7th International Workshop on Ring-Imaging Cherenkov Detectors (RICH 2010)
Cassis, France, 3-7 May 2010

The KM3NeT Neutrino Telescope

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04.05.2010

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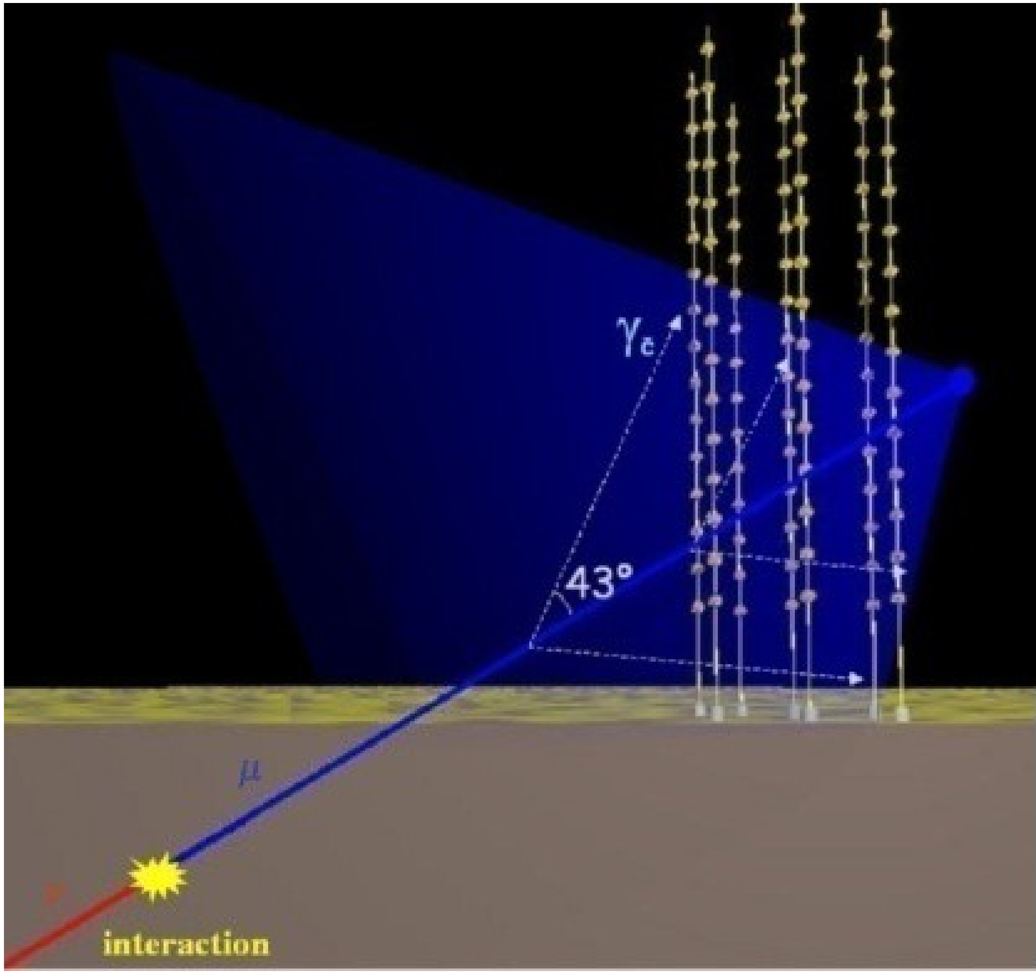
KM3NeT

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

The Neutrino Telescope World Map

What is KM3NeT ?

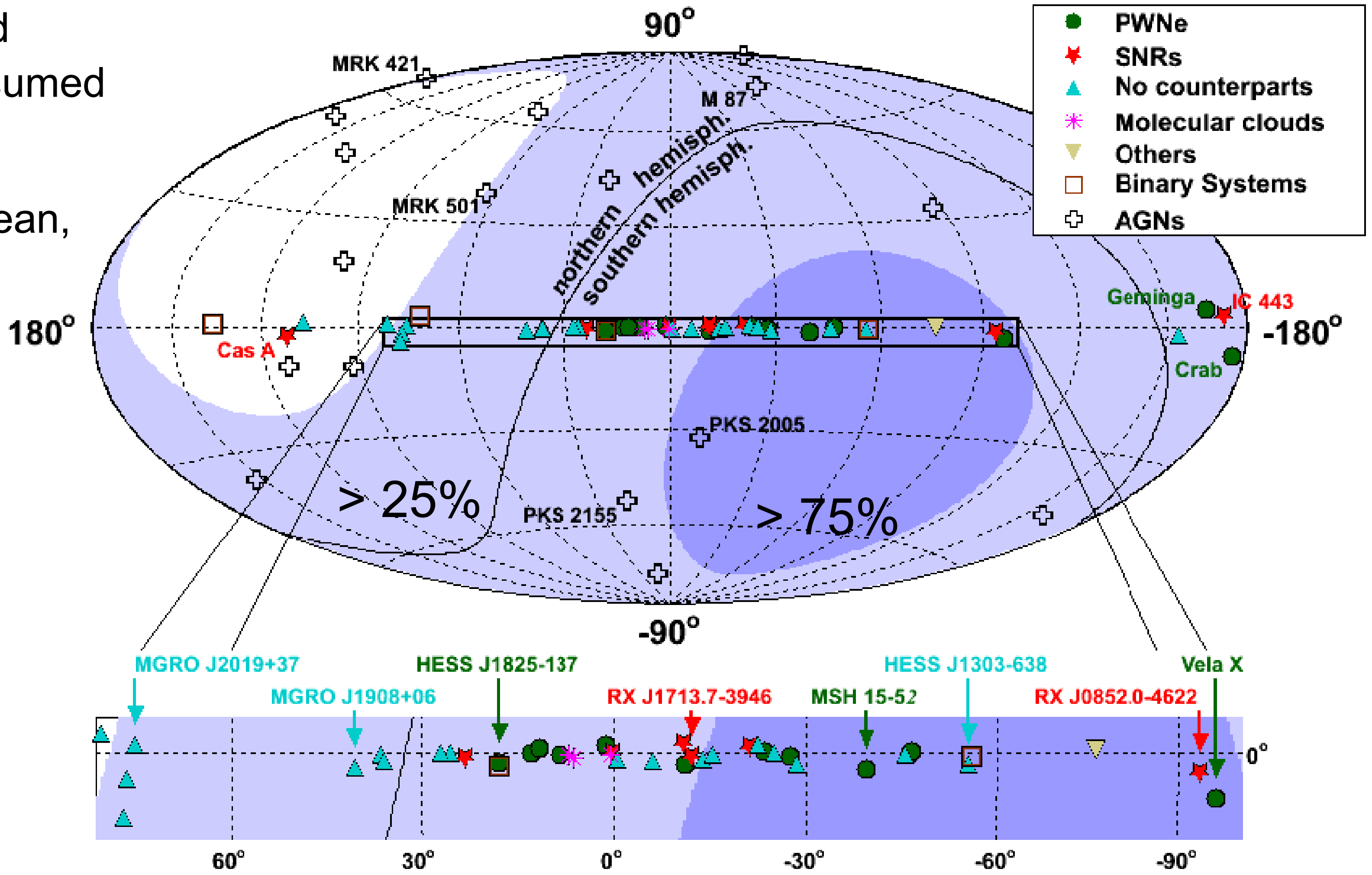
- Future cubic-kilometre scale neutrino telescope in the Mediterranean Sea
- Exceeds Northern-hemisphere telescopes by factor ~50 in sensitivity
- Exceeds IceCube sensitivity by substantial factor
- Focus of scientific interest: Neutrino astronomy in the energy range 1 to 100 TeV
- Provides node for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



