Results of RICH CLARO calibration and threshold scans

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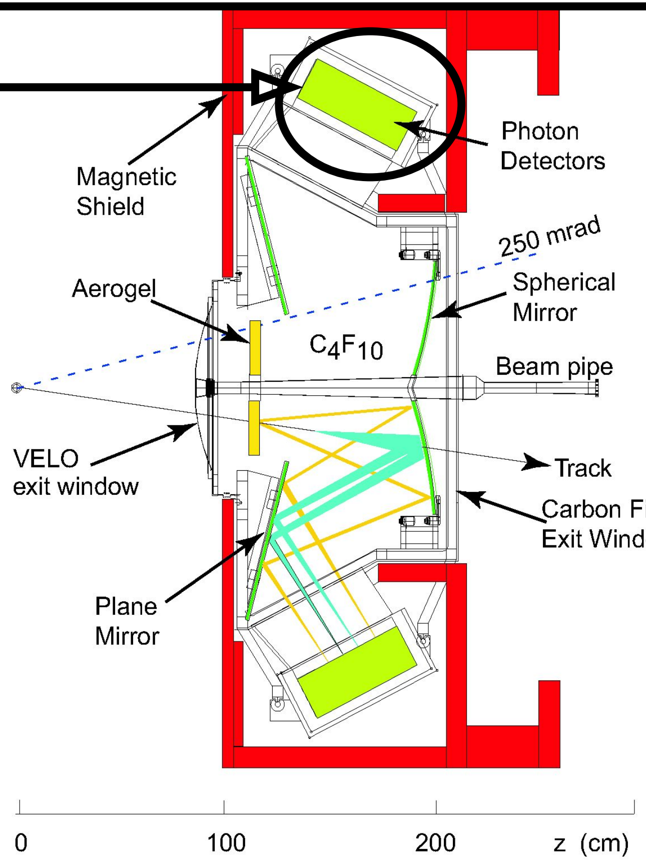
RICH Upgrade

- LHC Upgrade 2019: <u>higher luminosity</u> ($2 \cdot 10^{33} cm^{-2} s^{-1}$) and <u>higher rates</u> (40 MHz)
- LHCb RICH1 and RICH2 need upgrade
- RICH-Upgrade:
  - New Photodetectors : Multi-anode PhotoMultiplier Tubes (MaPMT)
  - New read-out: CLARO board

Replace photon detectors and electronics



RICH-1 schematic picture

MaPMTs and CLARO

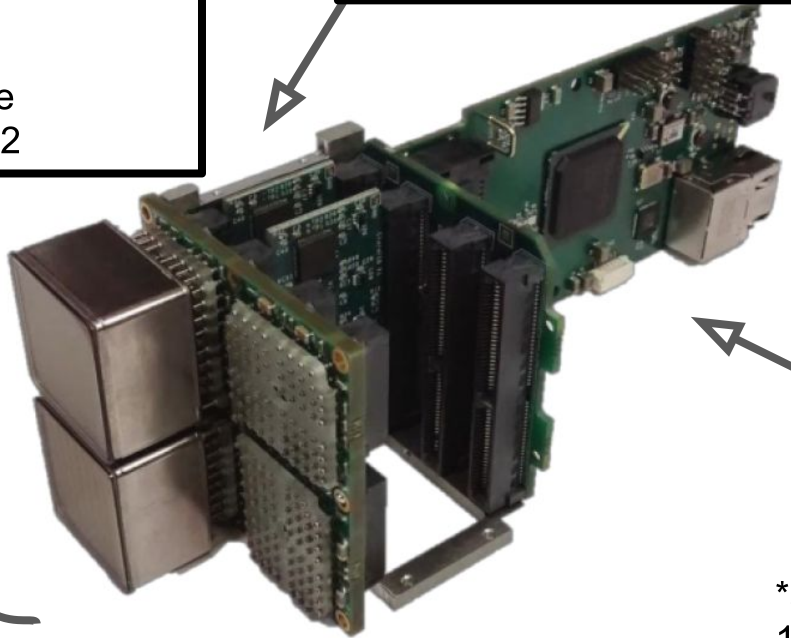
CLARO:

- digital output: 1 or 0
- 40 MHz counting frequency
- recovery time ~ 25 ns
- 64 threshold levels,
- tolerates up to 10 kGy
- 640 fF capacitor integrated for calibration.

MaPMT: 1inch X 1inch, 64 channels

- Higher resolution
- Low cross-talk
- Good time response
- Hamamatsu R13742

Elementary cell (EC)
EC-R type to be used in
RICH 1 + inner RICH-2

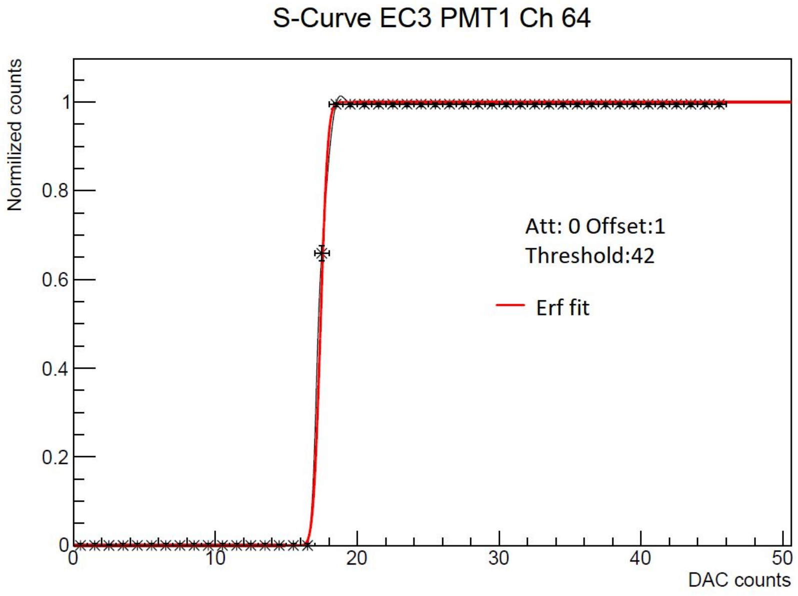


FPGA

MaPMT and CLARO

*arXiv:[physics.ins-det]
1610.10006v1

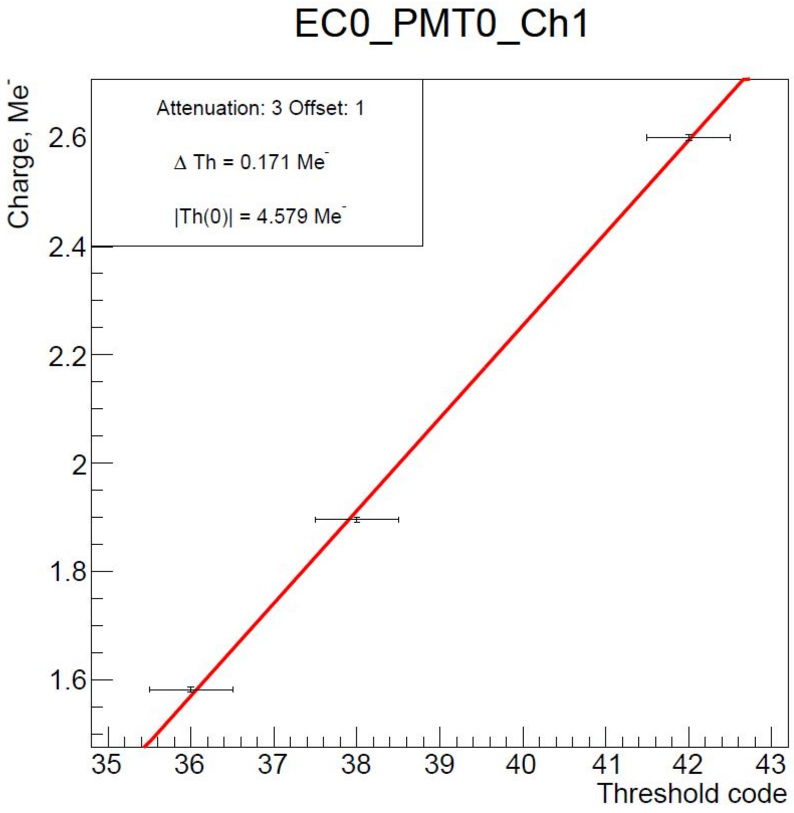
MaPMTs and CLARO



Step 1: for a given threshold value known amount of charge is injected to CLARO **(DAC scan)**

S-curve: if injected charge is **lower than threshold** value the CLARO output is **0**; if it is **higher** the CLARO output is **1**.

MaPMTs and CLARO



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S-curve: if injected charge is **lower than threshold** value the CLARO output is **0**; if it is **higher** the CLARO output is **1**.

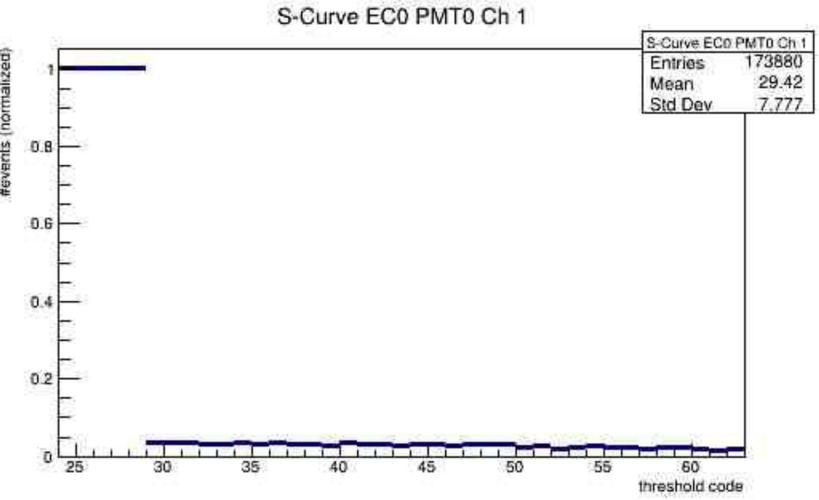
Step 2: find **transition point** from 0 to 1, using S-curve. Find the **calibration curve** for each channel.

Calibration curve: relation between threshold code and amount of charge that corresponds to transition point.

Transition point in DAC counts is transferred to charge value using:

$$Charge = 15.6ke^{-} \cdot DACcode$$

MaPMTs and CLARO



Step 1: for a given threshold value known amount of charge is injected to CLARO **(DAC scan)**

Step 2: find **transition point** from 0 to 1, using S-curve. Find the **calibration curve** for each channel.

Step 3: perform a **threshold scan**.

S-curve: if injected charge is **lower than threshold** value the CLARO output is **0**; if it is **higher** the CLARO output is **1**.

Calibration curve: relation between threshold code and amount of charge that corresponds to transition point.

Threshold scan: by illuminating each channel number of registered events at each threshold is recorded

Final goal (and step 4)

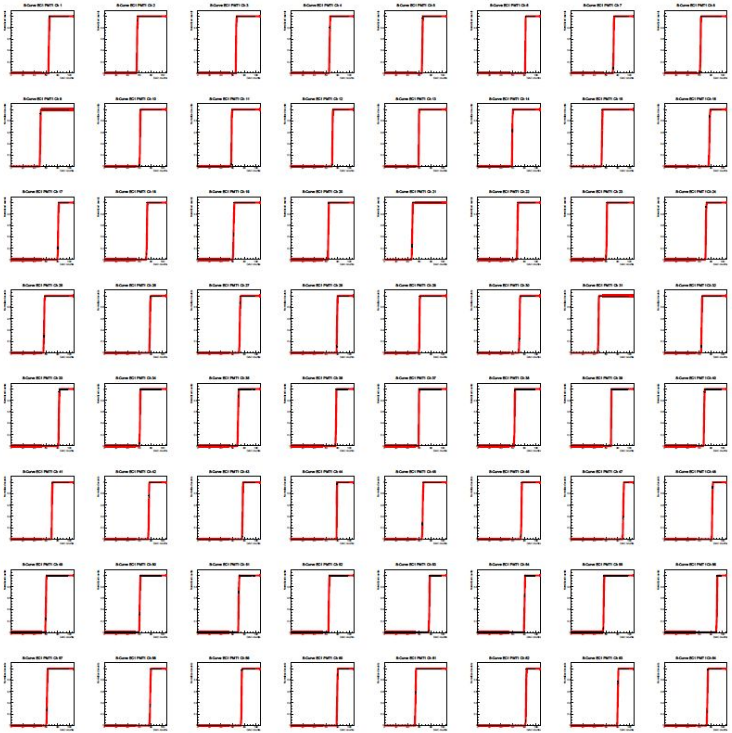
After calibration:

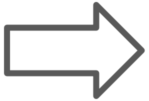
1. Characterize PMTs using CLARO set-up in SysLab.
2. Compare PMT characteristics (i.e. gain) with measurements taken during quality and insurance of MaPMTs with different read-out based on measurement of the pulse height.
3. Find the CLARO threshold.
4. Results will be used for the RICH operation during the Run III.

