Searches for point-like sources of cosmic neutrinos with 11 years of ANTARES data

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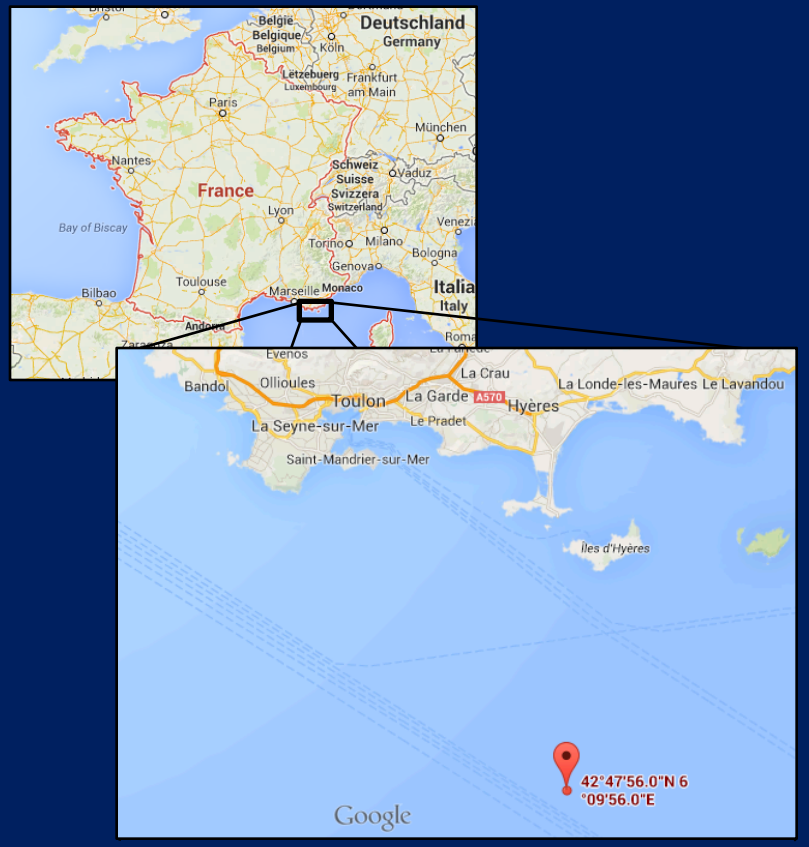
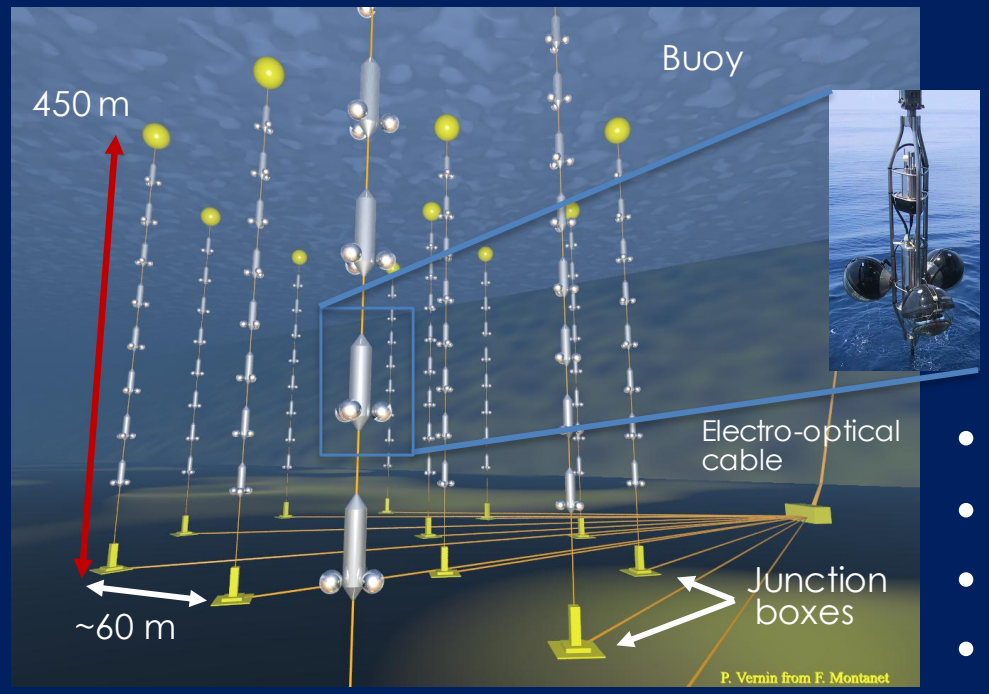
The ANTARES neutrino telescope

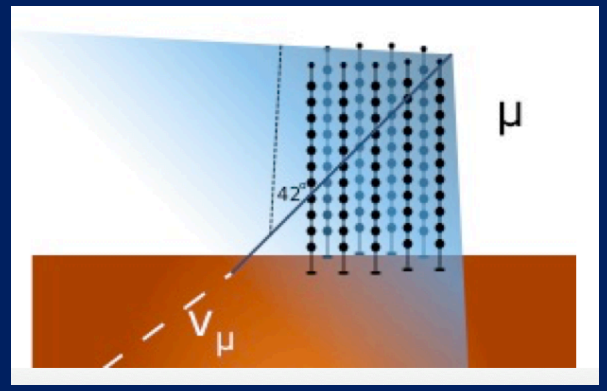
- First detection line installed in early 2006
- Completed in 2008
- 2475 m depth in the Mediterranean Sea
- 40 km offshore from Toulon



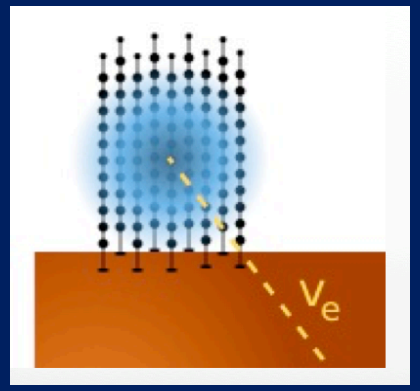


- Three-dimensional array of 885 PMTs
- 12 vertical lines, 25 storeys
- 3 PMTs per storey
- PMT facing 45° downwards

