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Measurement of cosmic-ray carbon and oxygen nuclei spectra with CALET

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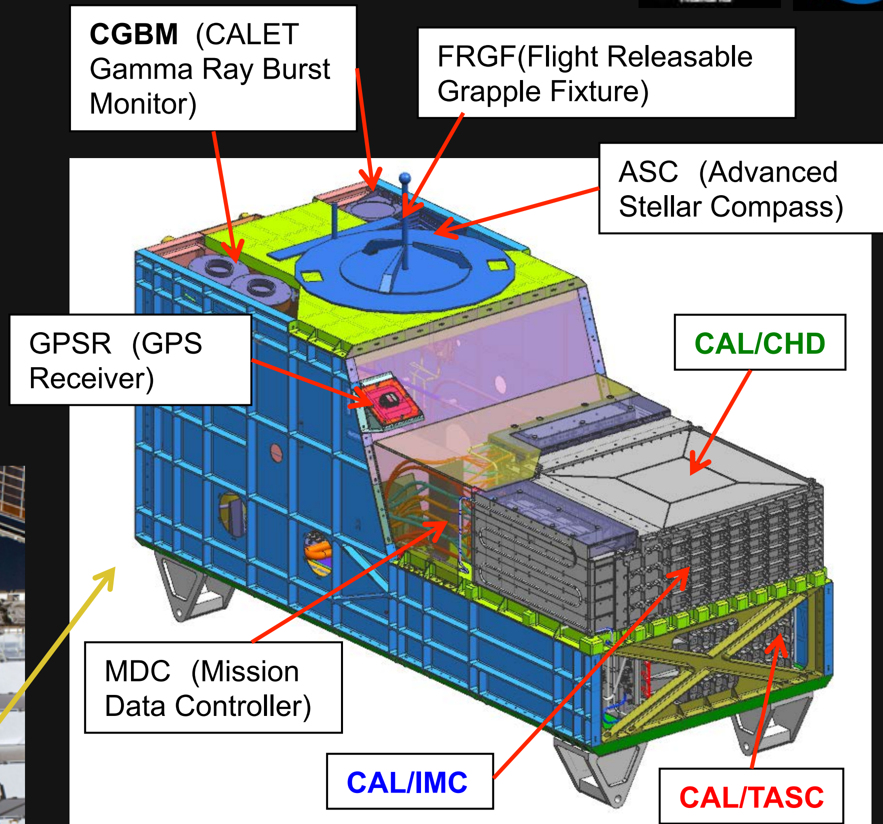
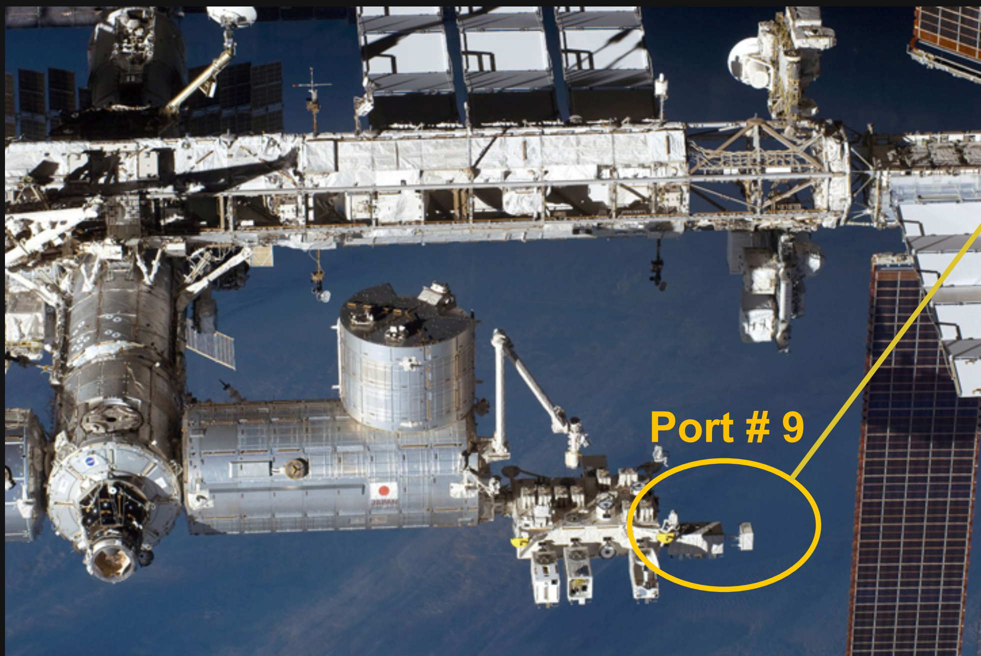
On behalf of the CALET collaboration

CALET payload

Launched on Aug. 19th 2015 on the Japanese H2-B rocket

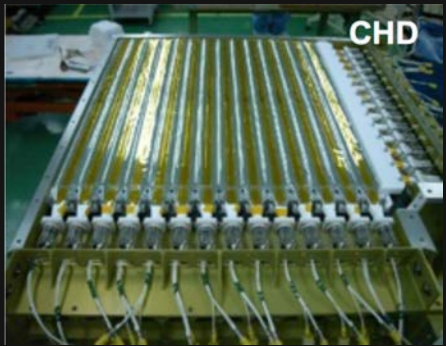
Emplaced on JEM-EF port#9 On Aug. 25th 2015

