Measurement of the energy spectra of carbon and oxygen nuclei in cosmic rays with CALET

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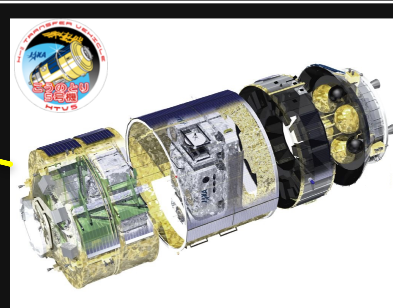
University of Siena & INFN

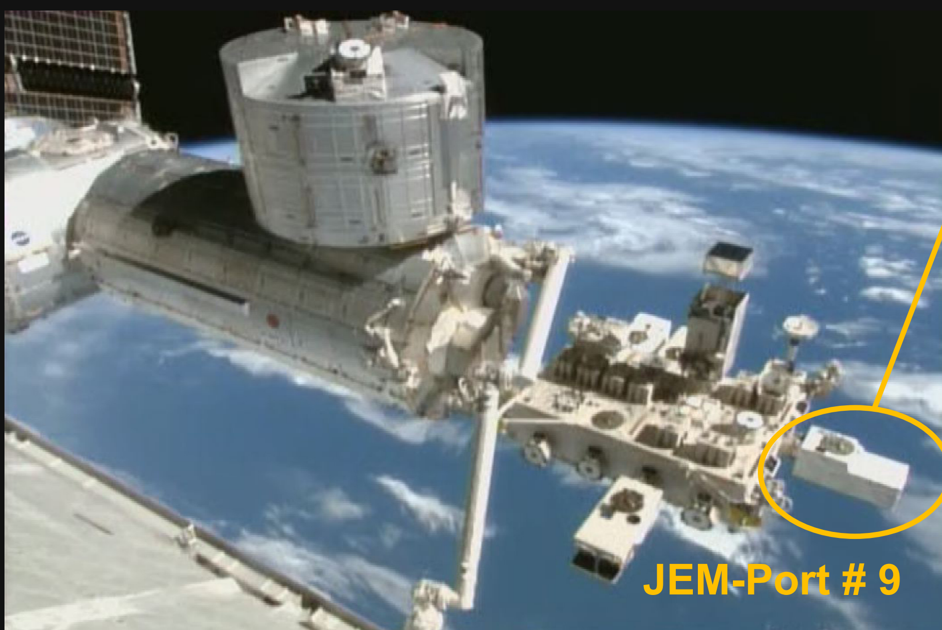
On behalf of the CALET collaboration

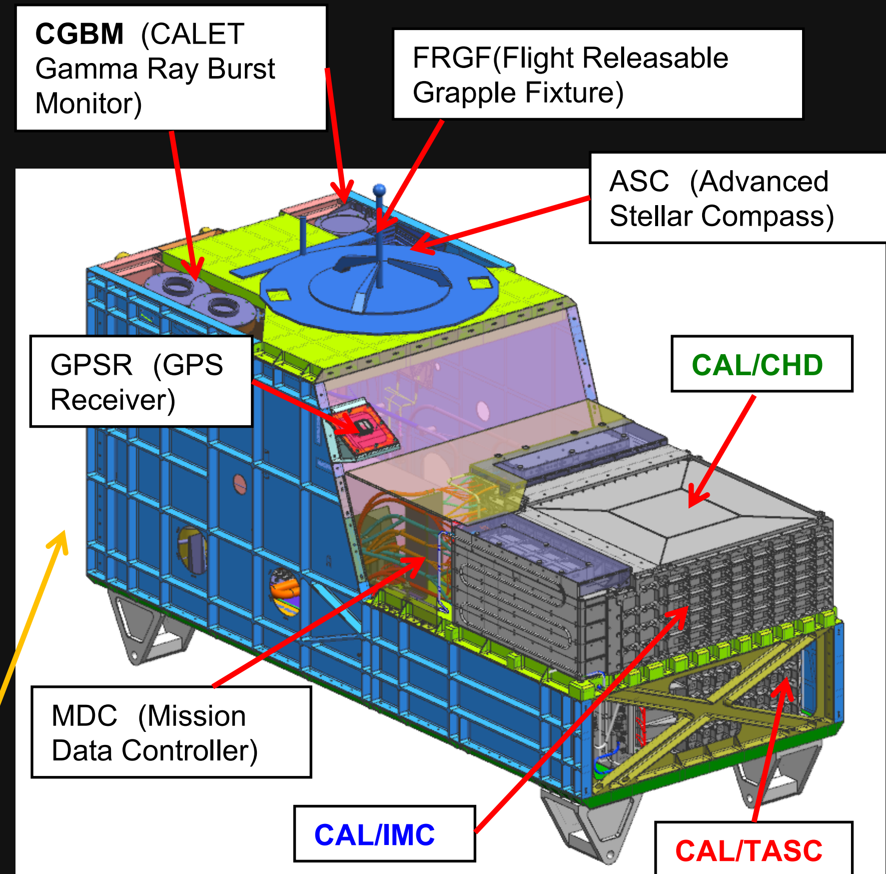
ICRC2019 36th International Cosmic Ray Conference · Madison, WI, USA
THE ASTROPARTICLE PHYSICS CONFERENCE

CALET payload



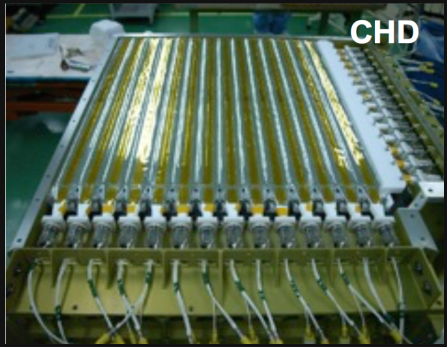
Launched on Aug. 19th 2015
on the Japanese H2-B rocket
Emplaced on JEM-EF port#9
On Aug. 25th 2015

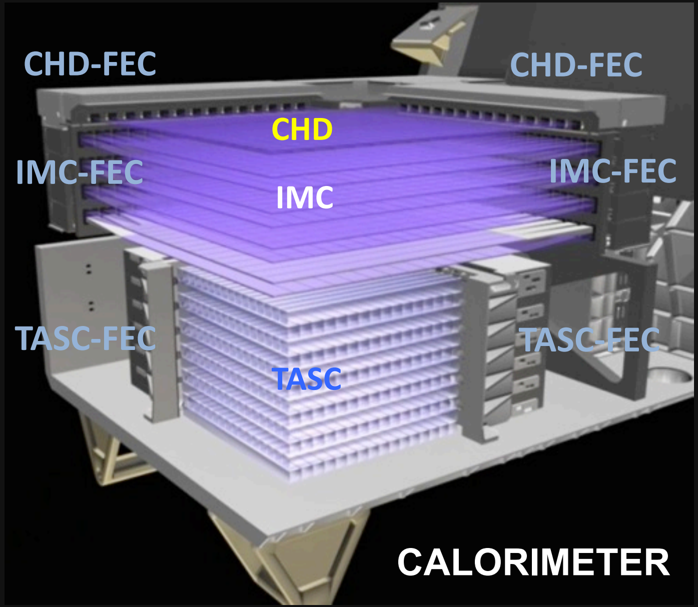




- Mass: 612.8 kg
- JEM Standard Payload Size
  1850 mm (L) × 800 mm (W) × 1000 mm (H)
- Power Consumption: 507 W (max)
- Telemetry: Medium 600 kbps (6.5GB/day) /
  Low 50 kbps

CALET instrument





CGBM

Detector	Measure	Geometry/Material	Readout
CHD (Charge Detector)	**Charge (Z=1-40)**	**Plastic Scintillator 14 paddles × 2 layers (X,Y) Paddle size: $3.2\times1\times45$ cm^3**	**PMT+CSA**
IMC (Imaging Calorimeter)	**Tracking Particle ID**	**448 Scifi × 16 layers (X,Y) 7 W layers (3 X_0) Scifi size: $1\times1\times448$ mm^3**	**64 MAPMT+ ASIC**
TASC (Total Absorption Calorimeter)	**Energy e/p separation**	**16 PWO logs × 12 layers (X,Y) log size: $1.9\times2\times32.6$ cm^3 Total thickness: 27 X_0 , ~1.2 λ**	**APD/PD + CSA PMT+CSA (for Trigger)**

CALET main scientific objectives

Science Objectives	Observation Targets	Energy range
Nearby CR sources	Electron spectrum	100 GeV – 20 TeV
Dark Matter	Signatures in e/γ spectra	100 GeV – 20 TeV
CR Origin and Acceleration	Electron spectrum p-Fe individual spectra Ultra Heavy Ions ($26<Z\leq40$)	1 GeV – 20 TeV 10 GeV – 10^3 TeV few GeV/n
Galactic CR Propagation	B/C sub-Fe/Fe ratios	Up to some TeV/n
Solar Physics	Electron flux	< 10 GeV
Transient phenomena (GRB, e.m. counterpart of GW)	Gamma and X-rays	7 keV – 20 MeV

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Spectrum hardening: precise measurement of the transition region for each nuclear species and extension to TeV energy

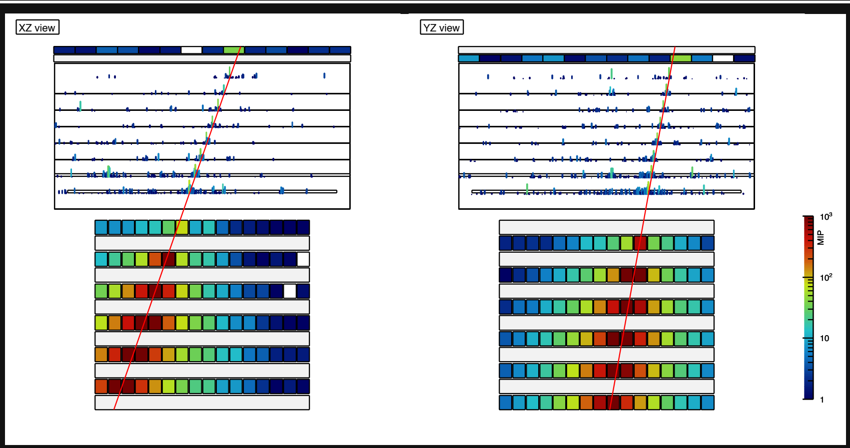
Wide dynamic range (1-10^6 MIP)
Large thickness (**30 X_0 , ~1.3 λ**)
Excellent charge ID (~0.2 e)

CALET can cover the whole energy range previously investigated in separate subranges by magnetic spectrometers and calorimeters.

Selection for C,O candidate events

Analyzed Flight Data:

- 1124 days (Oct. 13, 2015 to Oct. 31, 2018)
- Geometrical acceptance: 510 cm^2 sr



- HE shower trigger
- Offline trigger confirmation (Edep> 50 MIP in IMC-X/Y78, Edep> 100 MIP in TASC-X1)
- Tracking with IMC
- Acceptance Cut (events crossing CHD, TASC top and bottom excluding 2 cm from the edges)
- Track quality cut
- Charge ID (CHD dE/dx and multiple dE/dx sampling along the track in IMC)
- Background estimate
- Energy measurement and unfolding
- Flux calculation

Tracking for CR nuclei

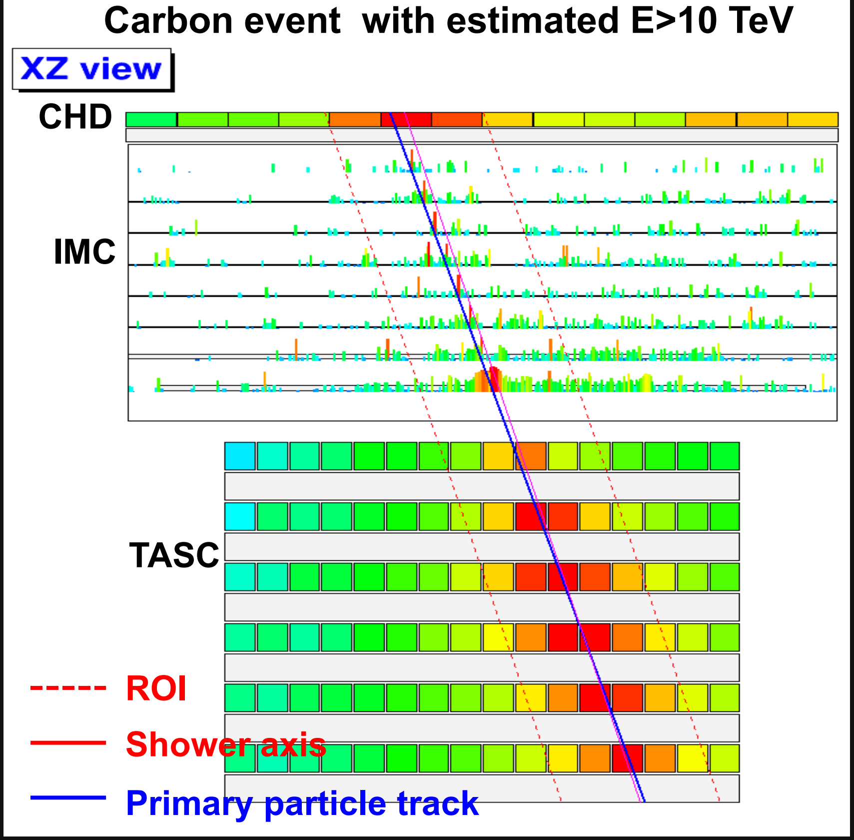
Tracking is used to:

- determine CR arrival direction
- define the geometrical acceptance
- identify CHD paddles and IMC scifi's crossed by CR particle → Particle ID

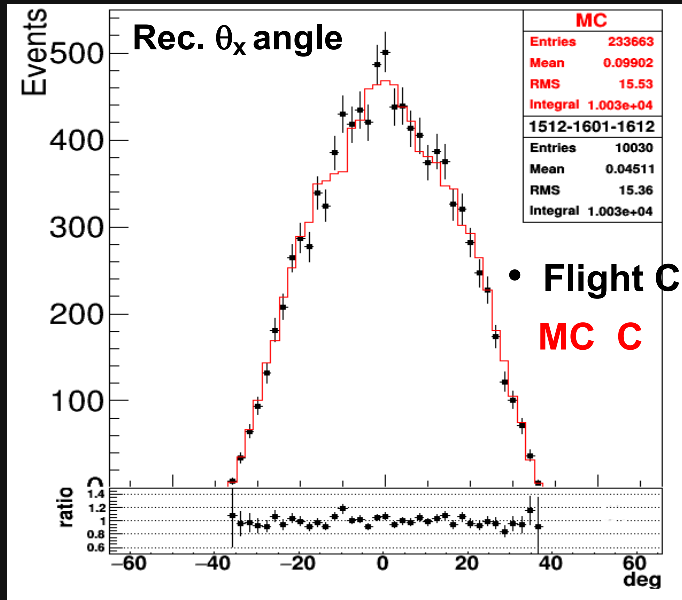
Tracking exploits IMC fine granularity and imaging capability.

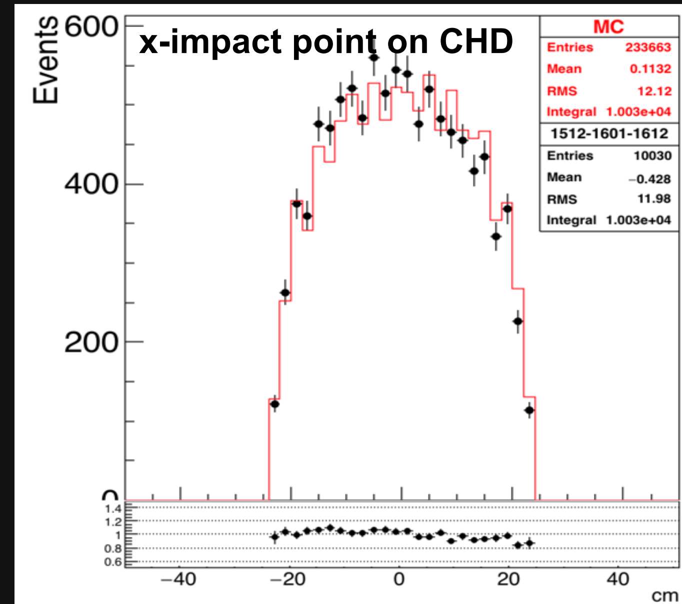
Combinatorial Kalman Filter algorithm provides robust track finding and fitting.

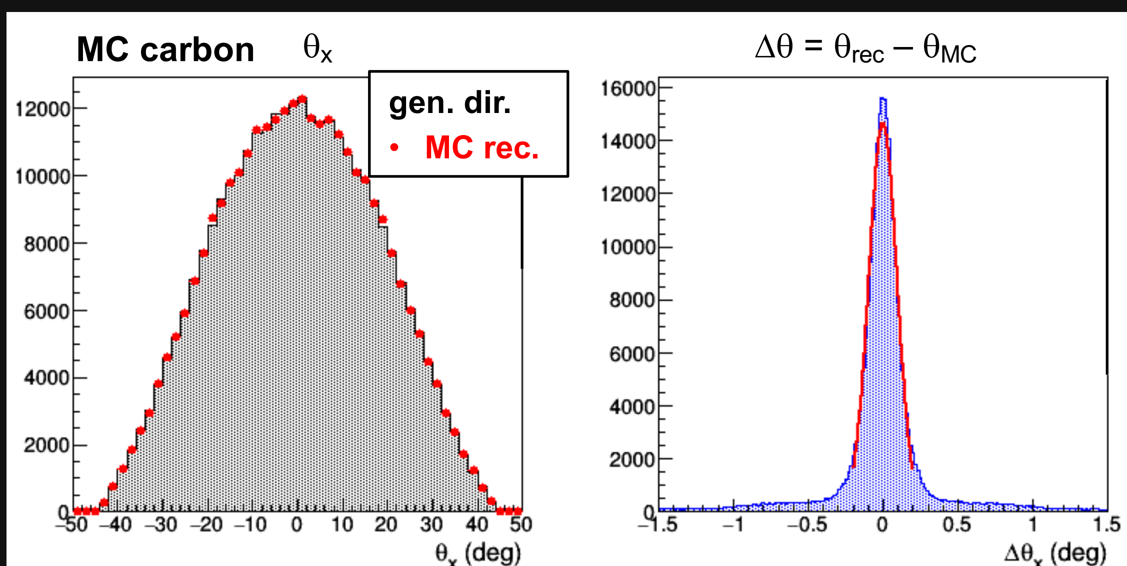
- Uses coordinates of Scifi's clusters inside a ROI (region-of-interest) defined by TASC shower axis.
- Runs separately on X/Y projections of the 3D track.
- Multiple track candidates.
- Primary particle track is associated with largest energy deposited in IMC and TASC.



Tracking performance





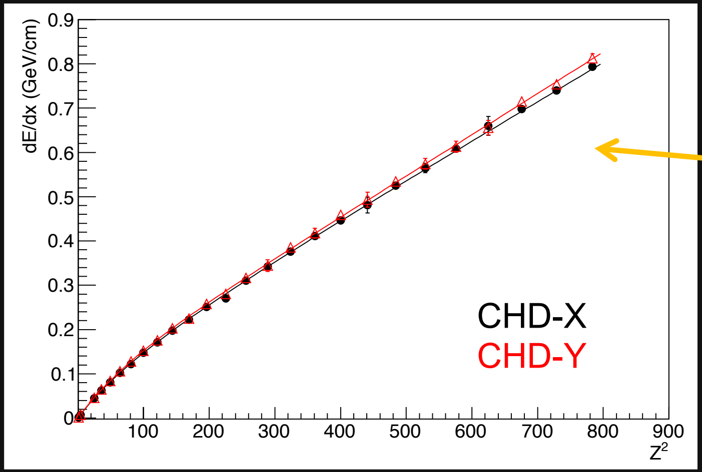


In BCNO region

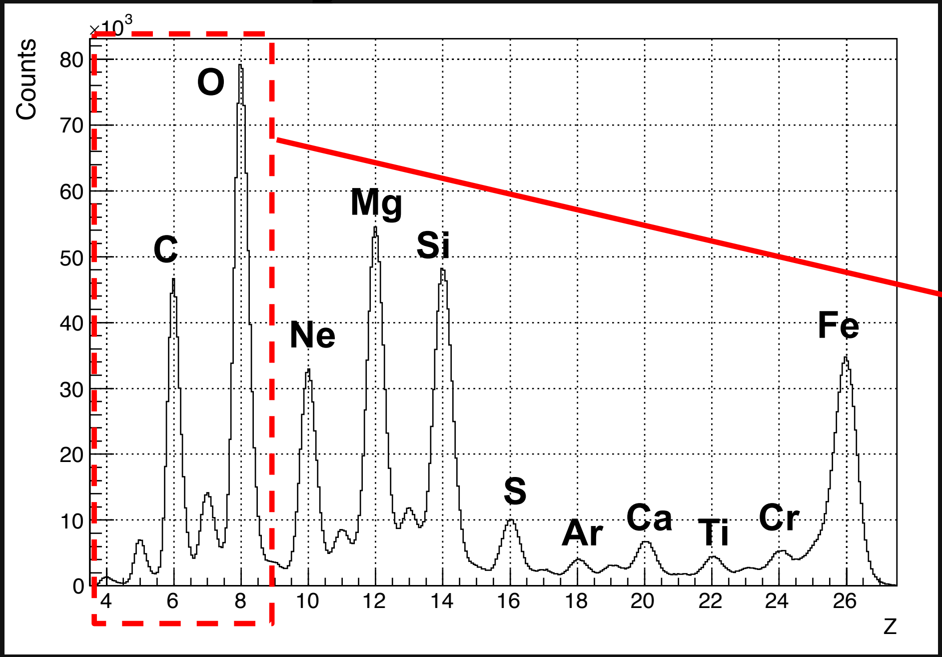
Angular resolution: 0.09°

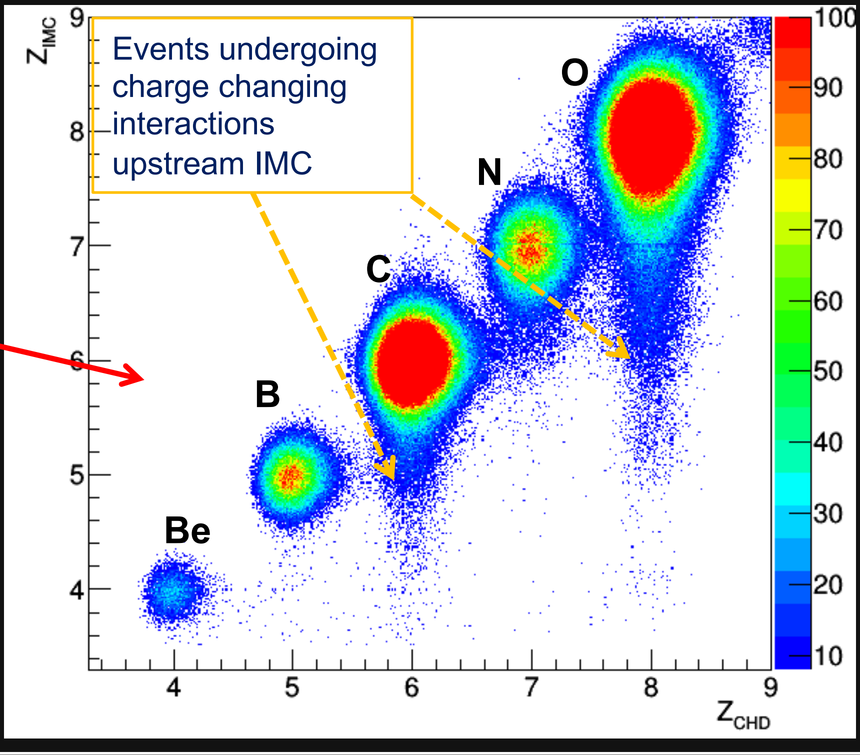
CHD IP resolution: 240 μm

Charge identification

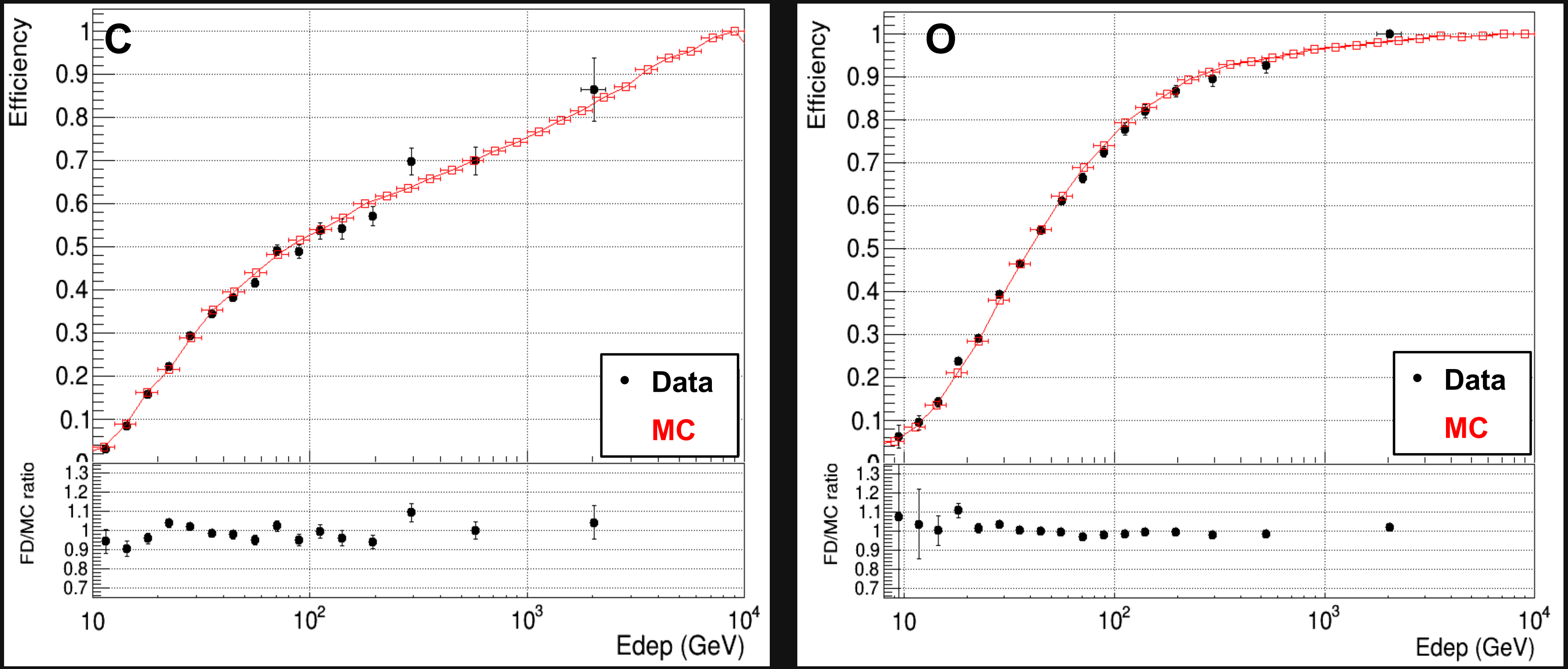


- Redundant charge measurements by combined CHD and multiple dE/dx in IMC fibers in the first 4 X/Y layers.
- Non linear response to Z^2 due to light saturation in the scintillators is corrected using a core+halo model (Voltz).
- Excellent resolution:
  - CHD σ_Z ~0.15 e (BCNO), ~0.28 e (Fe)
  - IMC σ_Z ~0.2 e in BCNO region



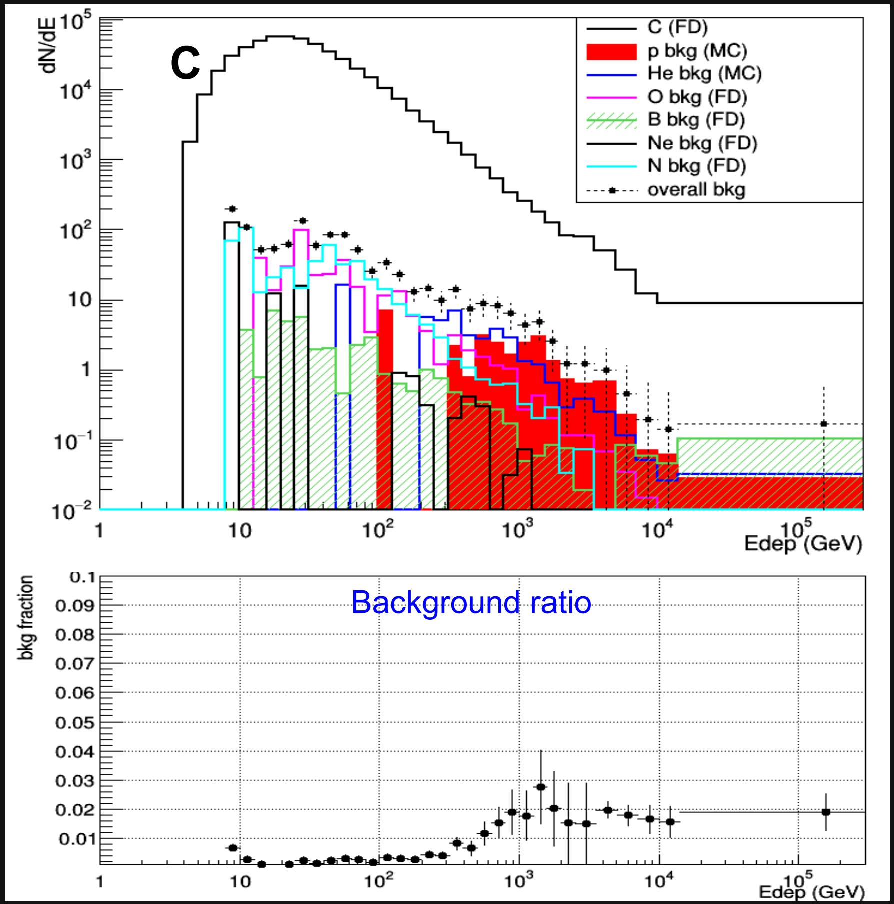


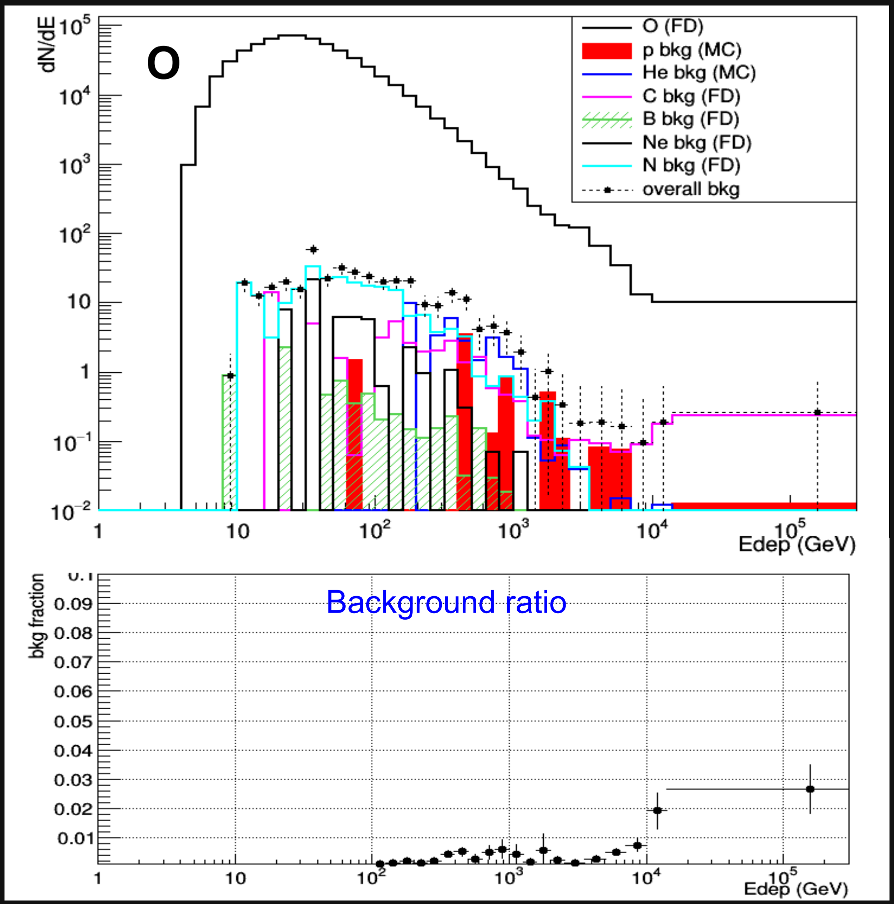
High-energy trigger efficiency



- 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



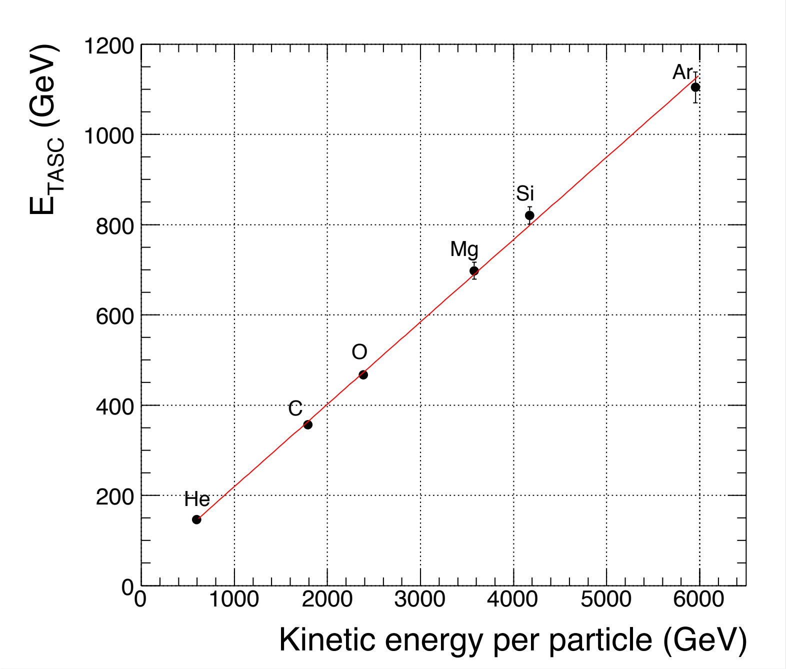


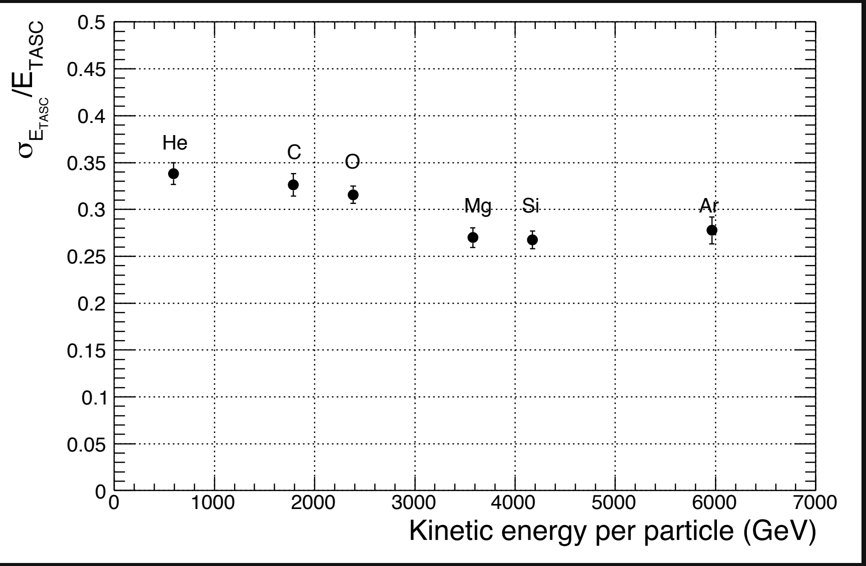
- dN/dE distributions of Z>4 nuclei mis-identified as C/O are estimated from data.
- Background due to p/He is computed by normalizing MC distributions to the real fluxes
- Total background is few % in all energy bins

TASC energy scale

- Beam test calibration at CERN-SPS with ion fragments beam (Z/A=2) at 150 GeV/n.
- Good linearity up to maximum available beam energy (~ 6 TeV)
- Fraction of particle energy released in TASC is ~20%

  Energy resolution 30-35%





Energy unfolding

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

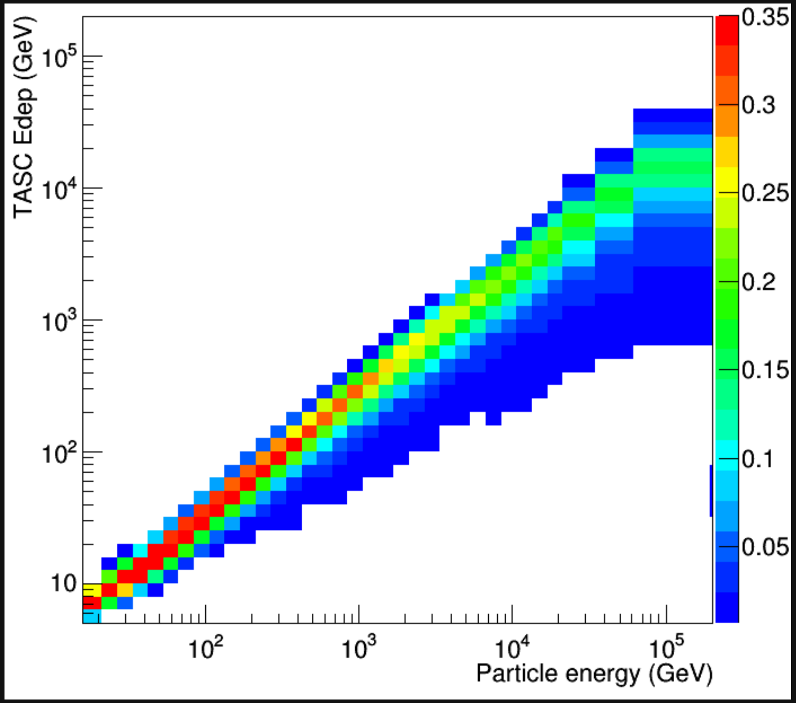
  Digitization of signals and trigger were modelled accurately in simulation and tuned using beam test results and flight data.

- MC is used to estimate:
  - tracking and charge ID efficiencies
  - the energy response ("smearing") matrix

- TASC thickness ~1.2 λ for proton

  → Incomplete containment of hadronic showers and large event-to-event fluctuations

  → Iterative bayesian unfolding to get the primary energy spectrum



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

Flux measurement

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

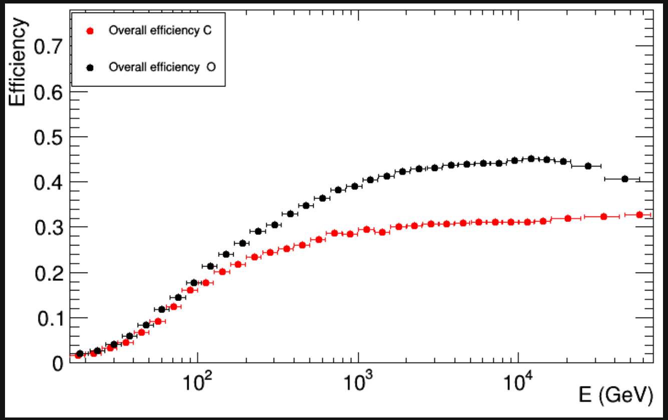
N(E) : bin counts of the unfolded energy distribution

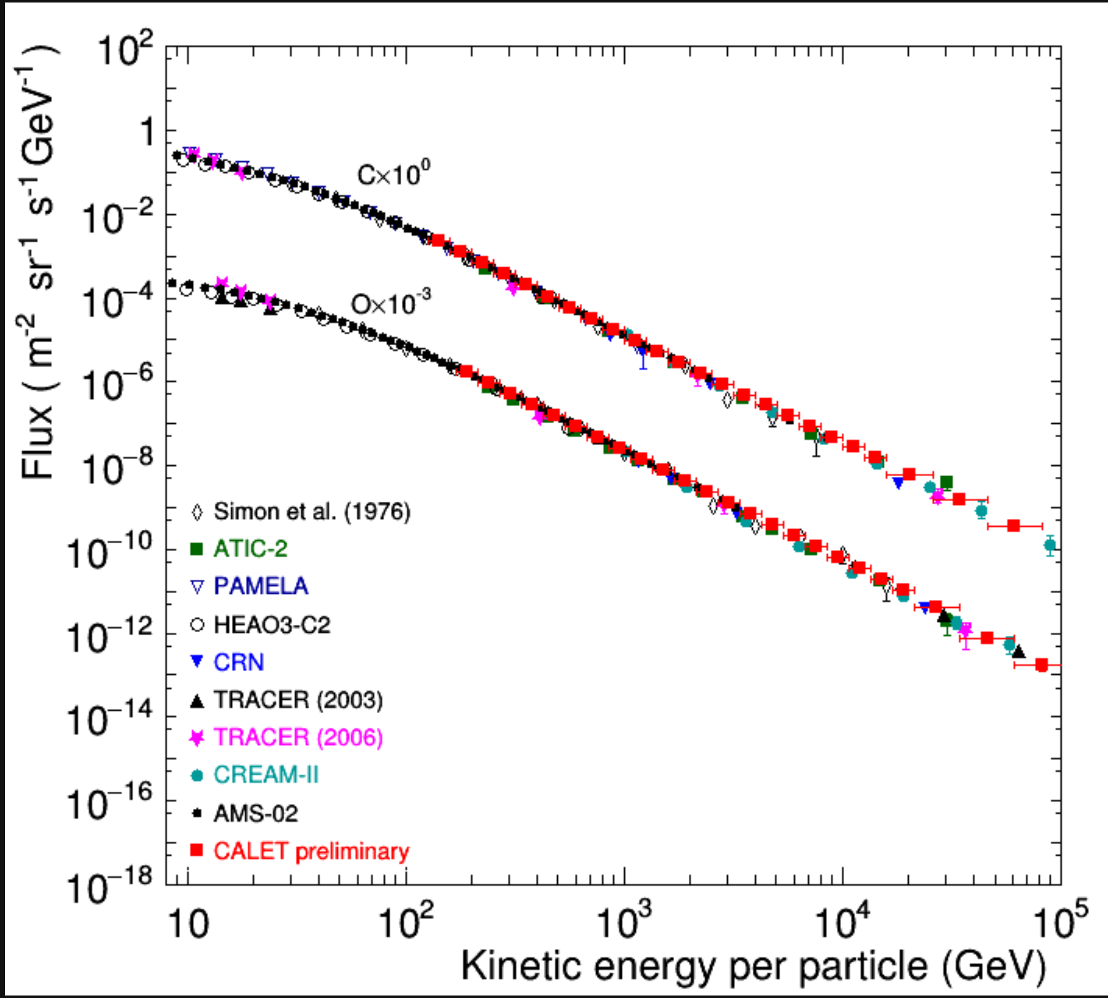
ΔE: energy bin width

T: Live Time, ~84% of observing time

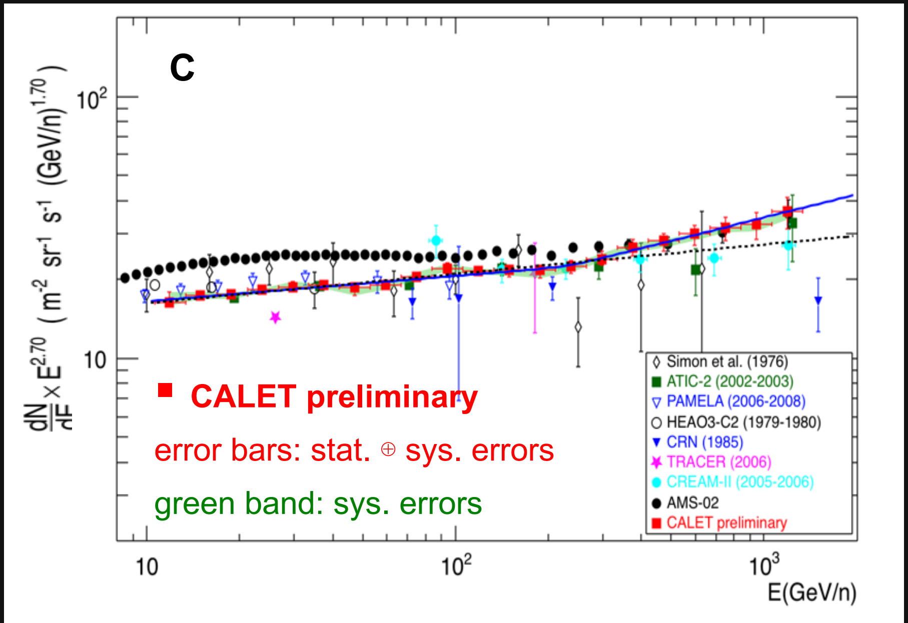
SΩ: Geometrical acceptance

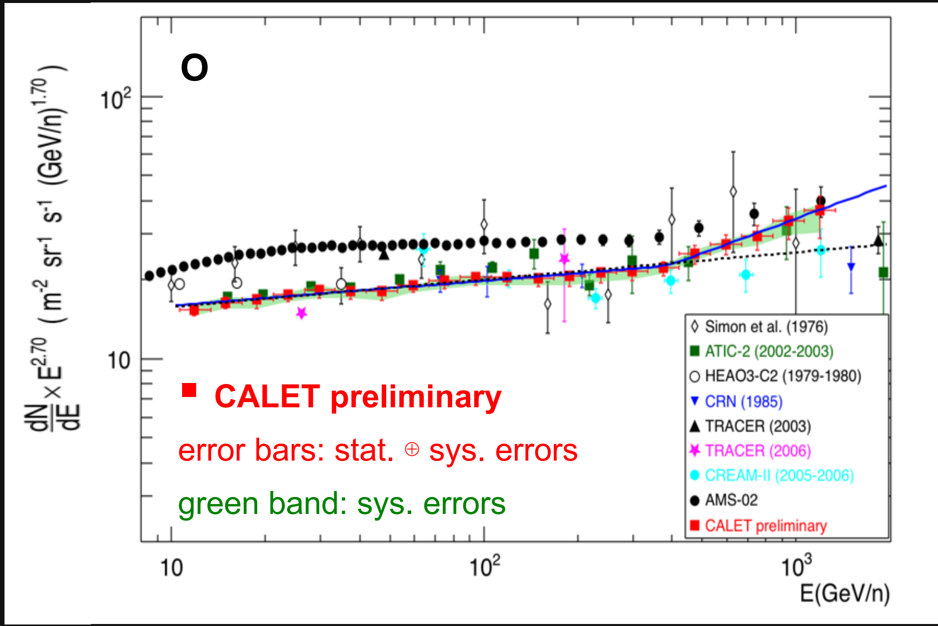
ε(E): selection efficiency





Preliminary C and O energy spectra

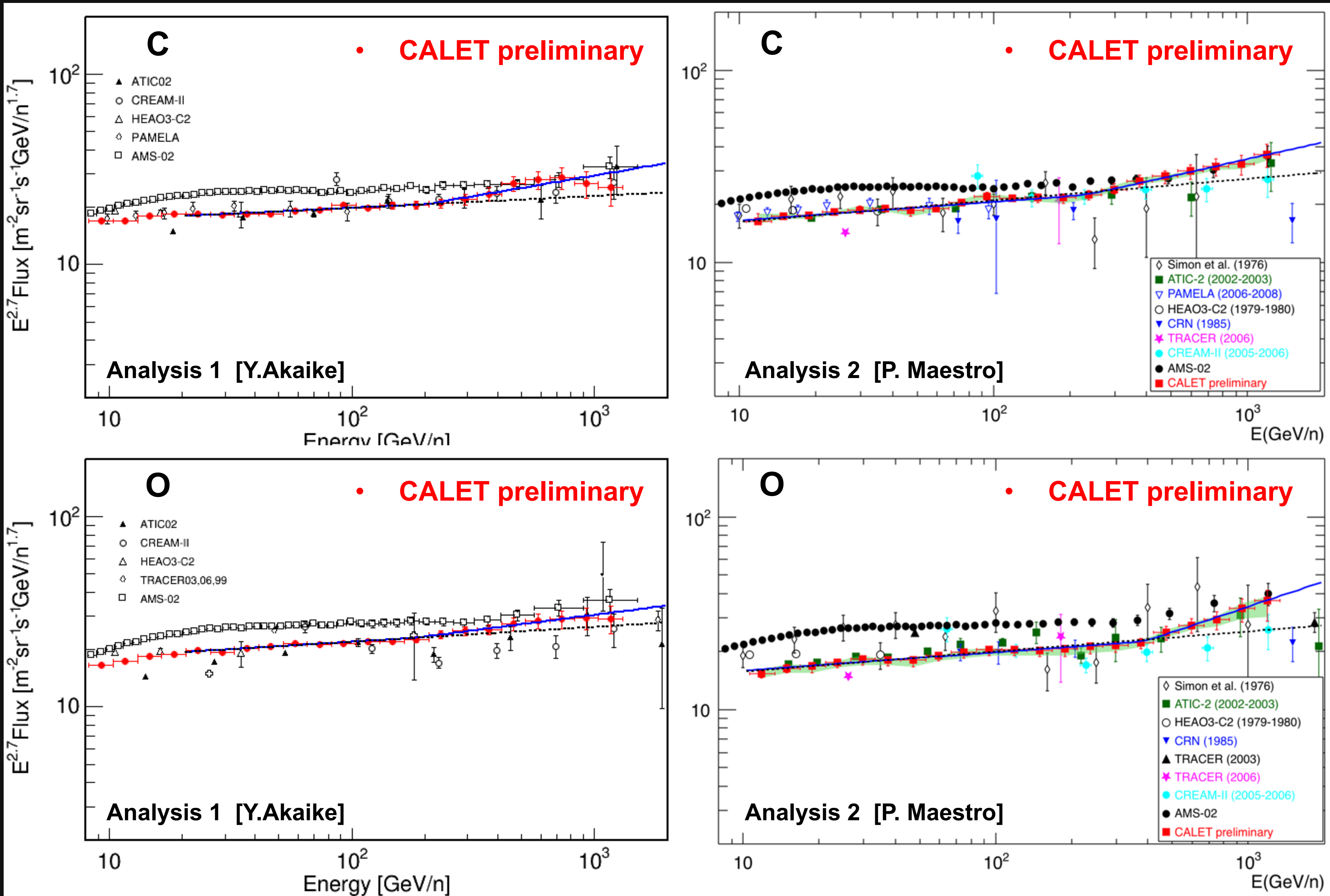




Preliminary evaluation of systematics errors include uncertainties in trigger efficiency, acceptance, event selection efficiencies, unfolding.

Additional sources (energy scale, hadronic interaction models) are being investigated.

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 100 TeV of particle energy using 37 months of data.

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

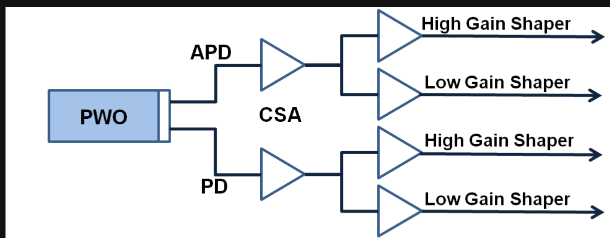
Independent analyses were carried out using different event selection procedures and MC simulations. Preliminary results are consistent.

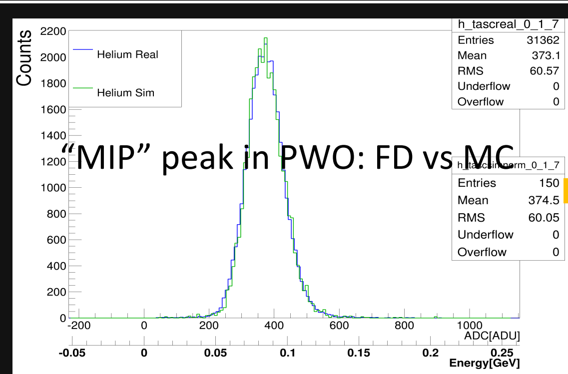
Further studies with increased statistics at high energy and detailed assessment of systematic uncertainties are ongoing.

BACKUP

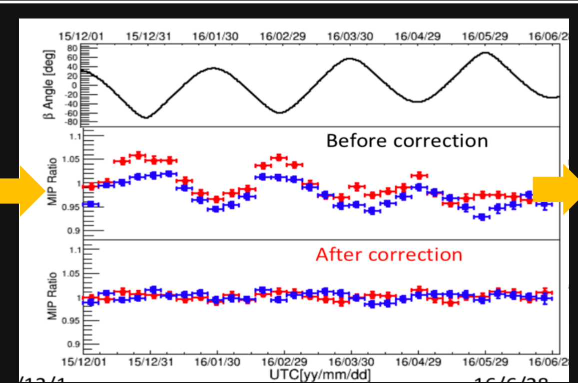
TASC calibration

Y. Asaoka et al. (CALET Collaboration) Astropart. Phys. 91 (2017) 1



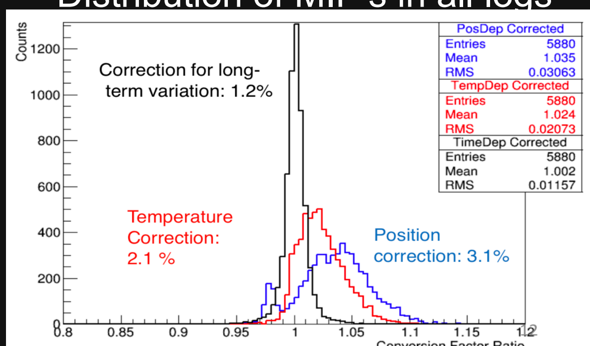


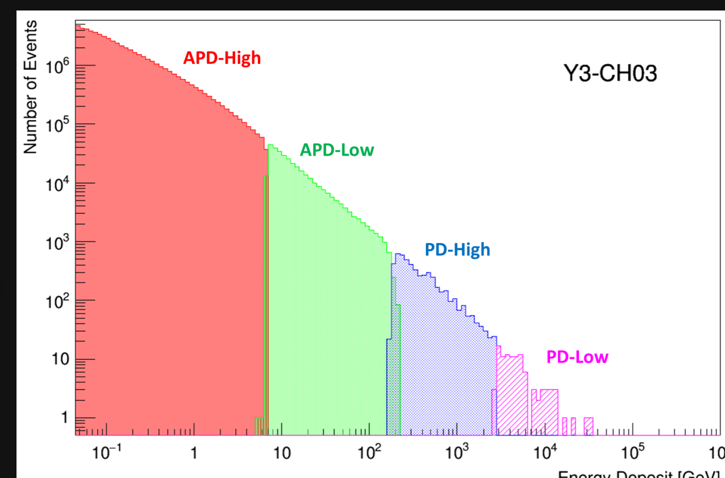
Calibration on orbit with p and He MIP's



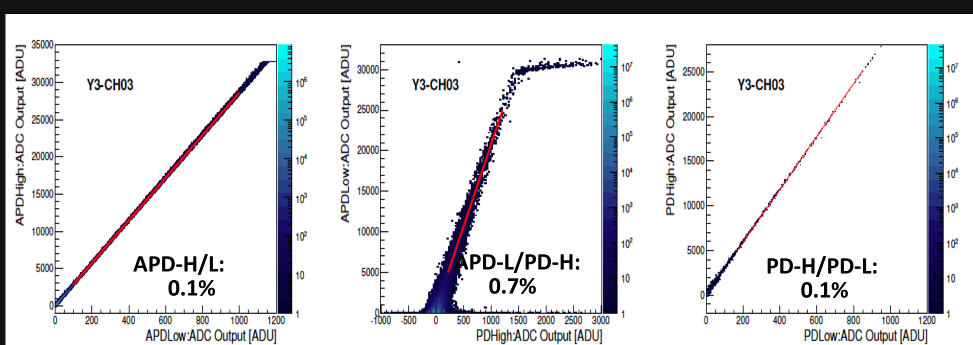
Corrections for position, temperature, and latitude (due to rigidity) dependence

Distribution of MIP's in all logs





Energy distribution in one PWO log.
Dynamic range of each channel: **1 - 10^6 MIP**



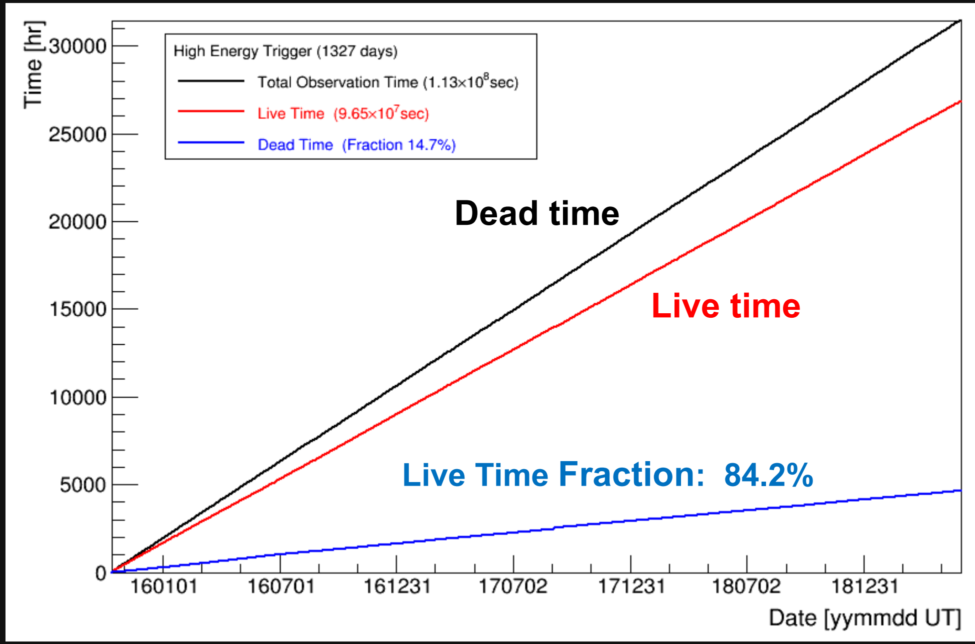
Gain ranges calibrated by UV laser irradiation on ground
Correlation of gain ranges calibrated in-flight

Observations with High Energy Trigger (>10GeV)

Observation by High Energy Trigger for 1327 days : Oct.13, 2015 – May 31, 2019

- The exposure, SΩT, has reached ~116 m^2 sr day for electron observations under continuous and stable operations.
- Total number of triggered events is ~1.8 billion with a live time fraction of 84.0 %.

Accumulated observation



Distribution of deposit energies (ΔE) in TASC