Astroteilchenphysik in Deutschland: Status und Perspektiven
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The KM3NeT Project

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KM3NeT

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

KM3NeT

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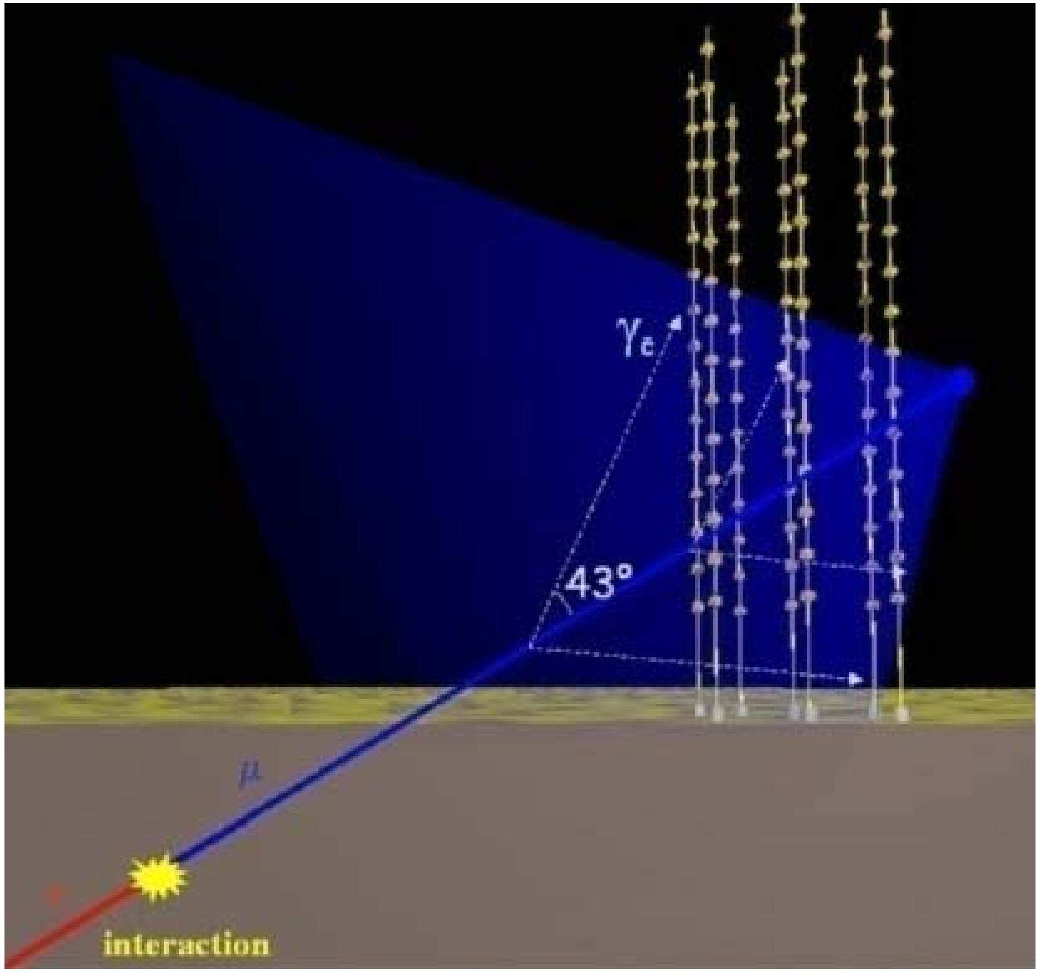
What is KM3NeT ?

- 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 ≤5 years
  - Operation over at least 10 years without “major maintenance”

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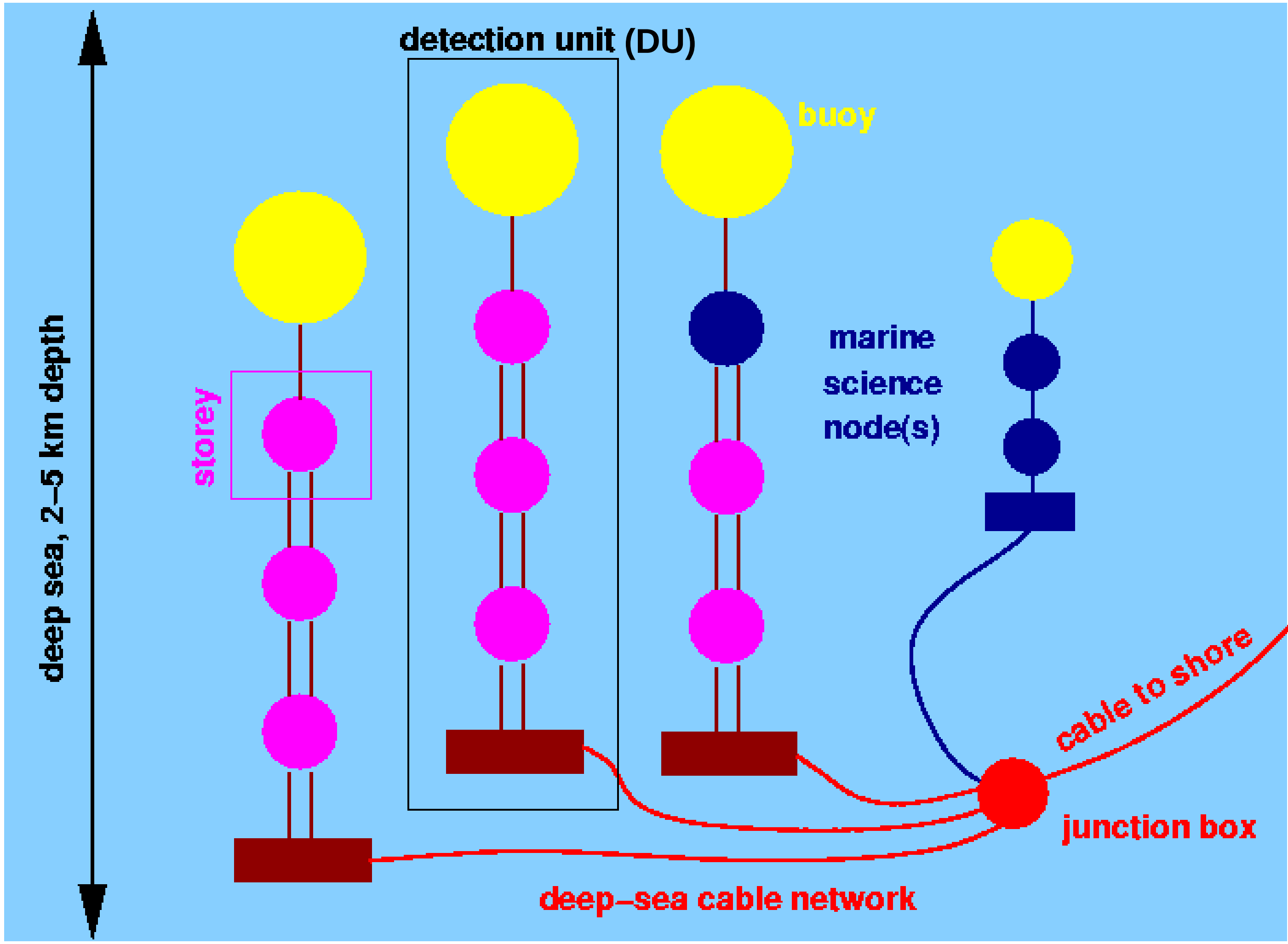
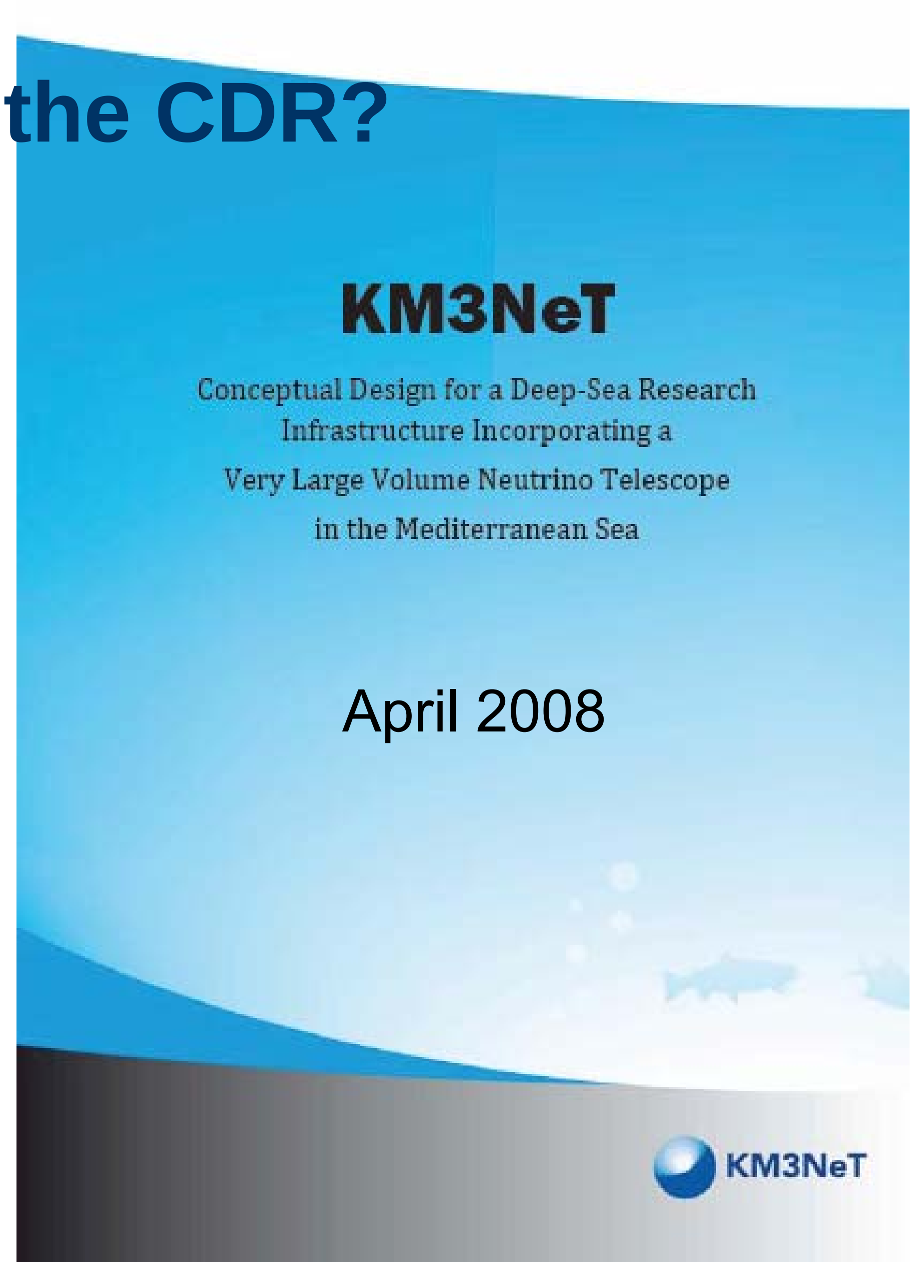
The KM3NeT Research Infrastructure (RI)