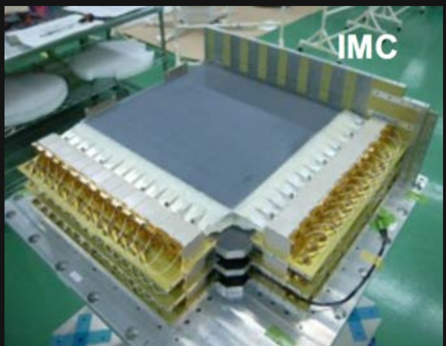


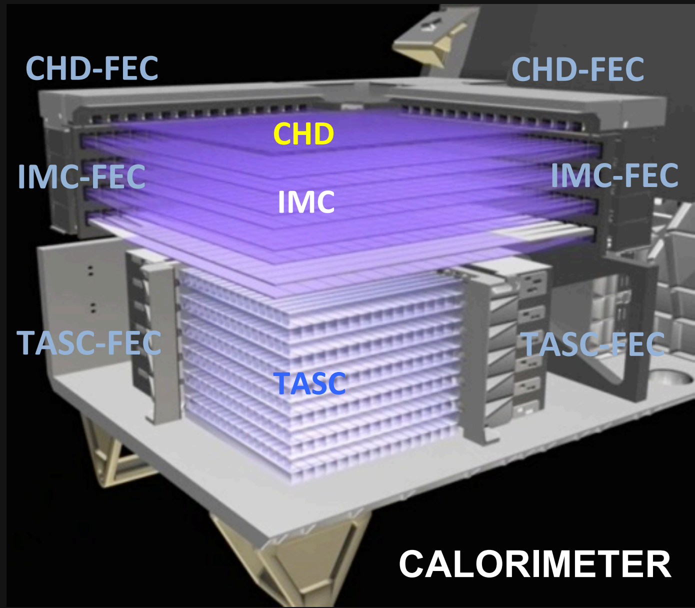


- Mass: 612.8 kg
- JEM Standard Payload Size 1850 mm (L) × 800 mm (W) × 1000 mm (H)
- Power Consumption: 507 W（max）
- Telemetry: Medium 600 kbps (6.5GB/day) / Low 50 kbps

CALET instrument







CGBM

Detector	Measure	Geometry	Readout
CHD (Charge Detector)	**Charge (Z=1-40)**	Plastic Scintillator 14 paddles × 2 layers (X,Y) Paddle size: 3.2×1×45 cm^3	PMT+CSA
IMC (Imaging Calorimeter)	**Tracking Particle ID**	448 Scifi × 16 layers (X,Y) 7 W layers (3 X_0) Scifi size: 1×1×448 mm^3	64 MAPMT+ ASIC
TASC (Total Absorption Calorimeter)	**Energy e/p separation**	16 PWO logs × 12 layers (X,Y) log size: 1.9×2×32 cm^3 Total thickness: 27 X_0 , ~1.2 λ	APD/PD + CSA PMT+CSA (for Trigger)

Analysis procedure for C/O selection

- High-Energy Triggered (HET) events
- Offline shower trigger to remove penetrating particles
- Tracking with IMC
- Charge assignment based on CHD and IMC
- Background estimate
- Energy measurement and unfolding
- Flux calculation

Tracking for CR nuclei

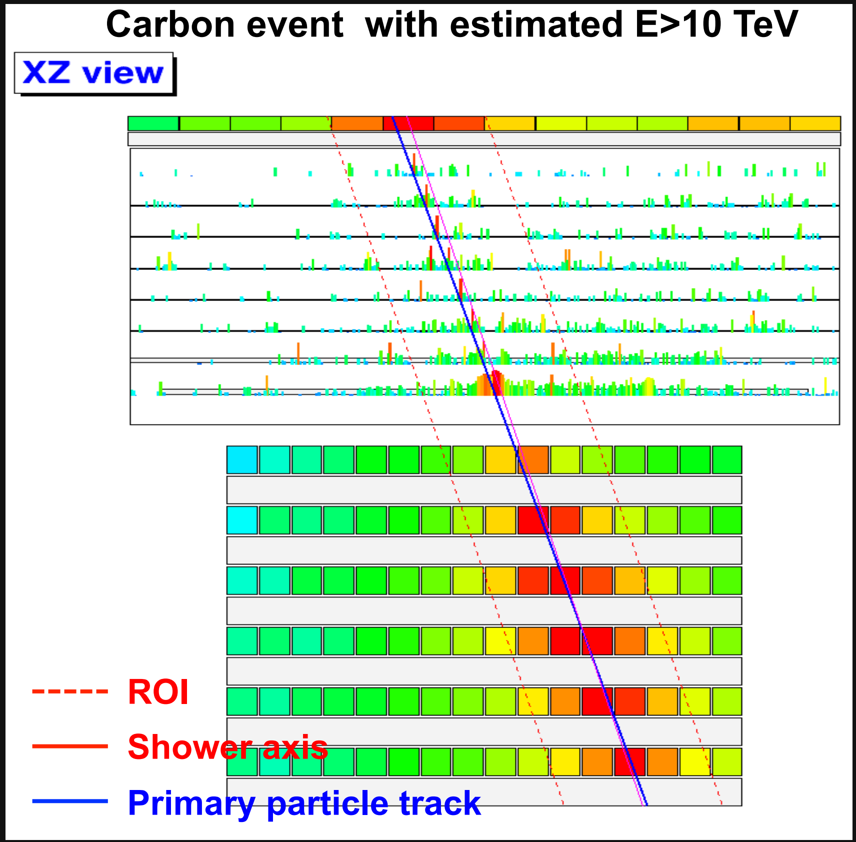
Tracking is used to:

- determine CR arrival direction
- define the geometrical acceptance (events crossing CHD, TASC top and bottom layers within 2 cm from the edge)
- identify CHD paddles and IMC scifi's crossed by CR particle → Particle ID

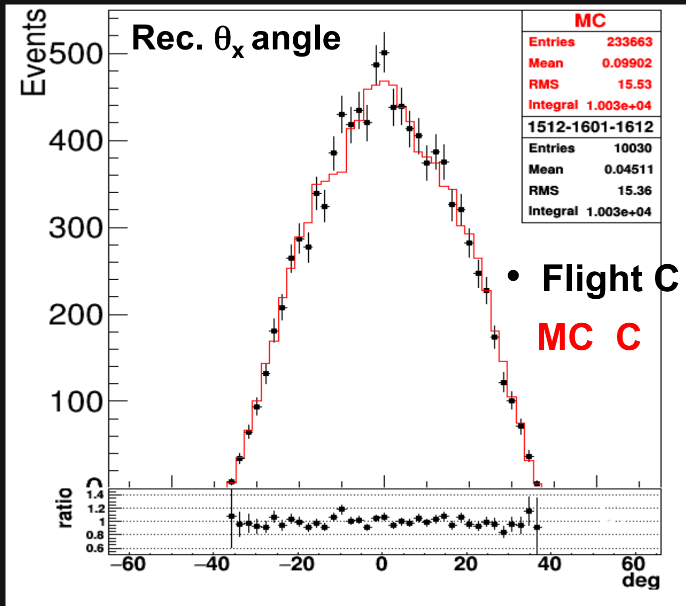
Tracking exploits IMC fine granularity and imaging capability.

