

Highlights from the ANTARES Neutrino Telescope



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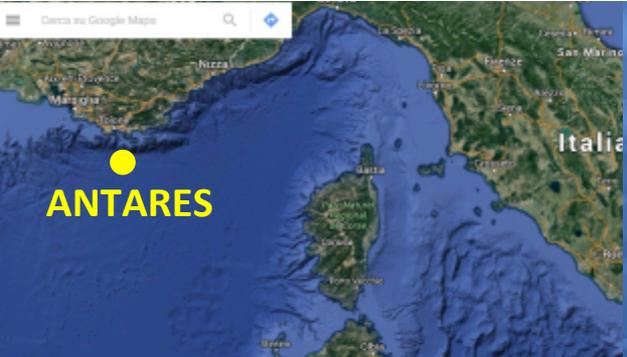


The ANTARES Neutrino Telescope

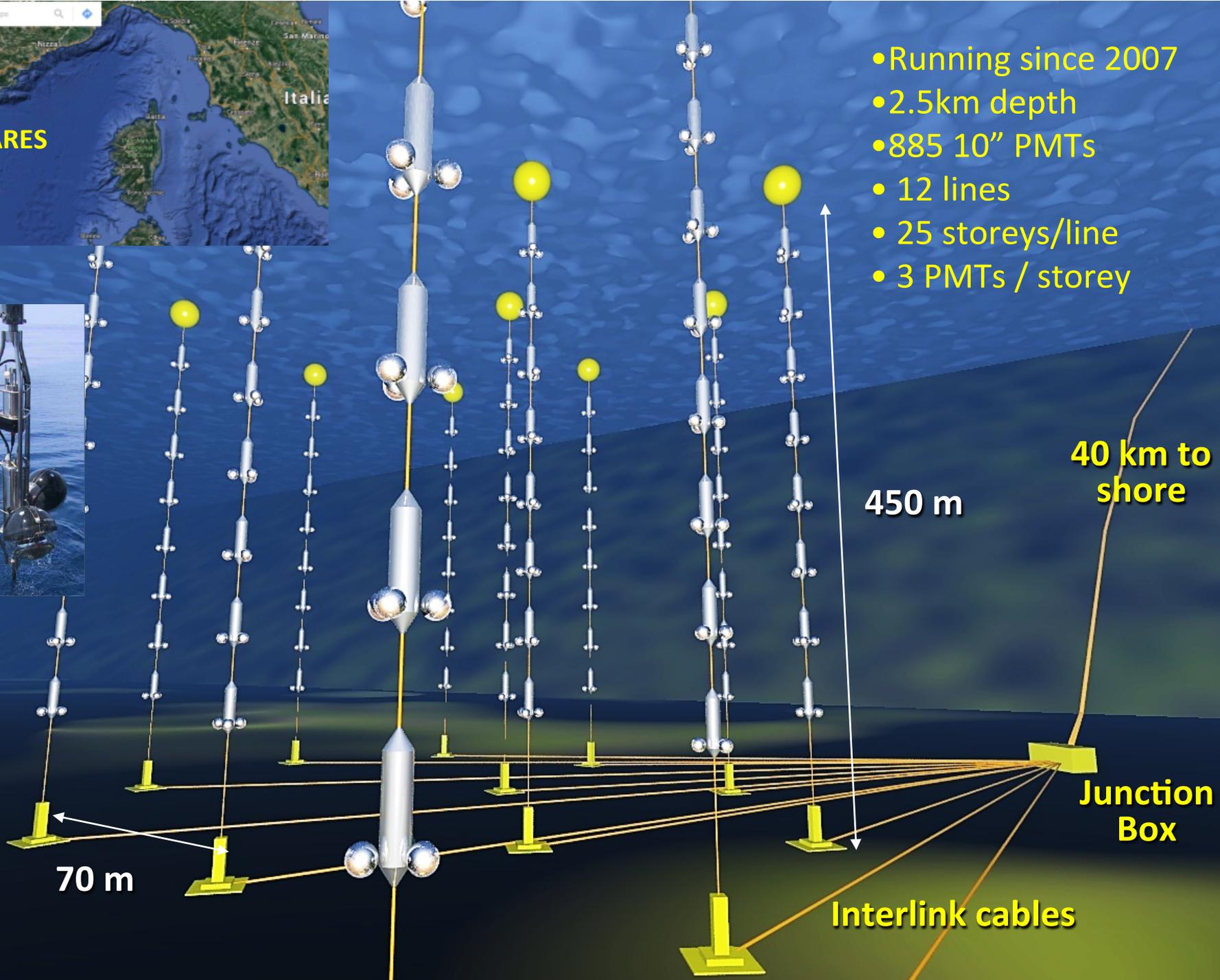
- Largest underwater neutrino telescope running since 2007 (complete 2008)
- Excellent view of galactic center region with high angular resolution
=> interesting constraints possible on Galactic component of IceCube signal

- **Neutrino astrophysics**
- **Multi-messenger observations**
- **Dark matter**
- *Atmospheric neutrinos (oscillations)*
- *Exotic particles search: nuclearites, monopoles*
- *Acoustic neutrino detection*
- *Earth and Sea sciences*

} *not covered in this talk*



- Running since 2007
- 2.5km depth
- 885 10" PMTs
- 12 lines
- 25 storeys/line
- 3 PMTs / storey

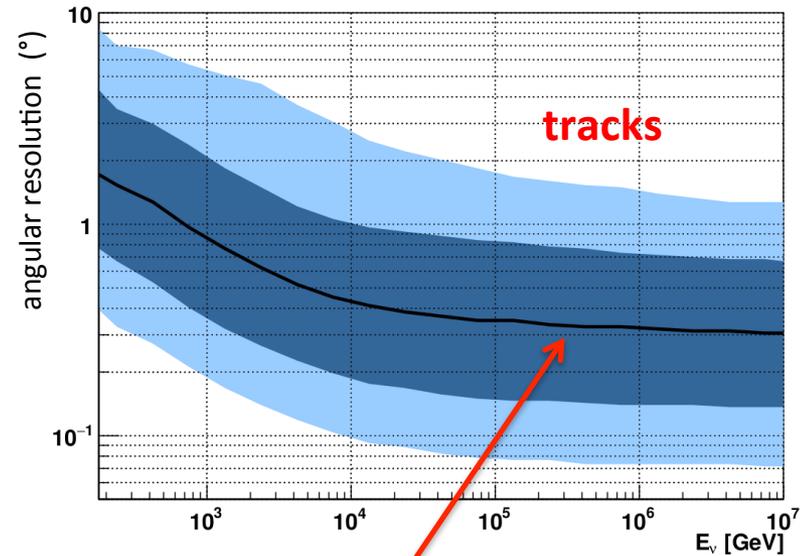


ANTARES performance

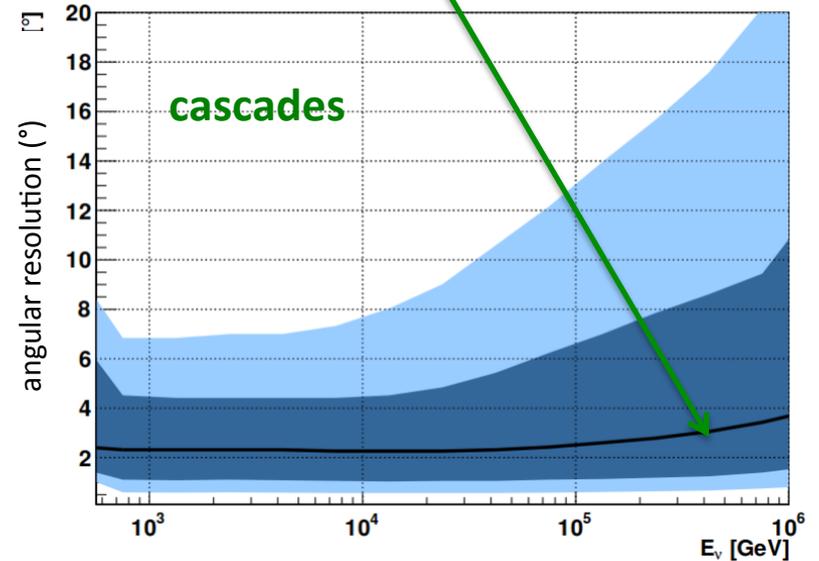
- Upgoing **track events** (ν_μ CC)
- Angular resolution $< 0.4^\circ$ for $E_\nu > 10$ TeV
- 90% purity

