

APPEC Technology Forum 2015
Low Light-Level Detection in Astroparticle Physics and in Medical Applications
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Photodetection in KM3NeT

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PHYSICS



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The plan for the next 30 minutes:

- The KM3NeT project: Concept and overview
- Light detection in KM3NeT
- Prototype results
- Timelines
- Summary



KM3NeT

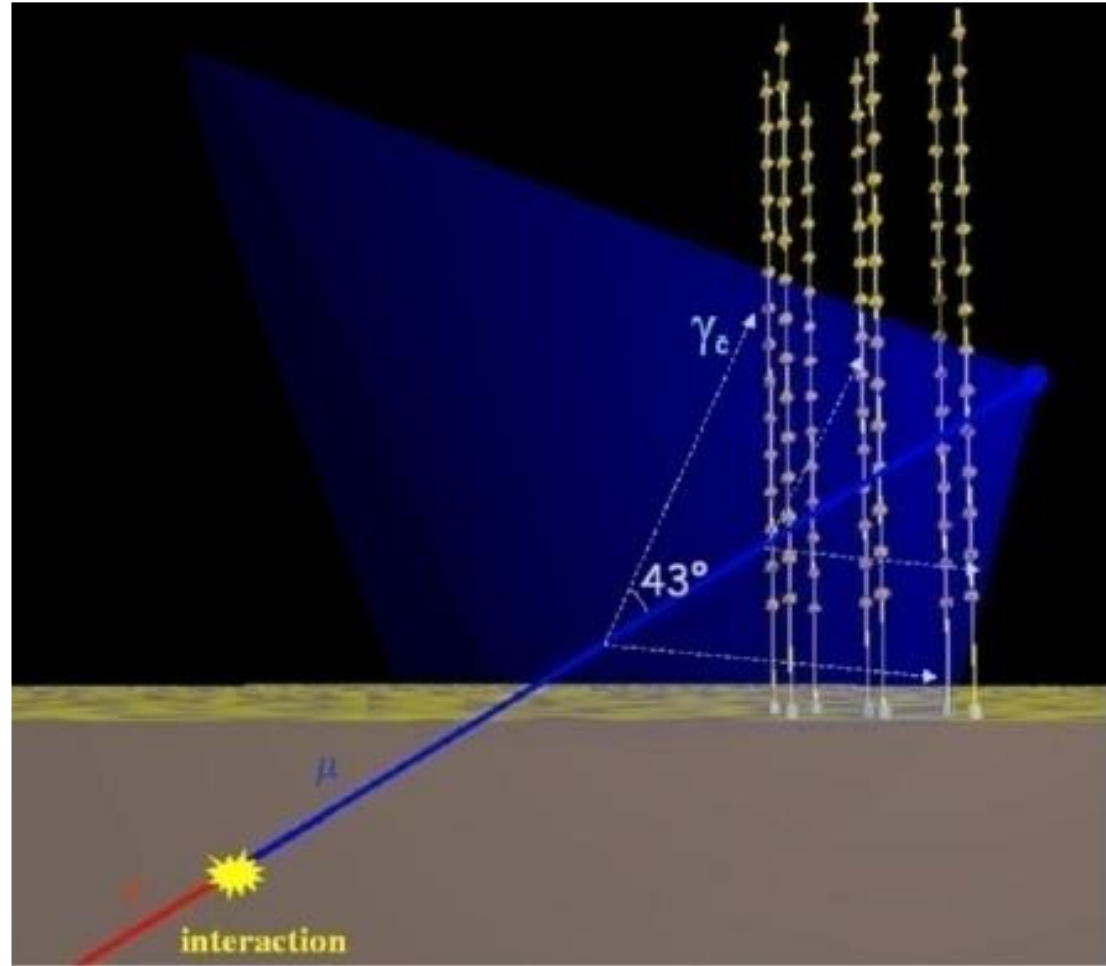


The KM3NeT project: Concept and overview

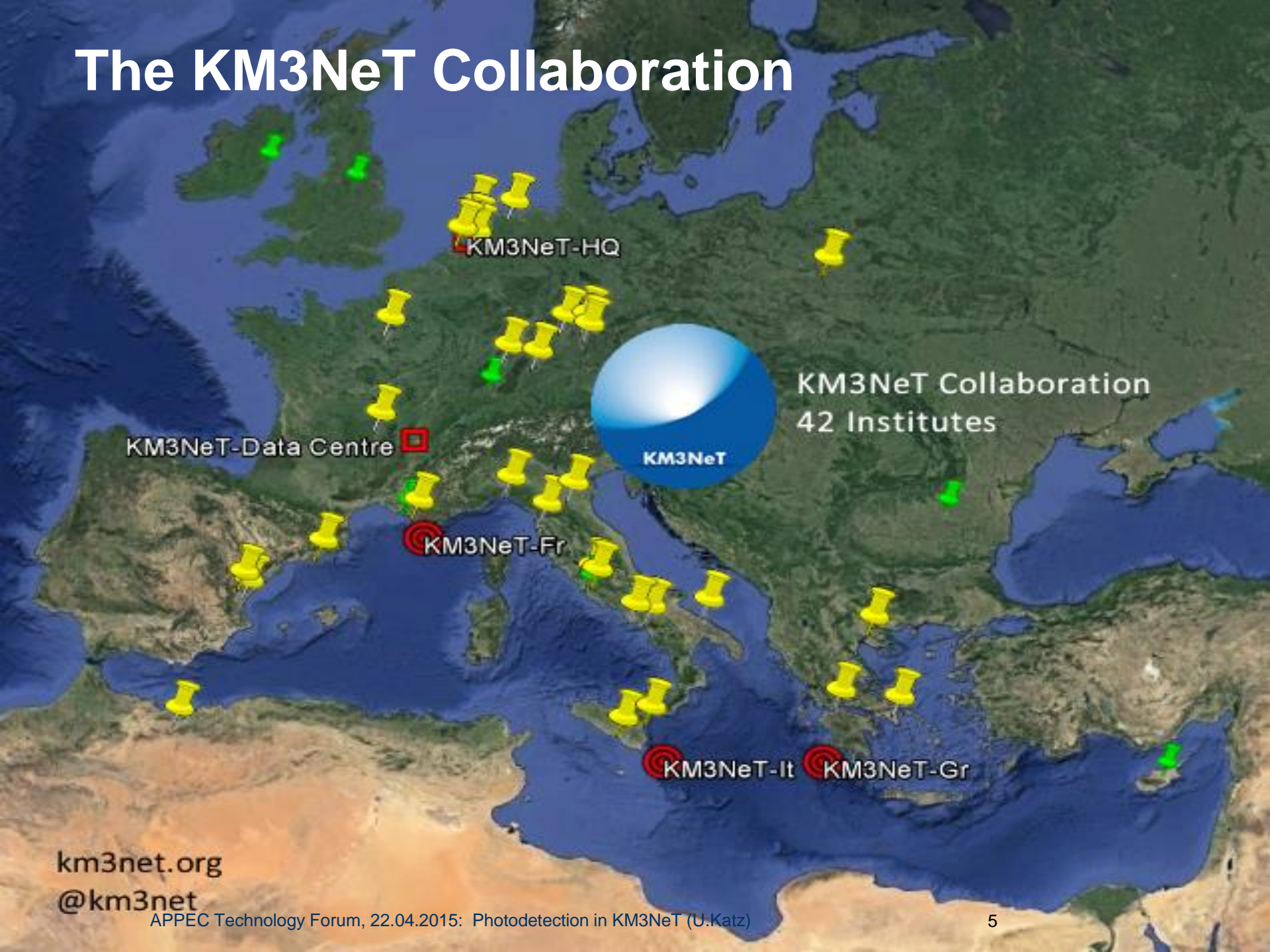


How does a neutrino telescope work?

