Point Source Detection and Flux Determination with PGWave

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PGWAve Introduction

PGWave is one of the background-independent methods to detect Point Sources in high-energy astrophysics as X-ray and gamma-ray observations (low statistics).

<u>Outline</u>:

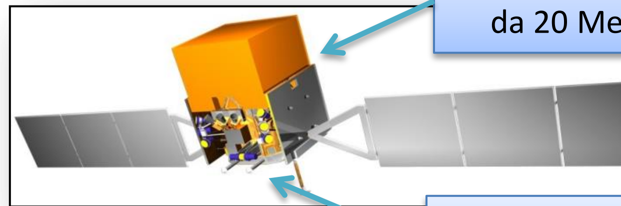
1. Fermi Large Area Telescope

2. Fermi-LAT Sky - Modelling the diffuse emission

3. PGWave: a background independent method for Point Source studies

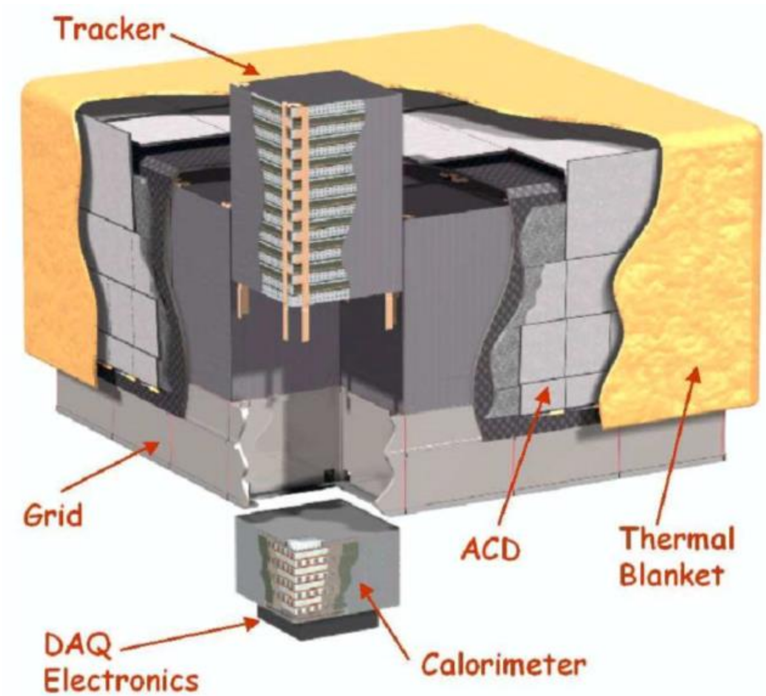
Fermi Large Area Telescope

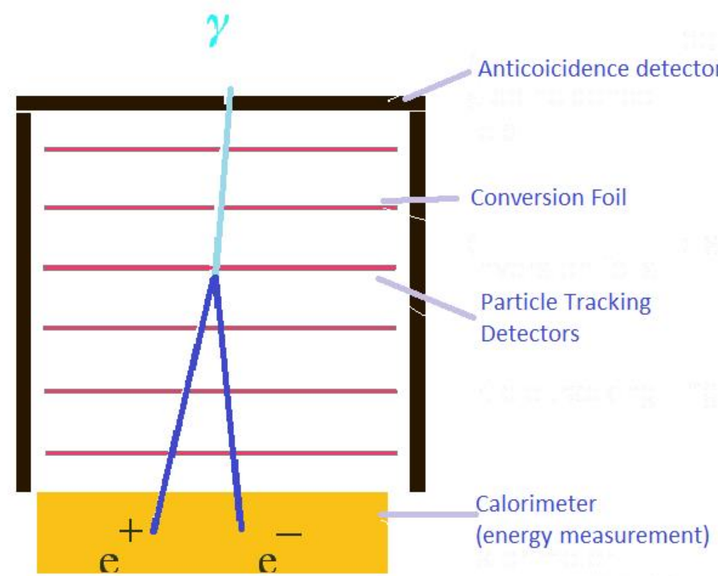
Fermi satellite was launched on 11 June 2008



