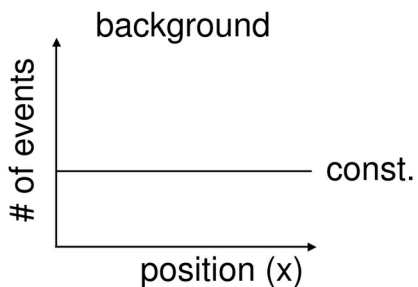
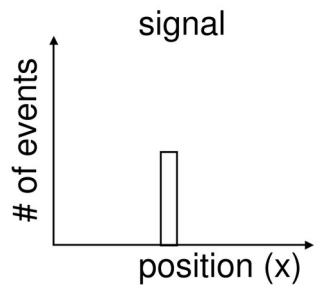


Thoughts on Point Sources

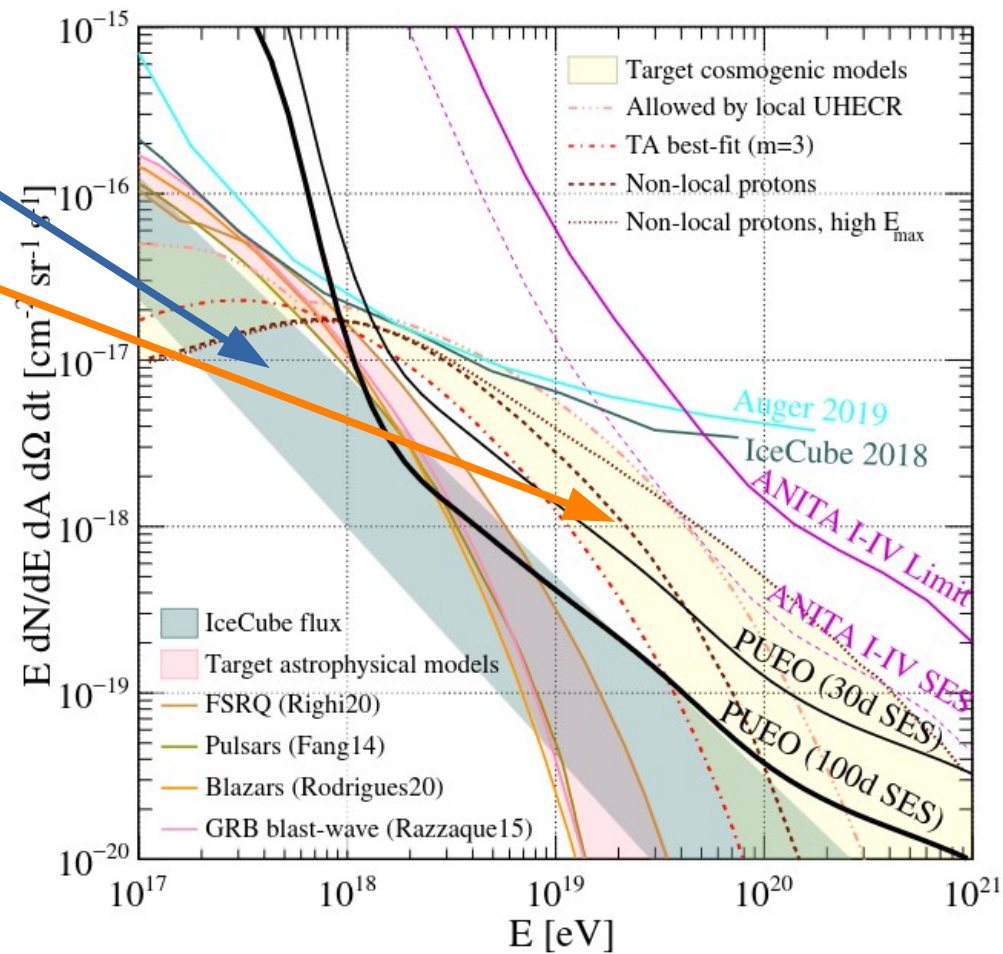
Will Luszczak
2024 PUEO Collaboration Meeting
6/4/2024

