Characterization of the 80mm diameter Hamamatsu PMTs for KM3NeT

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on behalf of KM3NeT Collaboration

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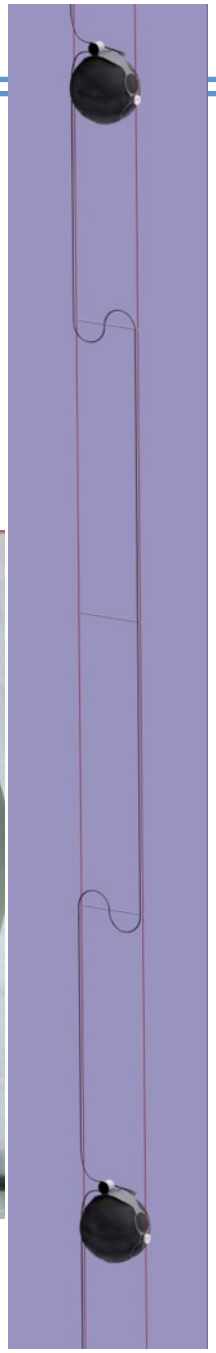
Optical Module for KM3NeT

Digital Optical Module (DOM)

- 31 3-inch photomultipliers
- 17-inch glass sphere
- PMT bases and read-out electronics housed inside the sphere

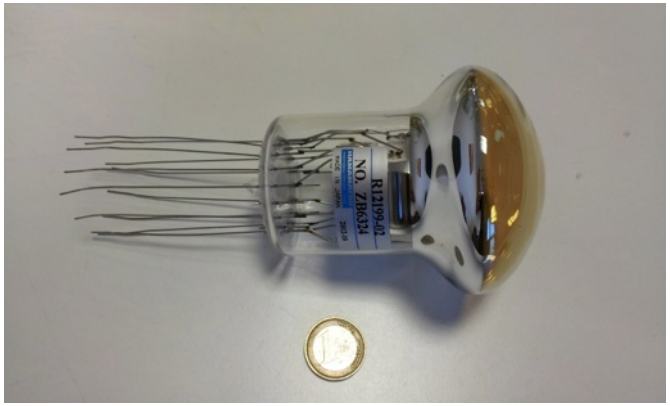


Main specifications for the KM3NeT photomulipliers

- Quantum efficiency at 470 nm **: 18% min. – 20% typ.**
- Quantum efficiency at 404 nm **: 25% min. – 28% typ.**
- Voltage for gain 3 x 10^6 **: 900 V min. – 1300 V max.**
- Transit Time Spread (TTS) 0.3 pe threshold (FWHM) **: 5.0 ns max – 4.5 ns typ.**
- Dark count at 20 deg and 0.3 pe threshold (12 hour dark adaption)**:**
  2000 Hz max. – 1500 Hz typ.
- Prepulses (100 ns – 10 ns) **: 1% max.**
- Delayed pulses (10 ns – 60 ns) (pulses delayed with no main pulse at correct time) **: 3.5 % max.**
- Early after pulses (10 ns – 100 ns) **: 2% max.**
- Late after pulses (100 ns – 10 µs) **: 10% max.**

A proposed photomultipliers

R12199-02 Hamamatsu
- Hemispherical (mushroom) shape
- 80-mm diameter
- Bialkali photocathode
- 10-stages



200 PMTs delivered and tested in 3 sites:
- ECAP Erlangen
- INFN Catania
- NIKHEF Amsterdam

Group	Number of PMTs
Nikhef	30
INFN Catania	22
ECAP	158
Cross measurements	
Nikhef-ECAP	5
INFN-ECAP	3
Nikhef-INFN-ECAP	1
Total	**200**

Measurement condition and setup

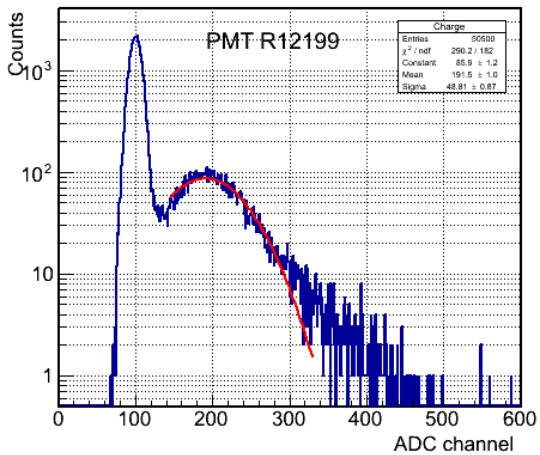
- gain condition of 5 E6
- whole photocathode illuminated
- Light sources:
  - Pulsed
  - Attenuated up to the single photo electron condition
  - ECAP and NIKHEF : fast LED (Picoquant), 800 ps FWHM, 470nm and 400nm
  - INFN Catania: laser (Picoquant), 50ps FWHM, 410nm
- PMTs powered by 2 types of passive bases
- Readout:
  - anode signals sampled by Lecroy Waverunner oscilloscope 1 GS/sec
  - NIM modules;
  - CAMAC (Nikhef)

NIKHEF base

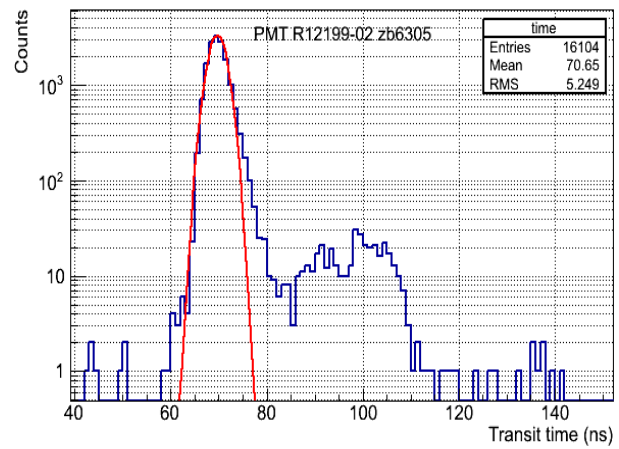
ECAP / Catania base

Comparative measurements

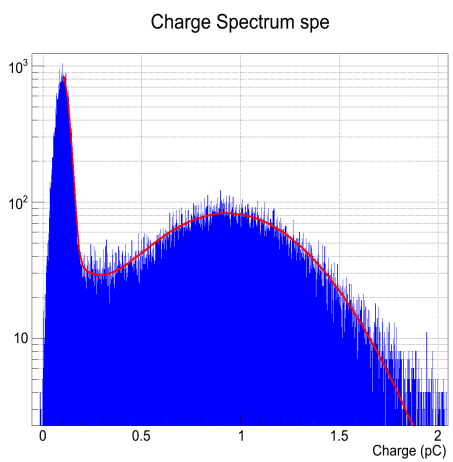
Comparative measurements to validate procedures and setups



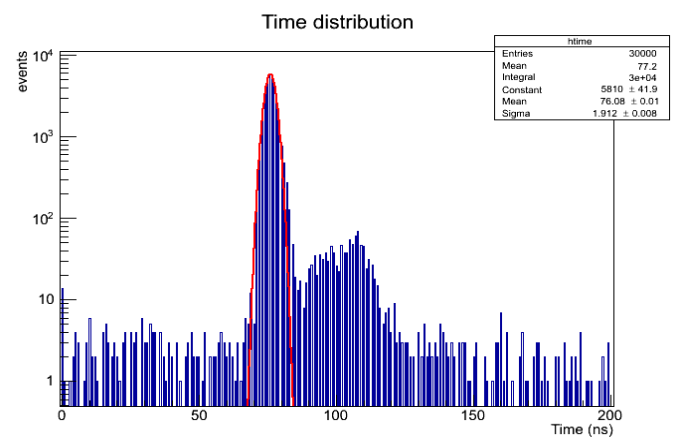
Charge spectrum by ECAP



Time spectrum by ECAP



Charge spectrum by INFN Catania



Time spectrum by INFN Catania

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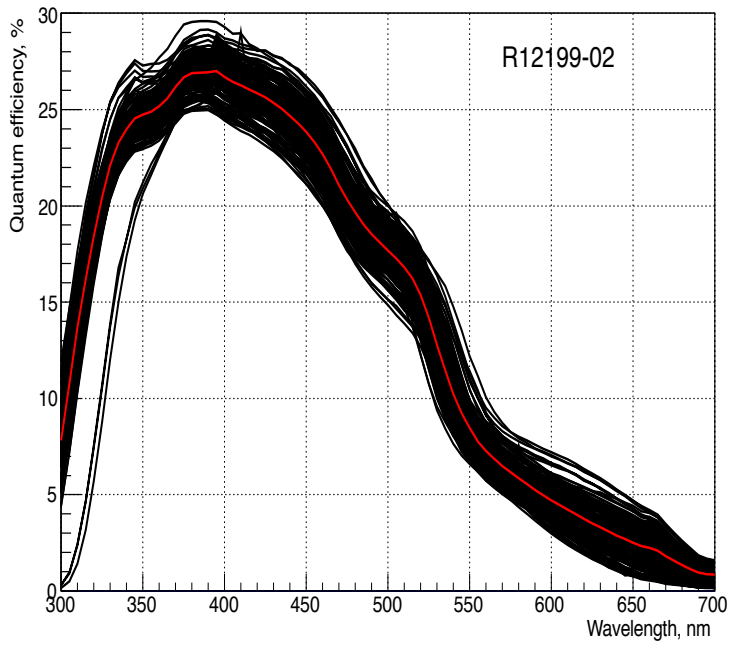
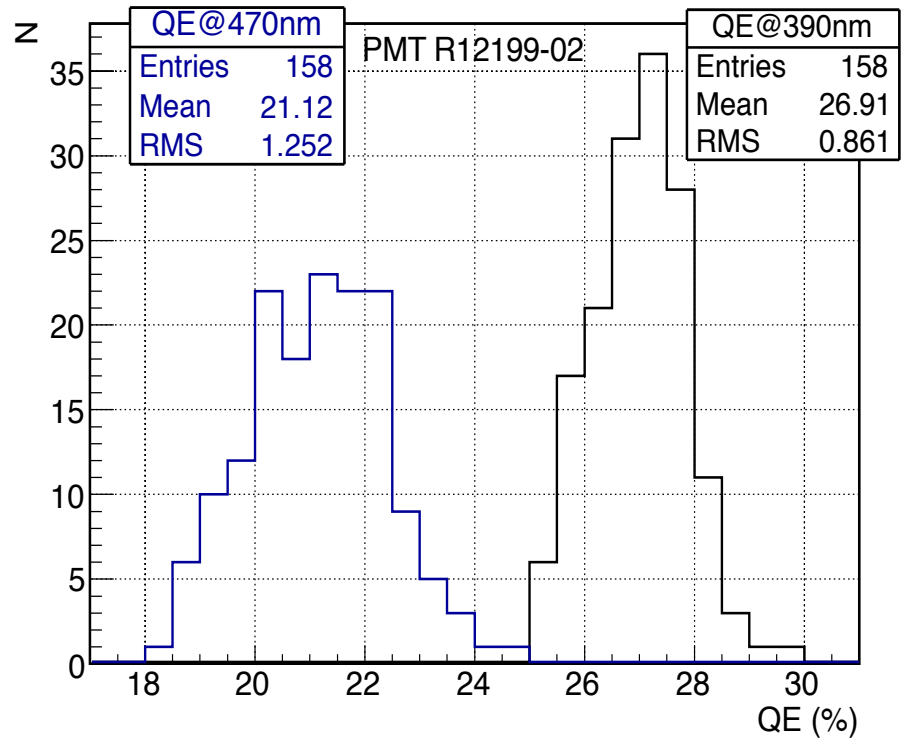
Quantum Efficiency

Specifications:

QE at 470 nm : 18% min. – 20% typ.

QE at 404 nm : 25% min. – 28% typ.





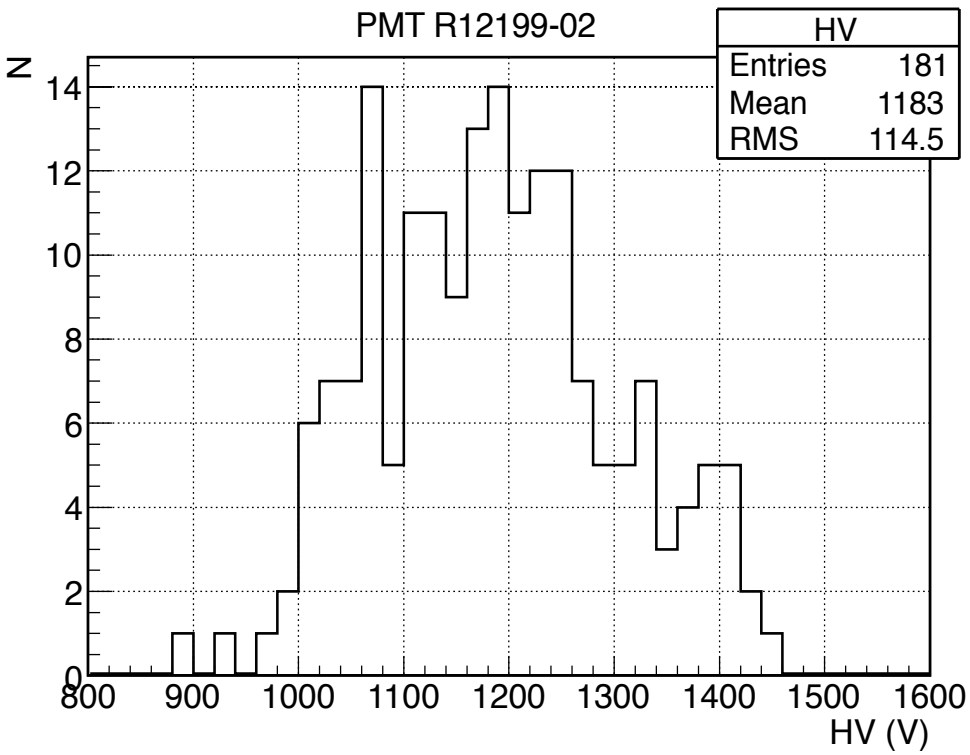
QE	Min [%]	Max [%]	Mean [%]
@ 470 nm	18	25	21
@ 390 nm	25	30	27

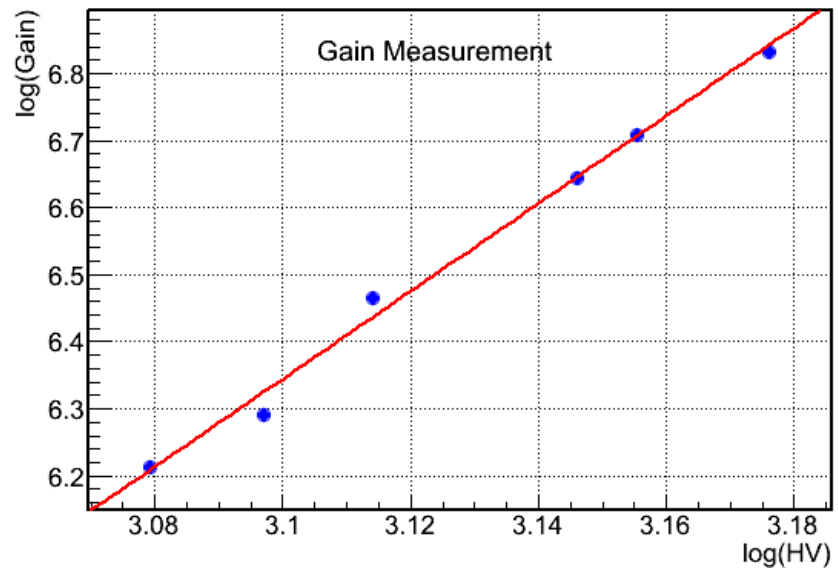
- **Values measured comply with specifications**

Nominal voltage measurements

Specifications:

- Voltage for gain 3 x 10^6 **: 900 V min. – 1300 V max.**





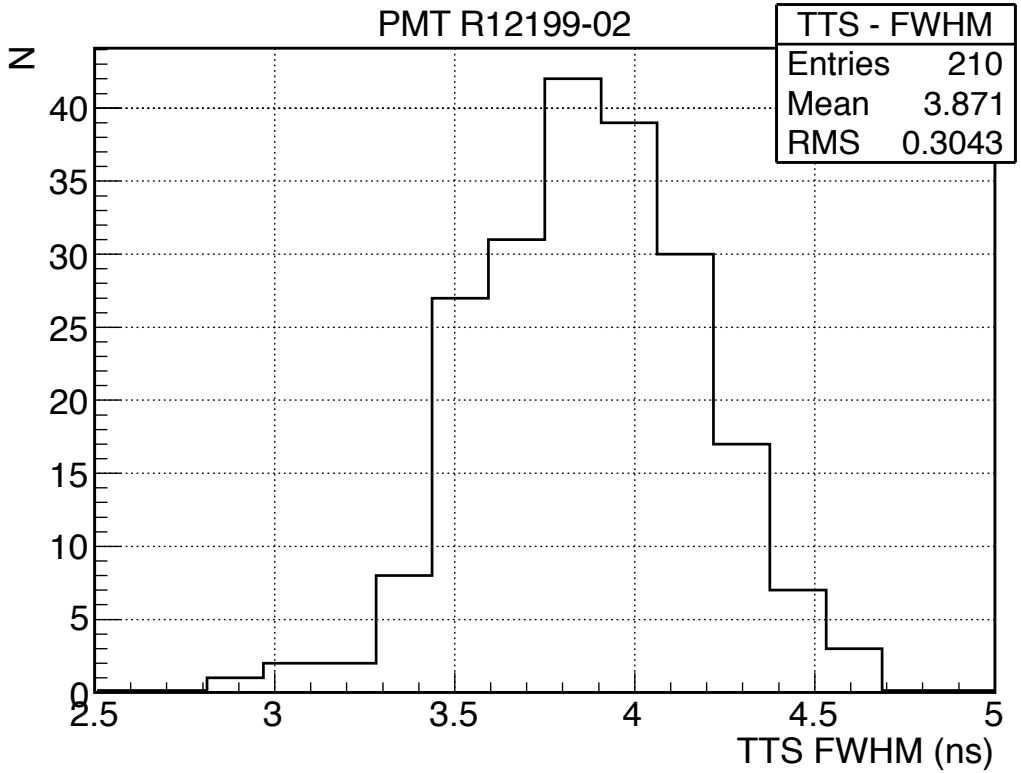
Nominal Voltage	Min [V]	Max [V]	Mean [V]
Gain 5 E 6	900	1450	1183

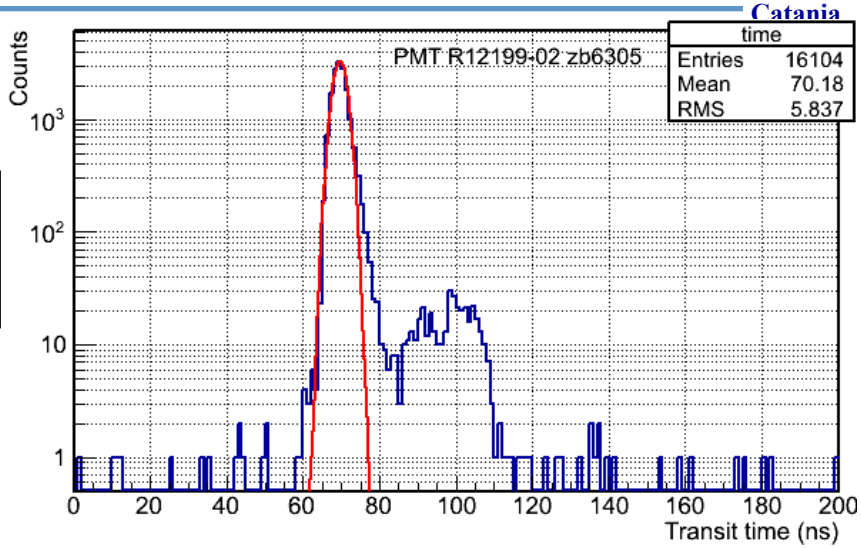
- **Considering the typically gain-slope measured (≈ 6.5) , the values comply with the requirements for the lower gain (**3 x 10^6 **)**

Transit Time Spread (TTS)

Specifications:

- FWHM 0.3 pe : **5.0 ns max. – 4.5 ns typ.**





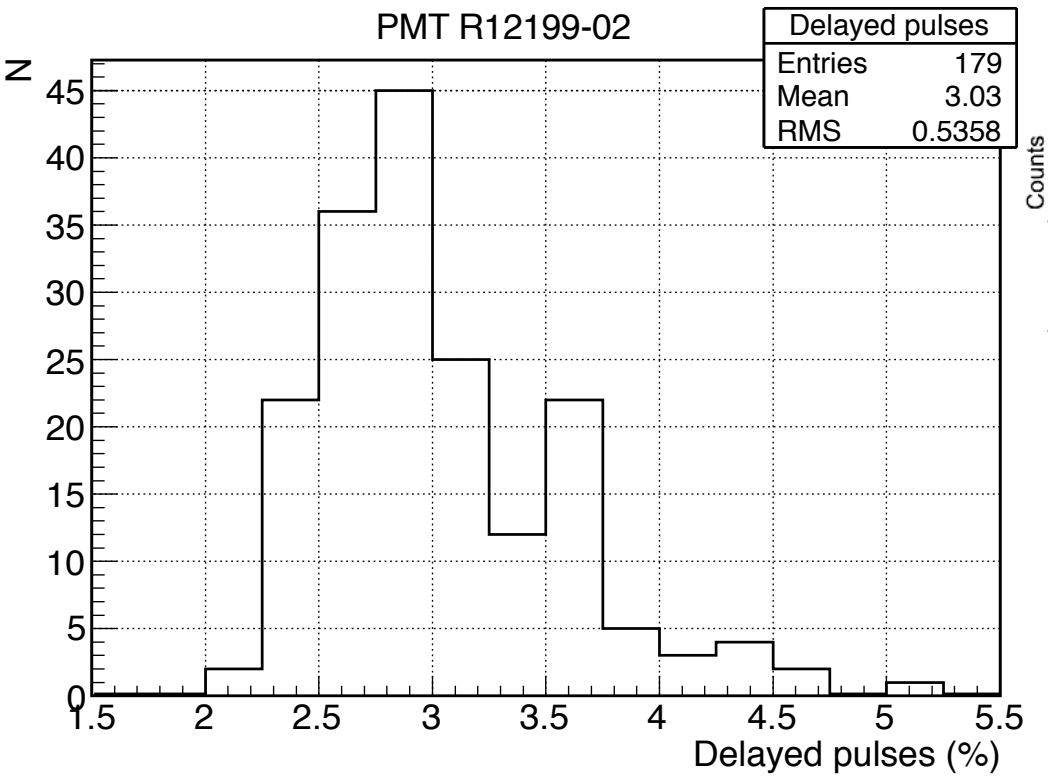
Effective TTS could be larger : non-gauss shape

- **the measured values comply with specifications**

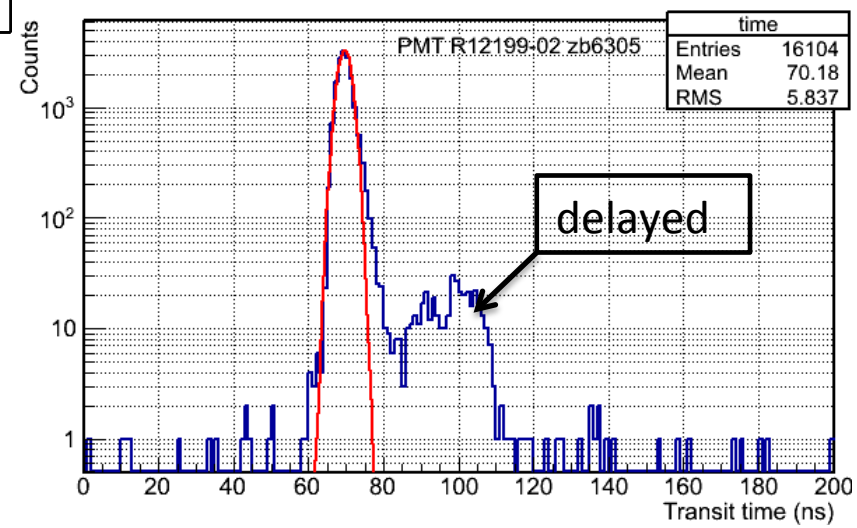
TTS	Min [ns]	Max [ns]	Mean [ns]
FWHM	2.8	4.7	3.9

Delayed pulses measurements

Pulses 10 ns – 60 ns later than the regular main pulse, in place of it
The fraction was measured with laser in spe condition: number of delayed pulses on number of mains
Specification: 3.5 % max.



Measured on the TT spectrum



Typical delayed time distribution:
Peaked 30 ns after main pulse

delayed	Min [%]	Max [%]	Mean [%]
fraction	2	5	3

- **The mean value meets requirement**
- **Some PMTs higher than max value**

further information in V.Giordano talk

After pulses measurements

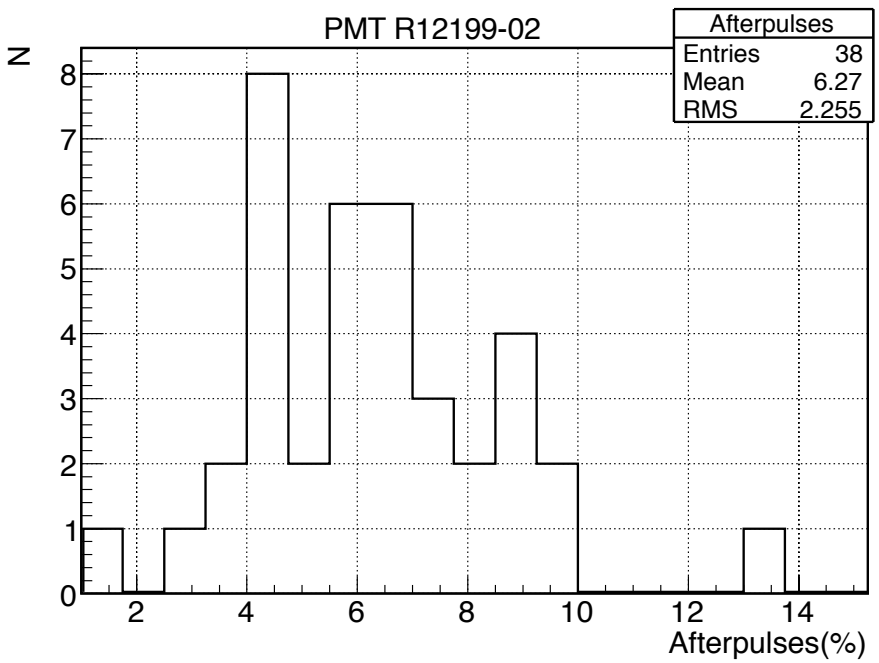
Noise pulses that follow the main pulses:

- Early after pulses, AP1, (10 ns – 100 ns) (luminous reaction on electrodes)
- Late after-pulse, AP2, (100 ns – 10 µs) (ionization of residual gas)

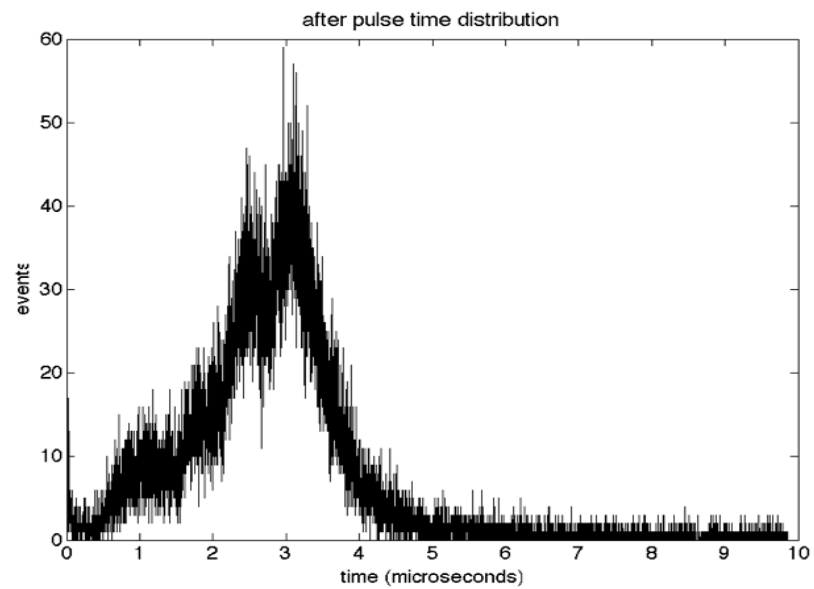
The fraction was measured with laser in spe condition: number of after pulses on number of mains

Specification:

- Early after pulses **: 2% max.**
- Late after-pulse **: 10% max.**



All after pulses in the range 10ns – 10 µs



Typical time distributions of after pulses

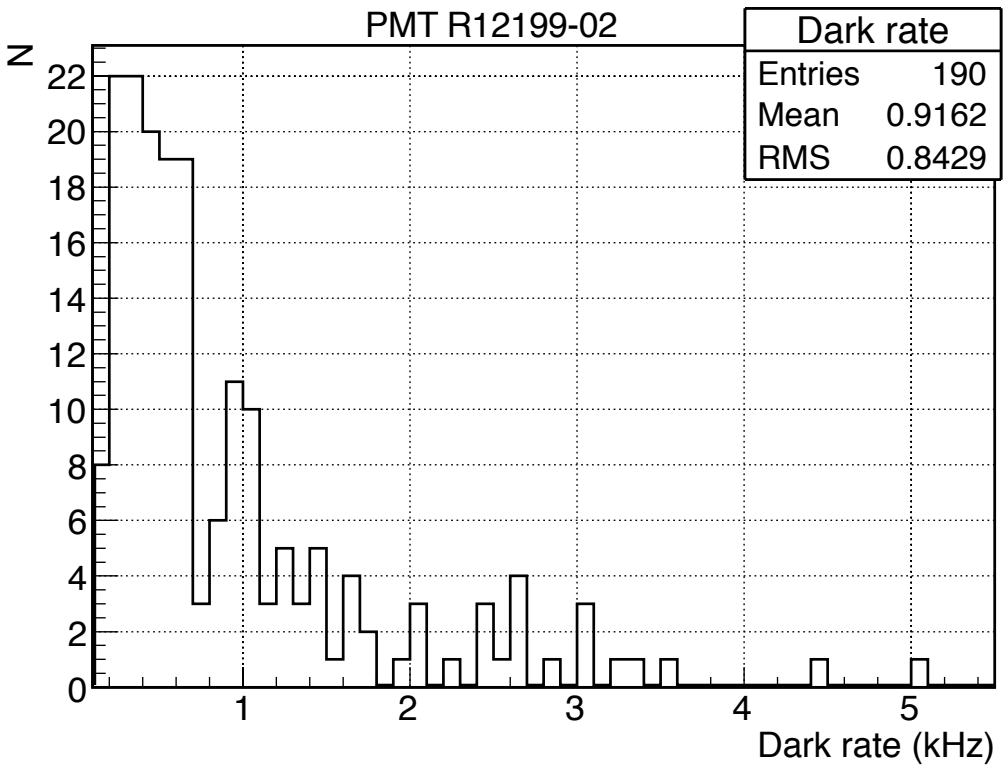
AP	Min [%]	Max [%]	Mean [%]
fraction	2	13	6.3

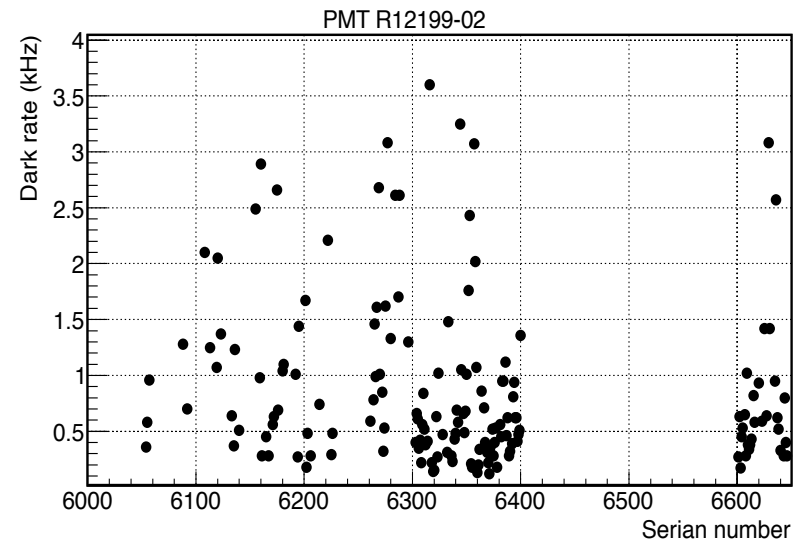
- **Considering that measurements deal with AP1 + AP2, the values meet requirements**

further information in V.Giordano talk

Dark count rate measurements

Measurements conditions: 20 deg, 0.3 pe threshold, at least 12 hours of dark adaption:
Specification: 2000 Hz max. – 1500 Hz typ.





- **82 % meet the requirement**
- **… in future the max value required could be reduced to 1500 Hz**

DC rate	< 1.00 kHz [%]	< 1.25 kHz [%]	< 1.50 kHz [%]	< 2.00 kHz [%]	Mean DC rate [Hz]
	64	73	78	82	916

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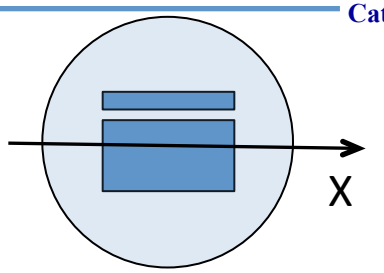
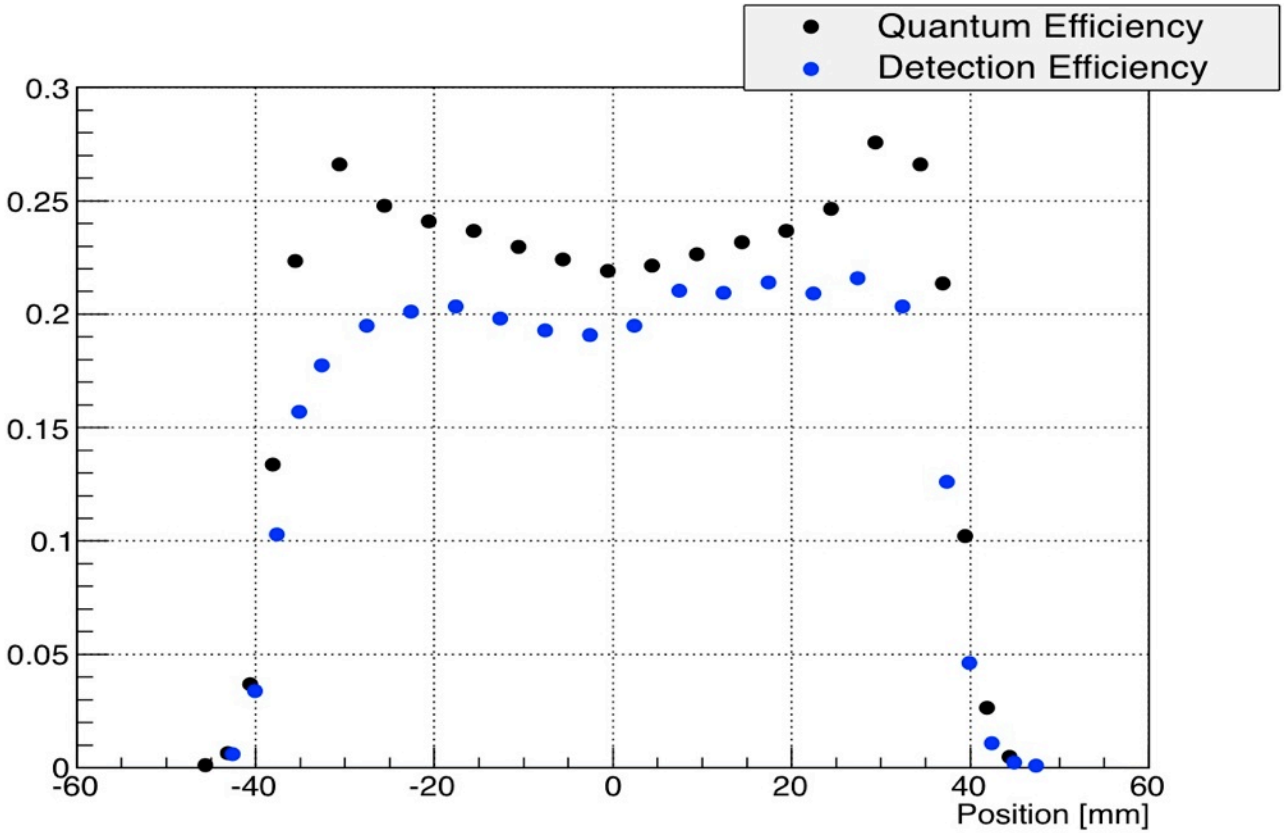
Effective area measurements

QE measurements: monochromator

DE measurements : 470nm fast LED, optical fiber, XY-scanner

Effective diameter ~76mm





Conclusions

200 80-mm diameter Hamamatsu PMTs type R12199-02 were tested in 3 test sites for the KM3NeT project:

- Common test procedures have been defined and validated by cross checks among the three test sites

- Main parameters meet the KM3NeT requirements:

QE, Nominal Voltage, TTS, Delayed and after pulses

- Dark rate distribution has a relatively long tail

(18% above the maximum value of 2kHz)

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