

# Searches for diffuse fluxes of cosmic neutrinos with the ANTARES telescope

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On behalf of the ANTARES Collaboration

6th RICAP

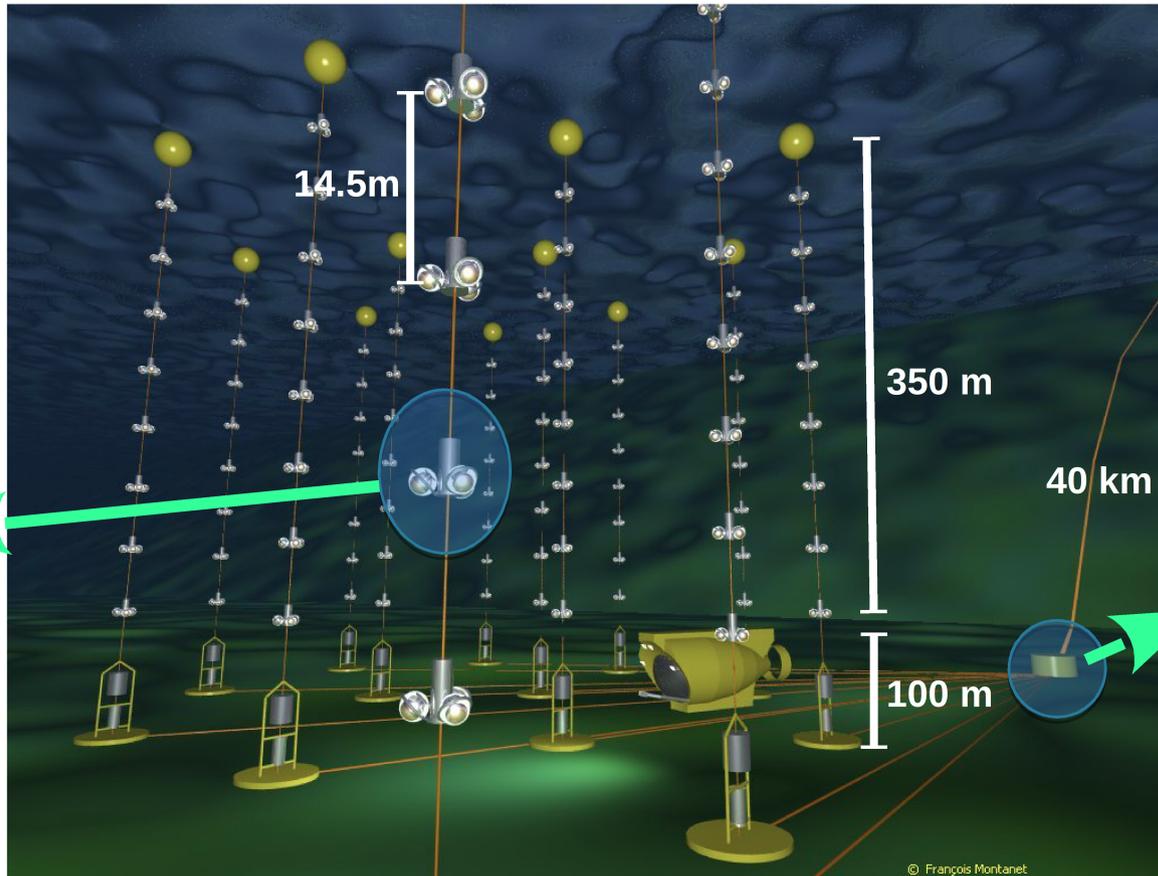
Frascati, 21<sup>st</sup> – 24<sup>th</sup> June 2016

# The ANTARES detector

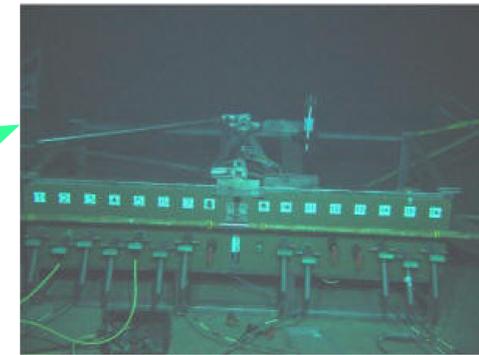
885 Optical  
Modules on 12 lines  
25 storeys/line  
3 OMs/storey



Storey: 3 10" PMTs,  
off-shore electronics



Shore station:  
Triggering and filtering



Junction Box

**Looks for all-flavour neutrino events, detecting Cherenkov light in the medium**  
**In the Mediterranean Sea (Toulon): Southern sky visibility in the  $\nu_{\mu}$  CC channel**  
**→ Galactic Centre and most of the Galaxy, with many  $\gamma$ -sources**  
**Depth of  $\sim 2500$  m: atmospheric muon background reduced**

