

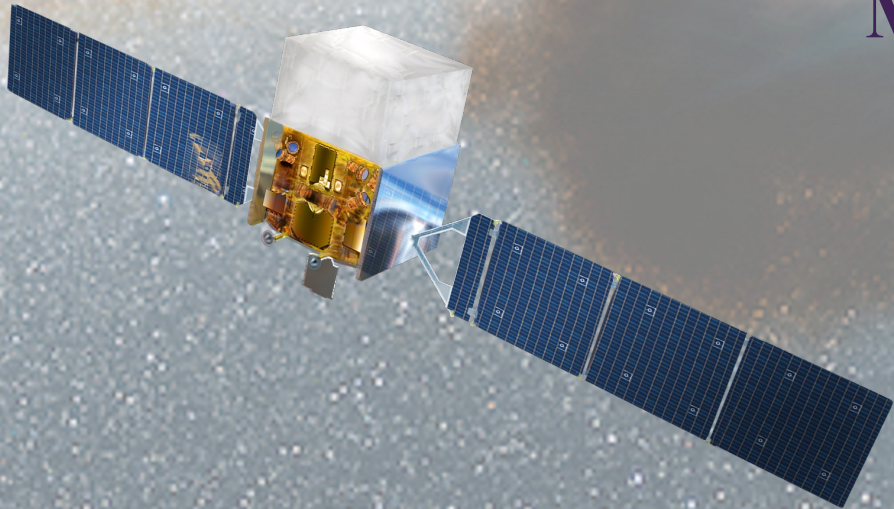
Search for correlations between Fermi LAT very high energy photons and active galactic nuclei

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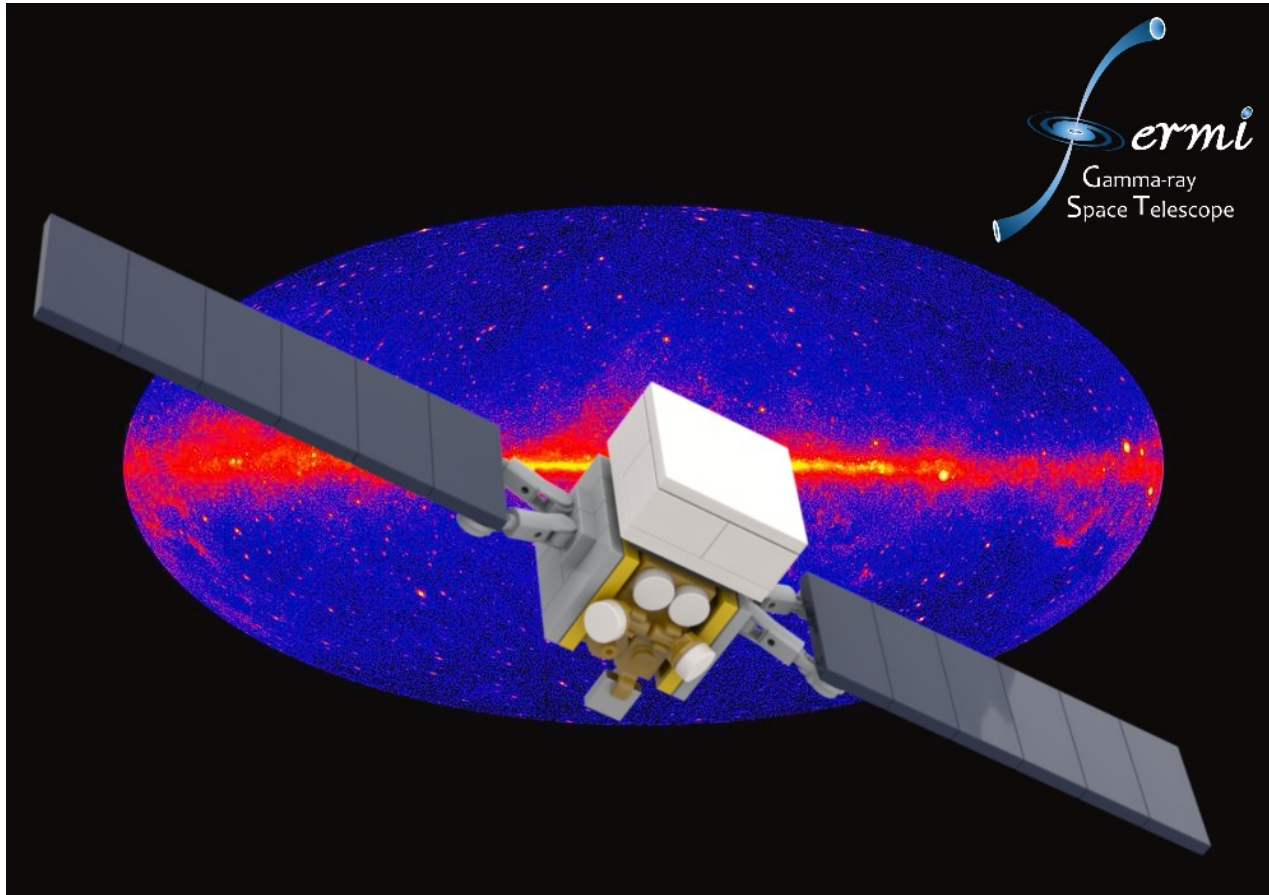
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20.05.2026



