4th Workshop on Very Large Volume Neutrino Telescopes (VLVν09),
Athens, Greece, October 13-15, 2009

Status of the KM3NeT Project

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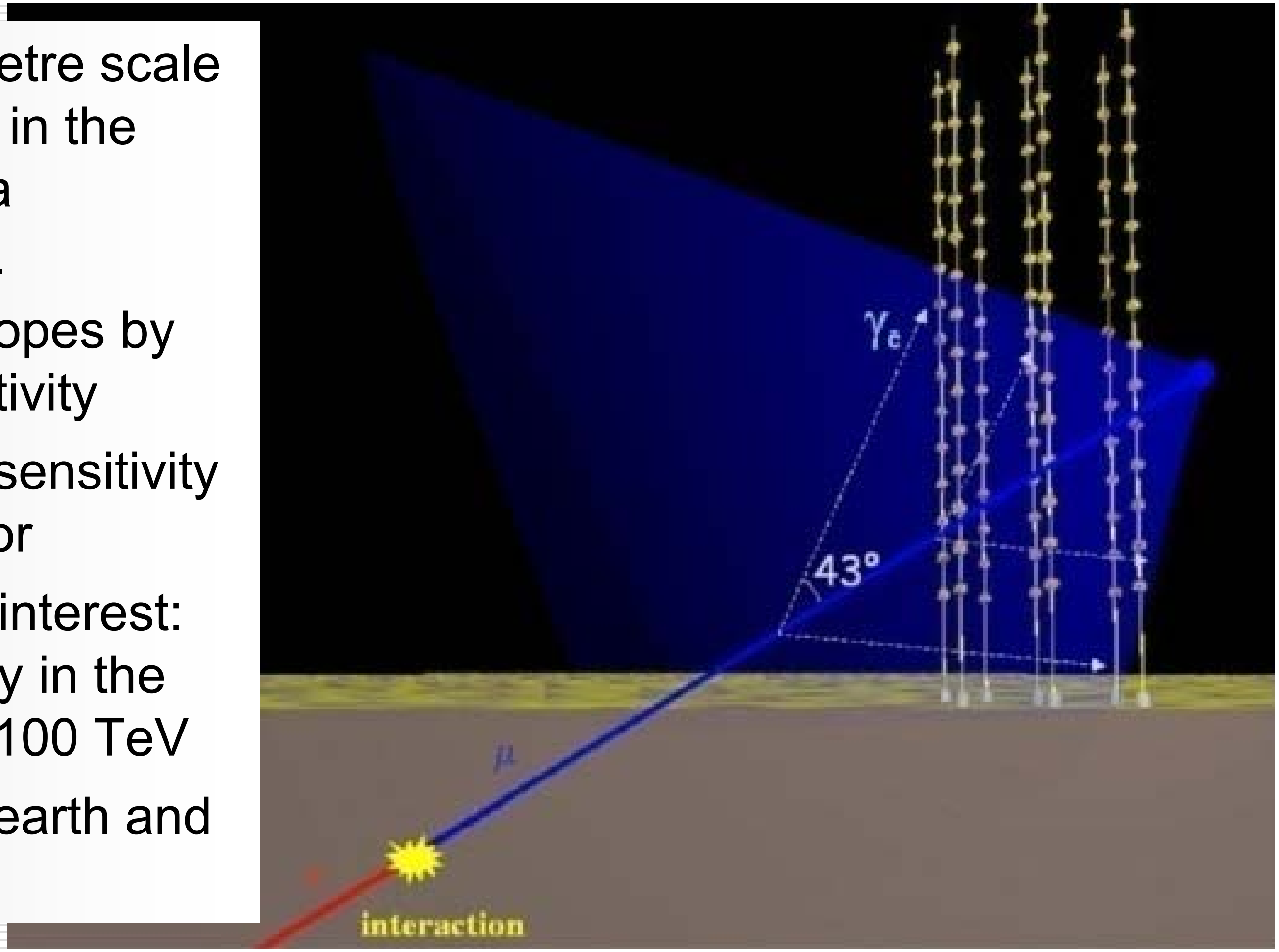
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

- The Challenge
- Technical solutions: Decisions an options
- Physics sensitivity
- Cost and implementation
- Summary

What is KM3NeT ?

- Future cubic-kilometre scale neutrino telescope in the Mediterranean Sea
- Exceeds Northern-hemisphere telescopes by factor ~50 in sensitivity
- Exceeds IceCube sensitivity by substantial factor
- Focus of scientific interest: Neutrino astronomy in the energy range 1 to 100 TeV
- Provides node for earth and marine sciences

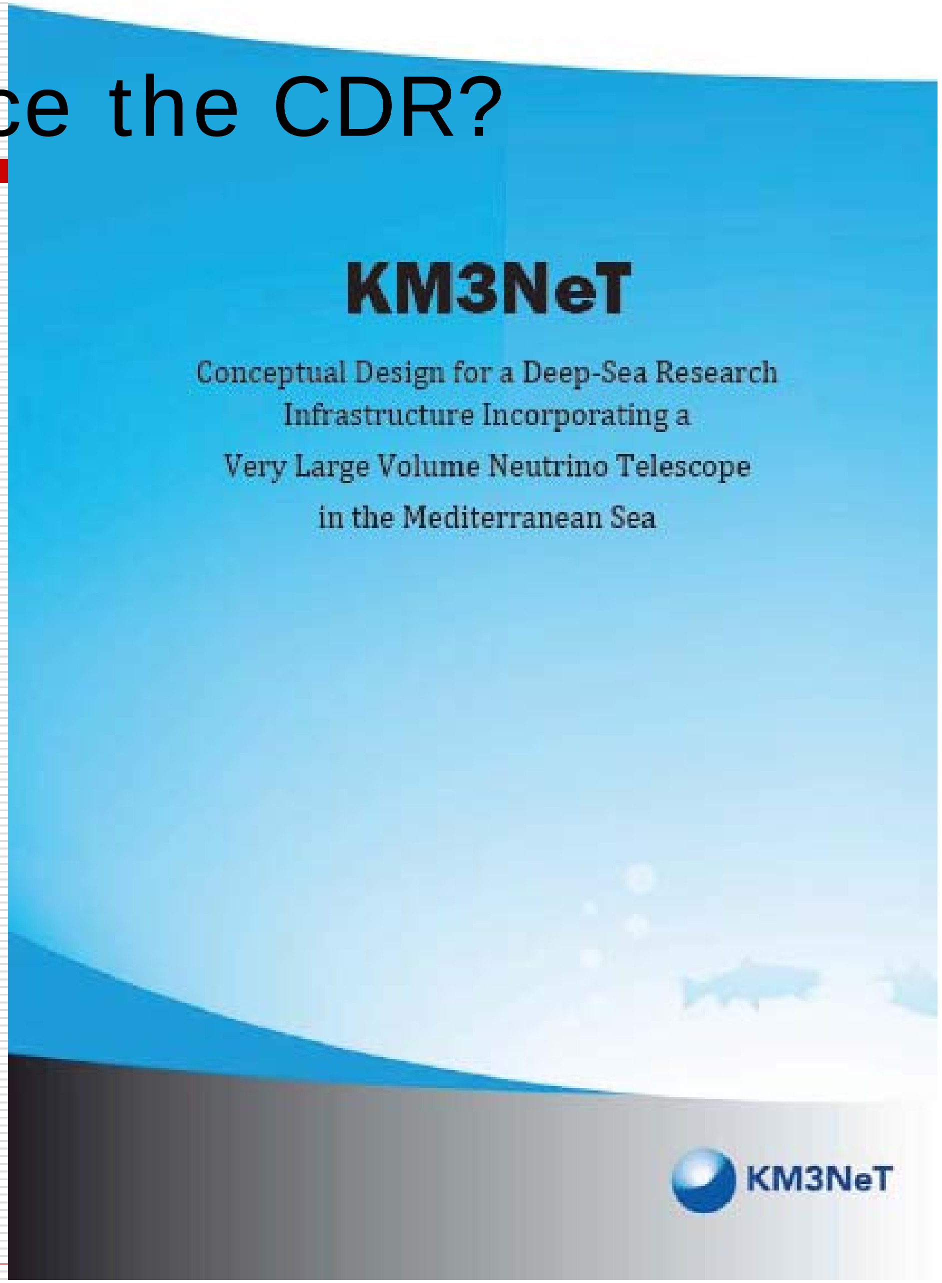


The Objectives

- Central physics goals:
  - Investigate neutrino "point sources" in energy regime 1-100 TeV
  - Complement IceCube field of view
  - Exceed IceCube sensitivity
- Implementation requirements:
  - Construction time ≤4 years
  - Operation over at least 10 years without "major maintenance"

What Happened since the CDR?

- Three different complete design options worked out to verify functionality and allow for competitive optimisation
- Extensive simulation studies to quantify sensitivities
- Decision on common technology platform



Reference to Parallel Sessions

A lot of details not presented here
will be covered in the parallel sessions!

The Challenges 1: Technical Design

- **Technical design**
  Objective: Support 3D-array of photodetectors and connect them to shore (data, power, slow control)
  - Optical Modules
  - Front-end electronics
  - Readout, data acquisition, data transport
  - Mechanical structures, backbone cable
  - Sea-bed network: cables, junction boxes
  - Calibration devices
  - Deployment procedures
  - Shore infrastructure
  - Assembly, transport, logistics
  - Risk analysis and quality control

Design rationale:

Cost-effective
Reliable
Producible
Easy to deploy

The Challenges 2: Site & Simulation

- **Site characteristics**
  Objective: Measure site characteristics (optical background, currents, sedimentation, …)

- **Simulation**
  Objective: Determine detector sensitivity, optimise detector parameters;
  Input: OM positions/orientations and functionality, readout strategy, environmental parameters
  - Simulation (using existing software)
  - Reconstruction (building on existing approaches)
  - Focus on point sources
  - Cooperation with IceCube (software framework)

Examples

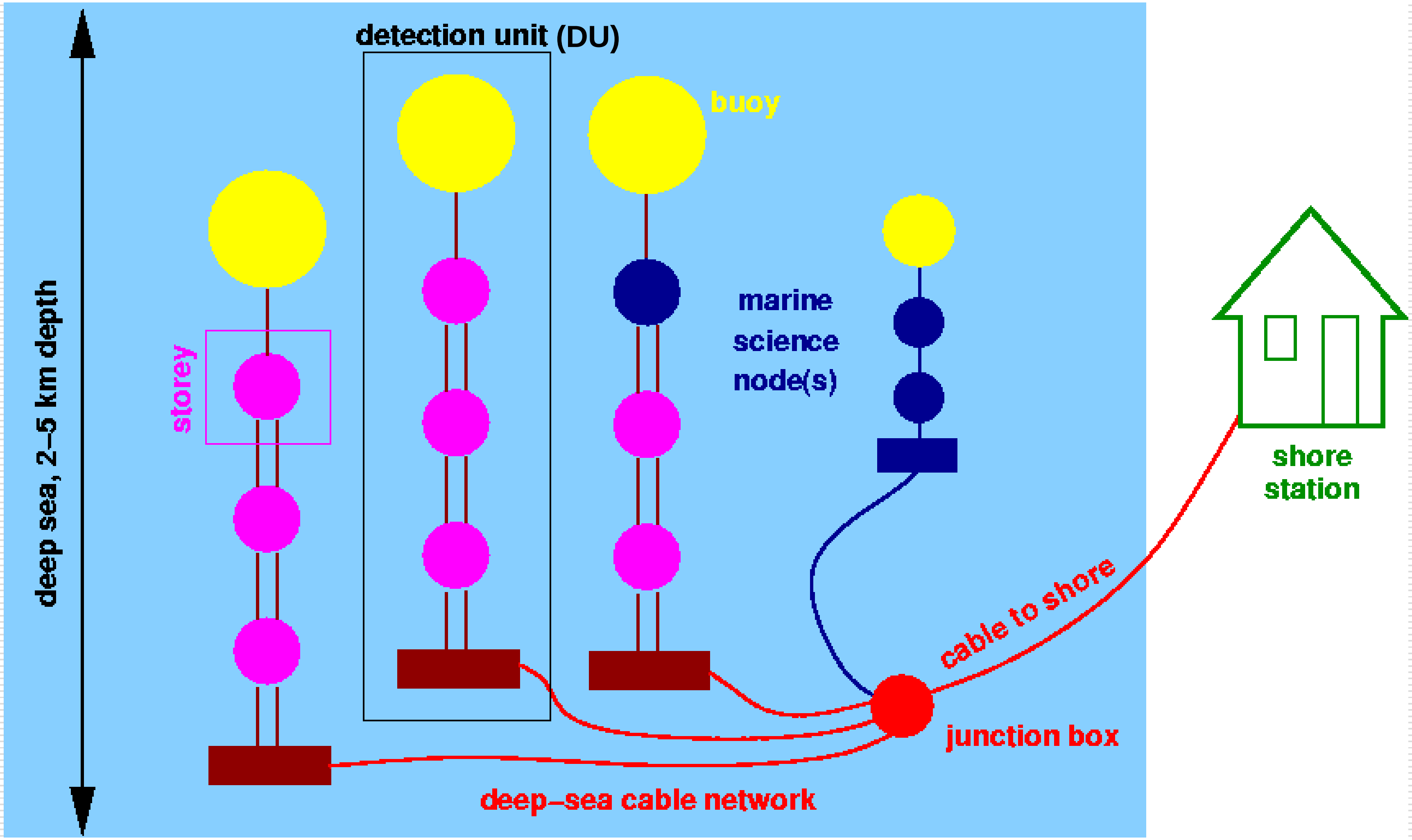
The Challenges 3: Towards a RI

- **Earth and marine science node**
  Objective: Design interface to instrumentation for marine biology, geology/geophysics, oceanography, environmental studies, alerts, ...

