KM3NeT

(http://www.km3net.org)

Deep-sea data transfer at the KM3NeT neutrino telescope

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For the KM3NeT Consortium

What is KM3NeT*?

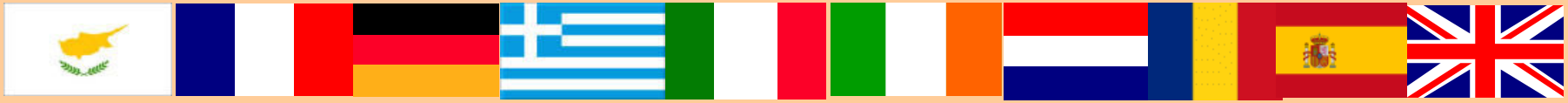
A Research Infractructure in the deep Mediterranean Sea -

combining a next generation *km^3-scale deep water Cherenkov neutrino telescope*
with a *permanent infrastructure for deep-sea sciences:*
Oceanography, Marine Biology, Environmental Science,
Geology & Geophysics

- **E.U. – funded 3-year design study (2/2006 ➔ 12/2009)**
  with 9M€ of European Union FP6 funding
  leading to a technical design report (TDR) end 2009
  (CDR published in April 2008)
- **A 'Preparatory Phase' (2/2008 - 2011)**
  funded through the European Union FP7 programme
  allowing collaboration & governance structures to be put in place,
  relations with industry established,
  development and characterisation of prototypes
  with a view to construction starting 2011 ➔
- ***On the ESFRI* roadmap**
  ***European Strategy Forum on Research Infrastructures**

The KM3NeT Consortium

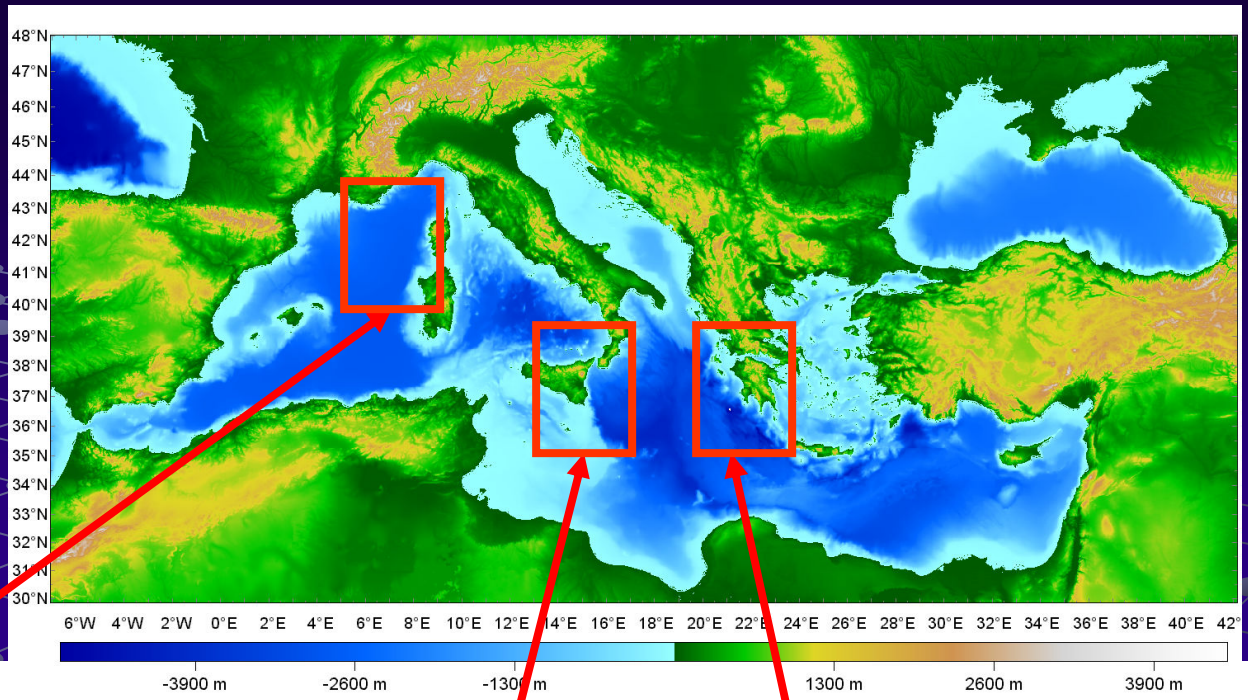
41 Institutes from 10 European Countries + *participants from the three present-day Mediterranean ν projects*

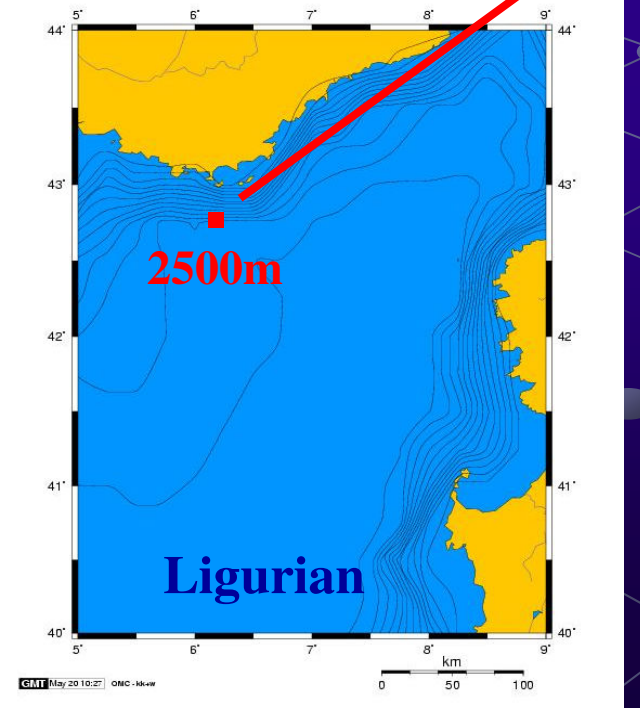


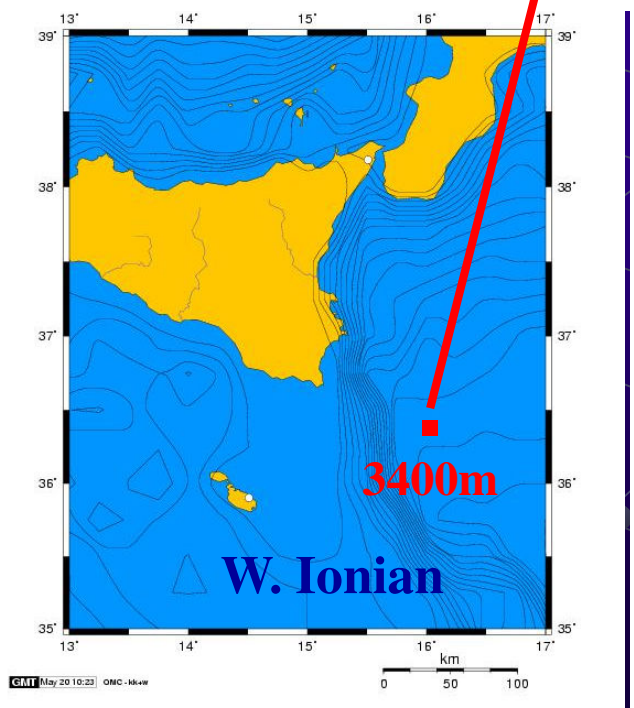
Cyprus: Univ. Cyprus Nicosia
France: CEA/Saclay, CNRS/IN2P3 (APC Paris, CPP Marseille, IReS Strasbourg), Univ. Haute Alsace/GRPHE), IFREMER
Germany: Univ. Erlangen, FTZ (Univ. Kiel), Univ. Tübingen
Greece: HCMR Anavissos, HOU Patras, NCSR Athens, NOA/Nestor Athens, Univ. Athens
Ireland: DIAS Dublin
Italy: CNR/ISMAR, INFN (Univs. Bari, Bologna, Catania, Genova, Napoli, Pisa, Roma-1, LNS Catania, LNF Frascati), INGV, Tecnomare SpA
Netherlands: NIKHEF/FOM Amsterdam, Univ. Amsterdam, Univ. Utrecht, KVI (Univ. Groningen), NIOZ
Romania ISS Bucharest
Spain: IFIC (CSIC) Valencia, Univ. Valencia, UP Valencia
UK: Oceanlab (Univ. Aberdeen), Univ. Leeds, Univ. Liverpool, Univ. Sheffield

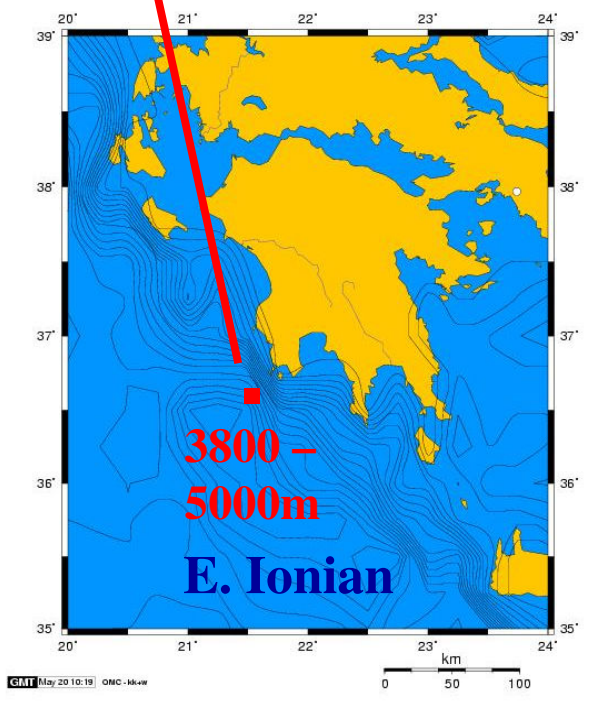
Particle/Astroparticle institutes (33) – Sea science/technology institutes (8) – Coordination

Possible sites for KM3Net in the Mediterranean Sea









The KM3NeT Vision

- Future cubic-kilometre scale neutrino telescope in the Mediterranean Sea
- Exceeds Northern-hemisphere telescopes by factor ~50 in sensitivity (compared with ANTARES)
- Exceeds IceCube sensitivity by substantial factor

  Angular resolution < 0.1° for muons with $E_\mu > 10$ TeV

- Focus of scientific interest: ν astronomy @ 1-100 TeV

  Production mechanisms of high energy νs (acceleration mechanisms etc.)

