Highlights from the ANTARES neutrino telescope

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on behalf of the ANTARES collaboration

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ANTARES: the largest Northern neutrino telescope

Scientific goals

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

Not discussed today

The ANTARES site

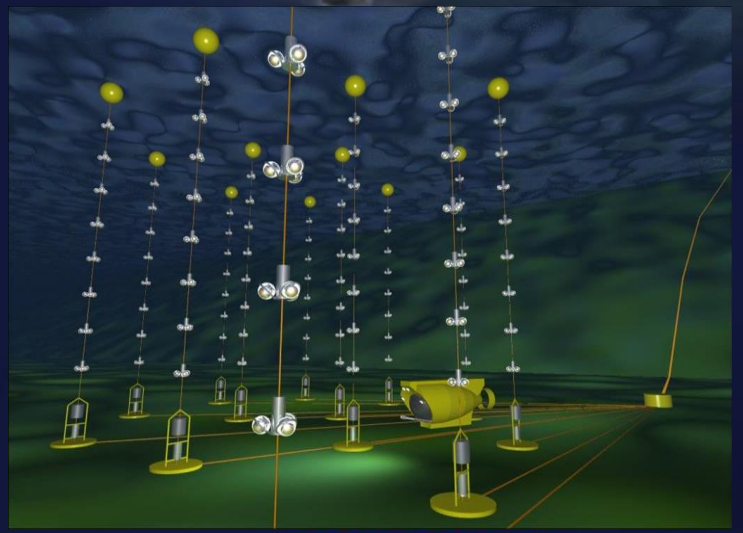
Toulon

Institut M. Pacha

control room

La Seyne-sur-Mer

Electro-optical
Cable of
40 km

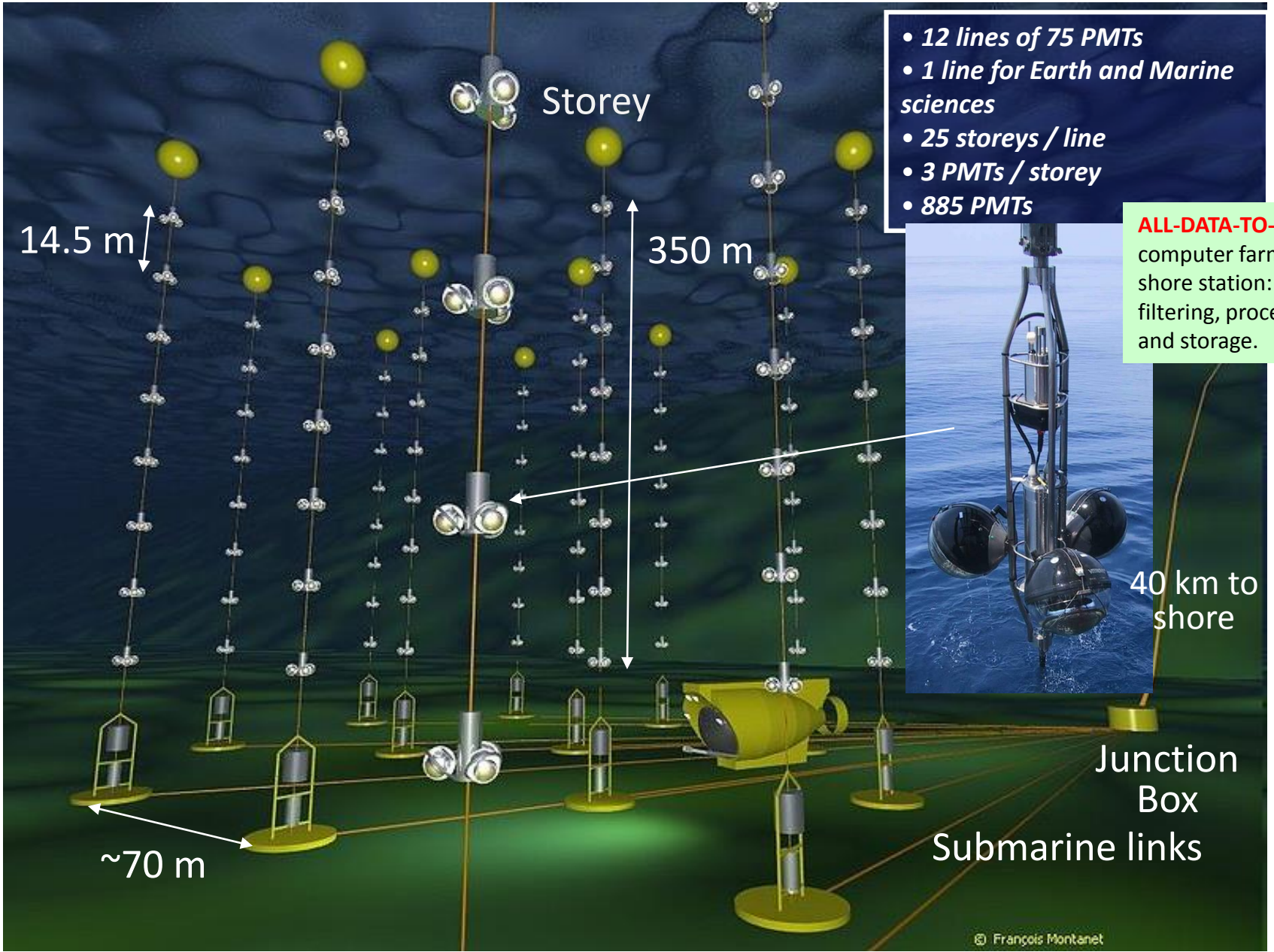


Site ANTARES

42° 50' N, 6° 10' E

2500 m under s.l.

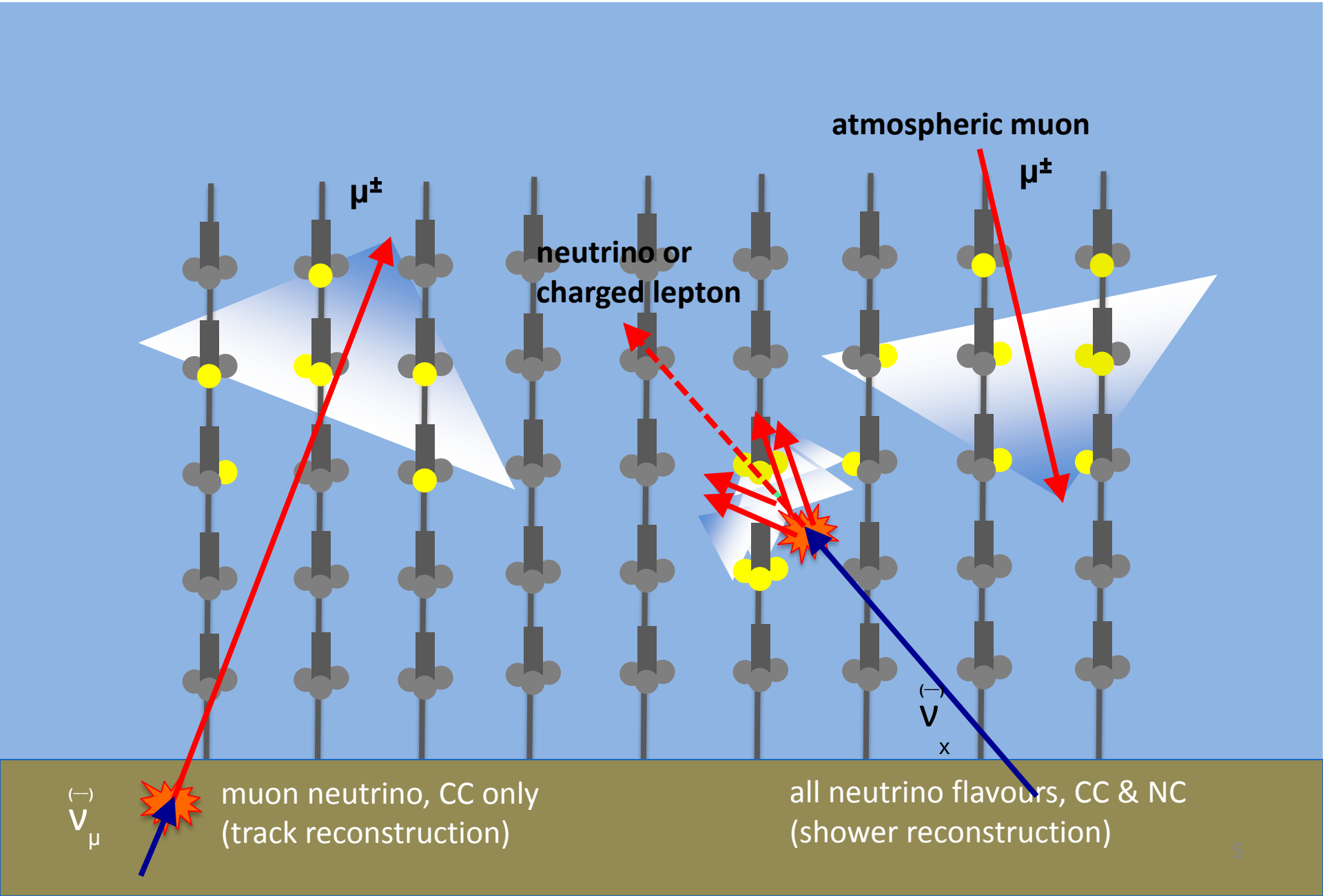
The telescope: full configuration since 2008



- *12 lines of 75 PMTs*
- *1 line for Earth and Marine sciences*
- *25 storeys / line*
- *3 PMTs / storey*
- *885 PMTs*

ALL-DATA-TO-SHORE: computer farm @ the shore station: data filtering, processing and storage.

