Abstract summary: we describe some methods for the identification of cosmic-ray protons with the Fermi-LAT.

Identification of Cosmic Ray Protons with the Fermi-LAT

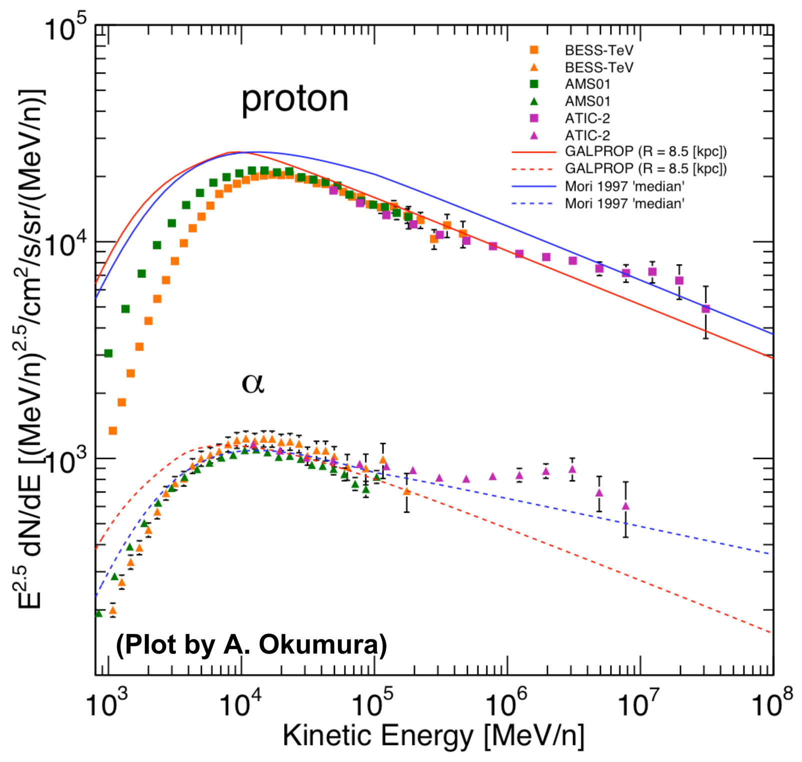
M. E. Monzani (SLAC National Accelerator Laboratory)
on behalf of the Fermi Large Area Telescope Collaboration

Abstract

The Fermi Large Area Telescope has been designed and optimized for the detection of gamma rays. However, as the recent results on the electron+positron spectrum demonstrate, we are able to identify and reconstruct signals from charged cosmic-ray particles as well. Some methods for the identification of proton signals in the LAT are being implemented, based on a set of basic cuts and also on a new multivariate analysis framework. We display the implementation of these methods, as well as the performance of the LAT for detecting and measuring cosmic-ray protons.

Detection and identification of protons

Protons constitute the dominant component of the cosmic-ray flux at the Fermi location and altitude. The reconstruction of proton energies and arrival directions would be a valuable addition to the LAT science output (at the very minimum, it would allow us to constrain our background models with greater precision). The first step in this process is the correct identification of proton signals in the detector.

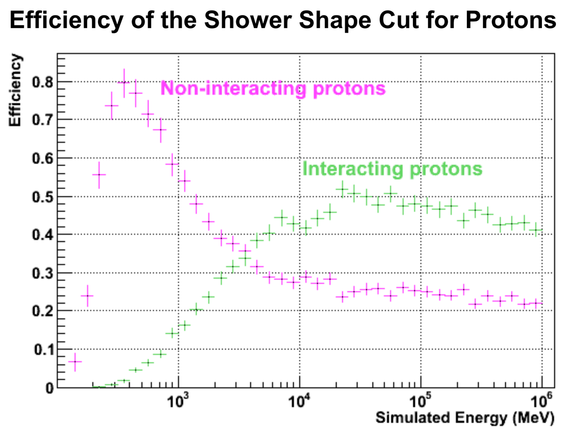


In this study, we will focus on the identification of CR protons in the energy range between approximately 10 GeV and 1 TeV, where the flux is maximum.

