International School on Nuclear Physics,
32nd Course: *Particle and Nuclear Astrophysics*
Erice, Sicily, 16–24 September 2010

Neutrino Astronomy with KM3NeT

was: Mediterranean Neutrino Telescopes - Status and Future

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17.09.2010

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Friedrich-Alexander-Universität Erlangen-Nürnberg

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KM3NeT

- Introduction
- Technical solutions: Decisions and options
- Physics sensitivity
- Cost and implementation
- Summary

KM3NeT

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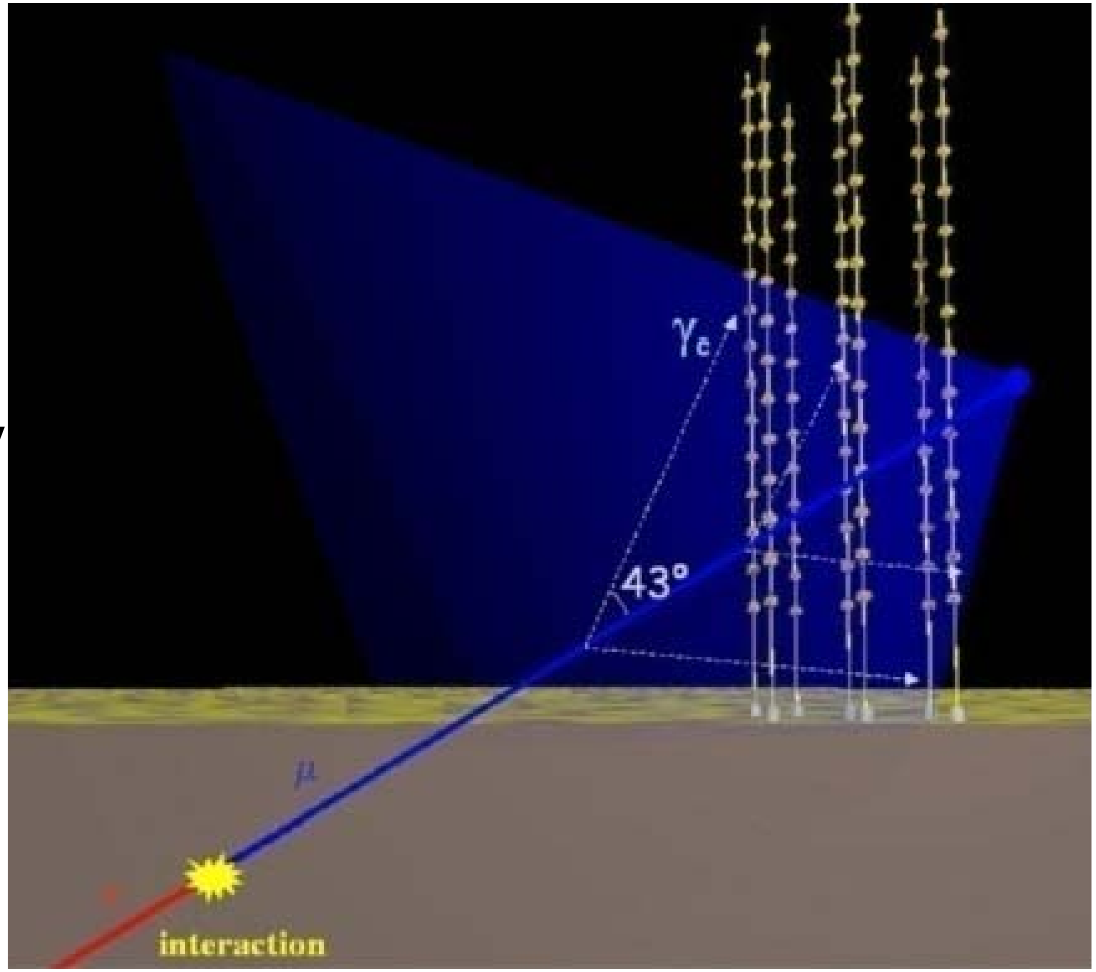
The Neutrino Telescope World Map

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
- Provides node for earth and marine sciences



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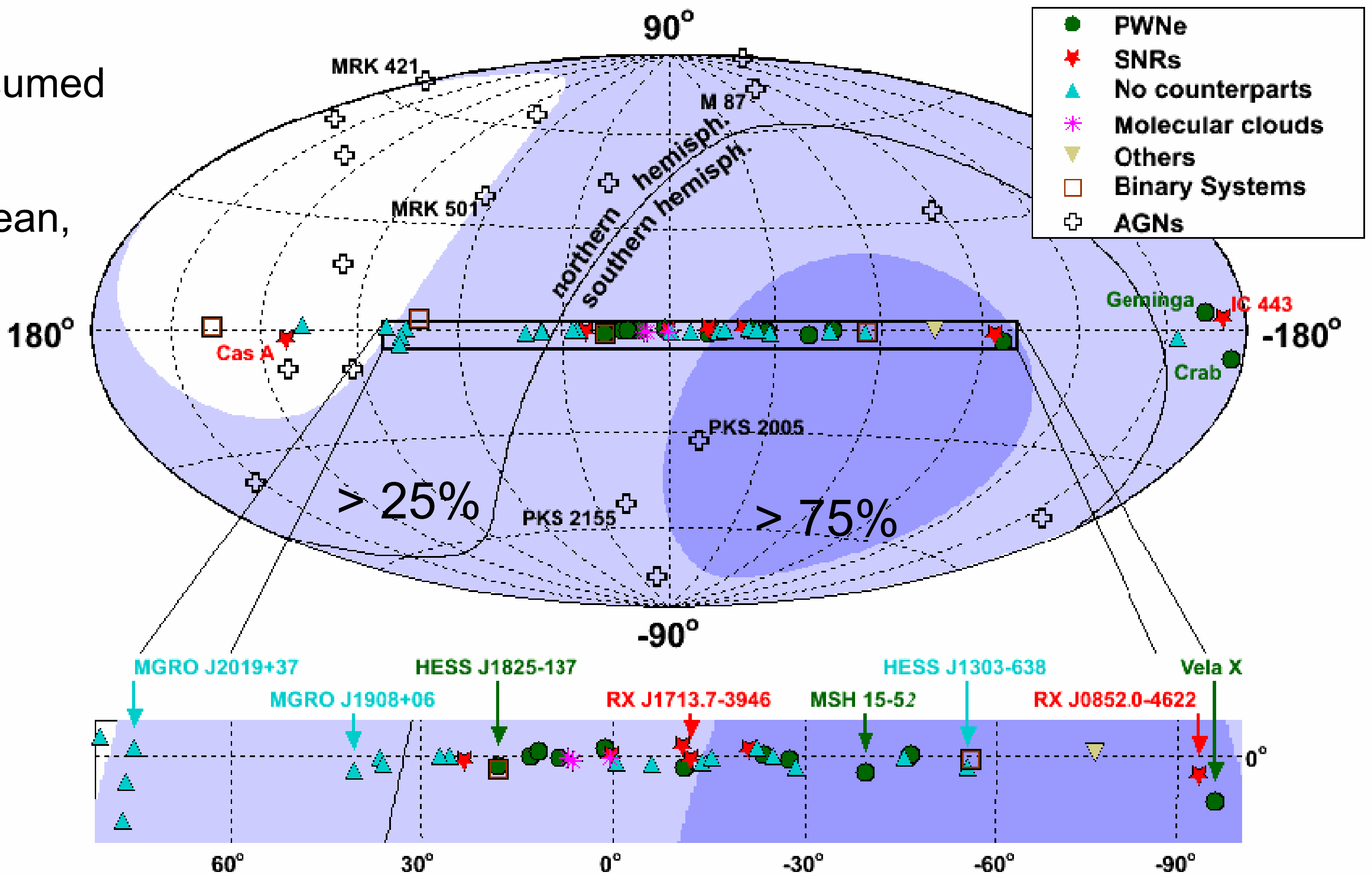
South Pole and Mediterranean Fields of View

2π downward sensitivity assumed

In Mediterranean, visibility of given source can be limited to less than 24h per day



