Observation of the extragalactic diffuse continuum gamma-ray emission with Fermi LAT

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***Abstract*. The Large Area Telescope (LAT) on the Fermi Gamma-ray Space Telescope provides tremendous advances for studying the high-energy diffuse gamma-ray emission at energies between 100 MeV and >300 GeV. Its large field-of-view of 2.4 sr and its effective area of up to 0.8 m^2, combined with a sky-survey observation strategy, allow for an almost uniform exposure of the whole sky with unprecedented statistics.**

The diffuse emission observed by the Fermi LAT is a superposition of several components. A highly structured Galactic component arising from the interactions of cosmic rays with the interstellar gas and radiation is dominant at low Galactic latitudes. The target of this study is an additional isotropic component which is considered to be of extragalactic origin. Other contributions include solar system sources including the gamma-ray albedo of the Earth, charged cosmic rays mis-classified as gamma-rays and stray photons from detected point sources.

Here we present an analysis of the intensity of the extragalactic diffuse gamma-ray emission observed by the LAT, based on careful modeling and subtraction of the detected LAT point sources and the mentioned foregrounds. The obtained spectrum and a comparison to results derived from EGRET observations of the isotropic diffuse gamma-ray emission will be presented at the conference.

***Keywords*: gamma rays:observation, diffuse radiation, extragalactic**

I. INTRODUCTION

A diffuse background emission that appears to originate outside the Milky Way is observed at all wavelengths from radio to gamma rays. These photons are believed to have different origins, some arising from truly diffuse processes, while others can be understood as the summed emission from many unresolved point sources too weak to be detected individually. At high-energy γ-ray energies (E>100 MeV) the dominant source of the extragalactic diffuse emission is believed to be emission from unresolved Active Galactic Nuclei (AGN). However, also contributions from star-forming galaxies, galaxy clusters, structure formation and un-triggered GRB have been discussed (for a recent overview see [3]).

The biggest challenge in the extraction of the extragalactic diffuse background (EGB) is the subtraction of the various strong foregrounds which exist in the Fermi LAT photon dataset. Most important are the contributions from the Galactic diffuse emission, the background from misclassified cosmic rays and from the resolved sources.

In this paper the various aspects of dealing with these foregrounds to achieve a reliable measurement of the EGB are presented. The instrumental background is suppressed by applying very stringent event selection criteria beyond the standard event selection. The diffuse emission originating from cosmic-ray interactions with the interstellar medium in the Milky Way is modeled based on the GALPROP [5], [6] package. Two independent analyses are applied to subtract the foregrounds and derive the EGB from the Fermi LAT dataset with the intent being mutual confirmation of the results.

II. DATA SELECTION

At trigger level, charged cosmic rays outnumber the detected gamma rays in the LAT by several orders of magnitude. However, through sophisticated multivariate background rejection techniques [2], this background from charged cosmic rays is reduced to levels suitable for gamma-ray analysis. However, the standard Fermi LAT event selection intended for low residual background studies (commonly dubbed the 'diffuse' class) still features a level of residual background comparable to the extragalactic diffuse emission [2].

To further reduce this contamination and obtain an extremely clean gamma-ray sample, specific additional event selection steps have been introduced for this analysis. They are dedicated to target residual heavy ions as well as protons and alpha particles that have inelastically scattered in the data sample.

Three event properties were used to perform this selection. The transverse shower size in the LAT calorimeter was required to be above a certain (energy dependent) minimum size to reject minimal ionizing heavy ions. The transverse shower size [1] was also demanded to be below an (energy dependent) maximum. Larger transverse sizes are typical of hadronic showers from interacting charged cosmic rays. As a further step to reject more residual heavy ions, the average charge deposit in the silicon tracker was required to be below an (energy dependent) threshold. Figure 1 shows a comparison of the described event properties for a 'clean' data sample, i.e., a data sample with a high gamma-ray to background fraction,

[1] In this case the track extrapolated from the silicon tracker is used as the shower axis because of higher rejection power

for a ’dirty’ data sample with a low gamma-ray to background fraction and for a sample of simulated γ-rays obtained with the GLEAM detector simulation. The ’clean’ sample is taken from the region of the inner Galaxy and only during periods when the Fermi spacecraft was in regions of low CR flux. The ’dirty’ sample on the other hand was obtained from high Galactic latitudes when the LAT was positioned in regions of high CR flux.

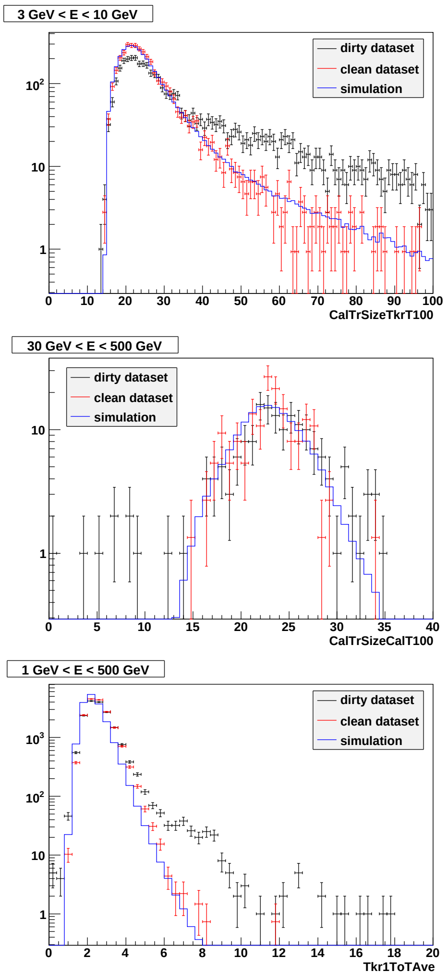

Fig. 1: Comparison of the distributions of event properties in the LAT for a data sample with low residual background, a data sample with high residual background and a simulation of γ-rays in the instrument. Shown are the transverse shower size (top), transverse shower size with shower size extrapolated from the silicon tracker (middle) and a variable correlated to the charge deposited in the silicon tracker (bottom). The energy range for each figure is chosen to obtain the best contrast between the low/high residual background samples.

The high background sample clearly shows features not visible in the low background and simulated samples. The distributions obtained from the simulation are in good quantitative agreement with the low background data sample. The described set of energy dependent veto cuts is used to remove such features indicative of residual CR background, while retaining the majority of the gamma rays. Figure 2 shows the effective area fraction retained with the additional event selection relative to the effective area of the standard ’diffuse’ selection. It is 85% or better for all energies between 100 MeV and 500 GeV.

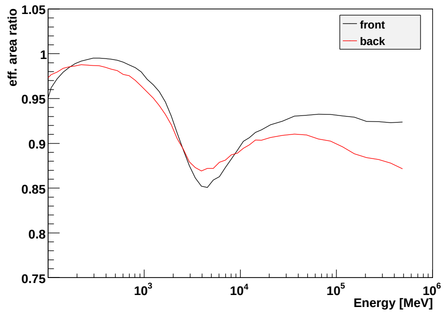

Fig. 2: Fraction of the effective area retained with the derived event selection relative to the standard LAT event selection. The two curves are for γ-rays converting in the part of the silicon tracker with thin converter foils (black) vs. events converting in the section with thick converter foils (red)

To obtain a measure of the data sample quality improvement due to the introduced selection one can split the data sample into independent subsets corresponding to observation periods with different average CR rates. Figure 3 shows the derived flux of the extragalactic diffuse component (relative to the flux derived from the total data sample) as a function of the average CR flux for the standard event selection and with the additional selection described here. The slope is significantly reduced, as a linear fit to the data samples shows. For convenience the CR rate recorded by the LAT is expressed here as the deadtime fraction, which is linearly correlated to the CR rate since each triggered and read out event incurs a certain instrumental deadtime.