# Why diffuse flux searches?

- Longstanding question:
  - What can ANTARES say about the IceCube signal?
- Many ways to address it:
  - All-sky analyses
  - “Special-regions”
    - Galactic Plane
    - Fermi Bubbles
  - Time dependent searches
    - Transient phenomena in the Galaxy translating to a diffuse excess

# All-sky searches

- The best fit to the IceCube observation is an isotropic power-law spectrum
- Different channels provide different best fits<sup>1</sup>
  - $\Gamma_{\text{IC}} = 2$  (upgoing tracks)  $\rightarrow \Phi_0^{1f}(100 \text{ TeV})^* \sim 0.9 \times 10^{-18}$
  - $\Gamma_{\text{IC}} = 2.5$  (All sky combined)  $\rightarrow \Phi_0^{1f}(100 \text{ TeV})^{**} \sim 2.2 \times 10^{-18}$
- ANTARES effective area in the Southern Sky at few tens of TeV is larger or equal with respect to IceCube
  - $\rightarrow$  IceCube-like events could be seen by ANTARES

<sup>1</sup> In units of  $(\text{GeV s sr cm}^2)^{-1}$

\* IC talk at Moriond 2016

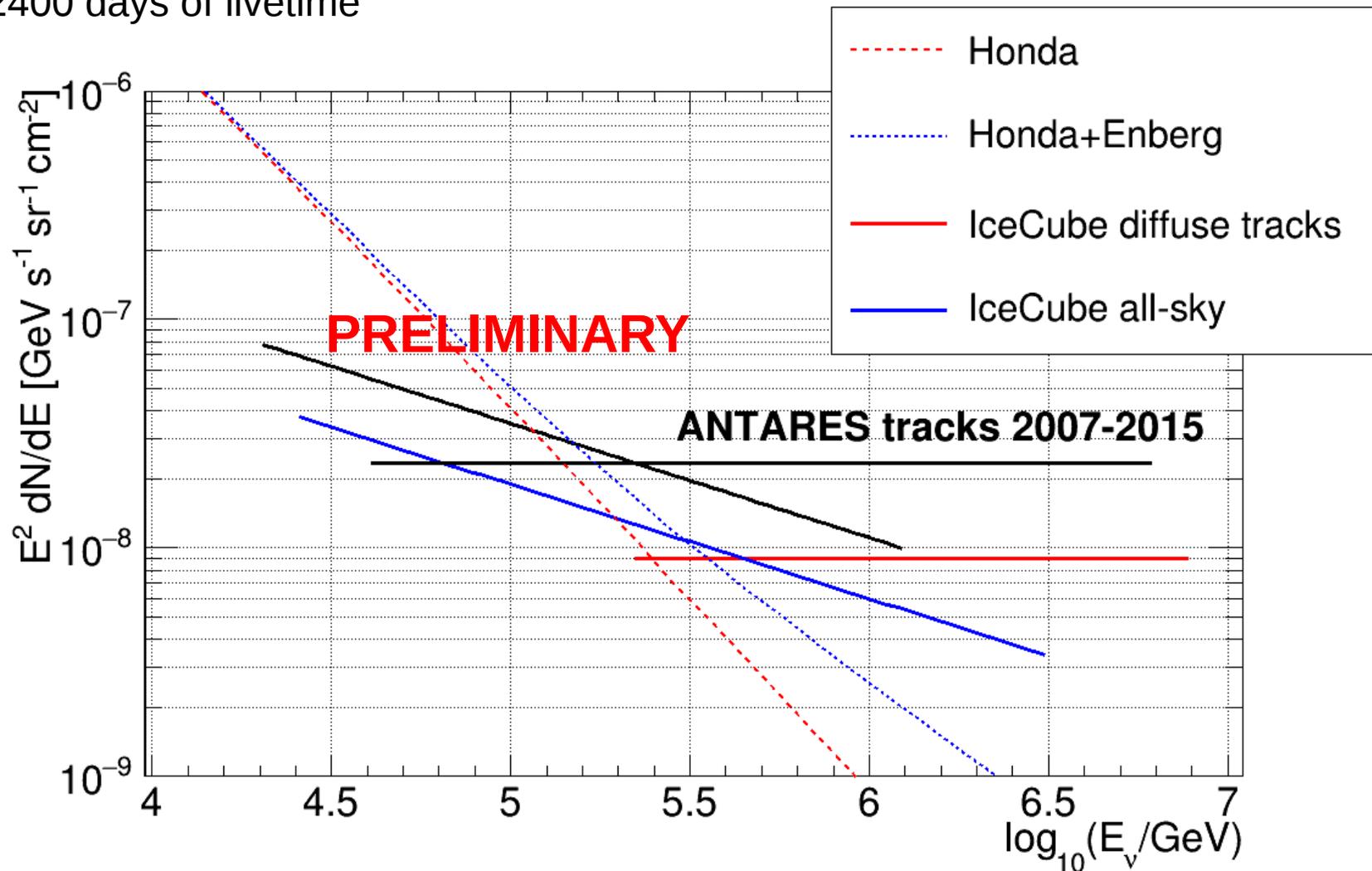
\*\* Astrophysical Journal 809, 98 (2015)

