CALET on the International Space Station: the first three years of observations

Paolo Brogi University of Siena for the CALET collab<u>oration</u>







Paolo Brogi – ICNFP2019 – Crete, August 26, 2019



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Detector overview

ELECTR





	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Measure	Charge (Z=1-40)	Tracking , Particle ID	Energy, e/p Separation
Geometry (Material)	Plastic Scintillator 14 paddles x 2 layers (X,Y): 28 paddles Paddle Size: 32 x 10 x 450 mm ³	448 Scifi x 16 layers (X,Y) : 7168 Scifi 7 W layers (3X ₀): 0.2X ₀ x 5 + 1X ₀ x2 Scifi size : 1 x 1 x 448 mm ³	16 PWO logs x 12 layers (x,y): 192 logs log size: 19 x 20 x 326 mm ³ Total Thickness : 27 X ₀ , ~1.2 λ _I
Readout	PMT+CSA	64-anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)@top layer



CALET overview



Overview of detector performances:

Geometric Factor:

1200 cm²sr for electrons, light nuclei 1000 cm²sr for gamma-rays 4000 cm²sr for ultra-heavy nuclei

- ΔE/E :
 - ~2% (>10 GeV) for e, gamma ~30-35 % for protons, nuclei
- e/p separation : 10⁻⁵
- Charge resolution: 0.15 0.3 e
- Angular resolution :

0.2° for gamma-rays > ~50 GeV

Main CALET science objectives:

- Electron observation in the 1 GeV 20 TeV energy range. Design optimized for electron detection: high energy resolution and large e/p separation power + e.m. shower containment.
 - Search for Dark Matter and Nearby Sources
- Observation of cosmic-ray nuclei in the 10 GeV - 1 PeV energy range.
 - Unraveling the CR acceleration and propagation mechanism(s)
- Detection of transient phenomena in space Gammaray bursts, e.m. GW counterparts, Solar flares, Space Weather

Scientific Objectives	Observation Targets	Energy Range
CR Origin and Acceleration	Electron spectrum Individual spectra of elements from proton to Fe Ultra Heavy Ions ($26 < Z \le 40$) Gamma-rays (Diffuse + Point sources)	1GeV - 20 TeV 10 GeV - 1000 TeV > 600 MeV/n 1 GeV - 1 TeV
Galactic CR Propagation	B/C and sub-Fe/Fe ratios	Up to some TeV/n
Nearby CR Sources	Electron spectrum	100 GeV - 20 TeV
Dark Matter	Signatures in electron/gamma-ray spectra	100 GeV - 20 TeV
Solar Physics	Electron flux (1GeV-10GeV)	< 10 GeV
Gamma-ray Transients	Gamma-rays and X-rays	7 keV - 20 MeV



High-Energy Triggered events



- •Observation with High Energy Trigger for 1327 days : Oct.13, 2015 May 31, 2019
- •The exposure, S Ω T, has reached ~116 m² 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 %.







Electron Identification



Simple Two Parameter Cut

- $\mathbf{F}_{\mathbf{E}}$: Energy fraction of the bottom layer sum to the whole energy deposit sum in TASC
- $\mathbf{R}_{\mathbf{E}}$: Lateral spread of energy deposit in TASC-X1

K cut parameter: $log_{10}(F_E) + 0.5 R_E (/cm)$

Boosted Decision Trees (BDT)

In addition to the two parameters in the left, TASC and IMC shower profile fits are used as discriminating variables.



In the final electron sample, the resultant contamination ratios of protons are:
 5 % up to 1 TeV ; 10% - 20% in the 1 - 4.8 TeV region, keeping a constant efficiency of 80 % for electrons.

• Simple K cut is used in the low energy region (< 500 GeV) while the difference in resultant spectrum are taken into account in the systematic uncertainty.



All Electron Spectrum by CALET



CALET: Phys.Rev.Lett. 120 (2018) 261102 (~ 2 x PRL2017)







Cosmic-Ray Proton Spectrum



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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 prior spectra of energy unfolding;
- Energy correction with beam test results;

- Difference of beam test model and flight model;
- Long term stability;



- 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.

0.5

0.4 0.3

0.2

0.1

 10^{2}

 10^{3}

10⁴

E (GeV)



Measurements of Ultra Heavy Nuclei

- CALET measures the relative abundances of ultra heavy nuclei (Z>26) up to Z = 40 (Zr)
- Trigger for ultra-heavy nuclei:

CHD, IMC1+2 and IMC3+4 are required

 \Rightarrow an expanded geometrical acceptance (4000 cm²sr)

• Energy threshold depends on the geomagnetic cutoff rigidity

Data analysis:

- Event Selection: Vertical cutoff rigidity > 4 GV & Zenith Angle < 60 degrees
- Contamination from neighboring charge are determined by multiple-Gaussian function

B.F. Rauch & W.R. Binns ICRC2019

CHD-X/Y IMC-1+2

IMC-3+4





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Onboard trigger for UH events



5×10⁻⁶ 4×10⁻⁶ 3×10⁻⁶

10⁻⁶ 7×10⁻⁷ 6×10⁻⁷ 5×10⁻⁷ 4×10⁻⁷ 3×10⁻⁷

Right Ascension

Summary of CALET/CAL γ -ray observations on GW candidates

		v		v				
	GCN	LIGO/Virgo	Trigger time	Events	90% C.L.	Summed	CAL	CAL
	No.	trigger	T ₀ (2019)	$T_0 \pm 60 { m s}$	U.L.	probability	α (°)	δ (°)
	24088	S190408an	04-08 18:18:02.288 UTC	0	2.3×10^{-6}	80%	352.9	8.3
	24218	S190425z	04-25 08:18:05.017 UTC	0	1.0×10^{-4}	5%	131.3	-43.6
	24276	\$190426c	04-26 15:21:55.337 UTC	0	2.5×10^{-5}	10%	183	-50.9
	24403	S190503bf	05-03 18:54:04.294 UTC	0	4.2×10^{-5}	10%	169	-45.5
	24495	S190510g	05-10 02:59:39.292 UT	0	-	No	295.7	50.8
	24531	S190512at	05-12 18:07:14.422 UT	0	$1.9 imes 10^{-5}$	10%	214.9	37.7
	24548	S190513bm	05-13 20:54:28.747 UT	0	6.0×10^{-5} †	5%	348	4.4
	24593	S190517h	05-17 05:51:01.831 UT	0	12	No	126.2	-31.9
	24617	S190519bj	05-19 15:35:44.398 UT	0	8 2	No	243.1	51.1
	24648	S190521g	05-21 03:02:29.447 UT	0	6.0×10^{-6}	30%	205.7	49.2
Ι	24649	S190521r	05-21 07:43:59.463 UT	0	-	No	225.3	51.4
>	24735	S190602aq	06-02 17:59:27.089 UT	0	2.9×10^{-4}	5%	127.5	45.1

Upper limits (U.L.) are given in $erg^*cm^{-2}s^{-1}$ for the energy range 10-100 GeV except for those marked with \dagger which are for 1-10 GeV

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Summary and perspectives



- CALET was successfully launched on Aug. 19th, 2015, and the observation campaign started on Oct.13th, 2015.
- Excellent performances and remarkable stability of the instrument have been achieved.
- As of May 31, 2019 total observation time is 1327 days with live time close to 84% of observation time. Nearly 1.8 billion events collected with low (> 1 GeV) + high energy (>10 GeV) triggers.
- In flight calibrations with p and He events + CERN beam tests with e, p and ion fragments.
- Linearity of energy measurements established up to 10⁶ MIP.
- Measurement of electron + positron spectrum in 11 GeV 48 TeV energy range, using full acceptance: observation of a flux reduction above 1 TeV.
- Direct measurement of proton spectrum in 50 GeV 10 TeV energy range: spectral hardening observed above a few hundred GeV.
- Preliminary analysis of primary elements up to Fe and secondary-to-primary ratios.
- Preliminary analysis of UH cosmic rays up to Z=40.
- Study of diffuse and point sources with gamma-rays.
- Follow-up observations of GW events in X-ray and gamma-ray bands: CALET's CGBM detected 159 GRBs in the energy range 7 keV-20 MeV.
- After an initial period of 2 years CALET observation time has been extended to 5 years at least.





Thanks for your attention!





BACKUP





Instrument overview





	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Function	Charge Measurement (Z = 1 - 40)	Arrival Direction, Particle ID	Energy Measurement, Particle ID
Sensor (+ Absorber)	Plastic Scintillator : 2 layers Unit Size: 32mm x 10mm x 450mm	SciFi : 16 layers Unit size: 1mm ² x 448 mm Total thickness of Tungsten: 3 X ₀	PWO log: 12 layers Unit size: 19mm x 20mm x 326mm Total Thickness of PWO: 27 X ₀
Readout	PMT+CSA	64 -anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)





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Electron identification (ii)

In the final electron sample, the resultant contamination ratios of protons are:



- 5 % up to 1 TeV; 10% 20% in the 1 4.8 TeV region, keeping a constant efficiency of 80 % for electrons.
- Simple two parameter cut is used in the low energy region while the difference in resultant spectrum are taken into account in the systematic uncertainty.









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;