- **Implementation**
  Objective: Take final decisions, secure resources, set up proper management/governance, construct and operate KM3NeT;
  - Prototyping and field tests
  - Cost estimates
  - Site decision
  - Time lines

Examples

The KM3NeT Research Infrastructure (RI)



Technical Design: Decisions and Options

- Detection Unit:
  - Optical Modules (2+1 options)
  - Front-end electronics
  - Data transport
  - Mechanical structures (3 options)
  - General deployment strategy
  - Calibration (detailed solutions under study)
- Sea-bed network
- Marine science node

Green:

Preferred/unique solution, subject to validation

Black:

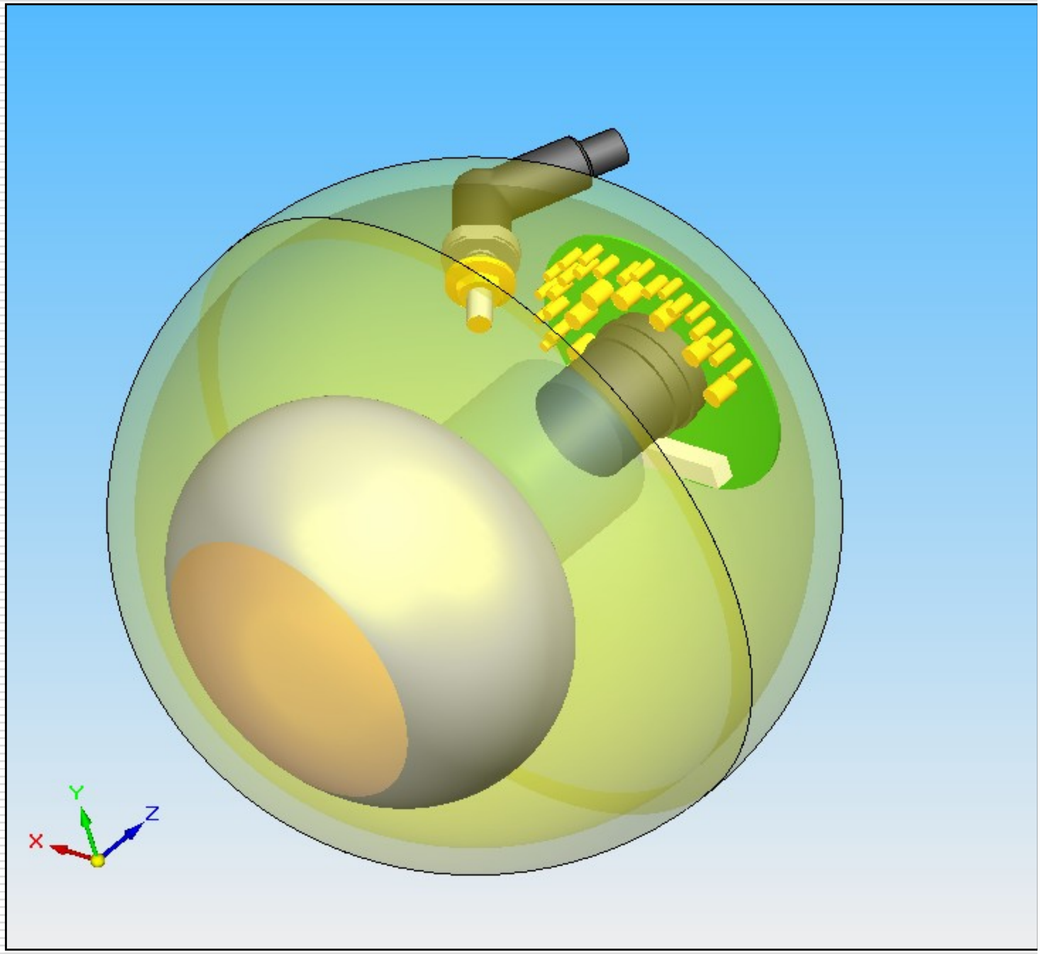
Several options

Some decisions require prototyping and field tests – too early to call!

OM "classical": One PMT, no Electronics

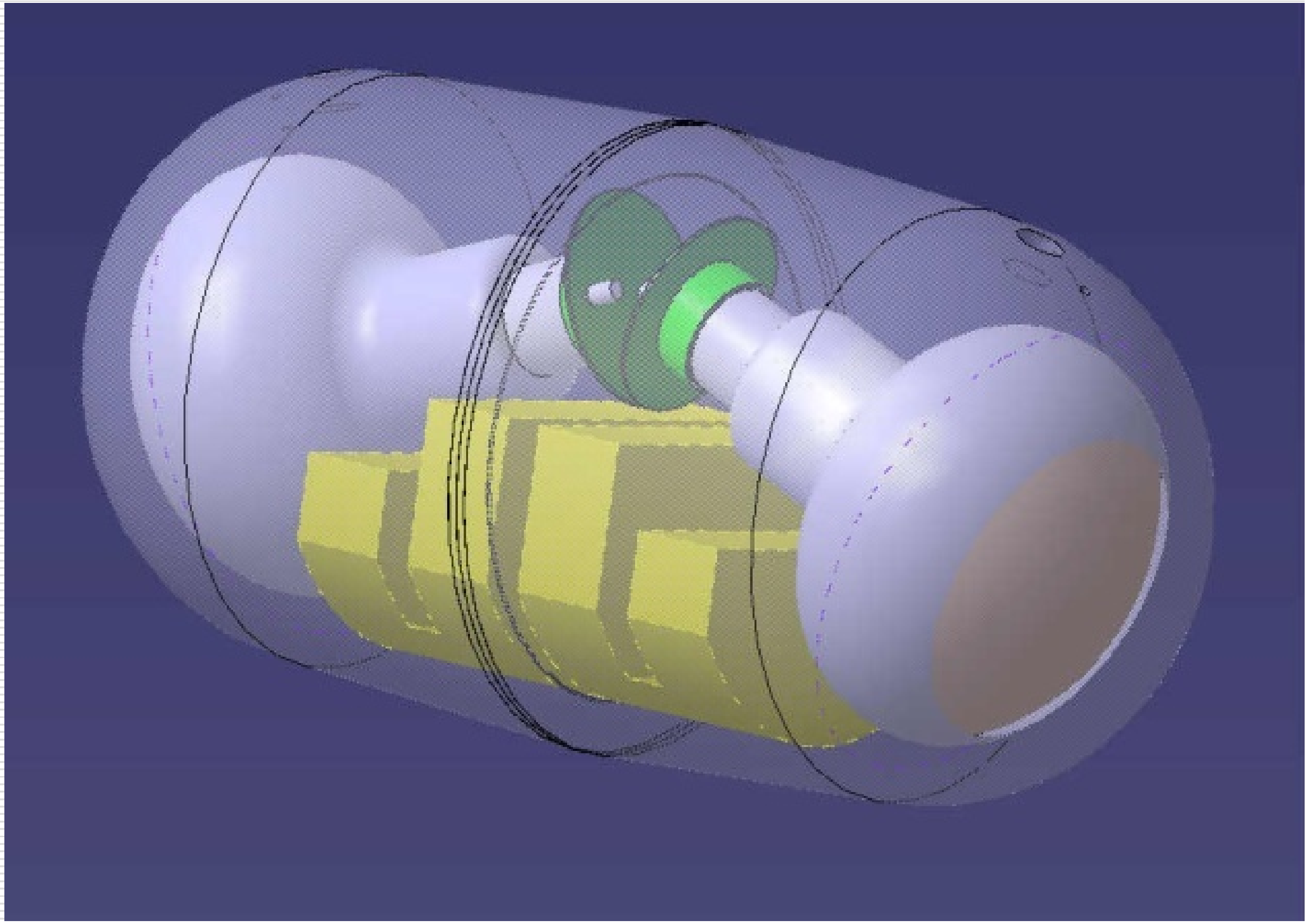
Evolution from pilot projects:

- 8-inch PMT, increased quantum efficiency (instead of 10 inch)
- 13-inch glass sphere (instead of 17 inch)
- no valve (requires "vacuum" assembly)
- no mu-metal shielding



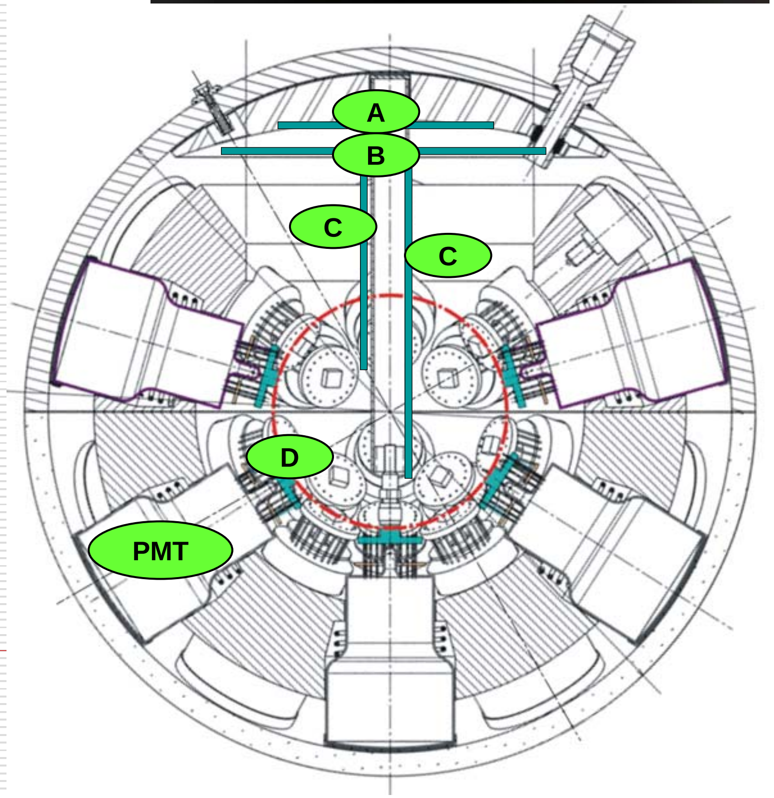
OM with two PMTs: The Capsule

- Glass container made of two halves (cylinders with spherical ends)
- Mechanical stability under study
- Allows for integrating electronics

