AMON Searches for Jointly-Emitting Neutrino+Gamma-Ray Transients

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AMON-Based Archival Analysis

In addition to real-time analysis, the AMON framework enables archival analysis:

1. helps us to better understand the datasets
2. explore different statistical approaches to generate AMON alerts for the network's follow-up partners

Current available neutrino and gamma-ray data:

* IceCube
* Fermi-LAT
* Swift
* ANTARES

This analysis:
IceCube public data +
Fermi-LAT public data

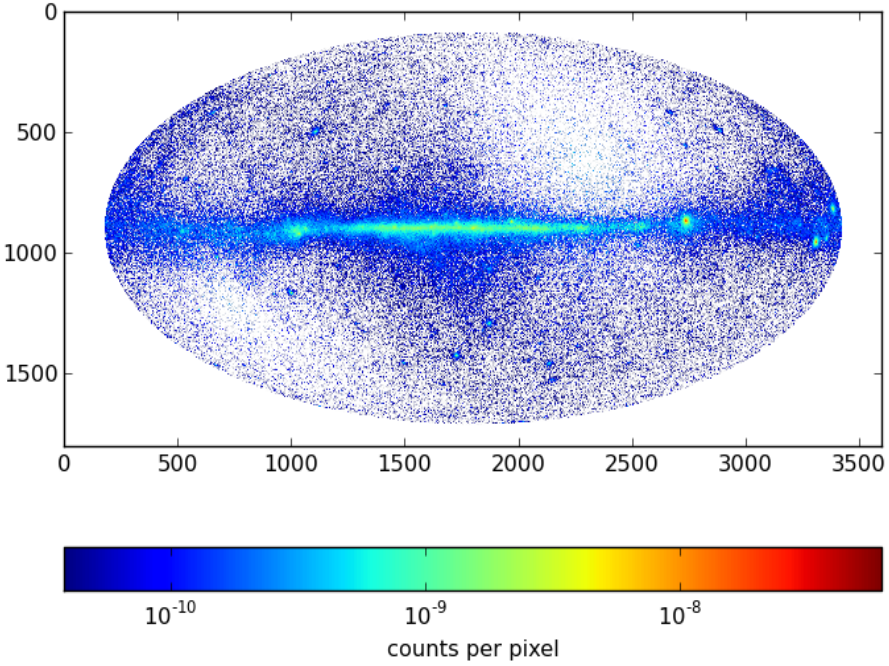
IceCube-Fermi Analysis

	IceCube	Fermi-LAT
Signal	Cosmic ν	Cosmic γ
Background	Atmospheric ν, CRs	Galactic γ, CRs
Energy	≥ 1 TeV	20 MeV – 100 GeV
PSF	Fisher: $\frac{1}{2\pi\sigma_\nu^2}\exp\left(-\frac{(\hat{x}_\nu-\hat{x})^2}{2\sigma_\nu^2}\right)$	King: $\frac{1}{2\pi\sigma_\gamma^2}\left(1-\frac{1}{\gamma}\right)\left[1+\frac{1}{2\gamma}\cdot\frac{(\hat{x}_\gamma-\hat{x})^2}{\sigma_\gamma^2}\right]^{-\gamma}$

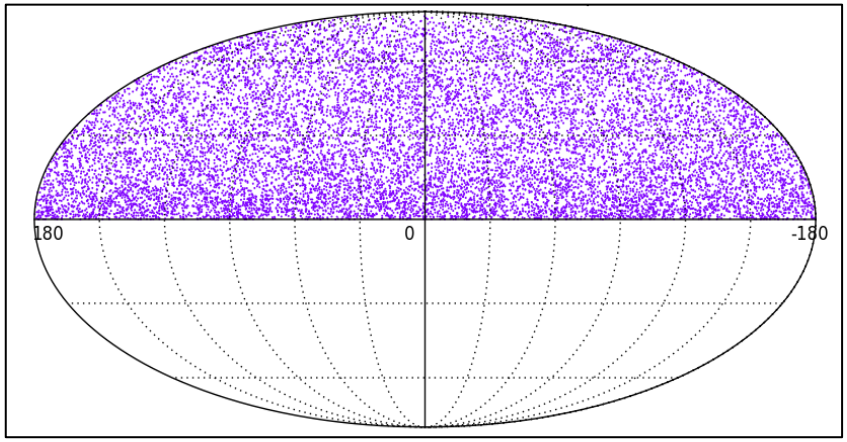
- Temporal overlap ≈ 41.5 weeks IC40, 1 year IC59
- Photon energy ≥ 200 MeV
- Photon and spacecraft zenith direction < 65°
- IC40: Northern hemisphere neutrinos only

