Study on 3-inch Hamamatsu Photomultipliers

V.Giordano, S.Aiello, E.Leonora
INFN-Catania
on behalf of the KM3NeT collaboration

Outline

- ✓ PMT 3inch in single photoelectron condition
- ✓ Study on spurious pulses:
  - Charge and Time distribution for pre and delayed pulses (spe)
  - Charge and Time distribution for afterpulses AP (type 1, type 2 and multiple AP2)

- ✓ Variation of transit time spread (TTS) and fractions of spurious pulses in different conditions of response of PMT (from spe to 3 pe and 5 pe)
- ✓ Study on effects of the Earth's magnetic field.

Study on effetcs of the Earth's magnetic field and study of noise and spurious pulses for a large area of Hamamatsu 10-inch PMTs are already published:

- ❖ **S.Aiello et al. TNS-IEEE (2012) doi: 10.1109/TNS.2012.2189245**
- ❖ **E.Leonora at al. TNS_IEEE (2014) doi: 10.1109/TNS.2014.2322655**

R12199-02 PMT 3-inch by Hamamatsu

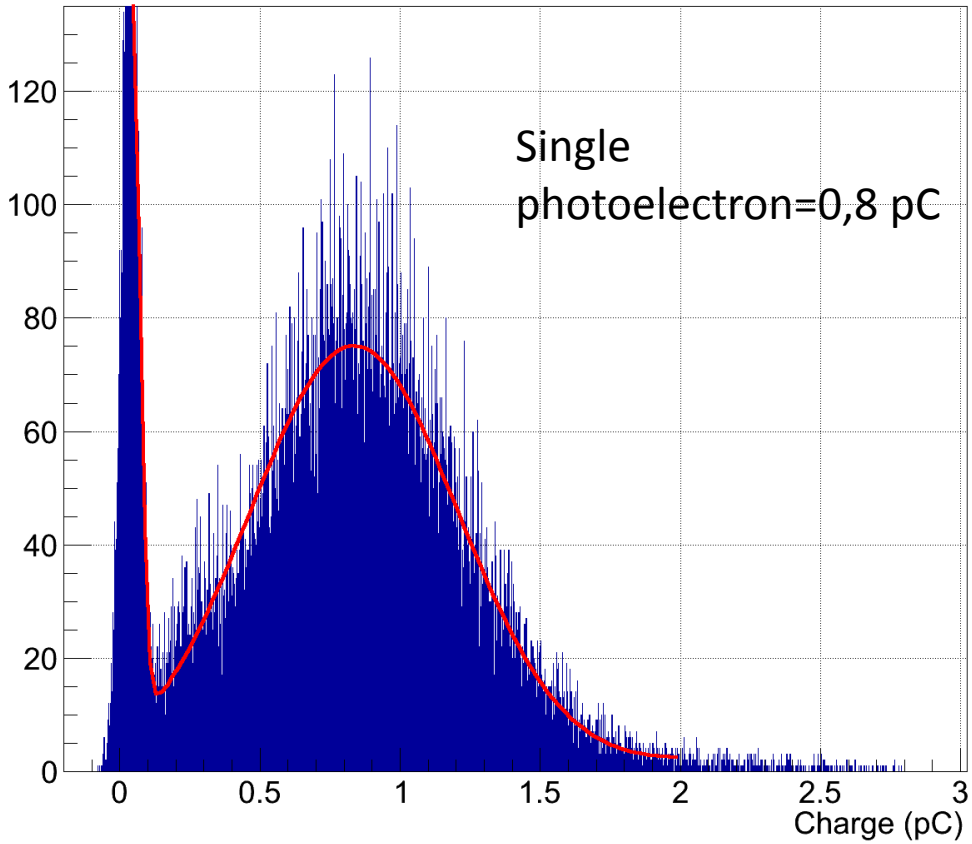
- Gain = $5*10^6$
- Mushroom shape
- Bialkali photocathode
- Passive base made by Erlangen group

31 HAMAMATSU 3-inch PMTs storey into a multiPMT optical module

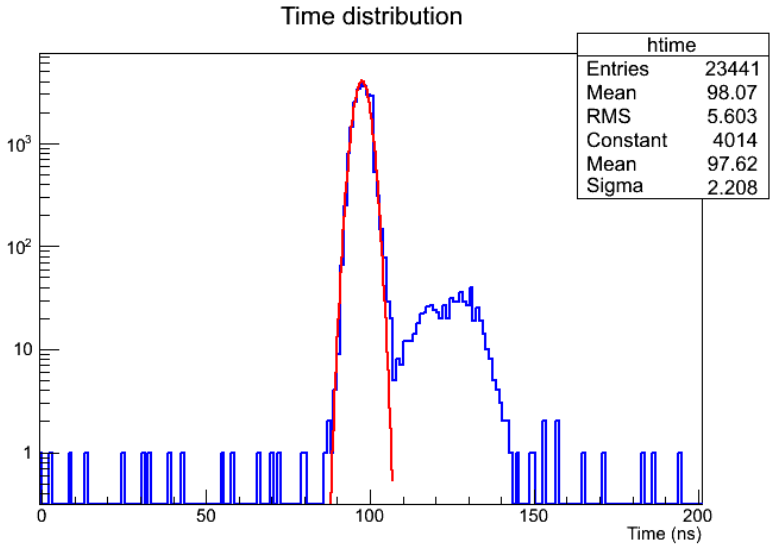
PMT characterization in spe conditions

Peak to valley ratio:

