Noise pulses on photomultipliers optically coupled to glass vessel

E. Leonora, S. Aiello, V. Giordano

INFN-Section of Catania
On behalf of KM3NeT Collaboration

The Optical Module

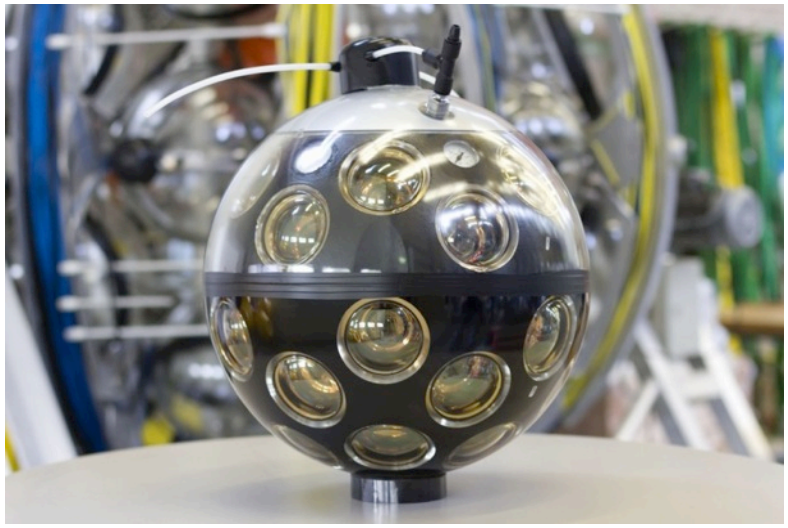
The key element of many deep-sea Cherenkov detectors is the so-called "optical module":

- transparent pressure-resistant glass sphere
- photomultipliers coupled to the glass by optical gel

Different design:

- Single large area photomultiplier in 13-inch or 17-inch glass sphere
- Multiple small area PMTs in 17-inch glass sphere

NEMO phase 2 OM
- 13" vessel
- 10" PMT
- mu-metal cage



KM3NeT DOM
- 17" vessel
- 31 PMT 3"

Effects of the glass on noise pulses

Earlier studies indicated that source of noise for an Optical Module is not only the PMT itself.
Light comes from the glass directly facing the photocathode in the pressure sphere, produced by:

- scintillation excited by energy deposited through radioactive decays in the glass material itself
- Cherenkov effect in the glass

Elements in the glass composition that causes light production:

- Potassium ^{40}K, the most abundant radioactive isotope in standard borosilicate glass
- Natural decay chains (Uranium, Thorium)
- Cerium:
  - Cerium oxide is used for glass polishing
  - Cerium is added to decolorize the glass
- Other lanthanides
- Iron

Measurements

A study has been conducted to quantify the contribute to the noise pulses of PMTs due to the presence of the external glass coupled by optical gel.

PMTs tested in two different configurations (12 h of dark adaption):
- the PMT naked
- the PMT optically coupled to the glass spheres by means of optical gel