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



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Challenge 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
  - → Readout, data acquisition, data transport
  - Mechanical structures, backbone cable
  - → General deployment strategy
  - → Sea-bed network: cables, junction boxes
  - → Calibration devices
  - Shore infrastructure
  - Assembly, transport, logistics
  - Risk analysis and quality control

Design rationale:

Cost-effective
Reliable
Producible
Easy to deploy

Unique or preferred solutions

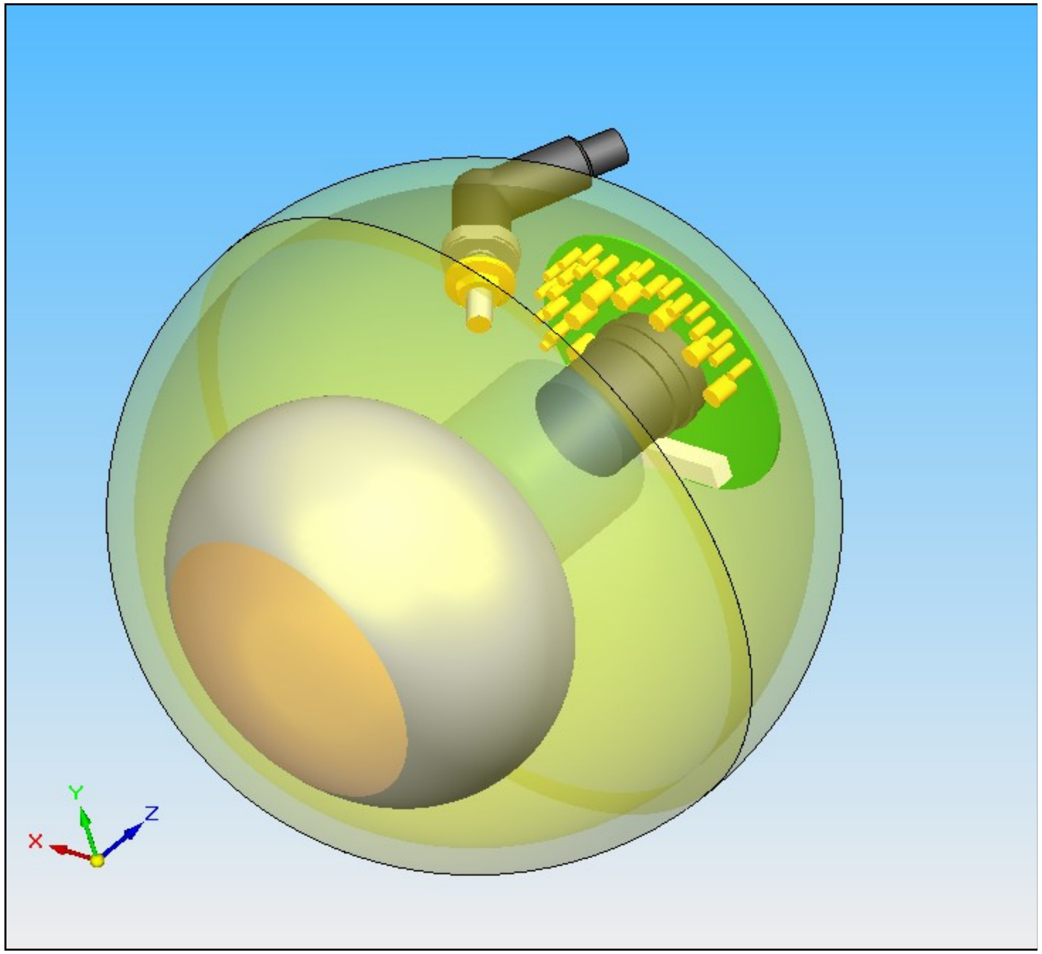
Further Challenges

- **Site characteristics**
  Objective: Measure site characteristics (optical background, currents, sedimentation, …)
- **Simulation**
  Objective: Determine detector sensitivity, optimise detector parameters;
- **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;

OM "classical": One PMT, no Electronics

<u>Evolution from pilot projects</u>:

- 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



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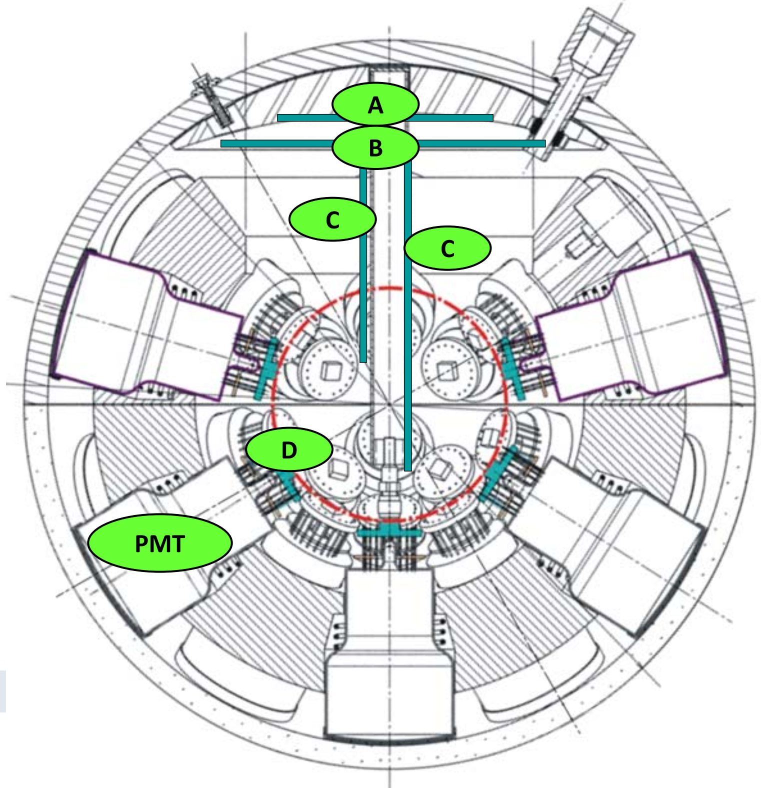
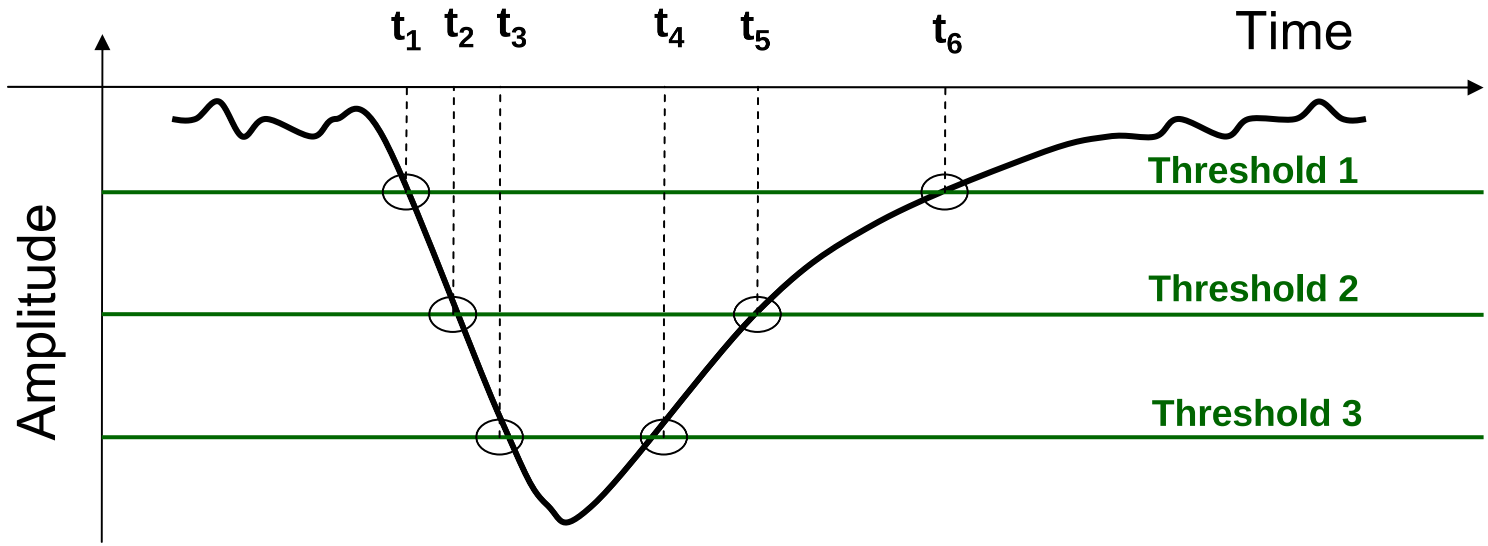
OM with many Small PMTs

