KM3NET HIGH LIGHTS

Piera Sapienza on behalf of the KM3NeT collaboration, CRIS 2016, Ischia

MOTIVATIONS & OBJECTIVES

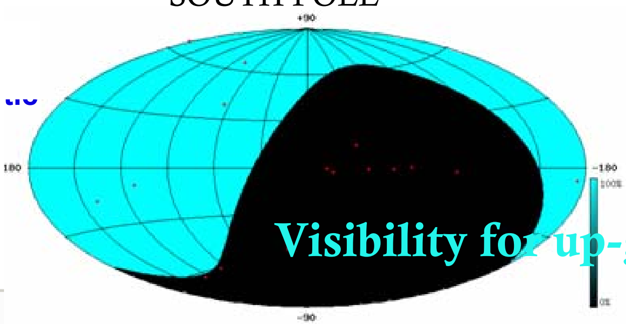
The IceCube discovery of HE cosmic neutrinos enforces the physics case of a km^3 neutrino telescope in the Mediterranean sea that surveys a large fraction of the sky including most of the galactic plane end the Galactic Centre

Galactic versus extra-galactic contribution in IceCube data

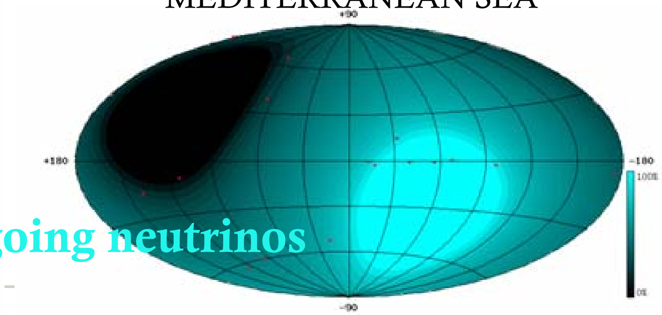
- quasi isotropic dominant component at high energy (E>100TeV) suggest extragalactic origin
- some hints for a galactic contribution at lower energy, but can be probed only marginally with IceCube and Antares

A much better angular resolution is achieved in deep sea w.r.t to ice

SOUTH POLE



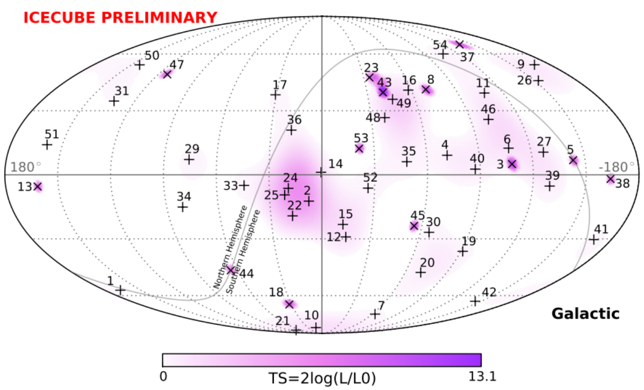
MEDITERRANEAN SEA

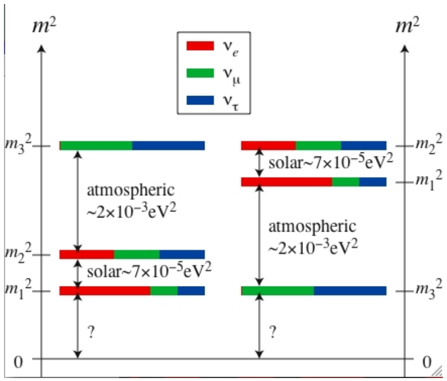


Visibility for up-going neutrinos

MOTIVATIONS & OBJECTIVES

KM3NeT is neutrino research infrastructure in the deep Mediterranean Sea

- discover and observe of high neutrino sources in the Universe (ARCA, off shore Capo Passero, It @ 3500 m depth)
- determine neutrino mass hierarchy (ORCA, off shore Toulon, Fr @2500 m depth)
- 



Same collaboration, same technology, two installation sites

KM3NeT is in the ESFRI road map

In this talk I will mostly focus on ARCA and high energy neutrinos

Letter of Intent of KM3NeT

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)

Cite as: arXiv:1601.07459 **[astro-ph.IM]**
(or **arXiv:1601.07459v1 [astro-ph.IM]** for this version)

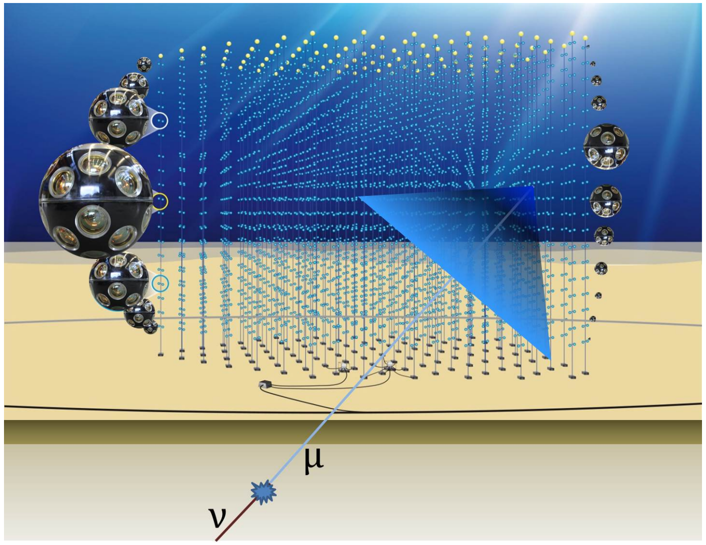
Recently published on Journal of Phys. G XXX

TECNOLOGICAL CHALLENGES

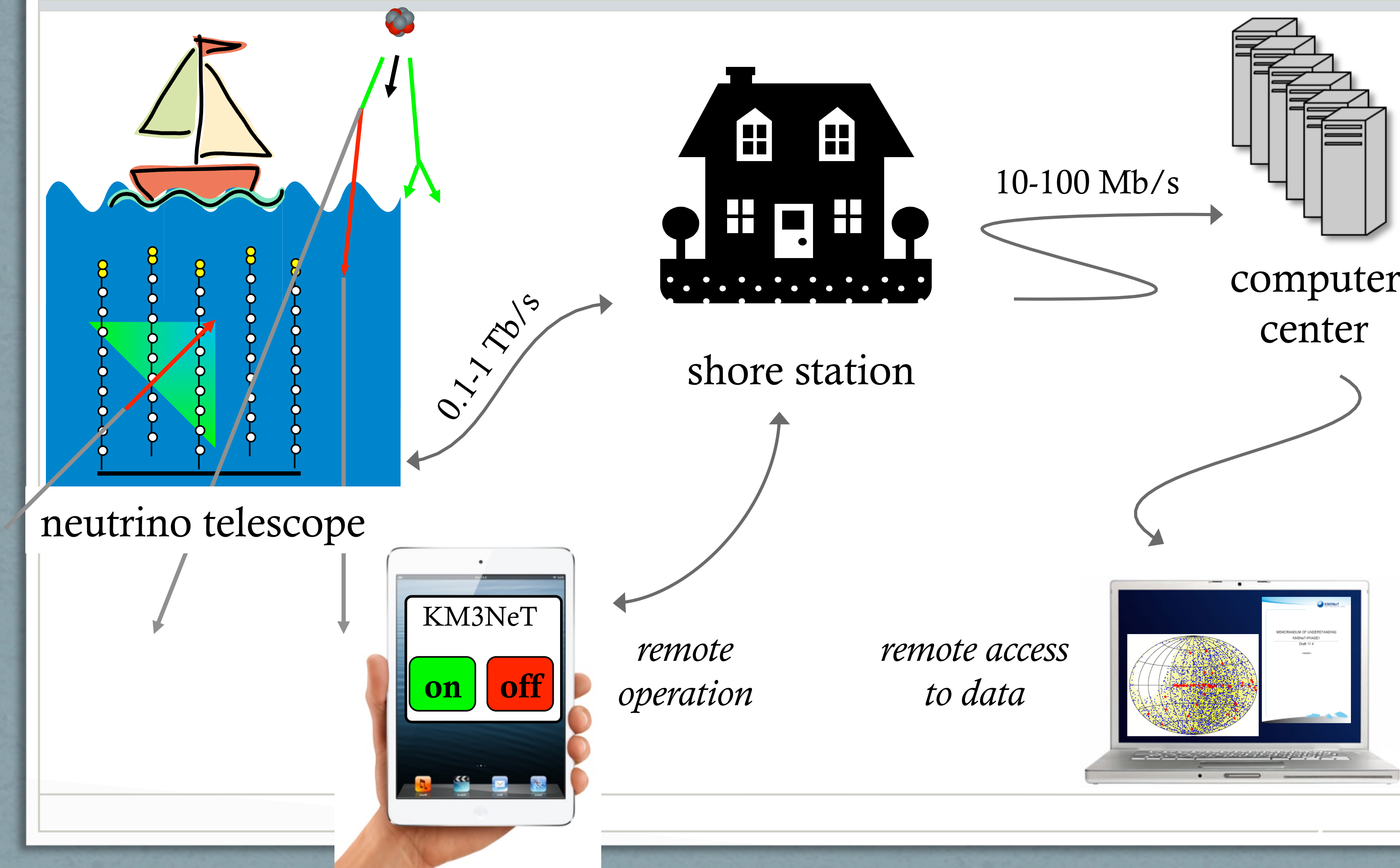
- Hostile environment due to huge pressure, corrosion, very limited accessibility, long duration experiment (> 10 years)
- Antares demonstrates that is possible to design, build, deploy and operate a deep see neutrino telescopes
- KM3NeT design takes profit of this experience, but a intense R&D program was necessary to develop technologies that could not be taken from Antares because of cost and increased size

