HIGH-ENERGY NEUTRINO ASTRONOMY WITH KM3NeT/ARCA

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KM3NET

KM3NeT is a research infrastructure in the Mediterranean Sea hosting neutrino detectors

- **KM3NeT/ARCA** (*A*stroparticle *R*esearch with *C*osmics in the *A*byss ☛ this talk)
  - discovery and observation of high energy (GeV ÷ PeV) neutrino sources ☛ a telescope offshore Capo Passero (Sicily-Italy) is in construction at a depth of 3500m
- **KM3NeT/ORCA** (*O*scillation *R*esearch with *C*osmics in the *A*byss ☛ talk of J. Hofestadt)
  - determination of the neutrino mass hierarchy ☛ a detector offshore Toulon (France) able to detect neutrinos of tens of GeV is in construction at a depth of 2500m

ORCA and ARCA same detector technology

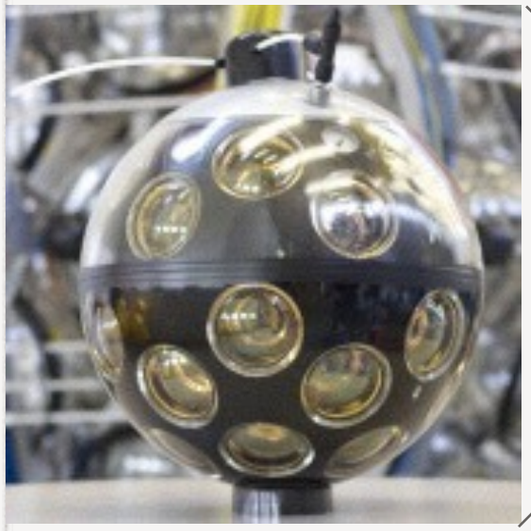
Details on the ARCA and ORCA physics performances and on the technical design in the recently published **Letter of Intent** ☛

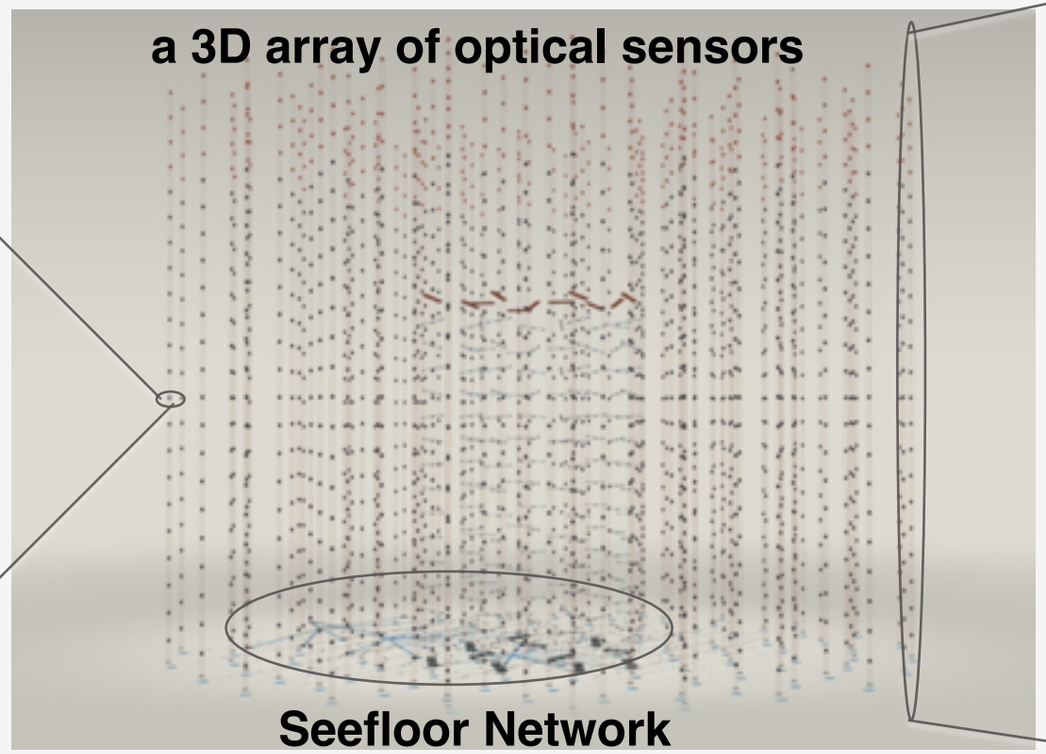

OPEN ACCESS
IOP Publishing
Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **43** (2016) 084001 (130pp)
doi:10.1088/0954-3899/43/8/084001

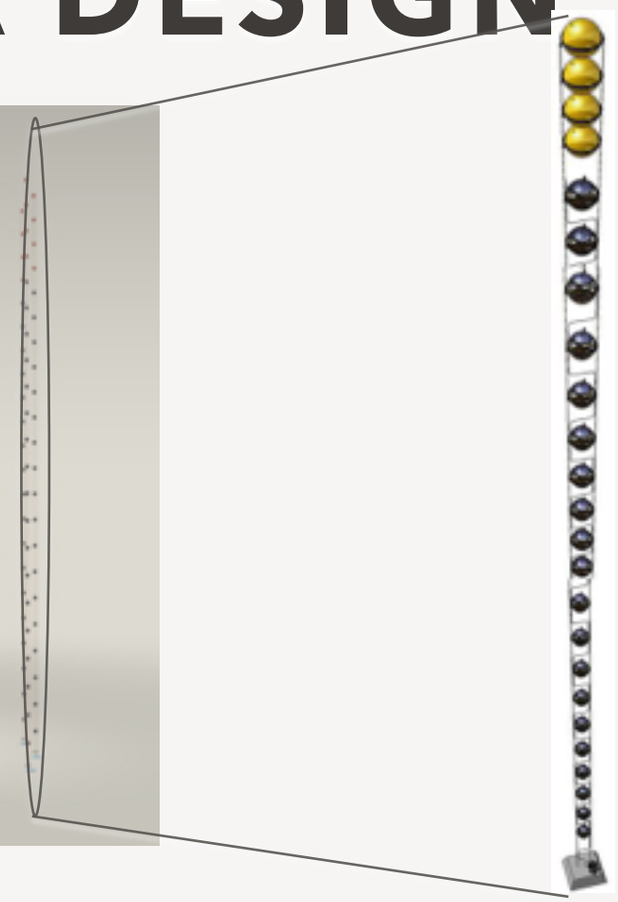
Letter of intent for KM3NeT 2.0

THE KM3NET/ARCA DESIGN

The optical sensor: the Digital Optical Module (DOM)



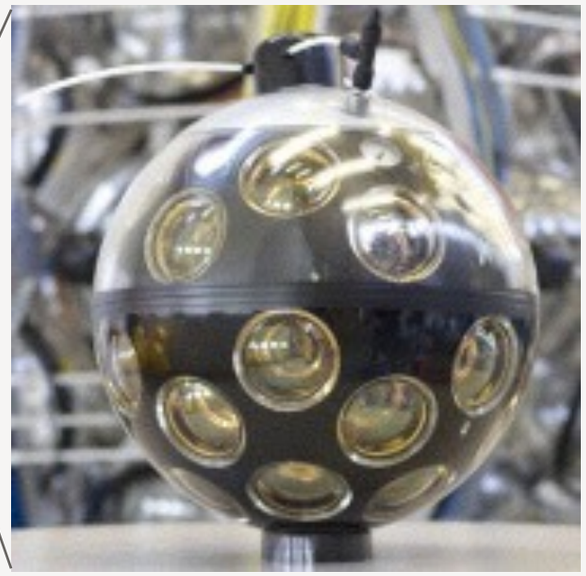




The Detection Unit (DU)

- The ARCA detector is made of 2 building blocks of 115 Detection Units (DU) each with 90 m DU interspacing (0.5 km3/block)
- The DU is a vertical slender string equipped with 18 Digital Optical Modules (DOM) 36 m distant. Each DOM consists of 31 3'' PMTs.
- 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

THE OPTICAL SENSORS AND THE DETECTION UNIT



The DOM is a new design for optical sensors developed in the collaboration. It is a 17″ glass sphere with inside:

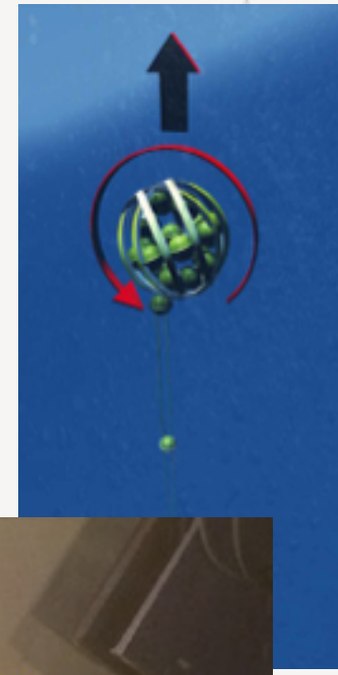
- 31 3″ PMTs (photocathode aerea ≃ 3 × 10″ PMTs)
- LED and Piezo
- FPGA readout

Hybrid white rabbit for time synchronization

DWDM for data transmission

The Launcher vehicle (2m diameter)

