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

Uli Katz
ECAP / Univ. Erlangen
17.09.2010

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Friedrich-Alexander-Universität Erlangen-Nürnberg

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

KM3NeT

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

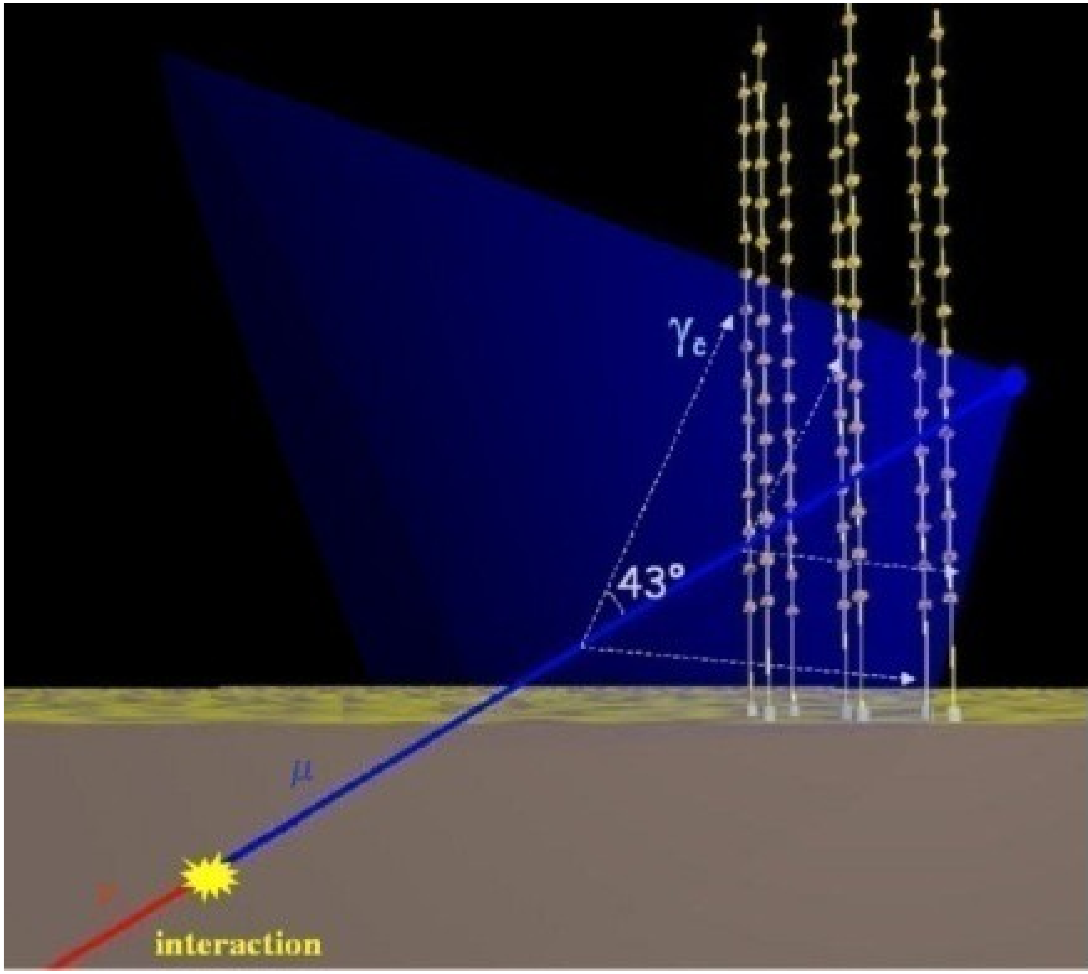
KM3NeT

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# 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



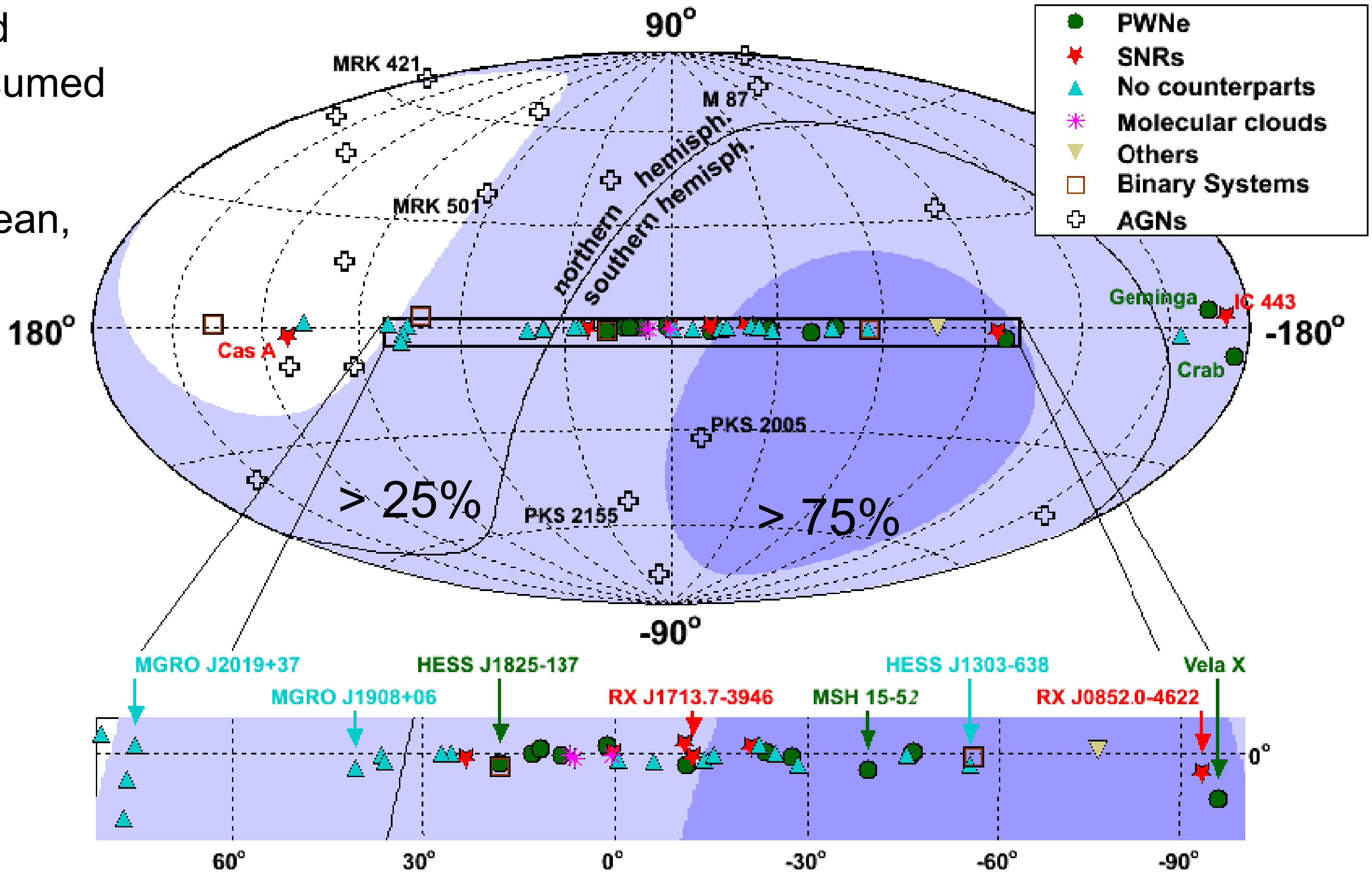



ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# 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




ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# 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"

# 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

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# 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

