PROCEEDINGS OF SCIENCE

Measurement of the all-electron spectrum through 1 TeV region with the CALET experiment

Sandro Gonzi[a,b,*], **Shoji Torii**[c], **Yosui Akaike**[c,d], **Eugenio Berti**[a,b] **and Lorenzo Pacini**[a,b,e] **for the CALET collaboration**

[a] *Dipartimento di Fisica e Astronomia, Università degli Studi di Firenze, Via G. Sansone 1, Sesto Fiorentino, Firenze, Italy*
[b] *INFN Sezione di Firenze, via G. Sansone 1, Sesto Fiorentino, Firenze, Italy*
[c] *Waseda Research Institute for Science and Engineering, Waseda University, 17 Kikuicho, Shinjuku, Tokyo, Japan*
[d] *JEM Utilization Center, Human Spaceflight Technology Directorate, Japan Aerospace Exploration Agency, 2-1-1 Sengen, Tsukuba, Ibaraki, Japan*
[e] *Istituto di Fisica Applicata "Nello Carrara", Consiglio Nazionale delle Ricerche, via Madonna del Piano 10, Sesto Fiorentino, Firenze, Italy*

E-mail: sandro.gonzi@fi.infn.it

The CALorimetric Electron Telescope (CALET) is a space experiment installed aboard the International Space Station (ISS). The instrument has been accumulating data since October 2015, searching for nearby cosmic-ray sources and dark matter signatures with accurate measurements of the inclusive spectrum of cosmic electrons and positrons up to the TeV region. The CALET main detector consists of a charge detector, an imaging calorimeter and a total absorption calorimeter: the total depth of the instrument for vertical incidence is about 30 radiation lengths. This design offers excellent performances in terms of the reconstruction of: the particle charge up to and above Iron, the primary track with an angular resolution better than 1°, the incident energy with a resolution better than 2% for electrons up to 1 TeV and a good proton/electron identification corresponding to a proton rejection factor of about 10^5. In this contribution the analysis steps for the measurement of the electron flux are discussed and, by exploiting the full statistics accumulated by the CALET experiment, the measurement of the inclusive spectrum of cosmic electrons and positrons (all-electron) is presented.

**** The European Physical Society Conference on High Energy Physics (EPS-HEP2021), ****
**** 26-30 July 2021 ****
**** Online conference, jointly organized by Universität Hamburg and the research center DESY ****

[*] Speaker

PoS(EPS-HEP2021)058

1. Introduction

The study of cosmic-ray electrons and positrons in the high-energy range provides a unique probe of nearby cosmic accelerators: since their diffusion distance above the energy of 1 TeV is limited to less than 1 kpc, only a few *supernova remnants* or *pulsars* located in the proximity of the Solar System can be deemed as their astrophysical sources. In addition, the apparent increase of the positron fraction over 10 GeV established by the Payload for Antimatter Matter Exploration and Light nuclei Astrophysics (PAMELA) [1] and the Alpha Magnetic Spectrometer (AMS-02) [2] experiments could involve the existence of some supposed positron sources with astrophysical or exotic origin as, in the order, nearby *pulsars* and *supernova remnants* or *dark matter*. A precise measurement of the inclusive spectrum of cosmic electrons and positrons (all-electron) in the TeV region might then reveal some peculiar spectral features which, compared to the ones expected by the numerous theoretical models available, can lead to a better understanding of the neighboring region of the Galaxy or to an improvement of cosmological models.

The CALorimetric Electron Telescope (CALET) [3] is a space experiment operating onboard the International Space Station (ISS) since October 2015 for long term observations of cosmic-rays. In this paper a preliminary CALET all-electron spectrum is presented and discussed in the energy range from 11 GeV to 4.8 TeV with flight data obtained from observations over about 5 years.

2. CALET detector

The CALET detector is an all-calorimetric instrument with a total vertical thickness equivalent to 30 radiation lengths (X_0) and 1.3 proton interaction lengths (λ_I), for particles at normal incidence, preceded by a charge identification system.

The total instrument has a field of view of $\sim 45°$ from zenith and an effective geometrical factor of $\sim 1,040$ cm^{2}sr for high-energy electrons. A charge detector (CHD), comprised of a pair of plastic scintillator hodoscopes arranged in two orthogonal layers, is placed at the top of the instrument in order to reconstruct the charge of the incident particle. The energy measurement relies on two independent calorimeters: a fine-grained preshower imaging calorimeter (IMC) followed by a total absorption calorimeter (TASC). The IMC is a sampling calorimeter alternating thin layers of Tungsten absorber, optimized in thickness and position, with layers of scintillating fibers read-out individually. The TASC is a tightly packed lead-tungstate (PbWO4; PWO) hodoscope, capable of almost complete absorption of the TeV-electron showers.

This design leads to excellent detector performances: an electromagnetic shower energy resolution of $\sim 2\%$ above 20 GeV and a protons rejection factor of $\sim 10^5$ make it possible to derive the all-electron spectrum well into the TeV region with a straightforward and reliable analysis.