The Objectives

- Central physics goals:
  - Investigate neutrino “point sources” in energy regime 1-100 TeV
  - Complement IceCube field of view
  - Exceed IceCube sensitivity
  - Not in the central focus:
    - Dark Matter
    - Neutrino particle physics aspects
    - Exotics (Magnetic Monopoles, Lorentz invariance violation, …)
- Implementation requirements:
  - Construction time ≤5 years
  - Operation over at least 10 years without “major maintenance”

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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
- 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 (technology and site), secure resources, set up proper management/governance, construct and operate KM3NeT;

The First-Generation Projects

- **ANTARES:**
  See presentation by Thomas Eberl, today 18:00-18:30

- **NEMO and NESTOR**
  Major contributions to R&D
  Site exploration

- **All 3 have become part of KM3NeT**

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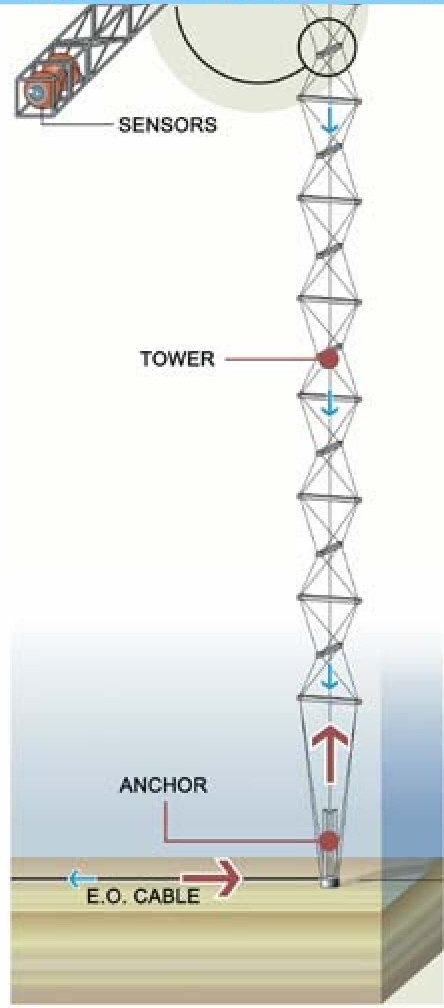
NEMO

- Extensive site exploration (Capo Passero near Catania, depth 3500 m);
- R&D towards km³: architecture, mechanical structures, readout, electronics, cables ...;
- Simulation.



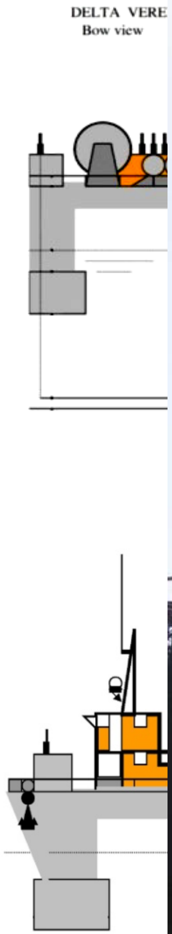
Example: Flexible tower

- ~10 m bar length, bars 30-40 m apart;
- 3 pairs of PMs per bar
- Unfurls after deployment as compact structure.

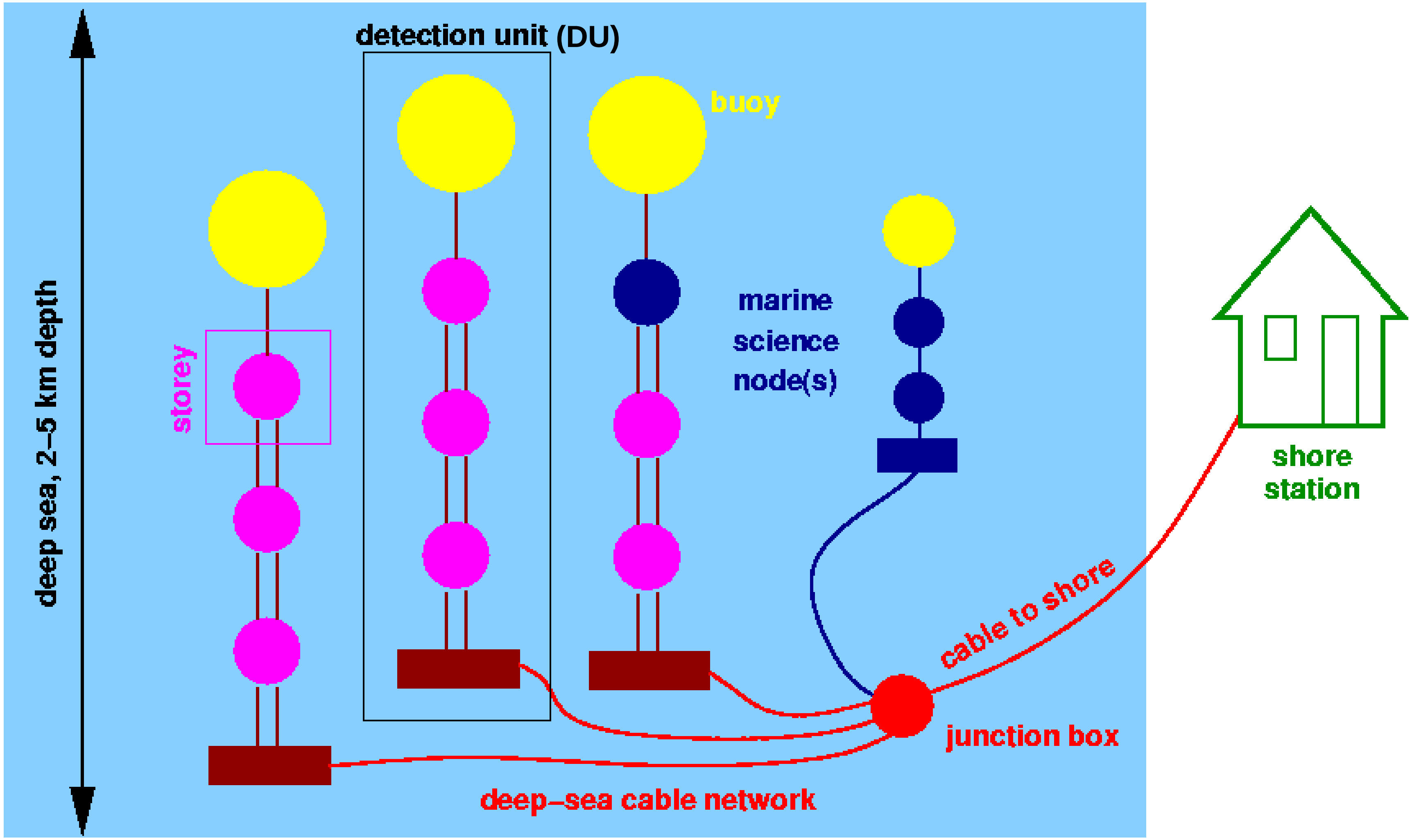
NESTOR

- Tower based detector (titanium structures).
- Dry connections (recover − connect − redeploy).
- Up- and downward looking PMs (15'').
- 4000-5200 m deep.
- Test floor (reduced size) deployed & operated in 2003.

NESTOR: the Delta-Berenike Platform



The KM3NeT Research Infrastructure (RI)



