The KM3NeT Digital Optical Module

NNN16

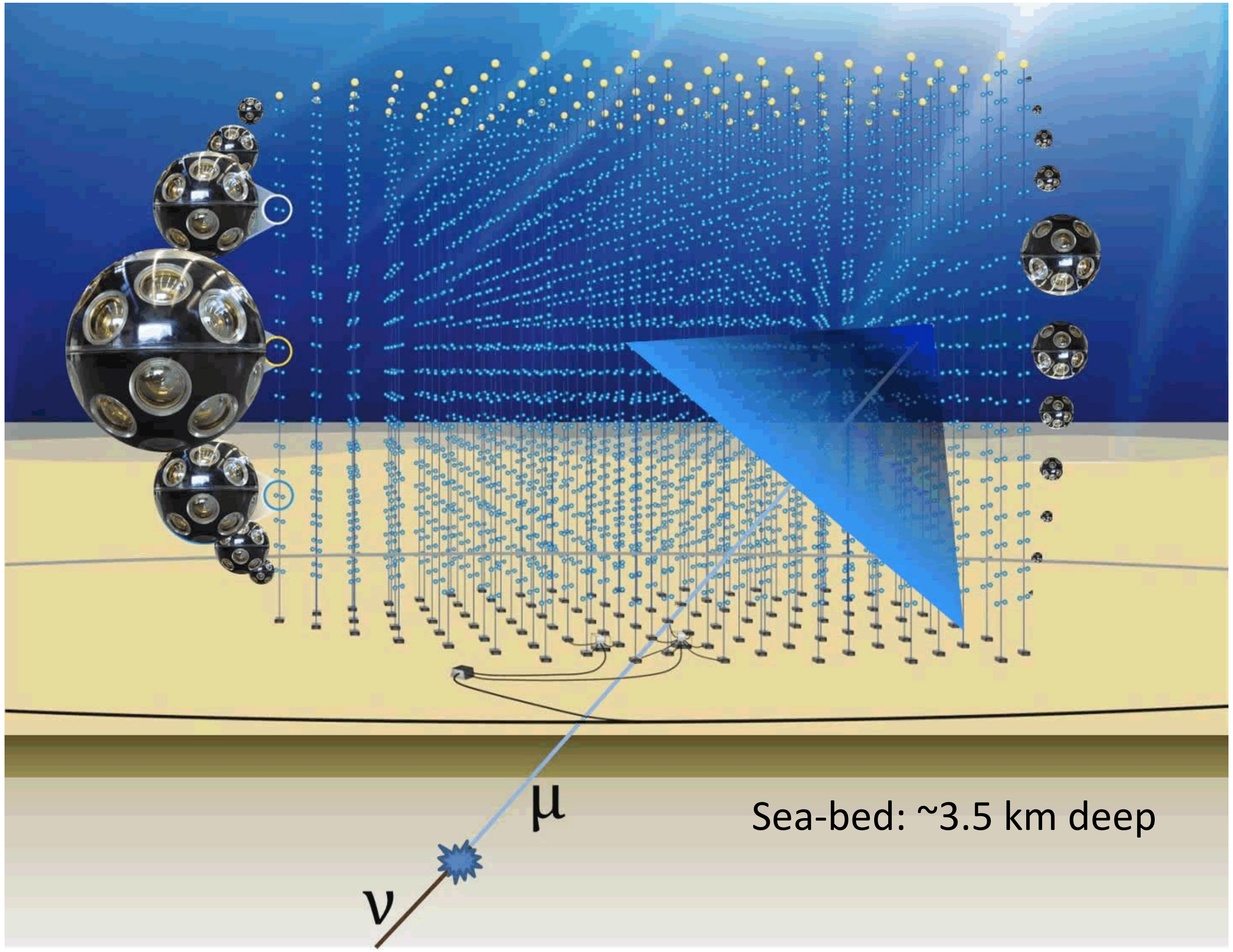
IHEP,Beijing

Ronald Bruijn

Universiteit van Amsterdam/Nikhef

Large Volume Neutrino Telescopes

Cherenkov light from the charged products of neutrino interactions in sea-water are detected by a sparse array of photo-multiplier tubes



Two *general* event types:

Tracks - Charged current (CC) υ_μ and υ_τ interactions

Showers - Neutral current υ interaction
- υ_e CC electromagnetic shower
- Vertex of CC interaction
- τ decay shower

ARCA & ORCA

High Energy Neutrino Astronomy:

ARCA: **A**stroparticle **R**esearch with **C**osmics in the **A**byss

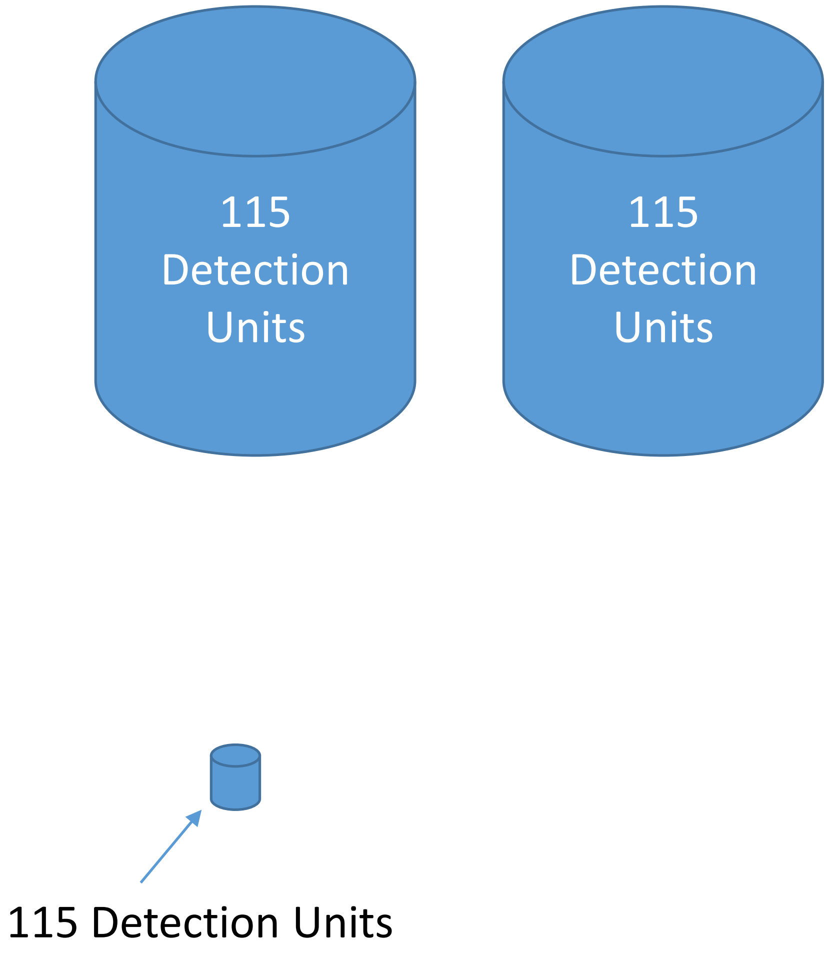
Large Detector: ~1 km^3 total
Sparsely instrumented: 36 m vertical spacing, 95 m horizontal
TeV-PeV Energies
Astrophysical Neutrinos

Same technology & layout, dimensions scaled

Neutrino Physics:

ORCA: **O**scillations **R**esearch with **C**osmics in the **A**byss

´Smaller´ detector: 5.7 Mton
More densely instrumented: 9m vertical spacing, 20m horizontal
GeV energies
Atmospheric neutrinos