- 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)



Front-End Electronics: Time-over-Threshold

From the analogue signal to time stamped digital data:



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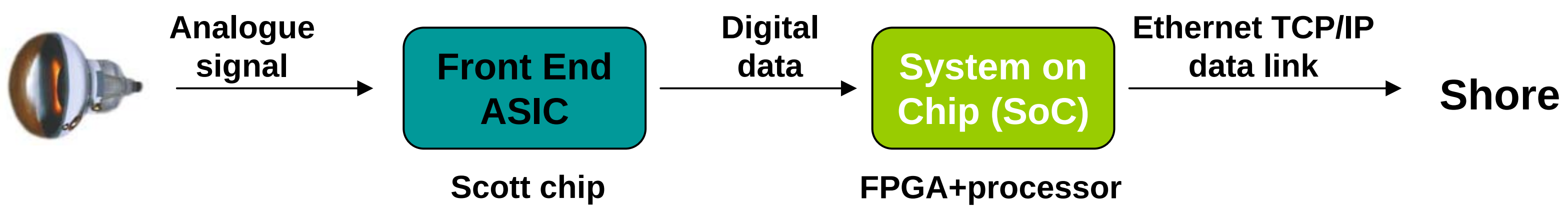
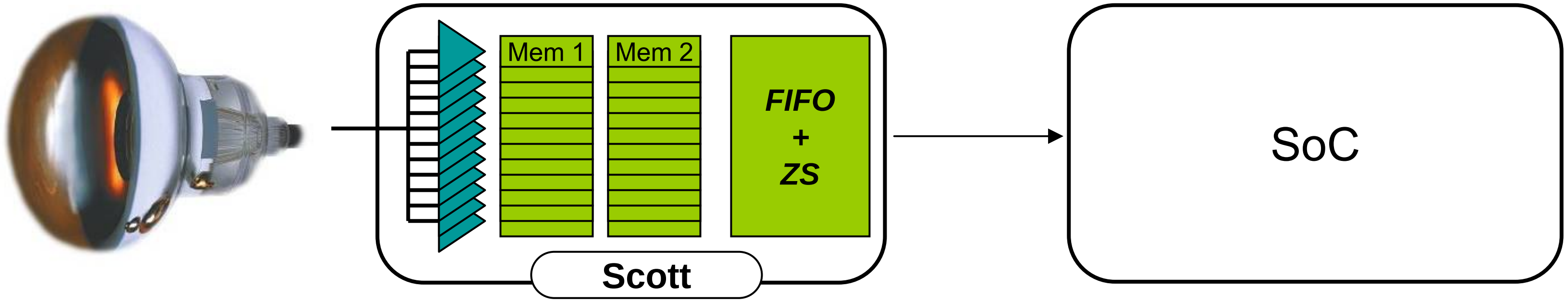
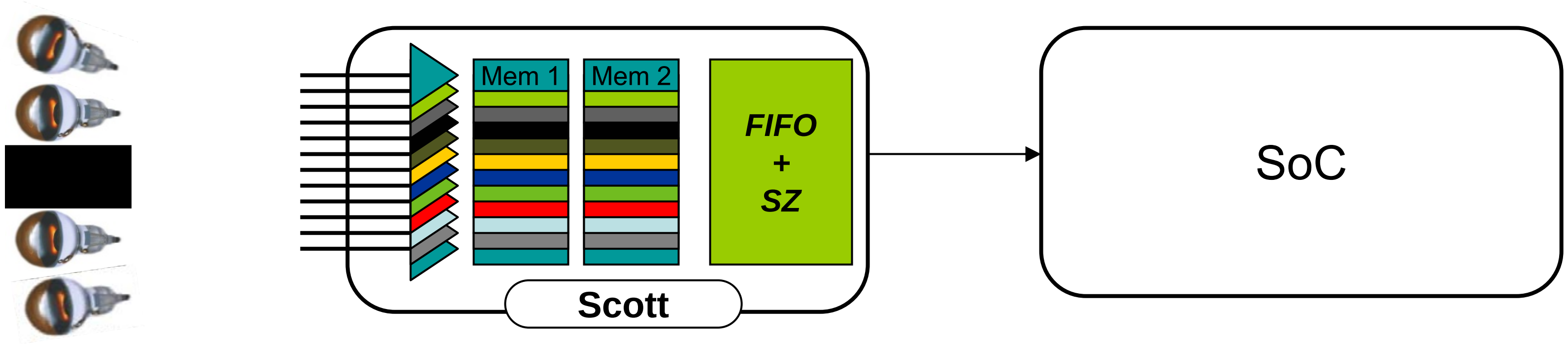


Same Readout for Single- and Multi-PMT OMs

- 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 ~ 25 Gbyte/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)

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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!

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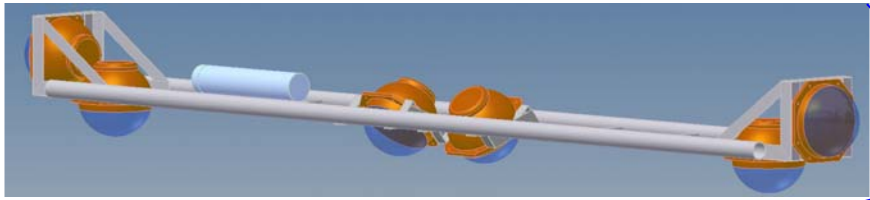
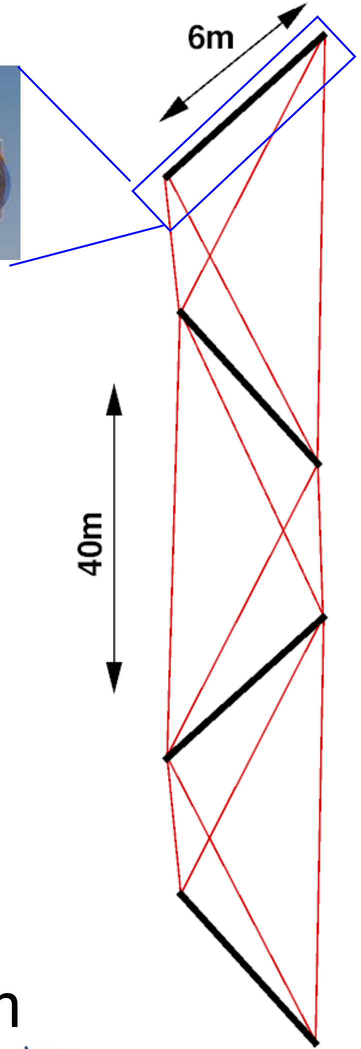
The Flexible Tower with Horizontal Bars