- Neutrino interacts in the (vicinity of the) telescope
- Charged secondaries cross the detector volume (water or ice) and stimulate Cherenkov emission
- Recorded by a 3D-array of photo-sensors
- Neutrino energy range : few GeV – above PeV (depends on density of instrumentation)



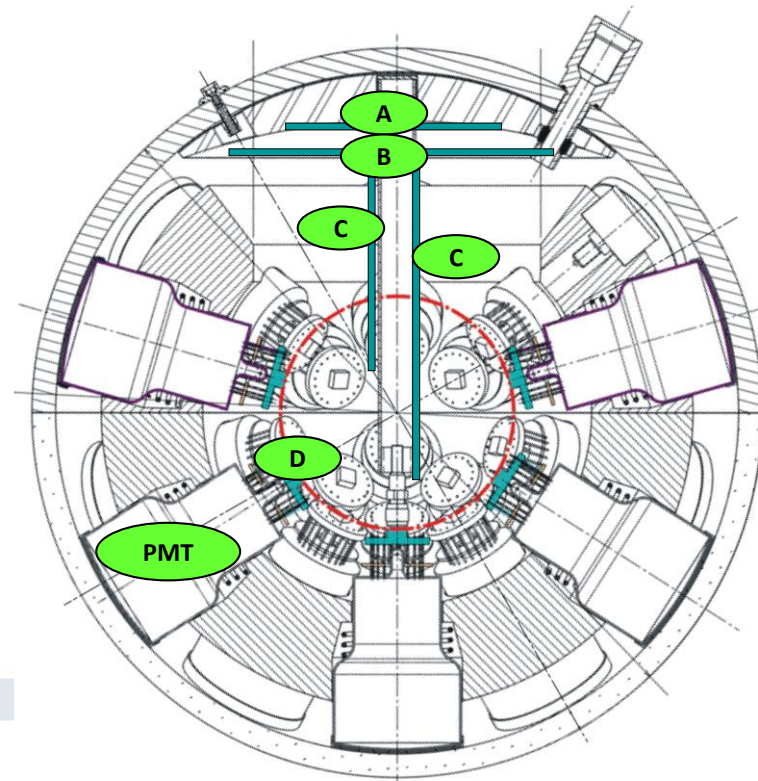
The KM3NeT Collaboration



km3net.org
@km3net

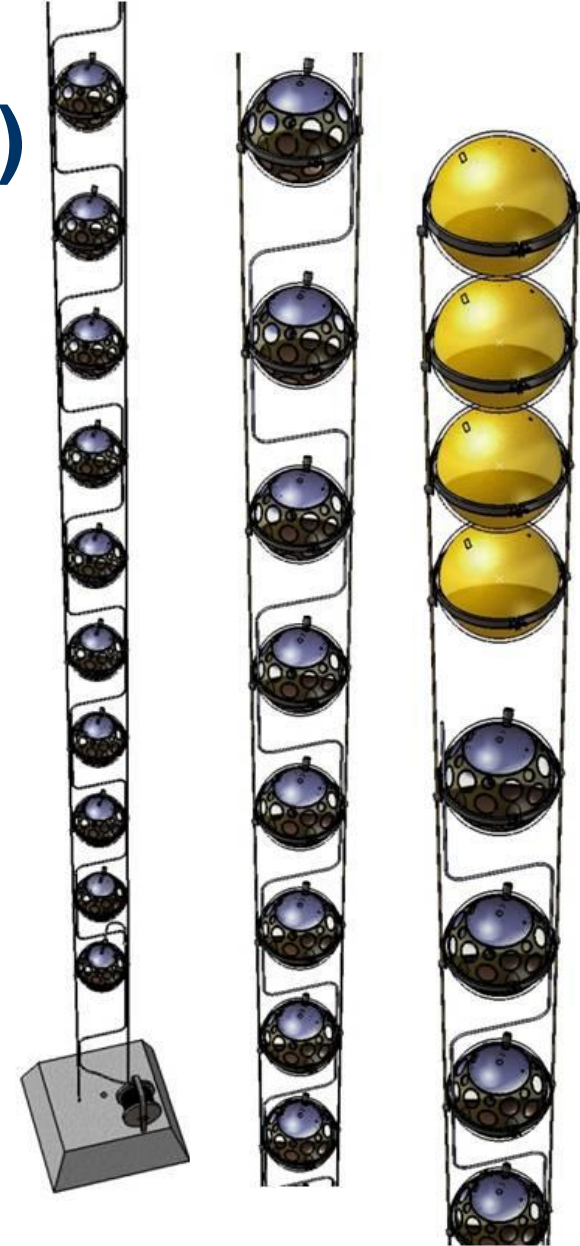
The KM3NeT DOM

- 31 3-inch PMTs in 17-inch glass sphere (cathode area~ 3x10-inch PMTs)
 - 19 in lower, 12 in upper hemisphere
 - Suspended by plastic structure
- 31 PMT bases (total ~140 mW) (D)
- Front-end electronics (B,C)
- Al cooling shield and stem (A)
- Single penetrator
- Advantages:
 - Increased photocathode area
 - 1-vs-2 photo-electron separation
→ better sensitivity to coincidences
 - Directionality
 - Cost / photocathode area



KM3NeT detection units (DUs)

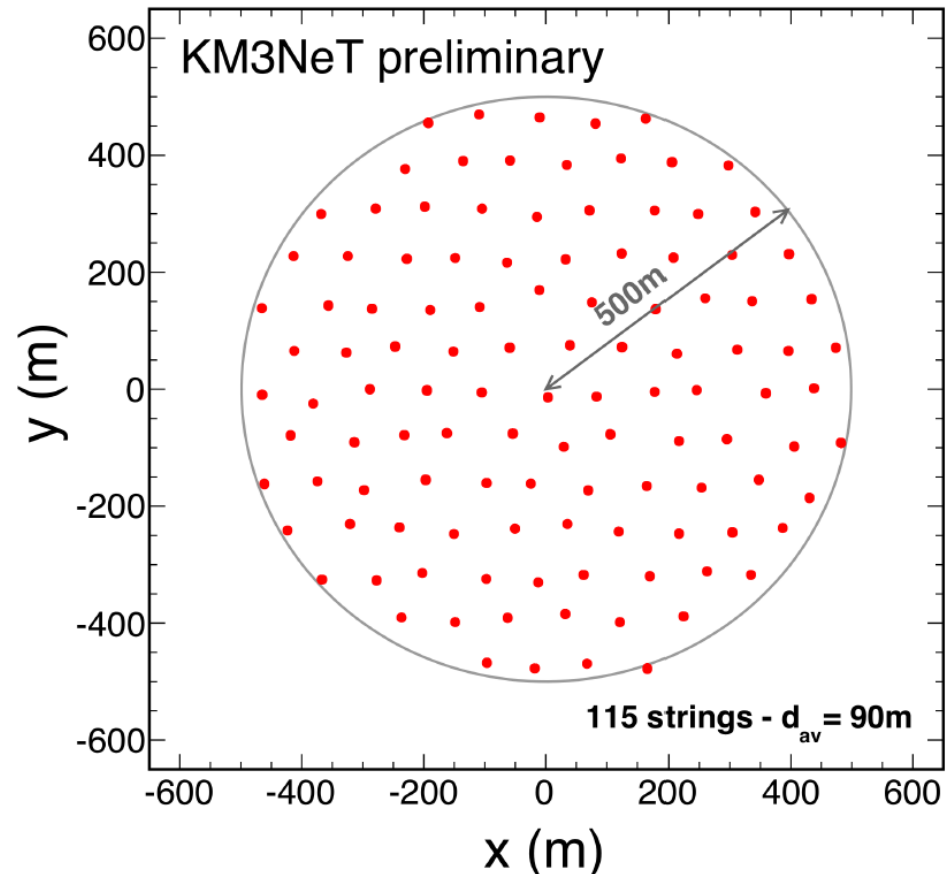
- Mooring line:
 - Buoy (syntactic foam)
 - 2 pre-stretched Dyneema[®] ropes (4 mm diameter)
 - 18 storeys (one DOM each)
- Electro-optical backbone (VEOC):
 - Flexible hose ~ 6mm diameter
 - Oil-filled
 - Fibres and copper wires
 - At each storey:
connection to 1 fibre + 2 wires
 - Break-out box with fuses at each storey:
One single pressure transition



The building block concept

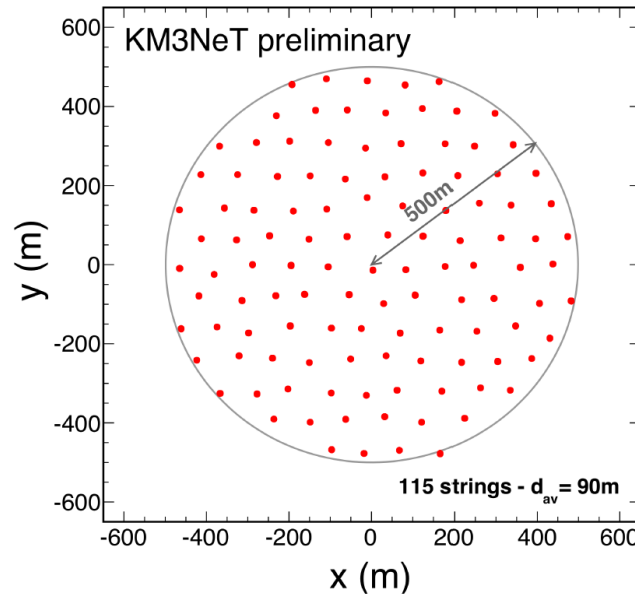
- Building block:
 - 115 detection units
 - Segmentation enforced by technical reasons
- Large block (neutrino astronomy)
 - Sensitivity for muons independent of block size above ~ 75 strings
 - One block \sim half IceCube
- Small block (neutrino oscillations)
 - Precision measurement of atmospheric neutrinos
 - One block ~ 6 Mtons
- Allows for staged, block-wise, multi-site installation

DU distance adjusted to scientific objective:
90-120 m for neutrino astronomy /
20 m for oscillation research