Fit expo+gaus

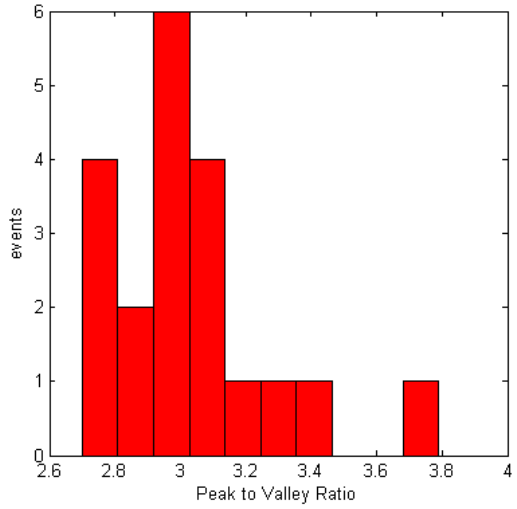


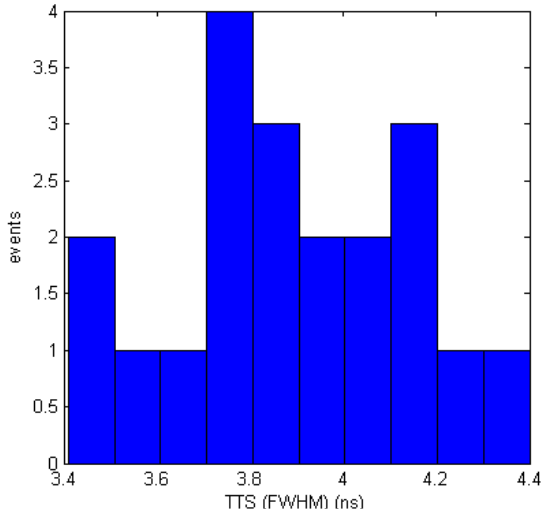
TTS ~ 4ns

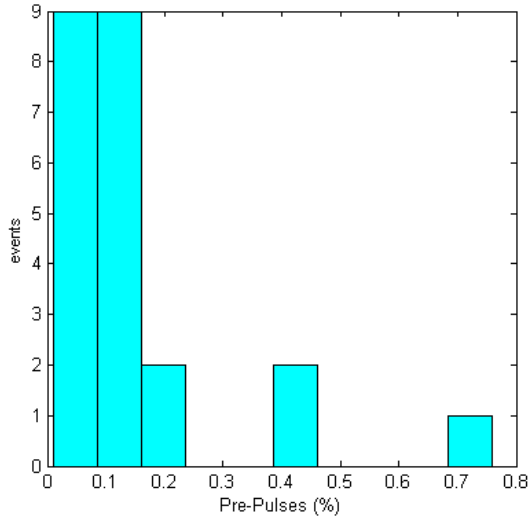


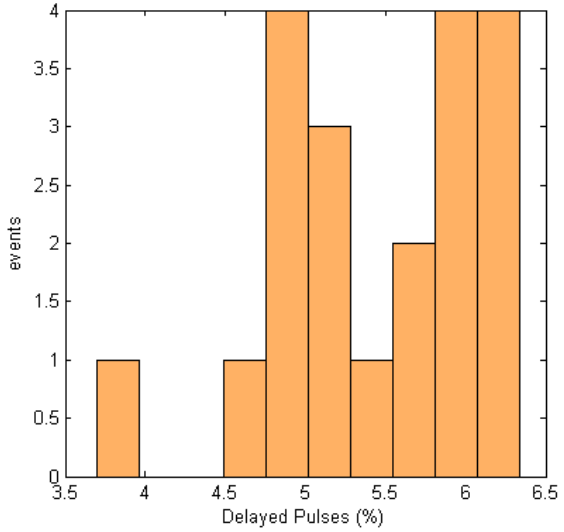
3-inch PMTs main properties

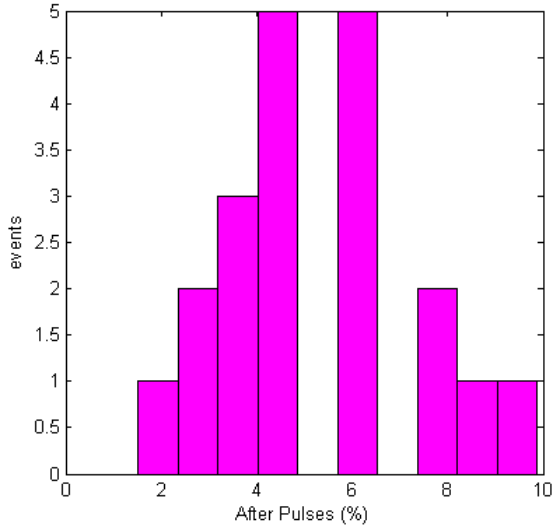
Set of 20 PMTs by HAMAMATSU 3-inch R12199-02 tested in INFN-Catania laboratory











Spurious pulses

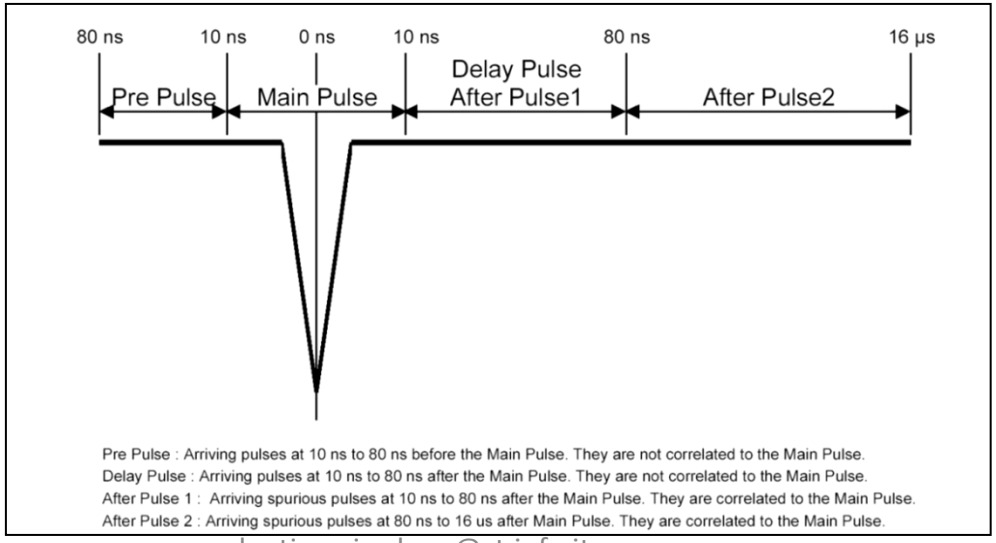
Spurious pulses not correlated with main pulse :

Pre-pulses : due to the direct photoelectron emission on the first dynode from the photons which passed the photocathode without interaction. The arrival time of pulse will be anticipated in confront of the main pulse.

Delayed: The primary photoelectron is reflected from the first dynode without a secondary electron emission, it turns towards the photocathode, makes a loop and only after it creates a cascade of electrons in the dynodes. The arrival time of the hit will be delayed in confront of the main pulse (delay 10ns-100ns).

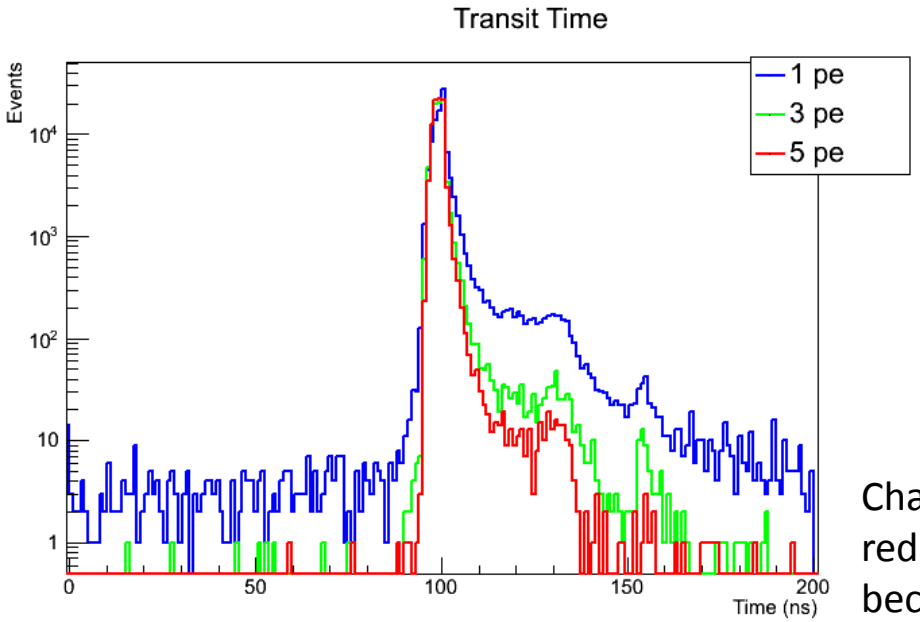
Spurious pulses time-correlated with the main PMT response:

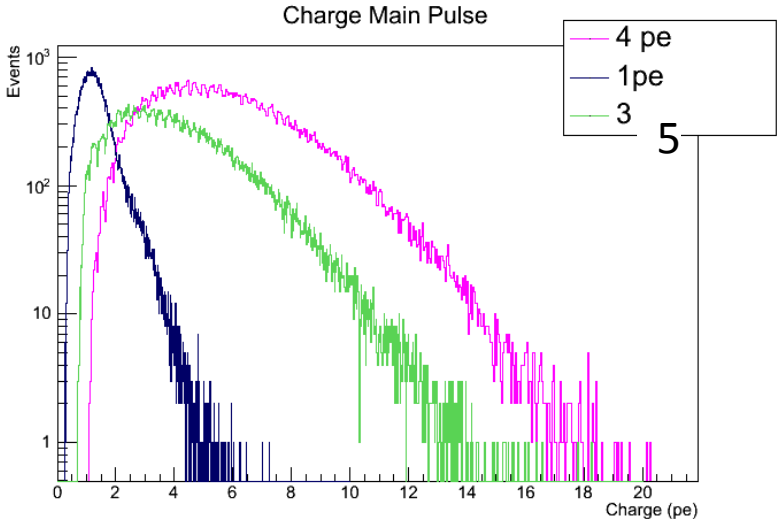
After pulses(type 1 , type 2, multiple after pulses): noise pulses that appear following the main PMT response to a detected light event. (100ns-5μs after Main pulse)



Characterization (1, 3, 5 pe)

Mean charge PMT rensponse of 1, 3 and 5 pe



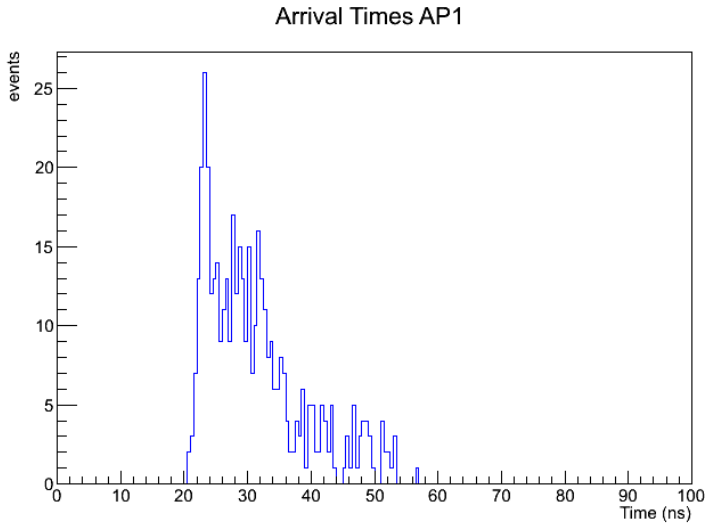


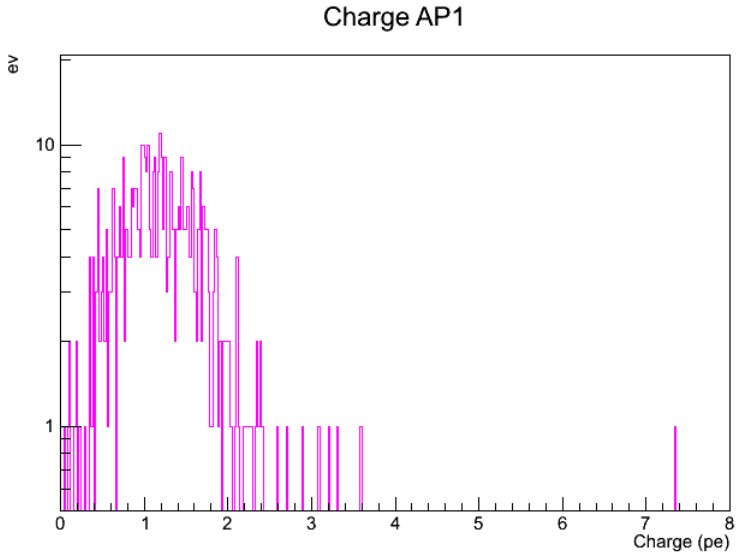
Changing PMT conditions from 1 to 5 pe, TTS is reducing and Pre pulses and delayed fractions became lower

conditions	TTS FWHM (ns)
1 pe	4,0
3 pe	3,0
5 pe	2,8

conditions	Pre-pulses	delayed
1 pe	0,3 %	6,40 %
3 pe	0,01 %	1,14 %
5 pe	0,002 %	0,47 %

After pulses type 1 (spe)

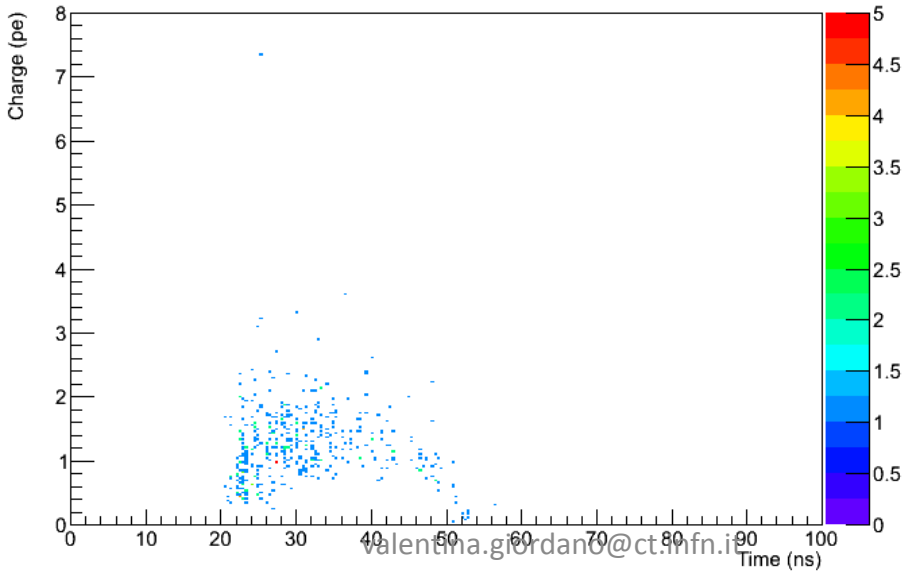




PMTs in SPE conditions

AP1 = 0,11 %

Fraction of AP1 lower than that of 10inch



Behaviour of AP1 looks very similar to 10-inch PMT.

valentina.giordano@ct.infn.it

After pulses type 2 (spe)

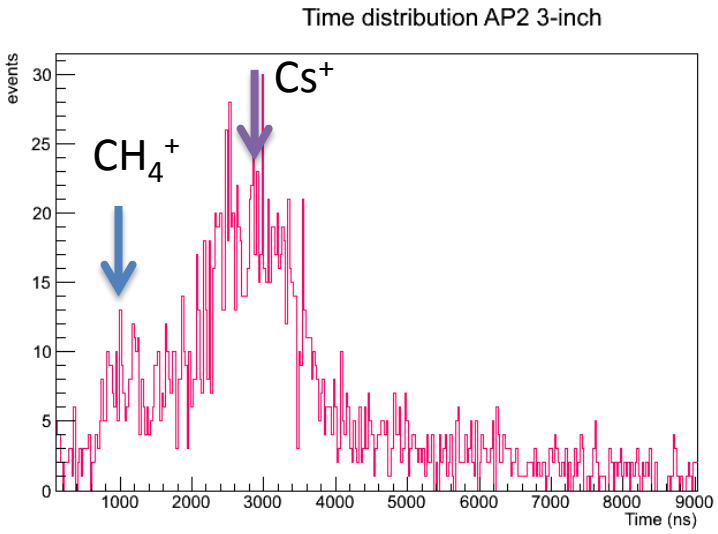
PMTs in SPE conditions

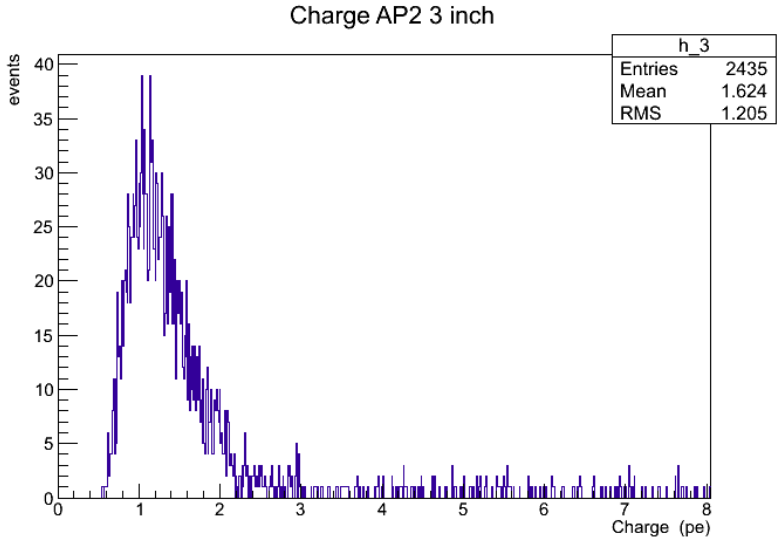
Fraction of AP2 lower than that of 10inch AP2 = 4,15 %

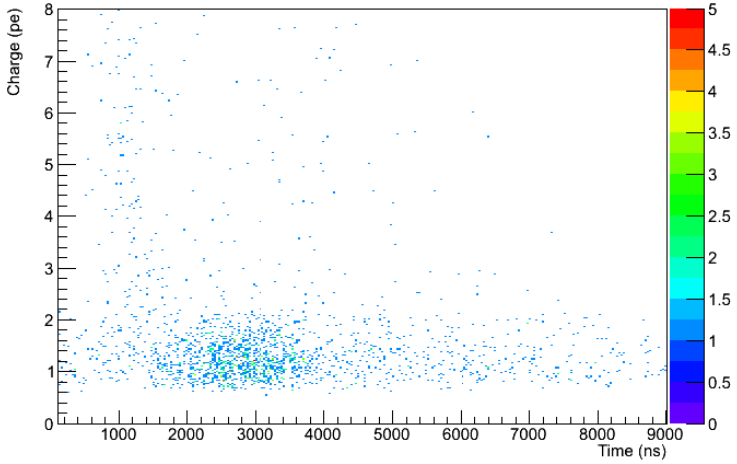
Two peaks like 10-inch at ~1μs and ~3μs for the two ions Cs^+ and CH_4^+ (time difference with 10-inch due to the geometry).

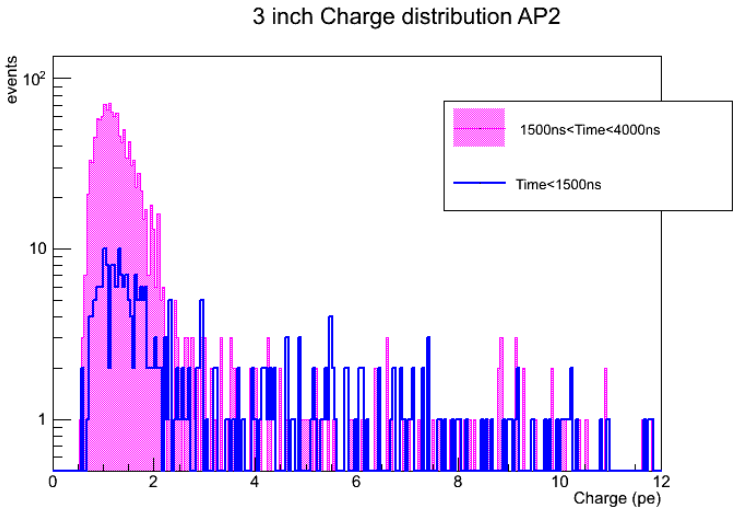
Higher mean charge for AP2 than AP1.

Time-Charge correlation has a behaviour similar to that of 10-inch with an higher charge component for the CH_4^+ peak.

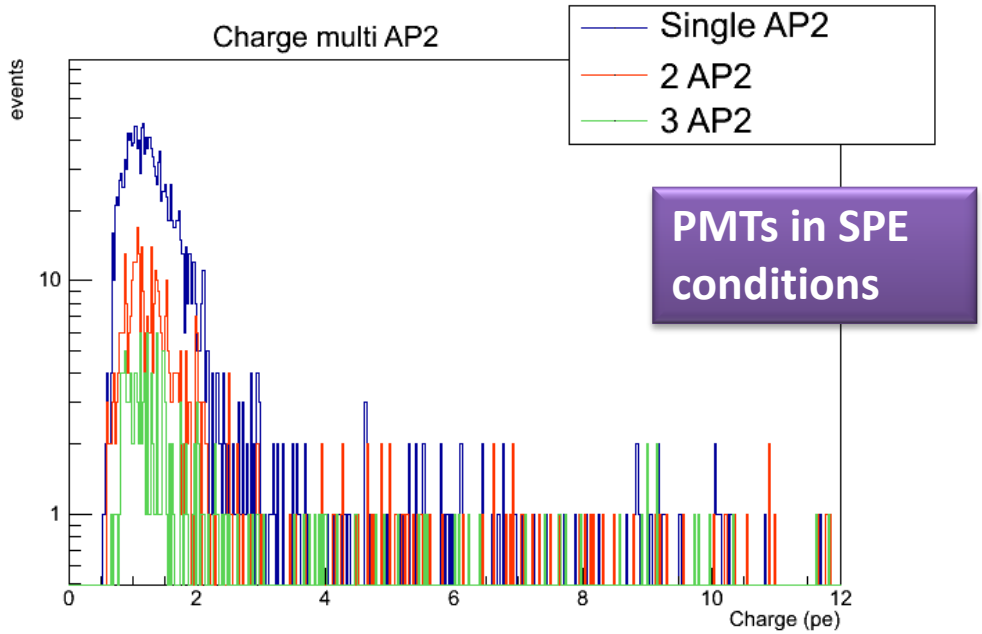








Multiple Afterpulse (spe)



PMTs in SPE conditions

Number of AP type 2	Events (%)	Mean Charge (pe)
1	3,81%	1,20
2	0,25%	1,21
3	0,07%	1,18
4	0,025%	1,22

Differently to 10-inch PMT , in 3 inch PMT multiple AP2 have a charge mainly of spe. Multiple AP2 show lower fractions in confront of 10-inch PMT.

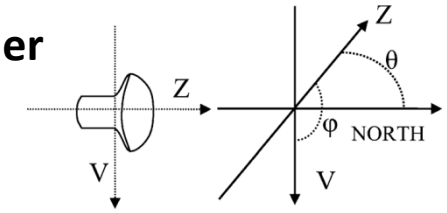
More on noise pulses on 10-inch PMTs here →

Noise Pulses in Large Area Optical Modules
Leonora, E. ; Aiello, S. ; Giordano, V. ; Randazzo, N. ; Longhitano, F. ; Presti, D.L. ; Pugliatti, C. ; Sipala, V.
Nuclear Science, IEEE Transactions on
Volume: 61 , Issue: 4 , Part: 2
DOI: 10.1109/TNS.2014.2322655
2014

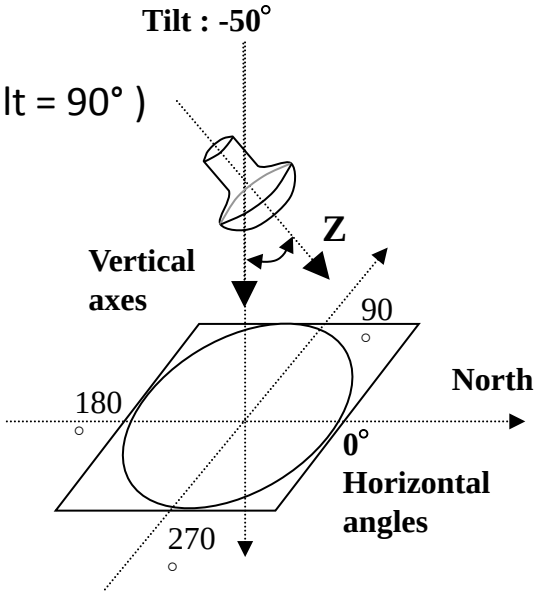
Influence of Earth's magnetic field

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

- **Influence of Eart's magnetic field on large area PMTs studied under KM3NeT design study S.Aiello et al. TNS-IEEE (2012) doi: 10.1109/TNS.2012.2189245**



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



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

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

Both PMTs have similar behaviour, we show the results for only one

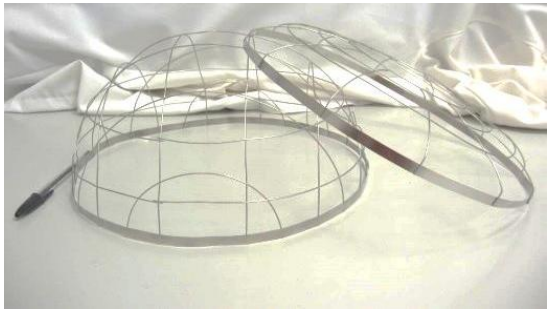
Measurements and conditions

For each PMT and for each position the following parameters were measured:

- Detection Efficiency
- Gain
- TT (relative)
- TTS (FWHM)

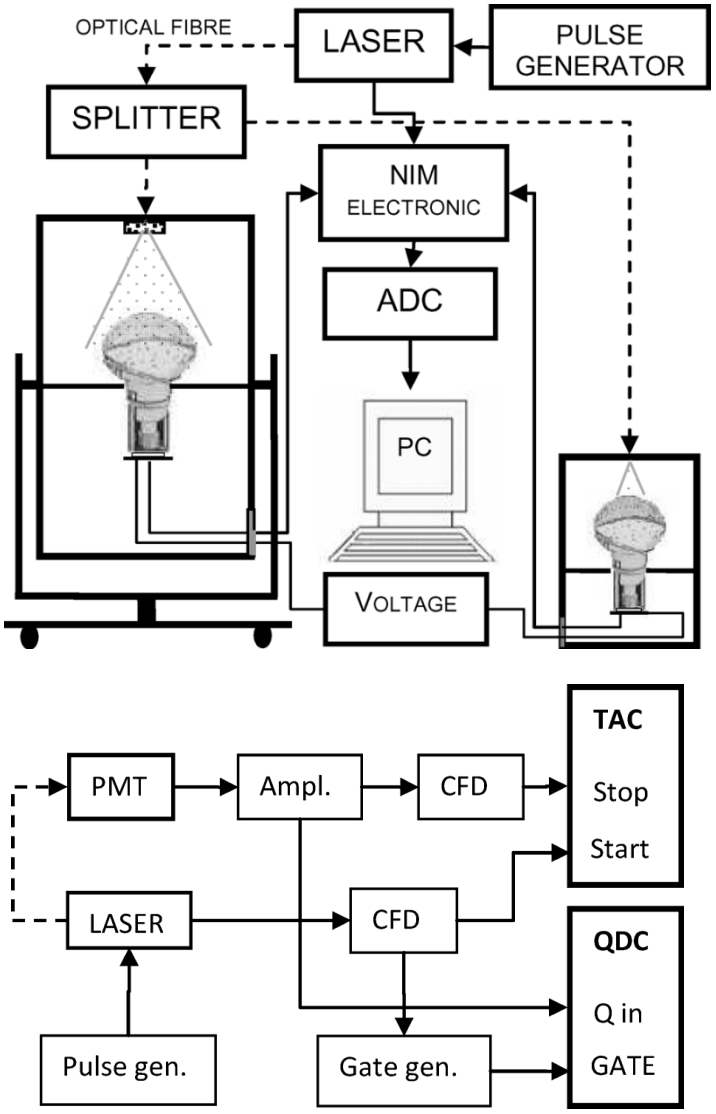
3-inchPMTs were powered with a passive base
3-inch PMTs were at same Gain condition = 5E+6

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



Picture of the box in tilted position

Setup

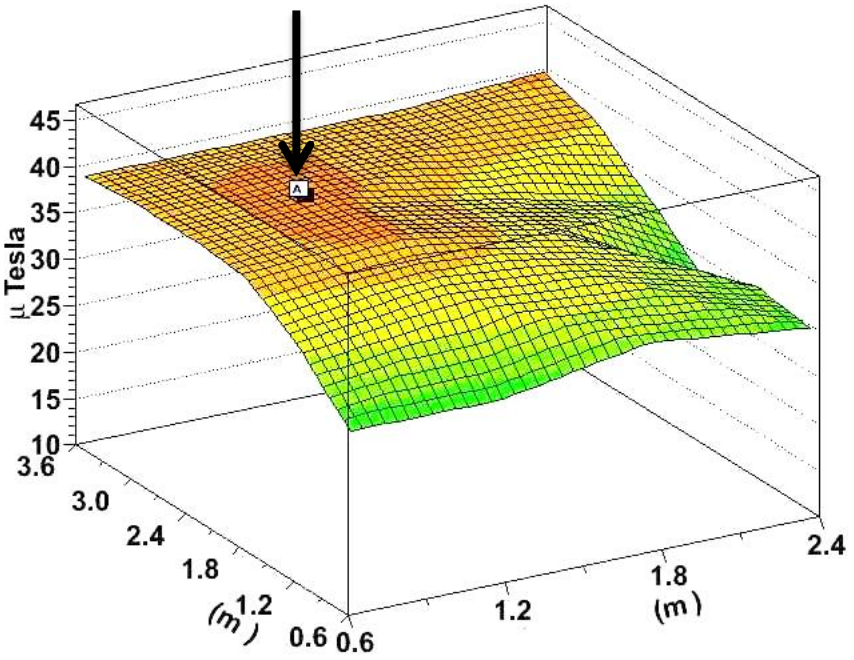


- A pulsed laser source (410nm, 60 ps width, 10KHz) attenuated in spe condition (Picoquant PDL 800-B)
- Light pulses conducted by means of multimode optical fibres
- An optical diffuser was used to produce homogeneous illumination over the photocathode
- Charge measurements made by NIM QDC 7422 Silena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

Measurements of the Earth's 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)

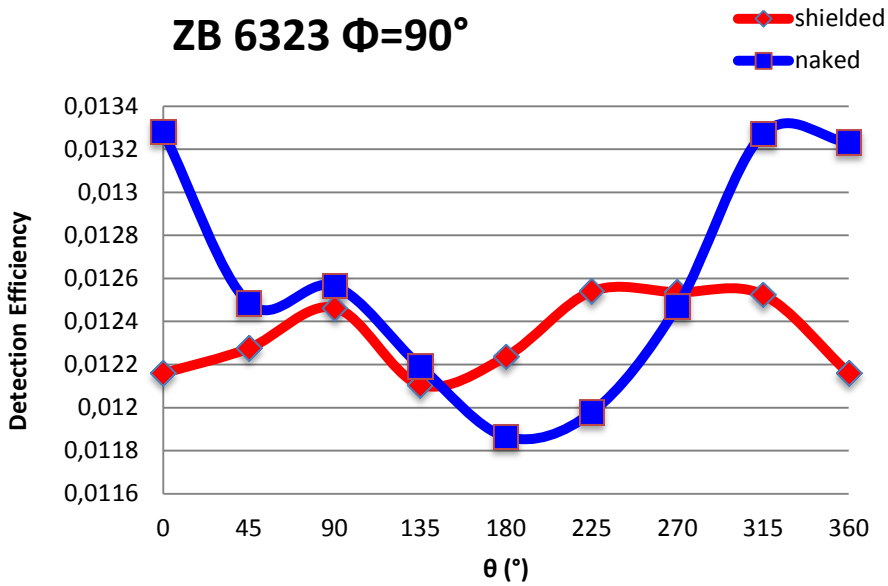


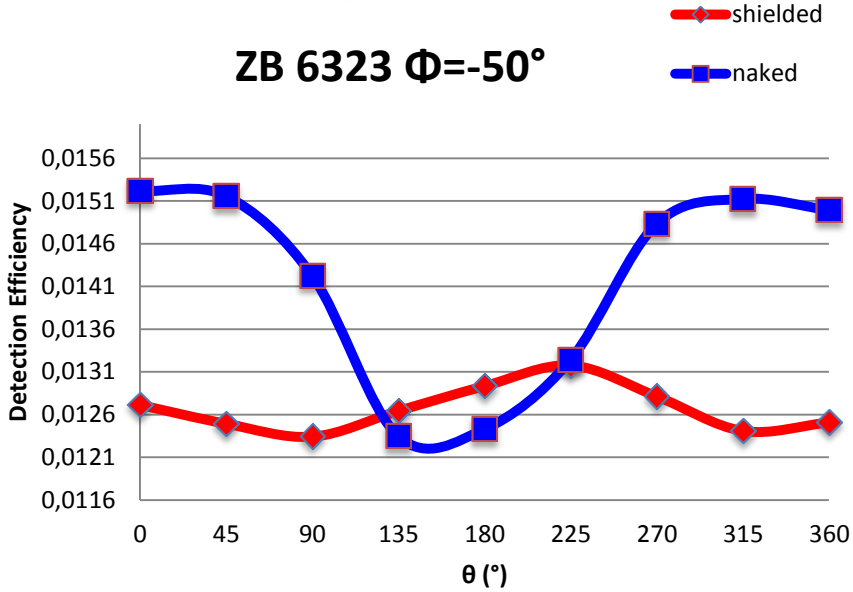
The signed point was selected as position of the Test BOX

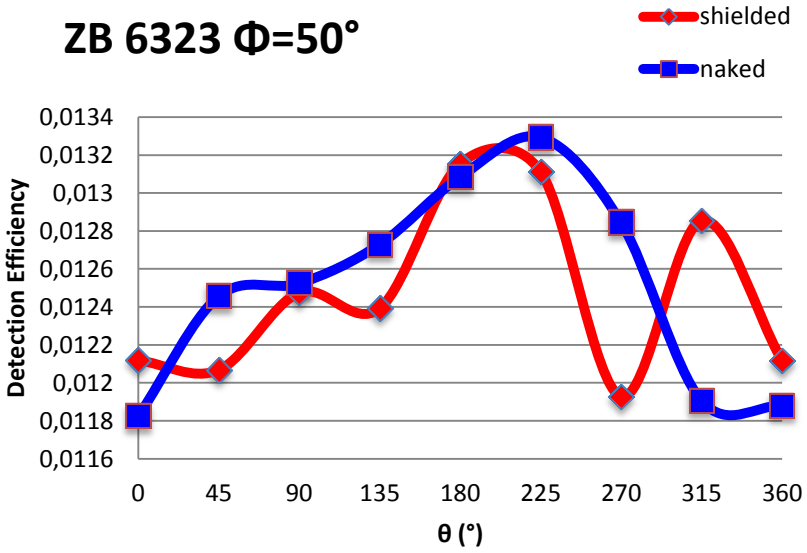
- B ≈ 40 μTesla

- good uniformity over 1 meter area

Detection Efficiency







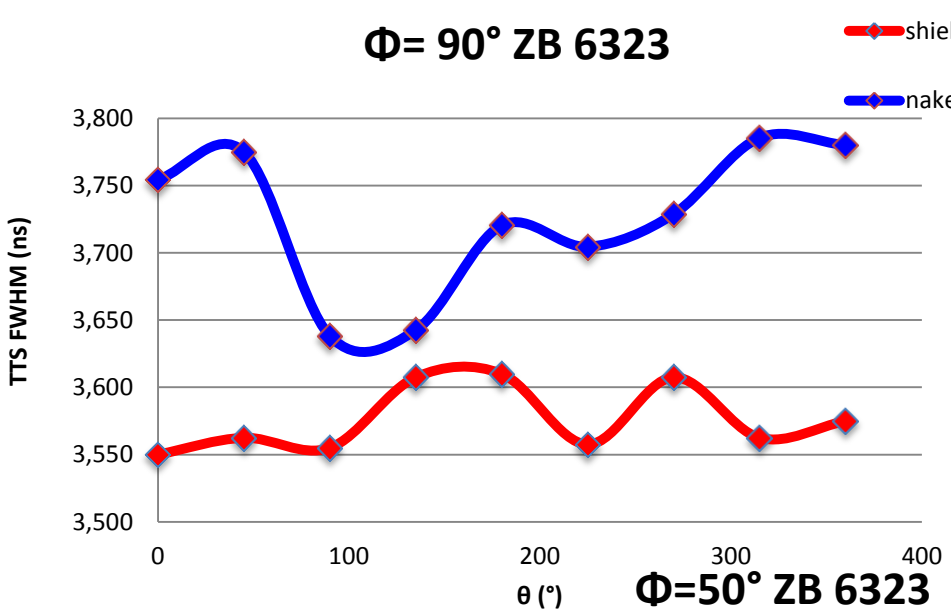
<u>detection efficiency:</u>

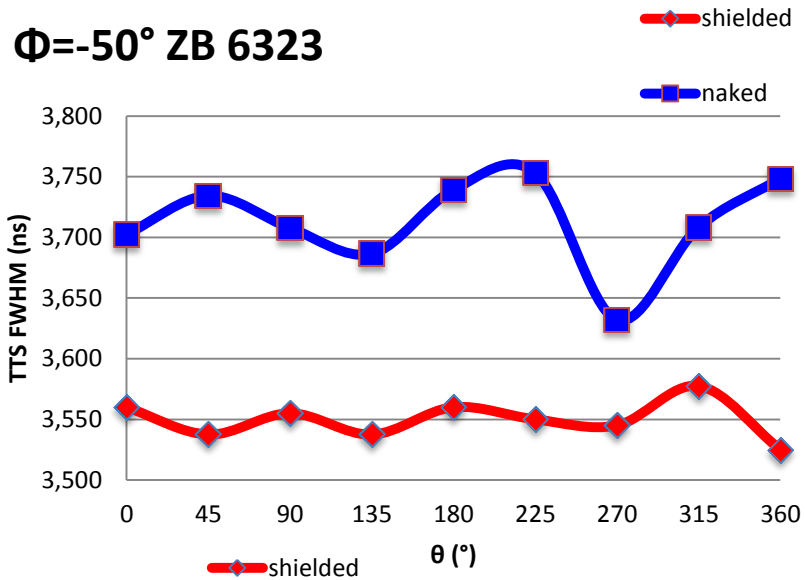
Ratio between the number of detected pulses and those emitted by the laser

Detection Efficiency

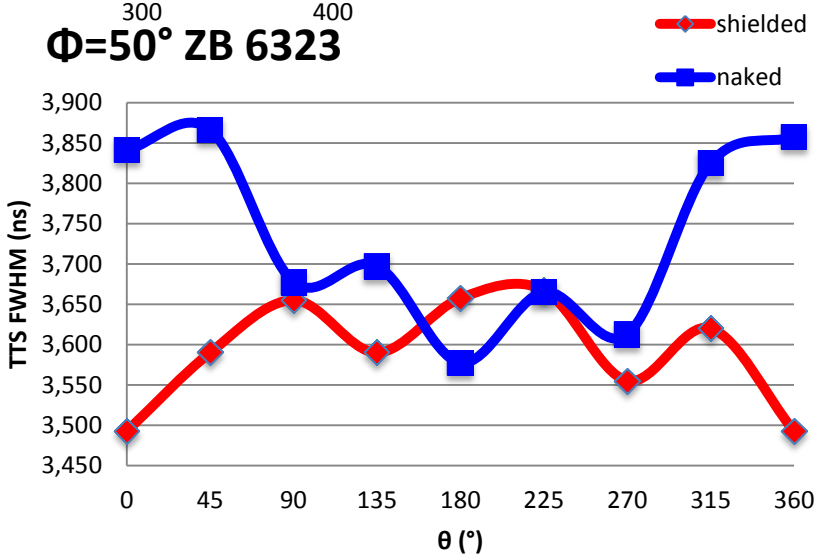
Detection Efficiency	Φ=90°		Φ=-50°		Φ=+50°	
	Naked	Shielded	Naked	Shielded	Naked	Shielded
Minimum value	0,01186	0,01234	0,01234	0,01234	0,01234	0,0119
Maximum value	0,01328	0,01317	0,01522	0,01317	0,01311	0,0132
Average Value	0,01258	0,01236	0,01417	0,01267	0,01235	0,01248
Maximum Variation	11,93 %	6,76 %	23,3%	6,75%	11,90%	11,10%
Max. var. 10-inch PMT	14,72%	1,69%			39,88%	5,56%

TTS (FWHM)





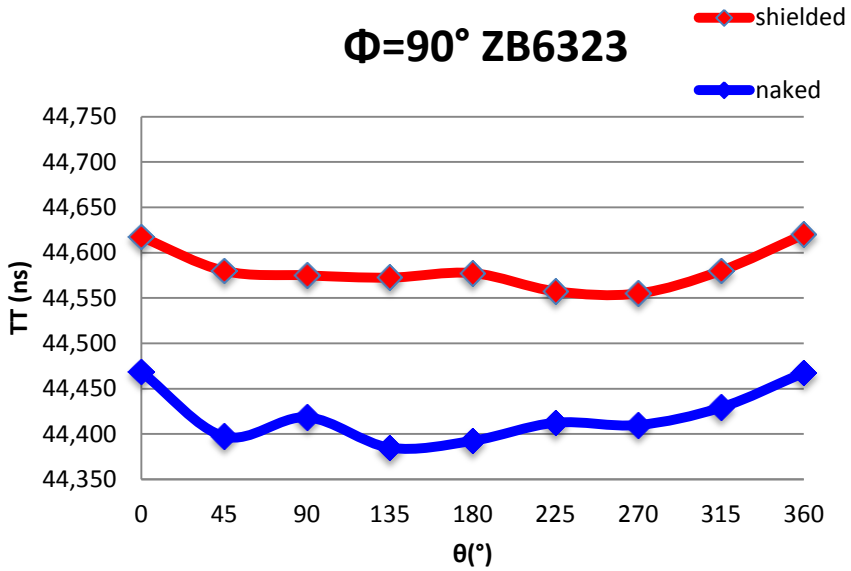
Transit Time Spread

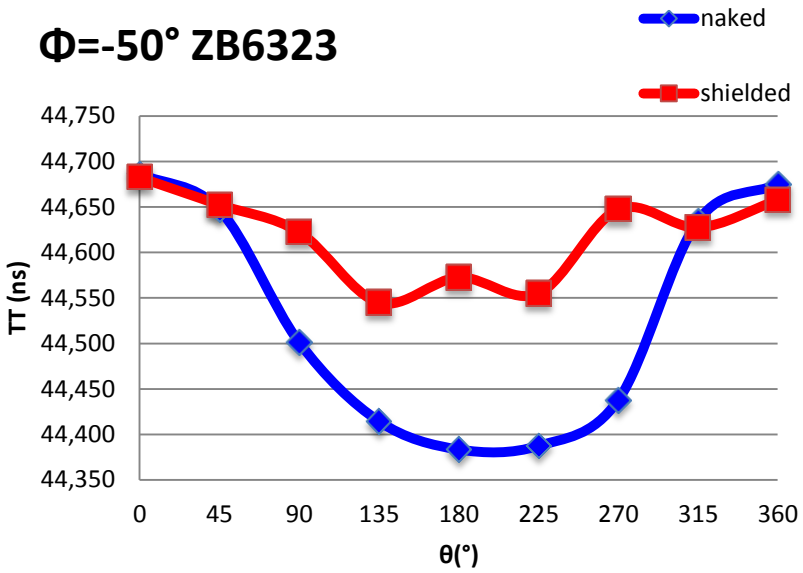


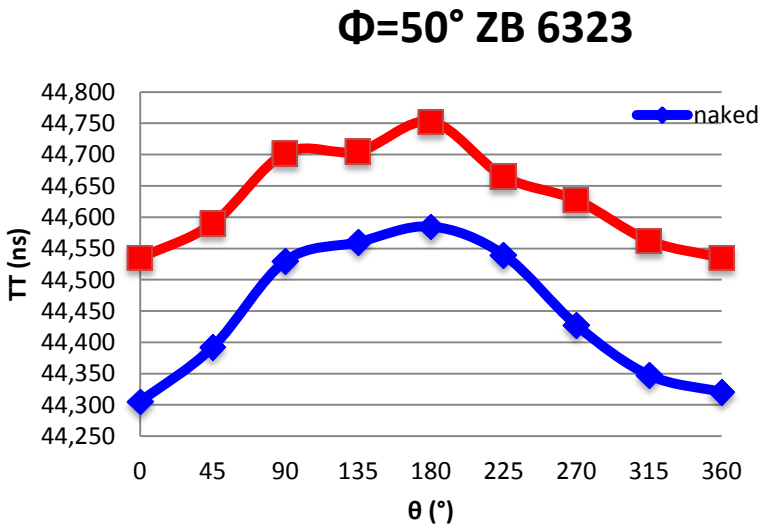
TTS (FWHM)

TTS (ns)	Φ=90°		Φ=-50°		Φ=+50°	
	Naked	Shielded	Naked	Shielded	Naked	Shielded
Minimum value	3,638 ns	3,550 ns	3,632 ns	3,525 ns	3,578 ns	3,492 ns
Maximum value	3,785 ns	3,610 ns	3,753 ns	3,577 ns	3,866 ns	3,667 ns
Average Value	3,725 ns	3,576 ns	3,713 ns	3,550 ns	3,708 ns	3,591 ns
Maximum Variation	4,04%	1,69%	3,30%	1,49%	8,10%	5,01%
Max. var. 10-inch PMT	9,71%	5,54%			10,47%	4,03%

Transit Time



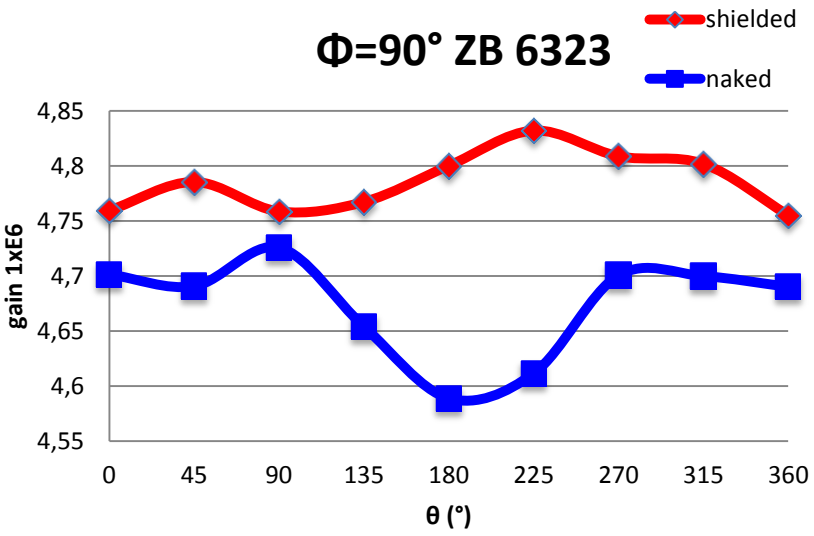


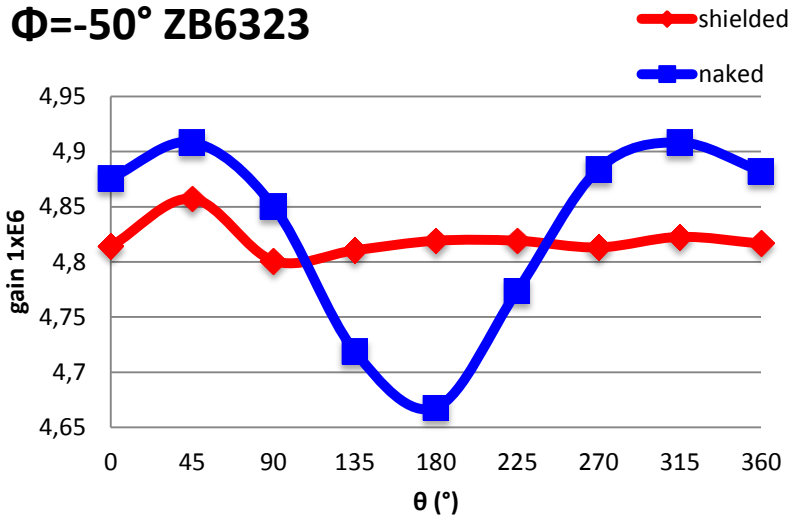


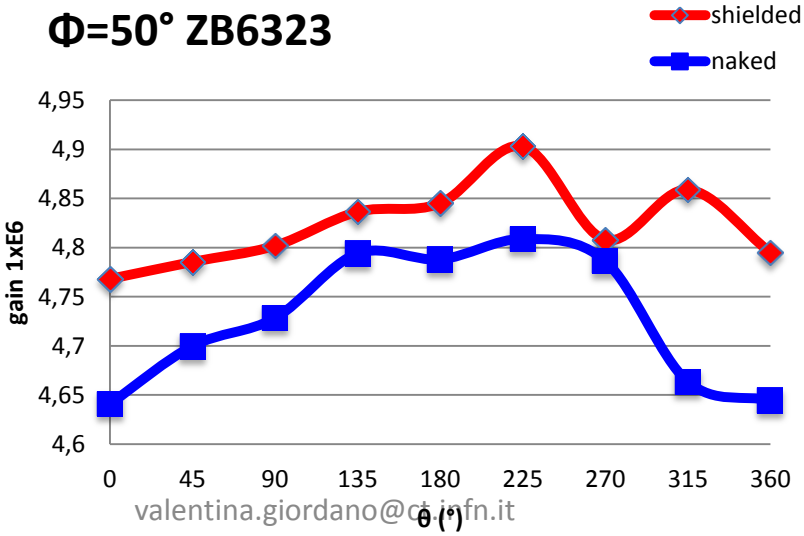
Transit Time

TT (ns)	Φ=90°		Φ=-50°		Φ=+50°	
	Naked	**Shielded**	**Naked**	**Shielded**	**Naked**	**Shielded**
Minimum value	44,385 ns	44,555 ns	44,384 ns	44,545 ns	44,305 ns	44,535 ns
Maximum value	44,469 ns	44,620 ns	44,715 ns	44,682 ns	44,585 ns	44,752 ns
Average Value	44,418 ns	44,582 ns	44,534ns	44,618 ns	44,445ns	44,631ns
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%

Gain


Φ=90° ZB 6323
shielded
naked
gain 1xE6
4,85
4,8
4,75
4,7
4,65
4,6
4,55
0
45
90
135
180
225
270
315
360
θ (°)


Φ=-50° ZB6323
shielded
naked
gain 1xE6
4,95
4,9
4,85
4,8
4,75
4,7
4,65
0
45
90
135
180
225
270
315
360
θ (°)


Φ=50° ZB6323
shielded
naked
gain 1xE6
4,95
4,9
4,85
4,8
4,75
4,7
4,65
4,6
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	2,98 %	1,62 %	5,10 %	1,79 %	4,10 %	2,83 %
Max. var. 10-inch PMT	27,81%	5,81%			28,59%	6,69%

Conclusion

- TTS (FWHM) ~ 4 ns (in 3 pe and 5 pe conditions it becomes lower)
- Pre-pulses and delayed are of spe charge (in 3 pe and 5 pe, fractions are lower and charge increases)
- AP1 mainly of spe,temporal peak at about 20 ns
- AP2 mainly of 1,6 pe ,temporal peaks at around 1μs and 3μs (Cs and CH_4^+). First peak with an higher charge contribution in confront of the second
- Single AP2 have a mean charge mainly of 1,2 pe
- Multiple AP2 (>1) with a lower statistic than 10-inch and mean charge of about 1,2 pe (See **E.Leonora at al. TNS_IEEE (2014) doi: 10.1109/TNS.2014.2322655**)

❖ Generally, the overall impact of the magnetic field was found to be smaller on 3-inch PMTs than 10-inch PMTs (See **S.Aiello et al. TNS-IEEE (2012) doi: 10.1109/TNS.2012.2189245**)

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

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

❖ For 3-inch PMTs, the Detection Efficiency is the parameter with higher variations with magnetic field.

Thank you for your attention