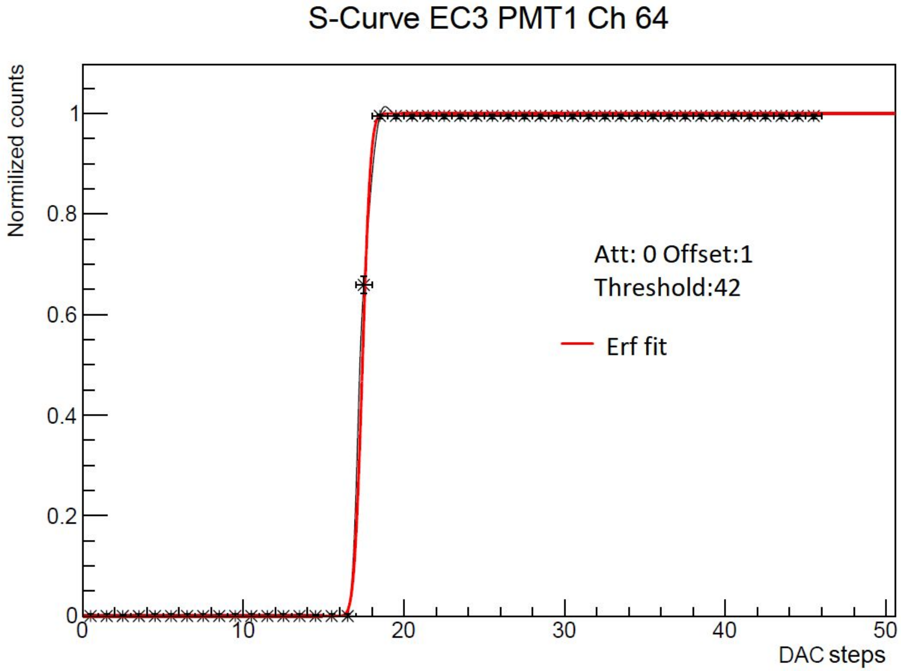
DAC scans and fit of S-curve

$$Fit = \frac{(1 + Erf[(x-a)/b])}{2}$$

a - transition point;
b - width of noise.





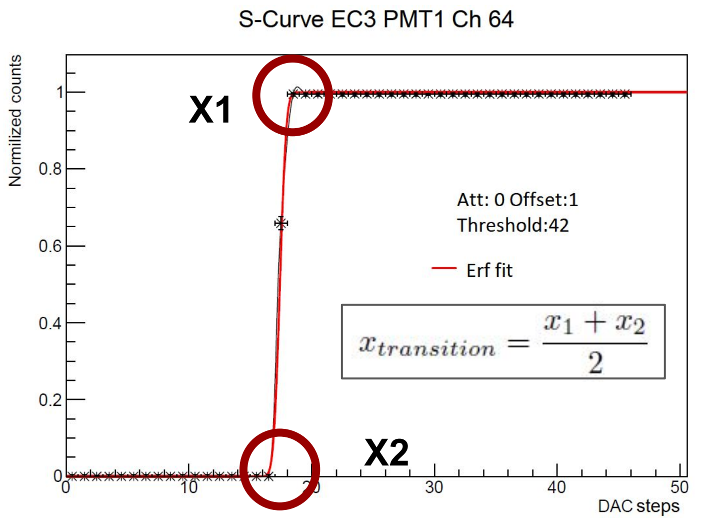


S-curve for one of the channels

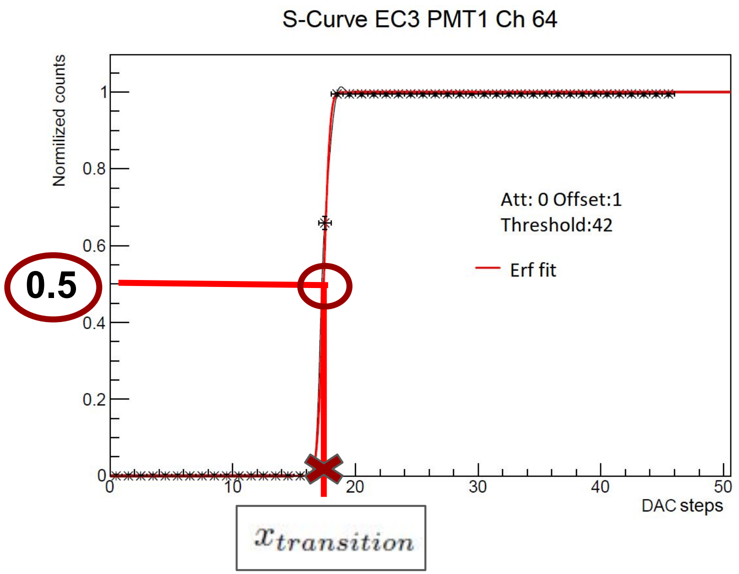
Transition point

Two ways of finding the transition point:

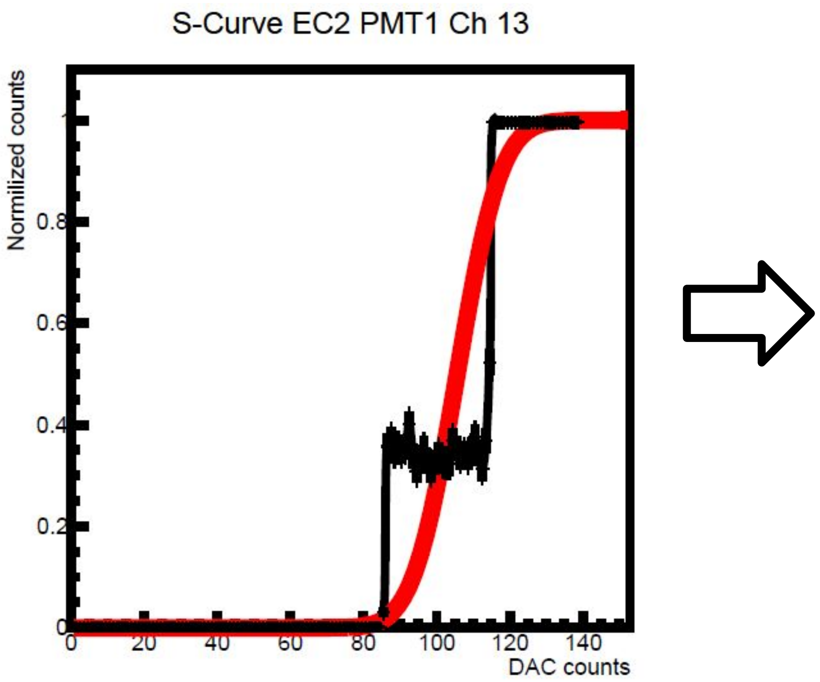
1. Middle point calculation (MP)



2. From fit



Noisy channels

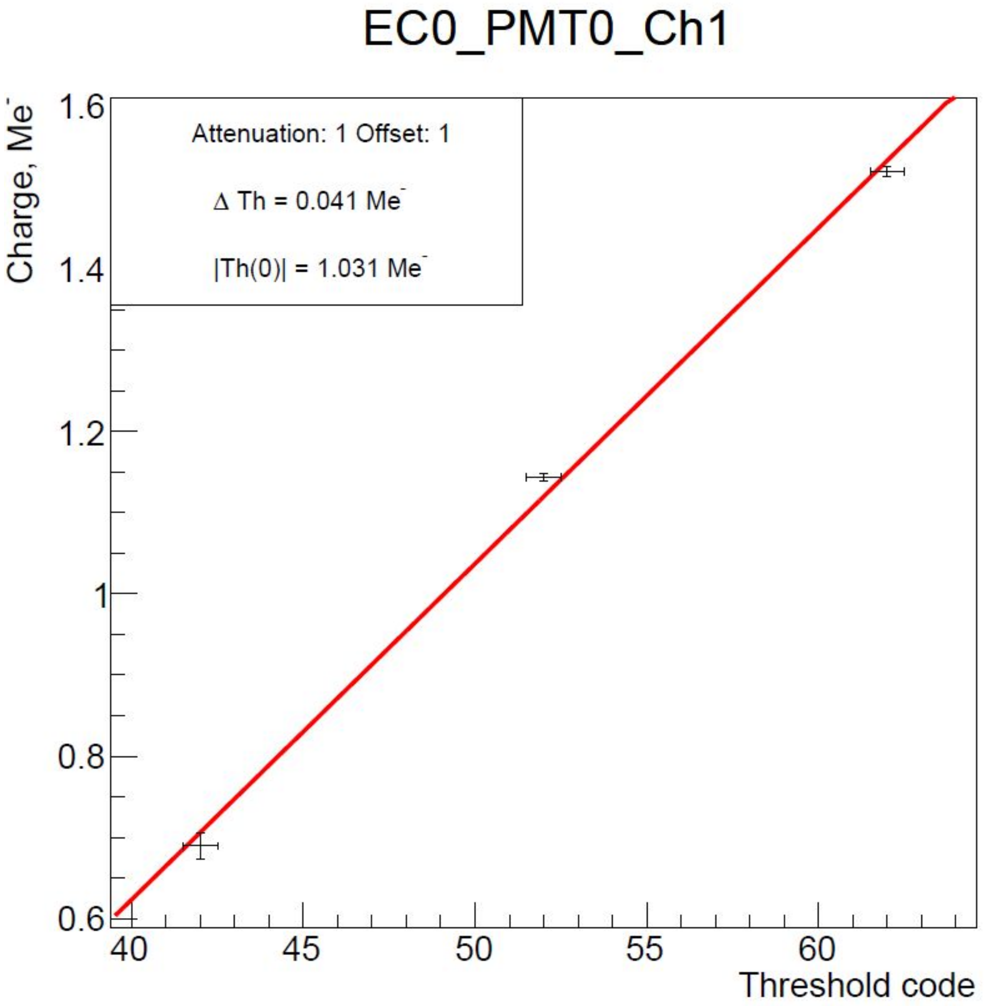


- Fit has high χ^2 value - can be used to find the noisy channels
- Every channel that has $\chi^2 > 2.5 \cdot \chi^2_{max}$ is noisy
- If the noisy channel is detected:
  - Use middle point calculation for transition point

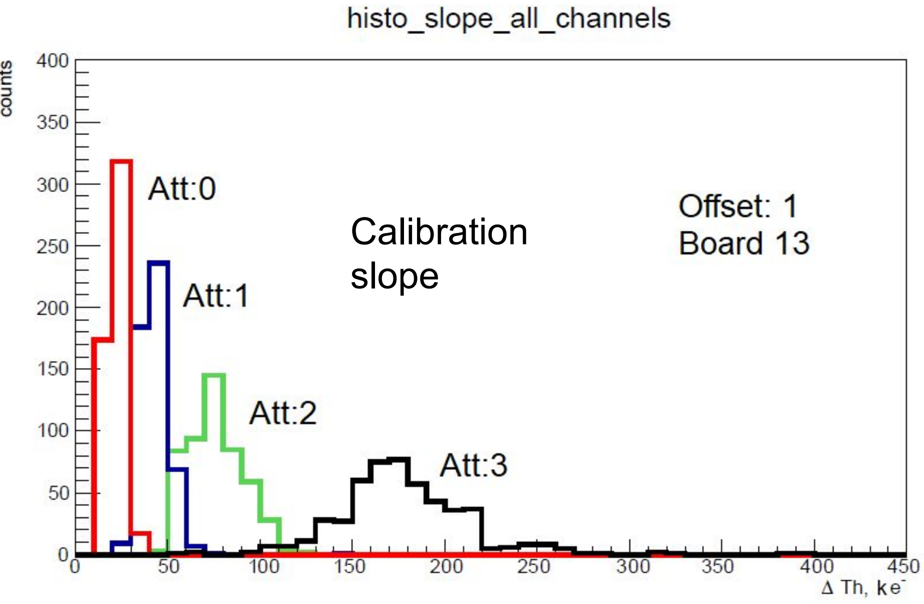
Calibration results

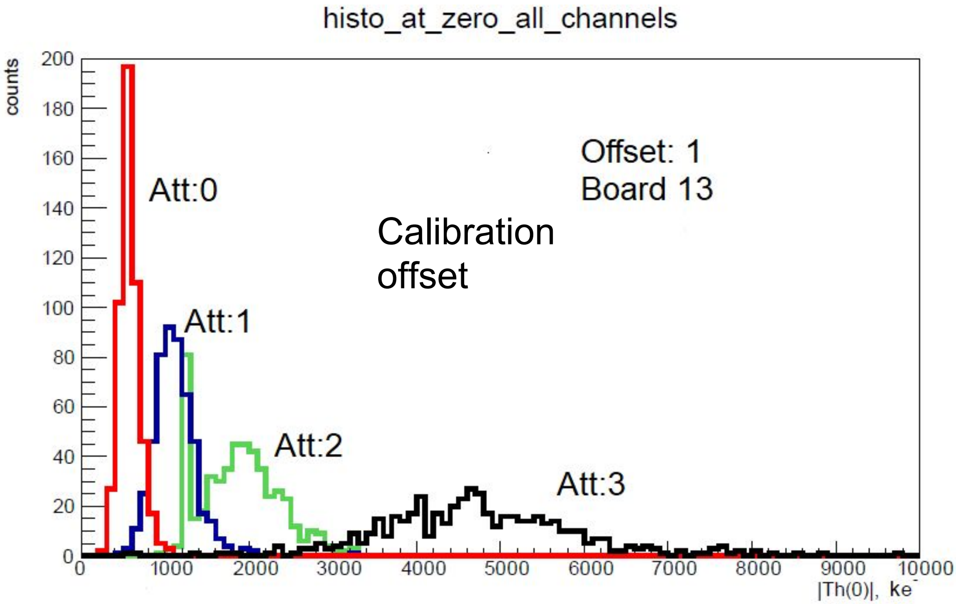
Example of calibration of one of the channels.

