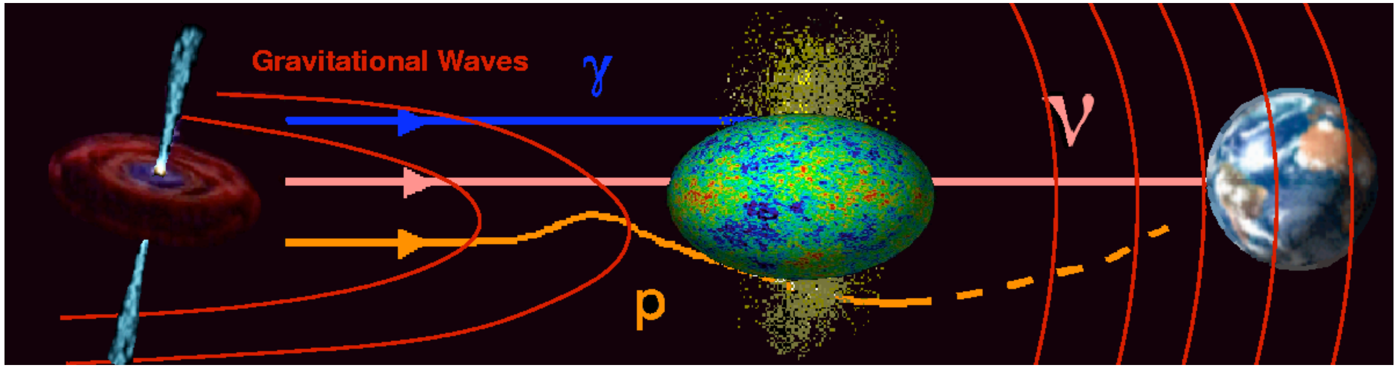
RICAP-13 Roma International Conference on AstroParticle Physics

Recent results from the ANTARES neutrino telescope

Véronique Van Elewyck
(APC & Université Paris Diderot)
for
the ANTARES Collaboration

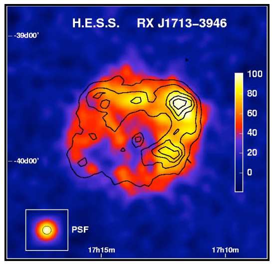
Neutrino astronomy: why and how



- Long-range, weakly-interacting messengers
- Point back to their source
- Signature of hadronic processes in the high-energy universe:

$$p + p(\gamma) \rightarrow \pi^{\pm} + X$$
$$\hookrightarrow \mu + \nu_\mu$$
$$\hookrightarrow e + \nu_\mu + \nu_e$$

SNR



Nature 432 (2004) 75

AGN jets and lobes

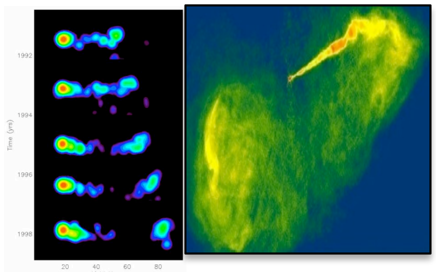


Image courtesy of NRAO/AUI

GRB

NASA/Swift/Stefan Immler

(could also reveal so far hidden sources)

- Main target: high-energy neutrinos
  - TeV → PeV range
  - all flavors

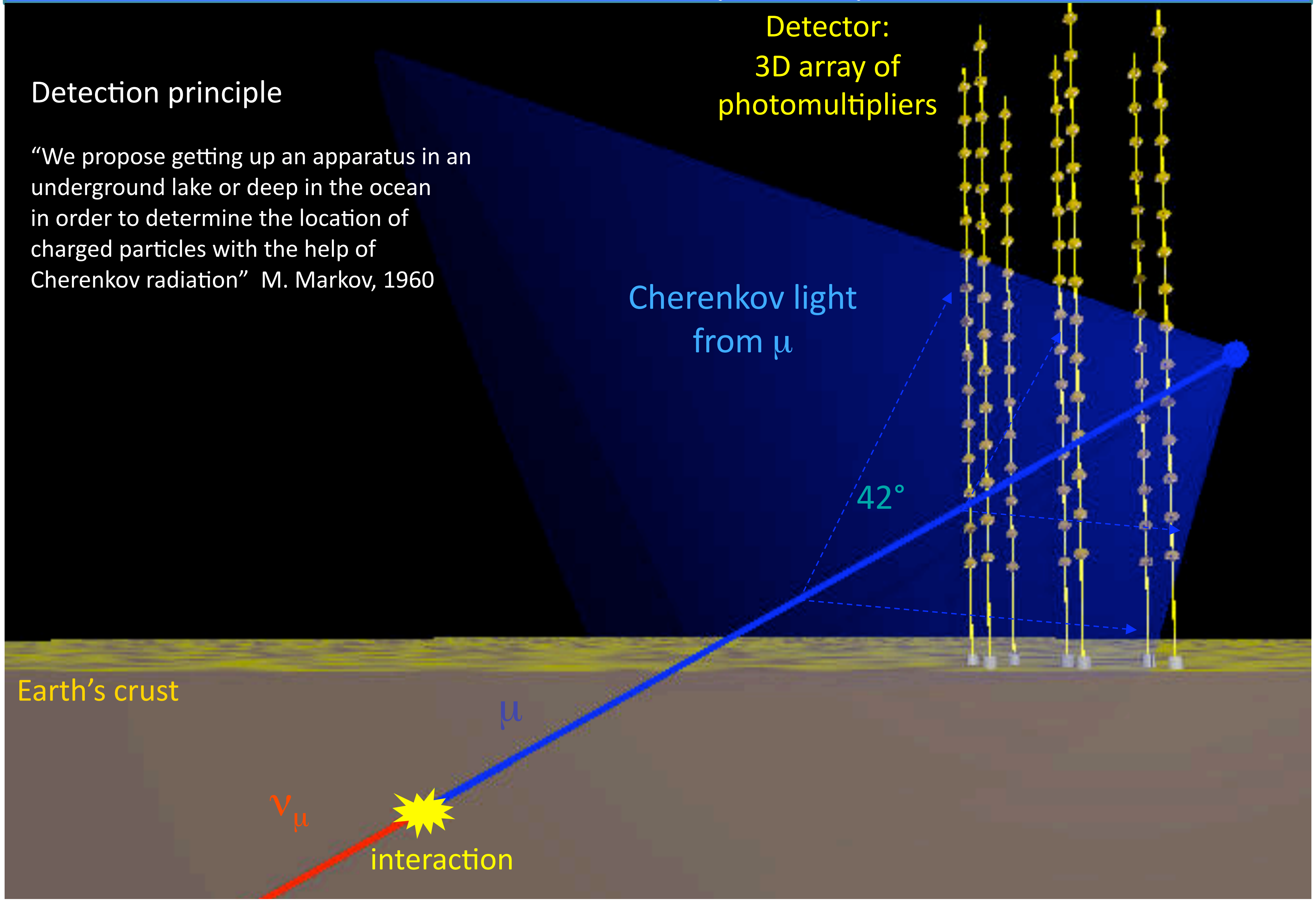
$$\nu_e : \nu_\mu : \nu_\tau = 1:2:0 \xrightarrow{\text{oscillations}} \nu_e : \nu_\mu : \nu_\tau = 1:1:1$$

