Measurements of Nuclei Fluxes in Cosmic-rays with CALET

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Measurements of Cosmic-Ray Nuclei

Nuclei measurement in GeV – TeV energy region

- Primary individual spectra
  - cosmic-ray acceleration and propagation
  - hardening of spectra
- Secondary-to-primary flux ratio
  - cosmic-ray propagation
  - energy dependence of diffusion coefficient

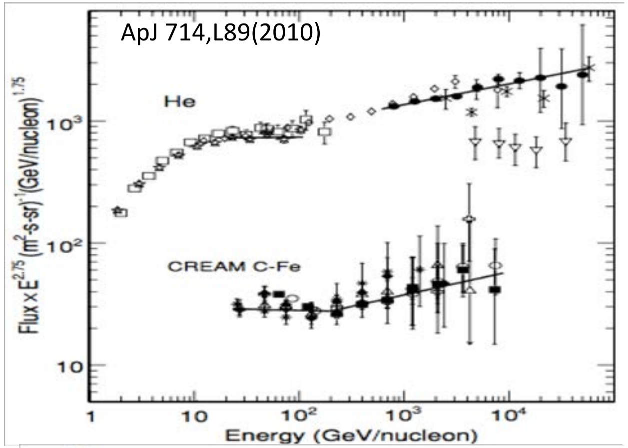
Measurements with CALET

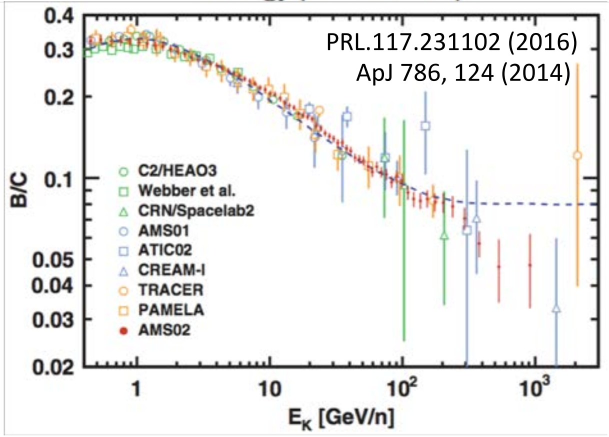
Energy spectra from Proton to Iron

- Charge measurement in Z = 1 – 40
  - Charge resolution: 0.18*e*(C)-0.3*e*(Fe)
- Energy measurement in 10GeV - 1000TeV
  - Dynamic range : 1-10^6MIP (~1000TeV)

This presentation:

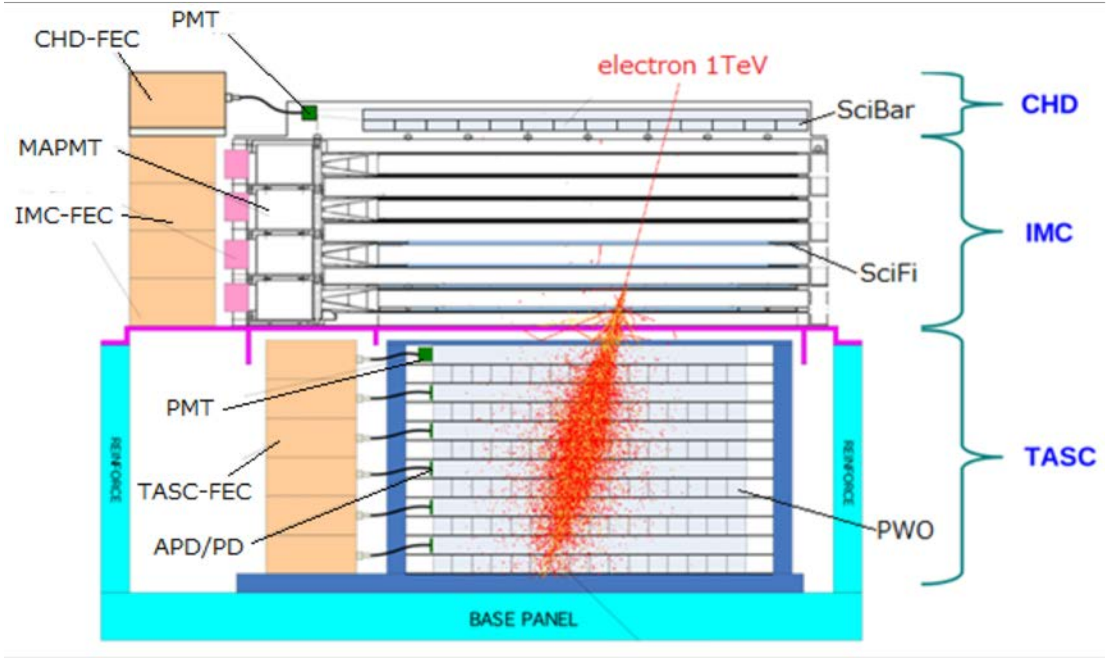
- Energy spectra of heavy primary elements
- Boron-to-carbon flux ratio