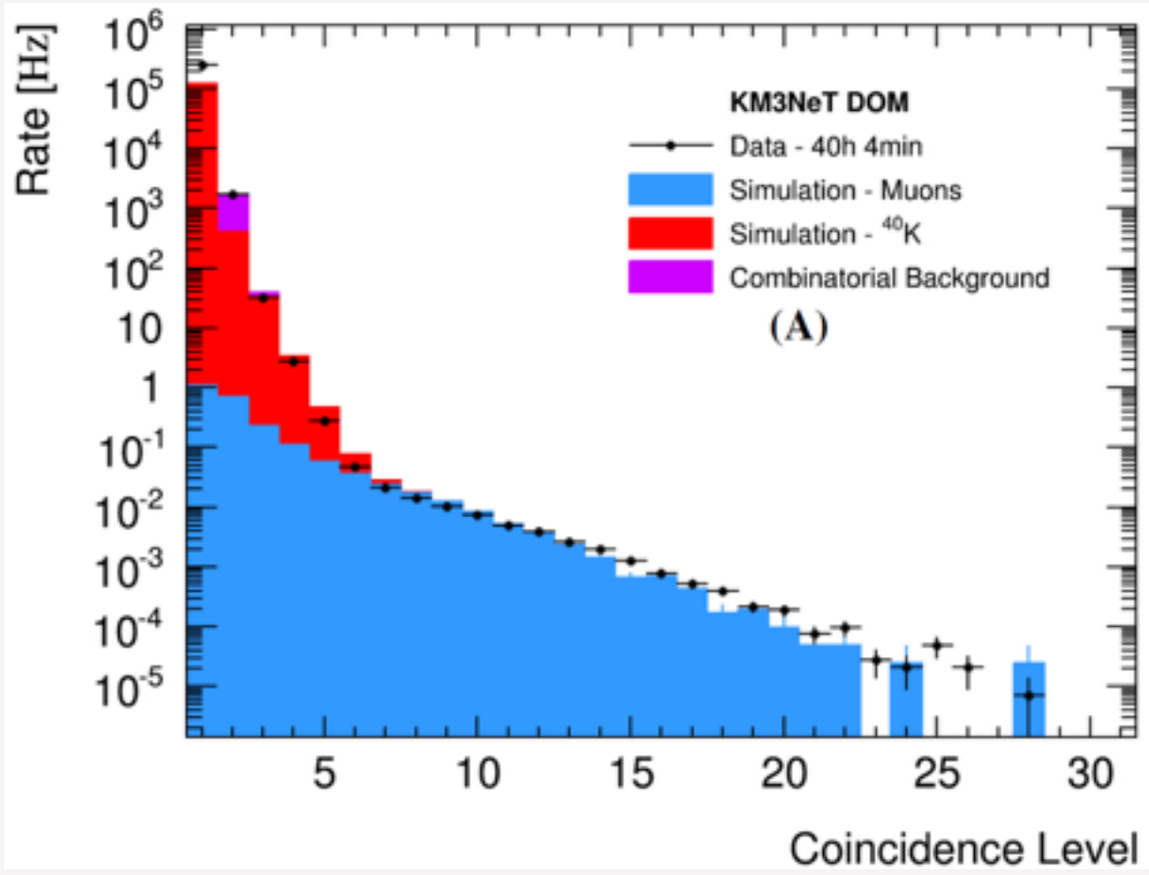
- rapid deployment
- autonomous unfurling
- recoverable



THE DOM PROTOTYPE

DOM prototype deployed at Antares site April 2013

validation of DOM capabilities in situ

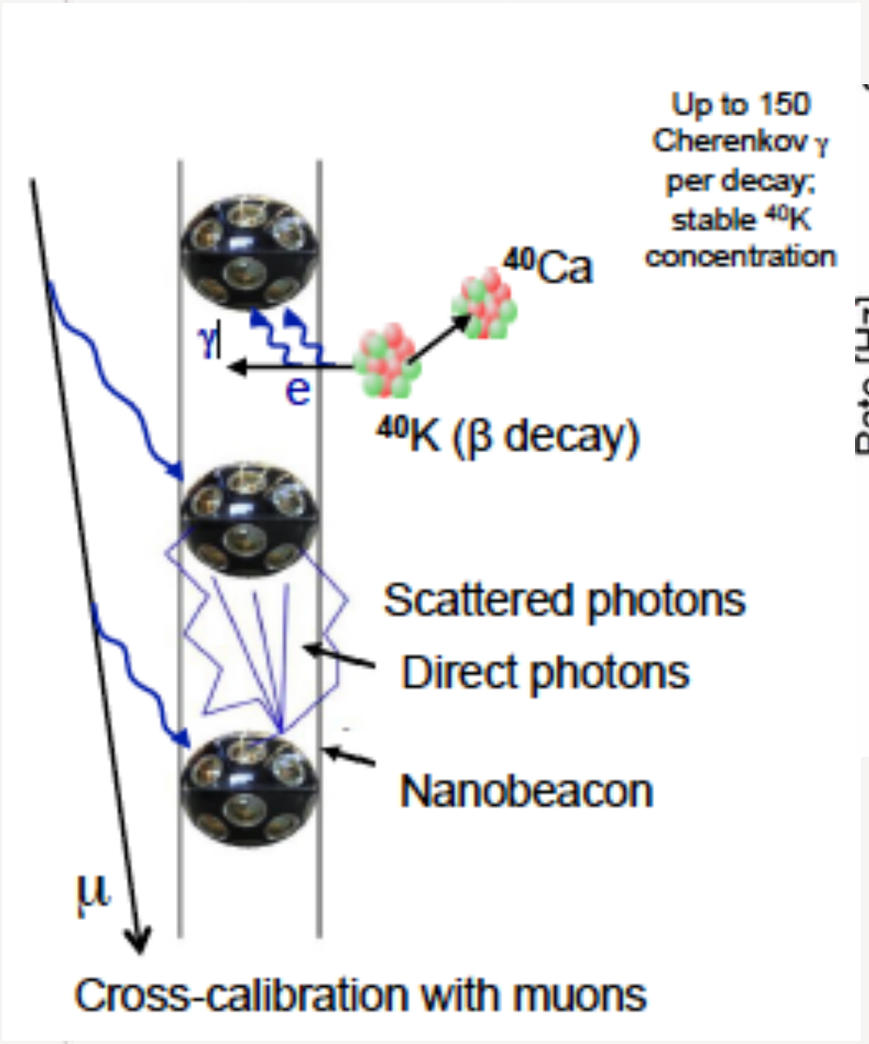


Proved that with a single DOM the selection of events from atmospheric muons is possible

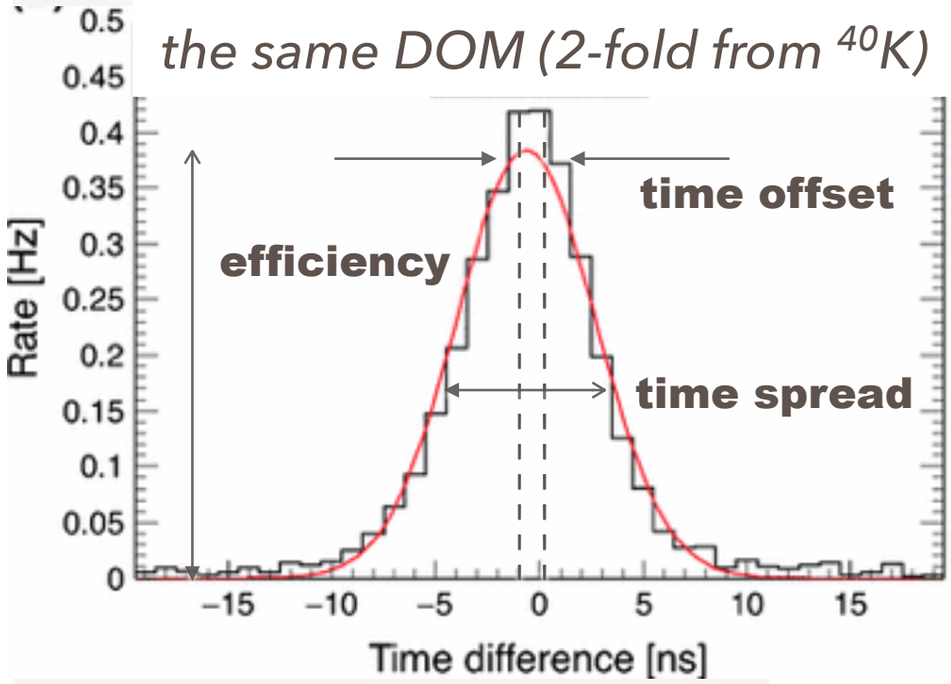
Result published in Eur. Phys. J. C (2014) 74: 3056

THE DU PROTOTYPE

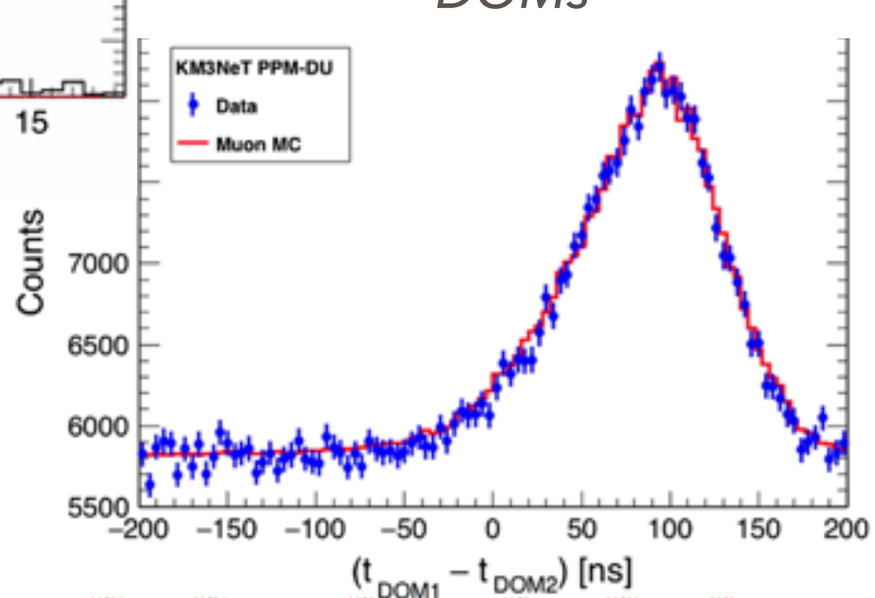
String prototype (3 DOMs) deployed at Capo Passero site May 2014



Time difference between PMTs in the same DOM (2-fold from ^{40}K)



Time differences between coincidences on the different DOMs



Proved that the time calibration between PMTs in the same DOM and between DOMs is feasible in a fast and reliable way

