Searching for Time-Dependent Neutrino Emission from Blazars with IceCube

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on behalf of the IceCube collaboration

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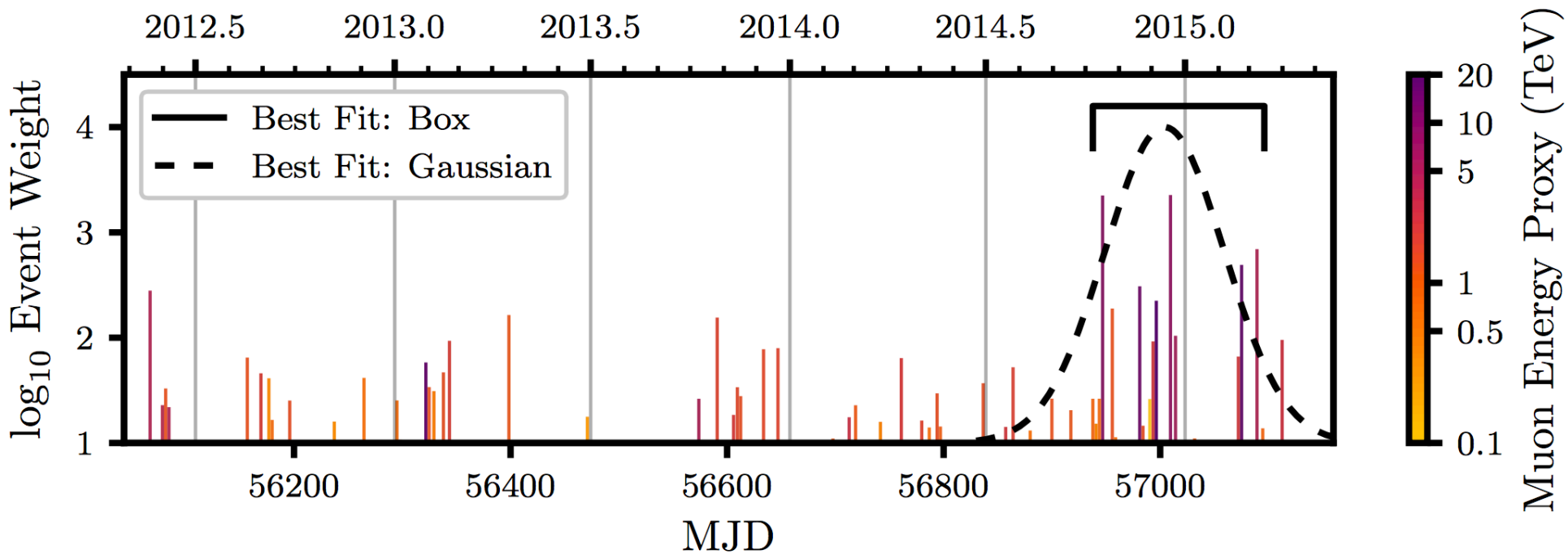
Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert

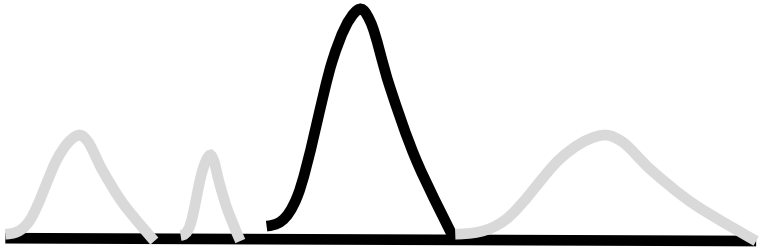
IceCube Collaboration*†

Science 361, 147-151 (2018)

