飛翔体観測(CALET)による高エネルギー宇宙線加速天体の研究

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CALET

令和四年度東京大学宇宙線研究所共同利用研究成果発表会

共同利用研究概要 (2022)

- 共同研究内容
  - CALET観測最適化のためのシミュレーション計算及びデータ解析
- 発表概要
  - CALET概要
  - 観測現状
  - 観測データ解析
  - まとめと展望
- 予算: 旅費 190千円 ➡ 全額繰越予定
- 共同利用: 計算機(シミュレーション計算)

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		弘前大学	市村雅一
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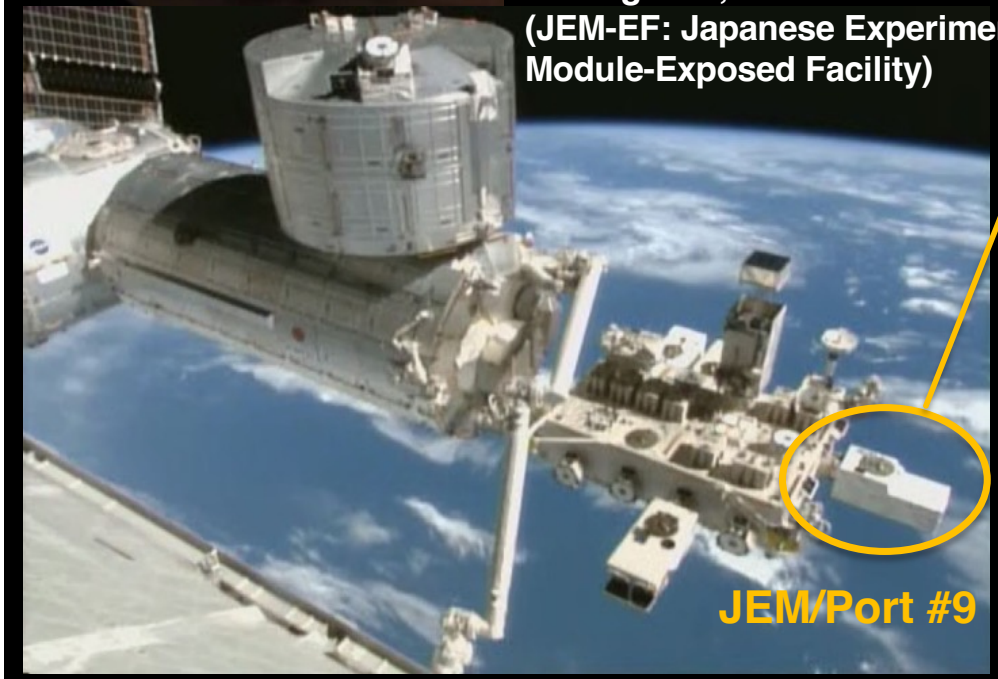
神奈川大学	田村忠久, 清水雄輝	茨木高専	三宅晶子
立命館大学	森正樹	大阪公立大学	常定芳基
横浜国立大学	片寄祐作	NASA/GSFC	Nick Cannady
ルイジアナ州立大学	川久保裕太	INFN-Pisa	Pier Marrocchesi

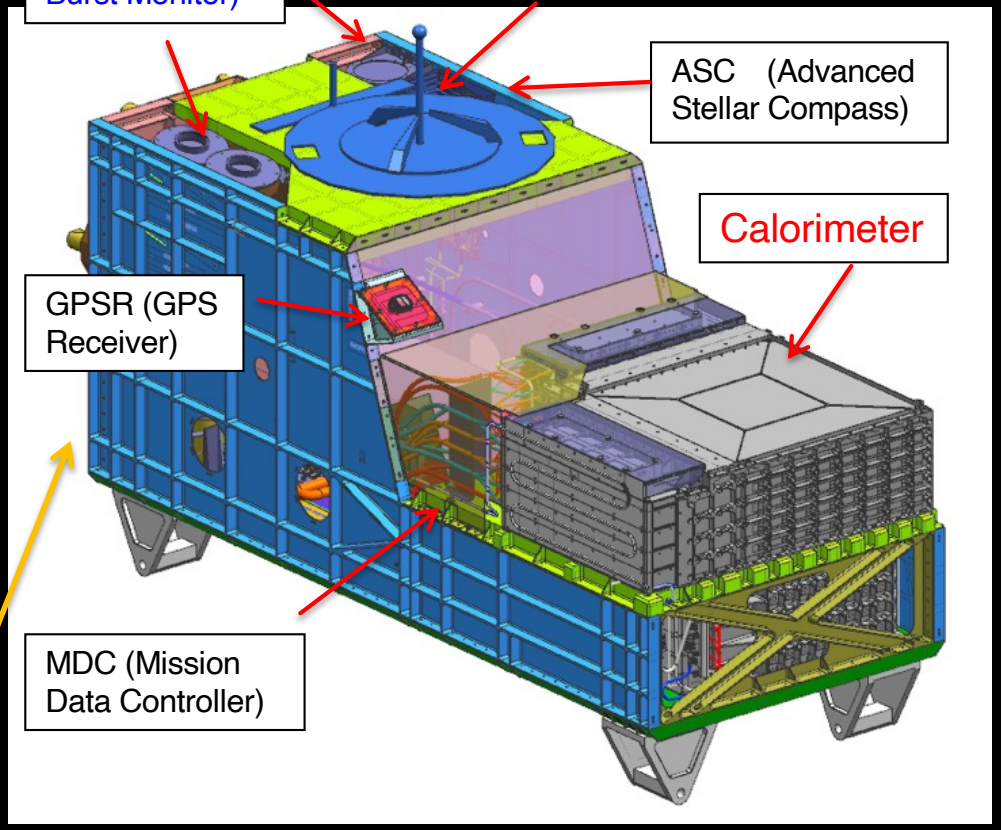
CALET Payload

Kounotori (HTV) 5

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

Emplaced on JEM-EF port #9 on Aug. 25th, 2015 (JEM-EF: Japanese Experiment Module-Exposed Facility)





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

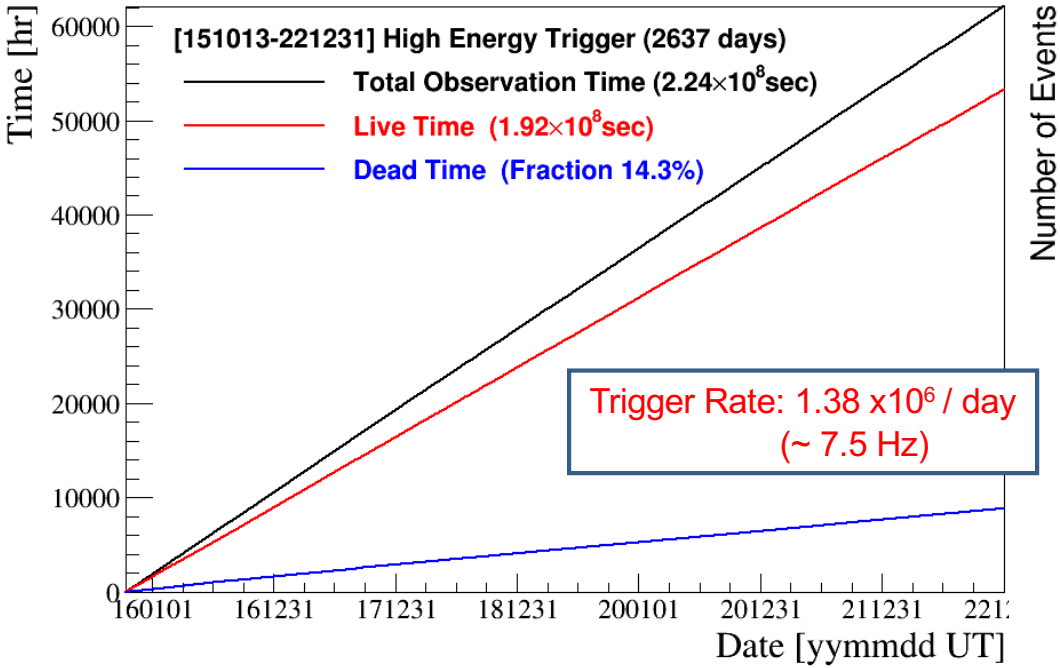
Observations with High Energy Trigger (>10GeV)

Observation by High Energy Trigger for 2,673 day : Oct.13, 2015 – Dec. 31, 2022

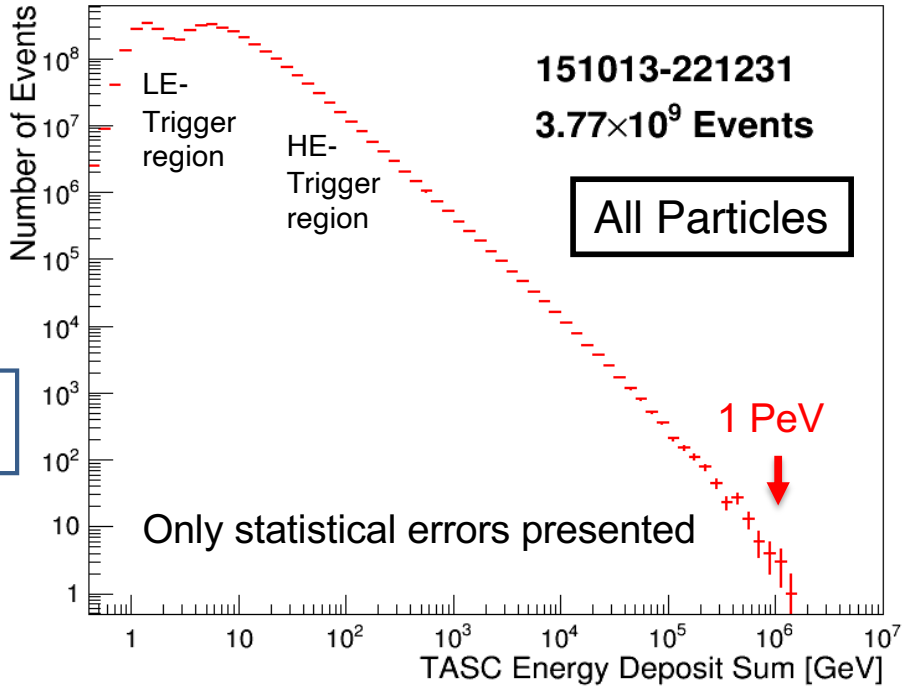
Over 7-year observation has been achieved !!