  Investigation of the nature of astrophysical objects

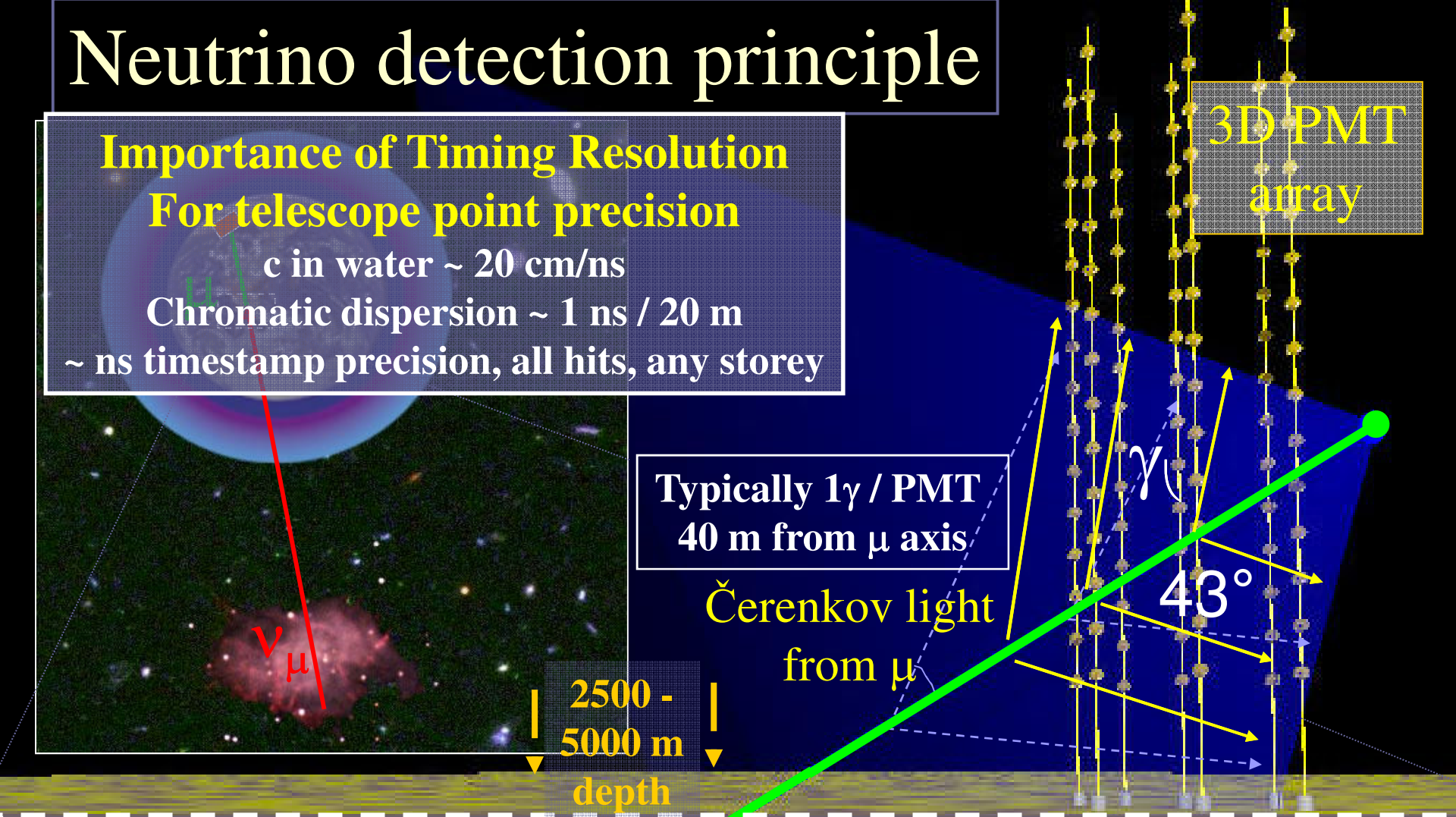
  Origins of cosmic rays

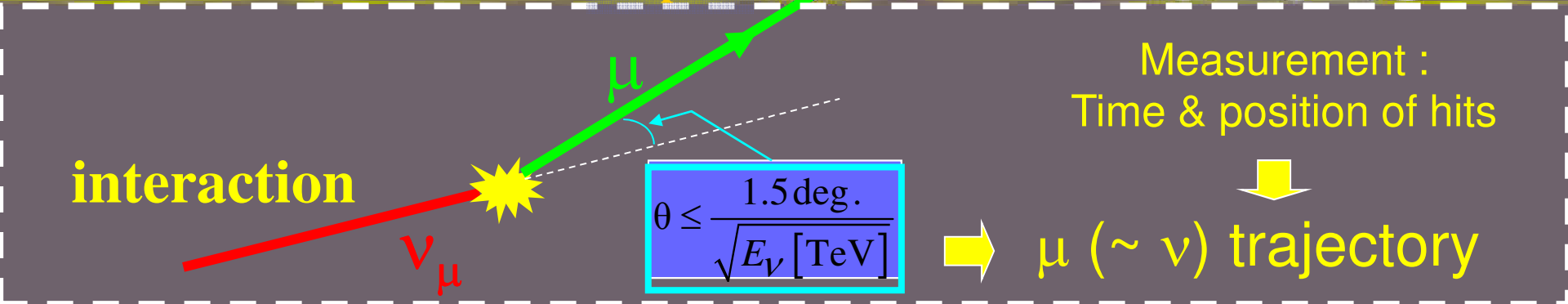
- Indirect search for dark matter
- Platform for deep-sea research (marine sciences)

Neutrino detection principle

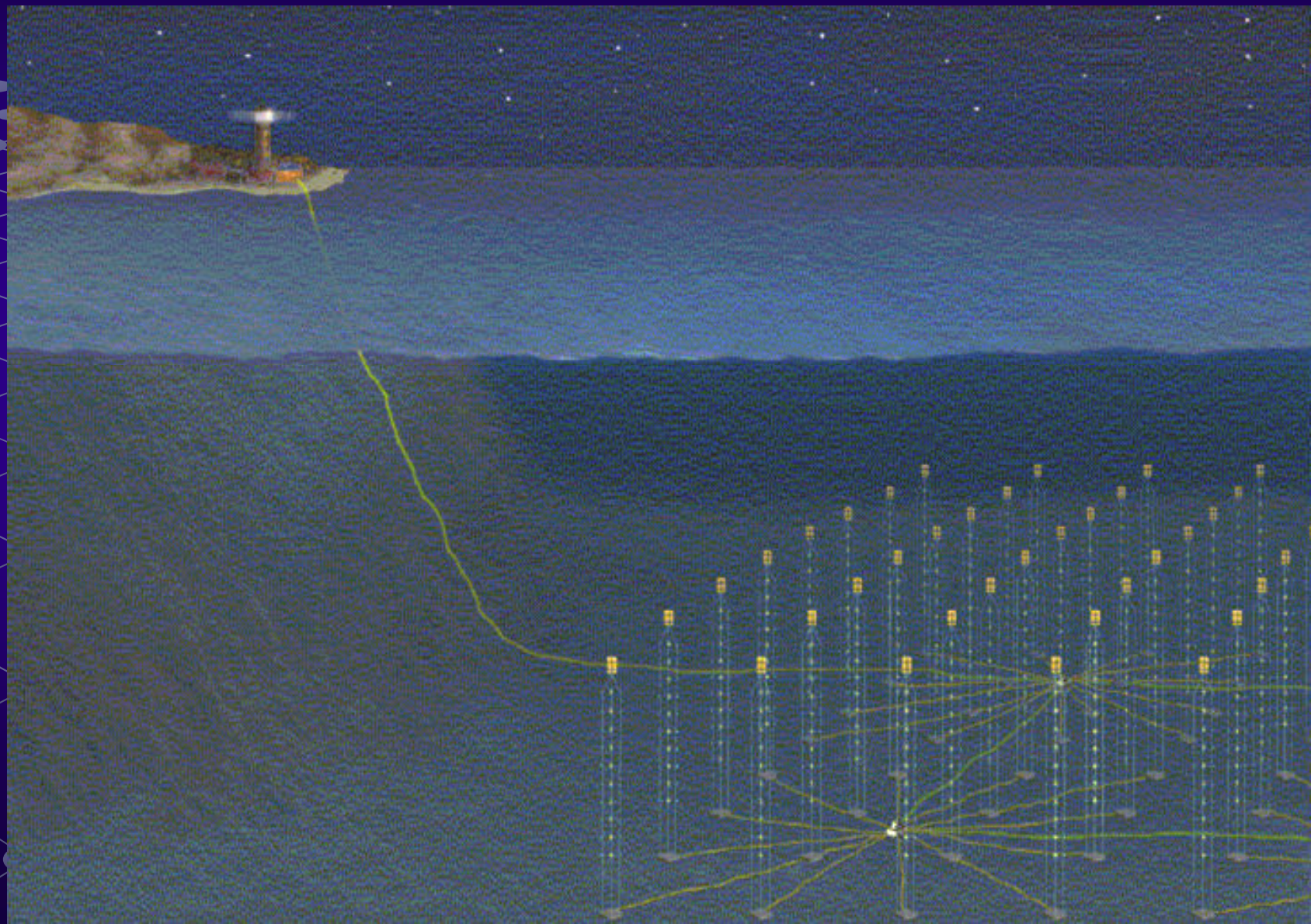
Importance of Timing Resolution
For telescope point precision

c in water ~ 20 cm/ns
Chromatic dispersion ~ 1 ns / 20 m
~ ns timestamp precision, all hits, any storey