How does a neutrino telescope work?



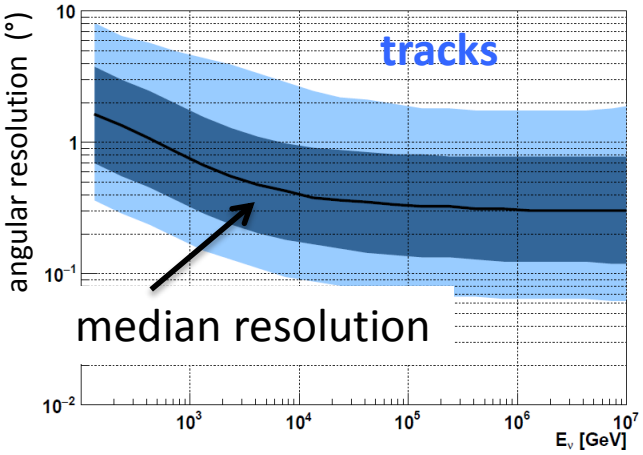
ANTARES performances

ANTARES angular resolution vs E$_\nu$

Tracks (ν_μCC) ideal tool for astronomy

Median **<0.4°** above 10 TeV

90% purity

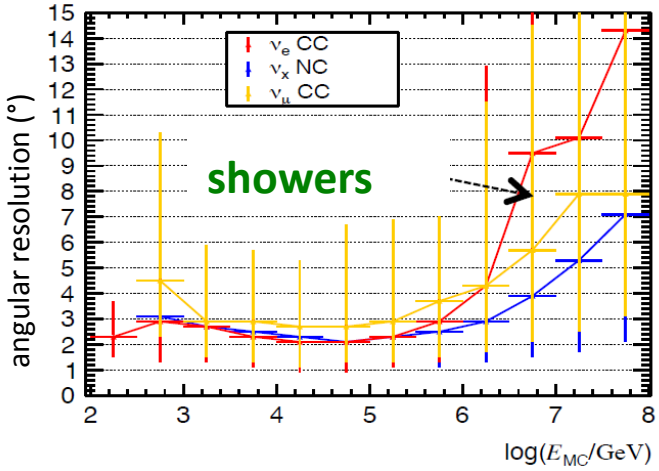


Upgoing **cascade events** (ν_eCC, NC)

Angular resolution **≈ 3°**

Shower confined within ≈ 10 m → Contained events

Good estimate of the ν energy, better than 10%

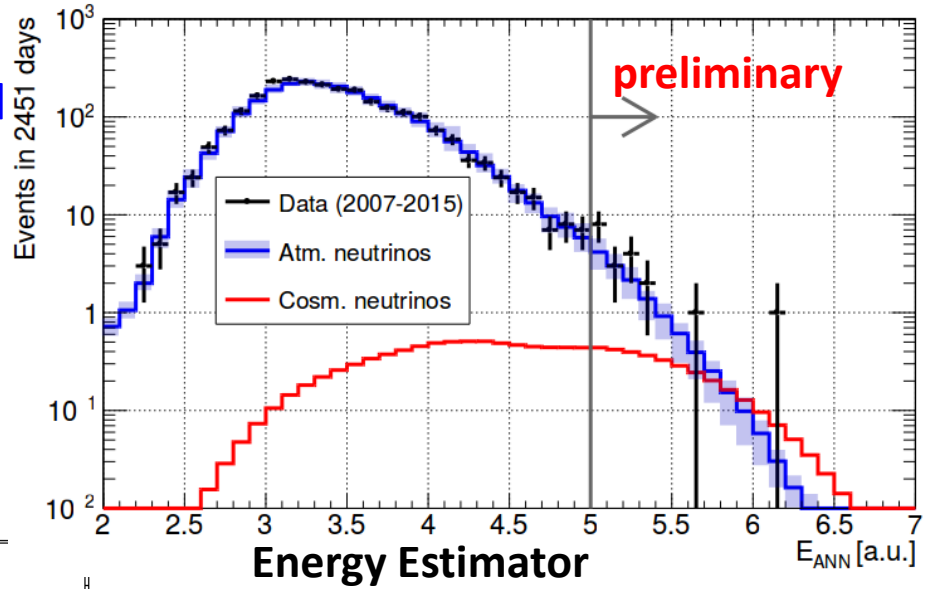


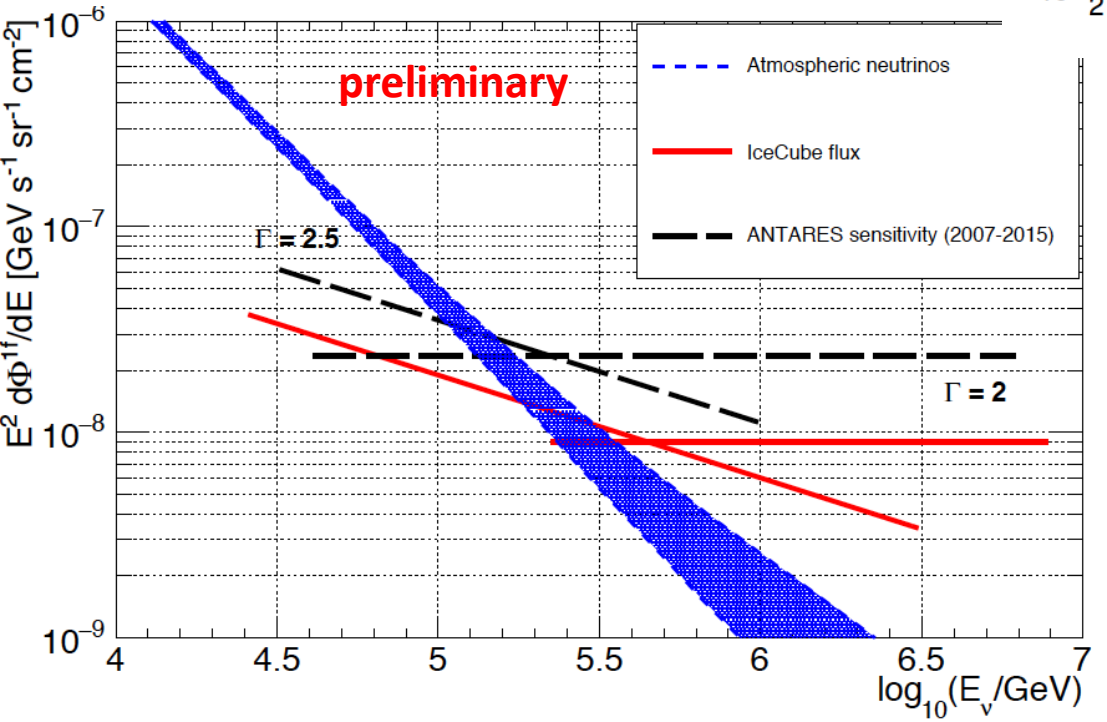
ANTARES searches for neutrino flux

1. Searches for a diffuse flux
2. Searches for point-like sources
3. Searches for diffuse flux with reduced search window
4. Transient/multimessenger studies

1. ANTARES diffuse flux (tracks)

- Search for excess of **reconstructed** HE events over the atmospheric { background
- Data: 2007-2015 **(2451 livedays)**
- Optimization based on IC best fit flux (spectral index Γ = 2 and 2.5)
- Variables checked with burn sample ('0' ending runs)