at source — at Earth

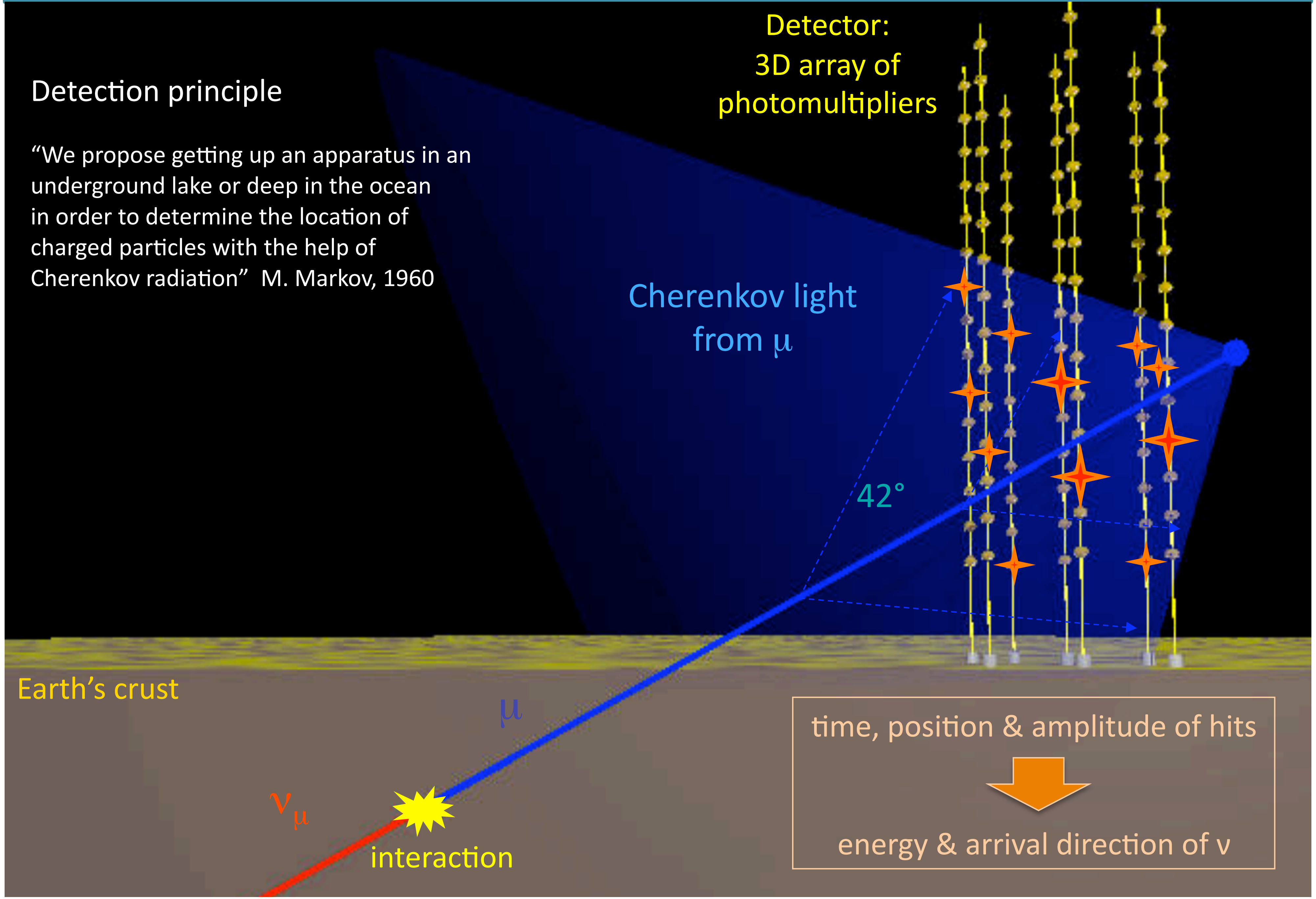
Neutrino astronomy: why and how

Detection principle

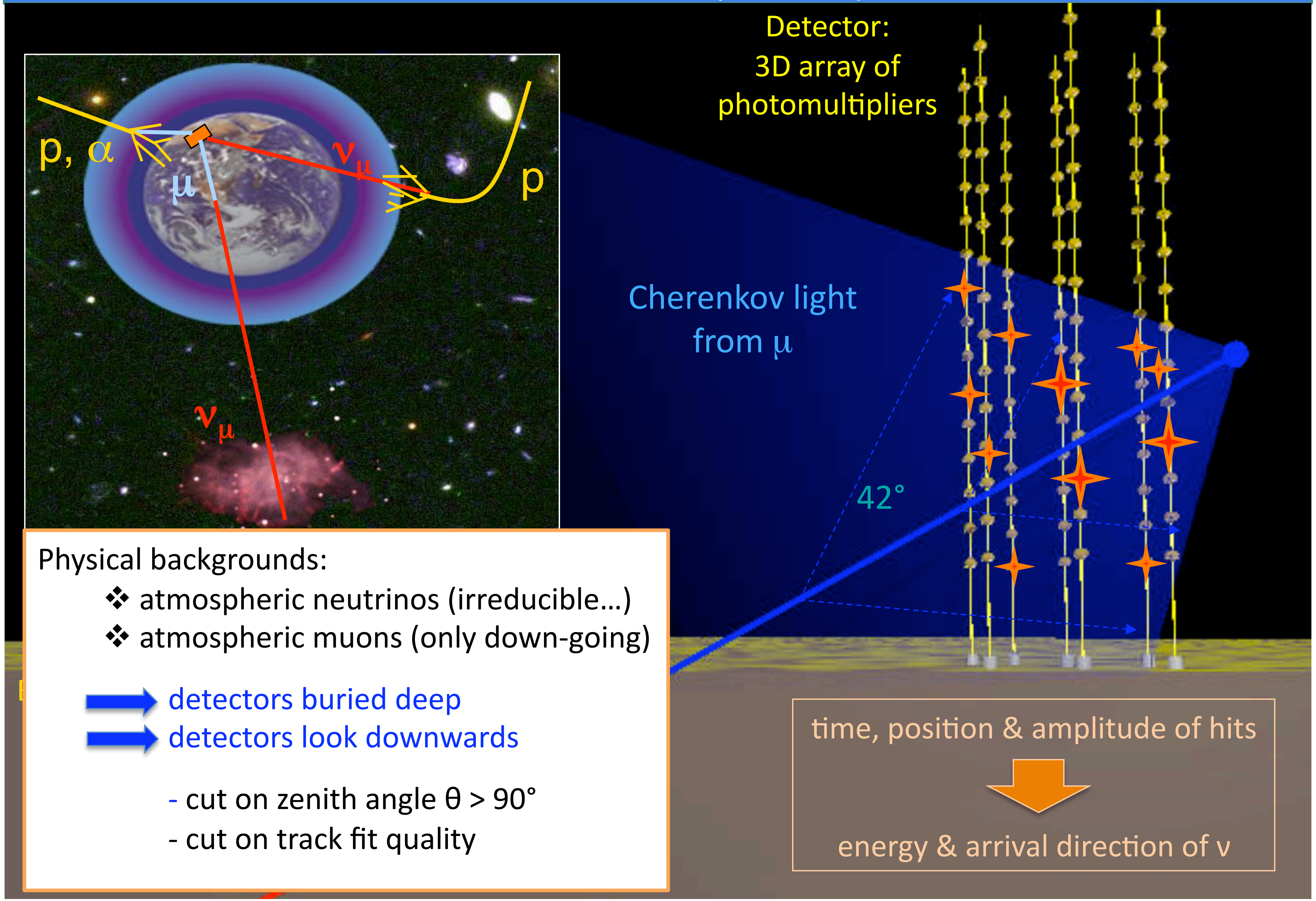
"We propose getting up an apparatus in an underground lake or deep in the ocean in order to determine the location of charged particles with the help of Cherenkov radiation" M. Markov, 1960



Neutrino astronomy: why and how



Neutrino astronomy: why and how



Physical backgrounds:

- atmospheric neutrinos (irreducible…)
- atmospheric muons (only down-going)

➡ detectors buried deep
➡ detectors look downwards

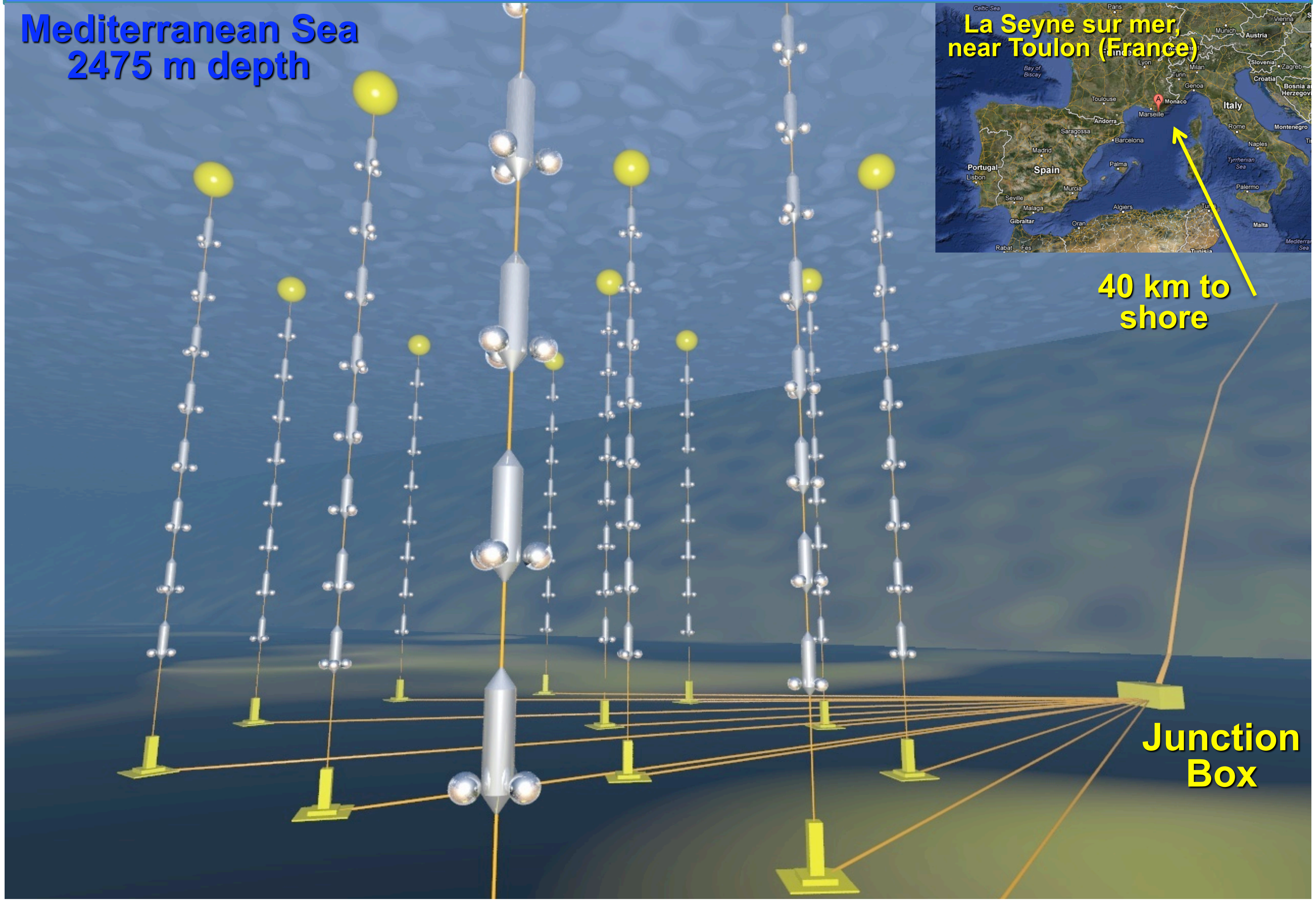
- cut on zenith angle θ > 90°
- cut on track fit quality

time, position & amplitude of hits

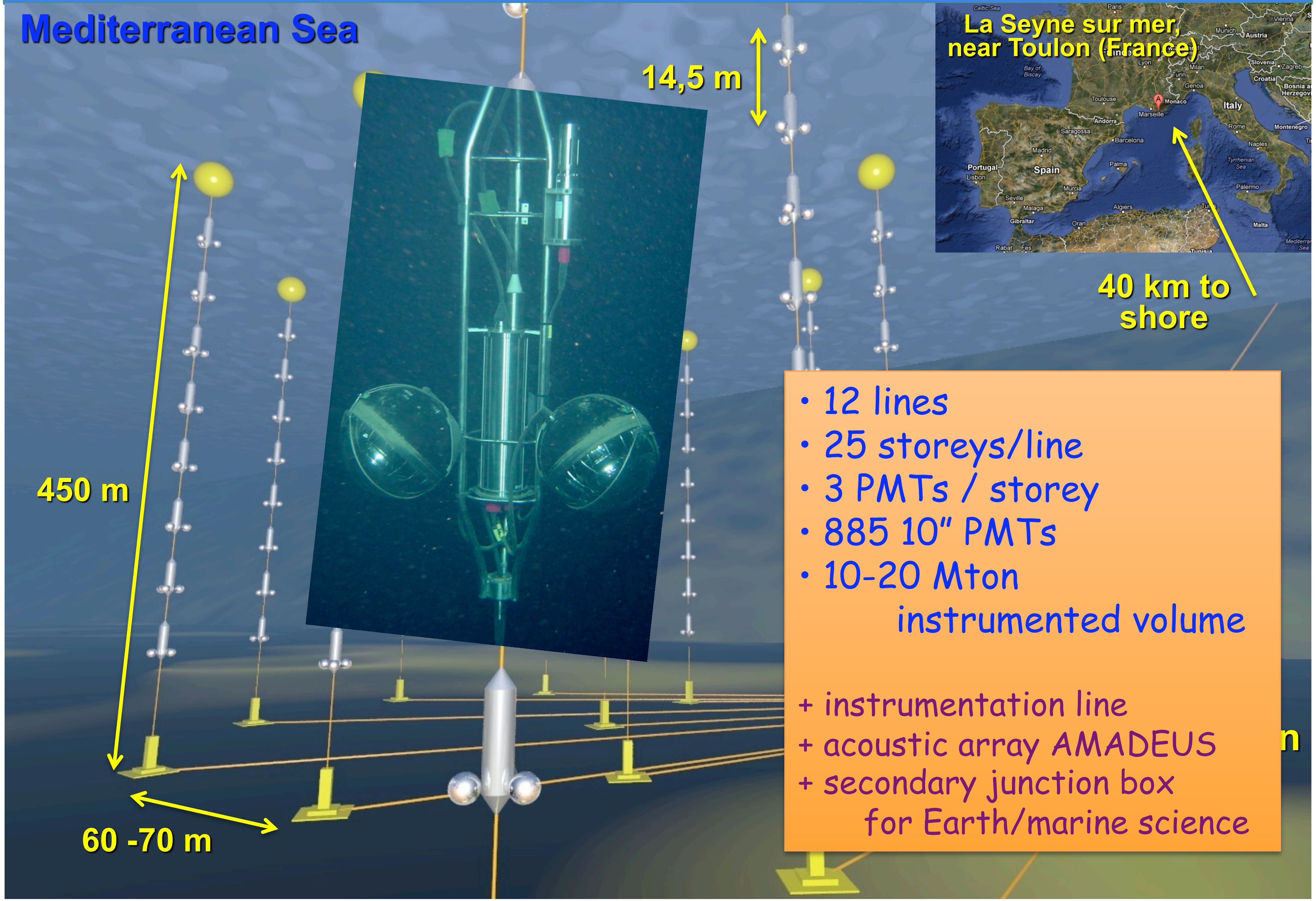
⬇

energy & arrival direction of ν

The ANTARES detector



The ANTARES detector



- 12 lines
- 25 storeys/line
- 3 PMTs / storey
- 885 10" PMTs
- 10-20 Mton instrumented volume

