Summary of the PMT measurement campaign with the DarkBox

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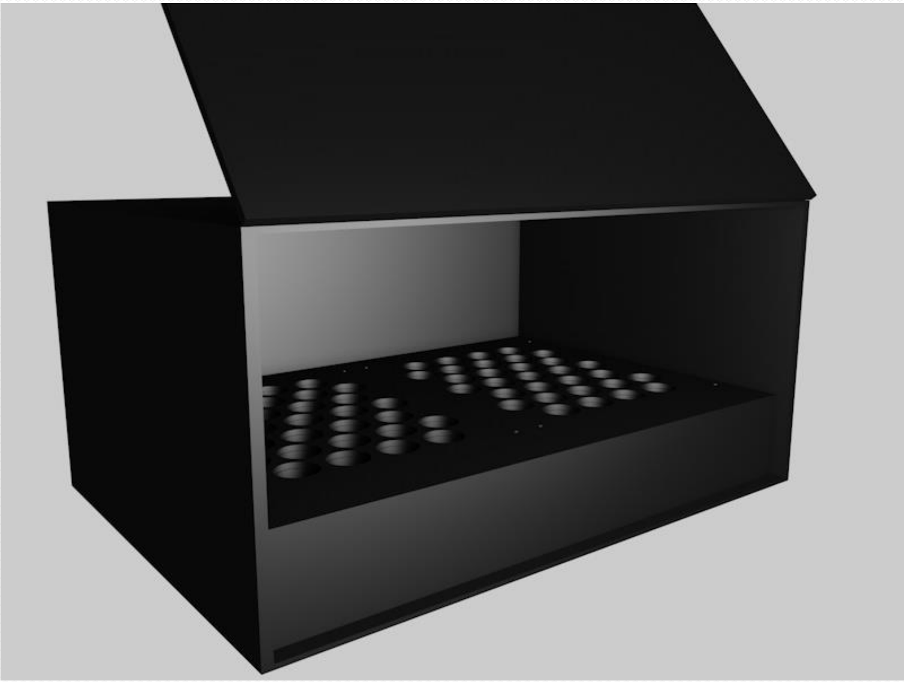
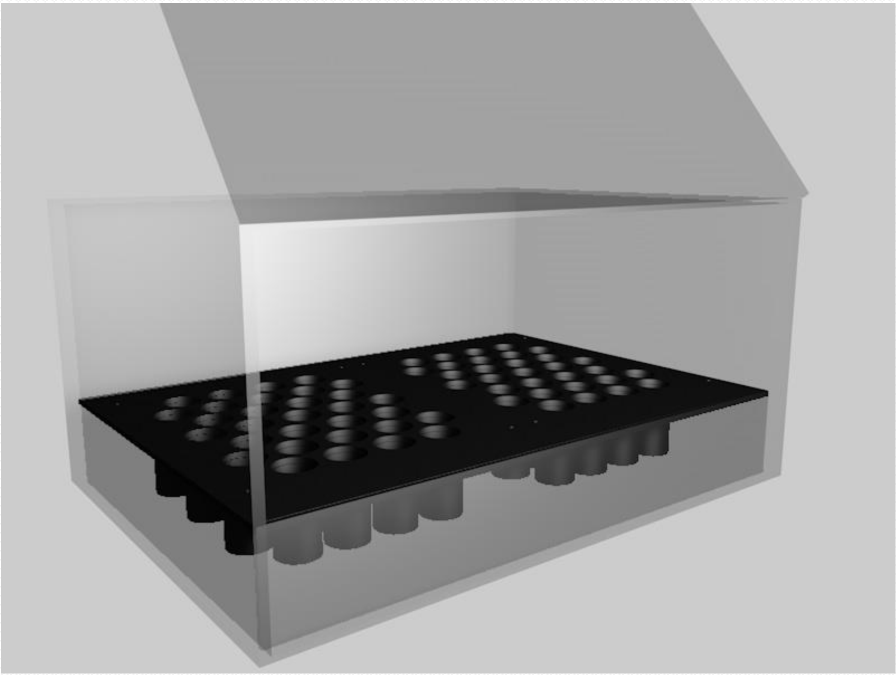
KM3NeT

The DarkBox: a high statistics PMT test facility

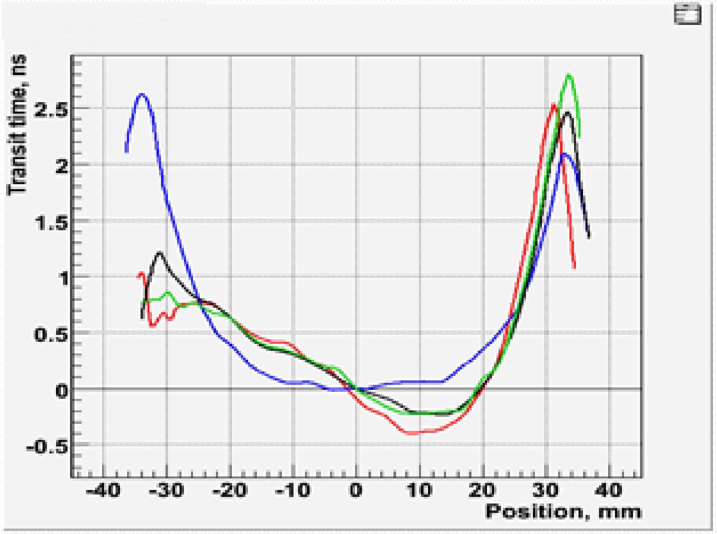
One DOM electronics allows to acquire data from 31 PMTs
Using two synchronized DOM electronics we can test 62 PMTs in parallel.

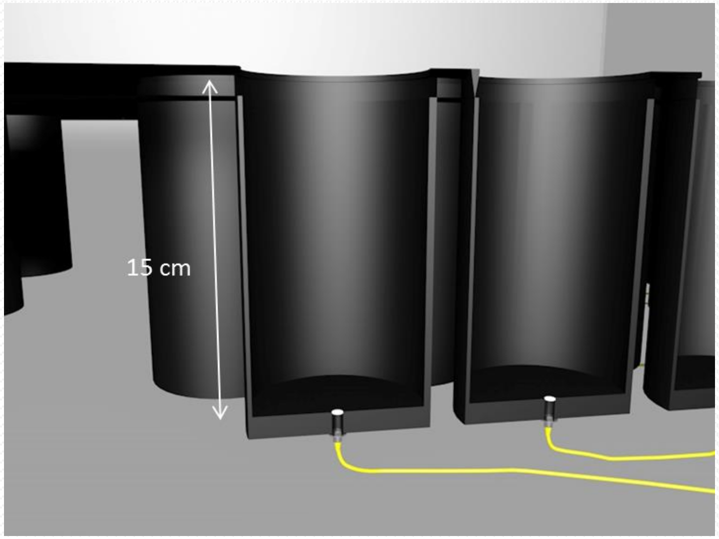


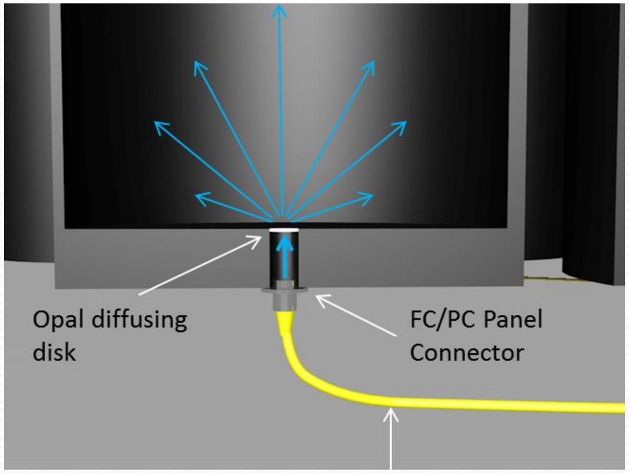


62 dark cylinders:
each PMT is optically isolated
with respect to the others

Optical components

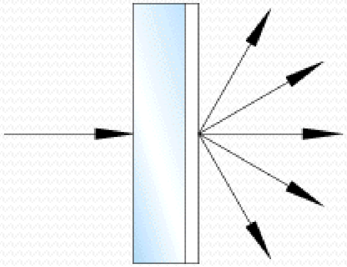


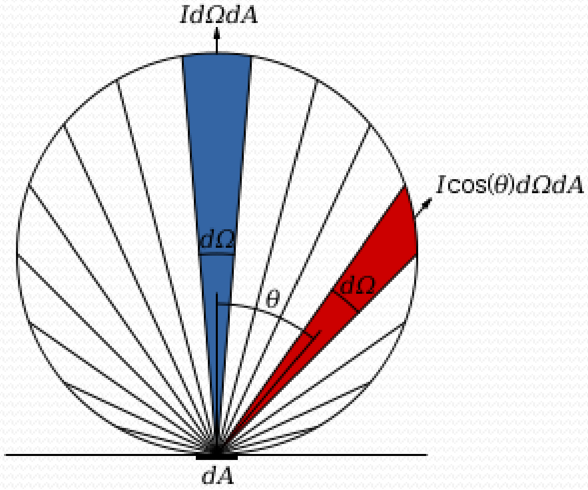




Optical fibre

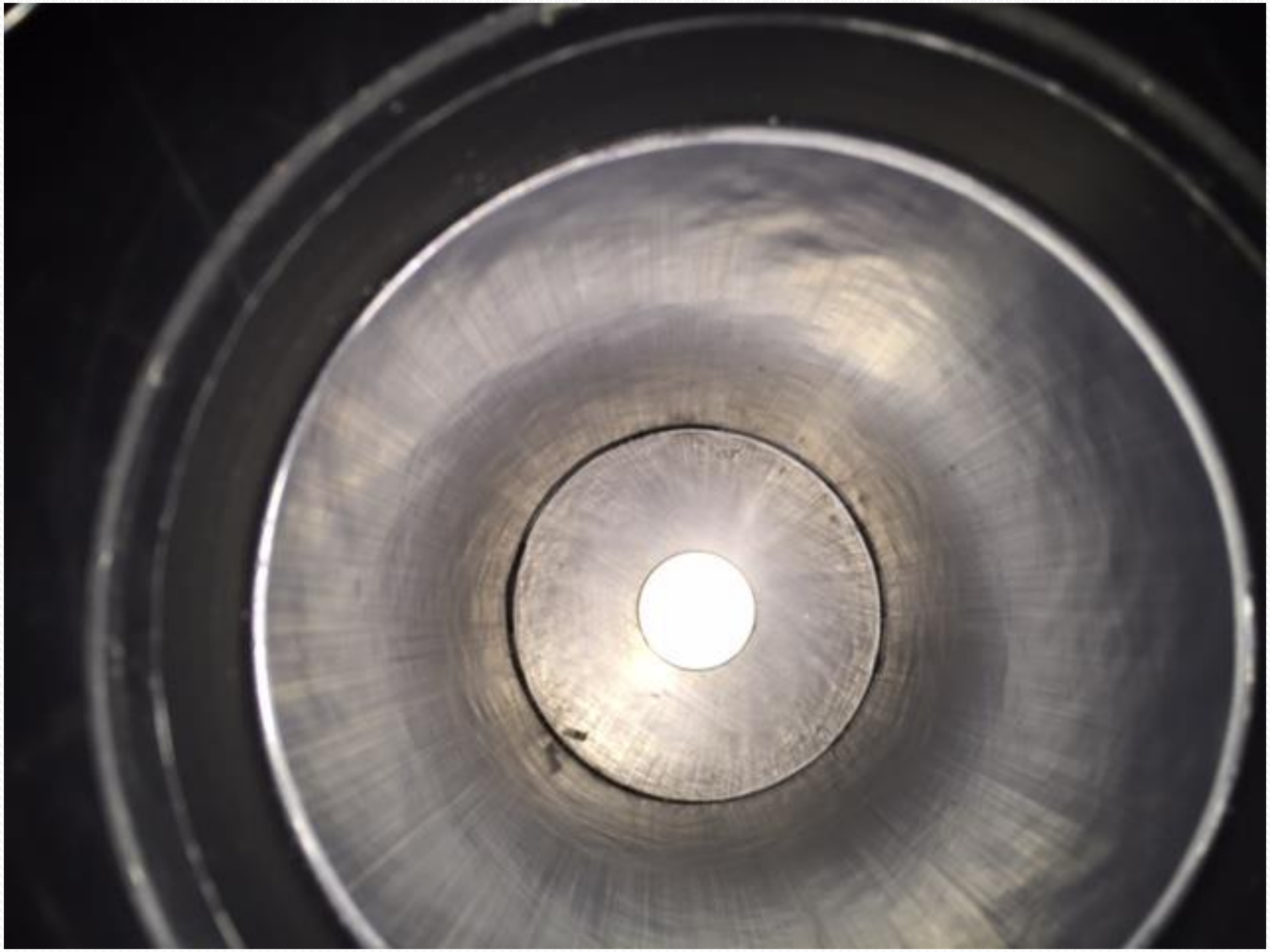
Near Lambertian Distribution





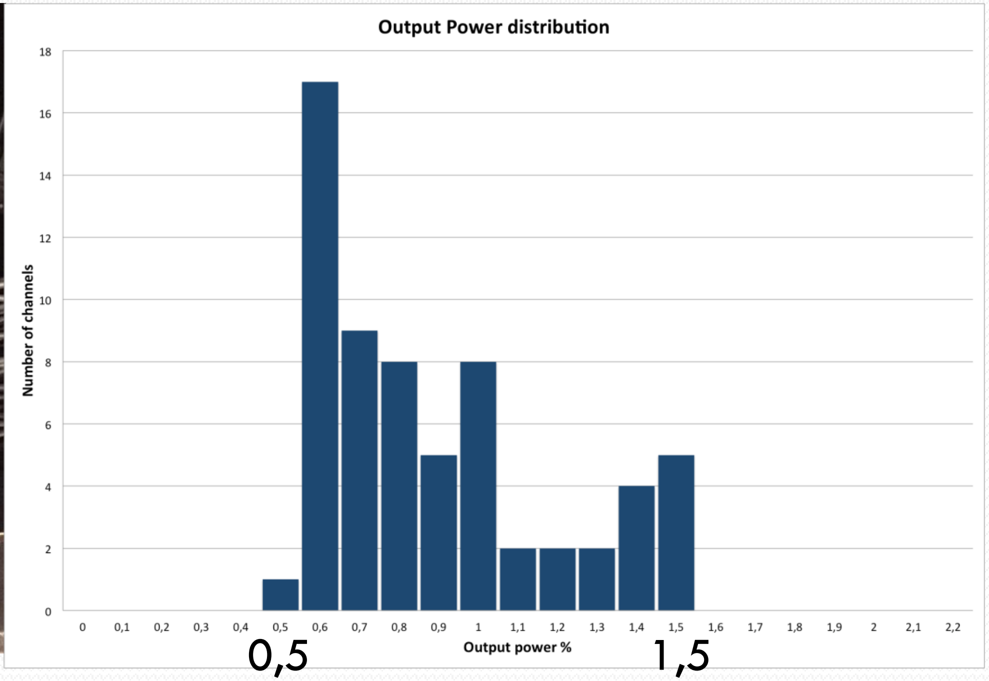
Optical components

The opal diffusing glass discs



Optical components

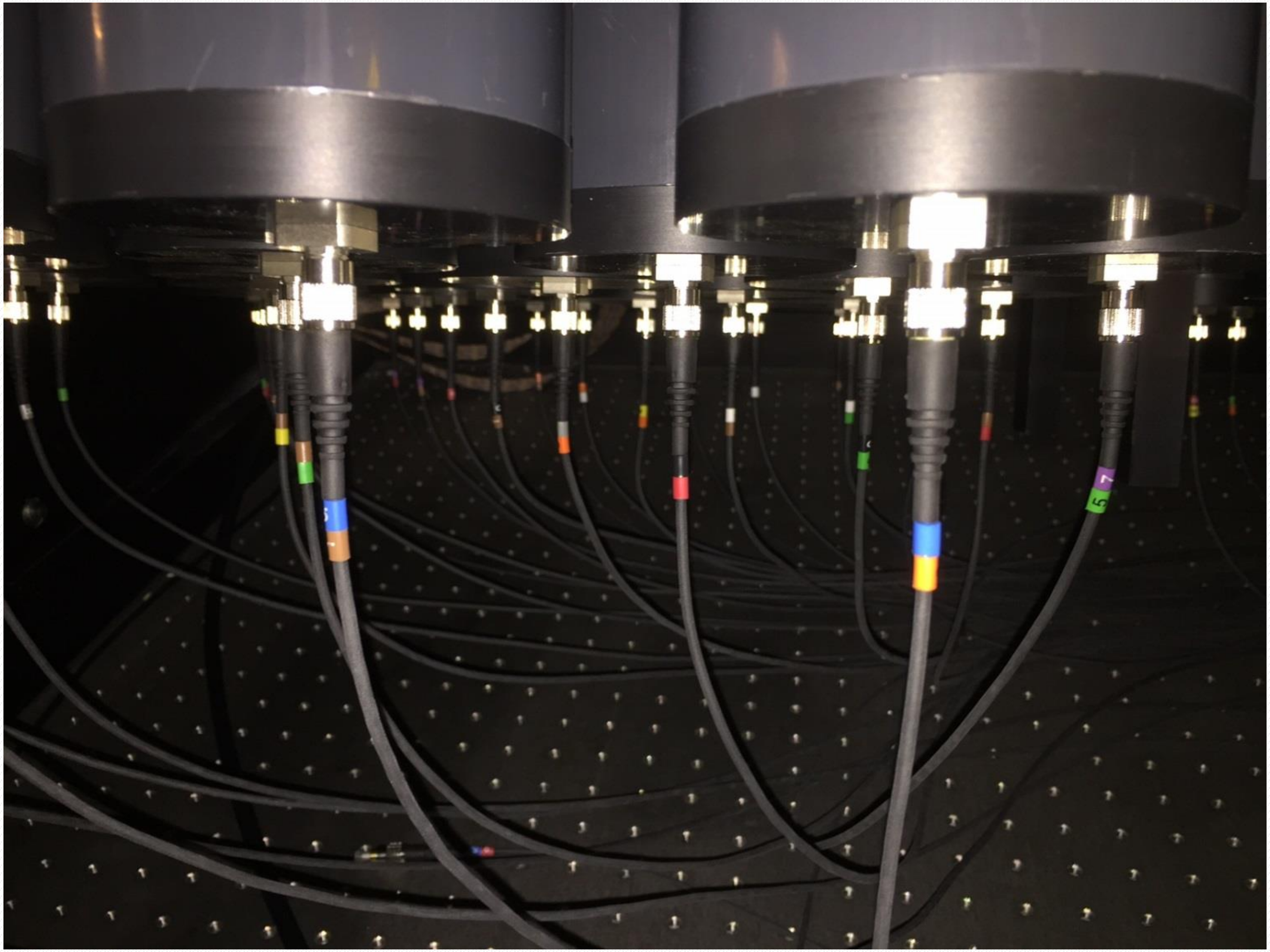
The optical splitter 1 input, 70 outputs



All outputs within 0,50% - 1,50% interval of the input power

Optical components

The optical splitter connected to the dark cylinders

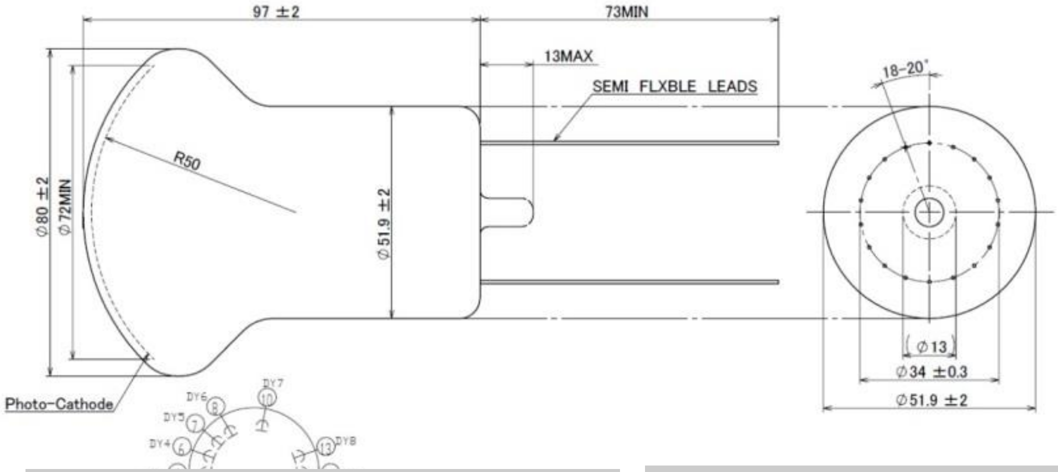


Optical components

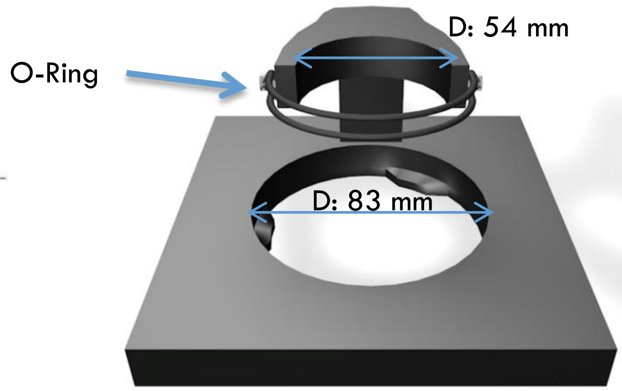
PiLas Mod. EIG2000DX	
Repetition rate (internal trigger)	50 Hz – 1 MHz
Repetition rate (external trigger)	Single shot – 1 MHz
External trigger input	TTL & VAR upt 120 MHz
External trigger pulse width	Typ. ≥ 4 ns
Synchronization output pulse width	typ. ≥ 4 ns for external triggering 50% duty cycle for internal oscillator
Typical jitter between synchronization trigger output and optical signal	typ. ≤ 4 ps
Warm-up time	< 5 minutes
LASER head	Wavelength 405 +/- 10 nm, spectral width < 7 nm, pulse width (FWHM) typ < 45 ps

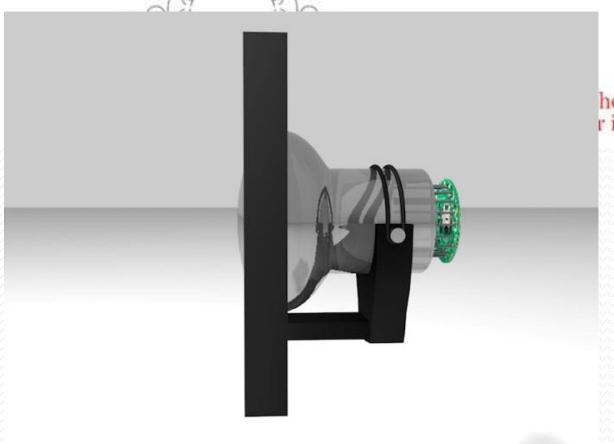
Mechanics

PMT Hamamatsu

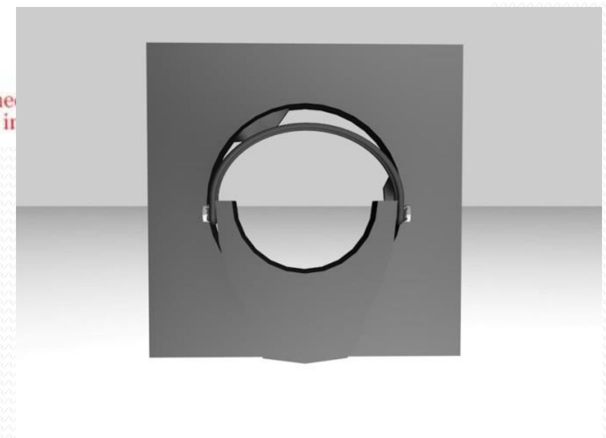


PMT holder unit

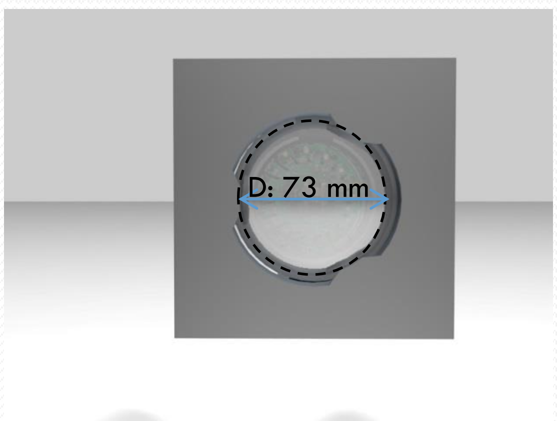




lateral



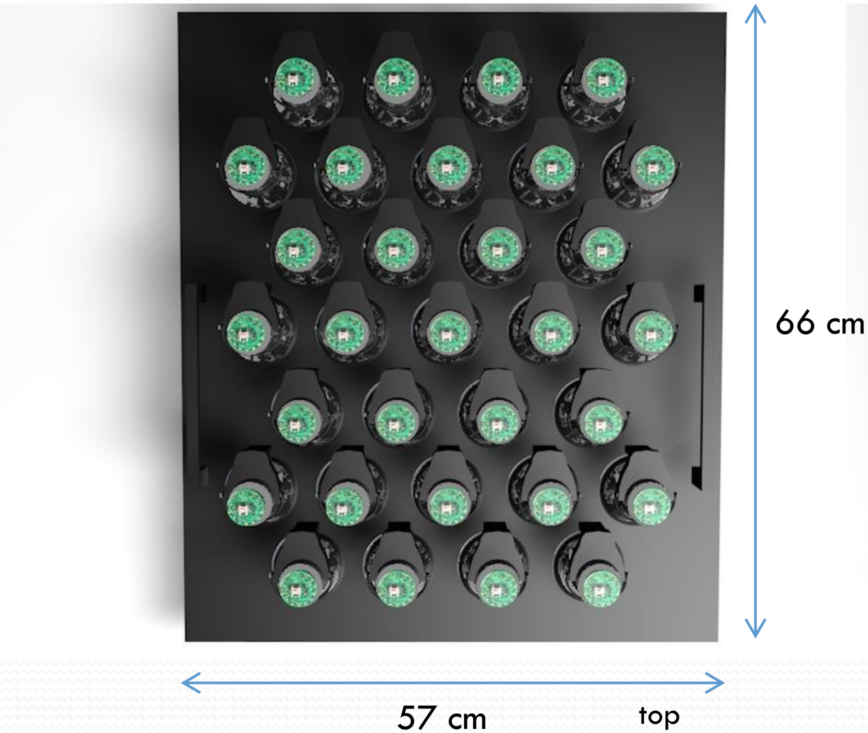
back



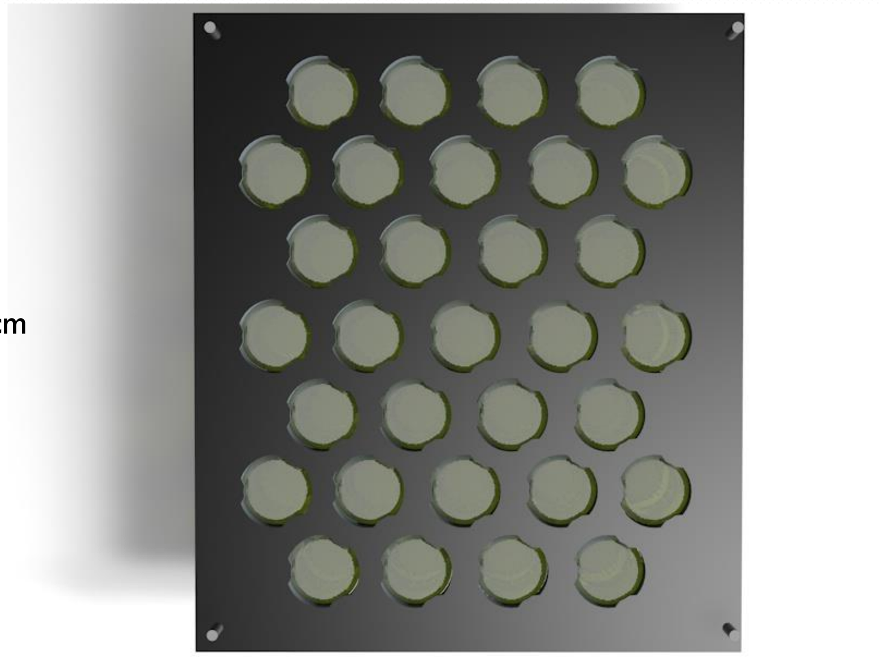
front

Mechanics

Two trays of 31 PMTs each



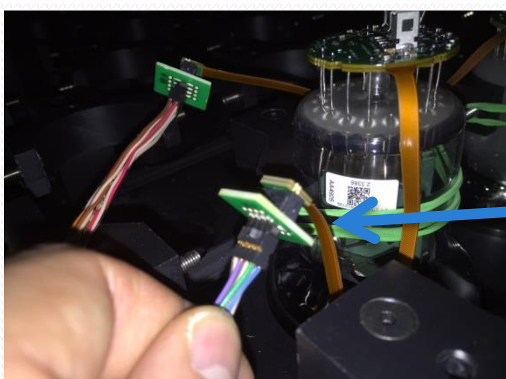
top



bottom

Electronics

PMT tray equipped with cable extensions from Bari (Thanks to Marco Circella)

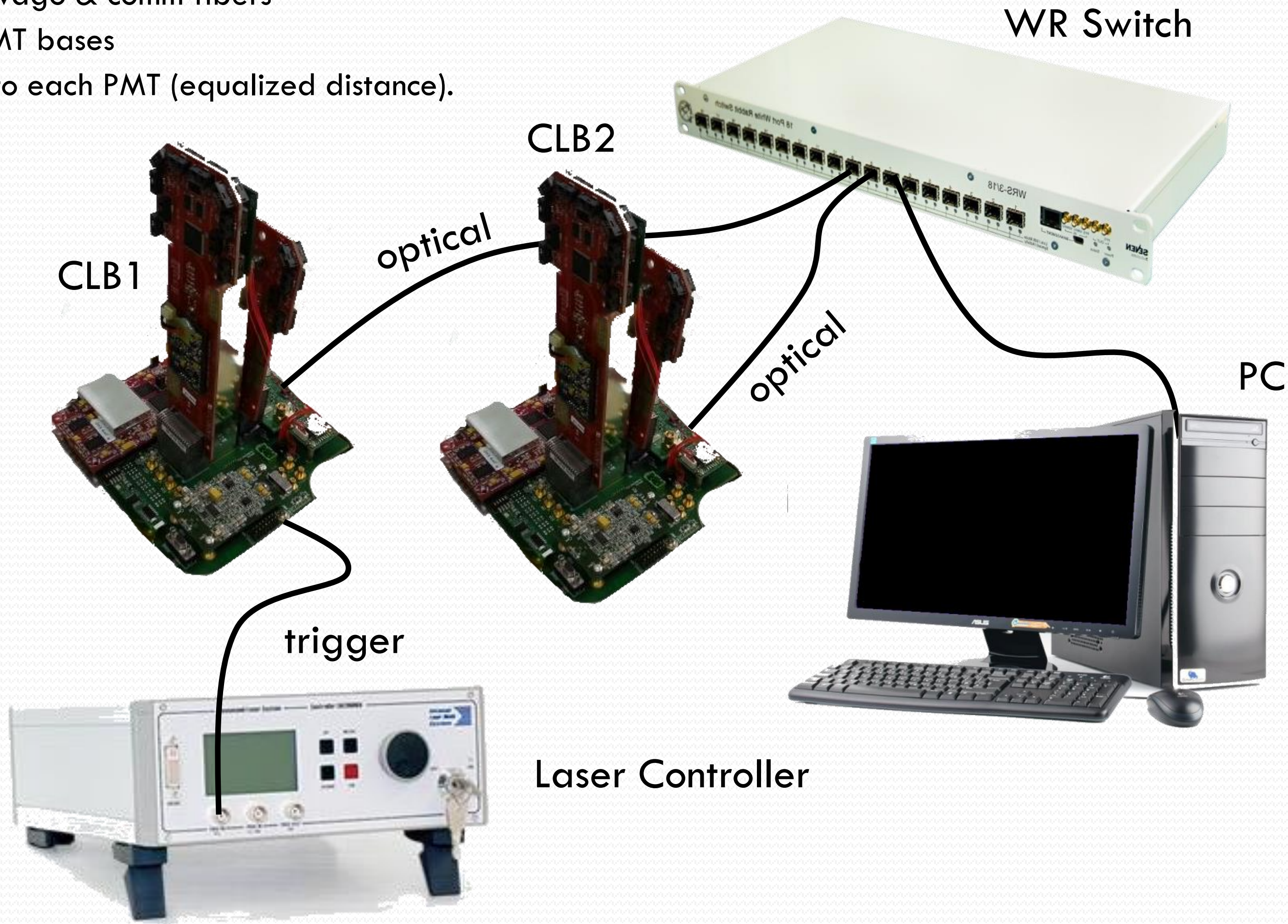


Removable connectors
For fast replacing

Electronics

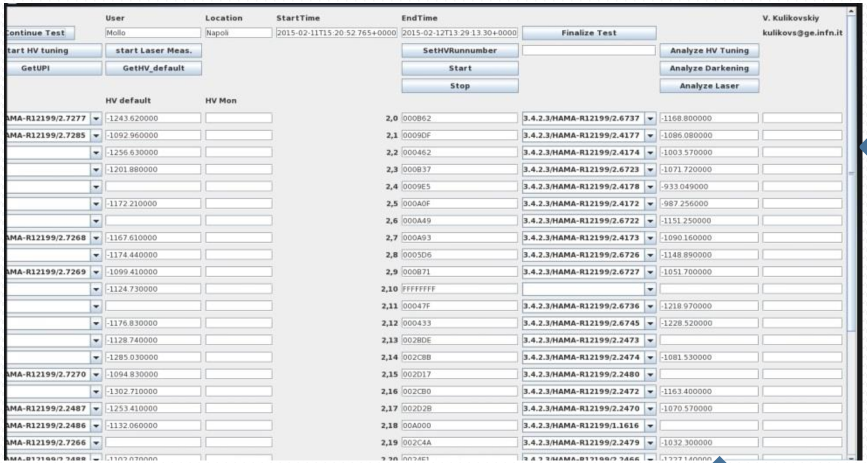
Electronics

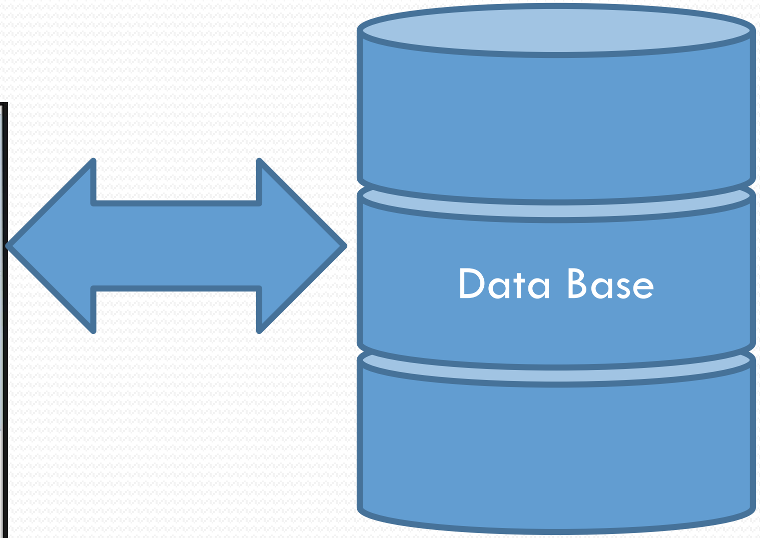
- "CLB I" with PPS signal modified (output is LEMO, signal is 20 KHz trigger, synchronized with PPS). V2.2
- "CLB II" V2.2 no modifications
- Laser Pilas Advanced Laser diodes
- White rabbit switch, SFP avago & comm fibers
- Extended cables for the PMT bases
- Calibrated Optical fibers to each PMT (equalized distance).



Software

Dark Box Control by V. Kulikovskiy





Detector Manager by C. Bozza

Dark Box Setup

- "CLB I" with PPS signal modified (output is LEMO, signal is 20 KHz trigger, synchronized with PPS). V2.2
- "CLB II" V2.2 no modifications
- Laser Pilas Advanced Laser diodes
- White rabbit switch, SFP and comm fibers
- Extended cables for the PMT bases
- Calibrated Optical fibers to each PMT (equalized distance).

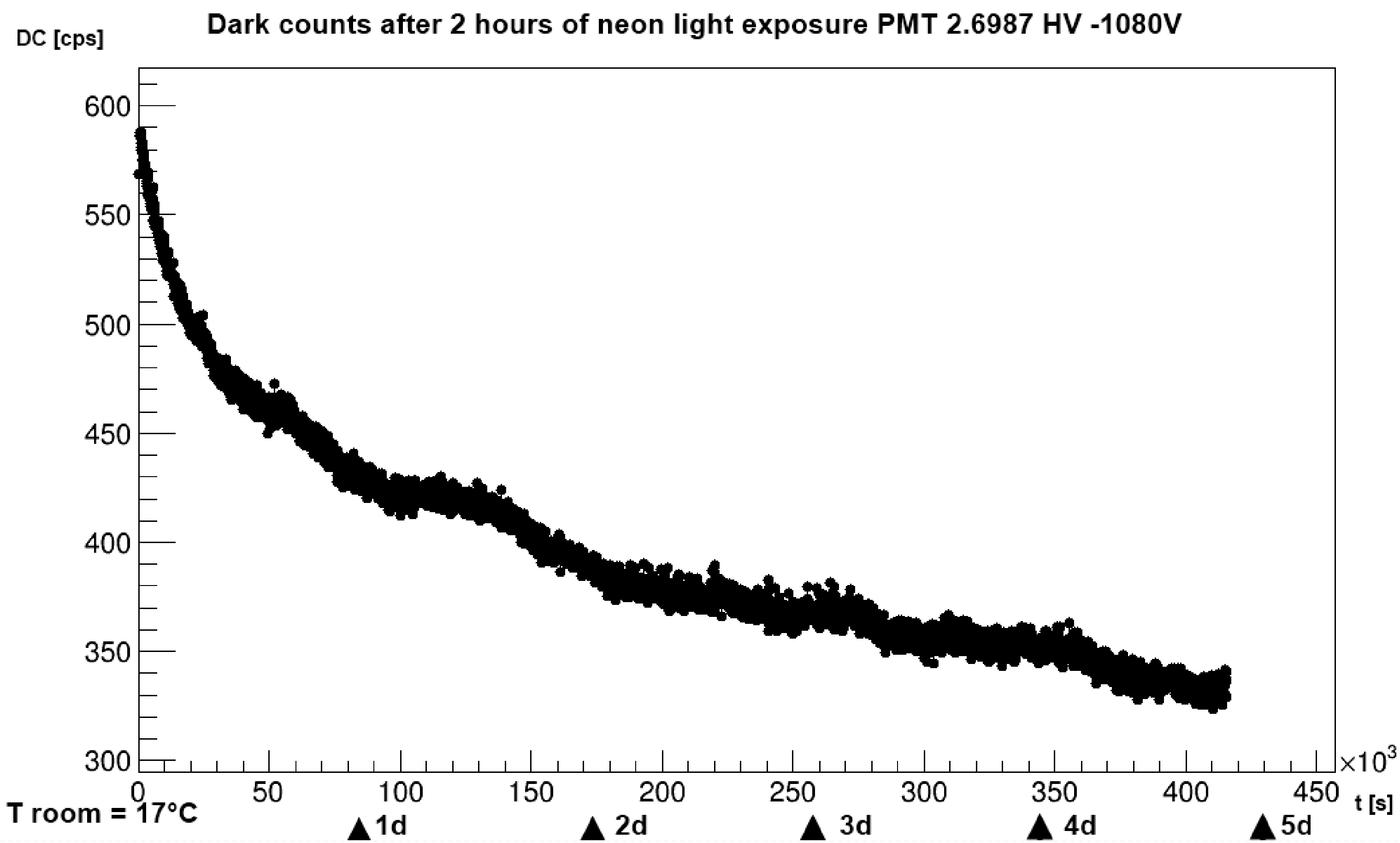
Pre-darkening

A test in order to verify the effect of the neon lights on the PMTs dark counts (DC) and to measure the recovery time needed was performed. We measured the dark rate of six PMTs (previously tested with the DarkBox) after weeks of darkening within the shipping box. After the measurements we moved the PMTs in a laboratory illuminated with fluorescent tube lights for two hours then, we moved the PMTs again in the dark box. After one hour of darkening with PMTs switched off we started the DC measurement.
The time needed in order to reach the initial values of dark counts is approx. a week.

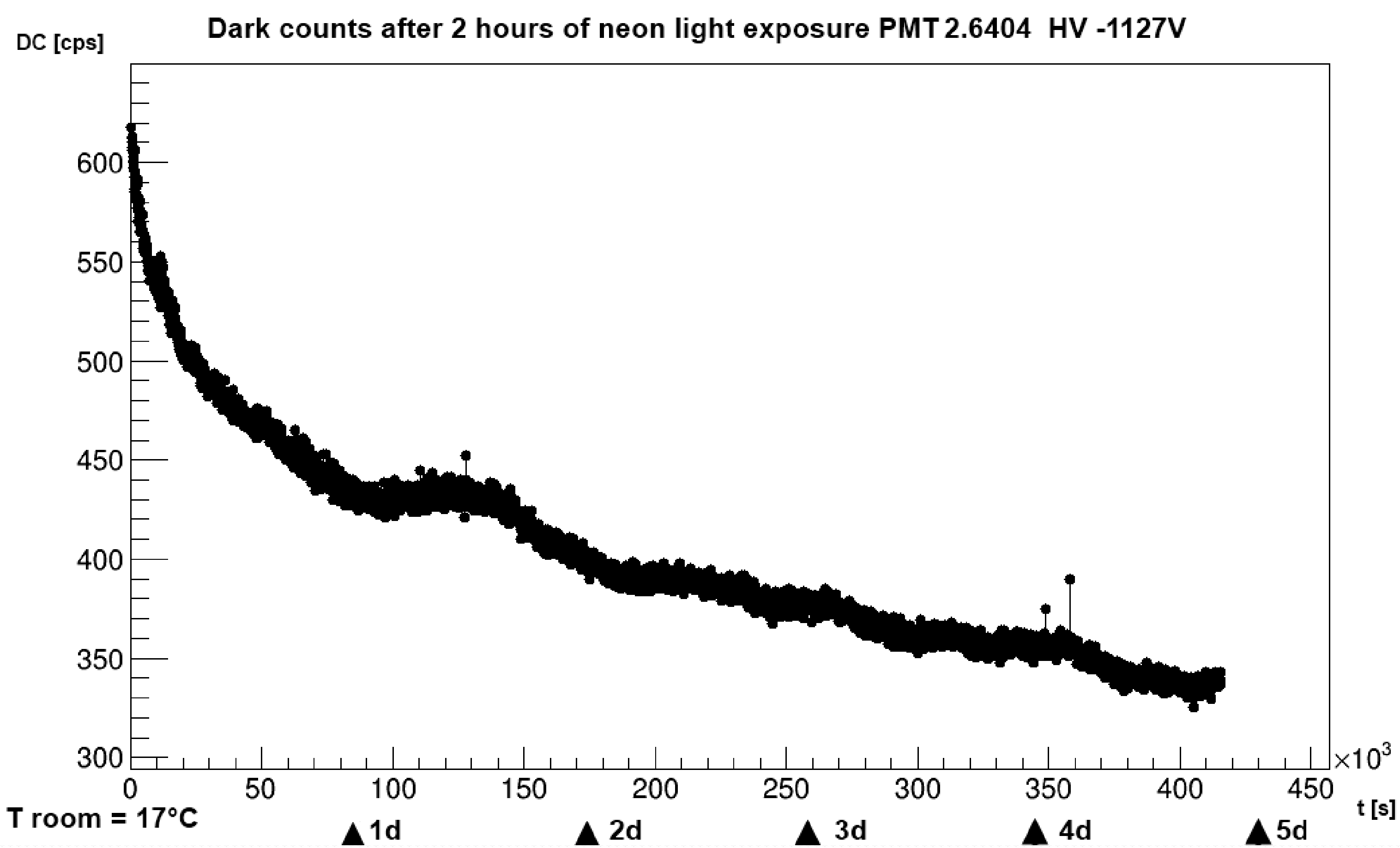
PROMIS ID	UPI	DC before light exposure [cps]	DC after one week from light exposure [cps]
002DFA	2.6972	420	385
000542	2.6987	295	341
002F38	2.6411	388	381
002EA4	2.7756	310	325
0030AC	2.6404	321	337
002F5A	2.6412	368	334

Elog entry: Qualification 547

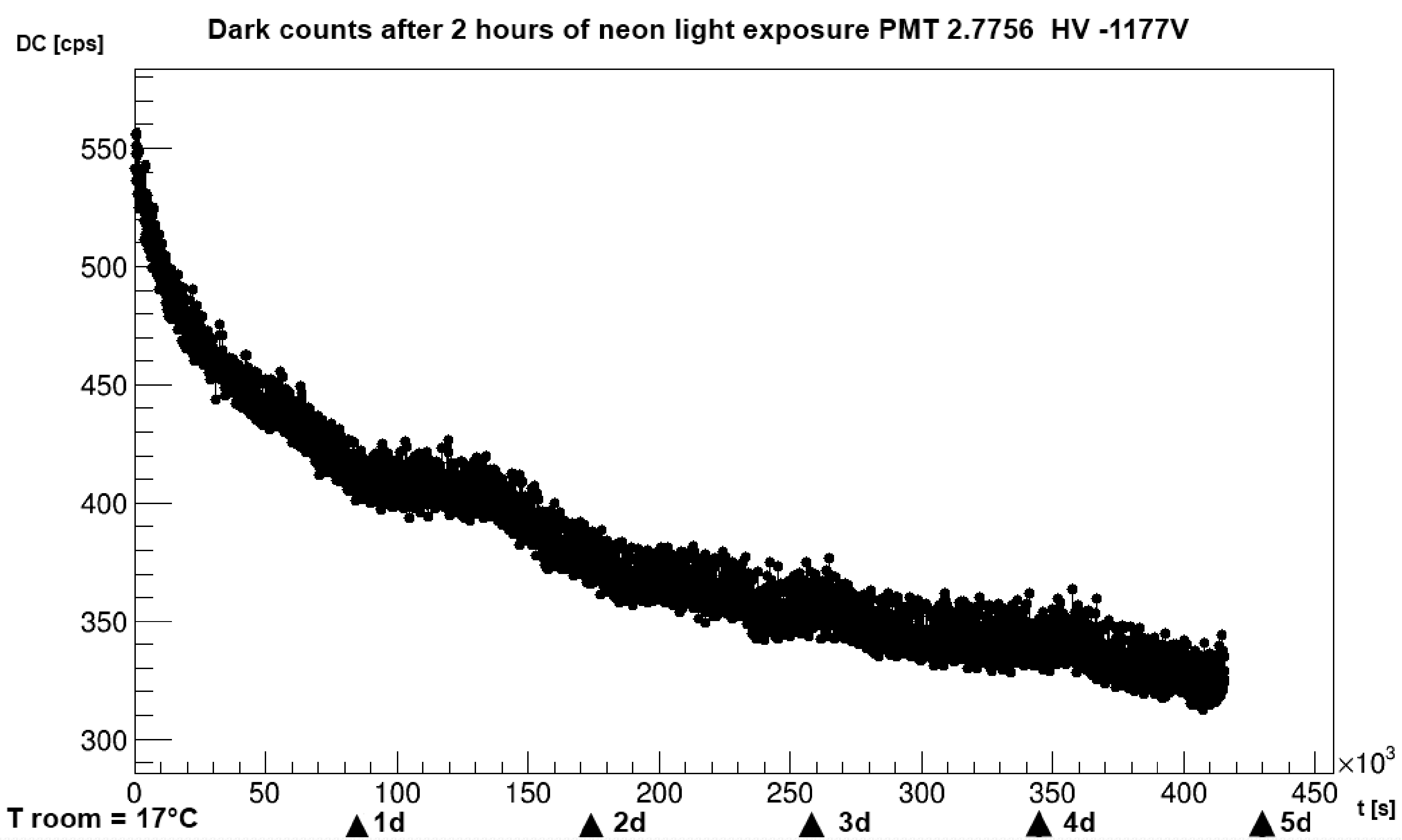
Plot show only the last 5 days



Plot show only the last 5 days



Plot show only the last 5 days



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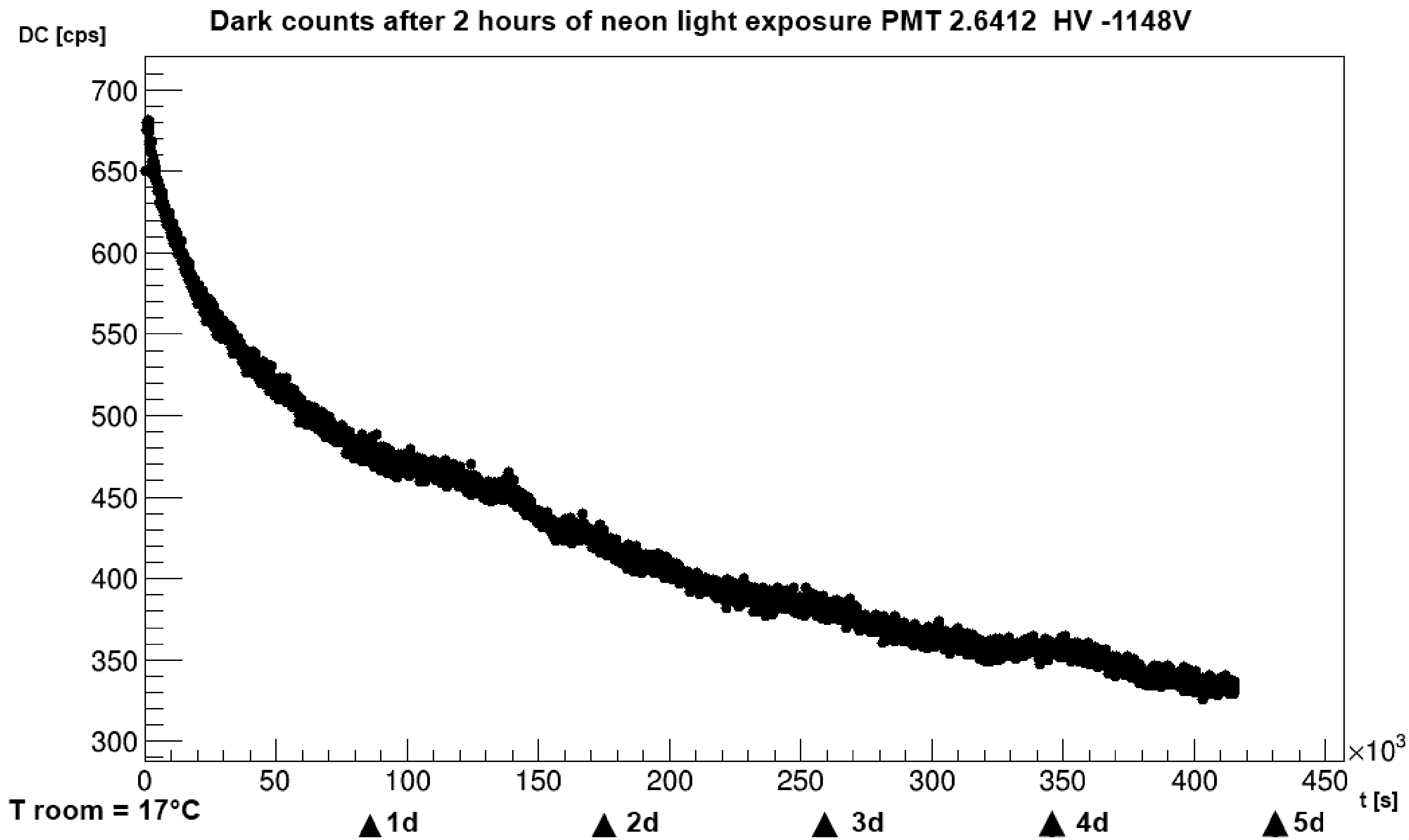
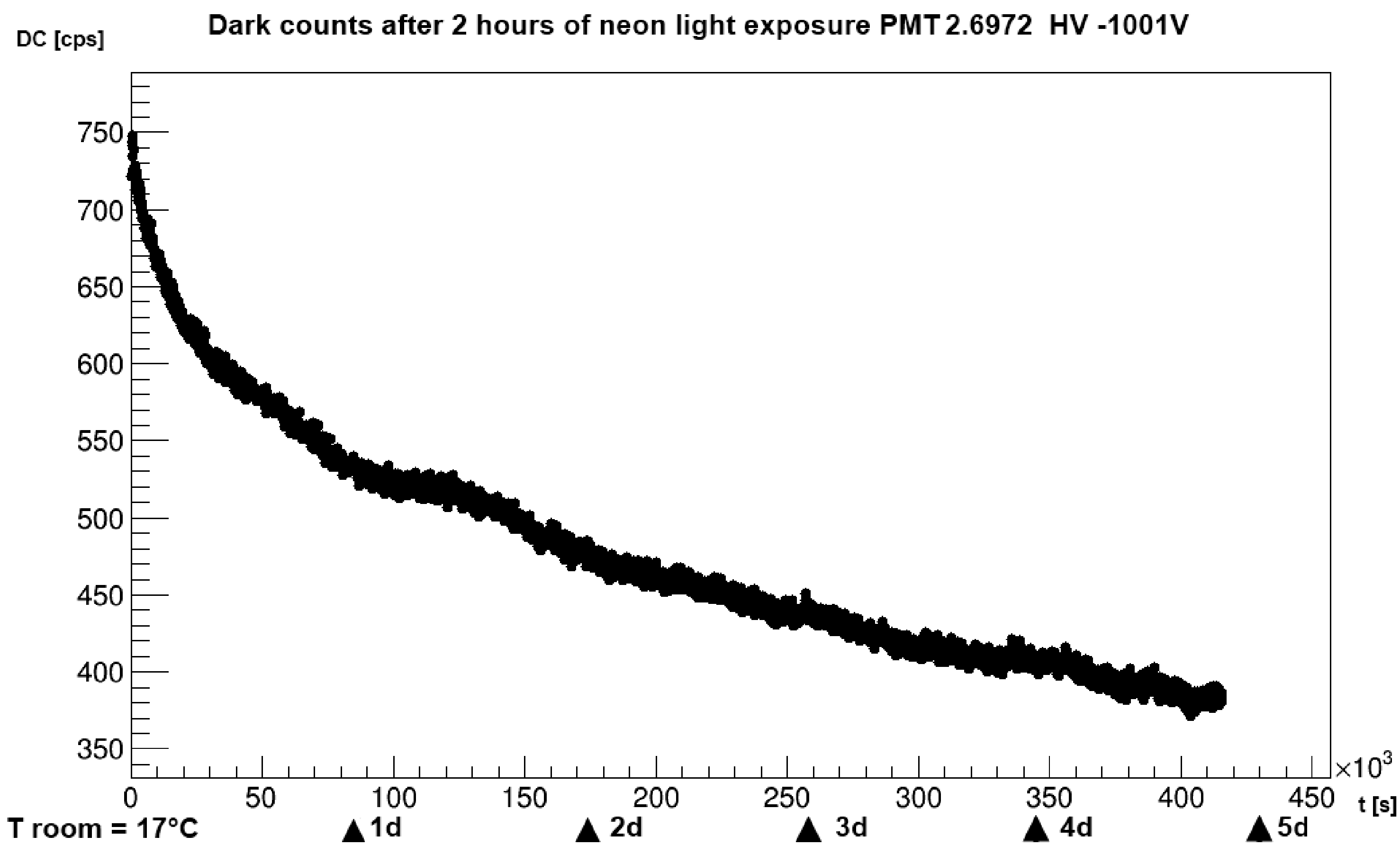
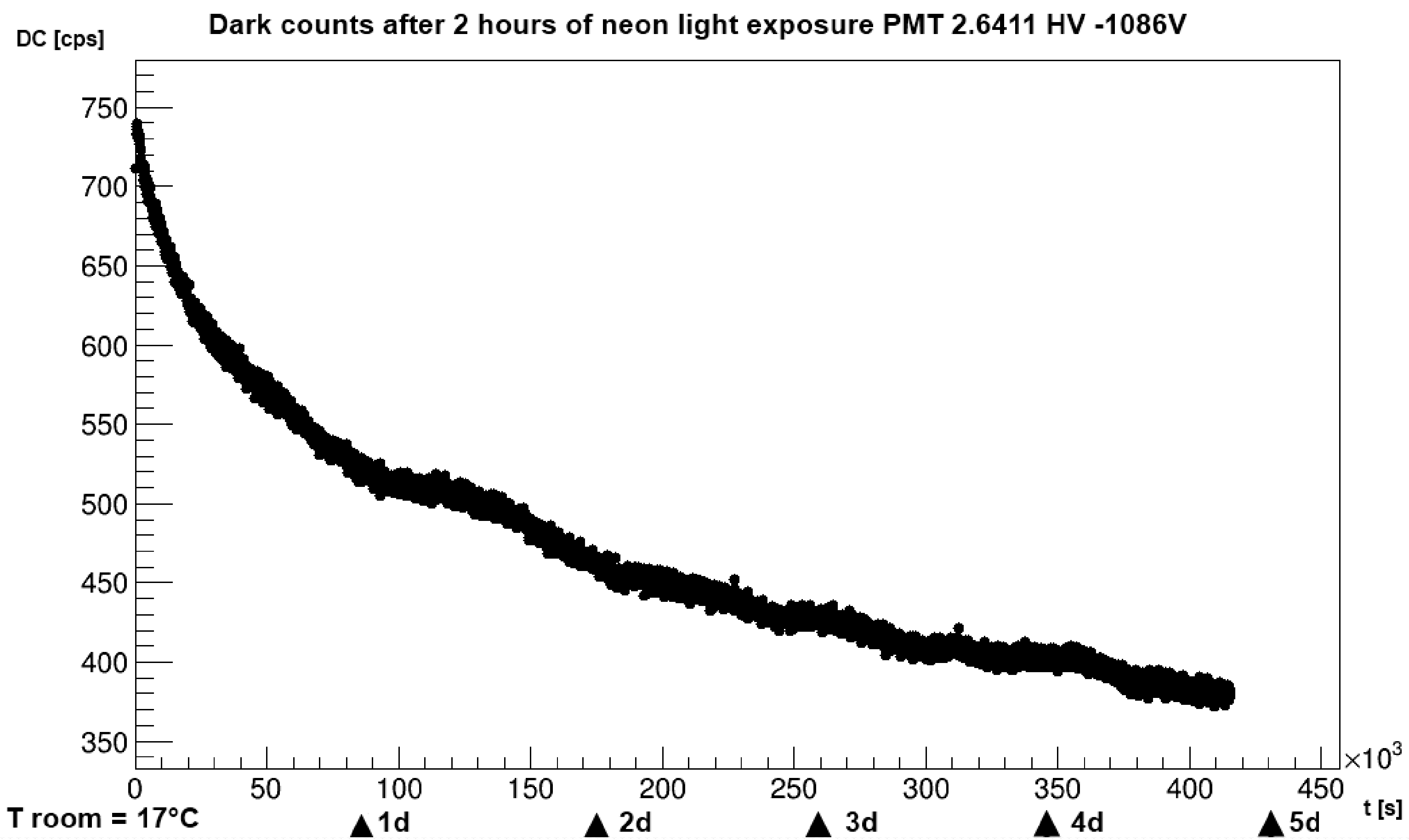


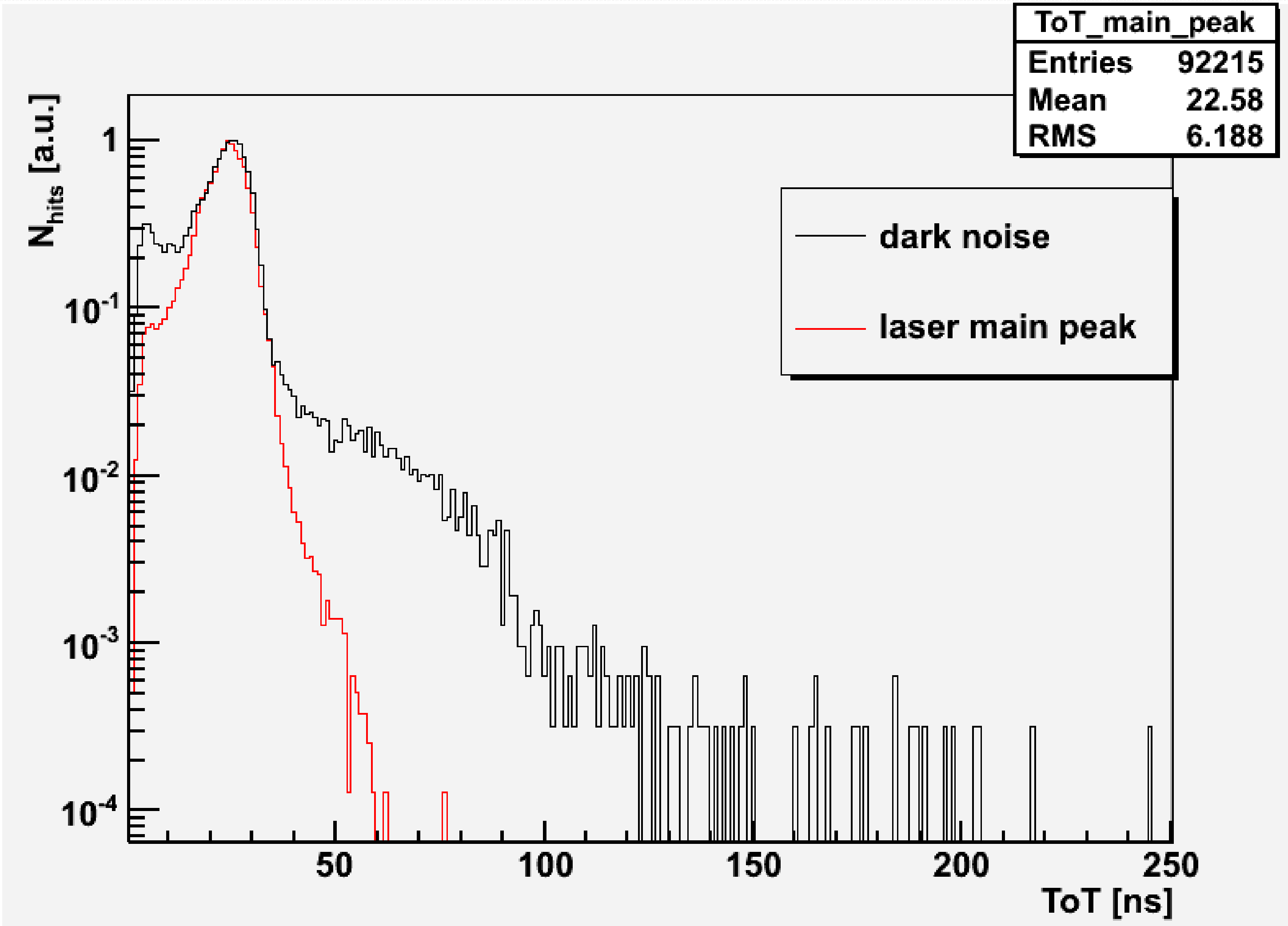
Plot show only the last 5 days



Plot show only the last 5 days

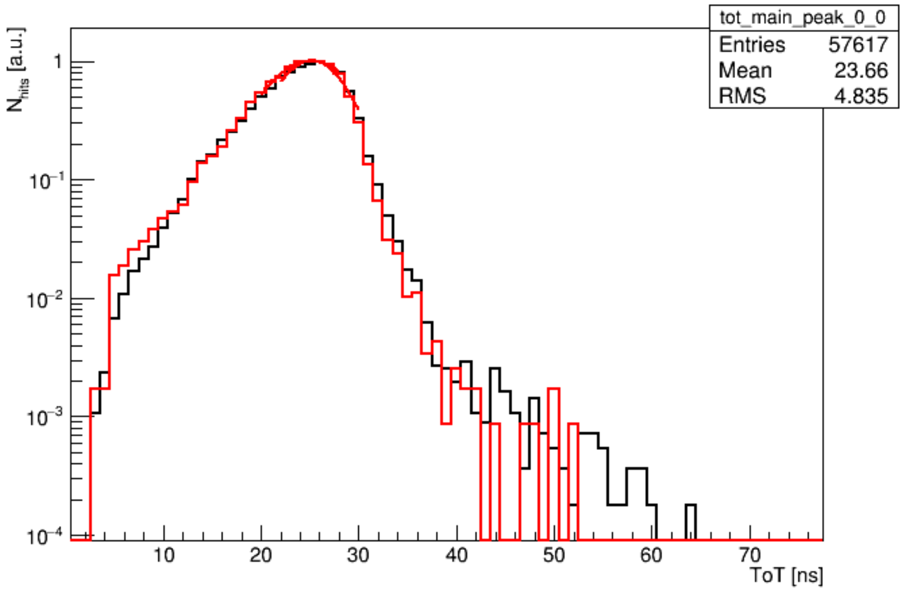


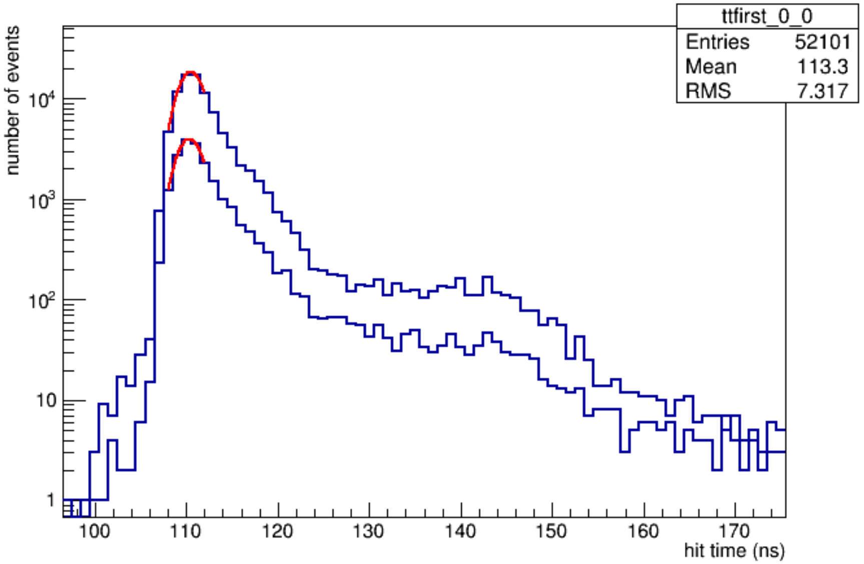
DarkBox Calibration



DarkBox Calibration

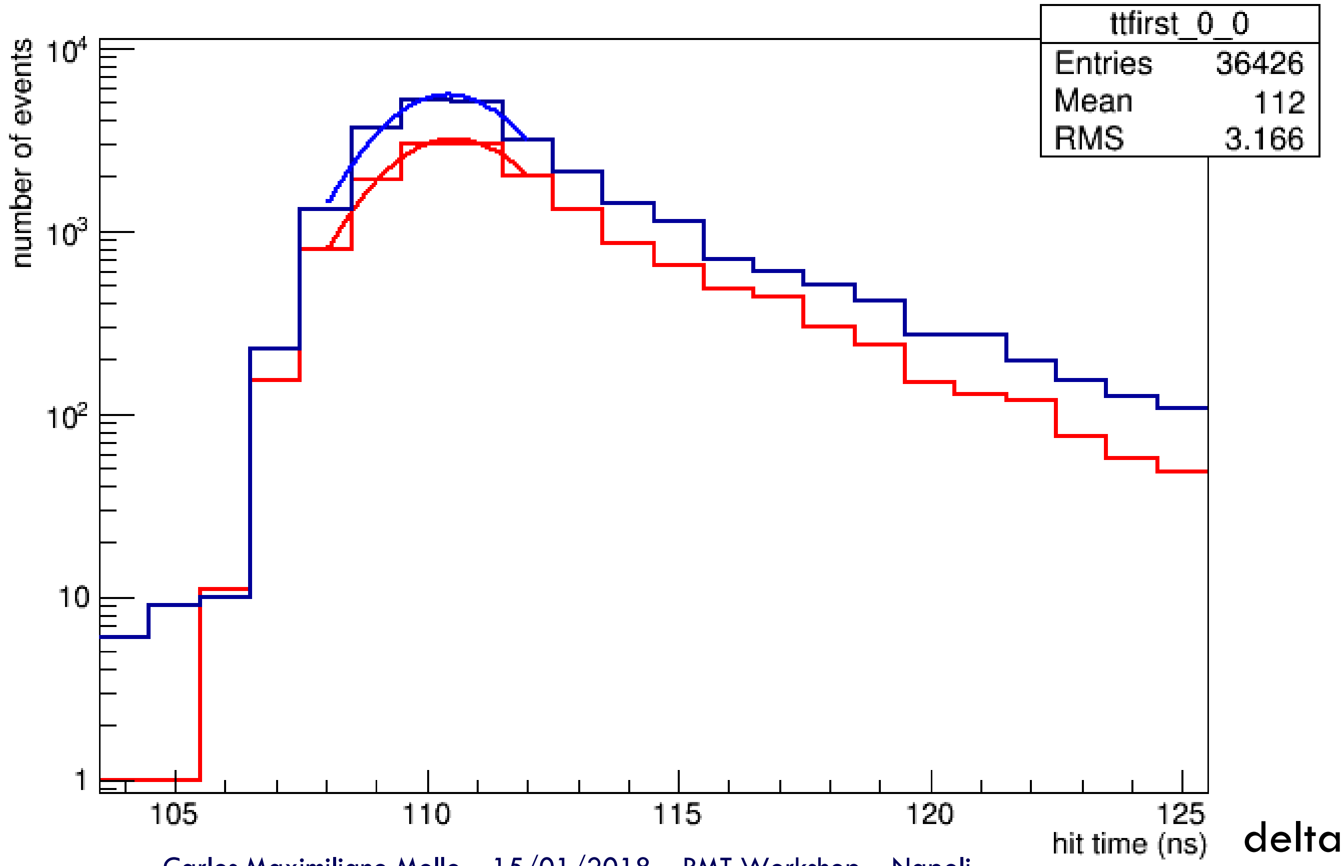
- 1 CLB drives laser, and reads PMTs
- The same channel evening/morning next day
- Laser + PMT to the same CLB
- delta T ~130+-25 ps difference between the same measurements





DarkBox Calibration 2 CLBs + WRS syncro

- CLB drives Laser and detects light with PMT at channel 0
- One CLB drives Laser, second one detects light with PMT at channel 0
- Hit time peak value difference is 120+-35 ps (from fit)

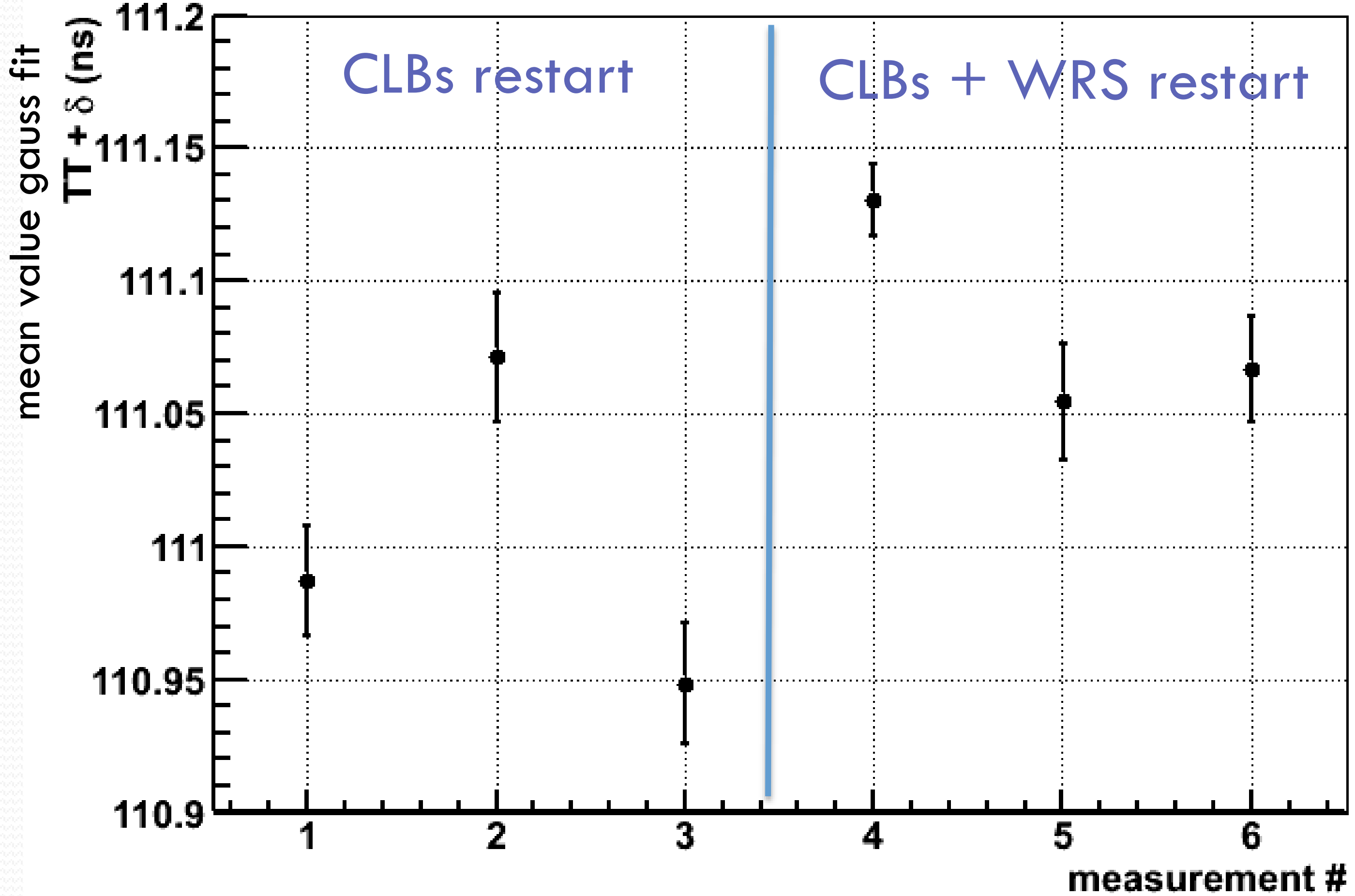


delta t(ns)

DarkBox Calibration

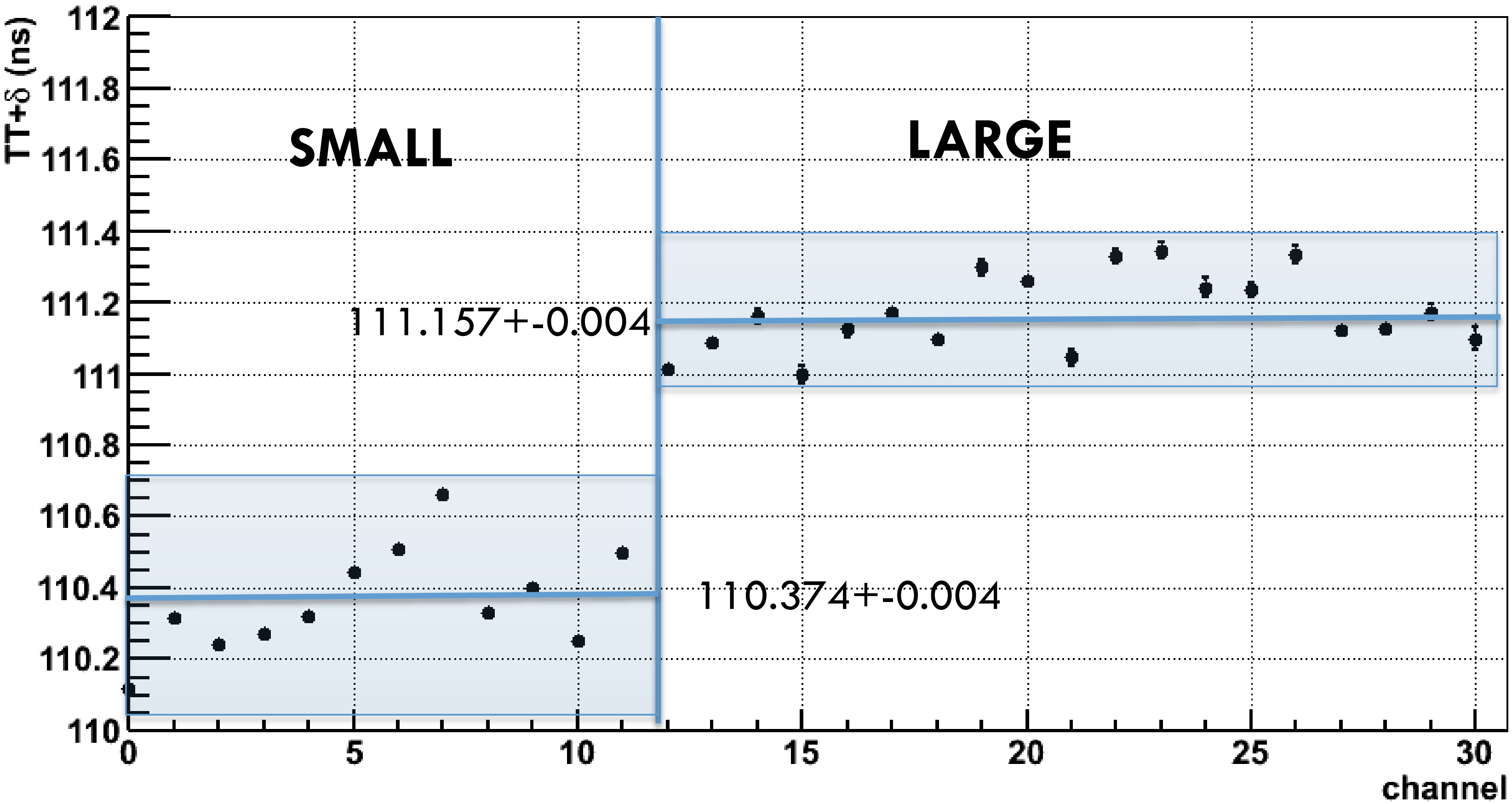
- Fixed latency:

  CLB I drivers Laser, CLB II reads PMT (ch 28)



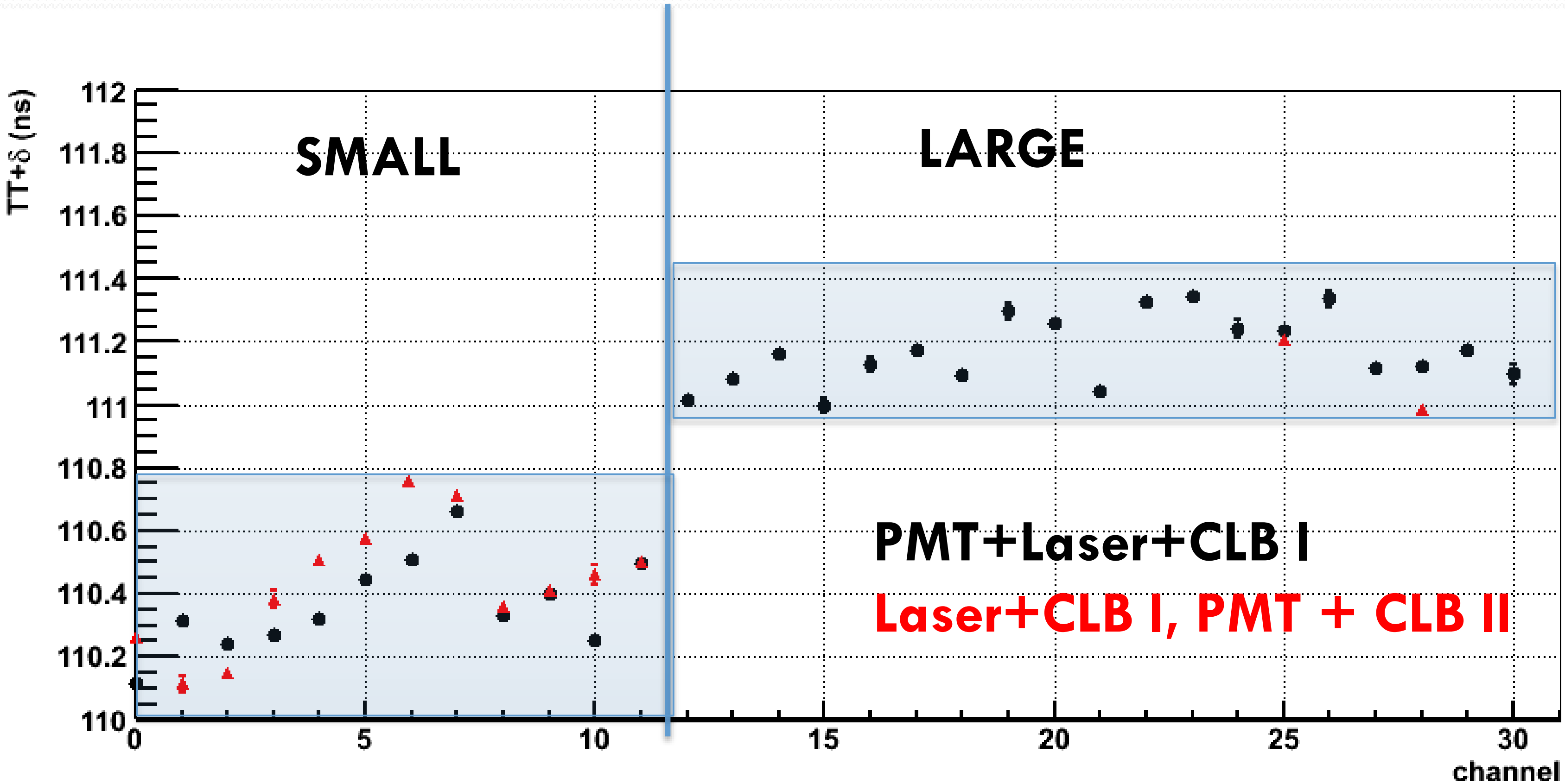
DarkBox Calibration

- delta T for all Octopus channels (same PMT and setup)
- Large-Small mean difference is 780 ps
- Max difference 1.4 ns



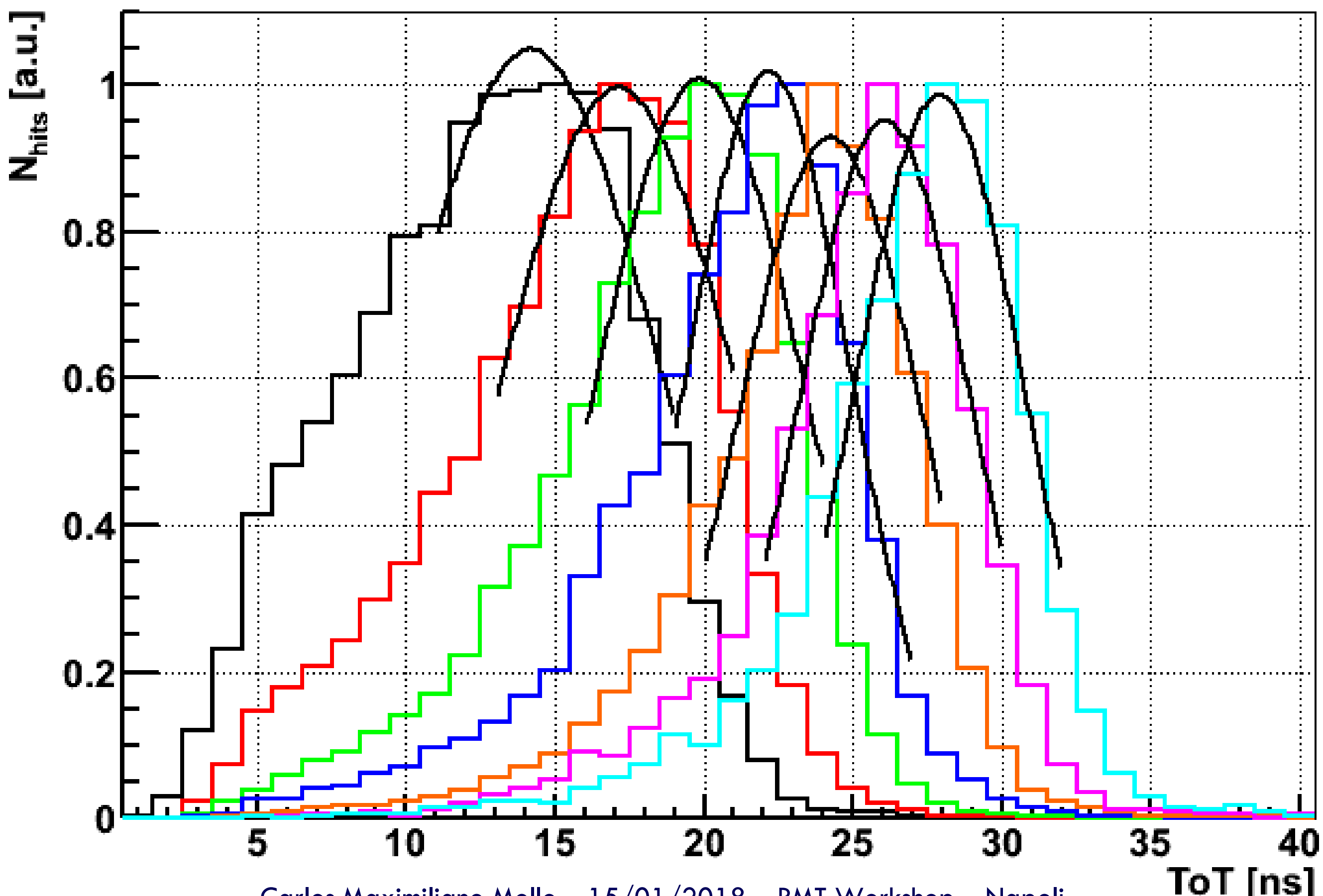
DarkBox Calibration

- Added measurements with other CLB + other octopuses (no laser attached to it)
- Scope – test CLB + Octopus channels
- The difference in delta t are smaller than 200 ps



HV tuning

- Hamamatsu provides the Nominal High Voltage obtained in Current mode operation. KM3Net works in pulsed mode.
- Tune HV : TOT 26.4 (reference by Oleg K. – average value og 600 PMT)
- Scan HV from Hamamatsu NHV -100 V; +50 V with a step 25 V
- Base Threshold 1095 mV (2F) → 0.3 p.e.



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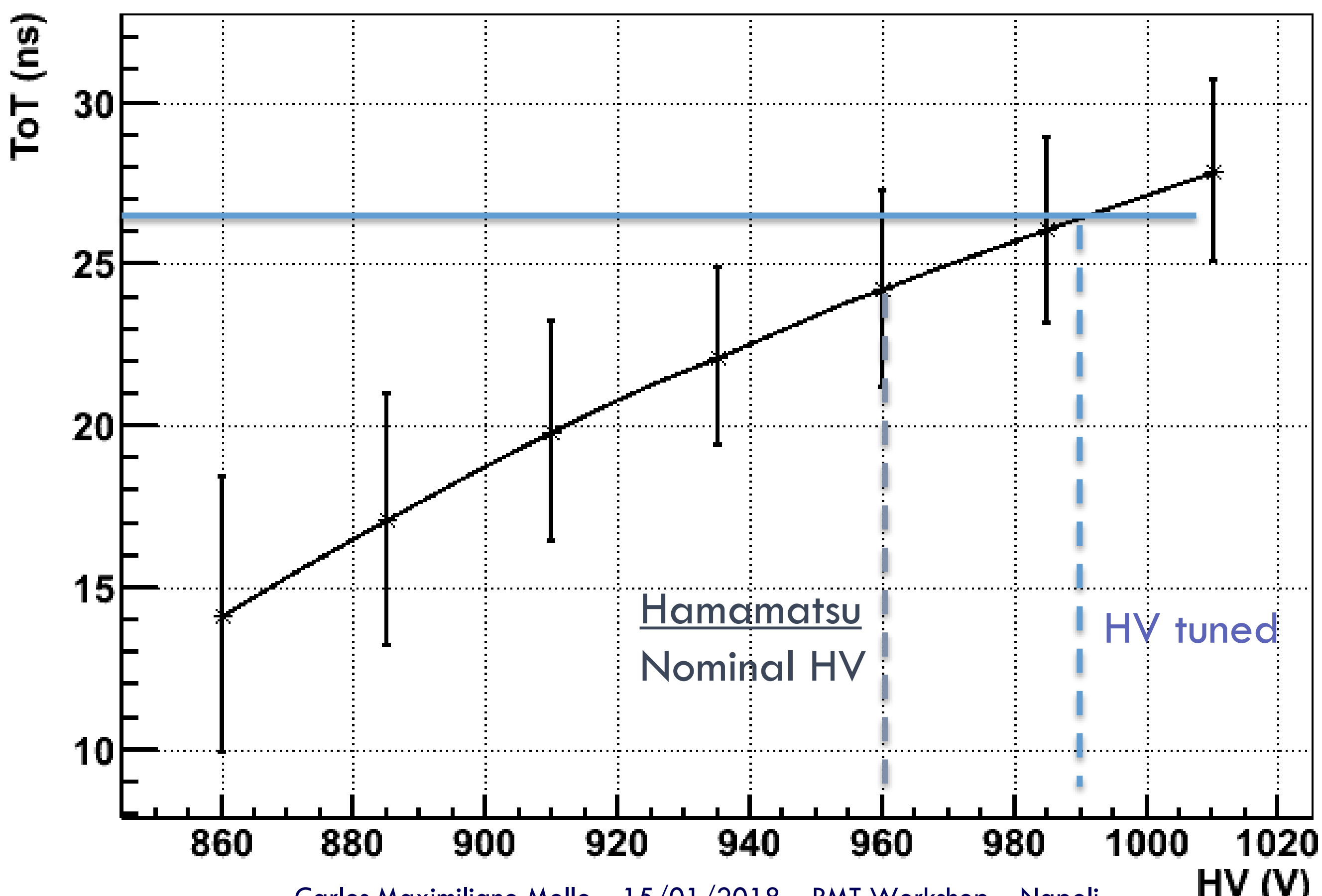
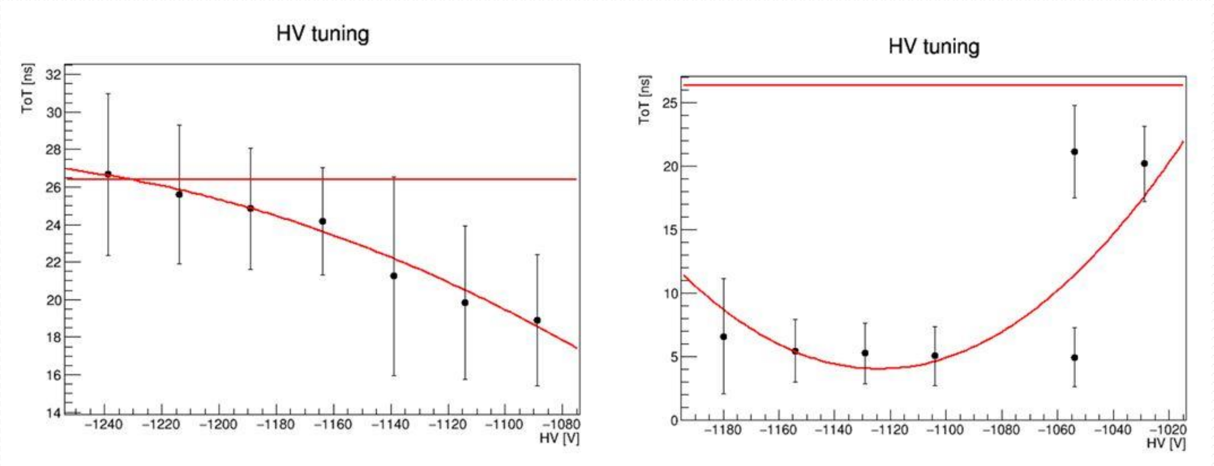


error is
gauss sigma

HV tuning fails

322 PMTs has not passed the test due to HV tuning failure



If the Promis ID is wrong the vendor HV is wrong too. The HV tuning starts from a HV value that is the vendor's one.
So many RED PMTs could be GREEN just testing them again with the correct vendor HV.

Test procedure

• Load PMTs on the trays	1 h
• Set Nominal HV	30 min
• HV tuning (including HV tuning analysis)	1 h 30 min
• Darkening	5 h
• LASER tests (TTS, prepulses, afterpulses and Delayed pulses)	30 min
• PMT selection after test results and packaging	30 min

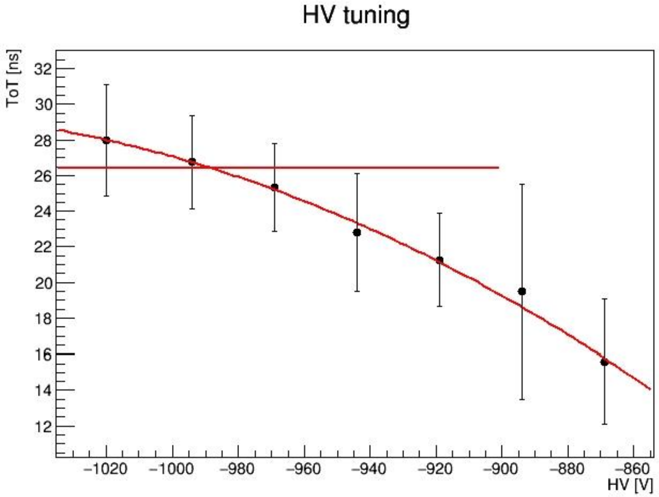
9 hours for each test

Thanks to a little modification on the LASER controller we can control each component remotely. At the moment we are performing 2 tests/Day.

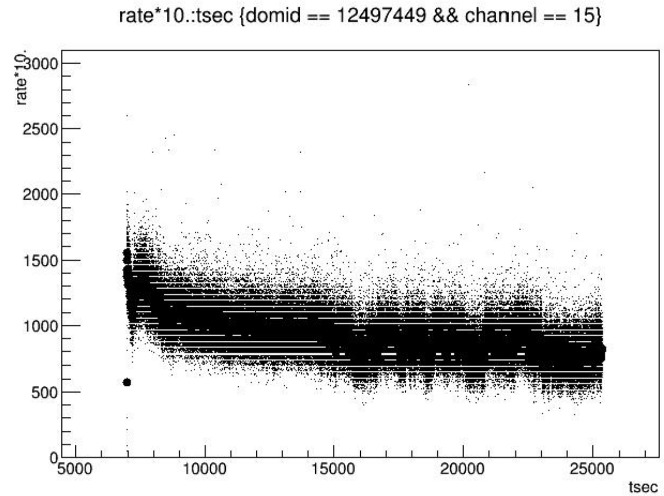
With another couple of cable extensions we can improve the test time of about 1h

Output test example

The HV tuning fit

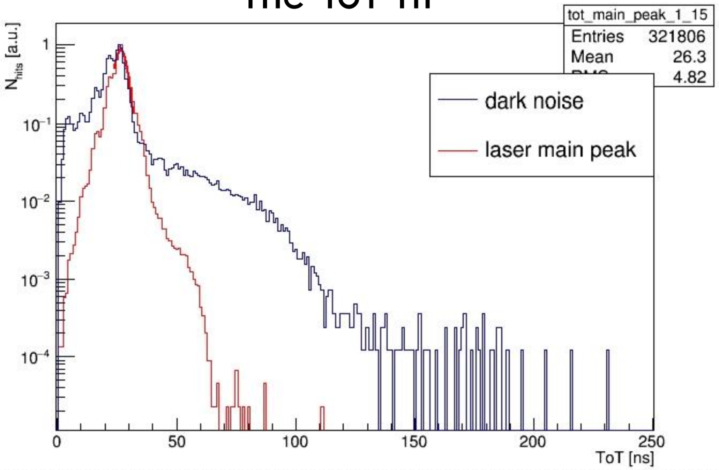


Dark Counts trend

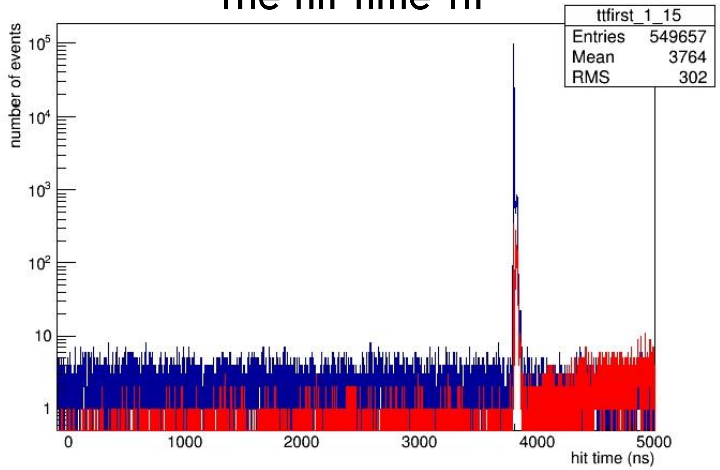


DarkBox test summary (Test #33)
PROMIS ID: 0005C4
Quality : GREEN
UPI : 3.4.2.3/HAMA-R12199/2.4082
Tuned HV : -987.94 V
DarkRate : 793.13 Hz
ToT peak : 26.8561 ns
Prepulses : 0.00292931%
Delayed : 0.0709103%
Afterpulses : 0.476641%
TT peak : 3793 ns
TT FWHM : 3 ns

The ToT fit



The hit time fit



Fast Acceptance protocol

We need tested PMTs as soon as possible! We need to define a FAST AND SAFE Protocol to identify good PMTs.

TRIAGE

GREEN	YELLOW	RED
PMTs within the specifications.	PMTs in wich one test goes wrong (i.e. HV tuning) OR dark counts from 2000 cps up to 3000 cps.	PMTs with very high Dark Counts (>3000 cps) or out of the specifications
Ready for the integration	To be tested again	To be tested again, if still RED a decision must be made (KM3NeT acceptance)

This is not an acceptance protocol for KM3NeT!

Is just a fast way to have good PMTs for the integration sites.

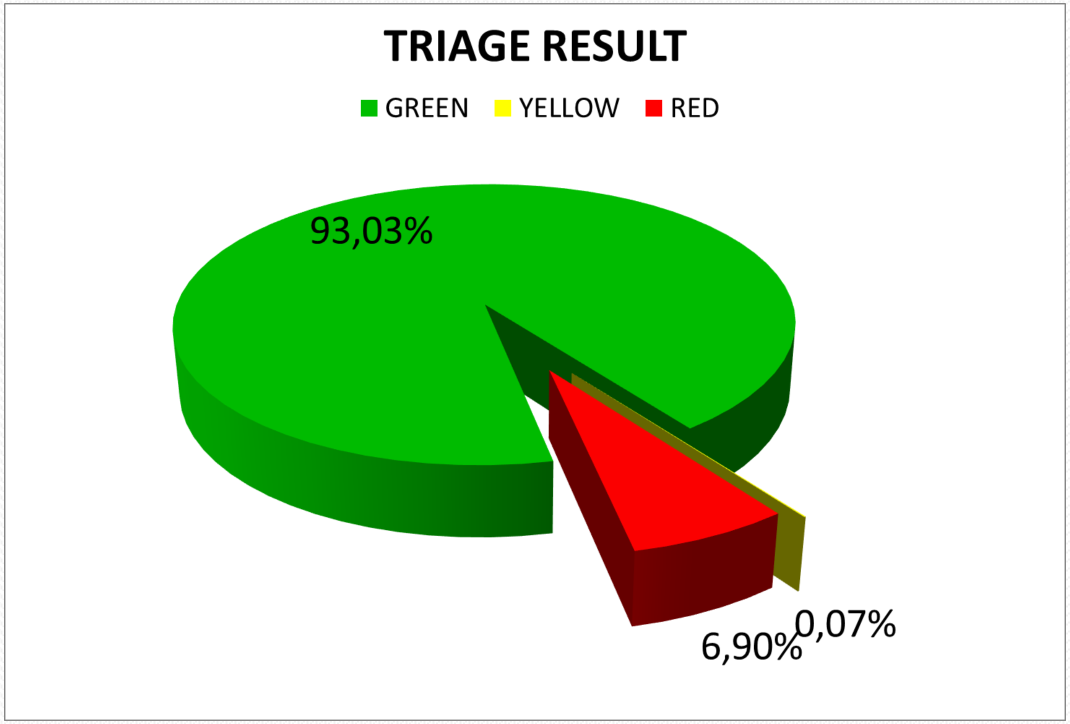
Final test results

After the re-test of 130 YELLOW PMTs and 856 RED PMTs we had 50 YELLOW PMTs. It was Decided to re-test them with a darkening time of 24 hours.

Results:

- 40 GREEN
- 5 YELLOW
- 5 RED

Total PMTs after retest of 50 re-tested yellow PMTs

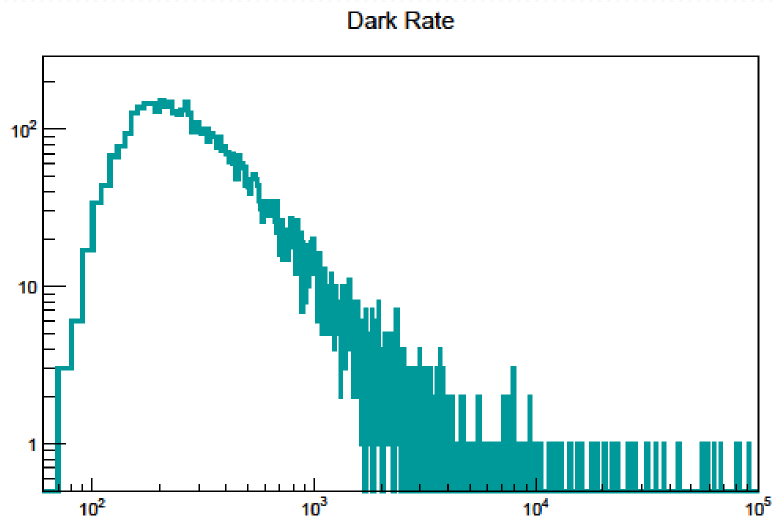


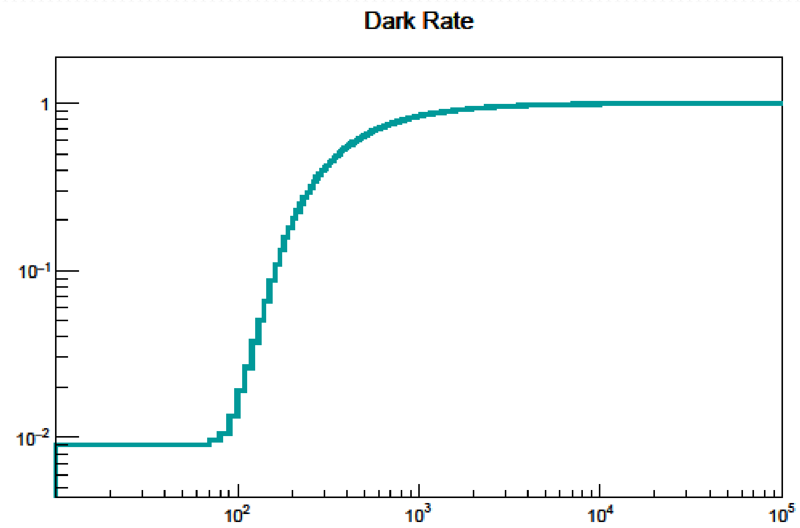
GREEN: 6483
YELLOW: 5
RED: 472

RED PMTs recovered: 53,03%
YELLOW PMTs recovered: 96,87%

Final test results

Dark rates ALL





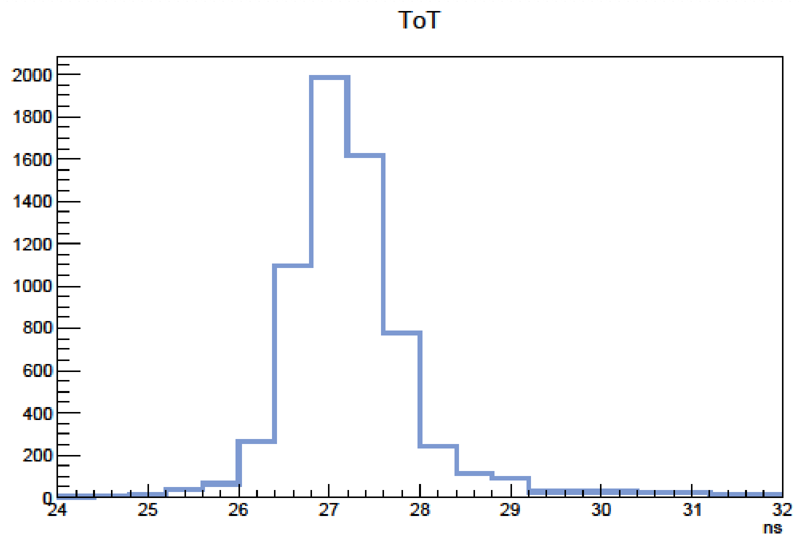
Dark counts at 20 deg C and 0.3 spe threshold within 12 hours:

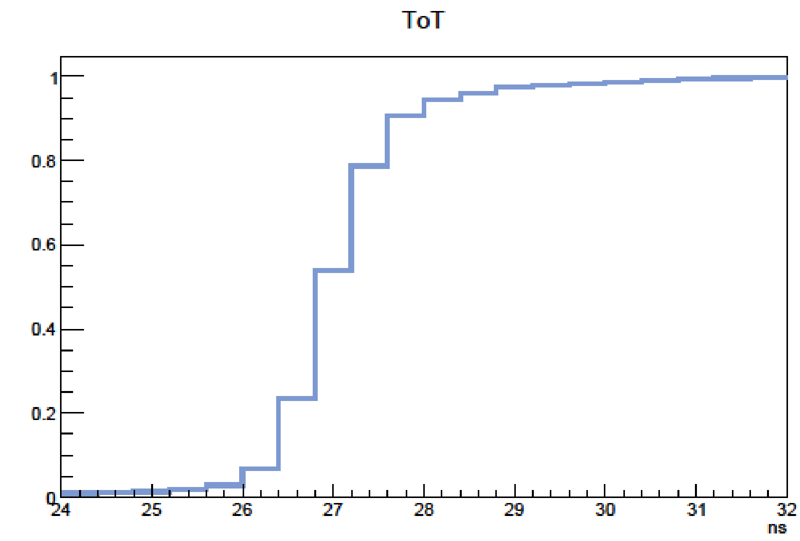
- 1500 cps typ. (89.7%)
- 2000 cps max. (92,9%)

85% < 1070 cps
89% < 1490 cps
95% < 2630 cps
98% < 5460 cps
99% < 9130 cps

Final test results

ToT ALL



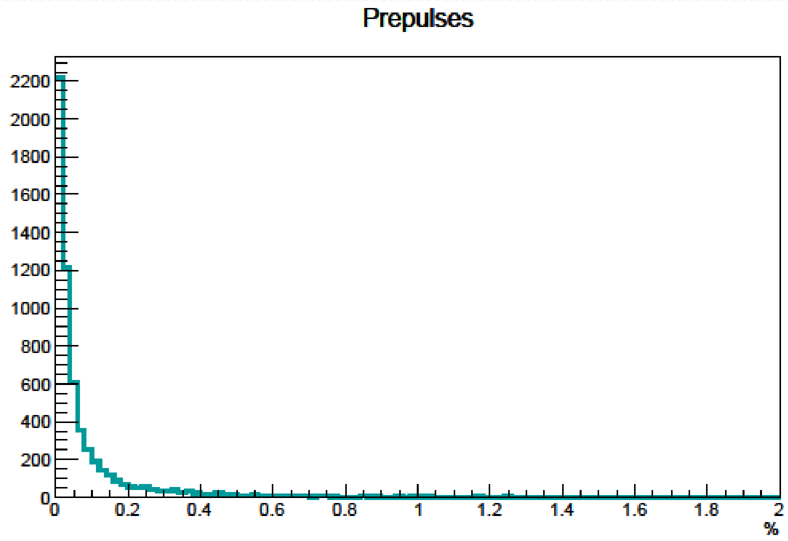


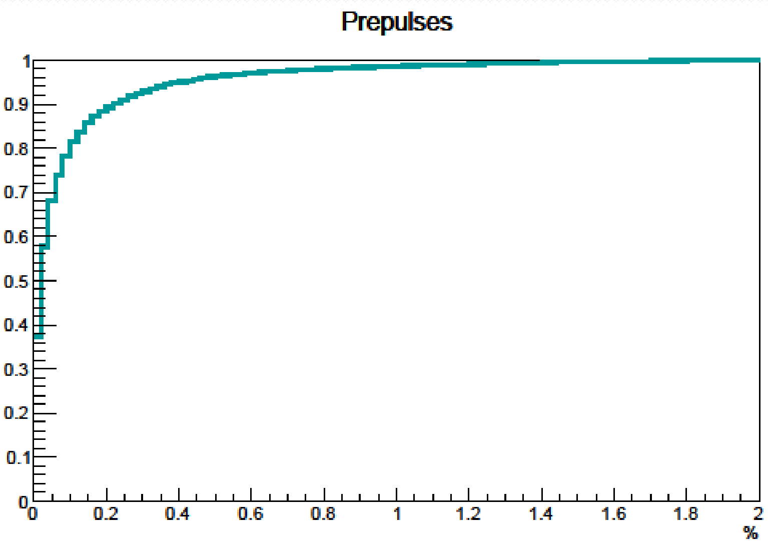
ToT: 27.1 $\pm$ 0.5 ns

NO.	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	Constant	1.95545e+03	3.31033e+01	2.36070e-01	6.42487e-06
2	Mean	2.71566e+01	6.59424e-03	6.03524e-05	-1.76085e-02
3	Sigma	4.99883e-01	5.54941e-03	2.07381e-05	1.03240e-01

Final test results

Prepulses ALL





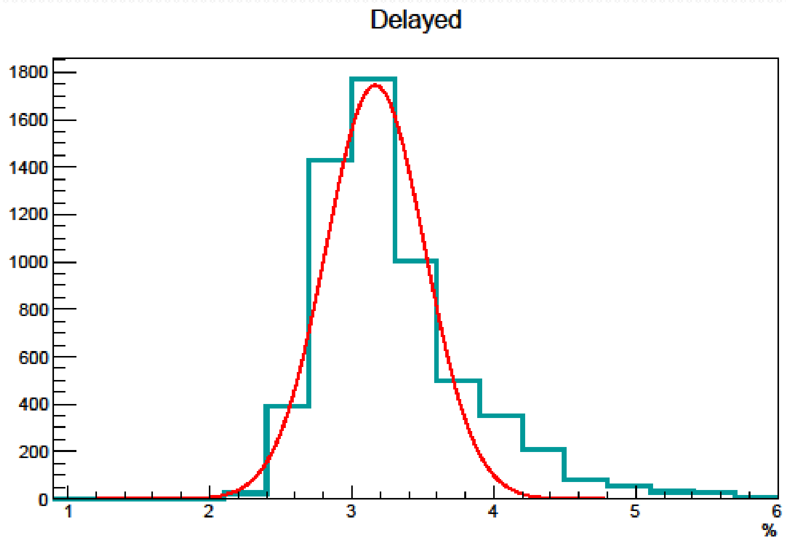
Prepulses between -60 ns and -10 ns:

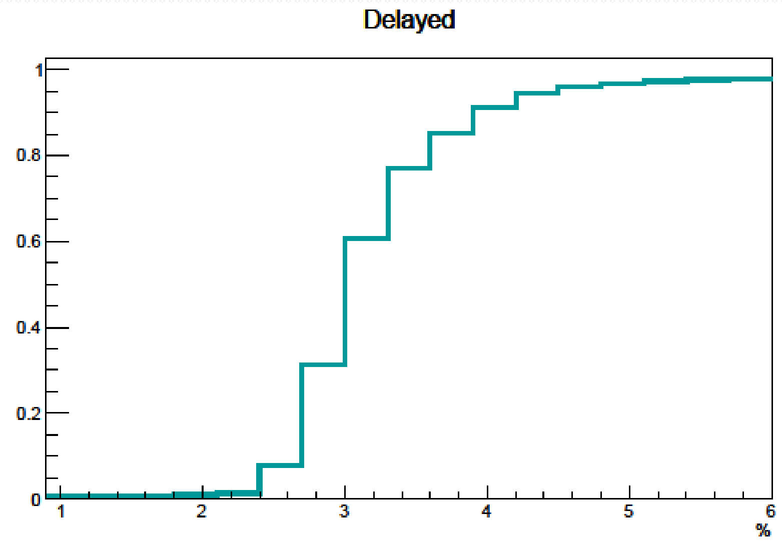
- 1% typ. (97,8%)
- 1.5% max. (98,8%)

85% < 0.16 %
91% < 0.24 %
95% < 0.42 %
98% < 0.82 %
99% < 1.20 %

Final test results

Delayed Pulses ALL





Delayed pulses: 3.2 ± 0.3 %

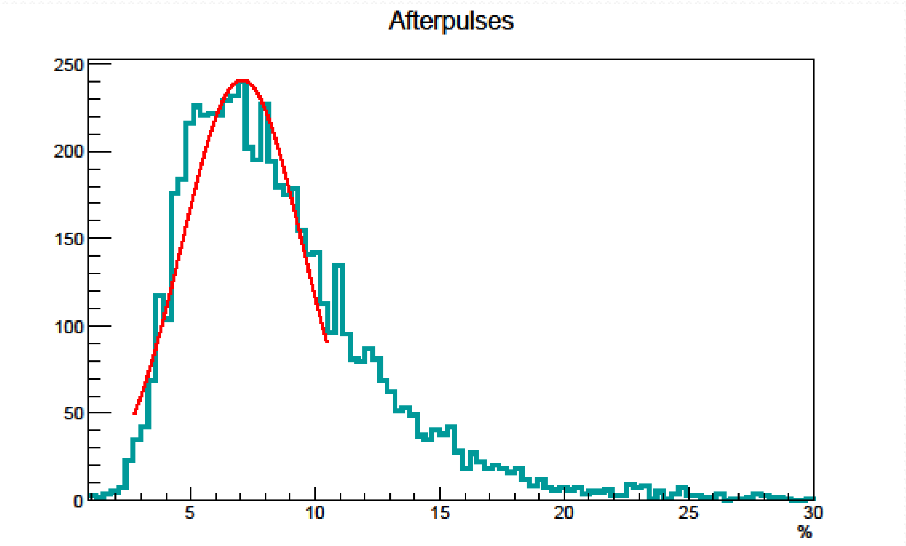
NO.	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	Constant	1.74615e+03	3.23823e+01	3.13527e-01	-5.28851e-06
2	Mean	3.16627e+00	6.73859e-03	6.25039e-05	1.46766e-02
3	Sigma	3.48020e-01	4.21744e-03	2.49388e-05	-2.70357e-02

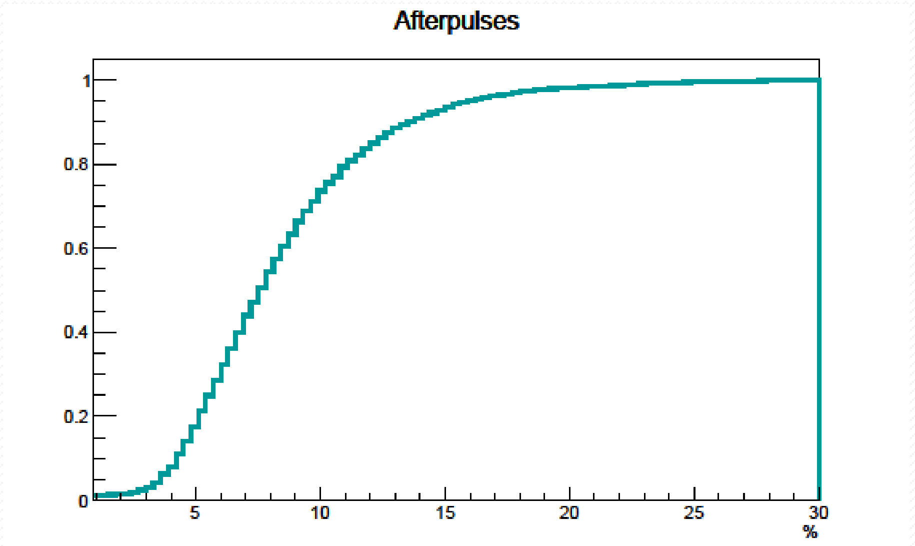
Delayed pulses between 15 ns and 60 ns (i.e. pulse arriving late with no pulse at correct time):

- 3.5 % typ. (73,5 %)
- 5.5 % max. (98,5 %)

Final test results

Afterpulses ALL





Afterpulses: 7.2 ± 2.4 %

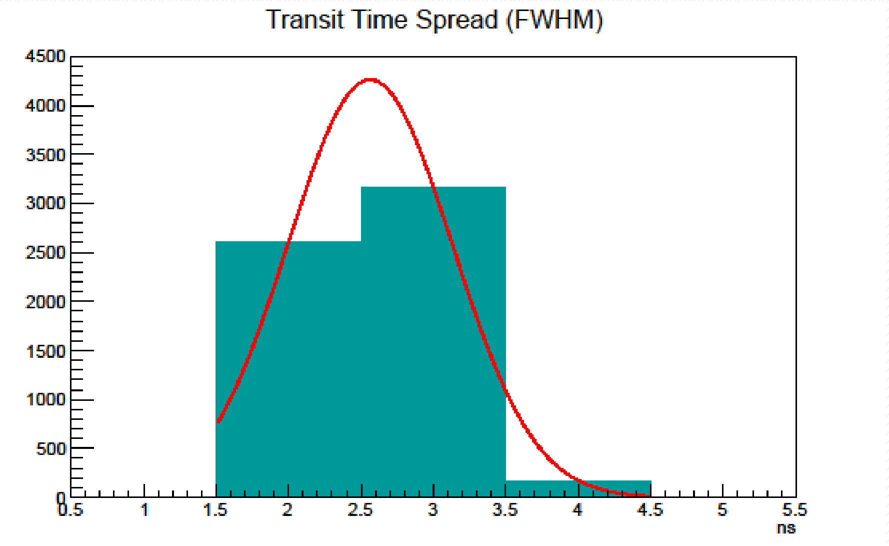
NO	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	Constant	2.40958e+02	4.83007e+00	-1.68602e-02	-1.15780e-04
2	Mean	7.06440e+00	5.45156e-02	1.12946e-04	6.77774e-03
3	Sigma	2.43315e+00	5.49366e-02	-4.50349e-05	-1.46000e-01

Late after-pulses between 100 ns and 10 us:

- 10 % typ. (71,4 %)
- 15 % max. (92,4 %)

Final test results

TTS ALL

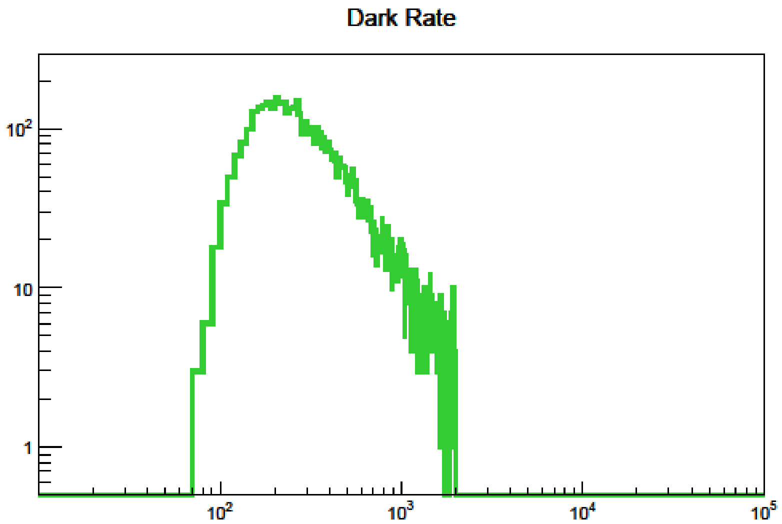


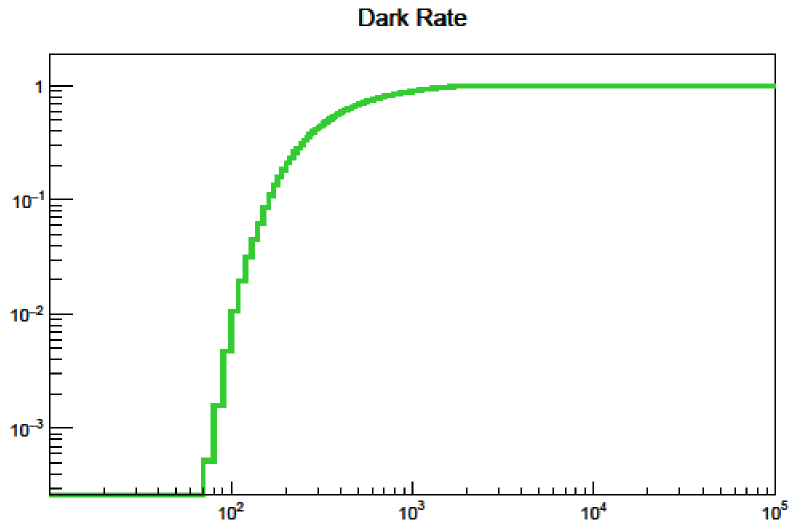
TTS: 2.6 ± 0.6 ns

NO	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	Constant	4.26268e+03	7.78017e+01	2.70070e-02	4.80071e-07
2	Mean	2.56299e+00	7.87677e-03	7.68896e-06	1.12190e-03
3	Sigma	5.66615e-01	7.87494e-03	1.74721e-06	2.52584e-03

Final test results

Dark rates GREEN

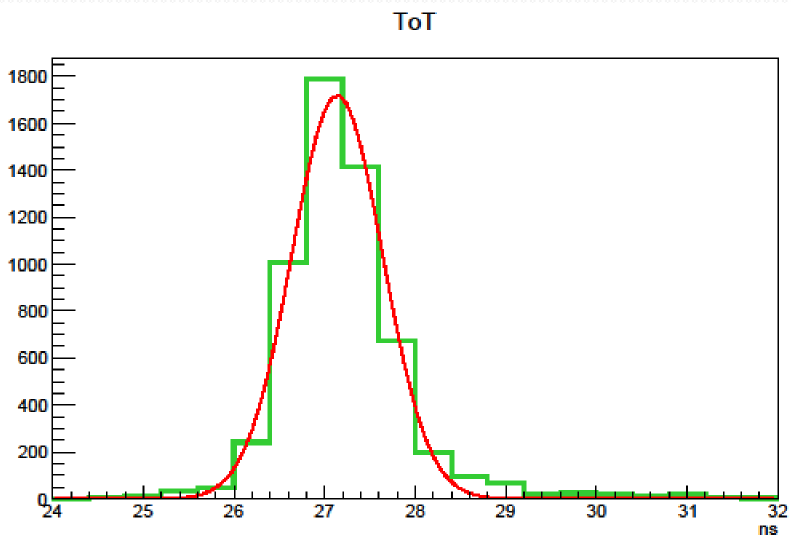


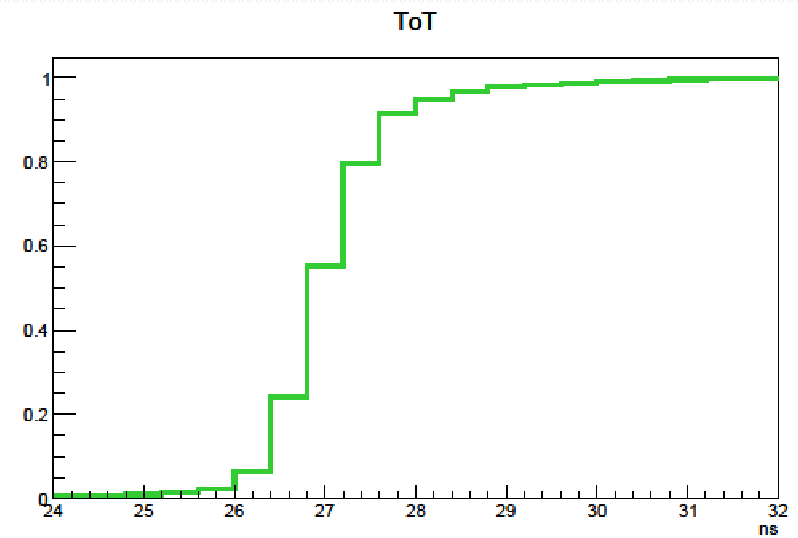


85% < 850 cps
90% < 1030 cps
95% < 1360 cps
98% < 1680 cps
99% < 1840 cps

Final test results

ToT GREEN



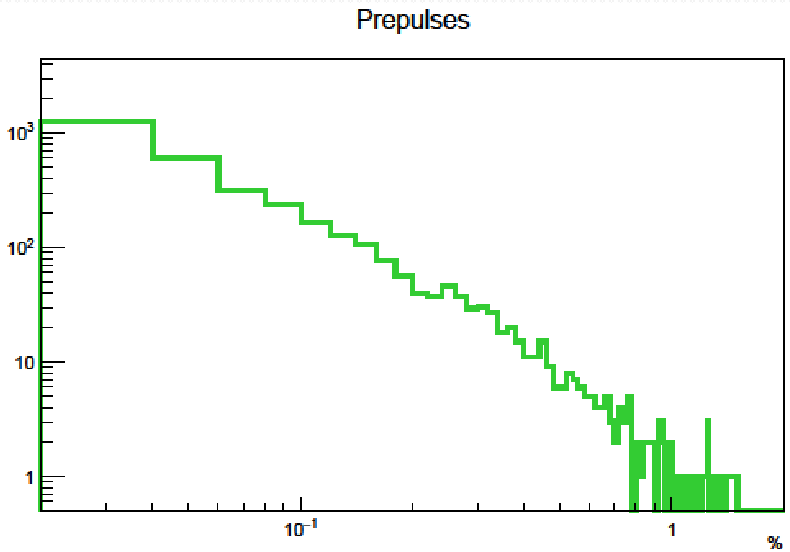


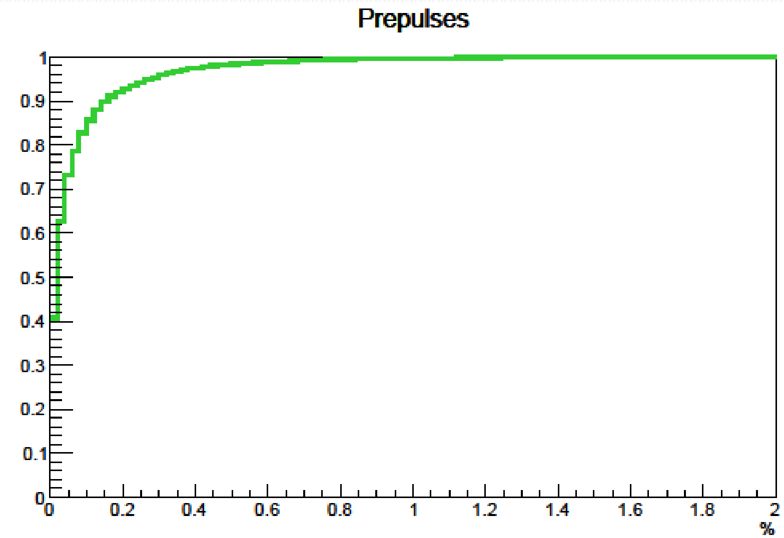
ToT: 27.1 ± 0.5 ns

NO.	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	Constant	1.71977e+03	3.09572e+01	2.01156e-01	1.38358e-06
2	Mean	2.71399e+01	7.01510e-03	5.84667e-05	-3.08259e-03
3	Sigma	4.99847e-01	5.87814e-03	2.03997e-05	1.25413e-02

Final test results

Prepulses GREEN

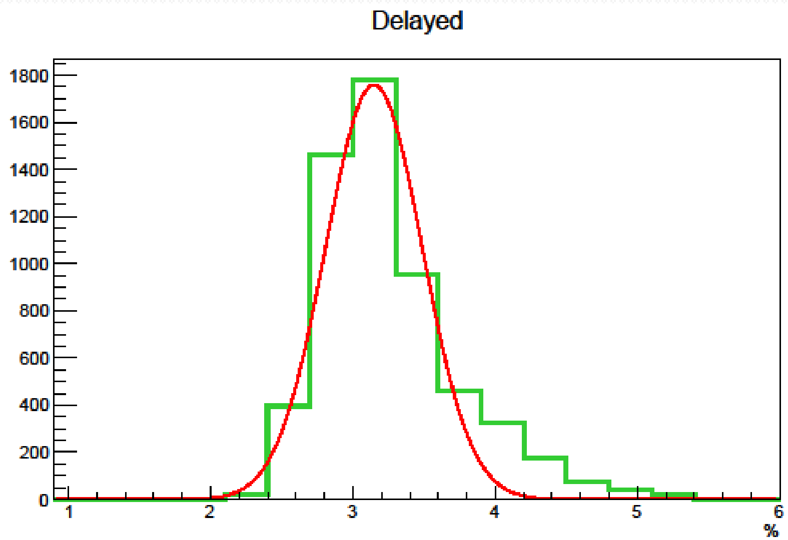


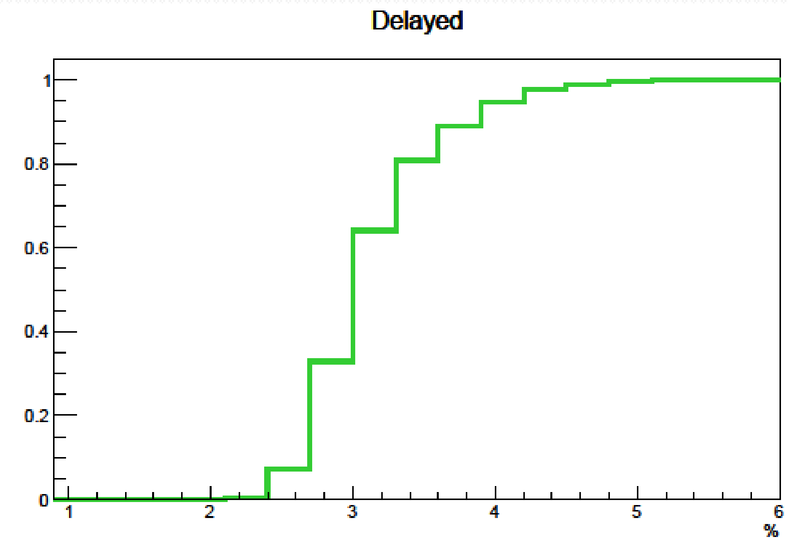


85% < 0.12 %
91% < 0.18 %
95% < 0.30 %
98% < 0.48 %
99% < 0.66 %

Final test results

Delayed Pulses GREEN



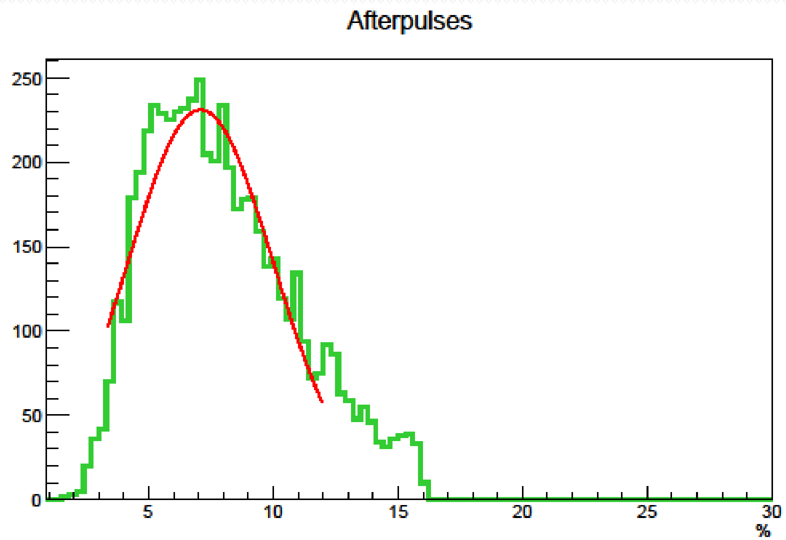


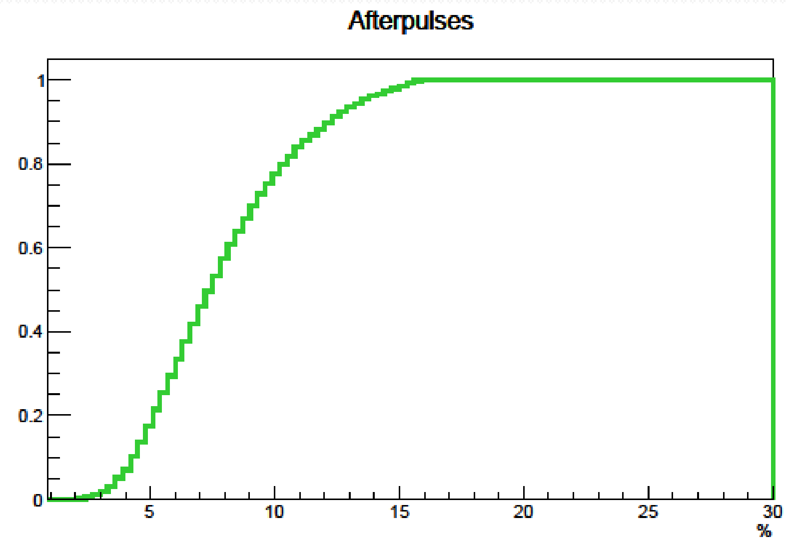
Delayed pulses: 3.1 $\pm$ 0.3 %

NO.	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	Constant	1.76168e+03	3.39285e+01	3.24138e-01	-2.11545e-06
2	Mean	3.14773e+00	6.47870e-03	6.27782e-05	7.81600e-03
3	Sigma	3.39754e-01	4.46385e-03	2.85827e-05	-1.64899e-02

Final test results

Afterpulses GREEN



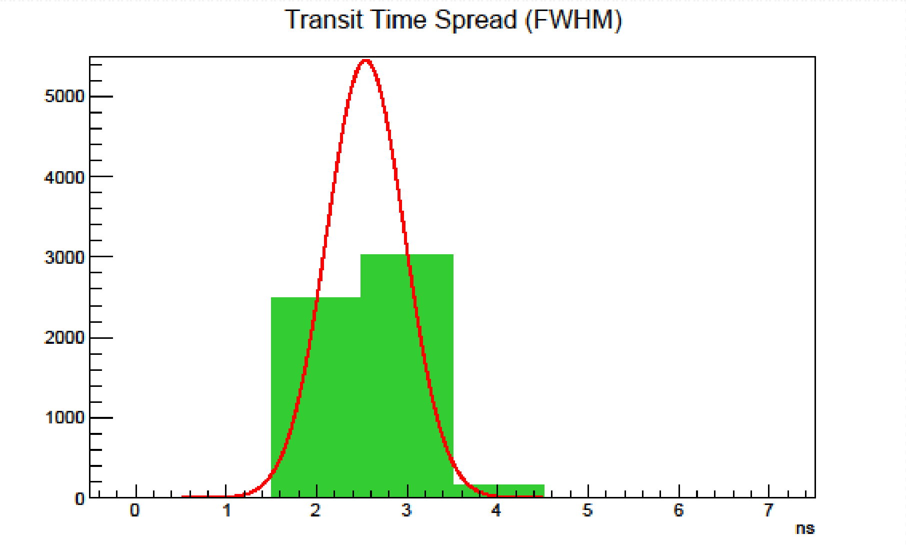


Afterpulses: 7.1 ± 2.9 %

NO	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	Constant	2.31121e+02	4.52094e+00	1.56305e-02	7.77533e-06
2	Mean	7.08029e+00	5.79604e-02	2.67652e-04	1.89935e-04
3	Sigma	2.92765e+00	7.17130e-02	2.84968e-05	2.25752e-03

Final test results

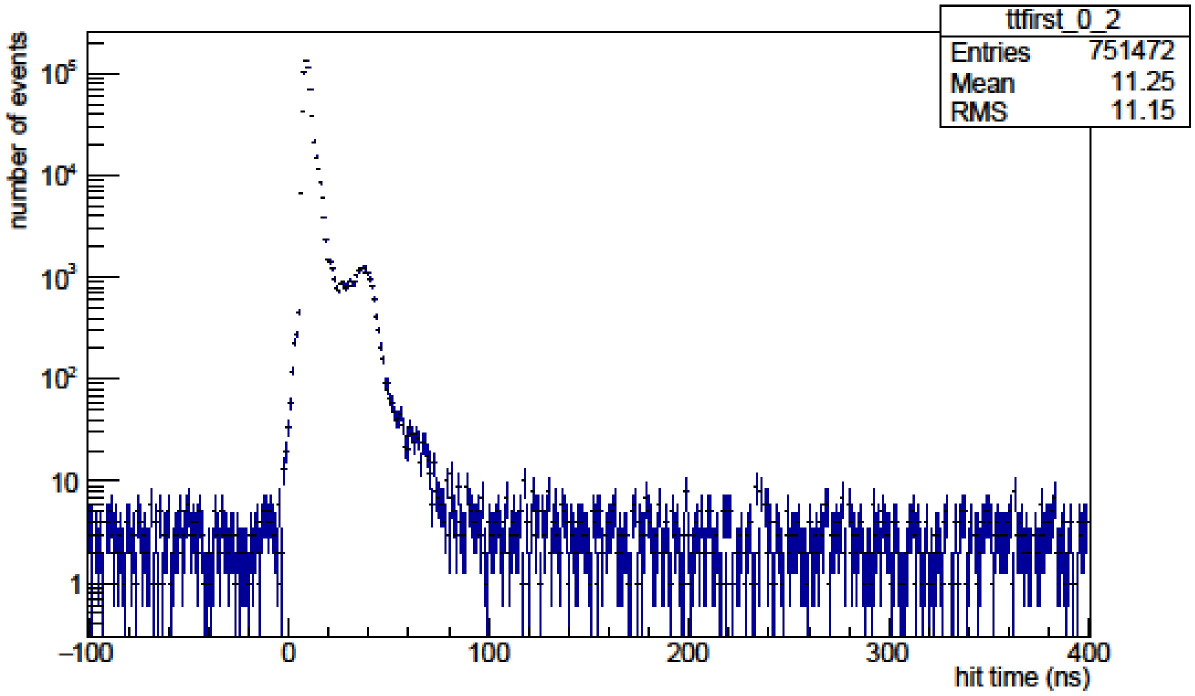
TTS GREEN



TTS: 2.5 ± 0.4 ns

NO	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	Constant	5.45648e+03	1.72582e+02	4.34001e-01	-3.25981e-06
2	Mean	2.54206e+00	6.27925e-03	2.88585e-05	1.39497e-02
3	Sigma	4.28361e-01	8.68543e-03	1.41196e-05	-1.24344e-02

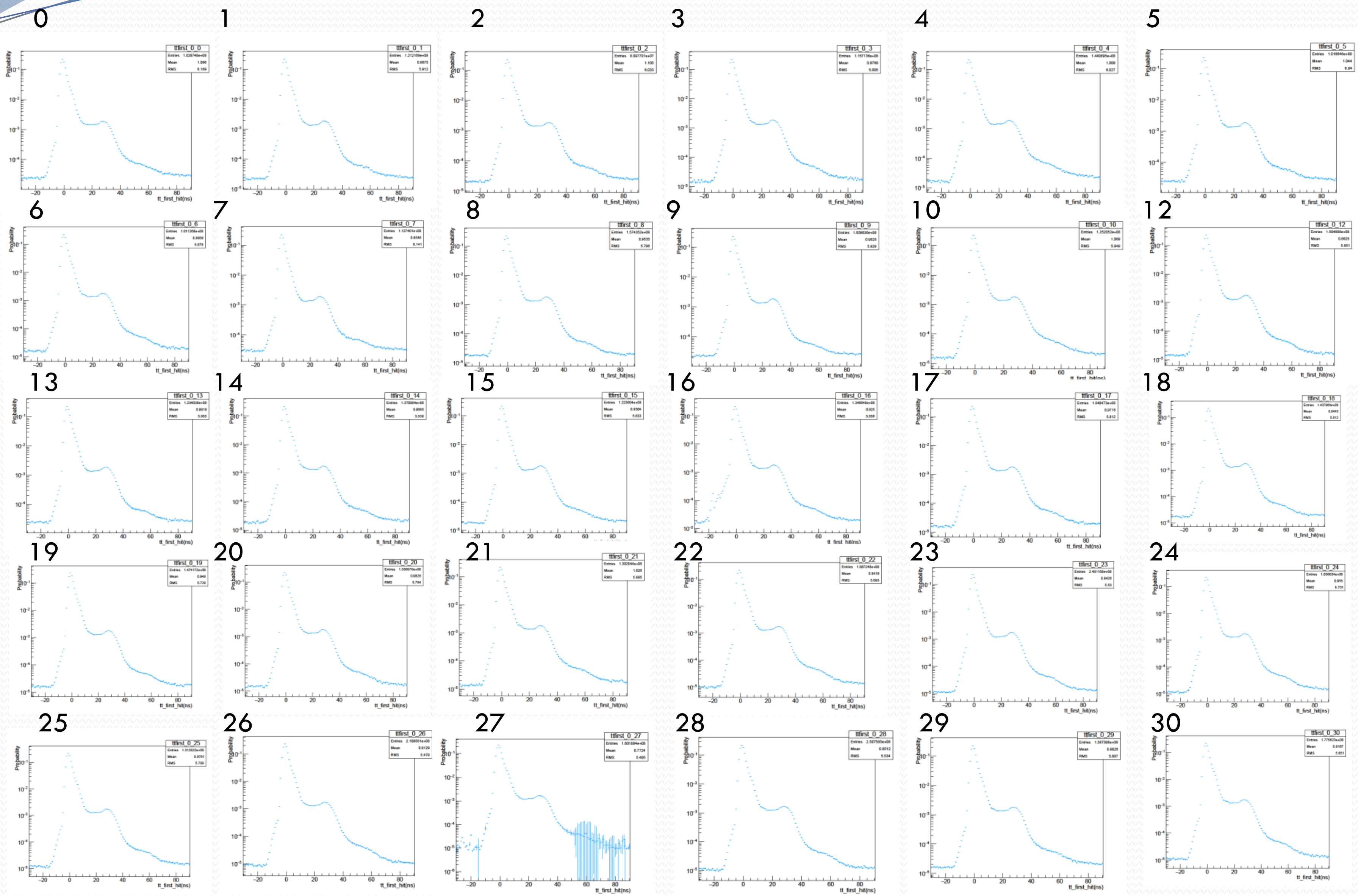
First hits distribution



We can have a distribution that contains info from all PMTs

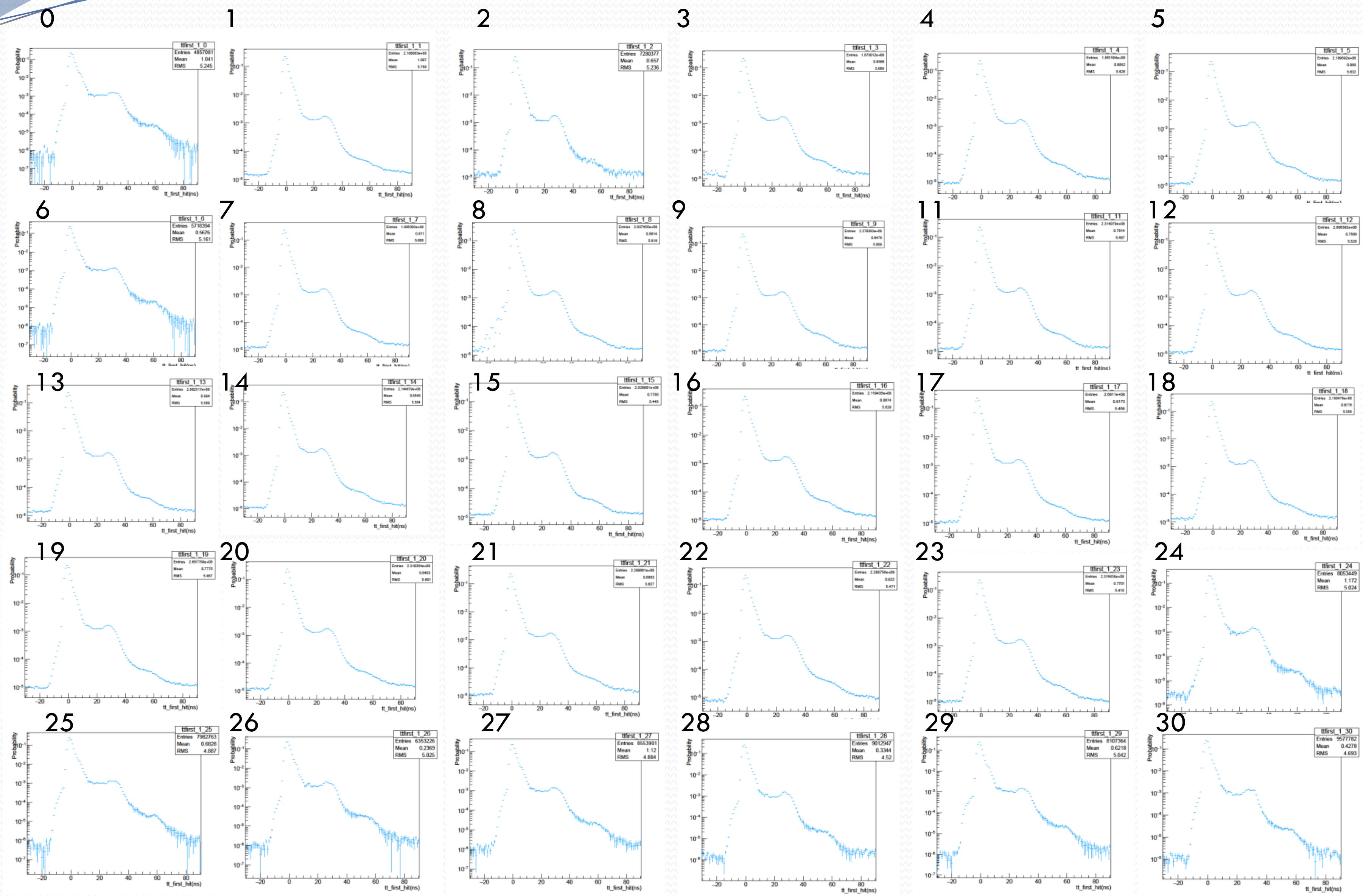
average of all normalized and shifted distributions

TT first Hit average dist. by chan.   tray 0



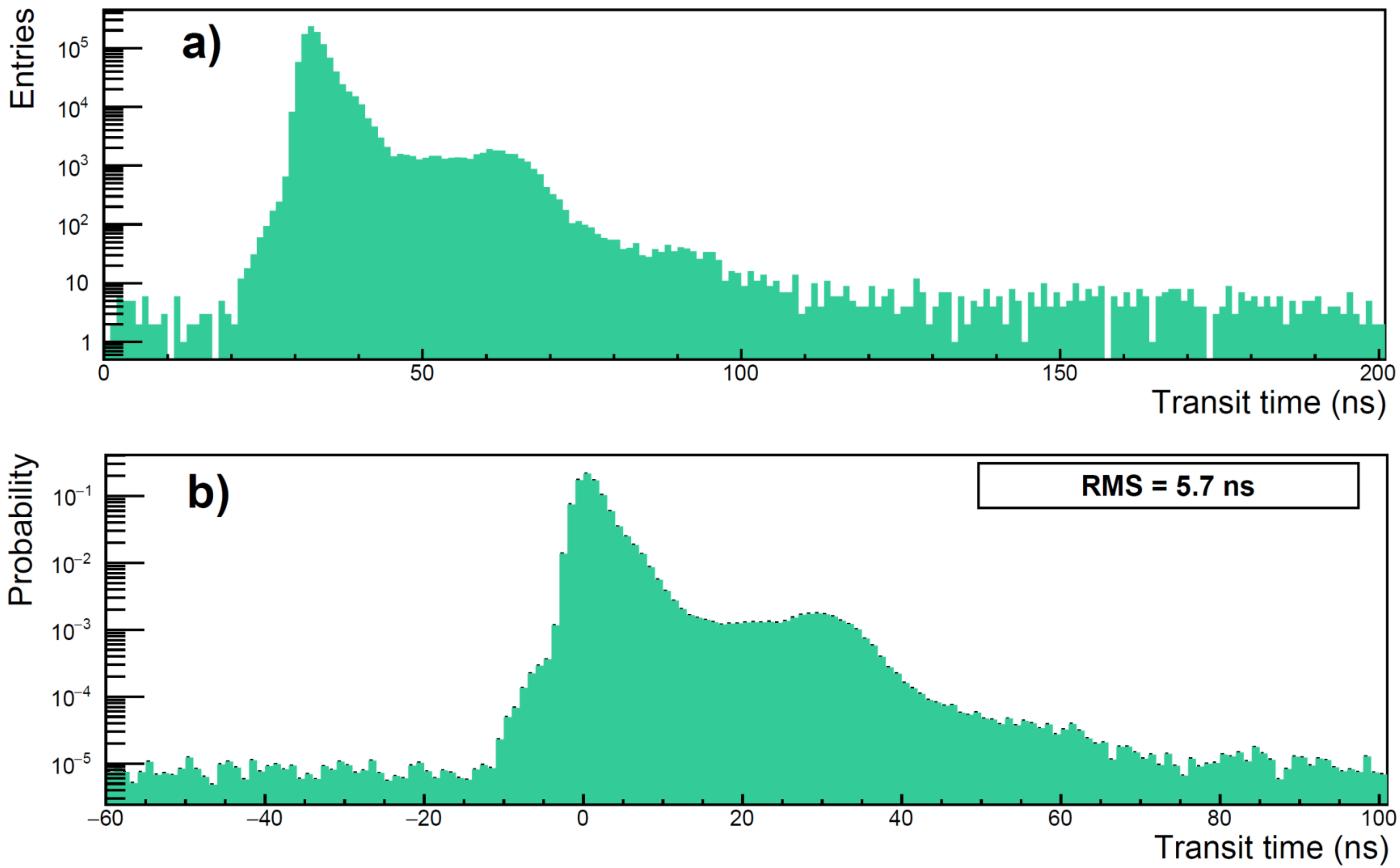
Channel 11 not used.

TT first Hit average dist. by chan. tray 1



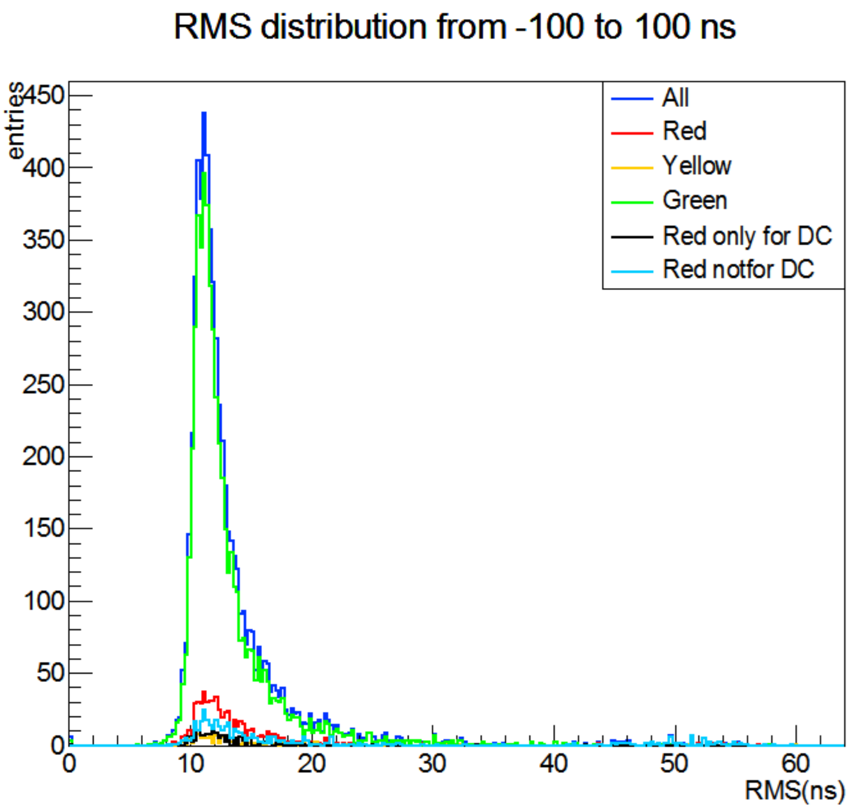
Channel 10 not used.

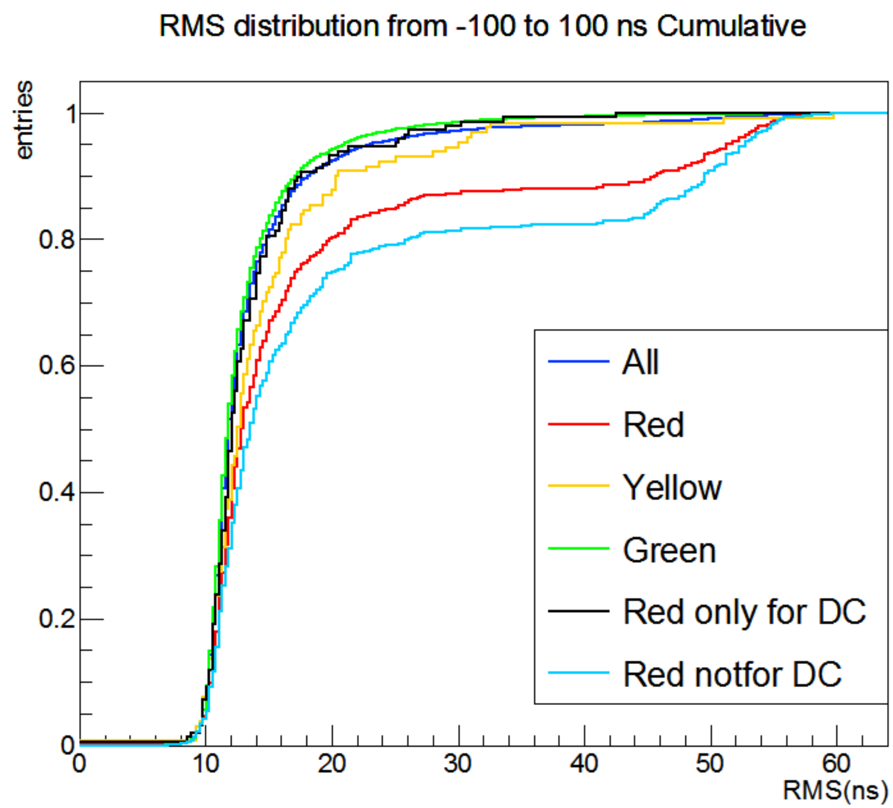
First Hit TT all channels
Average histogram of all 6960 PMTs



RMS study

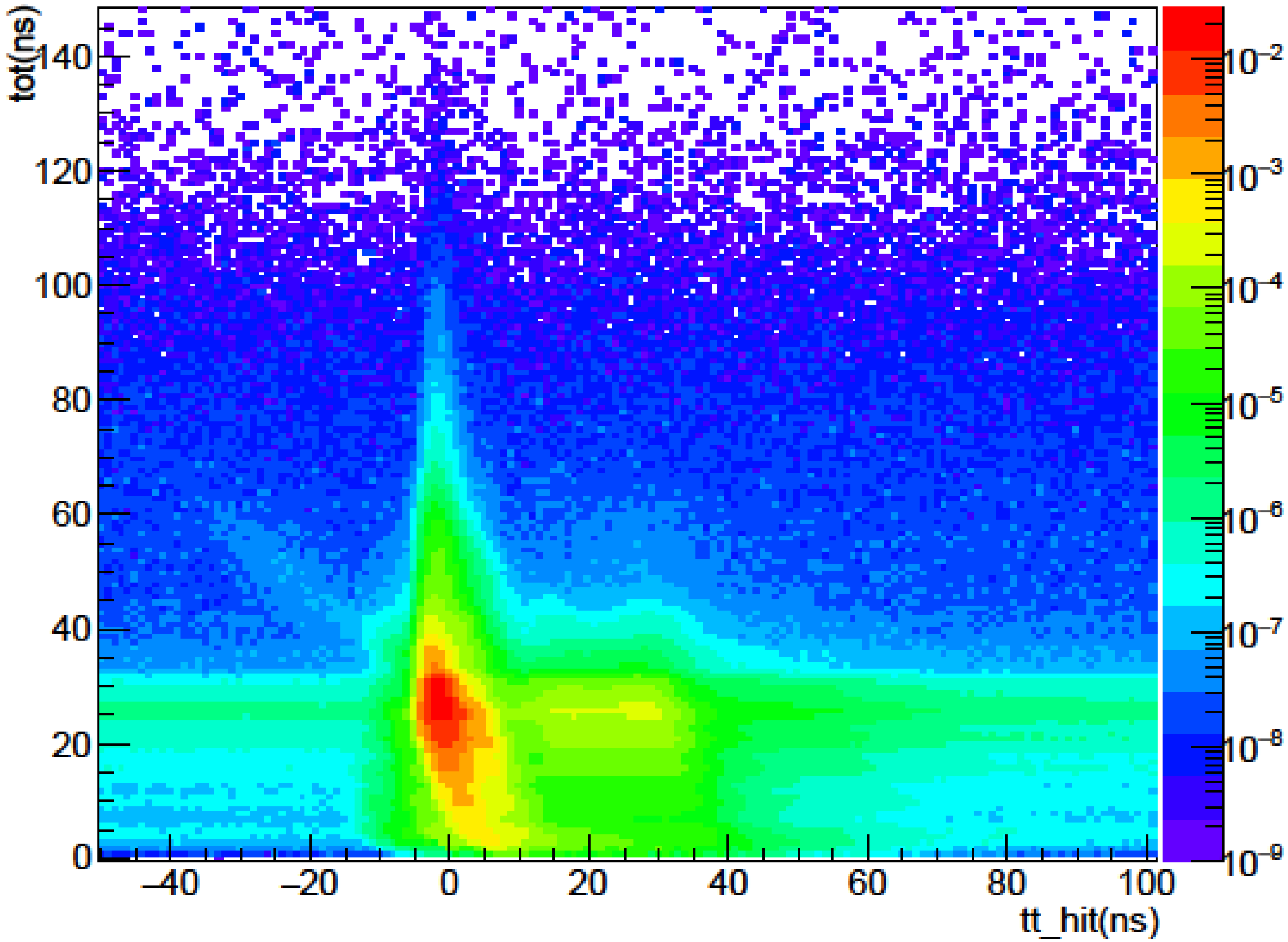
RMS distribution superimposed



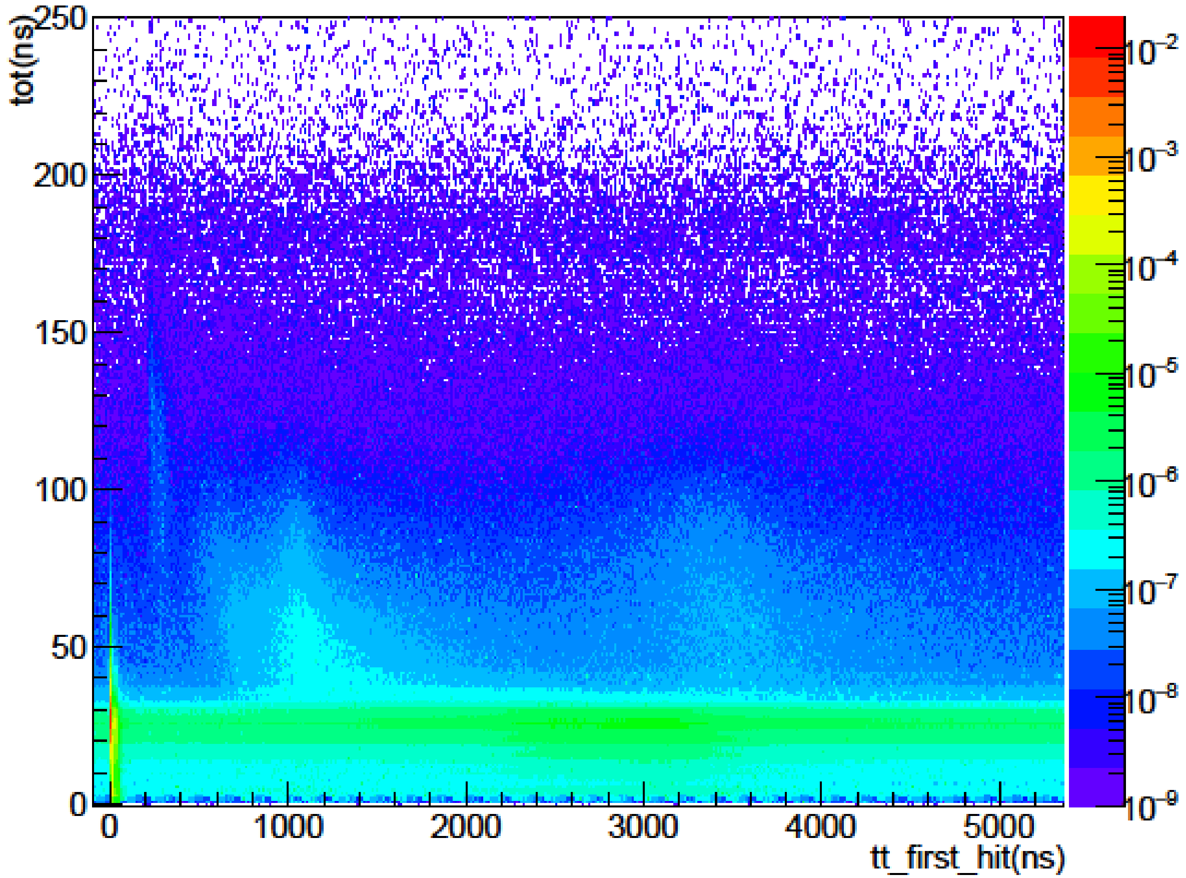


RMS of the hit time between -100 and 100 ns is a good parameter to indentify spurious pulses anomalies.

ToT vs TT all hits (near the laser time)

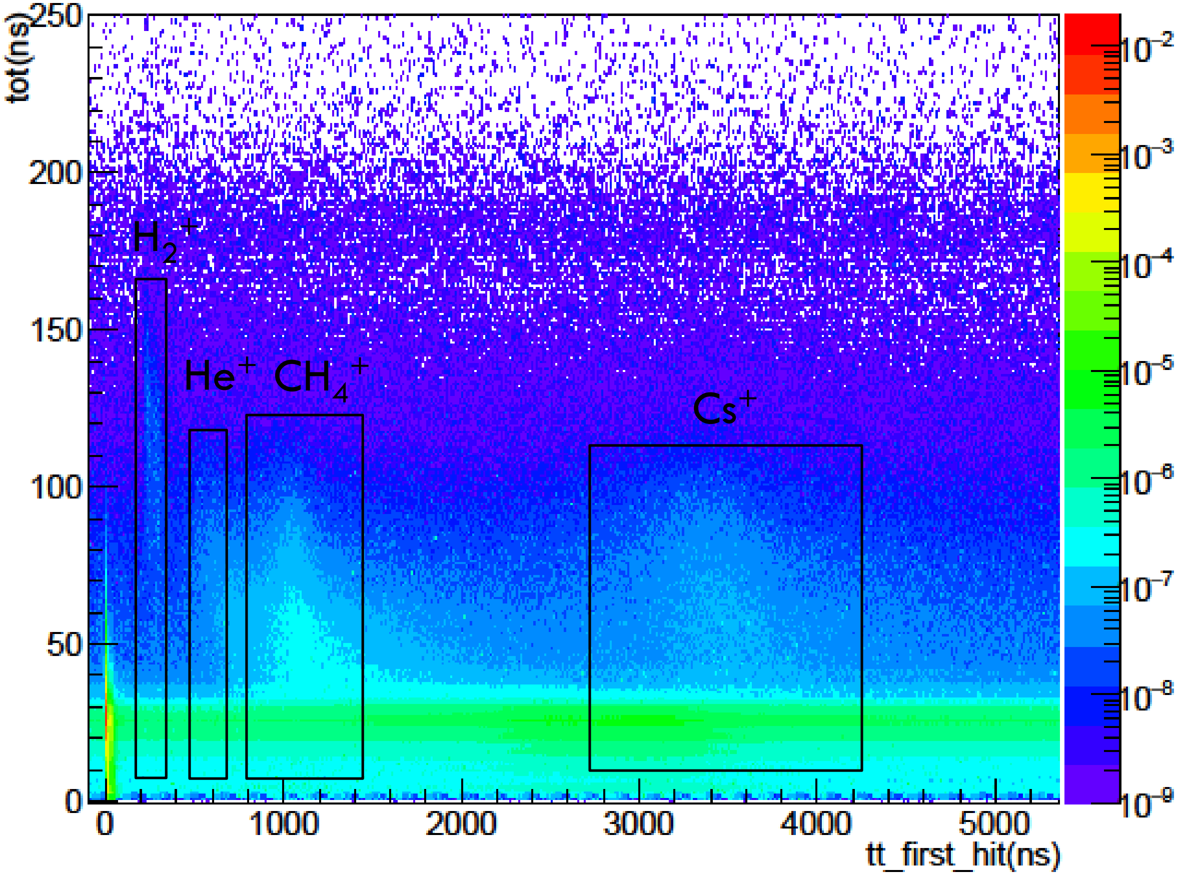


Afterpulses identification



afterpulse source	duration (typ.)
luminous reactions	20 to 100 ns
ionization of residual gases:	
- in the electron-optical input system	H_2^+: 0.3 μs
	He^+: 0.4 μs
	CH_4^+: 1 μs
- in the electron multiplier	1 to several μs, e.g. 3 μs for Cs^+

Afterpulses identification

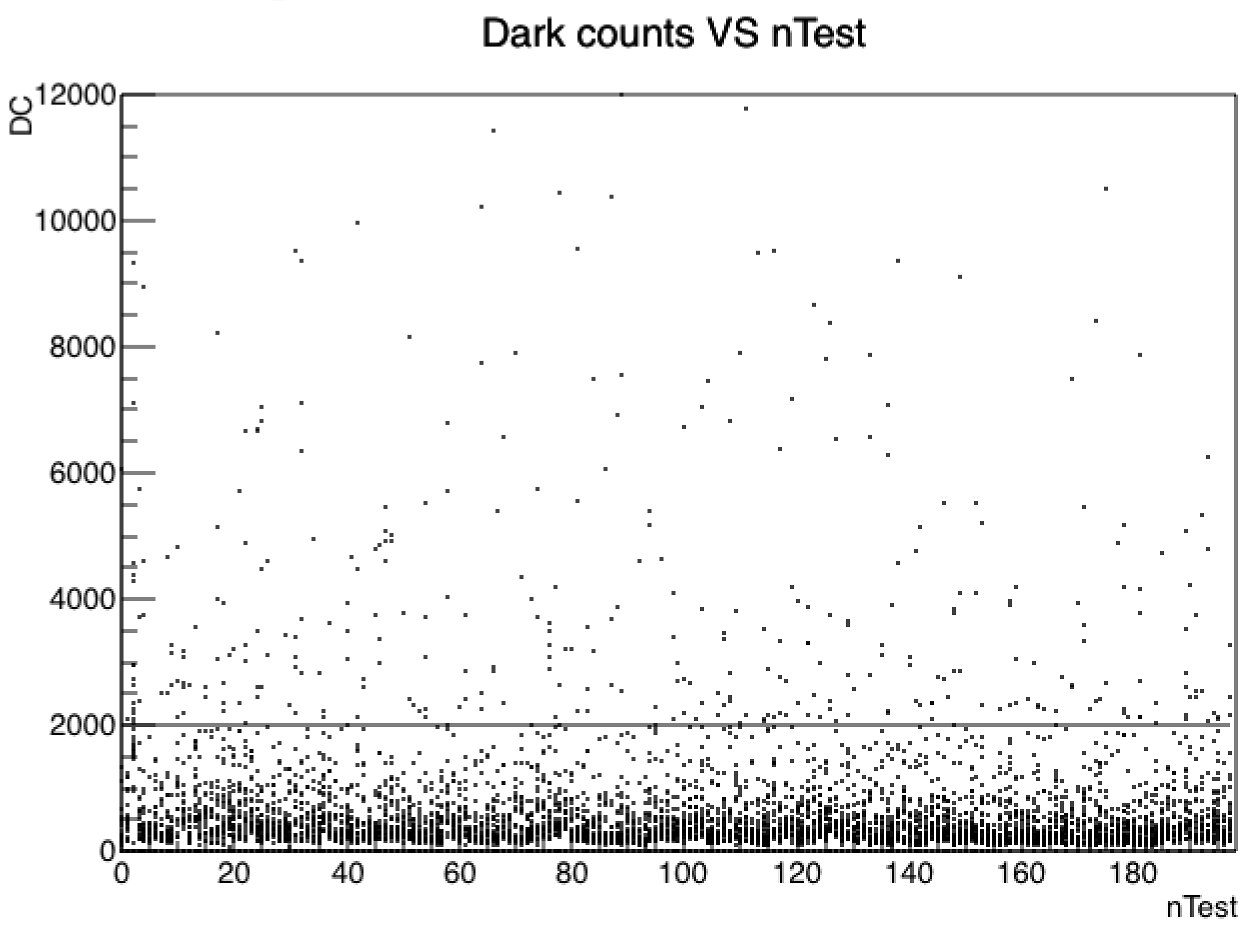


afterpulse source	duration (typ.)
luminous reactions	20 to 100 ns
ionization of residual gases:	
- in the electron-optical input system	H_2^+: 0.3 μs
	He^+: 0.4 μs
	CH_4^+: 1 μs
- in the electron multiplier	1 to several μs, e.g. 3 μs for Cs^+

Dark Box performances monitoring

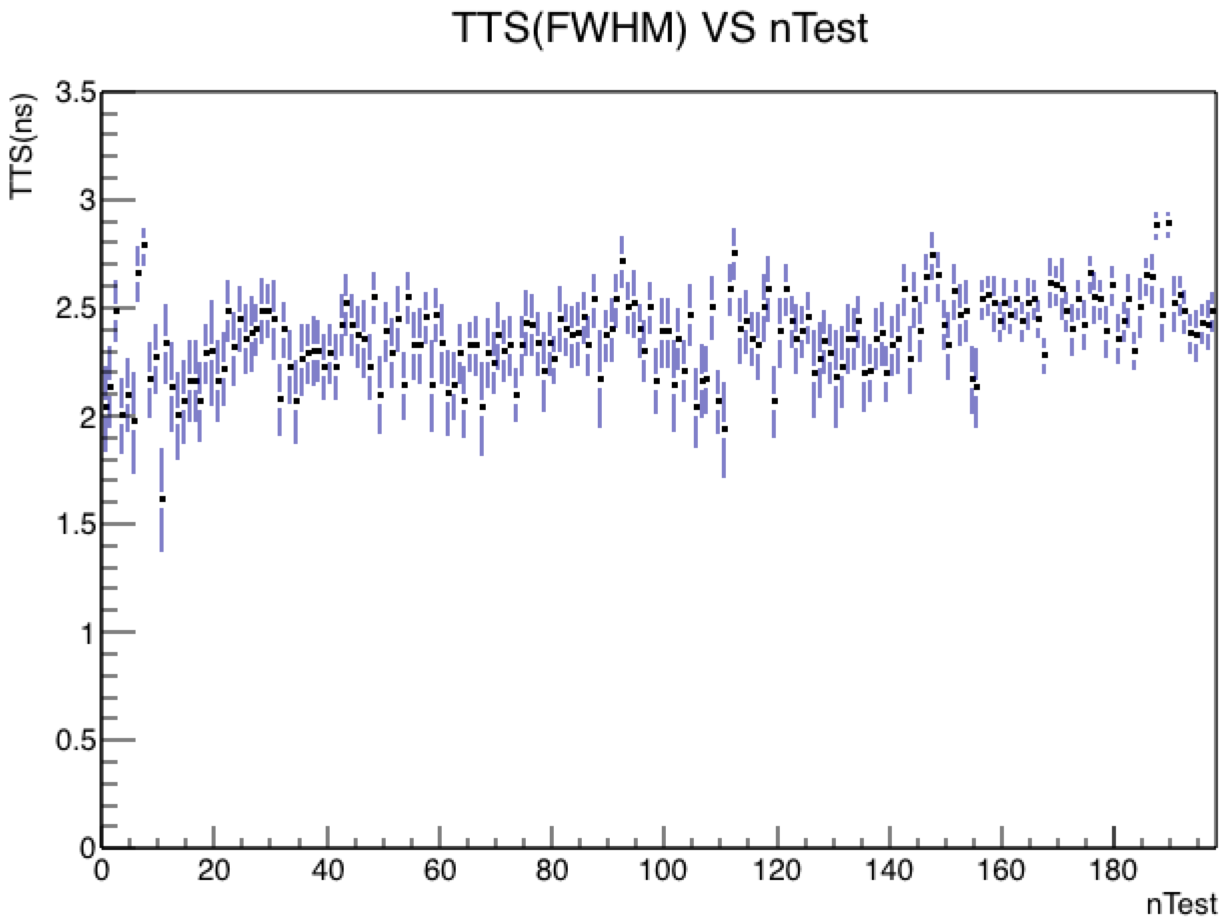
- Distribution of the averages of parameters measurements in a tray.
- 99 tests done = 198 average values for each parameter

Dark Box performances monitoring



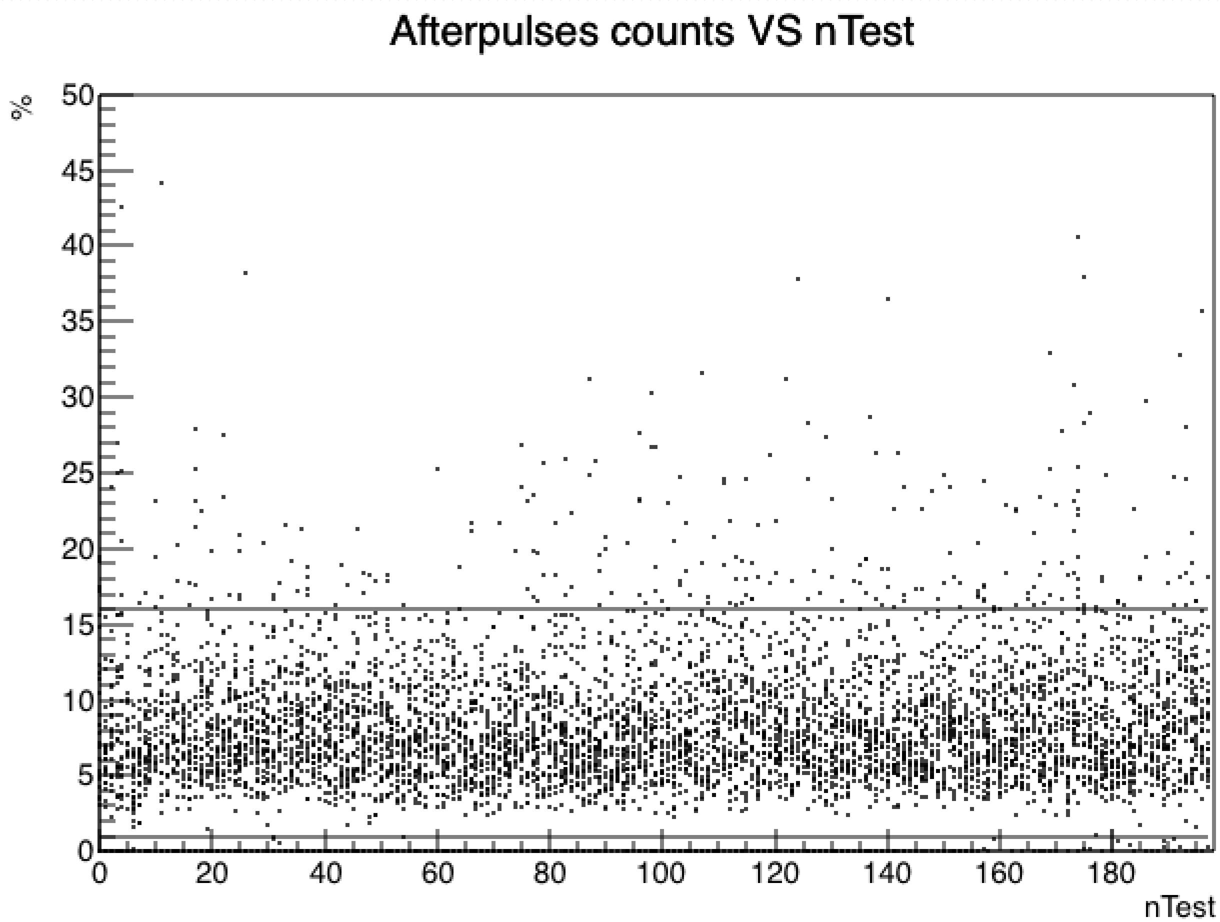
Quite flat and good values

Dark Box performances monitoring



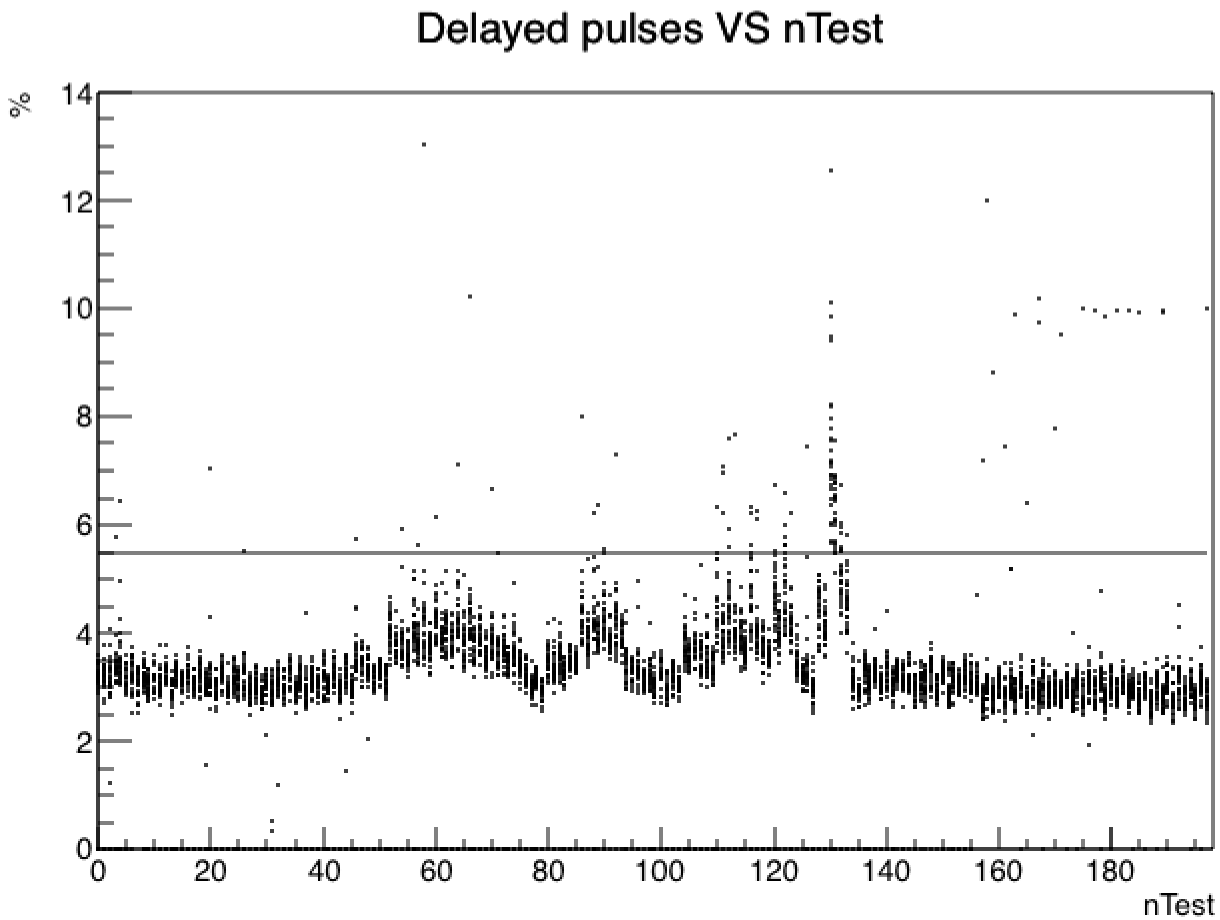
Quite flat and good values

Dark Box performances monitoring



Quite flat and good values

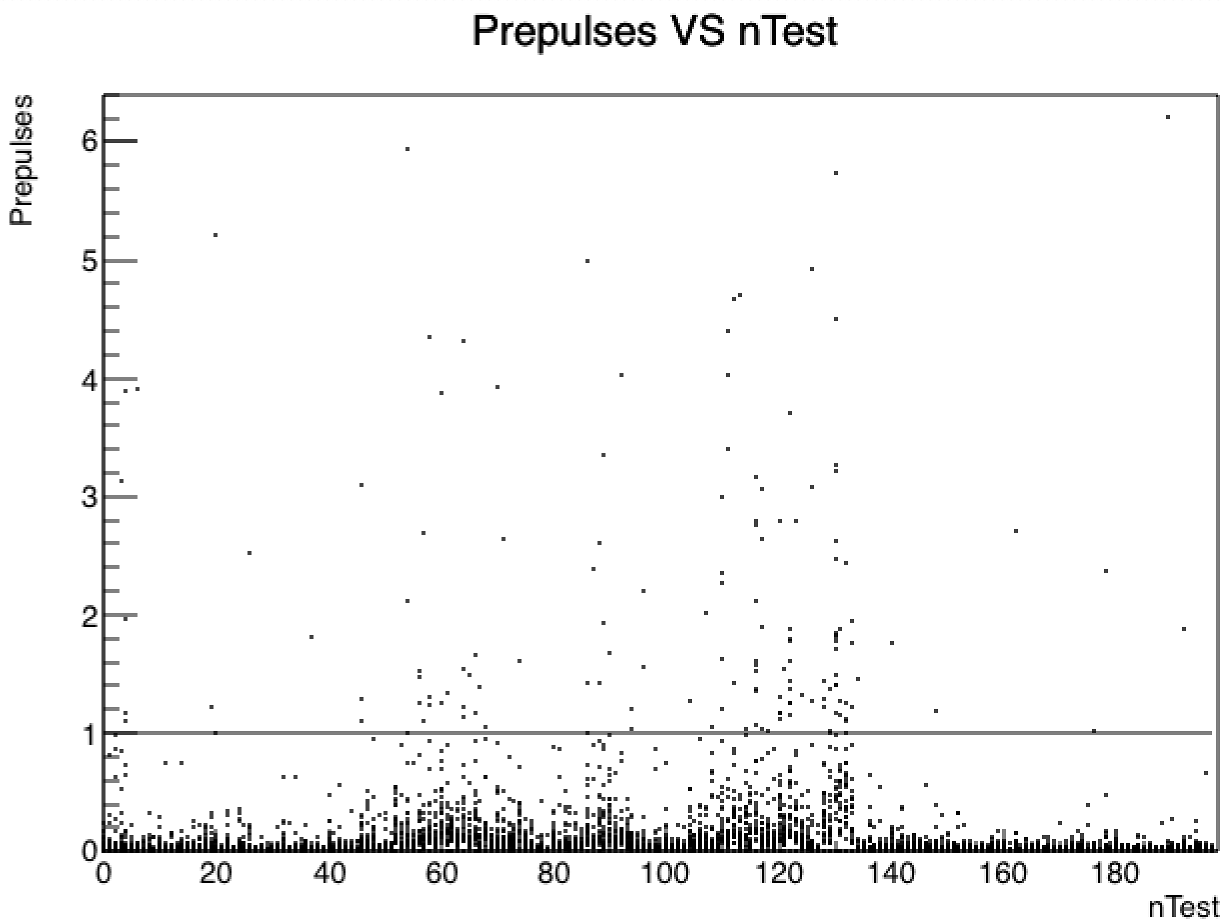
Dark Box performances monitoring



Some statistical anomalies due to a dependecy of the measurement to the laser conditions

This «instability» was fixed from test 77

Dark Box performances monitoring

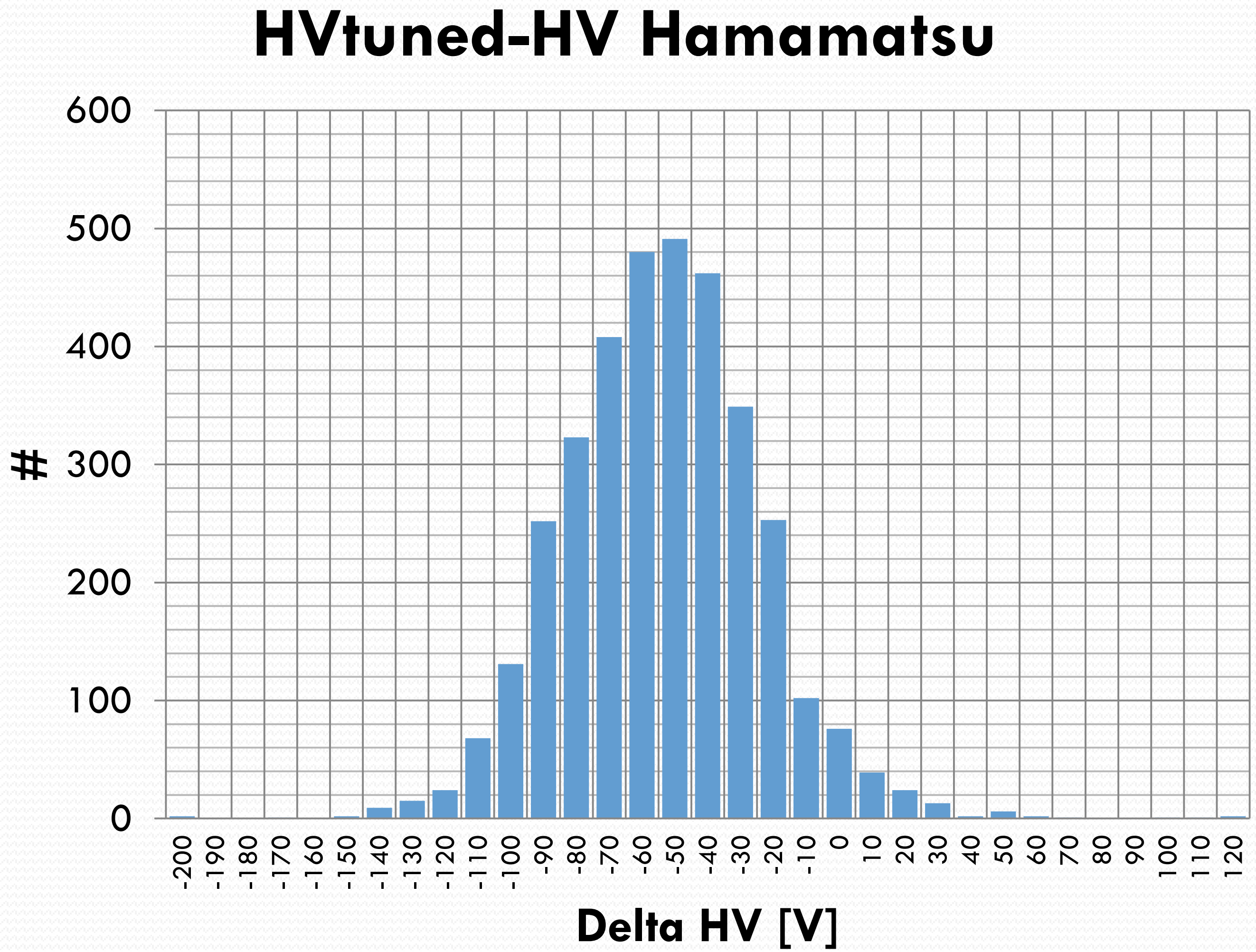


Some statistical anomalies due to a dependecy of the measurement to the laser conditions

This «instability» was fixed from test 77

About PMTs HV

Distribution of the HVtuned and HVvendor difference

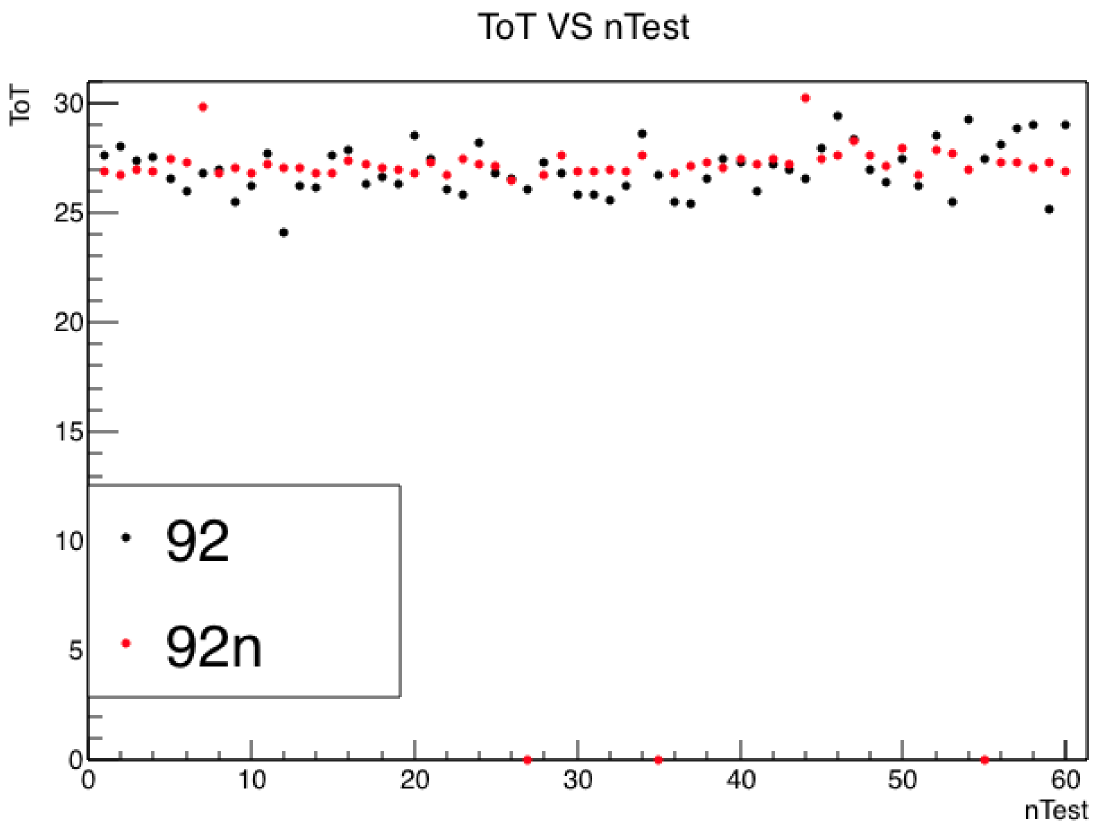


The sigma of this distribution is 20V approx (FWHM=50V). The distribution is centered on -50V

About PMTs HV

Two tests performed with HV tuning and with VendorHV-50V

The test 92 was performed adopting the classic method (test 92n with HV tuning) and was porformed again setting all HV to the HVvendor – 50V value (test 92).

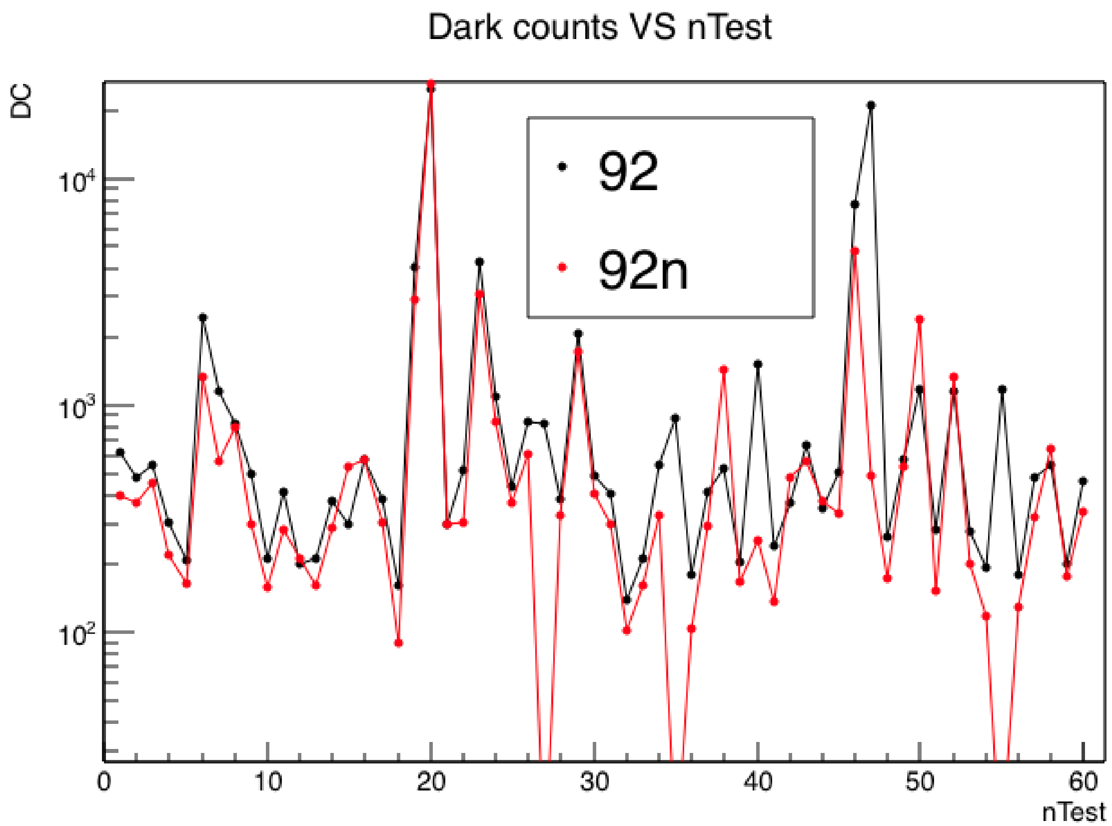


Obviously the ToT in test 92n is much more stable but as you can see the differences are not too high. In addition this calibration could be performed after DU integration.

About PMTs HV

Two tests performed with HV tuning and with VendorHV-50V

The test 92 was performed adopting the classic method (test 92n with HV tuning) and was porformed again setting all HV to the HVvendor – 50V value (test 92).

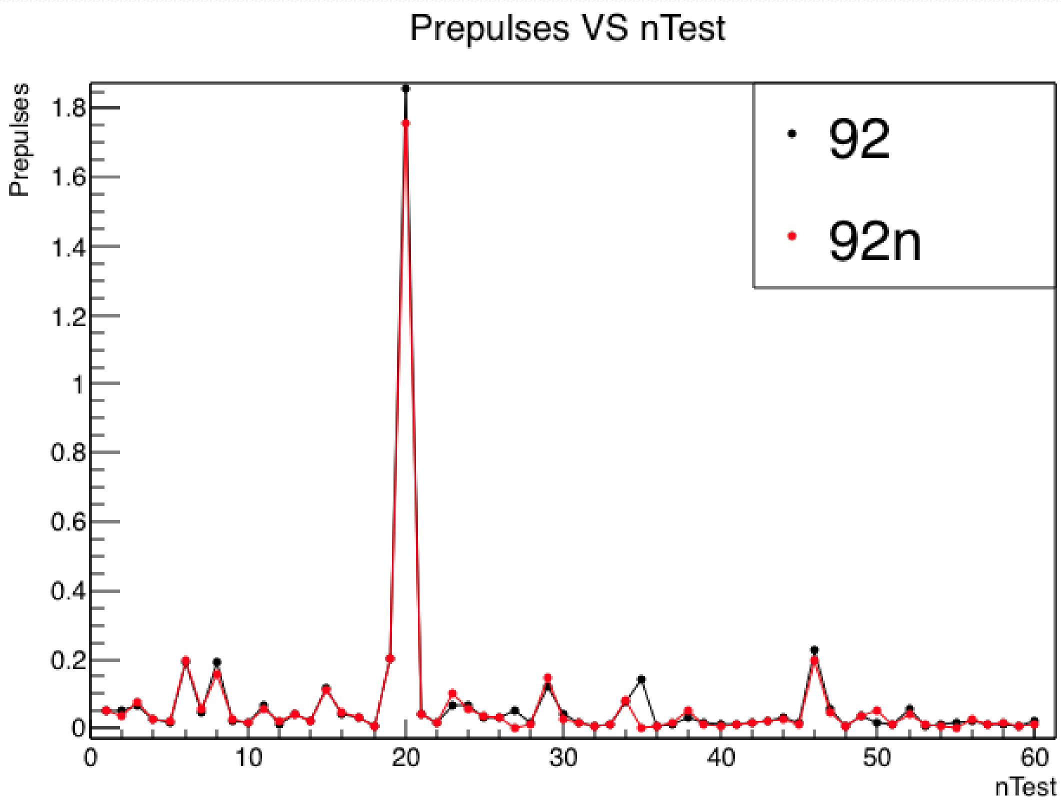


Here the DC for both tests. The differences are negligible but during the HV tuning 3 PMTs do not passed the test (3 DC=0 points)

About PMTs HV

Two tests performed with HV tuning and with VendorHV-50V

The test 92 was performed adopting the classic method (test 92n with HV tuning) and was porformed again setting all HV to the HVvendor – 50V value (test 92).

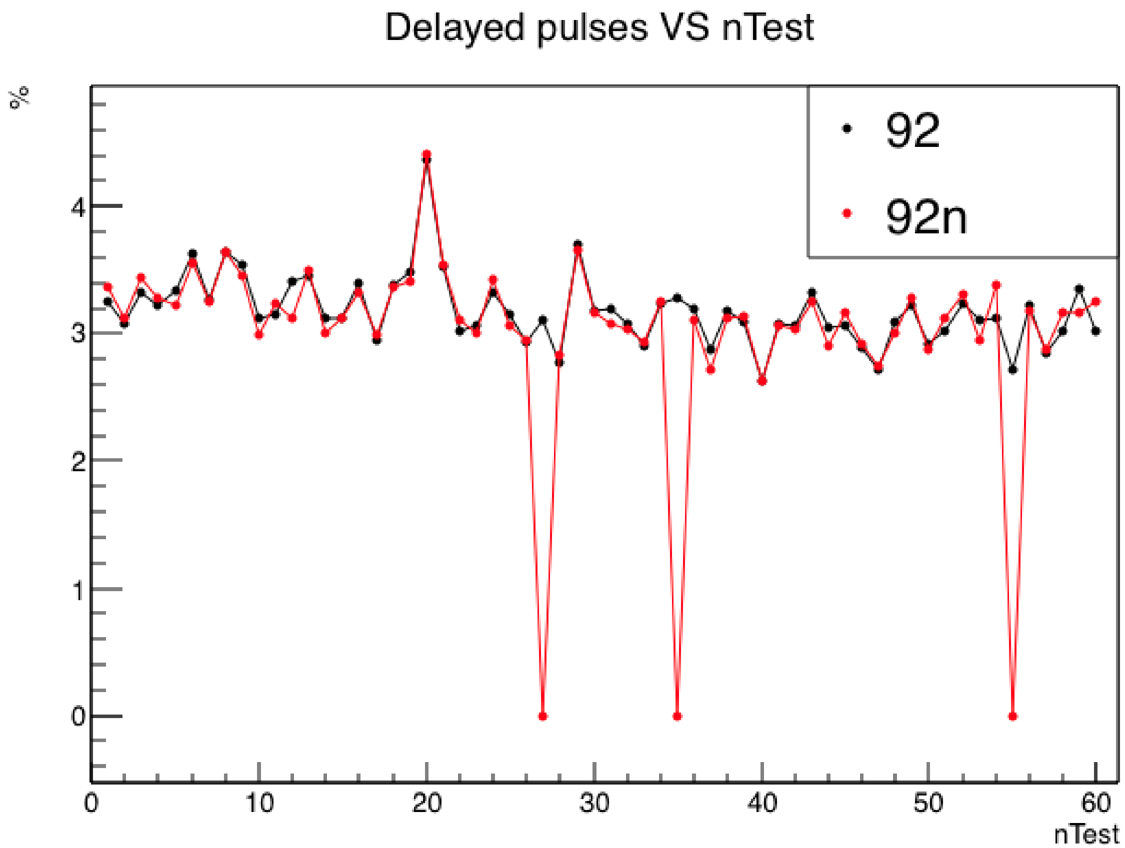


Here the prepulses, we have almost the identical behaviour for both tests.

About PMTs HV

Two tests performed with HV tuning and with VendorHV-50V

The test 92 was performed adopting the classic method (test 92n with HV tuning) and was porformed again setting all HV to the HVvendor – 50V value (test 92).

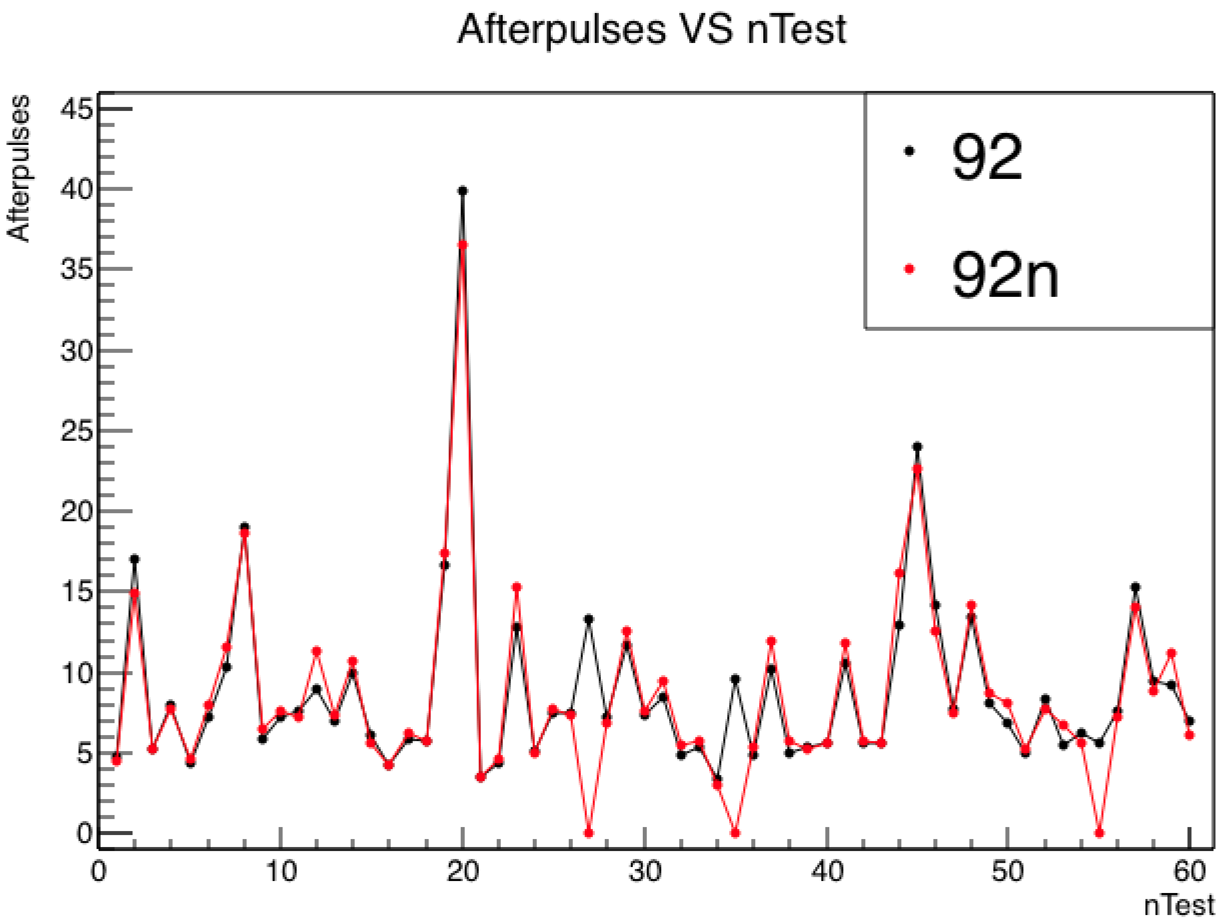


Also for the delayed pulses we have the same behaviour, the 3 zero peaks are for the PMTs that do not have passed the HV tuning.

About PMTs HV

Two tests performed with HV tuning and with VendorHV-50V

The test 92 was performed adopting the classic method (test 92n with HV tuning) and was porformed again setting all HV to the HVvendor – 50V value (test 92).

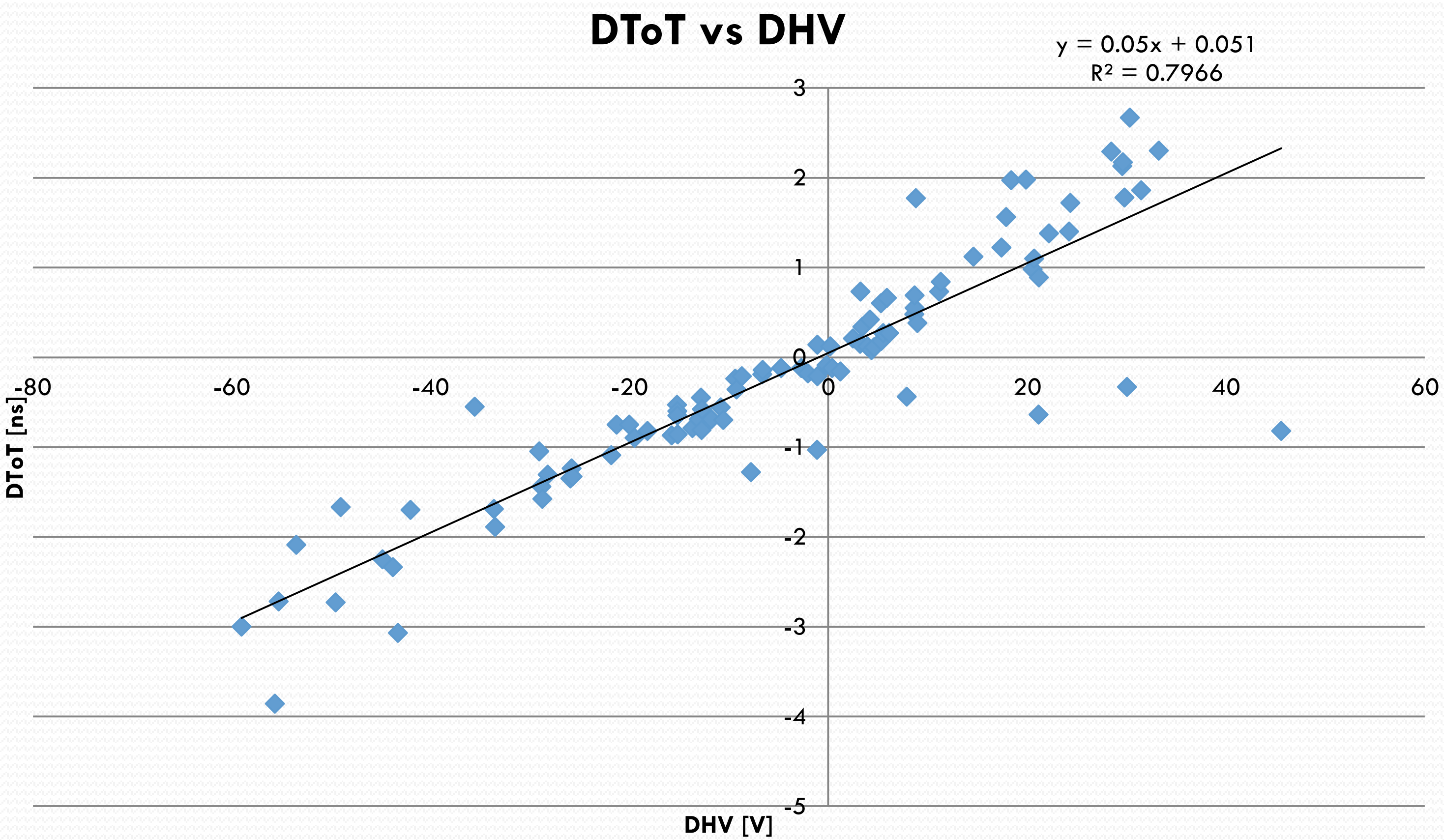


Also for afterpulses the two measurements are almost equal.

About PMTs HV

Also test 93 was performed with VendorHV-50V and performing the HV tuning.

ToT differences vs HV differences for both tests



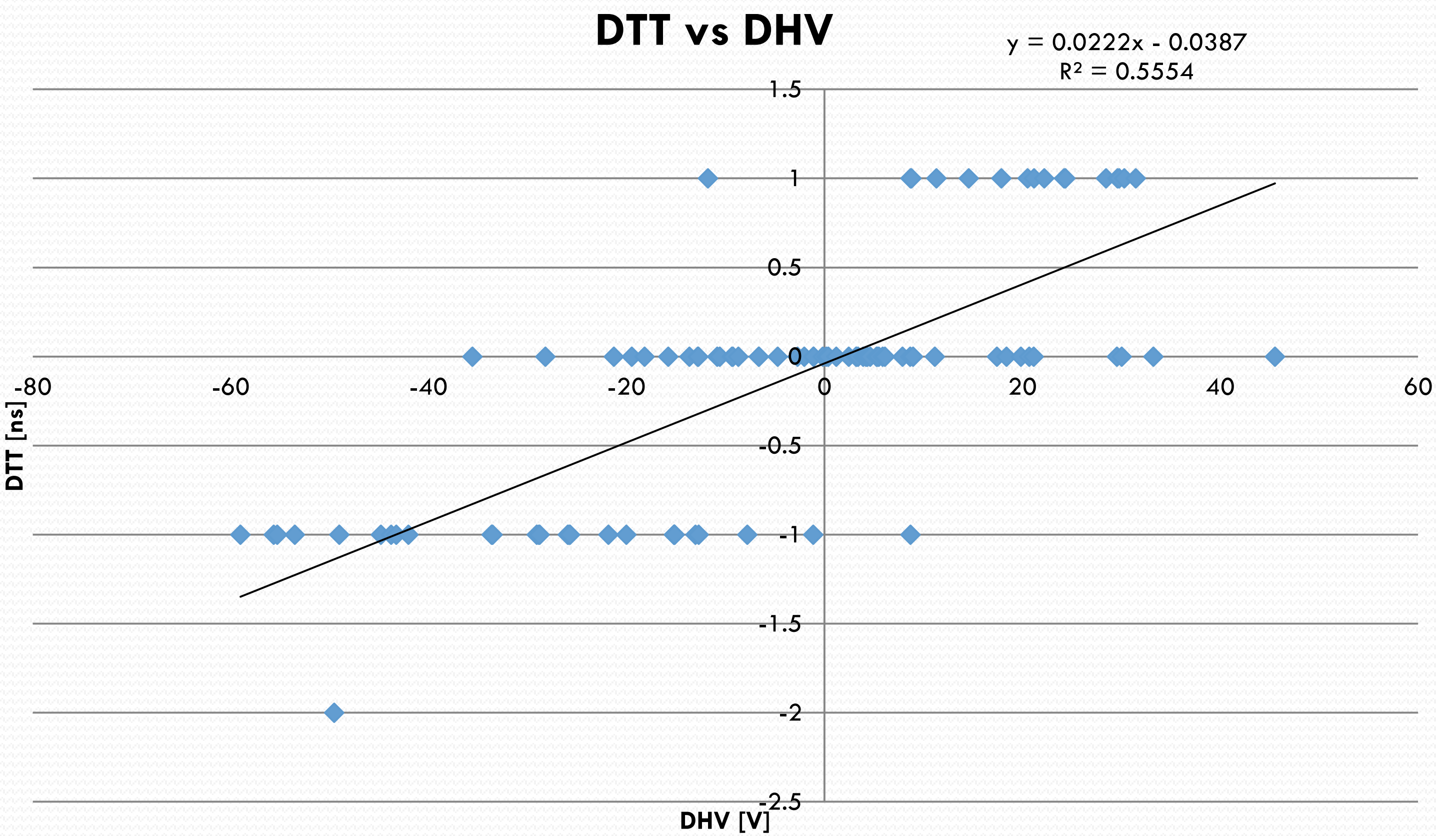
Linear approximation due to the small HV interval

Approx. 1 ns/20V

About PMTs HV

Also test 93 was performed with VendorHV-50V and performing the HV tuning.

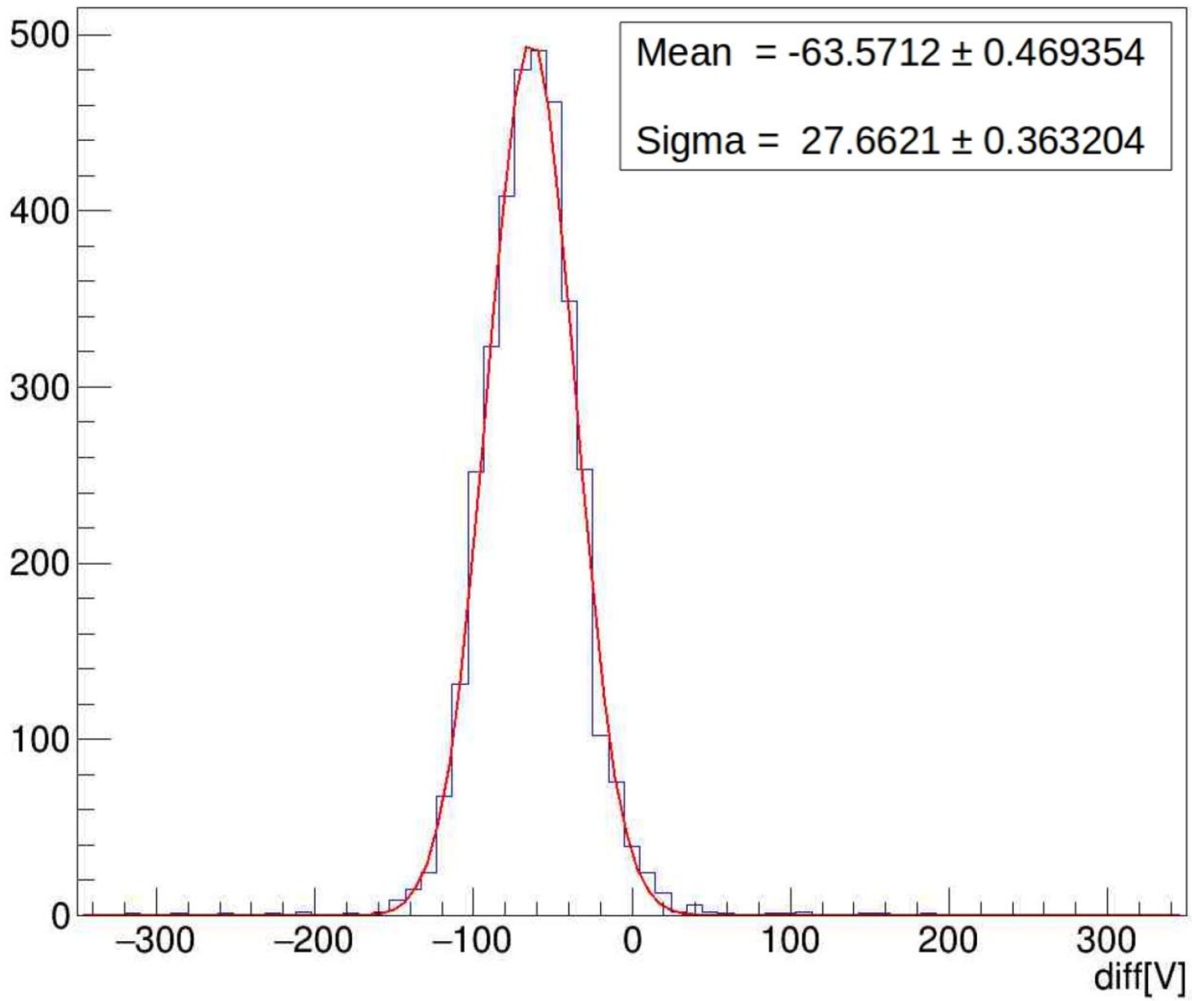
TT differences vs HV differences for both tests



Linear approximation due to the small HV interval

Approx. 1 ns/40V

About PMTs HV



Conclusions

- 6960 PMTs tested: 6483 green PMTs, 472 RED PMTs and 5 YELLOW PMTs.
- RED and YELLOW PMTs were replaced by Hamamatsu
- Small variations in HV have a small impact on PMTs performances.
- HV tuning fails if the promis ID is wrong (bit flip)
- The RMS of the hit time histogram is a good parameter to identify RED PMTs due to timing problems.
- Pre-darkening longer than a week is need to prevent effects due to sunlight or fluorescent light exposure