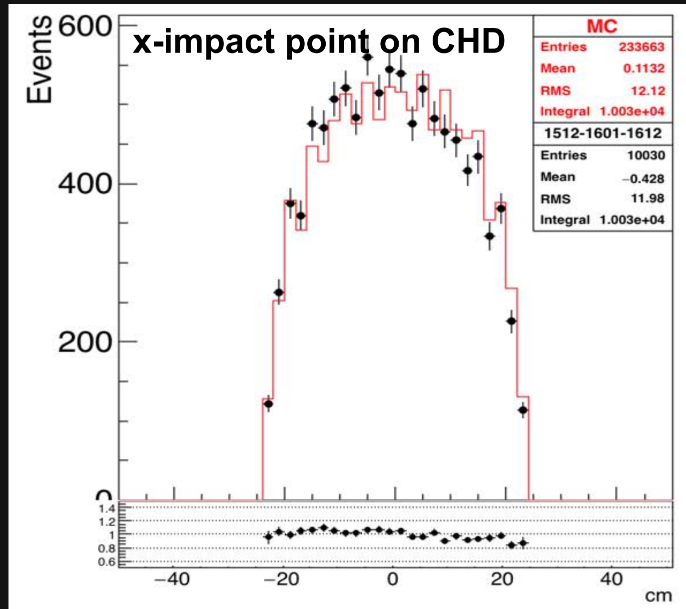
Combinatorial Kalman Filter algorithm provides robust track finding and fitting.

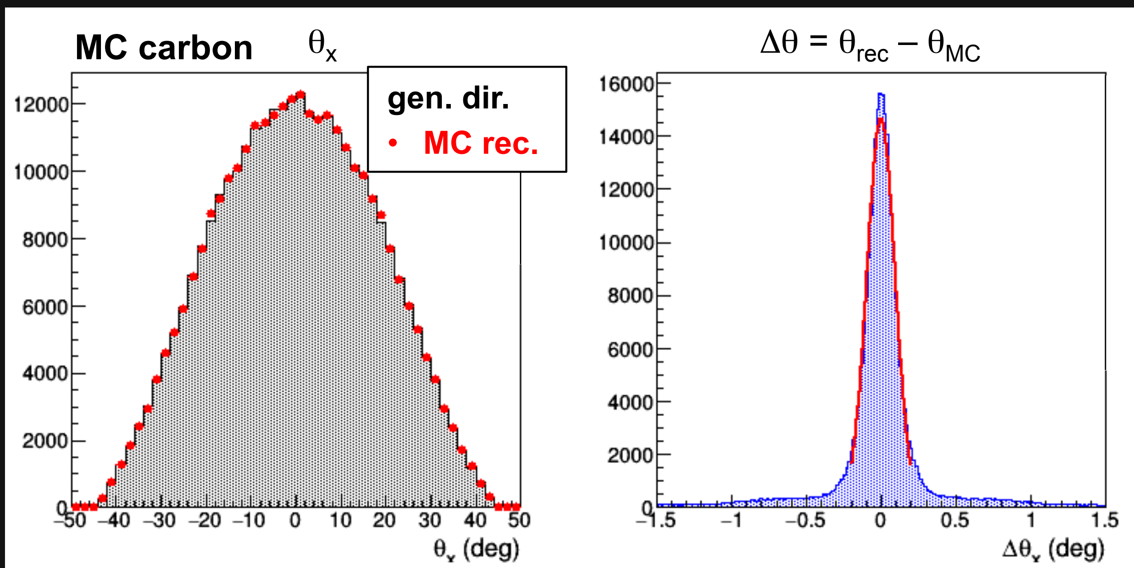
- Uses coordinates of Scifi's clusters inside a ROI (region-of-interest) defined by TASC shower axis.
- Runs separately on X/Y projections of the 3D track.
- Multiple track candidates.
- Primary particle track is associated with largest energy deposited in IMC and TASC.