- 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

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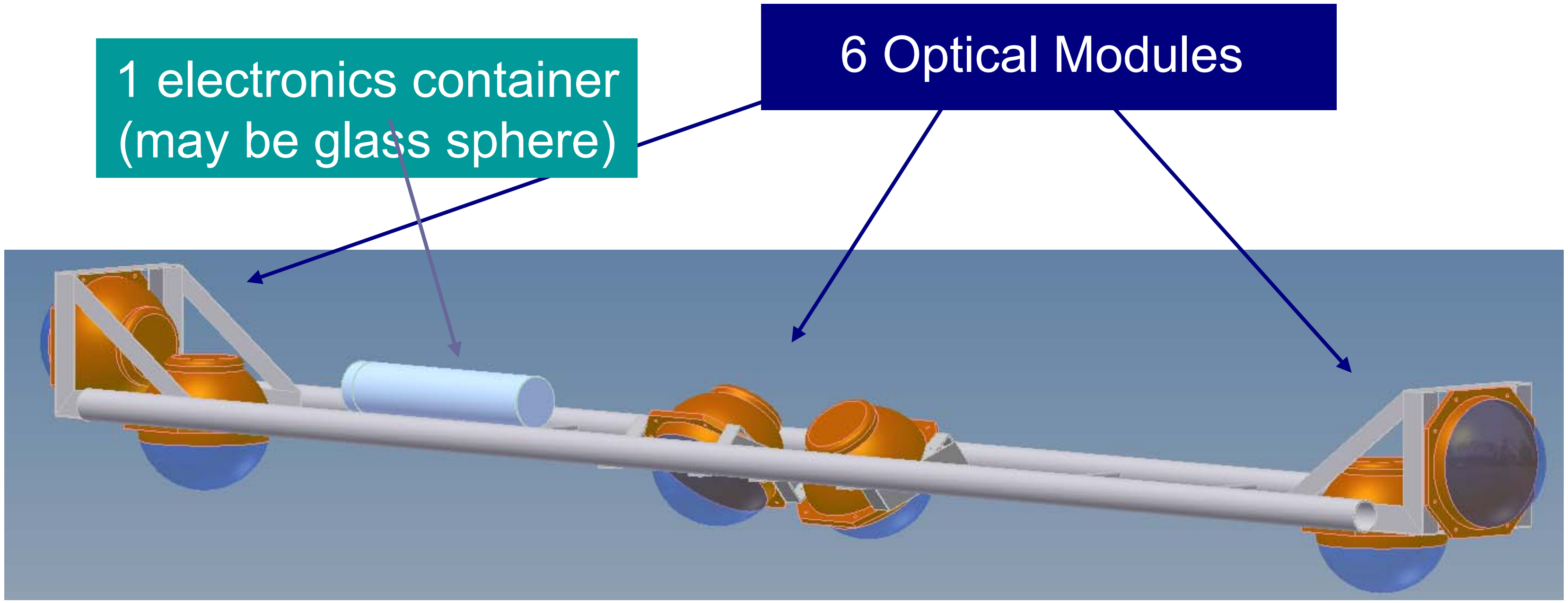
The Bar Storey

- 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

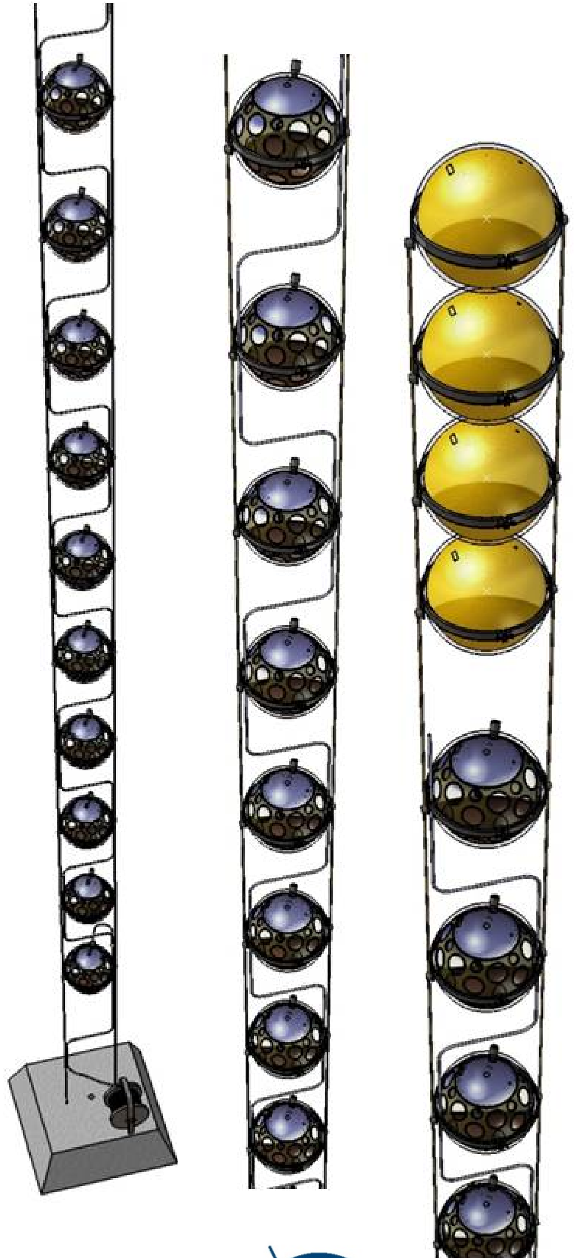
- Mooring line:
  - Buoy (empty glass spheres, net buoyancy 2250N)
  - Anchor: concrete slab of $1m^3$
  - 2 Dyneema ropes (4 mm diameter)
  - 20 storeys (one OM each), 30 m distance, 100m anchor-first storey
- Electro-optical backbone:
  - Flexible hose ~ 6mm diameter
  - Oil-filled

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

:

One single pressure transition

  - Star network between master module and optical modules



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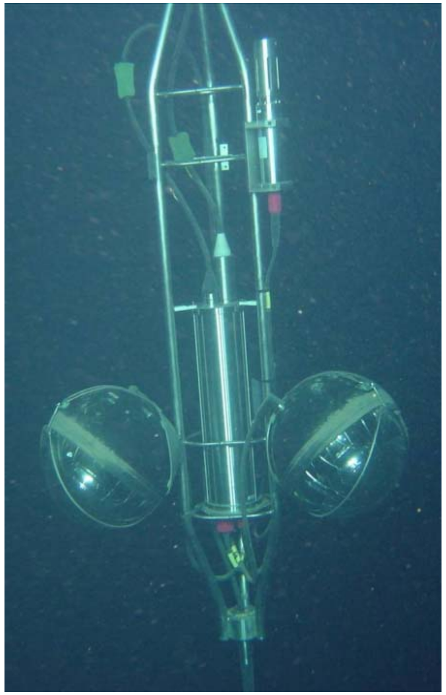
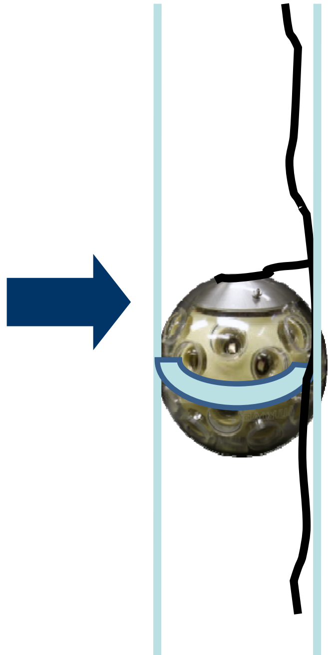
One Storey = one Multi-PMT OM

