THE KM3NET NEUTRINO TELESCOPE IN THE MEDITERRANEAN SEA

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FRONTIERS OF RESEARCH ON COSMIC RAY GAMMA - LA PALMA 26-29 AUGUST 2015

OUTLINE

MOTIVATION

DETECTOR DESIGN AND VALIDATION

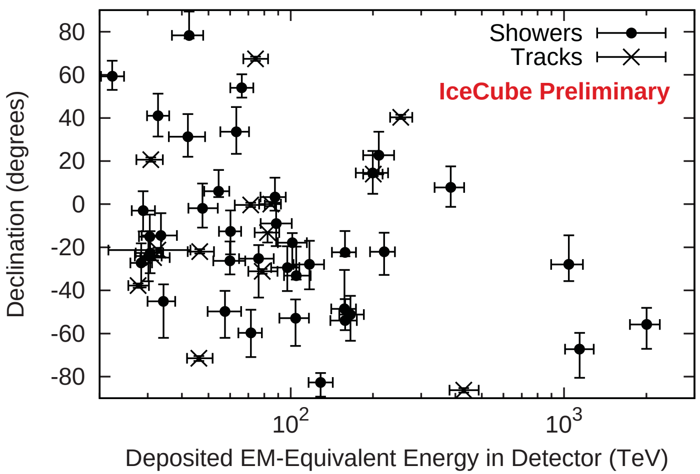
STATUS AND PLANS

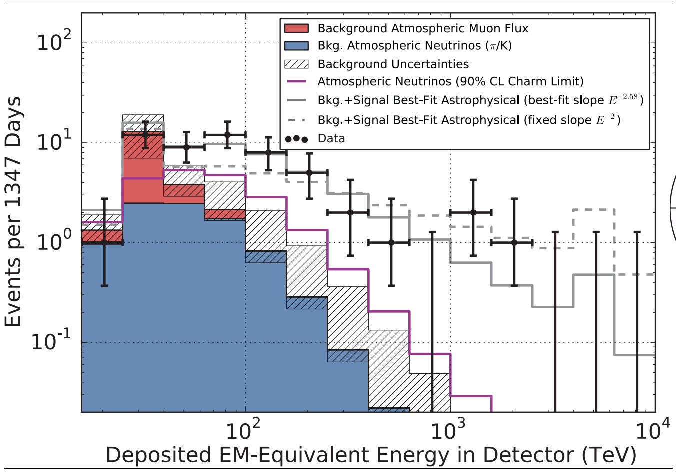
- KM3NET PHASE 1
- KM3NET 2.0
  - SENSITIVTY TO DIFFUSE AND POINT-LIKE SOURCE
  - SENSITIVITY TO GALACTIC GAMMA SOURCES
  - SENSITIVITY TO NEUTRINO MASS HIERACHY

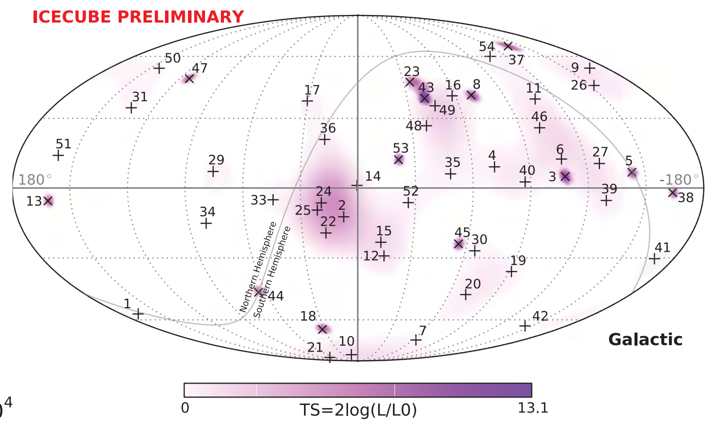
CONCLUSIONS

NEUTRINO ASTRONOMY ICECUBE RESULTS

53+1 high energy neutrinos observed in 4 years 6.5 σ (HESE) - Kopper ICRC 2015







Up-going muon track analysis: cosmic neutrino signal observed at 3.7σ

Flavour composition compatible with 1:1:1 at detector

Neutrino detection for E > 1 TeV with veto analysis

A 2.6 PeV track event reported very recently!

SPECTRAL SHAPE NOT FIRMILY ESTABISHED

- SPECTRUM SOFTER THAN E^{-2}? CUT-OFF AT PEV ENERGY?

NO HINTS OF NEUTRINO SOURCES

WHY KM3NET?

Two km^3 scale detectors needed in opposite hemispheres for full neutrino sky coverage

KM3NeT aims to be the largest deep sea infrastructure in Mediterranean Sea consisting of a network of neutrino telescopes with user ports for earth and sea sciences

KM3NeT w.r.t. IceCube

- wider field of view
- better angular resolution
- larger sensitivity

THE KM3NET NEUTRINO TELESCOPE

87% sky coverage including most of Galactic Plane and the Galactic Centre for up-going muos

Detection of Optical Cherekov radiation in GeV-PeV range

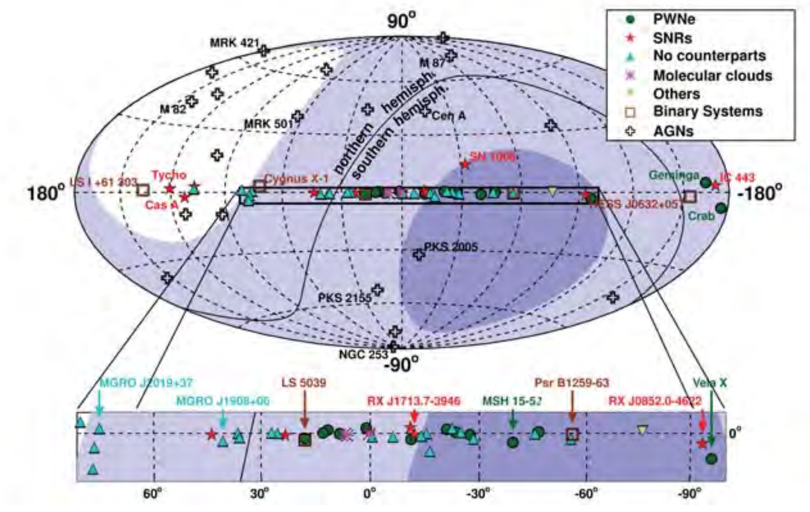
Detection units (DU) – vertical slender strings with multi-PMT digital optical modules (DOMs)

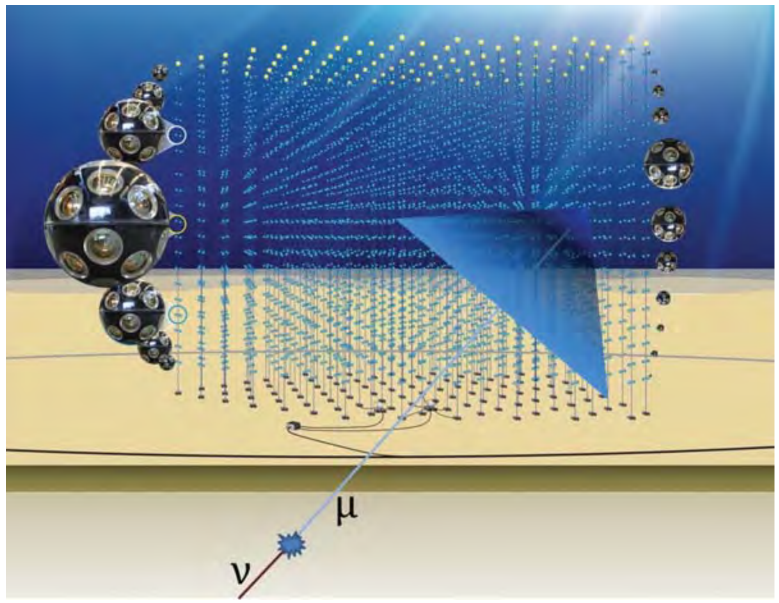
Each DU host 18 multi-PMT DOMs supported by two parallel ropes

