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Predicted CALET measurements of electron and positron spectra from 3 to 20 GeV using the geomagnetic field

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Abstract

The CALorimetric Electron Telescope (CALET) is an imaging calorimeter under construction for launch to the ISS in 2014 for a planned 5 year mission. CALET consists of a charge detection module (CHD) with two segmented planes of 1 cm thick plastic scintillator, an imaging calorimeter (IMC) with a total of 3 radiation lengths ($X_{\circ}$) of tungsten plates read out with 8 planes of interleaved scintillating fibers, and a total absorption calorimeter (TASC) with 27 $X_{\circ}$ of lead tungstate (PWO) logs. The primary objectives of the experiment are to measure the electron $e^- + e^+$ energy spectra from 1 GeV to 20 TeV, to detect gamma-rays above 10 GeV, and to measure the energy spectra of nuclei from protons through iron up to 1000 TeV. In this paper we describe how the geomagnetic field at the 51.6° inclination orbit of the ISS can be used to allow CALET to measure the distinct electron and positron fluxes. The positron fraction has been seen to rise above ~ 10 GeV by previous experiments (HEAT, AMS-01), and more recently to continue to increase to higher energies (~ 80 GeV for PAMELA, ~ 200 GeV for Fermi and ~ 350 GeV with the best statistics for AMS-02). Utilizing the geomagnetic cutoff, CALET will be able to distinguish electrons and positrons in the ~ 3–20 GeV energy range where the positron fraction turns upward to complement existing high statistics measurements.

Keywords: CALET; Cosmic ray; Positrons; Electrons; Positron fraction

1. Introduction

The positron fraction rises above ~ 10 GeV (Adriani et al., 2009) and recently has been seen to continue to increase to higher energies (~ 135 GeV for PAMELA in Adriani et al. (2013), ~ 200 GeV for Fermi in Ackermann et al. (2012), and ~ 350 GeV with the best statistics for AMS-02 in Aguilar et al. (2013)), as shown in the left plot of Fig. 1. The electron and positron fluxes multiplied by the cube of the particle energy (E^3) for PAMELA (Adriani et al., 2011, 2013) and Fermi (Ackermann et al., 2012) are shown in the right plot of Fig. 1, as well as the positron flux derived for AMS-02 from its positron fraction (Aguilar et al., 2013) and the PAMELA electron flux (Adriani et al., 2011). The relative rise of the positron flux above ~ 10 GeV is clear, and is seen to continue past ~ 200 GeV where the AMS-02 data results suggest it is leveling off. The locally observed rising positron fraction has generally been attributed to possible spectral contributions from pulsars or dark matter annihilation, but this feature might also arise from propagation effects.

The recent AMS-02 results are consistent with those from PAMELA, but show those of Fermi to be systematically offset to higher values. This plot also suggests that the better part of the systematic difference in the positron fraction between Fermi and other experiments lies mostly in their measurement of the positron flux. AMS-02 and PAMELA are both magnetic spectrometer instruments, while Fermi measured the positron fraction by exploiting the East-West effect of the geomagnetic field, and was able to push its measurement to higher energies by exploiting the earth shadow effect of the geomagnetic field. The CALorimetric Electron Telescope (CALET) can also employ the

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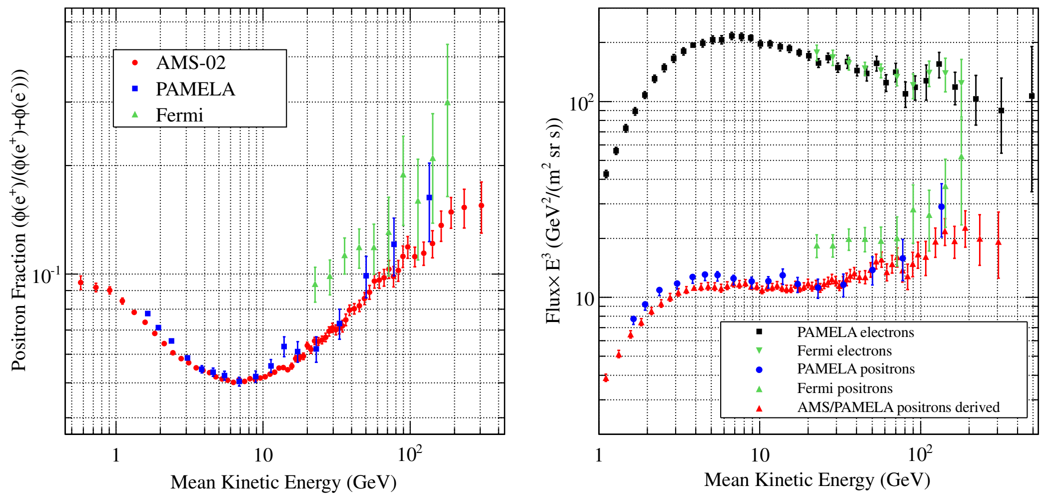

