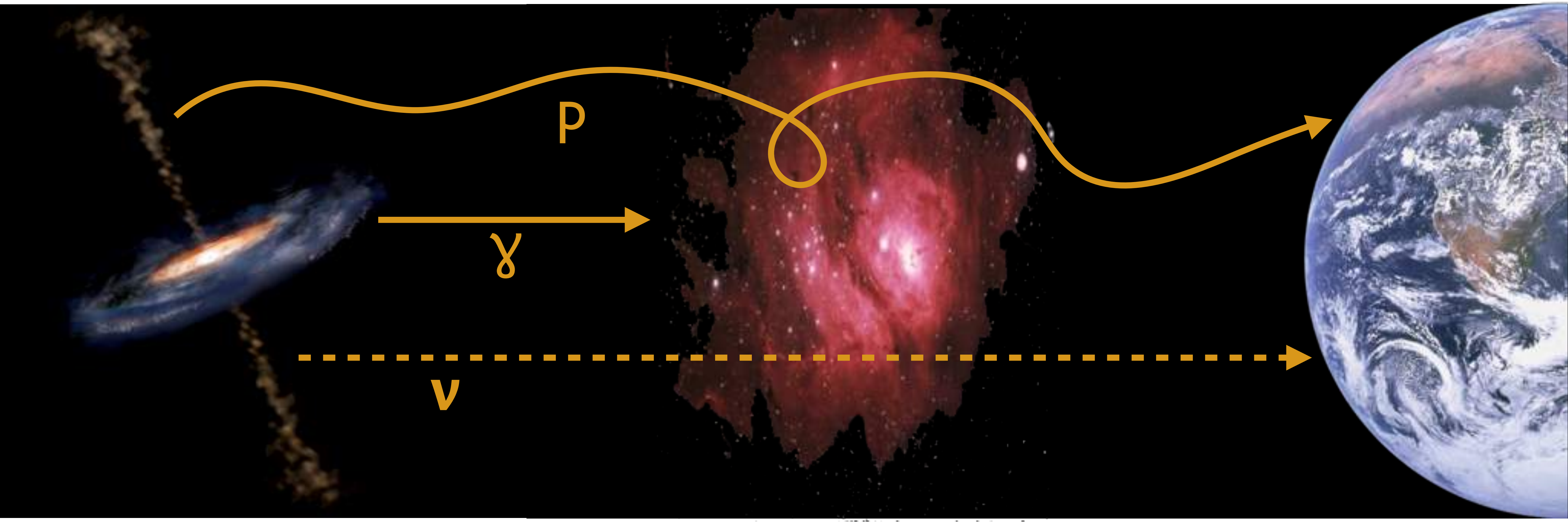
Latest news and prospects from neutrino telescopes in the Mediterranean

Alexis Coleiro (APC & Université Paris Diderot)
on behalf of ANTARES and KM3NeT collaborations

Lake Louise Winter Institute
Feb 12th, 2016

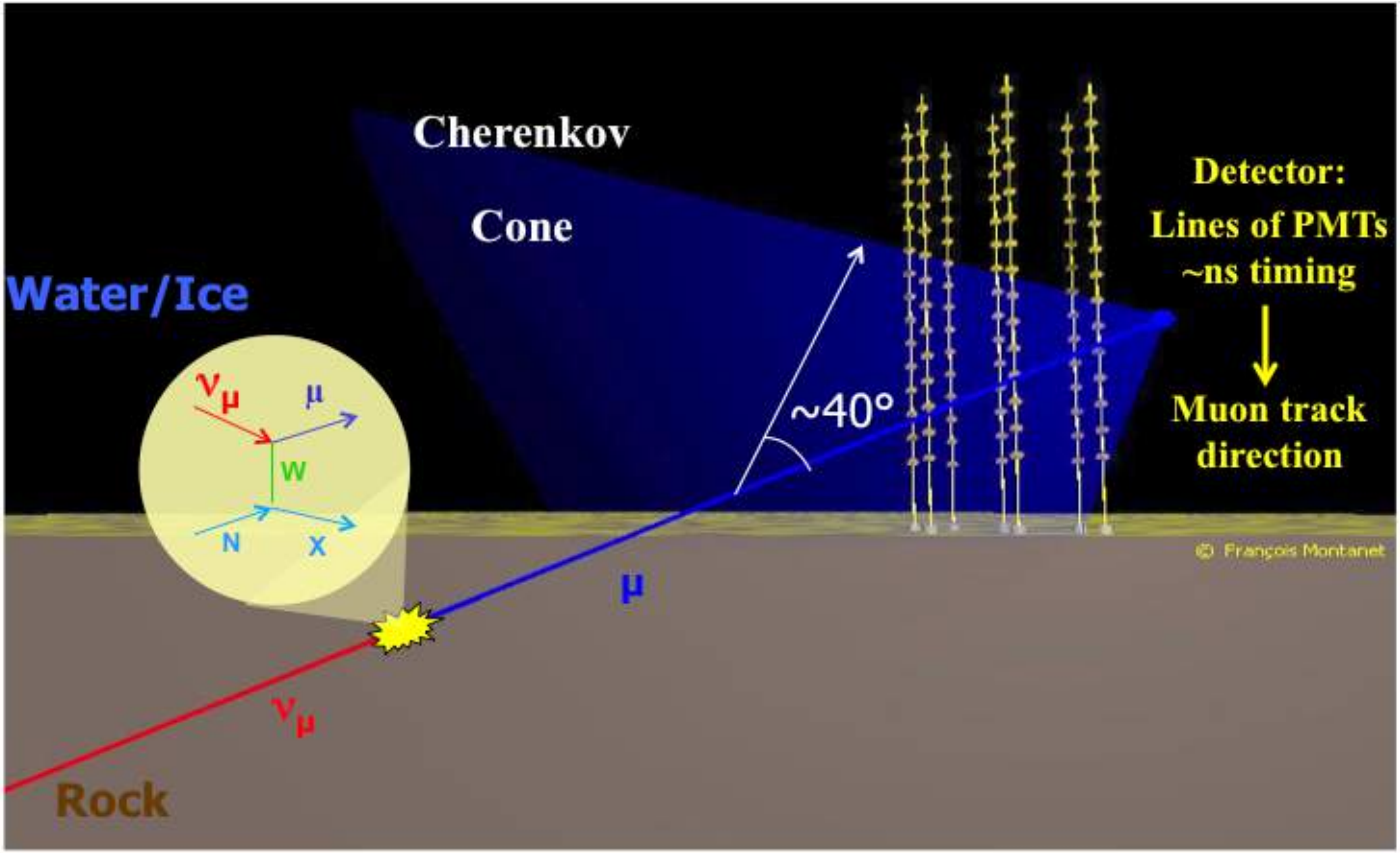
Neutrino astronomy



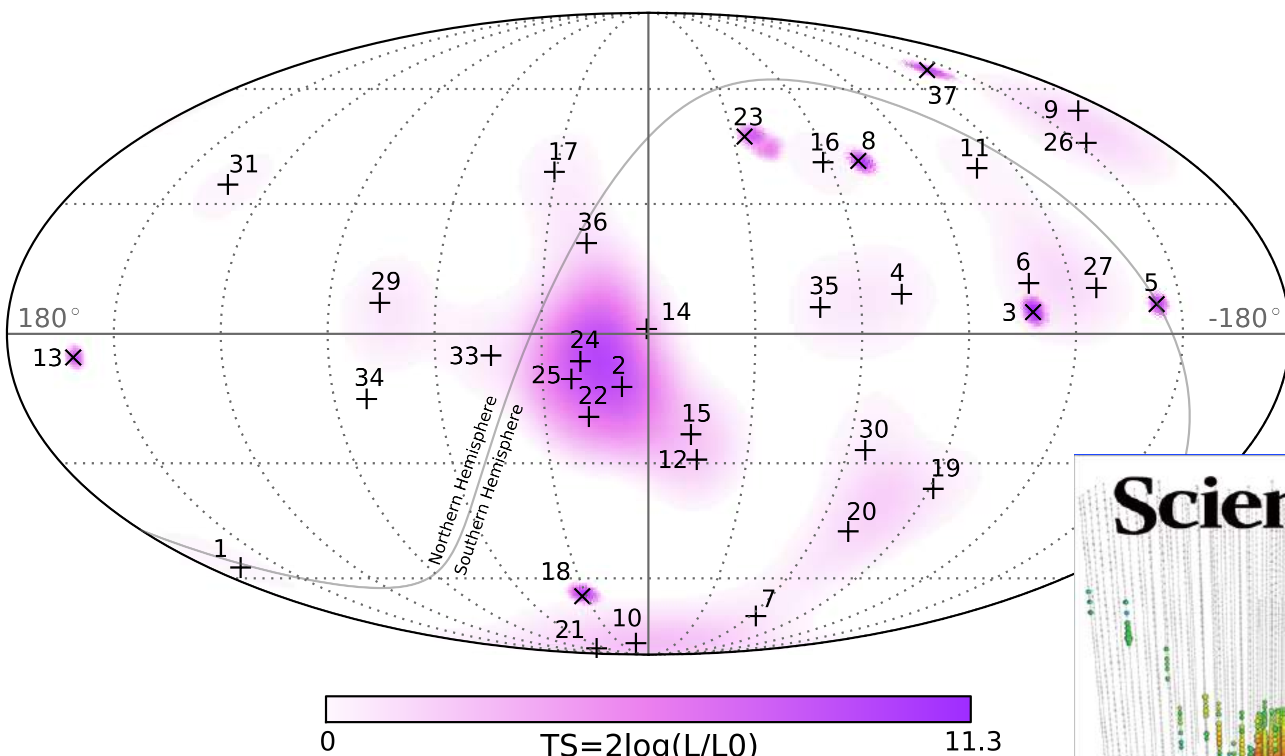
- Photons are absorbed by the ISM
- Protons are deviated by magnetic fields
- Neutrinos are neutral, stable and weakly interacting particles

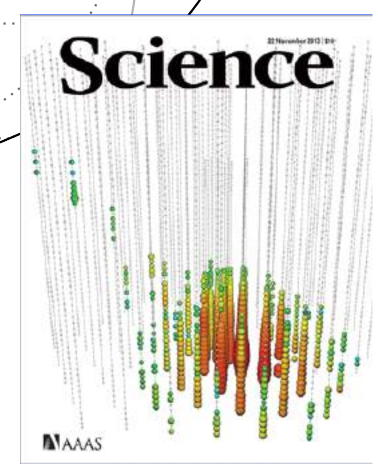
Signature of hadronic acceleration : sites of cosmic rays production

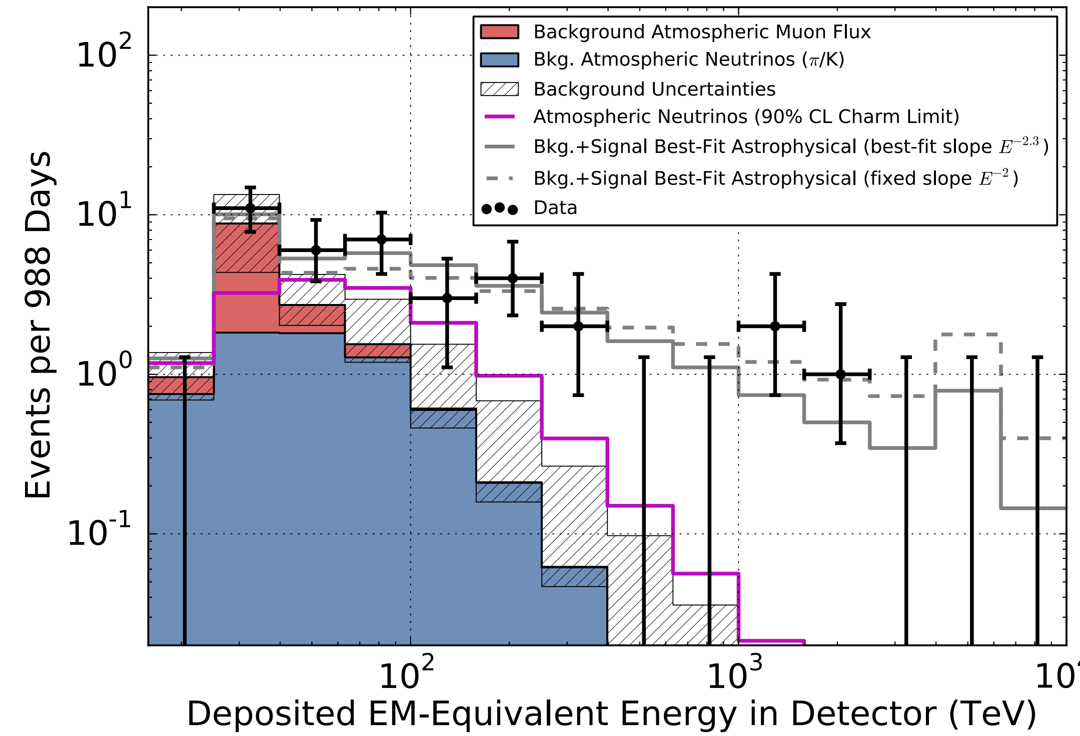
Neutrino astronomy



Neutrino astronomy







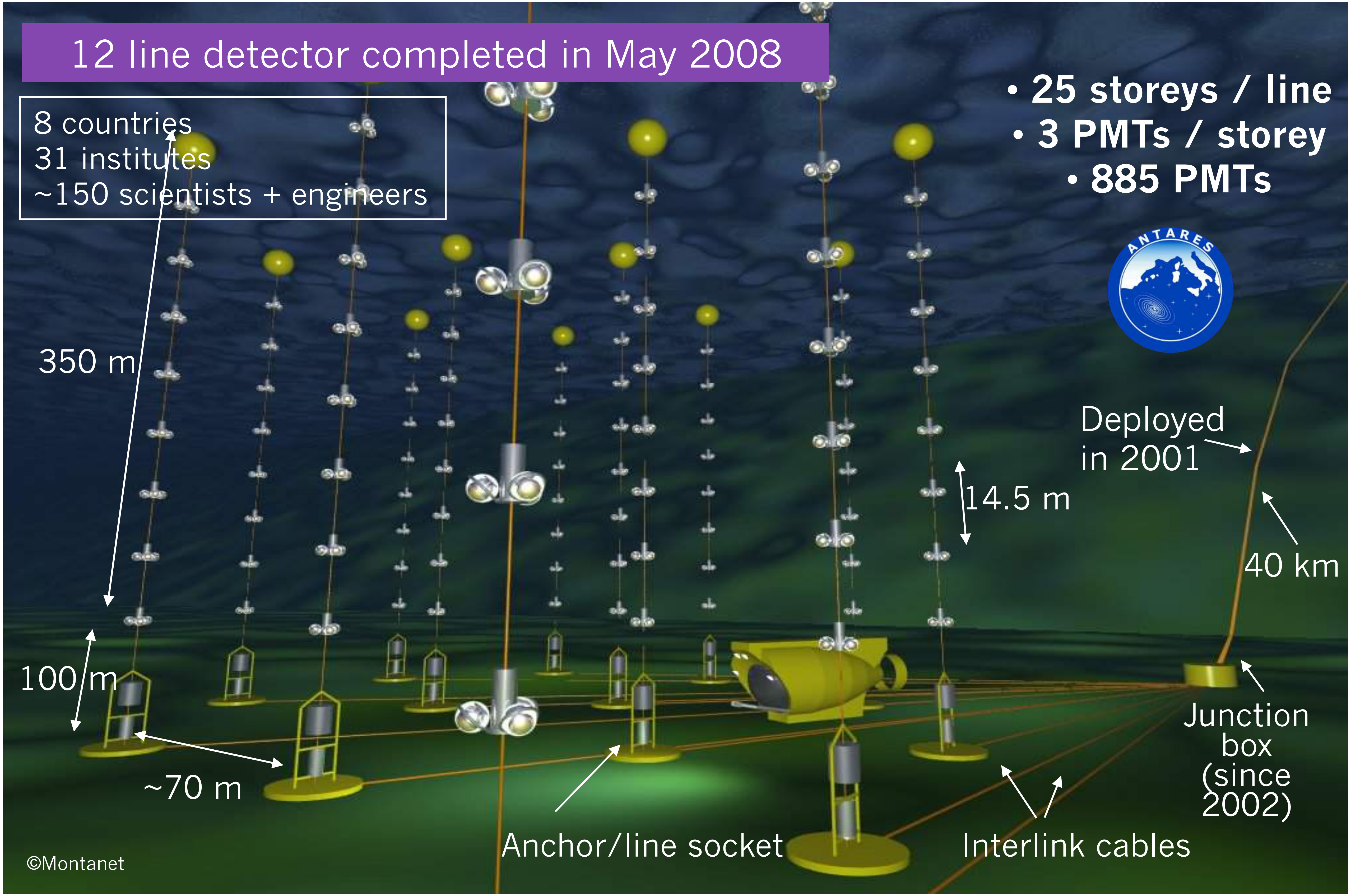
➜ *IceCube Collab., 2014, PRD 113*

➜ Which and where are the sources ??

- Need good angular and energy accuracy
- All neutrino-flavors to be taken into account
- Multi-messenger programs

Next generation of deep-sea neutrino telescopes will bring new constraints !!