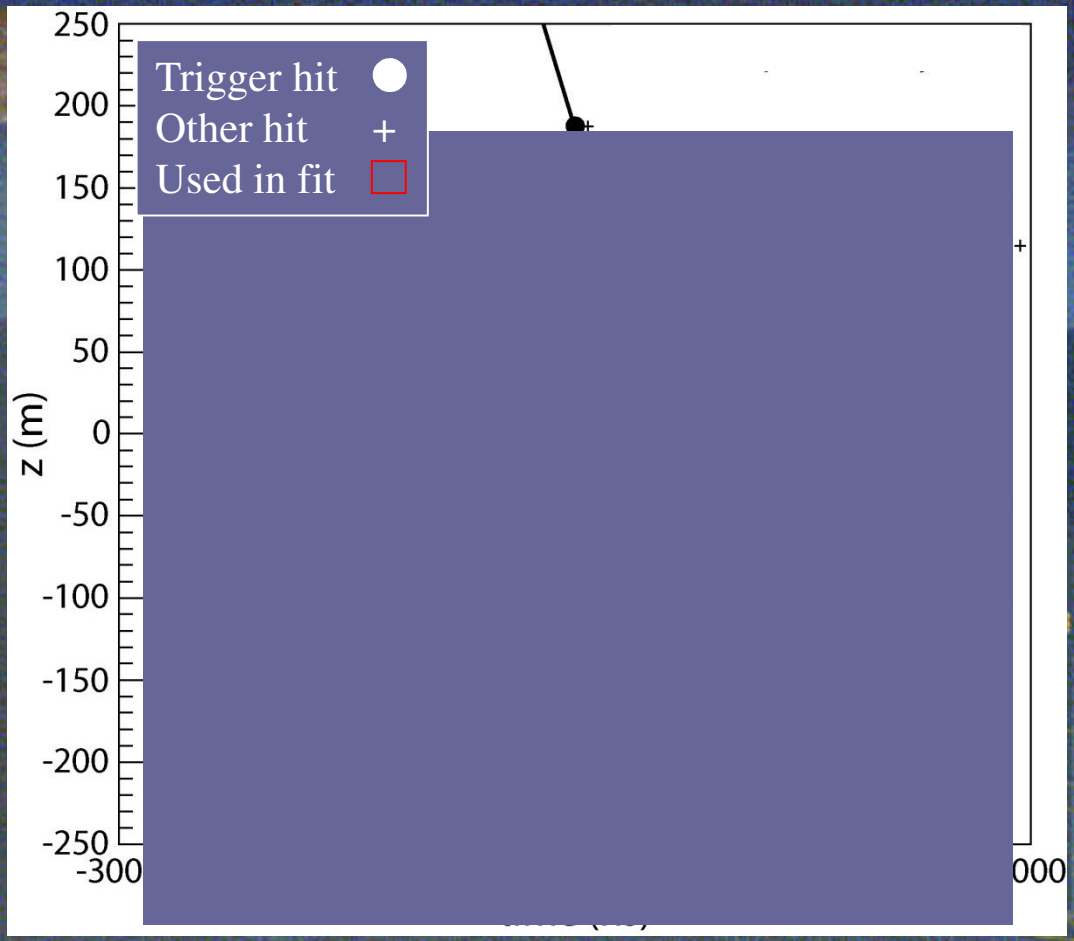


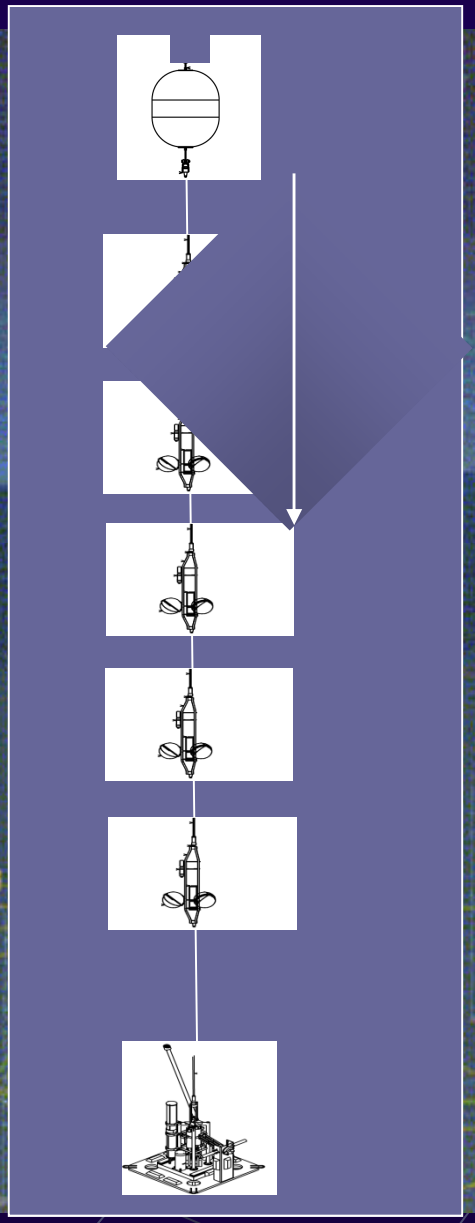


Downward muon Signature

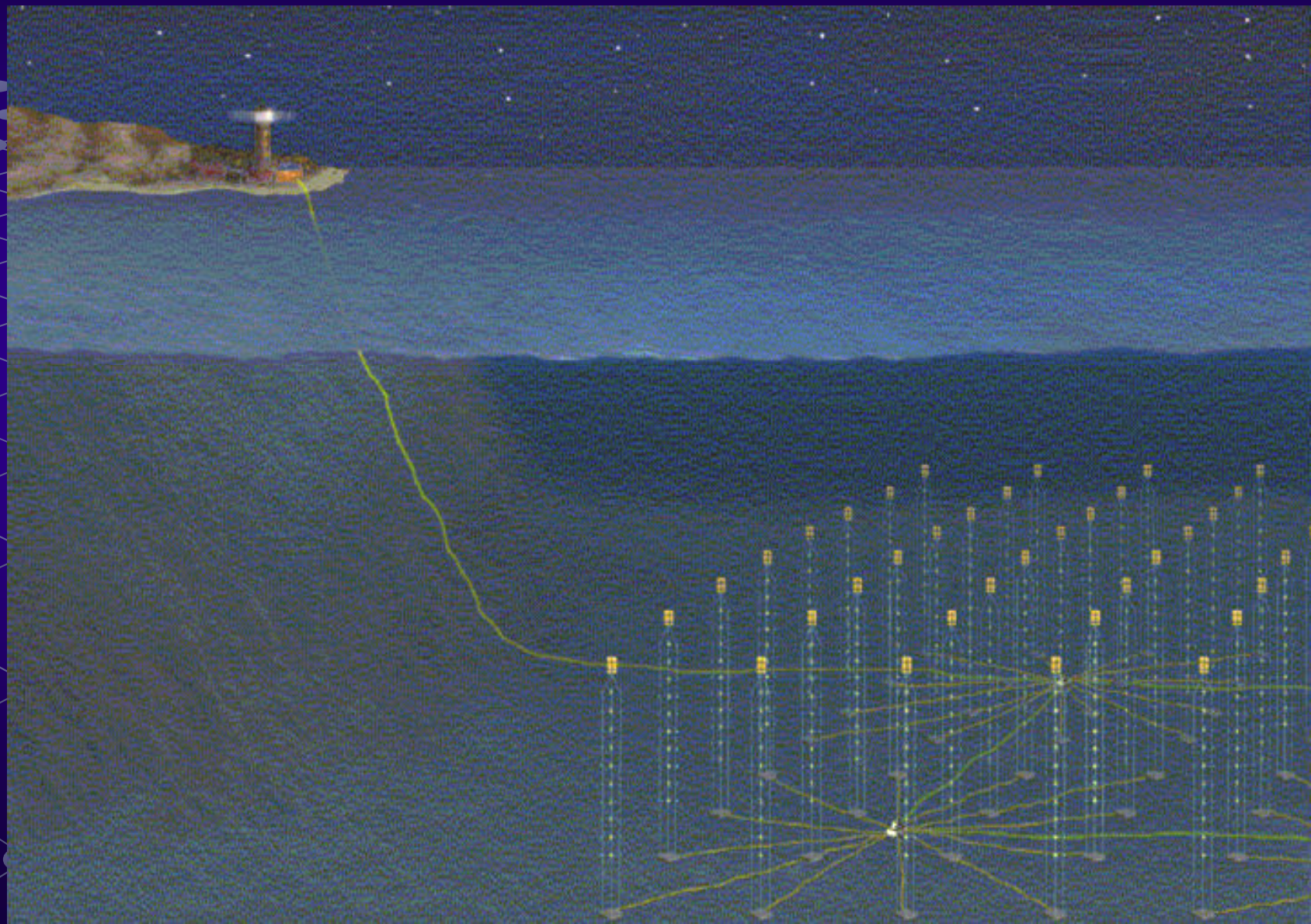


Downward muon Signature





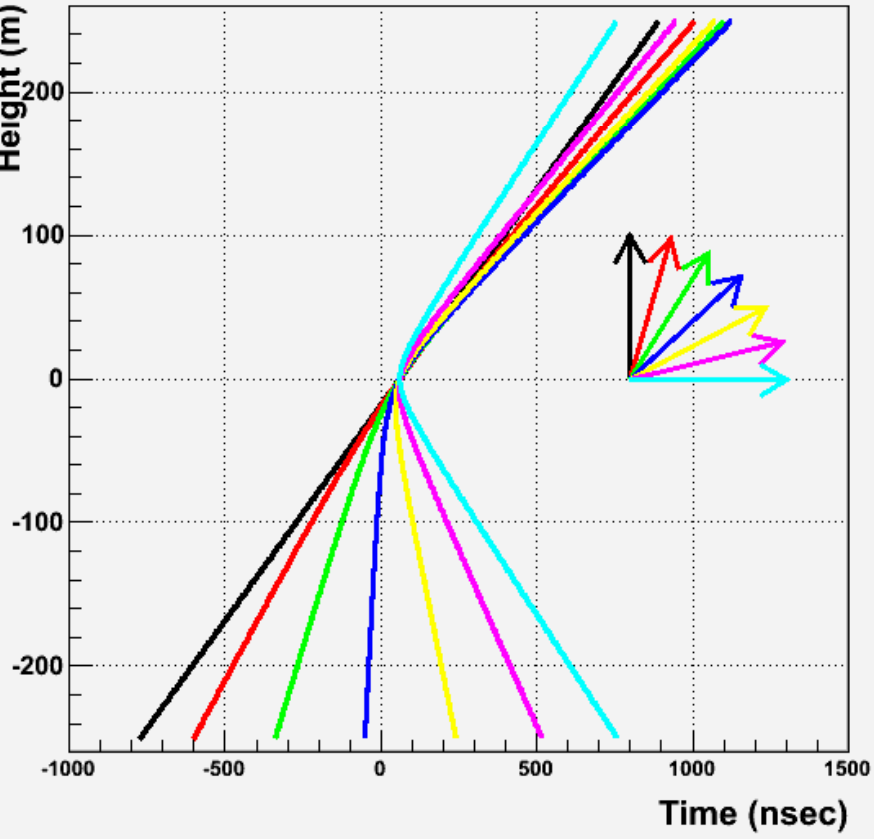
Downward muon Signature



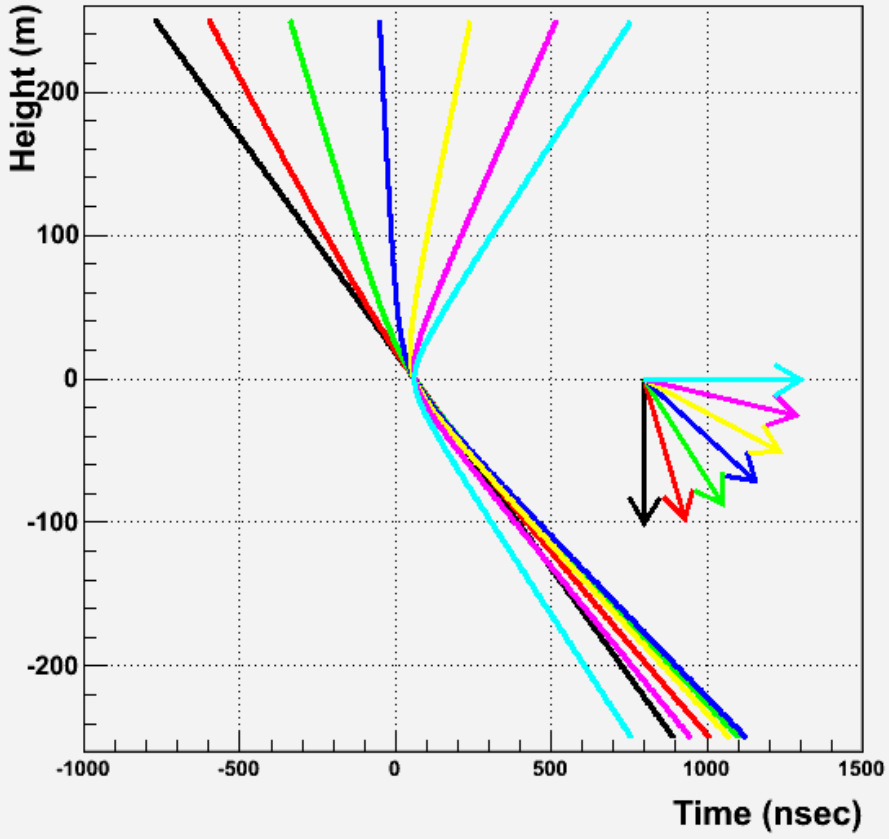
Muon signatures : general

=> Characteristic pattern in function of zenith angle and point of closest approach between line and track

upward



Downward (background)



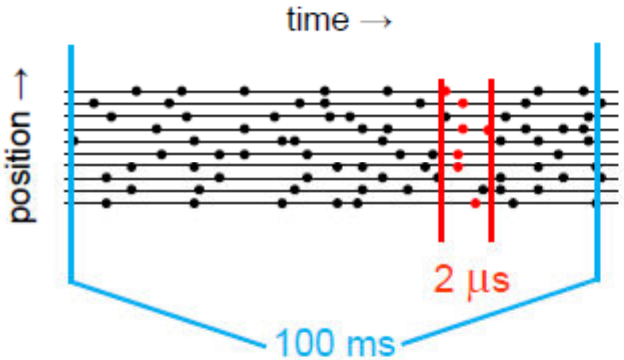
Deep-sea data transfer at KM3NeT

- Several hundred vertical detection lines,
  each of up to 120 optical modules (OMs) with PMTs,
  anchored to sea floor power & data transport network;
- Data acquisition will minimize offshore electronics,
  reducing difficult and expensive maintenance operations.
- ALL-DATA-TO-SHORE: - No off-shore triggering/filtering
  to combine signals from multiple OMs foreseen;
  ➔ all signals passing internal criteria (e.g. charge threshold)
  uploaded via fibreoptic telecommunications cable at overall worst case data rate of 100-400Gb/s using DWDM* colour multplexing
  [Dense Wavelength Division Multiplexing: up to 200 colours in 1550nm (C) band]*
- Data transport and routing issues are discussed.

