Test beam and clean room studies of ATLAS PPS modules with alternative bias rail geometries

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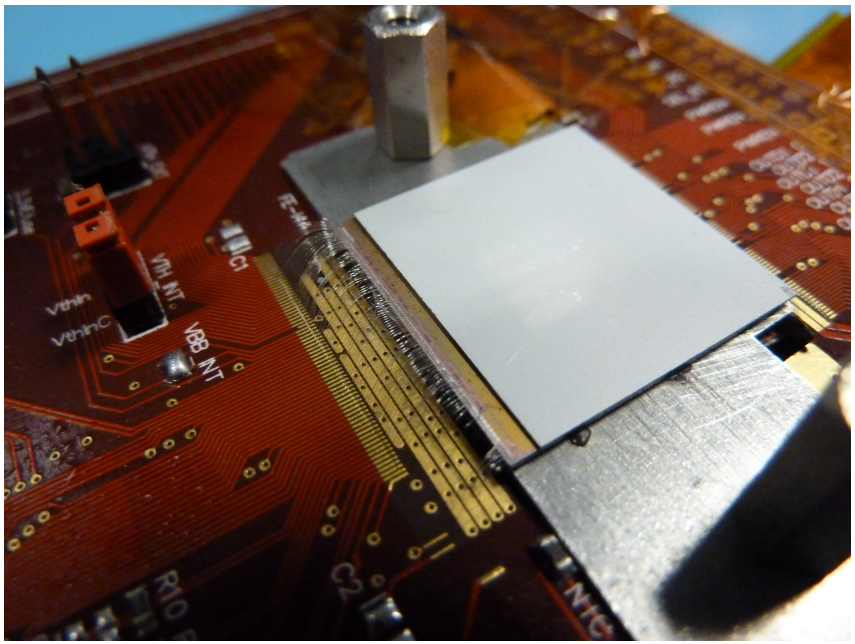
Contents

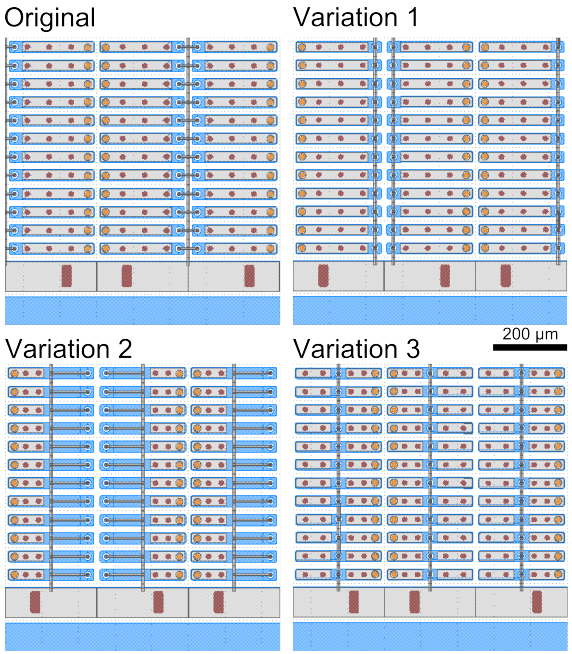


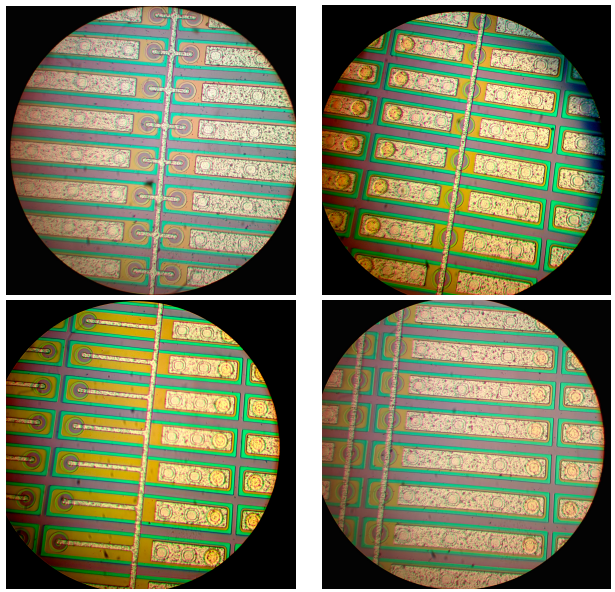
Introduction

- It is a known issue with planar pixel sensors that there is an efficiency loss under the bias rail after irradiation.
- This could be solved by removing the bias rail entirely.
  - The sensor could not then be tested before bonding to a readout card.
  - Possibly leading to a lower yield.
- Instead investigate alternative routing of the bias rail to see if a different design could improve the efficiency.
- Studies are done through tuning in the clean room and test beams.

Bias rail - collaboration with CiS

- FE-I4 compatible pixel sensors with alternative bias rail geometries to the current PPS layout.
- Aim is to find a solution that reduces the inefficiencies seen for this region within the pixel cell.
- Matrix contains several versions of bias rail geometry.

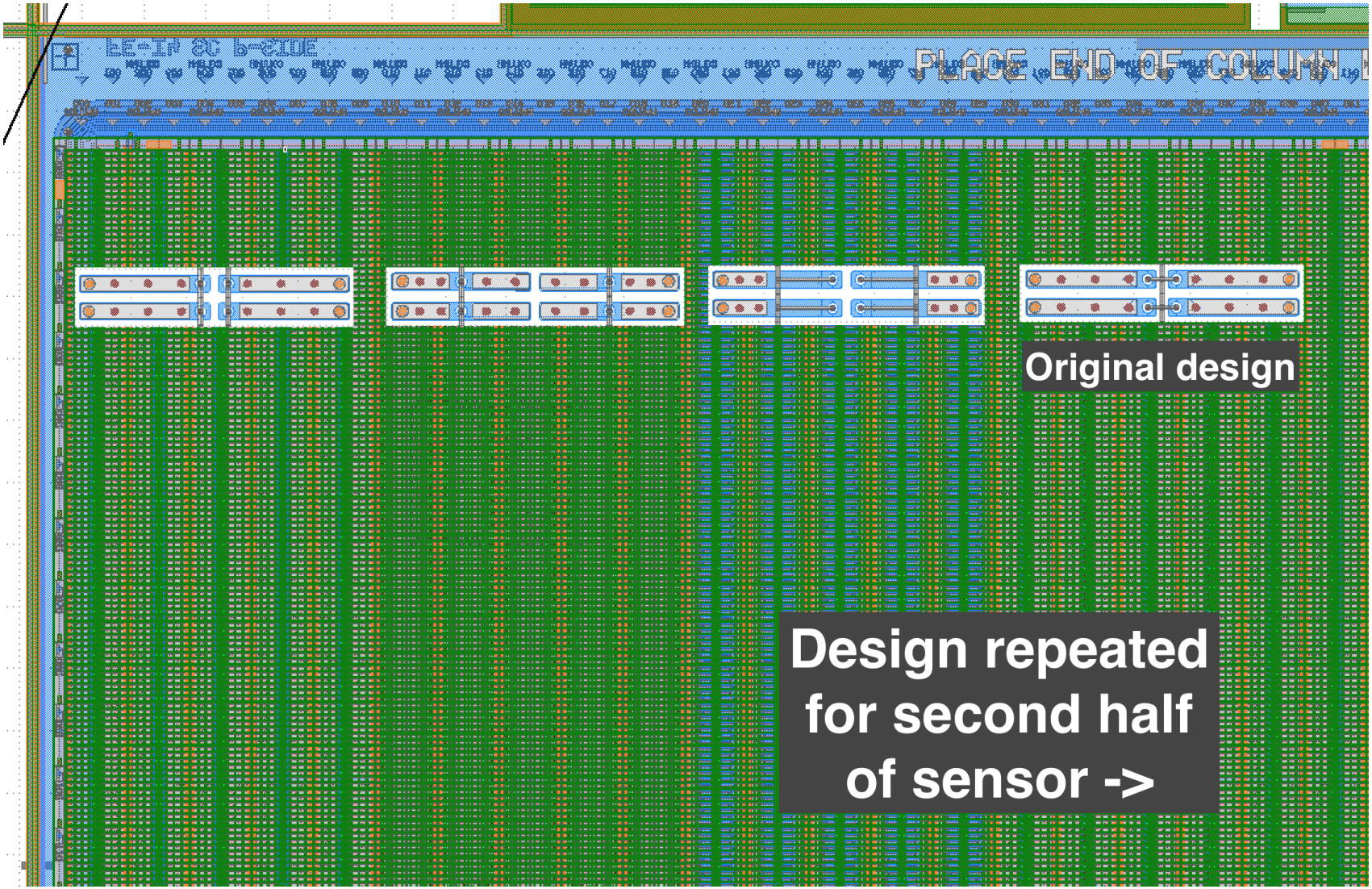




- All bias rail geometries photographed are on the same sensor, which was subsequently flip-chipped, and then wire-bonded to an FE-I4b readout card at CERN.
- Design by CiS.

- The bias rail is metallisation on top of an insulator without an implant below. It provides a reference potential to each pixel and connects to virtual ground.