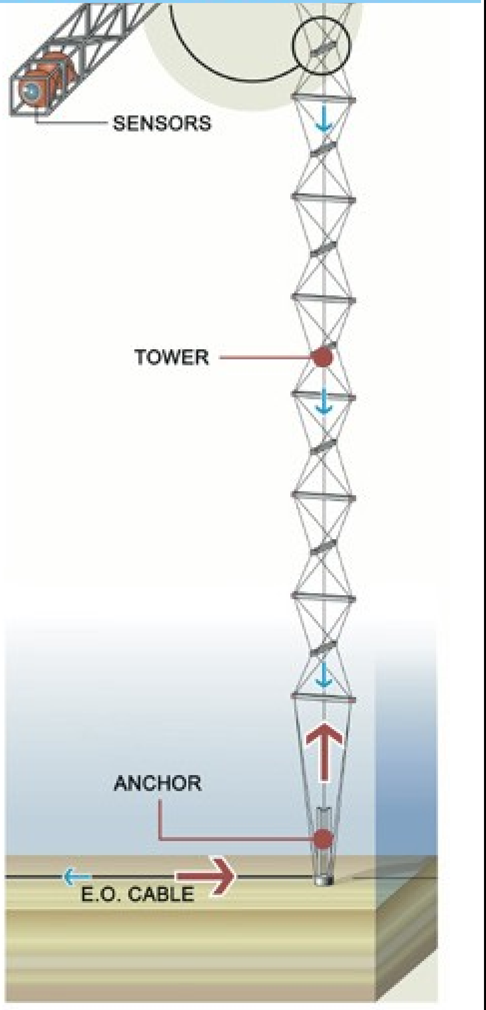
- **NEMO and NESTOR**
  Major contributions to R&D
  Site exploration

