Recent results from the ANTARES Deep Sea Neutrino Telescope

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on behalf of the ANTARES Collaboration

15th TAUP Conference @ Sudbury – 26 July 2017

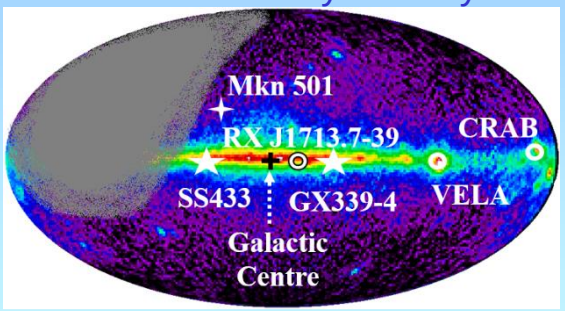
The ANTARES Neutrino Telescope

NIM A 656 (2011) 11

- **Largest underwater neutrino telescope** operating for 10 years now (complete in 2008)
- 12 line detector with 885 10'' PMTs installed by 2500 m depth off the coast of Provence (France)
- **O(11000) neutrinos detected** with Eν > 10 GeV

- **Excellent view of Galactic Centre region** with high angular resolution (0.3°-0.4° median)
  → **interesting constraint of possible galactic component** of the IceCube HE signal
- **Real time** data processing →generation of alerts (~5s) for multi-messenger searches

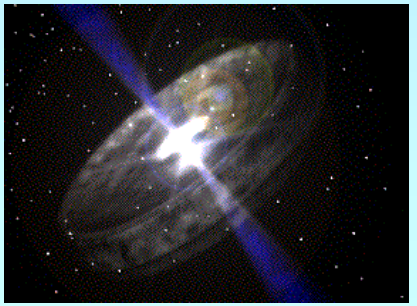
ANTARES sky visibility



- **Science scope of ANTARES:**
- **Neutrino astrophysics, search for HE CR origin**
- **Multi-messenger observations**
- **Indirect searches for Dark Matter**

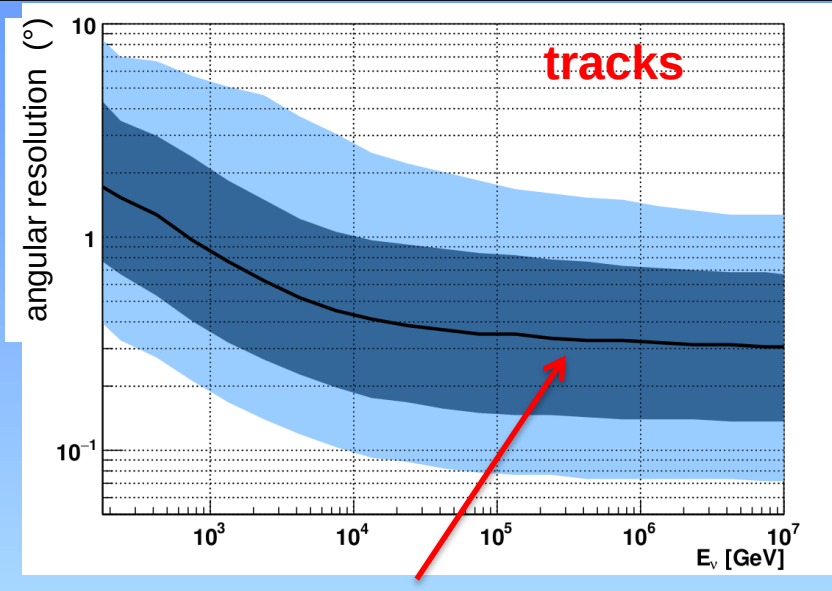
This talk

- Atmospheric neutrinos (oscillations, sterile neutrinos)
- Exotic searches (magnetic monopoles, nuclearites)
- Earth & Sea Sciences, environmental studies



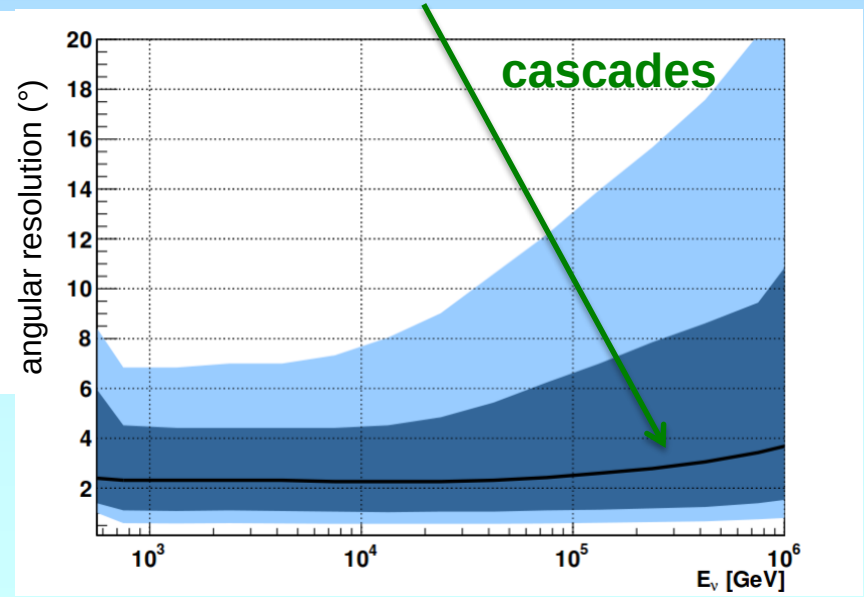
Reconstruction performances

- Upgoing **track events** (ν_μCC)
- Angular resolution < 0.4° for E_ν>10 TeV
- Energy resolution : factor 3
- 90% purity of neutrinos
- Large detection volume from μ range
  →ideal for neutrino astronomy
  →but large atmospheric μ bkg

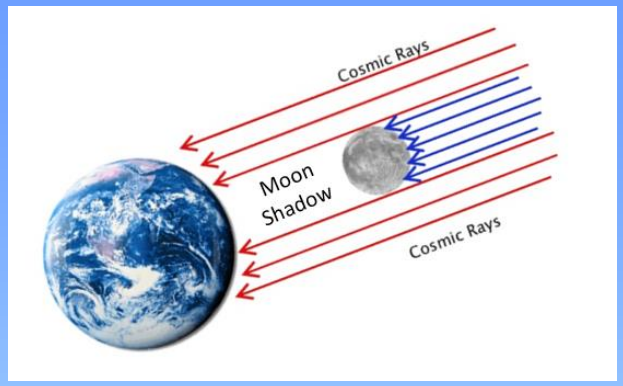


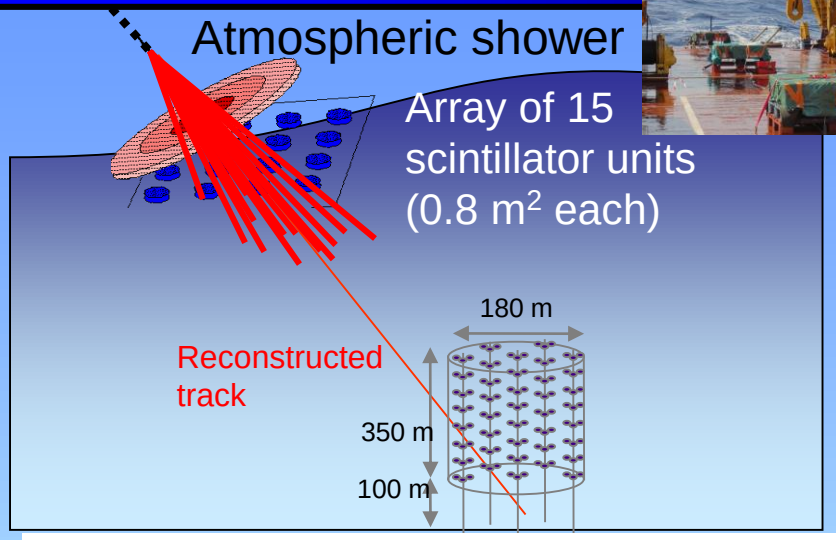
Median angular resolution vs Eν

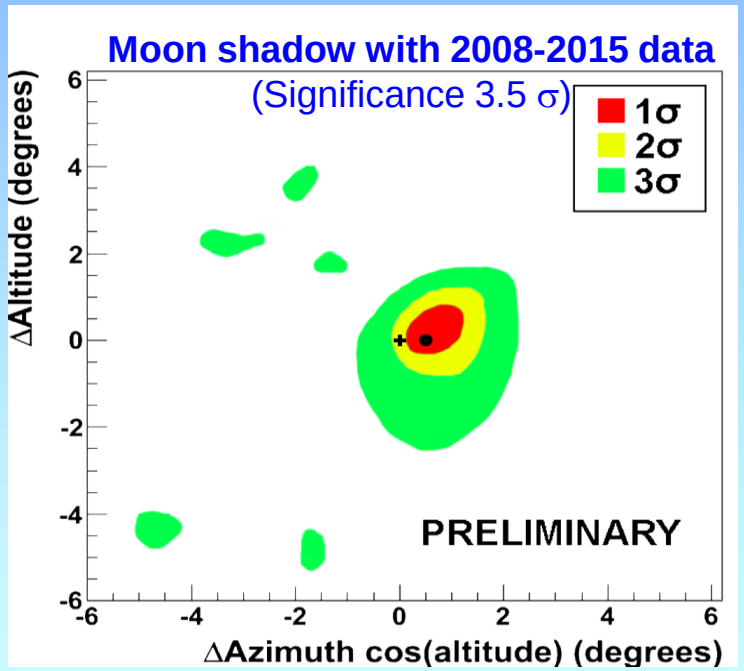
- Upgoing **cascade events** (ν_e/ν_τ CC, NC)
- Angular resolution < 3°
- Energy resolution for ν_eCC < 10%
- Contained events (small detection volume)
  →almost no atmospheric bkg