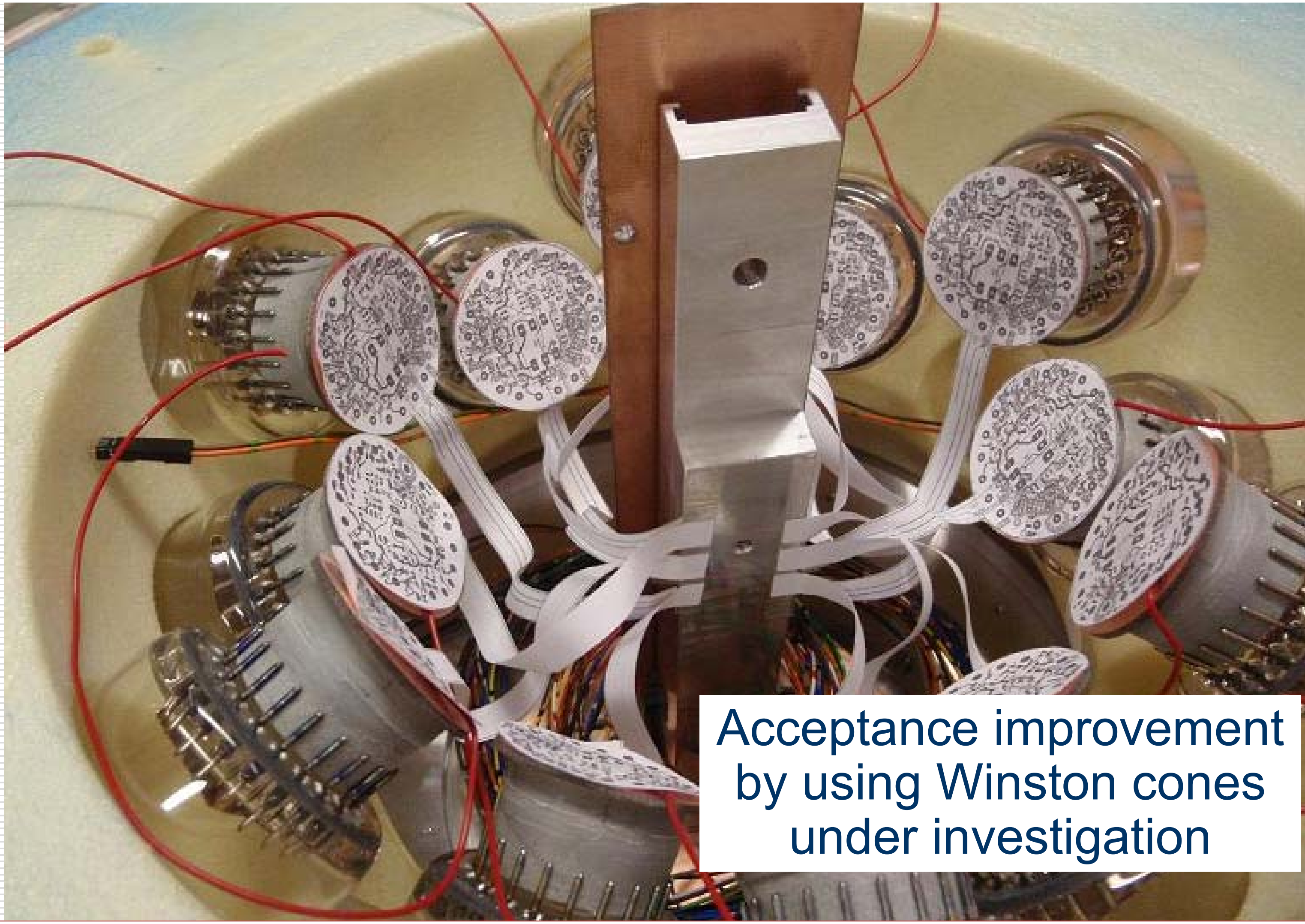


OM with many small PMTs

- 31 3-inch PMTs in 17-inch glass sphere (cathode area~ 3x10" PMTs)
  - 19 in lower, 12 in upper hemisphere
  - Suspended by compressible foam core
- 31 PMT bases (total ~140 mW) (**D**)
- Front-end electronics (**B,C**)
- Al cooling shield and stem (**A**)
- Single penetrator
- 2mm optical gel (ANTARES-type)



A Multi-PMT OM Prototype



Acceptance improvement by using Winston cones under investigation

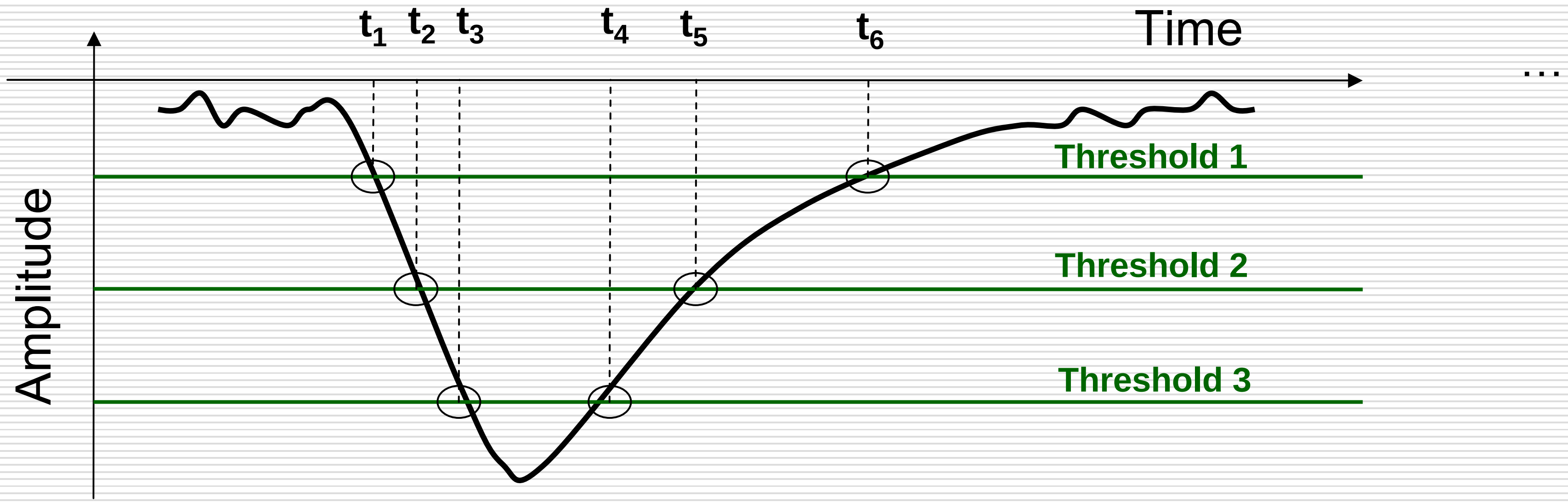
Optical Module: Decision Rationale

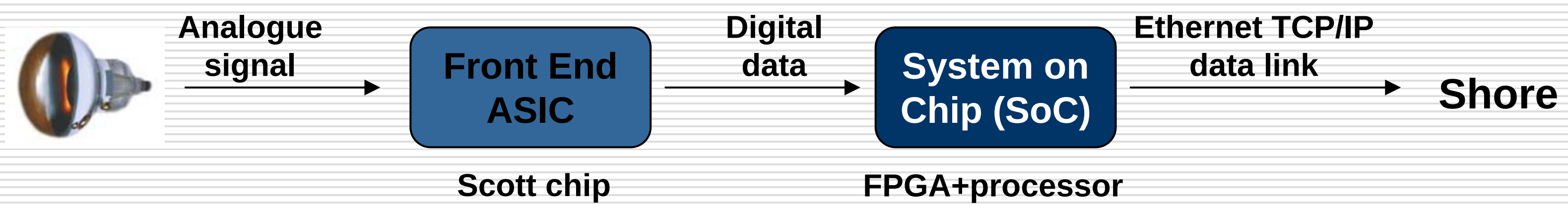
- Performance
- Cost
- Risk and redundancy
- Mechanical structure

- … and last not least: Availability of PMTs!

Front-end Electronics: Time-over-threshold

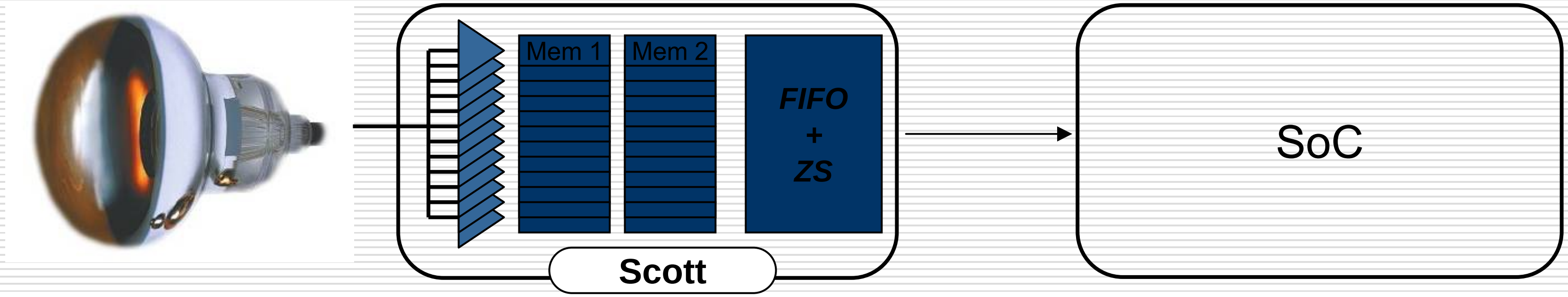
From the analogue signal to time stamped digital data:



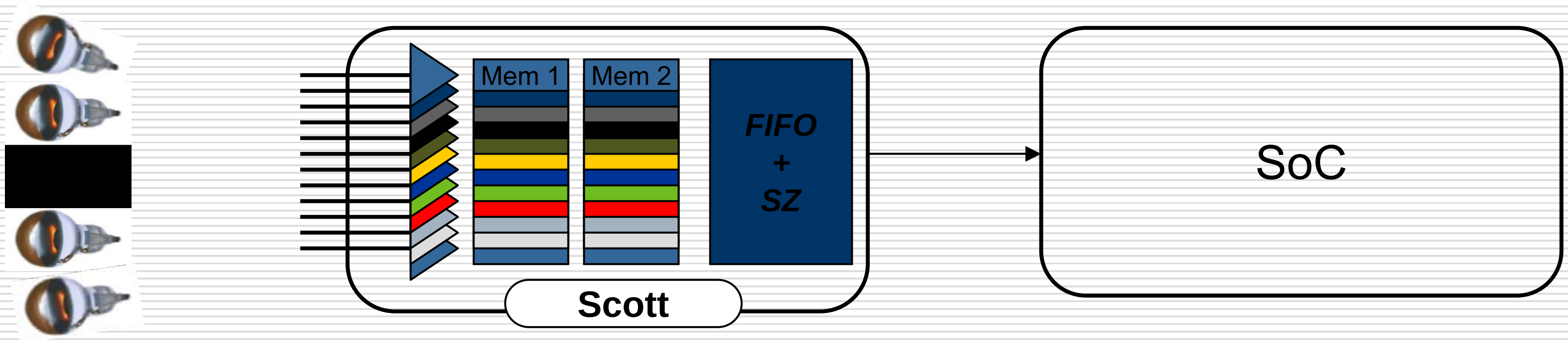


Same Readout for Single- and Multi-PMT OMs

- N thresholds for 1 PMT



- N/k thresholds for k PMTs



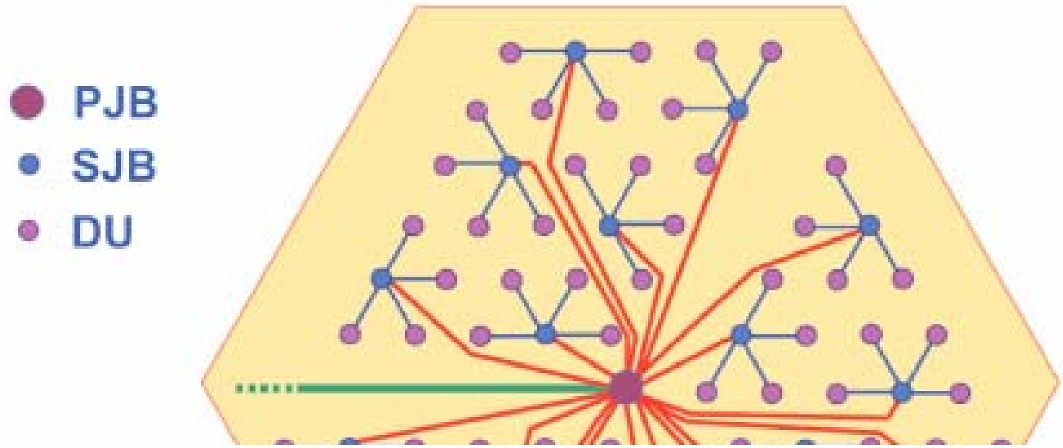
Data Network

- All data to shore:
  Full information on each hit satisfying local condition (threshold) sent to shore
- Overall data rate ~ 100-300 Gbit/s
- Data transport:
  Optical point-to-point connection shore-OM
  Optical network using DWDM and multiplexing
  Served by lasers on shore
  Allows also for time calibration of transmission delays
- Deep-sea components:
  Fibres, modulators, mux/demux, optical amplifiers
  (all standard and passive)

The Sea-Floor Infrastructure

- Requirements:
  - Distribute power
  - Support data network
  - Slow control communication
- Implementation:
  - Hierarchical topology
  - Primary & secondary junction boxes
  - Commercial cables and connectors
  - Installation requires ROVs

Example configuration:



- Layout and topology:
  - Depends on DU design, deployment procedure and "detector footprint"
  - Important for risk minimisation and maintainability
  - Ring topologies also considered

DUs: Bars, Strings, Triangles

- Flexible towers with horizontal bars
  - Simulation indicates that “local 3D arrangement” of OMs increases sensitivity significantly
  - Single- or multi-PMT OMs
- Slender strings with multi-PMT OMs
  - Reduced cost per DU, similar sensitivity per Euro
- Strings with triangular arrangements of PMTs
  - Evolution of ANTARES concept
  - Single- or multi-PMT OMs
  - “Conservative” fall-back solution

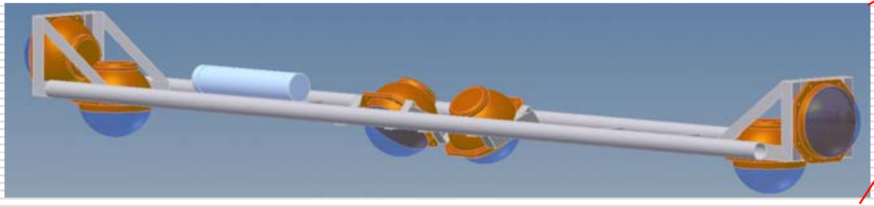
Reminder:

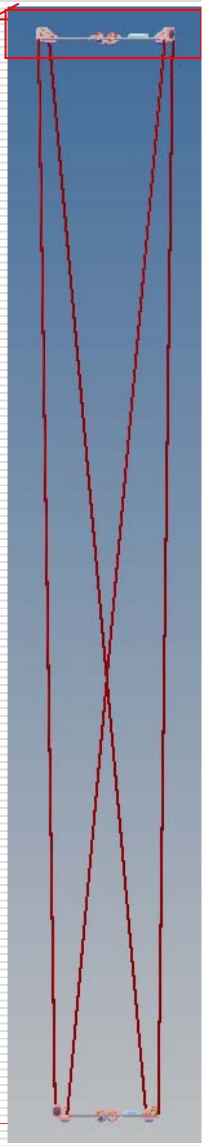
Progress in verifying deep-sea technology can be slow and painful

Careful prototype tests are required before taking final decisions

This is a task beyond the Design Study!

