Recent Results from the ANTARES Neutrino Telescope

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Introduction

Neutrino Astronomy:

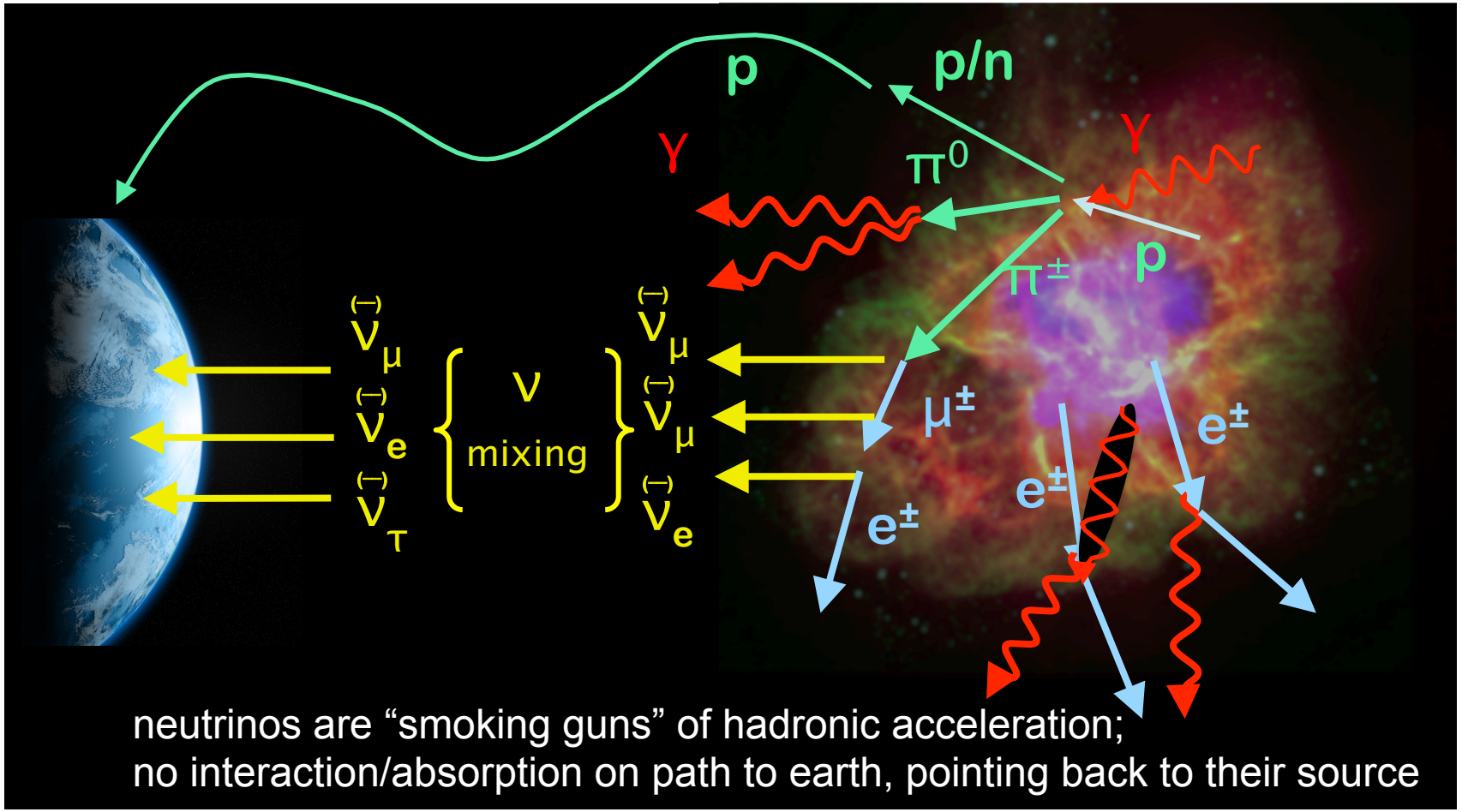
The “big picture” discussed in Kara Hoffman’s talk on Wednesday

Highlighted topics in this talk:

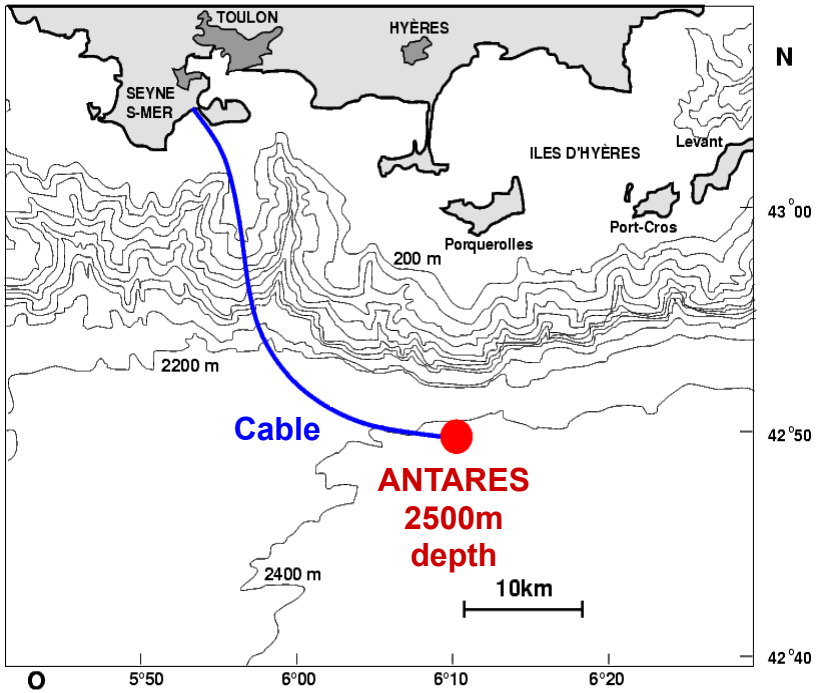
- Diffuse fluxes
- Point sources
- Multi-messenger searches
- Dark Matter
- Acoustic neutrino detection
- Not discussed: GRBs, atmospheric neutrinos, nuclearites, magnetic monopoles, neutrino oscillations, associated sciences,…

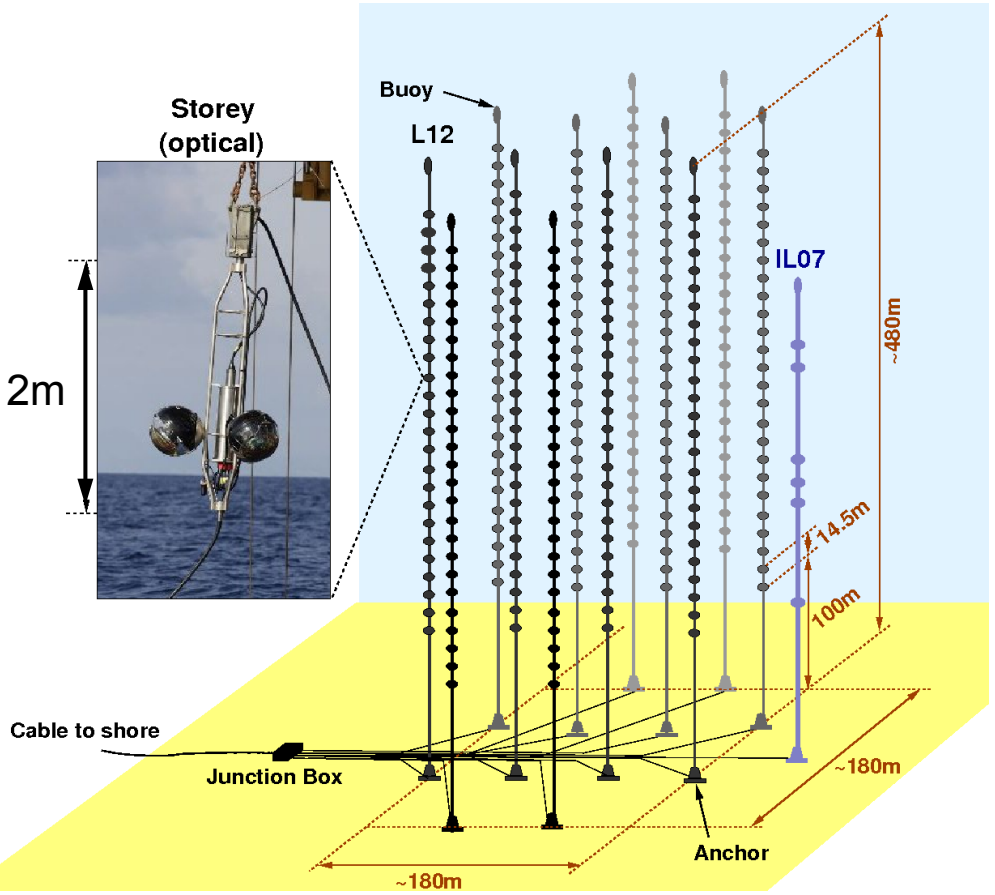
} Main motivation to build a neutrino telescope