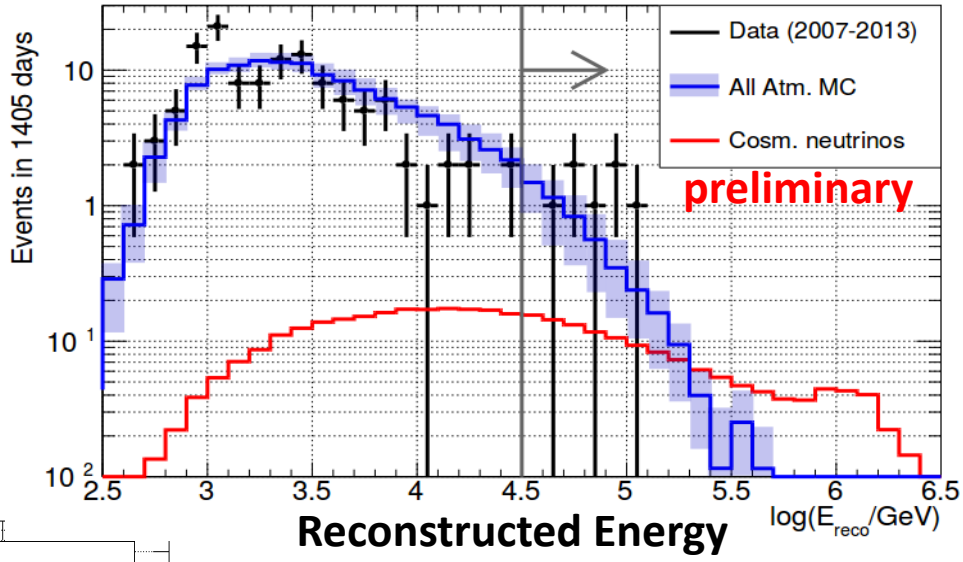


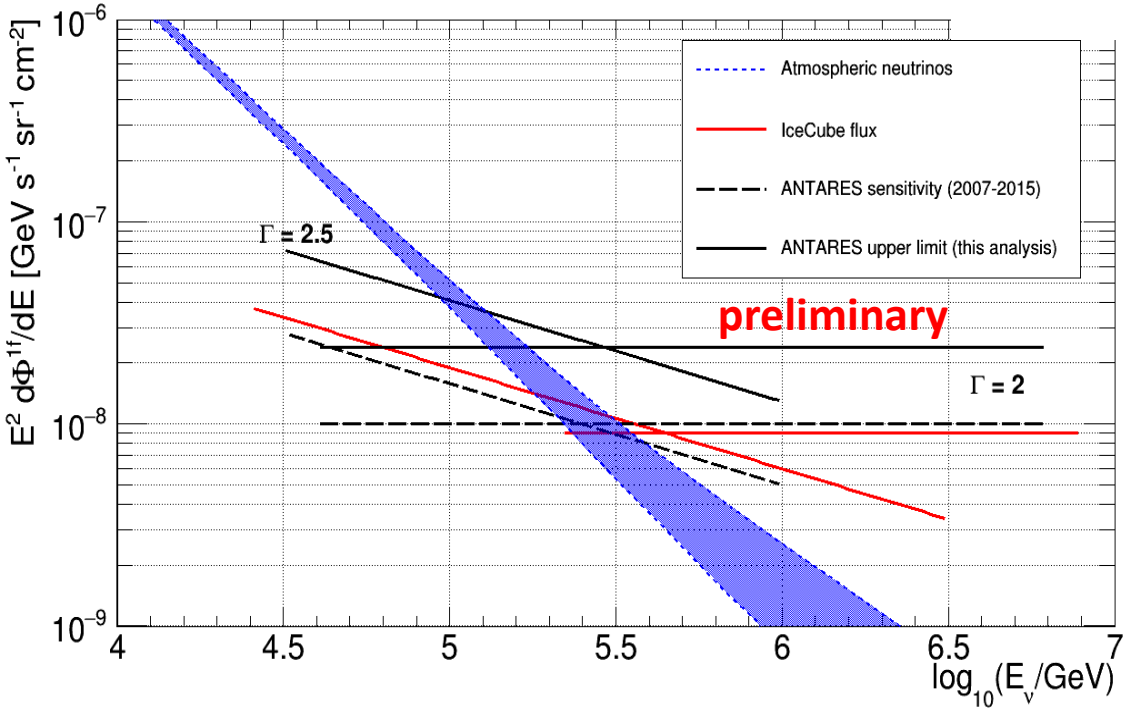
Above E_{cut}:

- Background: 13.5 ± 3
- IC-like signal: 3 events
- Observed: **19 events**

1. ANTARES diffuse flux (cascades)

- Search for excess of **reconstructed** HE events over the expected atmospheric background
- Data: 2007-2013 **(1405 livedays)**
- Optimization based on IC best fit flux (spectral index Γ = 2 and 2.5)
- Variables checked with burn sample ('0' ending runs)



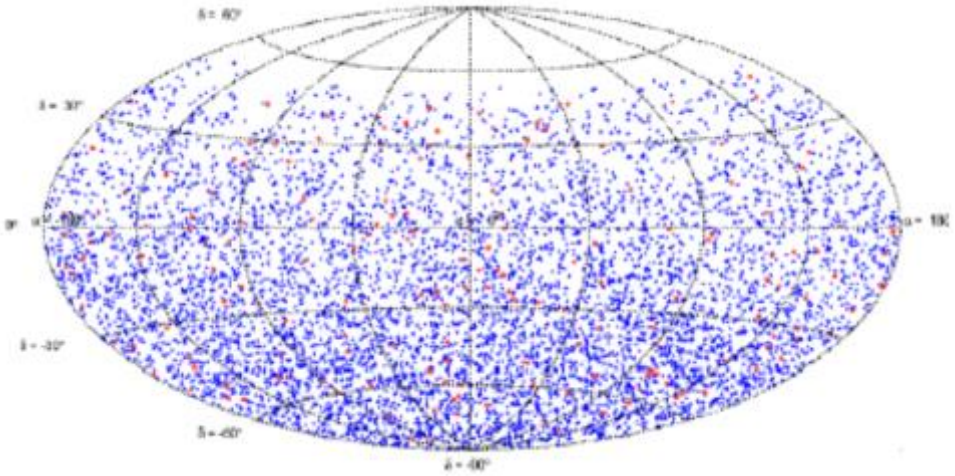


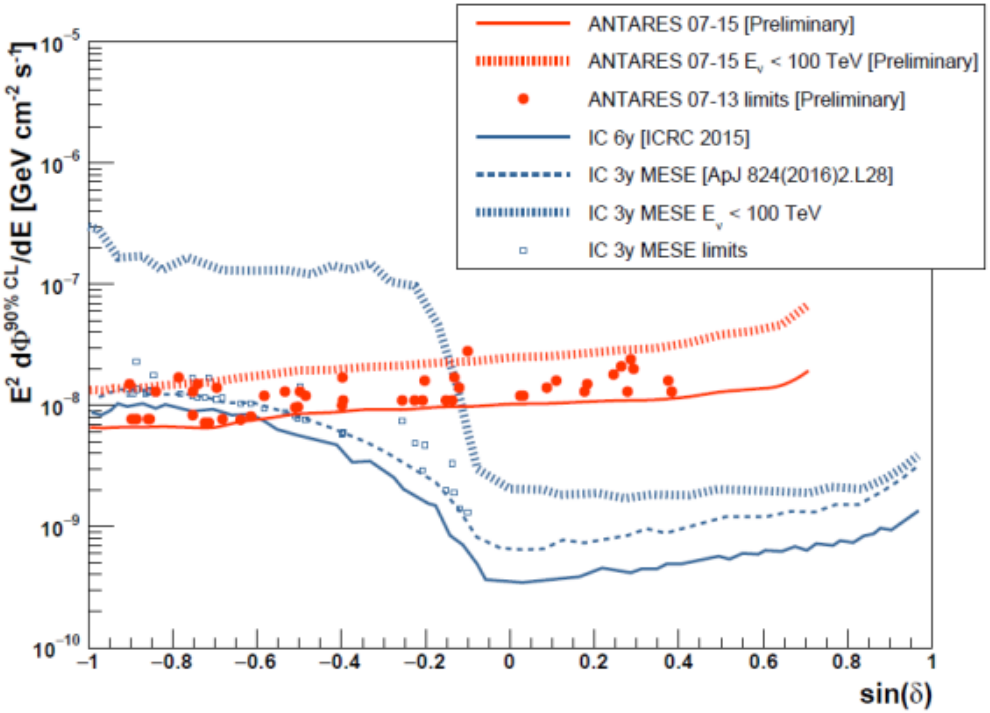
Above E_{cut}:

- Background: 5± 2
- IC-like signal: 1.5 evts
- Observed: **7 evts**

ANTARES combined **upper limits** and sensitivity (2007-2015) tracks + showers

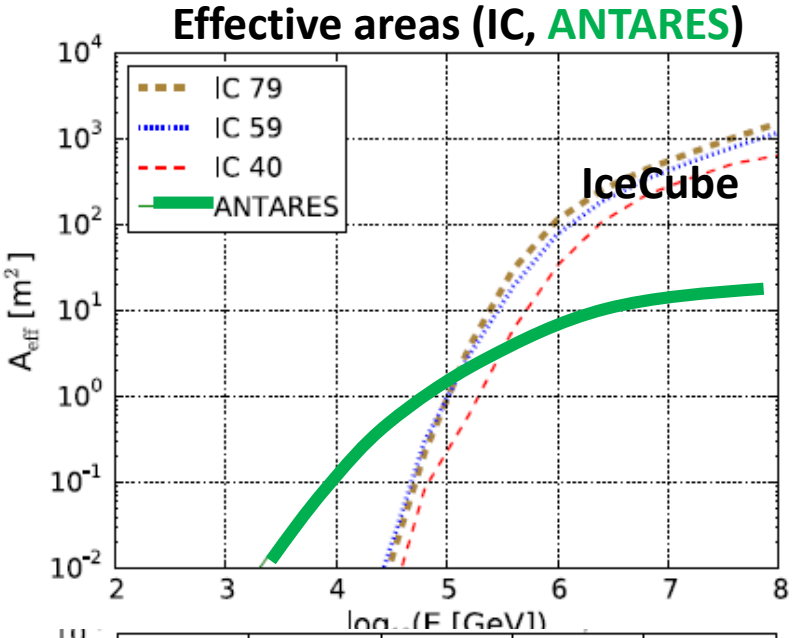
2. Point sources

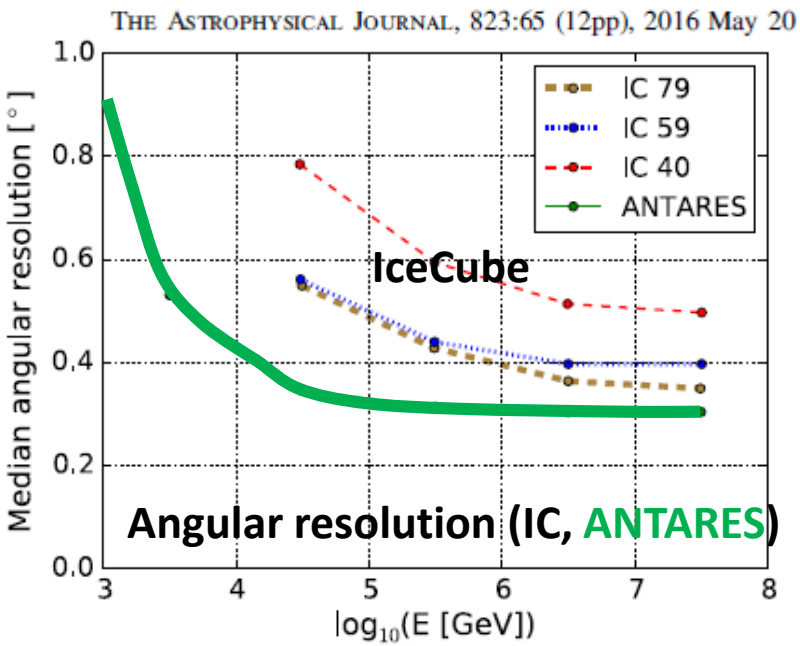


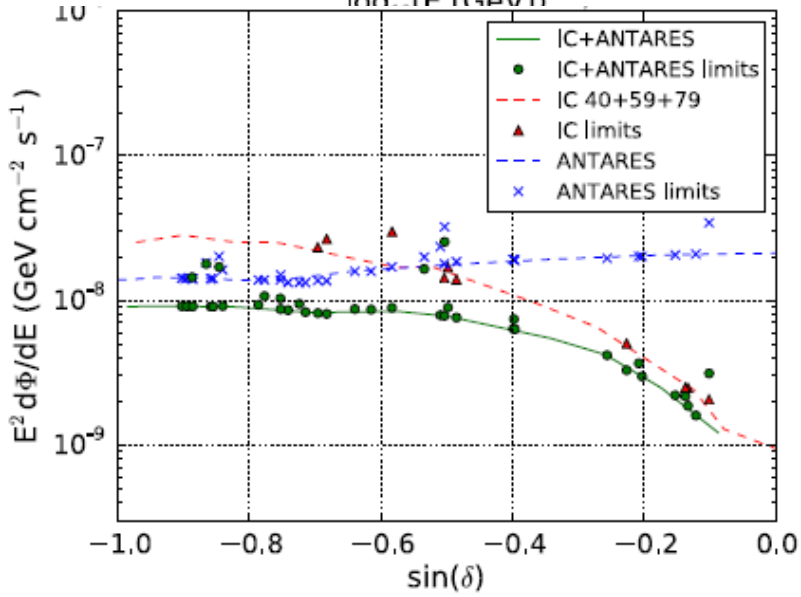


- 2007-2013: 1690 days
  (+2014-2015 next weeks)
- **6490 tracks**
  172 cascades
- Unbinned all-sky search
- 54 candidate sources +
  8 HESE μ
- Best limit for E<100 TeV

2. Joined ANTARES-IceCube PS searches







- Combined 90% CL sensitivities (green line) and limits (points) for E^{-2} spectrum.
- Blue (Red) curves/points indicate ANTARES (*IceCube*) sensitivities/limits

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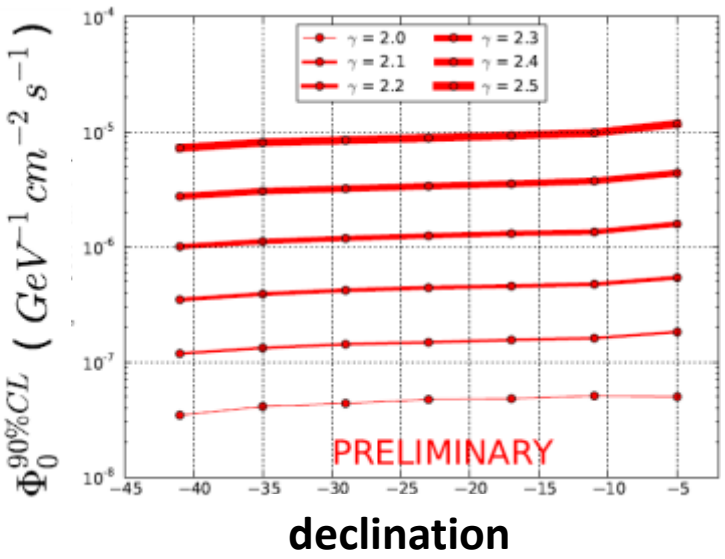
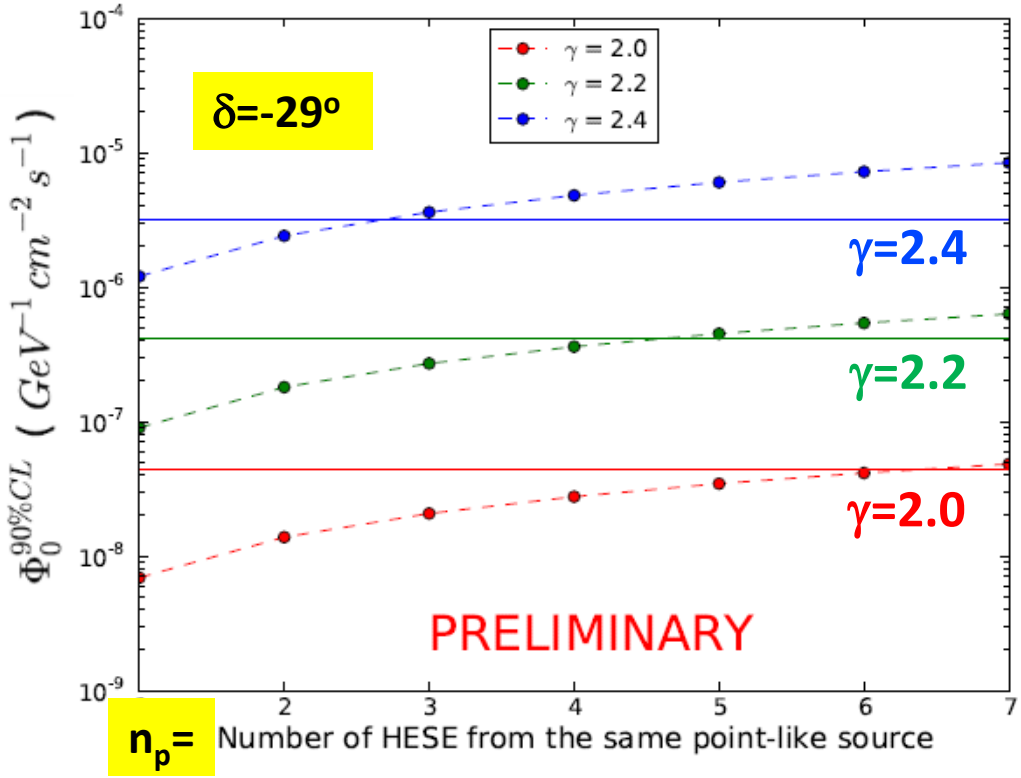
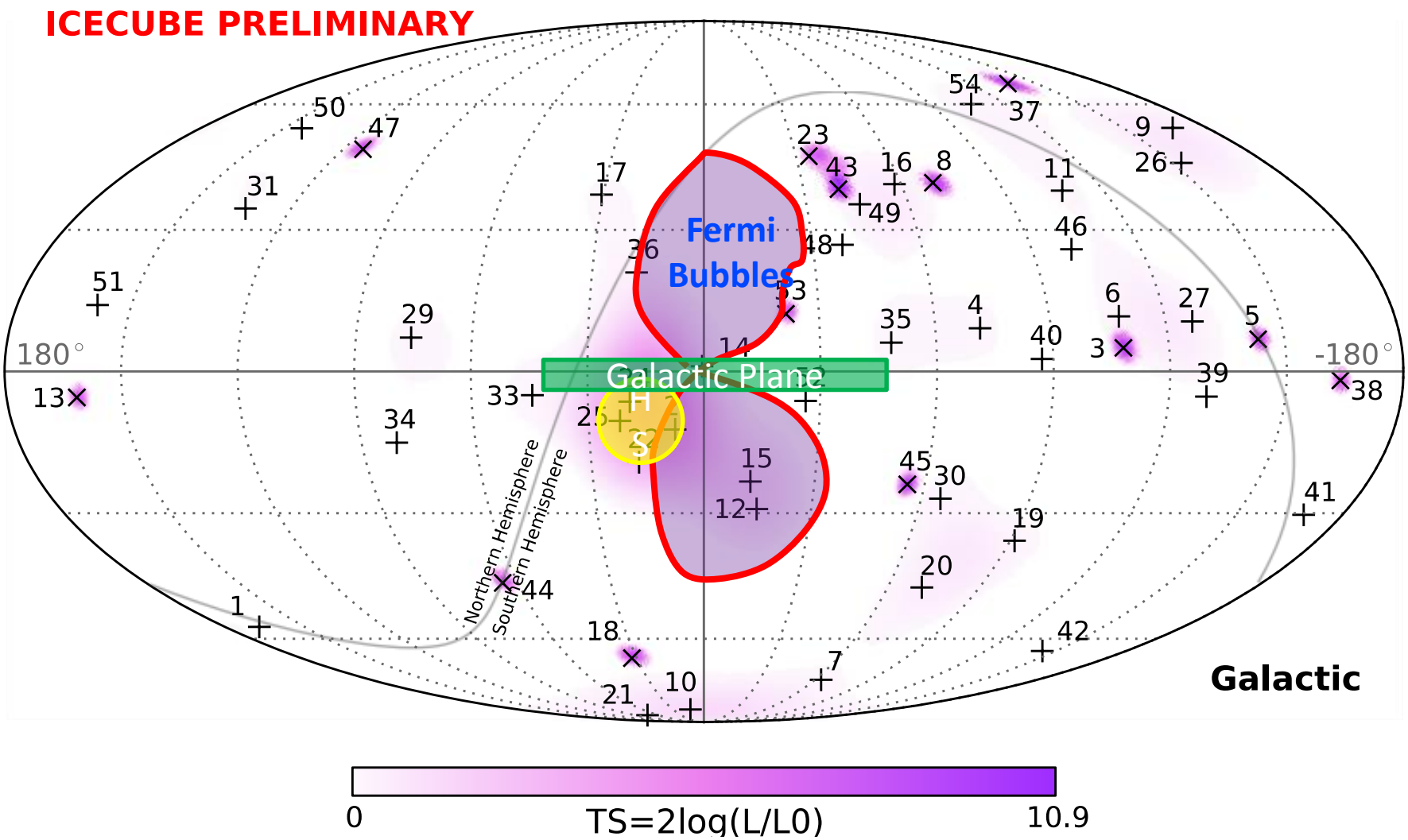
2.What about the IC signal? Hidden PS producing n_p HESE?