- The exposure, SΩT, has reached to ~230 m^2 sr day for electron observations by continuous and stable operations.
- Event number of HE triggered events (>10 GeV) is ~1.73 billion with a live time fraction of about 86 %. Total event number triggered over 1 GeV is ~3.77 billion.

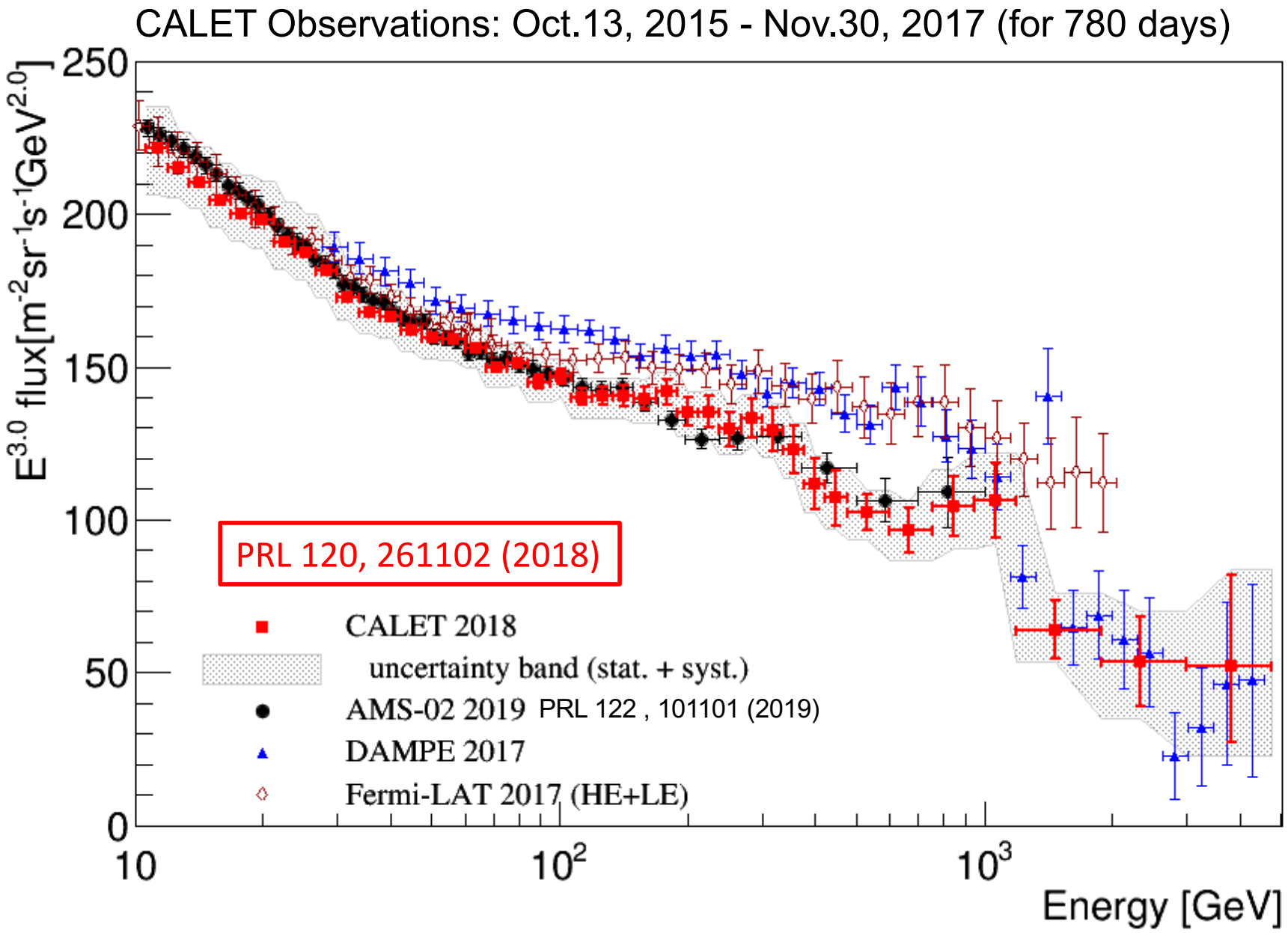
Accumulated observation time (live, dead)