The ANTARES neutrino telescope

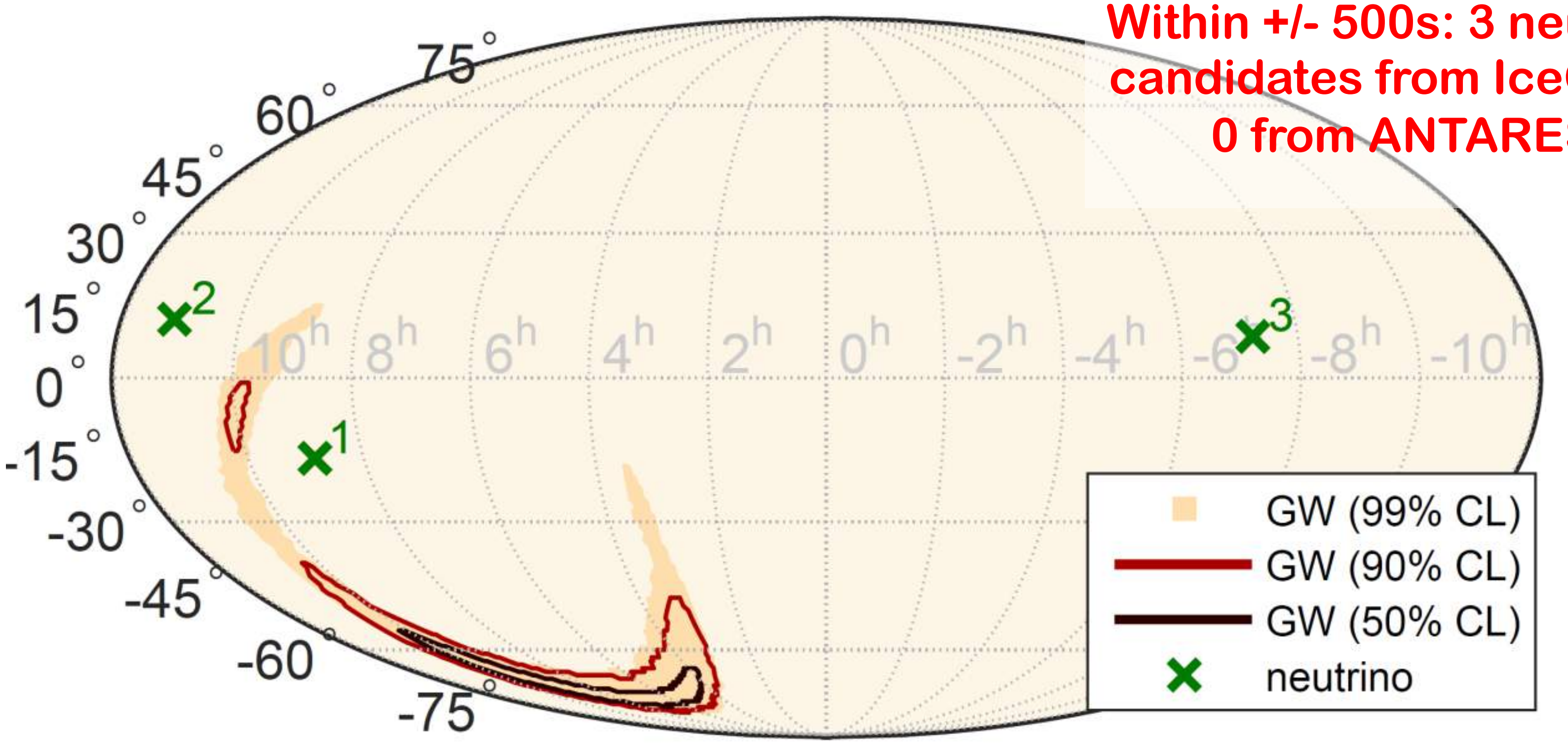


Neutrino follow-up of the first GW event

GW alert triggered by adv.-LIGO on sept. 14, 2015

➜ Online follow-up by ANTARES and IceCube

Within +/- 500s: 3 neutrino candidates from IceCube, 0 from ANTARES



Expected number of background events:

4.4 for IceCube
0.014 for ANTARES

#	ΔT [s]	RA [h]	Dec [°]	σ [°]	E_{μ}^{obs} [TeV]	fraction
1	+37.2	8.84	-16.6	0.35	175	12.5%
2	+163.2	11.13	12.0	1.95	1.22	26.5%
3	+311.4	-7.23	8.4	0.47	0.33	98.4%

https://dcc.ligo.org/public/0123/P1500271/013/GW150914_neutrino.pdf

Neutrino follow-up of the first GW event

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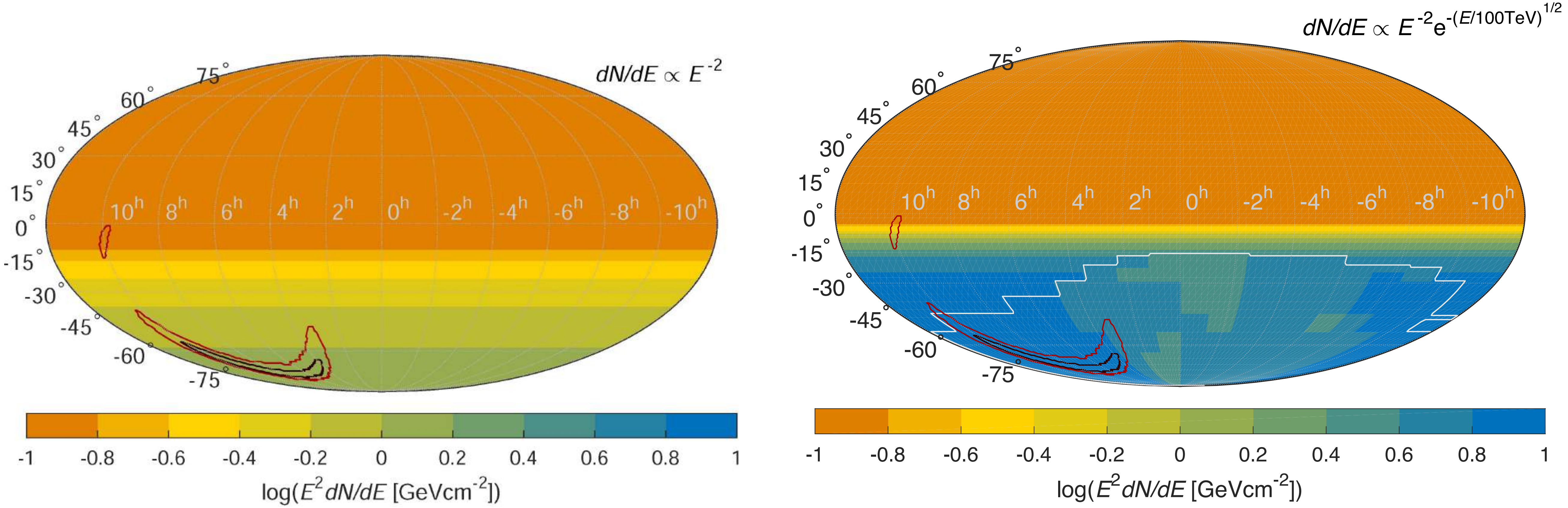
➜ Online follow-up by ANTARES and IceCube

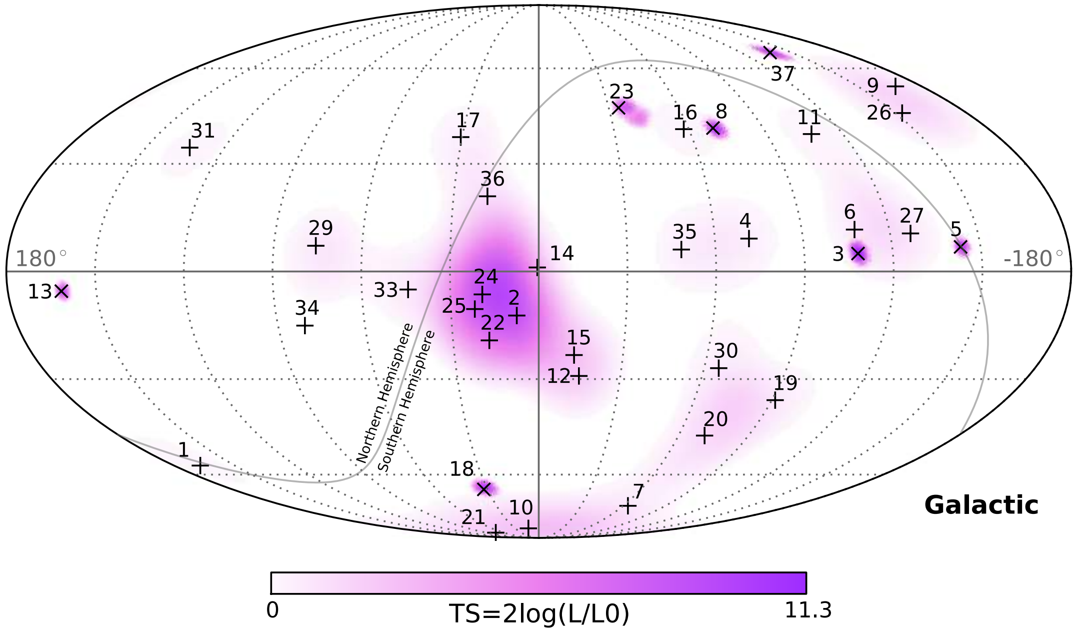


➜ Integrating emission between [100 GeV; 100 PeV] and [100 GeV; 100 TeV]:

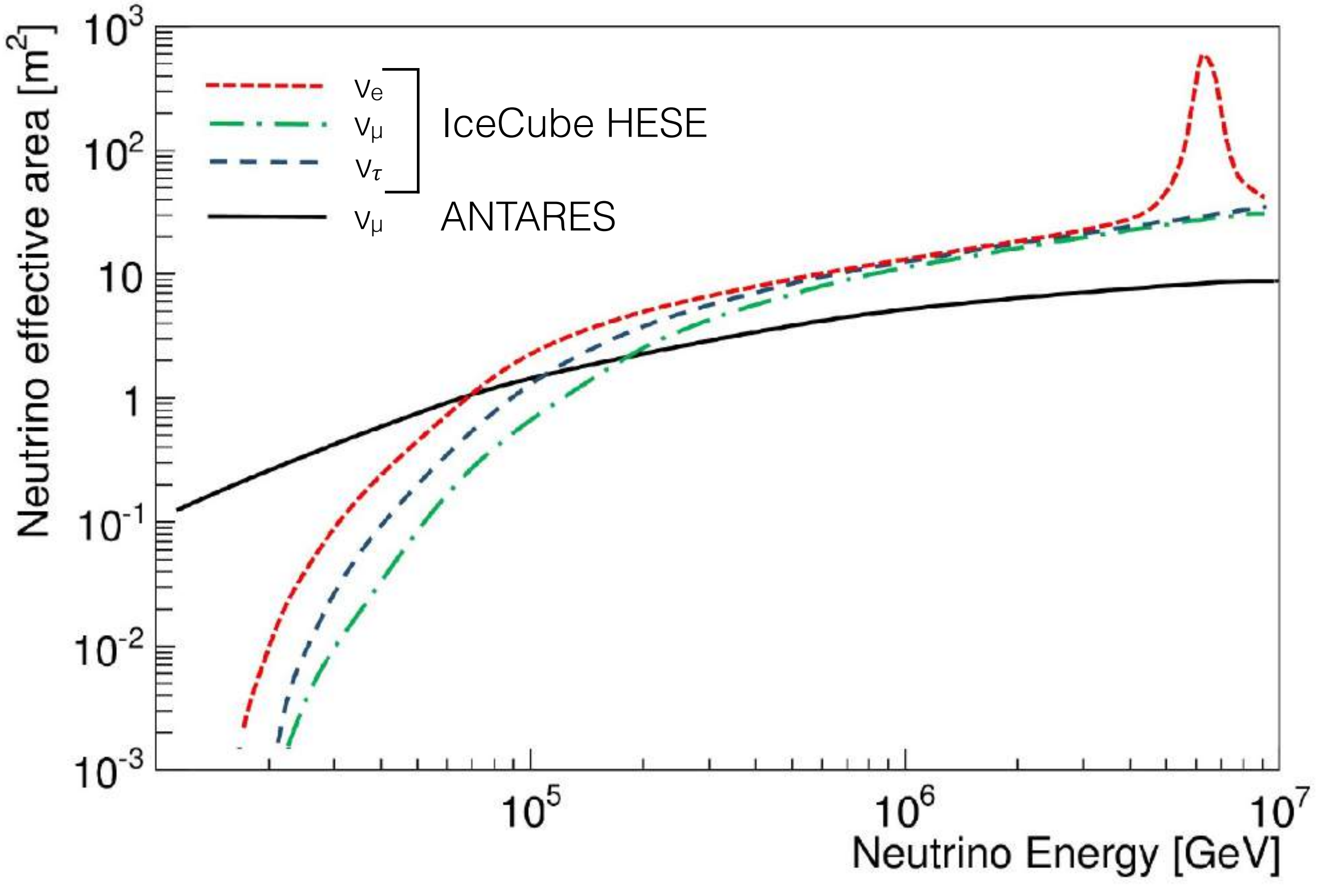
$$E_{\nu,\mathrm{tot}}^{\mathrm{ul}} \sim 10^{52}\text{–}10^{54} \left(\frac{D_{\mathrm{gw}}}{410\,\mathrm{Mpc}}\right)^2 \mathrm{erg}$$

What can ANTARES say about the IceCube results ?

> Constraints in the Galactic Center region



Effective area in the Galactic Center region



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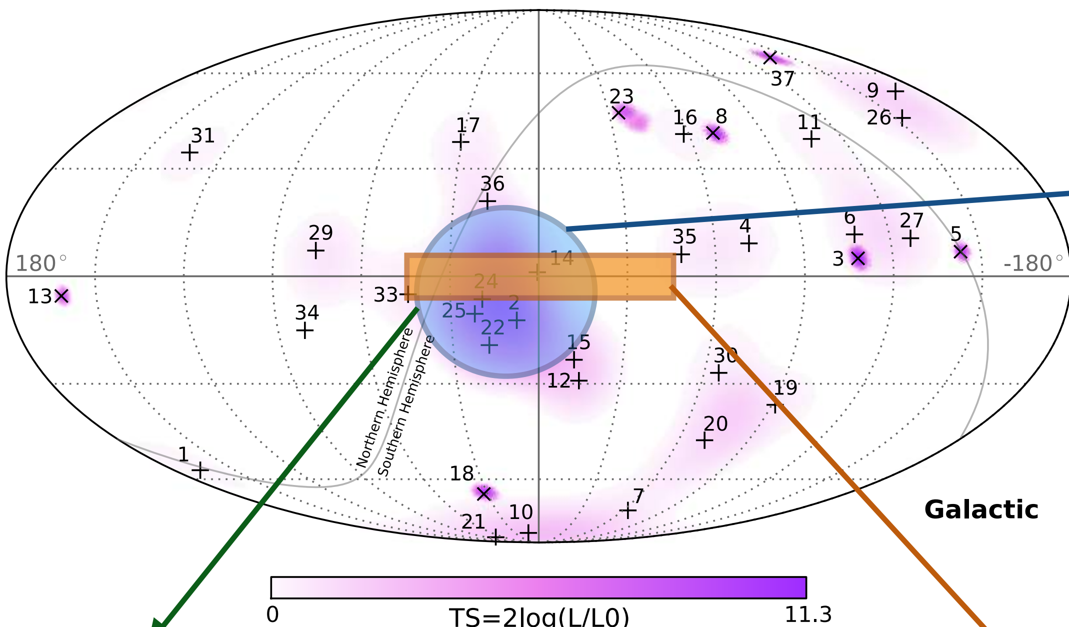
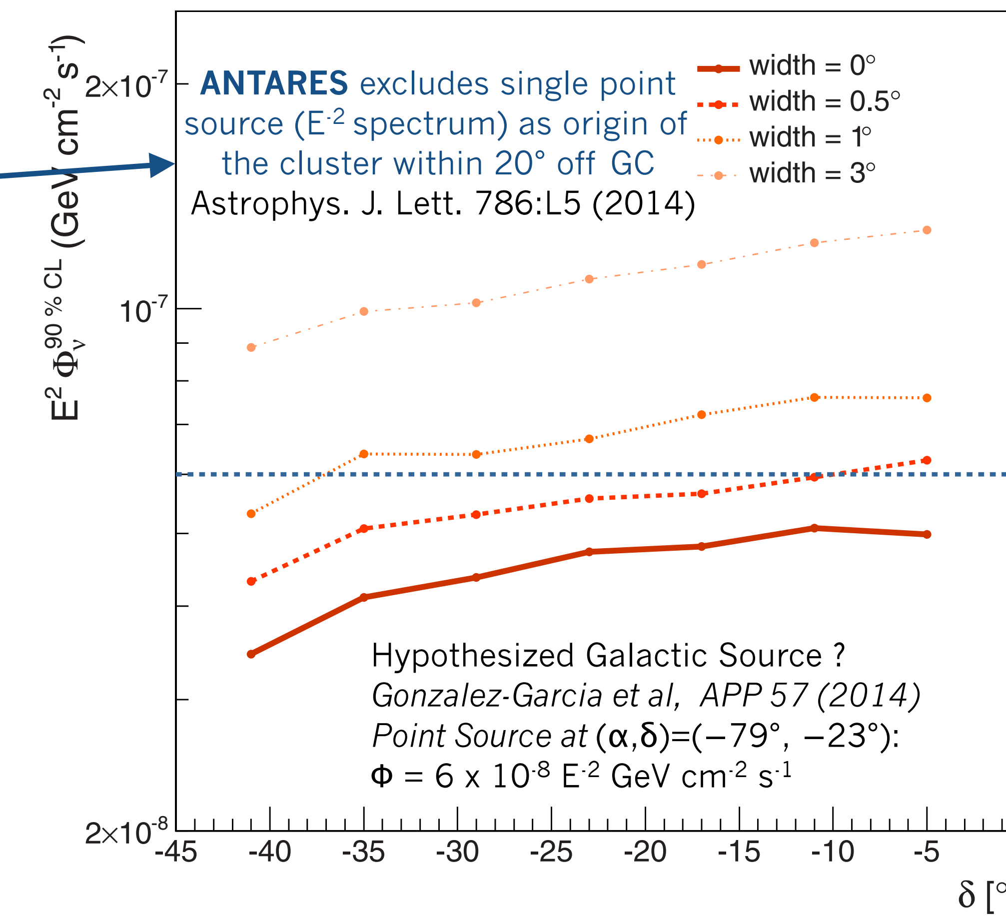
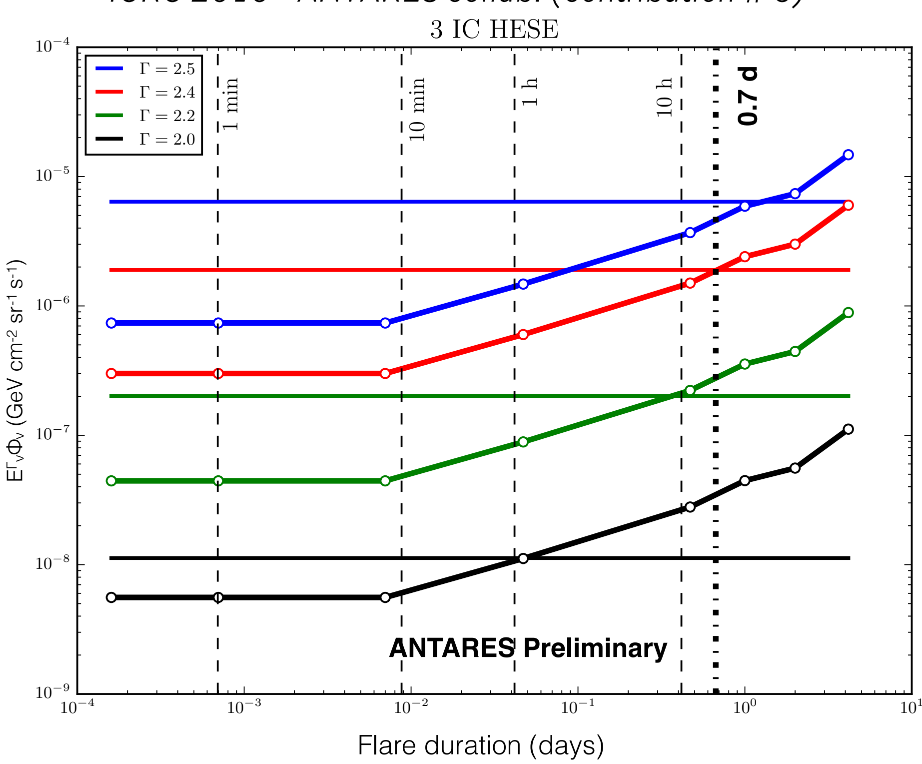




