CALET on the International Space Station: a precise measurement of the iron spectrum

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on behalf of CALET collaboration

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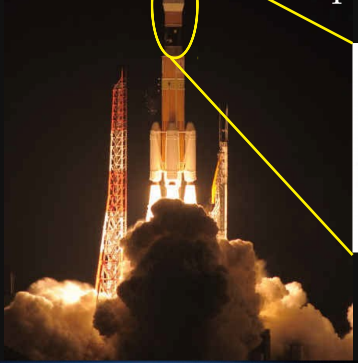
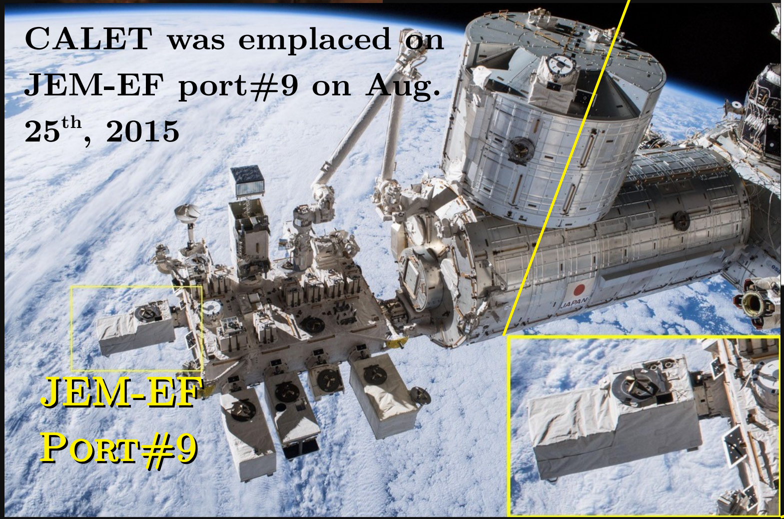
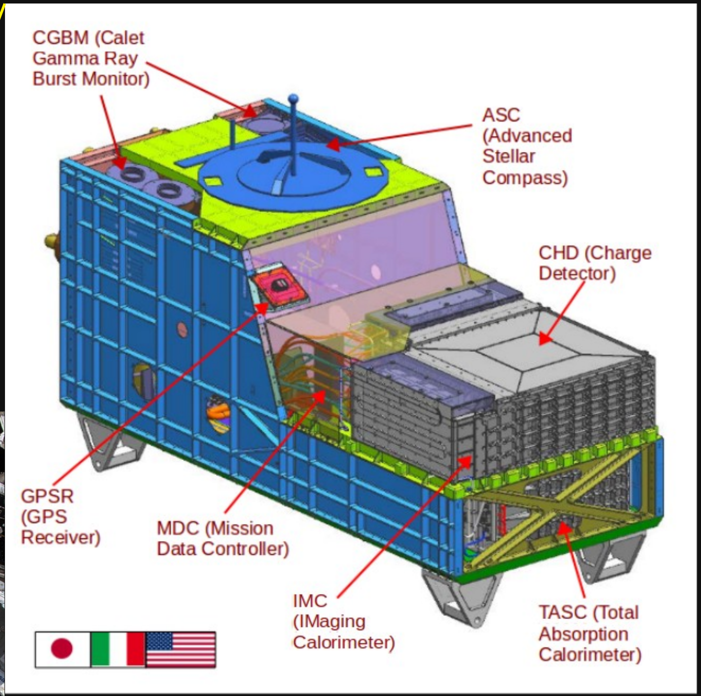
CALET PAYLOAD

CALET launch on Aug. 19th, 2015 on Japanese H2-B rocket



CALET was emplaced on JEM-EF port#9 on Aug. 25th, 2015





JEM Standard Payload

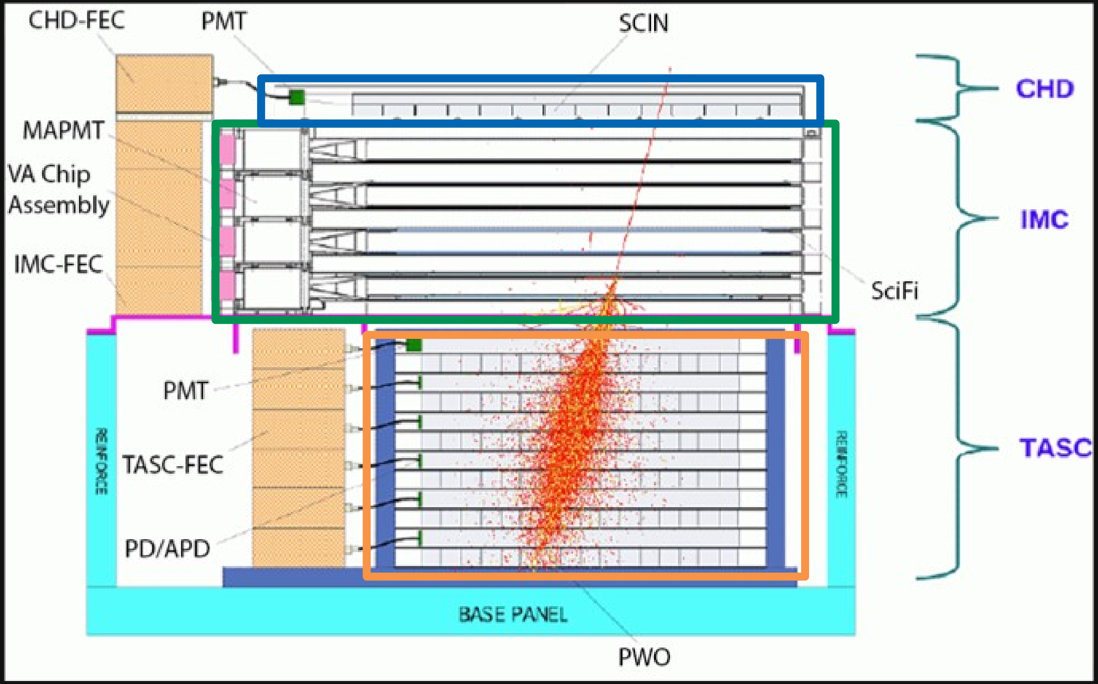
- Mass: 612.8kg
- Size: 1850 mm (L) x 800 mm (W) x 1000 mm (H)
- Power Consumption: 507 W (max)
- Telemetry: Medium (Low) 600 (50) kbps (6.5GB/day)