- A Point Source with $\Phi_0 E^{-\gamma}$ can produce some of the HESE?
- The ANTARES 90% C.L. upper limit excludes that a single point-like source produces n_p>6 HESE, assuming γ=2.0.
- A single point-like source yielding n_p>3 is excluded for γ=2.3





3. “Enhanced” diffuse flux ?



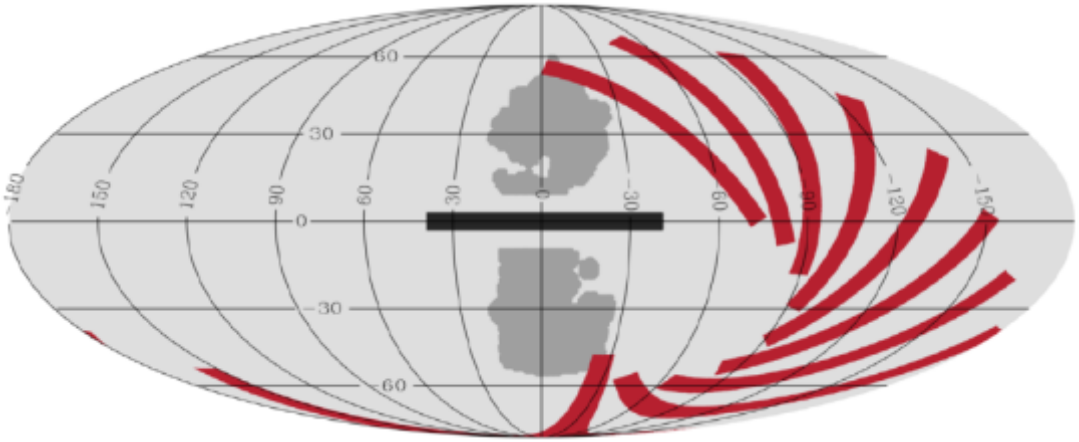
3. The Galactic ridge

- ν's and γ-rays produced by CR propagation

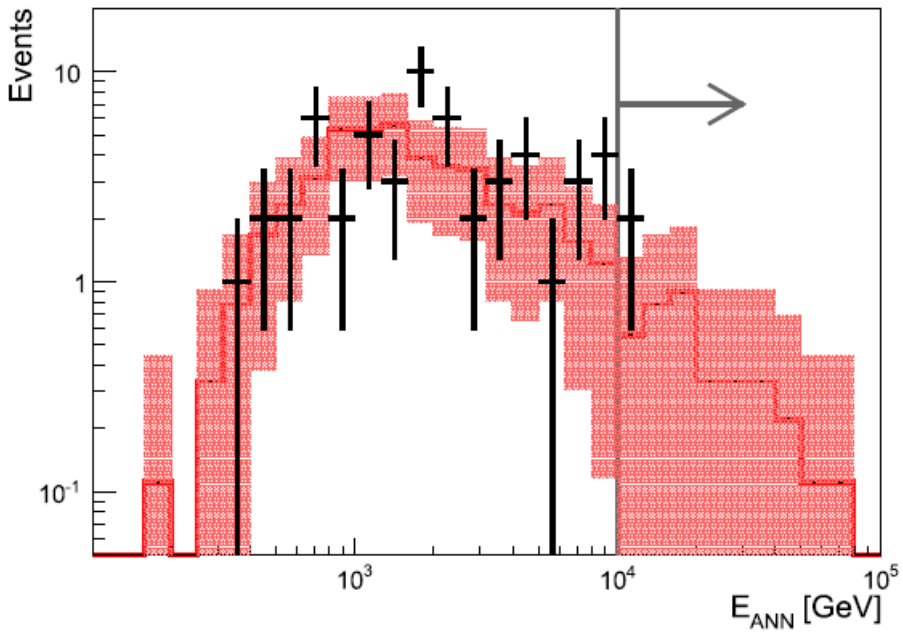
$$p_{CR} + p_{ISM} \rightarrow \pi^0 \pi^{\pm} \ldots$$

$$\pi^0 \rightarrow \boldsymbol{\gamma\gamma(EM\ cascade)}$$

$$\pi^{\pm} \rightarrow \boldsymbol{\nu_\mu, \nu_e} \ldots$$



- Search for ν_μ, data 2007-2013
- Search region |l|<30°, |b|<4°
- Cuts optimized for Γ=2.4-2.5
- Counts in the signal/off zones
- No excess in the HE neutrinos
- 90% c.l. upper limits: 3<E_ν<300 TeV
- **Phys Lett B760 (2016) 143**



Physics Letters B 760 (2016) 143–148

Contents lists available at ScienceDirect

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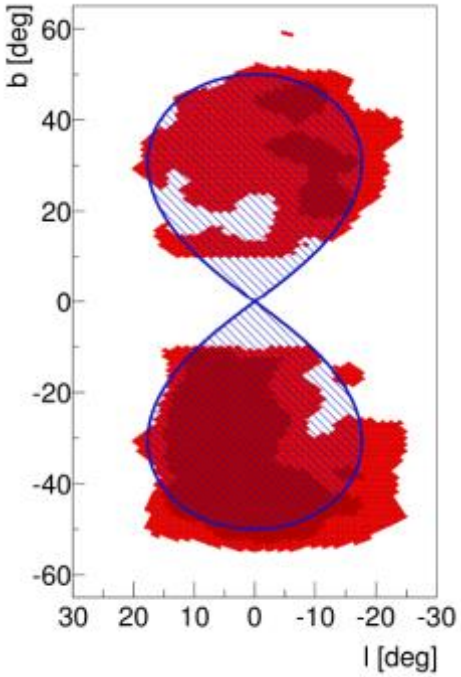
Constraints on the neutrino emission from the Galactic Ridge with the ANTARES telescope

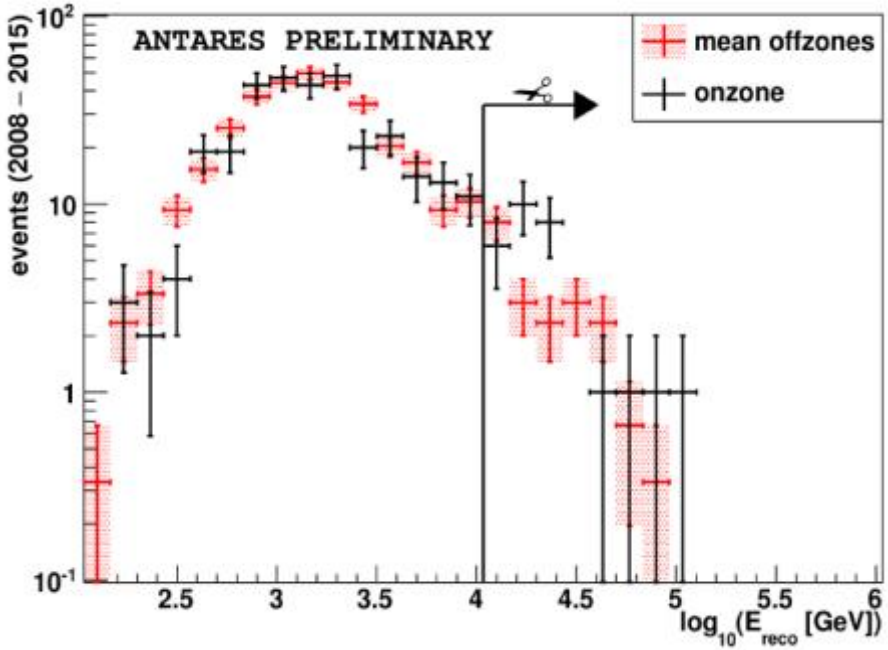
S. Adrián-Martínez [a], A. Albert [b], M. André [c], M. Anghinolfi [ab], G. Anton [d], M. Ardid [a]