- 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





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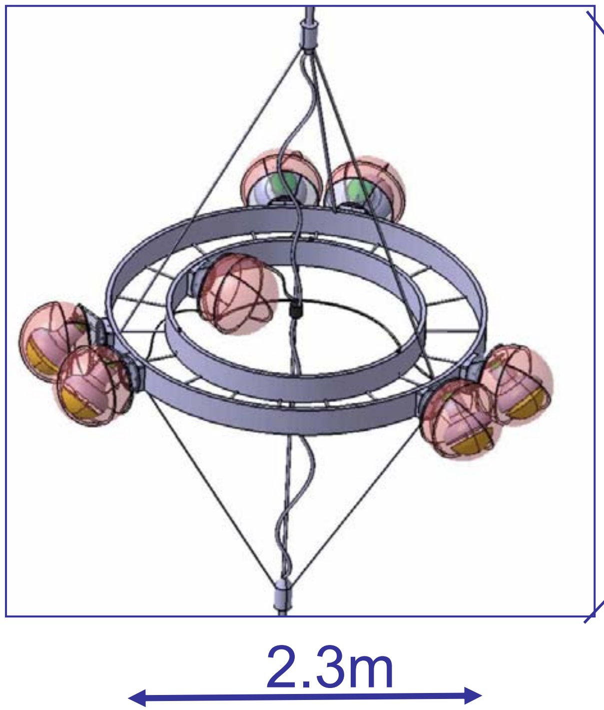
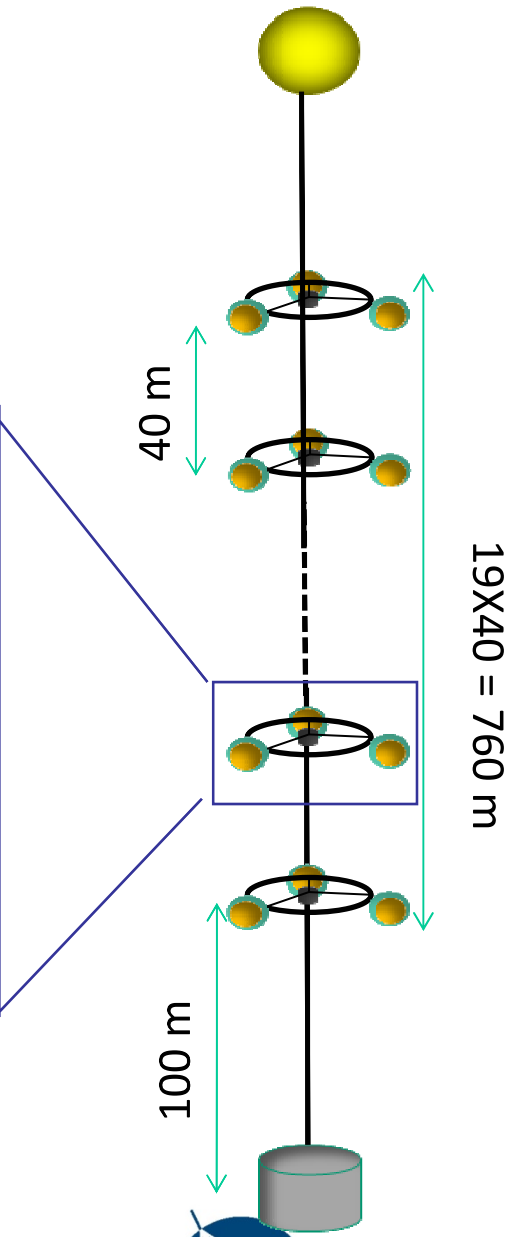
Triangle Structure

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





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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 concepts need to be thoroughly tested and verified
- Connection to seabed network by ROV
- Backup solution:
  "Traditional" deployment from sea surface

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A Flexible Tower Packed for Deployment

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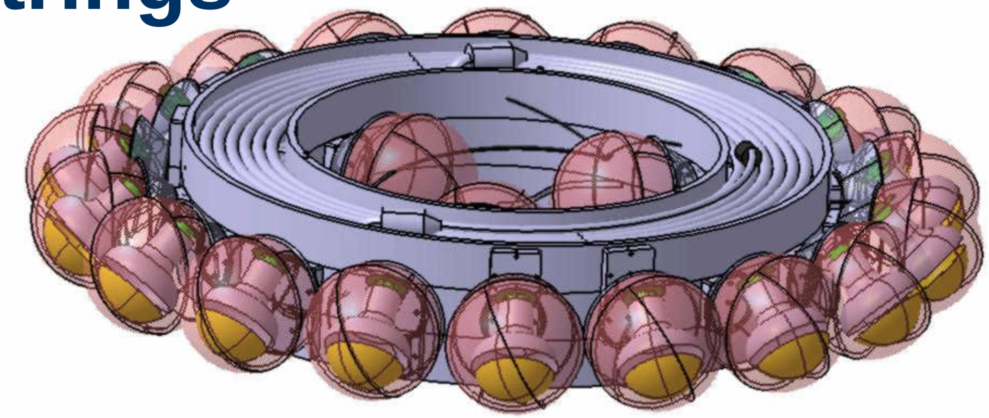
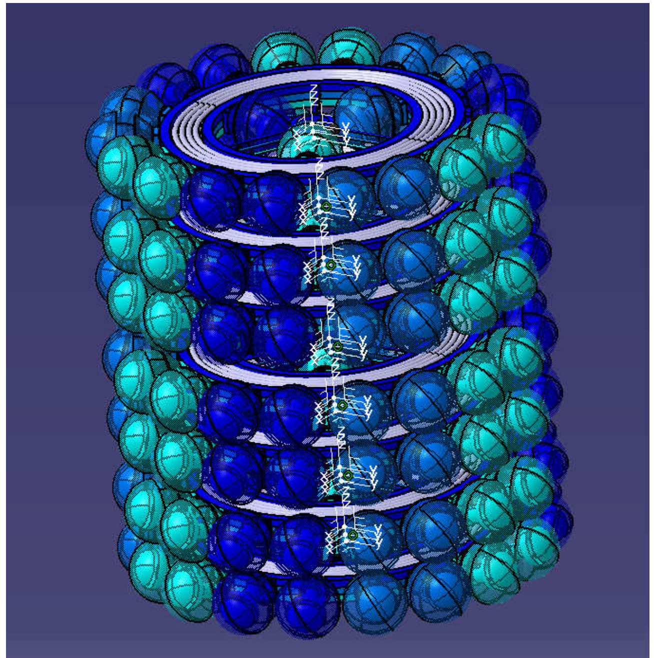
Compactifying Strings



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

3 triangles

DU



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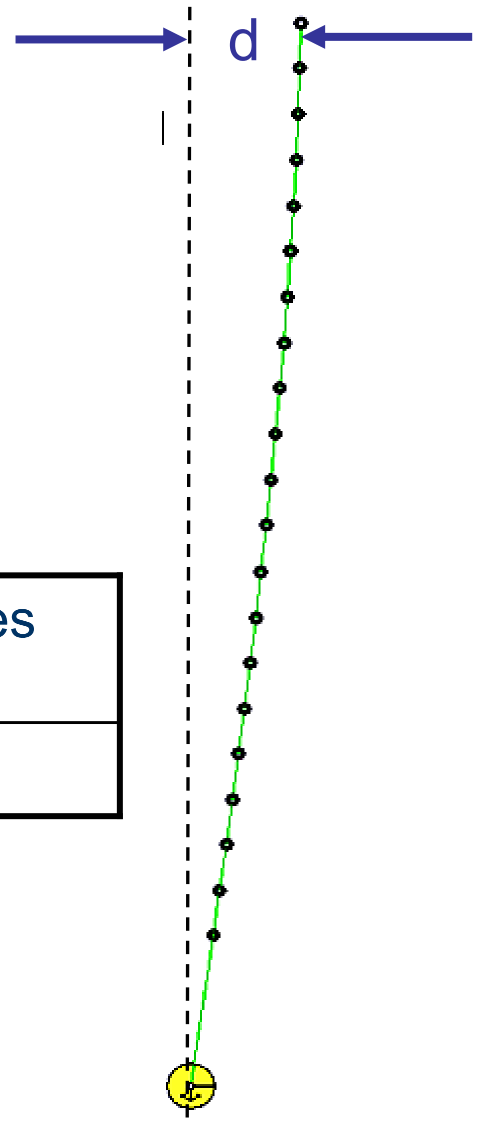
Hydrodynamic Stability

- 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]	triangles d [m]
30	84.0	83.0	87.0

- Torsional stability also checked



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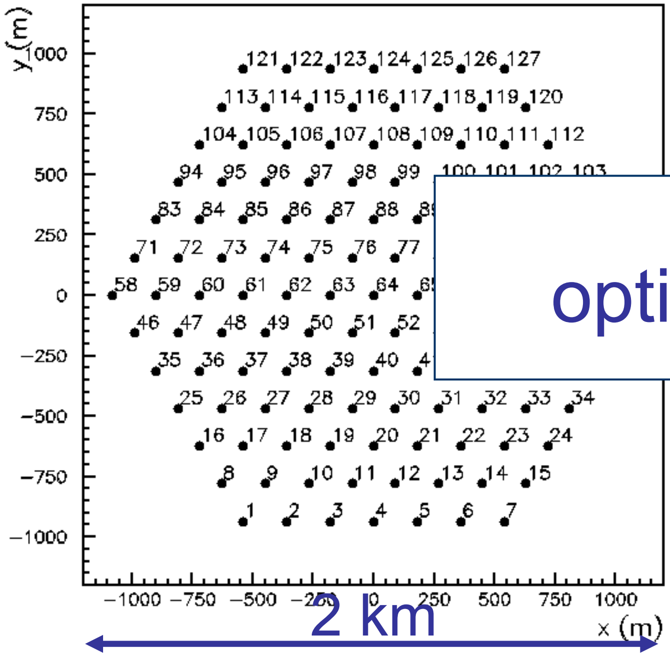
Detector Building Blocks

