The effects of Earth's magnetic field on 3-inch diameter photomultipliers used in KM3NeT neutrino telescope.

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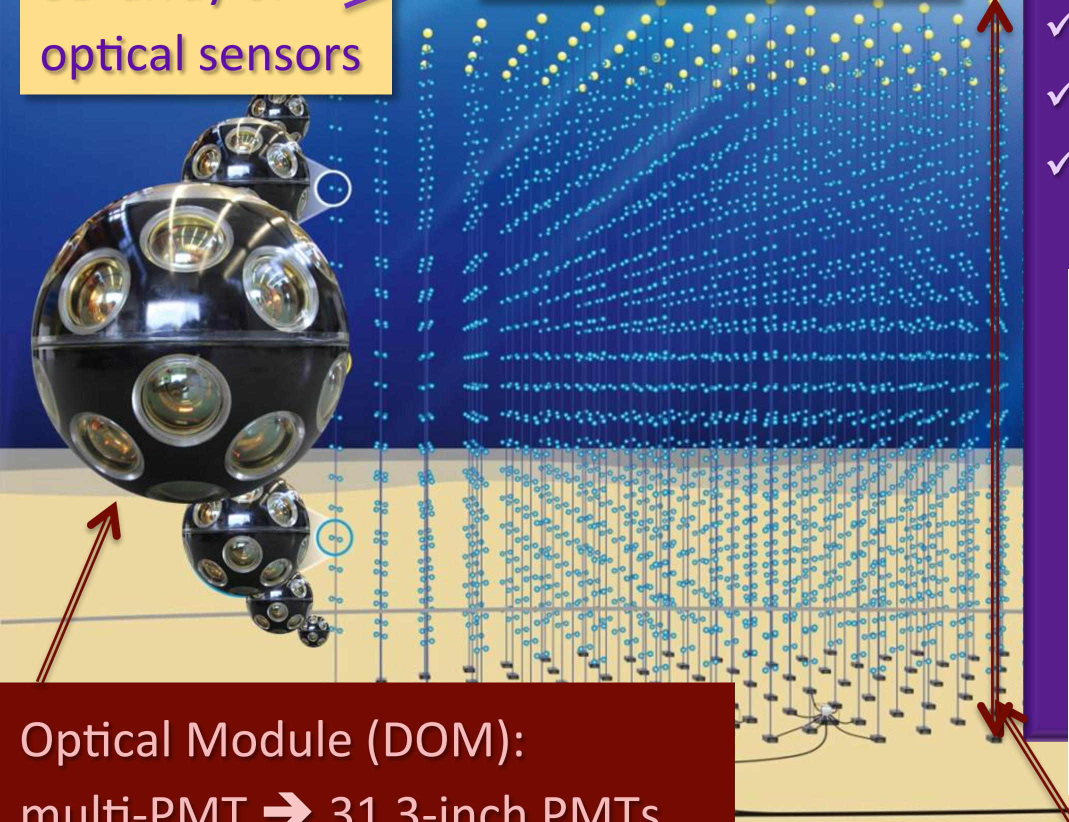
VLVNT- 15
University of Rome "La Sapienza"
Rome, September 14-16, 2015

An artist impression of KM3NeT

Detection principle→ measure optical Cherenkov radiation in deep-water emitted by leptons emerging from neutrino interactions

3D-array of optical sensors

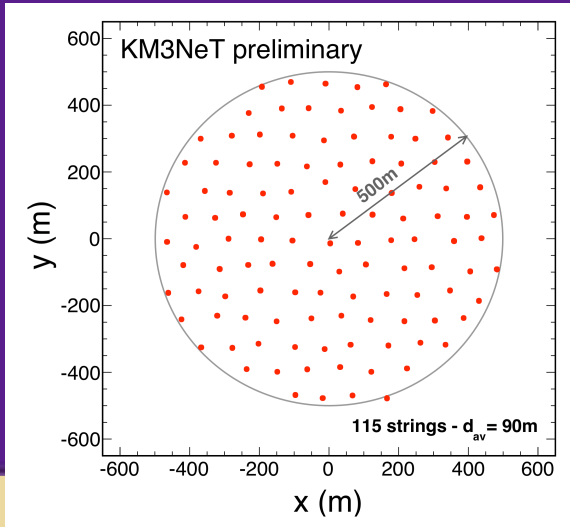
Building block concept

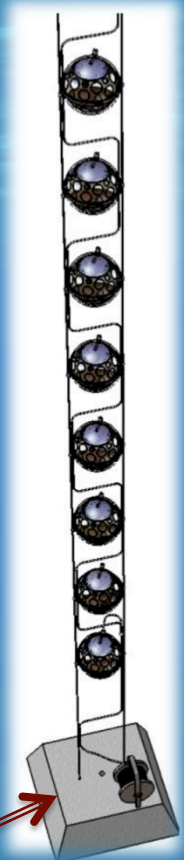


Optical Module (DOM):
multi-PMT ➔ 31 3-inch PMTs

KM3NeT/ARCA building block:

- ✓ 115 Dus
- ✓ 36 m DOM spacing
- ✓ ~0.5 km^3





Detection Unit (DU)

- ➢ Digital Optical Module (DOM) = pressure resistant glass sphere containing PMTs and electronics
- ➢ Detection Units (DU) = vertical string like structures hosting DOMs, environmental sensors,…

R12199-02 PMT 3-inch by Hamamatsu

For all projects where PMT orientation is critical, the variations on characteristics due to magnetic field must be investigated

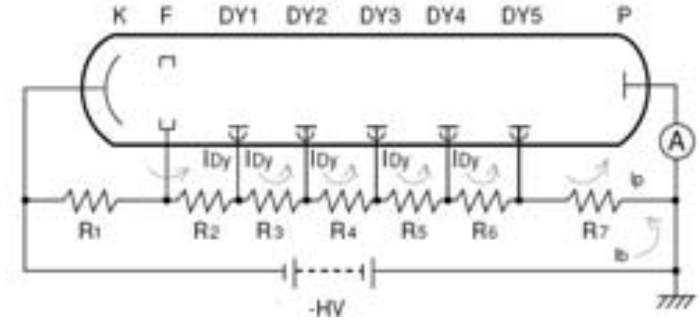
31 PMTs of 3-inch PMTs into the DOM

- Gain = $5*10^6$
- Mushroom shape
- Bialkali photocathode
- Passive base made by Erlangen team of KM3NeT