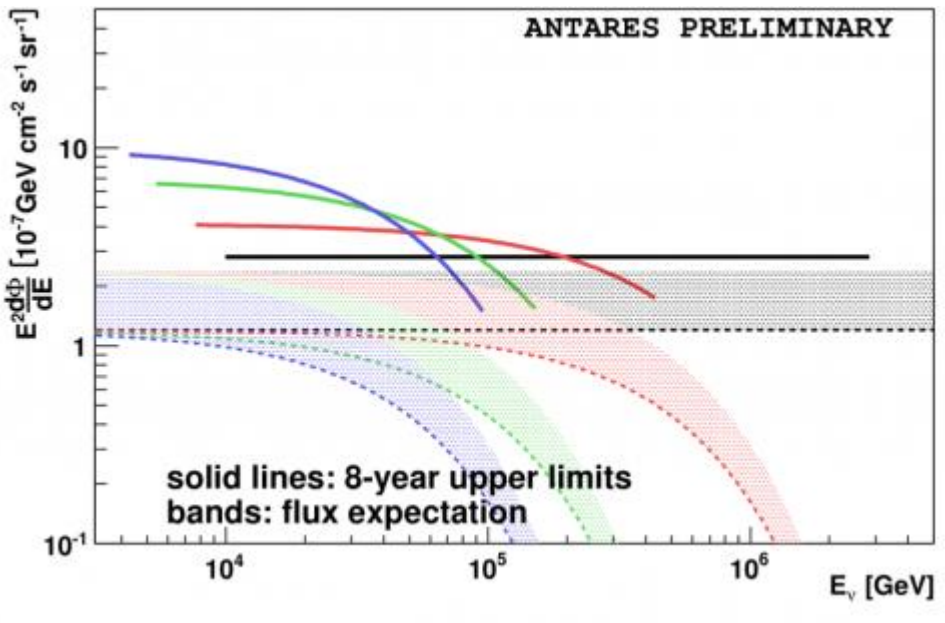
3. ν from Fermi Bubbles

- ν can check the hadronic origin of the emission from the bubbles
- E^{-2} ,$E^{-2.18}$ spectra [Lunardini et al. PRD92 (2015)] and different cutoff : 50, 100, 500, ∞ TeV
- comparison on-zones/off-zones (3) of $\Delta\Omega$=0.66 sr
- 2008-2015 analyzed (806+366+**593 (new)** days).
- **28** events observed /**19.7** average bck expected
- Excess of 1.5σ (lower than in the previous analysis)



ANTARES EPJ C (2014) 74:2701



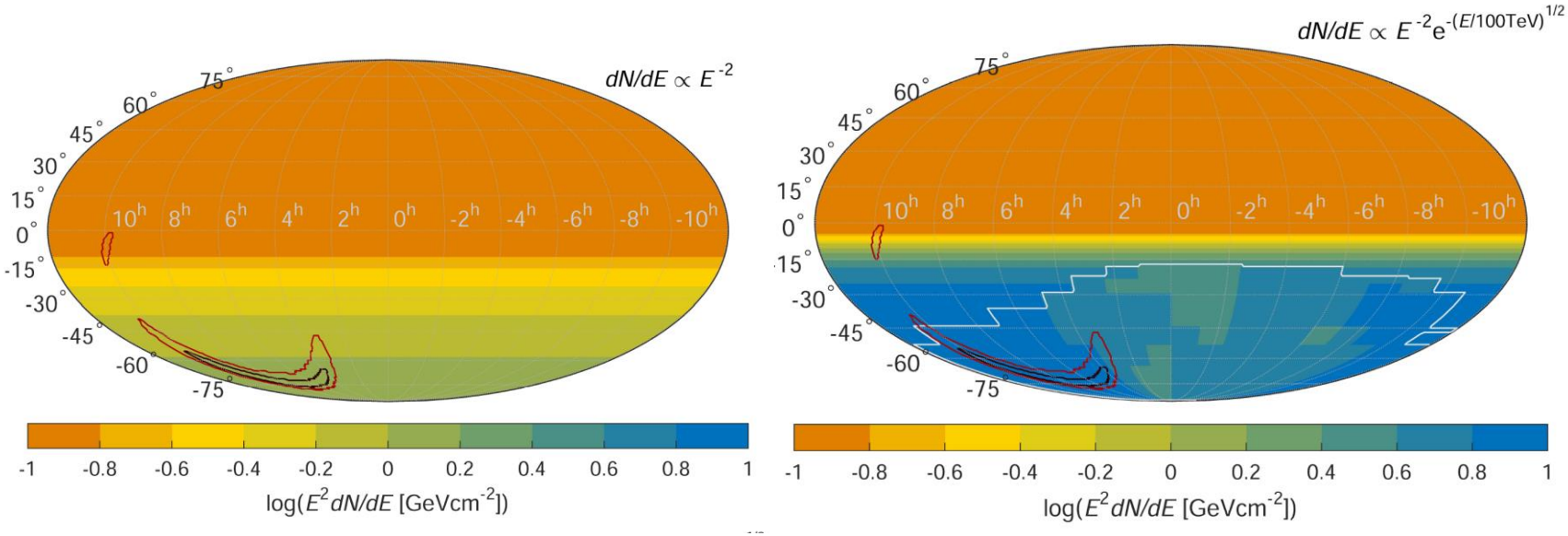


4. Multimessenger program

Multi wavelength follow-up of neutrinos

	Radio	**Visible**	**X-ray**	**GeV-ray**	**TeV-ray**	**GW**	}
	MWA	TAROT ZADKO MASTER	Swift	Fermi-LAT	HESS HAWC	Ligo Virgo	IC
Alerts	12/yr	30/yr	6/yr	(Offline)	(1-10/yr)		(Offline)

Neutrino follow-up of GW150914



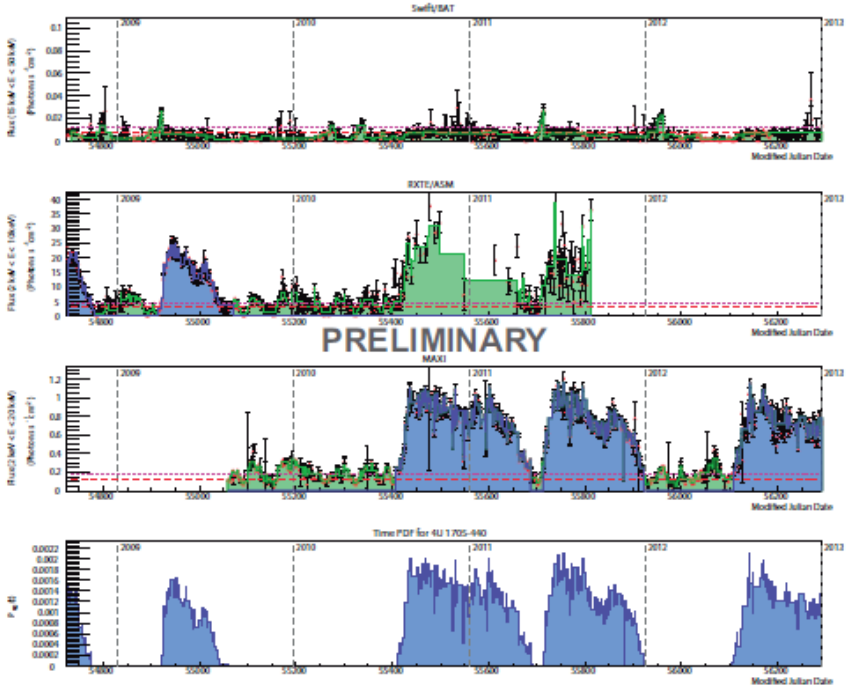
- Limits from ANTARES dominates below O(100 TeV) (white line)
- Size of GW150914 : 590 deg^2 ANTARES resolution: <0.5 deg^2
- GW resolution much improved with LSC+Virgo; better localization for further follow-up
- Limits on total energy radiated in neutrinos: <10% GW
- Future: Receive / send alerts in real time

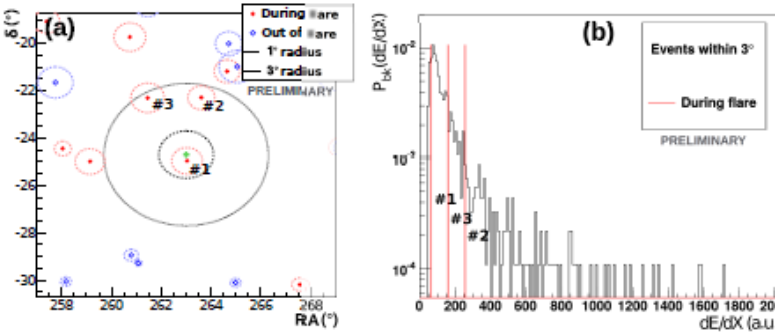
$$E^{ul}_{\nu,tot} \sim 10^{52}\text{–}10^{54} \left(\frac{D_{gw}}{410\,\mathrm{Mpc}}\right)^2 \mathrm{erg}$$