Tracking performance





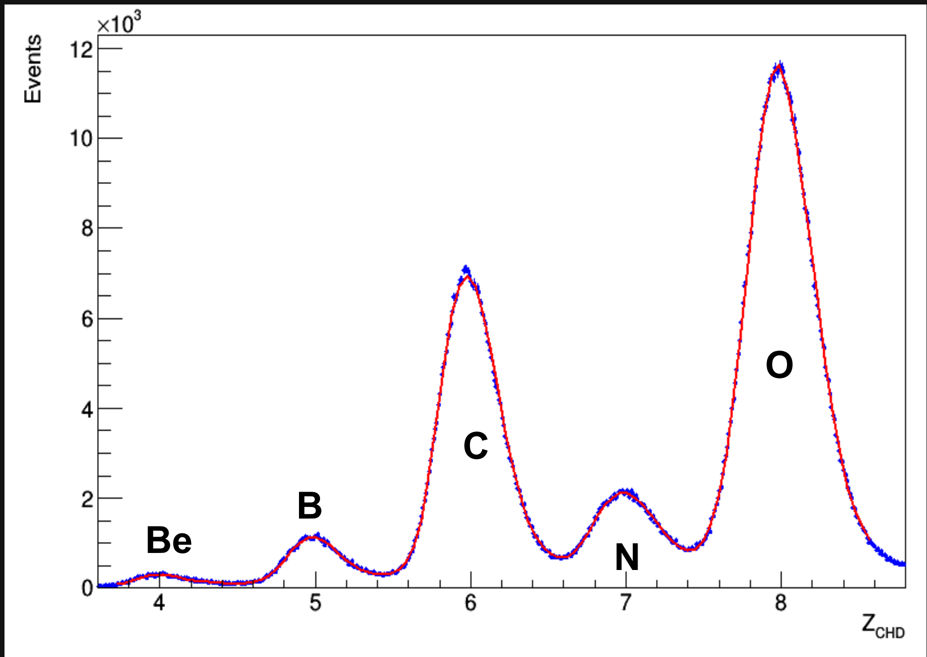


In BCNO region

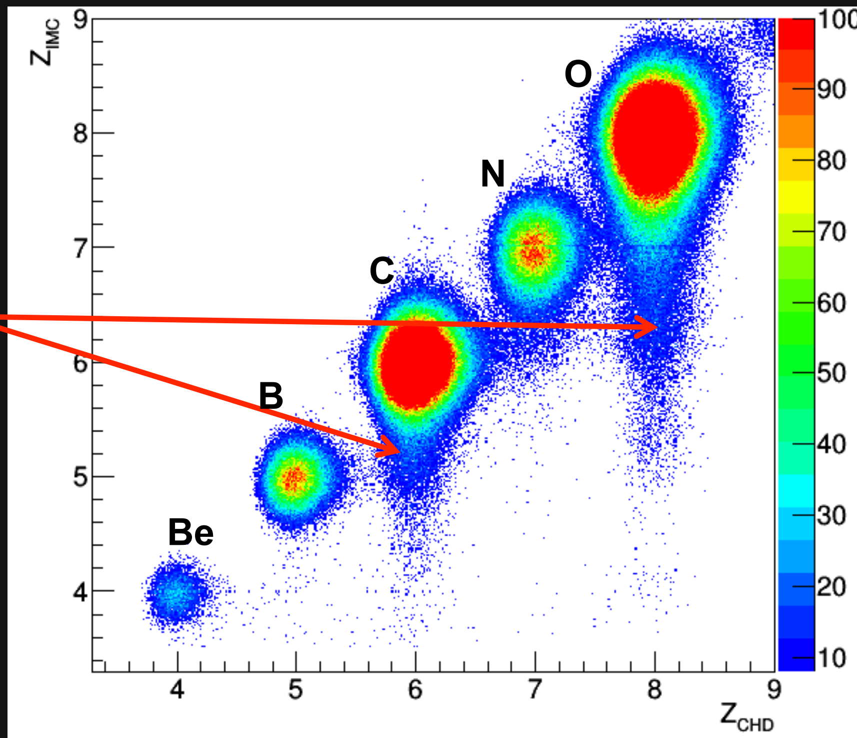
Angular resolution: 0.09°

CHD IP resolution: 240 μm

Charge identification

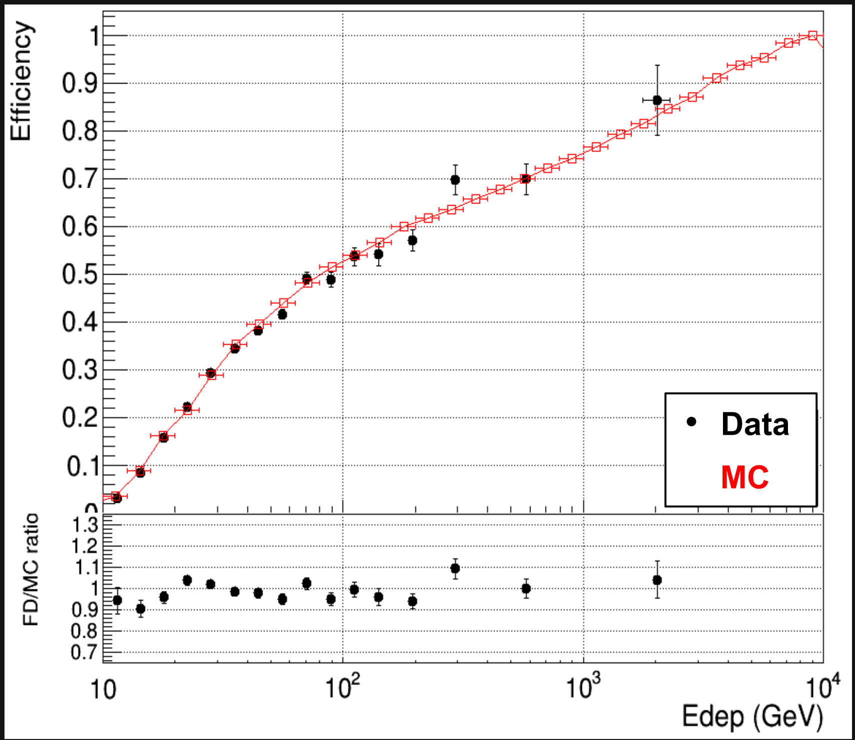


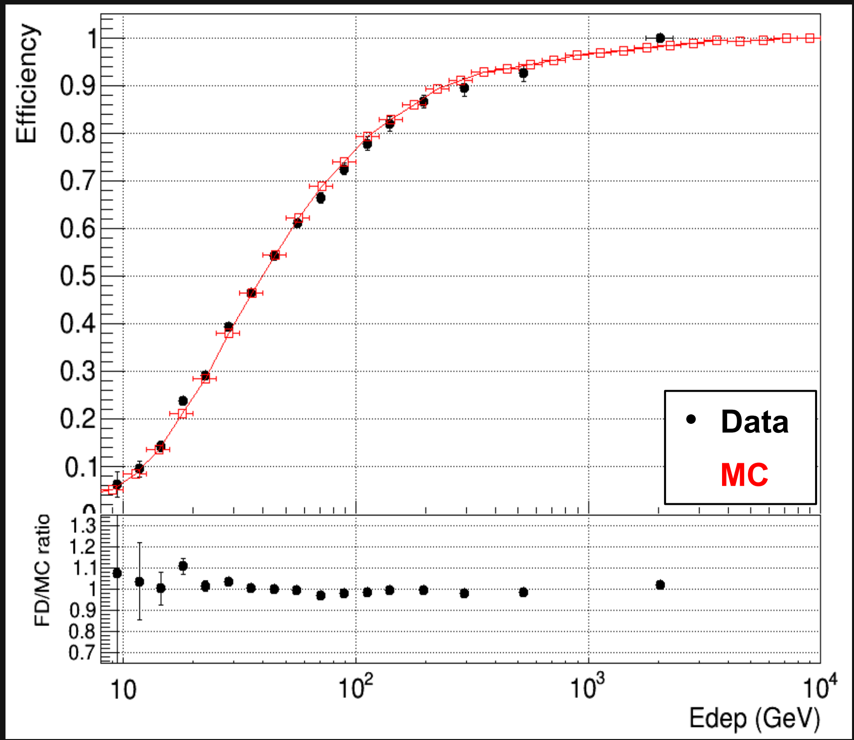
- Redundant charge measurements by combined CHD layers and multiple dE/dx in IMC fibers
- Non linear response to Z^2 due to light saturation in the scintillators is corrected using a core+halo model (Voltz).
- Excellent resolution: CHD σ_Z ~0.15 e, IMC σ_Z ~0.2 e in BCNO region



