A Search for IceCube events in the direction of ANITA neutrino candidates

Anastasia Barbano[1], Teresa Montaruli[1], **Alex Pizzuto**[2], Justin Vandenbroucke[2]
for the IceCube Collaboration
[1]Université de Genève, [2]University of Wisconsin-Madison

ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY

ICRC 2019: Madison, WI

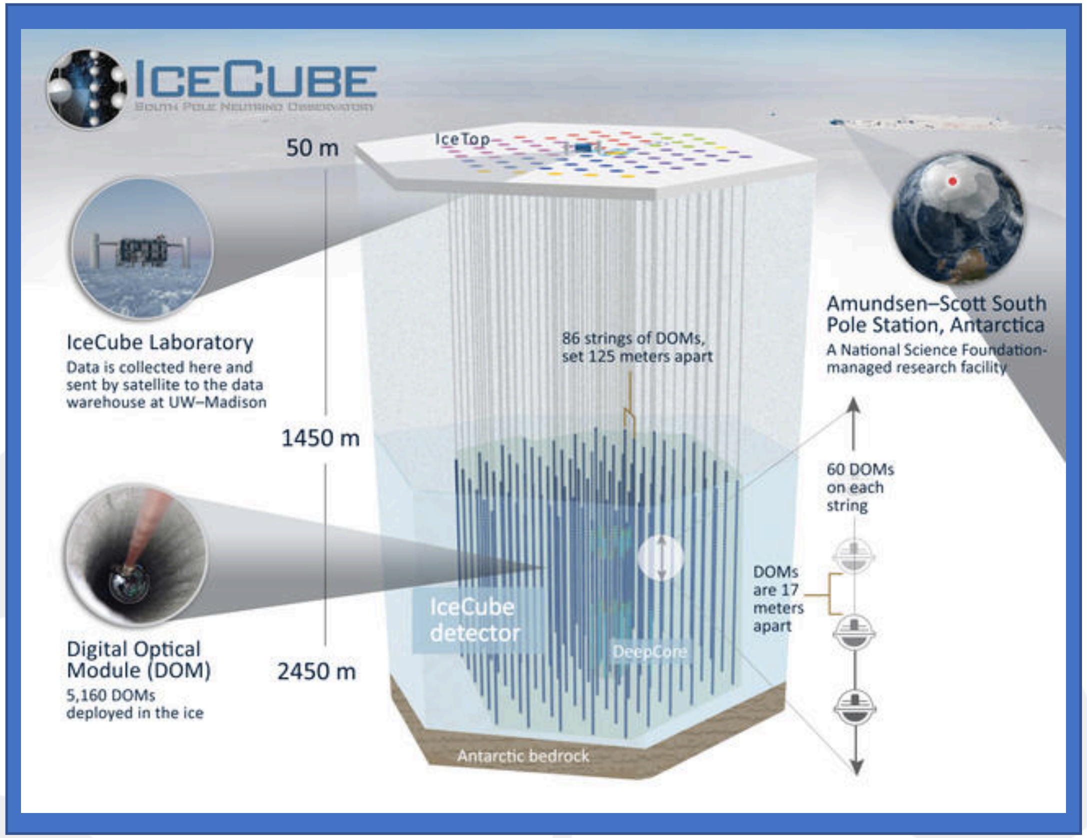
Motivation

ANITA has detected two anomalous events in addition to one candidate from a search for Askaryan emission

Anomalous events are inconsistent with a diffuse neutrino flux interpretation

These inconsistencies could be evaded if the events originated from an astrophysical point source

Sources of EeV neutrinos detected by ANITA should be detectable by other observatories



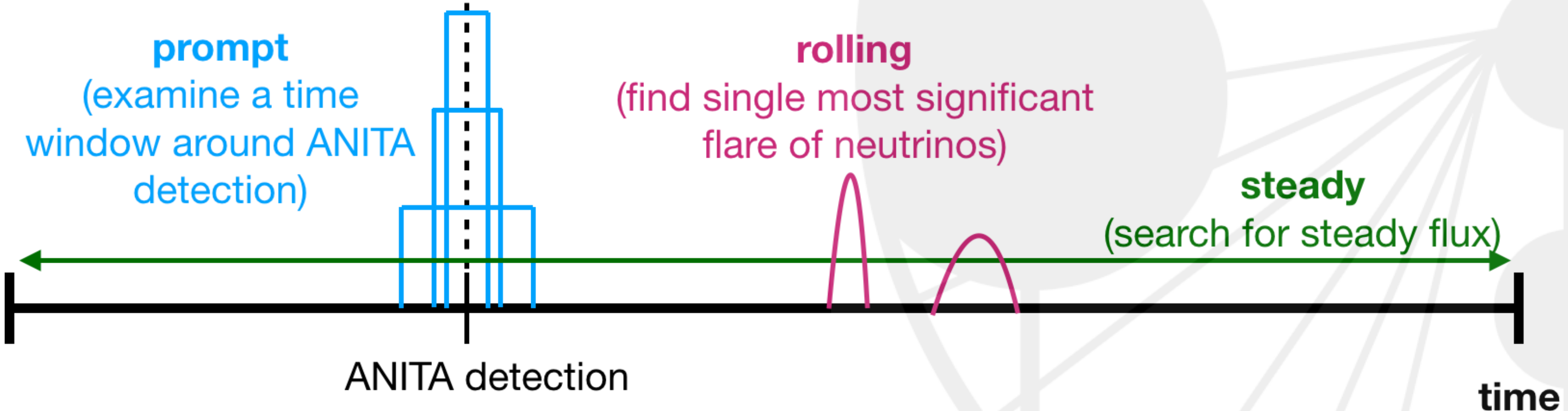
	AAE-061228	AAE-141220	AC-150108
Detection Channel	Geomagnetic	Geomagnetic	Askaryan
Date (UTC)	2006-12-28	2014-12-20	2015-01-08
Time (UTC)	00:33:20.0	08:33:22.5	19:04:24.2
RA, Dec (J2000)	282°.14, +20°.33	50°.78, +38°.65	171°.45, +16°.30
Localization Uncertainty	1°.5 × 1°.5, 0°.0	1°.5 × 1°.5, 0°.0	5°.0 × 1°.0, +73°.7
Reconstructed Energy (EeV)	0.6 ± 0.4	$0.56^{+0.30}_{-0.20}$	≥ 10
Earth Chord Length (km)	5740 ± 60	7210 ± 55	-

Point Source Followup

Lack of candidate source class → 3 complementary model independent searches

1. Prompt
   Search for spatially and temporally coincident signal between ANITA and IceCube on short timescales ($\leq 10^5$ seconds)
2. Rolling
   Search for spatial and temporal clustering in IceCube data (don't require temporal coincidence with ANITA)
3. Steady
   Time-integrated search for spatial clustering