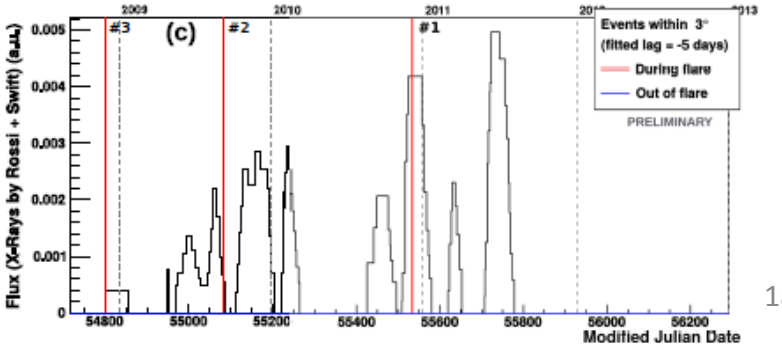
Phys.Rev. D93 (2016) no.12, 122010

ν_μ associated with GeV and TeV γ-ray flaring blazars and X-ray binaries

- Search for ν's (2008-2012) correlated with high activity state
- **Blazars** monitored by FERMI-LAT and IACTs (**JCAP 1512 (2015), 014)**
- **33 X-ray binaries** during flares observed by Swift-BAT, RXTE-ASM and MAXI. Transition states from telegram alerts (paper in prep.)
- No significant excess (best post-trial 72% for GX 1+4).
- Upper limits on ν fluence and model parameters constrain

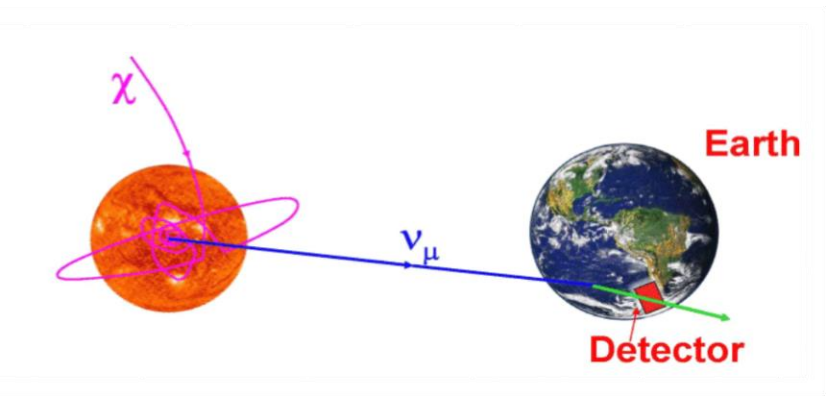






Dark Matter searches

Searches for a possible ν_μ excess due to DM annihilation from the Galactic center, the Sun core, the Earth nucleus



Dark Matter from the Sun and the Galactic Centre

$$X_{\mathrm{WIMP}}\bar{X}_{\mathrm{WIMP}} \rightarrow n\bar{n},\ \mathrm{b\bar{b}},\ \mathrm{W^-W^+},\ t^-t^+,\ m\bar{m}$$

- Gravitational trapping and accumulation of DM particles in the centre of astrophysical objects like the Sun and the Galactic centre
- DM annihilation would be produce a HE neutrino flux ➔ **very clean signature** **no significant astrophysical backgrounds** expected
- ν_μ spectrum →WIMPSIM [Blennow,Edsjö,Ohlsson,arXiv:0709.3898]
- Bkg estimated from time scrambled data.

No excess observed

DM from the Sun

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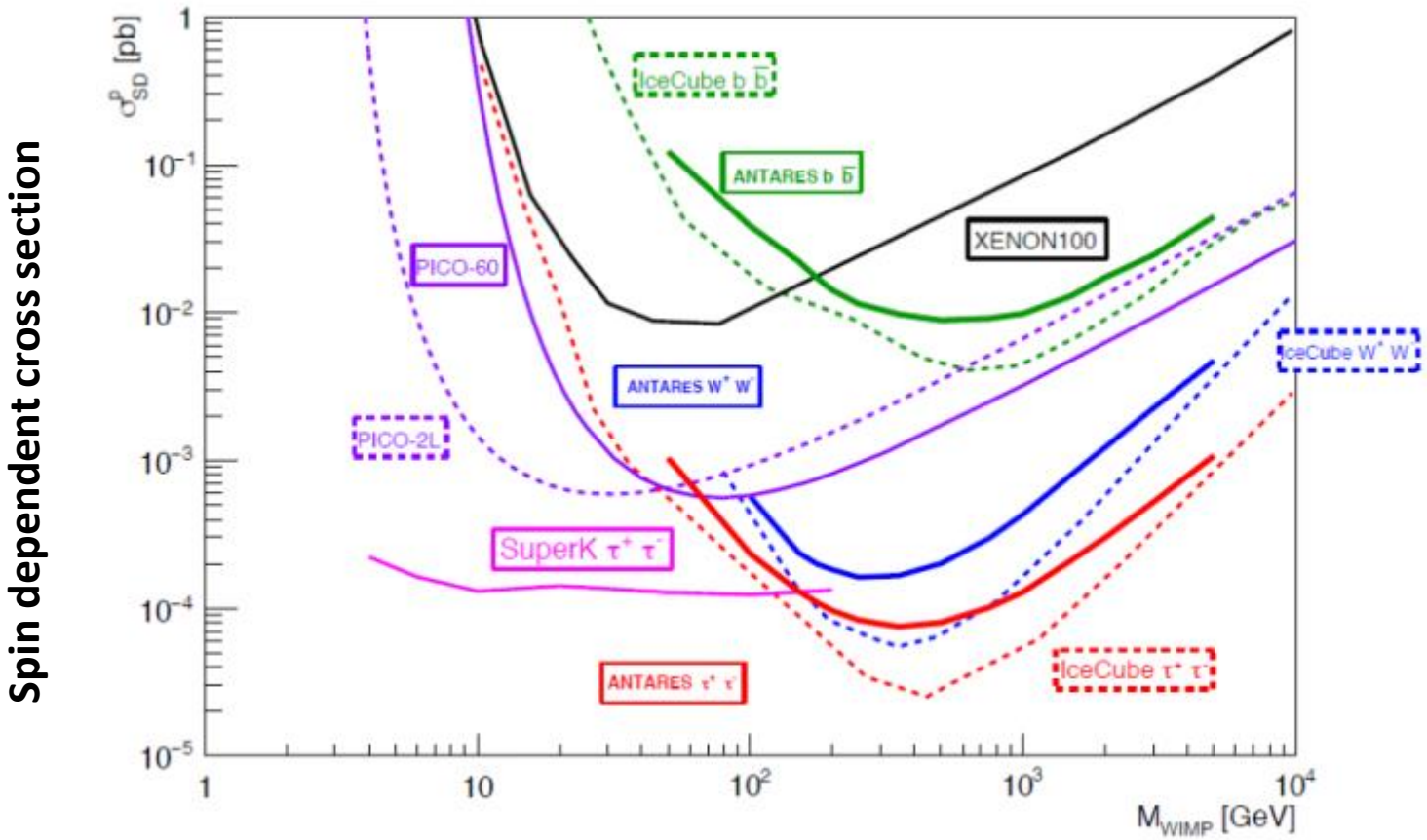


Limits on neutrino flux transformed in scattering cross section limit

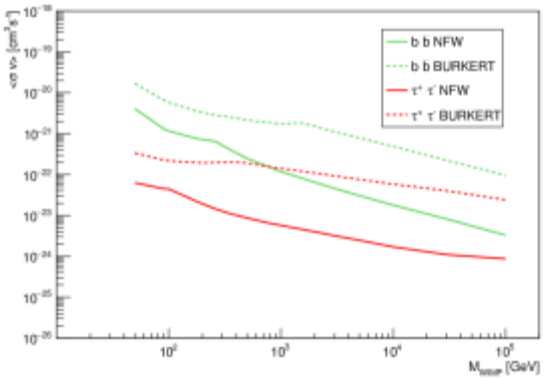
Neutrino telescopes → **most restrictive limits for spin-dependent** cross section

