# White Rabbit in KM3NeT

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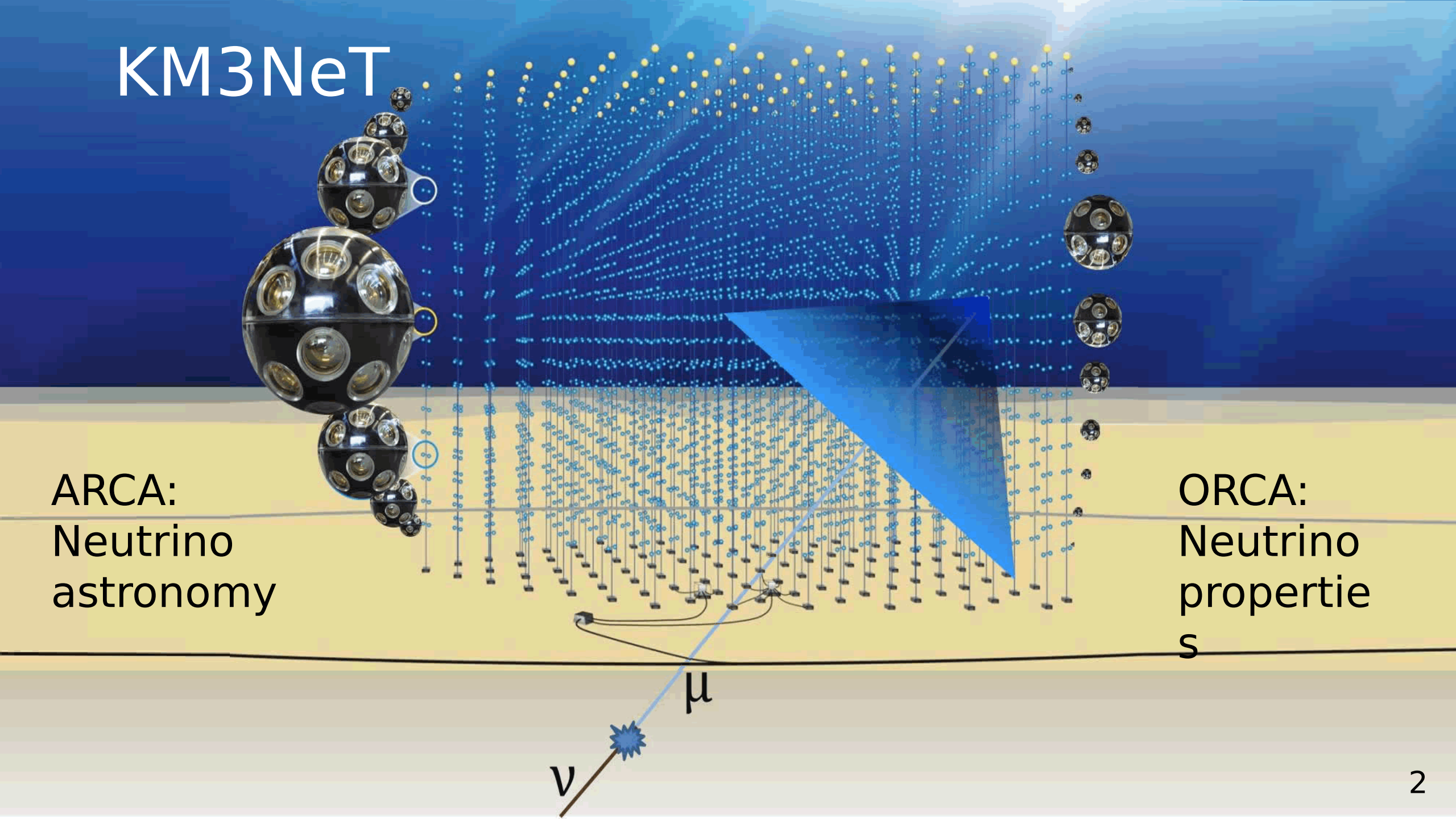
NIKHEF

9th White Rabbit Workshop
15 March 2016

Supported by EC ASTERICS Horizon2020 grant 653477

# KM3NeT




ARCA:
Neutrino
astronomy

ORCA:
Neutrino
propertie
s

# KM3NeT Construction

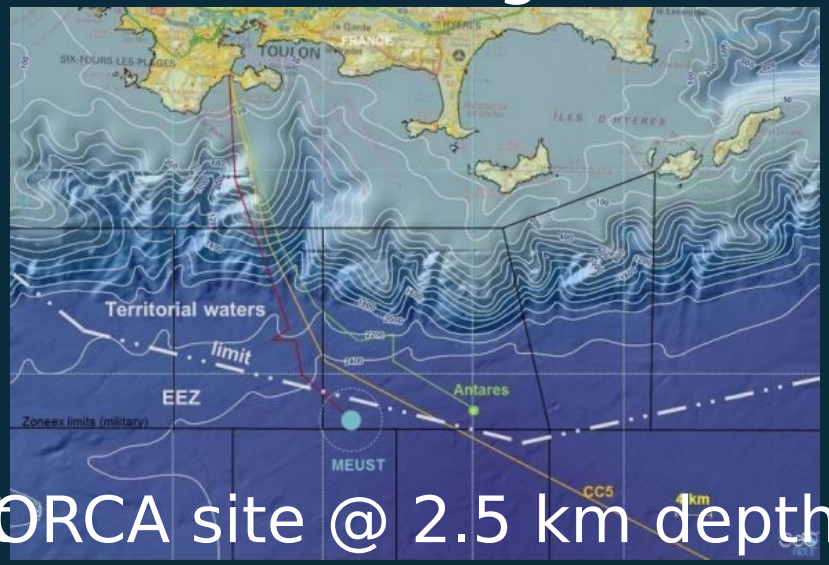
Phase 1: 2015 - 2017

- ARCA: 24 Detection Units, containing 13400 PMTs
- ORCA: 7 Detection Units, containing 4000 PMTs

