Highlights of the ANTARES Neutrino Telescope

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on behalf of the ANTARES collaboration

HEP-EPS 2017, 6 Jul 2017 - Venezia

ANTARES: the largest neutrino telescope in the Nothern hemisphere

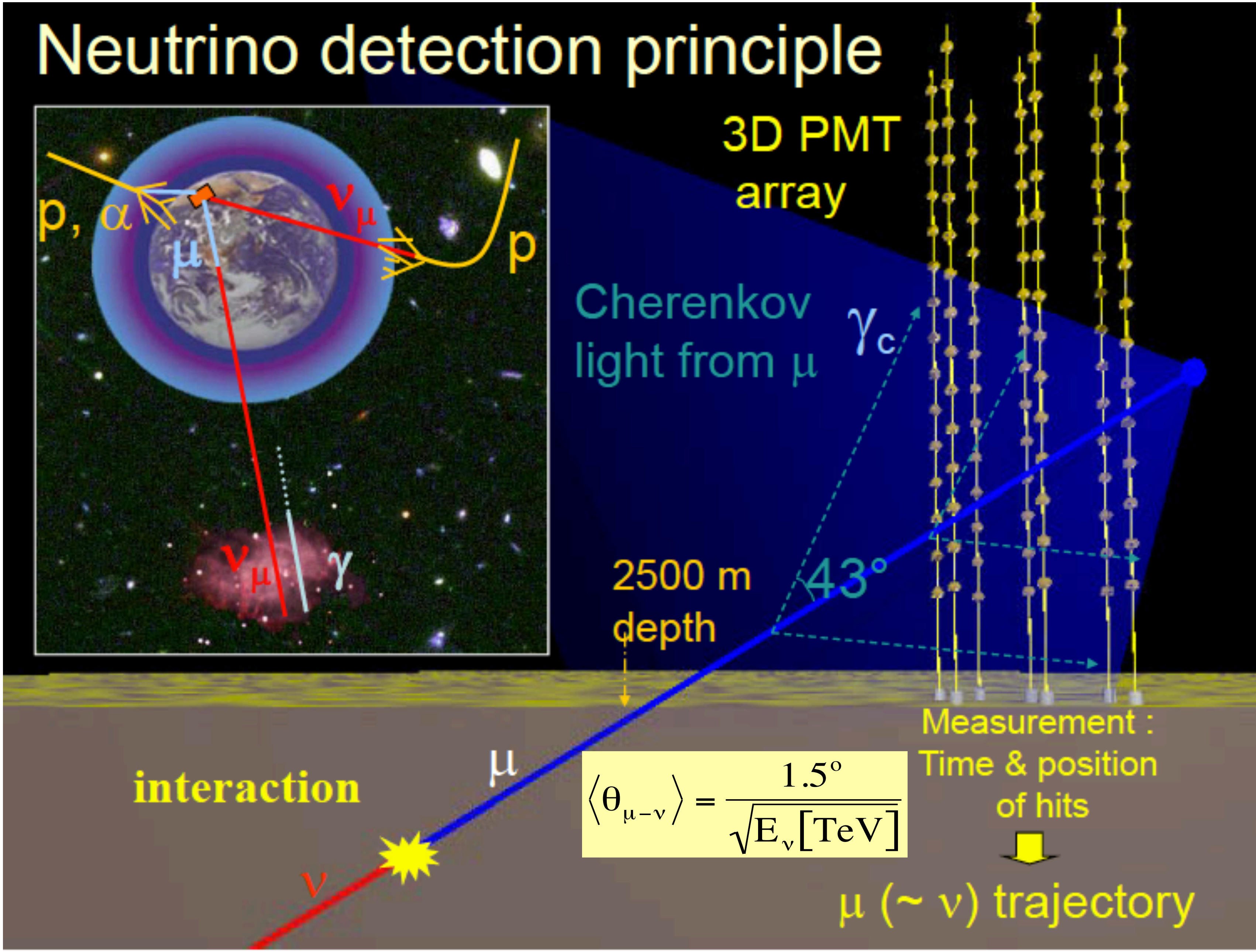
2006 PARTIAL CONFIGURATION
2008 COMPLETED

Scientific goals

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

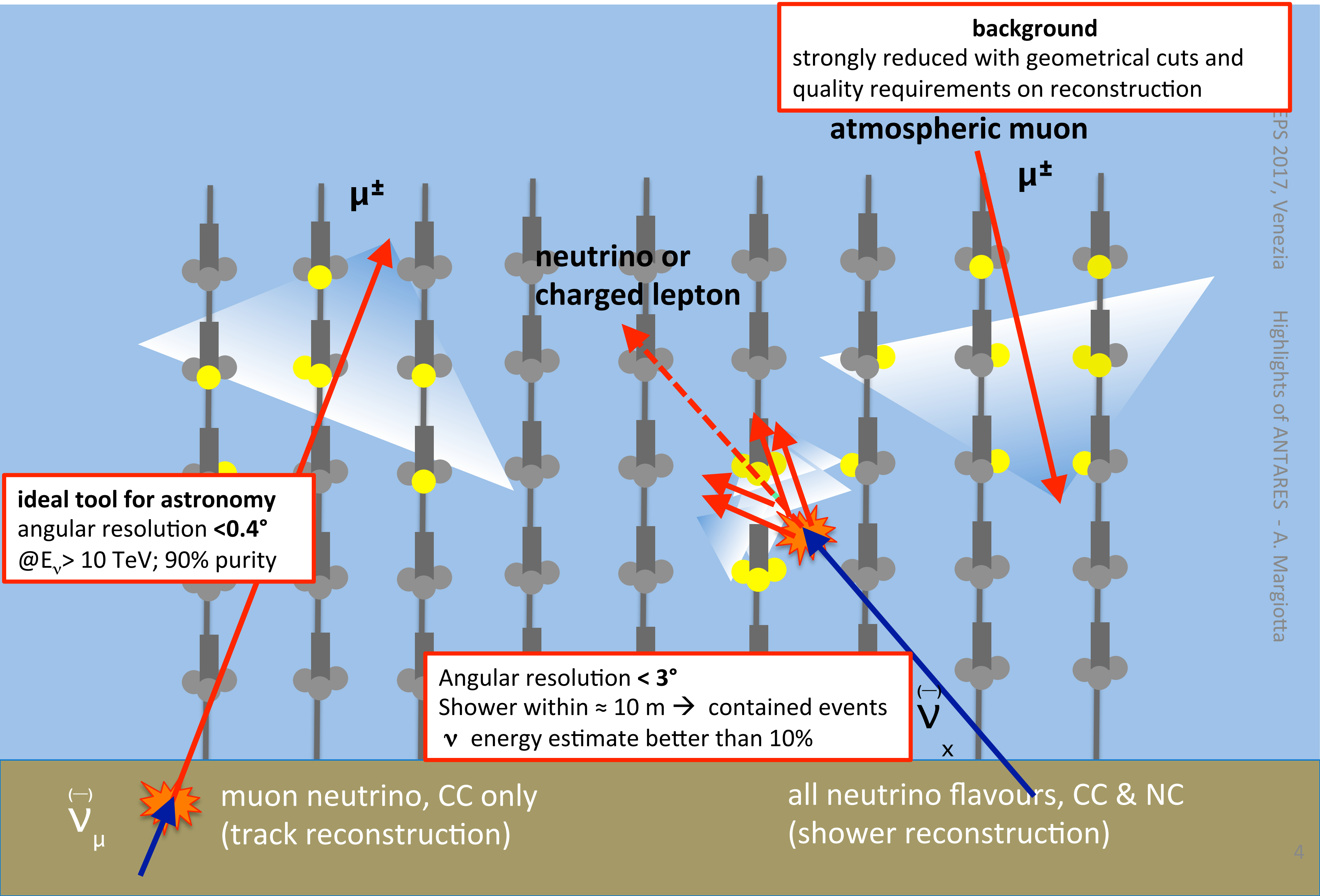
Not discussed today

How does a ν telescope work?