Bias rail layout

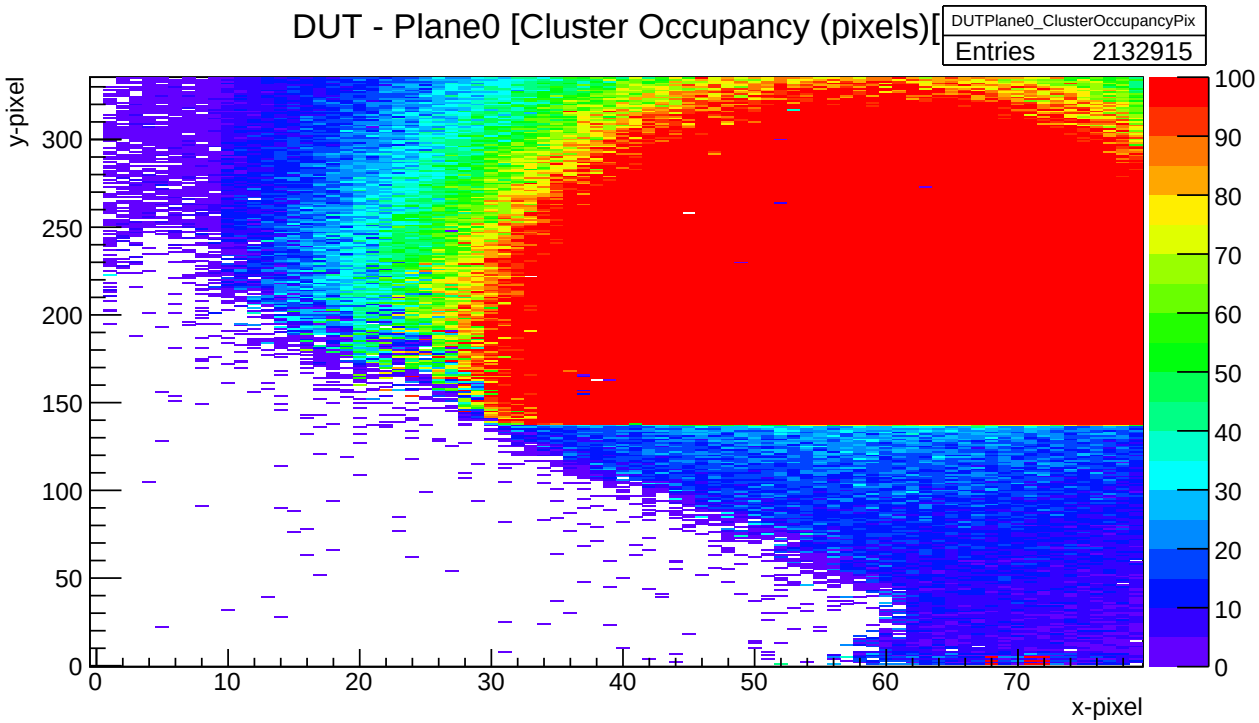


The story so far...

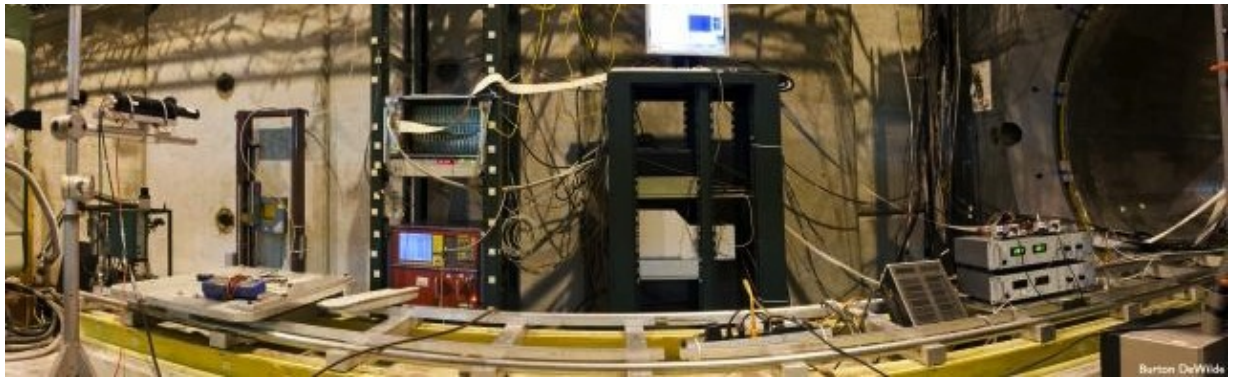
CERN 2014 Test Beam(s).
With sample No. 1.

The sensor

- Sample tuned to 3200e threshold, 7 TOT at 24k with RCE.
- It was already known that the sensor has a section of disconnected pixels due to uneven applied pressure during bonding to the FEI4 read-out chip.
  - Should not effect comparison of different bias rail regions as the geometry is repeated, as shown in the previous slide.

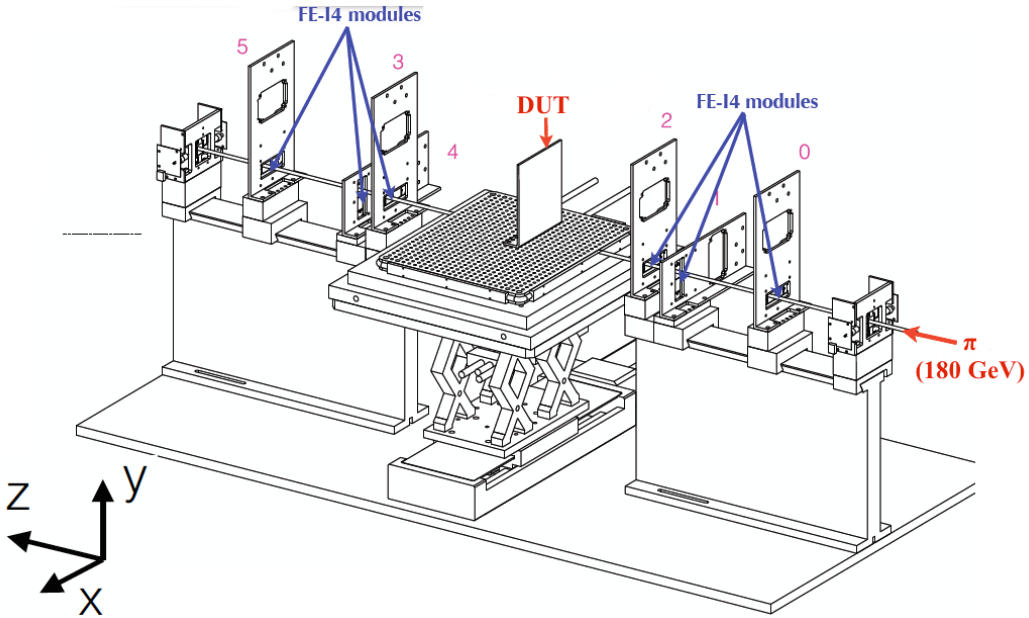


Test Beam Setup

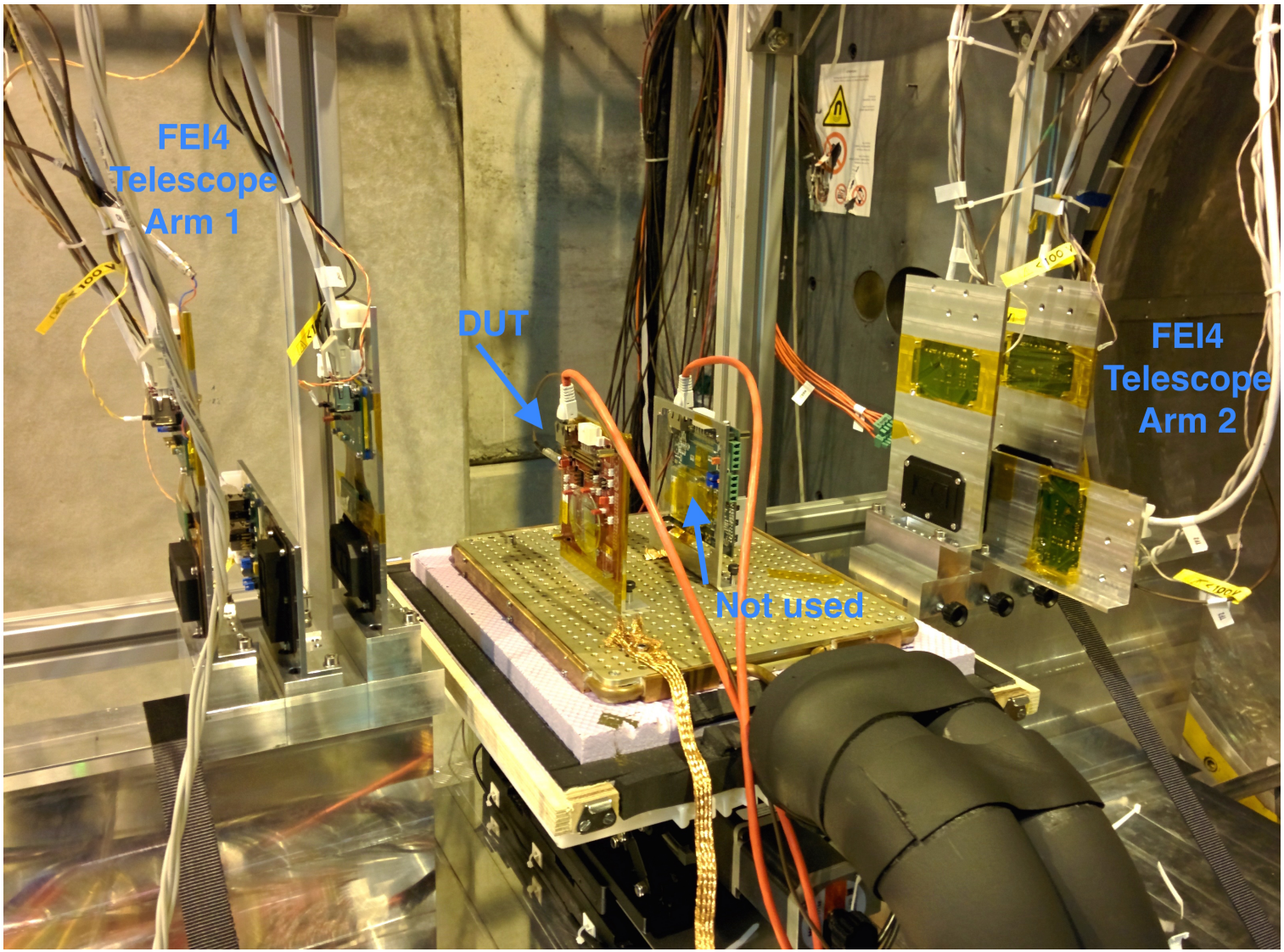


- Data taken at the CERN SPS beam line in November 2014.
- Used the Geneva University FE-I4 telescope.