# Tracks analysis

- Exploiting the  $\nu_{\mu}$  CC channel
- Upgoing events and quality criteria to reject atmospheric muons background
- Energy cut to select cosmic neutrino candidates
- Analysis optimised on run-by-run Monte Carlo
  - Data are blinded until the analysis has been completely optimised
  - Cut chain defined on track quality parameters
    - Atmospheric muon contamination < 1%
  - Energy cut based on Artificial Neural Network
    - Emphasize the harder neutrino cosmic spectrum over the soft atmospheric contribution

# Sensitivity – tracks only

2400 days of livetime



90% C.L. sensitivity about 2 times larger than the IceCube best fits  
(depending on the spectral index)

# Gain with showers

- Exploiting all-flavour neutrino events
- Shower-like events are reconstructed with great accuracy by ANTARES
  - Worse angular resolution but better energy energy resolution with respect to tracks
    - Improve the discrimination power between atmospherics and cosmics
  - A safe rejection of atmospheric muons is feasible
- Adding showers can significantly boost the sensitivity

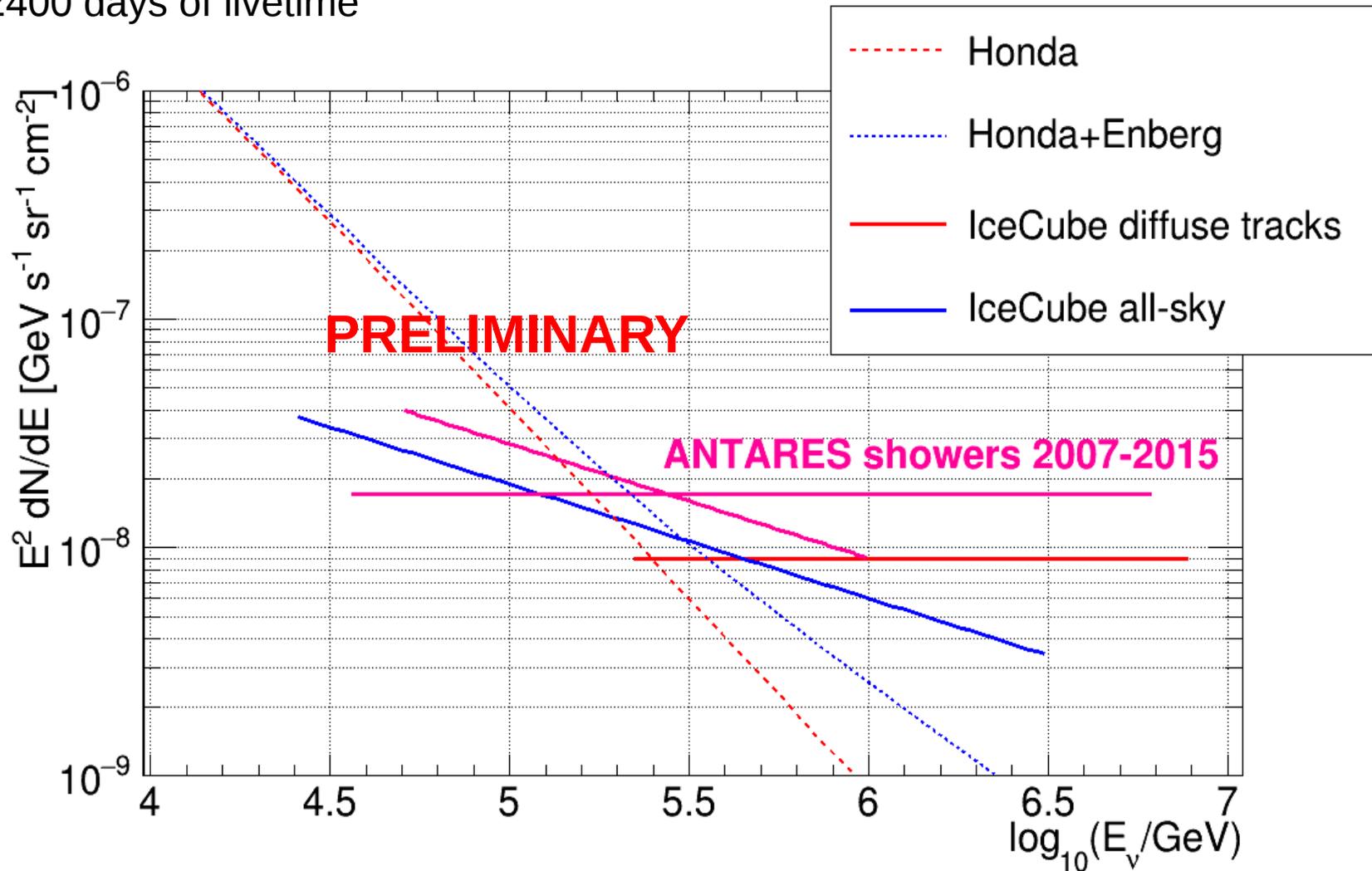
# Shower channel sensitivity

- Point-like sources search<sup>1</sup> selection chain exploited
- Best cut on the estimated energy is **30 TeV**
- 5 bkg and 1.5-2 (depending on spectral index) signal events over the analysed 1400 d of equivalent livetime
  - Corresponding sensitivity is 1.5 – 1.9 x IC signal for 2400 days (2007-2015 whole sample)
- $\Gamma_{IC} = 2$  (tracks)  $\rightarrow \Phi_0^{1f}(100 \text{ TeV})^* \sim 0.9 \times 10^{-18}$ 
  - **ANTARES (showers) sensitivity (2400 d)  $\Phi_0^{1f}(100 \text{ TeV}) = 1.7 \times 10^{-18}$**
- $\Gamma_{IC} = 2.5$  (Combined)  $\rightarrow \Phi_0^{1f}(100 \text{ TeV})^{**} \sim 2.2 \times 10^{-18}$ 
  - **ANTARES (showers) sensitivity (2400 d)  $\Phi_0^{1f}(100 \text{ TeV}) = 3.3 \times 10^{-18}$**

<sup>1</sup> Presented at ICRC 2015

# Sensitivity – showers only

2400 days of livetime



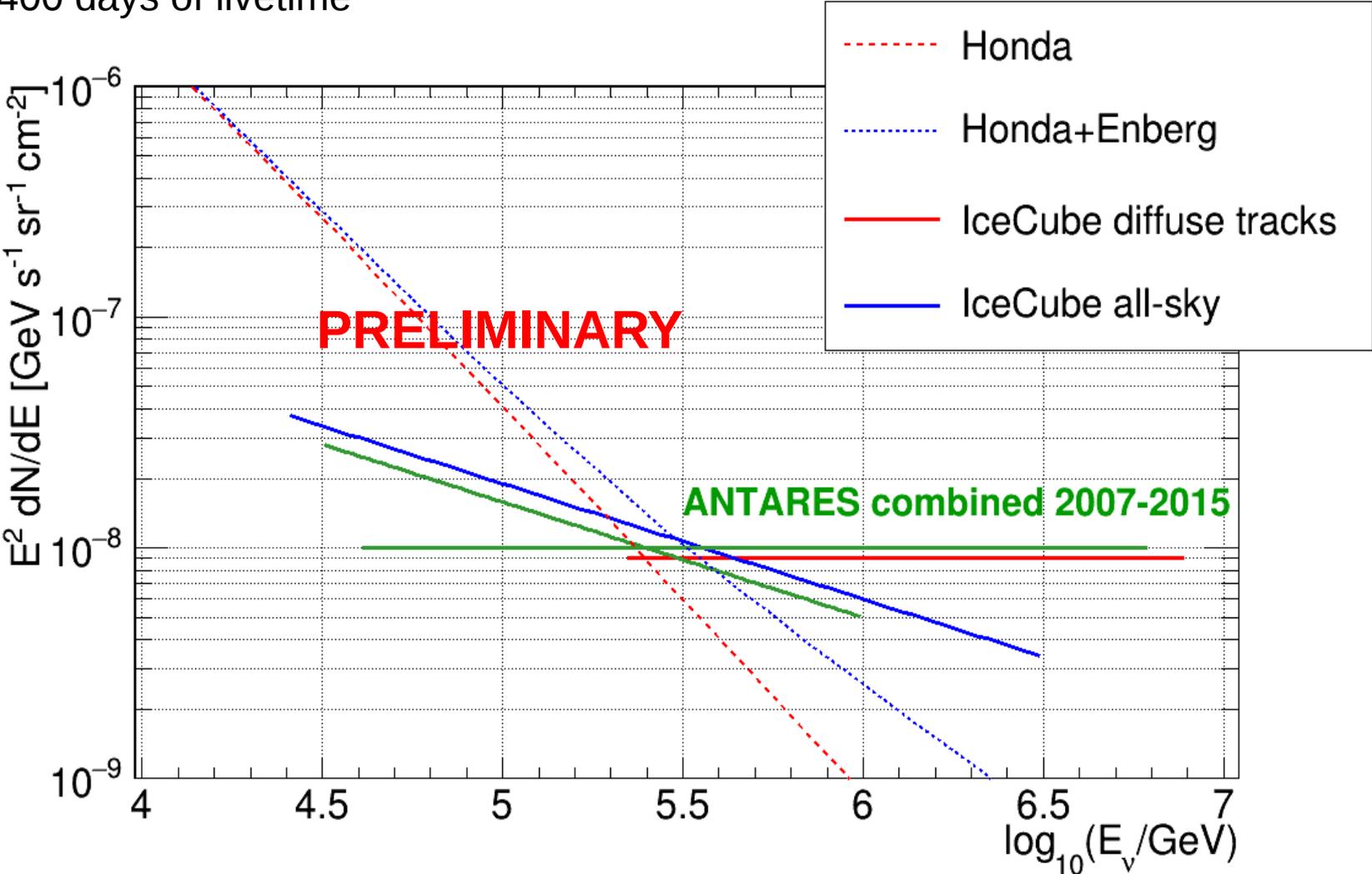
Sensitivity about 1.5 times larger than the IceCube best fits  
(depending on the spectral index)