CALET started scientific observations on Oct. 13th, 2015

More than 2.7 billion events collected so far.

The CALET instrument

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



CHD: Charge DetectorCharge

- 14x2 plastic scintillator paddles
- Single element charge ID from *p* to *Fe* and above ($Z = 40$)
- Charge resolution: 0.15 *e (C)*, 0.35 *e (Fe)*

IMC: Imaging Calorimeter

- SciFi belts (8x2x448, 1mm^2) + Tungsten plates (7 layers: $3X_0 = 0.2\ X_0 \times 5 + 1.0\ X_0 \times 2$)
- Track reconstruction and particle ID (up to $Z = 14$), shower imaging
- Angular resolution: ~ 0.1°, Spatial resolution on top CHD: ~200 µm

TASC: Total absorption calorimeter

- 16 x 12 PWO logs: 27 X_0 (for e^-), 1.2 λ_I (for *p*)
- Energy measurement
- Energy resolution: ~ 2% for e^- γ (>10 GeV), ~30-35% for *p* and nuclei

Nuclei Observations with CALET

One of main Objectives:

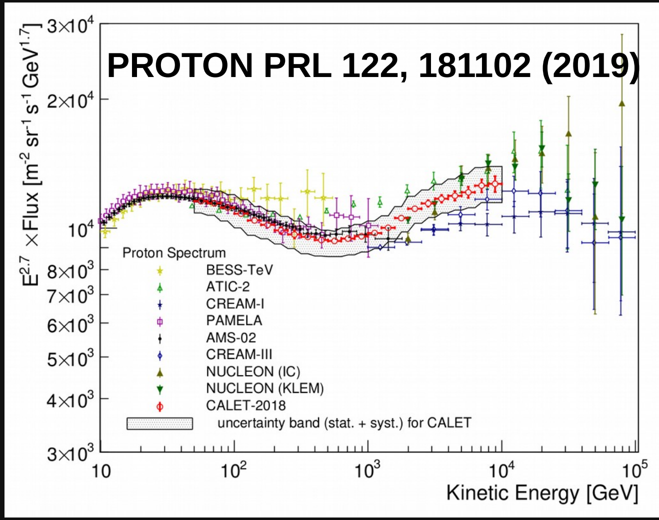
precise measurement of the transition region for each nuclear species and extension to TeV energy → Spectral hardening

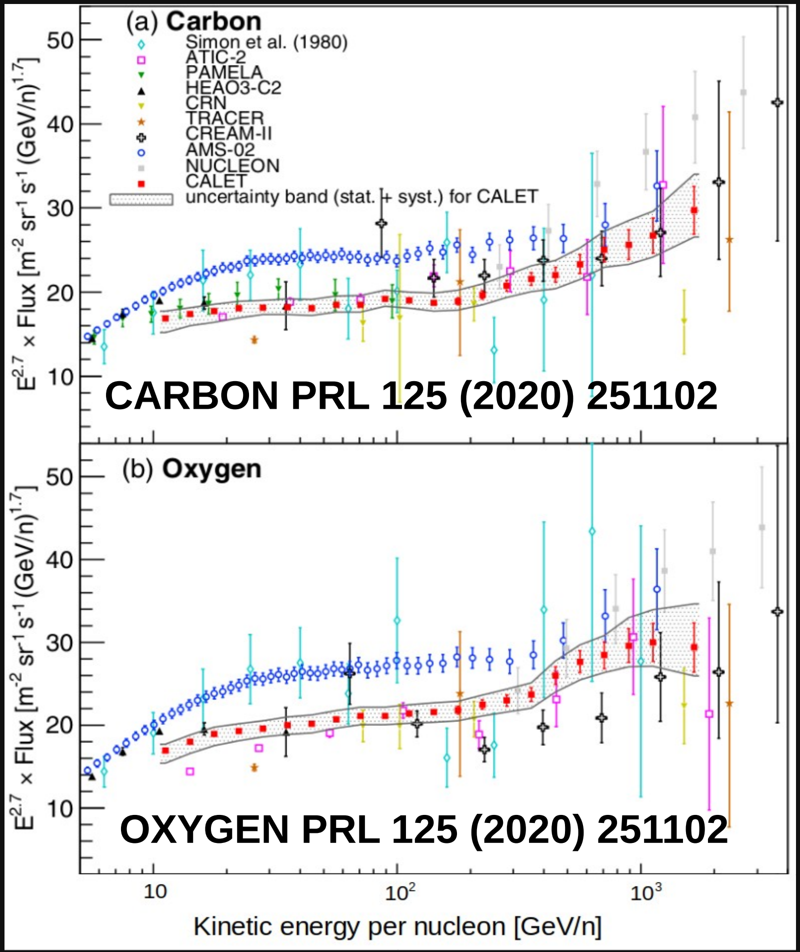
Wide dynamic range (1-10^6 MIP)

Large thickness (30 X_0 , ~1.3 λ_I)

Excellent charge ID (~0.2 *e*)

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



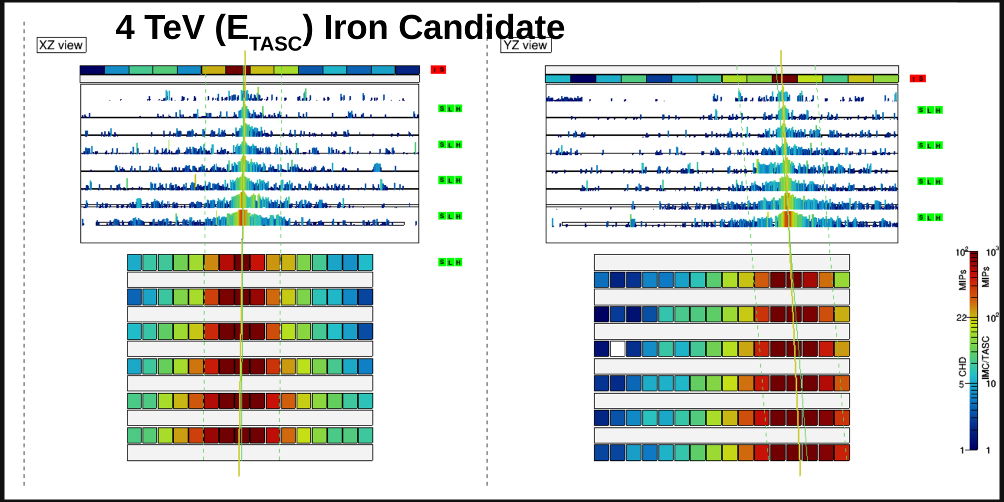


Energy spectra of proton, C and O indicate the spectral hardening at a few 100 GeV/n, what about iron?

Selection of Iron Events

Analysed calibrated flight data from Jan. 2016 to May 2020:

- 1613 days
- LiveTime: 3.3 x 10^4 hours
- 85.8% observation time



MC simulations

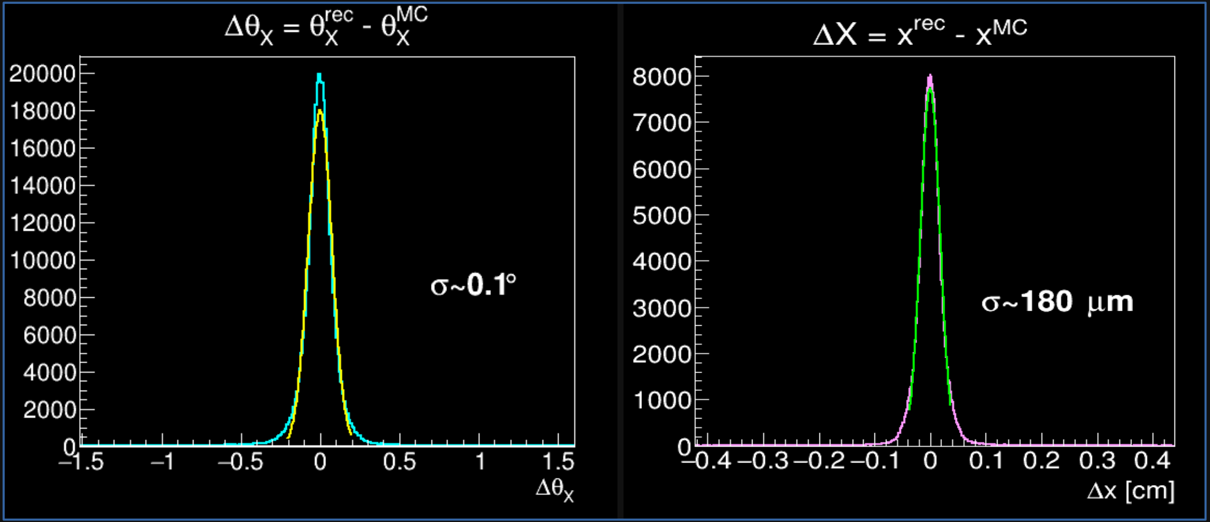
- Two independent MC simulations of the apparatus based on EPICS and FLUKA (w/ DPMJET-III)
- Digitization of signals and energy response tuned through beam test
- MC is used to estimate tracking and selection efficiencies and to determine the response ("smearing") matrix

Selection criteria

1) HE shower trigger
2) Shower event selection: selects interacting particles
3) IMC reconstructed track
4) Acceptance Cut: selects events crossing the detector from top CHD to bottom TASC within 2 cm from the edge
5) Charge Consistency Cut: removes charge-changing particles in the upper part of the detector
6) Charge ID with CHD

Tracking:

based on a combinatorial Kalman Filter that exploits the fine granularity of IMC to reconstruct tracks with high precision



Tracking provides:

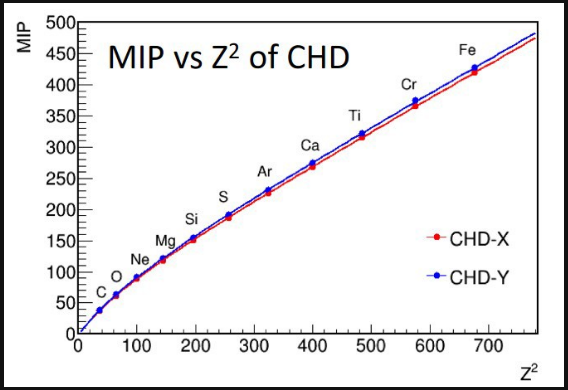
- Cosmic ray arrival direction
- Geometrical acceptance
- CHD paddles and IMC fibers crossed by the track (for charge ID)

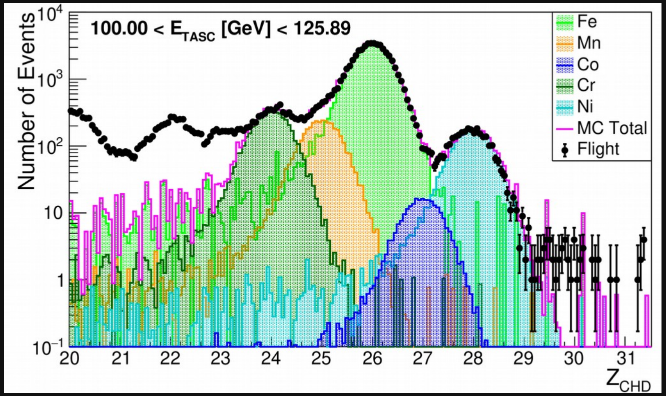
Iron performance:

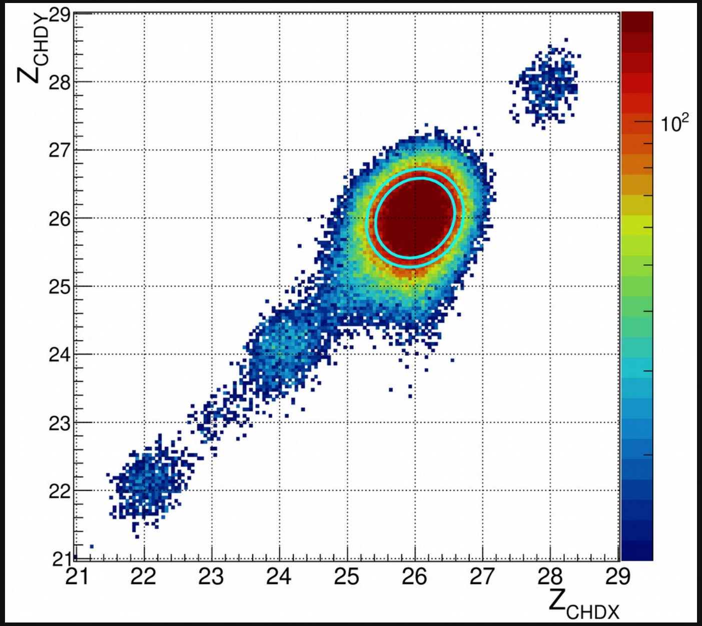
- Angular resolution: ~0.1°
- Spatial resolution on top CHD: ~180 μm

Charge Identification

The charge Z is recostructed by measuring the ionization deposits in the CHD.







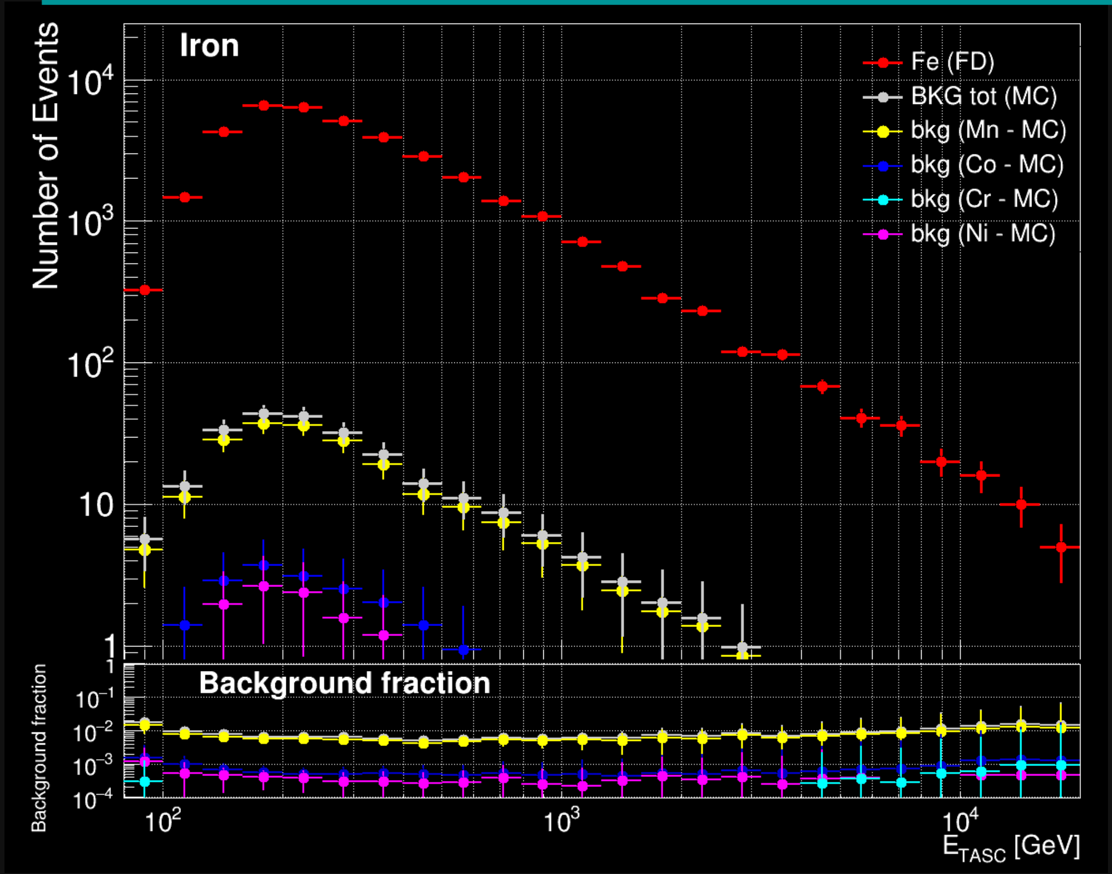
Non linear response to Z^2 due to the quenching effect in the scintillators is corrected using a "halo" model.

- ✔ In order to remove background events interacting in CHD the Charge Consistency Cut is applied: $|Z_{CHDX}-Z_{CHDY}|<1.5$
- ✔ Charge resolution σ_Z for iron $0.35e$.

Iron events are selected within an ellipse centered at $Z = 26$, with $1.25\ \sigma_x$ and $1.25\ \sigma_y$ wide semiaxes for Z_{CHDX} and Z_{CHDY}, respectively, and rotated clockwise by 45°

Iron candidates and background estimation

dN/dE_{dep} for iron and its neighbours after the selections



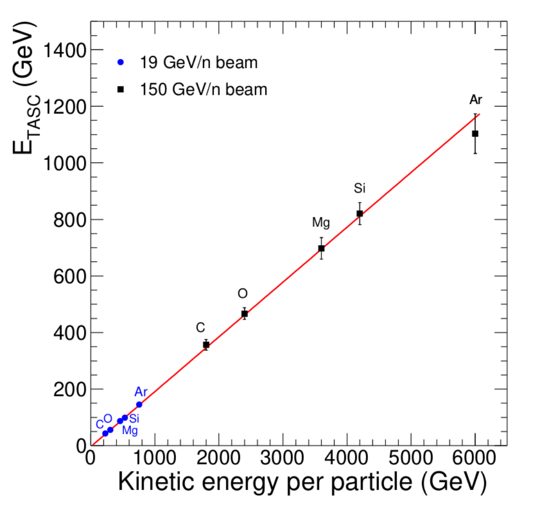
The iron most dominant source of contamination is given by neighbour nuclei misidentified as Fe.

- The number of contaminating events is estimated by MC simulation
- The total contamination is few percent in all energy bins and it is subtracted from the iron sample before doing the unfolding.

Energy measurement and Unfolding

Beam Test Calibration (CERN-SPS in 2015):

- ✔ MC energy tuning with beams of accelerated ion fragments (A/Z = 2) of 150 GeV/c/n.
- ✔ Good linearity up to maximum available beam energy (~6 TeV)
- ✔ Fraction of particle energy released in TASC is ~20%
- ✔ Energy resolution 30-35%



Correction:

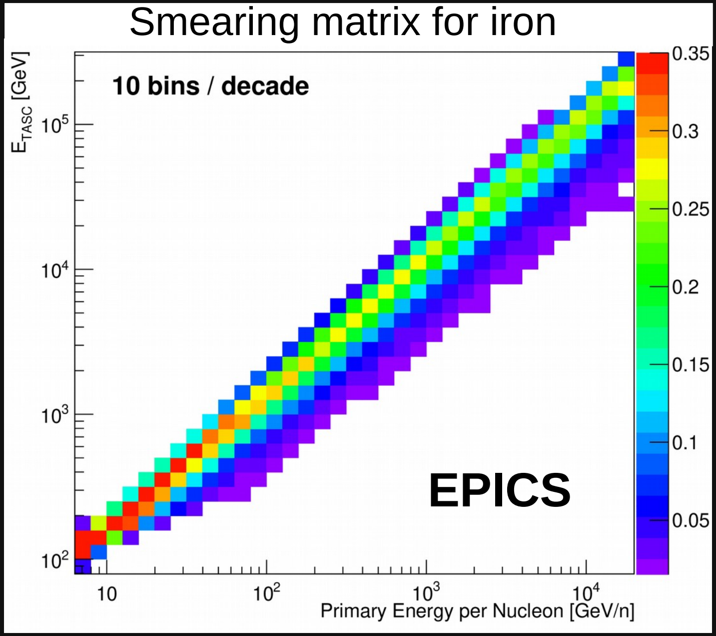
➔ 6.7% for $E_{TASC} < 45$ GeV;

➔ 3.5% for $E_{TASC} \geq 350$ GeV;

➔ linear interpolation for $45 \leq E_{TASC} < 350$ GeV

Energy unfolding:

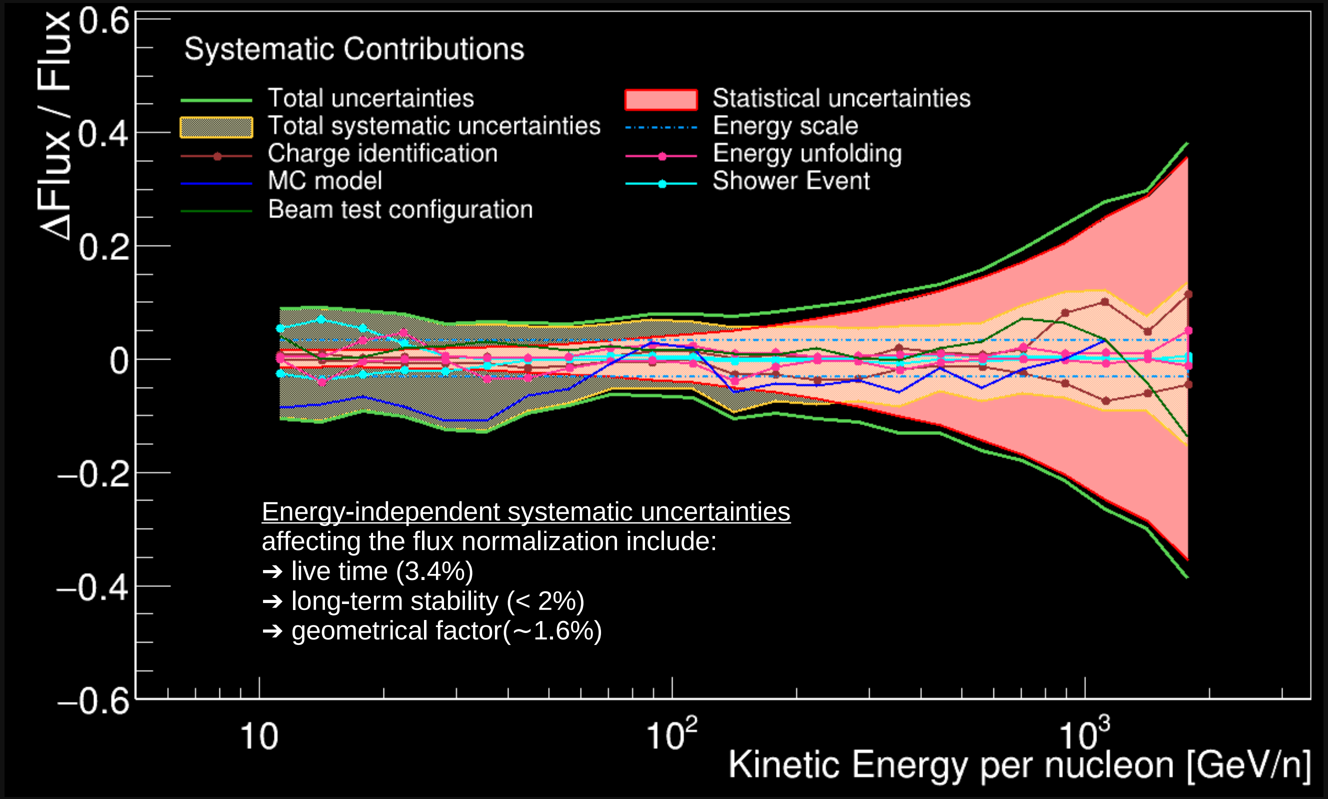
applied to correct for bin-to-bin migration effect and obtain primary energy spectrum



The smearing matrix is computed using Epics MC. The unfolding is performed by an iterative method based on the Bayes theorem.

The systematic uncertainties

Breakdown of systematic uncertainties



Energy Dependent:

- Charge identification
- Energy scale correction
- Unfolding
- MC model
- Shower Event
- Beam Test configuration

Energy Independent:

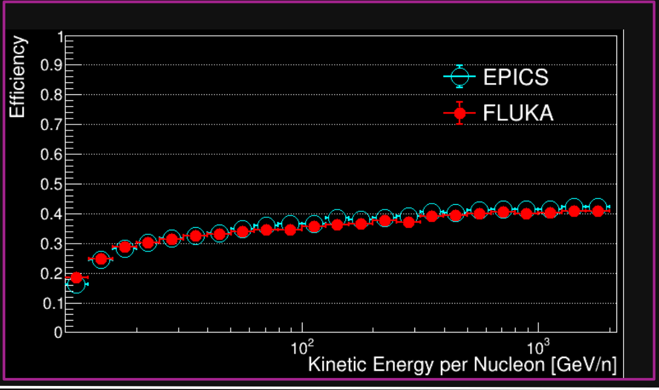
- Live Time
- Long Term stability
- Geometrical factor

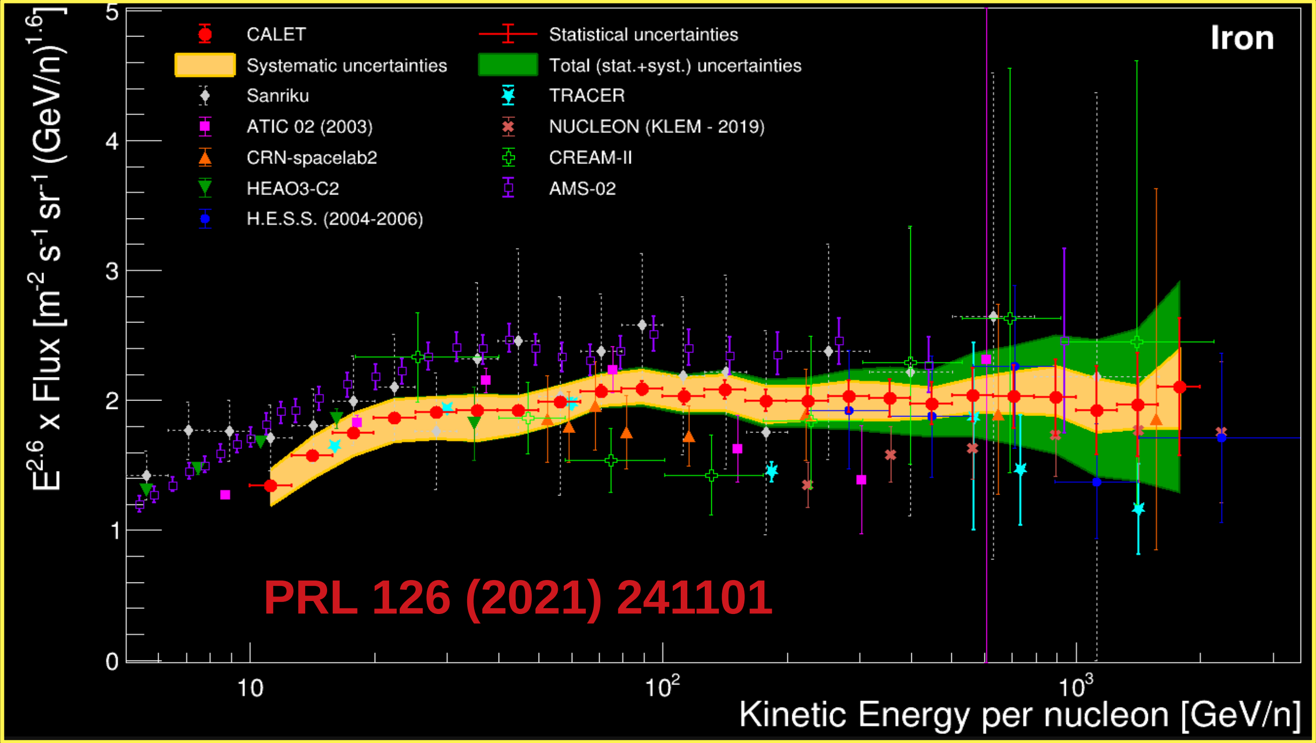
The iron flux

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

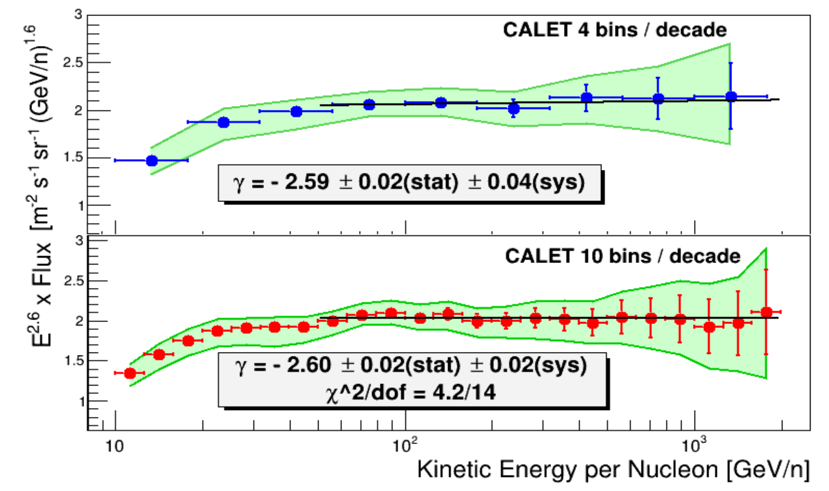
$$N(E) = U\left[N_{obs}(E_{\mathrm{TASC}}) - N_{bg}(E_{\mathrm{TASC}})\right]$$

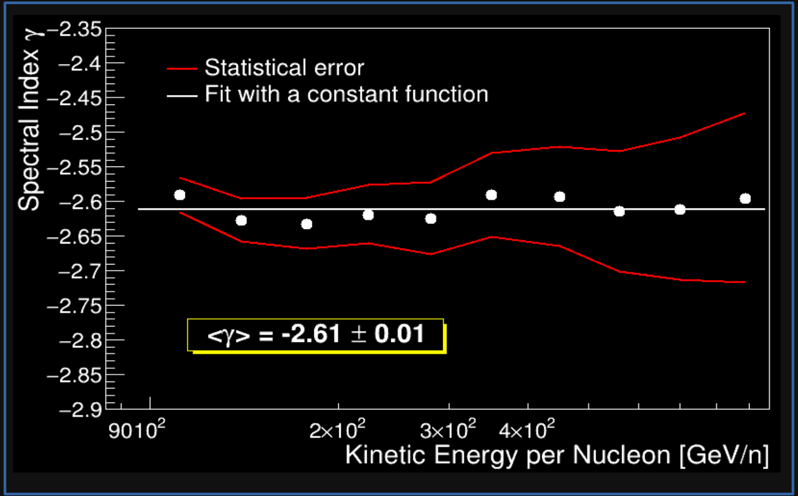
- N_{obs}: observed events in each bin of E_{TASC}
- N_{bg}: contaminating events in each bin of E_{TASC}
- U: unfolding operator
- ΔE: bin width
- ε(E): global efficiency
- SΩ: geometrical factor (~416 cm² sr)
- T: total live time (3.3 x 10^4 h)





Spectral Index





Fitting function from 50 GeV/n to 2 TeV/n (single power law:)

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

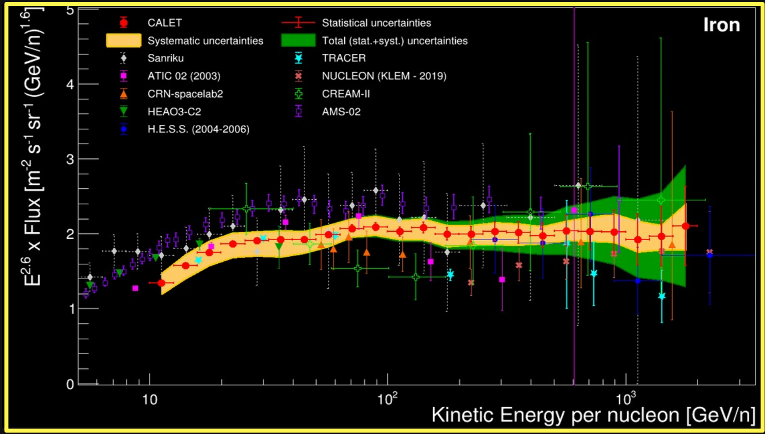
To study the energy dependence of the spectral index in a model independent way, the spectral index is calculated by a fit of

$$\gamma = \frac{d[\log(\Phi)]}{d[\log(E)]}$$

in energy windows centered in each bin and including the neighbor ± 3 bins.

The iron flux above 50 GeV/n is compatible within the errors with a single power law.

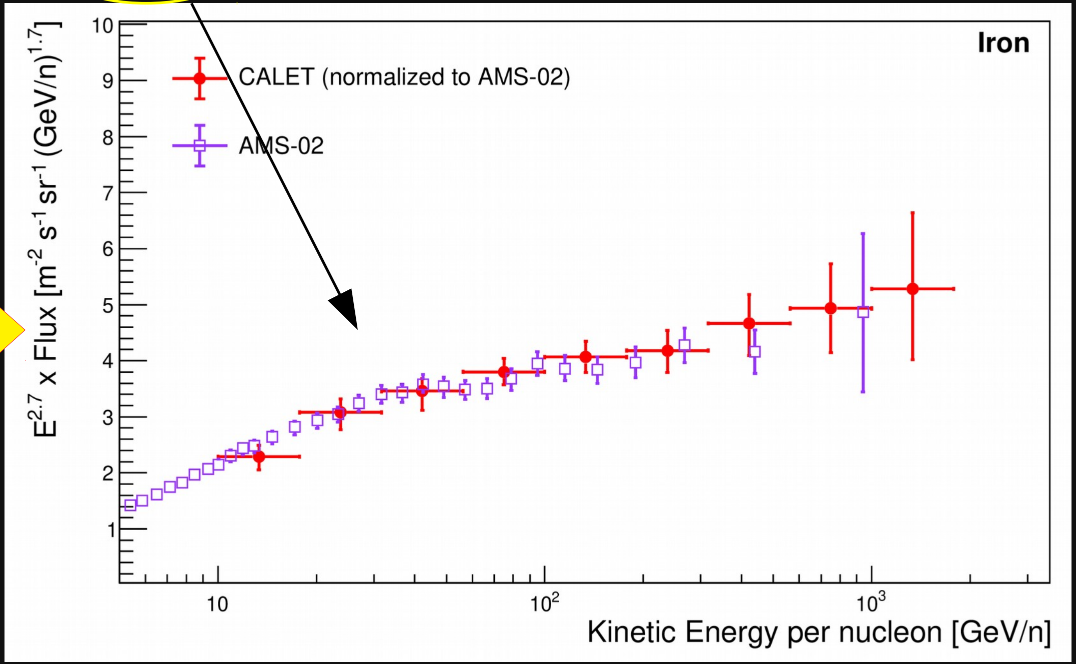
A comment on normalization and spectral shape



- Good agreement between CALET and ATIC, Tracer, HESS and CRN
- Different normalization with respect to NUCLEON and AMS.

Here CALET has been multiplied by 1.20 to adjust to AMS normalization

Also, the spectrum has been multiplied by $E^{2.7}$



Conclusions

- CALET measured the iron flux between 10 GeV/n and 2 TeV/n with significantly better precision than most of existing measurements
- The spectrum is compatible with a single power law above 50 GeV/n with a spectral index of -2.60 ± 0.03
- The uncertainties given by our present statistics and large systematics do not allow us to draw a significant conclusion on a possible deviation from a single power law.
- This measure is consistent within the uncertainty error band, both in spectral shape and in normalization with other available measurements. However there is a difference in normalization with respect to AMS-02 by ~20%
- Systematic checks for possible causes on this normalization issue are under study.

Thank you!