- Made of six FE-I4 modules (250 μm x 50 μm), with the DUT in the centre.
- Readout with the RCE.
- Triggered with telescope planes 0 and 5.
- Many thanks to Bane and Mathieu for their support in taking the data.

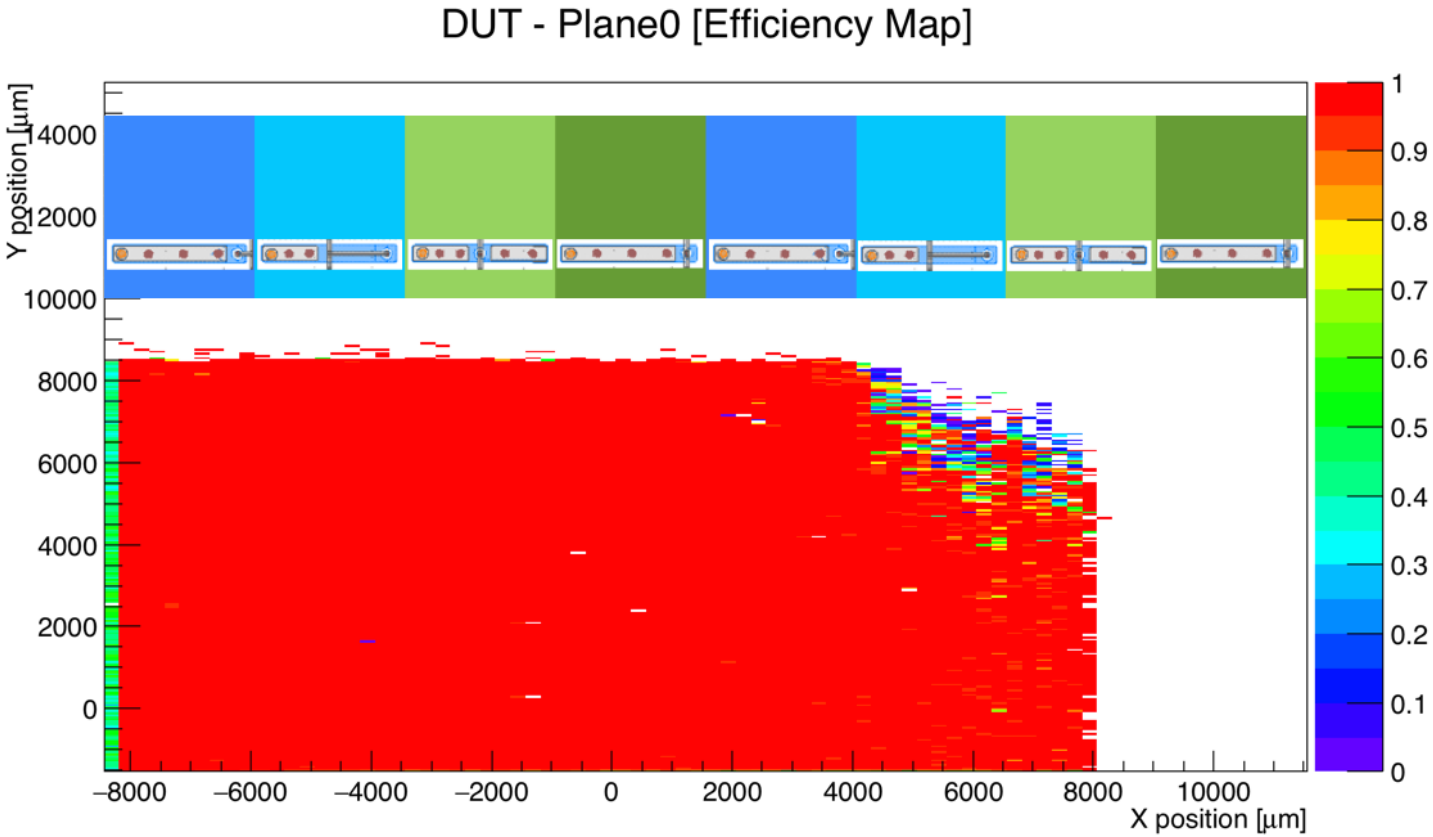


Test Beam Setup



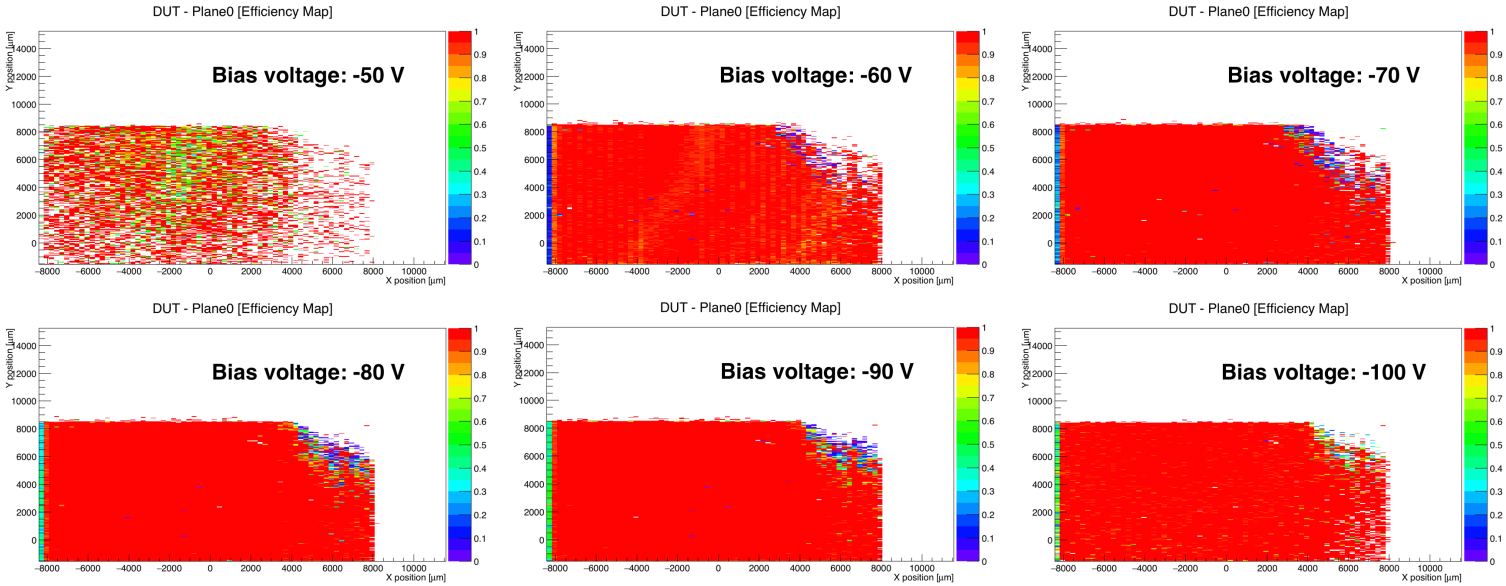
Efficiency

Note: the plot is rotated compared to the occupancy plot and so the pixel geometry is reversed (colours show repetition).

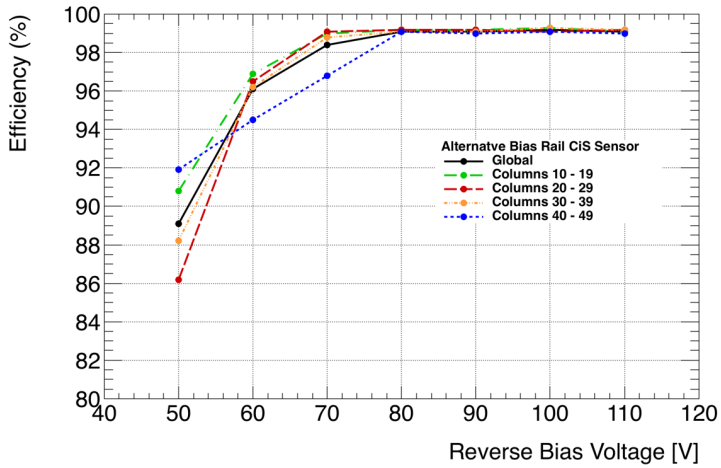


- Majority of pixels show an efficiency of $\sim$1.
- No sign of lower efficiency for a specific layout.