LAT (Large Area Telescope)
da 20 MeV a >300 GeV

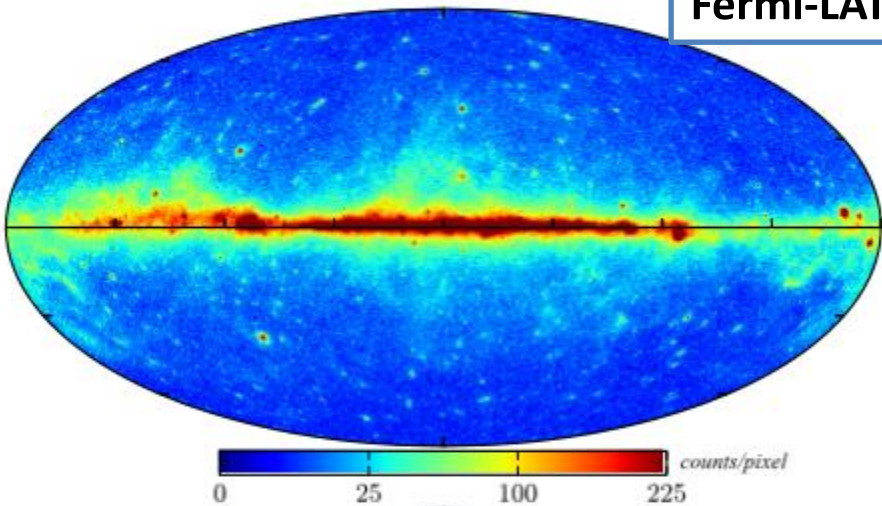
GBM (Glast Burst Monitor)
Da 1 keV a 30 MeV