# Shower channel unblinding

- **A first sample of 1405 days (out of 2007-2013 data) has been unblinded for the shower channel**
- Expectations from MC:
  - 5 background events (3 atmospheric muons, 2 atmospheric neutrinos)
  - ~2 signal events (depending on the spectral index, for all flavour)
- 7 events observed in data
  - Compatible with the expectations for background + signal
  - The excess is not significant, but more data are being analysed

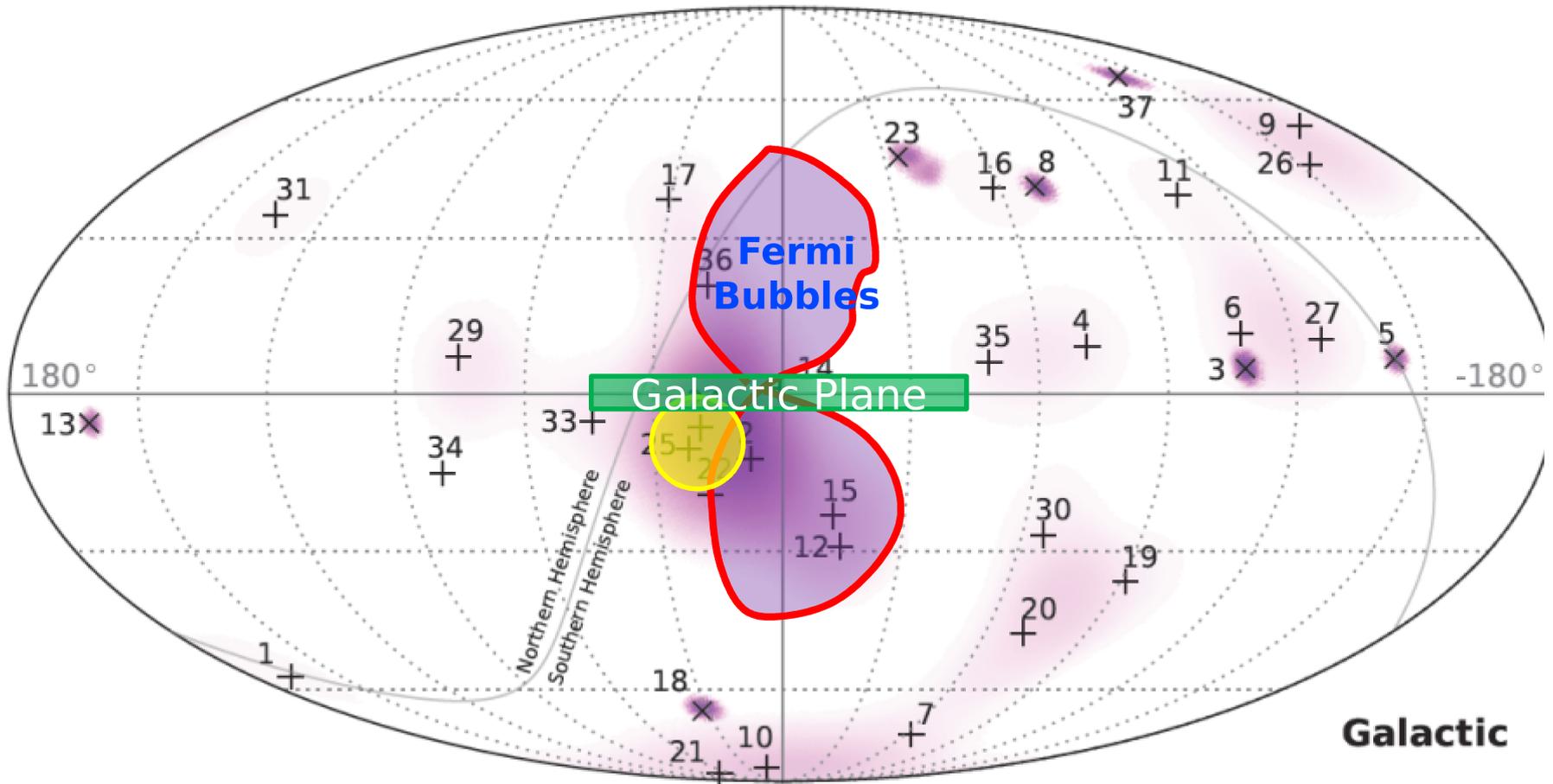
# Combined sensitivity

2400 days of livetime