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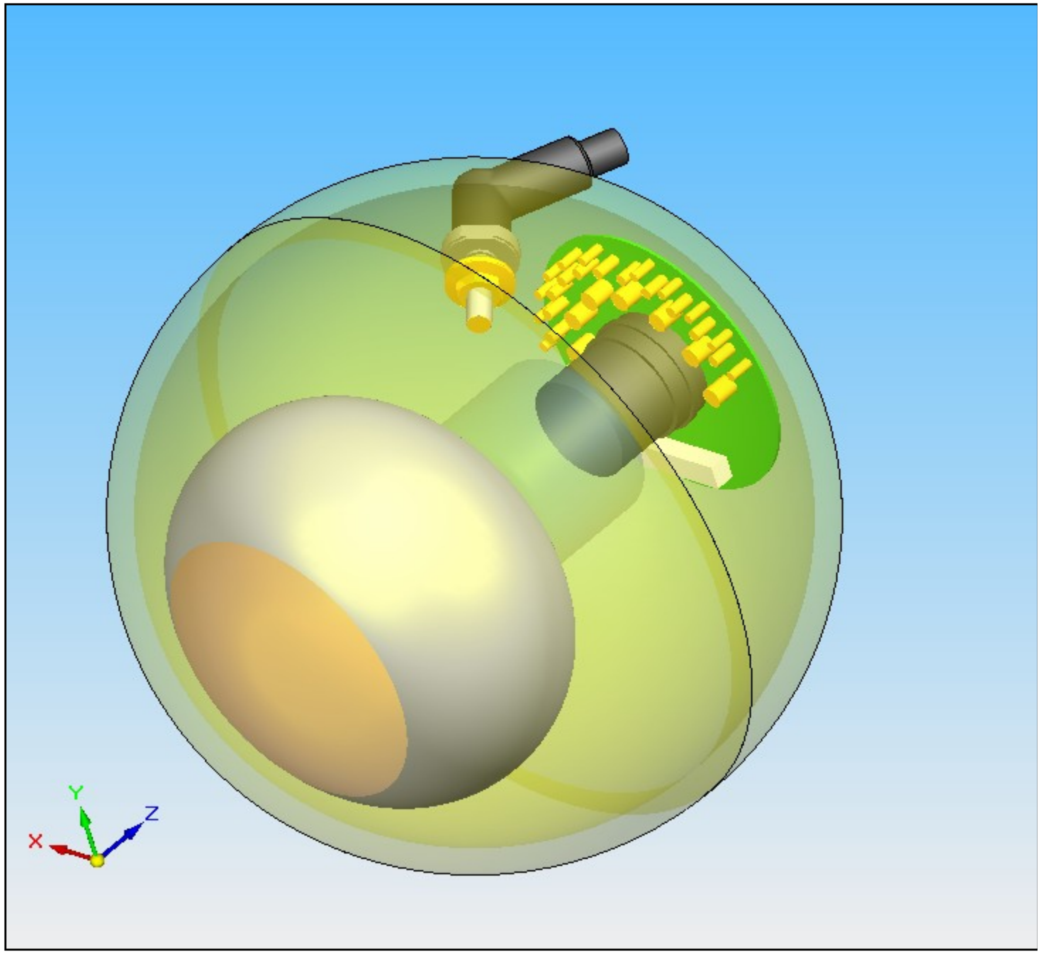
OM "classical": One PMT, no Electronics

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



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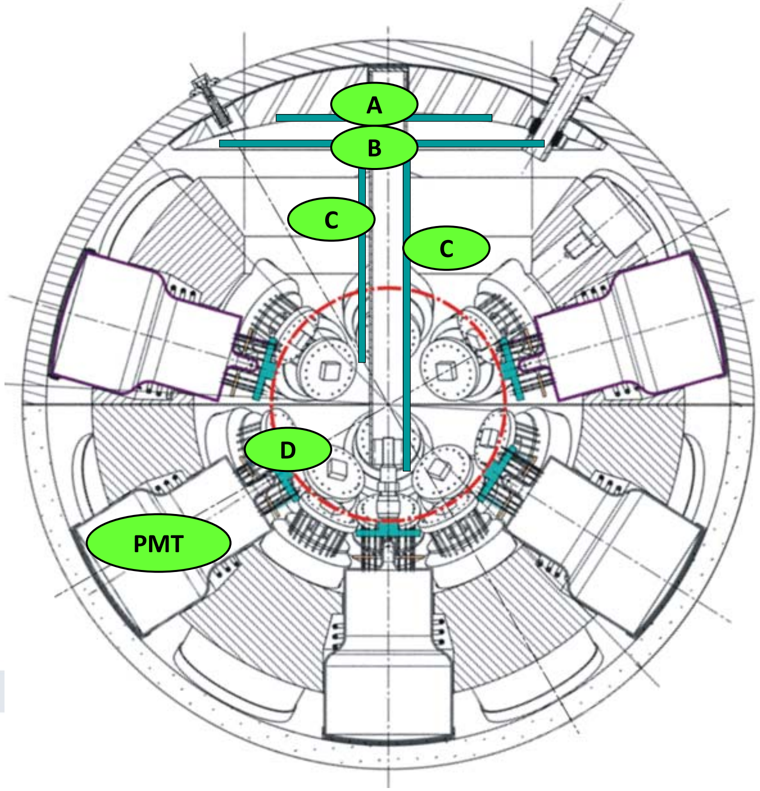
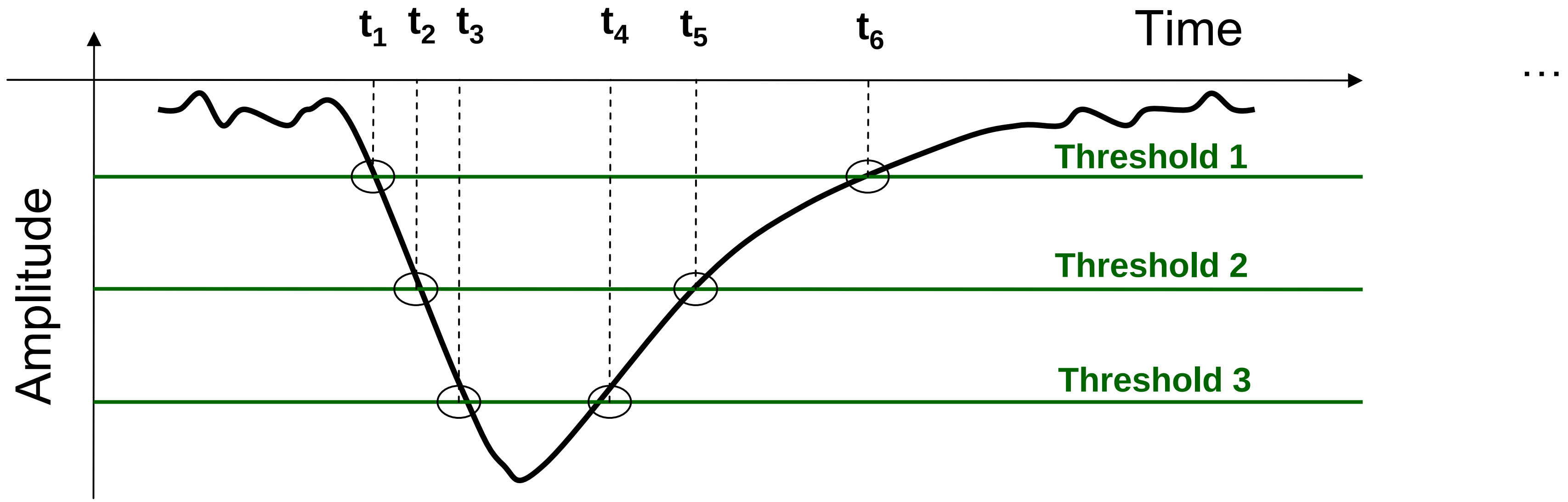
OM with many Small PMTs

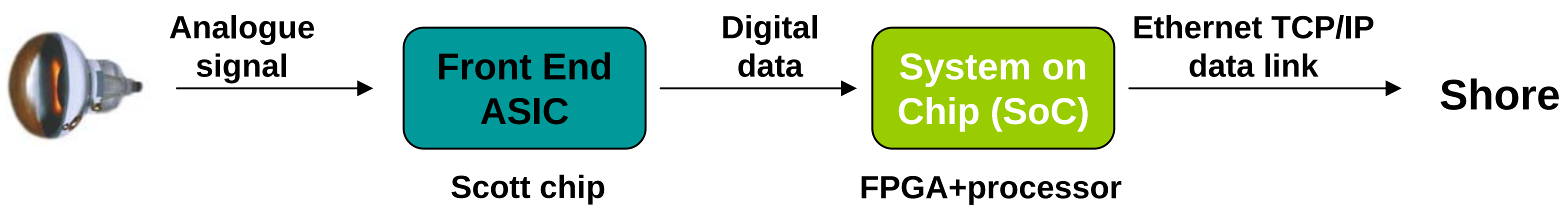
- 31 3-inch PMTs in 17-inch glass sphere (cathode area~ 3x10” PMTs)
  - 19 in lower, 12 in upper hemisphere
  - Suspended by compressible foam core
- 31 PMT bases (total ~140 mW) (**D**)
- Front-end electronics (**B,C**)
- Al cooling shield and stem (**A**)
- Single penetrator
- 2mm optical gel
- Advantages:
  - increased photocathode area
  - improved 1-vs-2 photo-electron separation → better sensitivity to coincidences
  - directionality



