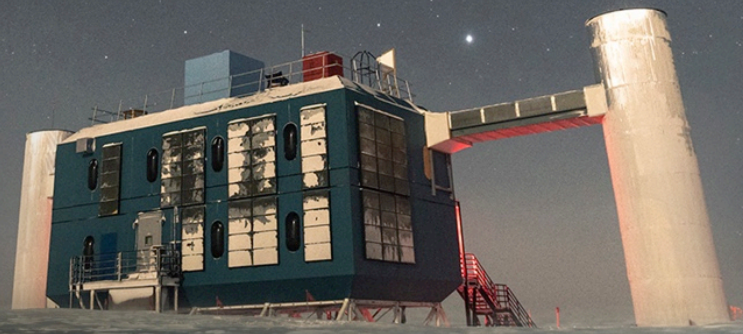
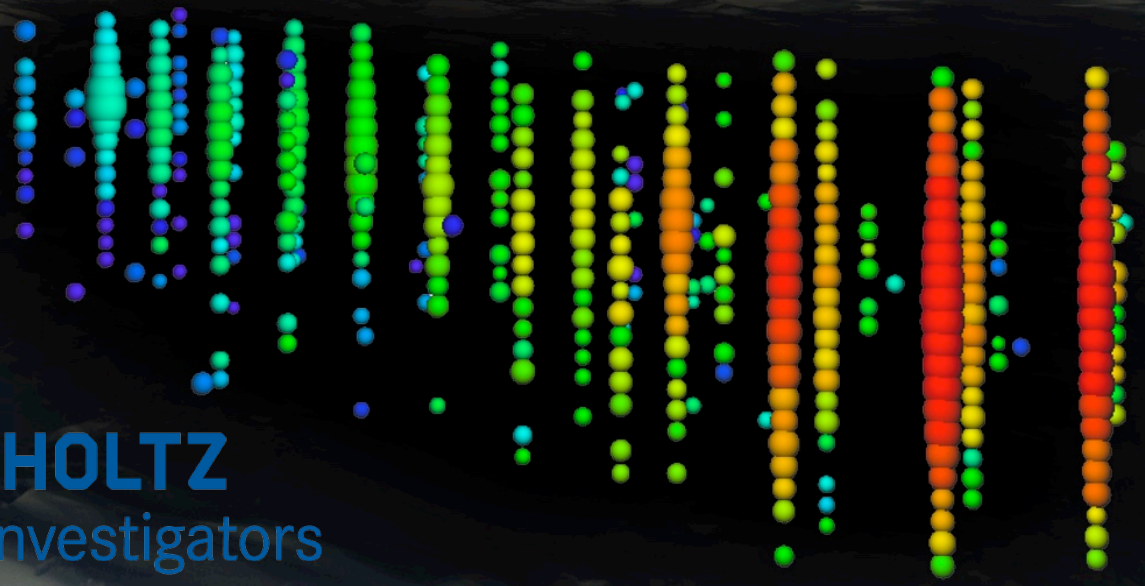
Optical Counterparts to High-Energy Neutrinos

Anna Franckowiak for the neutrino counterpart group





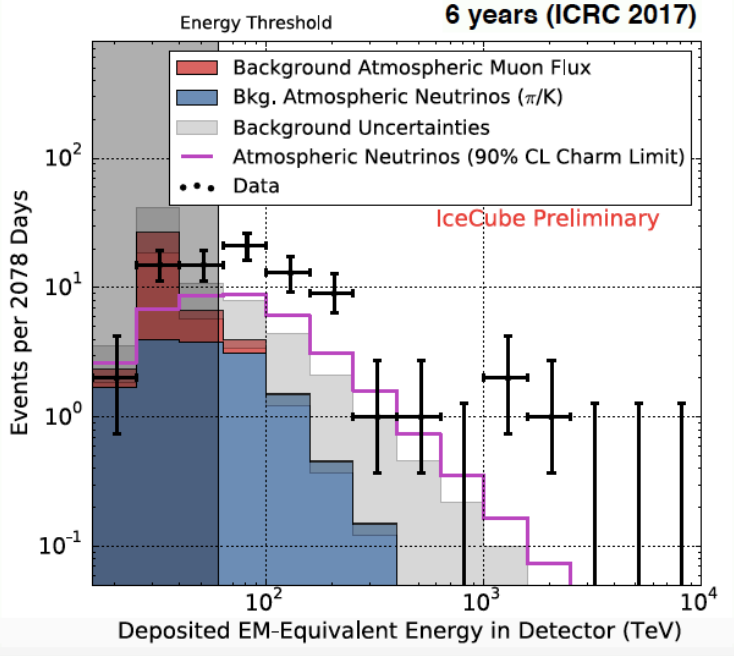
HELMHOLTZ
Young Investigators

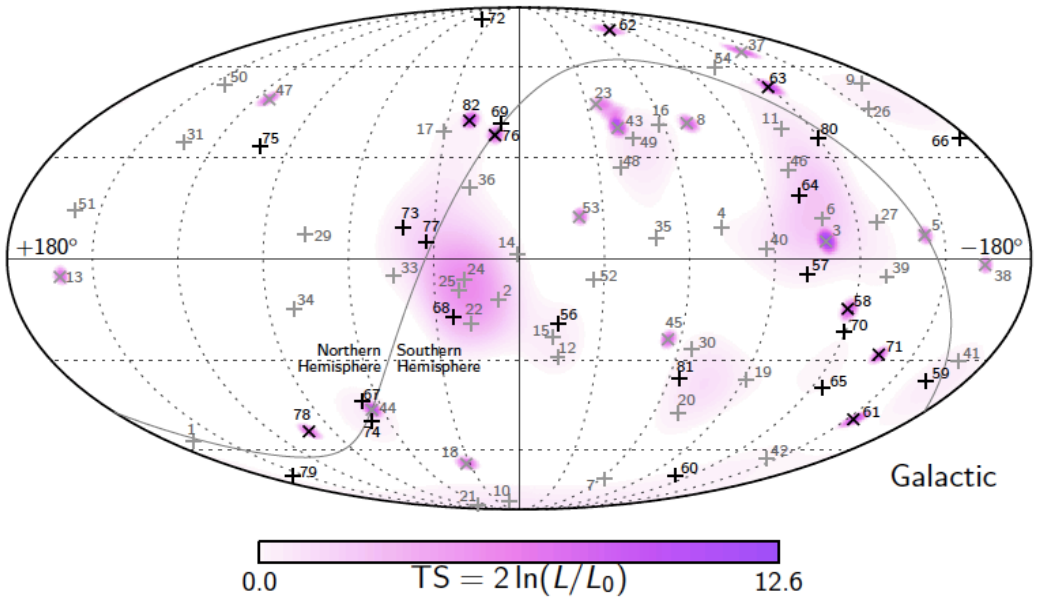
ZTF Collaboration Meeting, Stockholm, Aug. 6, 2018

DESY.

Science Motivation

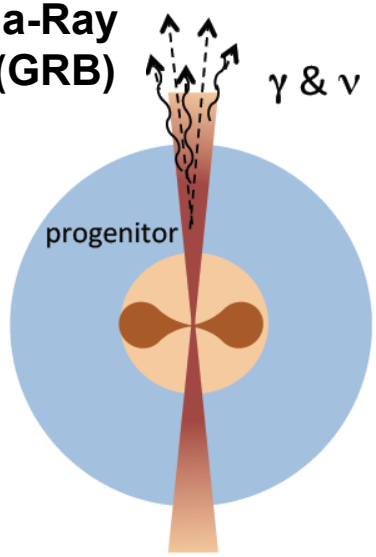
Detection of diffuse flux of cosmic neutrinos



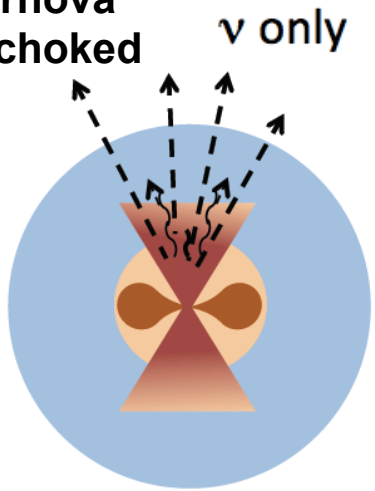


No clustering around Galactic Plane → Extragalactic origin

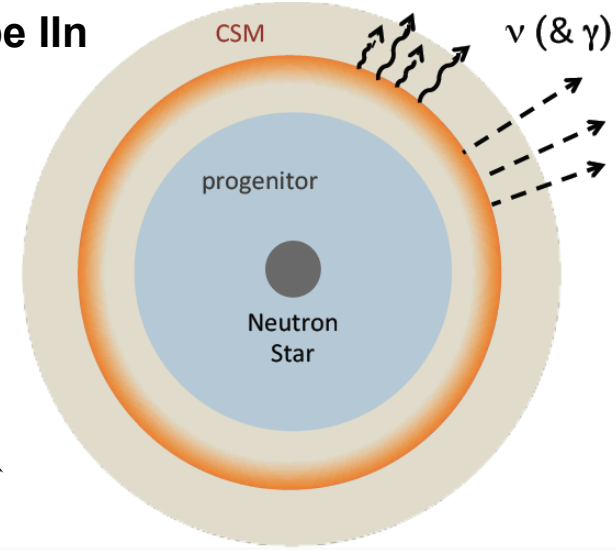
Gamma-Ray Burst (GRB)



Supernova with choked jets



Supernova Type IIn



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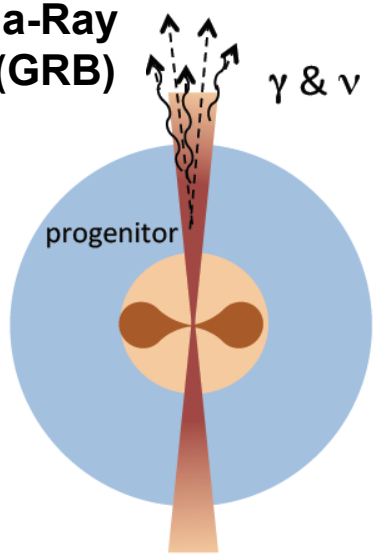

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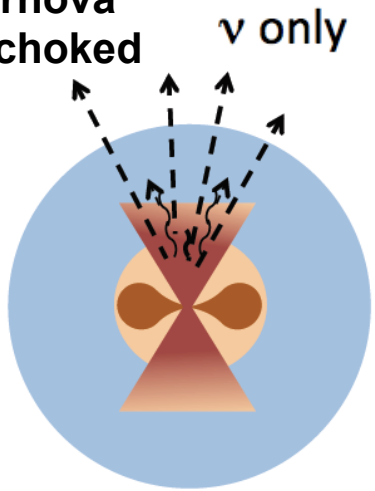

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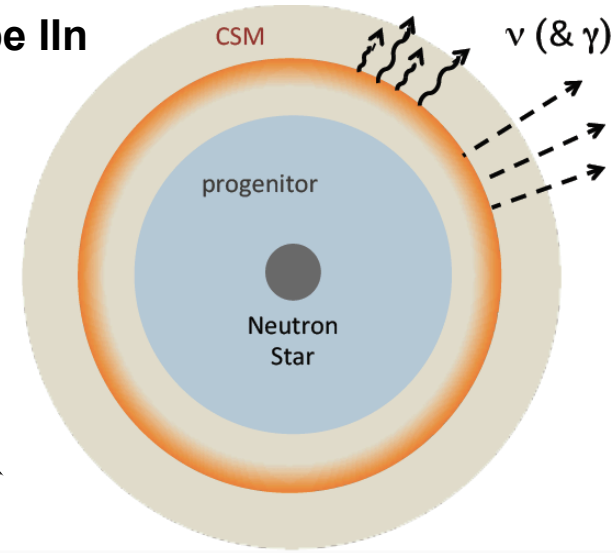
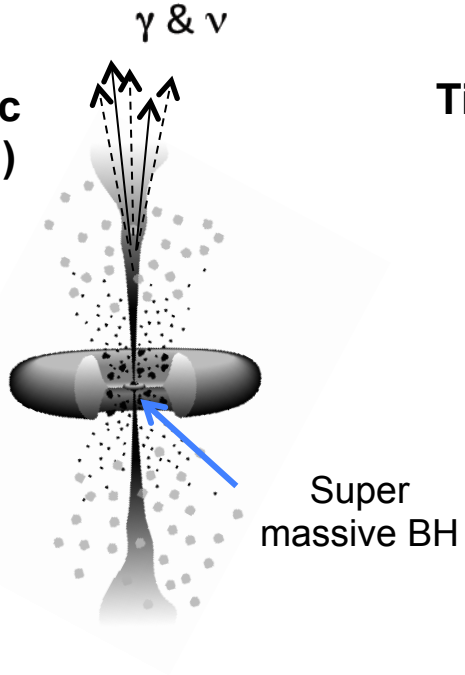
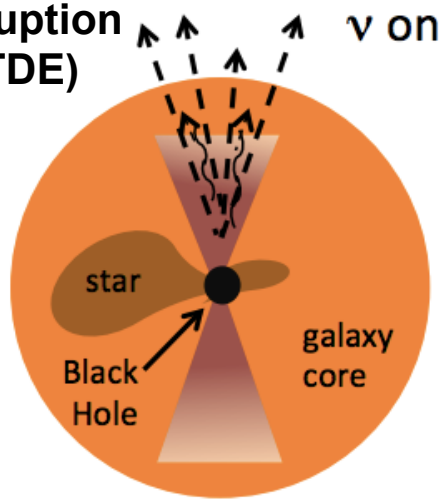


Active Galactic Nucleus (AGN)

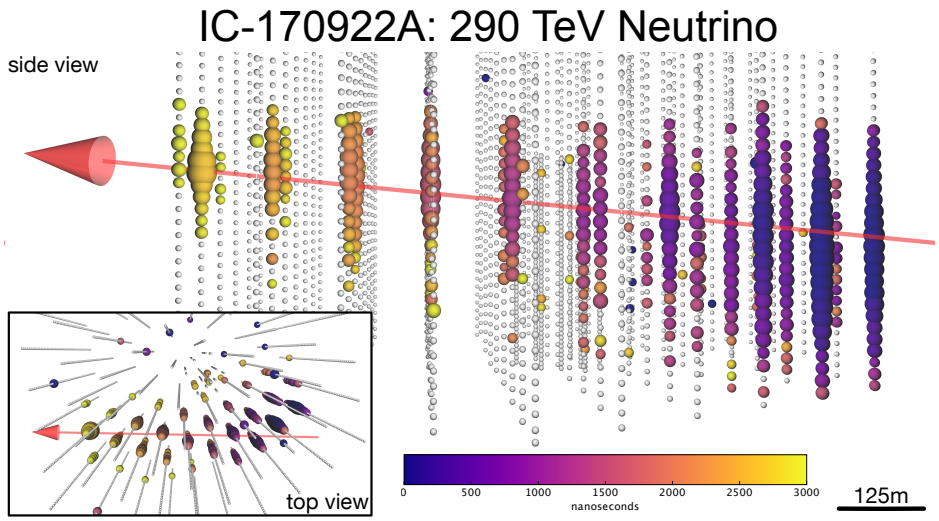


Tidal Disruption event (TDE)



First Compelling Candidate

Gamma-ray Blazar TXS 0506+056



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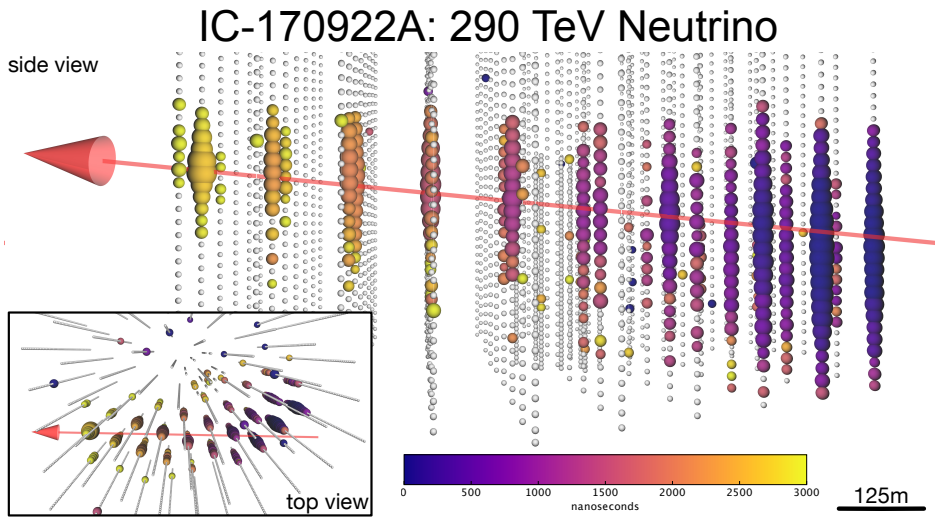
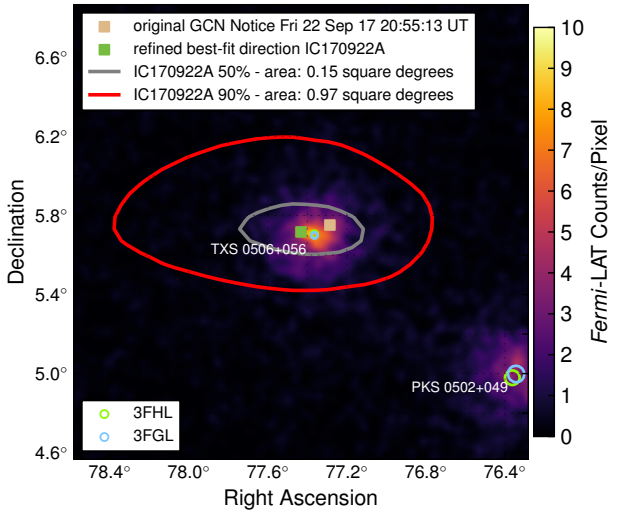
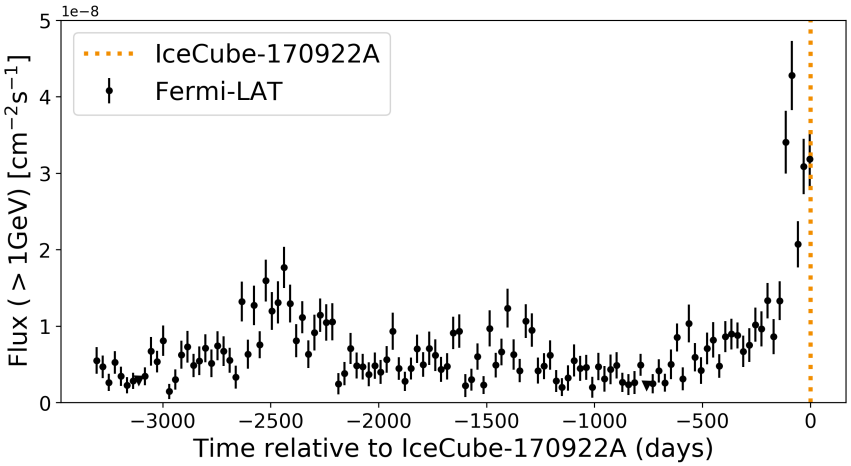
Gamma-ray Blazar TXS 0506+056







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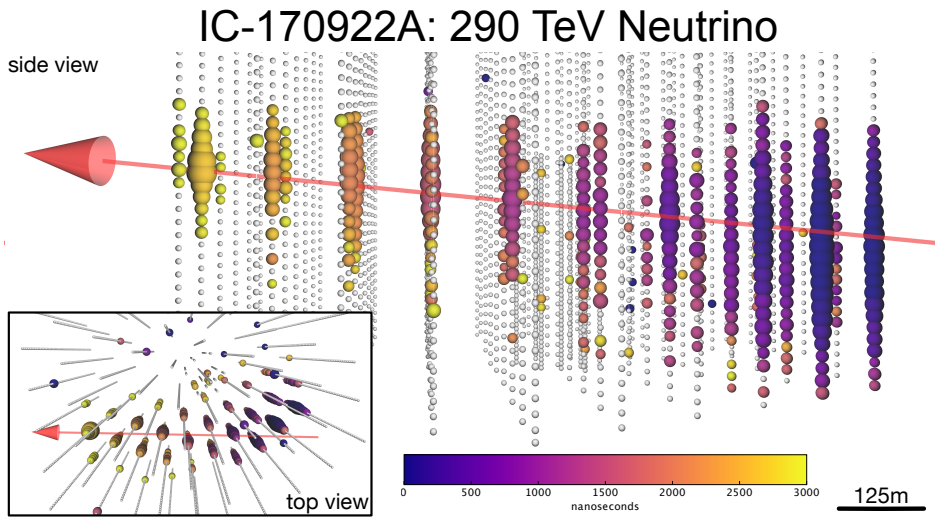
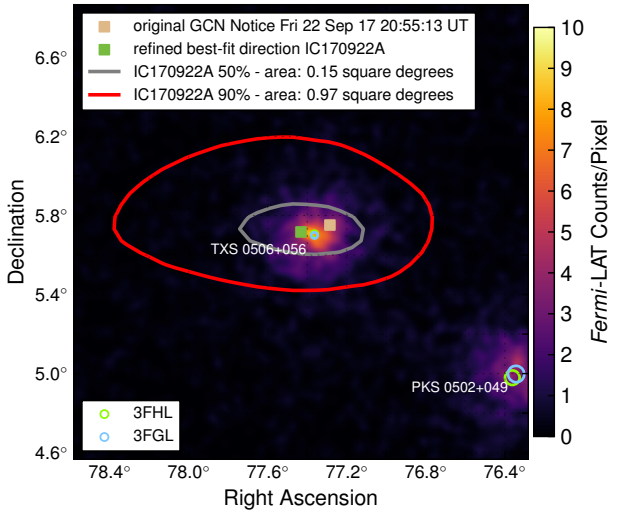
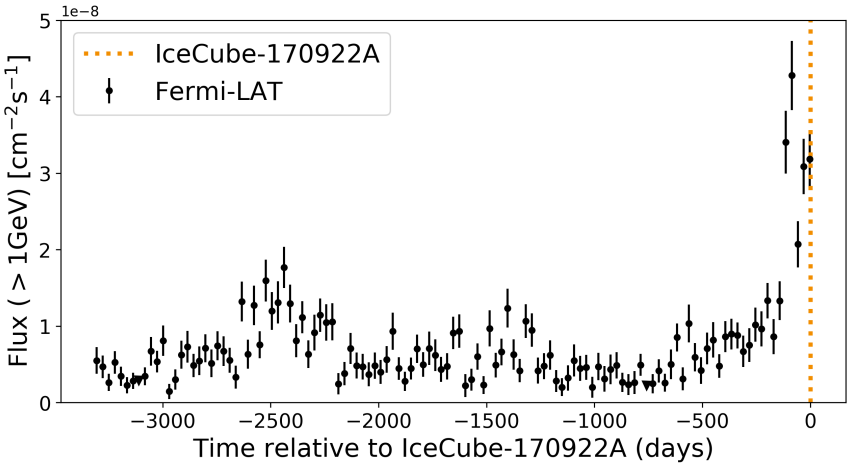
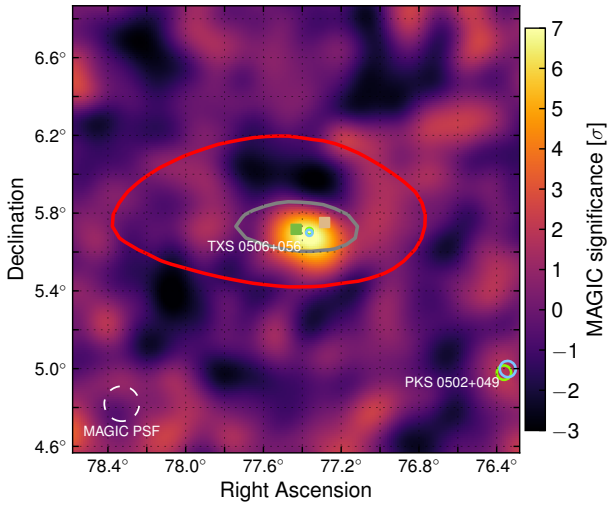