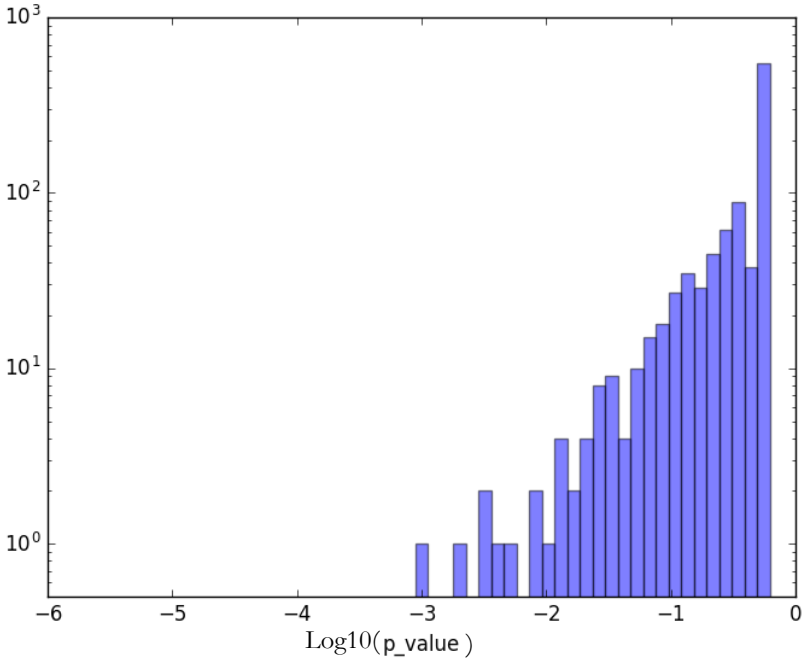


We have seen evidence of a neutrino flare from one blazar that was uncorrelated with gammas.
Is there evidence of significant flares from other blazars?

Analysis: Apply the untriggered time-dependent flare search (same analysis as for TXS 0506+056) on the source list consisting of the Fermi 3LAC catalog



Step 1: Identify the **most significant neutrino flare** in the direction of each 3LAC object



Step 2: Evaluate the significance of the distribution of p-values with the binomial test

Time-dependent maximum likelihood method

Based on neutrino **distance** from search direction, **energy, and time** from search time window

Number of signal neutrino events

$$L = \prod_{i=1}^{N} \left[\frac{n_s}{N} S_i + \left(1 - \frac{n_s}{N}\right) B_i \right]$$

Total number of neutrino events

Time-dependent maximum likelihood method

Penalty term for short time windows (T_L: total lifetime)

$$D = -2\log\left[\frac{T_L}{\hat{T}_\sigma} \times \frac{L(\hat{n}_s = 0)}{L(\hat{n}_s, \hat{\gamma}, \hat{T}_o, \hat{T}_\sigma)}\right]$$

<u>p-value</u>: Compare value of test statistic D with the distribution of values from scrambled data