Power and data distributed by a single backbone cable with breakouts at DOMs

All data to shore

Building blocks of 115 DUs each, allow for a distributed detector





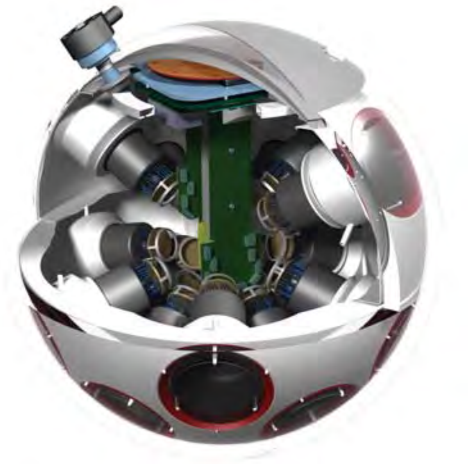
THE KM3NET MULTI-PMT DOM

Segmented cathode area 31 x 3"PMTs equivalent to 3 Antares/IceCube/NEMO Optical Module

Advantages

- good optical background rejection
- directionality
- almost homogenous coverage

=> better detection of downgoing tracks and contained events



Instrumentation inside DOM (LED & piezo, compass and tiltmeter)

THE KM3NET DETECTION UNIT

18 optical module per string

17”

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

Launcher vehicle

rapid deployment
autonomous unfurling
recoverable

IN SITU PROTOTYPE VALIDATION

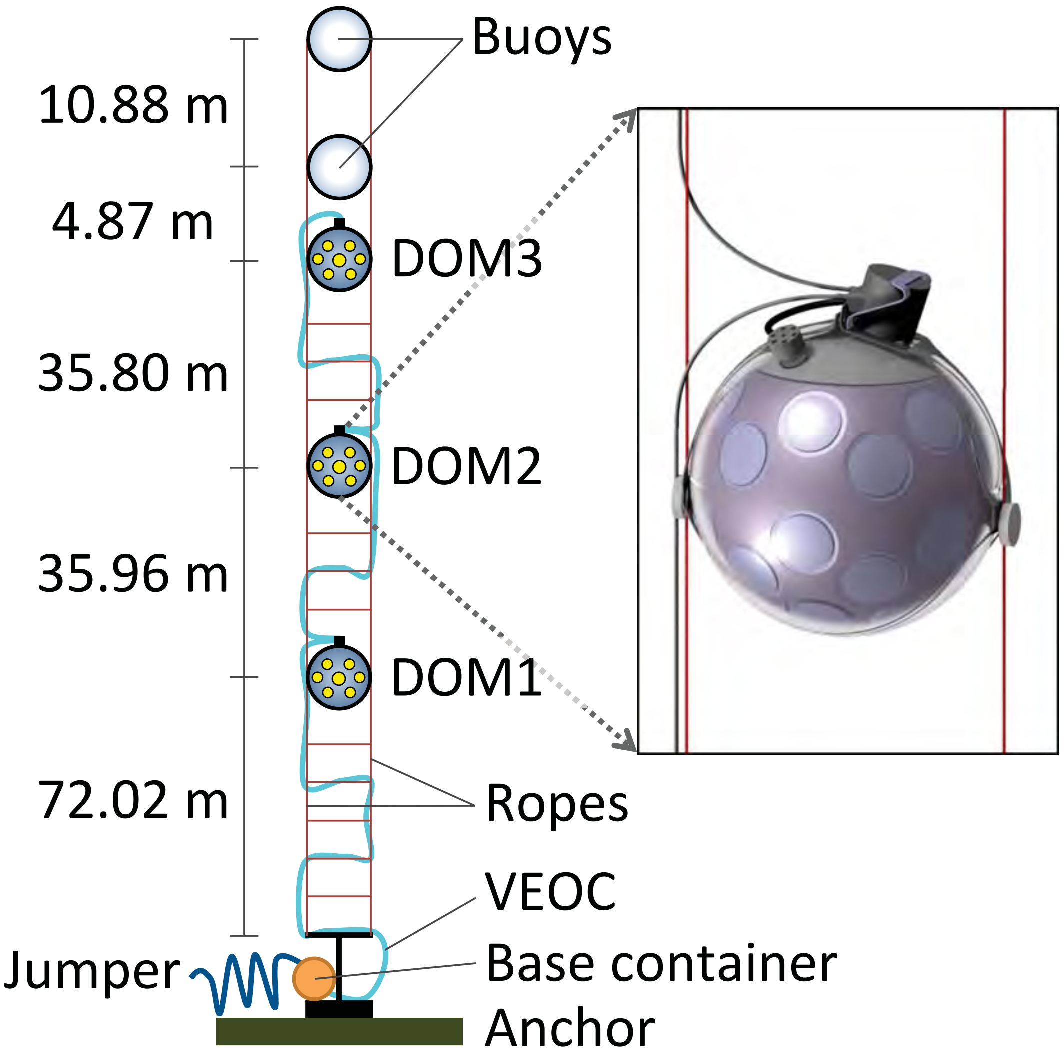
Harsh environment: 2500-3500 m depth

- Accessibility
- Pressure
- Corrosion
- …

Antares demonstrated the feasibility of a deep sea neutrino telescope, however several of the technologies cannot be applied to km3net because expensive or not scalable

In situ prototype validation of detector components is a necessary step towards construction

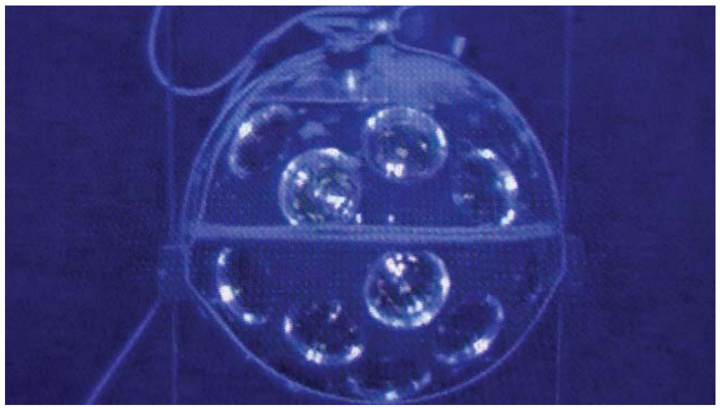
DETECTION UNIT PROTOTYPE



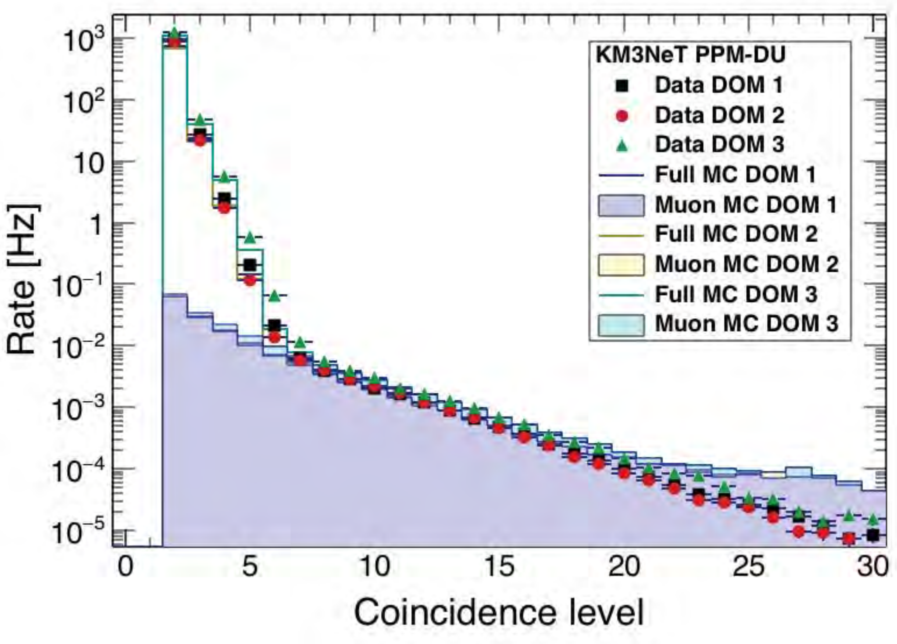
Prototype DU with three DOMs

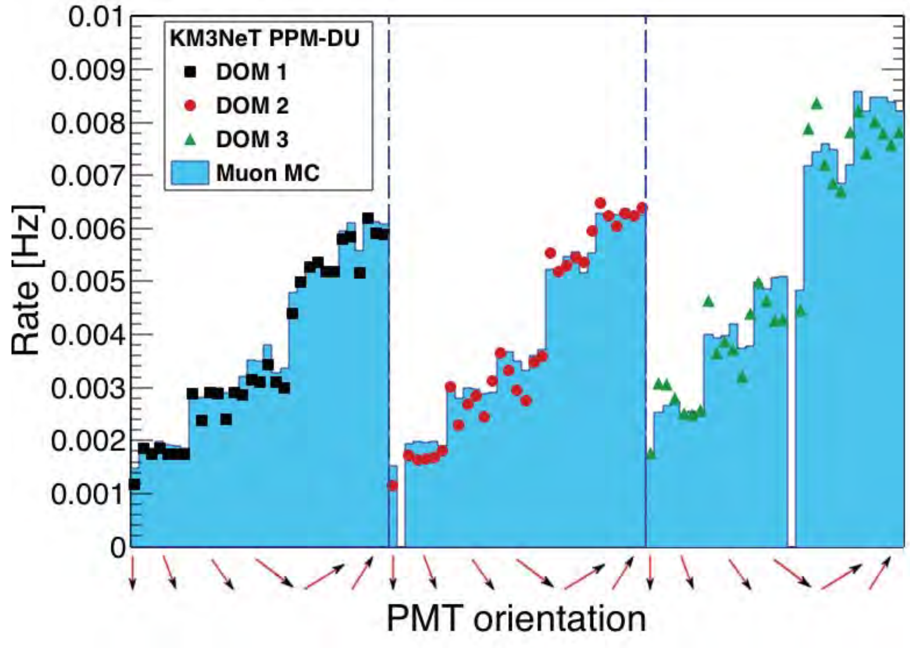
Deployed at the KM3NeT-It site at 3500m depth

