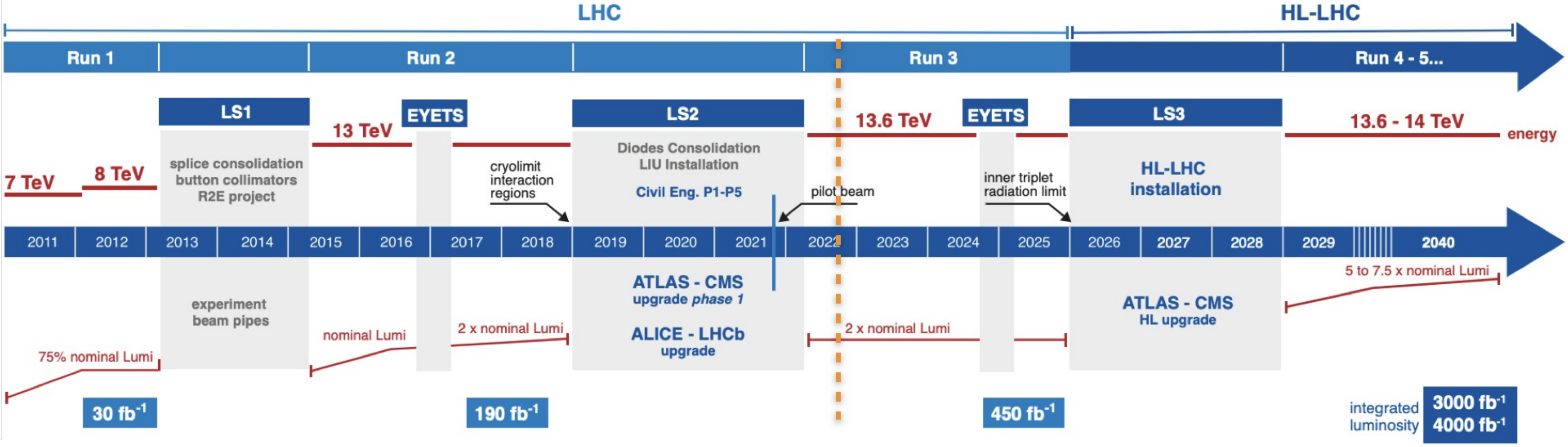
The CMS Phase II Outer Tracker Upgrade at Fermilab

Nicolò Salimbeni

Final presentation Italian summer school

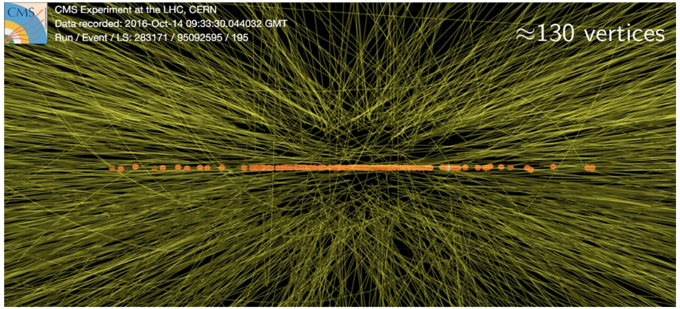
09/27/2023

LHC timeline, why do we need to update CMS?



At high luminosity less than 1 month is required to collect the luminosity of the full Run 2

Challenging conditions: very high occupancy and radiation damage



New tracking Modules

The tracking system is updated mostly to include tracking information in the level one trigger (L1), selecting only events with a certain value of transverse momentum.

These requirements are not that easy to satisfy, the detectors must be:

- very fast, to send info to L1 trigger every bunch crossing time (25 ns)
- radiation hard due to increased luminosity

↓

We need a special silicon detector that is fast, able to select hit from particles with high transverse momentum and radiation hard

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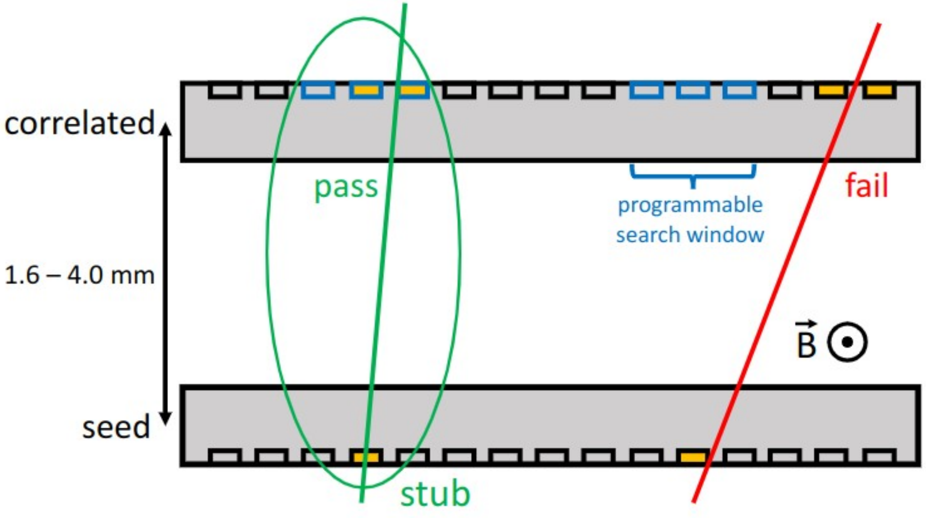
Strip-Strip module (2S) and Pixel-Strip module (PS)

These new modules are made of a “sandwich” of two silicon detectors. The sensors are parallel to each other and separated by a few millimeters gap.

When a particle hit the lower sensor a window in the upper one is opened.

Then only if the particle hits the upper window is selected



The angle of the track is a function of $\vec{B}$ (known) and p_T. Selecting different windows we can accept only particles in a specific range of p_T.

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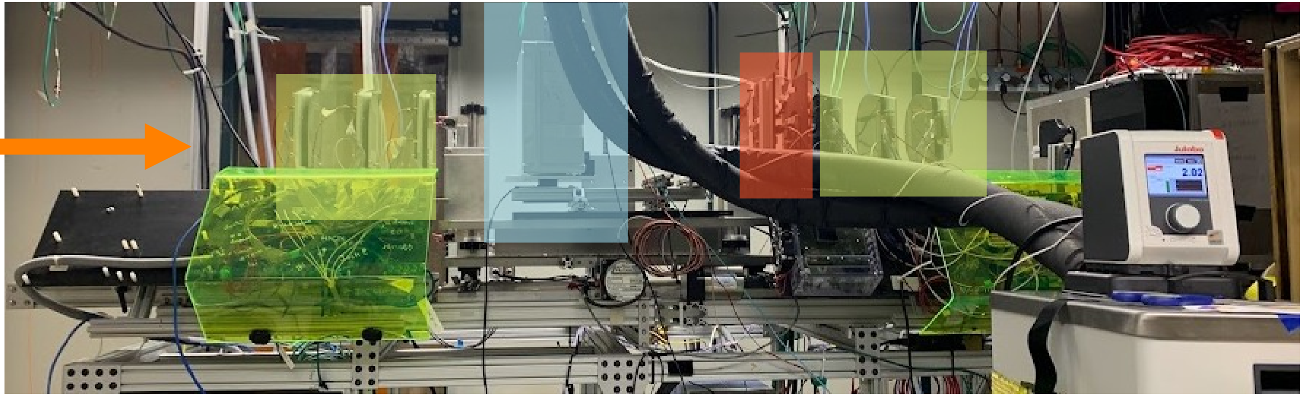
Fermilab test beam facility

beam



- 120 GeV proton beam
- DAQ: Off The Shelf Data Acquisition (OTSDAQ)
- Telescope: Silicon strips + pixels

Module irradiation

At fermilab a PS module is currently under test.

Half of the module was irradiated with 400 MeV protons.

- Fully irradiated side
- Not irradiated side

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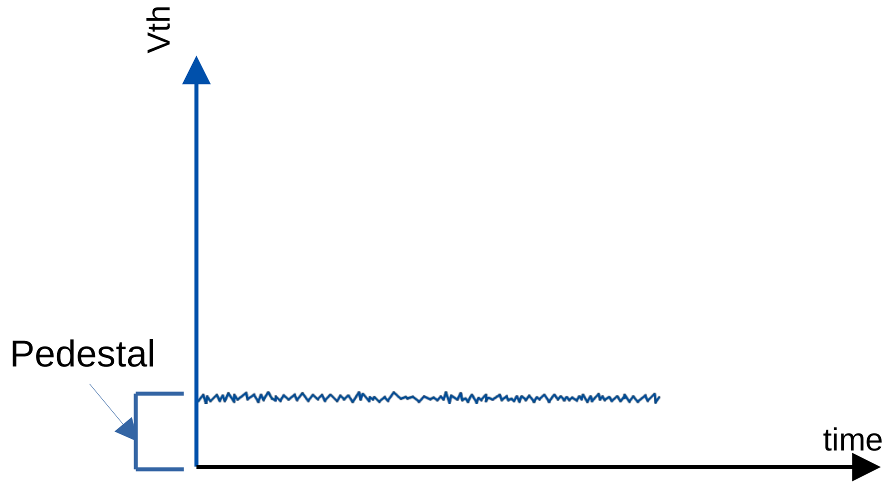
The first thing to do is to know exactly the threshold used in electrons



The example presented is for SSAs, but the procedure is the exact same for MPAs.