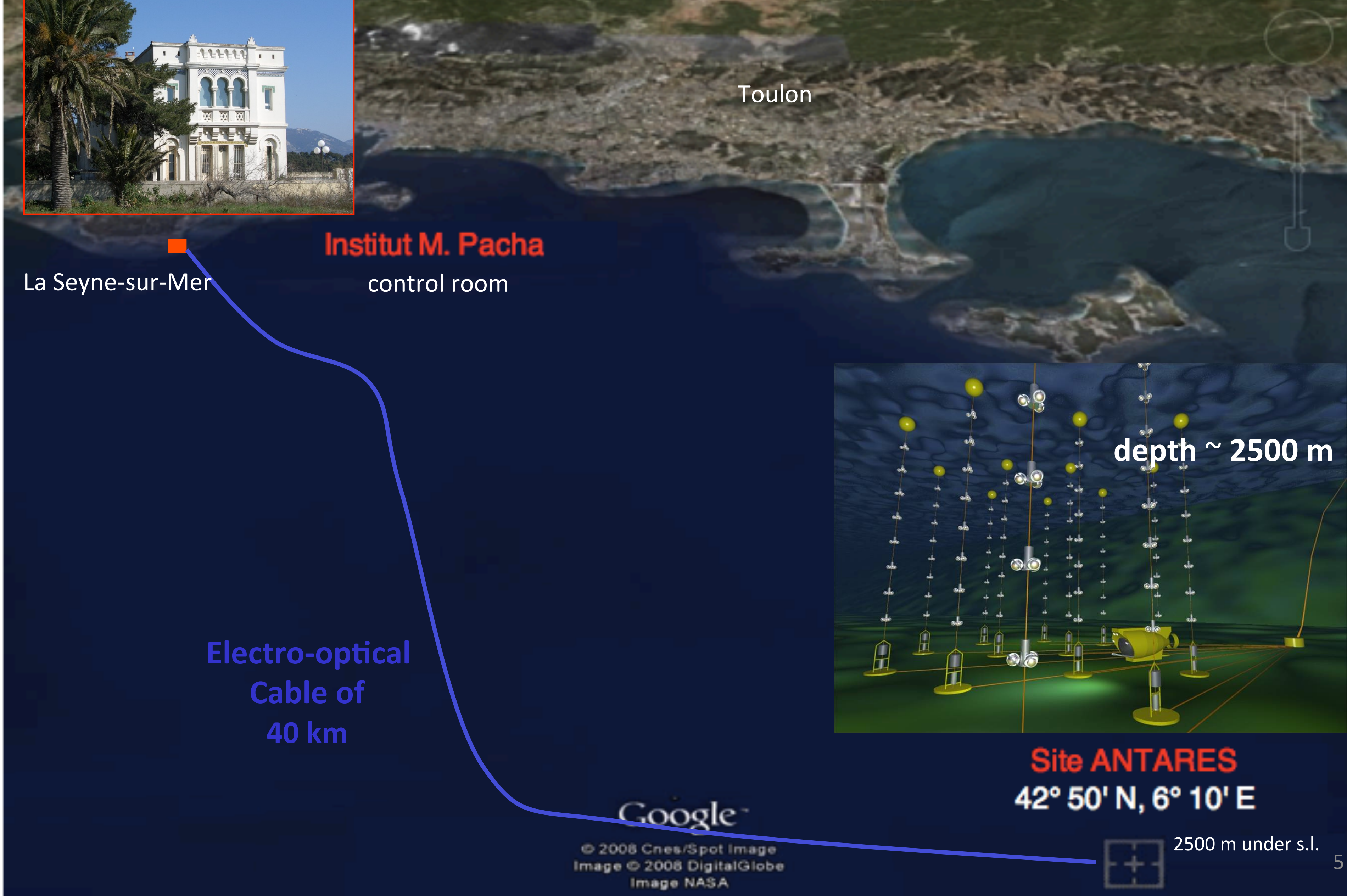


$$\langle\theta_{\mu-\nu}\rangle = \frac{1.5^{o}}{\sqrt{E_{\nu}[TeV]}}$$

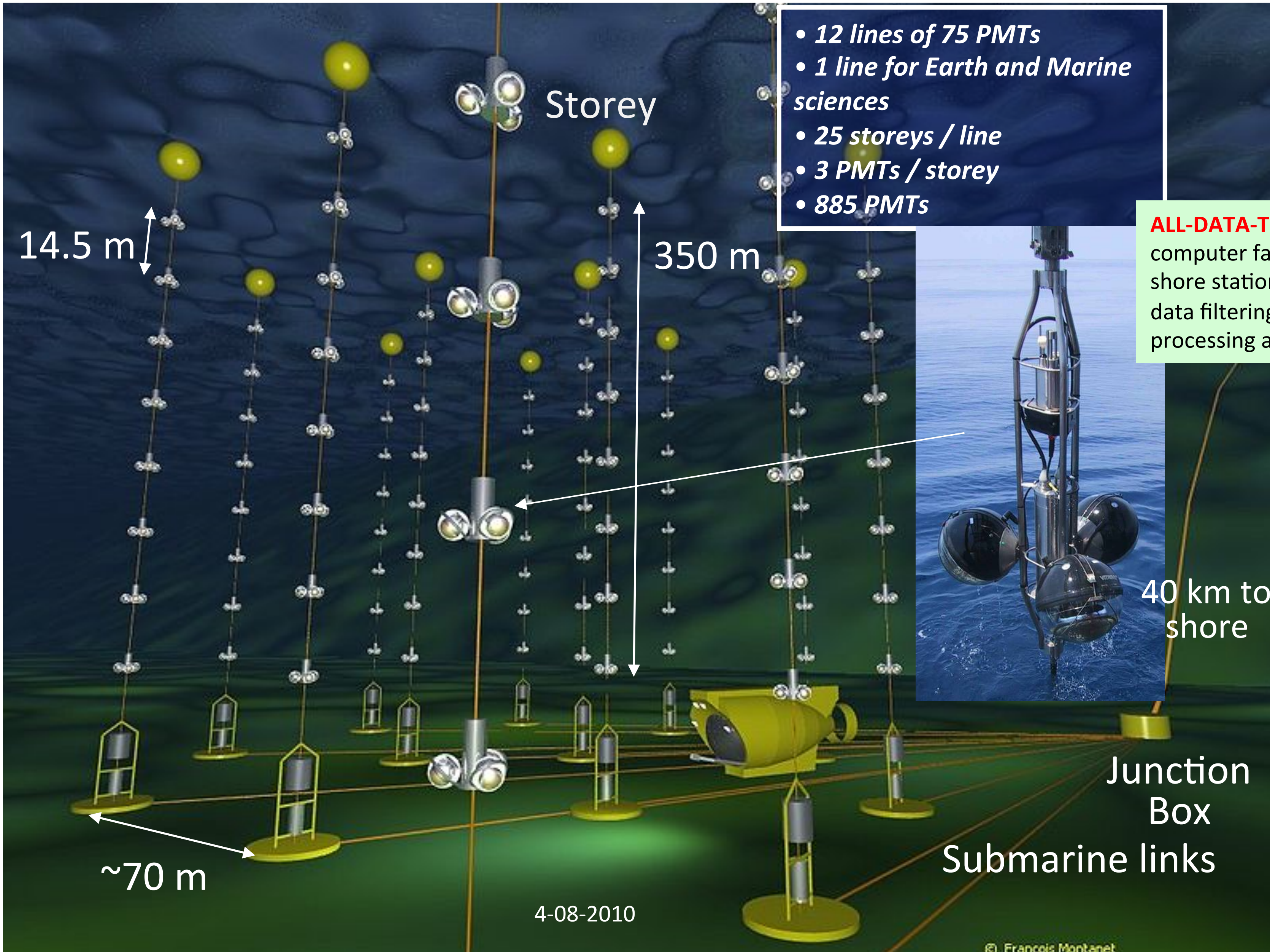
Event topology



The ANTARES site



The telescope: full configuration since 2008



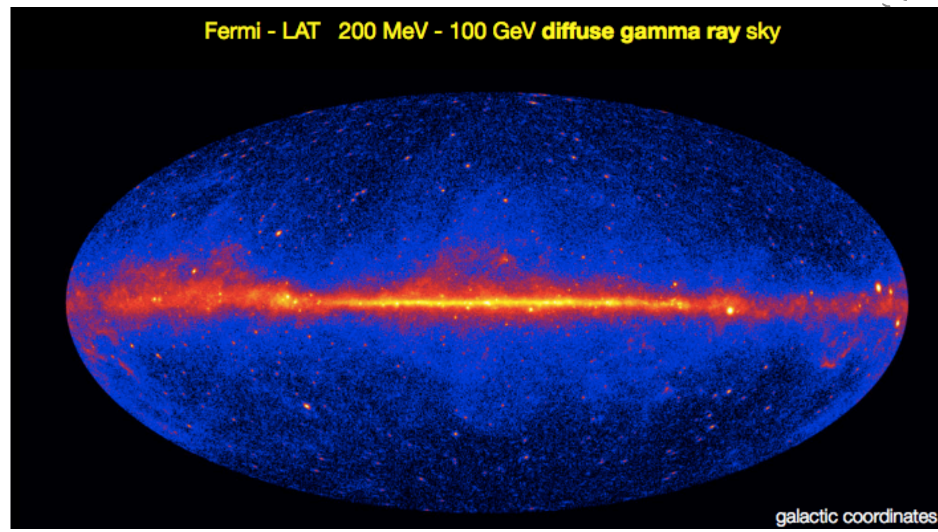
- ***12 lines of 75 PMTs***
- ***1 line for Earth and Marine sciences***
- ***25 storeys / line***
- ***3 PMTs / storey***
- ***885 PMTs***

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

Neutrino astrophysics

Search for fluxes of high energy cosmic neutrinos

- Individual sources (point-like and extended sources)
- Diffuse flux (not identifiable single source)



Galactic sources: near objects

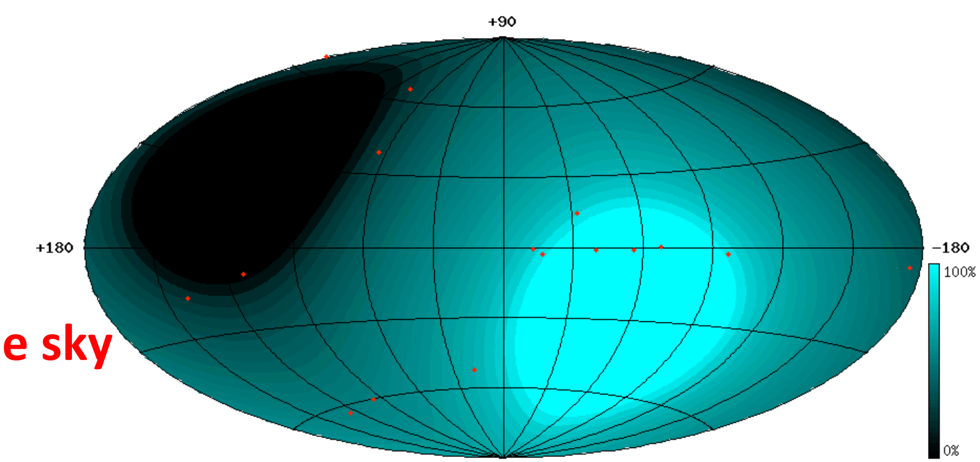
lower luminosity requirements

- Micro-quasars
- Supernova remnants
- Magnetars
- Galactic Centre and Galactic ridge

Extra-galactic sources:

most powerful accelerators in the Universe

- AGNs
- GRBs



ANTARES visible sky

ANTARES search for point-like sources of cosmic νs

9 years of ANTARES data – all neutrino flavours:

7629 track-like + 180 shower-like events

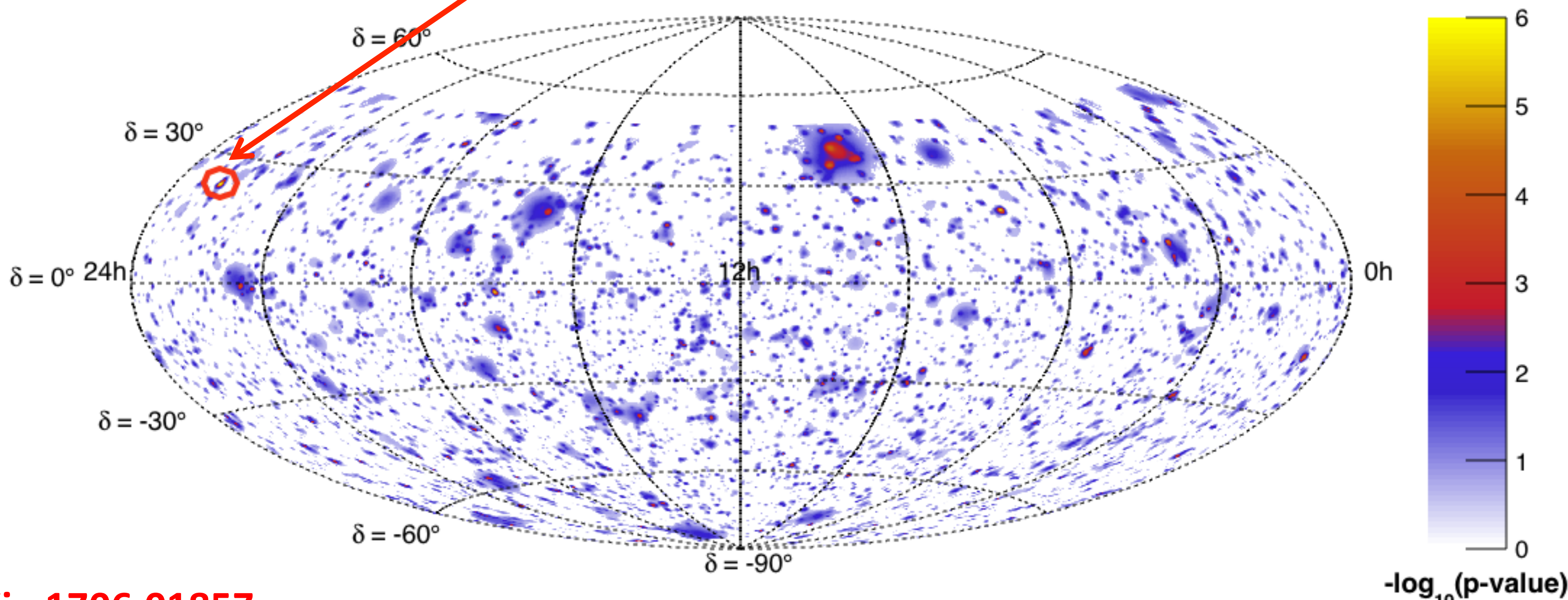
2007-2015 – Total livetime = 2423.6 d

arXiv:1706.01857

Full sky search

Search for an excess of signal events located anywhere in the ANTARES visible sky without any assumption about the source position → ANTARES visible sky divided in 1°×1° (r.a x decl.) boxes. → Maximum Likelihood analysis searching for clusters

decl. δ = 23.50, r.a. α = 343.80 = most significant cluster (≈ 1.9 σ)