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

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# NEMO


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



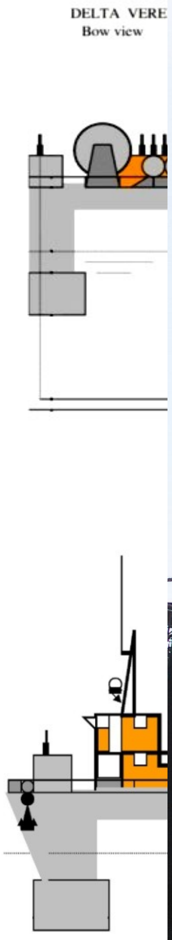

Example: Flexible tower

- ~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

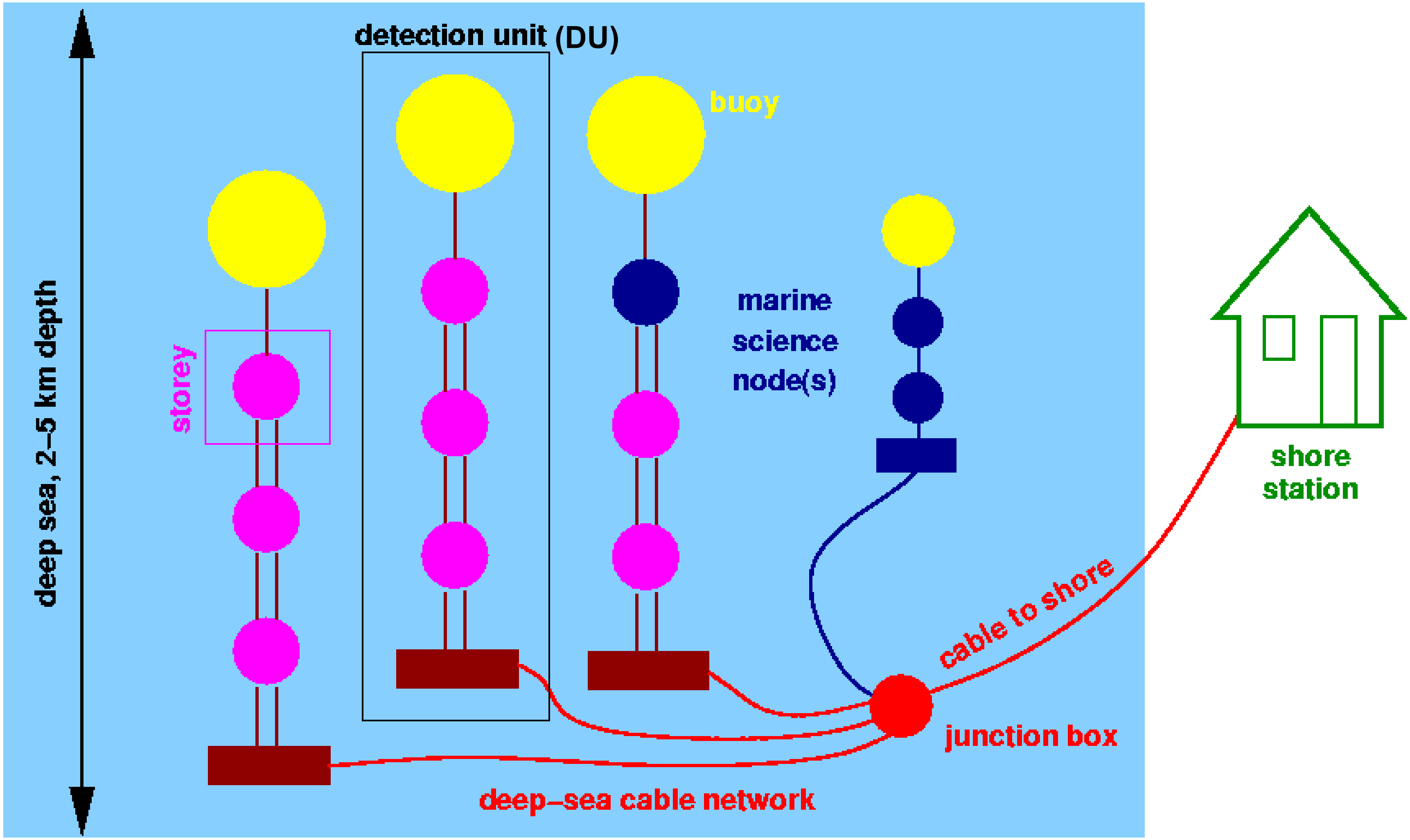




n

NeT

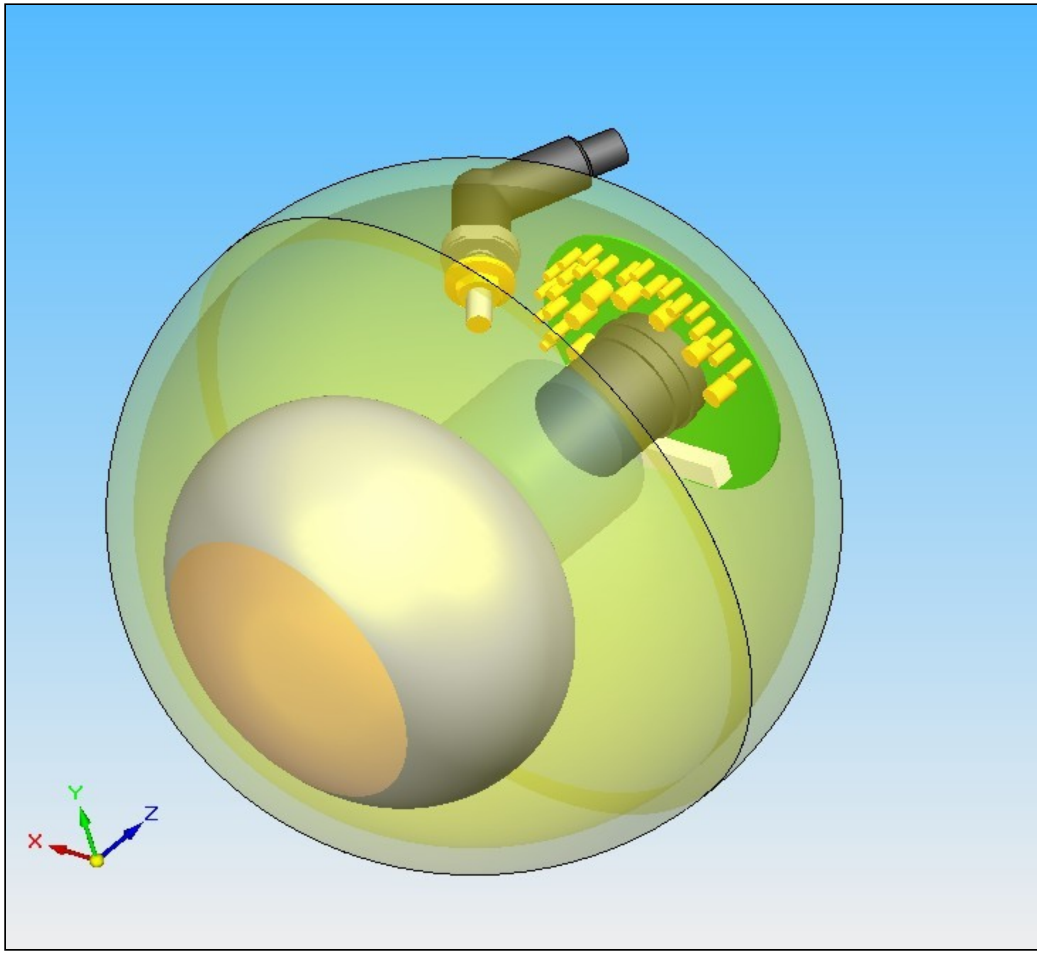
# The KM3NeT Research Infrastructure (RI)



# OM "classical": One PMT, no Electronics

Evolution from pilot projects:

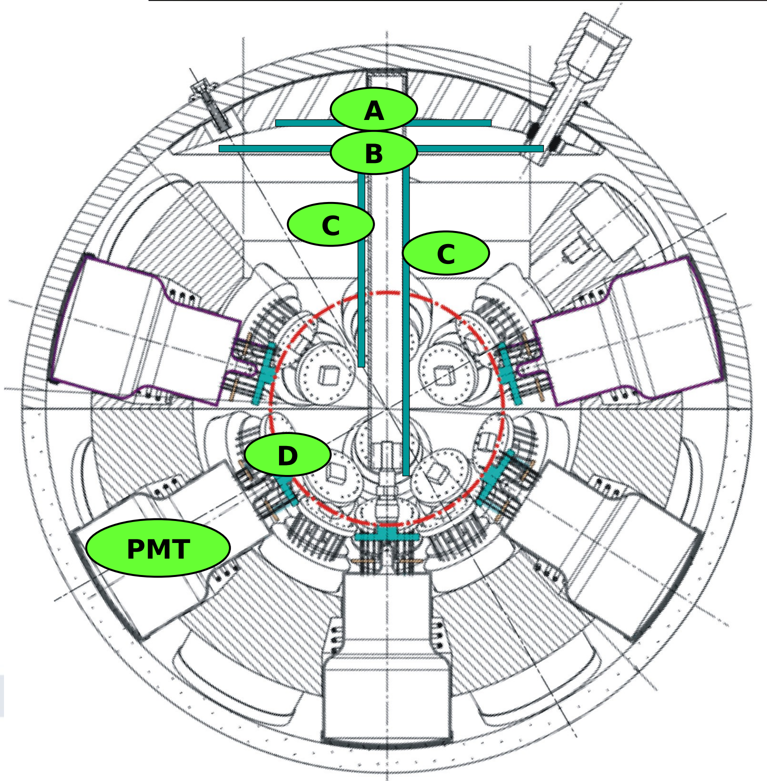
- 8-inch PMT, increased quantum efficiency (instead of 10 inch)
- 13-inch glass sphere (instead of 17 inch)
- no valve (requires "vacuum" assembly)
- no mu-metal shielding




ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

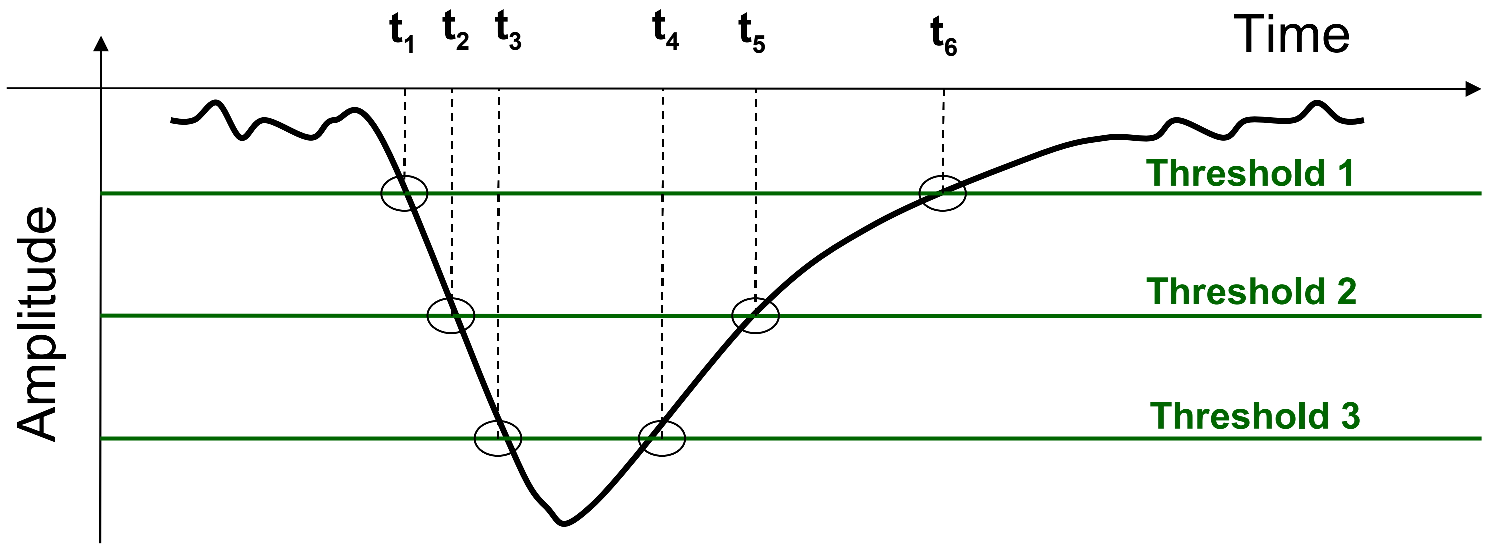
# OM with many Small PMTs

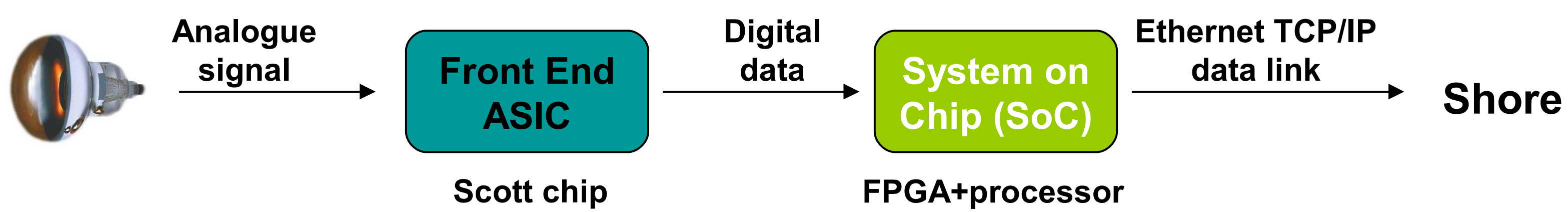
- 31 3-inch PMTs in 17-inch glass sphere (cathode area~ 3x10” PMTs)
  - 19 in lower, 12 in upper hemisphere
  - Suspended by compressible foam core
- 31 PMT bases (total ~140 mW) (**D**)
- Front-end electronics (**B,C**)
- Al cooling shield and stem (**A**)
- Single penetrator
- 2mm optical gel
- Advantages: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