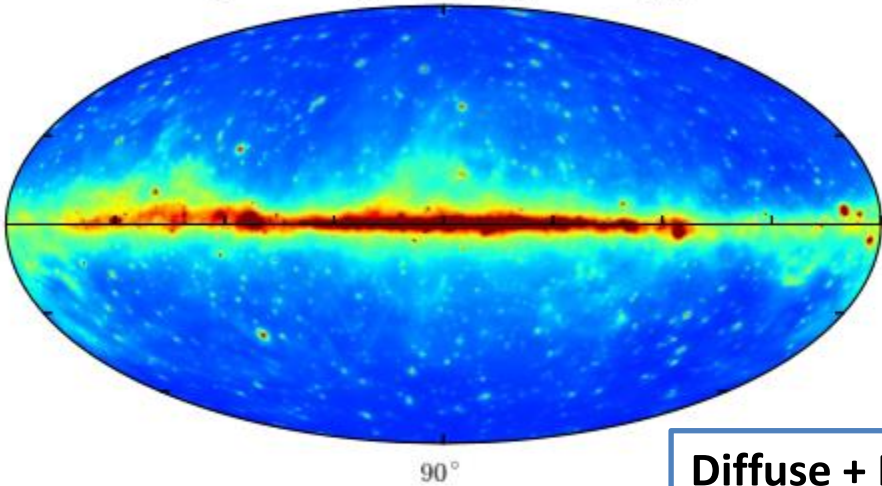




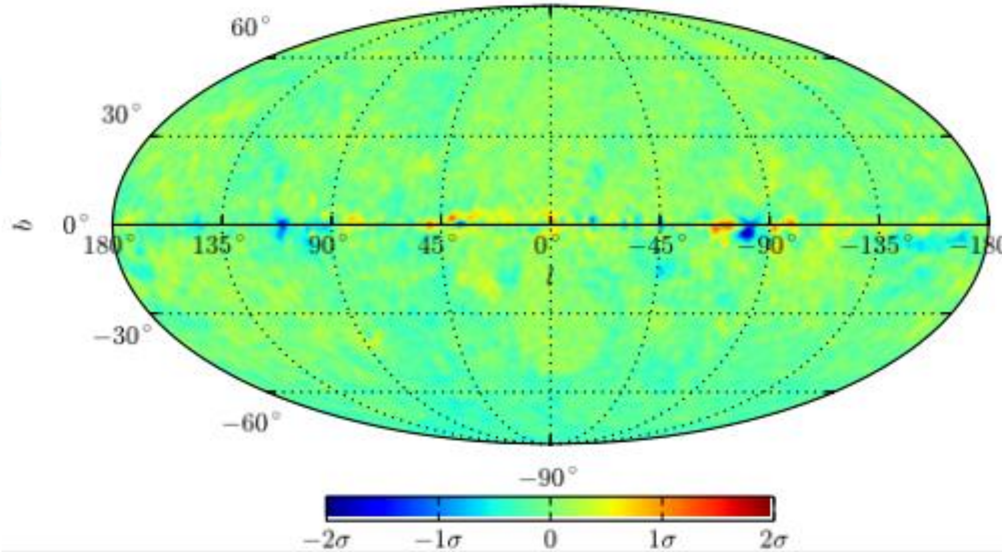
Fermi-LAT Sky and Diffuse Model

Fermi-LAT Sky



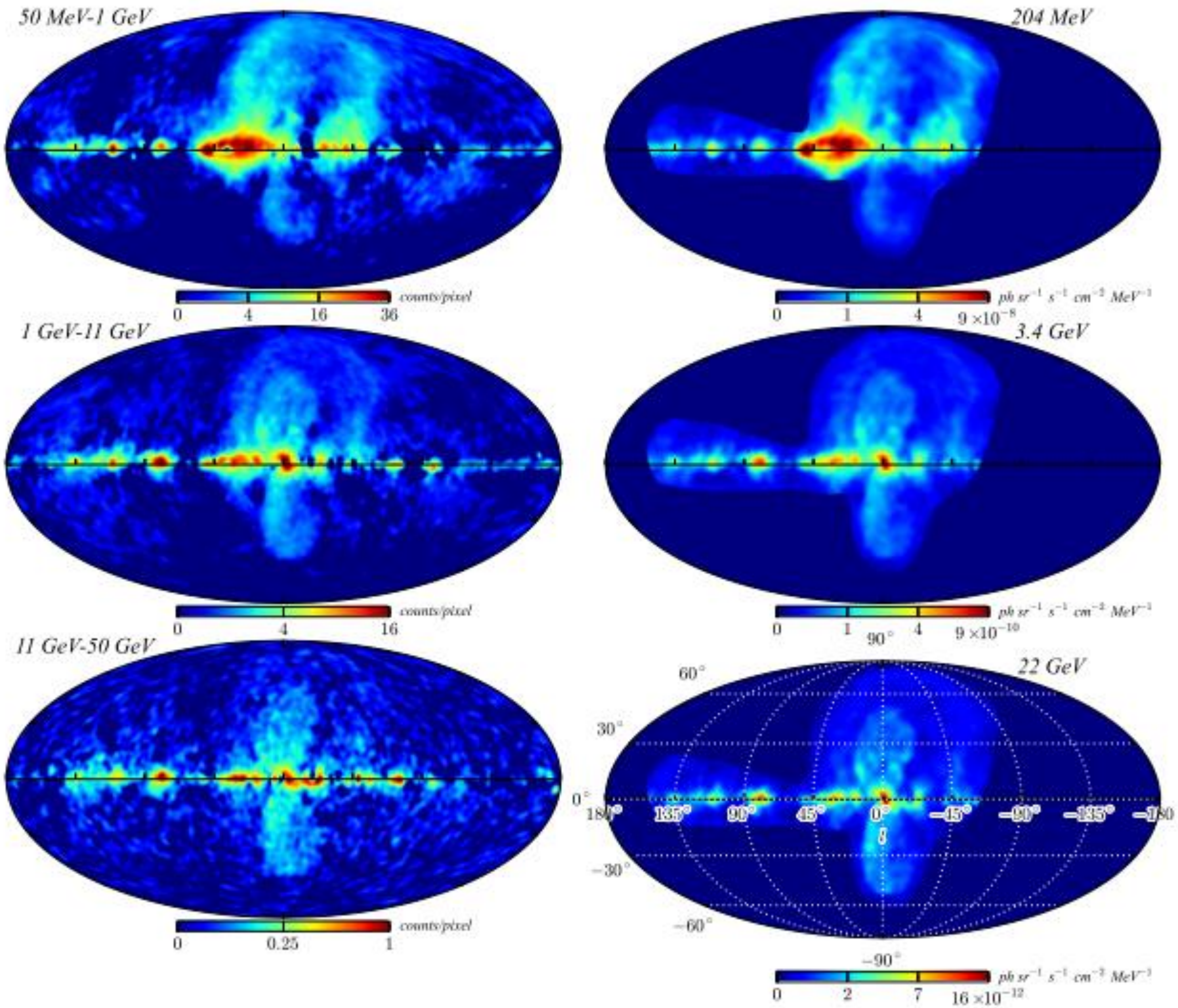


Diffuse + PS Model



Residual map

Interstellar Emission Energy Model



Left: positive difference between the LAT count map and the count map obtained with this model in three energy bands

PGWAve Introduction

One of the largest uncertainties in the Point Source (PS) studies, at Fermi-LAT energies, is the uncertainty in the diffuse background.
In general there are two approaches for PS analysis:

- **background-dependent methods** (include modeling of the diffuse bkg)
- **background-independent methods**

We study PGWave, which is one of the background-independent methods already used in the Fermi-LAT catalog pipeline for finding candidate sources. We use it not only for source detection, but especially to estimate the flux without the need of a background model.

