KM3NeT

a cubic-kilometre-scale deep water neutrino telescope for the Mediterranean Sea

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for the KM3NeT Consortium

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Università degli Studi di Pisa

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I.N.F.N. - Pisa

Outlook

Introduction

- **Neutrino Astronomy**: Motivations, Neutrino Production, Expected Fluxes
- Submarine Observatories: **Cherenkov Telescopes**
  - The South Pole: IceCube
  - The **Mediterranean Sea** → a **full-coverage** of the Sky

The pilot projects: ANTARES, NEMO, NESTOR

The KM3NeT Consortium

KM3NeT Design Study - Conceptual Design Report (CDR)

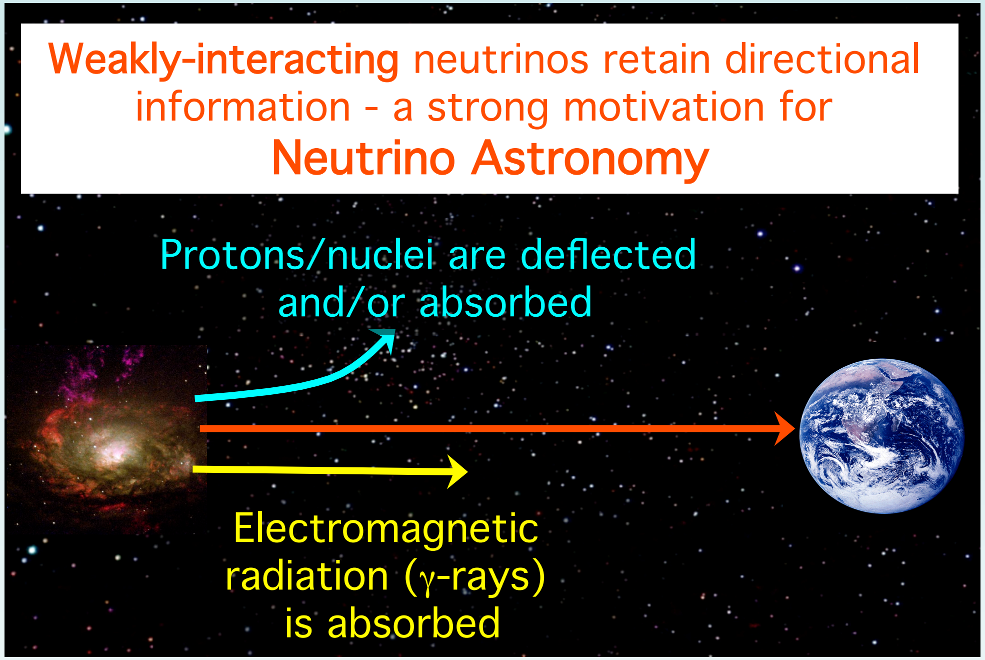
- Design Goals
- Detector Layout and Expected Detector Performances
- Technical Implementations: OMs, DAQ, Data/Power Transmission, Deployment
- Site Investigations
- Associated Sciences

→ Technical Design Report (TDR) → Preparatory Phase (PP)

Summary and Perspectives - KM3Net Timeline

Neutrino Astronomy

a Multi-Messenger Approach in the Astrophysical Research



Astrophysics

UHECν$_s$ as a diagnostic of astrophys. processes

- astrophysical sources, acceleration engines
  - neutrino observations can discriminate between different acceleration mechanisms (hadronic/e.m.)
- cosmic rays propagation → **GZK** cut-off → Cosmogenic neutrino flux

Particle Physics

- Neutrino Physics
- $\sigma_{\nu N}$ at $E>E_{acc.}$
- NewPhysics beyond SM (strongly interacting ν_s)

Cosmology

- EHECν absorption on CνB
- top-down models (TD, DM and WIMPs)

UHEν$_s$ Production

Bottom-Up Models (Acceleration)	Top-Down Models (Annihilation/Decay)
Galactic SNRs Pulsars/PWNe Microquasars	WIMPs TDs Z-bursts
Extra-Galactic AGN GRB	
GZK	

Weak interaction

at the same time

a great opportunity for discoveries

and

a gigantic obstacle for detection

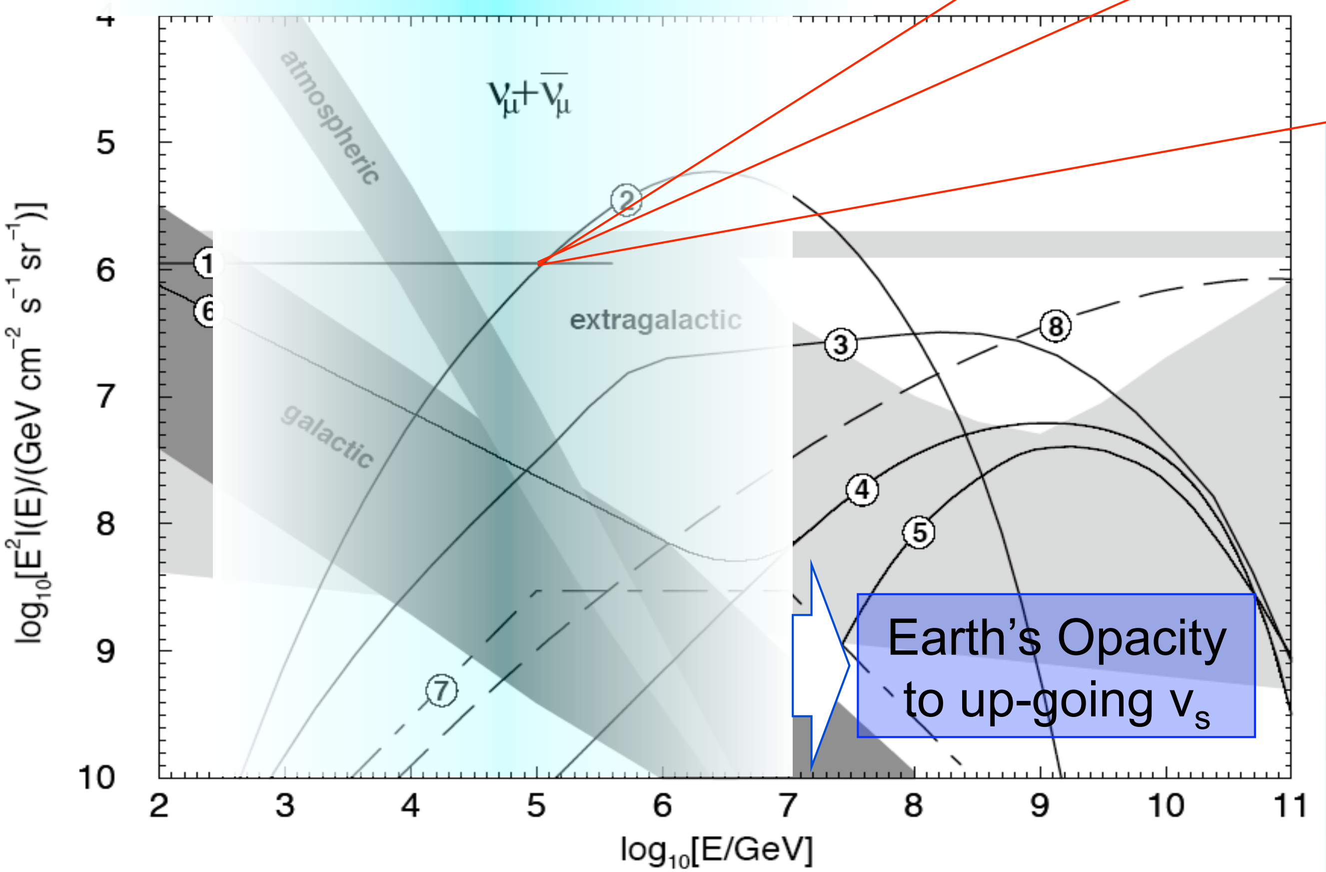
↓

the Challenge of Neutrino Detection

Neutrino Fluxes and Neutrino Detectors

Optimal Sensitivity Energy Range
for Underwater/Ice Cherenkov Telescopes
1TeV – 10 PeV

$$Flux\Big|_{@10^5 GeV} \sim \frac{3\cdot 10^{-5}}{GeV\cdot m^2\cdot yr\cdot sr} \sim \frac{3\cdot 10^{1}}{GeV\cdot km^2\cdot yr\cdot sr}$$



(1-4 and 6) AGN models; (5) GZK; (7) GRB; (8) topological defects [adapted from Learned and Mannheim, Annu. Rev. Nucl. Part. Sci. 50 (2000)]

