# Thoughts on Point Sources

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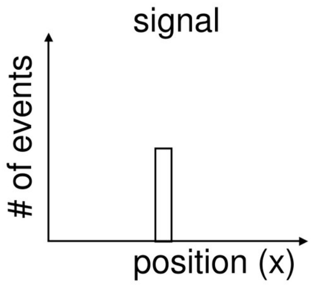
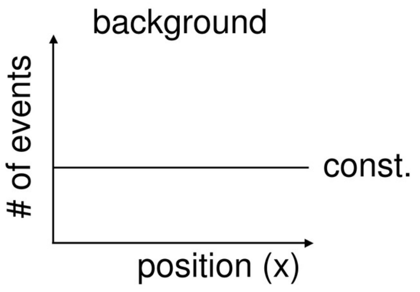
2024 PUEO Collaboration Meeting
6/4/2024

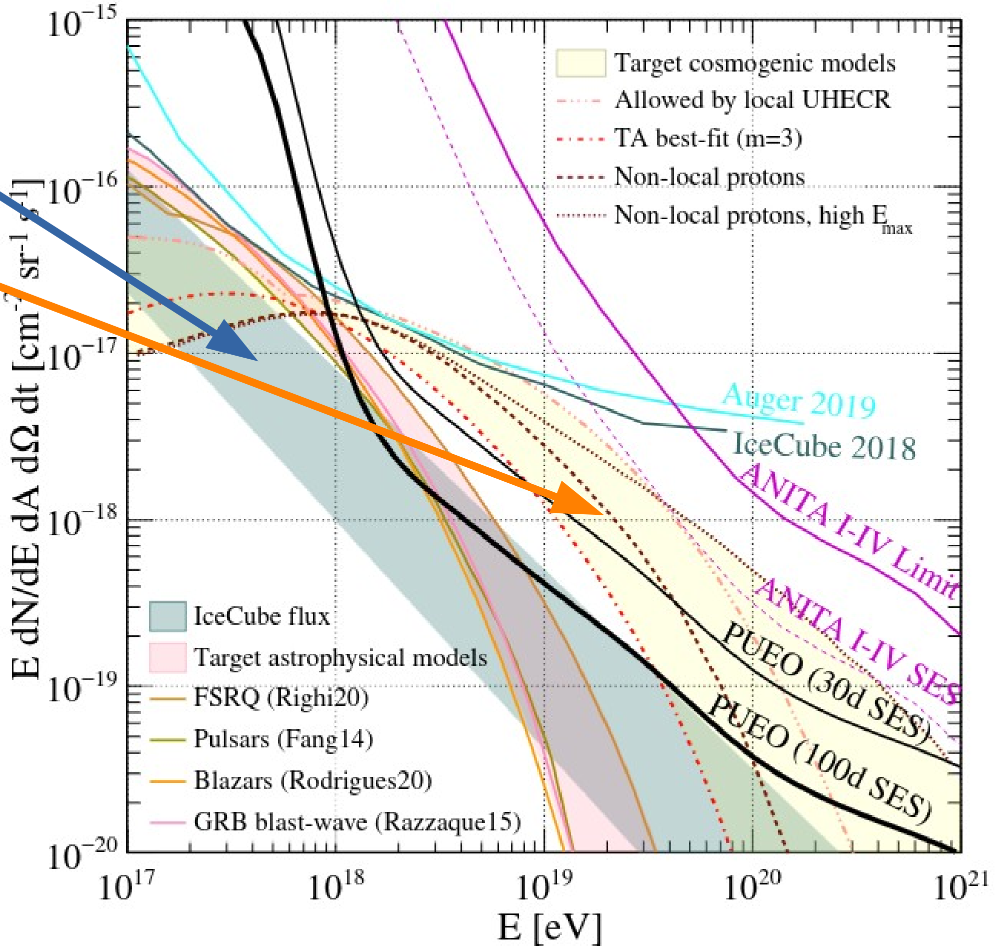
Clustered near sources

Isotropically distributed



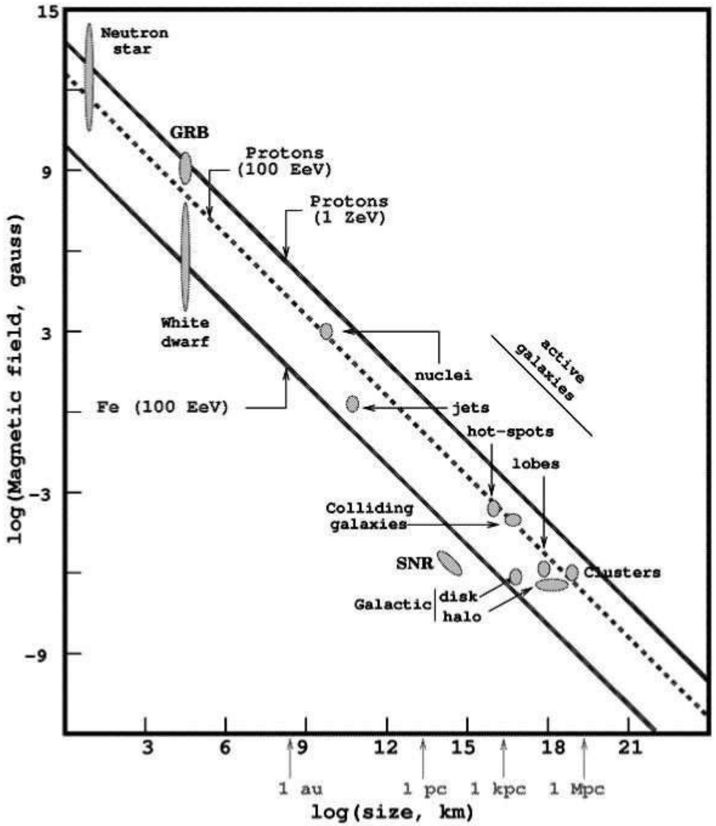




(Before detector response/exposure)

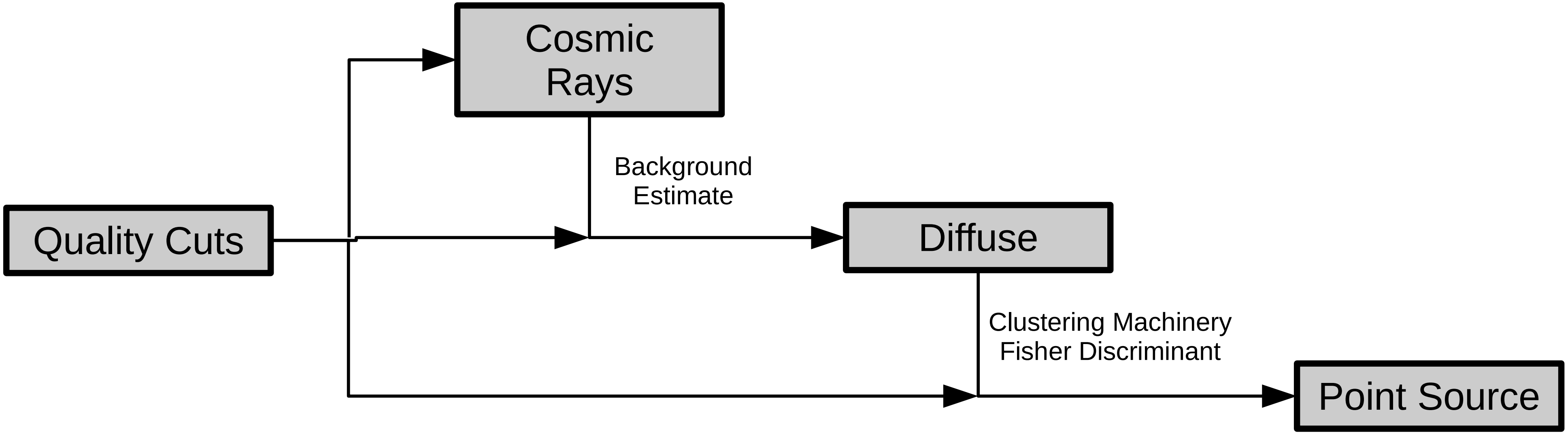


# Minimal Requirements

- 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



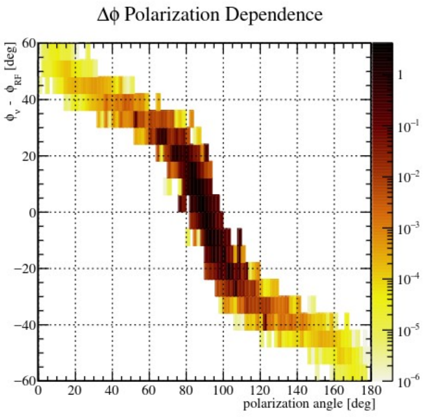
# Similarities with Diffuse Analysis

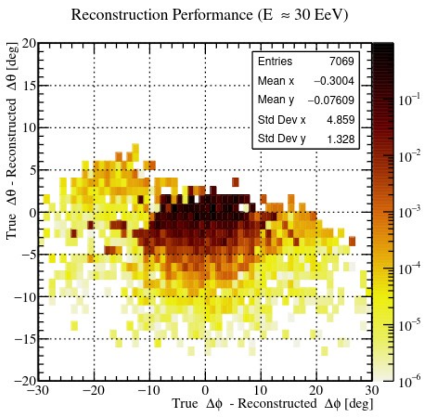
- Quality cuts to remove digitizer glitches, payload blasts, other poorly characterized events
- Fisher discriminant used to select for neutrino-like events
- Spatial isolation parameter to remove clustered anthropogenic backgrounds
- Restrict to VPol events

https://arxiv.org/abs/2010.02869

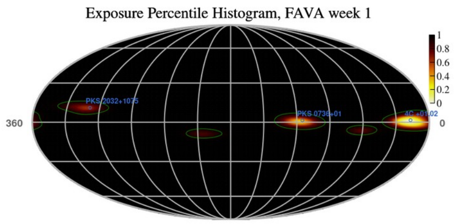
# Point Source Part

- “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 Δth and Δphi
- 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




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



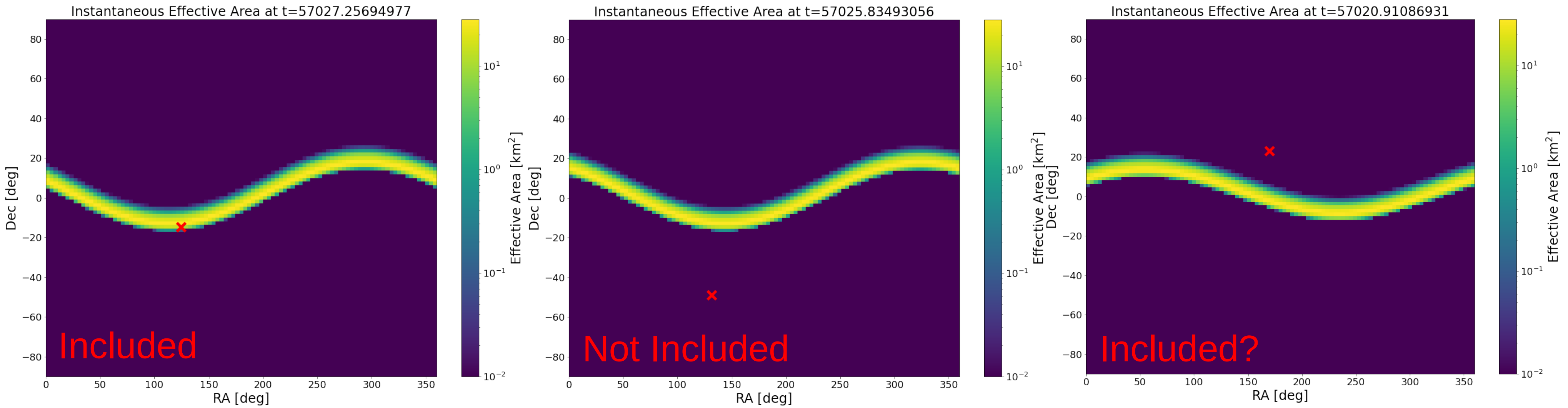
# Which Sources?

- 2 IceCube Source Candidates
- 20 Blazars (3FGL/FAVA)
- 10 GRBs
  - T0 during flight
  - -30 deg < dec < 30 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 |

# Example: GRBs

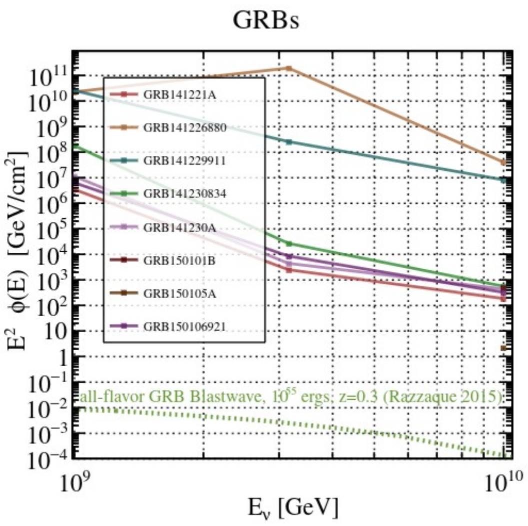


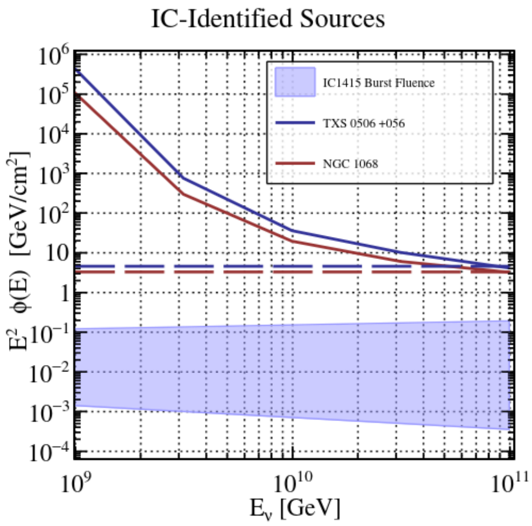
# Limits

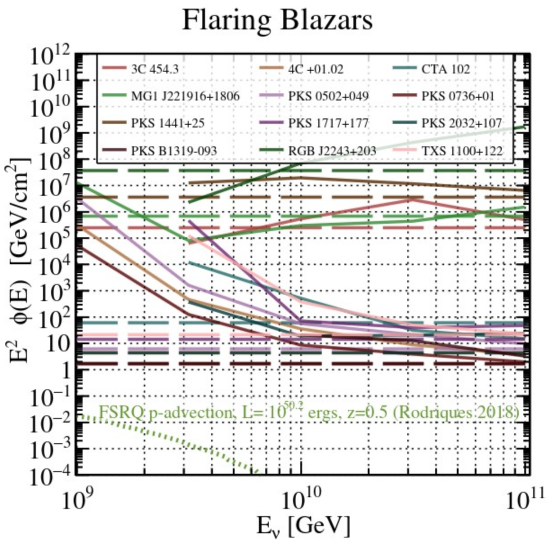
$$u.l.(E^2\Phi(E)) = \left\langle \frac{FC_{90}(n_{obs}, \mu_{bg}) \cdot E}{\epsilon A_{eff}(E) \cdot \Delta} \right\rangle$$

- 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