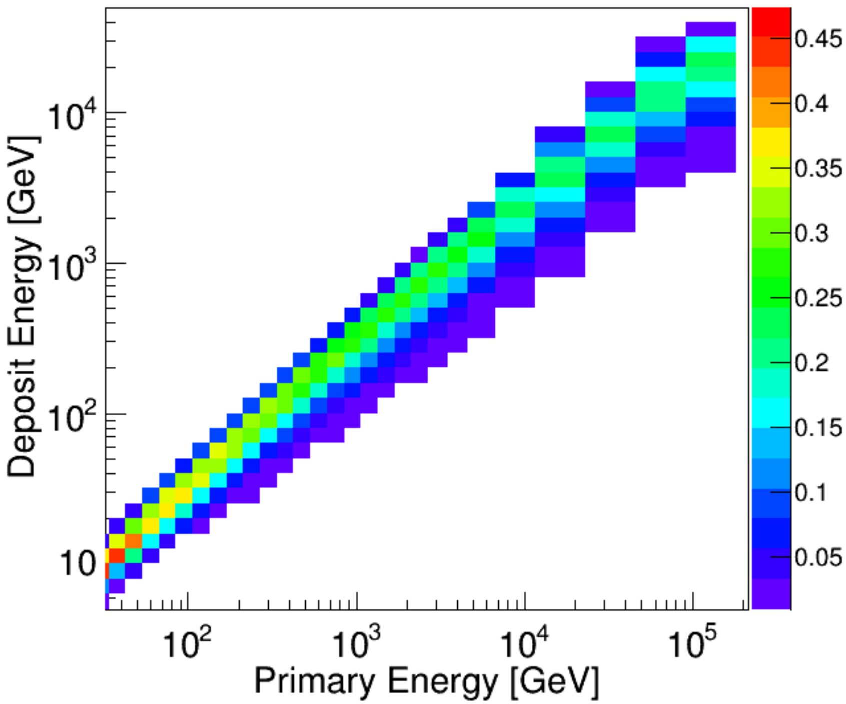
- the main source is carbon
- total background is at most 4%

Energy measurement and unfolding

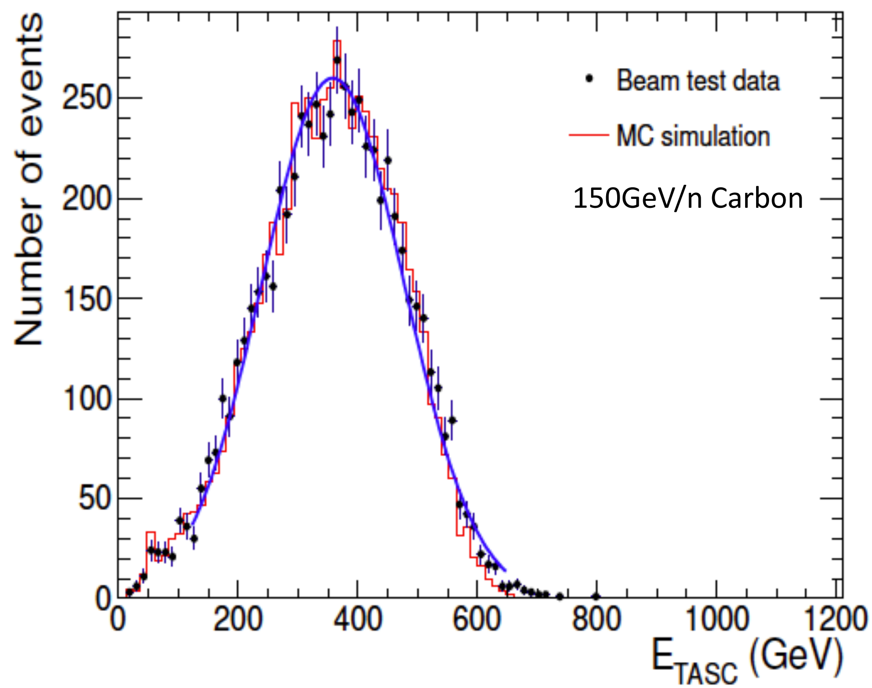
- Iterative Bayesian unfolding
  - Initial assumed spectrum: f(E)=A x $E^{-2.60}$
    A: normalization constant
    from charge distribution in CHD
  - Response function is made by MC simulation
    ΔE [GeV] vs E_0 [GeV]