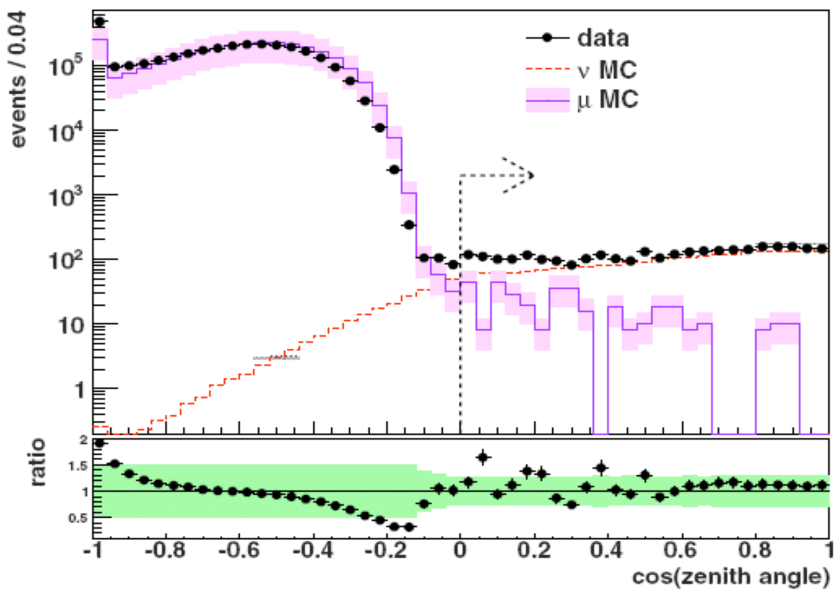
+ instrumentation line
+ acoustic array AMADEUS
+ secondary junction box for Earth/marine science

ANTARES performance

❖ 12-line data taking since 2008;
physics duty cycle ≈ 85%
(sea campaigns/high bioluminescence periods)

❖ ~20 atmospheric muons per sec

directional cut
+ quality cut on likelihood
of track fit
(based on PDFs of
hit time residuals)



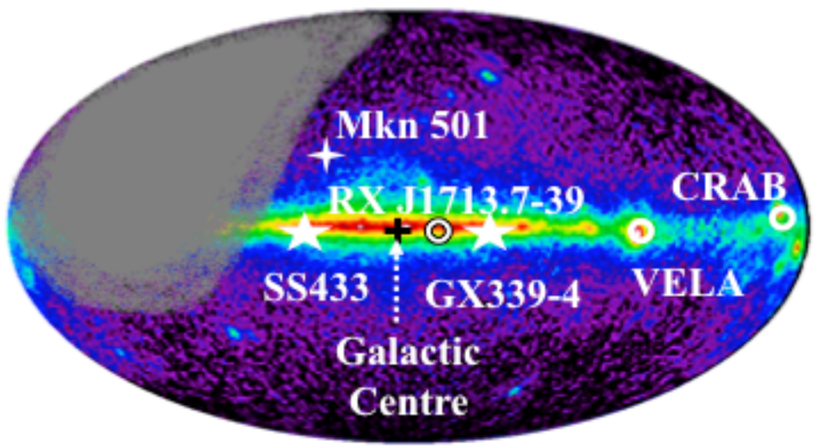
❖ ~5 atmospheric neutrinos per day
(> 7000 neutrinos detected so far)

❖ Real-time data processing

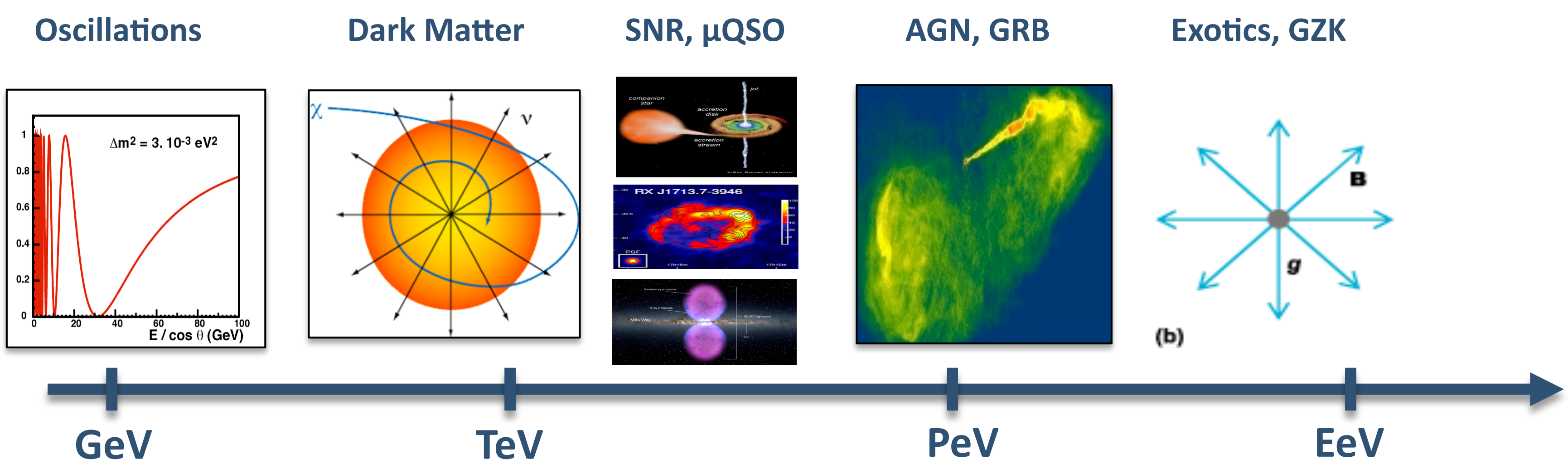
❖ Effective area ≈ 1 m^2 at 30 TeV

❖ Median angular resolution 0.3° – 0.4°

❖ Visibility: $\frac{3}{4}$ of the sky, most of the Galactic Plane



Science with ANTARES



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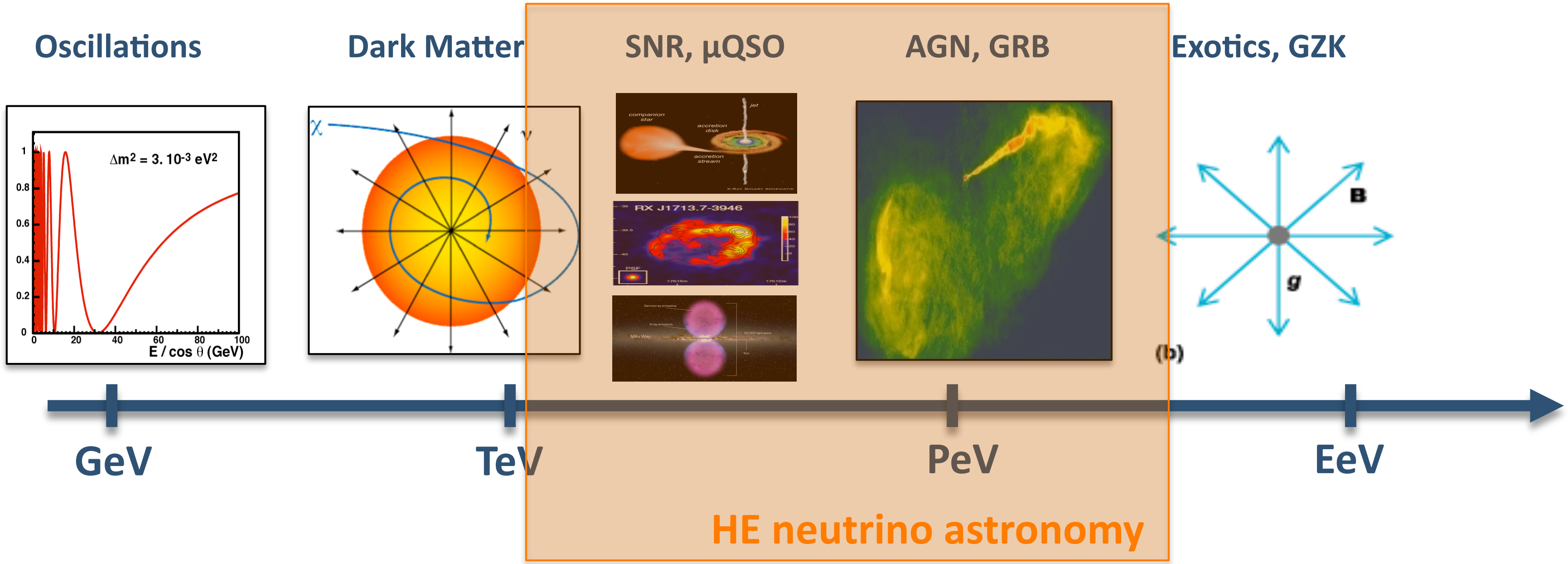
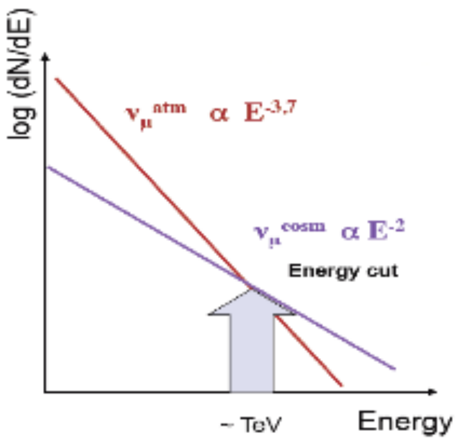


How to identify cosmic neutrinos ?