Operational since May 2014



DOM PROTOTYPE RESULTS





Photon counting

Directional sensitivity

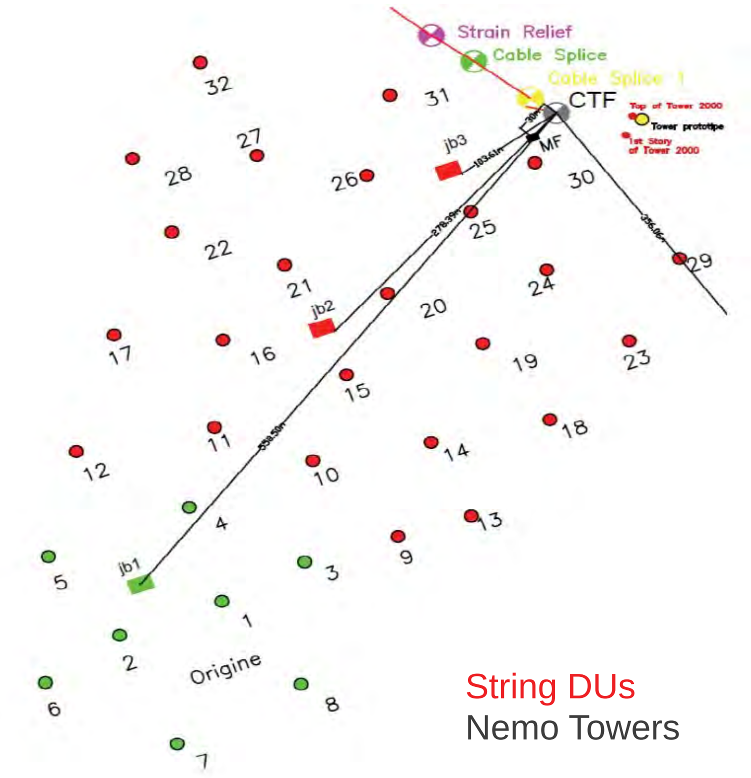
High coincidence level clearly select muon events

Muon events (coincidence level >7)

KM3NET PHASE-1

KM3NeT Phase-1: Proof of feasibility of network of neutrino detectors

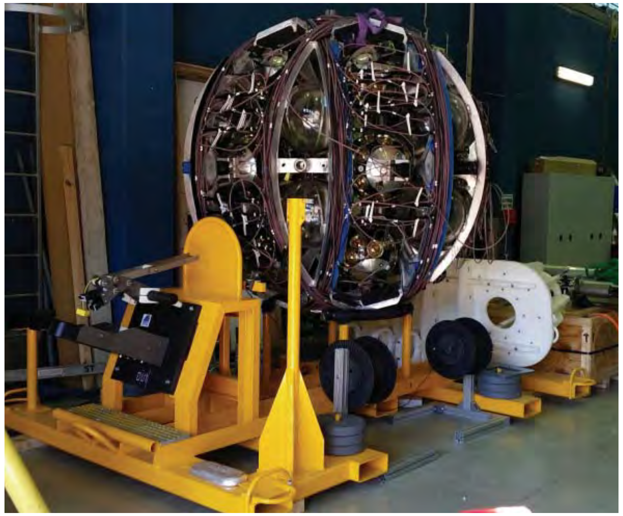
- Started in January 2014
- Funded with 31 million Euro
- Detection Unit deployment in 2015-2016
- Two sites
    - KM3NeT-It (24 Strings + 8 towers)
    - KM3NeT-Fr (7 DUs)



KM3NeT-It instrumented volume is 0.1 km^3,

i.e. 10 times larger than Antares

DETECTION UNIT PRODUCTION



First full DU already integrated and ready for deployment at the KM3NeT-Fr site

Integration of the second DU in progress. To be deployed at the KM3NeT-It sit

THE KM3NET 2.0 PROPOSAL

The detection of cosmic neutrinos in IceCube and the measure of θ_{13} triggered the KM3NeT 2.0 proposal

Two-site infrastructure

- ARCA detector for high energy neutrino astronomy at the KM3NeT-It site (off-shore Capo Passero 3500 m depth)
- ORCA detector for NMH studies with atmospheric neutrinos at the KM3NeT-Fr (off-shore Toulon 2500 m depth)
- Additional cost: 90 M€ (not yet funded)
- Proposed to ESFRI
- LoI in preparation

