A search for candidate TeV emitters in the high-latitude *Fermi* unassociated sources

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on behalf of the *Fermi* LAT Collaboration

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Summary: We report the results of an analysis to identify candidates for very high energy (VHE; E > 100 GeV) emission from the *Fermi* high-latitude unassociated sources in the year-1 catalog. The goal of this work is to select the most promising unassociated *Fermi* sources for joint observations with *Fermi* and the VHE instruments.

Abstract: We report the results of an analysis to identify candidates for very-high-energy (VHE; E > 100 GeV) emission from the *Fermi* high-latitude ($|b| > 10$) unassociated sources in the year-1 catalog under development by the LAT team. These are sources with no known counterparts at other wavelengths. Since VHE instruments are pointed instruments with small fields of view and low duty cycles, their observing programs need to be planned carefully to identify the most promising targets for observation. The scientific potential of combined *Fermi* and VHE observations has already been demonstrated with a number of joint VHE-*Fermi* papers. The goal of this work is to select the most promising unassociated *Fermi* sources for joint observations with *Fermi* and the VHE instruments.

1. Methodology:

1.1 Preliminary scan:

A preliminary scan of the catalog was done to select unassociated sources above galactic latitudes of 10° that had potential to be VHE emitters based on their flux, and spectra. The following cuts were used to get the initial list:

- l Galactic latidude l > 10°
- Flux (E > 100 MeV) > 2 x 10^{-9} cm^{-2} s^{-1}
- Photon Index < 2.0
- Number of predicted photons > 20

This list contains 80 candidates corresponding to ~ 11% of the total number of unassociated sources. The galactic coordinates of these candidates are shown in Figure 1.

1.2 Detailed analysis:

These sources were then re-analyzed to search for curvature in their spectra. For each source, events were selected from a region of 10° radius centered on the catalog coordinates for that source. These data were analyzed using the standard *Fermi* analysis software (ScienceTools v9r15p3; IRF P6_V3_DIFFUSE) available from the HEASARC. All of the *Fermi* sources in the field of view were modeled and the background emission was modeled using a galactic diffuse emission model and an isotropic component[1]. Events were analyzed using an unbinned maximum likelihood method[2,3].

The sources were modeled using a power law covering two overlapping energy ranges: (**100 MeV - 300 GeV**) and (**1 GeV - 300 GeV**). In addition, a log parabola covering the full energy range (**100 MeV - 300 GeV**) was used to search for curvature. Both spectral functions are shown below.

Power law: $F(E) = \frac{dN}{dE} = F_0 \left(\frac{E}{E_0}\right)^{-\Gamma}$ **Log parabola:** $F(E) = \frac{dN}{dE} = F_0 \left(\frac{E}{E_0}\right)^{-\left(\alpha+\beta\cdot\ln\left(\frac{E}{E_0}\right)\right)}$

The likelihood values of the power law and log parabola fits over the full energy range were compared and a χ^2 statistical test was used to calculate the probability of curvature in the photon spectrum. The covariance matrices were used to calculate the 1-sigma confidence intervals of the spectral energy distribution (SED) for each spectral model. The energy range of the SED starts at 100 MeV and terminates at the energy of the most energetic photon associated with each source. Figures 2-3 show SED examples for sources with and without evidence for curvature.

1.3 Predicting TeV flux:

For sources where there was no evidence for curvature, the flux above 100 MeV and the spectral index obtained from the power-law fit were used to estimate the flux in the VHE band (**200 GeV - 1 TeV**). The *Fermi* spectrum was extrapolated to higher energies assuming *no break* in the spectrum and the flux was absorbed for the extragalactic background light (EBL) with the model of Franceschini et al. (2008)[4]. A redshift value of $z = 0.2$ was used for all sources.

For those sources where a log parabola was a better fit, the flux and spectral index obtained using the power-law fit above 1 GeV were used for the extrapolation to the VHE band. Given that curvature was detected in the *Fermi* energy band it is likely that the predicted TeV flux is overly optimistic. But given the lack of knowledge about the redshift of these sources, we consider the brightest ones as good *fillers* in under-populated RA bands. Table 1 lists the 10 most promising unassociated *Fermi* sources for the VHE band using our methodology.

2. Results:

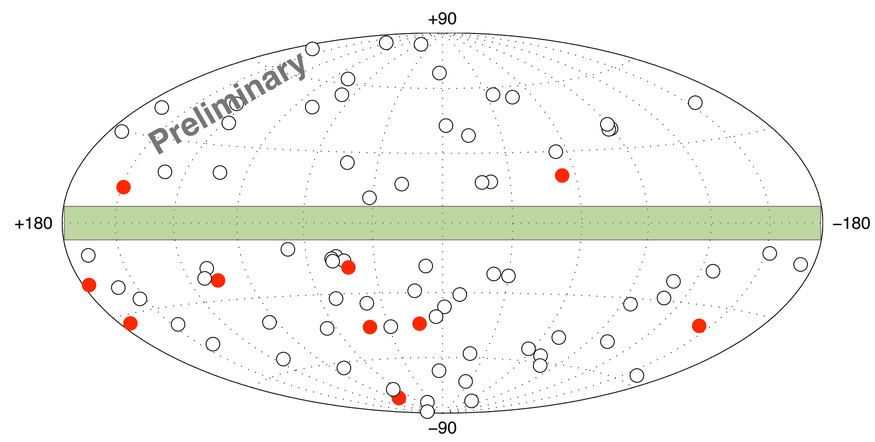

Fig. 1: Spatial distribution of the 80 candidates selected for this study in galactic coordinates. The solid red circles correspond to the top 10 candidates shown in Table 1. The green shaded region corresponds to the ±10° exclusion region centered on the galactic plane.