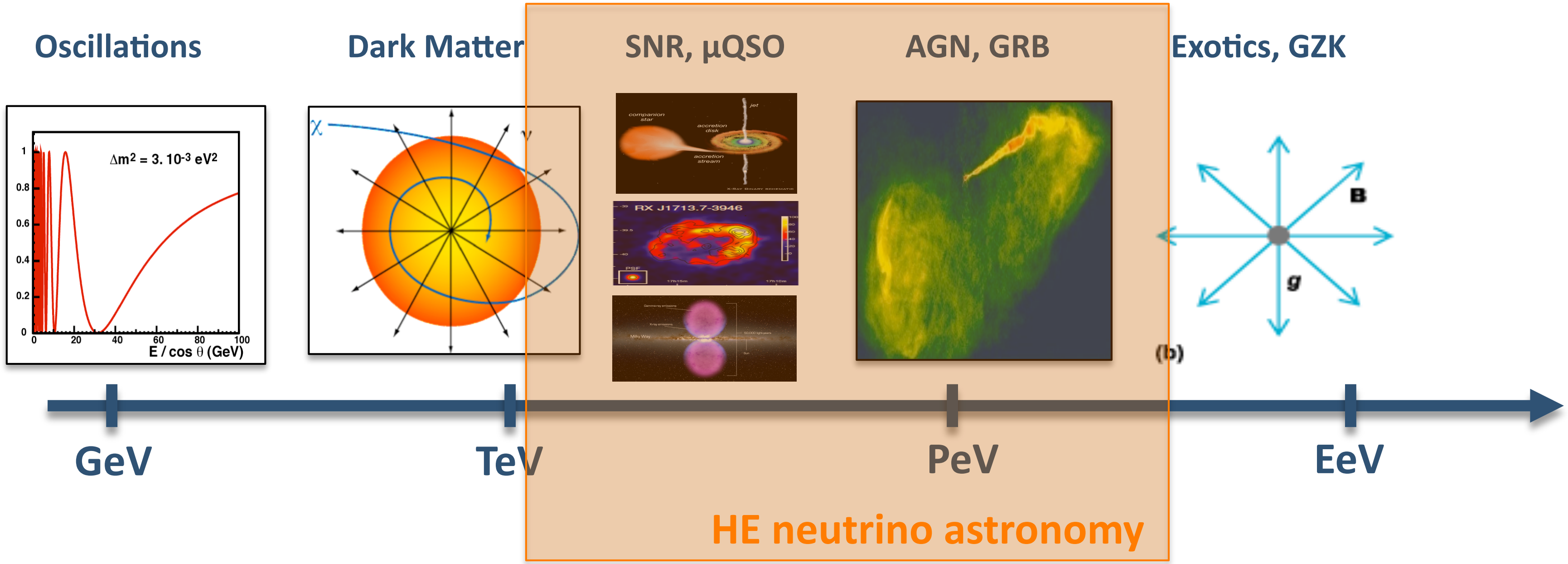
❖ excess at high energies
diffuse flux analyses



❖ anisotropies (clustering) on the sky
point source searches

❖ time &/or space coincidence with other astrophysical signals
multi-messenger strategies

Science with ANTARES



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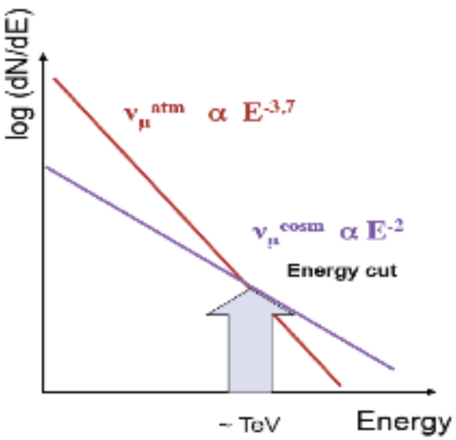


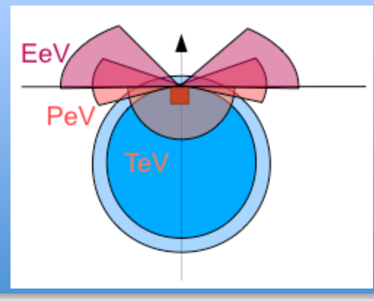
❖ anisotropies (clustering) on the sky

point source searches

❖ time &/or space coincidence with other astrophysical signals

multi-messenger strategies

REMEMBER the Earth becomes opaque to neutrinos at ≈PeV energies:



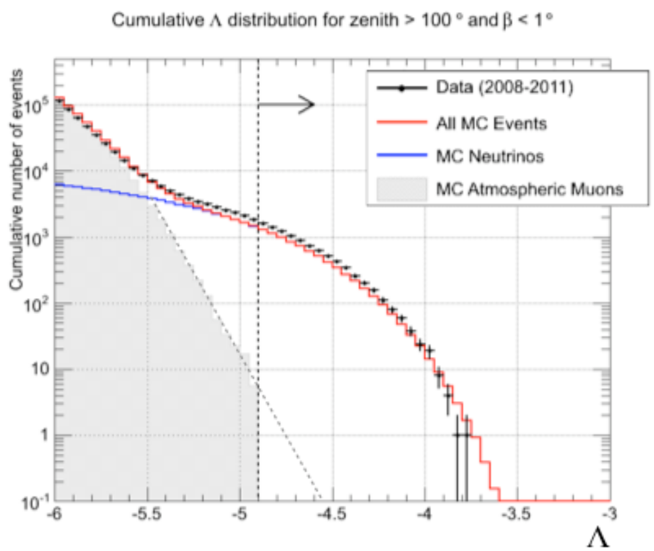
Searches for diffuse fluxes

❖ Search for all-sky diffuse flux of cosmic neutrinos

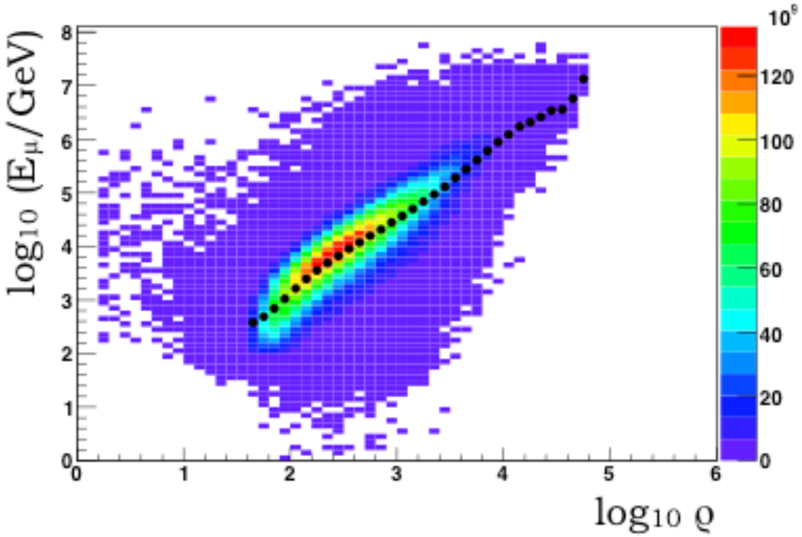
- Updated analysis: 2008-2011 (855 days livetime); muon neutrinos only
- Optimisation tuned on burn sample of 10% data
- Reconstruction of atmospheric ν_μ energy spectrum with unfolding procedure

- Main challenges:

Low (<1%) contamination by atmospheric muons
upgoing tracks with strict quality cuts



Reliable neutrino energy estimator
based on muon dE/dx



Final sample: 1531 neutrinos, 5 muons (est. background)

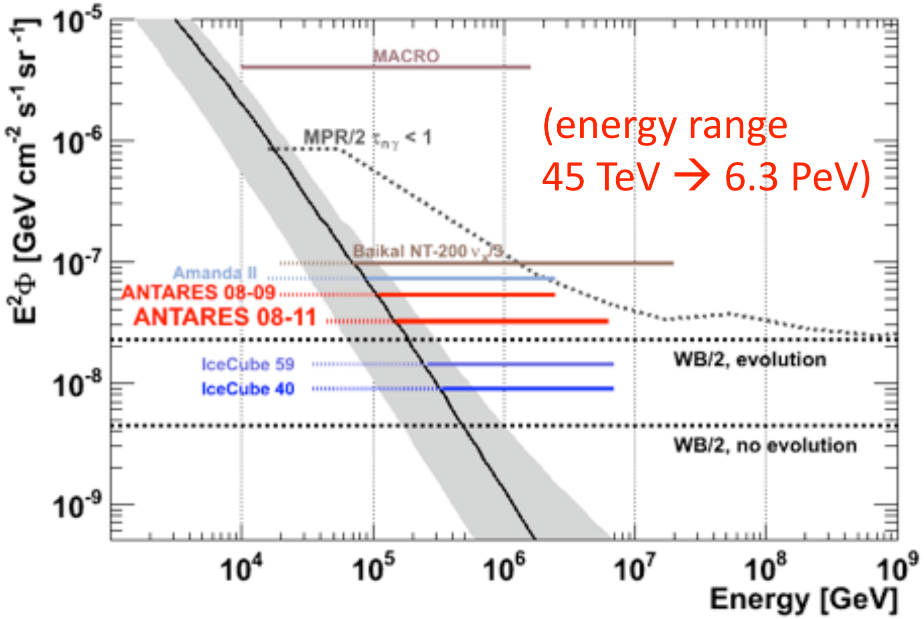
Searches for diffuse fluxes

❖ Search for all-sky diffuse flux of cosmic neutrinos

- Updated analysis: 2008-2011 (855 days livetime); muon neutrinos only
- Optimisation tuned on burn sample of 10% data
- Reconstruction of atmospheric ν_μ energy spectrum with unfolding procedure

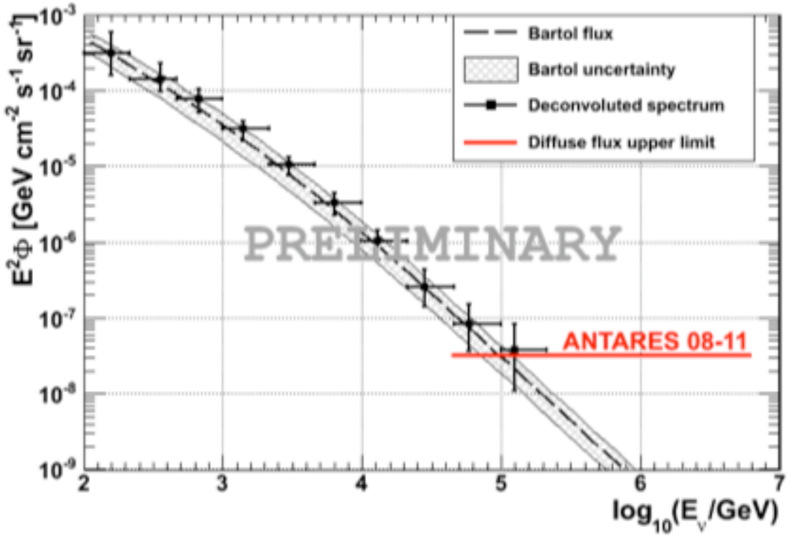
✓Improved limit on diffuse cosmic ν_μ flux

$$E^2 \Phi_{90\%\ c.l.} = 3.2 \times 10^{-8}\ \mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}}$$