Calorimeter

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



CHD: Charge Detector

Charge measurements (Z=1-40)

- Plastic scintillator paddles 14 x (X, Y)

  Unit size: 32mm x 10 mm x 450 mm

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)

TASC: Total Absorption Calorimeter

Energy measurement, Particle ID

- PWO logs 16 x 12 layers

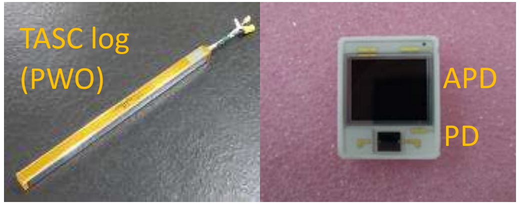
  Unit size: 19 mm x 20 mm x 326 mm

  27 X_0 for electrons

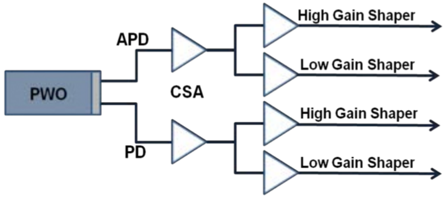
  1.2 interaction length for protons

Energy measurements

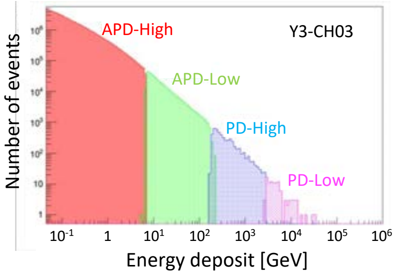
TASC read-out system



APD: 100mm²
S8664-1010
PD: 5.8mm²
S1227-33BR



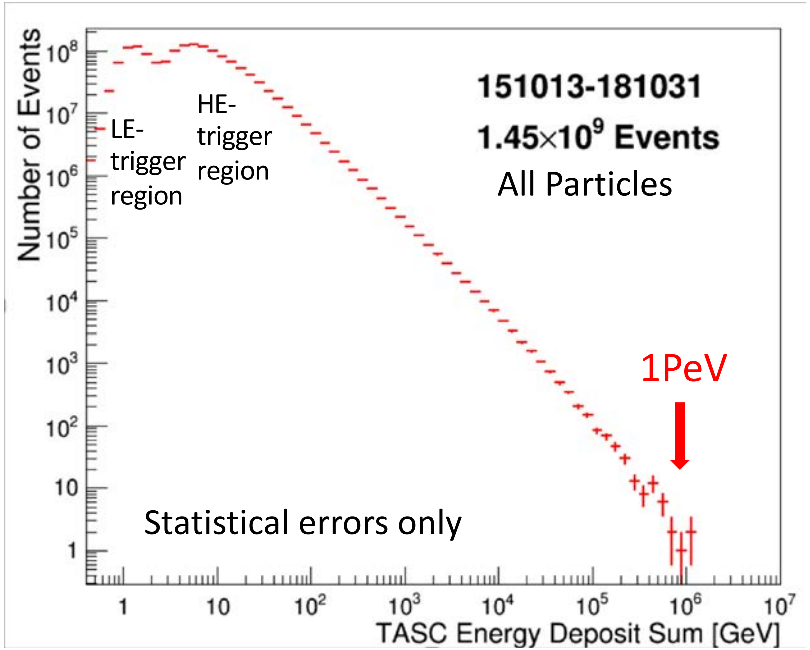
Example of energy distribution of one PWO log



<u>Calibration:</u>

- MIP calibration using cosmic-ray proton and helium is carried out to equalize all channel gains and monitor long-term stability
- The correlation between adjacent gain ranges is calibrated by using in-flight data in each channel
- The linearity was calibrated using UV laser irradiation on ground