KM3NET TELESCOPE DESIGN

- Detection principle Optical Cherekov radiation
  - 6 order of magnitude in energy (GeV-PeV)
  - All flavor detection
- A 3D array built with a modular design
- optical sensor: multi-PMT (DOM)
- vertical slender strings host 18 DOMs supported by two parallel ropes: Detection units (DU)
- Building blocks of 115 DUs each
- Power and data distributed by a single backbone cable with breakouts at DOMs
- Sea network of submarine cables and Junction Boxes connected to shore via a main e/o cable
- All data to shore



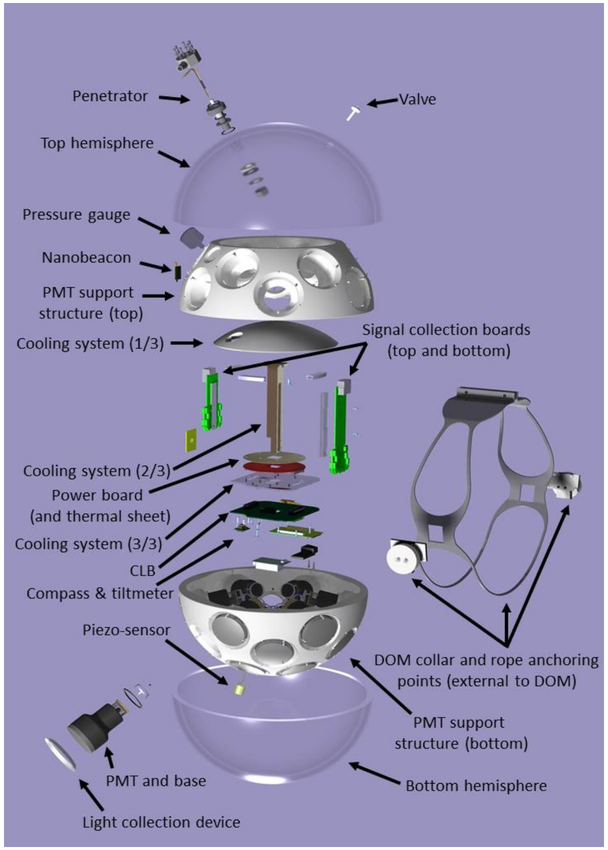
KM3NET ARCHITECTURE



DOM - Digital Optical Module

← 17" →

- 31 x 3" PMTs
- LED & acoustic piezo inside
- Tiltmeter/compass
- Gbit/s fibre DWDM
- Hybrid white rabbit



- Digital foton counting
- Directional information
- Wide angle of view
- Improved rejection cabability
- Compact and cost effective design: 1 DOM equivalent to 3 Antares OM

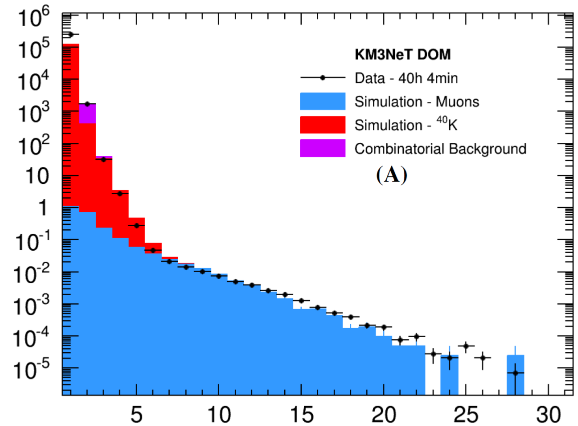
DETECTION UNIT

18 DOM are integrated on a string and arranged on the LOM, mounted on the anchor and are ready for deployment

Compact structure
Rapid deployment
Autonomous unfurling
Recoverable

Prototype validation in situ

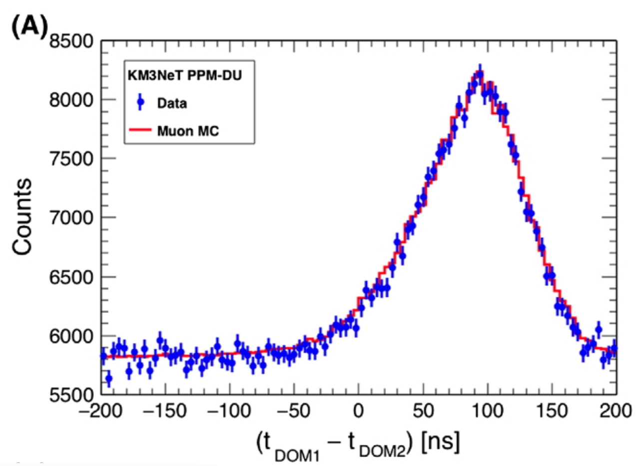
Prototype DOM deployed at Antares site April 2013