Results published in Eur. Phys. J. C 76 (2016) 76:54

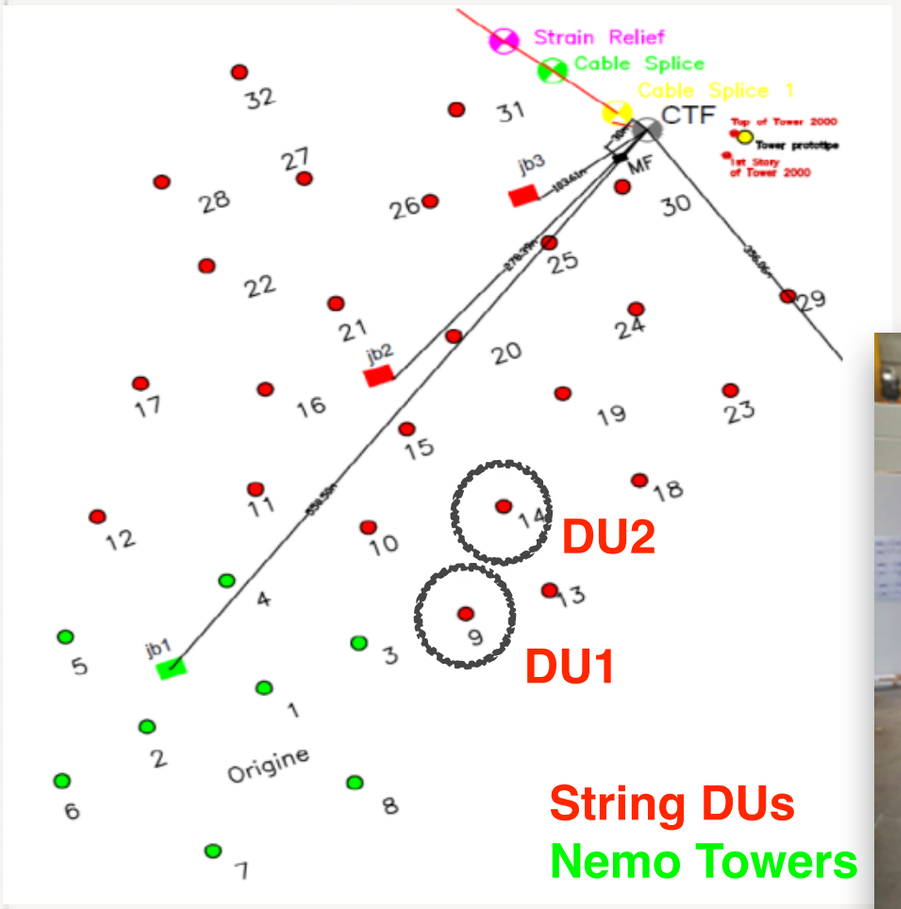
THE KM3NET PHASED IMPLEMENTATION

Phase	Building blocks		Number of DUs		Physics goal		Status
	ARCA	ORCA	ARCA	ORCA	ARCA	ORCA	
1	0.2	0.06	23	7	Proof of feasibility and first science results. Joined analysis with ANTARES data		Fully funded. First 2 DUs installed and functioning at Capo Passero
2.0	2	1	230	115	All flavor astronomy. Study of the neutrino signal reported by IceCube.	Determination of the neutrino mass hierarchy	Not yet funded
3	6	-	690	-	Neutrino astronomy including Galactic sources.		Not yet funded

KM3NET-PHASE1: THE FIRST DUS INSTALLED

Two lines in operation at Capo Passero site: the first one deployed in December 2015, the second one in May 2016.

ARCA phase-1 footprint



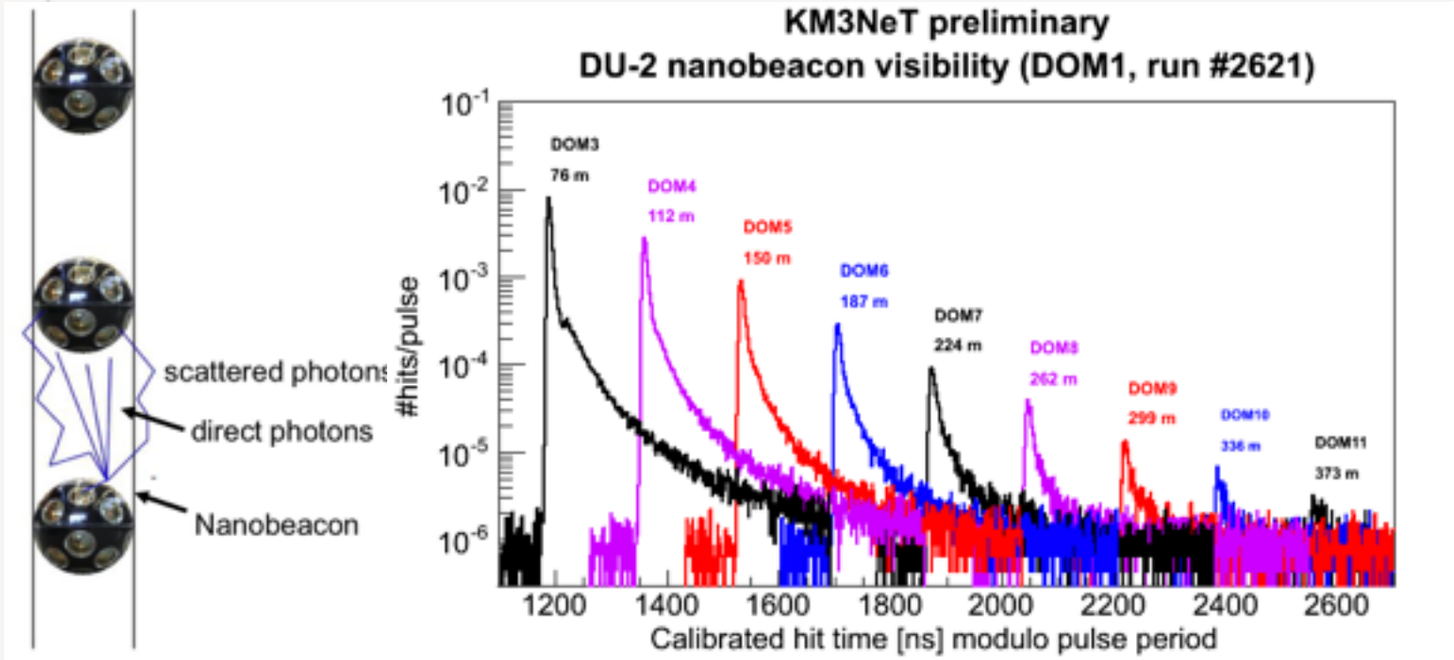
CTF: Cable Termination (Frame)
: Secondary Junction boxes
: Tower DU
: String DU
PPM-DU

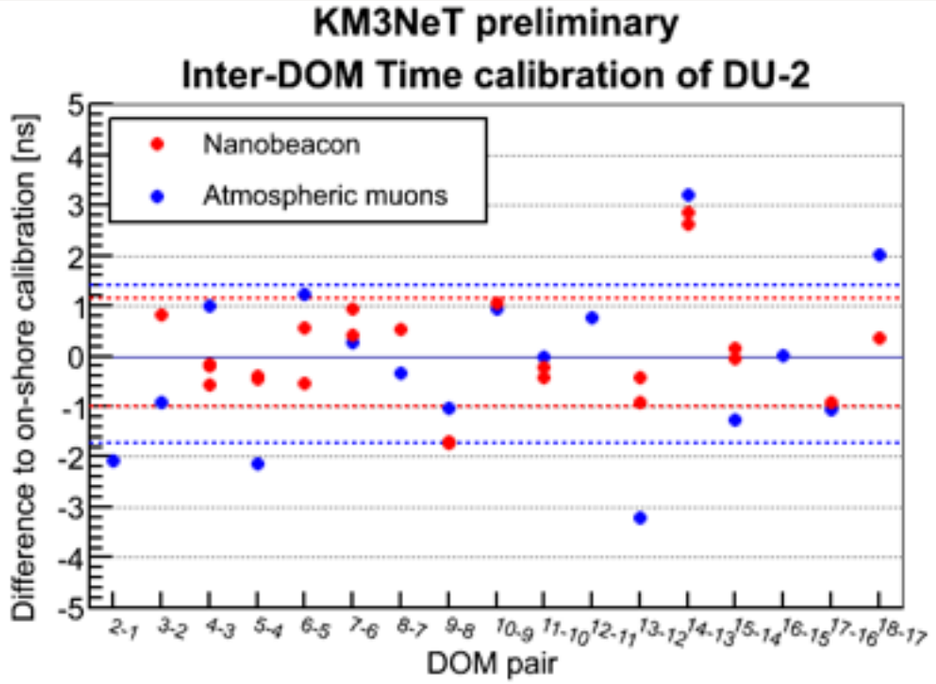
Junction Box

Capo Passero shore station

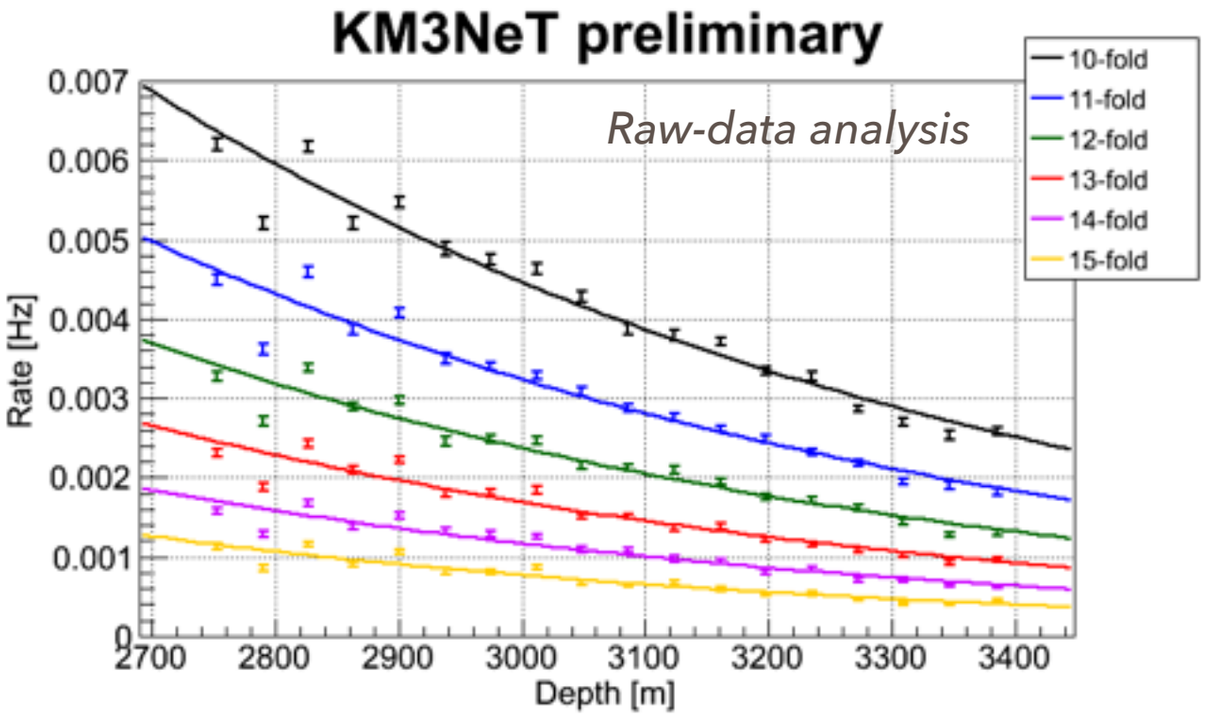
ARCA DU1 at the sea bottom

FIRST RESULTS FROM ONE OF THE FIRST DUS INSTALLED





Comparison of calibration with LED nanobeacons and atmospheric muons in agreement. In situ nanobeacon calibration and on-shore laser calibration agree to ≈1 ns