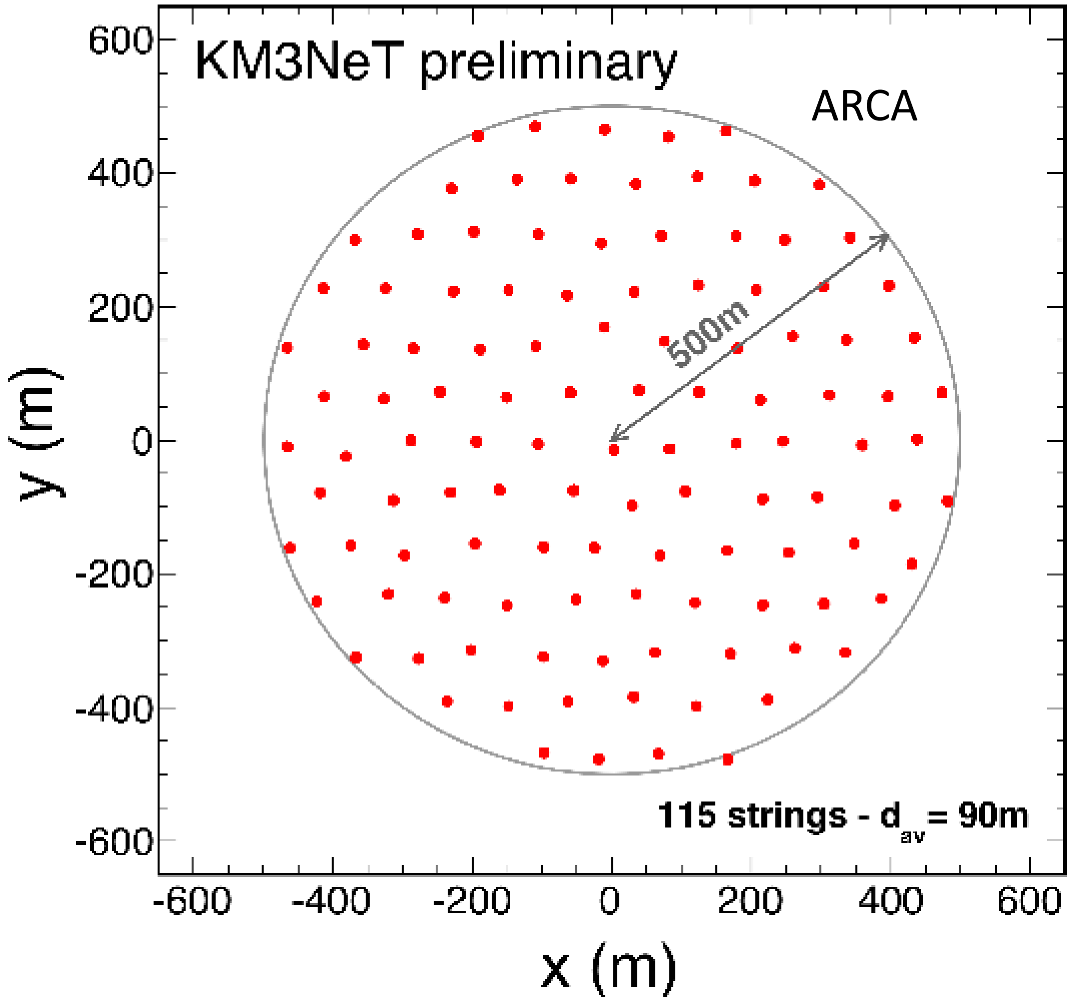
KM3NeT Design

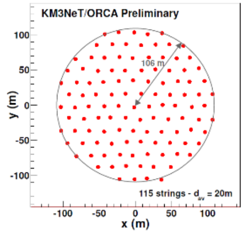
Detection Units:

18 optical modules per vertical string
~36m or 9m between optical modules
Lowest optical module ~100m or 40m above seabe
Two Dyneema® ropes
Backbone: 2 copper conductors; 18 fibres (+spares
Break out of cable at each optical module
Base module with DWDM at anchor
Cable for connection to seafloor network
Cost saving design

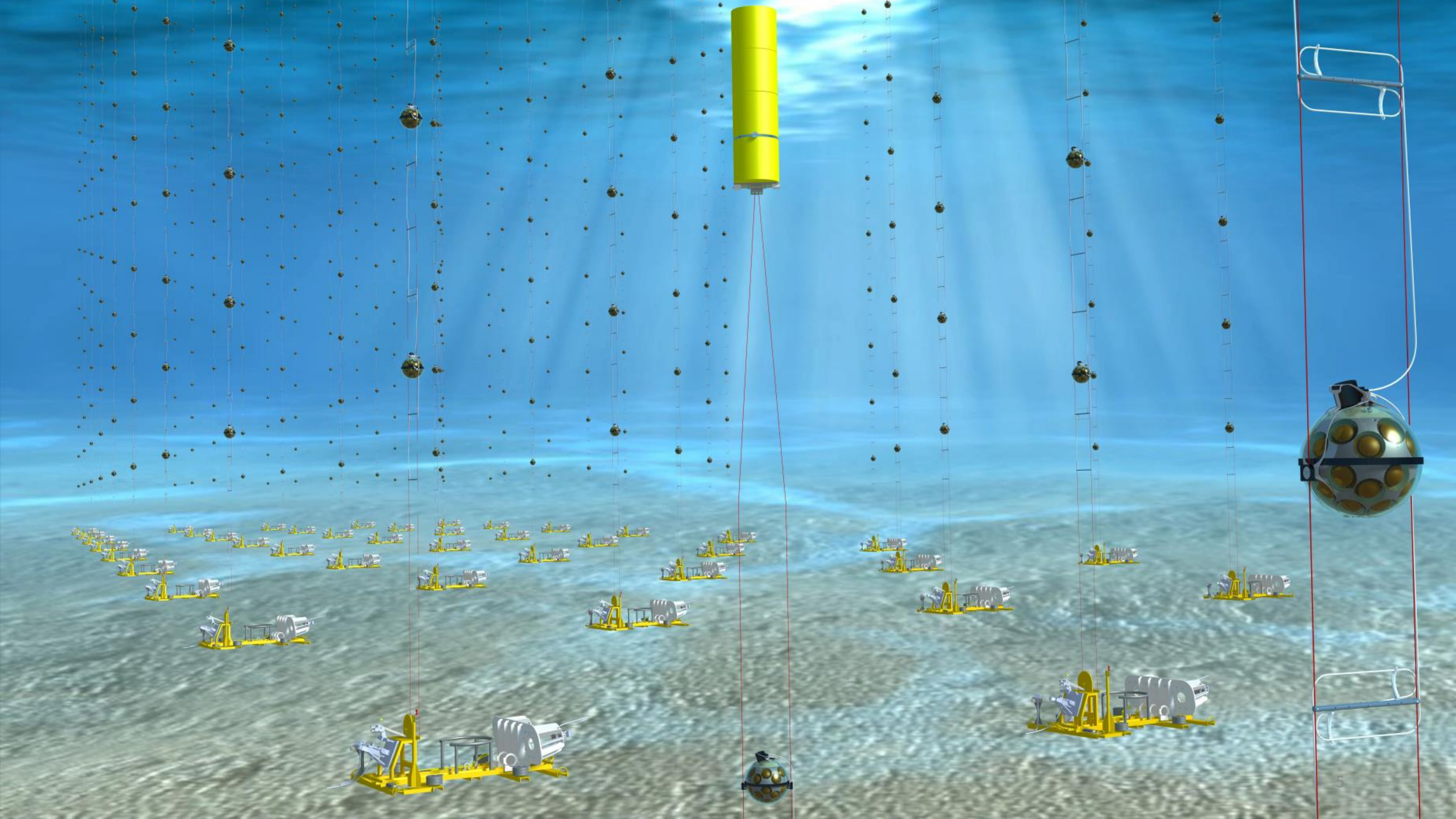
Infrastructure:

Detector building blocks of 115 detection units
Sea-bed infrastructure
(facility for long term high-bandwidth connection for sea-science, biology etc.)
Optical data transmission
All-data-to-shore
Filtering/Trigger on-shore in computer farm





ORCA



Multi-PMT Concept

Segmented photocathode : 31 3” PMTs in a 17” sphere
(equivalent to 3 10” PMTs)

+ All front-end and digitization electronics, slow control sensors and supporting mechanics

KM3NeT
Digital **O**ptical **M**odule
(DOM)