Measurements and conditions

For each position the following parameters were measured:
- Detection Efficiency (Ratio between the number of detected pulses and those emitted by the laser)
- Gain
- Transit Time (TT) (relative)
-Transit Time Spread (TTS) (FWHM)

3-inchPMTs were powered at Gain condition = 5E+6 (in final DOM configuration will be 3E+6)
Step K-DY1-DY2-… = 2 :1 :1 : …

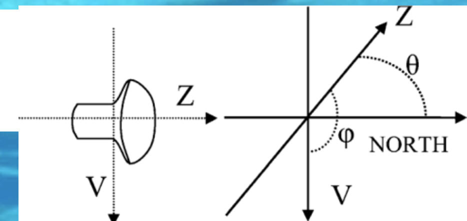


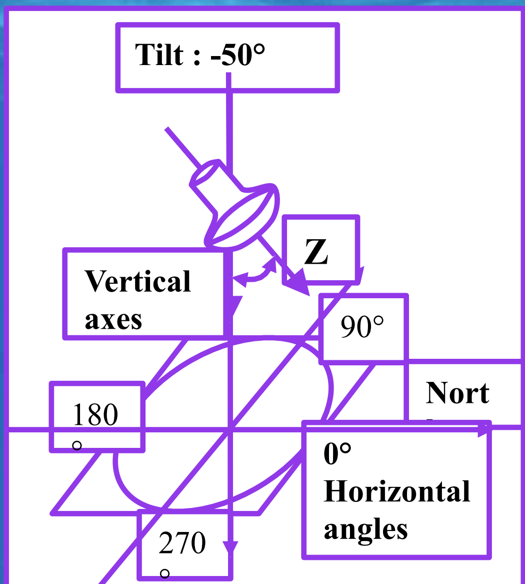
(Inside DOM, base is active powered with a step K-DY1-DY2-… = 3 :1 :1 : …)

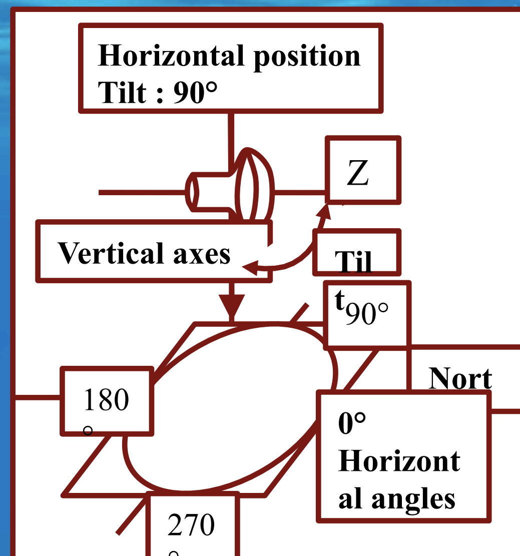
All measurements were made on PMTs un-shielded and repeated with a mu-metal magnetic shielding

Positions measured

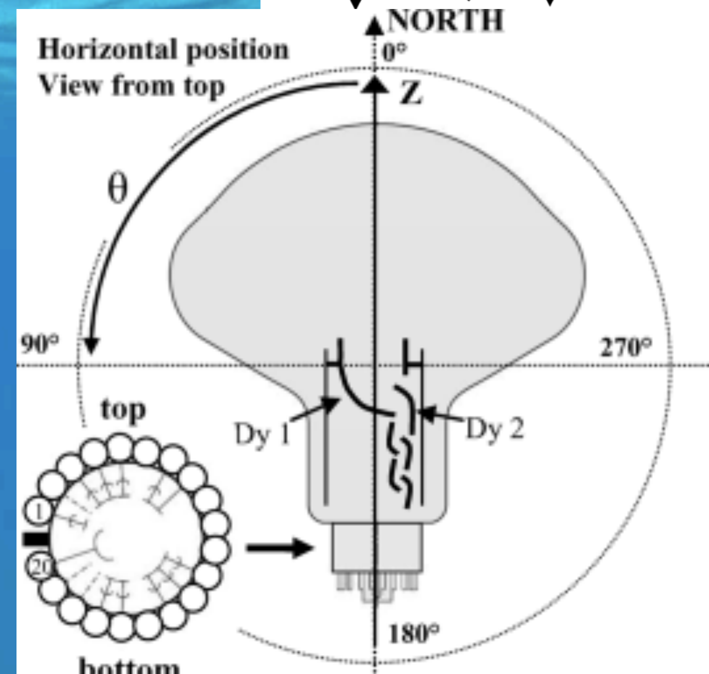
Tests on two 3-inch PMTs in 3 inclinations:
- 50° upwards (Tilt = +50°) ; 50° downwards (Tilt = -50°); horizontal (Tilt = 90°)







Top view



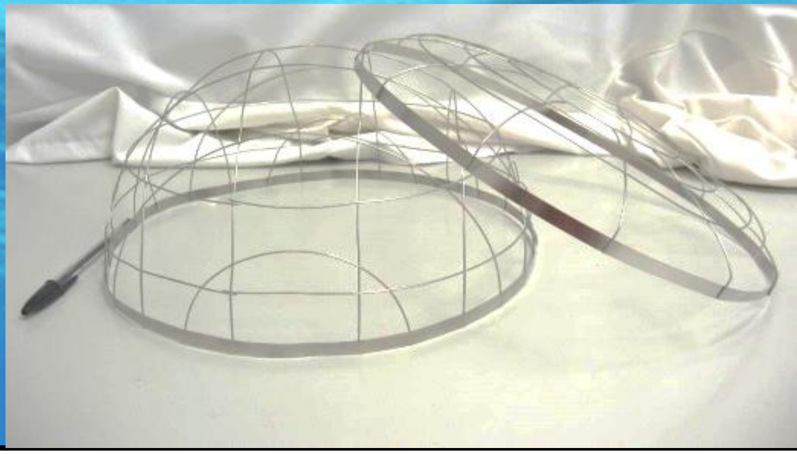
For each inclination, the PMT under test was rotated 360° around its vertical axis in 45° steps

PMT starts its rotation from the same position with respect to the box and to the Earth's magnetic field