THE KM3NET/ARCA DETECTOR

2 Building blocks

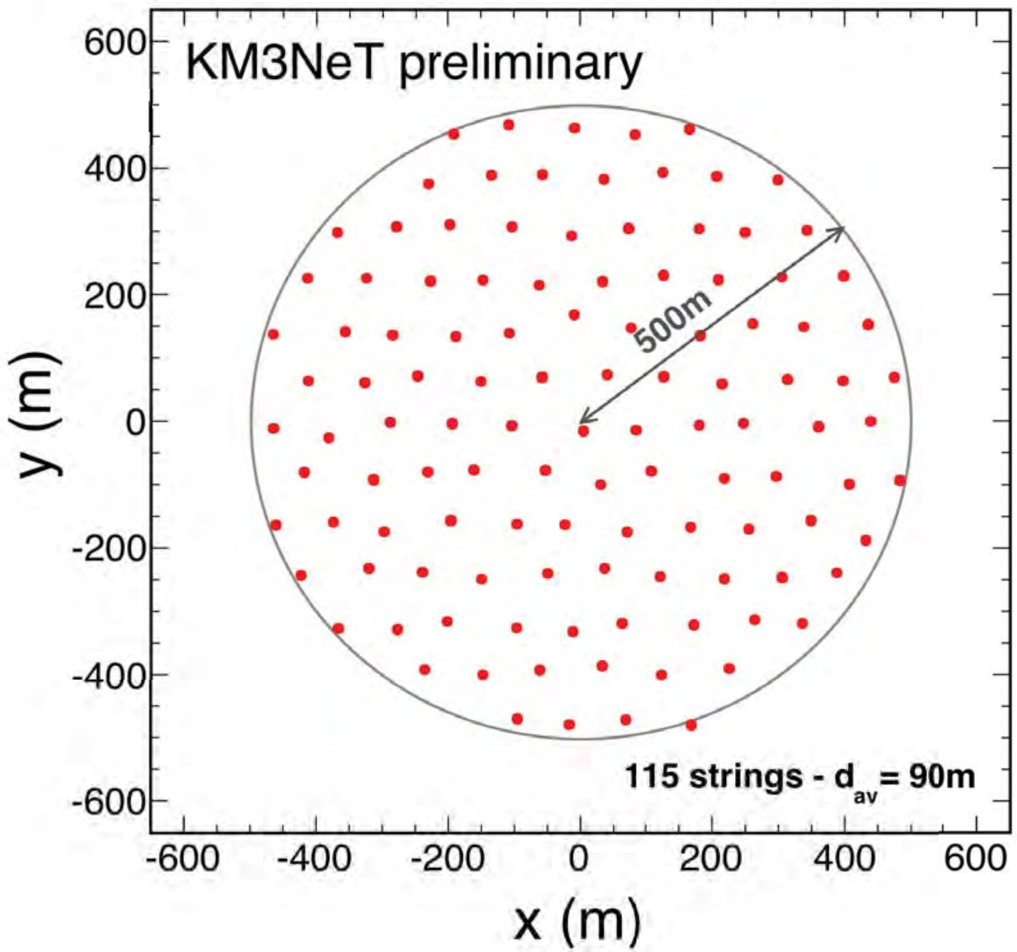
115 detection units (DU) pe

18 DOM per DU

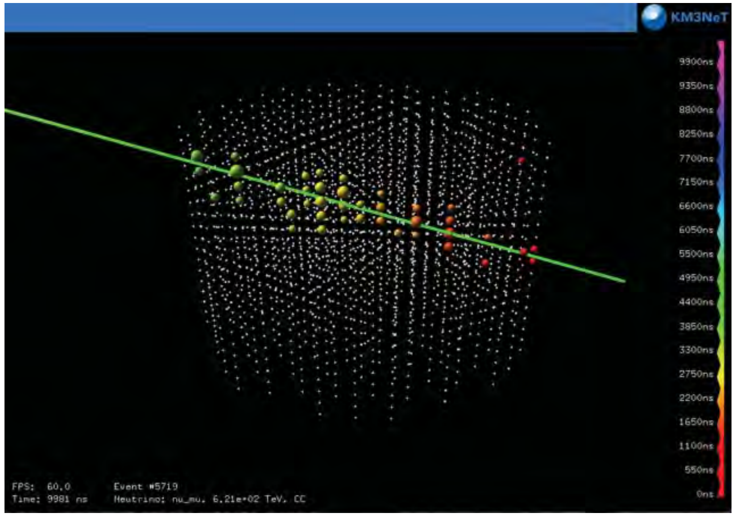
Vertical DOM spacing 36 m

Inter-DU spacing 90 m

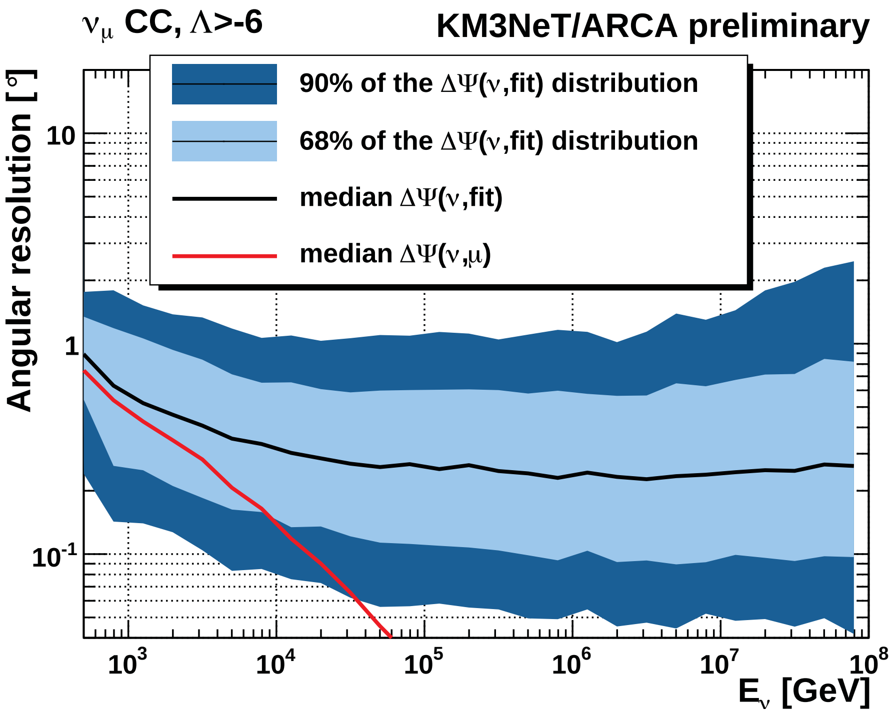
Total volume ≈1 km^3



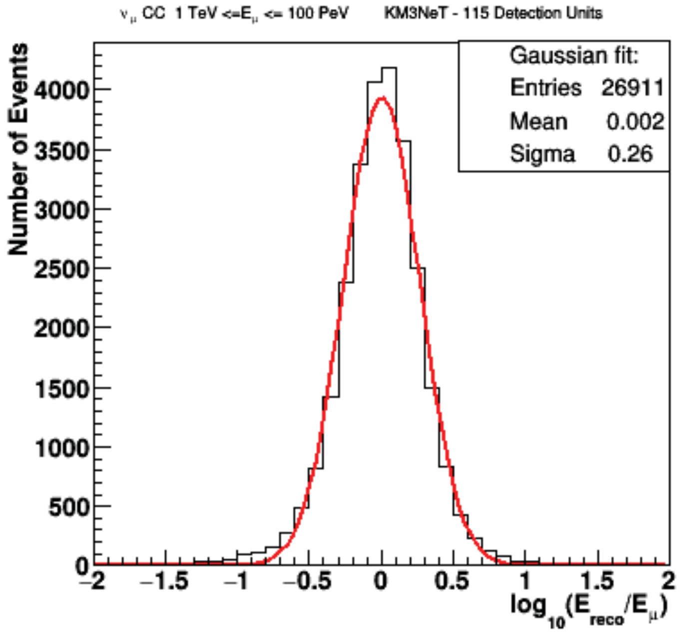
KM3NET/ARCA TRACK RECONSTRUCTION



620 TeV CC ν_μ event

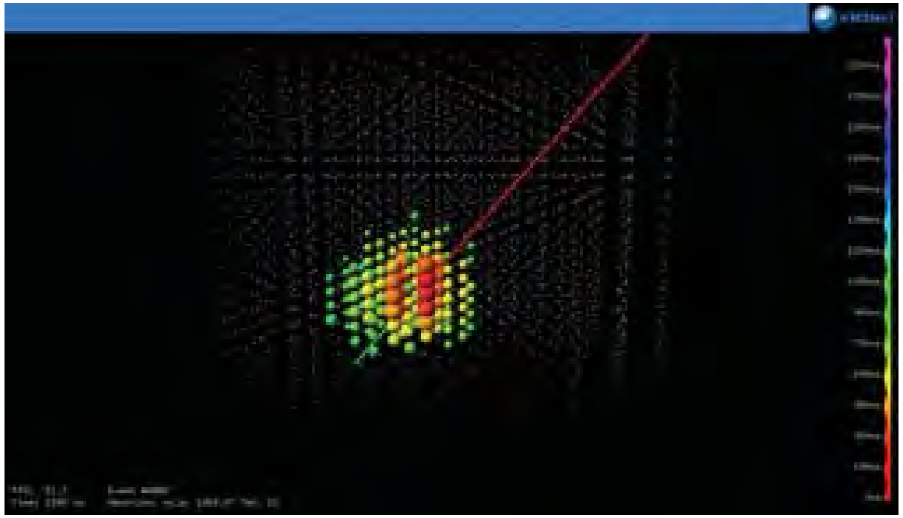


Angular resolution about 0.2° (E_ν>10 TeV)