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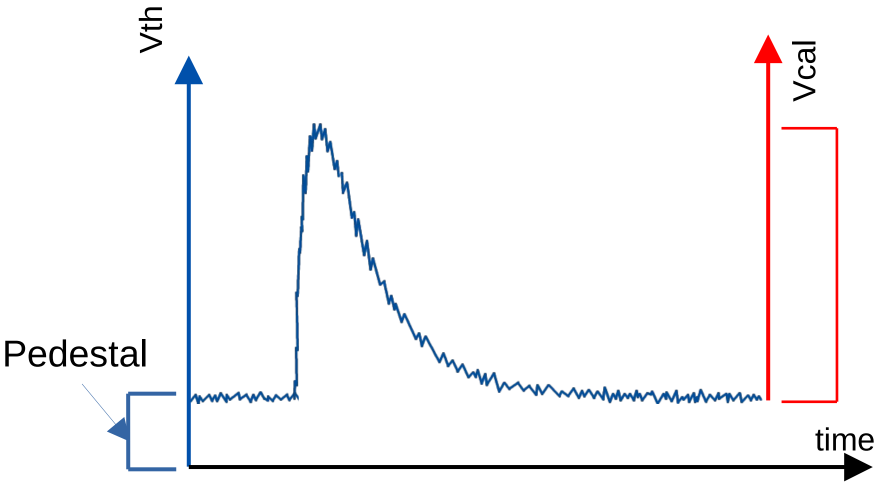
- To find the pedestal of each pixel/strip we used a constant injected signal in the readout, where Vcal is the register used to inject charge.



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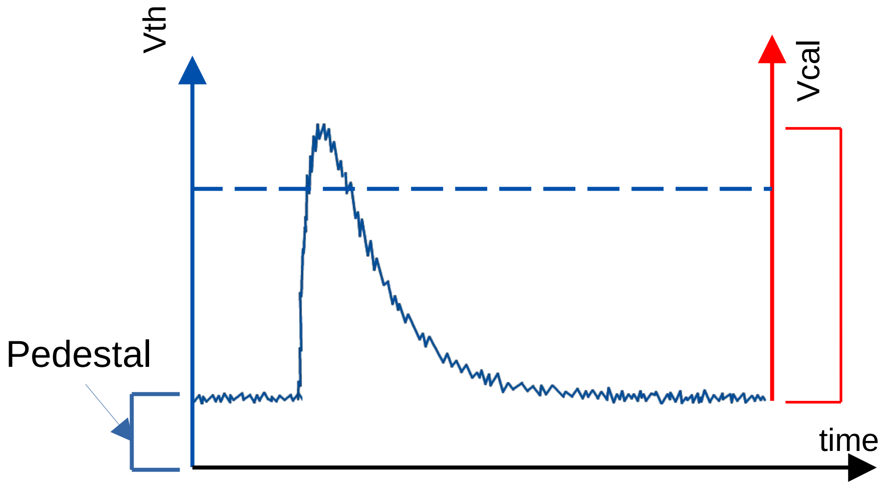
- To find the pedestal of each pixel/strip we used a constant injected signal in the readout, where Vcal is the register used to inject charge.
- Then by doing a threshold scan we obtain an S curve whose value at 50% occupancy corresponds to the sum of the injected signal plus the pedestal. Vth is the register used to control the threshold.



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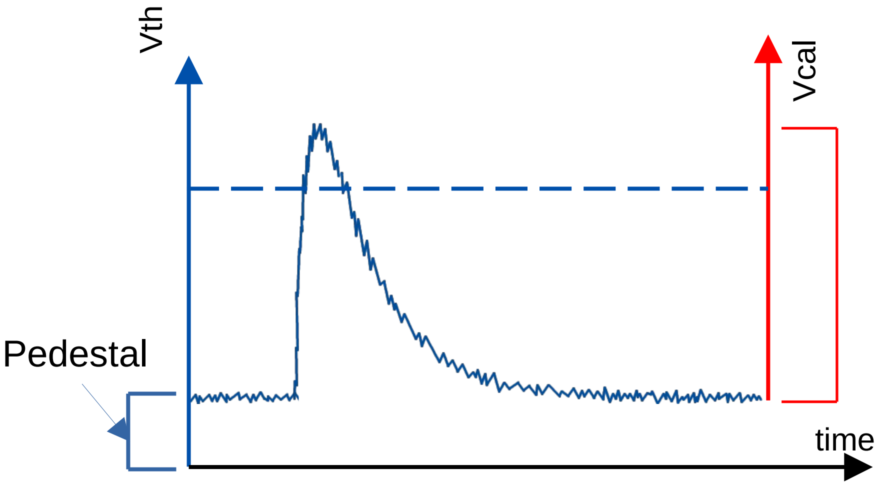

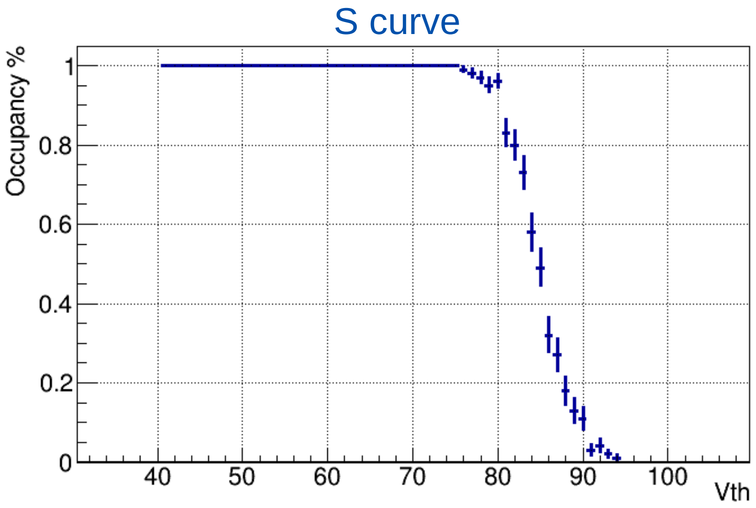

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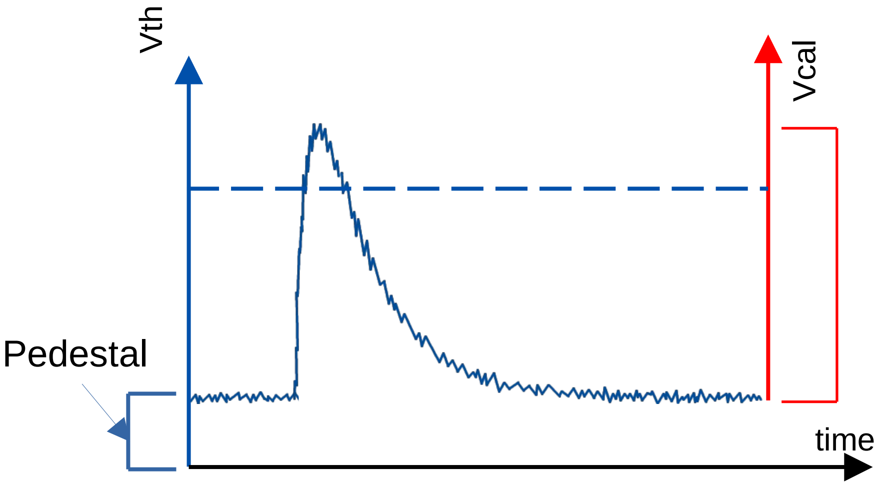

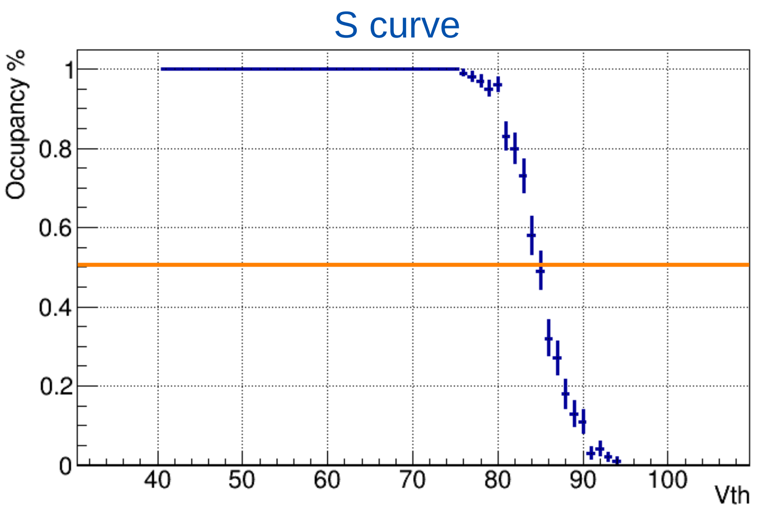

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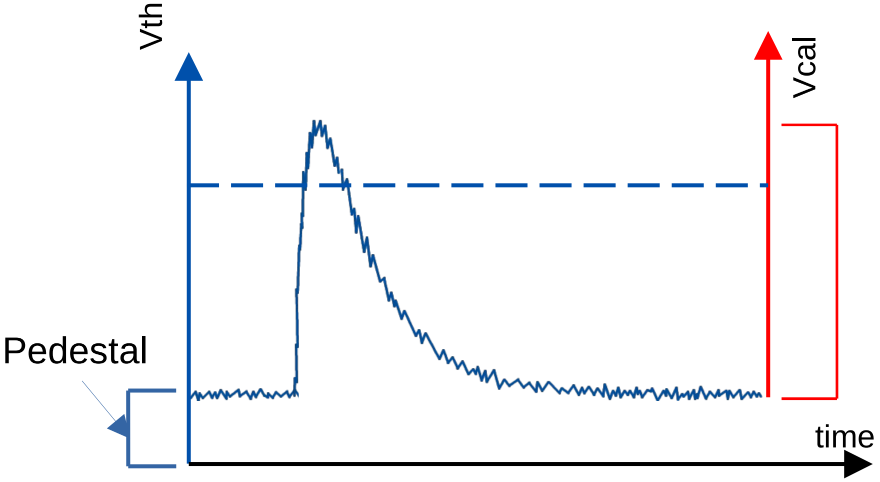