Neutrinos from Cosmic Accelerators



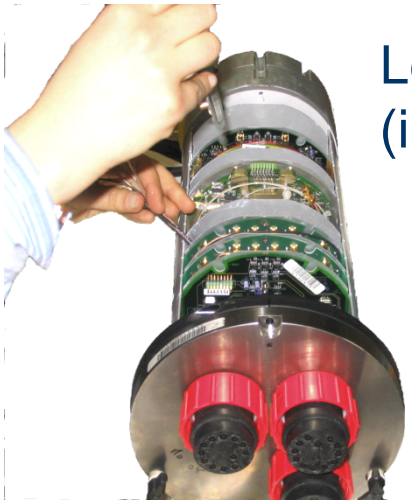
The ANTARES Detector



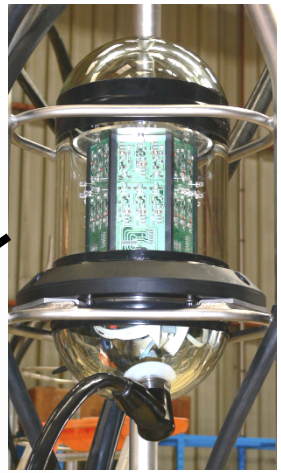


12 lines with 25 storeys each;
3 PMTs/storey;
total of 885 PMTs

A Storey: The Basic Detector Element

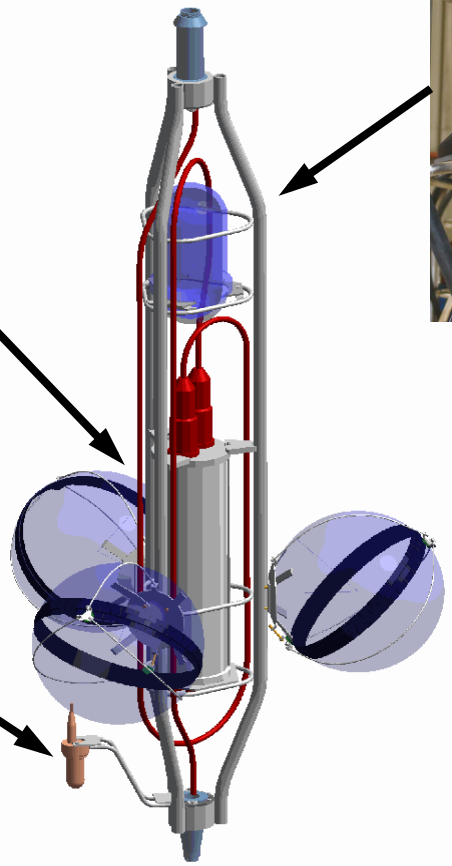


Local Control Module
(inside a titanium cylinder)



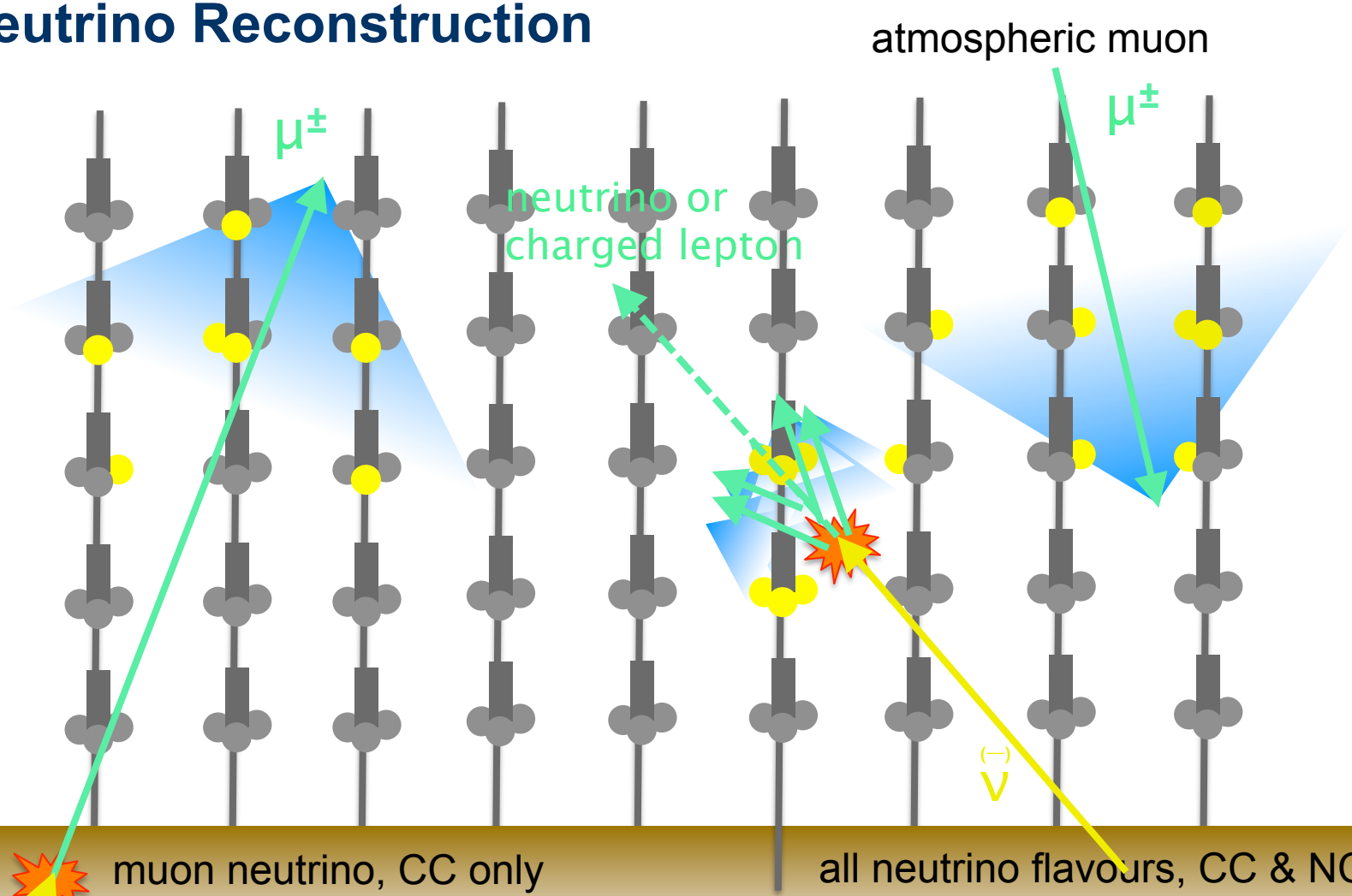
Optical Beacon
(blue LEDs) for
timing calibration
(4 per line)

Hydrophone RX
(5 per line)

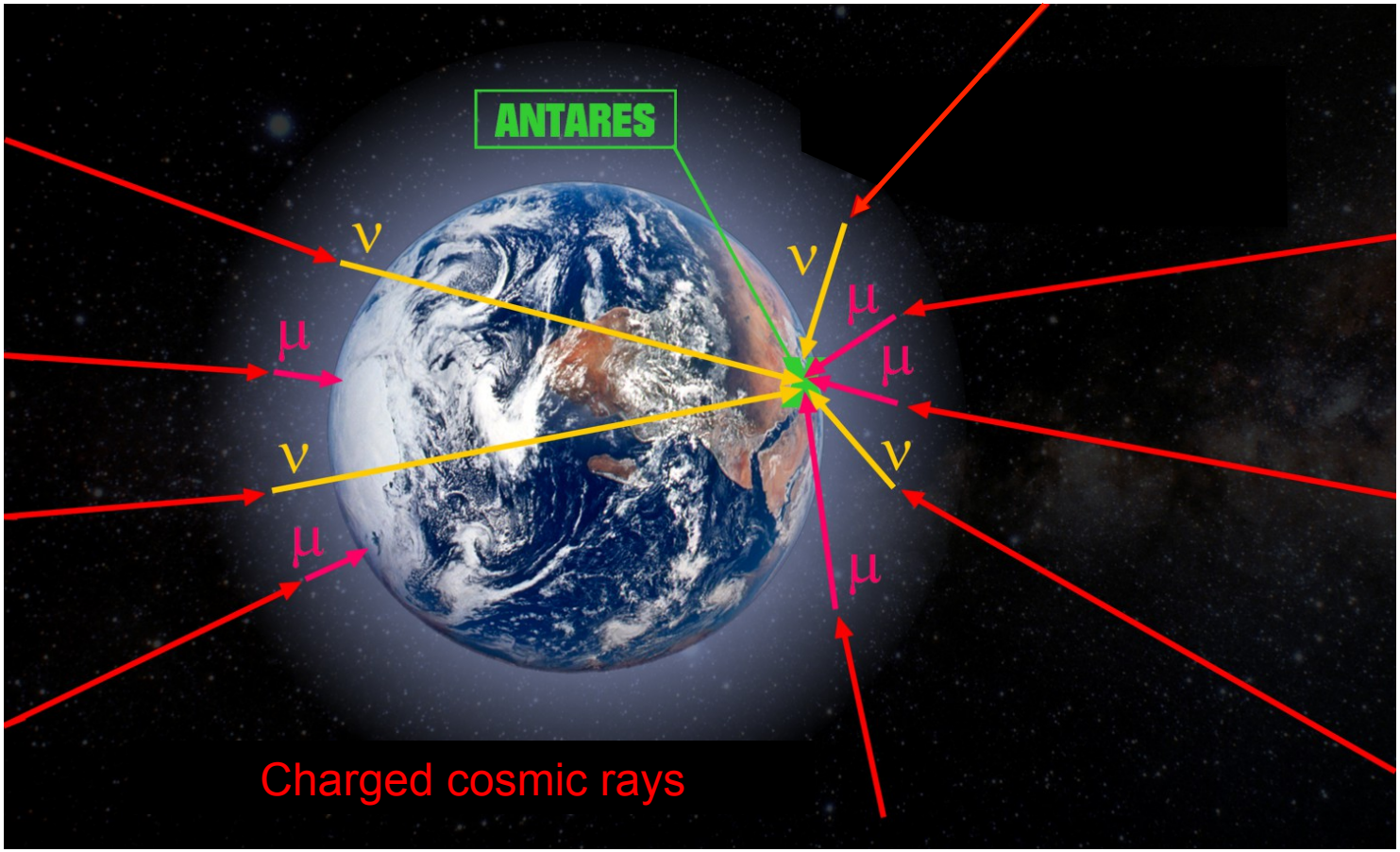


Optical Module:
17” glass sphere
10” PMT Ham. R7081-20
(14 stages)