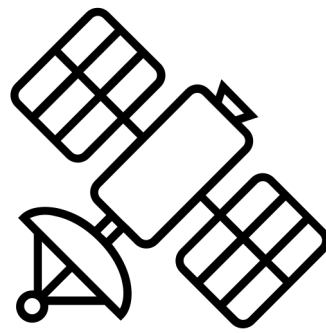
Fermi LAT



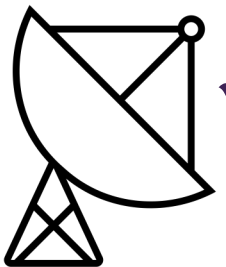
The Fermi Large Area Telescope (LAT) is the primary instrument on board of NASA's Fermi Gamma-ray Space Telescope.

The principal objective of the LAT is to conduct a long term high sensitivity full-sky gamma-ray observations of celestial sources in the energy range from ~ 20 MeV to >300 GeV.

Motivation

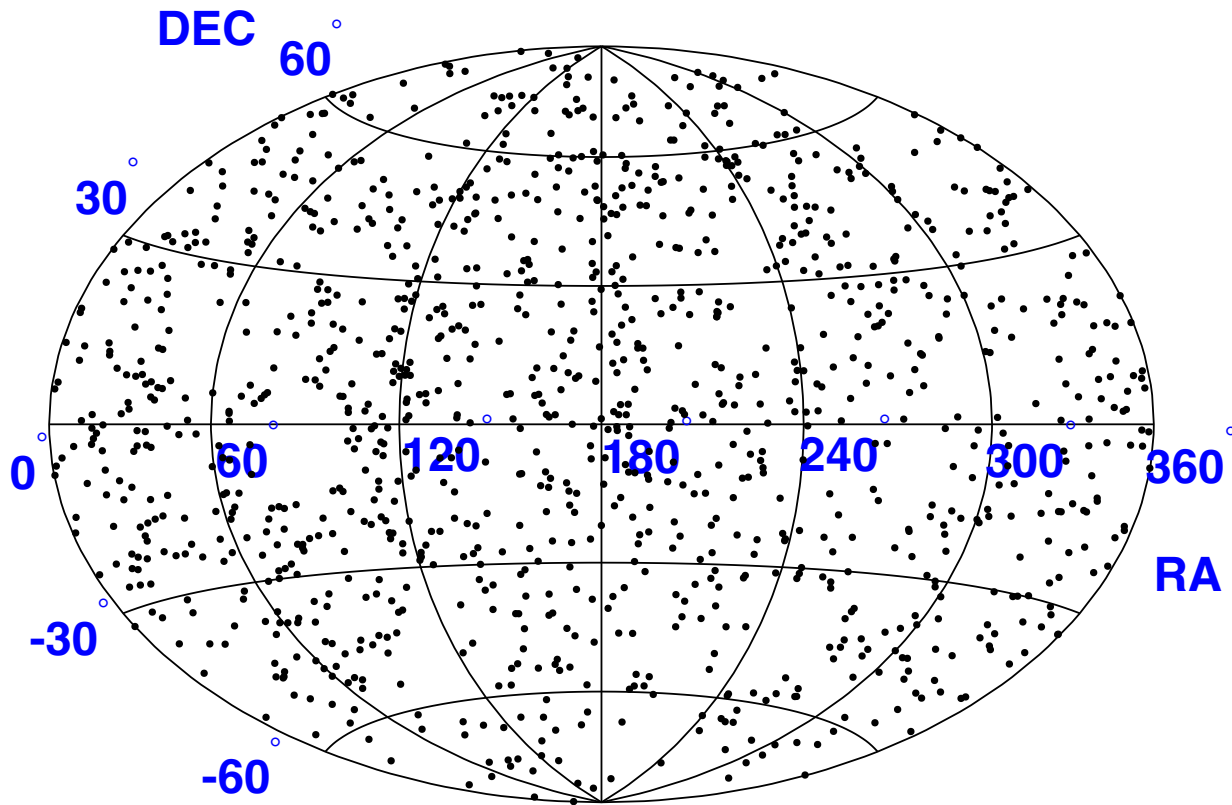


- In 2023 for different analysis isotropic samples of blazars were constructed (Kudenko&Troitsky, 2024). Those samples were based on Radio Fundamental Catalogue and Fermi LAT 4FGL Catalogue.
- Use recently constructed isotropic set of radio loud AGNs.
- Search for population of radio loud AGNs which also emit gamma rays with energies >100 GeV using Fermi LAT data and which are not present in 4FGL Catalog of Fermi LAT data.



