Searching for Counterparts to Cosmic Neutrinos Using the Fermi LAT Satellite

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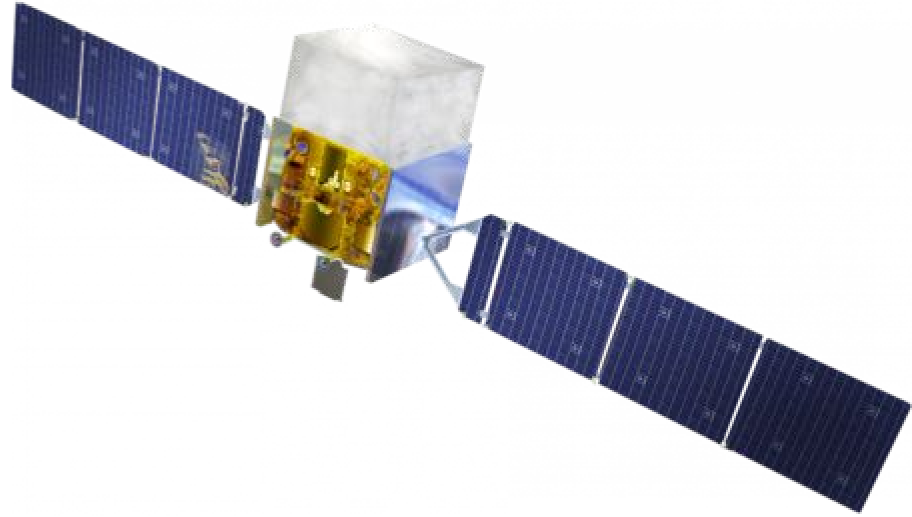
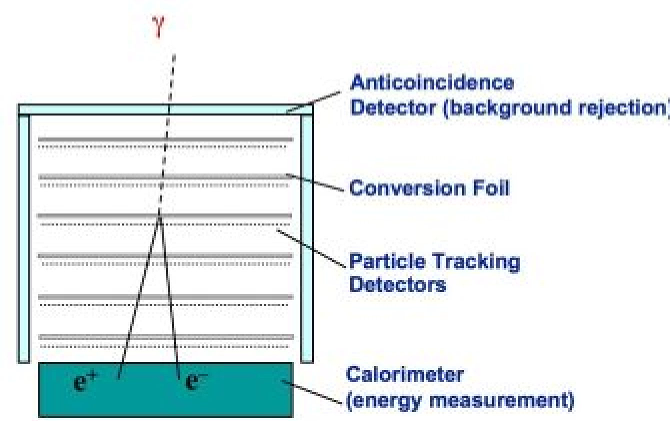
- Multimessenger event: an astrophysical event seen with two or more of the four messengers (photons, neutrinos, cosmic rays, gravitational waves)
- No known sources of high-energy astrophysical neutrinos
- Many models predict correlated neutrino and gamma ray production
- Time sensitive coincident analysis can identify or limit neutrino/gamma coincidences

Fermi LAT

- FOV: 2.4 steradians (20% of full sky)
- Surveys whole sky every 3 hours
- Energy range of 100 MeV to 300 GeV
- Data concurrent with IceCube 40-string (IC40) and 59-string (IC59)
- Chance to see coincident neutrinos and gamma rays



Top: Fermi satellite
Bottom: LAT detector



Coincident Analysis

Coincidence requirements:

Temporal: $\Delta t = \pm 100$ s

Spatial: $\Delta\theta < 5°$

IC40 run:

April 2008 to May 2009

Fermi begins operation in July 2008

1.3×10^4 neutrinos

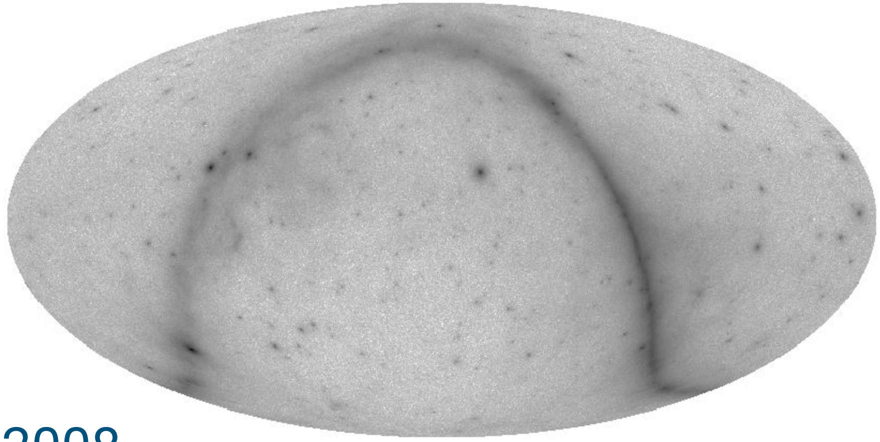
1.6×10^7 photons

IC59 run:

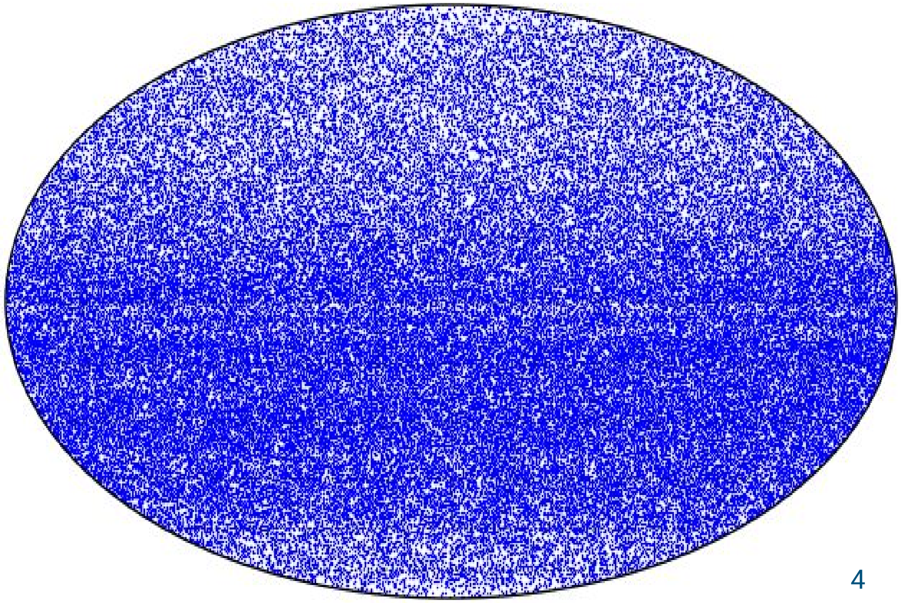
May 2009 to May 2010

1.1×10^5 neutrinos

1.8×10^7 photons



Sky map of fermi events concurrent with IC59 (top) and the IC59 neutrinos (bottom).