IC40-Fermi Analysis

Fermi-LAT exposure corrected map



IC40 neutrino data in northern hemisphere

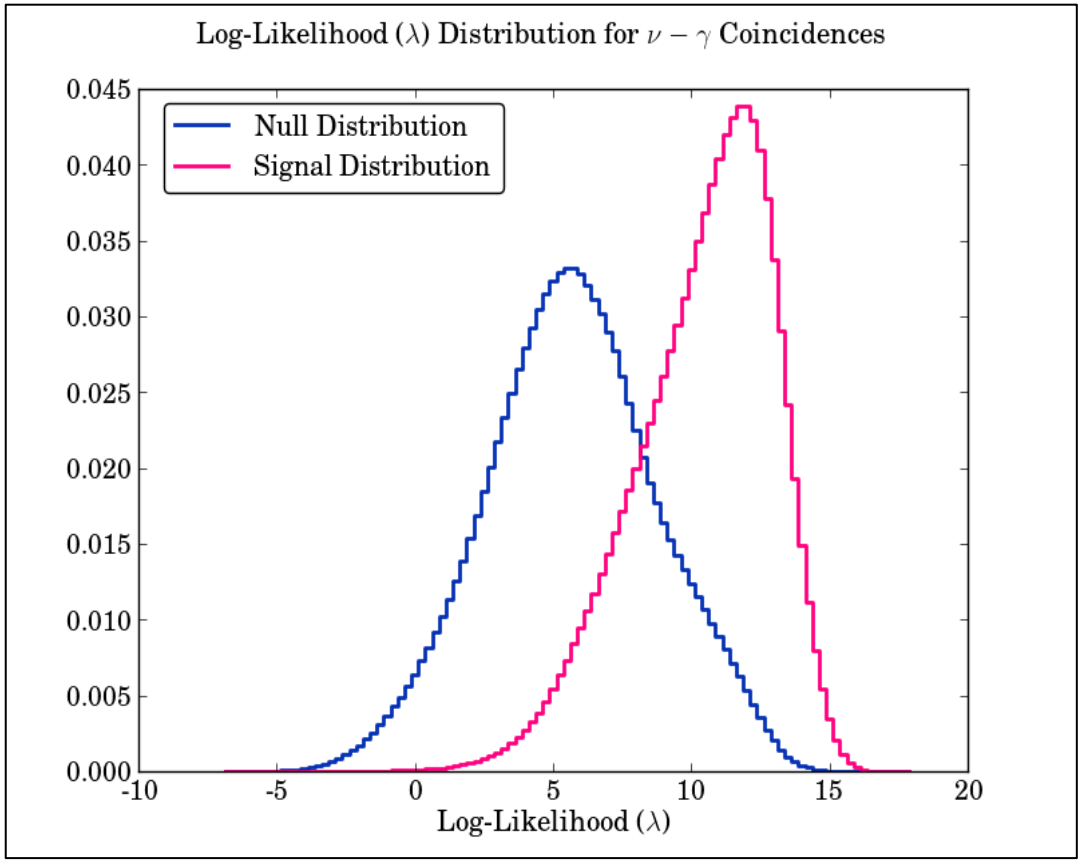


- ≈ 4×10^6 photon events
- ≈ 15,000 neutrino events
- Spatial coincidence: < 10°
- Temporal coincidence: ± 50 s

Null and Signal Distributions

To test the analysis effectiveness:

- 10,000 scrambled data tests: random timestamps and RA scrambled accordingly, Dec unchanged
- 10,000 signal data tests



Un-binned log-likelihood function:

$$\lambda = 2\ln(P_{LAT}(\hat{x}\,|\,\hat{x}_\gamma)P_{IC}(\hat{x}\,|\,\hat{x}_\nu)) - 2\ln(B(\hat{x}_\gamma))$$

$B(\hat{x}_\gamma)$ is the background rejection term

$$B(\hat{x}) = \int \Phi(\hat{x},E)A(\hat{x},E)dE \frac{\int \left(\frac{dN}{dE}\right)_{test} dE}{\int \left(\frac{dN}{dE}\right)_{test} A(\hat{x},E)dE}$$

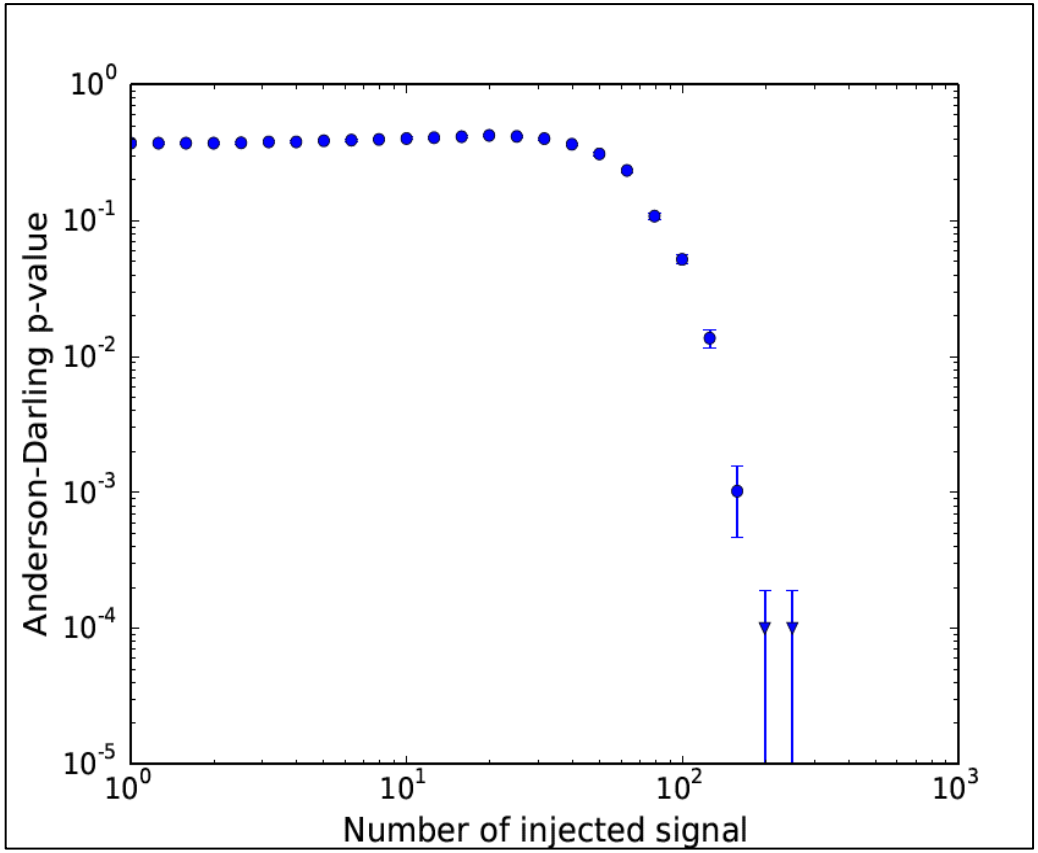
$$\propto \frac{\text{event rate}(\hat{x})}{\text{exposure}(\hat{x})}$$

Defining Statistical Excess

Anderson-Darling test for signal and null distributions:

$$A = n\int_{-\infty}^{\infty} \frac{(F_n(x) - F(x))^2}{F(x)(1-F(x))} dF(x)$$

We furthermore inject false signal photons (spectral index 2.2)

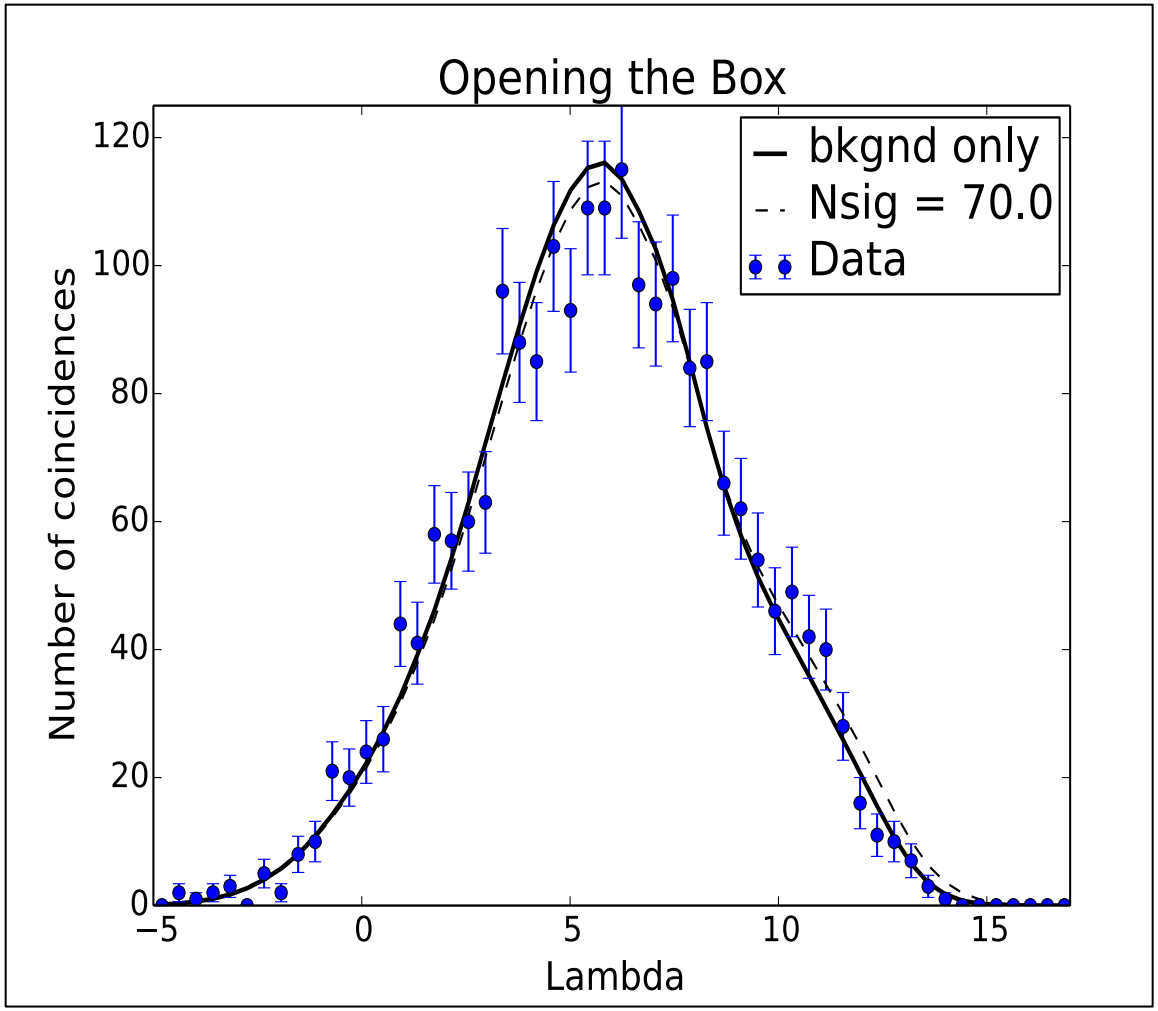


Results with the un-blinded data

Un-blinded histogram in comparison with the background model and a theoretical model with Nsig=70

Un-blinding the data: 2138 coincidences were found within the cuts of $\psi \leq 10^{\circ}$ and $|\Delta t| \leq 50$ s

AD test on this data yields ≈ 70 $\nu + \gamma$ coincidences. The p-value for this observation = 4%



How do we vet the signal?

- Three tests:
  - Multiplicity (one ν - multi γ)
  - ΔT (concentration within acceptance)
  - Source map

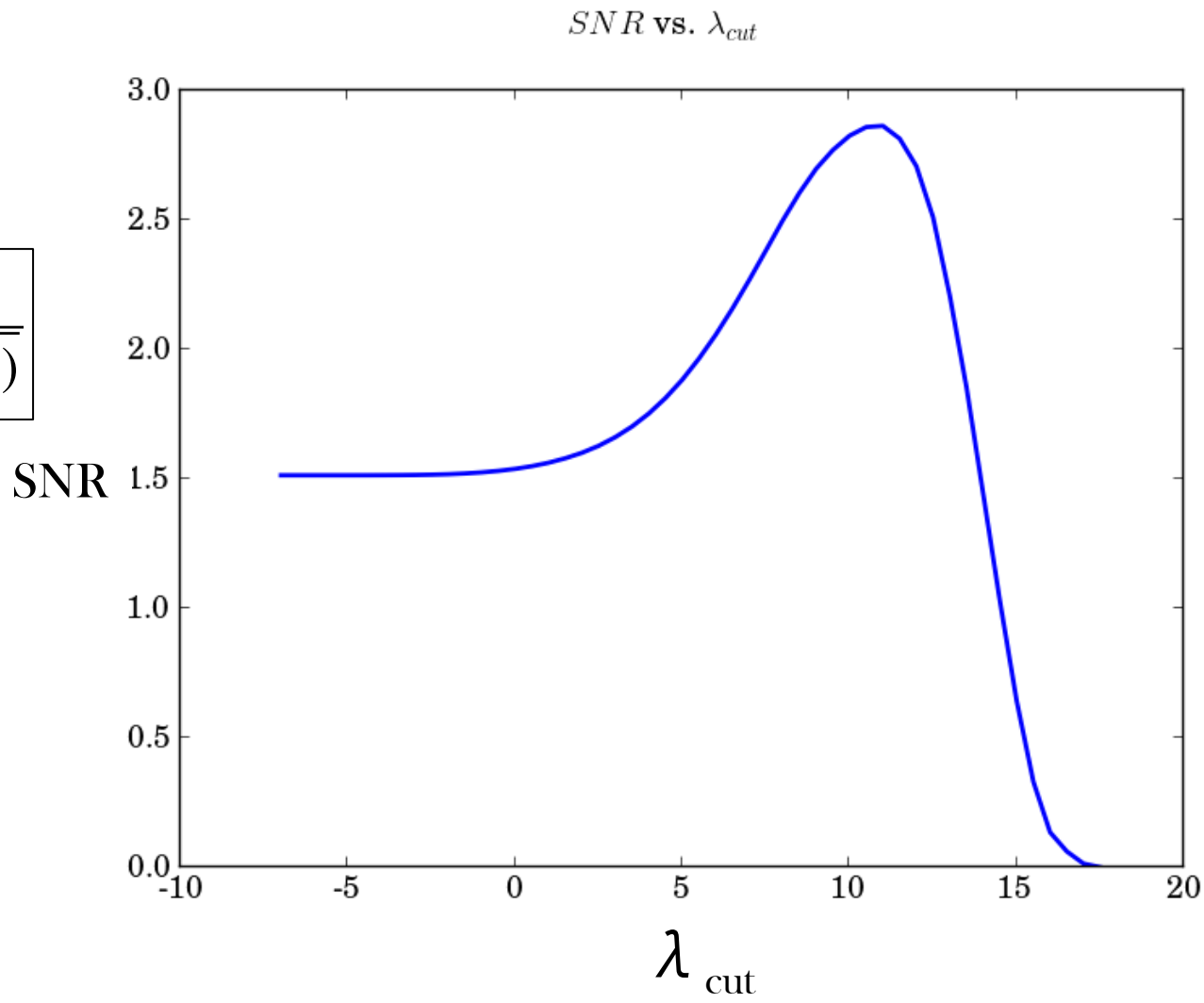
- Test for events with high log-likelihood (λ)
- Nsig=70: 2σ detection

High log-likelihood Events: Find λ_{cut}

Find λ_{cut} of the maximum signal to noise ratio (SNR)

$$SNR = \frac{N_{inj}(>\lambda_{cut})}{\sqrt{N_{bk}(>\lambda_{cut}) + N_{inj}(>\lambda_{cut})}}$$

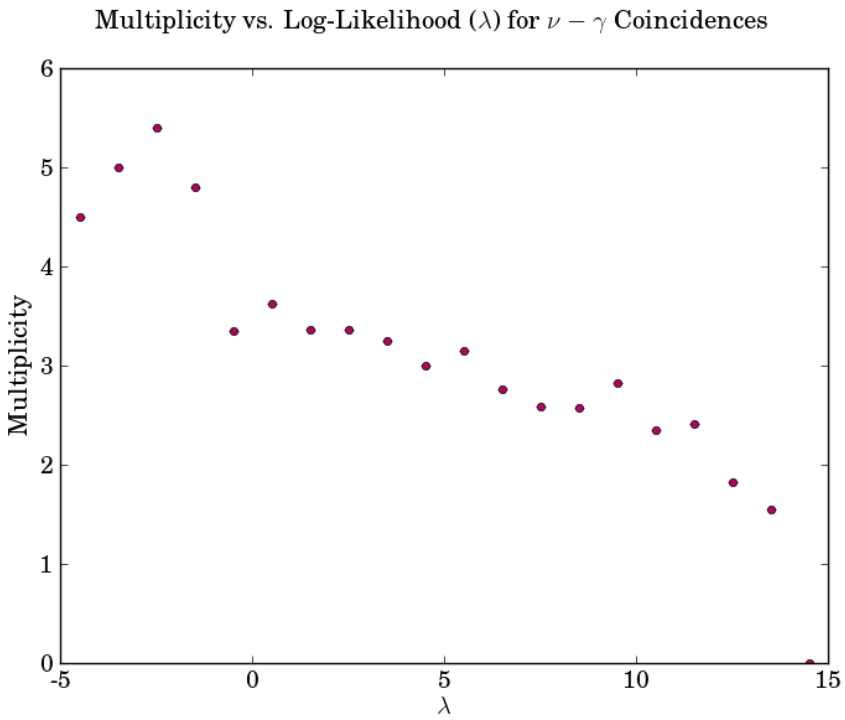
$\lambda_{cut} = 11$
Nsig = 70
Ncoinc = 2138
Ncoinc($>\lambda_{cut}$) = 111

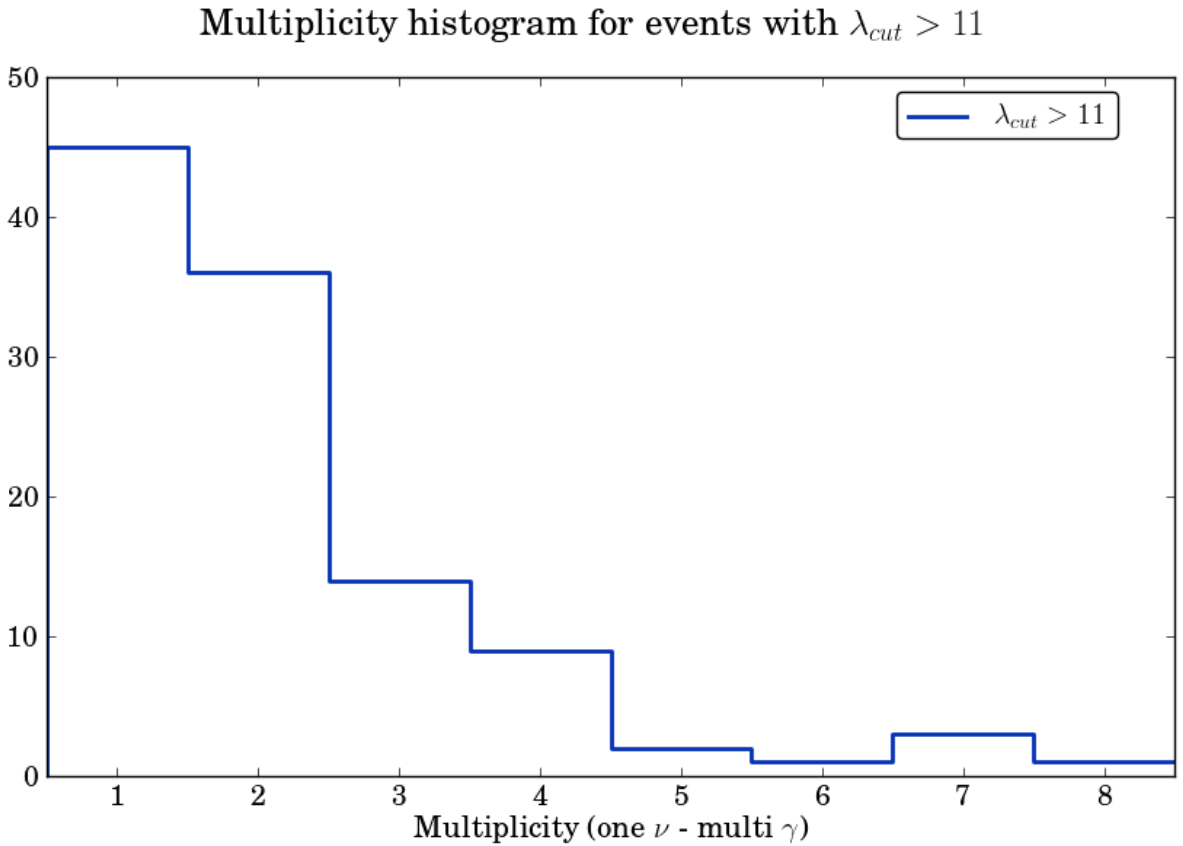


Multiplicity (one ν - multi γ)

Multiplicity = coincidence of one ν and multiple γ's

Larger multiplicity at lower log-likelihood values due to the background



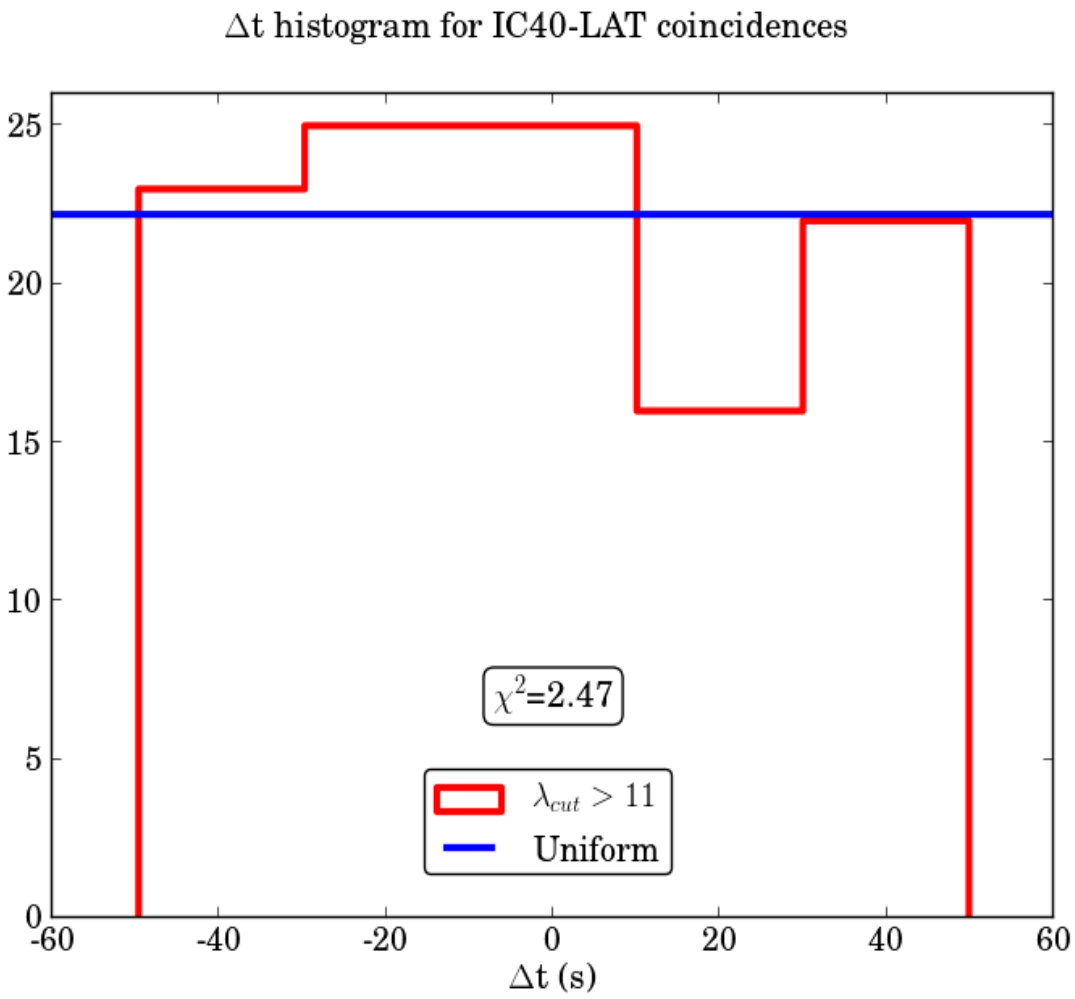


No significant excess above the background expectations

ΔT distribution

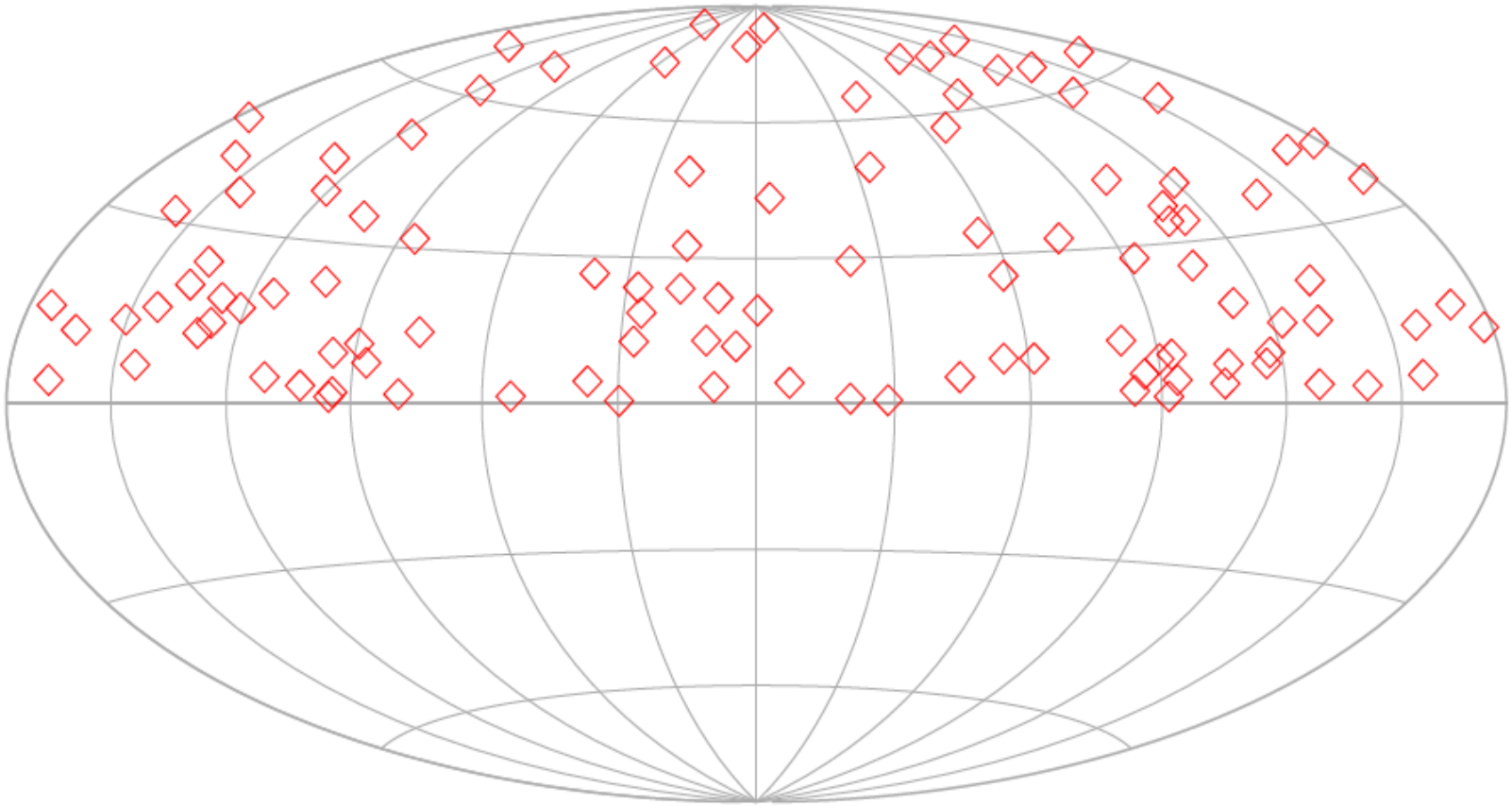
We also check the ΔT distribution:
No significant difference between time bins seen

χ^2/ndf = 2.47/5



Source Map

Sky map of ν-γ pairs with $\lambda > 11$

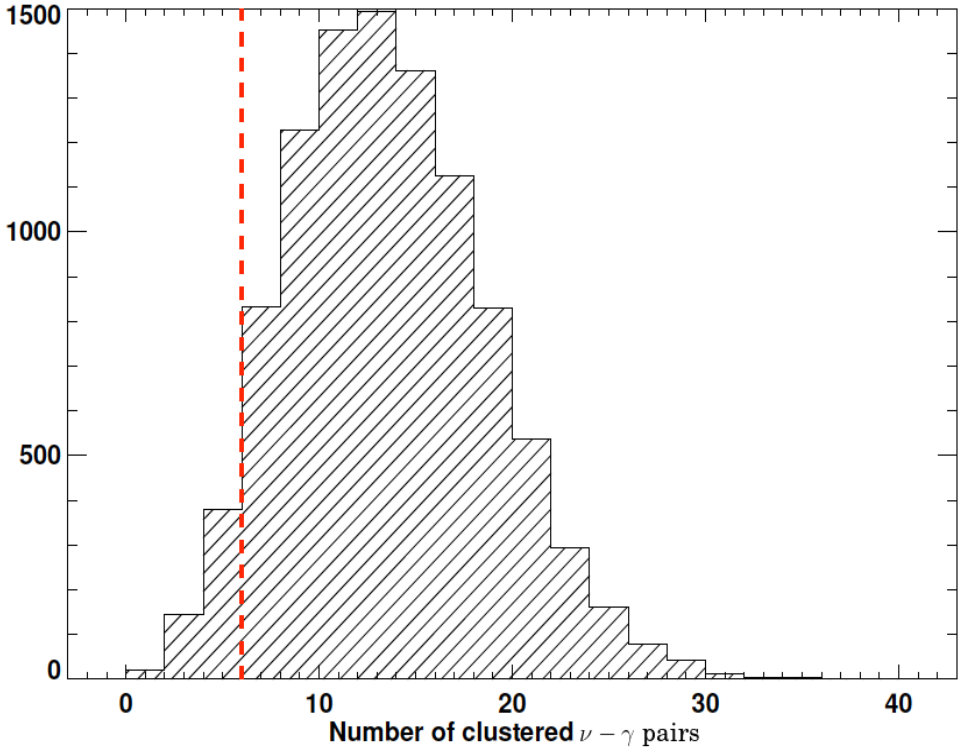


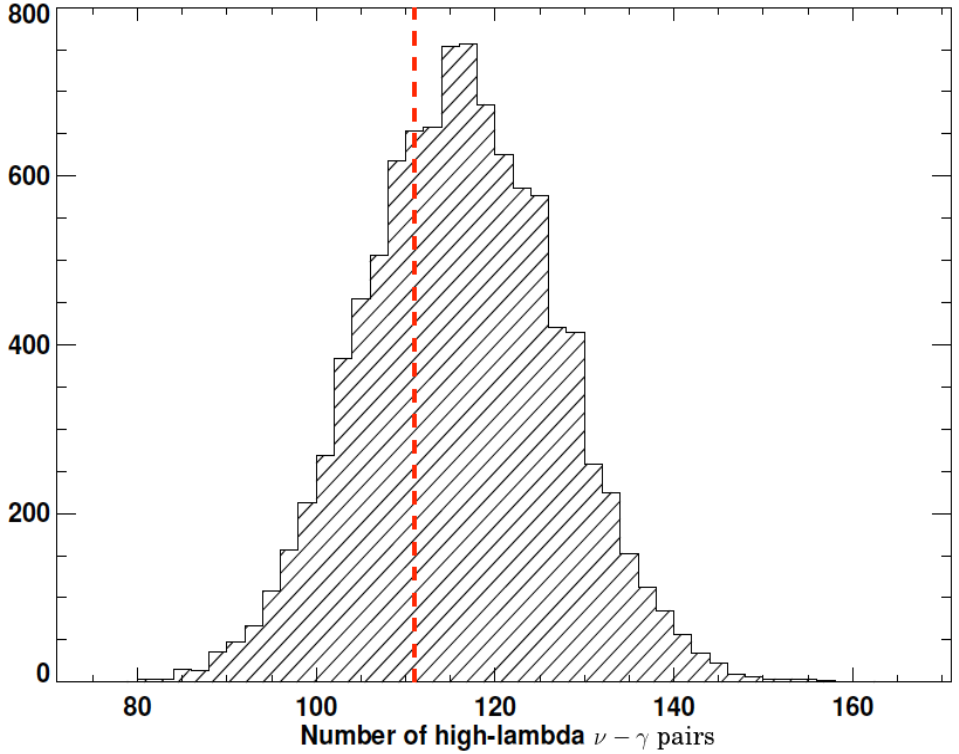
Six ν-γ pairs lie within 2° of another pair

Clustering of ν-γ pairs

Number of ν-γ pairs with high log-likelihood values

No evidence of an excess of clustered high log-likelihood ν-γ pairs in the real data





Summary

- We performed several statistical tests on observed data using the background and signal datasets:
  - AD test shows about 70 signal out of 2138 found coincidences
  - Multiplicity, ΔT, and clustering shows no signal excess

- There is no significant signal excess between IC40 and Fermi-LAT data

- Looking at IC59 and Fermi-LAT data next!

Thanks for your attention