# 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

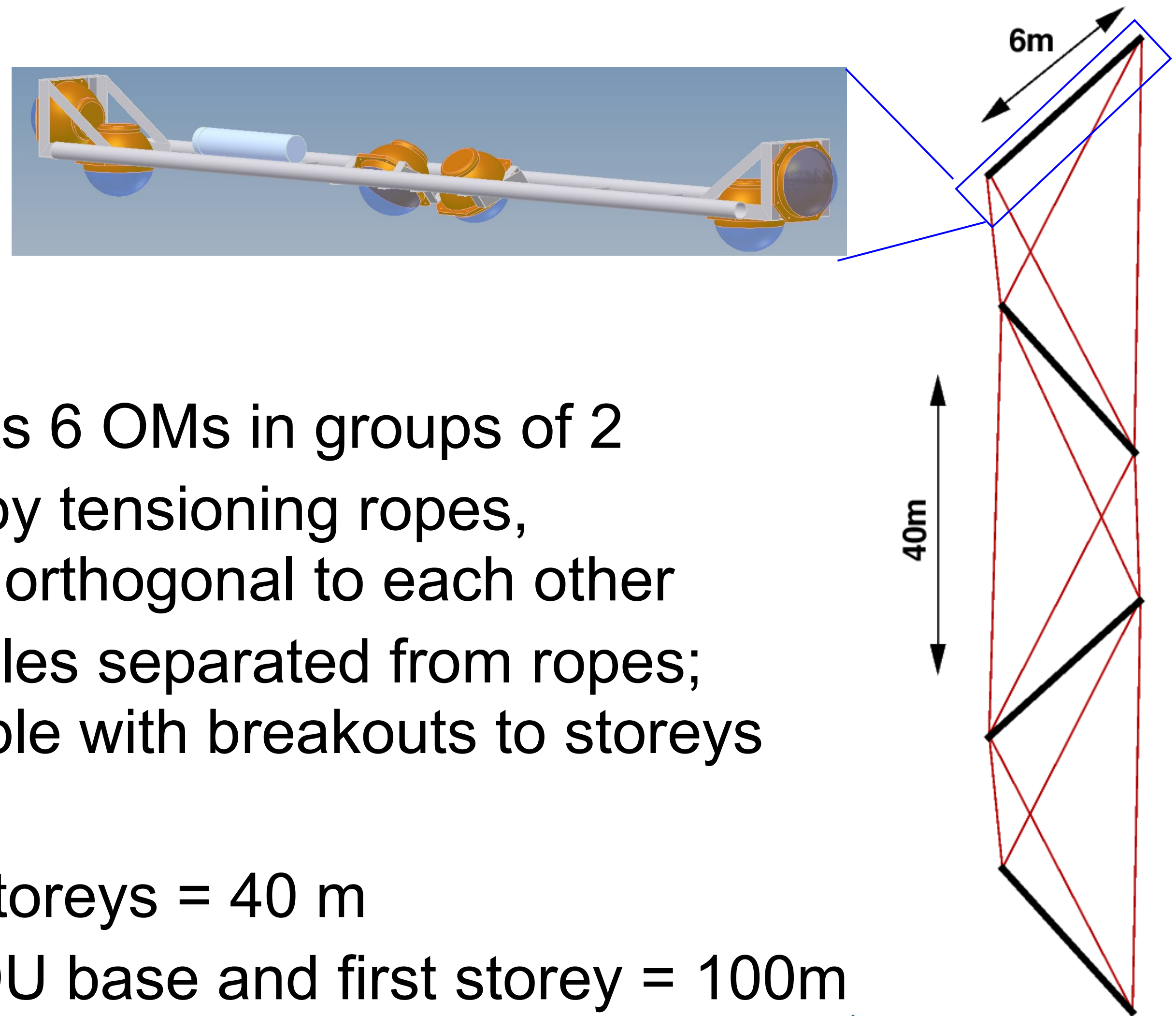
Reminder:

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

Careful prototype tests are required before taking final decisions

This is an ongoing task

# The Flexible Tower with Horizontal Bars

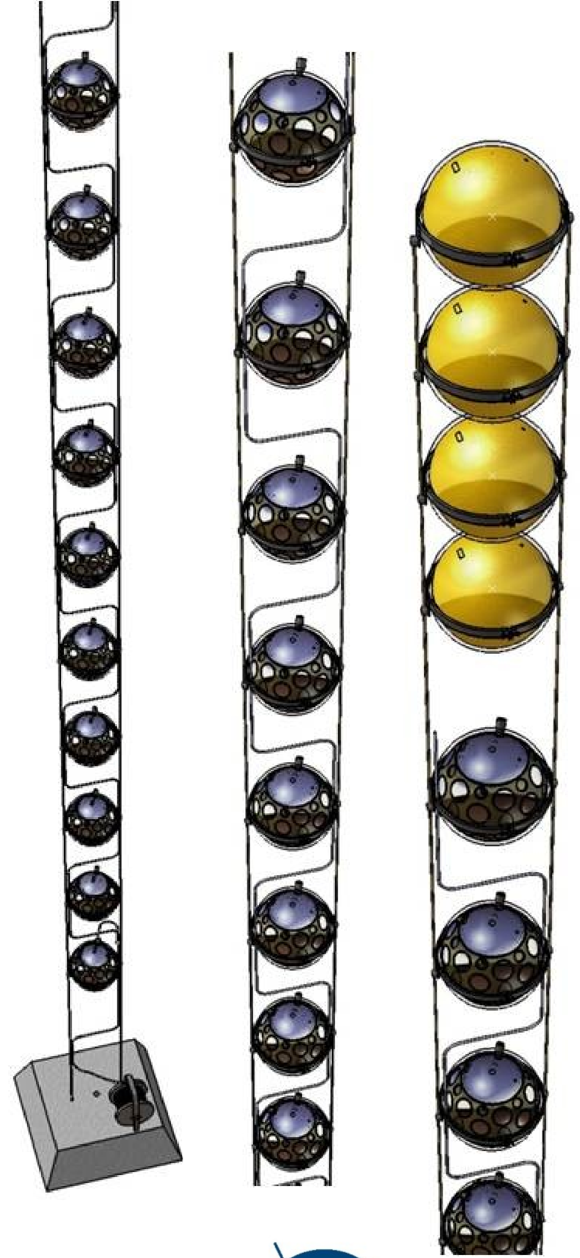



- 20 storeys
- Each storey supports 6 OMs in groups of 2
- Storeys interlinked by tensioning ropes, subsequent storeys orthogonal to each other
- Power and data cables separated from ropes; single backbone cable with breakouts to storeys
- Storey length = 6m
- Distance between storeys = 40 m
- Distance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

# 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
  - :
    One single pressure transition
  - Star network between master module and optical modules