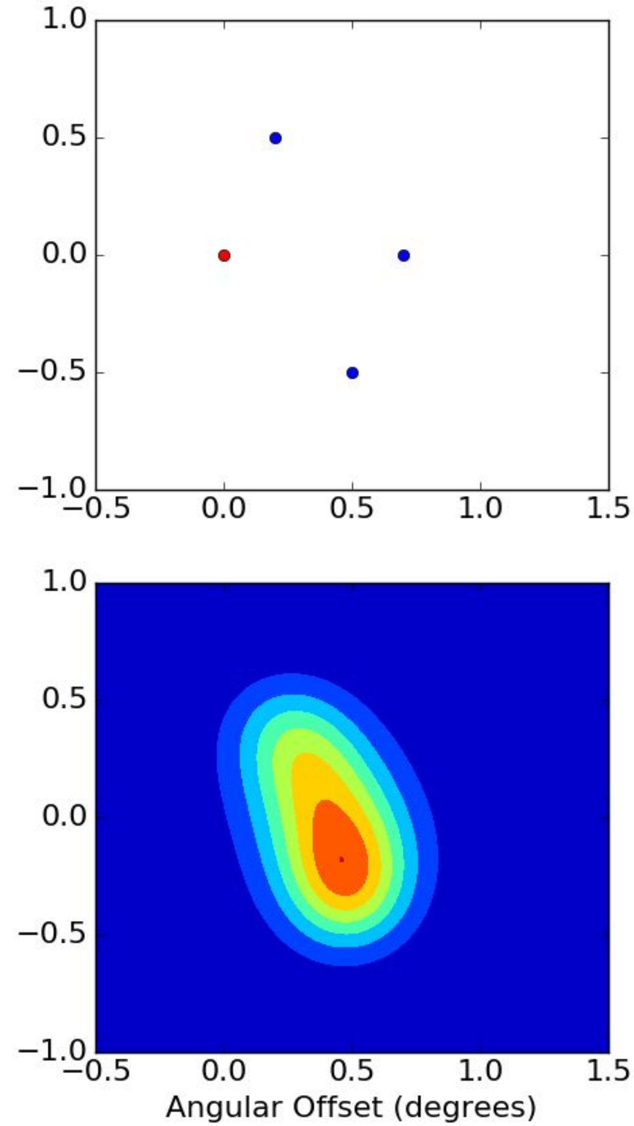


Localization

- Arrival direction of particles is uncertain, given by Point Spread Function (PSF)
- Localize coincidence by max overlap of PSFs
- Rank coincidence by log likelihood statistic:

$$\lambda = 2\ln \frac{(P_{\gamma 1} P_{\gamma 2} \ldots P_{\gamma n})\, n!\, (P_{\nu})}{B(\vec{x})^{n}}$$

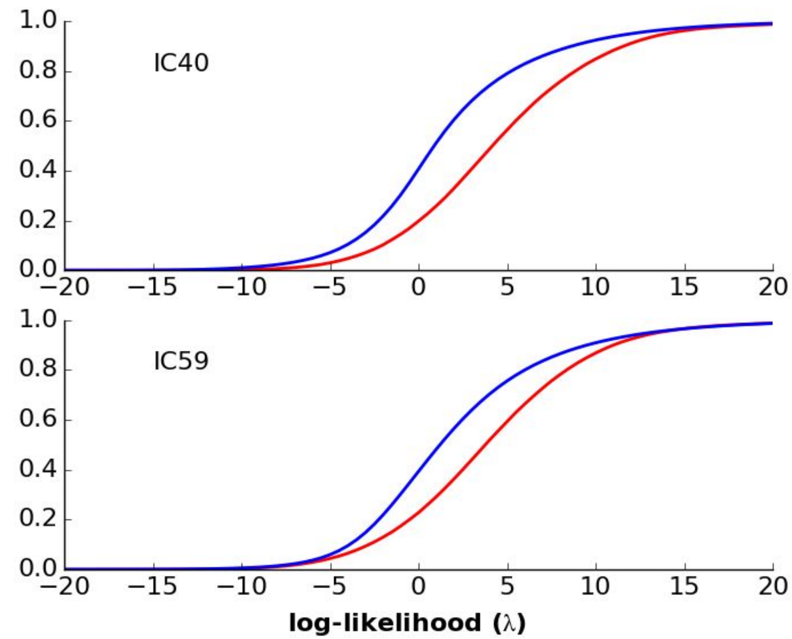
- Higher Lambda - more significant coincidence



Top: a four particle multiplet with one neutrino (red) and three photons (blue)
Bottom: overlap of the four PSFs