arXiv:1706.01857

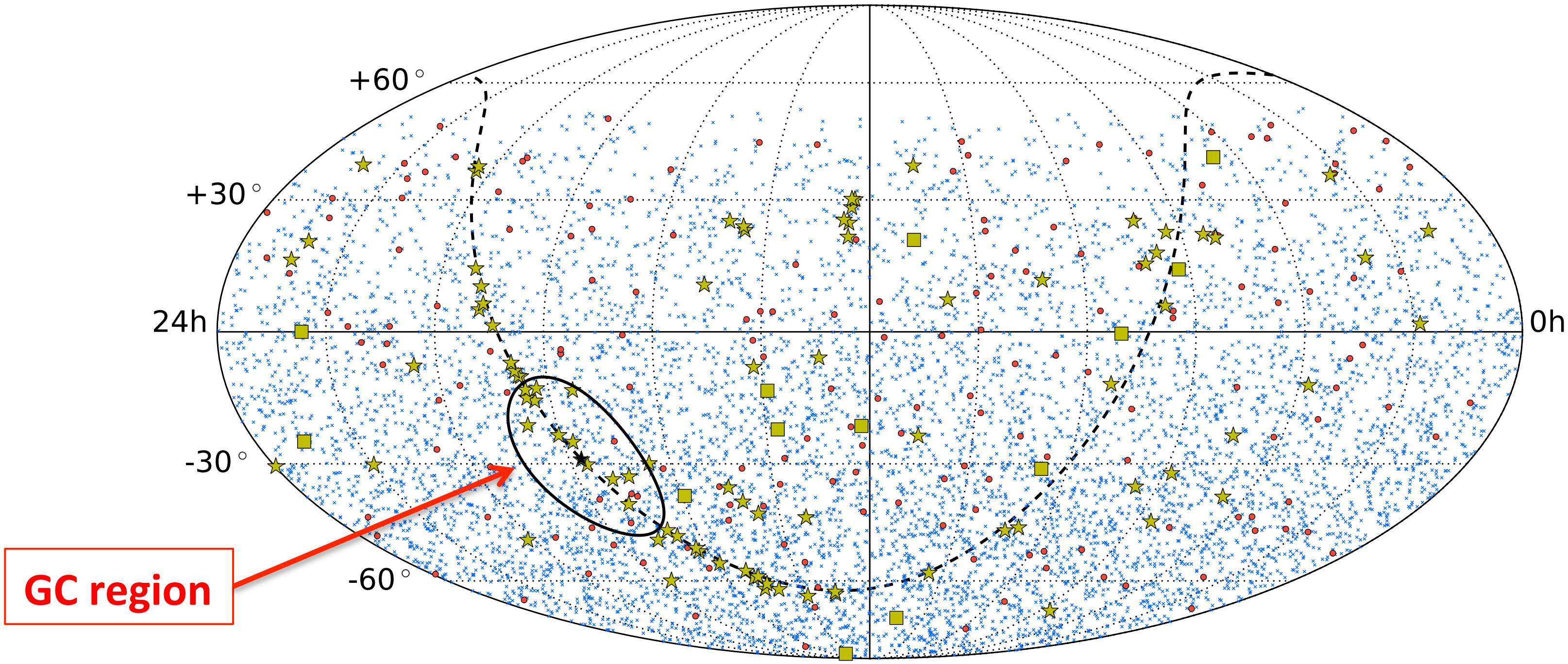
equatorial coordinates

Candidate list search

Red : cascades
Blue: tracks

□ IC HESE – 13 track-like events

☆ candidate sources – 106 known astrophysical sources

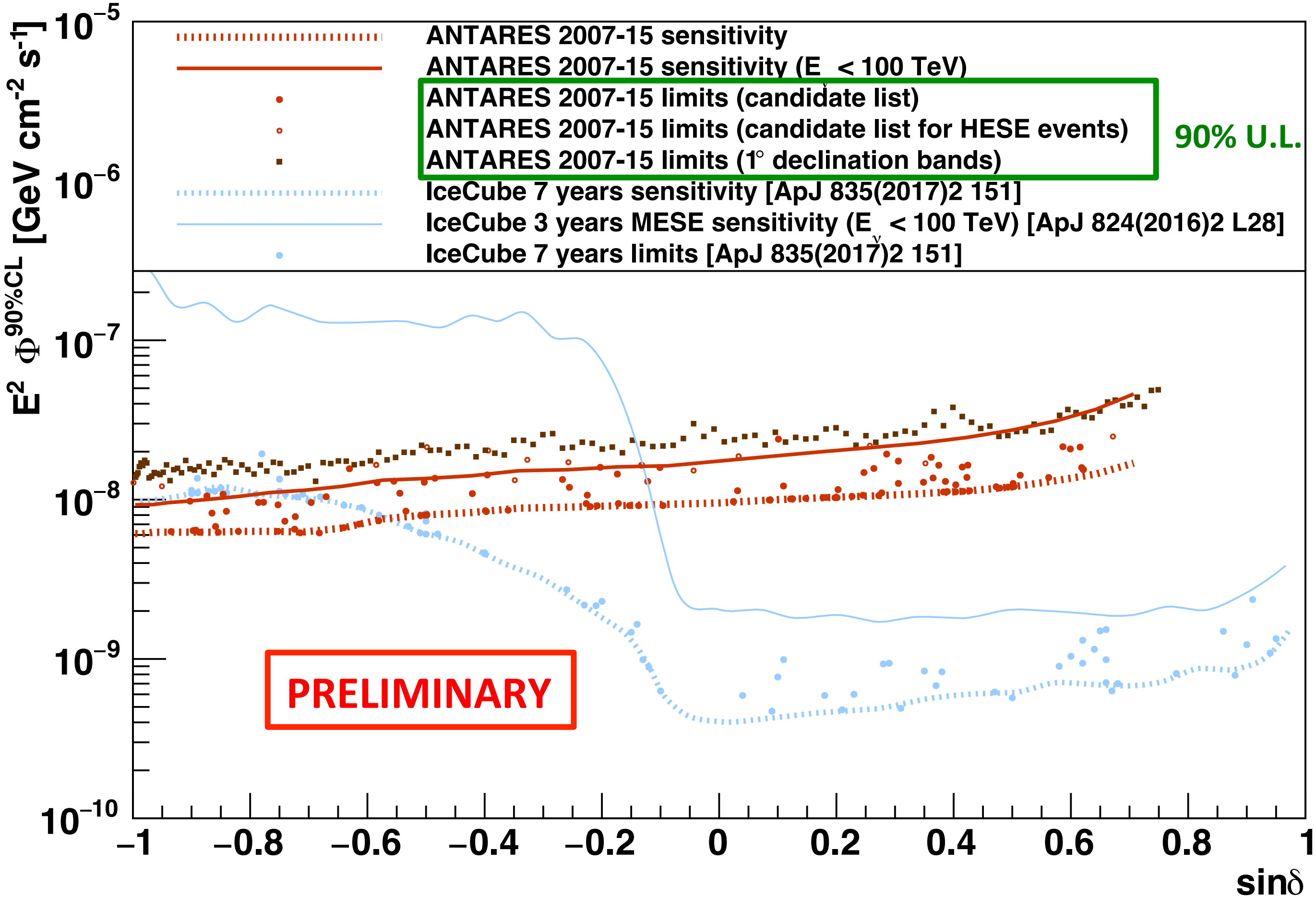


equatorial coordinates

arXiv:1706.01857

No significant excess found so far

Sensitivity and upper limits

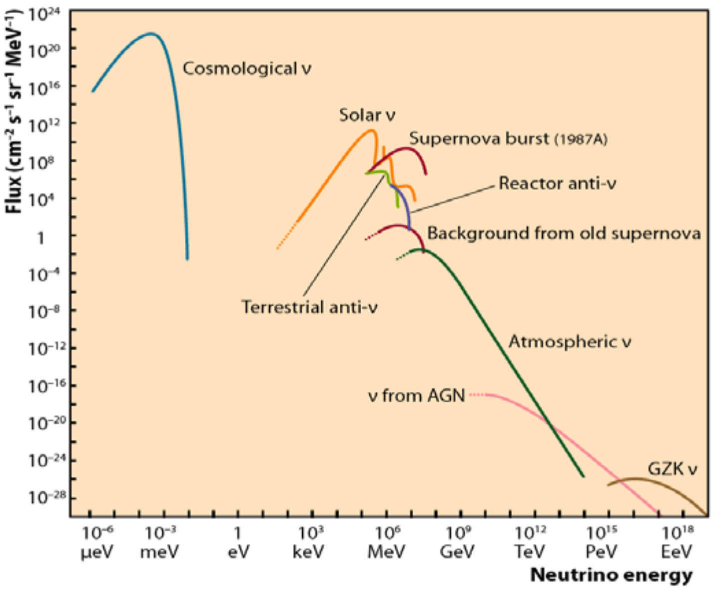


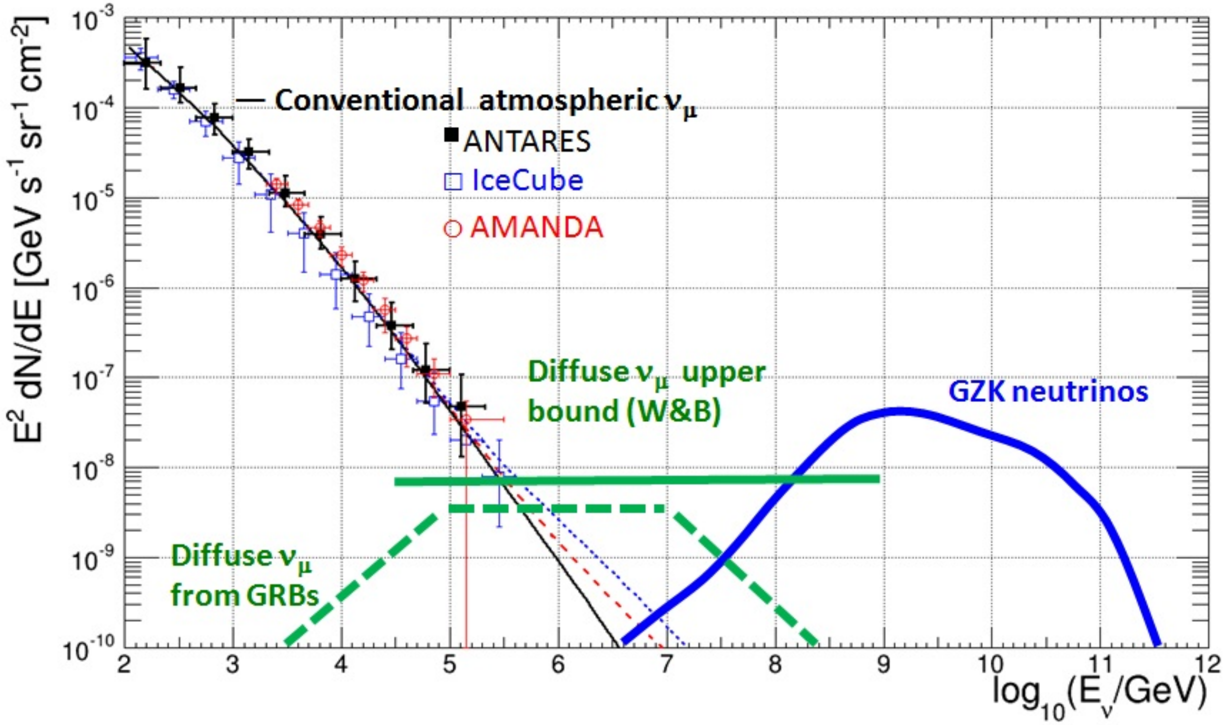
arXiv:1706.01857

Diffuse flux search

νs from unresolved sources, GZK, Z-jets…

Search for excess of HE events over the expected atmospheric background (softer spectrum ~ 3.7)





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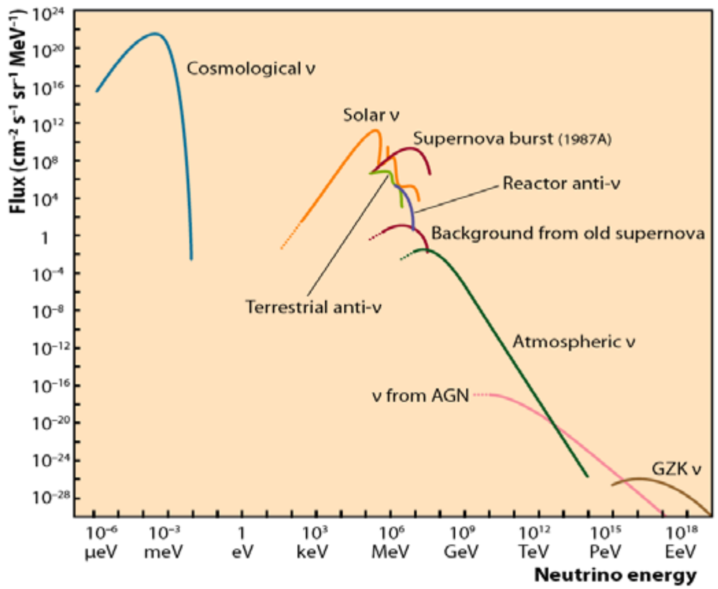
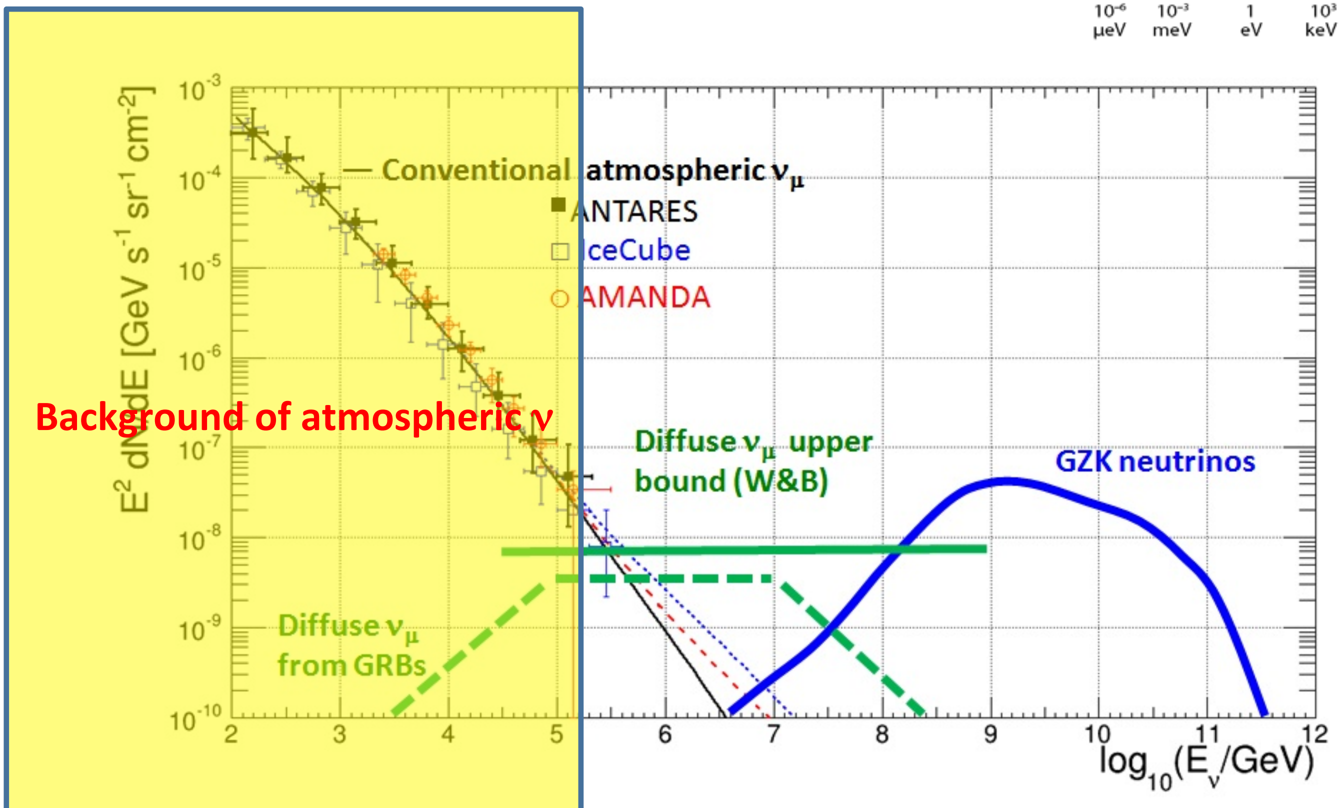