Previous limit published in PLB 696 (2011) 16

✓Measurement of atmospheric ν_μ spectrum

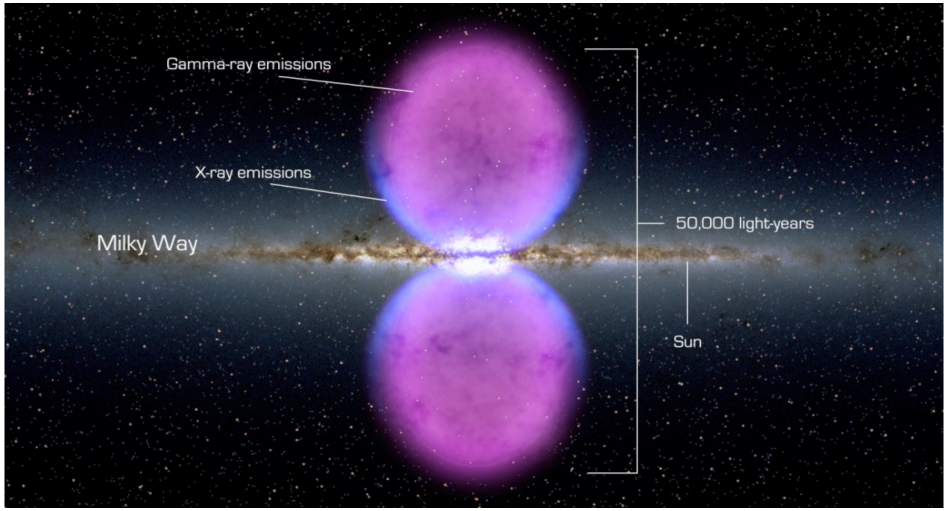


Paper in preparation

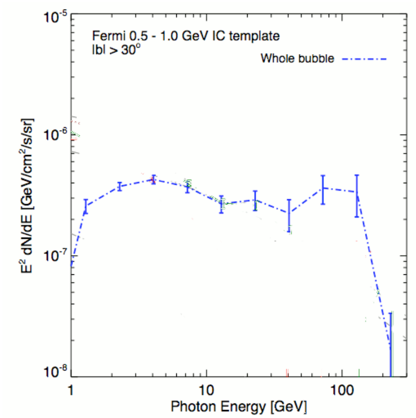
Searches for diffuse fluxes

❖ Search for a neutrino emission from the Fermi bubbles

➢Excess of ɣ- (and X-)rays in extended "bubbles" above and below Galactic Center



➢ Homogenous intensity, hard (E^{-2}) spectrum with probable cutoff



➢ Origin still debated;

promising Galactic wind model involves hadronic processes (*Crocker & Aharonian, PRL 2011*):

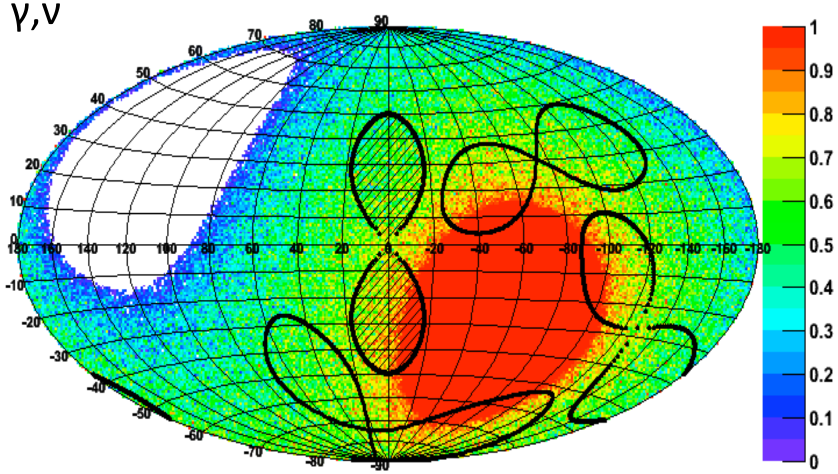
accelerated cosmic rays interacting with ISM → π → γ,ν

CR expected cutoff at 1 – 10 PeV

$\Phi_\nu \approx 0.4 \times \Phi_\gamma$

➢ In the field of view of ANTARES

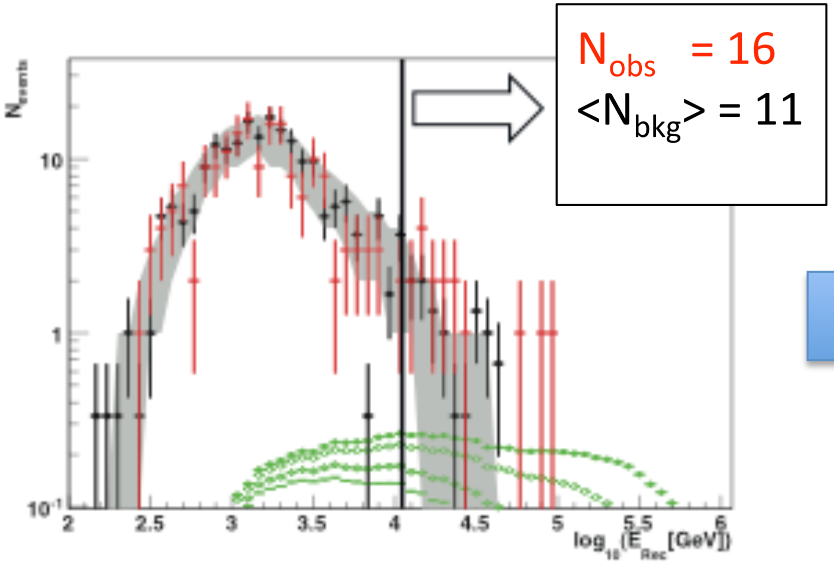
background estimated from average of 3 non-overlapping "off-zone" data regions (same size, shape and average detector efficiency)



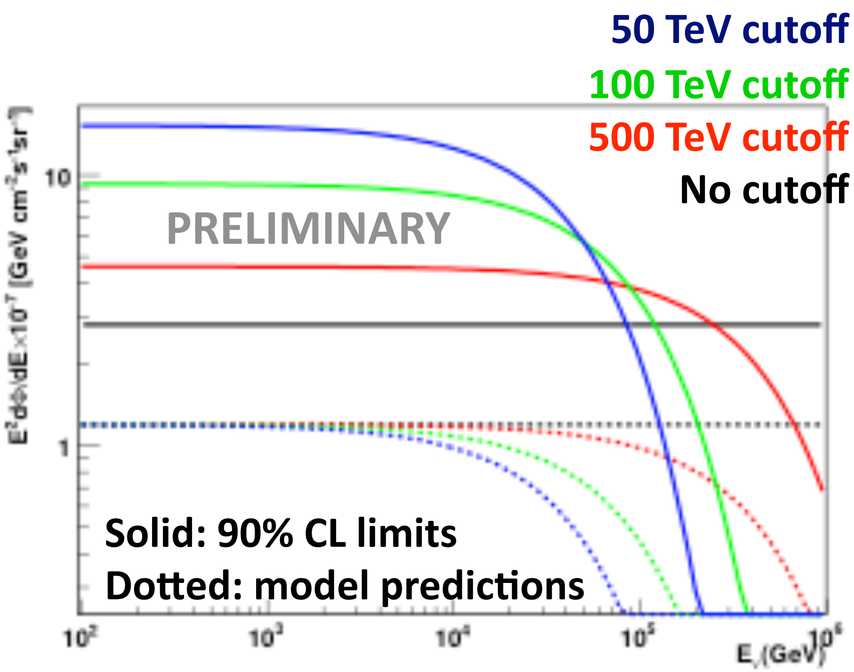
Searches for diffuse fluxes

❖ Search for a neutrino emission from the Fermi bubbles

- 12-line data sample: May 2008- Dec 2011 (806 days livetime); muon neutrinos only
- E_ν estimation based on Artificial Neural Networks procedure
- optimisation tuned on off-zone background events



No excess observed



on-zone
off-zone average
expected signal (≠ cutoff)

Paper in preparation

Search for neutrino point sources

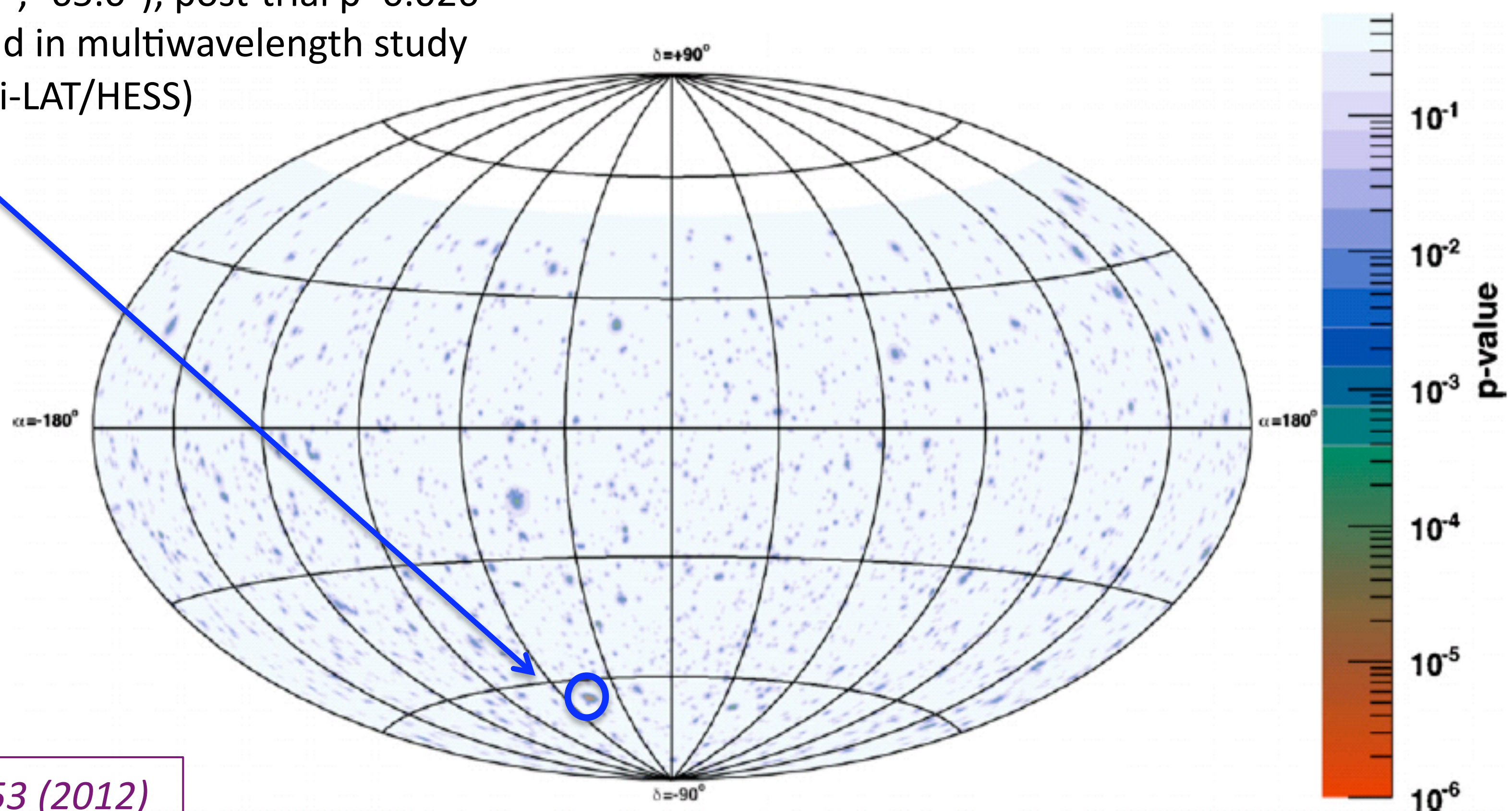
❖ Full-sky search for steady neutrino PS

- Updated analysis: Jan 2007- Dec 2010 (813 days)
- 3058 neutrino candidates (85% purity)

Median angular resolution 0.46° ± 0.1°

- No statistically significant excess

best cluster at (-46.5°, -65.0°), post-trial p=0.026
No counterpart found in multiwavelength study (Gallex/ROSAT/Fermi-LAT/HESS)



(skymap in equatorial coordinates)

Astrophys. J. 760:53 (2012)

