The KM3NeT Project

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• The Challenge
• Technical solutions: Decisions and options
• Physics sensitivity
• Cost and implementation
• Strategy and 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 $\leq 5$ years
  - Operation over at least 10 years without “major maintenance”
The KM3NeT Research Infrastructure (RI)

detection unit (DU)

buoy

marine science node(s)

storey

deep-sea cable network

shore station

junction box

deep sea, 2-5 km depth
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
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

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 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:

- \( t_1 \), \( t_2 \), \( t_3 \), \( t_4 \), \( t_5 \), \( t_6 \) - Time

- Amplitude

- Threshold 1
- Threshold 2
- Threshold 3

Analogous 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

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

- 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 1m³
  - 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
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 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 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

Successful deployment test
12-14 Feb. 2010
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 30 cm/s observed
  - Mostly homogeneous over detector volume
- Deviation from vertical at top:

<table>
<thead>
<tr>
<th>Current [cm/s]</th>
<th>flexible tower d [m]</th>
<th>slender string d [m]</th>
<th>triangles d [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>84.0</td>
<td>83.0</td>
<td>87.0</td>
</tr>
</tbody>
</table>

- Torsional stability also checked
Detector Building Blocks

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

Footprint optimisation is ongoing

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

Slender string:
310 DUs, distance 130 m
Optimisation Studies

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

![Graph showing sensitivity ratio vs. DU distance for two different values of $\alpha$]

- $\alpha = 2.2$
- $\alpha = 2.0$
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 $E^{-2} \nu$ 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 (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
Cost Estimates: Results

- Result of cost estimates (per building block):

<table>
<thead>
<tr>
<th>Concept</th>
<th>DU Cost (M€)</th>
<th>No. of DUs</th>
<th>Total DU Cost (M€)</th>
<th>Seaﬂoor Infrastr. (M€)</th>
<th>Deployment (M€)</th>
<th>TOTAL COST (M€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible towers</td>
<td>0.54</td>
<td>127</td>
<td>68</td>
<td>8</td>
<td>11</td>
<td>87</td>
</tr>
<tr>
<td>Slender strings</td>
<td>0.25</td>
<td>310</td>
<td>76</td>
<td>13</td>
<td>14</td>
<td>103</td>
</tr>
<tr>
<td>Triangles</td>
<td>0.66</td>
<td>127</td>
<td>83</td>
<td>8</td>
<td>7</td>
<td>99</td>
</tr>
</tbody>
</table>

- 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
Point Source Sensitivity (1 Year)


- Observed Galactic TeV-γ sources (SNR, unidentified, microquasars)
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
The Marine Science Node: Layout

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

Safety Radius

Max. 10 km

Telescope site

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

- Next steps: Prototyping and design decisions
  - final decisions require site selection
  - expected to be achieved in ~18 months
- Timeline:
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
  → Well positioned to reap the fruit of 2 decades of efforts!
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:

Jerry, 20 kg

... then this is KM3NeT:

George, 110 kg