Predicted neutrino fluxes are very **LOW**

+

weak interactions

↓

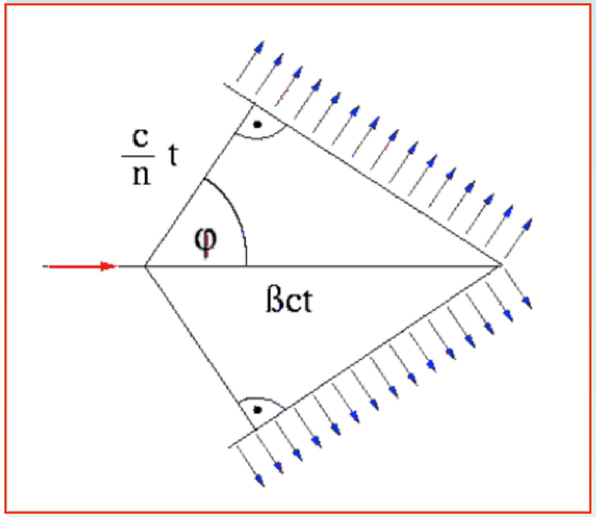
Cubic kilometer scale detectors are required

↓

Natural Target (ICE, WATER)

DEPTH → screening of daylight
→ prevent atmo. μ contamination

High Energy Neutrino Detection
Cherenkov Telescopes



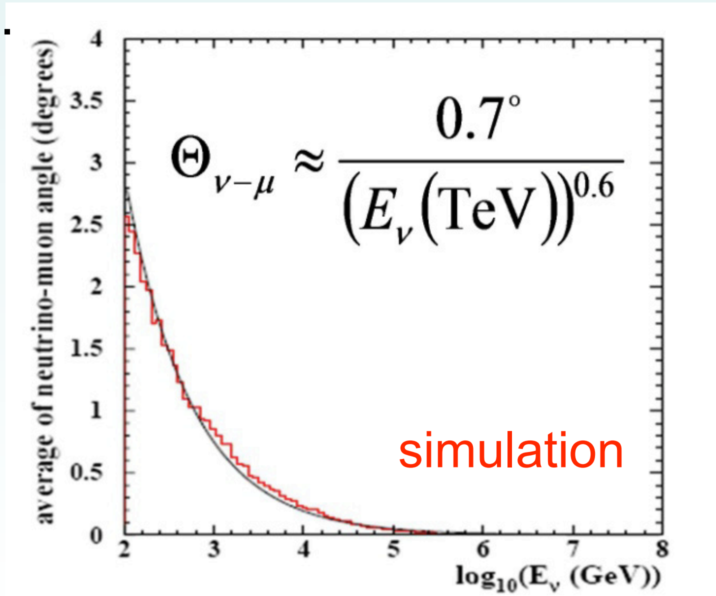
Cherenkov neutrino telescopes look for **ultra-relativistic** (β~1) **muons** produced in charged current neutrino interactions:

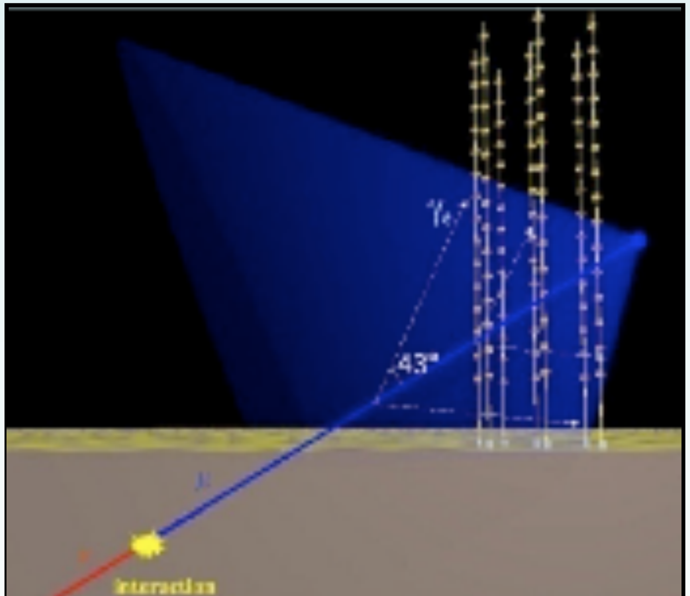
refractive index of the medium (water or ice) *n>1*
➔ light speed in the medium ***c/n* < *βc*** particle speed
➔ **coherent emission of Cherenkov light**

➔**Cherenkov angle**: $\cos\varphi = \frac{1}{n\beta}$ in water: n~1.35 ➔φ~ 43°

Detectors are made up as **a regular grid of PMTs**. The muon direction is reconstructed from the times of arrival of photons at the PMTs and the PMT positions.

Once that the muon track direction has be identified, **pointing properties** of the telescope are assured by the fact that at high energies the muon direction is almost collinear to the primary neutrino.





AMANDA/IceCube
Baikal
ANTARES, NEMO, NESTOR → KM3NeT

The South Pole and the Mediterranean Sea

a full-Sky coverage

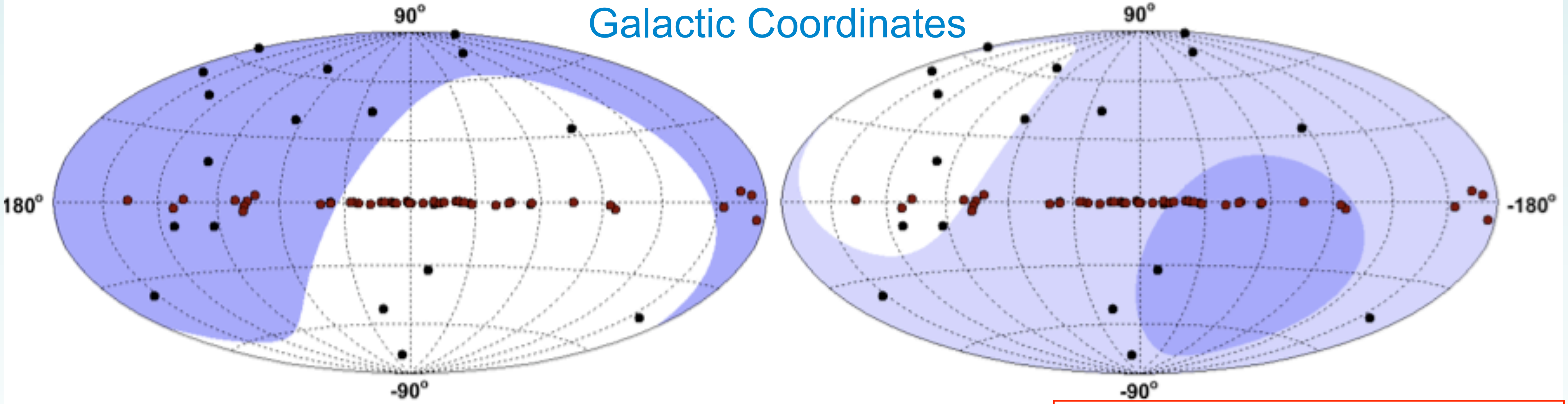
(2π isotropic flux ("up-going ν_s "))

