Time-Dependent Searches for Neutrino Point Sources with IceCube

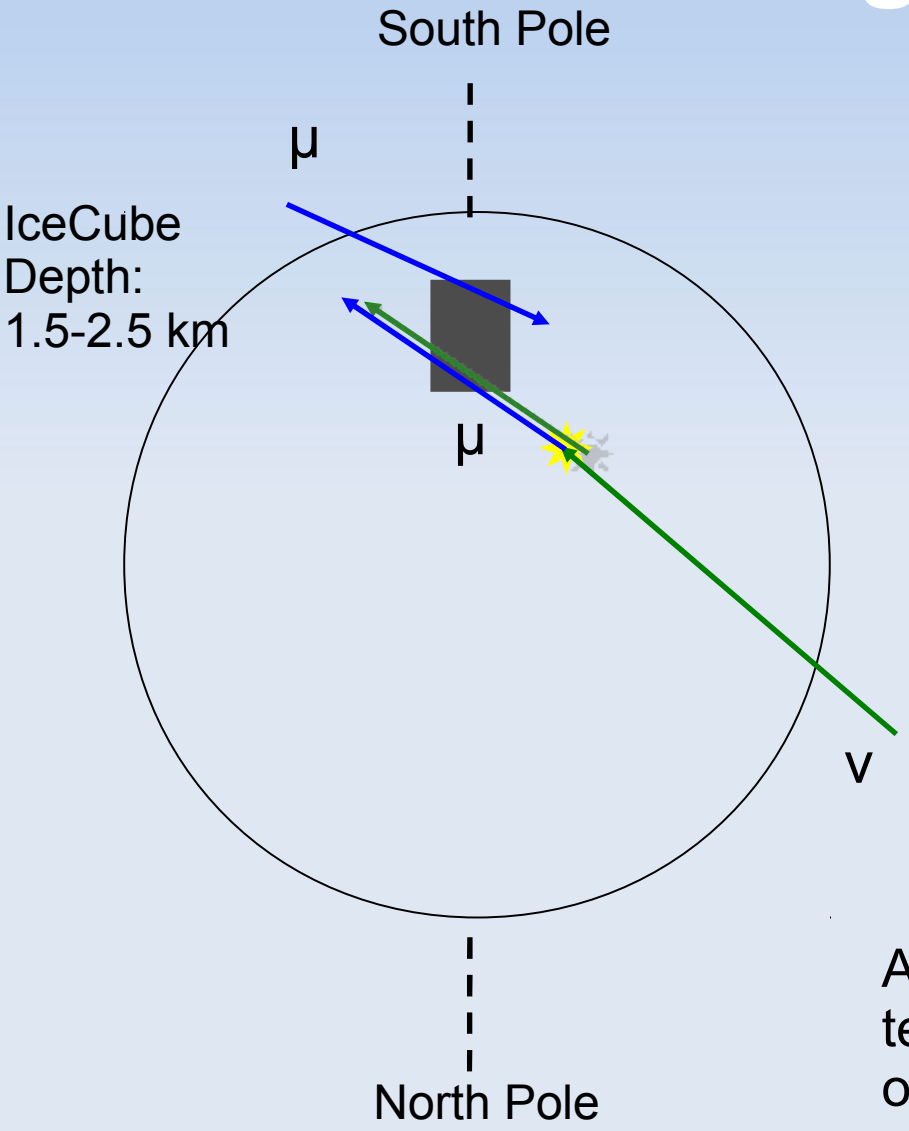
Mike Baker
for the IceCube collaboration

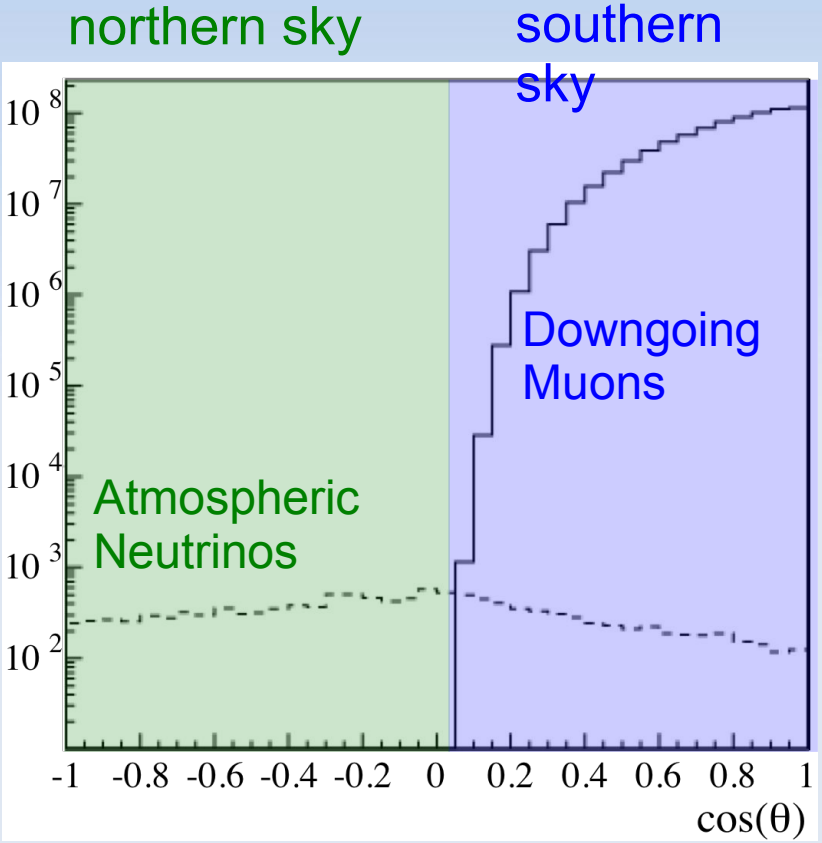
Trieste, 8 September, 2010

We have made a time-integrated search for point sources using the IceCube 40-string data. In addition, we have made several different analyses looking for timing structure for neutrino signals.

* Search for periodic neutrino emission from binary systems
* Search for neutrinos in coincidence with GeV-TeV photon flares
* Search for generic clustering in time and space of neutrinos

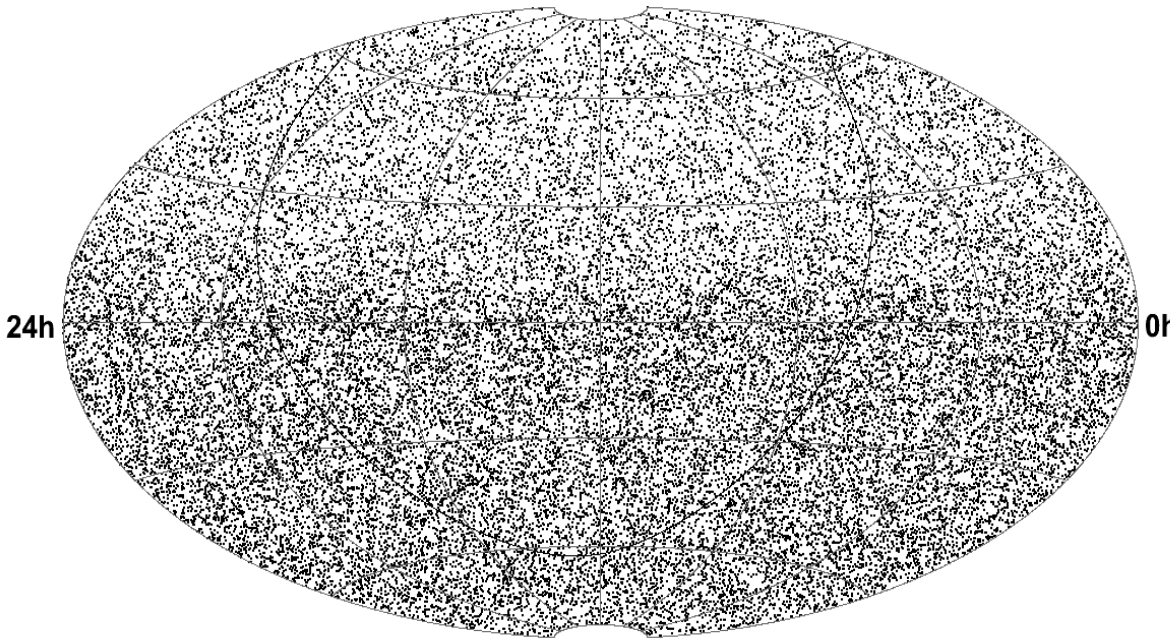
Backgrounds

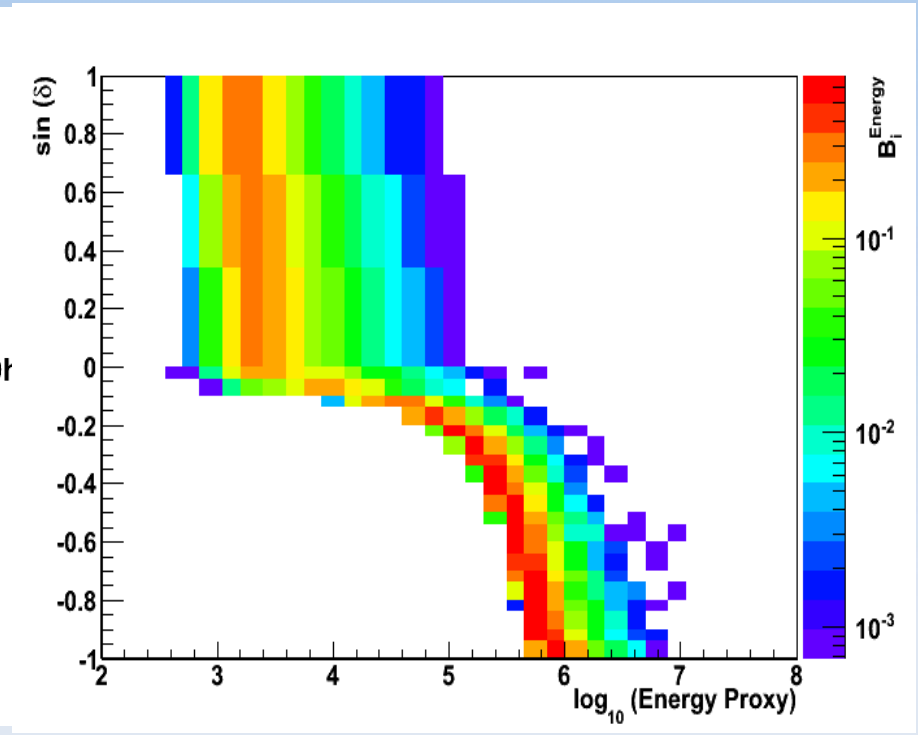




Atmospheric backgrounds for extra-terrestrial neutrino searches at the depth of IceCube

Northern Hemisphere





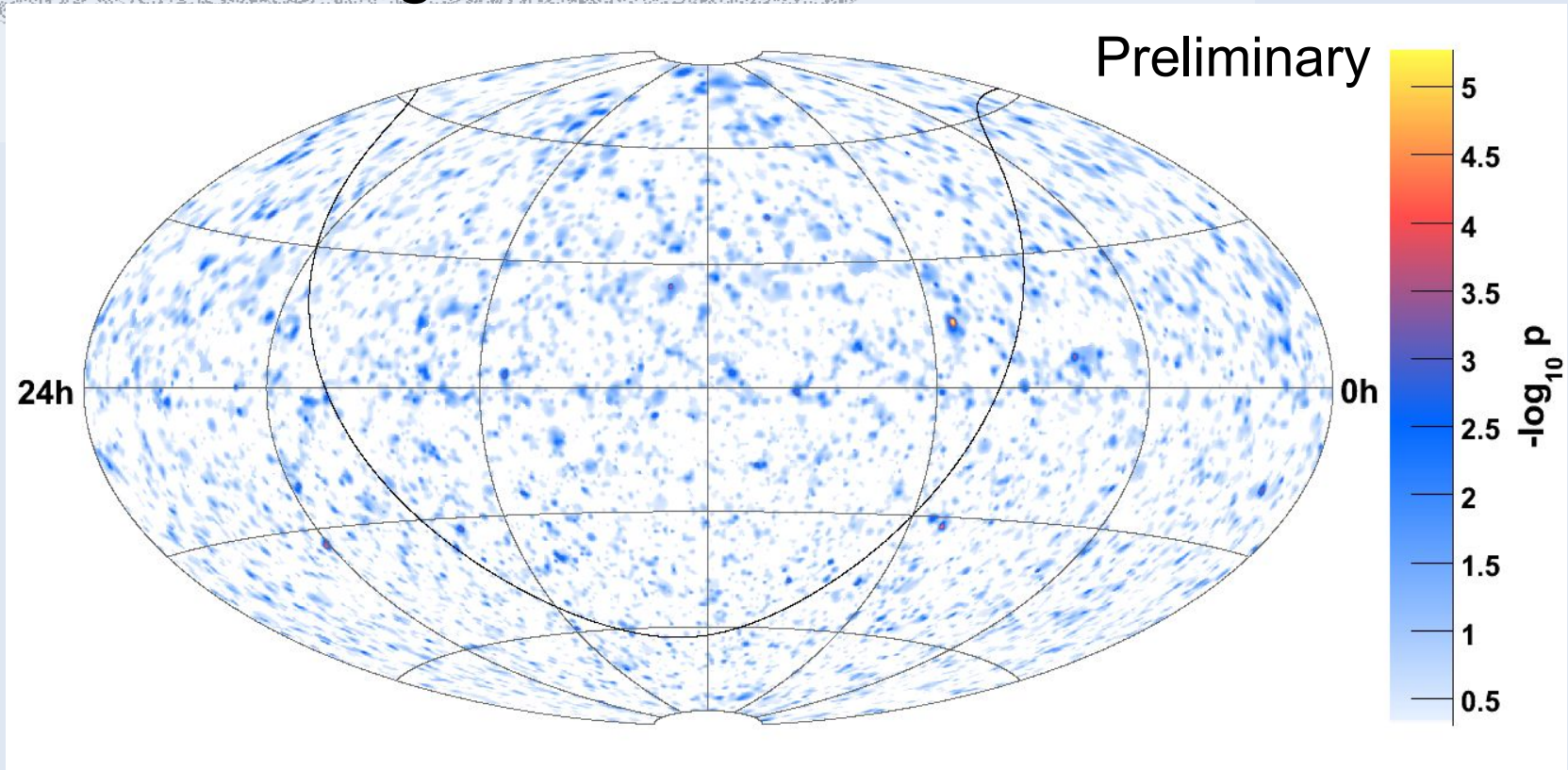
Southern Hemisphere

The event selection takes neutrinos from the northern sky. These are mainly atmospheric neutrinos with ~TeV energies.

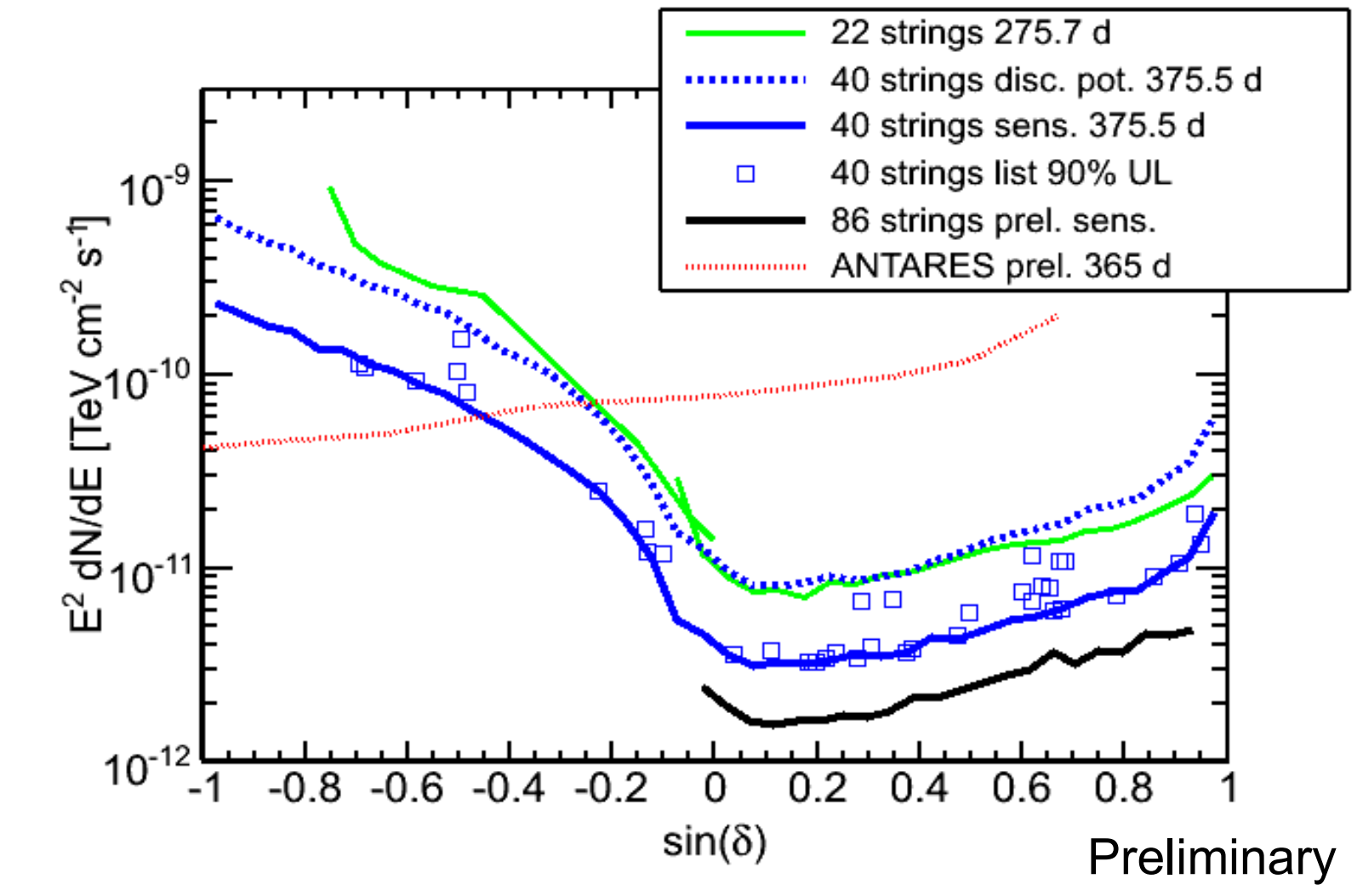
We also use energy cuts to get a sample of ~PeV muons from the southern sky, which are predominantly muons from cosmic ray air showers.

These analyses and the time-integrated search use an unbinned likelihood method, using the track angular uncertainty of individual events (0.5-1°) and energy information to find a best-fit spectral index.

No significant clustering of neutrinos is found – a more significant clustering is found in 18% of scrambled maps.

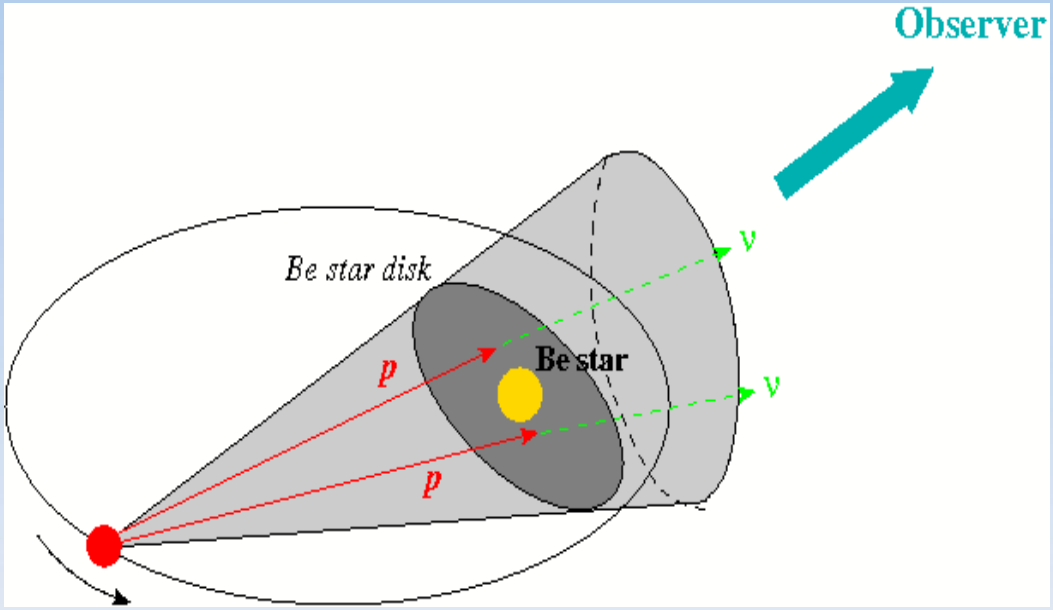


J. Dumm et al., 31st ICRC, Łódź 2009



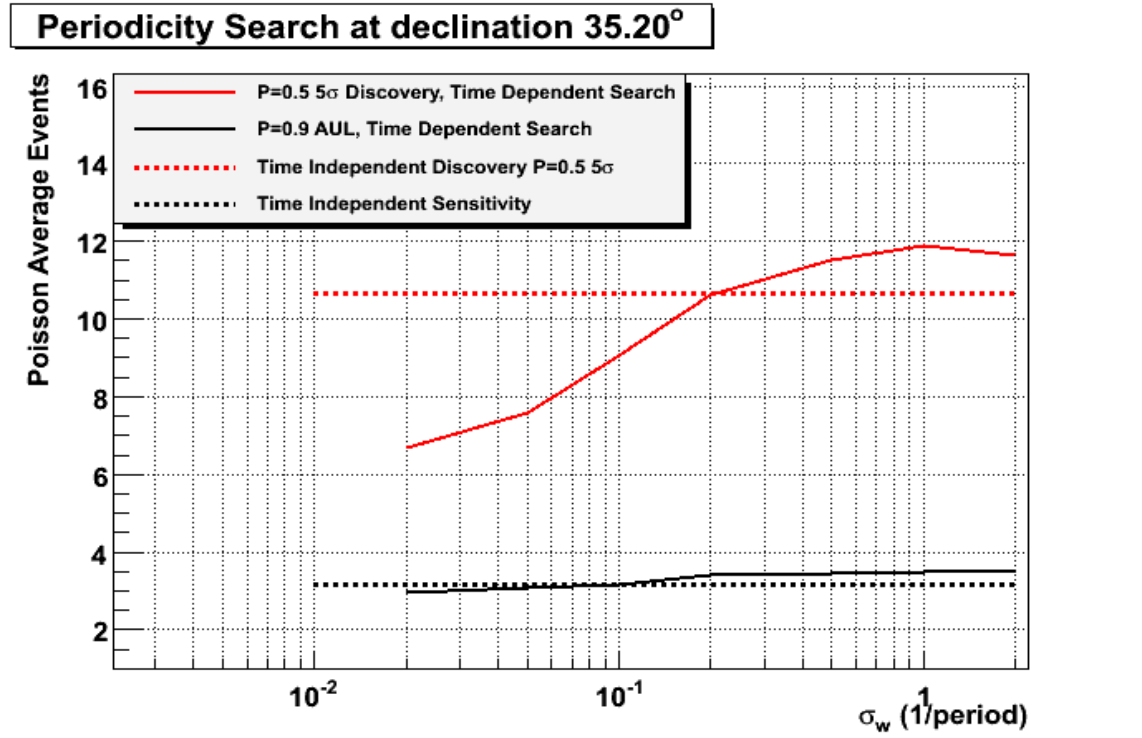
Limits for the time-integrated search: Median Feldman-Cousins 90% sensitivity and upper limits for source list, also the 5-σ 50% Discovery Potential.

Binary system search

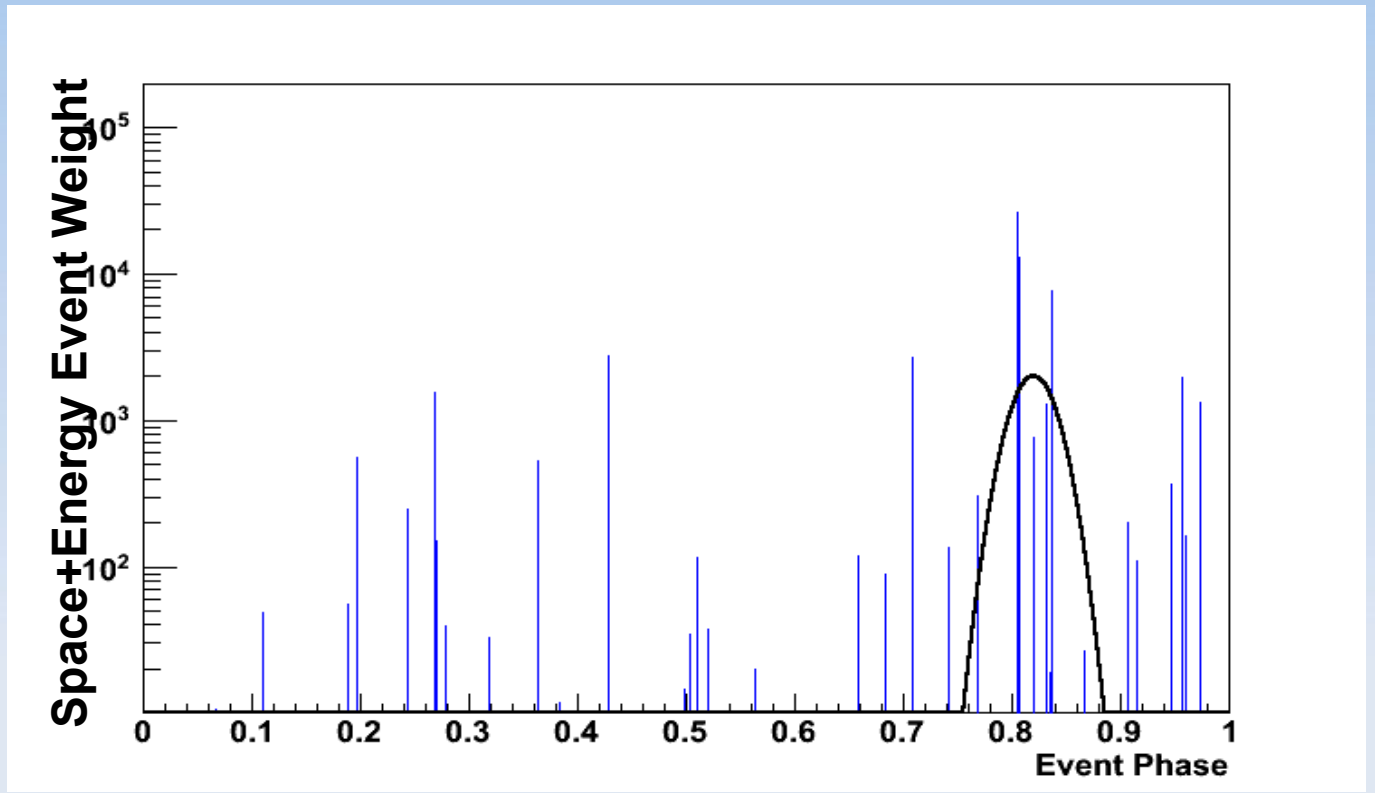


Binary systems in the galaxy where one member is a compact object are potential sources of particle acceleration.

We search for a periodically repeating cluster of events and leave free the phase and fix the period as measured in the optical



We search for a best-fit Gaussian describing the events in phase.



After accounting for looking at 7 sources, the p-value is 1.8%.

The most significant source is Cygnus X3 – the three highest-weight events come in 1/20 of the period, which corresponds to a 15-minute window of the 4.8 hour orbit. Above is the event weights as a function of the period.

The result is interesting, but it is still compatable with background. The time of the events is still blinded, and an analysis looking for correlation with photon flares is in development.

MWL Triggered Flare Search

Blazars are candidate sources for UHECRs, and hence neutrinos, and exhibit variability in HE photon wavebands on the order of days. We VHE light curves and 1-day binned lightcuves from the Fermi LAT to motivate a cut in time for a point-source search.

We leave a flux threshold as a free parameter, to find the best answer to the question: ”At what flux of the lightcurve does neutrino emission turn on?”

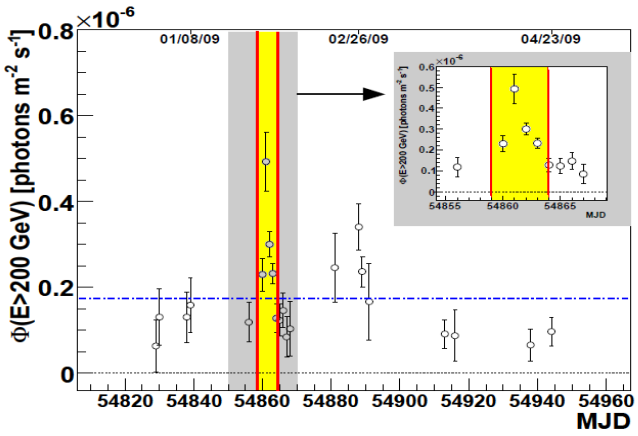
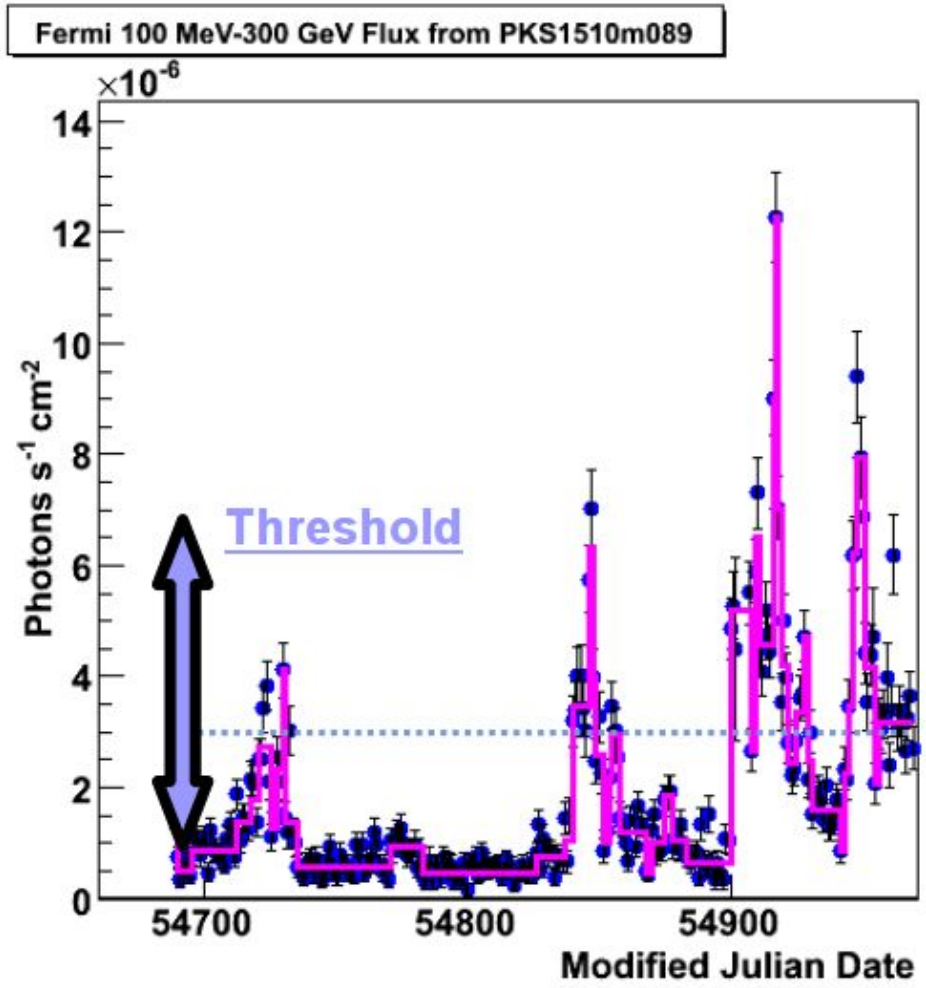
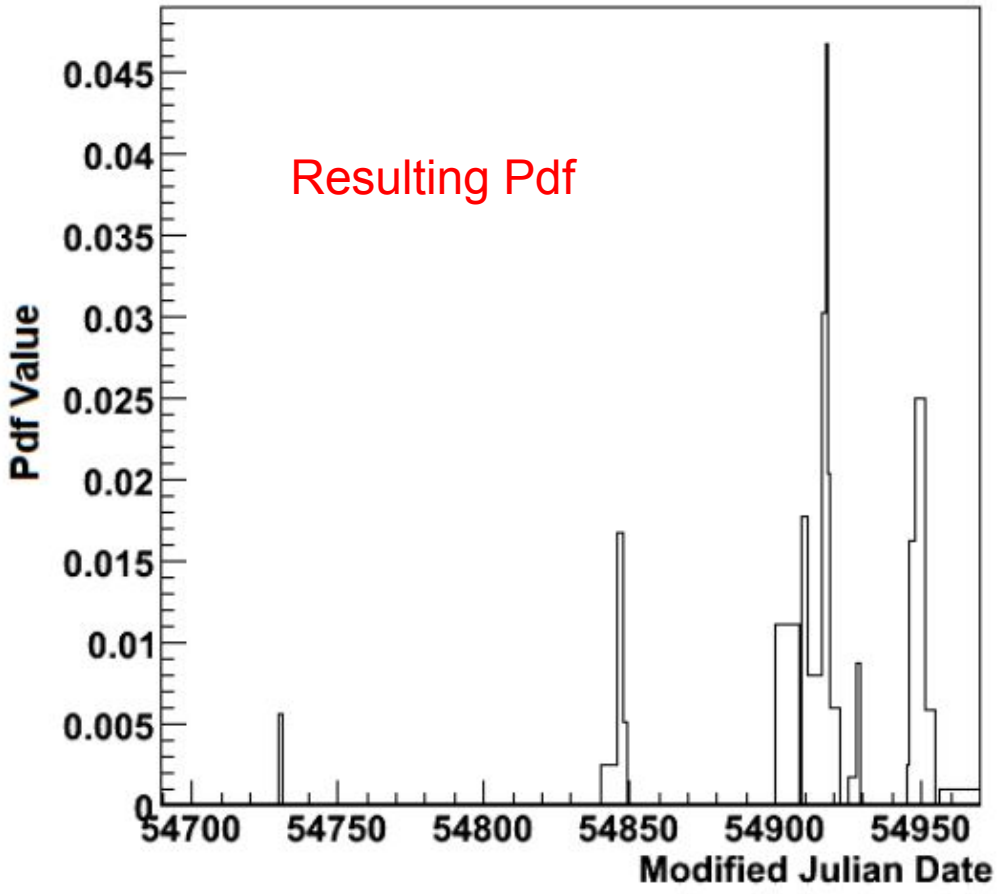


Fig. 3. The daily light curve in units of integral flux above 200 GeV, $\phi(E > 200\text{GeV})$ from 1ES 1218+304 assuming a spectral shape, $dN/dE \propto E^{-\Gamma}$ with $\Gamma = 3.18$. The inset shows the flaring nights in more detail.

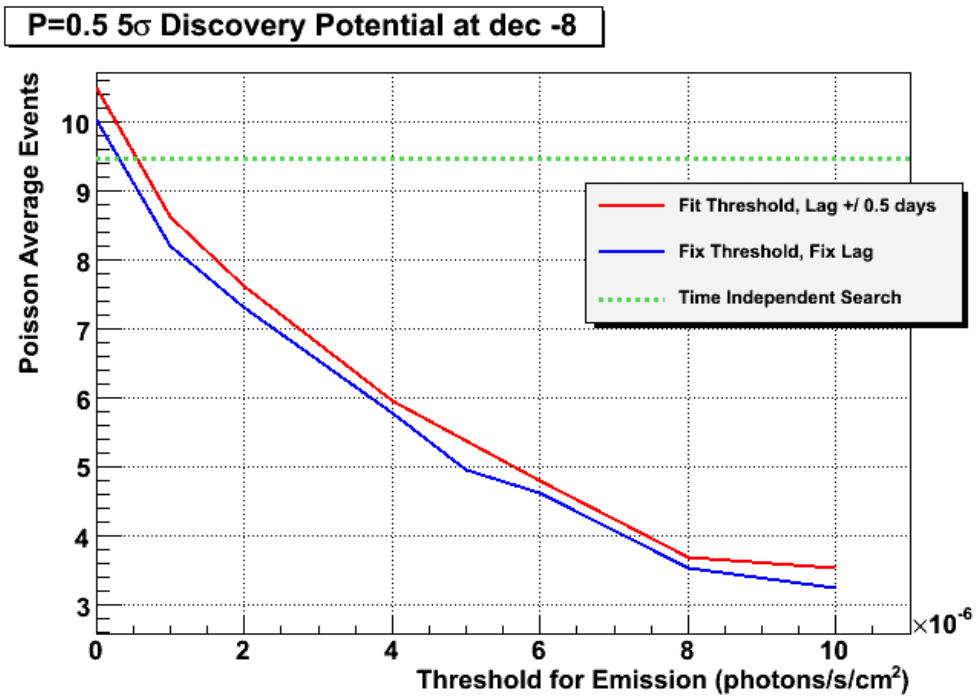
From: A. Imran et. al. ICRC 0510

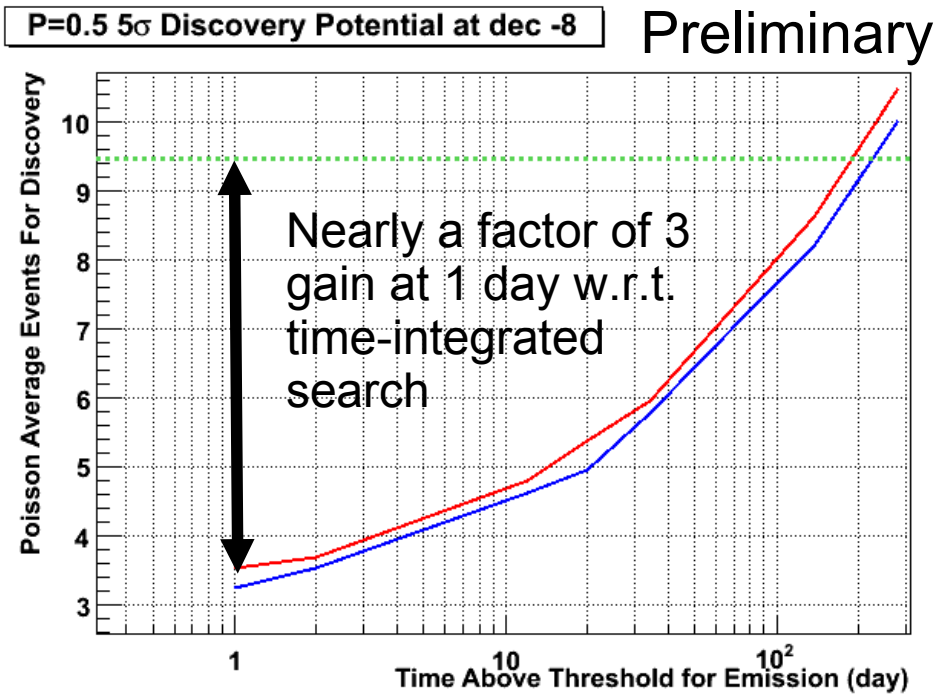




As an example, here is the discovery potential for the lightcurve of PKS 1510-089.

We compare several methods, all using the lightcurve:
In **blue** is the hypothetical case where we know the best cut on threshold and any lag.
In **red** is the case used in the analysis, where we fit the threshold and allow a short lag as a method of interpolating the lightcurve.

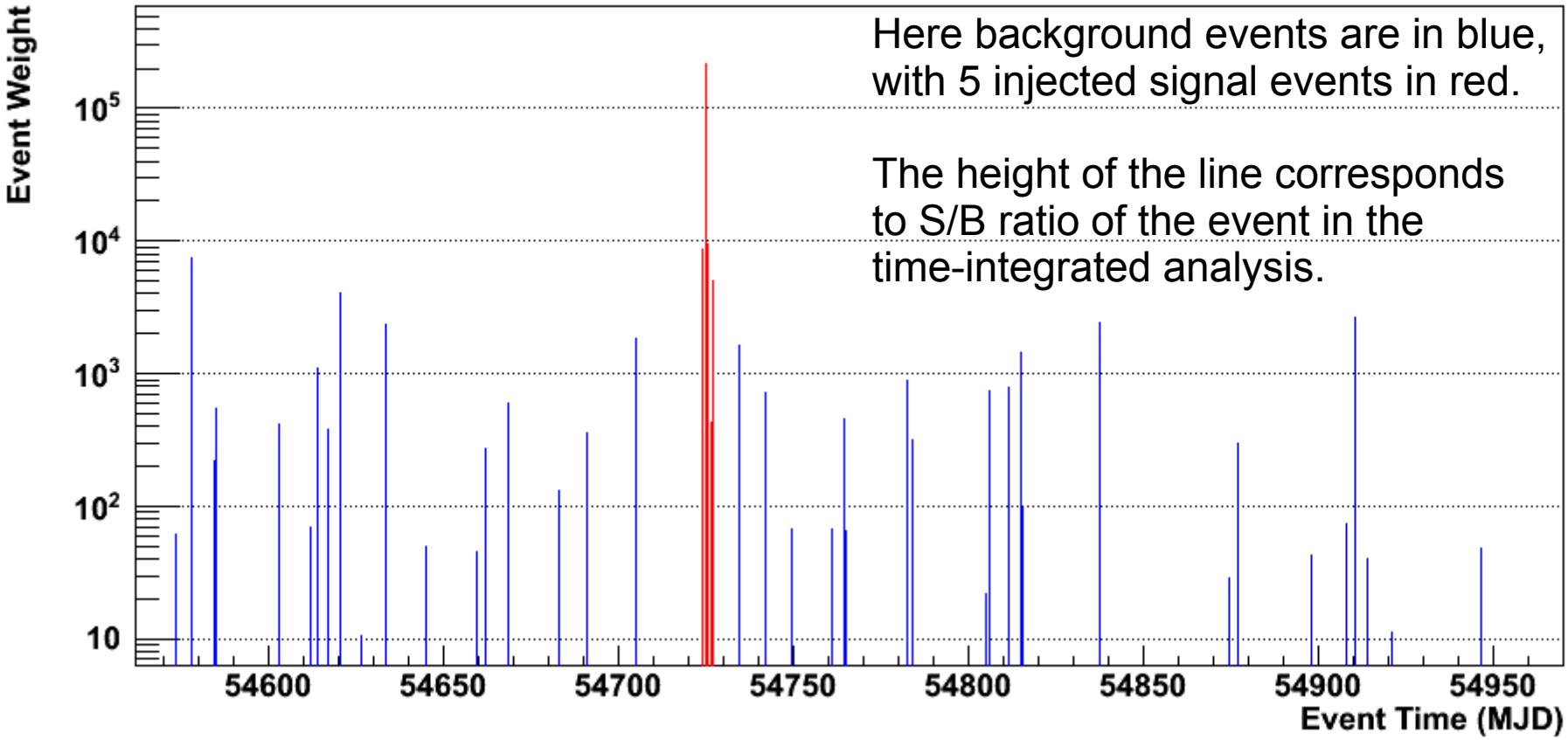




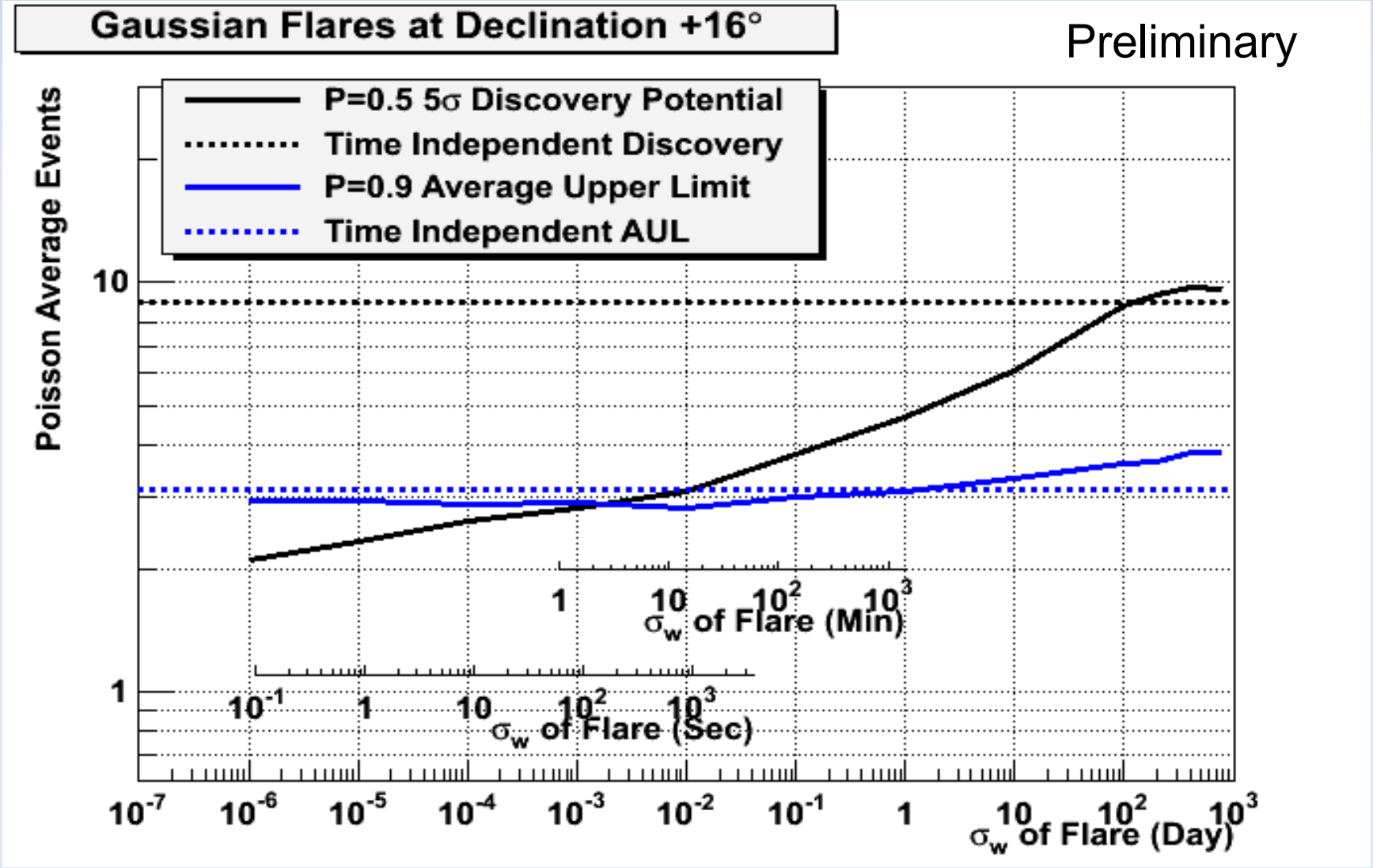
14 sources were tested. The highest significance is from a GeV flare of PKS 1502+106 from August 2008.
After trials, the p-value of the analysis is 29%

Untriggered All-Sky Flare Search

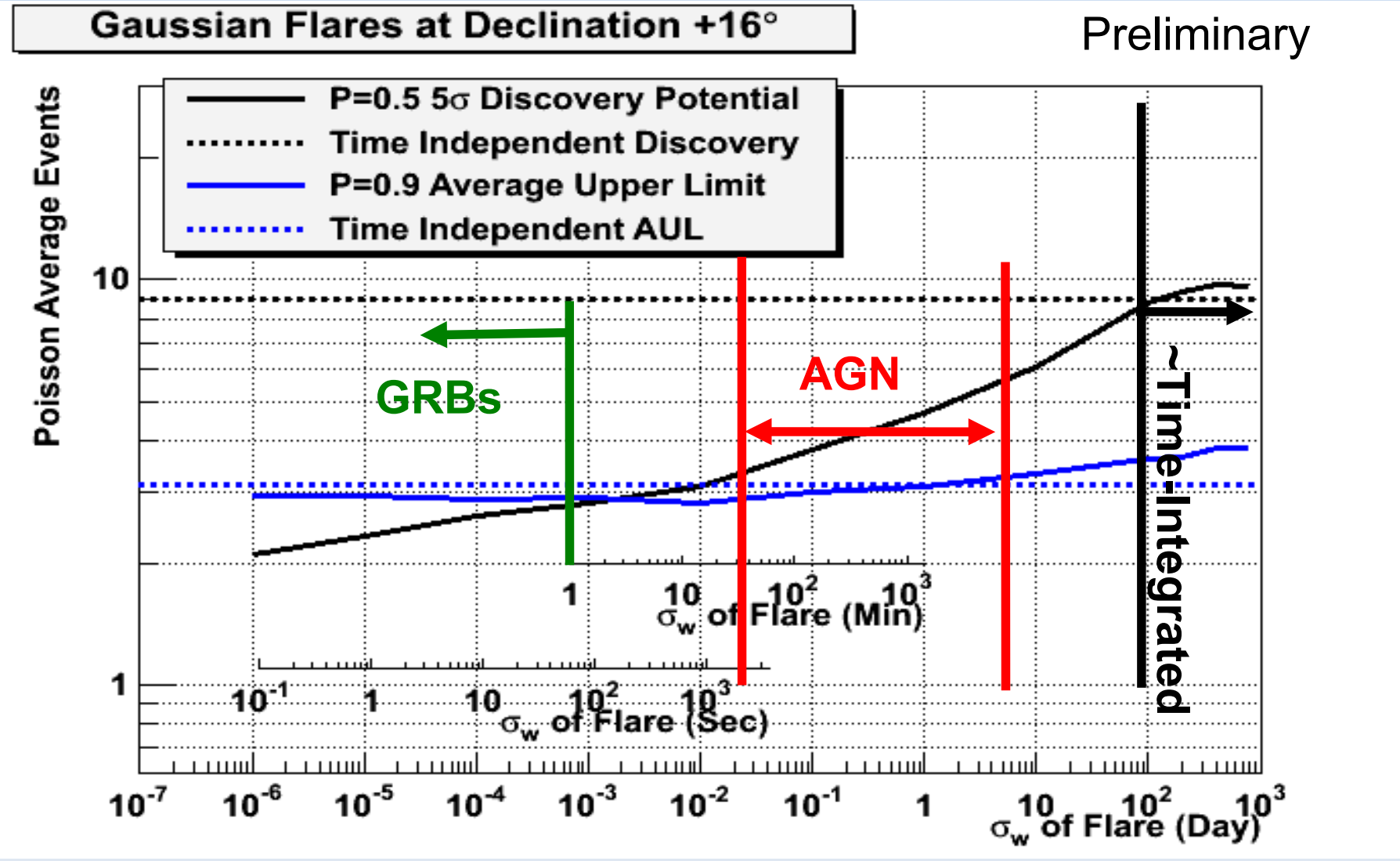
We have an interest in performing a general search which covers many orders of magnitude of flare duration to find occurrences undetected or undetectable with photon emission. We fit for the best mean and sigma of a Gaussian in time to find the strongest clustering in time from a given source location.

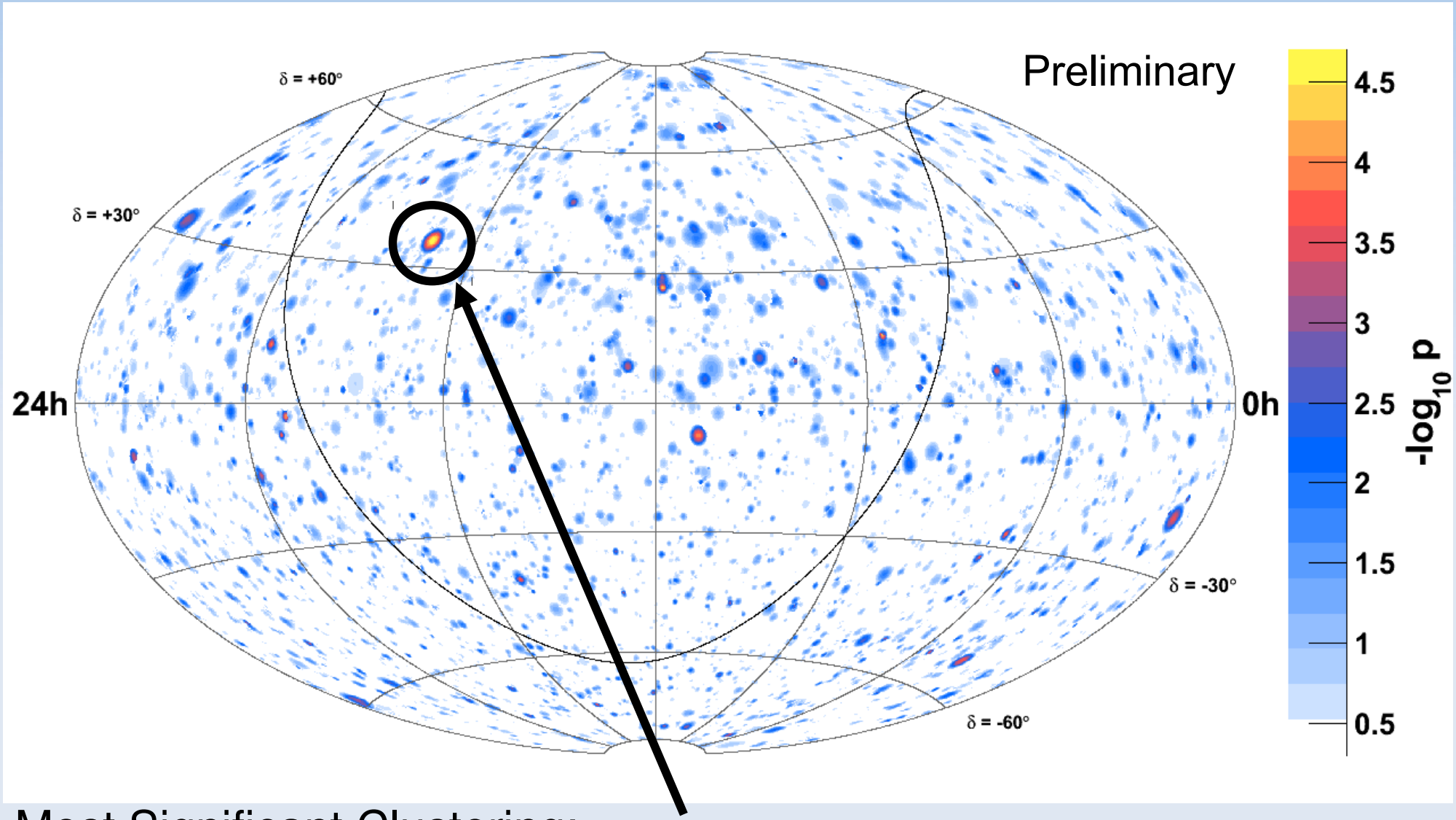


We find that by looking for a clustering of events in time we can dramatically reduce the number of events needed to see a discovery compared to a time-integrated search, and can make a detection which is below the upper limit in the general search.

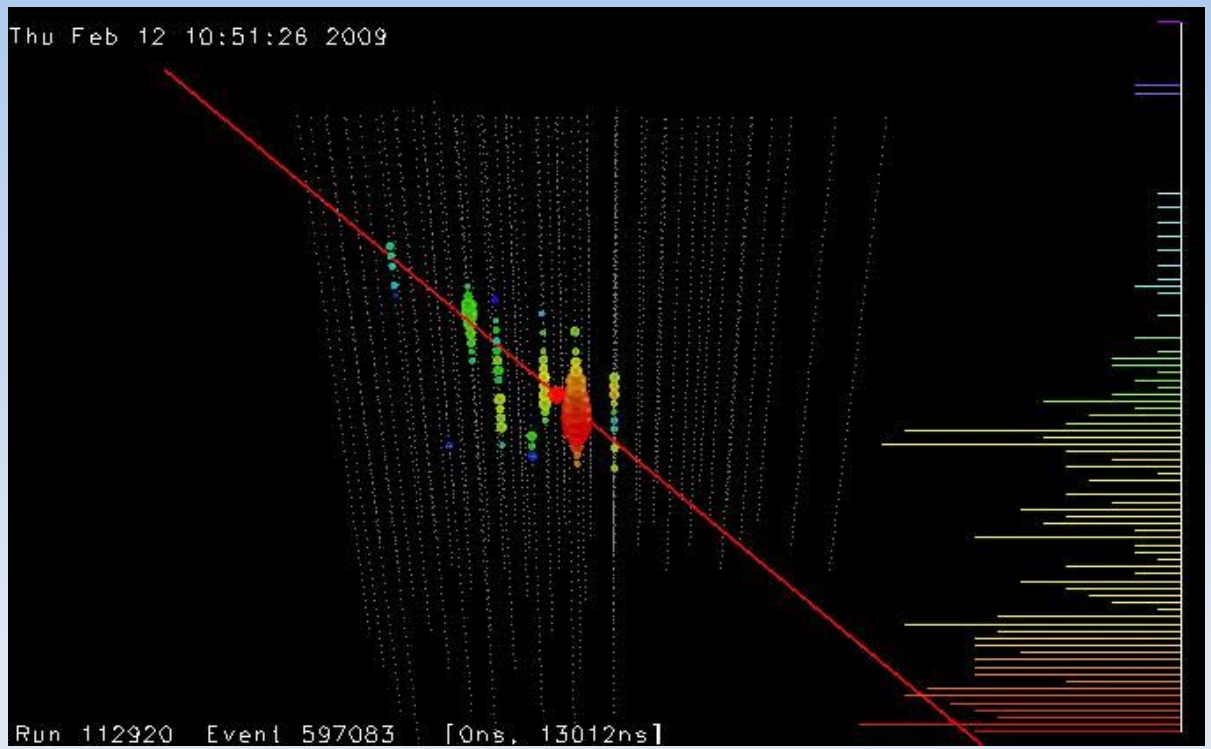


The method's performance is similar to that of the time-integrated analysis even for long flares, opening up the possibility of looking from GRB timescales to steady sources. For flat emission, only 10% more signal is needed for discovery than a PS search even when we add two degrees of freedom to the likelihood.





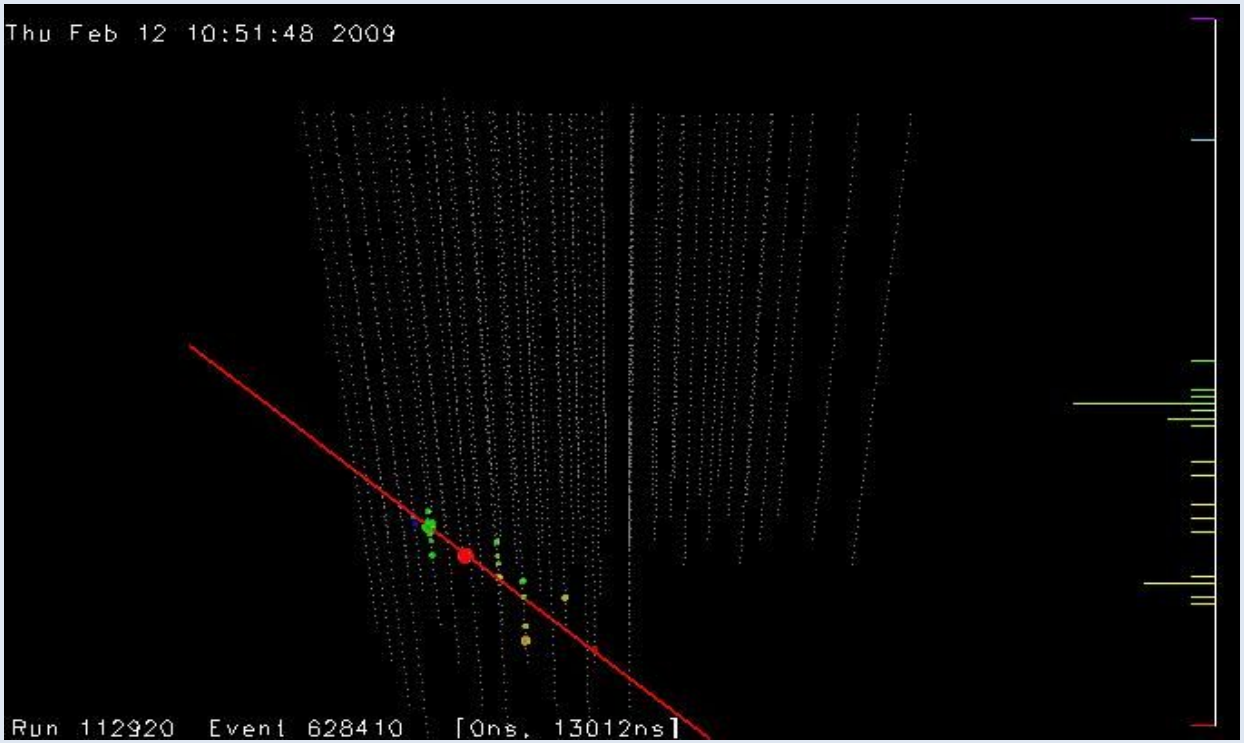
Most Significant Clustering:
-log10(estp): 4.68 at 16h 59' RA and 36.25° dec.
The mean is at: 54874.7 MJD and the Gaussian flare width is 15 seconds.
56% of scrambled skymaps find a clustering with higher significance.



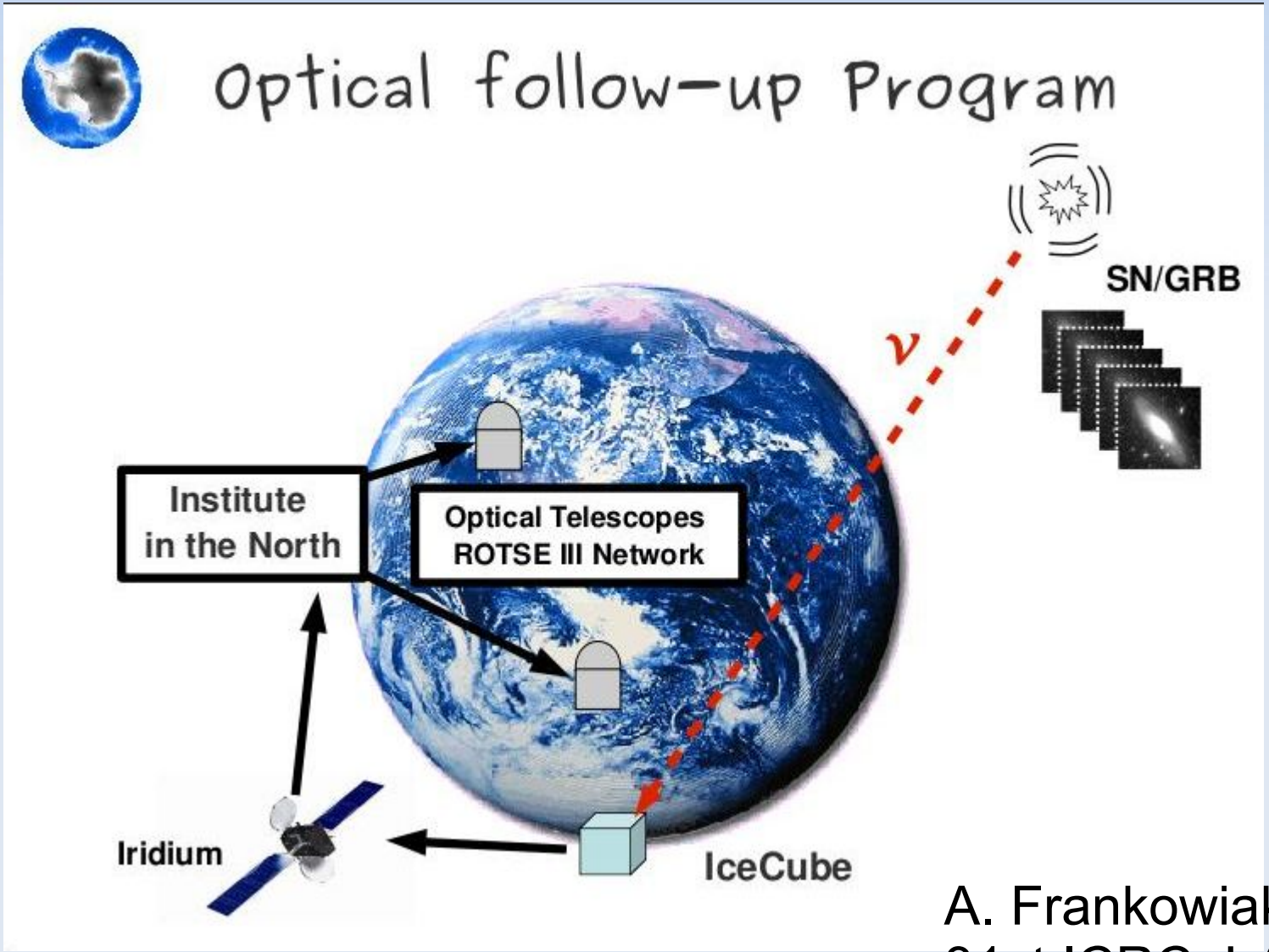
The best clustering corresponds to two events which are 22 seconds apart. There is a spatial separation of 2.01 degrees between the events.

Angular uncertainty = 0.60 deg
# Hit DOMs = 65
Energy = ~30 TeV

Angular uncertainty = 1.96 deg
# Hit DOMS = 17
Energy = ~3 TeV

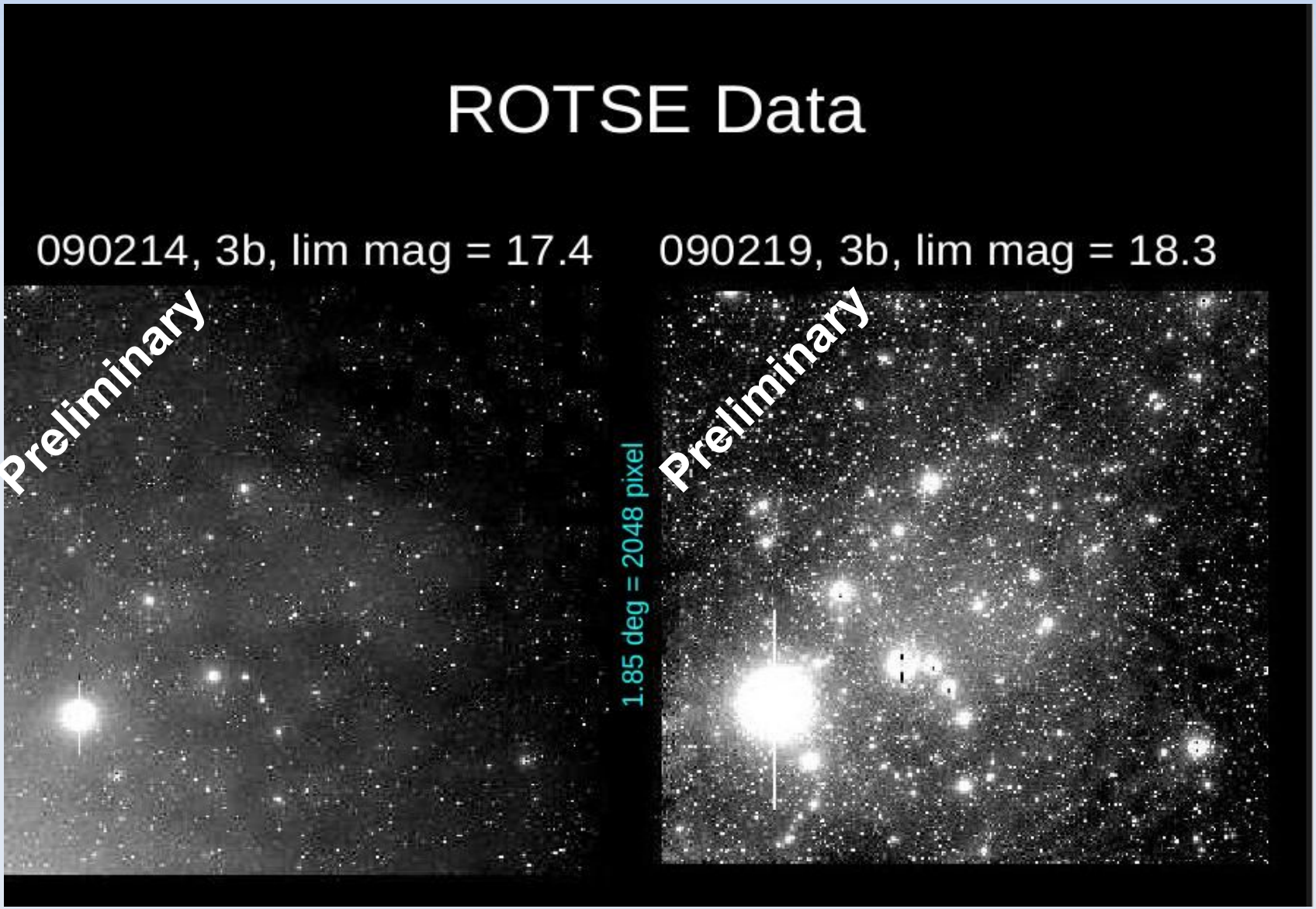


IceCube has an optical follow-up program with ROTSE and sends real-time alerts when neutrino events are detected close in time and space. This event pair was one of the alerts sent in 2009.



A. Frankowiak,
31st ICRC, Łódź 2009

Optical data was first taken 39 hours after the events, with 14 days of observations after that. There is no indication of variability from the optical data.



In summary, we have performed a number of time-dependent searches with IceCube 40-string data:

– Periodic neutrino emission from 7 microquasars (Final p-value 1.8%, consistent with background fluctuation)

– Neutrinos correlated with GeV/TeV gamma emission from 14 selected blazars (Final p-value 29%)

– All-sky search for space and time clustering of events (Final p-value 56%).

No significant time-dependent neutrino emission was detected.

Future plans are to follow up on the Cygnus X3 observation with the 59-string data and also to add stacking to flaring searches.

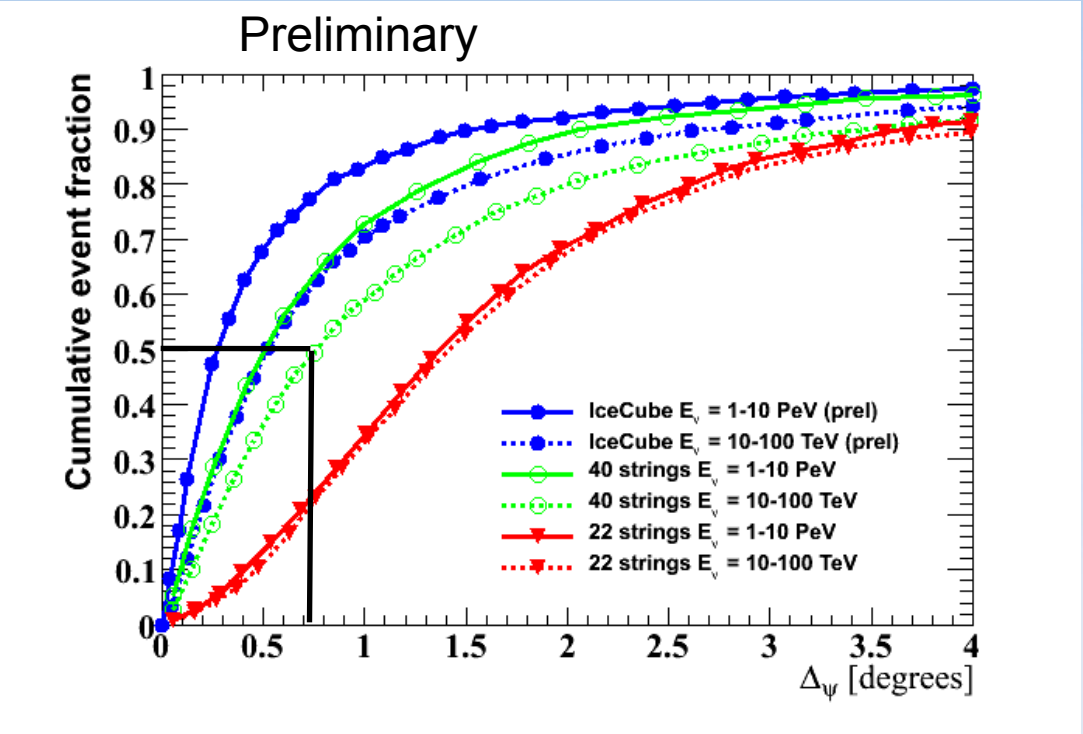
Backup

Median of the PSF for E^{-2} neutrino spectrum:

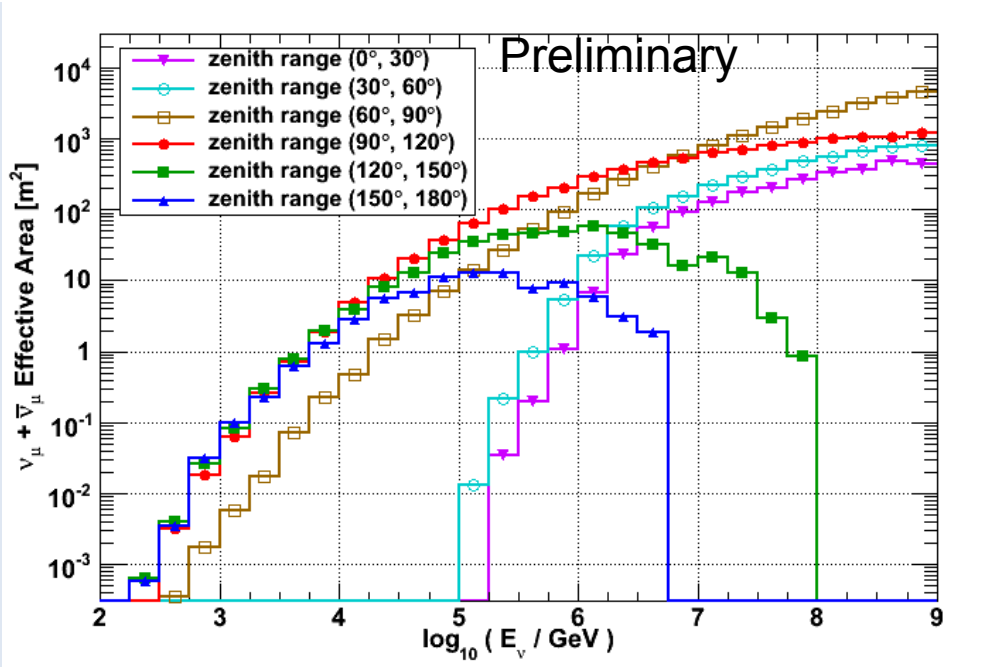
0.7° in northern sky

0.5° in southern sky

(difference due to energy of events in final sample)



Solid-angle averaged effective area to an equal flux of $\nu_\mu + \bar{\nu}_\mu$, reconstructed within 2° of truth for 6 declination bands

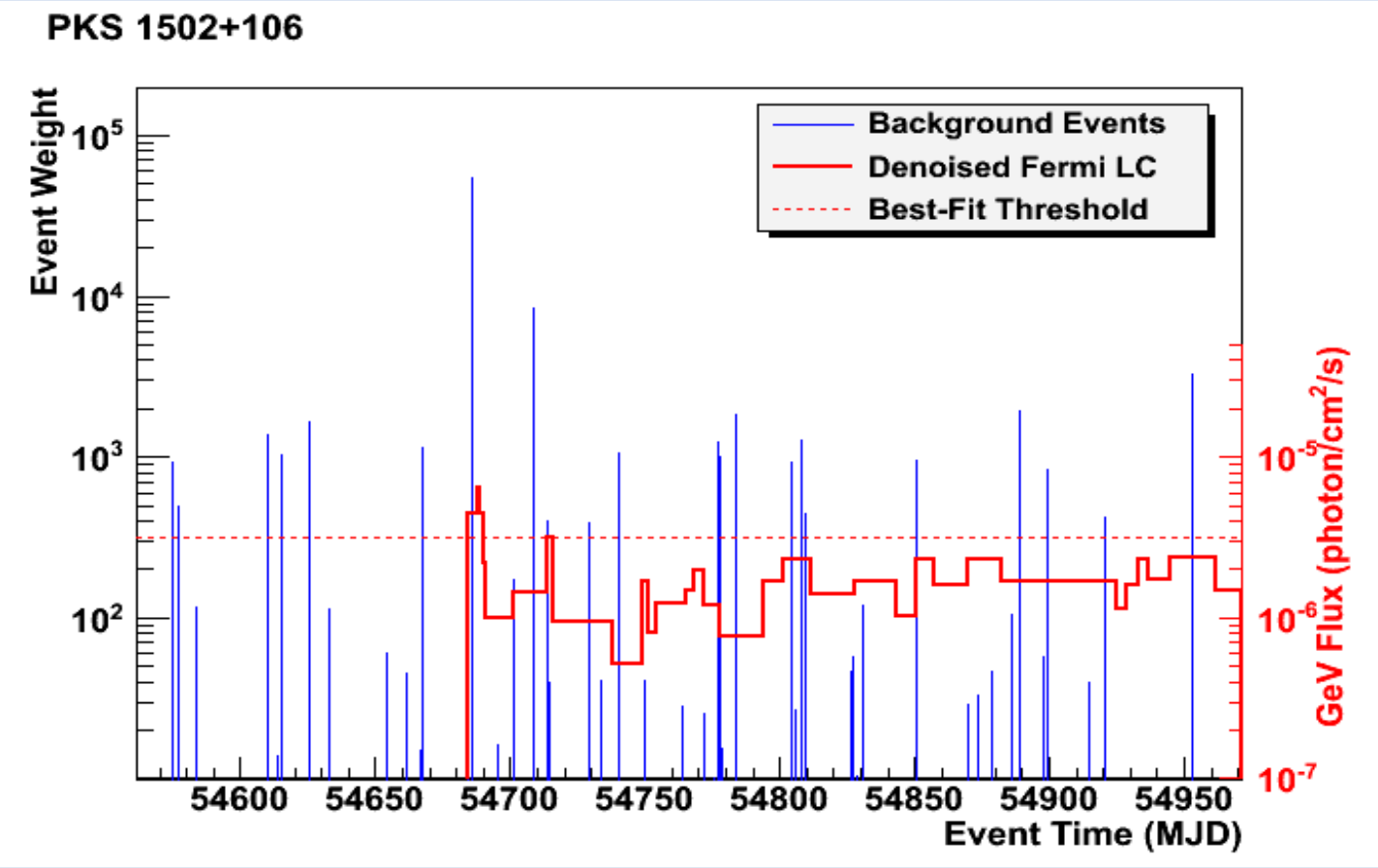


The periodic analysis looked at 7 sources, and these are the best-fit parameters and pretrial p-values:

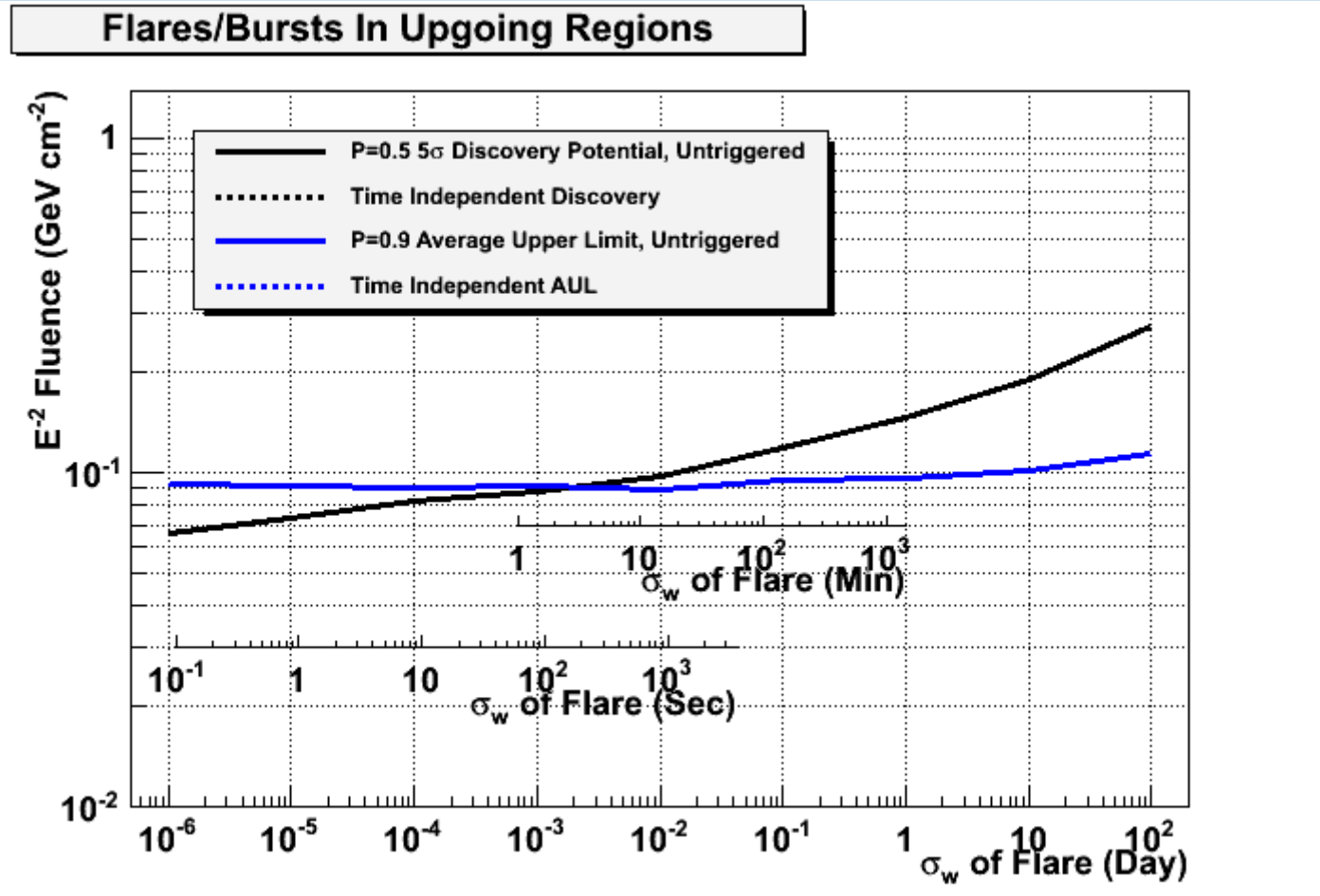
Source	(Ra, Dec)	Period	pretrialP	NSrc	Gamma	mean	sigma_w
Cygnus X3	**(308.107,40.958)**	**0.199679**	**0.00186**	**4.27**	**3.75**	**0.820**	**0.02**
SS433	(287.957,4.983)	13.0821	0.3523	2.15	2.89	0.601	0.02
Cygnus X1	(299.591,35.202)	5.5929	0.0793	1.39	1.54	0.708	0.02
LS I +61 303	(40.132,61.229)	26.498	0.2271	1.83	3.95	0.521	0.02
GRS 1915+105	(288.798,10.946)	30.8	0.4266	2.03	3.95	0.986	0.045
XTE J1118+480	(169.545,48.037)	0.16993	0.2784	2.40	2.35	0.872	0.131
GRO J0422+32	(65.428,32.907)	0.21214	0.0373	2.95	3.06	0.800	0.02

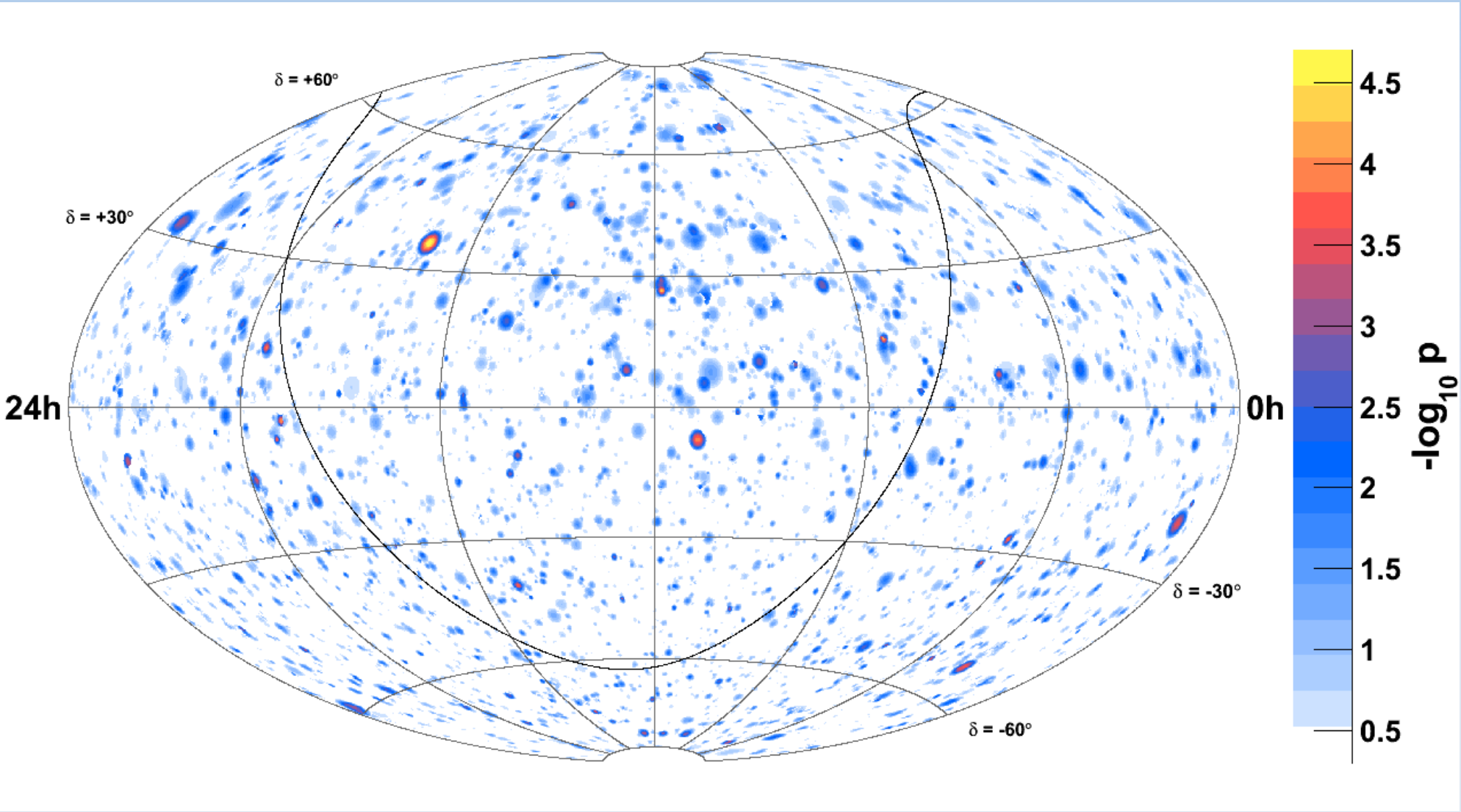
Minimum P-value: 0.00186146 Best Source: Cygnus X3

The best source found was one high-energy event during a GeV flare of PKS 1502+106, but it finds only one event. After trials, the p-value of the analysis is 29%.

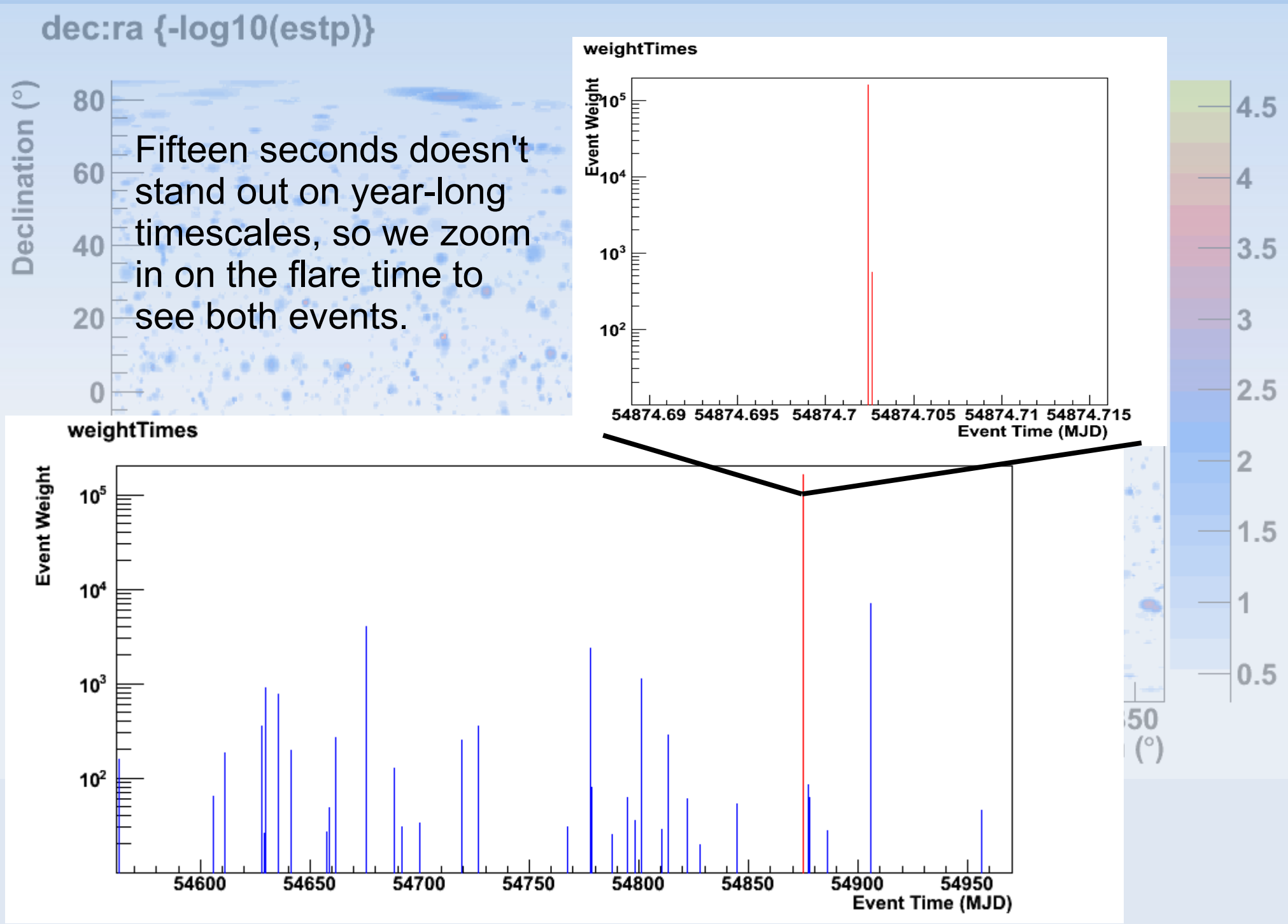


I also had a look at what the Discovery potential and upper limit looks like in terms of fluence. The fluence required is within a factor of a few of the naked-eye GRB.

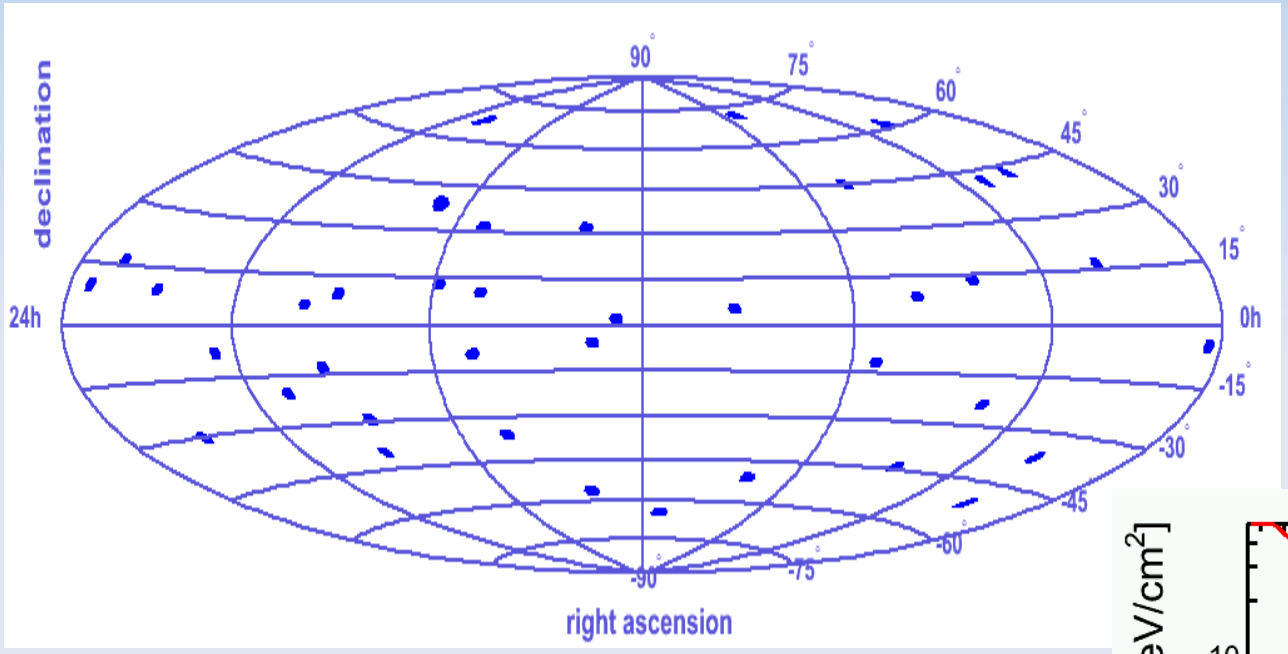


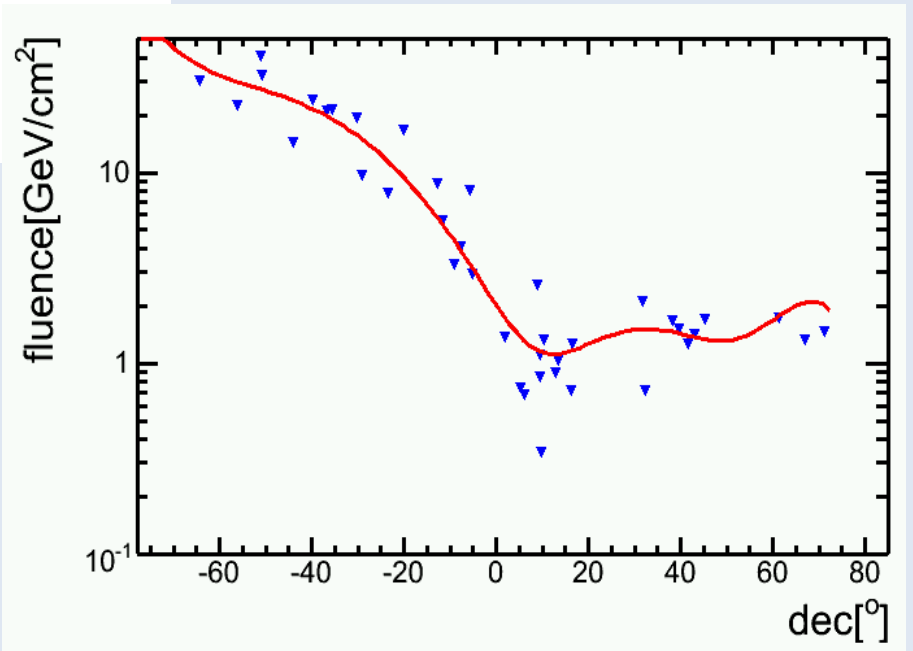


Here is the skymap in RA and dec of the p-value at each location for the all-sky untriggered search.


dec:ra {-log10(estp)}
Declination (°)
80
60
40
20
0
Fifteen seconds doesn't stand out on year-long timescales, so we zoom in on the flare time to see both events.
weightTimes
Event Weight
10^5
10^4
10^3
10^2
54874.69 54874.695 54874.7 54874.705 54874.71 54874.715
Event Time (MJD)
weightTimes
Event Weight
10^5
10^4
10^3
10^2
54600 54650 54700 54750 54800 54850 54900 54950
Event Time (MJD)
4.5
4
3.5
3
2.5
2
1.5
1
0.5

We also performed an untriggered flare search a smaller list of sources seen to be variable by Fermi-LAT to test with a time-clustering algorithm, but no source stood out. The p-value after trials was 94%





J. Bazo-Alba, et al. paper In Preparation