Scrambled Results

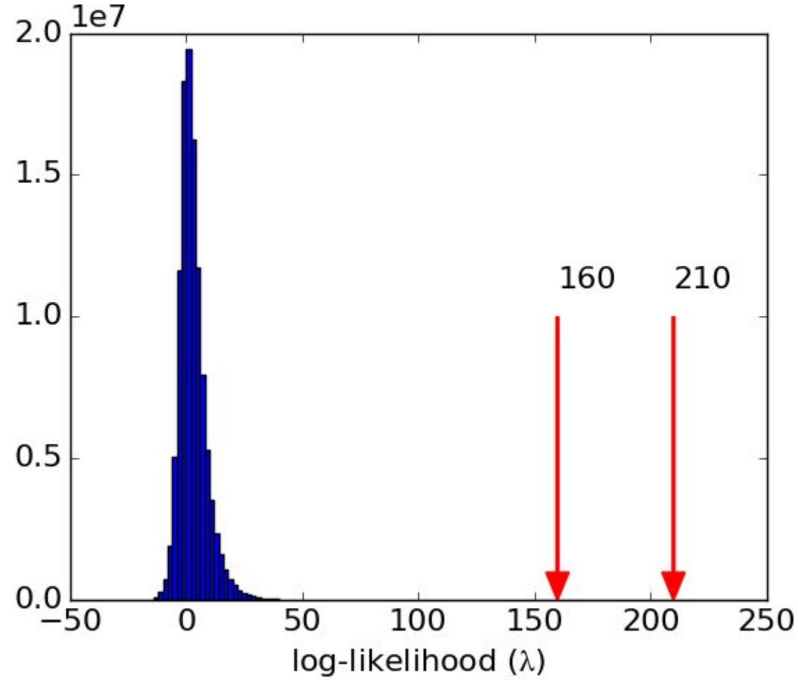
- Results of 10000 background scrambles:
- IC40:
  - BG - 1089.7±30 events
  - Data - 1128 events
- IC59:
  - BG - 11056±98 events
  - Data - 11143 events
- Two ways to identify a cosmic signal:
  - Look for excess high lambda events
  - Inject signal events



Cumulative histograms of lambda values for IC40 (top) and IC59 (bottom). Null distributions are in blue, signal in red.

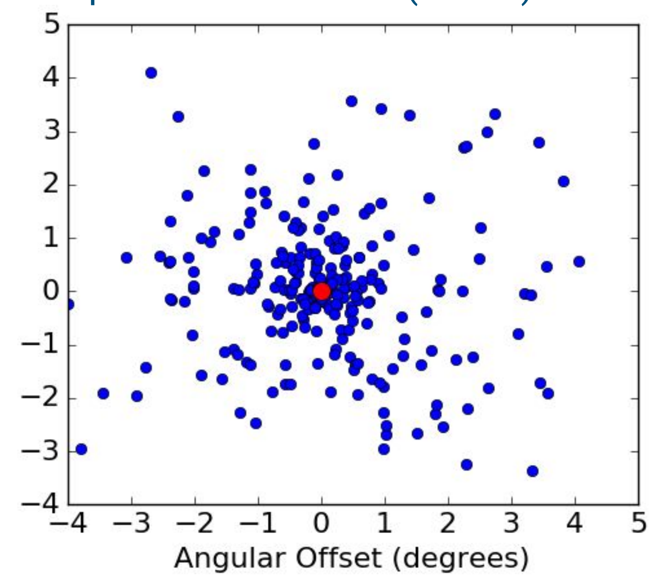
Threshold Results

- Distribution of lambda gives us threshold limits
- 1 event per 10 scrambles:
  - IC40: λ>64
  - IC59: λ>160
- 1 event per 100 scrambles:
  - IC40: λ>100
  - IC59: λ>210
- IC40 results:
  - λ_{max}=98.3
- IC59 results:
  - λ_{max}=118.5



Histogram of the null lambda values for IC59 with two thresholds shown: 1 per 10 scrambles (λ>160) and 1 per 100 scrambles (λ>210)

254 photons arising from GRB 090902426, in coincidence with a scrambled IceCube neutrino. λ=3907.7