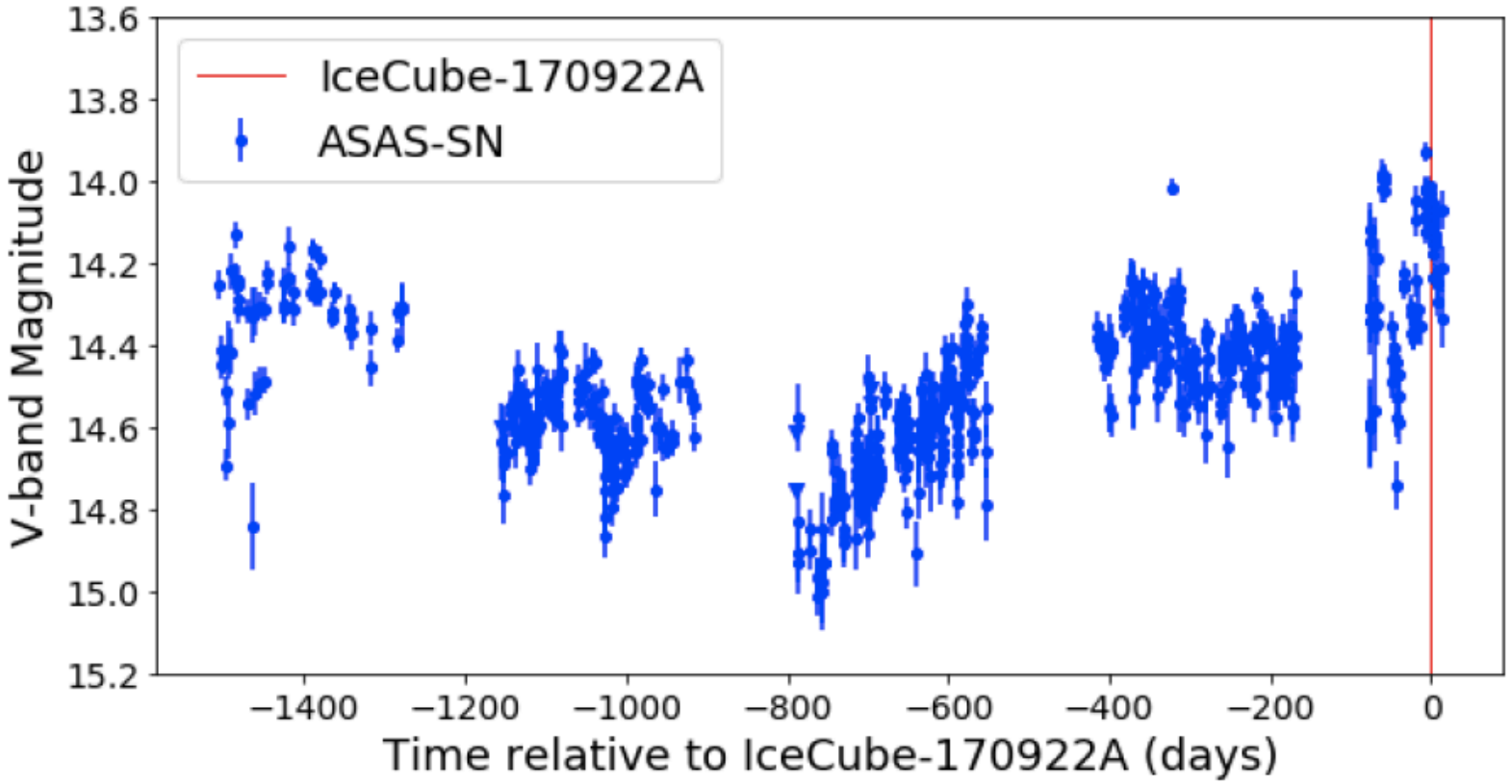






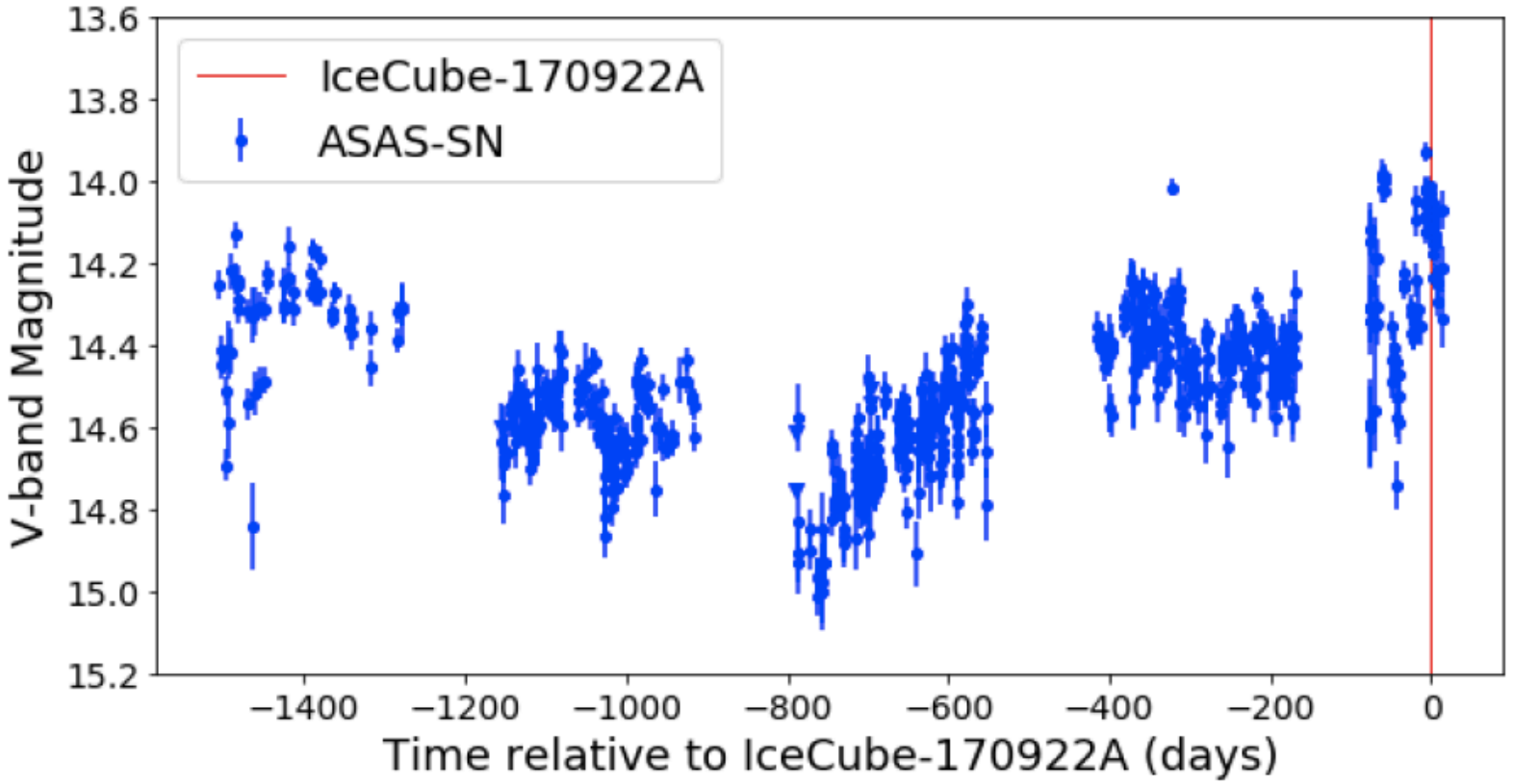
First Compelling Candidate

Gamma-ray Blazar TXS 0506+056



First Compelling Candidate

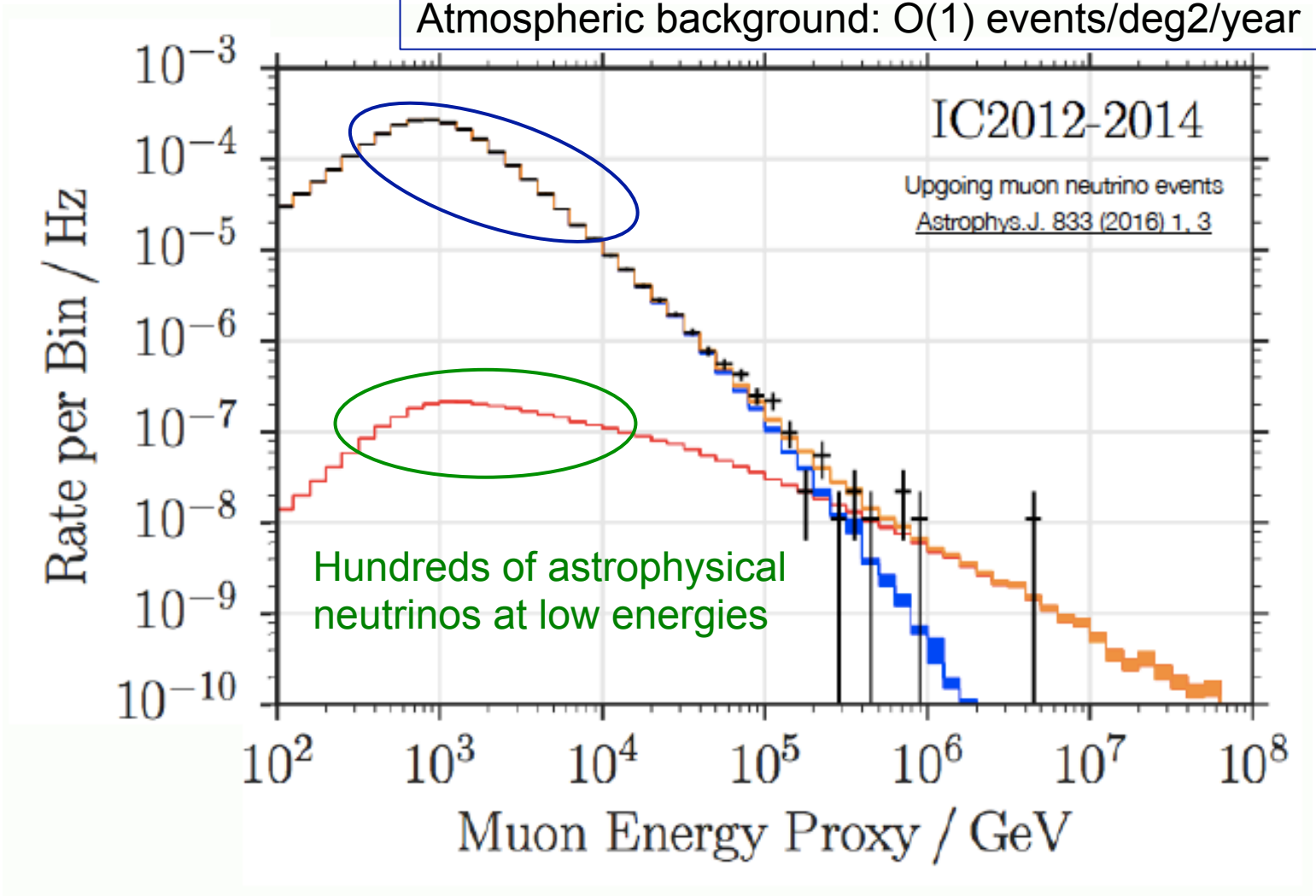
Gamma-ray Blazar TXS 0506+056



BUT (from blazar stacking analysis) gamma-ray blazars can produce only ~10% the diffuse neutrino flux

Two Strategies

Atmospheric background: O(1) events/deg2/year



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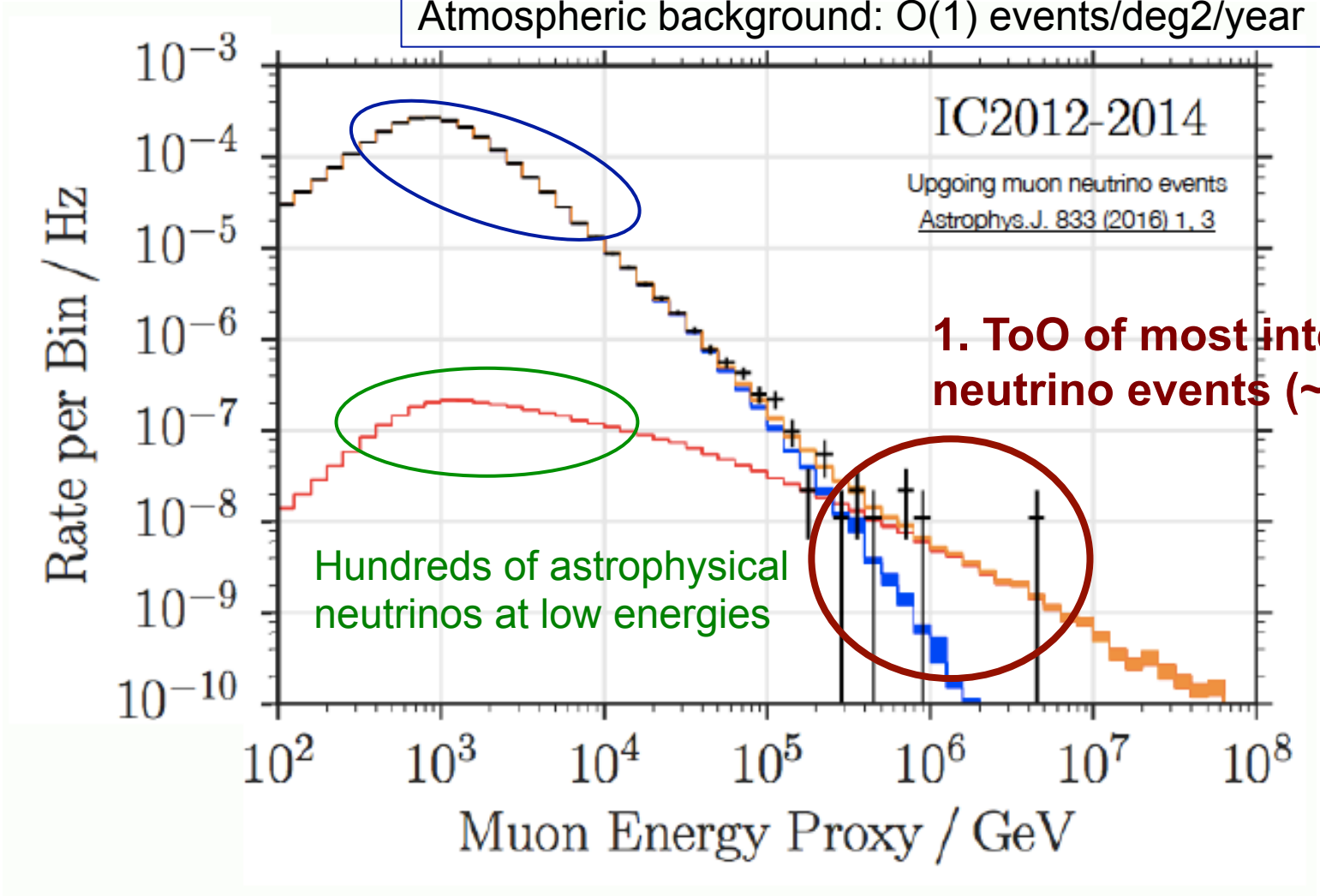
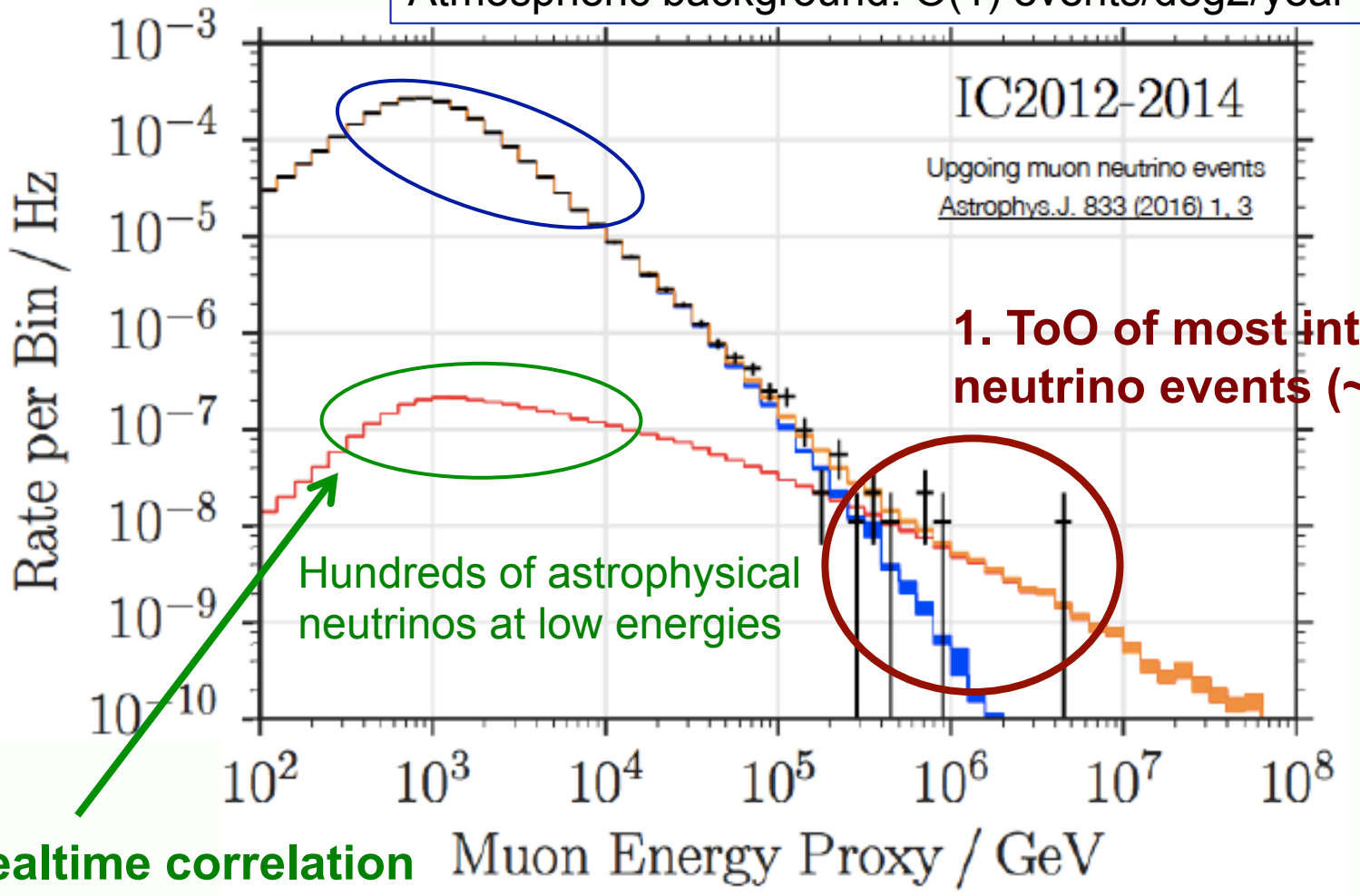
Atmospheric background: O(1) events/deg2/year



1. ToO of most interesting neutrino events (~10/yr)

Two Strategies

Atmospheric background: O(1) events/deg2/year



1. ToO of most interesting neutrino events (~10/yr)

2. Realtime correlation with optical candidates

1. ToO of interesting neutrinos

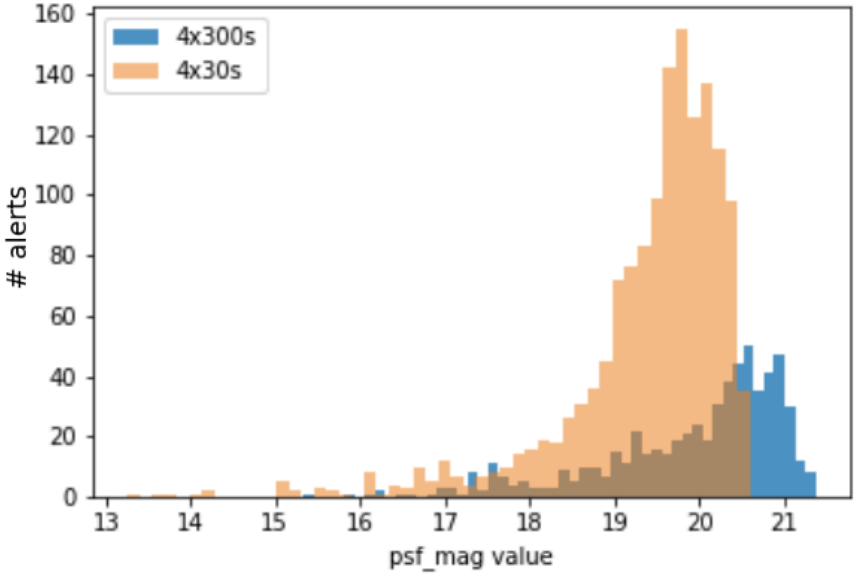
- **High-energy (>100TeV) single events (~8/year)**
  - High-energy starting track event on April 23: was identified as background and retracted → no follow-up

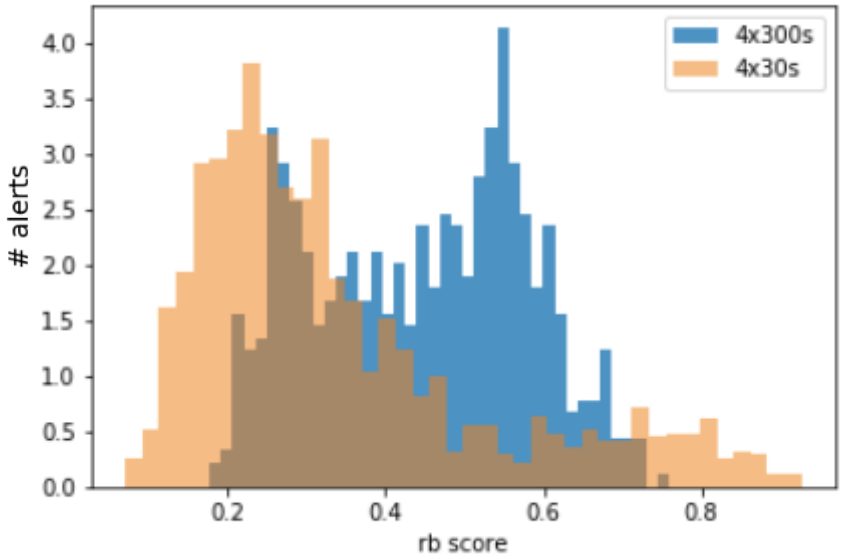
- **Multiplets: ≥2 neutrinos within 100sec (~6/year)**
  - Doublet on June 11, two ~1TeV events, 0.3 sec and 3 deg apart
  - ZTF observations on June 12 and 13, two 300 sec images each night (manually added to scheduler, in the future done by follow-up marshal)
  - Cone search for candidate with AMPEL, can go back in time and stay active for a given time period

Problem of long exposures

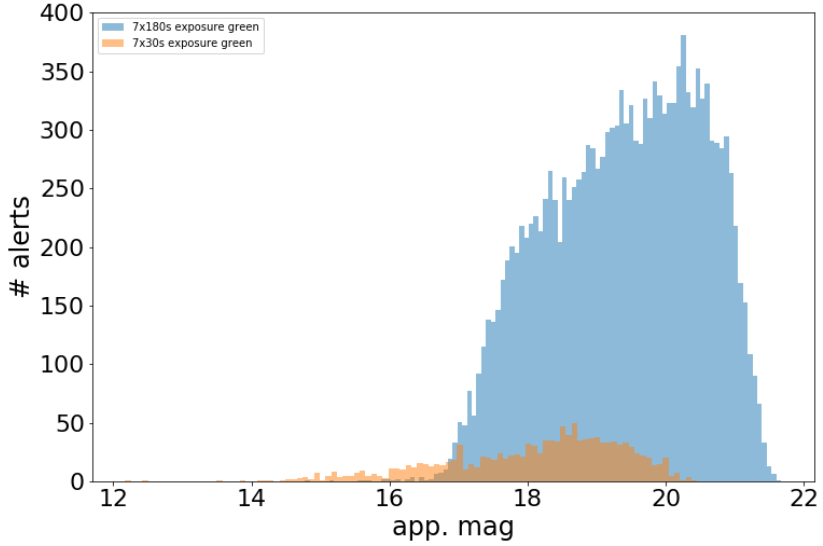
Checks done by
Ludwig Rauch

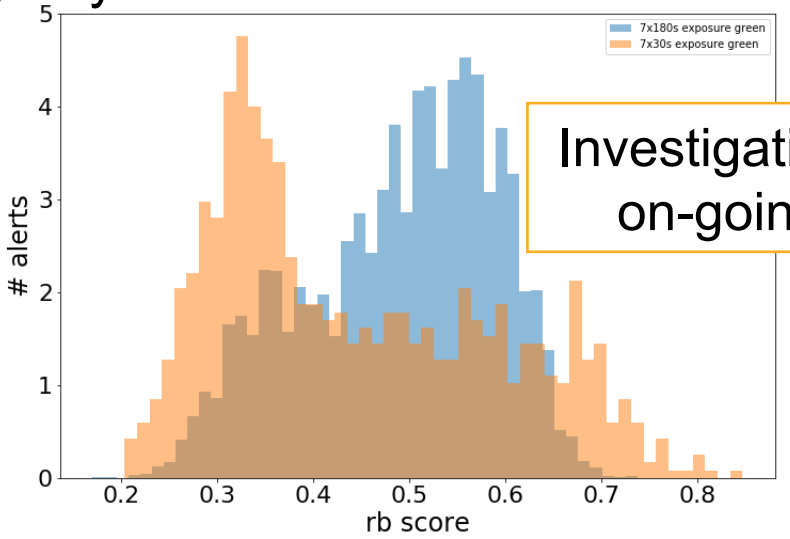
Neutrino follow-up, June 12/13





GRB follow-up, July 28

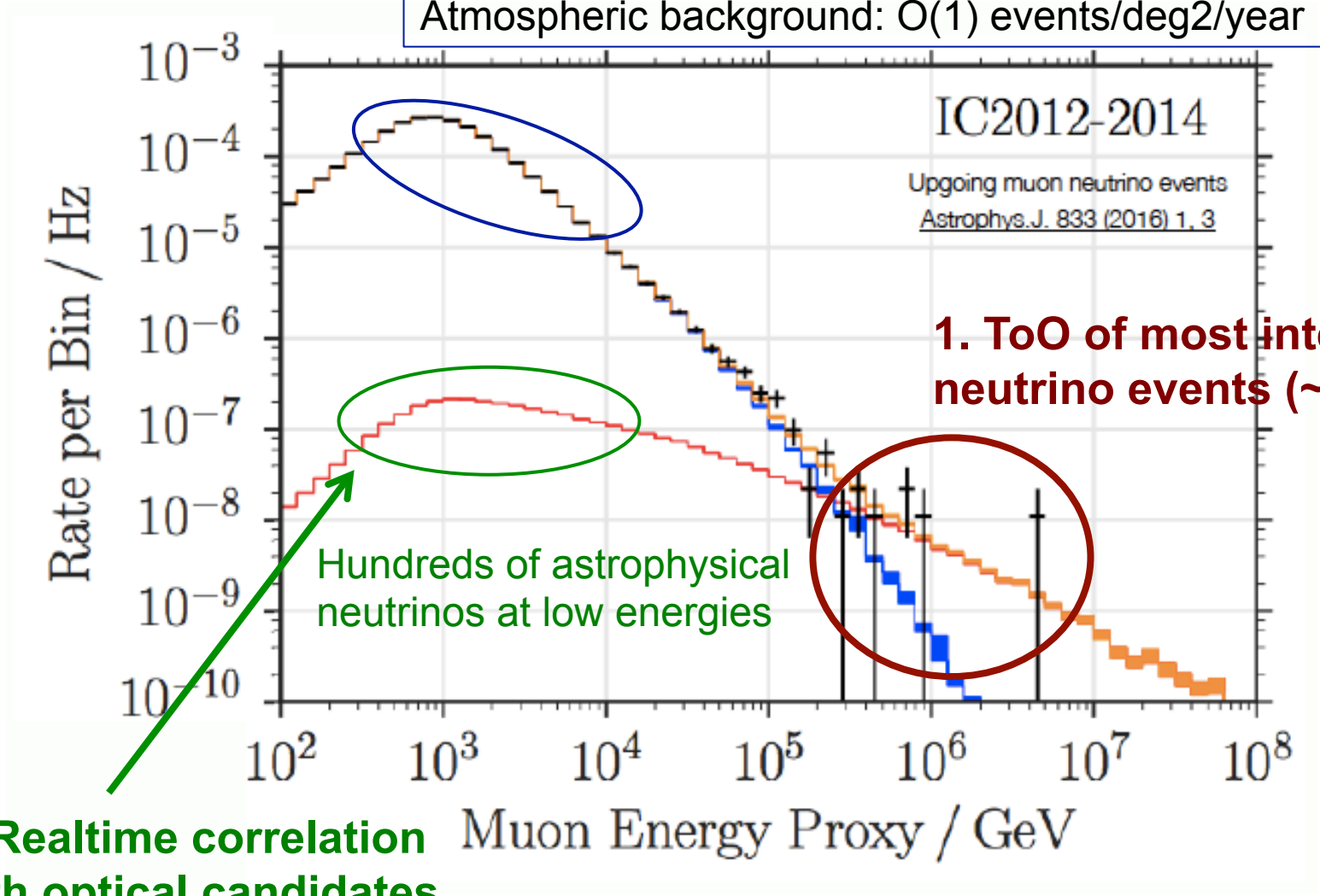




Investigations on-going

Two Strategies

Atmospheric background: O(1) events/deg2/year



1. ToO of most interesting neutrino events (~10/yr)

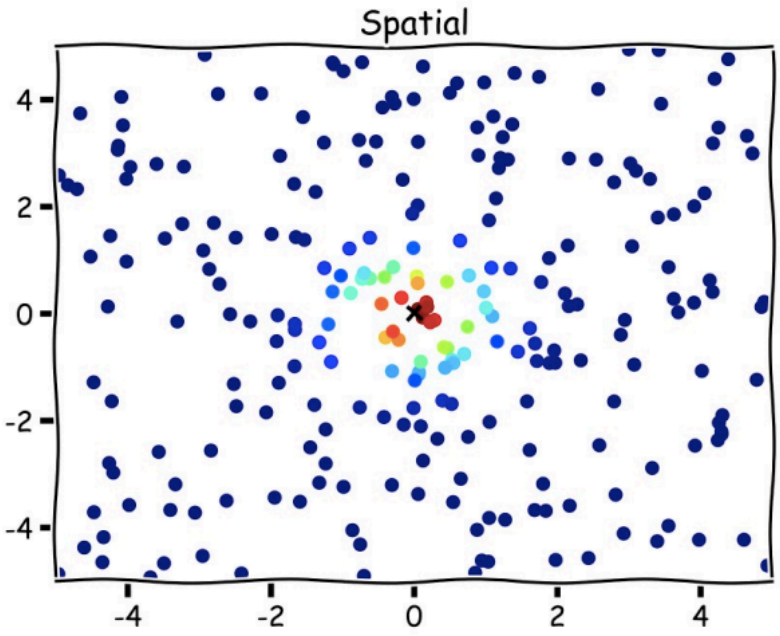
Hundreds of astrophysical neutrinos at low energies

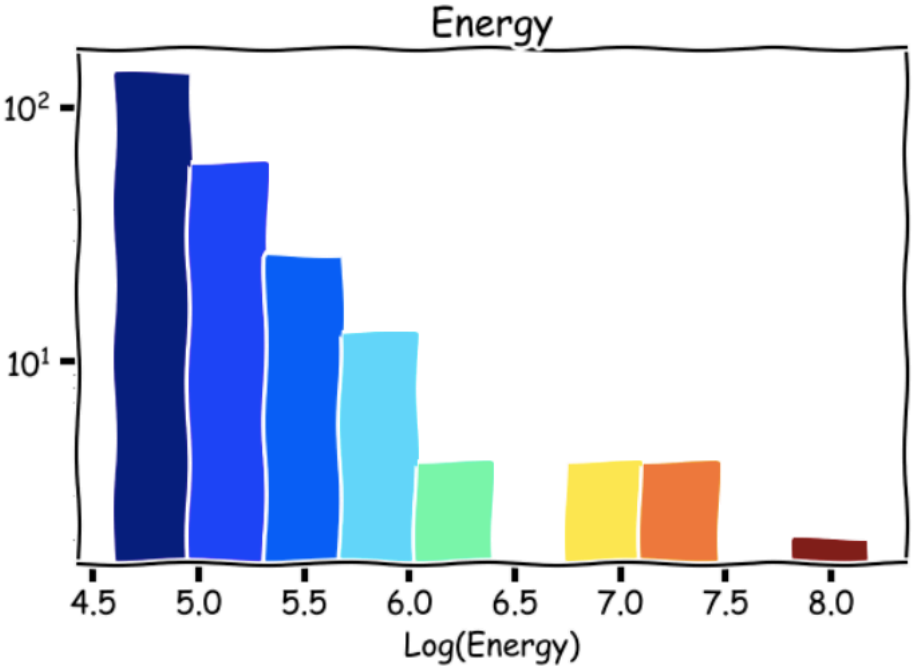
2. Realtime correlation with optical candidates

2. Realtime correlation

- Neutrino stream from IceCube to AMPEL (~100 per day)
- For each optical transient look for neutrinos coincident in space and time → calculate *test statistic (TS)*

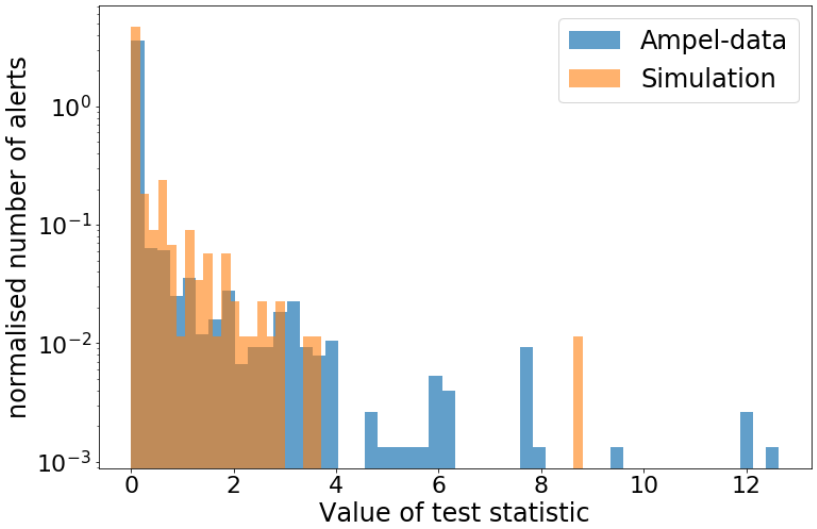
$$TS = -2\log\frac{\mathcal{L}(\mathrm{ns})}{\mathcal{L}(\mathrm{ns}=0)} = -2\sum_{\mathrm{i}=0}^{\mathrm{N}}\log\left(1+\frac{\mathrm{ns}}{\mathrm{N}}\left(\frac{\mathcal{S}}{\mathcal{B}}-1\right)\right)$$

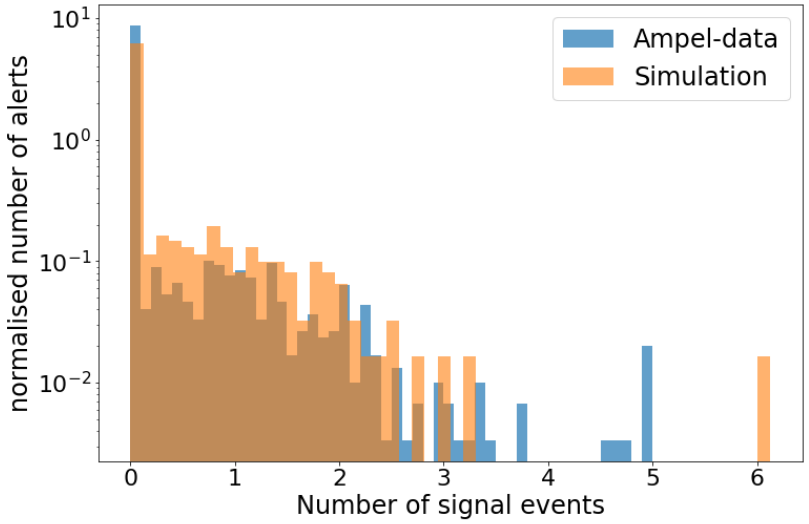




2. Realtime correlation

- Neutrino stream from IceCube to AMPEL (~100 per day)
- For each optical transient look for neutrinos coincident in space and time → calculate *test statistic (TS)*
- First tests of TS distribution of real candidates compared to simulation





2. Realtime correlation

- Neutrino stream from IceCube to AMPEL (~100 per day)
- For each optical transient look for neutrinos coincident in space and time → calculate *test statistic (TS)*
- First tests of TS distribution of real candidates compared to simulation
- Transients reaching TS threshold can be pushed to GROWTH marshal
- Summary is sent to SLACK every day
- High TS candidates will be scheduled for spectroscopic follow-up
- Classified objects will be used in a neutrino stacking analysis to be sensitive to a weak signal from a source population.

SLACK Summary Example

Today — new messages

AMPEL-live APP 3:00 PM

UPDATE! Alert summary for 2018-08-06.

WOW!!! We found 409 transients last night. 🎉 That's loads! Now we just need to figure out what to do with all of them...

The results are summarised below.

robert 3:00 PM

Summary: 2018-08-06

```
,ztf_name,ra,dec,magpsf,sgscore1,rb,most_recent_detection,first_detection,n_detections,distnr,distpsnr1,isdiffpos,_id,DESY_NEUTRINO,T2-ts,T2-nsMax
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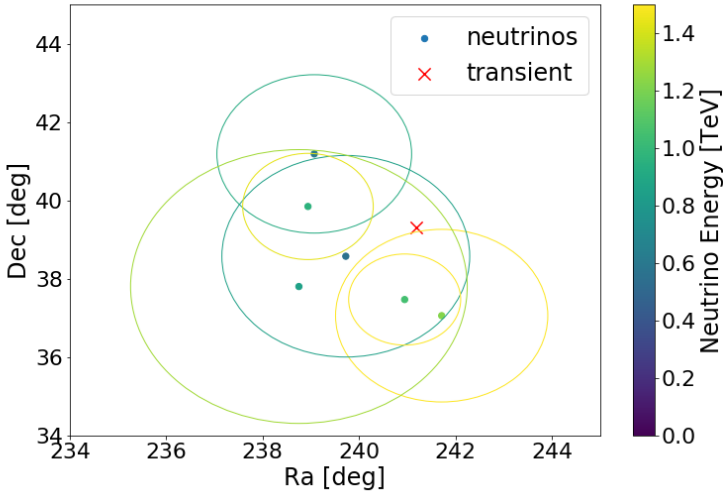
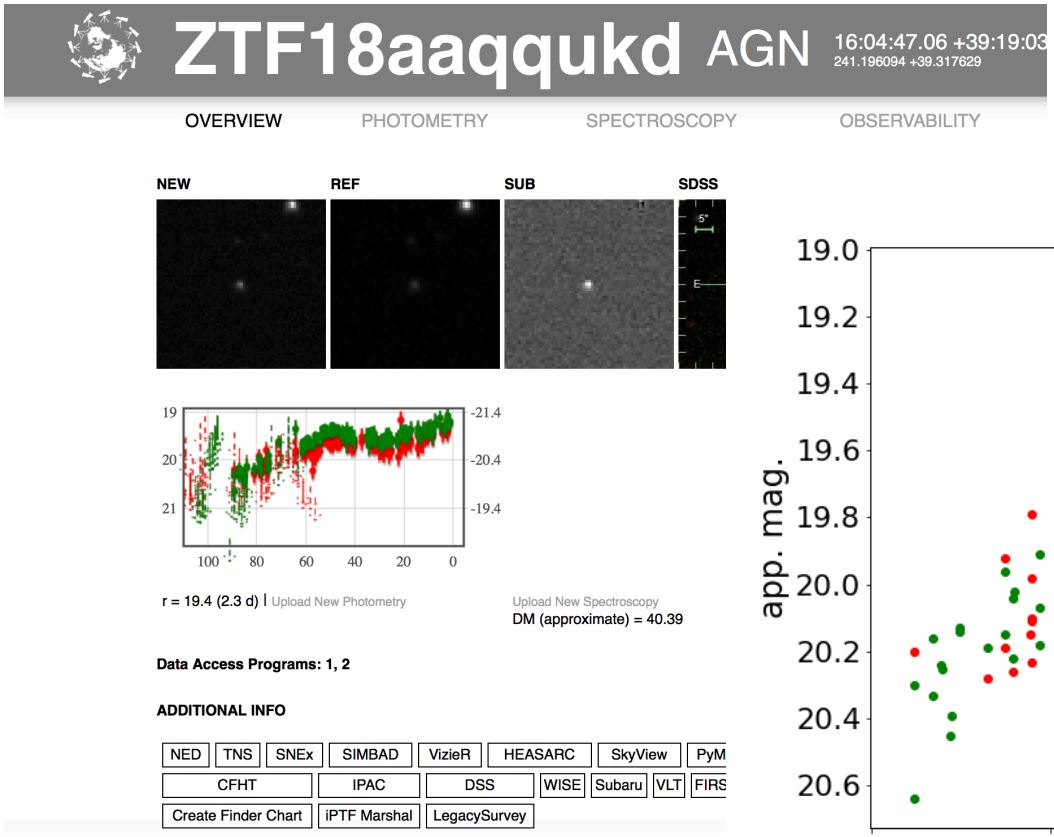
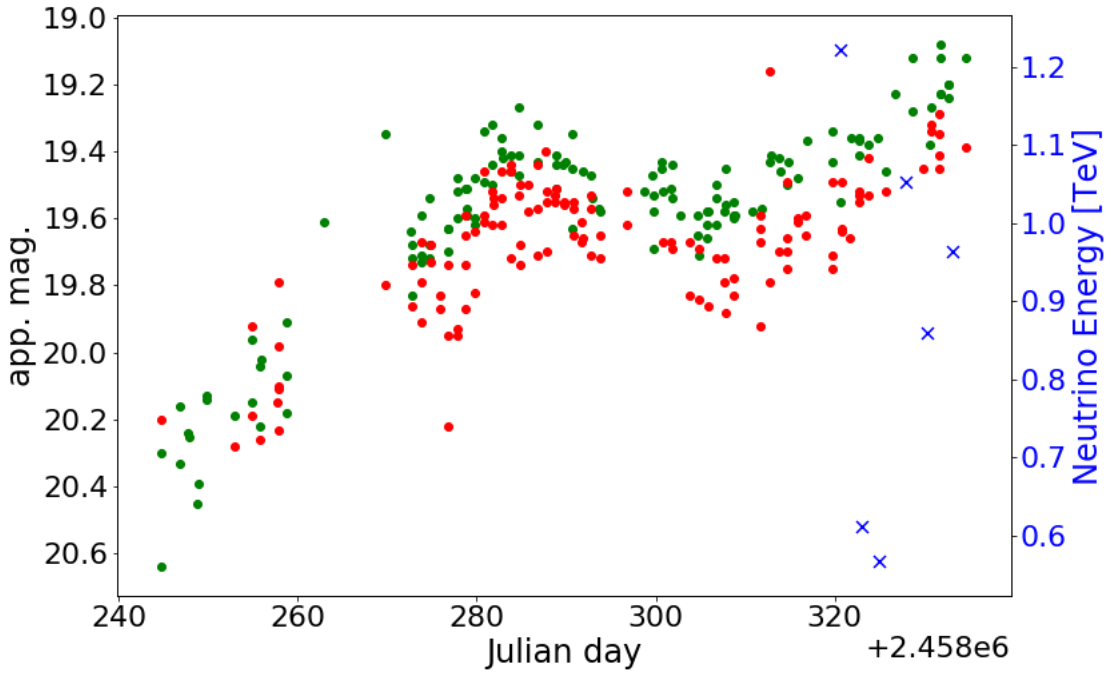
Example high TS event







Summary

- Two searches for neutrino counterparts in place
  1. ToO triggered by most interesting neutrinos
     - Successfully observed neutrino position, no interesting candidates found
  2. Search for clusters of low-energy neutrinos in spatial and temporal coincidence with optical transients
     - Real-time neutrino stream injected to AMPEL, real-time correlation in place
     - Currently in *commissioning phase* to adjust TS threshold
- Next Steps
  - Report to IceCube collaboration after commissioning phase
  - Include dedicated monitoring of predefined promising source lists (e.g. Fermi blazars)

Backup

$$\mathcal{L} = \prod_{i=1}^{N} \frac{N_s}{N}\mathcal{S} + (1 - \frac{N_s}{N})\mathcal{B}$$

$$\mathcal{S}(E_\nu, \Delta T, \Delta\Psi, \sigma) = P_{\text{sig}}^{\text{space}}(\Delta\Psi, \sigma) P_{\text{sig}}^{E}(E_\nu) P^{T}(\Delta T)$$

$$\mathcal{B}(E_\nu, \Delta T, \Delta\Psi) = P_{\text{BG}}^{\text{space}} P_{\text{BG}}^{E}(E_\nu) P^{T}(\Delta T)$$

Space term

$$\mathcal{P}_{\text{sig}}^{\text{space}} = \frac{1}{2\pi\sigma^2} e^{(\Delta\Psi)^2/(2\sigma^2)}$$

$$\mathcal{P}_{\text{BG}}^{\text{space}} = \frac{\mathcal{P}(\sin\theta)}{2\pi}$$

Energy term

$$\mathcal{P}_{\text{sig}}^{E} = \epsilon_{\text{sig}}(E, \theta, \gamma)$$

$$\mathcal{P}_{\text{BG}}^{E} = \epsilon_{\text{BG}}(E, \theta)$$

Time term

$$P^{T} = Box(t_{start}, t_{end})$$

6