<u>Fit variables</u>

$\hat{n}_s$: Number of signal events

$\hat{\gamma}$: Energy spectral index, $E^{-\gamma}$

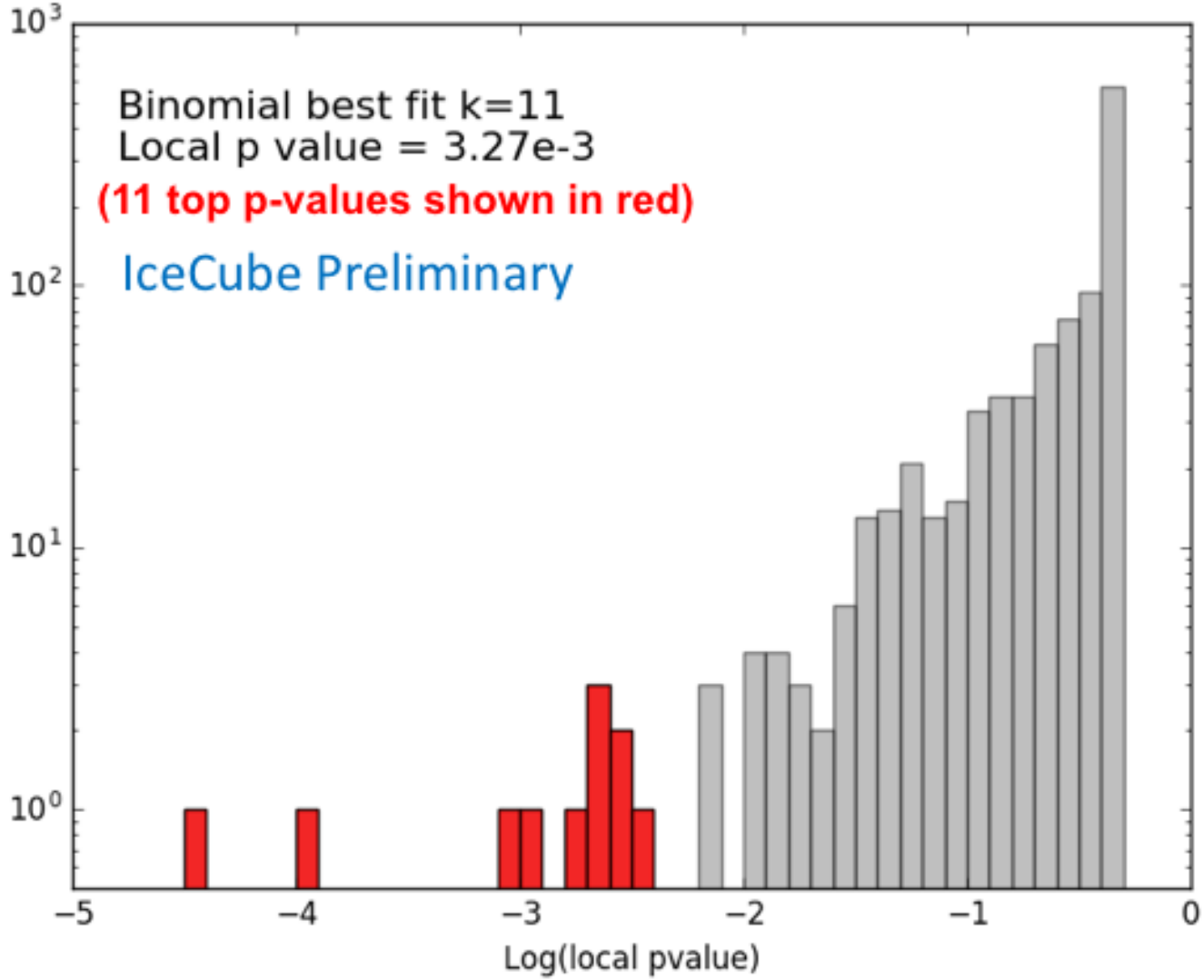
$\hat{T}_O$: Time of flare

$\hat{T}_\sigma$: Time width of flare

Most significant objects from the 3LAC catalog

Name	Counterpart	Optical class	RA [°]	Dec [°]	$\hat{n}_s$	$\hat{\gamma}$	$\hat{T}_o$ [MJD]	$\hat{T}_W$ [days]	p-value
3FGL J0509.4+0541	TXS 0506+056	bll	77.36	5.69	12.3	2.2	57000	1.2×10^{2}	3.47×10^{-5}
3FGL J0325.2+3410	1H 0323+342	nlsy1	51.17	34.18	2.0	1.7	57326.2938	1.7×10^{-3}	1.00×10^{-4}
3FGL J1129.0+3705	B2 1126+37*	agn	172.29	37.15	4.0	3.3	56501.385	6.0×10^{-2}	9.56×10^{-4}
3FGL J1129.0+3705	MG2 J112910+3702*	bll	172.31	37.05	4.0	3.3	56501.385	6.0×10^{-2}	1.01×10^{-3}
3FGL J1230.9+1224	M 87	rdg	187.71	12.39	3.0	3.4	57730.0307	2.7×10^{-3}	1.91×10^{-3}
3FGL J1127.8+3618	MG2 J112758+3620*	fsrq	172.00	36.34	4.0	3.3	56501.386	6.0×10^{-2}	2.03×10^{-3}
3FGL J0929.4+5013	GB6 J0929+5013†	bll	142.31	50.23	5.3	1.9	57758.0	1.2	2.26×10^{-3}
3FGL J1715.7+6837	S4 1716+68	fsrq	259.06	68.61	2.0	4.0	57469.17919	5.4×10^{-5}	2.36×10^{-3}
3FGL J1125.9+2007	4C +20.25	fsrq	171.49	20.10	5.7	2.6	56464.1	5.2	2.79×10^{-3}
3FGL J1508.6+2709	RBS 1467	bll	227.18	27.15	17.3	2.9	57440	1.7×10^{2}	2.84×10^{-3}
3FGL J0930.0+4951	1ES 0927+500†	bll	142.66	49.84	5.4	2.0	57758.0	1.2	3.27×10^{-3}