Phase 2: 2017 - 2020

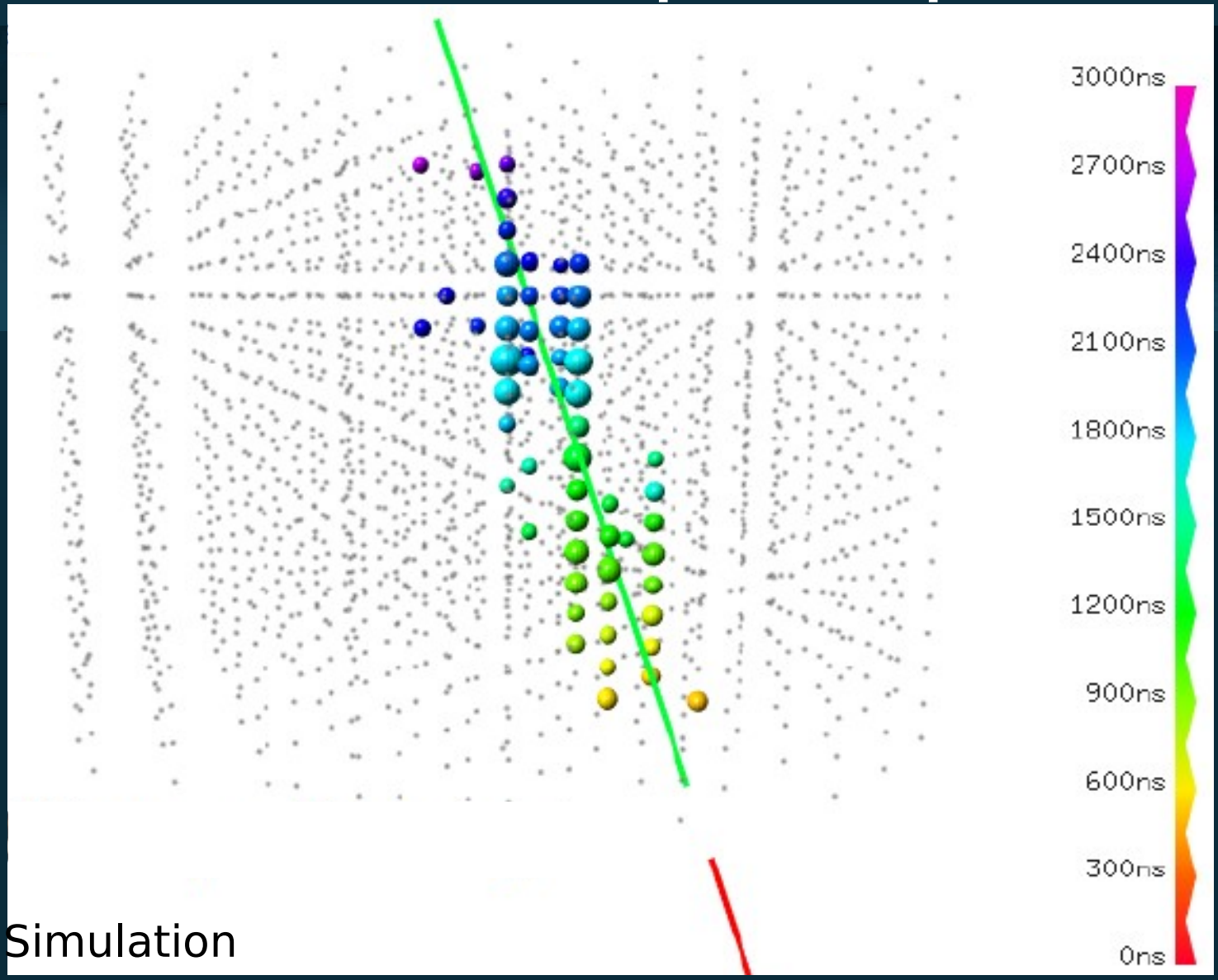
- ARCA: 230 Detection Units, containing 128000 PMTs
- ORCA: 115 Detection Units, containing 64000 PMTs