Search for neutrino point sources

❖ Search in candidate PS list

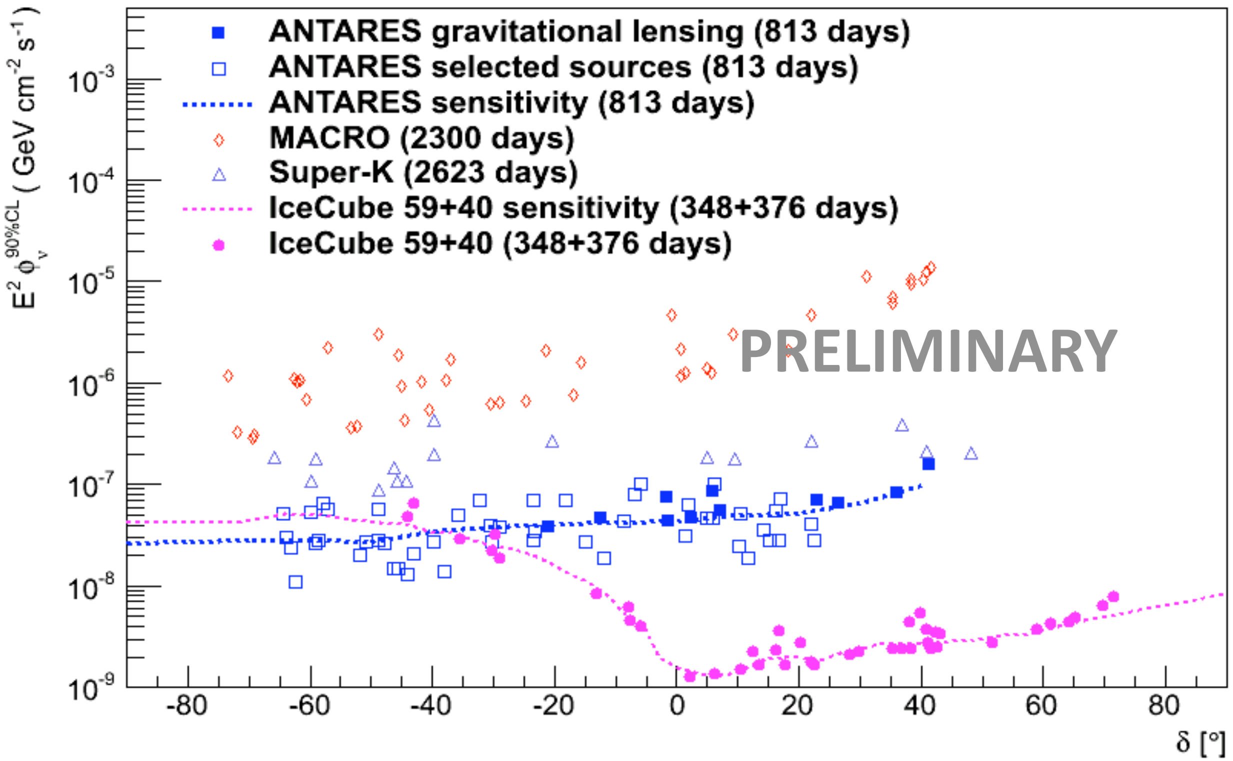
- list of 51 preselected candidate sources gamma-ray emitters in ANTARES field of view
  Astrophys. J. 760:53 (2012)

- NEW ! + 11 candidates associated to gravitational lensing:

9 lensed quasars + 2 massive galaxy clusters

- No statistically significant excess

most significant:
HESS J1023-57 (p=0.41)



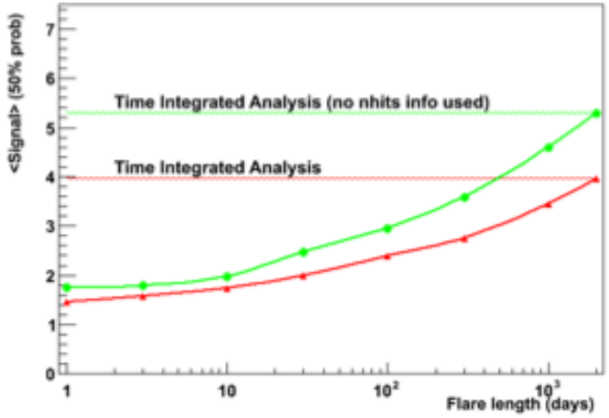
- Most stringent limits for large part of Southern Sky (including RXJ1713, Vela X)
- sensitivity x3 w.r.t. previous analysis (2007-2008)

Searches for transient sources

➢ Multi-messenger search for transient sources: time AND direction known

- reduced background
- improved sensitivity:

2-3 ν per source sufficient to claim 5σ discovery (50% prob.)
(even 1ν for very short transients such as GRBs !)



❖*See slides by A. Sánchez Losa (Parallel D)*

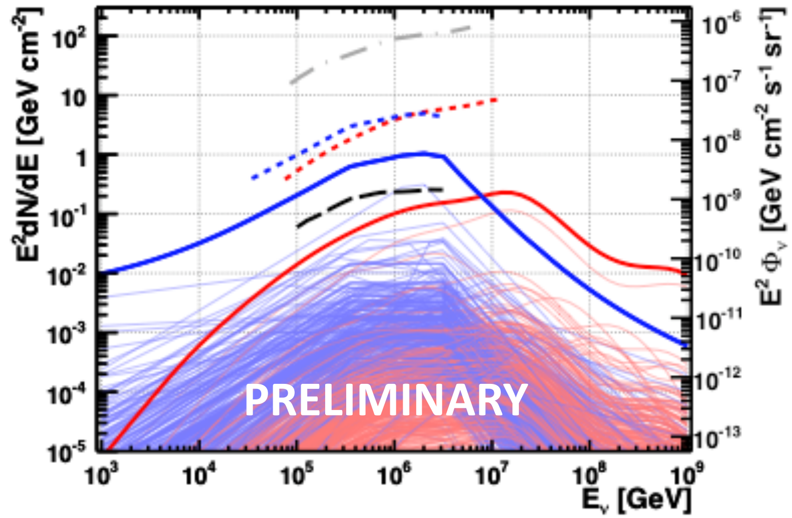
❖ Search for neutrinos in coincidence with GRBs

➢ Stacking analysis of GRBs from 2008 – 2011:
297 long GRBs, total prompt emission duration: 6.55 hours
Multi-messenger info from FERMI/SWIFT/GCN

➢GRB simulations of expected neutrino fluence:
- NeuCosmA *[Hümmer et al. (2010)]*
- Guetta *[Guetta et al. (2004)]*

➢ Quality cut optimized for NeuCosmA model & highest signal discovery probability

➢ No event found within 10° window from GRB
(expected 0.48 (Guetta), 0.0041(NeuCosmA))



Grey: previous ANTARES limit (40 GRBs, 2007)
(JCAP 03(2013) 006)

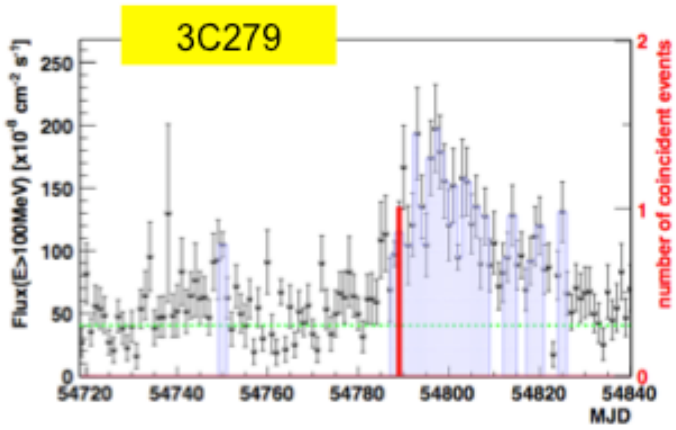
Black: IceCube IC40+59 (215 GRBs)

Searches for transient sources

❖ Search for neutrinos in coincidence with 10 flaring blazars

- from Fermi catalogue (2008)
- 1 event detected in coincidence of 3C279 (within 0.56°): post-trial probability p=0.1

Astropart. Phys. 36 (2012) 204

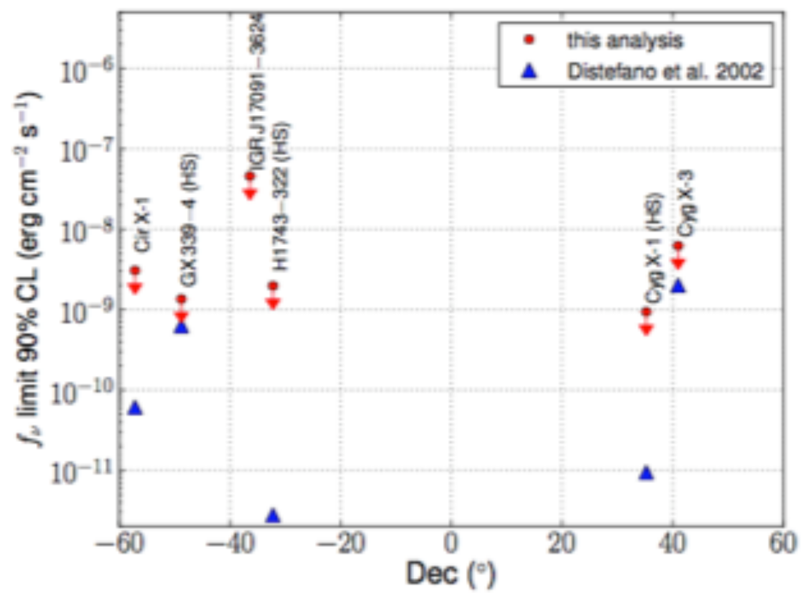


- Updated analysis 2008-2012 ongoing: Fermi + Cherenkov telescopes (HESS/MAGIC/VERITAS)

❖ Search for neutrinos in coincidence with 6 microquasars

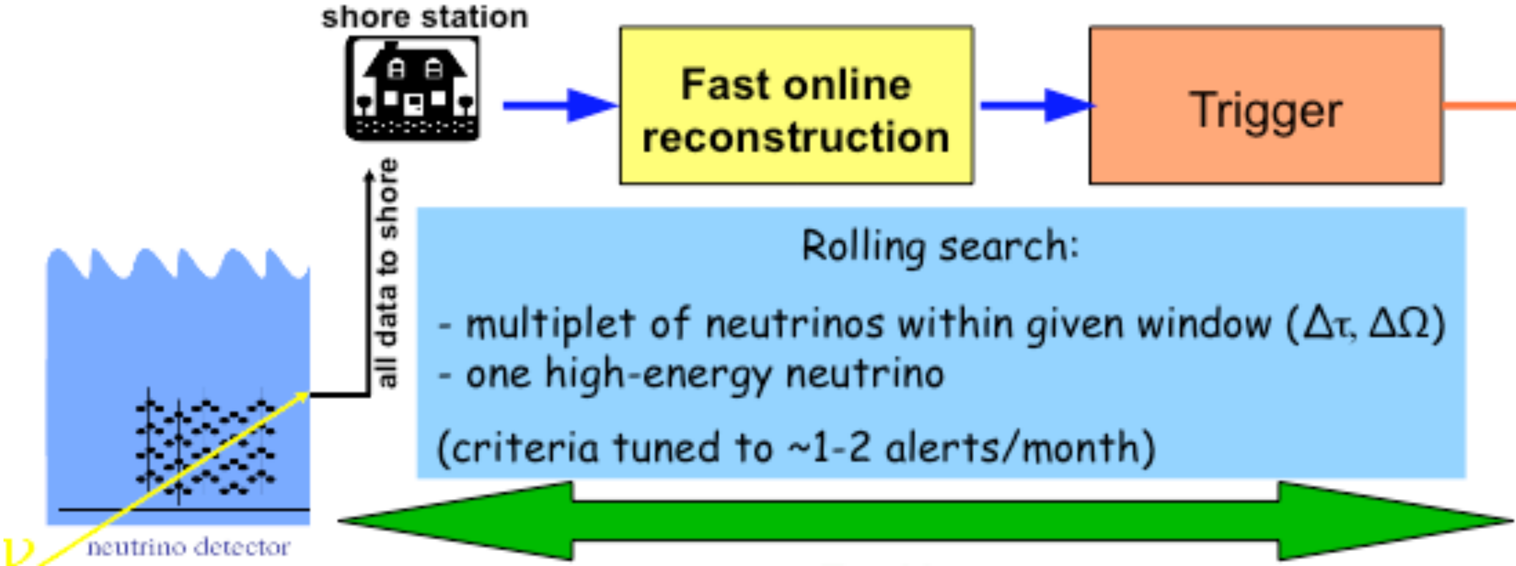
- µquasars with X-ray or γ-ray outbursts in 2007-2010
- No events detected in coincidence
- Flux limit assuming $\phi \approx E^{-2} e^{-\sqrt{E/100TeV}}$