How significant is this distribution of p-values? Use the binomial test to quantify



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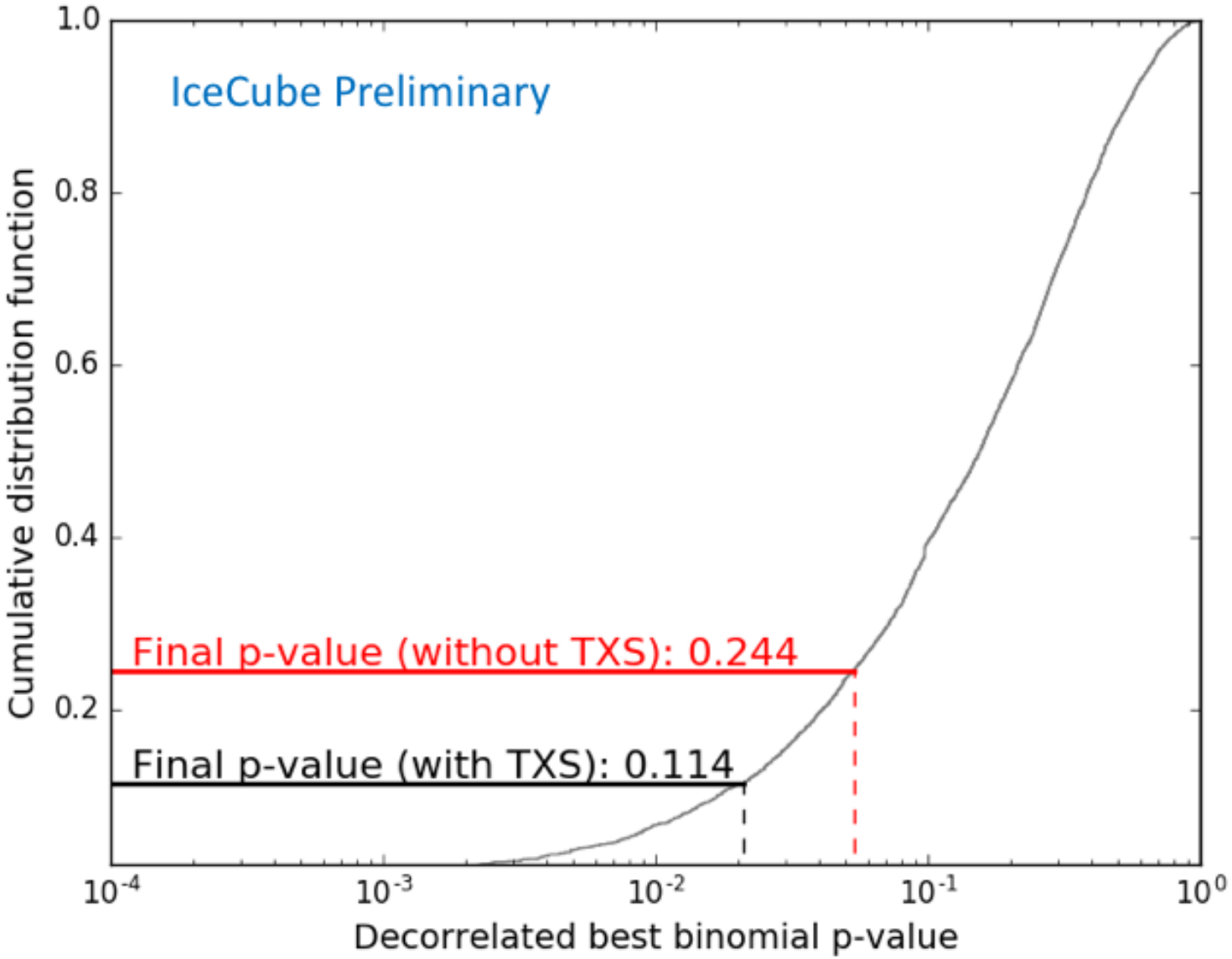