Visibility IceCube (South Pole)
- 100%
- 0%

IceCube
http://icecube.wisc.edu/

Visibility KM3NeT (Mediterranean)
- > 75%
- 25% – 75%
- < 25%

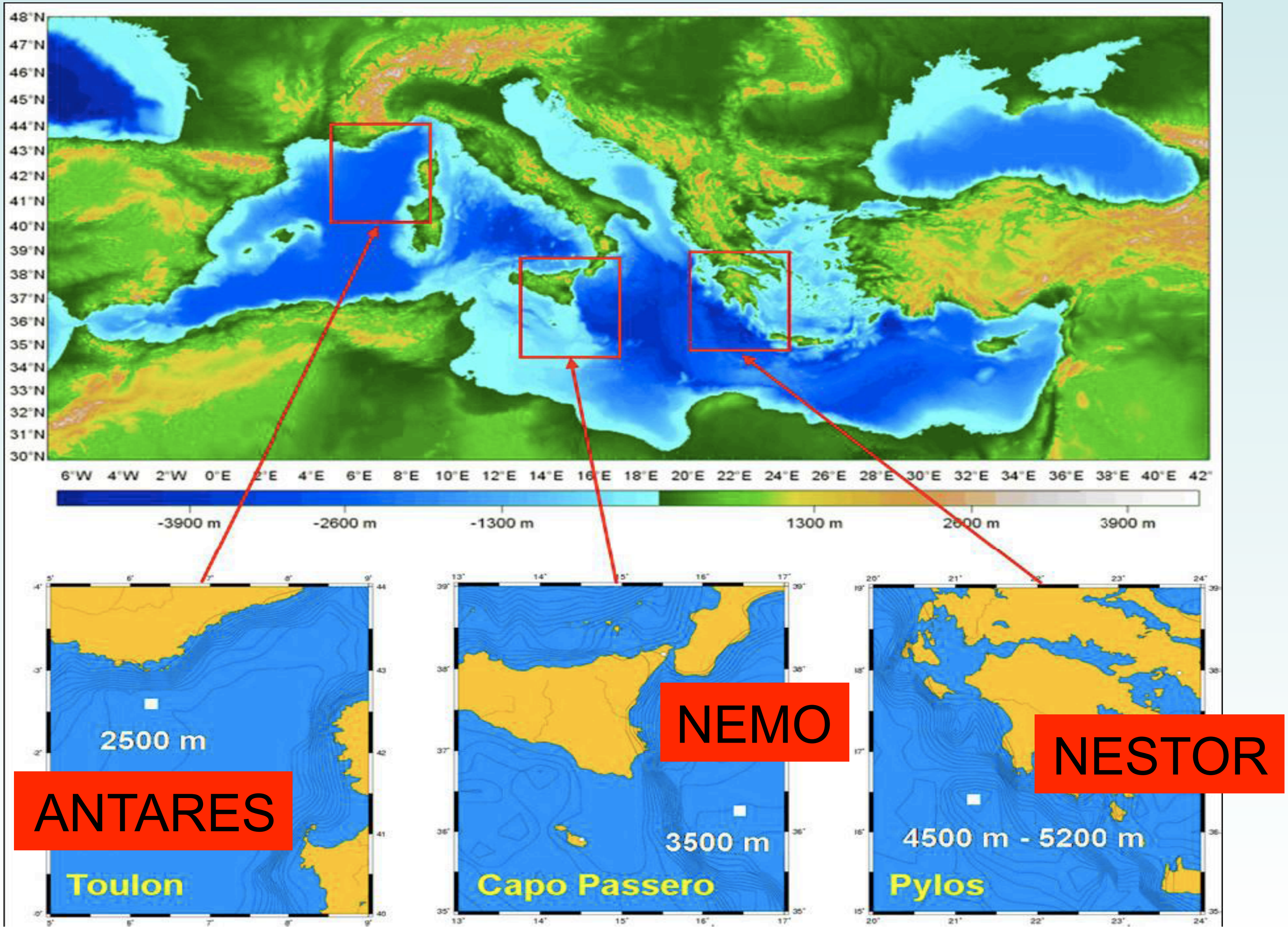
Galactic Coordinates



TeV γ-ray sources
- Galactic
- extra-Galactic

a northern hemisphere neutrino observatory is a must

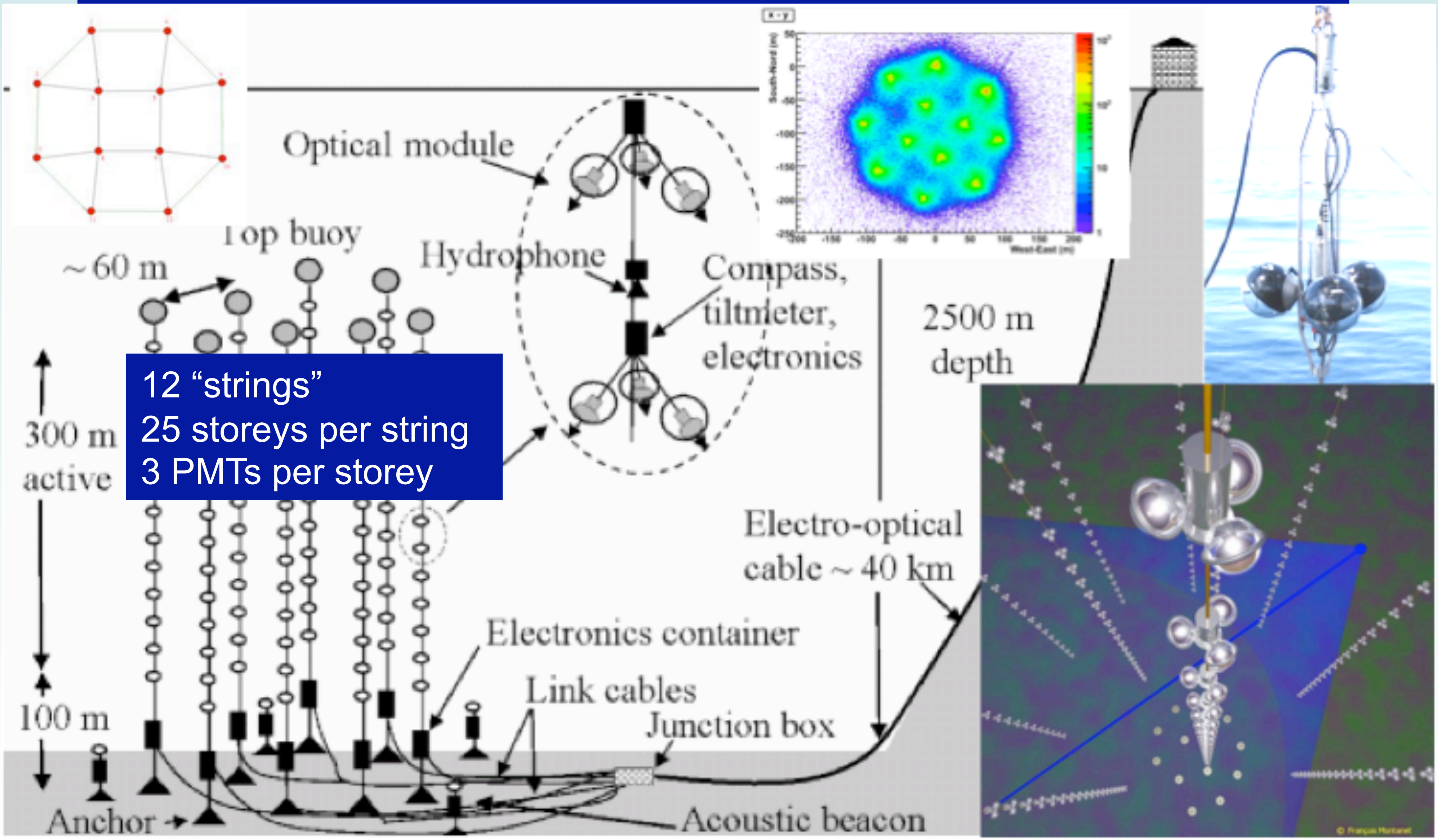
Mediterranean Sea
The pilot projects



ANTARES

Completed in June 2008
data taking and analysis ongoing

The largest (0.1 km^2) operating neutrino telescope in the Northern emisphere



12 "strings"
25 storeys per string
3 PMTs per storey

NEMO

NEUTRINO MEDITERRANEAN OBSERVATORY

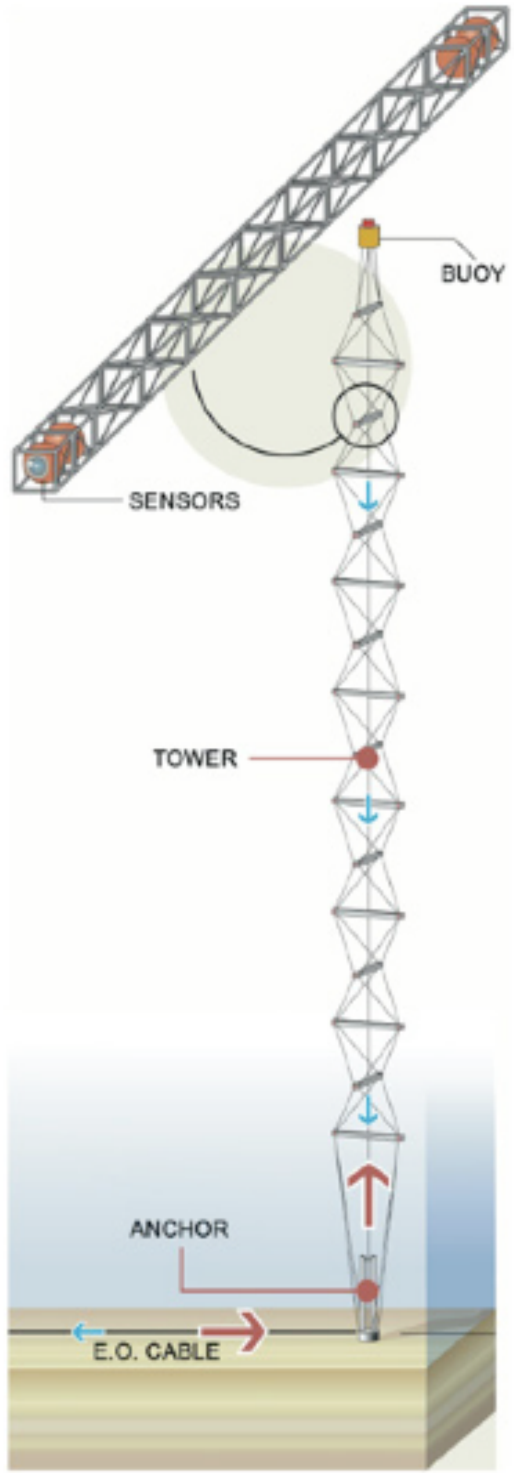
→multi-disciplinary investigations of the submarine environment
→development of technological solution (mechanics and electronics)

Key-point:

compact (arms~10m) semi-rigid structure (**tower**)
deployment as compact, self-unfurling structures

NEMO-Phase1 (2002-2006):
realization and deployment of a “mini-tower” (4 storeys, 4 PMTs each) in the NEMO test-site (~2000m depth, 25km off **Catania**, Sicily)