The Flexible Tower with Horizontal Bars



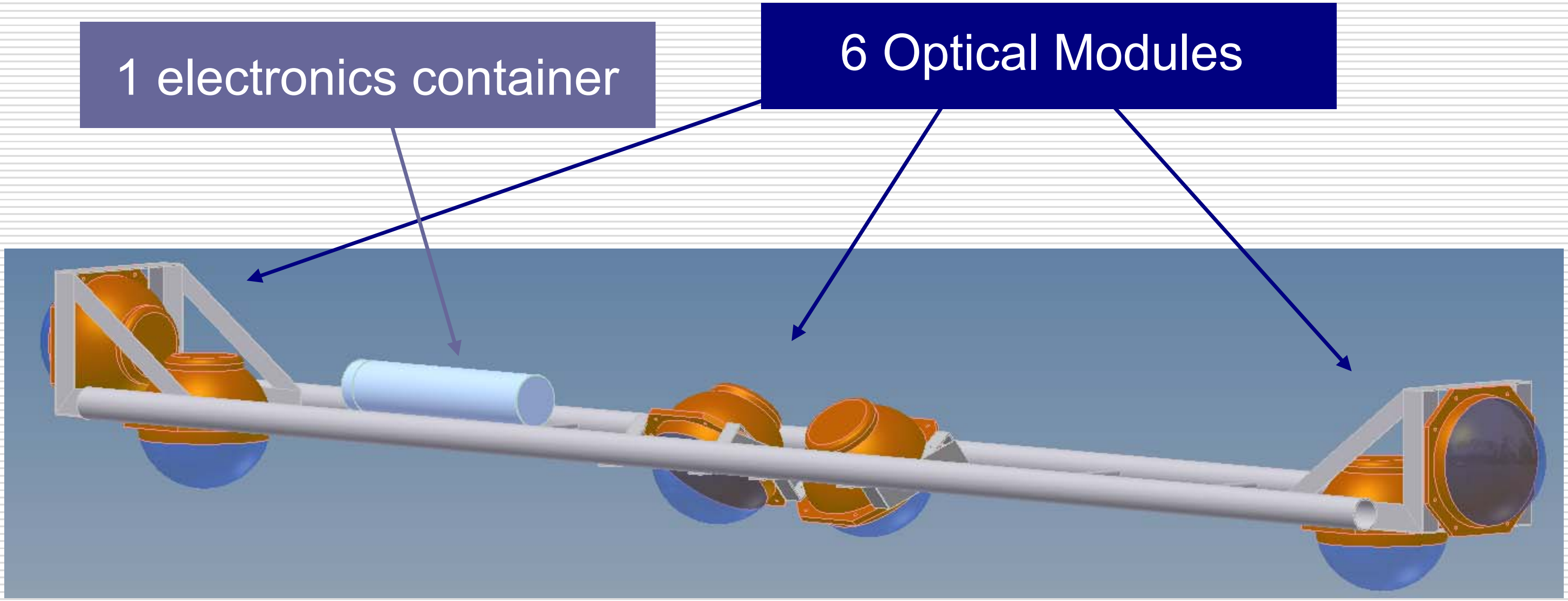


<u>Semi-rigid system of horizontal elements (storeys) interlinked by tensioning ropes:</u>

- 20 storeys
- Each storey supports 6 OMs in groups of 2
- Storeys interlinked by tensioning ropes, subsequent storeys orthogonal to each other
- Power and data cables separated from ropes; single backbone cable with breakouts to storeys
- Storey length = 6m
- Distance between storeys = 40 m
- Distance between DU base and first storey = 100m

The Bar Storey

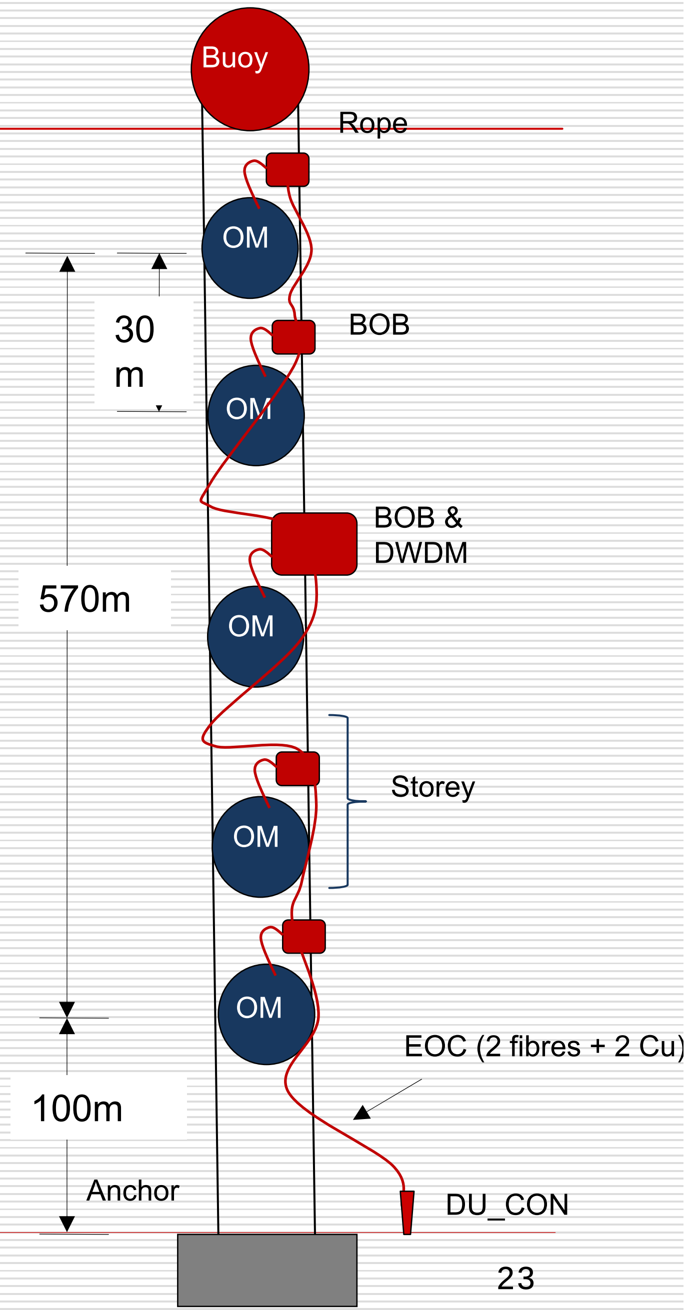
- Light structure in marine Aluminium
- Total mass 115 kg, weight in water 300N
- Overall length x width = 6 m x 46 cm



The Slender String

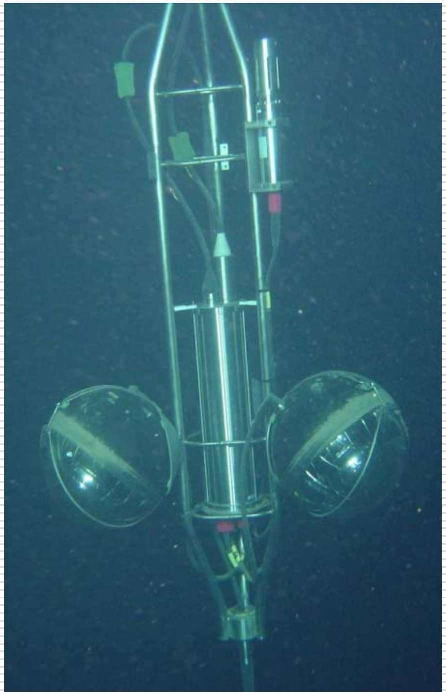
- Mooring line:
  - Buoy (empty glass spheres, net buoyancy 2250N)
  - Anchor: concrete slab of $1m^3$
  - 2 Dyneema ropes (4 mm diameter)
  - 20 storeys (one OM each), 30 m distance, 100m anchor-first storey
- Electro-optical backbone:
  - Flexible hose ~ 6mm diameter
  - Oil-filled
  - At each storey: 1 fibre+2 wires
  - Star network between master module and optical modules

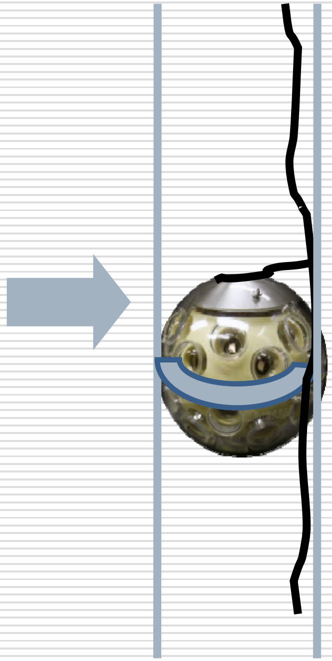
New concept, needs to be tested. Also for flexible tower if successful



One Storey = one Multi-PMT OM

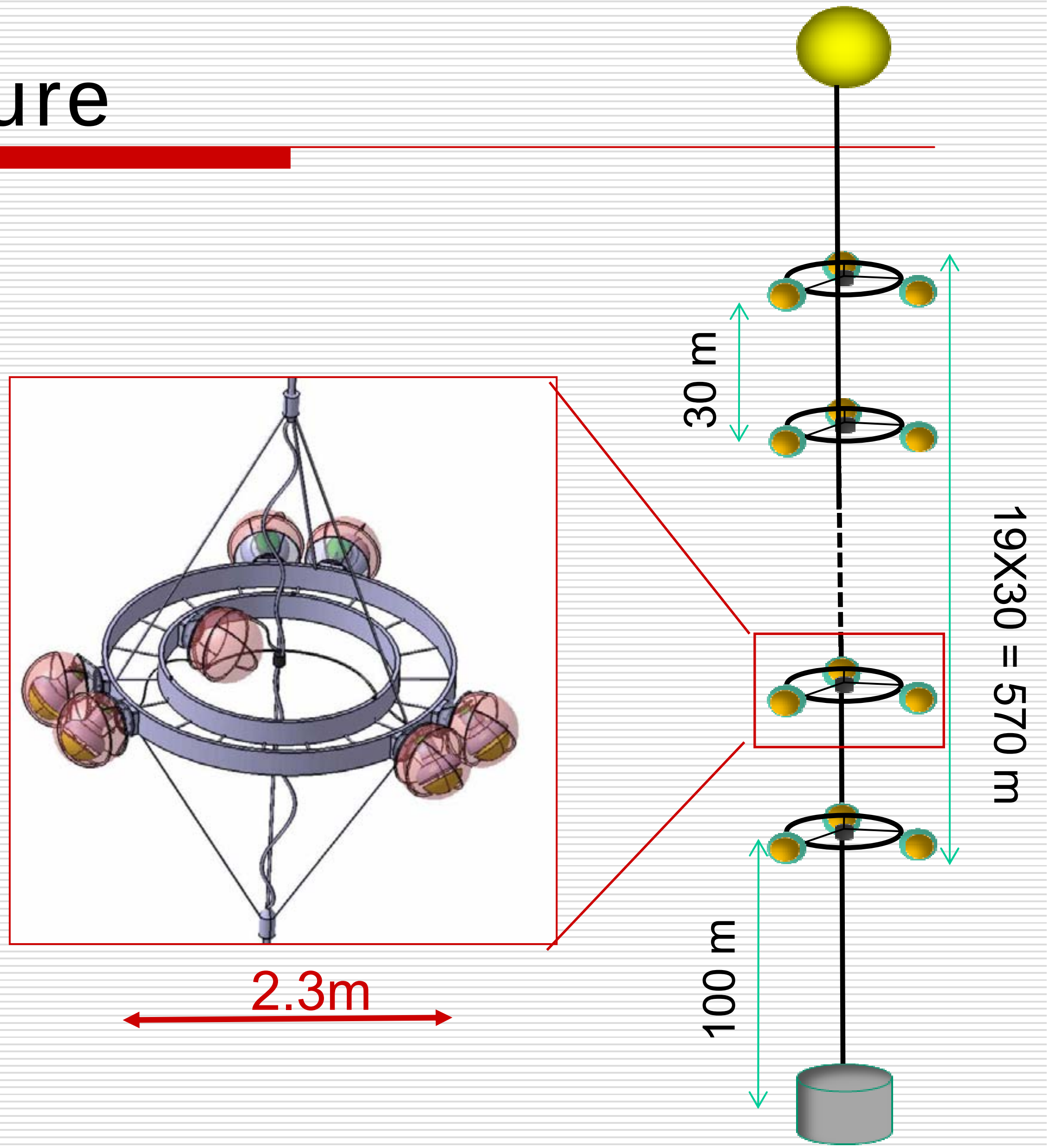
- Physics performance;
  - Photocathode area per storey similar to ANTARES
  - Excellent two-photon separation (random background rejection)
  - Looking upwards (atmospheric muon background rejection)
- Cost / reliability;
  - Simple mechanical structure
  - No separate electronics container
  - No separate instrumentation container





