KM3NeT/ARCA AND EARTH SCIENCE

R. Coniglione for the KM3NeT collaboration
INFN-LNS - Catania (Italy)

https://www.km3net.org 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)
  - 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)
  - 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

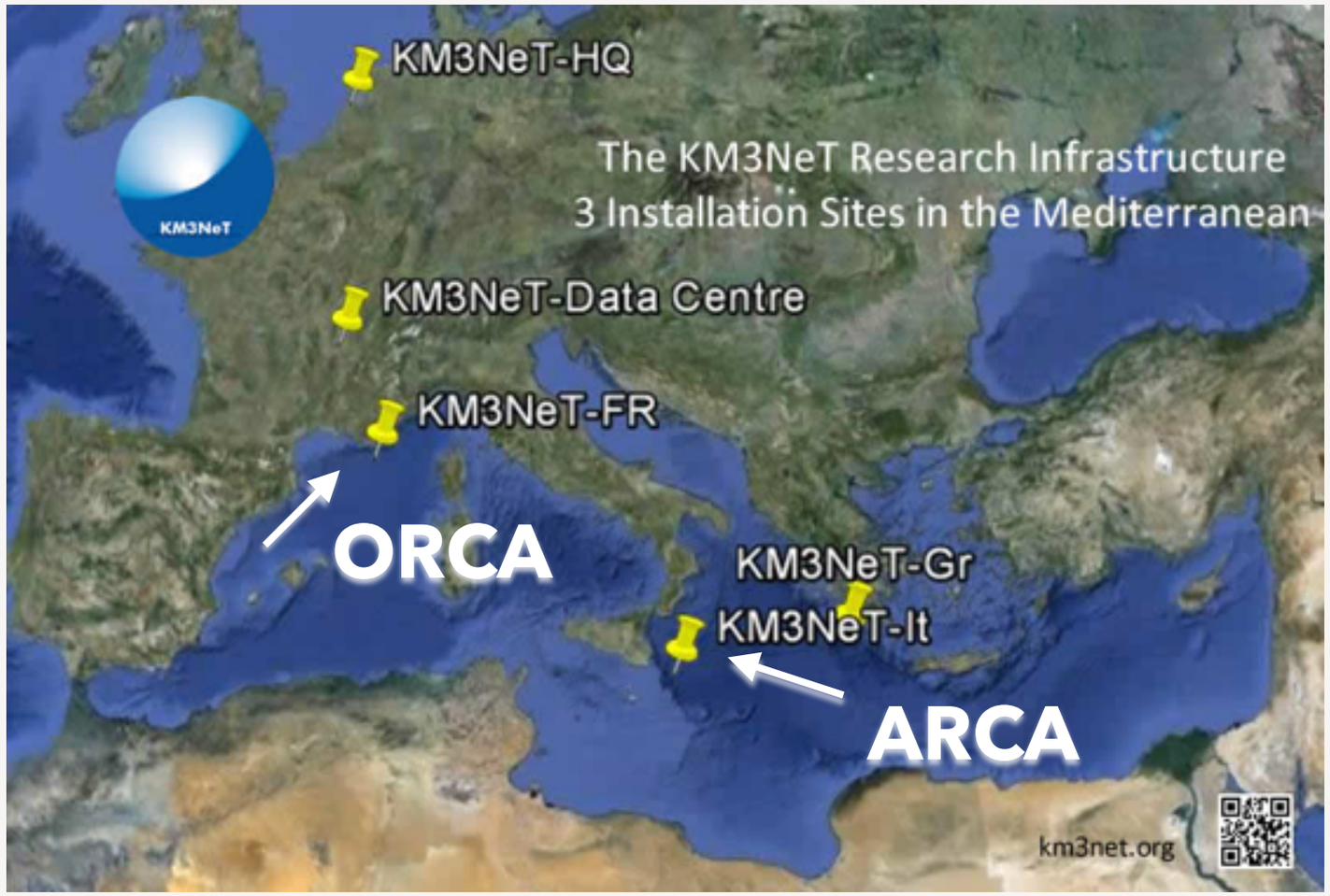
Details on the ARCA and ORCA physics performances and on the technical design in the **Letter of Intent** ☛


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

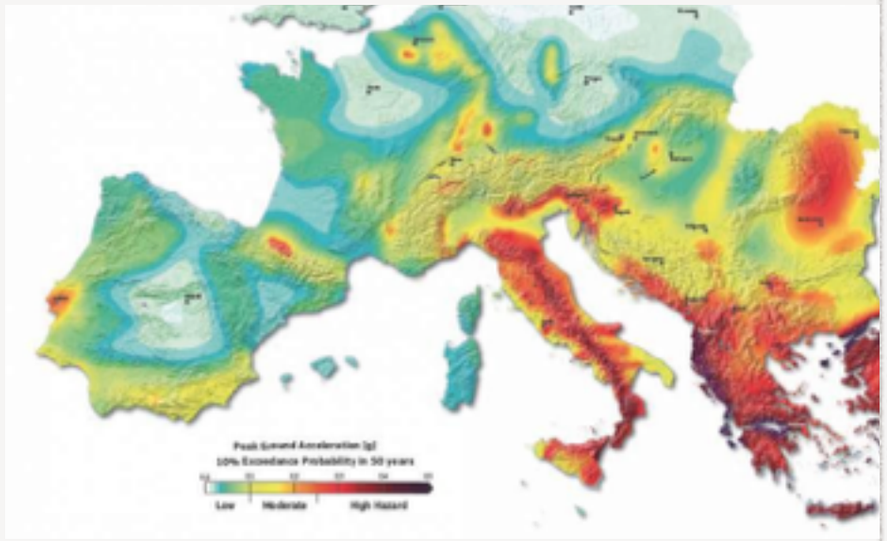
KM3NET

KM3NeT is a cabled deep sea observatory with a continuous and steady power supply enabling real time data acquisition.



map of earthquakes in the Mediterranean area

from http://www.share-eu.org



Real time monitoring of sea and Earth conditions

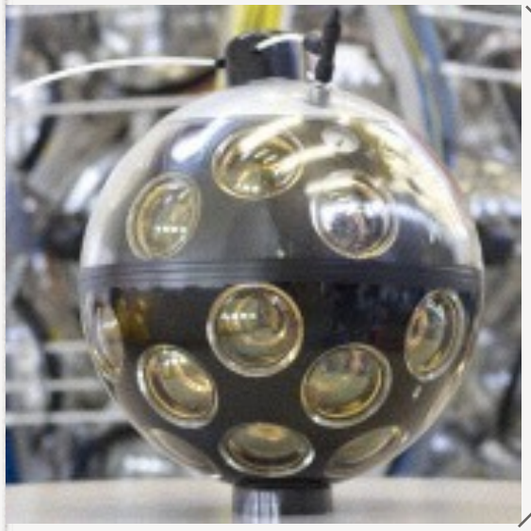
KM3NET

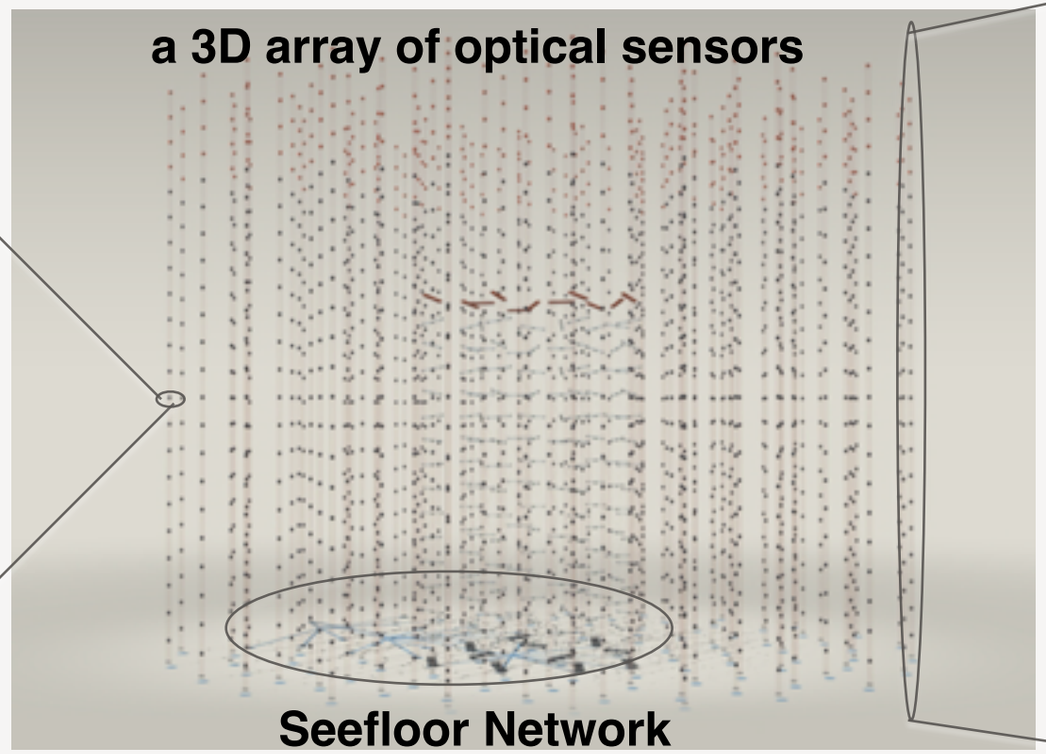
KM3NeT and Earth Science with muons and neutrinos

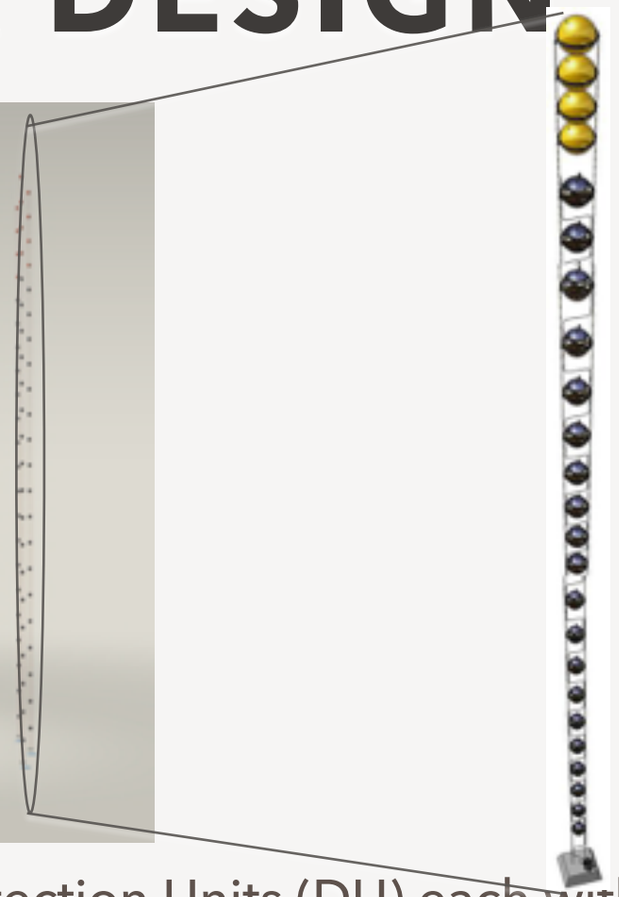
- **Tomography of the Earth from the study of atmospheric neutrino oscillations with KM3NeT/ORCA** 👉 for first predictions see S. Bourret for the KM3NeT coll. at Neutrino 2016 http://neutrino2016.iopconfs.org/home
- **Study of the seafloor dynamics measuring the flux of atmospheric muons with KM3NeT/ARCA (method proposed by Prof. Tanaka)** 👉 first considerations in this talk
- **Tsunami monitoring measuring the flux of atmospheric muons with KM3NeT/ARCA (method proposed by Prof. Tanaka)** 👉 to be studied

THE KM3NET/ARCA DESIGN

The optical sensor: the Digital Optical Module (DOM)



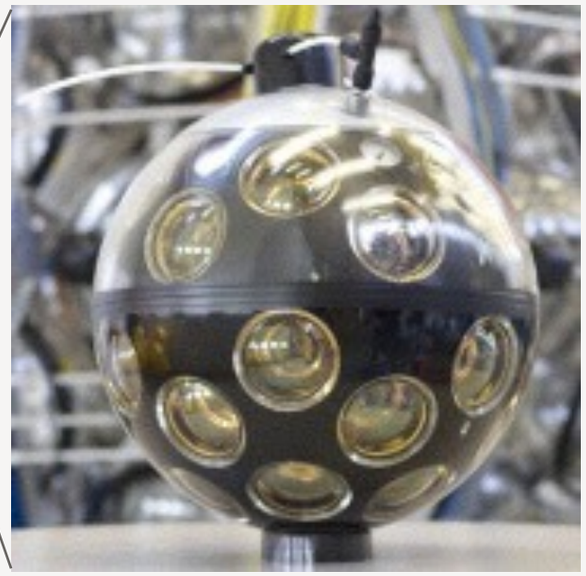




The Detection Unit (DU)

- 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. First DOM at 100m and last DOM at 712m from the sea bottom.
- 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:

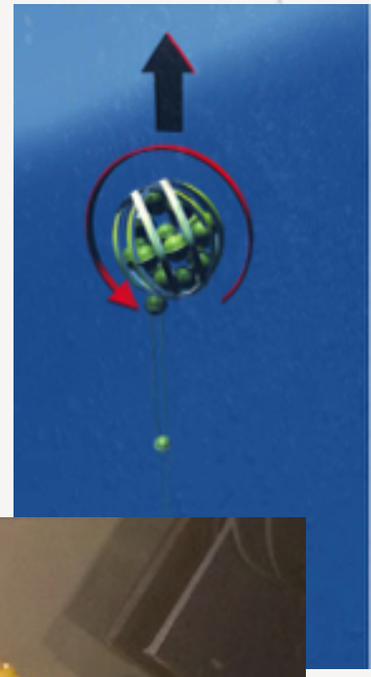
- 31 3″ PMTs (photocathode aerea ≃ 3 × 10″ PMTs)
- LED and Piezo
- FPGA readout

Hybrid white rabbit for time synchronization

DWDM for data transmission

The Launcher vehicle (2m diameter)

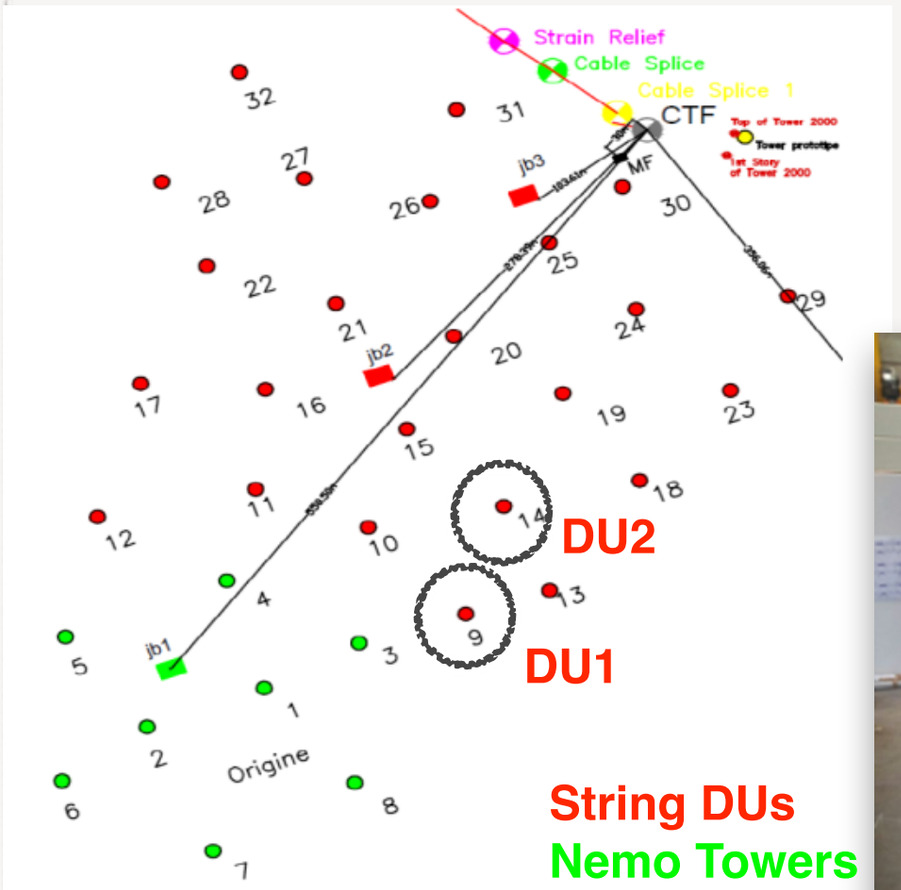
- rapid deployment
- autonomous unfurling
- recoverable



KM3NET/ARCA: CURRENT STATUS

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



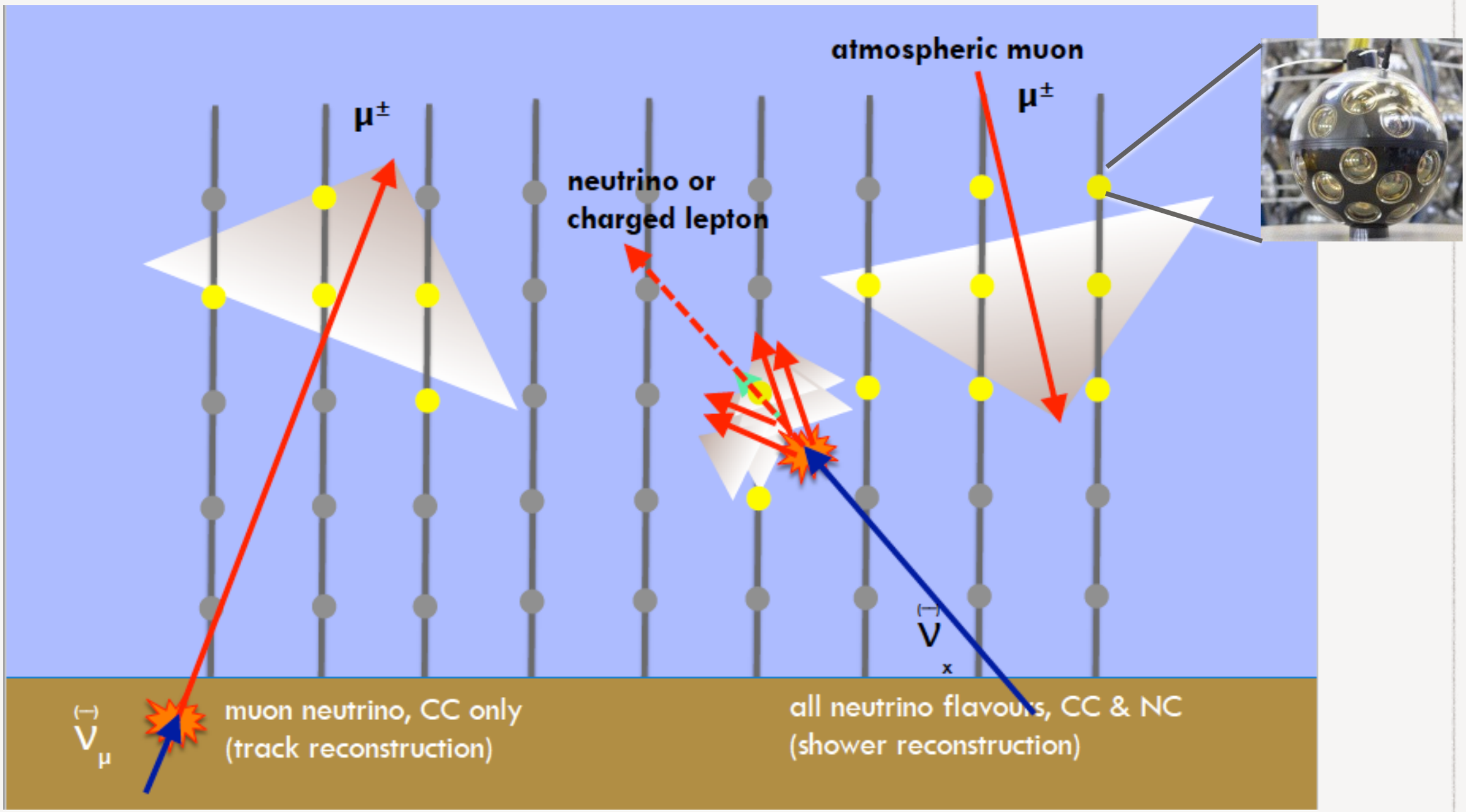
CTF: Cable Termination (Frame)
: Secondary Junction boxes
: Tower DU
: String DU
PPM-DU

Junction Box

Capo Passero shore station

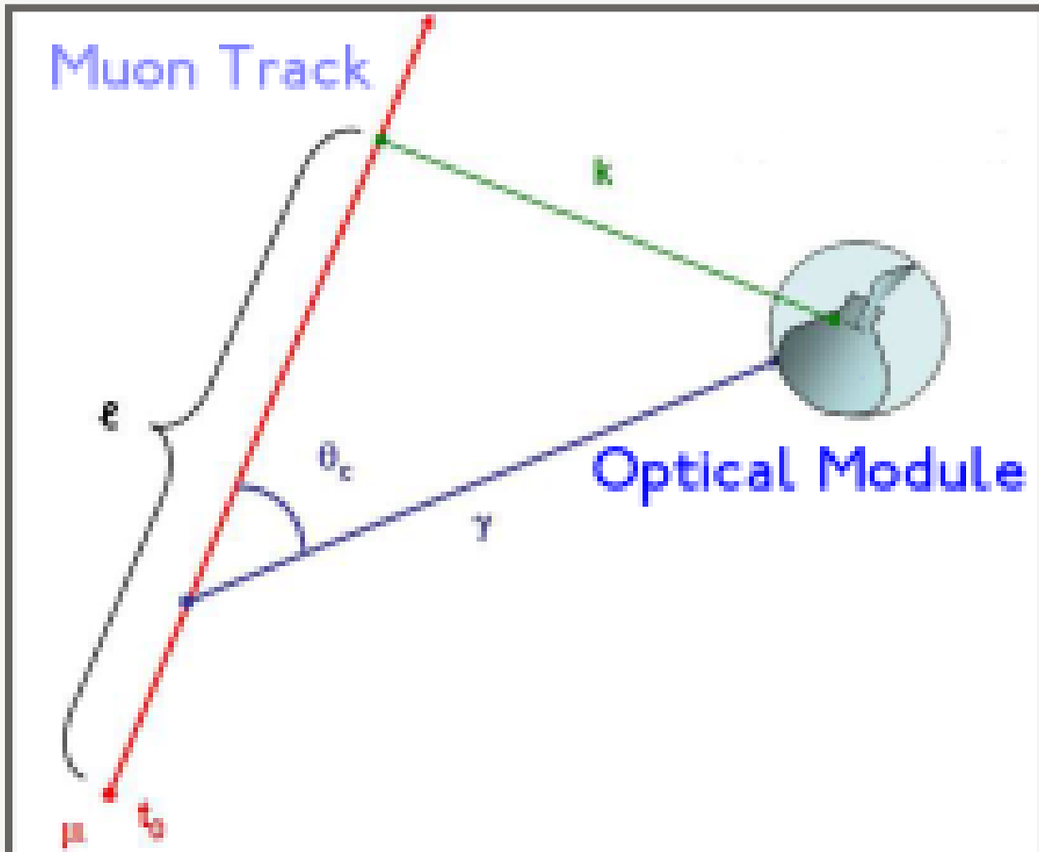
ARCA DU1 at the sea bottom

PRINCIPLE OF HIGH ENERGY MUON AND NEUTRINO DETECTION



PRINCIPLE OF THE TRACK RECONSTRUCTION CODE

From the Cherenkov photon arrival times and PMT positions the track direction can be estimated