- Events undergoing charge-changing interactions upstream the IMC are clearly identified in IMC vs. CHD signal crossplot.
- Consistency between dE/dx in IMC X/Y views and CHD is required to remove early interacting nuclei in the detector.
- C/O events are selected by a ±2σ cut around peak value

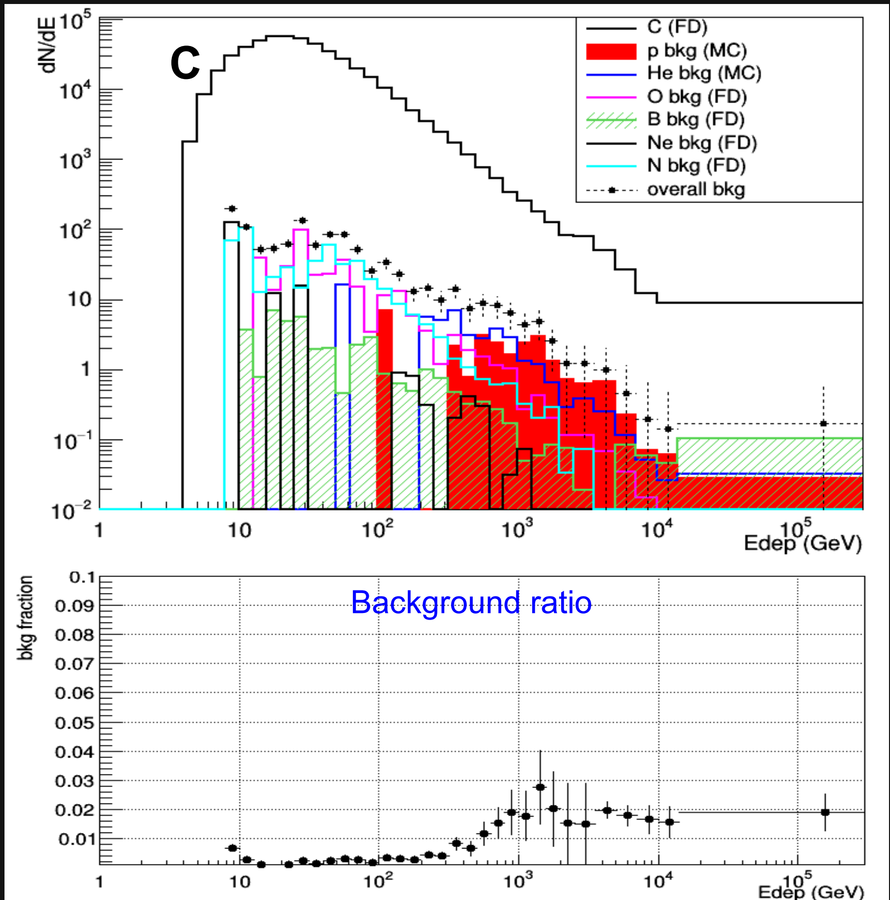
High-energy trigger efficiency

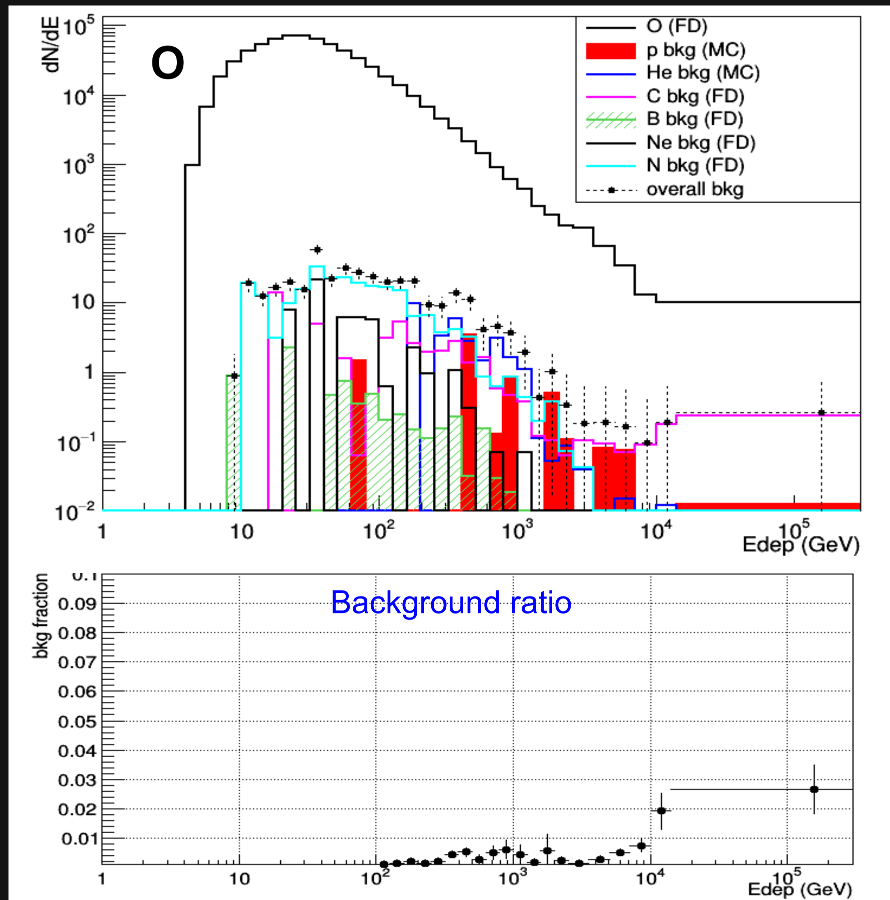




- High-Energy Trigger (HET) is the primary CALET mission trigger.
- It is based on the coincidence of signals in last four IMC layers and top TASC layer, with thresholds chosen to ensure >95% efficiency for electrons > 10 GeV
- HET efficiency for nuclei is measured using subset of data taken with same trigger logic but lower thresholds (allowing to trigger also penetrating particles).
- HET is modelled in simulation: good agreement between MC and flight data

C/O dN/dE and background estimate





- dN/dE distributions of Z>4 nuclei mis-identified as C/O are estimated from data.
- Background due to H/He is computed by normalizing MC distributions to the real fluxes
- Total background is few % in all energy bins

Energy unfolding

Two detailed MC simulations of CALET instrument were developed based on Fluka and Epics with hadronic package DPMJET-III.