(Levinson, Waxman (2001) & DiStefano (2002))



Other multi-messenger programs

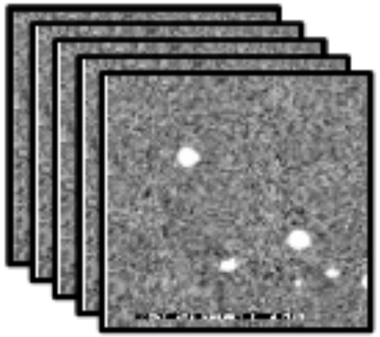
❖ Alerts and follow-up program: TAToO



optical telescopes (TAROT/ROTSE/ ZADKO/Skymapper)

Total latency: alert sending (<1s) + repositioning (<10s)

- large sky coverage, high duty cycle
- no hypothesis on the nature of the source
- sensitivity improved: 1 doublet is 3σ discovery, 1 triplet is 5σ !
- system active since 2009 with optical telescopes, now extended to SWIFT/XRT



T_0, T_0 +1, 3, 9 and 27 days

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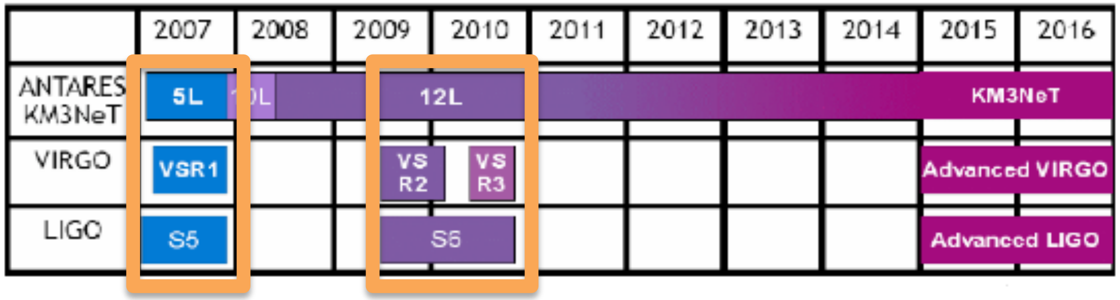
Other multi-messenger programs

❖ Search for neutrinos in coincidence with gravitational waves: GWHEN

Main motivations: - plausible common sources (microquasars, SGR, GRBs)
- discovery potential for hidden sources (e.g. failed GRBs)

Joint collaboration with GW interferometers VIRGO (Italy) & LIGO (USA)



➤ GW/HEN common challenge: faint signals on top of abundant noise/background

➤ Search methodology: combine GW/HEN events lists + search for time coincidences (±500s)

Other multi-messenger programs

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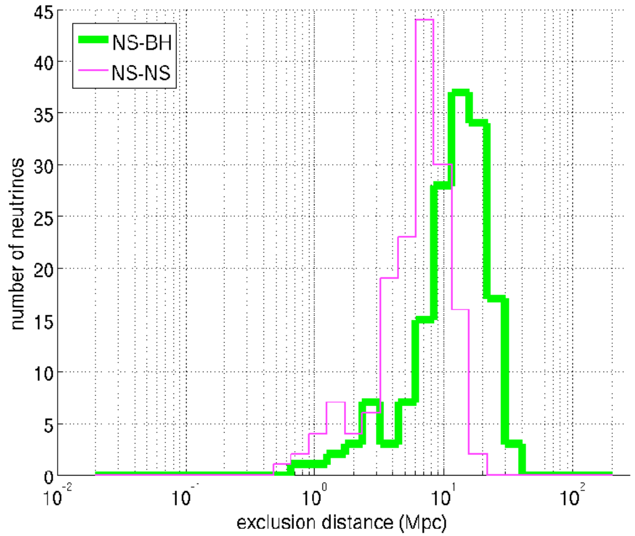

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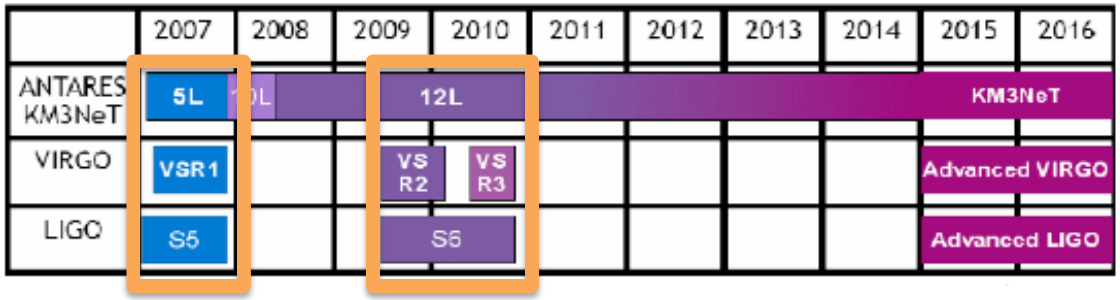


➢ GW/HEN common challenge: faint signals on top of abundant noise/background

➢ Search methodology: combine GW/HEN events lists + search for time coincidences (±500s)

➢ First analysis completed with 2007 concomitant dataset

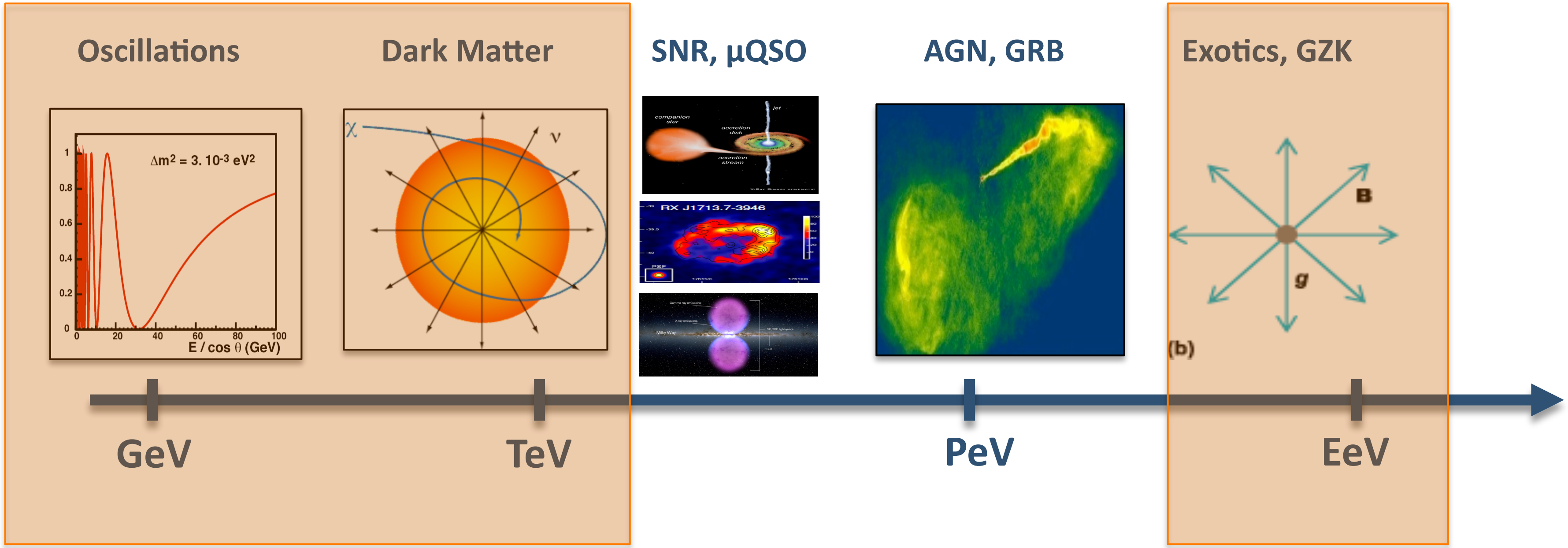
No coincidence found ➡ exclusion distances on common GW/HEN emittors

ANTARES & LIGO & VIRGO Coll., accepted in JCAP

➢ Analysis of 2009-2010 dataset ongoing

❖See talk by I. Di Palma (tomorrow plenary)

More science with ANTARES



❖ Search for relativistic magnetic monopoles

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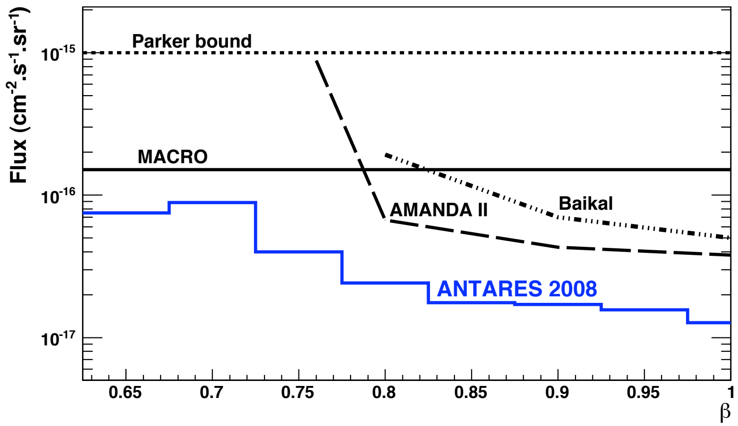


Particle physics with ANTARES

❖ Measurement of atmospheric neutrino oscillations

➢ Two-flavour mixing approximation:

$$P(\nu_\mu \to \nu_\mu) \approx 1 - \sin^2(2\theta_{32})\sin^2\left(\frac{1.27\Delta m_{32}^2 L}{E_\nu}\right) = 1 - \sin^2(2\theta_{32})\sin^2\left(\frac{1.27\Delta m_{32}^2 D_{Earth}\cos\Theta}{E_\nu}\right)$$

unknown

measurable

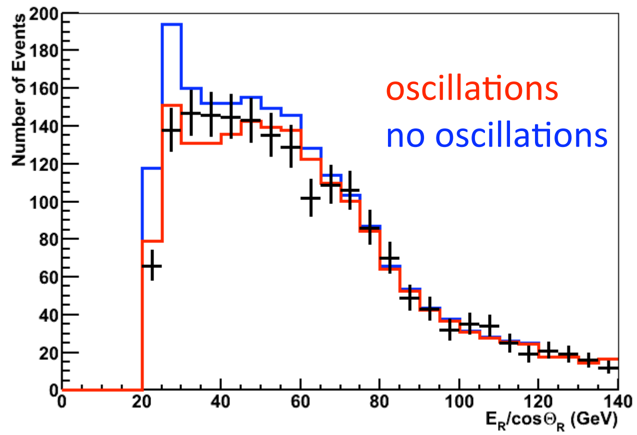
world data: first oscillation minimum at $\cos\Theta = 1,\ E_\nu = 24$ GeV (typical μ range ≈ 120 m)