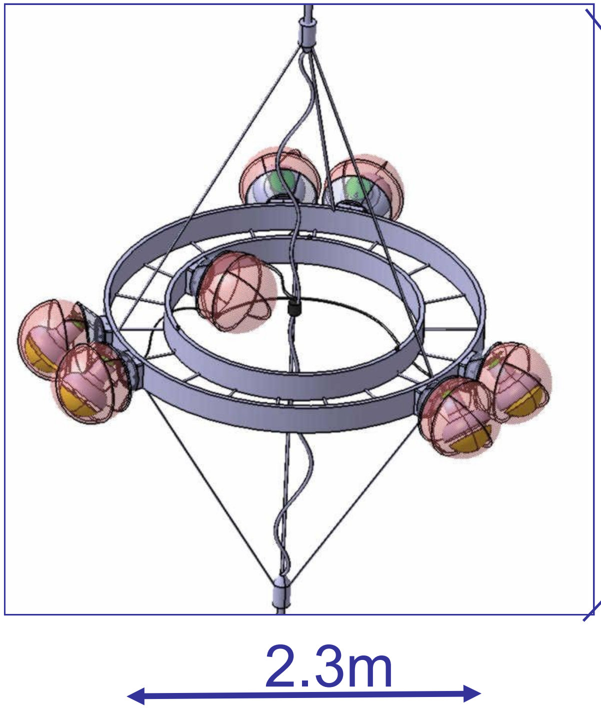
New concept, needs to be tested. Also for flexible tower if successful

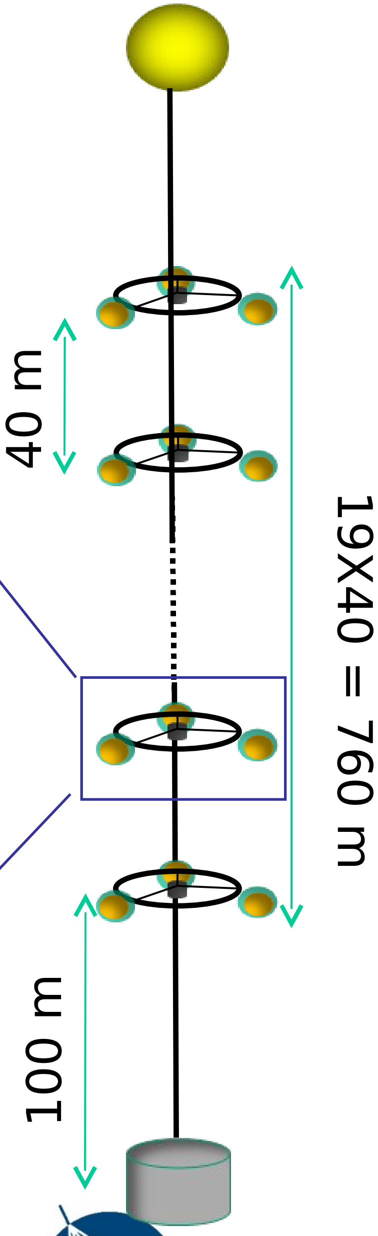


ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# 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






ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

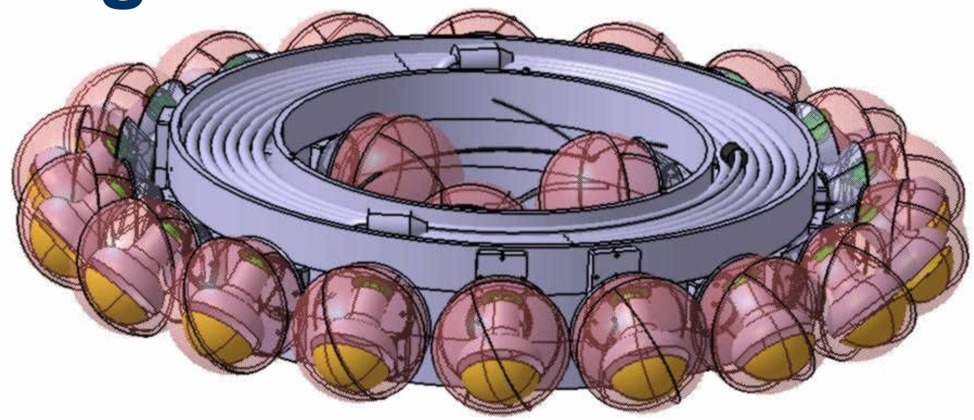
# Deployment Strategy

- 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

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# A Flexible Tower Packed for Deployment

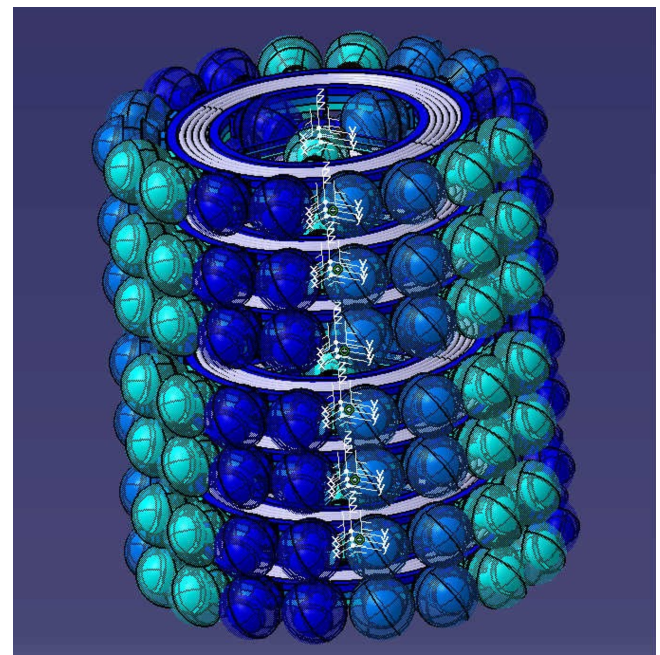
# Compactifying Strings



Slender string rolled up for self-unfurling:


3 triangles

DU

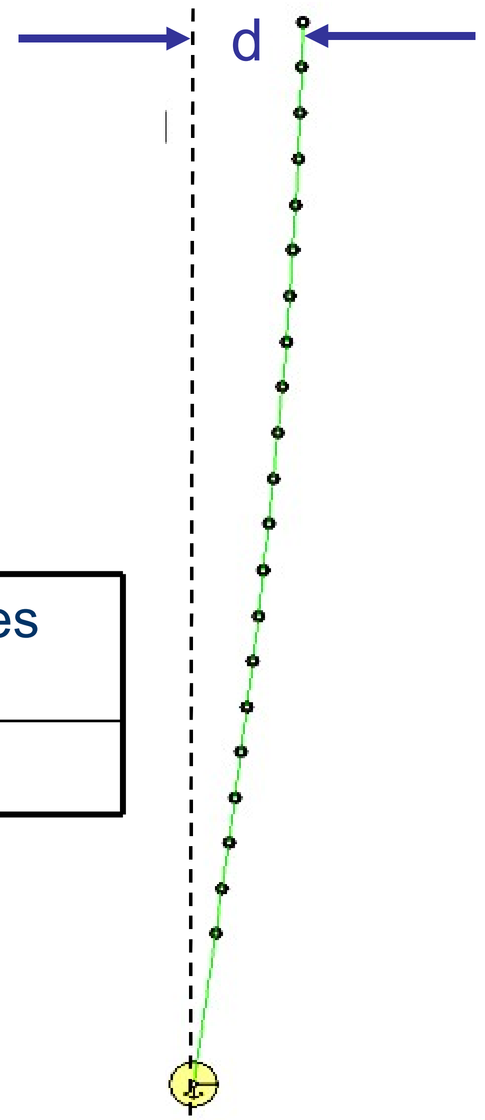


# Hydrodynamic Stability

- 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

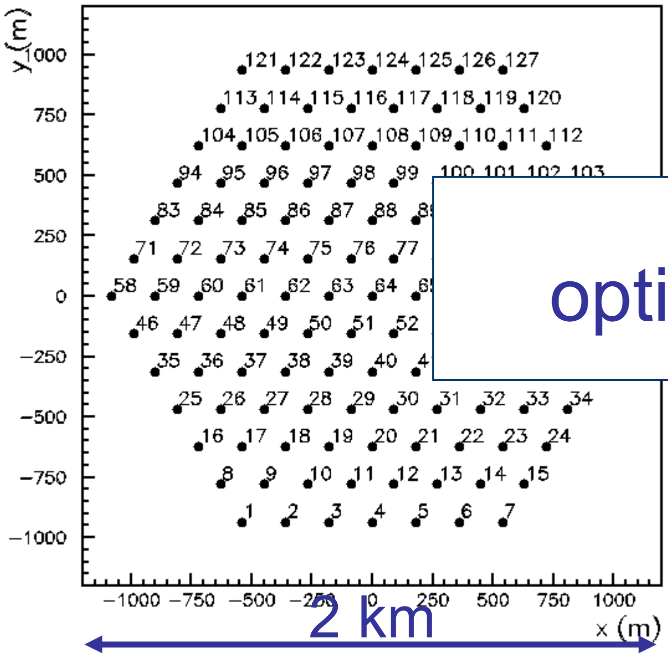



ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# Detector Building Blocks

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

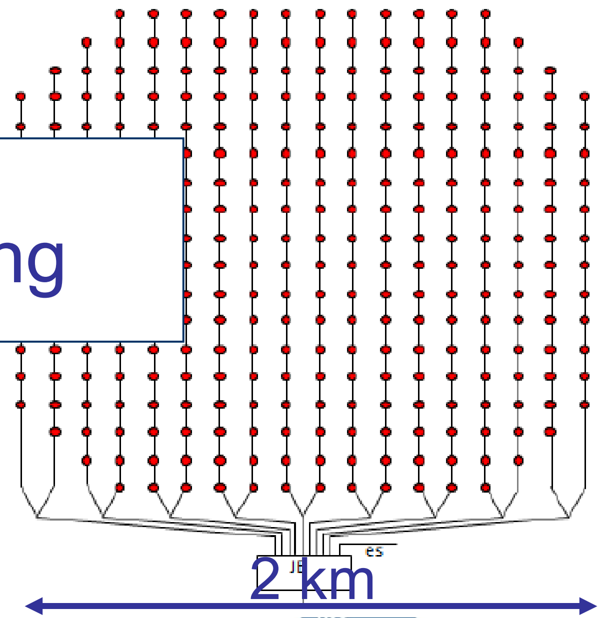
} different „building block footprints“




**<u>Bars, triangle:</u>**
**127 DUs,**
**distance 180/150 m**

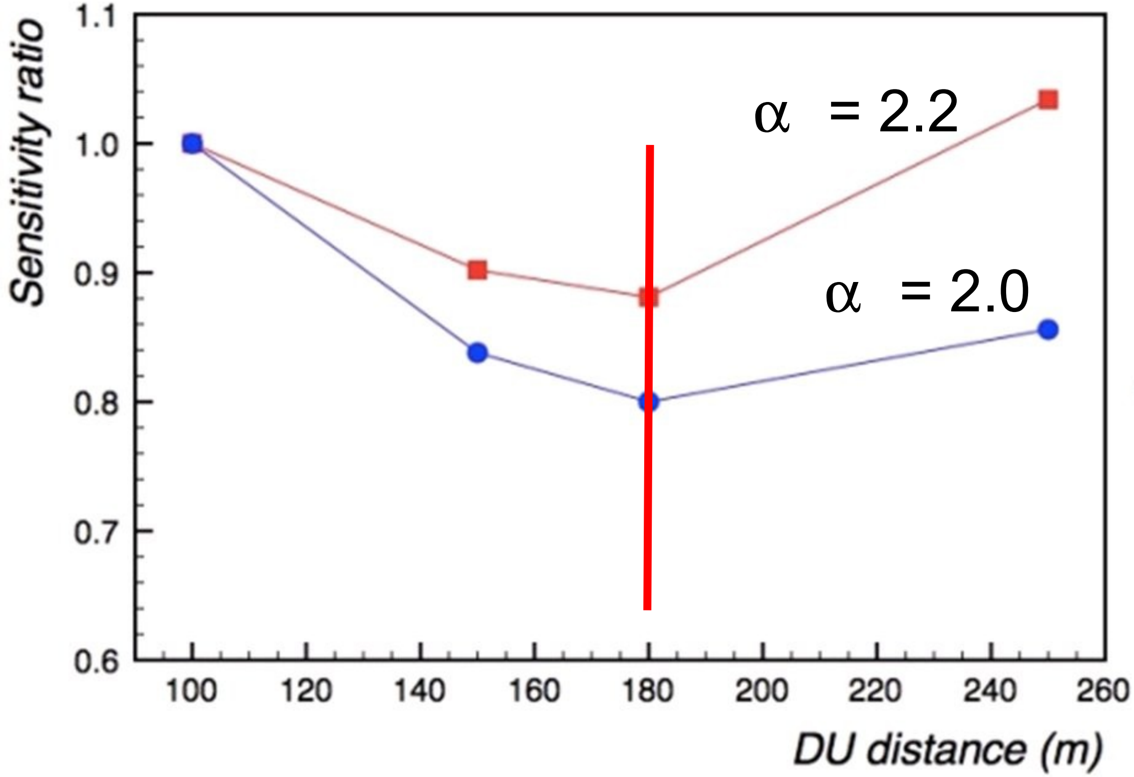
Footprint optimisation is ongoing