Music box or auto-piano principle…

"All-data-to-shore" concept

background rates on 10□PMTs
can reach ~100 -200 kHz
(bioluminescence)



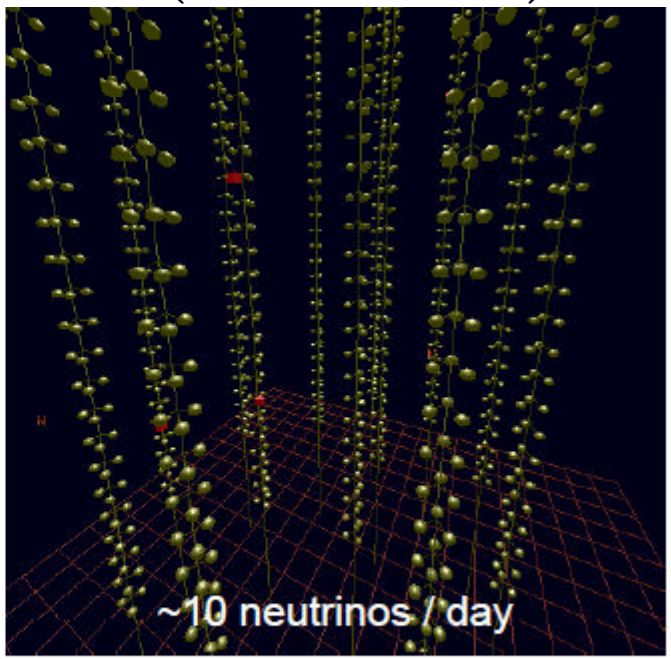
GB/s

data filter

1 Mb/s

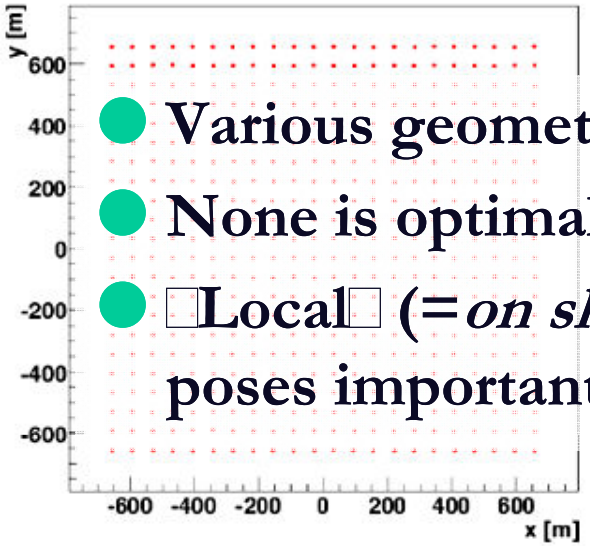
offline reconstruction

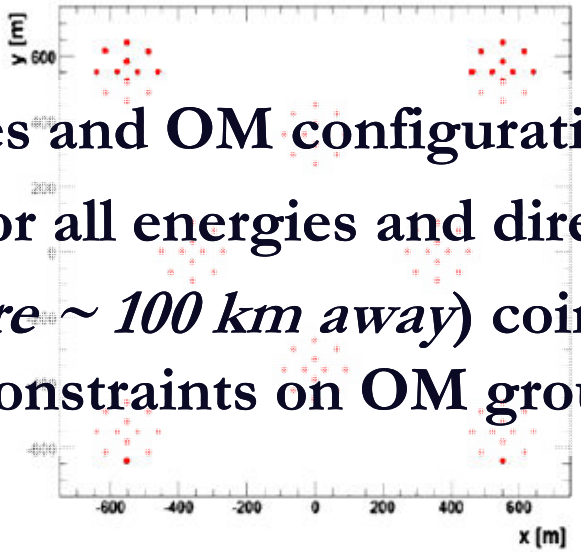
track

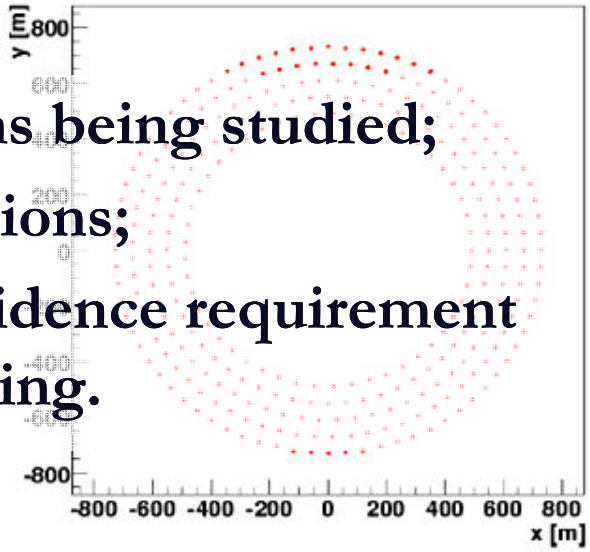


determination of muon track

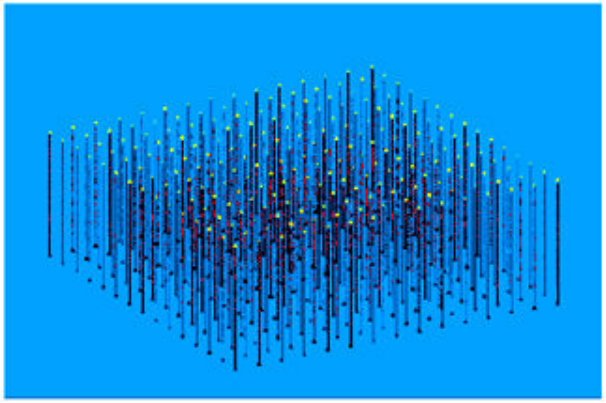
Configuration Studies

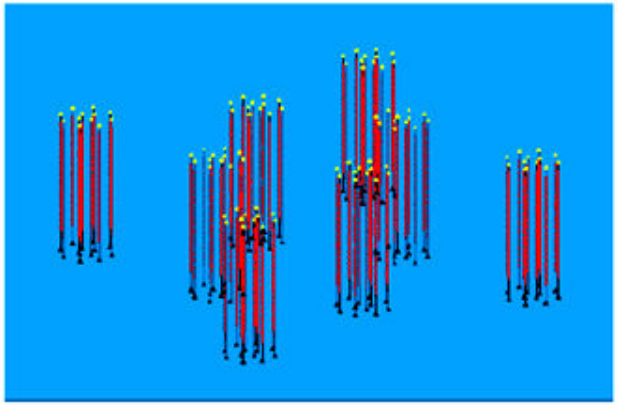


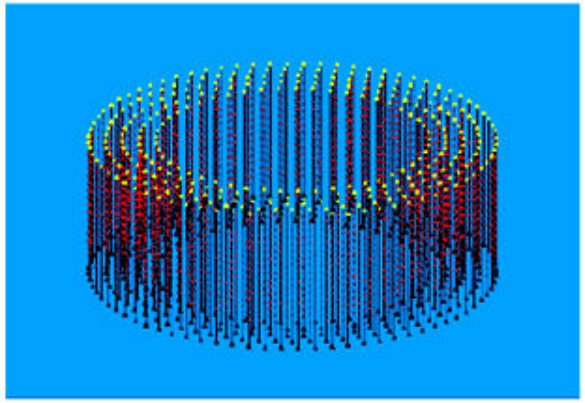




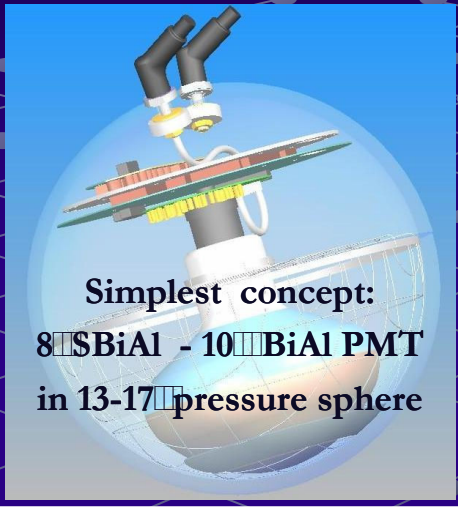
- Various geometries and OM configurations being studied;
- None is optimal for all energies and directions;
- "Local" (=*on shore ~ 100 km away*) coincidence requirement poses important constraints on OM grouping.







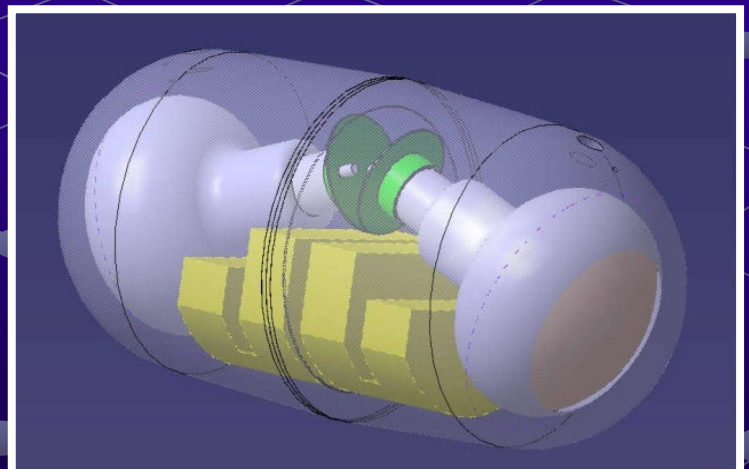
Optical Module Concepts



Simplest concept:
8 SBiAl - 10 BiAl PMT
in 13-17 pressure sphere

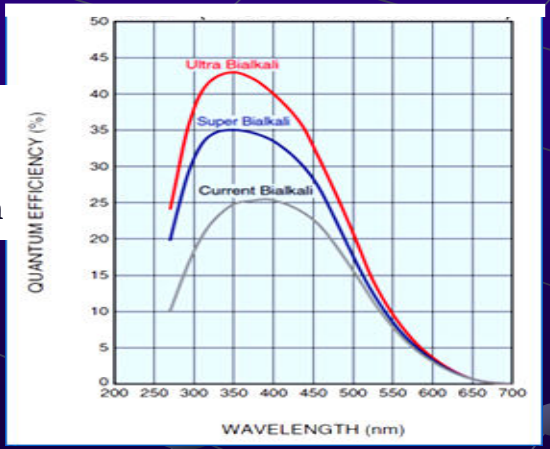
Multi-PMT Optical Module: 31 * 3 PMs in 17 sphere

- increased photocathode area
- improved 1-vs-2 photo- electron separation
- directionality



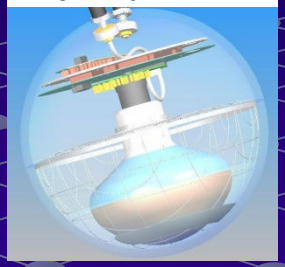
Capsule concept: 2 x 8 SBiAl PMTs
Envelope: 2*10 hemispheres fused to cylinders.
R&D with Schott; must withstand > 400 bar

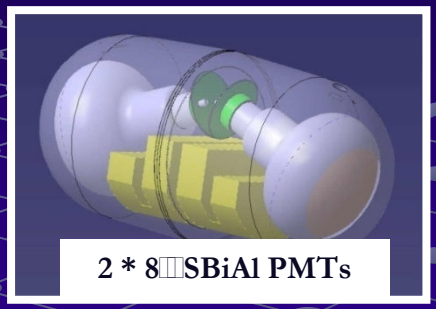
High QE bialkali p.c.
(≥30%: any chosen tube)
extends Cherenkov horizon



Data Rates for detection lines under worst case (^{40}K + bioluminescence burst) conditions

8□- 10□PMT





2 * 8□SBiAl PMTs

Multi-PMT OM:
31 * 3□PMTs

Normal I_{dark} + ^{40}K decays (salt) (10□ PMT)+ micro-organism bioluminescence @ -2500m (ANTARES) ~ 45 KHz

Can peak @ 250 KHz levels (macro-organism passage) ; design for worse case.

91 detection line variant

- Detection line of 20 storeys each 3 OMs , eq 250KHz;
- 6 bytes TOT(48b) per SPE hit;
- 720 Mb/s per full detection line;
- 91 lines ➔ 65 Gb/s

127 detection line variant

- Detection line of 20 storeys each 3 OMs , eq. 2*250KHz
- ~10 -12 bytes TOT(80 -96b) per SPE hit;
- ~3Gb/s per full detection line;
- 127 lines ➔ 370 Gb/s

Multi-PMT optical module variant (300 lines)

- Detection line of 20 storeys, each 1 OM of 31* 3□PMTs;
- 22.5 KHz noise per tube & 6 bytes (48 bits)/ SPE ➔ 1.1Mbps /tube
- 670 Mb/s per full detection line;
- 300 lines ➔ 200 Gb/s

Such high levels (macro-organism spate) rare & seasonal (ANTARES)

A proposed readout scheme with shore based lasers and off-shore reflective electro absorption modulators (R-EAMS)

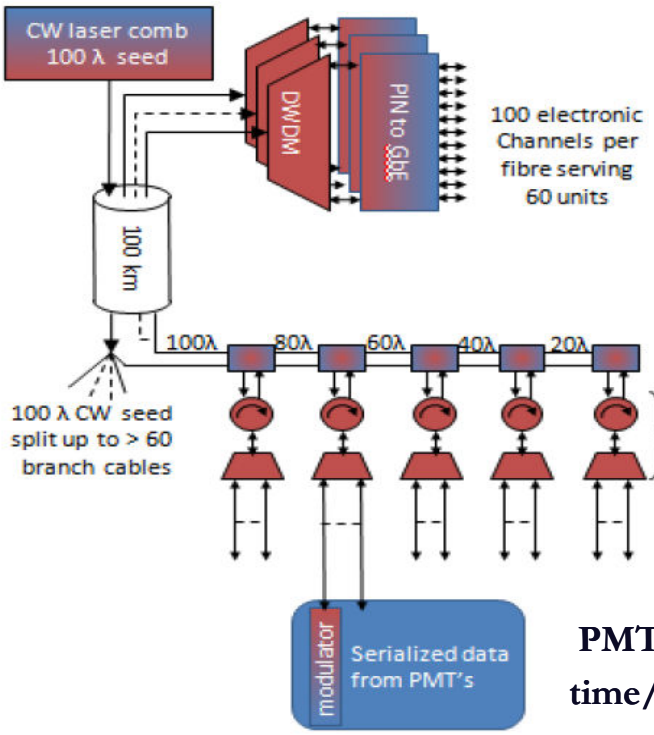


Figure 9 Schematic view of the fibre topology in the data acquisition system.