Test of photon counting capabilities and directional sensitivity of DOM

Eur. Phys. J. C (2014) 74:3056

Prototype DU (three DOMs) deployed in Capo Passero May 2014



Test of DU structure functionality

Test of intra-DOM and inter-DOM calibration

Eur. Phys. J. C (2016) 76:54

ARCA DETECTOR LAY OUT

ARCA: Astronomy Research with Cosmics in the Abyss

To be installed in the Italian site of the
KM3NeT infrastructure

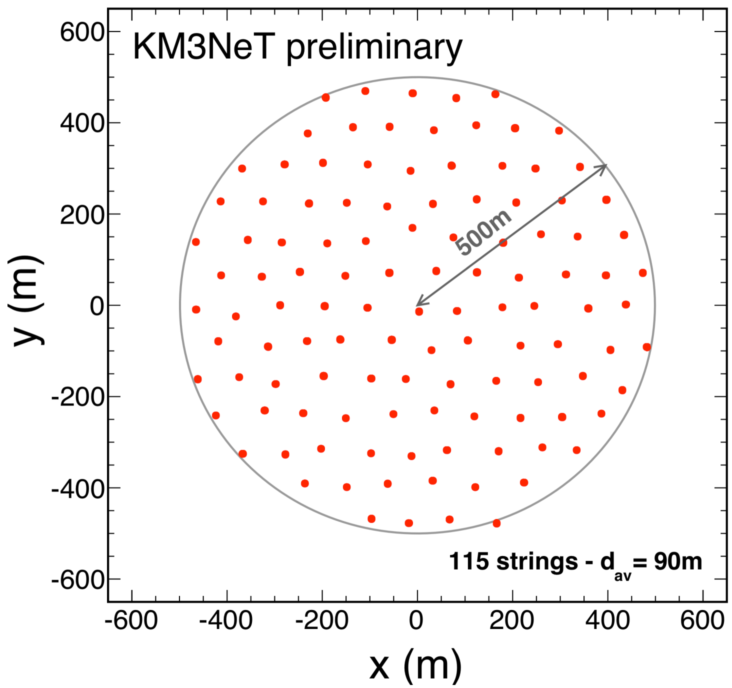
115 detection units/building block

18 DOM per DU

Vertical DOM spacing 36 m

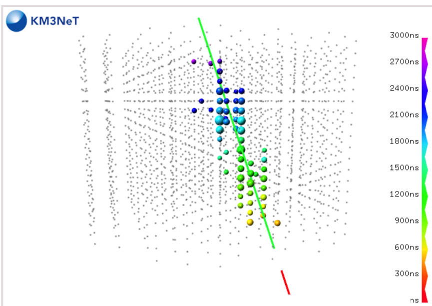
Inter-DU spacing 90 m

2 building blocks => instrumented volume 1 km^3

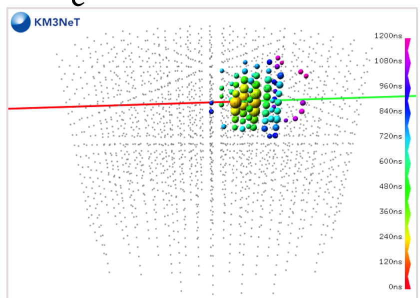


ARCA: EVENT TOPOLOGIES AND DETECTOR RESPONSE

Upgoing track like ν_μ CC event

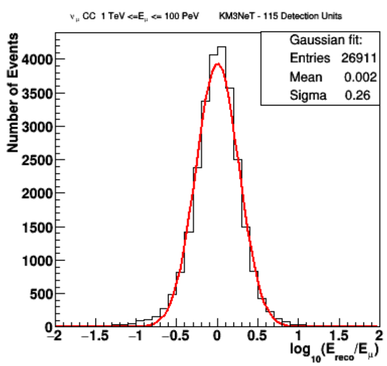


Contained shower ν_e and NC event

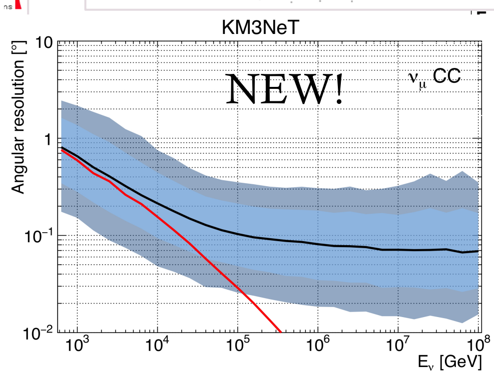


ν_μ are the golden channel for neutrino astronomy

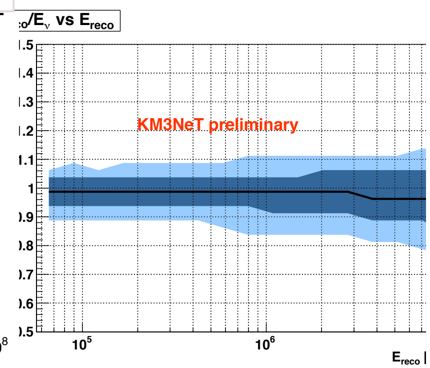
Deep sea water properties, i.e. long scattering length allow to achieve very good angular resolution



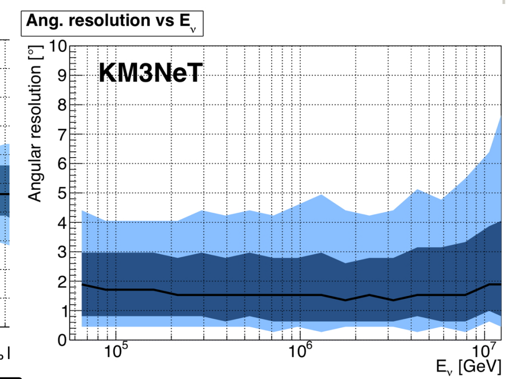
Energy resolution about 0.3 in logE μ



Angular resolution about 0.1° (E_ν>10 TeV)



Energy resolution about 10%

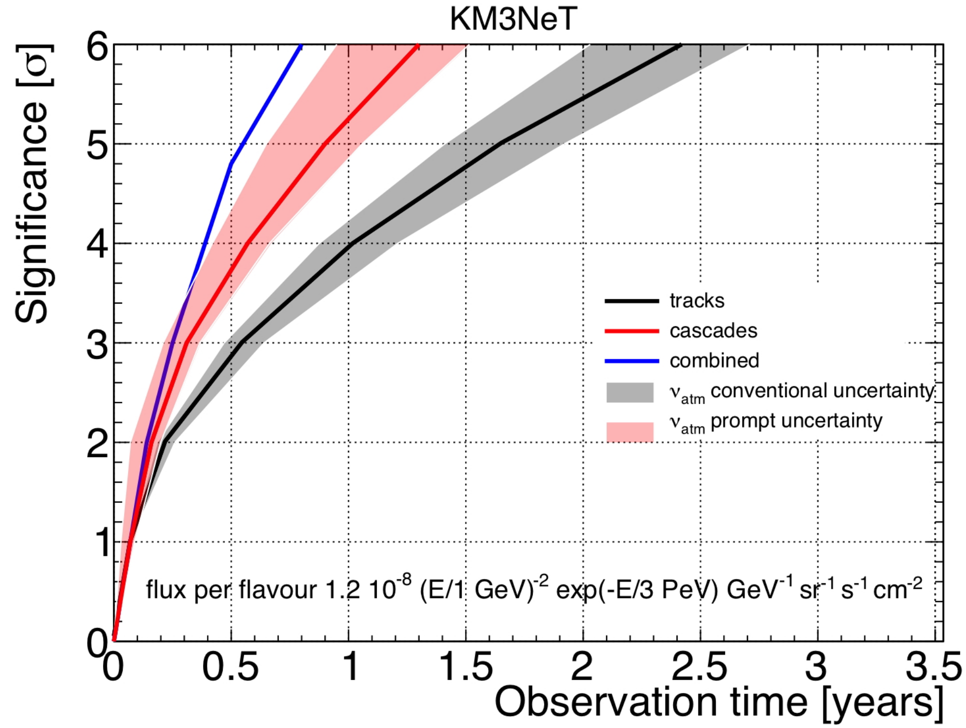


Angular resolution about 2° (E_ν>10 TeV)

ARCA SENSITIVITY TO NEUTRINO DIFFUSE FLUX

Analysis for the track events:

- **Track channel:** analysis for up-going events based on Max. likelihood
  Pre-Cuts on θ_{zen} >80°, Λ (reconstruction quality parameter), N_{hit} (number of hits -> parameter related to the muon energy)

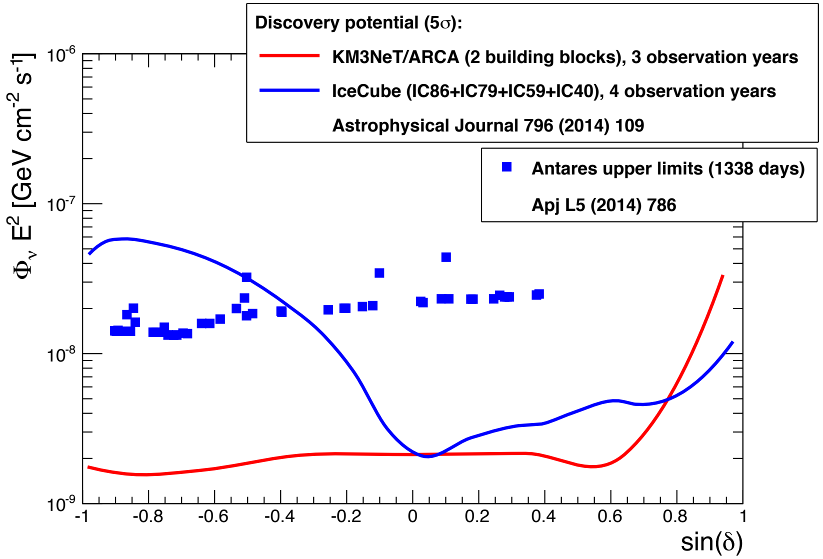


Discovery at 5σ significance (50% probability) in less than one year

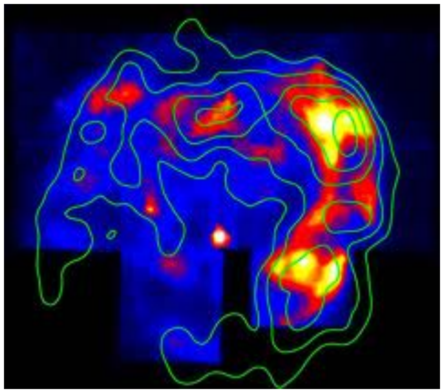
SENSITIVITY TO POINT-LIKE SOURCES – E^{-2} up going ν_μ

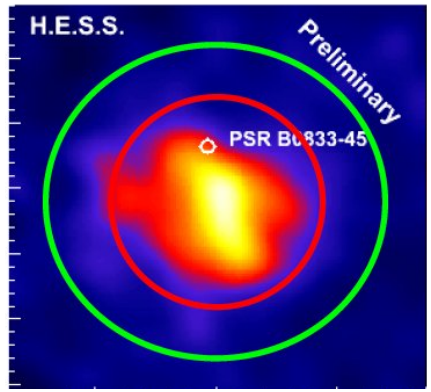
ARCA can survey almost the whole scale with a discovery potential @ 5σ about one order of magnitude better than IceCube for equivalent exposure

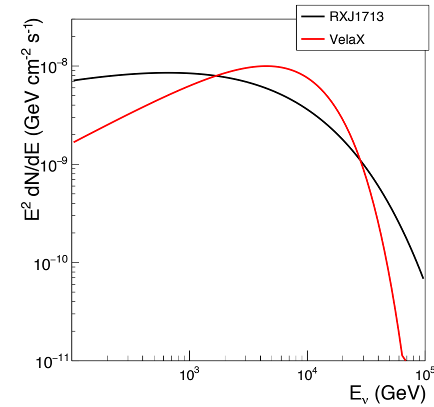
ANTARES upper limit for 1338 day also reported