**<u>Slender string:</u>**
**310 DUs,**
**distance 130 m**



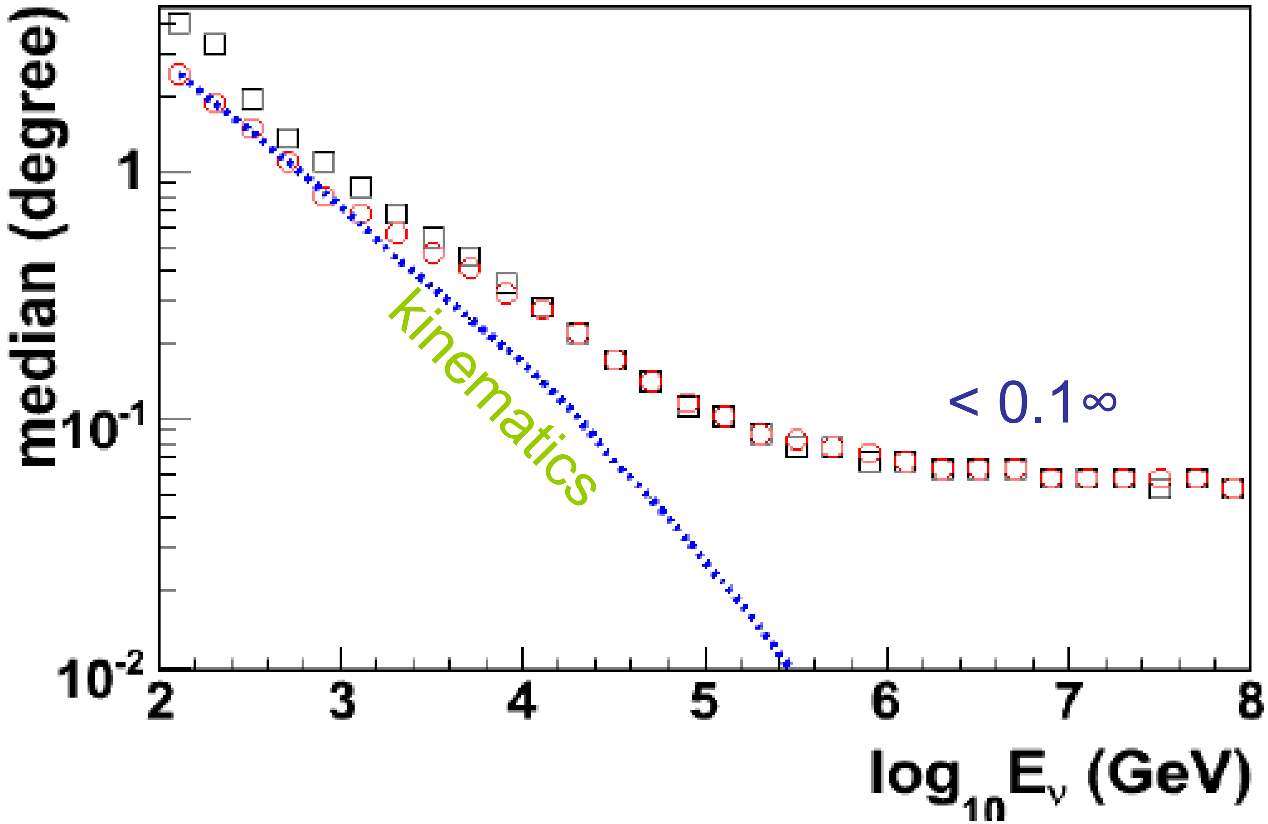
# Optimisation Studies

<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)

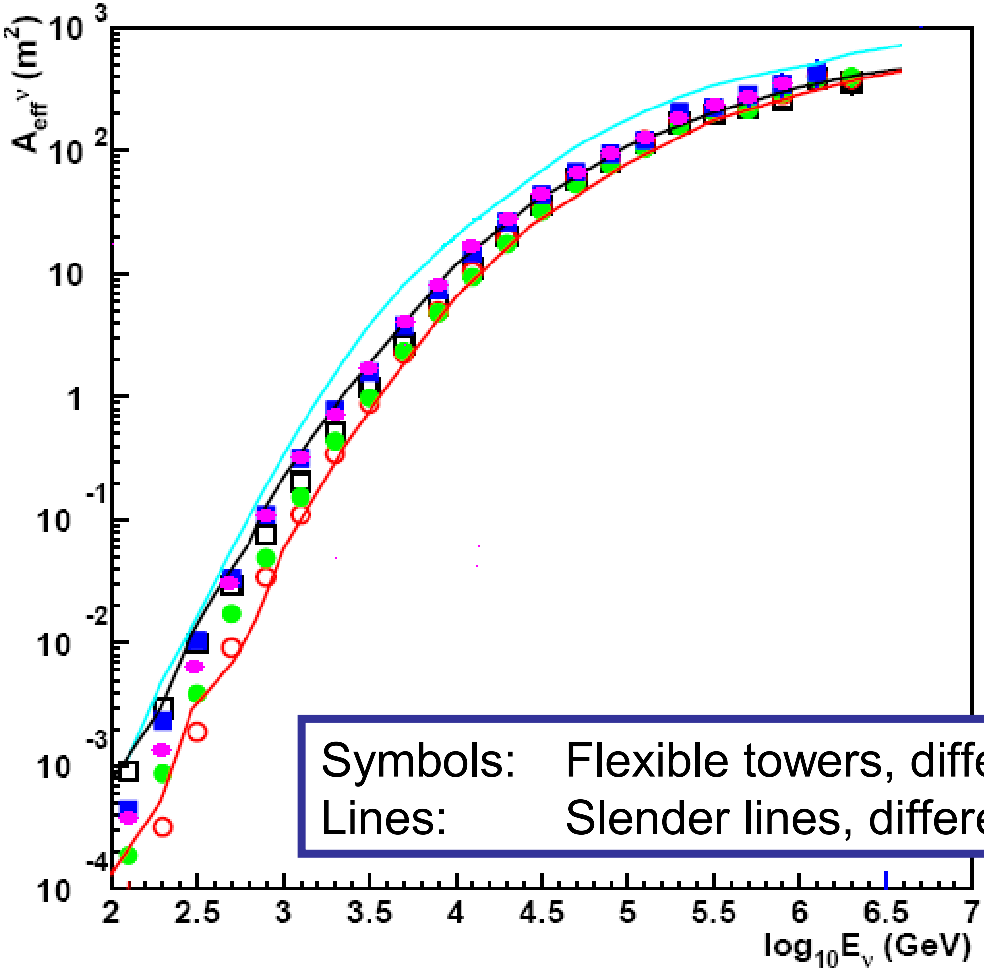


# Angular Resolution

- 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

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# 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



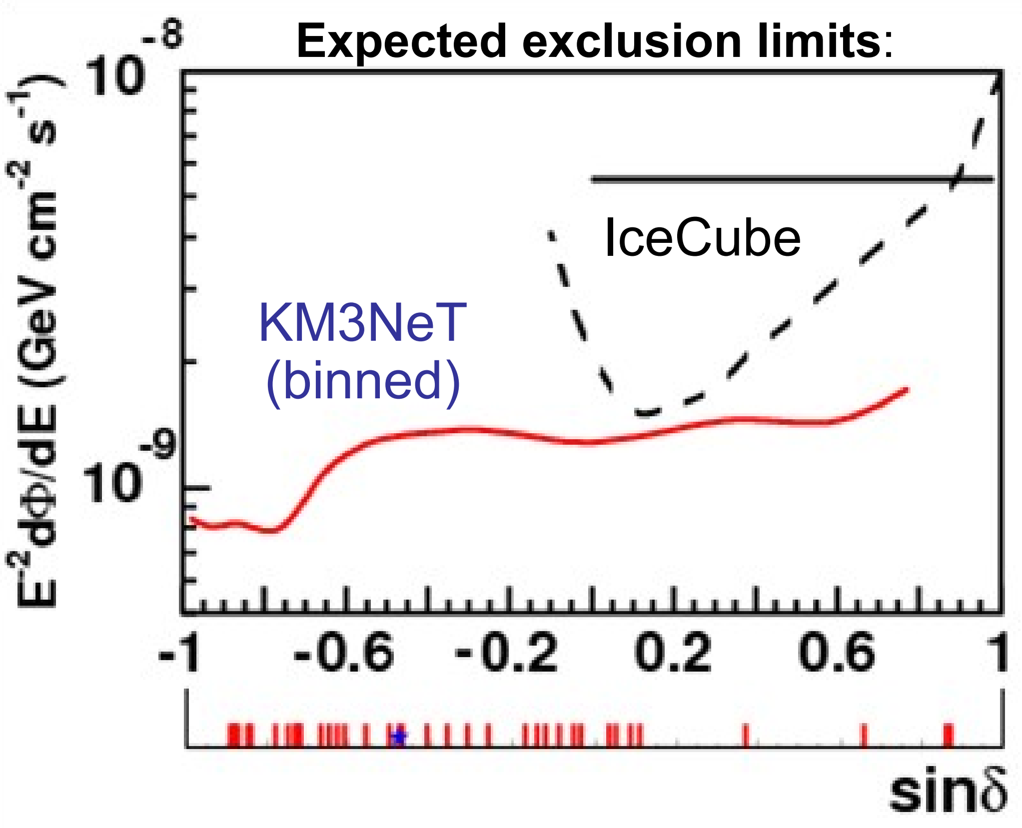
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# 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