3. Data Analysis

The results obtained by the analysis of 1815 days of flight data, collected with a high-energy shower trigger [4] and a consistently high live time fraction ($\sim 86\%$), are presented below following an analysis procedure similar to that used in the latest publication of the CALET Collaboration on this topic [5]. Monte Carlo (MC) simulations of electrons and protons, performed with EPICS

[6] and Geant4 [7] frameworks, were used to evaluate event selection and event reconstruction efficiencies, energy correction factor and background contamination. The "electromagnetic shower tracking" algorithm, developed to take advantage of the electromagnetic shower shape and IMC design concept, was used to reconstruct the shower axis of each event.

A group of pre-selections was applied to obtain a well reconstructed sample of electron candidates, removing contamination from events outside acceptance and particles with charge $Z > 1$: (1) an off-line trigger confirmation, (2) a geometrical condition, (3) a track quality cut to ensure reconstruction accuracy, (4) a charge selection using CHD, (5) a longitudinal shower development and (6) a lateral shower containment consistent with those expected for electromagnetic cascades. The energy of incident electrons is reconstructed using a dedicated energy correction function.

Two different protons rejection algorithms are applied, depending on the energy, to further suppress the contaminating proton background: a simple two-parameter cut (K-cut, used below 500 GeV) and a multivariate algorithm (based on Boosted Decision Tree, BDT, used above 500 GeV). In the final electron sample, the resultant contamination ratios of protons are ~5% up to 1 TeV, and 10% - 20% in the 1 - 4.8 TeV region, while keeping a constant high efficiency of 80% for electrons. The absolute energy scale was based on simulations and extensive accelerator calibrations and shifted by + 3.5% as a result of a study of the geomagnetic cutoff energy.

Systematic uncertainties include errors in the absolute normalization for a total of 3.2% together with energy dependent errors (not including the shift in the energy scale). The energy dependent errors include those obtained from BDT stability, trigger efficiency in the low-energy region, tracking dependence, dependence on methods of charge identification, and of electron identification as well as MC model dependence.

4. Results and Discussion

Figure 1 shows the extended cosmic-ray all-electron spectrum obtained in this analysis [4] using the observed events with statistics increased by a factor of 2.3 since the last publication [5].

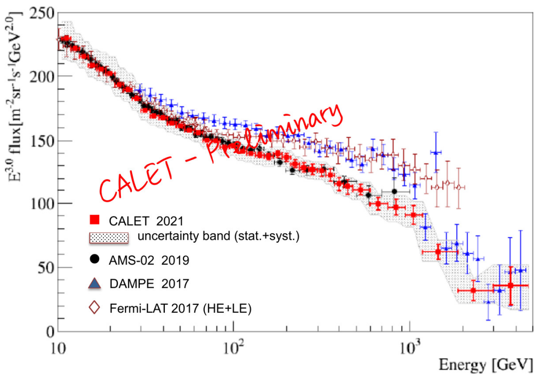

Figure 1: Cosmic-ray all-electron spectrum measured by CALET from 11 GeV to 4.8 TeV, where the gray band indicates the quadratic sum of statistical and systematic errors (not including the uncertainty on the energy scale). Also plotted are direct measurements in space [8–10] for comparison.

Comparing with the other recent experiments in space (AMS-02 [8], DArk Matter Particle Explorer (DAMPE) [9] and Fermi Large Area Telescope (Fermi-LAT) [10]), the spectrum shows good agreement with AMS-02 data below 1 TeV. In the energy region from 40 to 300 GeV, the power-law index of CALET's spectrum is found to be -3.128±0.019, which is consistent with other experiments within errors. However, the spectra measured by DAMPE and Fermi-LAT are considerably harder from 300 to 600 GeV than the spectrum measured by CALET. The DAMPE and Fermi-LAT results exhibit a higher flux than that of CALET from 300 GeV up to near 1 TeV, indicating the presence of unknown systematic effects. To check if the CALET spectrum is consistent with a possible break at 0.9 TeV, as suggested by DAMPE's observations, the same energy binning as DAMPE was adopted to show the spectrum. A broken power law steepening from -3.151±0.012 by -0.873±0.178 fits CALET data well, with $\chi^2 = 11.64$ and number of degrees of freedom (NDF) equal to 29. This result is consistent with DAMPE regarding the spectral index change of 0.7±0.3. A single power-law fit over the same energy range gives an index -3.197±0.011 with χ^2/NDF=54.50/30, which means that the broken power law is favored with 6.55 σ significance over the single power law. On the other hand the flux in the 1.4 TeV bin of DAMPE's spectrum, which might imply a peak structure, is not compatible with CALET results at a level of significance greater than 4 σ, including the systematic errors from both experiments.

The details of the interpretation of the all-electron spectrum and its implications of the nearby source contribution have been treated in [11]. However, in order to have conclusive information of the nearby source contribution in the TeV region, we need to extend the energy spectrum above 5 TeV with a further increase of the statistics and a reduction of the systematic errors in the analysis.

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