SENSITIVITY TO POINT-LIKE GALACTIC SOURCES



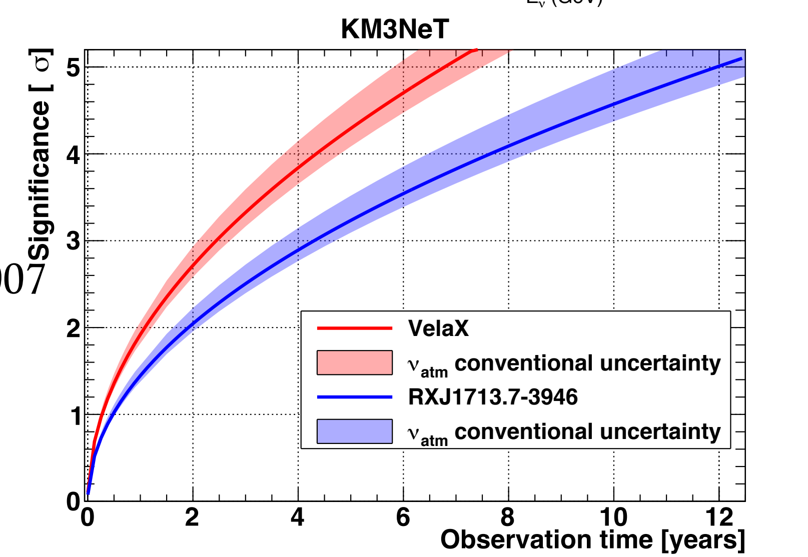




HE gamma emission observed by HESS in SNRs
Neutrino spectra predicted using gamma spectra

- ¶ S.R. Kelner, *et al.*, PRD 74 (2006) 034018
- § F.L. Villante and F. Vissani, PRD 78 (2008) 103007

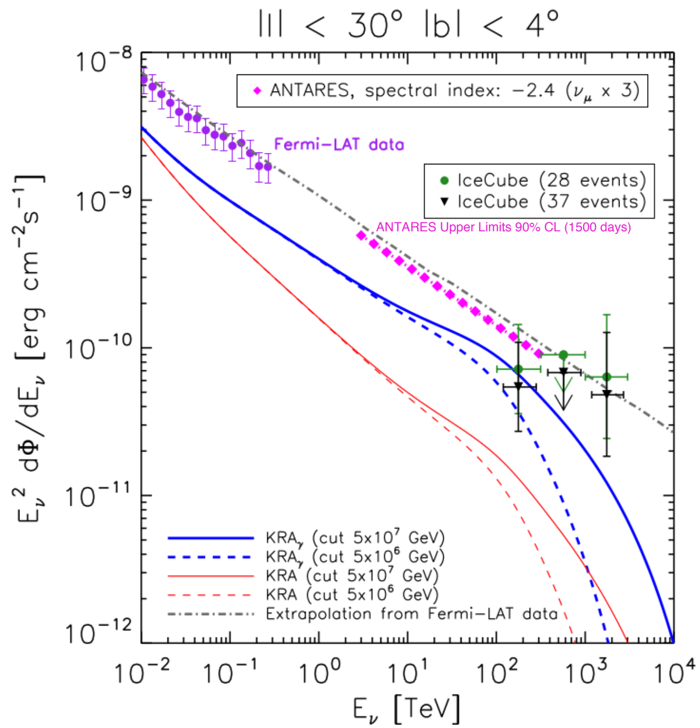
Hypotheses: 100% hadronic emission and transparent source

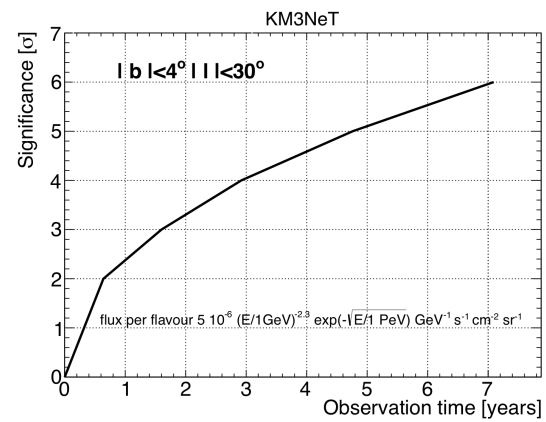


DIFFUSE FLUX FROM THE GALACTIC PLANE

ARCA sensitivity to a flux from a region of the Galactic Plane near the Galactic Center
Neutrino flux estimate based on a radially-dependent cosmic-ray transport properties

D. Gaggero et al., proceedings ICRC2015





Discovery at 5σ significance (50% probability) in about 5 years

A PHASED APPROACH TOWARDS KM3 TELESCOPE

Phase	Blocks	Primary deliverables
1	0.2	Proof of feasibility and first science results (7 ORCA strings/ 24 ARCA strings)
2.0	2 *ARCA*	Study of neutrino signal reported by IceCube All flavor neutrino astronomy
	1 *ORCA*	Neutrino mass hierarchy
3	1+6	Neutrino astronomy including Galactic sources

KM3NeT phase-1

Proof of feasibility of network of neutrino detectors:

- Funded with 31 million euro
- 31 detection units will be deployed in 2015-2017

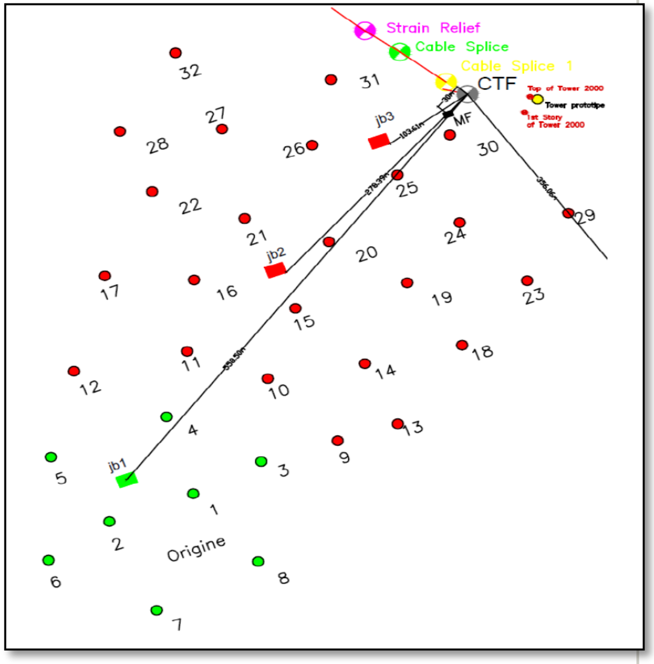
➢ KM3NeT-It off shore Capo Passero - 24 DUs

➢ KM3NeT-Fr off shore Toulon -7 DUs

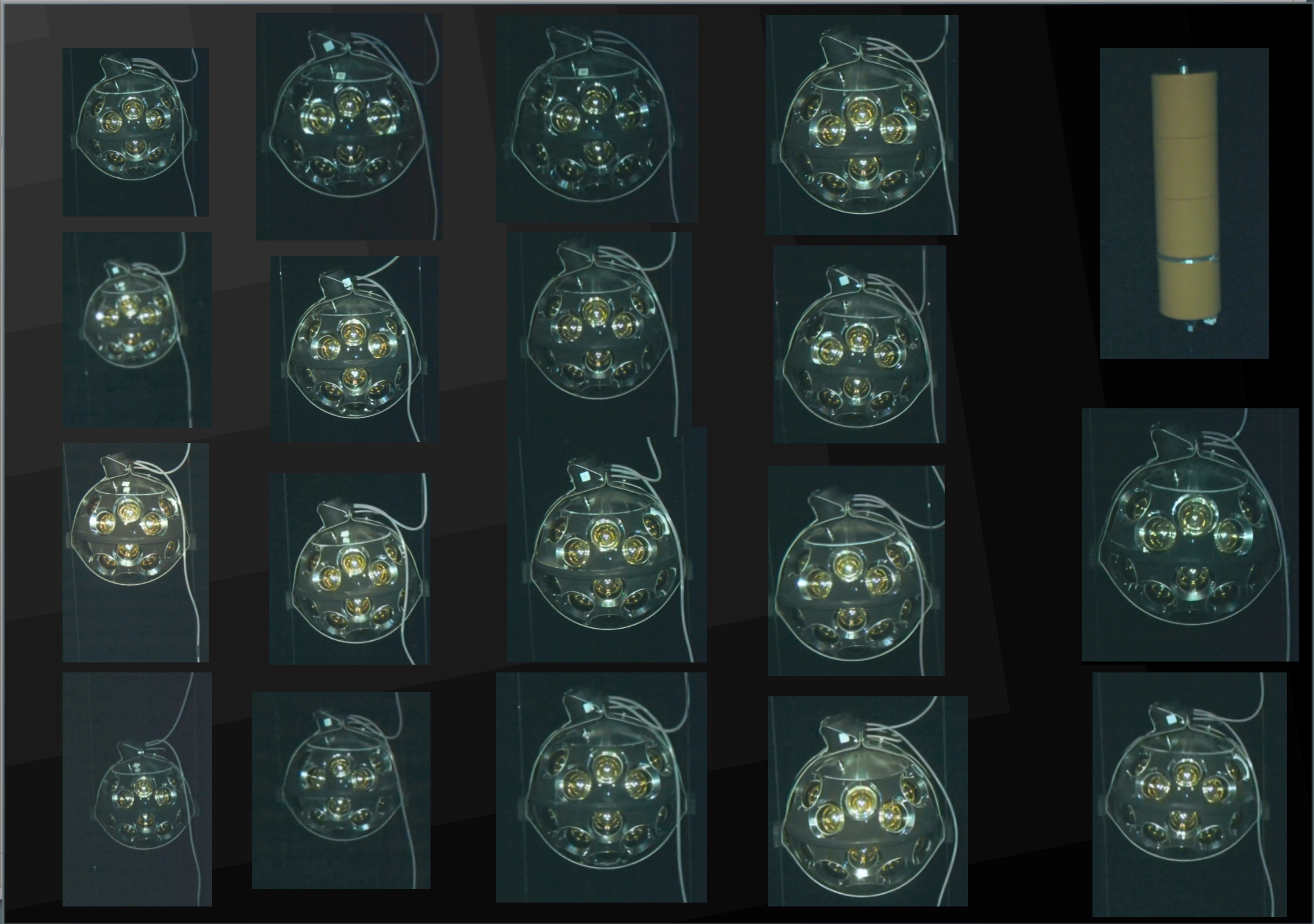
➢ Three DUs deployed at Capo Passero site