- Upgoing **cascade events** (ν_e/ν_t CC, NC)
- Angular resolution $< 3^\circ$
- Energy resolution for ν_e CC better than 10%

Angular resolution vs E_ν



median resolution



All flavour point source search

- 2007-2015(2424 days):
7629 tracks, 180 cascades
- Unbinned all-sky search
- 103 Candidate sources (including
13 IceCube HESE tracks)

- No significant excess
- Best limits for part of Southern Hemisphere
- Excellent sensitivity for $E_\nu < 100$ TeV

PRELIMINARY

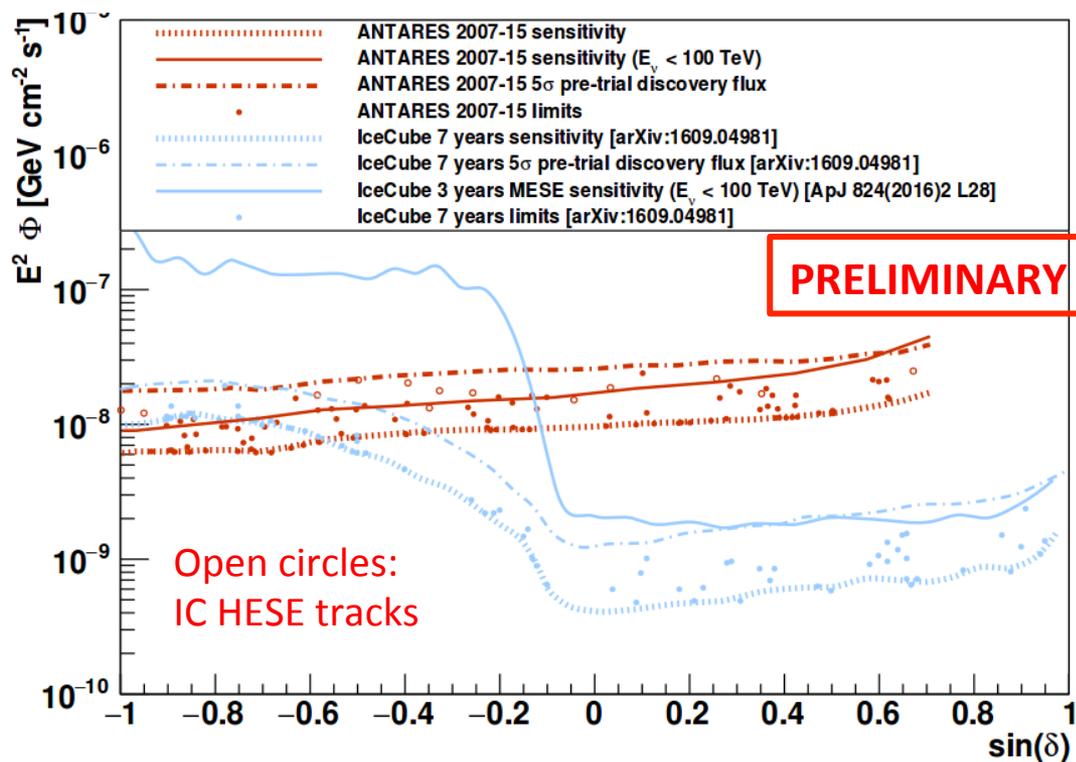
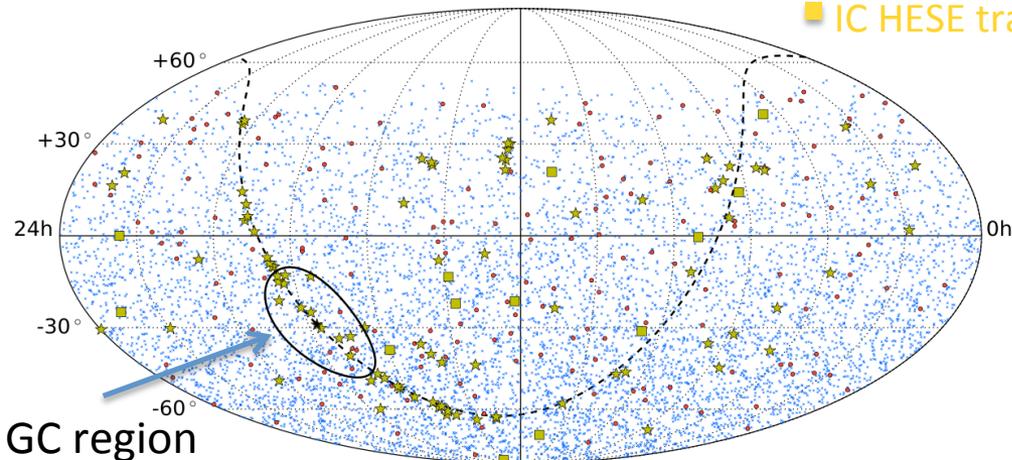
Blue: Tracks

Red: Cascades

★ Candidate Sources

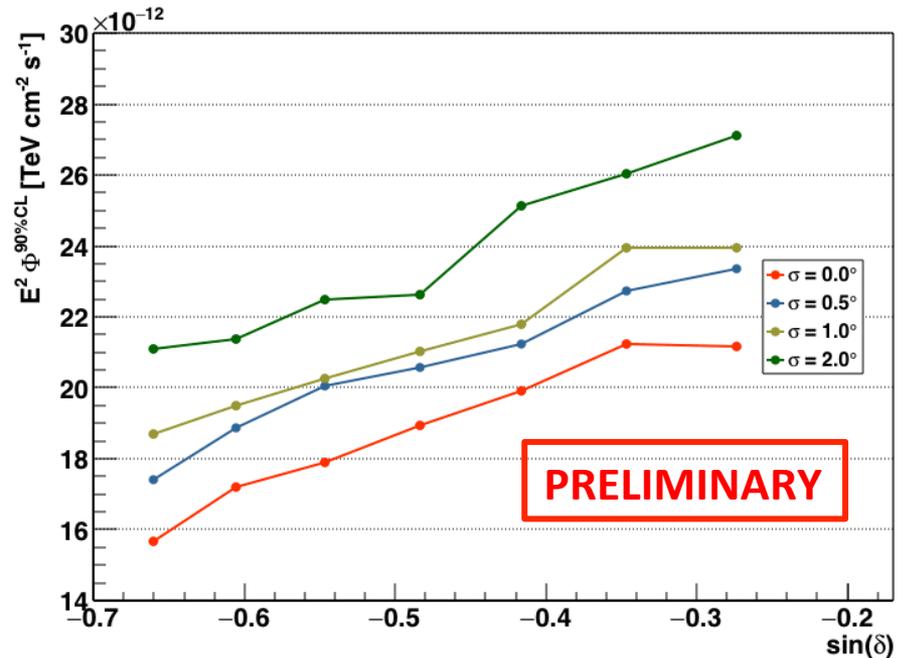
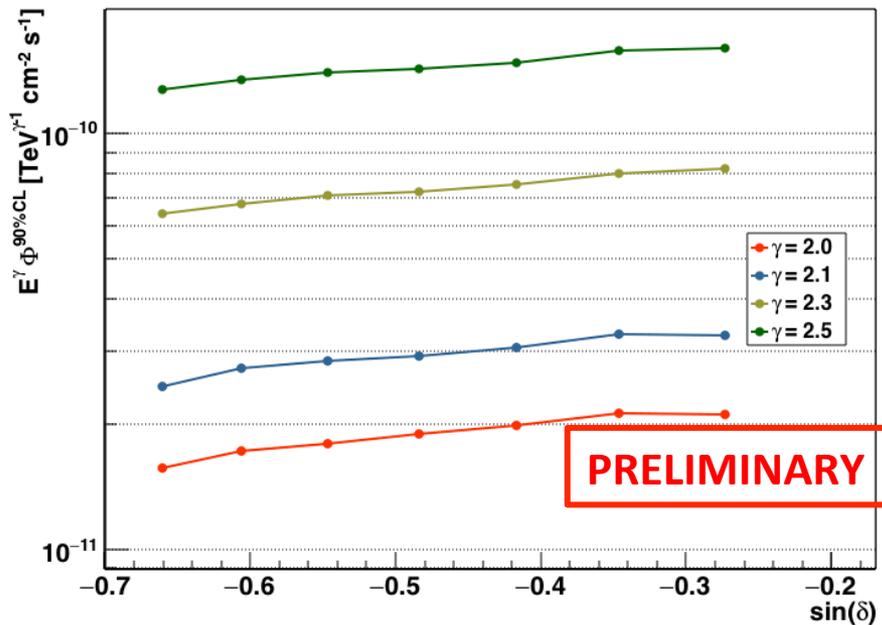
Source

■ IC HESE tracks



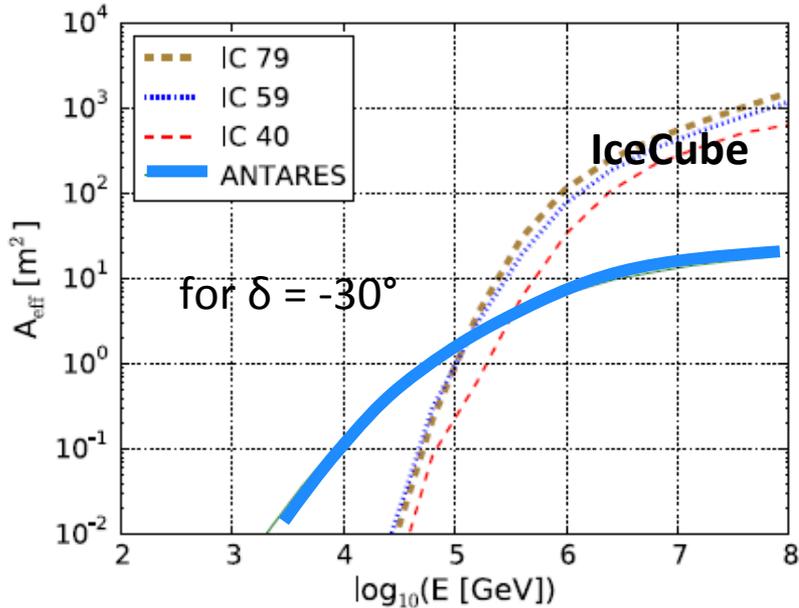
Focus on Galactic Center Region

- Dedicated search in Galactic Center region
- Limits for different spectral indices and different source extensions

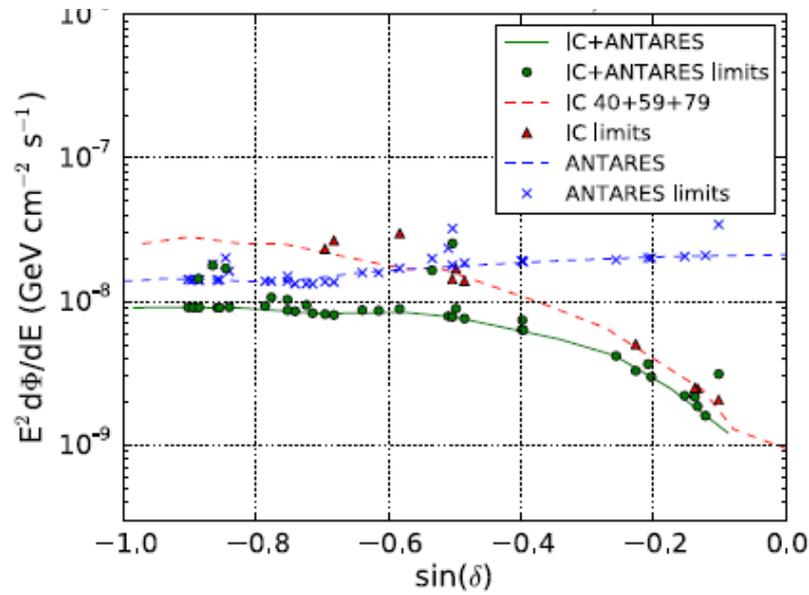
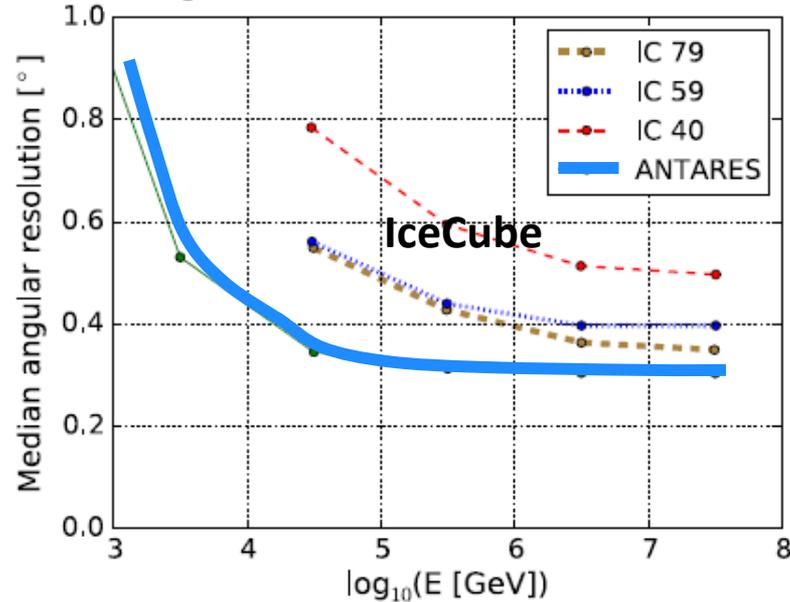


Combined ANTARES-IceCube PS search

Effective areas (IC, ANTARES)



Angular resolution (IC, ANTARES)



- IC 79 & IC59 & IC40 + 6 years of ANTARES
- Combined sensitivities (green line) and 90% CL limits (points) for E^{-2} spectrum.
- Blue (Red) curves/points indicate ANTARES (IceCube) sensitivities/limits

Probing neutrino emission from the Galactic Plane

Previously: Signal/off-zone analysis

2007-2013 data, track events

no excess found

PLB 760, 143 (2016)

New all-flavour analysis

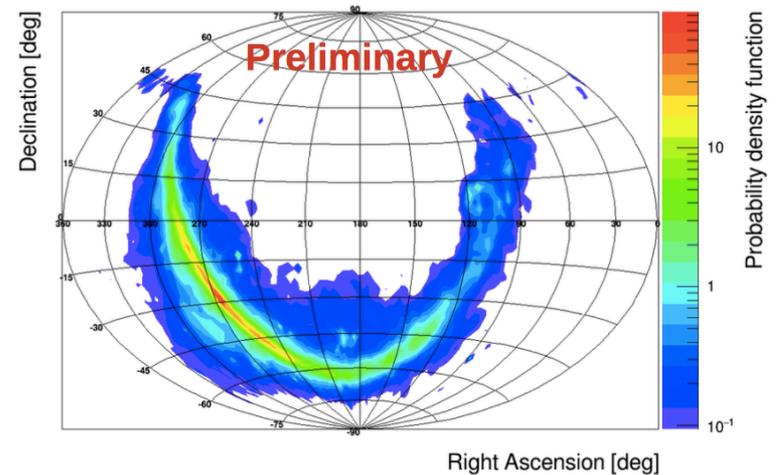
2007-2015 data, track&cascade events

Likelihood approach probing KRA γ model

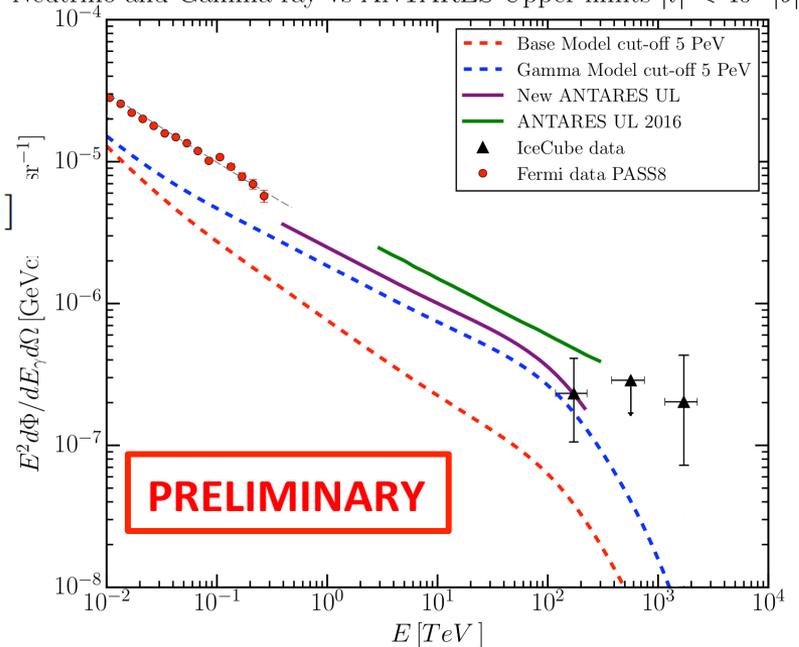
Limit at 1.3*KRA γ model

$$L_{sig+bg} = \prod_{evt} [n_{sig} \cdot pdf_{sig}(\alpha^{evt}, \delta^{evt}, E^{evt}) + n_{bg} \cdot pdf_{bg}(z^{evt}, \delta^{evt}, E^{evt})]$$

PDF for track events according to KRA γ model



Neutrino and Gamma-ray vs ANTARES Upper limits $|l| < 40^\circ$ $|b| < 3^\circ$

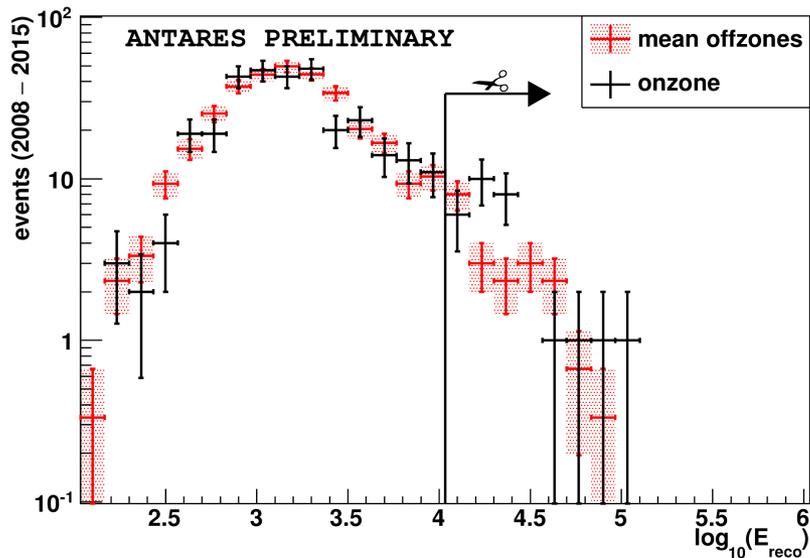
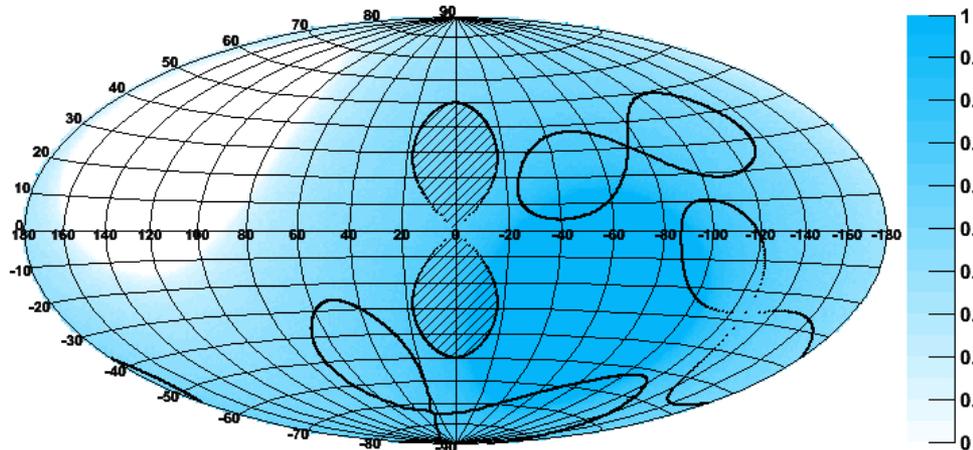


Probing neutrino emission from the Fermi Bubbles

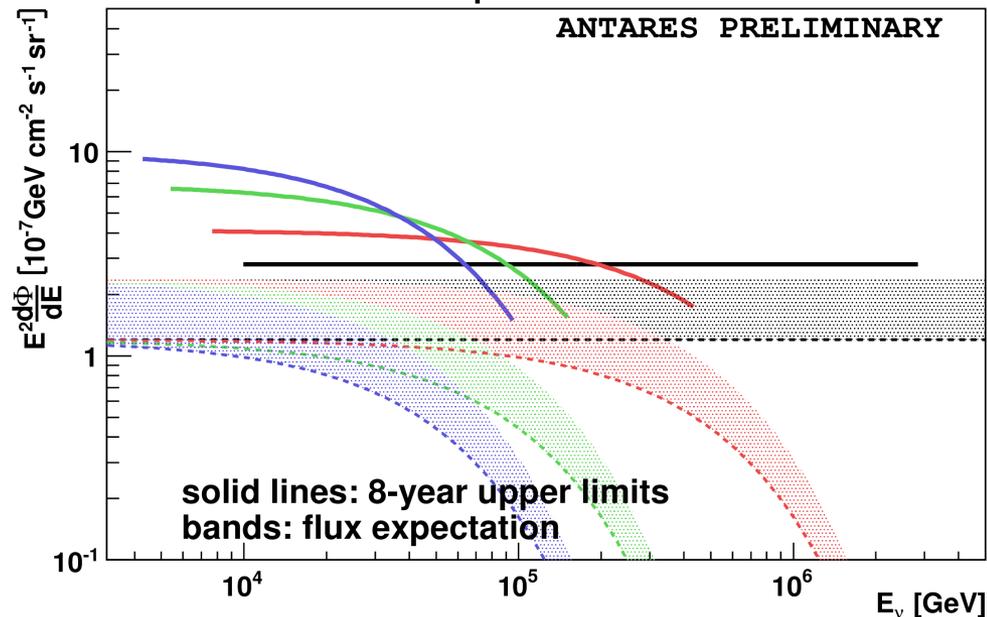
New analysis 2008-2015

- only tracks
- energy threshold
- no significant excess
- ongoing work to include cascades

Visibility signal and off-zones



E^{-2} spectrum



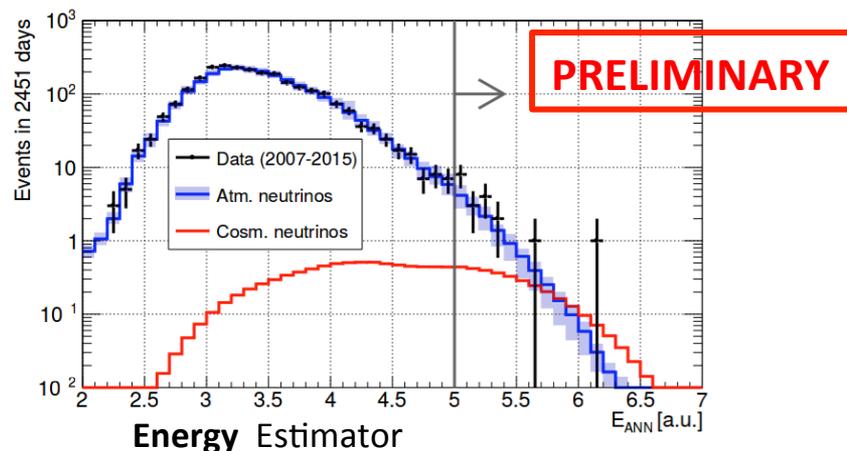
Diffuse flux (all flavour analysis)

Tracks

Data: 2007-2015 (**2451 livedays**)

Above E_{cut} : Bkg: 13.5 ± 3 evts, IC-like signal: 3 evts

Observed: 19 evts

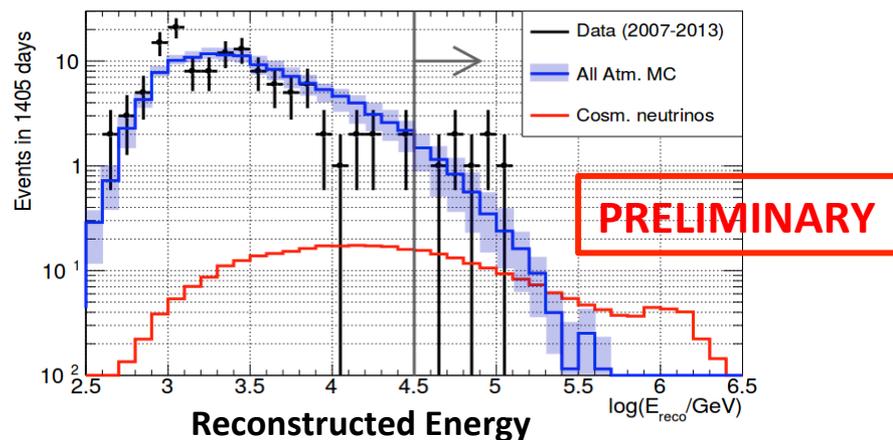


Cascades

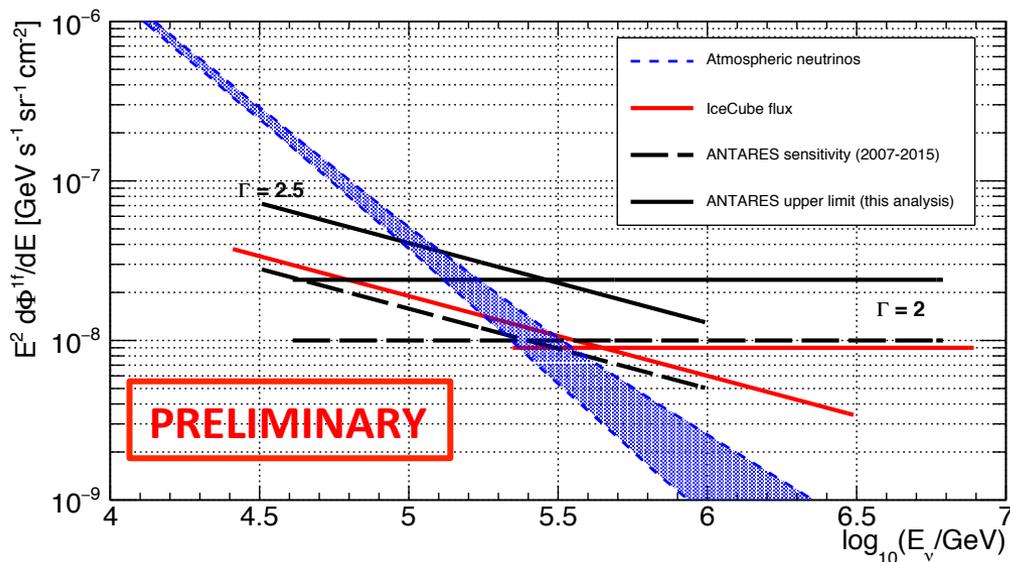
Data: 2007-2013 (**1405 livedays**)

Above E_{cut} : Bkg: 5 ± 2 evts, IC-like signal: 1.5 evts

Observed: 7 evts



ANTARES
combined upper
limits and
sensitivities
(2007-2015)
tracks + cascades



Limits for four bright GRBs

GRB 080916C, GRB 110918A, GRB 130427A, GRB130505A

arXiv 1612.08589

Special data taken over 200s after GRB trigger, no data filtering
(available for GRB 130427A and GRB 130505A)

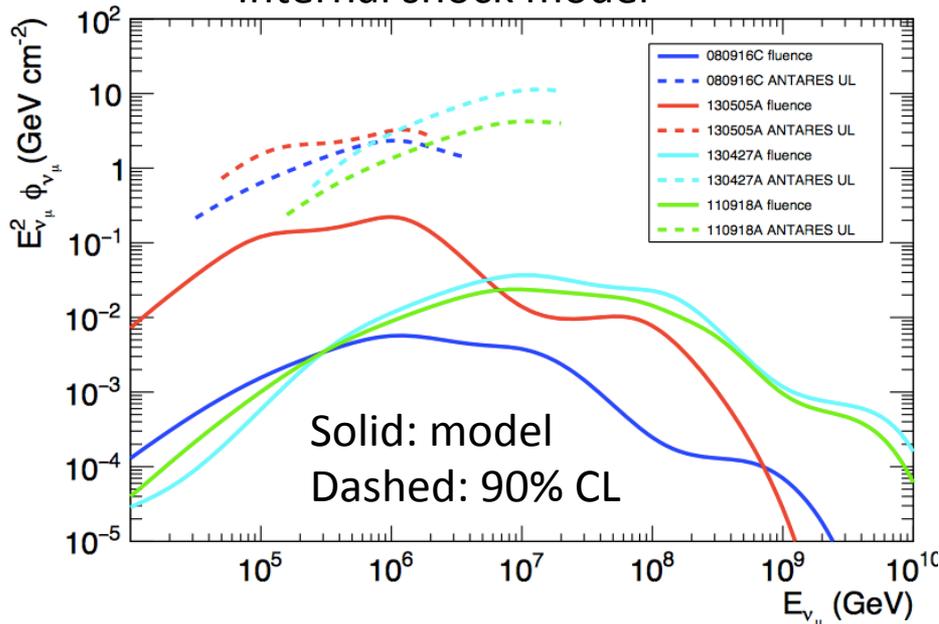
Models probed:

Internal Shock model -> regular event reconstruction

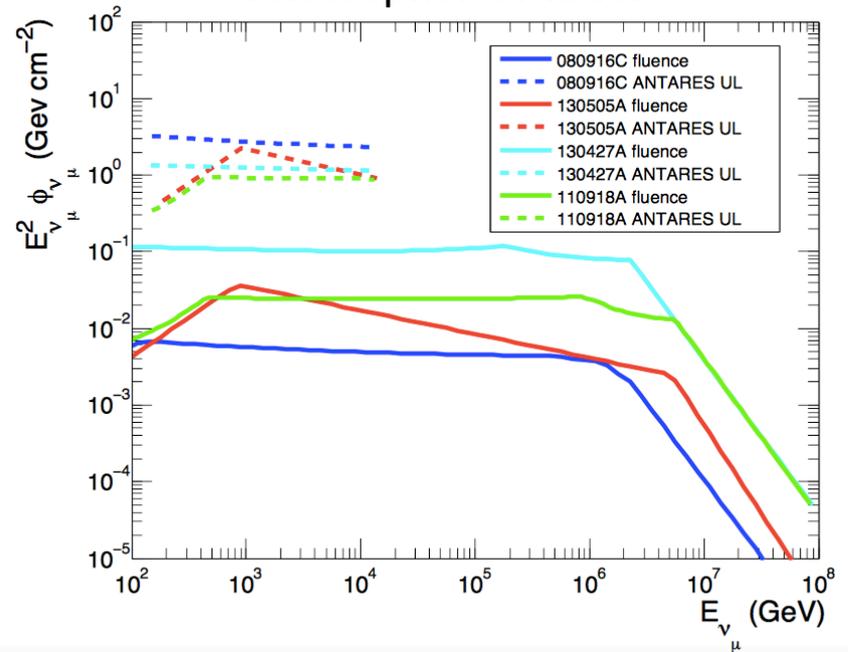
Photospheric model -> lower energies, unfiltered data samples

with dedicated low energy reconstruction used

Internal shock model



Photospheric model



Stacked search for time shifted neutrinos from Gamma Ray Bursts

New analysis sensitive to delayed neutrino emission (up to 40 days) and Lorentz Invariance violating effects

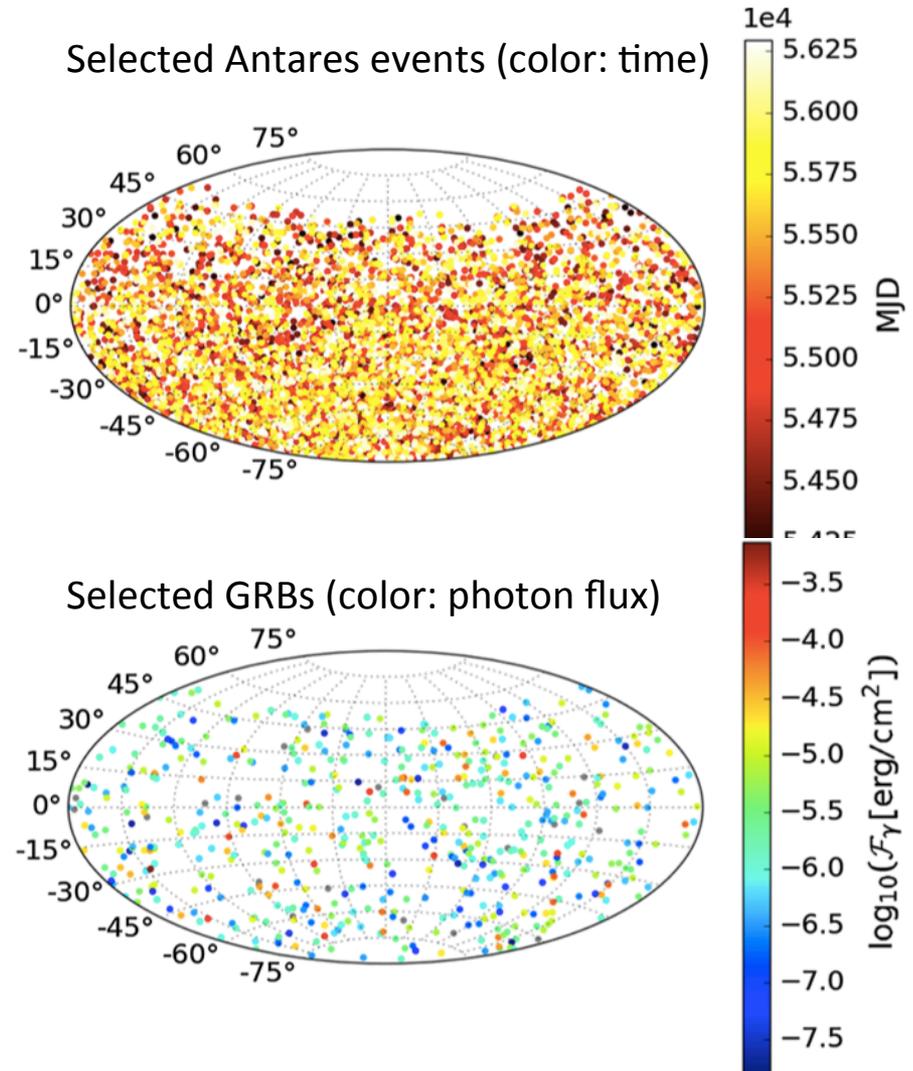
Antares data 2007-2012

No events found in predefined spatial and timely distance

- > in 98.8% randomized maps more correlations
- > constrains <1 neutrino per 100 GRBs

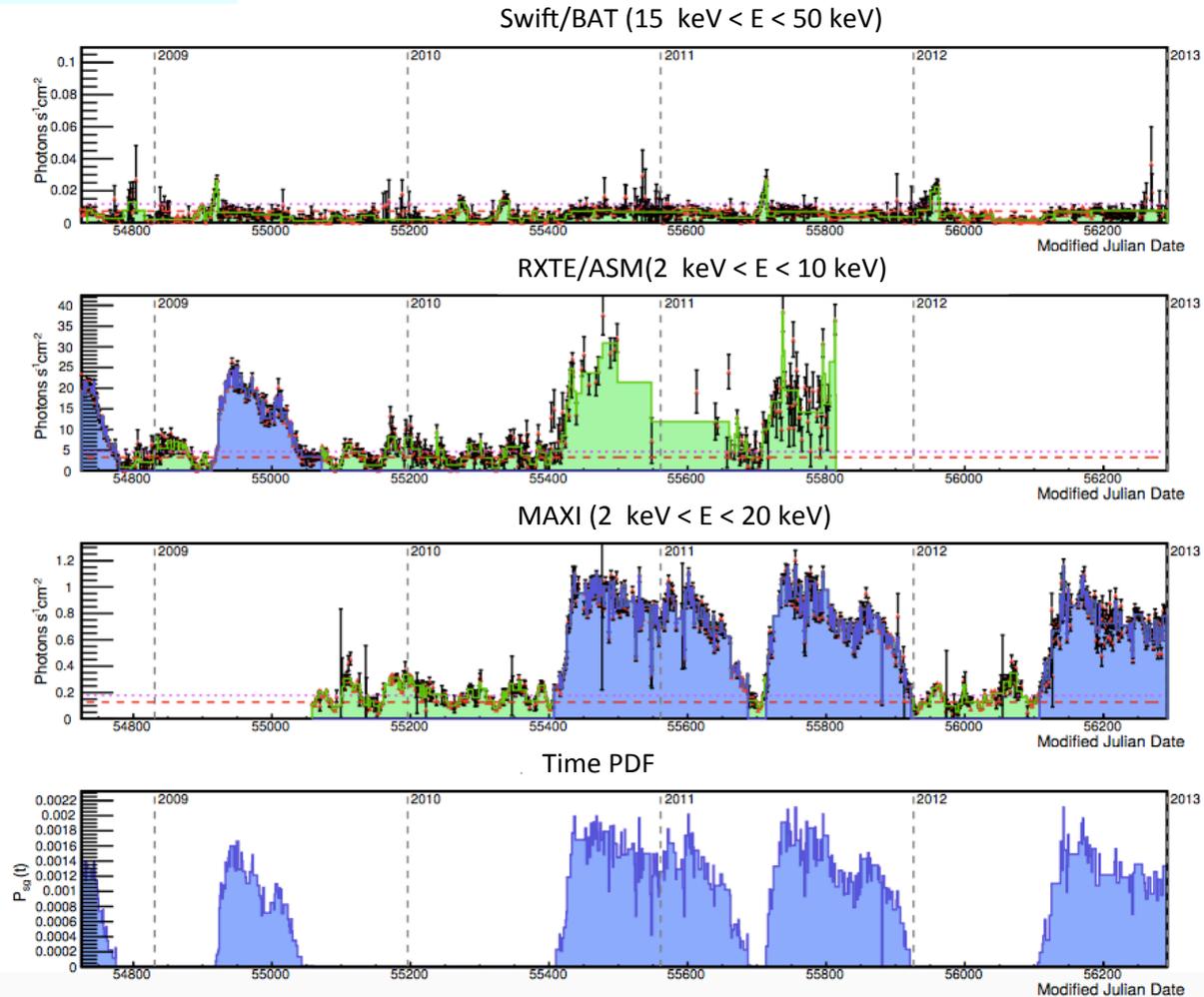
IC40 (public data)