Errors on x-axis: 0.5 threshold code.



Calibration results: distribution of parameters

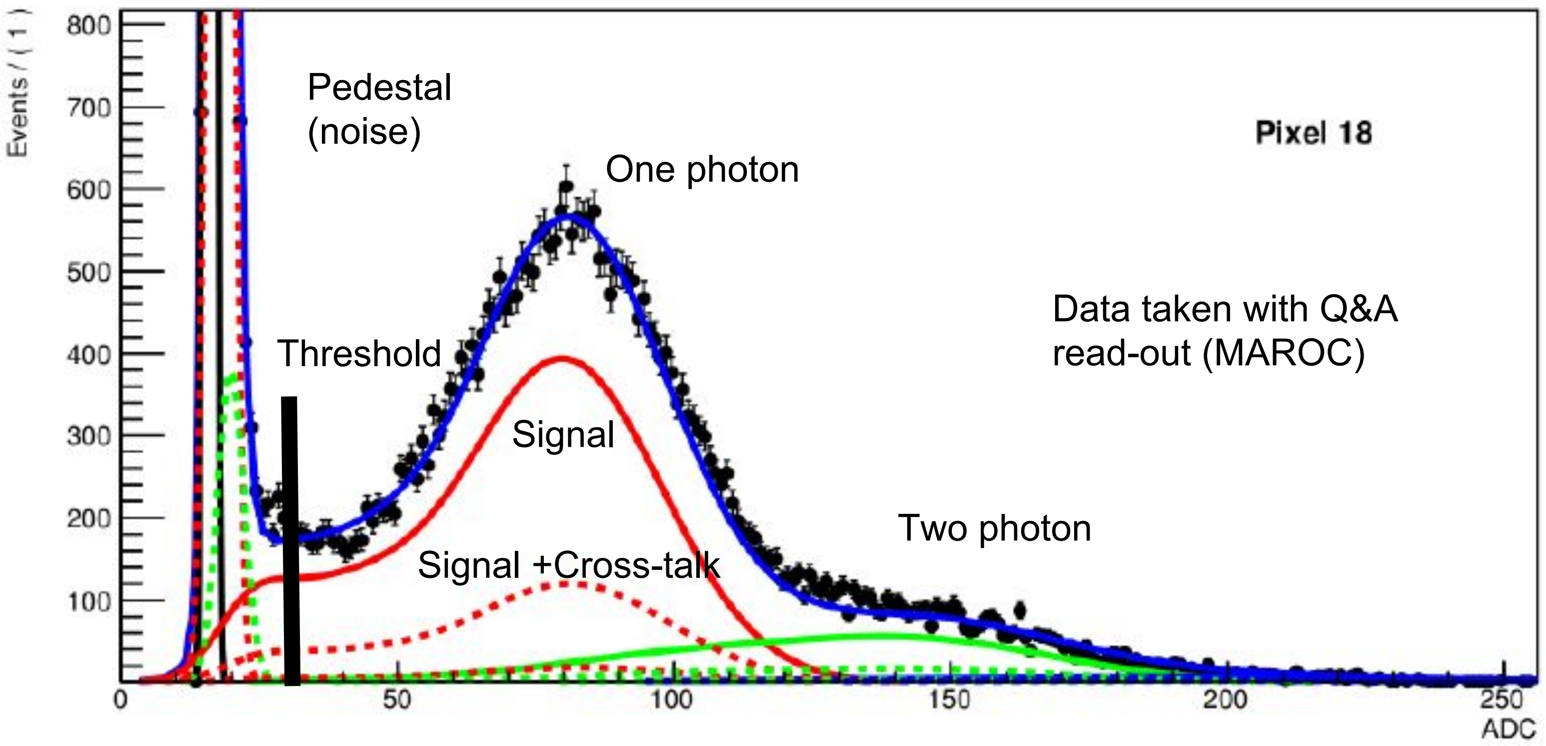




Attenuation: attenuation of signal in 2^{att} times.

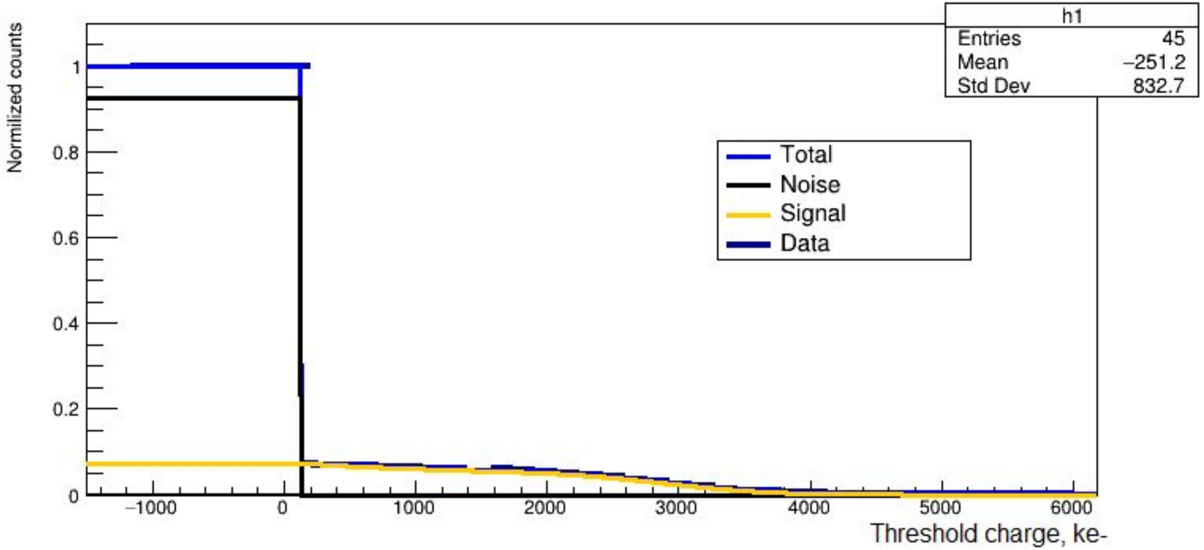
Threshold scan

Single photon spectra = derivative of threshold scan



The MaPMTQ&A model was developed for PMT Q&A will be used to fit the threshold scan

Threshold scans fit: MaPMTQ&A model



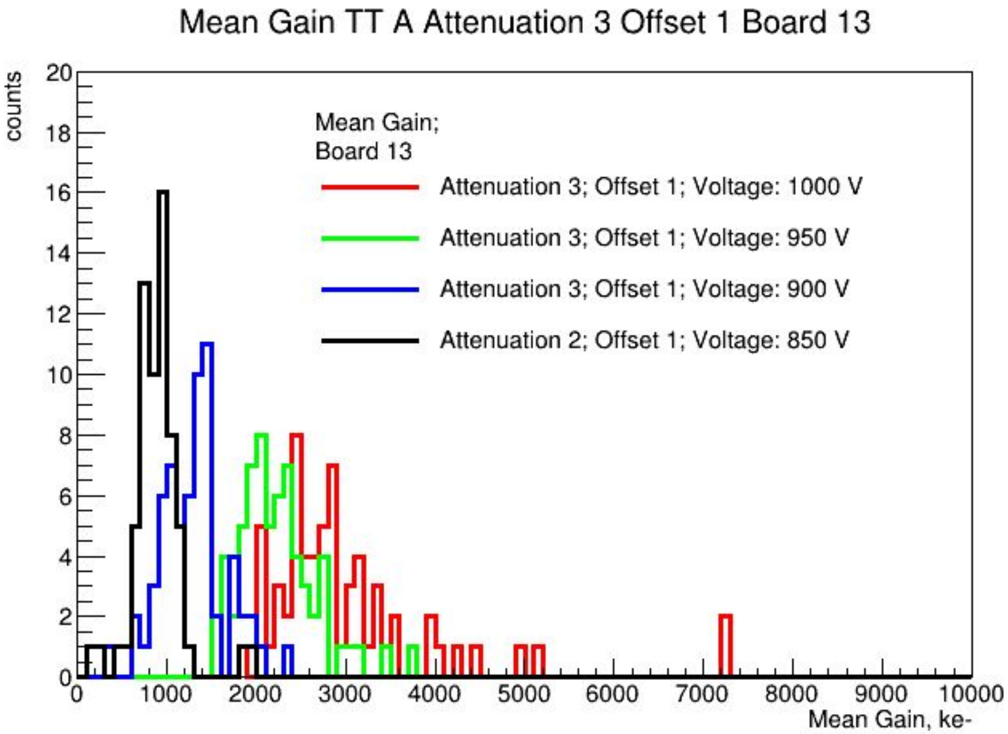
NO cross-talk

$$\underbrace{\sum_{0} Poisson(1,\mu)\cdot C(P_{miss})\cdot 0.5\cdot\left(1-Erf\left(\frac{x-x_p}{\sigma\cdot\sqrt{2}}\right)\right)}_{signal} + \underbrace{Poisson(0,\mu)\cdot 0.5\cdot\left(1-Erf\left(\frac{x-x_p}{\sigma\cdot\sqrt{2}}\right)\right)}_{noise}$$

x_p is pedestal
μ is occupancy
P_{miss} is gain missed in the valley

*Occupancy: rate of getting one photoelectron signal
** Counts are normalized to the number of triggers

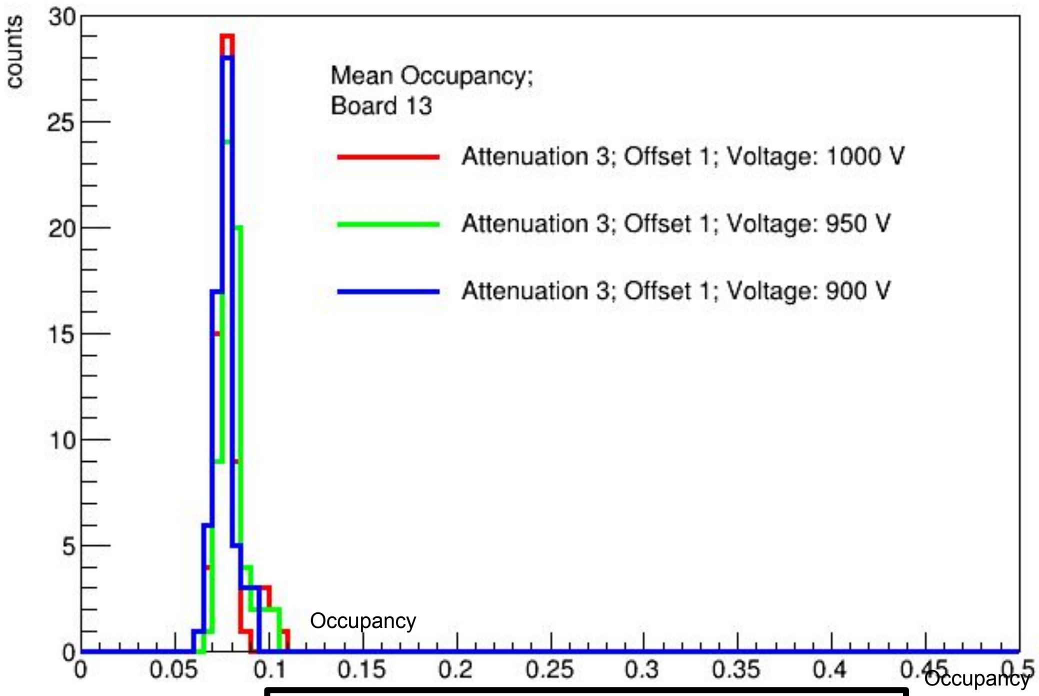
Threshold scans: Gain distribution at different voltage



Distribution of gain for 64 channels of PMT TT A

Voltage: Voltage applied to the channel cathode

Threshold scans: Occupancy distribution different voltage



Distribution of occupancy for 64 channels of PMT TT A

No dependence on cathode voltage

Conclusions

- Calibration of the CLARO has been done in order to properly find threshold and PMT characteristics;
- Two methods of finding the calibration parameters are used with Erf fit as the main method.
- Threshold scans were fitted and MaPMTs parameters were estimated, i.e. gain, occupancy.
- Gain and occupancy dependence on cathode voltage follow the expectations.