- Beam test at CERN-SPS
  - Accuracy of the energy measurement of MC simulation is tested with ion fragments beam (Z/A=2) at 13, 19, 150 GeV/n
  - The energy response derived from MC simulations was tuned using the beam test results

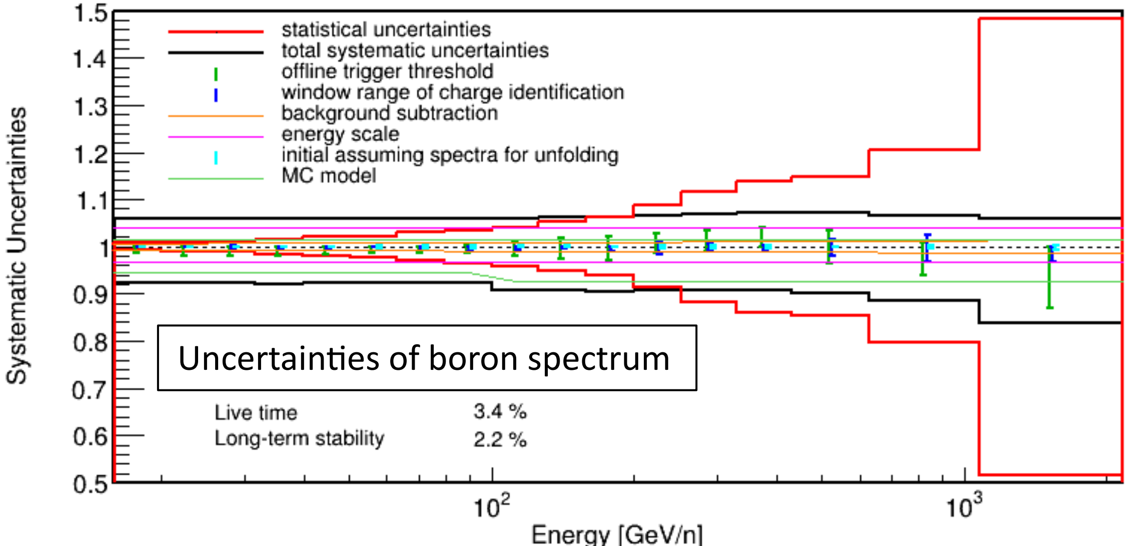
Response matrix of Boron

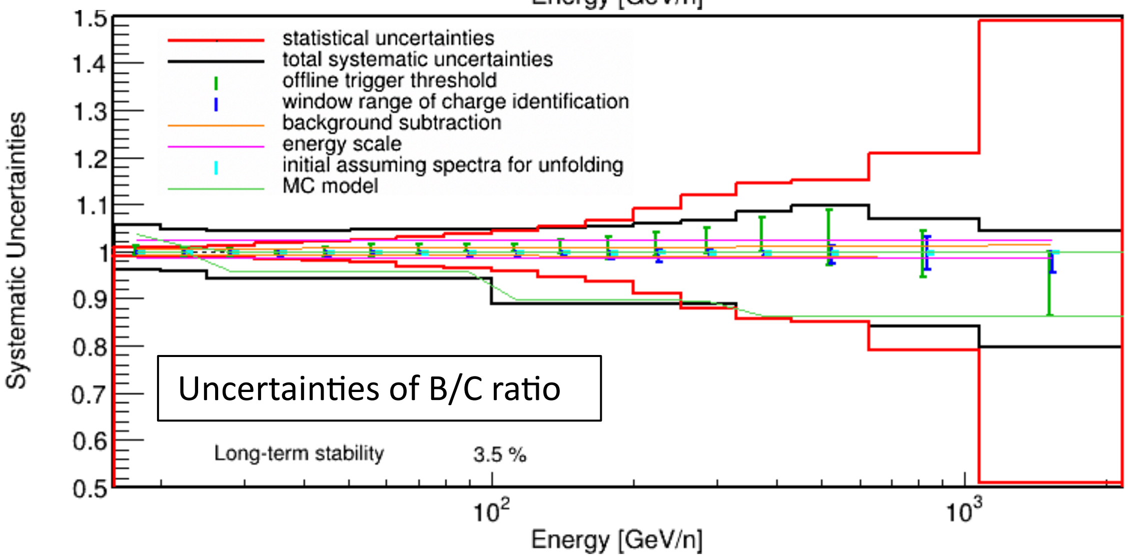