Events in agreement with background expectation



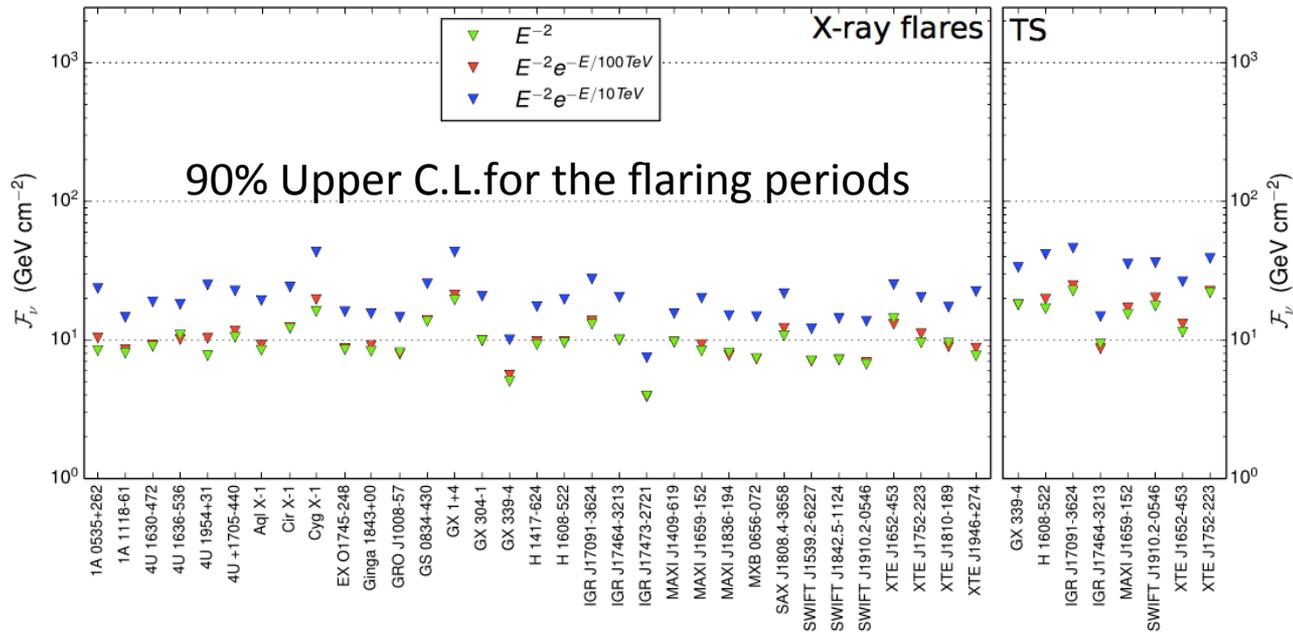
Constraints on neutrino emission by flaring X ray Binaries

Light curve examples
source 4U 1705_440



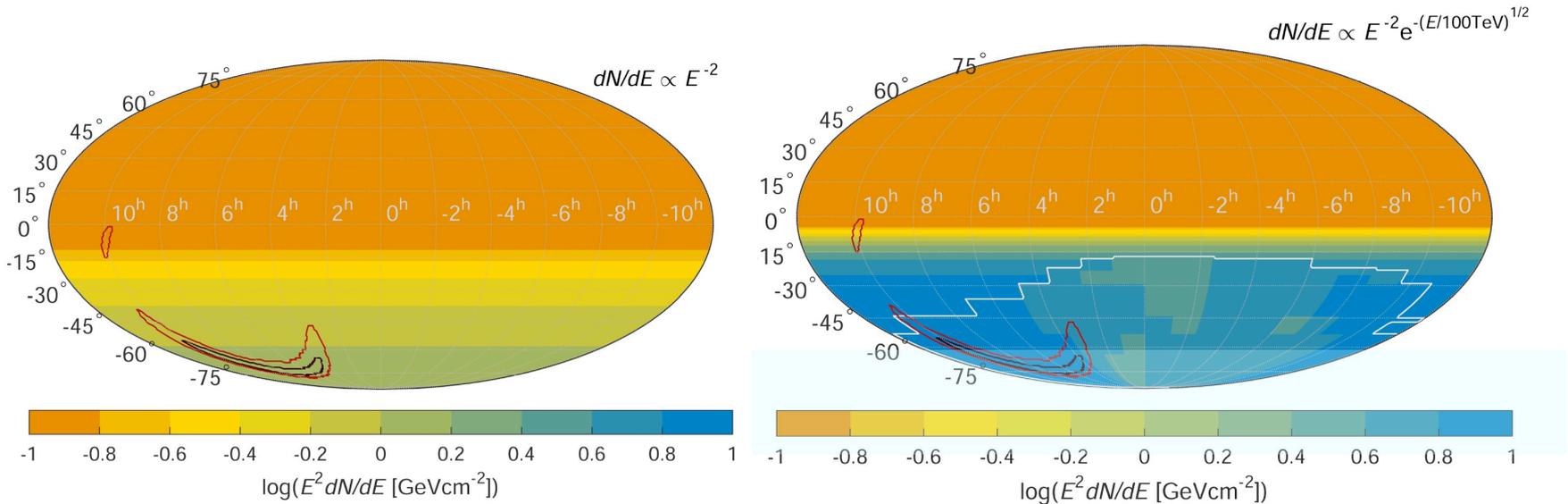
Constraints on neutrino emission by flaring X ray Binaries

Using track events from 2008-2012



Neutrino follow-up of GW150914

joint ANTARES/IceCube/LigoSC/Virgo. Phys.Rev. D93 (2016), 122010

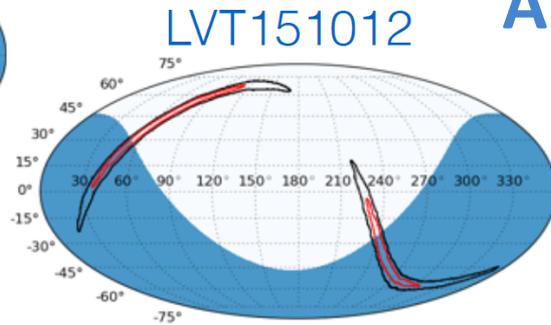
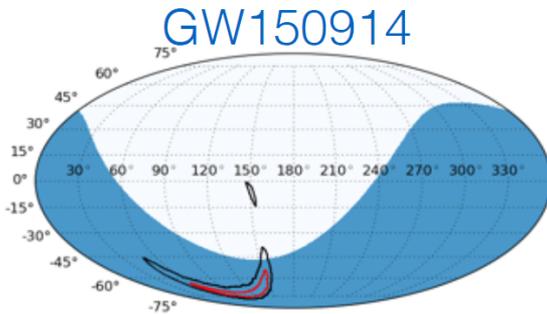


- Within ± 500 s:
 - No ANTARES events (0.015 expected)
 - 3 IceCube events (not in GW location, 4.4 expected)
- Limits from ANTARES dominates for $E_\nu < 100$ TeV
- U.L. from IC dominate $E_\nu > 100$ TeV
- Limits on total energy radiated in neutrinos: $< 10\%$ GW
- Future: Receive / send alerts in real time

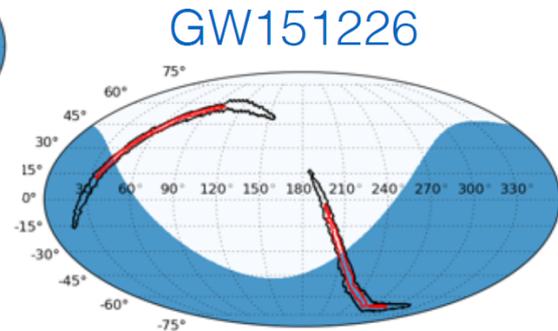
Neutrino follow-up of GWs

3 alerts sent by LIGO during the run 01 (2015/09 → 2016/01):

- GW150914: merging of 2 BHs ($M= 36/29 M_{\odot}$ - 410 Mpc - 5.1σ) **published**
 - LVT151012: merging of 2 BHs ($M= 23/13 M_{\odot}$ - 1000 Mpc - 1.7σ)
 - GW151226: merging of 2 BHs ($M= 14/7 M_{\odot}$ - 440 Mpc - $>5 \sigma$)
- } Paper in preparation**