Front-End Electronics: Time-over-Threshold

From the analogue signal to time stamped digital data:





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

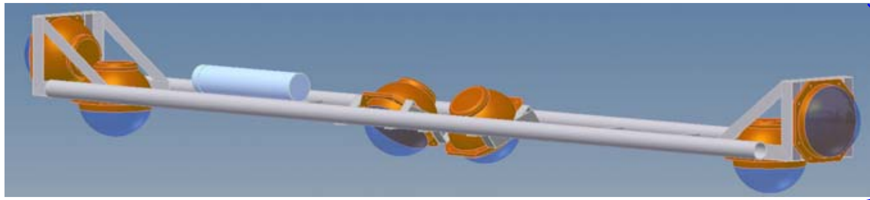
<u>Reminder:</u>

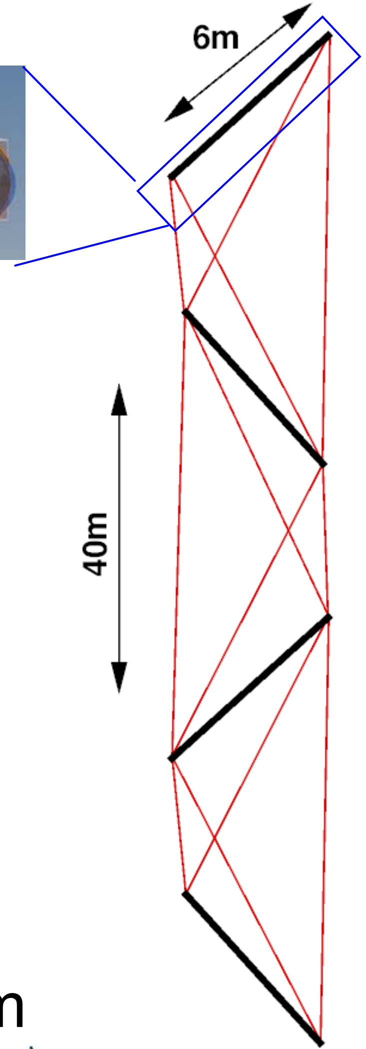
Progress in verifying deep-sea technology can be slow and painful

Careful prototype tests are required before taking final decisions

This is an ongoing task

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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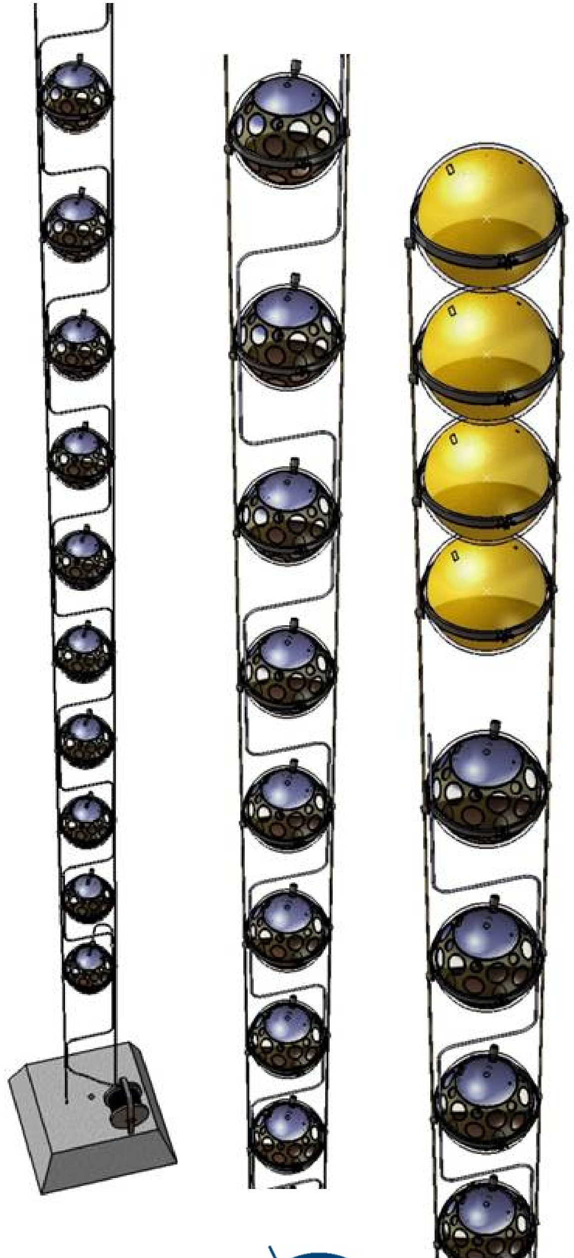
The Slender String

- 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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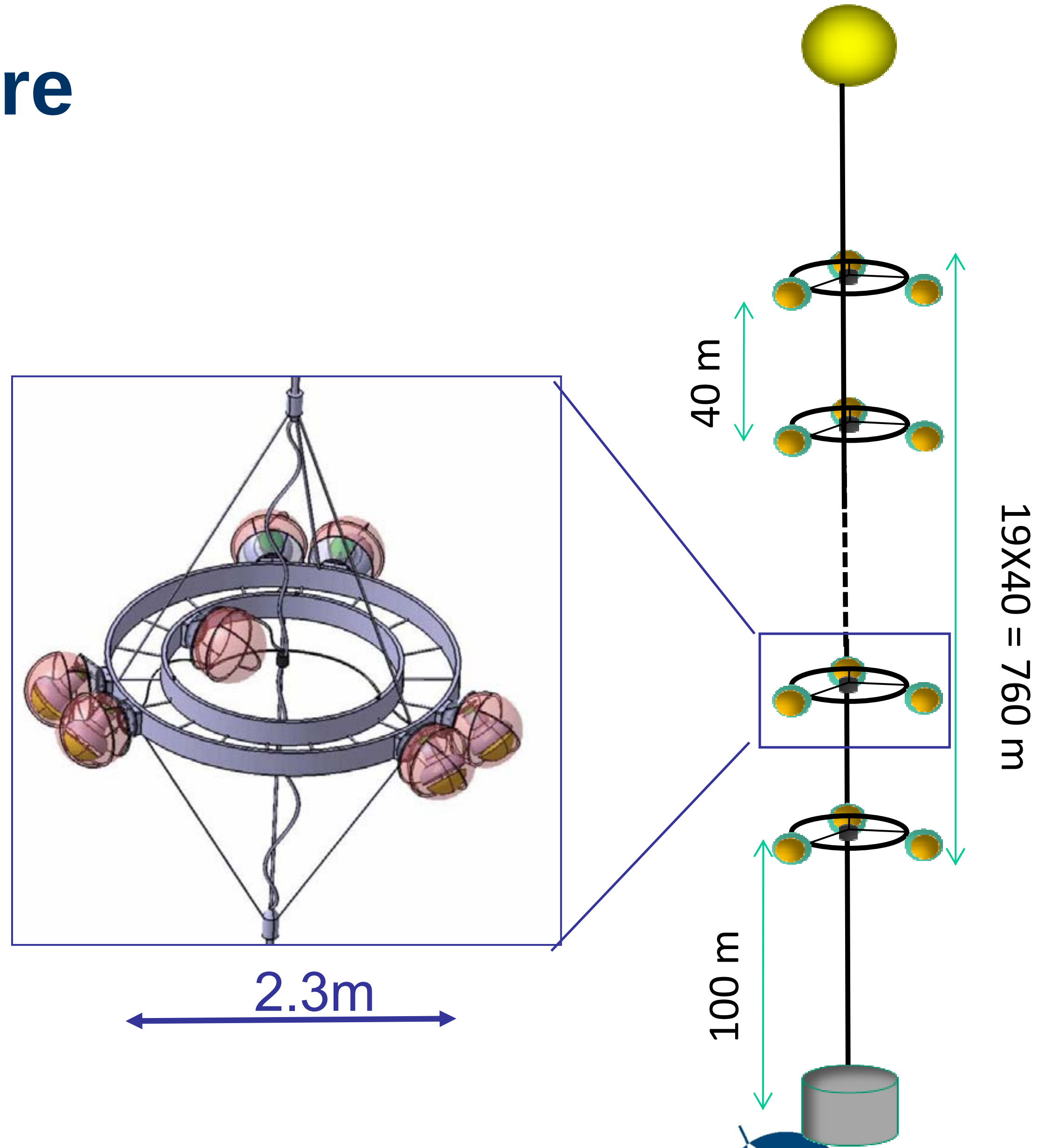
Triangle Structure