Proton selections with simple cuts: the High Acceptance class

The main tool for detecting charge particles in the LAT is the Anticoincidence Detector (ACD). However, the discrimination of protons from electrons and positrons relies on the entire development of the particle signal in the Tracker and in the Calorimeter.

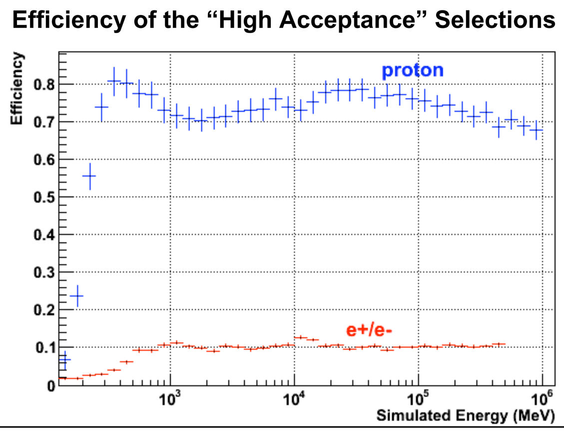
Efficiency of the Shower Shape Cut for Protons



As an example, we show here the efficiency of a cut based on the shape of the particle shower in the CAL, for protons that undergo/don't undergo hadronic interactions in the CAL.

We thus define a "High Acceptance" proton class, which features a high and uniform efficiency for protons and a suppression of a factor 10 of the e^+/e^- background, in the energy range of interest.

Efficiency of the "High Acceptance" Selections



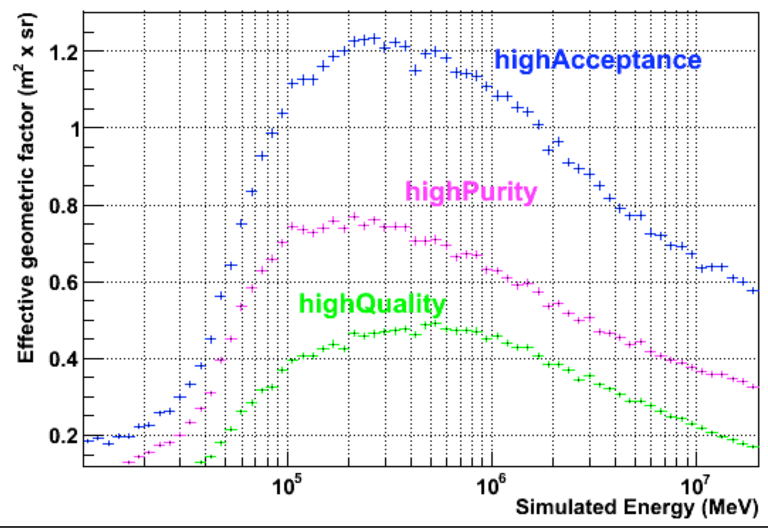
More selections with simple cuts: the High Acceptance/High Quality classes

Using advanced information from the TKR signal, we can improve the purity of the protons sample, by removing most of the contamination from alphas and metals (Z>2), obtaining a "High Purity" proton class.

Moreover, we can add some quality requirements to the reconstructed proton track, to define a "High Quality" proton class.

The plot shows the effective geometric factor for the different proton classes: the High Acceptance class features a maximum of 1.2 $m^2 \cdot sr$ (with an overall contamination from non-protons of approx. 20%), while the High Quality class reaches a maximum of 0.5 $m^2 \cdot sr$ (with a total background from non-protons of order 5%).

Effective Geometric Factor for the 3 different Proton classes



A new multivariate approach to proton identification

We have developed a new analysis method, based on a multivariate approach, for the identification of protons in the LAT. This method makes use of the ROOT Toolkit for Multivariate Data Analysis (TMVA), through a custom-made graphical interface (TMine), which has been developed within the Fermi-LAT collaboration.

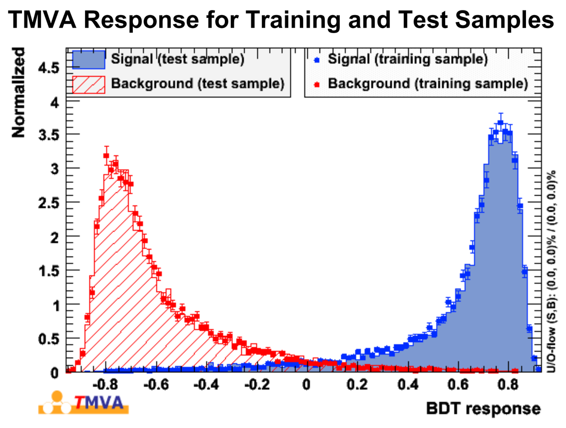
We choose to base our analysis on Boosted Decision Trees (BDT), in continuity with the event selection strategies already in place for the identification of photons and electron/positrons.

The "All Hadrons" class

We decided to break down the problem of selecting proton signals in the LAT in its two main components: first we try to distinguish hadrons from leptons and then we try to separate protons from alphas and metals (Z>2). We execute our analysis after the ACD precuts, on events that have been rejected as candidate photons.

For the first step of this analysis (the hadrons/leptons separator), we grow a single classification tree, which contains 8 variables, and involves all the different subdetectors of the LAT. The results of the training process look very promising.

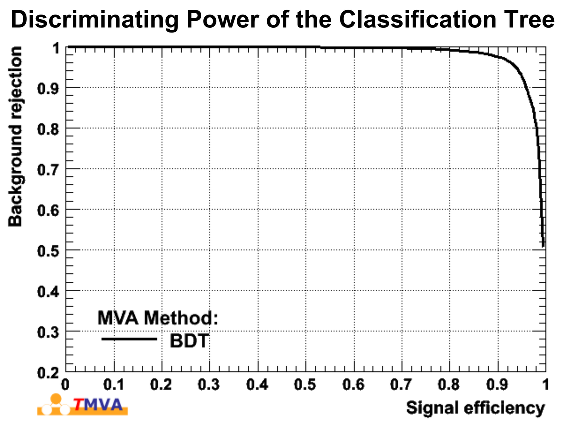
TMVA Response for Training and Test Samples



Left: the response distributions are very well separated and devoid of internal structures.

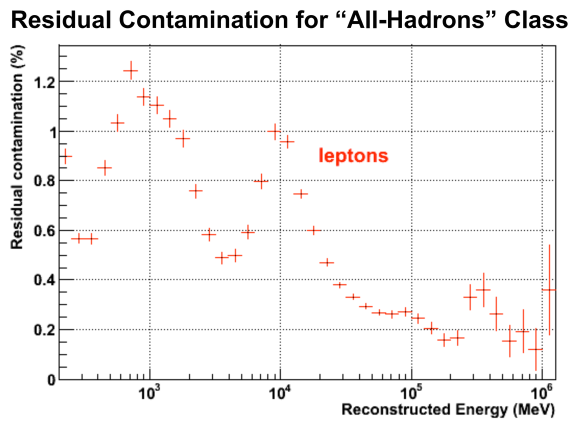
Right: the discriminating power features a 99% background rejection, while preserving 83% of the signal.

Discriminating Power of the Classification Tree

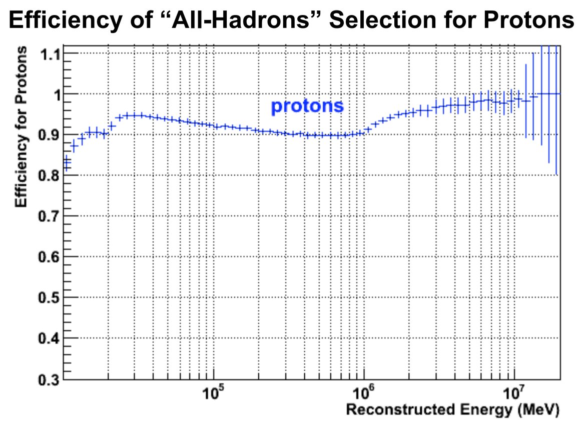


We can define an "All Hadrons" class by cutting on the discrimination parameter: in the plots below, we can see that the residual leptons contamination is always of order 1% or smaller (left), that the efficiency for protons is constant over a wide energy range and greater than 90% (center) and that the effective geometric factor for protons peaks at 2.3 $m^2 \cdot sr$ at 400 GeV.

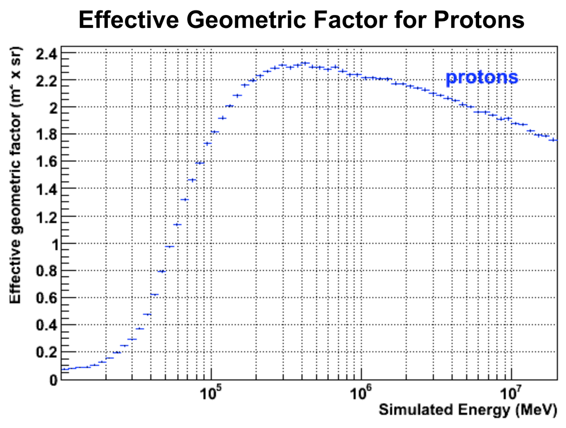
Residual Contamination for "All-Hadrons" Class



Efficiency of "All-Hadrons" Selection for Protons



Effective Geometric Factor for Protons

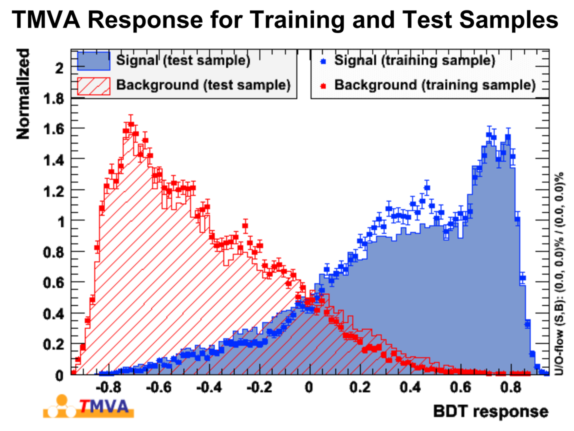


The "Proton Only" class

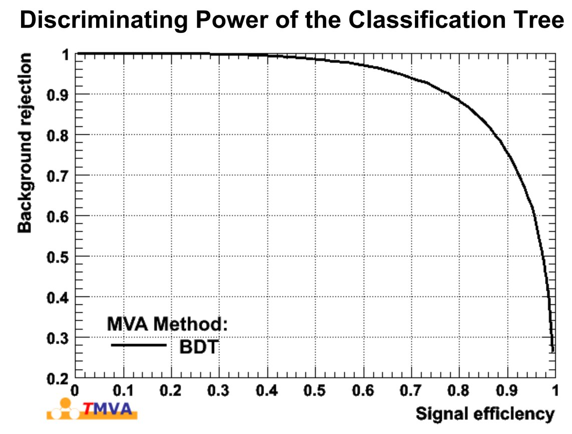
The second step of this analysis requires to distinguish protons from alphas and heavier nuclei (Z>2). For this purpose, we grow a Classification Tree to be executed after the hadron/lepton classifier. The issue of discriminating protons from alphas is particularly delicate, because in case of hadronic interactions in the CAL the signals from the two particles are very similar: hence, this classification tree will make use of many more variables than the hadron/lepton one.

The response distributions look reasonably separated, even though the separation is not as good as in the hadron/lepton case. The discriminating power is still acceptable (we can reject 99% of the background, preserving approximately half of the signal).

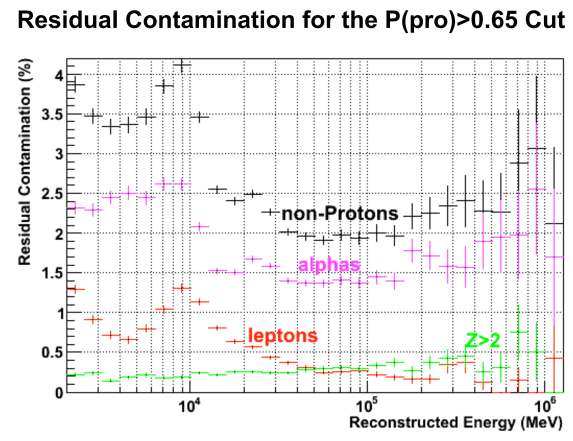
TMVA Response for Training and Test Samples



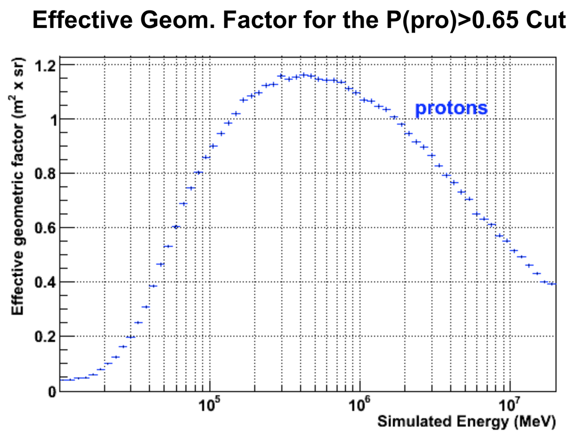
Discriminating Power of the Classification Tree



Residual Contamination for the P(pro)>0.65 Cut



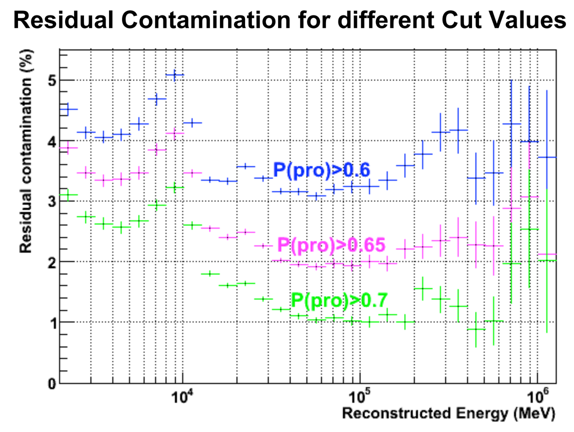
Effective Geom. Factor for the P(pro)>0.65 Cut



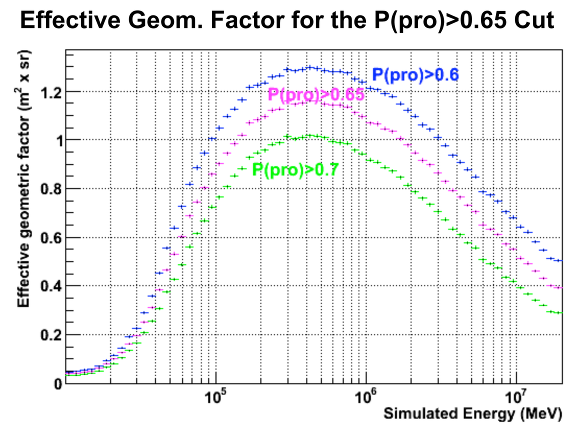
The plot on the left shows the components of the residual contamination for a fixed cut (P>0.65) on the discriminating parameter: the background is dominated by alphas, as expected, and is of order 3%. The effective area for protons peaks at 1.16 $m^2 \cdot sr$ at 400 GeV.

We compare the residual contaminations and geometric factors for 3 different values of the proton predictor cut: even with the cleaner class (background under 2%), the effective area reaches 1.02 $m^2 \cdot sr$ at 400 GeV.

Residual Contamination for different Cut Values



Effective Geom. Factor for the P(pro)>0.65 Cut



Acknowledgements

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