Caveat: searches must include large ANITA localization uncertainty



Point Source Followup

Lack of candidate source class → 3 complementary model independent searches

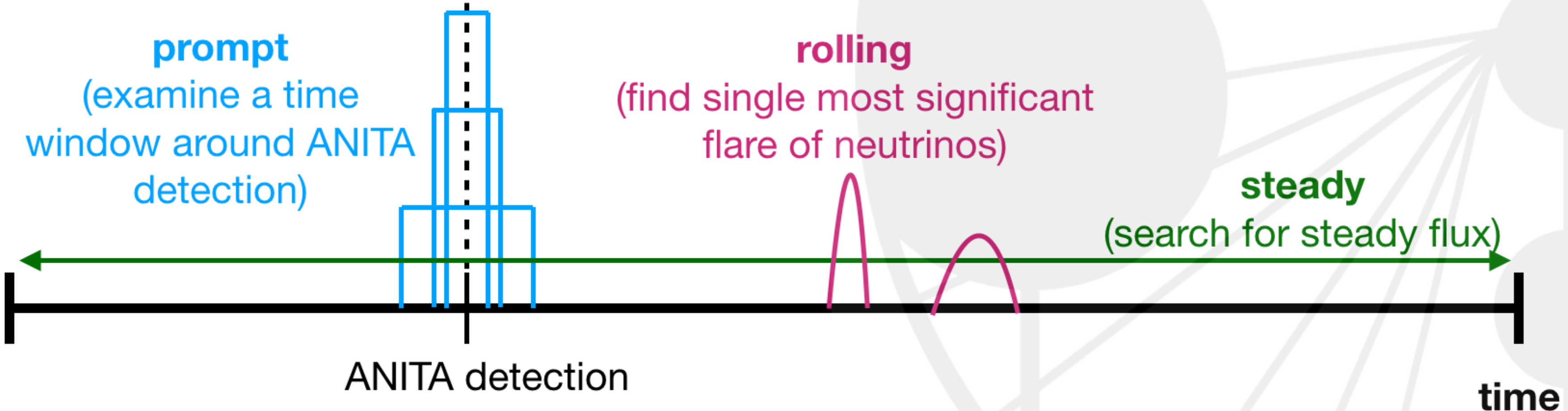
1. Prompt
   Search for spatially and temporally coincident signal between ANITA and IceCube on short timescales ($\leq 10^5$ seconds)
2. Rolling
   Search for spatial and temporal clustering in IceCube data (don't require temporal coincidence with ANITA)
3. Steady
   Time-integrated search for spatial clustering

Caveat: searches must include large ANITA localization uncertainty

"Searches for Common Source of Gravitational Waves and Neutrinos"
R. Hussain (Tuesday 5:15)

"Searches for time-dependent neutrino emission from blazars"
E. O'Sullivan (Saturday 2:45)

"Recent Results for All Sky Time-Integrated Point Source Searches using 10 years of IceCube Data"
T. Carver (Saturday 2:00)



Likelihood

We incorporate the ANITA event uncertainties through the use of a prior:

$$\mathscr{L} = \lambda \prod_{i=1}^{N} \left(\frac{n_s}{n_s + n_b} S\left(\mathbf{x}_i, \mathbf{x}_s, \alpha\right) + \frac{n_b}{n_s + n_b} B\left(\mathbf{x}_i, \mathbf{x}_s\right) \right) \cdot P_A\left(\mathbf{x}_s\right)$$

And perform three analyses for different emission timescales:

Prompt

Search for spatial and temporal coincidence between IceCube and ANITA

$$\lambda = \frac{\left(n_s + n_b\right)^N}{N!} \cdot \exp\left[-\left(n_s + n_b\right)\right]$$

binned in time around ANITA event

Rolling

Search for excess in IceCube data clustered in time, but offset from the ANITA event time

$$\lambda = 1$$

$$T_i^{\text{signal}} = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{\left(t_0 - t_i\right)^2}{2\sigma_t^2}}$$

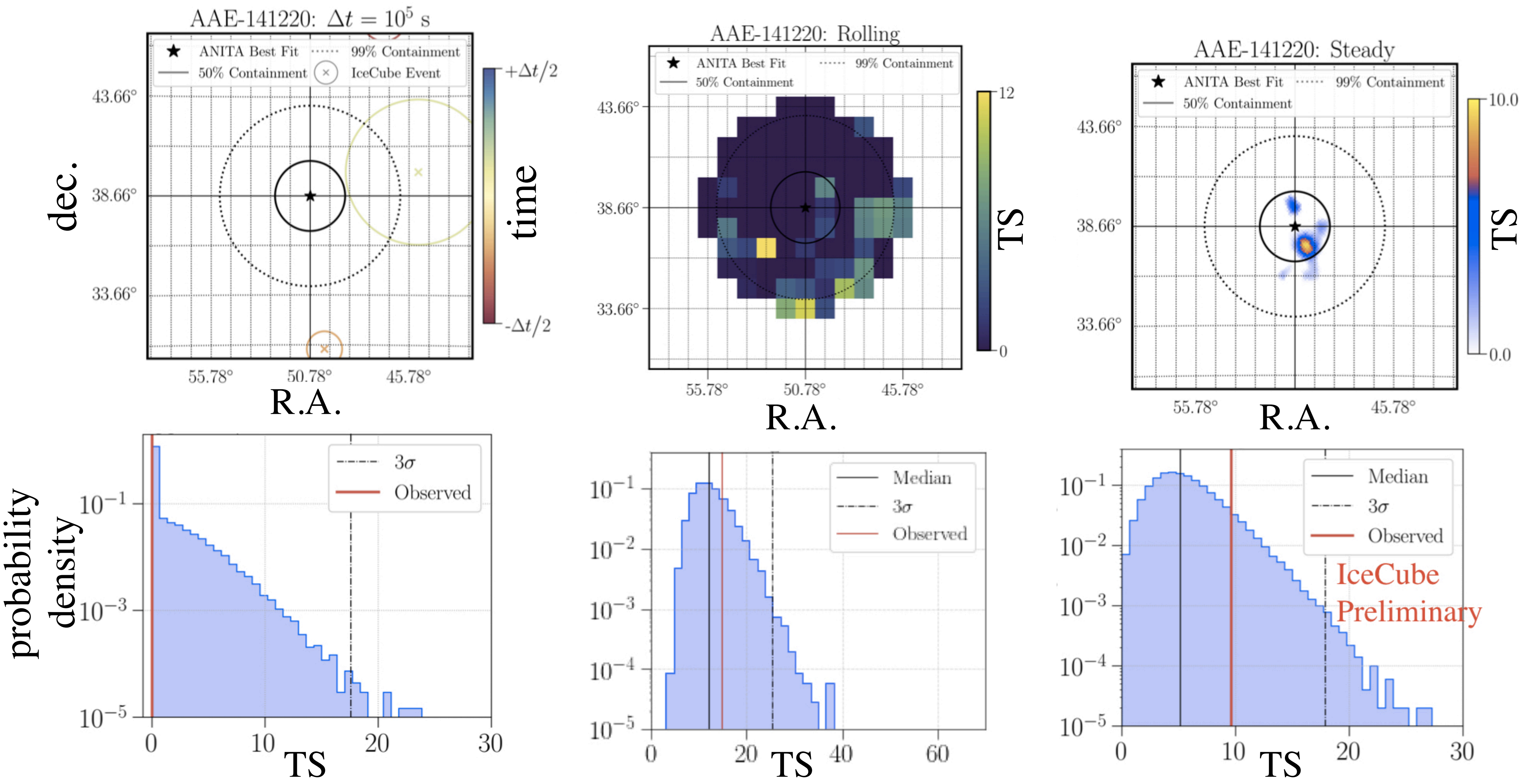
Steady

Search for constant emission over many years of IceCube data

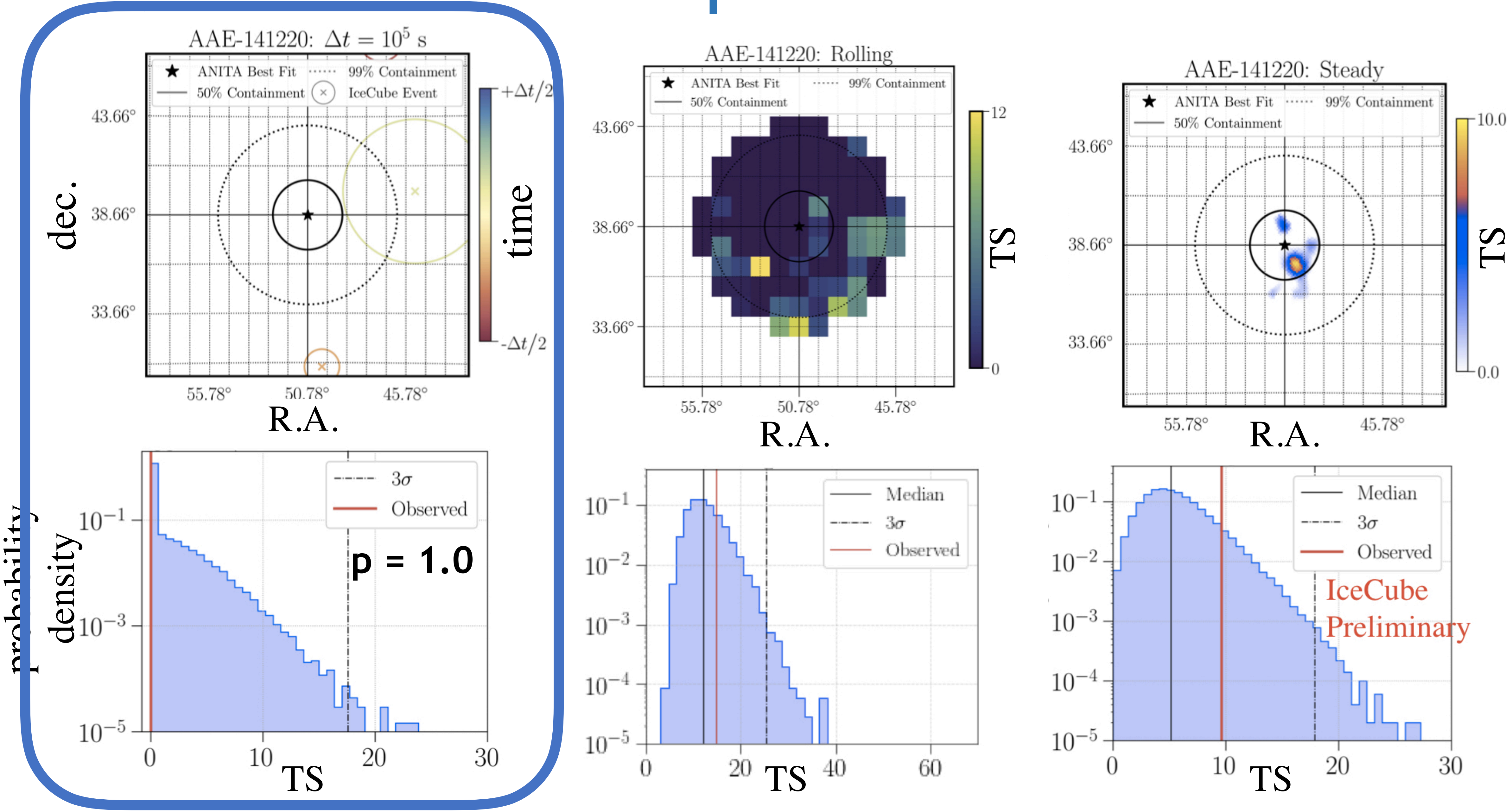
$$\lambda = 1$$

uniform in time for 7 years of data