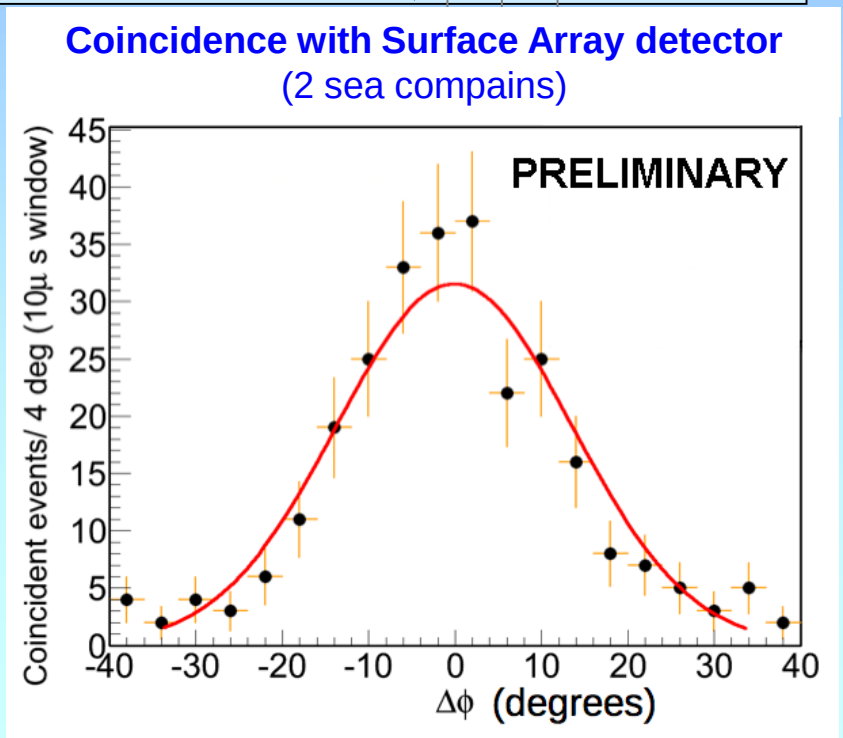
Check of Detector Absolute Pointing





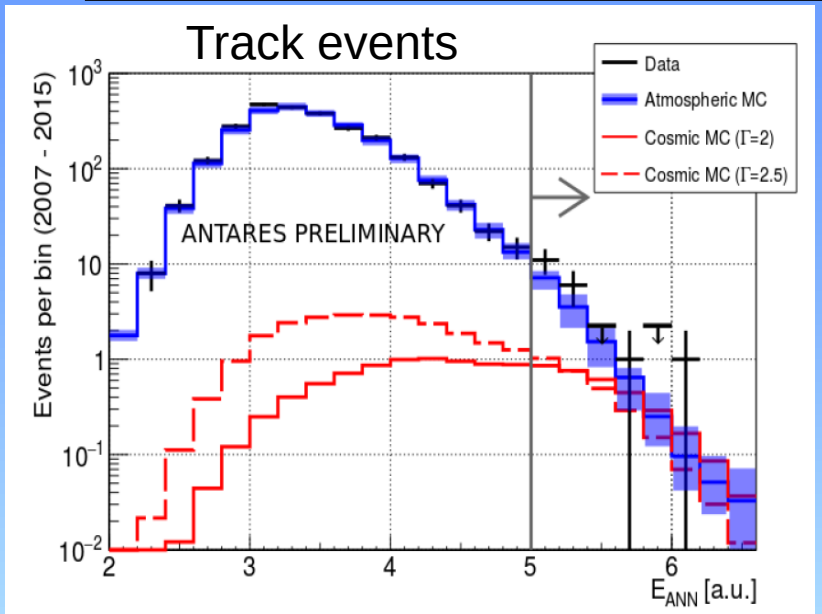


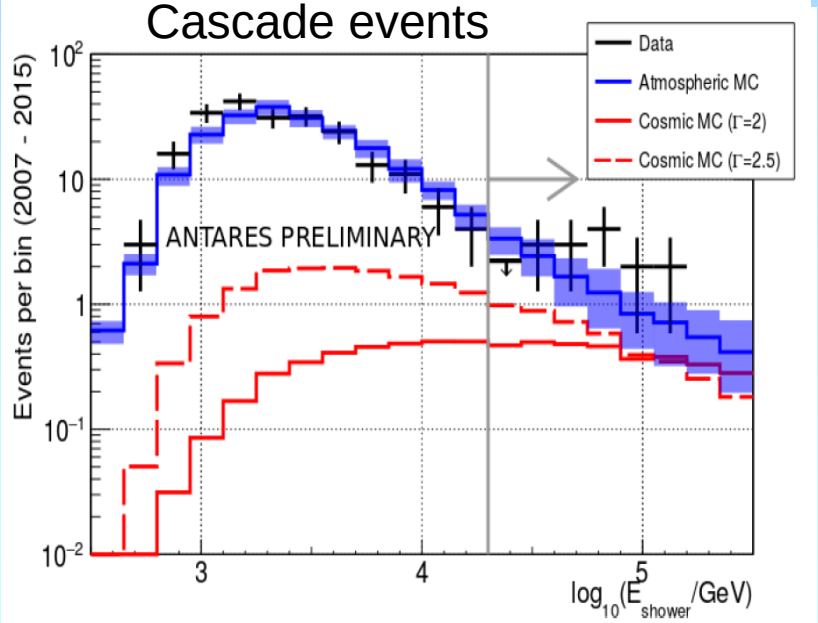
Angular resolution for down-going muons :
0.73°± 0.15°



📖 POS (ICRC2017) 1053

Search for HE Neutrino Excess (aka 'Diffuse Flux')





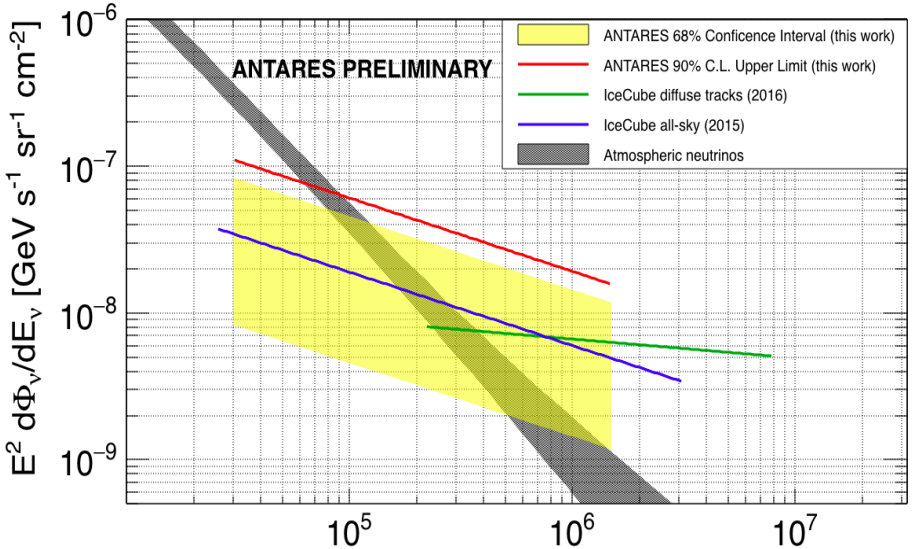
All sky/all flavour neutrino search with 2007-2015 data (2450 livedays)

Total events above energy thresholds :

- Expected : 24±7 bkg, ~8 from IceCube flux
- Observed : 33

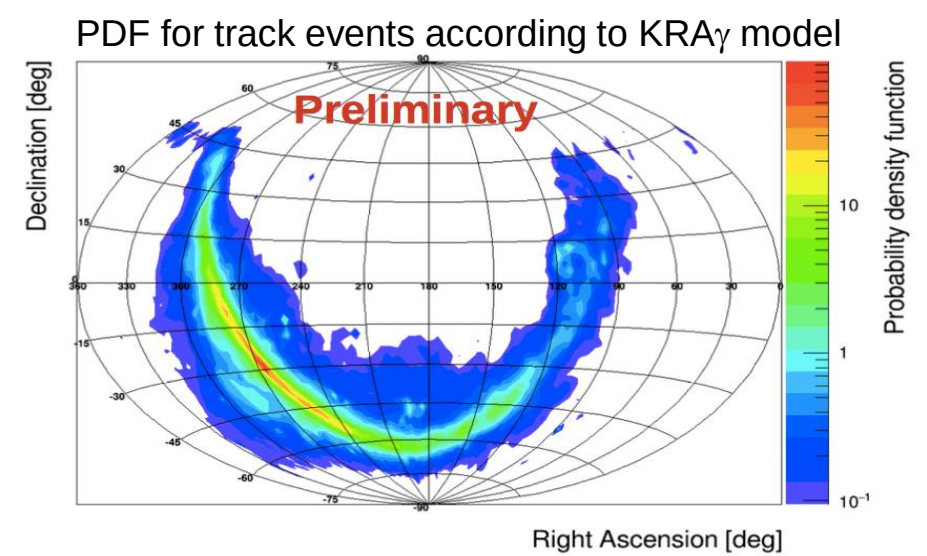
→ **Small excess not significant but compatible with IceCube flux**

Combined upper limit assuming $E^{-2.5}$ spectrum



📖 POS (ICRC2017) 993

Study of Galactic Ridge



- Guaranteed galactic neutrinos from CR interactions with matter
- Does it contribute to IC flux?

- Test 'KRAγ' model -> spectrum and morphology reproduce Fermi & Milagro data
- Analysis uses full model morphology and spectrum

New all-flavour analysis :