  ➢ one not working to be recovered by the end of July

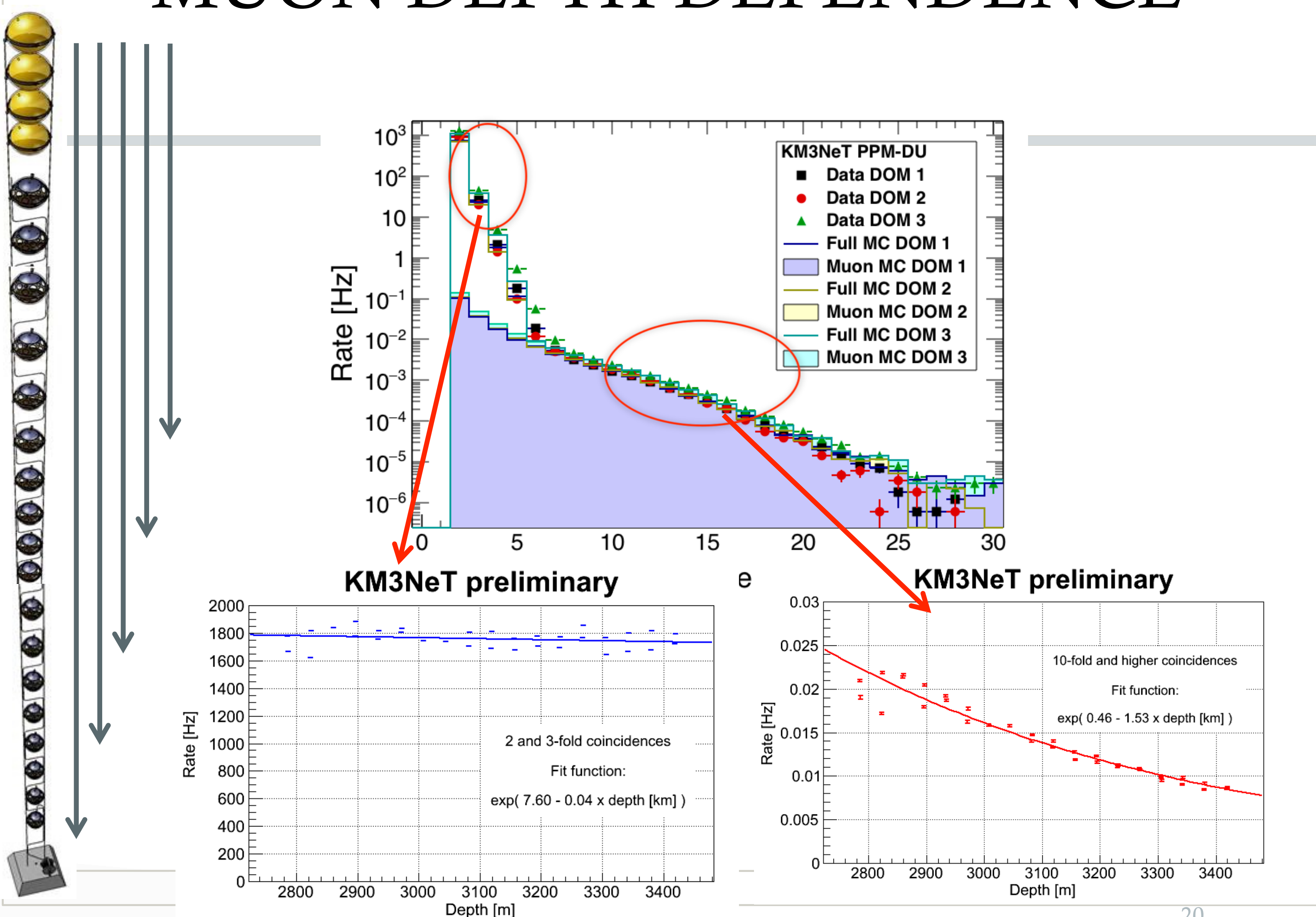
➢ ARCA phase 1 will be the largest neutrino telescope in the Northern hemisphere (0.1 km^3, i.e. 10 x Antares!)



