Search for point-like neutrino sources over the Southern Hemisphere with the ANTARES and IceCube neutrino telescopes

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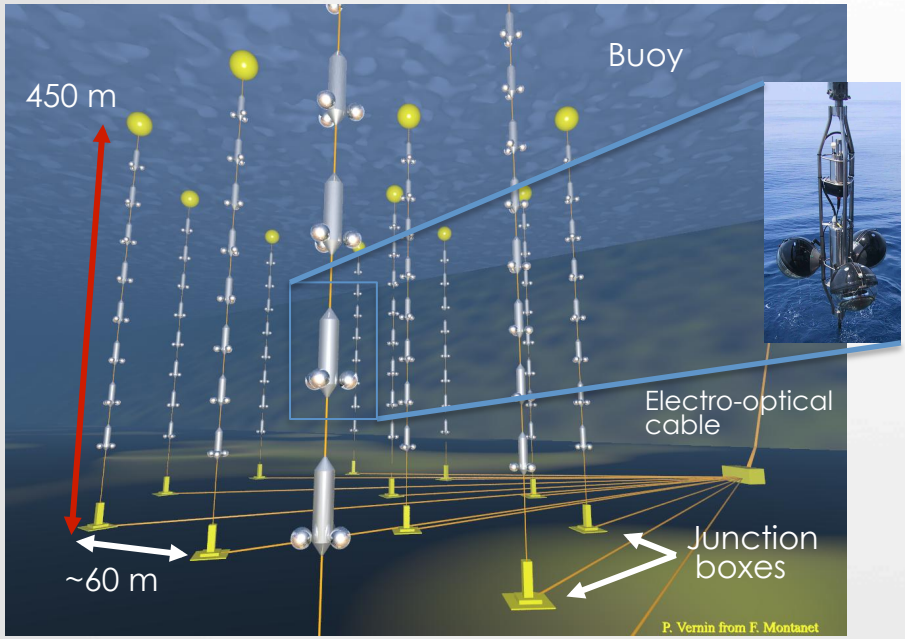
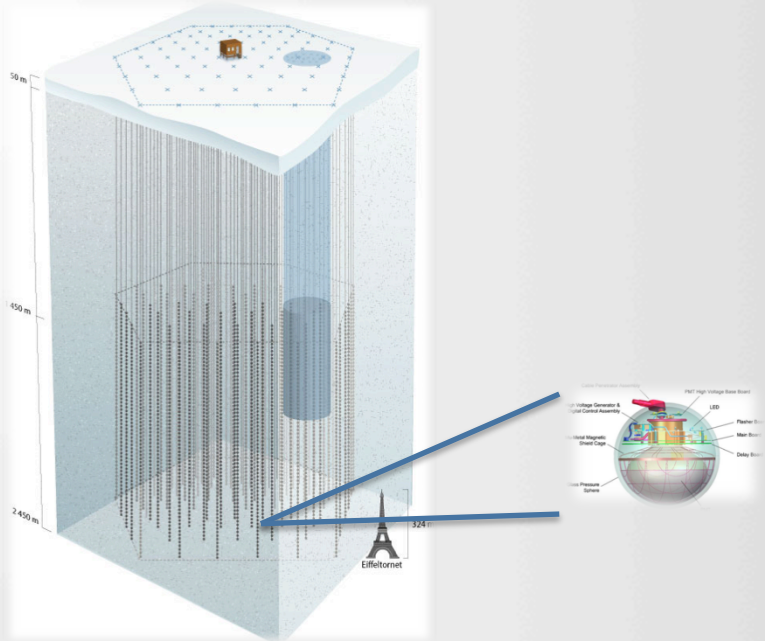
The ANTARES and IceCube detectors





- Largest neutrino telescope in the Northern Hemisphere
- 12 lines with 25 storeys (3 OMs each)
- 2500 m deep in the Mediterranean Sea

- Largest neutrino telescope (1 km^3)
- ~2500 m deep in Antarctica
- 86 strings with 60 DOMs
- 17 m between DOMs
- 125 m between strings

Complementarity for the **Southern Sky**:

- ANTARES has better sensitivity for $E_\nu < 100$ TeV
- IceCube has a better sensitivity for high energy events

Data samples

- Combined point source analysis for the **Southern Sky**.