- ✓ Key idea: no masking of the Galactic plane

Set of blazars



This set consists of **1177** radio-loud objects detected in the experiments with very long baseline interferometry (VLBI).

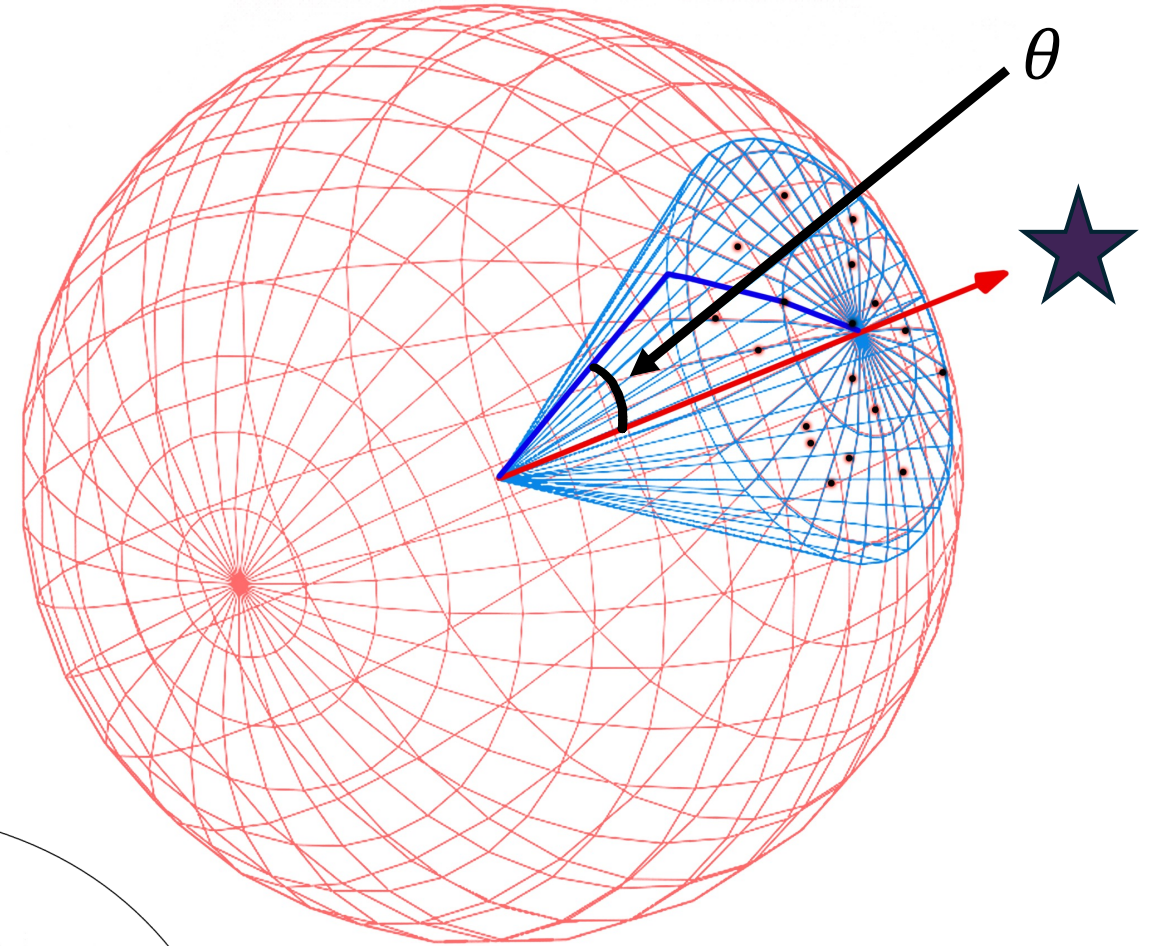
- $F_{8GHz} \geq 0.055$ Jy, where F_{8GHz} – photon flux at 8 GHz in Jy*.

$$*1 \text{ Jy} = 10^{-26} \frac{Wt}{m^2 \cdot Hz} = 10^{-23} \frac{erg}{s \cdot sm^2 \cdot Hz}$$

This set meets our requirements of isotropy on the sphere, which are listed at (Kudenko&Troitsky, 2024).

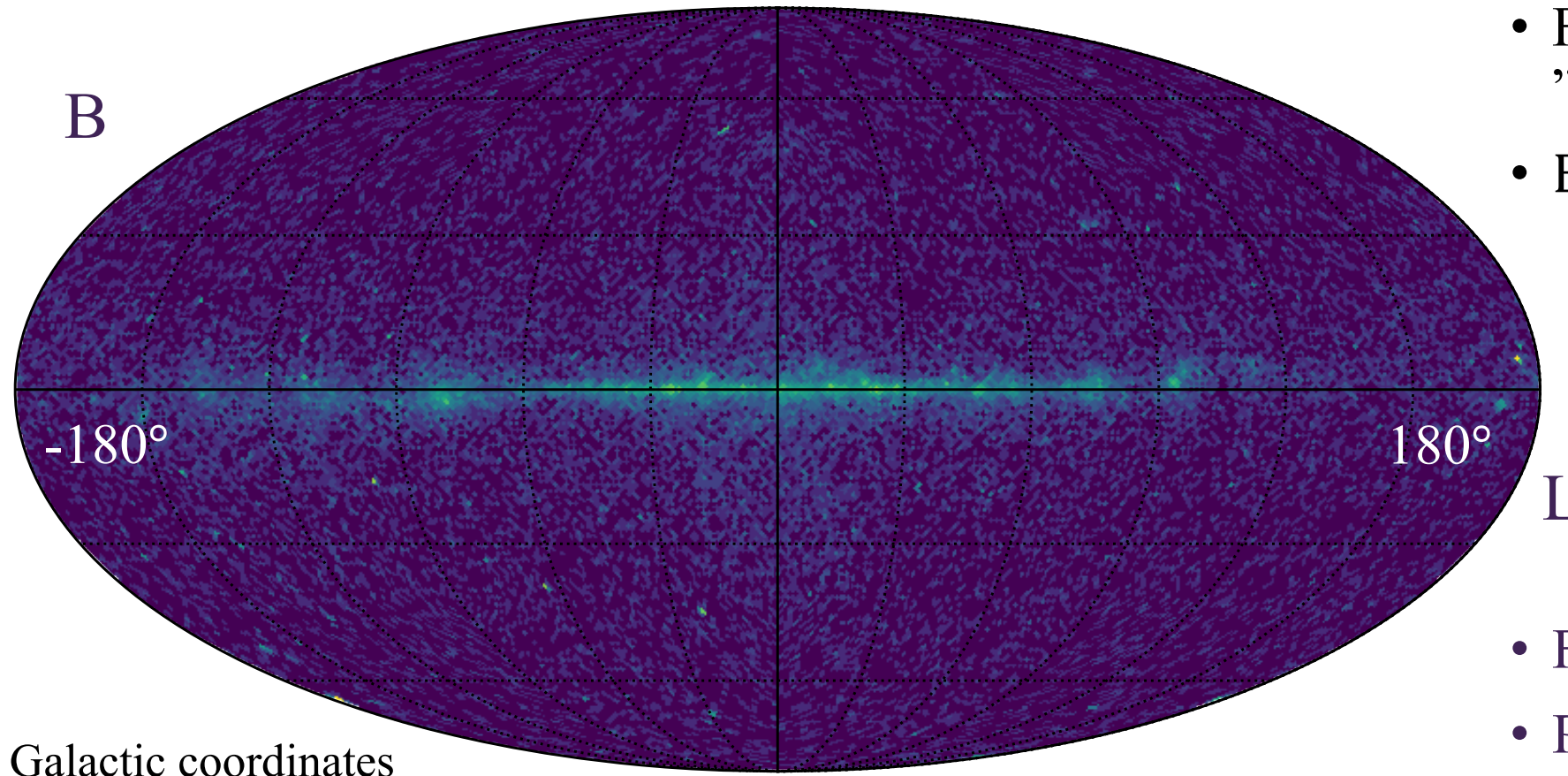
Pair counting method

For given set of sources and fixed angle θ , the number of pairs “cosmic ray-source” separated by angular distance less or equal than θ were calculated. After that real data was replaced by large number of randomly generated Monte Carlo sets of cosmic rays and the same procedure was repeated. This was made in order to calculate the p-value measuring how often this or larger number of pairs can be observed by chance.



Fermi LAT data

$E \geq 100 \text{ GeV}$



- Fermi LAT:
"P8R3_SOURCE_V3"
- $E_\gamma \geq 100 \text{ GeV}$

- Front converted events
- $\text{PSF}_{95\%} \approx 0.25^\circ$

Kernel density estimation

Kernel density estimation (KDE) – is a non-parametric method to estimate the probability density function of a random variable.

➤ It is needed to make simulated event sets for pair-counting method.

Probability density function is defined as follows:

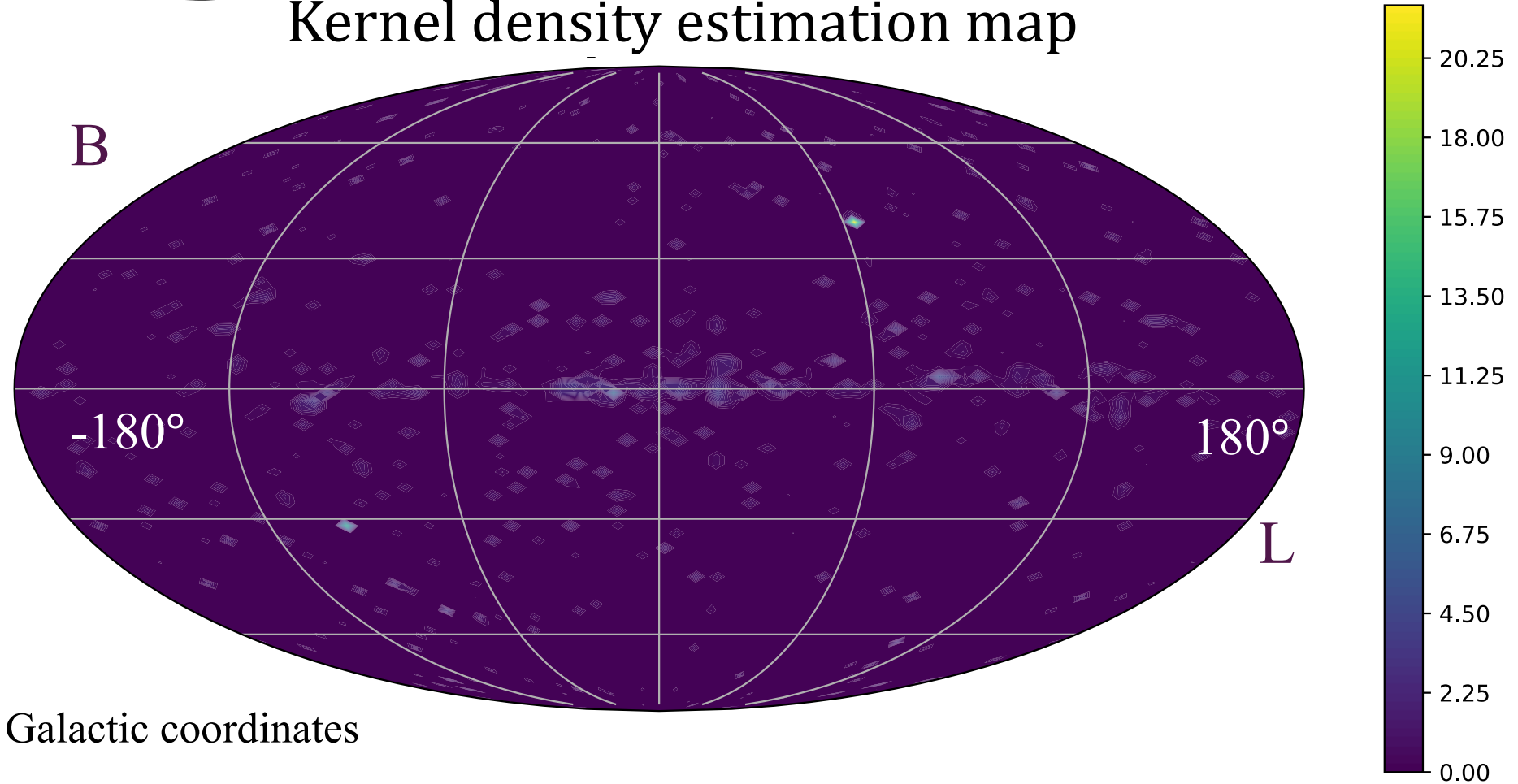
$$f_h(\mathbf{x}) = \frac{1}{n} \sum_{i=1}^n K_h(\mathbf{x}, \mathbf{x}_i),$$

where n – total number of photons, \mathbf{x}_i - coordinate of a photon on sphere detected by Fermi LAT, h - bandwidth,

$$K_h(\mathbf{x}, \mathbf{x}_i) = \frac{\exp(2 \cos(\mathbf{x} \cdot \mathbf{x}_i)/h^2)}{2\pi h^2 \sinh 2/h^2}$$

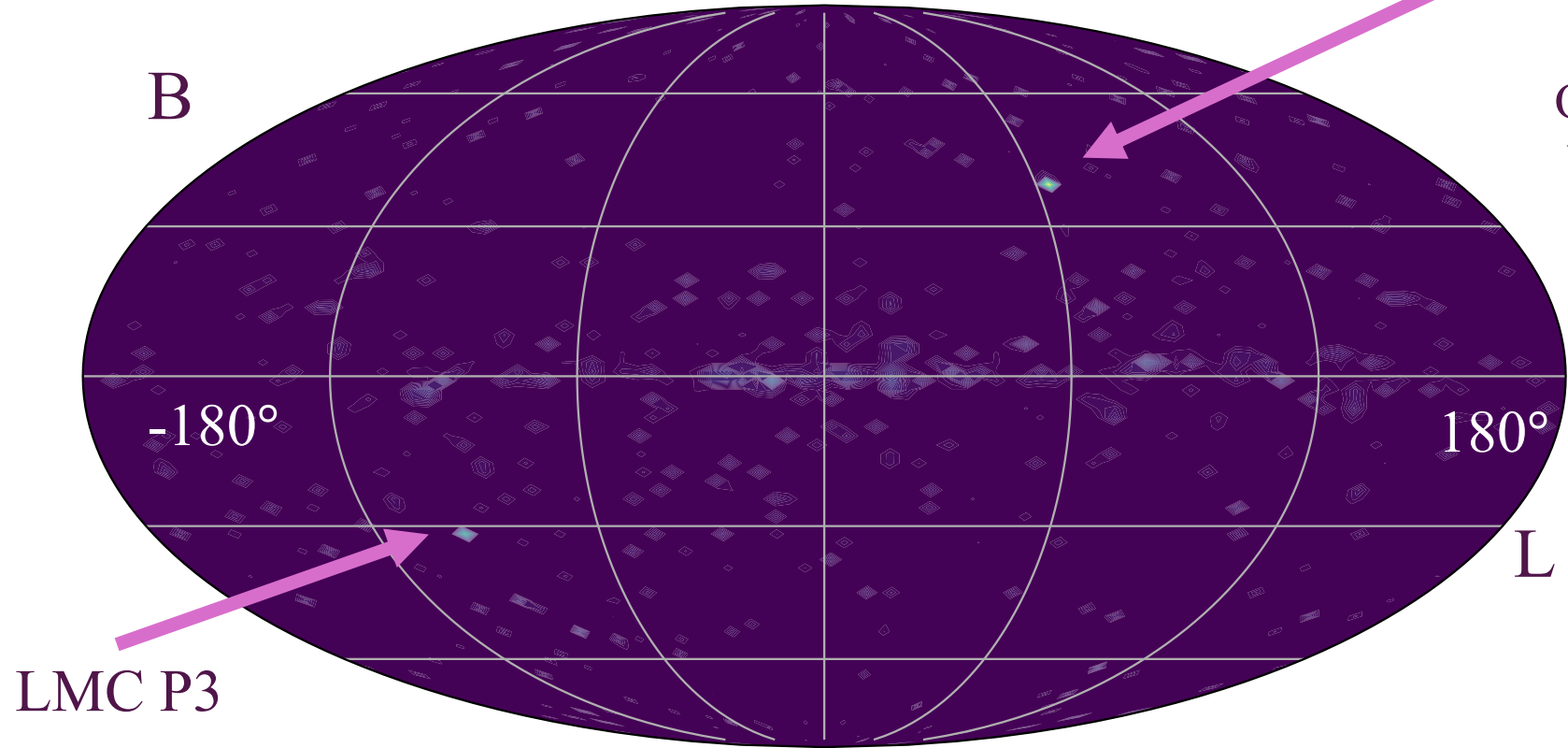
Kernel density estimation

Kernel density estimation map



Kernel density estimation

Kernel density estimation map



Markarian 501

One of the nearest and brightest TeV blazars

LMC P3

Galactic coordinates

Binary system of a compact object and a star

Intuition

1. Too wide bandwidth



Simulated samples are too different from real data



Minimal p-value is unrealistically low in the absence of sources

(false positive)



2. Too narrow bandwidth

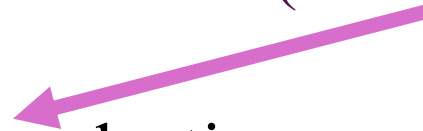


Simulated samples are too similar to real data



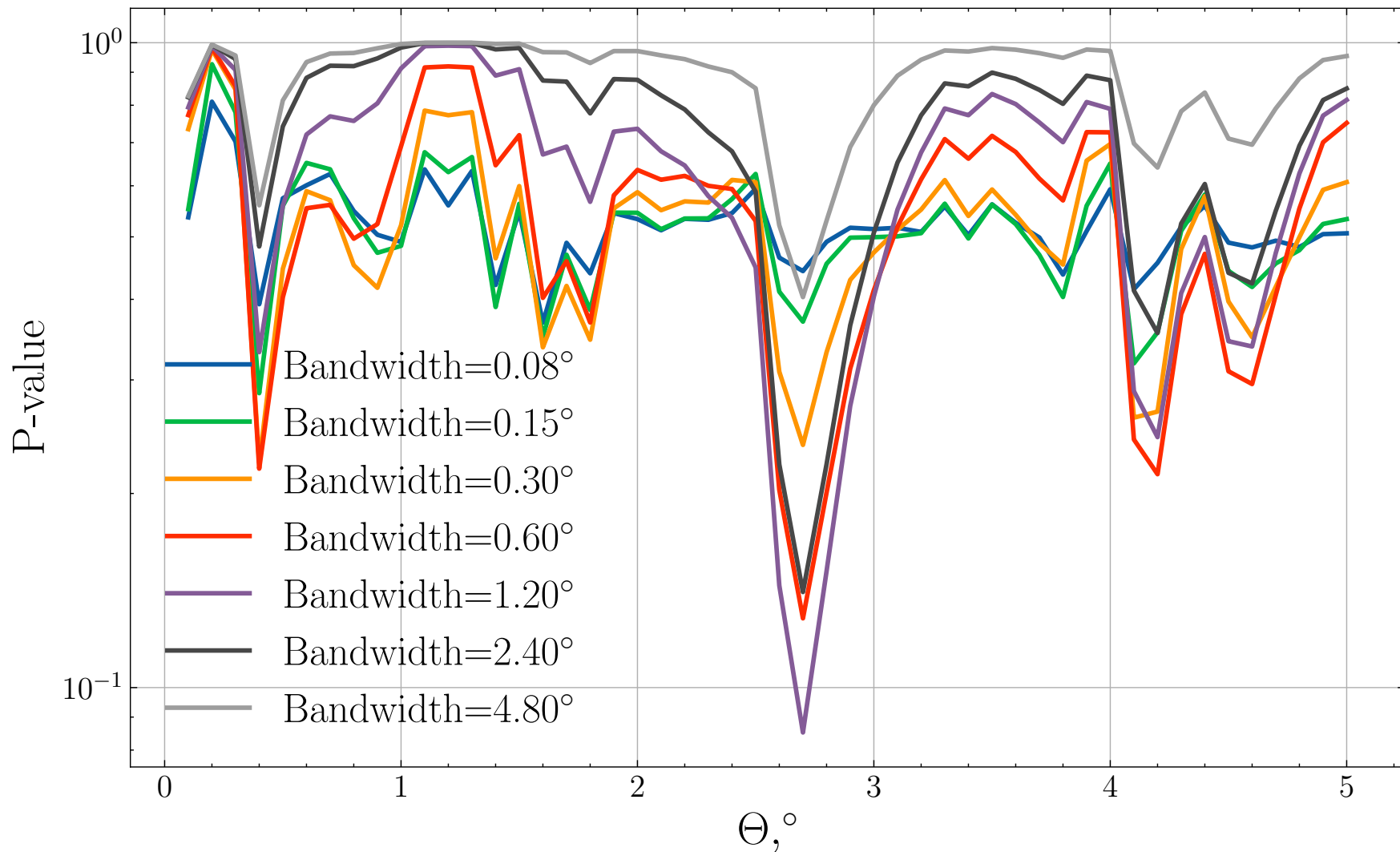
P-value is unrealistically high in the presence of sources

(false negative)



