IL NUOVO CIMENTO **45 C** (2022) 146
DOI 10.1393/ncc/i2022-22146-0

Communications: SIF Congress 2021

Measurement of the cosmic-ray electron and positron spectrum with the Calorimetric Electron Telescope on the International Space Station

S. Gonzi(1)(2)(*), Y. Akaike(3)(4), E. Berti(1)(2), G. Bigongiari(5)(6), P. Brogi(5)(6), C. Checchia(5), P. Maestro(5)(6), P. S. Marrocchesi(5)(6), L. Pacini(1)(2)(7), F. Stolzi(5)(6) and S. Torii(3) on behalf of the CALET Collaboration

(1) *Dipartimento di Fisica e Astronomia, Università degli Studi di Firenze - Firenze, Italy*
(2) *INFN, Sezione di Firenze - Firenze, Italy*
(3) *Waseda Research Institute for Science and Engineering, Waseda University Tokyo, Japan*
(4) *JEM Utilization Center, Human Spaceflight Technology Directorate, JAXA Ibaraki, Japan*
(5) *Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, Università degli Studi di Siena - Siena, Italy*
(6) *INFN, Sezione di Pisa - Pisa, Italy*
(7) *Istituto di Fisica Applicata "Nello Carrara", CNR - Firenze, Italy*

received 31 January 2022

Summary. — The CALorimetric Electron Telescope (CALET), operating onboard the International Space Station (ISS) since October 2015, is an experiment dedicated to high-energy astroparticle physics. The primary scientific goal of the CALET mission is to perform a high-precision measurement of the inclusive spectrum of cosmic electrons and positrons (all-electron) up to the multi-TeV region, where the shape of the spectrum can indicate the presence of nearby cosmic-ray sources or dark matter signatures. In this contribution, the analysis procedure that led to a precise measurement of the all-electron flux up to several TeV with the full statistics collected by the CALET experiment is presented and results are briefly discussed.

1. – Introduction

The study of cosmic-ray electrons and positrons in the high-energy range provides a unique probe of nearby cosmic accelerators: due to the intense energy loss during diffusion, the observed electrons above 1 TeV can only be produced by sources within 1 kpc and therefore only few supernova remnants or pulsars located in the proximity

(*) E-mail: sandro.gonzi@fi.infn.it

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, respectively, nearby pulsars or dark matter. A precise measurement of the inclusive spectrum of cosmic electrons and positrons (all-electron) in the TeV region might thus 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 existing 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. Over the past few years, the CALET Collaboration performed a direct measurement of several cosmic-ray spectra, specifically of electron and positron (up to 4.8 TeV) [4,5], proton (up to 10 TeV) [6], carbon and oxygen (up to 2.2 TeV/n) [7] and iron (up to 2.0 TeV/n) [8].

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. In detail: in sect. **2** the CALET detector is described, in sect. **3** the analysis procedure is explained and in sect. **4** results are presented, in comparison with those achieved by other direct measurements in space and available in literature.

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.

The total instrument has a field of view of about 45° from zenith and a geometrical factor of about 1040 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 ($PbWO_4$; PWO) segmented calorimeter, capable of almost complete absorption of the TeV-electron showers. In addition, a combination of the calorimetric observations with the ones performed with a dedicated gamma-ray burst monitor (CGBM) allows the CALET Collaboration to carry out gamma-ray astronomy.

The CALET design allows reaching an electromagnetic shower energy resolution of about 2% above 20 GeV and a protons rejection factor of about 10^5, making possible to extend a well established and understood analysis procedure to the high-energy region.

3. – Data analysis

A sample of 1815 days of flight data, collected with a high-energy shower trigger and a consistently high live time fraction (∼86%) in the full detector acceptance [9], has been processed by 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 [10] and GEANT4 [11] frameworks, were used to evaluate event selection and event reconstruction efficiencies, energy correction factors and the background contamination. The "electromagnetic shower tracking" algorithm, developed to take advantage of the electromagnetic shower shape and IMC design, was used to reconstruct the shower axis of each event.

A group of pre-selections allowed obtaining a well reconstructed sample of electron candidates, removing events outside acceptance and particles with charge $Z > 1$:

1) an off-line trigger confirmation, to select a flat region of the discriminator efficiency;

2) a geometrical condition selection, to select a given acceptance region;

3) a track quality selection, to ensure reconstruction accuracy;

4) a charge selection, to remove background events from helium and heavier nuclei;

5) a longitudinal shower development selection, to suppress part of the hadronic showers;

6) a lateral shower containment selection, to further suppress the hadronic showers.

The energy of the electrons was reconstructed using a dedicated correction function.

After pre-selections, most of the residual proton background was removed by using dedicated rejection algorithms: 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 about 5% up to 1 TeV, and 10%–20% in the energy range from 1 TeV to 4.8 TeV, while keeping a constant high efficiency of 80% for electrons.

Systematic uncertainties include errors in the absolute normalization for a total of 3.2% together with energy dependent errors as BDT stability, trigger efficiency in the low-energy region, tracking dependence, dependence on methods of charge identification, electron identification and MC model dependence.