Rate of high coincidence events in the DOMs reflects the behavior of the atmospheric muon intensity as a function of the depth

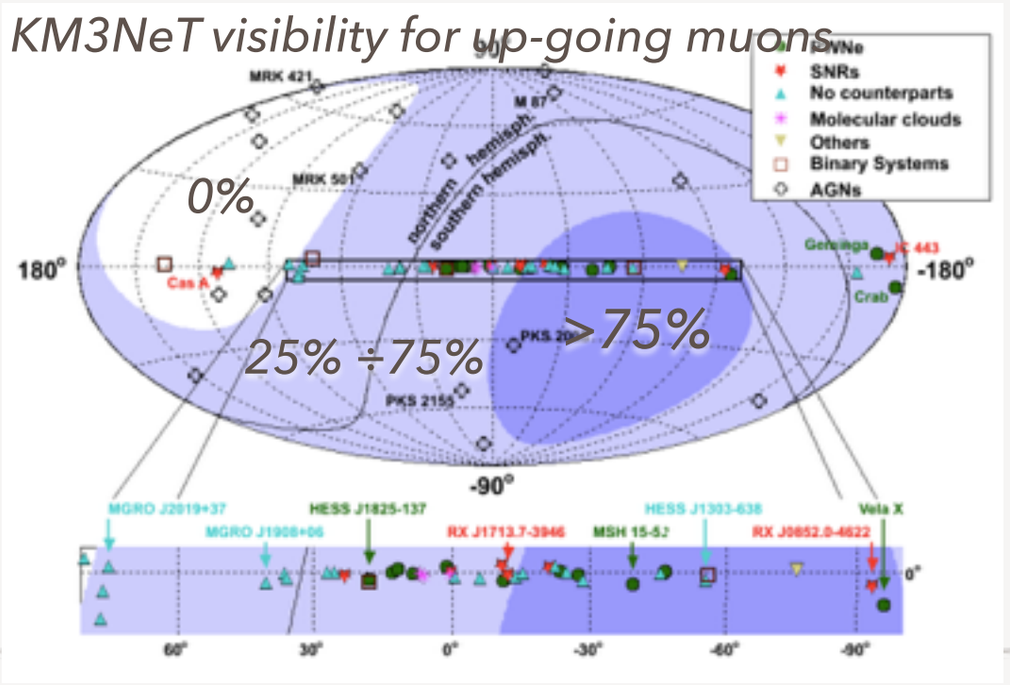
THE KM3NET/ARCA PECULIARITIES

Current knowledge:

- Origin of the detected IceCube cosmic flux not yet known. Tension in the energy slope of the measured high energy muon neutrinos from Northern Hemisphere and the full sky all flavour data. Presence of a galactic component not excluded (arXiv:1607.08006)
- High energy neutrinos from known sources not yet observed.

KM3NeT-ARCA can probe the Universe from a different field of view with a better angular resolution

KM3NeT visibility for up-going muons



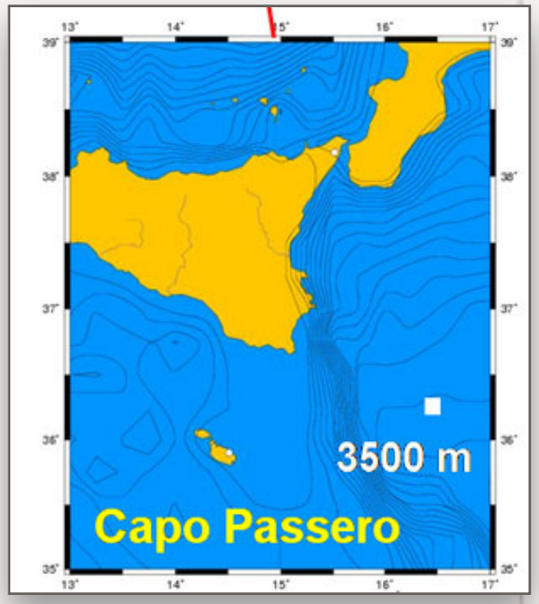
sea water is a clean and homogeneous medium

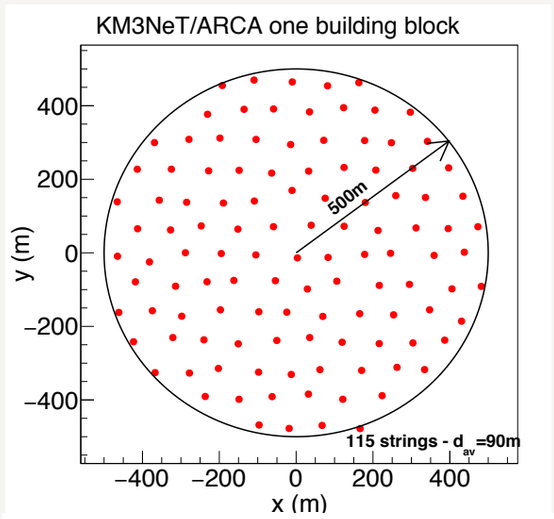
THE KM3NET/ARCA LAYOUT

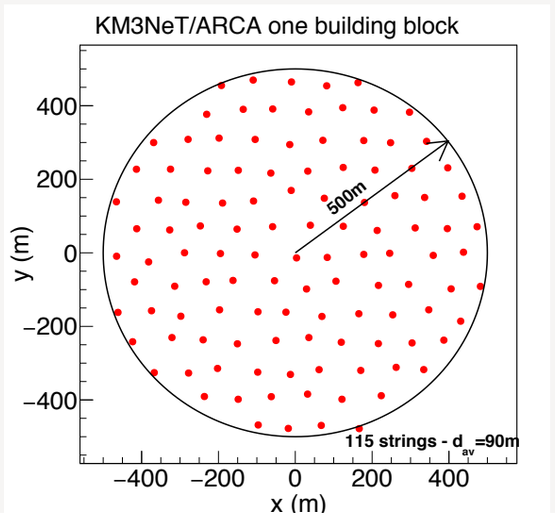
KM3NeT-ARCA: two building blocks of 115 DUs (together about 1 km3) being installed at the Italian site at 3500m

- ★ 18 DOM per DU
- ★ Vertical DOM spacing 36 m
- ★ Inter-DU spacing 90 m

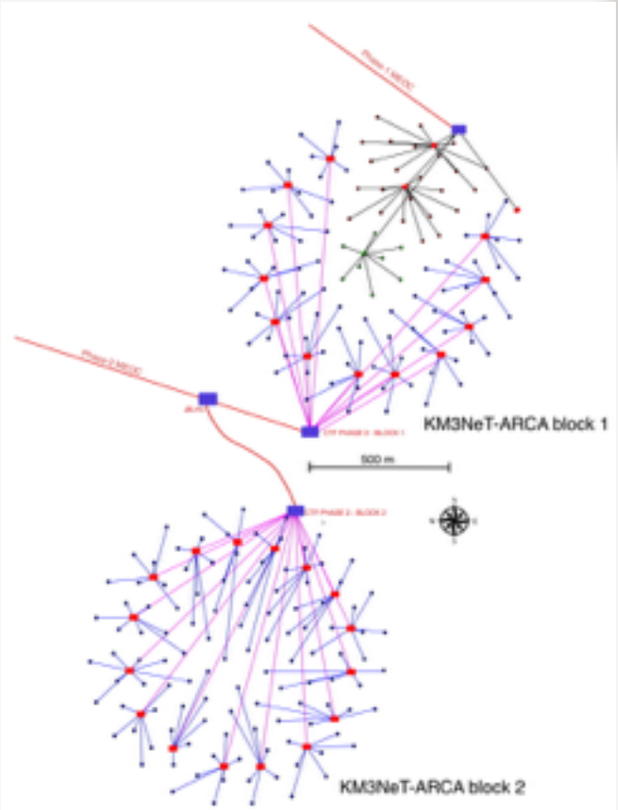
Italian site location







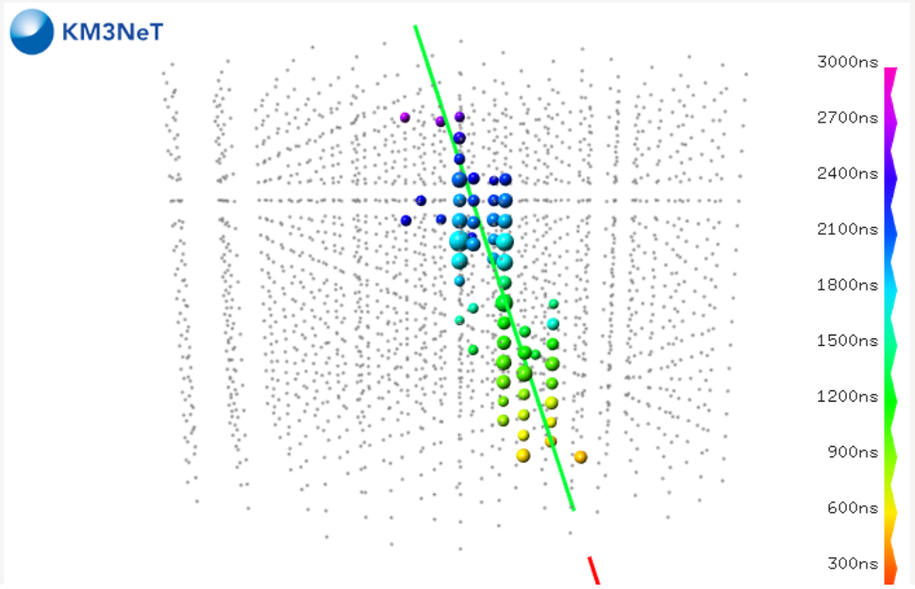
MC layout

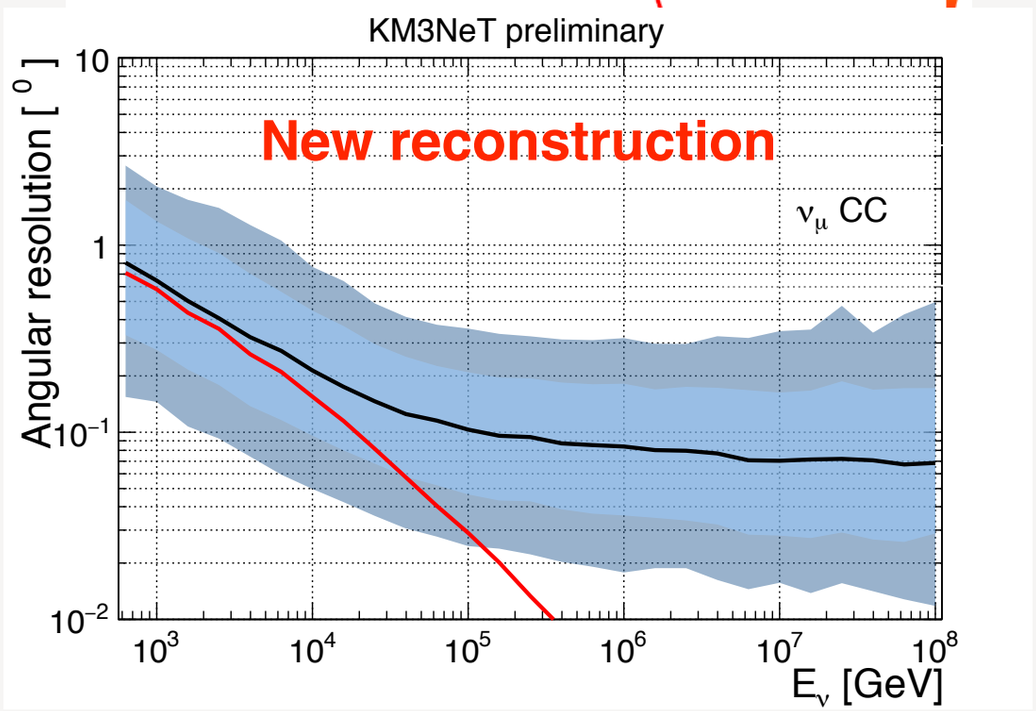


Detector layout

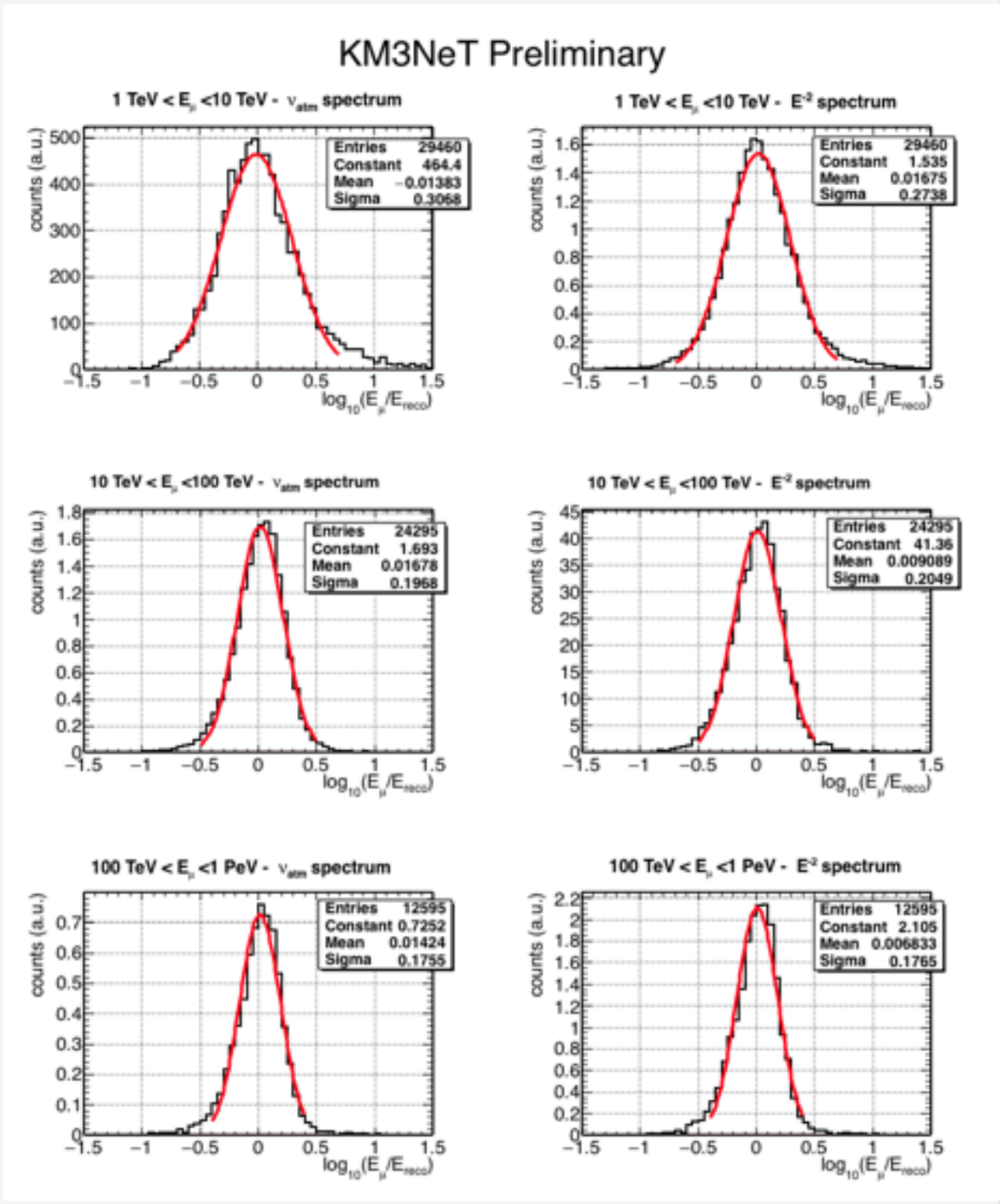
THE KM3NET/ARCA RESOLUTION FOR "TRACK-LIKE" EVENTS

"Track-like" events mainly from ν_μ CC interactions





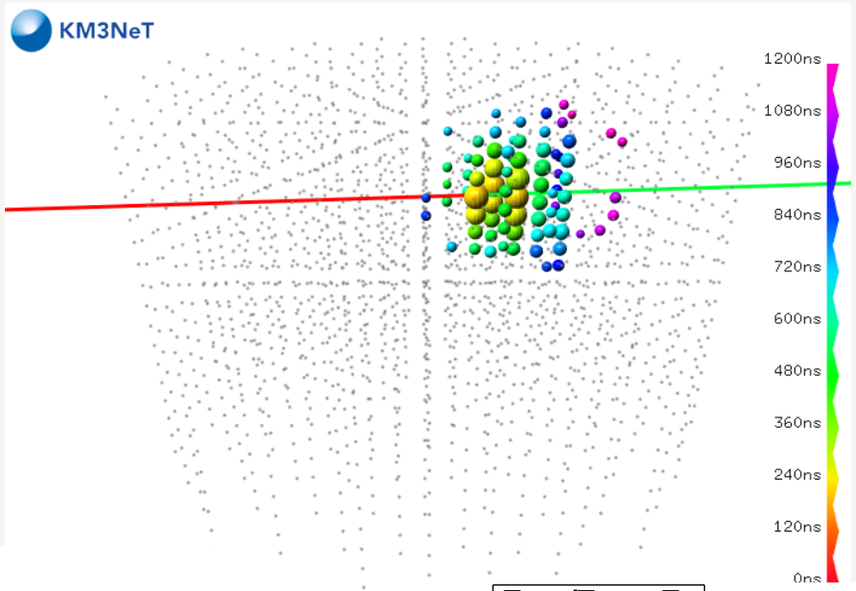
angular resolution better than 0.2° for E_ν>10 TeV and 0.1° for E_ν>100 TeV