The tracks and showers channels are completely disjoint by the definition of their individual event selection chains → gain in sensitivity by combining the two

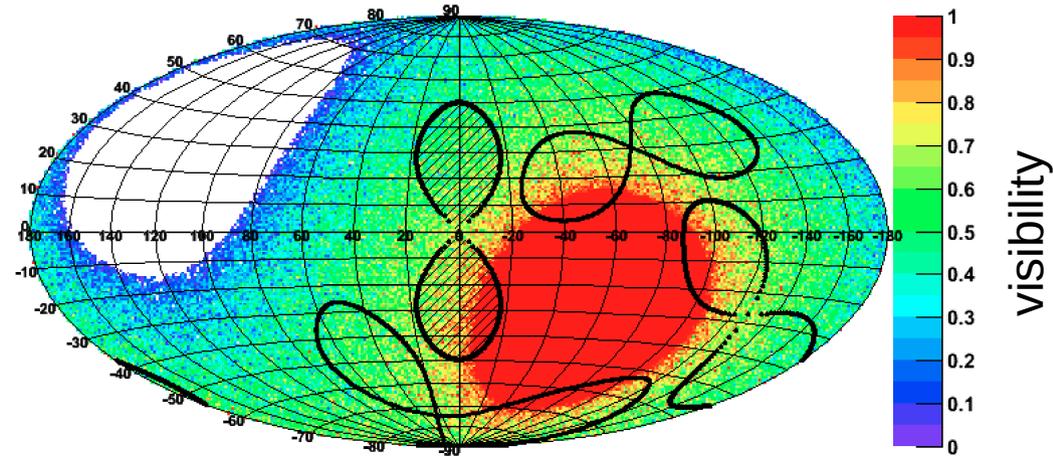
# Special regions



A certain amount of IC events could be produced from small sized areas of the sky, not resolved in the shower channel by IceCube  
Point source origin already excluded by ANTARES, thanks to its angular resolution for this region of the Sky

# Special regions – Fermi Bubbles

- On/Off zone search:
  - Bkg from 3 off-zones, where no signal is expected, same shape/efficiency/coverage
- Energy estimator cut:
  - Reject atmospheric events