Triangle Structure

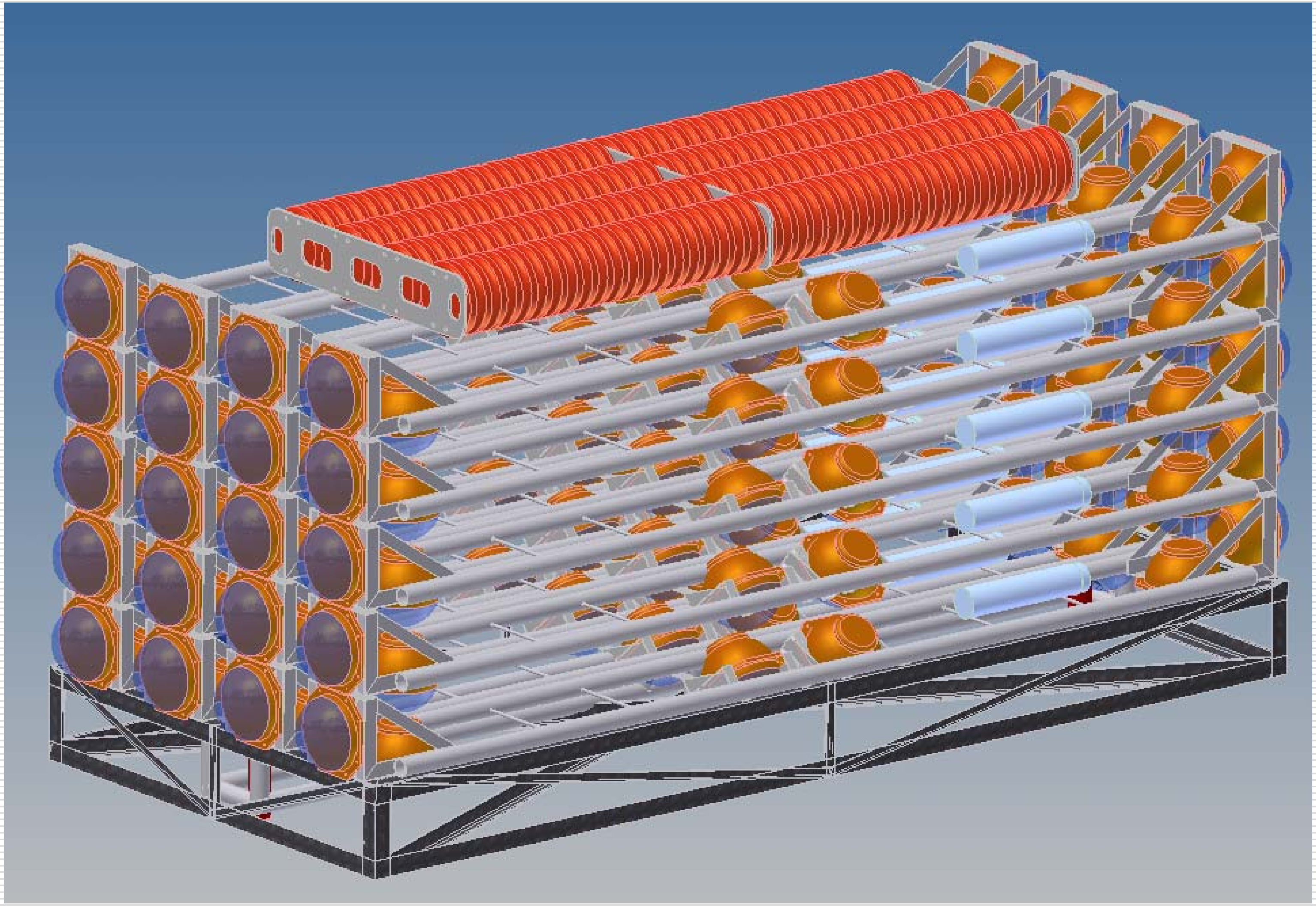
- Evolution from ANTARES concept
- 20 storeys/DU, spacing 30-40m
- Backbone: electro-optical-mechanical cable
- Reduced number of electro-optical penetrations
- Use ANTARES return of experience



Deployment Strategy

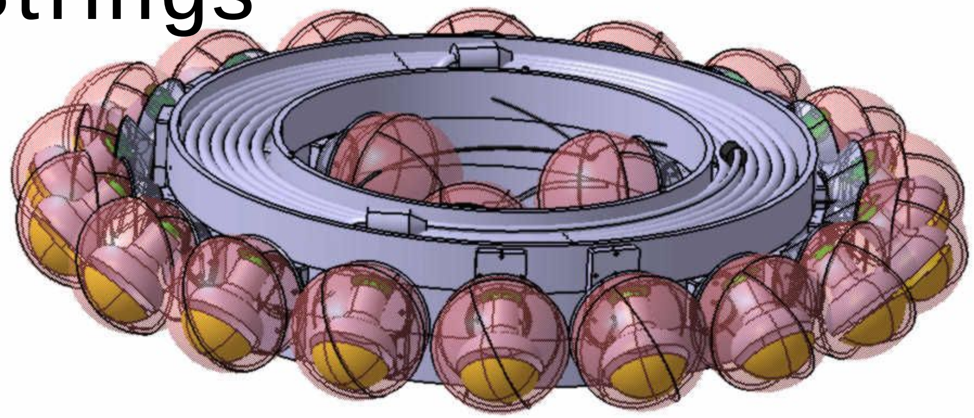
- All three mechanical solutions:
  Compact package – deployment – self-unfurling
  - Eases logistics (in particular in case of several assembly lines)
  - Speeds up and eases deployment;
    several DUs can be deployed in one operation
  - Self-unfurling concept for all three mechanical structures;
    needs to be thoroughly tested and verified
- Connection to seabed network by ROV
- Backup solution:
  "Traditional" deployment from sea surface

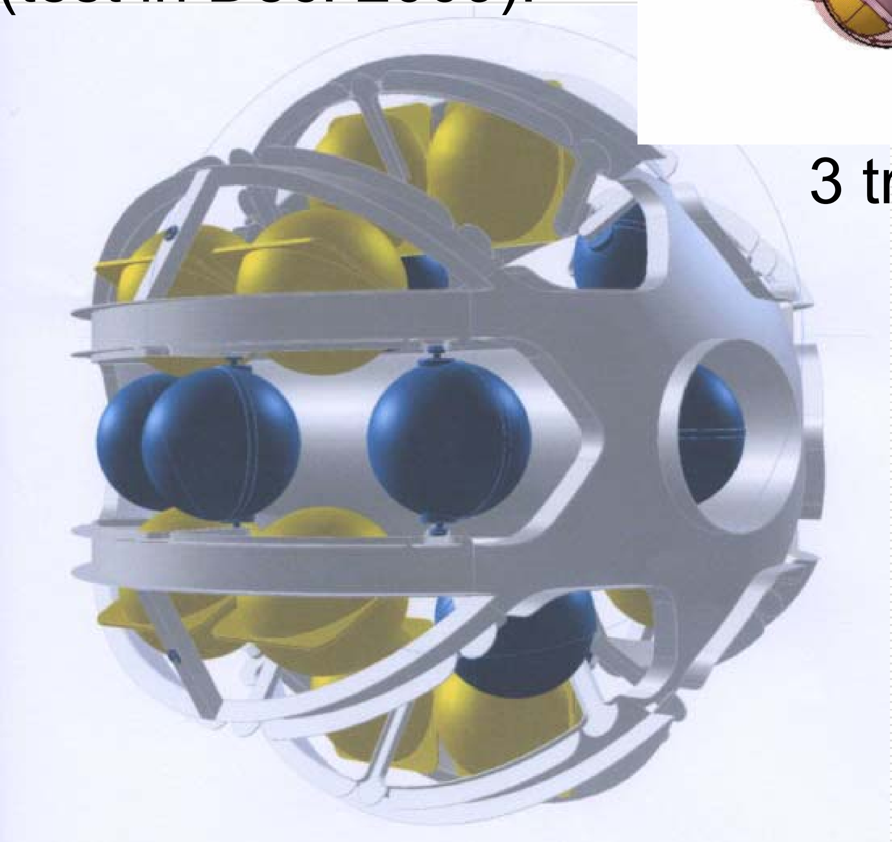
A Flexible Tower Packed for Deployment



Compactifying Strings

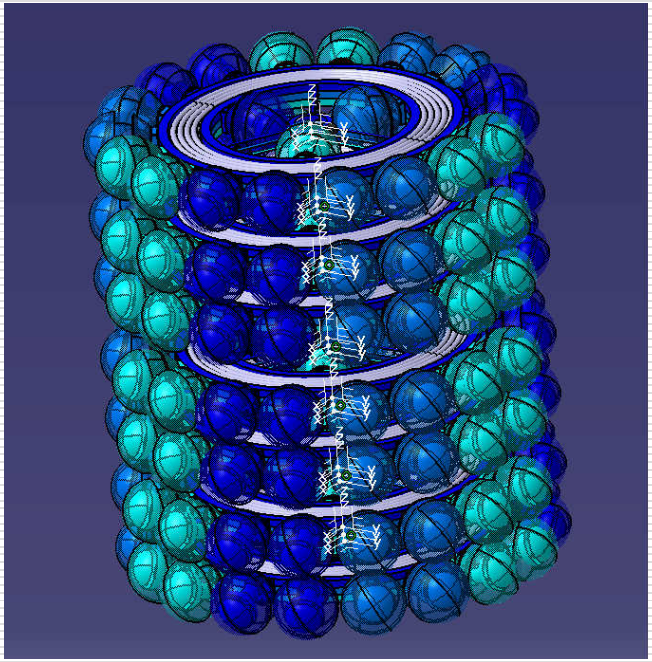
Slender string rolled up for self-unfurling (test in Dec. 2009):





3 triangles

DU

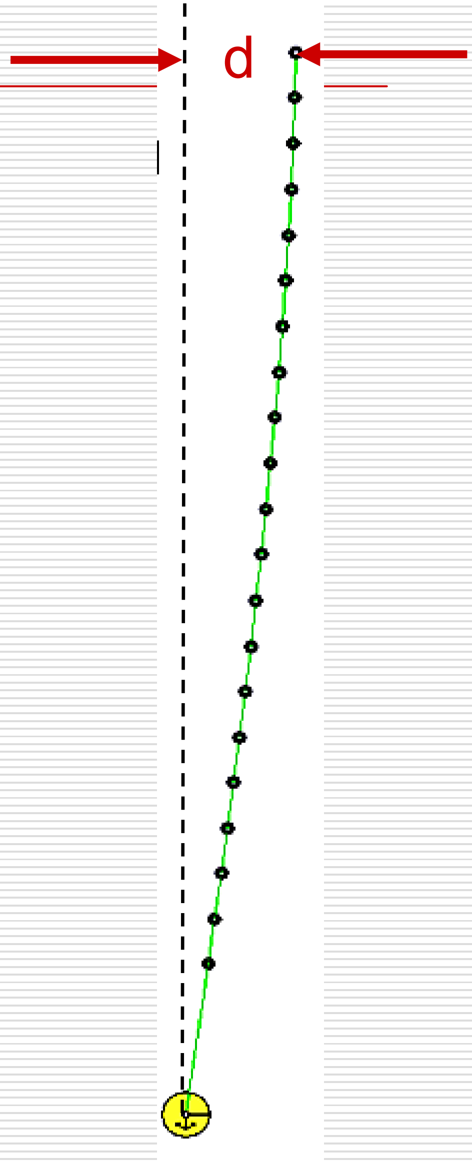


Hydrodynamic Stability

- DUs move under drag of sea current
  - Currents of up to 30cm/s observed
  - Mostly homogeneous over detector volume
  - Deviation from vertical at top:

Current [cm/s]	flexible tower d [m]	slender string d [m]
10	9.4	7.5
30	84.0	70.0

- Torsional stability also checked



Calibration: Position ...

- Relative positioning (OMs with respect to each other)
  Required precision: ~40cm
  - Acoustic triangulation:
    Transponders at DU anchors, receivers on each storey
    Hydrophones or Piezo sensors glued to inside of glass spheres
    ANTARES system provides precision of few cm
  - Compasses and tiltmeters
  - Line shape fits (parameters: sea current velocity/direction)
- Absolute pointing
  (required precision: better than angular resolution)
  - Position and depth of DU sockets
  - Floating surface array in coincidence with detector (temporary!)

… and Time

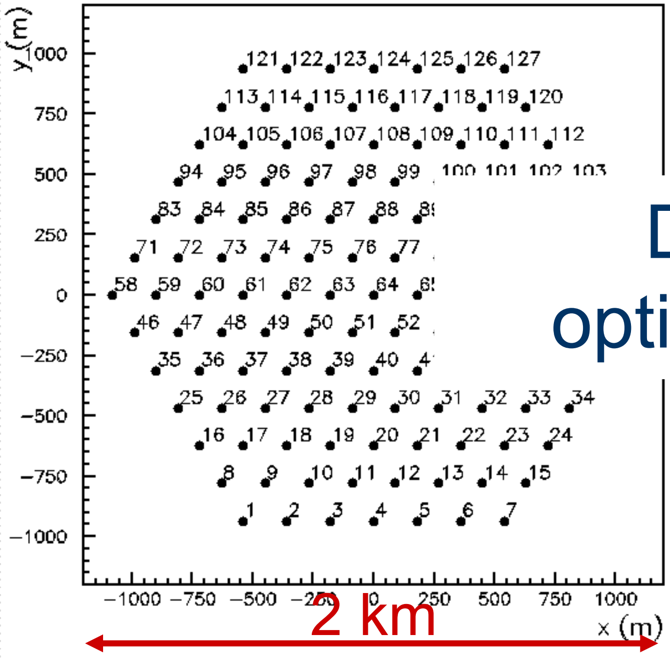
- Travel times shore-OM-shore of calibration signals for measuring time delays
- Illumination of OMs with dedicated calibration flashers to monitor PMT transit times and front-end electronics delays
  - "Nanobeacons": LEDs with rise time ~2ns, to be operated in OMs to illuminate adjacent OMs
  - Other options (e.g. lasers) under study
- Absolute timing: Through GPS, precision ~1μs

A Work Platform: Delta Berenike

Detector Configurations

- Different DU designs
  - require different DU distance
  - differ in photocathode area/DU
  - are different in cost

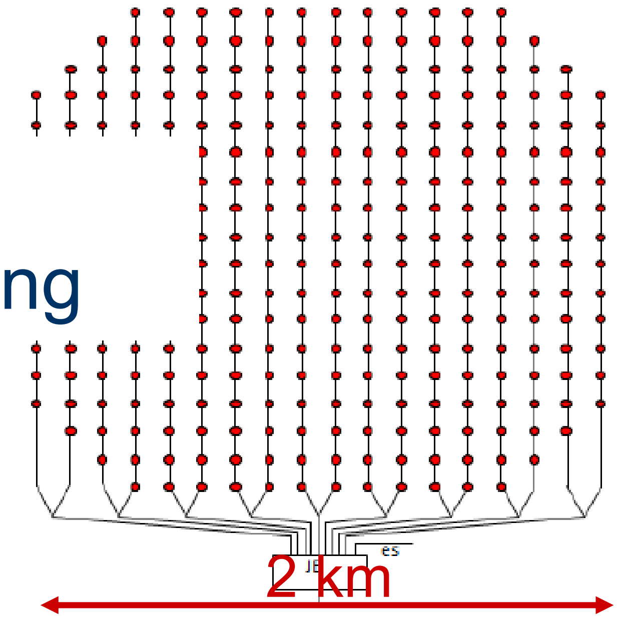
} different „detector footprints“



Bars, triangle:
127 DUs,
distance 180/150 m

Detector footprint optimisation is ongoing

Slender string:
310 DUs,
distance 130 m



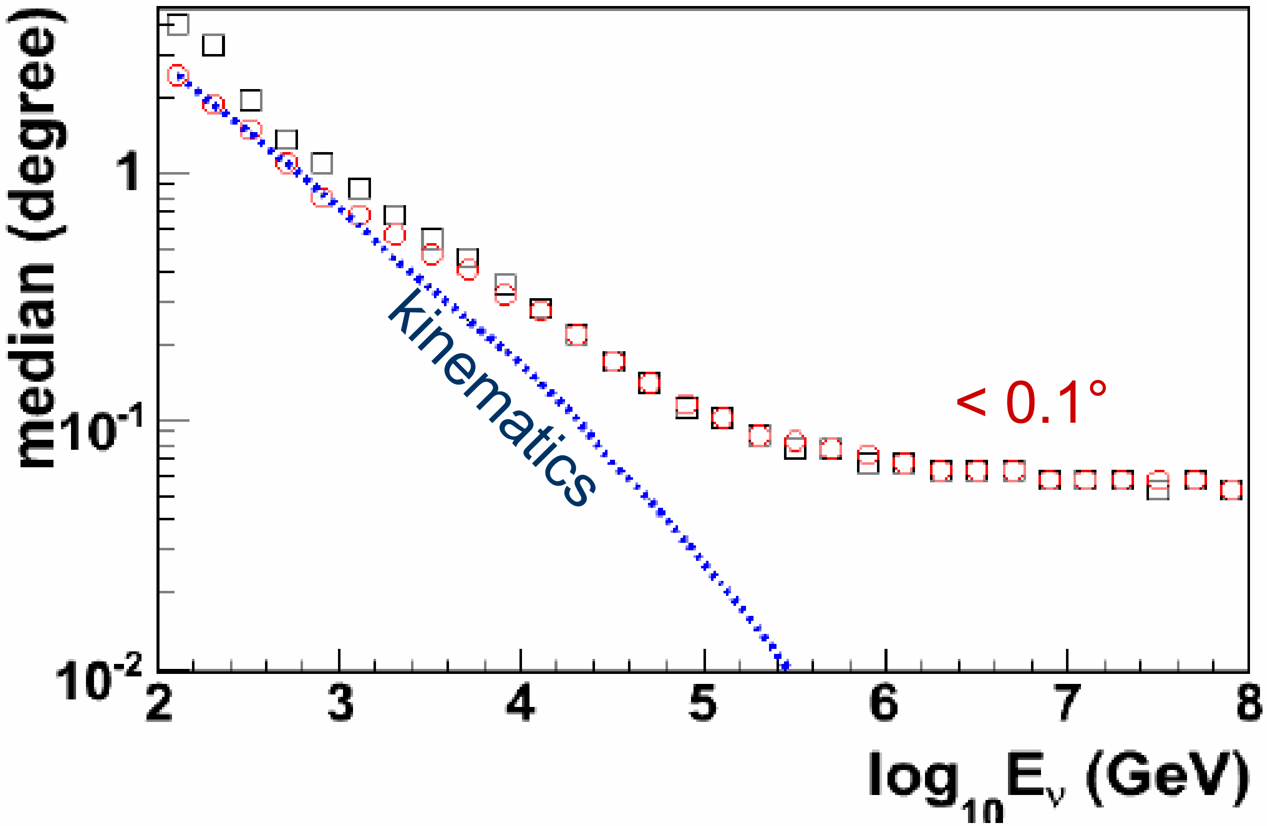
Sensitivity Studies and Optimisation

- Detailed simulation based on
  - simulation code used for ANTARES and (partly) for IceCube
  - reconstruction algorithms (based on ANTARES, some new approaches)
  - fruitful cooperation with IceCube on software tools (software framework, auxiliaries, …: THANK YOU!)
  - benchmark parameters:
    effective area, angular resolution and
    sensitivity to E^{-2} ν flux from point sources
- Detector optimisation
  - horizontal/vertical distances between DUs/OMs
  - storey size
  - orientation of OMs, …

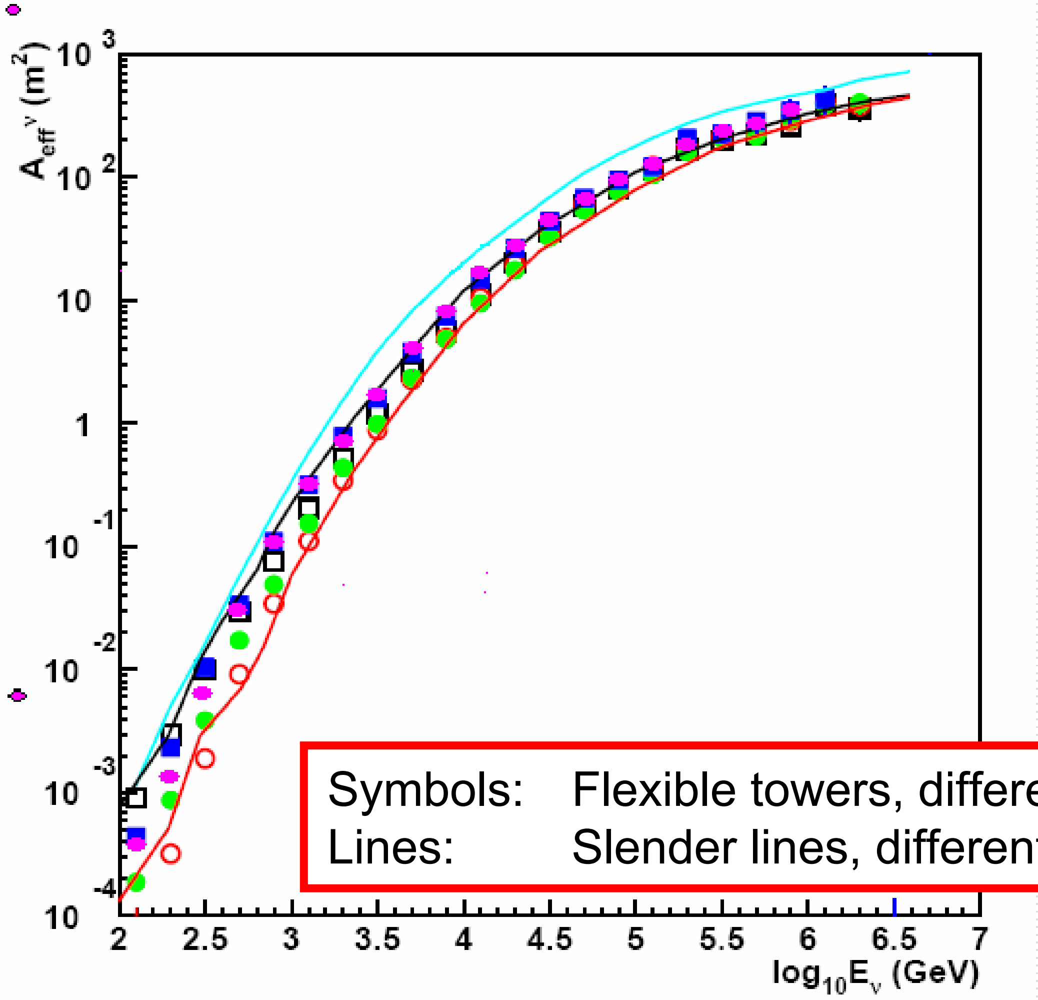
Many activities ongoing,
tuning to final configuration necessary

Angular Resolution

- Investigate distribution of angle between incoming neutrino and reconstructed muon
- Dominated by kinematics up to ~1TeV



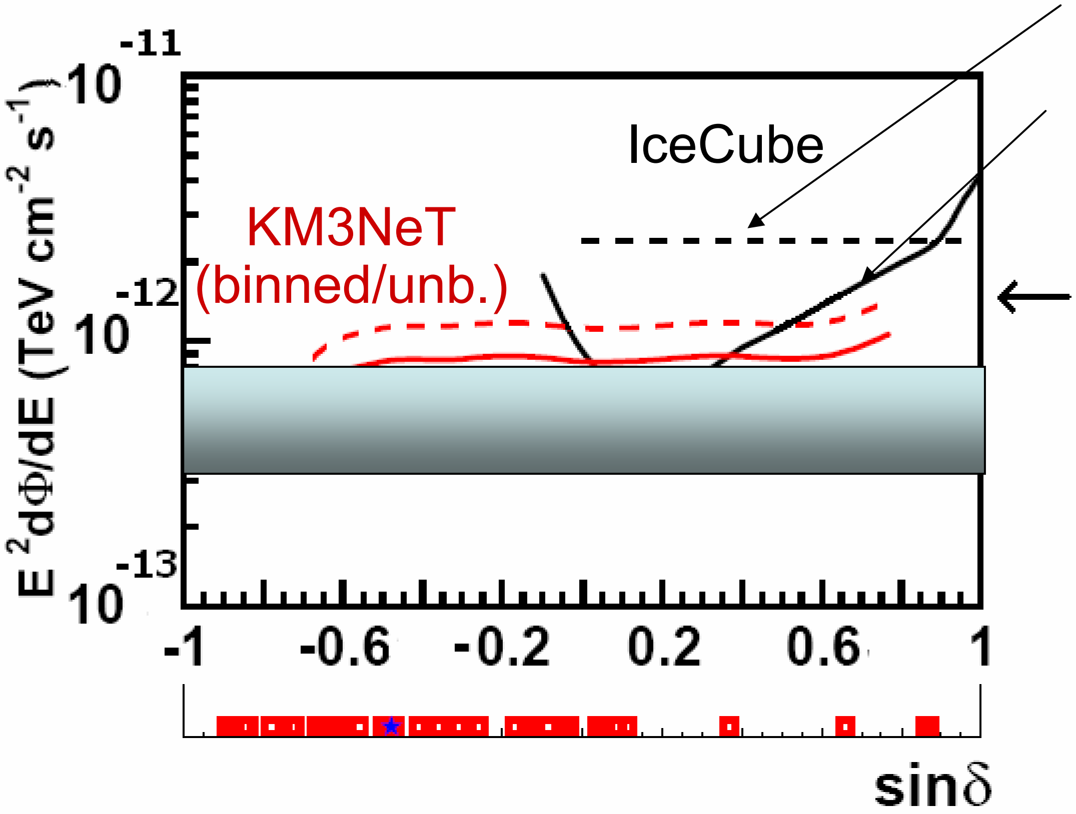
Effective Areas



Symbols: Flexible towers, different quality cuts
Lines: Slender lines, different quality cuts