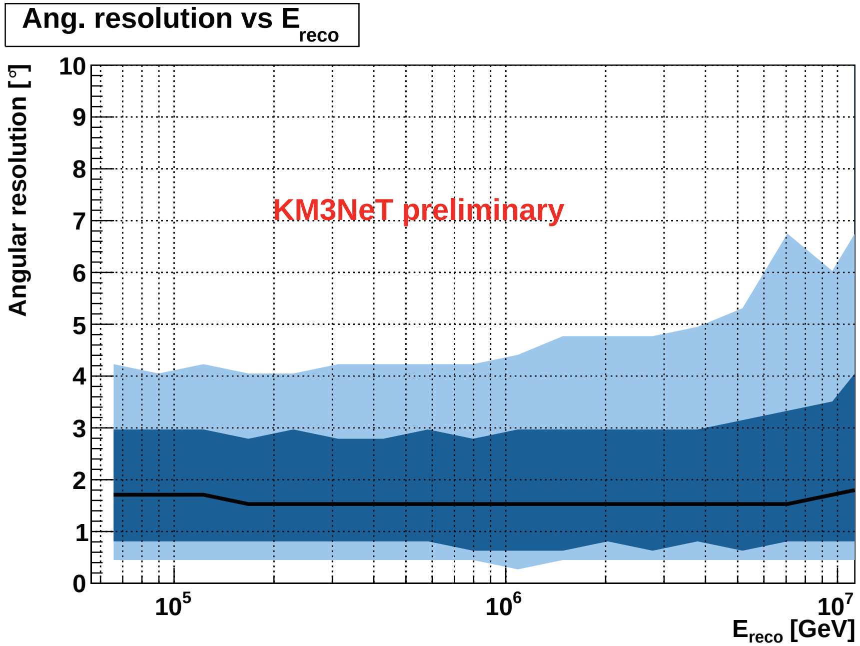


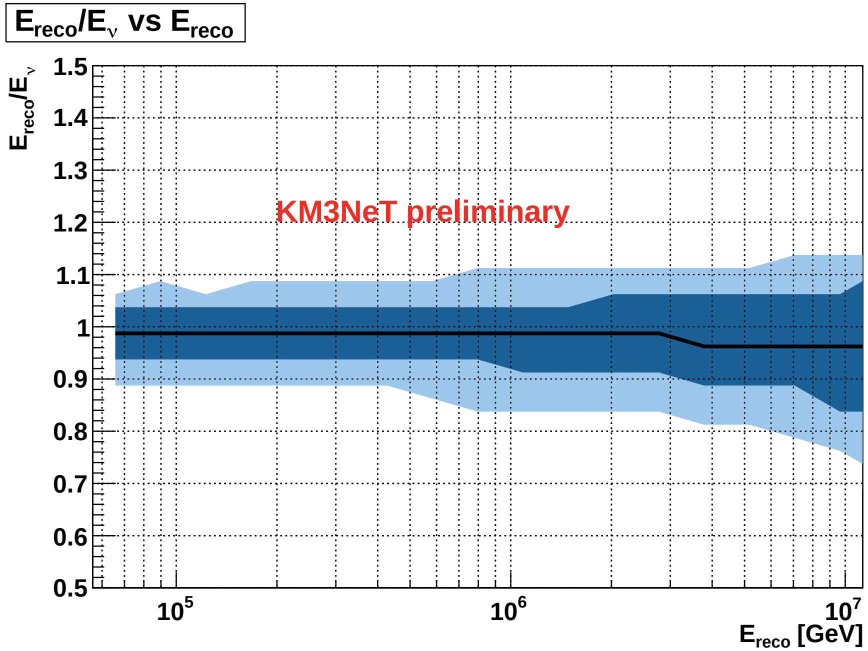
Energy resolution about 0.26 in logEμ ($1\ \text{TeV} < E_\nu < 100\ \text{PeV}$)

KM3NET/ARCA CASCADE RECONSTRUCTION



1083 TeV CC ν_e event



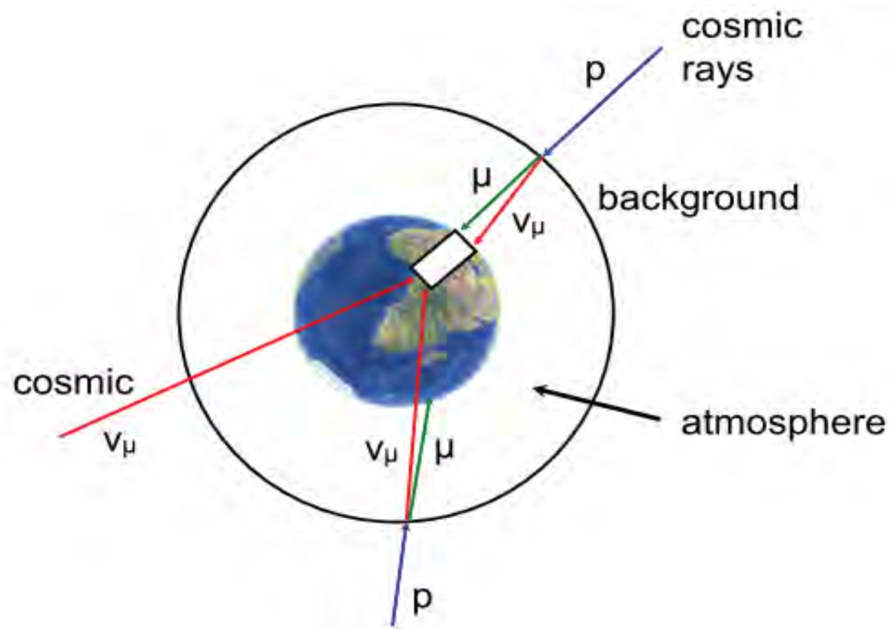


Angular resolution about 2°

Energy resolution < 10%

SIGNALS AND BACKGROUNDS IN COSMIC NEUTRINO SEARCH

LOOKING FOR A NEEDLE IN HAYSTACK



- Atmospheric muons and neutrinos represent a huge background for high energy cosmic neutrino detection
- Signal and background events are indistinguishable on a single event basis but show different spectra, flavour, energy and angular distributions
- Up-going and contained events are muon-free

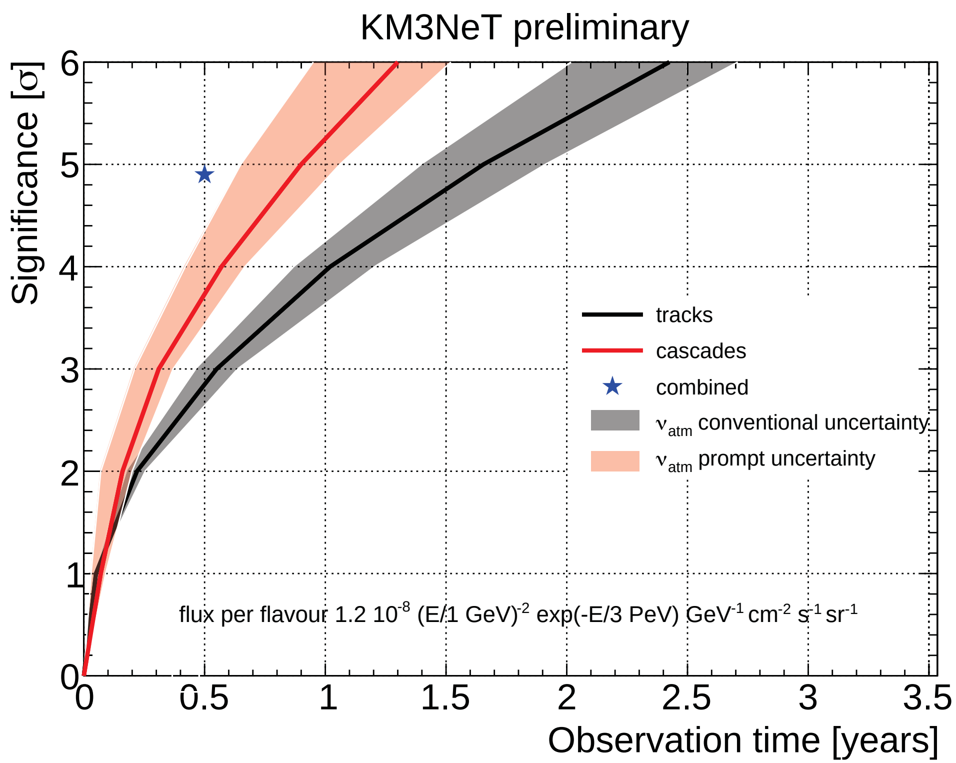
SIGNAL	BACKGROUND
Track-like and Cascade events	MostlyTrack-like levents from atmospheric muons and neutrinos
Hard benchmark spectra E^{-2}	Soft spectra $E^{-3.7}$ – $E^{-3.7}$

* Atmosferic neutrinos represent a background for high energy neutrino astronomy but are the “signal” for Neutrino Mass Hierarchy mesurement (ORCA)