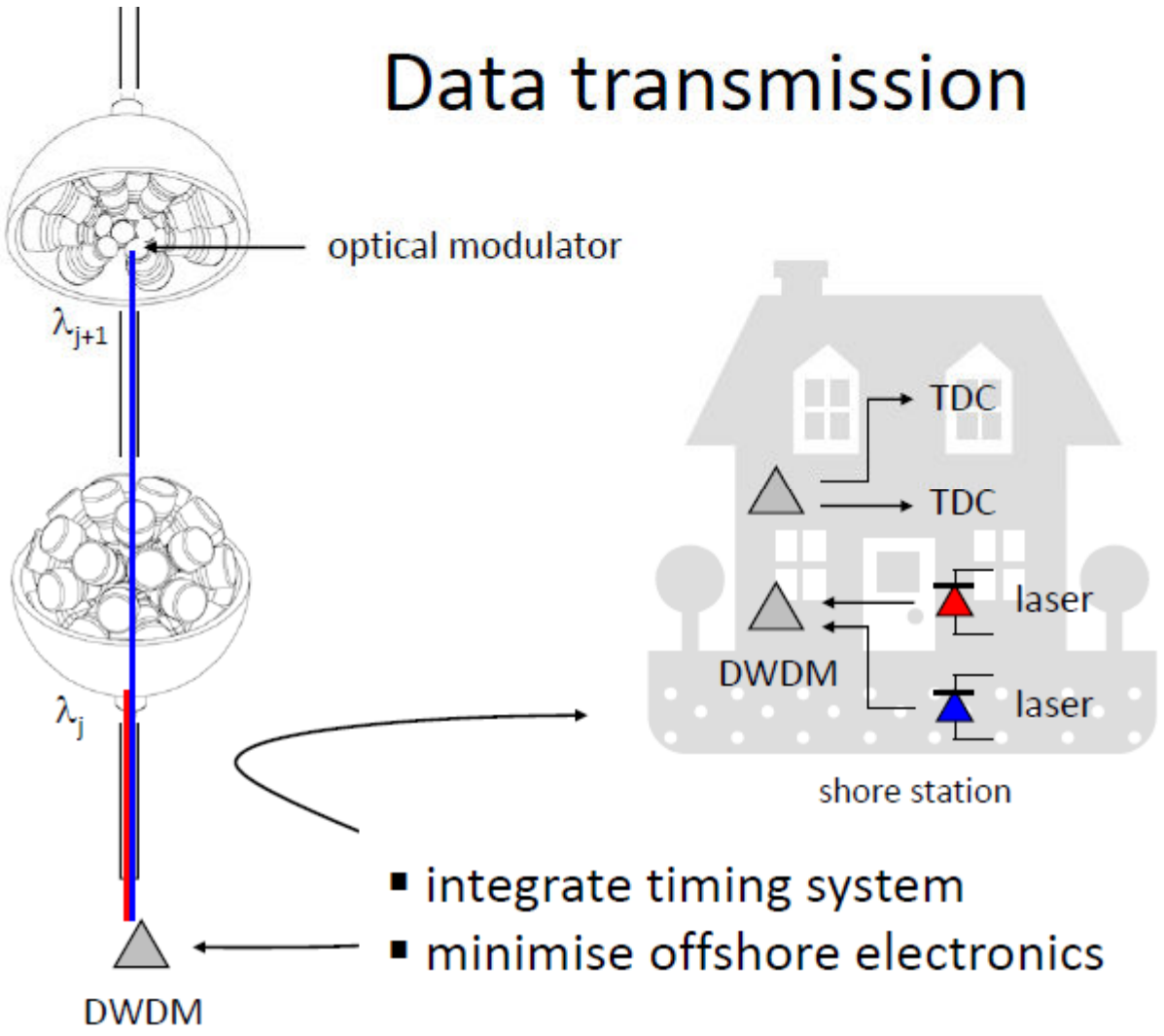
Example: 100 colours interrogate modulators in 20 optical modules on each of 5 detection lines

Bidirectional: a circulator in each detection line

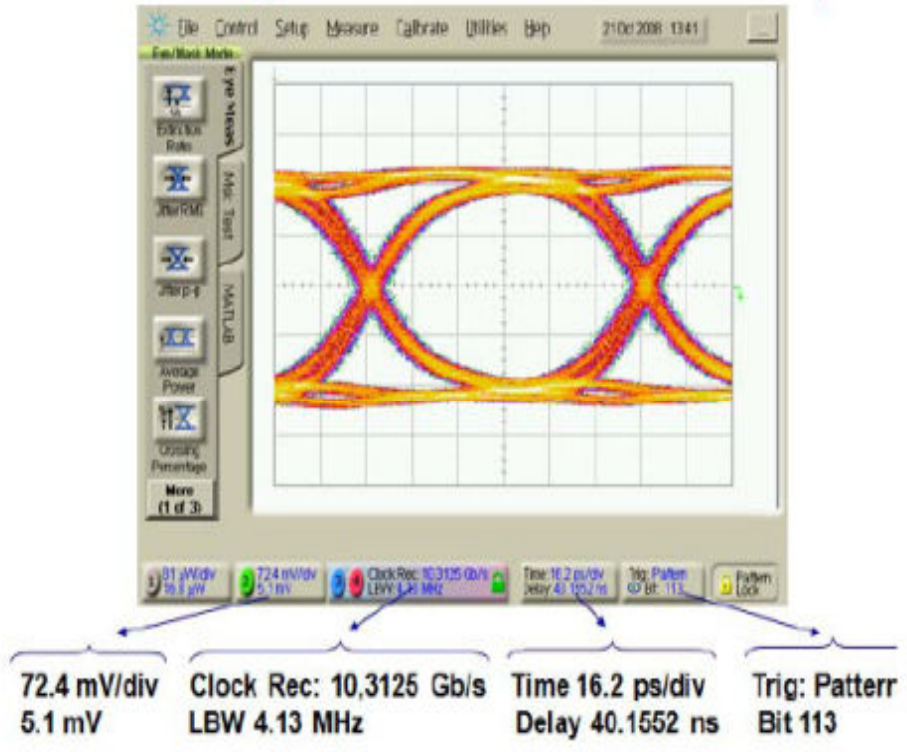
PMT signal readout via time/multiple thresholds

- Present data transmission rates reaching 40Gb/s per DWDM λ in C (1550nm) band
- 25 GHz colour channel spacing (~ 0.25 nm) gives 200 chans; 50 GHz gives 100 ch
- KM3NeT data rates conservative by these standards ~ < 25 Gb/s per fibre; 100 chans

Local coincidences formed 100 km away; TDCs can be onshore, timing between arriving edges but ASICs also under development incorporating T.O.T. (see talk by L. Caponetto)



Proposed readout scheme with shore based lasers and off-shore reflective electro absorption modulators (R-EAMS)



10 Gb/s demonstration: one colour interrogating Passive R-EAM @10 Gb/s through 100 km monomode fibre approximating KM3NeT configuration

Getting the data to shore: 50-100 km of deep sea fibre-optic telecommunications cable:

Mfrs: Alcatel-Lucent, Nexans, Tyco, Norddeutsche Seekabelwerke…

Delivery by rail or cable ship loading at factory

Use DWDM* in C band (1530 - 1565 nm)
(Dense Wavelength Division Multiplexing)
Presently up to 200 colours @ 25 GHz spacing

Chromatic dispersion can complicate life

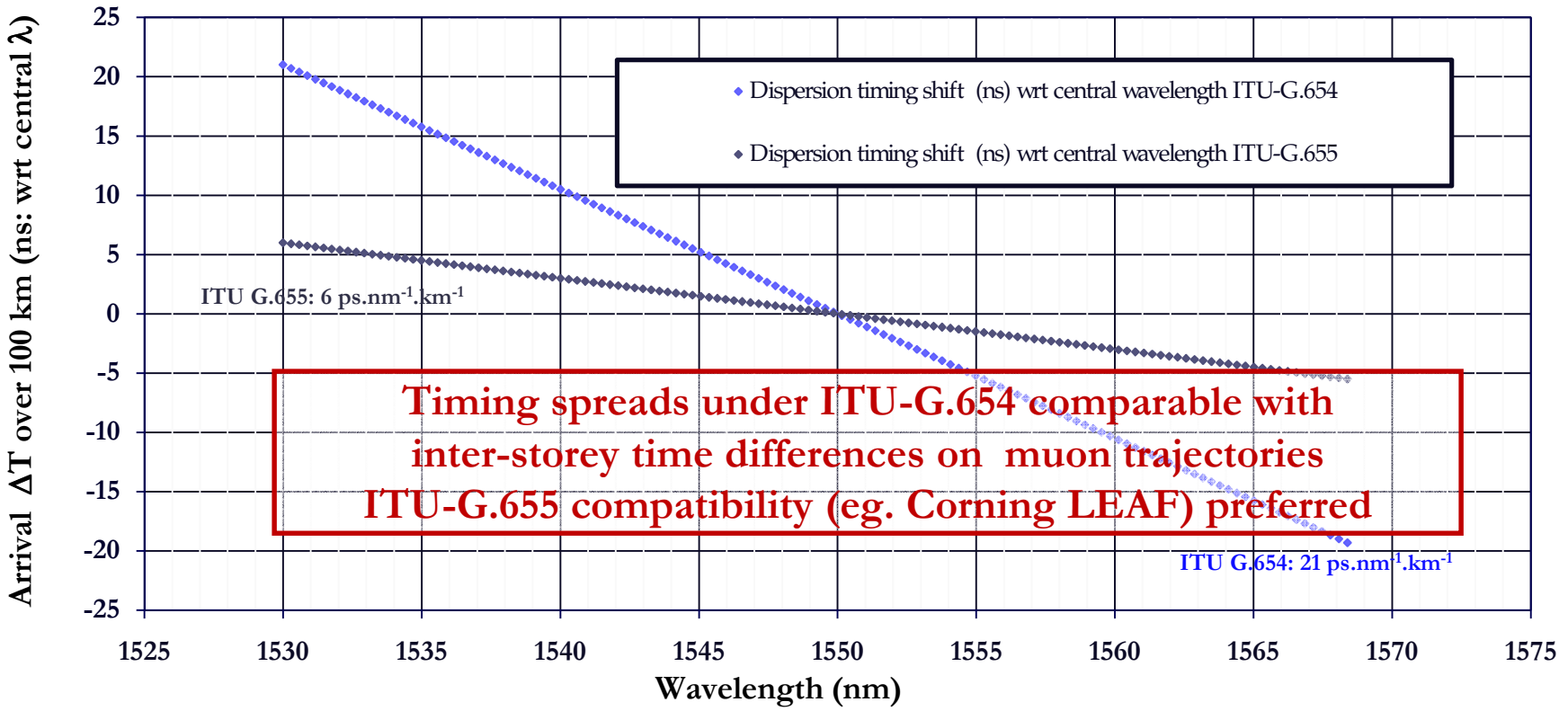
(signals can arrive ~ 10 ns apart over 100 km, depending on λ)

INTERNATIONAL TELECOMMUNICATION UNION

ITU-T G.655 (10/96)