On/Off zones - Gal. coordinates

2008-2013 data

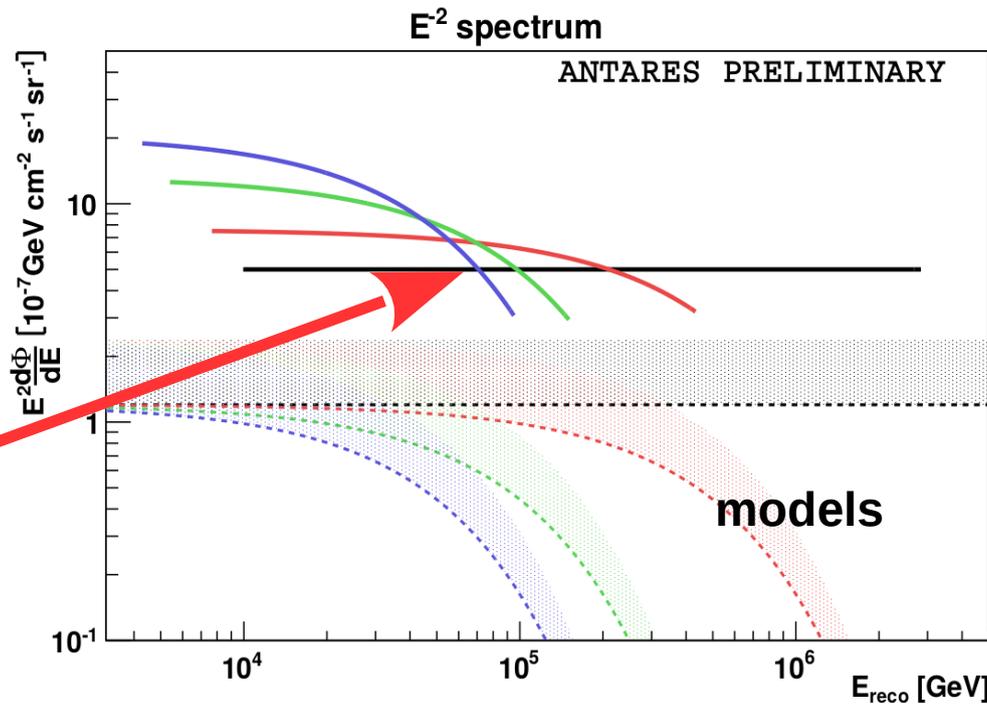
$N_{\text{obs}} = 22$

$\langle N_{\text{bkg}} \rangle = 13$

1.9 $\sigma$  excess



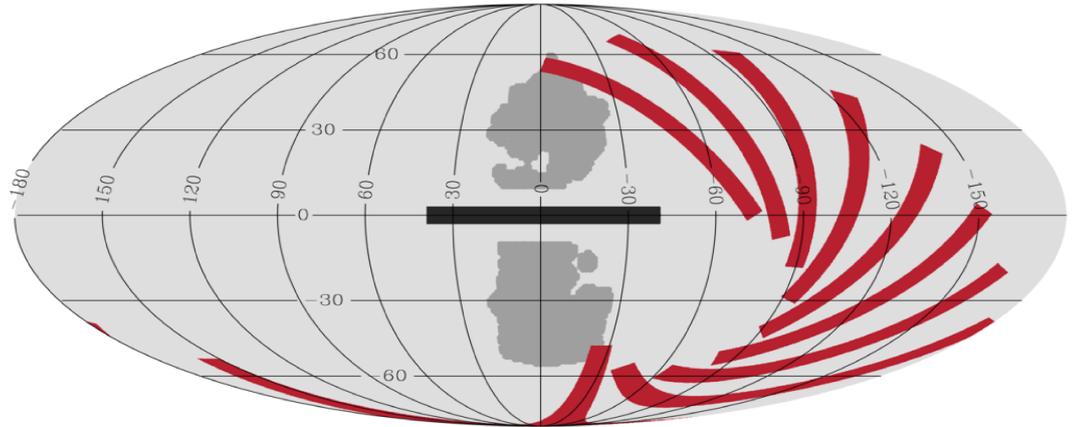
**Upper Limits**



Shower events being added also here and dataset expanded up to 2015

# Special regions – Galactic Plane

- On/Off zone search:
  - Bkg from 9 off-zones, where no signal is expected, same shape/efficiency/coverage
- Energy estimator cut:
  - Reject atmospheric events

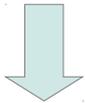


On/Off zones - Gal. coordinates

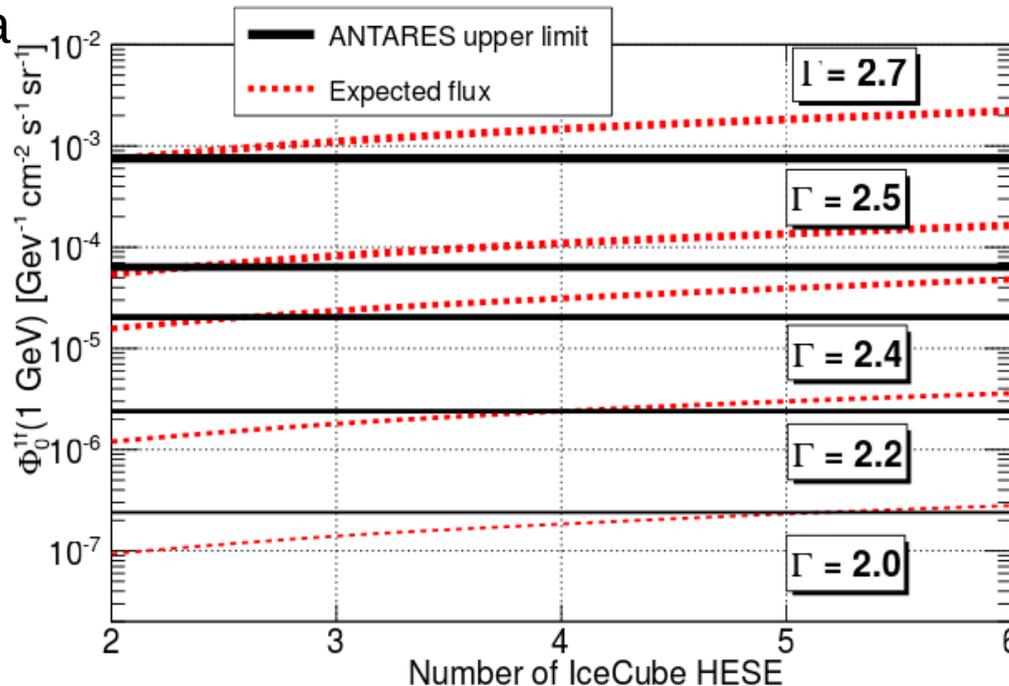
2007-2013 data

$$N_{\text{obs}} = 2$$

$$\langle N_{\text{bkg}} \rangle = 3.7$$



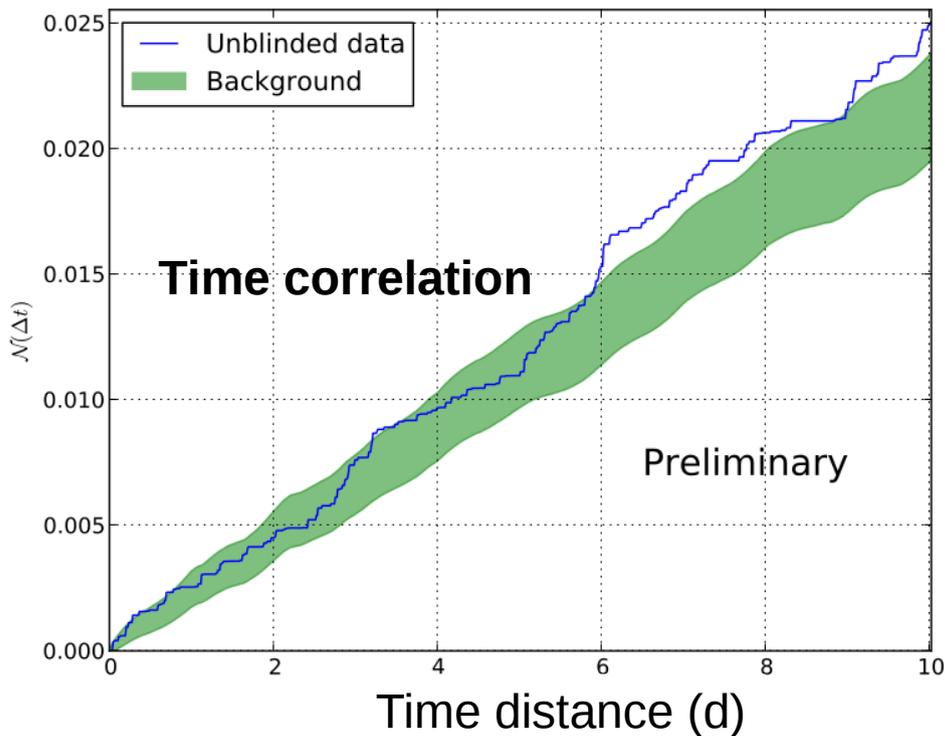
Underfluctuation



Shower events being added also here and dataset expanded up to 2015

# An insight on the Galactic Center

- Transient source at Sgr A\* might be the origin of a few IceCube events (*Bai et al. 2014*)
- Searched for time correlation between IceCube and ANTARES events close to the GC
- No significant correlation



Upper limits from null observation:  
exclude that 2 or more HESE  
originate from the region around the  
GC for flares ranging from 0.5 to 0.01  
days in duration for  $E^{-2.5}$  to  $E^{-2}$  spectra

# Conclusions and outlook

- Many efforts ongoing towards the observation of a cosmic signal analogous to that of IceCube
  - Cascades are a fundamental addition to improve the sensitivity
  - Data sample up to 2015 to be unblinded soon by many analyses
- Testing all-sky fluxes: sensitivities close to the cosmic signal
  - 2007-2013 show promising results
  - Data up to 2015 to be added and both tracks and showers to be unblinded
- Testing special regions:
  - Already put constraints on the origin of the IceCube flux from our Galaxy
  - More data to come and showers being added