Distribution of deposit energies (ΔE) in TASC

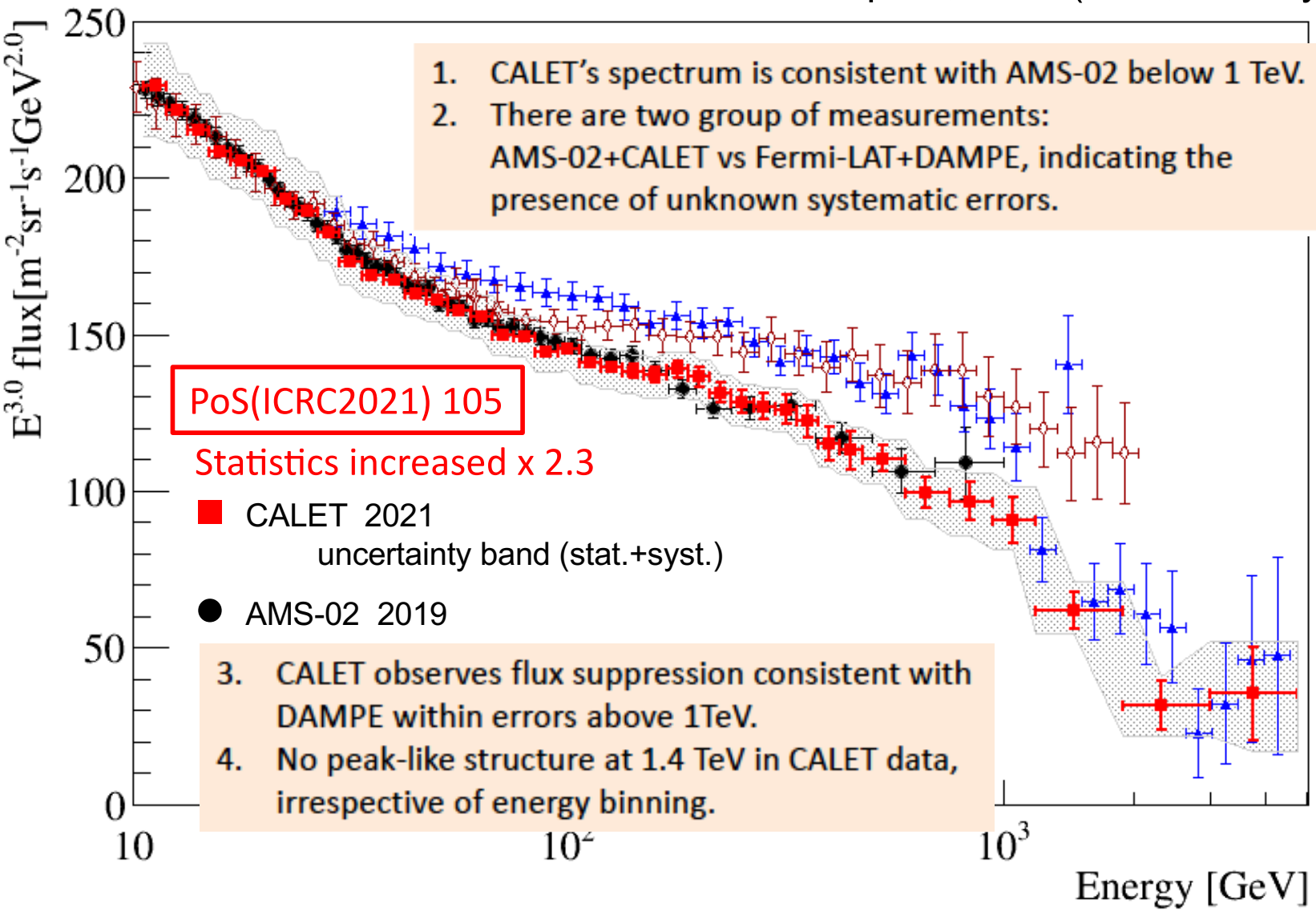


Electron Spectrum

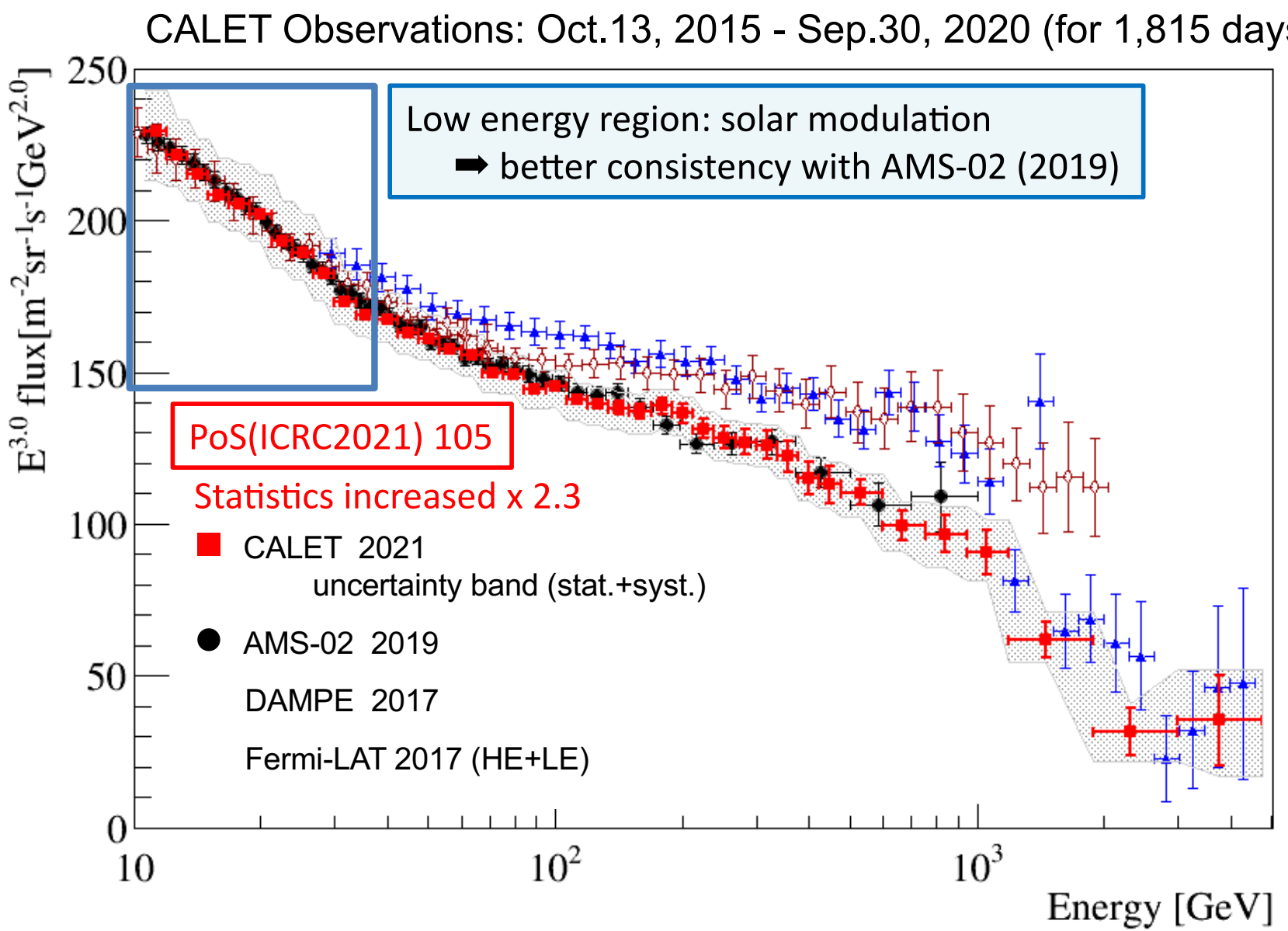


Electron Spectrum

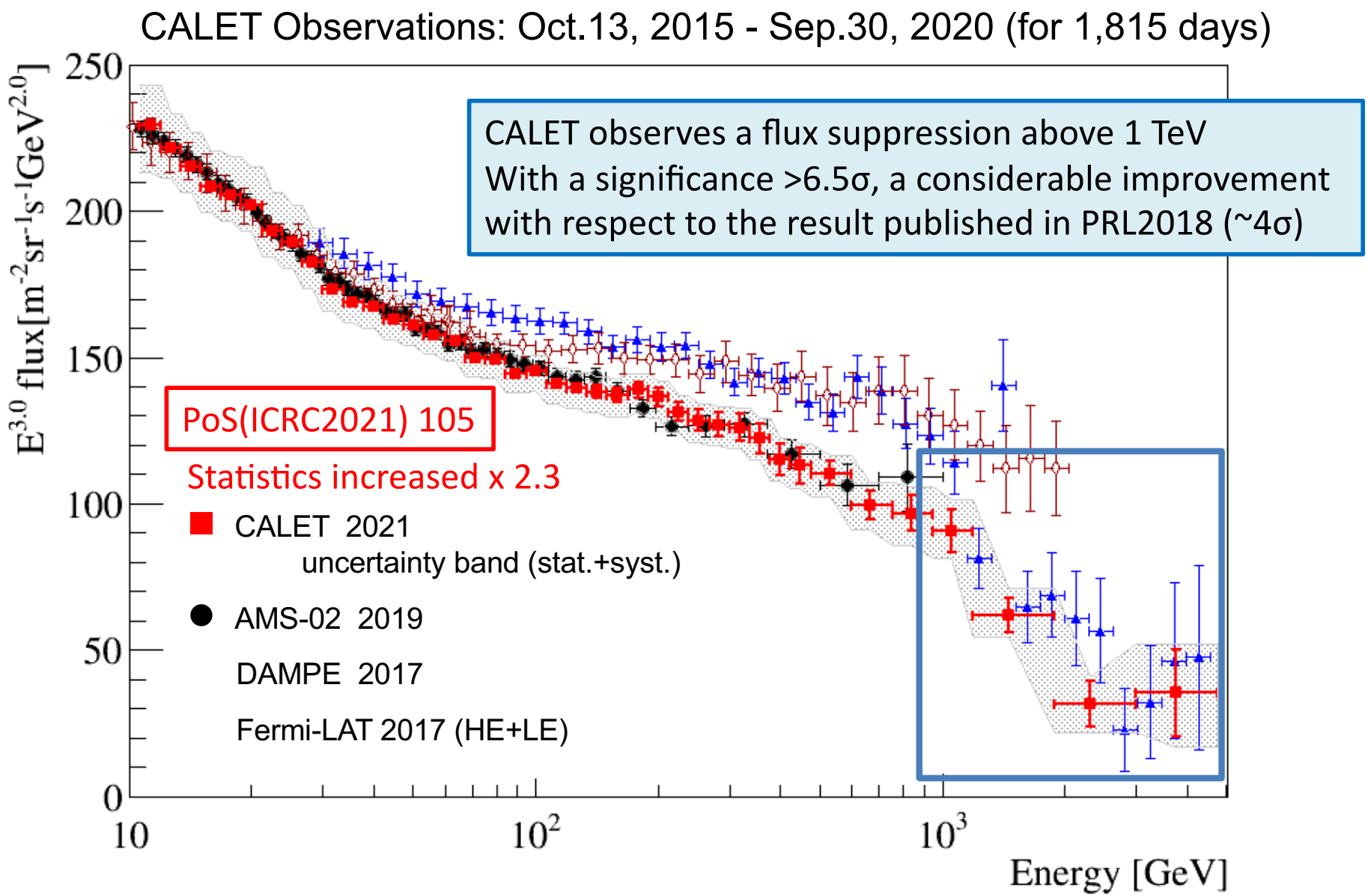
CALET Observations: Oct.13, 2015 - Sep.30, 2020 (for 1,815 days)



Electron Spectrum



Electron Spectrum

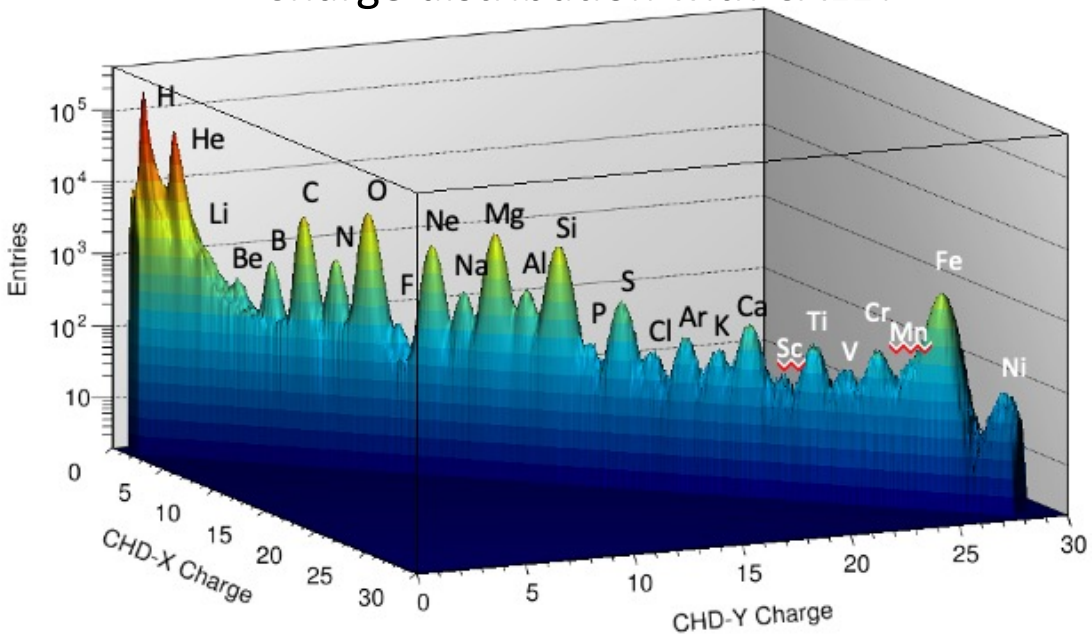


Publications of Nuclei Spectra by CALET

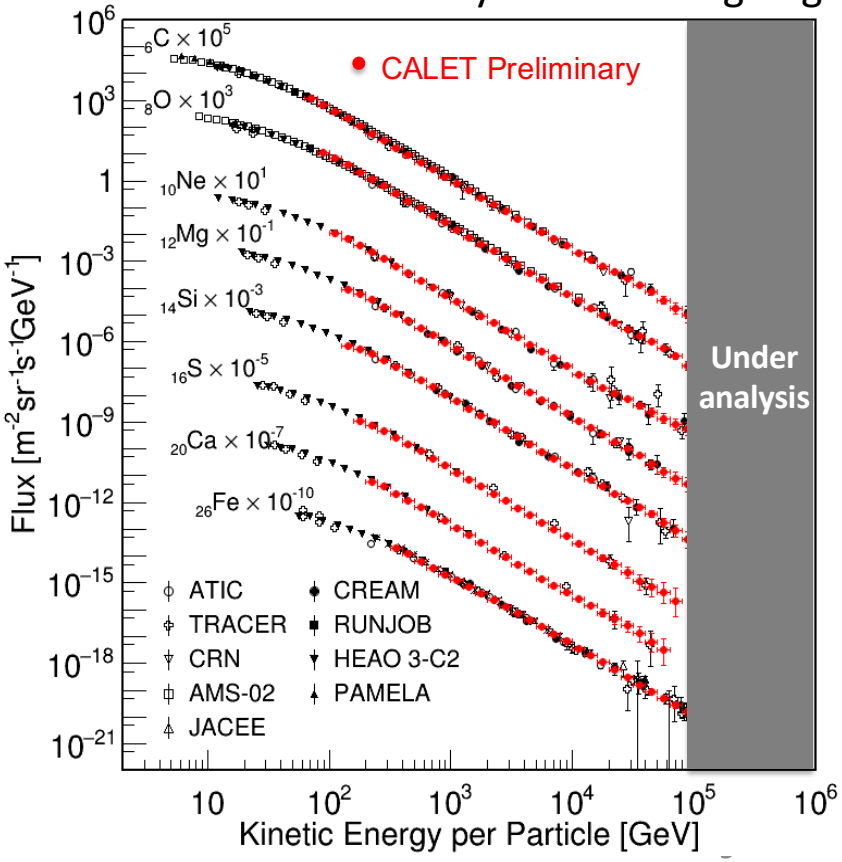
CALET is exploring the Table of Elements in the multi-TeV domain
with excellent charge-ID of individual elements

Proton: PRL **122** 181102 (2019)
PRL **129** 101102 (2022) New!
C, O and C/O: PRL **125** 251102 (2020)
Fe: PRL **126** 241101 (2021)
Ni and Ni/Fe: PRL **128** 131103 (2022) New!
B and B/C: PRL **129** 251103 (2022) New!