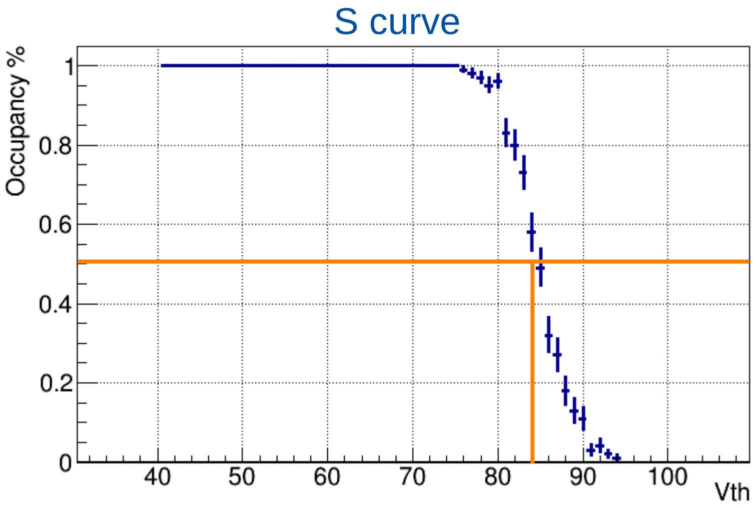

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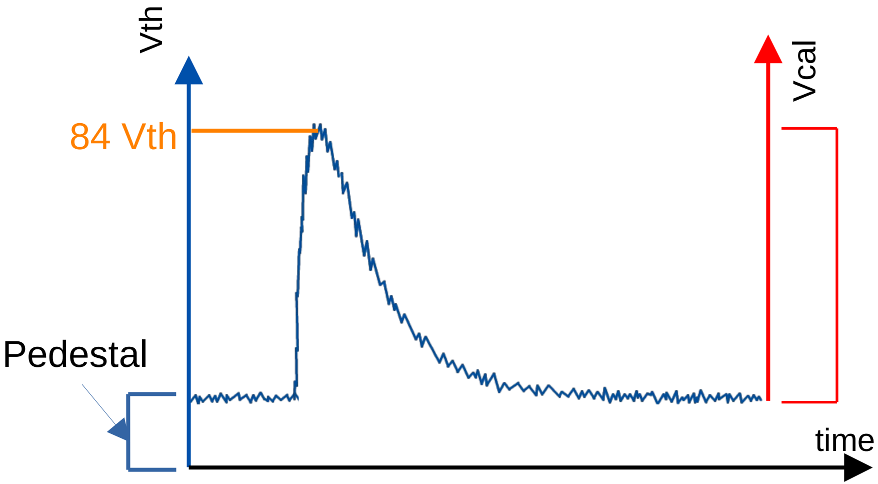

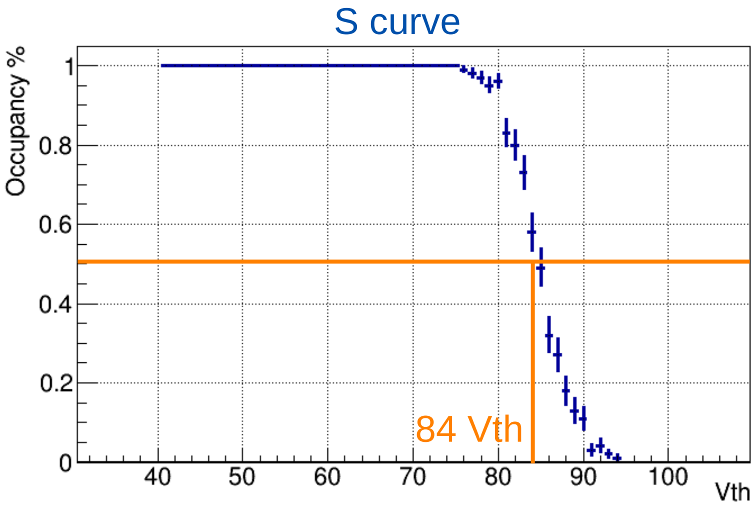

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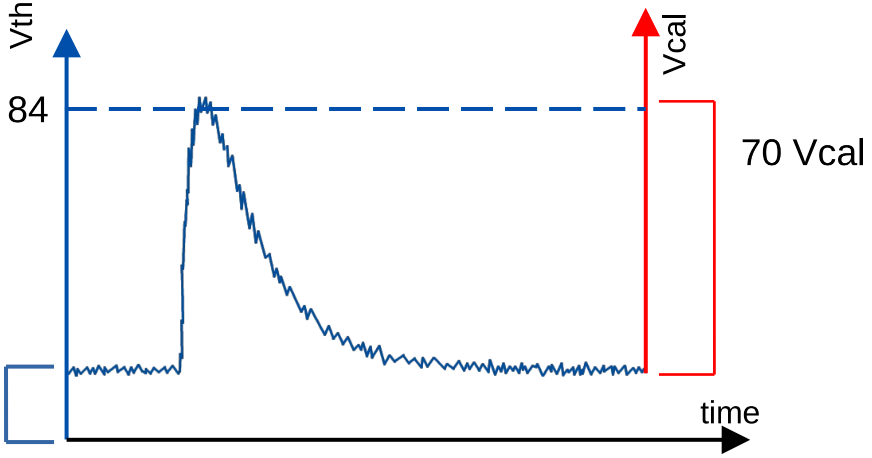
Pedestal analysis

- Since we know the conversion into electrons for both Vth and Vcal it is possible to find the pedestal. (We get the same values for irradiated and non irradiated detector)



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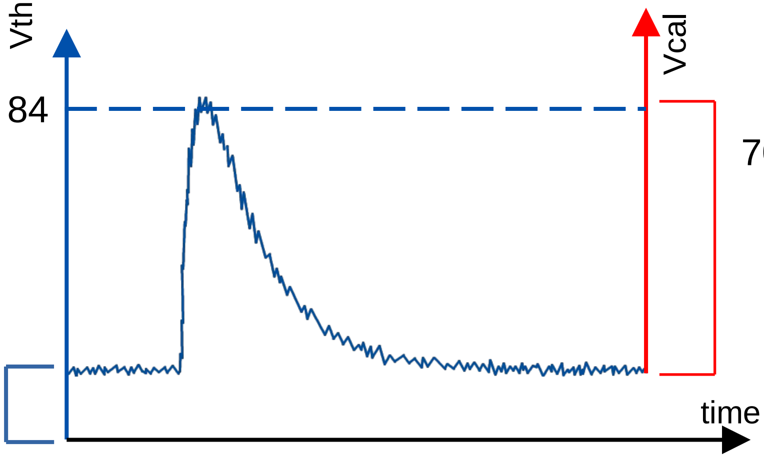

70 Vcal = 17010 e^- = 68 Vth

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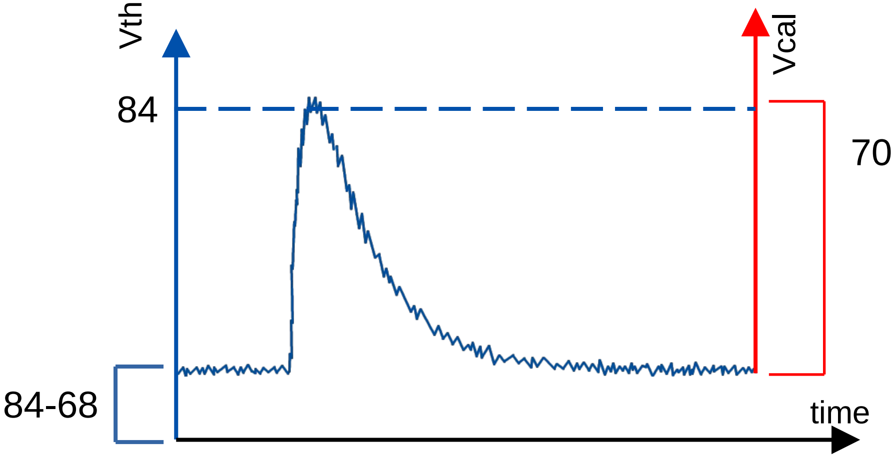

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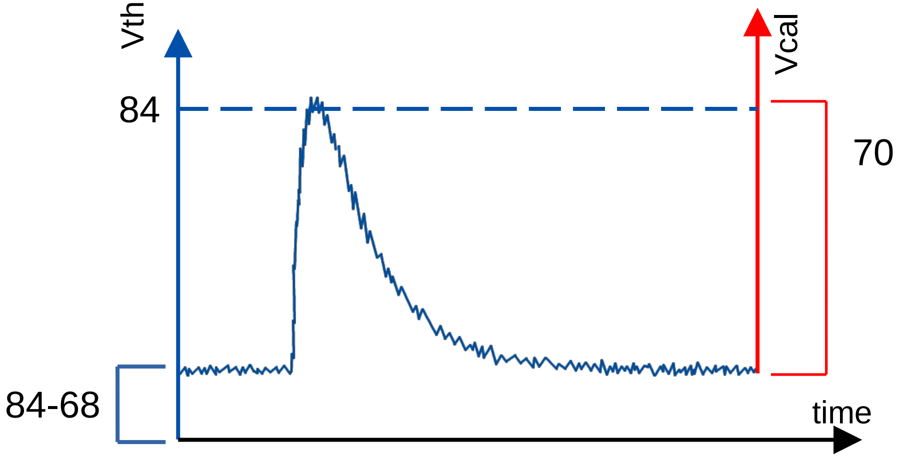


70 Vcal = 17010 e^{-} = 68 Vth

In conclusion the pedestal is 16, so when we convert the threshold into electrons the formula is:
$(V_{th} - 16) \times 250$ electrons

The example presented is for SSAs, but the procedure is the exact same for MPAs.