➢ Dedicated low-energy data sample:

2007-2010 (863 active days)

20 GeV < E_ν < 100 GeV

median angular resolution 0.8° (multi-line) → 3° (single-line)

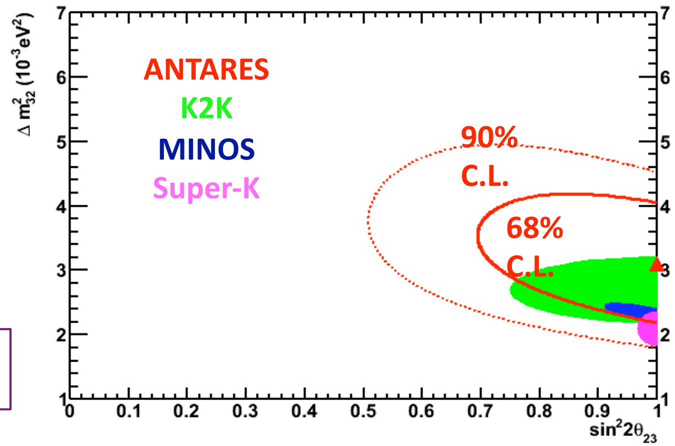


➢ First measurement of neutrino oscillation parameters by neutrino telescope !

(now also measured by IceCube)

➢ Underlines the potential of low-energy extensions of the detector:

→ORCA feasibility study for the measurement of neutrino mass hierarchy (KM3NeT)

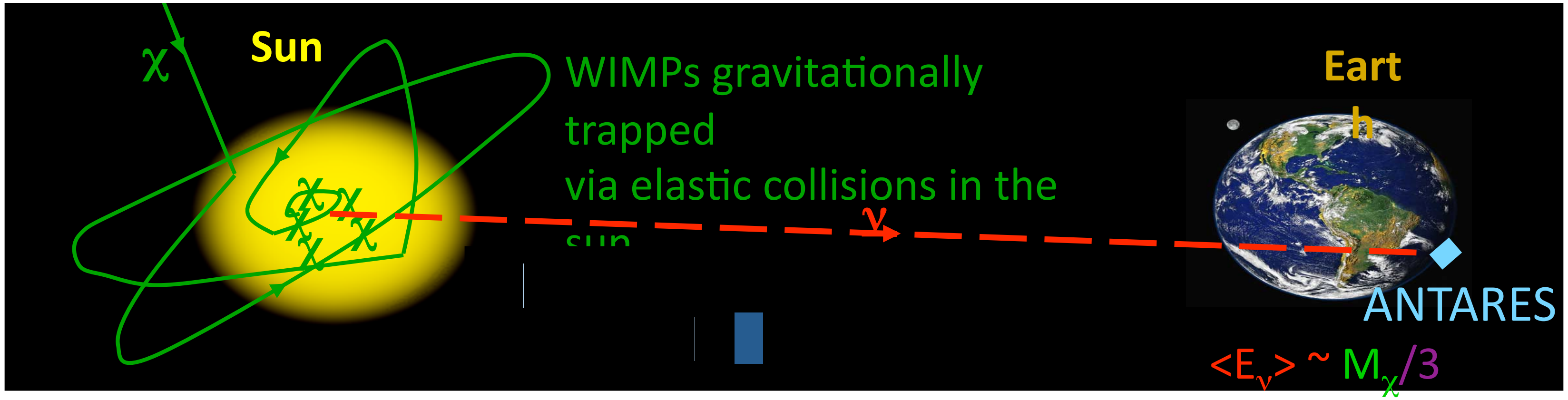


❖ *See talk by J.J. Hernandez (later)*

Phys. Lett.B 714 (2012) 224

Particle physics with ANTARES

❖ Search for neutrinos from DM annihilation in the Sun



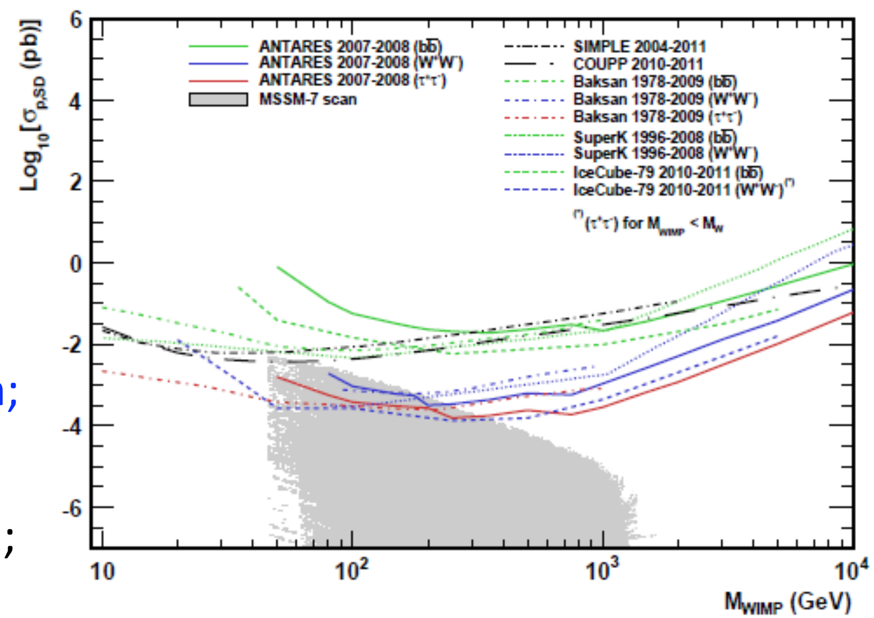
➢ Muon neutrino data sample 2007-2008; signal simulation with WIMPSIM

➢ clean exotic signal expected from the Sun (not from the Galactic Center)

➢ Limits on muon neutrino flux from Sun
limits on WIMP annihilation cross-section; most competitive for spin-dependent σ

➢ ongoing analysis with full sample 2007-2012; includes single-line events

❖*See slides by J. de D. Zornoza (Parallel C)*



arXiv:1302.6516, submitted to JCAP

Summary

ANTARES underwater neutrino telescope:

- Largest neutrino telescope in the Northern Hemisphere
- Proven ability to detect neutrino-induced muons
- Good performance in neutrino astrophysics
  - sensitivity optimized for Galactic Centre region
  - science reach extended through multi-messenger programs

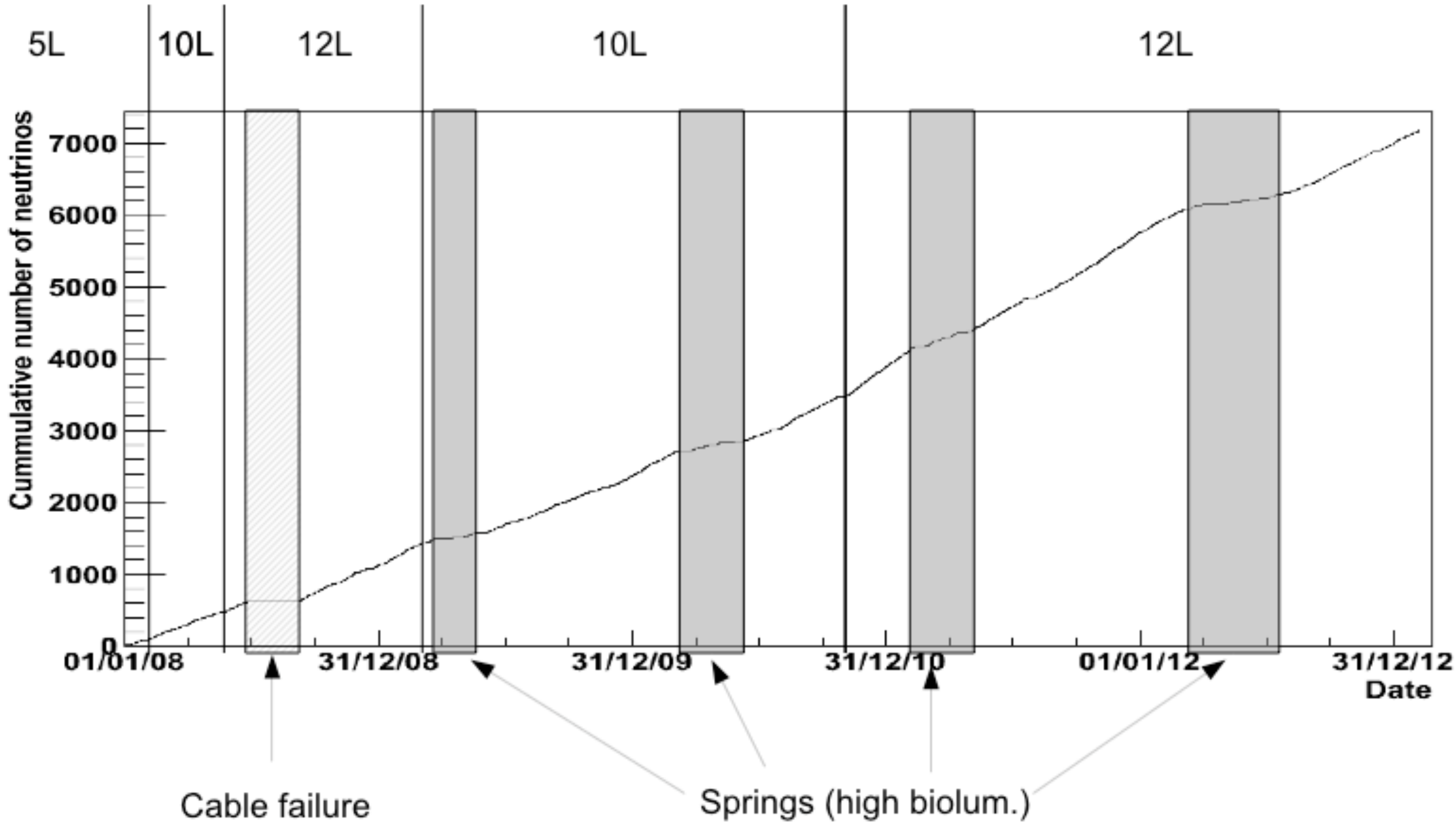
  …but no cosmic signal detected yet
- Larger detector desirable in the Northern Hemisphere: KM3NeT

- Diverse physics program:
  - exotics
  - dark matter
  - oscillations …

  + interest for a possible low-energy extension: ORCA

- Many mature analyses, some competitive results, more to come
- Exciting science ahead !

BACKUP



5L
10L
12L
10L
12L
Cummulative number of neutrinos
7000
6000
5000
4000
3000
2000
1000
0
01/01/08
31/12/08
31/12/09
31/12/10
01/01/12
31/12/12
Date
Cable failure
Springs (high biolum.)