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Time Calibration of the ANTARES Neutrino Telescope

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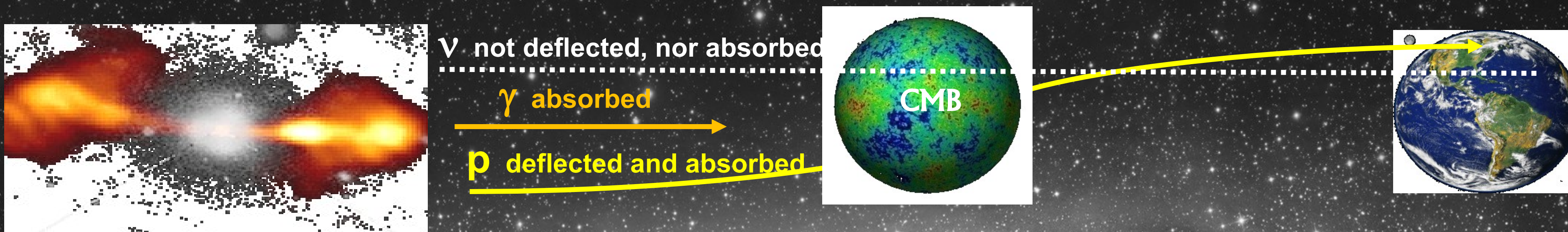
On behalf of the ANTARES collaboration

http://antares.in2p3.fr

NEUTRINO AS A NEW MESSENGER FROM THE DEEPEST UNIVERSE



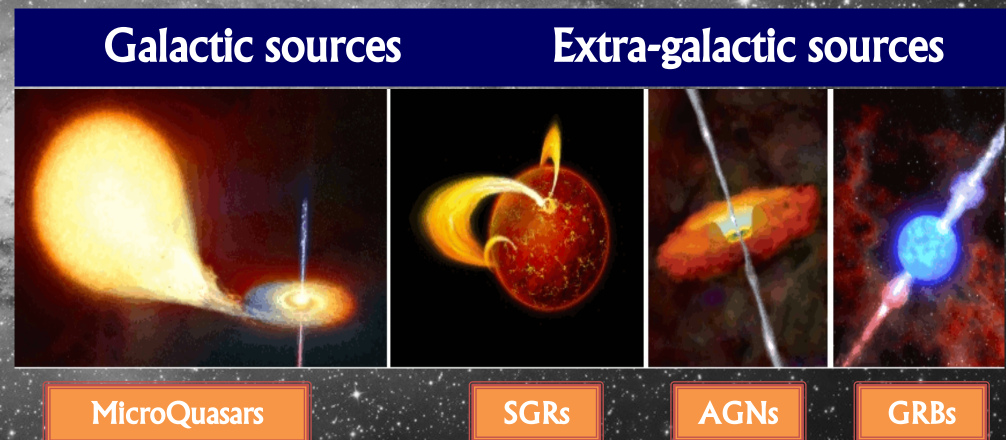
Protons are deflected by magnetic fields ($E_p < 10^{19}$ eV)

UHE protons interact with the CMB ($E_p > 10^{19}$ eV → 30 Mpc)

Neutrons decay (~10 kpc at E ~ EeV)

Photons interact with the EBL (~100 Mpc) and CMB (~10 kpc)

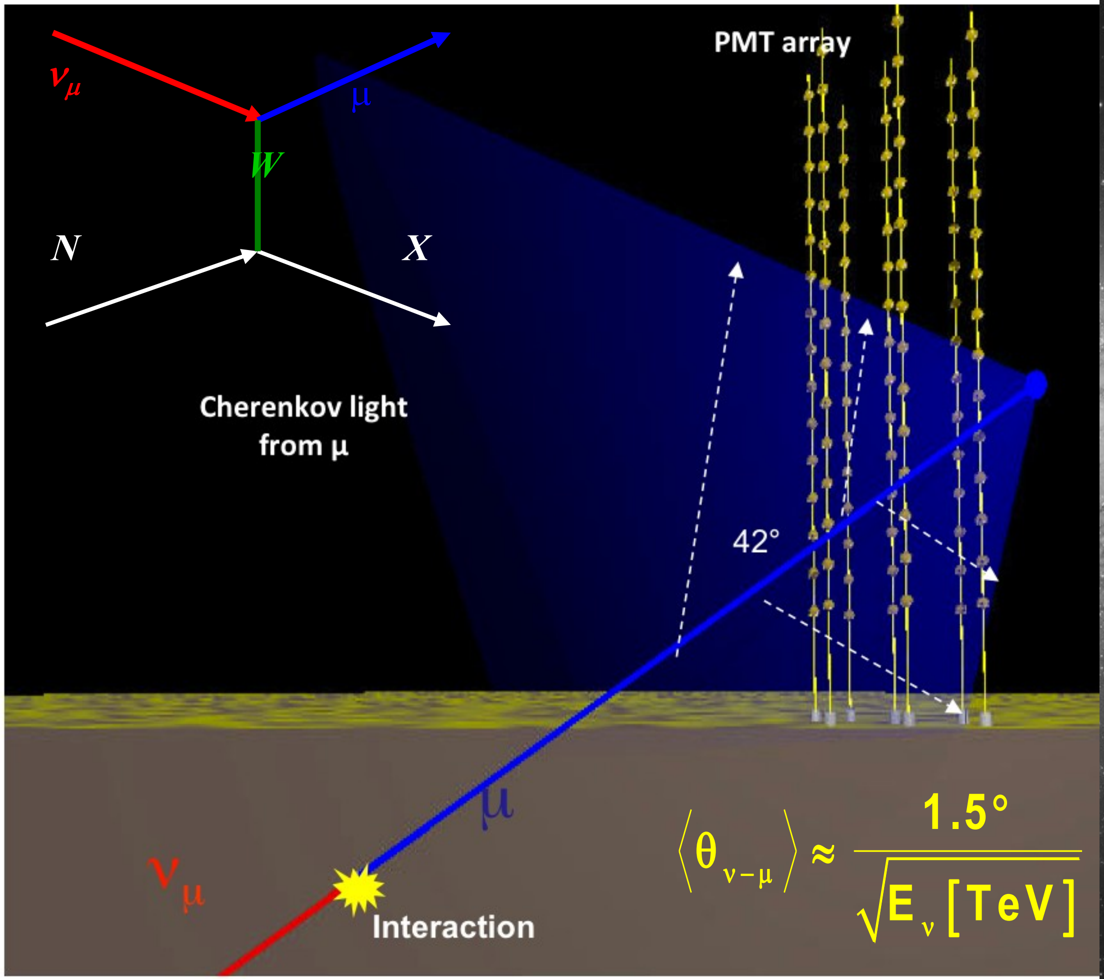
Neutrinos are neutral weakly interactive particles and they can come from dense astrophysical objects at large distances



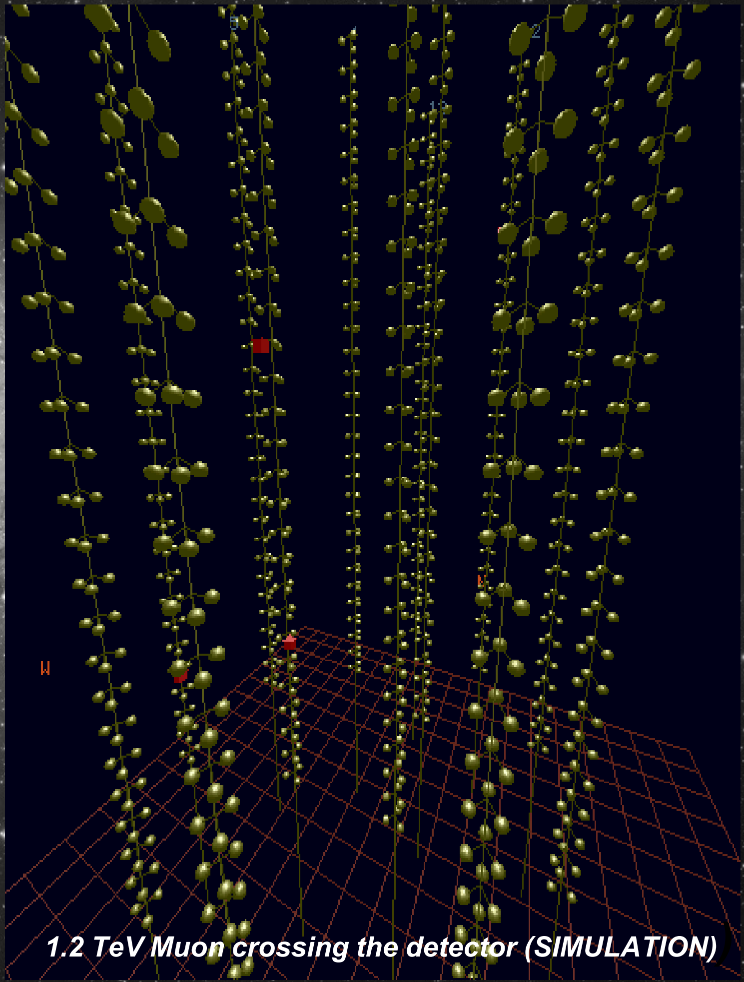
- Origin of cosmic rays (CR) → 10^{20} eV ?
- CR acceleration mechanism ?
- Origin of relativistic jets ?
- Dark matter ?

Large mass detectors required !

DETECTION PRINCIPLE IN NEUTRINO TELESCOPES



$$\langle \theta_{\nu-\mu} \rangle \approx \frac{1.5°}{\sqrt{E_\nu [TeV]}}$$



1.2 TeV Muon crossing the detector (SIMULATION)

Main detection channel:

ν_μ ➔ relativistic μ ➔ Cherenkov light in a cone (ν_e and ν_t can also be detected)

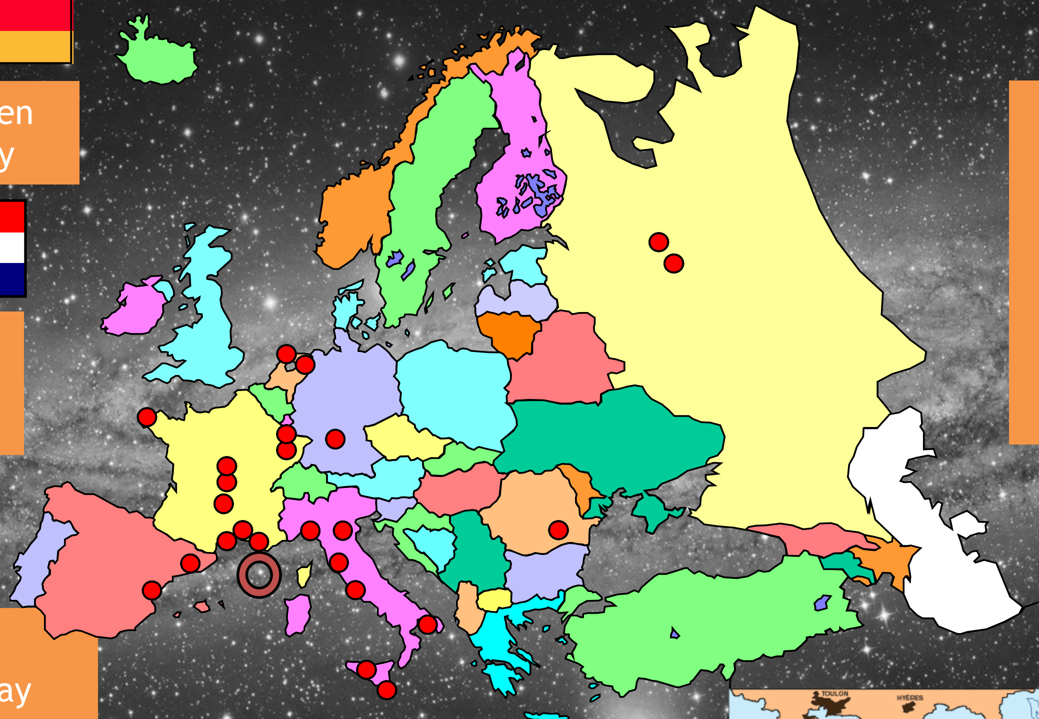
Reconstruction of μ trajectory (~ ν) from **timing** and **position** of PMT hits

THE ANTARES COLLABORATION

- University of Erlangen
- Bamberg Observatory

- NIKHEF (Amsterdam)
- KVI (Groningen)
- NIOZ Texel

- CPPM, Marseille
- DSM/IRFU/CEA, Saclay
- APC, Paris
- LPC, Clermont-Ferrand
- IPHC (IReS), Strasbourg
- Univ. de H.-A., Mulhouse
- IFREMER, Toulon/Brest
- C.O.M. Marseille
- LAM, Marseille
- GeoAzur Villefranche

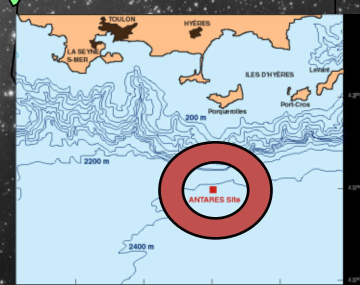


IFIC, Valencia
UPV, Valencia
UPC, Barcelona

- University/INFN of Bari
- University/INFN of Bologna
- University/INFN of Catania
- LNS - Catania
- University/INFN of Pisa
- University/INFN of Rome
- University/INFN of Genova

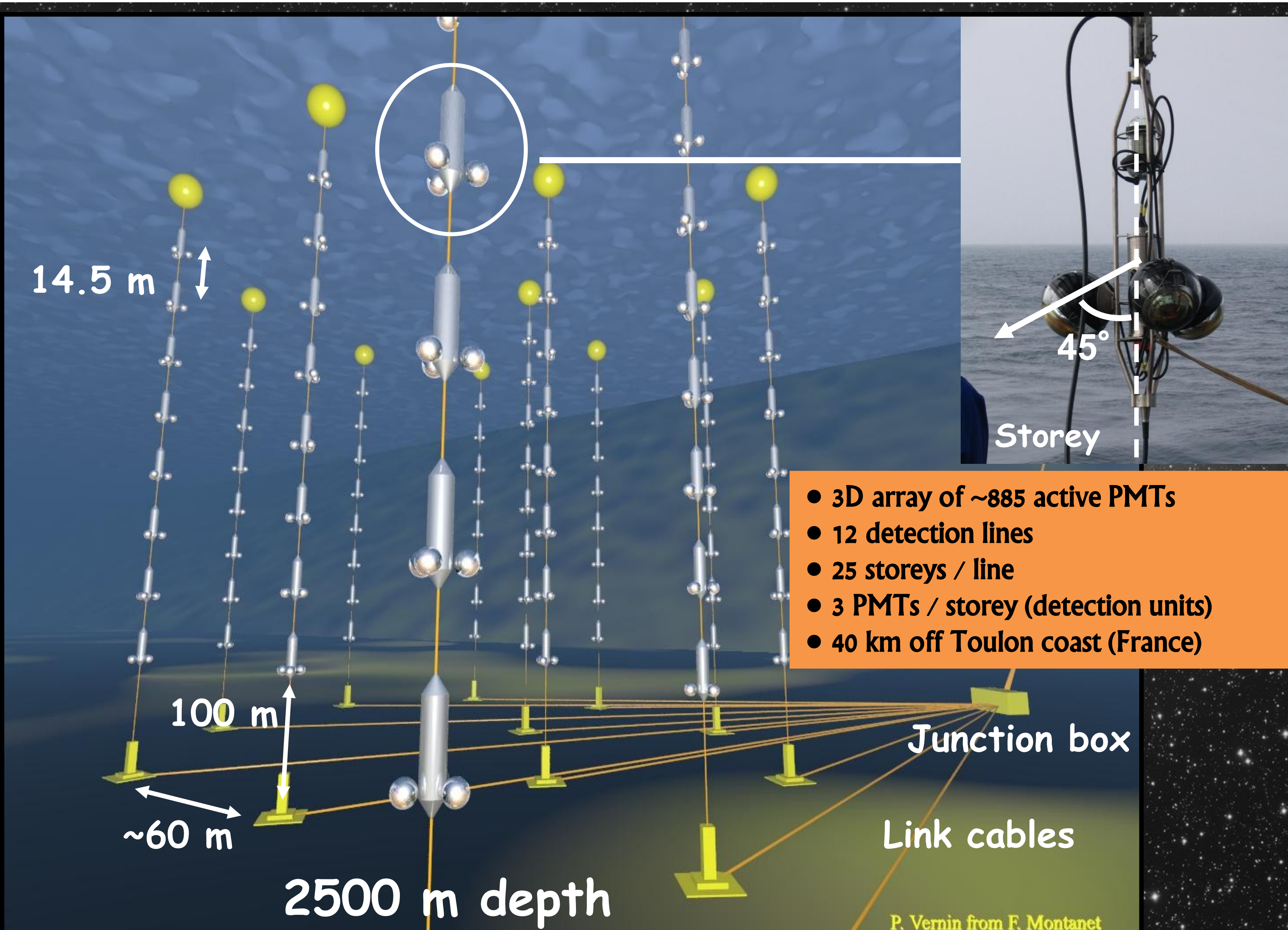
- ITEP, Moscow
- **Moscow State Univ**

ISS, Bucarest

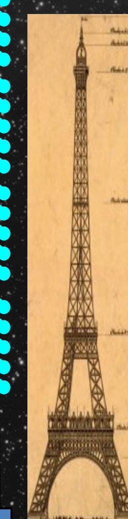


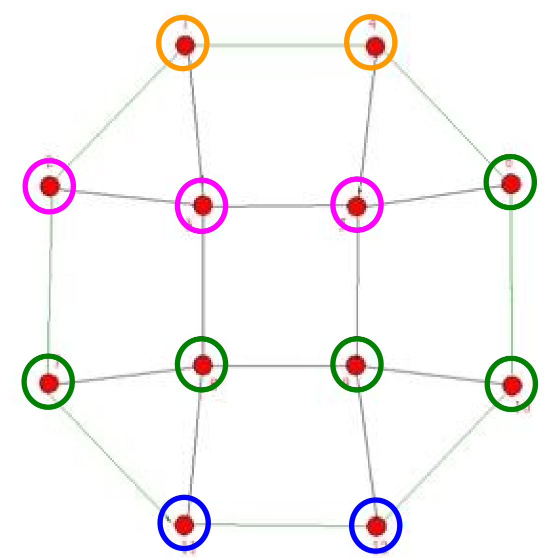
7 COUNTRIES
28 INSTITUTES
~ 150 SCIENTISTS AND ENGINEERS

THE ANTARES NEUTRINO TELESCOPE



- 3D array of ~885 active PMTs
- 12 detection lines
- 25 storeys / line
- 3 PMTs / storey (detection units)
- 40 km off Toulon coast (France)



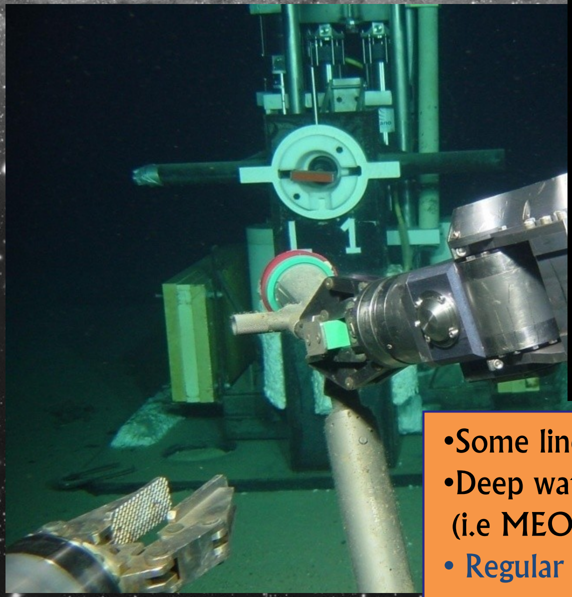


Lines 1-2: 2006

Lines 3-5: 01 / 2007

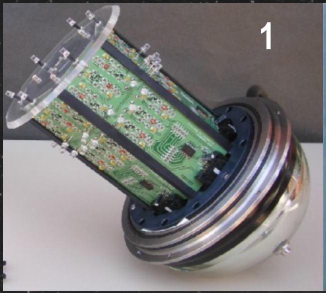
Lines 6-10: 12 / 2007

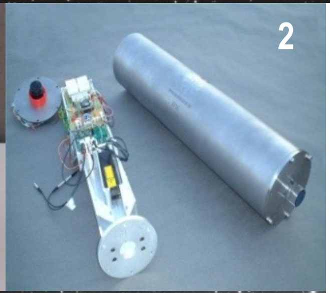
Lines 11-12: 05 / 2008



- Some line has been repaired along the time (i.e L12)
- Deep water operations have been a success (i.e MEOC).
- Regular maintenance of in-situ infrastructure.

THE ANTARES NEUTRINO TELESCOPE – Basic detector element





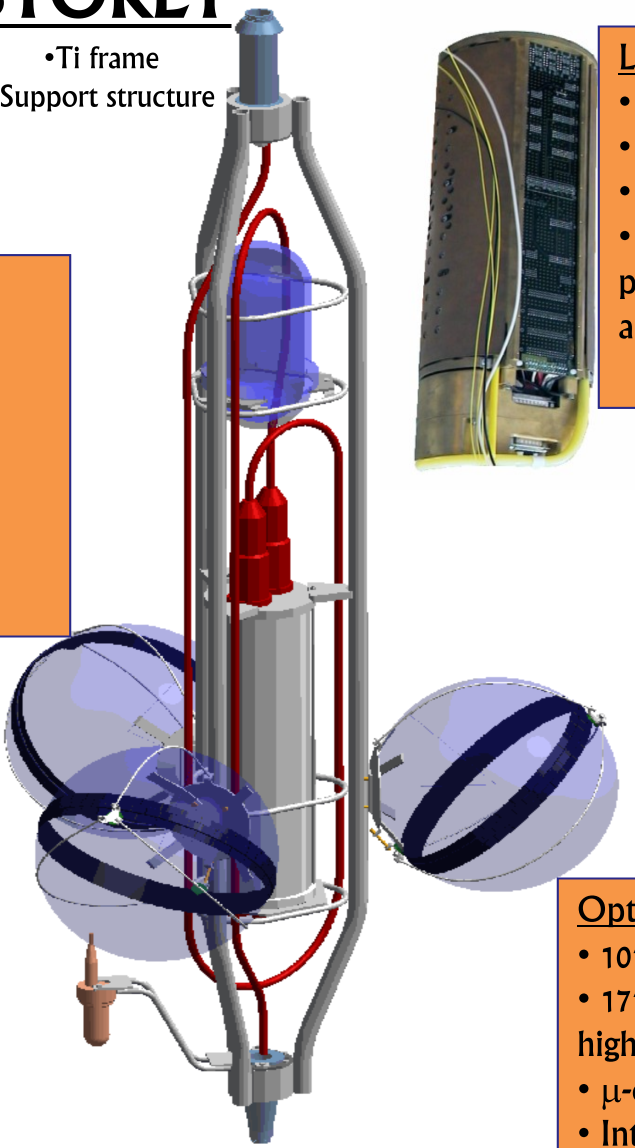
<u>1. Optical beacon with blue LEDs (LOB):</u>
- 4 / line (F2, F9, F15, F21)
- Timing calibration
- Optical properties monitoring

<u>2. Optical beacon with green LASER (LB):</u>
- 2 / throughout the detector (bottom L7, L8)
- Timing calibration
- Positioning

<u>Hydrophone (Rx):</u>
- Acoustic positioning

STOREY

- Ti frame
- Support structure

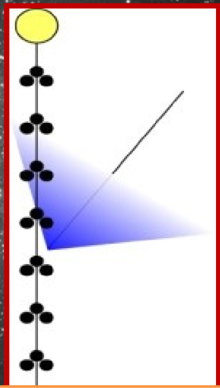


<u>Local Control Module (LCM):</u>
- Ti cilinder
- Front-end electronics
- Clock board, tilt/compass
- ARS card (2 / PMT): analogic signal processing and digitization. Time and amplitude of signal. Trigger system.

<u>Optical module (OM):</u>
- 10'' Hamamatsu PMT (TTS≈1.3 ns)
- 17'' glass sphere (gel, optical coupling) high pressure resistant
- μ-cage (earth magnetic field shield)
- Internal LED monitor TT of PMT

Time Calibration requirements

Absolute time resolution -> Can be determined with a precision better than 100 ns (enough to correlate with astrophysics processes)



Relative time resolution -> Chromatic dispersion and scattering amounts to **σ ~ 2 ns** (at 50 m)

-> TTS and PMT electronics contributions are less than **2 ns**

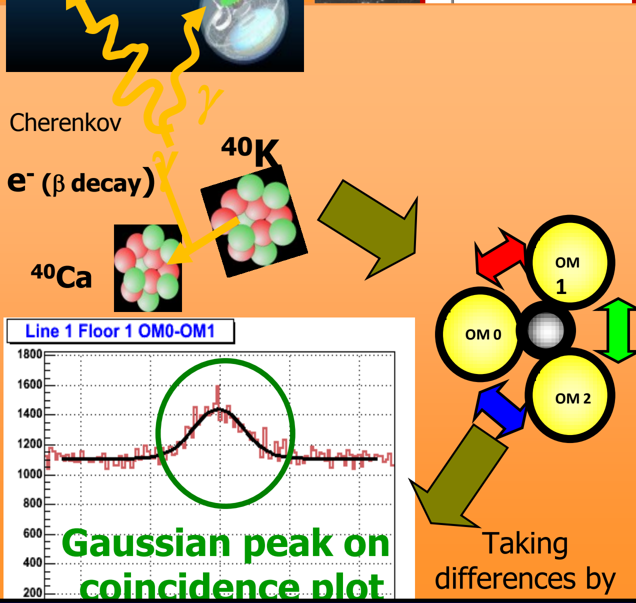
-> Time precision required for calibration offsets is **σ ≤ 1 ns**

Before deployment, the time calibration constants are determined in the ***laboratory***

Time resolution cross-checks

-> For OMs in the same storey, ^{40}K can be used for charge and intra-storey time calibration

-> Reconstructed muons can be used to further refine and cross-check the determination of the time constants



Time Calibration main idea

Track reconstruction requires the knowledge of the relative arrival times of the Cherenkov photons at the PMTs and therefore only their time offsets.

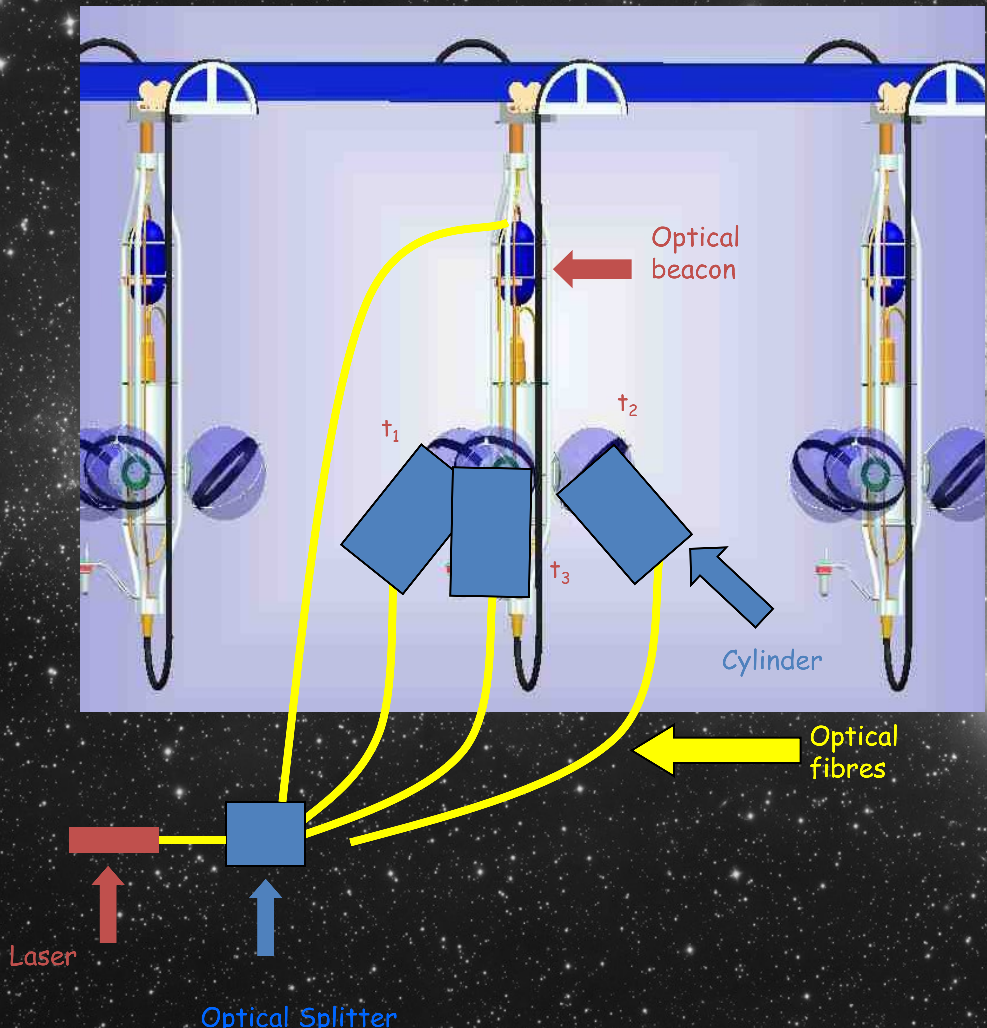
The time elapsed between the incidence of a photon on the photocathode of the PMT and the time stamping of the associated signal must be determinated.

The main goal of the **clock system** is to provide a common signal to synchronize the readout of the OMs (20 KHz generator on shore)

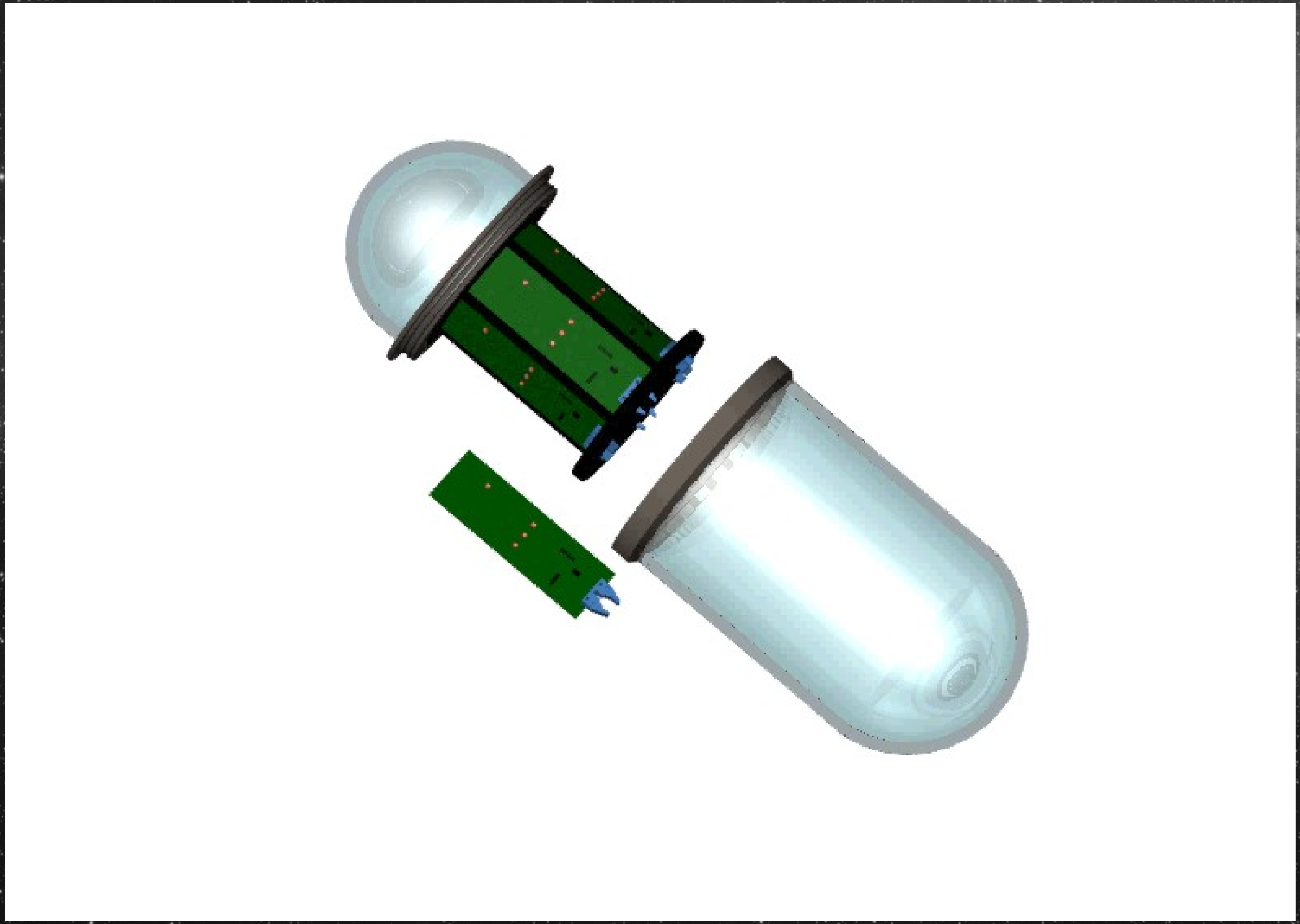
***In situ* measurement** of the time offsets of all the OMs is performed with the optical beacon system (two kind of complementary devices):

- LED beacons that emit blue light (470 nm) - relative time offsets among OMs of the same line
- Laser beacons that emit green light (532 nm) - relative time offsets among lines

Laser calibration at the CPPM dark room

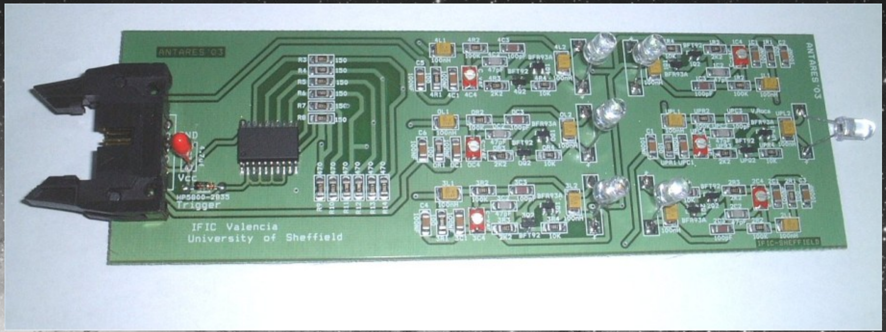


LED beacon

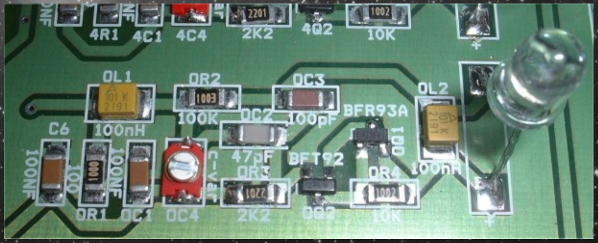


LED beacon components

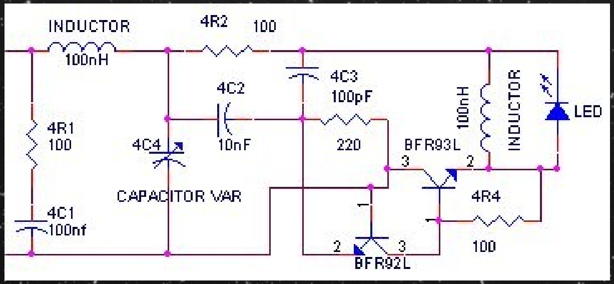
Hexagonal mounting
(six vertical faces)



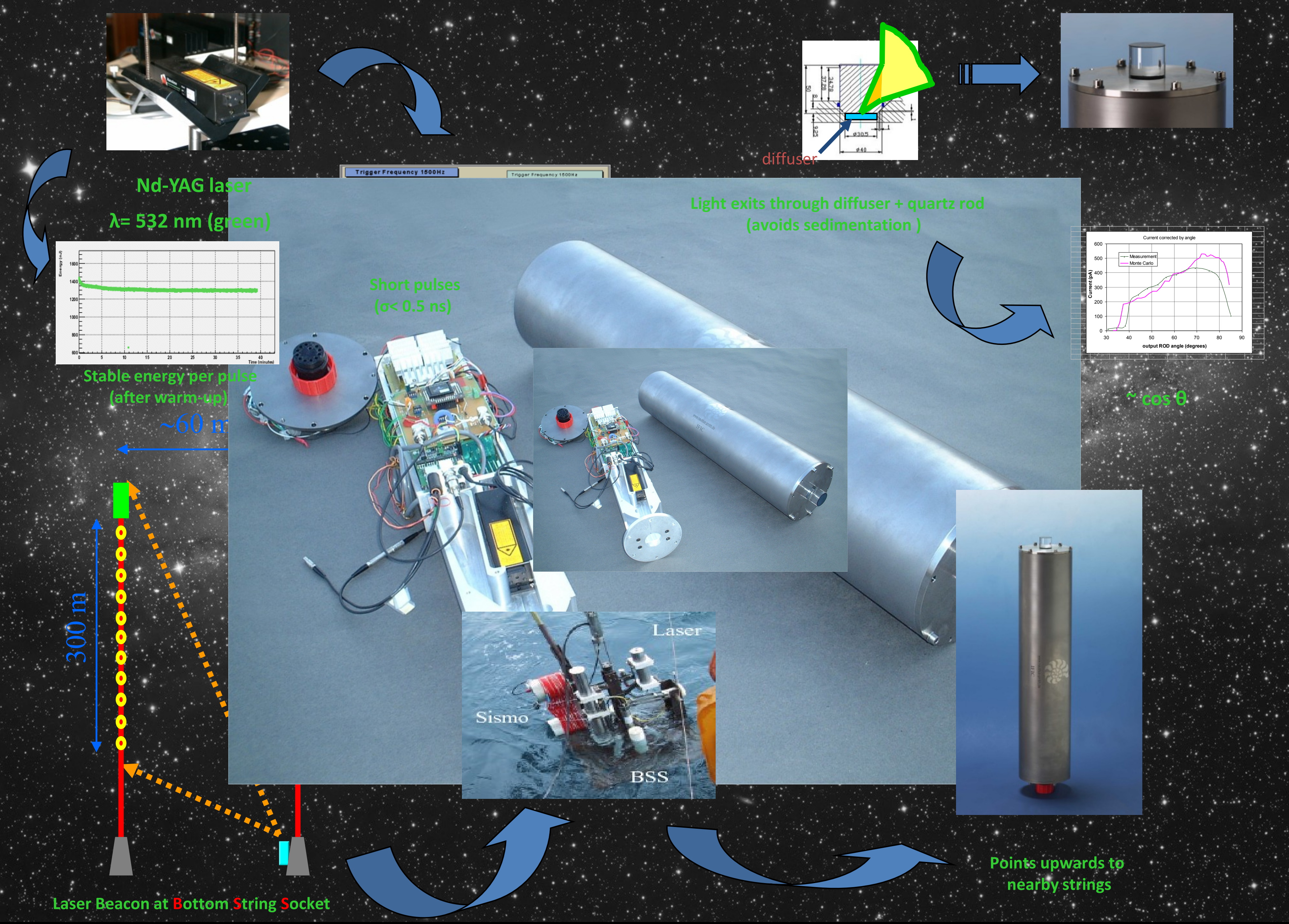
Six LEDs per face
(one looking upwards)



Sheffield pulser



LASER beacon

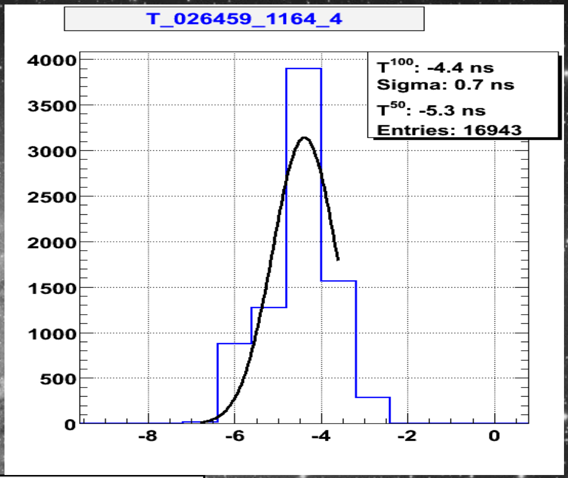


Nd-YAG laser
λ= 532 nm (green)
Stable energy per pulse
(after warm-up)
Trigger Frequency 1500Hz
Short pulses
(σ< 0.5 ns)
diffuser
Light exits through diffuser + quartz rod
(avoids sedimentation)
Current corrected by angle
Measurement
Monte Carlo
Current (pA)
output ROD angle (degrees)
~ cos θ
~60 m
300 m
Laser
Sismo
BSS
Points upwards to
nearby strings
Laser Beacon at Bottom String Socket

Time Offsets determination

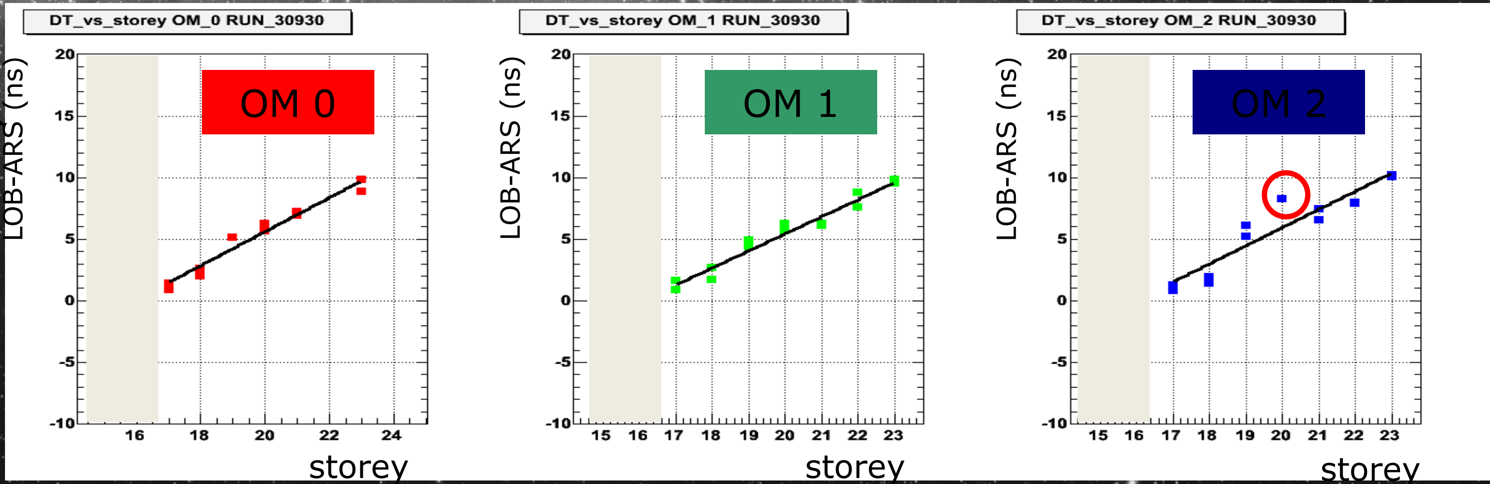
Time residuals **should be** characterized by mean values well centered at zero

$$\Delta t = t_{OB} - t_{OM} - \frac{d}{c_{water}}$$



However, there is a linear delay due to the combination of Early photon + Walk effect

Deviations from the straight line are used for **calibration**

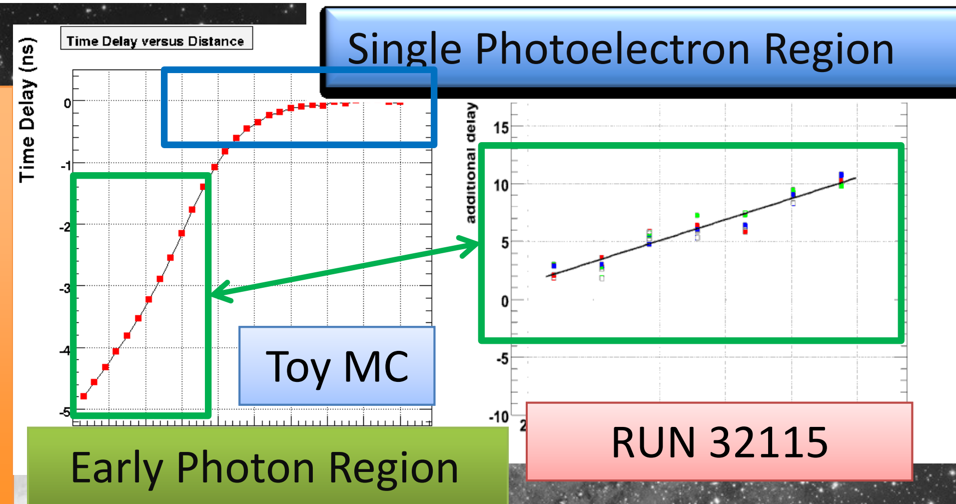


Early photon effect

The early photon effect appears at high light regimes.

It produces a delay in the arrival time similar to the walk effect.

The PMT is unable to resolve multiple photons arriving at the same time. Only the arrival time of the earliest photons is recorded.

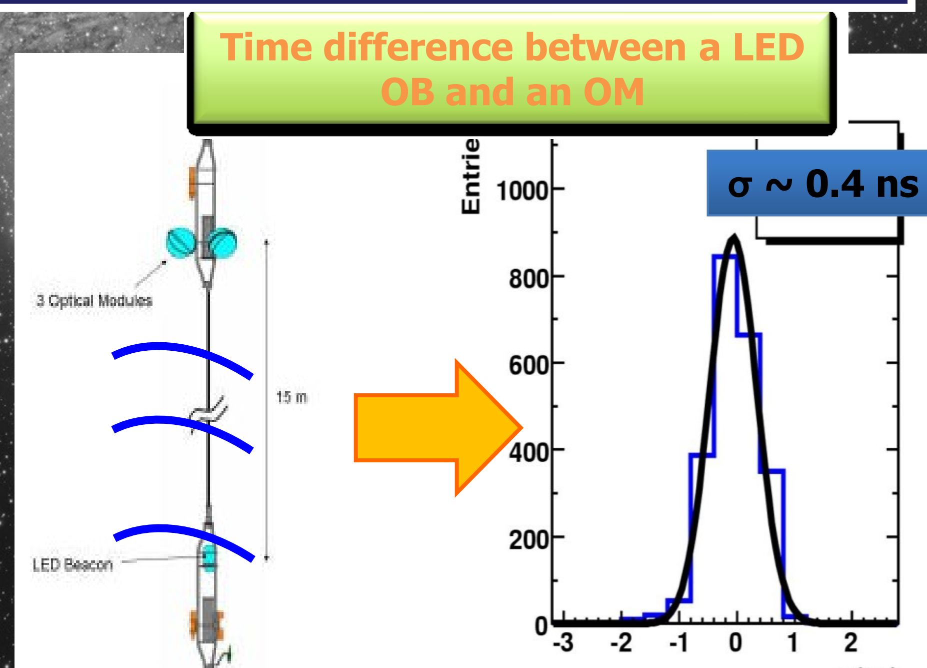


Time Resolution

$$\sigma^2 = \frac{\sigma^2_{TTS}}{N_{pe}} + \frac{\sigma^2_{water}}{N_\gamma} + \sigma^2_{OB} + \sigma^2_{elec}.$$

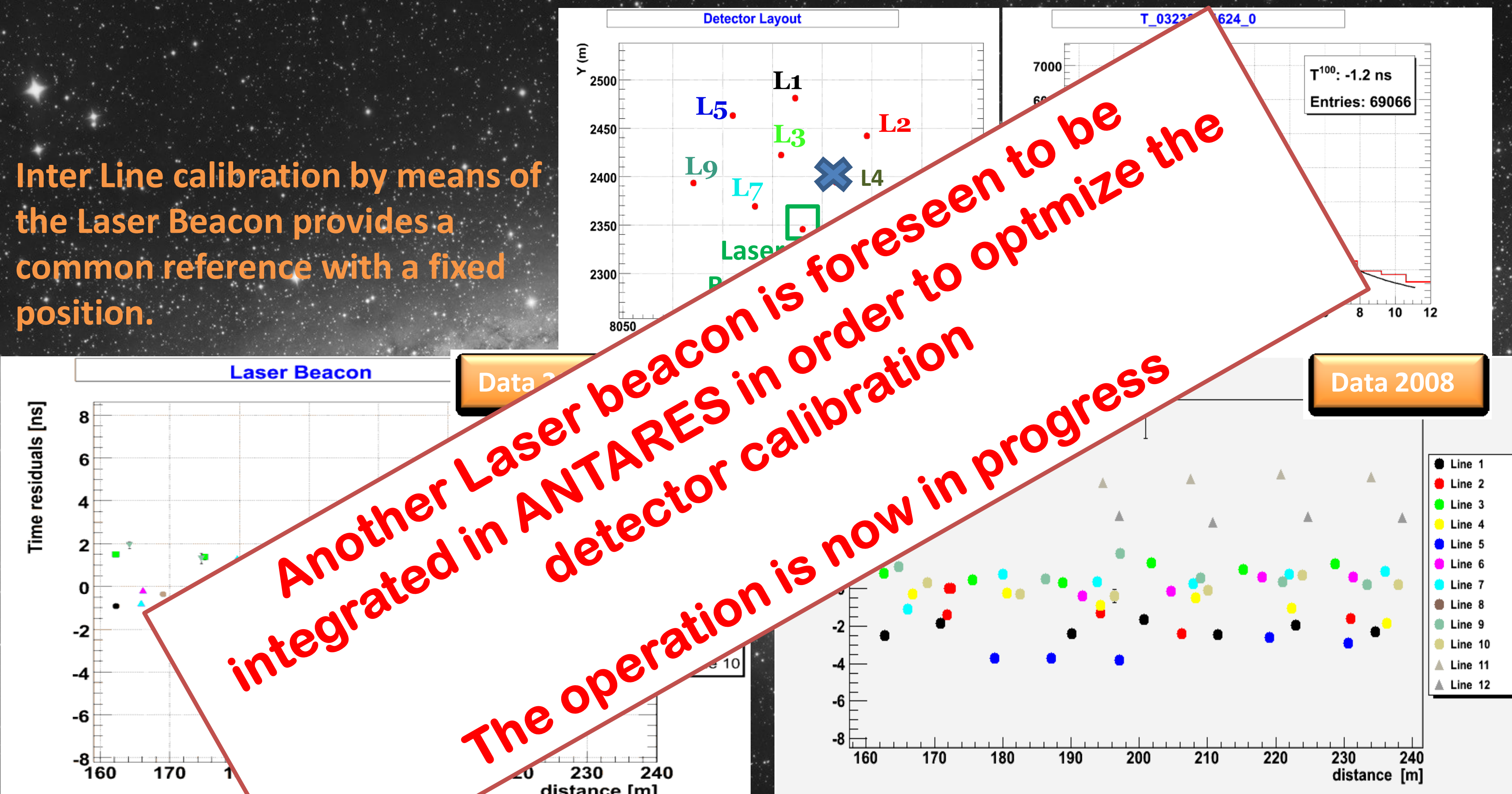
0 0 0

Electronics contribution less than 0.5 ns



Laser beacon

Inter Line calibration by means of the Laser Beacon provides a common reference with a fixed position.



Another Laser beacon is foreseen to be integrated in ANTARES in order to optmize the detector calibration

The operation is now in progress

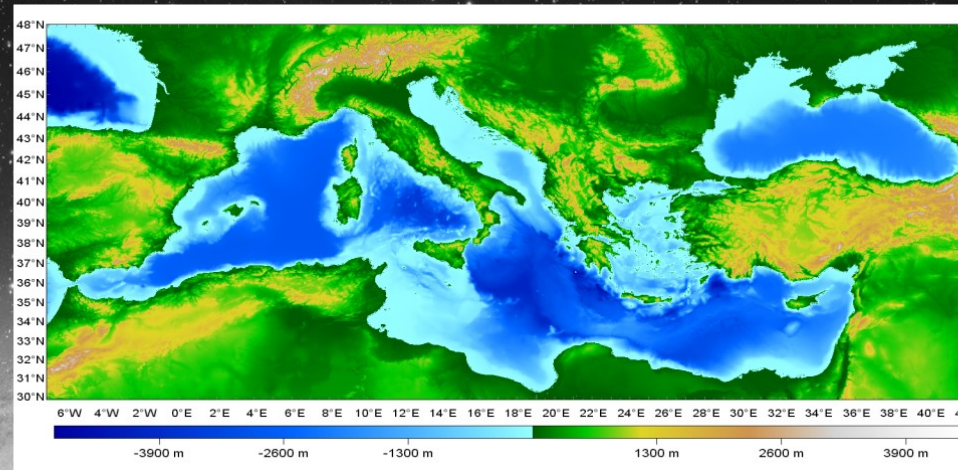
- Range from 16… …level) to 240 m (lack of statistics)
- Mean value of t… …me difference Laser - ARS for each floor
- Data points fitted to a straight line (photo electron region)
- **Intra Line calibration possible**

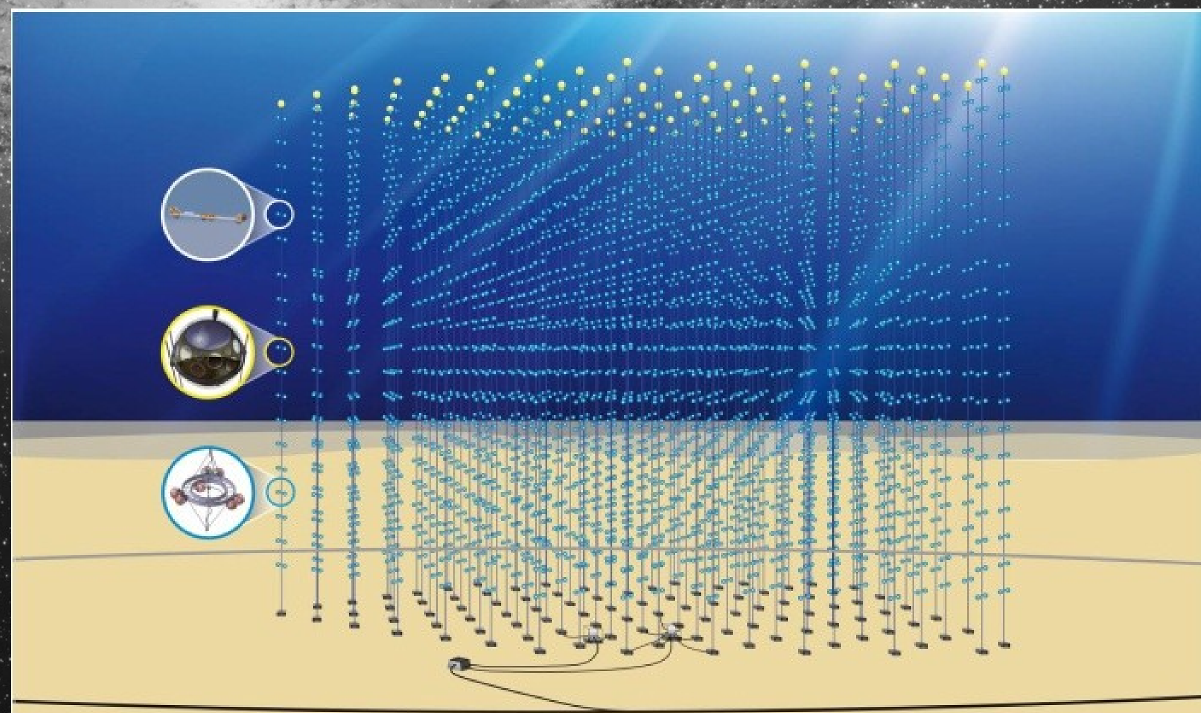
KM3NeT

KM³ Neutrino ***T***elescope

It will be a network of nodes for marine and earth science investigations.

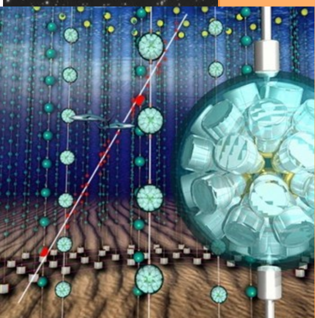
The telescope will occupy an area of several square KM of the seabed and the marine and earth science nodes are located far enough to avoid interference with the neutrino telescope but close enough to make use of a common deep sea cable network.





Decoupling inter-intra D.U. Calibration systems

INTRA D.U. Calibration:

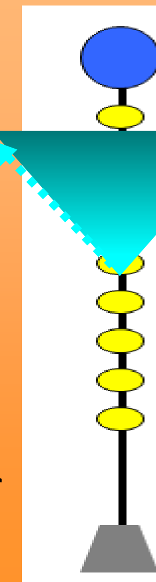


Nano-Beacon Single LED housed insi

- Less expensive and high redunda
- Not triggered by the clock t
- Frequency of several k

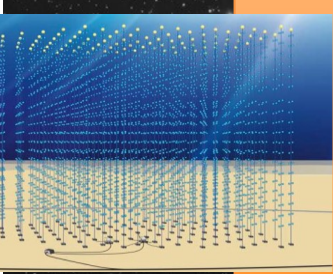
  (300 Hz @ ANTAR

- Avoid cumb ... per nanobe



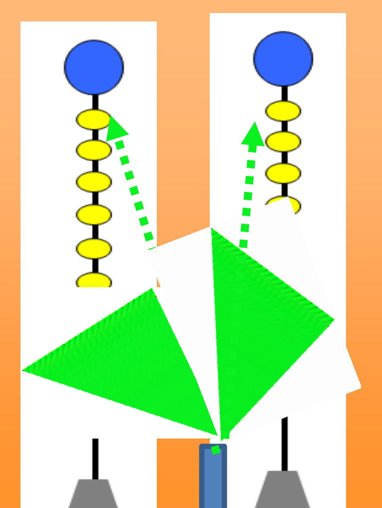
See Robert's talk and poster ID. 13 "Time Calibration in the KM3NeT Neutrino telescope

IN



La

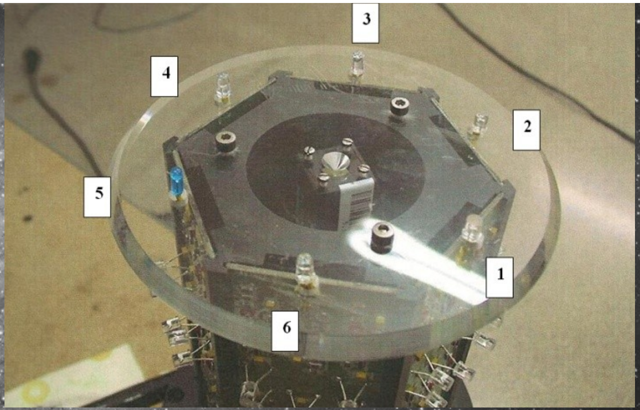
- Hig ... horter pulses (< 1 ns)
- No s ... ded
- More ... t less redundancy required
- Tunable ... quid Crystal Optical attenuator
- Collimated beam -> Diffusion device needed



Special LED Beacon

A LED Beacon (L12F2) with 4 LED candidates for KM3NeT is presently working in ANTARES

2 UV LEDs and 4 different Blue LEDs



LED model	Rise time (ns)	λ (nm)	FWHM (º)	Intensity (pJ)
CB26	2.4	470	23	150
CB30	2.0	472	28	90
NSPB500S	3.2	470	20	170
AB87	2.4	470	51	130

RUN	LED	N. Flashes
45161	AVAGO CB 26	20061
45162	AVAGO CB 30	21461
45163	AVAGO AB87	20486
45164	NSPB500S	20061

Standard ANTARES setup

Frequency = 300 Hz

Duration = 1-2 min

Some Calibration Runs have been analyzed

THE CANDIDATE LED FOR PRE PRODUCTION MODEL OF KM3NeT IS THE NSPB500S

Conclusions

The completion of the ANTARES telescope has opened a new window to the neutrino Southern sky

The track reconstruction algorithms are based on PDF of the photon arrival times to PMTs, therefore in order to ensure an optimal performance a precise time calibration of the detection system is crucial

An onshore calibration performed in the aboratory provides a preliminary time calibration

Once the detector is deployed in the sea, time calibrations are performed in situ with a system of optical beacons

The adopted calibration systems and methods attain a relative time calibration between detector elements of less than 1 ns, as required

The technology experience gained in ANTARES is quite important, and now used for the future KM3NeT neutrino telescope

Thanks
for your attention