Magnetic shielding

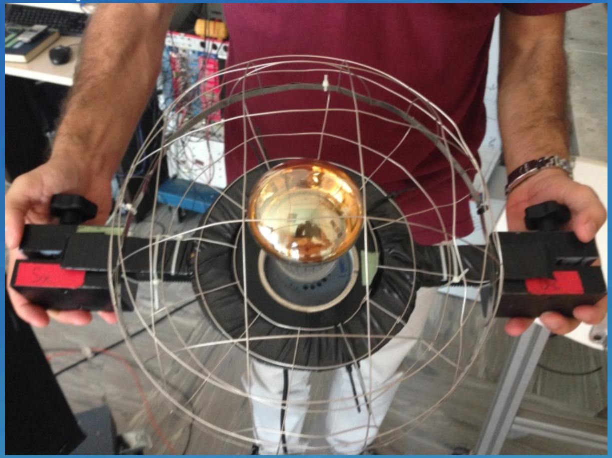
Characteristics of the cage of mu-metal wire (ITEP, Moscow):

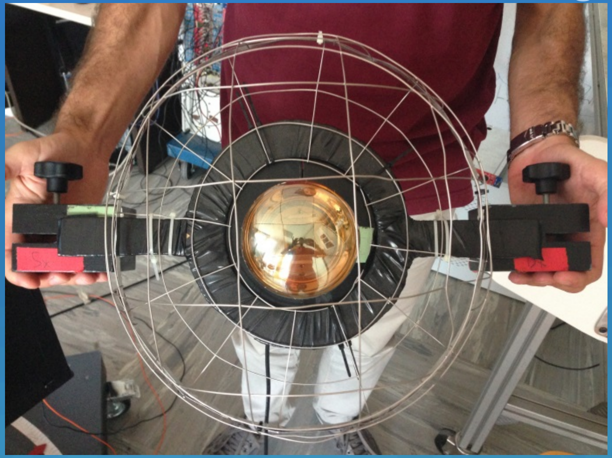
- **Cage used for 10-inch PMTs in KM3NeT-Italy**
- **a hemispherical part (30 cm diameter, 14 cm height)**
- **a flat part (30 cm diameter) with a hole in its centre (12 cm diam.)**
- **wire of 1 mm of diameter**
- **pitch of 68 x 68 mm**
- **average shielding measured ≈ a factor 4**

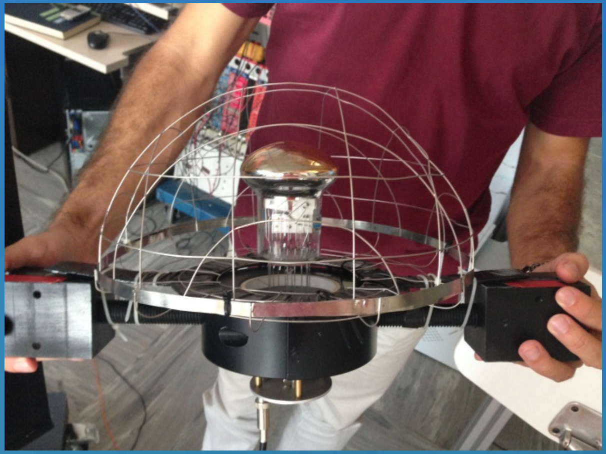


Opened Mu-metal cage

In pictures below: 3-inch PMT shown inside the mu-metal cage.