- Samples used:
  - **IC 40 strings:** 375 days, 22796 events
  - **IC 59 strings:** 348 days, 64240 events
  - **IC 79 strings:** 316 days, 59009 events
  - **ANTARES 2007-2012:** 1338 days, 4136 events

- All these samples have already been used for point-source analysis in their respective collaborations.

Search method: Likelihood

- Likelihood for the analysis:

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

j : Sample (ANT, IC40, IC59, IC79).
i : Event in sample j.

n^j_s related to each sample with the relative contribution of each experiment:

$$n_s^j = C^j(\delta) n_s$$

IceCube signal PDF

$$S_i^{IC} = \frac{1}{2\pi\sigma_i^2} e^{\frac{-|x_s - x_i|^2}{2\sigma_i^2}} P_s(E_i, \sigma_i \mid \delta_i)$$

ANTARES signal PDF

$$S_i^{ANT} = \frac{1}{2\pi\beta_i^2} e^{\frac{-|x_s - x_i|^2}{2\beta_i^2}} P_s(E_i, \beta_i)$$

IceCube background PDF

$$B_i^{IC} = B^j(\delta_i) P_b(E_i, \sigma_i \mid \delta_i)$$

ANTARES background PDF

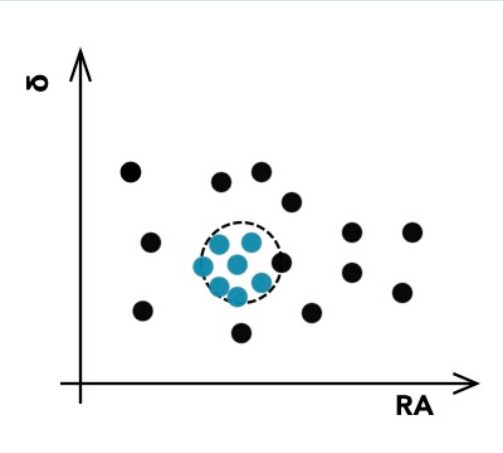
$$B_i^{ANT} = B(\delta_i) P_b(E_i, \beta_i)$$

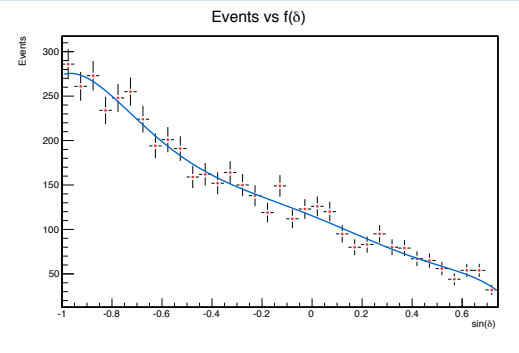
[See arXiv:physics/0401045v1 for the justification on the use of P(E, beta)]

Search method: Likelihood

Signal PDF:

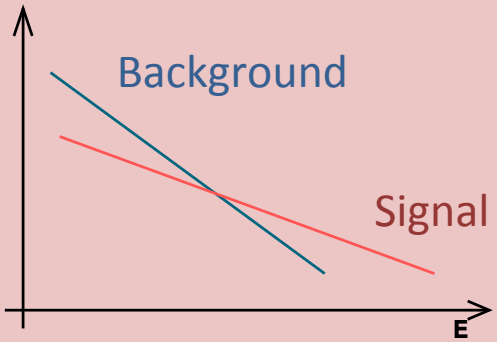
$$S_i = \frac{1}{2\pi\beta_i^2} e^{\frac{-|x_s - x_i|^2}{2\beta_i^2}} P_s(E_i, \beta_i)$$