Energy distribution with beam test



Statistics and systematic uncertainties





<u>Systematic uncertainty sources</u>

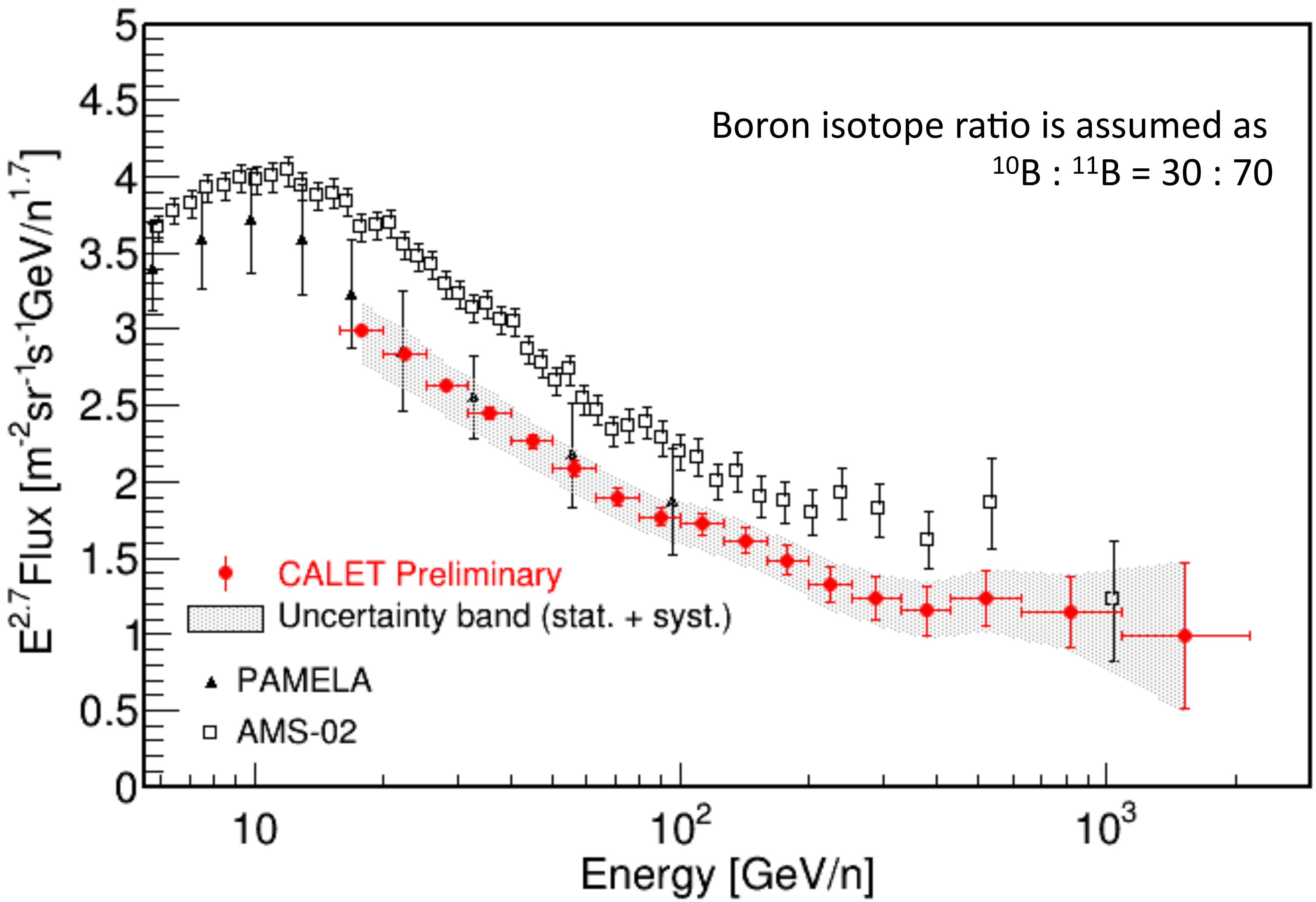
Energy dependent:
- trigger efficiency
- charge identification
- background subtraction
- energy unfolding
- MC model
  (EPICS:DPMJET3 and Geant4:FTFP-BERT)