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

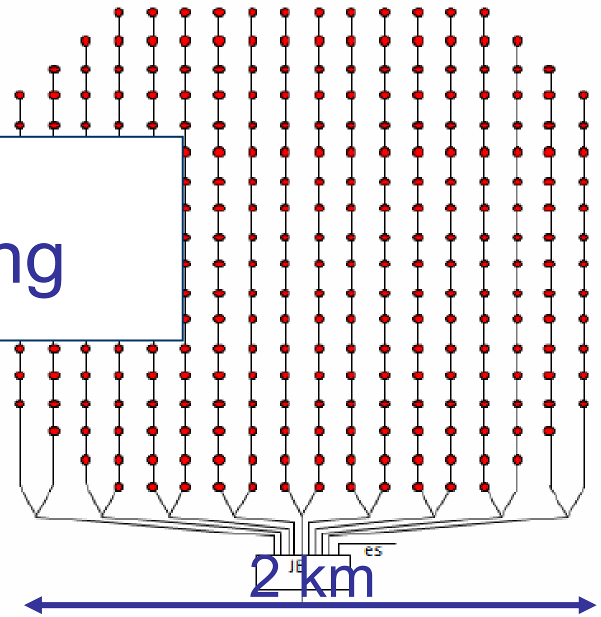
} different „building block footprints“



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

Footprint optimisation is ongoing

Slender string:
310 DUs,
distance 130 m



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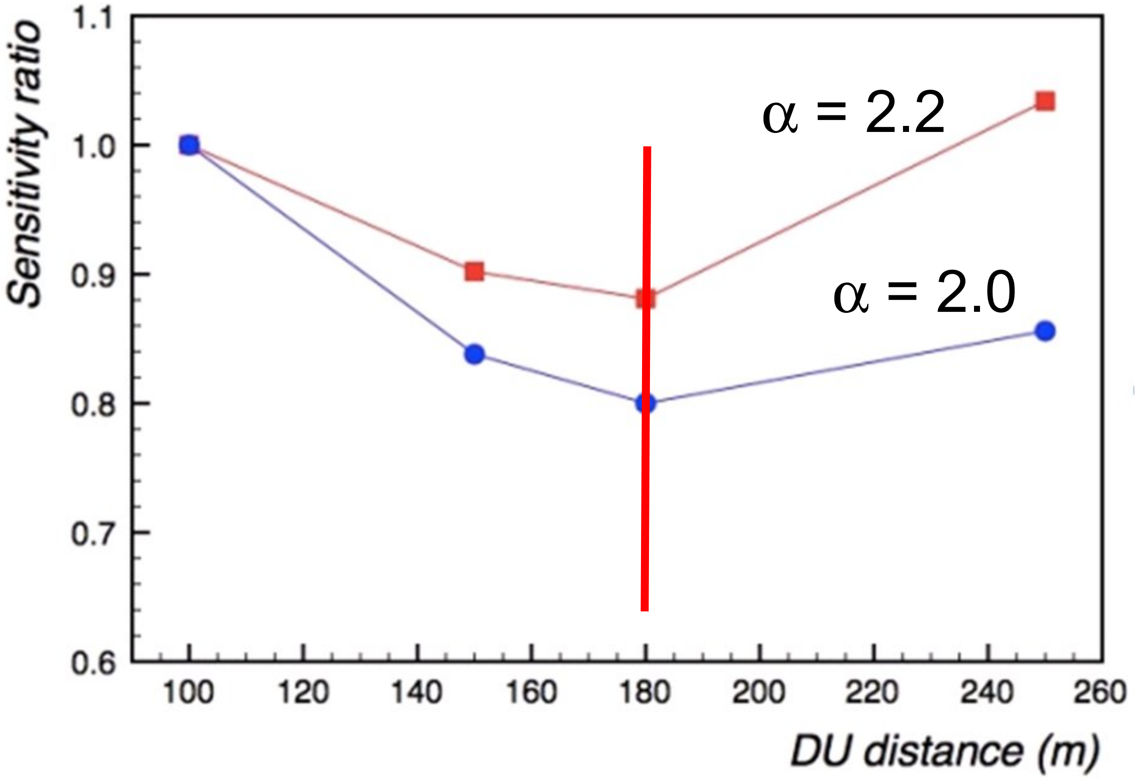
Optimisation Studies

Example: Sensitivity dependence of point-source search on DU distance for flexible towers (for 2 different neutrino fluxes ~$E^{-\alpha}$, no cut-off)



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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

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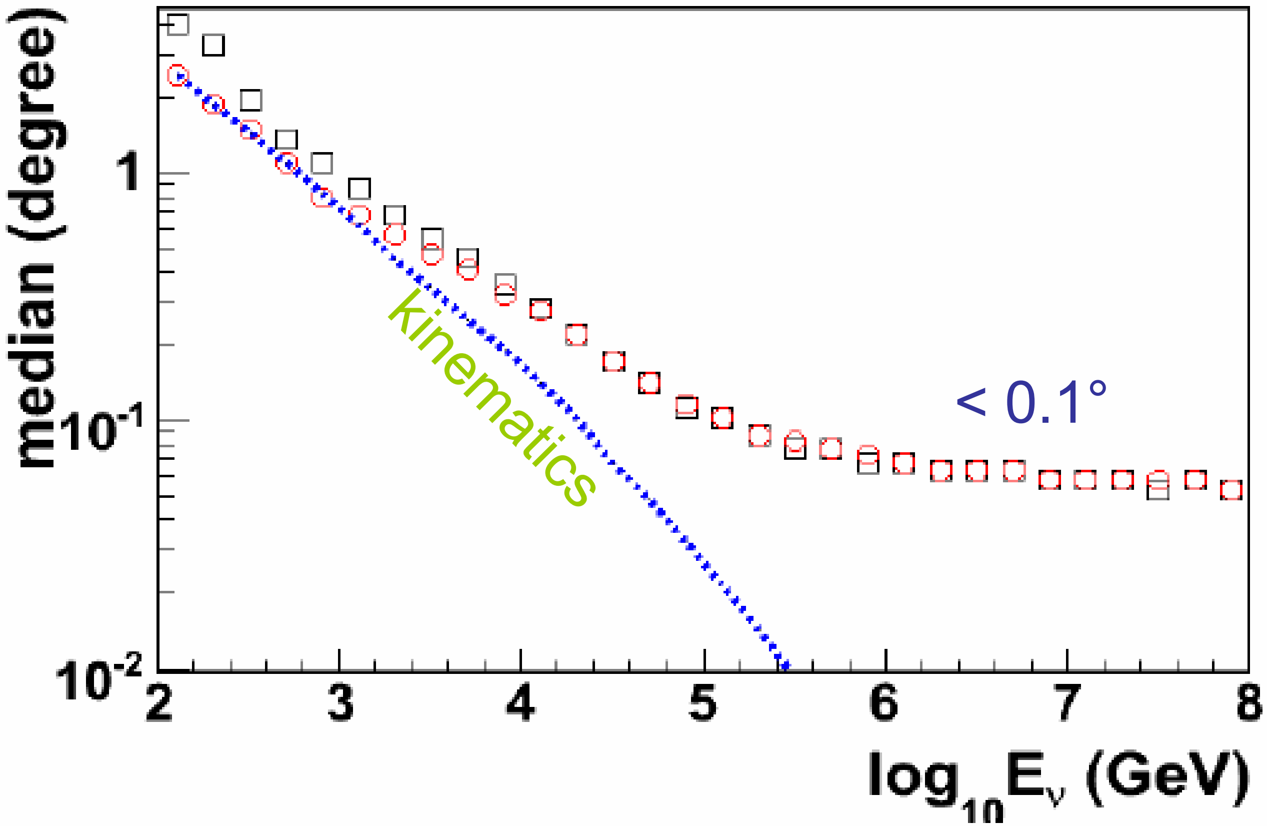
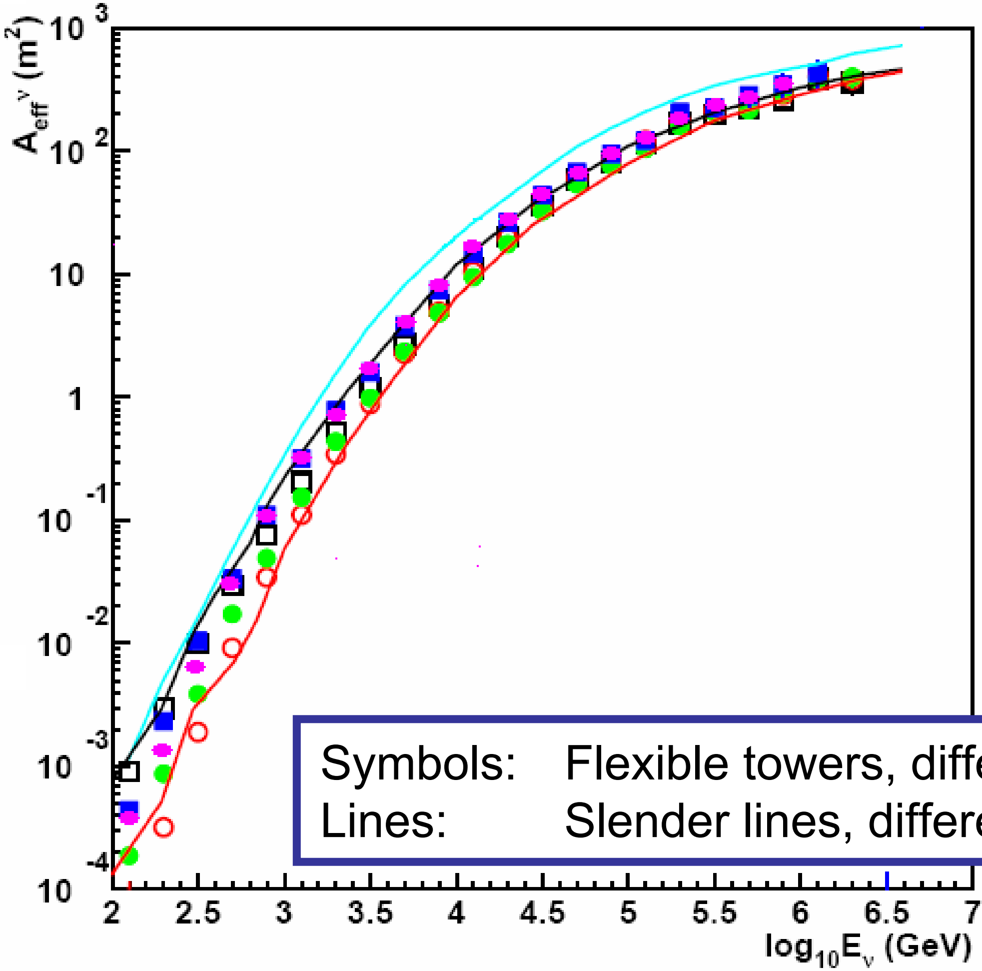
Angular Resolution

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



Effective Areas (per Building Block)



- Results very similar for hard quality cuts
- Flexible towers with bars and slender strings "in same ballpark"
- Driven by overall photocathode area

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

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Cost Estimates: Assumptions

- Estimate of investment cost
  - no personnel costs included
  - no contingency, no spares
- Assumptions / procedure:
  - Quotations from suppliers are not official and subject to change
  - Common items are quoted with same price
  - Sea Sciences and Shore Station not estimated
  - Estimates worked out independently by expert groups and carefully cross-checked and harmonised thereafter

Cost Estimates: Results

- Result of cost estimates (per building block):

Concept	DU Cost (M€)	No. of DUs	Total DU Cost (M€)	Seafloor Infrastr. (M€)	Deploy-ment (M€)	TOTAL COST (M€)
Flexible towers	0.54	127	68	8	11	87
Slender strings	0.25	310	76	13	14	103
Triangles	0.66	127	83	8	7	99

- Assembly man power (OMs, DU…) is roughly estimated to be 10% of the DU cost

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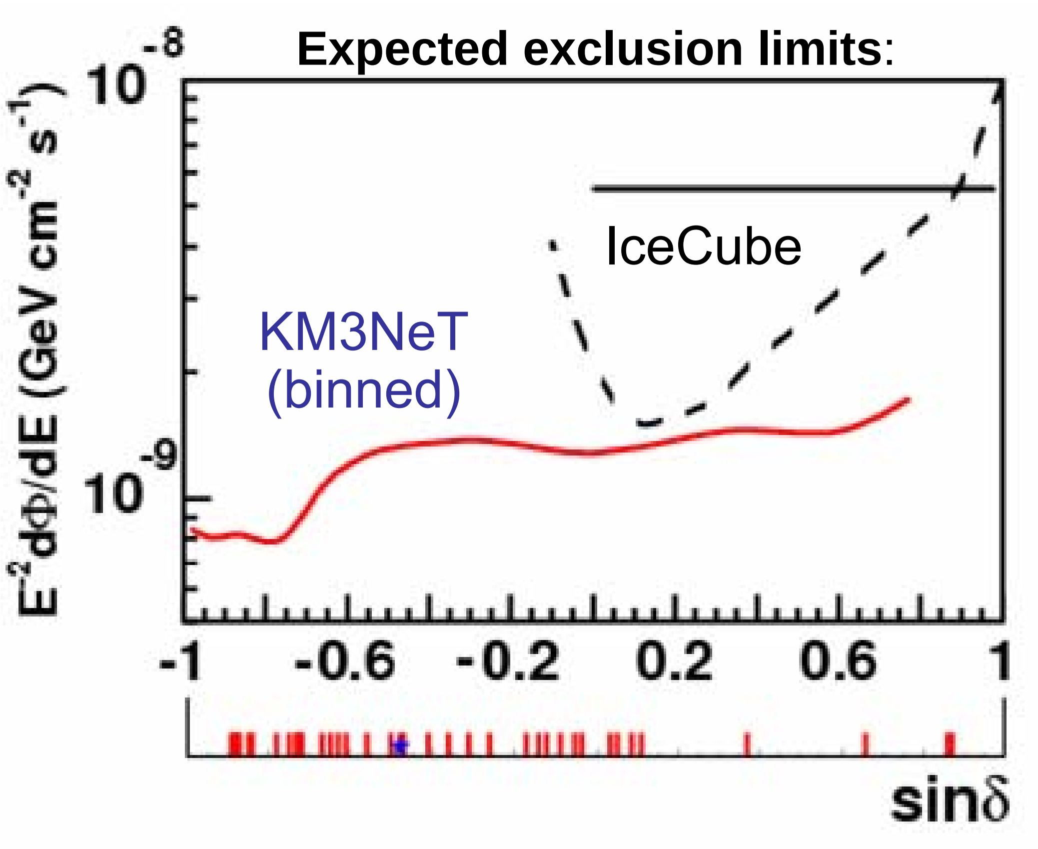
KM3NeT: Full Configuration

- 2 “building blocks” needed to achieve objectives
- Increases sensitivity by a factor 2
- Overall investment ~220 M€
- Staged implementation possible
- Science potential from very early stage of construction on
- Operational costs 4-6 M€ per year (2-3% of capital investment), including electricity, maintenance, computing, data centre and management

Point Source Sensitivity (1 Year)



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

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

□ 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)

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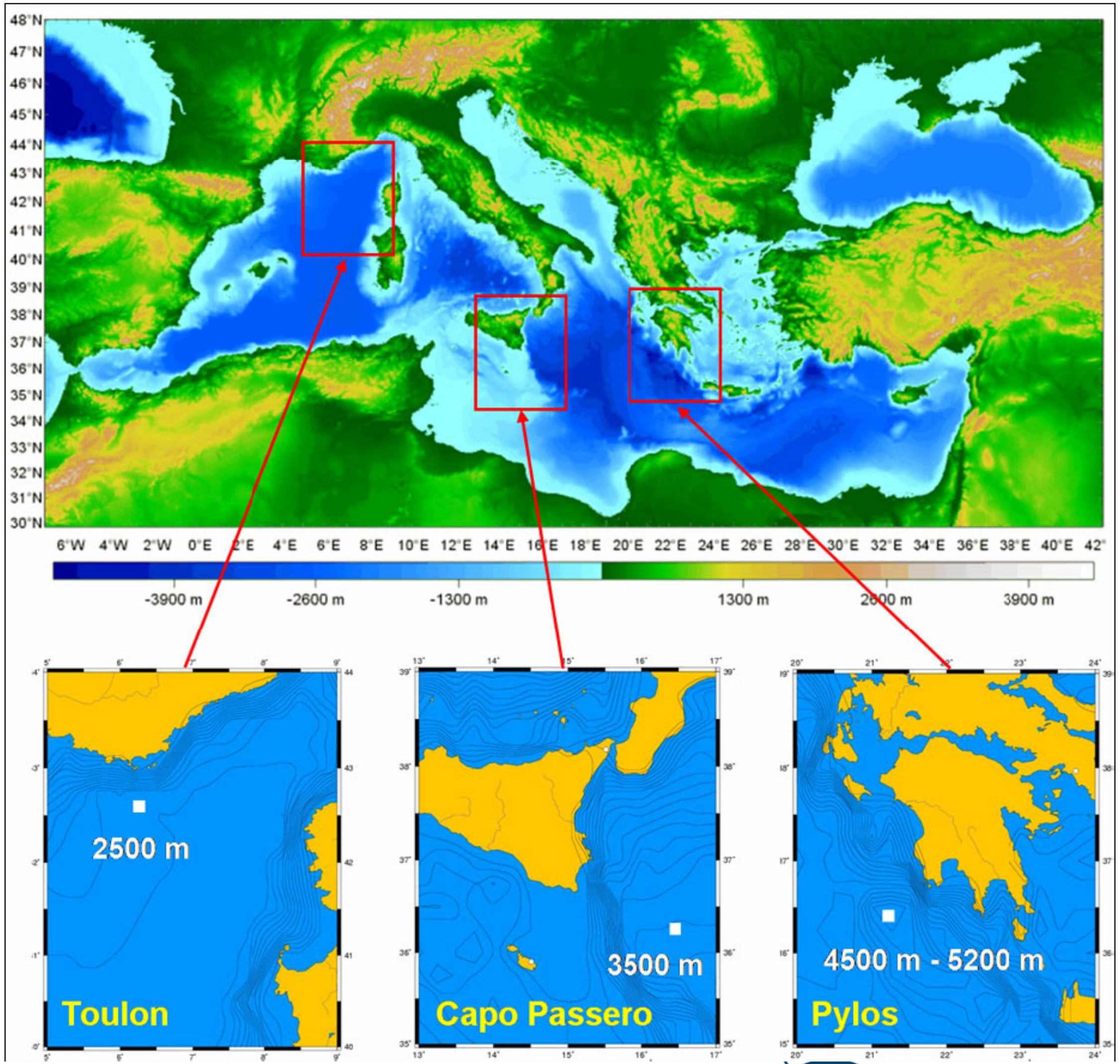
Candidate Sites