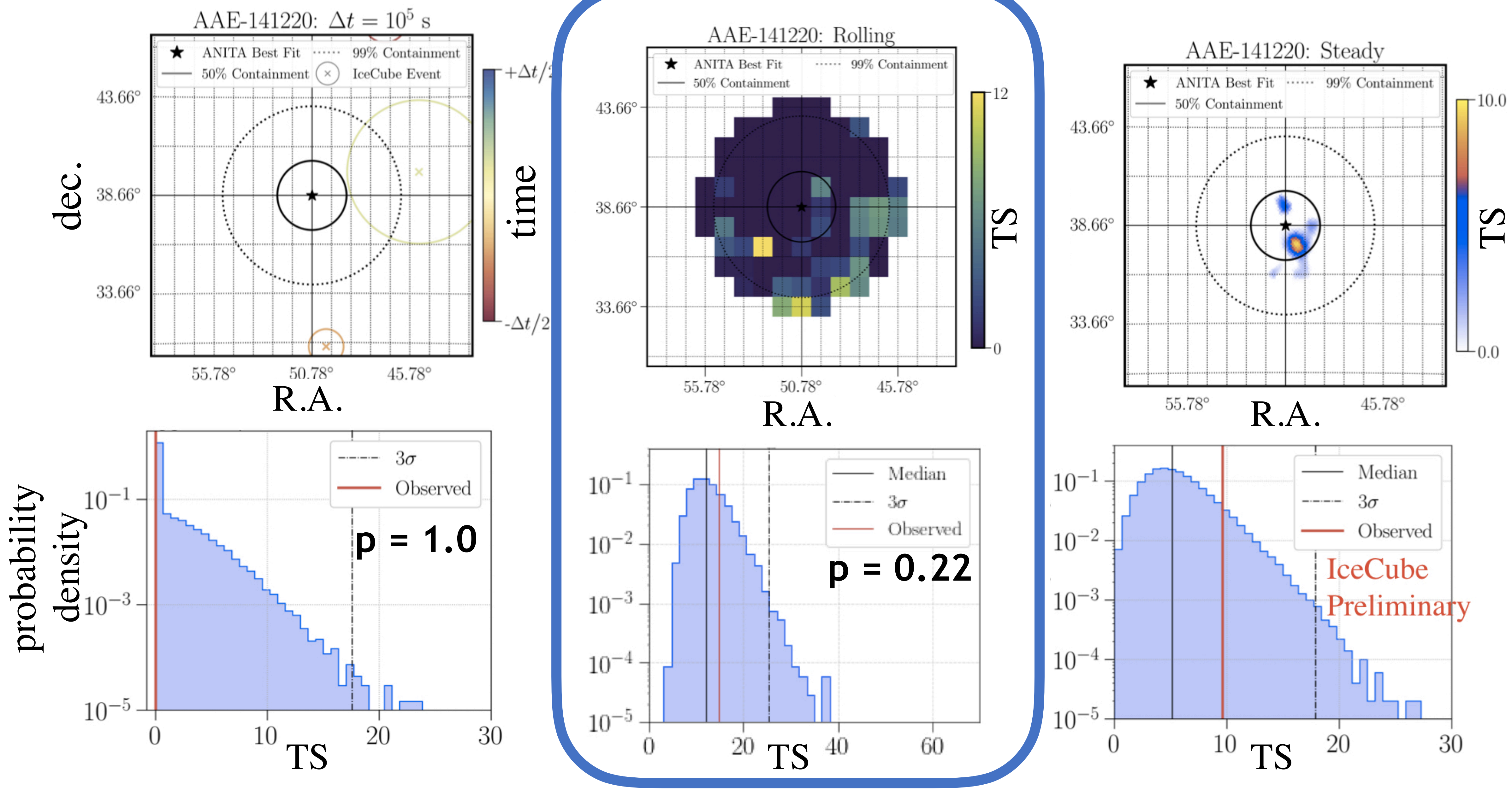
Point source followup: Results



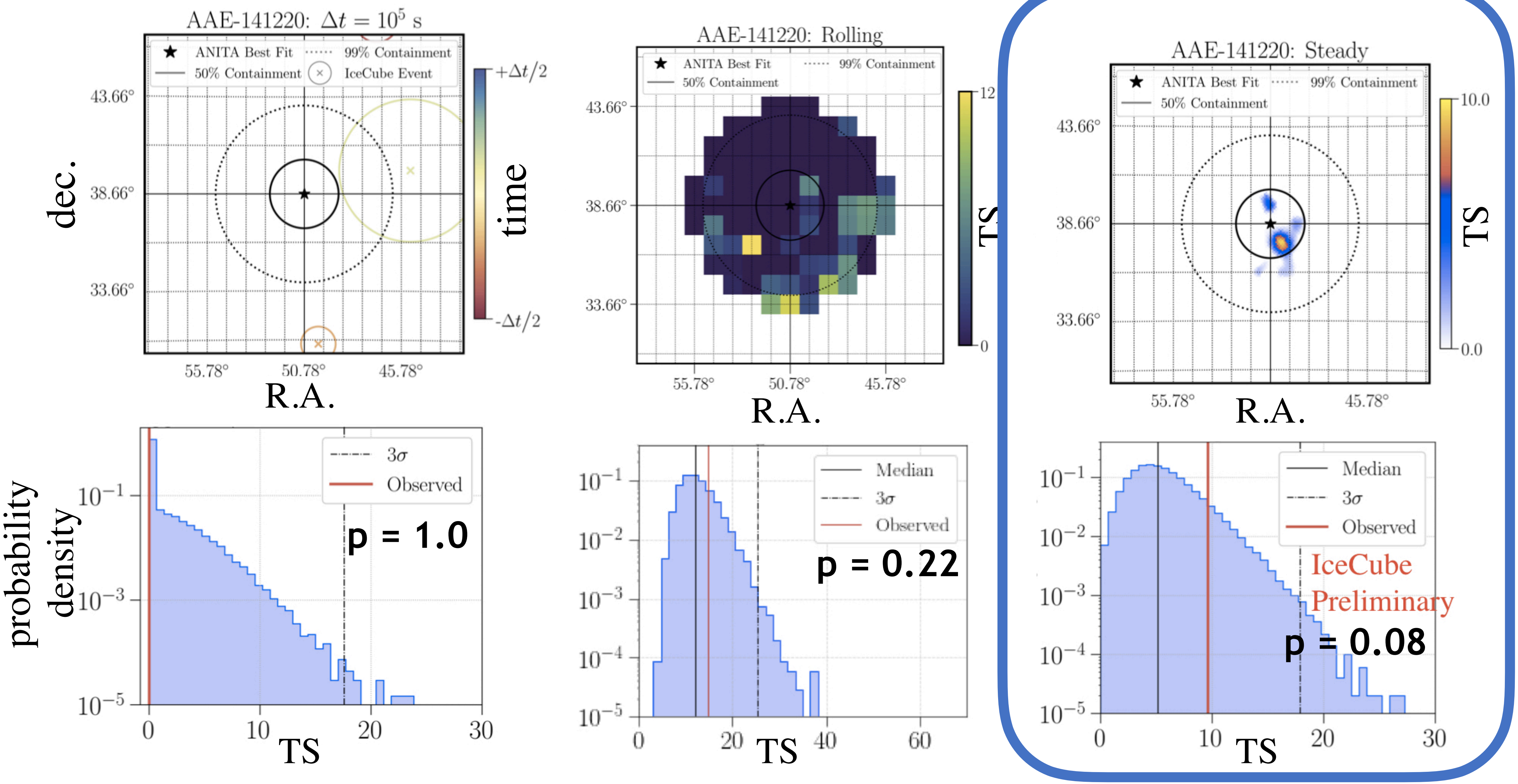
Point source followup: Results



Point source followup: Results

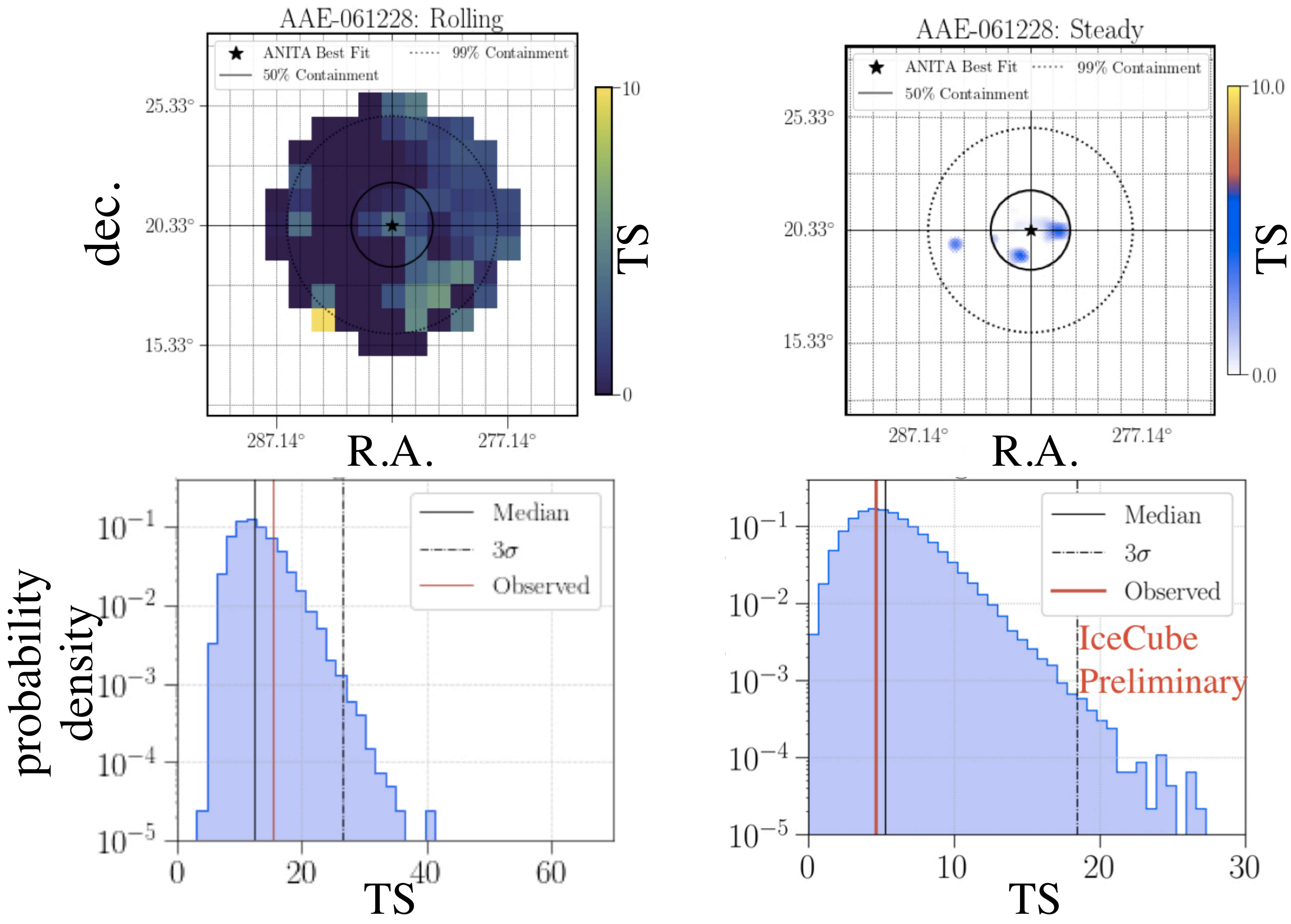