Data sample

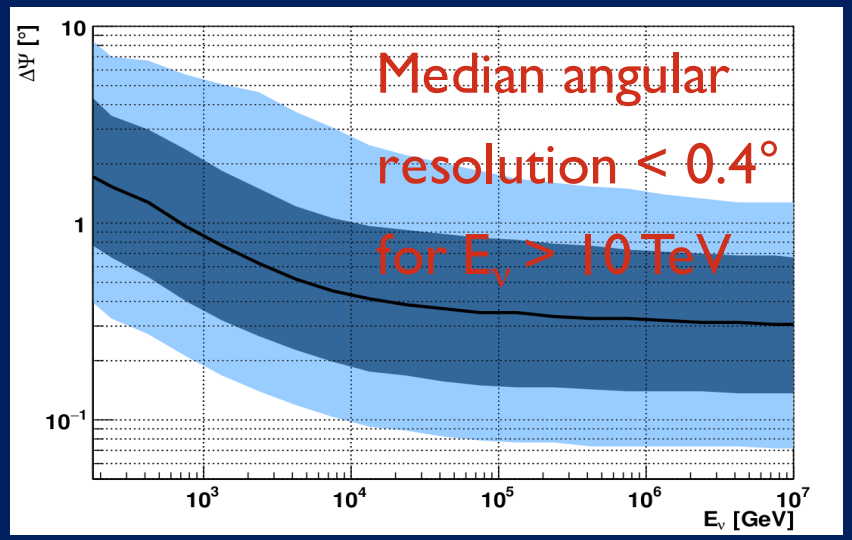


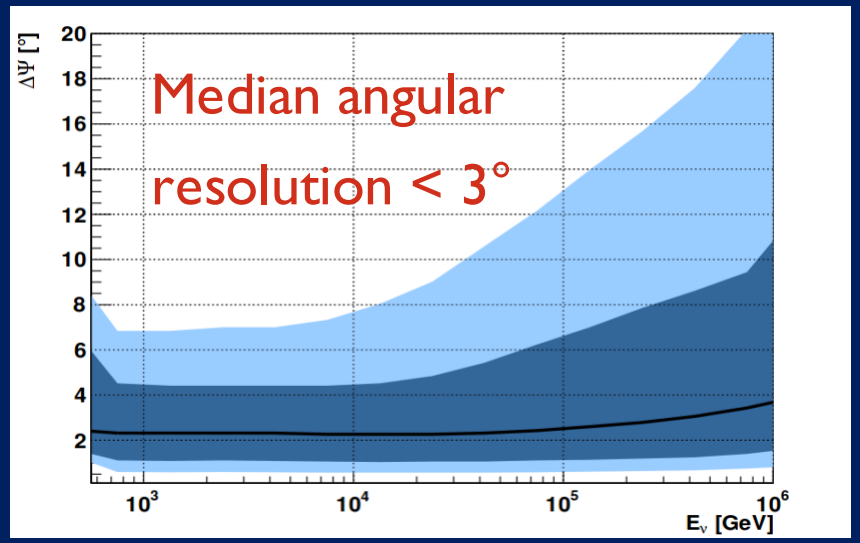
Track-like events:
ν_μ (ν_τ) neutrino
CC interaction near the detector



Shower-like events:
all neutrinos NC, ν_e,ν_τ CC interaction inside or very close to the detector

Period: Jan 29, 2007 to Dec 31, 2017
Livetime: 3136 days
Events: 8754 tracks and 195 showers
Same event selection as in the 9 years ANTARES point-source analysis
Phys. Rev. D96 (2017) 082001





Method: Unbinned Likelihood

Time
independent
approach

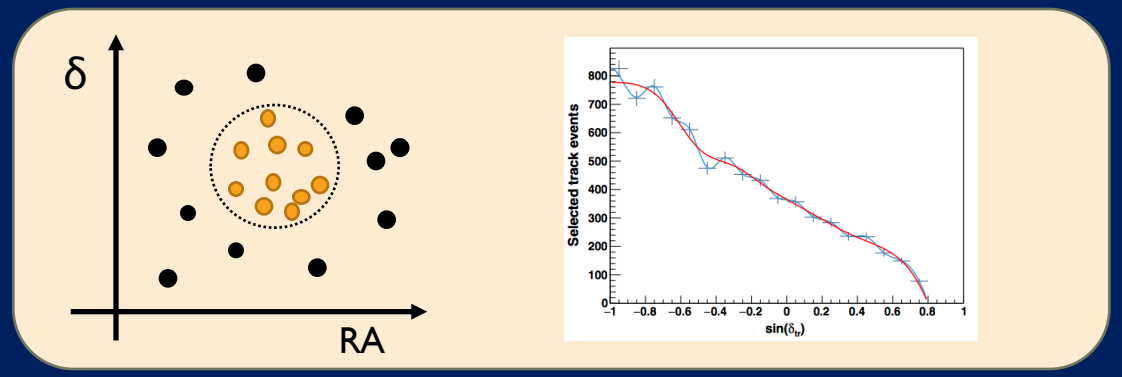
$$\log L_{s+b} = \sum_j \sum_{i \in j} \log\left[\mu_{sig}^j S_i^j + N^j B_i^j\right] - \mu_{sig}$$

J: sample (tracks or showers)
i: event in sample J

N: total # of events
μ_{sig}: # of fitted signal events

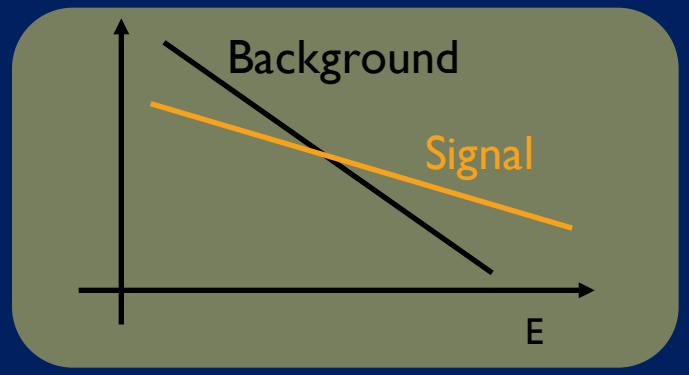
Signal PDFs:

$$S_i = S^{space} \cdot S^{energy}$$



Background PDFs:

$$B_i = B^{space} \cdot B^{energy}$$



Source spectrum hypothesis: E^{-2}

Method: Unbinned Likelihood

Time dependent approach

$$\log L_{s+b} = \sum_j \sum_{i \in j} \log\left[\mu_{sig}^j S_i^j + N^j B_i^j\right] - \mu_{sig}$$

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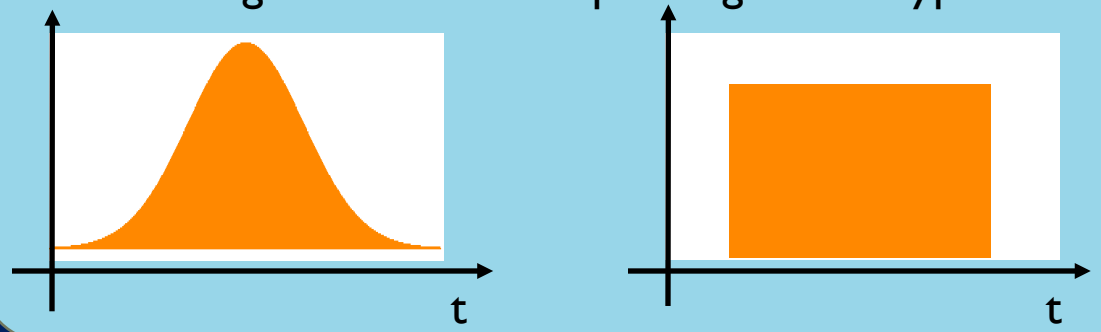
Signal PDFs:

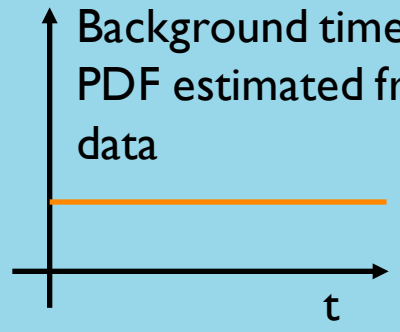
$$S_i = S^{space} \cdot S^{energy} \cdot S^{time}$$

Different Signal time PDFs depending on the type of search



Background PDFs:

$$B_i = B^{space} \cdot B^{energy} \cdot B^{time}$$



Searches

All-sky search

- Scan of the ANTARES visible sky in squares of 1°x1°
- Most significant cluster: cluster with lowest p-value
- Source location free to vary in the likelihood maximization within the 1°x1° boundaries

Candidate list searches

- Search for cosmic neutrinos from the location of preselected candidates
- Three candidate searches:

➢ 112 known astrophysical objects (TeVCat sources)
➢ 75 IceCube tracks (HESE, EHE, alerts)

➢ 54 IceCube tracks (HESE, EHE): space and time correlation

Eta Carinae

$(\alpha, \delta) = (161.27°, -59.68°)$

- Dedicated search for cosmic neutrinos from the stellar binary Eta Carinae assuming three different predicted neutrino spectra

TXS 0506+056

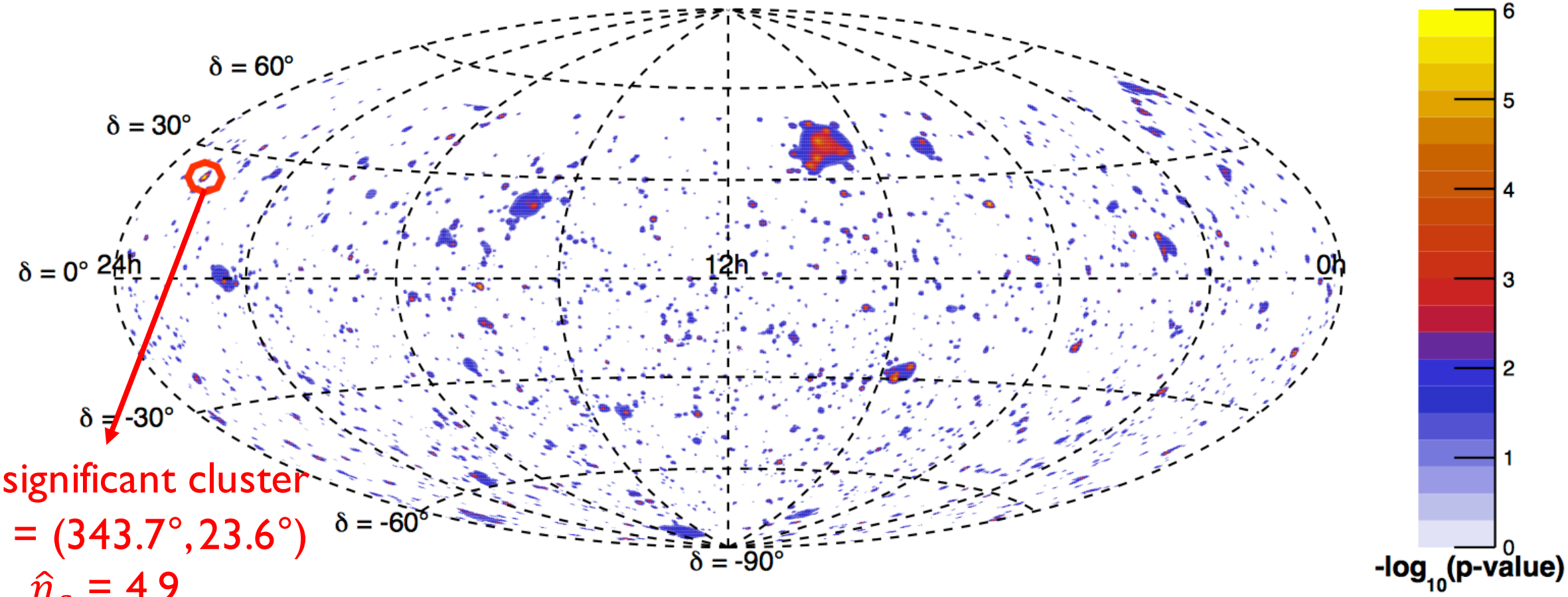
$(\alpha, \delta) = (77.36°, 5.69°)$

- Dedicated search for
  - ➢ steady emission
  - ➢ transient emission

from the direction of the blazar

Results: All-sky search

PRELIMINARY



Most significant cluster

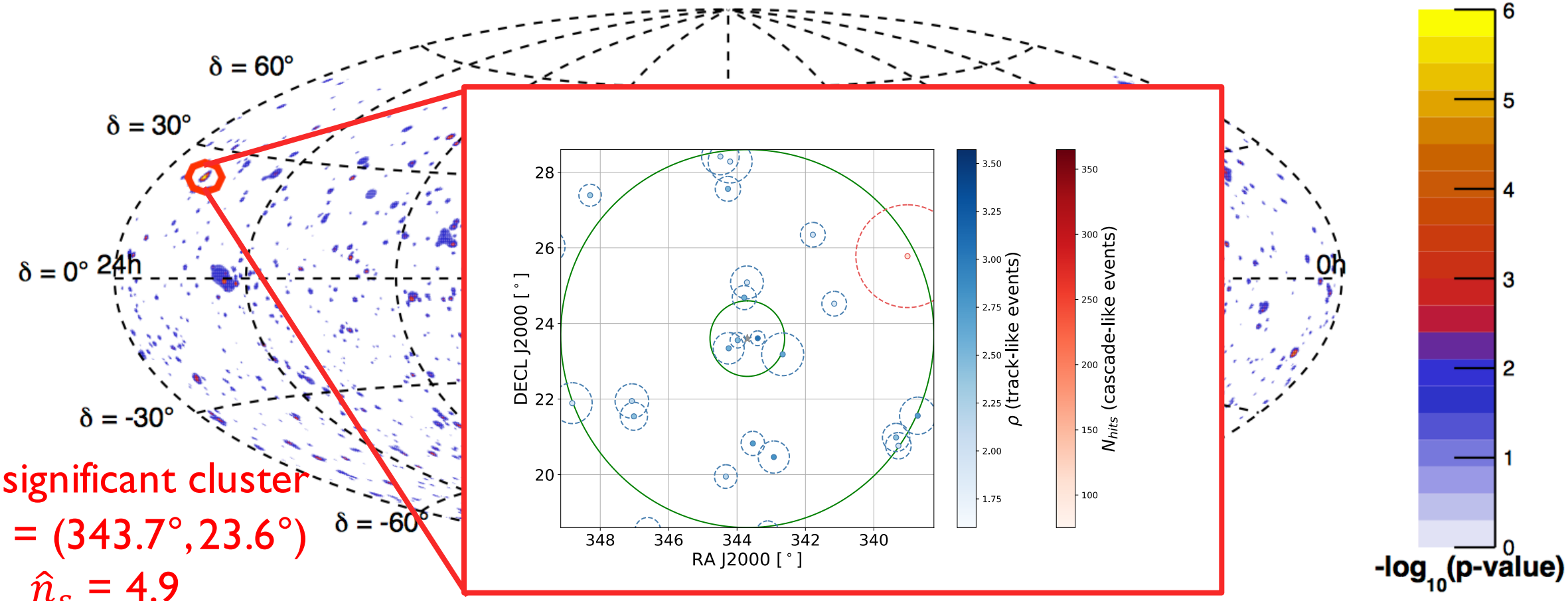
$(\hat{\alpha}, \hat{\delta})$ = (343.7°, 23.6°)

$\hat{n}_s$ = 4.9

23% (1.2σ) post-trial

Results: All-sky search

PRELIMINARY



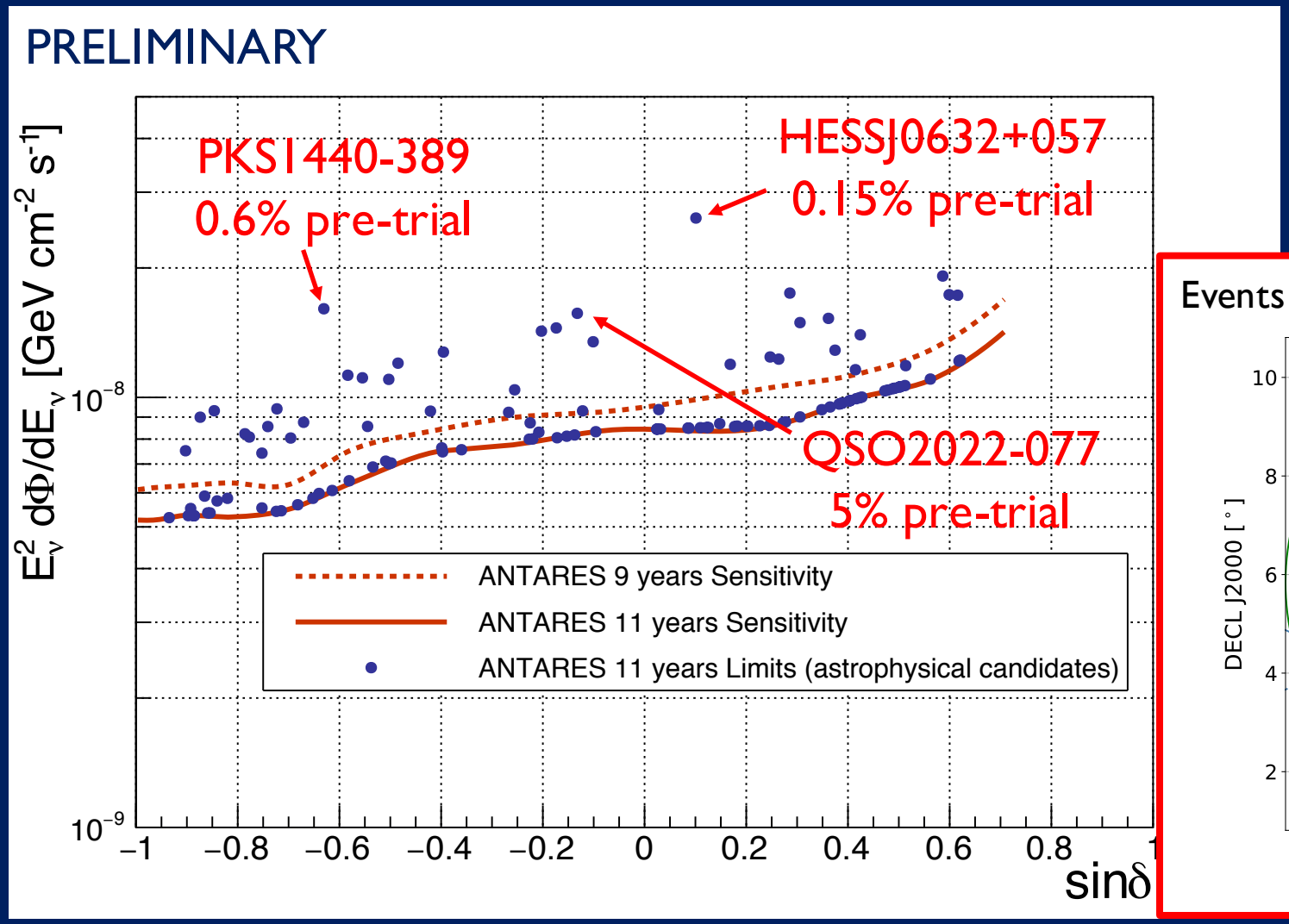
Most significant cluster

$(\hat{\alpha}, \hat{\delta}) = (343.7°, 23.6°)$

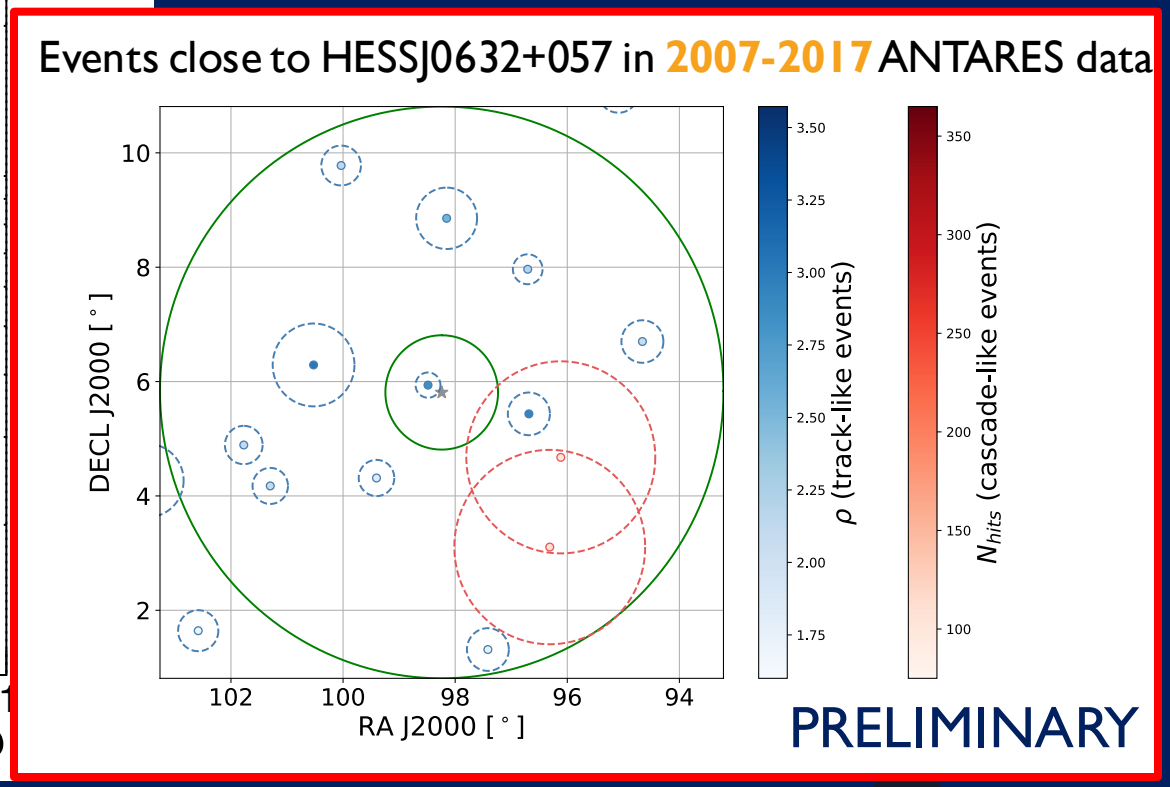
$\hat{n}_s = 4.9$

23% (1.2σ) post-trial

Results: Candidate list search

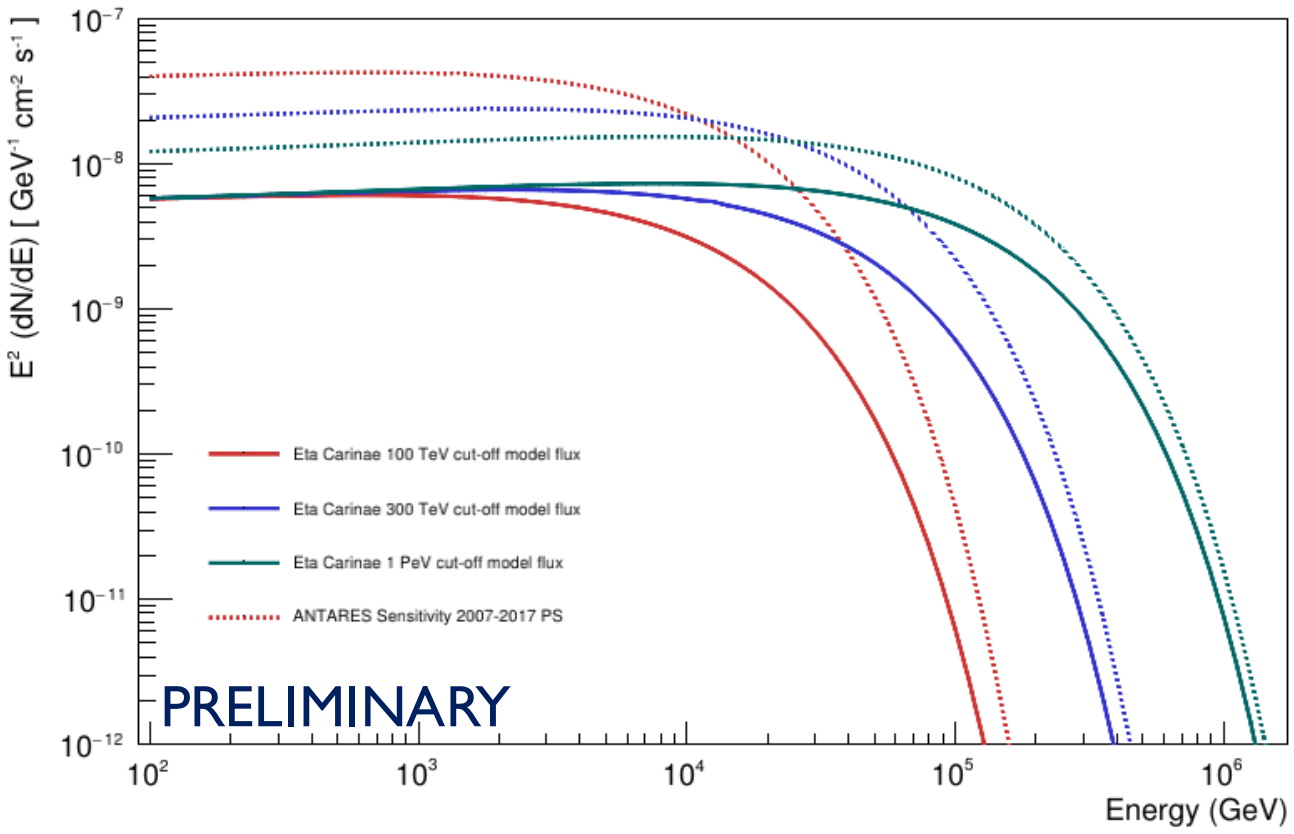


Most significant source
HESSJ0632+057
$\hat{n}_s = 2.7$
16% (1.4σ) post-trial



Results: Eta Carinae

Spectrum models according to **Phys.Rev. D96 (2017) no.12, 123017**



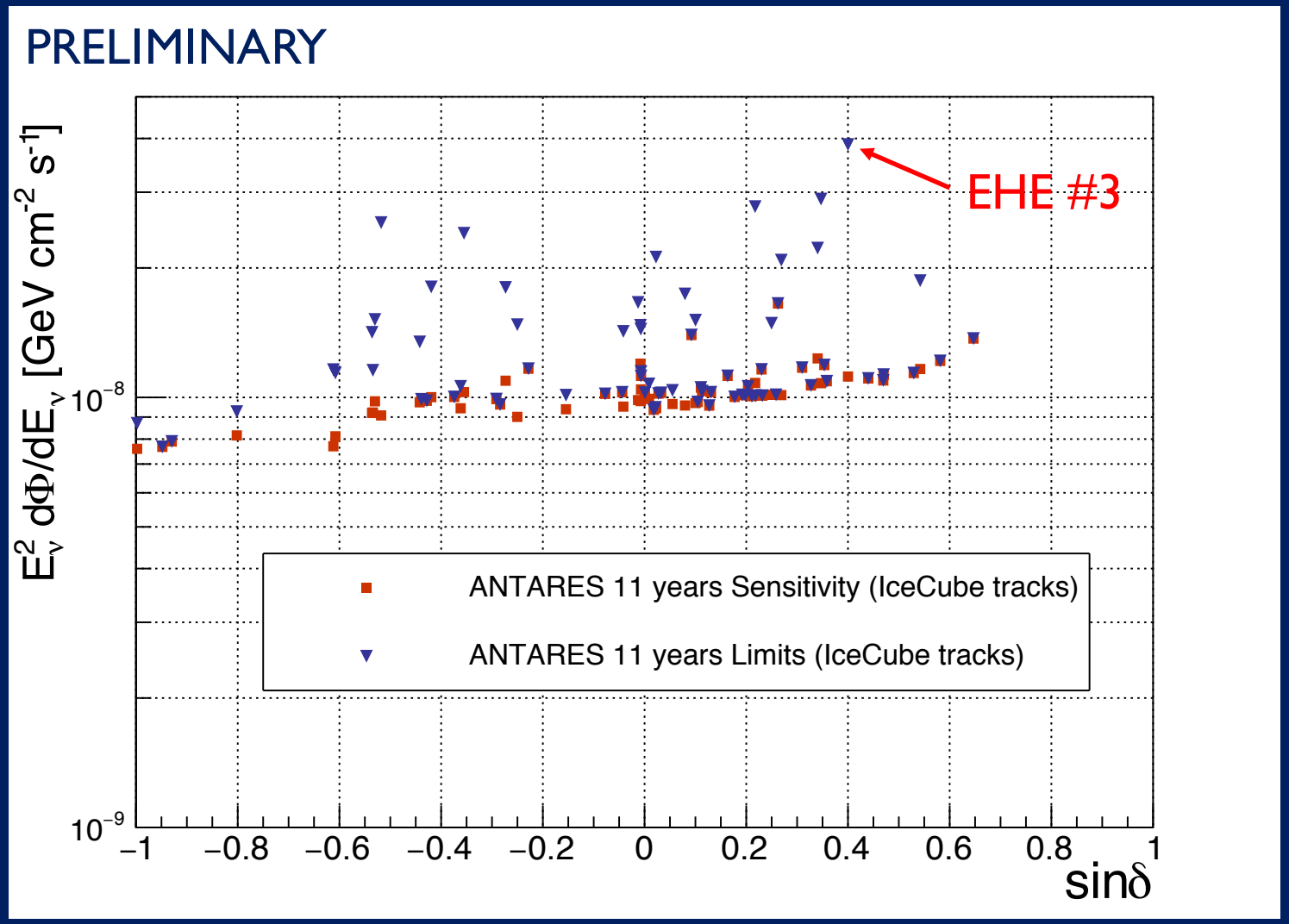
- Dedicated search at the location of Eta Carinae
- Neutrino spectrum of the form:

$$\frac{dN}{dE_\nu} = \Phi_0 (E_\nu)^{-2} \exp\left(-\frac{E_\nu}{E_{cut}}\right)$$

- Three values of the energy cut-off
- 90%C.L. Upper limits on the neutrino flux:

E_{cut}	$\Phi^{90\%C.L}/\Phi_0$
100 TeV	6.9
300 TeV	3.6
1 PeV	2.1

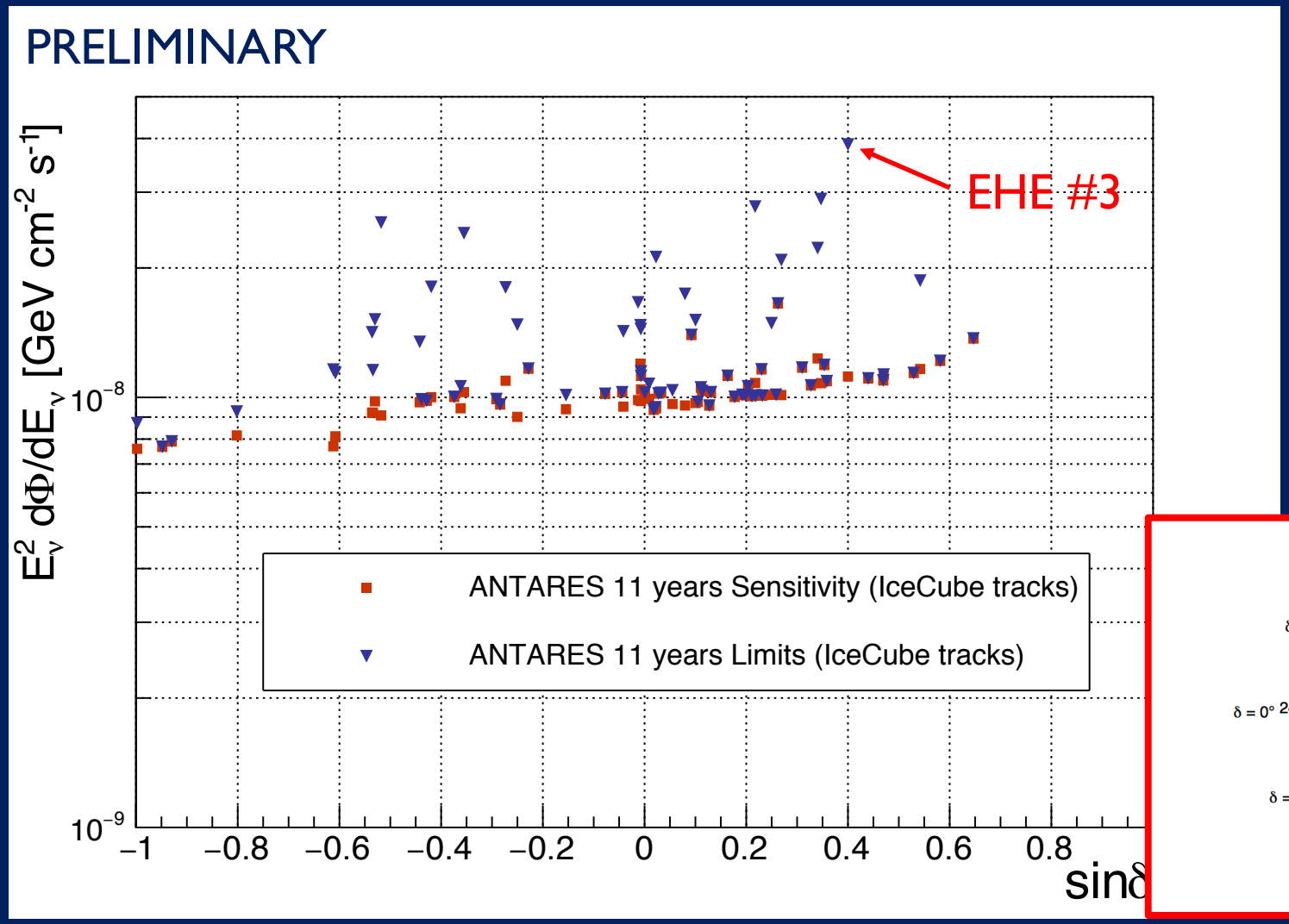
Results: IceCube tracks search



Most significant IceCube candidate
EHE ID3
$\hat{n}_s$ = 4.9
1.5% (2.4σ) post-trial

Best-fit coordinates:
$(\hat{\alpha}, \hat{\delta}) = (343.7°, 23.6°)$

Results: IceCube tracks search



Most significant IceCube candidate
EHE ID3
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1.5% (2.4σ) post-trial

Best-fit coordinates:
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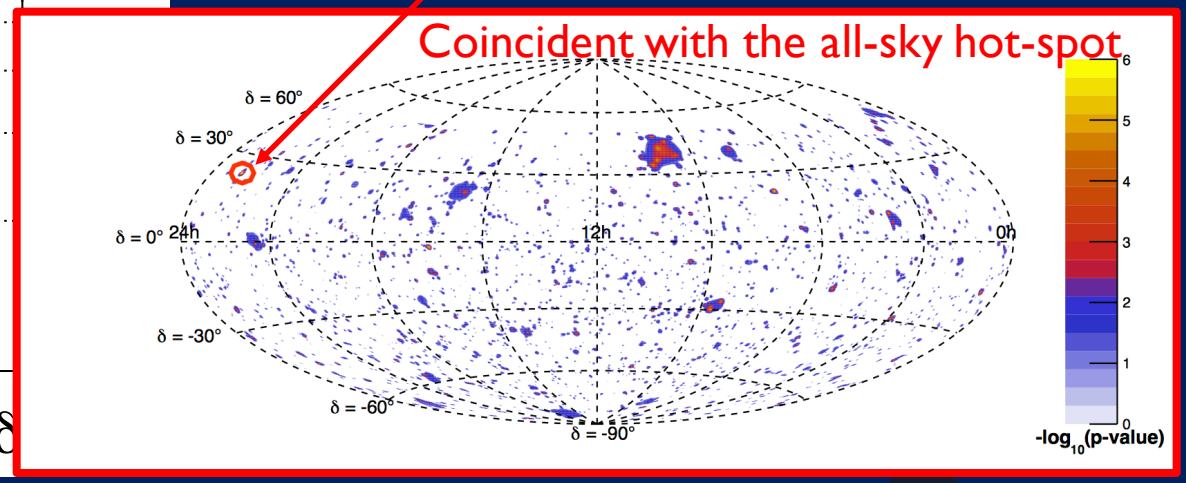
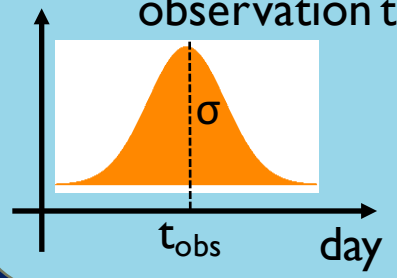


Astrophys.J. 879 (2019) no.2, 108

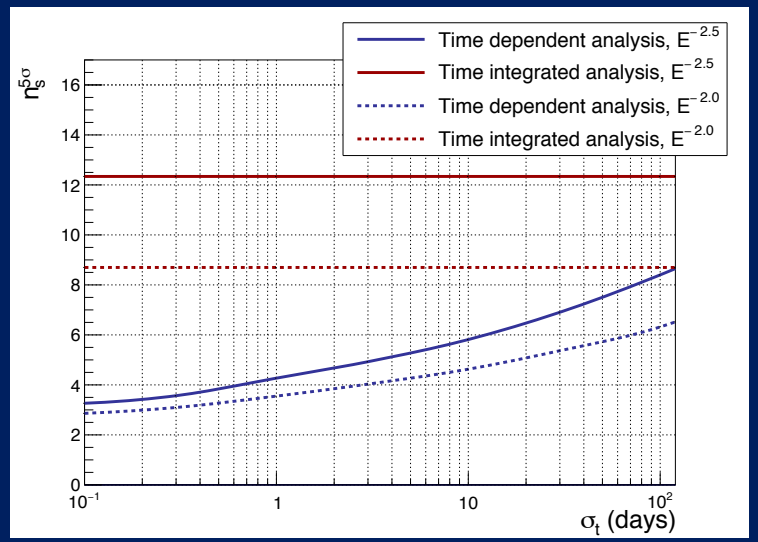
Time/Space correlation with IceCube tracks

$$\text{Likelihood } PDF = P^{space} \cdot P^{energy} \cdot P^{time}$$

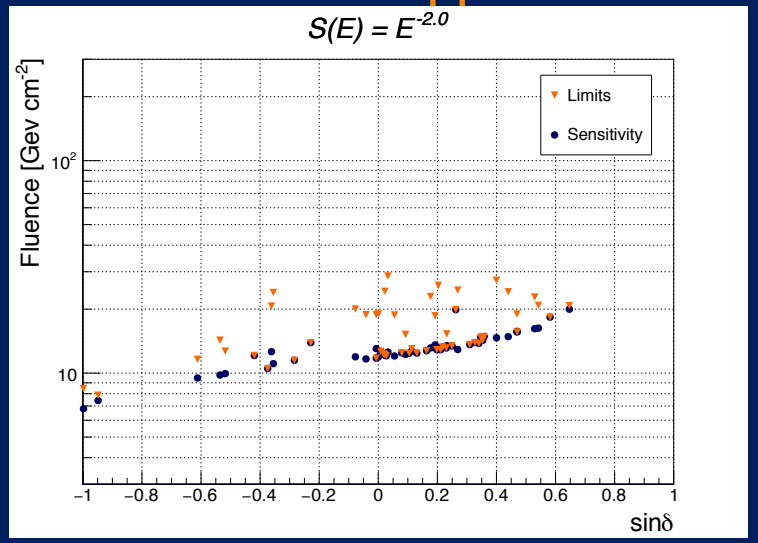
σ = flare duration
t_{obs} = IceCube track observation time

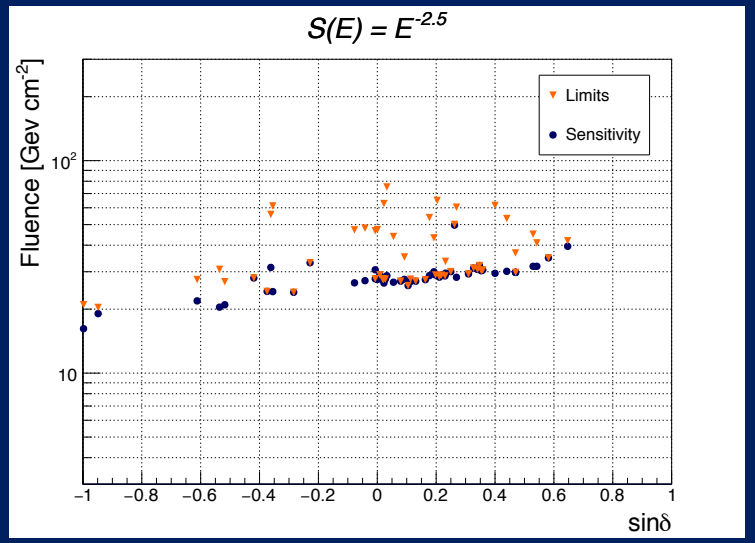


Flare duration additional free parameter
0.1 days ≤ σ ≤ 120 days



90% C.L. upper limits on the neutrino fluence:





Most significant candidate
EHE ID15
$\hat{n}_s$ = 2.2
$\hat{\sigma}_s$ = 120 days
3.7% pre-trial
90% post-trial

Search for steady emission from TXS 0506+056

- TXS 0506+056 added to the list of 106 neutrino source candidates analysed in the latest ANTARES point-source search (Phys. Rev. D **96**, 082001 (2017))

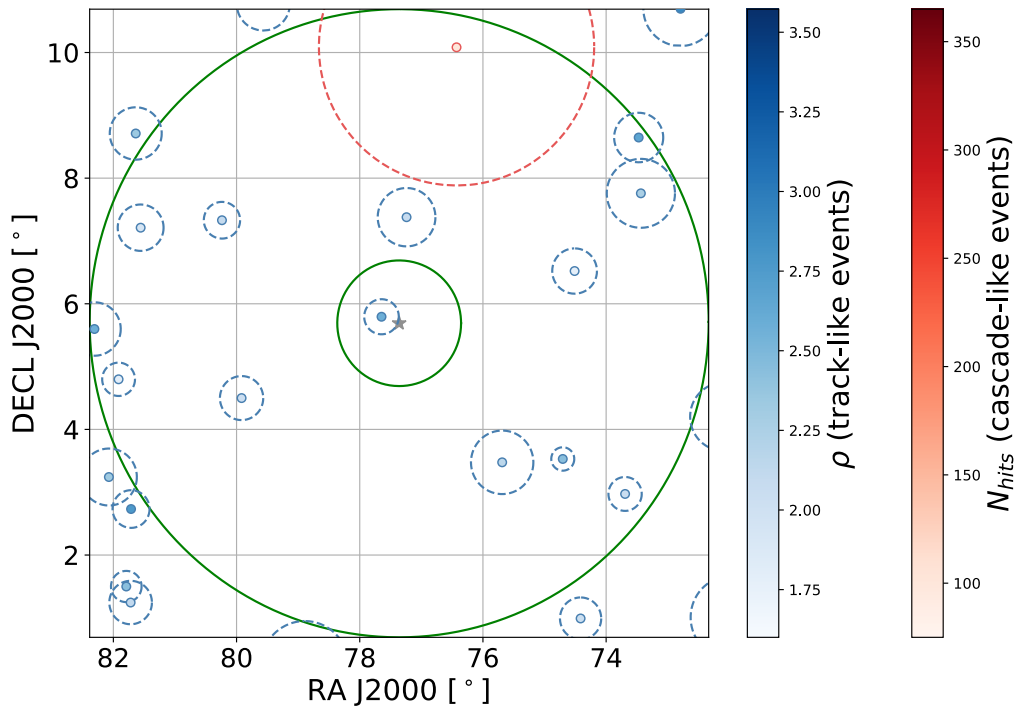
- TXS 0506+056 third most significant source

- Best fitted # of signal events μ_{sig} = 1.03
- 3.4% pre-trial p-value
- 87% post-trial p-value

- 90% C.L. flux upper limits on the flux:

Spectrum	$\Phi^{90\%}_{100\mathrm{TeV}}$ [10^{-18} GeV^{-1}cm^{-2}s^{-1}]
$E^{-2.0}$	1.6
$E^{-2.3}$	1.4
$E^{-2.5}$	1.0

Events close to TXS 0506+056 in 2007-2017 ANTARES data



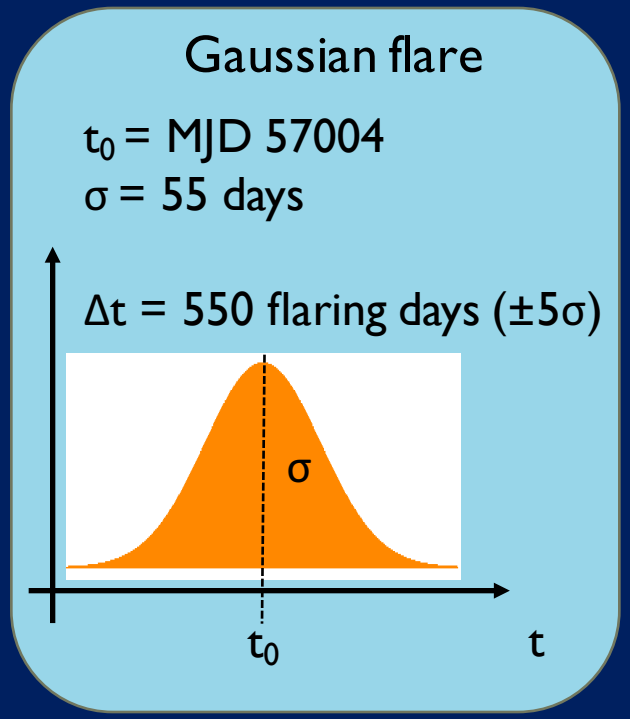
- Closest event at 0.3° from the source position
- Recorded on December 12, 2013
- Only 9% of ν events have higher estimated energy

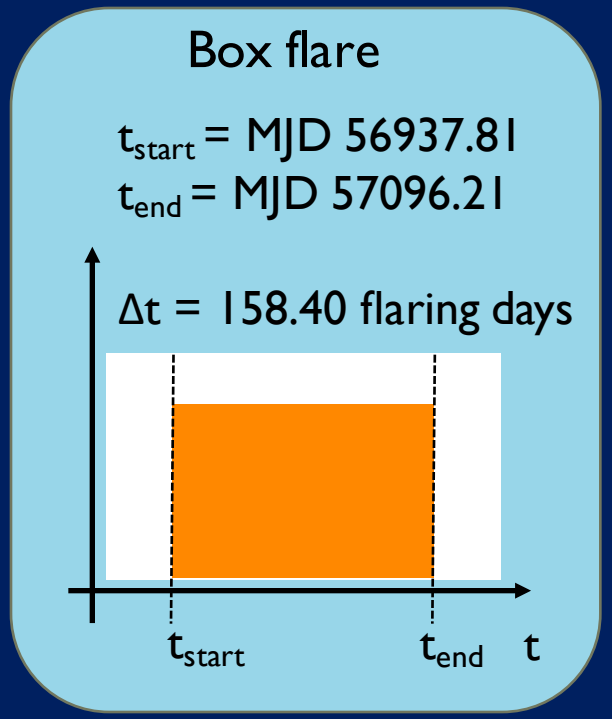
Search for transient emission from TXS 0506+056

$$PDF = P^{space} \cdot P^{energy} \cdot P^{time}$$

- Bursting period defined by the two profiles provided by the IceCube Collaboration:
  - Gaussian flare (centered on December 13, 2014)
  - Box flare (centered on December 26, 2014)

- No signal found during either of the considered flares
- 90% C.L. upper limits on the neutrino flux derived for the Gaussian-shaped period:





Spectrum	$\Phi^{90\%}_{100\mathrm{TeV}}$ [10^{-18} GeV^{-1}cm^{-2}s^{-1}]	5%-95% energy range
$E^{-2.0}$	4.6	2.0 TeV – 3.2 PeV
$E^{-2.1}$	4.4	1.3 TeV – 1.6 PeV
$E^{-2.2}$	4.2	1.0 TeV – 1.0 PeV

For the box-shaped period the flux normalization factors are a factor 3.3 higher

Summary

- Various searches for steady and transient point-like neutrino sources presented
- No significant point-like emission found, upper limits set on neutrino flux and fluence
- All-sky search: largest excess with 1.2σ post-trial at (α, δ) = (343.7°, 23.6°)
- Candidate list over astrophysical objects: largest excess with 1.4σ post-trial found for HESSJ0632+057
- Candidate list over IceCube tracks: largest excess with 2.4σ post-trial found for EHE ID3
- Candidate list over IceCube tracks (time-dependent): largest excess with 90% post-trial found for EHE ID15
- Upper limits on the neutrino flux and fluence from TXS 0506+056
- Upper limits on the neutrino flux for three proposed neutrino emission models for Eta Carinae

NEW PUBLIC DATA

Data set for the 2007-2017 ANTARES search for cosmic neutrino point sources

Available here:

http://antares.in2p3.fr/publicdata2017.html