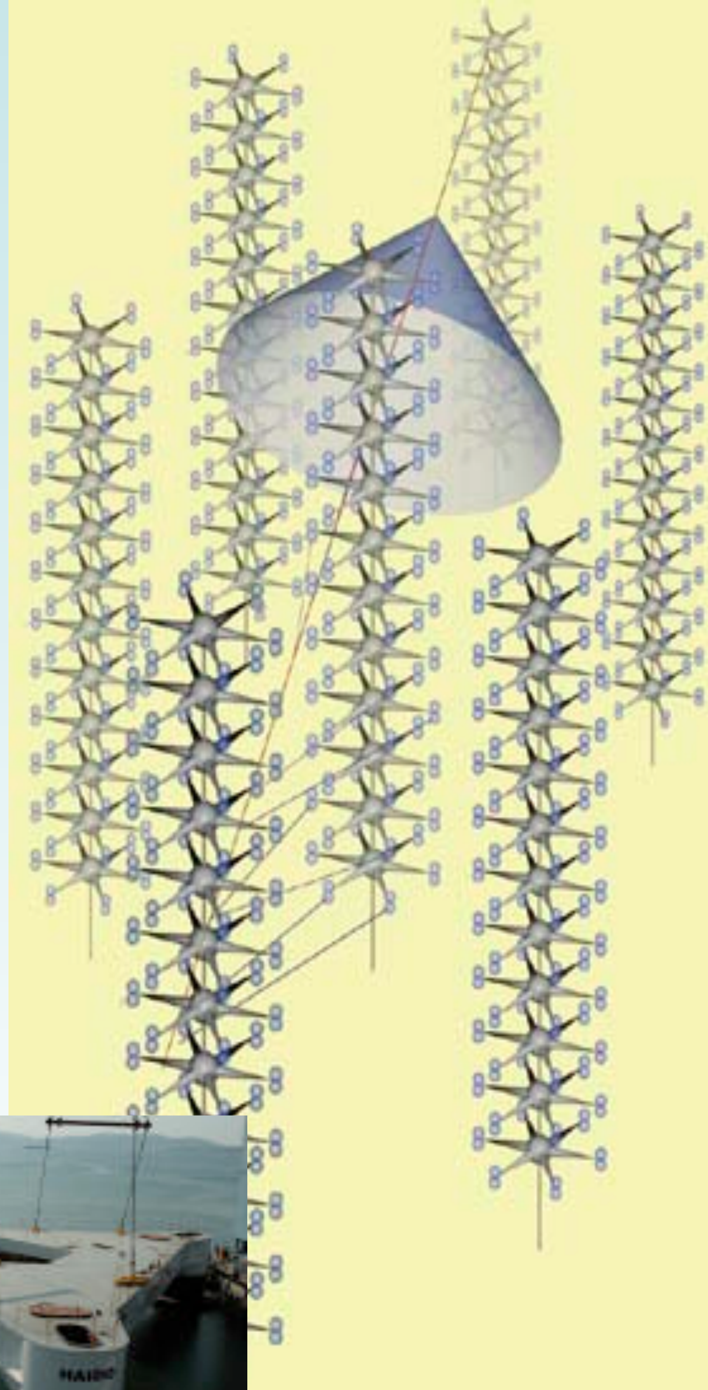
NEMO-Phase2 (ongoing):
realization and deployment of a full NEMO in the **Capo Passero** site (3500, depth, 100km off-shore)
status: 100km electro-optical cable deployed underwater;
shore station infrastructure completed



NESTOR

Key-point:

extended rigid **star**-like structure
suitable for a "clustered" detector layout



MILESTONES

• 2002: deployment of a multidisciplinary (optical modules + environmental sensors) deep-sea station (4100m depth), cable-connected to shore (project LAERTIS)

• 2003: deployment of a test-floor (12 PMTs), ~1 month of data-taking and environment monitoring

• 2008: **Delta-Berenike** deployment platform released from dock

height = 5.3m
side = 51m/44m

…towards the km3

The KM3NeT Consortium

http://www.km3net.org/

THE GOAL

• connect people working in the field of **high-energy neutrino telescopes**, **marine research** and **deep-sea technology** communities

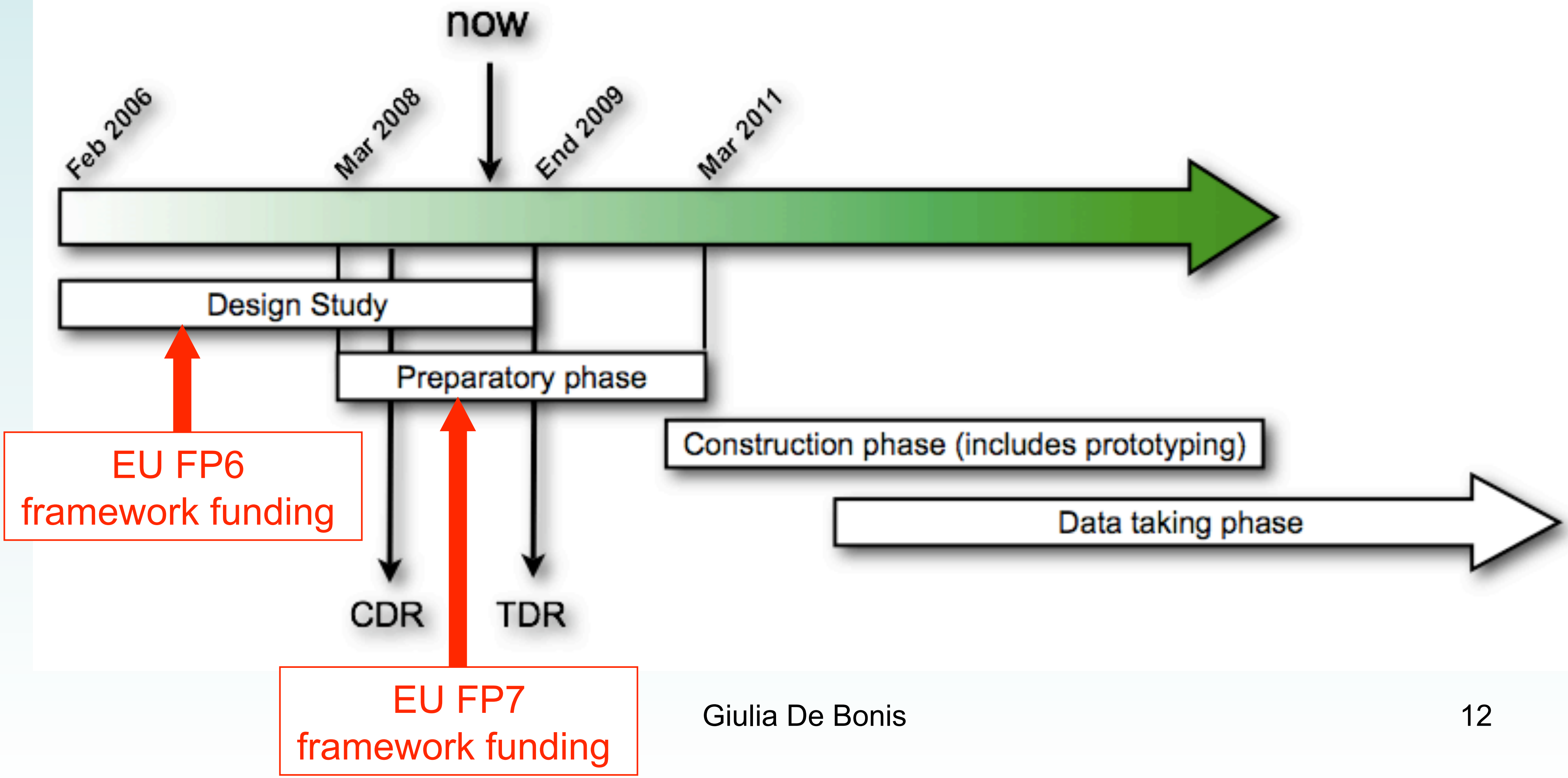
• share experiences gained with the pilot projects

• carry on **a unique project for a cubic kilometer detector in the Mediterranean Sea**

The **full list** of the institutes and university groups constituting the Consortium is available @KM3NeT web site

KM3NeT Timeline

2006: KM3NeT selected out by **ESFRI** (the European Strategy Forum on Research Infrastructures) to be included in the **European Roadmap for Research Infrastructures.**



02/2006→12/2009

EU FP6
framework funding

KM3NeT Design Study

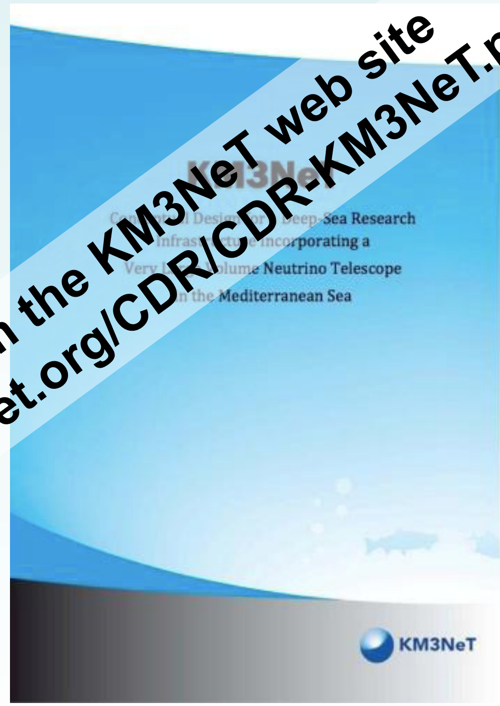
Design Study: development of a **cost-effective design** for a km^3-sized deep-sea infrastructure housing a neutrino telescope and providing long-term access for deep-sea research.