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



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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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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

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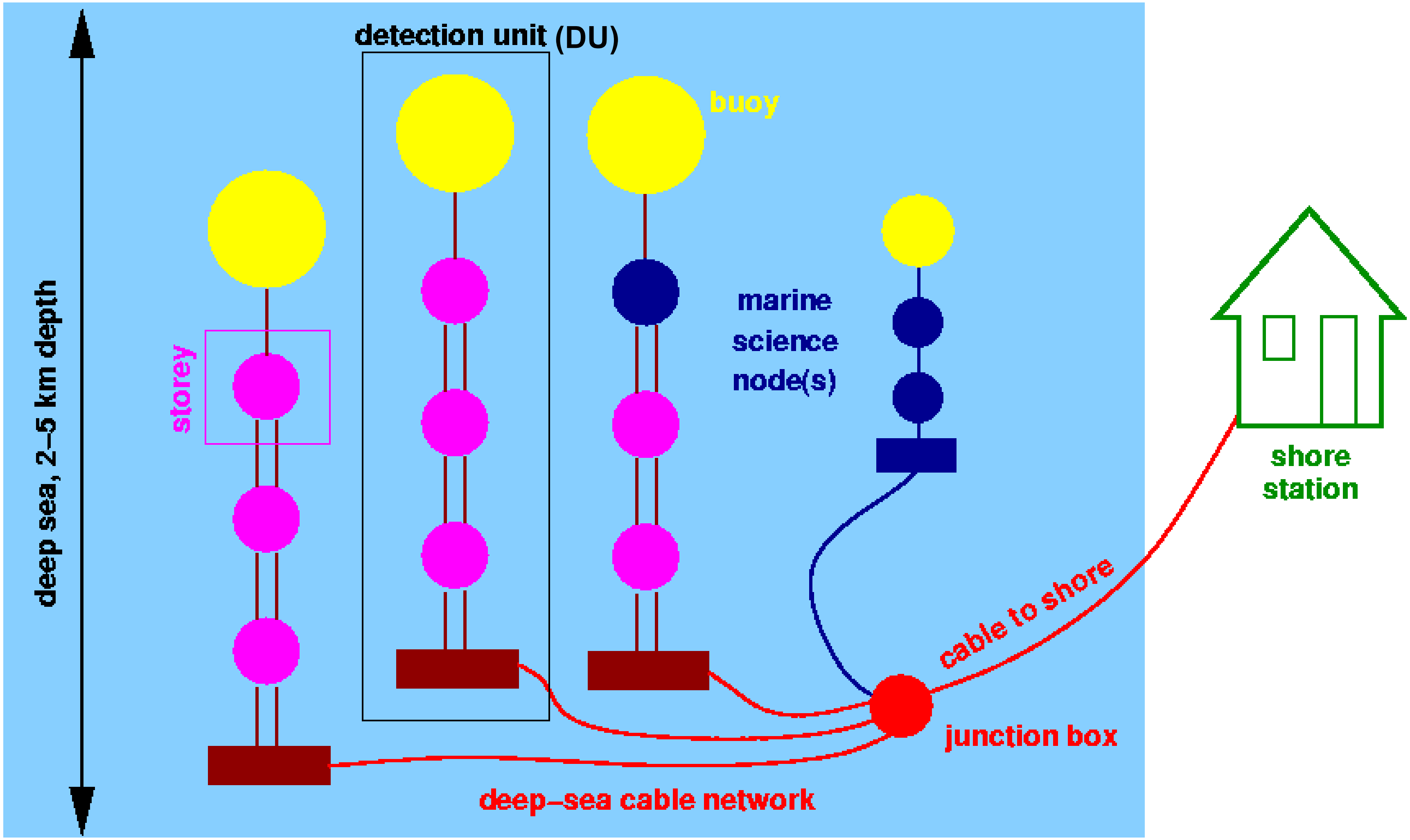
Further Challenges

- **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 KM3NeT Research Infrastructure (RI)



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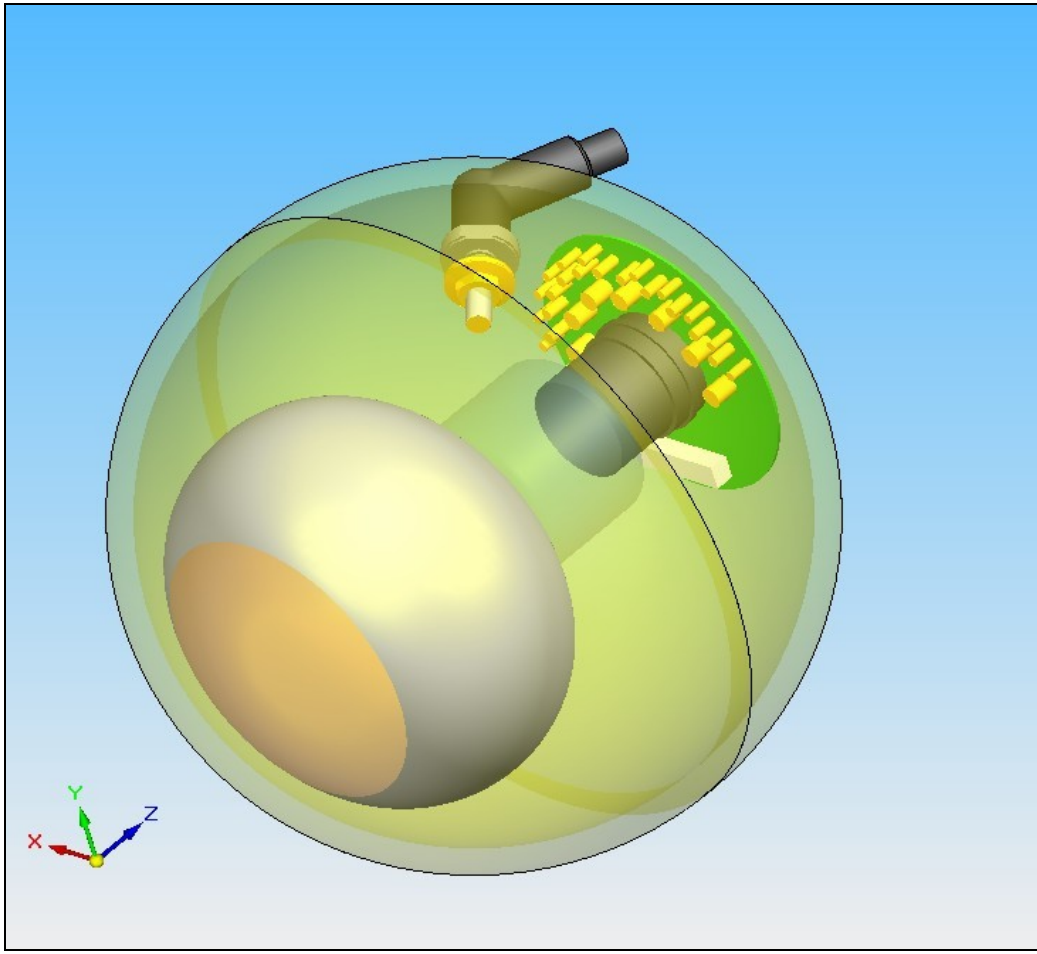
OM "classical": One PMT, no Electronics