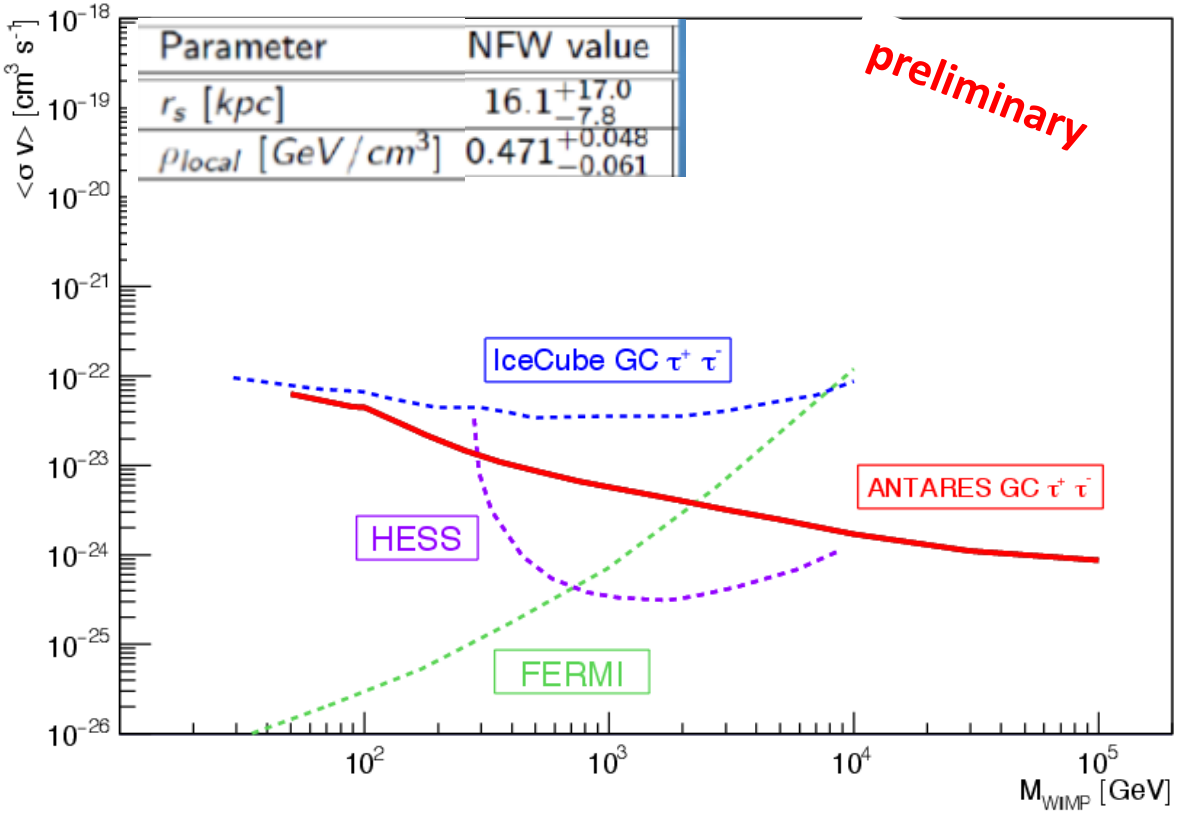
DM from the Galactic Center

- **Northern** hemisphere: **very good visibility of the GC** (Ice Cube: *veto* used)
- J-factor s calculated with CLUMPY (A.Chardonnier et al., Comp.Phys.Comm. 183, 656, 2012)

$$\frac{d\Phi}{dE}(E_\gamma, \psi, \theta, \Delta\Omega) = \frac{1}{4\pi} \frac{\langle\sigma_{ann} v\rangle}{2m_\chi^2} \frac{dN^i}{dE}$$ **Particle physics**

DM distribution x $$\int_0^{\Delta\Omega} d\Omega \int_{l.o.s} \rho^2(r(s, \psi, \theta))ds.$$



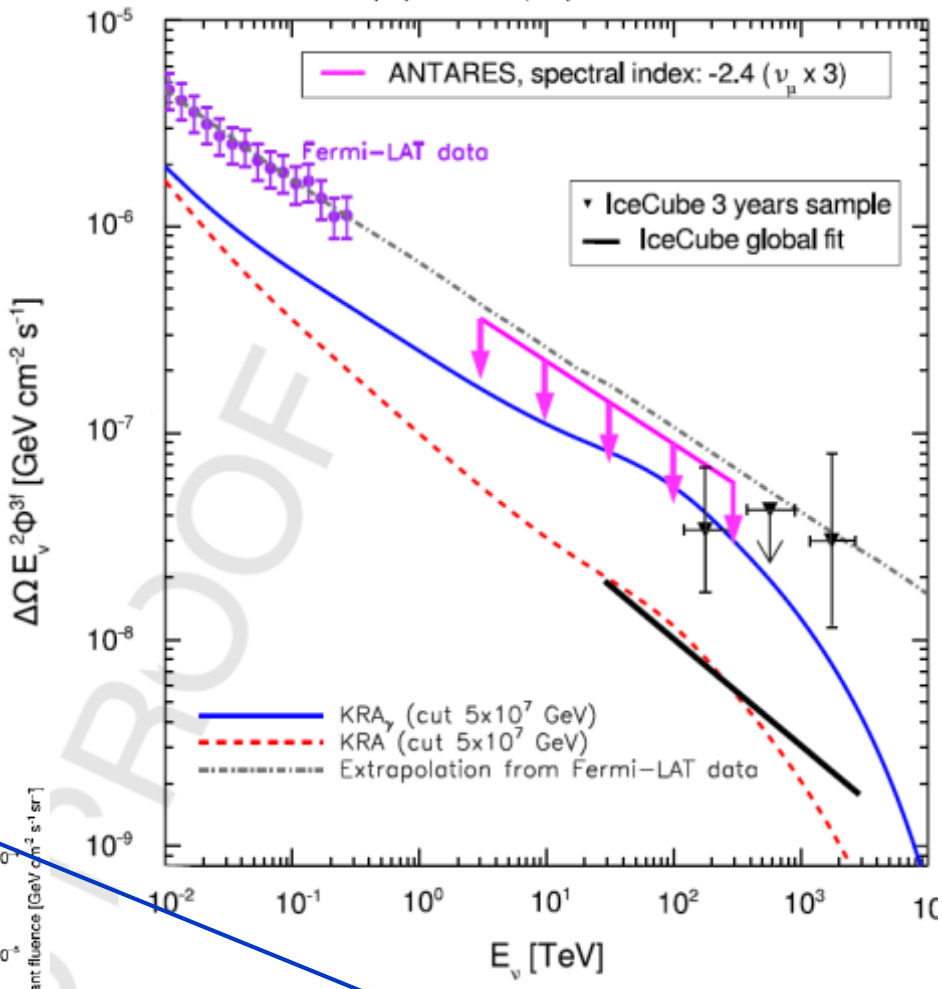


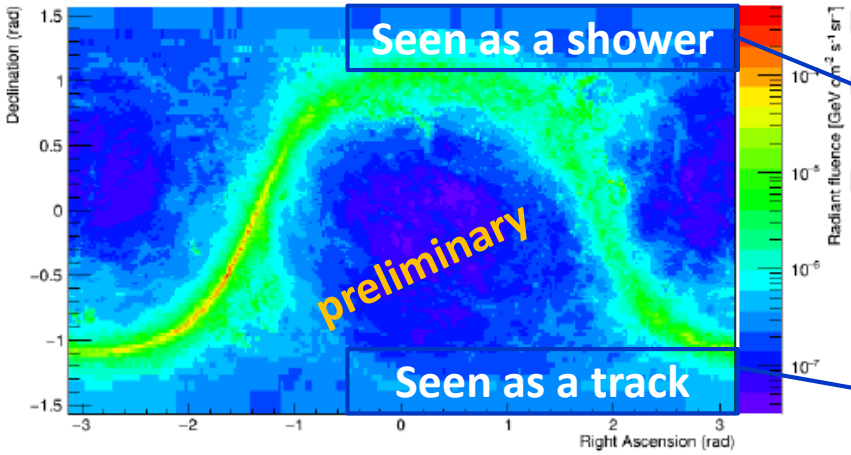
Summary

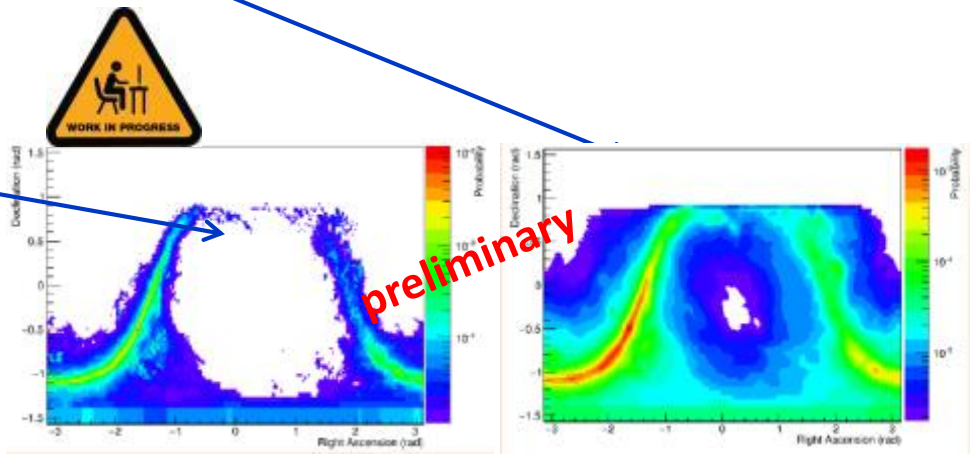
- **Search for a neutrino flux from the Southern sky** competitive sensitivities and excellent angular resolution in both ***track*** and ***cascade*** events:
  - Upper limits on known GeV-TeV γ-ray sources $<10^{-8}$ GeV/(cm^2 s)
  - A point-like source yielding >3 HESE is excluded for $\gamma \geq 2.3$
  - Sensitivity for a diffuse flux close to the level of the IC signal
- **Significant contribution** to understand the origin of cosmic neutrinos observed by IceCube
- Detailed study of **extended** regions (Galactic plane, Fermi Bubbles)
  - no ν_μ excess from the Galactic ridge/IC hot spot;
- A large **multimessenger** effort
  - EM radiation: radio (MWA), optical, X-ray, γ-rays (LAT,IACTs)
  - Gravitational Wave observatories and IceCube
- Important contribution to the indirect searches for **Dark Matter**

The future: KM3NeT

- The simple extrapolation of the *Fermi*-LAT γ-ray measurement to the IC ν flux in the Galactic Plane area excluded
- For a neutrino flux $\propto E^{-2.5}$ ≥ 3 HESE originating in this region excluded at 90% c.l.
- **More information soon** (tracks up to 2015+cascades) and max-likelihood analysis







- ν's yield (positions and E): **KRAγ model**