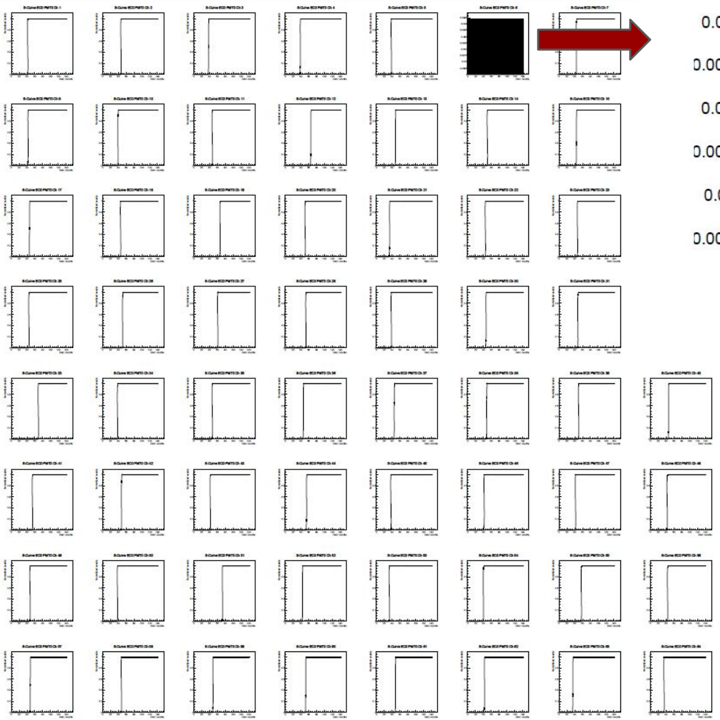
Future plans

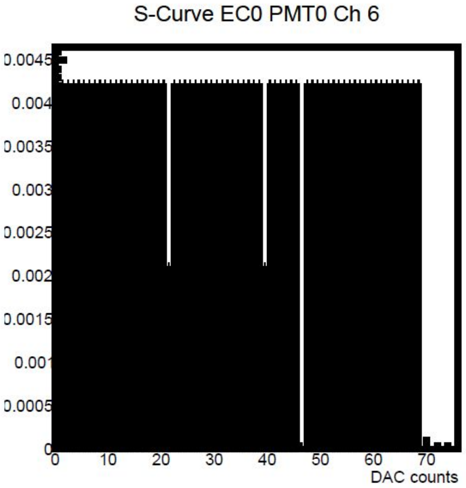
- Cross-talk implementation into the MaPMTQ&A fit model;
- Compare measured PMT parameters with ones measured in the Q&A (using another read-out board)
- Define the proper CLARO threshold value for each channel using the fit information.

Thank you for your attention

BACK UP SLIDES

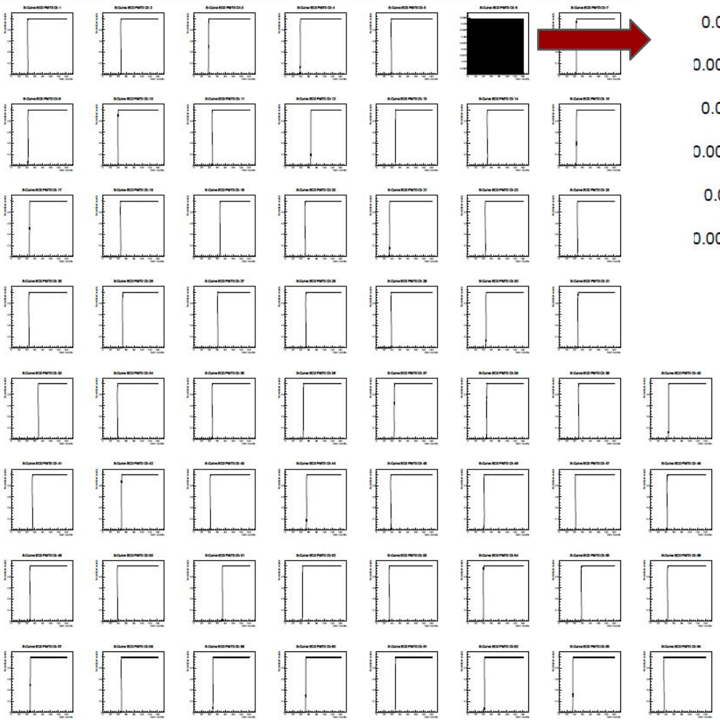
DAC scans and p nnels

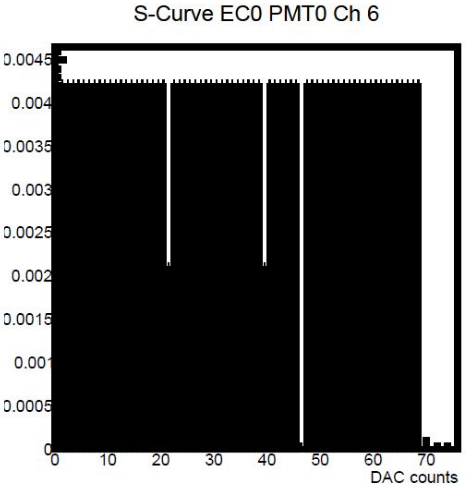




EC 0 PMT 0 All Channels
before preselection

DAC scans and p nnels

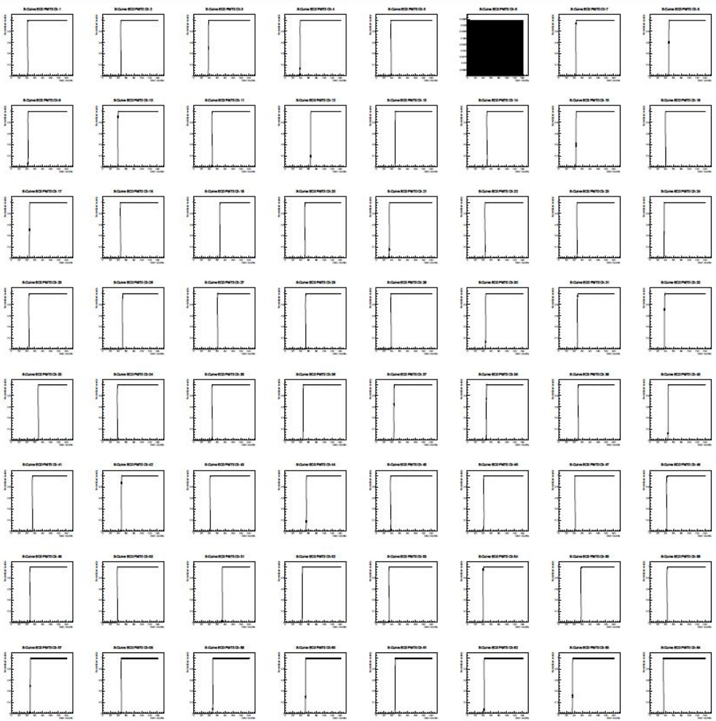




If <u>first</u> DACcount <u>> 0.1</u> or <u>last < 0.9</u> ignore the channel

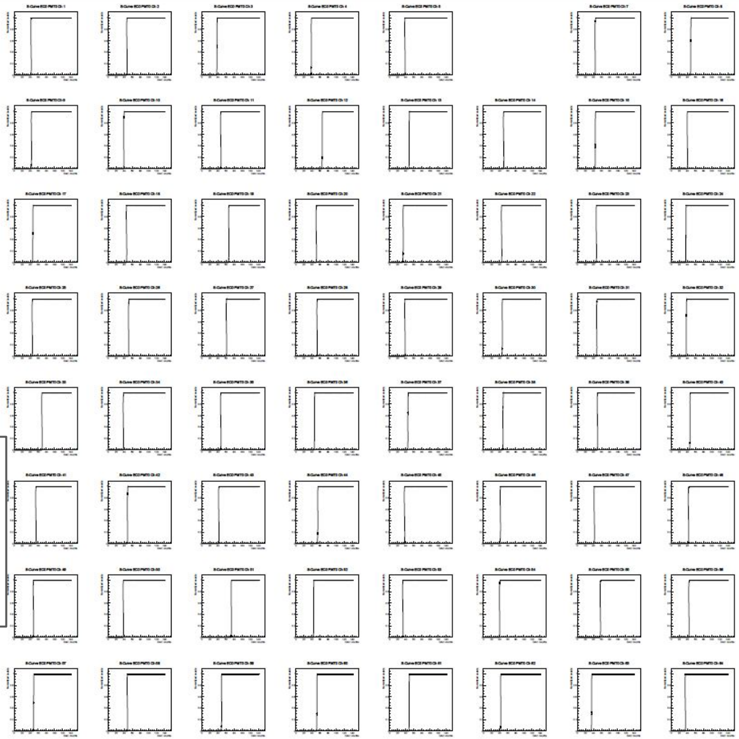
EC 0 PMT 0 All Channels before preselection

DAC scans and preselection of channels



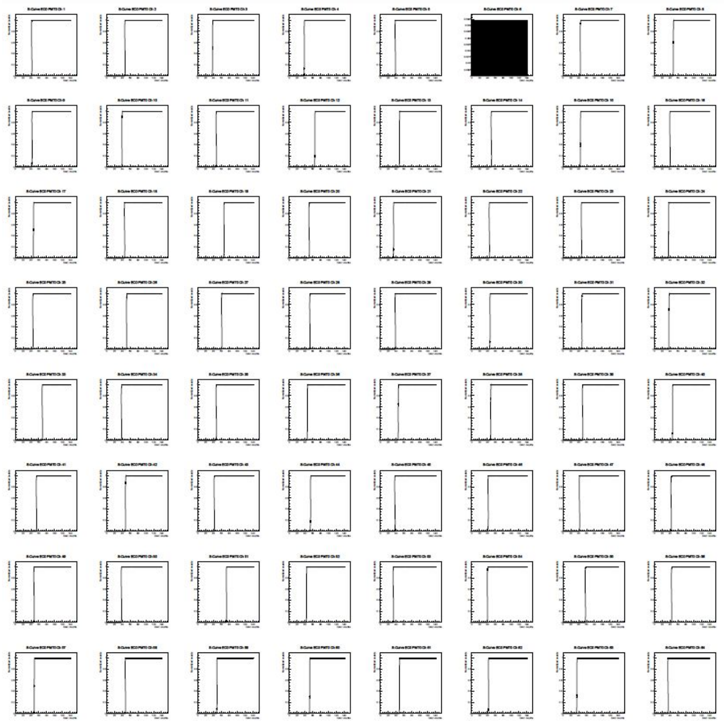
EC 0 PMT 0 All Channels
before preselection

If <u>first</u> DACcount <u>> 0.1</u> or <u>last < 0.9</u> ignore the channel



EC 0 PMT 0 All Channels
after preselection

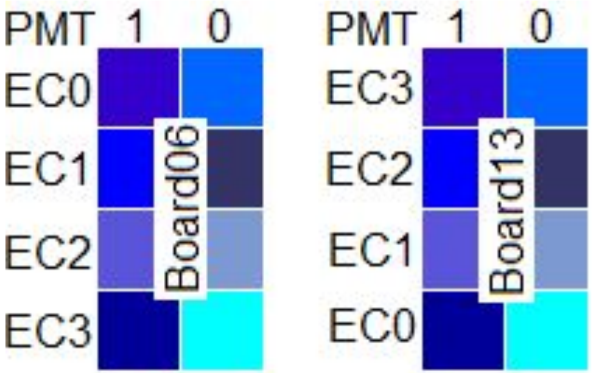
DAC scans and preselection of channels



EC 0 PMT 0 All Channels
before preselection

The data was taken in July-August 2018 in SysLab using the RICH prototype with help of Giovanni Cavallero, Tonino Sergi et al.

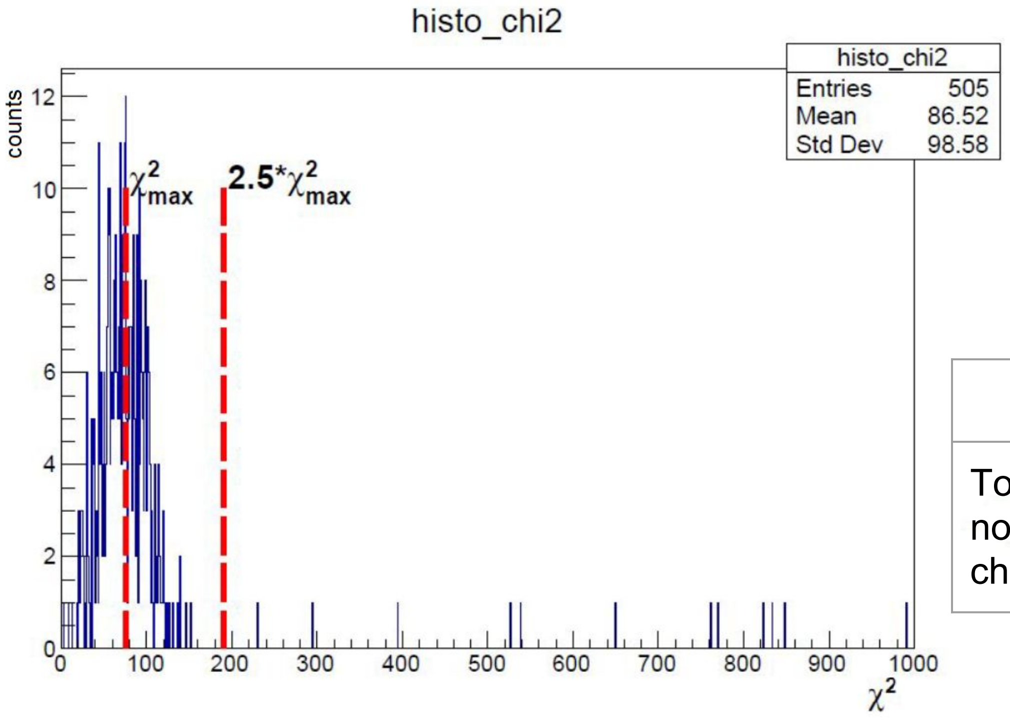
PMTs configuration



OR

Both boards

Chi2 cut on good/noisy channels



1. Define the most probable χ^2_{max}
2. Every channel that has $\chi^2 > 2.5 \cdot \chi^2_{max}$ uses middle point calculation