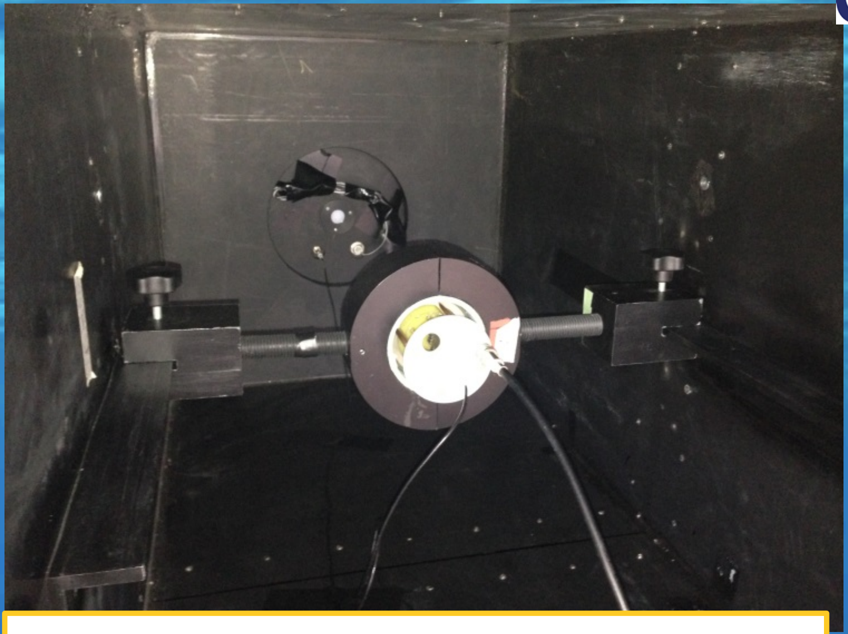






Measurement facility

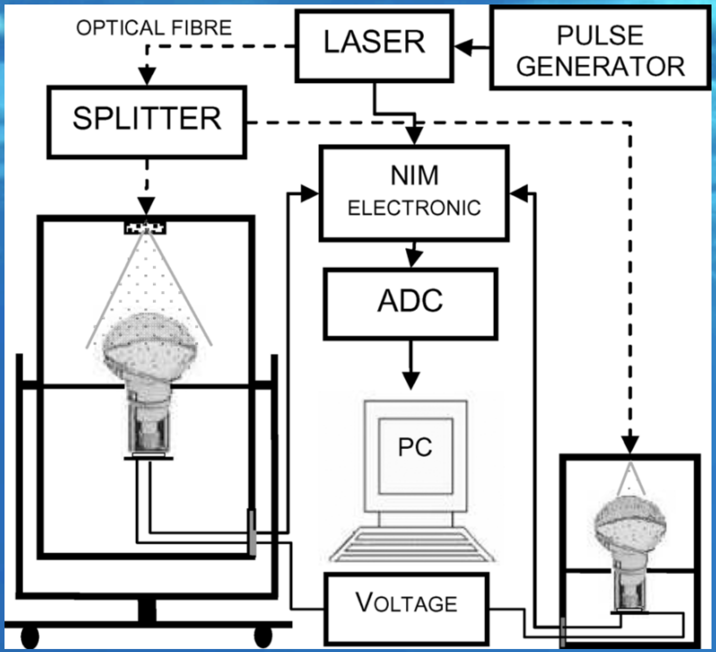
Picture of the box in tilted position

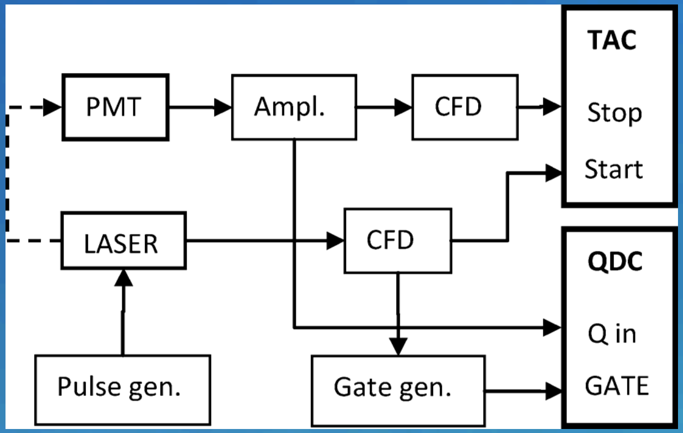


Mechanical support of PMT inside the dark box

- **A dark box (1 m x 0.5 m x 0.5 m) able to rotate 360° with respect to vertical axis and to change its vertical inclination.**
- **No magnetic materials were used in its construction**

Setup





- A pulsed laser source (410nm, 60 ps width, 10KHz) attenuated in spe condition (Picoquant PDL 800-B)
- Light pulses conducted by means of multimode optical fibres
- An optical diffuser was used to produce homogeneous illumination over the photocathode
- Charge measurements made by NIM QDC 7422 Silena
- Time measurements made by NIM 7072T FAST
- A second PMT was used as monitor of the light source

Magnitude of magnetic field

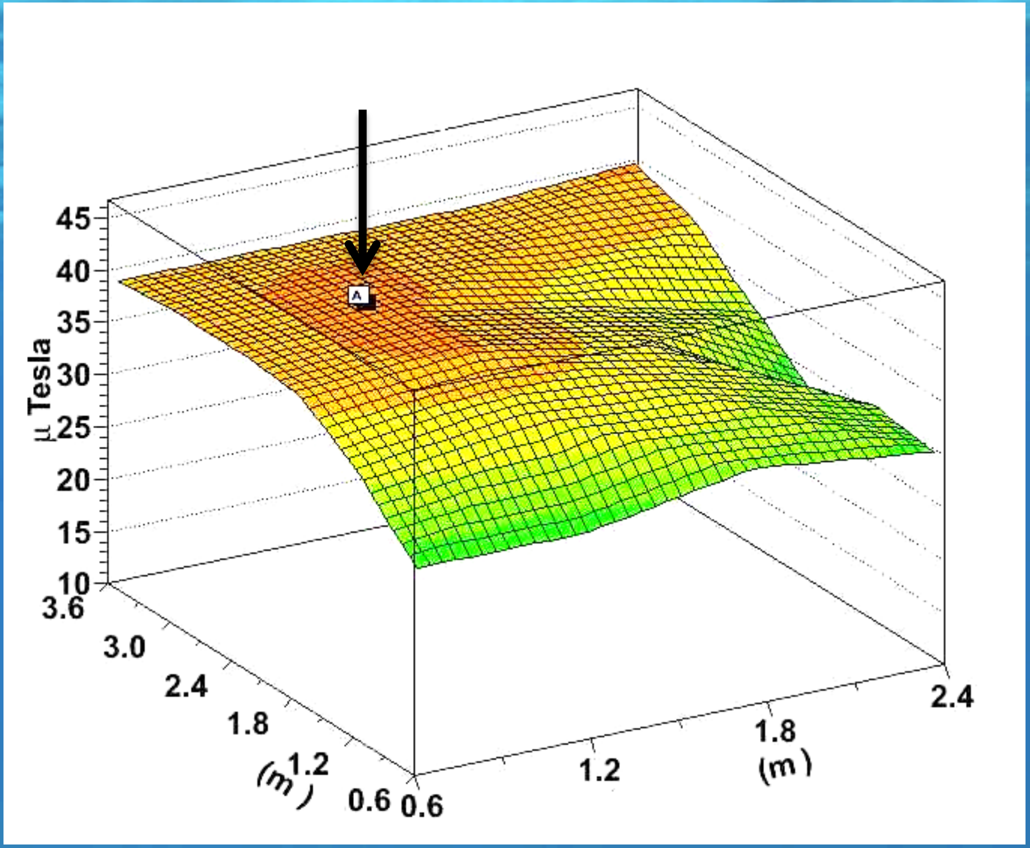
Magnitude and uniformity of the Earth's magnetic field were measured in the place of the test.

Map of the local measurements of Earth's magnetic field (step 0.6 m)

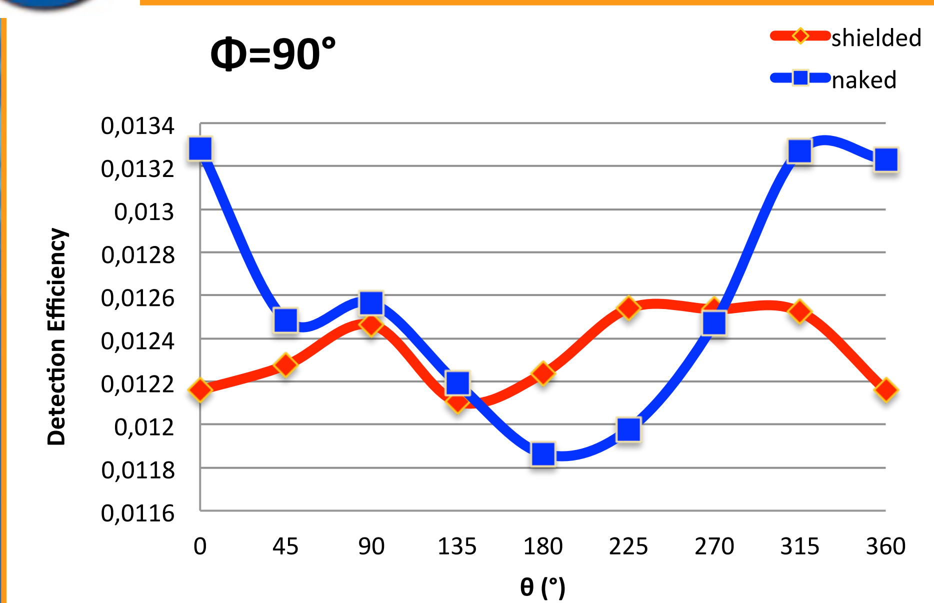
The signed point was selected as position of the Test BOX

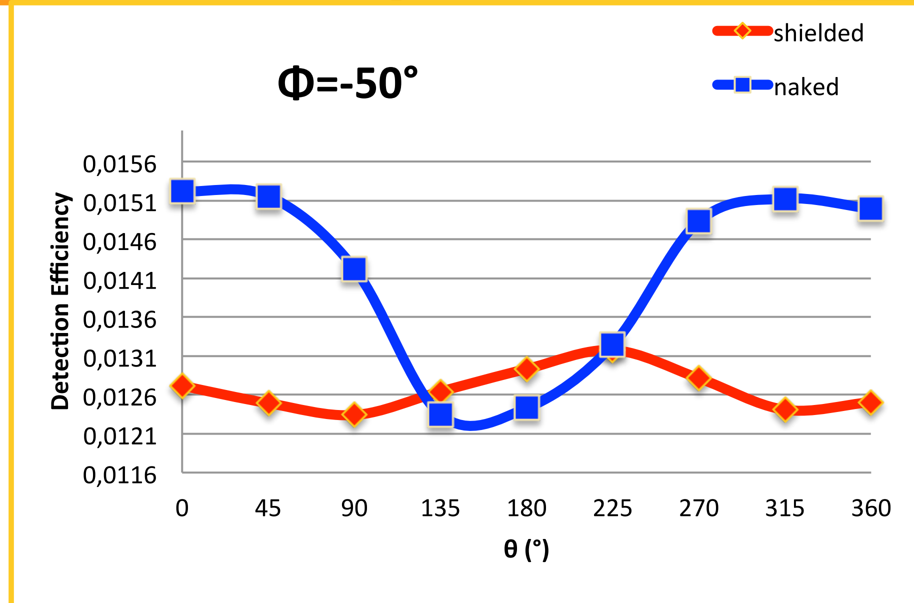
- B ≈ 40 μTesla

- good uniformity over 1 meter area

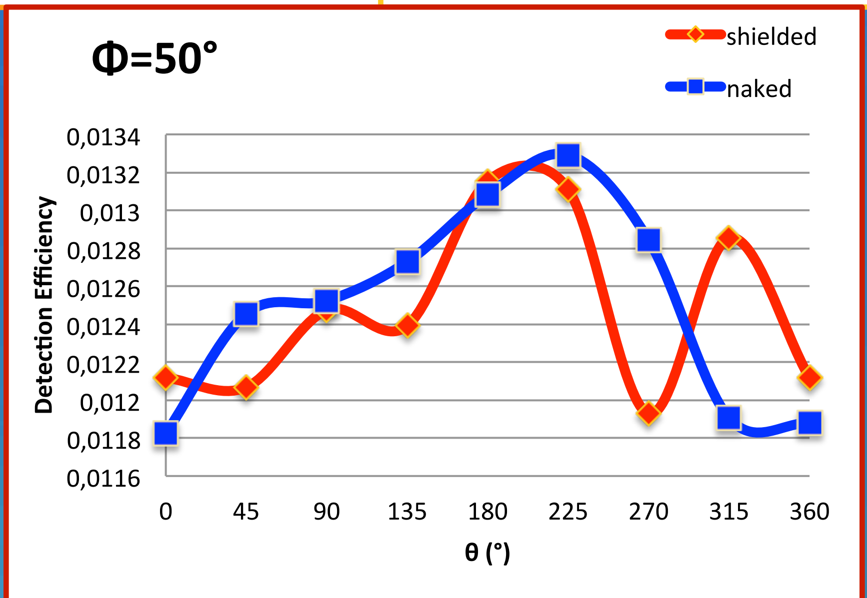


Detection Efficiency





detection efficiency:
Ratio between the number of detected pulses and those emitted by the laser

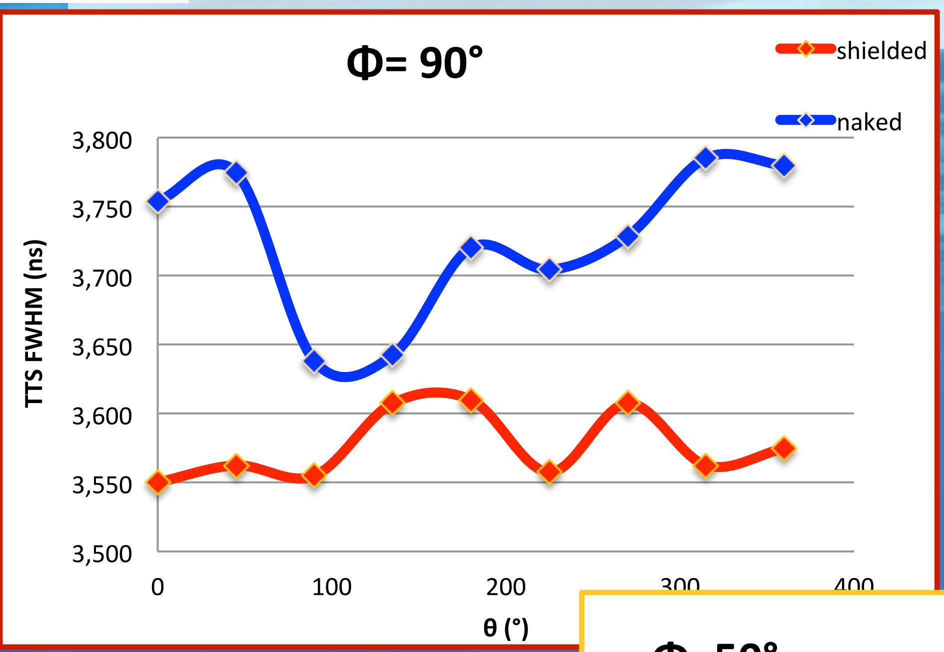


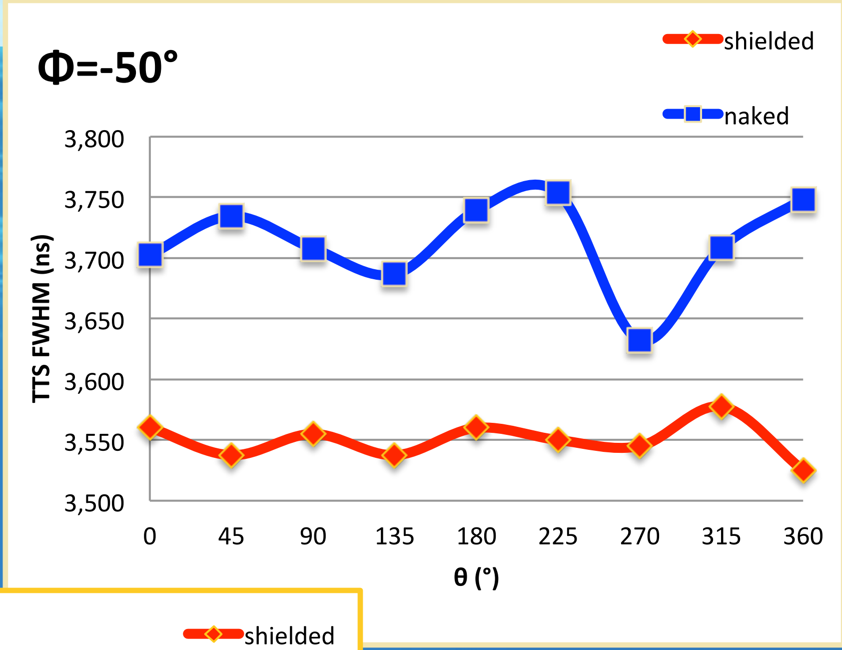
Detection Efficiency

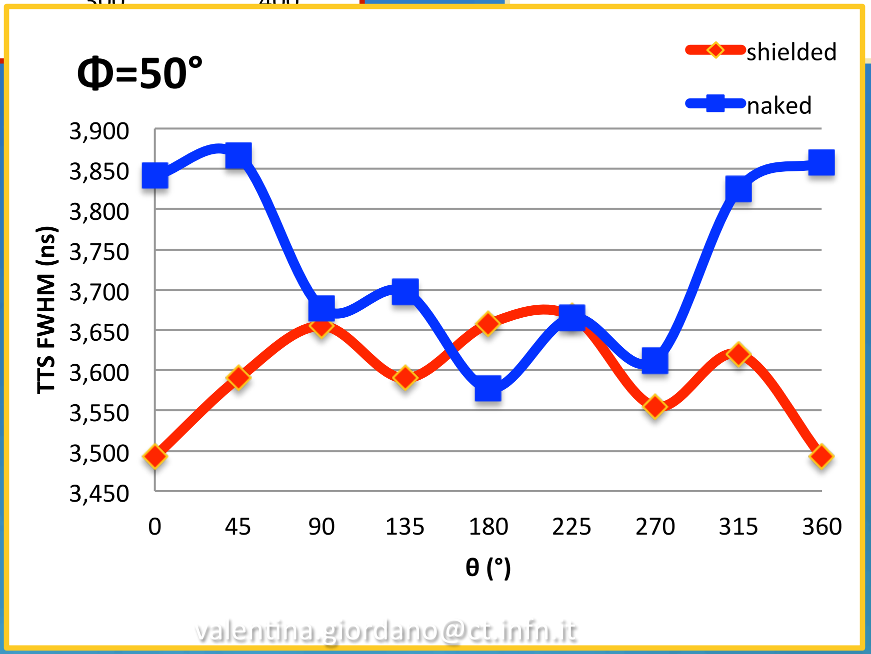
Influence of Eart's magnetic field on large area PMTs of 10-inch by Hamamatsu studied for KM3NeT-Italia S.Aiello et al. TNS-IEEE (2012) doi: 10.1109/TNS.2012.2189245

Detection Efficiency	Φ=90°		Φ=-50°		Φ=+50°	
	Naked	Shielded	Naked	Shielded	Naked	Shielded
Minimum value	11,86 E-3	12,34 E-3	12,34 E-3	12,34 E-3	12,34E-3	11,90 E-3
Maximum value	13,28 E-3	13,17 E-3	15,22 E-3	13,17 E-3	13,11 E-3	13,20 E-3
Average Value	12,58 E-3	12,36E-3	14,17 E-3	12,67 E-3	12,35 E-3	12,48 E-3
Maximum Variation	11,9 %	6,8 %	23,3%	6,7%	12,0%	10.1%
Max. var. 10-inch PMT	14,72%	1,69%			39,88%	5,56%

TTS (FWHM)







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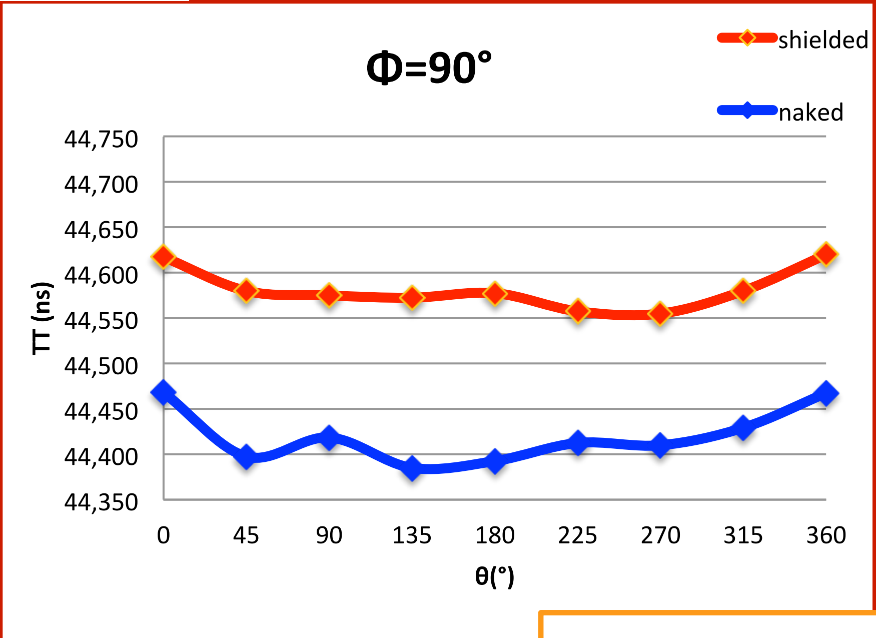
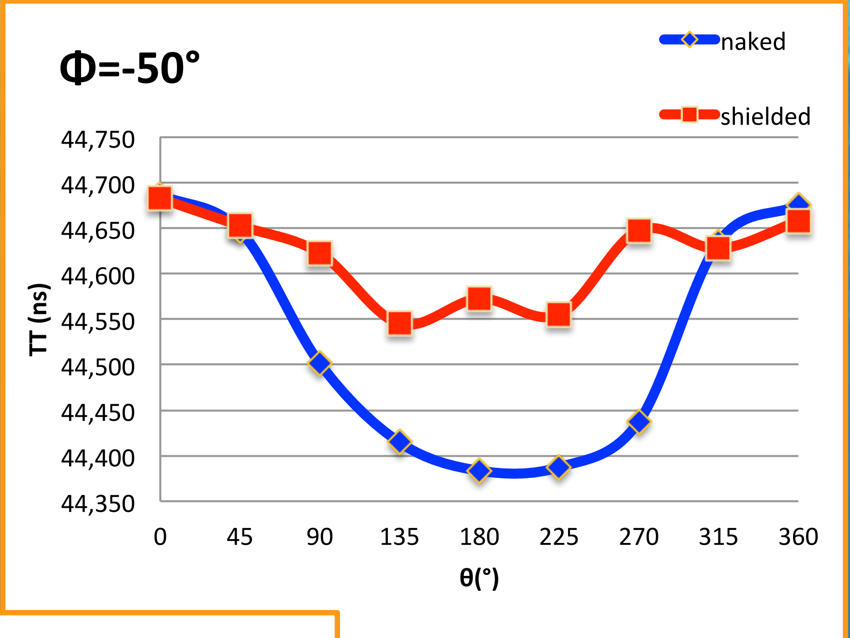
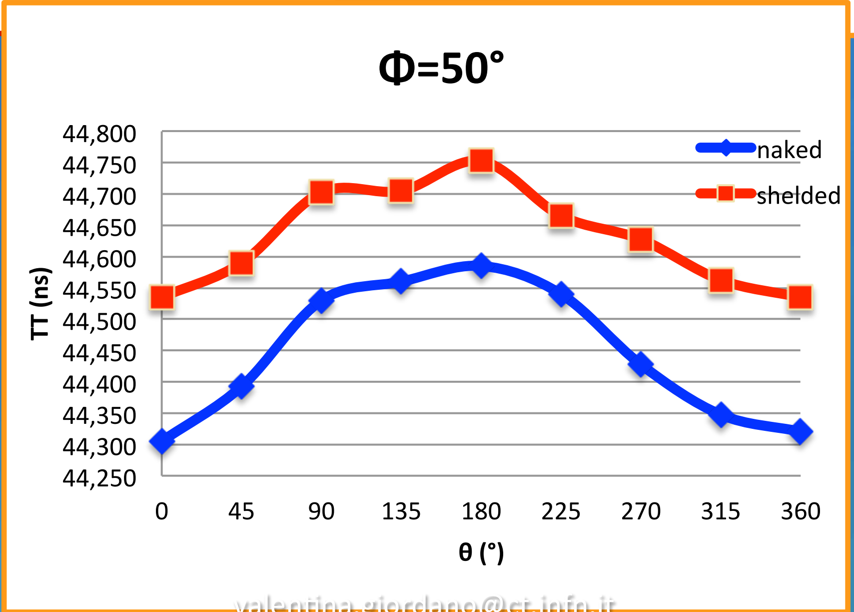
TTS (FWHM)

TTS (ns)	Φ=90°		Φ=-50°		Φ=+50°	
	Naked	Shielded	Naked	Shielded	Naked	Shielded
Minimum value	3,64 ns	3,55 ns	3,63 ns	3,52 ns	3,58 ns	3,49 ns
Maximum value	3,78 ns	3,61 ns	3,75 ns	3,58 ns	3,87 ns	3,67 ns
Average Value	3,72 ns	3,57 ns	3,71 ns	3,55 ns	3,71 ns	3,59 ns
Maximum Variation	4,0%	1,7%	3,3%	1,5%	8,1%	5,0%
Max. var. 10-inch PMT	9,71%	5,54%			10,47%	4,03%

Transit Time (relative)







Transit Time

TT (ns)	Φ=90°		Φ=-50°		Φ=+50°	
	Naked	**Shielded**	**Naked**	**Shielded**	**Naked**	**Shielded**
Minimum value	44,38 ns	44,55 ns	44,38 ns	44,54 ns	44,30 ns	44,53 ns
Maximum value	44,47 ns	44,62 ns	44,71 ns	44,68 ns	44,58 ns	44,75 ns
Average Value	44,42 ns	44,58 ns	44,53 ns	44,62 ns	44,44 ns	44,63 ns
Maximum Variation	0,19%	0,14%	0,70%	0,31%	0,60%	0,48%
Max. var. 10-inch PMT	0,38%	0,25%			0,37%	0,26%