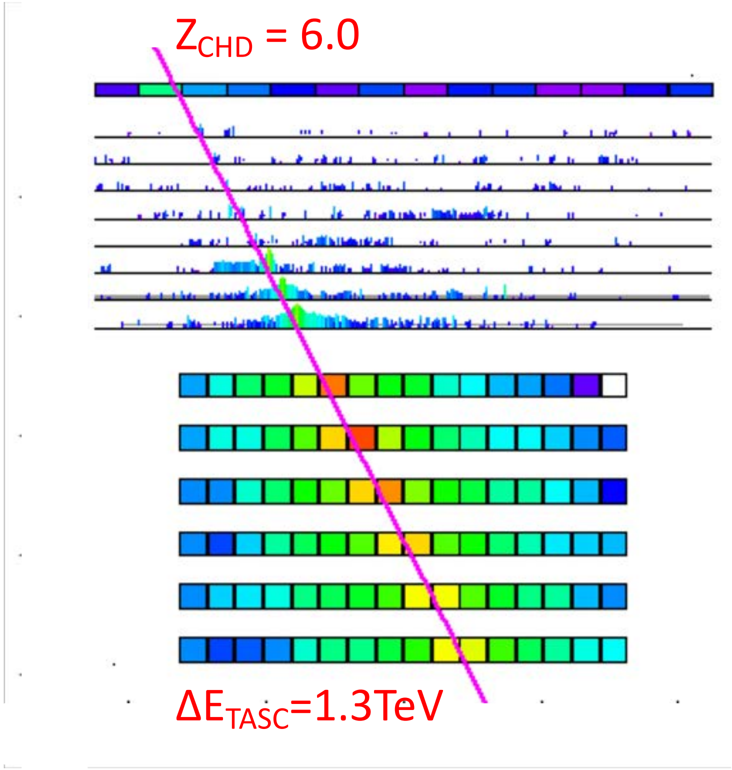
Distributions of deposit energies in TASC



The TASC energy measurements have successfully been carried out in the dynamic range of 1 GeV – 1PeV

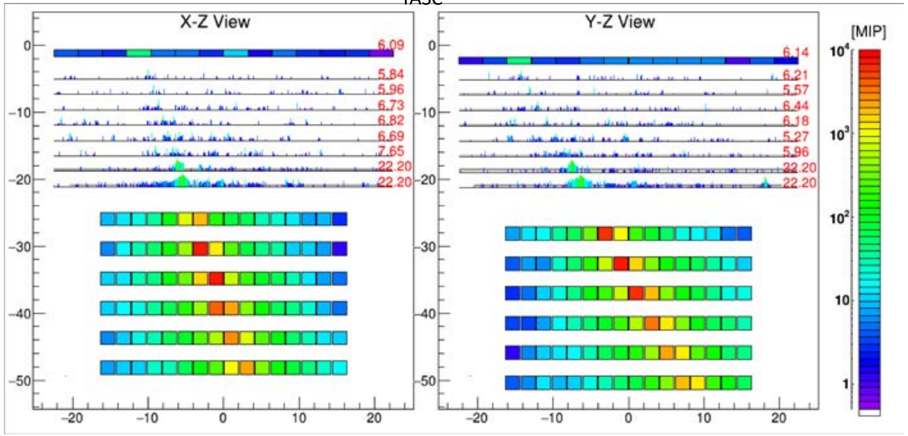
Nuclei analysis procedure

1. Onboard High energy trigger
   - Coincidence of IMC-X78, IMC-Y78 and TASC-X1
   - Energy threshold is set to detect 10 GeV electrons
2. Offline shower trigger
   - NmipIMC-X78, Y78 > 50MIP & NmipTASC-X1 > 100MIP
3. Tracking with IMC
   - select events satisfied geometrical condition
   - identify the impact point
4. Charge consistency with CHD and IMC
   - remove backgrounds
   - maintain charge resolution
5. Charge selection with CHD
   - estimate background
6. Energy measurements and unfolding
   - measure energy with TASC
   - unfold energy spectrum by Iterative Bayesian process
7. Flux Calculation