Diffuse flux

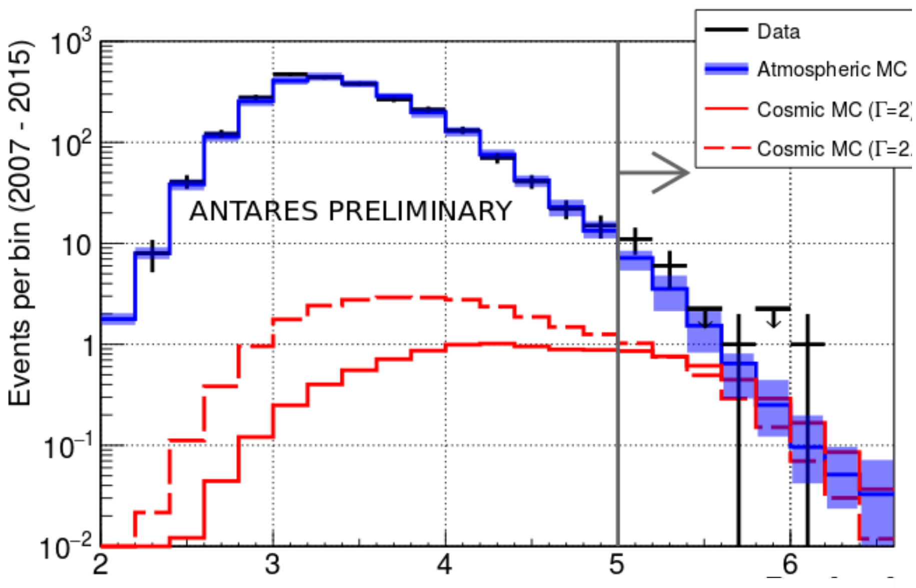
TRACKS

Data: 2007-2015 **(2450 livedays)**

Above E_{cut}: Bkg: 13.5 ± 4 evts

IC-like signal: 3 evts

Observed: **19 evts**



Energy Estimator (proxy in a.u.)

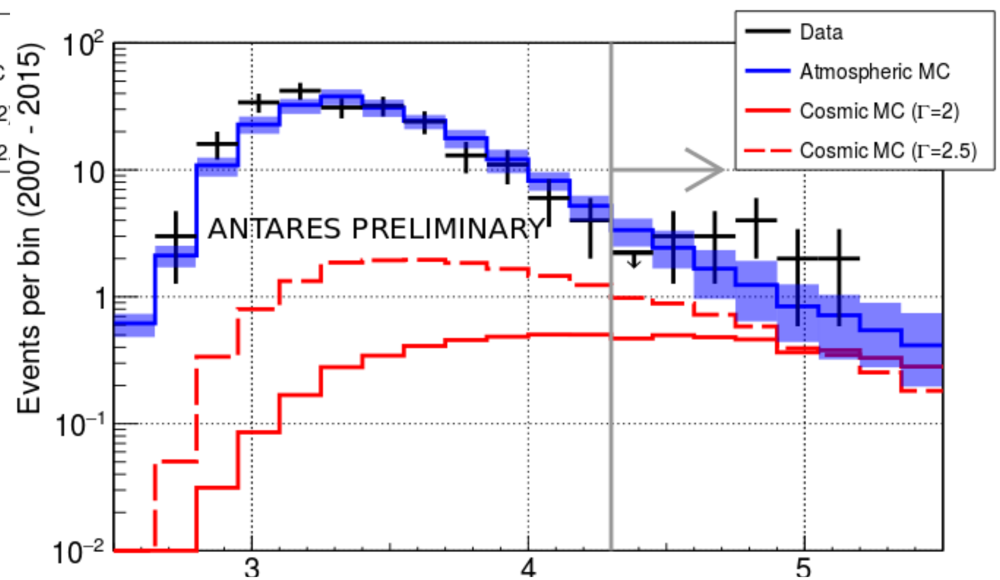
SHOWERS

Data: 2007-2015 **(2450 livedays)**

Above E_{cut}: Bkg: 10.5± 4 evts

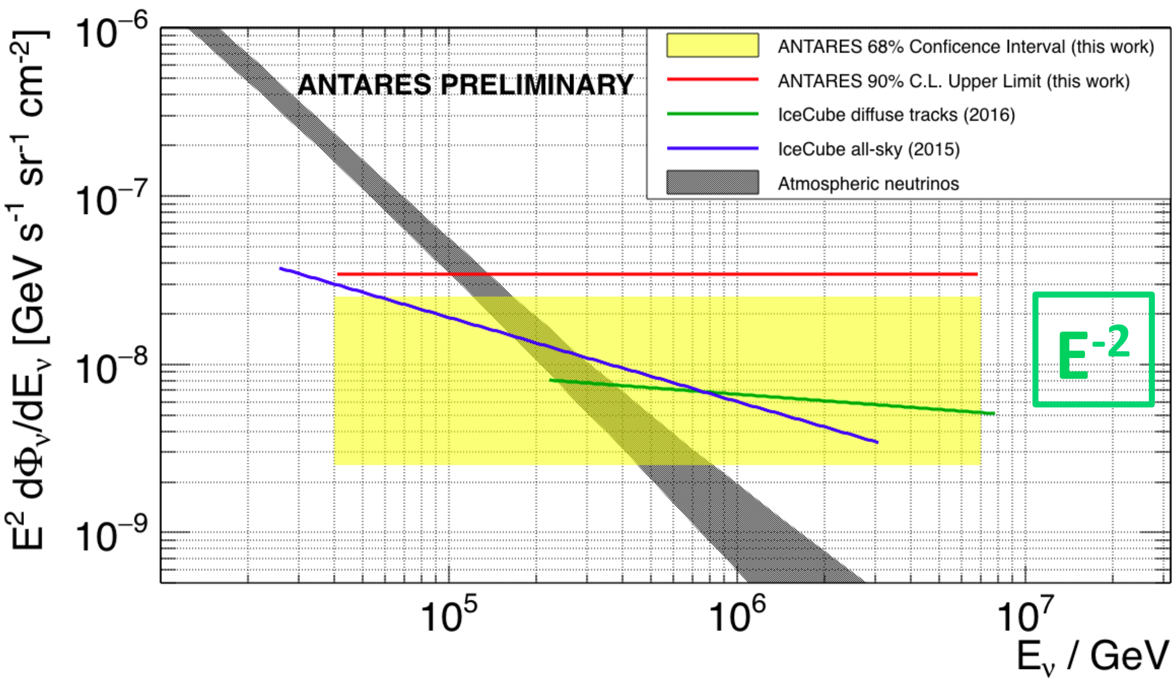
IC-like signal: 4 evts

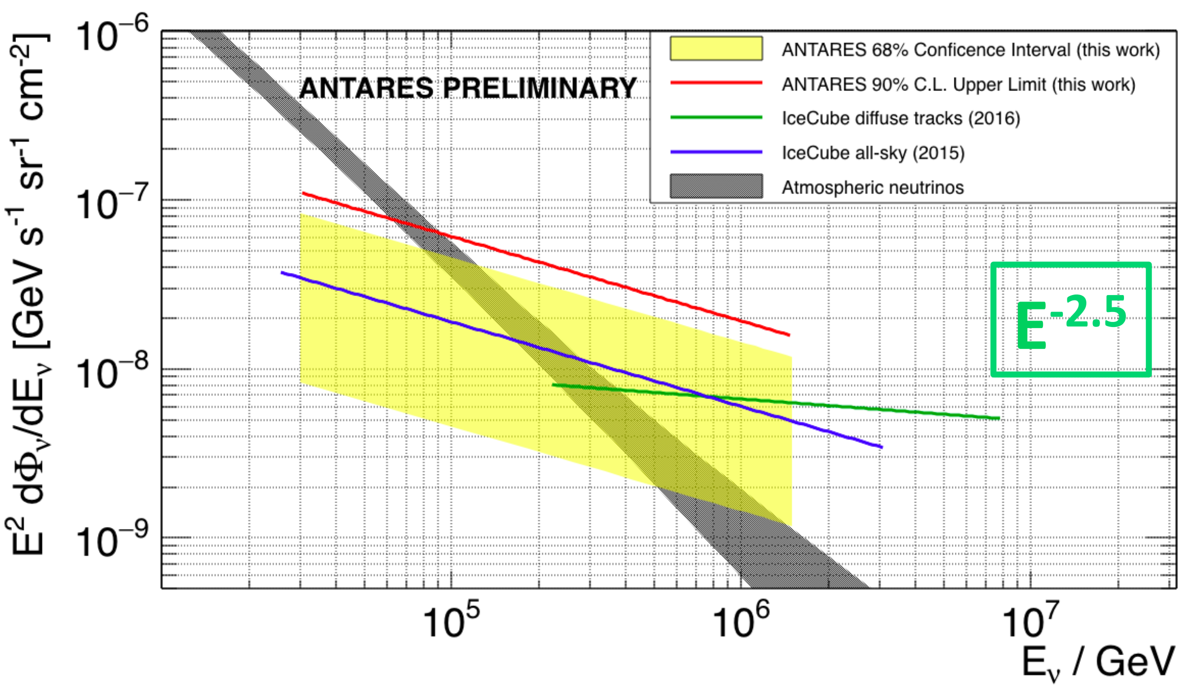
Observed: **14 evts**



Reconstructed Energy $\log_{10}(E_{sh}/GeV)$

Reliable energy estimate required



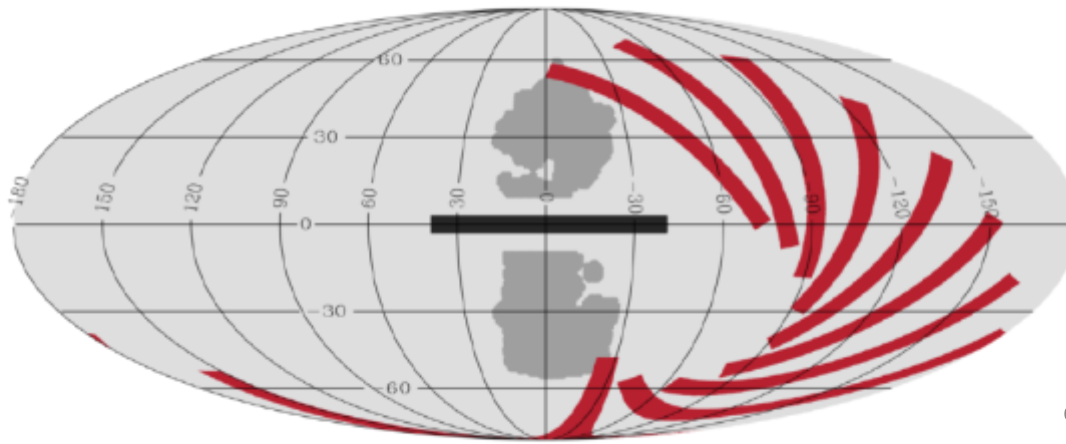


Upper limit at 90% C.L.
68% confidence interval
for the combined track and shower analysis (systematics included)

