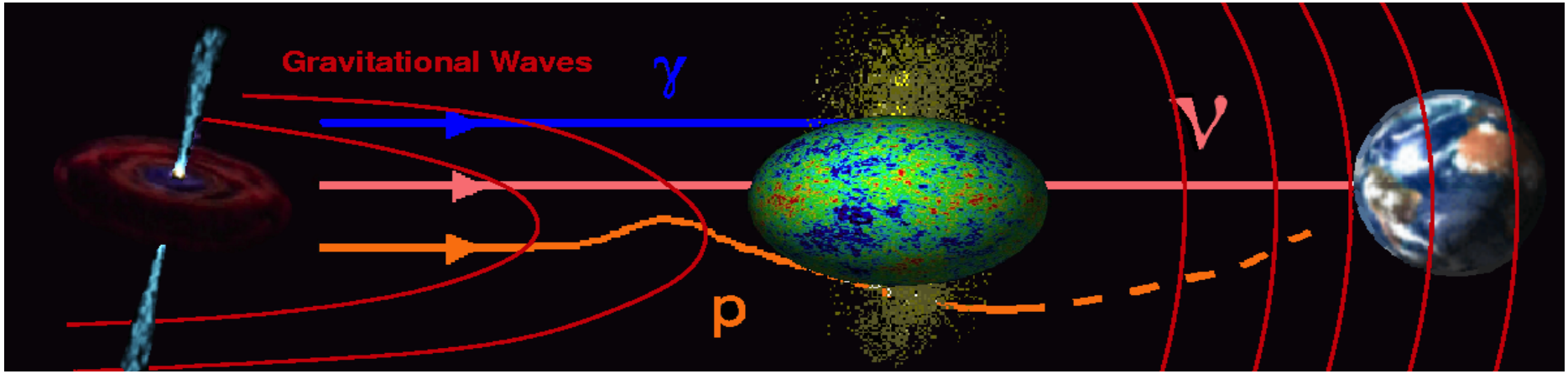
Neutrino Astronomy in the Mediterranean Sea

Multi-messenger astronomy



Neutrino

⇒Transient sources

⇒ Cosmological distances

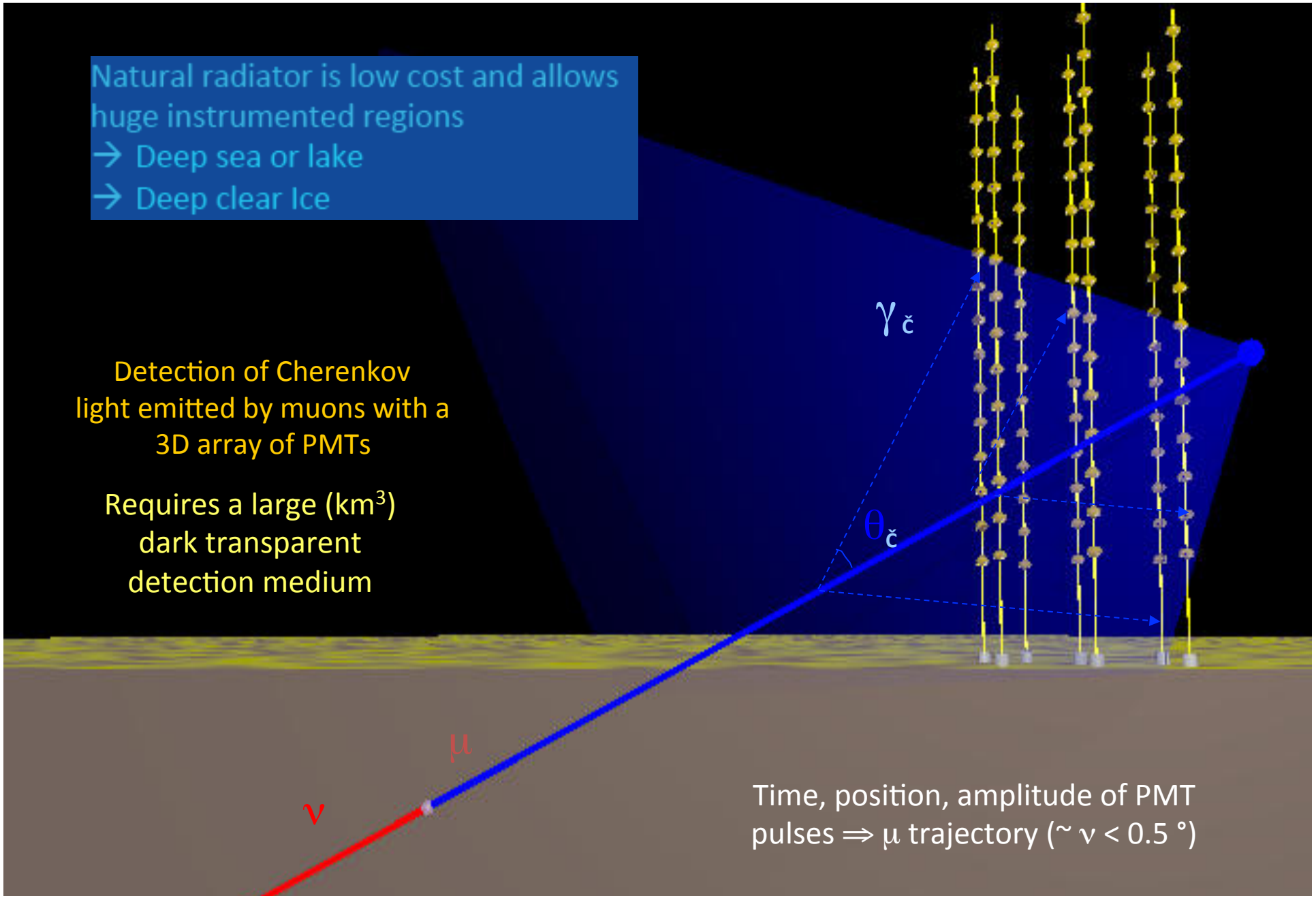
⇒ Core of astrophysical bodies

⇒ Point source

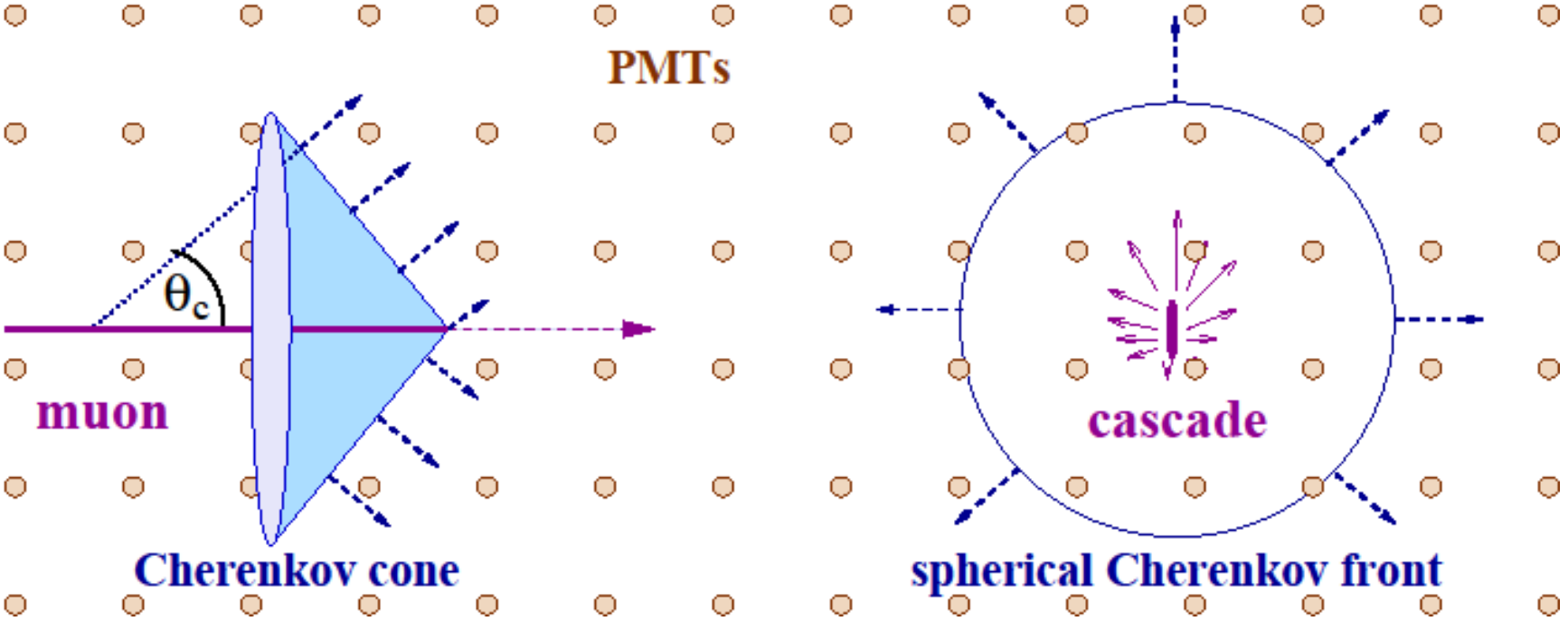
⇒ Unambiguous signature of hadronic acceleration