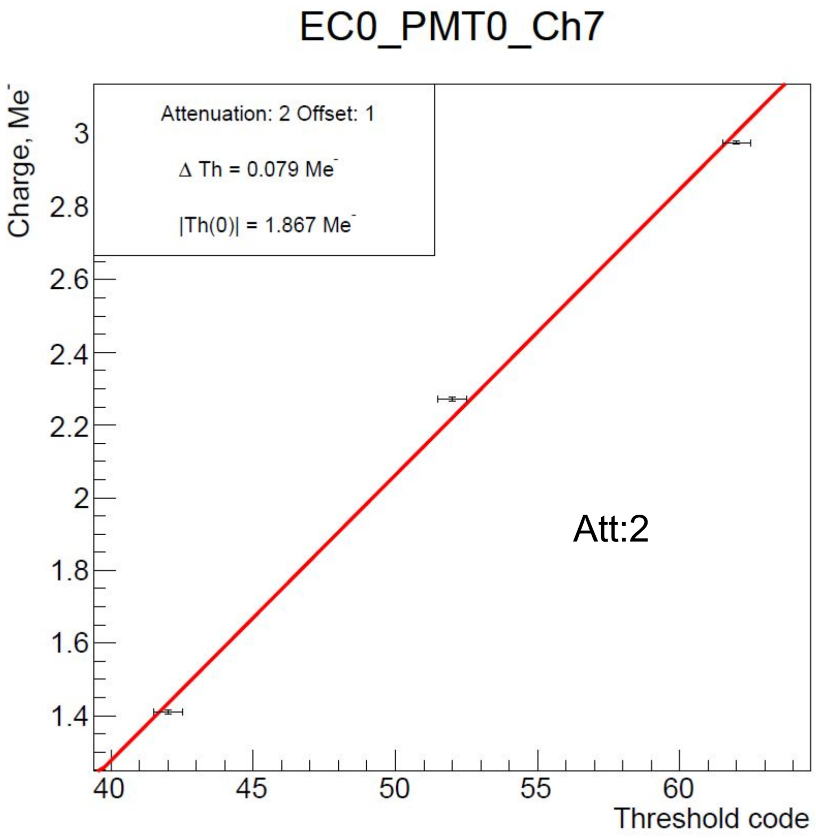
	Board 13	Board 06
Tot Num of noisy channels	91/15360 * (**~0.6%**)	338/15360 (**~2.2%**)

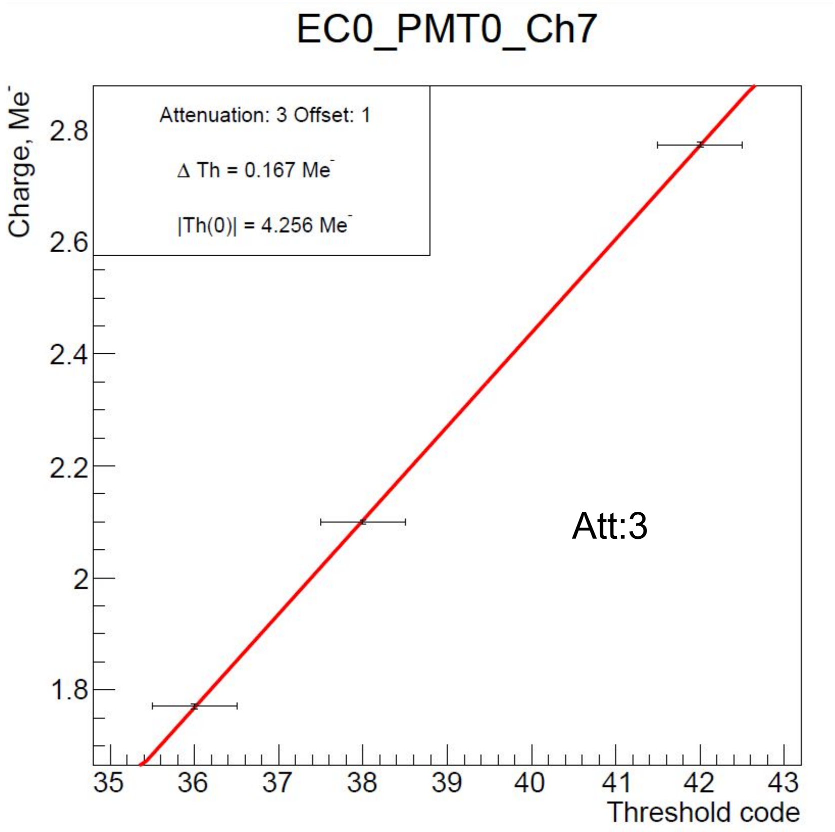
Board 06 has almost 3.5 times more noisy channels than Board 13

* 5(att+off)*3(threshold)*4EC*4PMT*64Ch=15360

Offset 1

More calibration results



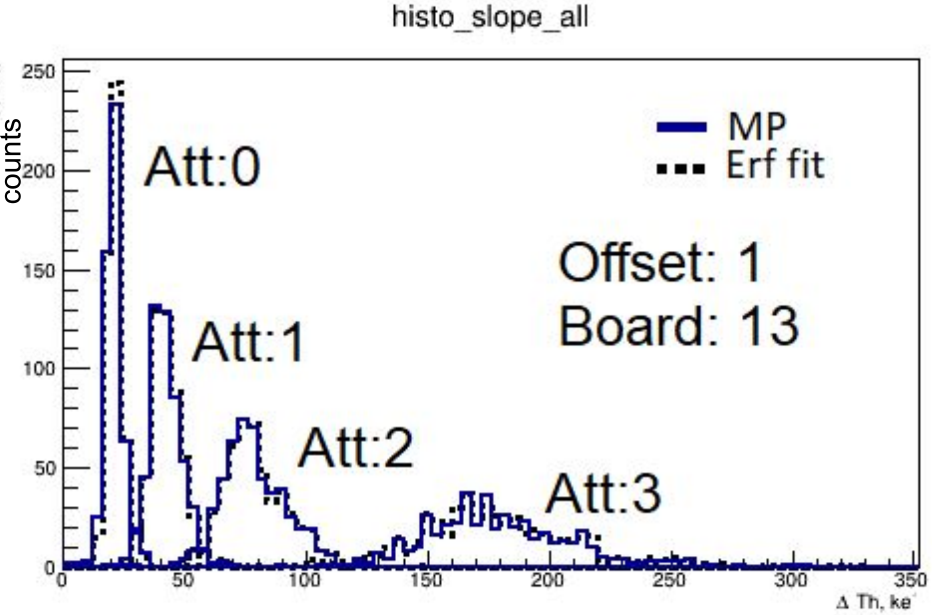


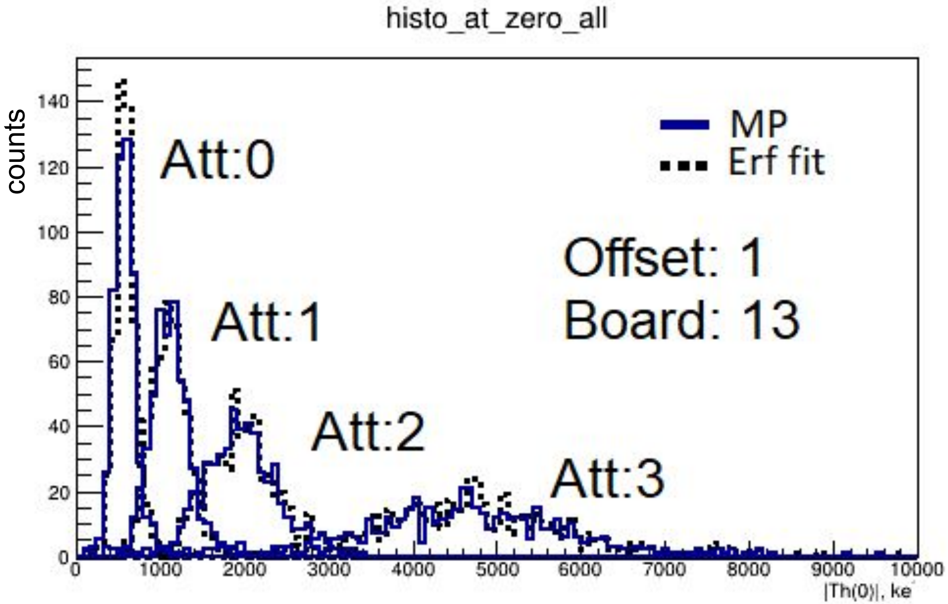
Error on transition point

Middle point calculation	From fit
$$x_{transition} = \frac{x_1 + x_2}{2}$$ $$\Delta x_1 = x_1 - x_{transition}$$ $$\Delta x_2 = x_{transition} - x_2$$ $$x_{transition} - \Delta x_2 < x_{transition} < x_{transition} + \Delta x_1$$	$$x_{transition} = par0$$ $$\Delta x = \Delta par0$$ $$x_{transition} - \Delta x < x_{transition} < x_{transition} + \Delta x$$

Errors calculated from fit are smaller then values from middle point error calculation. <u>Using fit as the main method to find the transition point.</u>

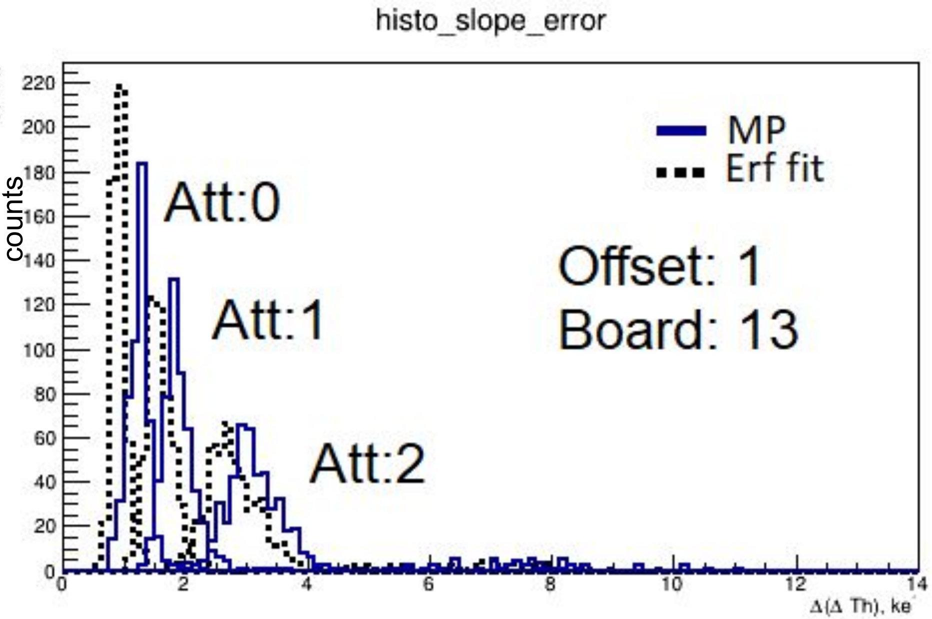
Calibration result: compare MP and Erf fit; Board 13

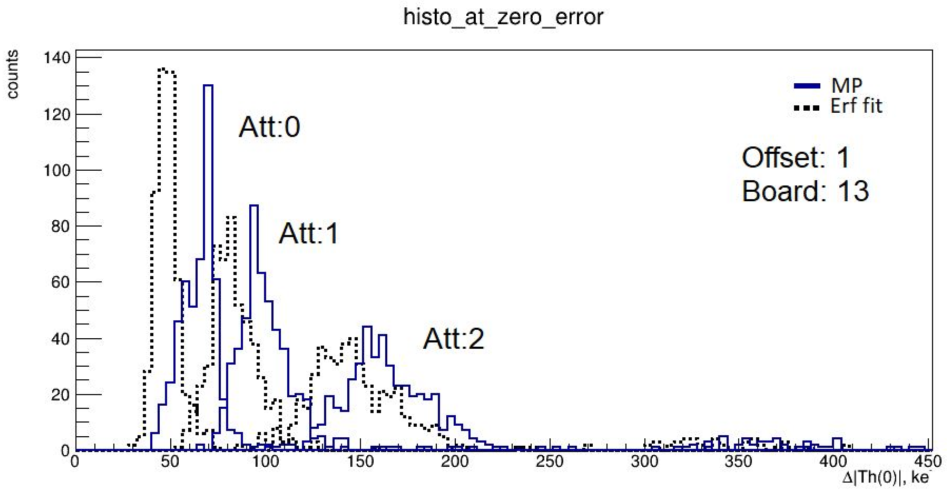




Results are comparable

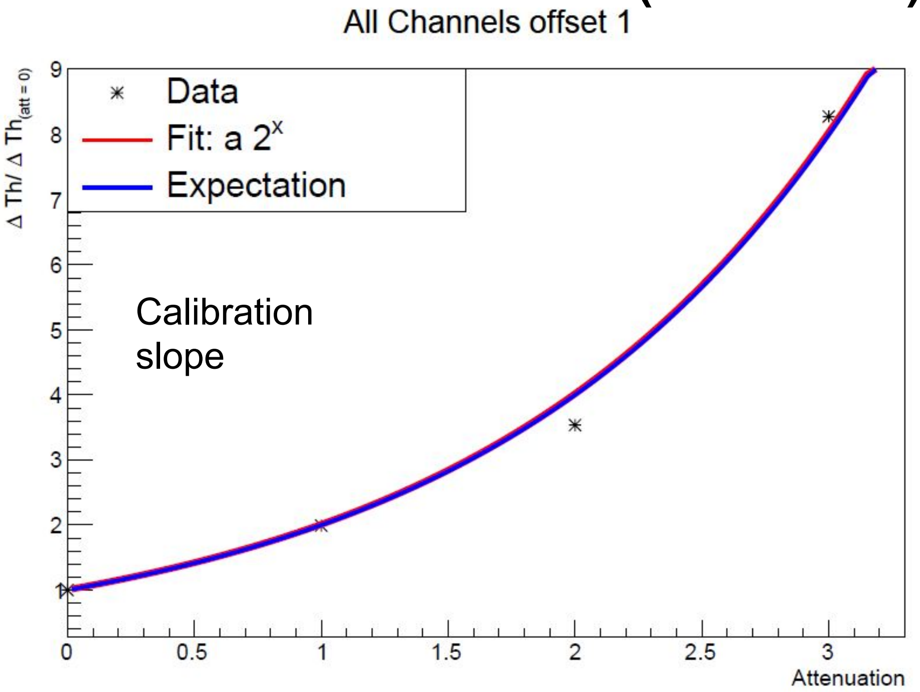
Calibration result: compare MP and Erf fit errors; Board 13