The multi-disciplinary activities of the KM3NeT Consortium are organized in **working packages**, covering all the main features in the design study of a neutrino submarine telescope; amongst them:

- **physics analysis and simulation**, to investigate the performance of different detector options;
- **shore, sea-surface and deep-sea infrastructure**, to carry on site-selection activity and to develop deployment and recovery procedures;
- design of the **optical modules**;
- design of the **readout and data acquisition system**;
- interactions with **associated sciences**, as biology, geology, oceanography.

→ CDR (Conceptual Design Report)

published in April 2008 →



Download from the KM3NeT web site
http://www.km3net.org/CDR/CDR-KM3NeT.pdf

→ TDR (Technical Design Report)

by the end of 2009

Neutrino Telescope Design Goal
CDR Indications and Constraints

- instrumented volume > 1 km^3
- lifetime > 10 yr without major maintenance
- construction and deployment < 4 yr
- budgetary constraint 200-250 M€

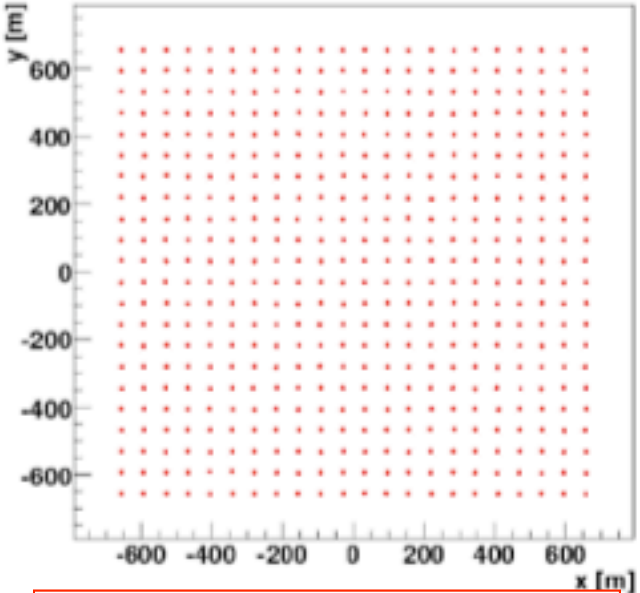
- optimal sensitivity to neutrinos in the energy range 1 TeV –1 PeV
- angular resolution < 0.1° (Ev > 100 TeV)
- some technical requirements:
    - time resolution < 2ns (RMS)
    - position resolution < 40cm (RMS)

→ crucial for the track reconstruction algorithms

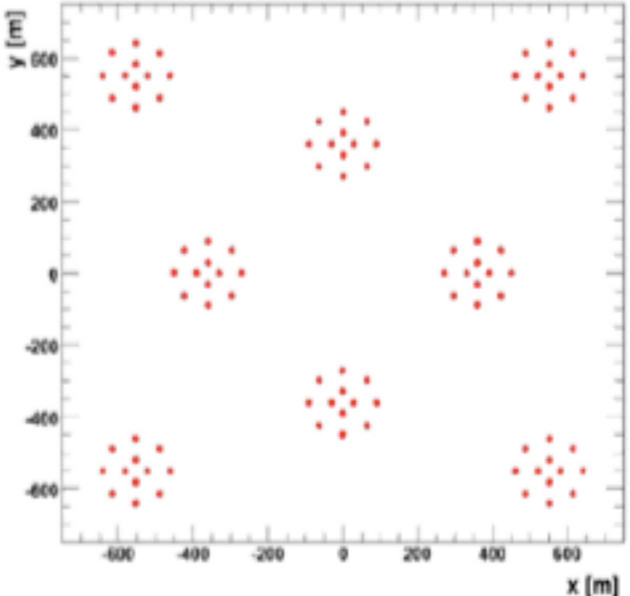
Detector Layout

No configuration is optimal for all energies and directions

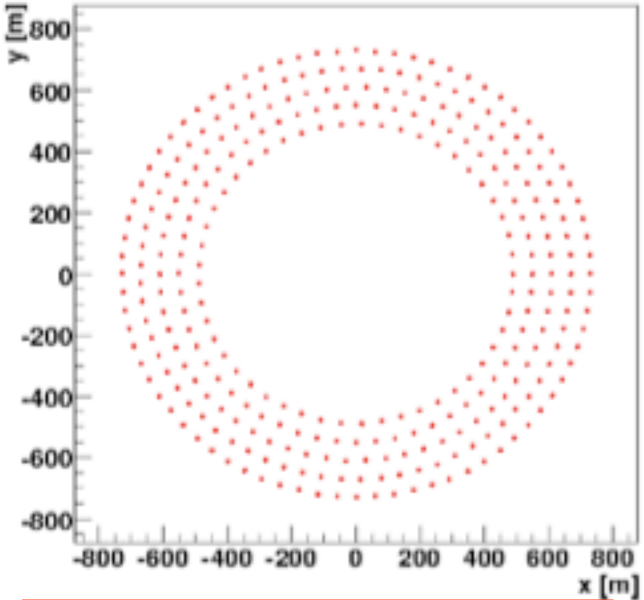
→ the final layout depends on the physical priorities



Intermediate E (1-100 TeV)
good ang. Reso.
(Point-Source Search)



Low Energies
(Dark Matter Search)

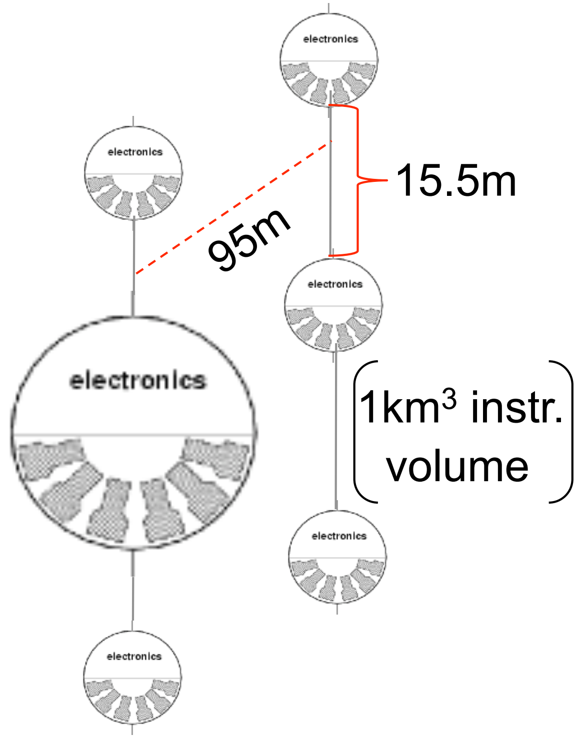


Very High Energies
poorer ang. reso. (GZK ν_s)