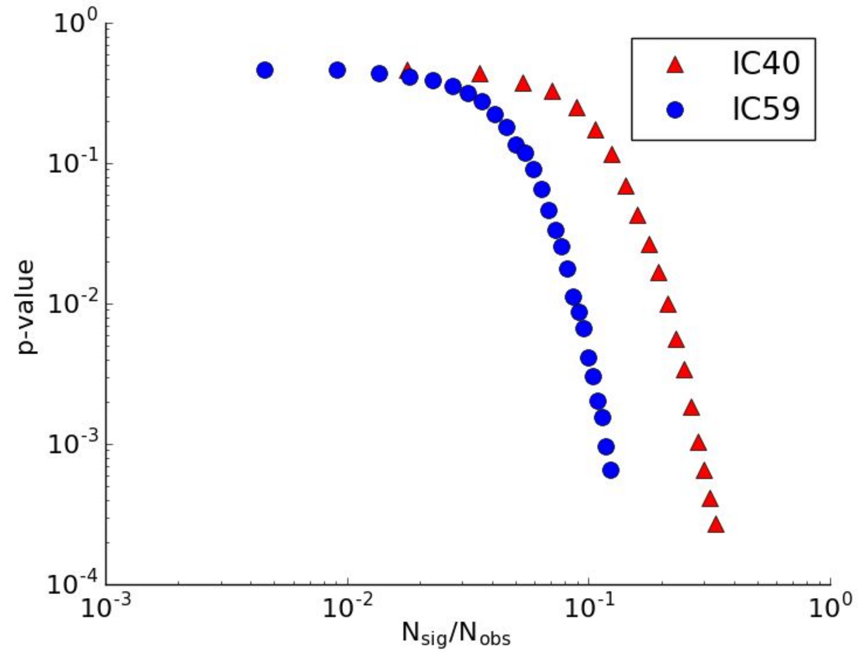


Signal Injection

- Create signal events by:

1. Center photon and neutrino PSFs, and place all particles weighted by their psfs
2. Put coincidence at random sky location
3. Calculate lambda value

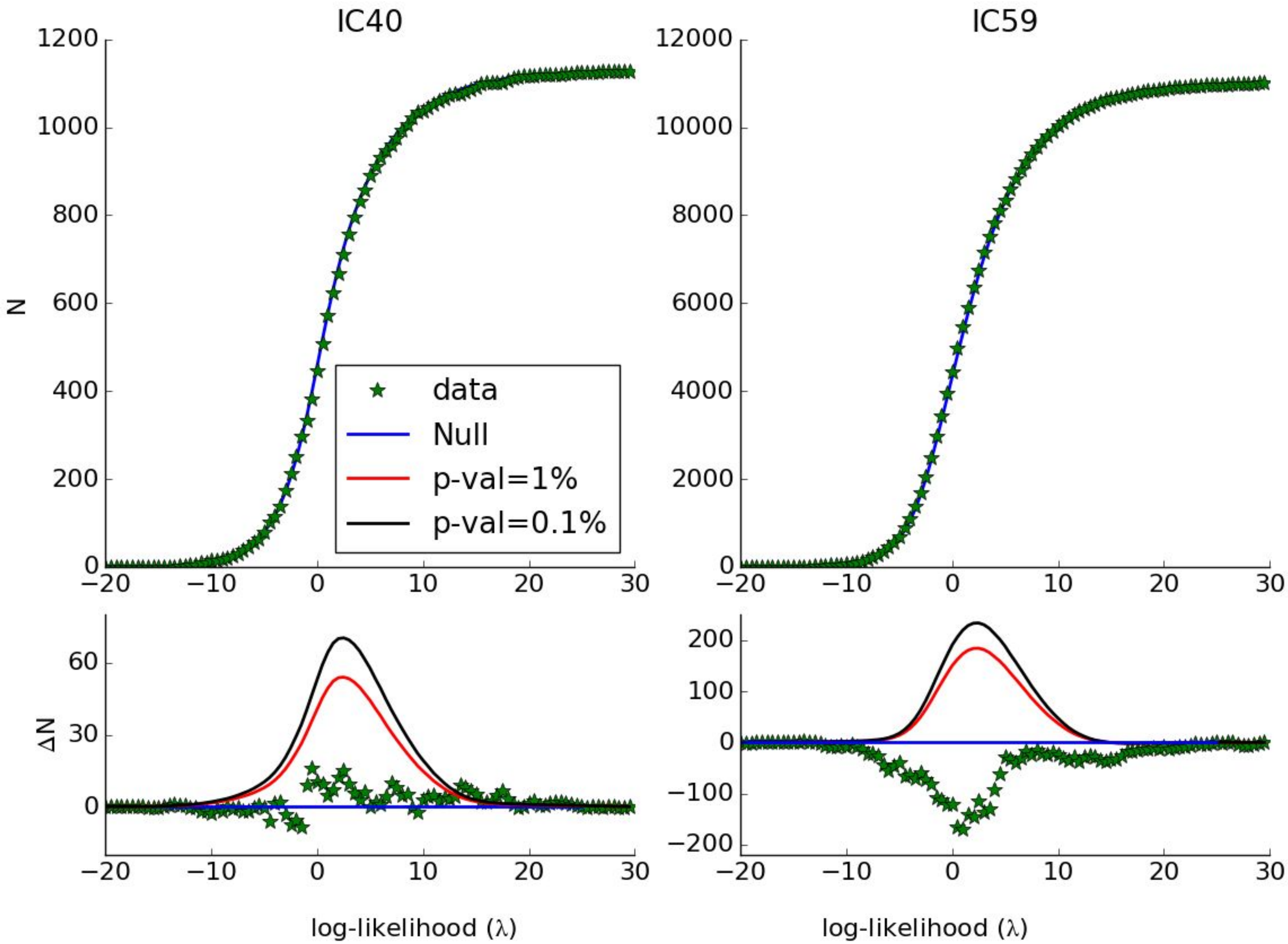
- Inject signal events into the null distribution
- Use Anderson-Darling k-sample test to test for statistical excess of signal events



Anderson Darling (AD) k-sample test statistic vs number of injected signal events for IC40 (red) and IC59 (blue).

	1% P-value	0.1% P-value
IC40	240 events	320 events
IC59	980 events	1280 events

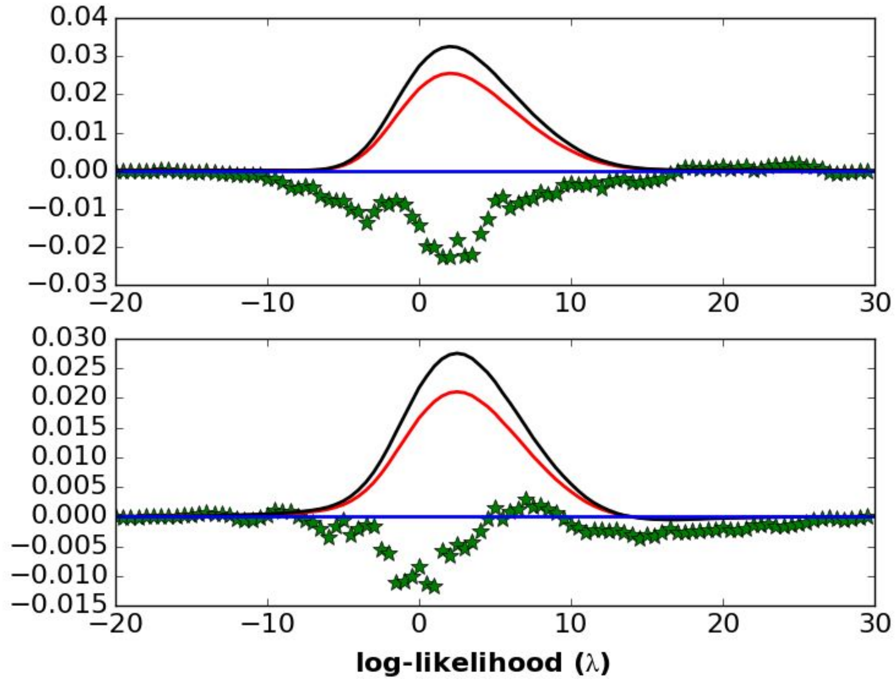
Results of the Signal Injecti



Results of the Anderson-Darling test shown with the residuals of different signal injections. IC40 has a p-value of 63%. IC59 has a p-value of 8%.

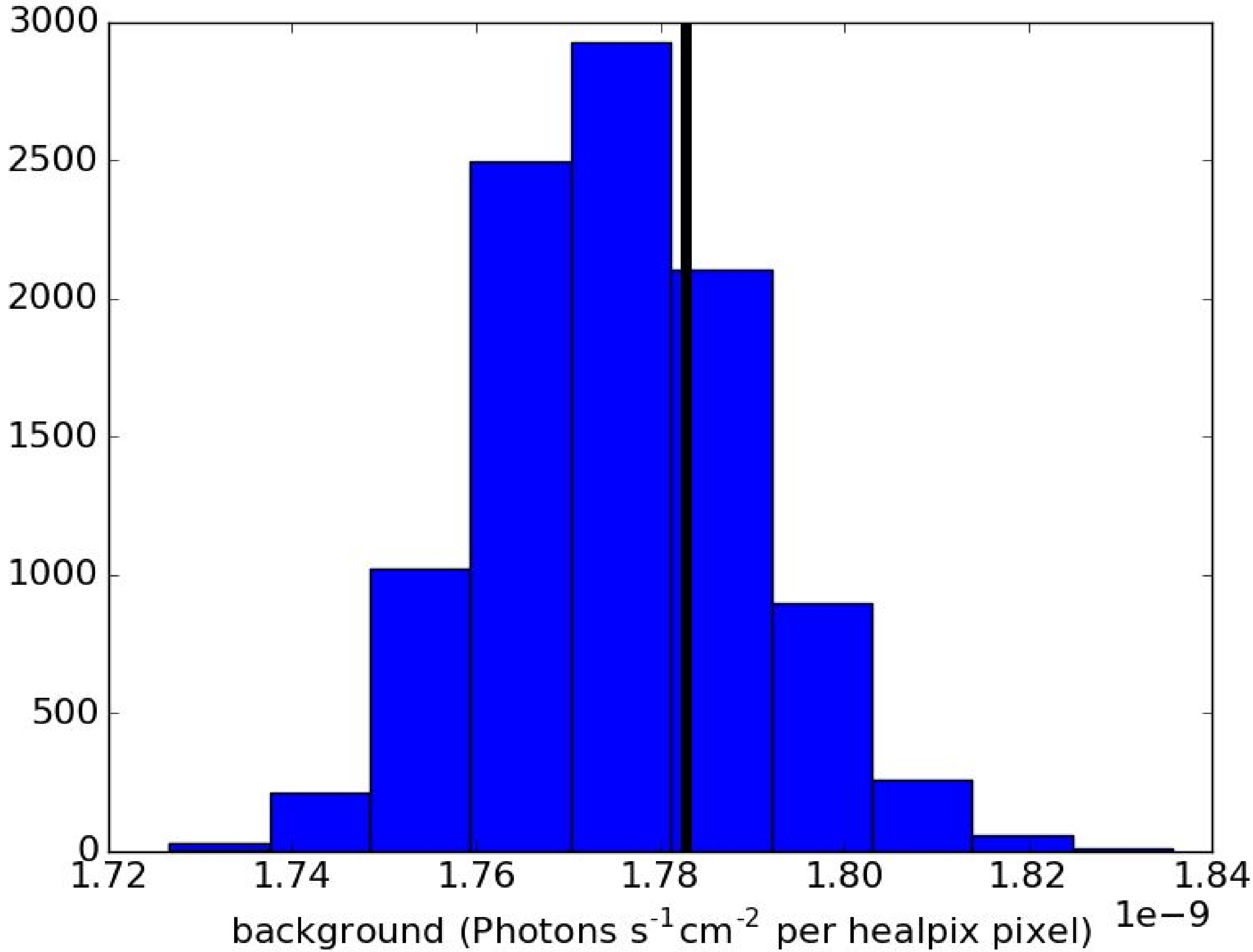
Unexpected Behavior

- IceCube background different in north/south hemispheres
- Statistical excess only persists in northern hemisphere
- Possible causes of low-λ excess:
  - Correlation between neutrino and photon positions
  - Signal with a soft power law
  - Systematic error in IceCube PSF



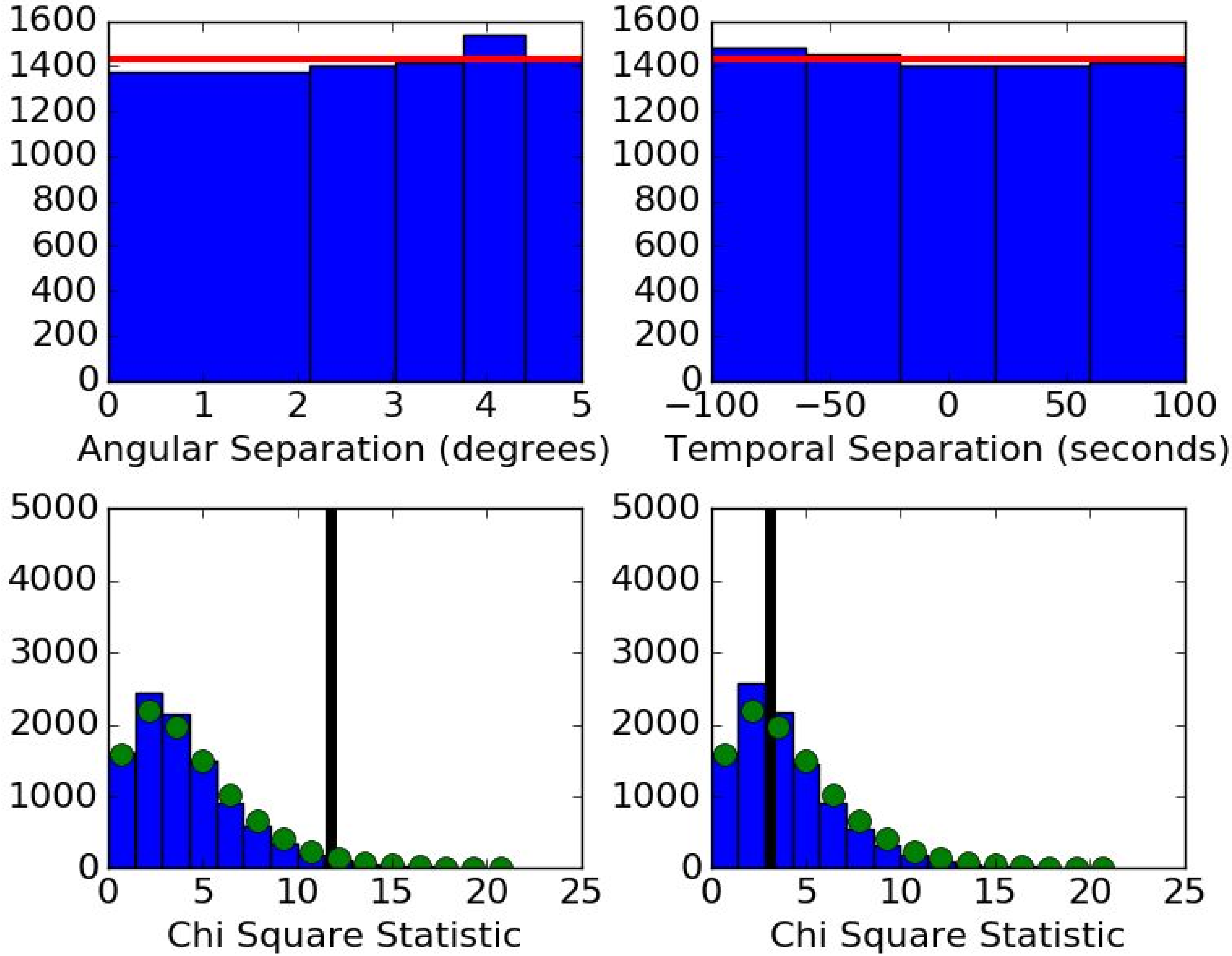
Residuals shown with 1% and 0.1% signal injections for both the Northern hemisphere (top, p-value of 6%) and the Southern hemisphere (bottom, p-value of 45%)

Signal Vetting



Histogram of photon count rate (photons s^{-1} cm^{-2} per healpix pixel) at the location of scrambled northern IceCube neutrinos. Value for the real data shown in black.

Signal Vetting



Upper Plots: Histograms of photon-neutrino spatial (left) and temporal (right) separation. Background is shown in red.

Bottom Plots: Results of a chi square test for each scrambled dataset (blue histogram) plotted with a theoretical chi square distribution (5 DOF). Unscrambled results shown in black.

Conclusions and Future Plans

- Developed a time sensitive coincident analysis for IceCube and Fermi data
- Methods sensitive to rare high-multiplicity events, such as gamma-ray bursts
- Methods also sensitive to a population of cosmic signals
- Analysis can be extended to cover all archival Fermi and IceCube data
- Working on real time analysis code to be included in the AMON architecture

References

- Abbasi, R. et al. 2012, Nature, 484, 351
- Böttcher, M. 2005, ApJ, 621, 176
- Finke, J. D., Razzaque, S., & Dermer, C. D. 2010, ApJ, 712, 238
- Kadler, M. et al. 2016, ArXiv e-prints
- Keivani, A. et al. 2015, ICRC2015
- Murase, K. 2014, ArXiv.org, 1410.3680