Mutli-wavelength/messenger analysis → Modeling of the source

Detection technique



Event topologies



Muon track from CC muon neutrinos

- Angular resolution 0.5°/0.1° for ice/water 1km³
- dE/dx resolution factor 2-3

Cascade from CC electron/tau and NC all flavour interactions

Angular resolution 10°/3° at 100 TeV for ice/water

Energy resolution ~ 15%

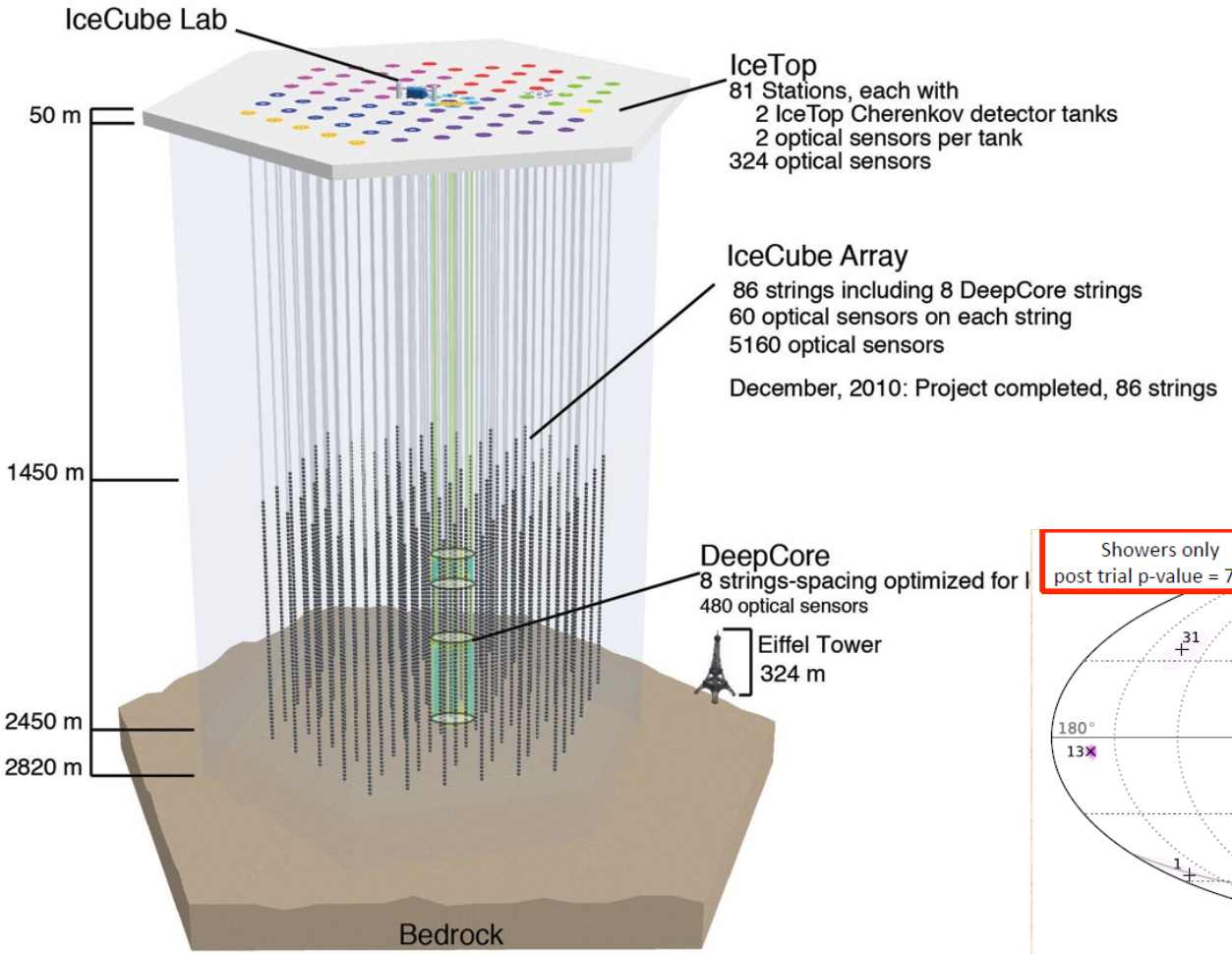
Neutrino telescopes (TeV)

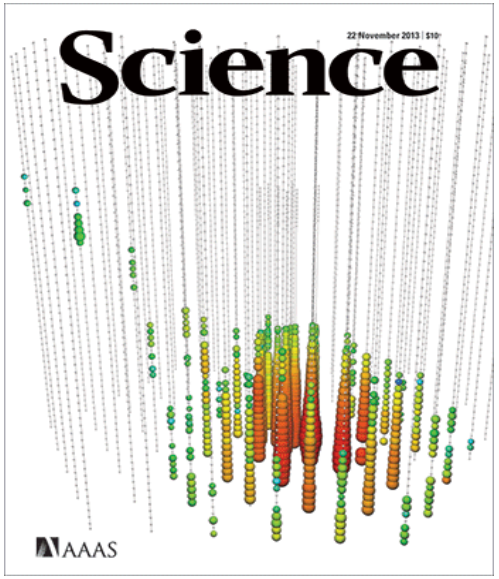
{ANTARES, BAIKAL, ICECUBE} currently working

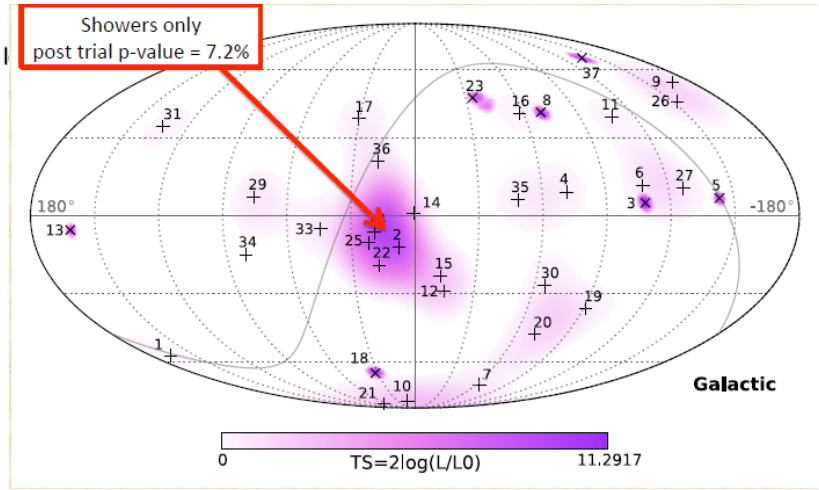
{ANTARES, NEMO, NESTOR} ∈ KM3NeT collaboration

A field recently opened !

The IceCube detector at South Pole







Compatible with isotropic diffuse flux

Water Versus Ice

- Complementarity to IceCube South Pole

  Excellent view of Galaxy

- Long (homogeneous) scattering length

  Good pointing accuracy

- Deep sites: 2500→5000m

  Shielding from downgoing muons

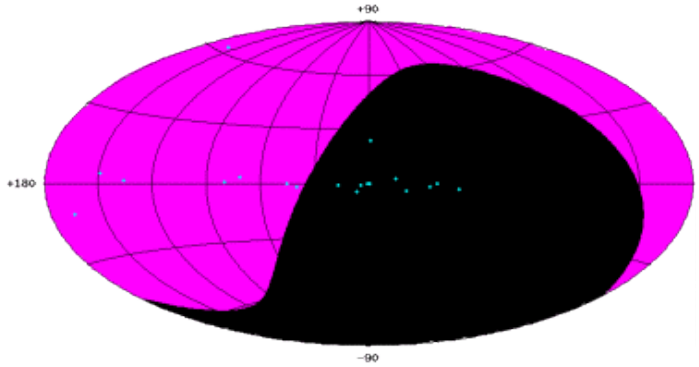
- Logistically attractive

  Close to shore (deployment / repair)