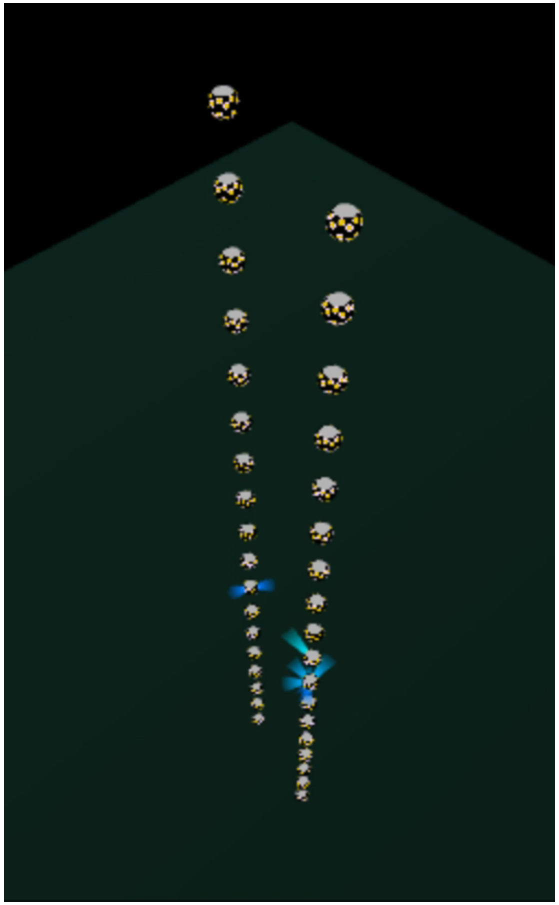
The FirsT DU installed in situ 3500 m

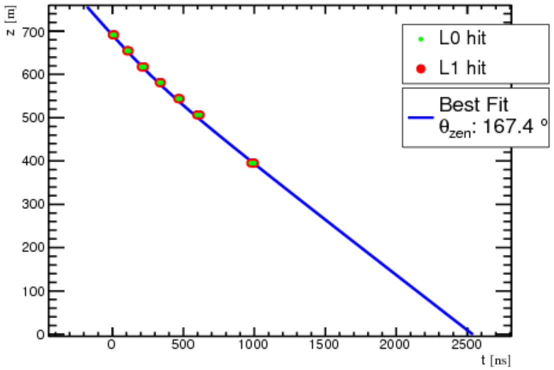


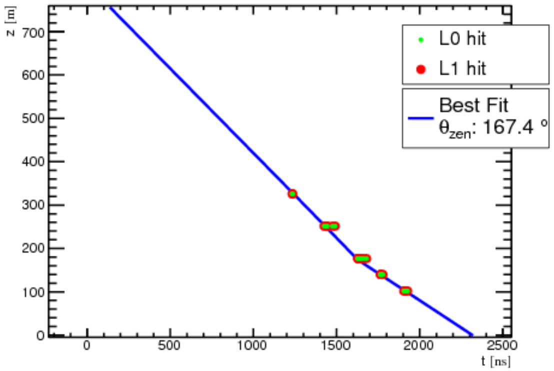
MUON DEPTH DEPENDENCE



TWO STRING EVENT





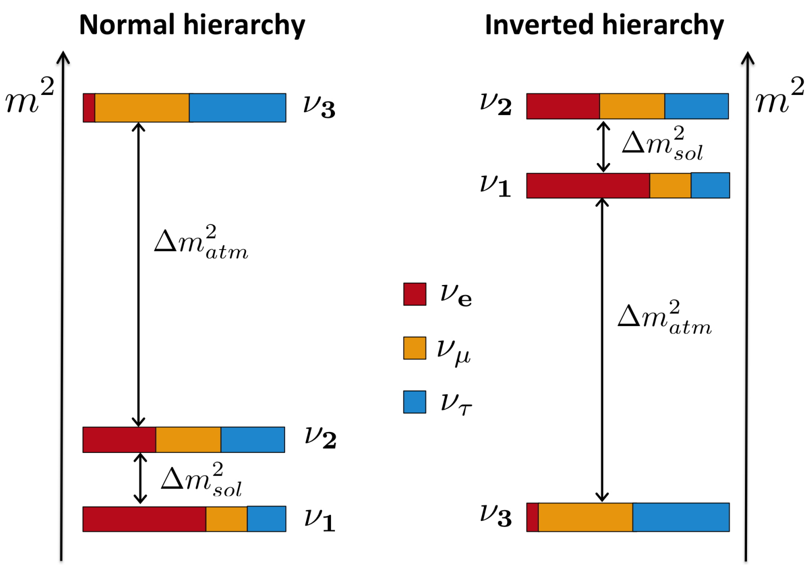


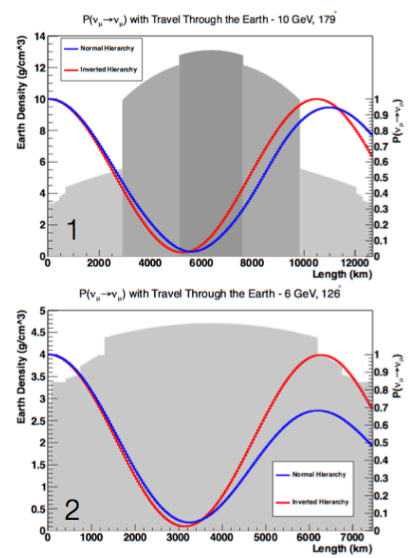
MEASURING NMH WITH ATMOSPHERIC NEUTRINOS IN THE DEEP SEA

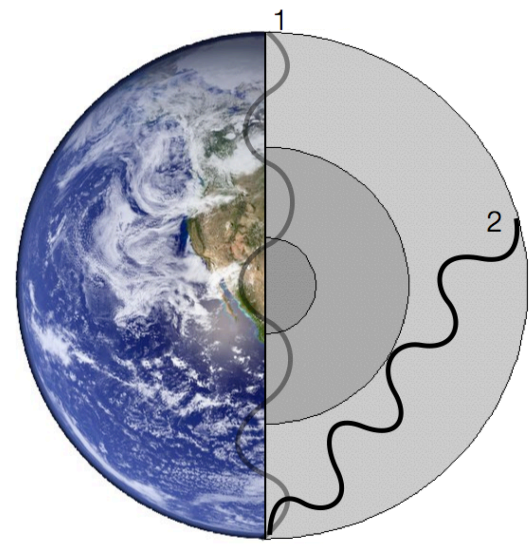
Measurement of the Mass Hierarchy with atmospheric neutrinos passing through Earth in a deep sea Cherenkov detector at GeV energy

