Capability of electron identification for the CALET measurement.

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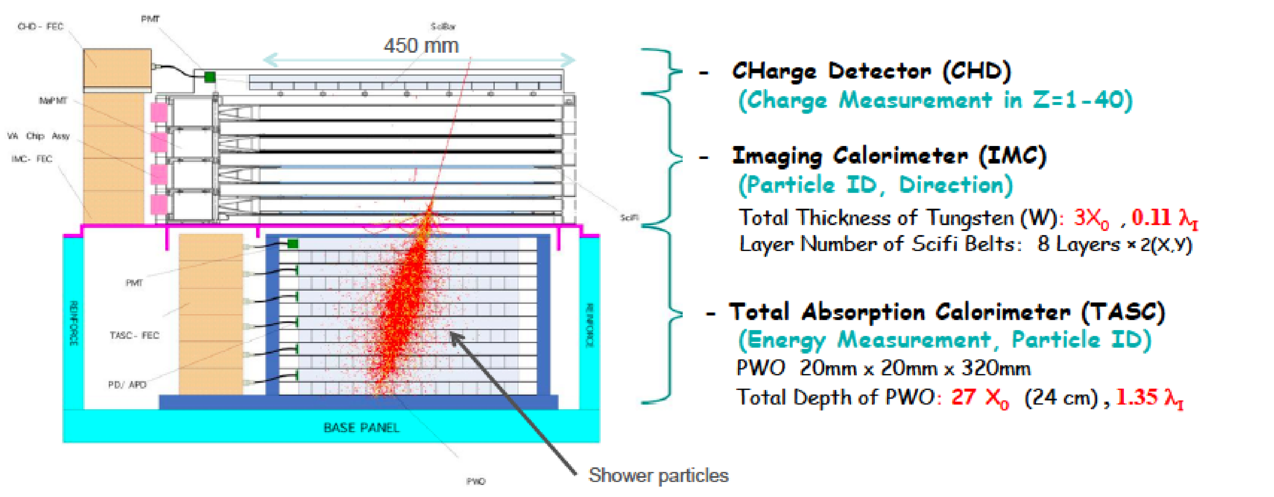
The CALET experiment

The CALorimetric Electron Telescope (CALET) is a calorimetric experiment for the direct measurement of high energy cosmic ray spectra. The apparatus was installed to the International Space Station (ISS) in August 2015.

The CALET mission is designed for the measurement of the cosmic ray electron+positron (hereafter "electron") spectrum up to few TeV, the proton and nuclei (from Helium to Iron) spectra up to hundred TeV/nucleon and the precise measurement of the high energy gamma-rays. The electron energy spectrum can provide unique information about nearby cosmic ray sources, e.g. Supernova remnants, while the measurement of high energy nucleus spectra provides important information about the propagation of particles in the Galaxy.

The CALET calorimeter consists of three main detectors: a "Total AbSorption Calorimeter" (TASC) composed of PWO bars with a good energy resolution for electrons thanks to its thickness of about 27 X_0; an "IMaging Calorimeter" (IMC) with 8 layers of scintillating optical fibers, interleaved with thin tungsten sheets and a "CHarge Detector" (CHD) composed by two layers of segmented plastic scintillators.