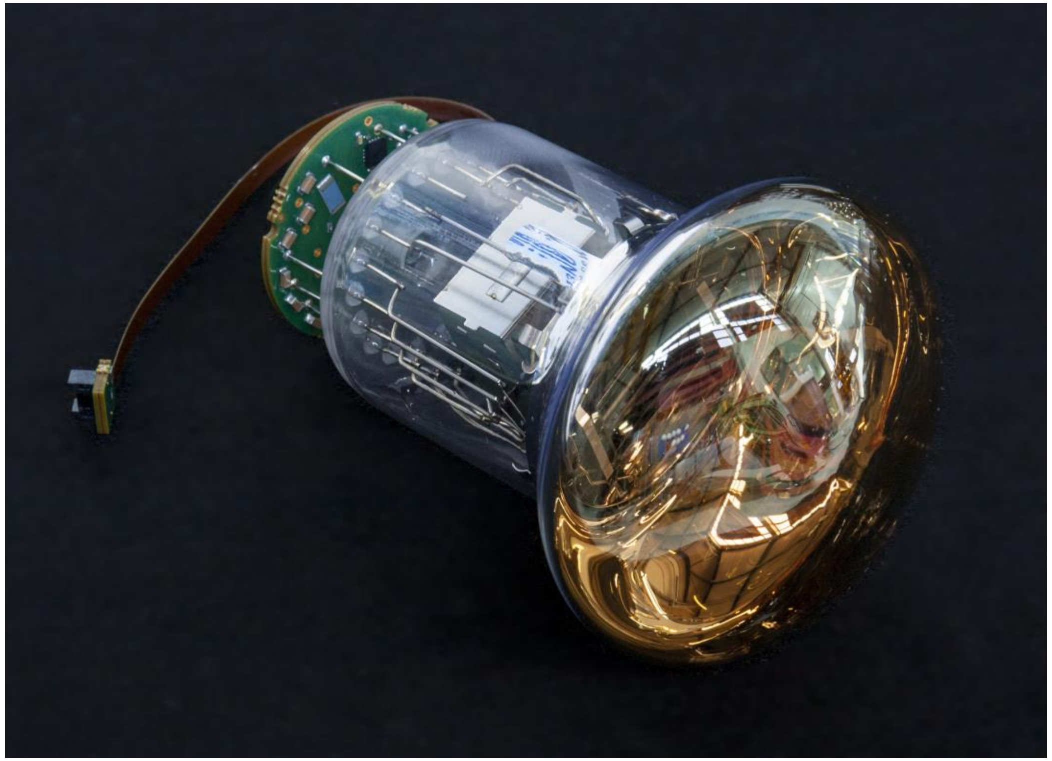
Advantages

- Large photocathode area
- Directional Sensitivity
- Photon Counting
  (1 vs 2 vs … photons, background suppression)
- Less overhead
- Cost effective
- Minimal glass penetrations

PMTs

Main PMT Specifications:

➢ Timing	≤2ns (RMS)
➢ QE@ 404 nm	≥23%
➢ QE@470 nm	≥18%
➢ Collection efficiency	≥90%
➢ Photon counting purity	100% (by hits, ≤7)
➢ Dark Count (0.3 p.e.)	< 2 kHz
➢ Price/cm2	≤10" PMT



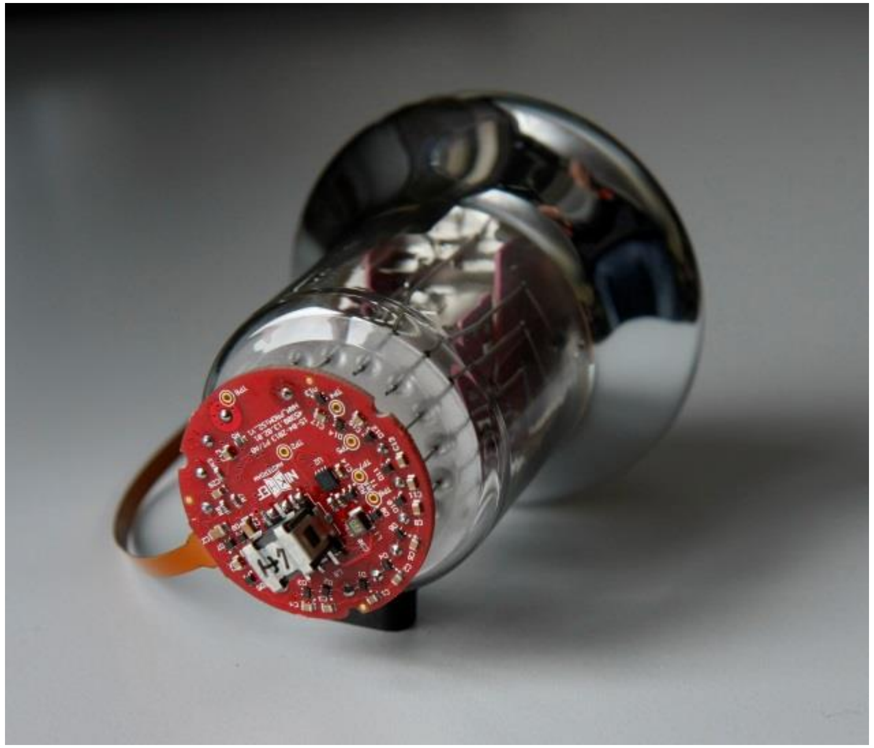
Suppliers:

- Hamamatsu (R12199)
    - (currently used in KM3NeT phase-1 detector)
- ETEL (D792)
- HZC (XP53B20, development ongoing)
- Melz

PMT Bases

PMT base – KM3NeT design

- HV generation on the base
  - Cockroft-Walton circuit
  - Input 3.3 V
  - Output to -1400 V
  - Controlled by custom ASIC : **Coco**
- Time-over-threshold readout (ToT)
  - Custom ASIC: **PROMiS**
  - Pre-amplifier
  - Digitization on the base
  - LVDS signal output
- LOW power (140 mW for 31 PMTs)
- HV and threshold adjustable over I2C
- Each base has a unique electronic identifier
- 3.3 V, I2C, LVDS over thin kapton cable
- Adjustable for different PMT manufacturers

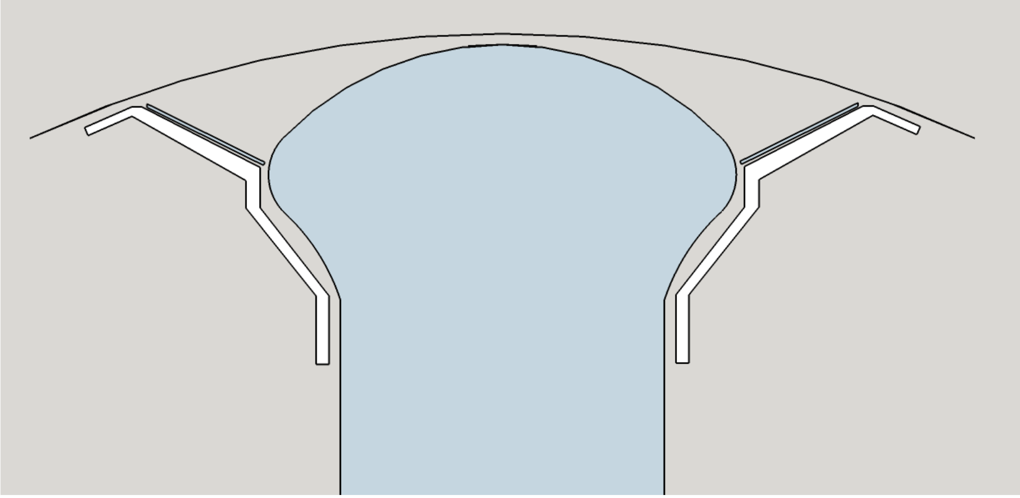


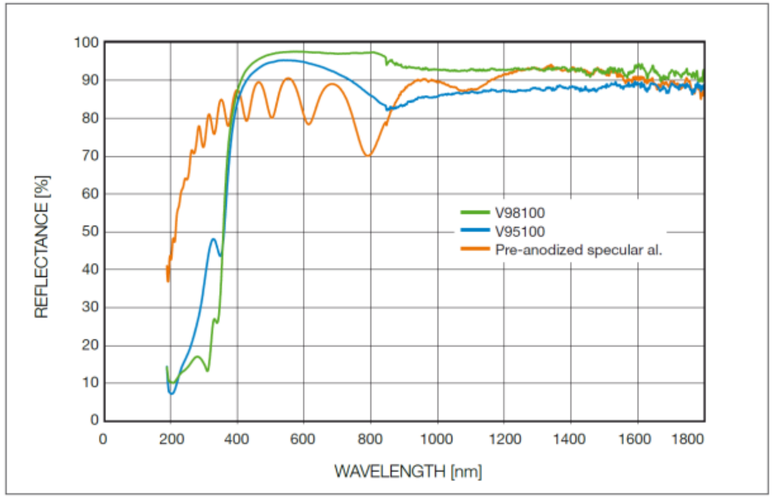
Negative HV on photo-cathode

Gain: $3 * 10^6$

HV tuned to set ToT to a specific value at fixed threshold

Reflector rings



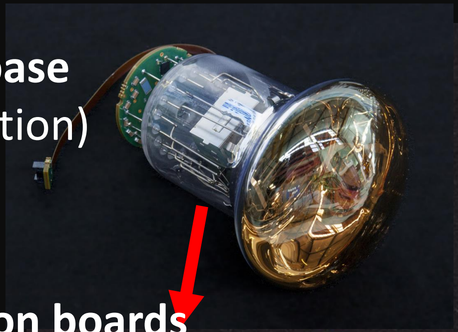


Reflector rings around PMTs increase light yield with 20-40 % and improve directionality