Oscillation signal enhanced at resonance energy in matter

Very challenging experiment…







ORCA DETECTOR LAY OUT

ORCA: Oscillation Research with Cosmics in the Abyss

To be installed in the French site of the KM3NeT infrastructure at 2500 m depth

One building block with 115 detection units

18 DOM per DU

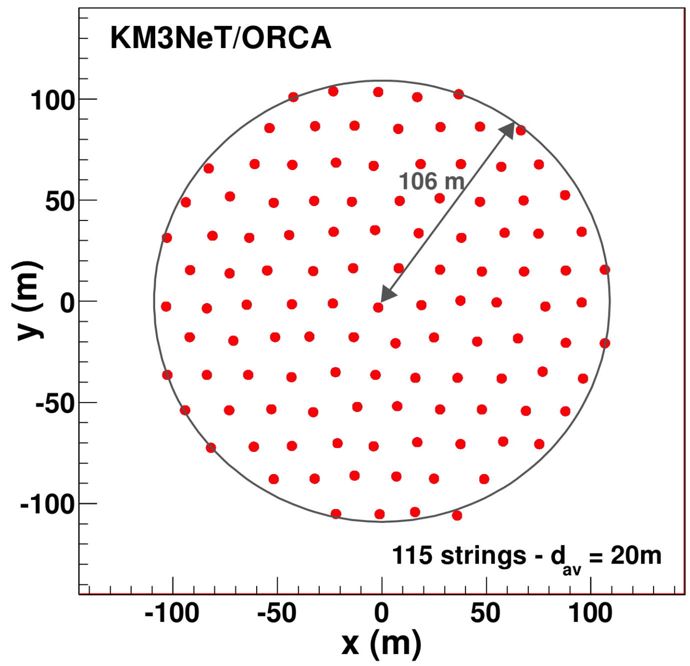
Vertical DOM spacing 9 m

Inter-DU spacing 20 m

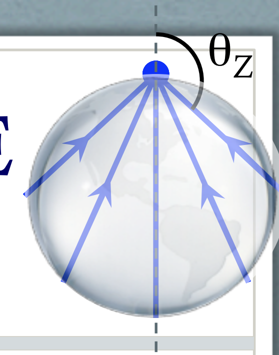
Instrumented volume ≈7 Mton

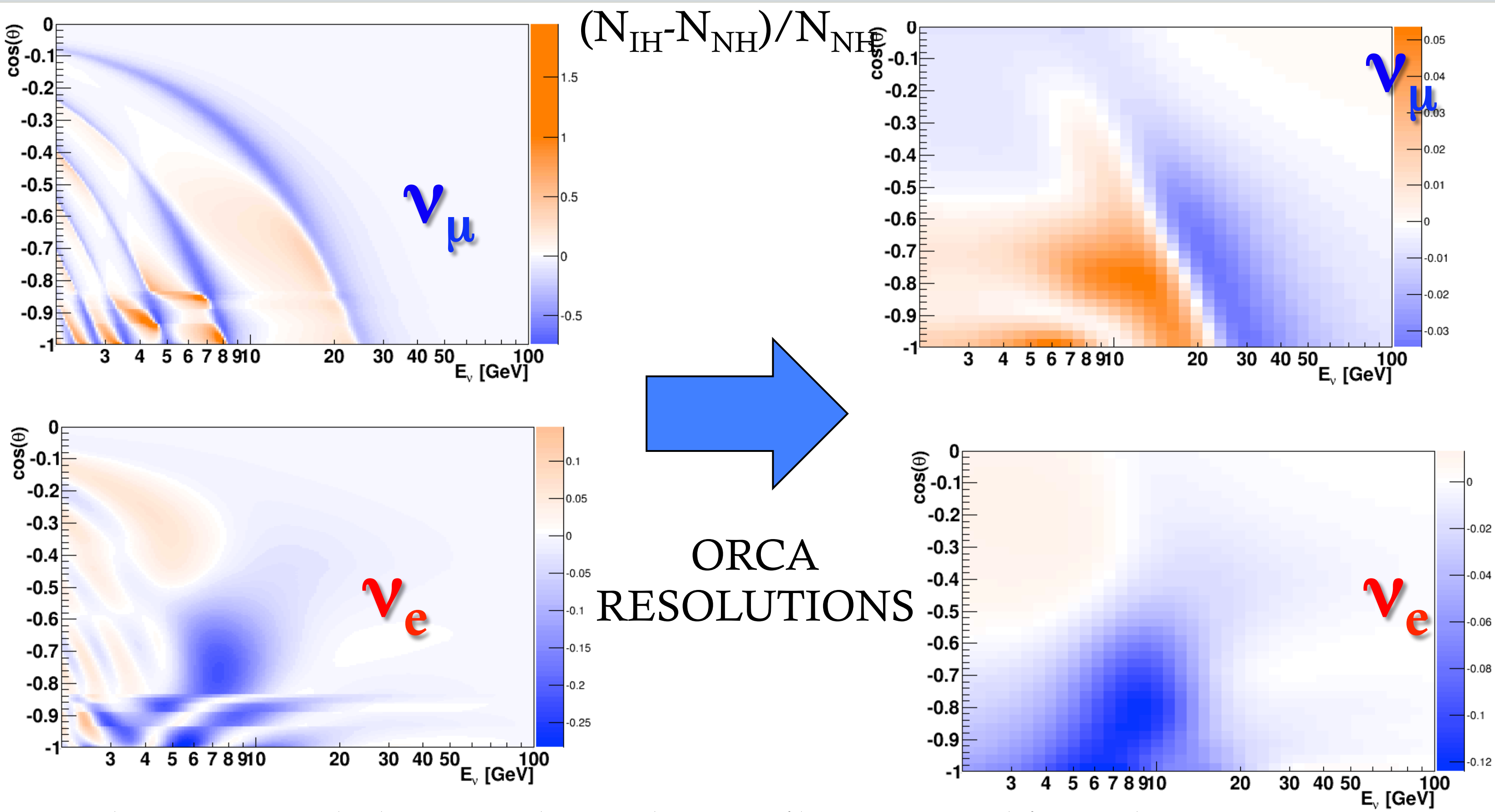
6 m

First ORCA string to be deployed in 2016



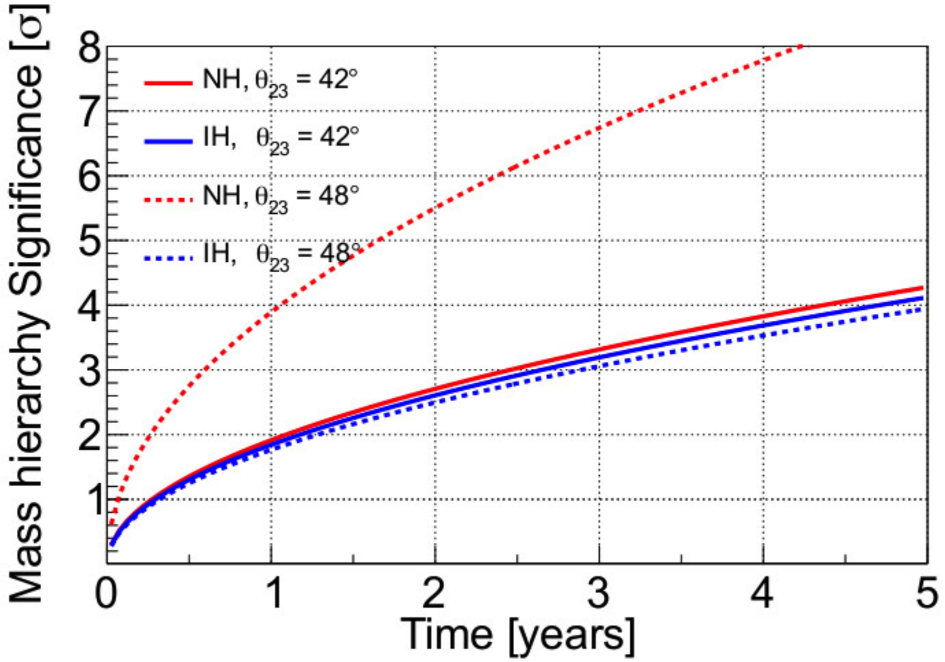
NMH EXPERIMENTAL SIGNATURE





Both muon- and electron-channels contribute to net hierarchy asymmetry
Electron channel more robust against detector resolution effects

ORCA: NMH SENSITIVITY



Full MC production
Trigger simulation, track and shower reconstruction included
Particle identification and muon background taken into account
Major systematics investigated
Vertical distance optimized (9m)

Still to be done
Exploit inelasticity
Improve reconstruction

ORCA is a very competitive experiment within a window of opportunity

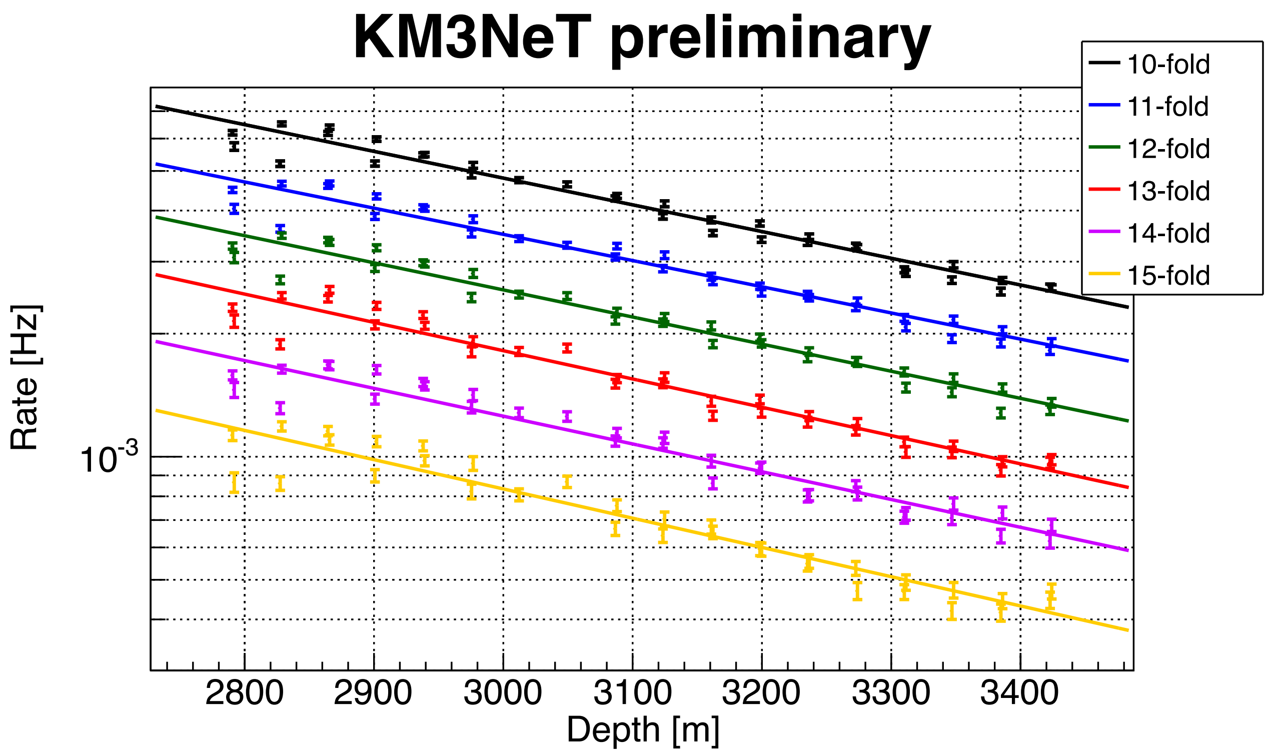
CONCLUSIONS AND PERSPECTIVES

- KM3NeT will soon take over as the biggest detector in the Northern Hemisphere (KM3NeT phase-1 will be ≈ 0.1 km^3)
- Next phase (KM3NeT 2.0) to follow
  - ARCA (≈ 1 km^3) to be installed at the Italian node of the KM3NeT distributed infrastructure
  - ORCA (≈ 7 Mt) to be installed at the French node
- Exciting physics prospects
  - Investigate the neutrino sky with unprecedented resolution and sky coverage with ARCA
  - Determine Neutrino Mass Hierarchy with ORCA

BACK UP

DEPTH DEPENDENCE PRELIMINARY

Capo Passero site 3500 m depth



NMH experiments

Widths indicate main uncertainty

LBNE/NOVA: δ cp

JUNO: σ E (3.0-3.5%)

ORCA/PINGU/INO: θ_{23}

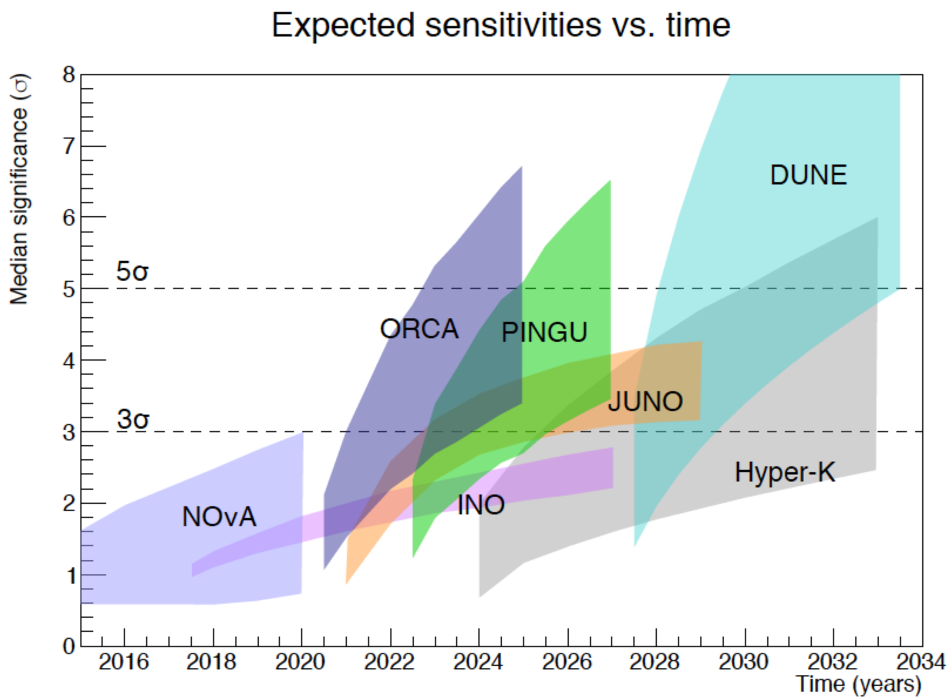
Other projections assume worst case parameters (1st oct)