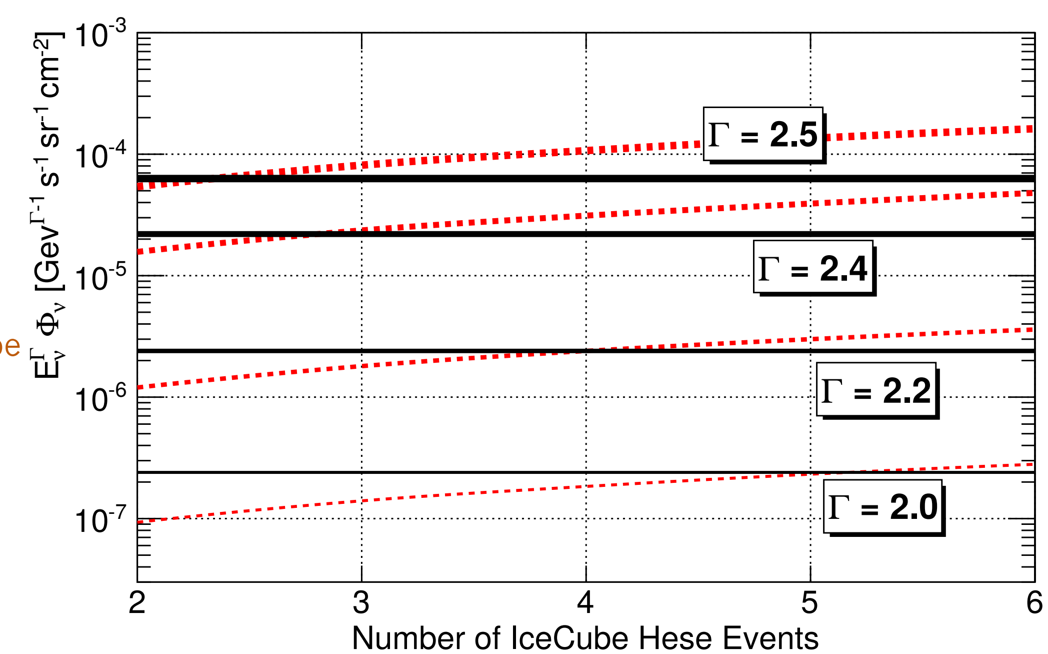
ANTARES excludes single point source (E^{-2} spectrum) as origin of the cluster within 20° off GC
Astrophys. J. Lett. 786:L5 (2014)

Hypothesized Galactic Source ?
Gonzalez-Garcia et al, APP 57 (2014)
Point Source at $(\alpha,\delta)=(-79°, -23°)$:
$\Phi = 6 \times 10^{-8}\, E^{-2}$ GeV cm^{-2} s^{-1}

ANTARES constrains the IceCube signal event contribution to a transient neutrino flux in the Galactic Plane
ICRC 2015 - ANTARES collab. (contribution # 3)

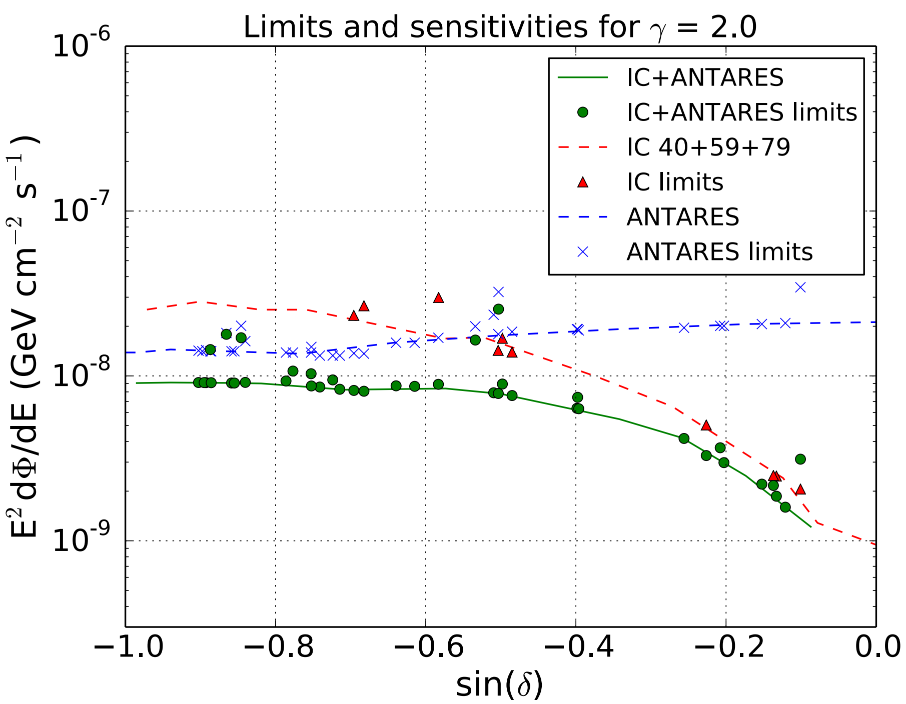


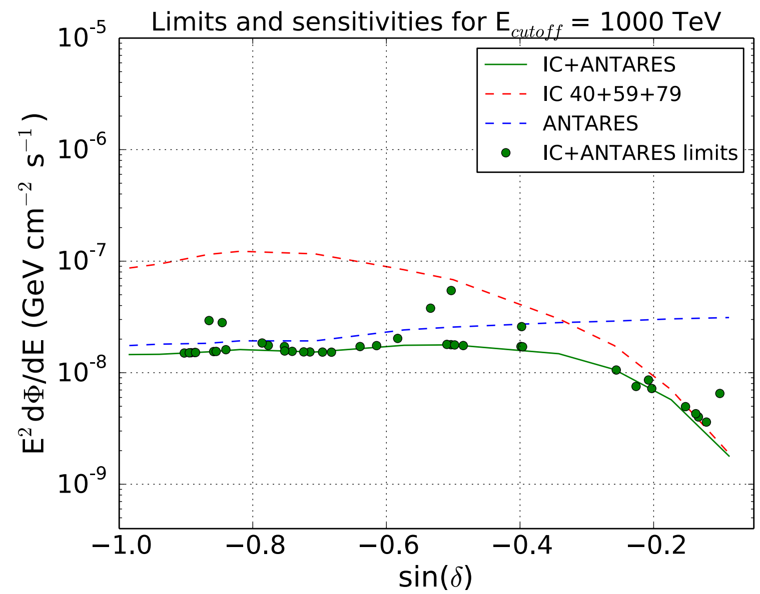
ANTARES constrains the IceCube signal event contribution to a diffuse neutrino flux in the Galactic Plane
arXiv:1602.03036

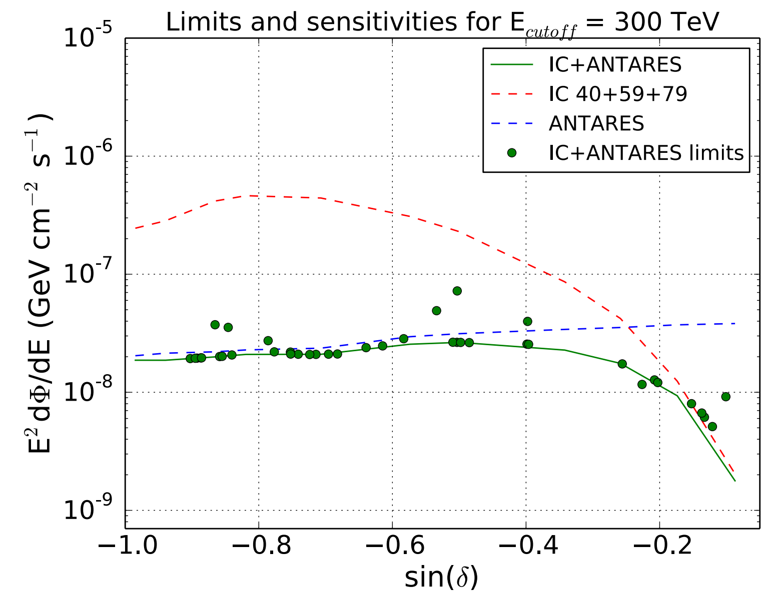


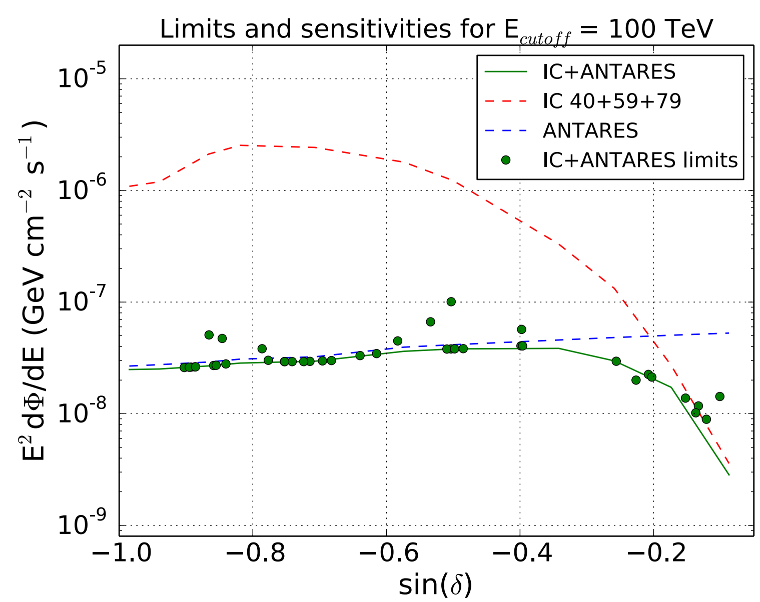
What can ANTARES say about the IceCube results ?

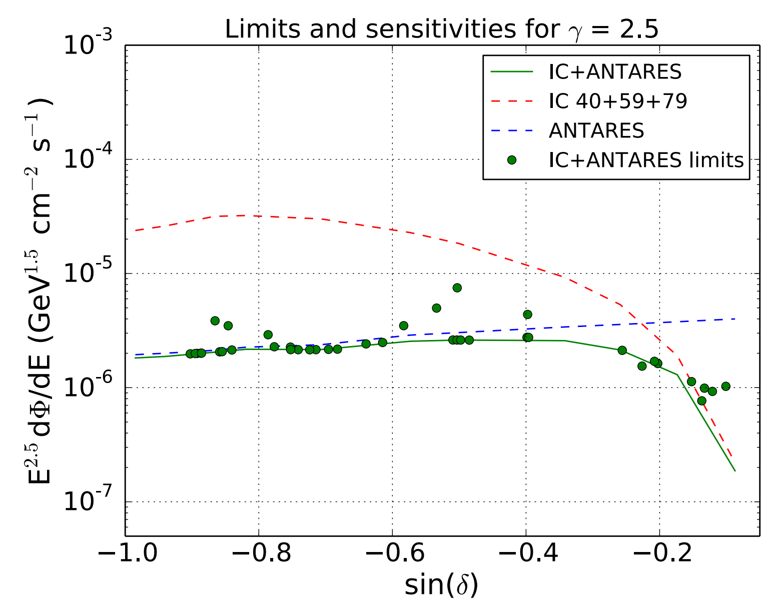
> ANTARES / IceCube joint analysis: http://arxiv.org/abs/1511.02149







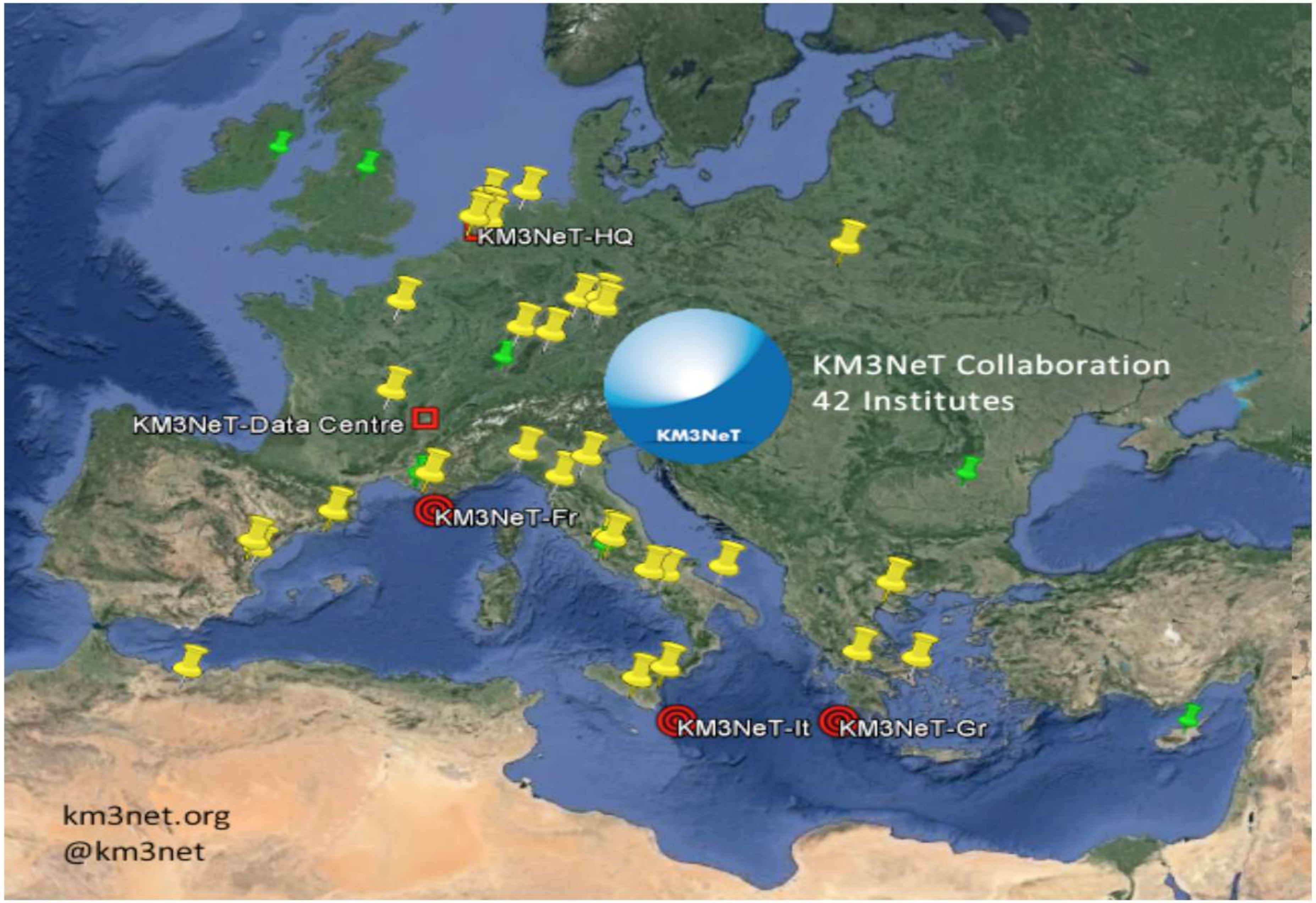




Increasing the sensitivity to point-like sources **up to a factor of two** w.r.t. individual analyses

KM3NeT

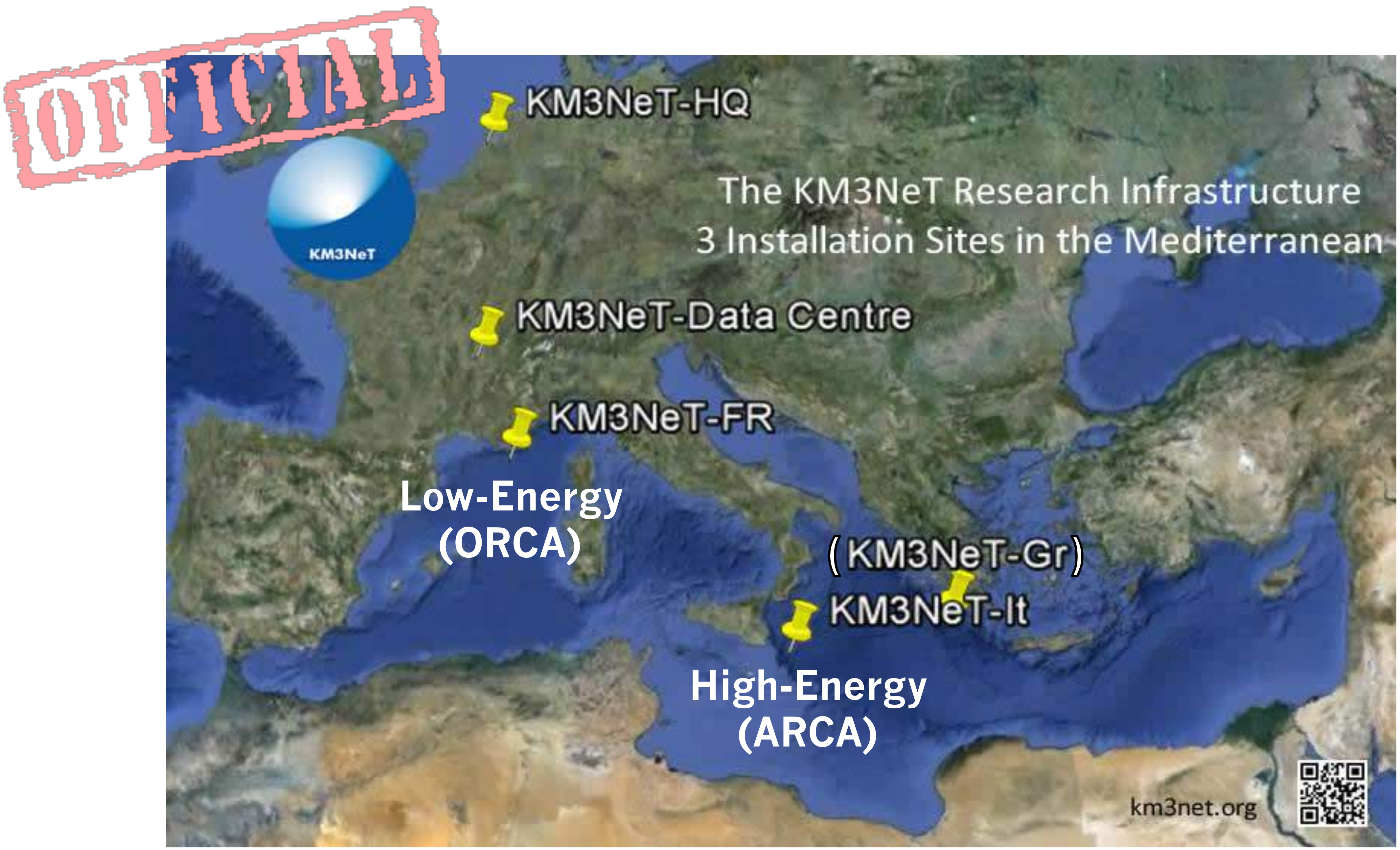
The Collaboration: 240 people, 42 institutes, 12 countries



KM3NeT

Distributed research infrastructure with <u>2 main physics topics</u>:

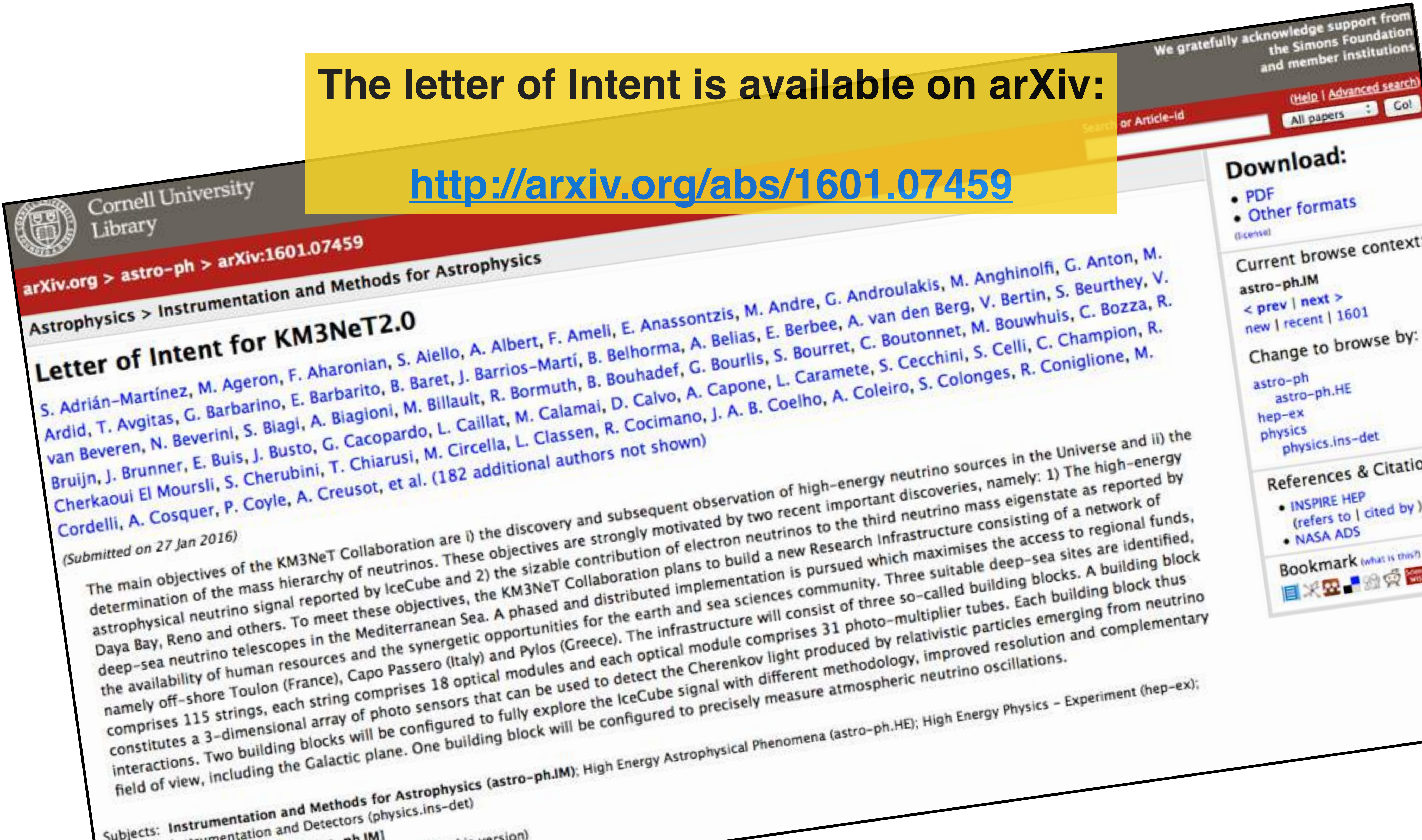
Oscillations and **A**stroparticle **R**esearch with **C**osmics in the **A**byss



KM3NeT - Letter of Intent

The letter of Intent is available on arXiv:

http://arxiv.org/abs/1601.07459



We gratefully acknowledge support from the Simons Foundation and member institutions

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arXiv.org > astro-ph > arXiv:1601.07459

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All papers Go!

Astrophysics > Instrumentation and Methods for Astrophysics

Letter of Intent for KM3NeT2.0

S. Adrián-Martínez, M. Ageron, F. Aharonian, S. Aiello, A. Albert, F. Ameli, E. Anassontzis, M. Andre, G. Androulakis, M. Anghinolfi, G. Anton, M. Ardid, T. Avgitas, G. Barbarino, E. Barbarito, B. Baret, J. Barrios-Martí, B. Belhorma, A. Belias, E. Berbee, A. van den Berg, V. Bertin, S. Beurthey, V. van Beveren, N. Beverini, S. Biagi, A. Biagioni, M. Billault, R. Bormuth, B. Bouhadef, G. Bourlis, S. Bourret, C. Boutonnet, M. Bouwhuis, C. Bozza, R. Bruijn, J. Brunner, E. Buis, J. Busto, G. Cacopardo, L. Caillat, M. Calamai, D. Calvo, A. Capone, L. Caramete, S. Cecchini, S. Celli, C. Champion, R. Cherkaoui El Moursli, S. Cherubini, T. Chiarusi, M. Circella, L. Classen, R. Cocimano, J. A. B. Coelho, A. Coleiro, S. Colonges, R. Coniglione, M. Cordelli, A. Cosquer, P. Coyle, A. Creusot, et al. (182 additional authors not shown)

(Submitted on 27 Jan 2016)

The main objectives of the KM3NeT Collaboration are i) the discovery and subsequent observation of high-energy neutrino sources in the Universe and ii) the determination of the mass hierarchy of neutrinos. These objectives are strongly motivated by two recent important discoveries, namely: 1) The high-energy astrophysical neutrino signal reported by IceCube and 2) the sizable contribution of electron neutrinos to the third neutrino mass eigenstate as reported by Daya Bay, Reno and others. To meet these objectives, the KM3NeT Collaboration plans to build a new Research Infrastructure consisting of a network of deep-sea neutrino telescopes in the Mediterranean Sea. A phased and distributed implementation is pursued which maximises the access to regional funds, the availability of human resources and the synergetic opportunities for the earth and sea sciences community. Three suitable deep-sea sites are identified, namely off-shore Toulon (France), Capo Passero (Italy) and Pylos (Greece). The infrastructure will consist of three so-called building blocks. A building block comprises 115 strings, each string comprises 18 optical modules and each optical module comprises 31 photo-multiplier tubes. Each building block thus constitutes a 3-dimensional array of photo sensors that can be used to detect the Cherenkov light produced by relativistic particles emerging from neutrino interactions. Two building blocks will be configured to fully explore the IceCube signal with different methodology, improved resolution and complementary field of view, including the Galactic plane. One building block will be configured to precisely measure atmospheric neutrino oscillations.

Subjects: Instrumentation and Methods for Astrophysics (astro-ph.IM); High Energy Astrophysical Phenomena (astro-ph.HE); High Energy Physics - Experiment (hep-ex); Instrumentation and Detectors (physics.ins-det)

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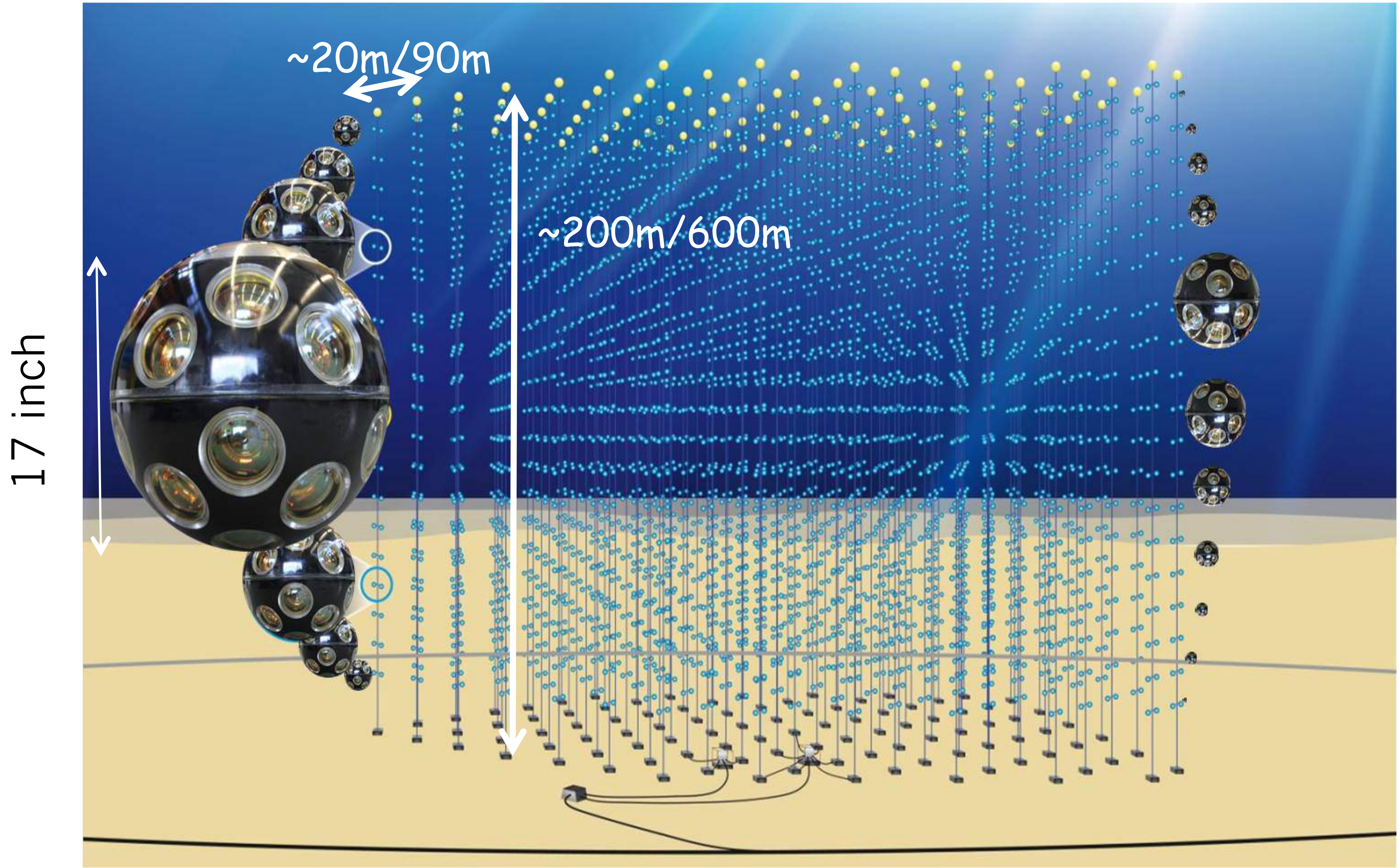
KM3NeT



- 18 OMs / line
- 31 3'' PMTs
- Digital photon couting
- Wide angle of view
- More photocathode than 1 ANTARES storey
- Cost reduction w.r.t. ANTARES

A phased implementation

	BLOCKS	PRIMARY DELIVERABLES
PHASE 1	0.25	shore and deep-sea infrastucture at KM3NeT-Fr and KM3NeT-It + 31 lines (3-4 x ANTARES) Proof of feasibility & first results
PHASE 2	2 ARCA	Measurement of IceCube signal All-flavour neutrino astronomy
	1 ORCA	Neutrino mass hierarchy
PHASE 3	6 (+1)	Neutrino astronomy including Galactic sources (…and a beam to ORCA ?)

31 M€ FUNDED and ONGOING

+95 M€

80-90 M€
Letter of Intent on Arxiv 01/27/16
30-40 M€

+110 M€

220-250 M€ ESFRI Roadmap

Status of Phase-1

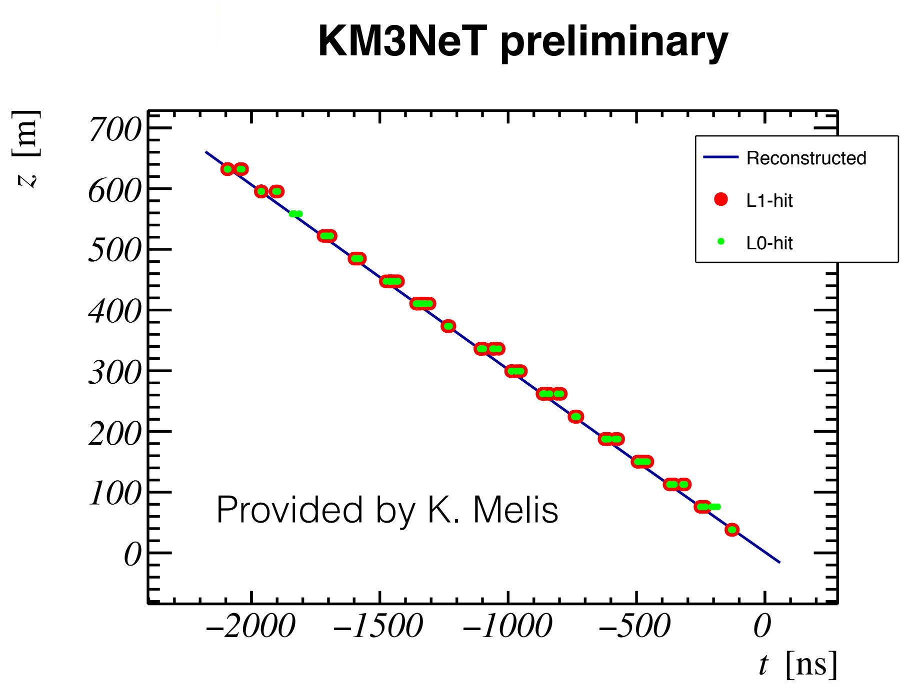
December 4th, 2015: first line deployed at Capo Passero (Sicily)

04/12/2015:
Laid on sea-bed
Unfurled
Powered on
Taking data!

First reconstructed μ seen!

Status of Phase-1

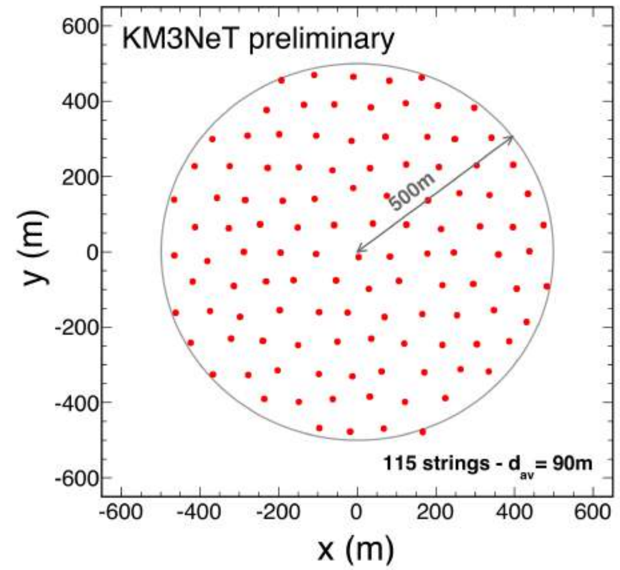
December 4th, 2015: first line deployed at Capo Passero (Sicily)

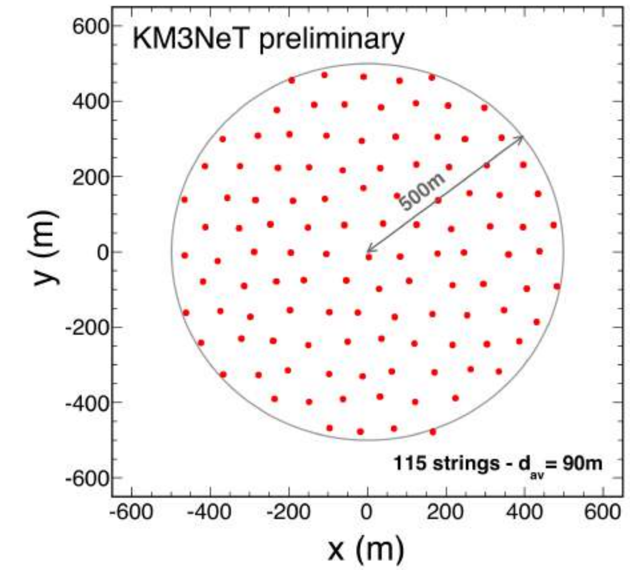


KM3NeT / ARCA - Expected performances

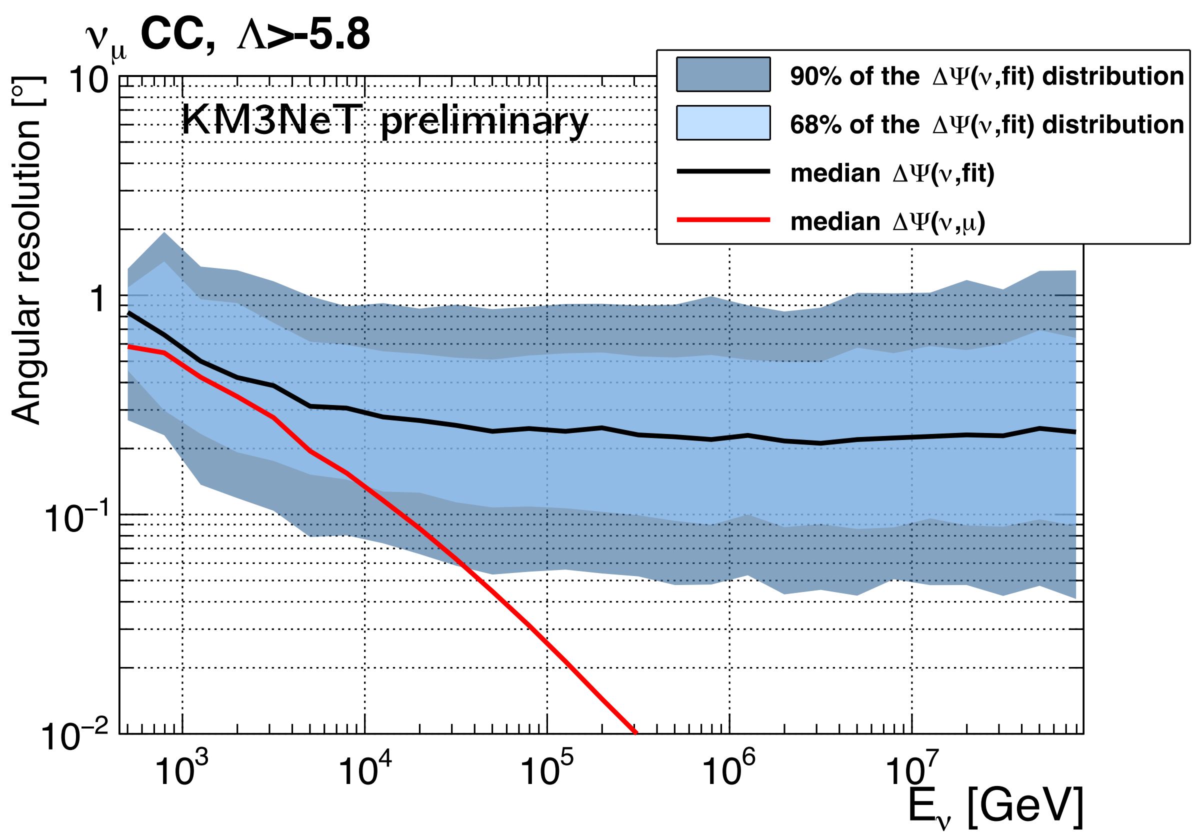
ARCA Phase-2
2 building blocks
in KM3NeT-It