	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) - 2 -

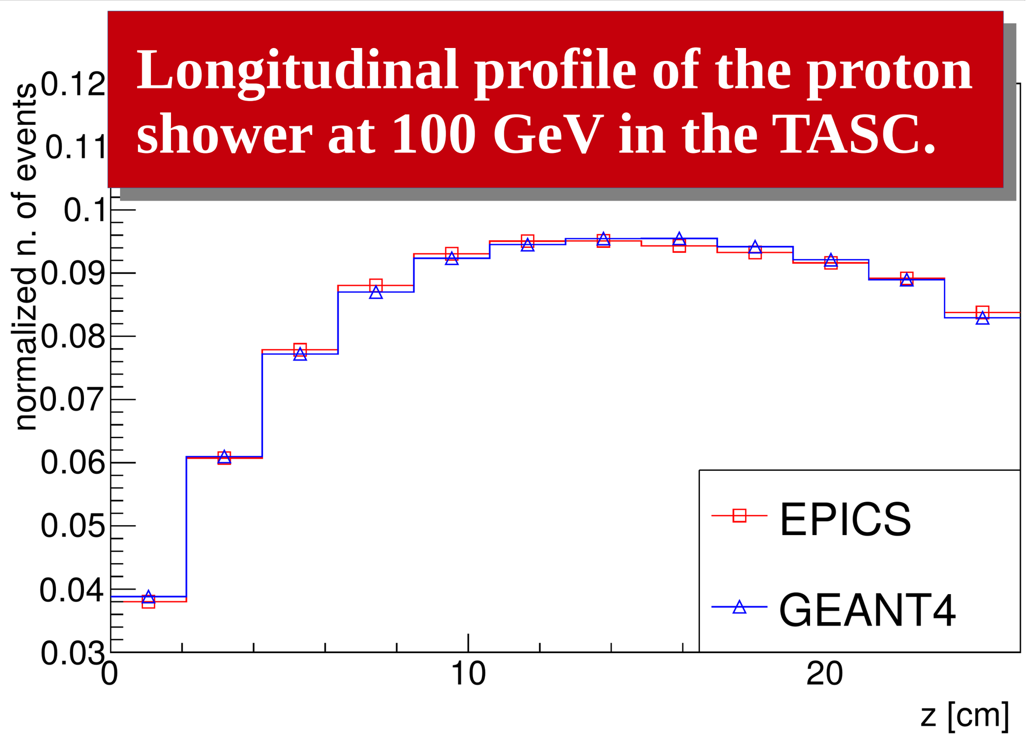
Monte Carlo simulation

Several Monte Carlo simulations of the detector were developed. The present work features the expected electron/proton (e/p) separation with simulations based on the EPICS and GEANT4 packages.

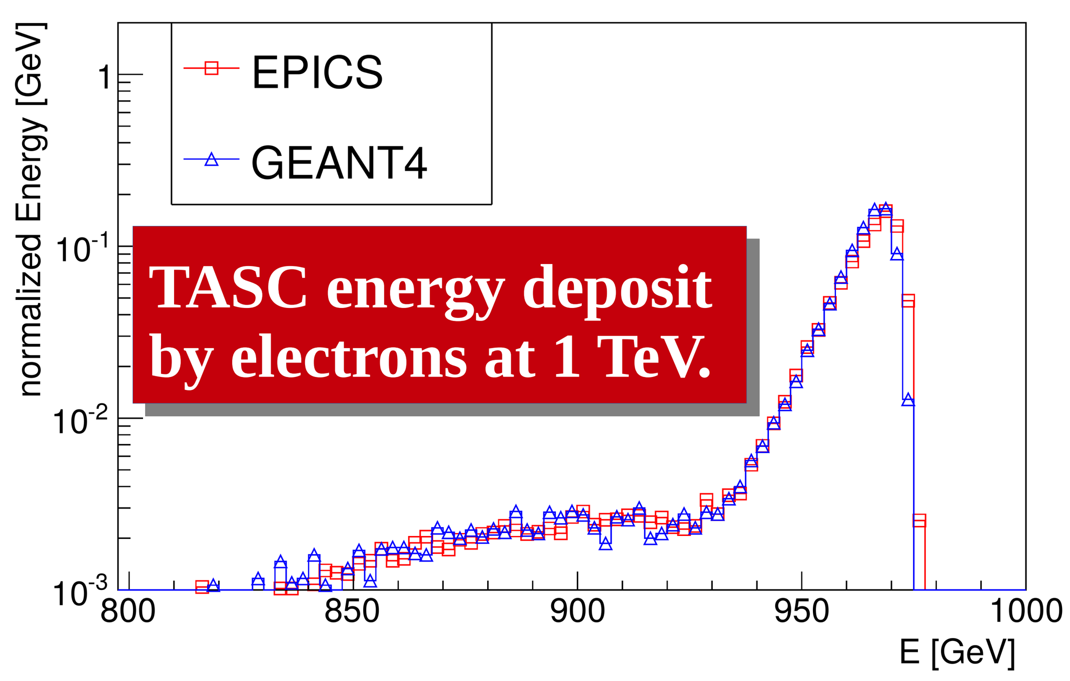
EPICS: version 9.20, hadronic interaction model DPMJET-III.
GEANT4: version 10.01.p02 and FTFP-BERT physics list.