ORCA timeline, assumes start construction 2017 for 3 years

LBNE from LBNE-doc-8087-V10

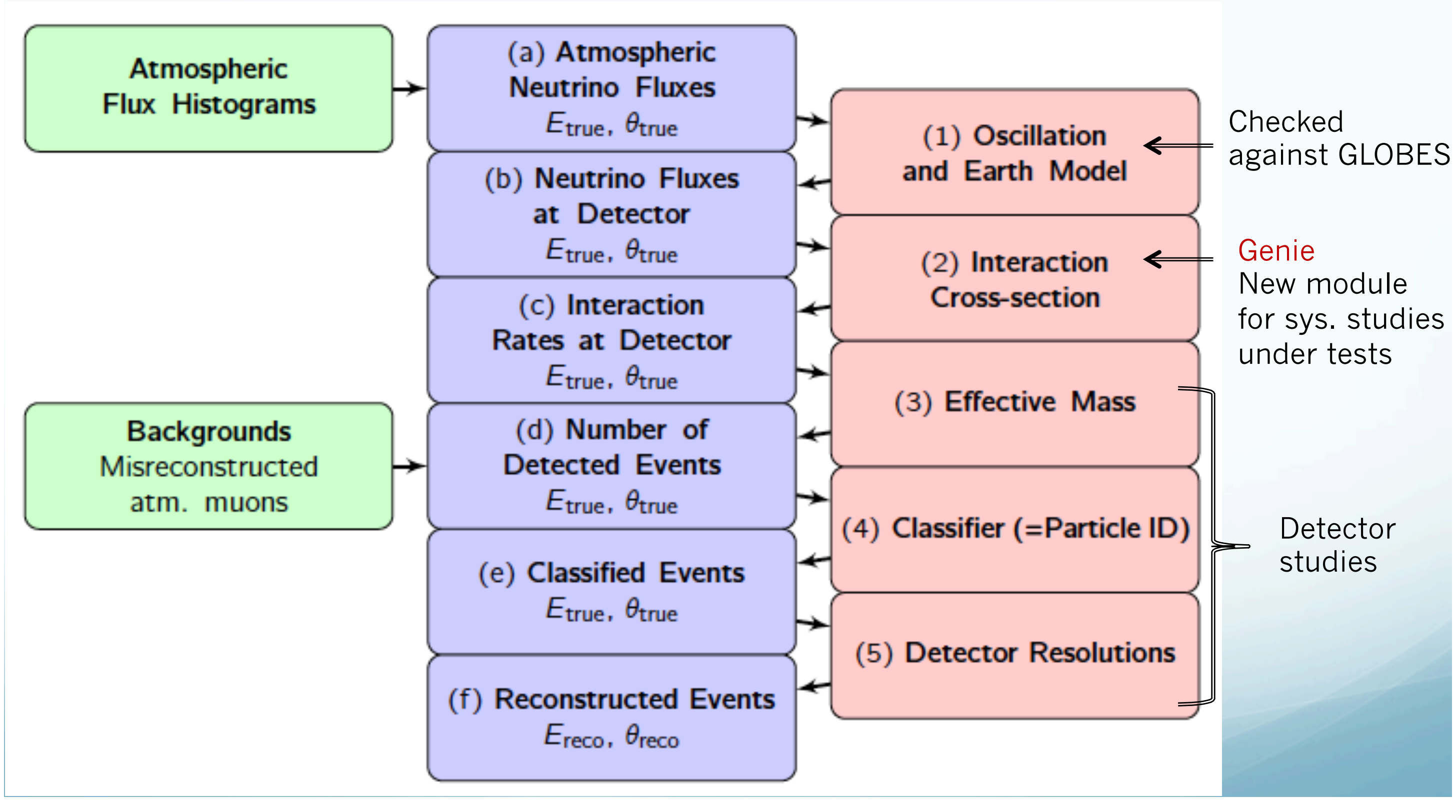
PINGU from MANTS 2015

Others Blennow



3 sigma determination of neutrino mass hierarchy in 3/4 years

Global Fit


Atmospheric Flux Histograms
(a) Atmospheric Neutrino Fluxes
E_{true}, θ_{true}
(b) Neutrino Fluxes at Detector
E_{true}, θ_{true}
(c) Interaction Rates at Detector
E_{true}, θ_{true}
Backgrounds Misreconstructed atm. muons
(d) Number of Detected Events
E_{true}, θ_{true}
(e) Classified Events
E_{true}, θ_{true}
(f) Reconstructed Events
E_{reco}, θ_{reco}
(1) Oscillation and Earth Model
(2) Interaction Cross-section
(3) Effective Mass
(4) Classifier (=Particle ID)
(5) Detector Resolutions
Checked against GLOBES
Genie
New module for sys. studies under tests
Detector studies

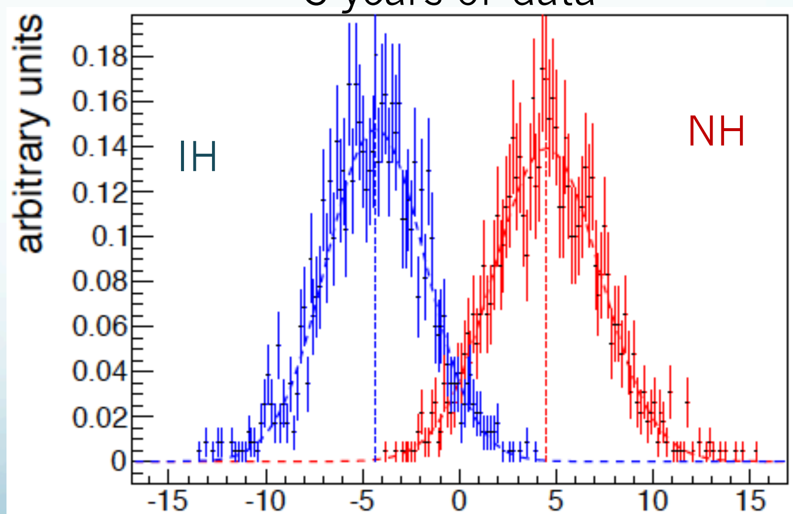
ORCA SENSITIVITY

1. Random set of oscillation parameter values generated (uncorrelated)
2. 2 (tracks, cascades) x 2D (E_{rec}, θ_{rec}) histograms = 1 PE
3. Compute Likelihood given both hypotheses
4. Fit mixing parameters assuming both NH and IH (max likelihood)
5. Compute ΔlogL = log(L(NH)/L(IH))

$$S_{NH} := \frac{\mu_{NH} - \mu_{IH}}{\sigma_{IH}}.$$

(median significance to exclude the IH)

3 years of data



ORCA INPUT

parameter	*true value distr.*	*initial value distr.*	*treatment*	*prior*
θ_{23} [°]	$\{40, 42, \ldots, 50\}$	uniform over $[35, 55]$ †	fitted	no
θ_{13} [°]	8.42	$\mu = 8.42$, $\sigma = 0.26$	fitted	yes
θ_{12} [°]	34	$\mu = 34$, $\sigma = 1$	nuisance	N/A
ΔM^2 [10^{-3} eV^2]	$\mu = 2.4$, $\sigma = 0.05$	$\mu = 2.4$, $\sigma = 0.05$	fitted	no
Δm^2 [10^{-5} eV^2]	7.6	$\mu = 7.6$, $\sigma = 0.2$	nuisance	N/A
δ_{CP} [°]	0	uniform over $[0, 360]$	fitted	no
overall flux factor	1	$\mu = 1$, $\sigma = 0.1$	fitted	yes
NC scaling	1	$\mu = 1$, $\sigma = 0.05$	fitted	yes
$\nu/\bar{\nu}$ skew	0	$\mu = 0$, $\sigma = 0.03$	fitted	yes
μ/e skew	0	$\mu = 0$, $\sigma = 0.05$	fitted	yes
energy slope	0	$\mu = 0$, $\sigma = 0.05$	fitted	yes

Table 7: Default parameter settings used for the LLR analysis. Where μ and σ are given, they refer to a Gaussian distribution. The † indicates that the initial values for θ_{23} are generated in a special way: a total of seven initial values is tried. They are $x + i \times 5°$, where x is the randomly drawn value and $i \in [-3, -2, \ldots, 3]$.

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