

**KM3NeT PMT Workshop**  
**Napoli, 15 January 2018**

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## The PMTs in the KM3NeT DOMs

PMTs are the real heart of KM3NeT DOMs and their most crucial component. Every solution, every choice, every adopted technology is finalized to have an optimal use of PMTs and to provide the best working environment to PMTs

Therefore PMTs play a central role in DOM integration. Special focus on

- handling
  - storage
  - tests
  - PMT-related DOM Integration issues
- 
- ✓ A discussion on ORCA-DU2 DOMs will follow, focused on DOM Integration parameters
  - ✓ In the end, a DOM Integration wishlist for the outcome of this workshop will be provided

## PMT handling

ESD protection measures for KM3NeT reference document is

KM3NeT\_ELEC\_2016\_001 - ESD \_ Protection\_Measures \_ in\_KM3NeT\_v1

Note:

The activities inside KM3NeT DOM Integration requiring ESD measures are:

- Installation of electronics boards inside DOMs and base modules
- Functional (intermediate) test of DOMs

No specific ESD rule is established for the mounting of PMTs inside DOMs. Formally not requiring ESD precautions. The only hint is the following:

“Tests of PMTs equipped with bases (after installation of the base, each pair of PMT equipped with its base is coated with a high-resistivity layer which shields all ESDS devices of the base)”

**DOM Integration teams are currently adopting for the mounting of PMTs inside the DOM the same ESD precautions adopted for the installation of electronics. Shall we keep this or we can relax it?**

Any indication concerning ESD and mechanical handling during integration and transportation?

## PMT storage

No specific document exists in KM3NeT for the storage of PMTs at a DOM Integration level.

Three different levels:

1. storage of PMTs BEFORE integration
2. storage of PMTs DURING integration
3. storage of complete DOMs

Storage has an impact on PMT performances. DOM Integration sites follow some basic indications for pre-darkening, while for the storage of PMTs during integration the only rule is to avoid, “as much as possible” the exposition to direct or diffuse sunlight, with the requirement of using LED lights in the integration lab. This constraint came from the PMT group and it is met by all DOM Integration sites.

No particular constraints on:

- Pre-darkening conditions
- Environmental conditions for the three levels of storage
- ESD precautions during storage

Currently, common (known) constraints on environmental conditions for PMT storage are adopted.

Specific environmental conditions are defined during DOM Integration steps and during DOM test stages

## PMT installation

Installation of PMTs inside the 3D-printed PMT support structure:

- every PMT has its own location
- An O-Ring is used to fix the PMT and to prevent optical gel leak
- Two different cases:
  - early stage (old PMT support structures): a ring of silicon mastic was applied under the head of PMTs in order to reduce electro-static discharges
  - current stage (current version of PMT support structures): PMTs are quickly and safely installed inside structures, no silicon mastic is applied

Connection of PMT pigtailed to Octopus boards

- the connector in use (SAMTEC 0.80 mm Tiger Eye™ Micro Terminal Strip) is really fragile
- some issues with broken pins → PMT channel loss during acceptance tests (some NCRs around)
- After the connection, the octopus boards are hanging (kept by PMT pigtailed). In early stages it was mandatory to use a mechanical support for the octopus. Then deprecated as redundant. Some sites are still using it as a precaution. Any (possibly definitive) indication?

## PMT tests

Two levels of tests are performed on PMTs during DOM Integration:

- Functional test: check of electrical connection of PMTs only (as a consequence, a first-stage check of PMT positioning is done). Common issues:
  - PMT channel loss due to broken/bent pin in the pigtail connector (still in time to replace the PMT or to repair the connector)
  - Wrong PMT-Base association. Due to “bit flip” (NCR 2015\_074). **Not correctable**
- Acceptance tests: analysis of working parameters of PMTs (ToT and dark counts). Also correlation and positioning are checked. Remarks:
  - In early stages, only TESTED PMTs were integrated inside DOMs.
  - Currently only NON-TESTED PMTs are integrated. This required a re-definition of PMT acceptance parameters

Email sent to the DOM-INT mailing list last 06 August.

## Motivation:

- with the upcoming (and current) DOM production based on the integration of non-tested PMTs, a definition of new criteria for DOM acceptance tests is mandatory
- it is inadequate to keep the criteria used in the past, and this is confirmed by the large number of NCRs raised about dark rates and ToTs.

## Method:

- an analysis of the 7000 PMTs tested in the darkbox facility in Naples has been performed

## Preliminary:

- use the information available for tested PMTs in order to respect the constraint to allow up to three "bad" PMTs per DOM
- the assumption is that being all the non-tested PMTs belonging to the same batch of the 7000 tested PMTs the features of PMTs to be integrated are well described by the tested sample.

## Remark:

- With the use of untested PMTs, no screening on "bad" PMTs (red and yellow, in the triage coding adopted by KM3NeT) is possible. The percentage of red PMTs has been calculated to be about 3.5%, this means that on average we expect about **one red PMT per DOM**.

## Time over Threshold

### Current criterium:

- the old acceptance range for PMTs integrated in DOMs was  $24\text{ns} < \text{ToT} < 30\text{ns}$ . This range was chosen in order to be “close” to the value of ToT (26.4ns) corresponding to the operational gain of  $3 \times 10^6$ .

### Preliminary:

- for all the 7000 tested PMTs an HV tuning has been mandatory in order to define the operational HV corresponding to a ToT of 26.4ns. The results of the tests on the sample of 7000 PMTs showed that, on average, the tuned values of HV are higher of 63.5V (in absolute value) with respect to the HV provided by the vendor.

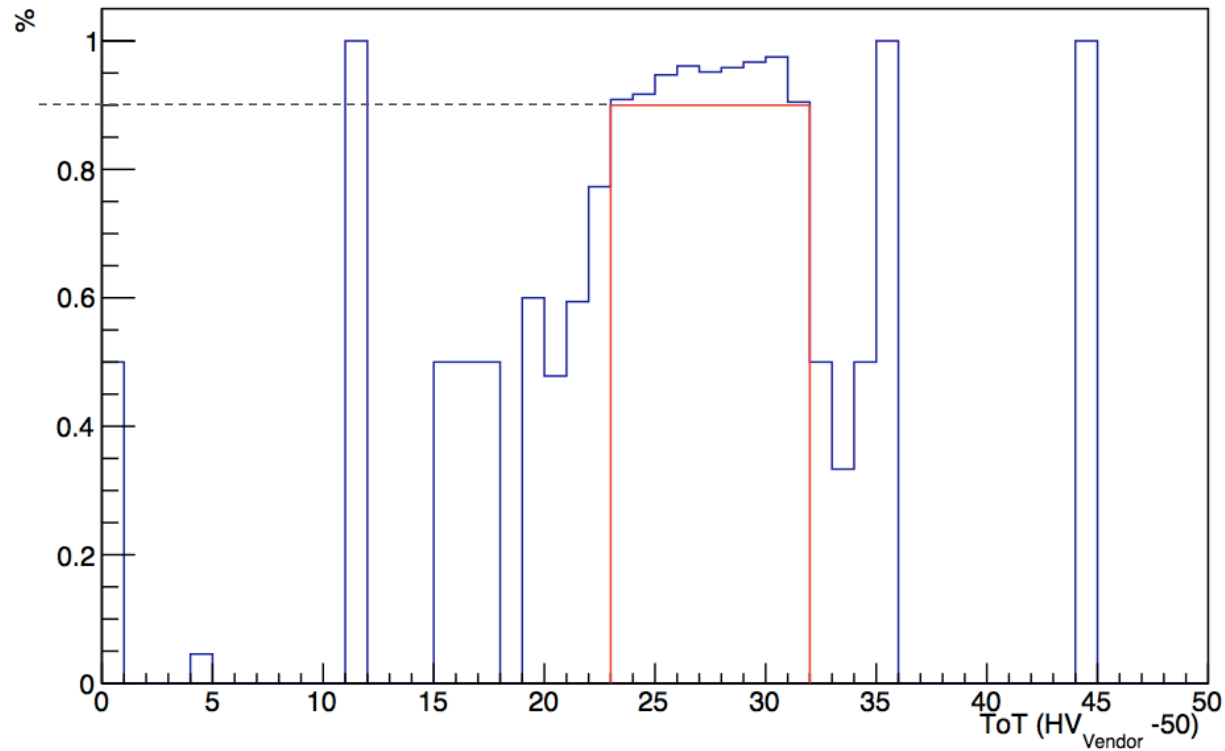
### Analysis:

- for non-tested PMTs the reference operational value for the HV is HV\_vendor-50.
  - Reason: the HV-tuning is a step-process. It is centered on the HV vendor value and proceeds in steps of 25V (over and below the central value). Therefore statistics is available only for the HV\_vendor-50V value.
  - Consideration: such statistics can be considered fully indicative, provided the negligible difference of about 10V wrt the HV\_tuned central value
- it has been taken as a reference the results of the **first** tests on all the 7000 PMTs (it means including red and yellow, obviously). It has been analyzed the fraction of PMTs having **final** ToT between 24ns and 30ns (current acceptance criterium) as a function of the values of the **first** ToT measured at HV\_vendor-50.