PMT tested:
- 10-inch R7081 Hamamatsu
- 3-inch R12199-02 Hamamatsu

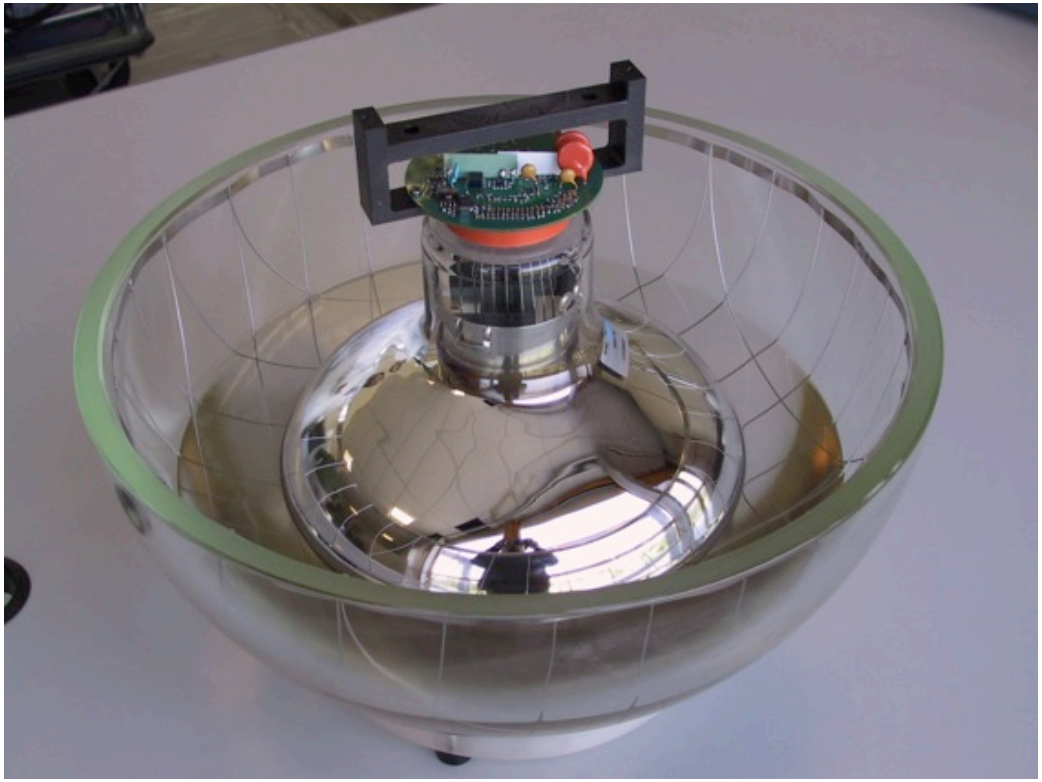
Glass vessels tested:
- 13-inch diameter, 12-mm thickness Nautilus (Vitrovex®)
- 17-inch Nautilus diameter, 15-mm thickness (Vitrovex®)
- 17-inch Benthos diameter, 15-mm thickness

Optical gel used
- Wacker silgel 612 bicomponent (A and B)

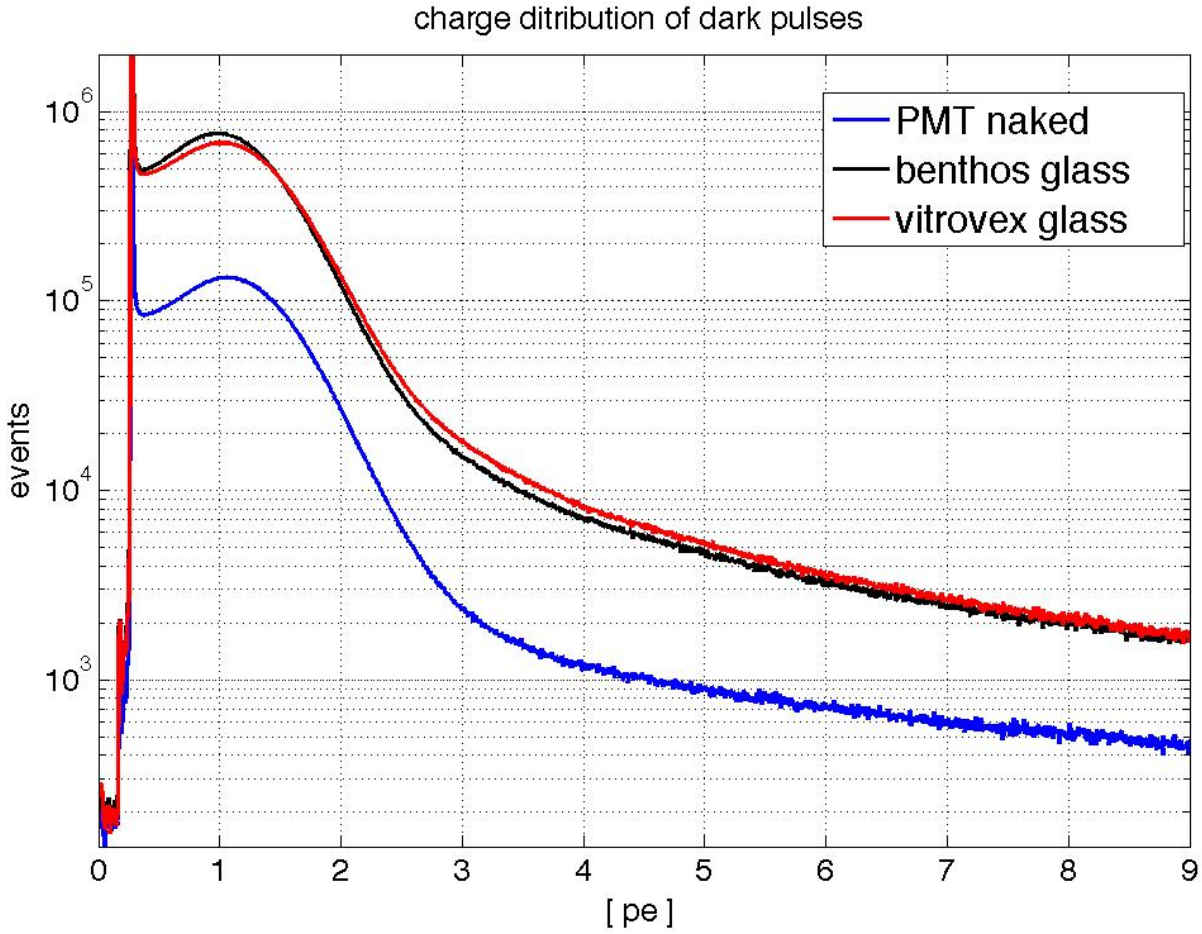
Test on 17-inch glass sphere with 10-inch PMT

