# HGCAL Hexaboard: Single Module Calibration

Summer school work project

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# Sequence of the prodtest



1. Pedestal run
2. Pedestal scan
3. Inverted $V_{ref}$ scan
4. Non-inverted $V_{ref}$ scan
5. Phase scan
6. Sampling scan
7. Injection scan (not done in the .py is commented)

Each phase of the test produces plots and histograms, which are discussed and showed in the following slides.

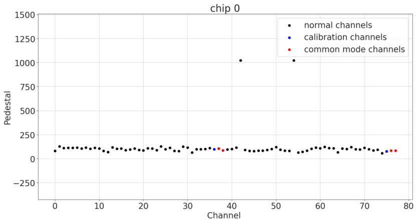
# Pedestal run

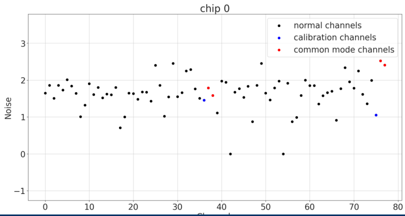


- During the test, the pedestal of each channel was acquired multiple times at a specific frequency.
- The Pedestal run returns an average pedestal value and a noise (root mean square of the all data obtained) for each channel.

# Pedestal run

## 1 Hexaboard prodtest

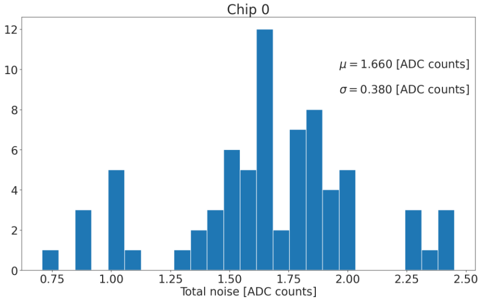



- A low density Hexaboard was used. The module is divided into 3 symmetric parts, each managed by an HGCROC. Each part can be further divided into 2 halves, each managed by half of chip's channels.
- For simplicity, the results shown here and in the following slides are from only one chip.
- The graphs show that the typical pedestal value is $\sim 100$ ADC counts, while the noise is $\sim 1.5 - 2$ ADC counts.

# Pedestal run

## 1 Hexaboard prodtest




- Distribution of the total noise for each channel. As said before, the noise is about $1.5 - 2$ ADC counts.

# Pedestal scan

## 1 Hexaboard prodtest

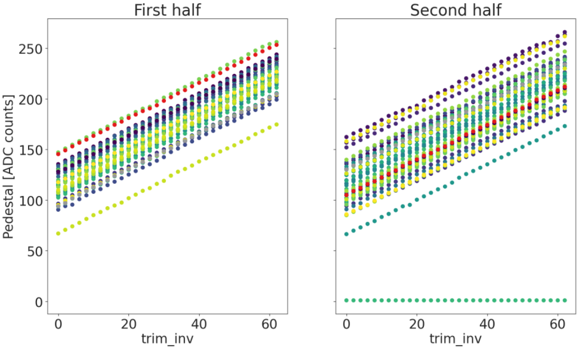
An increasing leakage current of the sensor is expected while it is irradiated. Since the DC level of the preamplifier exactly follows the leakage current change, an input DAC is needed to maintain the dynamic range.

We have to set the *trim_inv* (i.e. the inverted $V_{ref}$ of the DAC) in order to set the DC level of the shaper and so the ADC pedestal.

# Pedestal scan

1 Hexaboard prodtest

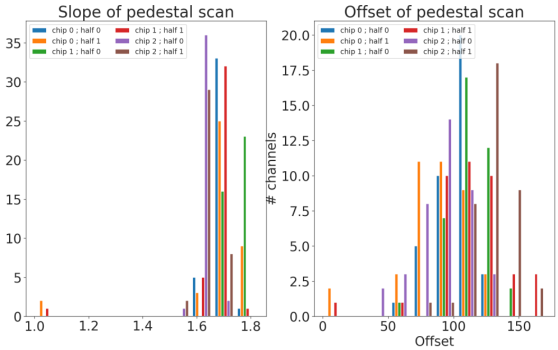
This test scans the $V_{ref}$ of the DAC (range 0 - 62 mV, steps of 2 mV) and estimates the pedestal for each channel and for all values of $V_{ref}$.




- It appears that each channel follows a linear trend while $V_{ref}$ increases.
- However there are channels that do not seem to respond correctly.

# Pedestal scan

## 1 Hexaboard prodtest




- Computing a linear fit of the previous data, we may compare the slope and the offset of each line (avg slope $\sim 1.6-1.7$, avg offset $\sim 60-150$).
- Also here, the presence of non-working channel is evident, as indicated by slopes and offsets that are significantly different from the average.

# Inverted and non-inverted $V_{ref}$ scan

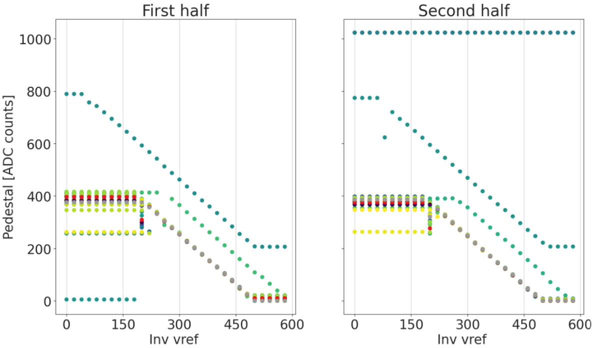


The inverted $V_{ref}$ is scanned again in this phase, however the range is bigger than the previous scan.

For each value of $V_{ref}$ (inverted or non-inverted) the scan estimates the average (with respect to a specific number or samples) of pedestal and noise.

# Inverted $V_{ref}$ scan

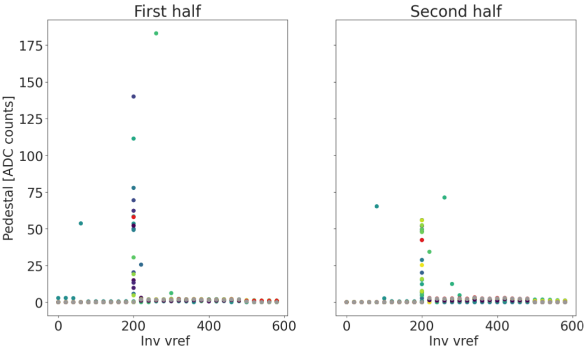
## 1 Hexaboard prodtest




- The pedestal remains steady up to $\sim$ 150 mV, when it starts to decrease linearly.
- When the voltage is low the pedestals appear more or less the same, except for some channels that appear non working.

# Inverted $V_{ref}$ scan

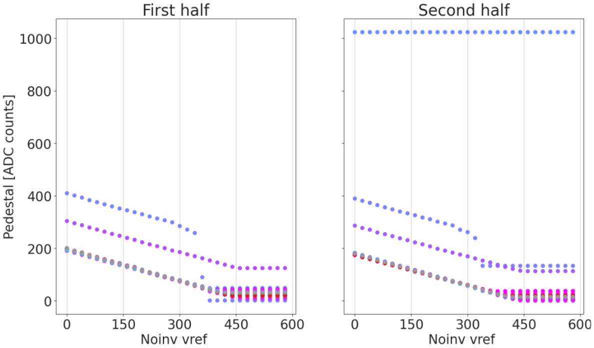
## 1 Hexaboard prodtest




- The noise remains stable for almost every voltage value. However there appear to be certain ”*resonance*” voltages characterized by higher values of the noise.

# Non-inverted $V_{ref}$ scan

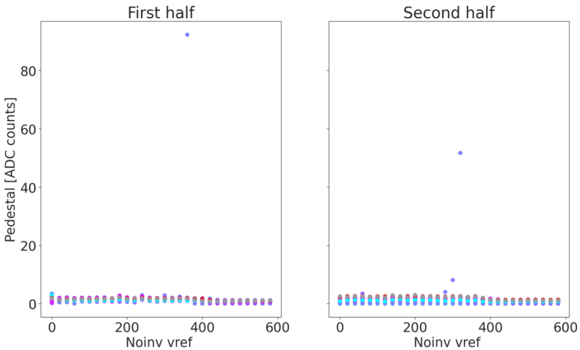
## 1 Hexaboard prodtest




- The pedestal trend is the same of before, however here it starts to decrease immediately and remains unchanged at the value of $\sim 0$ ADC counts, after $\sim 450mV$.

# Inverted $V_{ref}$ scan

## 1 Hexaboard prodtest




- Again the noise seems independent to the voltage.
- On the contrary of before there is no *resonance* voltage.

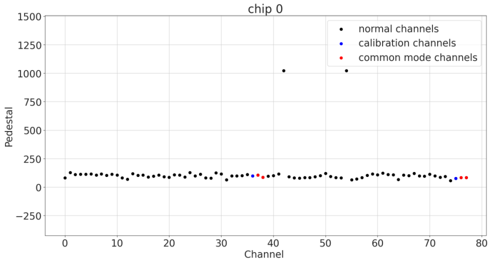
# Trimming

After all these scans, we can set the DC level of the front-end electronics in order to set the pedestal of each channel to be as similar as possible to the others. This operation is called **trimming**

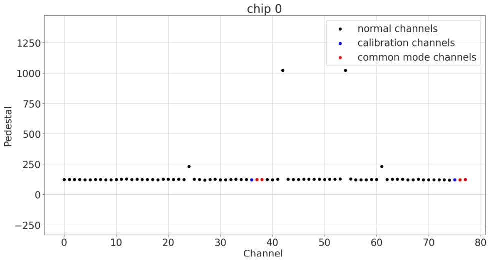
# Before vs After trimming

## 1 Hexaboard prodtest

**Before**




**After**

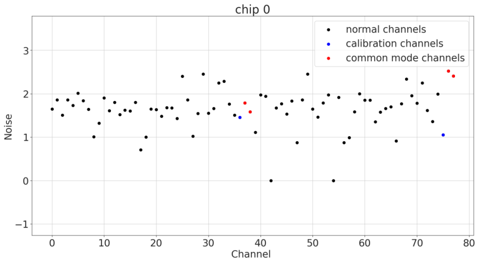



As expected, after trimming the pedestals are more or less all aligned to the same value.

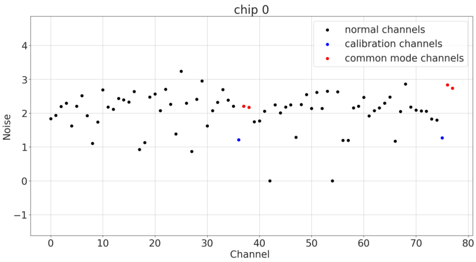
# Before vs After trimming

## 1 Hexaboard prodtest

**Before**




**After**

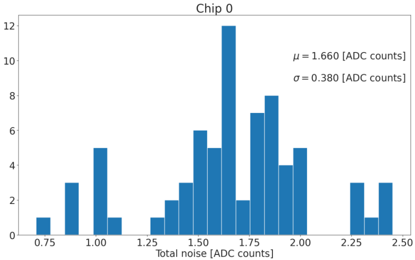



We may expect that, after trimming the noise remains unchanged, since it is almost independent to DC levels of electronics. However here it can be noticed a slight increase of the noise per each channel.

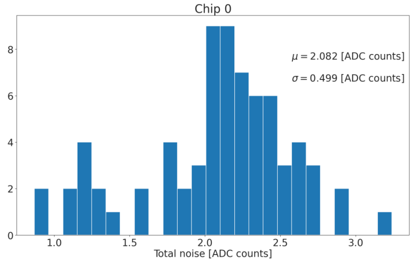
# Before vs After trimming

## 1 Hexaboard prodtest

**Before**




**After**




Again, also here the light increase of the noise is evident. The *trimmed* histogram is just shifted a bit to higher noise values.

# Phase scan

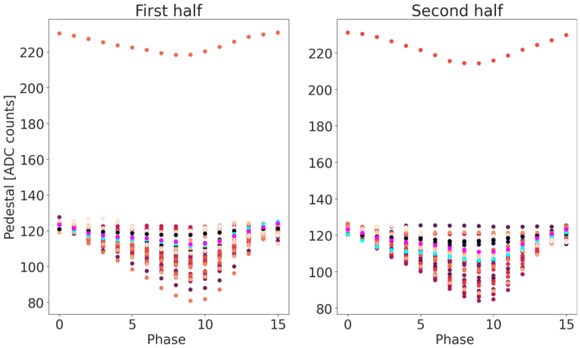


This test scans the phase parameter and returns the pedestal, the average pedestal (among channels of the same half) and noise for every value of the phase.

Ideally, we may expect that nothing changes after a shift of a signal. So, we should expect flat distribution for all the variables estimated.

# Phase scan

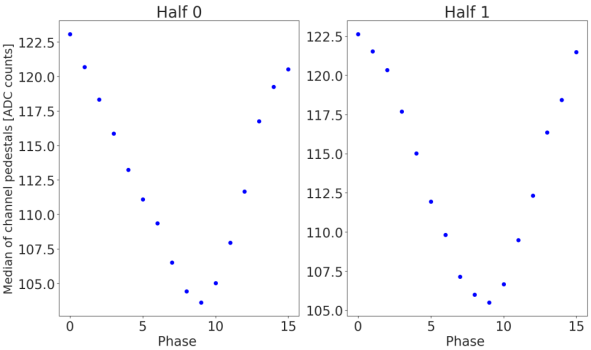
## 1 Hexaboard prodtest




- Apart from "*anomalous channels*", there is a common general trend of the pedestal as a function of the phase parameter.

# Phase scan

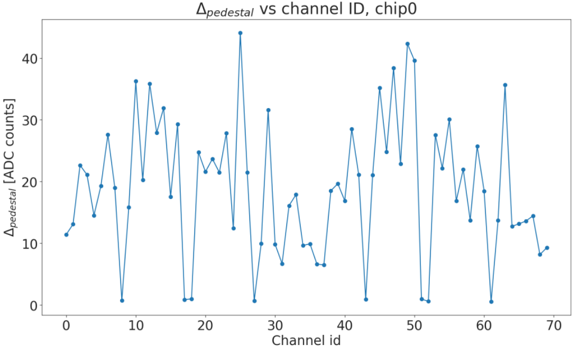
## 1 Hexaboard prodtest




- By eye, the avg pedestal trend appears parabolic with a minimum in correspondence of $8-9$ of the phase parameter.

# Phase scan

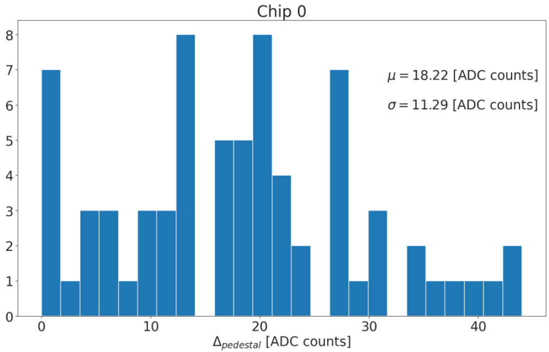
## 1 Hexaboard prodtest




- $\Delta_{pedestal}$ is the difference between the maximum and minimum pedestal in the phase scan sampling.
- With this graph we can see which channel is more affected by phase scan (i.e. high $\Delta_{pedestal}$ value)

# Phase scan

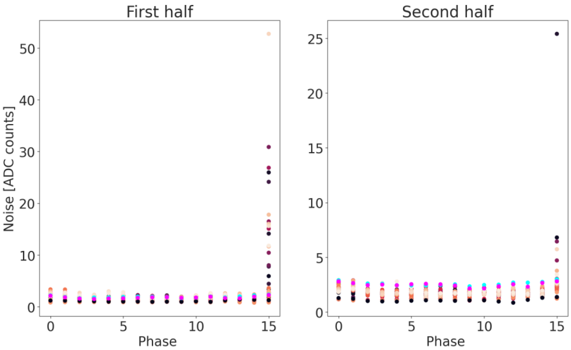
## 1 Hexaboard prodtest




- The reason why the histogram is not completely flat is due to the different "parabola" of each channel.
- The reason why we do not have a single value of $\Delta_{pedestal}$ imply the difference of the trend of the pedestal with respect to the phase scan.

## Phase scan

### 1 Hexaboard prodtest




- As expected the noise remains flat as a function of the phase parameter. However at a phase parameter value of 15 there is a significant increase of the noise.

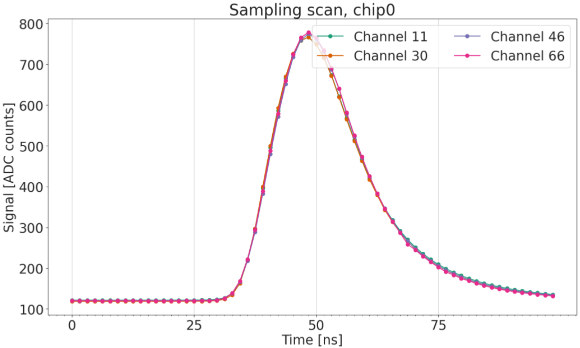
# Sampling scan



In this test we reconstruct the pulse of the shaper after the injection in 4 channels (2 per half).
This test could be seen as a time scan of the ADC, ToA and ToT variables for just 4 channels.

# Sampling scan

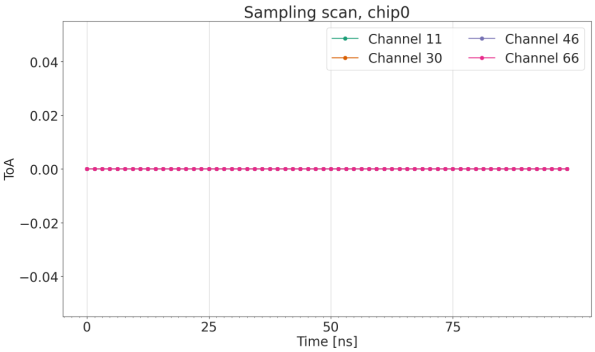
## 1 Hexaboard prodtest




- The shape of the pulse seems reasonable for a silicon detector.
- All injected channel behaves in the same way as expected.

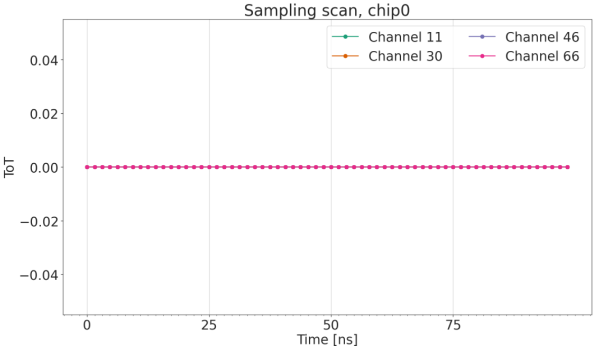
# Sampling scan

## 1 Hexaboard prodtest




- We expected a *step-function* trend, however it seems that something does not enable the acquisition of the ToA variable.

# Sampling scan
## 1 Hexaboard prodtest




- Same problem of before

# Sequence of the ToA test

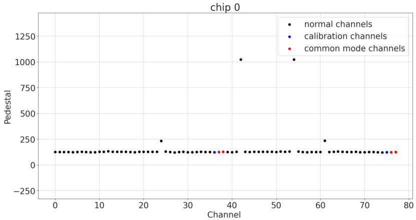
## 2 ToA scan

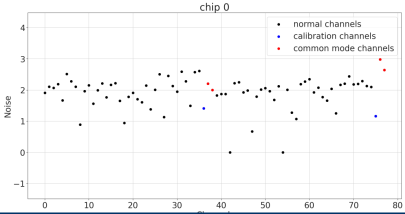
1. Pedestal run
2. ToA_vref scan
3. Pedestal run
4. Trim_ToA scan

In this test the after-trimming configuration is used.

# First Pedestal run

## 2 ToA scan

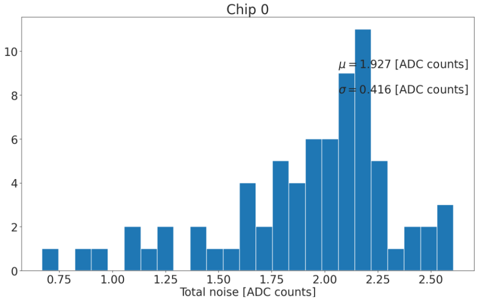



- The pedestals appear exactly the same as in the last pedestal run.
- The noise per channel fluctuates and does not take the same value of the last pedestal run. However it may be expected a compatible distribution.

# First Pedestal run

## 2 ToA scan




- Distribution of the total noise for each channel. The histogram differs from the last pedestal run only due to statistical fluctuations.

# ToA $V_{ref}$ scan



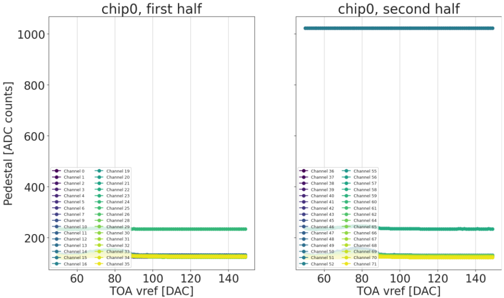
There are two discriminators per channel, one for the ToT measurement, the other for the ToA. Two global 10b-DACs allow the user to adjust the thresholds of the discriminators and two local triming 5b-DACs allow to reduce the dispersion per channel. The 10b-DAC have 1 mV LSB, the trimming 5b-DAC have 0.25 mV LSB. The thresholds are computed as following:

$$\text{ToA\_threshold} = \text{ToA\_vref} < 9:0 > - \text{Trim\_dac\_toa} < 4:0 >$$
$$\text{ToT\_threshold} = \text{ToT\_vref} < 9:0 > - \text{Trim\_dac\_tot} < 4:0 >$$

The following phase scans the variable ToA $V_{ref}$, estimating, for each value of ToA $V_{ref}$, the pedestal, the noise and the ToA efficiency.

# Pedestal vs ToA $V_{ref}$

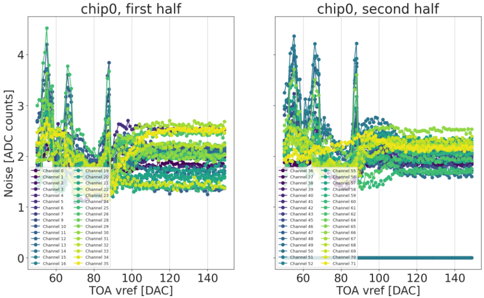
## 2 ToA scan




- Apart from few channels, most of them are almost independent on the variable ToA $V_{ref}$. However a little "bump" can be observed at about 70-80 ToA $V_{ref}$.

# Noise vs ToA $V_{ref}$

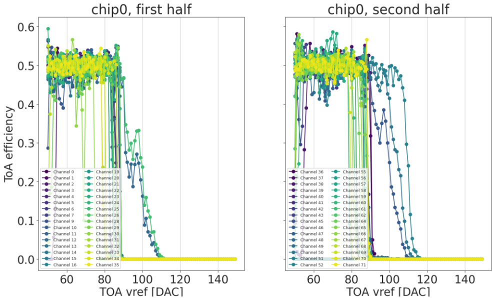
## 2 ToA scan




- The noise for each channel appears steady for values of ToA $V_{ref} > 100$. However unpredictable oscillations of the noise are evident, for lower values of the scanned variable.

# ToA efficiency vs ToA $V_{ref}$

## 2 ToA scan




- The ToA efficiency appears independent of ToA_vref up to a value of 80 ToA_vref where the efficiency starts going down to 0.
- Some channels do not follow the average trend and the efficiency starts to decrease before or after the average breakdown ToA $V_{ref}$.

# Second pedestal run

## 2 ToA scan

The same results and considerations showed in the previous pedestal run could be presented also here. This second run is important to check if something went wrong during the ToA scan

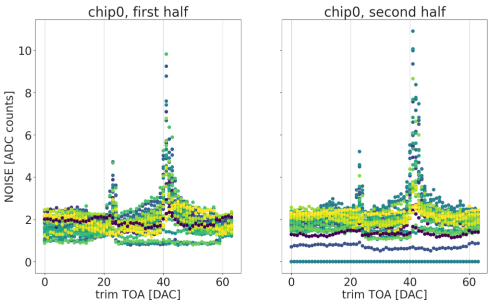
# Trim_ToA scan



As mentioned before, the ToA threshold is given by two variables: the Toa_vref and the Trim_dac_ToA. In this phase the Trim_dac_ToA is scanned, estimating the noise and the ToA efficiency.

# Noise vs Trim_ToA

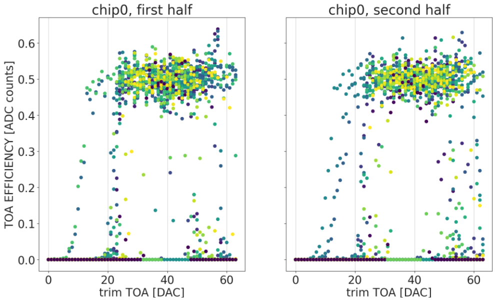
## 2 ToA scan




- The noise per each channel appears almost flat for all values of Trim_ToA. However there are some values of Trim_ToA where the noise assumes very high values. It appears that these Trim_ToA values are the same in every chip of the module.

# ToA efficiency vs Trim_ToA

2 ToA scan




- The ToA efficiency per channel remains stable at 0.5 only in the range of 20-50 Trim_ToA value. Outside of this interval the efficiency is roughly 0.

# Sequence of the ToT test

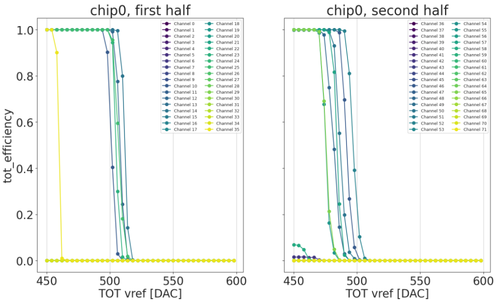


1. Pedestal run
2. ToT_vref scan
3. Pedestal run
4. Trim_ToT scan

In this test the after-trimming configuration is used.
(To be more precise the script runs another ToA scan, an injection scan and finally the ToT scan).

# ToT effieciency vs ToT $V_{ref}$

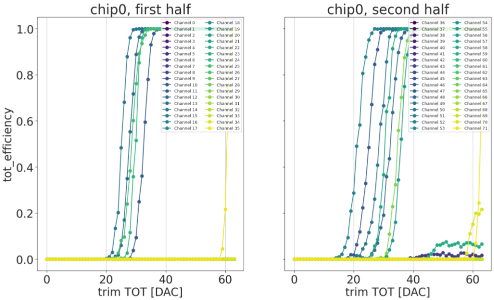





- Definition of ToT efficiency?.
- The ToT efficiency appears independent of ToT_vref, and equal to 1, up to a value of 500 ToT_vref where the efficiency starts collapsing to 0.

# ToT effieciency vs Trim_ToT

## 3 ToT scan




- Definition of ToT efficiency?.
- Apart from values less than $\sim 30$ Trim_ToT, where the efficiency appears very low, the ToT efficiency is almost equal to 1 for each channel.

# Injection scan

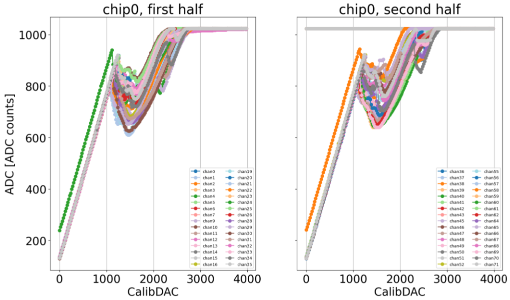


This test scans the Calib_DAC (injection value) parameter, returning plots of mean ADC, ToT, ToA and their efficiencies for each channel.

Two injection scans are actually performed: the first uses the LowRange of injection (0.5pF injection capacitance) while the second uses the HighRange (8 pF injection capacitance).

# ADC vs Calib_DAC

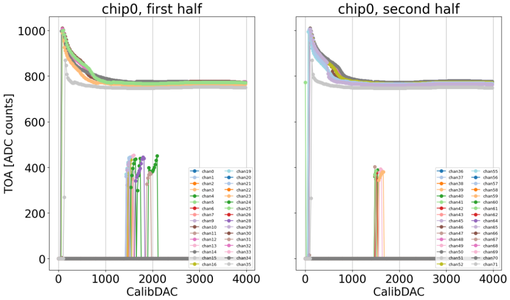
## 4.1 Low range injection scan




- A linear increase was expected, however for almost every channel an unusual oscillation is observed.
- Each channel reach saturation after $\sim$ 3000 Calib_DAC.

# ToA vs Calib_DAC

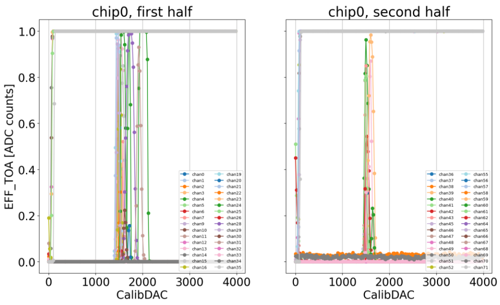
## 4.1 Low range injection scan




- A step function trend was expected, however there are some channels that appear non-working.

# ToA efficiency vs Calib_DAC

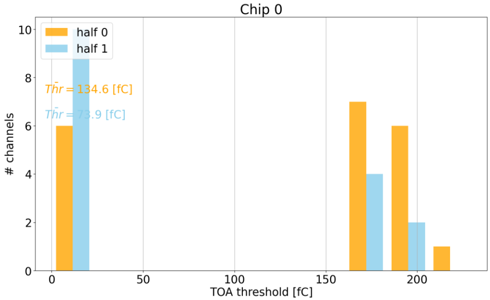
## 4.1 Low range injection scan




- The ToA efficiency is equal to 1 except for the non-working channels mentioned earlier.

# ToA threshold

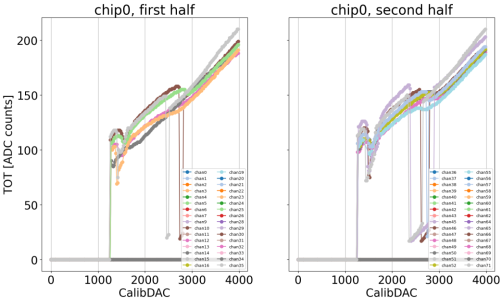
## 4.1 Low range injection scan




- This plot shows the computed threshold per channel of the ToA discriminator.
- why there are channels with very high ToA threshold?

# ToT vs Calib_DAC

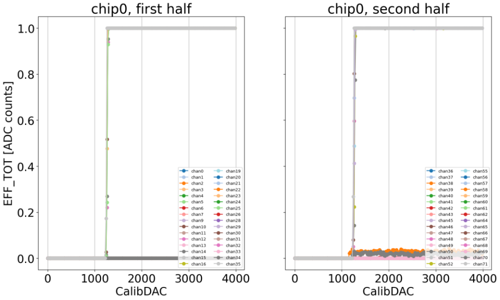
## 4.1 Low range injection scan




- A step function trend was expected, however no channel shows that behaviour.
- A general linear increase is observed that could be due to the Low range of the injection. Maybe the ADC is not so far from the ToT threshold.

# ToT efficiency vs Calib_DAC

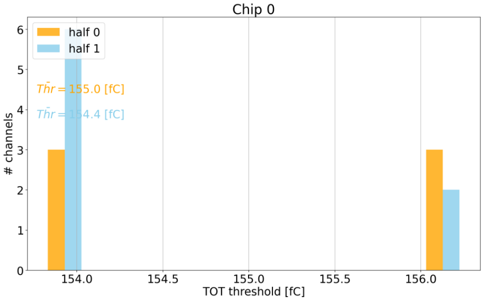
## 4.1 Low range injection scan




- The ToT efficiency is equal to 1 except for the non-working channels.

# ToT threshold

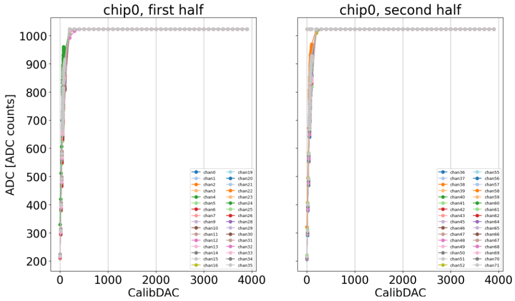
## 4.1 Low range injection scan




- This plot shows the computed threshold per channel of the ToT discriminator.

# ADC vs Calib_DAC

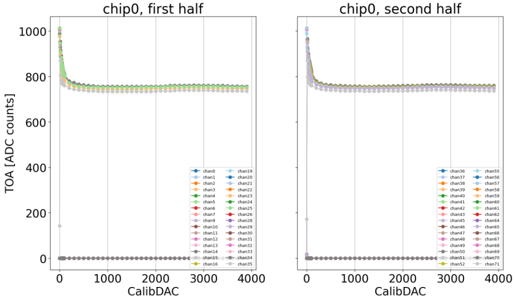
## 4.2 High range injection scan




- Almost every channel follows the expected linear trend until it reaches saturation at approximately 400 Calib_DAC.

# ToA vs Calib_DAC

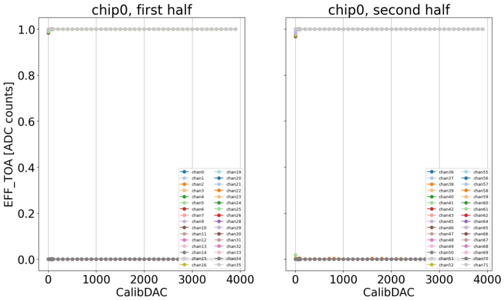
## 4.2 High range injection scan




- As expected, a step function trend is showed.

# ToA efficiency vs Calib_DAC

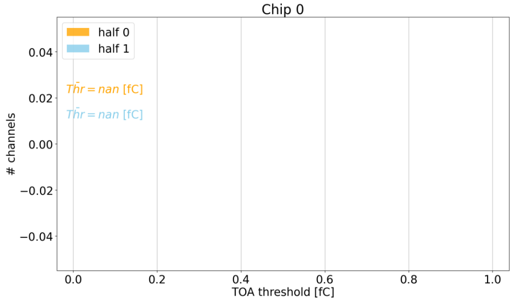
## 4.2 High range injection scan



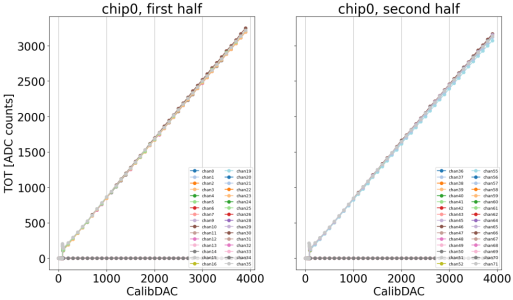

- The ToA efficiency is equal to 1 except for the non-working channels.

# ToA threshold

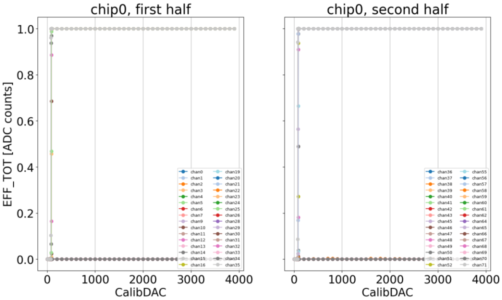
## 4.2 High range injection scan




- This plot should have showed the computed threshold per channel of the ToA discriminator.
- Probably, something went wrong during the execution of the analysis script.



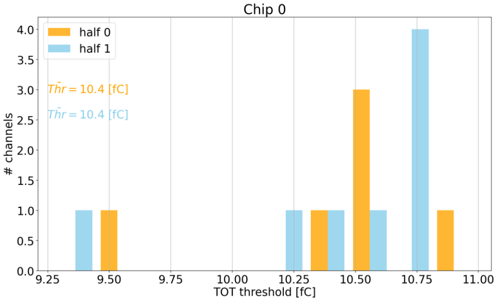

- A step function trend was expected, however no channel shows that behaviour.
- Apart from non-working channels, a perfect linear trend is observed.




- The ToT efficiency is equal to 1, except for the non-working channels.

# ToT threshold

## 4.2 High range injection scan




- This plot shows the computed threshold per channel of the ToT discriminator.
- In the Low range injection scan the same threshold was one order of magnitude higher than the threshold showed here.