The described approach is mainly targeted at residual background from charged CRs above 1 GeV. However, also below that energy charged particle background exists from secondary cosmic rays produced in the atmosphere of the earth. Accordingly, the selection presented here may be amended as effective ways to reduce contamination at low energies are found.

III. Modeling of the Galactic diffuse emission contribution

The foreground emission of diffuse γ-rays from the Galaxy needs to be modeled carefully since it has potentially a large influence on the isotropic extragalactic diffuse emission. In the case of the LAT predecessor EGRET it was shown that the used galactic diffuse emission model had a large impact on the derived extragalactic intensity [4], [7]. The galactic diffuse model used for this analysis is developed in close connection with the

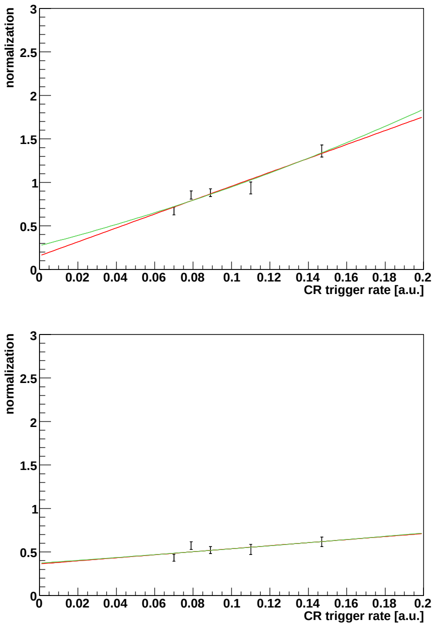

Fig. 3: Ratio of derived isotropic diffuse flux for independent observations at various CR trigger rates to the diffuse flux obtained from the full sample. Top corresponds to the standard data selection bottom corresponds to the event selection introduced here. The energy range shown is 6 GeV - 12 GeV.

determination of the large-scale Galactic diffuse gamma-rays [8] and based on a calculation of CR propagation in and interacting with the interstellar medium with the GALPROP code. A study is in progress to evaluate the impact of small changes in the diffuse emission model on the extragalactic diffuse flux. Several models with different cosmic-ray injection and propagation parameters compatible with the Fermi LAT data and local data on CR observations are created and used to estimate the systematic uncertainty attributed to the modeling.

IV. Analysis techniques

Two independent analysis techniques are used to cross-calibrate the determination of the extragalactic diffuse emission spectrum.

The first is based on a simultaneous maximum-likelihood all-sky fit of point sources, the galactic diffuse emission model and an isotropic component which represents the diffuse emission attributed to be of extra-galactic origin. The galactic diffuse emission is further split into several components in this approach, corresponding to different types of interstellar gas (molecular, atomic, ionized hydrogen) and radiation as well as corresponding to different spatial regions (inner, local, outer Galaxy) which are considered individually. Details of this technique are described in [1].

The second technique is based on the method used in [4]. The flux predicted by point sources and the galactic diffuse model for individual regions on the sky is compared to the flux obtained with the LAT instrument. A linear fit to this distribution yields an offset, which is equivalent to the non-modeled contributions, here the extragalactic diffuse emission.

While they use independent approaches to extract the EGB, however, both methods rely to some extent on the same Galactic diffuse model as an input and the related uncertainties are present in both analyses.

The spectrum of the EGB derived from the described methods will be shown at the conference.

V. Summary

Two independent analyses of the extragalactic diffuse gamma-ray emission seen by the Fermi LAT are currently performed. Due to the low intensity expected of the isotropic component [2] a tighter event selection than the standard LAT event selection is needed, rejecting more residual background from charged CRs. The Galactic diffuse emission is a very strong foreground for this study. It is modeled based on the GALPROP CR propagation and interaction code and the impact of variations of the Galactic diffuse model on the extragalactic diffuse emission are investigated.

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[2] In the case of a dominant contribution from unresolved point sources the measured diffuse background depends on the point source sensitivity of the instrument. Thus, compared to its predecessor EGRET the contribution of unresolved AGN to the Fermi LAT diffuse background is expected to shrink to about 15%-40% [2] of the EGRET value.