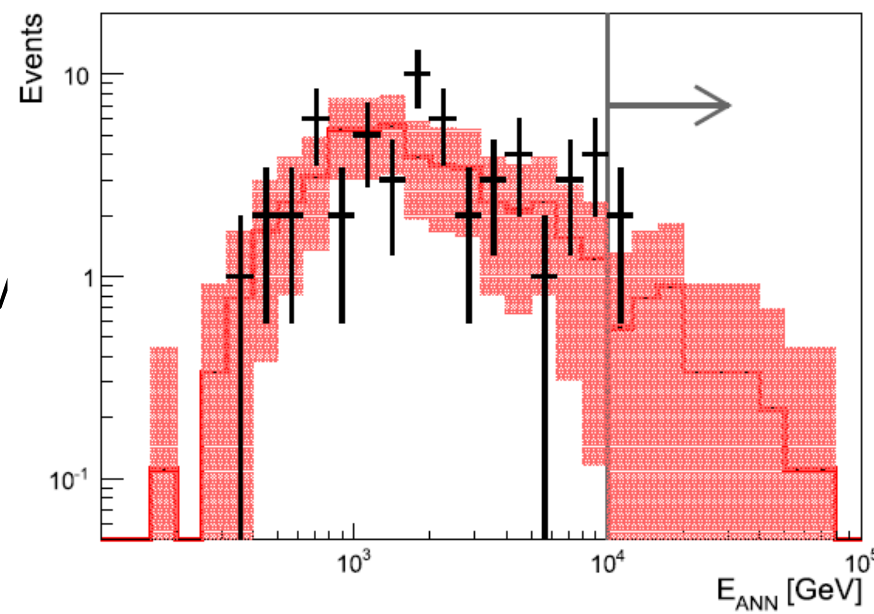
The Galactic ridge - 1

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

  $p_{CR} + p_{ISM} \rightarrow \pi^o\, \pi^+\, \pi^-$ ...
  $\pi^o \rightarrow \gamma\gamma$ (EM cascade)
  $\pi^\pm \rightarrow \nu_\mu\, \nu_e$ ...



- Search for ν_μ, data 2007-2013
- Search region $|l|<30^\circ$, $|b|<4^\circ$
- 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: $3<E_\nu<300$ TeV



Phys.Lett. B 760(2016)143

Physics Letters B 760 (2016) 143–148

Contents lists available at ScienceDirect

Physics Letters B

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www.elsevier.com/locate/physletb

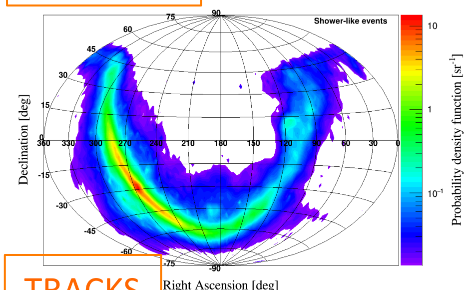
Constraints on the neutrino emission from the Galactic Ridge with the ANTARES telescope

The Galactic ridge – 2 → new analysis

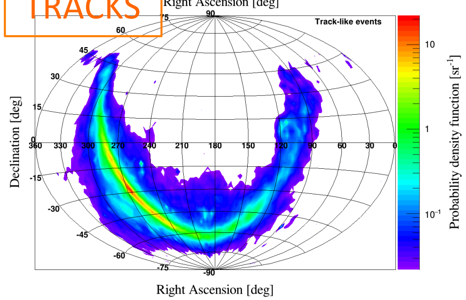
Tracks + showers 2007-2015 →LT = 2423.6 d

Maximum Likelihood analysis

SHOWERS



TRACKS



Probability density function of the signal for shower and track-like events (5PeV cutoff model)

Background extracted from data

arXiv:1705.00497

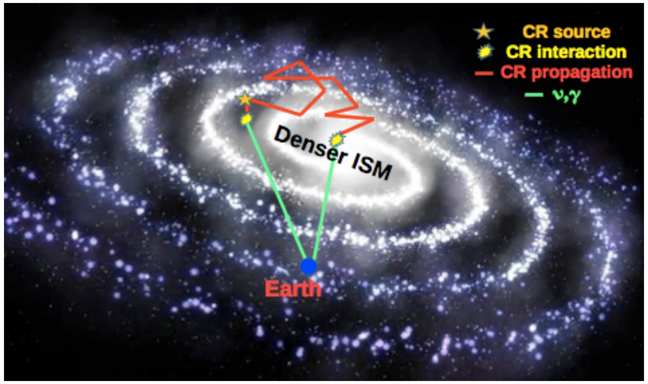
KRA$_\gamma$ - radially dependent model for CR transport in the Galaxy : δ(R)~1/R

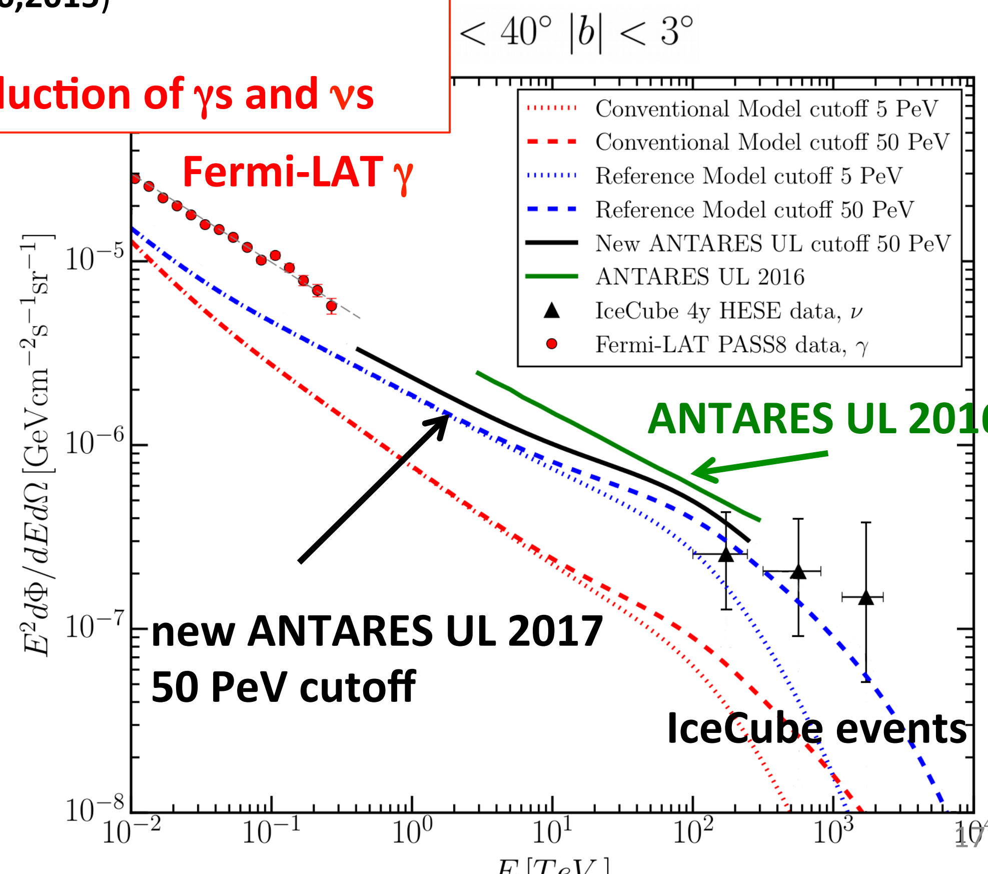
Astroph. J. Lett. 815(2015)L25

arxiv:1702.01124

PoS, ICRC2015:1126,2015)

Enhanced production of γs and νs



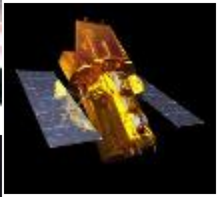


Multimessenger program

Intense effort in working with other collaborations

- better understanding of the sources and of the physics mechanisms
- increase detector sensitivity (uncorrelated backgrounds)

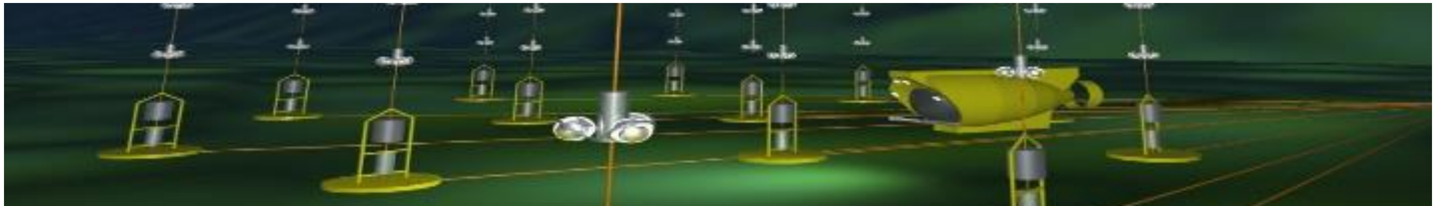





Multi wavelength follow-up of neutrinos

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



Real-time (follow-up of the selected neutrino events):