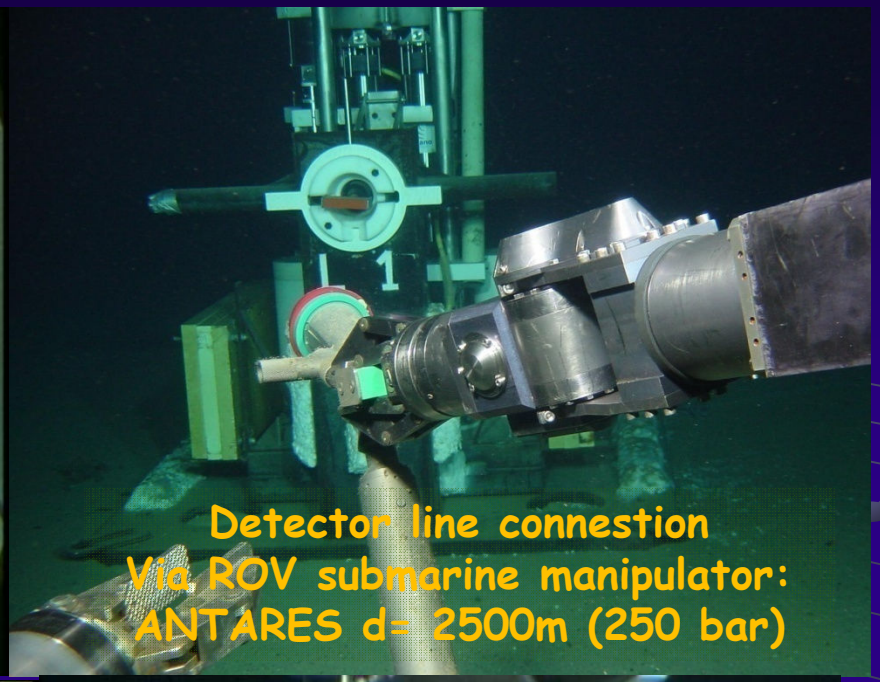
TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

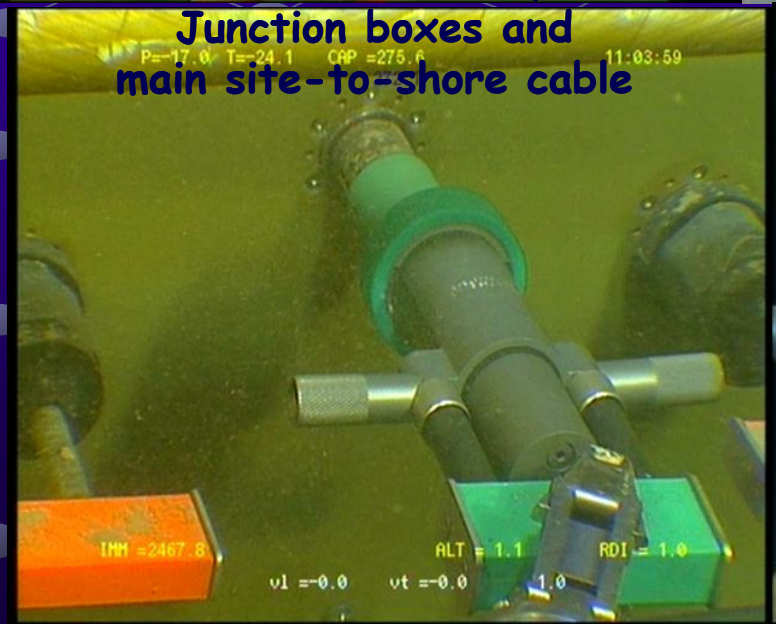


Submarine detector line connection

Deep sea connections needed to heirarchy of Junction boxes and main site-to-shore cable

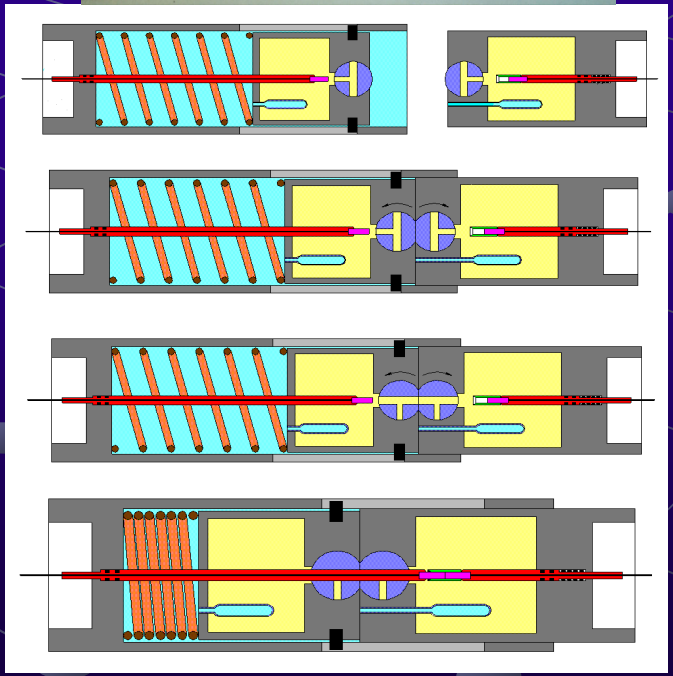


Detector line connestion
Via ROV submarine manipulator:
ANTARES d= 2500m (250 bar)



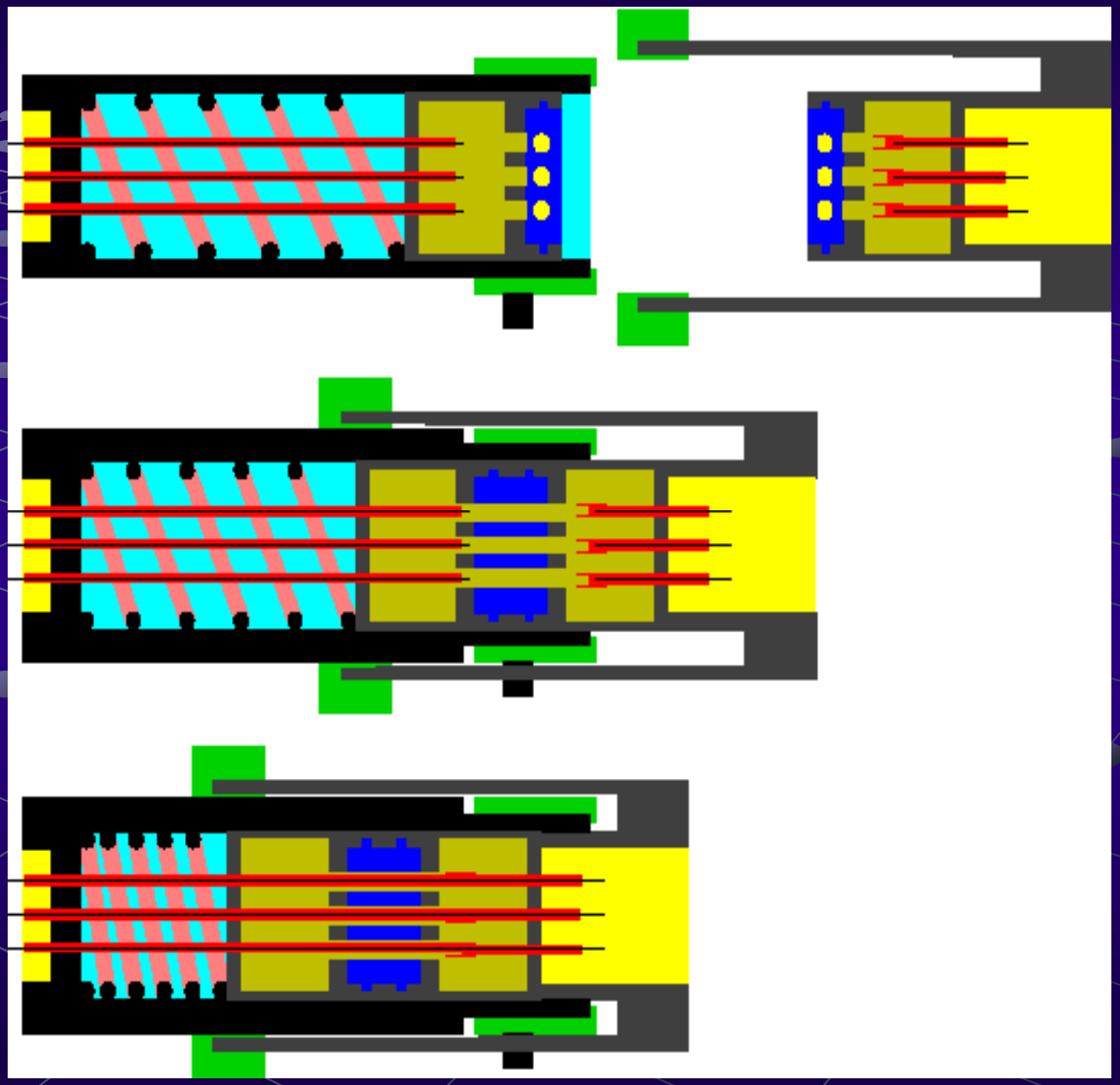
Deep-sea mateable connector M/F oil volume mixing

Schématique fonctionnement connecteur ODI



CONNECTOR SOCKET AND PLUG

ANTARES has seen problems with monomode (7um) core alignment in these connectors: New types anticipated



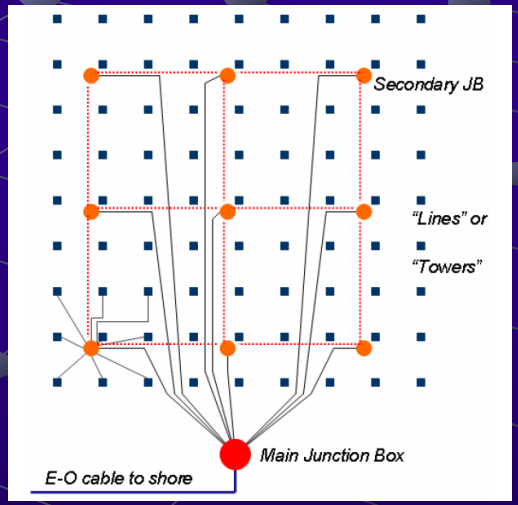
Scalable Sea-Floor Cabling

A Km^3 detector means many detector units to be cabled. ANTARES experience teaches us that ROV wet-mateable connections (particularly fibreoptic) are a weak point.

Reduce the numbers of wet-mateable connectors (also new types on the way)

Interconnections in detection lines using 'penetrators' and fusion splices inside optical modules:

Various "Star" and "ring" data/power cabling layouts being considered



Unipolar 10kV D.C. or A.C. (p.p.) delivered by site-top-shore cable: reduced to ~ 400V in primary and/or secondary junction boxes for seabed and vertical link distribution (see talk of M. Sedita)

Hierarchical sea floor data/ power connection: possible schemes with varying levels of power and dataflow redundancy and scalability of construction

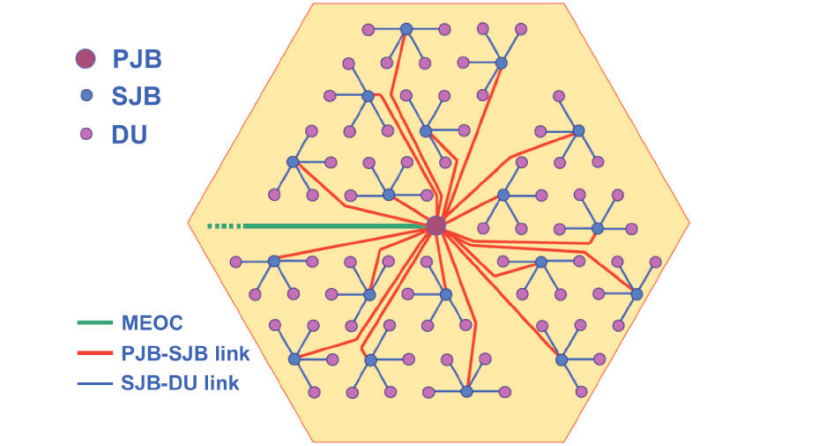
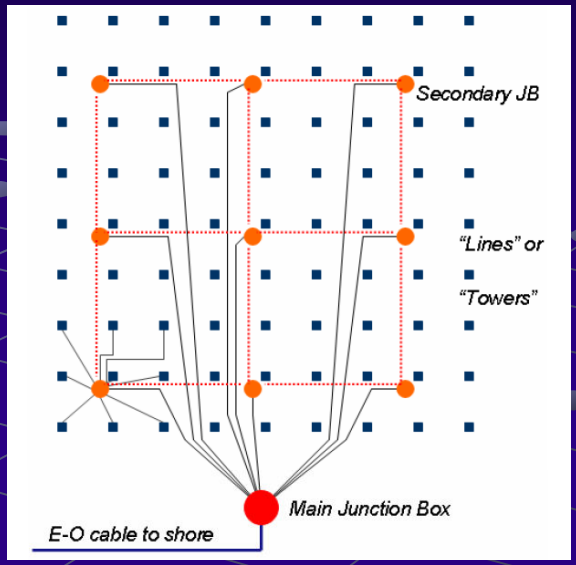
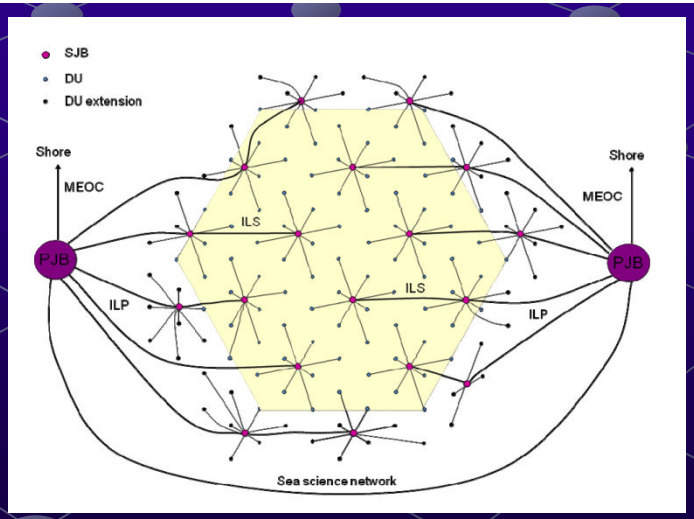
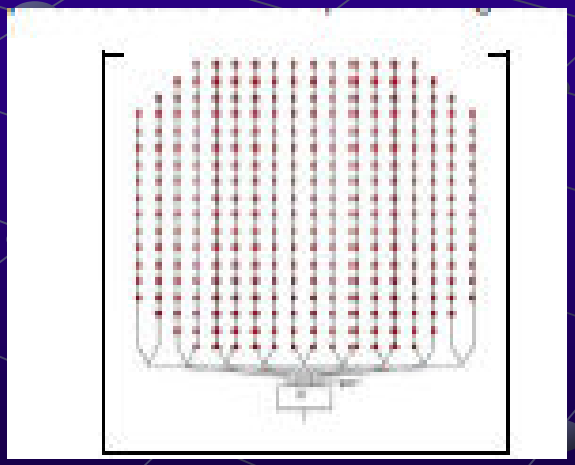