➜ Confirmation of IceCube signal

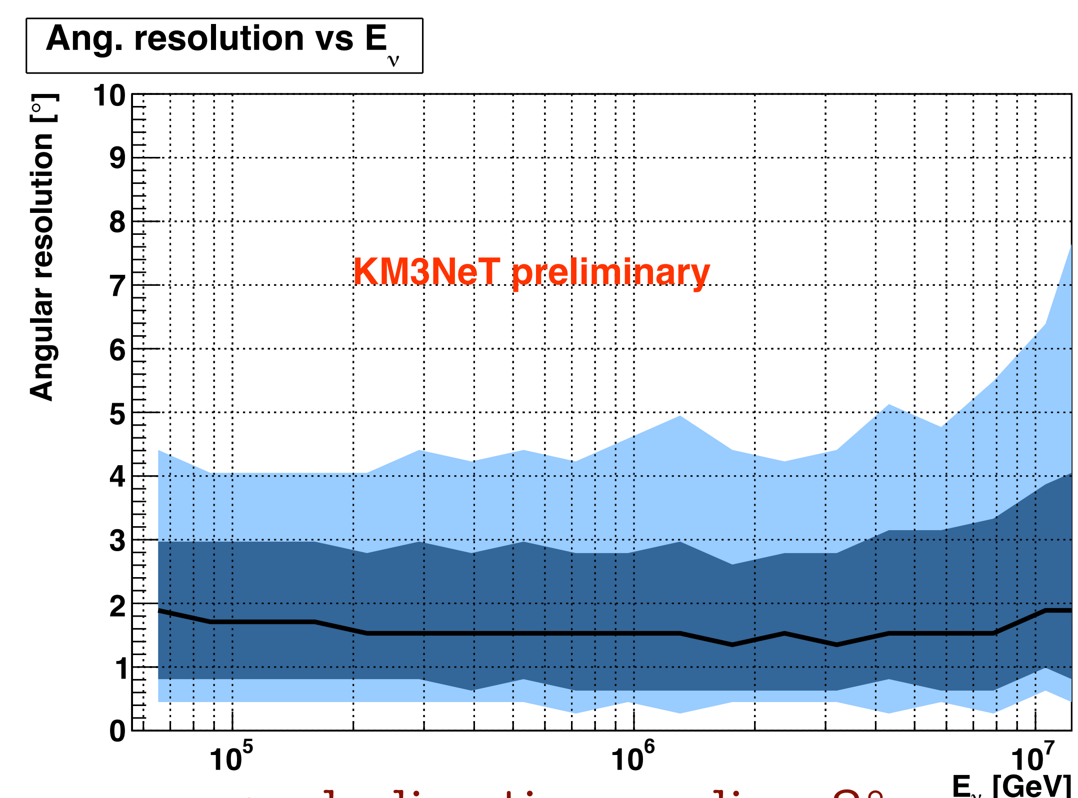




Good reconstruction performances both on **tracks** (muon CC channel) and **showers** (electron CC here)



neutrino direction : 0.3° at 10 TeV



cascade direction: median=2°

KM3NeT / ARCA - Sensitivity to diffuse flux

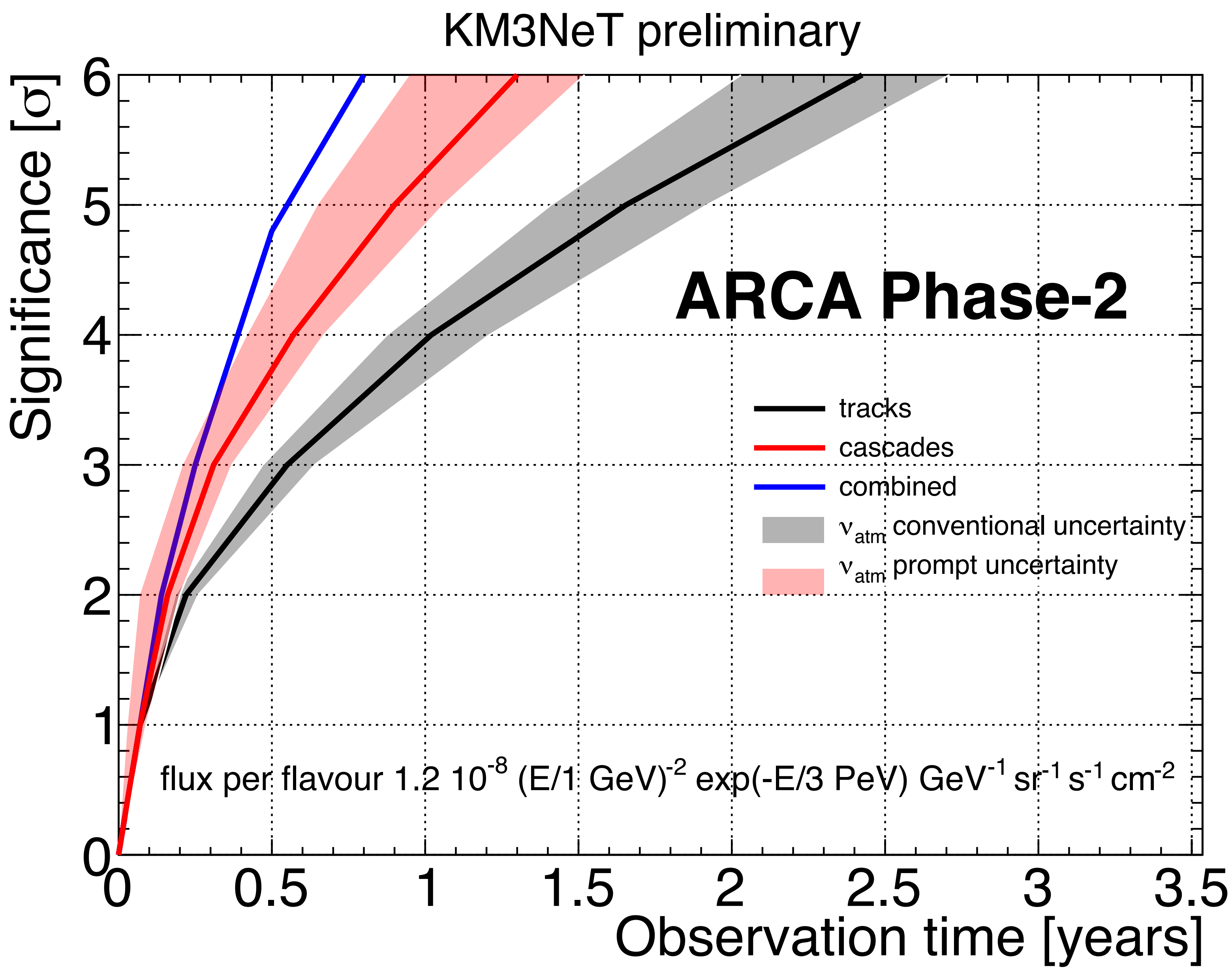
> Single-flavored energy spectrum parametrized as:

$$\Phi(E_\nu) = 1.2 \times 10^{-8} \cdot \left(\frac{E_\nu}{\text{GeV}}\right)^{-2} \cdot \exp\left(-\frac{E_\nu}{3\,\text{PeV}}\right) \quad \text{GeV}^{-1}\,\text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}$$

5-σ significance:

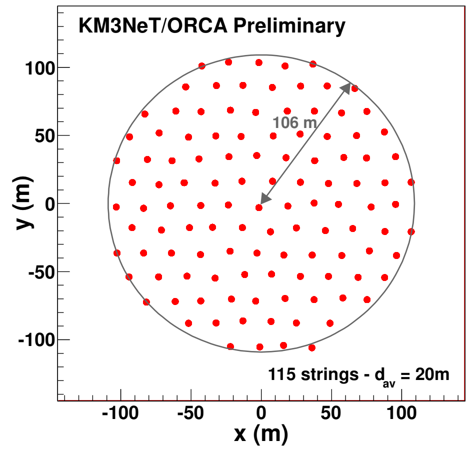
Tracks: 1.5 - 2 yrs
Cascades: < 1 yr
Combined: ~6 months

with atmo. muons self-veto



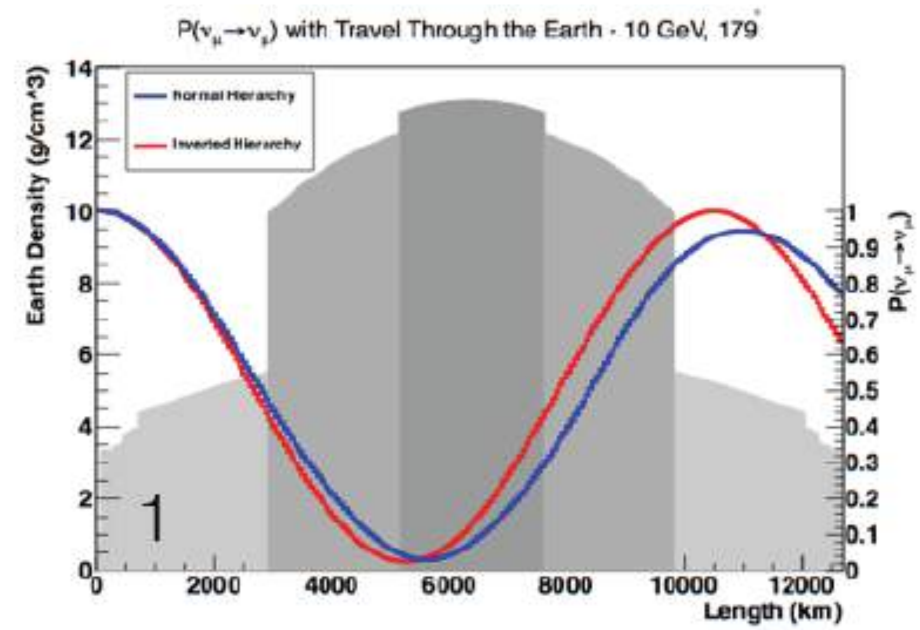
KM3NeT / ORCA - Neutrino mass hierarchy

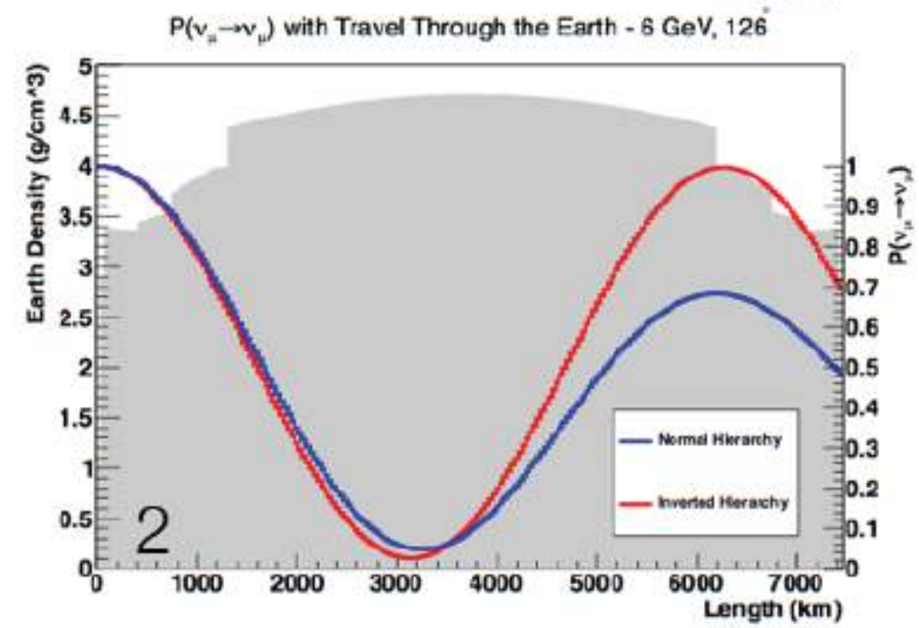
ORCA Phase-2
1 building blocks
in KM3NeT-Fr

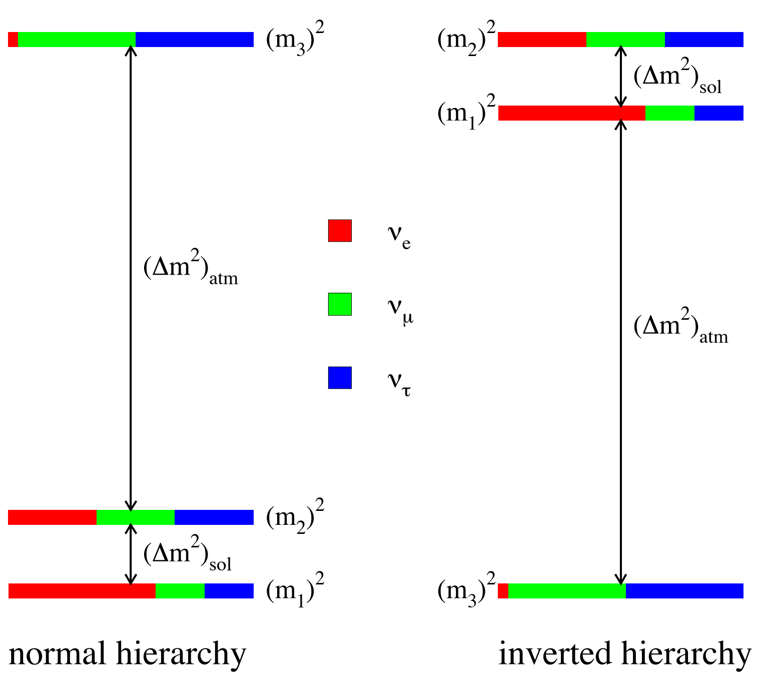


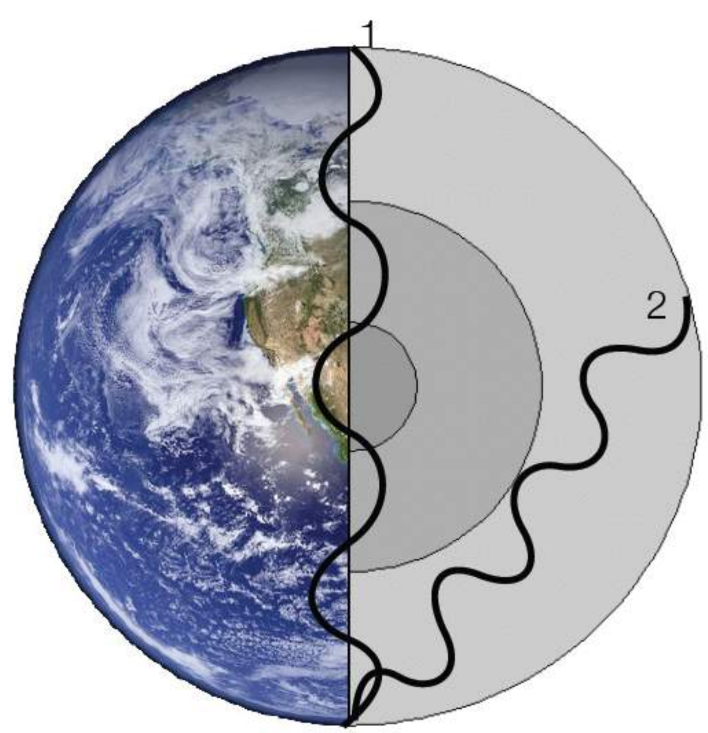
➜ Measurement of the neutrino mass hierarchy with atmospheric neutrinos (1-20 GeV)