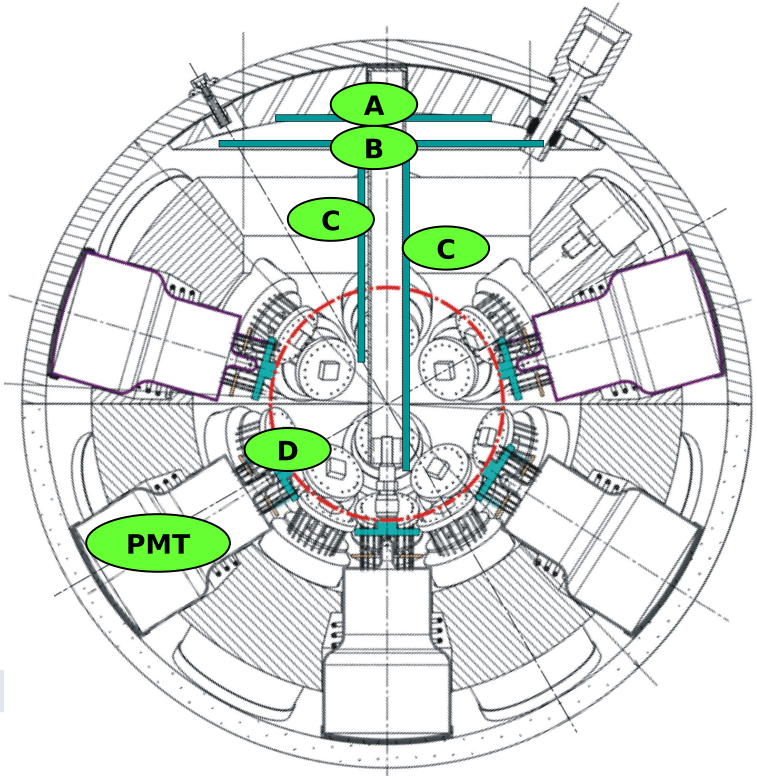
<u>Evolution from pilot projects</u>:

- 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



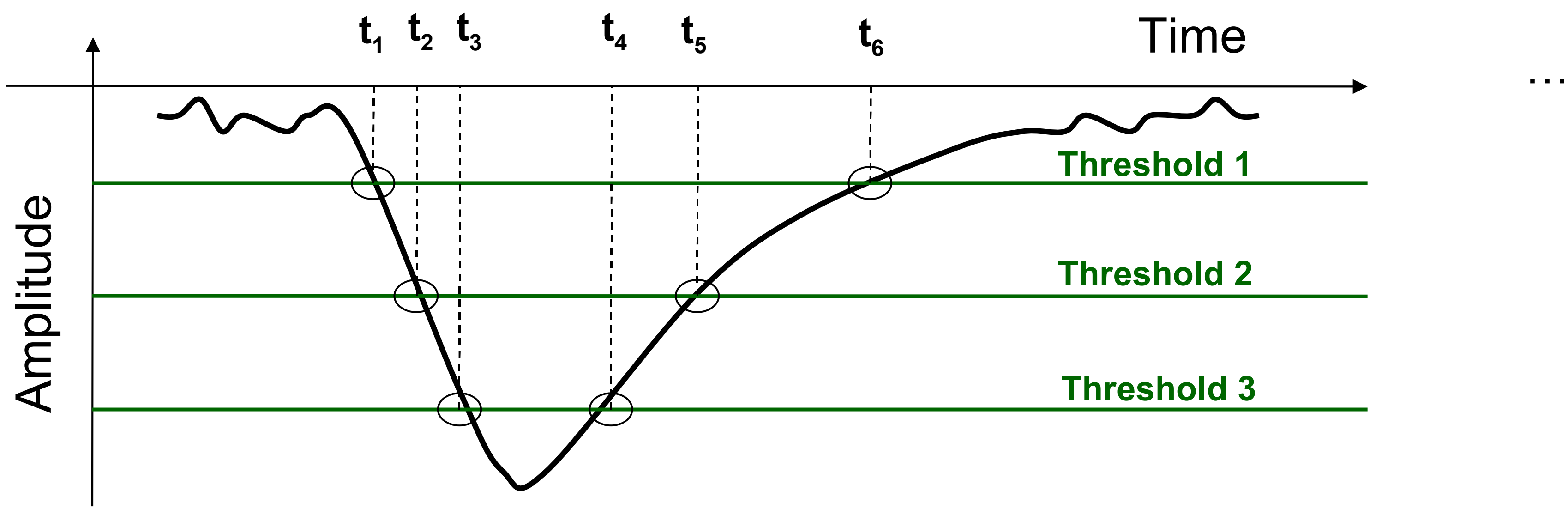
OM with many Small PMTs

- 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

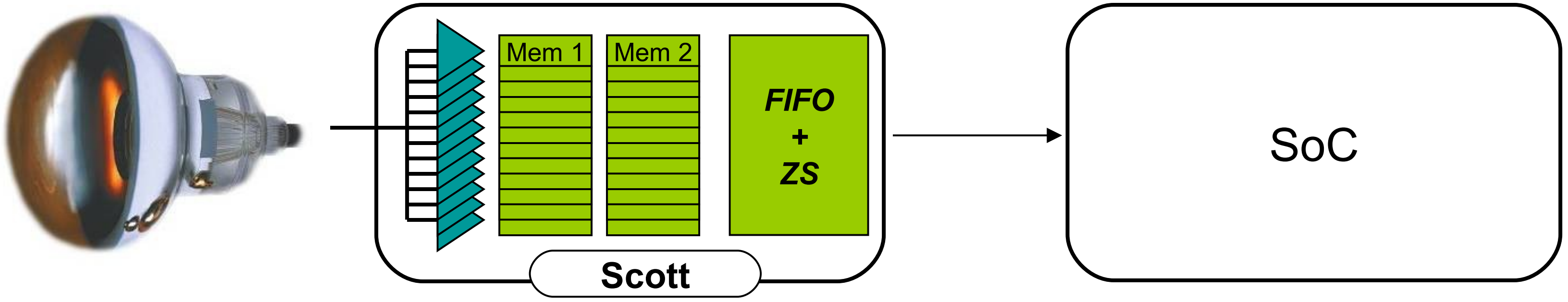
From the analogue signal to time stamped digital data:



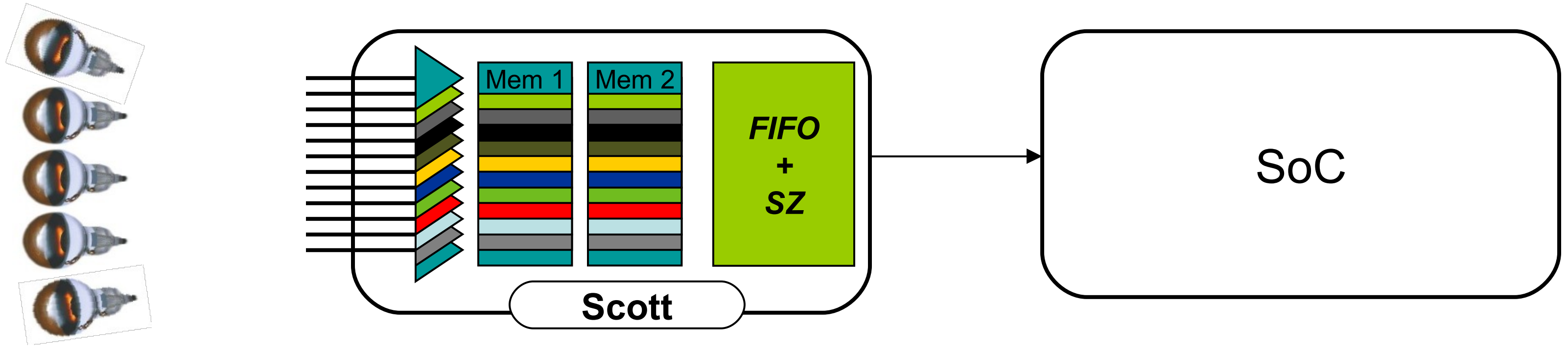
Analogue signal → **Front End ASIC** (Scott chip) → Digital data → **System on Chip (SoC)** (FPGA+processor) → Ethernet TCP/IP data link → **Shore**

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)

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 a task beyond the Design Study!

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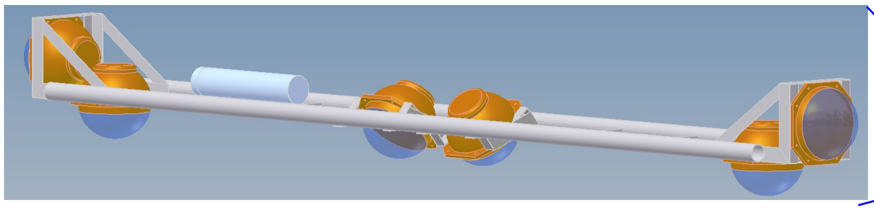
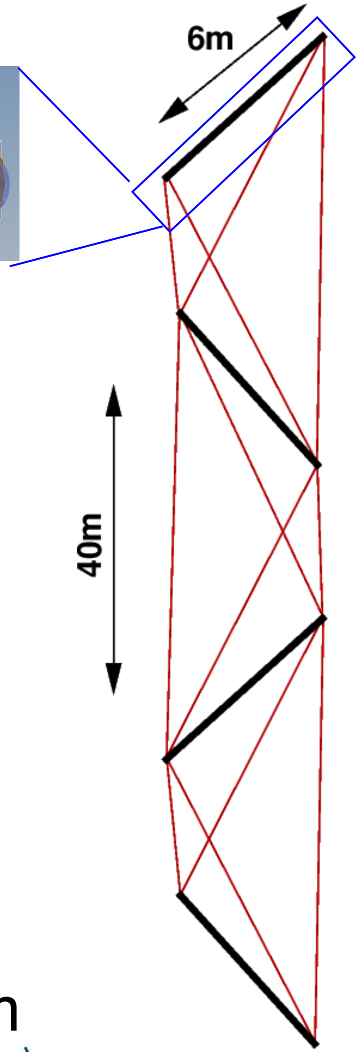
The Flexible Tower with Horizontal Bars





- 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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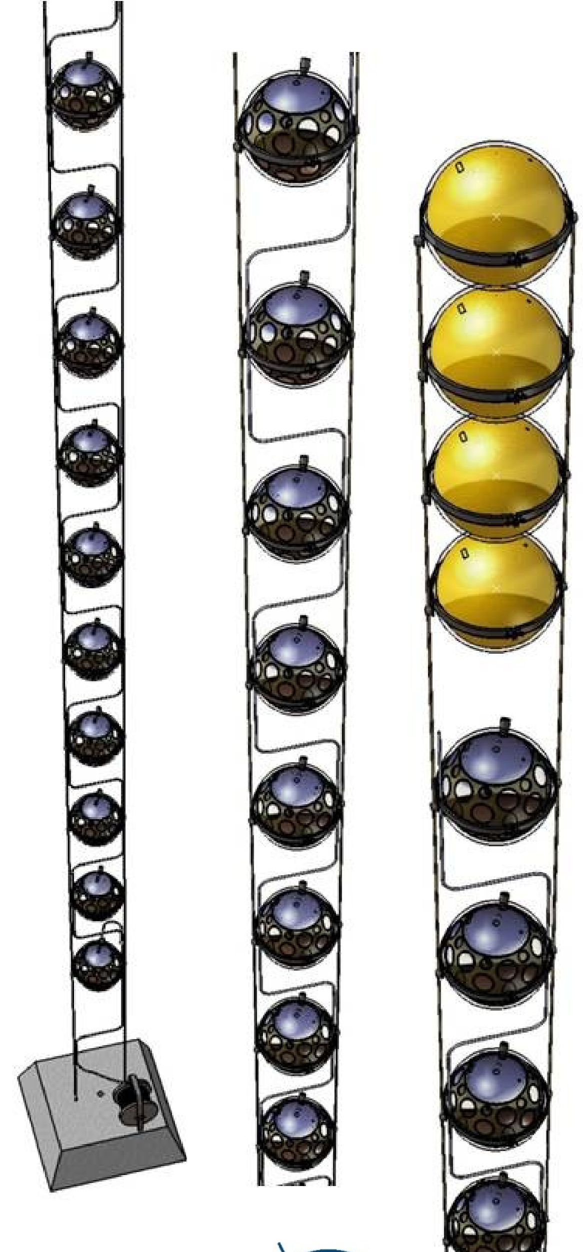
The Slender String

- 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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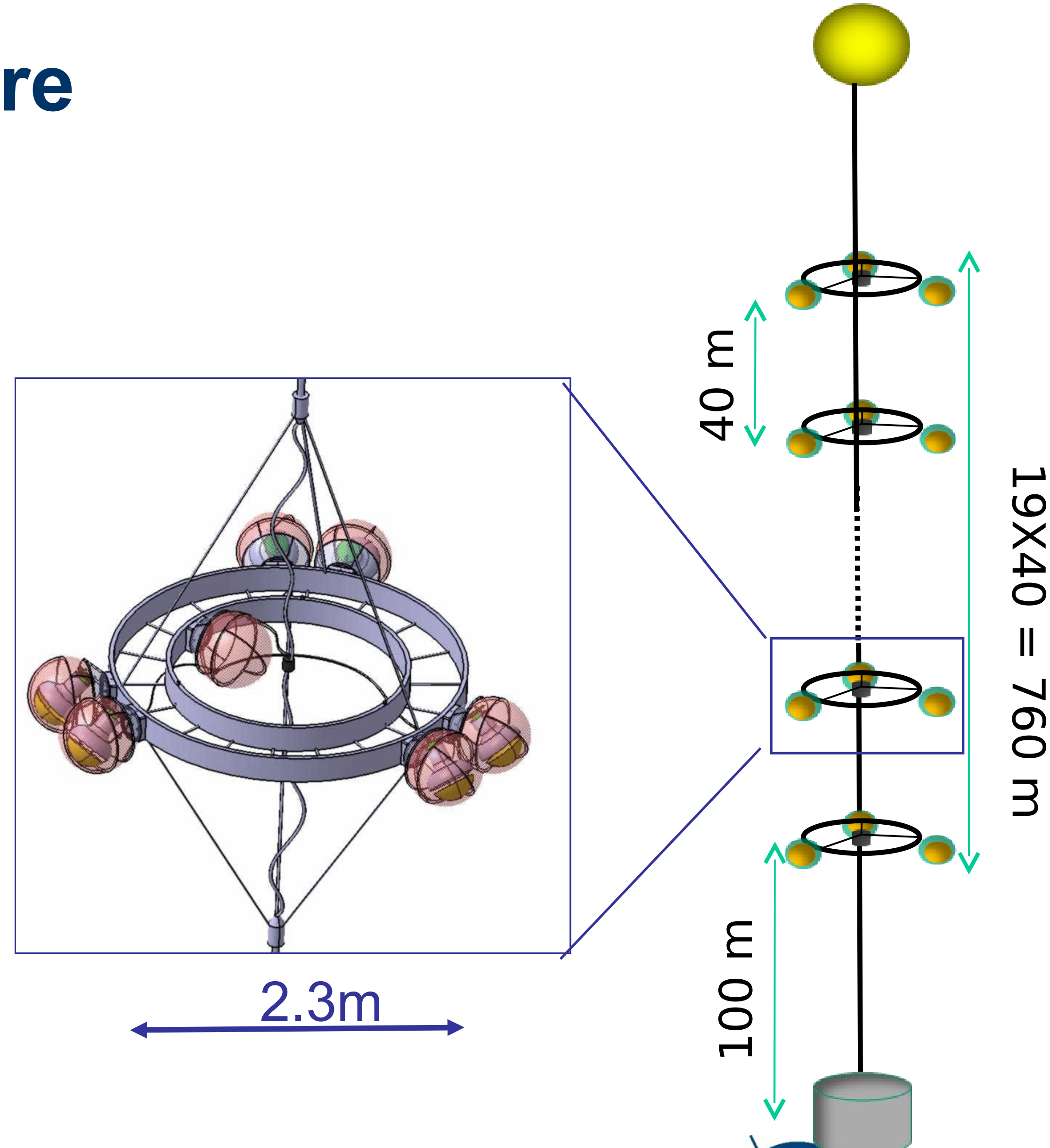
Triangle Structure

- 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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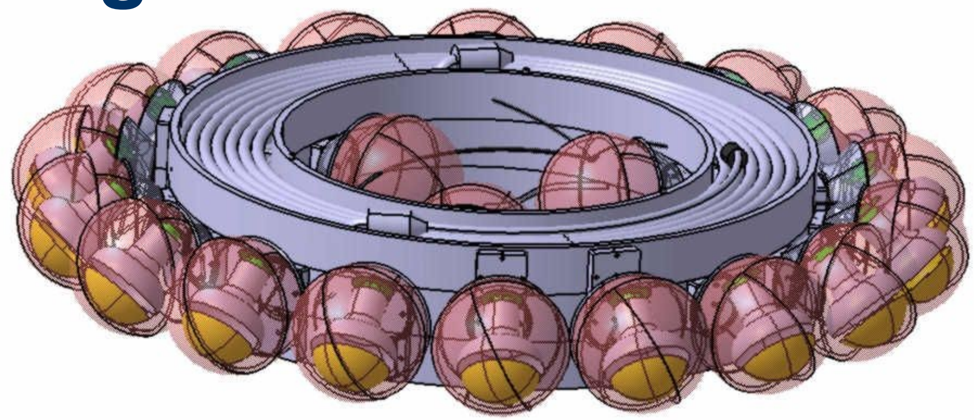
Deployment Strategy

- 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

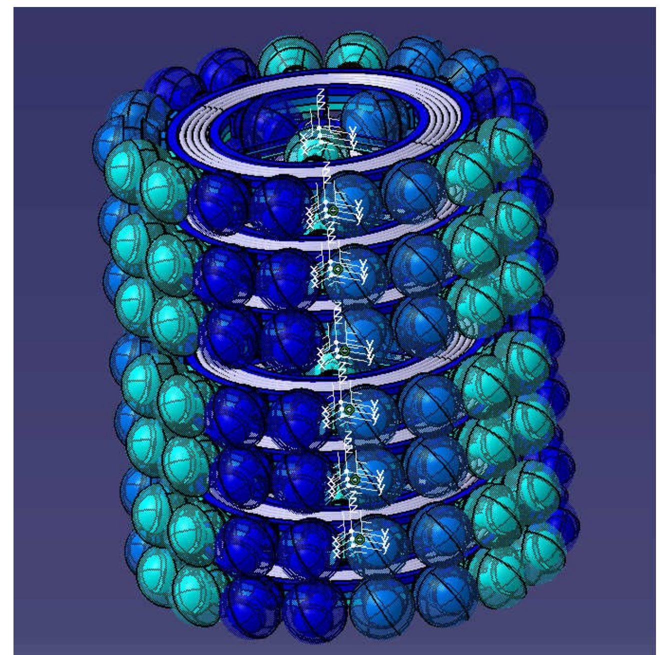
Slender string rolled up for self-unfurling:



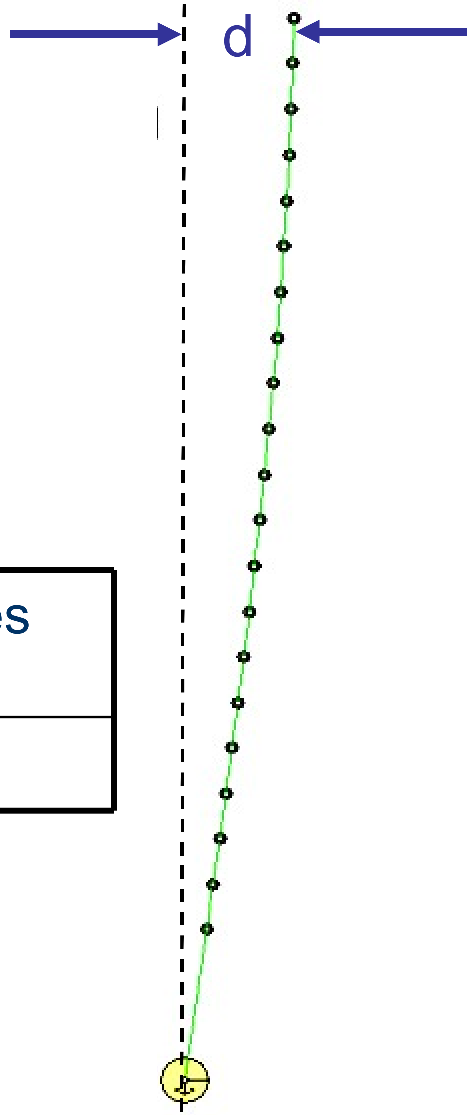
Successful deployment test 16. Dec. 2009

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:

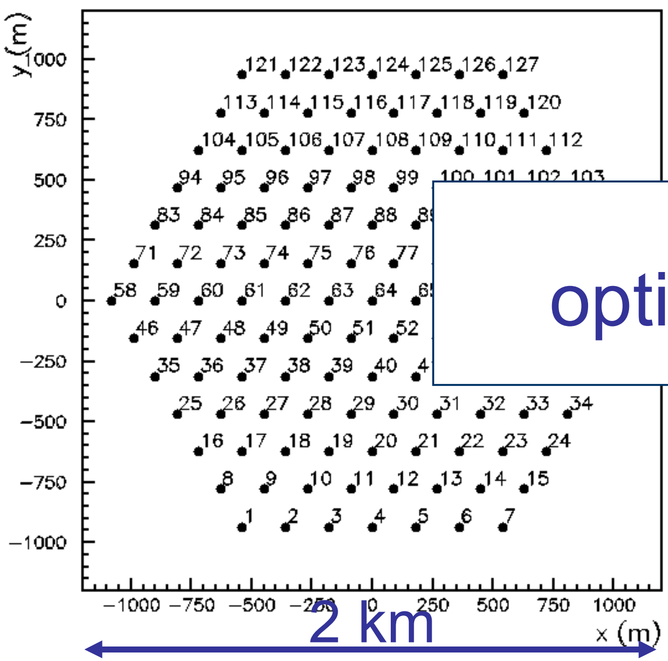
Current [cm/s]	flexible tower d [m]	slender string d [m]	triangles d [m]
30	84.0	83.0	87.0

- Torsional stability also checked

Detector Building Blocks

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

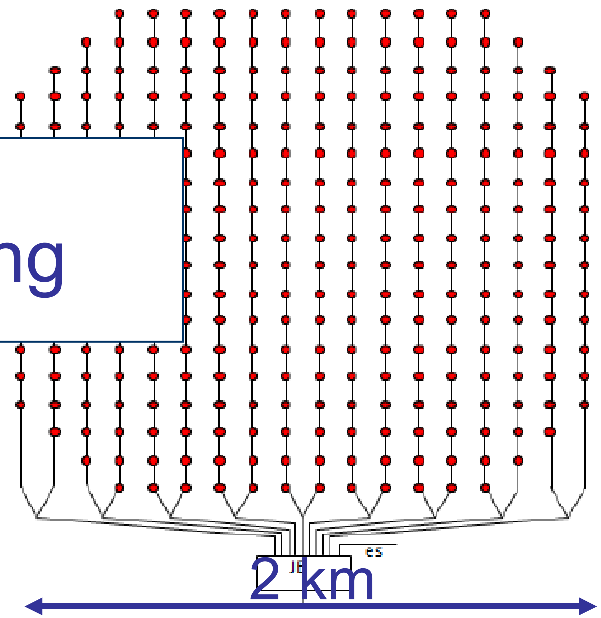
different „building block footprints“



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

Footprint optimisation is ongoing

Slender string:
310 DUs,
distance 130 m



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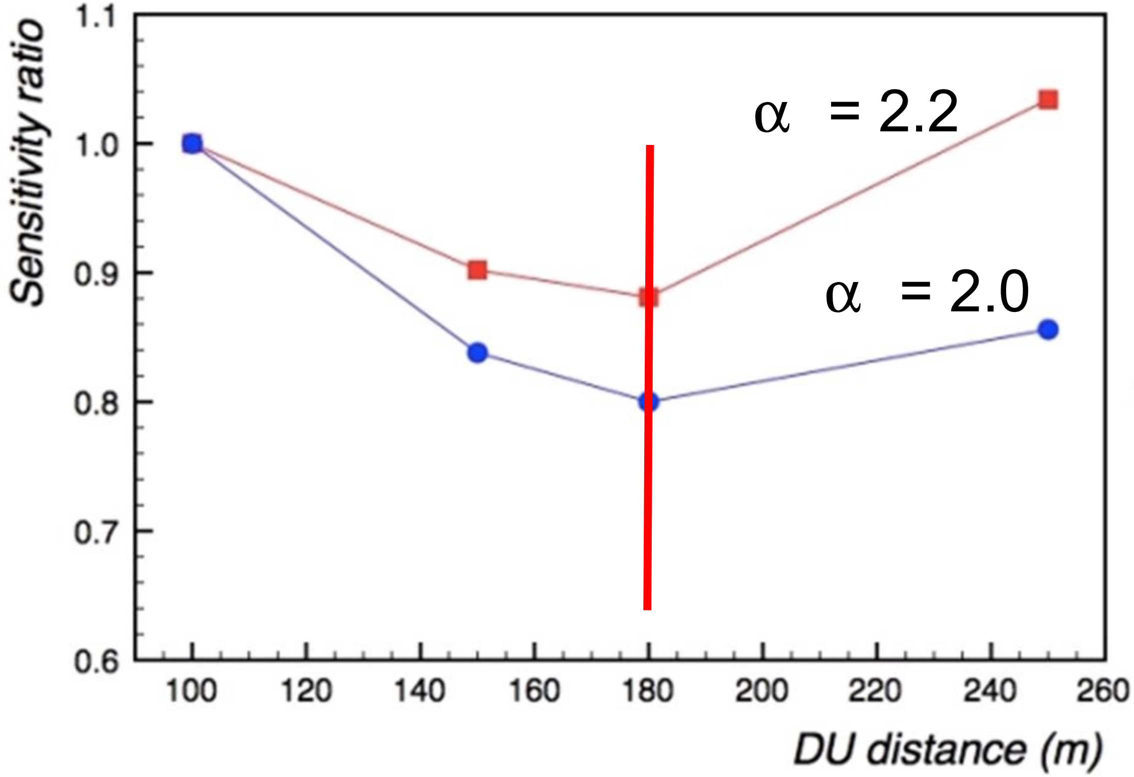
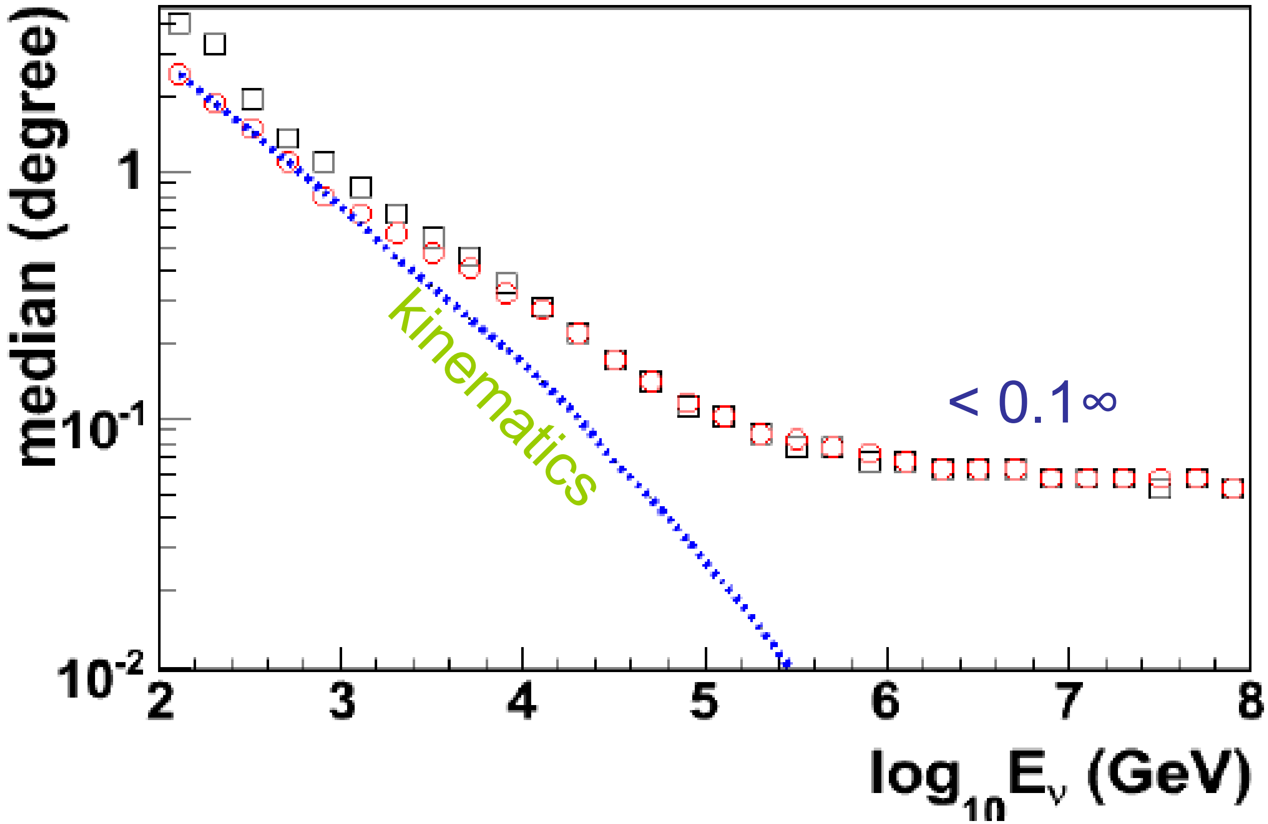
Optimisation Studies

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

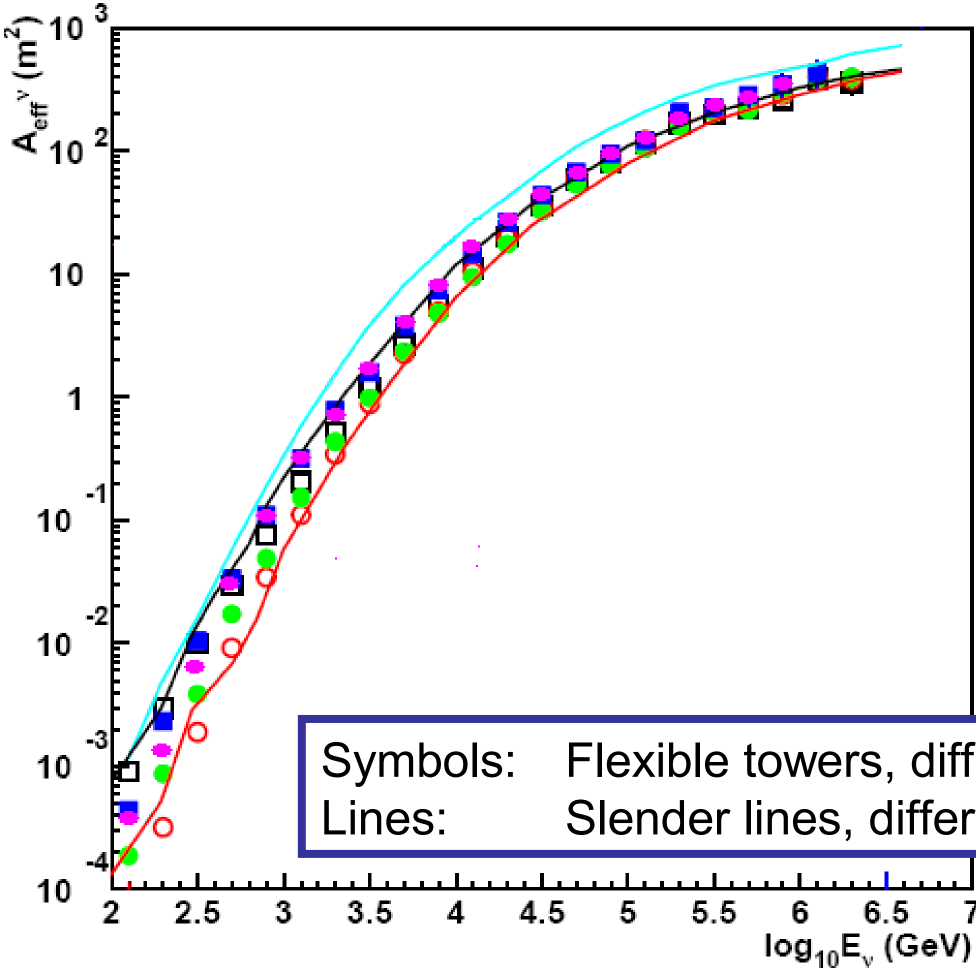


Angular Resolution

- 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

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

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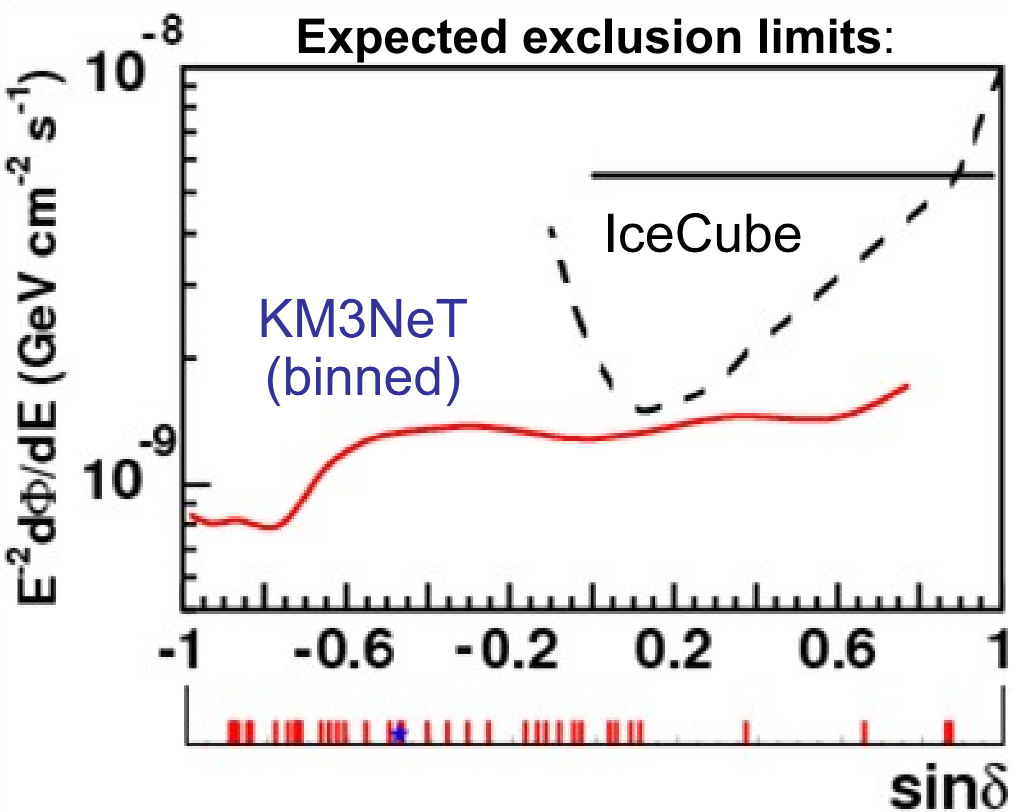
KM3NeT: Full Configuration

- 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

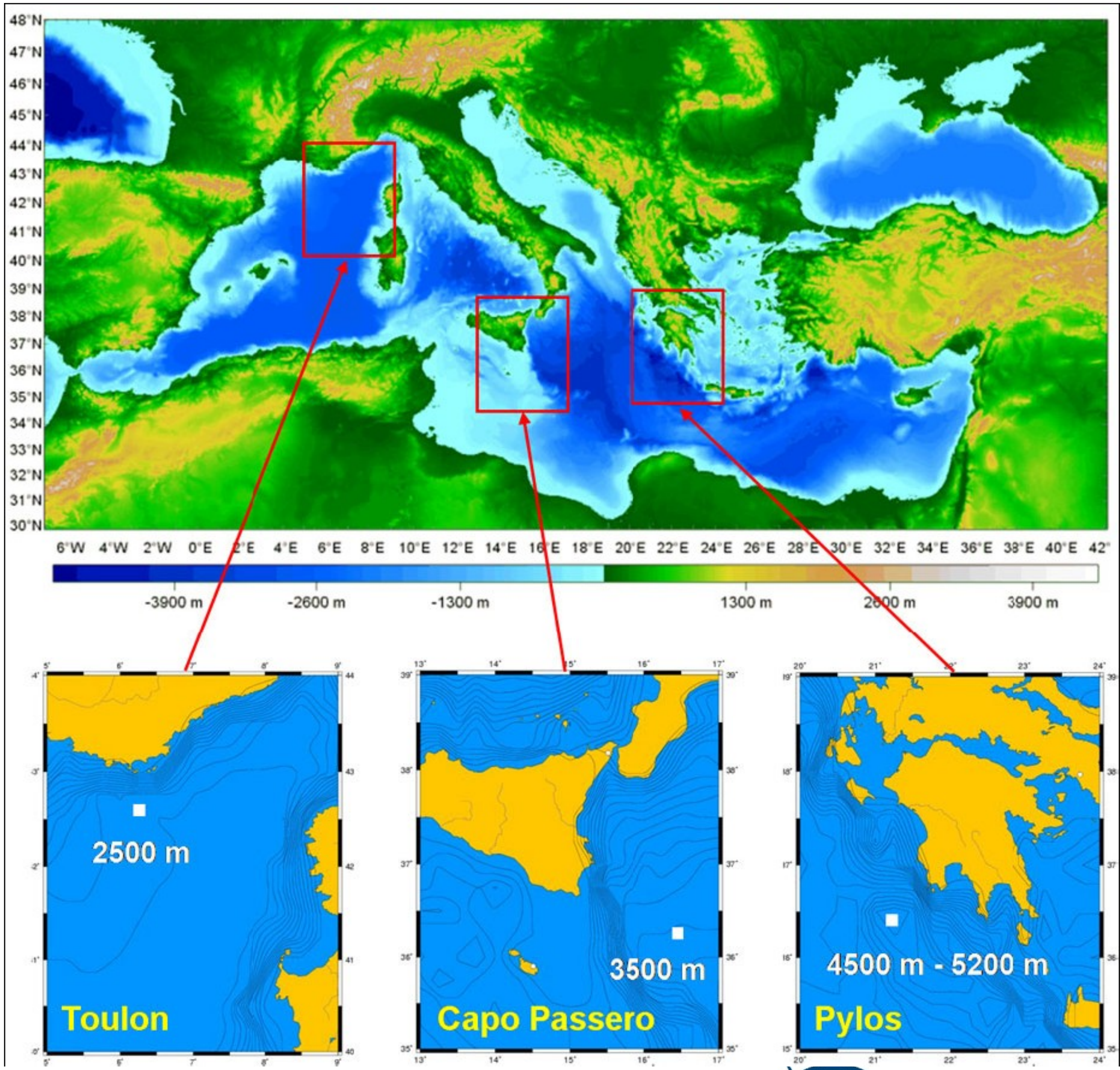
Observed Galactic TeV-γ sources (SNR, unidentified, microquasars)

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

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

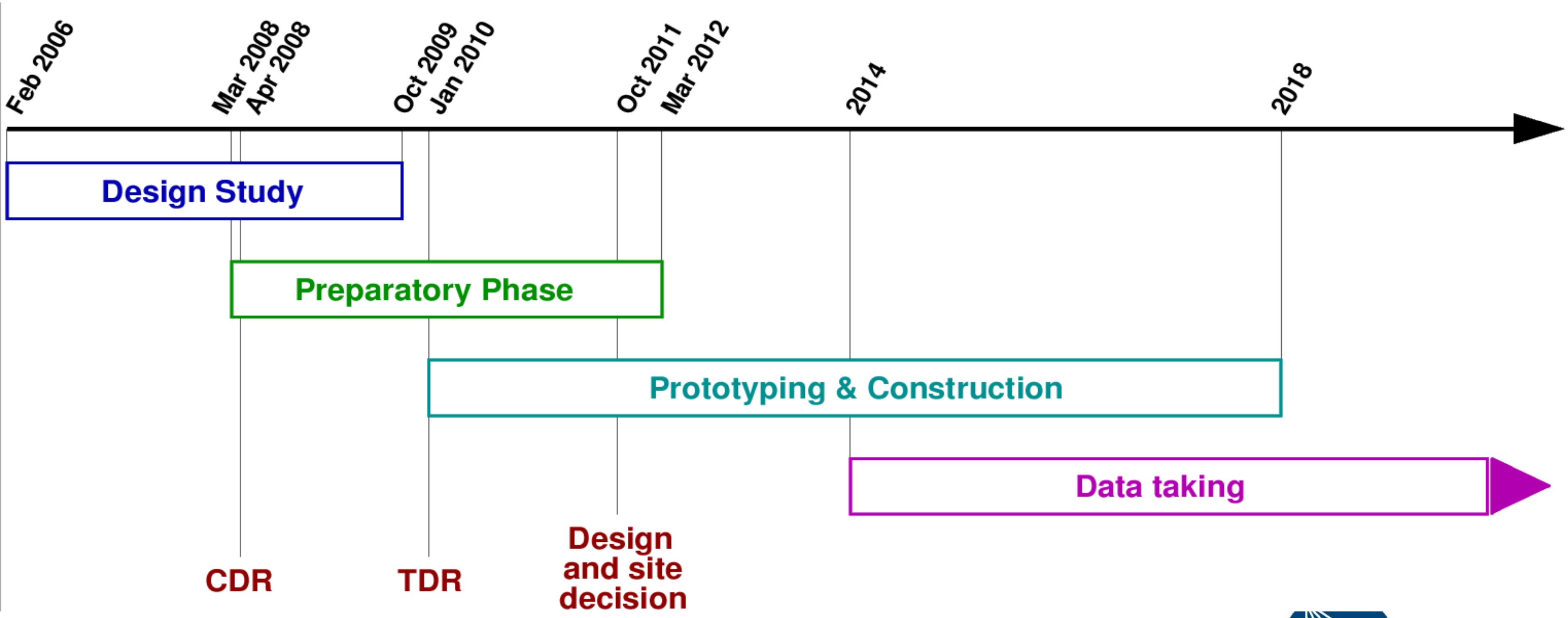
Candidate Sites

- 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



Next Steps and Timeline

- Next steps: Prototyping and design decisions
  - TDR public in 3-4 weeks
  - final decisions require site selection
  - expected to be achieved in 18 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 18 months
- 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.

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