Energy independent
- live time
- long-term stability

Energy scale
- beam test calibration

Preliminary energy spectrum of Boron

CALET preliminary result is consistent with PAMELA, but lower than AMS-02



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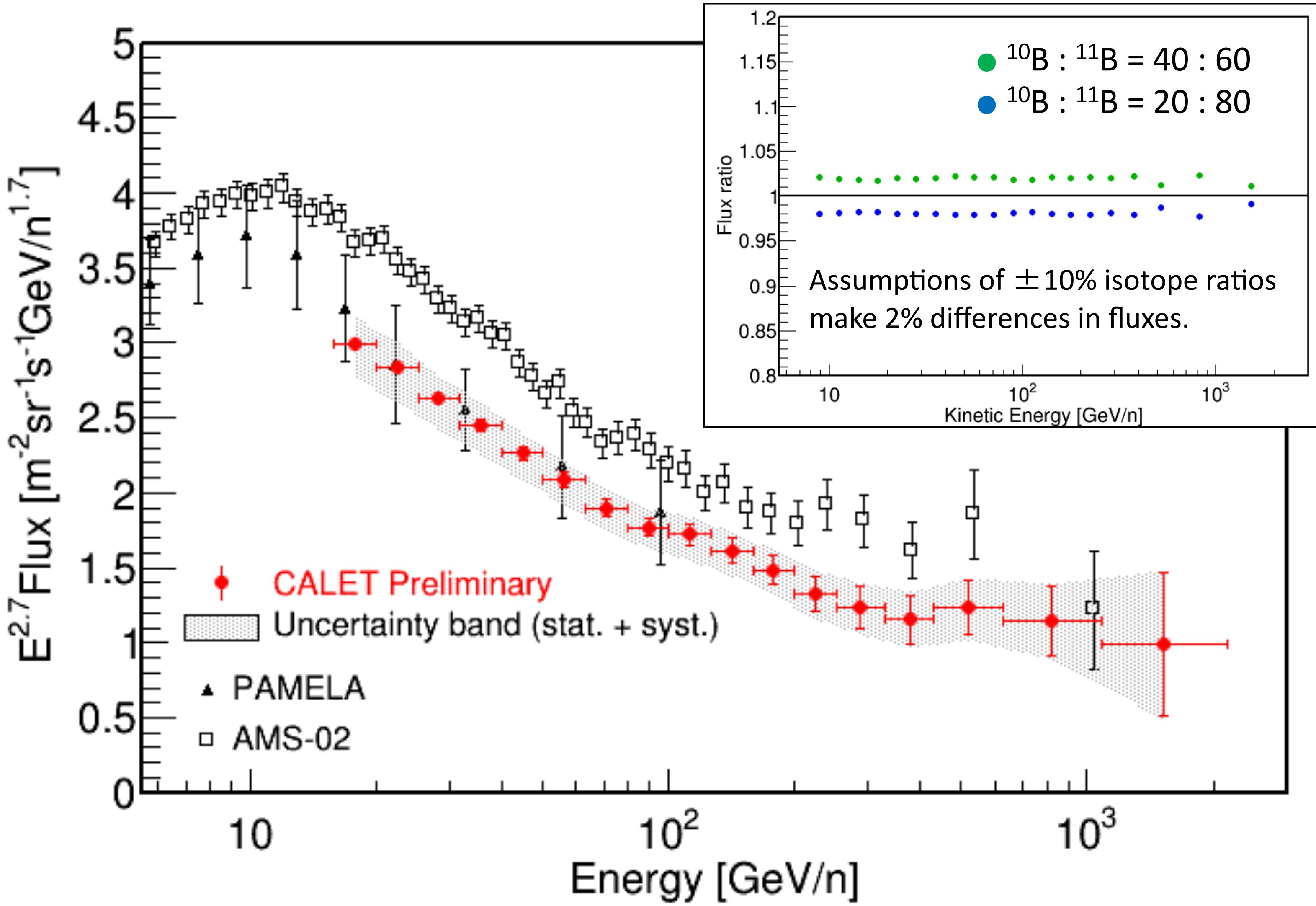