ANTARES visibility



Dark Matter in the Sun and Galactic Center

Accumulation and annihilation in massive objects

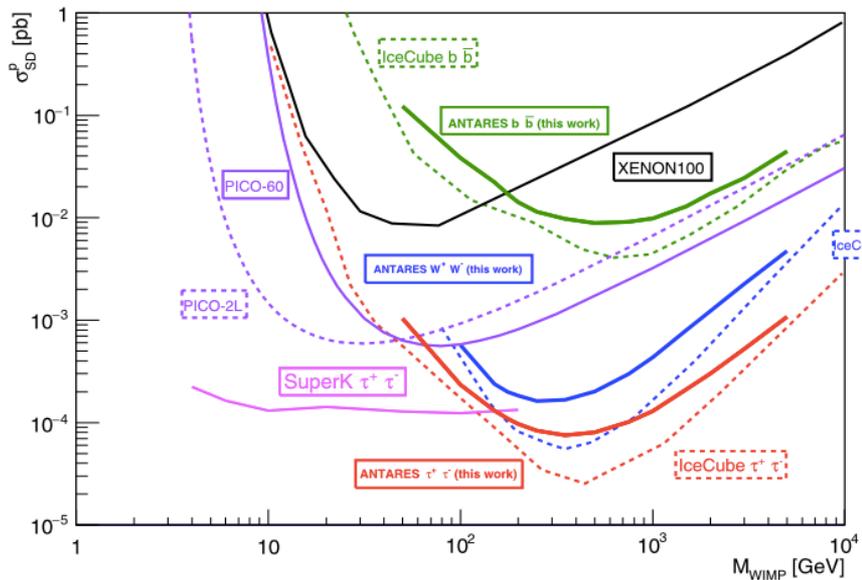
$$X_{\text{WIMP}} \bar{X}_{\text{WIMP}} \rightarrow \nu \bar{\nu}, b \bar{b}, W^- W^+, \tau^- \tau^+, \mu^- \mu^+$$

Selection cuts tuned separately for different channels and WIMP masses

Sun

Using track events from 6 years of data

90% C.L. Upper Limit on spin dependent cross section

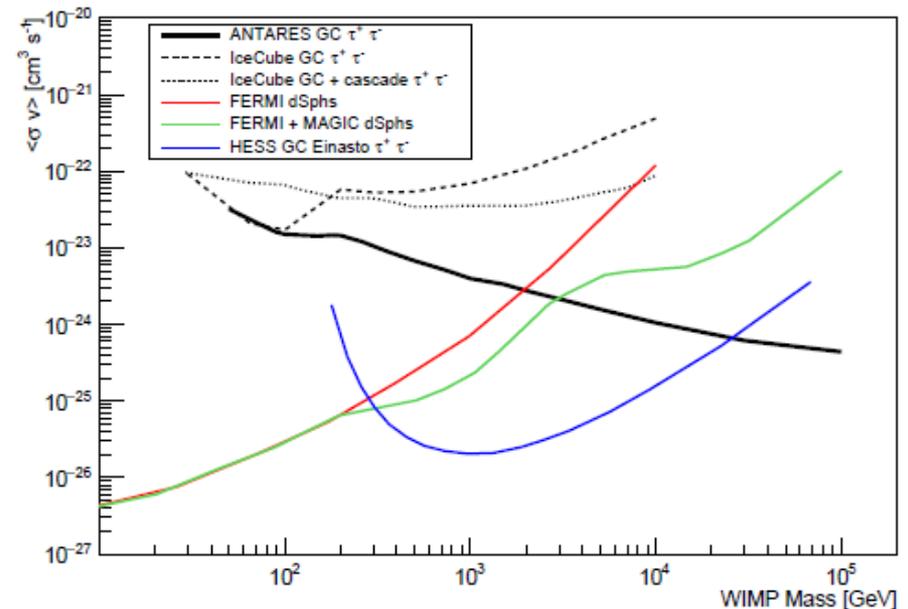


PLB 759, 69 (2016)

Galactic Center

Using track events from 9 years of data

90% C.L. Upper Limit on annihilation cross section

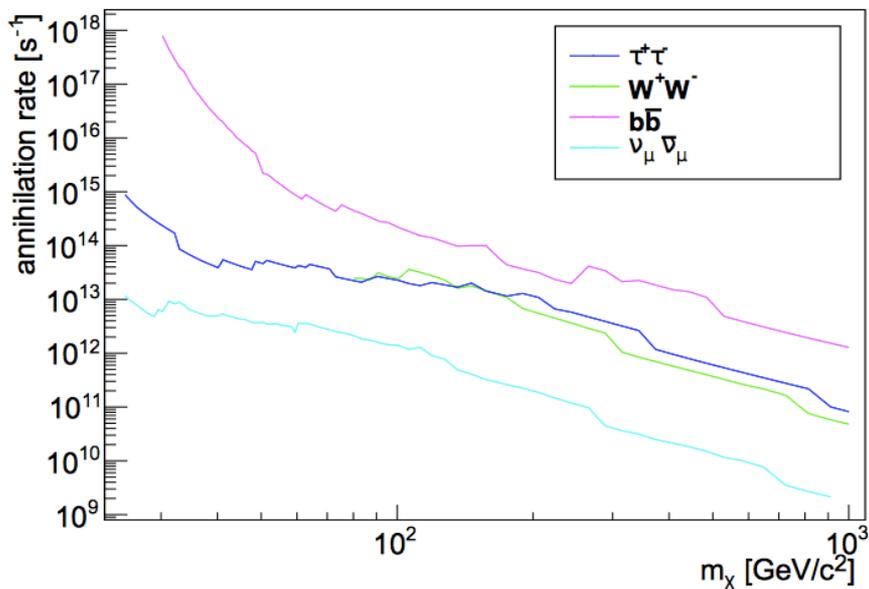


arXiv 1612.04595

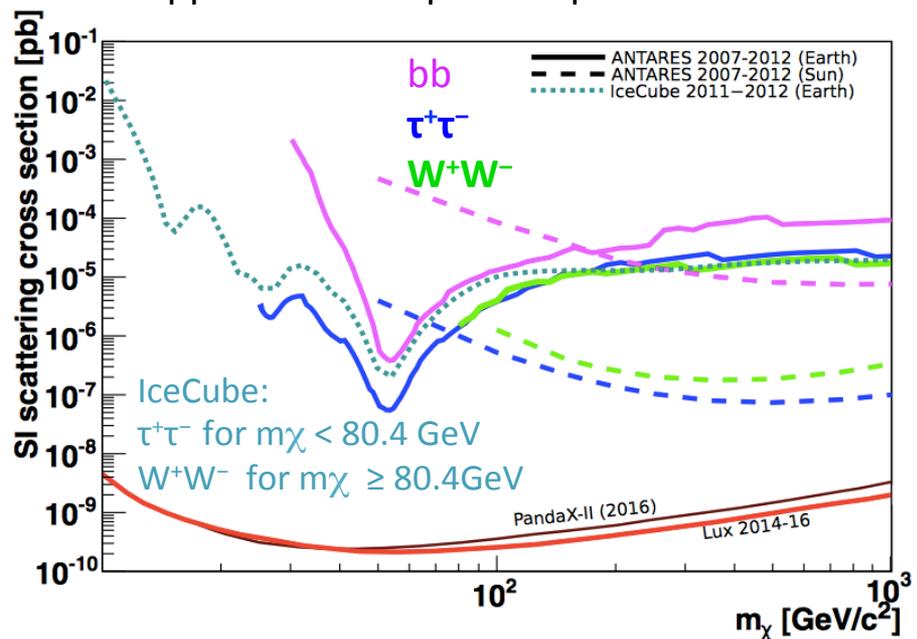
Dark Matter in the Earth

- Looking for almost vertically upward going tracks
- 1192 days live time (2007-2012)
- Selection optimized separately for different WIMP masses

90% C.L. Upper limit on annihilation rate



90% C.L. Upper Limit on spin-independent cross section



Summary and outlook

ANTARES is delivering a variety of interesting physics results

- Unprecedented angular resolution of 3 degrees for cascades achieved,
=> All flavour neutrino interactions (to be) included in analyses
- Several results on the possible neutrino emission from the Southern sky
=> constraining origin of the IceCube signal
- Competitive sensitivity in Dark Matter observations
- Combined analyses with IceCube performed and in the works
=> optimal sensitivity on neutrino fluxes (point sources, galactic plane, dark matter)
- Many multi-messenger results exploiting also information from external observatories and also sending neutrino alerts for follow-up

Demonstration of the great potential of deep-sea Neutrino Telescopes