Dark pulses were measured for two optical modules:

- 10-inch R7081 Hamamatsu PMT
- mu-metal cage
- Wacker silgel A:B = 2:1
- two 17-inch glass vessels, produced by Benthos and Nautilus (Vitrovex).



Charge distribution of dark pulses



The presence of the external glass sphere that surrounds the PMT causes a considerable increase in the rate of dark pulses at different amplitudes.

Dark Count rate

The increment of the dark pulse rate with respect to the naked PMT was measured for the two different brands of glass vessels, at three different thresholds (1/3 pe, 2 pe and 4 pe)

	naked	Benthos 17”		Vitrovex 17”	
THR [pe]	DC rate [Hz]	DC rate [Hz]	**Incr. [Hz]**	DC rate [Hz]	**Incr. [Hz]**
1/3	660	3600	**2940**	3432	**2772**
2	52	291	**240**	333	**281**
4	16	103	**87**	111	**95**

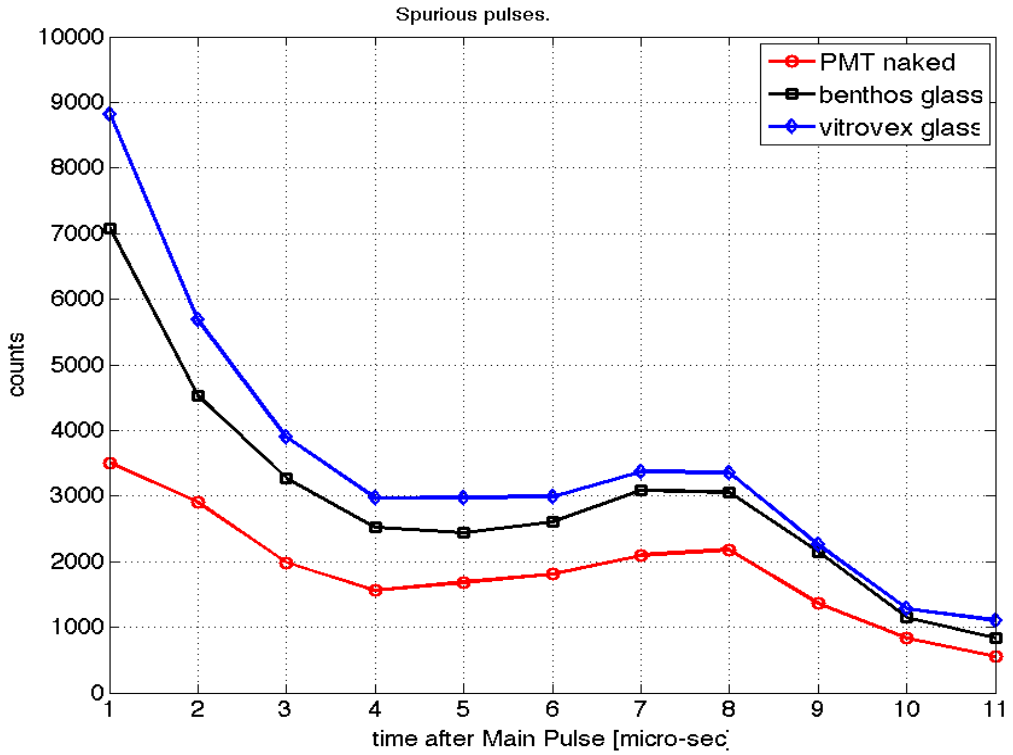
$$\text{Incr.} = \text{Rate}_{\text{glass}} - \text{Rate}_{\text{naked}}$$

- For pulses with amplitude over 1/3 pe, the increment was of about 2800 – 3000 Hz
- For pulses exceeding the 2 pe threshold, the increment ranges between 240 – 280 Hz
- Over 4 pe , the increment ranges between 87 – 95 Hz

Pulses following an initial pulse: threshold of 1/3 pe

The noise pulses that follow an initial pulse have been measured, in a range of time of 11 μs. Three thresholds: (1/3 pe, 2 pe and 4 pe)

Trigger: an initial dark pulses
Acquisition: counting the pulses following the initial pulse



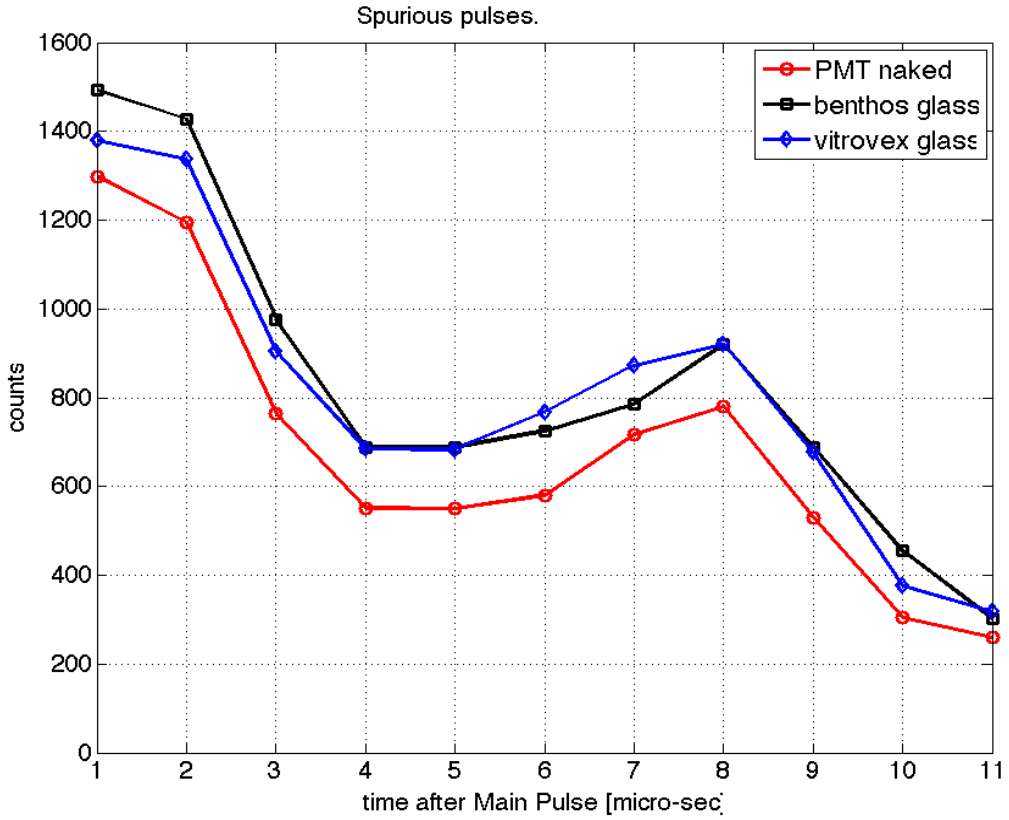
- The light coming from the glass produces a sequence of pulses time correlated
- Considerable increase in single pe pulses 1μs delayed from the first pulse

(100% for benthos glass, 150% for vitrovex glass)

- The increment decrease with the delay time increasing, maintaining values higher than the 40% for both brands of glasses.