4. – Results and discussion

Figure 1 shows the cosmic-ray all-electron spectrum [9] obtained with a statistic increased by a factor of 2.3 since the last publication on this topic [5]. Results are compared with those achieved by other experiments carried out in space: AMS-02 [12], DArk Matter Particle Explorer (DAMPE) [13] and Fermi Large Area Telescope (Fermi-LAT) [14].

The CALET spectrum is in agreement with the AMS-02 data below 1 TeV. In the energy range between 40 and 300 GeV, the power-law index of the CALET spectrum has the value of -3.128 ± 0.019, which is consistent, within the errors, with the results of the mentioned experiment. However, the spectra measured by DAMPE and Fermi-LAT are considerably harder than the one measured by CALET in the energy range between 300 and 600 GeV. Anyway, their results exhibit a higher flux in the energy range between 300 GeV and 1 TeV and this may indicate the presence of some unknown systematic effects. In order to check if the CALET spectrum is consistent with the spectral break observed by DAMPE at about 0.9 TeV, a fit has been performed with a smoothly broken power-law model in the energy range from 55 GeV to 4.8 TeV, while fixing the break energy at 914 GeV. The result of the fit is a spectral index changing from -3.151 ± 0.012 by -0.873 ± 0.178 with $\chi^2 = 11.64$ and a number of degrees of freedom equal to 29:

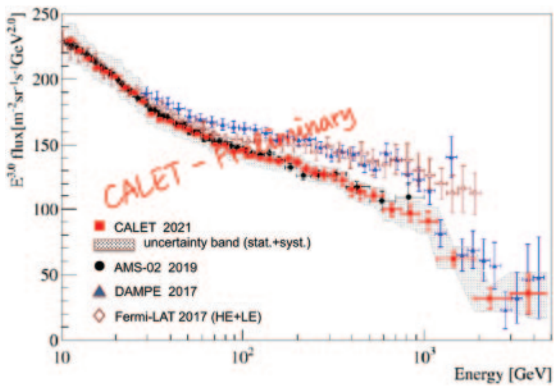

Fig. 1. – Cosmic-ray all-electron flux (multiplied by $E^{3.0}$) measured by CALET in the energy range from 11 GeV to 4.8 TeV: the dotted band denotes the quadratic sum of statistical and systematic errors (the uncertainty on the energy scale is not included). CALET data are superimposed to those achieved by other recent direct measurements in space [12-14] and available in literature.

this result is consistent with the DAMPE one, where the spectral index change was -0.7 ± 0.3. The smoothly broken power-law hypothesis is favored with a significance of 6.55 σ over a single-power-law hypothesis tested over the same energy range. Finally, the trend observed in the DAMPE spectrum near the value of 1.4 TeV, 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 evaluated by both experiments.

A preliminary interpretation of the all-electron spectrum and its astrophysical implications has been provided [15]: however, in order to have conclusive information about this subject, it will be necessary 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.

REFERENCES

[1] Adriani O. *et al.*, *Nature*, **458** (2009) 607.

[2] Accardo L. *et al.*, *Phys. Rev. Lett.*, **113** (2014) 121101.

[3] Torii S., Marrocchesi P. S. *et al.*, *Adv. Space Res.*, **64** (2019) 2531.

[4] Adriani O. *et al.*, *Phys. Rev. Lett.*, **119** (2017) 181101.

[5] Adriani O. *et al.*, *Phys. Rev. Lett.*, **120** (2018) 261102.

[6] Adriani O. *et al.*, *Phys. Rev. Lett.*, **122** (2019) 181102.

[7] Adriani O. *et al.*, *Phys. Rev. Lett.*, **125** (2020) 251102.

[8] Adriani O. *et al.*, *Phys. Rev. Lett.*, **126** (2021) 241101.

[9] Torii S. *et al.*, in *Proceedings of 37th International Cosmic Ray Conference (ICRC2021), Berlin (Germany) - Online, 12–23 July 2021*, *PoS(ICRC2021)*, **395** (2021) 105.

[10] Kasahara K., in *Proceedings of 24th International Cosmic Ray Conference (ICRC1995), Rome (Italy), 28 Aug–8 Sep 1995*, edited by Iucci N. and Lamanna E., Vol. **1** (Editrice Compositori, Bologna) 1995, p. 399.

[11] Allison J. *et al.*, *Nucl. Instrum. Methods A*, **835** (2016) 186.

[12] Aguilar M. *et al.*, *Phys. Rev. Lett.*, **122** (2019) 101101.

[13] Ambrosi G. *et al.*, *Nature*, **552** (2017) 63.

[14] Abdollahi S. *et al.*, *Phys. Rev. D*, **95** (2017) 082007.

[15] Motz H. *et al.*, in *Proceedings of 37th International Cosmic Ray Conference (ICRC2021), Berlin (Germany) - Online, 12–23 July 2021*, *PoS(ICRC2021)*, **395** (2021) 100.