Efficiency characterization of PS module

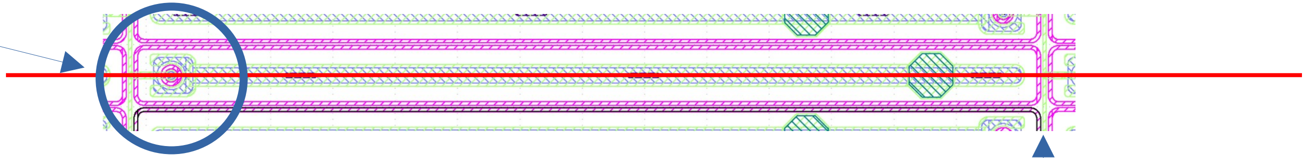
Nicolò Salimbeni

Final presentation Italian summer school

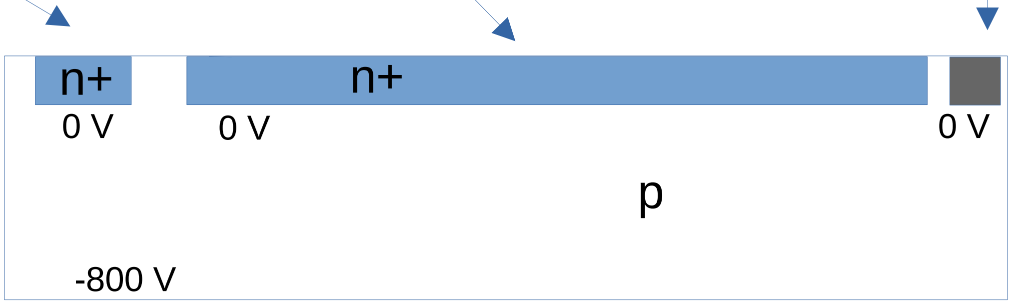
09/27/2023

Low efficiency for pixels in the not irradiated side

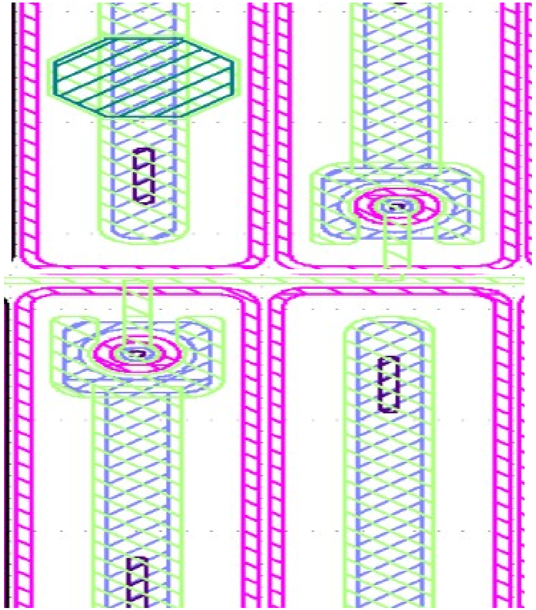
The efficiency for a silicon detector should be close to 100%, we get 98.5%. Why?



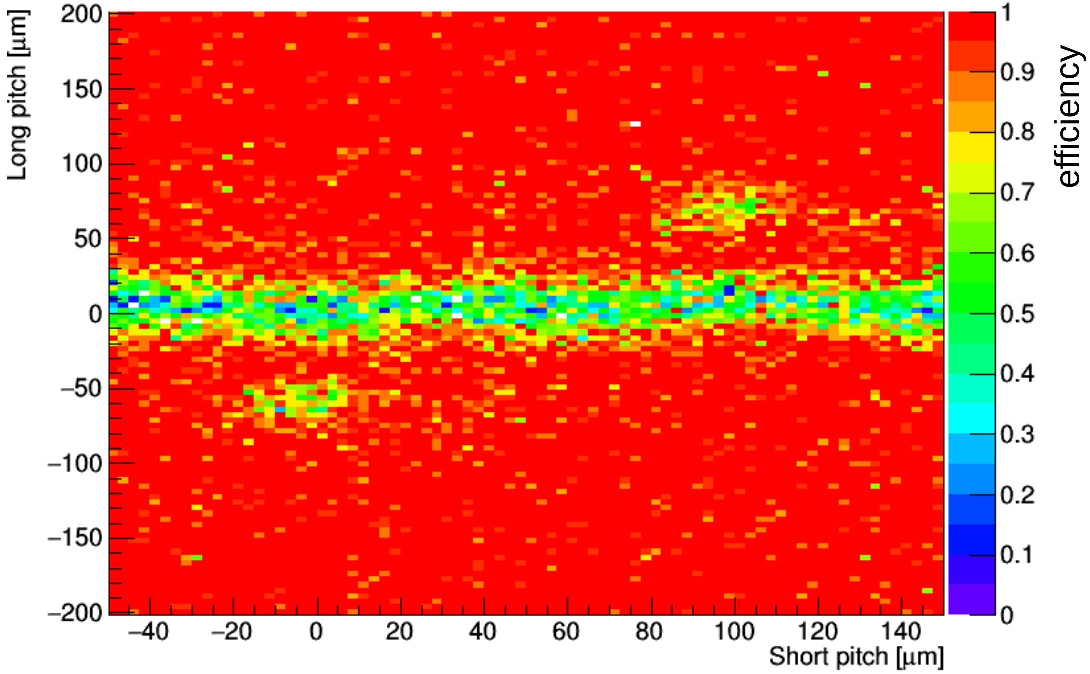
Let's take a vertical section of just one pixel



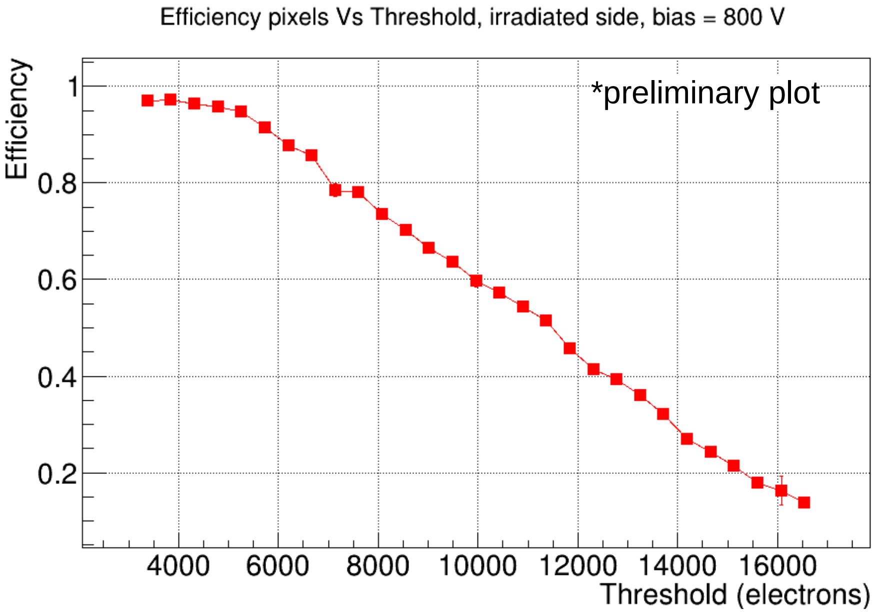
Close up of the 2D efficiency map

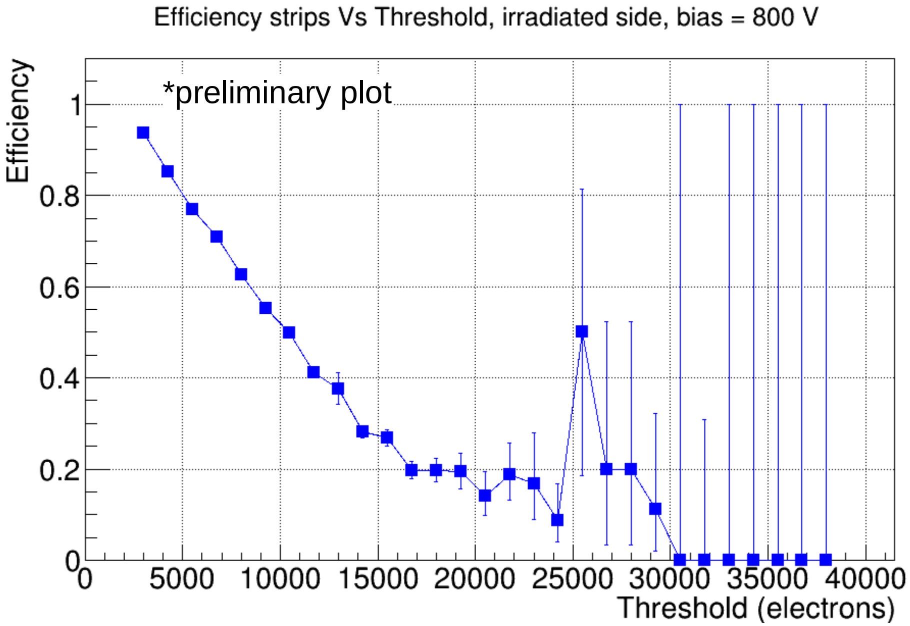


2D efficiency zoom



Efficiency as a function of the threshold, irradiated side





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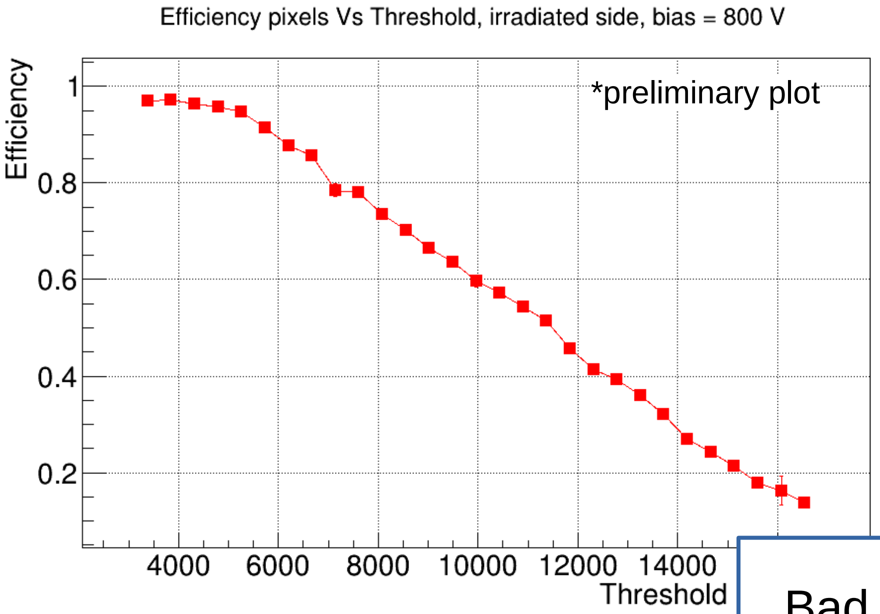

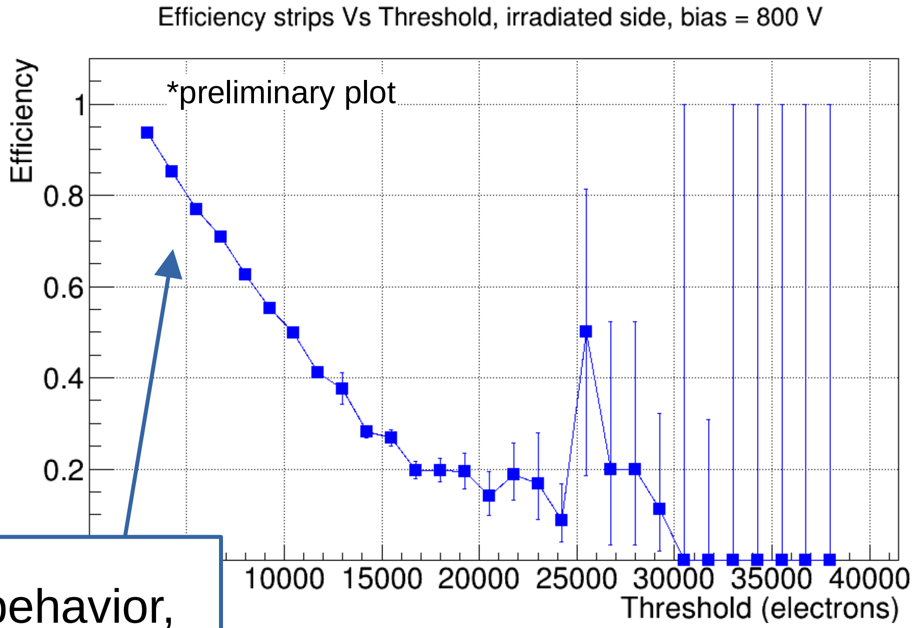

Bad behavior, why?

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PS module noise occupancy characterization

Nicolò Salimbeni
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How do we compute the noise occupancy?

Noise occupancy usually defined as:

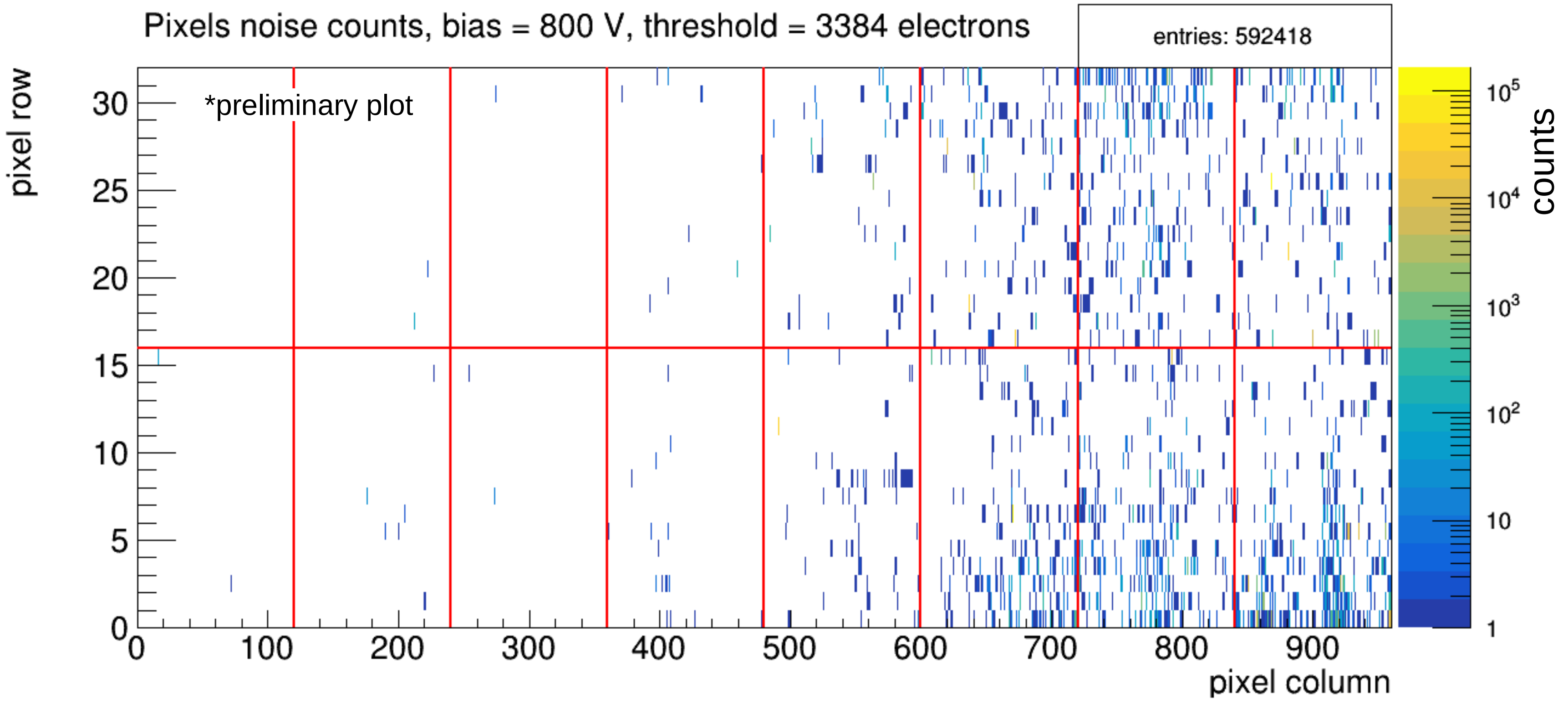
$$\frac{\text{number of hits in one pixel or strip}}{\text{number of triggers}}$$

Ideally we would perform this analysis pixel by pixel (strip by strip) but it is not possible since we don't have enough statistics

↓

What we do instead is: $$\frac{\text{total numer of hits}}{\text{number of triggers} \times \text{number of pixels (strips) in the detector}}$$

2D map noise counts, highest bias and lowest threshold, pixels



How to cut the "noisy" pixels?

During the analysis some pixels turned out to be very noisy (occupancy ≈ 10 %), since we don't know yet the cause we'll call them "noisy" for brevity.

We know that some pixels don't work as expected. We need to cut them, but how can we decide when a pixel is "noisy"?

↓

We decided that we can accept a module noise occupancy up to 10^{-6}

↓

We take the worst scenario possible, highest bias voltage and lowest threshold, only irradiated chips. Then we choose the cut according to the requirements.

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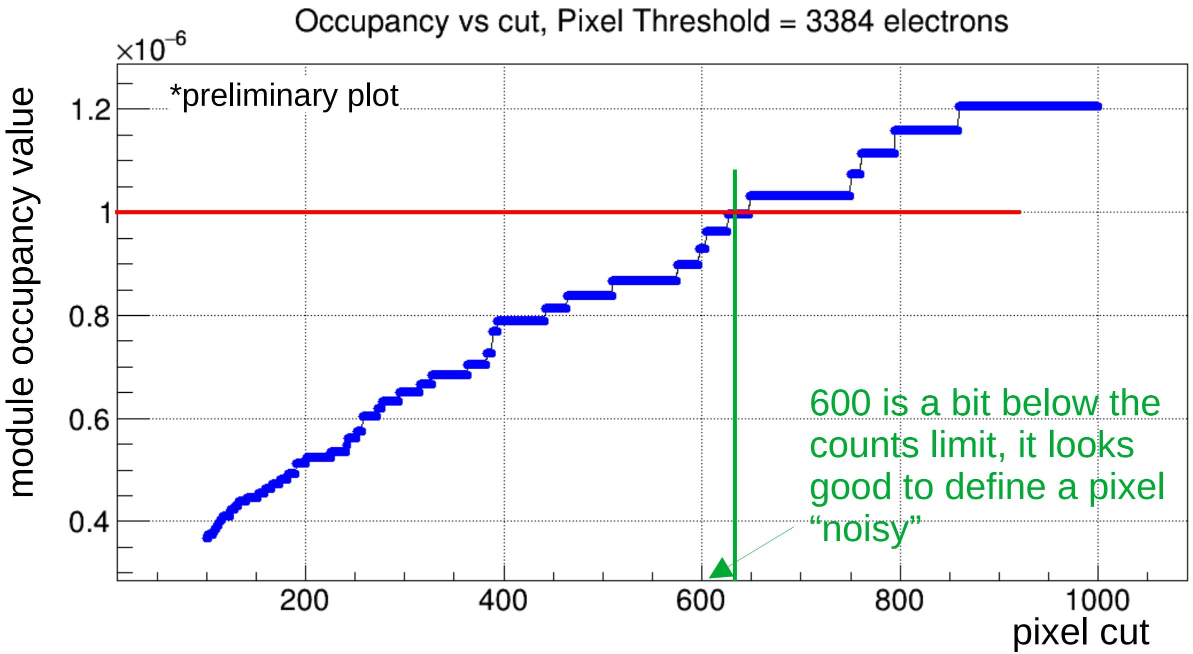
Study of the worst scenario

We plotted the occupancy of the irradiated chips as a function of the cut



cut = number of counts in a single pixel after which it is excluded from the analysis

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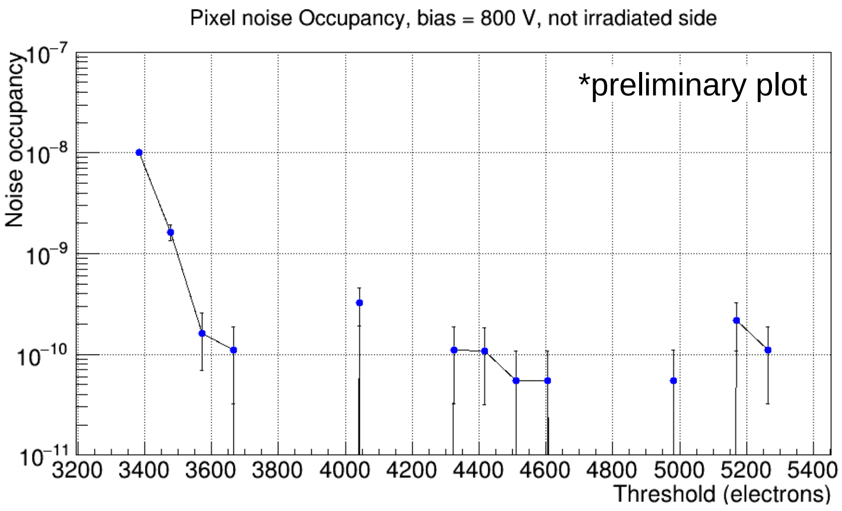
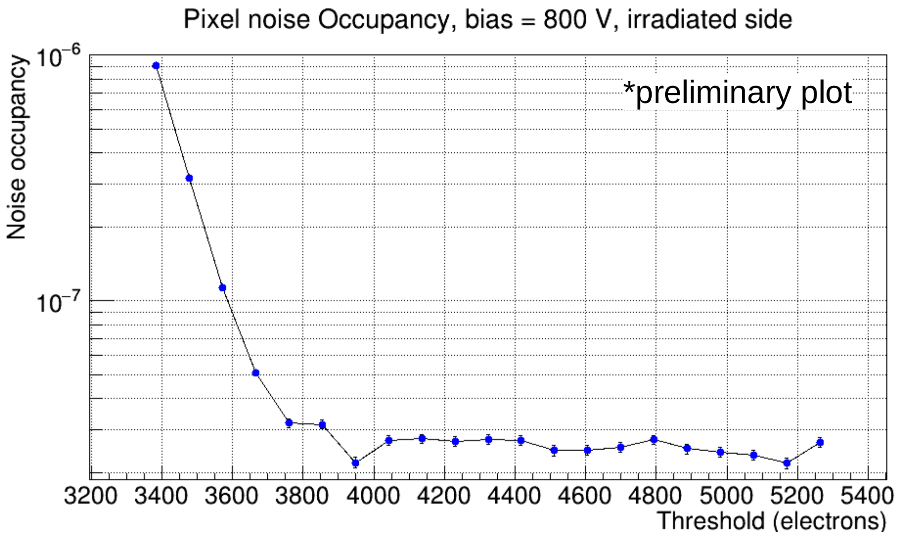
Noise counts as a function of the threshold, pixels





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How many pixels (strips) are we cutting? is it a problem?

We are removing 40 pixels (3 strips), 0.13% (0.15%) of the total, in the worst scenario possible.

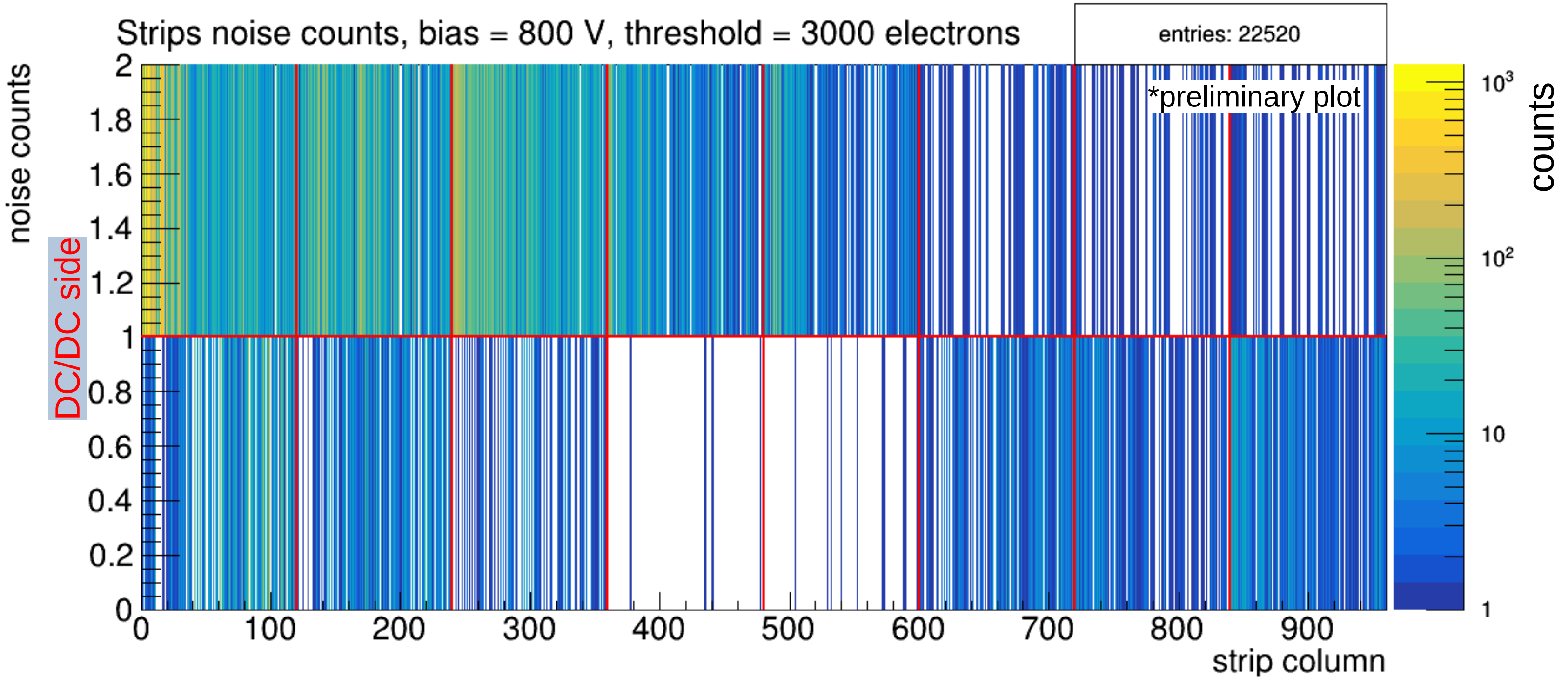
↓

The trimming procedure was forced to mask 1% of pixels because they are untrimmable.

↓

Adding a 0.13% to the already 1% masked pixels is not a big loss, for the strips these are the only ones that are ignored.

2D map noise counts, highest bias and lowest threshold, strips



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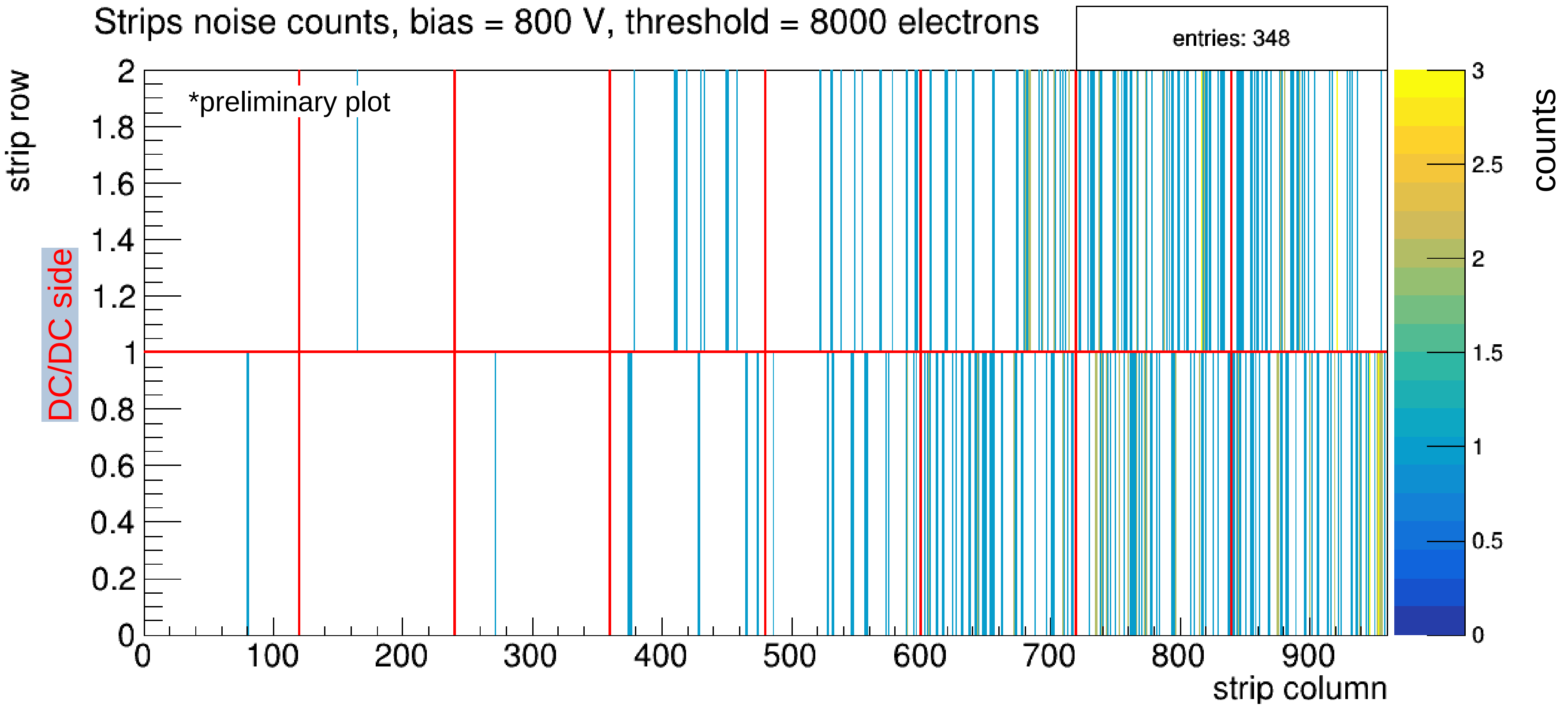
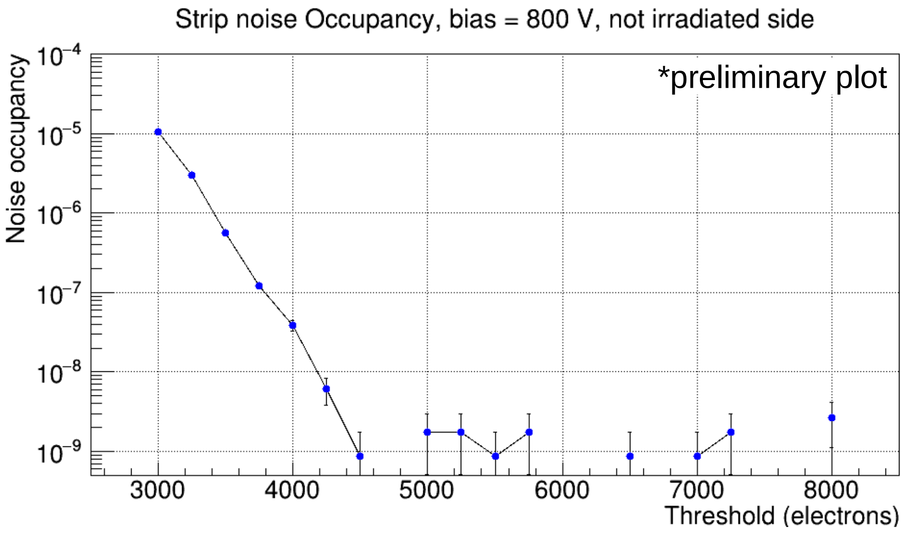
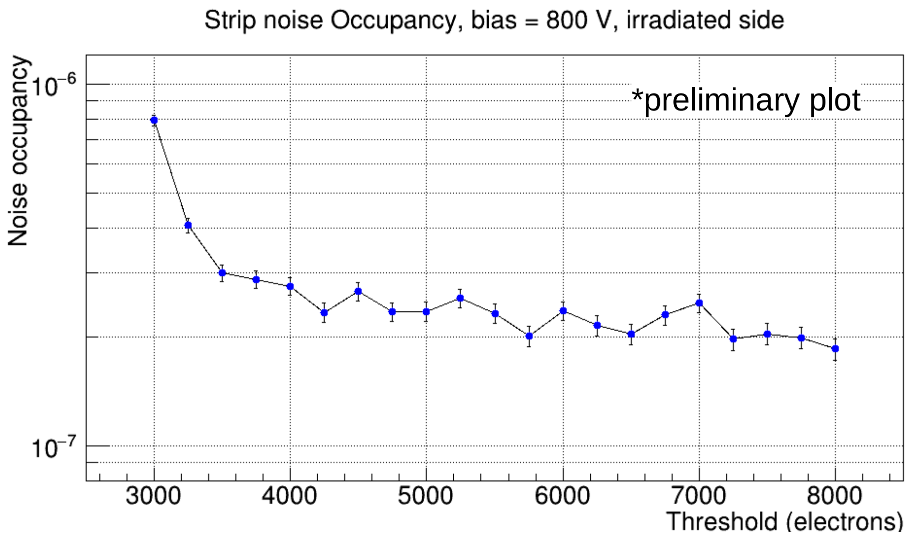


Noise counts as a function of the threshold, strips





Noise and efficiency together

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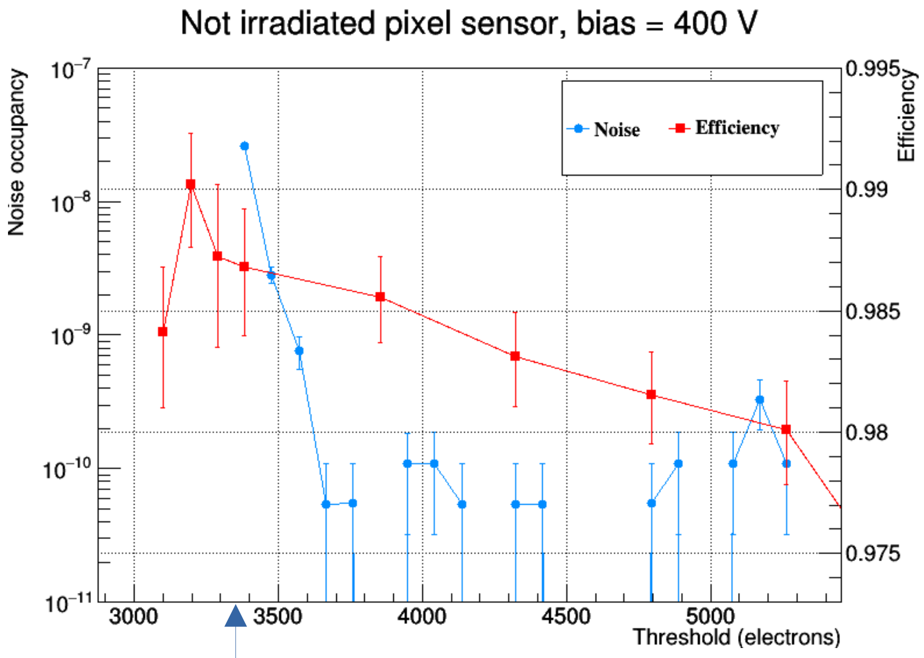
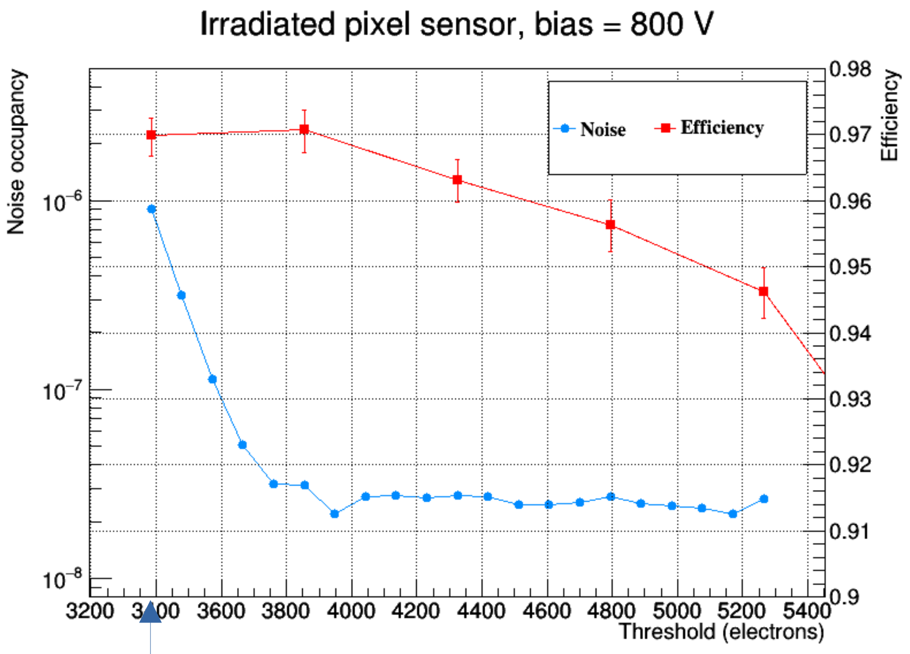
Noise counts as a function of the threshold, pixels





Threshold used for data taking

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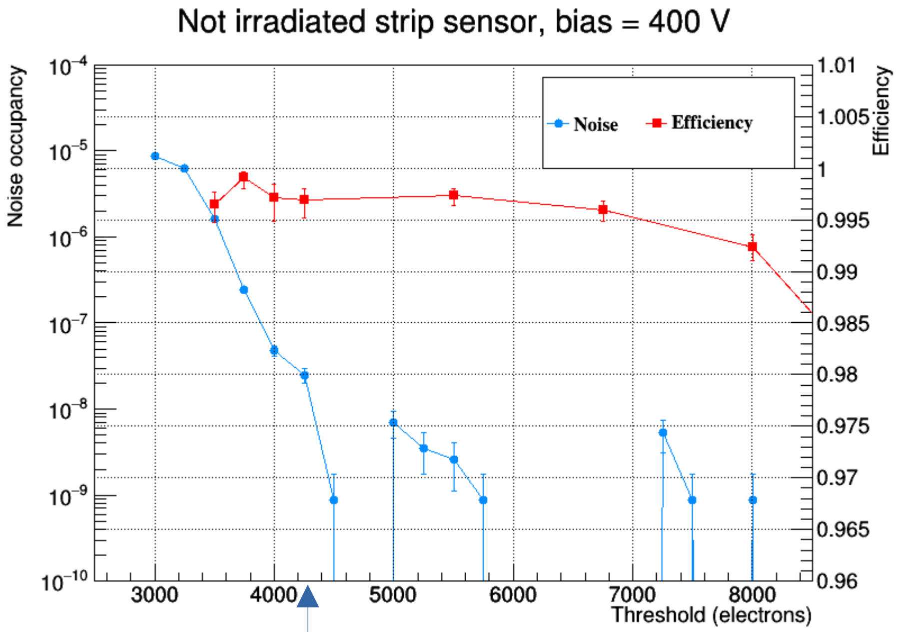
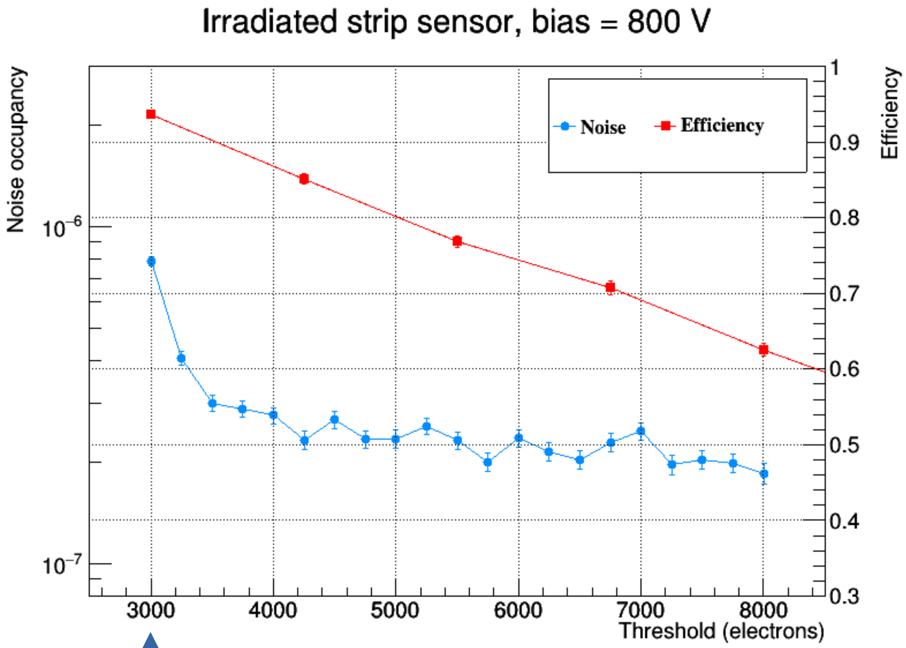
Noise and efficiency as a function of the threshold, strips





Threshold used for data taking

Calibration from threshold to electrons in details

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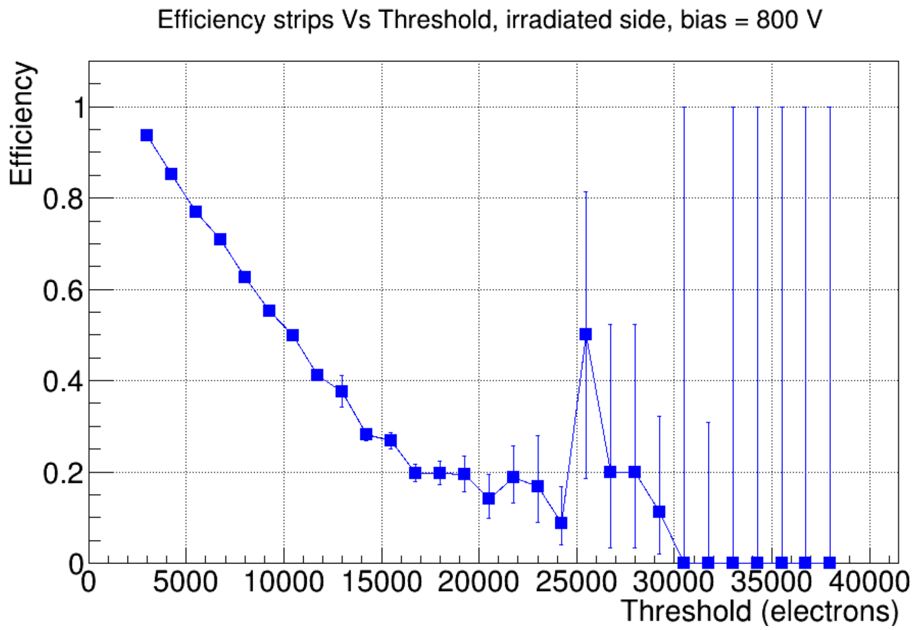
Maybe the calibration is wrong

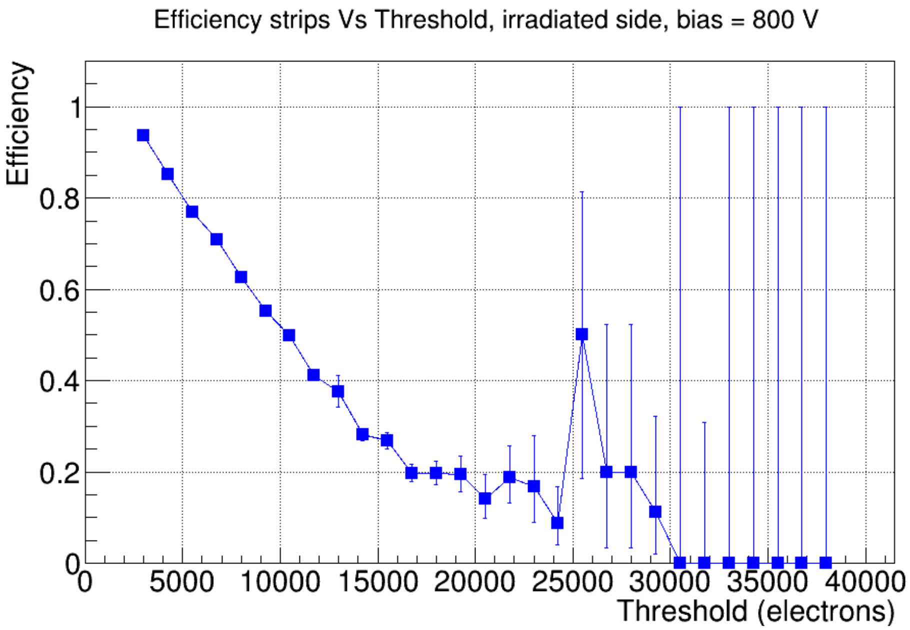
A possible explanation for the inefficiency of the strips is that we were using a threshold higher than expected, in fact we weren't sure about the conversion in electrons.



Maybe the calibration is wrong

A possible explanation for the inefficiency of the strips is that we were using a threshold higher than expected, in fact we weren't sure about the conversion in electrons.

When the data was taken the first point was expected to be at 3000 electrons, but maybe the real threshold was actually higher.



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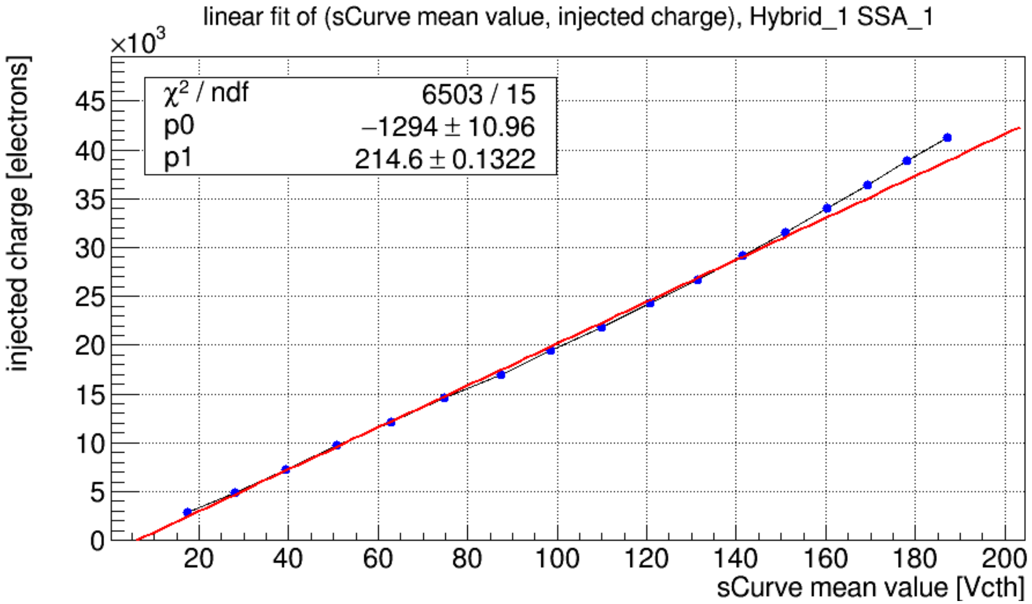
How can we get a more precise conversion for Vth?

We measured the average Vth as a function of the injected charge in each sensor, then using a linear fit it's possible to have a new conversion.



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The new value for Vth

From the linear fit we can extract the conversion into electrons for 1 Vth, which is 214, and the pedestal, which is 6 Vth.

↓

The conversion used before was 1 Vth = 250 electrons and pedestal at 13 Vth, we found the problem.

↓

During the beam test we thought we were taking data at a threshold of 3000 electrons, but in reality we were at 4000!

Summary

- Extracted threshold in electrons from S-curve measurement
- Estimated cut for noisy channels based on maximum module occupancy 10^{-6}
  - ~40 channels offline masked
- Measured efficiencies and noise occupancies as a function of the threshold
  - Source of inefficiency in the pixels due to punch through structure
  - Inefficiencies in the strips after irradiation being investigated, the threshold used was not correct

Thank you for your attention

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Backup slides

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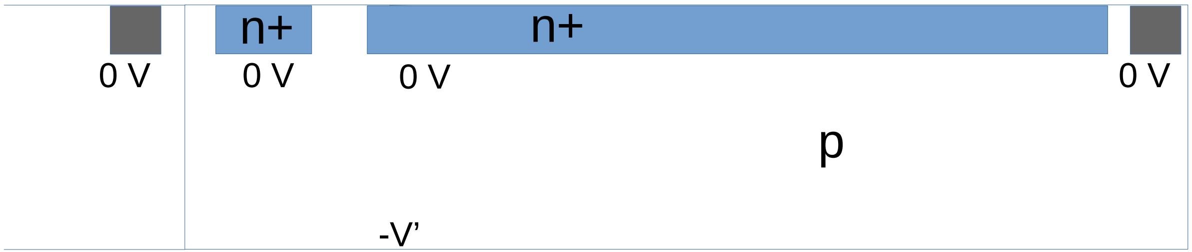
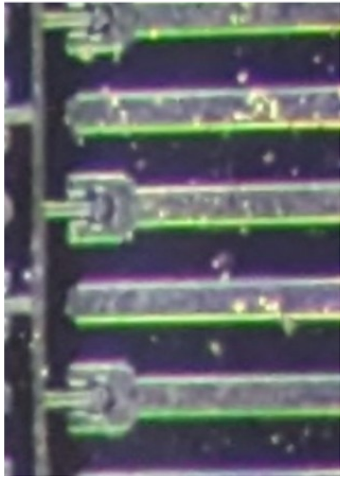
Why the punch through is needed?





After the production every module is checked using an IV curve. Ideally we would check pixel by pixel, but since it's not possible we need a way to connected them all together only for this procedure without actually use a physical implant (during the real data acquisition they must be isolated). This is possible applying the voltage for the IV curve only on the punch through.
To do this we use a rail to connect all the punch through together and then we ground the rail.
The problem is that the rail than is left grounded also during the data taking so it collects charges "stealing" them from the read out system.