Pulses following an initial pulse: threshold of 2 pe

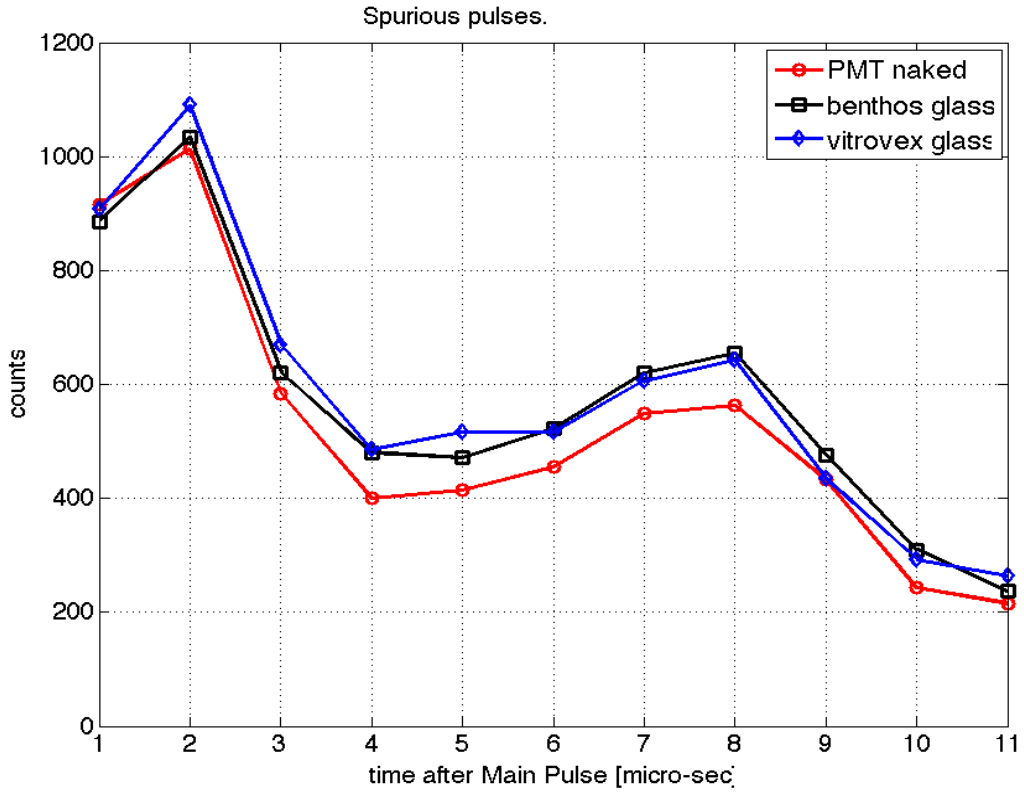
Trigger: an initial dark pulses
Acquisition: counting the pulses following the initial pulse



- For the pulses with amplitude over 2 pe an increase is visible lower than 1 pe signals
- After a slight increase in the first microseconds, the value of the increment doesn't seem to depend with the delay time, with an average value around the 20%.
- The trend of the two brands of glasses seems to be the same.

Pulses following an initial pulse: threshold of 4 pe

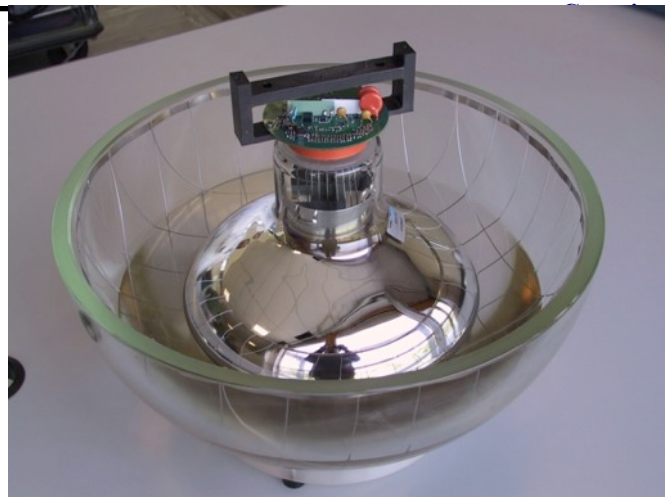
Trigger: an initial dark pulses
Acquisition: counting the pulses following the initial pulse

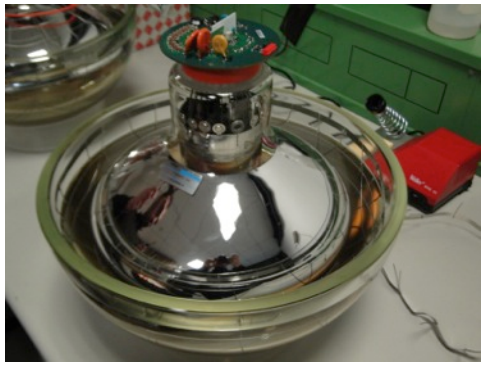


- For the pulses over 4 pe , an increase in the number of the counts has been also measured, lower than those for pulses with lower amplitude.
- After an increase in the range 1 to 4 microseconds, the increment seems to be independent by the delay time, with an average value around the 15%.
- The trend of the two kinds of glasses seems to be the same.

Comparison with a 13-inch OM with 10-inch PMT

- 13-inch glass vessel by Nautilus
- 10-inch R7081 Hamamatsu PMT
- mu-metal cage
- Wacker silgel A:B = 2:1





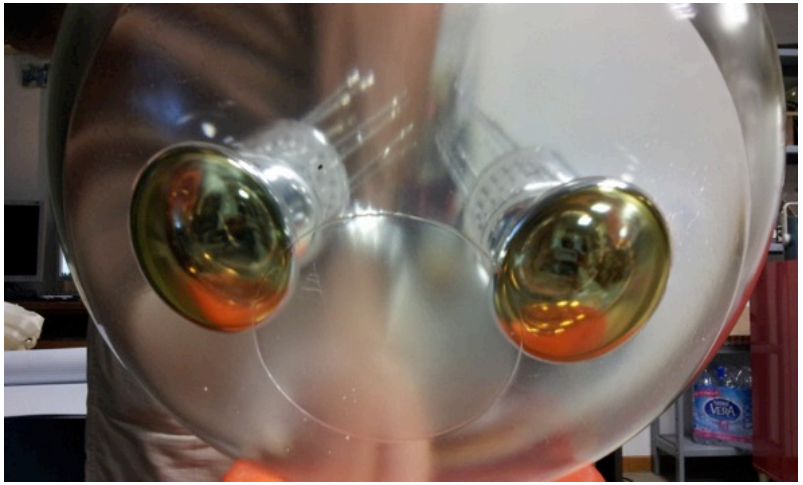
	PMT 10” Dark Cout rate [Hz]		
THR [pe]	Benthos 17”	Vitrovex 17”	Vitrovex 13”
1/3	3600	3432	3200
2	292	333	222
4	103	111	96

Same size PMTs in different size glass spheres have similar DC rate

→ The increment of the DC rate depends on the area of the PMT photocathode

Test on 3-inch PMTs coupled to 17-inch glass sphere

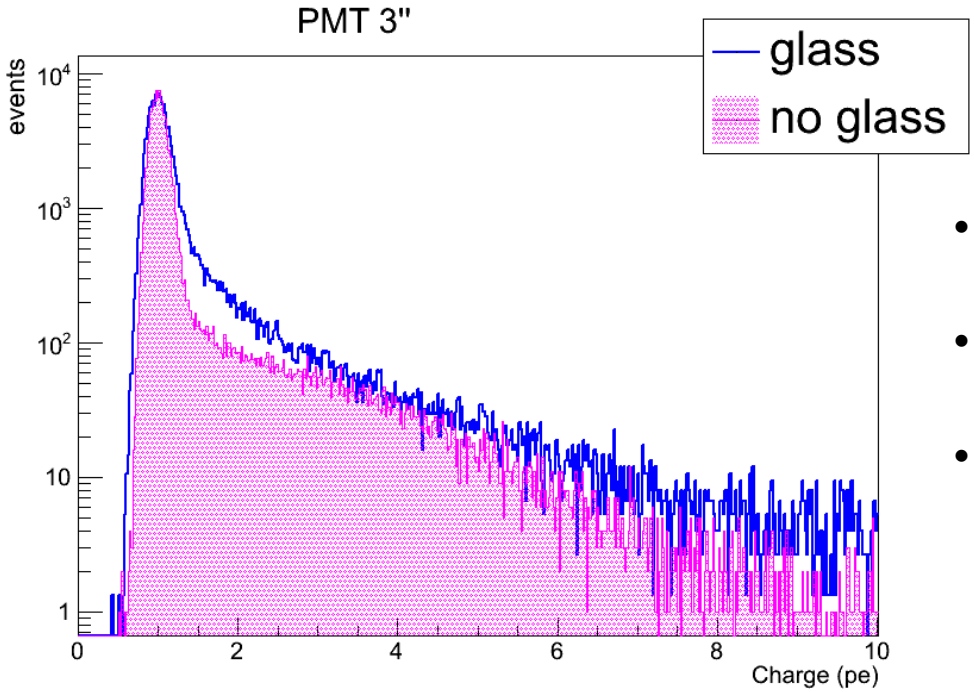
- 17-inch glass vessel by Nautilus
- 2 PMTs 3-inch R12199-02 Hamamatsu
- Wacker silgel A:B = 1.5:1



Test on 3-inch PMTs coupled to 17-inch glass sphere

Comparative measurements on Dark Current rate and charge distribution on the 3" PMTs naked and optically coupled to the glass

	PMT 3" 6308 DC rate			PMT 3" 6328 DC rate			PMT 10" DC rate
THR [pe]	Naked [Hz]	Glass [Hz]	**Incr. [Hz]**	Naked [Hz]	Glass [Hz]	**Incr. [Hz]**	**Incr. [Hz]**
1/3	432	1115	**683**	350	1018	**668**	**2772**
2	13	37	**24**	13	37	**23**	**281**
4	4	12	**8**	5	14	**9**	**95**



$$Incr. = Rate_{glass} - Rate_{naked}$$

- An increment of about 700 Hz in rate of dark pulses was measured with the glass
- The increment in 3-inch PMT is lower than that measured in 10-inch PMT
- No full proportionality with the different active area between 3" and 10" PMTs (factor of about 10)

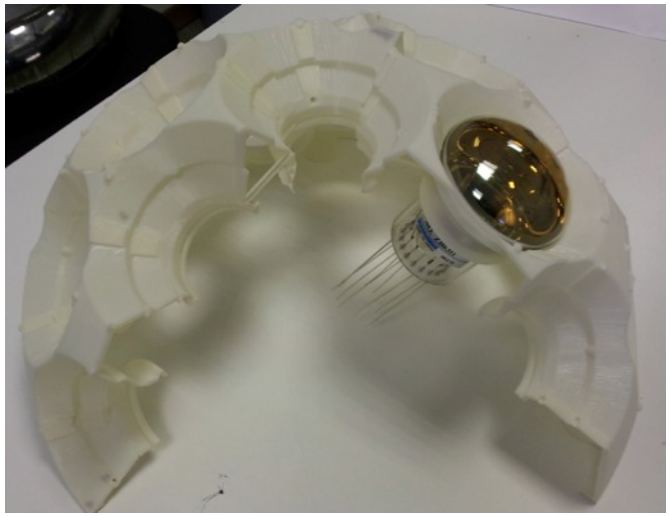
Test on 3-inch PMTs with 17-inch glass sphere + gel + ABS structure

To perform test in operative conditions, two PMTs were assembled in a prototypal piece of the internal structure of the DOM (made by INFN-Genova 3D printers , composed by 4 parts)

Material used:

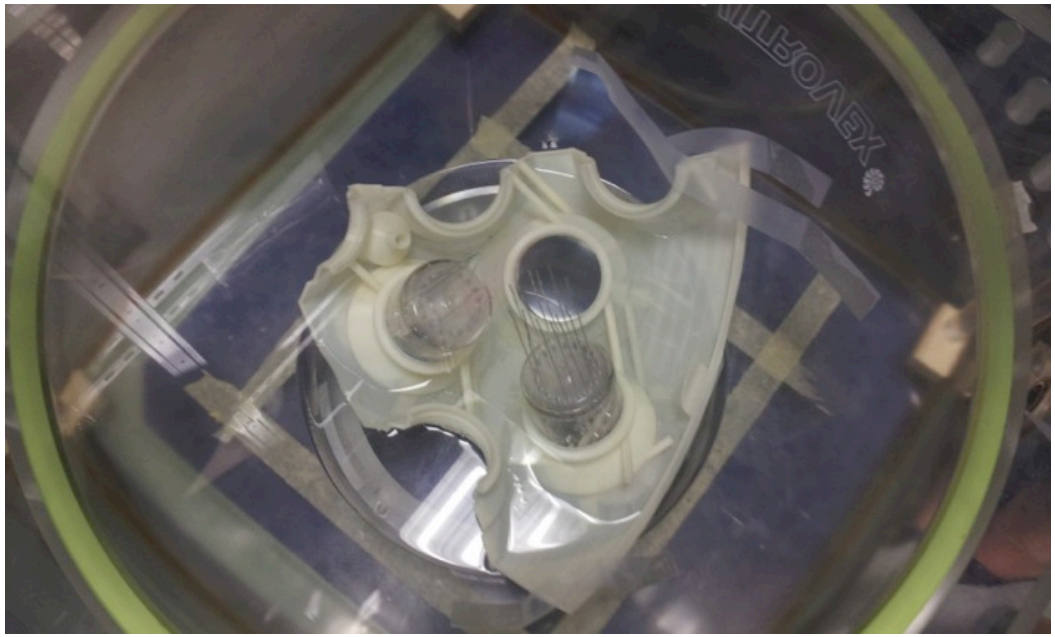
P430 ABS (Acrylonitrile Butadiene Styrene) ($C_8H_8 \cdot C_4H_6 \cdot C_3H_3N$)
A thermoplastic material widely used in 3D printers

- 17-inch glass vessel by Nautilus
- 2 PMTs 3-inch R12199-02 Hamamatsu
- A piece of prototypal ABS structure
- Wacker silgel A:B = 1.5:1



Test on 3-inch PMTs in 17-inch glass sphere +prototypal ABS structure

	PMT 3" 6108 DC rate			PMT 3" 6308 DC rate
THR [pe]	Naked [Hz]	glass+gel +ABS [Hz]	**Incr. glass+gel+ABS [Hz]**	**Increment glass+gel [Hz]**
1/3	1250	4001	**2751**	**683**
2	26	46	**20**	**24**
4	7	14	**7**	**8**



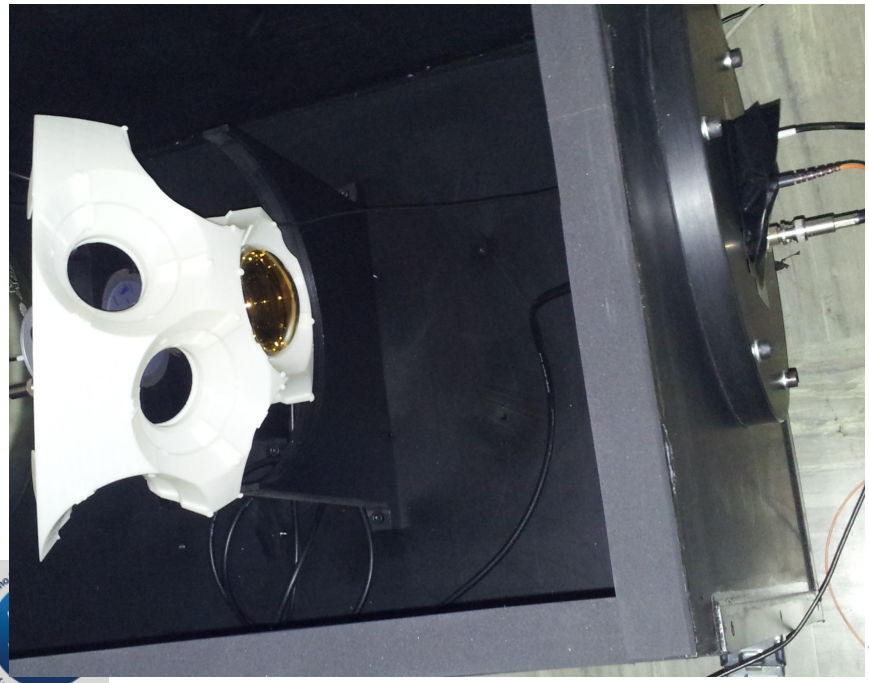
$$\text{Incr.} = \text{Rate}_{\text{glass}} - \text{Rate}_{\text{naked}}$$

- increment higher than that measured without ABS structure
- main increment for single pe

Effects of the ABS structure on 3-inch PMTs

Dark count rate was measured on 3 PMTs separately inserted without gel into a piece of the ABS structure

	PMT 6308 DC rate			PMT 6311 DC rate			PMT 6316 DC rate		
THR [pe]	Naked [Hz]	ABS [Hz]	**Incr. [Hz]**	Naked [Hz]	ABS [Hz]	**Incr. [Hz]**	Naked [Hz]	ABS [Hz]	**Incr. [Hz]**
1/3	432	937	**505**	670	1328	**658**	2162	2792	**630**
2	13	14	**1**	22	28	**6**	30	32	**2**
4	4	4	**0**	6	8	**2**	11	11	**0**



$$\text{Incr.} = \text{Rate}_{\text{glass}} - \text{Rate}_{\text{naked}}$$

- The prototypal ABS structure tested has an influence on DC rate of the PMT
- Mainly of 1 pe dark pulses

Conclusions

- A study about PMTs optically coupled with glass vessels was conducted and is still ongoing:
  - 10-inch and 3-inch PMTs
  - 13-inch and 17-inch glass spheres
  - Benthos and Nautilus glass spheres
- light coming from glass vessel influences the rate and charge distribution of PMT noise pulses

- PMT 10-inch:
  - Incremement of about 2800 Hz for 1/3 pe with glass and gel
  - No considerable difference between 13-inch and 17-inch glass spheres
  - The light coming from the glass produces a sequence of anode pulses time correlated with the first pulse, mainly of 1 pe delayed after few microseconds

- PMT 3-inch:
  - Increment of about 700 Hz for 1/3 pe with glass and gel
- a prototypal internal structure for DOM realized by 3D printers in ABS material influences the DC rate, mainly for single pe
  - Increment of about 600 Hz for 1/3 pe with only the structure
  - Increment of over 2 KHz for 1/3 pe with glass, gel and structure

…other tests and analysis are in progress !!!