Background PDF:

$$B_i = B(\delta_i) P_{bg}(E_i, \beta_i)$$



Relative fraction of signal events

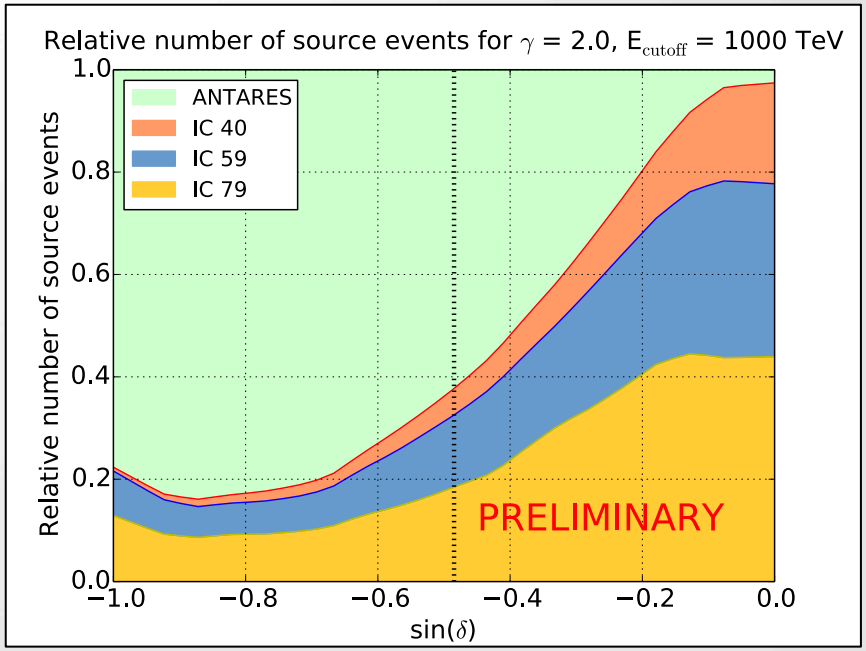
- Fraction of expected source events:

$$C^j\left(\delta, \frac{d\Phi}{dE_\nu}\right) = \frac{N^j\left(\delta, d\Phi / dE_\nu\right)}{\sum_i N^i\left(\delta, d\Phi / dE_\nu\right)}$$

where:

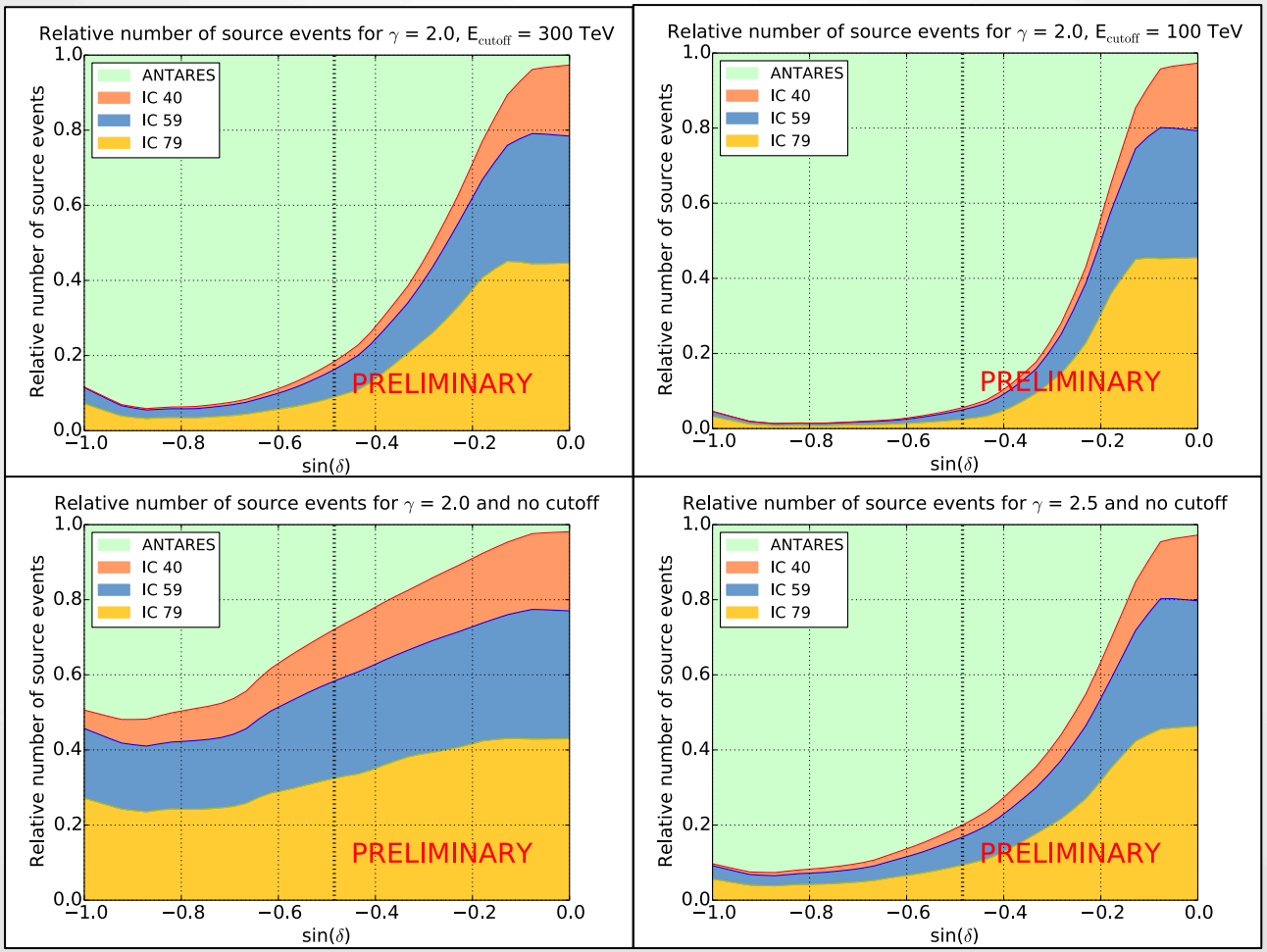
$$N(\delta) = \iint dE\, dt A_{eff}(E,\delta)\frac{d\Phi}{dE}$$

- Indicates the performance of detector at a given signal.
- Different flux assumptions:
  - Different energy spectra (E^{-2}, $E^{-2.5}$)
  - Energy cutoffs (100 TeV, 300 TeV, 1 PeV).



Relative fraction of source events for an E^{-2} energy spectrum and an exponential square-root energy cutoff of 1 PeV.

Relative fraction of signal events



Relative fraction of signal events for different energy source spectra. Exponential square-root energy cutoffs of 300 TeV (top-left) and 100 TeV (top right). Spectral index of E^{-2} and $E^{-2.5}$ without cut-offs (bottom right).

Search method: Likelihood

- Likelihood for the analysis:

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

n^j_s related to each sample with the relative contribution of each experiment:

$$n_s^j = C^j(\delta) n_s$$

- From this likelihood, we define the following test statistic:

$$TS = \log L^{\max}(n_s) - \log L(n_s = 0)$$

Search method: Strategies

Full Southern Sky search

- Evaluation of the TS in squares of 1°×1° over the Southern Sky
- Free parameters: n_s, δ_s, α_s