- 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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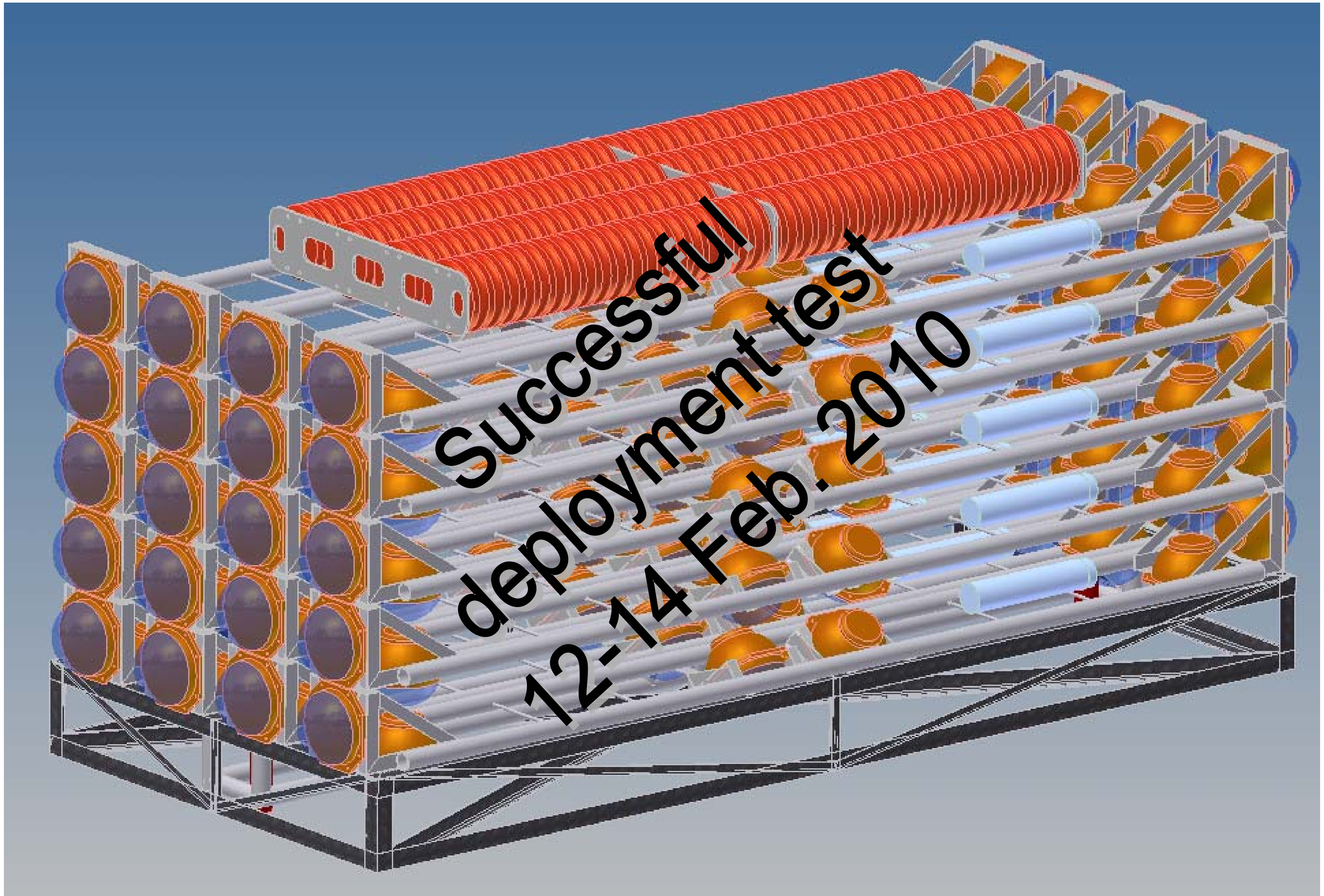
Deployment Strategy

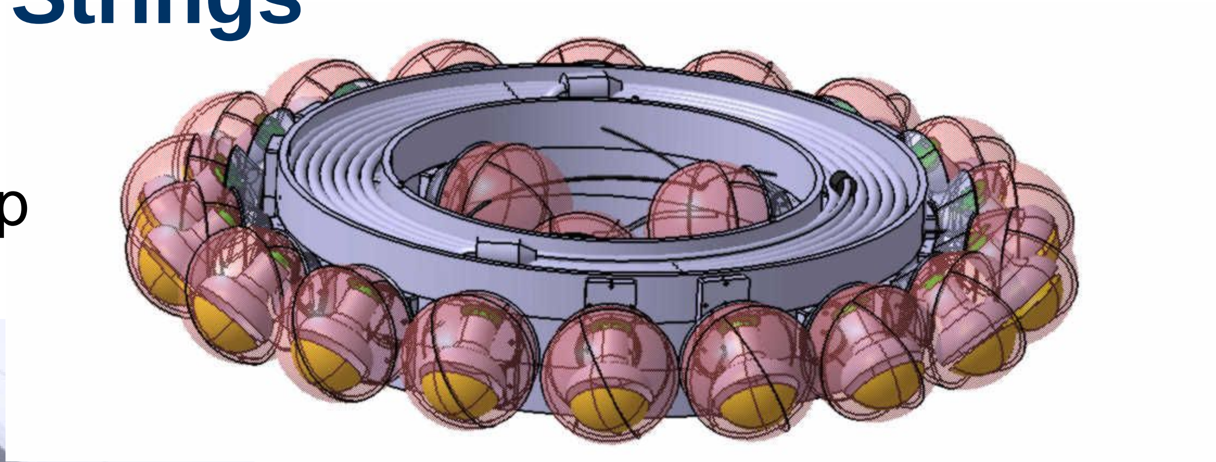
- All three mechanical solutions:
  Compact package – deployment – self-unfurling
  - Eases logistics
    (in particular in case of several assembly lines)
  - Speeds up and eases deployment;
    several DUs can be deployed in one operation
  - Self-unfurling concepts need to be thoroughly tested and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

A Flexible Tower Packed for Deployment



Compactifying Strings

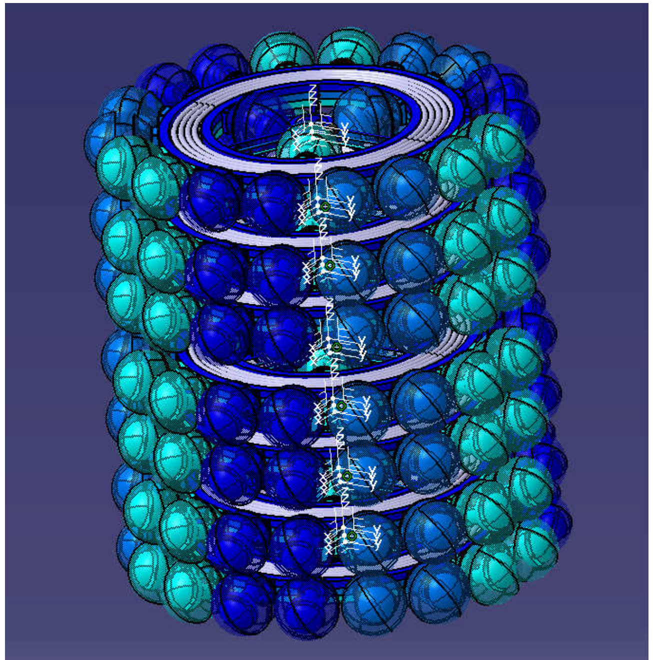
Slender string rolled up for self-unfurling:



3 triangles

↓

DU

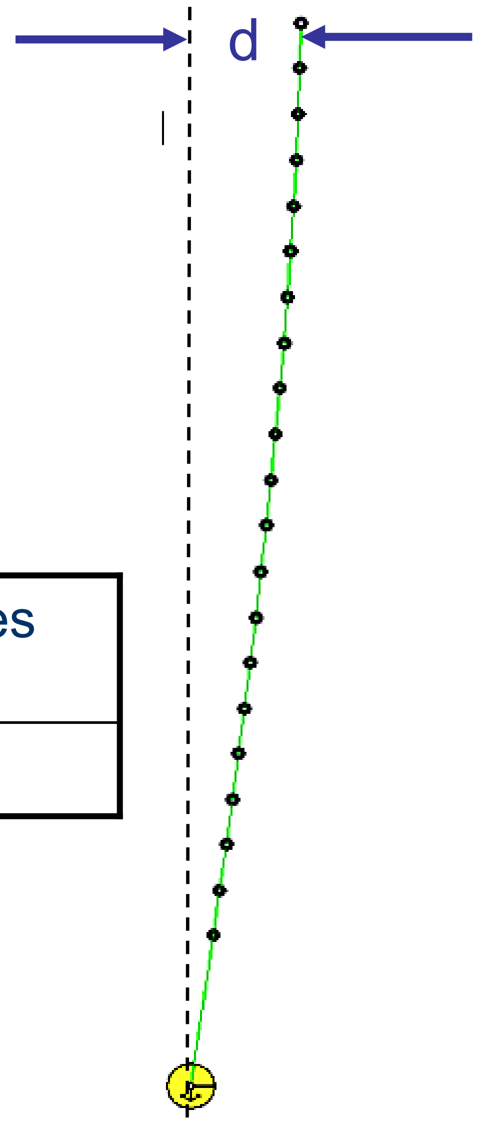


Hydrodynamic Stability

- 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]	triangles d [m]
30	84.0	83.0	87.0

- Torsional stability also checked



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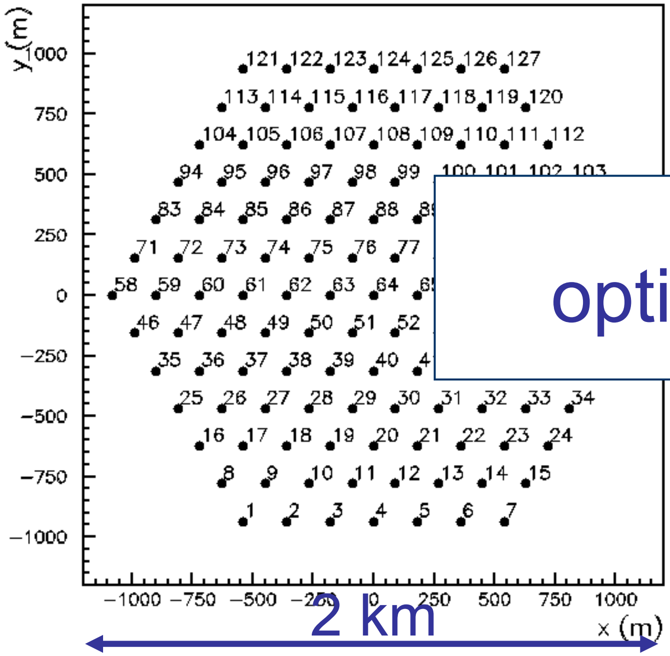
Detector Building Blocks