Fig. 17 – Example of a possible layout of the seafloor distribution system for 90 DUs. Extensions to configurations with a larger number of structures can be obtained by adding subgroups of 5 DUs + 1 SJB

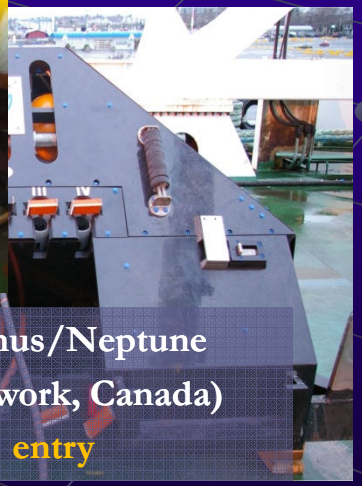






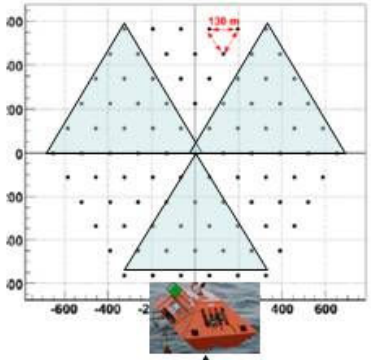
Standard Telecoms Universal Joint (UJ) Technology (penetrators)
allows to build a scalable sea floor Junction box network
without intermediate 10 kV HV connectors in the main trunk cables

Branching Unit (HV, fibres)
l-Lucent,
reenwich, UK)



Junction box (Venus/Neptune oceanographic network, Canada)
Penetrator entry

An idea for progressive deployment…



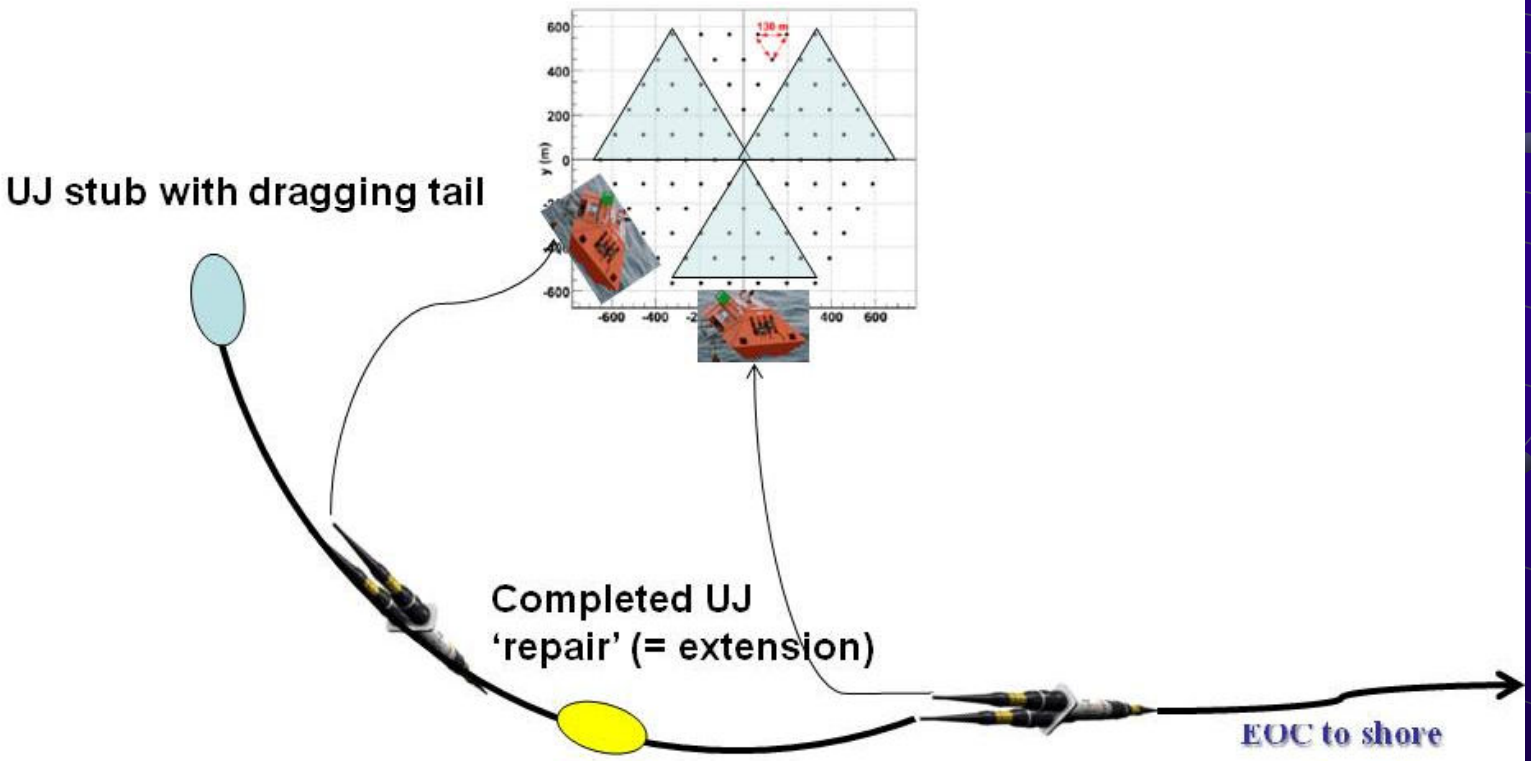
1: Single Branching Unit, Junction Box and UJ stub Terminating in recoverable single ended UJ box with acoustic transponder, dragging tail etc.

Universal Joint stub with dragging tail

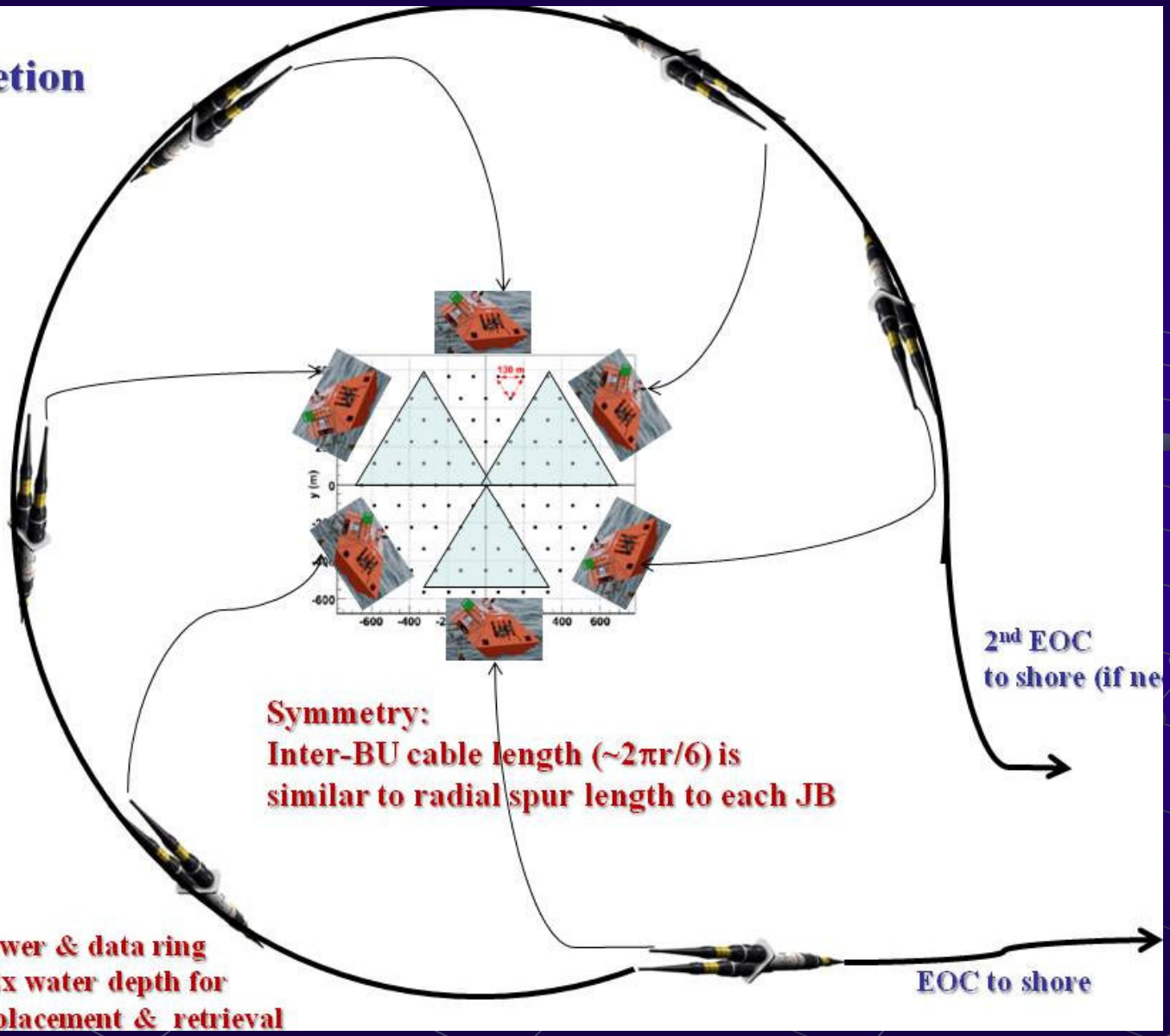
EOC to shore

An idea for progressive deployment…

2: Second BU, JB and UJ stub
Terminating in recoverable single ended UJ box with acoustic transponder, dragging tail etc.
Earlier-deployed UJ stub has been fished and jointed in continuation according to standard MECMA UJ jointing practice