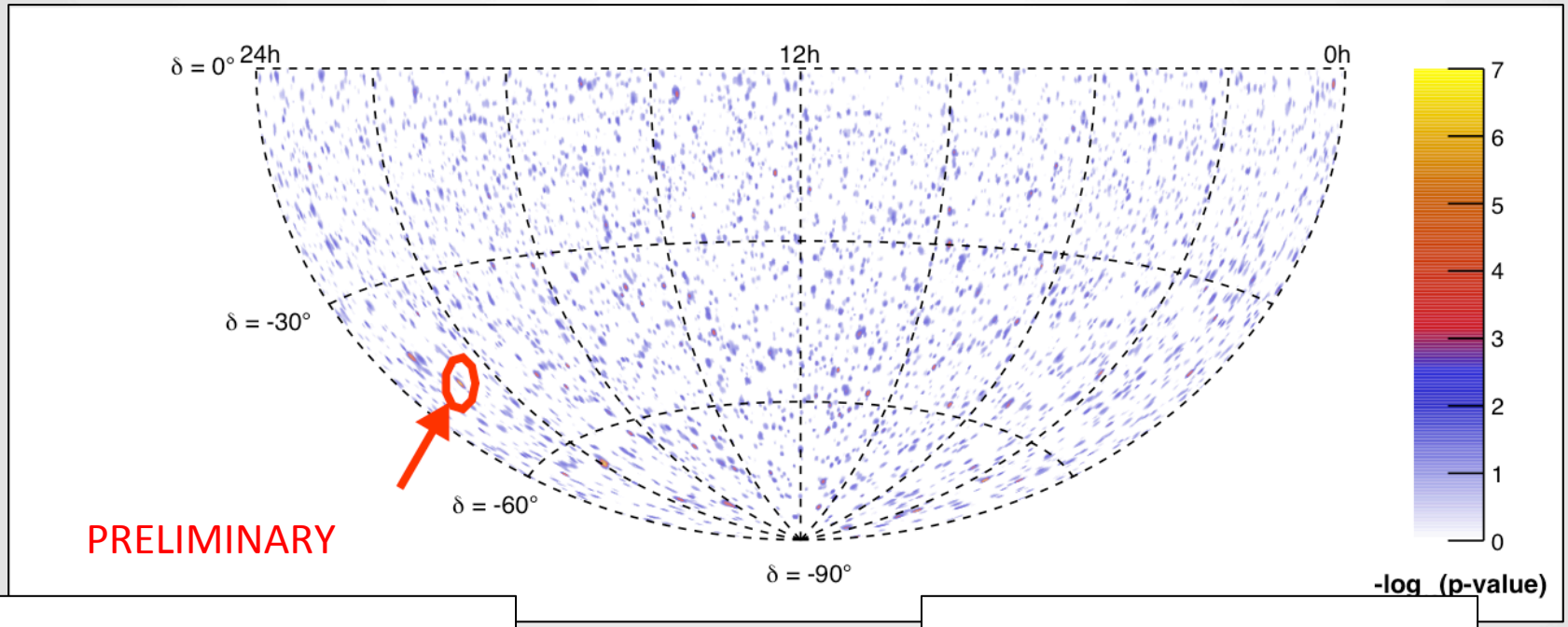
Candidate list search

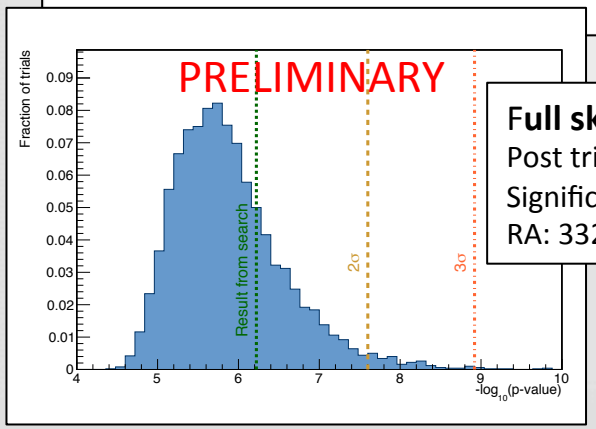
- List of 40 known sources which are neutrino source candidates.
- SNRs, AGNs, …
- Free parameter: n_s

Calculation of p-value:

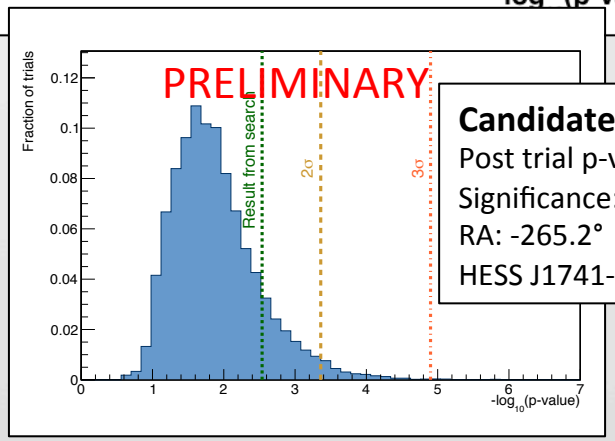
- TS distributions of only background calculated in steps of 1° in declination
- TS obtained for a given source is compared to the corresponding TS distribution according to its declination.

Results





Full sky search:
Post trial p-value: 0.24
Significance: 0.7σ
RA: 332.8° DEC: -46.1°

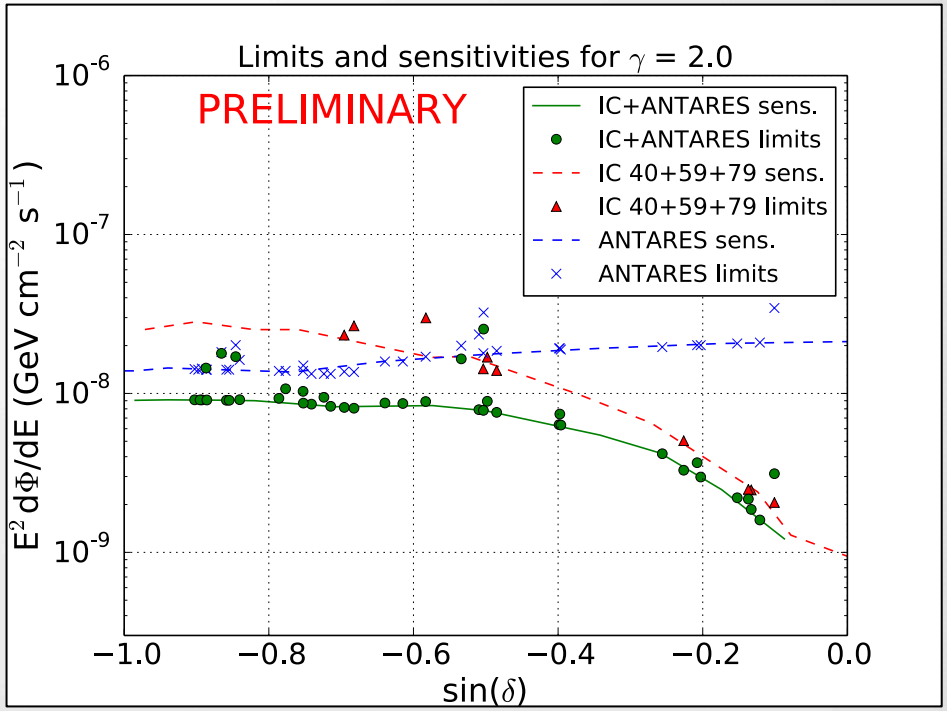


Candidate list:
Post trial p-value: 0.11
Significance: 1.2σ
RA: -265.2° DEC: -30.2°
HESS J1741-302