- optical telescopes [TAROT, ROTSE, ZADKO, MASTER]
- X-ray telescope [Swift/XRT]
- GeV-TeV γ-ray telescopes [HESS, HAWC]
- radio telescope [MWA]
- Online search of fast transient sources [GCN, Parkes]

APP 35 (2012) 530 (method)
JCAP02(2016)062 (optical and X)
ApJ 820 (2016) L24 (radio)

Multi-messenger correlation with:

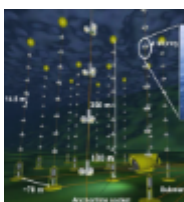
- Gravitational wave [Virgo/Ligo] — **JCAP 06 (2013) 008; PRD93 (2016), 122010**
- UHE events [Auger] — **ApJ 774(2013) 19**

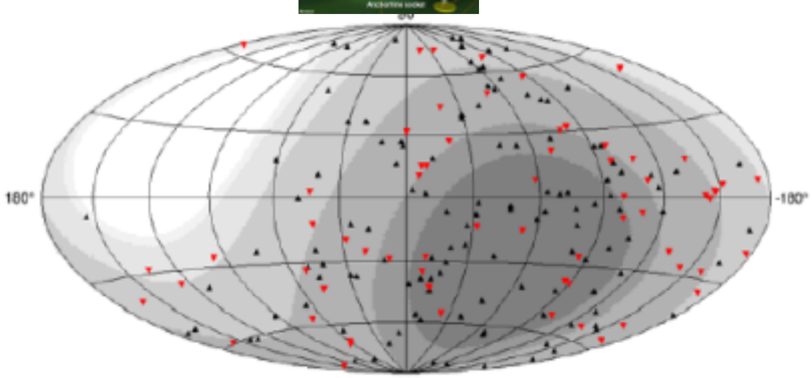
Time-dependent searches:

- GRB [Swift, Fermi, IPN] — **JCAP 1303 (2013) 006; Eur. Phys. J. C 77(2017) 20**
- Micro-quasar and X-ray binaries [Fermi/LAT, Swift, RXTE] — **JCAP 4 (2017) 019**
- Gamma-ray binaries [Fermi/LAT, IACT]
- Blazars [Fermi/LAT, IACT, TANAMI…] — **JCAP 1512 (2015), 014; A&A 576 (2015) L8**
- Crab [Fermi/LAT]
- Fast radio burst [radio telescopes] — **MNRAS 469 (2017) 4465**

Real-time follow-up (TAToO)

- M. Ageron et al., The ANTARES telescope neutrino alert system, APP 35 (2012) 530 (method)
- Adrián-Martínez et al., **Optical** and **X-ray** early follow-up of ANTARES neutrino alerts, JCAP02(2016)062
- Croft et al., Murchison Widefield Array Limits on **Radio** Emission from ANTARES Neutrino Events, ApJ 820 (2016) L24 (radio)





ANTARES trigger

- single HE ν (~10 TeV)
- single ν correlated to local galaxies for SNe (~1 TeV)
- doublet of ν's

External server

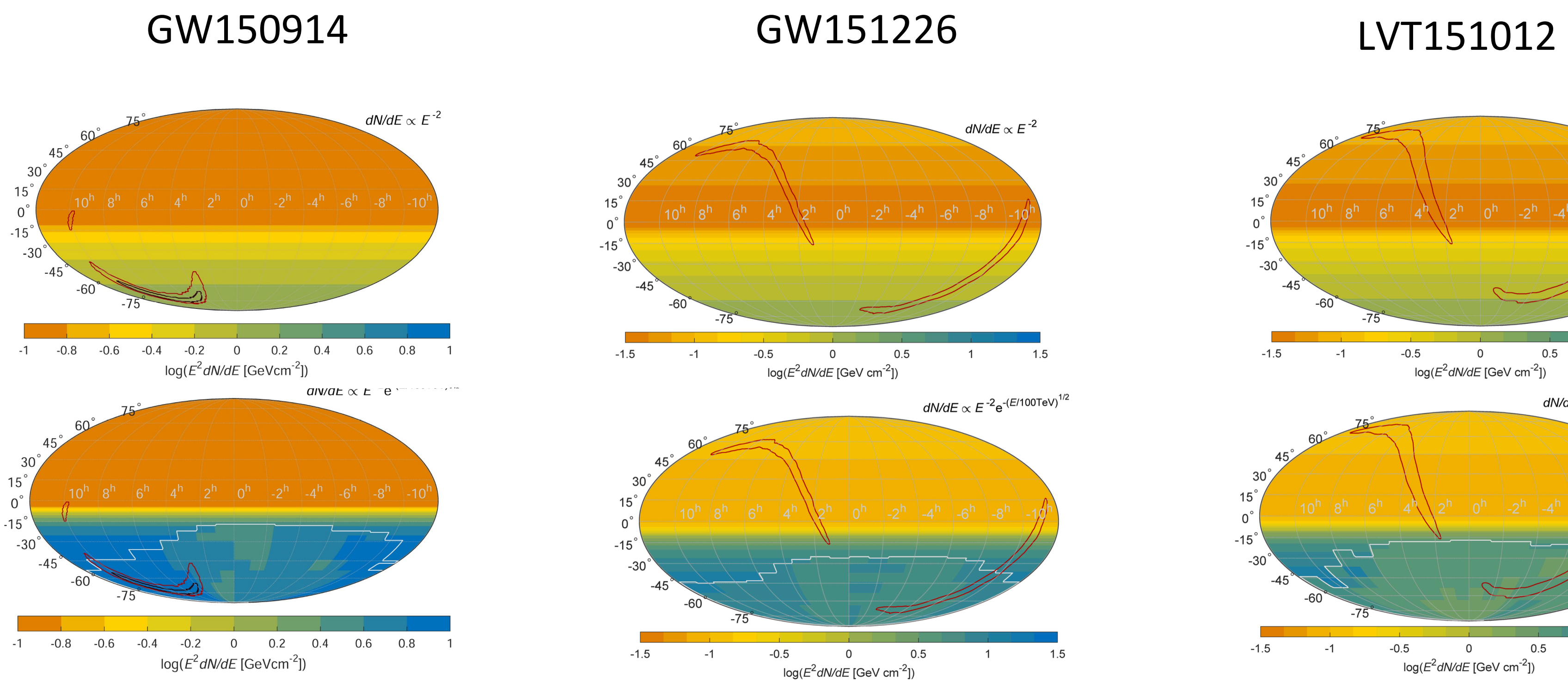
- TAROT
- ZADKO
- MASTER
- SWIFT
- MWA
- HESS
- HAWC
- GCN
- Mail SMS

Performances:

- **Time to send an alert: ~ 5 s**
- **Median angular resolution: 0.3° - 0.4°**
- First image of the follow-up: <20 s
- Dedicated optical image analysis

GW observation neutrino follow-up

joint analyses ANTARES/IceCube/LigoSC/Virgo



- No ANTARES events in ±500 s around event time
- ANTARES limits dominates for Eν < 100 TeV
- Size of GW150914 : 590 deg^2
- ANTARES resolution: <0.5 deg^2
- < 10% GW total energy radiated in ν

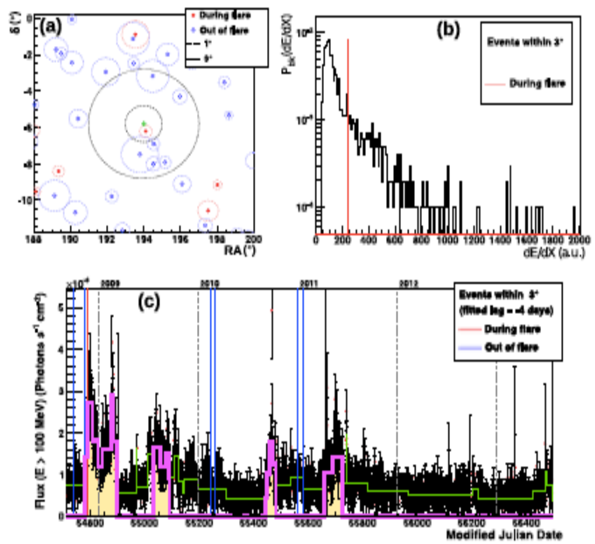
Phys.Rev. D93 (2016), 122010 + arxiv:1703.06298 (accepted on PRD)

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

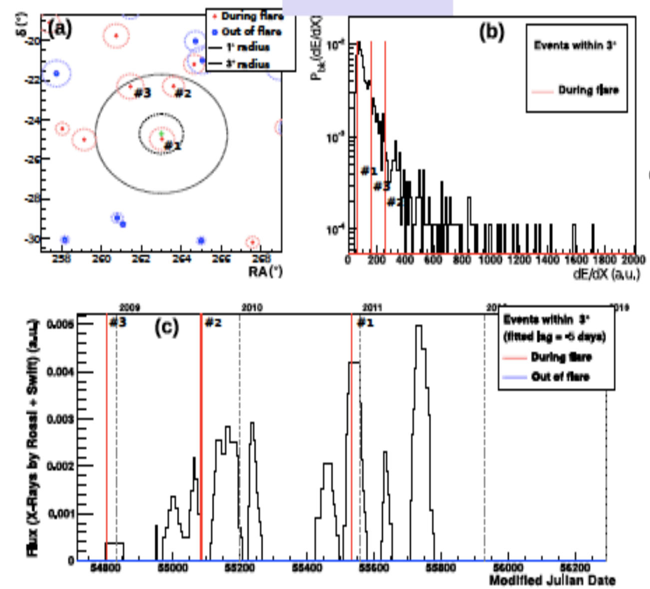
- Search for ν's (2008-2012) correlated with high activity state
- **Blazars** monitored by FERMI-LAT and IACTs (**JCAP 1512 (2015), 014)**
- **40 blazars + 33 X-ray binaries** during flares observed by Swift-BAT, RXTE-ASM and MAXI. Transition states from telegram alerts
- No significant excess
- Upper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