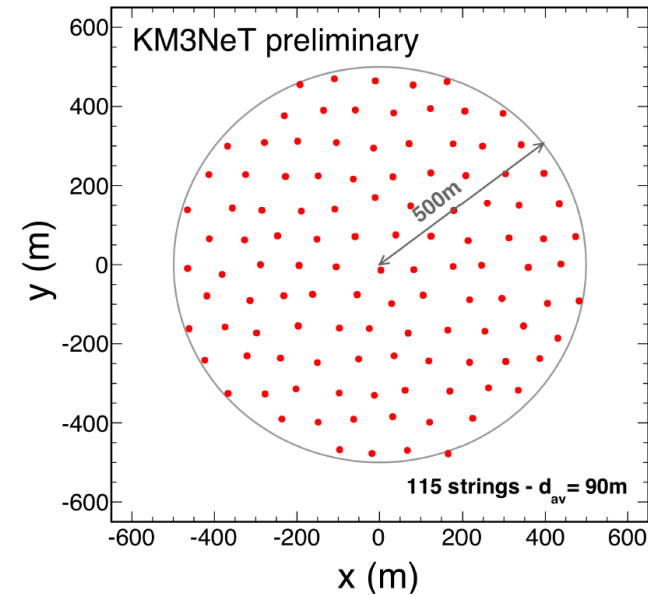
ARCA and ORCA

ARCA =
Astroparticle
Research with
Cosmics in the
Abyss

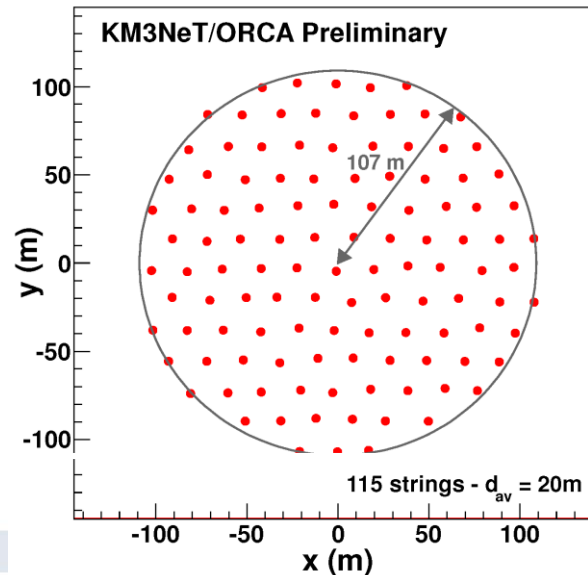


Vertical OM distance = 36 m

+



ORCA =
Oscillation
Research with
Cosmics in the
Abyss

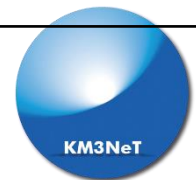


Vertical OM distance = 6 – 12 m



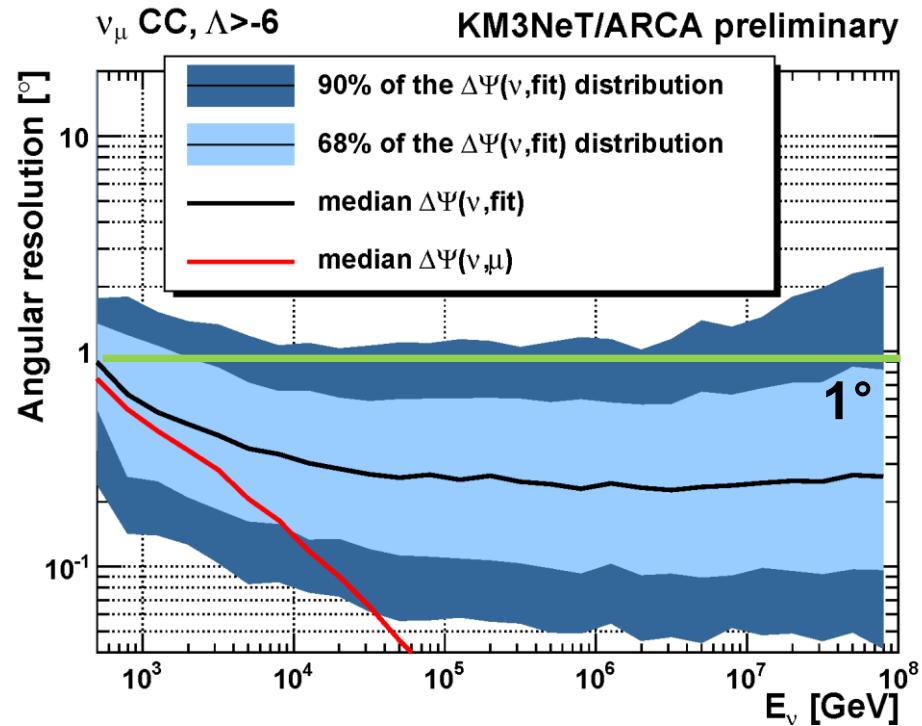
KM3NeT development

Phase	Blocks/ strings	Primary deliverables / site(s)	PMTs needed
1	0.2/31	Proof of feasibility and first science results; KM3NeT-Fr + KM3NeT-It sites	18.000
2.0	2/230	Measurement of neutrino signal reported by IceCube; All-flavor neutrino astronomy; KM3NeT-It site	+175.000
	1/115	Neutrino mass hierarchy; KM3NeT-Fr site	
3	6+1/805	Neutrino astronomy including Galactic sources; Multiple sites	+260.000

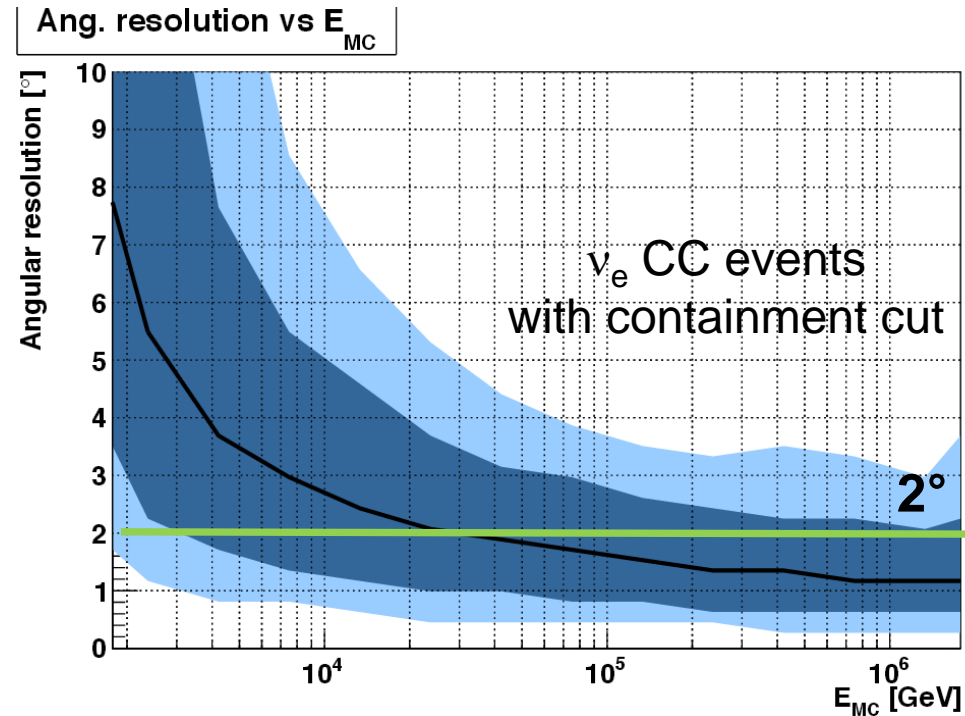


KM3NeT resolutions

Track-like events:



Cascades:

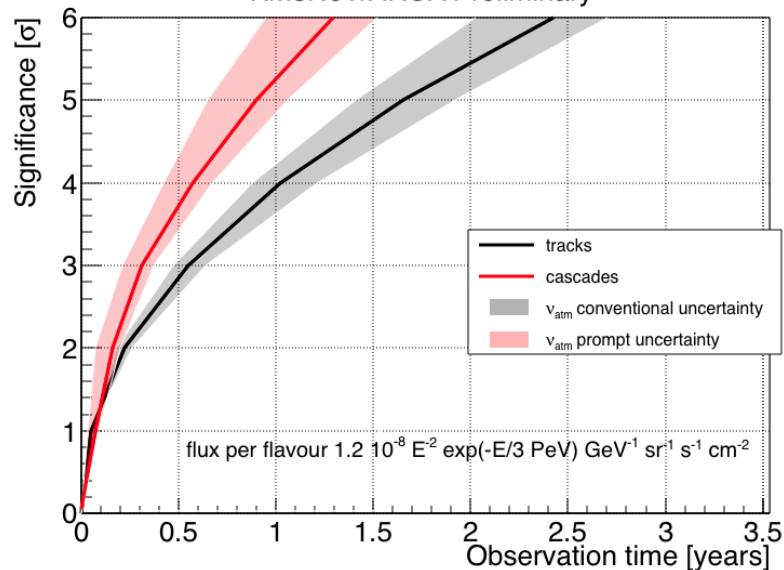


- Muon energy: $d(\log_{10} E) = 0.25-0.3$ at $E > 10$ TeV
- Cascade energy: 5-10% at $E > \text{some } 10$ TeV
- All-flavour neutrino astronomy in reach

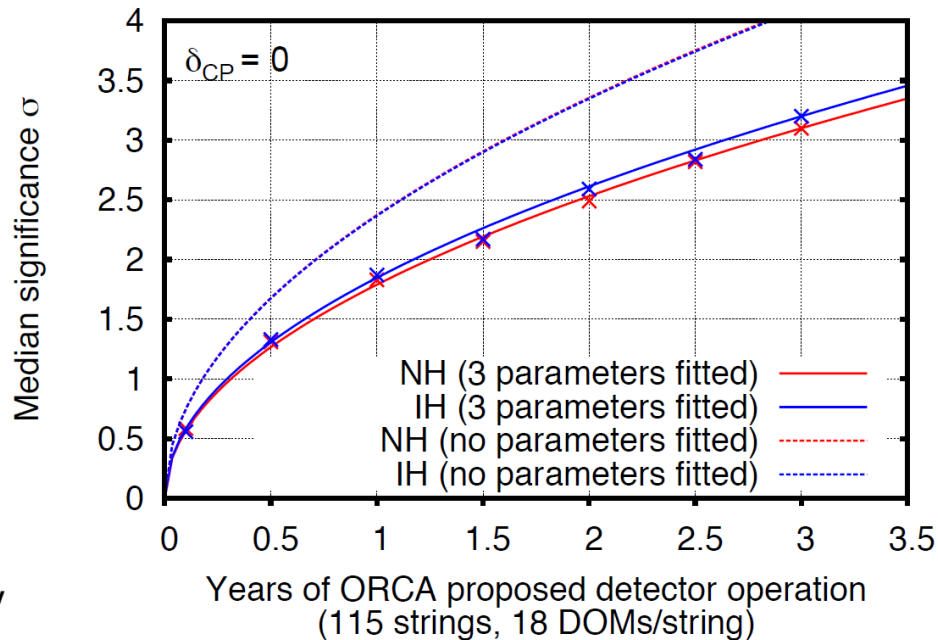


KM3NeT science objectives

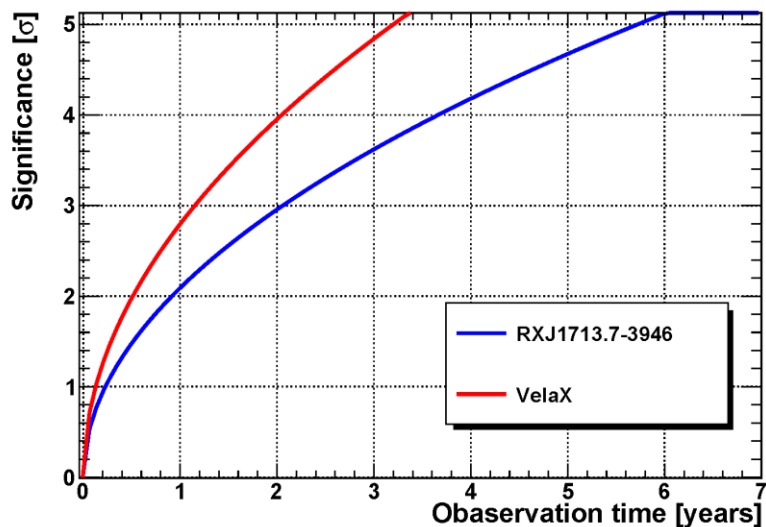
KM3NeT/ARCA Preliminary



KM3NeT/ORCA sensitivity (PRELIMINARY Feb 2015)



Full KM3NeT - (detector with 6 building blocks) - Preliminary



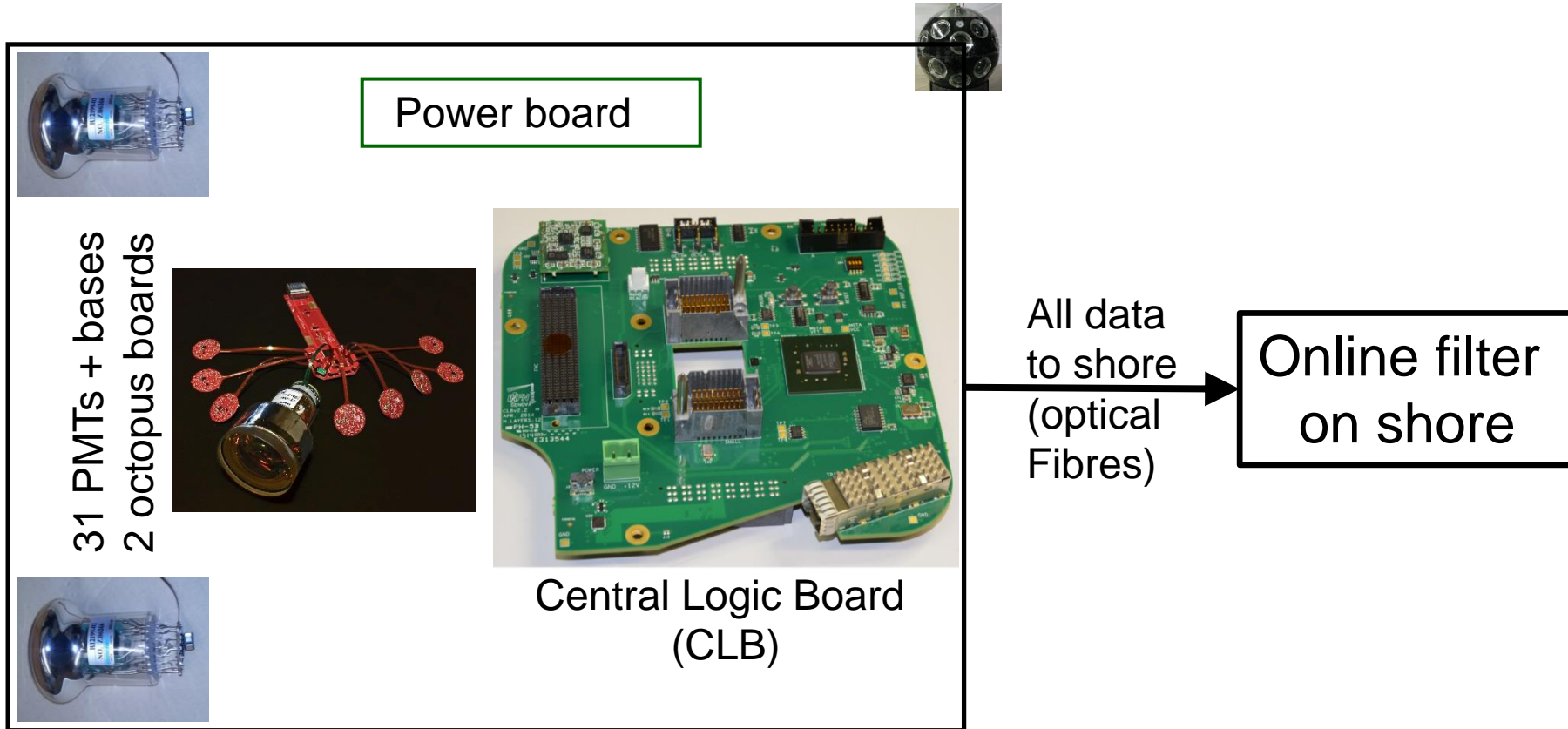
- All-flavour neutrino astronomy
- Precision measurements in neutrino physics
- Nodes for earth and sea science research



Light detection in KM3NeT



KM3NeT readout



HV for PMTs
Discrimination
w.r.t. predefined
threshold

Signal collection

FPGA for TDC (time & time over
threshold), time stamping (1 ns
precision);
Interface for time synchronisation:
Control of calibration devices;
Communication;

Implementation in DOM

- Reflective rings around PMTs (+27% light detection, see JINST 8 (2013) T03006)
- PMTs supported by plastic structure produced by 3D-printing
- Calibration: Acoustic sensor and compass + tiltmeter
- Electronics components attached to cooling structure
- One single penetrator for connection to vertical cable



PMT specifications

Parameter	Requirement
Photocathode diameter	> 72 mm
Nominal Voltage for Gain 3×10^6	900 – 1300 V
Gain slope = $\log_{10}(\text{gain})/\log_{10}(\text{HV})$	6.5 – 8.0
QE at 404 nm	> 23 %
QE at 470 nm	> 18 %
TTS (FWHM)	< 5 ns
Dark count rate (0.3 p.e. threshold)	< 2 kHz
Pre-pulses	< 1 %
Delayed pulses	< 3.5 %
Early afterpulses	< 2 %
Late afterpulses	< 10 %



PMTs available

+MELZ ...

ETEL D792

Hamamatsu R12199

HZC XP53B20

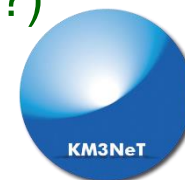


Fulfil specifications; orders placed / expected



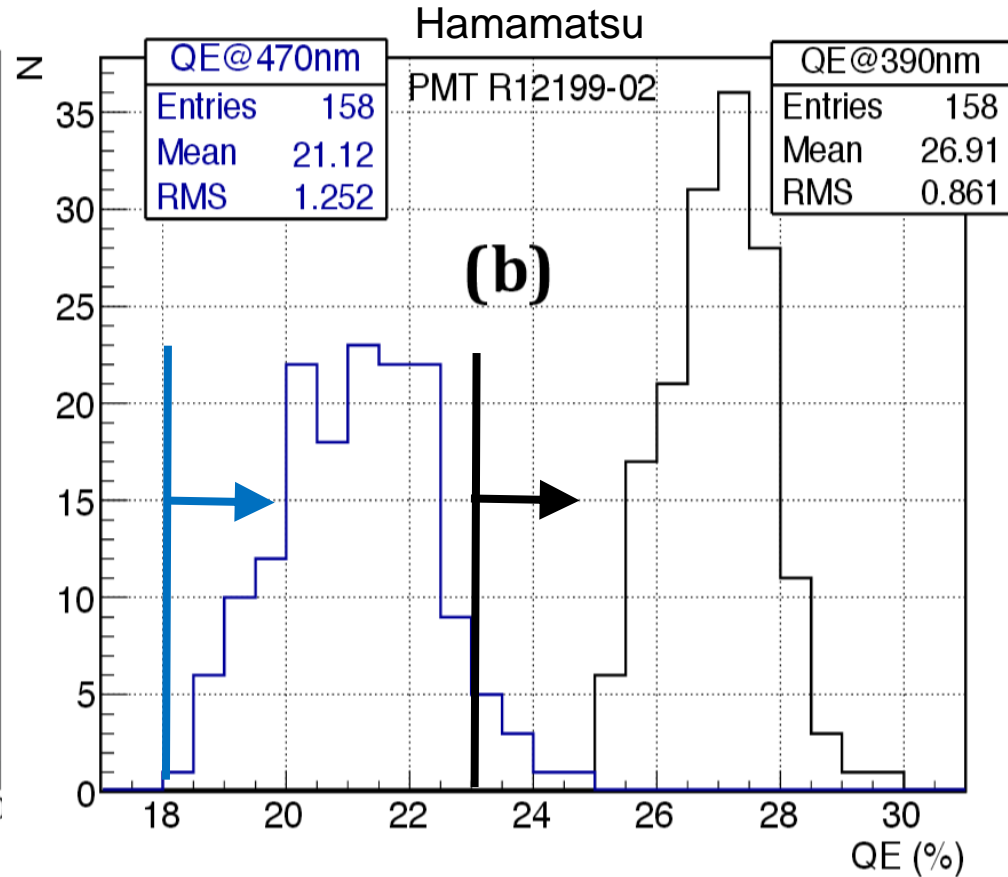
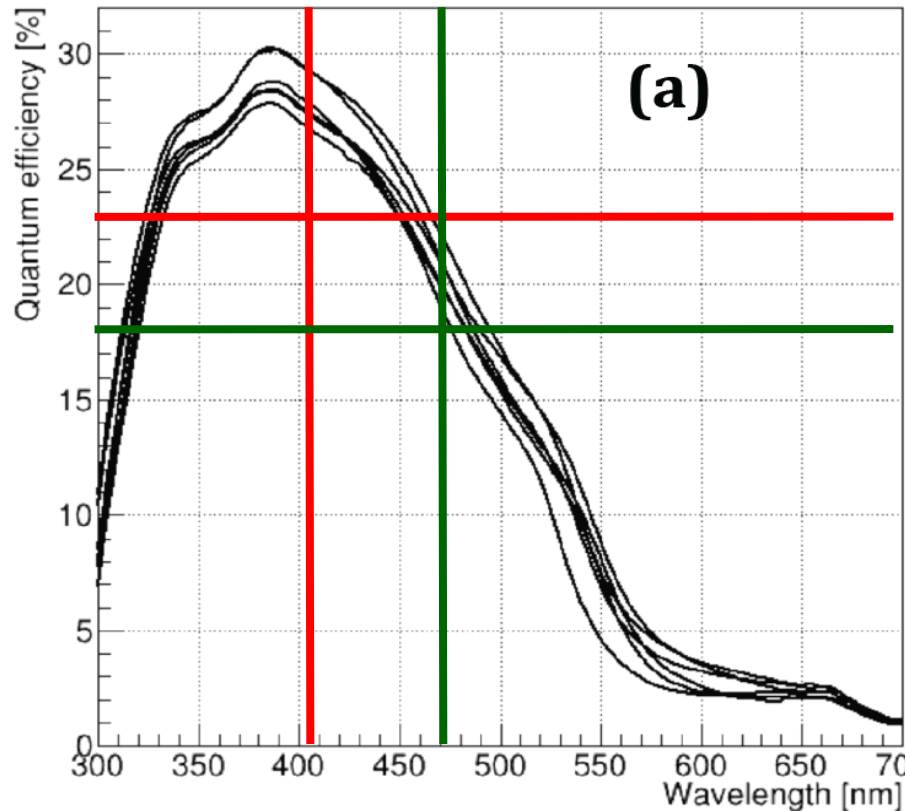
First prototype not yet compliant with specifications (gain, dark rate, afterpulses, ...), further development under way

Note: In all cases price/photocathode area < 10-inch tubes (MELZ?)



Some results of PMT measurements: QE ...

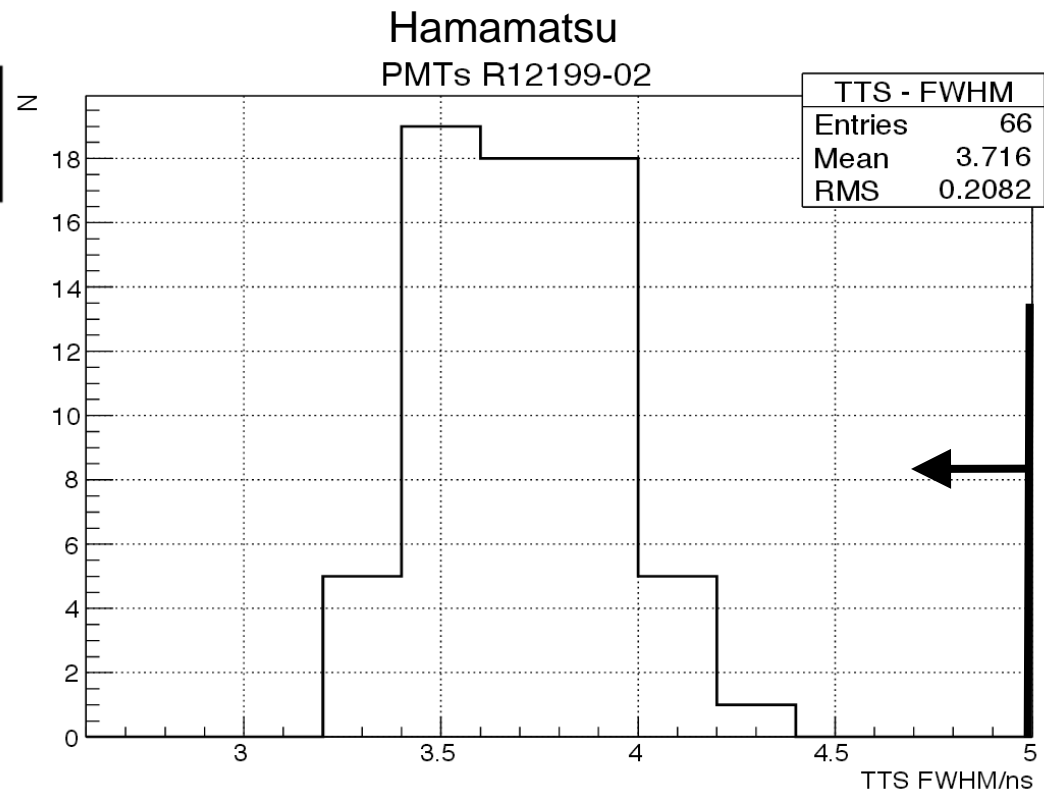
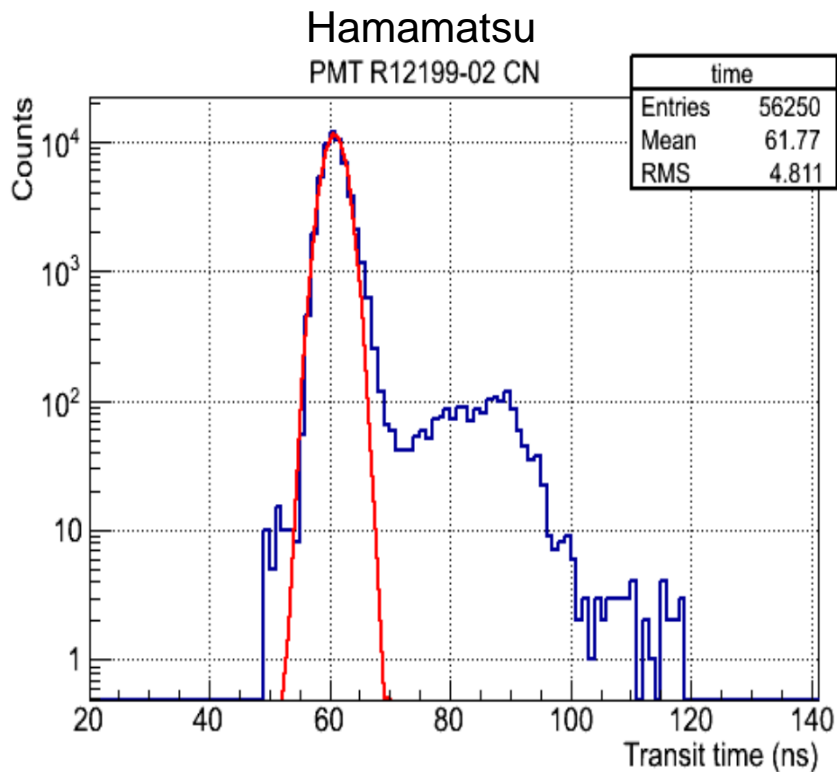
Absolute calibration, PMT ETL D792KFL



Note: These are “normal”, i.e. not super- or hyper-bialkali PMTs



... and TTS



All measurements for ETEL & Hamamatsu within specifications

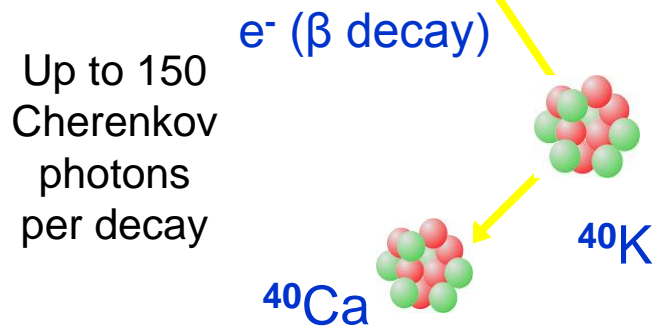
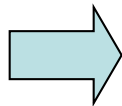
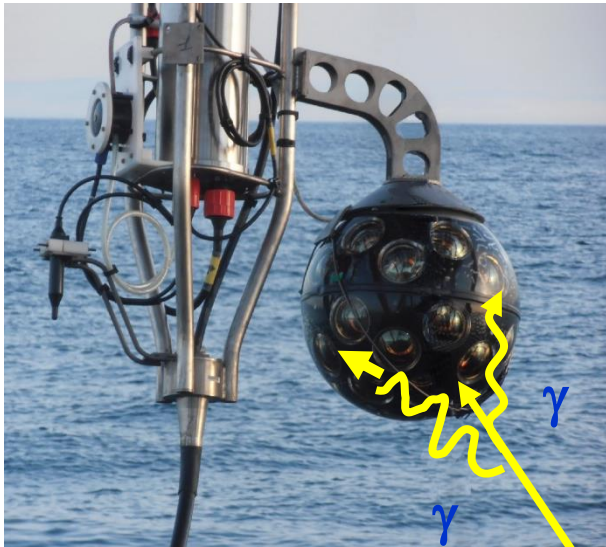


Prototype results



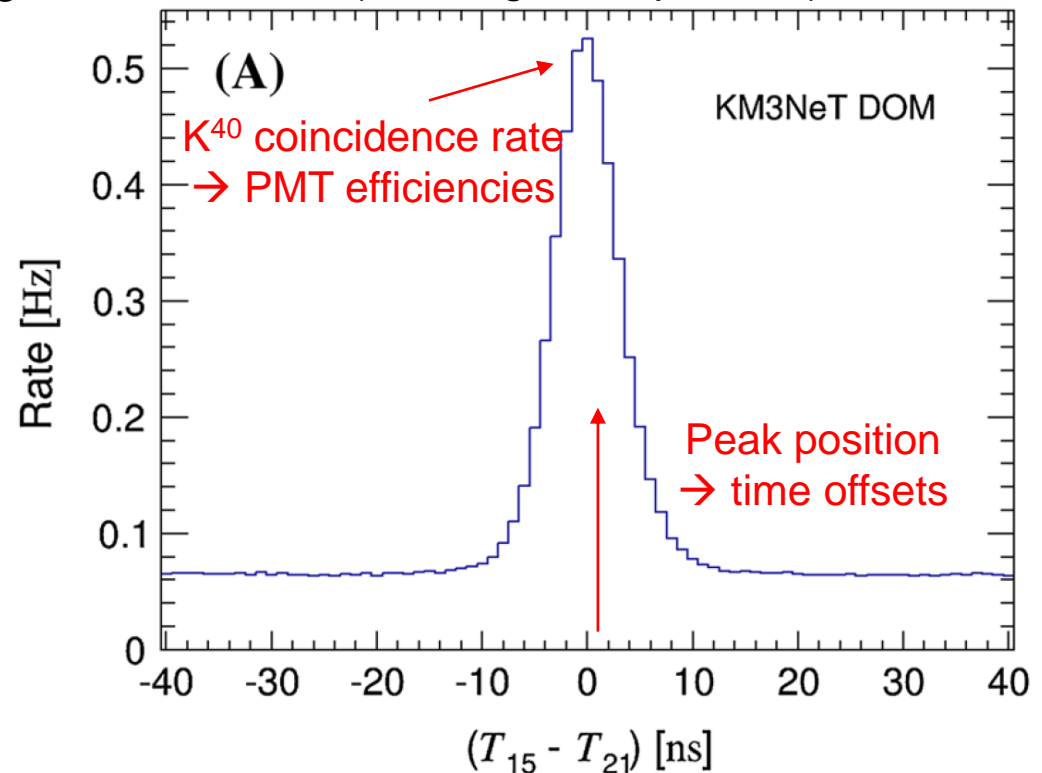
DOM prototype (PPM-DOM)

Deployed at
ANTARES in
April 2013



Concentration of ^{40}K is stable
(coincidence rate ~ 5 Hz on adjacent PMTs)

Coincidence rate on 2 adjacent PMTs
(33° angular separation)

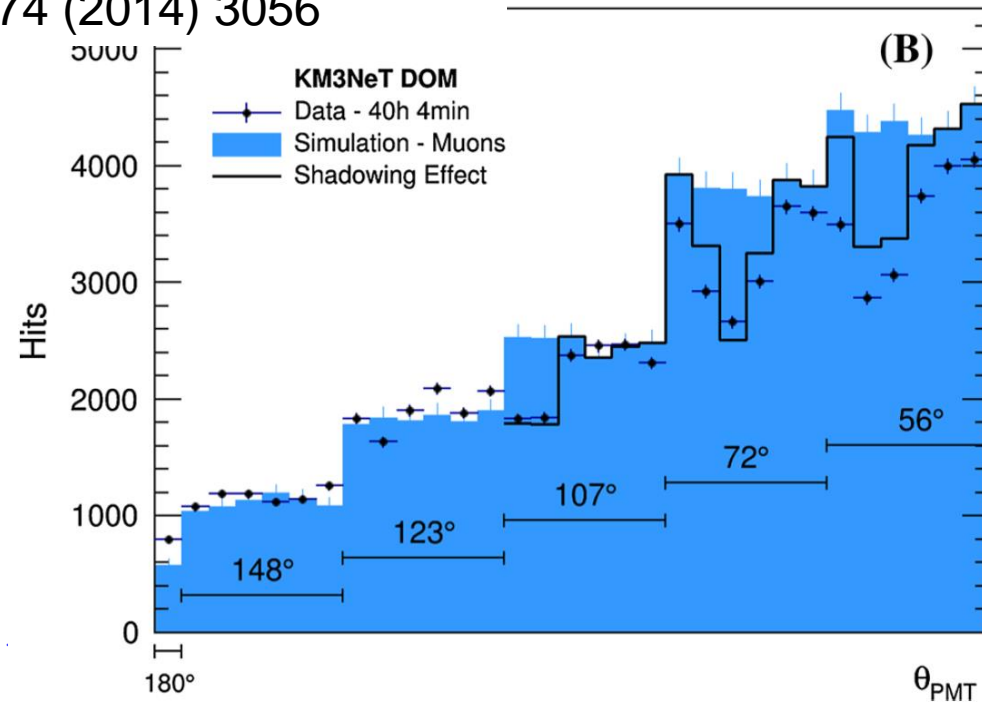
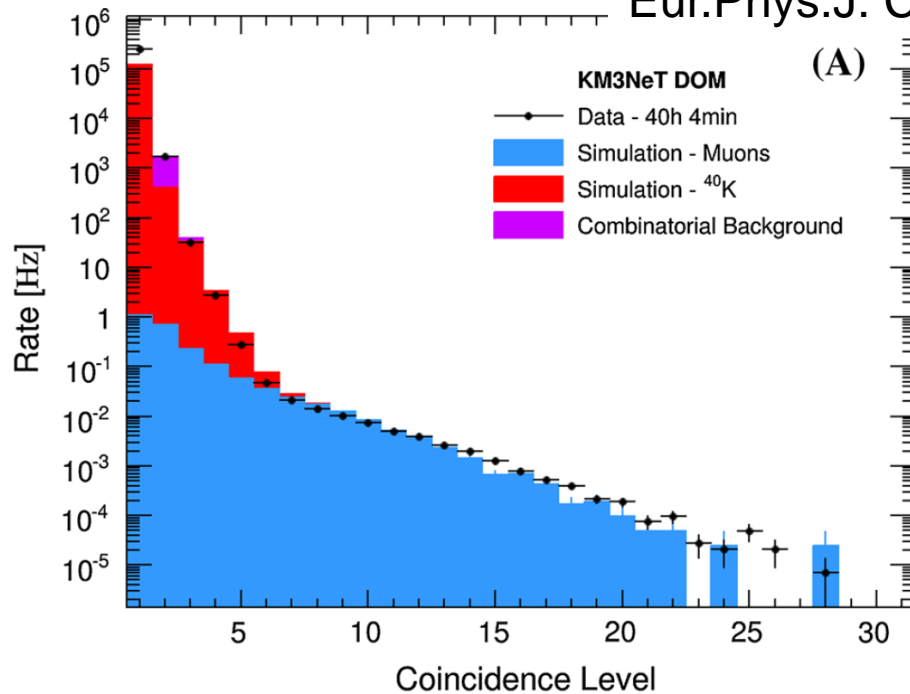


Eur.Phys.J. C74 (2014) 3056



PPM-DOM: Atmospheric Muons

Eur.Phys.J. C74 (2014) 3056

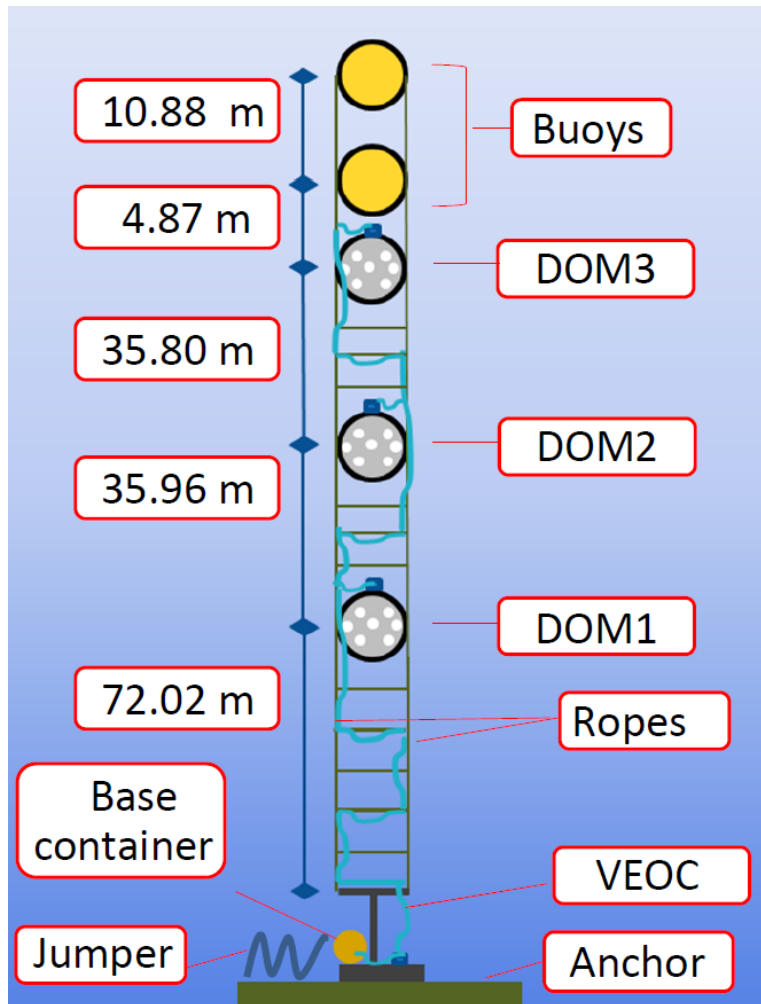


>5 coincidences within 20ns \Rightarrow
reduced K40 contribution,
dominated by atmospheric muons

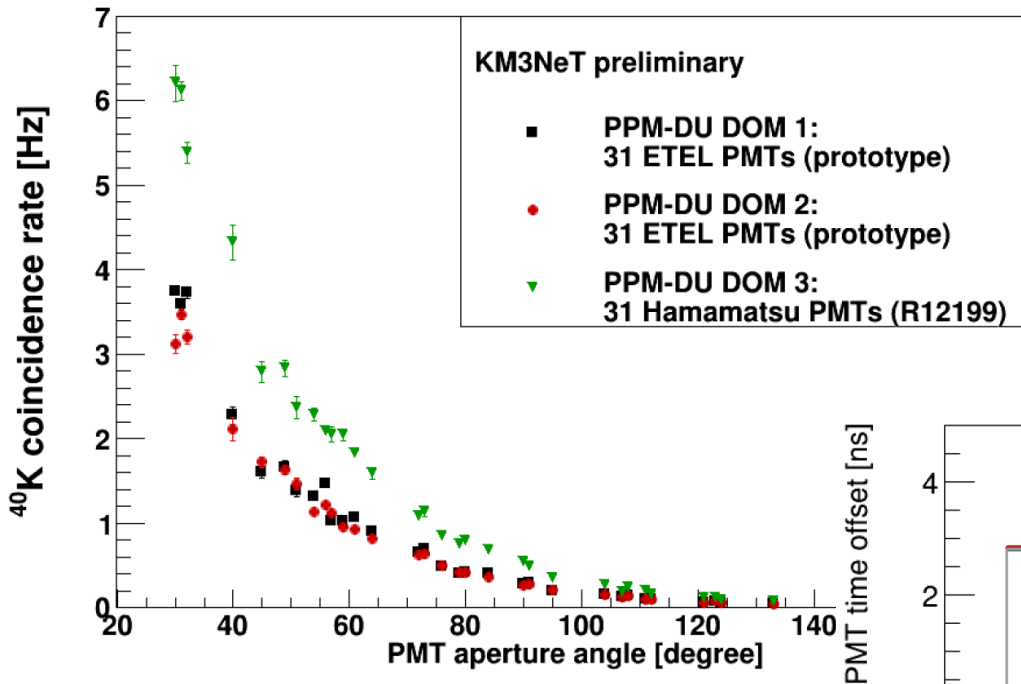
More upper PMTs in multi-hit events \Rightarrow
directional information
from single storey



DU mini-prototype (PPM-DU): 3 DOMs

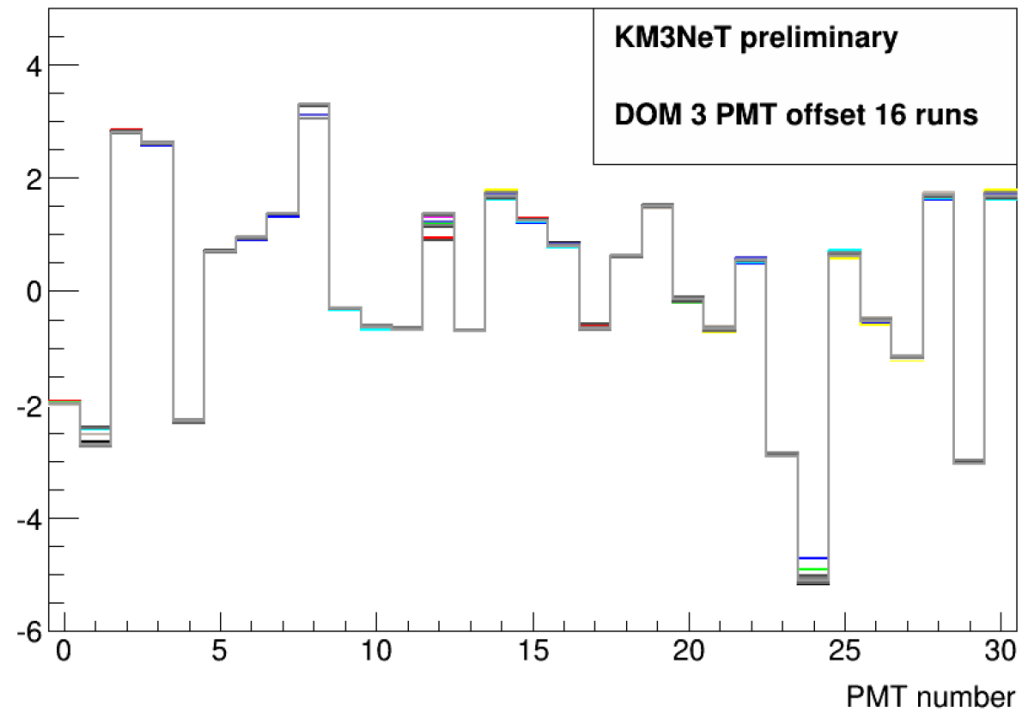


PPM-DU: Inter-DOM timing



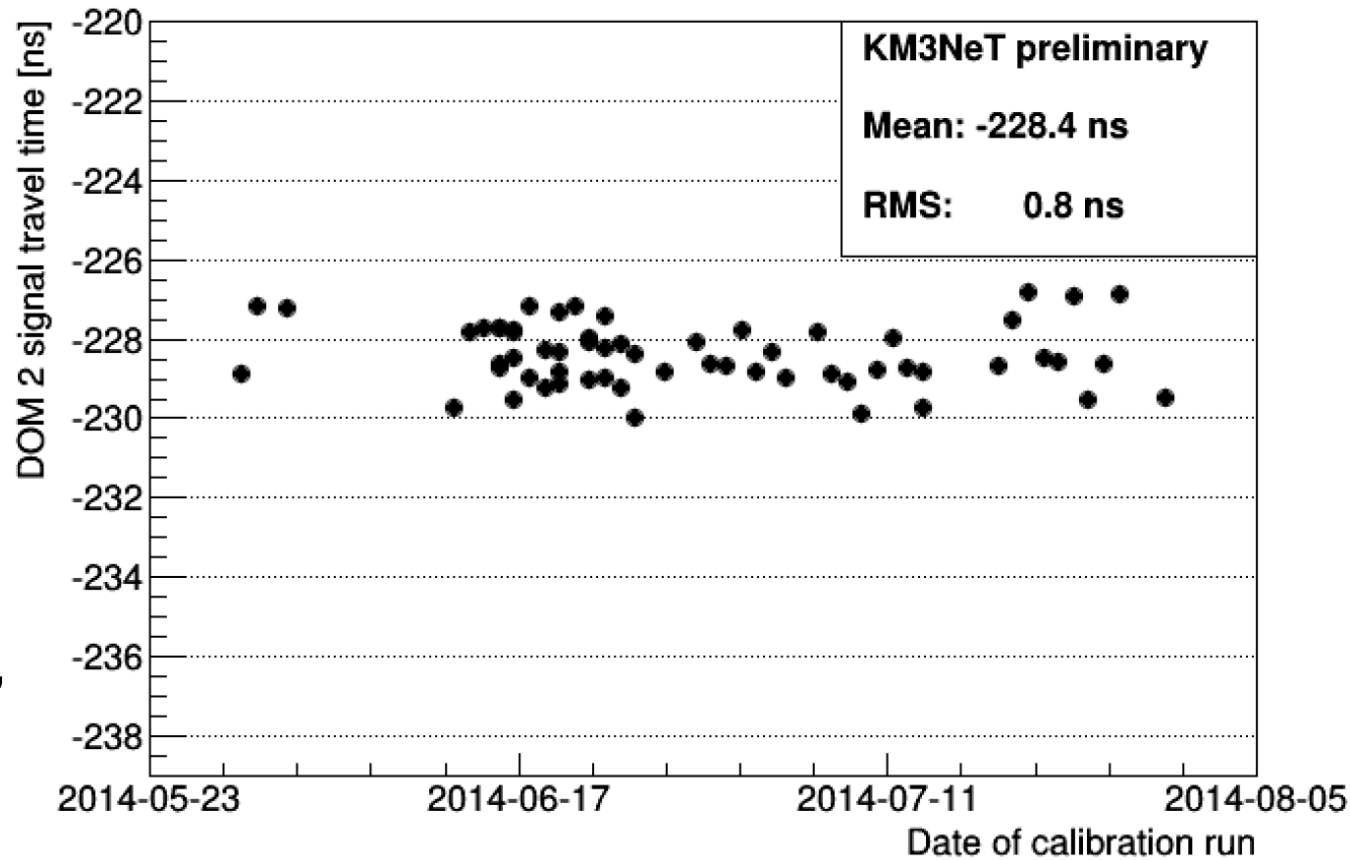
K40 coincidence rate as a function of the angle between PMTs.
Note: Different PMT types!

Relative timing calibration of
31 PMTs in DOM using coincidences.
Note: Extremely stable over many runs



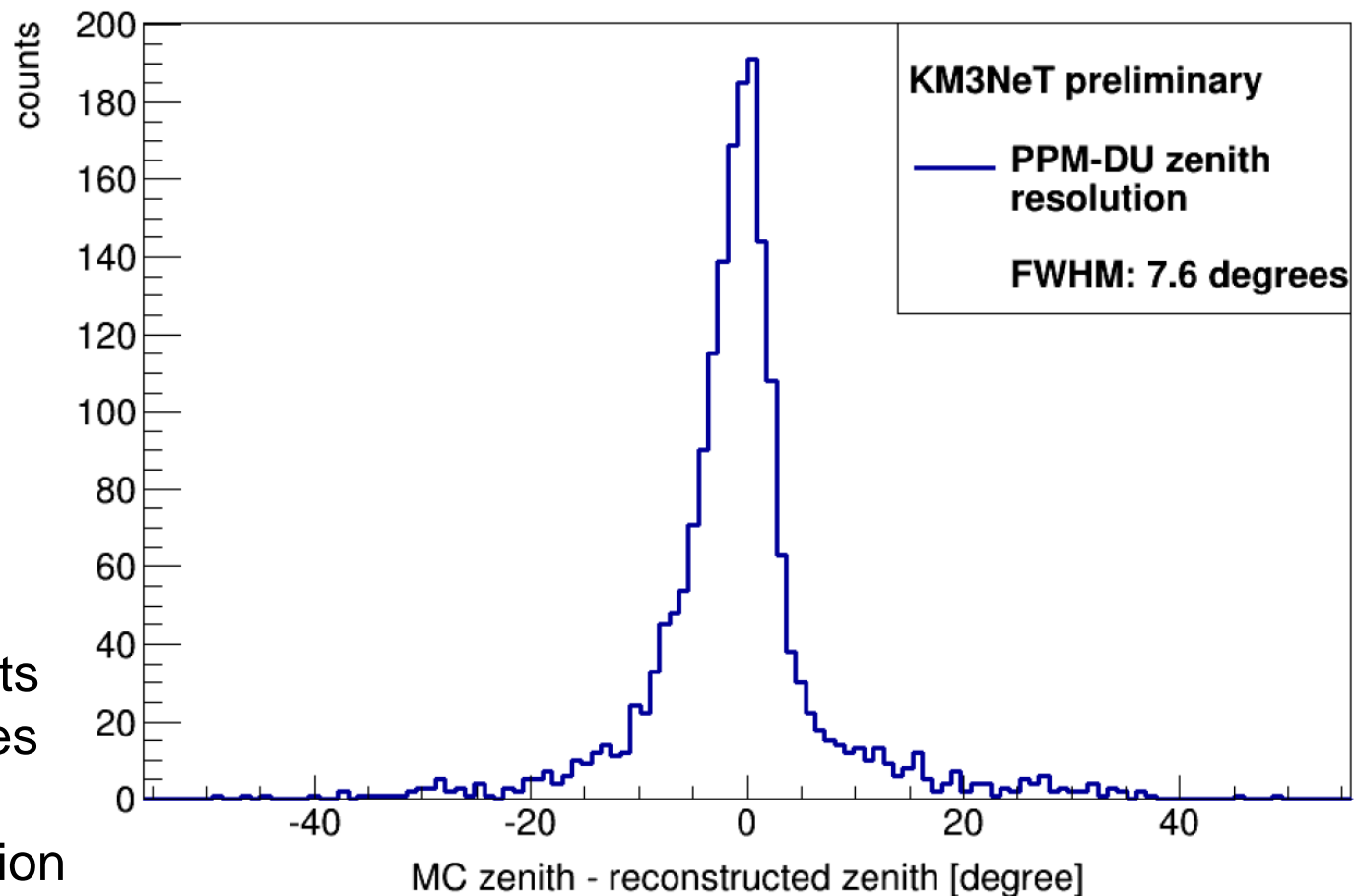
PPM-DU: Intra-DOM timing

- Calibration with pulsed LED
- Time difference – light travel time = Signal travel time
- Result very stable over several months, RMS of jitter < 1 ns



PPM-DU: Muon reconstruction

- Reconstruct muon trajectory from hits on 3 DOMs
- Ambiguities can be reduced by cuts on time differences
- 7° FWHM resolution achieved



Timelines



KM3NeT time lines and funding

Phase	Invest/M€	Time lines	Funding
1	31	2014-16: Construction (24 ARCA- and 6 ORCA-DUs)	secured
2.0	+55	2015: ESFRI proposal (decision 2016)	applications pending
	+40	2016-20: Construction 2022: Physics results	
3	+100-120	After 2020	to be defined



Summary



Summary and outlook

- KM3NeT is a future multi-site research infrastructure in the Mediterranean Sea
- Priority science goals:
 - All-flavour neutrino astronomy
 - Measurement of the neutrino mass hierarchy
- Light detection using multiple 3-inch PMTs per optical module
 - Concept technically proven
 - Prototypes and simulations show high potential
- KM3NeT construction has started (Phase-1), next phase (ARCA & ORCA) to follow in 2016-20

Stay tuned!