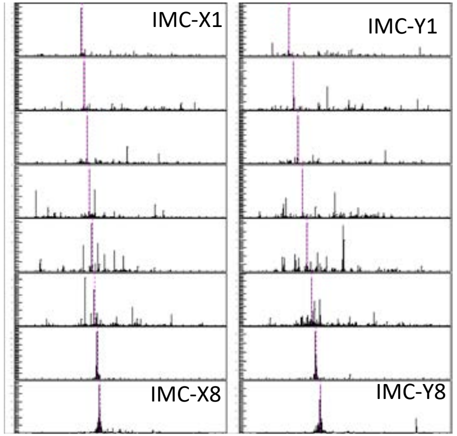


Tracking for nuclei events

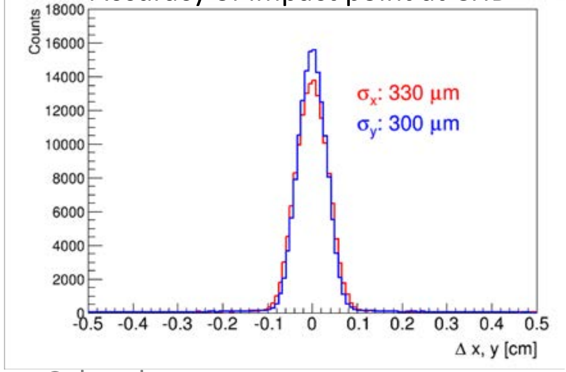
Carbon ΔE_{TASC} = 2.06 TeV



Pulse height of IMC



Accuracy of impact point at CHD



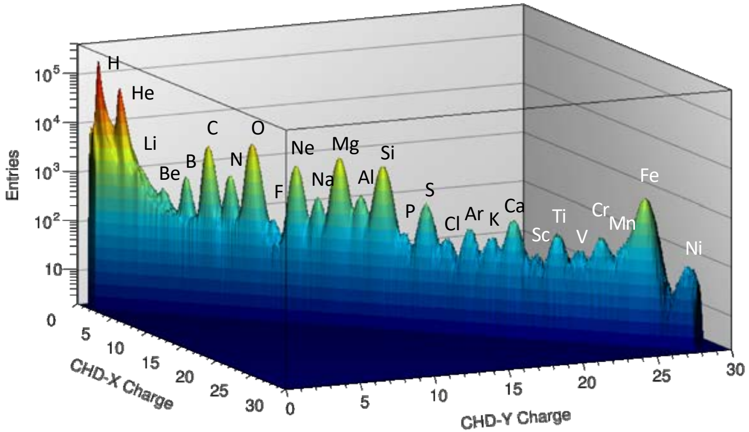
- Reconstruct shower axis with IMC signals
- Heavy nuclei can make many shower particles in IMC, which could be a large background for track; the signal of primary particle is commonly larger than the signals of the shower particles

⇨ Simple tracking methods: Least chi-square fitting is applied for the maximum clusters in upper 4 IMC layers.

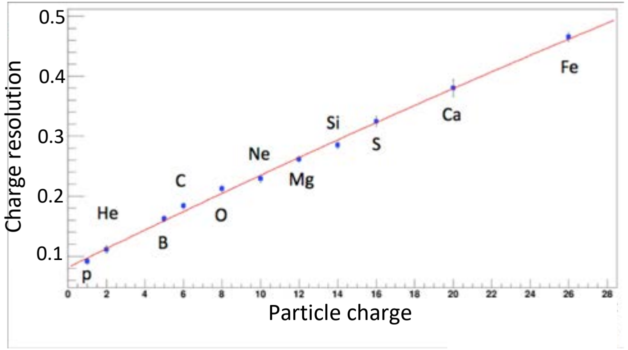
Charge resolution

- Non-linear response to Z^2 is corrected both in CHD and IMC using a model
- A clear separation between p, He, ~Z=8, can be seen from CHD+IMC data analysis

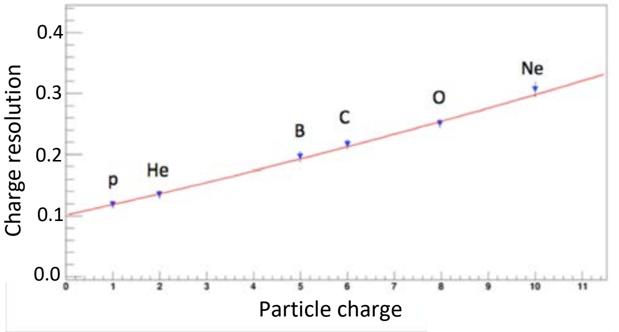
Charge with CHD-X vs CHD-Y



Charge resolution with 2layers of CHD



Charge resolution using multiple dE/dx measurements of IMC

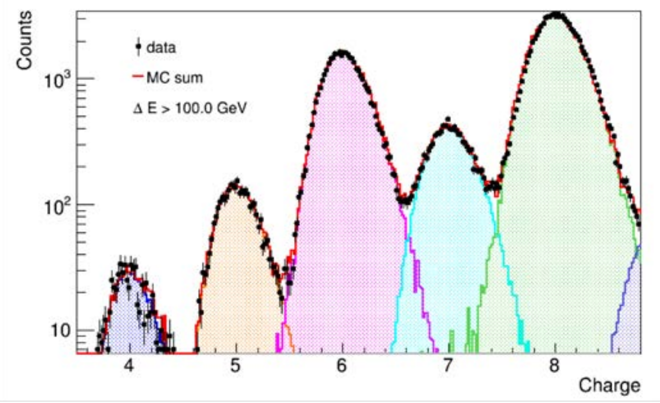


Charge identification and Background estimation

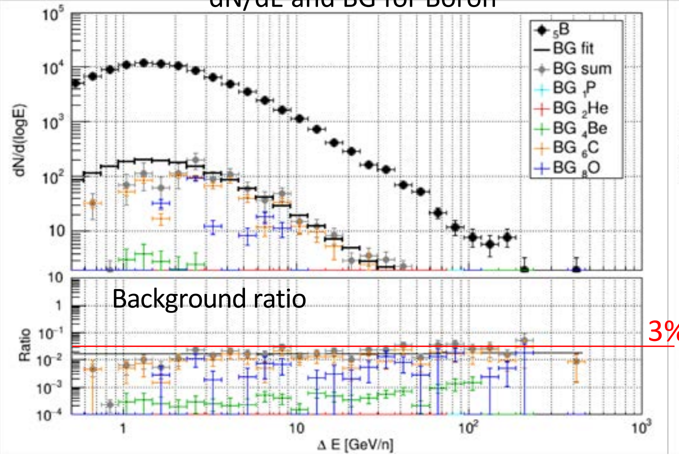
- Particle charge is identified with CHD
- Background is estimated by means of MC

MC data: EPICS v9.21 (Cosmos8.01)
DPMJET-III
Consider quenching, noise and etc.
Apply the same selection with flight data.

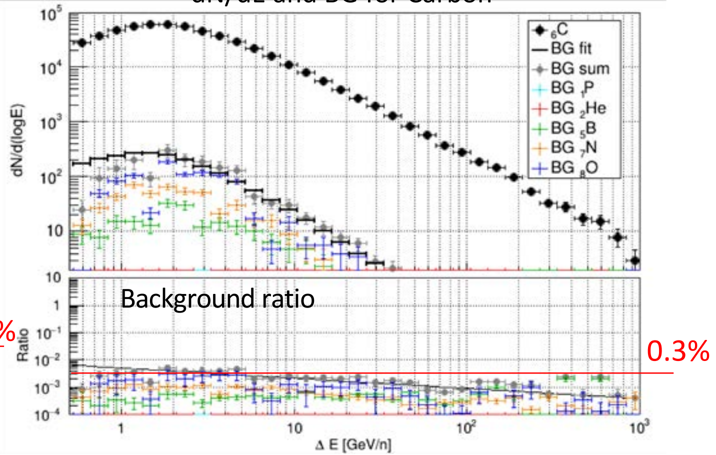
<u>Pre-selection</u>
- HE trigger
- Tracking + geometrical condition
- Charge consistency with CHD-X, Y and IMC
- Track width selection



dN/dE and BG for Boron



dN/dE and BG for Carbon

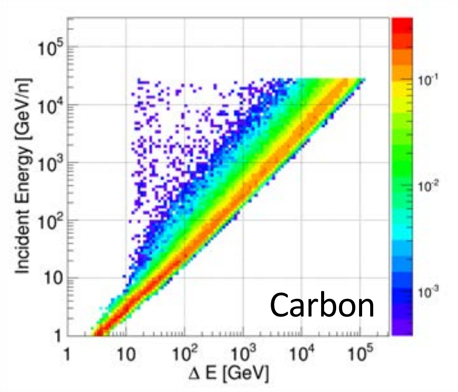


Energy unfolding

Characteristics of nuclei measurements with CALET calorimeter:

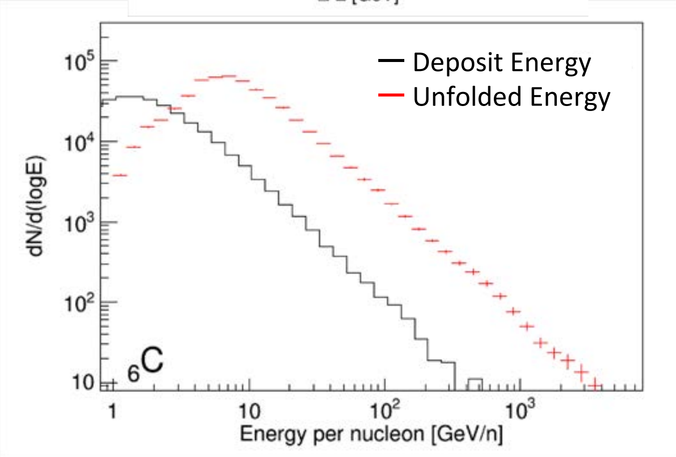
- thickness: 30 X_0 for electron, 1.3λ for proton
- σ(E)/E : 2% for electron, 30% for nuclei

➡ Need energy unfolding for nuclei to obtain primary energy spectrum



Iterative Bayesian unfolding

- Initial assuming spectra: f(E)=A x $E^{-2.60}$
  A is normalized by charge distribution in CHD
- Response function:
  ΔE [GeV] (deposit energy in calorimeter) vs E_0 [GeV]



Preliminary Flux of Primary Components

Flux measurements:

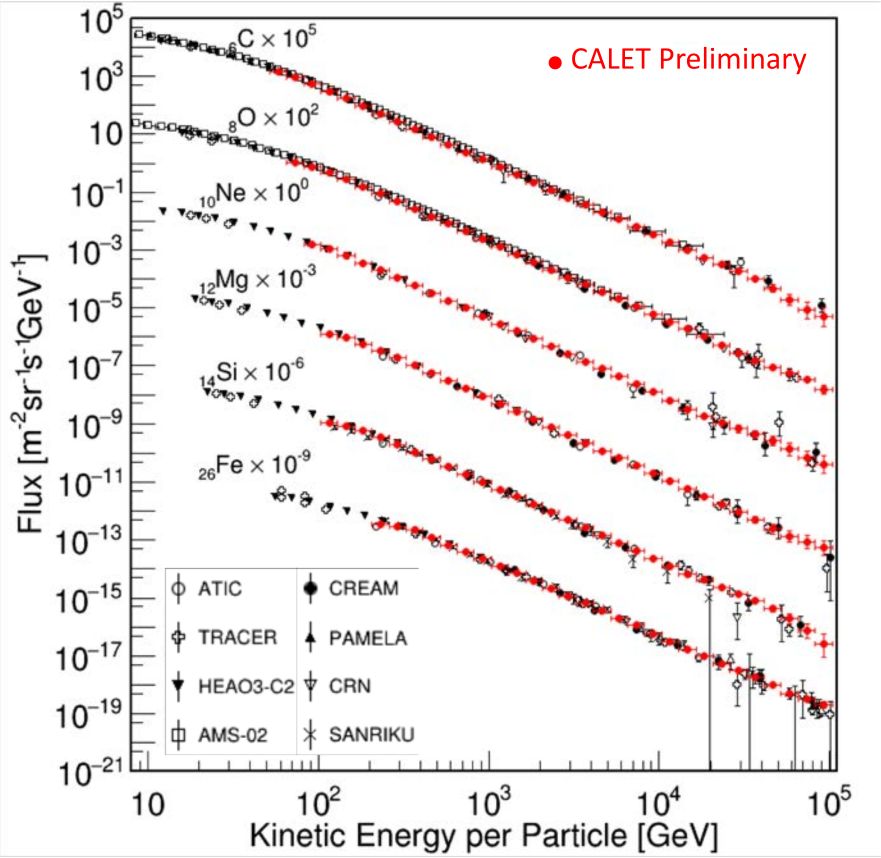
$$\Phi(E) = \frac{N(E)}{S\Omega\varepsilon(E)T\Delta E}$$