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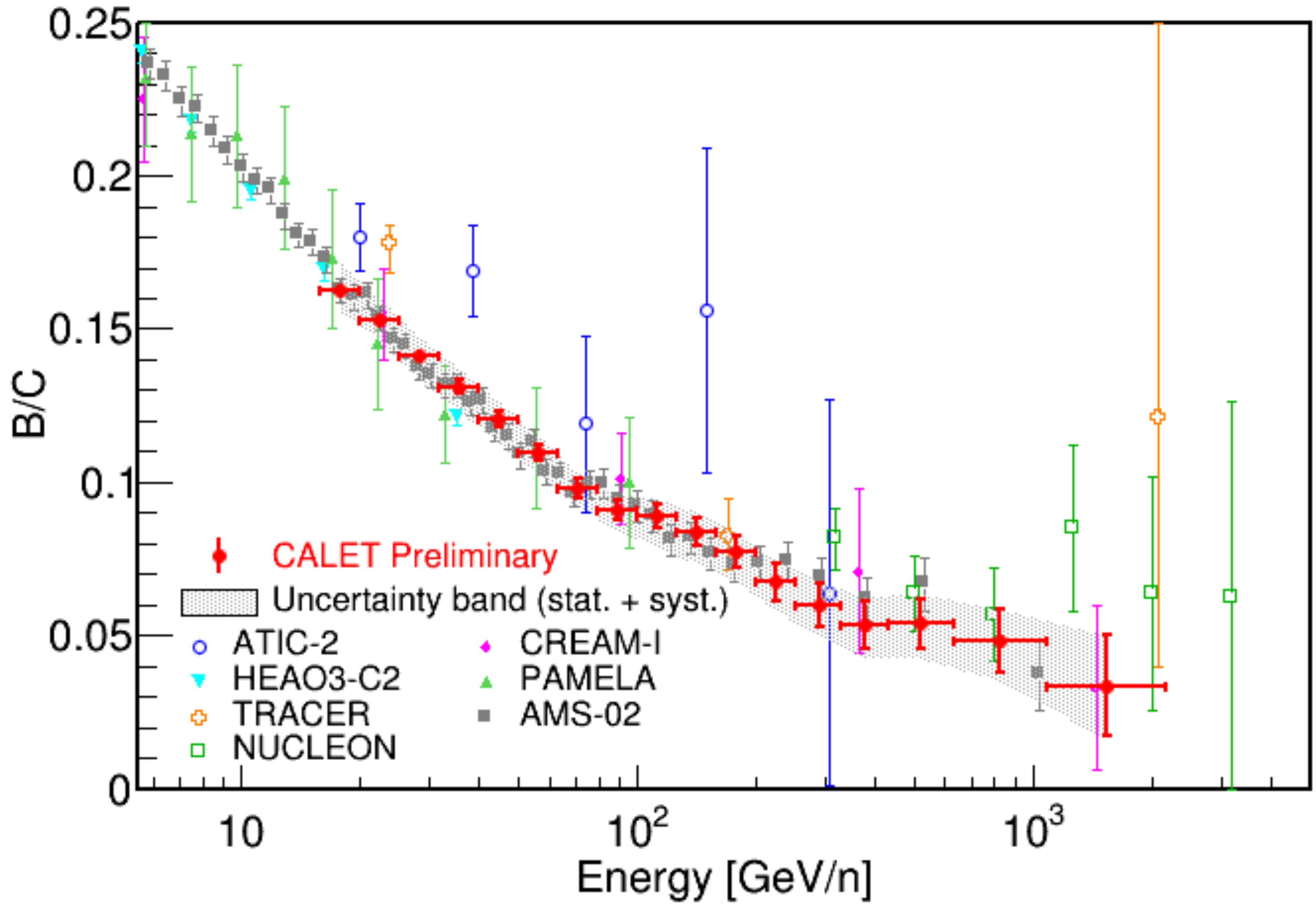
Preliminary result of B/C ratio

CALET preliminary result is well consistent with CREAM-1, PAMELA and AMS-02



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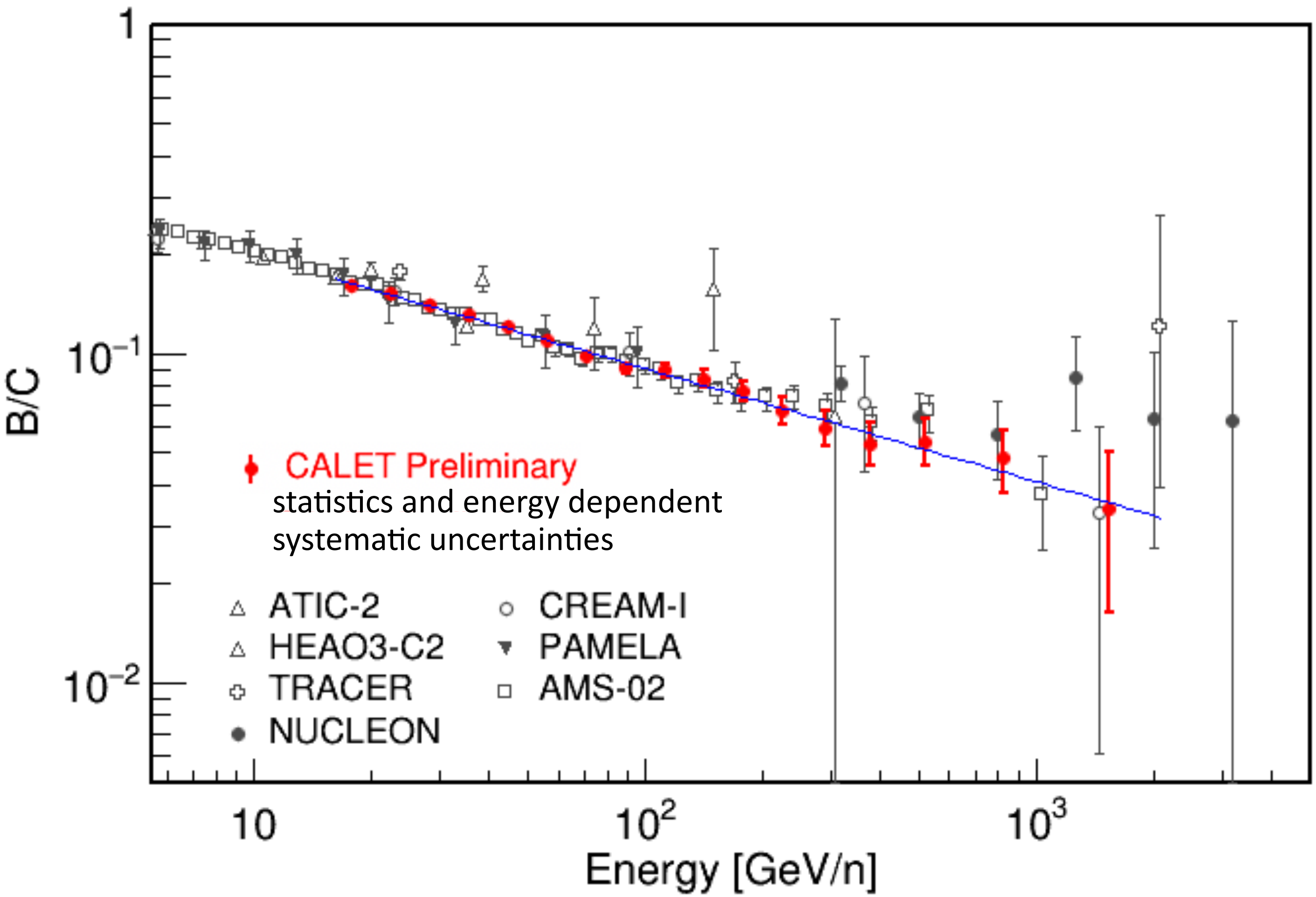
Fit with a single power law function

The B/C ratio is fitted by a single power law function: $(\mathrm{B/C}) = AE^{\delta}$

$$\delta = -0.344 \pm 0.012 (E > 20\ \mathrm{GeV/n}), \quad \chi^2/\mathrm{ndf} = 5.6/15$$



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Summary

- CALET was launched in August 2015 and is successfully carrying out observations of CR nuclei with stable operations.

- Preliminary result of boron spectrum is obtained from 16 GeV/n to 2.2 TeV/n.

- Preliminary result of B/C ratio is presented from 16 GeV/n to 2.2 TeV/n.
  - single power law fitting: E^{δ} gives δ = -0.344 $\pm$ 0.012 (E>20GeV/n)

- CALET has capabilities to measure not only the B/C ratio, but also sub-Fe/Fe ratio, and the analysis is ongoing

- Further observations until December 2024 are approved. We will collect higher statistics and achieve a further reduction of the systematic errors.