- 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



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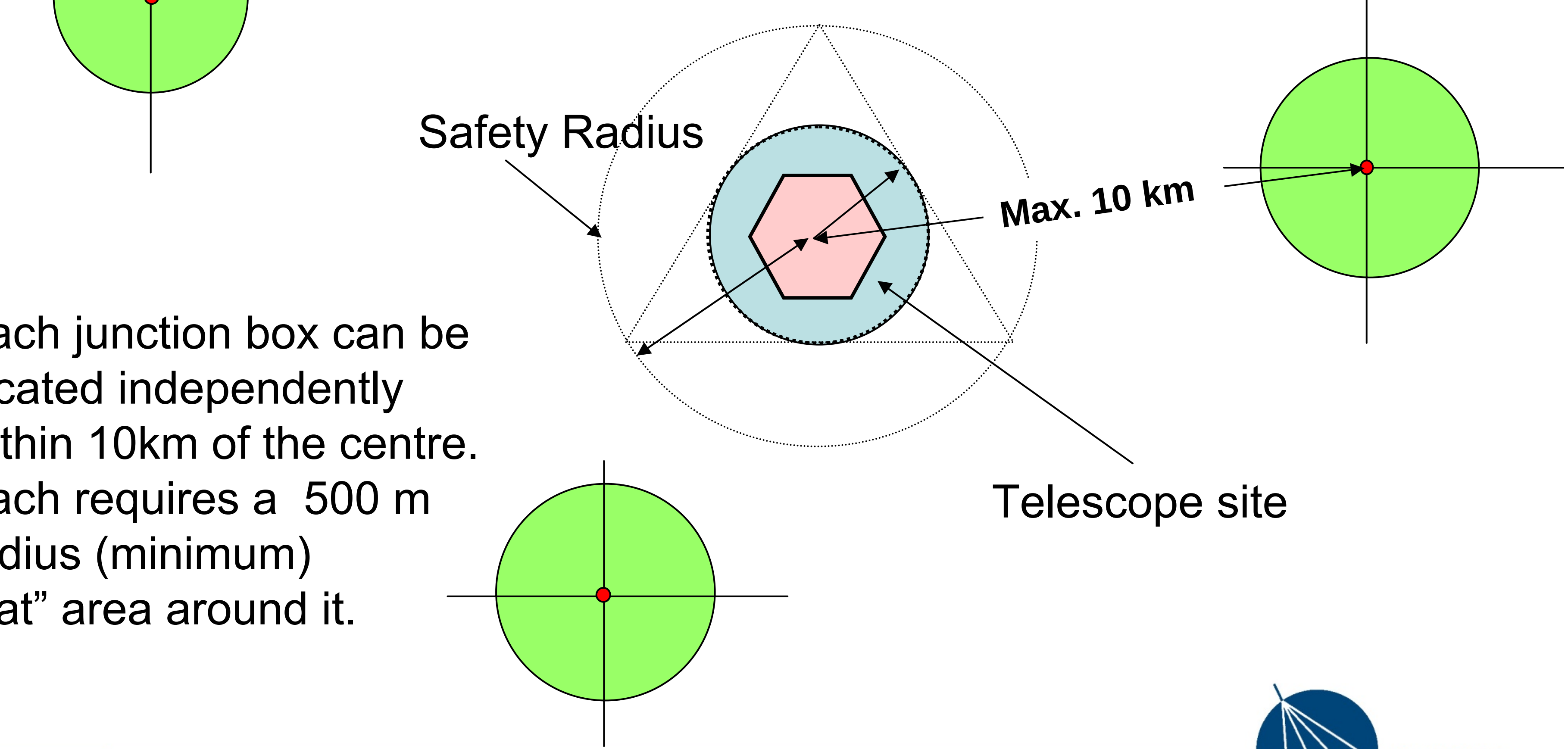
The Marine Science Node: Layout

- 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.

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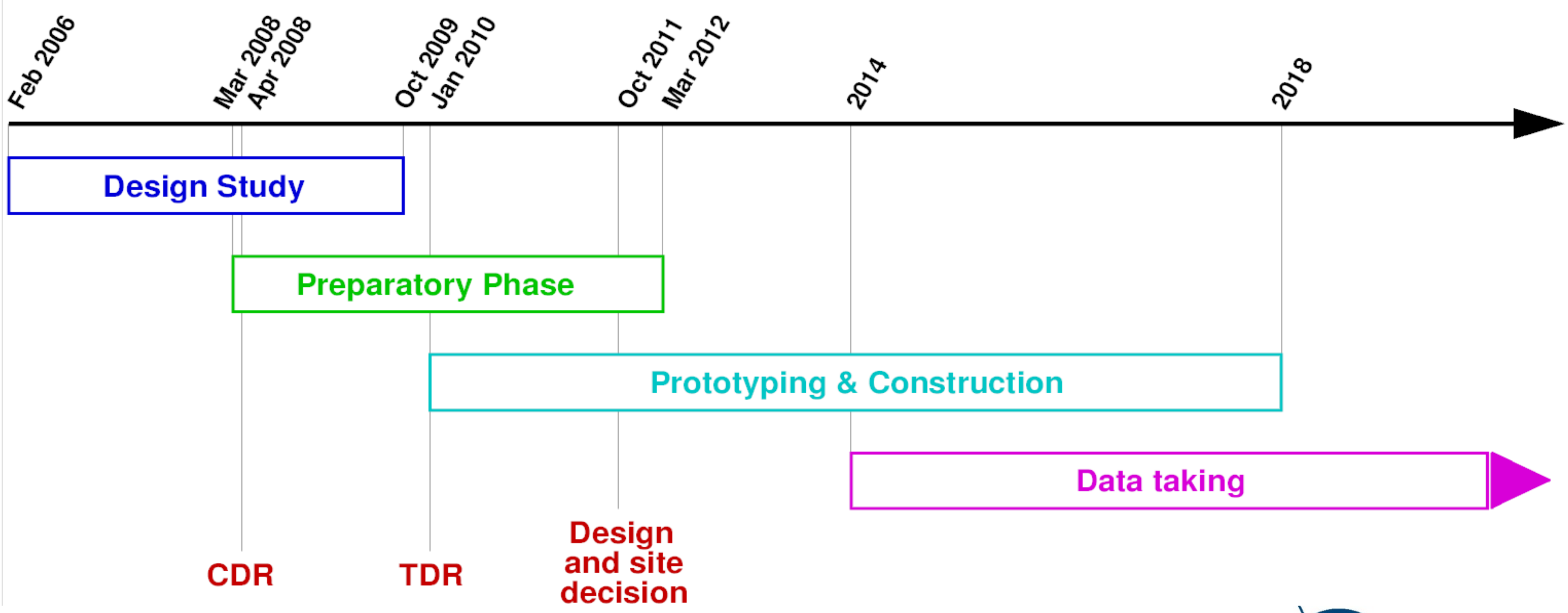
Next Steps and Timeline

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



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A Strategic View

- High priority on ASPERA & Astronet roadmaps, included in ESFRI list
- KM3NeT is a 3rd-generation rather than 2nd-generation instrument
  → No causal connection to IceCube discovery
- IceCube+KM3NeT = Global Neutrino Observatory
  → Requires substantial overlap in operation time
- German perspective:
  - Co-leading in IceCube
  - Important involvement in ANTARES
  - Coordination of KM3NeT Design Study

  } **Substantial BMBF funding**

  →Well positioned to reap the fruit of 2 decades of efforts!

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Conclusions

- A design for the KM3NeT neutrino telescope complementing the IceCube field in its of view and surpassing it in sensitivity by a substantial factor is presented.
- An overall budget of ~250 M€ will be required. Staged implementation, with increasing discovery potential, is technically possible.
- Within 18 months, remaining design decisions have to be taken and the site question clarified.
- Installation could start in 2013 and data taking soon after.

A Final Comparison (not Quite Serious …)

Imagine this is IceCube: