Underwater Neutrino Telescopes: Focusing on high energy neutrinos

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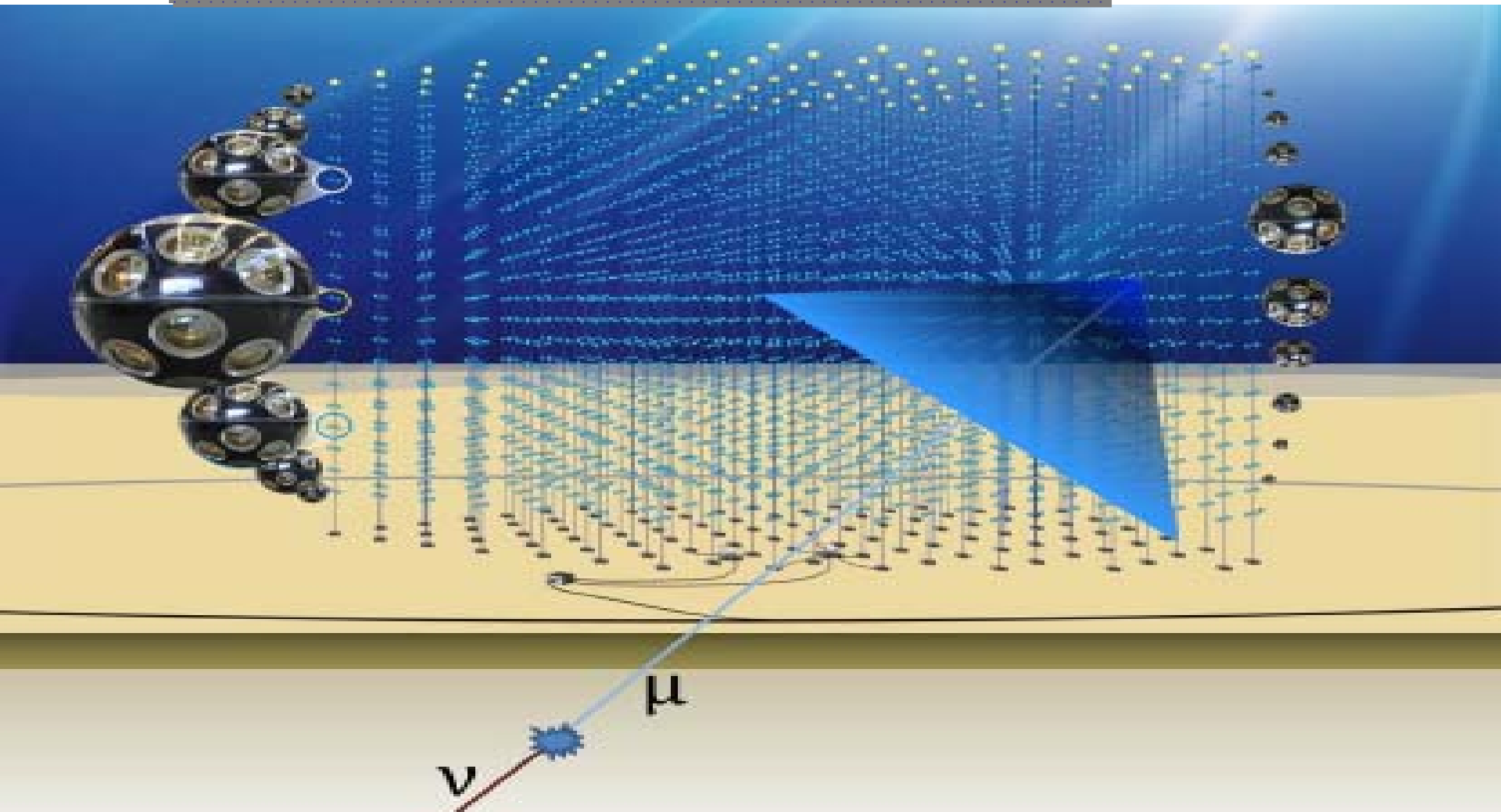
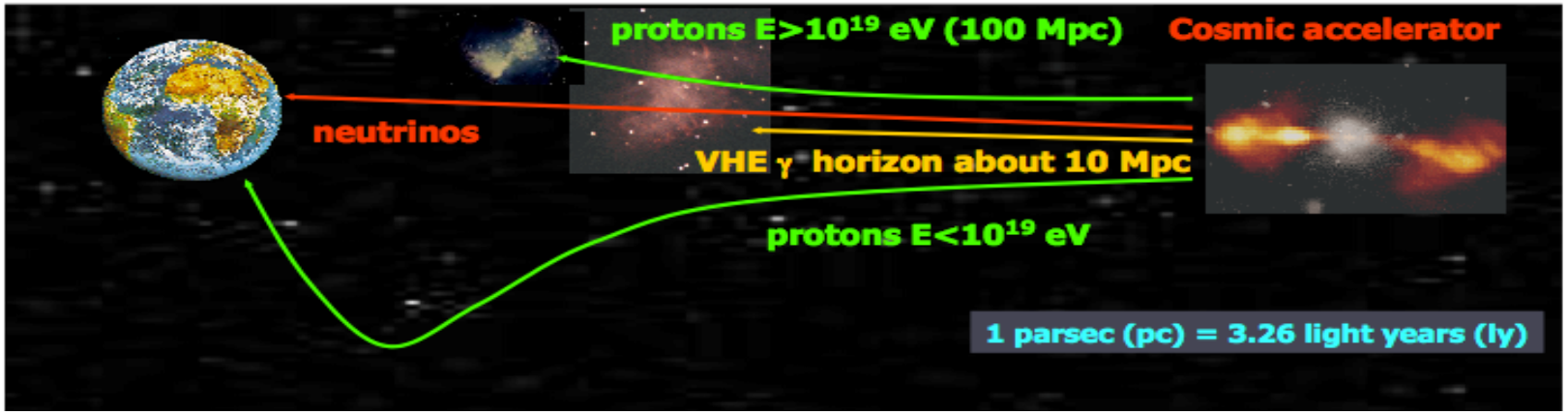




ν and γ produced in the interaction of high energy nucleons with matter or radiation

$$N + X \rightarrow \pi^{\pm}(K^{\pm}...) + Y \rightarrow \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu}) + Y$$
$$\downarrow$$
$$e^{\pm} + \bar{\nu}_{e}(\nu_{e}) + \bar{\nu}_{\mu}(\nu_{\mu})$$

$$N + X \rightarrow \pi^{0} + Y \rightarrow \gamma\ \gamma + Y$$

cosmic ray acceleration yields neutrinos and gammas with similar abundance and energy spectra

origin of UHE cosmic rays

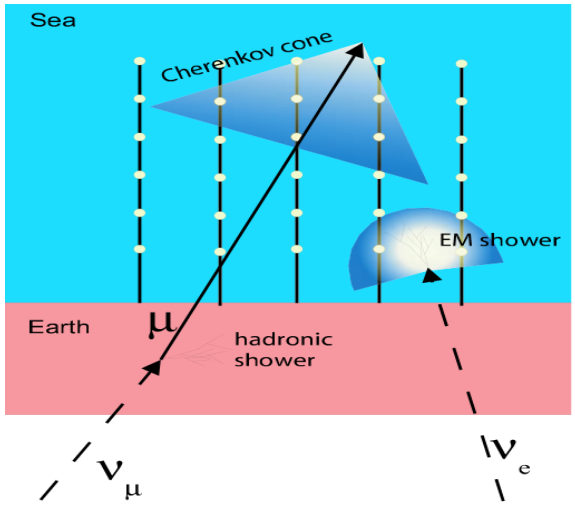
production mechanism of HE gamma-rays (hadronic or leptonic)

neutrinos:

unique messengers

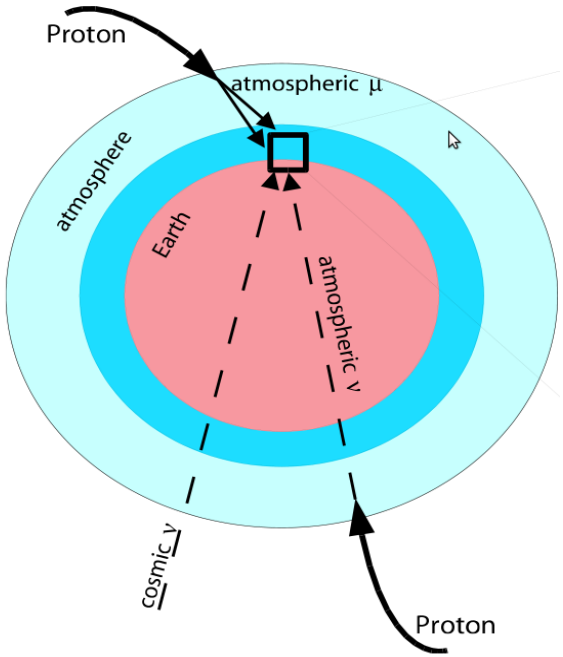
- **no interactions with ambient matter or radiation**
- **no deflection by magnetic fields**
- **information on the internal processes of the astrophysical sources inaccessible through photons or cosmic rays**

Underwater Neutrino Telescopes: Neutrino Observation



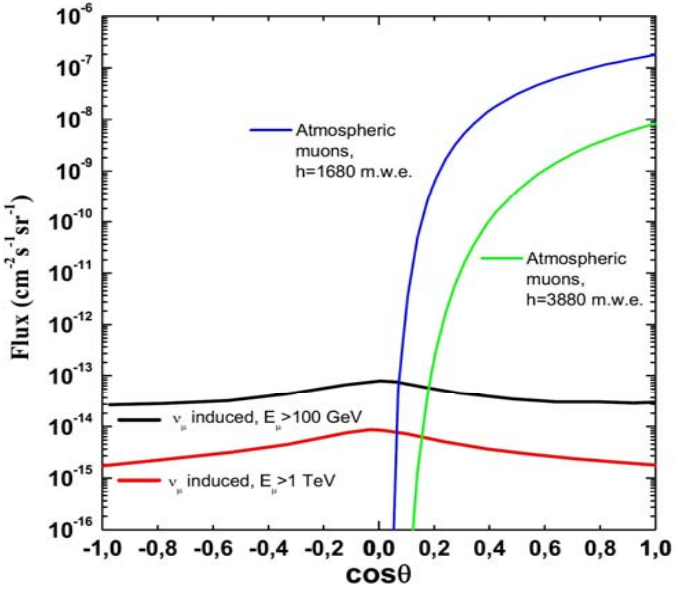
- Upward-going neutrinos interact in rock or water
- charged particles (in particular muons) produce Cherenkov light in water at 43° with respect to the neutrino direction
- light is detected by array of photomultipliers
- muon direction is reconstructed using PMT positions and photon arrival times
- the Earth provides screening against all particles except neutrinos

Background sources



• **cosmic ray interactions in the atmosphere produce $\pi^{\pm}$ and $K^{\pm}$ whose decays produce neutrinos - atmospheric neutrinos**

• **cosmic rays entering the atmosphere produce extensive air showers; a component of which are high energy muons – atmospheric muons**



<u>noise:</u> background from ^{40}K decays and from bioluminescence (life forms in the deep sea emitting light)

KM3NeT objectives

- **investigate neutrino "point sources" in the TeV energy regime**

galactic - Field of view includes the Galactic center and complements IceCube

⟶ Supernova Remnants, Microquasars

extragalactic ⟶ Active Galactic Nuclei, Gamma Ray Bursts

- **High-energy diffuse neutrino flux**

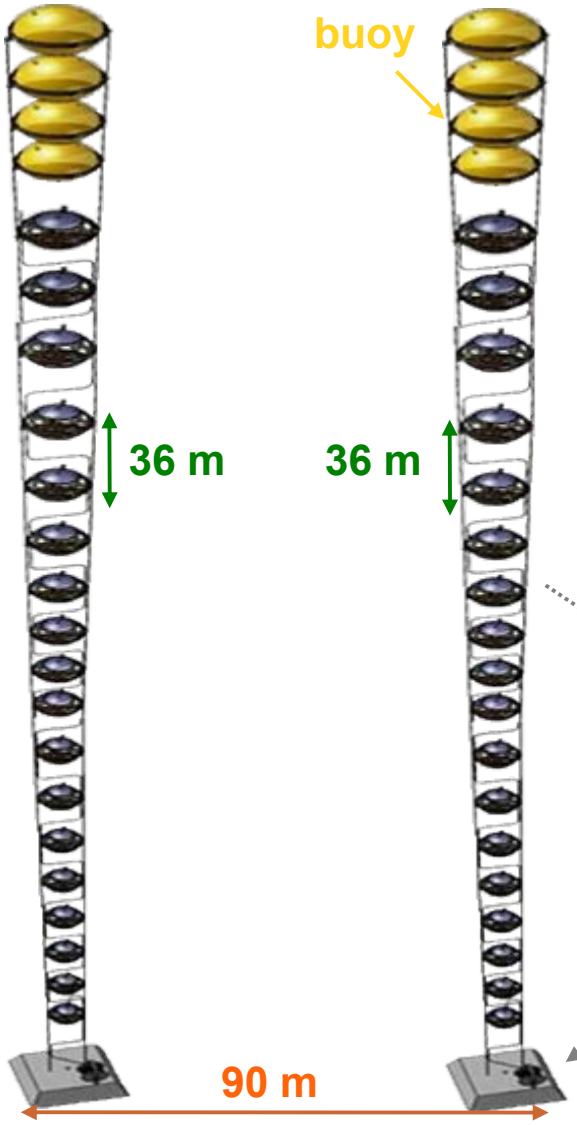
IceCube: 37 ν evts with 30 TeV < E_ν < 2000 TeV; establish extraterrestrial ν at 5.7σ

