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Nuclear and Particle Physics Proceedings 291–293 (2017) 36–39

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Fermi Large Area Telescope Observations of the gamma-ray emission from the Quiescent Sun

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Abstract

The high energy gamma-ray emission from the Sun is due to the interactions of cosmic ray (CR) protons and electrons with matter and photons in the solar environment. Such interactions lead to two component gamma-ray emission: a disk-like emission due to the nuclear interactions of CR protons and nuclei in the solar atmosphere and a space extended emission due to the inverse Compton (IC) scattering of CR electrons off solar photons in the whole heliosphere. The observation of these two solar emission components may give useful information about the evolution of the solar cycle by probing two different CR components (proton and electrons) in regions not directly accessible by direct observations. We present the results of the observations of the Sun with Fermi-LAT in the first 7 years on orbit, with the exception of the flaring periods. Significantly large photon statistics and improved processing performance allow us to explore both components of the emission in greater details and perform better comparisons of data with current models of the IC component. This allows us to probe CR electrons in the inner heliosphere which is not possible by other methods. Moreover, the longer period of observations allows us to study the variations of the emission between the maximum and the minimum of the solar cycle.

Keywords: gamma-rays, Sun, solar emission

1. Introduction

The high energy gamma-ray emission from the Sun is due to the interactions of cosmic ray (CR) protons and electrons with matter and photons in the solar environment. Such interactions lead to two component gamma-ray emission: a disk-like emission due to the nuclear interactions of CR protons and nuclei in the solar atmosphere and a space extended emission due to the inverse Compton (IC) scattering of CR electrons off solar photons in the whole heliosphere [1] [2] .

While the IC emission is brightest in the region within a few degrees from the Sun, even at larger elongation angles it can be comparable in intensity to the isotropic (presumably extra-galactic) gamma-ray background [3]. The flux for both components of the CR-induced emission is expected to change over the solar cycle due to the change of the heliospheric flux of the Galactic CRs in anticorrelation with the variations of the solar activity.

The observation of these two solar emission components may give useful information about the evolution of the solar cycle by probing two different CR components (proton and electrons) in regions not accessible by direct measurements.

https://doi.org/10.1016/j.nuclphysbps.2017.06.008

2. Data Selection and background

In our analysis we have evaluated the gamma-ray flux from the Sun using the data collected by the Fermi LAT in the first 7.5 years of operation from 2008 August 4 up to 2015 December 31. Of course, the data set used is much larger than the previously published [4], moreover the data are reprocessed with the new Pass 8 reconstruction and event-level analysis that is a comprehensive revision of the entire analysis chain and provides improved processing performance with respect to previous analysis: wider energy range, larger acceptance, better Point Spread Function (PSF), better background rejection, better control of systematic uncertainties [5] .

We select events in an energy range between 100 MeV and 30 GeV in a region of interest (ROI) of 20° centered on the Sun position. To reduce the contamination by the gamma-ray emission coming from CR interactions in the Earth's upper atmosphere our selection is refined by selecting events with zenith angles <100°. To reduce the systematic uncertainties due to bright gamma-ray emission from the Galactic plane we exclude the data taken when the Sun was within 30° of the plane. We further excluded the periods when the Sun was within 20° from the Moon or any other bright celestial source with integral flux F $\geq 2\times10^{-7}$cm^{-2}s^{-1} above 100 MeV, as reported in the 3FGL catalog [6]. We finally remove all solar flares observed in the period considered for the analysis. Because the Sun is a moving source, the analysis of its emission requires a special treatment, so the data are selected in a moving frame centered on the instantaneous solar position. Fig. 1 shows a Sun-centered count map of the solar emission components above 10 GeV, while Fig. 2 shows the Sun events as a function of the elongation angle for different energy thresholds (from top to bottom, E_{min}=0.5 GeV, 1 GeV, 5 GeV, 10 GeV). The peak corresponds to the disk events in the centre of the reference frame (θ=0, where θ is the elongation angle).

The correct evaluation of the background in the region around the Sun is of considerable importance for the analysis of the weak extended IC emission. The latter is expected to decrease with $\sim 1/\theta$ [1]. The background is mainly due to the diffuse Galactic and isotropic (presumably extra-galactic) gamma-ray emission averaged along the ecliptic and to weak point sources. The background is estimated with the trial off-time source method where an off-time source follows the path of the real source but at different times and at 90° distance (same path at different times) as shown in Fig. 3.

Fig. 4 shows the distribution of the events for both

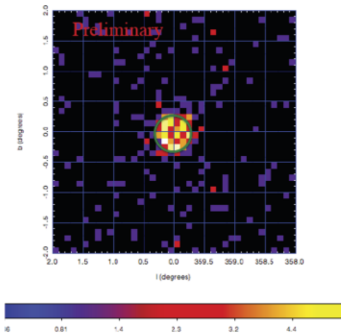

Figure 1: Photons counts map of the solar emission components above 10 GeV.

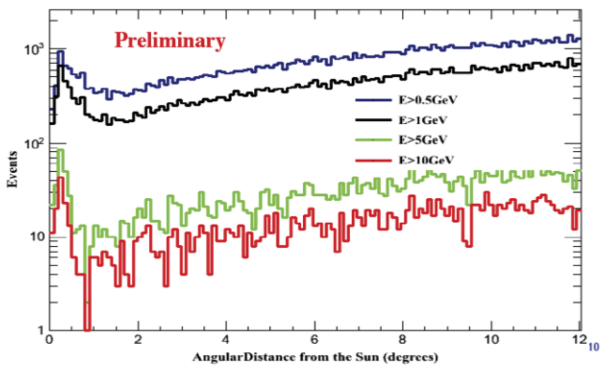

Figure 2: Sun events as a function of the angular distance from the Sun, for different energy thresholds. From top to bottom: E_{min}=0.5 GeV, 1 GeV, 5 GeV, 10 GeV