Results: Limits

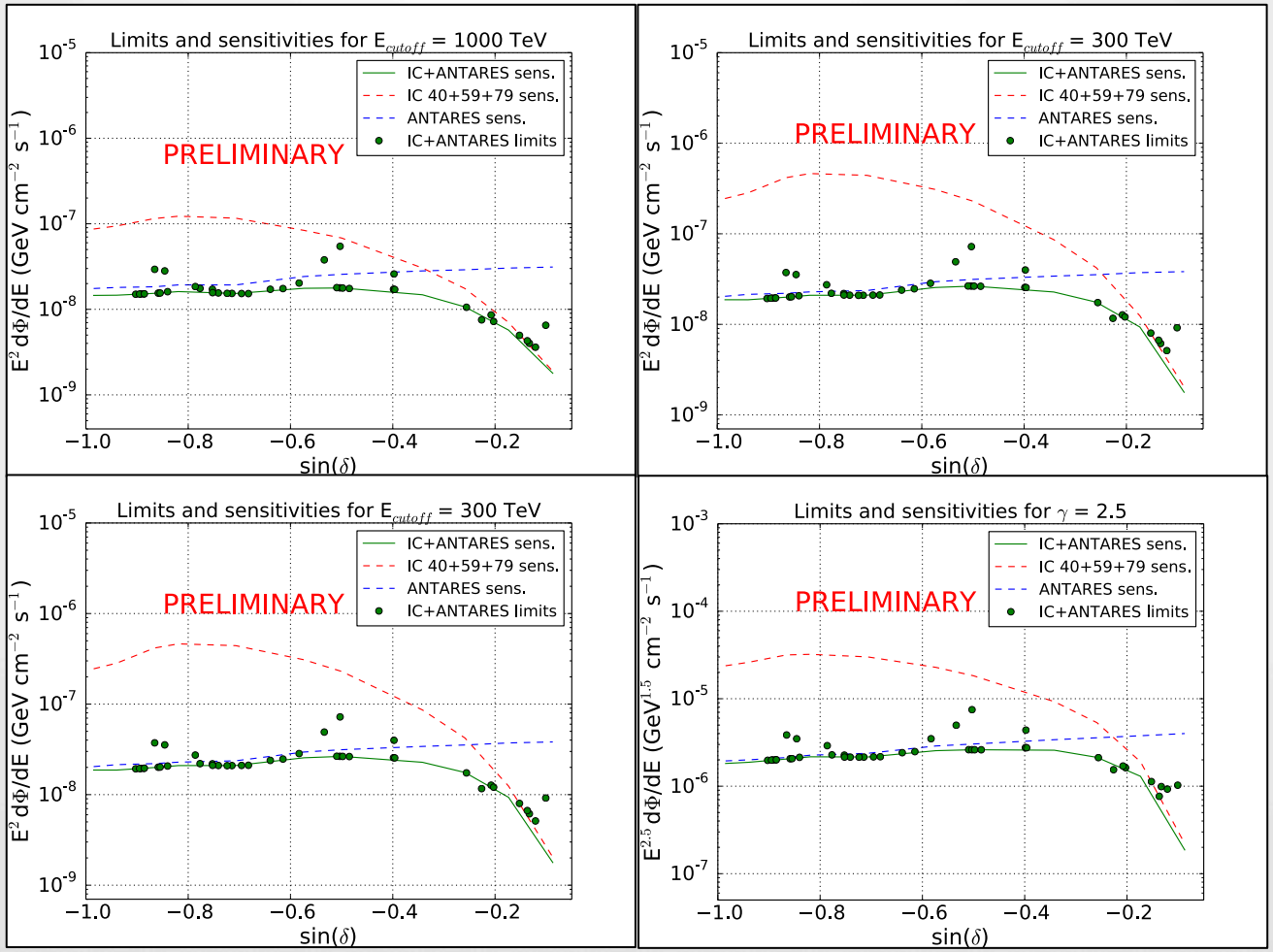
Source name	sin(δ)	n_s	Pre-trial p-value	Flux limit*
HESSJ1741-302	-0.50	1.6	0.003	2.5
3C279	-0.10	1.1	0.05	0.3
PKS0548-322	-0.53	0.9	0.07	1.6
ESO139-G12	-0.87	0.8	0.07	1.8
HESSJ1023-575	-0.85	0.8	0.08	1.7
RCW86	-0.88	0.2	0.11	1.4

*Flux limit in units of 10^{-8} GeV cm^{-2} s^{-1}



90% CL sensitivities and limits for an E^{-2} source spectrum using the Neyman method.

Results: Limits



Conclusions

- First combined search over the Southern Hemisphere with the ANTARES and IceCube neutrino telescopes.
- Sensitivity for point sources up to factor 2 improvement
  - Improvement varies depending on the source declination and assumed source spectra
- No significant clusters have been found.
- Full sky search: Largest excess with 0.7σ significance (post-trial) at (α, δ) = (332.8, -46.1)
- Candidate list: Largest excess found for HESS J1741-302 with 1.2σ significance.