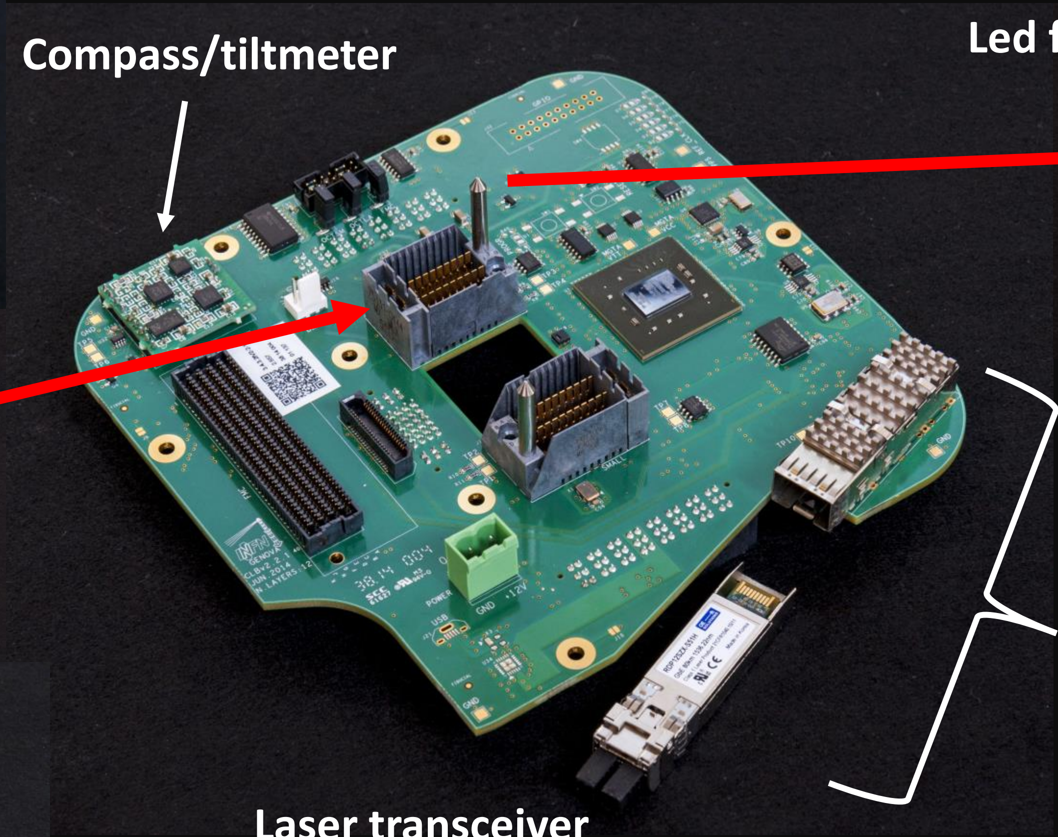
Aluminium coated with silver and protective layers

DAQ/Electronics

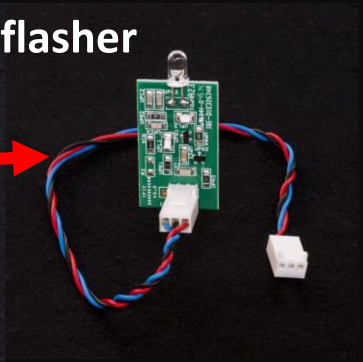
PMTs+base
(digitization)



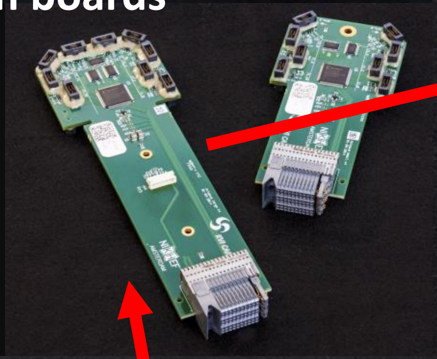
Compass/tiltmeter

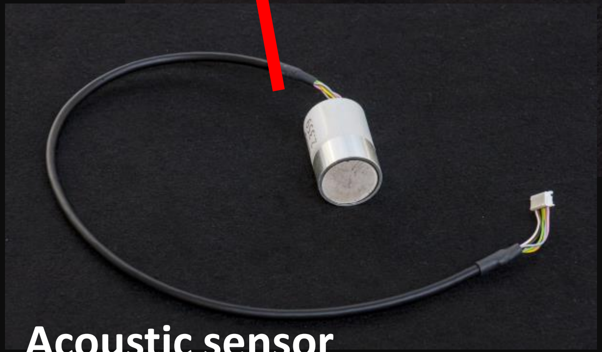


Led flasher



Signal collection boards
(addressing)





Acoustic sensor
(Piezo, digitization in device)

Laser transceiver
Each DOM has a defined
outgoing wavelength
Multiplexed outside DOM
Incoming is a broadcast

Central Logic Board (CLB)
FPGA :

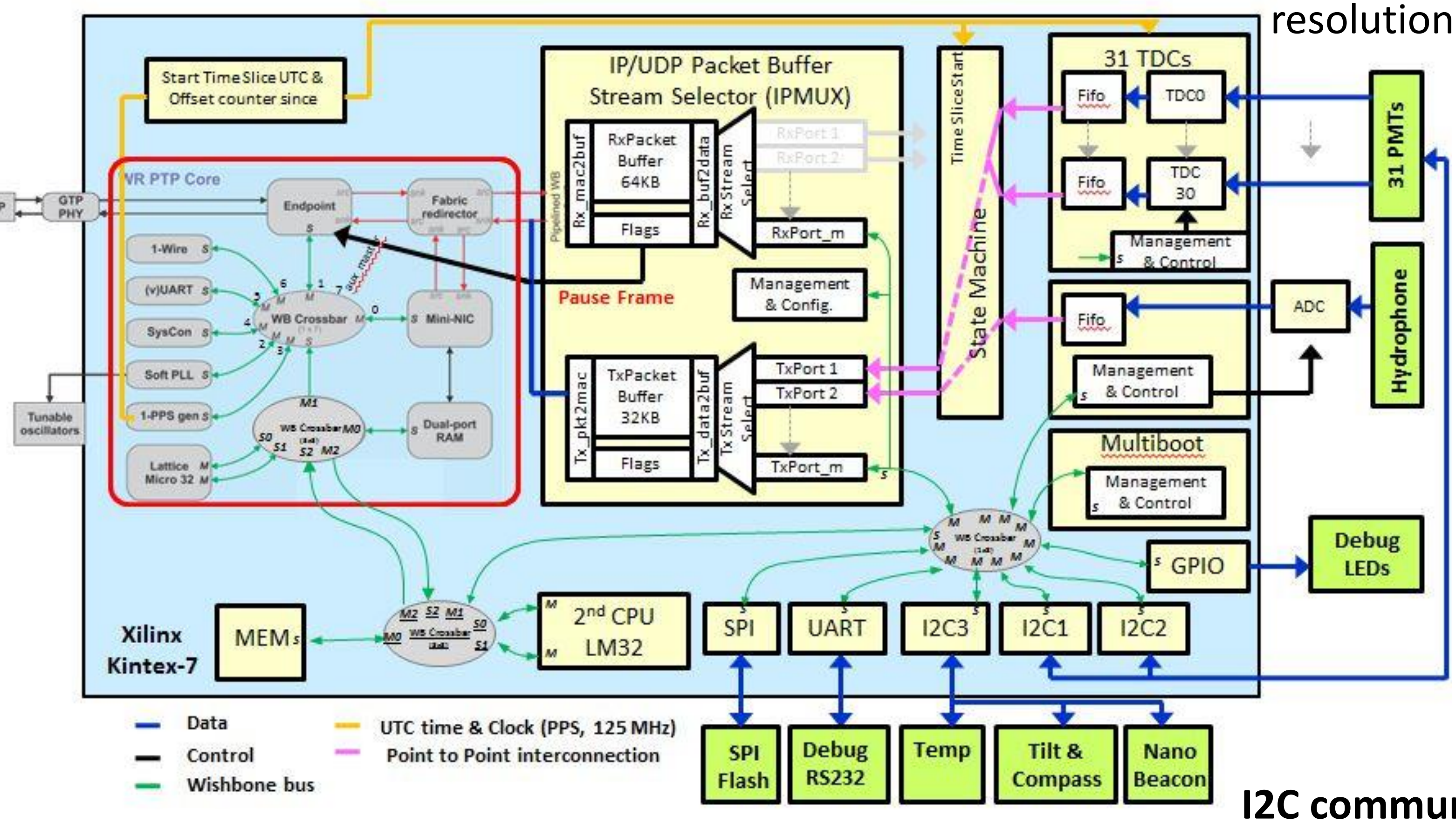
- DAQ pipeline
    - Nanosecond timestamping
- Ethernet packet generation
- White-Rabbit timing
- Slow control CPU (LM32)
- Under-water reprogrammable

DAQ/Electronics: FPGA

IP/UDP (ethernet) packet creation
Multiple streams
(PMTs, acoustic, monitoring)

High-Speed TDCs
LVDS inputs from PMTs
Hit time and ToT. $800\text{ps}/\sqrt{12}$ resolution

White Rabbit PTP core
for time synchronization and Ethernet over optical fibres.