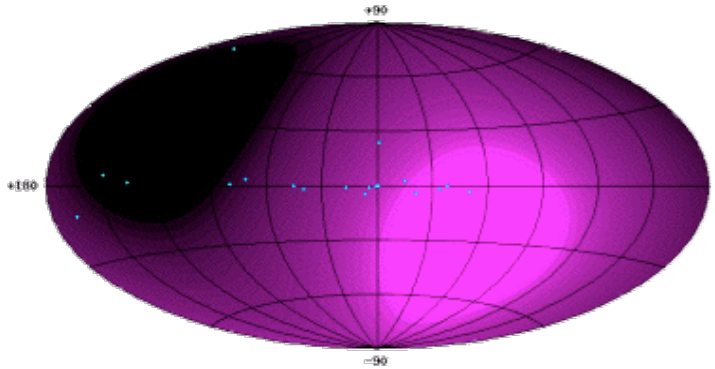
- K40 optical background

  Useful for calibration, but requires causality filters

South Pole visible sky



Mediterranean visible sky

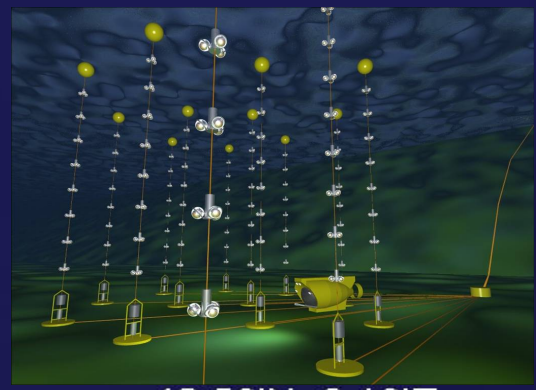


Most of the HESS TeV Sources visible by Northern NT

Toulon

M.Pacha

Antares

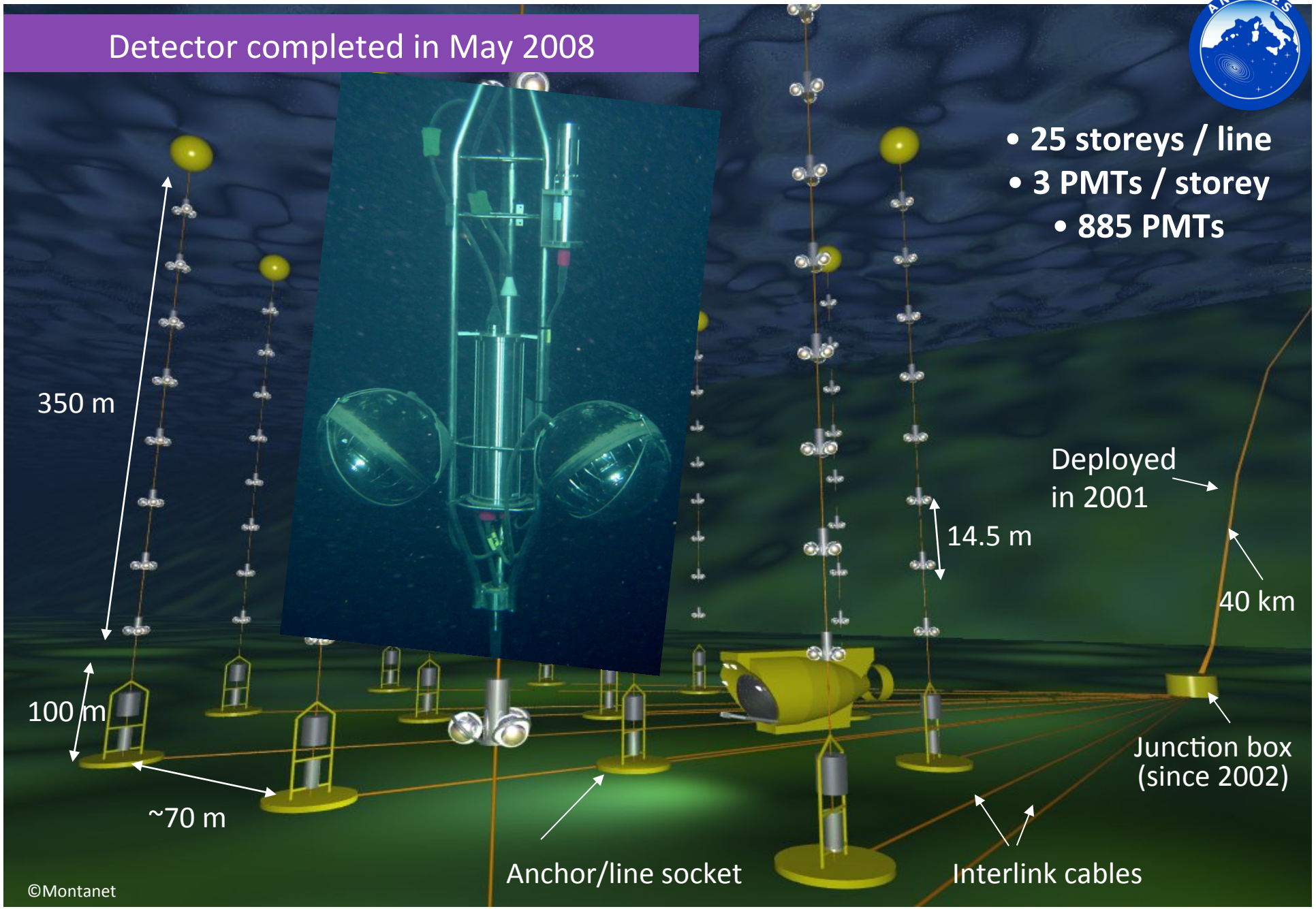


42 50'N, 6 10'E

Electro-optical
Cable of
40 km

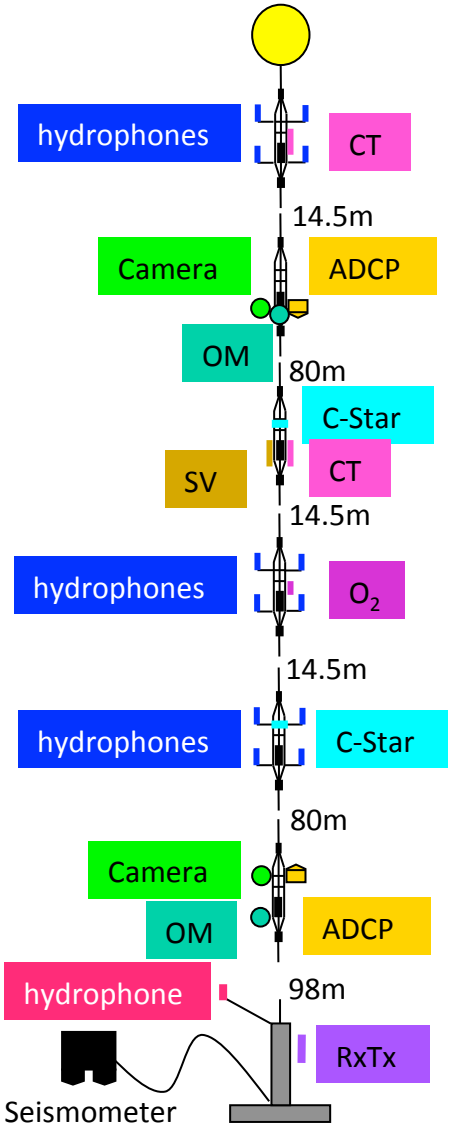
Google

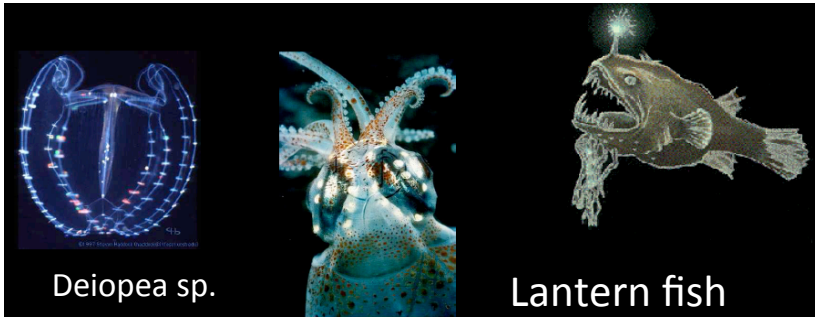
The ANTARES neutrino telescope



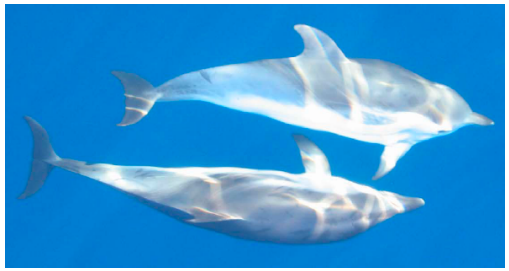
Sea science and Earthquakes

Instrumentation Line

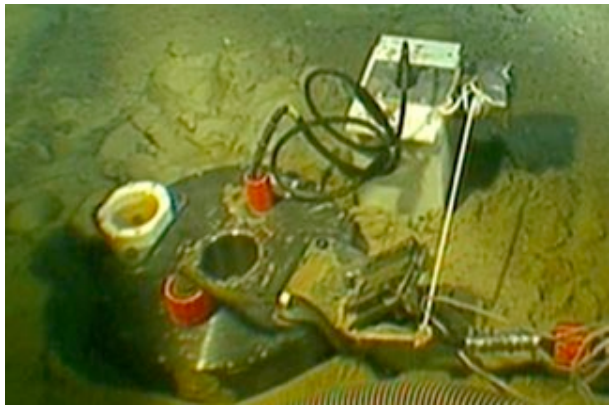




Acoustic noises



seismometer

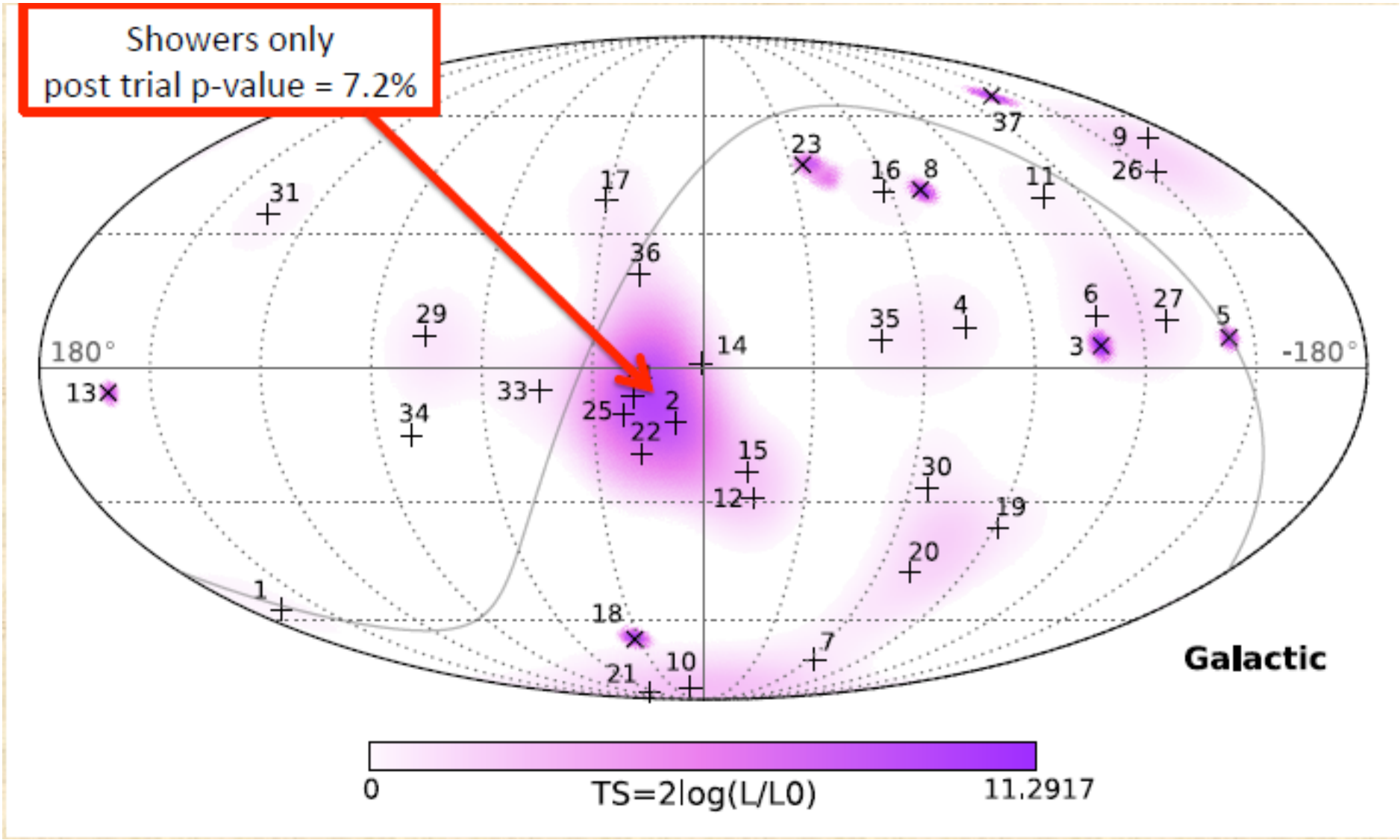