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

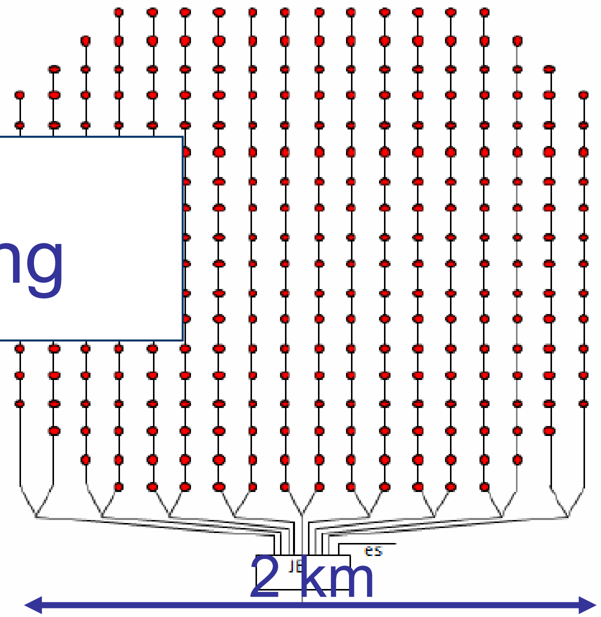
} different „building block footprints“



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

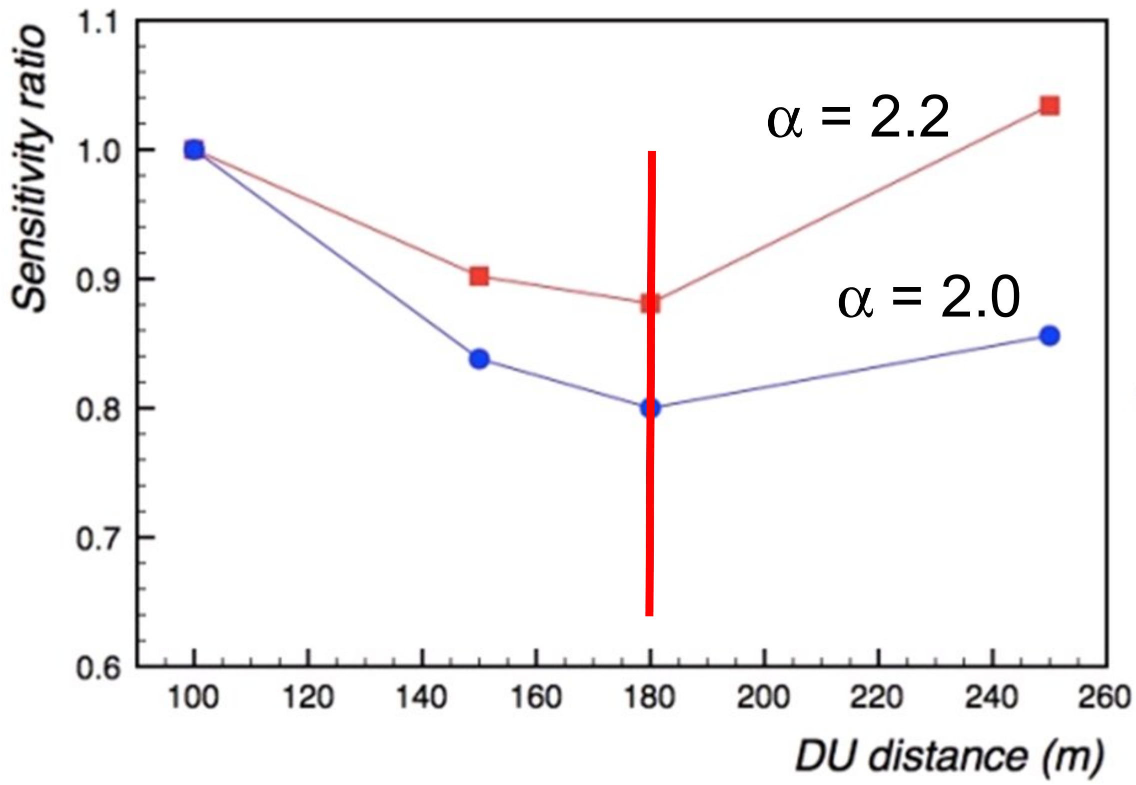
Footprint optimisation is ongoing

Slender string:
310 DUs,
distance 130 m



Optimisation Studies

<u>Example</u>: 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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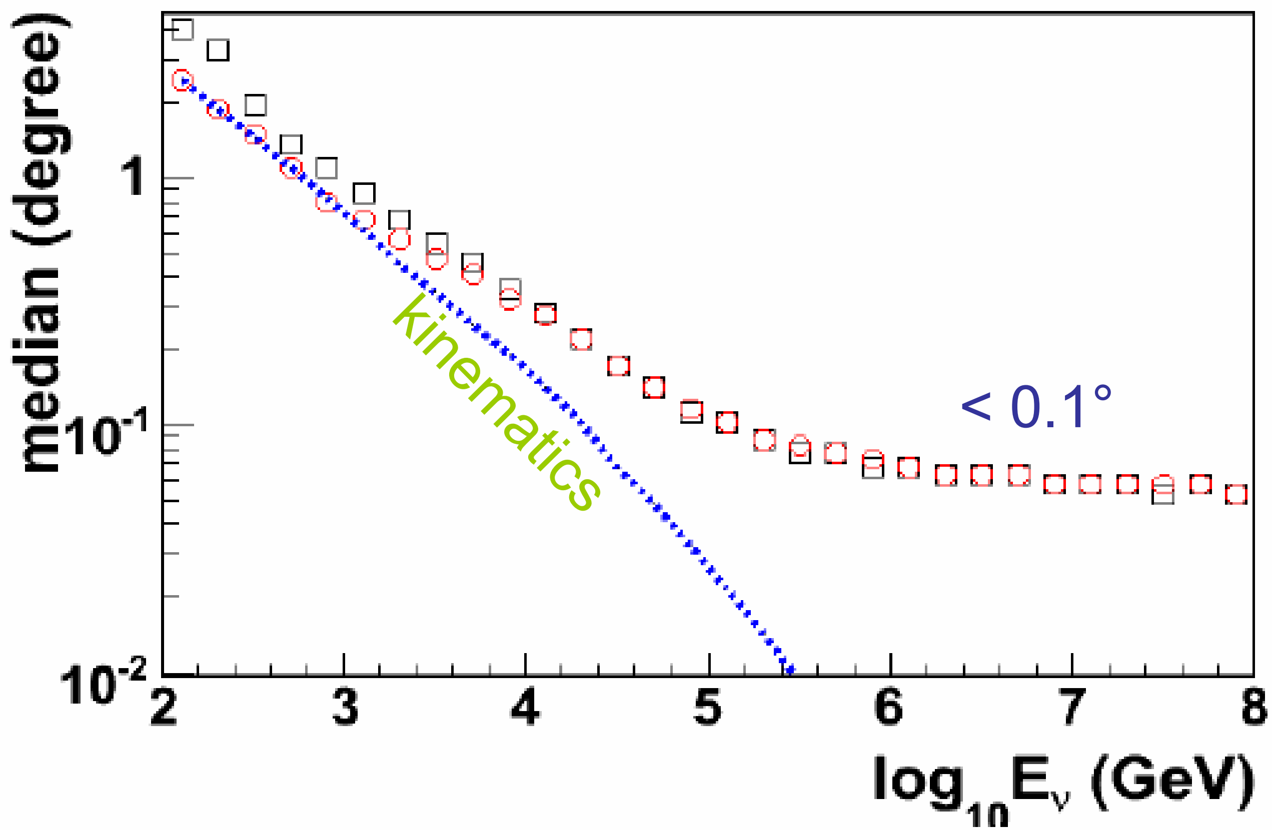
Angular Resolution

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



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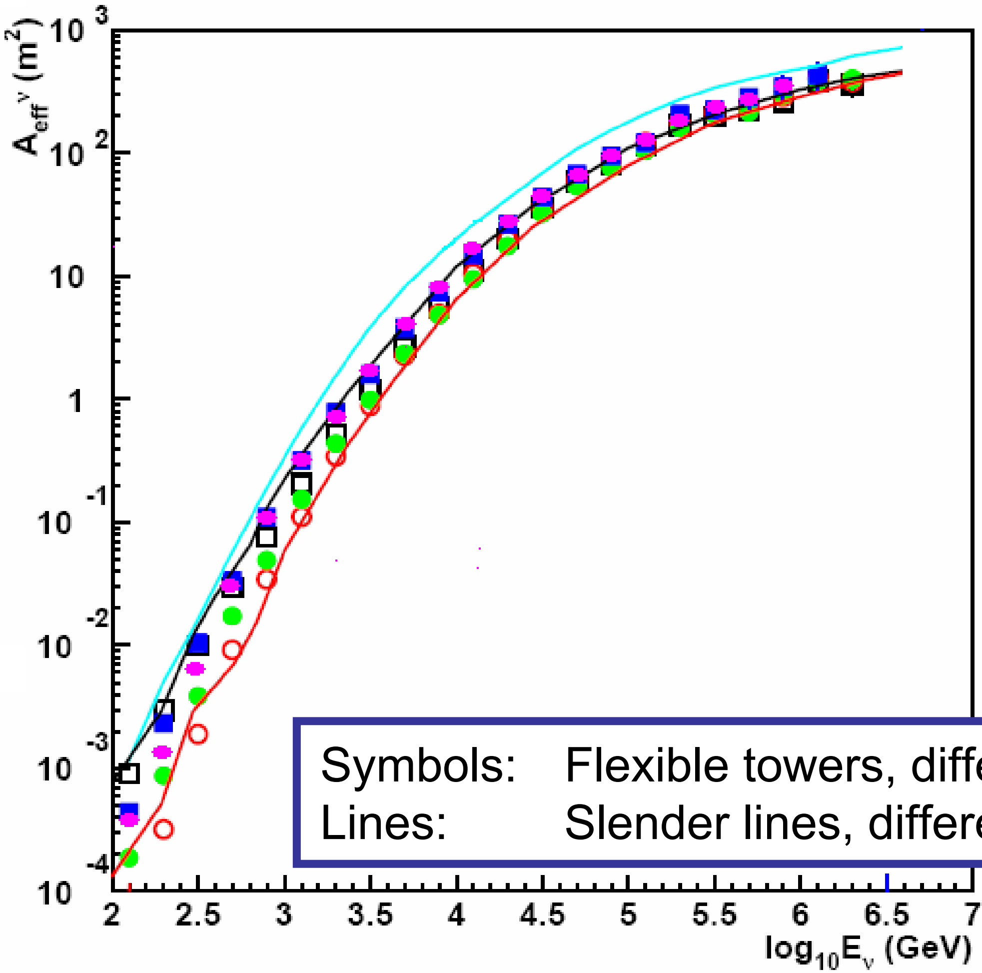
Effective Areas (per Building Block)



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

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

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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

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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

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

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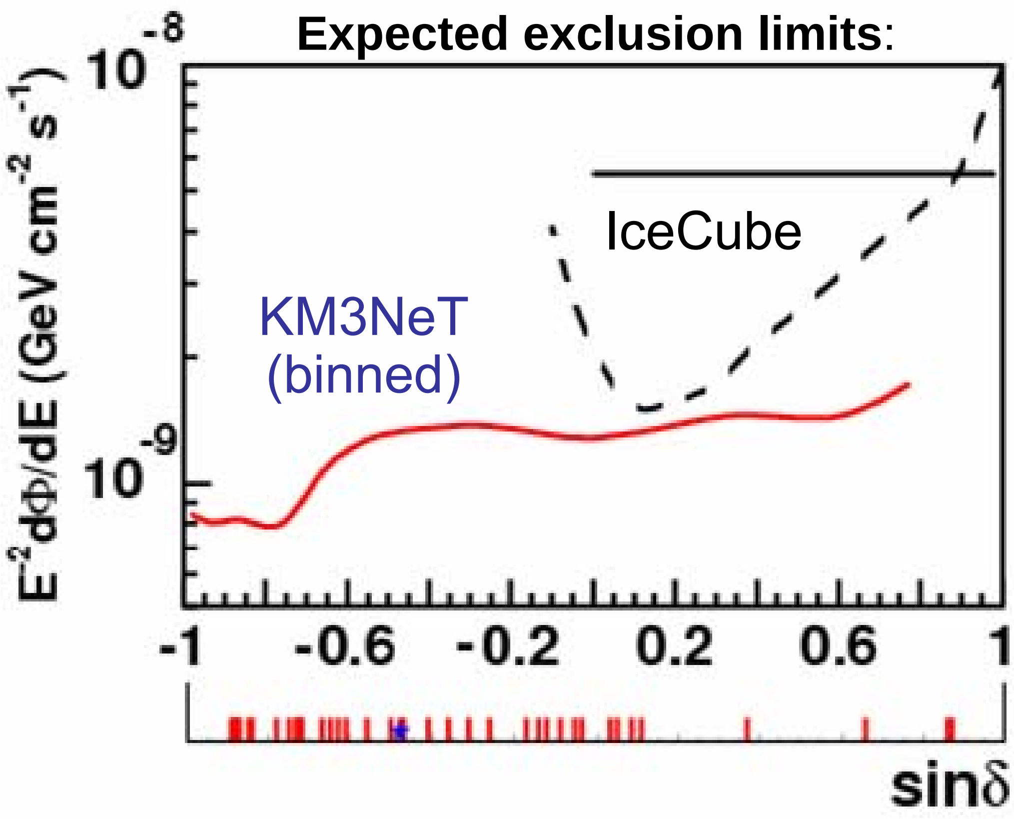
Point Source Sensitivity (1 Year)



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

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

Observation of RXJ1713 with 5σ within ~8 years

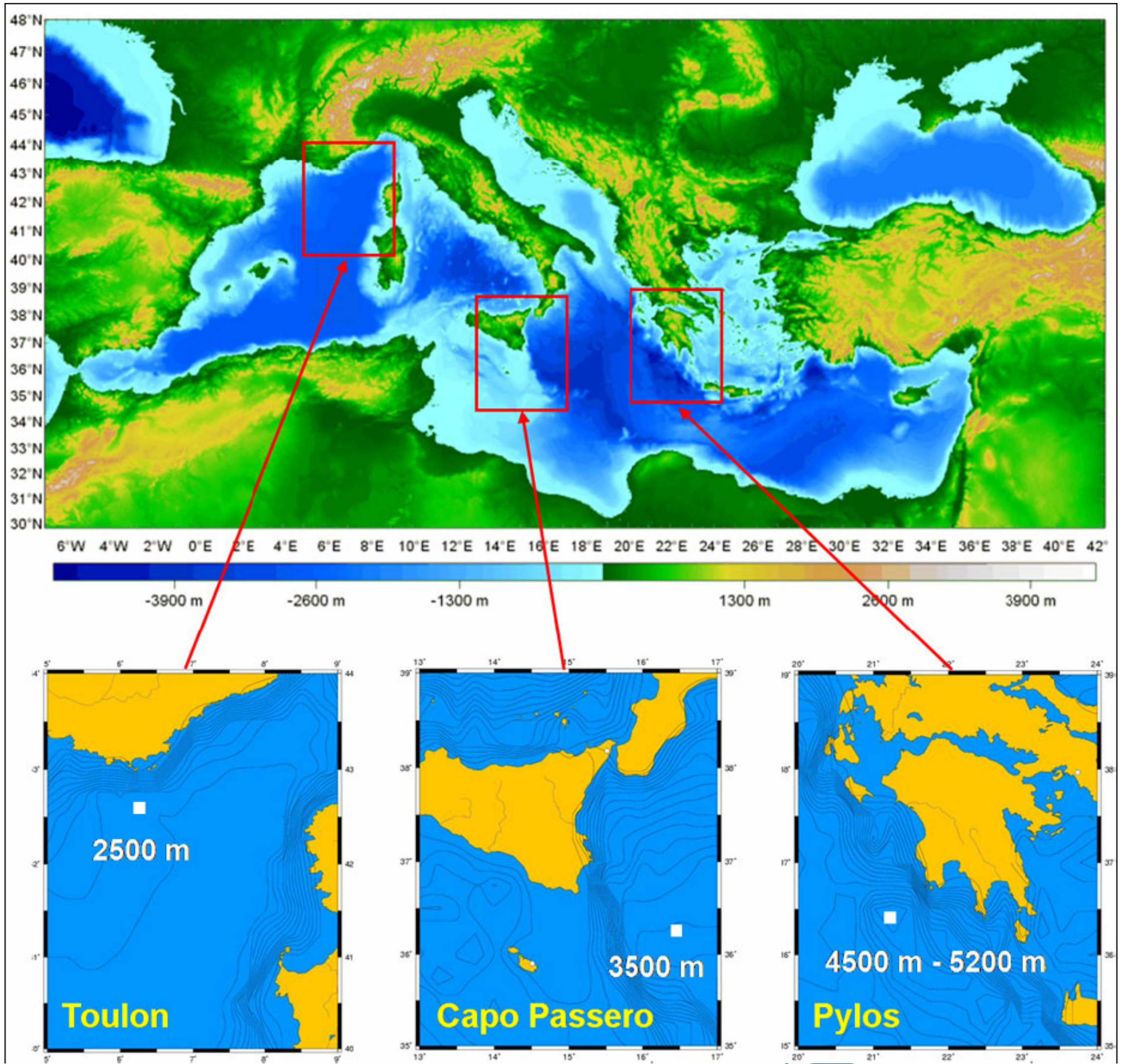
□ Observed Galactic TeV-γ sources (SNR, unidentified, microquasars)

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

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

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



Recent Developments

- Convergence towards a bar structure with multi-PMT OMs: 6m bars with 1 OM at each end
- Prototyping of components under way
- Simulation and “footprint” studies ongoing
- Possible cooperation with IceCube being explored (towards a Global Neutrino Observatory)

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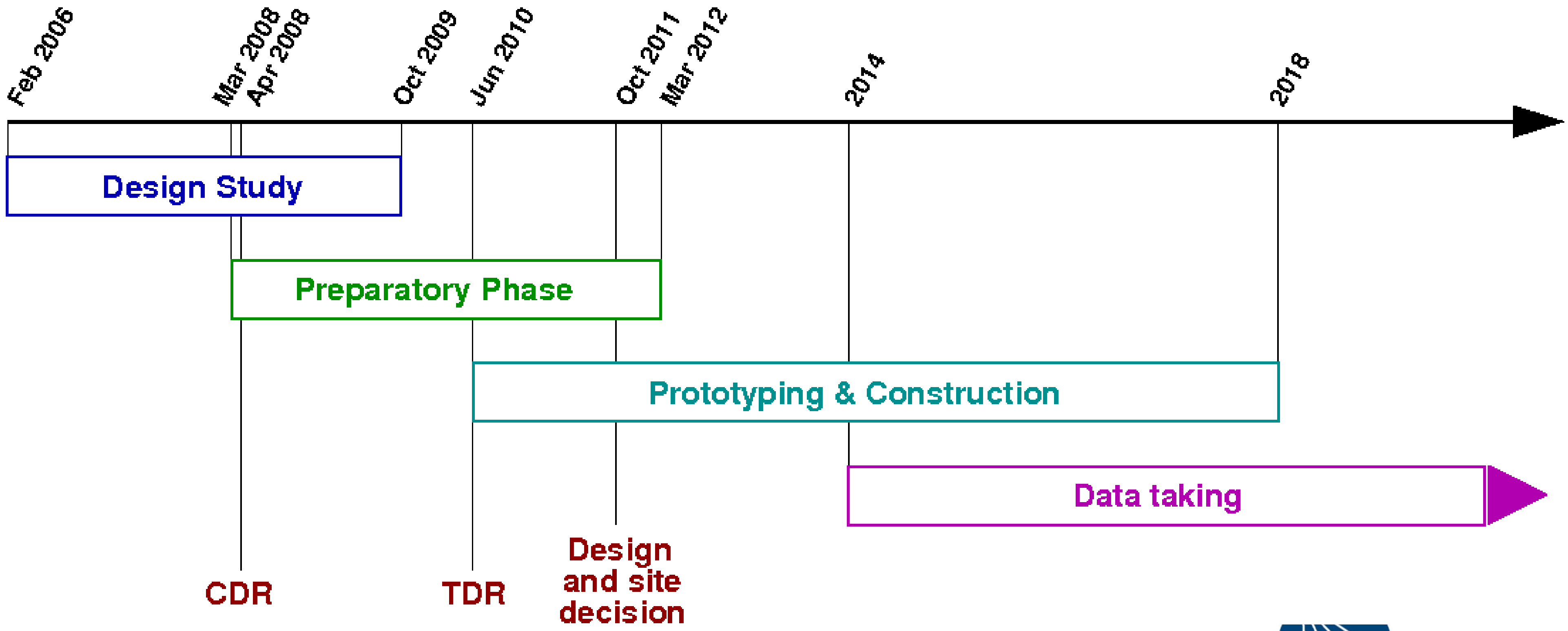
Next Steps and Timeline

- Next steps: Prototyping and design decisions
  - TDR public since June 2010
  - final decisions require site selection
  - expected to be achieved in 15 months
- Timeline:



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.
- Readiness for construction expected in 15 months
- An overall budget of ~250 M€ will be required. Staged implementation, with increasing discovery potential, is technically possible.
- Within 15 months, remaining design decisions have to be taken and the site question clarified.
- Installation could start in 2013 and data taking soon after.

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