Optical properties of deep sea water: excellent angular resolution

neutrino cross section is extremely low : very large active volume needed

Instrumented volume of several km3 : exceed IceCube sensitivity

KM3NeT Detector Configuration



- 6 blocks – each block has an almost hexagonal geometry with **115 strings** at **90m** distance. Each string has **18 floors** and each floor has **1** Optical Module (OM).
- OMs arranged in **vertical strings** with a height of almost **600m**.
- All data are transmitted to shore via an optical fibre network.
- Each OM consists of a **17" glass sphere**, equipped with **31 3" photomultipliers**.

Current activities within the KM3NeT Collaboration

Focusing on the observation of High Energy Neutrinos

➢ Muon Energy Reconstruction

- **the reconstructed muon is used to approximate the neutrino direction and energy => Improvement of the muon track reconstruction**

- **muon energy estimation: critical for differentiating muons from neutrinos originating from astrophysical sources from muons and neutrinos generated in the atmosphere**

Talk by E. Drakopoulou

➢ Atmospheric Muon Background Rejection

Talk by K. Pikounis

Atmospheric Muon Background Rejection

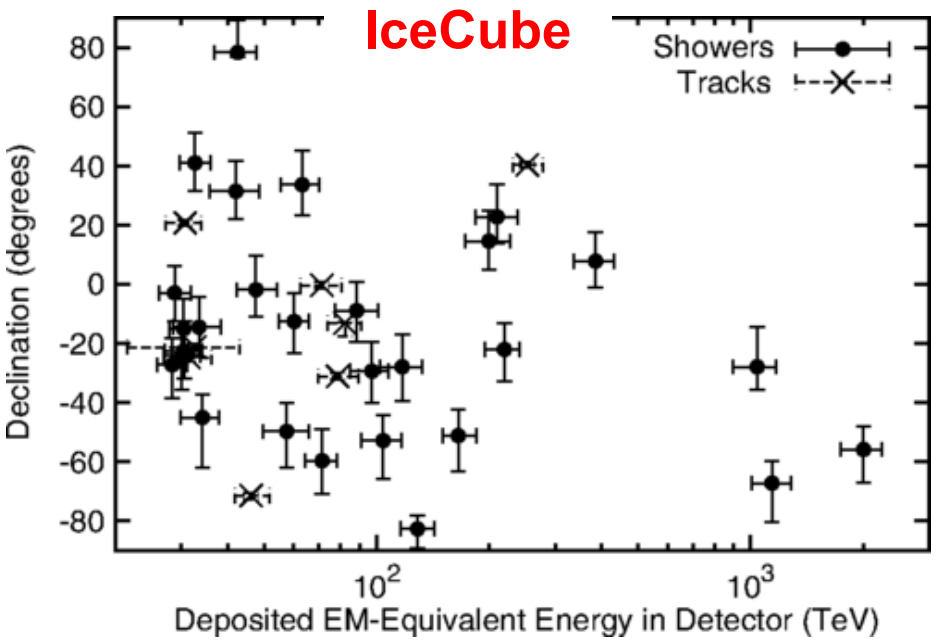
- the reconstructed muon is used to approximate the neutrino direction and energy
  → interaction vertex inside the detector leads to reliable reconstruction of E_ν

- **Recent IceCube results:** Observation of High-Energy Astrophysical Neutrinos in Three Years of IceCube Data

37 ν evts with 30 TeV < E_ν < 2000 TeV
a purely atmospheric explanation
rejected at 5.7σ

μ tracks: 9 events

showers: 28 events



IceCube requires that the reconstructed vertex is inside a volume smaller than the detector volume (fiducial volume)

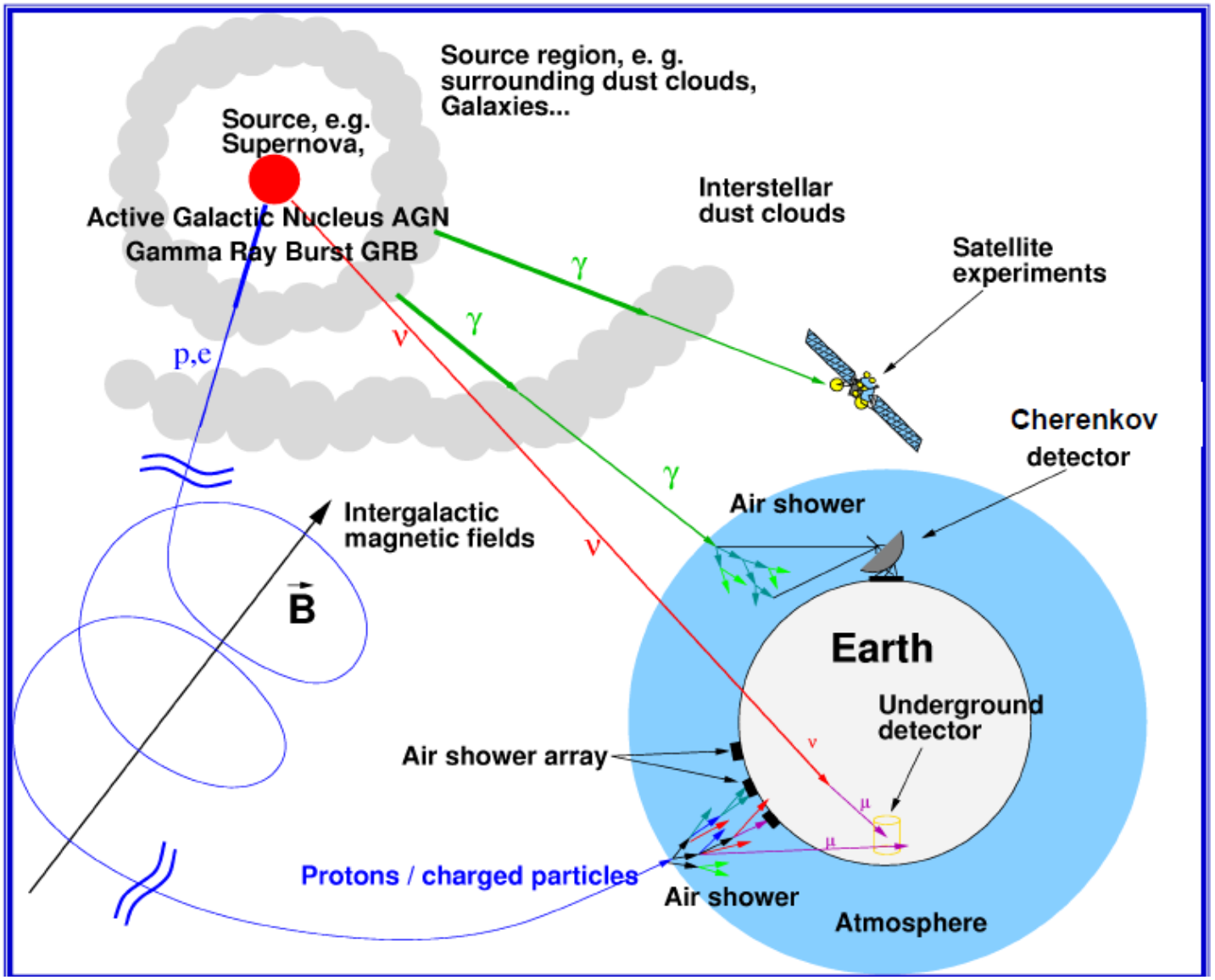
Extending to Higher Energies: GRBNeT

- Gamma Ray Bursts (GRBs) are emissions of γ-rays with short duration, associated with high energy phenomena in distant galaxies. Largest emissions of photon energy known to date.

- The possible origin of GRBs suggests mechanisms for the creation of the burst, consistent with the energy spectrum and flux of ultra high energy cosmic rays.

- Although the detection of high energy neutrinos (E>100 TeV) requires neutrino telescopes of sizes much larger than 1 km^3, the observation of GRB neutrinos can exploit the temporal and directional coincidence of an extragalactic neutrino signal with the signal from x or γ ray telescopes to allow for an essentially background free observation. This multi-messenger approach allows for a significant increase of the detection sensitivity with a relatively low cost solution.

GRBs


Source region, e. g.
surrounding dust clouds,
Galaxies...
Source, e.g.
Supernova,
Active Galactic Nucleus AGN
Gamma Ray Burst GRB
Interstellar
dust clouds
Satellite
experiments
γ
γ
γ
ν
p,e
Cherenkov
detector
Air shower
Intergalactic
magnetic fields
B
ν
Earth
Underground
detector
Air shower array
ν
μ
μ
Protons / charged particles
Air shower
Atmosphere

GRBNeT

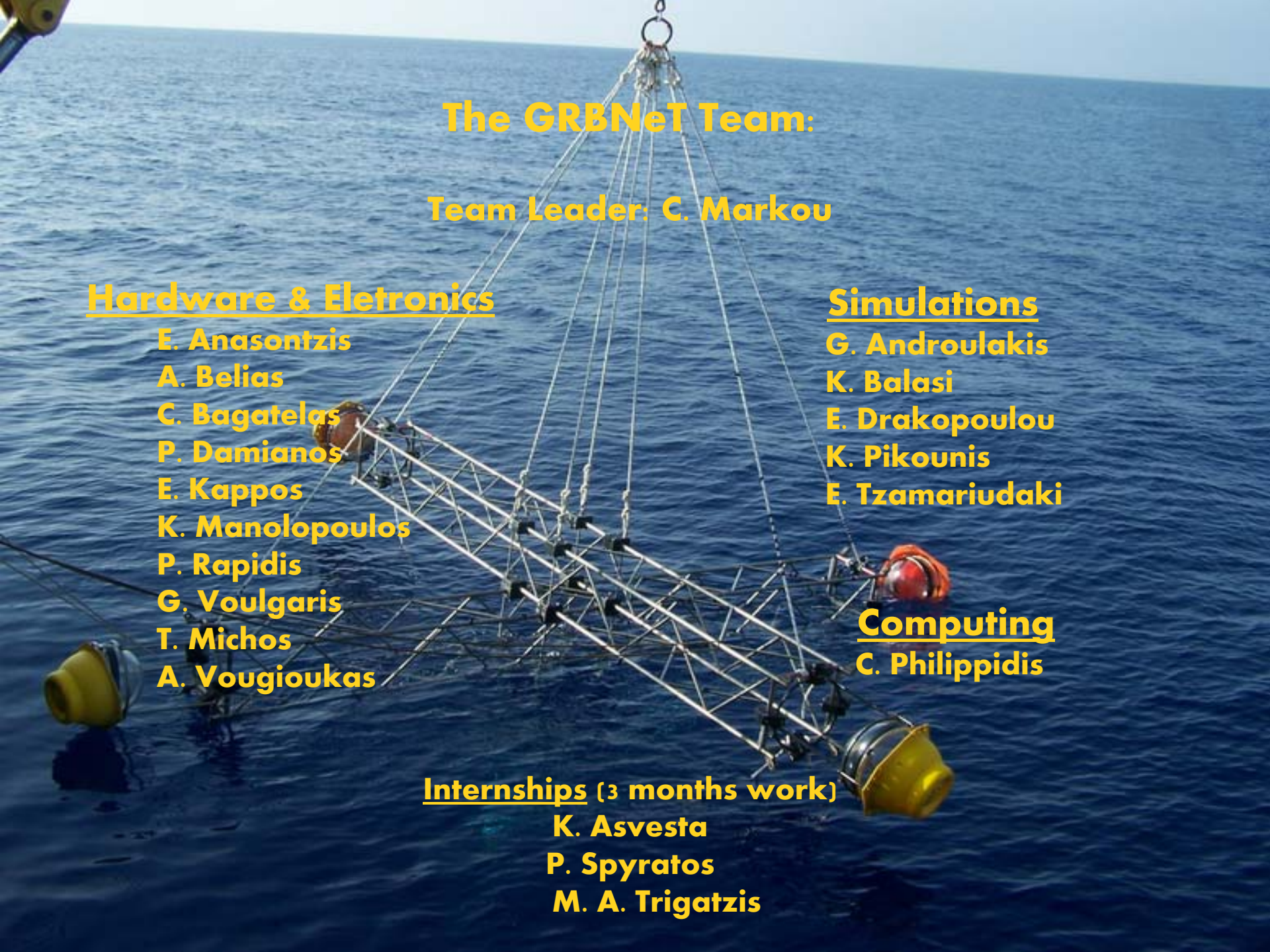
An autonomous detector for Neutrinos from Gamma Ray Bursts

GRBNeT : project for the development and construction of a prototype autonomous linear array of light detectors, to operate in the sea bottom

- No dependency on cables…
- Cost-effective and easy to deploy.
- Can be placed around any active underwater telescope.

- Use high thresholds to preserve power and operate for large time periods.
  - Appropriate for high energy neutrino events from GRBs.

collaboration of NCSR Demokritos, University of Athens, HCMR



The GRBNeT Team:

Team Leader: C. Markou

Hardware & Eletronics

E. Anasontzis
A. Belias
C. Bagatelas
P. Damianos
E. Kappos
K. Manolopoulos
P. Rapidis
G. Voulgaris
T. Michos
A. Vougioukas

Simulations

G. Androulakis
K. Balasi
E. Drakopoulou
K. Pikounis
E. Tzamariudaki

Computing

C. Philippidis

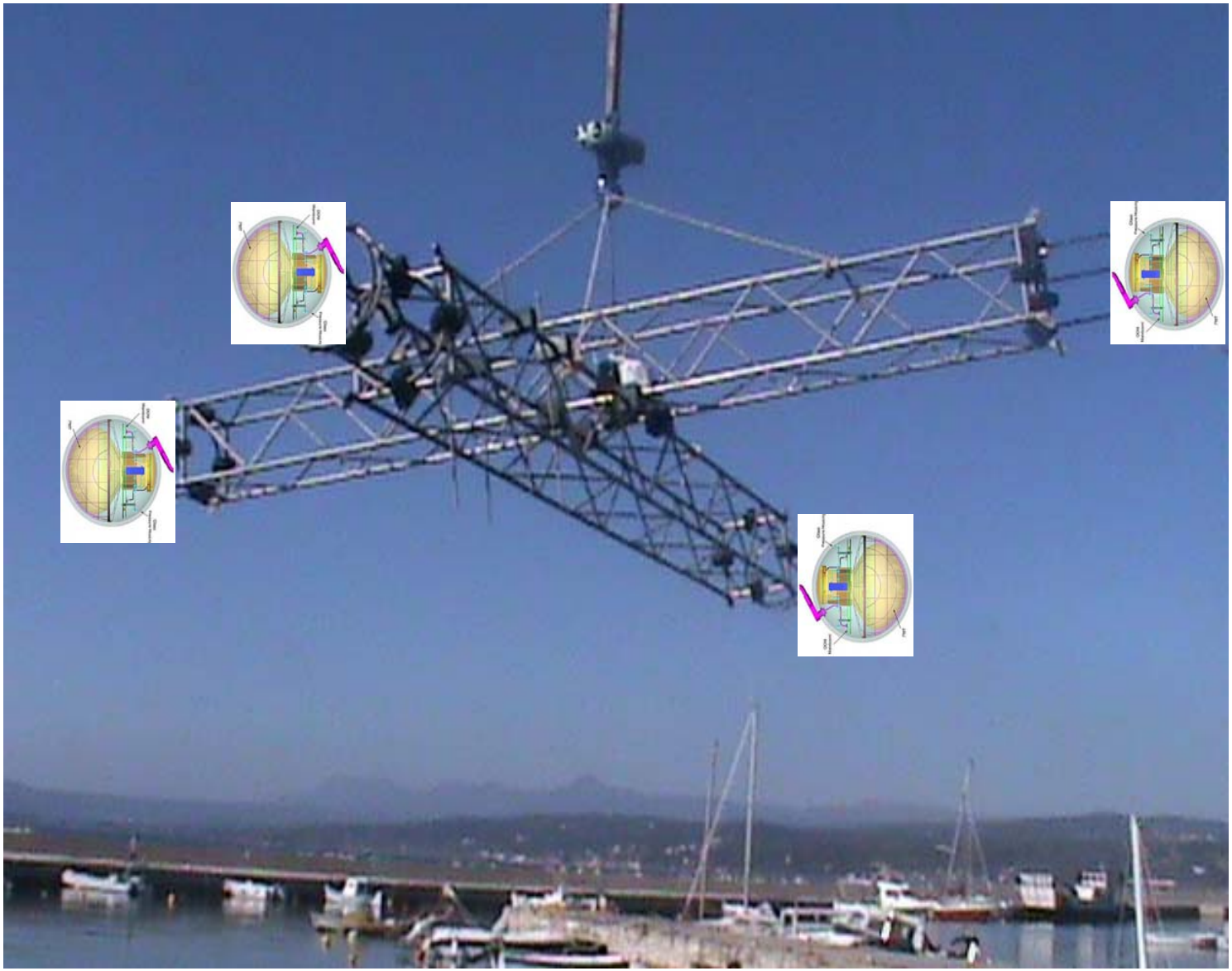
Internships (3 months work)

K. Asvesta
P. Spyratos
M. A. Trigatzis

GRBNeT

- PMTs to look towards the horizon for maximum sensitivity for UHE neutrinos – deep waters necessary to reduce atmospheric muon background.
- Very low power electronics have been designed from scratch with Cockroft-Walton multiplier powering up the PMTs.
- Operate at high signal thresholds to reduce data rate and minimize background (> 5 p.e)
- Each floor has its own trigger and DAQ system to minimize the risk of failure in the prototype.
- Timing provided by an cesium atomic clock synchronized with GMT at deployment.
- Synchronization between floors through LED beacons.
- All data to be stored locally and be recovered either through an acoustic modem or at recovery time.
- Power will be supplied by batteries at ambient pressure!

Detector layout



GRBNeT : Atmospheric Muon Background Reduction

Initial studies

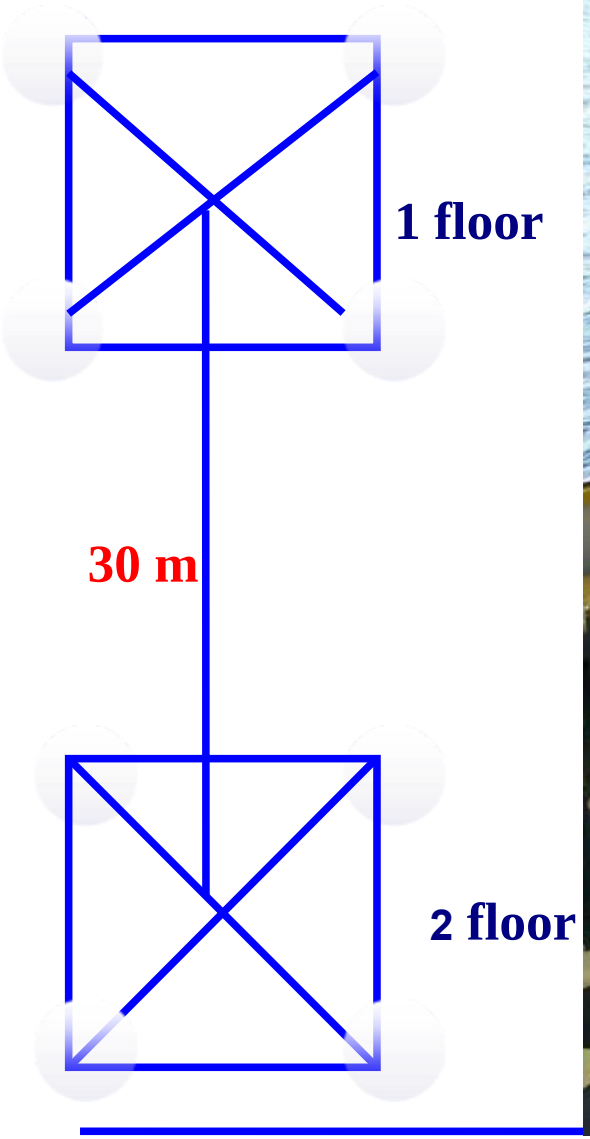
Threshold acceptance 3 p.e.

condition	muons/day
1 OM	2816
2 OMs on the same floor	579
3 OMs on the same floor	200

Threshold acceptance 5 p.e.

condition	muons/day
1 OM	1239
2 OMs on the same floor	271
3 OMs on the same floor	97

New Detector layout (2 floors)



GRBNeT

Currently:

- Mechanical structures are finished.
- Individual components identified / purchased / tested.
- Electronics prototypes under test.
- DAQ system under test.
- Deployment procedures have been finalized.
- Simulation of the new detector layout completed – analysis ongoing