Point source followup: Results

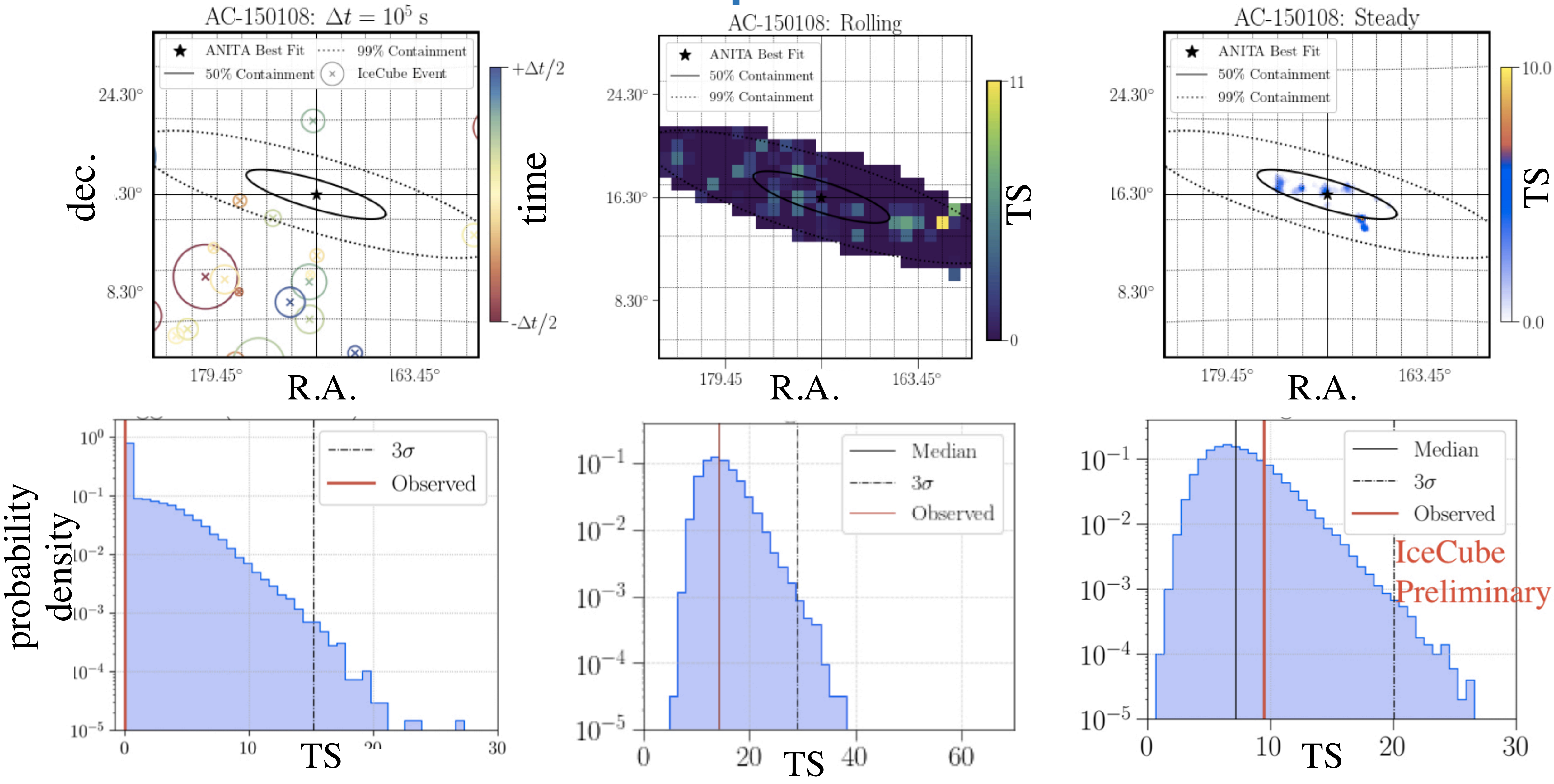


Point source followup: Results

No Prompt analysis for AAE-061228 as IceCube was in the early construction phase during 2006