Neutrino Reconstruction



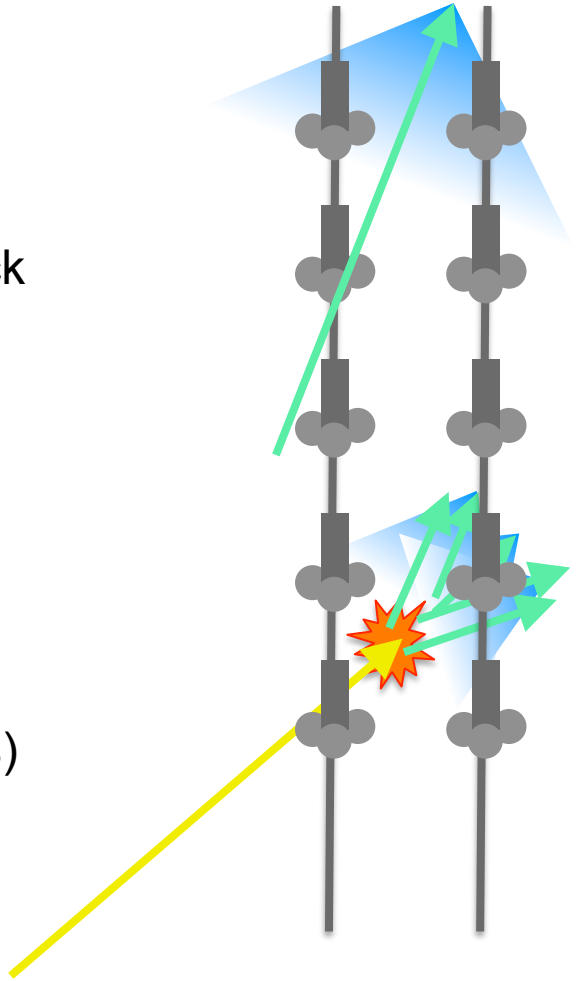
Atmospheric Neutrino Background



Diffuse Flux: Two Analyses

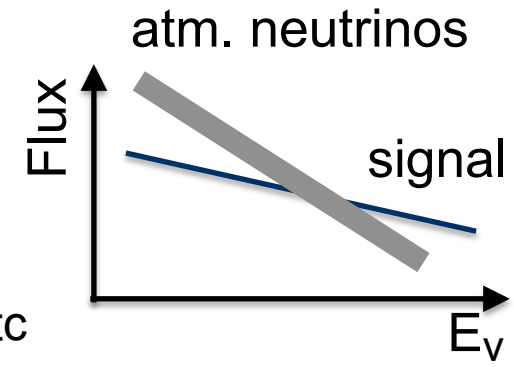
- Track reconstruction
  - sensitive to CC reactions of muon-neutrinos only
  - large effective volume due to length of muon track (several km for E > few GeV)
  - good angular resolution (typically better than 1^{o})

- Shower reconstruction
  - sensitive to all neutrino flavours, CC & NC
  - smaller effective volume
  - worse angular resolution (typically a few degrees)



Diffuse Flux: Analysis Strategy

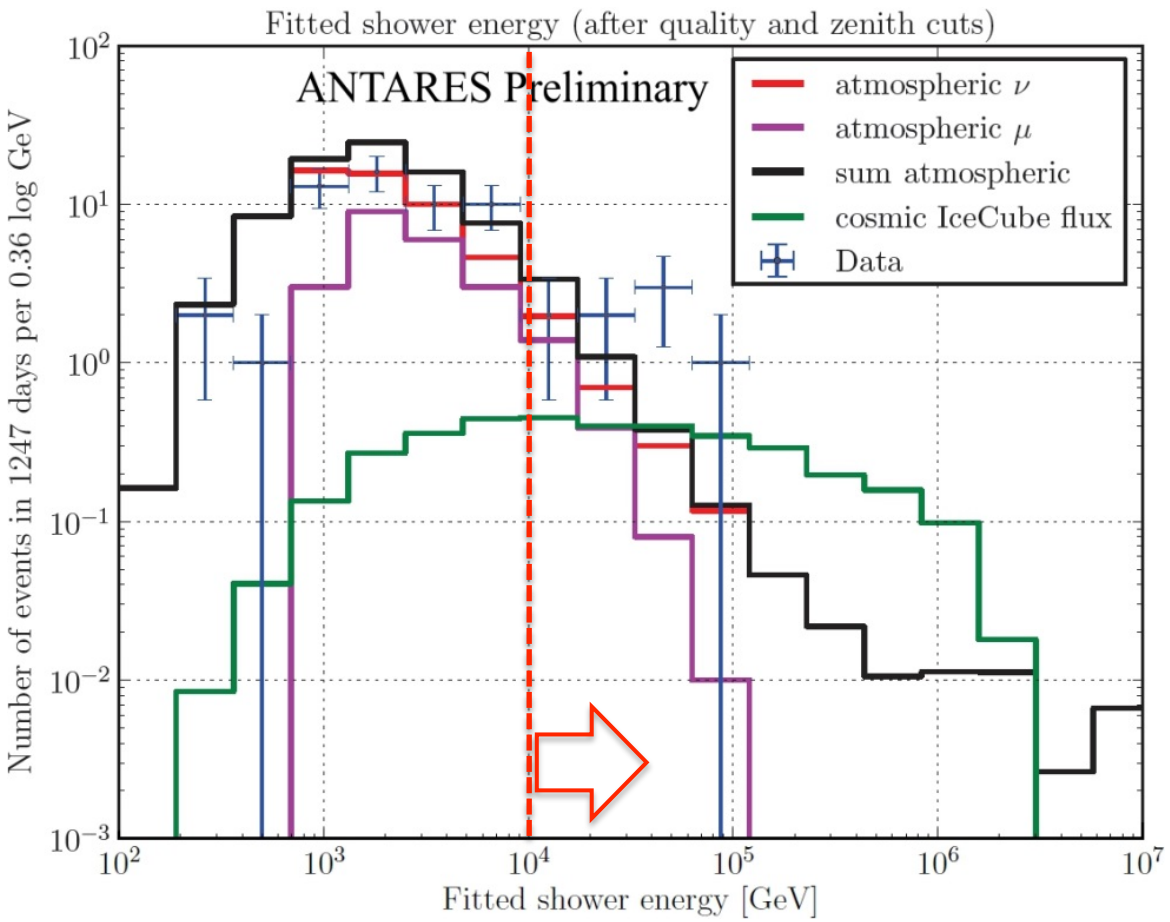
- "Generic" event selection strategy:
  - track/shower reconstruction using fit on PMT hit coincidences (define quality parameter, apply cuts)
    ⇨event sample selection for analysis
  - determine direction of incoming neutrino
    ⇨atmospheric muon rejection
  - energy estimator
    ⇨atmospheric neutrino rejection
  - specific cuts, e.g. minimum number of hits, lines, etc



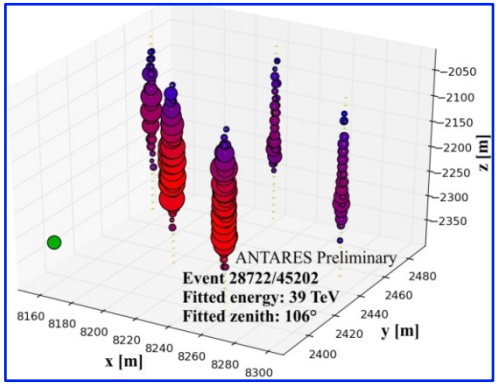
- Blinding strategy

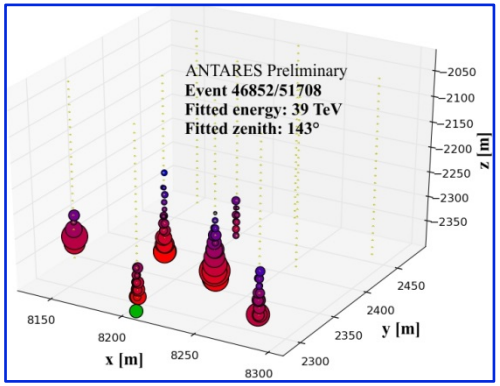
  Use MC simulations and 10% of data as "burn sample" to optimize cuts

Diffuse Flux: Showers



Two of the 8 observed events



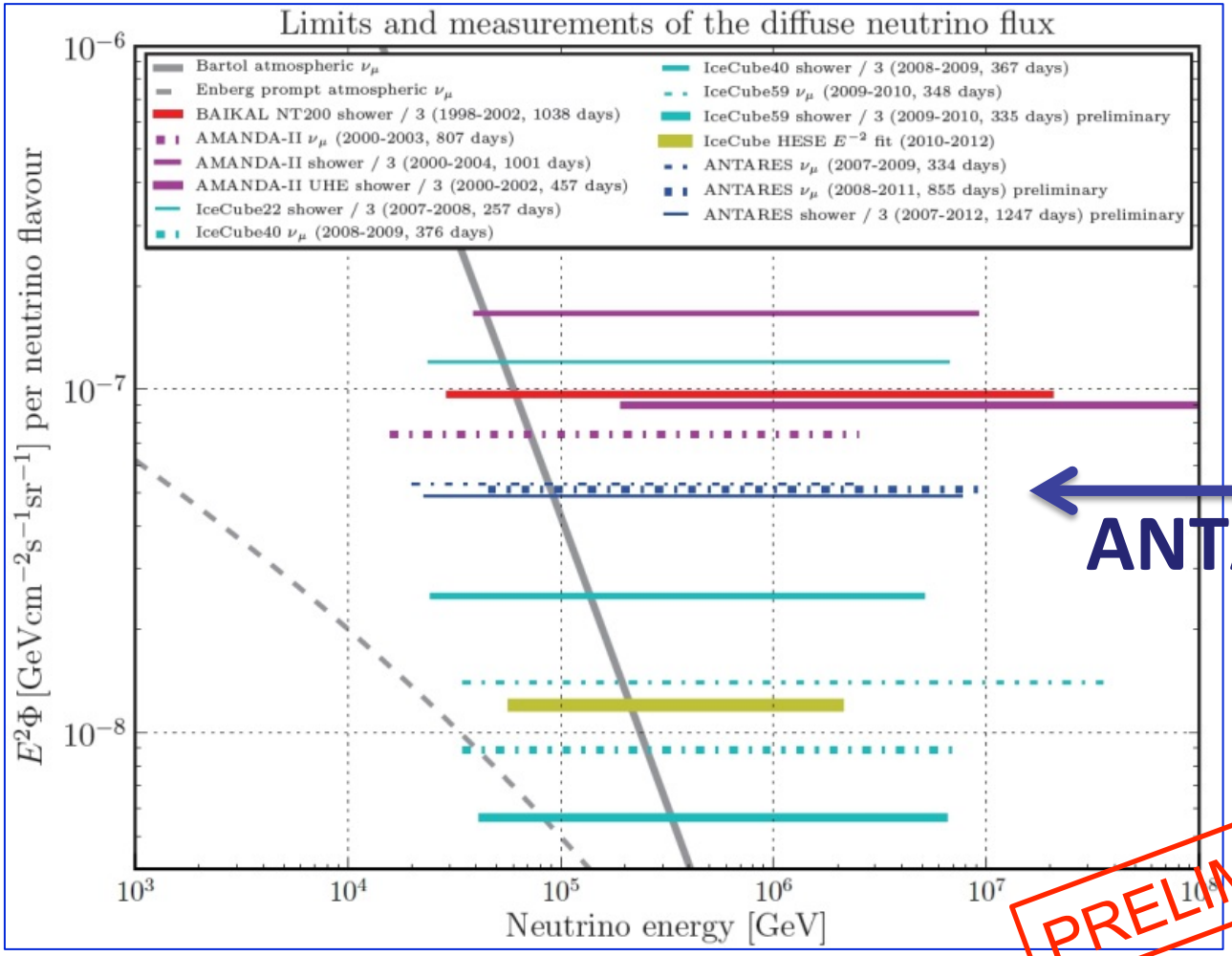


Diffuse Flux: Results

Analysis type	Showers	Track
Neutrino flavours	All flavours	Muonic
Period	2007-2012 (1247 days)	2007-2011 (885 days)
Exp. background events	4.9	8.4
Observed events	8	8
Upper limit $E^2 \cdot \Phi_{90\%}\ \left[\mathrm{GeV/(cm^2\,sr\,s)}\right]$ (per flavour, 90% CL, systematic included)	4.9×10^{-8}	5.1×10^{-8}
Energy range	23 TeV < E < 7.8 PeV	45 TeV < E < 10 PeV

PRELIMINARY

Diffuse Flux: Results

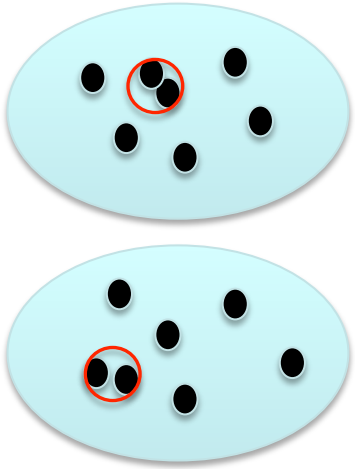


Point Sources

- Years 2007-2012 (1338 days):
  - 5516 neutrino candidates (angular reconstruction for 90 % better than 1^0)
  - signal/background (atm. neutrinos) separation with likelihood method

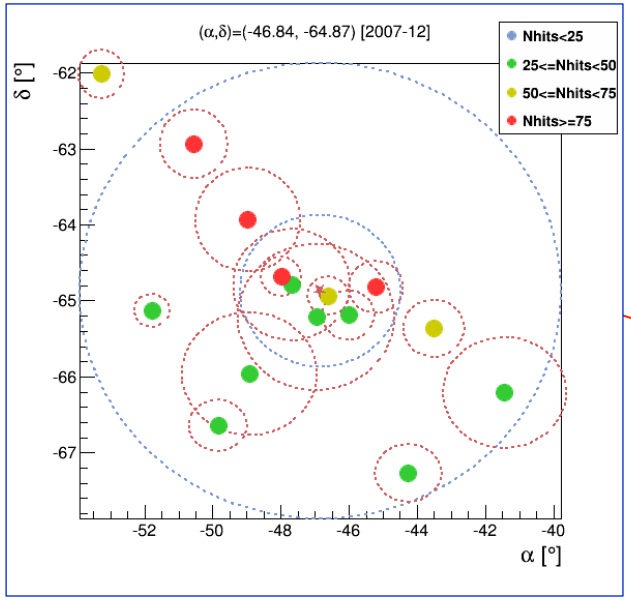
$$\log L_{s+b} = \sum_i \log \left[\frac{n_s}{N} S_i + \left(1 - \frac{n_s}{N}\right) B_i \right]$$

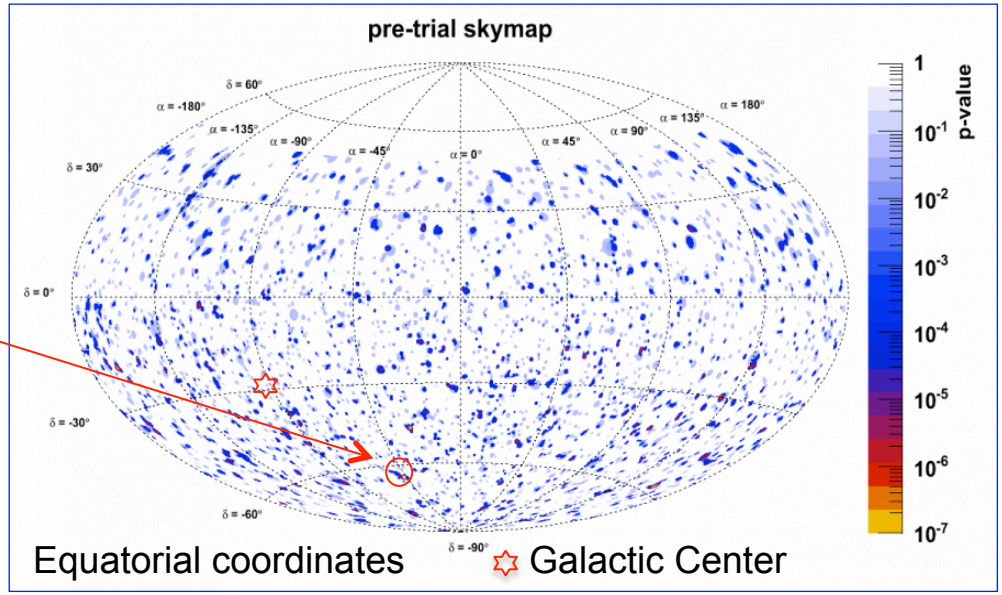
- Statistical Significance of a cluster of events:
  Determine p-value from a number of "pseudo-experiments" with only background
  - pre-trial p-value:
    fraction of pseudo-experiments reproducing a cluster equivalent to observed one
  - post-trial p-value:
    fraction of pseudo-experiments with at least one equivalent or larger cluster reproduced "anywhere"



Point Sources

- All-Sky-Search:
  - most significant cluster, 6 (14) events in 1° (3°) : p-value = 2.7% (2.2 σ)
  - compatible with background hypothesis

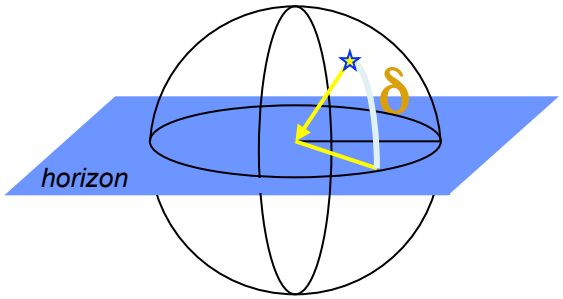


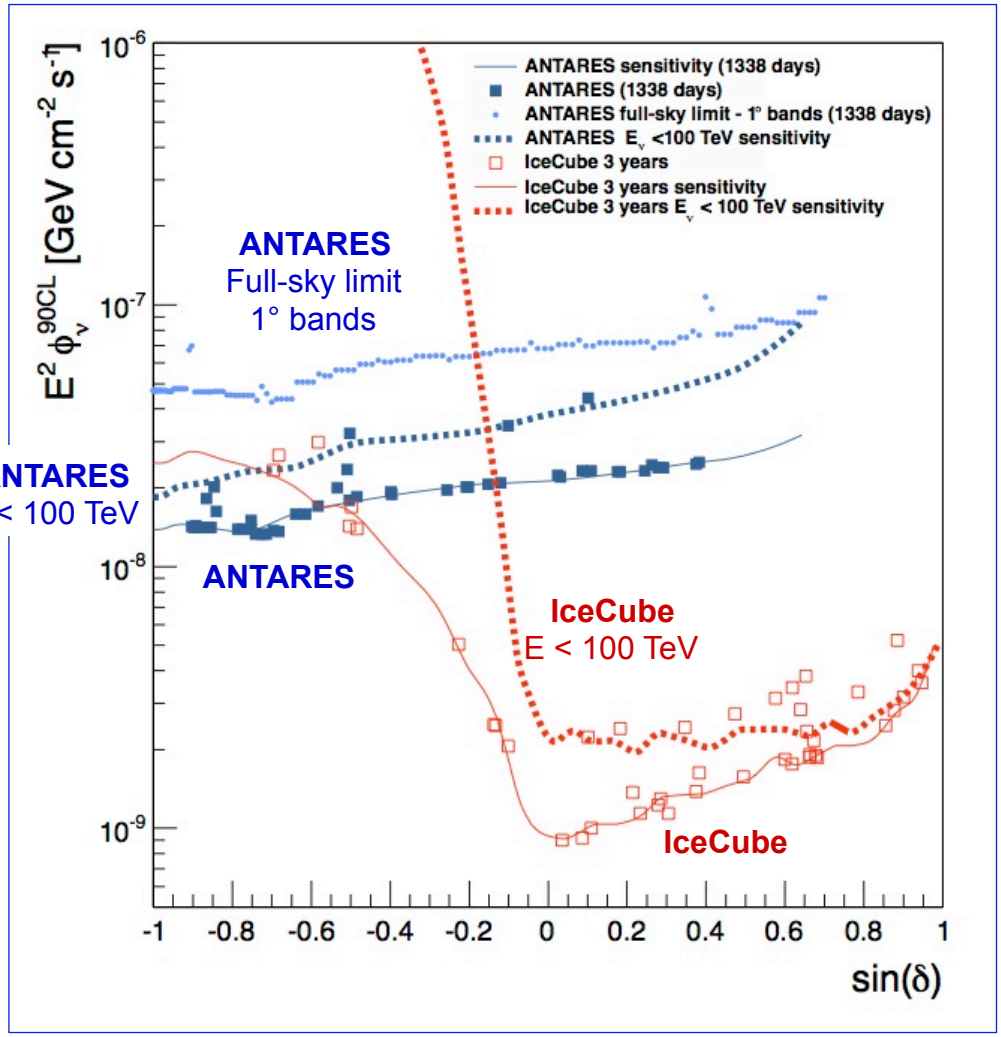


- Fixed search: List of 50 neutrino candidate sources:
  - max. p-value 6.1% (1.9 σ)

Flux Sensitivities and Limits

- ANTARES 2007-2012 (1338 days)
- IceCube 2008-2011 (1040 days)
- 90% C.L.



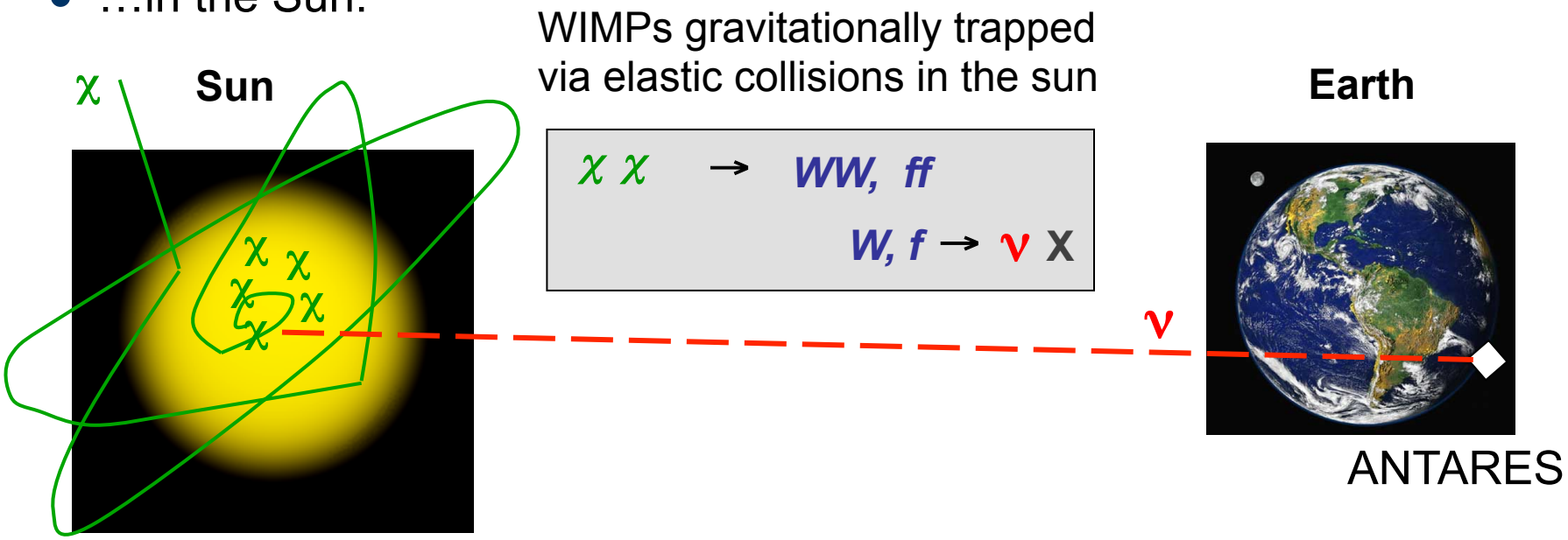


📖 APJL 786 (2014) L5

Indirect Searches for Dark Matter

Search for neutrinos from dark matter (WIMP) annihilations

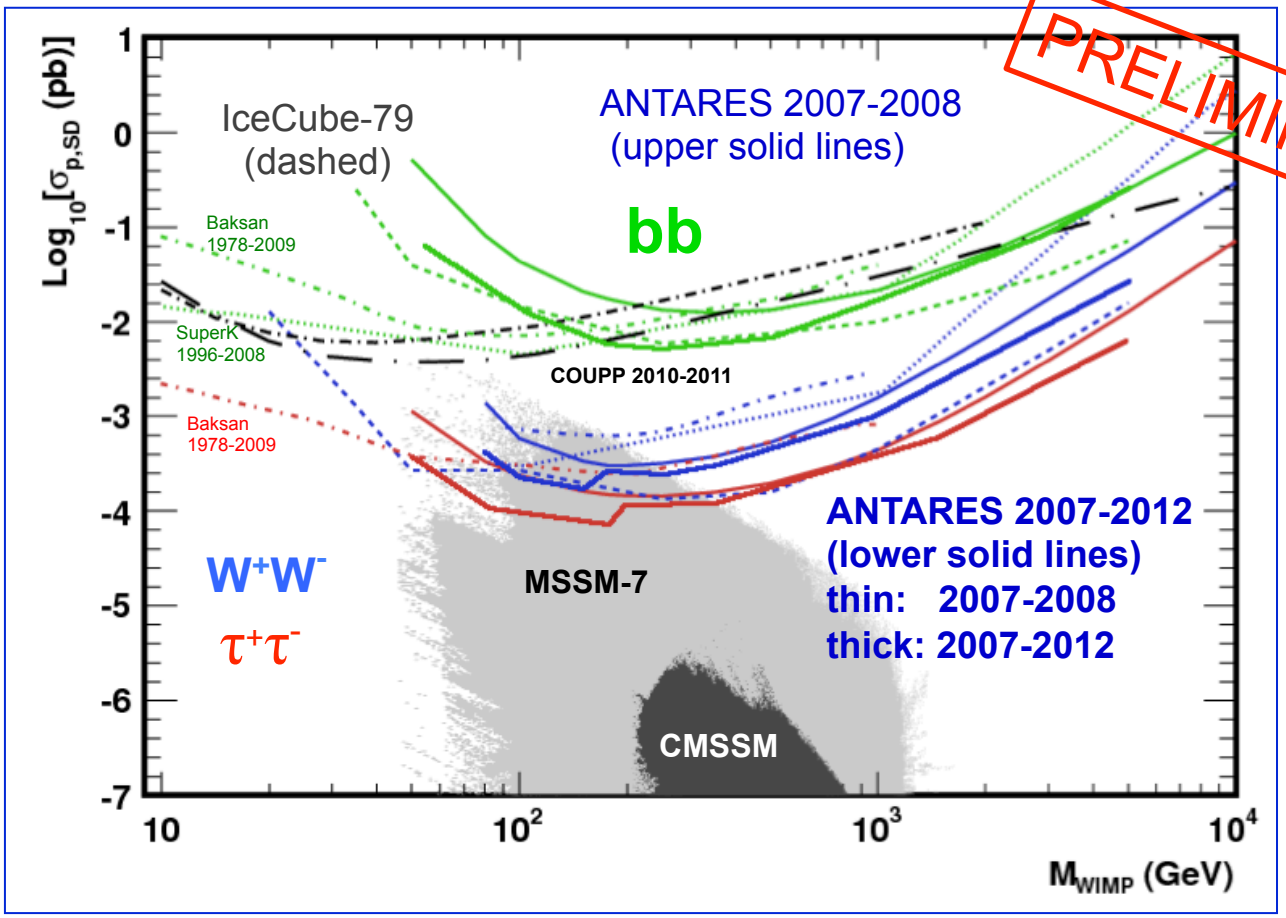
- …in the Sun:



- … in the galactic center:
  WIMPs self-annihilate according to $\langle \sigma_A v \rangle$ (halo model-dependent)

annihilation cross section ↗ ↖ relative velocity

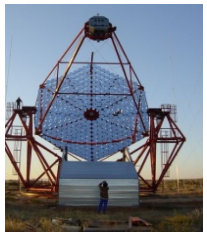
Sun – Limits on spin-dependent (SD) cross-sections

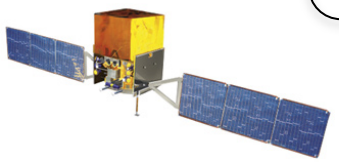


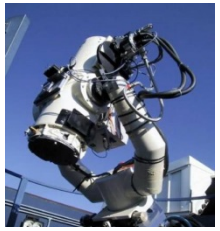
📖 JCAP11 (2013) 032

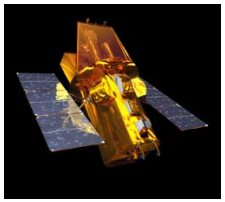
Still room for improvement in ANTARES: better reconstruction at low energies, unbinned method, more data “on tape”, …

Multi Messenger Program







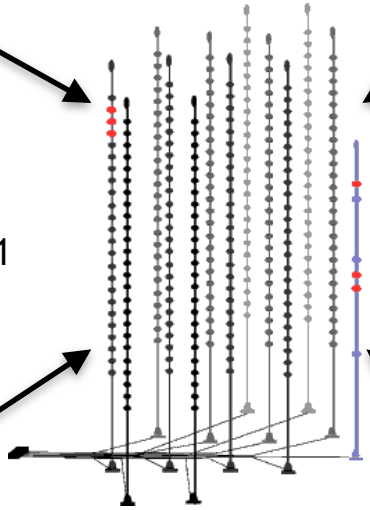


GeV-TeV γ-rays
Fermi / HESS…

📖 JCAP 03(2013) 006
📖 A&A 559 (2013) A9
📖 JCAP 05 (2014) 001

UHECR
Auger

📖 APJ 774 (2013) 19



Optic / X-ray
TAROT,
ROTSE, Swift,
ZADKO

📖 APP 36 (2012) 204
📖 A&A 559 (2013) A9

Gravitational
Waves
Virgo / Ligo

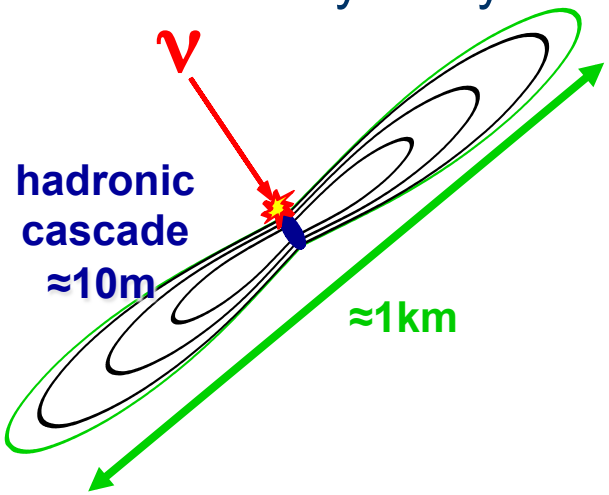
📖 JCAP 06 (2013) 008

Increases chances of detection:

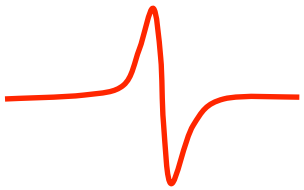
- common sources for different messengers.
- limits searches in time and space, Low backgrounds.
- uncorrelated backgrounds and systematics.

The AMADEUS System of ANTARES

Goal: feasibility study of acoustic detection techniques

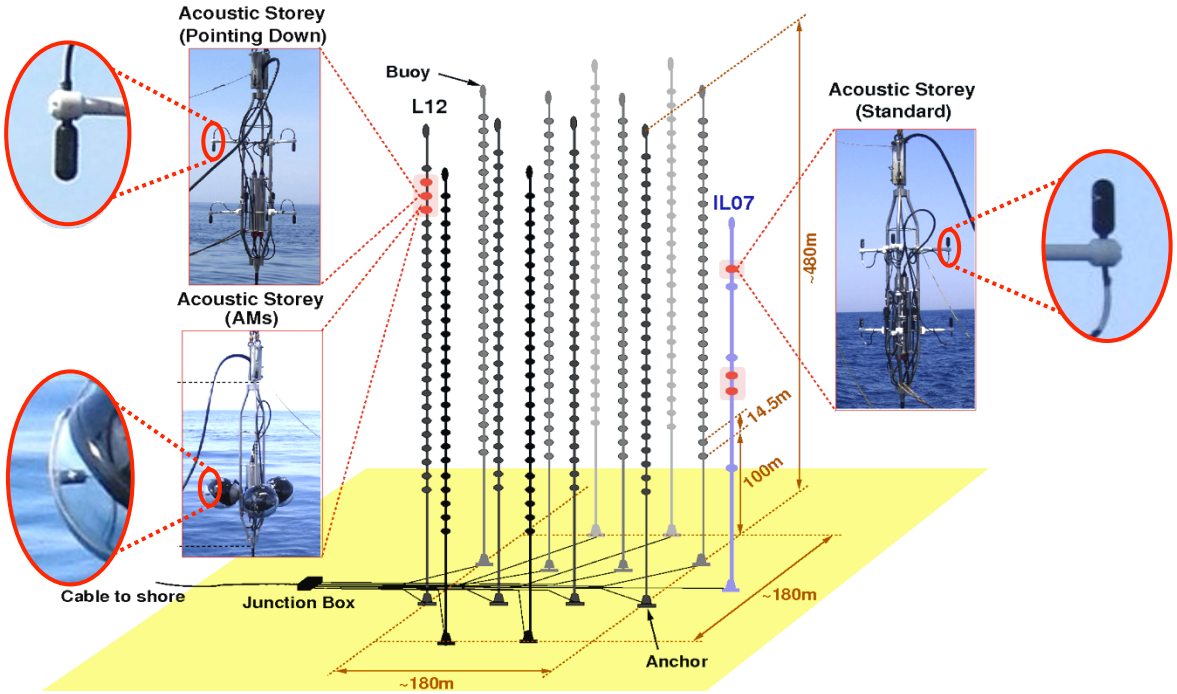


Expect bipolar pressure pulse:

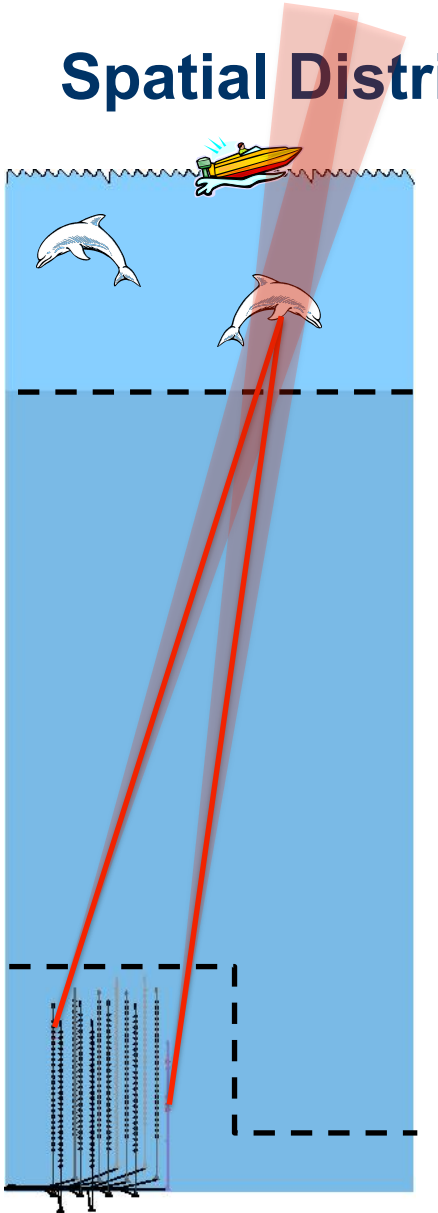


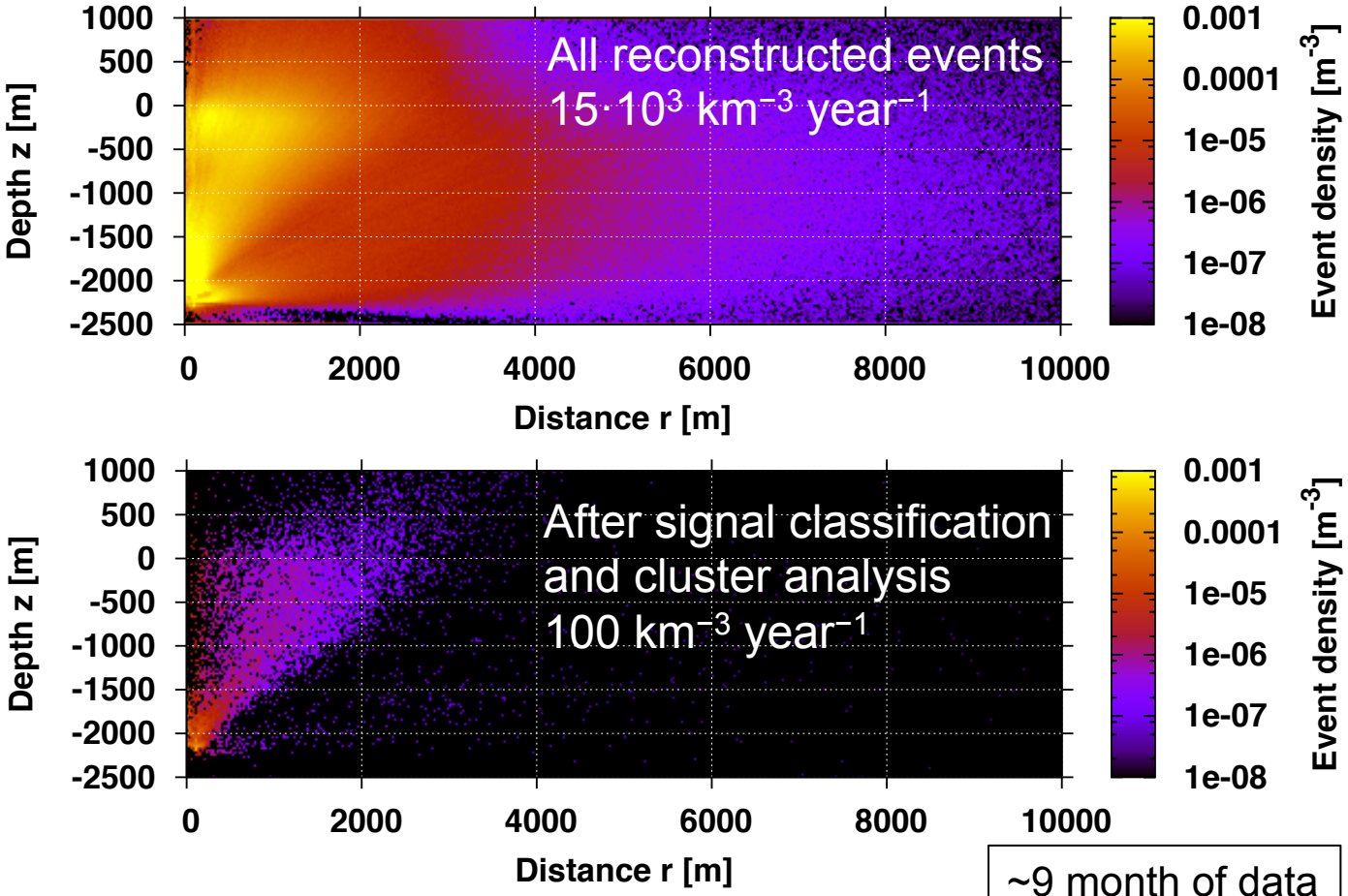
$E_\nu \gtrsim 1$ EeV

$f_{peak} = 10 \sim 20$ kHz



Spatial Distribution of Acoustic Transient Background





~9 month of data

Conclusions

- ANTARES is in its seventh year of operation
- Moderate size, but thanks to its location and excellent angular resolution, it is yielding unique results for diffuse flux, point source searches, dark matter and other subjects
- ANTARES will keep producing results until the next generation Mediterranean neutrino telescope, KM3NeT, takes over

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Thank you for your attention

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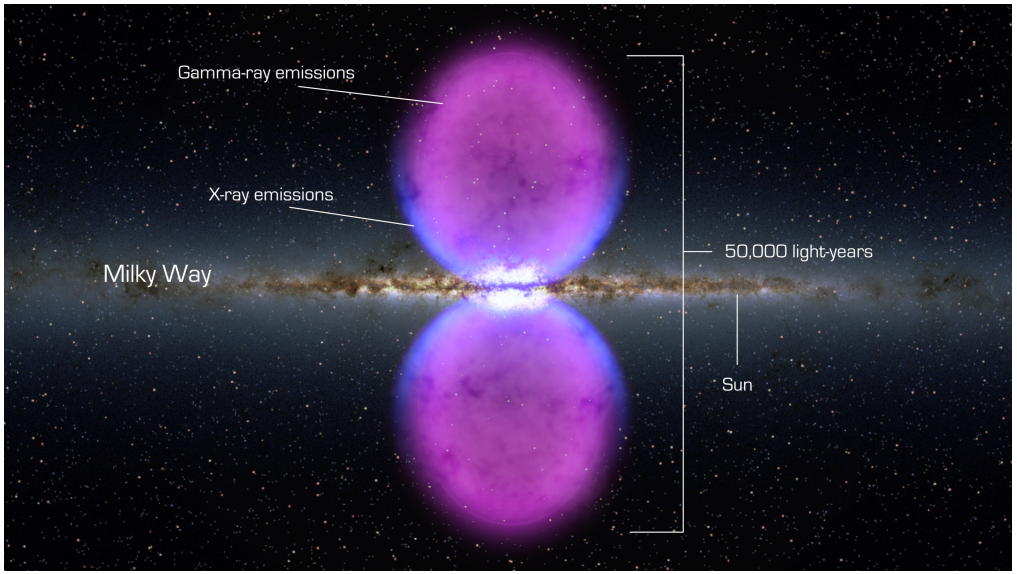
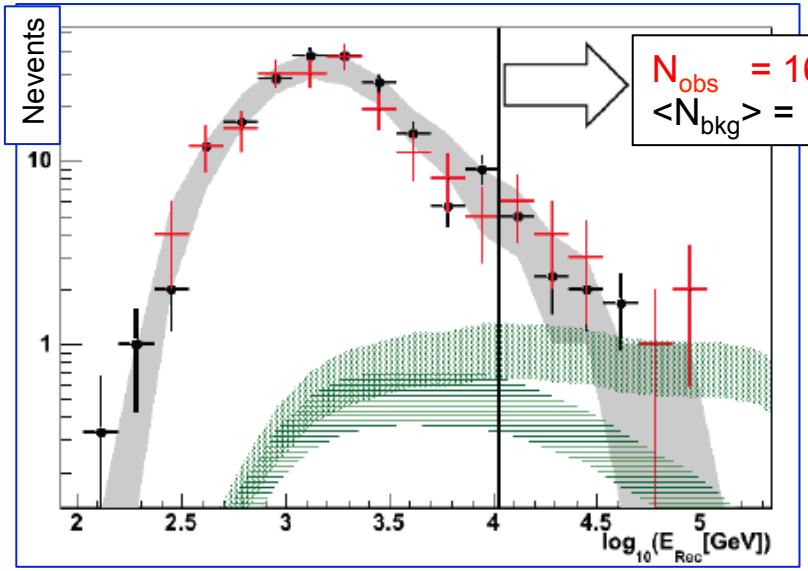
Backups

Diffuse Flux from Special Regions: Fermi Bubbles

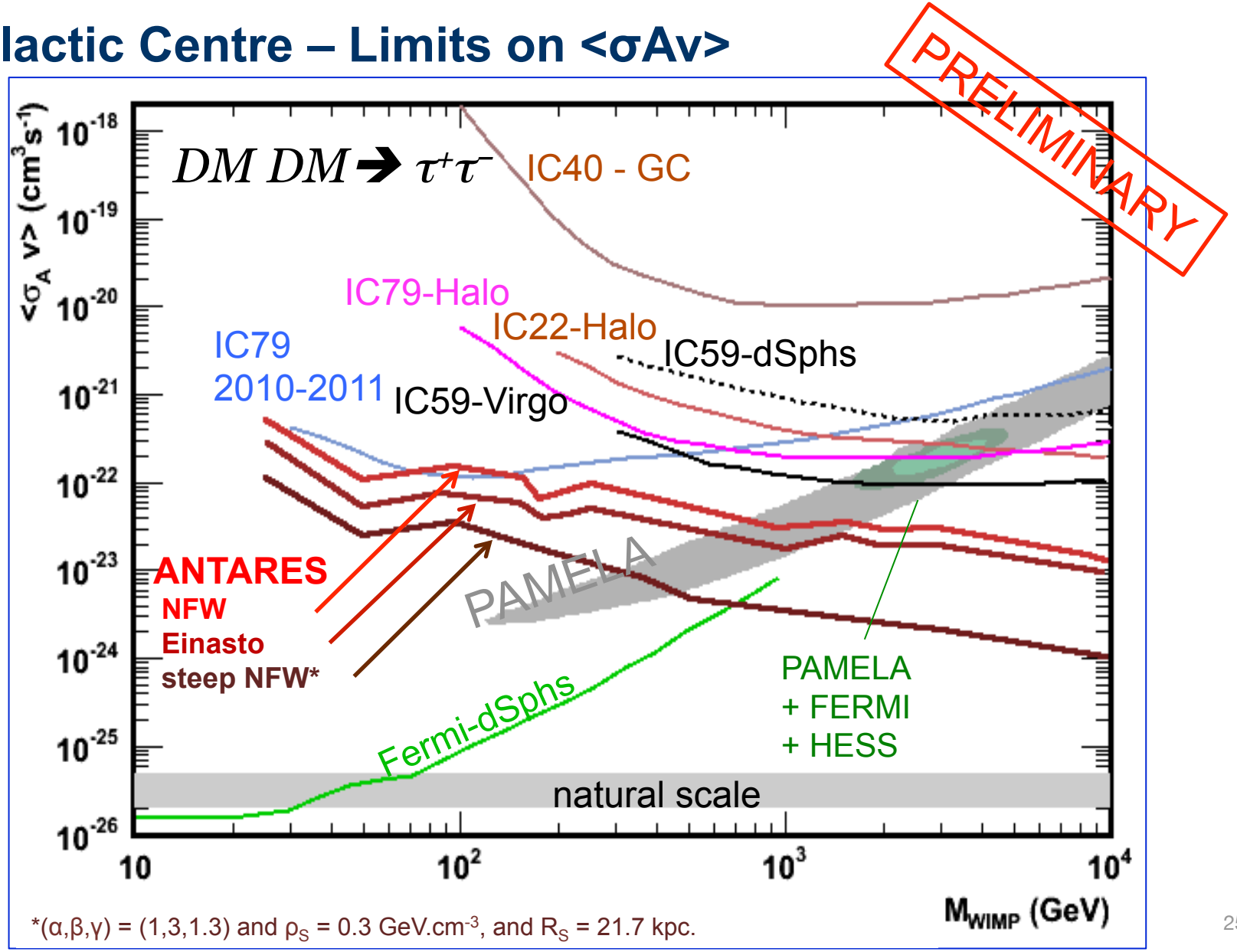
Excess of γ- (and X-) rays in extended "bubbles" above and below the Galactic Centre. Homogenous intensity, hard spectrum (E^{-2}) probably with cutoff.





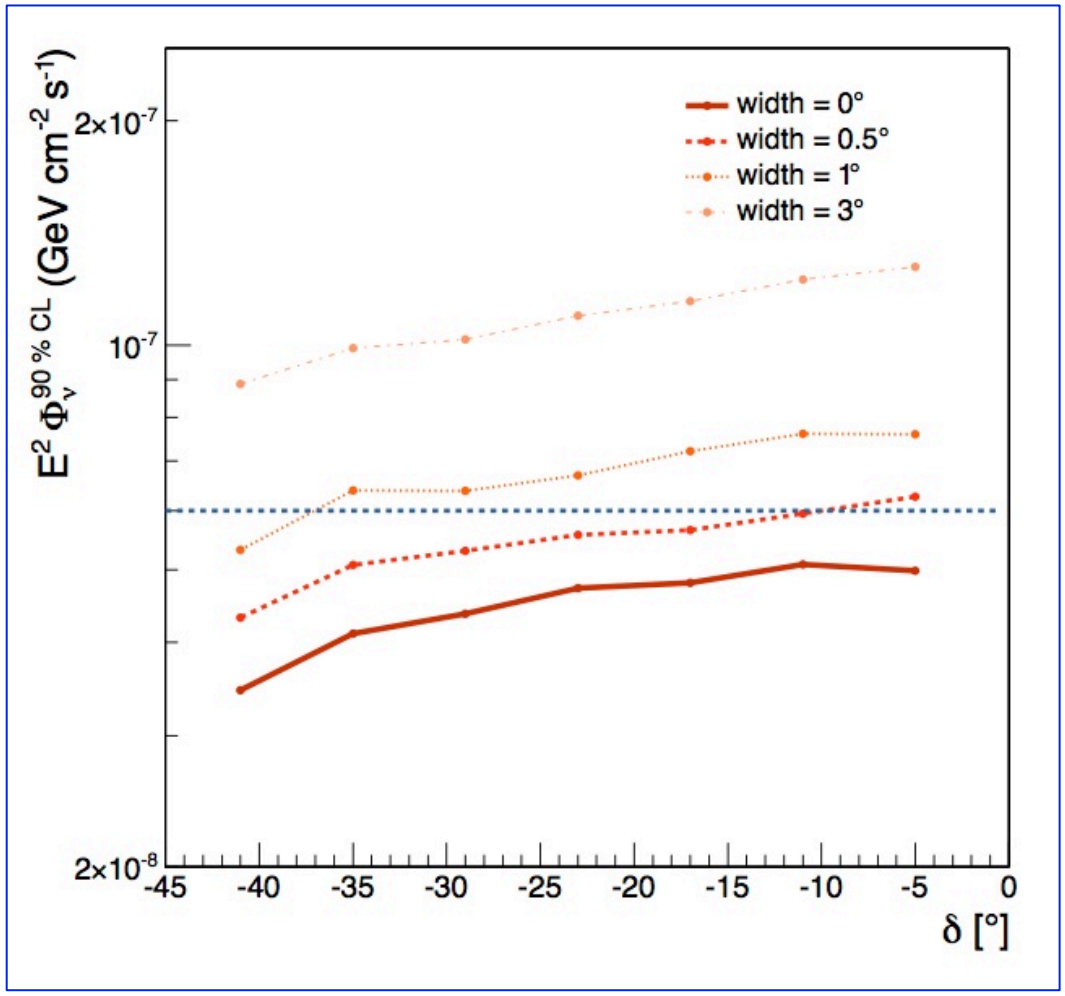
M. Su et al., ApJ. 724 (2010),
G. Dobler et al., ApJ. 717, 825 (2010),
M. Su & D.P. Finkbeiner ApJ 753, 61 (2012),
R. Yang et al., astro-ph 1402.040

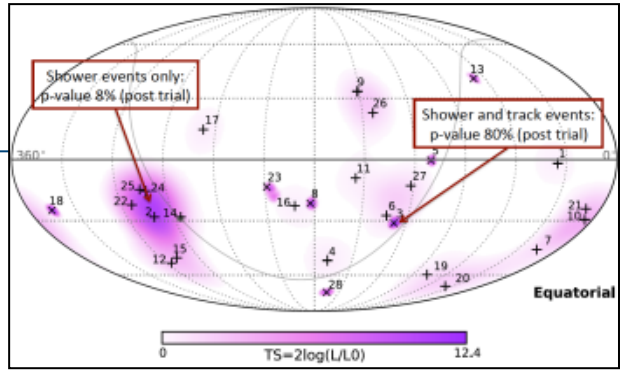
Galactic Centre – Limits on <σAv>



*(α,β,γ) = (1,3,1.3) and ρ_S = 0.3 GeV.cm^{-3}, and R_S = 21.7 kpc.

Source around the GC?





What about IC's cluster near the GC?

- Shower events have low angular resolution
- IC does not claim a signal.
  If it were a point source:

  $(\alpha,\delta)=(-79°, -23°)$;
  $\varphi_\circ = 6 \times 10^{-8}$ GeV cm^{-2} s^{-1}

(M. C. Gonzalez-Garcia, F. Halzen and V. Niro, arXiv1310.7194)

ANTARES:

- Point source search at different δ's
- Allow for extended sources:
  widths: 0°, 0.5°, 1° and 3°

ANTARES data excludes a point source as origin of the IceCube's cluster