ARCA site @ 3.5 km depth



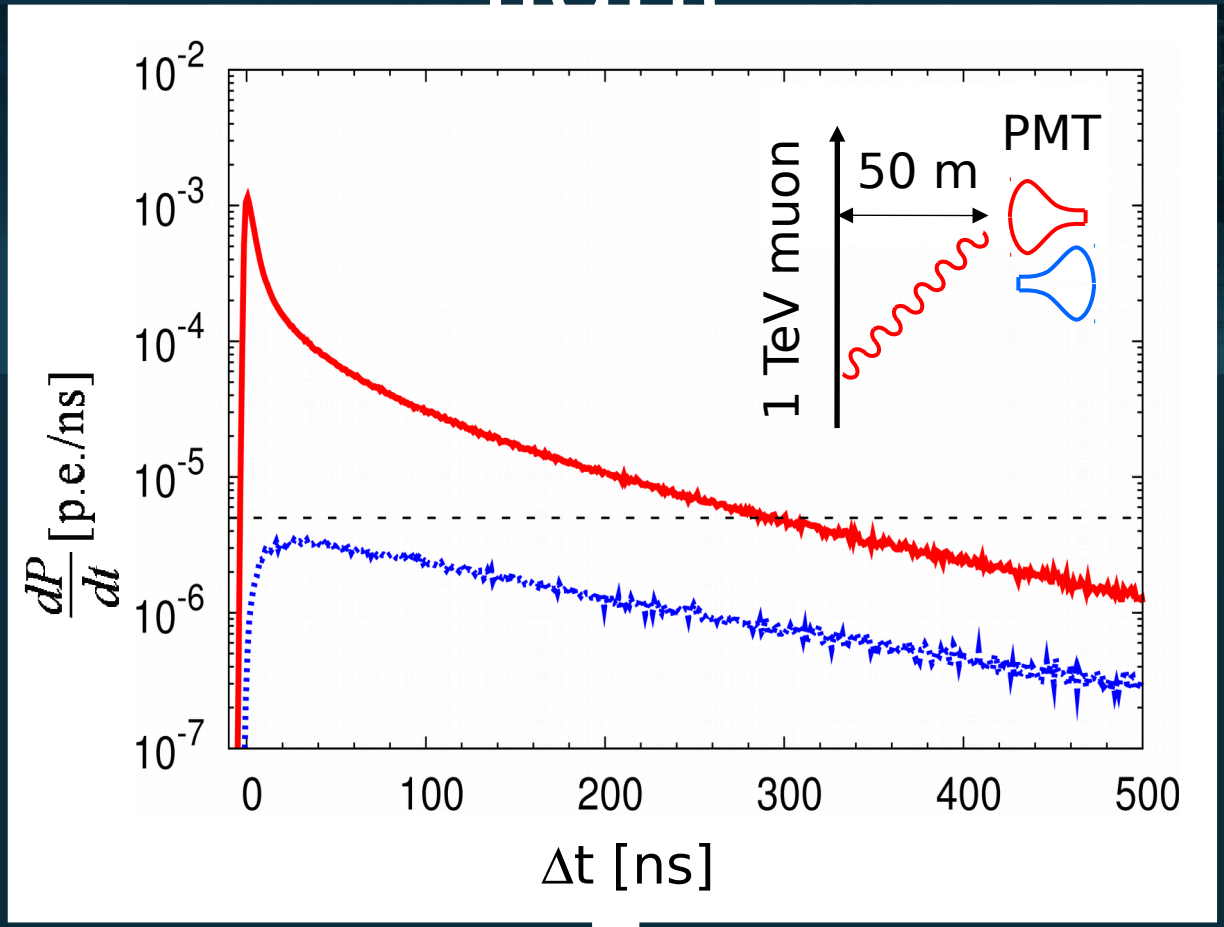

ORCA site @ 2.5 km depth

# Detection principle




Simulation

# Probability Density Function of muon light




Angular resolution 0.1 degrees

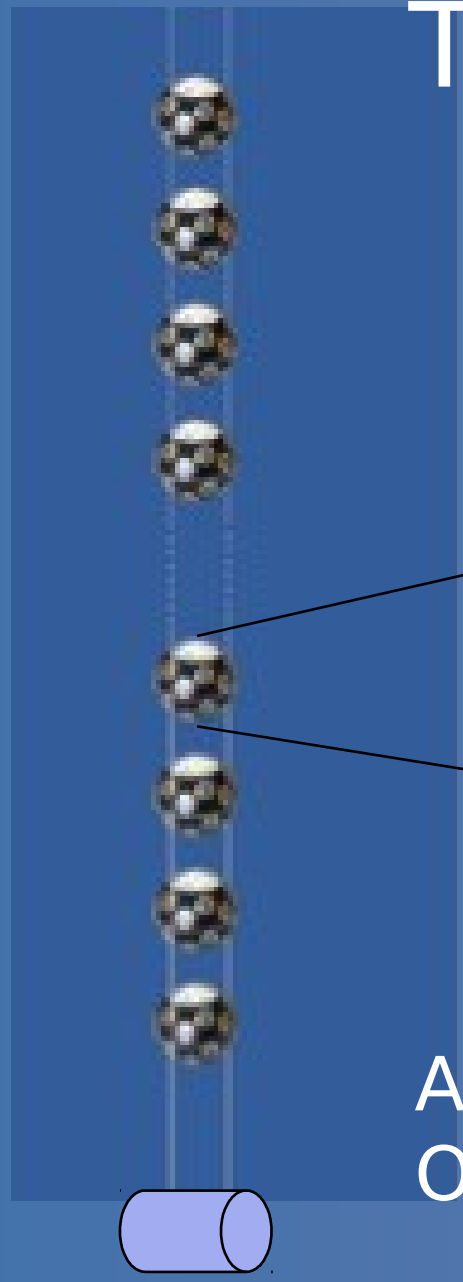
# Specifications for time calibration

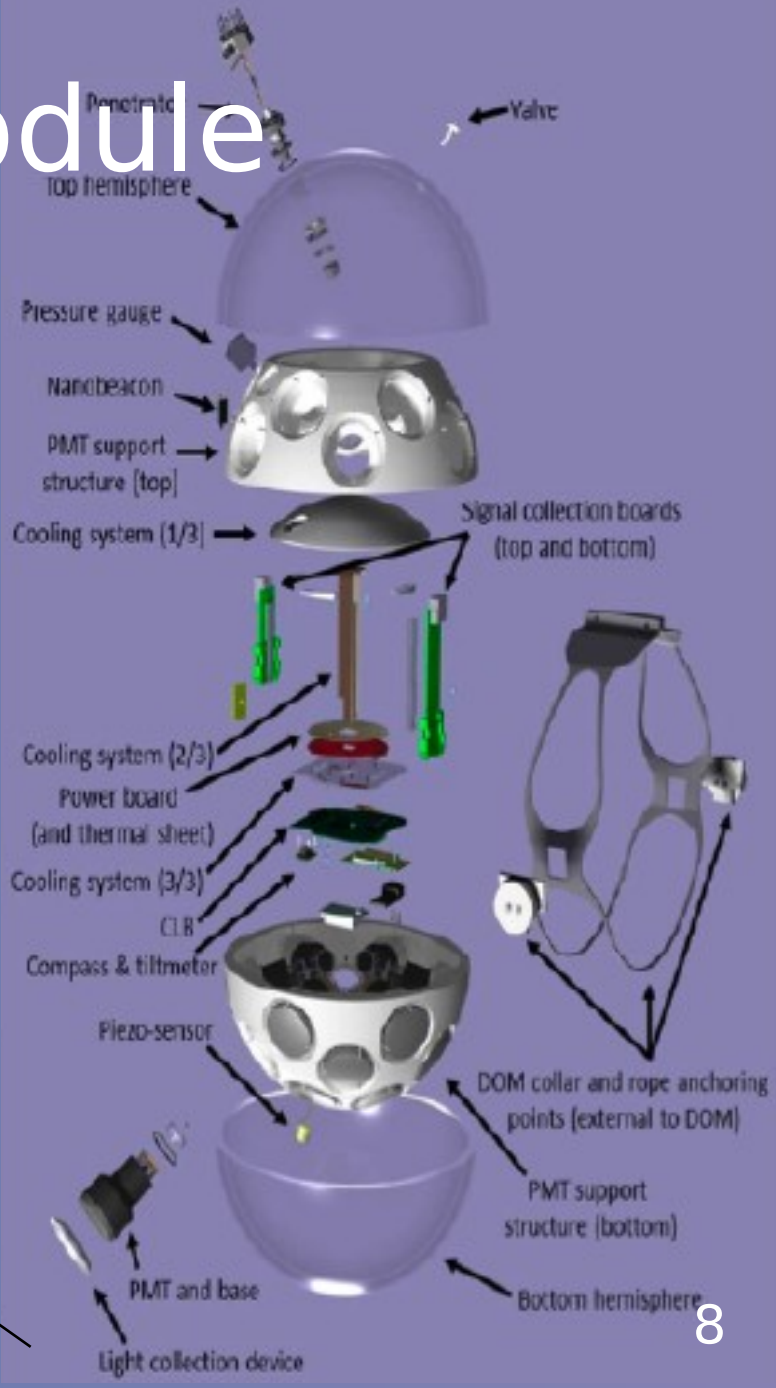
- The key observable in order to reconstruct a Cherenkov cone is the *difference* between the arrival time of the light on the PMTs.
- For the best possible angular resolution the *relative* arrival times should be known with an accuracy of better than 1 ns.
- The *absolute* time of the event should be known with an accuracy of the typical timescale of astrophysical phenomena.

# The concept

- The Cherenkov light is detected by a PMT and time stamped
- The time stamping is done using a clock that is synchronized to a master clock on shore
- The time offset of each PMT is measured before deployment
- The change in the time offset of each PMT after deployment can be corrected