SENSITIVITY TO NEUTRINO DIFFUSE FLUX

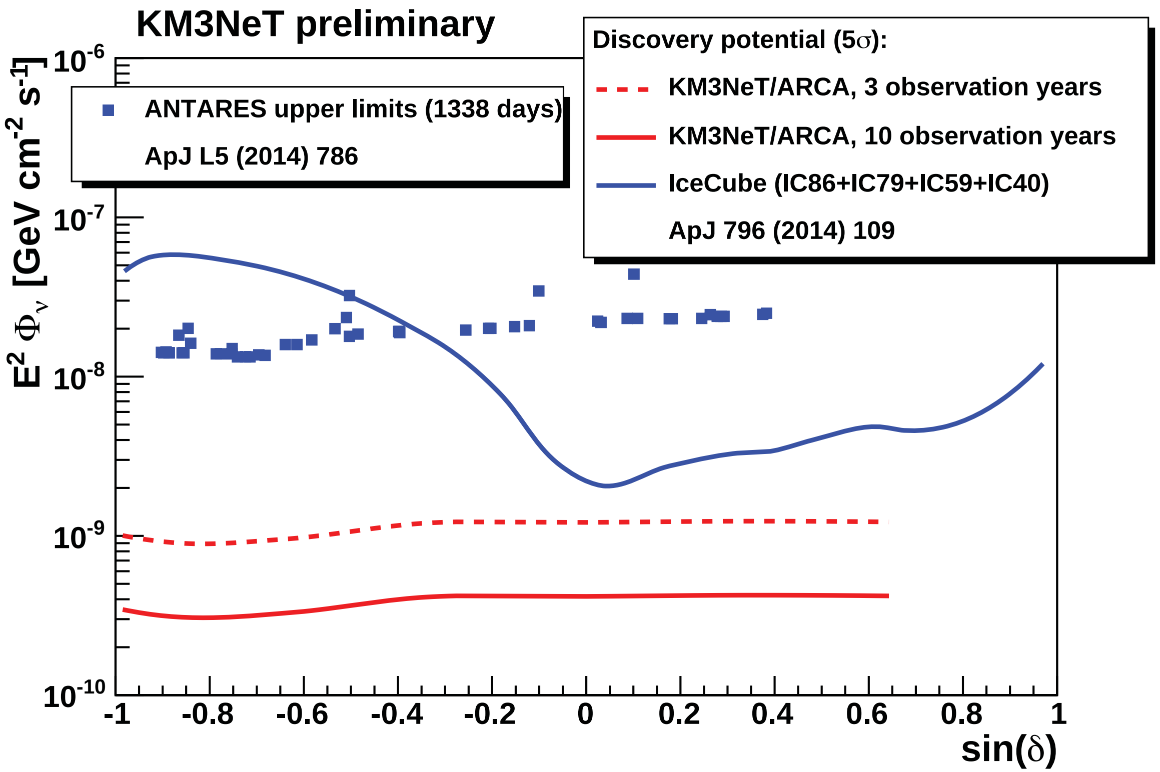
All neutrino flavour MC simulation and 3 years of live time for high energy atmospheric muons

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



POINT SOURCE DISCOVERY POTENTIAL E^{-2} SPECTRUM

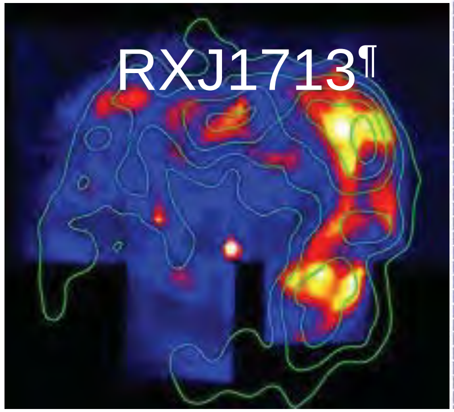
Upgoing tracks

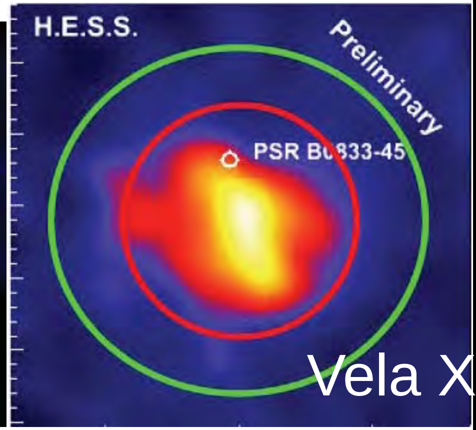


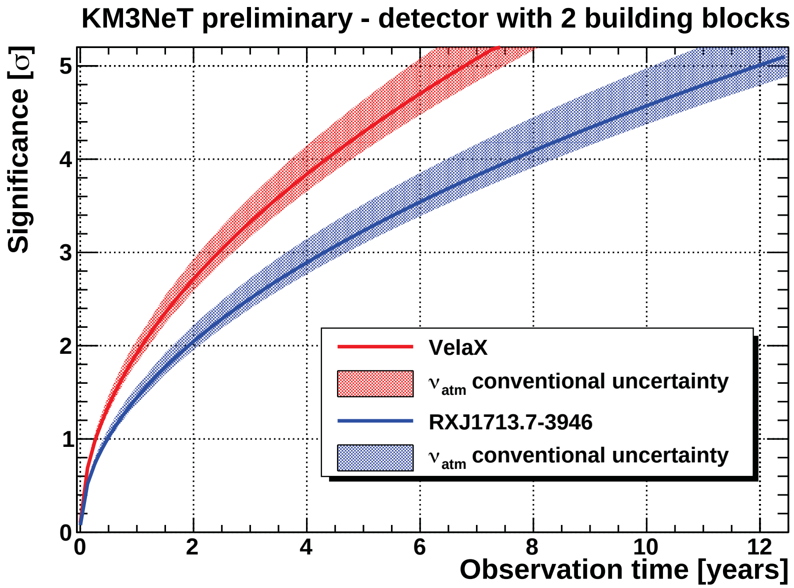
Better than IceCube for all source declination

GALACTIC SOURCES WITH KM3NET/ARCA

- HE gamma emission observed by HESS in SNRs
- Neutrino spectra predicted from 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, 0.6° disk emission