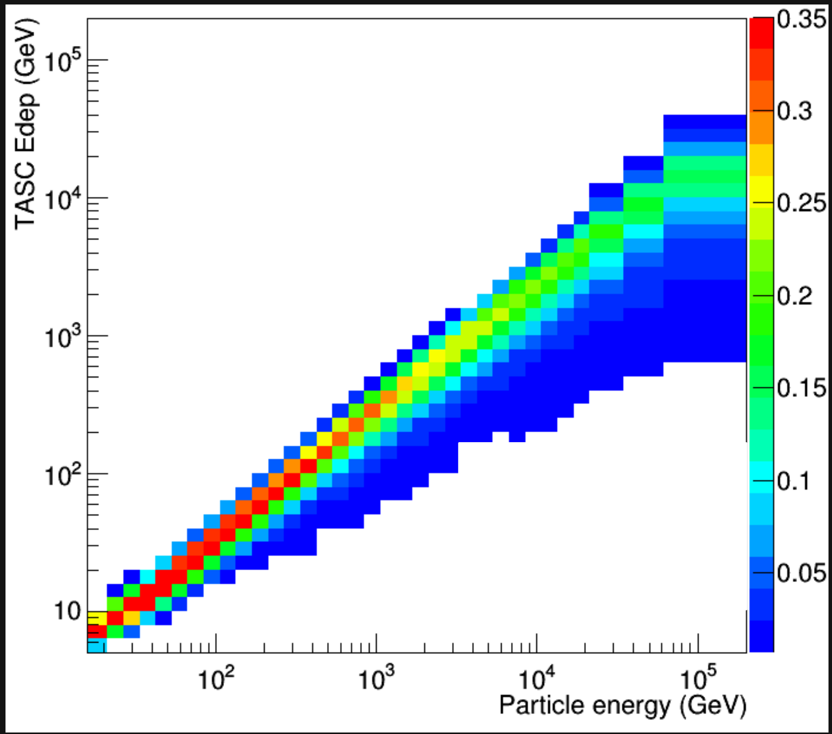
Digitization of signals and trigger were modelled accurately in simulation.

MC is used to estimate:

- the trajectory reconstruction and charge assignment efficiencies
- the energy response ("smearing") matrix

Energy bins are commensurate with rms resolution of TASC , ~30% for nuclei

Bayesian unfolding to get the primary energy spectrum



Each element S_{ij} of the smearing matrix represents the probability that events in the deposited energy bin *j* come from the primary particle energy bin *i*

Flux measurement

$$\Phi(\hat{E}) = \frac{N_i}{\varepsilon_i \times S\Omega \times T \times \Delta E_i}$$

N_i : unfolded events in energy bin *i* of width ΔE_i.

Ê: Median energy of energy bin *i* (Lafferty & Wyatt, NIMA 355 (1995) 541)

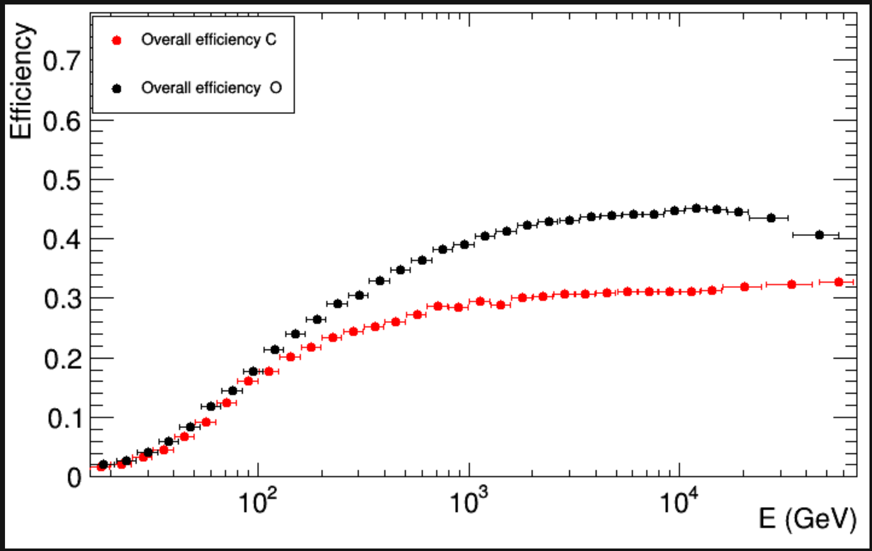
T: Live Time ~733 days (observation period 2015.10.13 – 2018.02.28)