Point source followup: Results



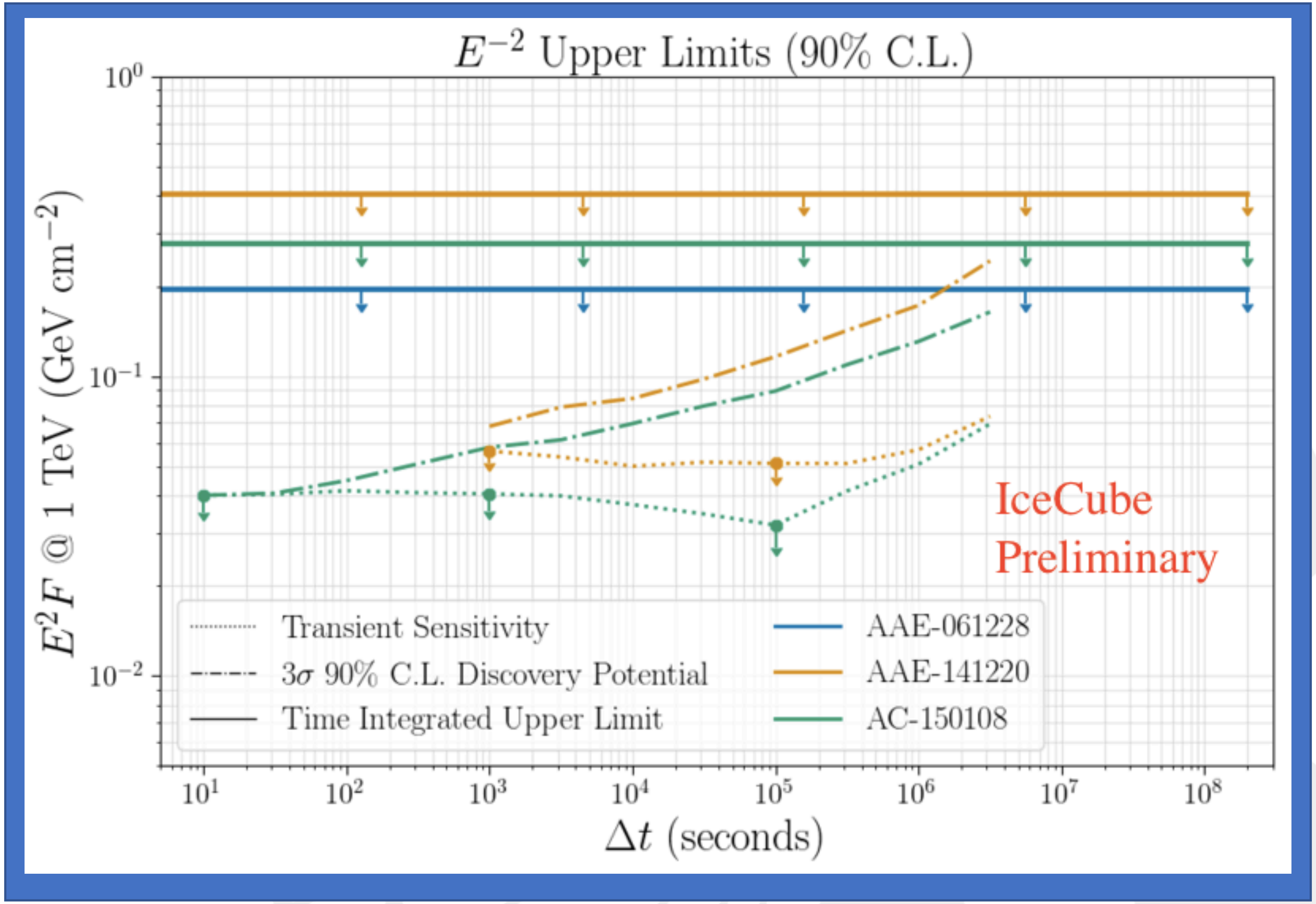
Point source followup: Limits

All results consistent with background

Limits set assuming constant emission over various timescales

For AAE-141220, we cannot probe the smallest times due to detector downtime beginning 0.5 seconds before the event time (lasting ~20 seconds)

For the timescales which we can constrain, how compatible is our non-observation with the ANITA detection?



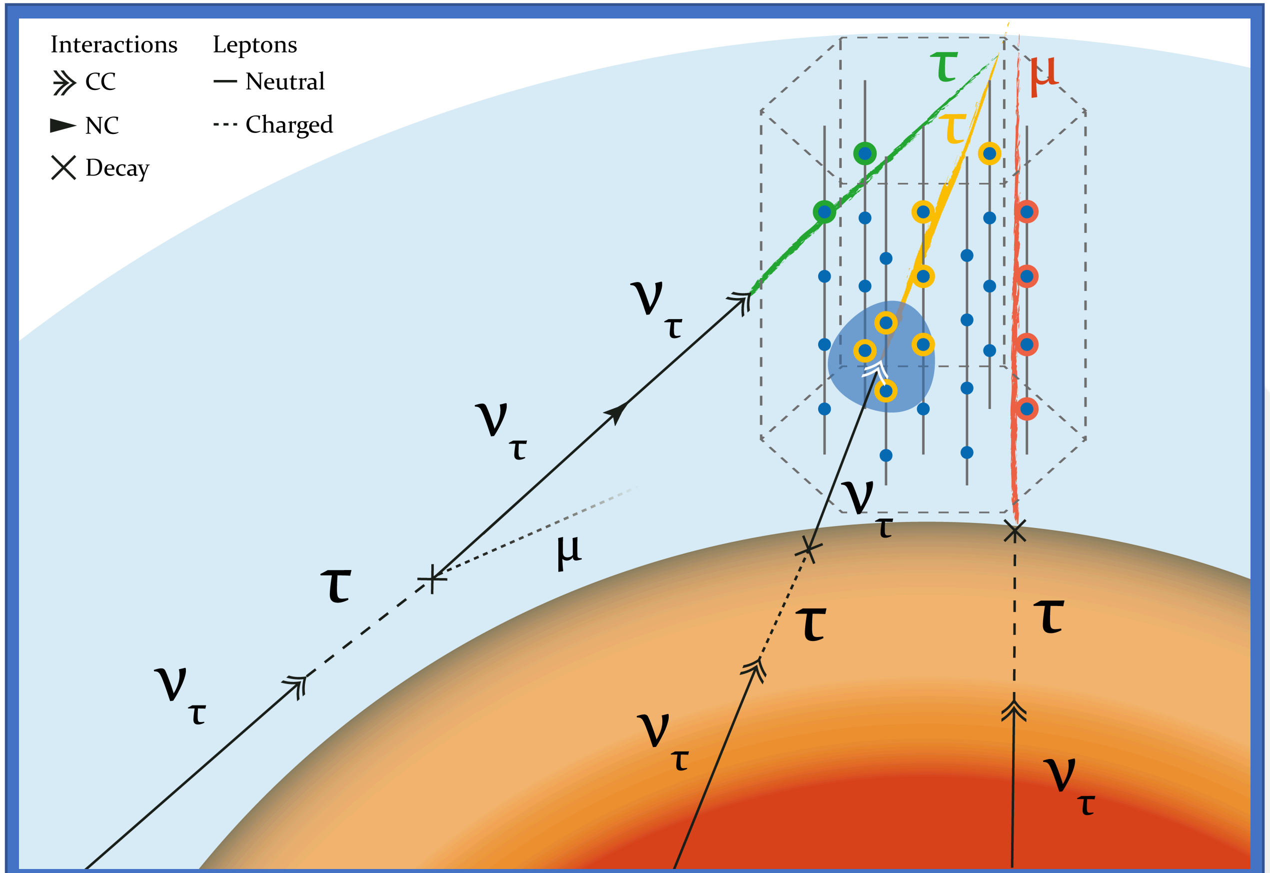
A Joint Interpretation

The anomalous ANITA events can each be interpreted as an incident ν_τ, detected as showers from an ~0.1 EeV τ

At high-energies, ν_τ regeneration gives rise to a secondary flux of lower energy ν_τ

For AAE-141220, every 0.1 EeV τ at ANITA, at IceCube there should also be:

(1) ~10^3 τ with energies 1 PeV - 10 PeV
(2) ~10^8 ν_τ with energies 1 PeV -10 PeV



From "Constraining anomalous ANITA detections with PeV neutrinos"
I. Safa (Poster session 2)

A Joint Interpretation

Procedure:

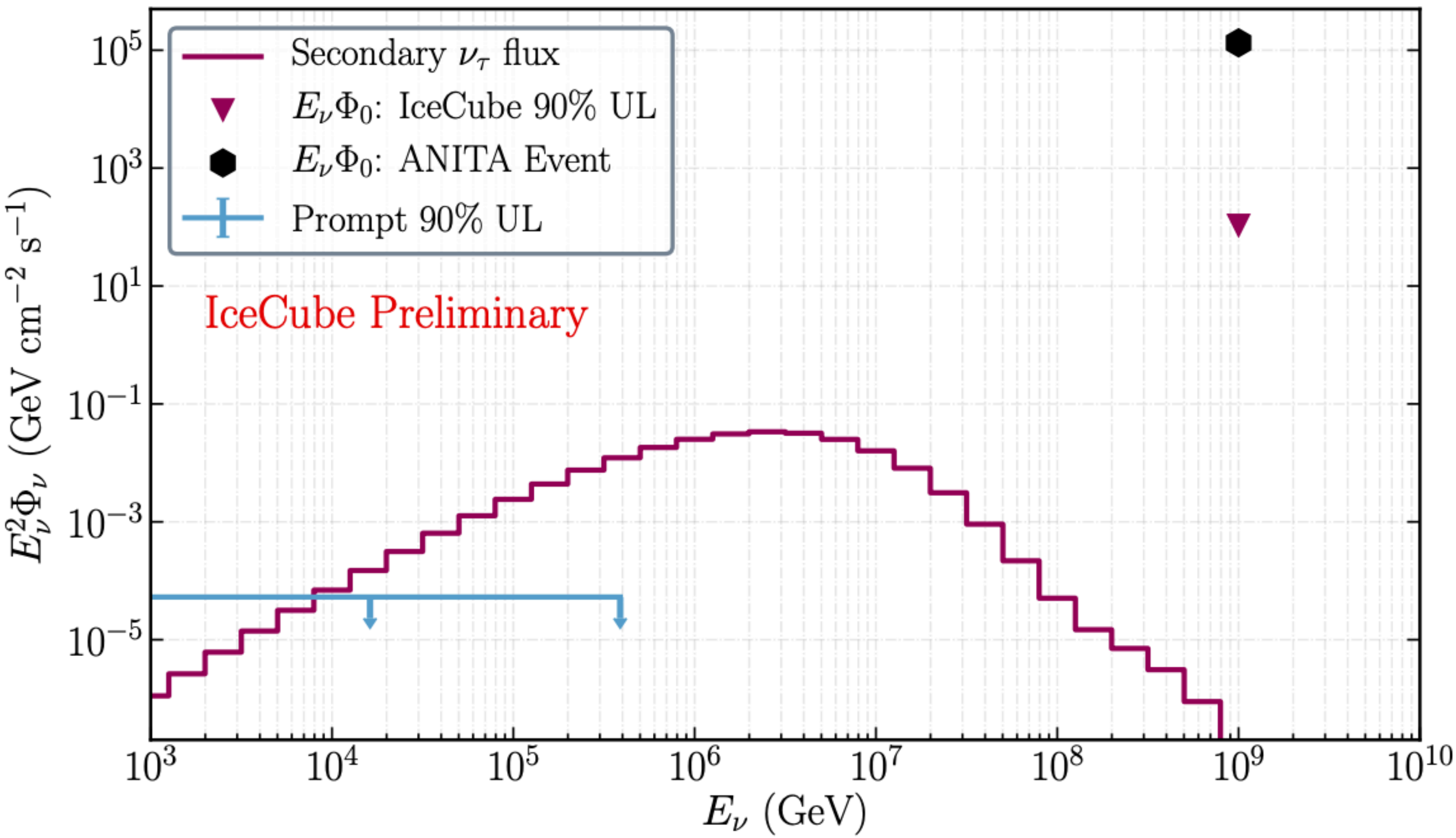
(1) Find the spectral shape most likely to result in ANITA detecting an event

- Delta function at 1 EeV

(2) Based on ANITA acceptance*, calculate best-fit normalization on this flux

(3) Calculate the upper limit of the normalization based on the non-observation of secondaries at IceCube