$N(E)$: Events in unfolded energy bin
$S\Omega$: Geometrical acceptance
$\varepsilon(E)$: Efficiency
T : Live Time
ΔE : Energy bin width

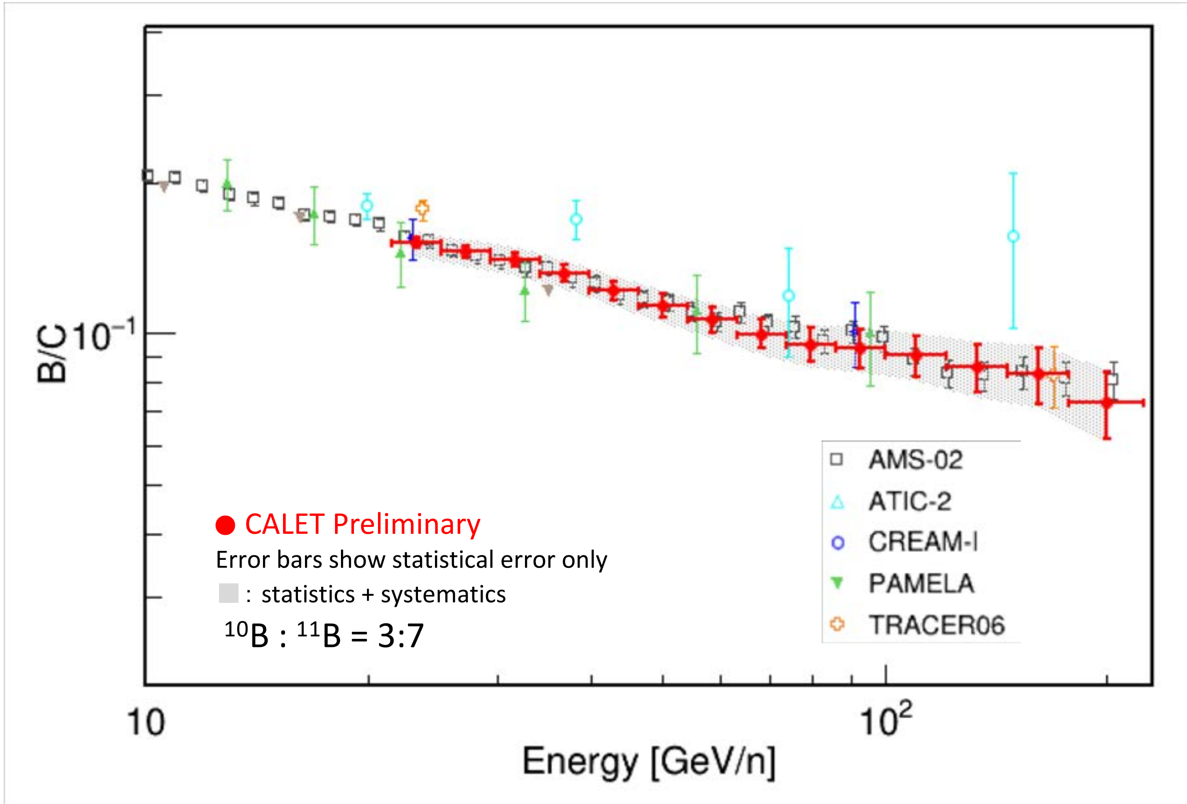
Observation period:

Oct.13 2015 – May.31 2018
(962 days)

5.6×10^6 events (C-Fe, ΔE>10GeV)



Boron-to-carbon flux ratio



Source of systematic uncertainties

- Trigger efficiency
- Charge consistency cuts
- Track width selection
- Window range for charge identification
- Background model of p and He spectra
- Initial assumed spectra for energy unfolding
- Energy correction base on beam test results
- Difference of beam test model and flight model
- Long term stability

Conclusions

- The ability of CALET to measure heavy cosmic-ray nuclei has been successfully demonstrated
  - Dynamic range for energy measurement: 1-10^6 MIP (1GeV – 1PeV)
  - Charge resolution: 0.18 for carbon, 0.30 for iron
- Using data from the 962 days of operation, preliminary analysis of nuclei has been successfully carried out
  - B/C ratio up to 200 GeV/n
  - primary cosmic-ray elements up to 100 TeV
- Independent analyses were carried out using different event selection procedures and MC simulations. Preliminary results are consistent.
- Further studies will provide the excellent energy spectra with high statistics in a wide energy range, and reveal details spectral features