SΩ: Geometrical acceptance 510 cm^2 sr

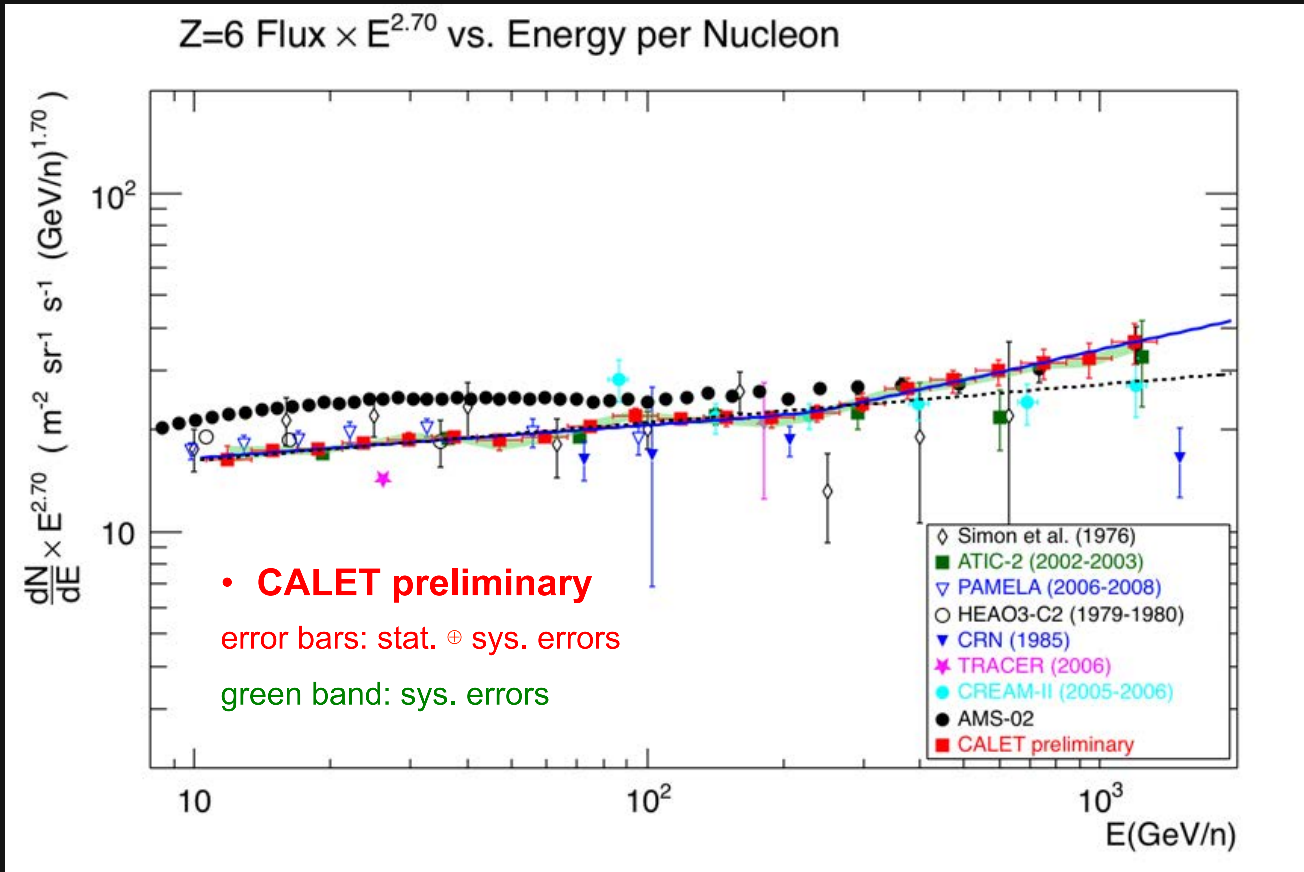
ε_i : selection efficiency in energy bin *i*

Selected events: C 462 $\times 10^3$

O 631 $\times 10^3$



Preliminary carbon energy spectrum



Systematics errors include uncertainties in trigger efficiency, event selection efficiencies, unfolding, acceptance.