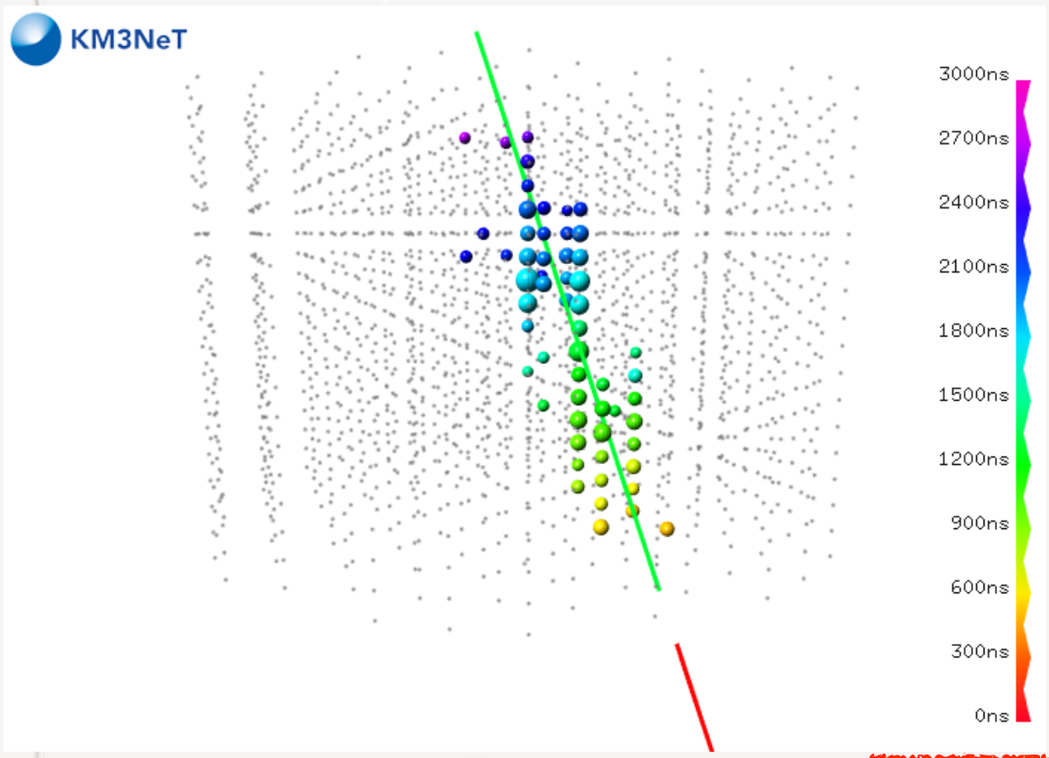
space-time relation

$$\Delta t = t_{theor} - t_{\exp}$$

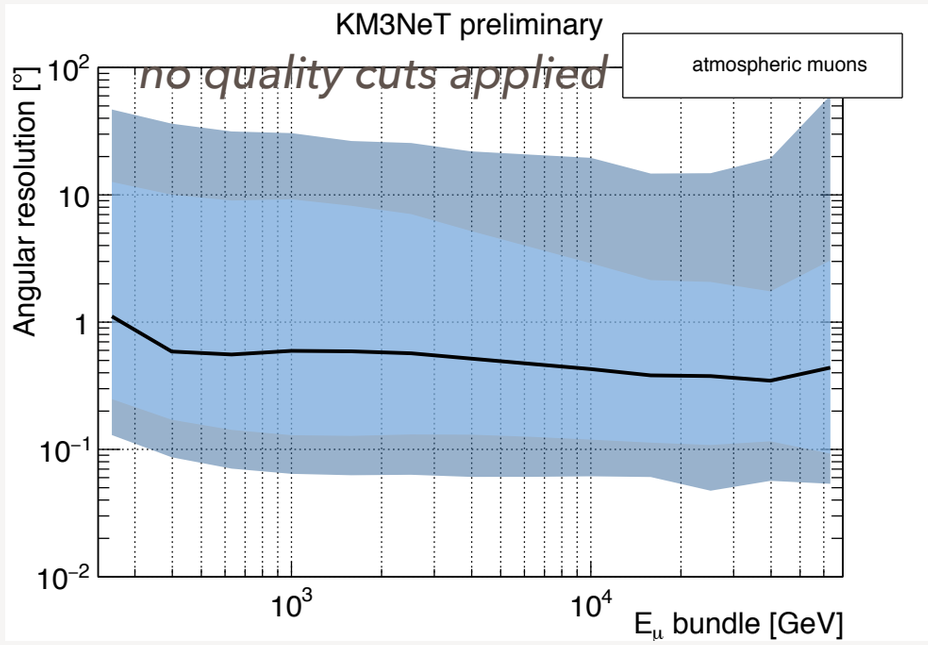
$$t_{theor} = t_0 + \frac{1}{c}\left(l - \frac{k}{\tan\vartheta_c}\right) + \frac{1}{v_g}\left(\frac{k}{\sin\vartheta_c}\right)$$

THE KM3NET/ARCA RESOLUTION FOR ATMOSPHERIC MUON EVENTS

"Track-like" events mainly from atmospheric muons



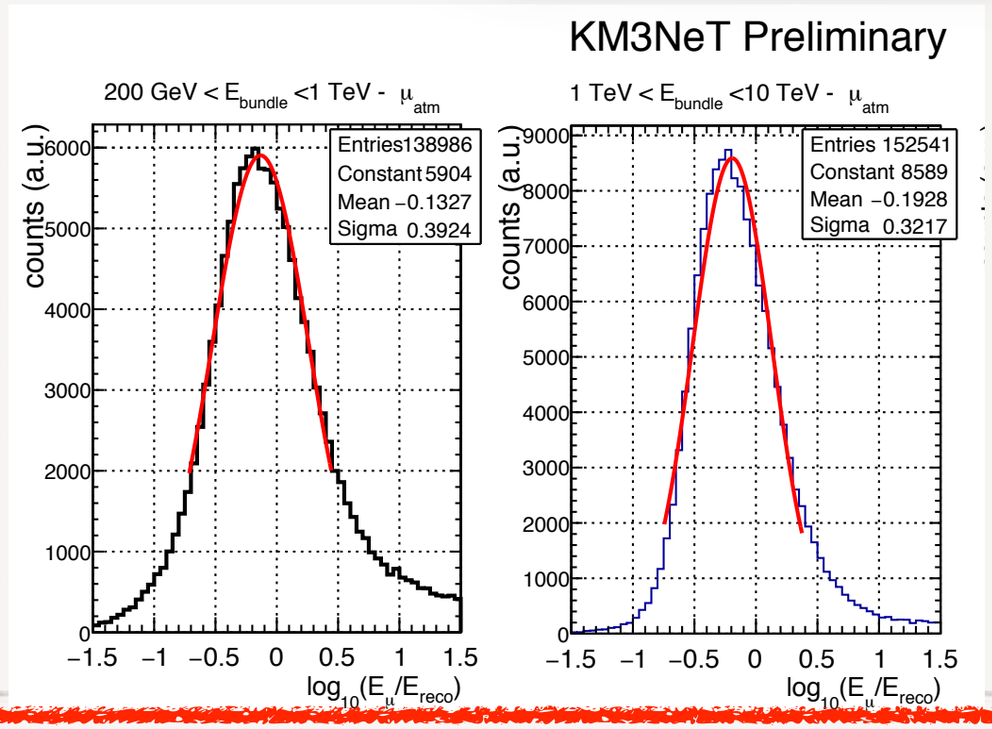
Angular resolution



no quality cuts applied

better than 1°

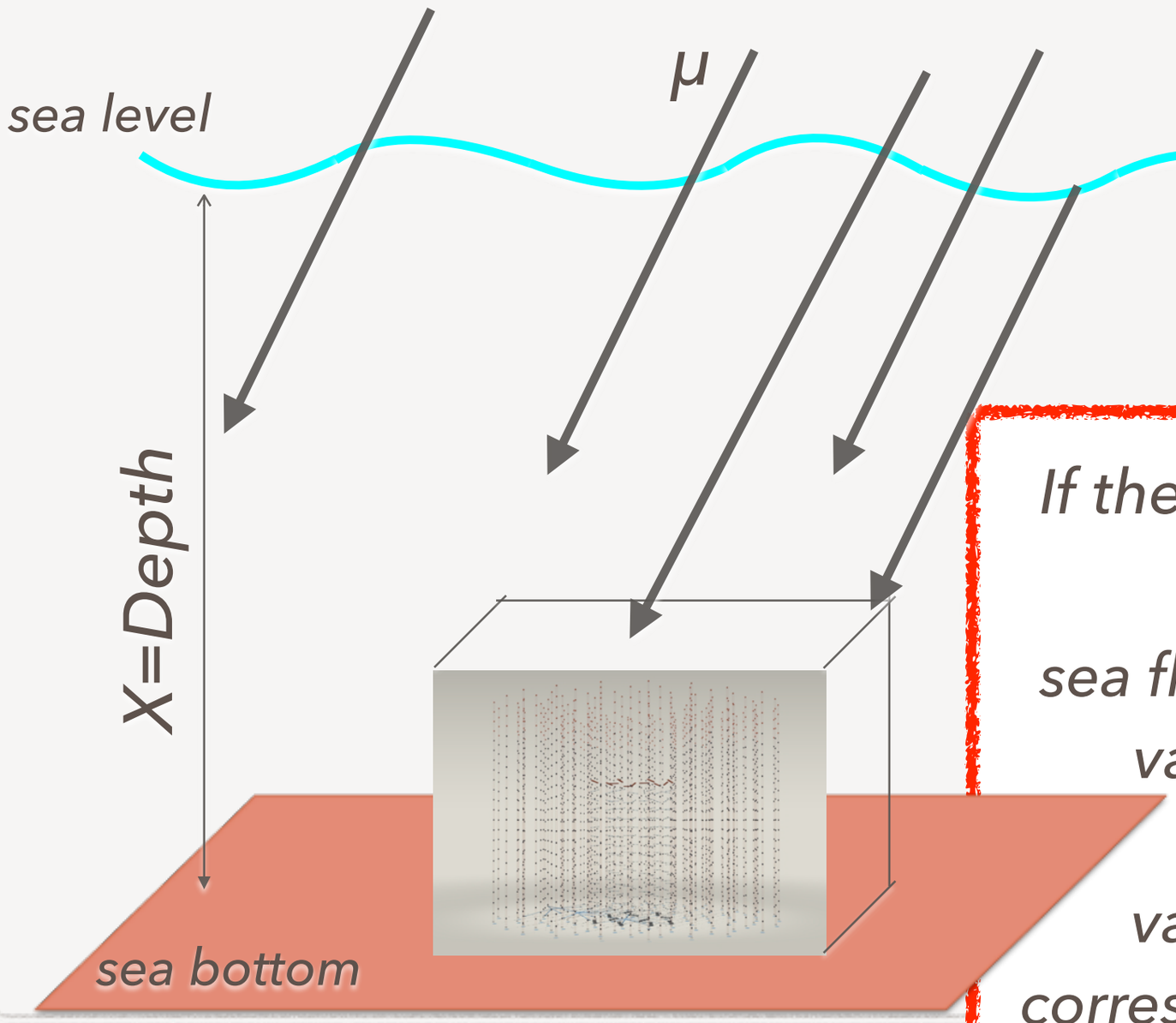
Energy resolution

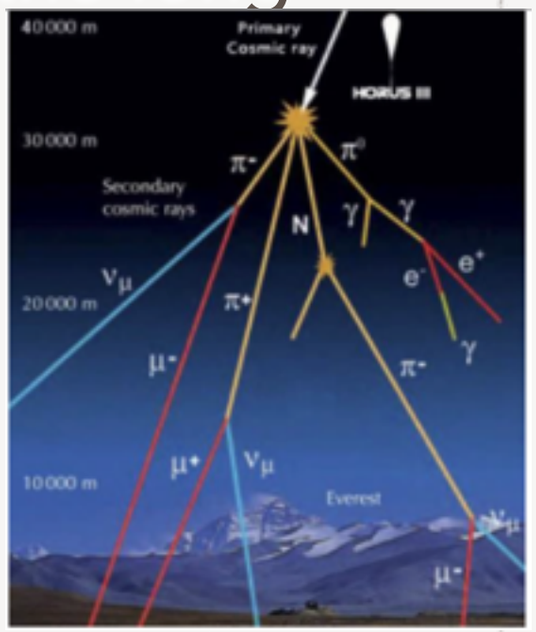


energy resolution ≈ 30% in $\log_{10}E$

STUDY OF THE SEAFLOOR DYNAMICS WITH KM3NET/ARCA

measure of the atmospheric muons flux to monitor the long term seafloor movements





If the sea level is taken as reference

👇

sea floor movement corresponds to a variation in the detector depth

👇

variation in the detector depth corresponds to a variation in the muon rate (muons are attenuated in water)

STUDY OF THE SEAFLOOR DYNAMICS WITH KM3NET/ARCA

In the Mediterranean uplift/subsidence of the seafloor of few cm in about 10 years is expected

👇

Is this measurement possible with KM3NeT ARCA detector?
Which precision on the muon rate measurement is required?

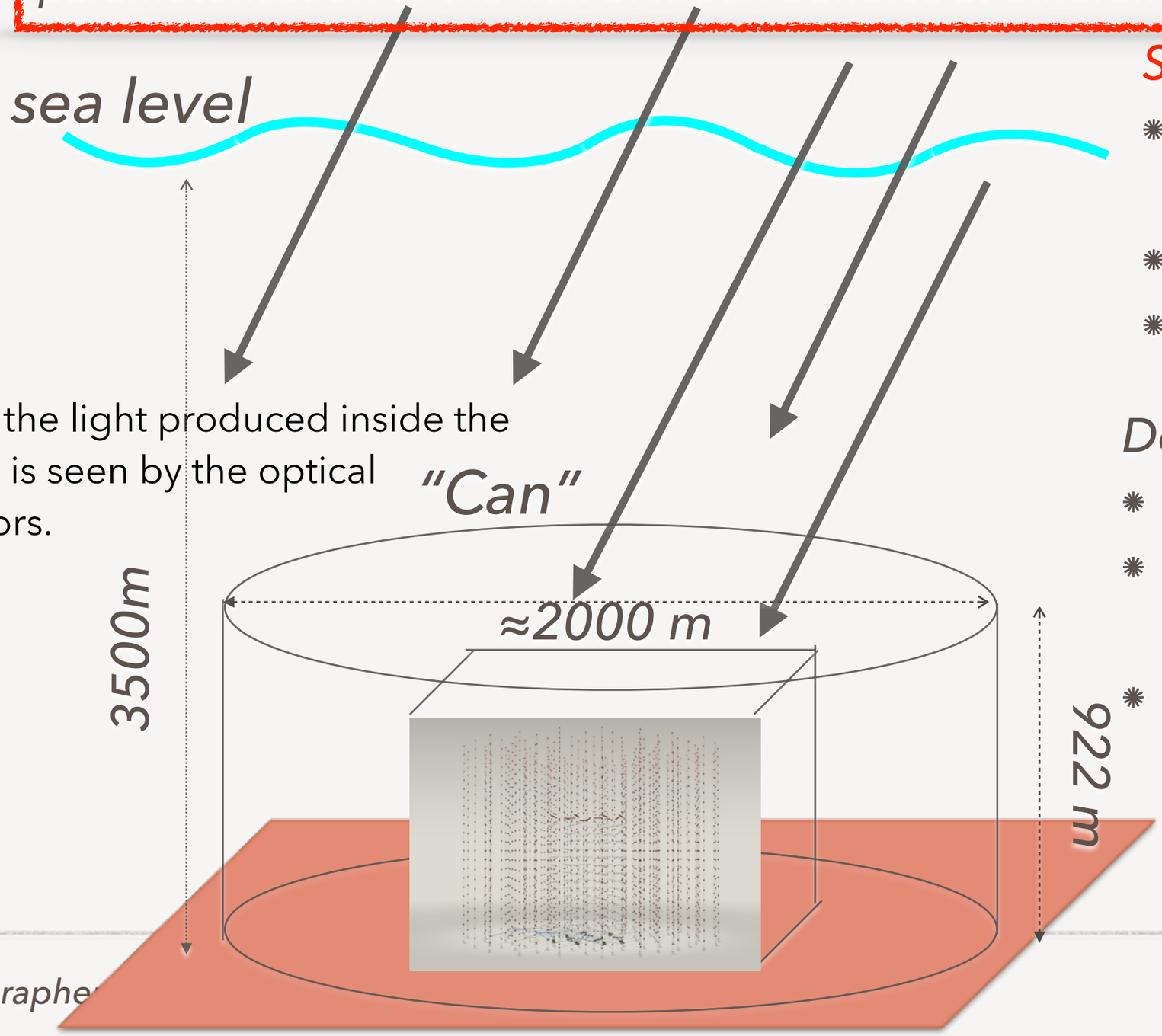
👇

Very preliminary considerations based on Monte Carlo simulations will be presented in the following slides

STUDY OF THE SEAFLOOR DYNAMICS: FIRST MONTECARLO SIMULATIONS

Atmospheric muons simulated with MUPAGE

Single and multiple atmospheric muon events are generated using a parameterisation of the flux of muon bundles at different depths and zenith angles



Simulated also:

- *muon propagation inside the can*
- *light in water*
- *detector response*

Dedicated Simulation

- *2 hours of livetime*
- *3 different depths (3490m, 3500m, 3510m)*
- *E_{bundle}>200 GeV*

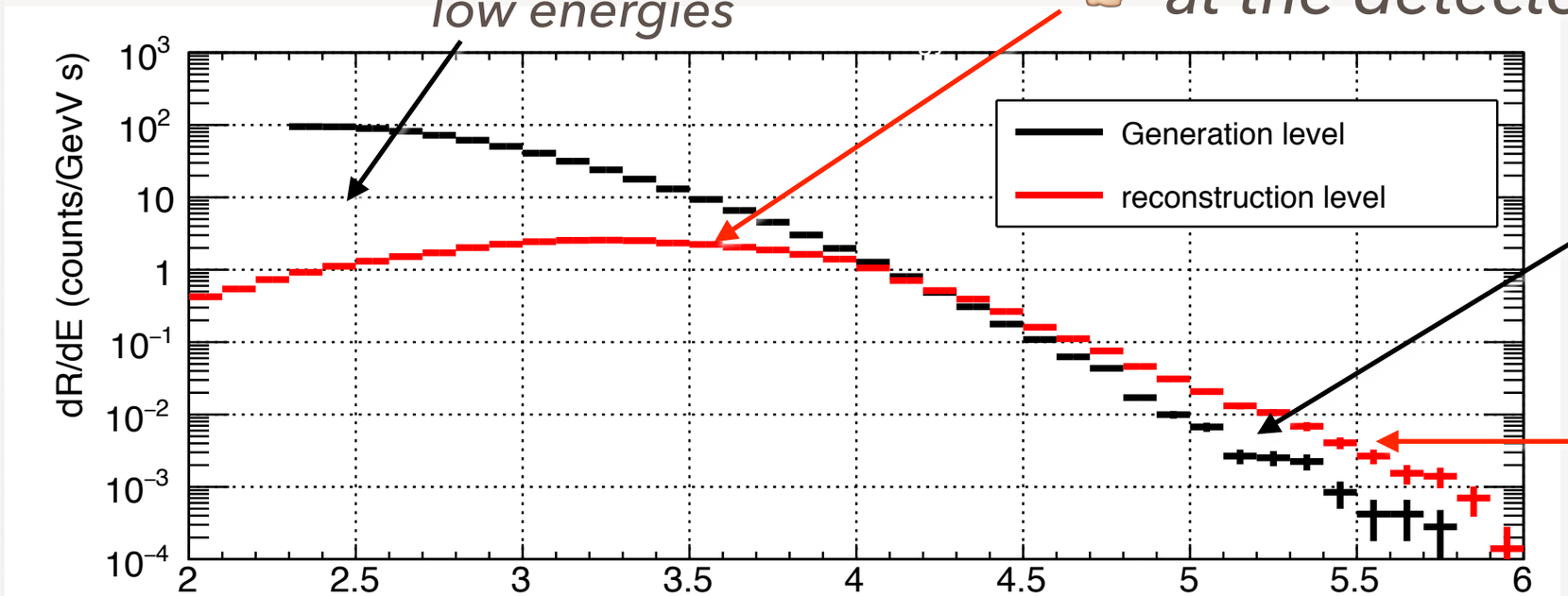
Muographe

THE ANGULAR AND ENERGY DISTRIBUTIONS OF ATMOSPHERIC MUON

low detector efficiency at low energies

reconstruction level

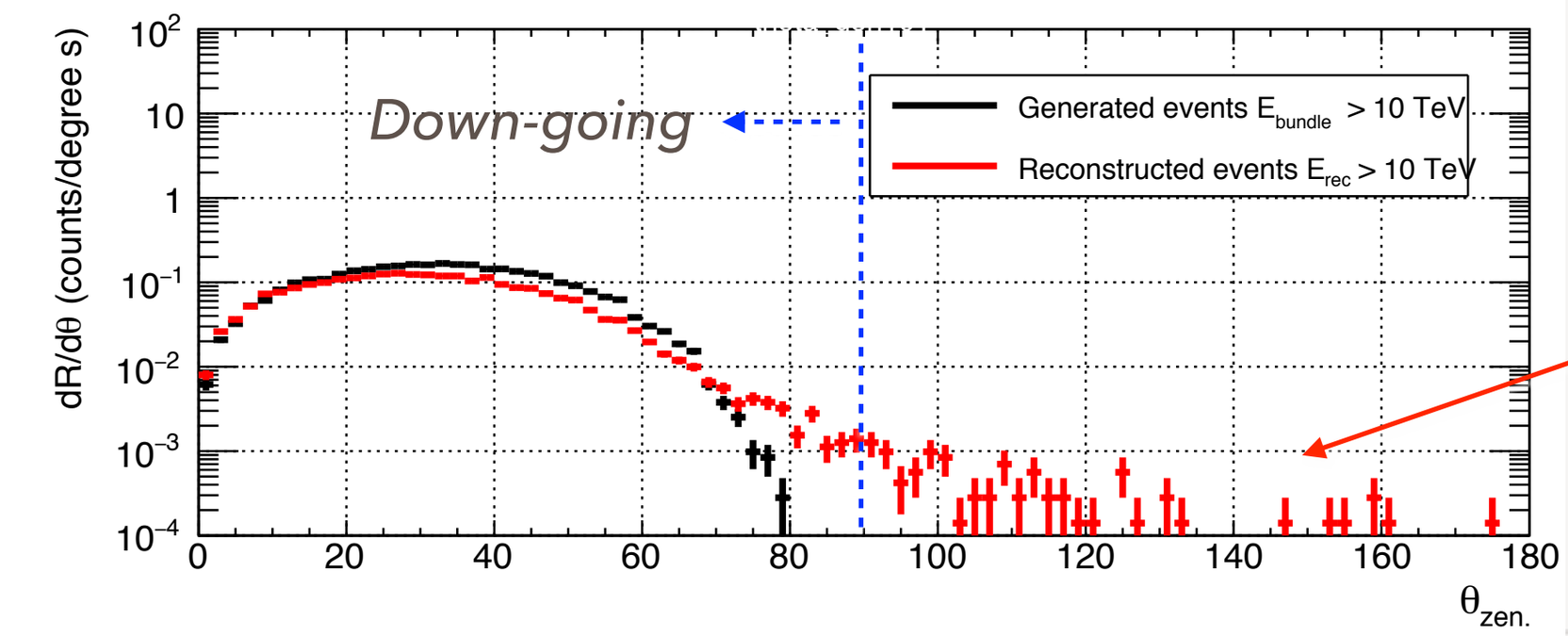
👉 *at the detector*



generation level

👉 *"can" level*

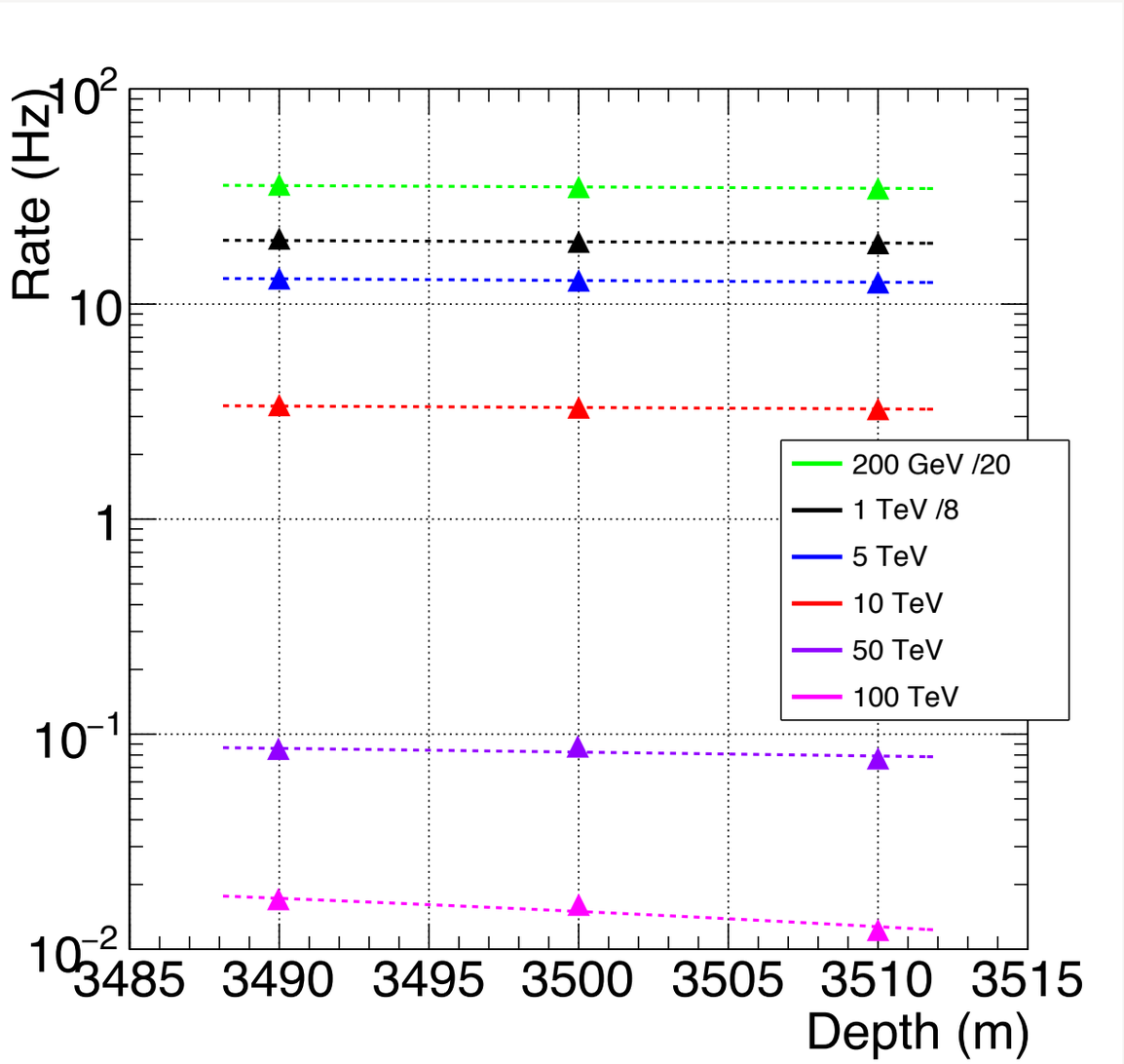
measured energy overestimated at high energy



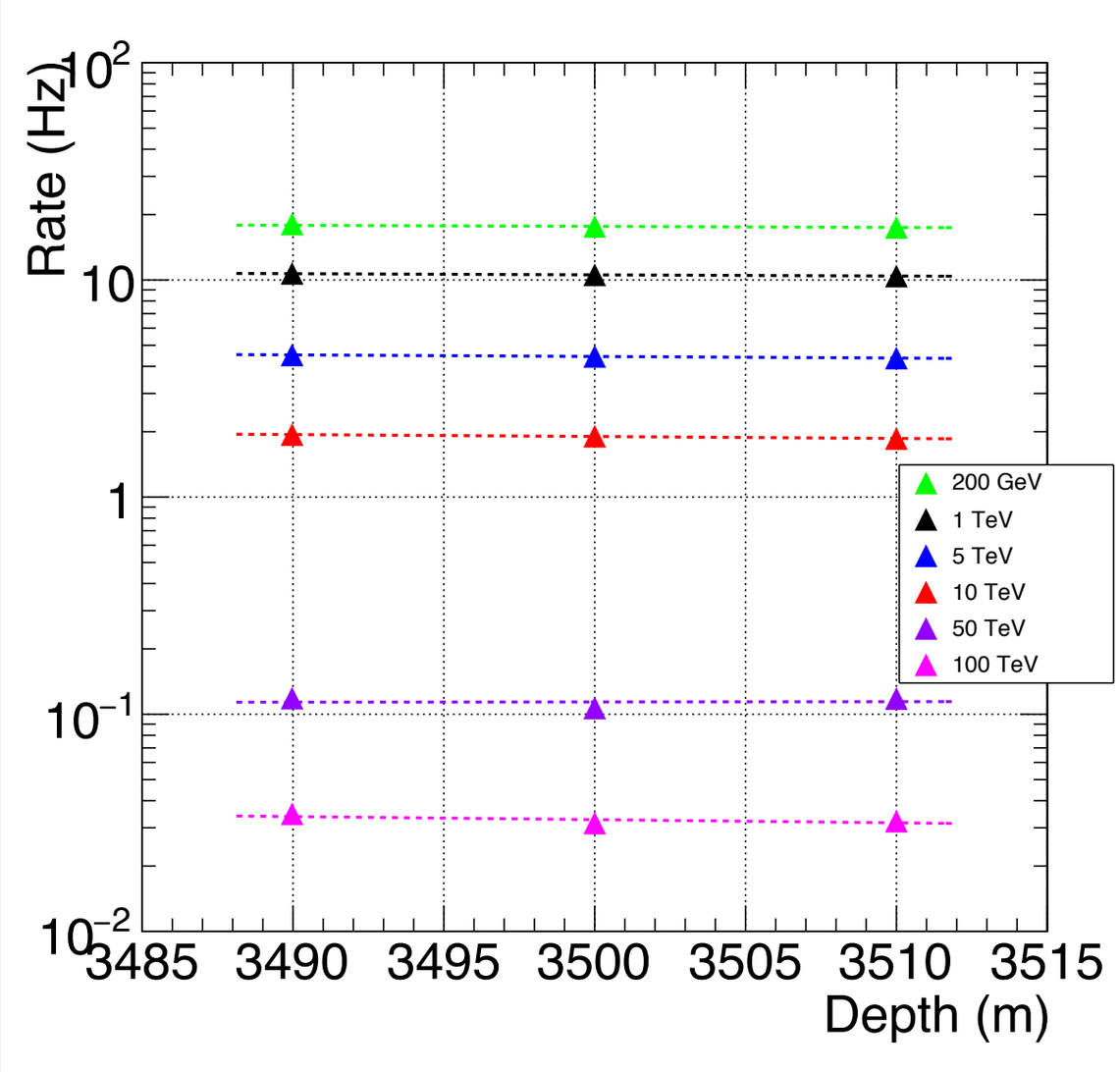
Tracks badly reconstructed as up-going

THE MUON RATE VS DEPTH

at generation level for different integration energy thresholds



at reconstruction level for different integration energy thresholds



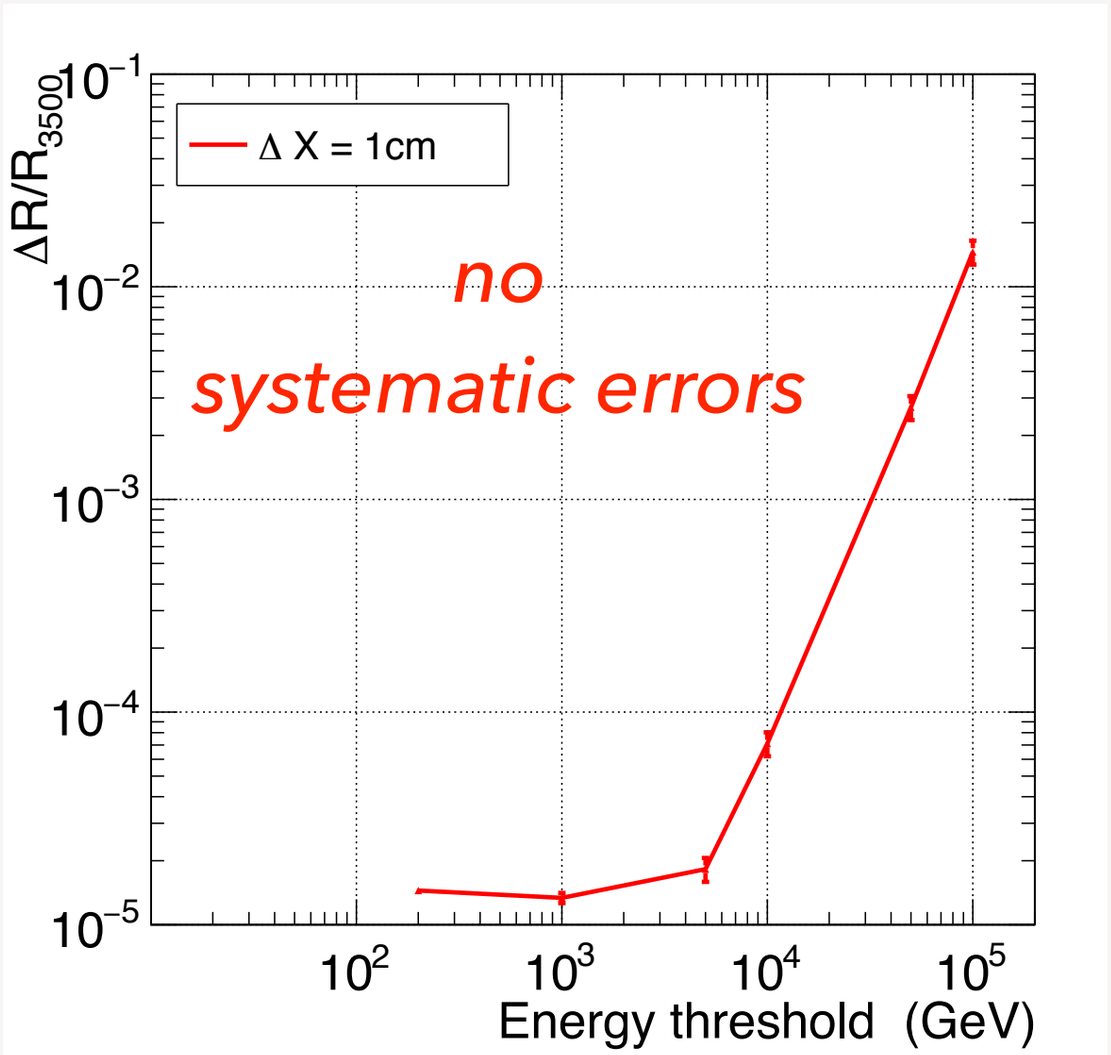
Linear behaviour of Rate vs Depth for “small” ΔDepth

ΔR/ΔD=constant

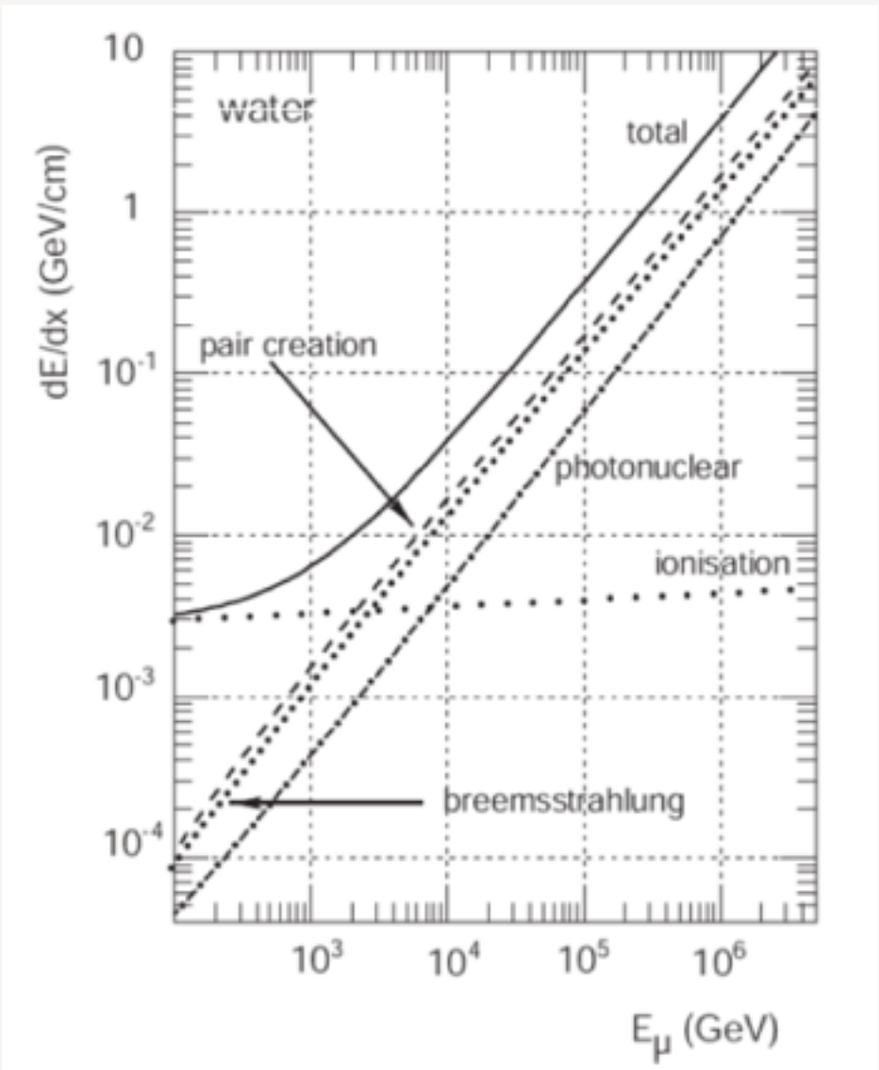
STUDY OF THE SEAFLOOR DYNAMICS: FIRST CONSIDERATIONS

at generation level

DR/R @ 1cm



muon energy loss in water



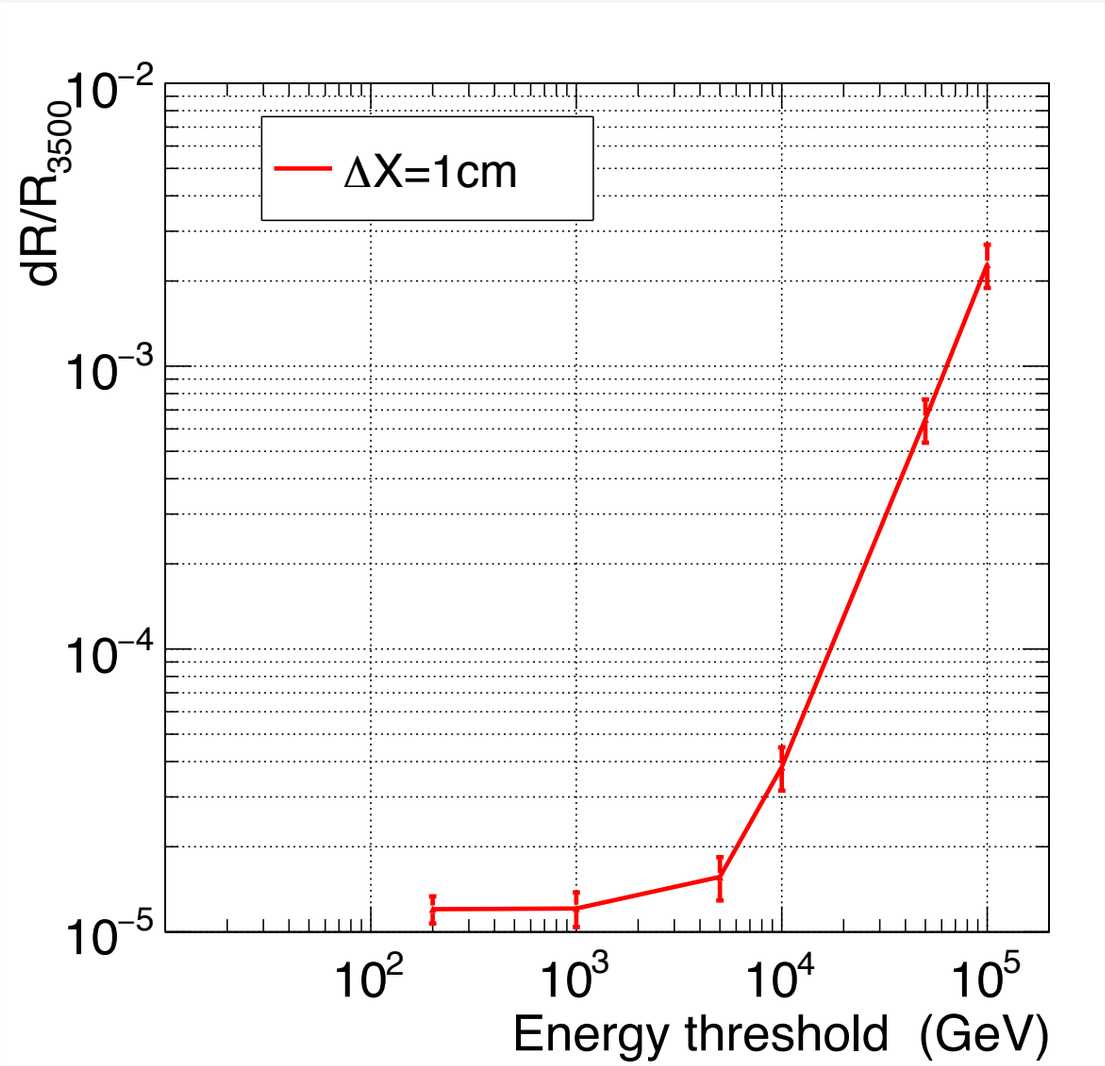
ΔR/R behaviour reflects the dE/dx behavior of particles in water

Higher the energy loss lower the precision required

STUDY OF THE SEAFLOOR DYNAMICS: FIRST CONSIDERATIONS

at reconstruction level

DR/R @ 1cm



only statistical errors are reported

no systematic errors

Rate measurement with a precision of the order of per ‰ for E_μ>50 TeV is required

STUDY OF THE SEAFLOOR DYNAMICS: FIRST CONSIDERATIONS

Can we measure on long time scale rates with a precision of ‰?

Systematic errors

Several aspects to be evaluated

- *variation of the medium properties*
- *variation in the detector response*

STUDY OF THE SEAFLOOR DYNAMICS: FIRST CONSIDERATIONS

Variation of the medium properties:

- *atmosphere*
  atmosphere density changes with the temperature (seasonal effect)
- *water optical parameters*
  water density and salinity changes with temperature (seasonal effect)
  absorption and scattering lengths

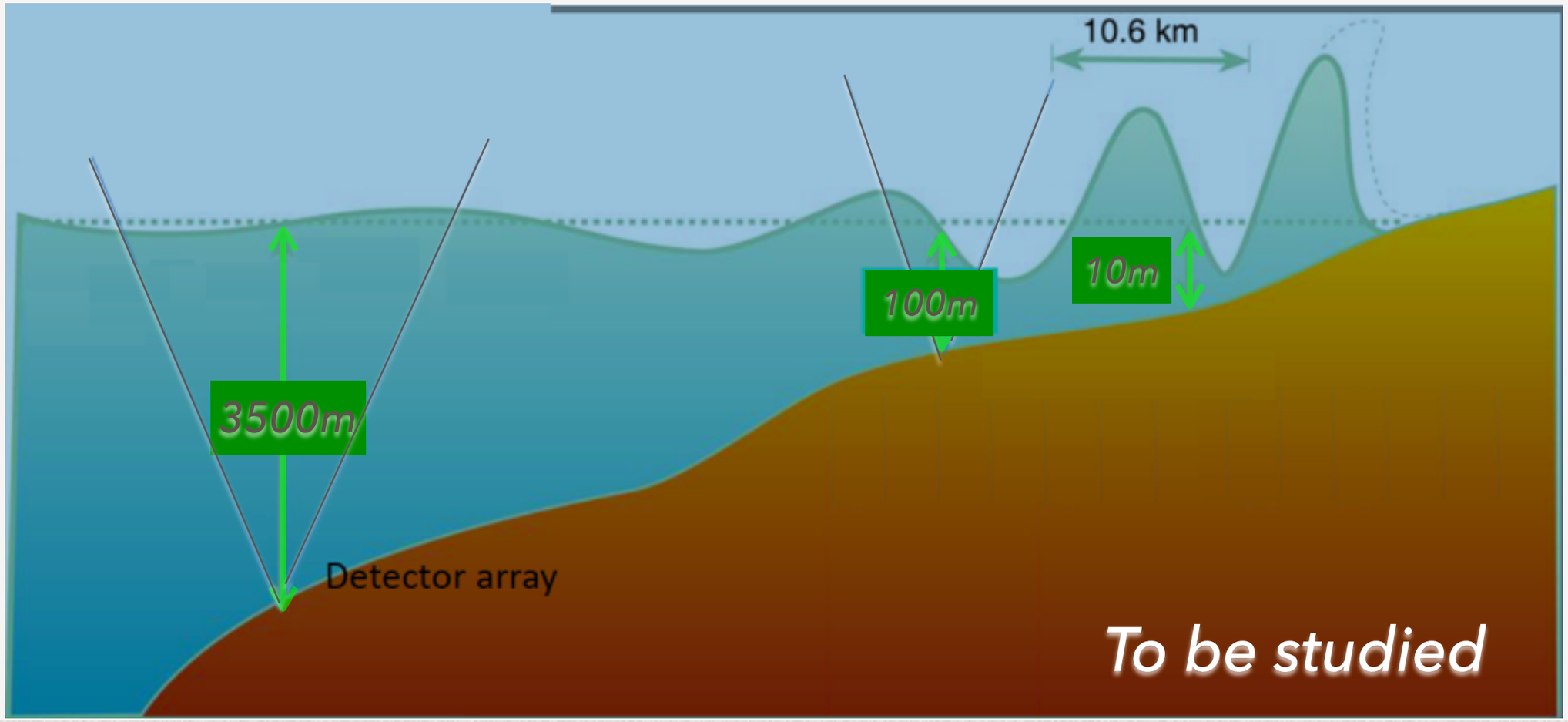
Variation in the detector response:

- *string movements*
  the strings are floating structures and their position changes under the sea current (seasonal effects).
- *detector calibration*
  time and PMT position
- *PMT efficiency*
  biofouling and sedimentation change the global efficiency of the detector. Not easy to measure with great accuracy
- *loss of PMTs and strings in a long time scale*

STUDY OF THE TSUNAMI ALERT SYSTEM BASED ON ATMOSPHERIC MUON FLUX MEASUREMENT

Measurement of the variation of atmospheric muon rate on short time scale.

Variation of the depth of the order of 5m above the detector. Transit time of the order of several minutes



SUMMARY

KM3NeT/ARCA is under construction in the Mediterranean sea:

- *two strings already deployed and operating at Capo Passero site*
- *KM3NeT/ARCA phase-1 (23 strings) already funded*
  - 👉 *completion foreseen for the end of 2017*
- *KM3NeT/ARCA (2 blocks of 115 DUs) completion foreseen for the end of 2020*

Very challenging program in Earth science with muons and neutrinos with KM3NeT/ARCA.
First considerations for the measurement of long term seafloor movement suggest a careful study of the systematic effects

Back up slides

THE KM3NET PROGRAM

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

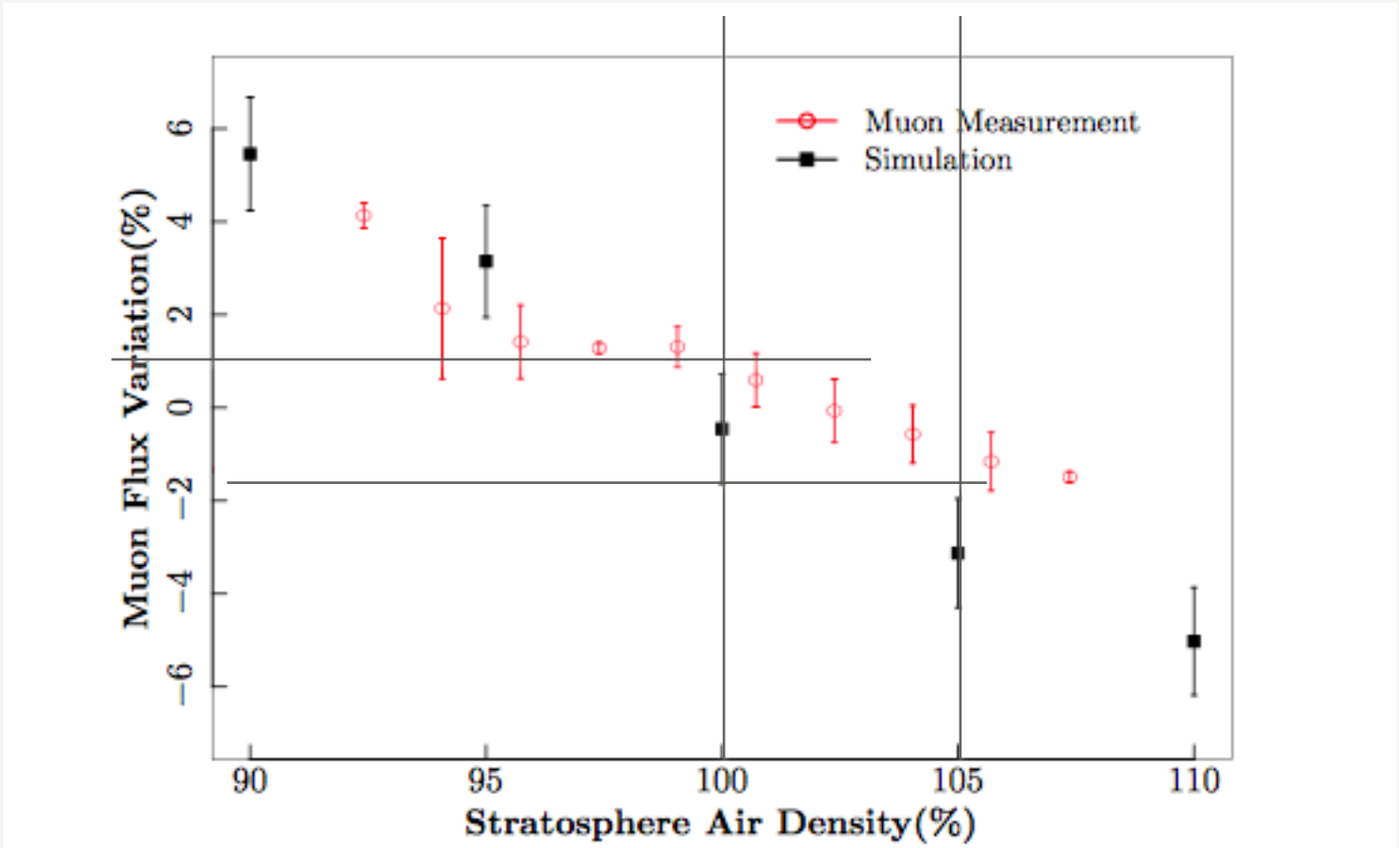


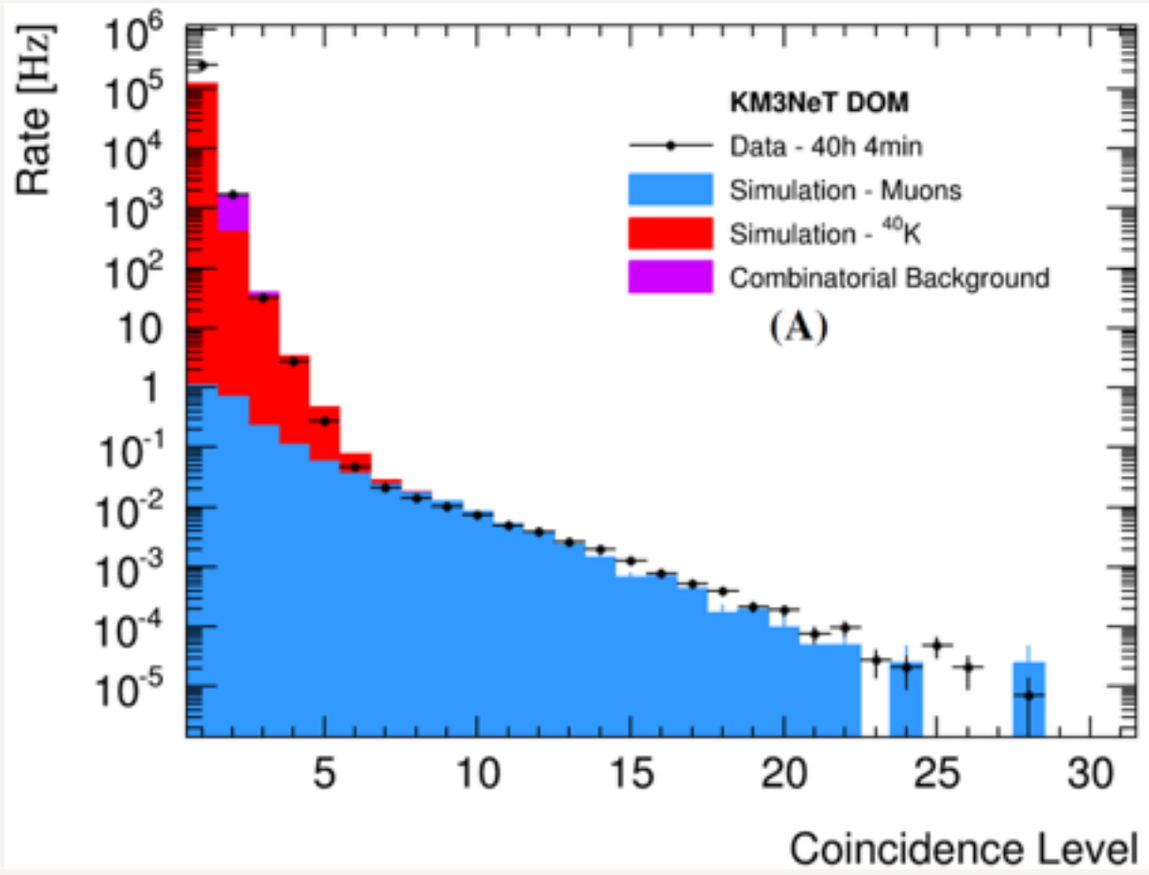
FIG. 4: (color online) Ground level muon flux percentage variation as a function of percentage variation of the stratospheric air density. The red-circle data points are from GSU measurement and the black-square from the simulated results. We only sample muon particles with kinetic energy ≥ 1 GeV at ground level which corresponds to the detector threshold. Note that the error bars in the figure are statistical only.

from https://arxiv.org/abs/1303.7191v1

THE DOM PROTOTYPE

DOM prototype deployed at Antares site April 2013

validation of DOM capabilities in situ

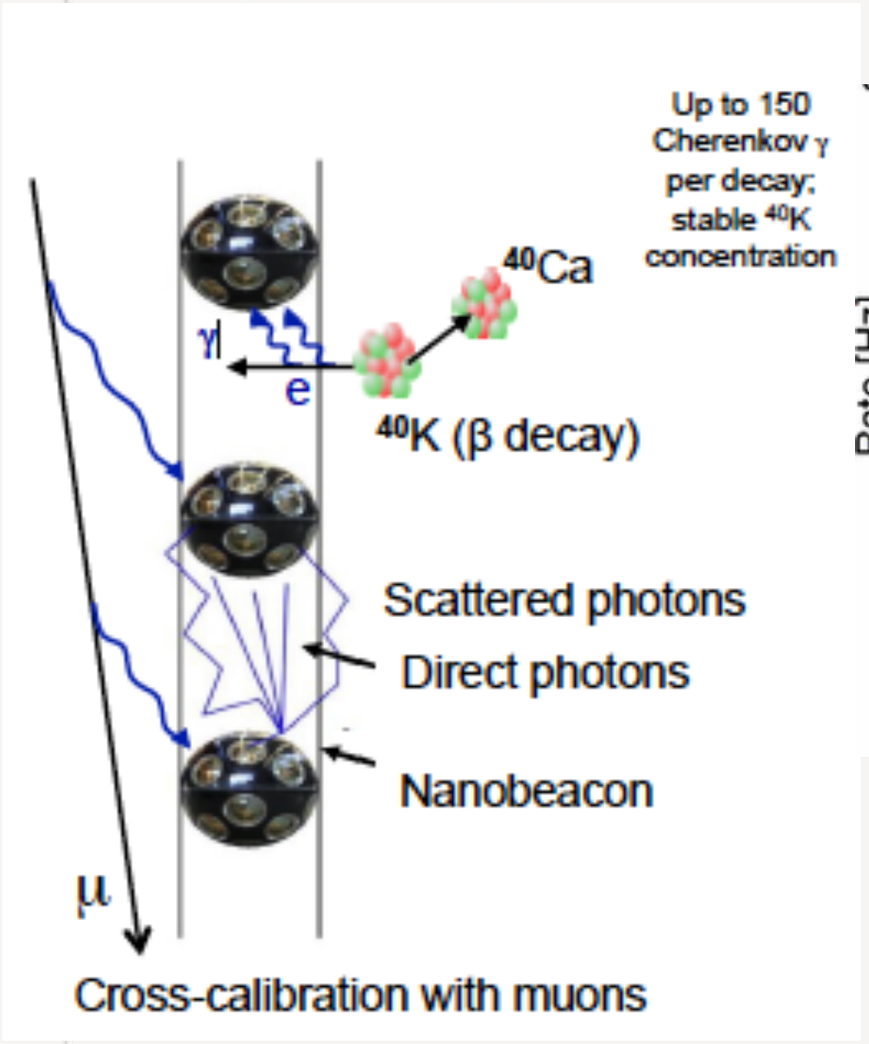


Proved that with a single DOM the selection of events from atmospheric muons is possible

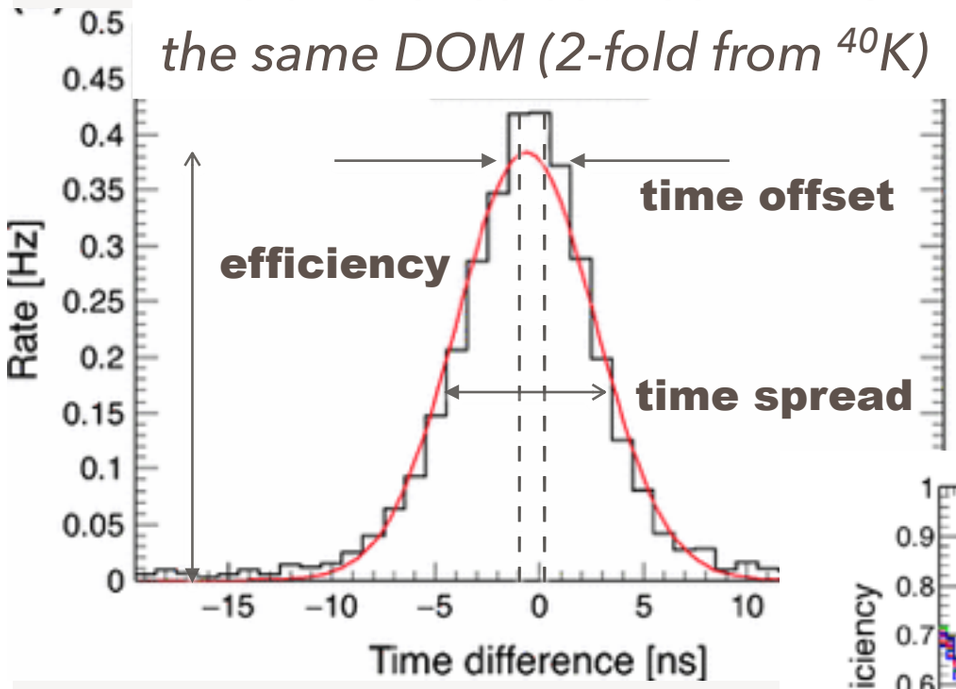
Result published in Eur. Phys. J. C (2014) 74: 3056

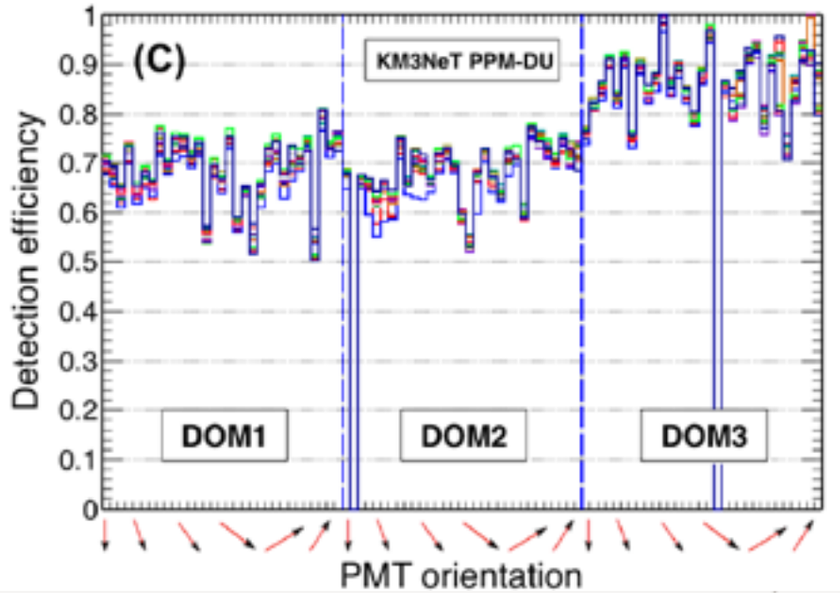
THE DU PROTOTYPE

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



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

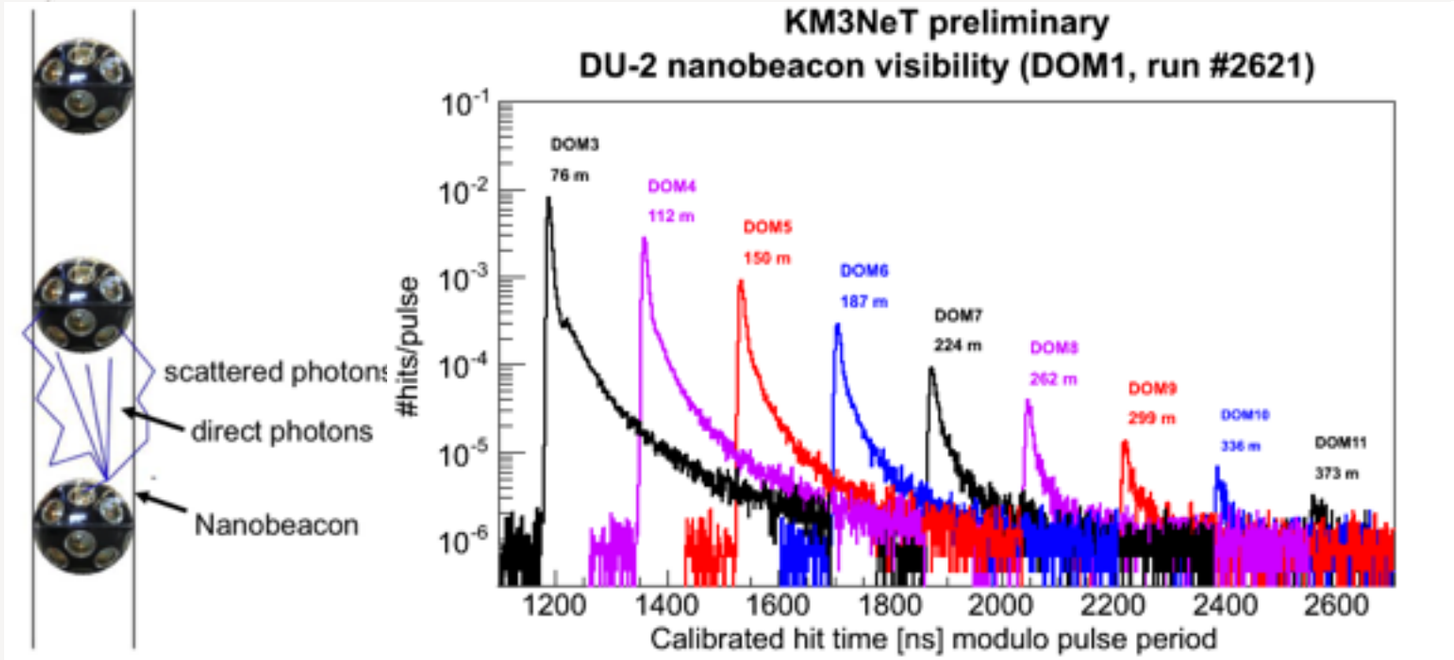


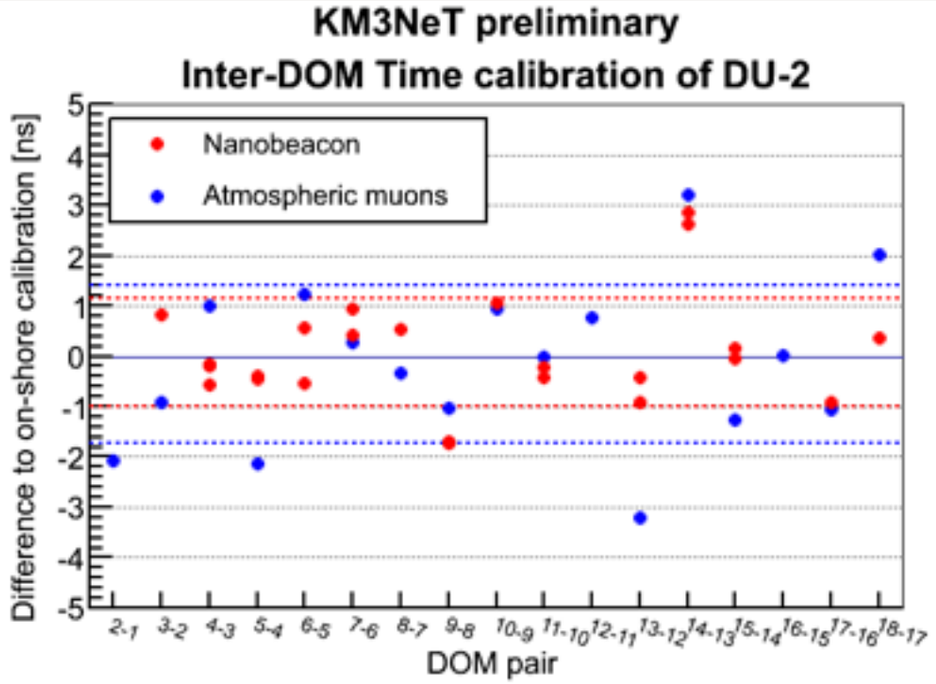


Proved that the time calibration between PMTs in the same DOM and between DOMs is feasible in a fast and reliable way

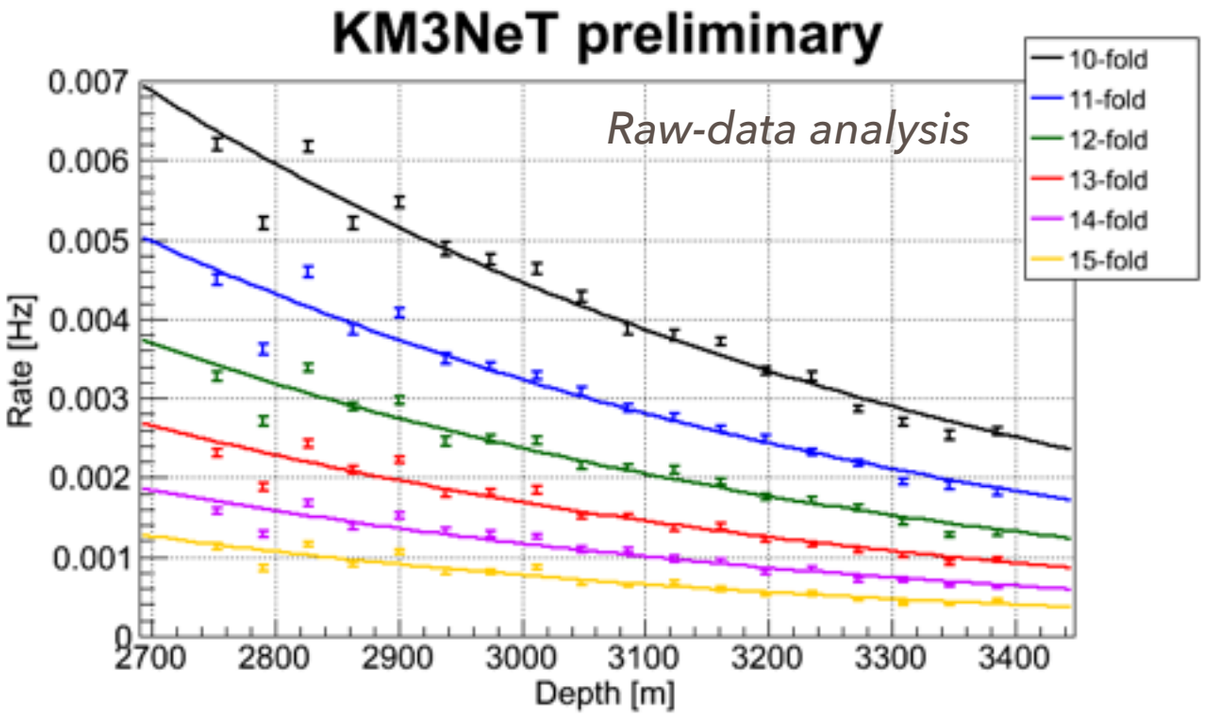
Results published in Eur. Phys. J. C 76 (2016) 76:54

FIRST RESULTS FROM ONE OF THE FIRST DUS INSTALLED



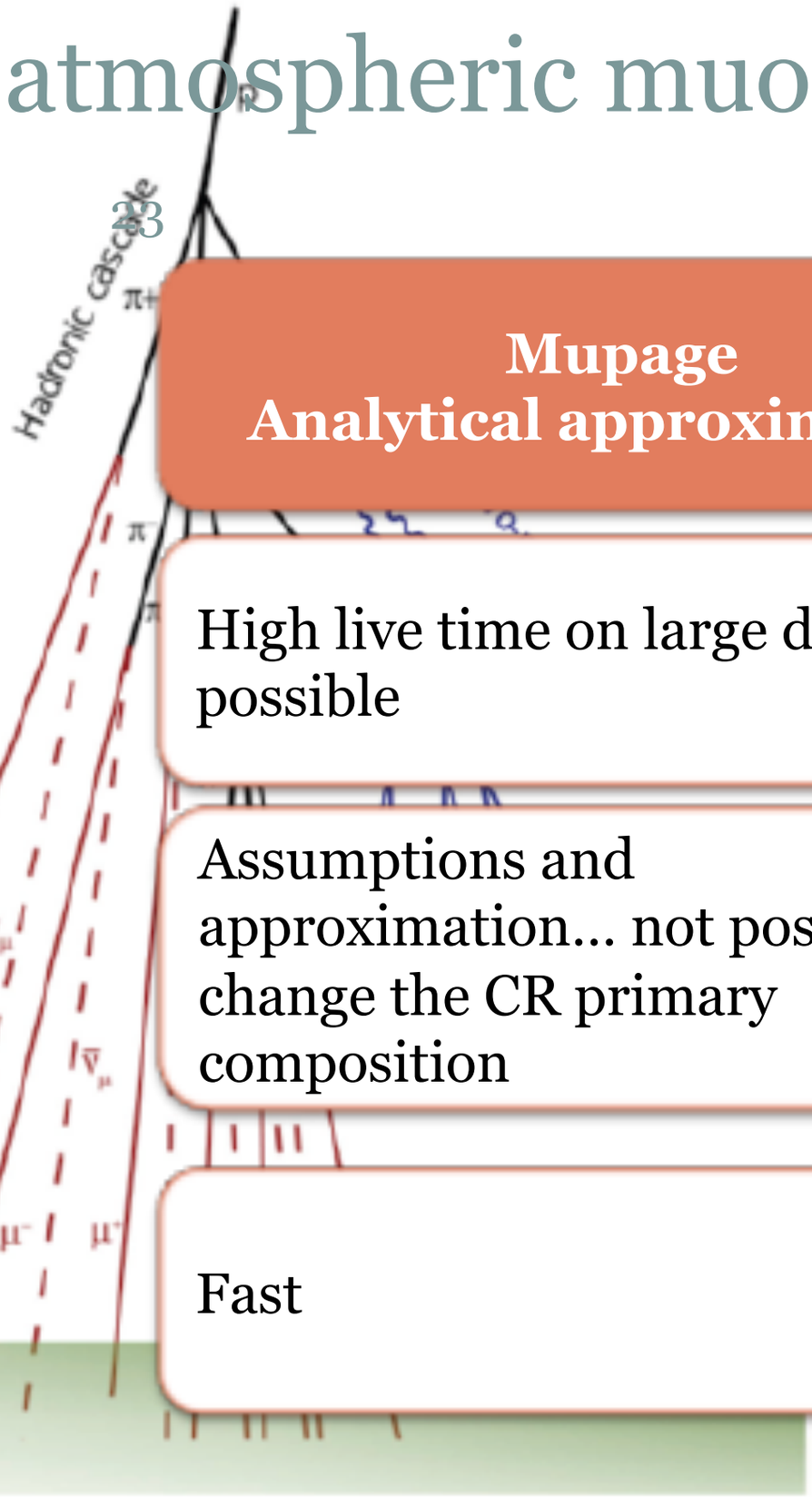


Comparison of calibration with LED nanobeacons and atmospheric muons in agreement. In situ nanobeacon calibration and on-shore laser calibration agree to ≈1 ns



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

Generation of atmospheric muons



CORSIKA
Full air shower simulation

Based on known models

The final events can be weighted- choose all the CR models (spectrum and composition)

Large computing time

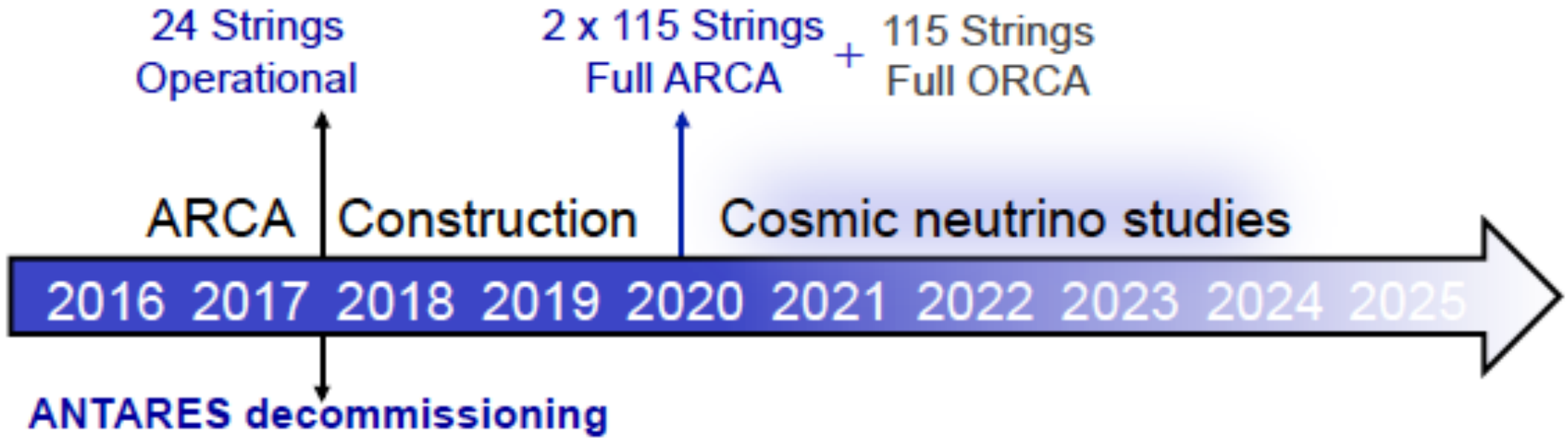
Mupage
Analytical approximation

High live time on large detector possible

Assumptions and approximation… not possible to change the CR primary composition

Fast

TIME LINE



Total KM3NeT cost: 125M€ (ARCA+ORCA)