Credit: IceCube





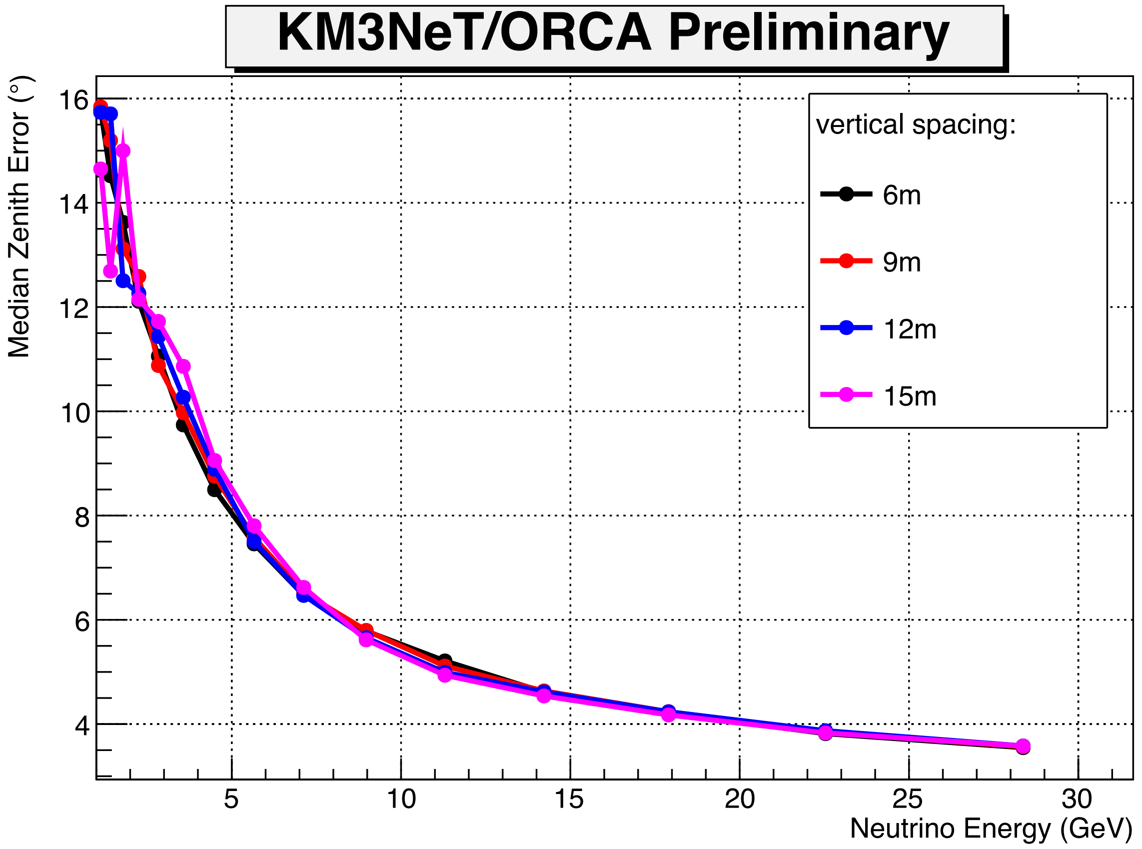




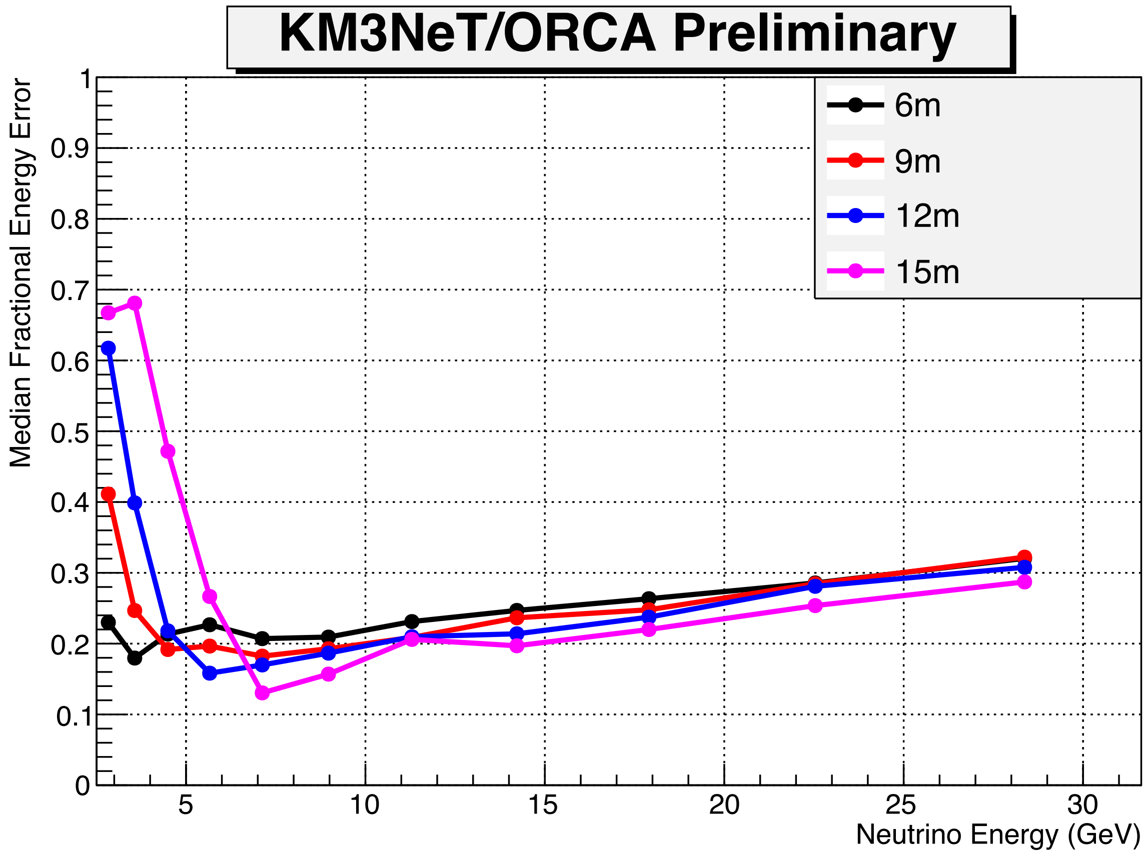
KM3NeT / ORCA - Expected performances

Need a good angular and energy resolution both for tracks and cascades events

> e.g.: tracks: ν_μ channel



Very good angular resolution

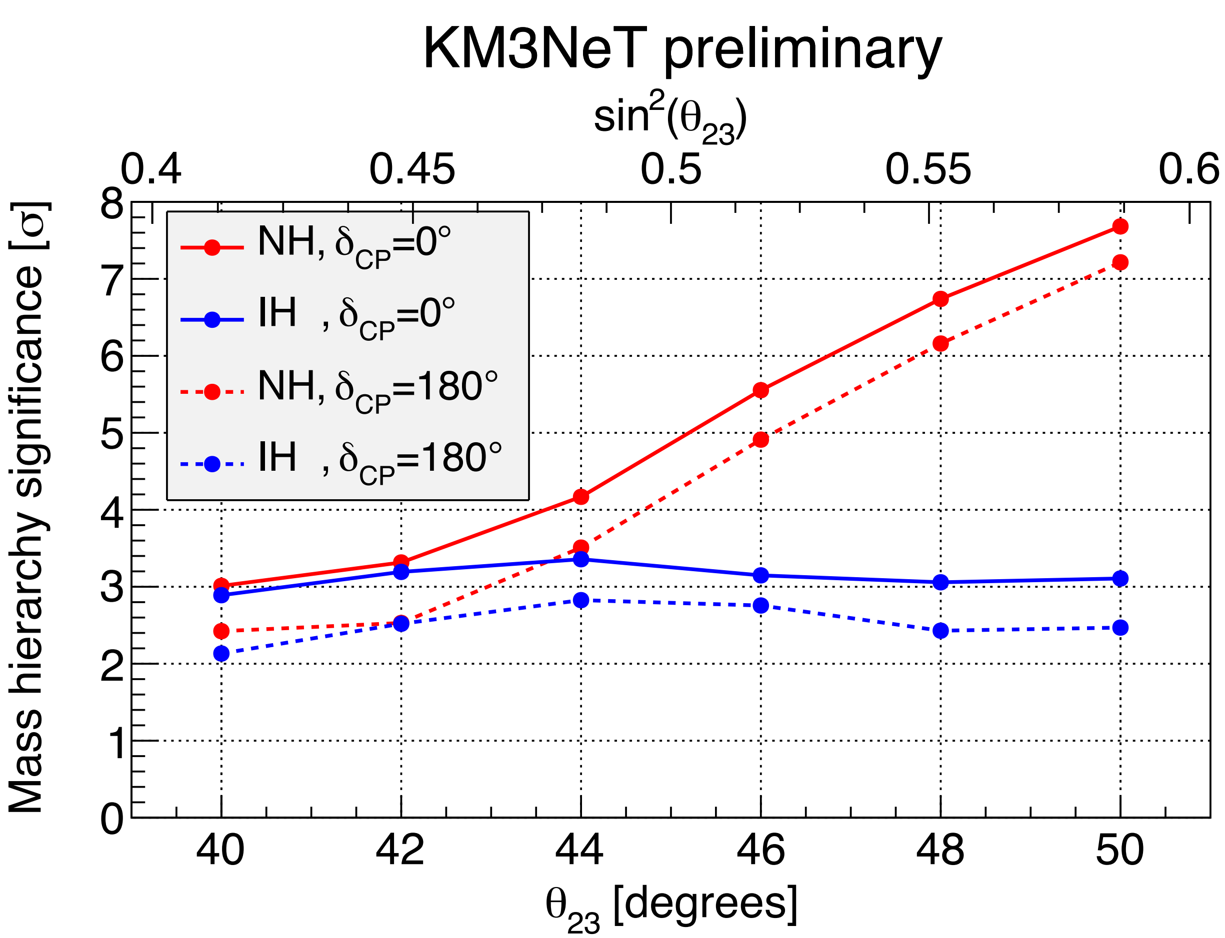


Energy resolution better than 25%

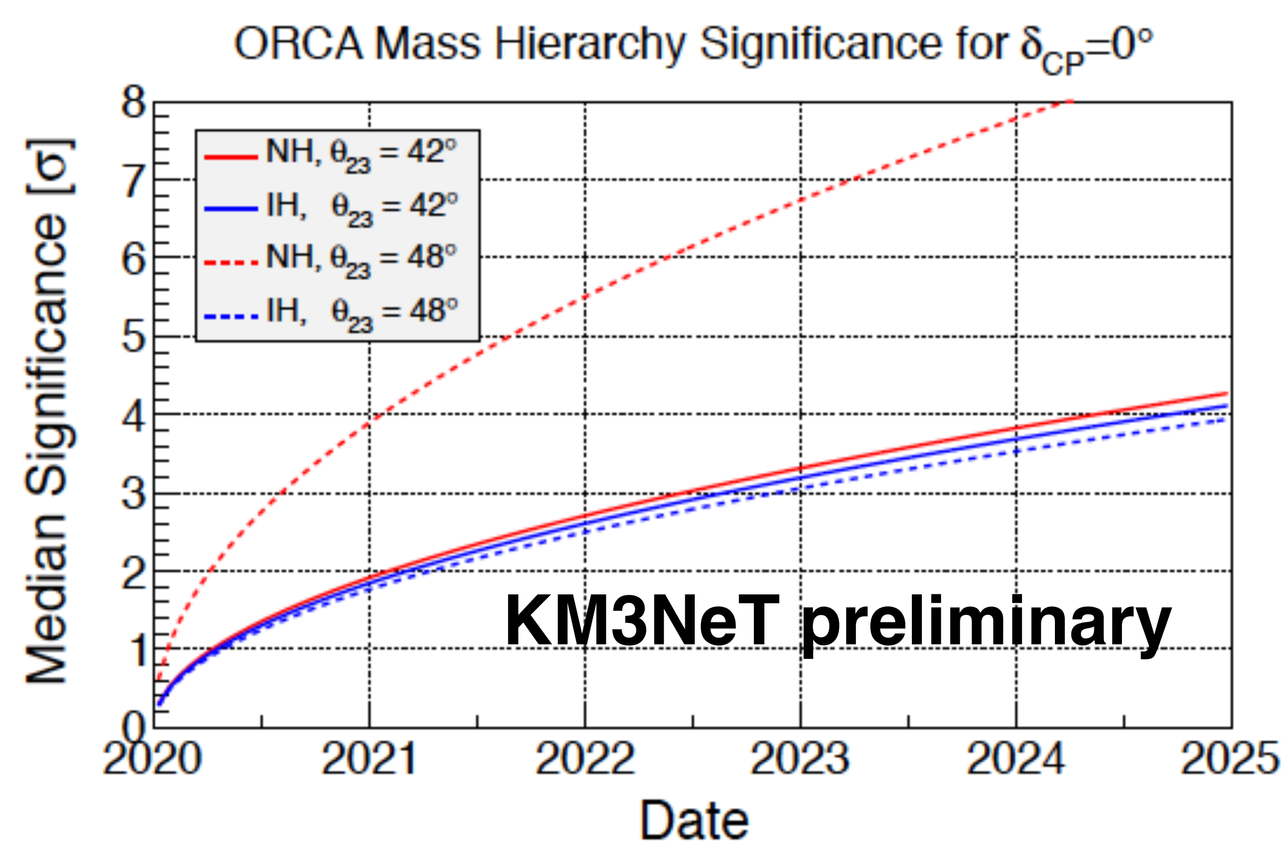
KM3NeT / ORCA - Expected sensitivity

ORCA's data = event rates as a function of the reconstructed neutrino energy and zenith angle.
Distinguish between the two mass hierarchy cases by comparing these to the expected rates

Projected sensitivity: ~3σ in 3 years, depending on true values of θ_{23} and δ_{CP}



For 3 yrs of data taking



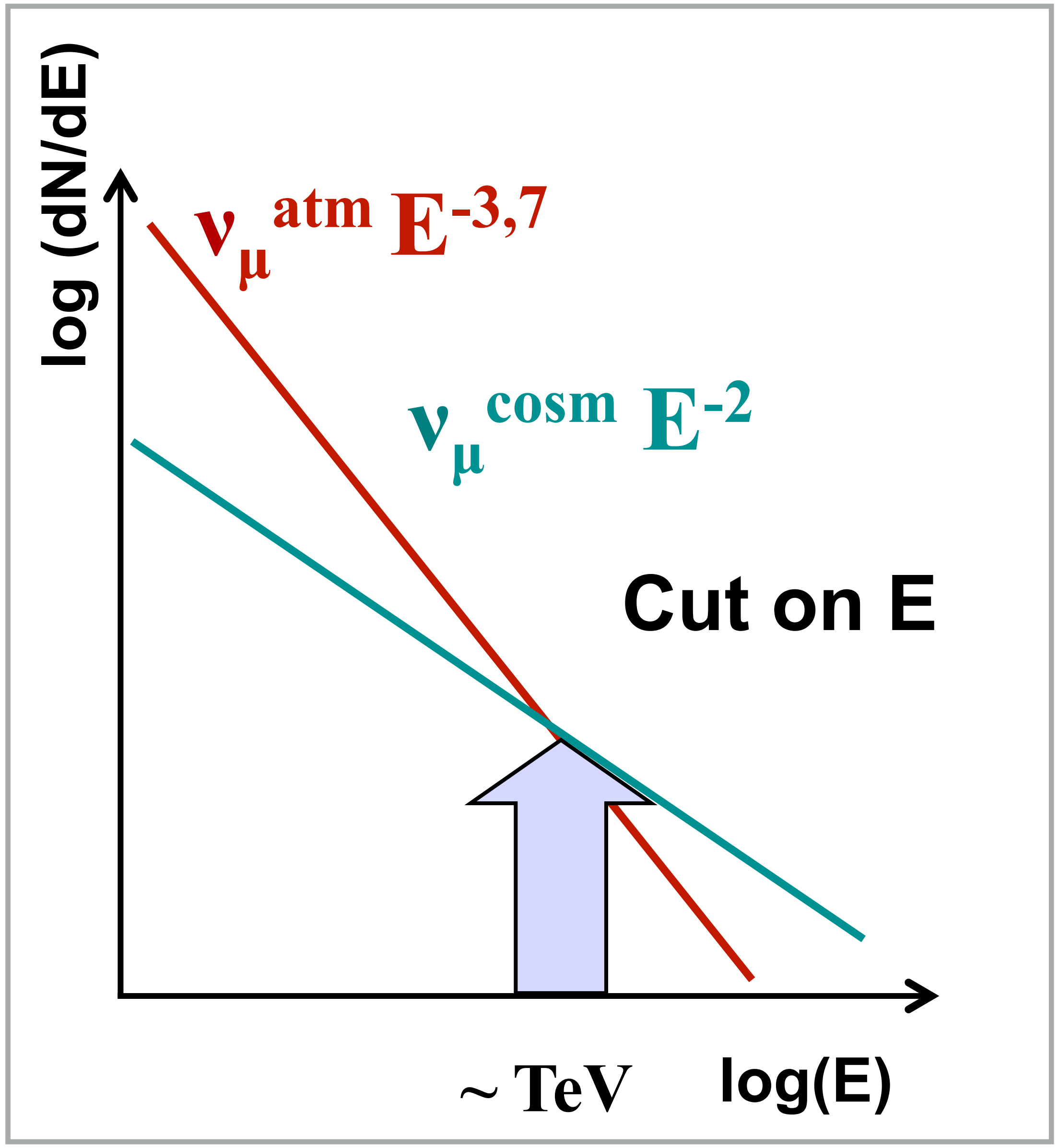
Conclusions and prospects

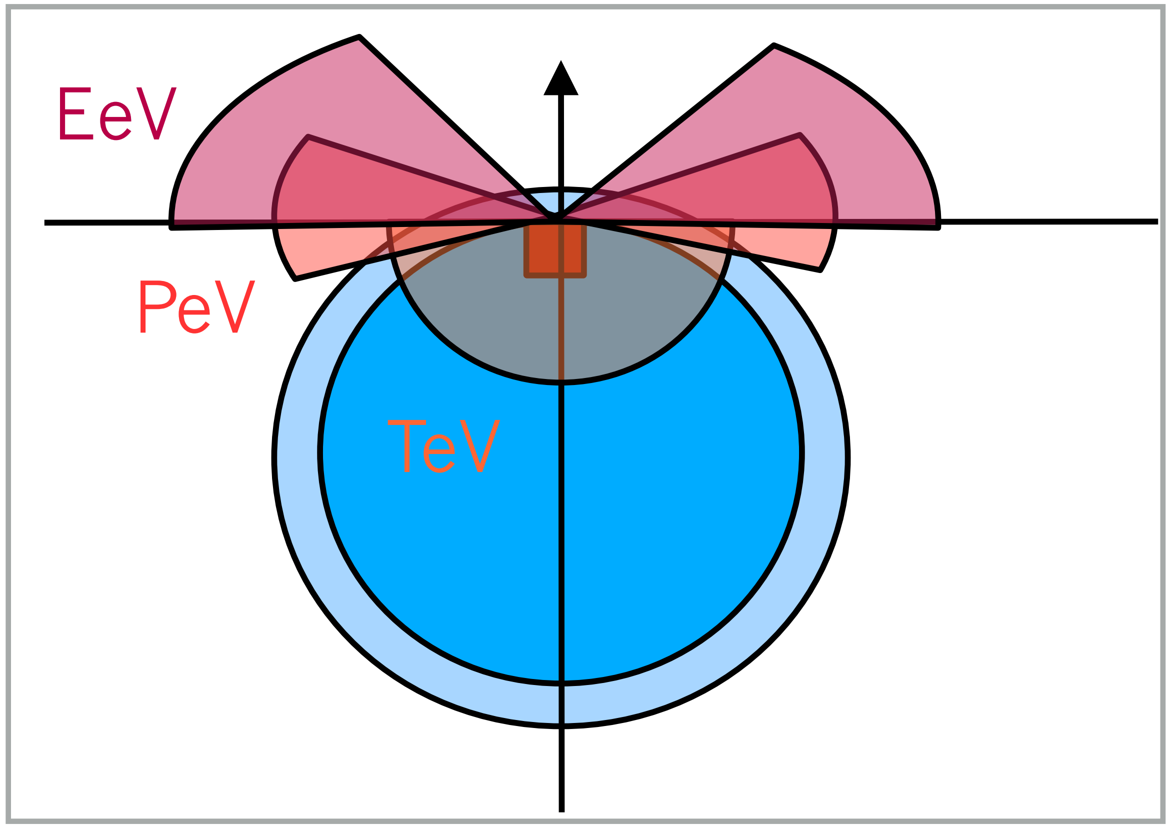
- ANTARES is still observing the sky
- Brings valuable constraints on the IceCube astrophysical signal
- KM3NeT is being deployed both in Italy and France sites
- Technology and detection performances validated by prototypes
- KM3NeT-It ➜ ARCA: HE neutrino astronomy
- KM3NeT-Fr ➜ ORCA: neutrino mass hierarchy
- Letter of Intent released on January 27th !
- Birth of a new window on the Universe…stay tuned !