PGWave: Wavelet Transform

PGWave is a method, based on **Wavelet Transforms** (WTs) [1], to detect sources in astronomical images obtained with photon-counting detectors, such as X-ray or gamma-ray images.

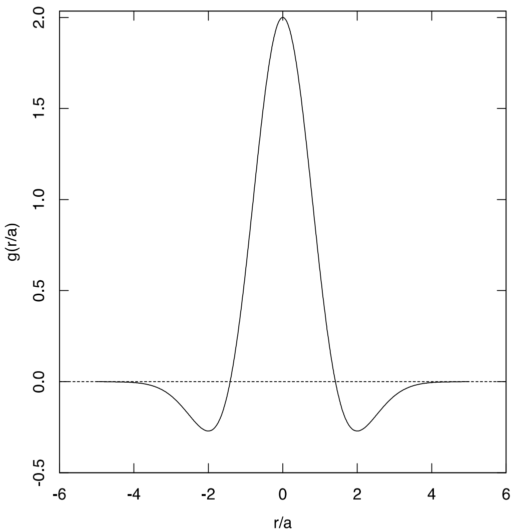
1. The WT of a 2-dim image *f(x,y)* is defined as:

$$w(x, y, a) = \iint g\left(\frac{x - x'}{a}, \frac{y - y'}{a}\right) f(x', y') dx'\, dy'$$

where *g(x/a,y/a)* is the generating wavelet, *x* and *y* are the pixel coordinates, and *a* is the scale parameter.

2. PGWave uses the 2-dim **"Mexican Hat"** wavelet:

$$g\left(\frac{x}{a}, \frac{y}{a}\right) \equiv g\left(\frac{r}{a}\right) = \left(2 - \frac{r^2}{a^2}\right) e^{-r^2/2a^2} \quad (r^2 = x^2 + y^2)$$



3. The peak of the WT for a source with Gaussian shape (N_{src} total counts and width σ_{src}) is:

$$w_{\text{peak}}(a) = \frac{2N_{\text{src}}}{(1 + \sigma_{\text{src}}^2/a^2)^2}$$

[1] Damiani F. et. al., A Method Based on Wavelet Transforms for Source Detection in Photon-Counting Detector Images, ApJ 483, 350, (1997)

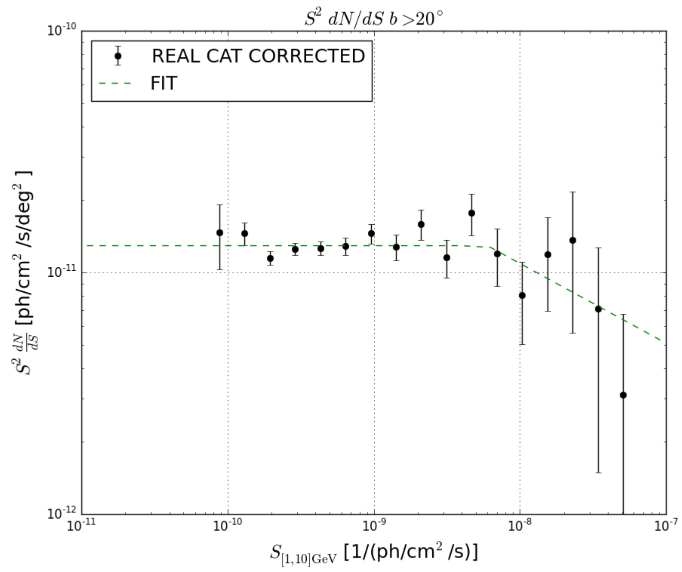
Monte Carlo Simulated Data

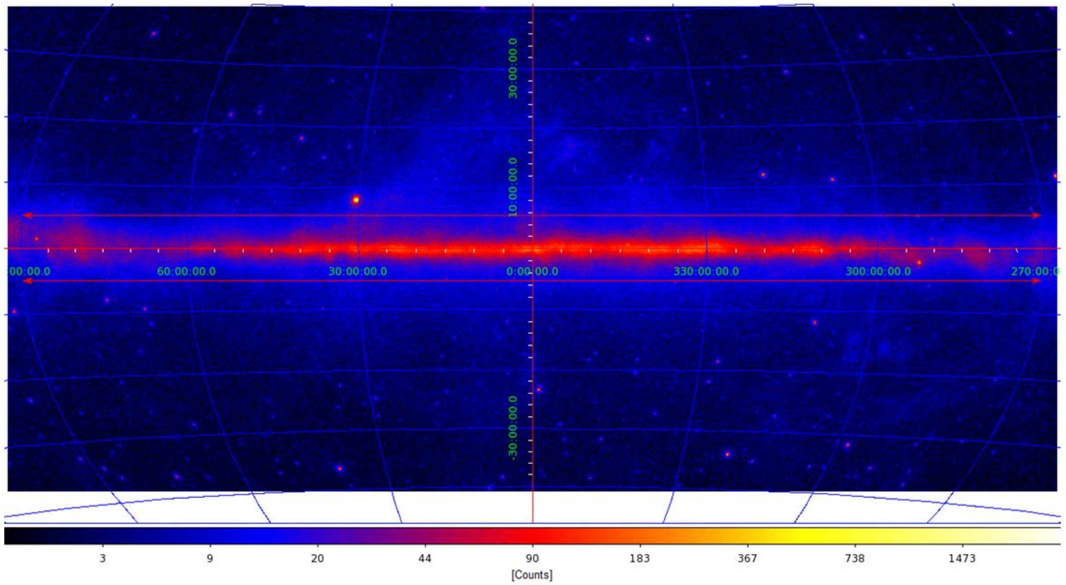
The MC simulated data were performed with gtobssim [1]. The simulation includes:

- galactic diffuse emission,
- isotropic background
- PS simulating fluxes* **

*LogN-LogS given by the green dashed line in Fig.

**Spectra: Power law with Spectral Index randomly choose from Gaussian distribution with μ = 2.30 and σ = 0.40 motivated by the distribution of extragalactic sources in 3FGL.





MC Parameters	
Energy	1-10 GeV
Interval of time	92 months
IRF	P8R2_SOURCE

[1] We thank Mattia Di Mauro (SLAC) for providing the MC data.

PGWave: Analysis

Selection:

1. We restricted the analysis in the area: -90°<LON<90°, -40°<LAT<40°.
2. We masked the Galactic Plane (-5°<LAT<5°)
3. We chose MC sources with a Flux > 10^-10 ph/cm^2/s

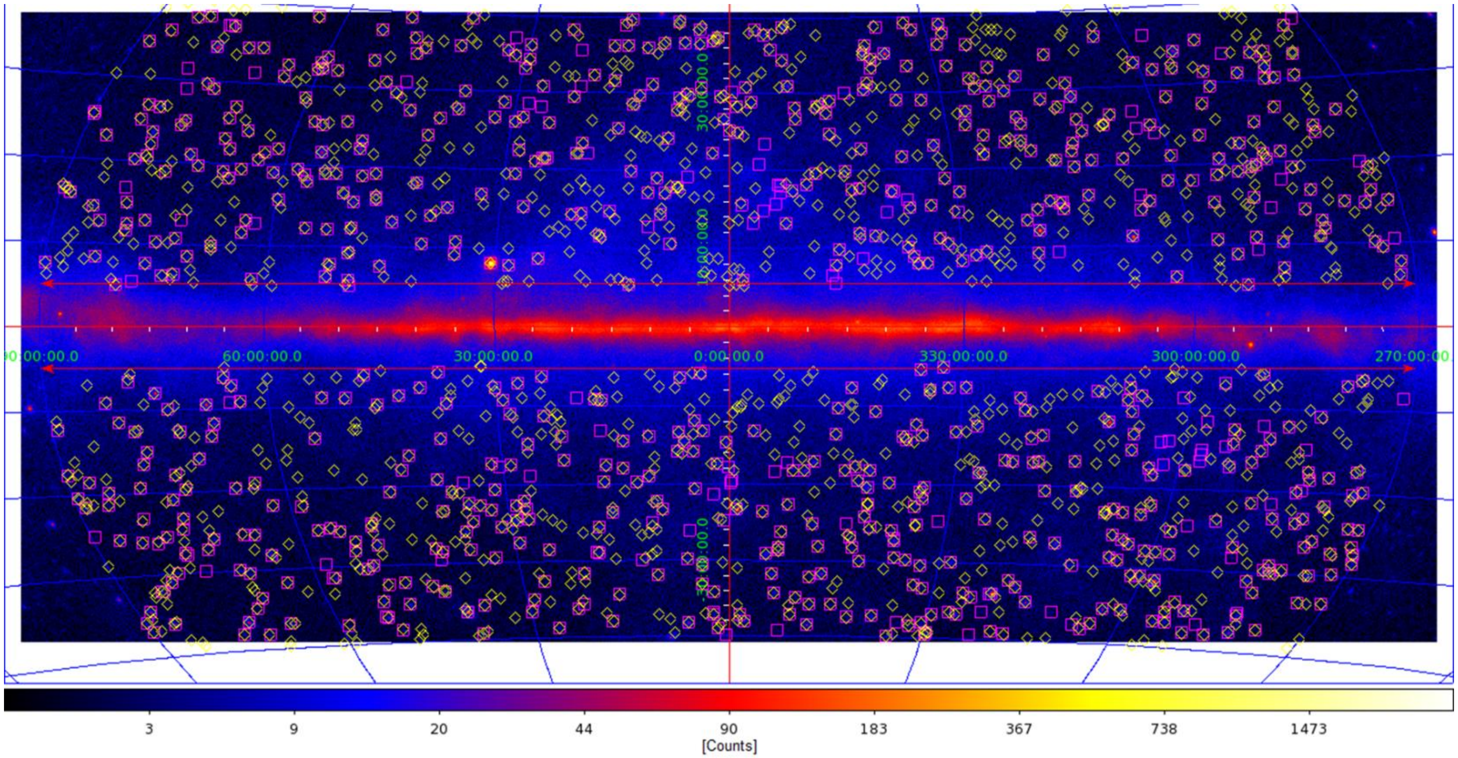
PGWave parameters	
Pixel dim.	0.1°
MH Wavelet Transform scale	0.3°
N° of sigma for the statistical confidence	3
Minimum number of connected pixels	5

PGWave: Point Source Detection

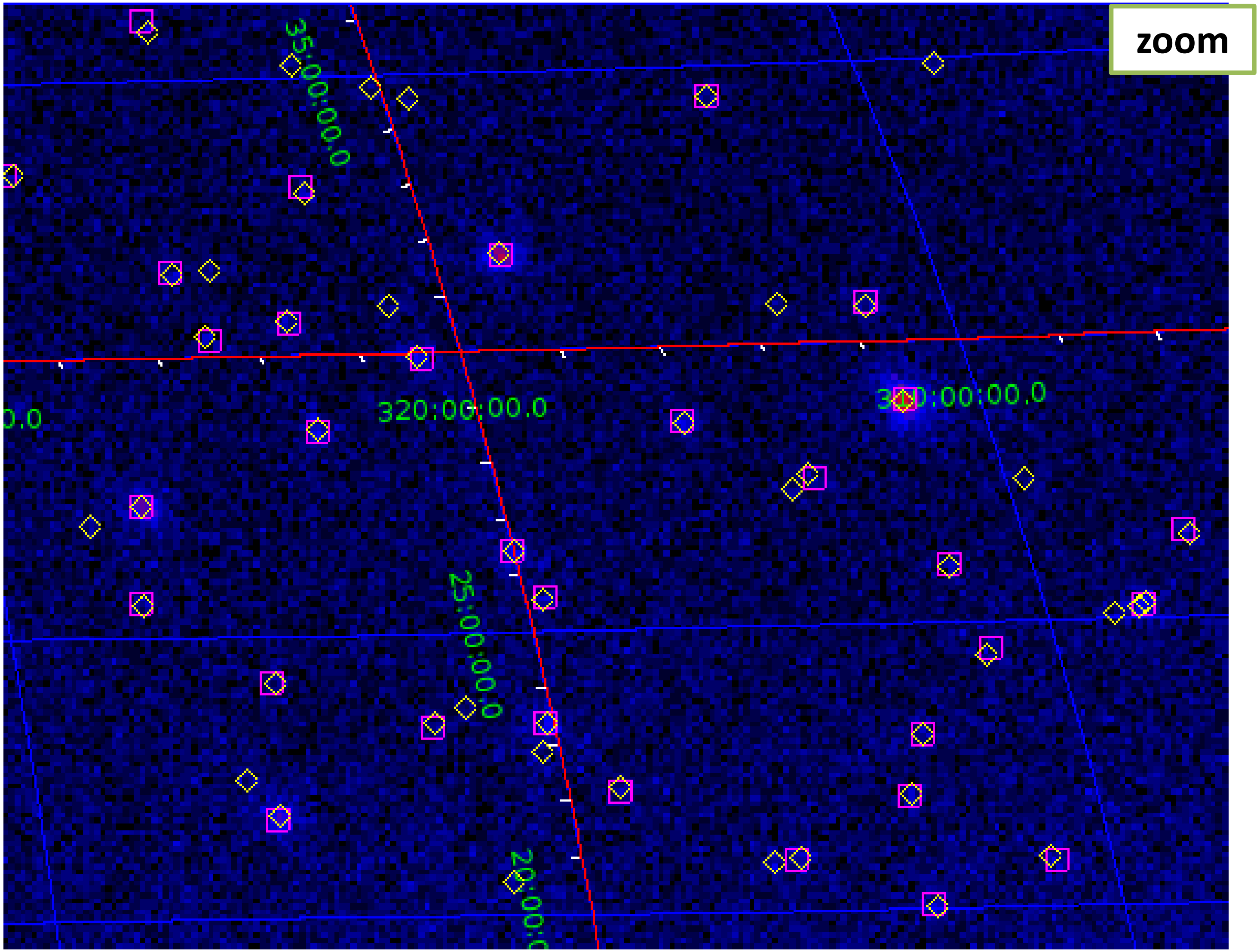
Association:

- Based on a positional coincidence.
- Tolerance radius 0.56° (similar to PSF at 2 GeV)
- Flux ordering

Results	PS (counts)	
MC Simulation (flux>10^-10 ph/cm^2/s)	1230	◇
PGwave	808	□
Associated	**720**	

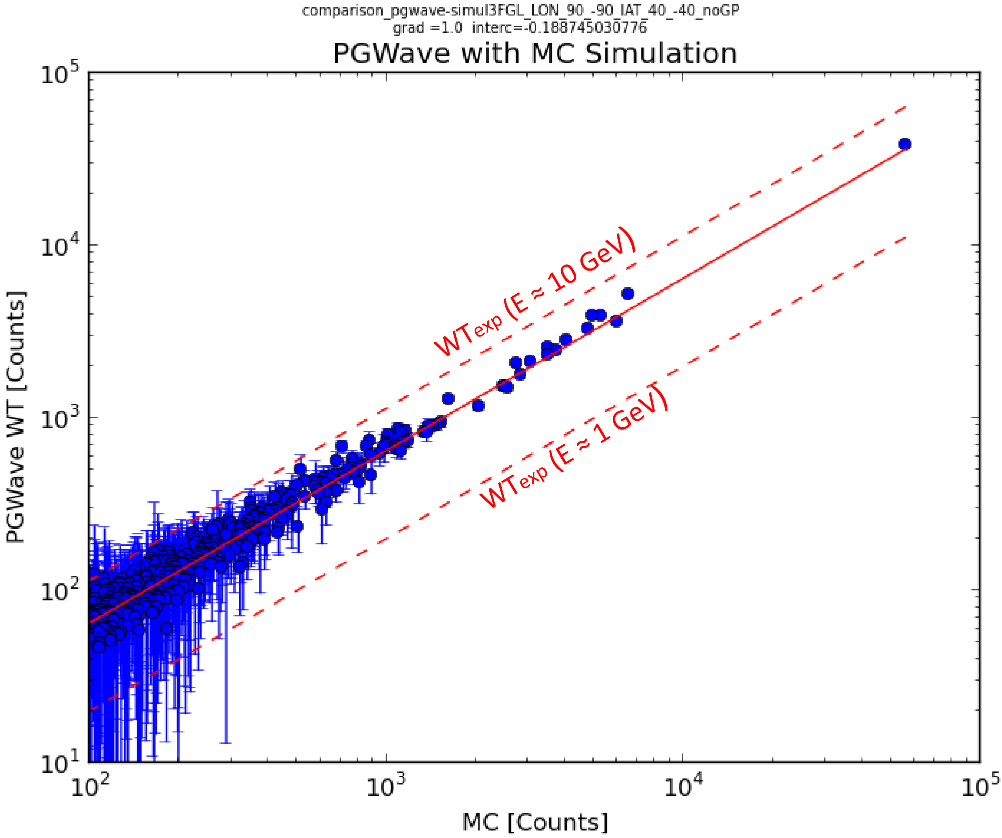


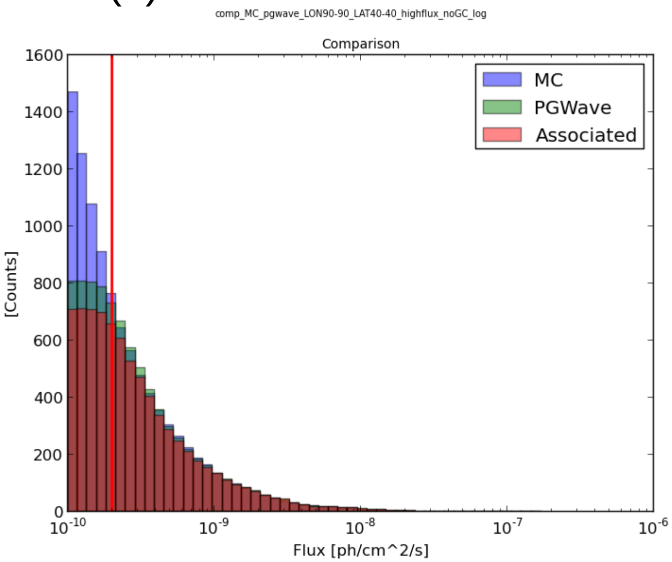
PGWave: Point Source Detection



PGWave: Flux Determination

- WT peak value is used for estimating the flux of the associated PS.
- Statistical uncertainty on WT-peak value is estimated by the tot. numb. of photons inside the circle with wavelet scale radius.
- To determine the best fit, we selected the associated PS with MC Counts > 100.
- To derive the bracketing values we used the PSF at 1 GeV and at 10 GeV for the P8R2_SOURCE data in the WT peak equation (3).



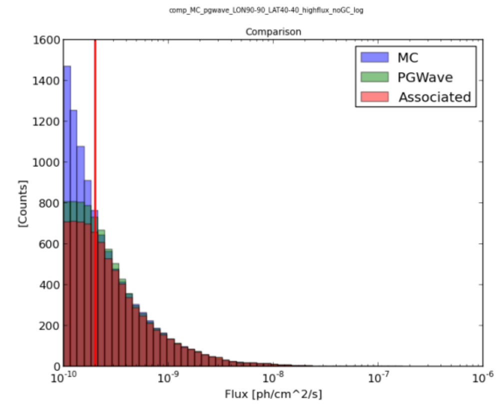


Plot of the MC input flux vs the WT peak value of the associated PS. A linear correlations is observed (as expected from Equation (3)).

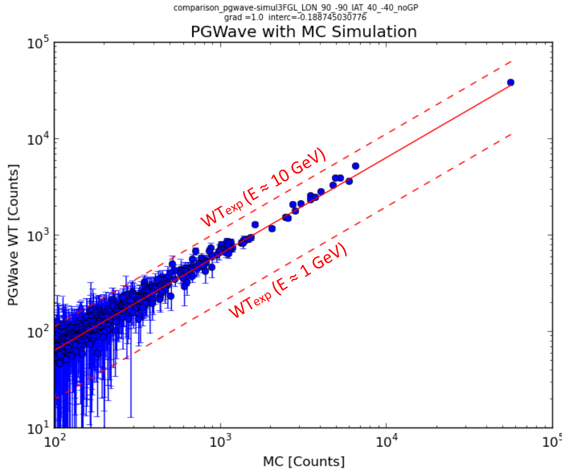
Summary of Pgwave test for MC data

We used PGWave to MC simulated data. In the MC data was present also an isotropic background. From the analysis we saw:

- PGWave PS detection works very well (more than 85 % of MC sources are found by PGWave above $2 * 10^{-10} \left(\frac{ph}{cm^2 s}\right)$)



- PGWave flux estimation show a very good correlation between the WT peak and the input MC flux (all the points are inside the expected values)



Future

PGWave is a very promising method for background independent estimation of the PS flux for high energy astrophysics.