Clustered near sources

Isotropically distributed

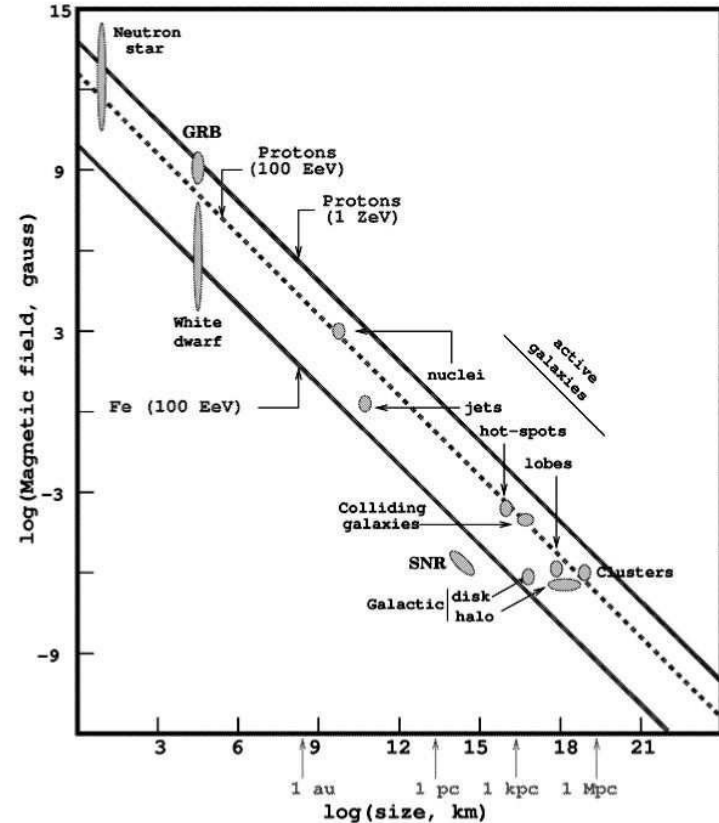


(Before detector response/exposure)

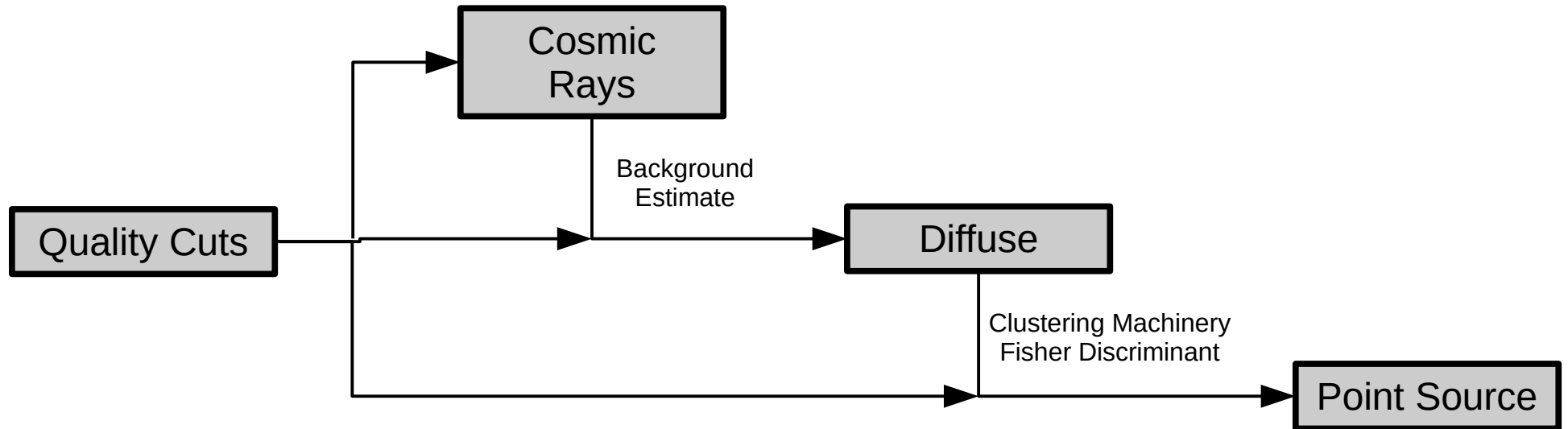


Minimal Requirements

- Sources with strong magnetic fields and/or dense local environments and/or large sources
 - No high energy cutoff to the astrophysical neutrino spectrum (UHE astrophysical neutrinos exist)
- Event candidates can be reasonably well localized (smaller than detector field of view)
- Backgrounds are either well characterized OR not correlated with source candidates



Analysis Progression



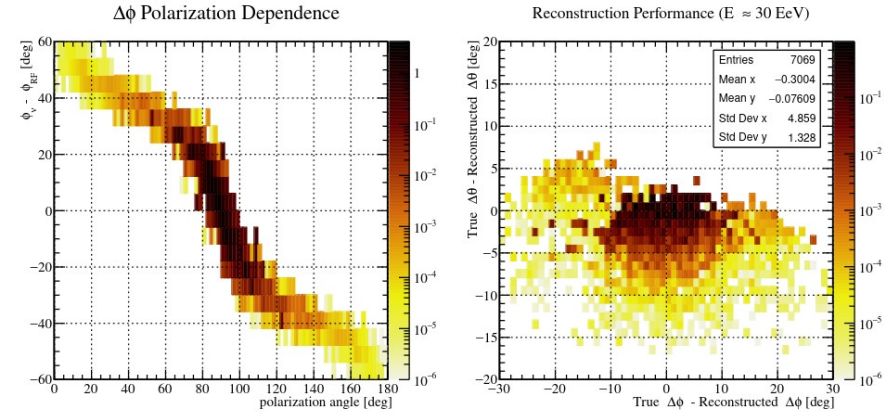
Similarities with Diffuse Analysis

- Quality cuts to remove digitizer glitches, payload blasts, other poorly characterized events
- Fisher discriminant used to select for neutrino-like events
- Spatial isolation parameter to remove clustered anthropogenic backgrounds
- Restrict to VPol events

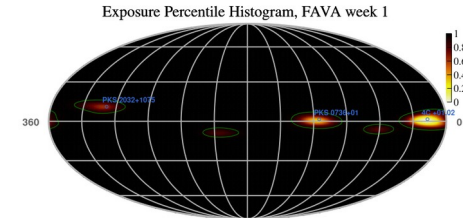
<https://arxiv.org/abs/2010.02869>

Point Source Part

- “Source distance parameter” (D) is introduced to measure how closely an event is associated with a source (class?)
 - D = value of the exposure percentile histogram at a particular event candidate location and time
- Approximate reconstruction of neutrino direction is used, constructed from optimizing a pair of polynomials for $\Delta\theta$ and $\Delta\phi$
- Backgrounds estimated from time shuffling (random offset between 1.5 and 22.5 hours)
- Cuts on diffuse analysis parameters and D are optimized for each source class



$$\text{sens.} \propto \left\langle \frac{FC_{90}(\text{Pois}(\mu_{BG}), \mu_{BG})}{\epsilon} \right\rangle,$$



Which Sources?

- 2 IceCube Source Candidates
- 20 Blazars (3FGL/FAVA)
- 10 GRBs
 - T0 during flight
 - $-30 \text{ deg} < \text{dec} < 30 \text{ deg}$
- 7 Supernovae
- 0 TDEs (were considered, but none happened during flight)

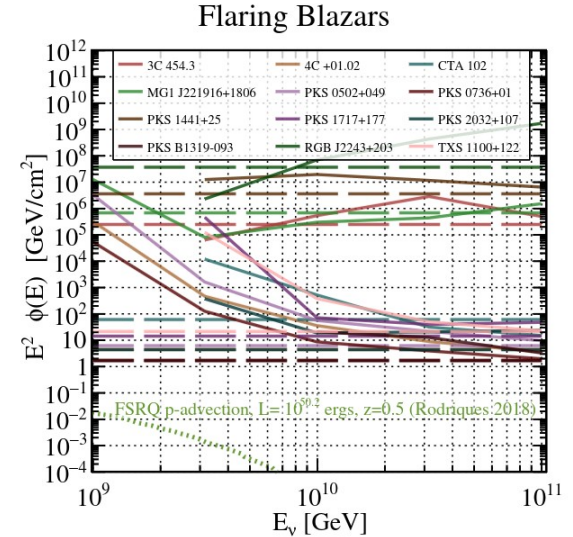
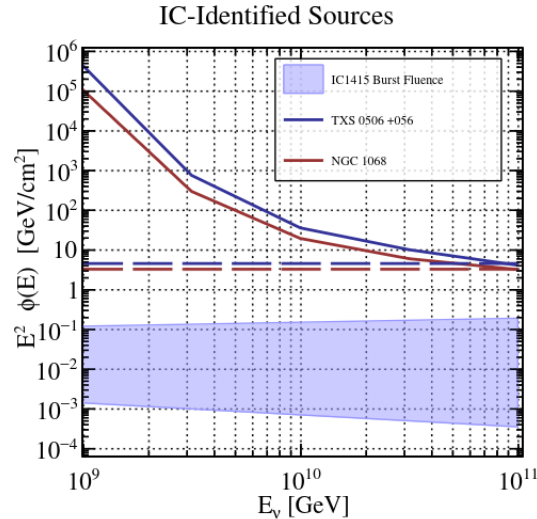
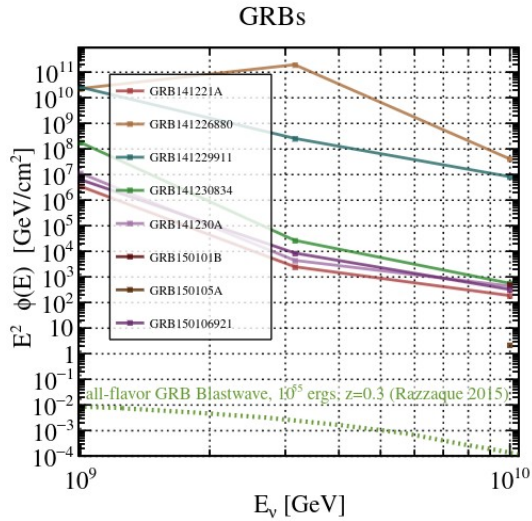
Objects Considered			
Object	Search	Coordinates	Times Considered (UTC)
TXS 0506+056	TXS 0506+056	$\alpha = 77.4^\circ, \delta = 5.7^\circ$	Full Flight
NGC 1068	NGC 1068	$\alpha = 40.7^\circ, \delta = -0.0^\circ$	Full Flight
3C 454.3	Flaring Blazar	$\alpha = 344^\circ, \delta = 16.1^\circ$	2014-12-15-15:43:38Z + 1 week
4C +01.02	Flaring Blazar	$\alpha = 17^\circ, \delta = 1.6^\circ$	2014-12-15-15:43:38Z + 4 weeks
* B3 1343+451	Flaring Blazar	$\alpha = 206^\circ, \delta = 44.8^\circ$	2015-01-05-15:43:38Z + 1 weeks
CTA 102	Flaring Blazar	$\alpha = 331^\circ, \delta = 11.7^\circ$	2014-12-22-15:43:38Z + 3 weeks
MG1 J221916+1806	Flaring Blazar	$\alpha = 335^\circ, \delta = 18.0^\circ$	2014-12-15-15:43:38Z + 2 weeks
* PKS 0402-362	Flaring Blazar	$\alpha = 61^\circ, \delta = -36.0^\circ$	2014-12-15-15:43:38Z + 4 weeks
PKS 0502+049	Flaring Blazar	$\alpha = 76^\circ, \delta = 5.0^\circ$	2014-12-22-15:43:38Z + 3 weeks
PKS 0736+01	Flaring Blazar	$\alpha = 115^\circ, \delta = 1.5^\circ$	2014-12-15-15:43:38Z + 2 weeks
PKS 1441+25	Flaring Blazar	$\alpha = 221^\circ, \delta = 25.0^\circ$	2014-12-15-15:43:38Z + 4 weeks
PKS 1717+177	Flaring Blazar	$\alpha = 260^\circ, \delta = 17.7^\circ$	2014-12-22-15:43:38Z + 2 weeks
* PKS 1830-211	Flaring Blazar	$\alpha = 278^\circ, \delta = -21.1^\circ$	2015-01-05-15:43:38Z + 1 weeks
PKS 2032+1075	Flaring Blazar	$\alpha = 309^\circ, \delta = 10.9^\circ$	2014-12-15-15:43:38Z + 1 weeks
* PKS 2052-47	Flaring Blazar	$\alpha = 314^\circ, \delta = -47.3^\circ$	2014-12-22-15:43:38Z + 2 weeks
* PKS 2142-75	Flaring Blazar	$\alpha = 327^\circ, \delta = -75.7^\circ$	2014-12-15-15:43:38Z + 1 weeks
PKS B1319-093	Flaring Blazar	$\alpha = 200^\circ, \delta = -9.3^\circ$	2014-12-15-15:43:38Z + 1 weeks
* PMN J2141-6411	Flaring Blazar	$\alpha = 325^\circ, \delta = -64.2^\circ$	2014-12-29-15:43:38Z + 1 weeks
RGB J2243+203	Flaring Blazar	$\alpha = 341^\circ, \delta = 20.3^\circ$	2014-12-15-15:43:38Z + 2 weeks
* S4 +1144+40	Flaring Blazar	$\alpha = 177^\circ, \delta = 40^\circ$	2014-12-22-15:43:38Z + 1 weeks
* S5 +1217+71	Flaring Blazar	$\alpha = 185^\circ, \delta = 71.1^\circ$	2014-12-15-15:43:38Z + 2 weeks
TXS +1100+122	Flaring Blazar	$\alpha = 166^\circ, \delta = 12.0^\circ$	2014-12-29-15:43:38Z + 2 weeks
GRB 141221A	GRB	$\alpha = 198.3^\circ, \delta = 8.2^\circ$	2014-12-21-08:07:02Z ^{+1day} _{-5min}
* GRB 141223240	GRB	$\alpha = 147.4^\circ, \delta = -20.7^\circ$	2014-12-23-05:45:34Z ^{+1day} _{-5min}
GRB 141226880	GRB	$\alpha = 163.9^\circ, \delta = 28.4^\circ$	2014-12-26-21:07:24Z ^{+1day} _{-5min}
GRB 141229911	GRB	$\alpha = 170.1^\circ, \delta = 23.1^\circ$	2014-12-29-21:51:39Z ^{+1day} _{-5min}
* GRB 141229A	GRB	$\alpha = 72.4^\circ, \delta = -19.2^\circ$	2014-12-29-11:48:59 ^{+1day} _{-5min}
GRB 141230834	GRB	$\alpha = 181.5^\circ, \delta = 11.6^\circ$	2014-12-30-20:00:25Z ^{+1day} _{-5min}
GRB 141230A	GRB	$\alpha = 57.0^\circ, \delta = 1.6^\circ$	2014-12-30-03:24:22Z ^{+1day} _{-5min}
GRB 150101B	GRB	$\alpha = 188.0^\circ, \delta = -10.9^\circ$	2015-01-01-15:23:00Z ^{+1day} _{-5min}
GRB 150105A	GRB	$\alpha = 124.3^\circ, \delta = -14.8^\circ$	2015-01-05-06:10:00Z ^{+1day} _{-5min}
GRB 150106921	GRB	$\alpha = 40.8^\circ, \delta = 0.3^\circ$	2015-01-06-22:05:53 ^{+1day} _{-5min}
* SN 2014dz	SN	$\alpha = 52.1^\circ, \delta = 38.0^\circ$	2014-12-10-00:00:00Z + 2 weeks
SN 2014dy	SN	$\alpha = 42.2^\circ, \delta = -0.8^\circ$	2014-12-10-00:00:00Z + 2 weeks
* SN 2015A	SN	$\alpha = 145.3^\circ, \delta = 35.9^\circ$	2015-01-02-00:00:00Z + 2 weeks
SN 2015B	SN	$\alpha = 193.6^\circ, \delta = -12.6^\circ$	2014-12-21-00:00:00Z + 2 weeks
SN 2015D	SN	$\alpha = 198.2^\circ, \delta = 12.6^\circ$	2015-01-06-00:00:00Z + 2 weeks
SN 2015E	SN	$\alpha = 48.4^\circ, \delta = 0.3^\circ$	2014-12-31-00:00:00Z + 2 weeks
SN 2015W	SN	$\alpha = 104.4^\circ, \delta = 13.6^\circ$	2015-01-02-00:00:00Z + 2 weeks

Limits

$$u.l.(E^2\Phi(E)) = \left\langle \frac{FC_{90}(n_{obs}, \mu_{bg}) \cdot E}{\epsilon A_{eff}(E) \cdot \Delta} \right\rangle$$

- Report model-independent and E^{-2} upper limits

$$u.l.(\Phi_0) = \left\langle \frac{FC_{90}(n_{obs}, \mu_{bg}) \cdot \phi_0}{\langle \epsilon \cdot A_{eff}(E) \rangle |_{\phi(E)}} \right\rangle$$



Considerations for PUEO

- Data will eventually be made public
 - What do we expect people to do with it?
- Realtime prospects?
 - Multi-messenger follow up of PUEO candidates?
 - PUEO follow up of multi-messenger alerts?
 - Deadline for this decision is probably November
- How should events identified by “upstream” (CR, diffuse nu) analyses be treated in the context of a PS search?
- Point source searches with other channels (cosmic rays?)
 - Everything rolled into one analysis, or multiple separate analyses?
 - Trials?

Trial Factors (ugh)

- Current standard is to trial correct for what you control
 - Global trial factor (all source searches ever done) not typically reported
 - Particle physics experiments don't seem to compute true global trial factors (e.g. they are not trial correcting for searches other particles, detectors): <https://arxiv.org/pdf/1606.03833>, <https://arxiv.org/abs/1005.1891>, <https://arxiv.org/pdf/1207.7214>, <https://arxiv.org/pdf/nucl-ex/0204008>
 - They **do** account for searching different decay channels
- We need to consider:
 - Number of source candidates
 - Different event channels (possibly)
- Important aspects:
 - Trial corrections should be determined pre-unblinding
 - There should be a deadline on deciding this
 - Clearly report the trial correction process in publication

To Do List (not necessarily in order)

- Decide source list
- Quality cuts*
- Fisher discriminant/spatial isolation framework*
- Implement fast neutrino direction reconstruction*
- Create framework for time shuffling events
- Add simulation of point sources to NiceMC
- Calculate exposure histogram(s)
- Decide trial correction factor
- Set analysis cuts
- Unblind and set limits/report a significance