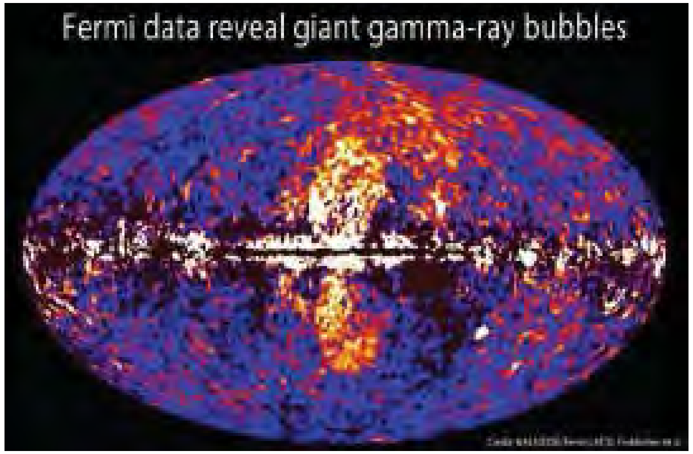




Vela X: 3σ in about 2 years
RXJ1713: 3σ in about 4 years

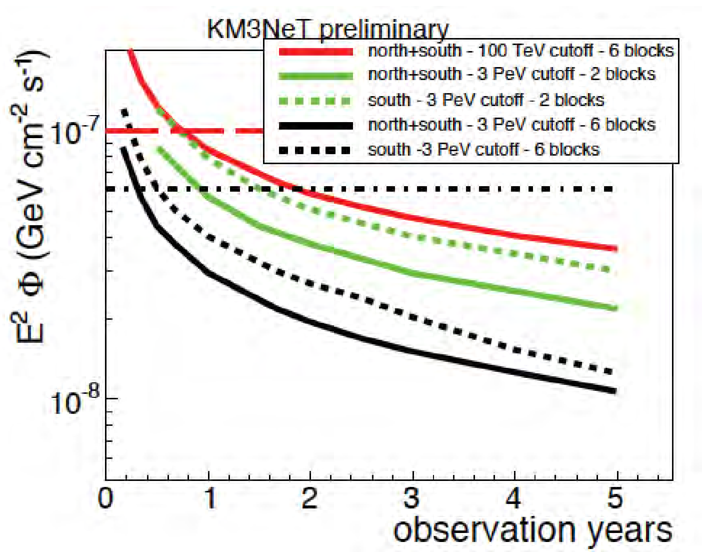
FERMI BUBBLES

Two huge extended regions above/below the Galactic Centre



Fermi detected hard gamma emission (E^{-2}) up to hundreds of GeV

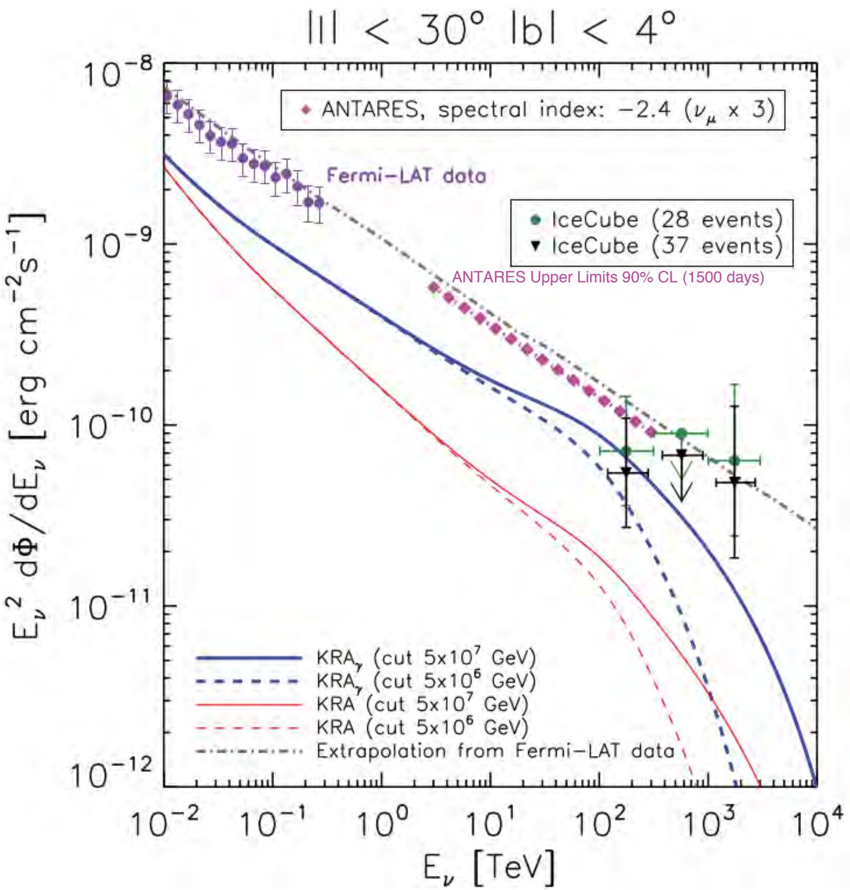
In case of hadronic emission neutrino flux expected, but detectable by neutrino telescopes only if $E_{cut\text{-}off}$ >100 TeV



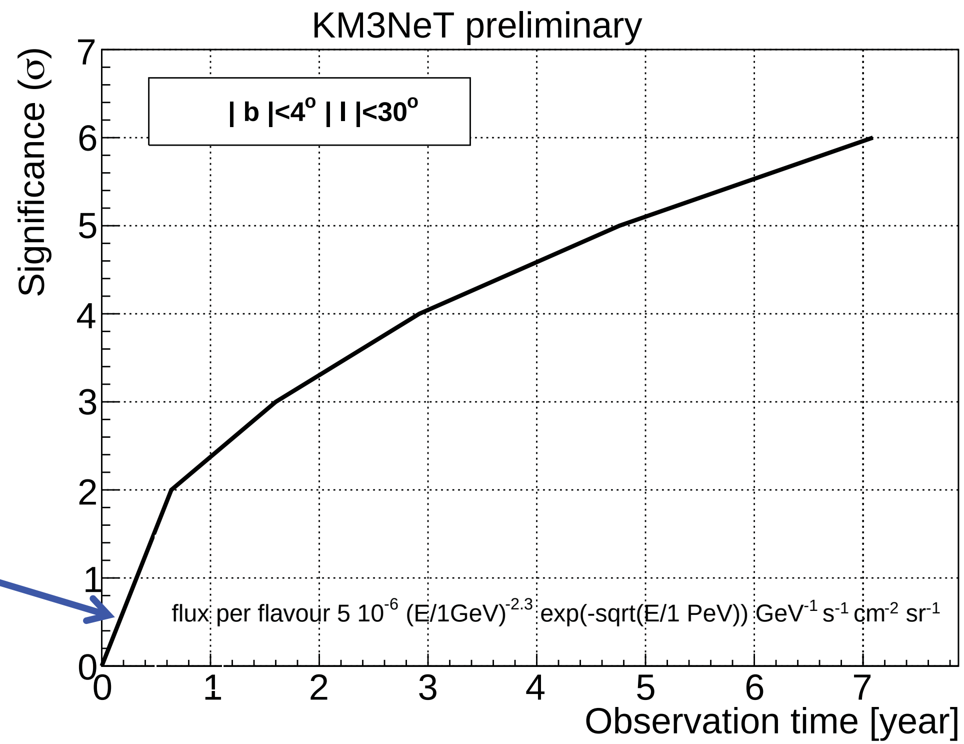
Results for 6 blocks published in Adrian Martinez et al Astroparticle Phys. 42 (2013) 7

DIFFUSE FLUX FROM THE GALACTIC PLANE

ARCA performance to a flux from a region of the Galactic Plane near the Galactic Center. Evaluation of the neutrino flux based on a radially-dependent cosmic-ray transport properties (D. Gaggero et al. 2015)



Preliminary results for up-going track events



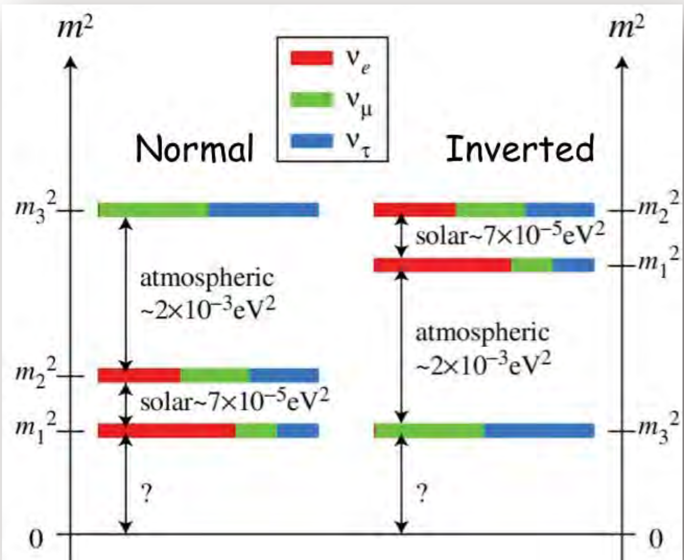
Discovery at 5σ significance (50% probability) in about 5 years

ORCA – ν OSCILLATION RESEARCH WITH COSMICS IN THE ABYSS

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…



$$E_\nu^{res} = \pm \frac{\Delta m^2_{13}\cos(2\theta_{13})}{2\sqrt{2}G_F N_e}$$

$$P_{e\to\mu} \approx P_{\mu\to e} \approx \sin^2\theta_{23}\sin^2(2\theta_{13}^{eff})\sin^2\left(\frac{\Delta_{13}^{eff}L}{2}\right)$$

$$\Delta_{13} = \frac{\Delta m^2_{13}}{2E_\nu} \qquad \sin^2(2\theta^{eff}_{13}) = \frac{\Delta^2_{13}\sin^2(2\theta_{13})}{\Delta^{eff}_{13}L}$$

$$\Delta^{eff}_{13} = \sqrt{|\Delta_{13}\cos(2\theta_{13}) - A|^2 + \Delta^2_{13}\sin^2(2\theta_{13})}$$