Upper limits require an overfluctuation at the 10^3 level for AAE-141220 to accommodate a point-source interpretation



ANITA acceptance from (A. Romero-Wolf et al. Phys. Rev. D 99, 063011), rescaled optimistically to the acceptance at the horizon to remove earth absorption effects

Conclusion

IceCube data are consistent with background in the direction of ANITA neutrino candidate events

We place limits on time-integrated muon-neutrino fluxes ($E^2 \Delta T (dN/dE)$) from the direction of the ANITA events for various timescales at the level of 5×10^{-2} GeV cm^{-2} for short time windows

Limits are also constraining for any tau-neutrino flux spectral shape

Future searches for point-sources with radio detectors can use this same procedure

Conclusion

IceCube data are consistent with background in the direction of ANITA neutrino candidate events

We place limits on time-integrated muon-neutrino fluxes ($E^2 \Delta T (dN / dE)$) from the direction of the ANITA events for various timescales at the level of $5 \times 10^{-2}\ \mathrm{GeV\ cm^{-2}}$ for short time windows

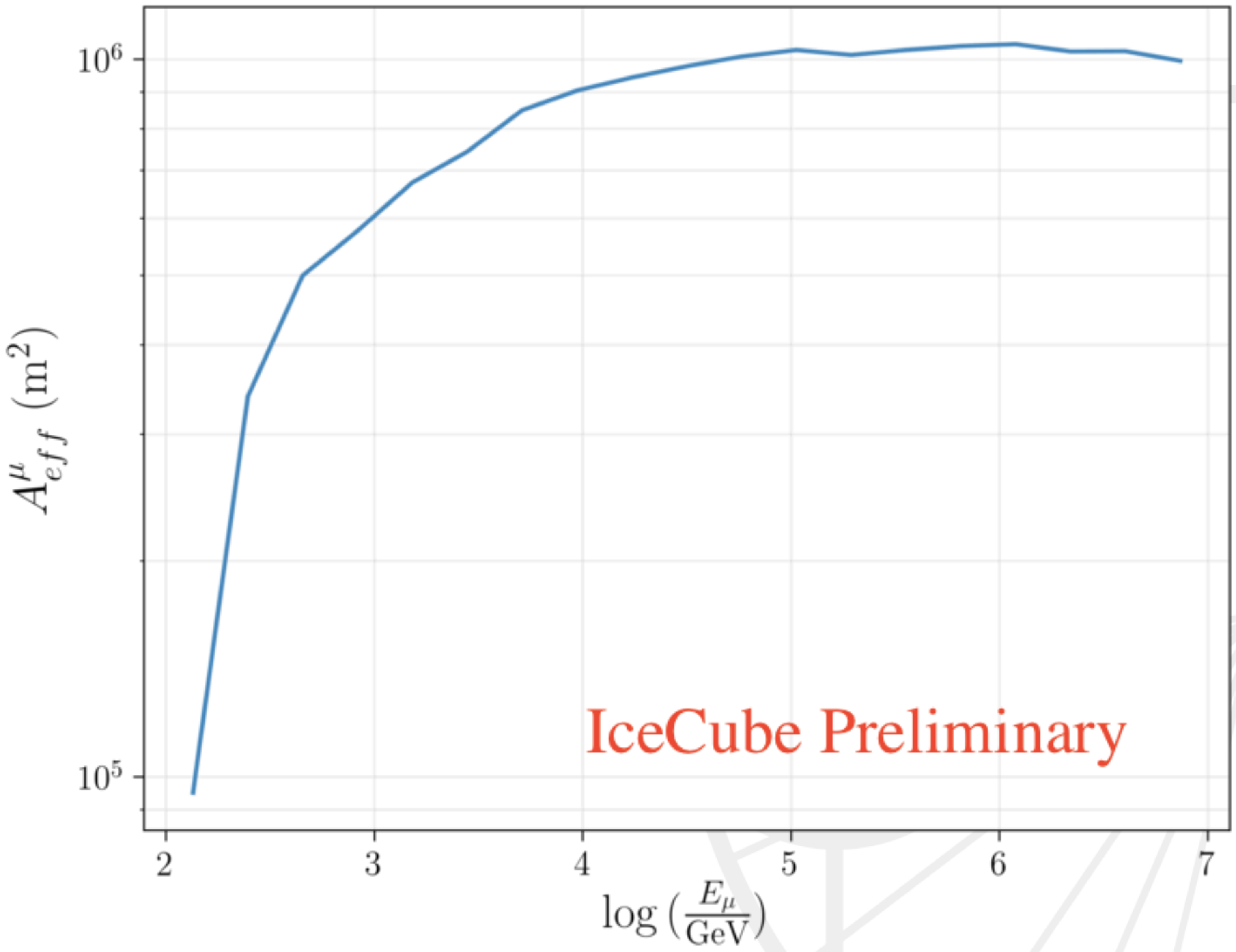
Limits are also constraining for any tau-neutrino flux spectral shape

Future searches for point-sources with radio detectors can use this same procedure

Thank you!

Backup Slides

Muon Effective Area



Expected Flux at IceCube

The expected number of taus detected by ANITA is given by:

$$N^{\tau} = \iint dE_{\nu} dE_{\tau} \Phi\left(E_{\nu}\right) P_{surv}^{\tau}\left(E_{\nu}\right) \frac{dN\left(E_{\tau}\right)}{dE_{\tau}} \xi_{acc}\left(E_{\tau}\right) \Delta T \quad \text{where} \quad \Phi\left(E_{\nu}\right) = \phi_0 \delta\left(E_{\nu} - E_0\right)$$

For the same incident flux, we can calculate the expected number of events at IceCube:

$$\begin{aligned} N^{\mu}_{\text{IceCube}} = & \int dE_{\mu} \int dE_{\tau} \int dE_{\nu} \Phi\left(E_{\nu}\right) P_{\tau}^{surv}\left(E_{\tau}; E_{\nu}\right) \frac{dN_{\tau}\left(E_{\tau}\right)}{dE_{\tau}} \frac{dN_{\mu}}{dE_{\mu}}\left(E_{\tau}, E_{\mu}\right) A_{eff}^{\mu}\left(E_{\mu}\right) \Delta T \\ & + \int dE_{\nu}' \int dE_{\nu} \Phi\left(E_{\nu}\right) P_{\nu}\left(E_{\nu}'; E_{\nu}\right) \frac{dN_{\nu}}{dE_{\nu}'}\left(E_{\nu}'\right) A_{eff}^{\nu_{\nu}}\left(E_{\nu}'\right) \Delta T \end{aligned}$$

Contribution relevant to this data sample

Neutral Current contribution (not relevant for our data sample)