# The Digital Optical Module
# DOM





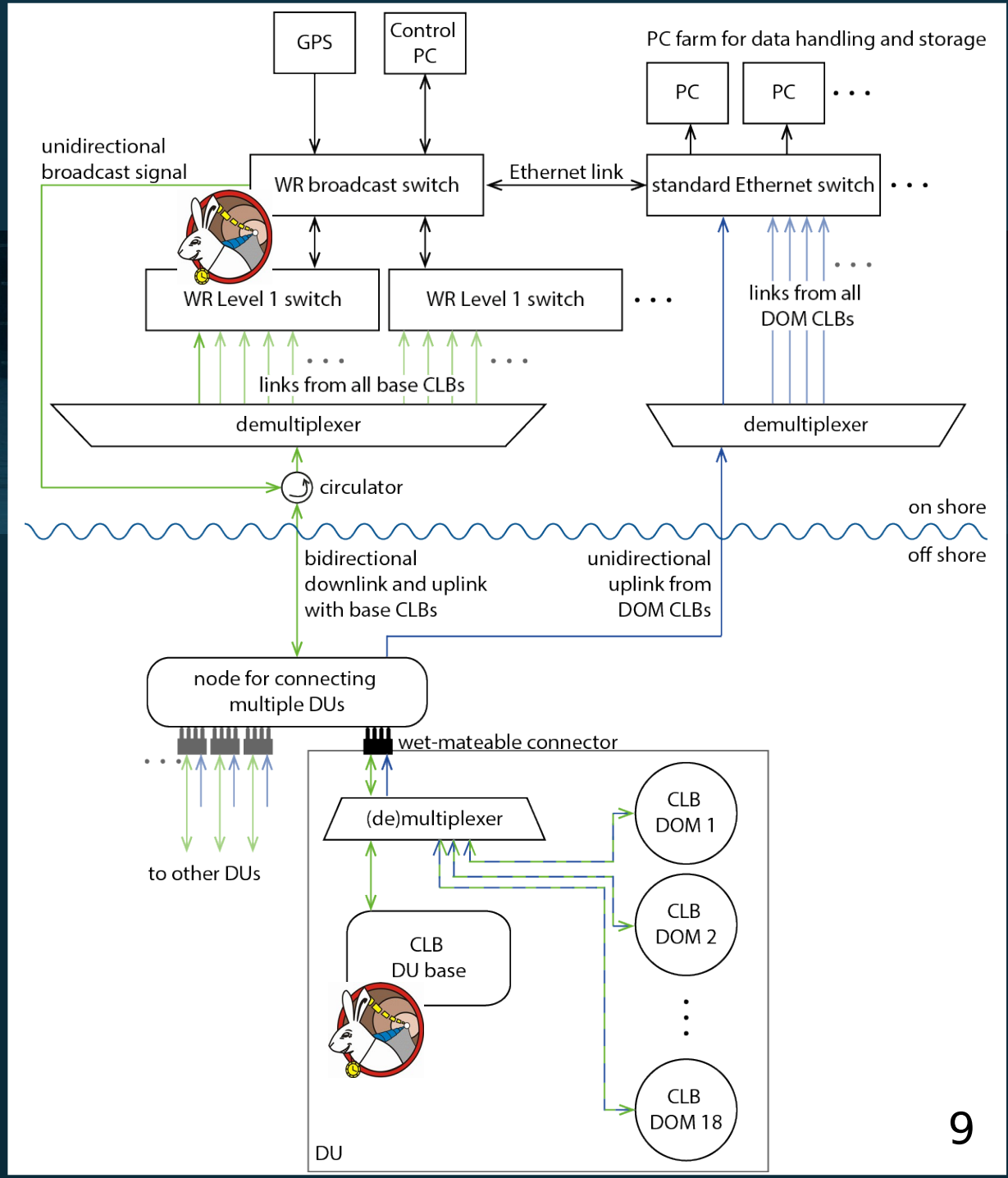

ARCA: 4140 clocks
ORCA: 2070 clocks

# KM3NeT network

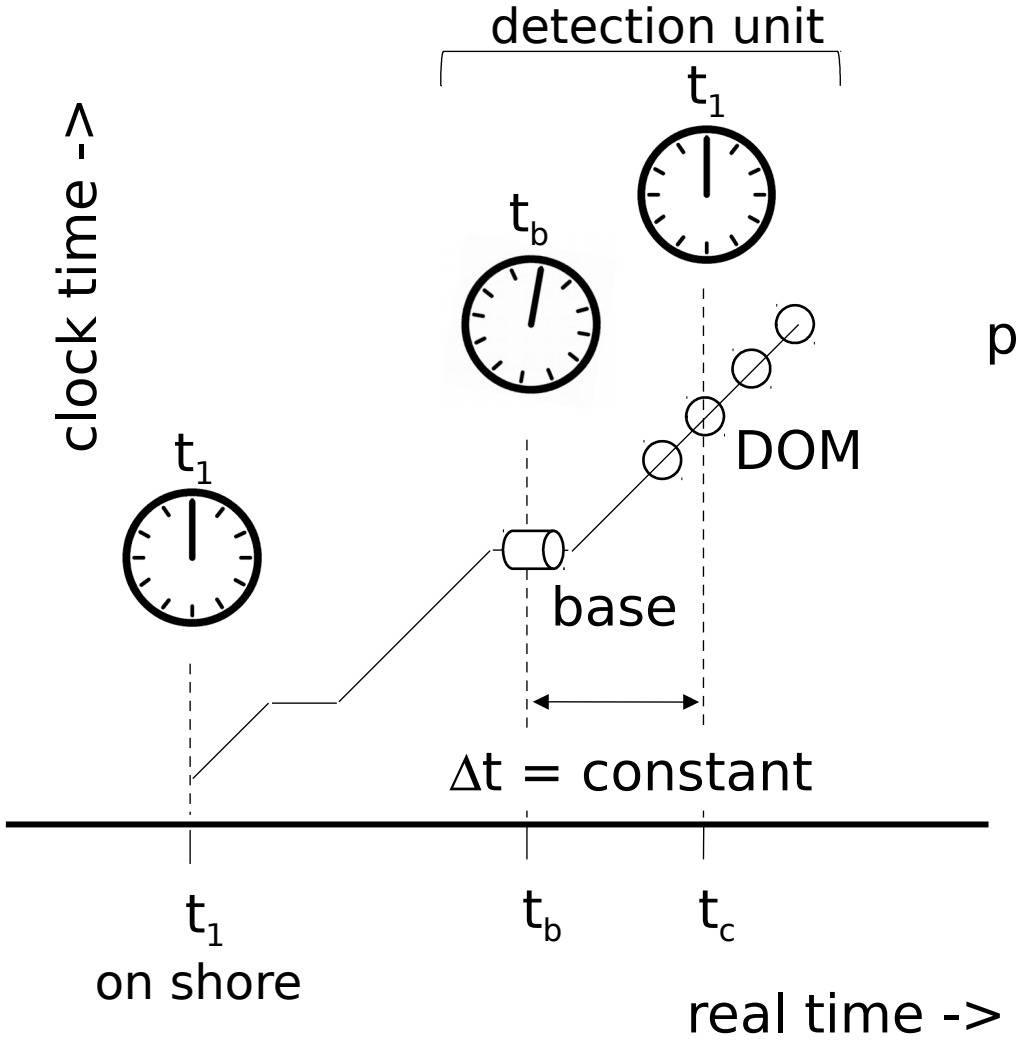
- Clock distribution based on a fiber-optic broadcast
  - Minimize active components in the deep sea
    - High cost of maintenance
    - High cost  of power
  - Downlink path to a DOM is different from its uplink (incompatible with WR)
  - Downlink path to the base in a string is the same as the uplink (almost compatible with WR)

## Hybrid solution

- Modified White Rabbit
- The base in the string runs a different White Rabbit than the DOMs



# Clock synchronization




**White Rabbit in the base**

WR allows to determine propagation delay master-slave

⇩

cable delay shore-base = time offset of string

**Clock synchronization in the DOM**

clock in DOM is set to $t_1$

⇩

fixed time offset of DOM due to propagation delay shore - DOM

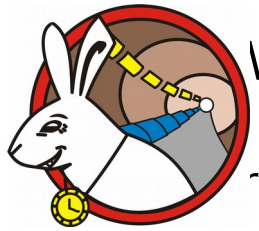
cable delay shore-base is common

# Clock synchronization

SHORE STATION

Power

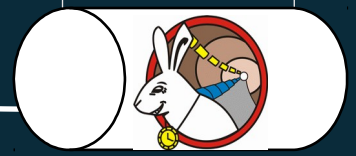
Detector

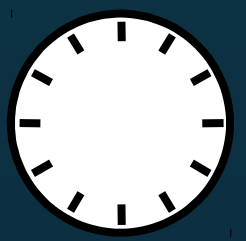



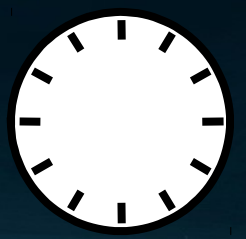
White Rabbit
Master
Broadcast switch

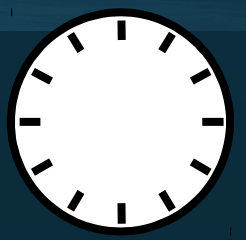
ANNOUNCE

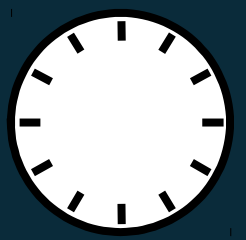
100 km

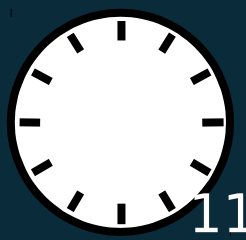




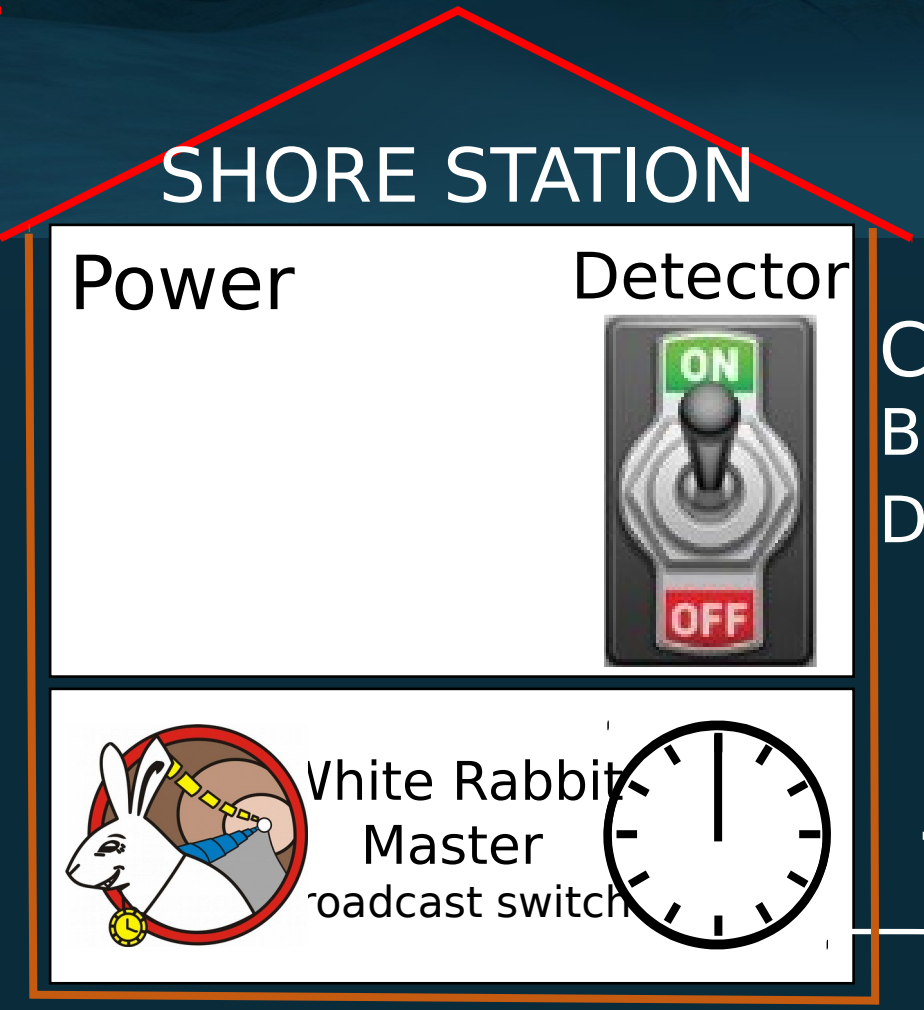








# Clock synchronization




Clock offset adjustment

Base: $offset_{MS} = t_1 - t_2 - delay_{MS}$

DOM: $offset_{MS} = t_1 - t_2 - \Delta rx_s$

# Clock synchronization

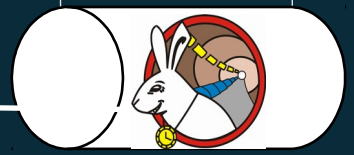
SHORE STATION

Power

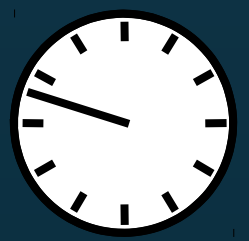
Detector

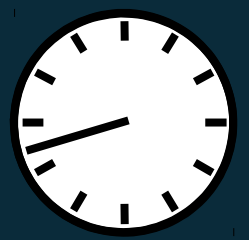

White Rabbit
Master
Broadcast switch

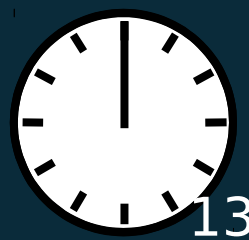
FREEZE



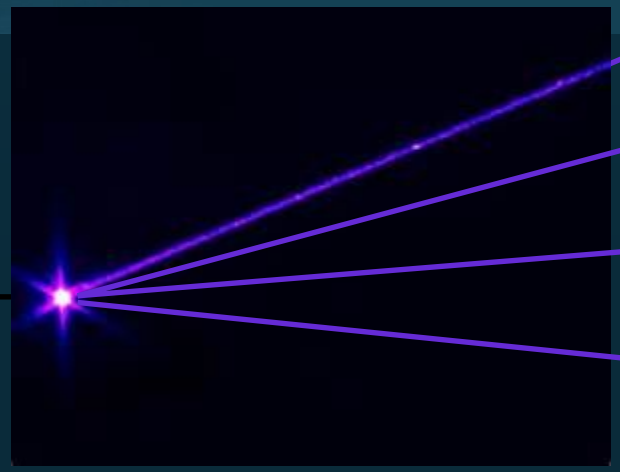
100 km





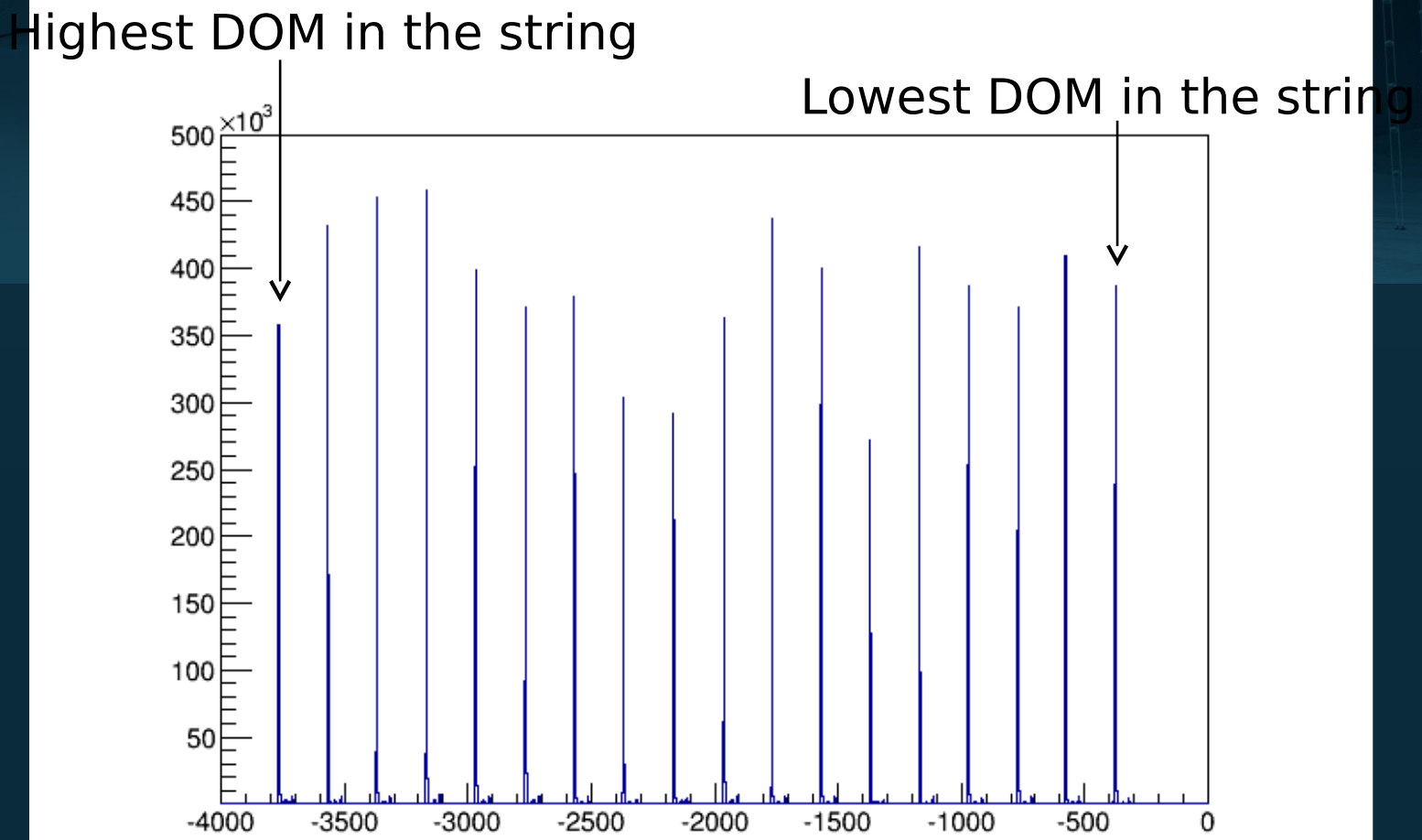


# Dark room calibration (in the



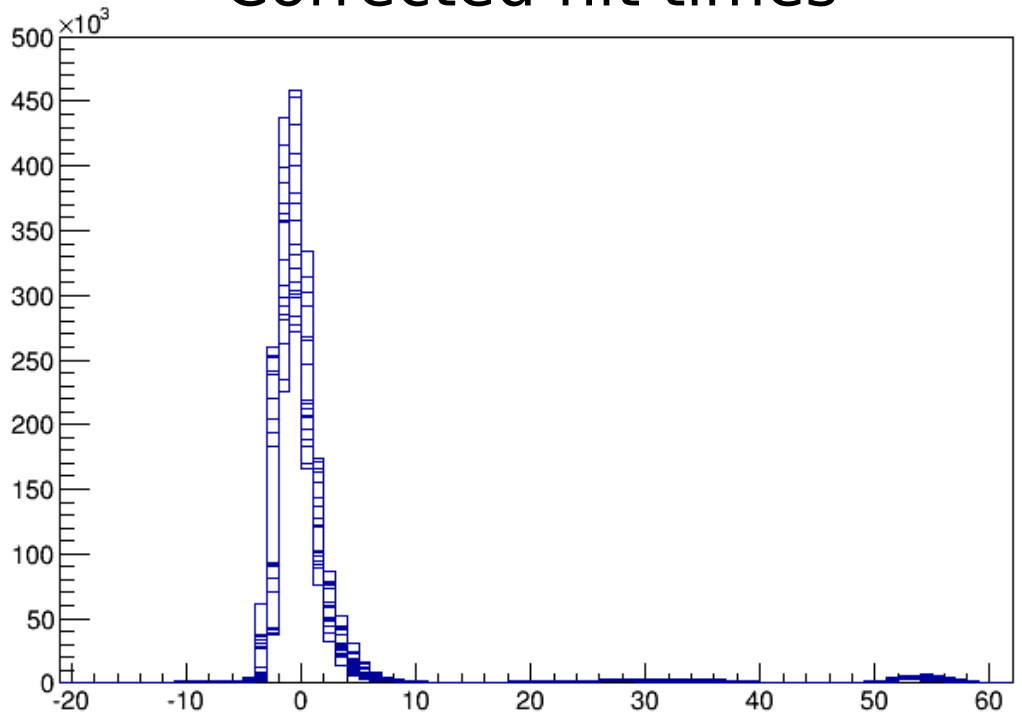

100 m

# Measured DOM offsets

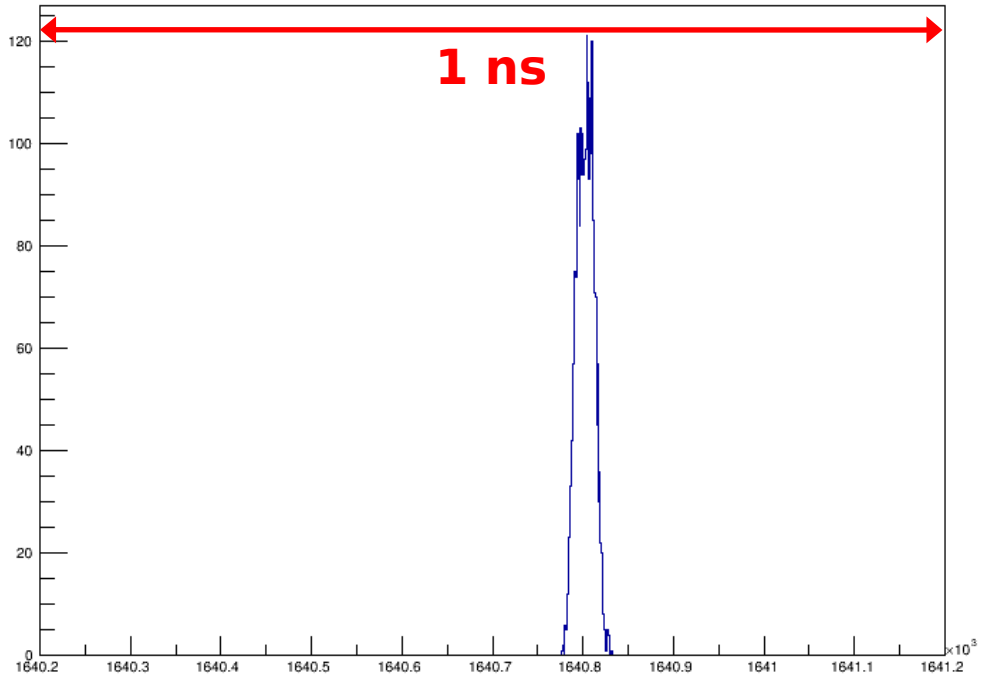


# Hit time correction dark room

Corrected hit times

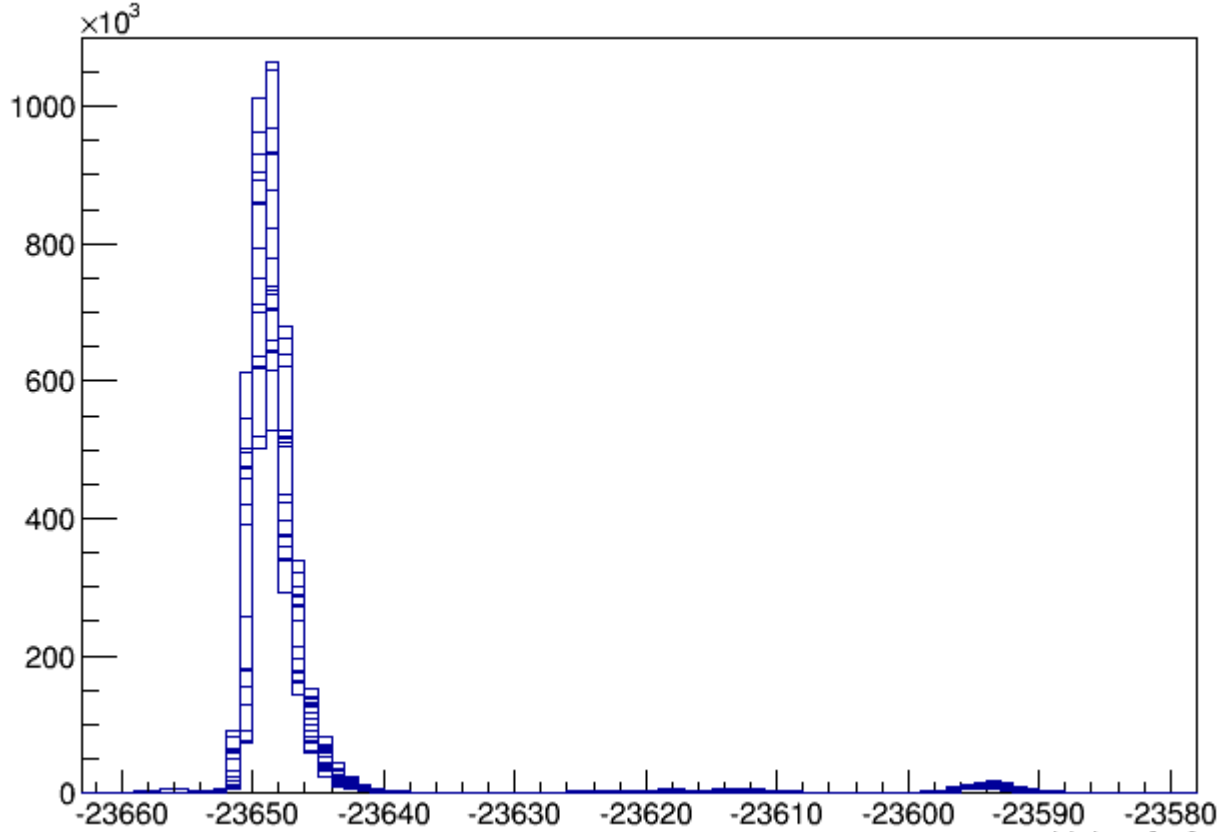



String offset in the lab

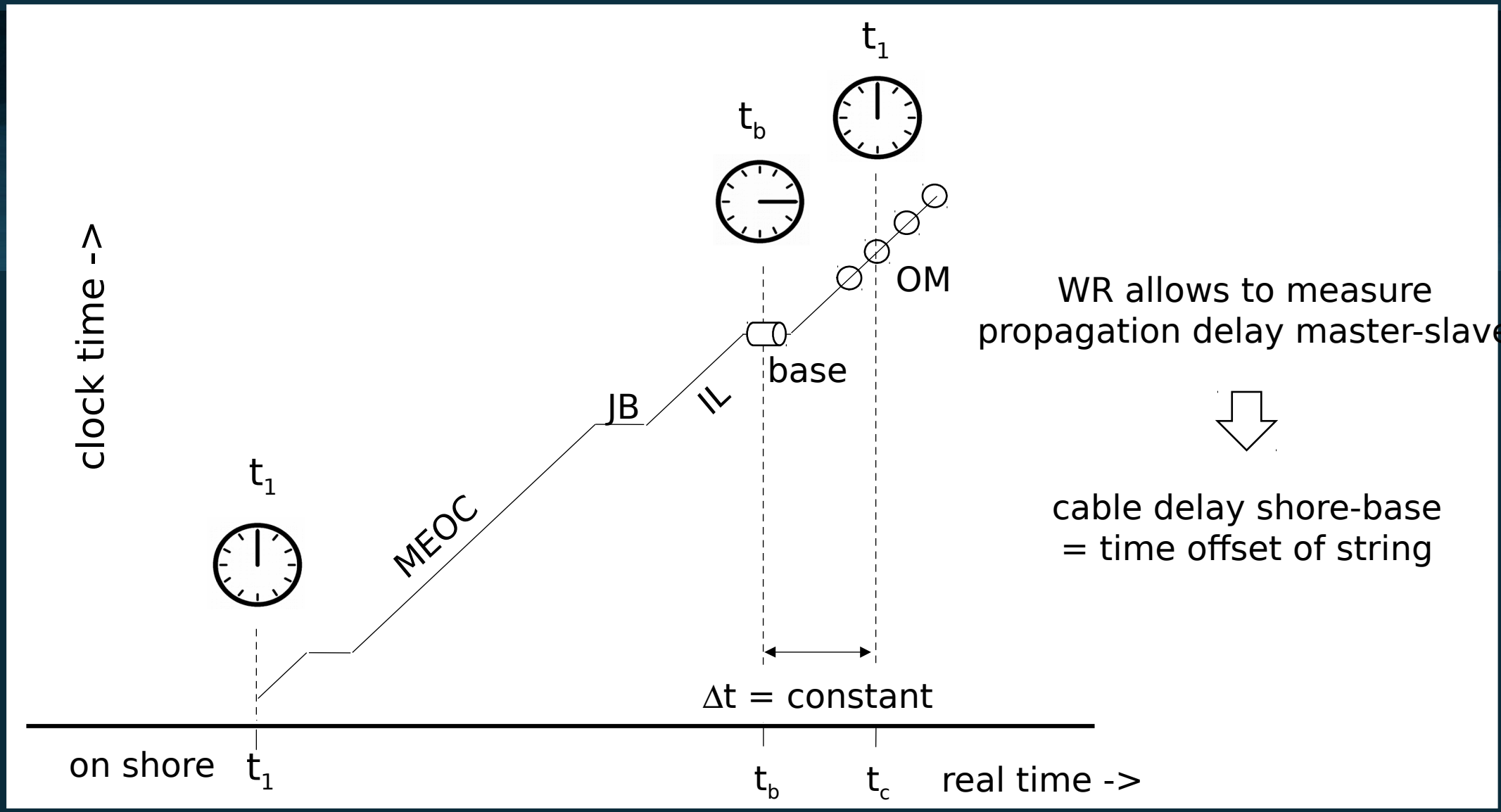


# Time offsets after “deployment”

Replaced master – base fiber in the dark room with 25 km fiber

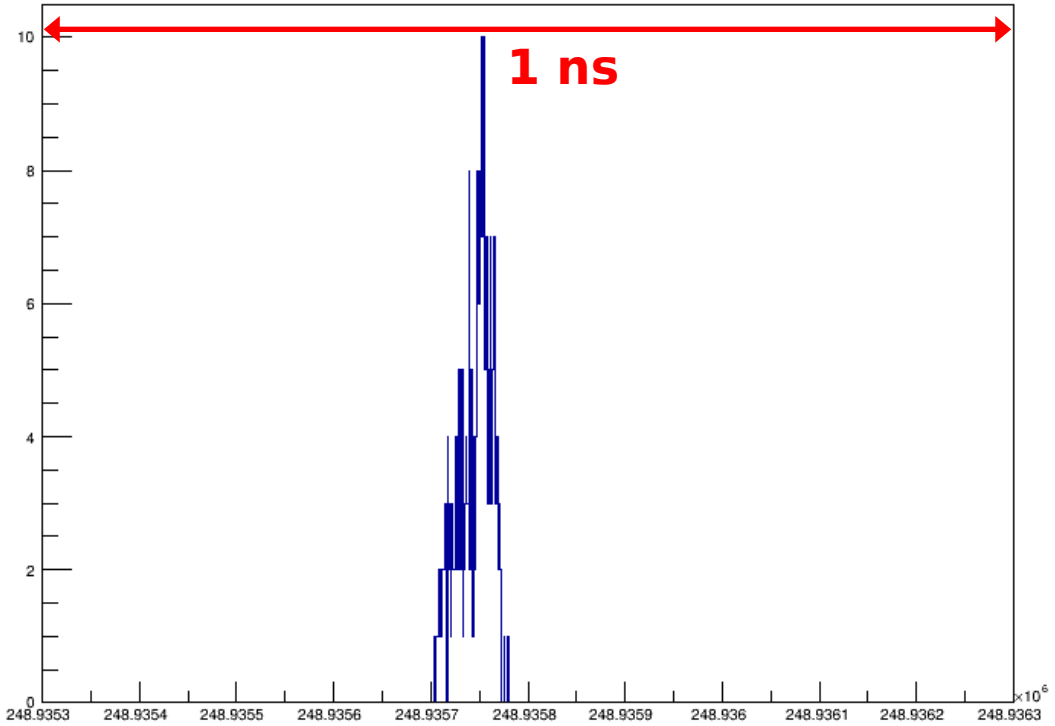


# After deployment

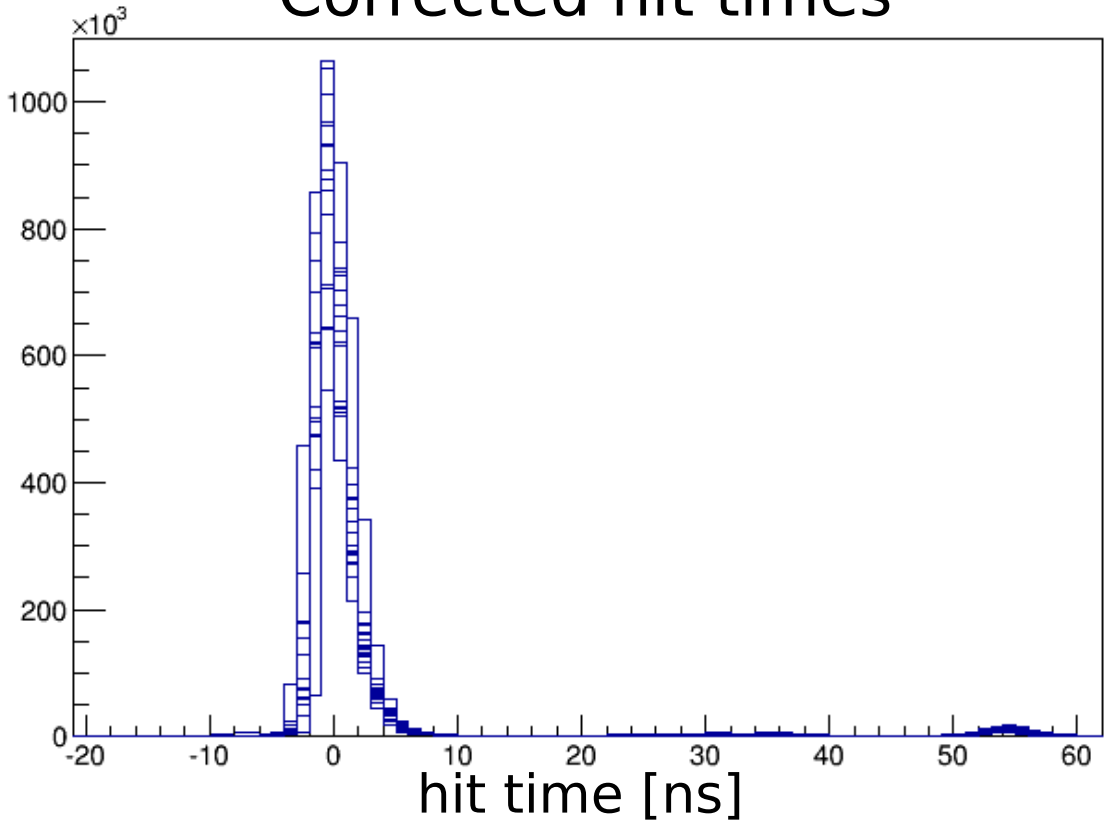


# String offset correction in situ

String offset “in situ”



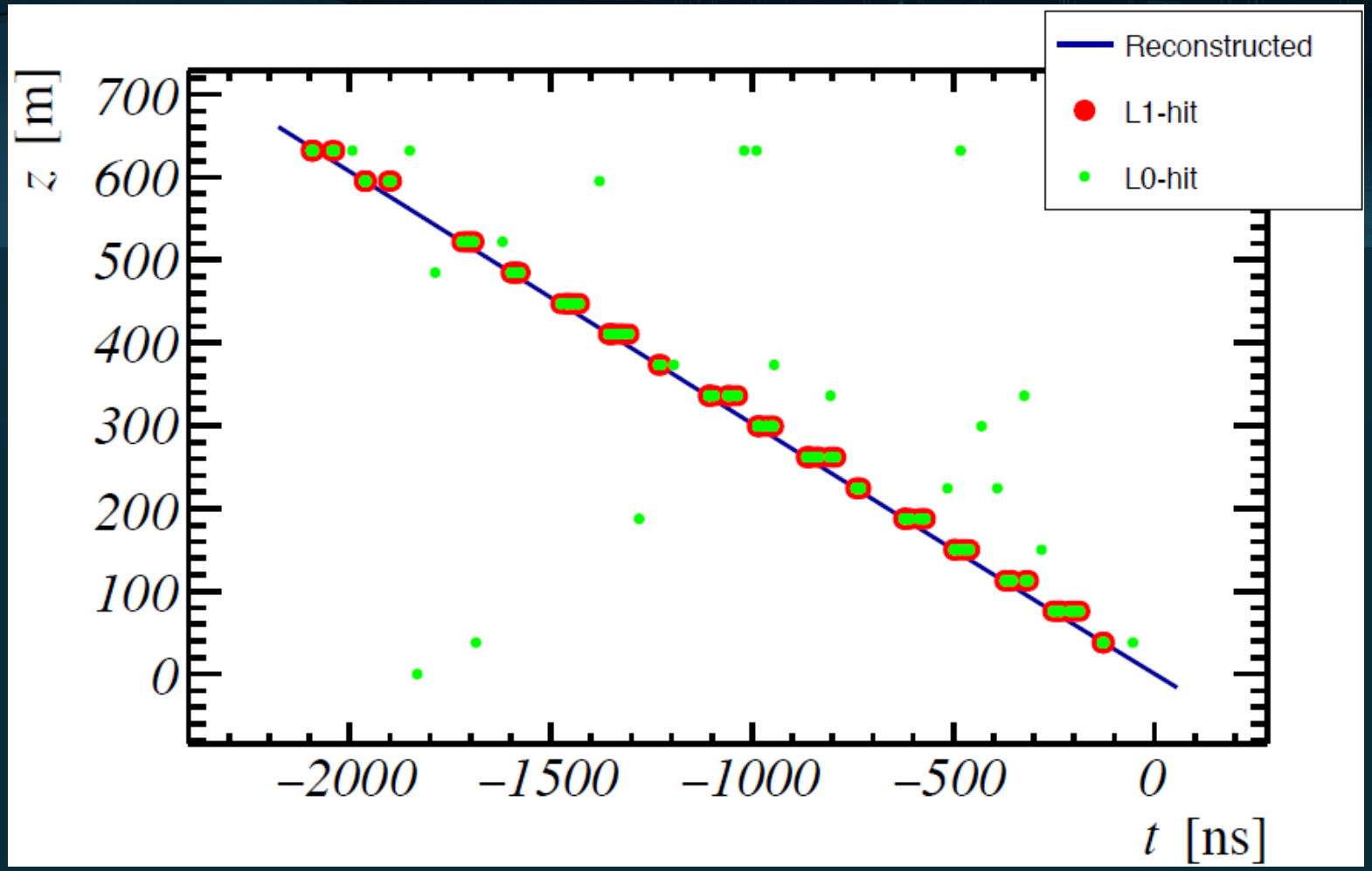

Corrected hit times




$\Delta MS_{in\_situ} - \Delta MS_{dark\_room}$ = string offset
(modulo laser period)

The time calibration obtained in the dark room can be restored in the sea

# Muon detected by the first Detection Unit



# Conclusions

- Hybrid solution in KM3NeT works
- Downlink: Distributed clock combined with White Rabbit
- Uplink: Data transfer from PMTs is decoupled from clock system