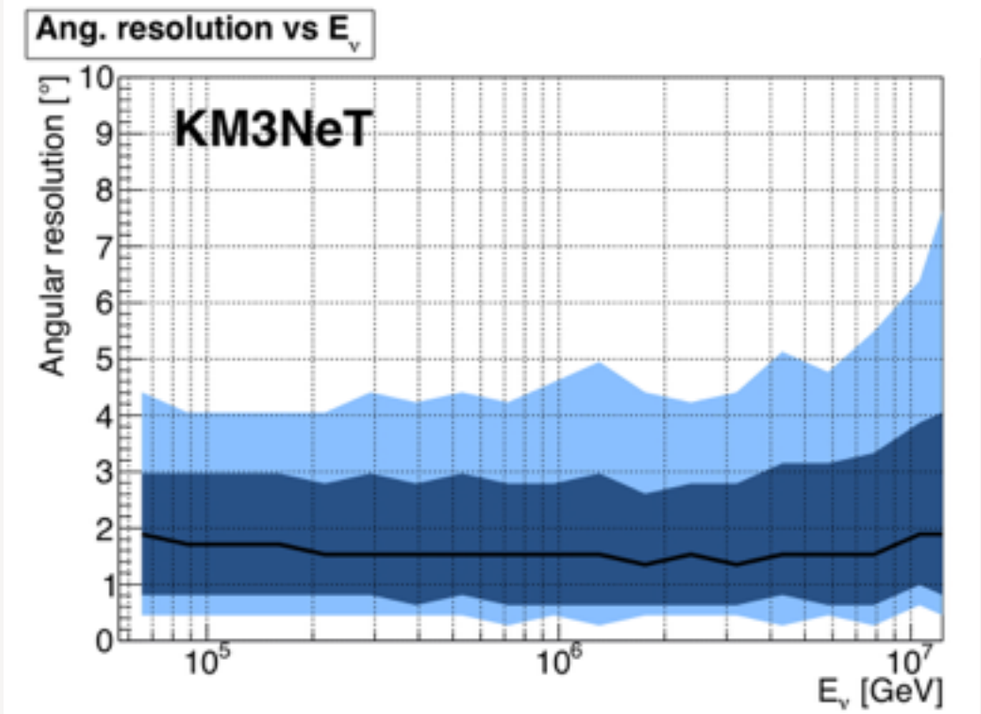


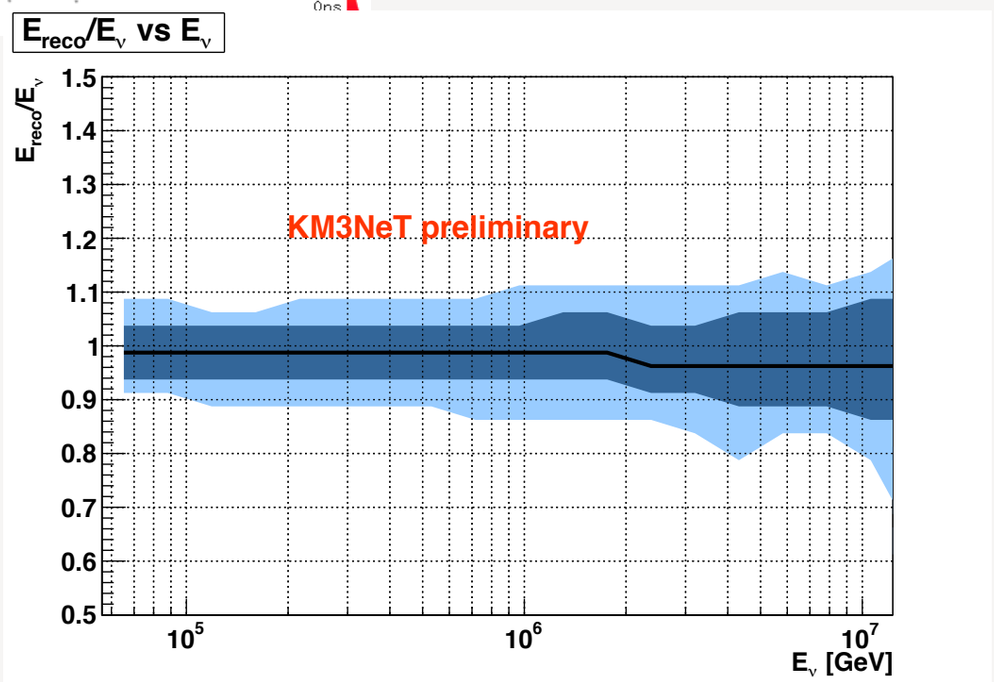
energy resolution better ≈ 20% of the $\log_{10}E_\mu$ for E_μ>10 TeV

THE KM3NET/ARCA RESOLUTION FOR "CASCADE" EVENTS

"Cascade-like" events mainly from ν_e CC and NC interactions







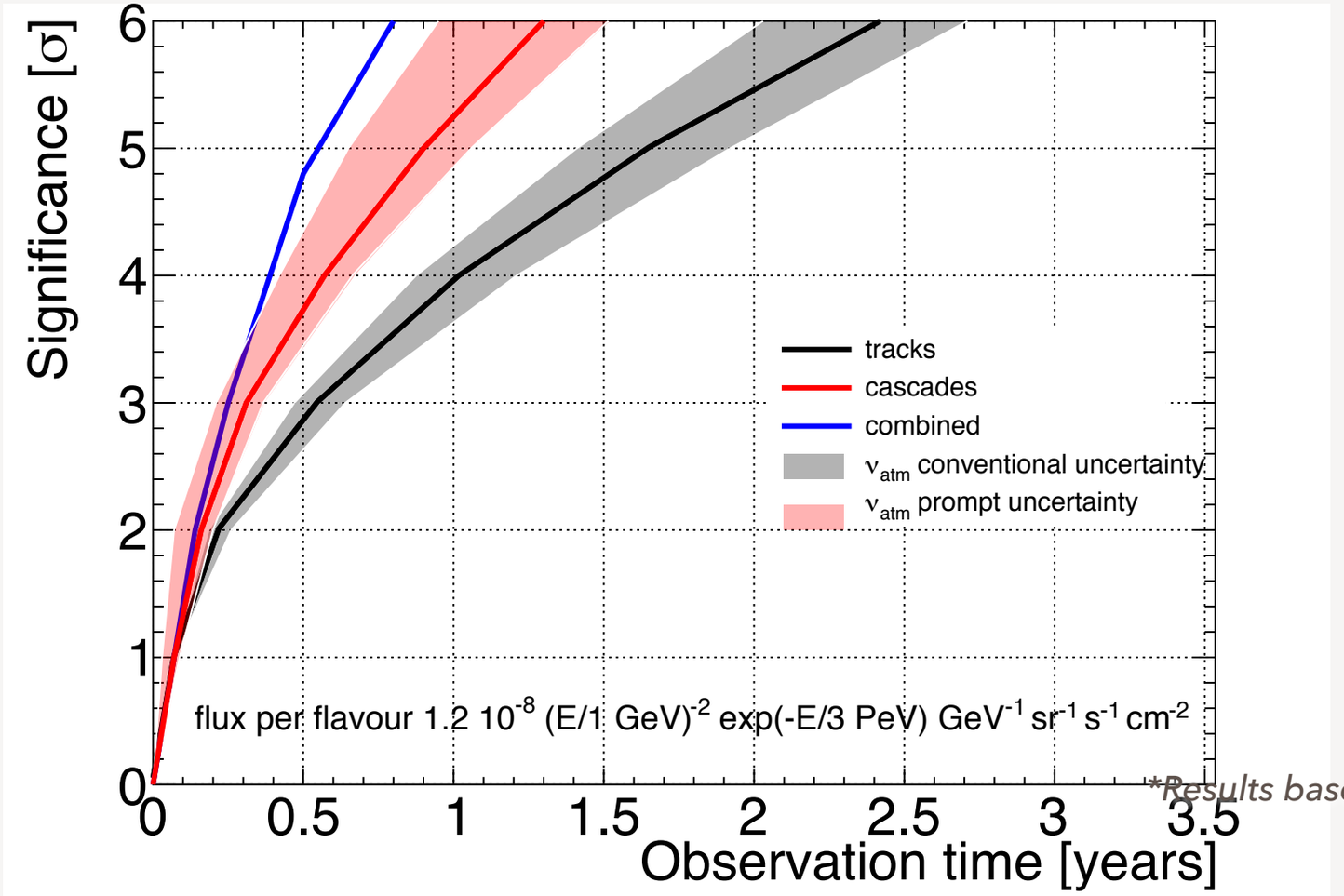
angular resolution better than 2°

energy resolution better ≈ 5% at 1σ

DIFFUSE FLUX*

Benchmark flux : IceCube flux (isotropic and flavour symmetric)

$$\Phi(E) = 1.2 \cdot 10^{-8} \left(E/1\ \text{GeV}\right)^{-2} \exp\left(-E/3\ \text{PeV}\right)\ \ \text{GeV}^{-1}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$$



- **Track channel**

Analysis for up-going events based on maximum likelihood of preselected events. Pre-cuts on θ_{zen} >80°, reconstruction quality parameter and N_{hit} (proxy for muon energy)

- **Cascade channel**

Containment cut on reconstructed vertex to remove atmospheric muons (excludes upper 100m layer)

All sky analysis based on BDT and maximum likelihood.

**Results based on the old track reconstruction*

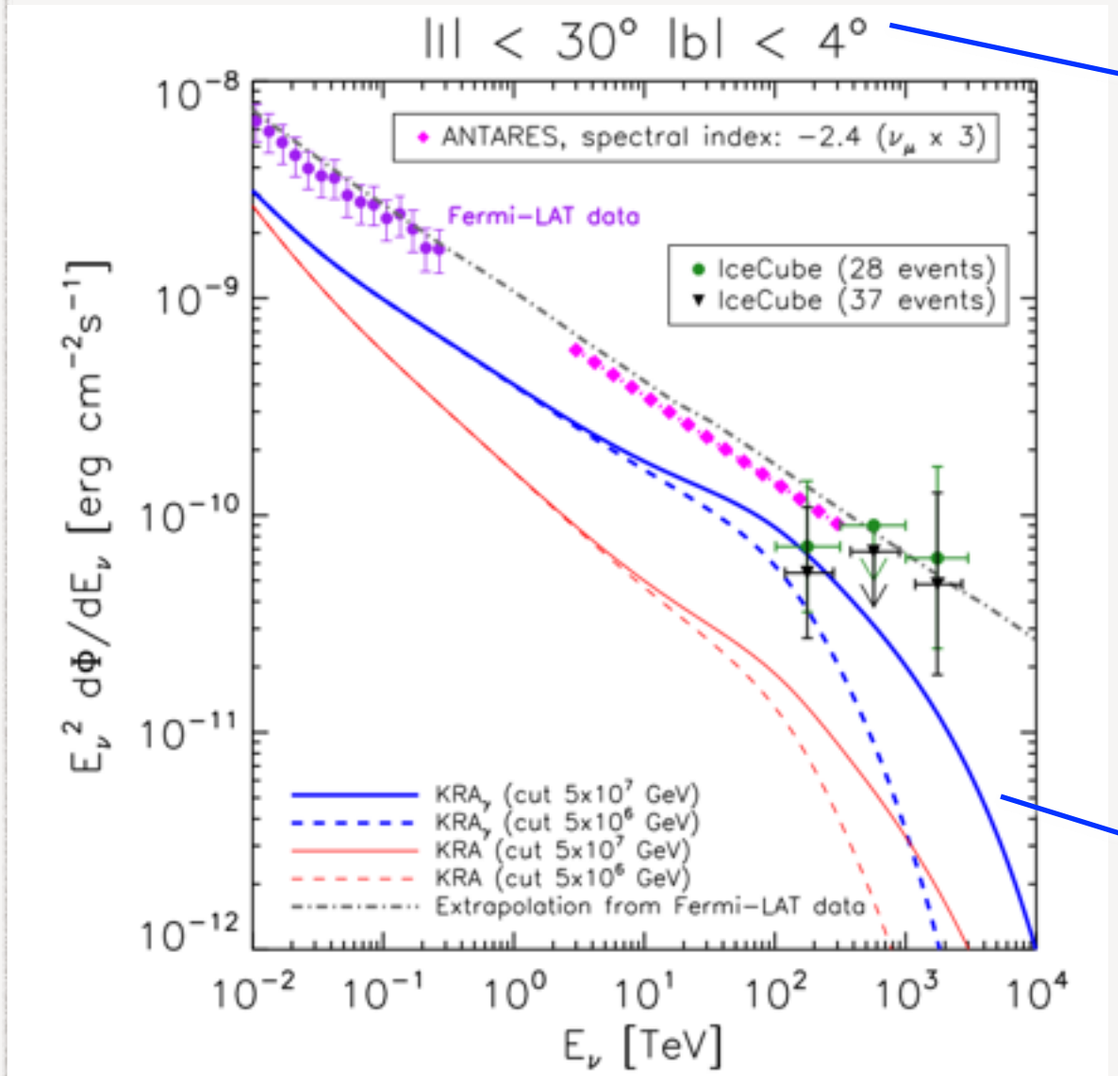
Discovery at 5σ (50% probability) in less than one year

