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Study of charged cosmic rays with the *Fermi* Large Area Telescope

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Abstract

The *Fermi* Large Area Telescope (LAT) is a space-based observatory conceived to study high-energy gamma rays, but also capable to detect cosmic-ray electrons and positrons. It is operating in low Earth orbit since June 2008 and thanks to its large acceptance, has collected the largest high-energy cosmic-ray electron sample to date, with more than 10k events above 1 TeV. The new Pass 8 event-level analysis, recently released by the *Fermi*-LAT Collaboration, provides several improvements, from the instrument simulation to the reconstruction algorithms, and opens new opportunity for cosmic-ray studies. In this talk we describe the instrument capabilities as a cosmic-ray detector and review its previous results. Recent new measurements and future prospects will also be discussed.

1. Introduction

The electron component of the primary cosmic-ray radiation is widely recognized as a unique probe to address a number of significant questions concerning the origin of cosmic rays and their propagation in our Galaxy. In fact, they tell us about the physical processes in their acceleration sites and the interstellar medium, as they propagate through the Galaxy. Moreover they are expected to provide indications of new physics, since they are possible products of decay or interaction of dark matter candidate particles.

Evolution of detector technology plays a major role in cosmic ray study, allowing more and more precise measurements and extending the explored energy range. Since instruments must be placed outside the shielding effect of the atmosphere, with balloon or, even better, in orbit, it turns out that improvements of satellite technology is also crucial. In this work we will describe the capability and the results of one of the most recent space based detector, the Large Area Telescope (LAT) [1] on board of the Fermi mission [2]. We will see how this detector behaves with cosmic ray electrons, its results and its future prospective related to a new event analysis package.

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2. Detection of cosmic-ray electrons with the Large Area Telescope

The Large Area Telescope, the main instrument on board the *Fermi* satellite, is conceived to study the gamma-ray sky at energy above ~20 MeV. Its design maximize the collection area and field of view (~ 2.4 sr at 1 GeV) in order to enhance the detector sky survey capability. In fact since its launch in June 2008, the LAT operates mainly in “rocking” mode trying to have a good exposure of the entire sky.

The core of the telescope is a tracker-converter subsystem, composed of position sensitive solid state detectors interleaved with tungsten foils to enhance interaction probability. The electromagnetic shower developed after interaction in the tracker is partially absorbed by a calorimeter composed of CsI bars in a hodoscopic configuration. In this way we can sample the longitudinal and transverse shape of the energy deposition, fit its profile and measure the energy of the incoming particle [3]. An anticoincidence detector surrounds the tracker and provides discrimination power for charged particles.

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The LAT trigger schema uses signal from all the subsystems, but the workhorse is the tracker one and requires signal in only 3 x-y consecutive layers. Therefore the LAT triggers on almost every particle that crosses the detector resulting in an average trigger rate of ∼ 2 kHz, most of which is cosmic-ray protons. In-orbit operation imposes a limit on the available bandwidth to transmit data to the ground, and a software filtering stage is required to remove obvious charged particles to reduce the particle rate. Since particle fluxes decrease quickly with energy we can disable the filter for high energy events without consuming too much bandwidth. All the events that deposit more than 20 GeV in the calorimeter are sent to the ground, allowing the study of high energy cosmic rays. Moreover a second filter instance is used to send to the ground a prescaled sample of all the triggers for diagnostic purposes. This sample can be used for physics measurements, allowing the study of lower energy particles, although the available statistics is reduced by the prescale factor of 250.

Events are processed on ground with an automated pipeline in order to reconstruct the event, measure particle energy and incoming direction, and give topological information to identify the particle type. While the reconstruction is designed for photons, it relies on the characteristics of electromagnetic showers and works very well also for electrons and positrons. For these particles, a dedicated selection stage has been built. It relies on the LAT capability to discriminate electromagnetic from hadronic showers based on the different topologies of the events in the three LAT subdetectors. We use the same selection strategy for cosmic rays as for gamma rays, with a decision tree analysis to boost the rejection power of the instrument. It is worth noticing that decision trees proved to be a powerful and reliable tool and are becoming a standard technique in the cosmic ray field.

The LAT response functions are evaluated using a detailed Monte Carlo simulation of the detector. Comparisons between flight data and Monte Carlo predictions are used to validate the latter and quantify the systematic uncertainties in our measurements.

It is important to note that the LAT does not carry a magnet on board to discriminate particle charge and it is not able to separate electrons and positrons based on information from its subsystems. On the other hand it does not suffer from size and mass limitation due to magnets and can take advantage of a large collecting area. Being in stable sky survey operation since 4 August 2008, the LAT has a very long exposure time and benefits from a very large statistics of collected cosmic rays.

3. Cosmic-ray $e^+ + e^-$ spectrum

The inclusive spectrum of $e^+ + e^-$ was published in 2009 [4] in the energy range 20 GeV – 1 TeV and extended down to 7 GeV in the 2010 paper [5]. It was obtained from the combination of two analyses, optimized for the two different on board filter instances described in section 2. In both cases the flux is obtained correcting the observed number of events with the effective geometry factor that describes the instrument's acceptance including the efficiency of the event selection. The residual hadron background is evaluated using a detailed Monte Carlo simulation of the instrument in its orbital environment and is subtracted from the number of observed counts. The residual contamination reaches a maximum of about 20% at 1 TeV. Figure 1 shows the result of this analysis, while its details, including a complete description of the cosmic-ray electrons selection is described in [5].

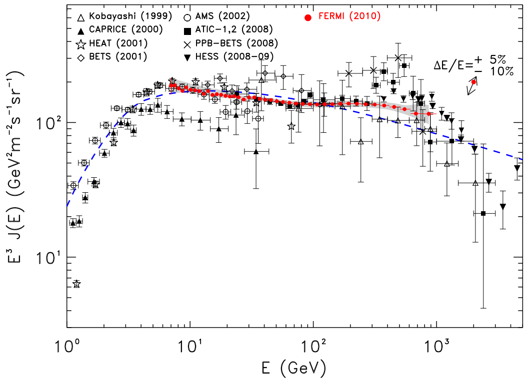

Figure 1: Cosmic-ray electron plus positron spectrum measured by the LAT (from [5]), compared with other previous measurements.

Below an energy of few tens of GeV, the effect of the Earth's geomagnetic field is no longer negligible and has to be taken into account. The magnetic field has the effect of shielding the Earth from cosmic rays therefore the spectrum shows a clear cutoff at low energy. Since we are interested in primary particles we have to find the minimum energy unaffected by the geomagnetic cutoff as a function of the orbital parameters of the *Fermi* satellite. We found convenient to organize data in bins of McIlwain L parameter since the cutoff can be reasonably described as a function of this quantity. In each bin we extracted, from the data itself, the cutoff value and the minimum energy to be used for the analysis. Combining the results in all McIlwain L bins leads to the low energy part of the spectrum.