Multiboot system
(fail-safe reprogramming)

LM32 CPU
Control from shore
(Slow control, DAQ pipeline, White Rabbit, other sensors)
Implements software state machine

UART
Serial terminal
Tunneled over ethernet

I2C communication
HV and thresholds
Compass/tiltmeter
Led Flasher
Temperature/Humidity

DAQ – Datastream from DOM

Digitized LVDS pulses are converted to t0 (leading edge) and ToT (width of pulse) by TDCs

Continuous datastream from PMTs is converted into ´hits´ : t0, ToT and PMT ID – 6 bytes

All hits for a specific duration (100 ms) are collected in ´frames´

Frames are formatted into IP/UDP packets and sent over 1Gb optical link

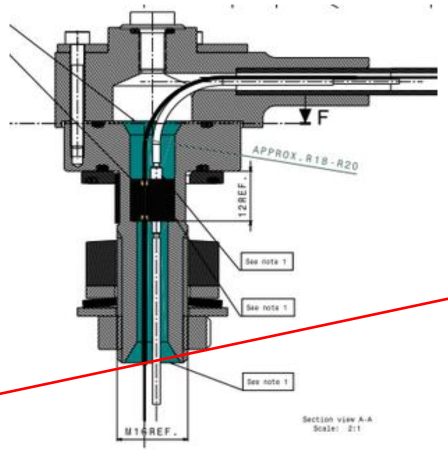
On- shore switching infrastructure and farm collects frames for all DOMs and assembles timeslices (100 ms snapshot)

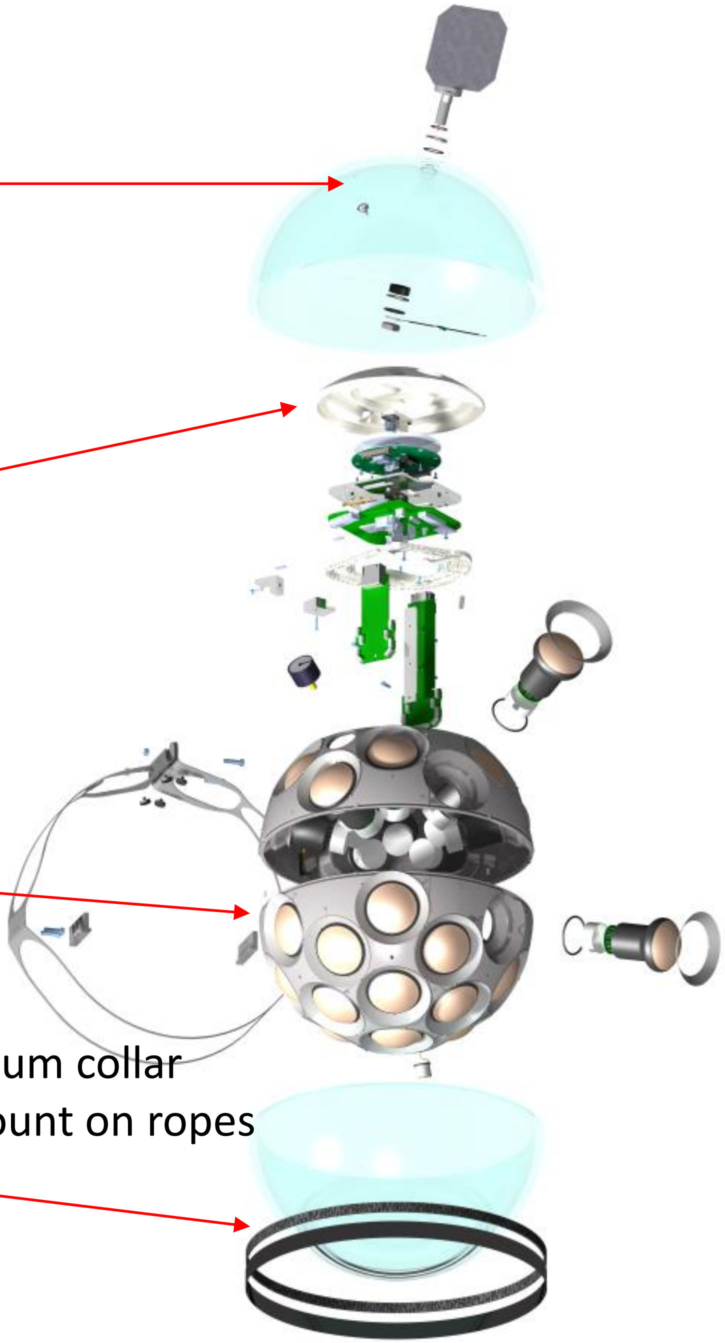
Trigger farm looks for correlated hits.

Interesting timeslices are stored

Selected Mechanics

´Penetrator´ (KM3NeT design)
- Feedthrough for power and optical fibre
- Holds of 400 bar





Cooling structure (mechanical support and passive cooling)

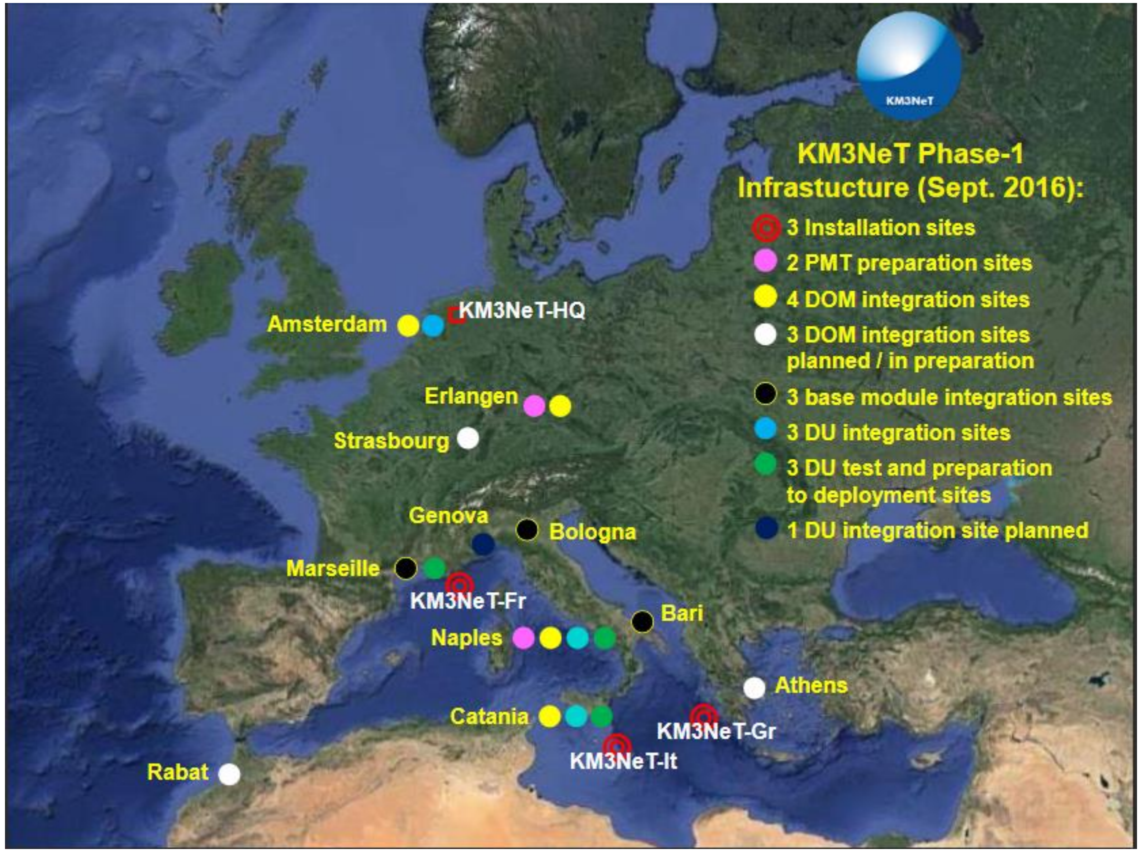
3D printed support structure (SLS)
- Defines PMT, piezo, led, … positions
- Barrier for optical gel

Glass sphere (comes in 2 halves) withstands up to 670 bar

Titanium collar to mount on ropes

DOM integration

With 1.5 FTE :
1 DOM takes 3 days ….
… but 5 take a week
(waiting for glue, gel etc.)



Integration, functional test, integration, acceptance test.

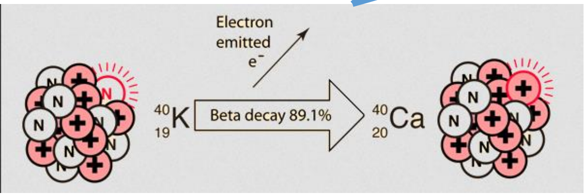
All components have their own identification (QR code) with associated database entry
(e.g. PMT calibration)

QA/QC system tracks components
Integrated in DOMs.

In-situ time calibration

Cherenkov photons

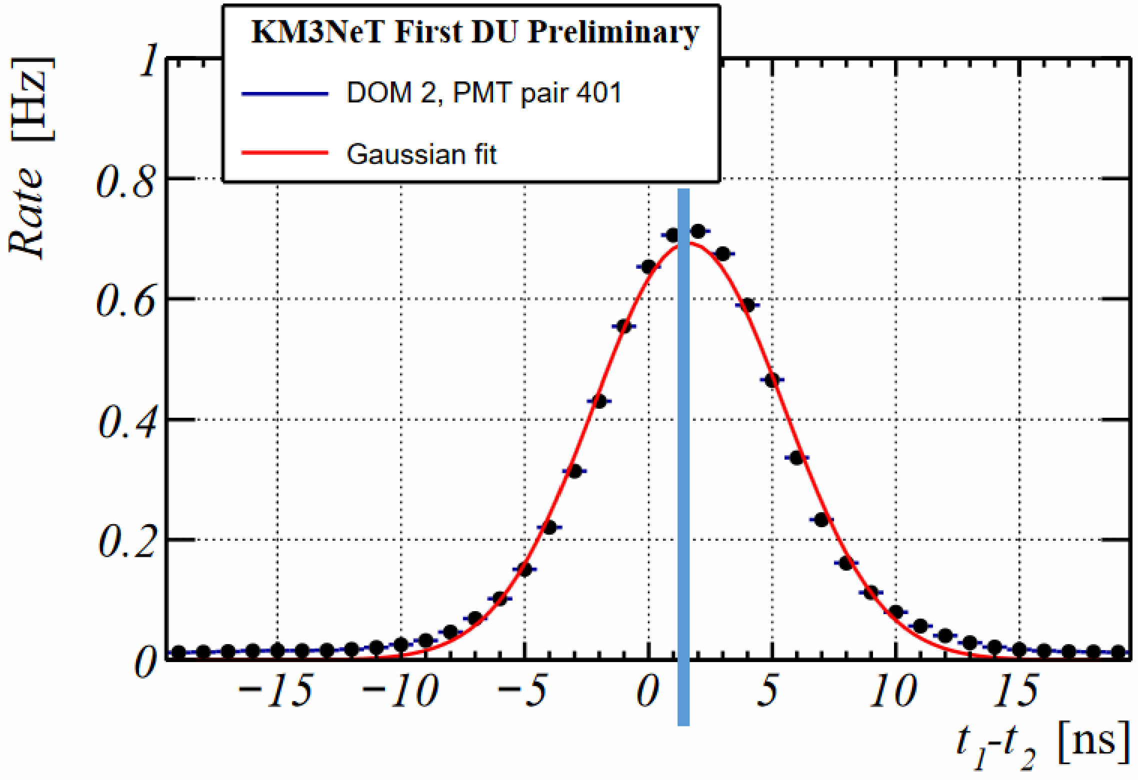
Photons from k40 decay
cause coincident hits



Muon

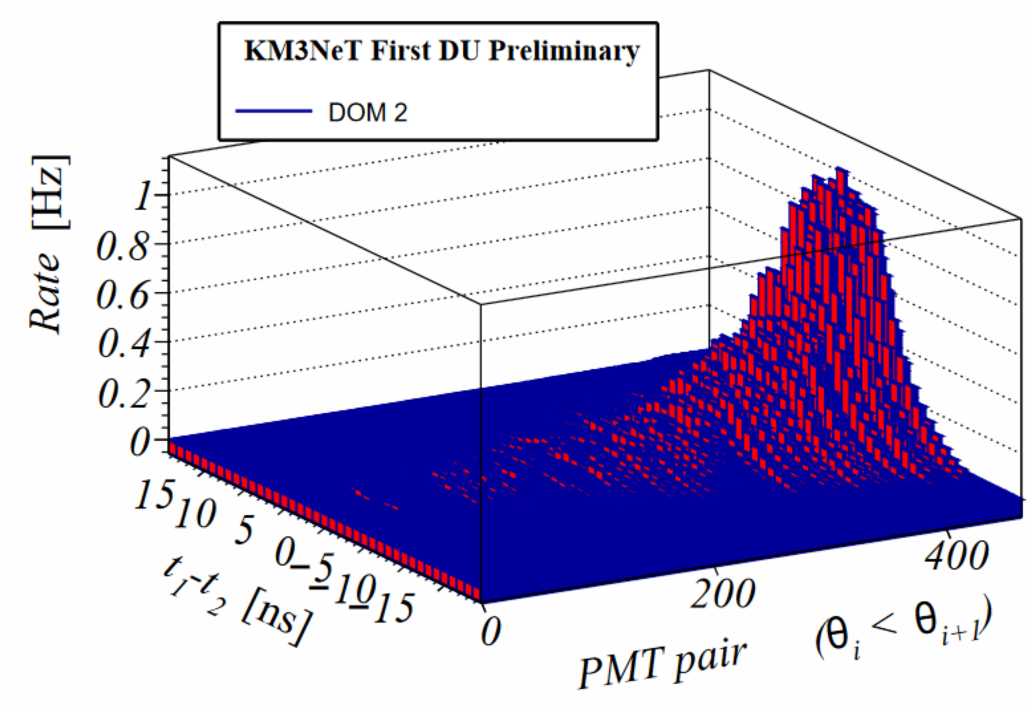
K40 time calibration

Time difference distribution between two PMTs in a DOM



Time offset between the two PMTs

All PMT pairs

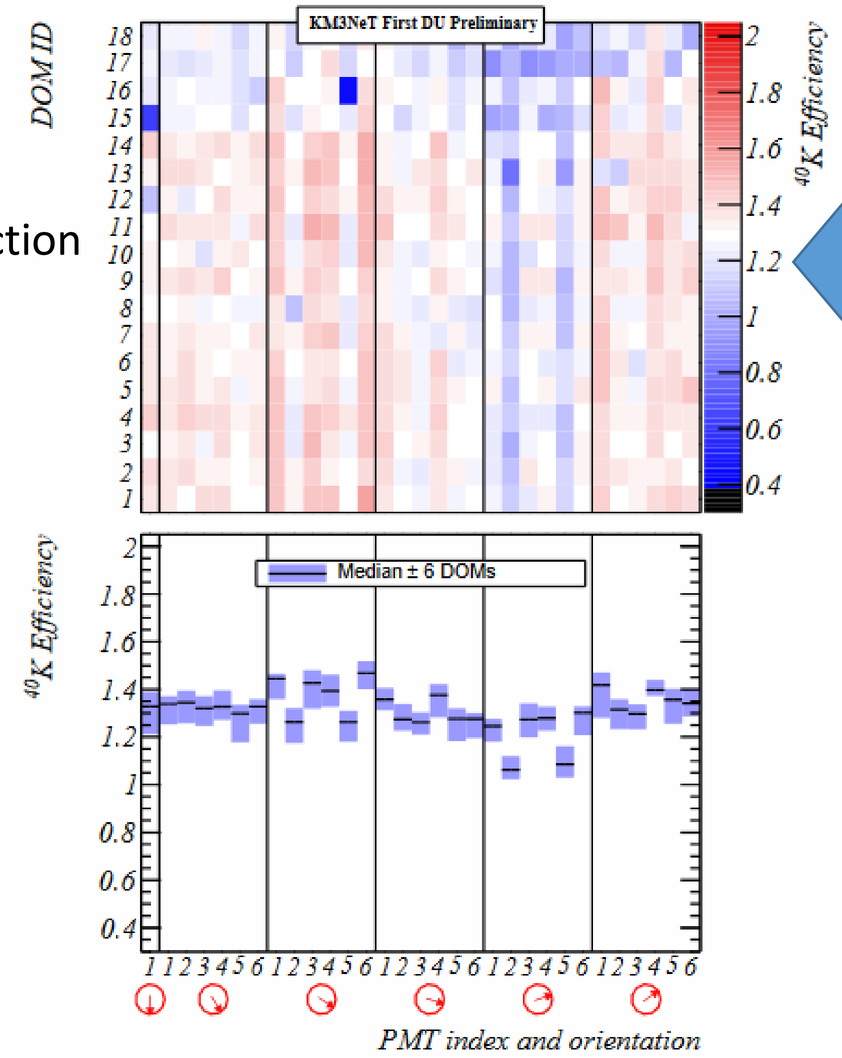


Information from k40 decay :
- time offset
- efficiency
- time spread

Understanding efficiencies

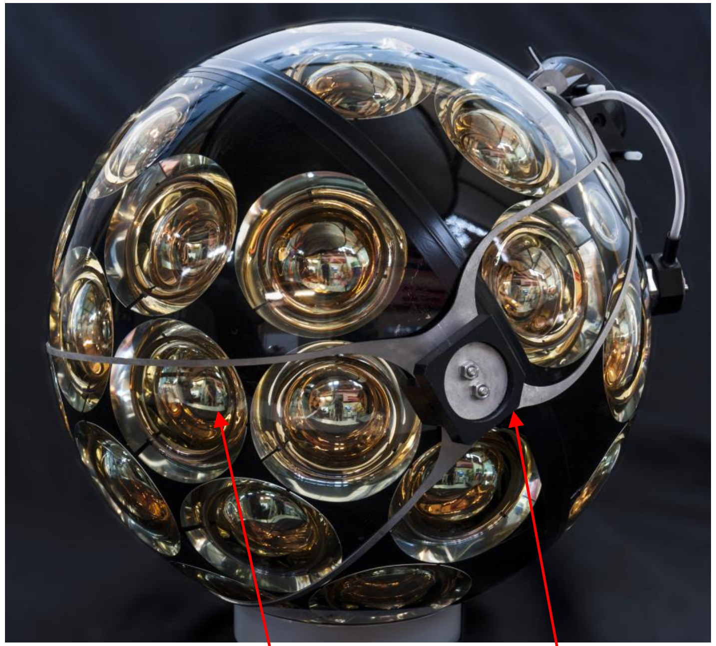
Coincidences give insight into relative efficiencies

Along detection unit



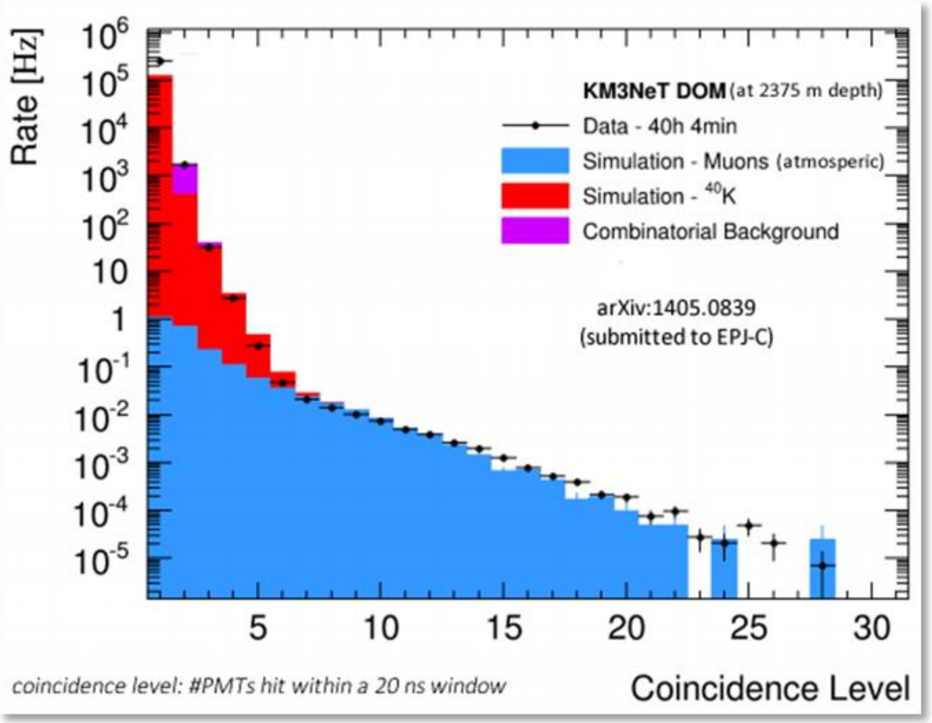
PMTs in DOM

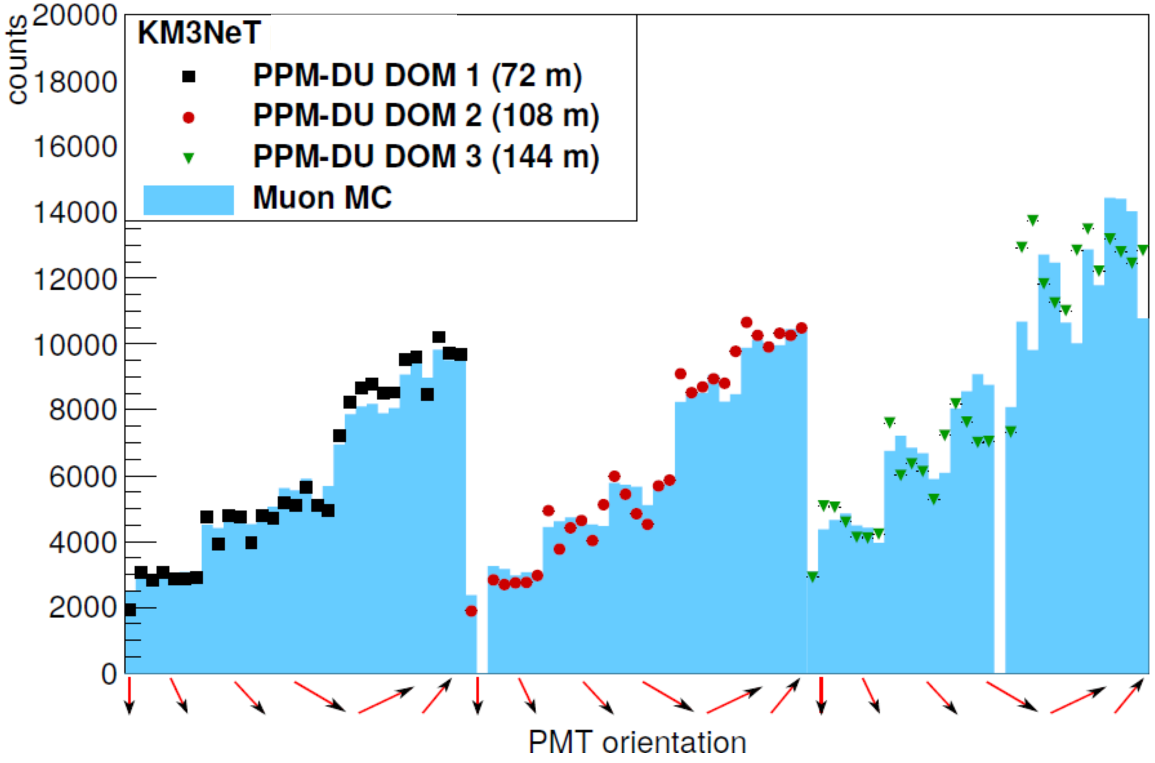
Vertical bands indicate influence of DOM mechanics



Photons are blocked

Photon counting and direction





Photon counting

(muons cause higher multiplicity coincidences)

Directional sensitivity

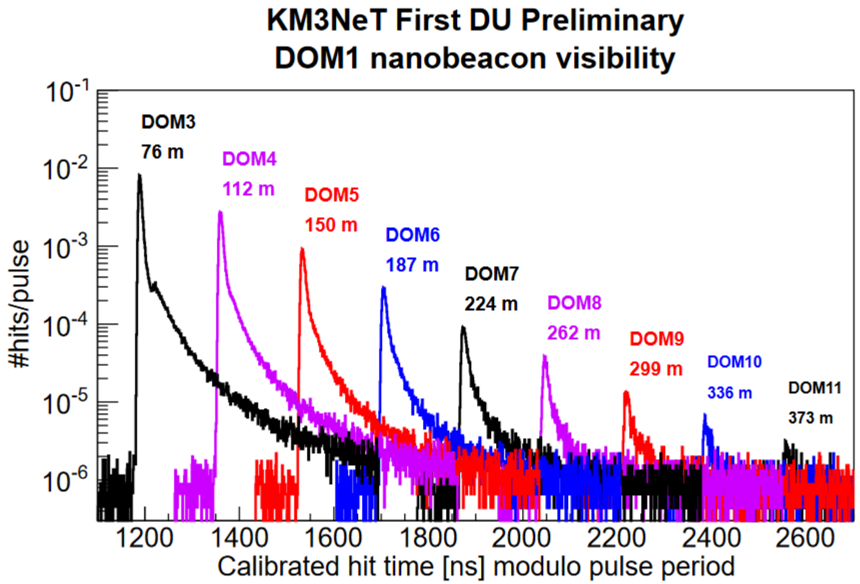
(photons from muons come from above)

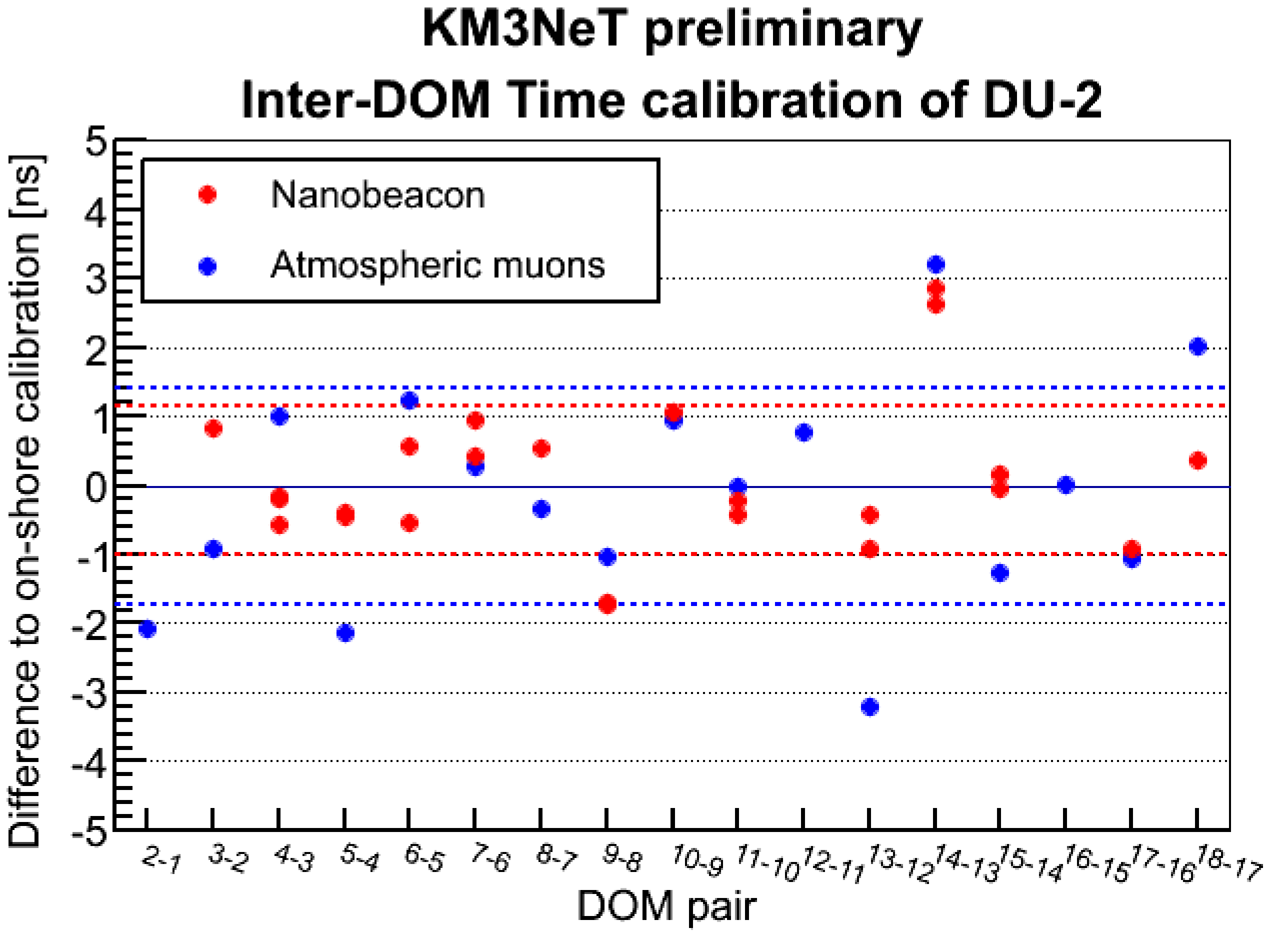
(data in these plots is from prototypes PPM-DOM (*Eur. Phys. J. C (2014) 74:3056*) and PPM-DU (*Eur.Phys.J. C76 (2016) no.2, 54*)

Inter-DOM calibration

Calibration between DOMs:

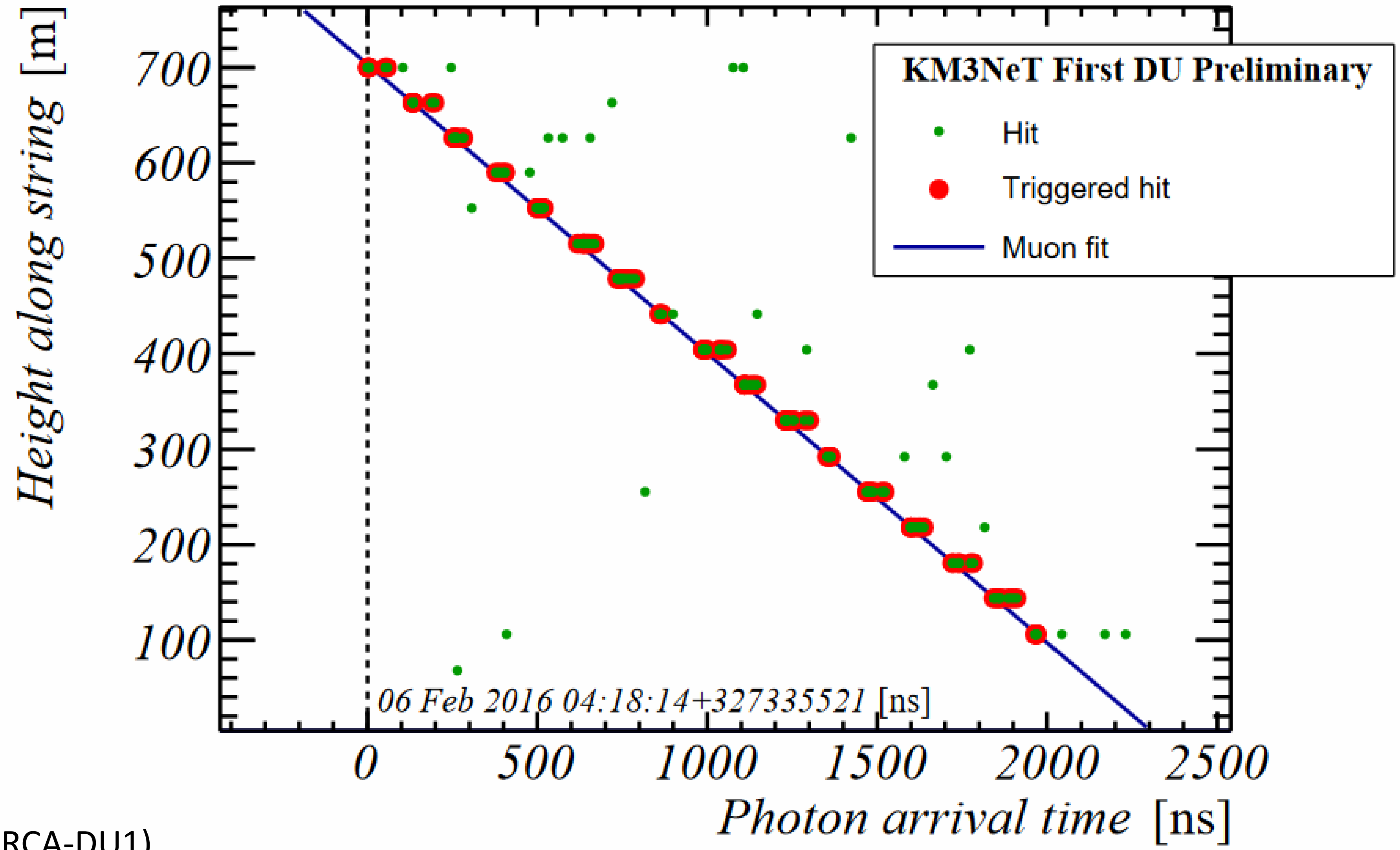
- Laser calibration in lab
- Led-flashers
- Atmospheric muons





(Data from ARCA –DU1 & 2)

Reconstructed event



(Data from ARCA-DU1)

Summary

- The KM3NeT Digital Optical Module maximizes physics potential of the ARCA and ORCA detectors
  - It provides:
    - Nanosecond-timing
    - Photon counting
    - Directional sensitivity
  - Design allows in-situ calibration
  - The design has been validated by prototypes and the first detection units