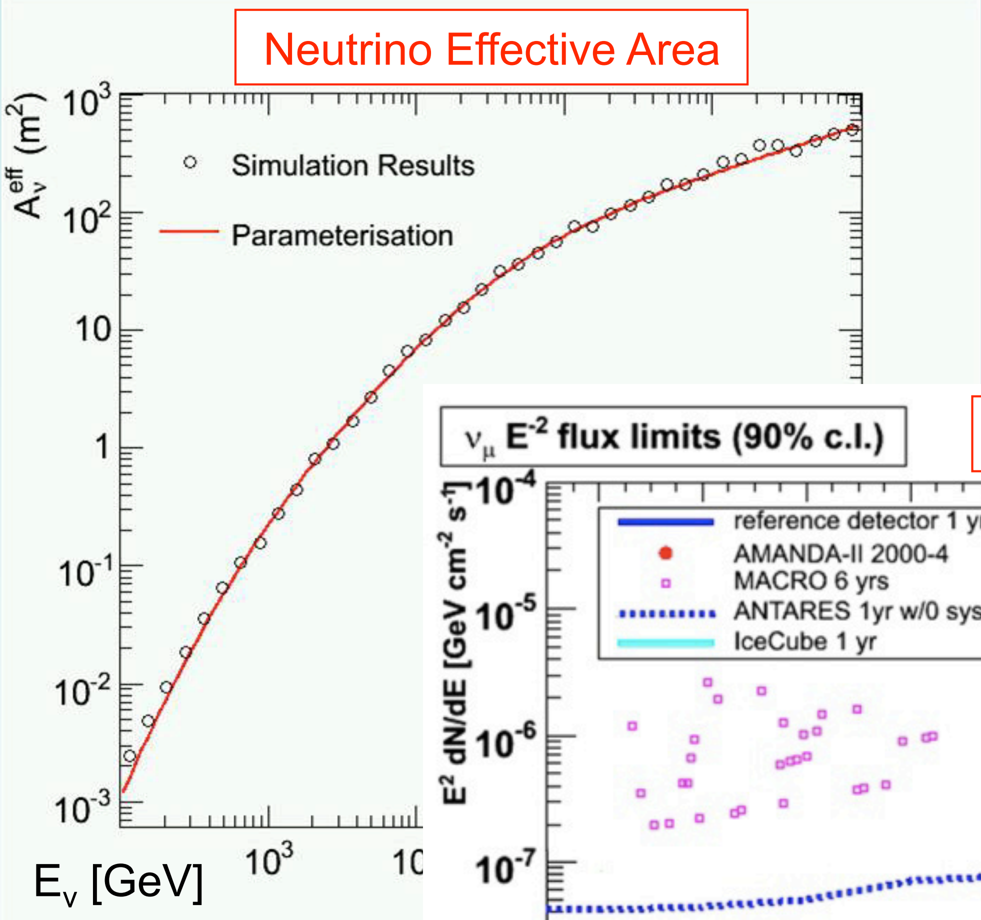
Simulation

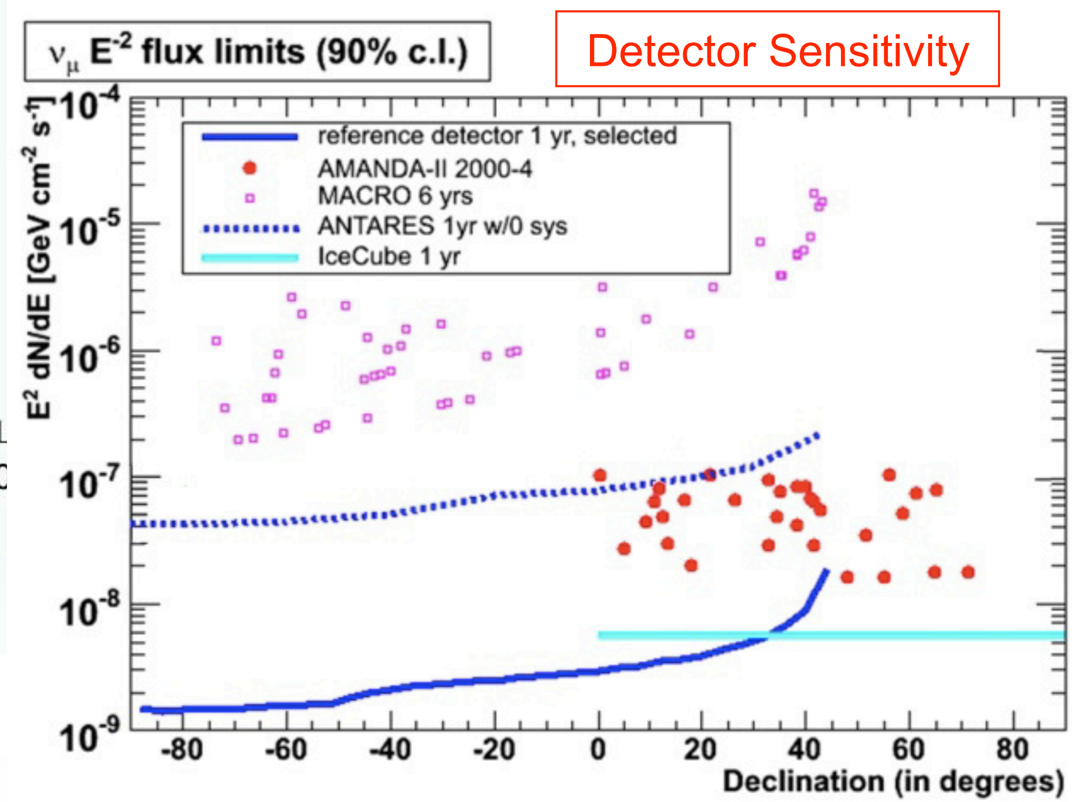
Detector Performances

"reference detector"
homogeneous configuration
225 (15x15) detection units
37 storey each, 1 OMstorey
21 3-inch PMTs per OM



(different detector designs can provide similar performances)

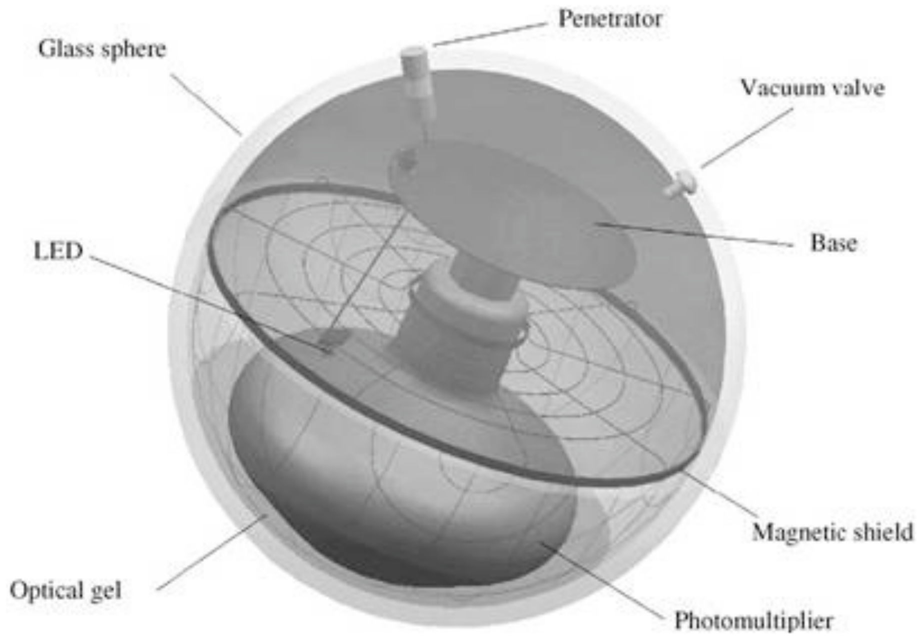




Optical Modules

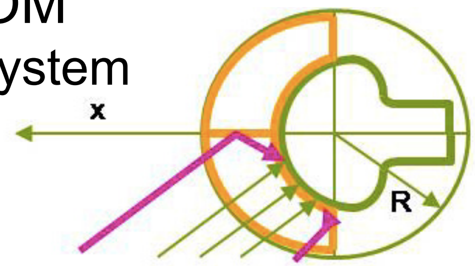
standard OM (pilot projects)

large-area (10”) hemispherical PMT (bi-alkali) in a 17” glass sphere



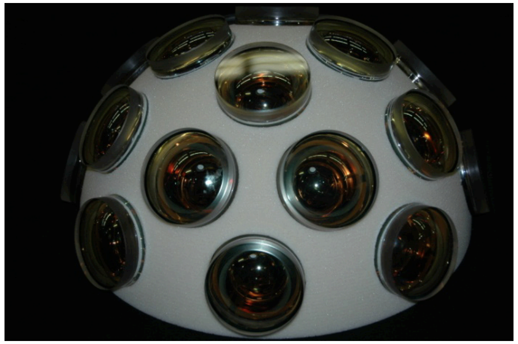
new concepts (under investigations)

- direction-sensitive OM
with a focusing mirror system

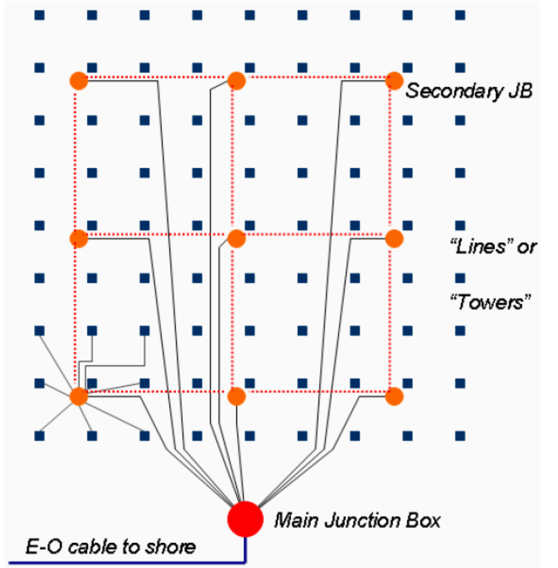


- 2/3 large-area PMTs
in a larger glass sphere (capsule)

- many (up to 40) 3” PMTs
→1vs2 p.e. separat.
→ directionality
→ maximise photocatode area



Data/Power Transmission



- power distribution through one or more **junction boxes**
- ~ **60kW** total power on-shore
- **electro-optical cable** (standard telecommunications cable)
- data transport: Dense Wavelength Division Multiplexing (**DWDM**) on optical fibre
- all data to shore (data-flow= some 100Gb/s)