## Time over Threshold

### Results



#### Remark:

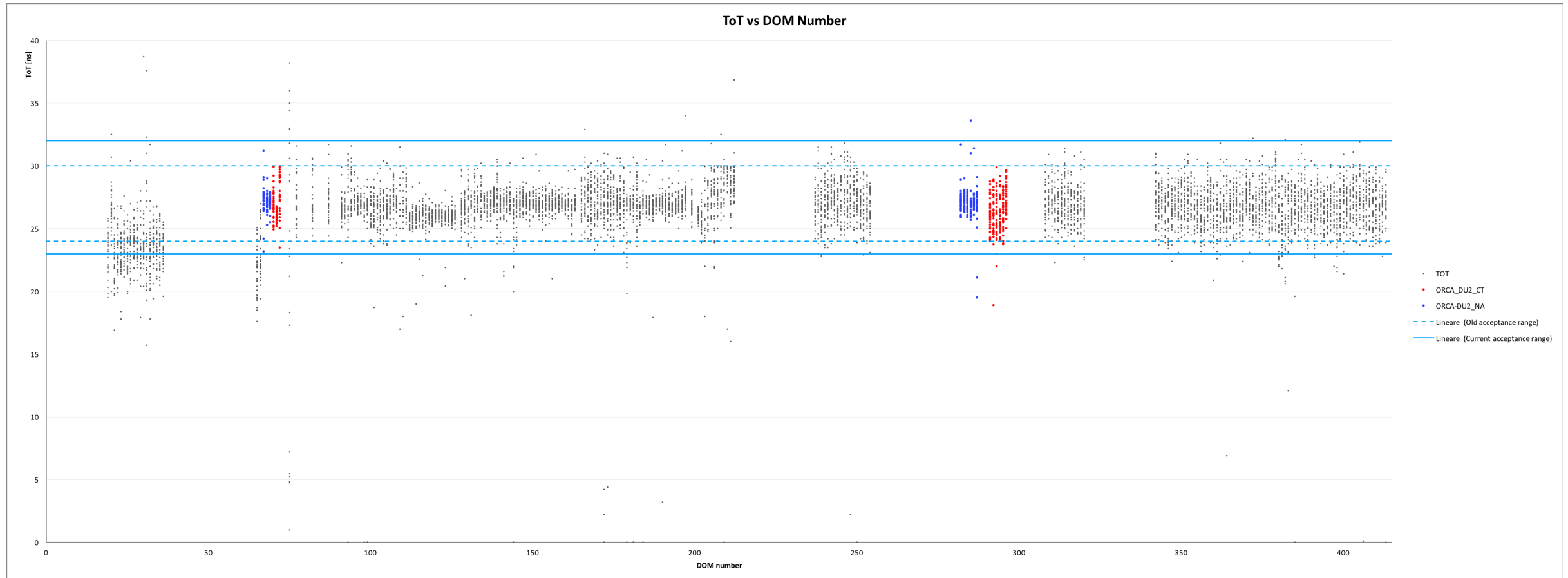
even for PMTs having, at HV\_vendor-50, an initial value of ToT between 24 and 30ns **the probability of success is never 1**. This is due to the fact that for some PMTs the **HV tuning can fail**, due to misbehavior of the PMTs. In this way, also this feature is taken into account.

The decision has been to set the new range for ToTs in the DOM acceptance tests between 23 and 32ns. In this range, PMTs have a probability of more than 90% to be ok. This means that less than the 10% of PMTs can be not-acceptable, corresponding to 3 PMTs per DOM. This is perfectly in line with the current acceptance criterium.

## Time over Threshold

### Statistic study

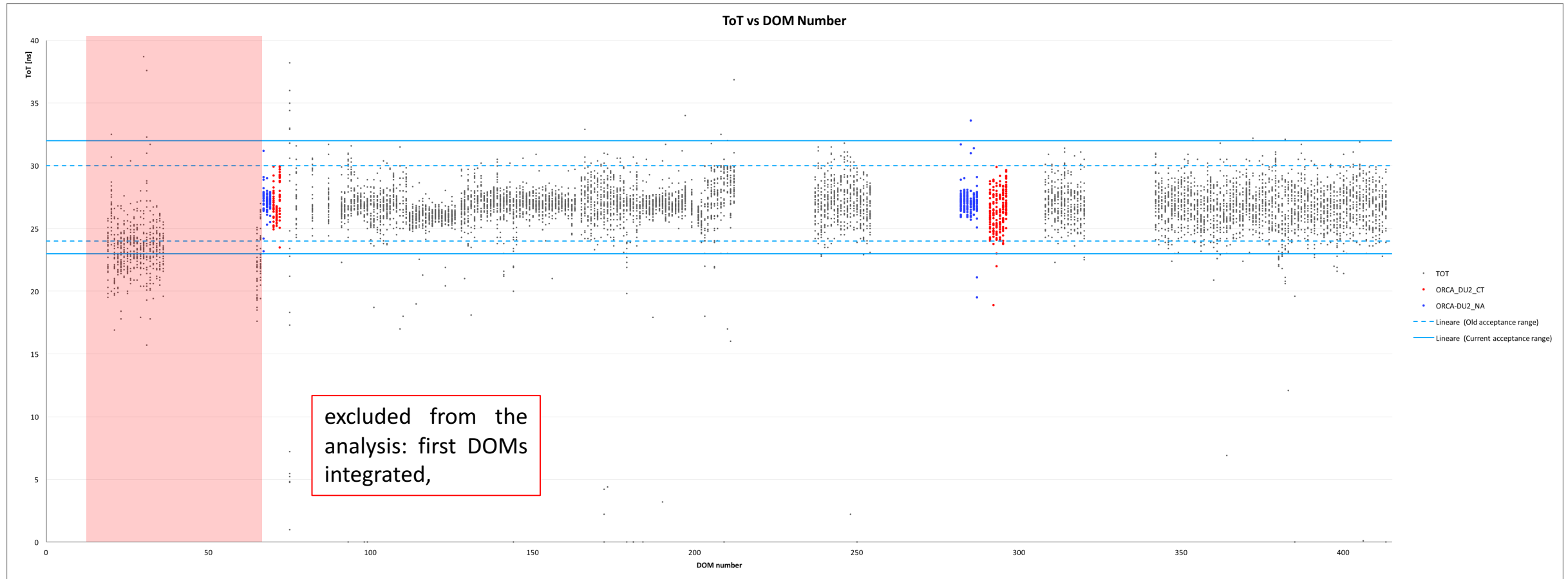
- a statistic study has been done considering ALL the DOMs integrated to date (for which the acceptance test sheet is available)
- for all the DOMs, it has been done a comparison between the current criterium and the new one



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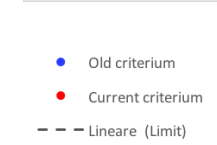
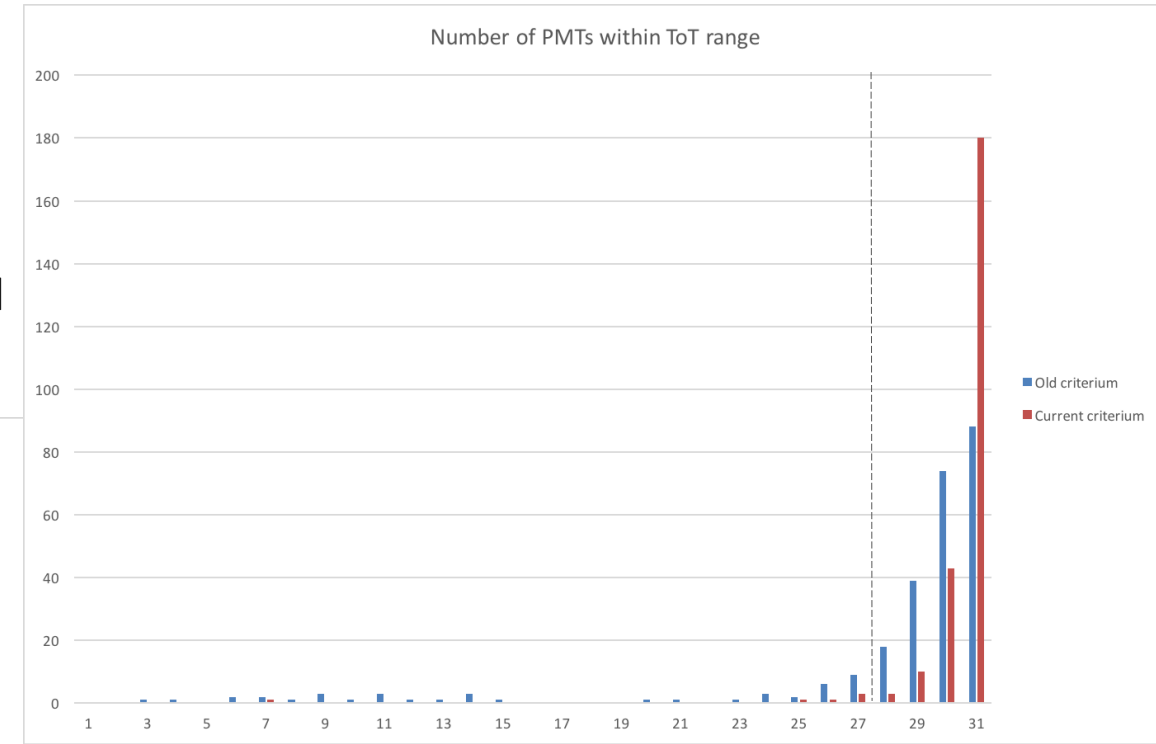
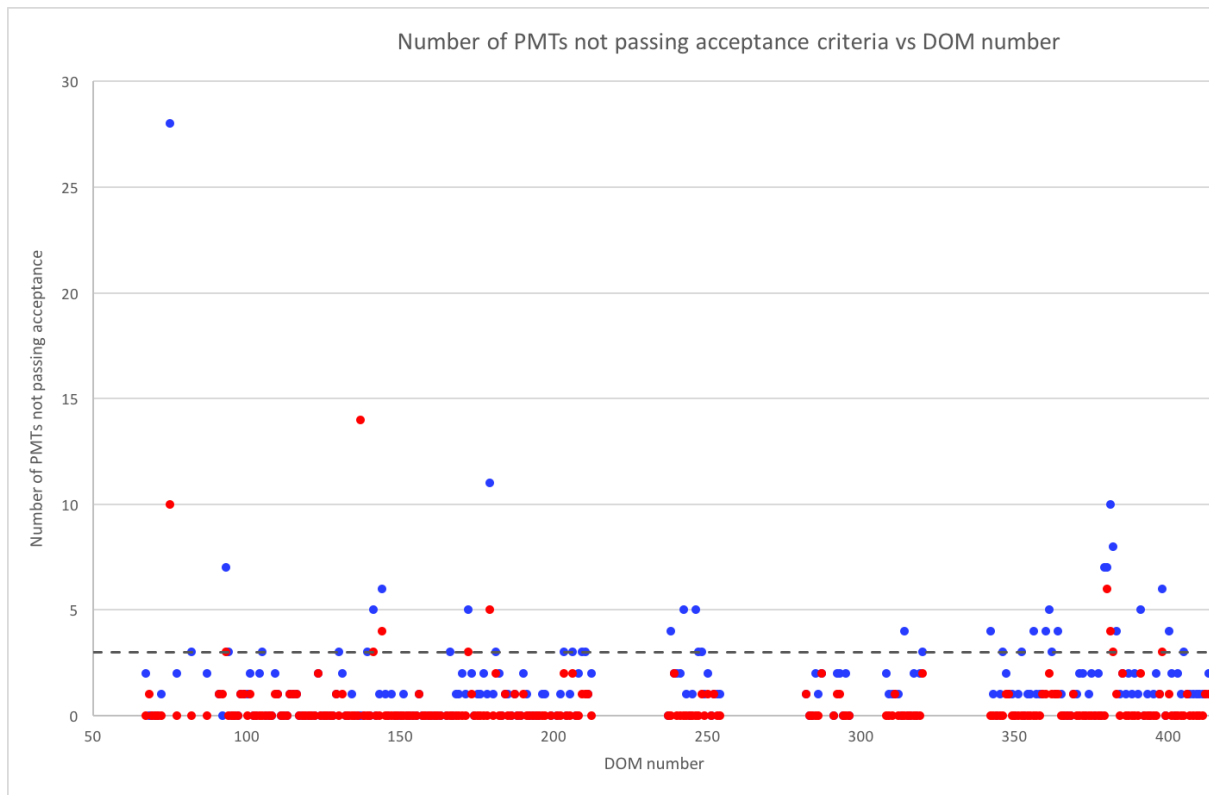


## Time over Threshold

### Statistic study

Results:

- with the proposed criterium, the 2.5% of the DOMs integrated so far is to be rejected (it was 10.4%!!!)



## Time over Threshold

### Considerations:

- If we examine the current NCRs, we can see that only a small fraction of DOMs can be classified as “problematic”. These cases have been addressed singularly.

### Accessory proposal: **how to address the cases of DOMs not passing the acceptance test for ToT**

- we consider for each PMT the **"failure" probability** as from the plot and we make a sum on all the 31 PMTs:
  - If the value is lower than 3 the DOM is accepted
  - otherwise it is rejected

This is to take into account that for most of the values in the new acceptance range the "success" probability is well above 90%. And of course this must be taken into account in case of problematic DOMs.

Proposal approved, this calculation has been integrated in the acceptance excel sheet and the calculation is done automatically.

- This will automatically address the NCRs and automatically close many of them (or just avoid to open an NCR at all, with just a warning...)
- This will reduce the number of "effective" NCRs
- A similar approach can be defined also for what concerns dark noise.

In case of further failure, the solution is to try a re-tuning in lab. Then waiver or rejection.

## DARK NOISE

### Old criterium:

- the old acceptance limit for dark noise in PMTs integrated in DOMs was **3500cps**. This value corresponds to a dark count limit of 2000cps in the darkbox, taken into account the additional contribution of DOM glass after integration.

### Constraint:

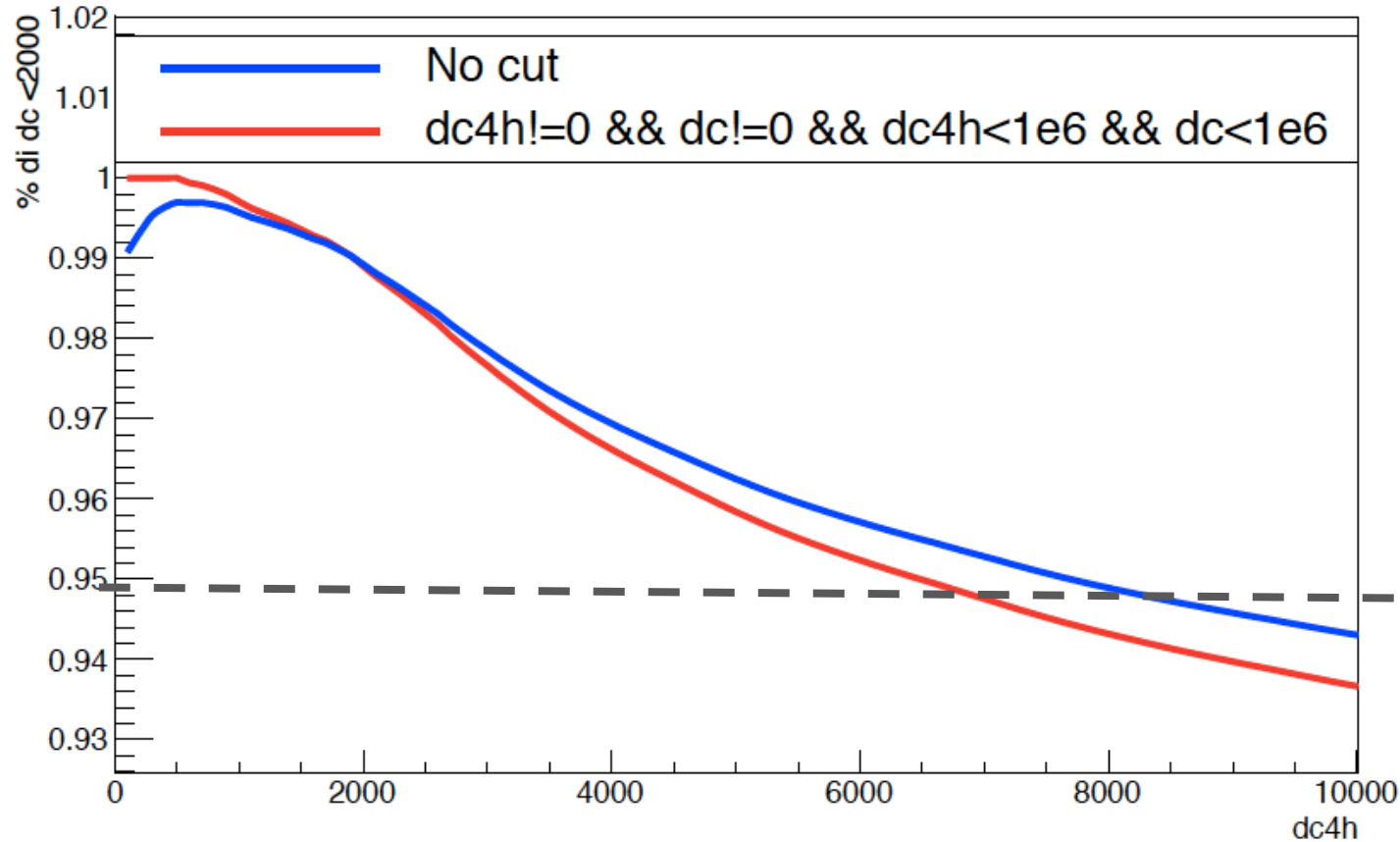
- The duration of the acceptance test is **4 hours** and this will be set as a constraint. The reason is that keeping this duration it will be possible in all the DOM integration sites to do (in optimal conditions) **2 acceptance tests per day per greenbox**.

### Analysis:

- all the 7000 tested PMTs have been taken into account (i.e. also PMTs that at the first test were tagged as red or yellow)
  - Reason: from now on **no screening will be available**, therefore in DOMs also red and yellow PMTs will be integrated. Both yellow and red PMTs have been re-tested, so for them more tests are available. Anyway, from now on the PMTs will be tested only once (inside DOMs), therefore only the **first** tests can be taken as a benchmark.
- the duration of the tests of the 7000 PMTs have been variable, therefore the **final** value of the dark noises correspond to an unknown test duration. In addition, different pre-darkening conditions for the 7000 PMTs are possible. This has a strong impact on the dark noise measurements.
- In order to define the current criterium, it has been analyzed the dark noise of all the 7000 tested PMTs. In particular, it has been plotted the fraction of PMTs having a **final** dark noise rate between 0 and 2000cps as a function of the **first** dark noise measured after 4 hours.

## DARK NOISE

### Results

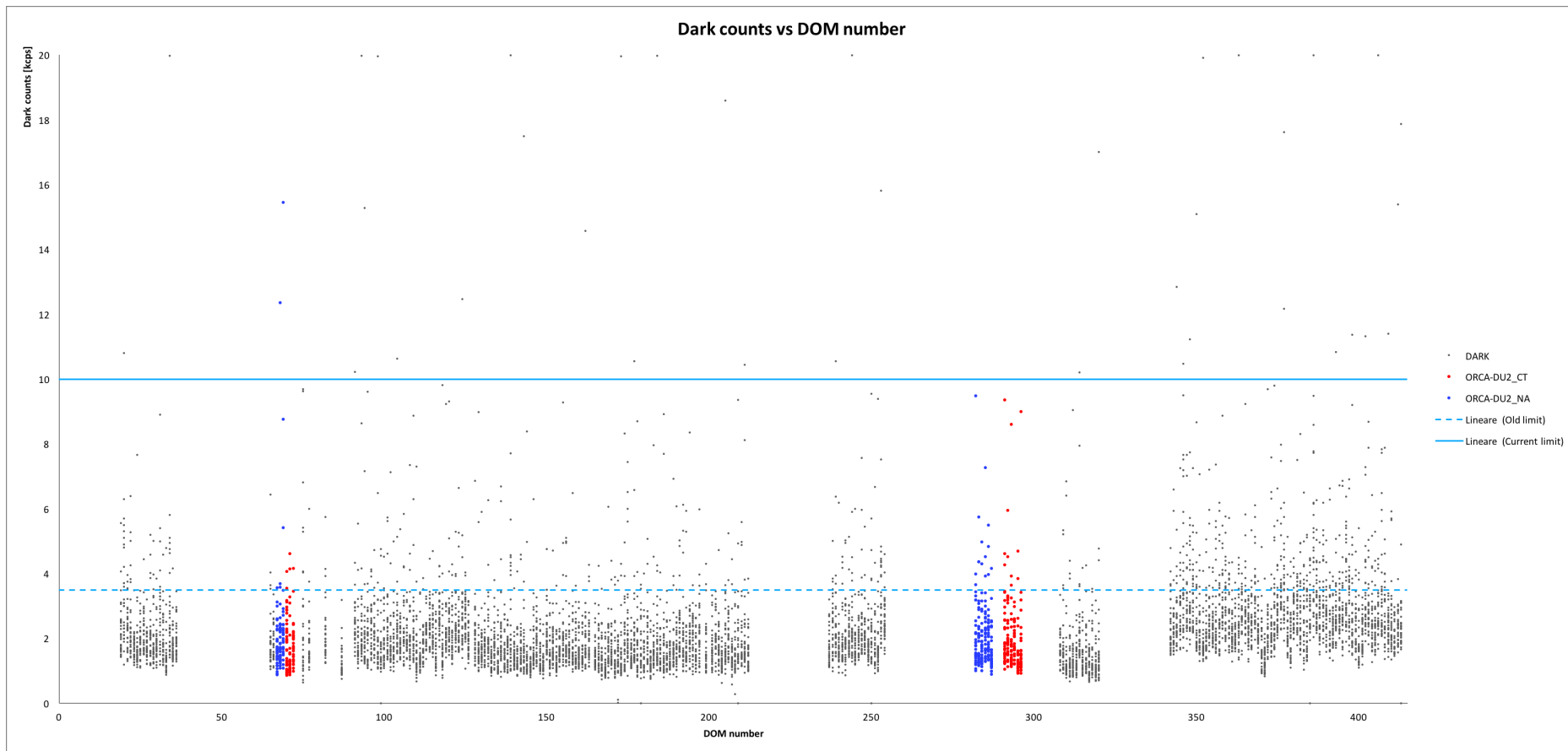


The decision has been to keep a conservative limit of 10kcps for PMTs integrated in DOMs. This value corresponds to the value in the plot of 8500cps (DOM glass contribution subtracted). This means that if all the 31 PMTs inside a DOM have a dark noise below 10kcps, only a fraction lower than 6% can be not-acceptable (that means <2 PMTs per DOM).

## DARK NOISE

### Statistic study

- a statistic study has been done considering ALL the DOMs integrated to date (for which the acceptance test sheet is available)
- for all the DOMs, it has been done a comparison between the old criterium and the current one





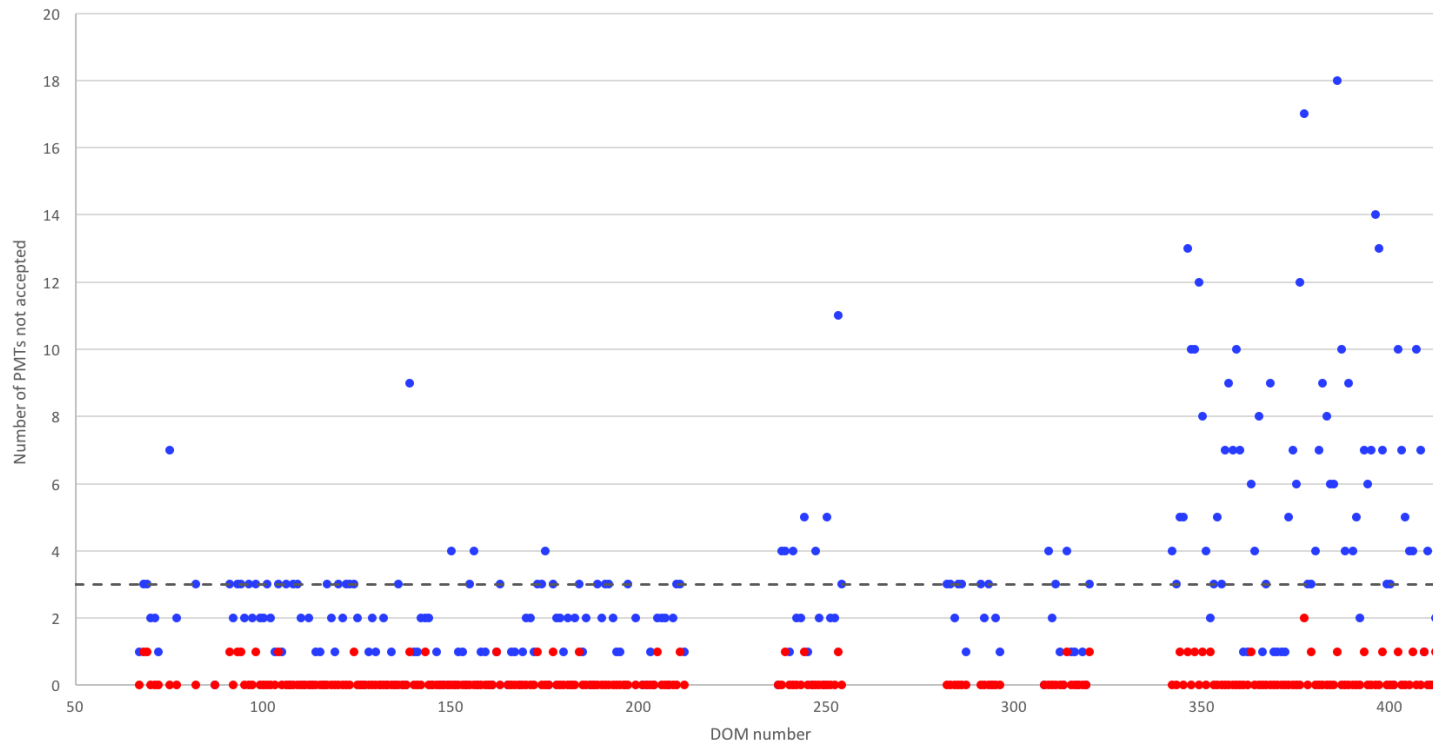
## DARK NOISE

### Statistic study

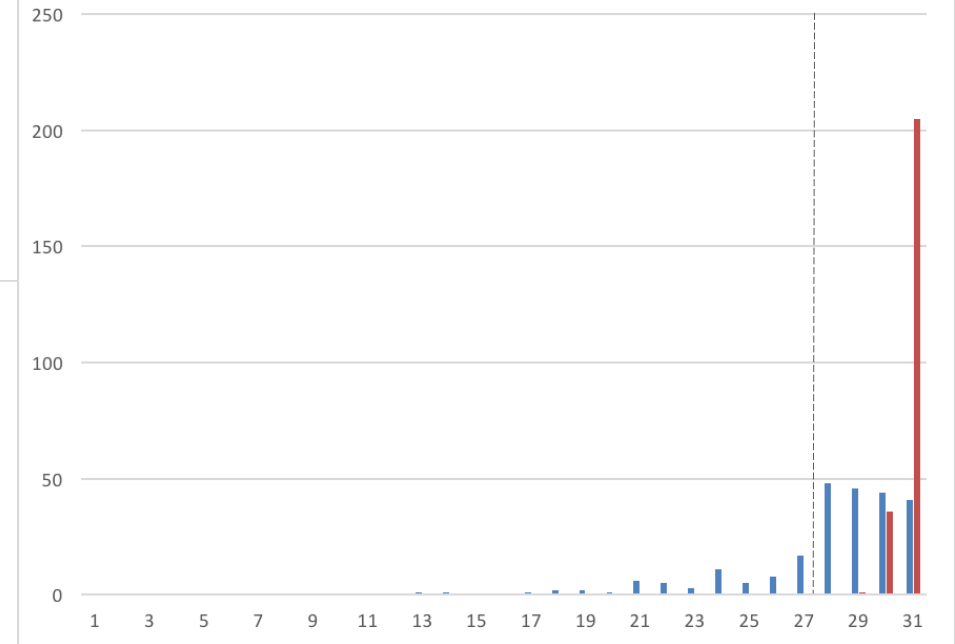
Results:

- with the proposed criterium, the 0% of the DOMs integrated so far is to be rejected (it was 26,2%!!!)

Number of PMTs not passing Dark Counts acceptance criteria vs DOM number



Numbers of PMTs passing Dark Counts acceptance criterium per DOM



• Old criterium  
• Current criterium  
 - - - Lineare (Limit)



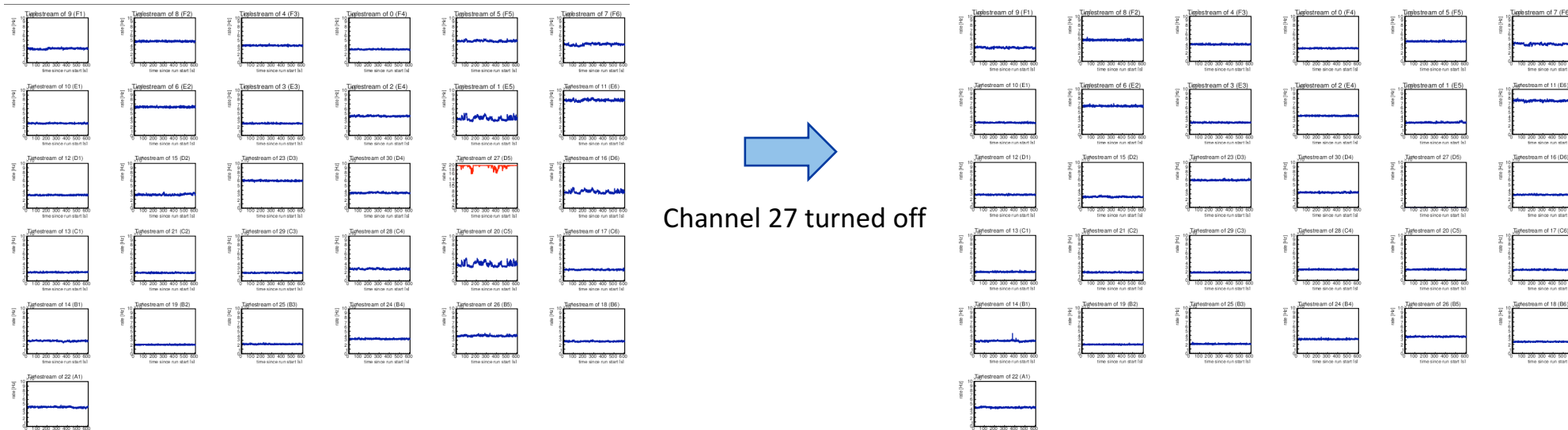
This led to a more relaxed pre-darkening for the most recent DOM production

## Final (?) remark

Currently we allow up to 3 PMTs failing the ToT acceptance test AND up to 3 PMTs failing the dark noise acceptance test. This means in principle up to 6 PMTs per DOM non-perfectly behaving. Can we do better?

Some points:

- According to the current acceptance criteria, a non-communicating PMT is equivalent to a PMT with Dark counts and/or ToT out of range
- No solution has been found yet to the issue of SPARKING PMTs (NCR 2017\_114)
  - some cases have been documented in which a noisy (sparking) PMT affects all the neighbor channels. Electrical effect? Optical?
  - Channel 27 is the most affected (same also in one of the DOMs of the PPM-DU!)
  - The issue has already been raised at a SC level, but a solution has not been found yet
  - Currently DOM Integrators have been asked to “take a look at possible sparking PMTs”, but a check procedure has not been yet defined and integrated in the DOM testing procedure. Just a visual check is done, very inefficient
  - To date, only a comment on the elog is done. Acceptance tests are passed and information on sparking PMTs is not recorded. It could be precious in the investigation of PMT performances after deployment.



### Final (?) remark

Currently we allow up to 3 PMTs failing the ToT acceptance test AND up to 3 PMTs failing the dark noise acceptance test. This means in principle up to 6 PMTs per DOM non-perfectly behaving. Can we do better?

What about launching a task force to try to find completely different acceptance criteria?

Our constraint: before being adopted, every new (or additional) check during DOM acceptance or functional test must be integrated in MRunAnalyzer and made as much automatic as possible, in order to keep constant the overall testing time. This will have a strong impact on DOM Integration rate.

Anyway....

please keep in mind that we are testing PMTs for the first time in the acceptance test. This means that we do this when all actions concerning PMTs are irreversible. In principle I agree with setting stricter criteria, but provided the irreversibility of the step if we set too much strict criteria we will have many and many DOMs that will never be used. If the solution will be a systematic waiver then the therapy becomes worse than the disease!

## Focus on ORCA-DU2 DOMs

It has been shown that some DOMs of ORCA-DU2 exhibit a decreasing trend in their ToT distributions. This will be a central matter of discussion during this workshop, with dedicated presentations.

DOM numbers

# on DU	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
# on DB	291	292	293	294	295	296	282	283	284	285	286	287	67	68	69	70	71	72
Int.site	Catania						Napoli									Catania		
Int. period	Spring 2017												Spring/Summer 2015					

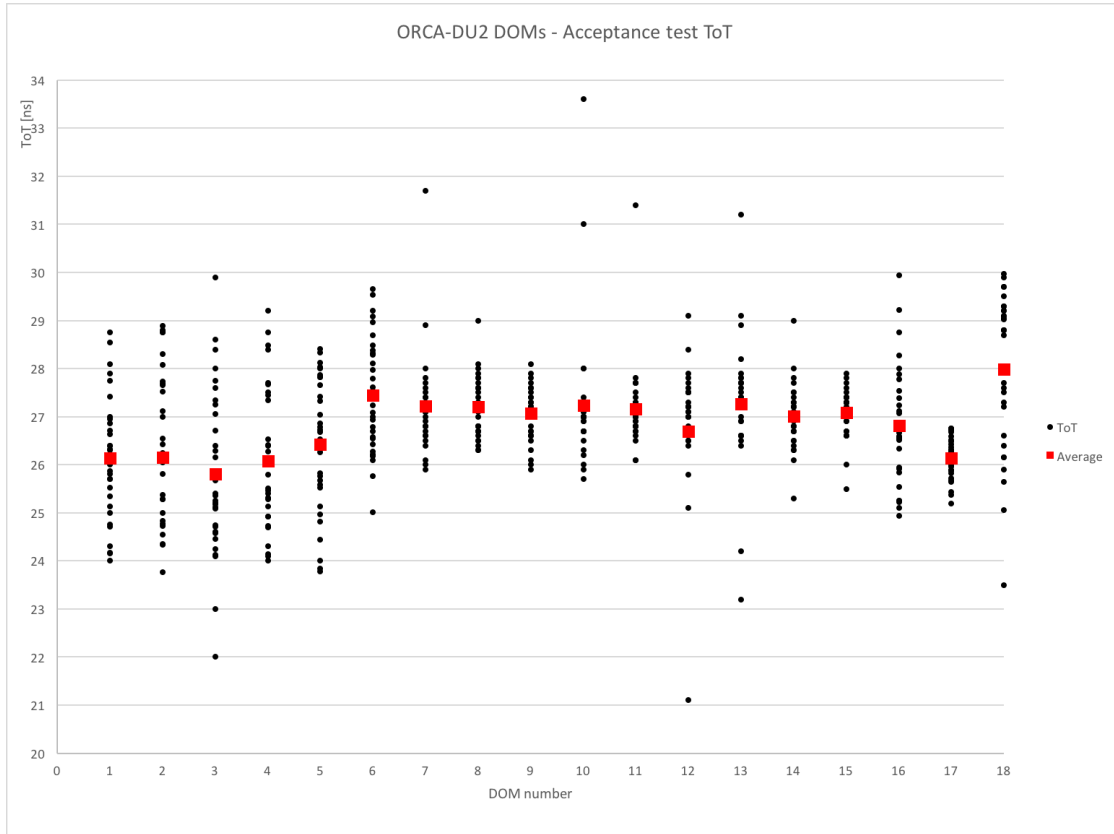
Some very important preliminary remarks on the DOM integration side:

- No anomaly has been noticed during the DOM Integration process. If anything is determining a strange behaviour of ORCA-DU2 DOMs this has been generated within the tolerances provided by the indications and the specifications included in the DOM Integration procedure and in the DOM testing official documents. **Therefore it should be avoided to talk about “Integration mistakes” or “Integration non-conformities”**
- All the DOMs deployed in ORCA-DU2 have successfully passed both the functional and the acceptance tests. All the measured parameters were within the limits set by the Collaboration. No NCR raised.

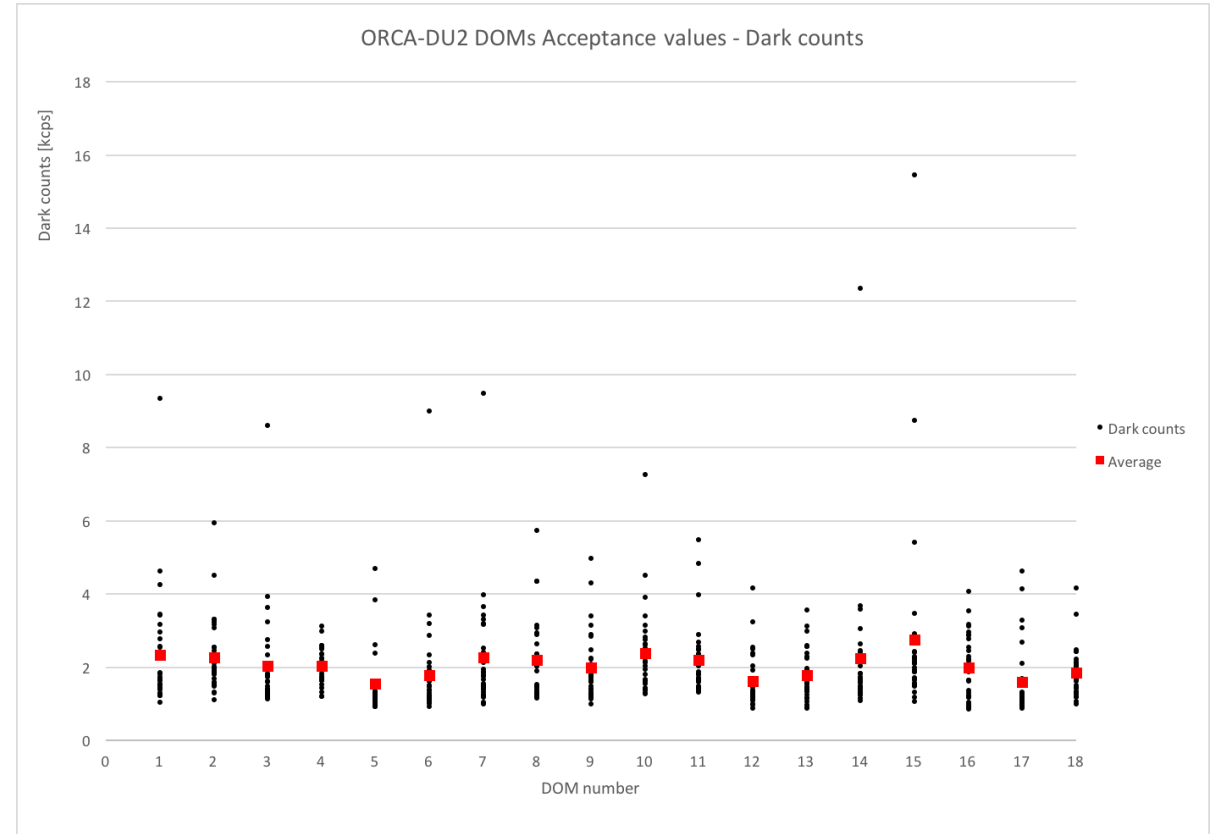
## DOM Acceptance parameters

This will be an indispensable, precious starting point for the upcoming discussion. This is how DOMs have been delivered to the DU Integration site

### ToT values



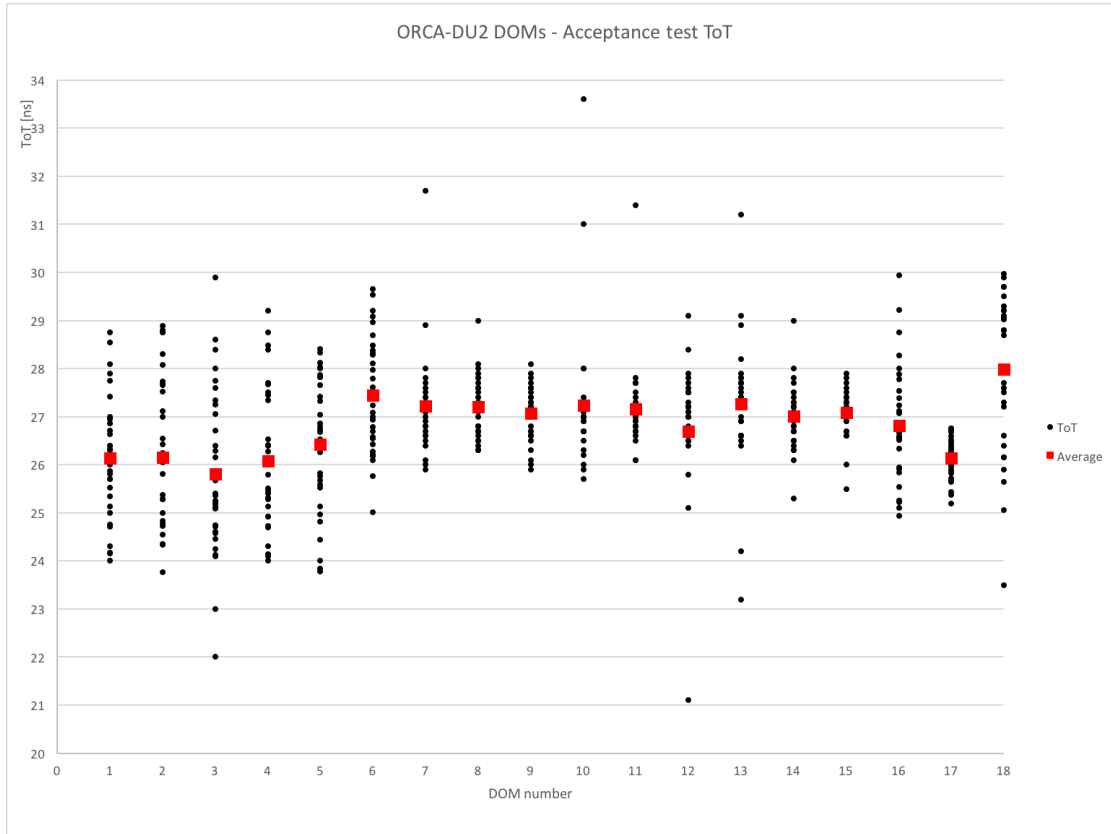
### Dark counts



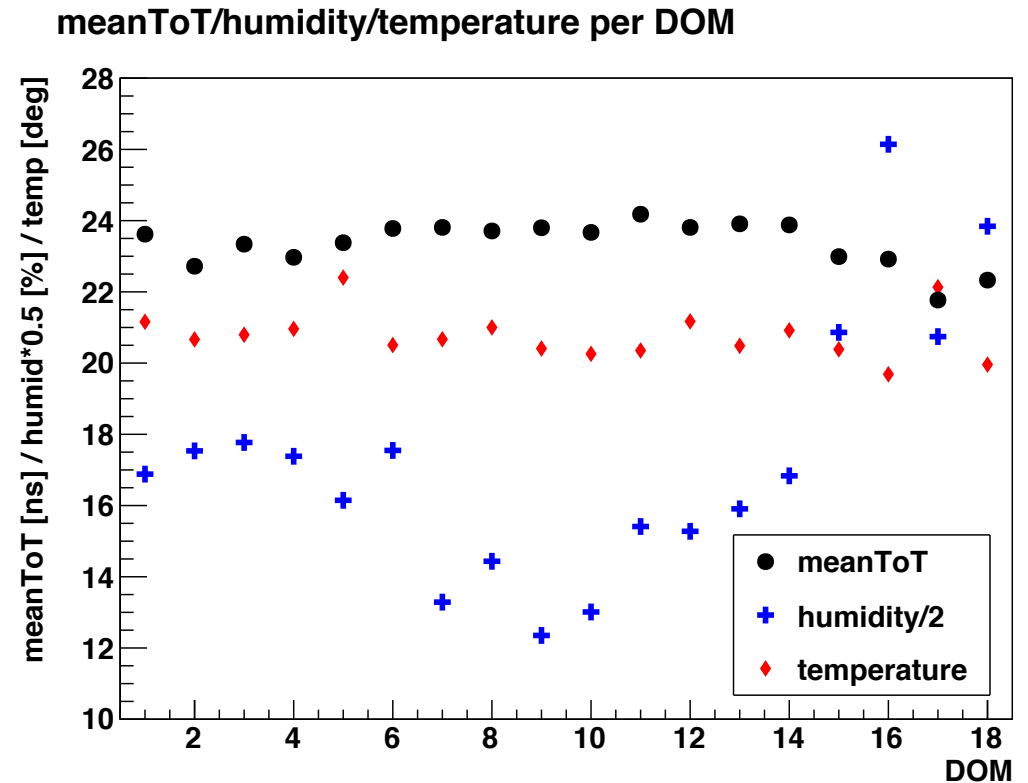
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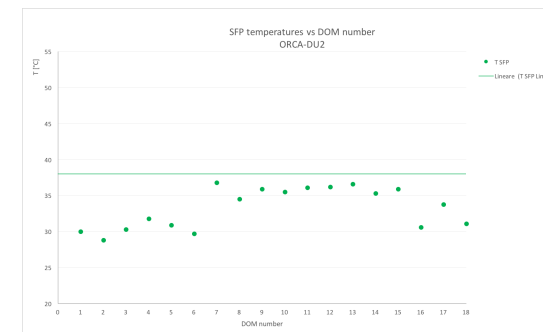
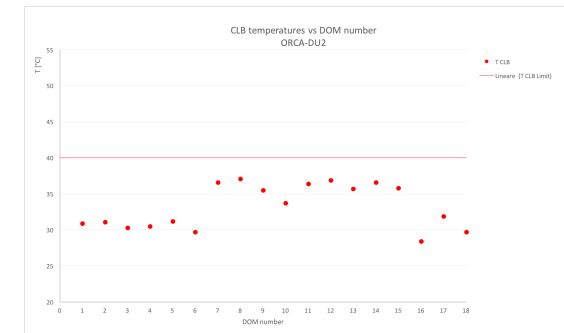
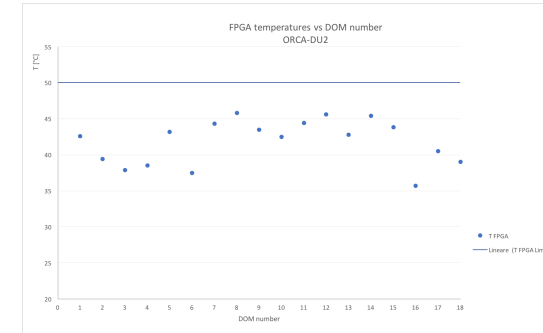
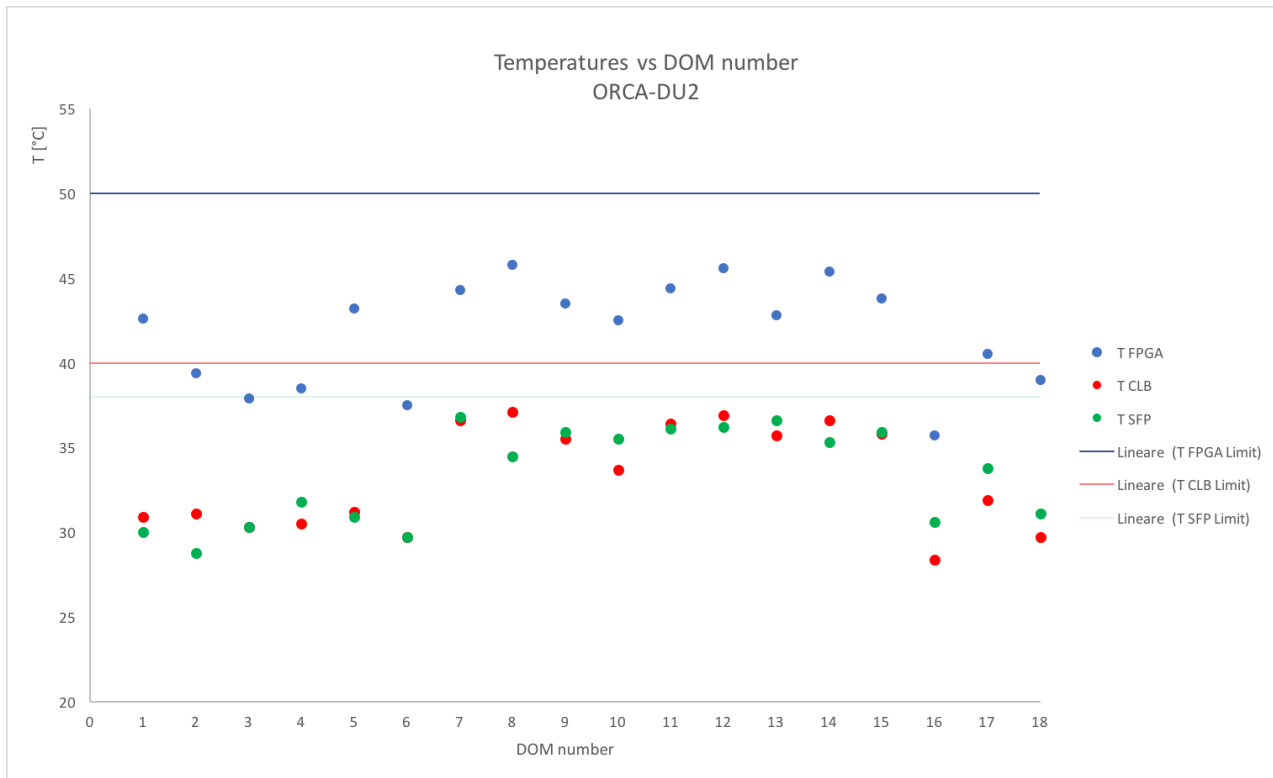
### After deployment



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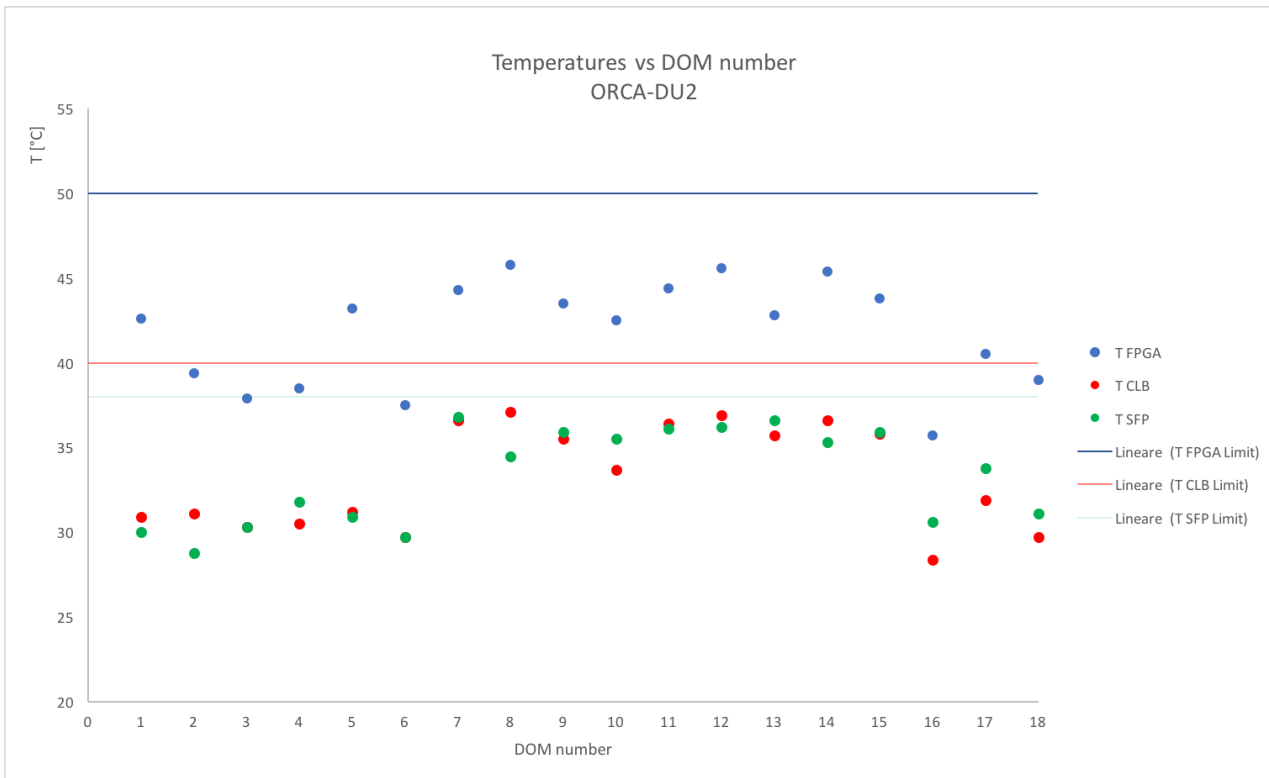
## Temperatures



# DOM Acceptance parameters

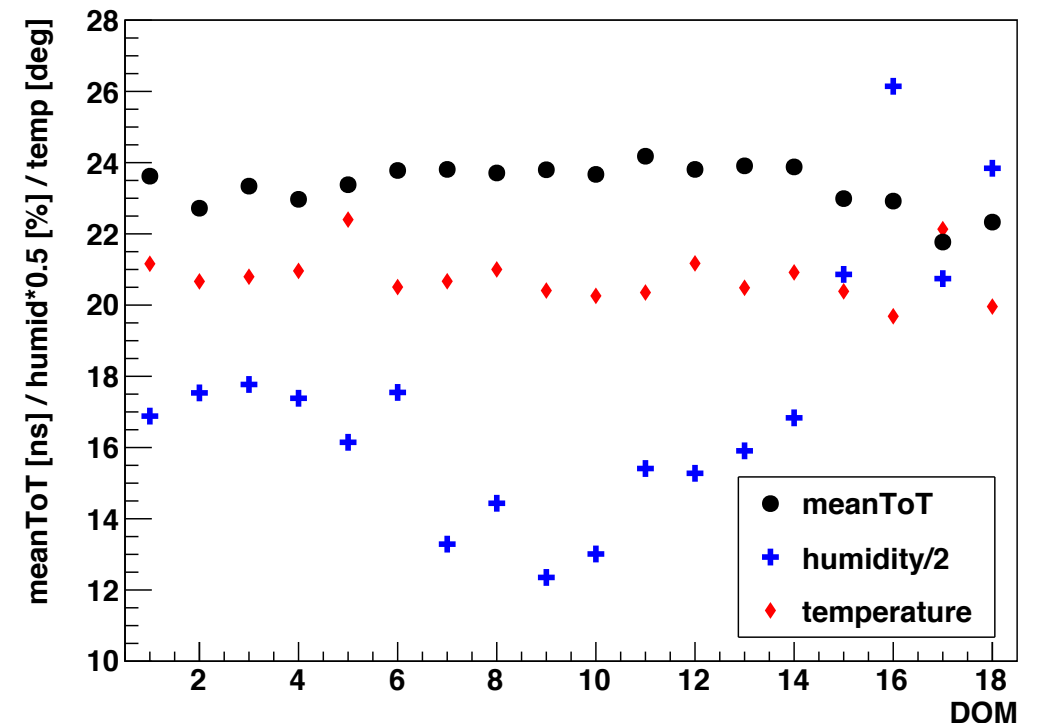
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## Lab Temperatures



## After deployment

meanToT/humidity/temperature per DOM

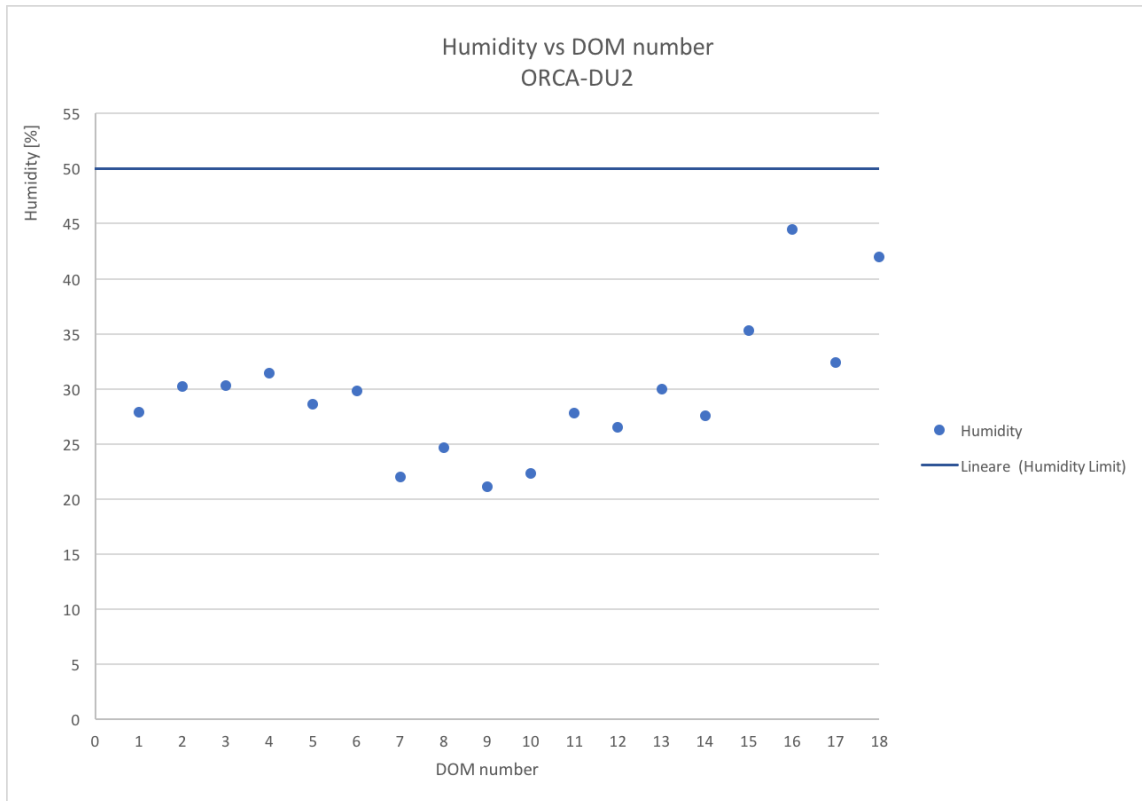




# DOM Acceptance parameters

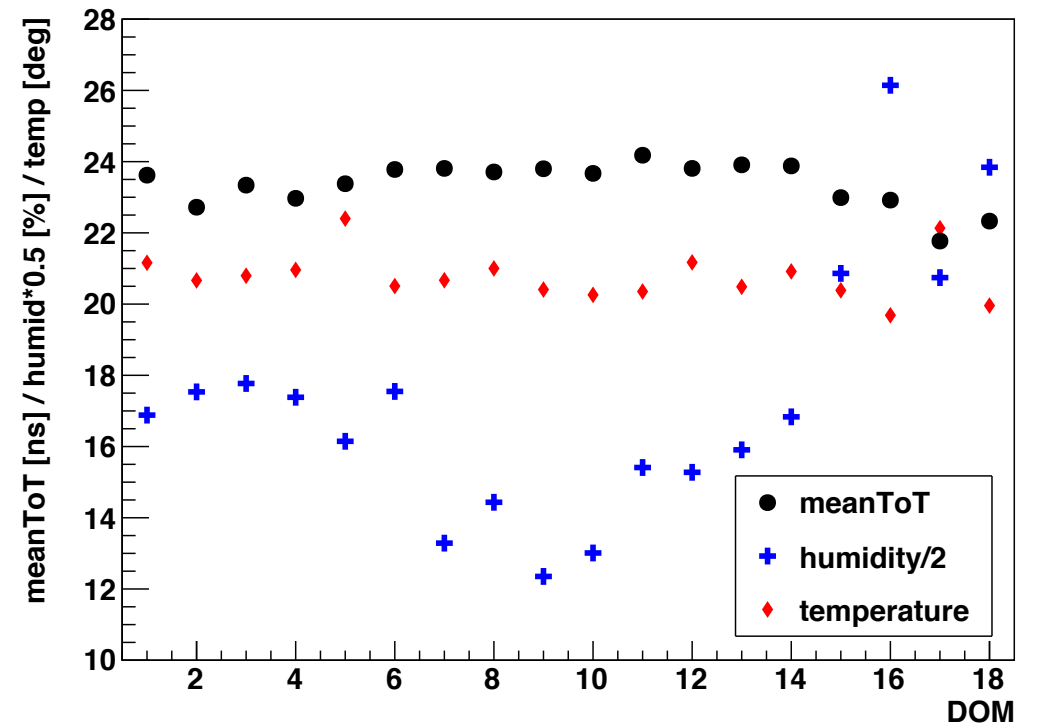
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## Lab Humidities



## After deployment

meanToT/humidity/temperature per DOM



## DOM Acceptance parameters

As DOM Integration team, some issues related to PMTs must still be defined:

- handling
- storage
- transportation
- sparking PMTs
- improved acceptance parameters and procedure