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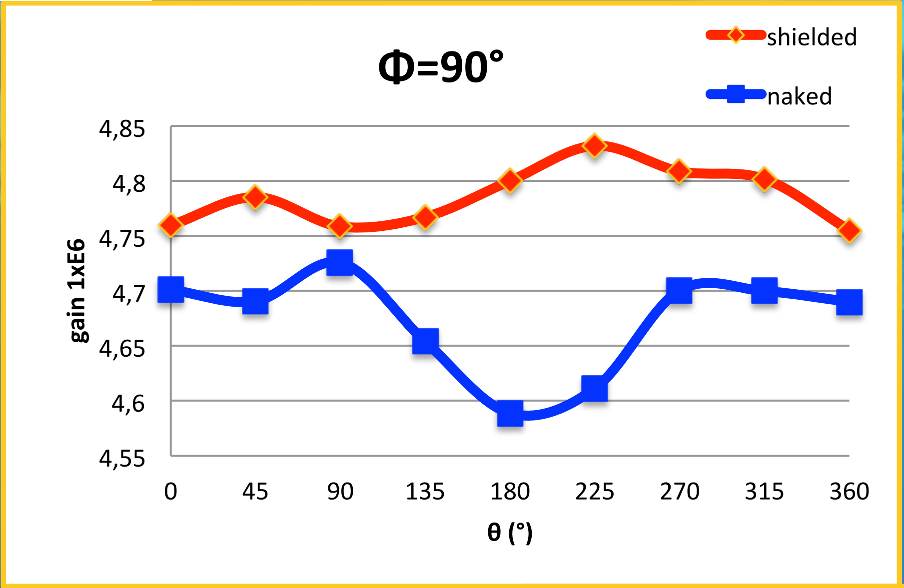
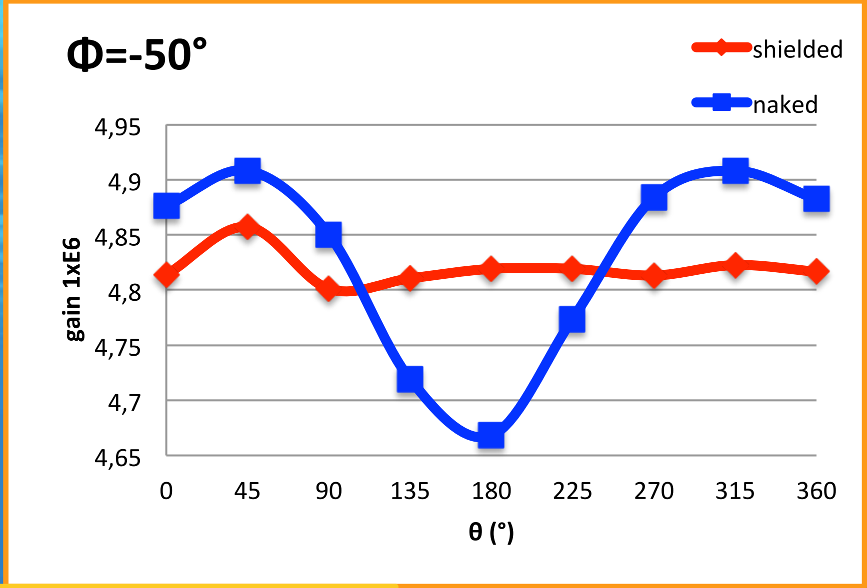
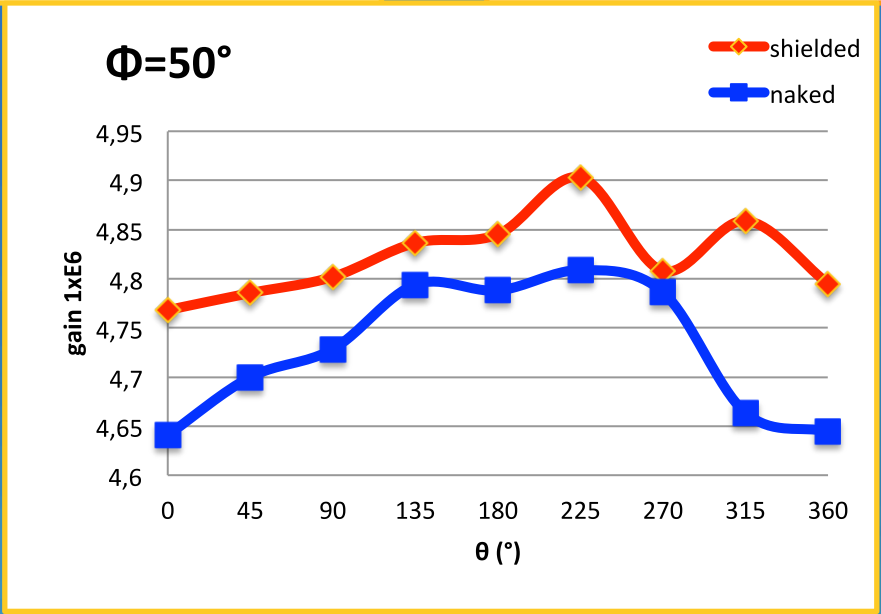
Gain


Φ=90°
shielded
naked
4,85
4,8
4,75
4,7
4,65
4,6
4,55
gain 1xE6
0
45
90
135
180
225
270
315
360
θ (°)


Φ=-50°
shielded
naked
4,95
4,9
4,85
4,8
4,75
4,7
4,65
gain 1xE6
0
45
90
135
180
225
270
315
360
θ (°)


Φ=50°
shielded
naked
4,95
4,9
4,85
4,8
4,75
4,7
4,65
4,6
gain 1xE6
0
45
90
135
180
225
270
315
360
θ (°)

Gain

GAIN	Φ=90°		Φ=-50°		Φ=+50°	
	Naked	Shielded	Naked	Shielded	Naked	Shielded
Minimum value	4,59 E+6	4,75 E+6	4,67 E+6	4,77 E+6	4,63 E+6	4,77 E+6
Maximum value	4,72 E+6	4,83 E+6	4,91 E+6	4,86 E+6	4,80 E+6	4,90 E+6
Average Value	4,67 E+6	4,78 E+6	4,83 E+6	4,81 E+6	4,72 E+6	4,82 E+6
Maximum Variation	3,0 %	1,6 %	5,1 %	1,8 %	4,1 %	2,8%
Max. var. 10-inch PMT	27,81%	5,81%			28,59%	6,69%

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Conclusion

For all projects where PMT orientation is critical, the variations on characteristics due to magnetic field must be investigated.

1. Generally, the overall impact of the magnetic field was found to be smaller on 3-inch PMTs than 10-inch PMTs used in KM3NeT-Italia project.

2. Maximum variations on Gain and TTS without shielding are significantly lower for 3-inch than 10-inch PMTs.

3. No significant magnetic effects were measured on Transit Time (value on maximum variations lower than 1%) .

4. The detection efficiency is the parameter with higher variations with magnetic field.
5. The magnetic effects seems not so high to justify the use of a magnetic shielding in optical modules made with 3-inch PMTs.

6. In the final design of the DOMs of KM3NeT the base of PMT have some differences with a different gain condition for PMTs thus effects could be different. Further measurements will be done as soon.

Thank you for your attention

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