Fig. 1. Left: AMS-02 (Aguilar et al., 2013), PAMELA Adriani et al. (2013) and Fermi (Ackermann et al., 2012) positron fraction energy spectra. Right: PAMELA (Adriani et al., 2011; Adriani et al., 2013) and Fermi (Ackermann et al., 2012) electron and positron fluxes and the derived AMS-02 positron flux (Aguilar et al., 2013; Adriani et al., 2011) multiplied by the cube of the particle energy (E^3).

rigidity cutoffs from the earth's geomagnetic field to measure the positron fraction at lower energies.

2. CALET instrument and objectives

CALET is an experiment designed principally for the detection of the highest energy electrons, and the instrument and its main scientific objectives have been discussed previously in Torii et al. (2011) and Yoshida et al. (2011). CALET is under construction for launch to the International Space Station (ISS) in 2014, and it consists of the main calorimeter (CAL) and dedicated CALET Gamma-ray Burst Monitor (CGBM) subsystems, as shown in the diagram on the left of Fig. 2. The side-view of the CAL in the right plot of Fig. 2 shows that it consists from top to bottom of a charge detection module (CHD) composed of two crossed layers of 3.2 cm wide × 1 cm thick × 44.8 cm long EJ204 scintillator paddles, an imaging calorimeter (IMC) composed of eight x-y planes of 448 1 mm^2 scintillating fibers interleaved with tungsten plates, and a total absorption calorimeter (TASC) with twelve crossed layers of 16 PWO logs that are 19 mm wide × 20 mm tall × 326 mm long. The IMC has 5 plates of 0.2 radiation length ($X_\circ$) thick above 2 plates of 1 $X_\circ$ thick tungsten (total of 3 $X_\circ$) spaced with structural honeycomb, and the TASC has 27 $X_\circ$ of PWO, giving the CAL a total of 30 $X_\circ$ and making it the deepest calorimeter yet flown in space. The active area of the CAL decreases from 44.8 cm on a side at the CHD and IMC to 32 cm on a side in the TASC, and has a total instrument geometry factor of 0.12 m^2 sr. The CAL detection efficiency and its energy resolution as a function of energy are shown in the left and right plots of Fig. 3 (Akaike et al., 2011), respectively.

As its name emphasizes, CALET is focused on measuring electrons, which the CAL will do for the total electron flux $e^- + e^+$ for energies from 1 GeV to 20 TeV owing to the great depth of the TASC. CAL will also measure gamma-rays with energies between 10 GeV and 10 TeV, as well as the energy spectra of the more abundant nuclei with $Z \leqslant 28$, due to the good charge resolution of the CHD (Marrocchesi et al., 2011). In addition to the spectra

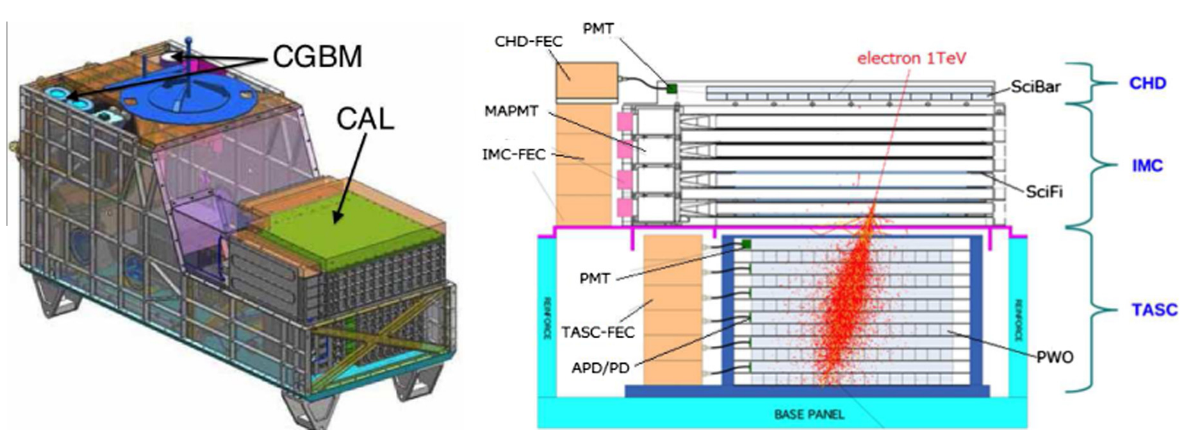

Fig. 2. Left: CALET instrument package showing CAL and CGBM subsystems. Right: CAL side-view showing CHD, IMC, and TASC detectors.