Back-up slides

Neutrino astronomy in the Mediterranean

> Look at high energy events

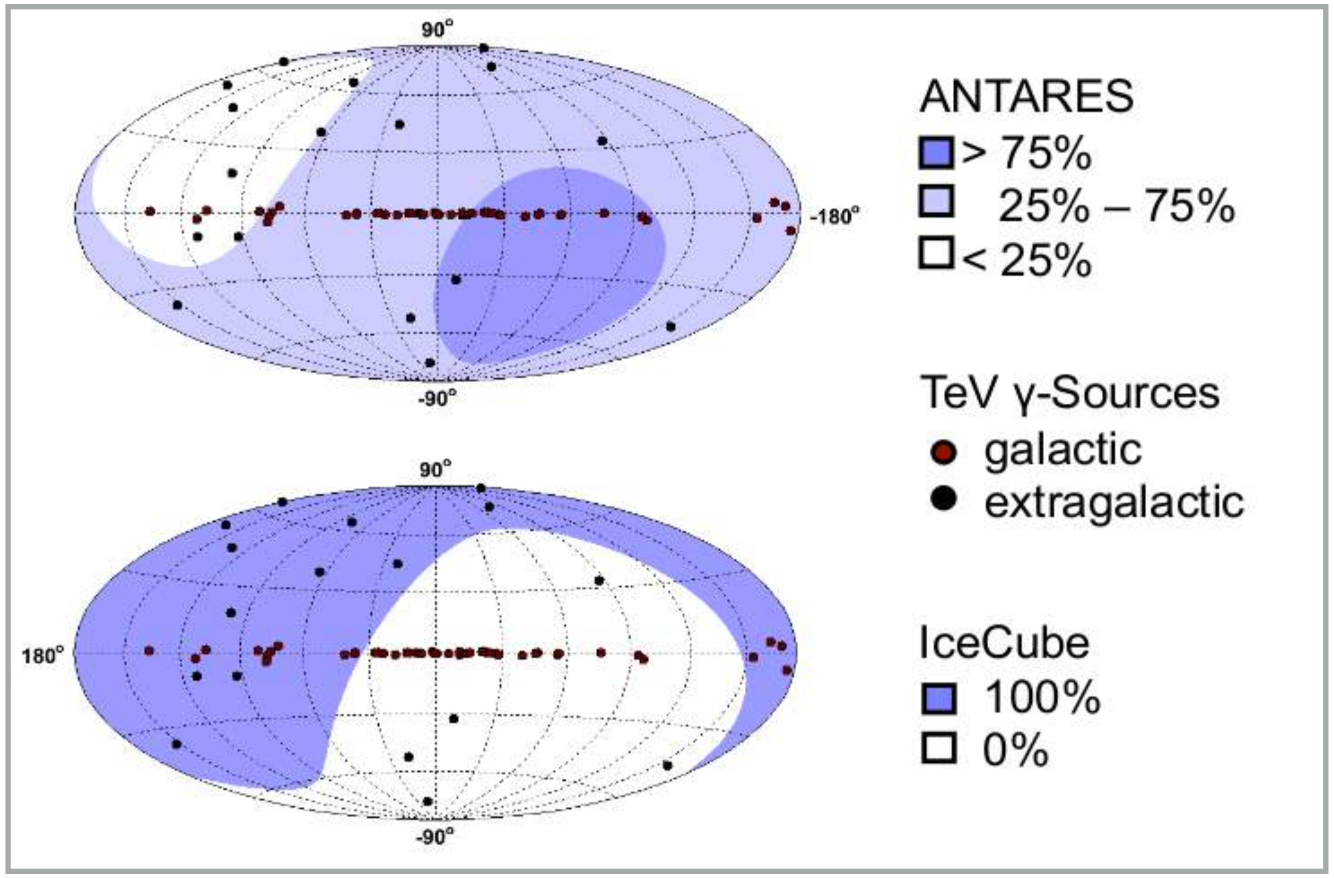


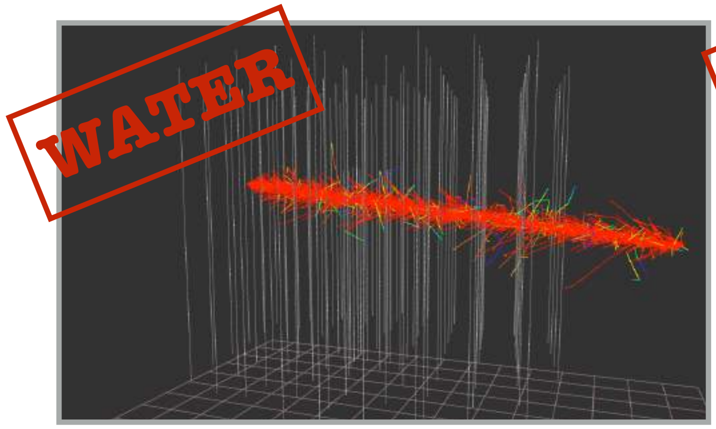


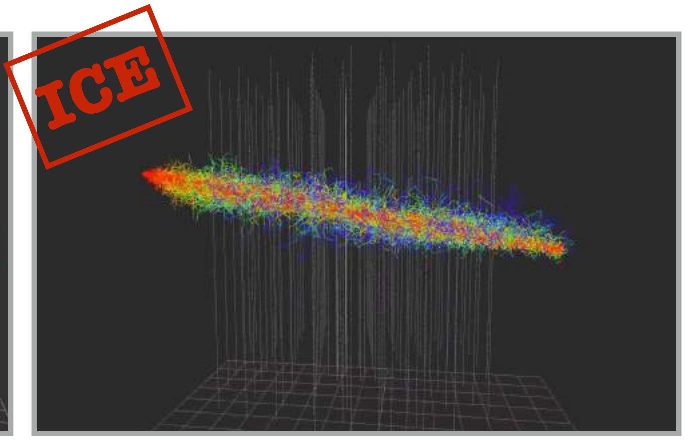
Neutrino astronomy in the Mediterranean

> Mediterranean / South Pole

- **Complementary coverage:**
  - galactic center / extragalactic sources
- **Good pointing accuracy / Calorimetry**
- **Optical noise (biolum) + K40 / no noise**
- **Absorption / diffusion**
- **Mediterranean : logistically attractive**

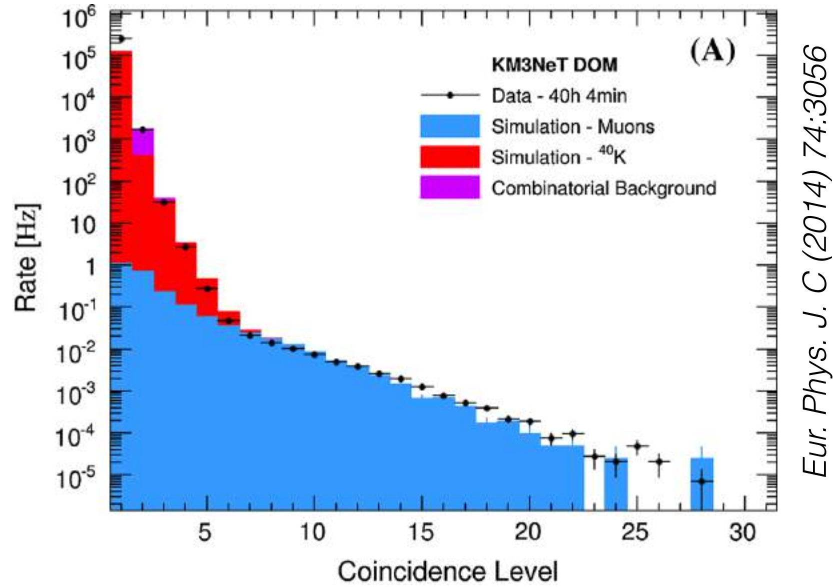






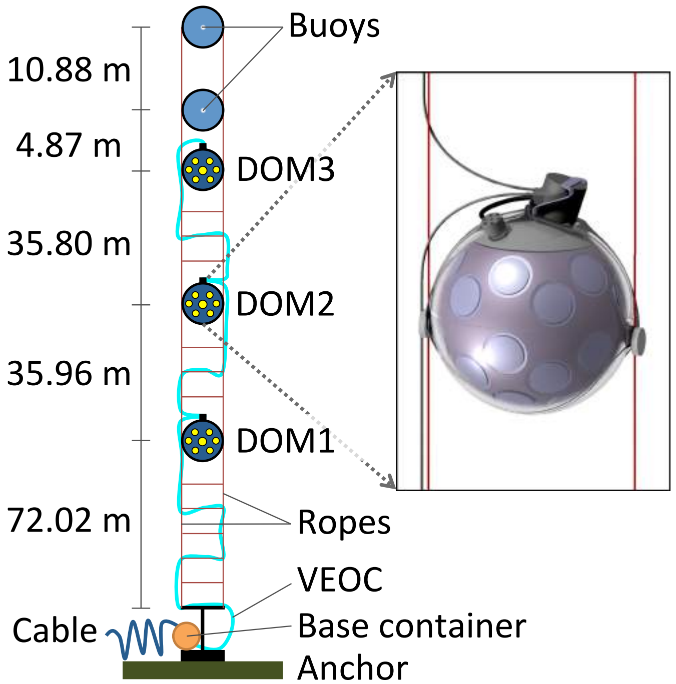
KM3NeT prototypes

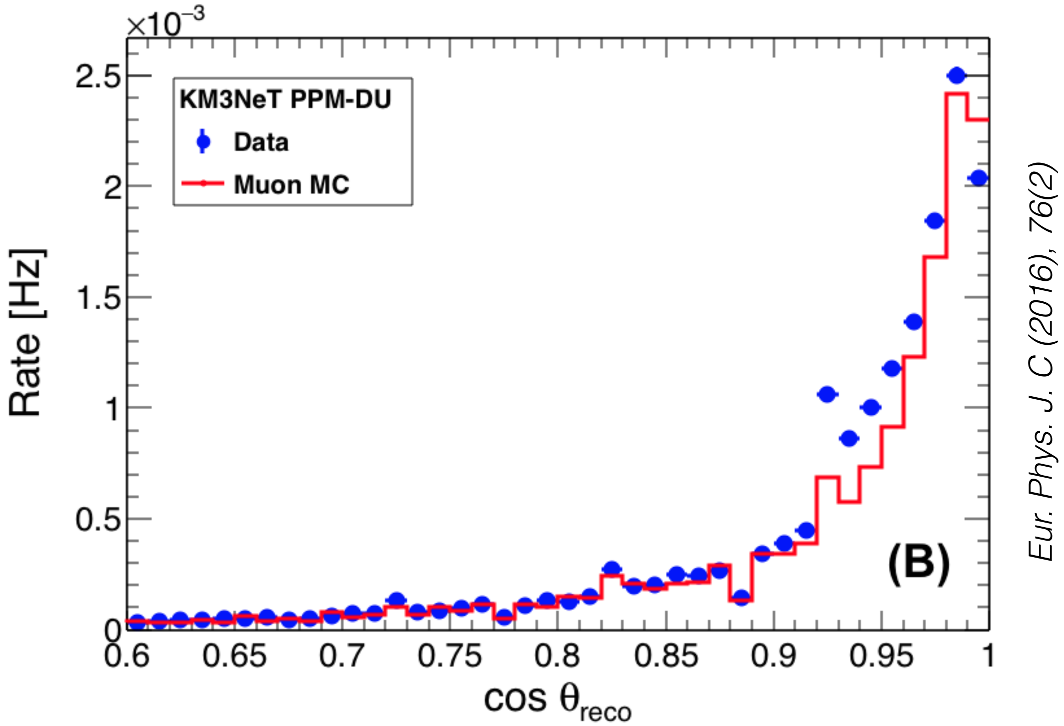
➜ **April 2013**: Optical module deployed at ANTARES (-2500 m)



Validation of photon counting & directionality performance

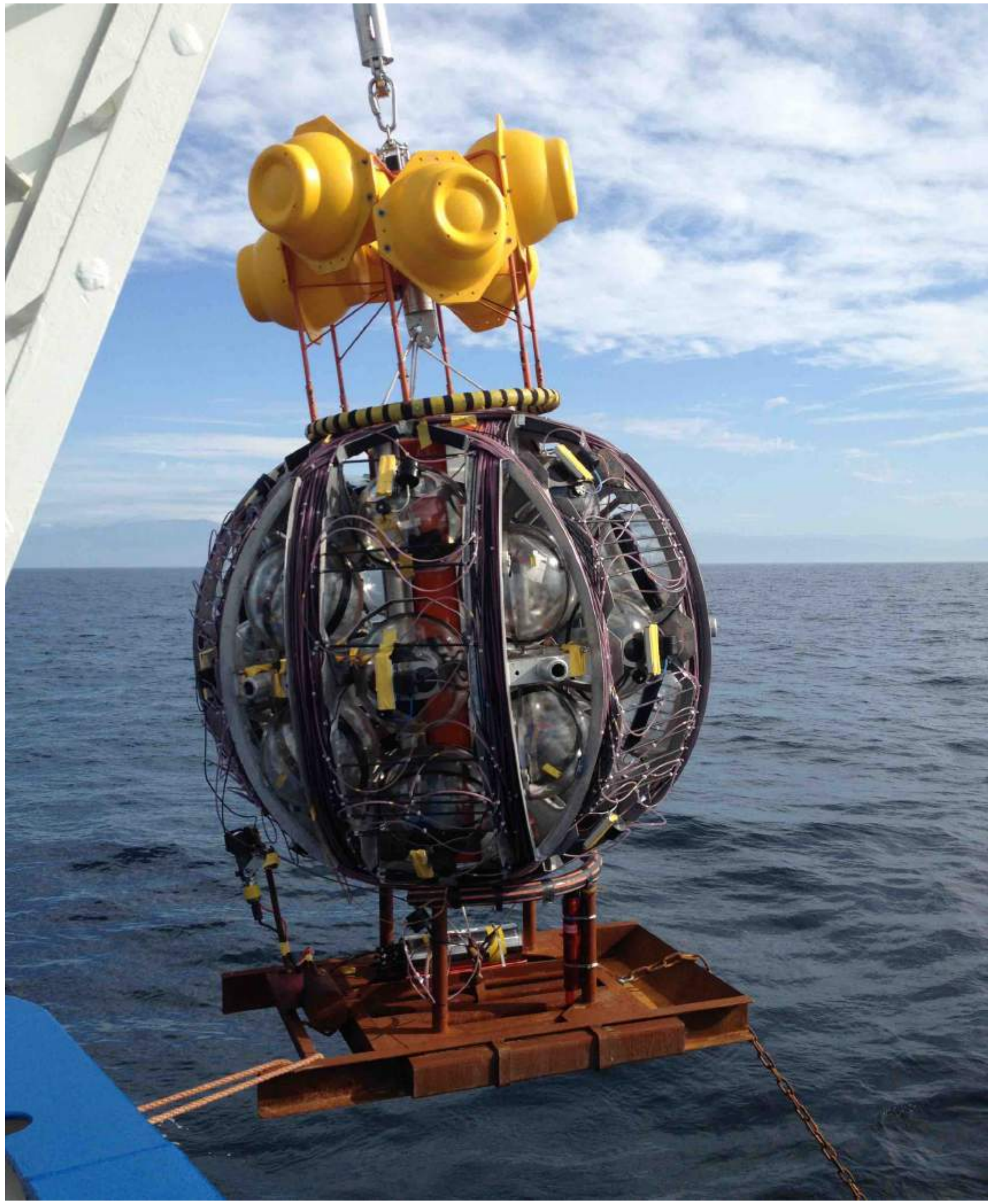
➜ **May 2014**: Mini string (3 storeys) deployed at Capo Passero

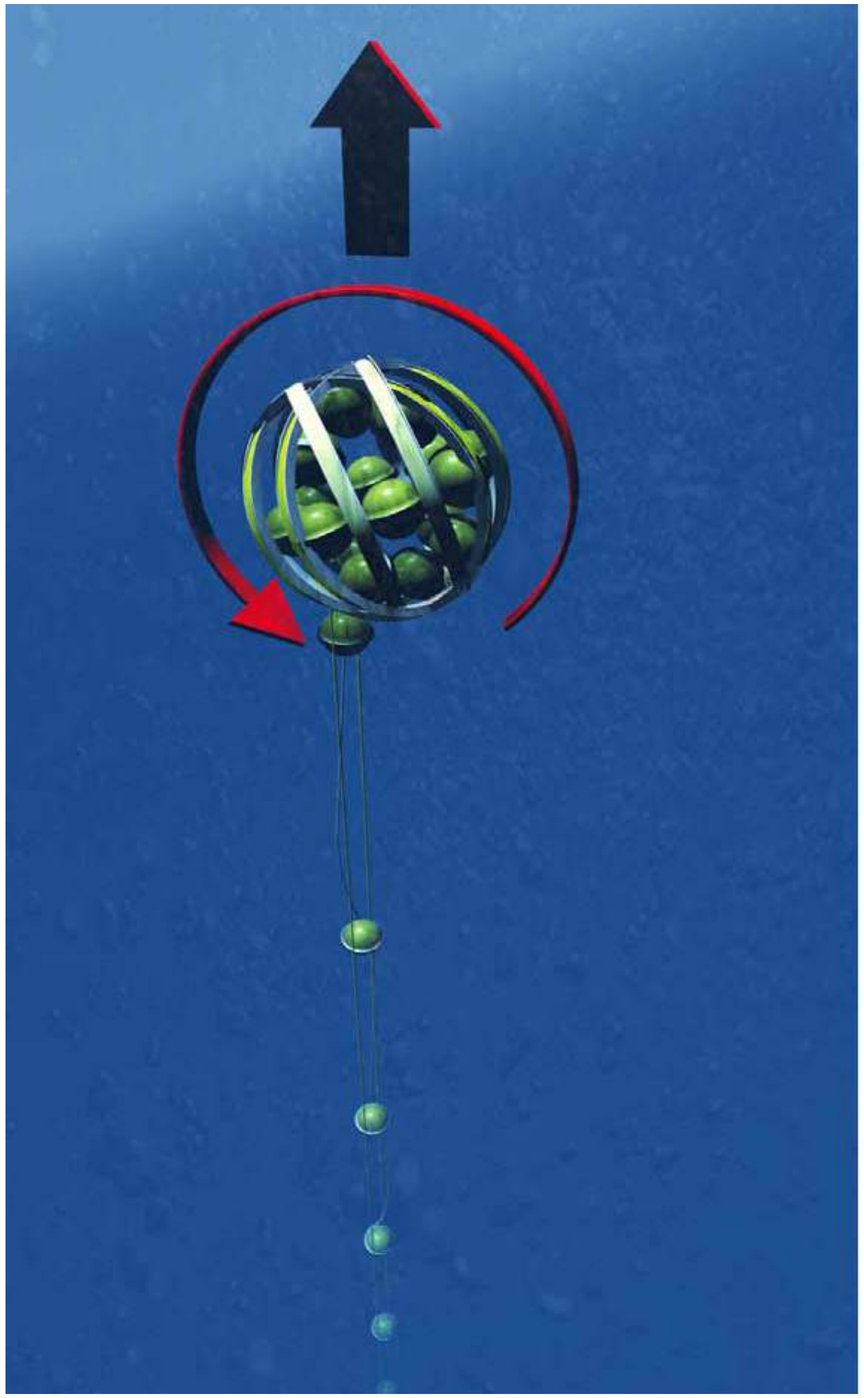




- First benchmark of DU integration and deployment
- Smooth operating and data taking
- Muon track reconstruction capabilities !