JCAP04(2017)019

3C279

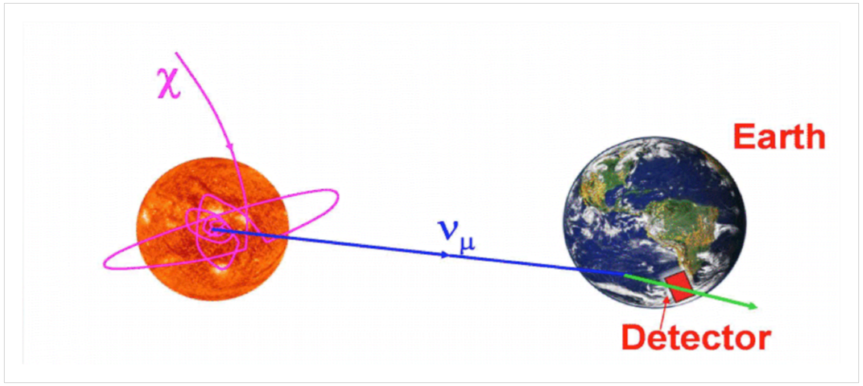


GX 1+4



DM→ ν

Dark Matter from the Sun the Earth and the Galactic Centre



- Gravitational trapping and accumulation of DM particles in the centre of astrophysical objects like the Sun, the Galactic centre and also the Earth
- DM annihilation would produce eventually a HE neutrino flux

  with no significant astrophysical backgrounds
- ν_μ spectrum →WIMPSIM [Blennow,Edsjö,Ohlsson,arXiv:0709.3898]
- Bkg estimated from time scrambled data.

No excess observed

JCAP, 10 (2015) 068
Phys.Lett. B 769 (2017) 249

The Galactic Center

5 annihilation channels

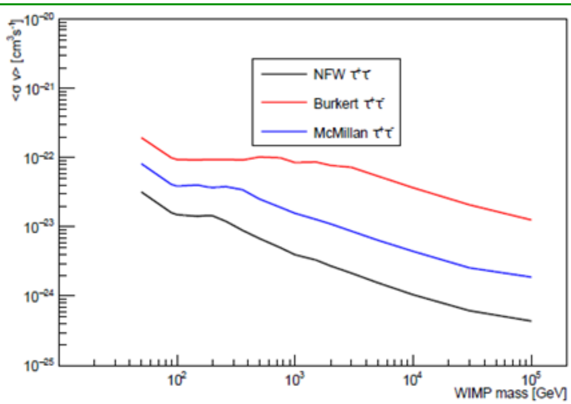
$$X_{\mathrm{WIMP}}\bar{X}_{\mathrm{WIMP}} \rightarrow \nu\bar{\nu},\ \mathrm{b\bar{b}},\ \mathrm{W^-W^+},\ \tau^-\tau^+,\ \mu^-\mu^+$$

3 DM halo models in the Milky Way
effect on the thermally averaged cross section

good visibility of the GC

only muon like events considered

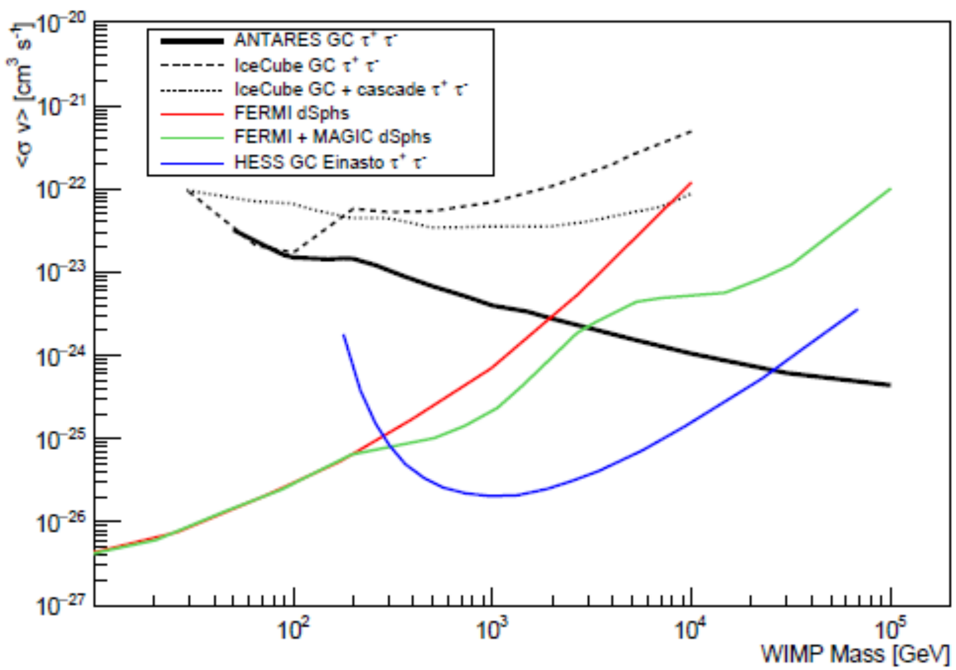
➔ angular resolution <0.4°



$$\frac{d\Phi_{\nu_\mu+\bar{\nu}_\mu}}{dE_{\nu_\mu+\bar{\nu}_\mu}} = \frac{<\sigma v>}{8\pi M^2_{\mathrm{WIMP}}} \cdot \frac{dN_{\nu_\mu+\bar{\nu}_\mu}}{dE_{\nu_\mu+\bar{\nu}_\mu}} \cdot J_{\mathrm{int}}(\Delta\Omega).$$

$$J_{\mathrm{int}}(\Delta\Omega) = \int_{\Delta\Omega}\int \rho^2_{\mathrm{DM}} \cdot dl \cdot d\Omega.$$

J-factor → ρ^2_{DM} integrated over a line of sight at an angular separation Ψ from the center of the source, depends on the halo model



Dark Matter annihilation in the Earth and the Sun

data collected between 2007-2012

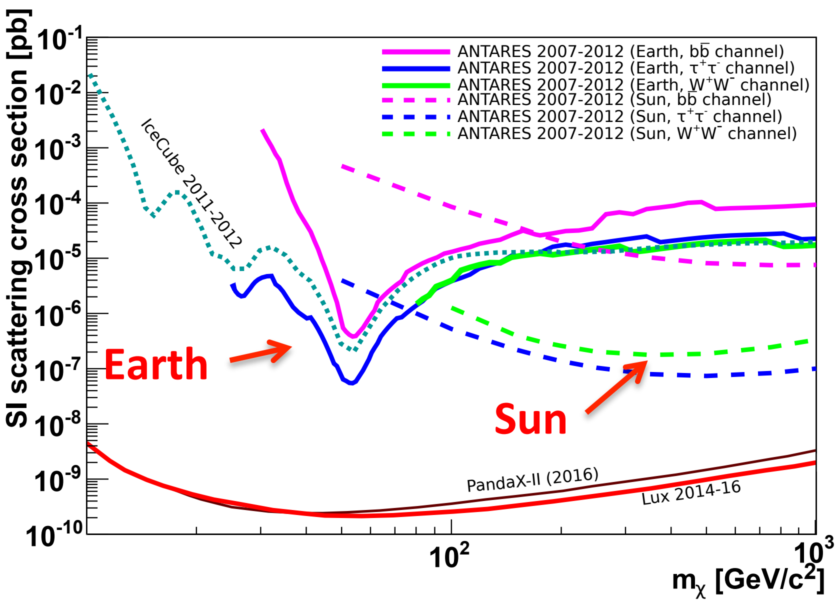
3 channels: $\tau^+ \tau^-$, $W^+ W^-$, $b\bar{b}$

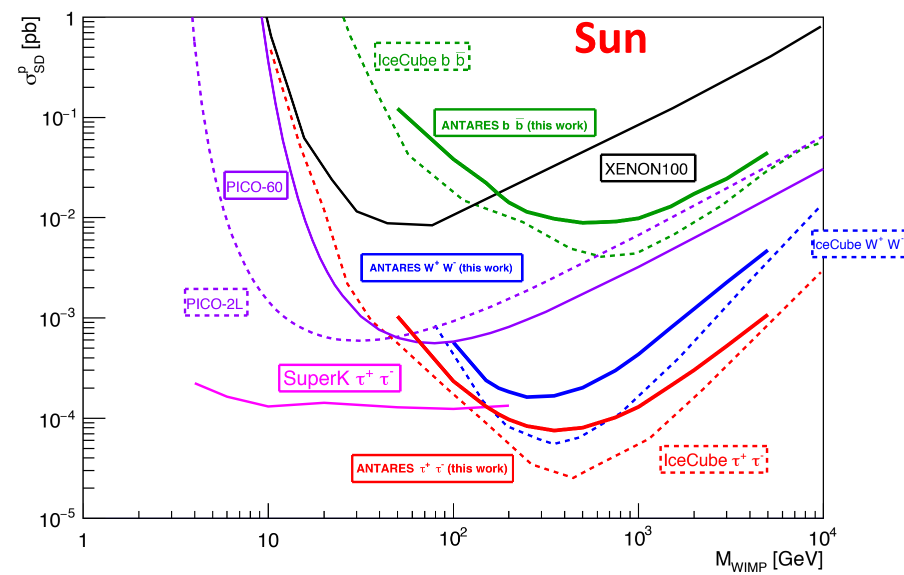
Limits on the **SI** WIMP-nucleon scattering cross-section

Limits on the **SD** WIMP-nucleon scattering cross section

Physics of the Dark Universe, 16 (2017) 41

Phys.Lett. B 759 (2016) 69





Summary

- **ANTARES→ the largest underwater neutrino telescope**
- **Search for a neutrino flux from the Southern sky**
- Huge **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**
- competitive sensitivities and excellent angular resolution in both ***track*** and ***cascade*** events because of
  - **OPTICAL PROPERTIES OF THE SEAWATER**
  - **LOCATION → Northern Hemisphere**
  - **DEPTH**

  Mediterranean Sea
- **main limitation → reduced size**

The future: KM3NeT/ARCA

(talk C. Distefano, on Sat morning)