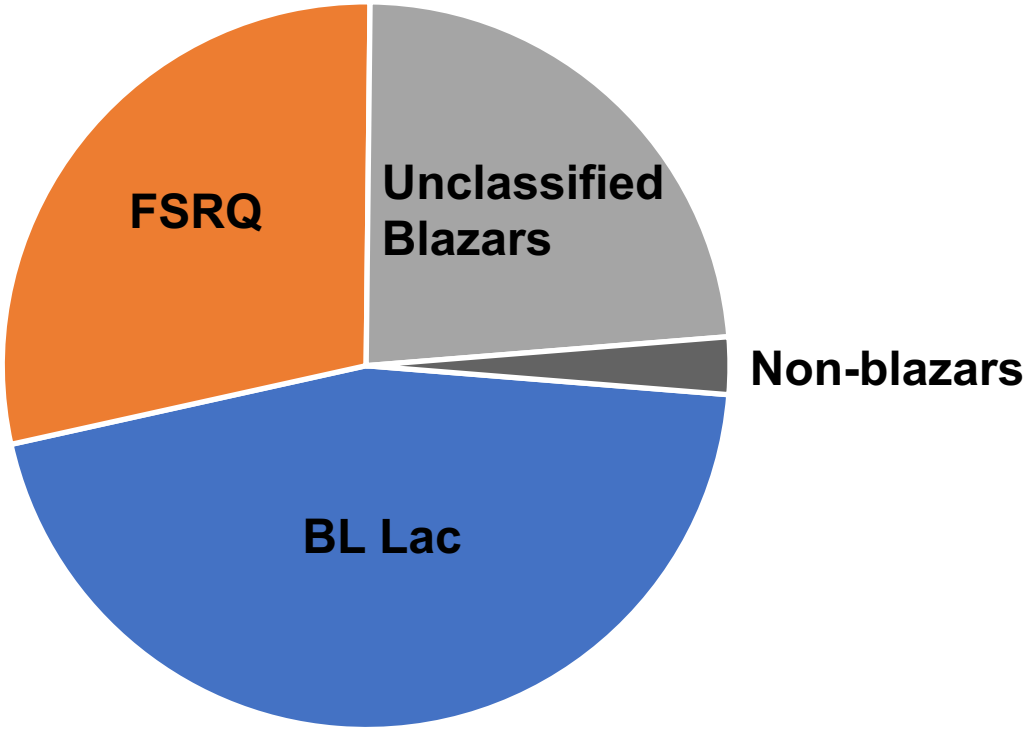
Correlations: one set of three and one set of two→ only 8 unique sources.
Re-evaluate the binomial probability
of seeing 8 or more p-values at 3.27e-3 or lower