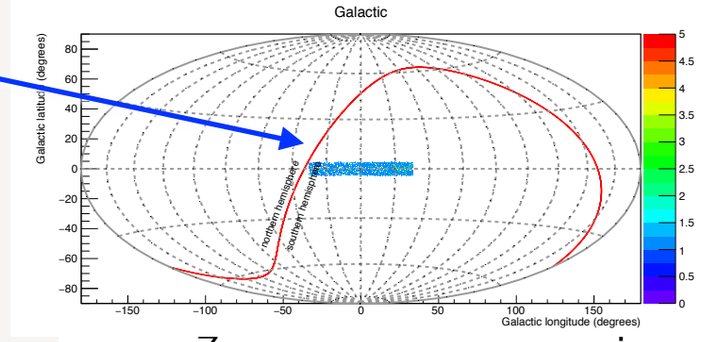
Details of the analysis in J. Phys. G: Nucl. Part. Phys. 43 (2016) 084001 (130pp)

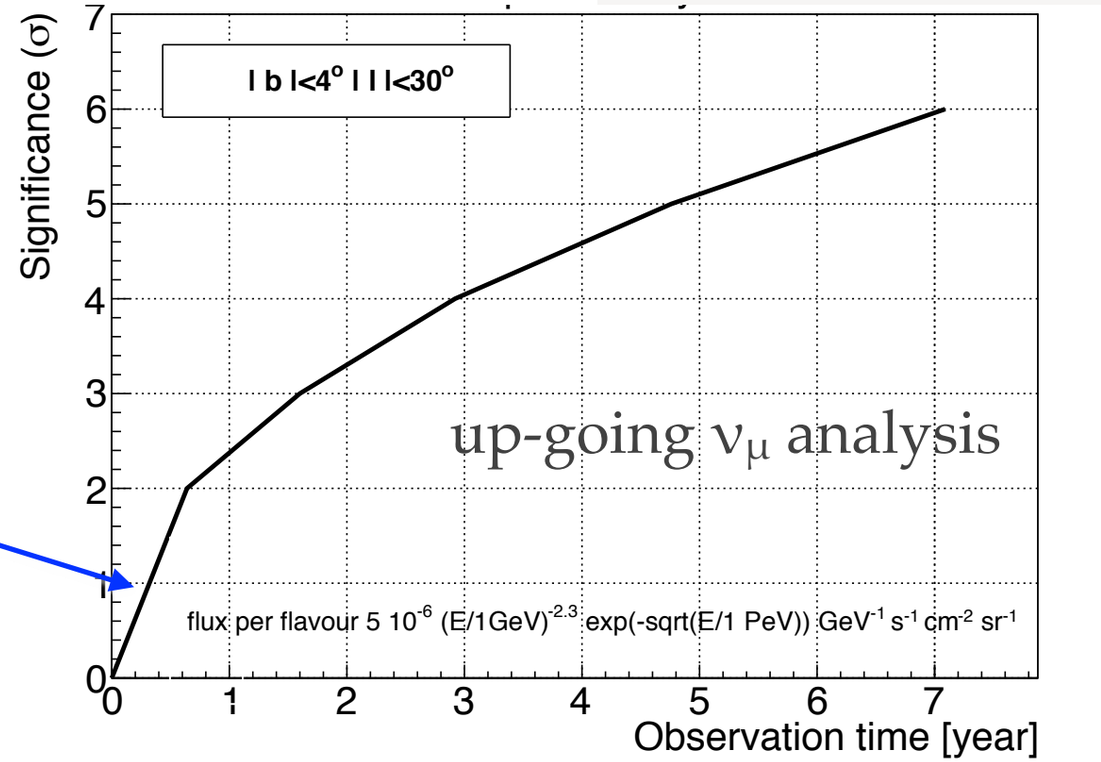
**Results based on the old track reconstruction*

DIFFUSE FLUX FROM GALACTIC PLANE*

Benchmark flux from D. Gaggero et al., proceedings ICRC2015. Evaluation of the neutrino flux based on a radially-dependent cosmic-ray transport properties







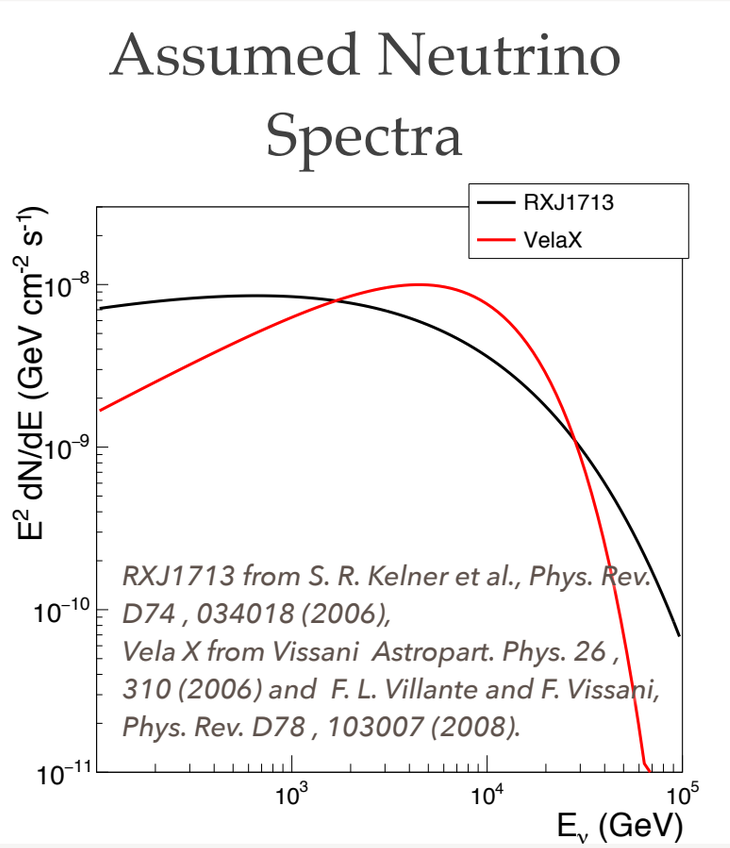
Discovery at 5σ (50% probability) in about 5 years

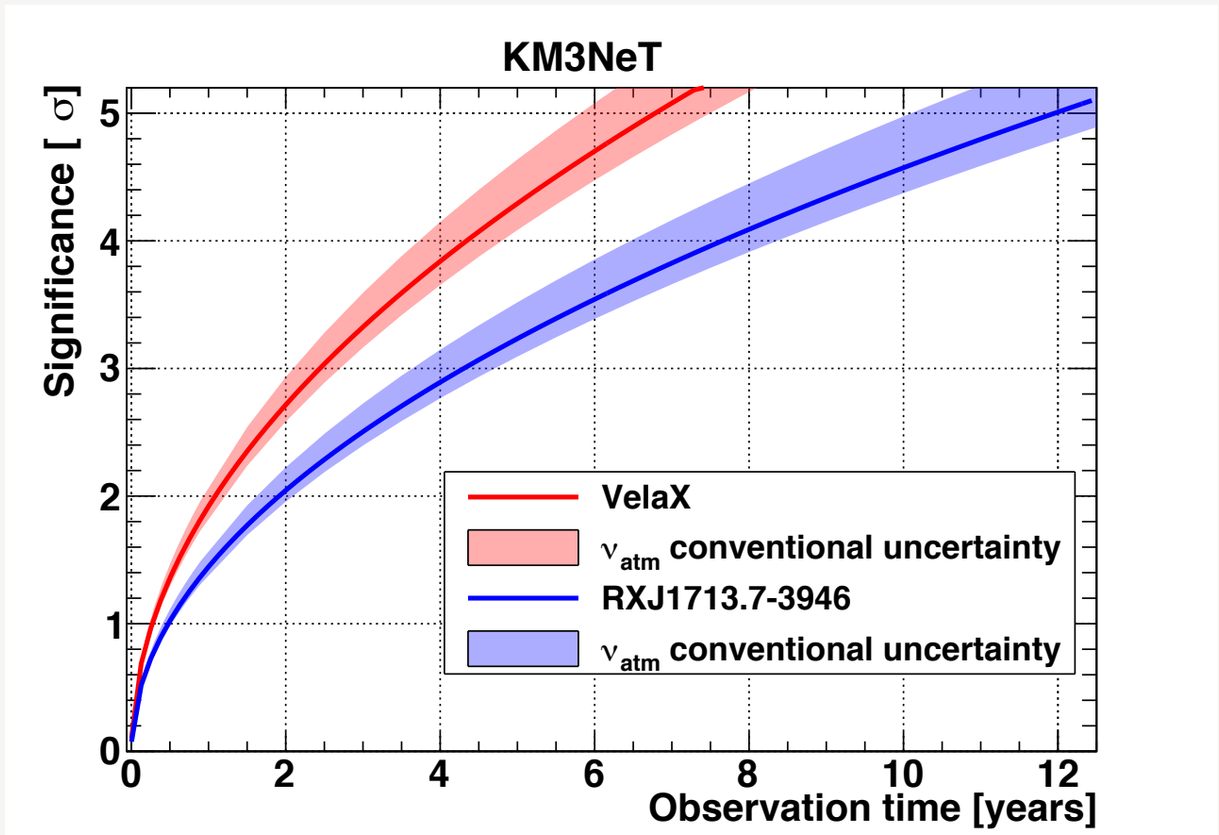
Details of the analysis in J. Phys. G: Nucl. Part. Phys. 43 (2016) 084001 (130pp)

**Results based on the old track reconstruction*

GALACTIC SOURCES*

The SNR RXJ1713 and the PWN Vela X
Spectra cutoffs of the order of few tens of TeV
Extension of the sources taken into account (0.6° for RXJ1713 and 0.8° for VelaX)





RXJ1713 ☛ Discovery at 3σ (50% probability) in ≈ 4 years

VelaX ☛ Discovery at 3σ (50% probability) in ≈ 2 years

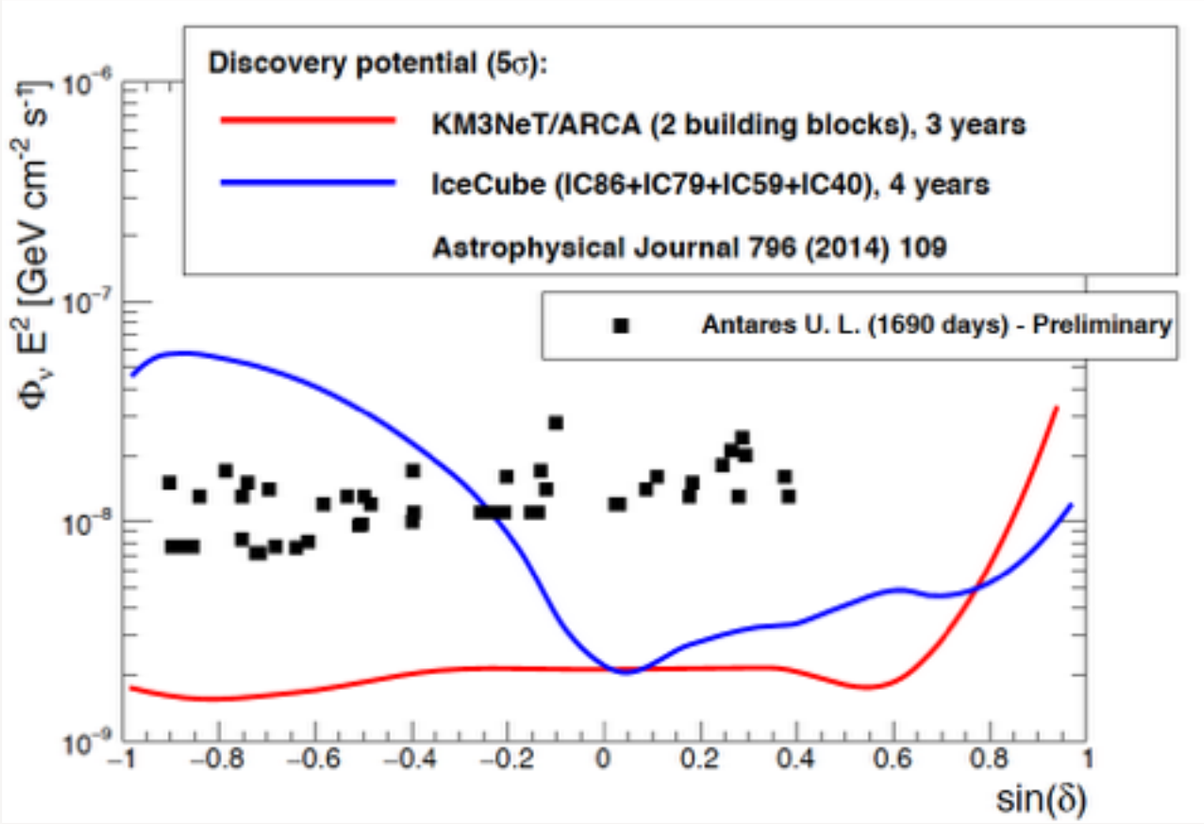
Details of the analysis in J. Phys. G: Nucl. Part. Phys. 43 (2016) 084001 (130pp)

**Results based on the old track reconstruction*

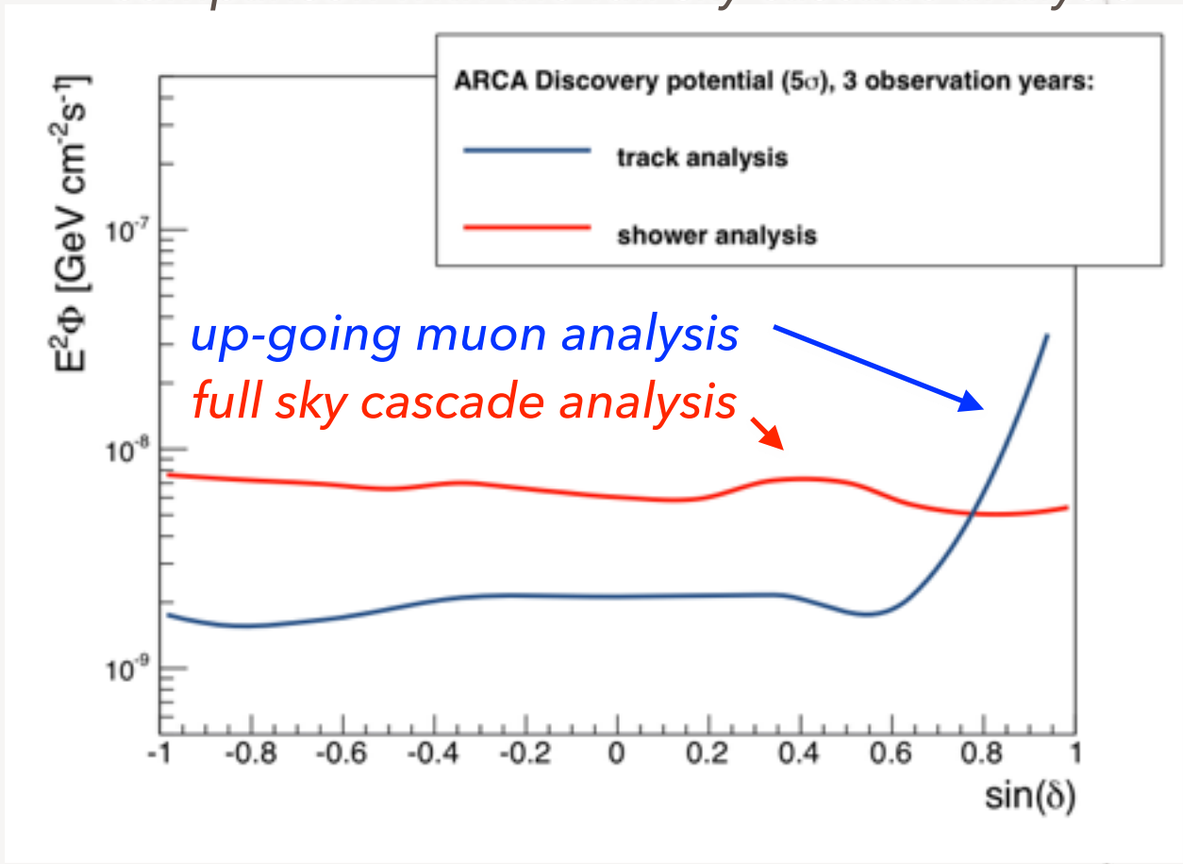
POINT-LIKE SOURCES*

Benchmark flux proportional to E^{-2} flux

up-going muon neutrinos analysis



comparison with the full sky cascade analysis



Better sensitivity (for equivalent exposure) and better sky coverage than IceCube

Details of the analysis in J. Phys. G: Nucl. Part. Phys. 43 (2016) 084001 (130pp)

**Results based on the old track reconstruction*

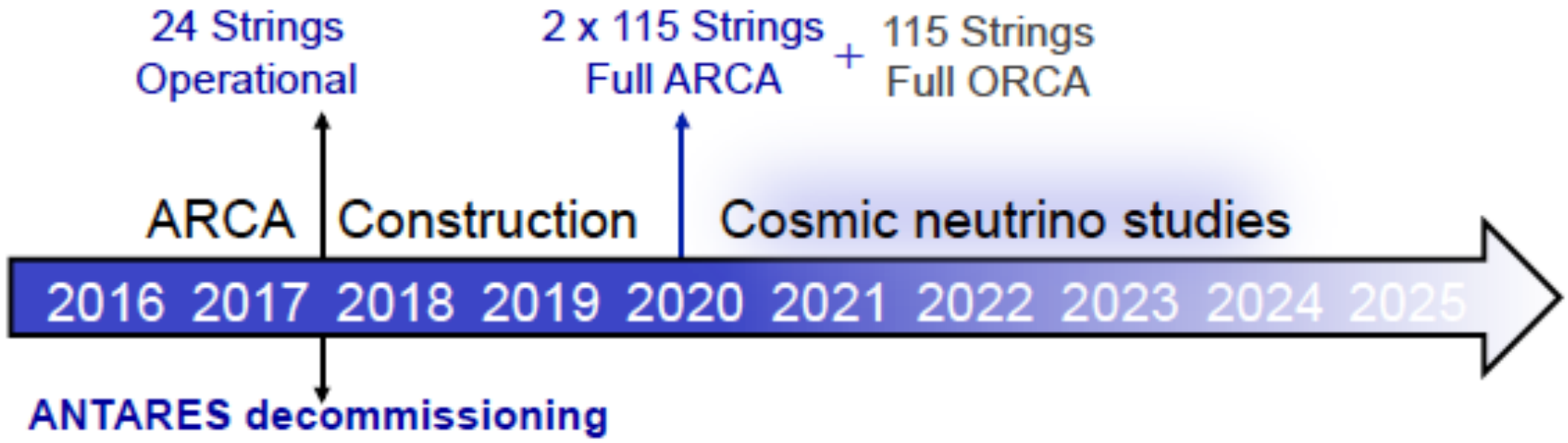
CONCLUSION

KM3NeT will soon take over from ANTARES as the biggest detector in the Northern Hemisphere (KM3NeT phase-1 will be ≈ 0.1 km^3)

- ★ KM3NeT phase-1: 2 DUs of ARCA already installed and fully functioning at the Italian site
- ★ Following phase KM3NeT 2.0
- ★ KM3NeT/ARCA (≈ 1 km^3) will be installed at the Italian node of the KM3NeT distributed infrastructure
- ★ Exciting physics prospects
  - ★ Investigate the neutrino sky with unprecedented resolution and sky coverage

Back up slides

TIME LINE



Total KM3NeT cost: 125M€ (ARCA+ORCA)