Charge distribution with CALET

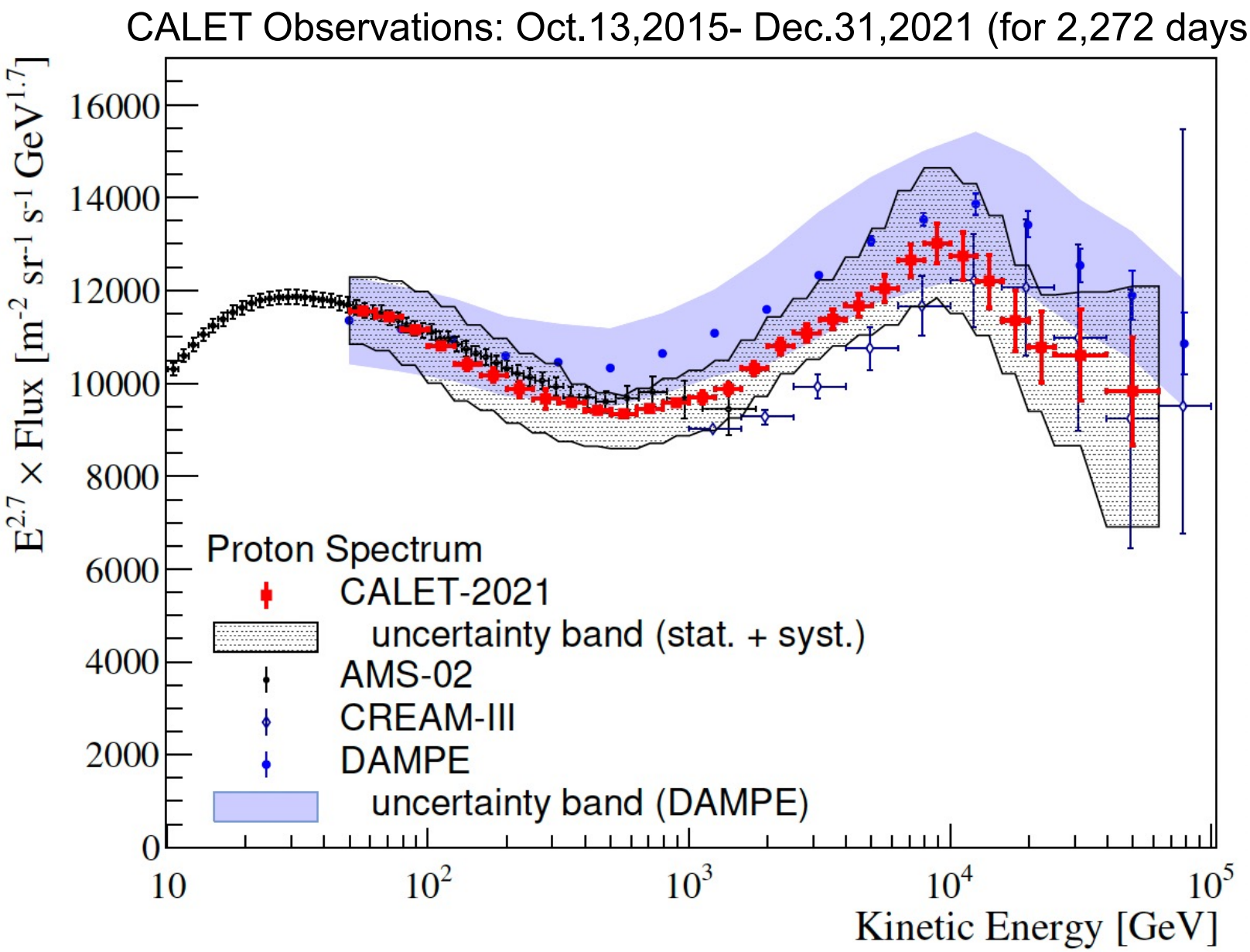


Other nuclei analysis is now ongoing



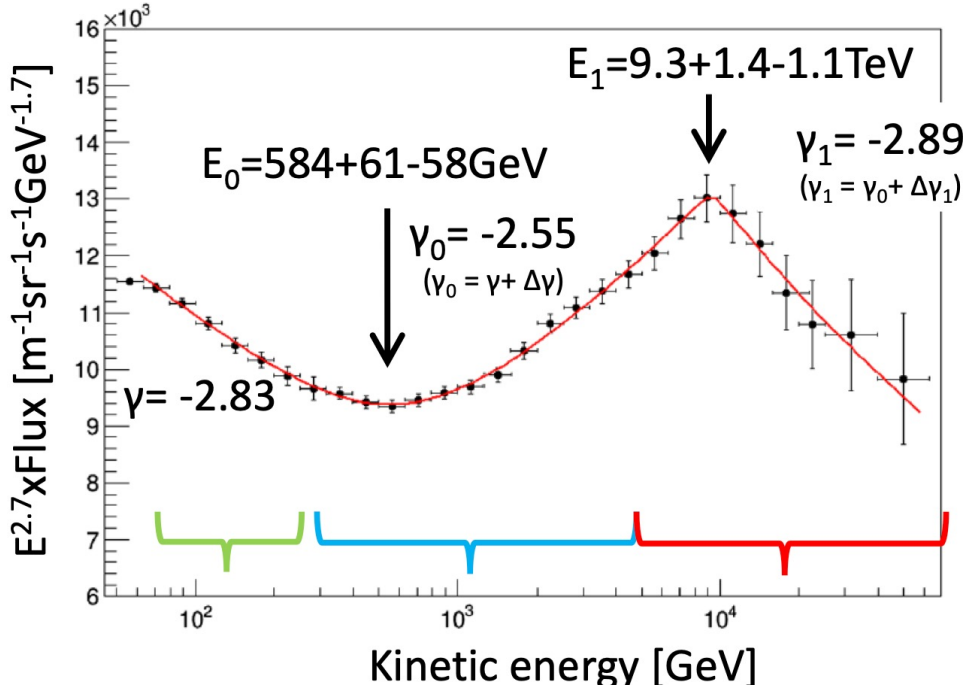
Proton Spectrum

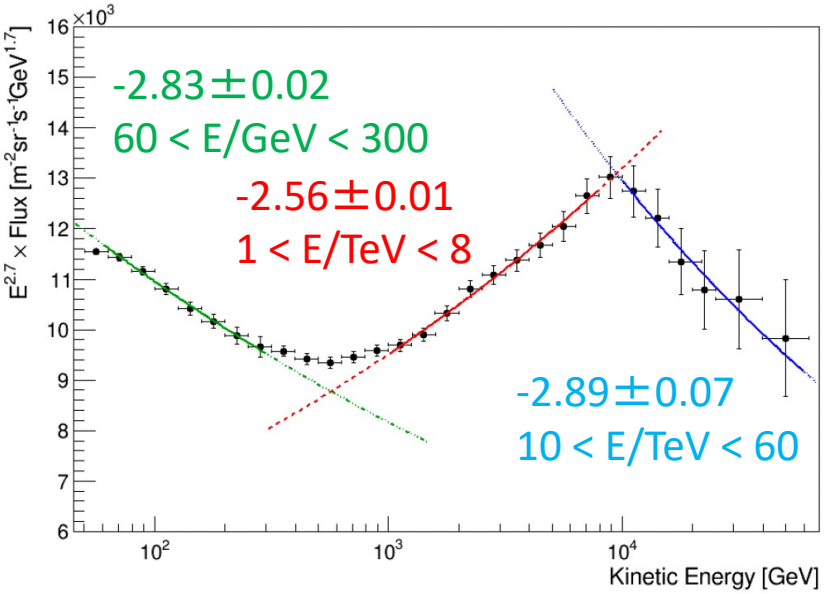
PRL 129, 101102 (2022)



Proton spectral index

PRL 129, 101102 (2022)

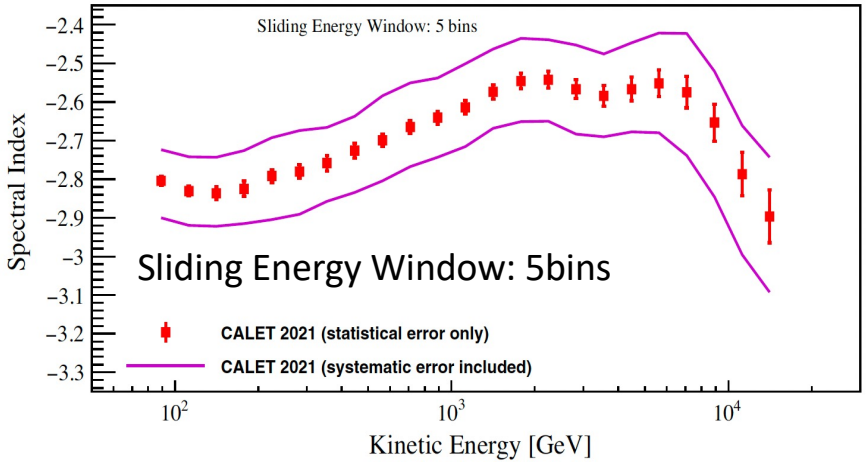




Fitting function (double broken power law):

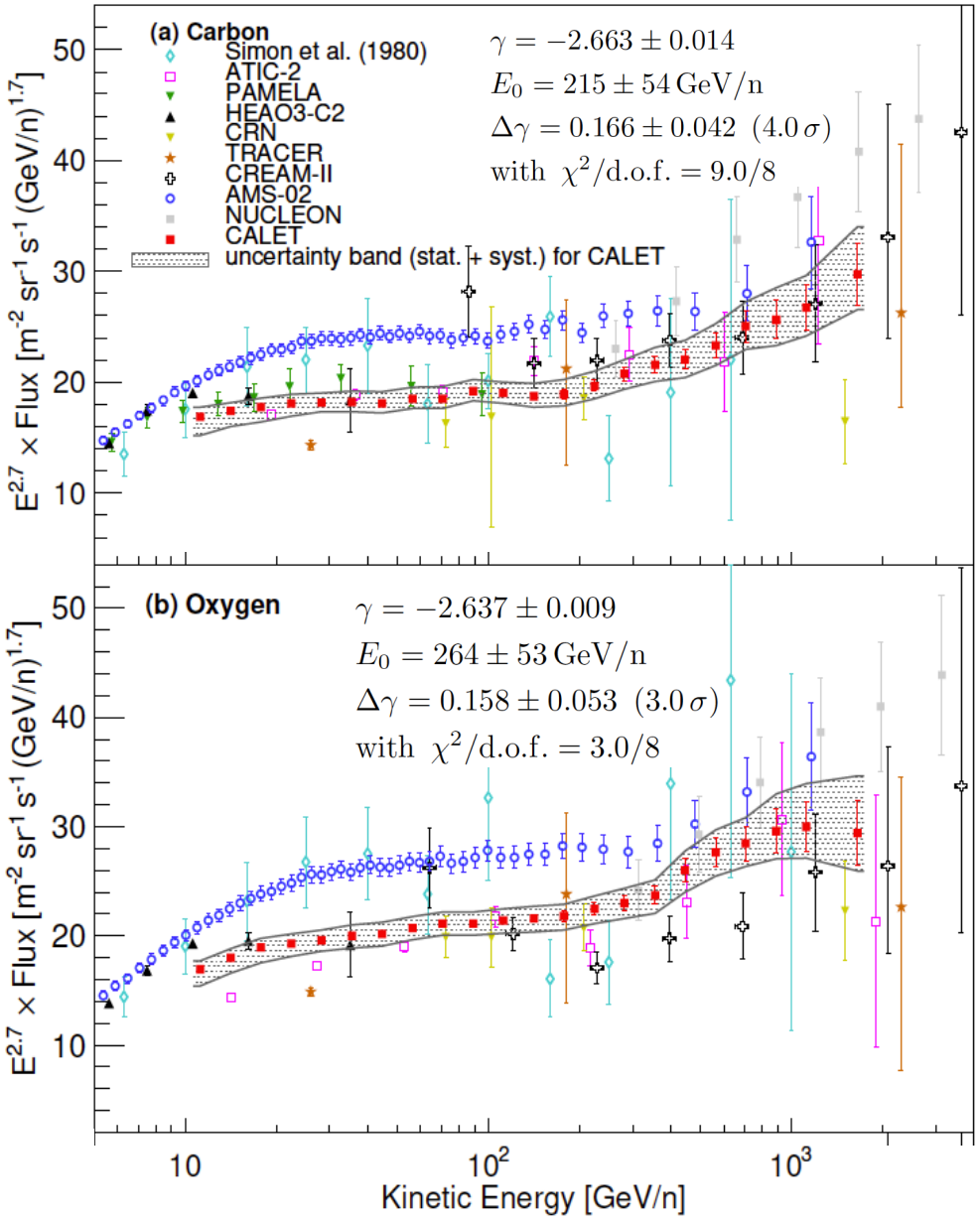
$$\Phi = E^{2.7} \times C \times \left(\frac{E}{1}\right)^{\gamma} \times \left(1+\left(\frac{E}{E_0}\right)^{s}\right)^{\frac{\Delta\gamma}{s}} \times \left(1+\left(\frac{E}{E_1}\right)^{s_1}\right)^{\frac{\Delta\gamma_1}{s_1}}$$

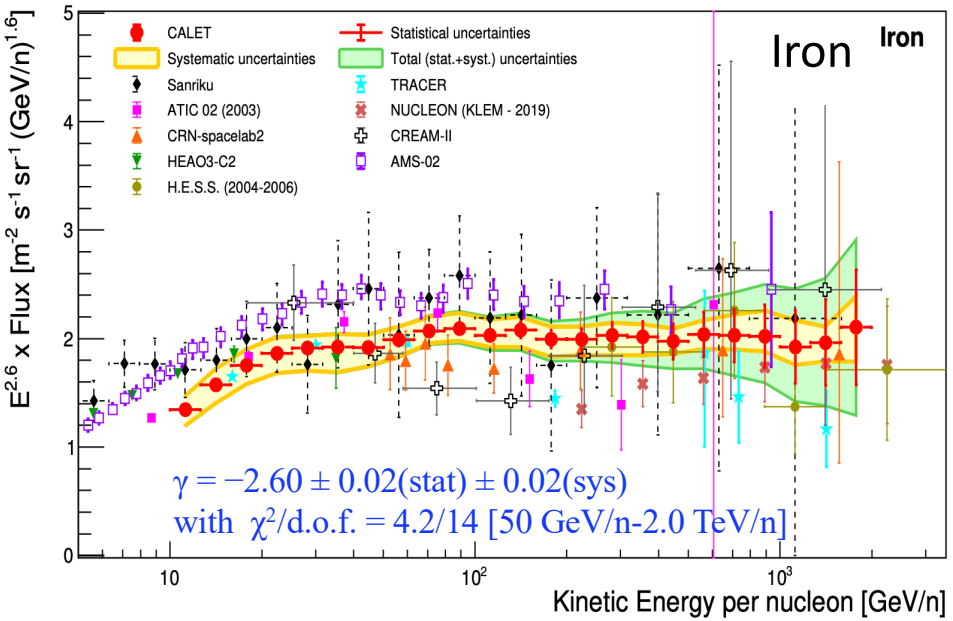
Low energy hardening softening



C, O and Fe spectra

PRL **125** 251102 (2020)
PRL **126** 241101 (2021)

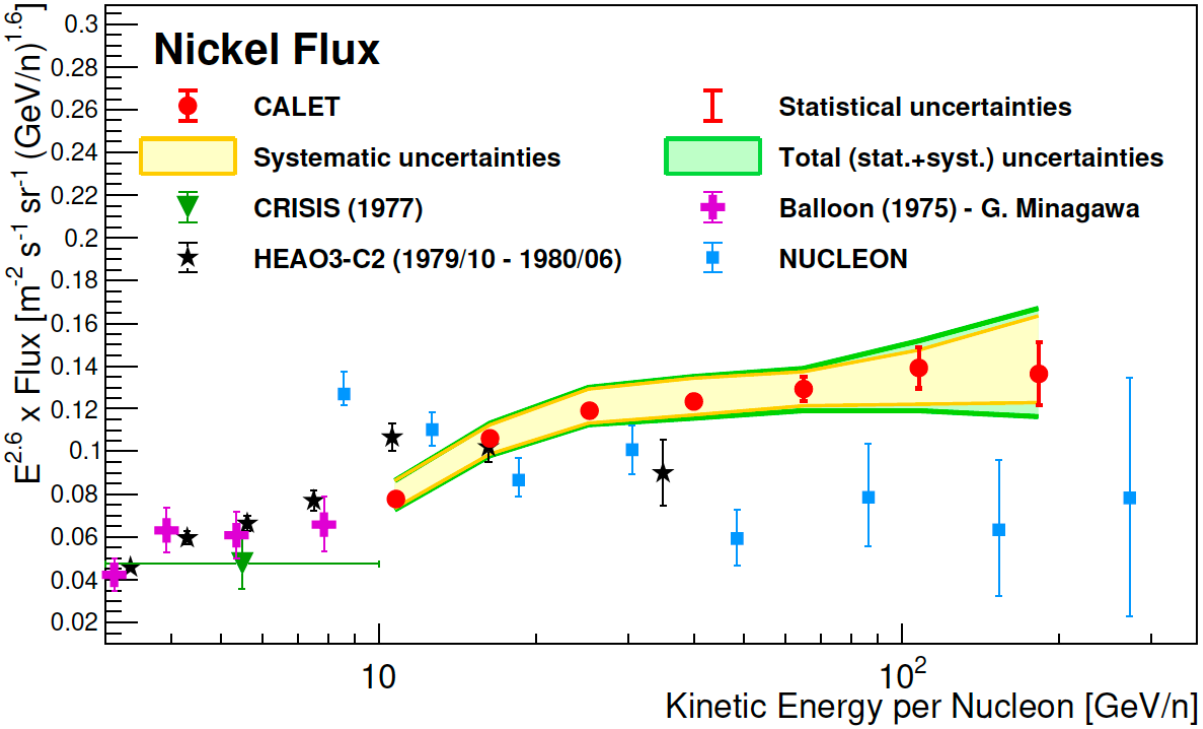


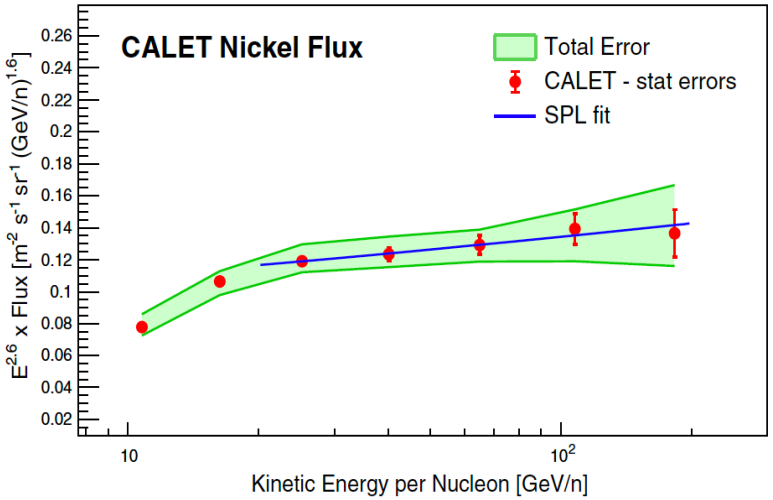


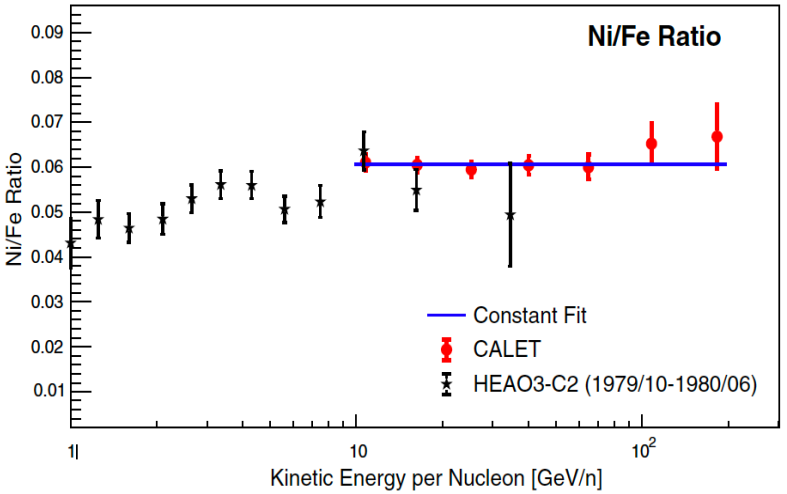
- C and O spectra indicate the spectral hardening
- Fe spectrum is compatible within the errors with a single power law

Nickel spectrum

PRL 128 131103 (2022)





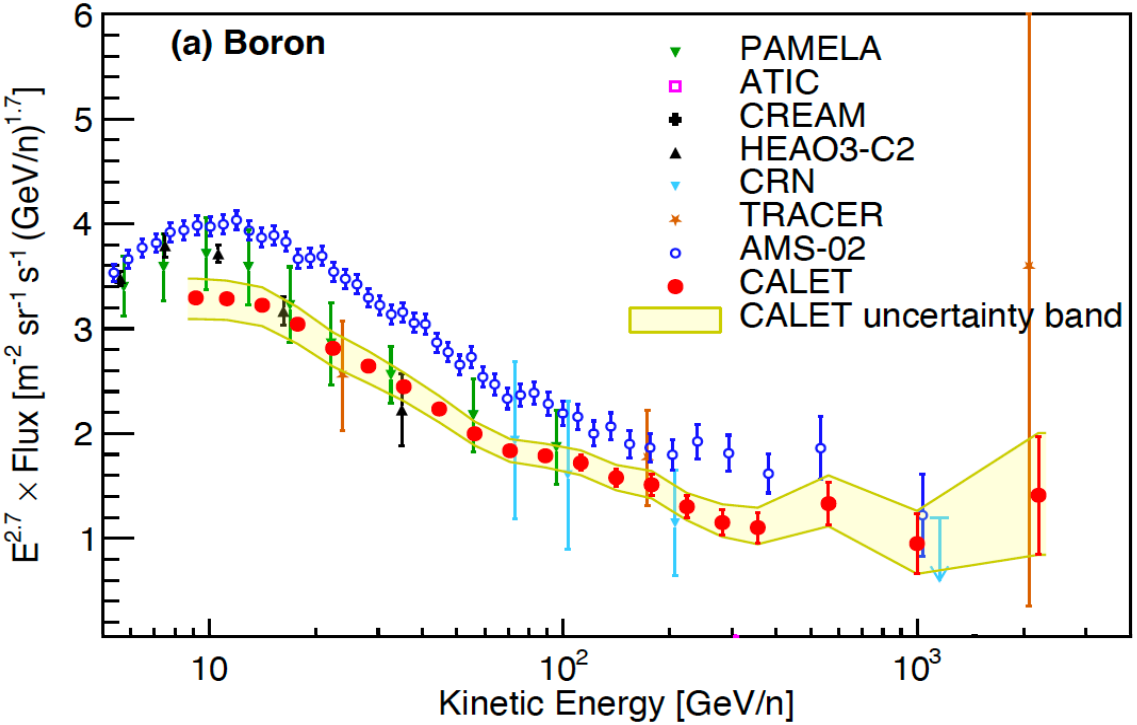


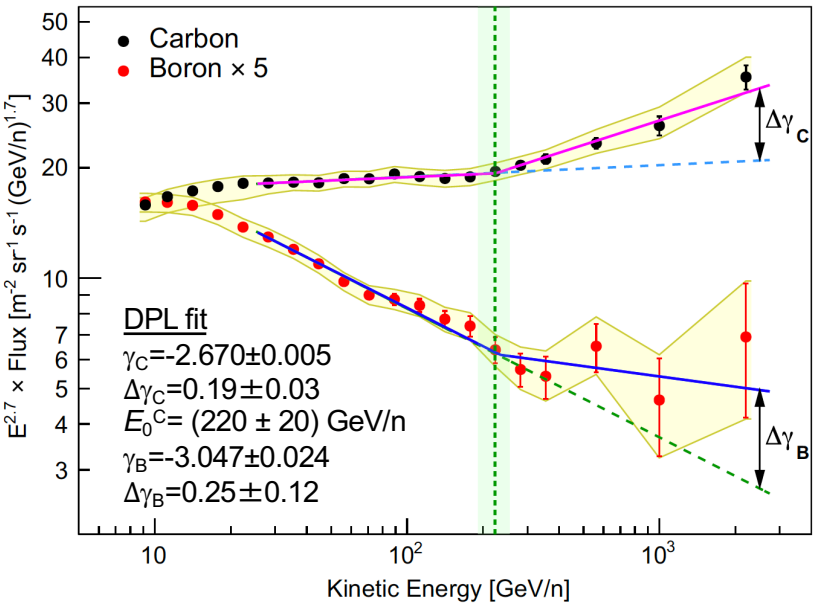
- Similar normalization with HEAO3-C2 and NUCLEON, through different spectral shape
- A single power-law fit:
  $\gamma = -2.51 \pm 0.07$ $E > 20$ GeV/n
- Ni/Fe ratio gives a constant value;
  0.061 ± 0.001

The nickel flux, above 20 GeV/n, is compatible within the errors with a single power law

Boron spectrum

PRL 129 251103 (2022)



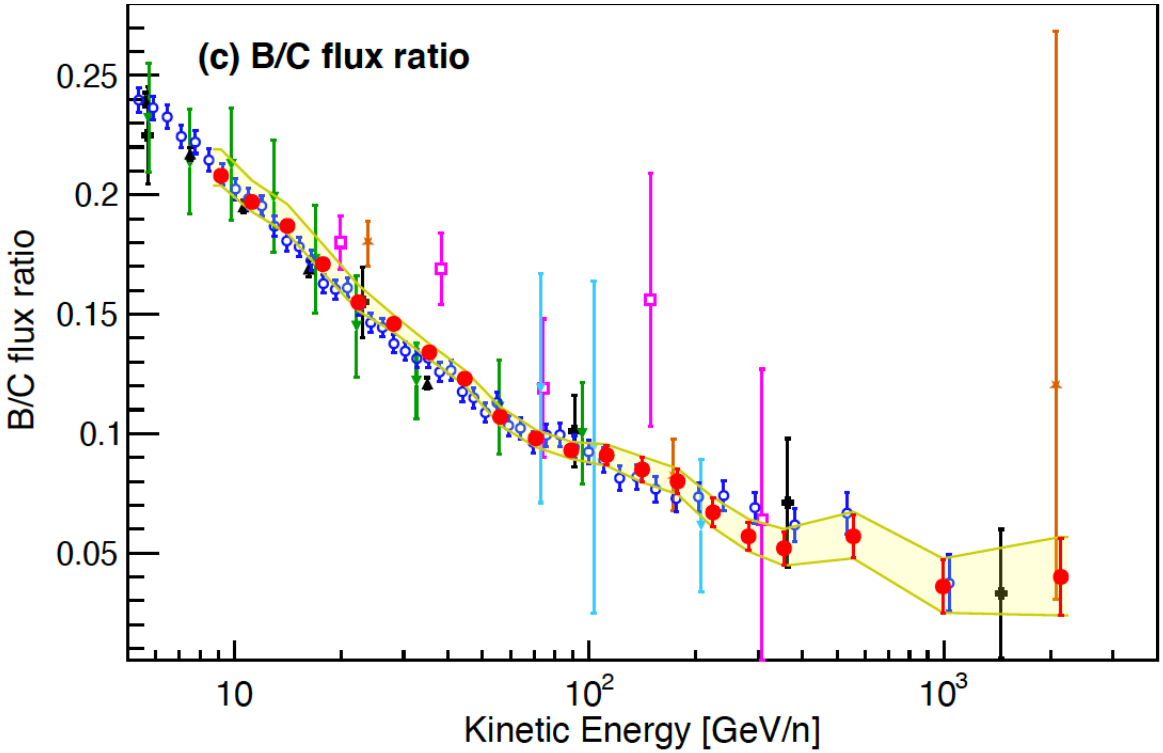


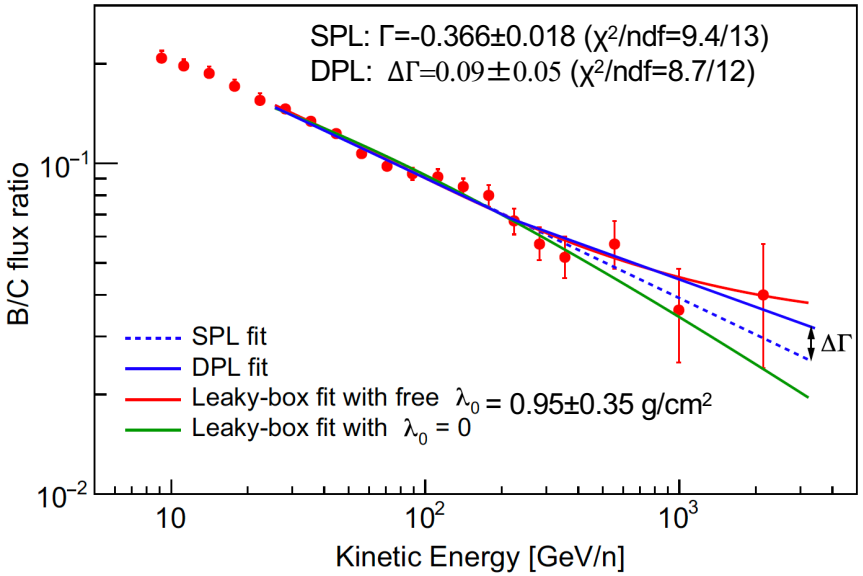
- The B spectrum is consistent with that of PAMELA and most of the earlier experiments, but the absolute normalization is in tension with that of AMS-02 like C, O and Fe fluxes.

The energy spectra are clearly different as expected for primary and secondary CRs, albeit with low statistical significance, that the flux hardens more for B than for C above 200GeV/n

Boron-to-carbon ratio PRL 129 251103 (2022)

Boron in cosmic rays are produced by the spallation reactions of primary CRs such as carbon
⇨ The B/C (primary-to-secondary) ratio includes a history of the propagation in the Galaxy.

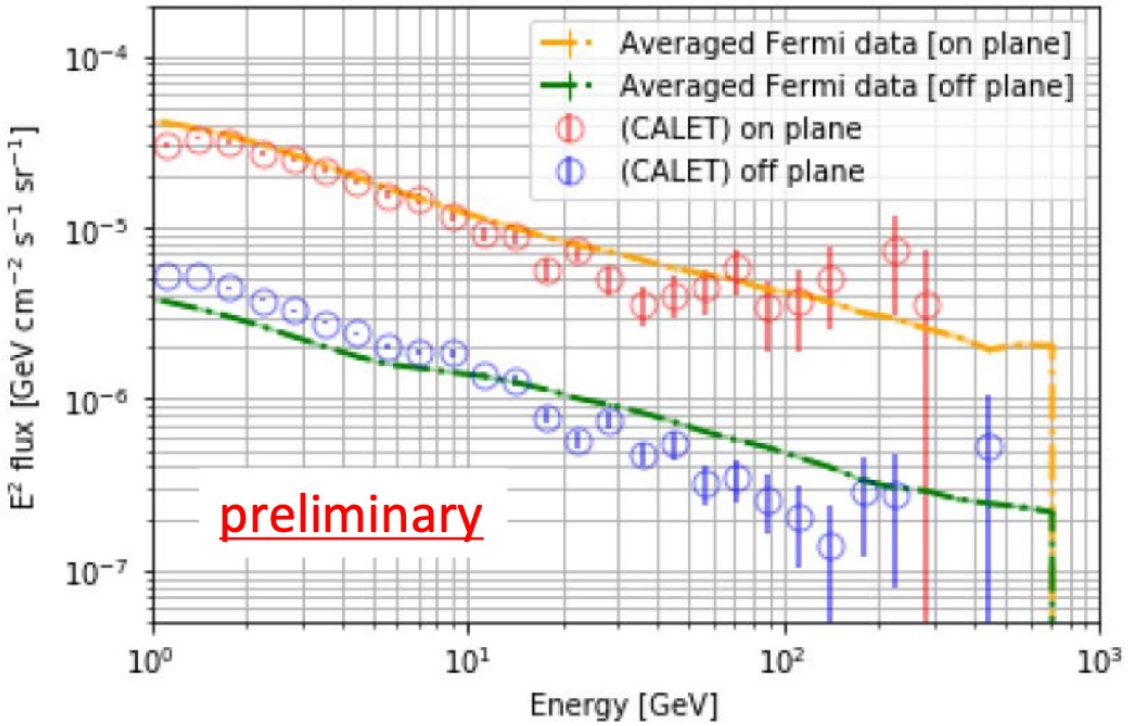




- The B/C ratio with CALET is consistent with the one measured by AMS-02
- A DPL function provides a better fit, suggesting a trend of the data toward a flatting of the B/C ratio at high energy
- “Leaky-box” (LB) approximate fit suggests the possibility of a non-null value of the residual path length

Diffusive Gamma-ray Flux

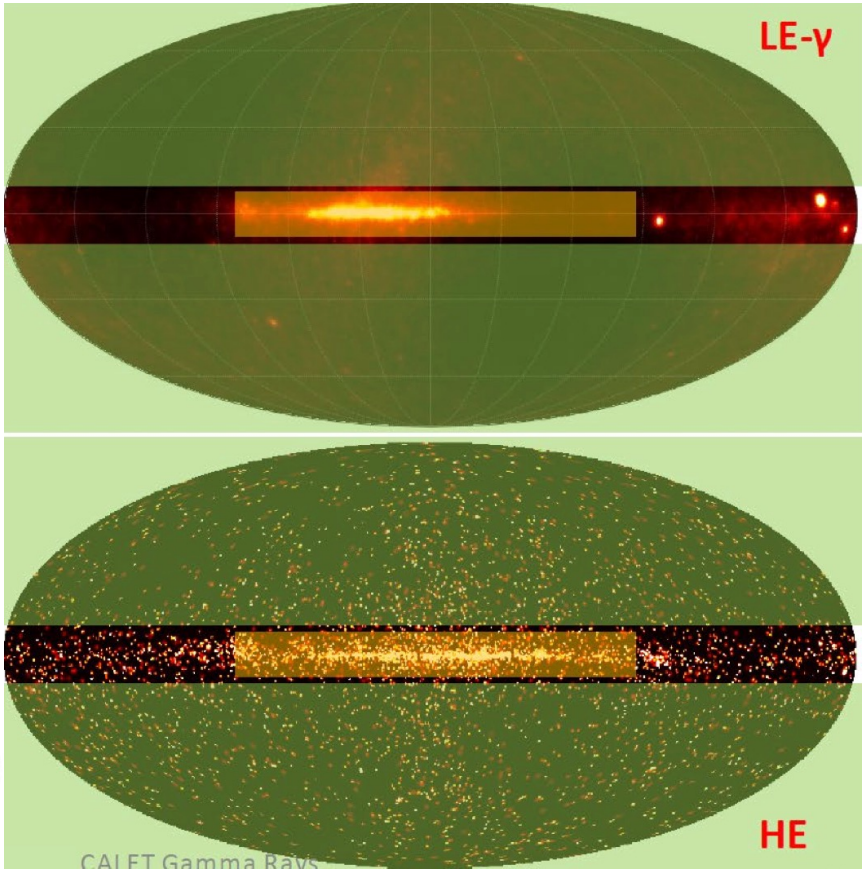
Diffusive emission:
On-plane and off-plane (Nov.2015 – Feb.2022)



On-plane: |b| < 8° & |l| < 80°

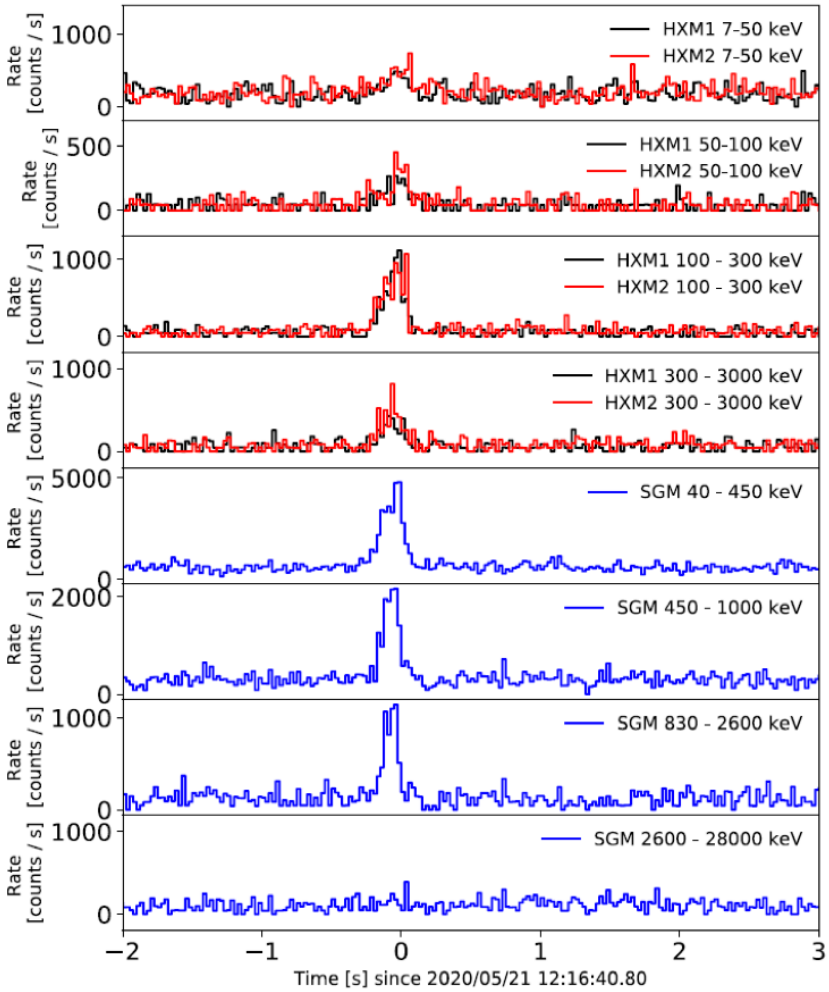
Off-plane: |b| > 10°

COSPAR(2022)

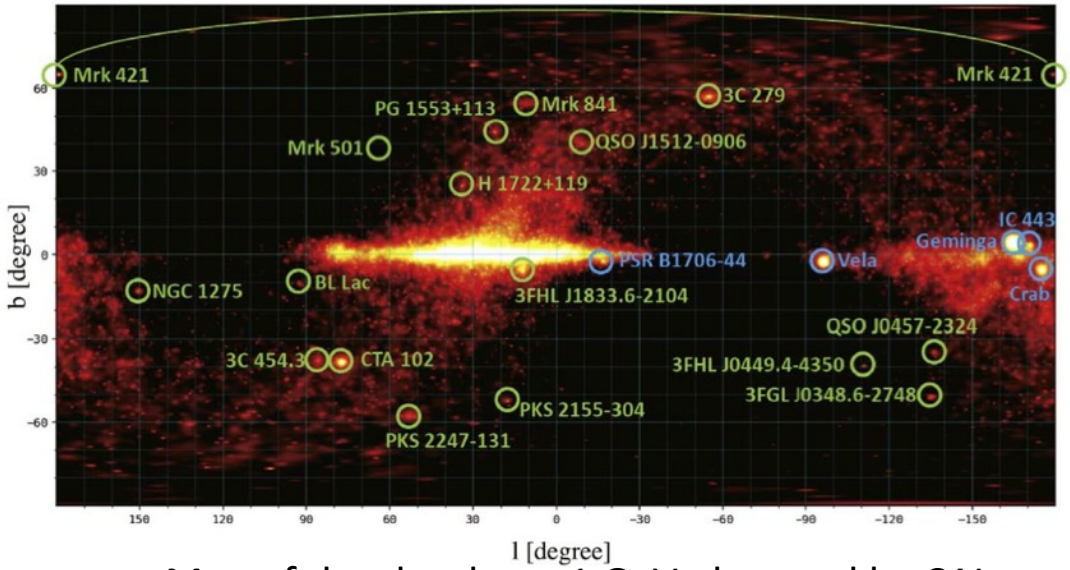


GRB Observations

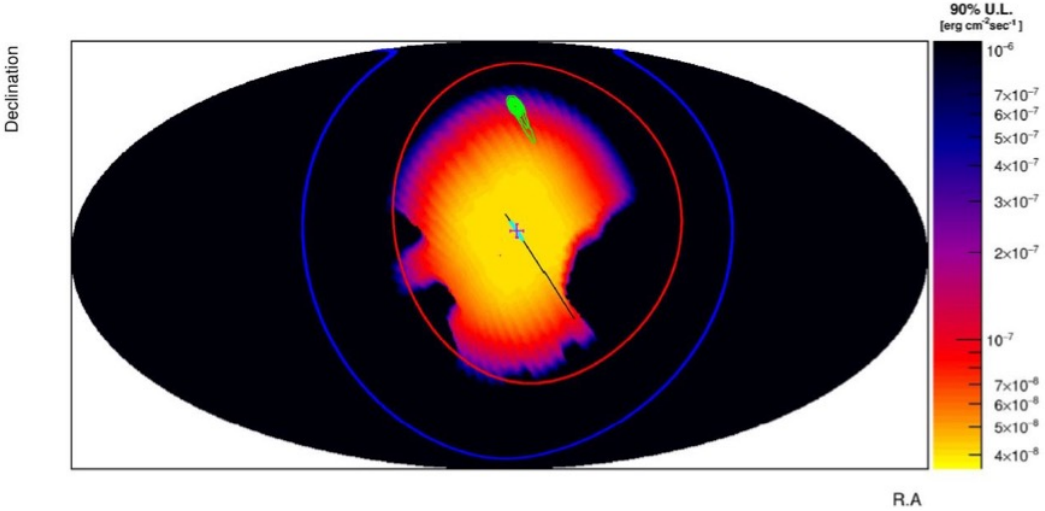
Astrophys. J 933, 85 (2022)



Time histories of counts observed in HXM1, HXM2, and SGM for GRB 200521A

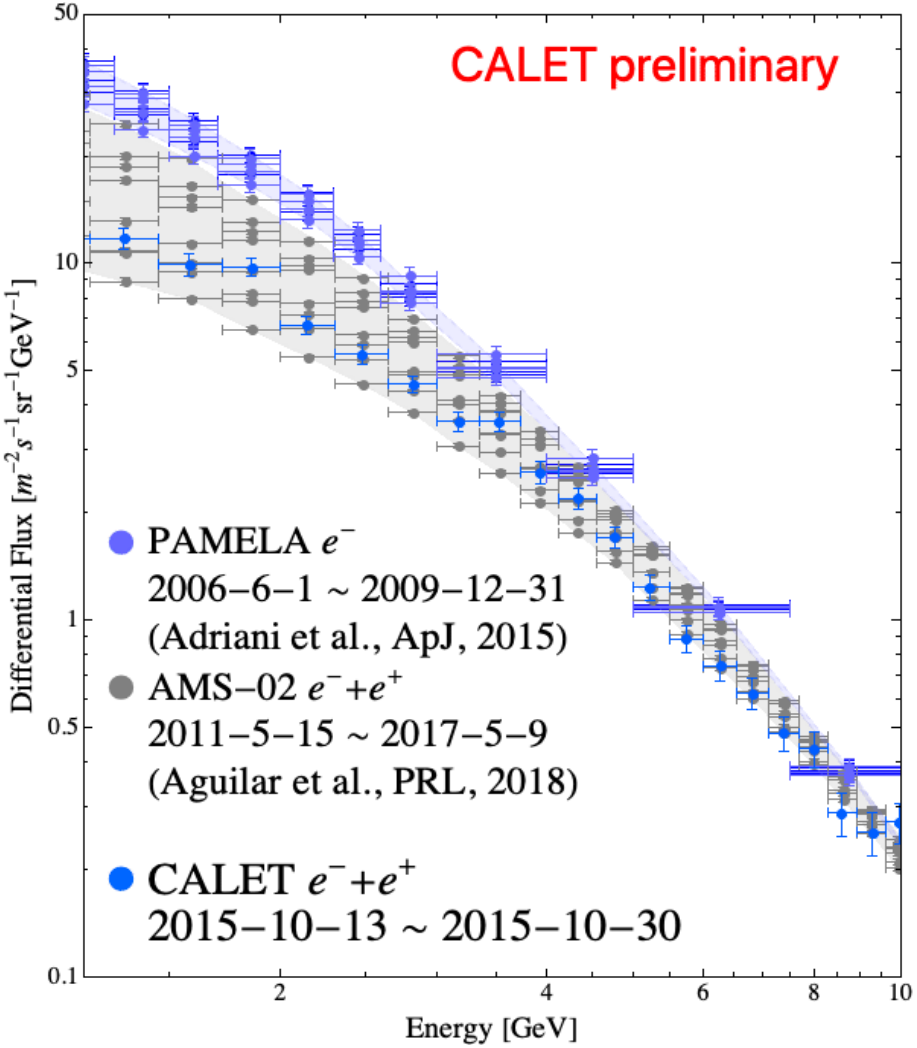


Map of the sky above 1 GeV observed by CAL



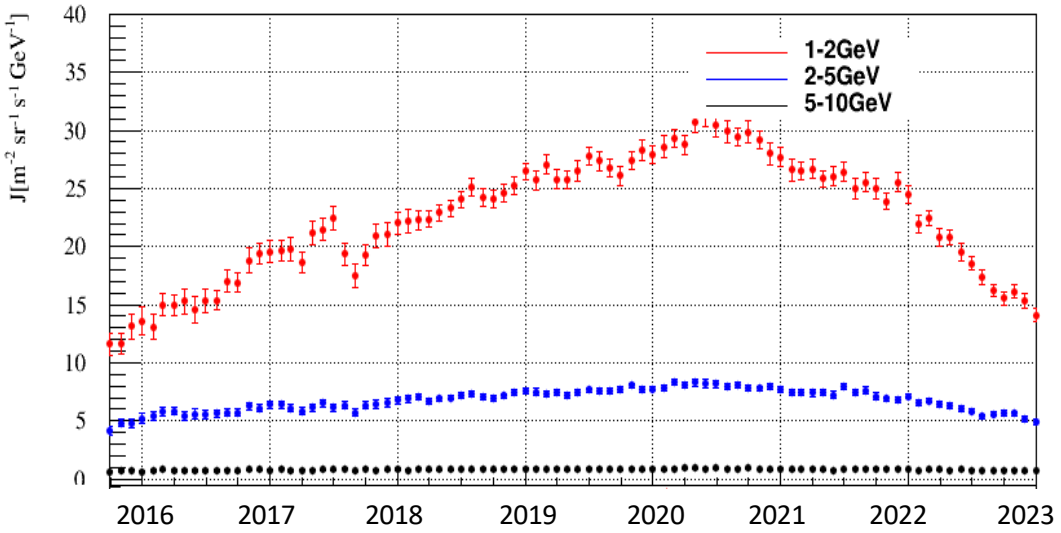
90% confidence level upper limits observed by CAL in the energy range 1-10 GeV during the interval ±60s around the time of GW 190408an reported by LIGO/Virgo. Red and blue circles are the HXM and SGM FOV, respectively

Solar modulation



- Continuous observation has achieved over 7 years and monitored the solar modulation
- Solar minimum in ~2020 was clearly observed in electron count rates
- Chare-sign dependence of the solar modulation of GCRs, predicted by drift-model is also observed.

Count rates of electrons



Summary

- CALET has been accumulating scientific data for over 7 years with excellent performance since October 13, 2015
- Linearity in the energy measurements established up to 10^6 MIP and continuous on-orbit calibration updates
- Following results have been achieved by now
  - Cosmic ray spectra
    - Electron and positron: 11 GeV – 4.8 TeV
    - Proton: 30 GeV – 60 TeV
    - Helium: 40 GeV – 250 TeV
    - Carbon, oxygen and C/O ratio : 10 GeV/n – 2.2 TeV/n
    - Iron: 10 GeV/n – 2.0 TeV/n
    - Nickel: 8.8 GeV/n – 240 GeV/n
    - Boron and B/C ratio: 10 GeV/n – 2.2 TeV/n
  - Study on solar modulation over 7 years
  - Observation of diffuse and point sources (+Sun) of gamma-rays
  - Gamma-ray burst detections and follow-up observation of GW events
- CALET mission was approved to be extended until the end of 2024 (at least) by JAXA/NASA/ASI