- Significant dependence on choice of quality cuts
- Flexible towers with bars and slender strings “in same ballpark”
- Driven by overall photocathode area
- Sensitivities from here on: flexible towers, conservative cuts

Point Source Sensitivity (3 Years)



Aharens et al. Astr. Phys. (2004) – binned method

R. Abbasi et al. Astro-ph (2009) scaled – unbinned method

Average value of sensitivity from R. Abbasi et al. Astro-ph (2009)

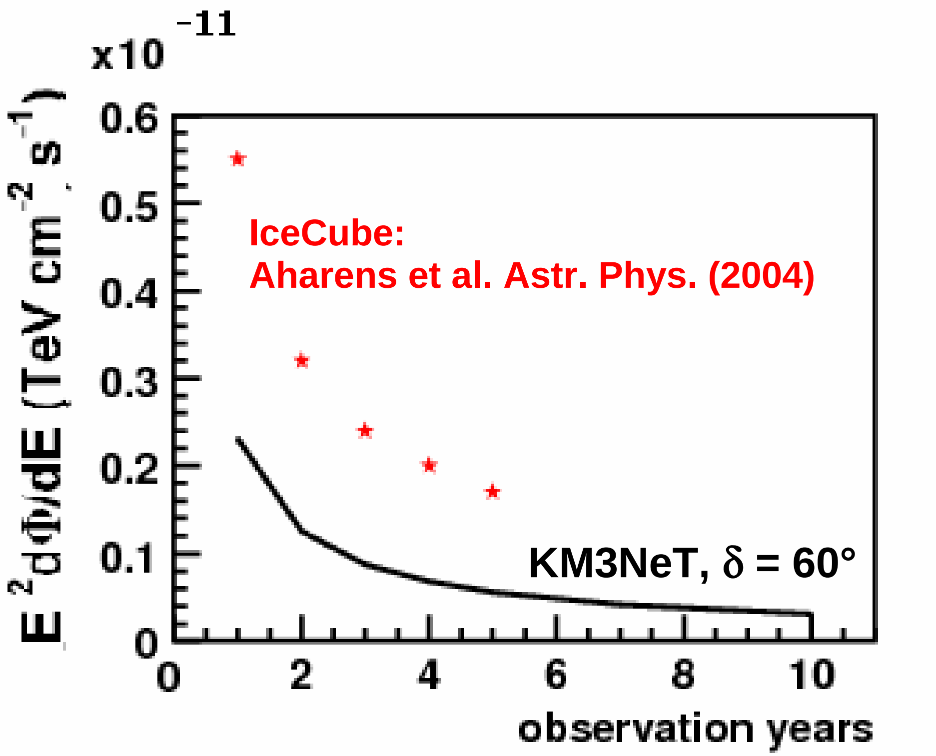
□ Observed Galactic TeV-γ sources (SNR, unidentified, microquasars)

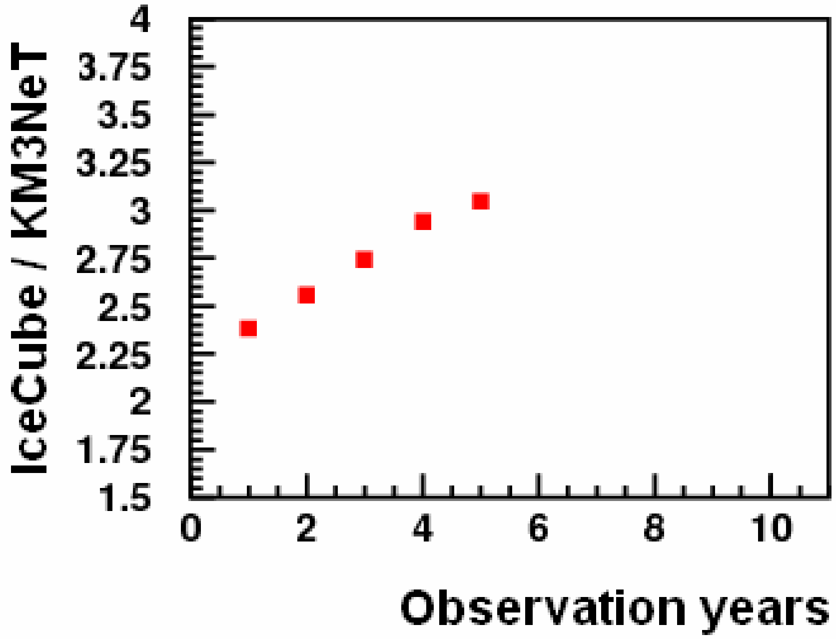
F. Aharonian et al. Rep. Prog. Phys. (2008)

Abdo et al., MILAGRO, Astrophys. J. 658 L33-L36 (2007)

Sensitivity Ratio KM3NeT/IceCube

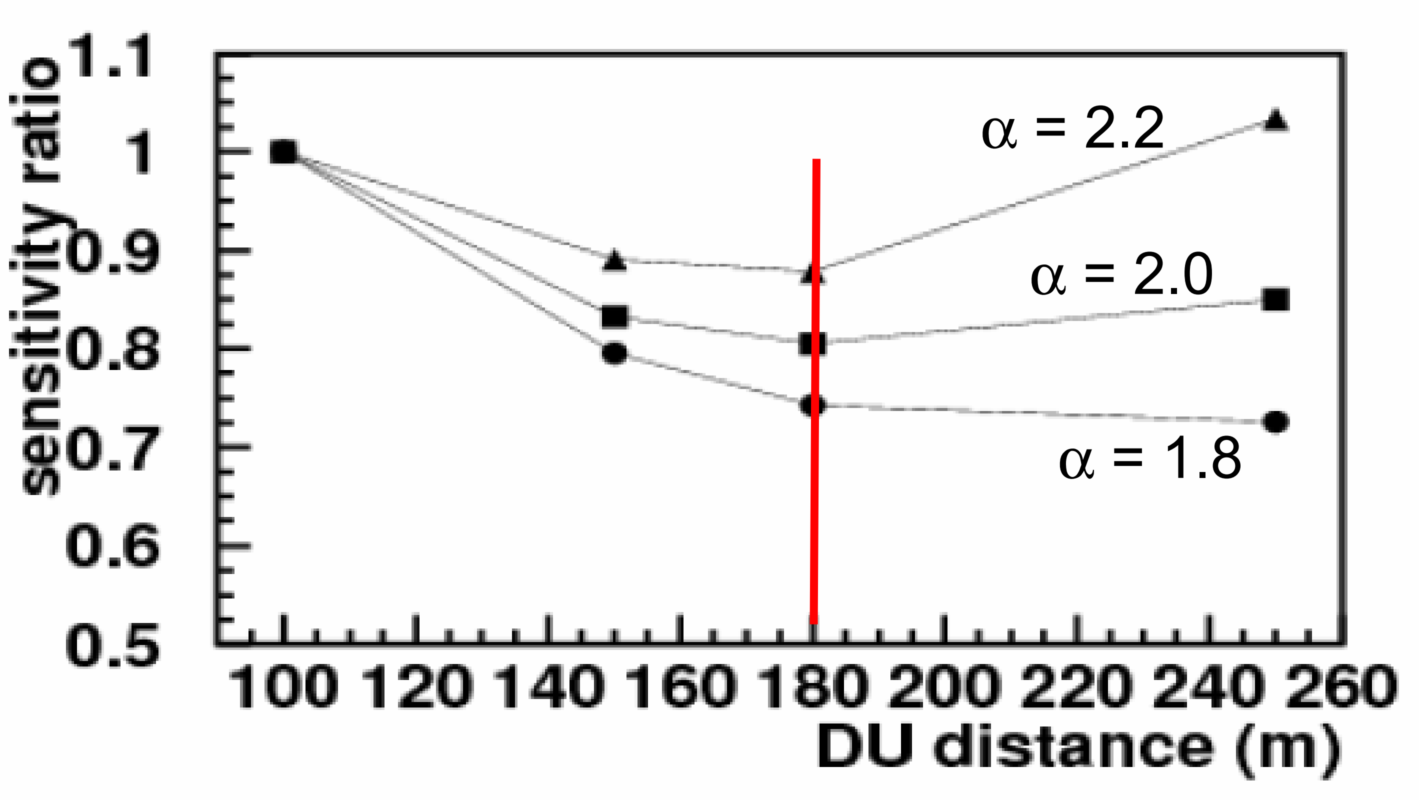
Compare sensitivity results for binned analyses as a function of observation times …





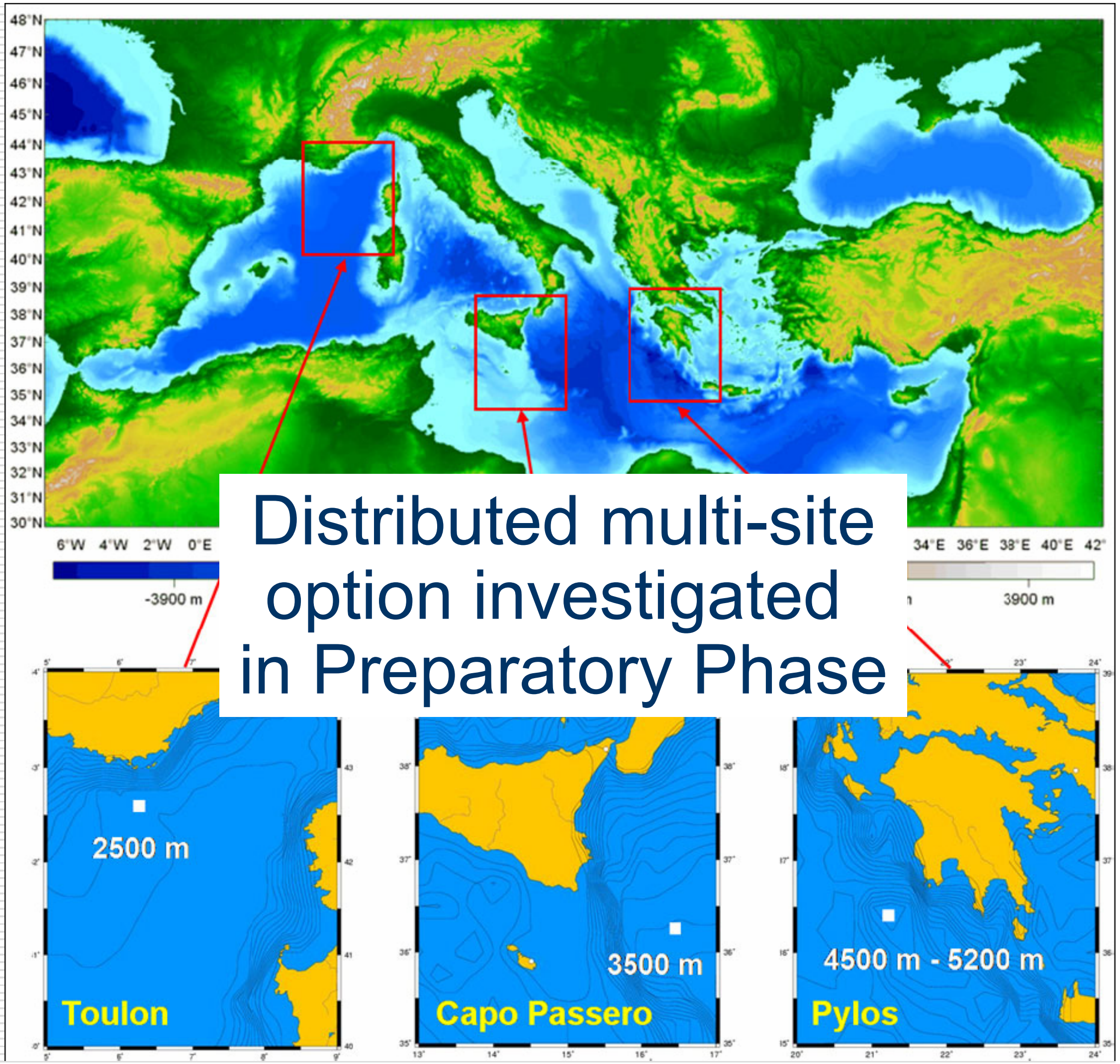
Optimisation Studies

Example: Sensitivity dependence on DU distance for flexible towers (for 3 different neutrino fluxes ~$E^{-\alpha}$, no cut-off)