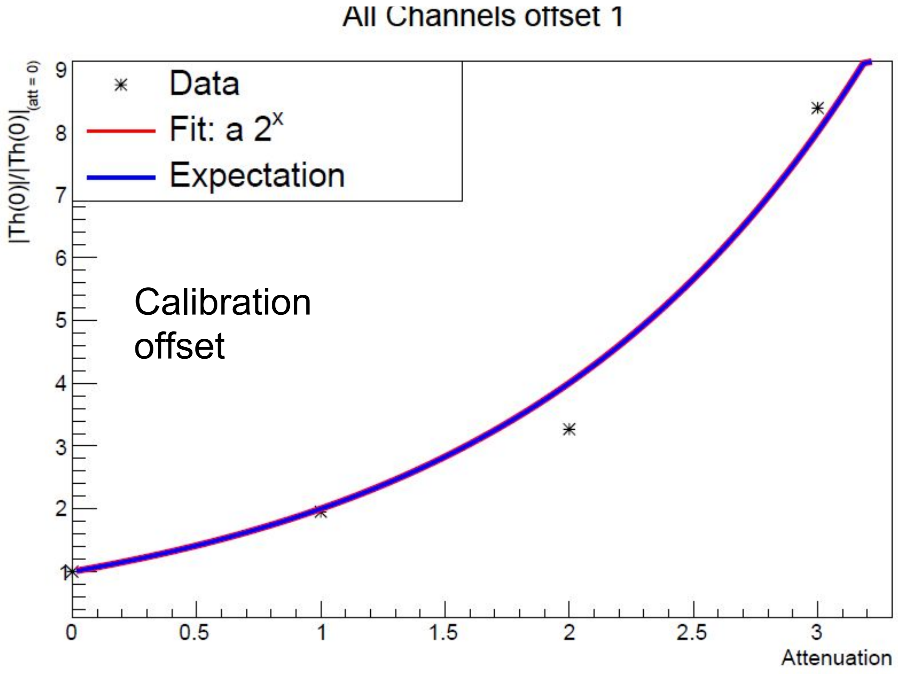




Erf fit errors are smaller!

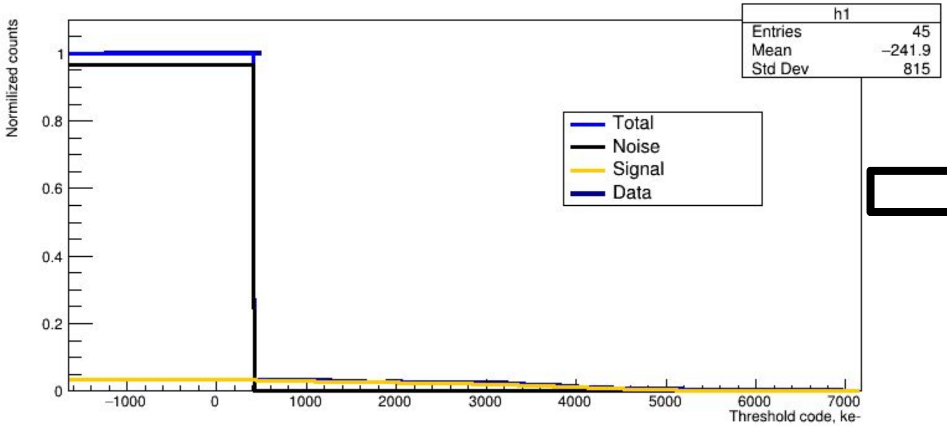
Calibration results (offset 1) Board 13

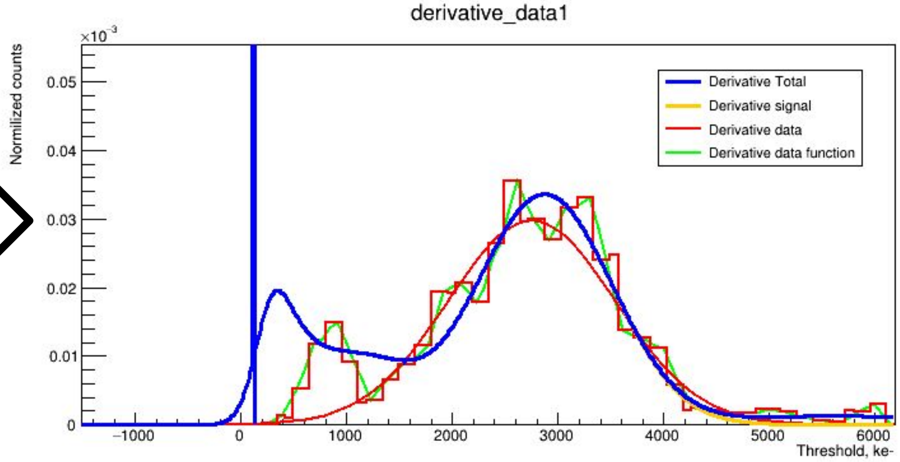




Averaged over all channels results on ΔTh and |Th(0)| for different attenuation

Threshold scans: derivative





Threshold scans: Problems

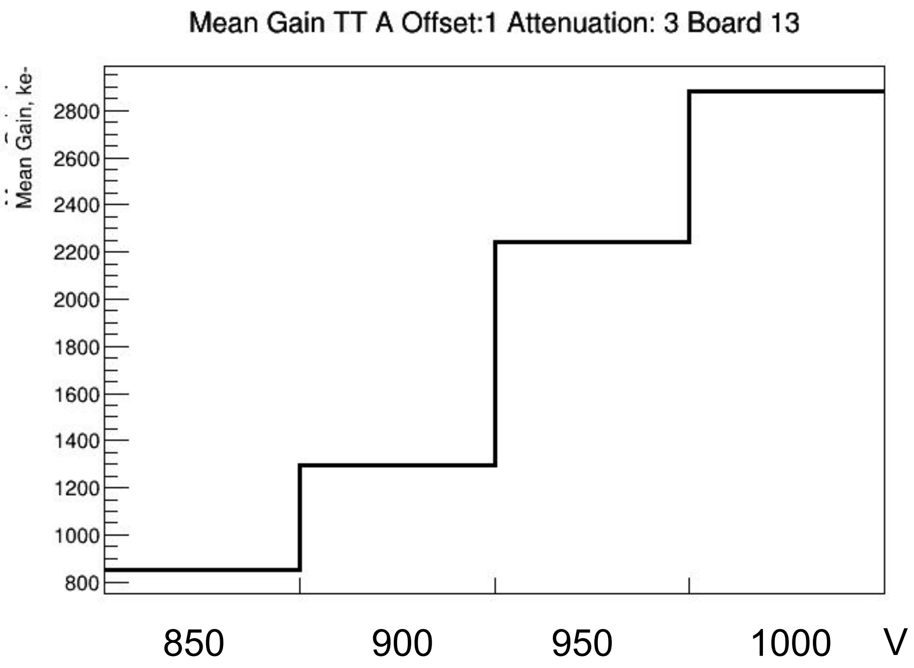
- Calibration should lead to pedestal situated at **0 ke-**, **BUT**

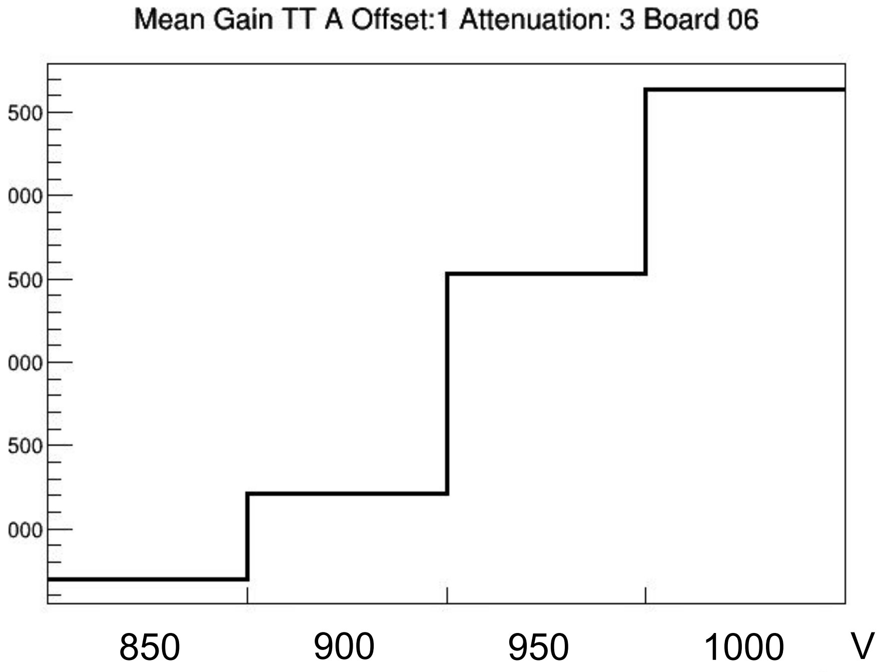
  Board 13 - around **100-200:ke-**; **Board 06** - around **500-600 ke-.**

  Reasons: still not perfect calibration of channels? Noisy channels?

- No cross-talk implemented in the model - in process

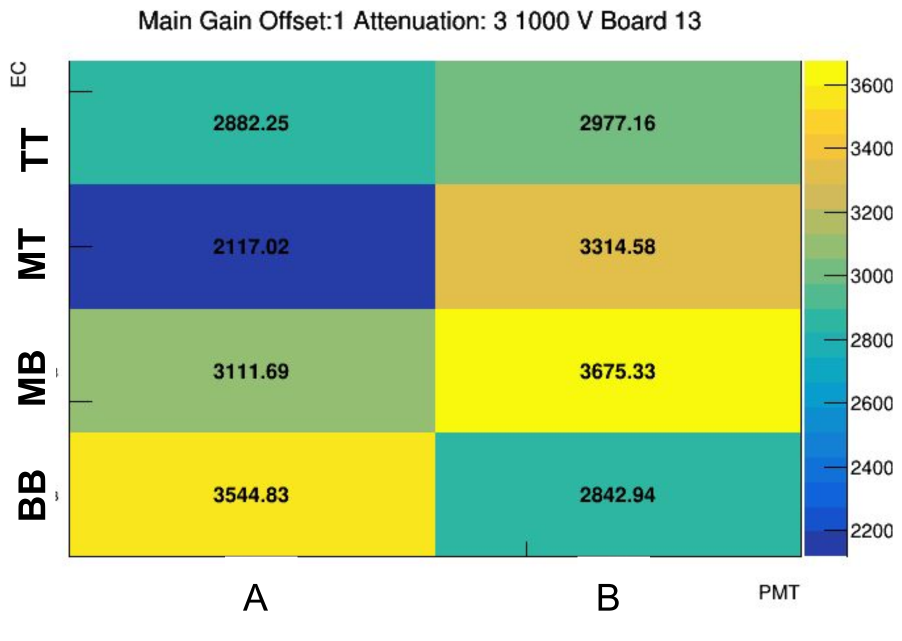
Threshold scans: Gain distributions Board 13 TT A

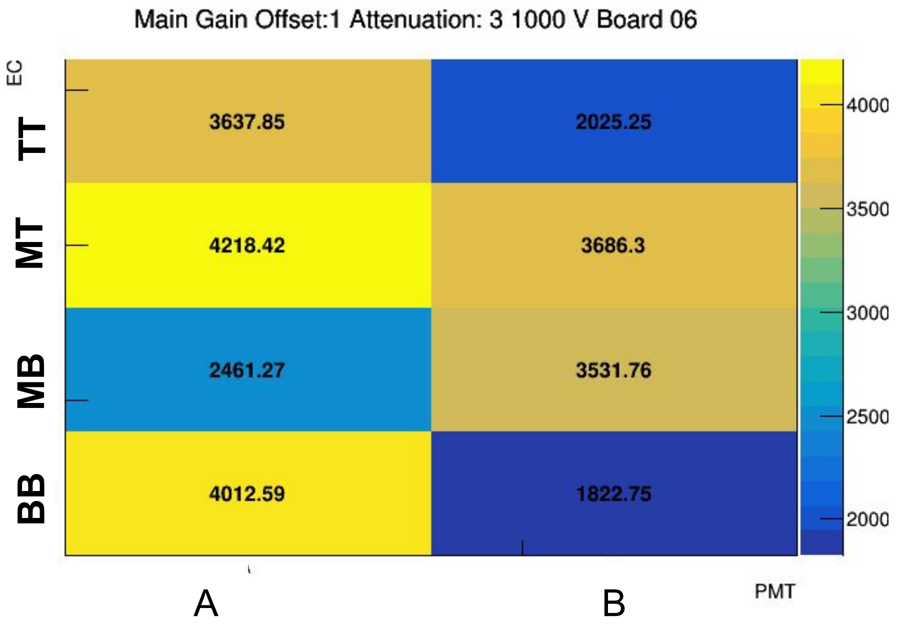




Mean gain for TT A channels at different voltages

Threshold scans: Gain distributions different position





Board 13

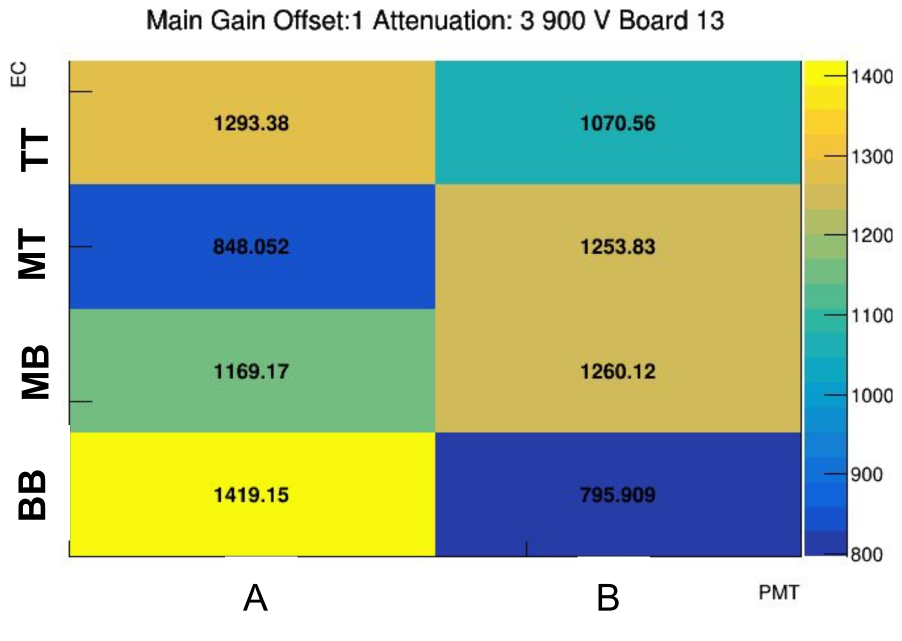
Max: 3675 ke-
Min: 2117 ke-

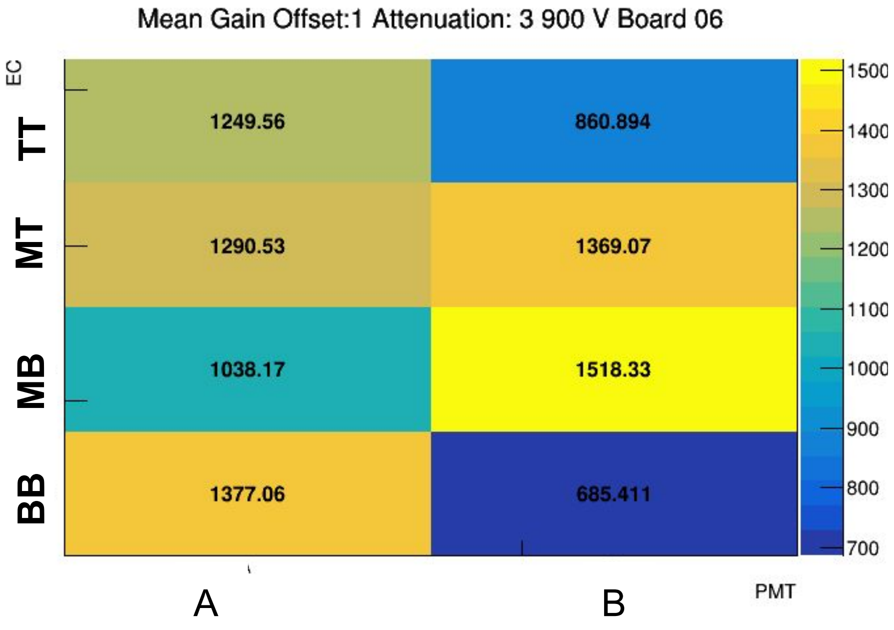
1000 V
Attenuation:3 Offset:1

Board 06

Max: 4218 ke-
Min: 1822 ke-

Threshold scans: Gain distributions different position





Board 13

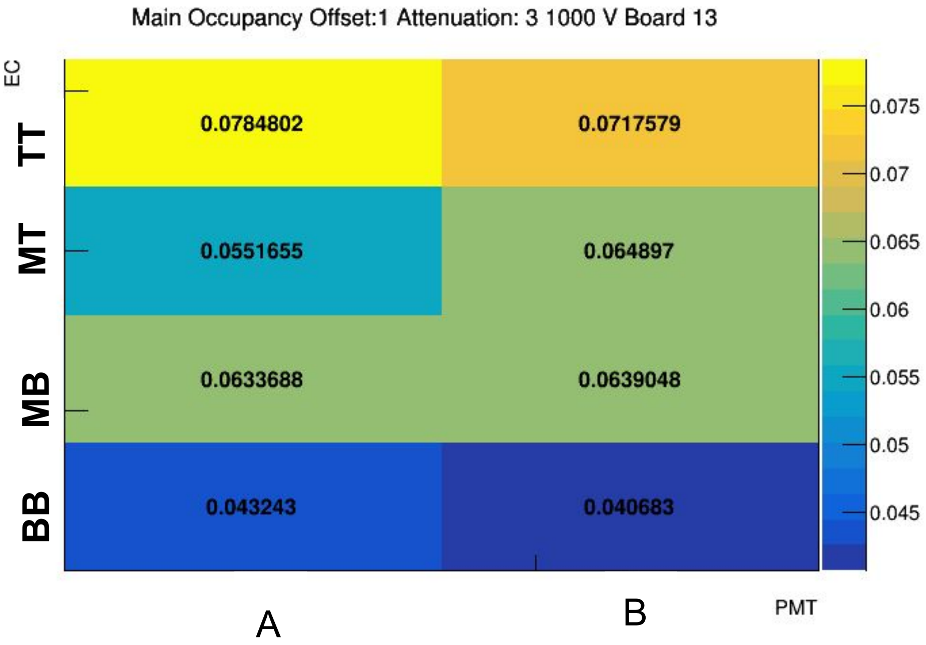
Max: 1419 ke-
Min: 795 ke-

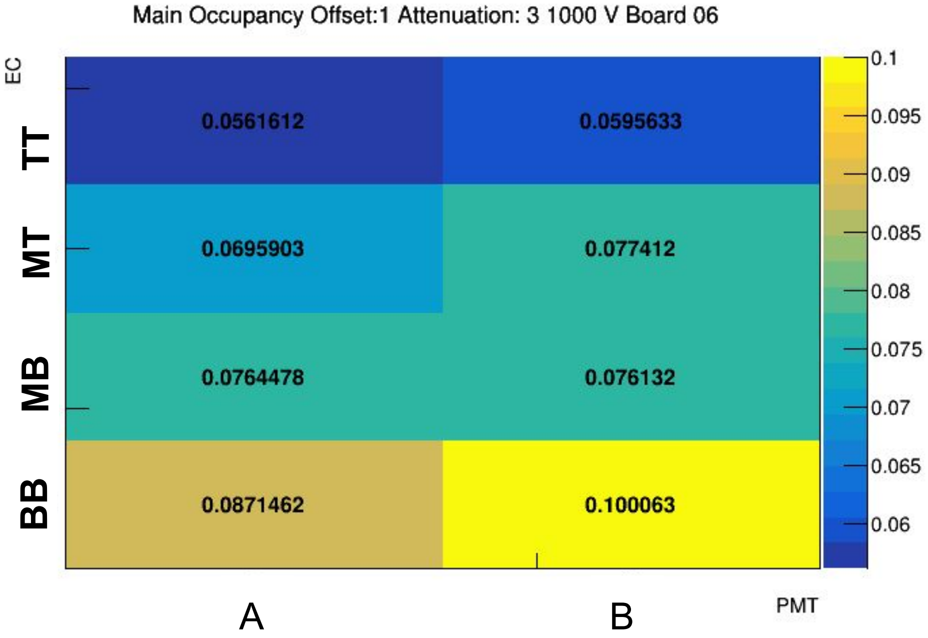
900 V
Attenuation:3 Offset:1

Board 06

Max: 1518 ke-
Min: 685 ke-

Threshold scans: Occupancy distributions different position





Board 13

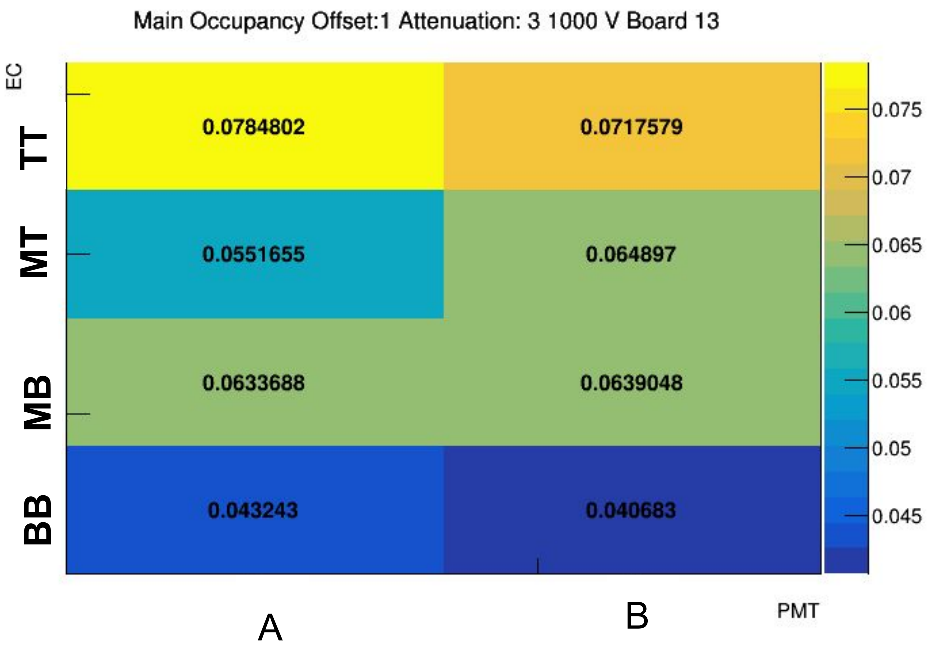
Max: 0.078
Min: 0.04

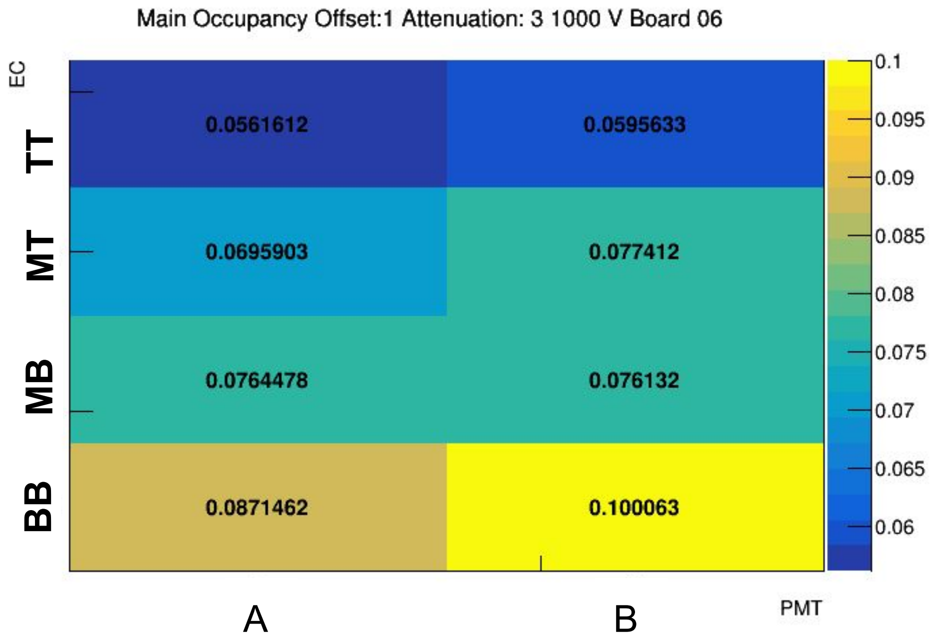
1000 V
Attenuation:3 Offset:1

Board 06

Max: 0.1
Min: 0.056

Threshold scans: Occupancy distributions different position





Board 13

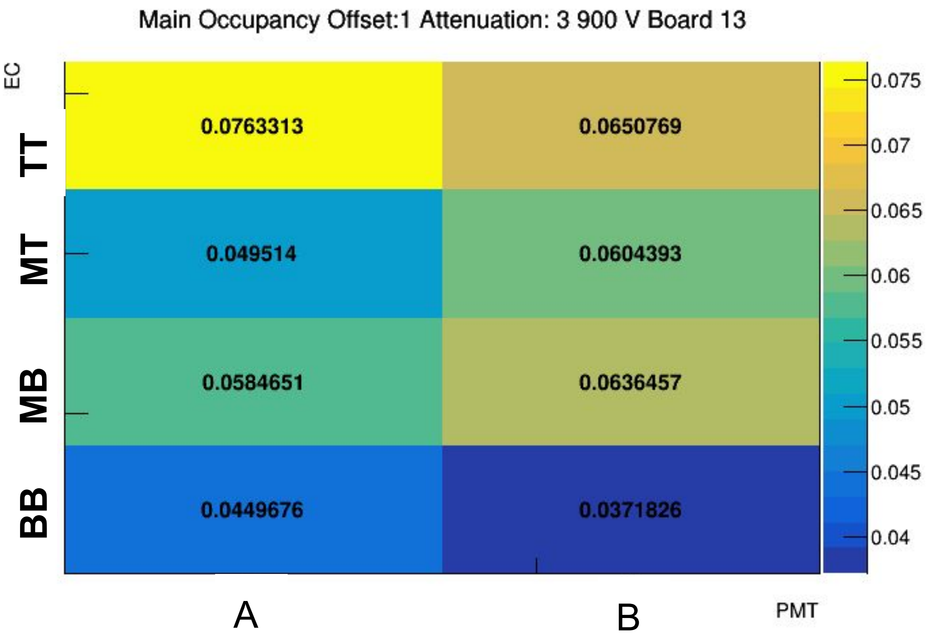
Max: 0.078
Min: 0.04

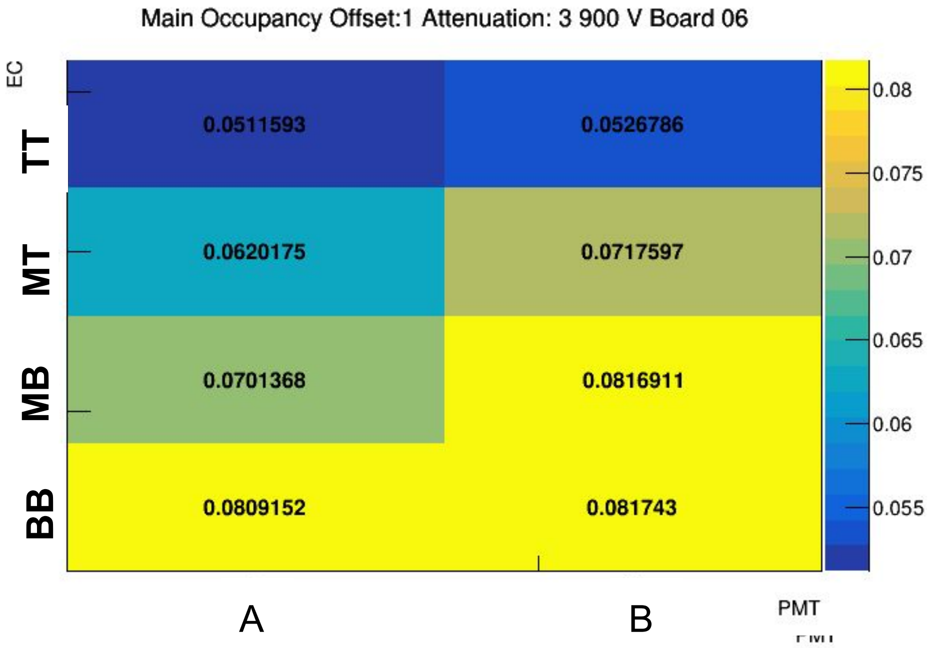
1000 V
Attenuation:3 Offset:1

Board 06

Max: 0.1
Min: 0.056

Threshold scans: Occupancy distributions different position





Board 13

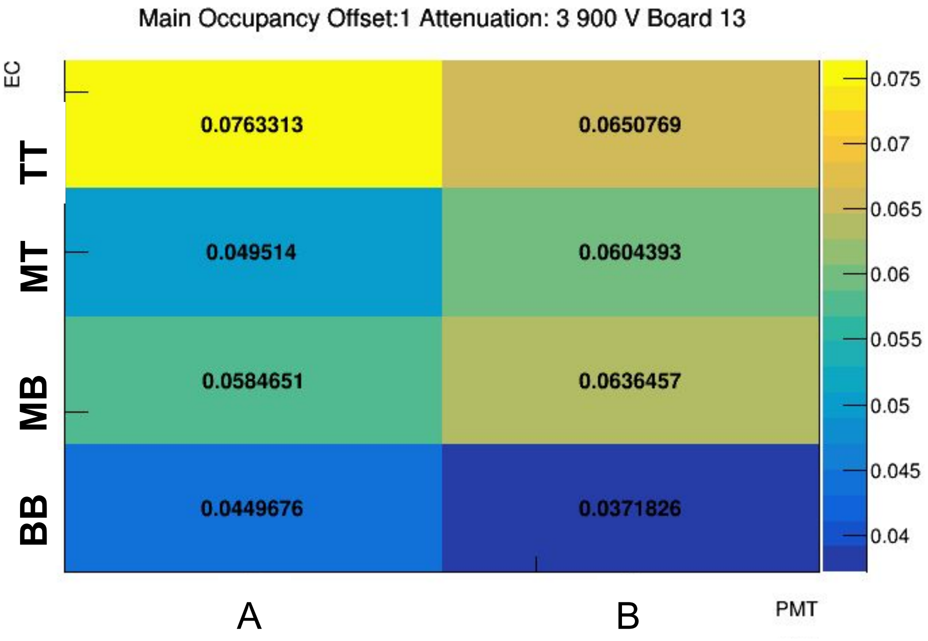
Max: 0.037
Min: 0.076

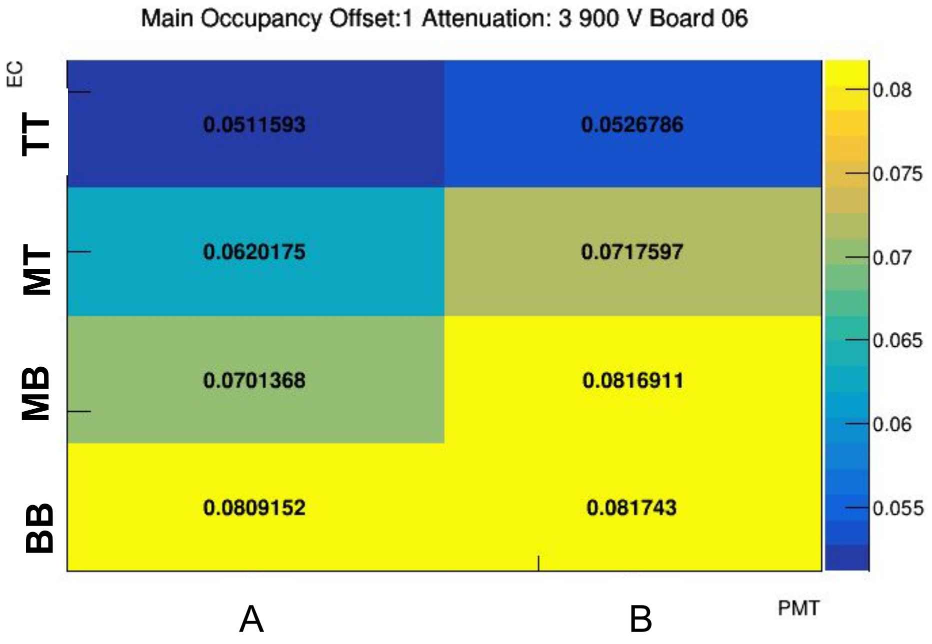
900 V
Attenuation:3 Offset:1

Board 06

Max: 0.051
Min: 0.081

Threshold scans: Occupancy distributions different position

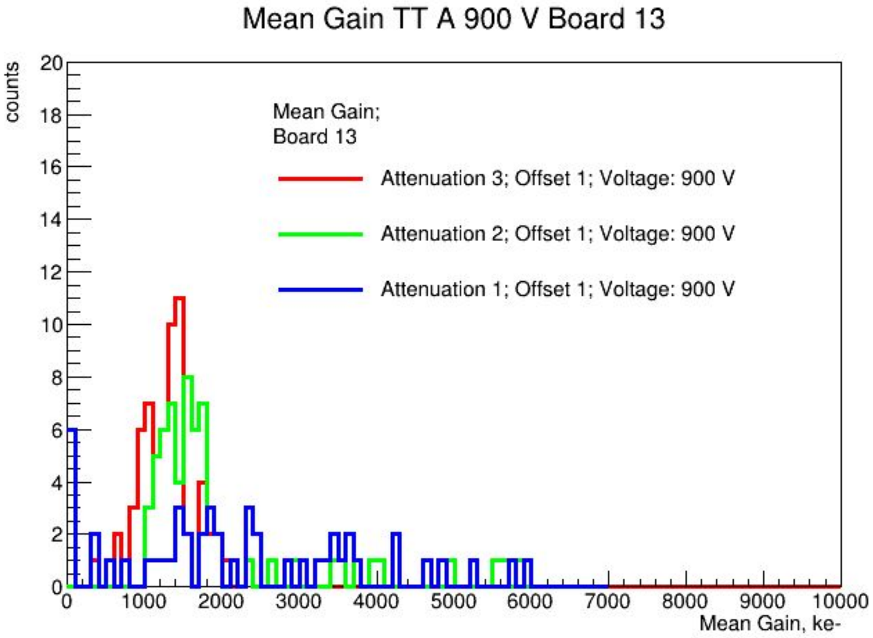


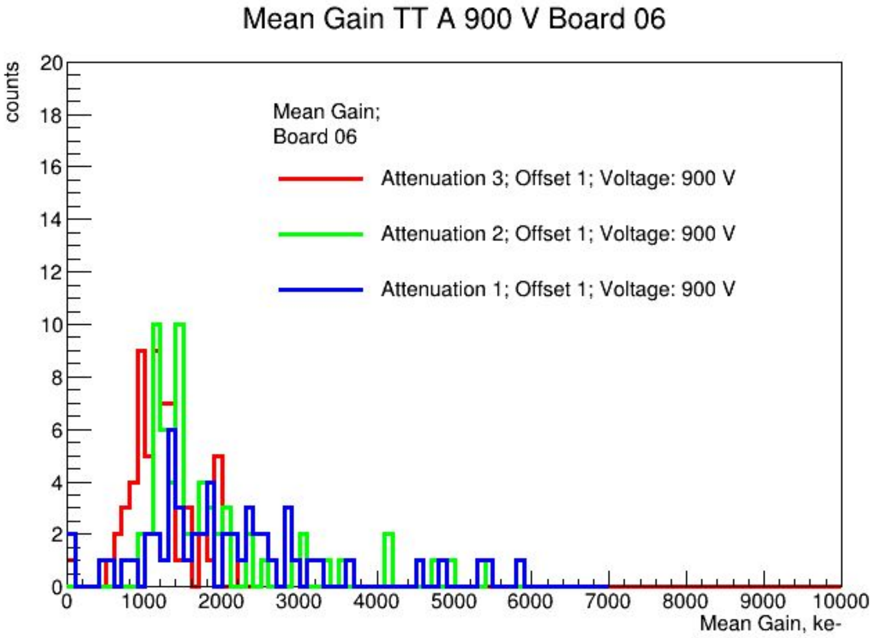


Board 13 **Board 06**

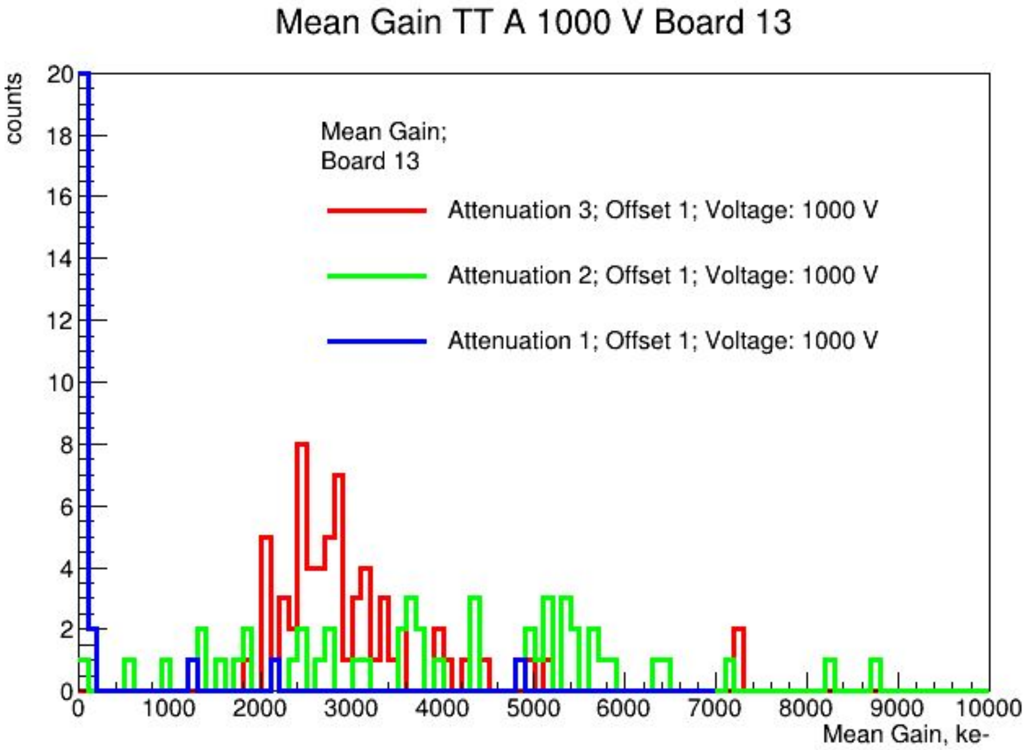
High/low occupancy PMTs remain high/low occupancy.

Threshold scans: Gain distribution different attenuation





Threshold scans: Gain distribution different attenuation



Threshold scans: Occupancy distribution different attenuation