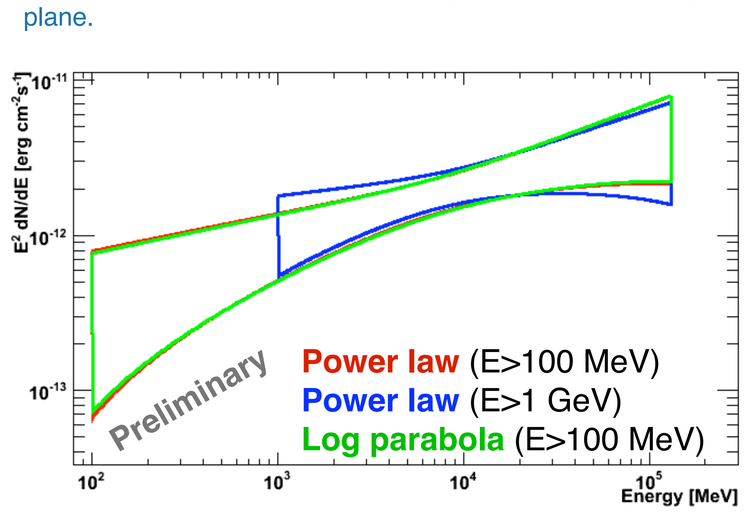

Fig. 2: SED of good TeV candidate showing no evidence for curvature in the *Fermi* energy band.

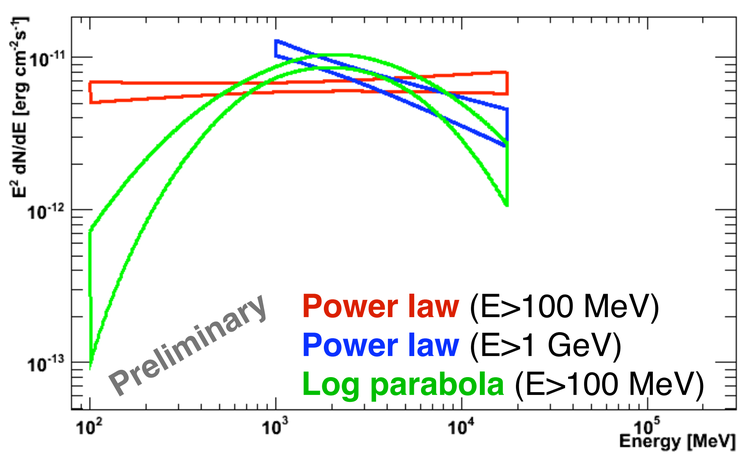

Fig. 3: SED of bad TeV candidate showing clear evidence for curvature.

Source Name	RA (J2000)	Dec (J2000)	Fermi Flux [E-09]	Fermi Index	E_{max} [GeV]	TeV Flux [10^{-12} cm^{-2} s^{-1}]	TeV Flux [Crab units]
TeV 01	00 22 22.1	-18 48 42.9	4.7 ± 1.4	1.65 ± 0.11	96	10.0	0.04
TeV 02	03 38 59.5	+13 12 39.7	4.1 ± 2.2	1.64 ± 0.18	133	8.91	0.04
TeV 03	21 18 18.4	-32 38 27.5	3.3 ± 1.7	1.61 ± 0.18	35	8.64	0.03
TeV 04	05 05 52.4	+61 22 32.7	4.1 ± 2.4	1.65 ± 0.18	131	8.39	0.03
TeV 05	13 07 40.4	-43 00 19.9	13 ± 4.1	1.84 ± 0.11	31	7.77	0.03
TeV 06	23 29 13.4	+37 55 29.9	6.5 ± 2.5	1.74 ± 0.13	71	7.51	0.03
TeV 07	04 39 53.6	-18 58 02.3	3.3 ± 1.5	1.65 ± 0.17	49	6.65	0.03
TeV 08	21 46 40.8	-13 45 30.3	7.9 ± 3.1	1.79 ± 0.15	52	6.60	0.03
TeV 09	20 14 26.0	-00 45 53.2	2.5 ± 2.2	1.65 ± 0.28	114	5.39	0.02
TeV 10	04 27 21.6	+20 26 06.0	2.2 ± 2.2	1.64 ± 0.29	71	4.89	0.02

Table 1: Predicted fluxes in the VHE energy band (200 GeV - 1 TeV) for a selection of *Fermi* unassociated sources.

3. Conclusions:

The methodology presented here allowed us to find promising candidate TeV emitters. The search for curvature in the energy spectrum allowed us to rule out several sources that would have been interesting when considering only the results of a power-law fit over the entire *Fermi* energy range.

For sources with slight curvature, using the flux and spectral index above 1 GeV is more realistic when estimating the flux in the VHE band. Some of these sources can still be good candidate TeV emitters.

For more details on this work please contact: *fortin@llr.in2p3.fr* *deirdre@llr.in2p3.fr* *elizabeth.c.ferrara@nasa.gov*

[1]http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html;
[2]Cash, W. 1979, ApJ, 228, 939;
[3]Mattox, J.R., et al. 1996, ApJ, 461, 396;
[4]Franceschini, A., et al. 2008, A&A, 487, 837;