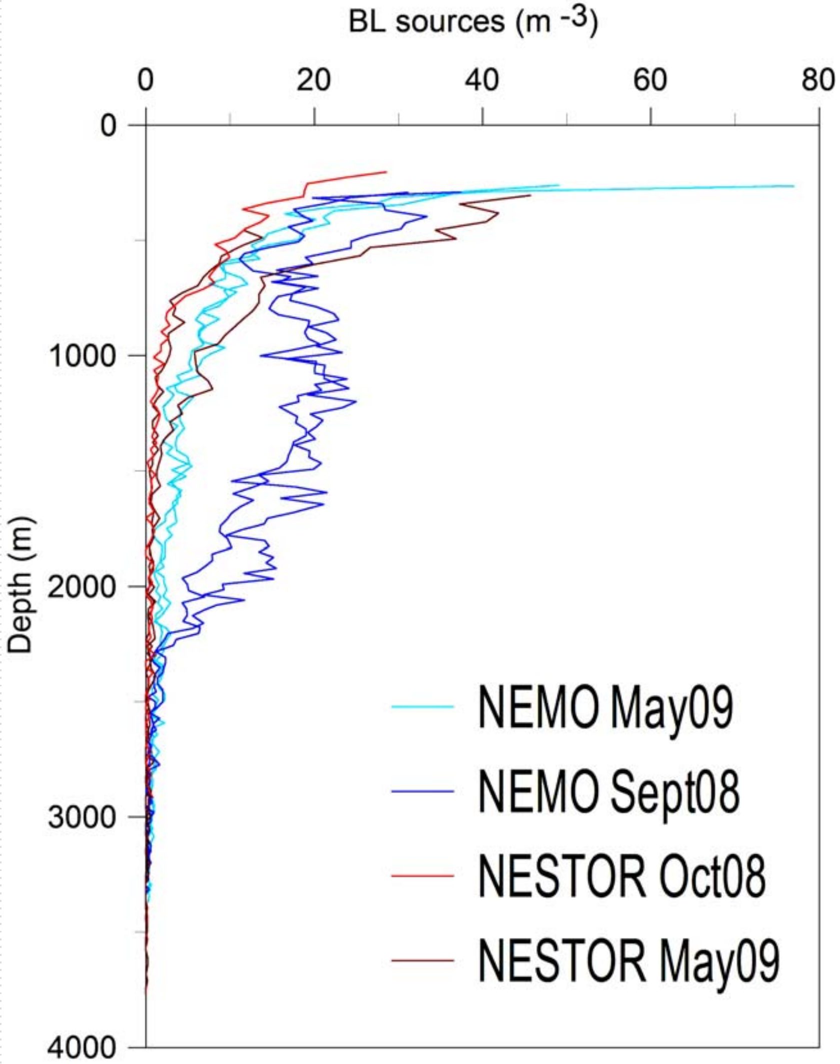
Candidate Sites

- Locations of the three pilot projects:
  - ANTARES: Toulon
  - NEMO: Capo Passero
  - NESTOR: Pylos
- Long-term site characterisation measurements performed
- Site decision requires scientific, technological and political input

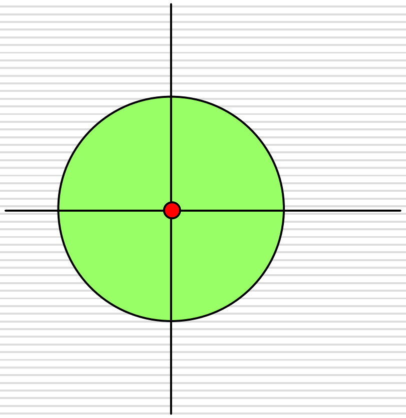


Site Characteristics

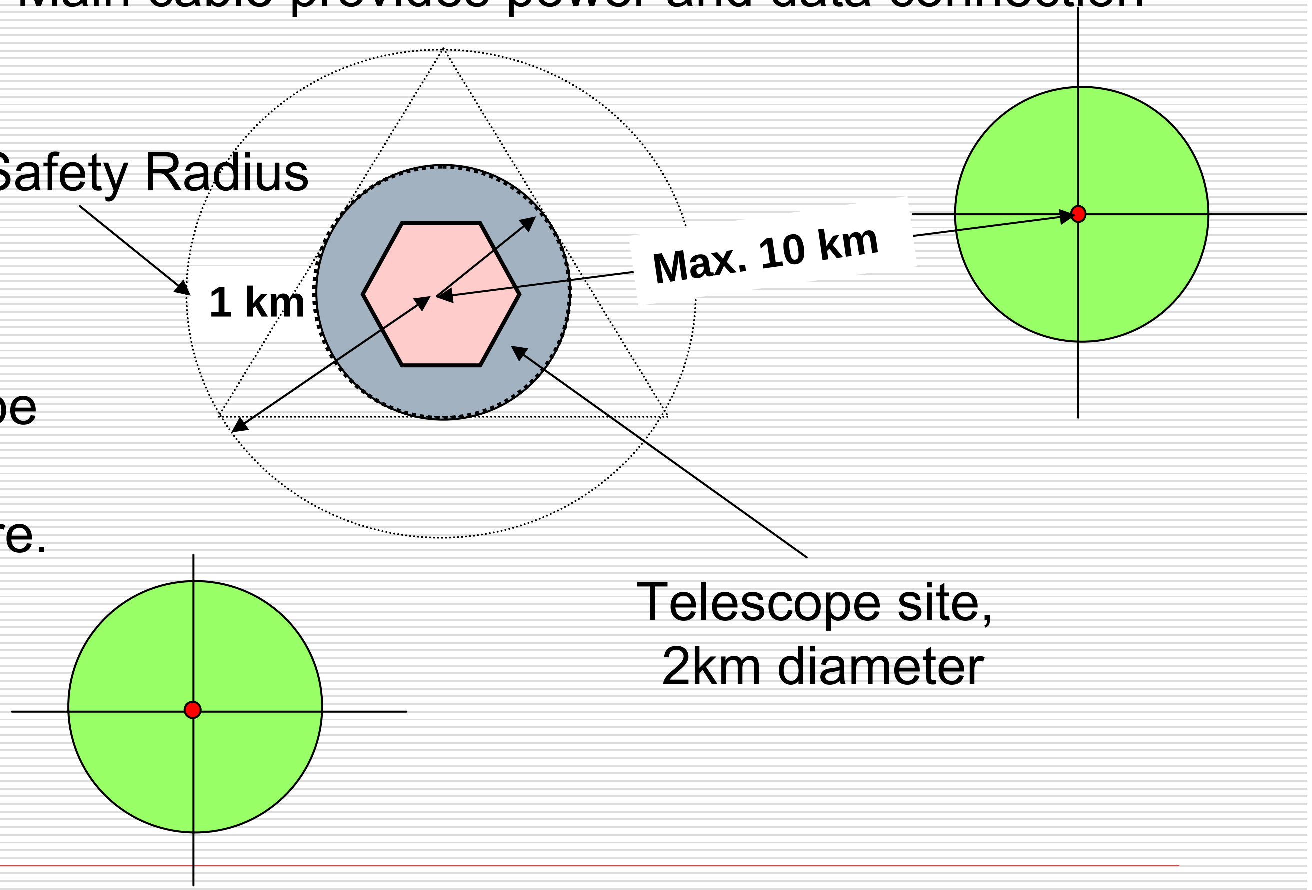
- Various relevant parameters:
  - depth (→ atm. muon background)
  - water transparency (absorption, scattering)
  - bioluminescence
  - sedimentation, biofouling
  - currents
  - …
- Plenty of new results, need to be digested
- Example: Direct measurement of bioluminescent organisms



The Marine Science Node: Layout



- Branches off primary junction box
- Implemented through specialised secondary junction boxes
- Main cable provides power and data connection



Each junction box can be located independently within 10km of the centre. Each requires a 500 m radius (minimum) “flat” area around it.

Earth & Marine Science Instrumentation

Examples:

- Lines of autonomous sensors such as seismographs
- Moorings containing suites of instruments to monitor surface water, water column, sea bed and subsea-floor in a co-ordinated manner
- Fixed structures with removable modules containing instruments such as cameras and flash lights, acoustic sensors and suites of oceanographic sensors such as the proposed ESONET standard instrumentation module
- Futuristic docking stations for gliders or autonomous underwater vehicles

Some Scientific Objectives

- Investigation of internal waves and short time-base oscillations in the water column using high-resolution temperature sensors distributed throughout the array
- Real time tracking of bio-acoustic emissions or vertical migration of organisms
- Oceanographic spatial and temporal scale measurements on a real time basis revolutionising existing oceanographic data applications
- Using PMT data to compare variations in their bioluminescence data with those obtained from conventional oceanographic instruments

Cost Estimates: Assumptions

- Estimate of investment cost
  - no personnel costs included
  - no contingency, no spares
  - no statement on operation cost
    (maintenance costs under study)
- Assumptions / procedure:
  - Quotations from suppliers are not official and subject to change
  - Junction box costs are roughly estimated
  - Common items are quoted with same price
  - Sea Sciences and Shore Station not estimated

Cost Estimates: Results

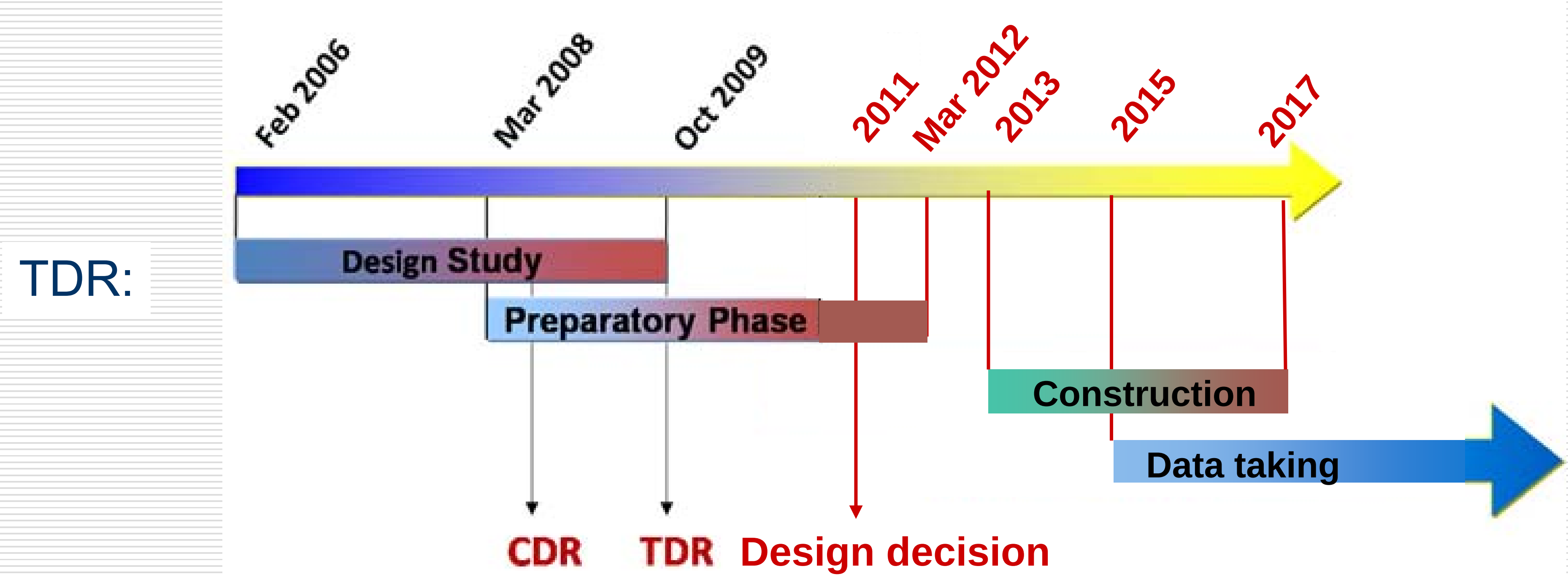
- Result of cost estimates:

Concept	DU Cost	No. of DUs	Total DU Cost	Seafloor Infrastr.	Deploy-ment	TOTAL COST
Flexible towers	535	127	67 945	8 460	10 962	87 193
Slender strings	254	300	76 200	12 971	13 515	102 686
Triangles	657	127	83 439	8 470	6 867	98 776

- Assembly man power (OMs, DU…) is roughly estimated to be 10% of the DU cost
- Note: Double sensitivity for double price …

Next Steps and Timeline

- Next steps: Prototyping and design decisions
  - organised in Preparatory Phase framework
  - final decisions require site selection
  - expected to be achieved in ~18 months
- Timeline:



Conclusions

- A design for the KM3NeT neutrino telescope allowing for construction of a “baseline version” for ~150 M€ is presented
- An extended version for ~250 M€ would substantially increase the physics potential
- Within 2 years, remaining design decisions have to be taken and the site question clarified
- Construction could start in 2013 and data taking in 2015
- A new milestone in the quest for neutrino astronomy is ahead!