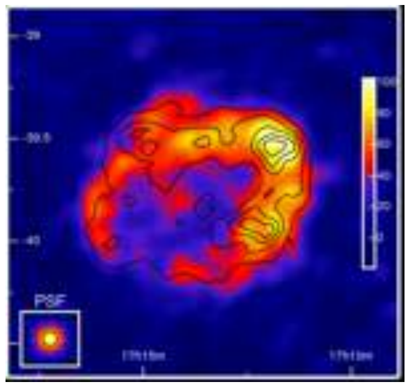
KM3NeT launcher vehicule





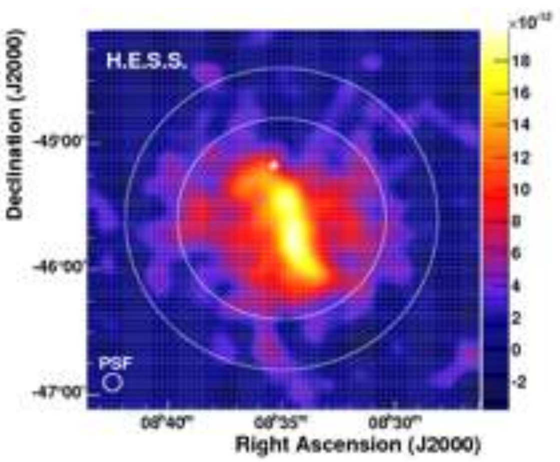
Rises to the surface while slowly rotating and releasing the OMs

KM3NeT / ARCA - Sensitivity to Galactic point sources

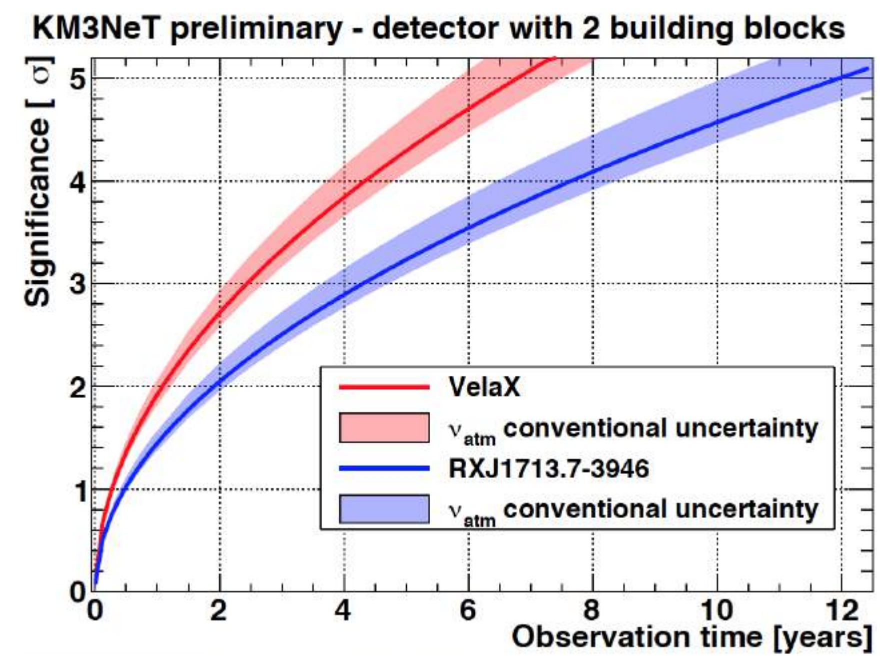


RX J1713.7-3946: $$\frac{d\phi}{dE_\nu} = 16.8 \times 10^{-15} \left[\frac{E_\nu}{1\,\mathrm{TeV}}\right]^{-1.72} \cdot \exp\left(-\sqrt{\frac{E_\nu}{2.1\,\mathrm{TeV}}}\right) \quad \mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}$$

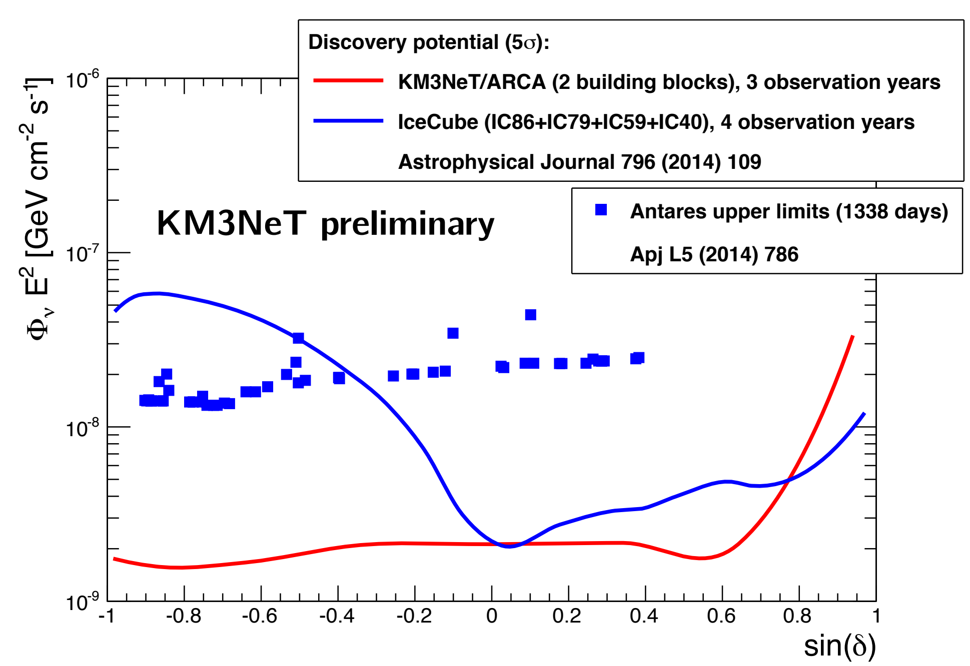
Vela-X: $$\frac{d\phi}{dE_\nu} = 7.2 \times 10^{-15} \cdot \left[\frac{E_\nu}{1\,\mathrm{TeV}}\right]^{-1.36} \cdot \exp\left(-\sqrt{\frac{E_\nu}{7\,\mathrm{TeV}}}\right) \quad \mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}$$



Point-like sources: **muon channel**



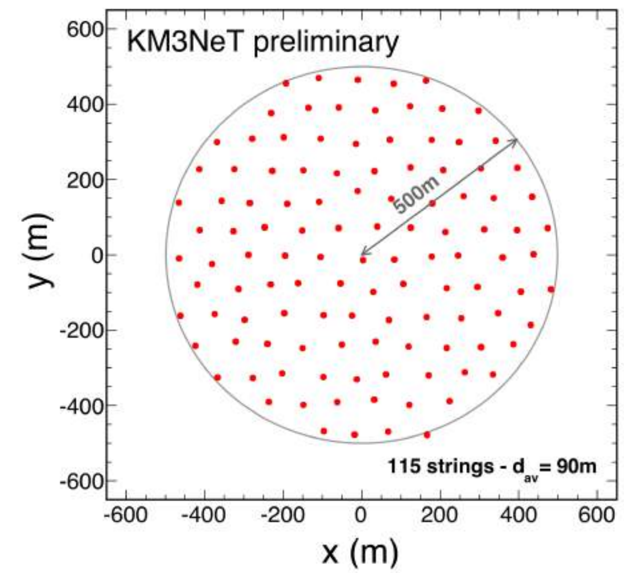
5σ discovery potential as a function of the source declination for one neutrino flavor for point-like sources with a E^{-2} spectrum (**3 yrs of data-taking**)

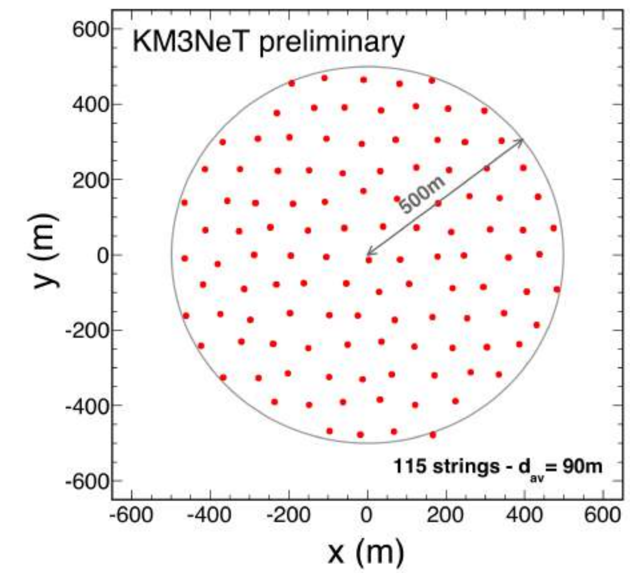


KM3NeT / ARCA - Expected performances

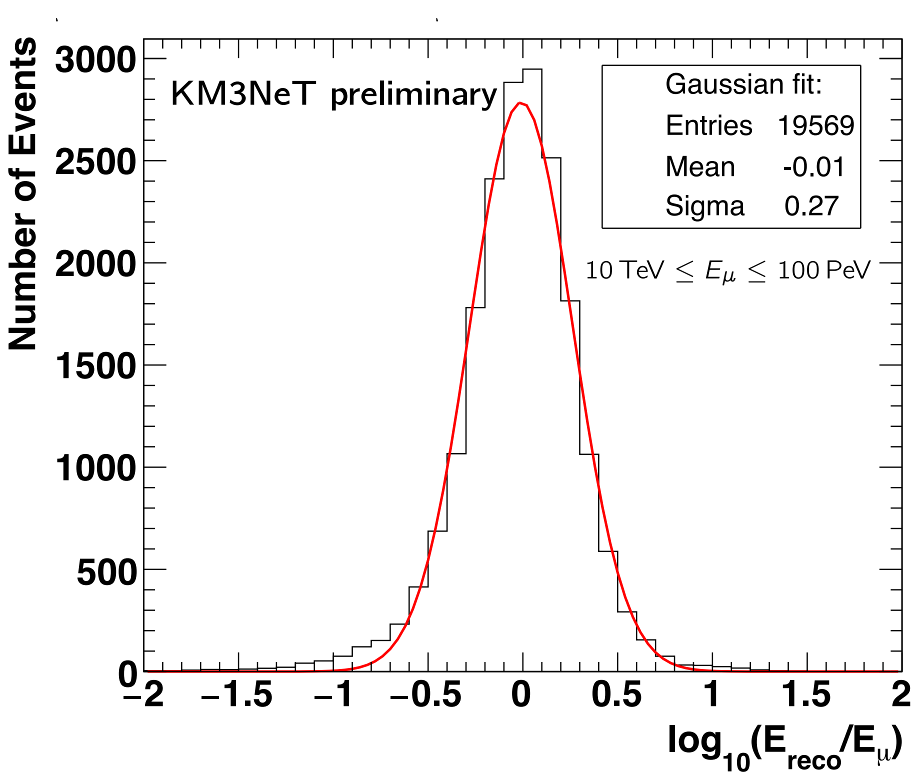
ARCA Phase-2
2 building blocks
in KM3NeT-It

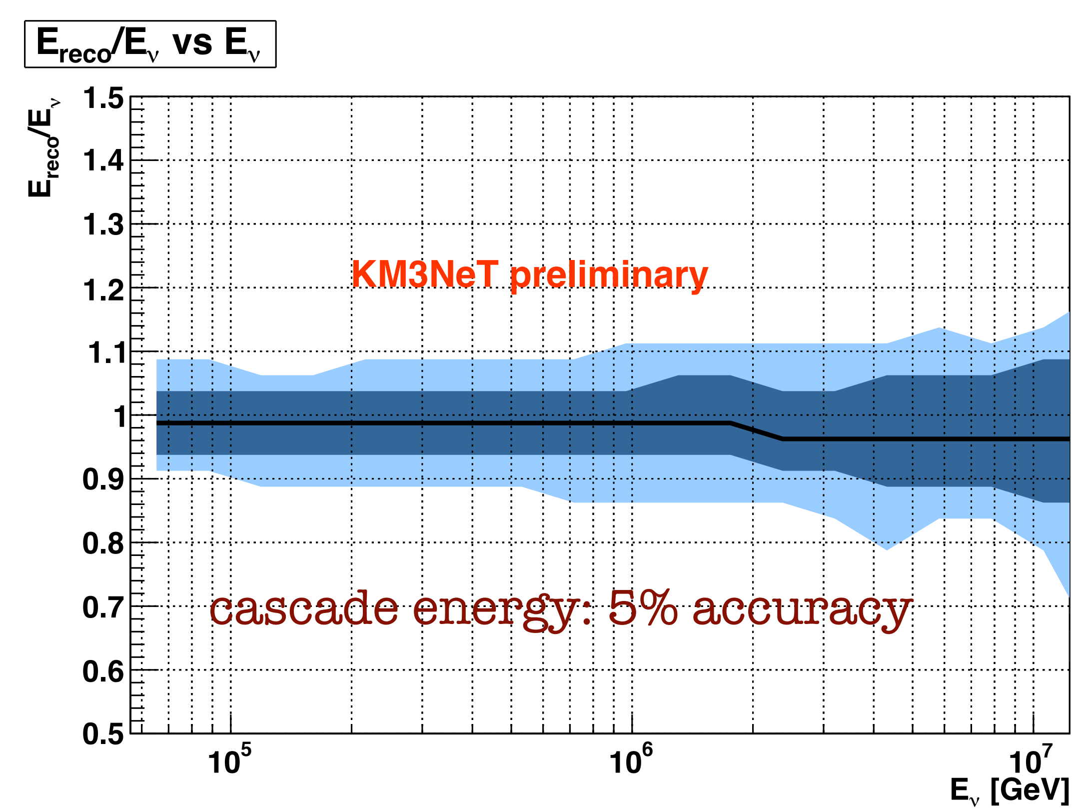
➜ Confirmation of IceCube signal





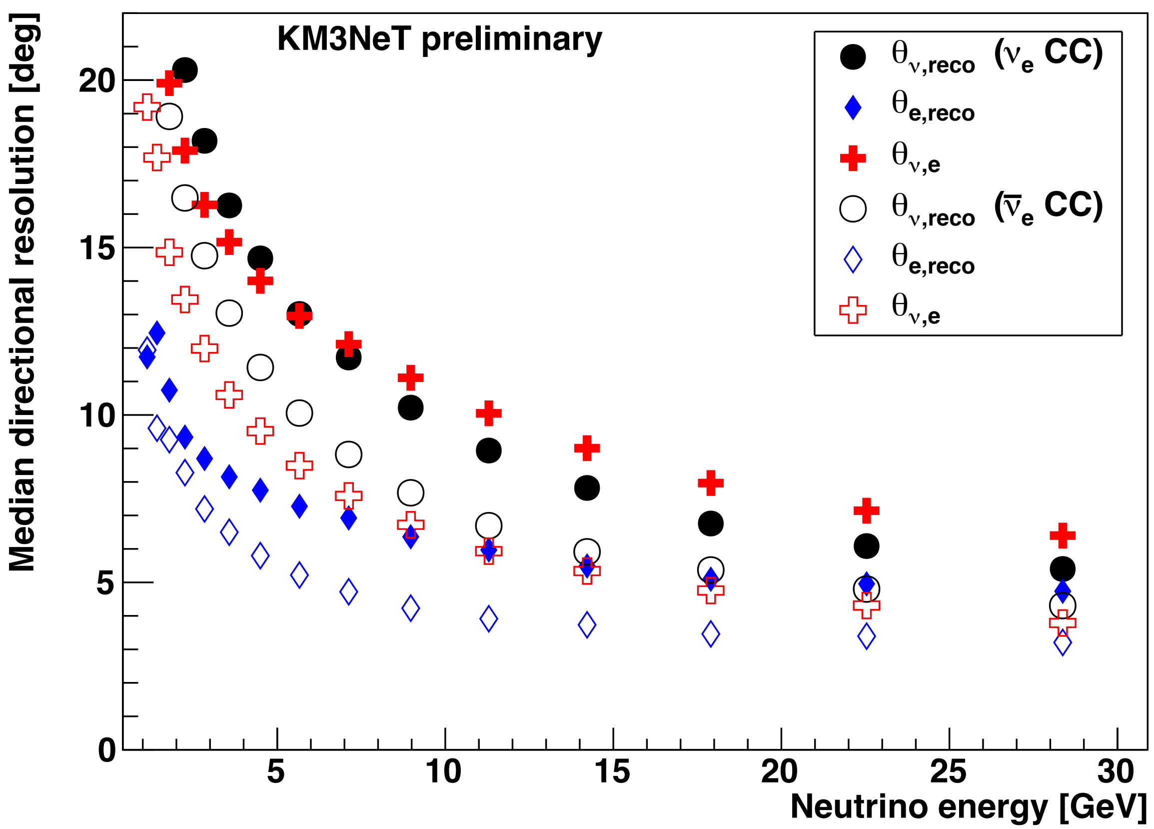
Good reconstruction performances both on **tracks** (muon CC channel) and **showers** (electron CC here)



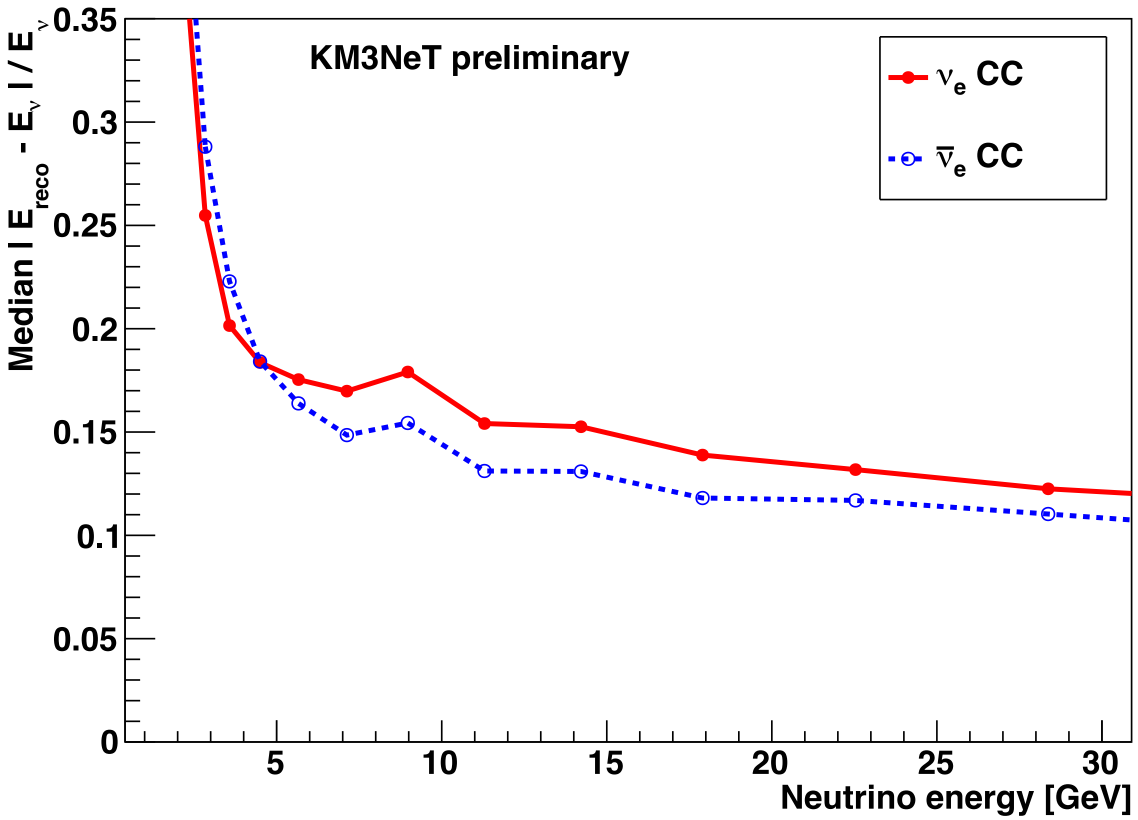


KM3NeT / ORCA - Expected performances

> Cascades: ν_e channel



Angular resolution <10° at 10 GeV



Energy resolution < 20% at 10 GeV