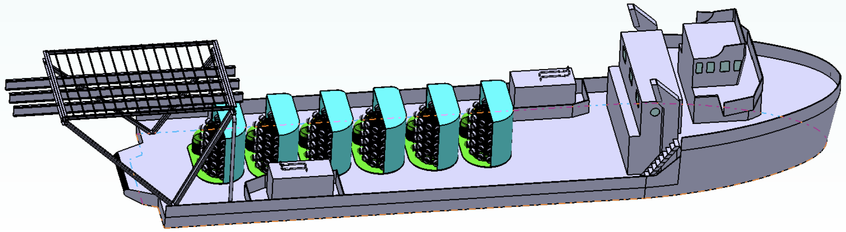
→ on-shore triggering

depends on:
- optical bkg
- detector layout
- OM design

progressive deployment has to take into account sea-floor cabling

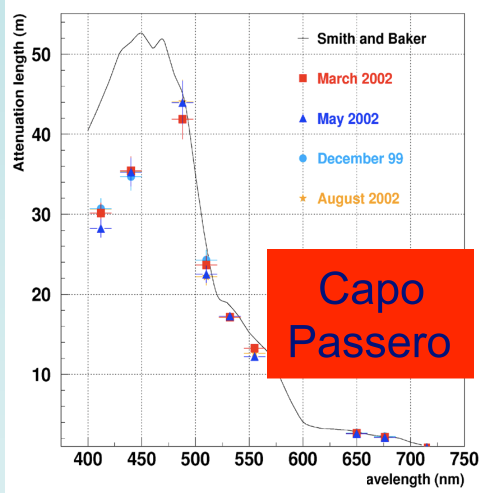
Deployment

- accurate positioning
- easy access, efficient procedures
- ships (compact structures) / dedicated platform (Delta-Berenike)
- use of ROV / AUV



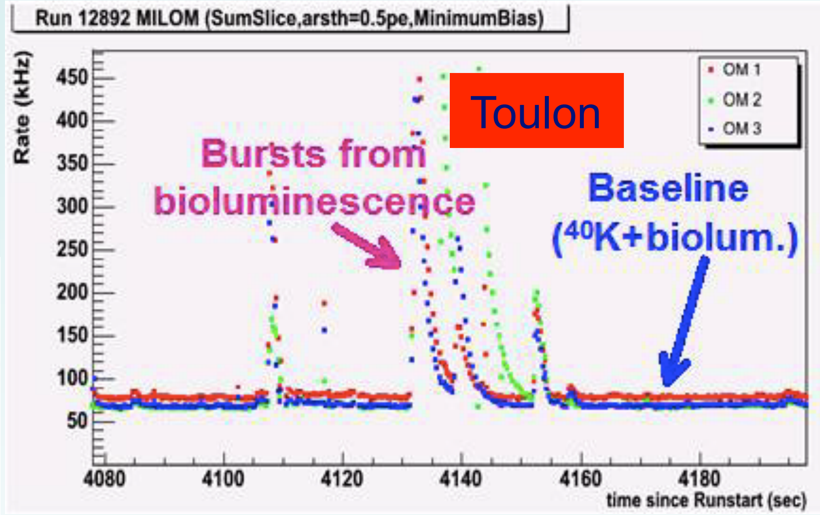
Giulia De Bonis

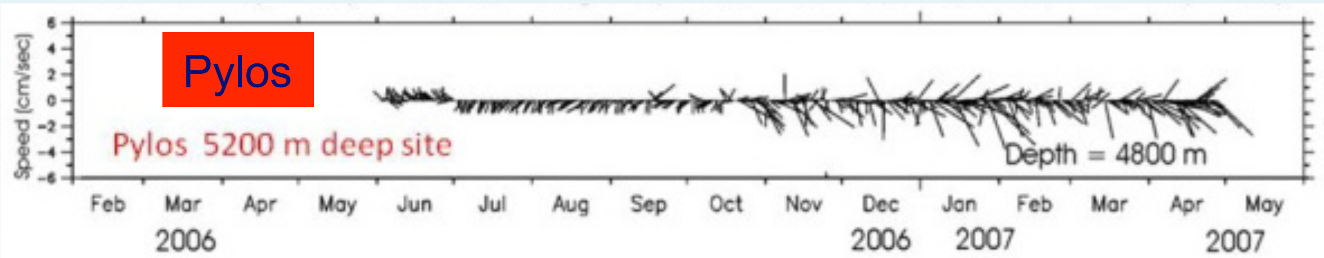
Site Investigation



Extensive sea campaigns carried out at the candidate sites (i.e. where the three pilot projects are operating), in order to monitor:

- water optical properties: light transmission
  - $L_a(\lambda)$ → abs. length
  - $L_b(\lambda)$ → scatt. length
  - $1/L_c(\lambda)=1/L_a(\lambda)+1/L_b(\lambda)$ → att. length
- optical background:
  - ^{40}K
  - bioluminescence
- deep sea currents (and correlation with other params)
- sedimentation and bio-fouling





Site choice will depend on scientific and infrastructural characteristics as well as political considerations
→ Preparatory Phase (PP) → **political convergence**

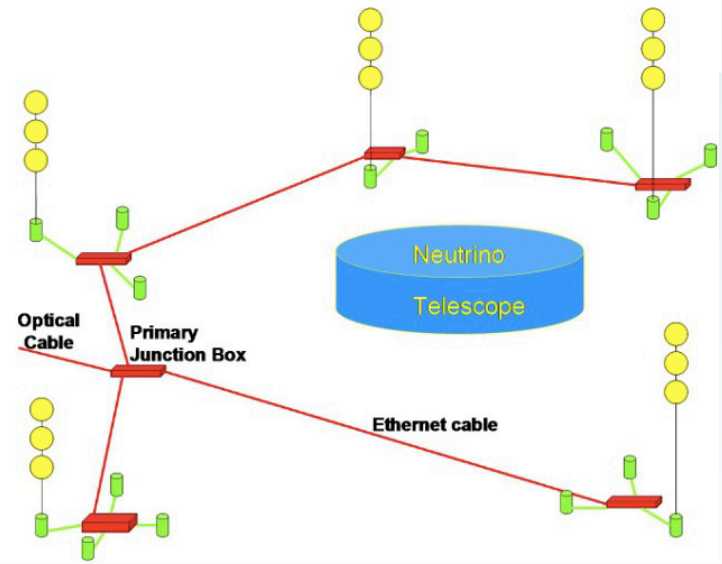
Associated Sciences

The KM3NeT infrstructure will offer a unique opportunity for a multidisciplinary observatory in the abyss

→ *long-term real-time* measurements in the deep sea:

• Oceanographic parameters (current velocity and direction)
• Environmental parameters (temperature, conductibility, salinity, pressure, natural optical noise from sea organisms)
• specialised instrumentation for seismology, gravimetry, radioactivity, geomagnetism, oceanography and geochemistry

Associated sciences nodes will be independent (dedicated secondary junction boxes) from the main installation of the neutrino telescope. The associated science infrastructure will be continually evolving; simple and cost effective upgrade of components is taken into account.



KM3NeT will become part of the **ESONET** (European Seafloor Observatory Network)

03/2008→03/2011

EU FP7
framework funding

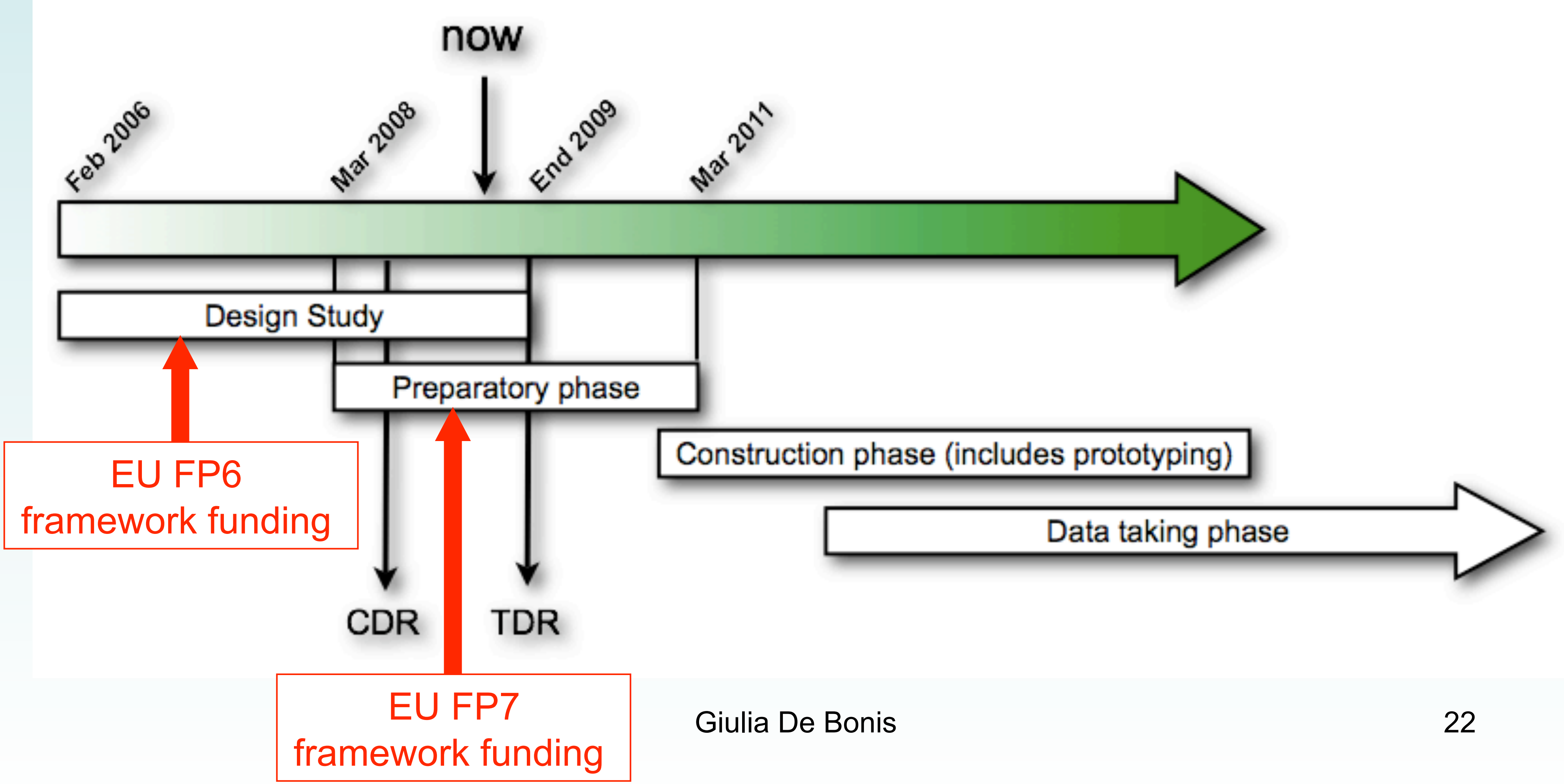
next step: KM3NeT Preparatory Phase (PP)

political and scientific convergence on the legal, governance, financial engineering and siting aspects

construction of the KM3NeT infrastructure is foreseen to start after the three year preparatory phase (2011).