Completion

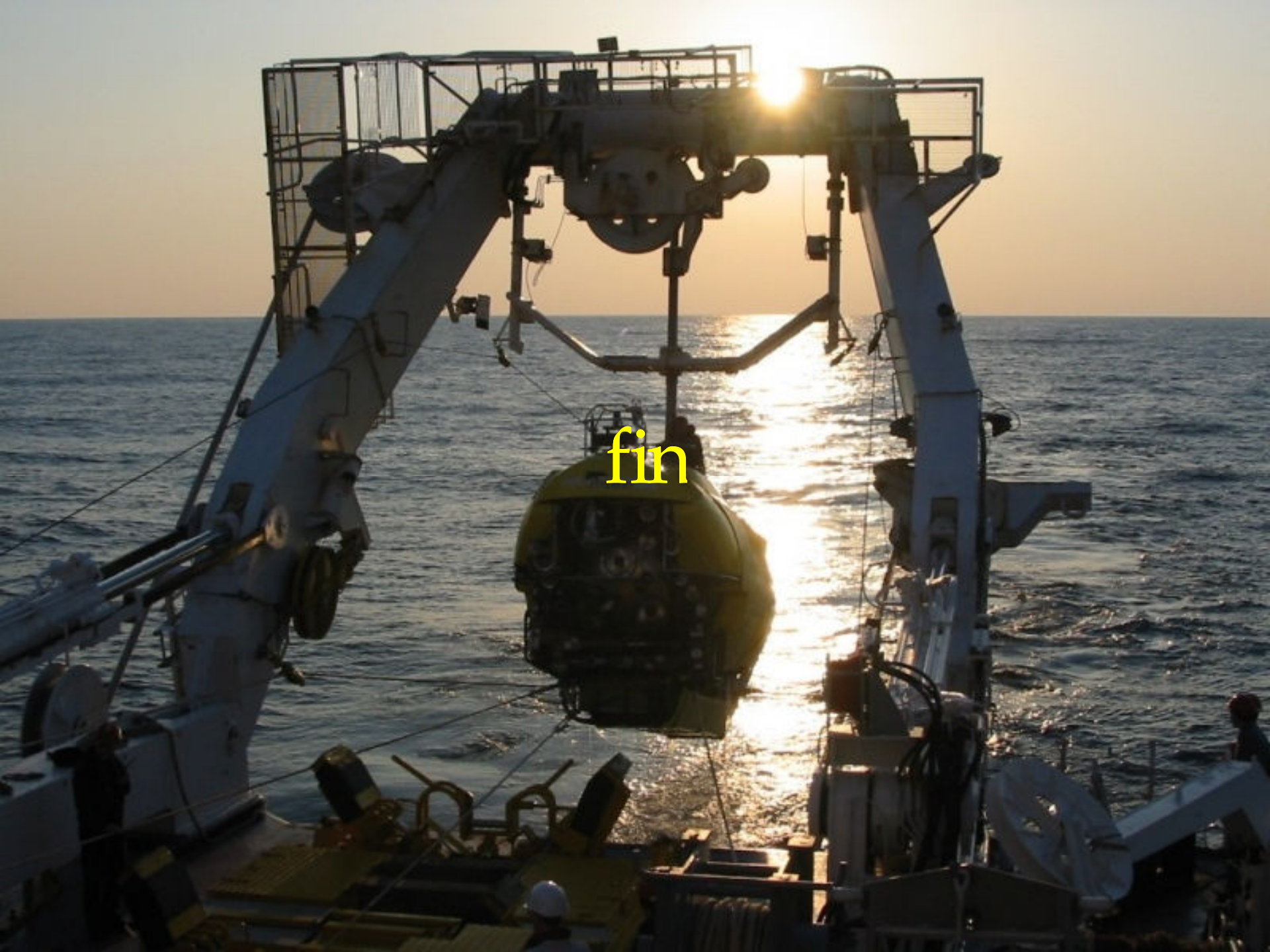

2nd EOC
to shore (if ne
Symmetry:
Inter-BU cable length (~2πr/6) is
similar to radial spur length to each JB
Circulating power & data ring
radius ~ 1.5 - 2x water depth for
individual JB placement & retrieval
EOC to shore

Summary

- **KM3NeT will be one of the biggest (3) detectors ever built (V>1km^3)**
  hundreds of detection lines anchored in sea floor matrix, height up to 1km;
- **Connection to the coast up to 100 km distant:**
  high bandwidth monomode fibreoptic transmission in standard telecoms cable;
- **Depth 2500 – 5000m (ambient pressures 250-500 bar)**
  connectivity issues, minimum possible deployed electronics
- **Innovative optical module designs proposed;**
- **Innovative readout scheme proposed with lasers on shore and modulators in optical modules: 1 colour /optical module or even/PMT**
  well within current telecoms bandwidth capabilities

➔ ***ALL DATA TO SHORE: (UPGRADABLE) SHORE PROCESSING***
(EVEN LOW - LEVEL COINCIDENCE TRIGGERING)
NOW CHEAPER THAN INACCESSIBLE SEA ELECTRONICS

KM3NeT CDR published April 2008 (ISBN 978-90-6488-031-5),
TDR now in preparation for publication - December 2009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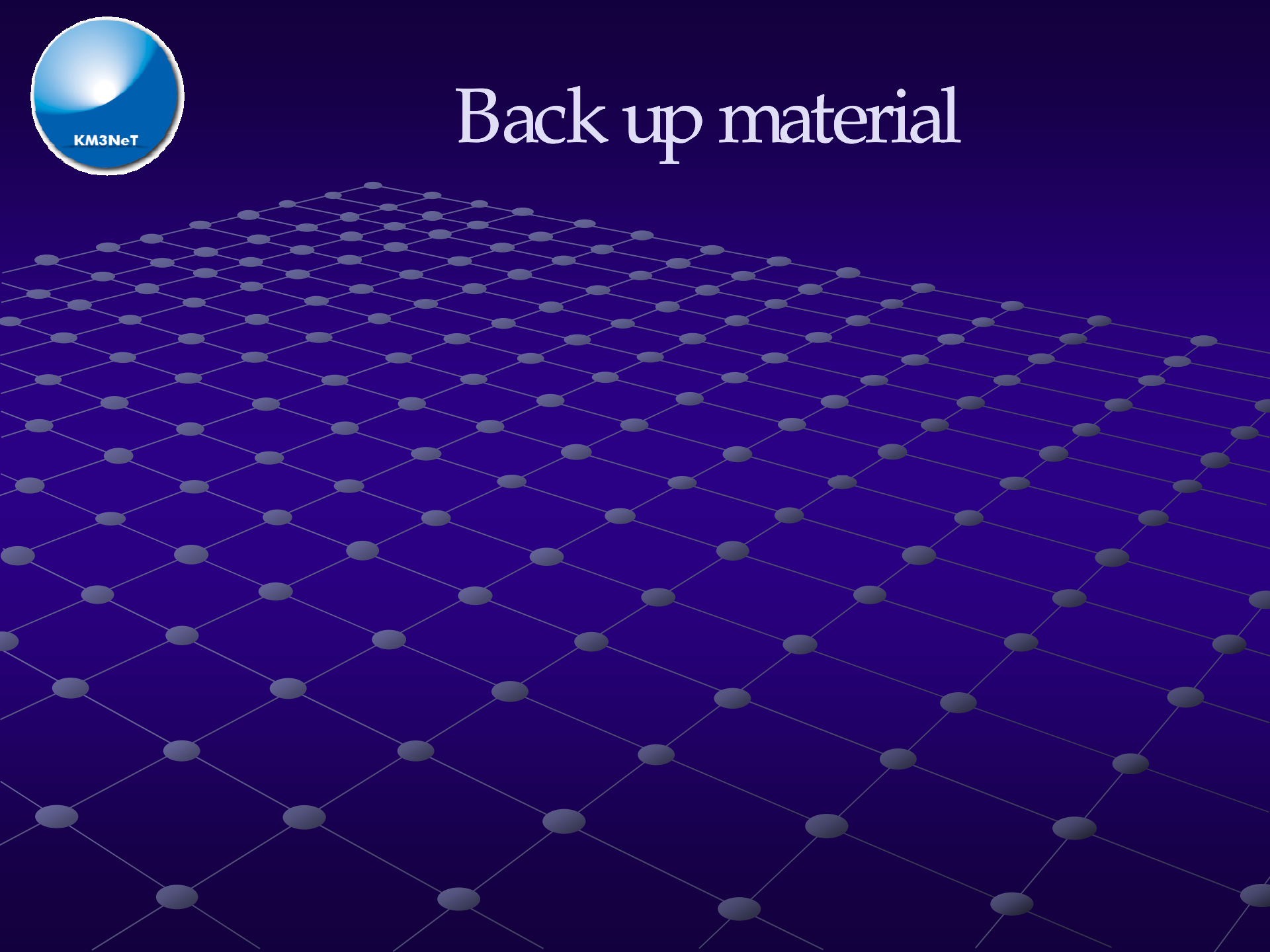
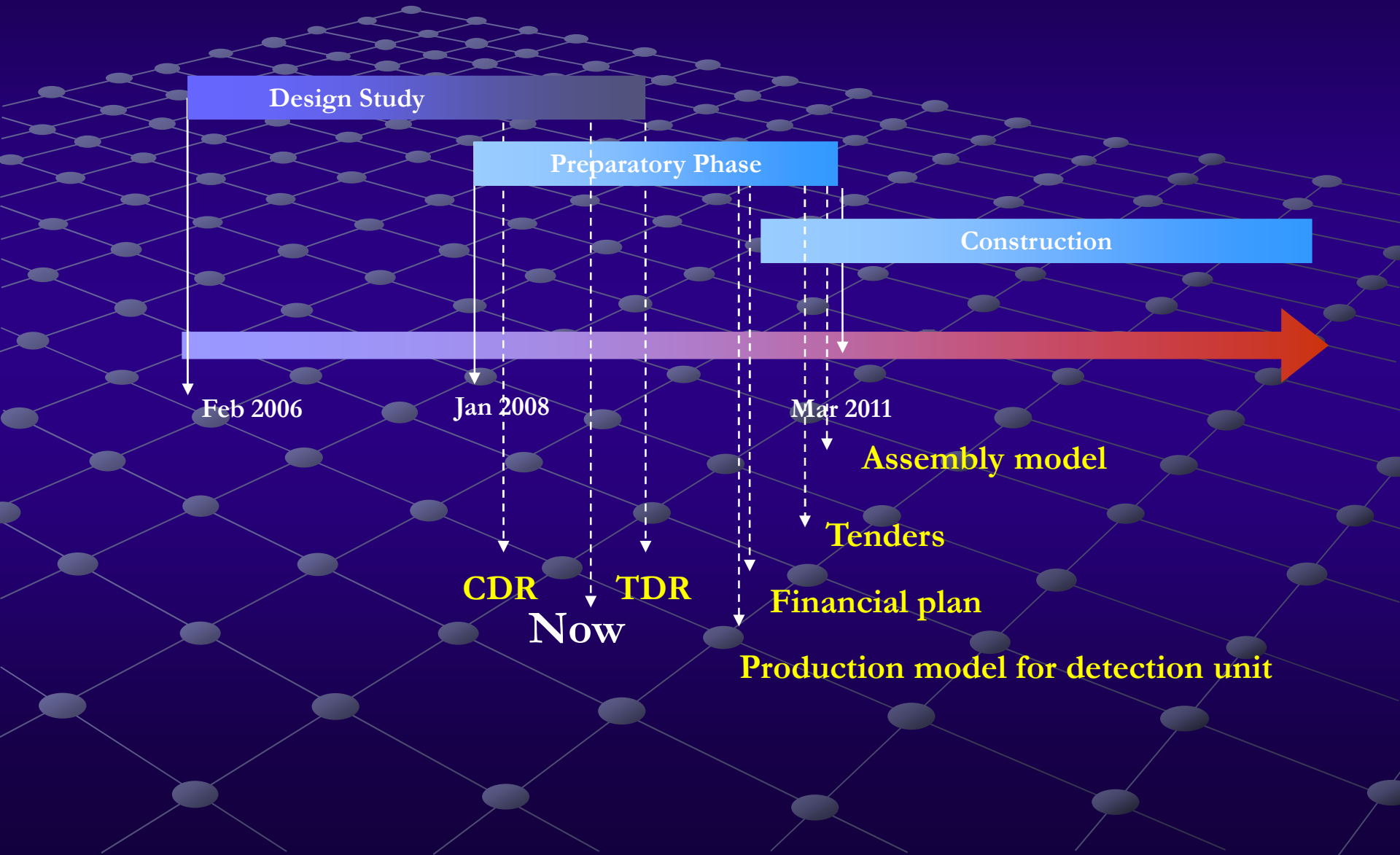


Back up material

KM3NeT timeline



The KM3NeT Conceptual Design Report

- Presented to the public at the VLVnT08 workshop in Toulon, April 2008
- Summarises (a.o.)
  - Physics case
  - Generic requirements
  - Pilot projects
  - Site studies
  - Technical implementation
  - Development plan
  - Project implementation