Final p-value determined by comparing to scrambled trials

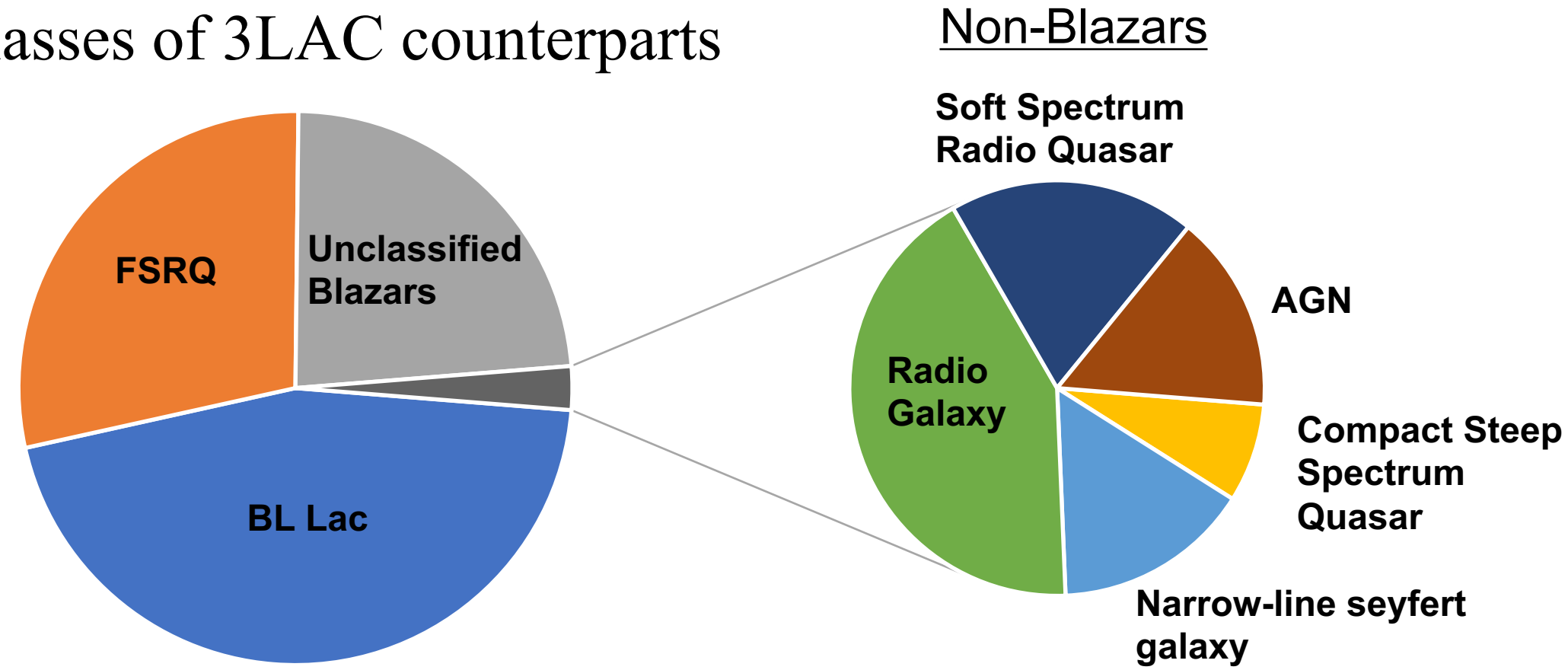


Optical Classes of 3LAC counterparts



A priori tests of two optical class subcatalogs:
FSRQ-only: k=45 with 4 correlations. Final p-value = 0.50.
BLLac-only: k=42 with 5 correlations. Final p-value = 0.60.
Both consistent with background hypothesis

Optical Classes of 3LAC counterparts



Though non-blazars are only 2.5% (26/1023) of our catalog, they make up 27% (3/11) of the top entries (including 2 of our top 3 entries)

Conclusion

- We performed a binomial test on the directions from the Fermi 3LAC catalog. We did not find a significant excess of flares relative to the results expected for background coincidences from atmospheric neutrinos.
- Here, we report the fit results for the 11 most significant objects in the 3LAC catalog.
- We will release the fit results for all objects in the 3LAC catalog in an upcoming publication.