In order to validate the complex geometry implemented in the simulations, common benchmarks between EPICS and GEANT4 has been carried out. A good agreement between the simulations was found, especially for the variables related to the TASC.

Longitudinal profile of the proton shower at 100 GeV in the TASC.



TASC energy deposit by electrons at 1 TeV.



Selection before the e/p discrimination cut

The present analysis takes into account events in the so called CALET acceptance A (acc. A). A particle is in acc. A if its initial direction crosses the top surface of the CHD, the top and the bottom of the TASC but with a fiducial cut excluding a lateral strip of width equal to 1.9 cm.

Before the cut used for the e/p identification, some selections are needed in order to take into account the detector trigger and avoid contamination from events outside the acceptance and heavier nuclei.

- Software trigger: requires a big energy deposit in the last 2 layers of the IMC and in the first layer of the TASC.
- Tracking algorithm: requires a track reconstructed by the Kalman filter technique.
- IMC Shower Concentration: avoids a considerable acceptance contamination by requiring a large energy deposit near the reconstructed trajectory in the last layer of the IMC.
- Charge selection: rejected events with the quadratic mean of the energy deposit in the hit paddles >3.5 MIP.

The total efficiency of these selection cuts is almost constant with the energy for electrons, ~97% at 1 TeV.

e/p separation with a single cut.

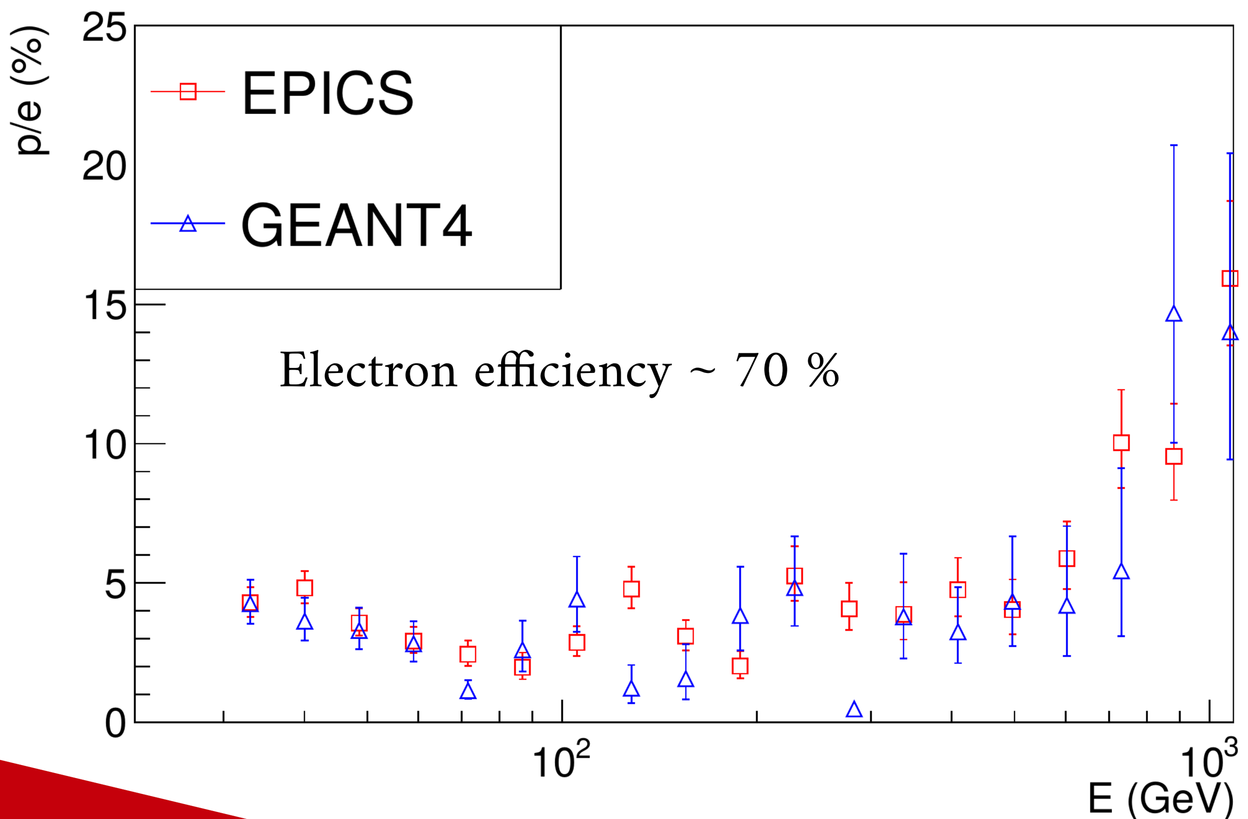
Since the proton abundance in cosmic rays is 100-1000 times larger than the electron one, a very good proton rejection power is required. The cut discussed here involves two variables:

- F_E fraction of energy deposited in the last TASC layer,
- R_E lateral weighted spread in the first TASC layer,

$$R_E = \sqrt{\frac{\sum_j (\Delta E_j \cdot (x_j - x_c)^2)}{\sum_j \Delta E_j}}$$

where x_c is the coordinate of the reconstructed particle track in the first TASC layer, x_j and ΔE_j are the coordinate of the center and the energy deposit in the jth PWO log respectively. In order to improve the cut efficiency for electrons, while keeping a good discrimination power, the cut is applied on a single variable obtained by combination of the two variables as follow: $K = log_{10}(F_E) + 0.65 \cdot R_E$

Expected residual proton contamination using the K variable with EPICS (red squares) and GEANT4 (blue triangles)



e/p separation with Multi Variate Analysis.

To improve the e/p discrimination up to the multi-TeV region, a Multi Variate Analysis (MVA) approach has been developed by using the Boosted Decision Trees (BDT) algorithm. The MVA analysis has been developed and optimized with the EPICS simulation. The variables include in the BDT analysis are: F_E, R_E, IMC shower concentration, the point of the maximum $t_{max} = (\alpha - 1)\theta$, the parameter θ and the χ^2 of the gamma fit of the shower profile in TASC, the parameters p1, p2 and the χ^2 of the parabolic fit of the shower profile in the IMC.

Gamma fit TASC

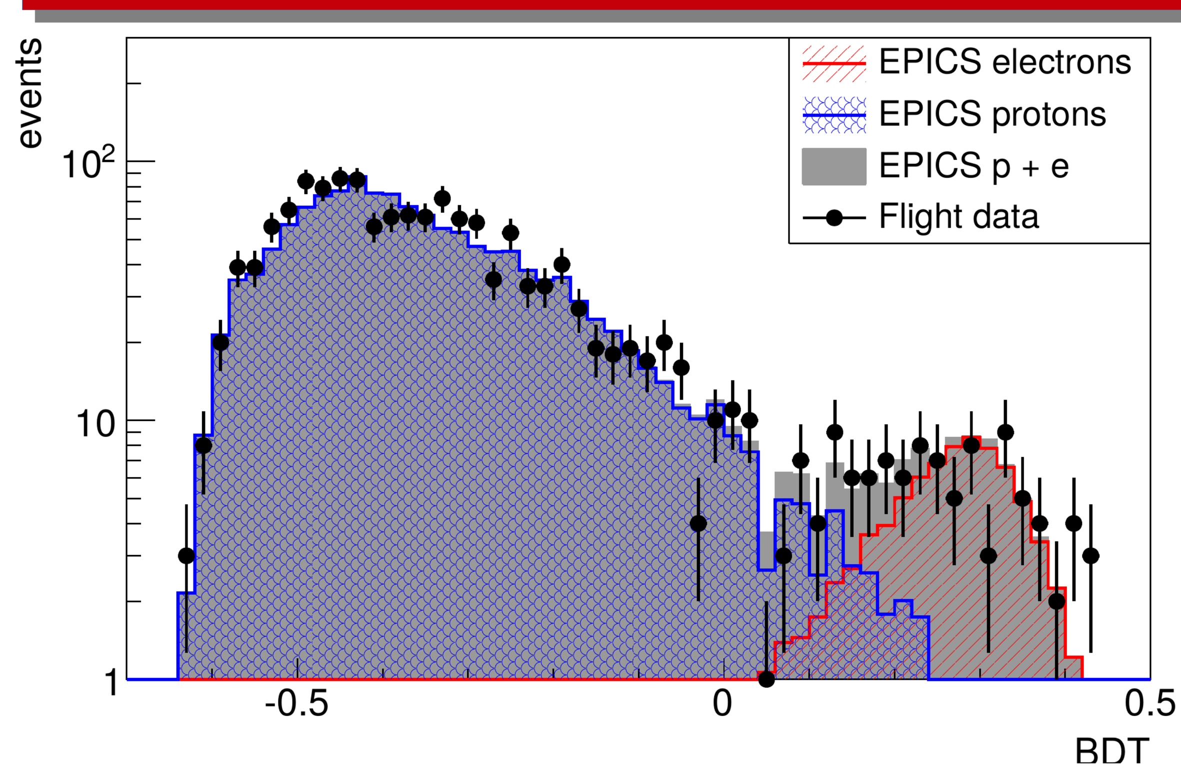
$$\frac{dE}{dt} = E_0 \frac{t^{\alpha-1} e^{\frac{t}{\theta}}}{\Gamma(\alpha)\theta^\alpha}$$

Parabolic fit in IMC

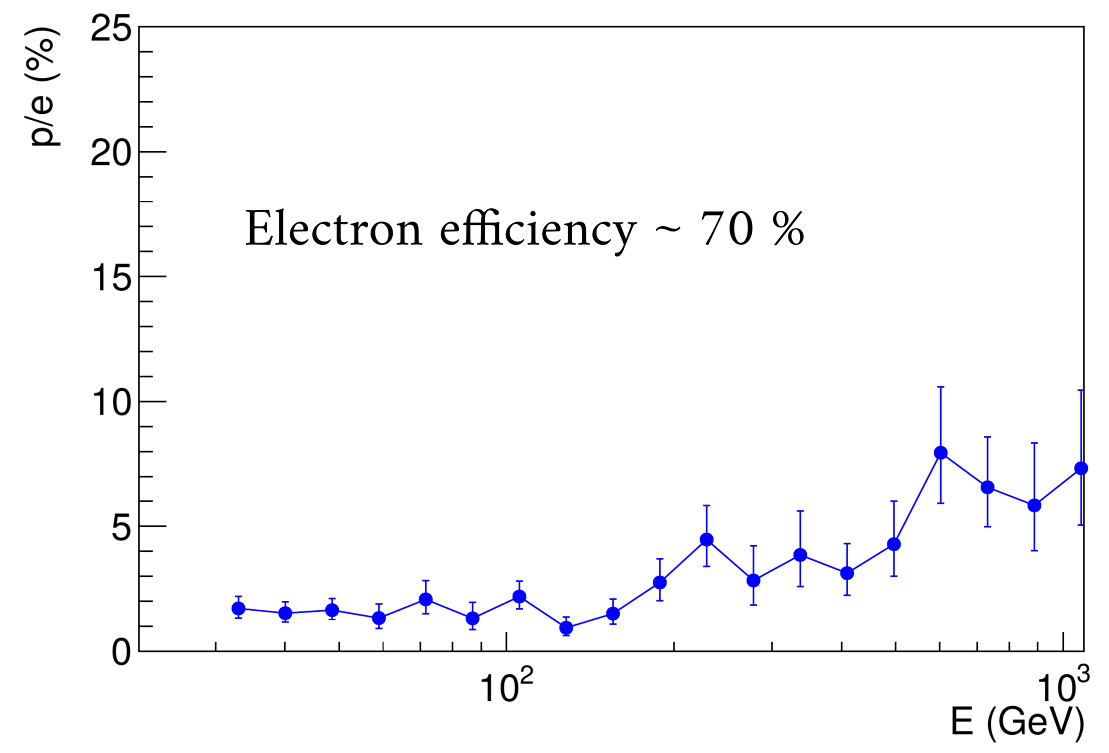
$$dE/dt = p_0 + p_1 \cdot t^2$$

The generated proton and electron events are separated in two samples, the first one used for the BDT training, and the other one for the calculation of the efficiency and the proton contamination.

Comparison between the flight data and the Monte Carlo simulations based on EPICS regarding the BDT variable above 810 GeV.



Proton contamination computed with the EPICS simulations using the MVA-BDT.



Conclusions: the analysis discussed here shows a reasonable agreement between the expected proton contamination in the measured electron spectrum computed with the EPICS and GEANT4 simulations with the K cut analysis. A MVA approach has been also developed and the proton contamination is smaller than the one expected with the K cut and remains below 10\% up to 1 TeV with an efficiency for electrons ~70%.