Single power-law fit

C = 12.55 ± 0.30

γ = -2.588 ± 0.006

χ^2/ndf = 38/19

$$\Phi = C\left(\frac{E}{1\ \mathrm{GeV}}\right)^{\gamma}$$

Smoothly broken power-law fit

C = 13.23 ± 0.37

γ = -2.604 ± 0.008

$\Delta\gamma$ = 0.200 ± 0.057

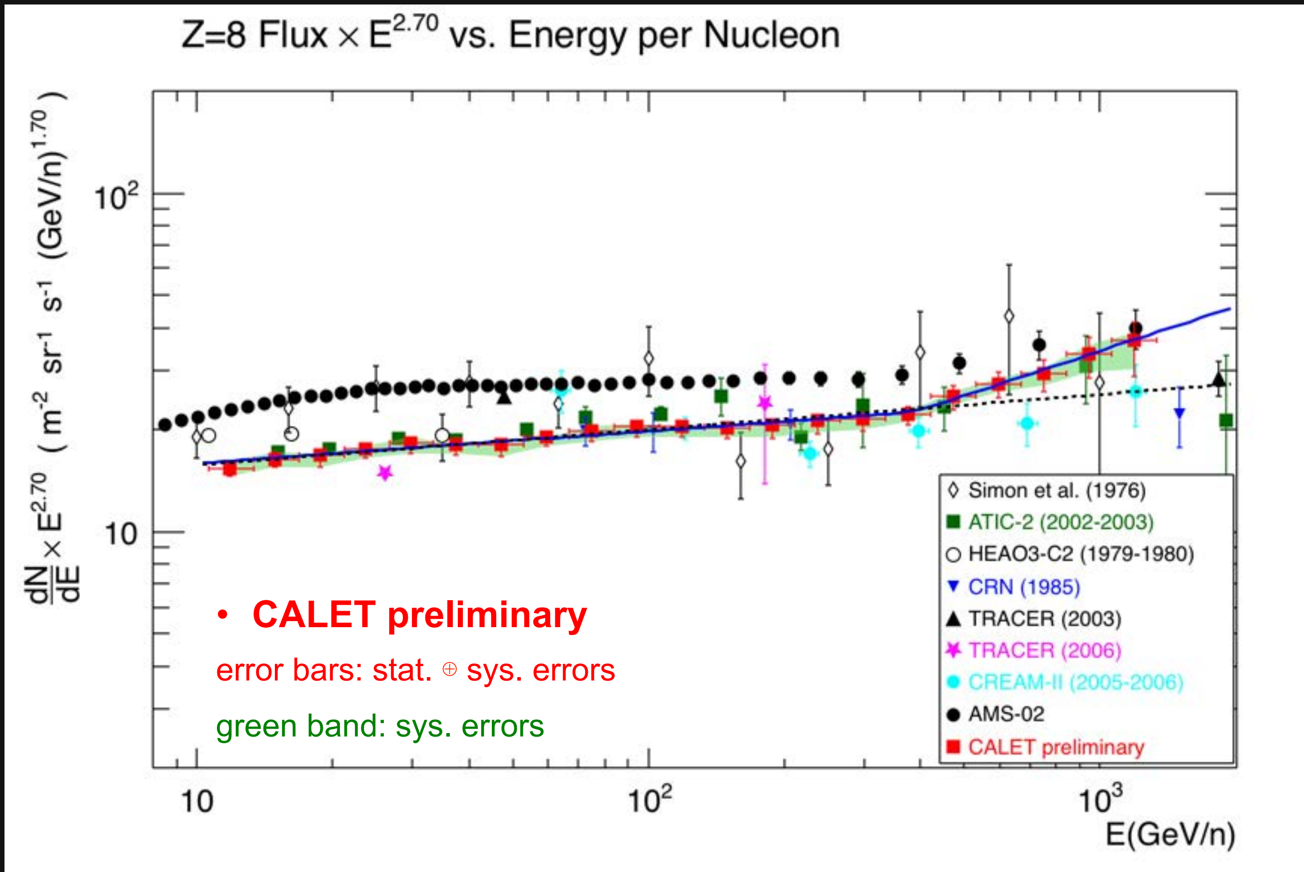
E_0 = 232 ± 55

s = 0.020

χ^2/ndf = 18.5/16

$$\Phi = C\left(\frac{E}{1\ \mathrm{GeV}}\right)^{\gamma}\left[1+\left(\frac{E}{E_0}\right)^{\frac{\Delta\gamma}{s}}\right]^{s}$$

Preliminary oxygen energy spectrum



Systematics errors include uncertainties in trigger efficiency, event selection efficiencies, unfolding, acceptance.

Single power-law fit

C = 12.38 ± 0.06

γ = -2.596 ± 0.001

χ^2/ndf = 27.5/19

$$\Phi = C\left(\frac{E}{1\ \mathrm{GeV}}\right)^{\gamma}$$

Smoothly broken power-law fit

C = 12.82± 0.35

γ= -2.605 ± 0.007

$\Delta\gamma$ = 0.34 ± 0.11

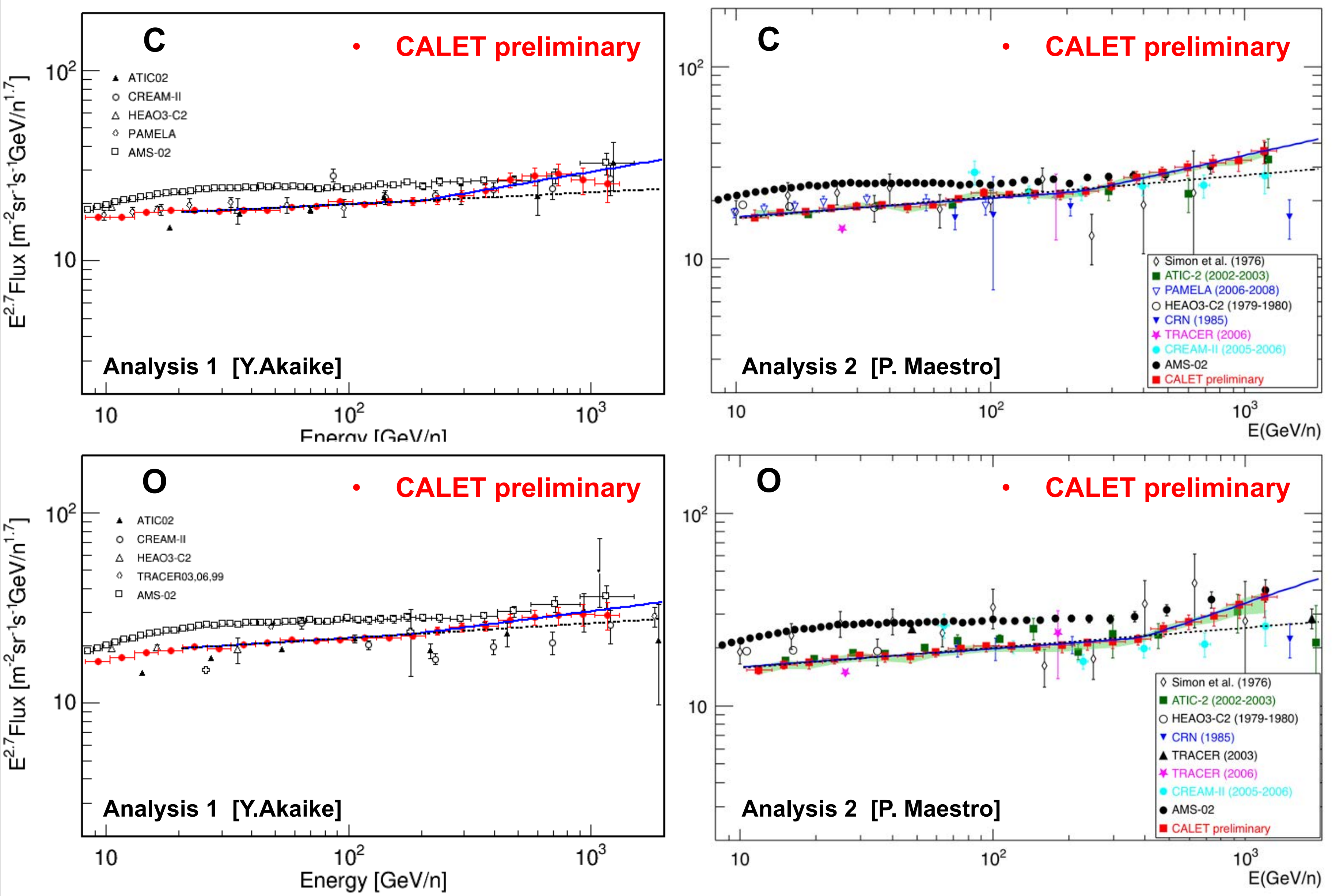
E_0 = 387 ± 185

s = 0.020

χ^2/ndf = 9.85/16

$$\Phi = C\left(\frac{E}{1\ \mathrm{GeV}}\right)^{\gamma}\left[1+\left(\frac{E}{E_0}\right)^{\frac{\Delta\gamma}{s}}\right]^{s}$$

Two independent analyses



Conclusions

CALET can measure heavy nuclei in CRs with an excellent charge separation over a wide energy range.

Preliminary measurements of the C and O differential fluxes have been carried out up to 2 TeV/n using 28 months of data.

Preliminary results demonstrate CALET capability to resolve spectral features in the CR spectra.

Independent analyses were carried out using different event selection procedures and MC simulations. Preliminary results are consistent.

Further studies with increased statistics at high energy and detailed assessment of systematic uncertainties are ongoing.