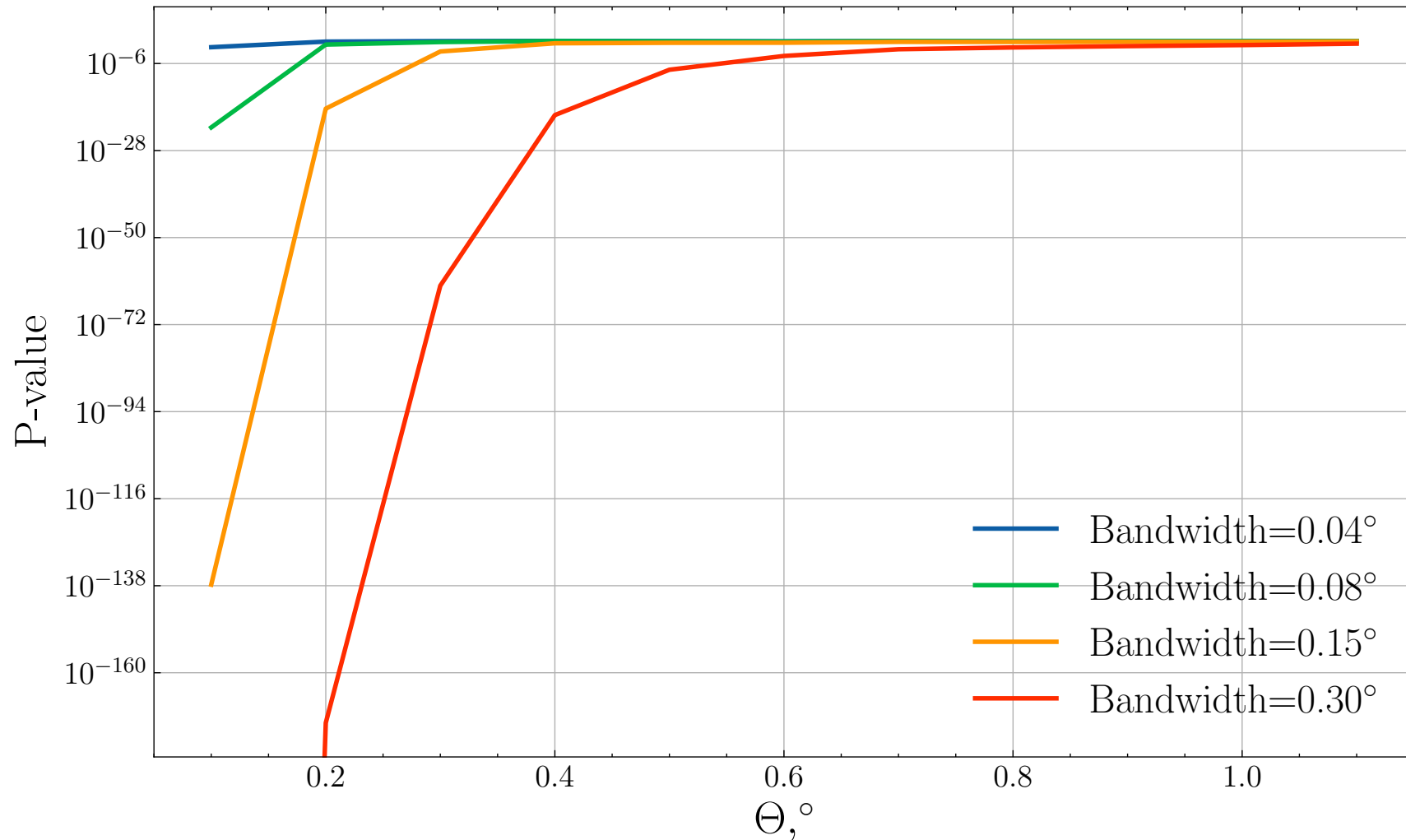
Bandwidth selection

Result – Intuition 1 – False Positive



- "Fake" sources – constructed as 156 BLL from (Veron, 2001) reflected from the galactic plane.
- To avoid false positive results minimal p-value for the accepted range of bandwidths should be higher than 1%.

Result – Intuition 2 – False Negative



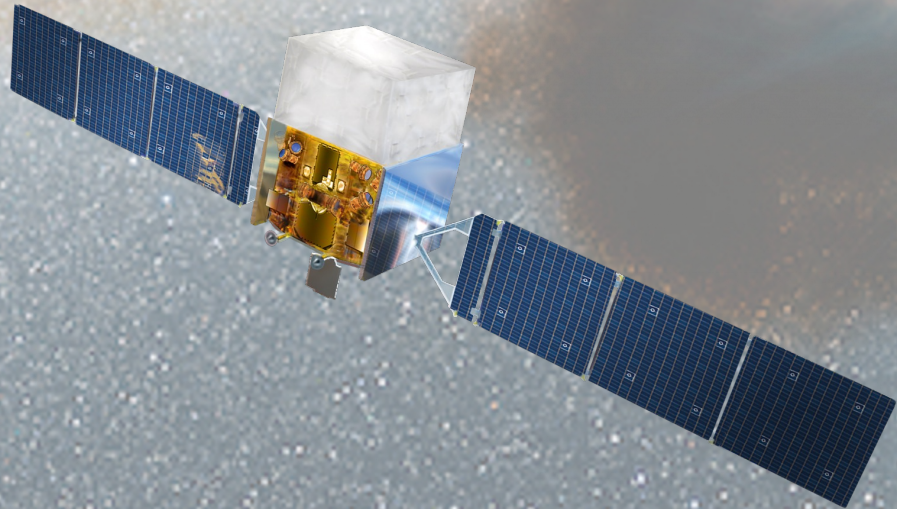
- Real sources – 322 objects from catalogue of sources bright in very high energy range ($E \gtrsim 10$ GeV, “TeV Cat”).
- To avoid false negative results minimal p-value for the accepted range of bandwidths should be not absurd.

Conclusion

- Results of the first intuition have shown that false positive results couldn't be obtained independently on bandwidth.
 - Results of the second intuition have shown that presence of “from-source” photons provides an absurd p-value highly dependent on bandwidth.
- Smoothing and shifting “from-source” events is not enough!
 - “From-source” events should be subtracted from the set of photons used for the construction of kernel density estimator. For example, by masking photon clusters around the sources. The size of the mask should be defined individually for each set of sources.

Thank you for your attention!

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**Russian Science
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