2007-2015 data, track & cascade events

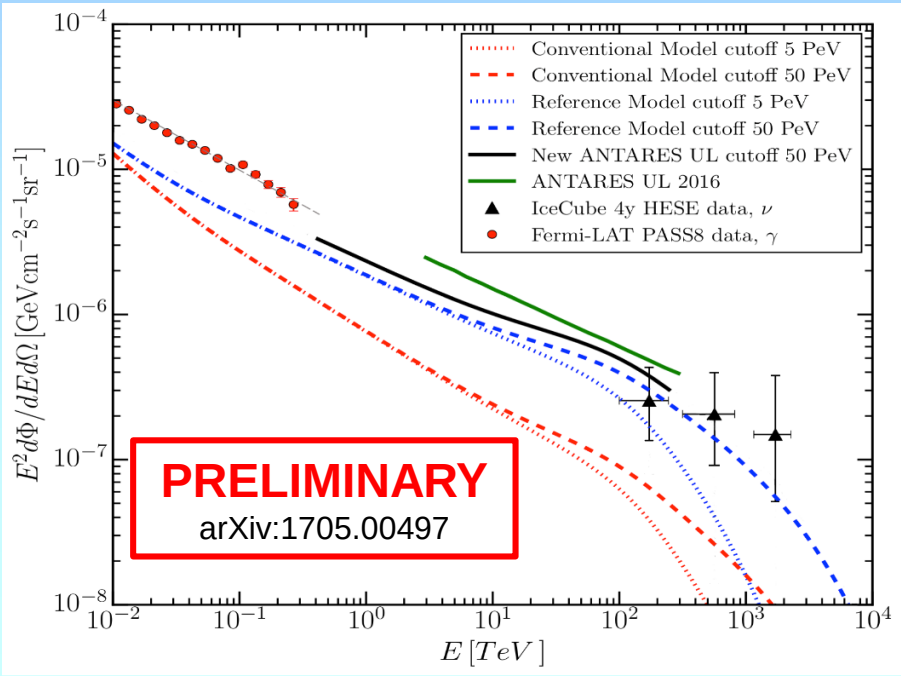
Likelihood approach probing KRAγ model

Limit at 1.25 x KRAγ model

At most 19% of HESE IC dataset can originate from CR diffusion

⇔ 5.6 out of the 30 HESE with Eν > 60TeV

Combination with IceCube ongoing

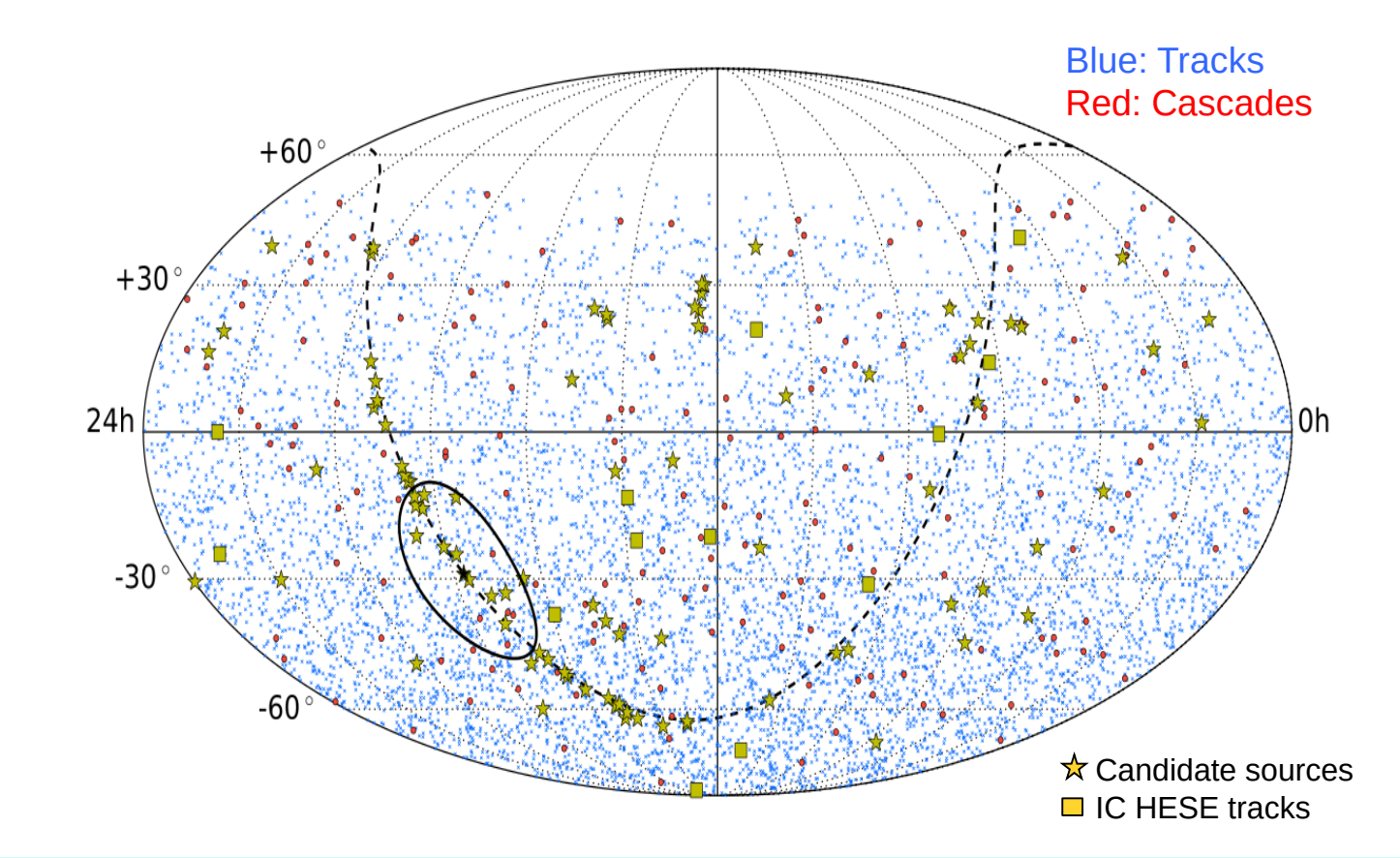


All flavour point source search with ANTARES

- **2007-2015 data set (2424 livedays) :**
  7629 tracks, 180 cascades

- Search for 106 candidate sources (Pulsars, SNRs,…)
  and 13 IceCube tracks from the HESE sample

📖 arXiv:1706.01857



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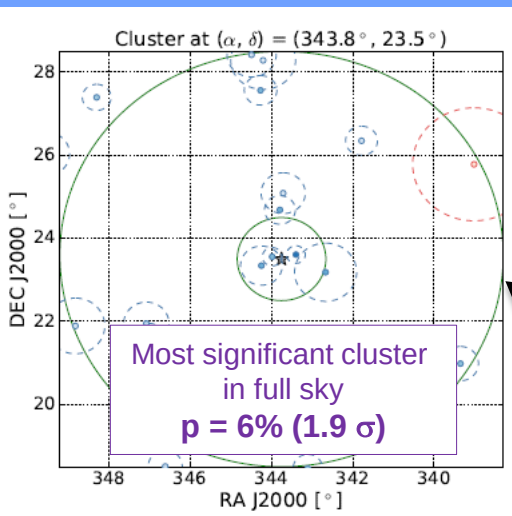
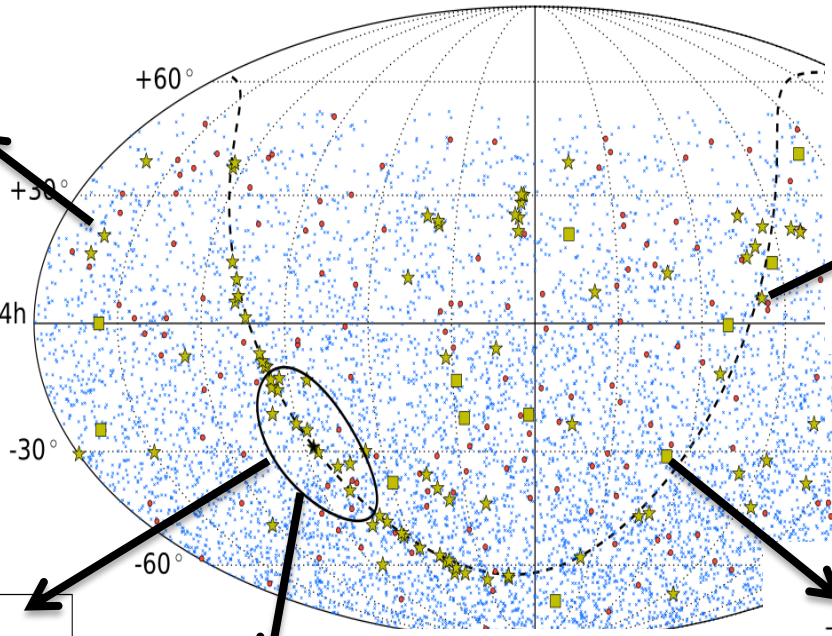
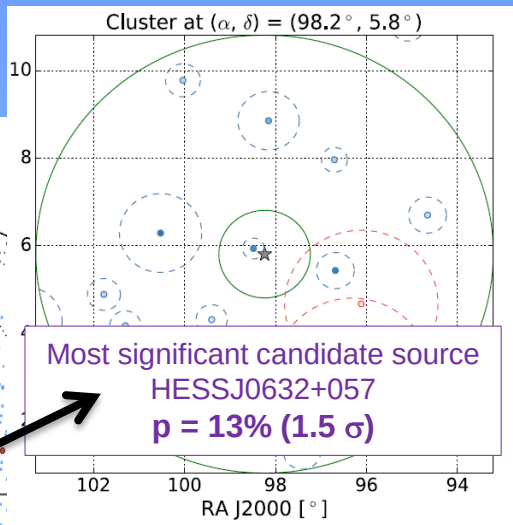


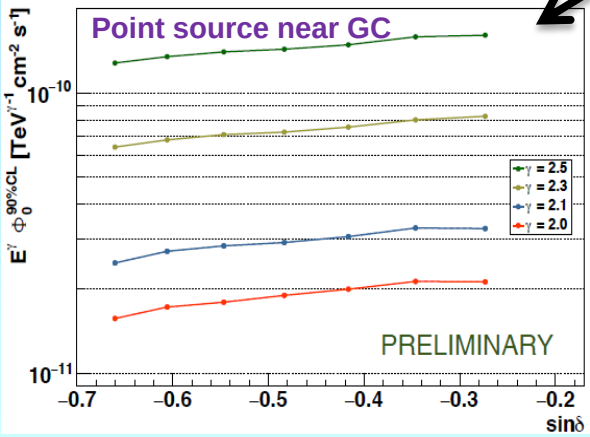
Most significant cluster in full sky
p = 6% (1.9 σ)

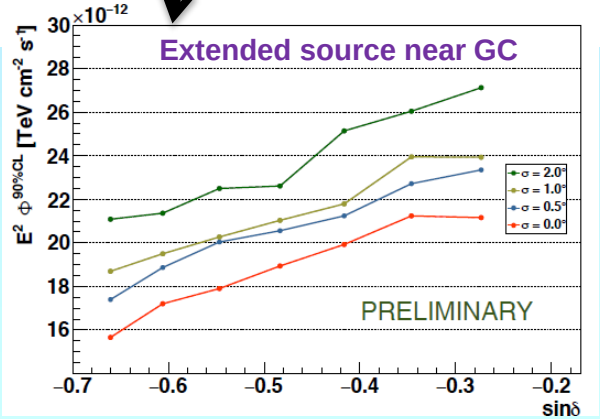
📖 arXiv:1706.01857

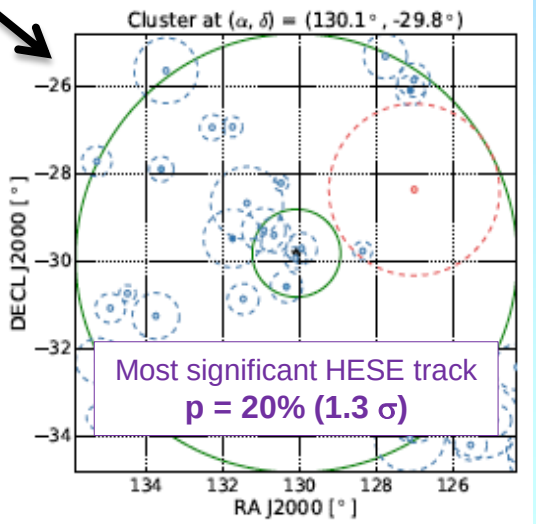




Most significant candidate source
HESSJ0632+057
p = 13% (1.5 σ)







Most significant HESE track
p = 20% (1.3 σ)

All flavour point source search with ANTARES

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- Search for 106 candidate sources (Pulsars, SNRs,…)
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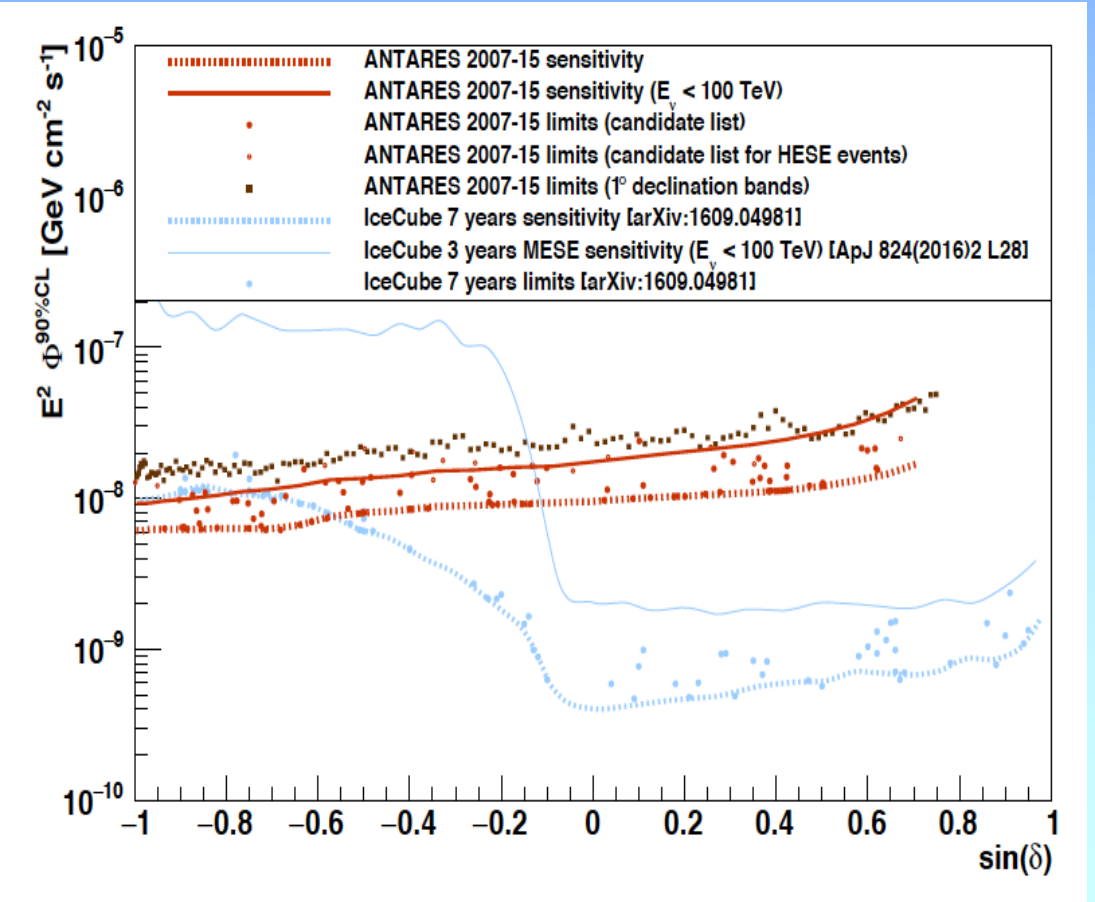
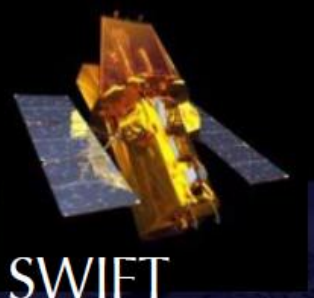


- **No significant excess found**
- Best limits for part of Southern Hemisphere for E_ν <100 TeV
- Relevant energy range for Galactic sources
- Results to be combined with latest IceCube search

ANTARES Multi-Messenger Alerts

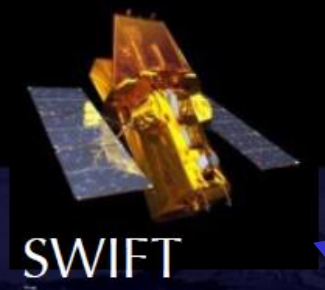
Send **real-time alerts** (5 s delay, precision 0.3°-0.4°) for neutrinos pairs, single neutrino close to direction local galaxies, single VHE neutrinos



256 alerts sent to robotic optical telescopes, 13 to Swift and a few to MWA & HESS
→ no significant transient associated to neutrinos so far

📖 Astropart. Phys. 35 (2012) 530
📖 Astrophys. J. 820 (2016) 24
📖 JCAP 02 (2016) 062
📖 arXiv:1705.08258

ANTARES Multi-Messengers Analyses

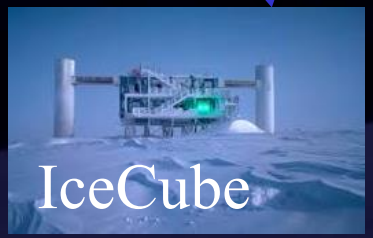


Milagro

Virgo

ANTARES

Parkes

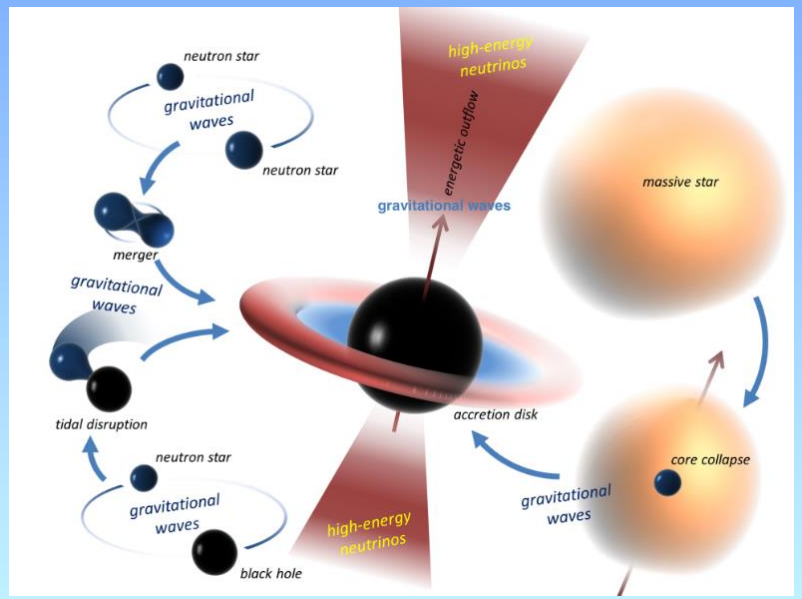


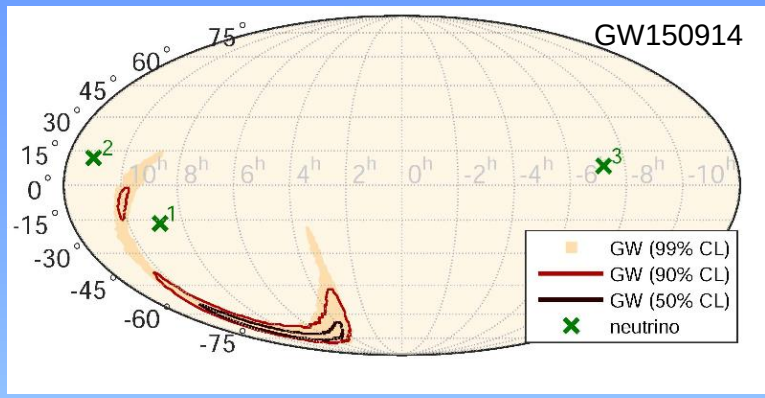
Multi-Messengers / Time Correlation Analyses

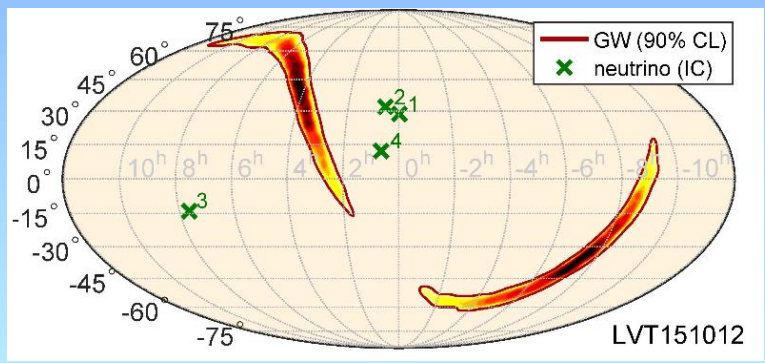
Object	Messenger	Telescope	Publication
Flaring Blazars	Gamma	FERMI/LAT	Astrop. Ph. 36 (2012) 204 JCAP 12 (2015) 014 POS (ICRC2017) 970
Flaring X-ray binaries	X & Gamma-rays	Swift, MAXI RXTE/ASM, Fermi/LAT	JCAP 04 (2017) 019
Flares from Mrk 421 and Mrk 501	Gamma	HAWK	POS (ICRC2017) 946
Gamma Ray Bursts	Gamma	Swift, GCN	JCAP 03 (2013) 006 A&A 559 (2013) A9 MNRAS 469 (2017) 906 EPJC (2017) 77:20
IceCube Events	Neutrino	IceCube	A&A Lett. 576 (2015) L8 arXiv:1706.01857
UHECR	CR	Auger, TA	ApJ 774 (2013) 19 POS (ICRC2017) 990
Galactic plane	**Model fit**	**Fermi, Milagro**	PLB 760 (2016) 143 arXiv:1705.00497
Fast Radio Bursts	Radio	SUPERB@Parkes, UTMOST, ASKAP	MNRAS (2017) 469 (4):4465
Fermi Bubbles	Gamma	Fermi	EPJC (2014) 74:2701 POS (ICRC2017) 1001
BH/NS mergers	**Gravitational waves**	**Ligo/Virgo (+Icecube)**	JCAP 06 (2013) 006 PRD 93 (2016) 122010 PRD 96 (2017) 022005

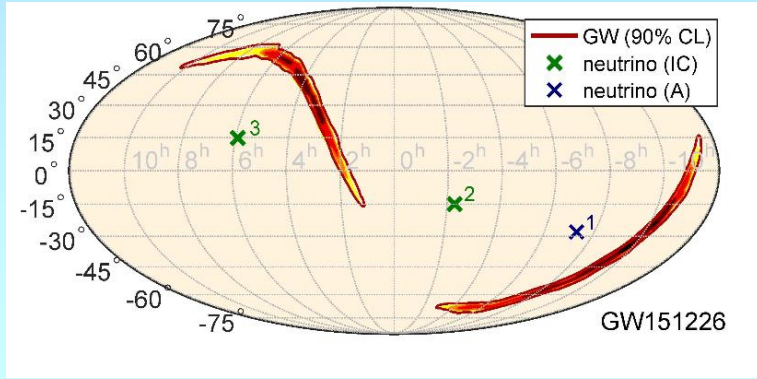
Search for Coincidences with Gravitational Waves

- Neutrino follow-up relevant in case of baryonic ejecta (mostly for BH/NS or NS/NS merging)
- Coincident neutrino signal would allow pinpointing the source (< 1°)







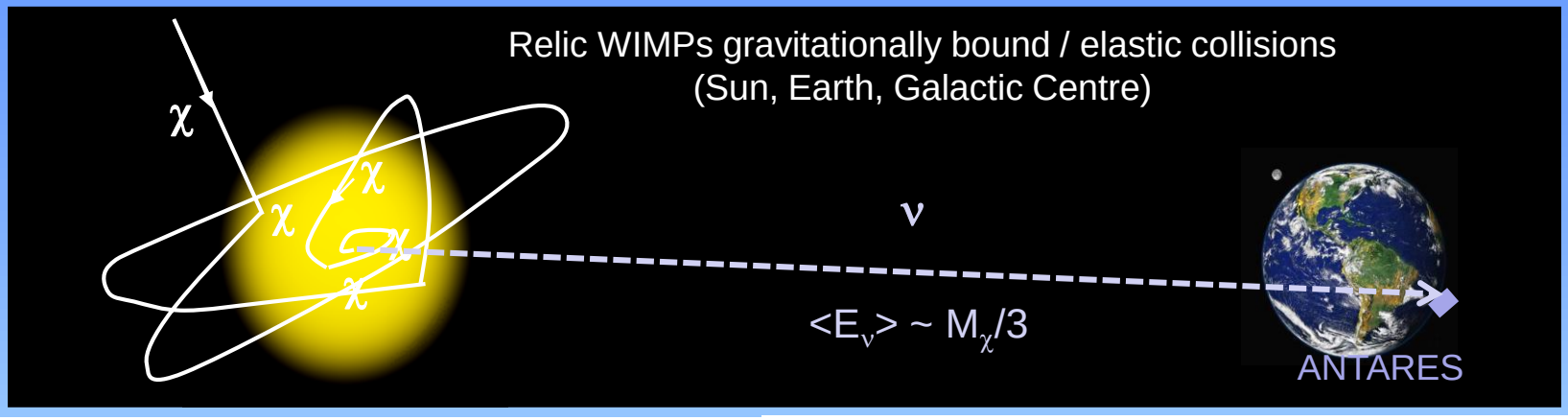


- Combined analysis Ligo/Virgo, IceCube and ANTARES (dominates for Eν < 100 TeV)
- **No counterpart observed so far** (in ±500 s)
  → **Total energy radiated in neutrinos <10%**

Now real time follow-up of ongoing science run

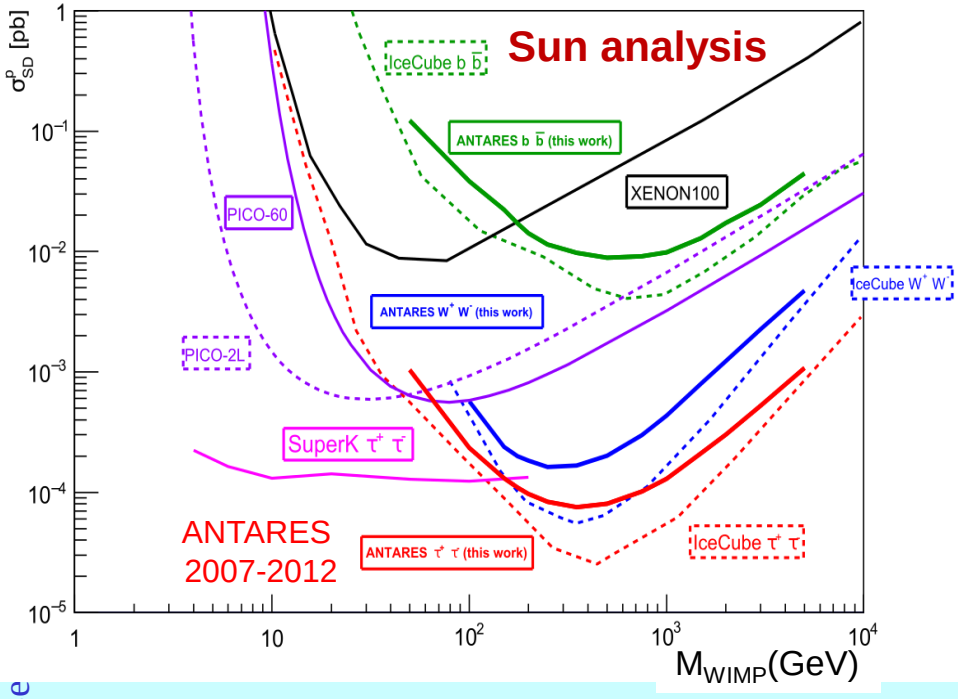
📖 PRD 93 (2016) 122010 📖 PRD 96 (2017) 022005

Indirect Searches for Dark Matter

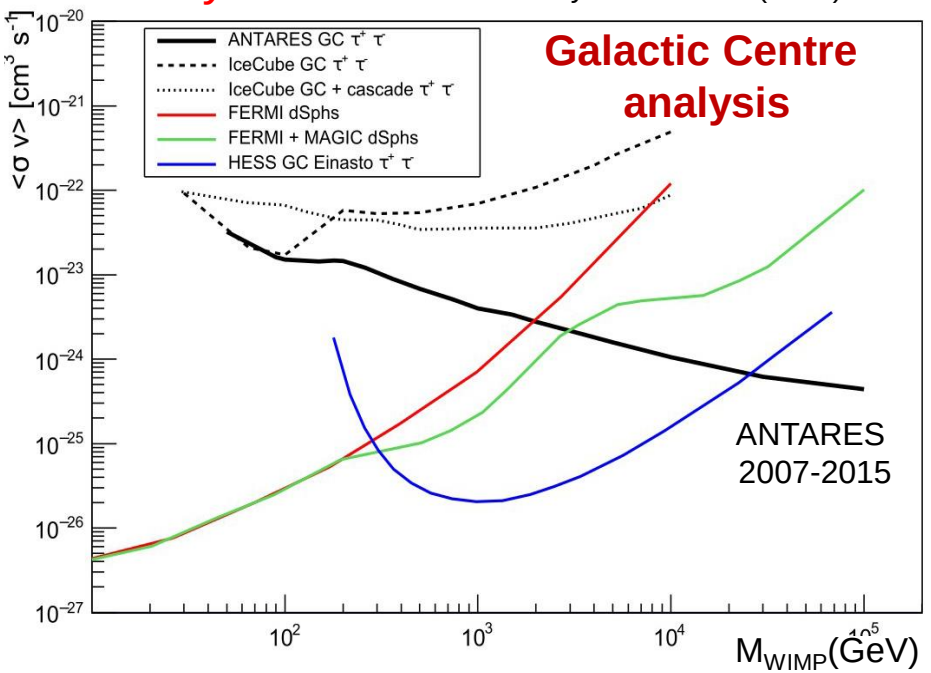


Track channel only

📖 Phys.Lett. B 759 (2016) 69



📖 Phys. Let. B 769 (2017) 249

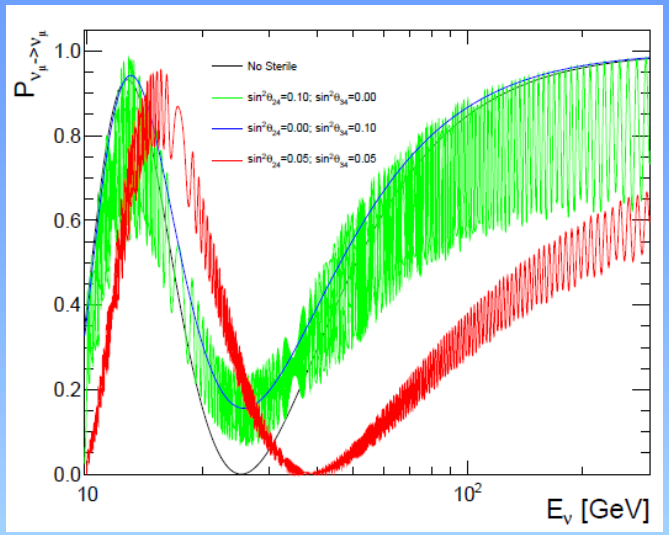


Also Secluded DM from the Sun : 📖 JCAP 05 (2016) 016
and DM from the centre of the Earth : 📖 Physics of the Dark Universe 16 (2017) 41

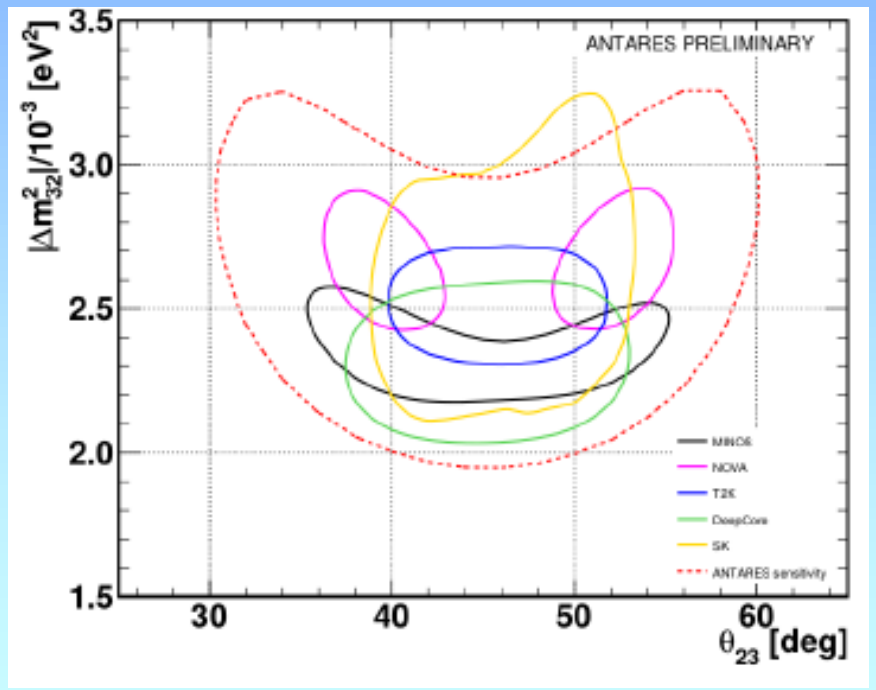
Oscillations of atmospheric neutrinos

New analysis on-going with dedicated energy reconstruction optimized for low energy events

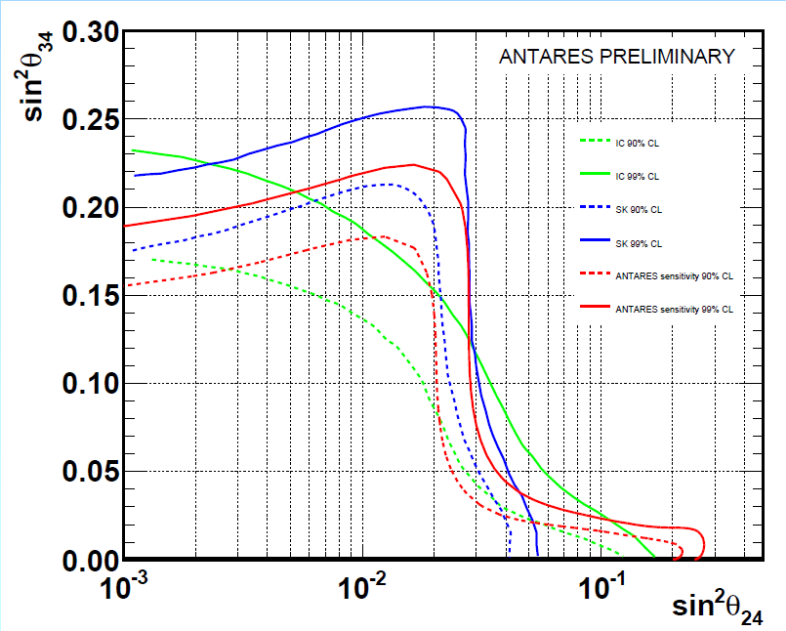
📖 POS (ICRC2017) 1026



Sensitivity to neutrino mixing parameters



Sensitivity to sterile neutrino



Data unblinding & results after Summer

Summary & Perspectives

- **ANTARES**, the largest Neutrino Telescope in the Northern Hemisphere, is celebrating **10 years of continuous data taking**
- Cascades events included in analyses with up to **3° angular resolution → all flavour neutrino searches**

- **Strongest limits for galactic point sources** in Southern Hemisphere with $E\nu < 100$ TeV
- Interesting constraints on **origin of IceCube signal**
- **Small excess of HE neutrinos**, of magnitude expected from IceCube cosmic flux

- **Many multi-messenger analyses** looking for transient sources (Radio, Optical, X/γ-Rays, TeV gammas, GW)
- **Competitive results in Dark Matter searches**

Demonstration of great potential of Deep Sea Neutrino Telescopes

→ To be exploited with KM3NeT

(cf talks of P. Sapienza on Tue. 25th & J. Hofestädt on Thu. 27th)