Video-monitoring

ANTARES is a multidisciplinary observatory

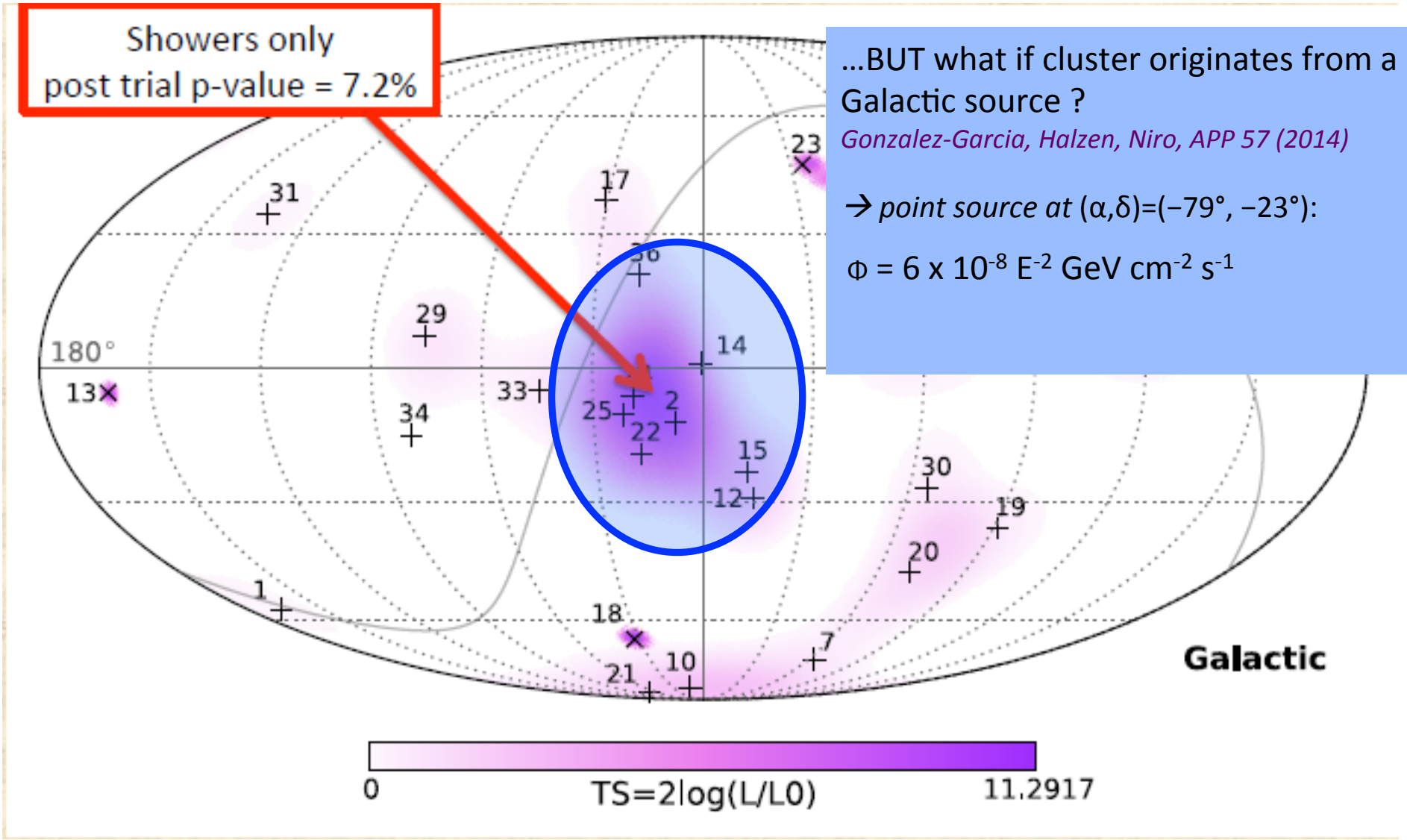
Follow up analysis: the IceCube signal

Hint of clustering near Galactic Center ? … no claim for signal



A source near the Galactic Center?

Hint of clustering near Galactic Center ? … no claim for signal

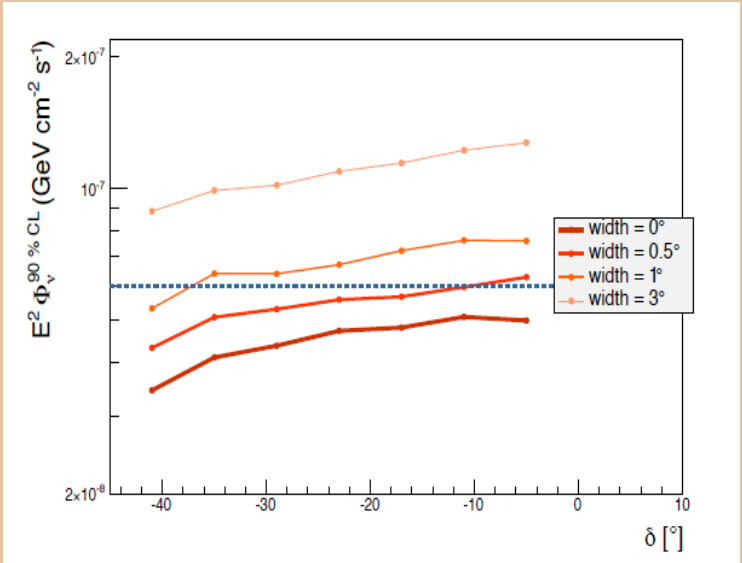


A source near the Galactic Center?

Hint of clustering near Galactic Center ? … no claim for signal

ANTARES search for neutrino source around GC:

-scan in declination
-allow for extended sources:
0°, 0.5°, 1°, 3°

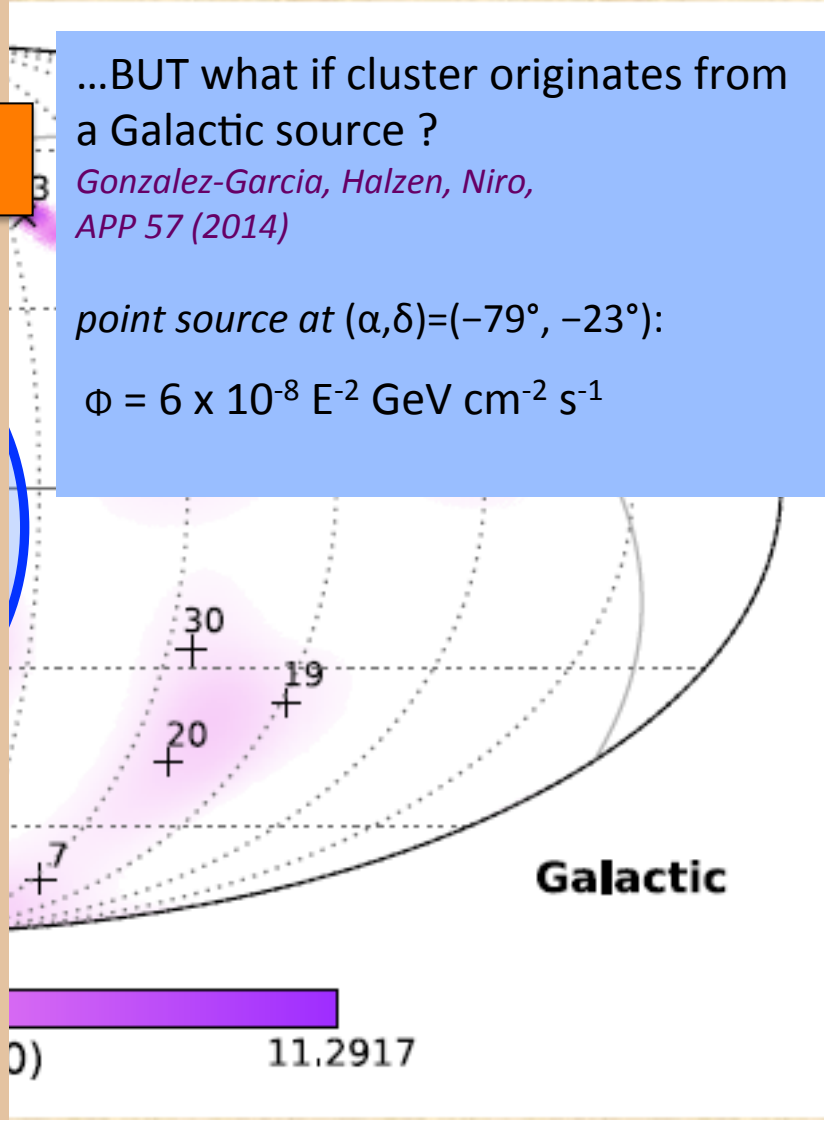


ANTARES excludes point source (up to 1° extension) as origin of the IceCube cluster