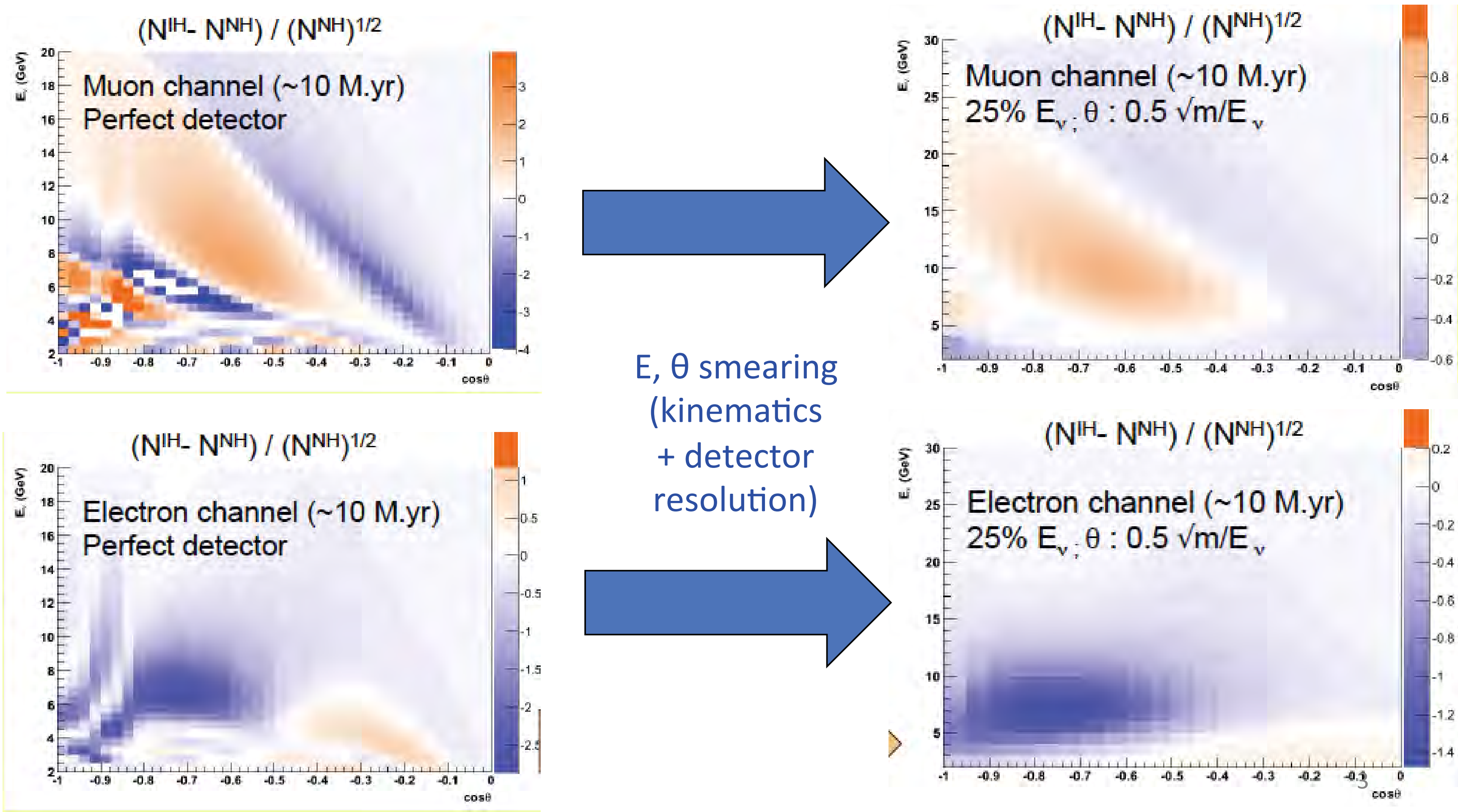
$A = \sqrt{2}G_F N_e$ for ν and $A = -\sqrt{2}G_F N_e$ for $\bar{\nu}$

METHOD TO DETERMINE NMH EFFECT

Both muon and electron channel contribute to net asymmetry in the atmospheric neutrino E_ν-$\cos\theta_\nu$ oscillogram

Electron channel more robust in *real* detector

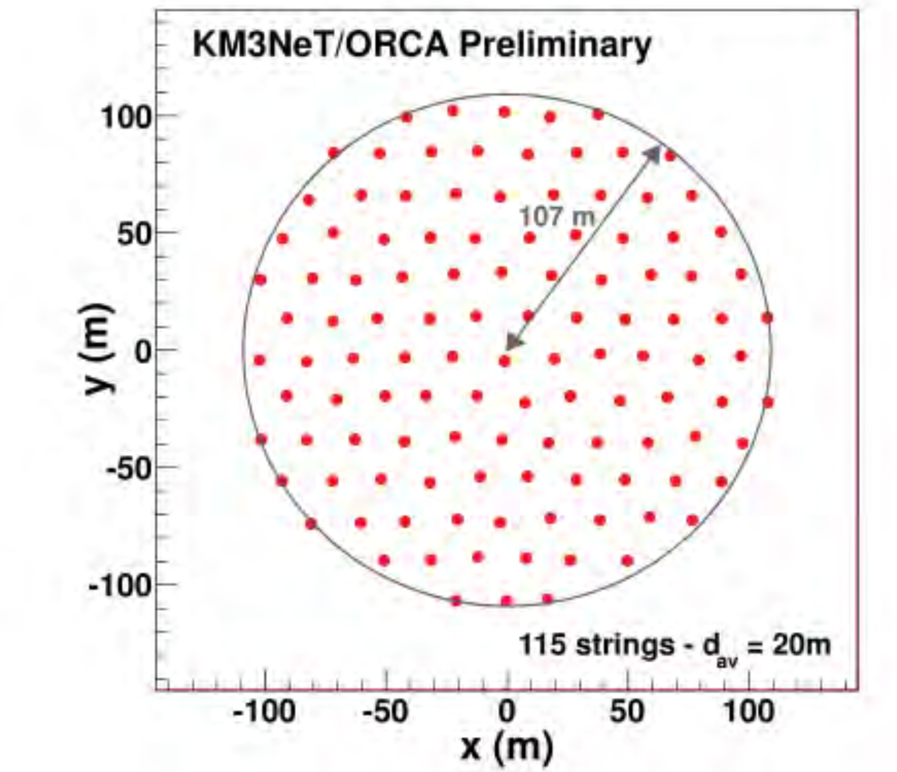
Maximum sensitivity between 5 GeV and 10 GeV



THE ORCA BENCHMARK DESIGN

SAME TECHNOLOGY BUT VERY DENSE DETECTOR

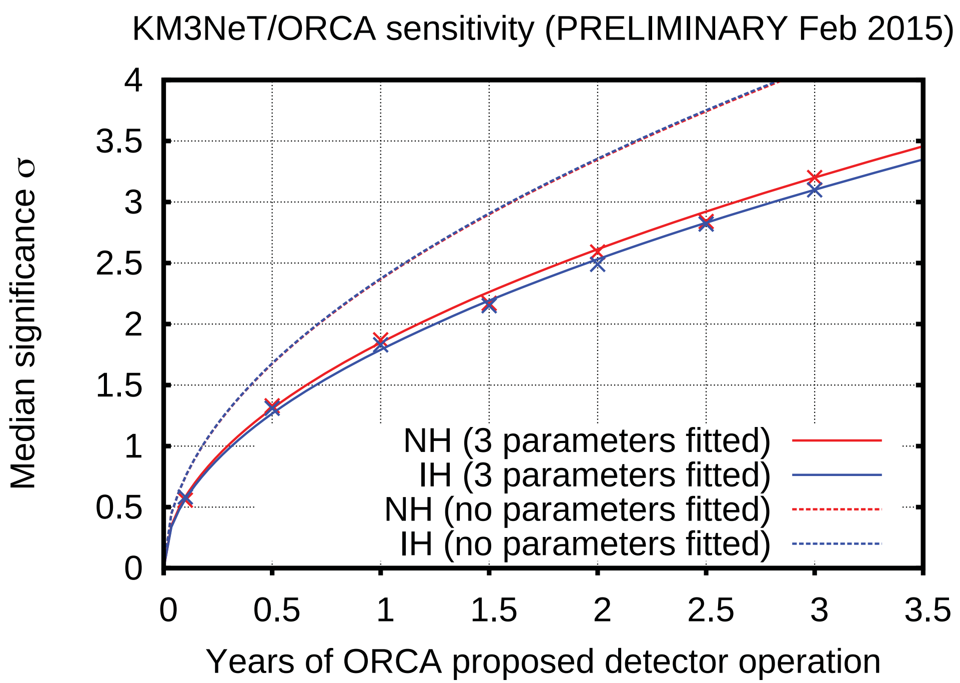
ENEREGY RANGE 1 – 20 GEV



1 block 115 strings
18 strings per DOM
20m strings spacing
6 m DOM spacing (to be optimized)
3.8 Mton instrumented volume

ORCA SENSITIVITY PRELIMINARY RESULTS

Sensitivity dependence on observation time ($\delta_{CP} = 0$)



- Track vs shower event classification
- Full MC detector response matrix
- Atmospheric muon contamination
- Neutral current event contamination
- Systematic uncertainties

Neutrino Mass Hierachy measured at 3σ level in about 3 years

ORCA - SYSTEMATICS EFFECTS

- Various systematic effects taking into account
  - Oscillation parameters
    - Δm^2, θ_{12} fixed; θ_{13} fitted within its error
    - ΔM^2, θ_{23}, δ_{CP} → fitted unconstrained
  - Flux, cross section , detector related

(average fluctuation w.r.t. nominal)

- Overall normalisation (2.0%)
- $\nu/\bar{\nu}$ ratio (4.0%)
- e/μ ratio (1.2%)
- NC scaling (11.0%)
- Energy slope (0.5%)
- →Fitted unconstrained

CONCLUSIONS

First phase of KM3NeT will be completed by 2016

- Definite proof of KM3NeT technology and check of telescope performance for ARCA and ORCA
- 0.1 km^3 times larger than Antares

Physics case for KM3NeT 2.0 defined

KM3NeT/ARCA can investigate the neutrino sky with unprecedented resolution and sky coverage

Preliminary KM3NeT/ORCA results encouraging

- futher improvements expected