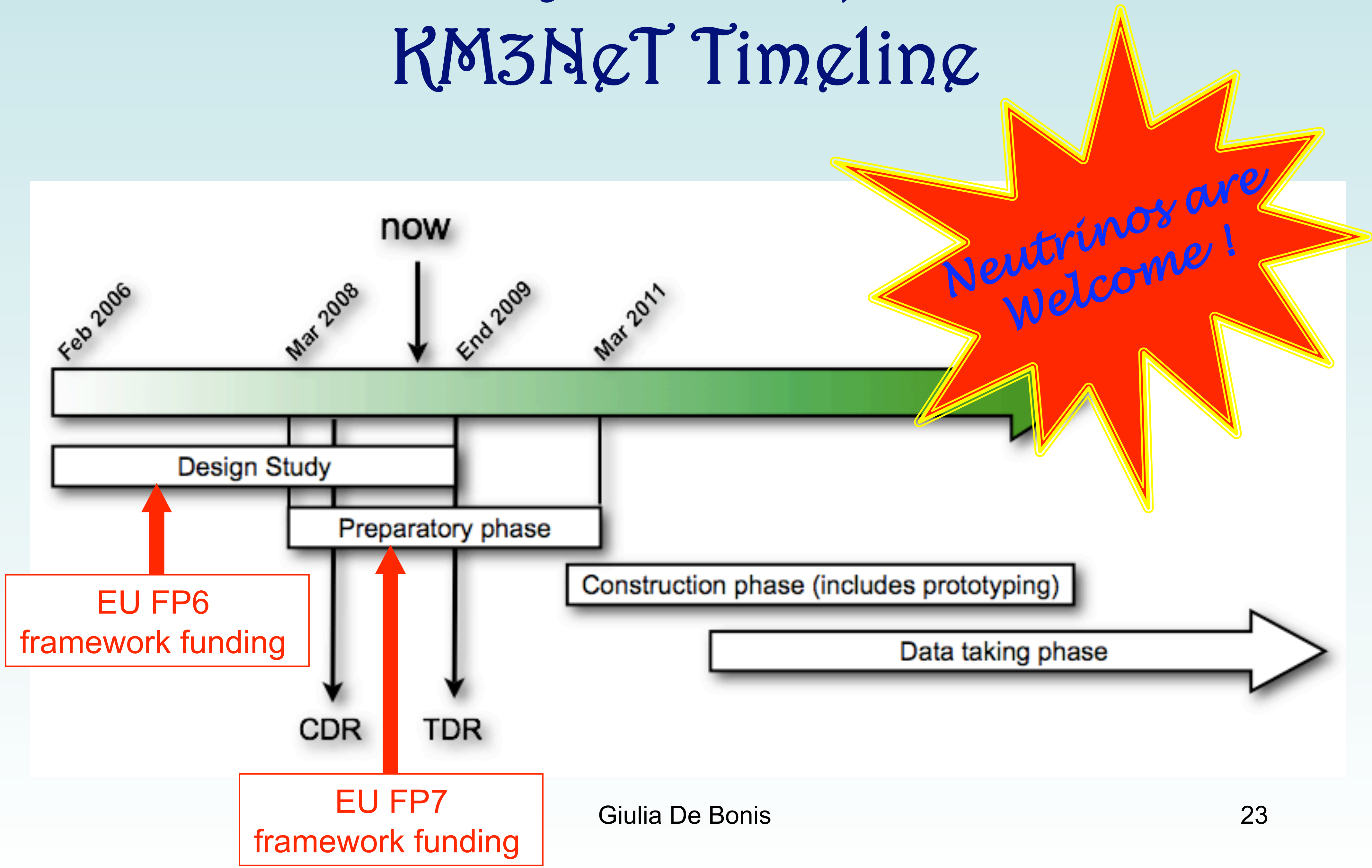
Include quality control and risk analysis

Summary and Perspectives
KM3NeT Timeline



Summary and Perspectives

KM3NeT Timeline



back-up slides

UHEν's Production: Acceleration
(*bottom-up* model)

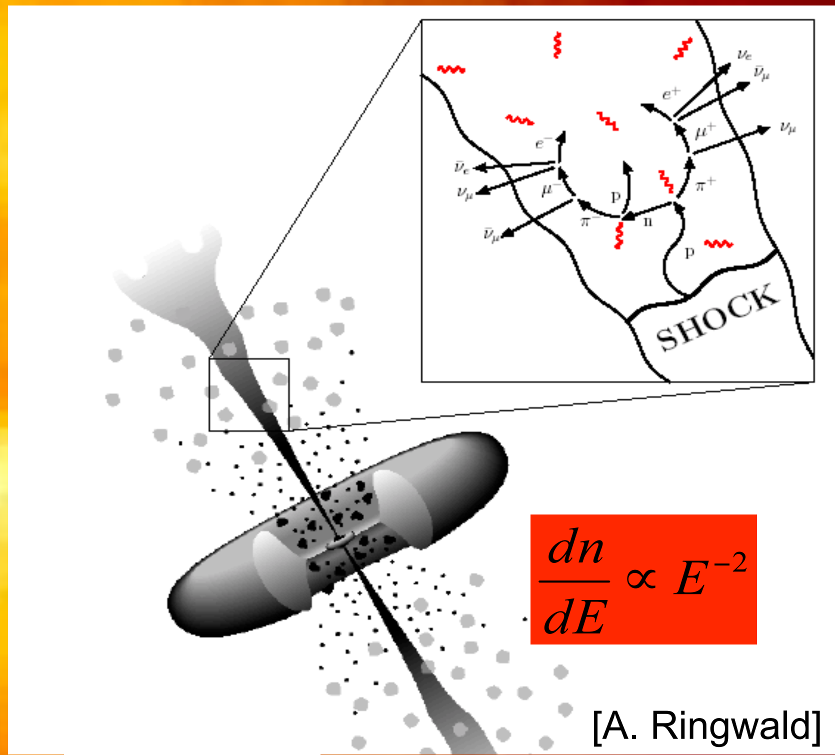
Fermi engine (AGNs, SNRs)

• *protons*, confined by magnetic fields, are accelerated through repeated scattering by **plasma shock front**;

• collisions of trapped protons with ambient plasma produce **γs** and **νs** through **pion photoproduction** mechanism:

$$p + N, \gamma \rightarrow X + \begin{cases} \pi^{\pm} \rightarrow \text{neutrinos} \\ \pi^{\text{o}} \rightarrow \gamma - \text{rays} \end{cases}$$

$E_\nu \sim 0.05\ E_p$



core of Galaxy NGC 4261
Hubble Space Telescope

CR Propagation → GZK cut-off

[Greisen – Zatsepin – Kuzmin]

The UHE CR horizon is limited by interactions with low energy background radiation

→ **Pion Photoproduction**

$$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow \begin{cases} p + \pi^{0}, & \pi^{0} \rightarrow \gamma\gamma \\ n + \pi^{+}, & \pi^{+} \rightarrow \mu^{+} + \nu_{\mu}, \quad \mu^{+} \rightarrow e^{+} + \overline{\nu}_{\mu} + \nu_{e} \\ & n \rightarrow p + e^{-} + \overline{\nu}_{e} \end{cases}$$

$E\gamma \sim 10^{-4}$ eV

(T~2.7 K)

⇒ $E_{th} \sim 3\times10^{19}$ eV

$n_{CMBR} \sim 400$ cm^{-3}

$\sigma_{p\gamma} \sim 100$ μbarn

⇒ $$\lambda_{att}^{pCMBR} = \frac{1}{\sigma_{p\gamma} n_{CMBR}} < 50 \text{ Mpc}$$

GZK NEUTRINOS (cosmogenic neutrino flux)

Neutrinos at $10^{17\text{-}19}$ eV predicted by standard-model physics through the GZK process

observing them is crucial to resolve the GZK puzzle

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