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# Point Source Sensitivity (1 Year)




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

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

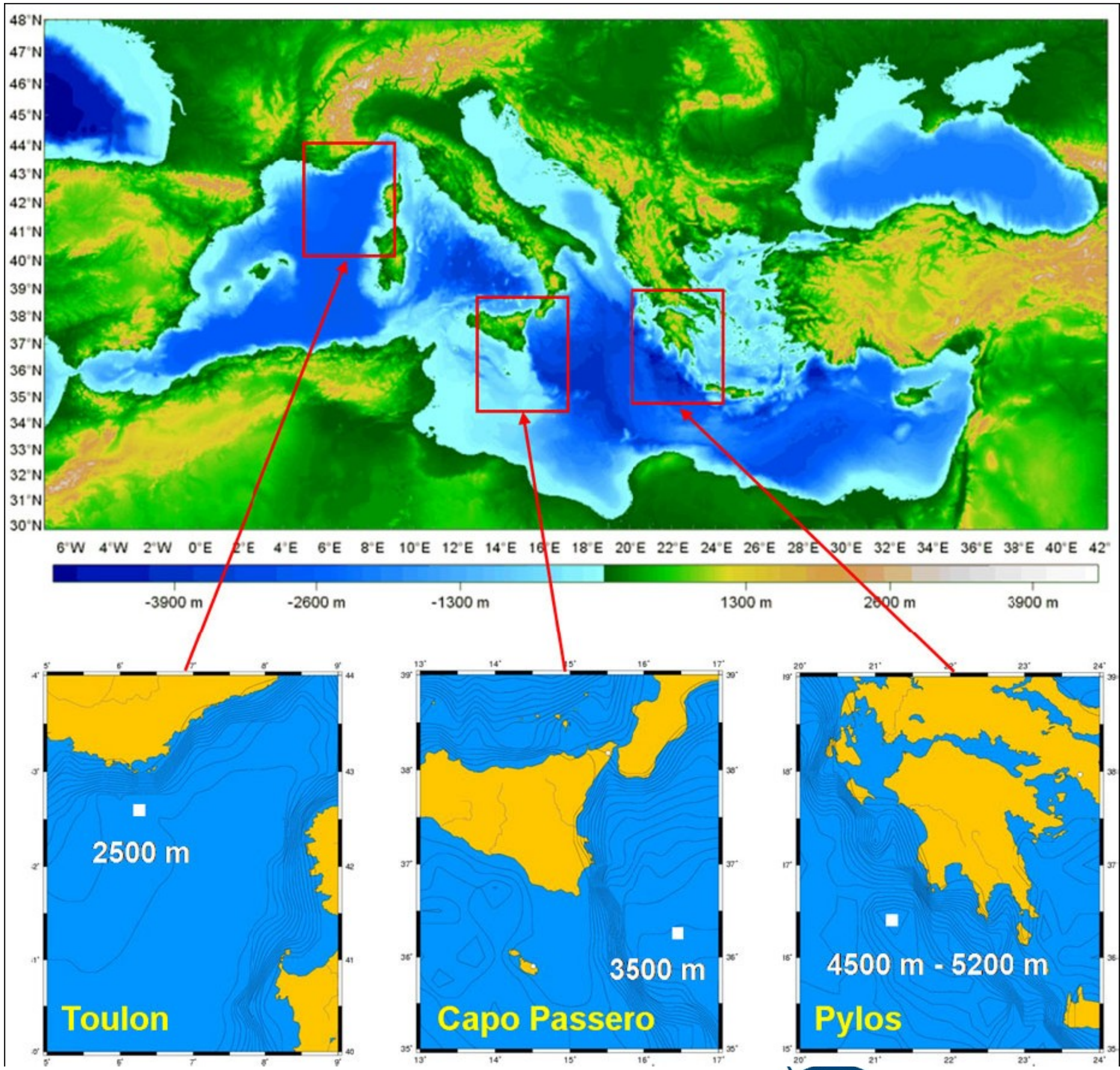
Observation of RXJ1713 with 5σ within ~8 years

□ 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)

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# 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




ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# Recent Developments

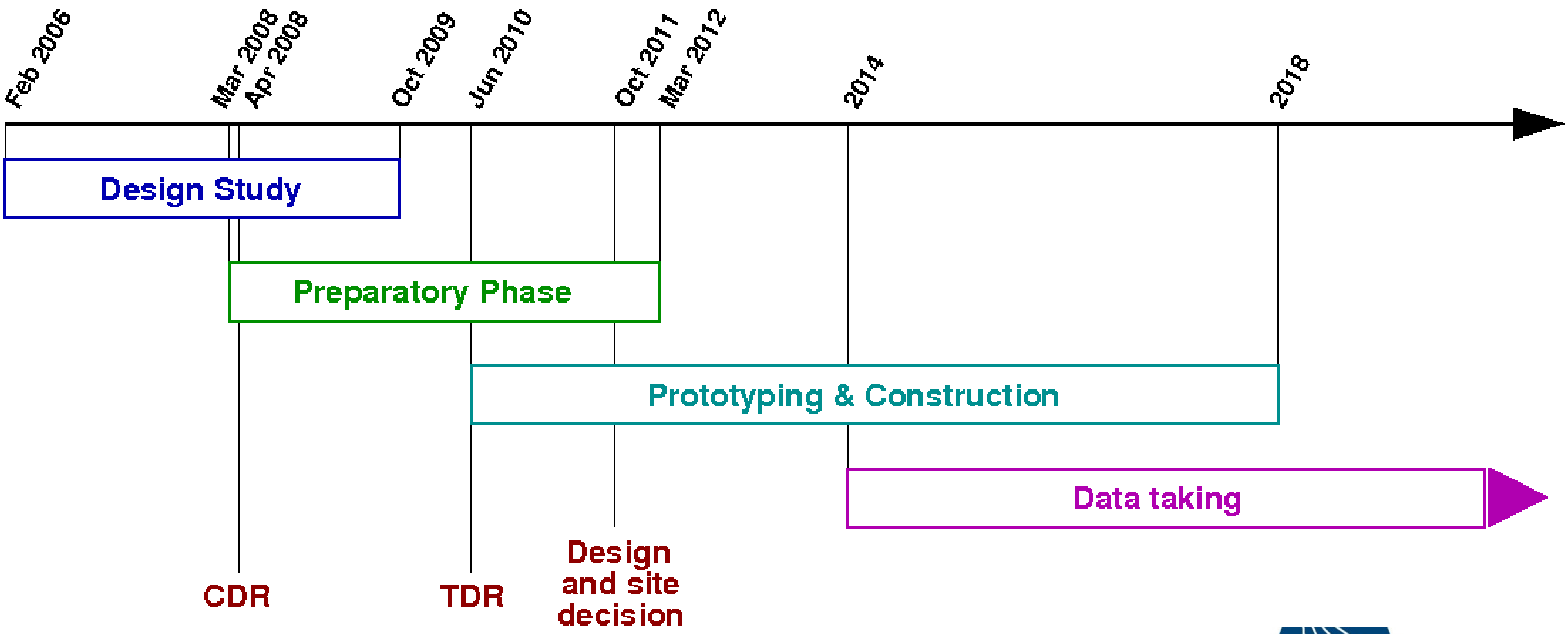
- Convergence towards a bar structure with multi-PMT OMs: 6m bars with 1 OM at each end
- Prototyping of components under way
- Simulation and “footprint” studies ongoing
- Possible cooperation with IceCube being explored (towards a Global Neutrino Observatory)



ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

# 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.

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS