Localization of Gamma-ray point sources with the GLAST LAT

Toby Burnett (University of Washington)
on behalf of the LAT collaboration

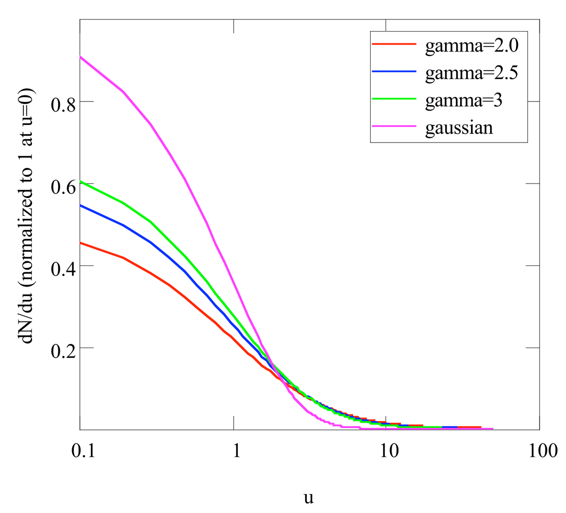
Abstract

A feature of the GLAST-LAT point spread function (PSF), as determined by Monte Carlo studies, and verified with particle beams, is that the projected distributions are not Gaussian, but have power-law tails. Also, widths vary according to a power of the gamma energy. The optimum statistical precision is obtained with a maximum likelihood fit, which is not equivalent to a weighted mean. Also, the maximum likelihood calculation can be much simpler than that used to define the spectrum, since only the part that depends on the location is relevant. We illustrate these points, and provide estimates of the localization for various sources.

The LAT PSF

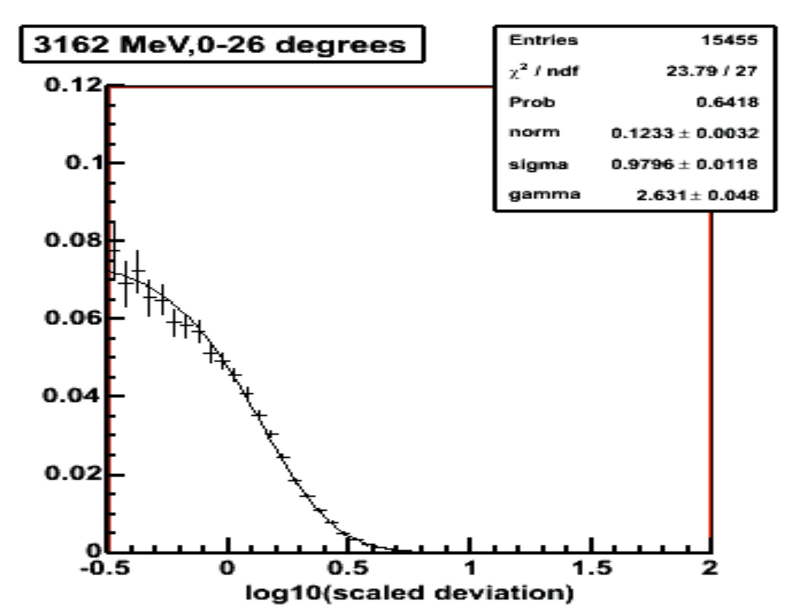
The LAT PSF, measured by Monte Carlo, and verified by test beams, has tails described by a power law in the angular deviation δ. This simple form depends on only two parameters, σ and γ, themselves dependent on angle and energy. We assume azimuthal symmetry about the source direction. Note that the limit as γ→∞ is a product of two Gaussians.

$$u = \frac{1}{2}\left(\frac{\delta}{\sigma(E)}\right)^2 \qquad f(u,\gamma) = \left(1 - \frac{1}{\gamma}\right)\left(1 + \frac{u}{\gamma}\right)^{-\gamma}$$

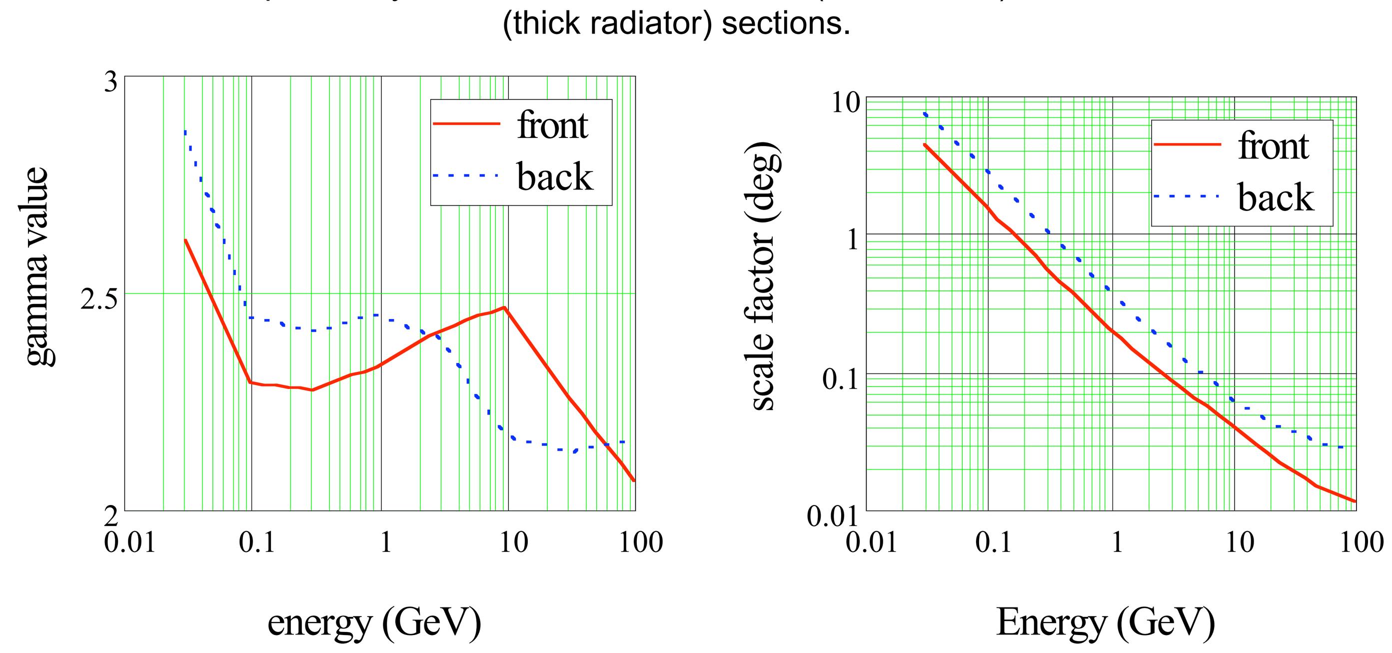


PSF Fit

Since the scale is dominated by multiple scattering up to several GeV, and (empirically) is proportional to $E^{-0.8}$ we scale the measured deviation by the factor before fitting. This plot shows the application of that model to MC data, for a range in energy and angle. We fit to the density in bins of this scaled deviation to determine the parameters. The final σ(E) is an interpolation of the fit values for different bins times the scale function.



Typical dependence of γ and σ, averaged over the field of view, independently for conversions in the front (thin radiator) and back (thick radiator) sections.



Predicted resolution

The point-source projected error is easily estimated from the PSF formula, assuming a maximum likelihood optimization.

$$\sigma_{proj}^2 = \frac{\sigma(E)^2}{t \cdot A(E) \cdot s(E) \cdot \int_0^{u_{max}} u \cdot \frac{\left(\frac{d}{du} f(u,\gamma(E))\right)^2}{f(u,\gamma(E)) + \frac{b(E)}{s(E)} \cdot 2\pi \cdot \sigma(E)^2} du}$$

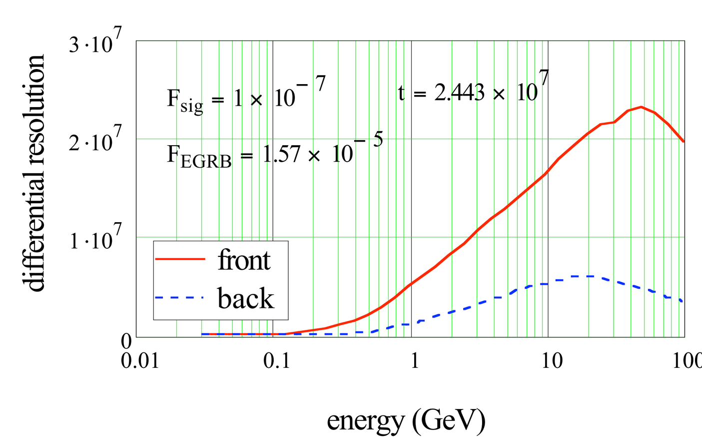
The function *b(E)* represents a uniform background flux (the estimate depends very weakly on this assumption), *A(E)* is the acceptance, *t* the total time, and *s(E)* the signal flux. If there is no background, the integral simplifies to (γ-1)/(γ+1).

Note that the naïve strategy of estimating the position by taking the mean results in the integral (for small background) being replaced by (γ-2)/γ. For γ=2.5, this is 50% worse, and as γ→2, becomes infinitely worse.

Using the DC2 estimates for the IRF and assuming

- background flux 1.5×10^{-5} cm^{-2} s^{-1} sr^{-1} for E>100 MeV, spectral index -2.1
- signal flux 1×10^{-7} cm^{-2} s^{-1} ,for E>100 MeV, index 2.0.

the above expression, inverted and integrated over energy, predicts a 1-σ error circle radius of 0.5 arcmin, which satisfies the requirement of the LAT Science Requirements Document (SRD).



The differential distribution of the resolution for the SRD case.

Note the dominance of the high energies: there is very little contribution below 1 GeV.

Measured Localization: Fits to DC2 sources

I have used the HealPixel source finder to measure localization of many sources. It is based on a very fast implementation of maximum likelihood analysis that fits to the point source fraction in each of eight energy bands, at a given source position, then optimizes the total likelihood with respect to position. It is currently limited to class A front only. (This, and the energy binning degrade the performance.) The shape of the likelihood function is a measure of the resolution. The next plot shows the distribution of projected resolutions for a variety of the DC2 sources. The histograms are for the following cuts on the flux of the sources: black, all events (526); red, flux>10^{-8} (374); blue, flux>10^{-7} (209); green, flux >10^{-6} (24).