Efficiency

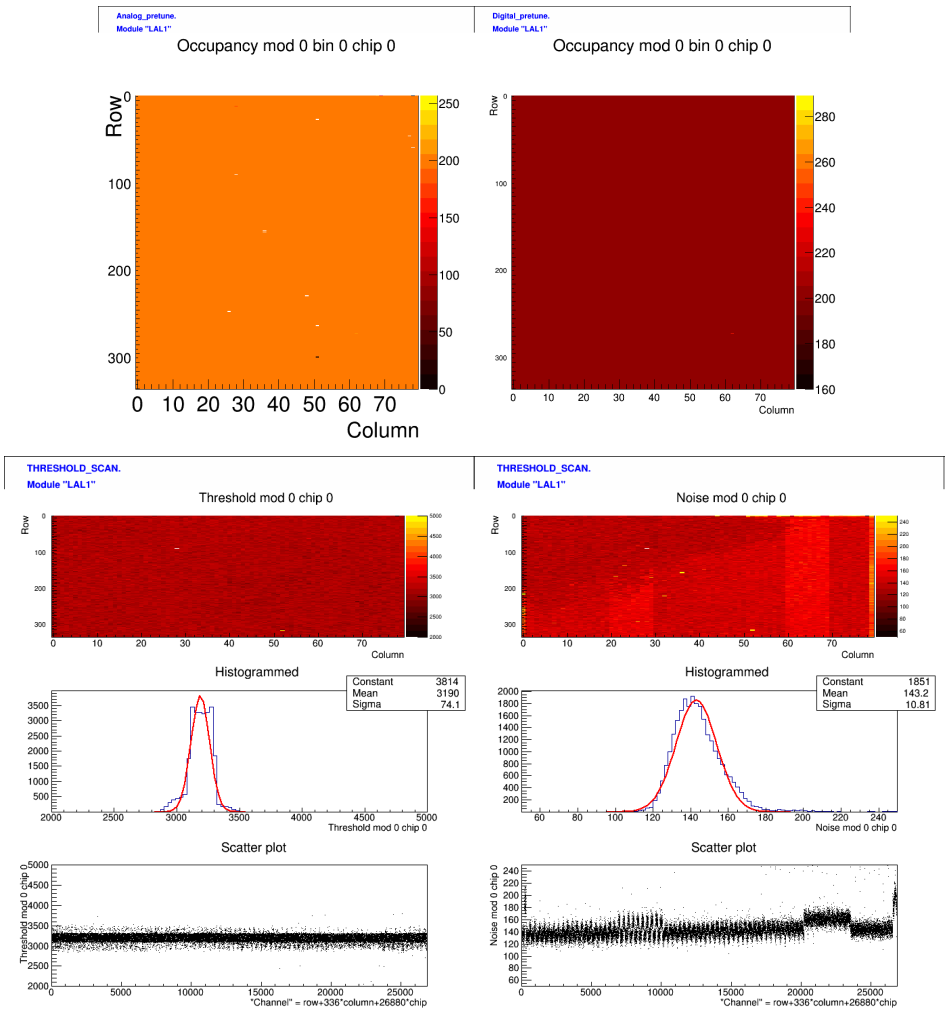


- Lower efficiency when sensor is not fully depleted (as expected).



Clean Room Testing
With samples No. 1 and No. 2.

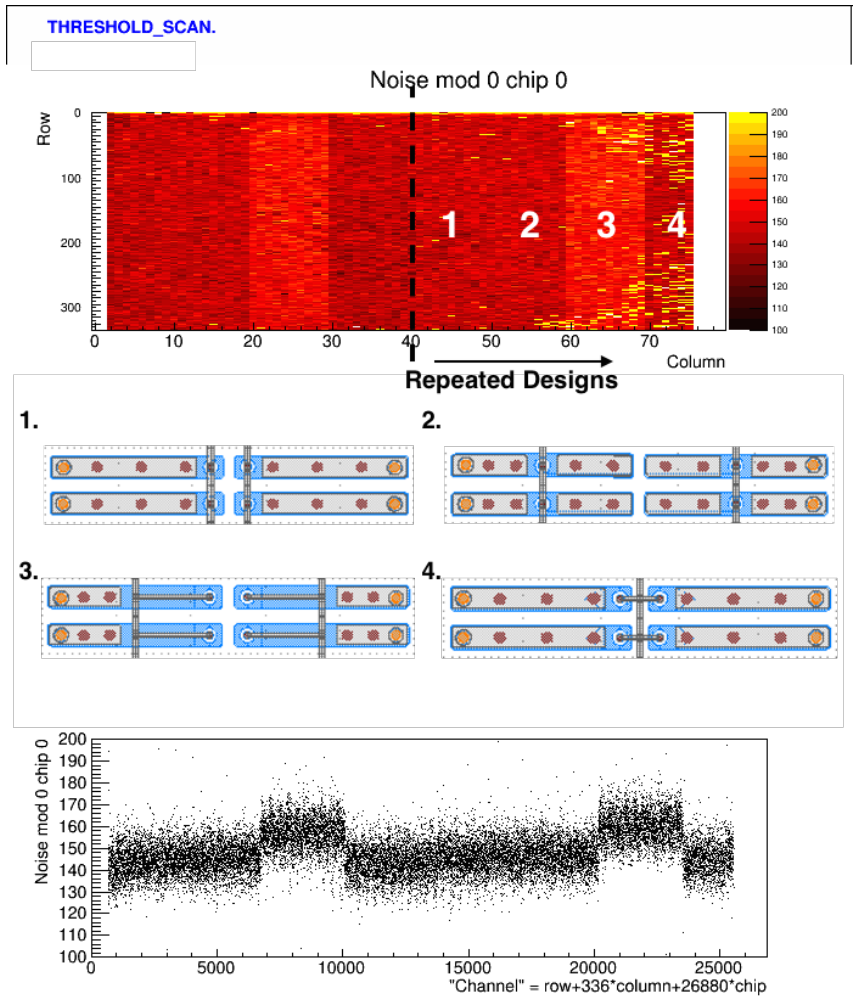
Sample 1 (LAL1)



- Device tuned in the clean room with USBPix to 3200e, 7 TOT at 24k.
- A clear increase of noise for one design was observed.
- Some alterations were required to the USBPix board to allow the device to be powered directly (instead of through the flat cable)
  - Thanks to Joern Grosse-Knetter for valuable advice!

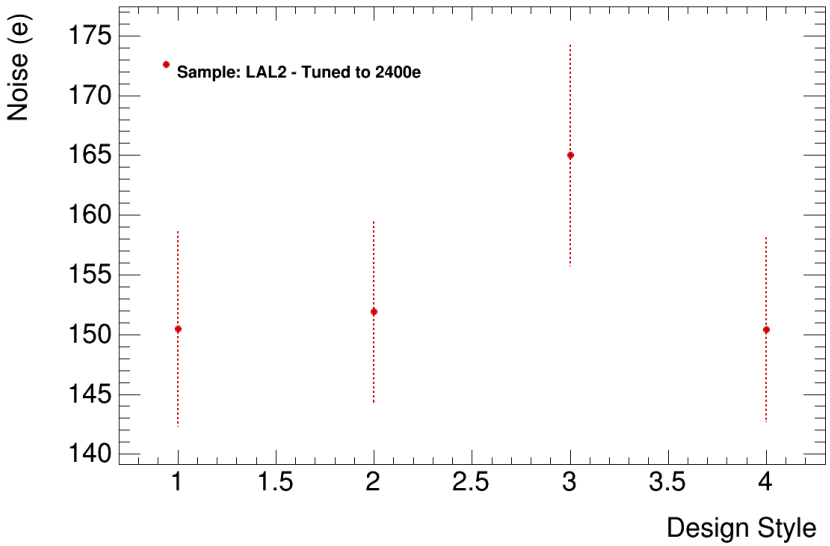
Sample 2 (LAL2)

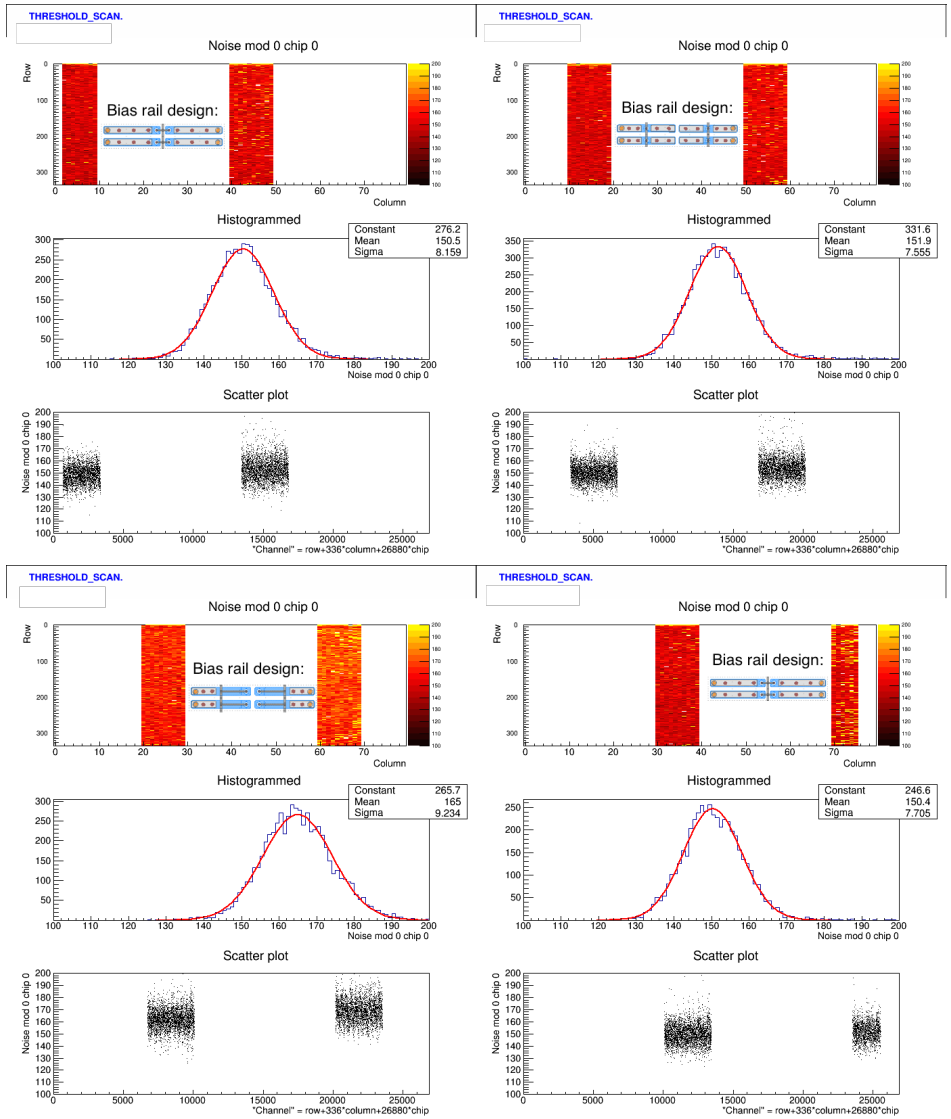
- Second batch of sensors successfully flip-chipped at LETI.
- This sample has the same layout as the previous sensor, but without the large 'dead' area.
- See the same feature as the previous sensor with increased noise for one design.



Noise comparison, 2400e

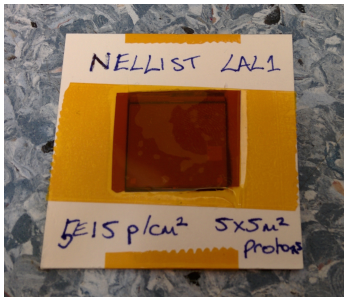
- Masks applied for threshold scans to isolate the noise measurement for each design.
- Clear increase from one design (as expected).





Irradiation and wire-bonding

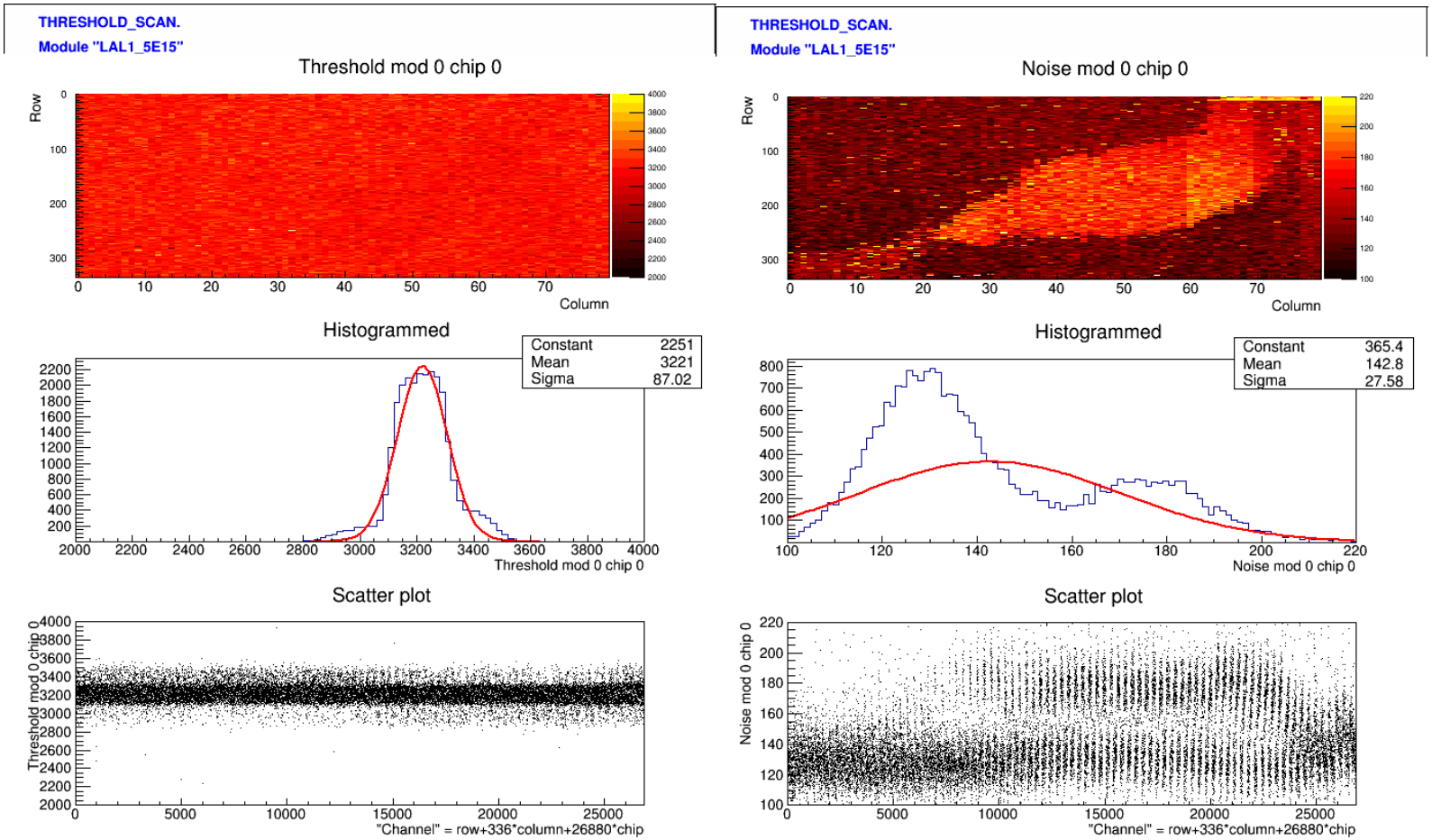
- The first sample, LAL1 was irradiated at CERN PS to $\sim$ 5 x 10^{15} n_{eq} cm-2 and was wire-bonded at the CERN wire-bonding lab.
- It was then tested in the clean room to see how the noise varies for the different designs after irradiation.



- Many thanks
  - Federico and Maurice for their advice and support with the irradiation!
  - Also to the CERN wire-bonding lab for fitting this sample in with short notice.
  - And to Bane and Karola for the use of the the CERN clean room and especially for troubleshooting the setup over the weekend!

Noise comparison - LAL1 5E15

After irradiation of 5 x 10^{15}, tuned to 3200e at -15 deg, -500V.

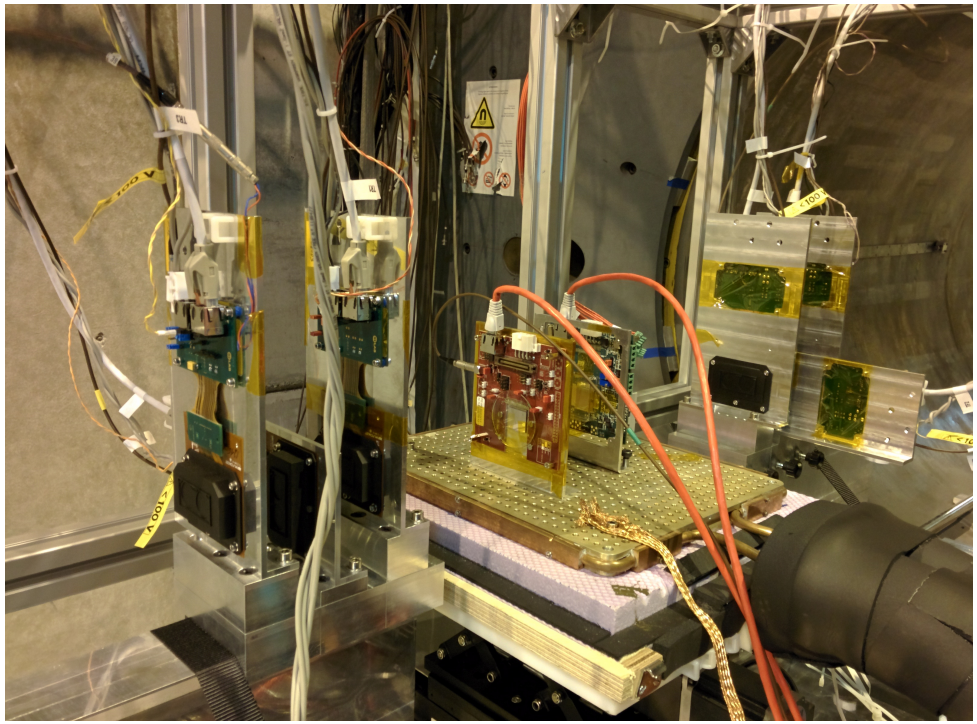


- Damage to the left was there before, but damage to the right occurred during/after irradiation.

CERN 2015 Test Beam(s).
With sample No. 1 and No. 2.

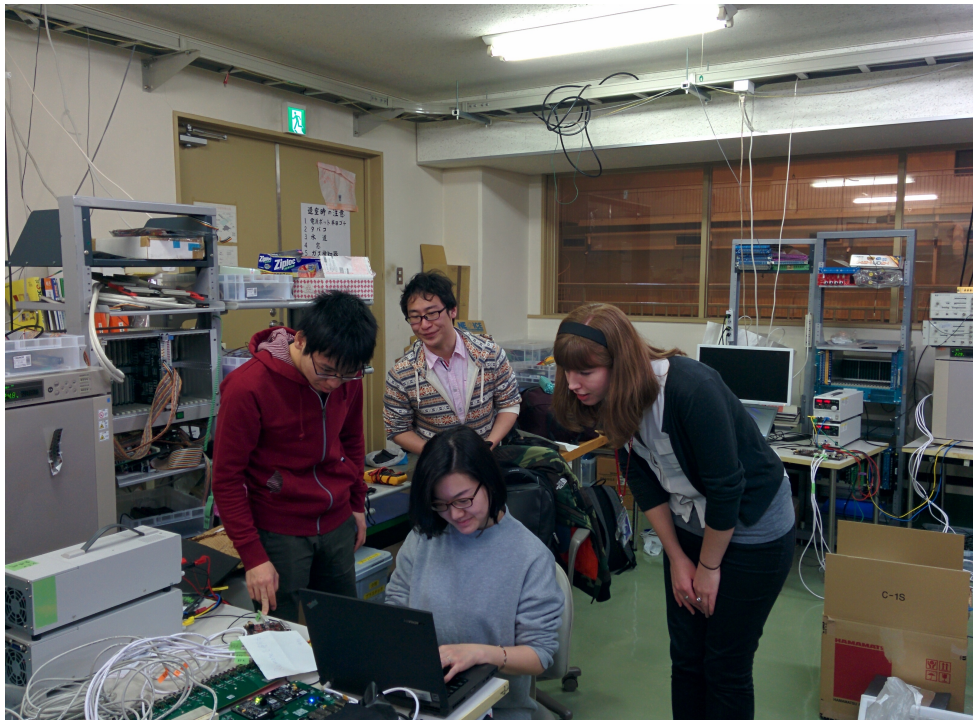
Test Beam - CERN

- Both LAL 1 and LAL 2 were tested in the CERN test beam in July, along with a control device.
  - Unfortunately, LAL1 did not survive and, after cooling to $\sim$ -40° only a handful of pixels could be read.

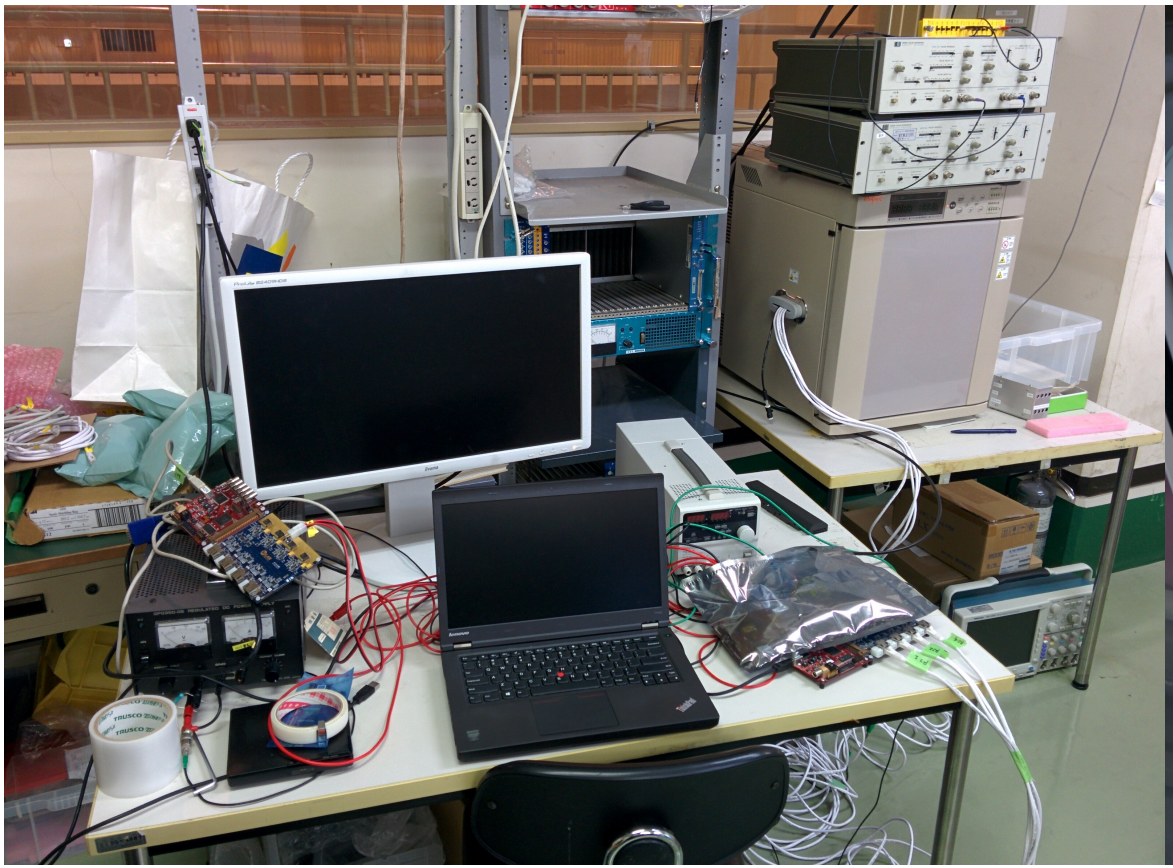


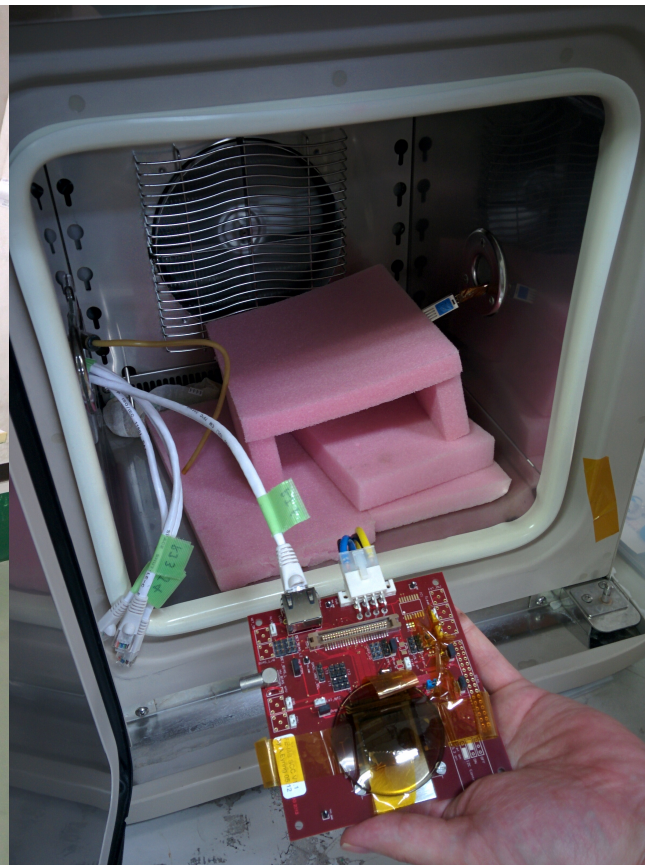
Measurements of sample No. 2 at KEK.

Many thanks to Koji Nakamura, Kazuyuki Sato, Junki Suzuki and Hiromi Sawai.



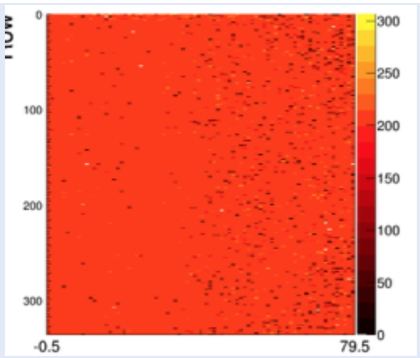
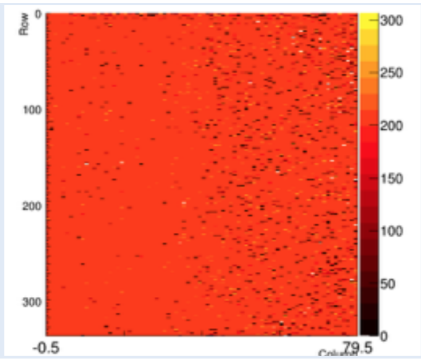
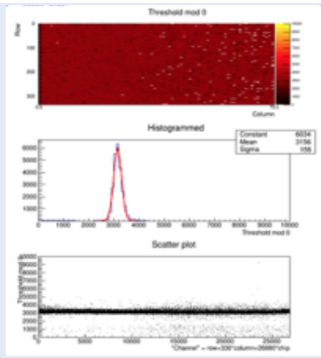
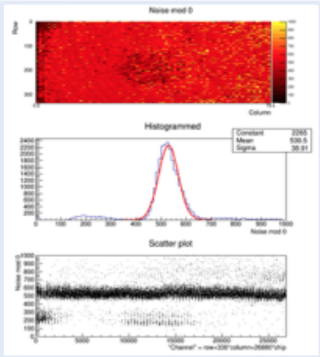
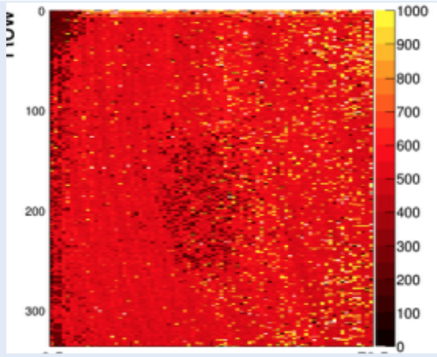
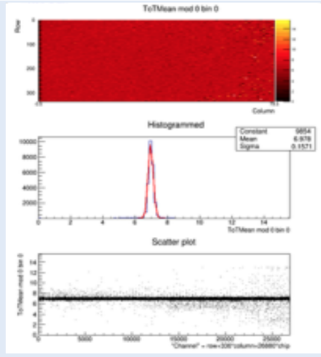
Measurements at KEK





Measurements at KEK

- Sample arrived safely in Japan and was tested prior to irradiation.
  - Tuning parameters: Threshold of 3000e, TOT tuned to 7 at 20ke.
  - Many thanks to Hiromi Sawai for performing these measurements.

Digital Test	Analog Test	Threshold Mean
		
Threshold Sigma	**Threshold Sigma Map**	**ToT Verif**
		

Measurements at KEK

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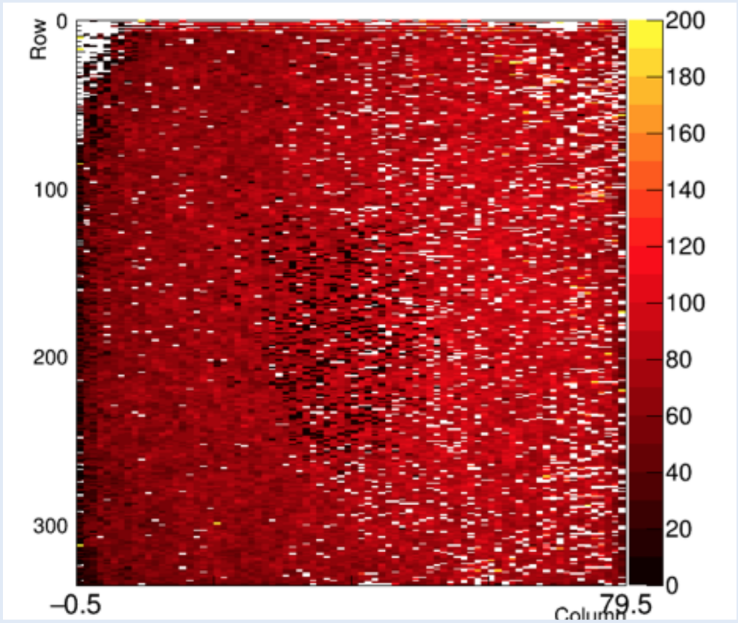
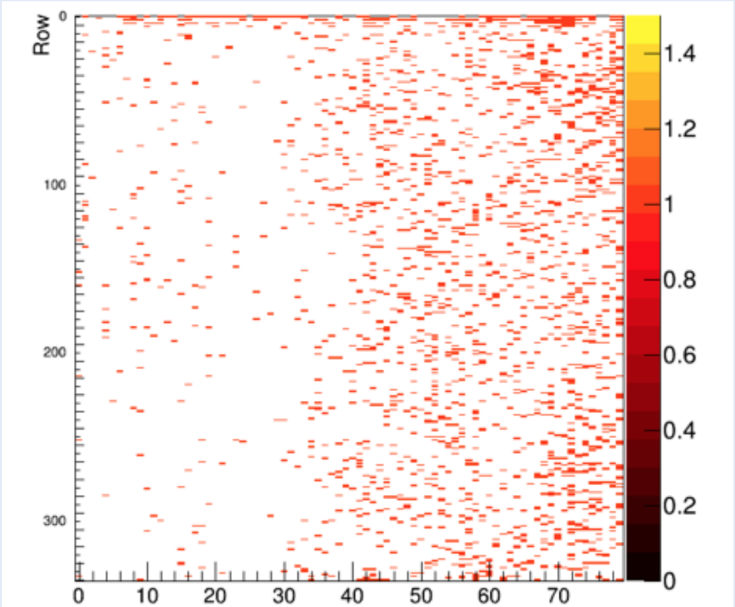
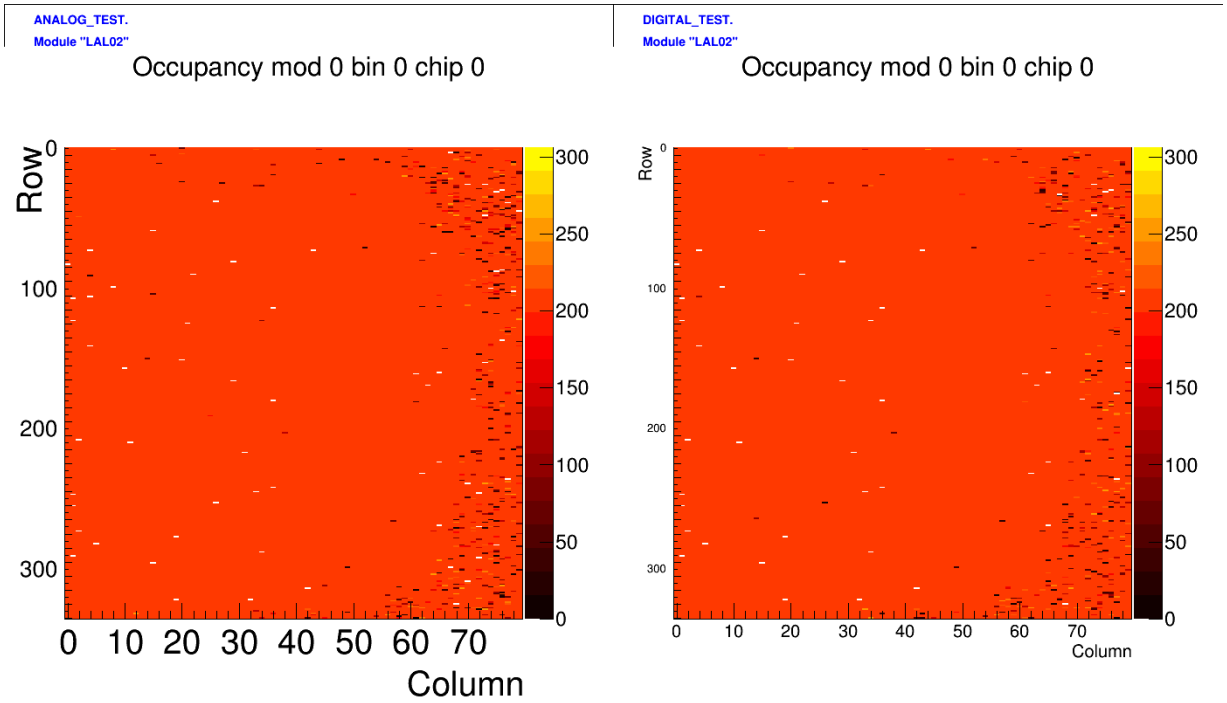
Source Scan	Mask
	

After irradiation

- Sample was irradiated to 3 x 10^{15} and kept in the freezer afterwards.
  - Tuning parameters: Threshold of 4000, TOT tuned to 7 at 5ke. Cooled to -30°.
  - Many thanks to Kazuyuki Sato for working with me to perform these measurements.



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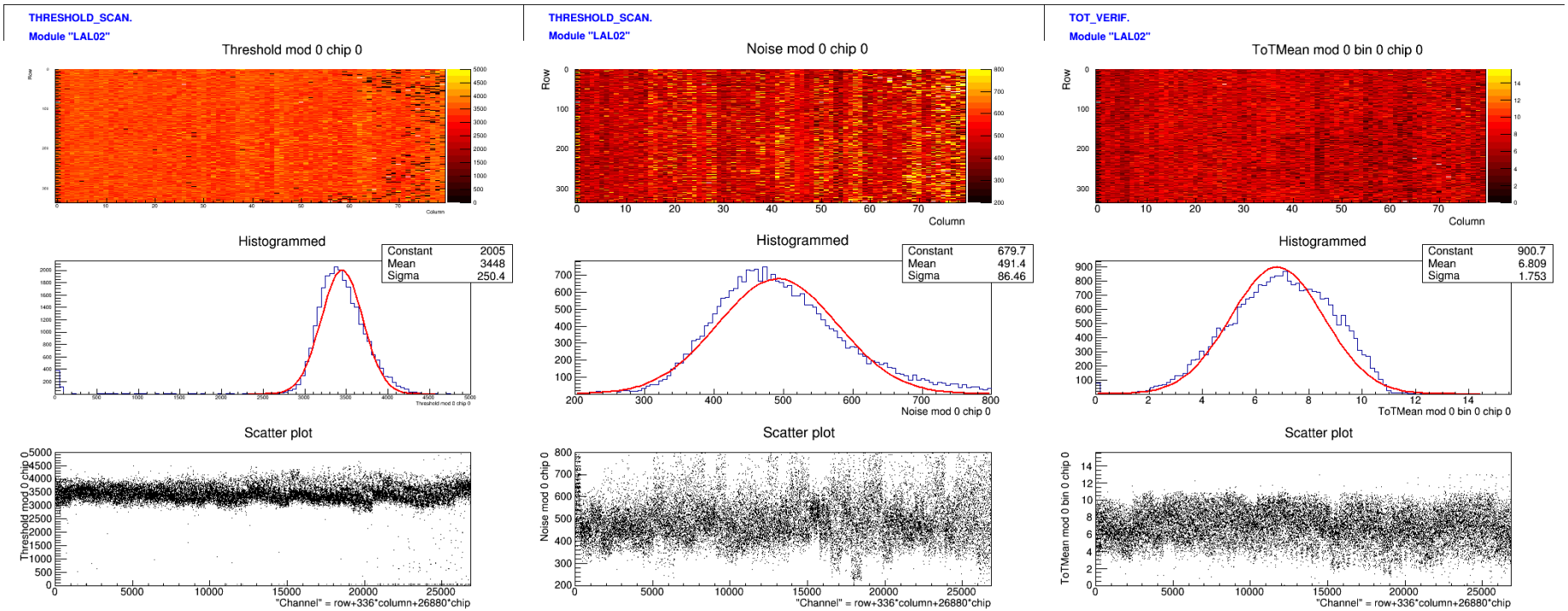

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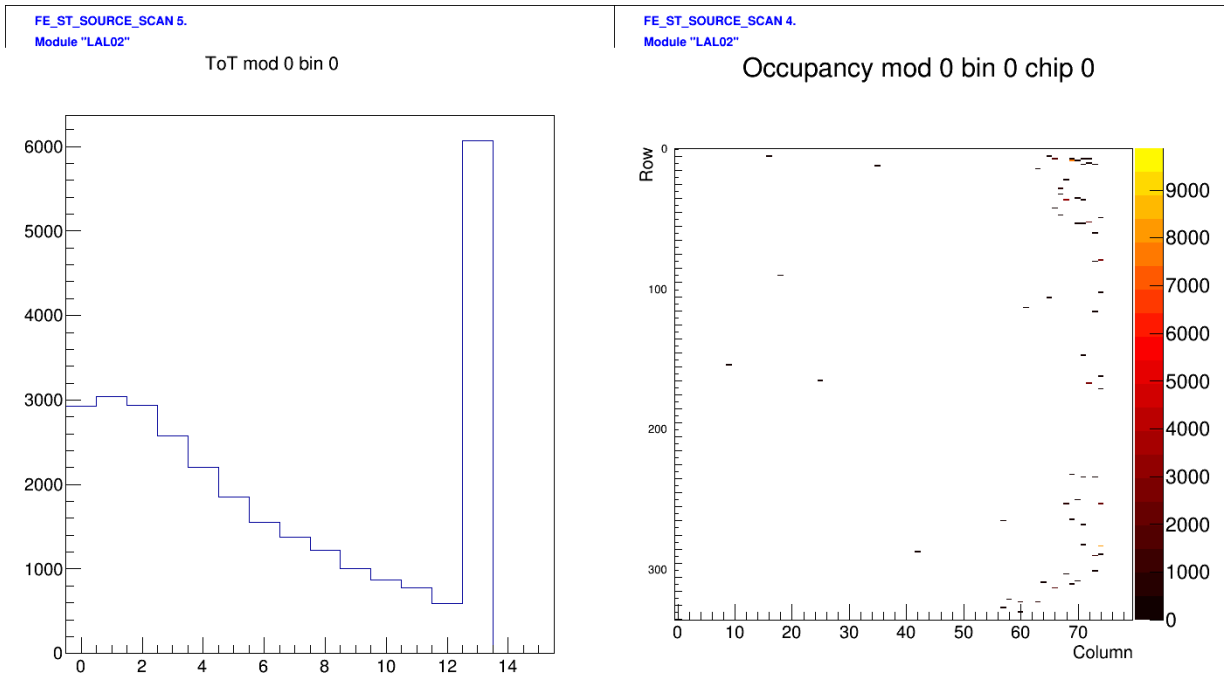


Conclusion from KEK studies:

- Results suggest that only a handful of pixels are connected. Since the irradiation is not unusually high, and the chip can be tuned successfully, our conclusion is that the bumps are disconnected due to thermal cycling. This can be tested by performing an x-ray scan of the sample.

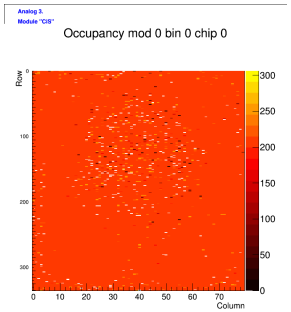
Next steps:

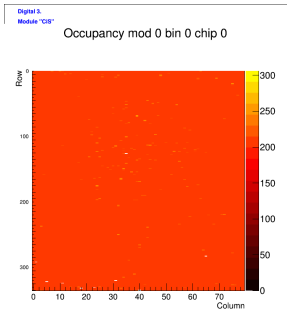
- Two additional samples with alternative bias rails were prepared for the CERN test beam (end of May).
  - One had good a IV profile and was measured in the test beam.
- A non-alternative-bias-rail sample, also bump-bonded at LETI, was thermal-cycle to test if this is the reason for the disconnection.

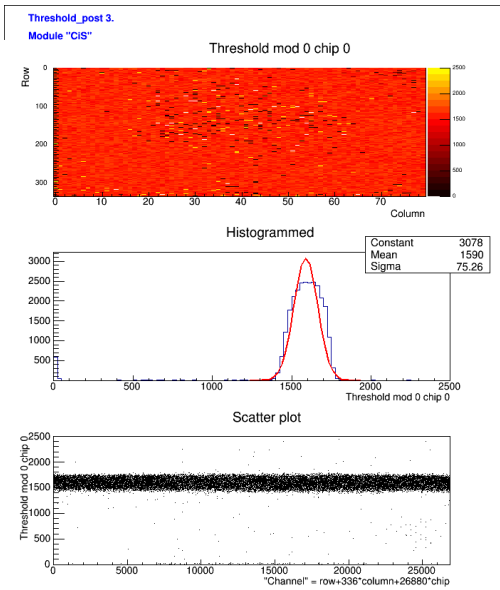
Thermal Cycle Measurements

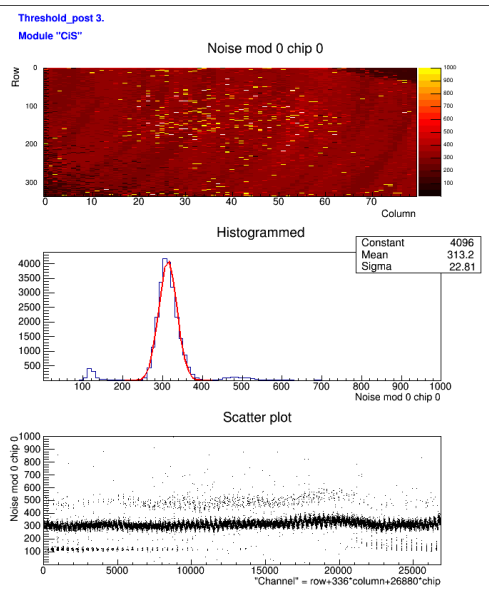
Tuned sample to threshold of 1600e with a TOT of 21,000 at 7 TOT with 20V.

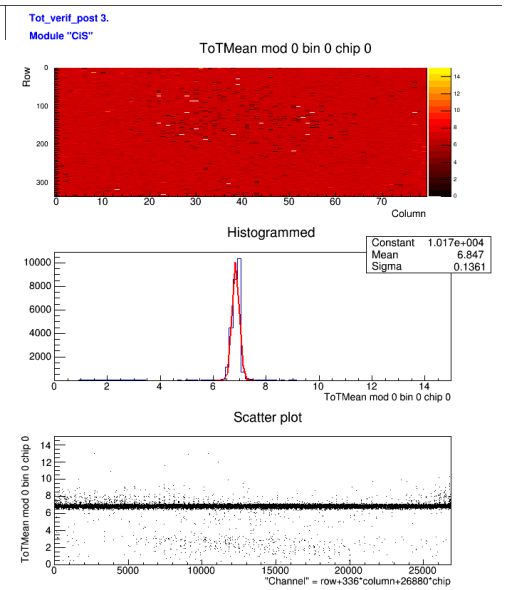
Before:





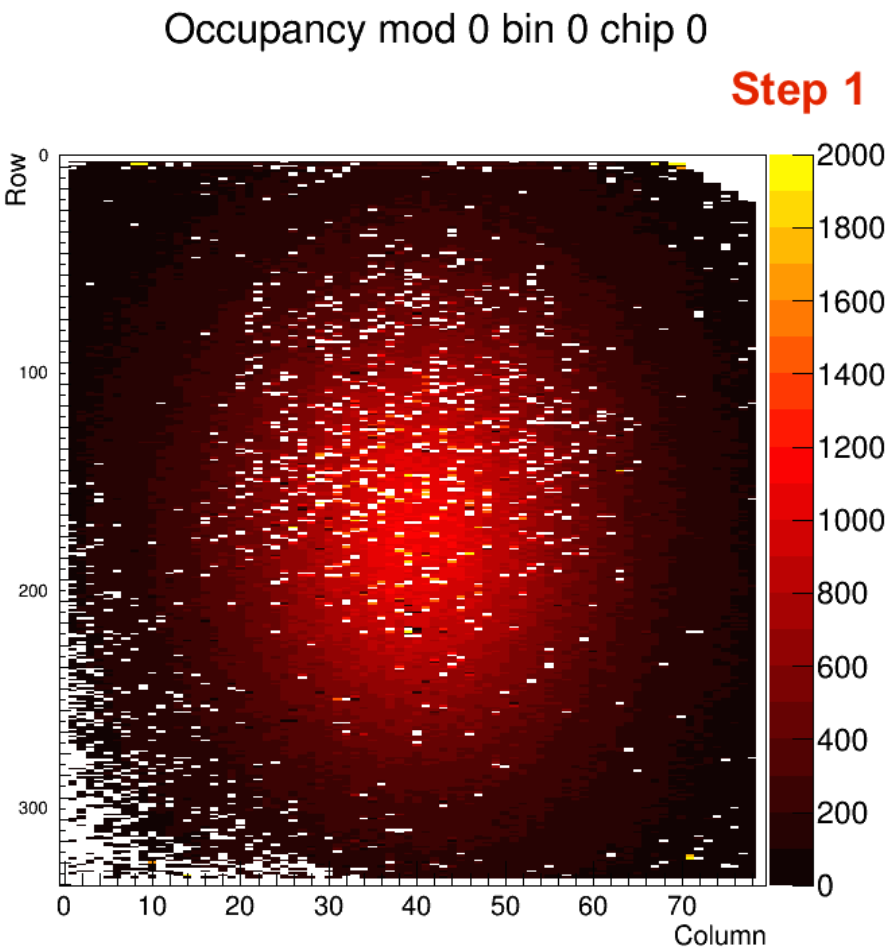


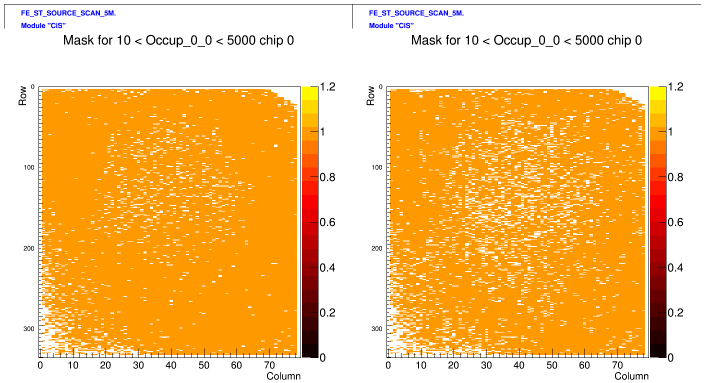


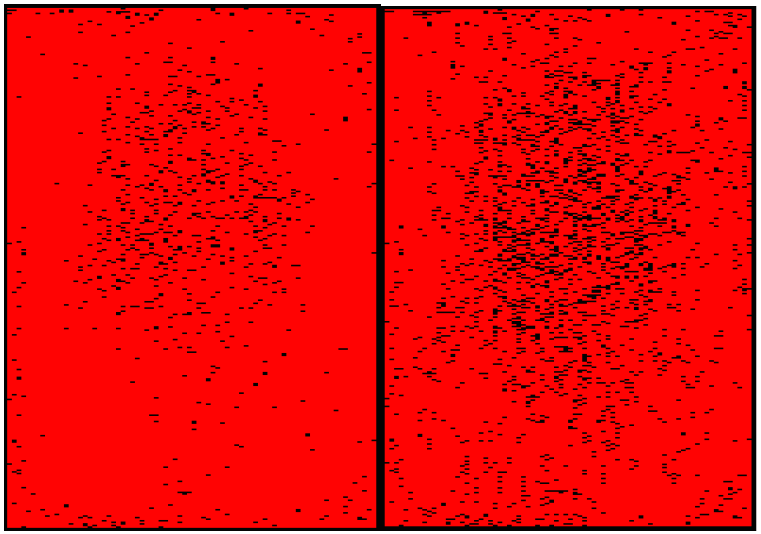


Thermal Cycle Measurements

Thermal cycled from 20° to -25° four times.







Conclusion from Thermal Cycling

Differences between study and "real-life":

- Slower thermal cycle
  - In real-life cases, the sample is placed directly into the freezer, instead of gradually changing the temperature.
- No handling in-between.
  - Sample was left in the climate chamber with the source in place.

Conclusions:

- Degradation of the performance of the device with thermal cycling has been shown.
- However, the exact nature of the degradation needs further investigation.

Thank you for your attention

Any questions?

Backup