Event-by-Event Analysis for TeV Electron Candidates with CALET on the International Space Station

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Abstract:

The Calorimetric Electron Telescope (CALET) is a deep electromagnetic calorimeter designed for the measurement of cosmic-ray electrons on the International Space Station. Deployed on the Exposed Facility of the Japanese Experiment Module since August 2015, it observes cosmic-ray electrons with energies up to above 10 TeV and hadrons up to PeV total energies. Above a few TeV, the decrease in the electron flux and increased contamination by protons in the boosted decision tree (BDT) selection introduce challenges to determination of the flux at the highest energies and the search for signatures of nearby accelerators. To address the proton contamination, we apply a dedicated event-by-event analysis to evaluate the likelihood of each candidate event being a real electron or a contaminating proton. In this work, we detail the implementation of the likelihood analysis based on physically motivated shower parameters in the CALET calorimeter. Large simulated electron and proton datasets tailored to the parameters of the observed candidate events are generated and studied to produce a likelihood parameter for the improved rejection of protons. The results are tied to the BDT selection in the flight data analysis and summarized for the currently identified candidate events. Finally, we discuss an expansion of this work presently under development to use BDTs trained specifically for each candidate to provide an additional figure of merit.

CALET – Calorimetric Electron Telescope

Measures:
- Cosmic-ray electrons 1 GeV–20 TeV
- Cosmic-ray hadrons 10 GeV–~1 PeV
- Gamma rays 1 GeV–10 TeV

Subdetectors:
- Charge Detector (CHD)
  2×14 plastic scintillating paddles
- Imaging Calorimeter (IMC)
  $8 \times 2 \times 448$ plastic scintillating fibers
- Total Absorption Calorimeter (TASC)
  $6 \times 2 \times 16$ lead tungstate logs

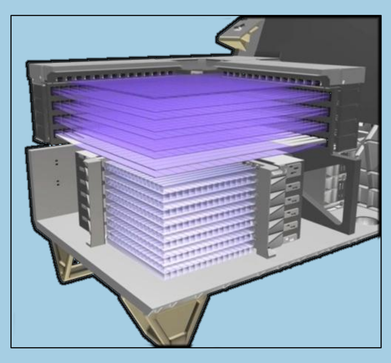

Figure 1. The CALET Calorimeter

Ene. Dep. Res. ~3%
Geom. Factor ~0.12 m^2sr
30 radiation lengths
1.2 proton interact. len.

Motivation

- Proton contamination for electrons increases above ~5 TeV
- Signatures for nearby accelerators could appear at ~10 TeV
- Statistics decrease quickly enough at these energies that each candidate event can be studied individually

Overview

- Large-scale simulations of electrons and protons done for each candidate electron event above ~3 TeV in flight data
- 13 physically-motivated parameters examined to compare showers from electron and proton simulated primaries
- A likelihood ratio is calculated and used to determine the residual proton background for each candidate event

Event selection + simulation

- Offline trigger
- Track quality
- Shower development
- Shower concentration
- Shower likelihood
- TASC-IMC consistency
- Charge cut
- Boosted Decision Tree

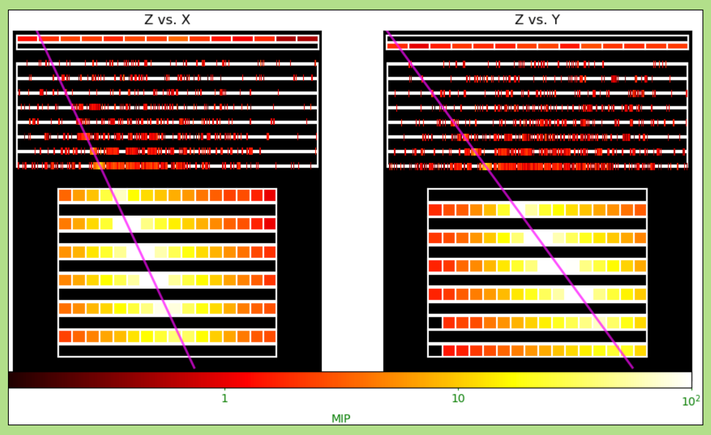

Figure 2. An example candidate from CALET flight data (2018/04/18) with reconstructed energy 12.04 TeV.

Simulation configuration (EPICS+Cosmos)
- Electrons: 10^5 events thrown for same primary energy and incident direction as flight data candidate
- Protons: 2×10^5–10^6 events thrown with same incident direction as real event and energy according to $E^{-2.7}$ spectrum from 1 to $10^3 \times$ the candidate TASC energy deposit sum

Parameters

- Lateral shower wid.
- TASC Y6 dep. frac.
- IMC concentration
- CHD paddle sum
- TASC fit show. max.
- TASC fit atten. const.
- TASC fit 5% depth
- TASC fit χ^2/d.o.f.
- IMC exp. fit const.
- IMC exp. fit slope
- IMC exp. Fit χ^2/d.o.f.
- IMC ratio 6–7
- IMC ratio max.

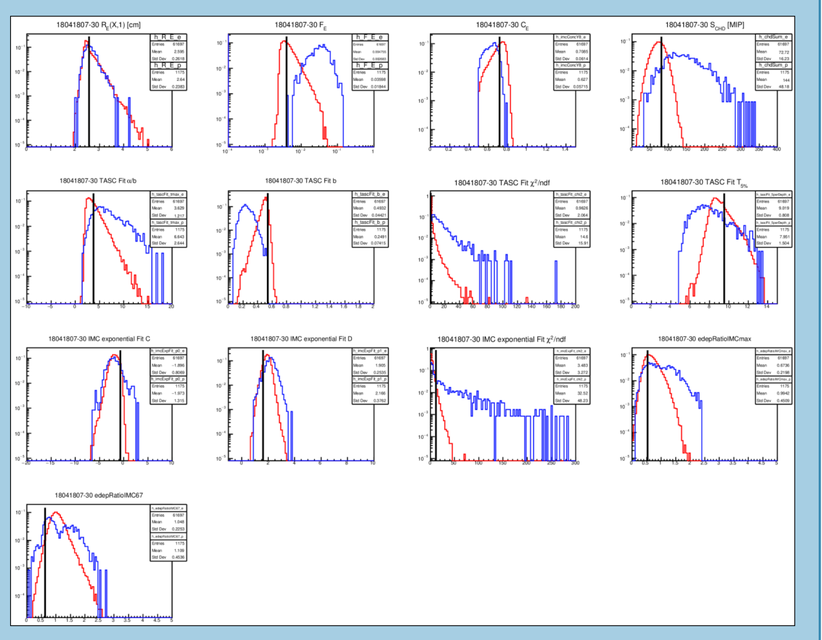

Figure 3. Electron (red) and proton (blue) parameter distributions for the same event as Fig. 2

Procedure

1. Filter simulations to match flight data selection conditions and candidate TASC energy deposit sum
2. Fill sim. electron and proton histograms of 13 parameters
3. Generate likelihood ratio dists for simulated electrons and protons
4. Calculate likelihood ratio for real candidate event
5. Scale likelihood dists to match flight data BDT parameter template fits
6. Fit Gaussian tail to estimate proton background from scaled proton hist. with LR larger than candidate

Likelihood ratio:

$$LR(k) = \log_{10} \prod_{i=1}^{13} \frac{p_e^{(k)}(i)}{p_p^{(k)}(i)}$$

where
k indexes event
i indexes parameter
with

$$p_s^{(k)}(i) = \frac{m_s^{(k)}(i)}{m_s^{(tot)}(i)}$$

where
s indexes species (e/p)
$m_s^{(k)}(i)$ is number in same bin as event k
$m_s^{(tot)}(i)$ is total number in histogram

Results

- Total identified candidates above 4.8 TeV were 35
- Enforcing same charge cut as standard analysis reduces candidates above 4.8 TeV to 23
- Several events above 4.8 TeV are identified as high-fidelity

Future work

- Submitted results in upcoming CALET electron publication
- Exploring relaxed charge cut
- Exploring use of BDT instead of likelihood ratio classification
- Future candidates being analyzed as they are found

Figure 4. Likelihood distributions for the same event as in Figs. 2 and 3. Red and blue represent simulated electrons and protons, respectively. The green curve shows the Gaussian tail fitted to the proton distribution for a conservative estimate of background. The black solid line is the value of the LR for the real candidate event. The dashed and dotted lines are 80% and 50% electron containment thresholds.

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