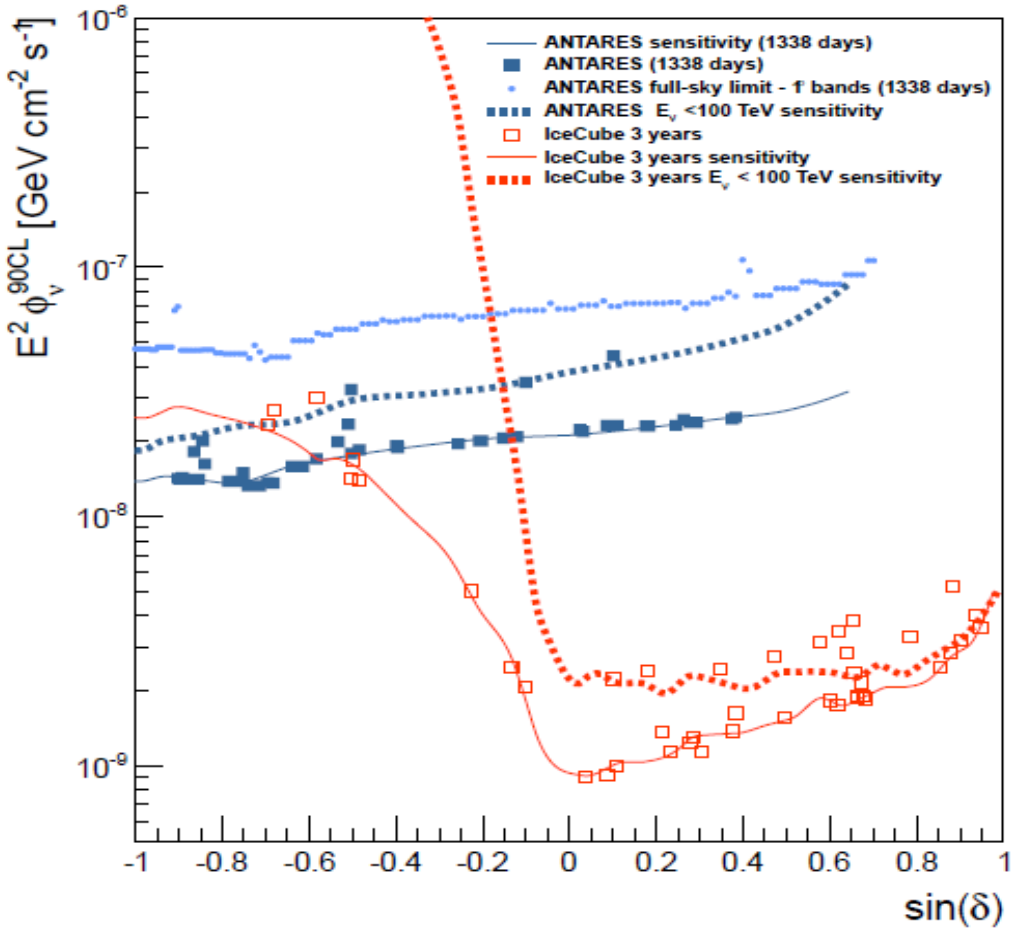
…BUT what if cluster originates from a Galactic source ?
Gonzalez-Garcia, Halzen, Niro, APP 57 (2014)

point source at (α,δ)=(−79°, −23°):

$\Phi = 6 \times 10^{-8}\ E^{-2}$ GeV cm^{-2} s^{-1}

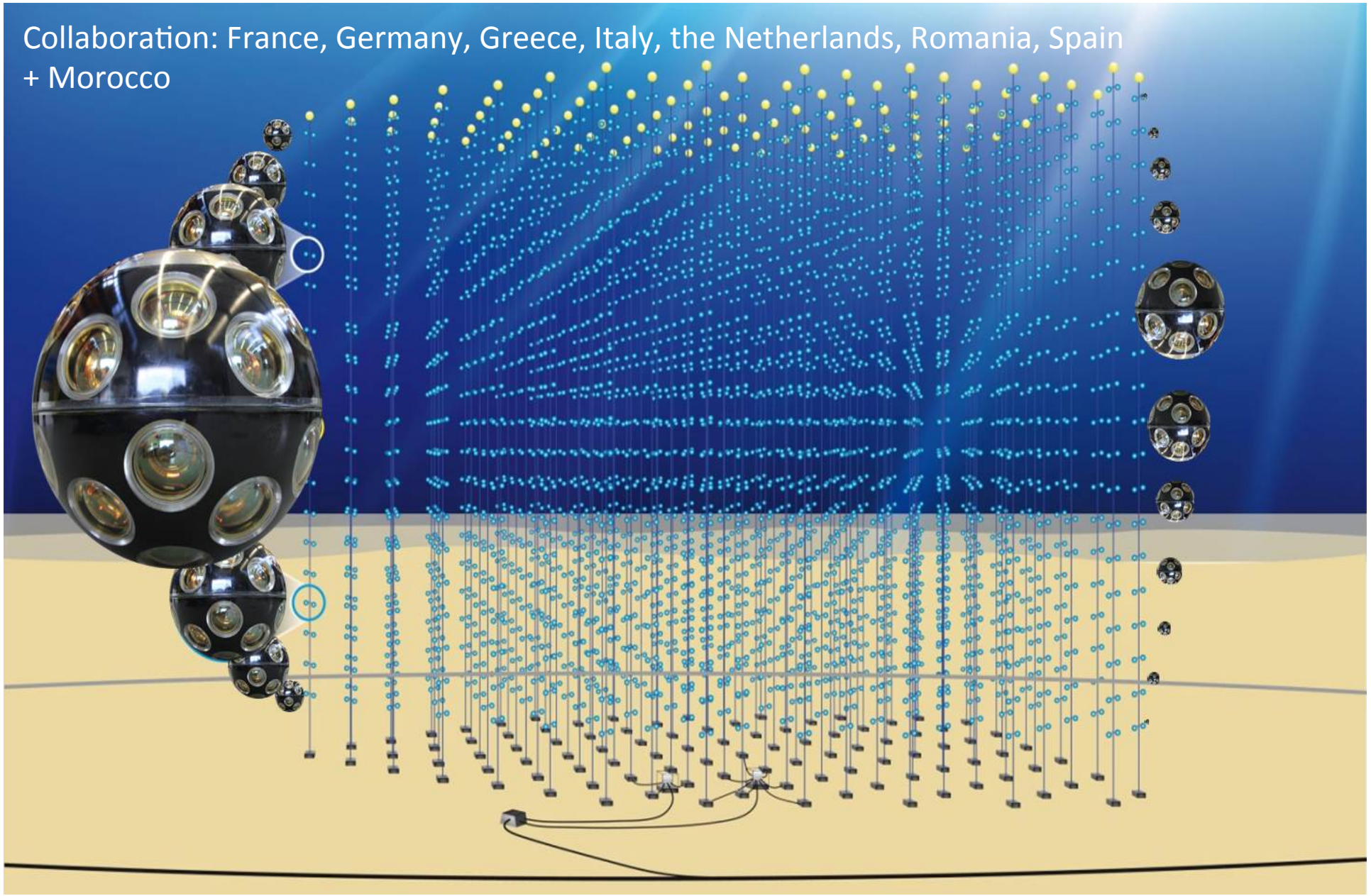


Current limits



ANTARES has the best limits < 100 TeV for the Southern Hemesphere

Next step = KM3NeT



KM3NeT

- Multi-km^3 deep sea neutrino telescope in the Mediterranean Sea, substantially exceeding ANTARES/IceCube in sensitivity

- Two sites: Toulon, France, and Capo Passero, Sicily

- Staged implementation:

  Phase-1 in progress (31 M€) 31 strings (2 sites) (local funding)
  Phase-1.5 (LoI in prep.) 230 strings (2 sites, 2 building blocks)
  Phase-2 600 strings (6 building blocks)

- Central physics goals:

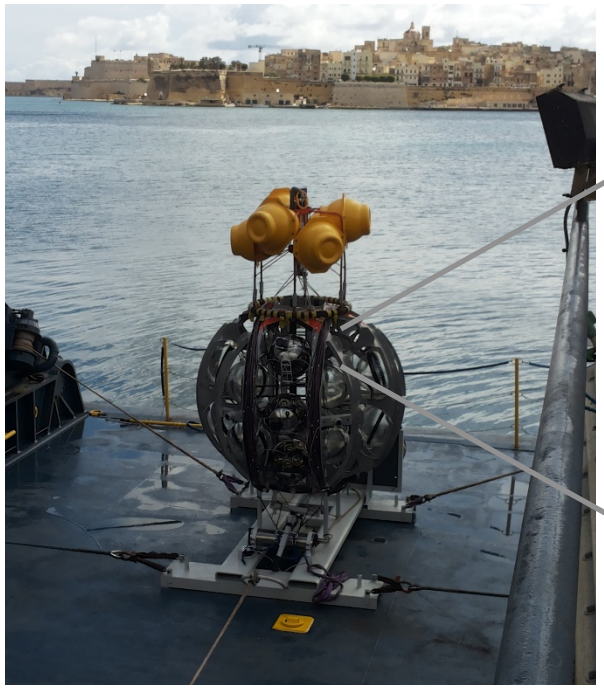
  - Investigation of IceCube signal (Phase 1.5)
  - Neutrino Astronomy (neutrino "point" sources) (Phase 2)

- Nodes for deep-sea research in marine sciences (EMSO)

- Possibility of a site optimised for low energy (neutrino mass hierarchy) under study→ ORCA (cf PINGU in the IC context 🕮 arXiv:1306.5846)

Design

Launcher vehicle



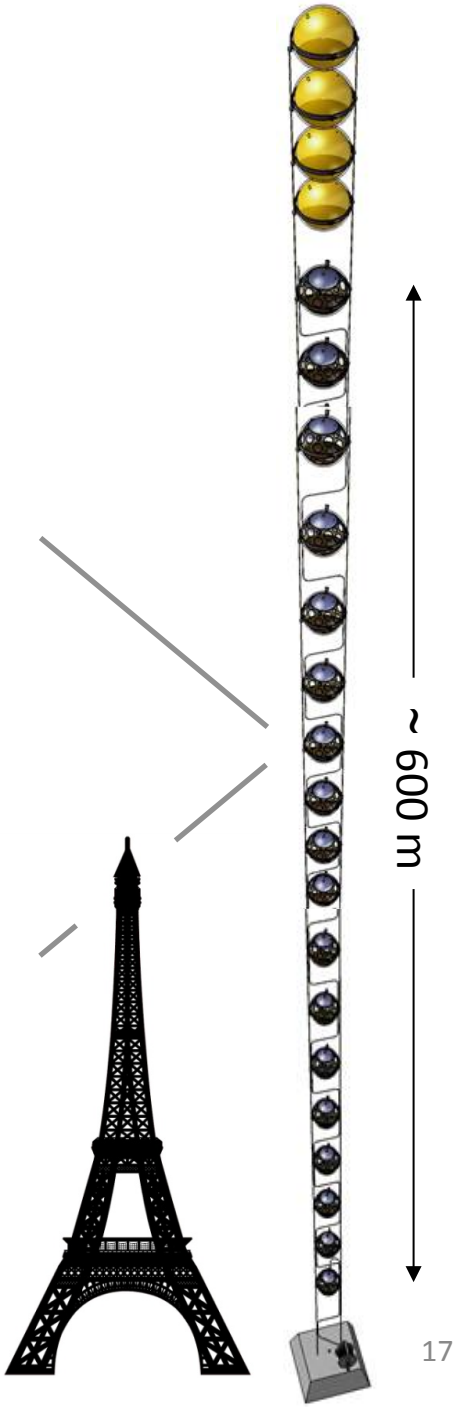
- *rapid deployment*
- *autonomous unfurling*
- *recoverable*

- Digital photon counting
- Directional information
- Wide angle of view

Optical module

17”

- *31 x 3” PMTs*
- *low-power HV*
- *LED & piezo inside*
- *FPGA readout*
- *White Rabbit*
- *DWDM*



3-inch PMTs

Key features:

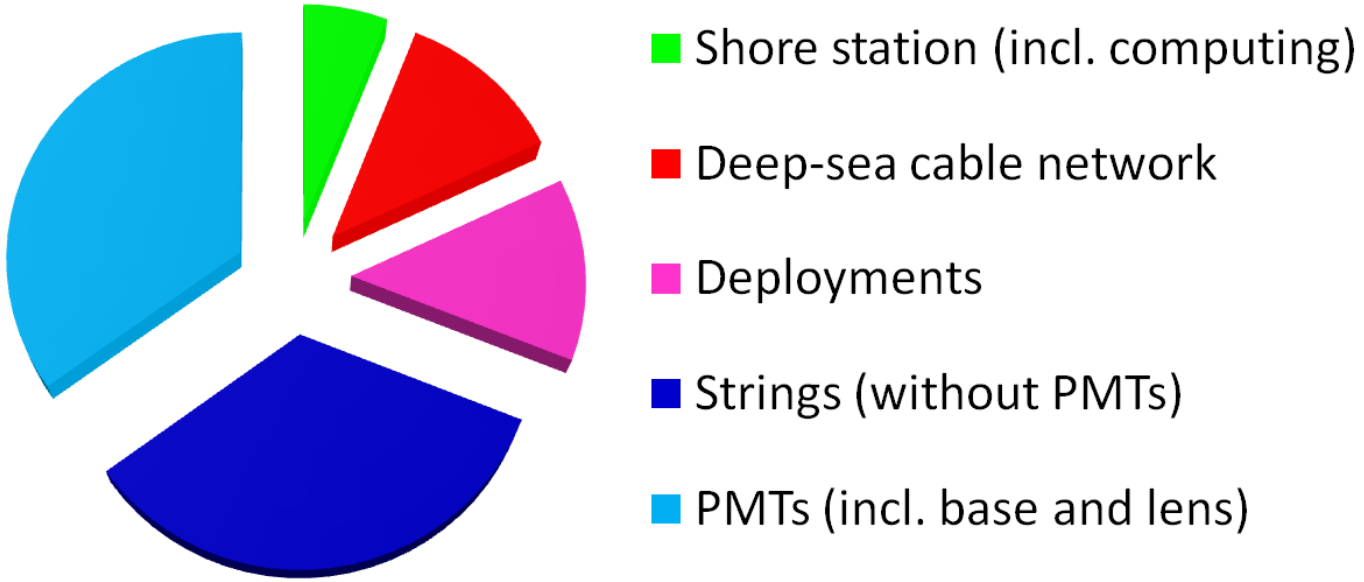
– timing	≤ 4.5 ns (FWHM)
– QE	≥ 25-30%
– collection efficiency	≥ 90%
– photon counting purity	100% (by hits, up to 7)
– price/cm^2	≤ 10” PMT

ETEL D792

Hamamatsu R12199

HZC XP53B20

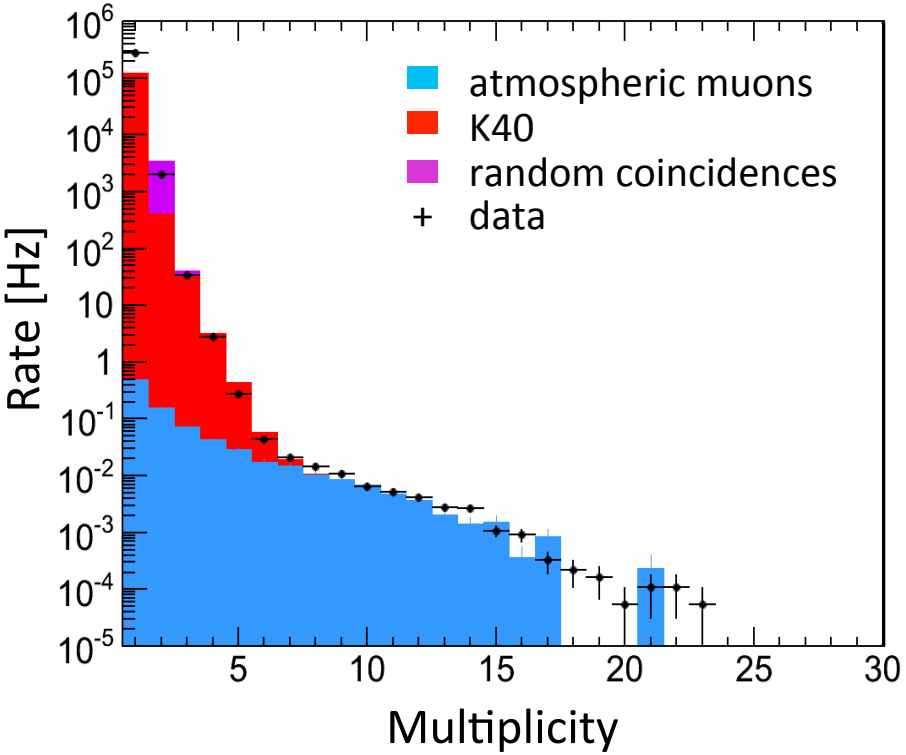
Cost

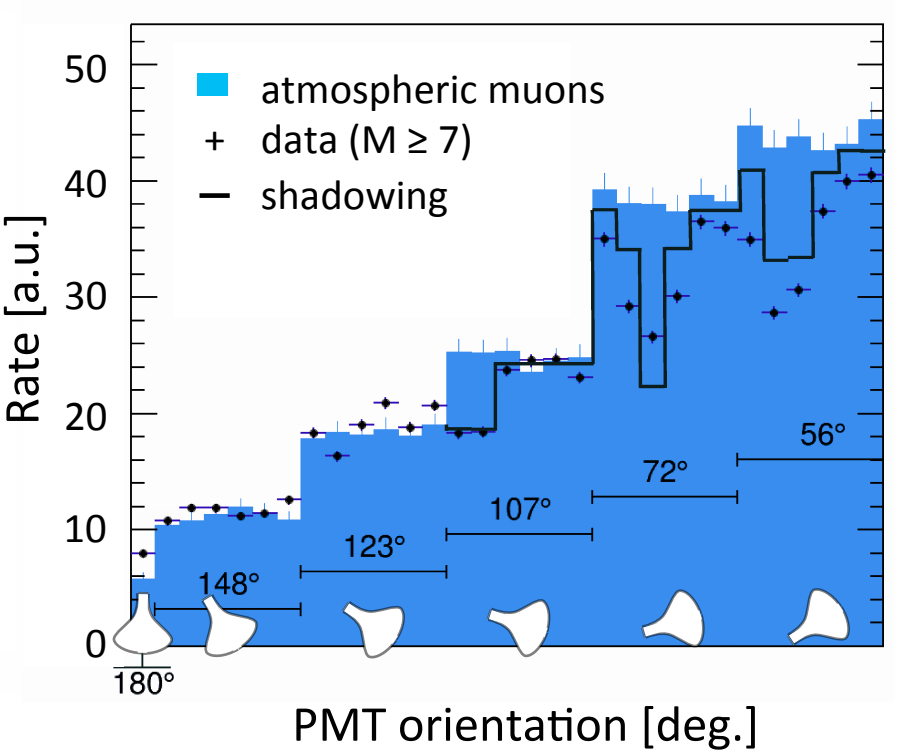


$ KM3NeT string ~ ¼ of $ Antares string

1st prototype

1st prototype





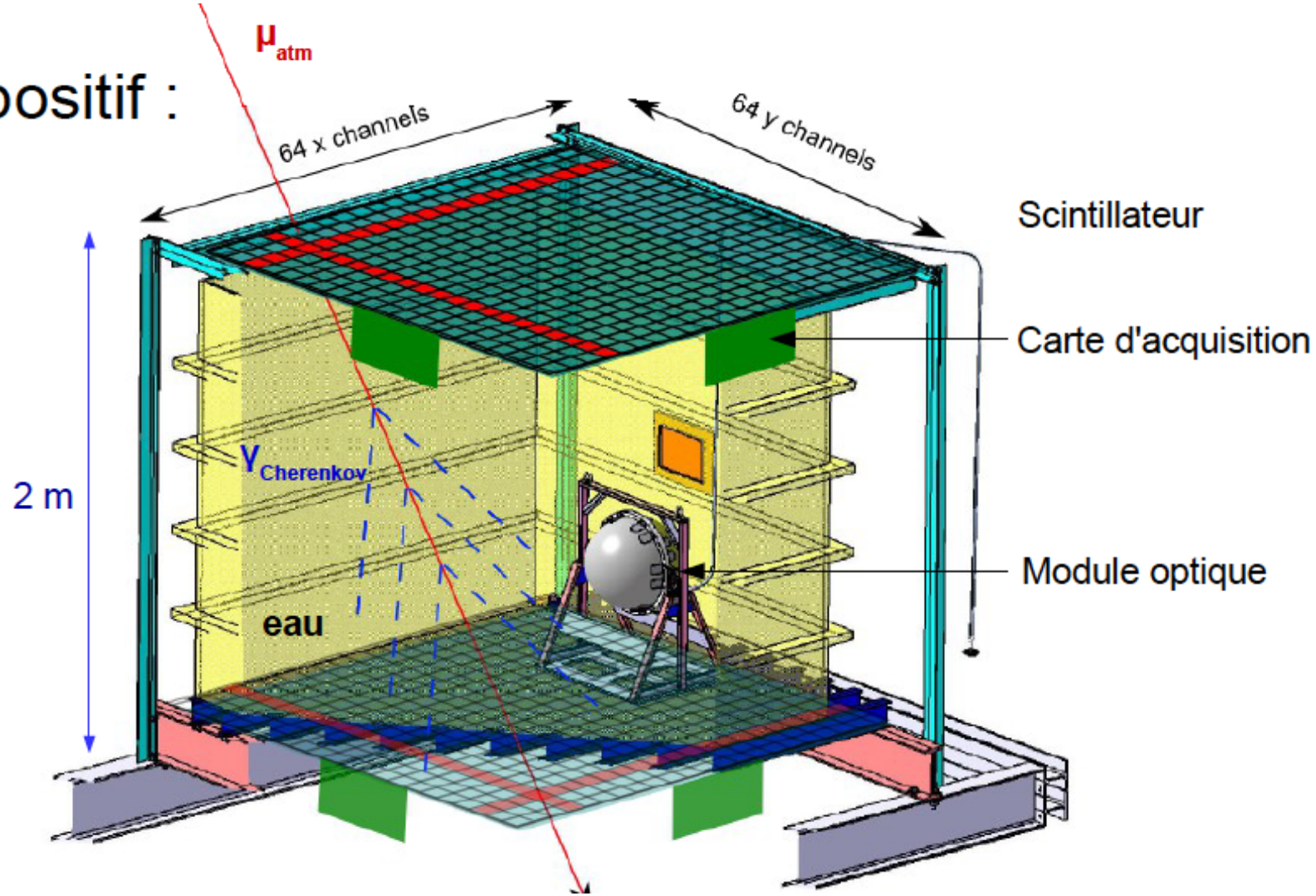
✓ photon counting

✓ directionality

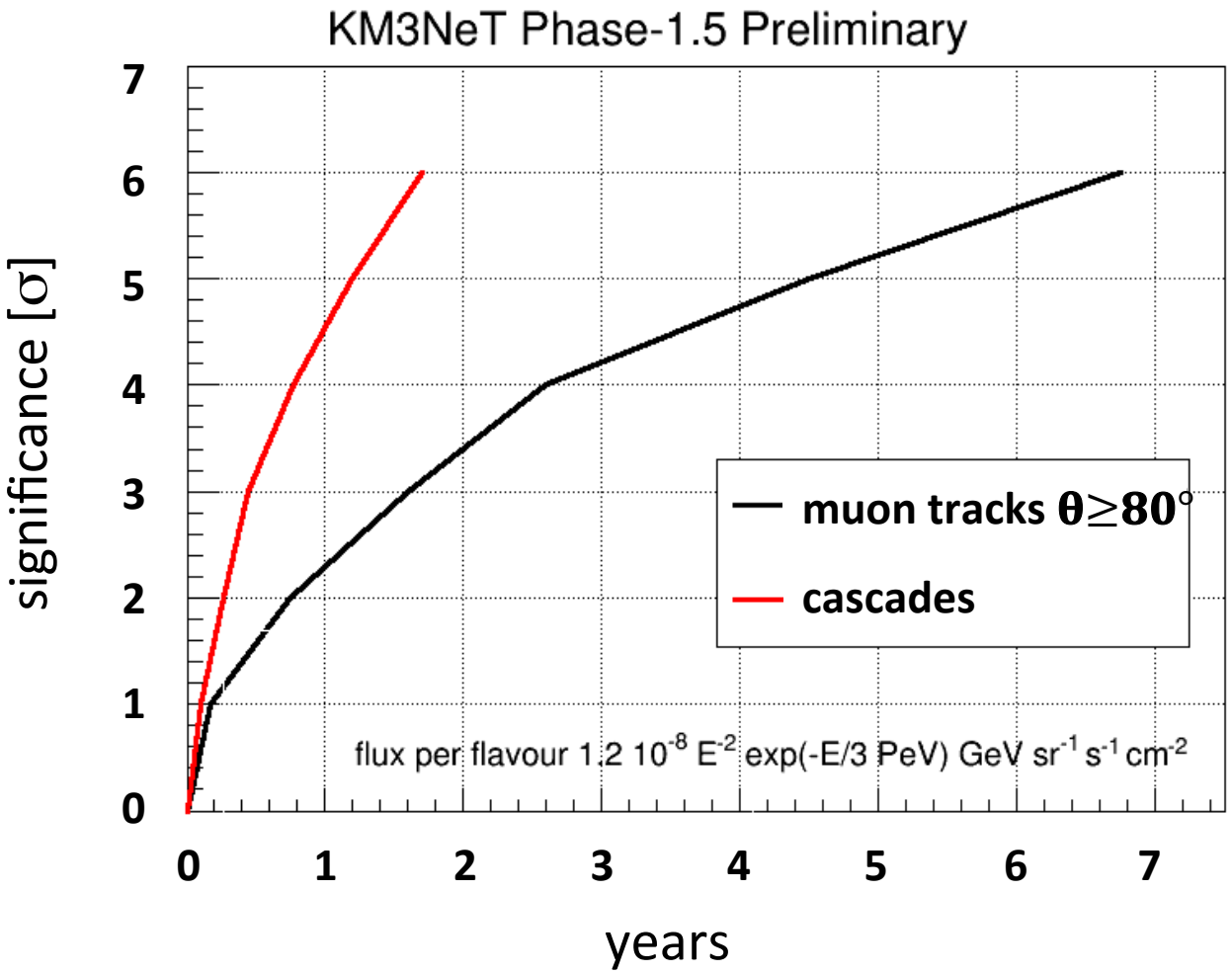
📖 http://arxiv.org/abs/1405.0839

Caracterisation test benches at APC

- Dispositif :

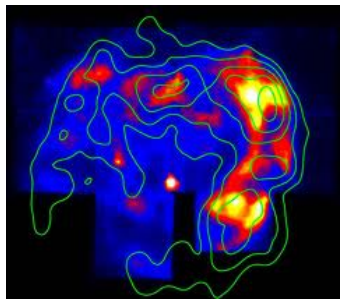


Sensitivity to the IC diffuse flux



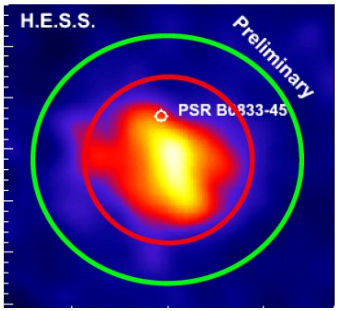
Sensitivity to Galactic Sources

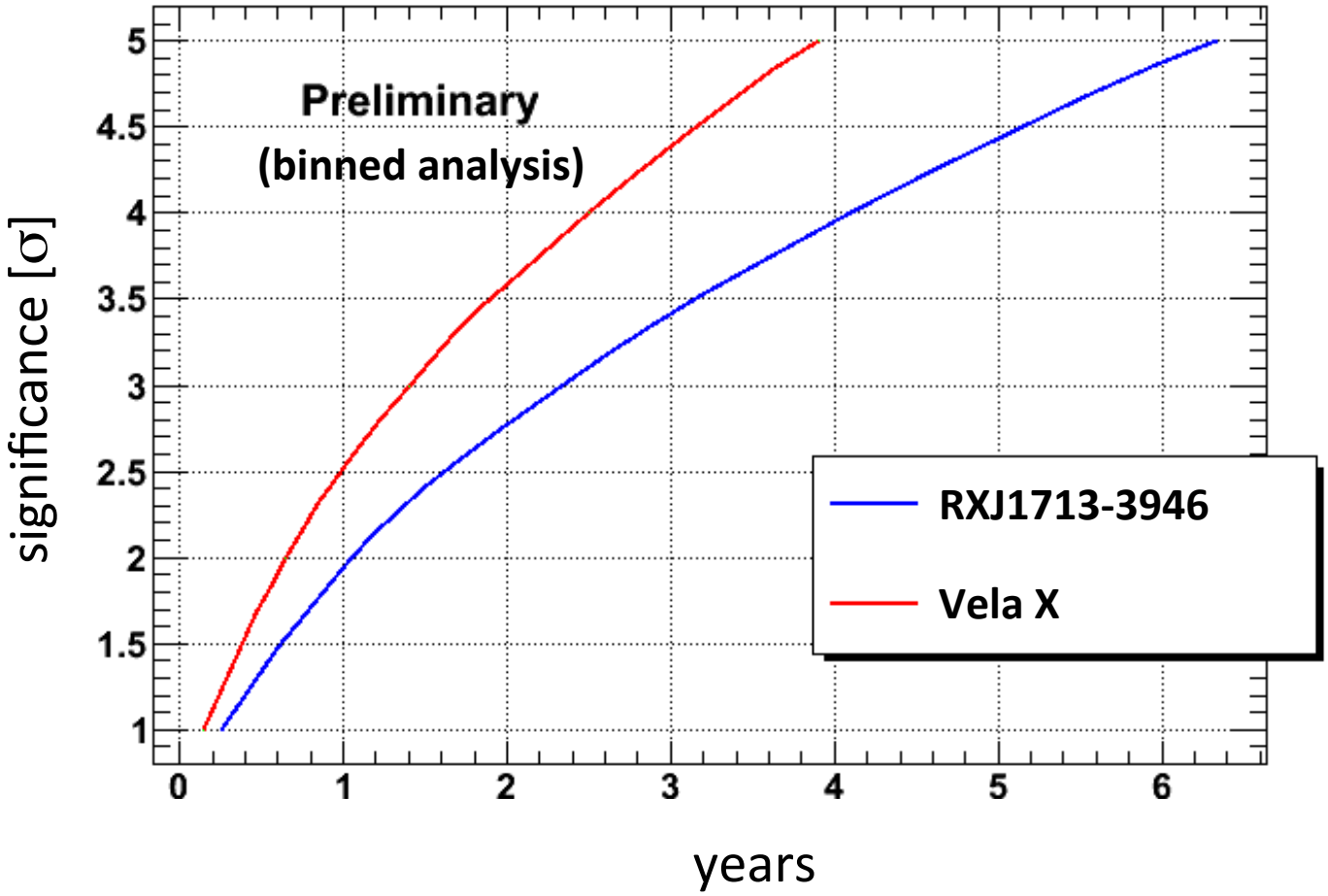
RXJ1713



📖 S.R. Kelner, *et al.*, PhRD 74 (2006) 034018.

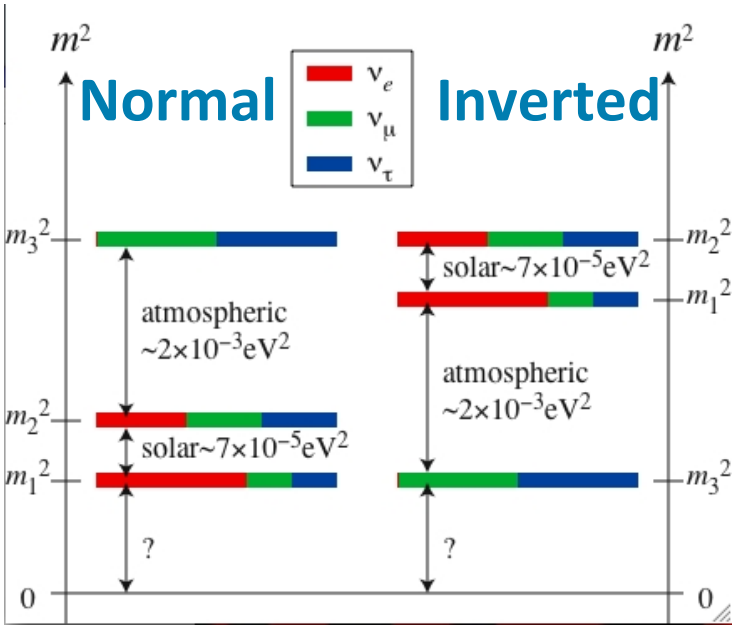
Vela X





📖 F.L. Villante and F. Vissani, Phys. Rev. D 78 (2008) 103007.

Measuring the neutrino mass hierarchy?



- Free 'beam' of neutrinos
- Broad range of baselines (50-1250km)
- Broad range of energies (~GeV-PeV)
- Composite of beam well understood:
  flux (nu)~1.3 flux (anti-nu)

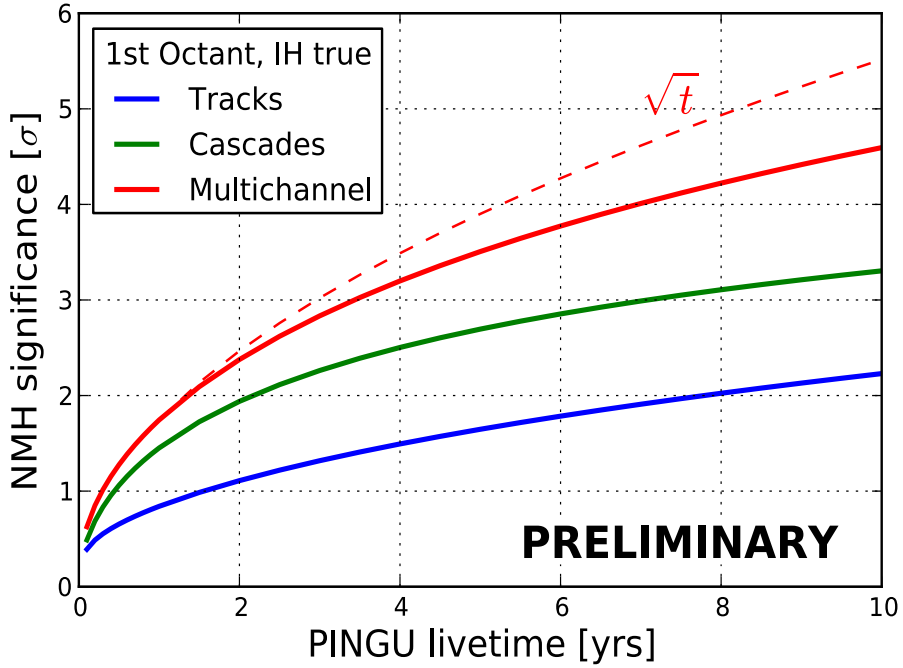
- mass effects lead to event rates at particular angles and energies which depend on the mass hierarchy and is opposite for neutrino/anti-neutrino
- At these energies $\sigma(\nu) \approx 2\sigma(\overline{\nu})$ so observe net effect

→ Fit of event count in Energy-Zenith space

📖 W. Winter : arXiv:1305.5539, Agarwalla et al. arXiv:1212.2238
📖 Akhmedov et al. JHEP 02 (2013) 082

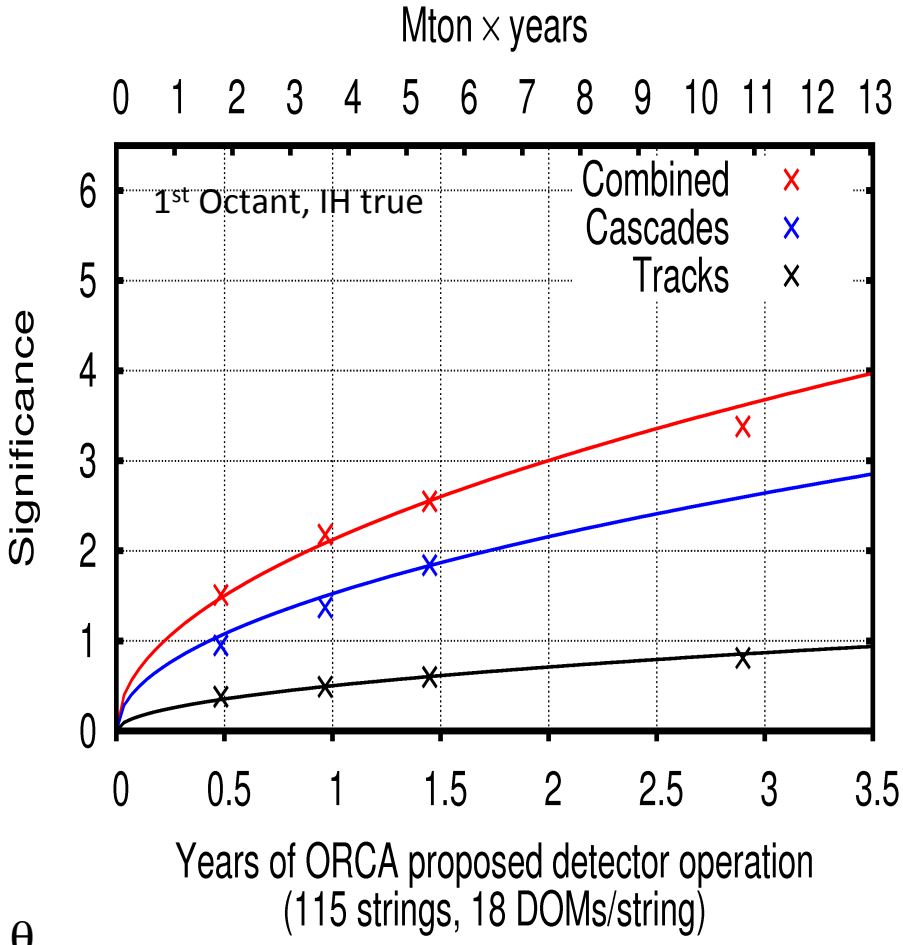
Mass Hierarchy Sensitivities

PINGU sensitivity (40 strings, 60 OM/string, 5m/25m)



Start 2021

ORCA sensitivity (115 strings, 18 OM/string, 6m/20m)



Start 2019

+ Factor ~4 improvement on value of θ_{23}
+ Measurement of octant