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Performance of thin n-on-p planar pixel sensors for the ATLAS ITK

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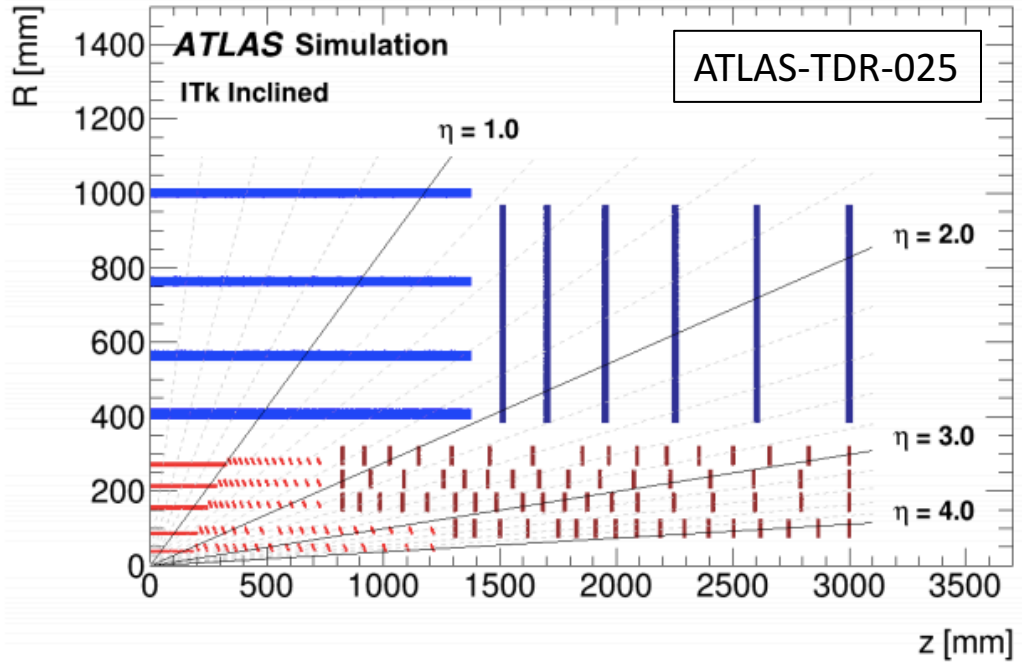
Introduction

- ATLAS detector upgrade for **High Luminosity phase (HL-LHC)**→ $\mathcal{L}_{instantaneous} = 7.5\times10^{34}\ cm^{-2}s^{-1}$.
- Inner detector replaced with new **all silicon Inner Tracker** (pixels + strips).
- **ITK requirements** for silicon pixel detectors include:
  - Higher granularity → Smaller pitch pixels of **50x50**μm^2 or **25x100**μm^2.
  - Radiation hardness → up to $3x10^{15}\ n_{eq}/cm^2$ for planar sensors.
  - Hit efficiency > 97% for HL-LHC (at Max 600V)

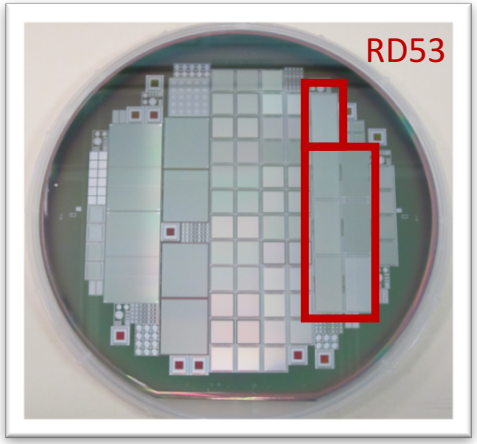
One quarter of the layout in r-z



Setup

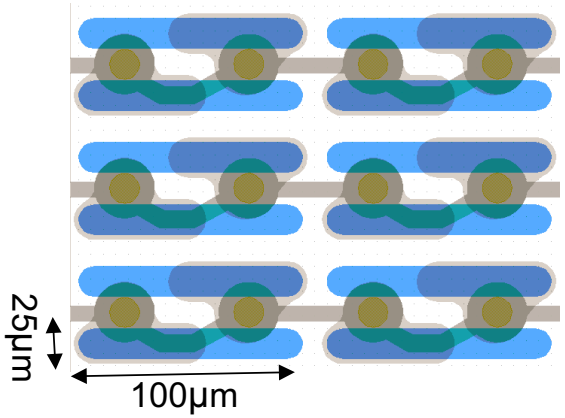
- Sensors are produced by FBK and assembled at IZM with the RD53a front-end on a single chip card.
- Presented modules were **Irradiated at CERN PS** Irrad facitility.
- Modules were measured before and after irradiation in a **testbeam setup** at CERN (120 GeV pions) and DESY (5 GeV electrons) .
- Data acquisition setup include Mimosa telescope planes, scintillators for external trigger, Bdaq53 readout, cooling chamber for controlled temperatures at -50 °C.
- Tracks **reconstruction using Eutelescope** and data is **analyzed using Tbmon2** software.
- All modules were tuned before measurement to achieve lowest possible threshold (~1000e).

Modules overview



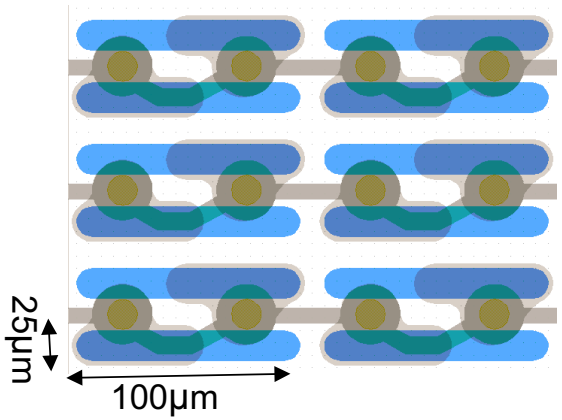
- RD53 n-in-p planar sensors are produced on 6’’ wafer by FBK.

Measured modules details:



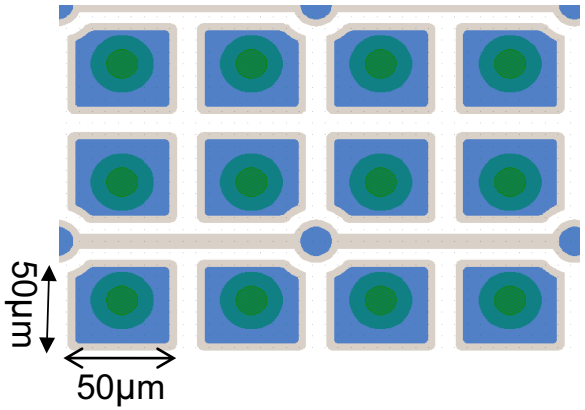
100-25-noPT

- thickness: 100µm
- cell: 25x100µm²
- No biasing dot
- Not Irradiated



130-25-noPT

- thickness: 130µm
- cell: 25x100µm²
- No biasing dot
- Irradiated at CERN PS



130-50-PT

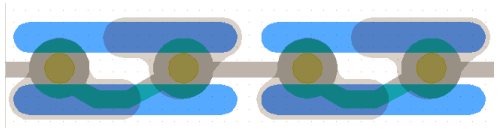
- thickness: 130µm
- cell: 50x50µm²
- With biasing dot
- Irradiated at CERN PS

Results

Non-Irradiated modules

Hit efficiency vs. bias voltage

Non-Irradiated

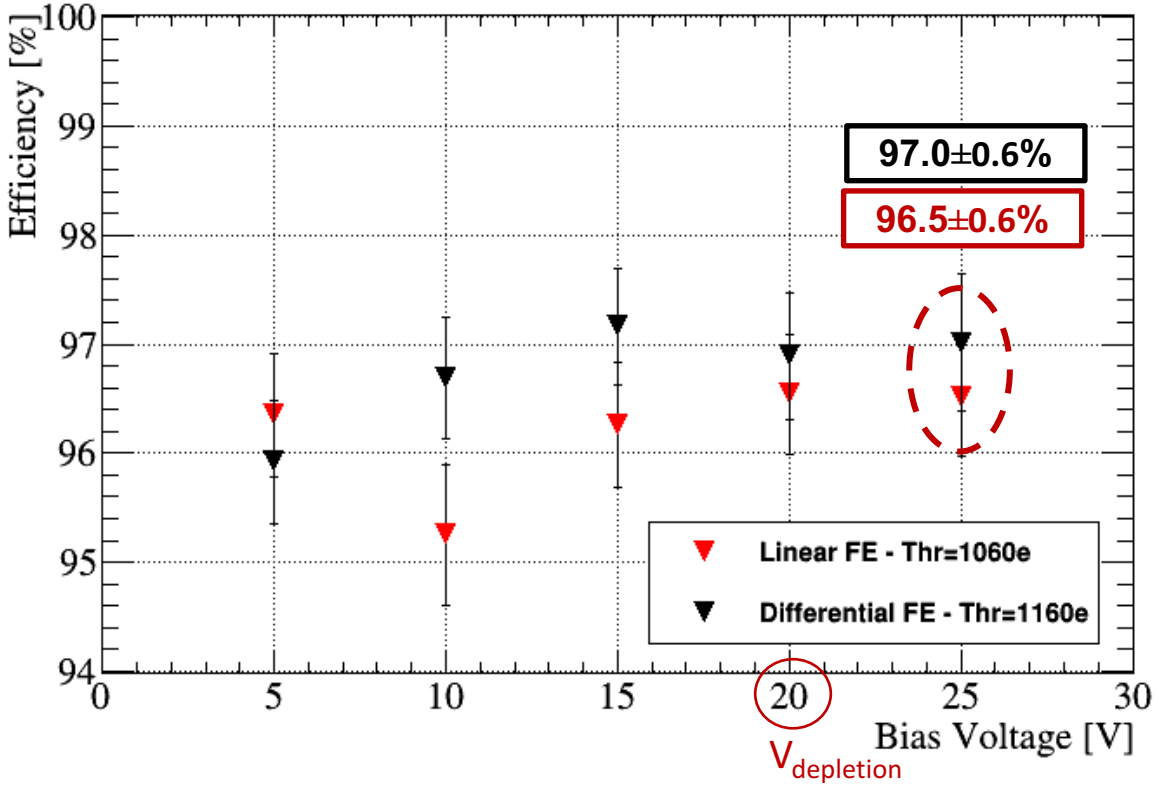


- **25x100µm²** pixel module with 100µm thick sensor, Non-irradiated.

- Tuned threshold:
  - Linear = 1060e
  - Differential = 1160e

- Depletion voltage for the sensor is **$V_{depletion}$ =20V**.

- Hit efficiency for Linear & Differential FE show similar results.



Results

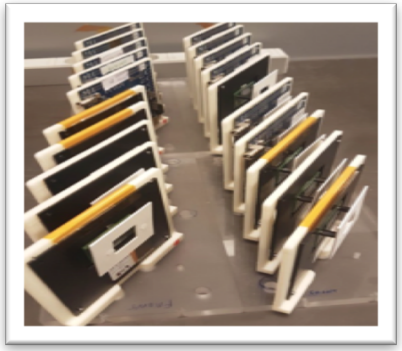
Irradiated modules

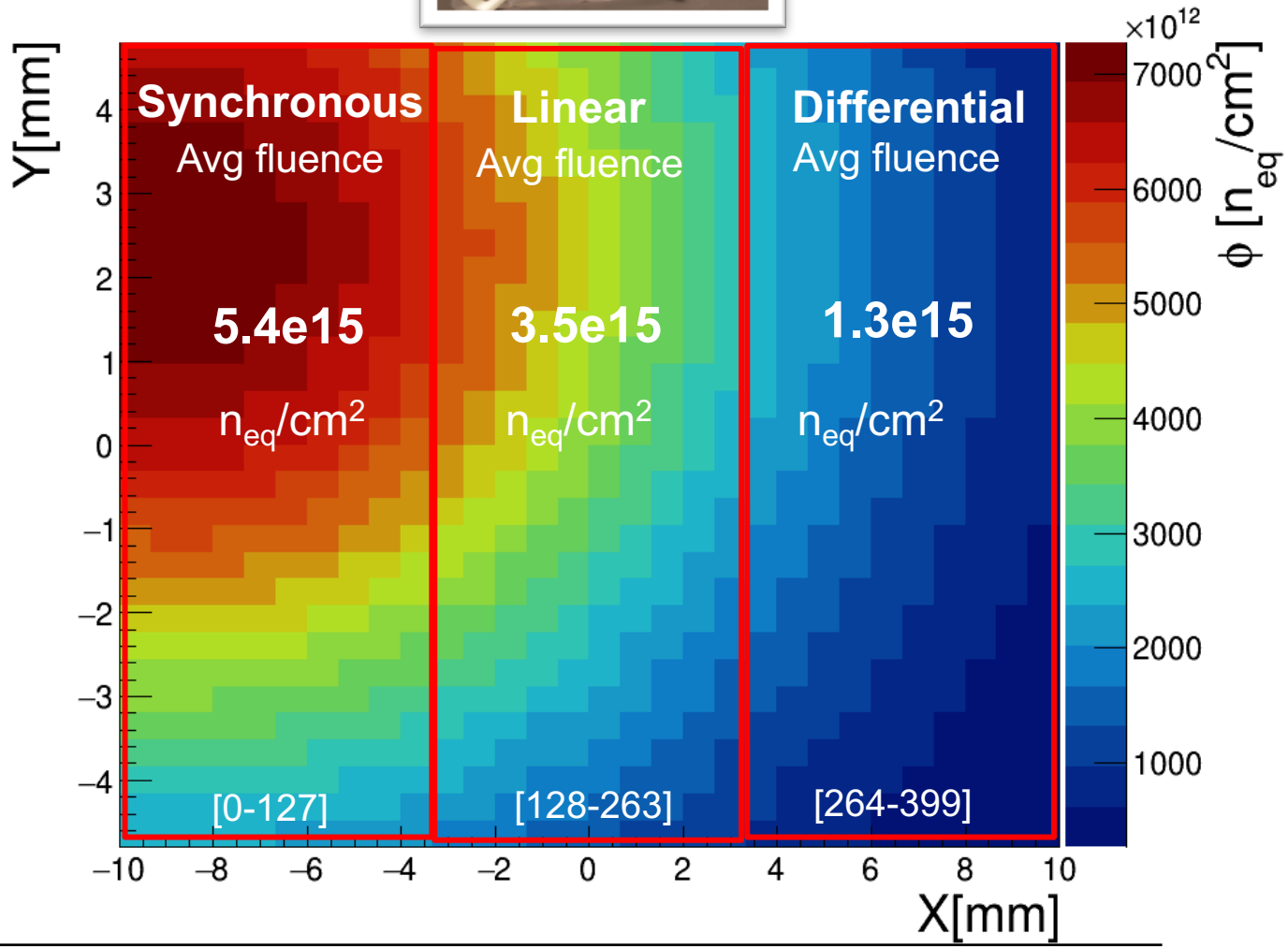
Module irradiation

- Irradiation at CERN PS Irrad facility → Inhomogeneous profile + irradiation beam misalignment.

- Fluence map is reconstructed from Beam Profile Monitor (BMP) with the dosimetry results measured on the foil sheet mounted behind the modules.

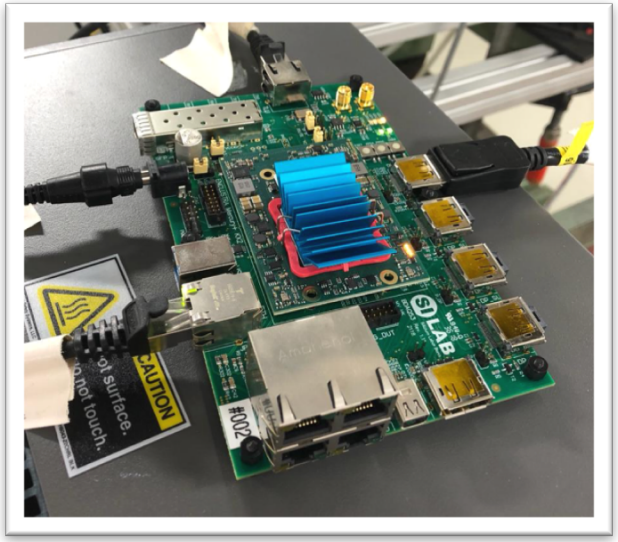
- Fluence analysis estimates **~20% uncertainty** from measurements and fitting.



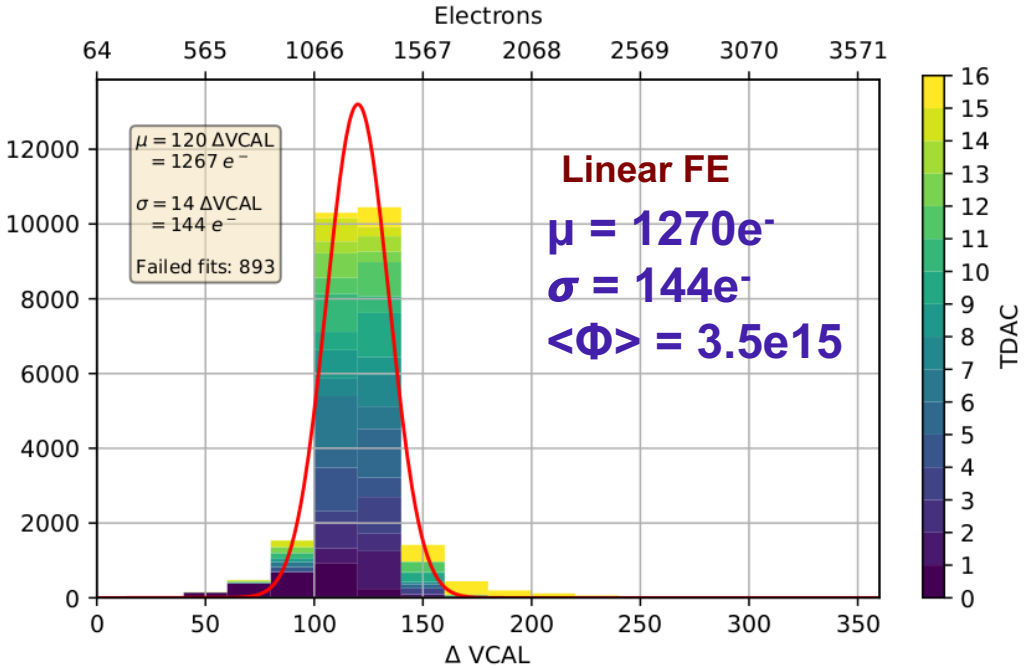


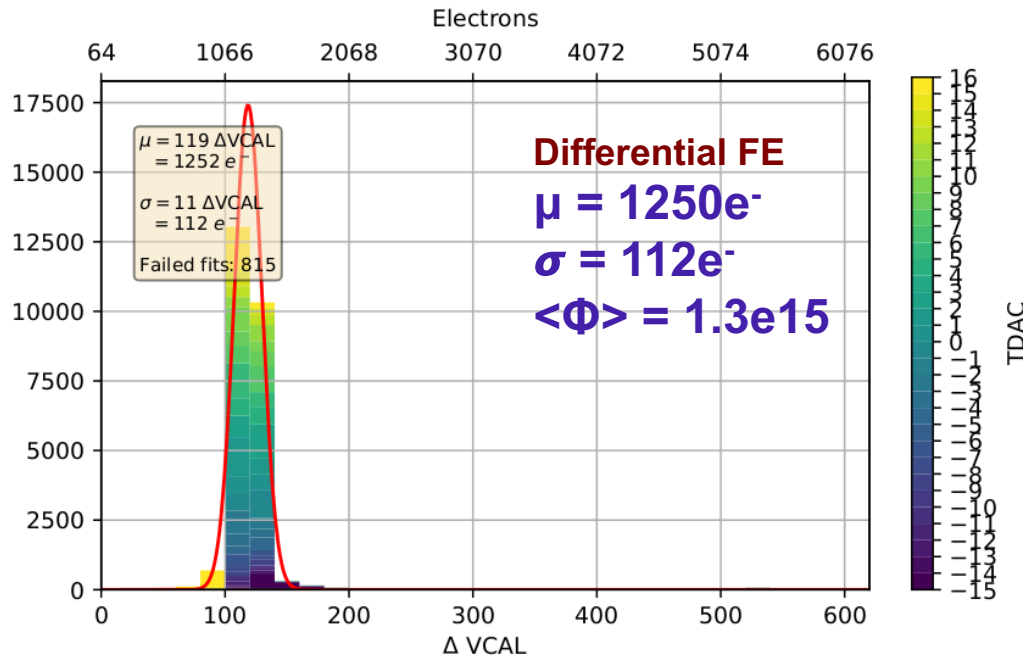
Tuning

- Tuning for RD53a chip is performed using the Bdaq53. Scanning processes is performed for each front-end flavor independently.

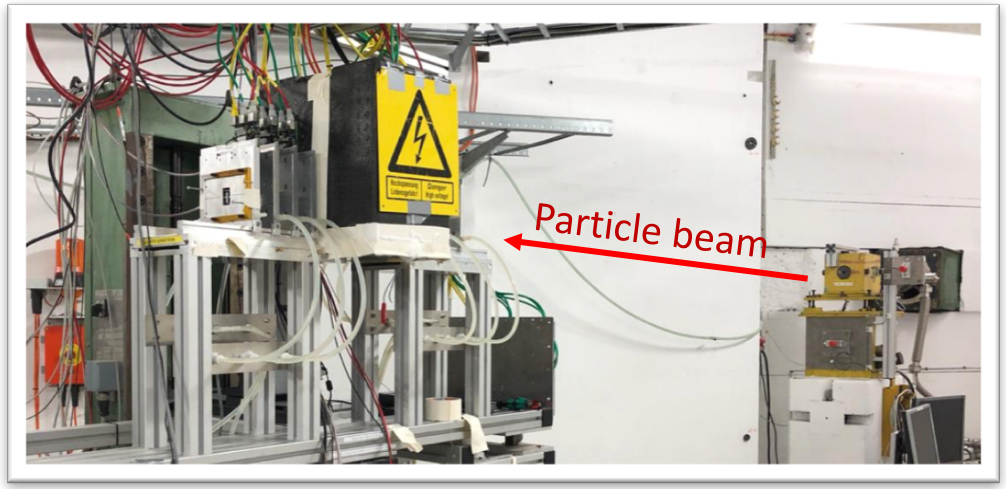


- Example of threshold distribution for a 25x100µm^2 irradiated module after tuning.





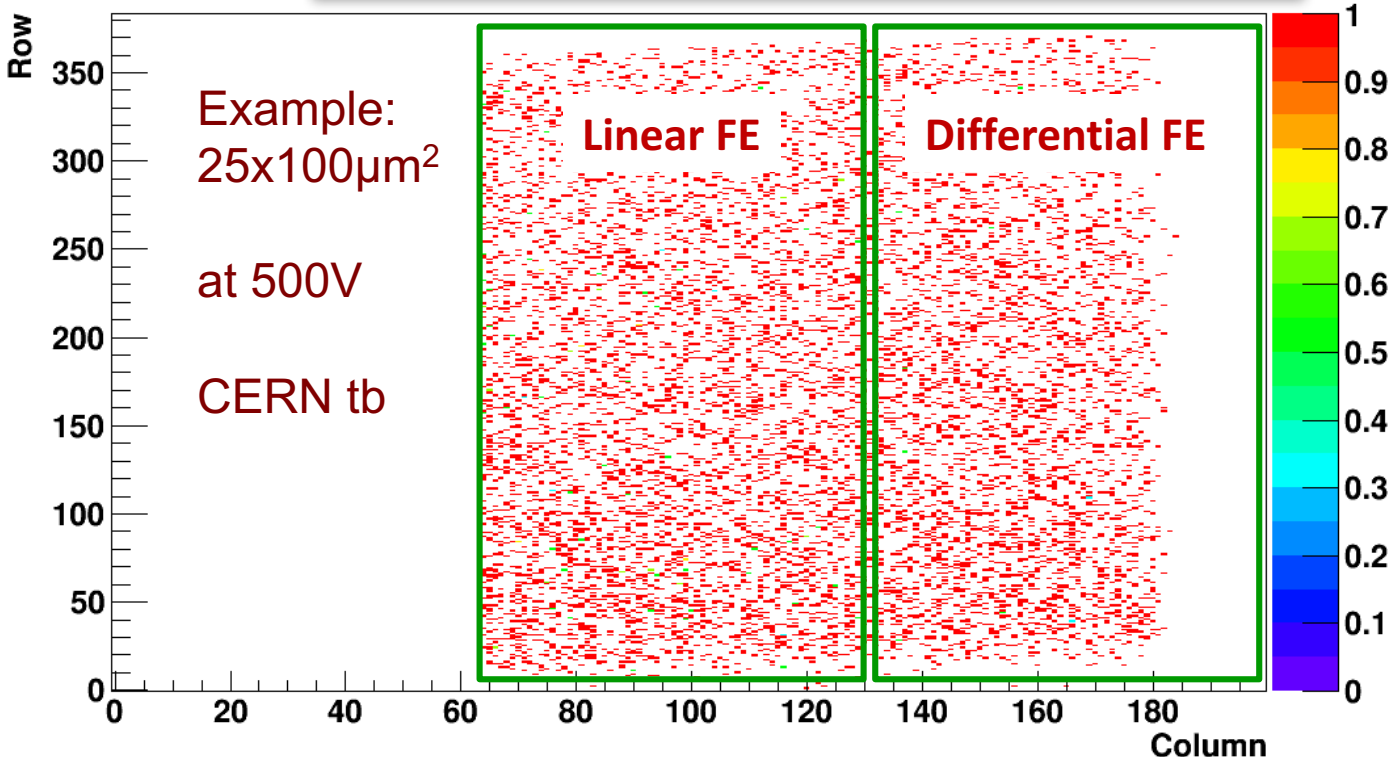
Analysis regions



- In the testbeam setup the sensors were centered on the particle beam to cover two front-ends at the same time.

- Hit efficiency map at **500V** measured at **CERN testbeam** setup.

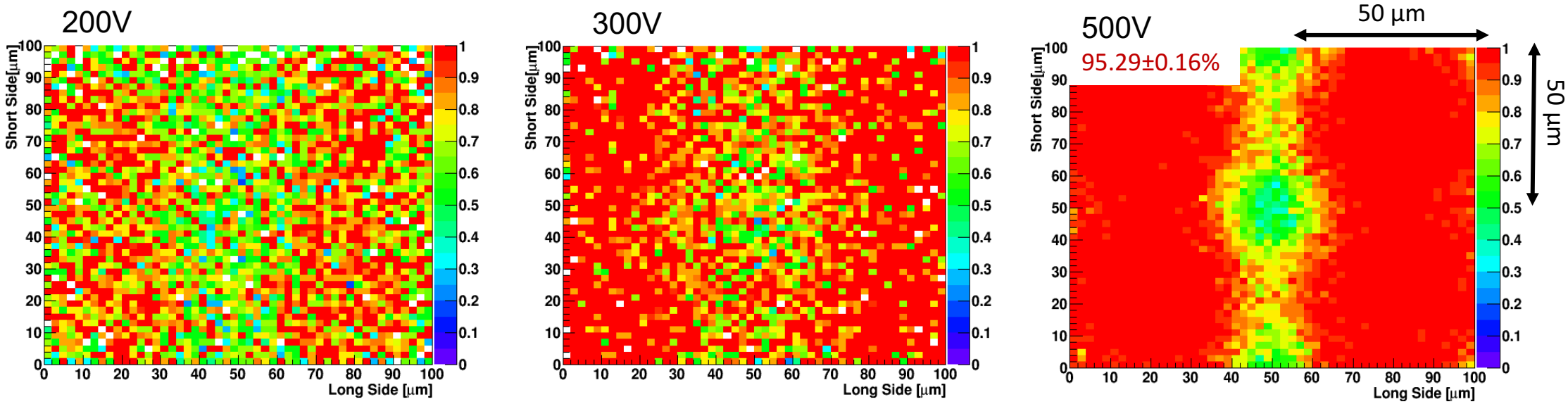
- Each front-end was analyzed separately using TBmon2.



In-pixel efficiency maps

Hit efficiency is defined as the fraction of reconstructed tracks crossing a module that have an associated hit in that module.

- 2x2 Pixel efficiency map shows the overall hit efficiency of the module .
- At 500V the hit efficiency is 95.29±0.16%.
- Significant **hit efficiency loss** is visible in the **biasing structure** region.



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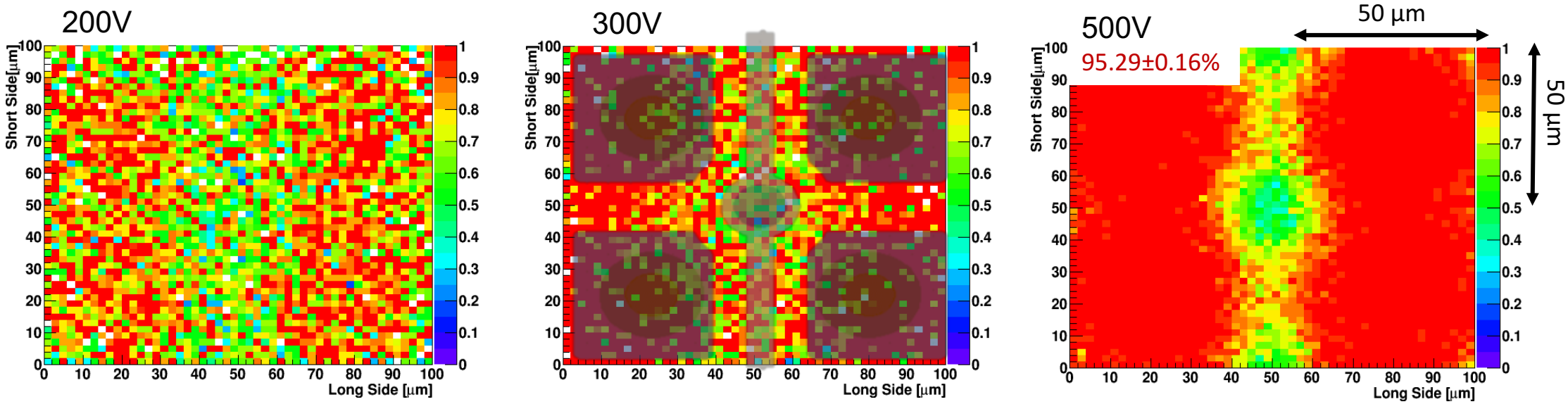
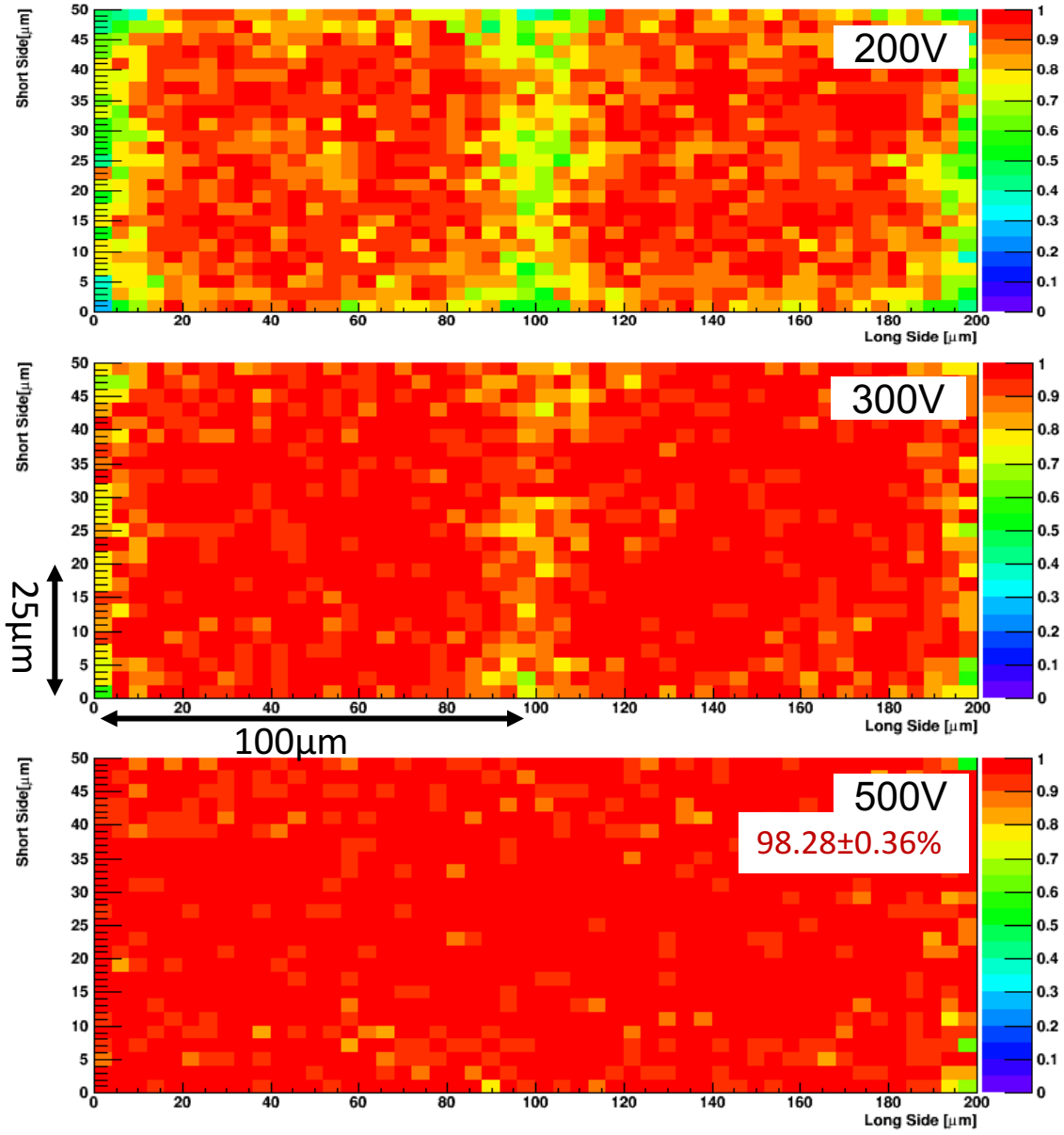


In-pixel efficiency maps

- 2x2 Pixel efficiency maps for a module with 25x100µm^2 cell size and no Biasing structure. Sensor design is overlaid on the pixel map.
- At 500V the hit efficiency is 98.3±0.4%.
- At 500V pixel efficiency map shows **uniform efficiency** due to the no biasing structure sensor design.



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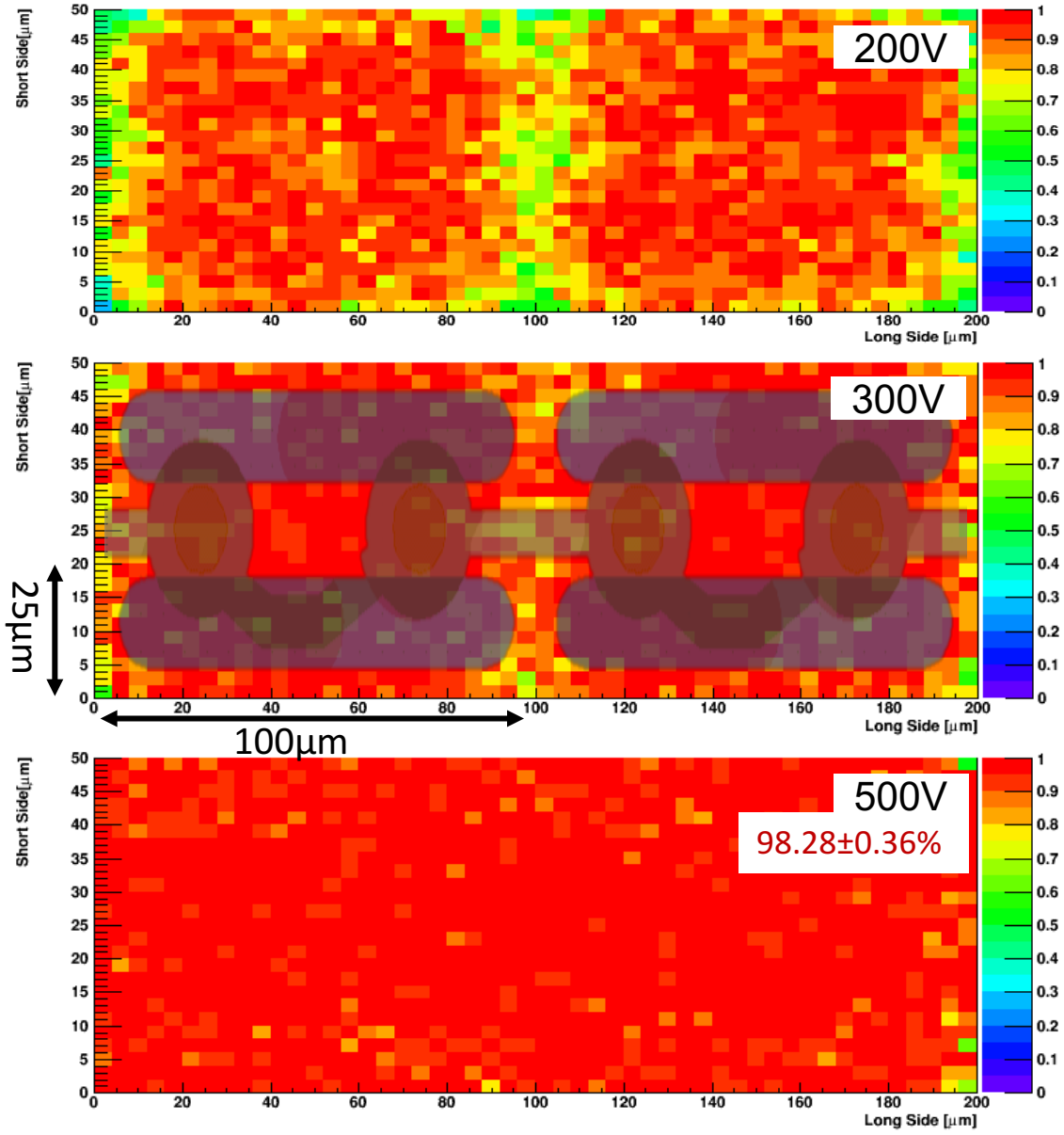
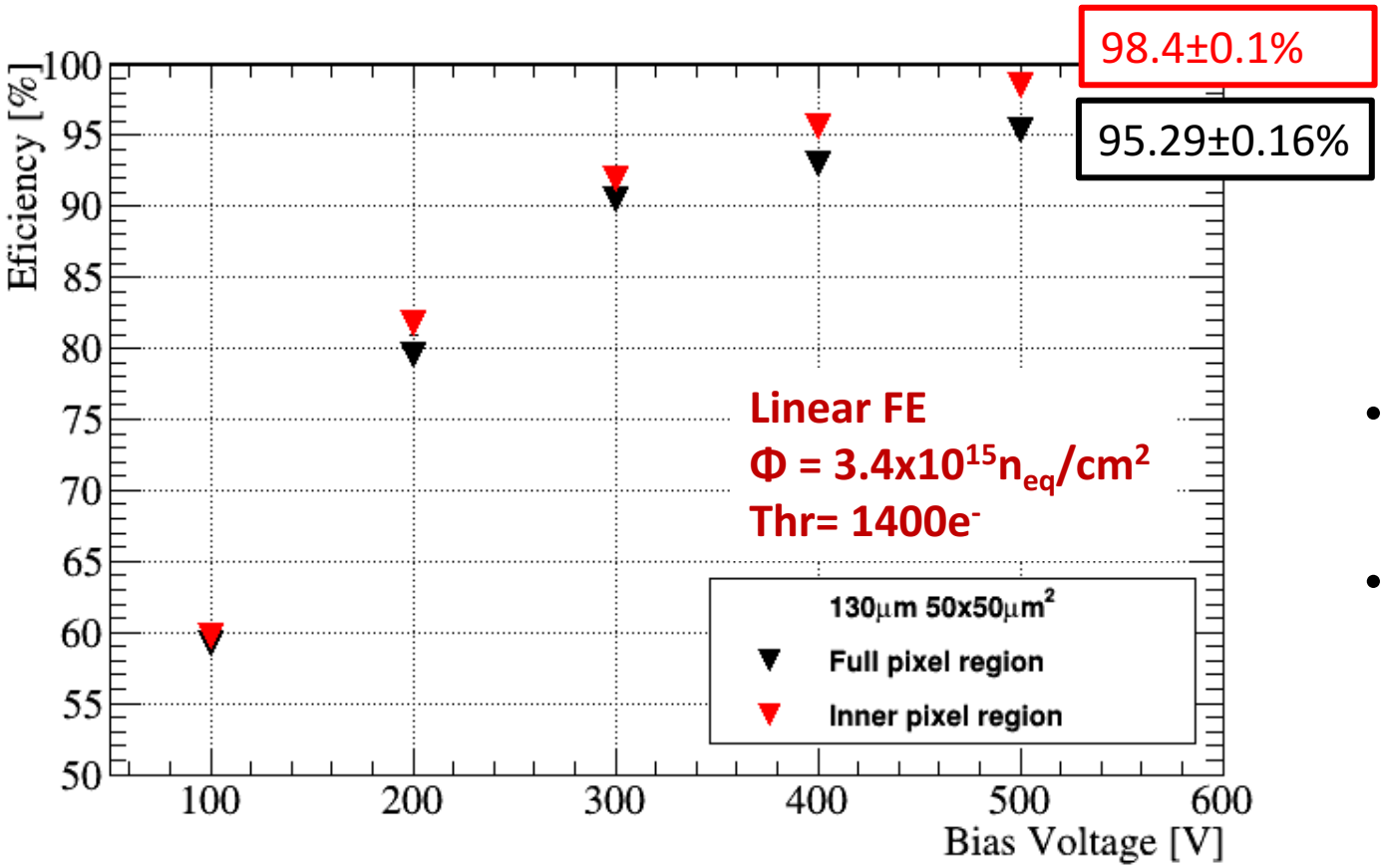
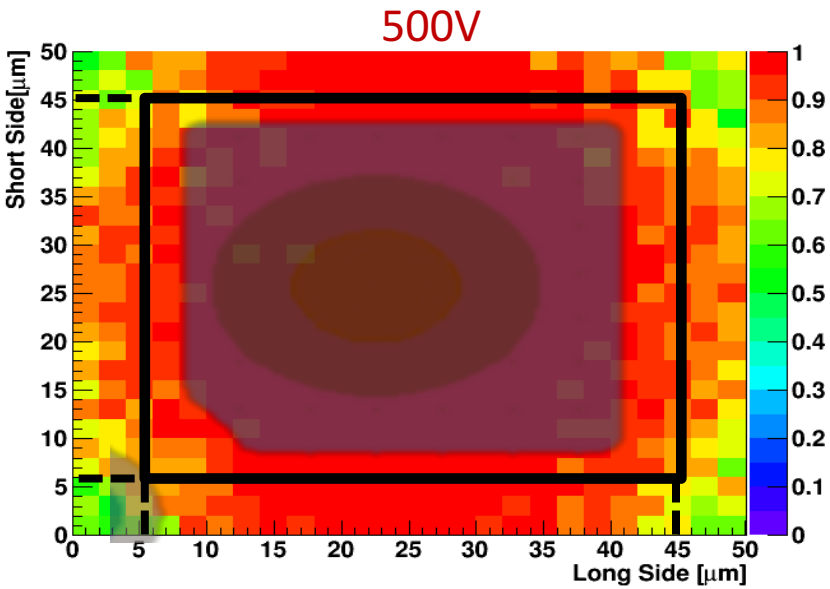


Hit efficiency: Fiducial region

- Studying the influence of biasing structure on the hit efficiency → comparing the hit efficiency of the full pixel geometry with the core pixel.





- Analysis restricted to **Linear FE**.
- Over all hit efficiency **increases by ~3%** in the fiducial region.

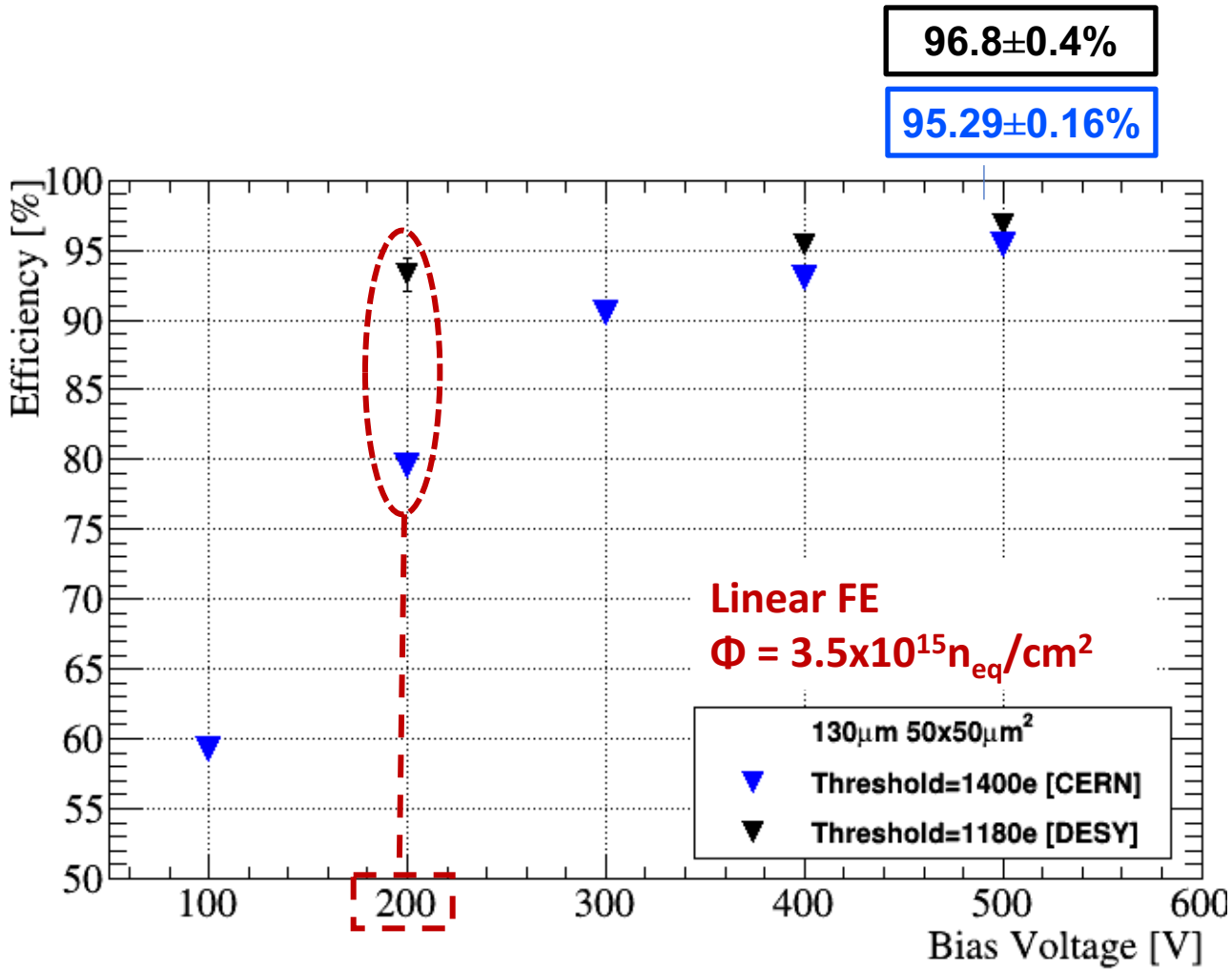
Hit efficiency vs. bias voltage: Threshold effect

- Overall hit efficiency for **50x50µm²** pixel module.

- Hit efficiency vs. bias voltage measured for **Linear front-end.**

- Tuned threshold:
  - ➢ 1400e⁻ (measured at CERN October 2018)
  - ➢ 1180e⁻ (measured at DESY December 2018)

- **For lower tuned threshold value**:
  - ✓ 15% Higher hit efficiency at 200V
  - ✓ Earlier saturation of hit efficiency at 400V



Hit efficiency vs. bias voltage

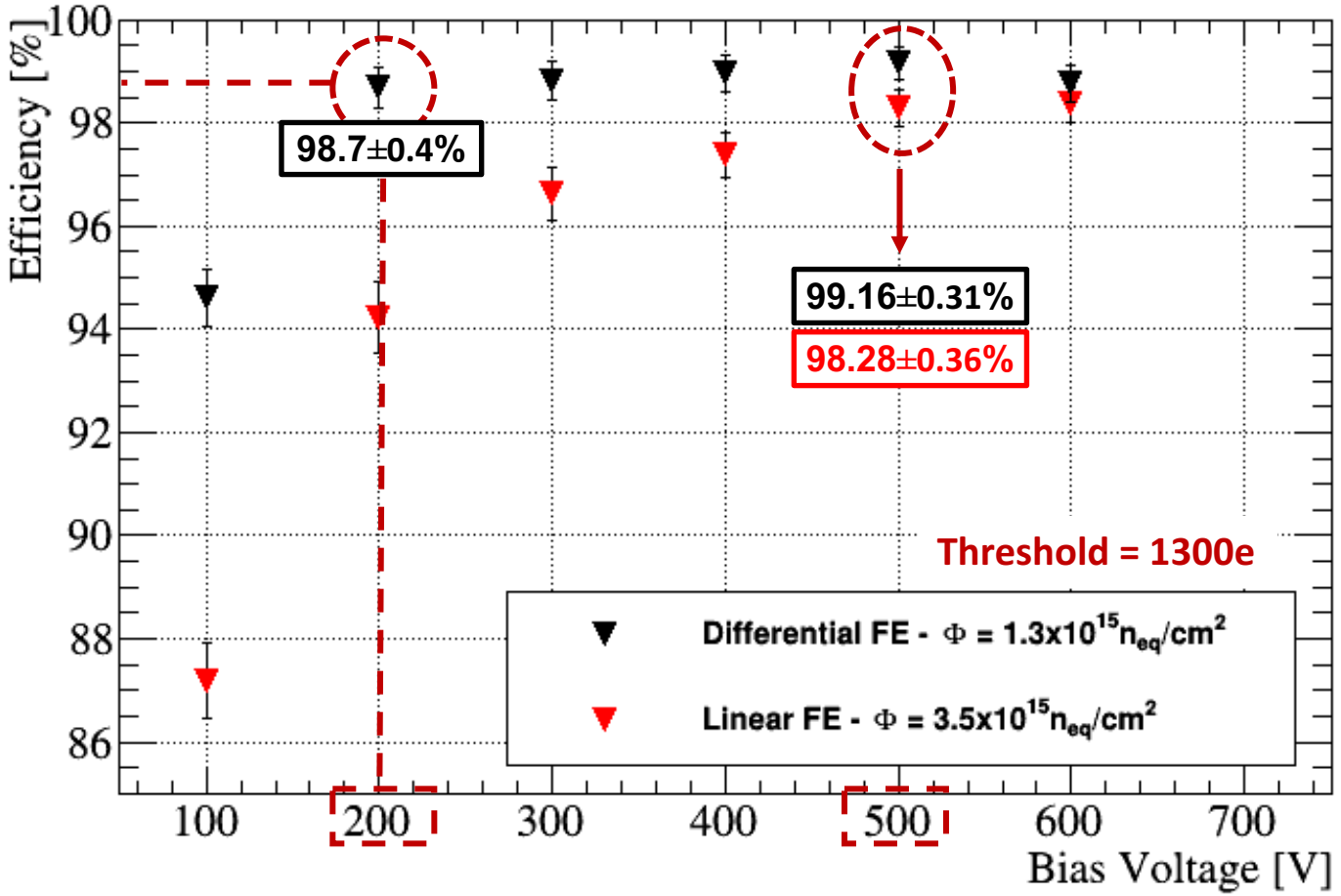
- Hit efficiency for an irradiated **25x100µm²** pixel module.

- Average fluence on:
  - Differential FE Φ = 1.3x10^{15} n_{eq}/cm^2
  - Linear FE Φ = 3.5x10^{15} n_{eq}/cm^2

- Similar tuned threshold value for both front ends of 1300e

- Hit efficiency saturation at 200V for Φ = 1.3x10^{15} n_{eq}/

- Hit efficiency saturation at 500V for Φ = 3.5x10^{15} n_{eq}/cm^2



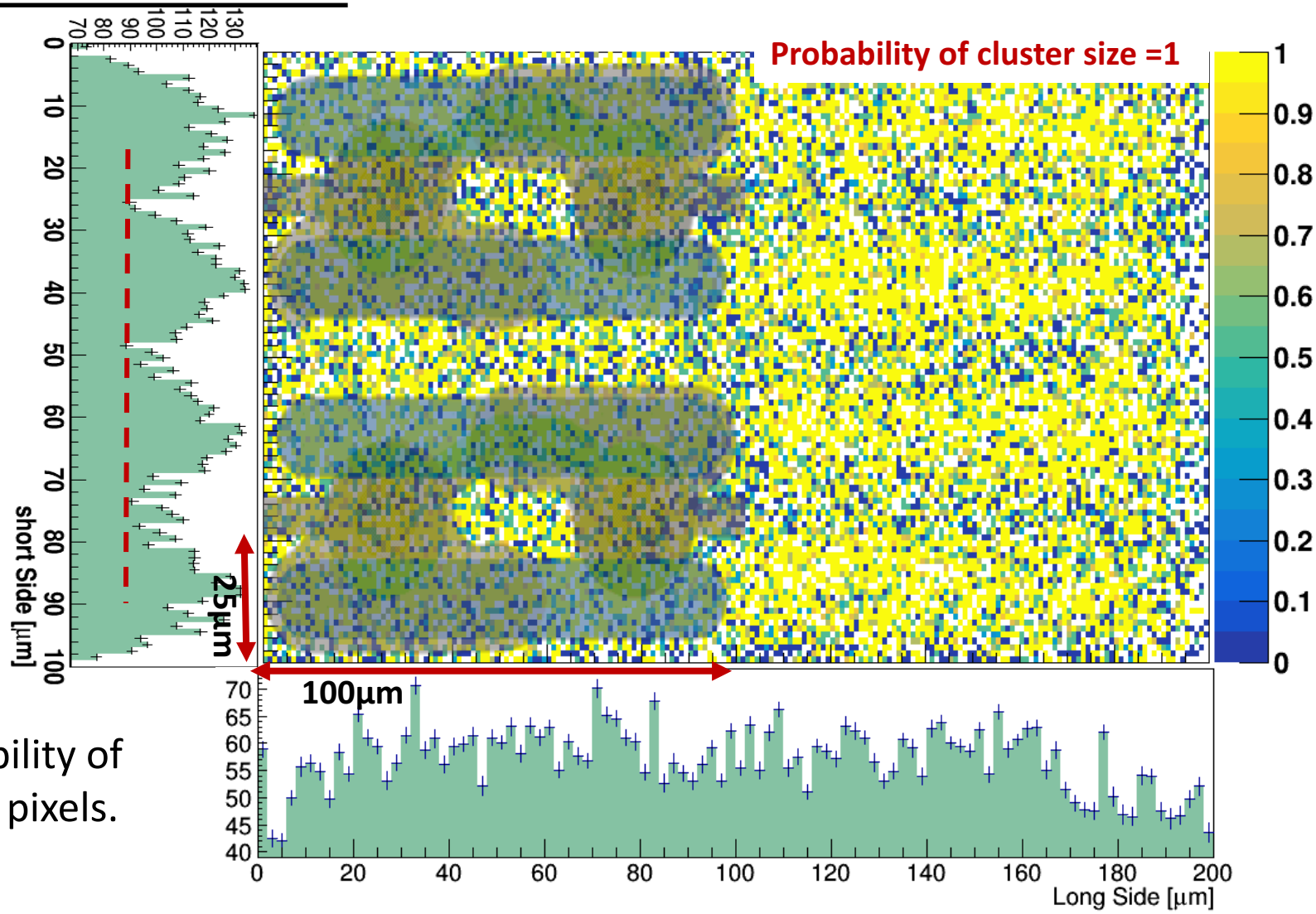
Cluster size and cross talk

- Irradiated **25x100µm²** module. Analysis region restricted to **linear FE**.

- From previous studies cross talk appears for all front ends.
  - ➢ Natalia Emriskova, RD53 Review Open Session

https://indico.cern.ch/event/769894/contributions/3229980/attachments/1765304/2865819/AFE_REVIEW_CERN_test_results.pdf

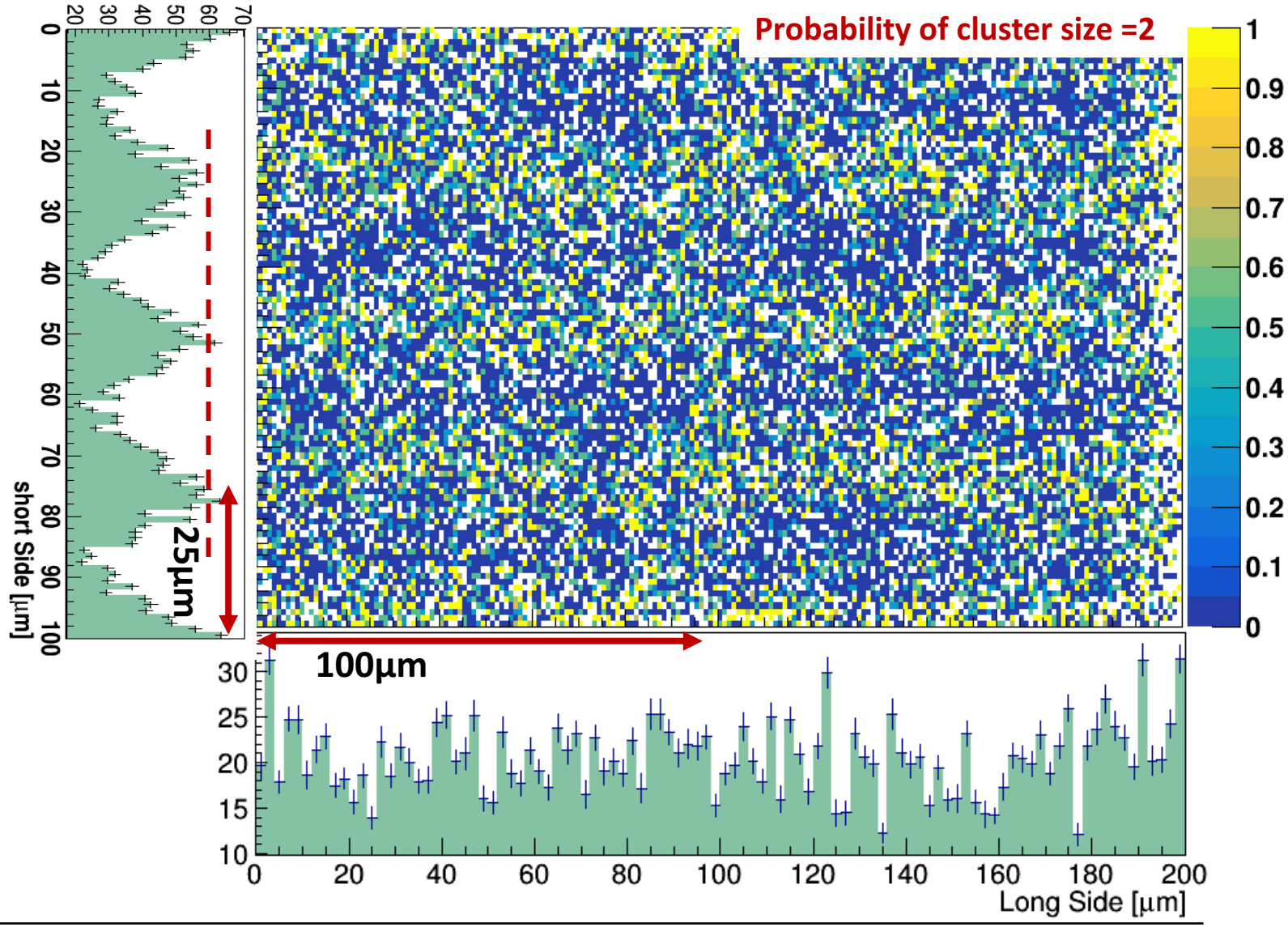
- Analysis of cluster size shows probability of cluster size >1 between neighboring pixels.



Cluster size and cross talk

- No indication of cross talk from studying the cluster size.

More statistics required



Conclusions

- At 500V, linear FE, $\Phi = 3.5 \times 10^{15}$ n_{eq}/cm^2 , threshold = 1400e **with permanent biasing structure** shows hit efficiency of 95.29±0.16% while when **excluding the biasing dot** the hit efficiency increases to 98.4±0.1%.

- 25x100µm² sensor with threshold=1250e
  - →Linear FE with $\Phi = 3.5 \times 10^{15}$ n_{eq}/cm^2 → hit efficiency about 98%.
  - →Differential FE with $\Phi = 1.3 \times 10^{15}$ n_{eq}/cm^2 → hit efficiency about 99%.

compatible with ITK requirements

- At 200V, irradiated module at $\Phi = 3.5 \times 10^{15}$ n_{eq}/cm^2 (linear FE) shows hit efficiency of 94.22±0.69% while with lower fluence of $\Phi = 1.3 \times 10^{15}$ n_{eq}/cm^2 (diff FE) it shows **15% increase of efficiency** of 98.7±0.4%.

- Testbeam data (at DESY) for 25x100µm² do not show indications of cross-talk → More data might be needed.

Outlook

- Waiting for 2 more modules to be assembled for testbeam measurements in May 2019.

- study the performance of non-irradiated front-end flavors with lowest achievable threshold for each flavor.

- An investigation on threshold homogeneity for RD53A for non-irradiated and irradiated modules is planned in March testbeam.

- Measurements of hit efficiency as a function of **fluence**. Irradiation planned at **Karlsruhe in 2019**:
  - $\Phi = 1x10^{15} n_{eq}/cm^2$
  - $\Phi = 2x10^{15} n_{eq}/cm^2$
  - $\Phi = 3x10^{15} n_{eq}/cm^2$

- New production of planar sensors from **FBK** arriving in few months.

Acknowledgments

✓Productions were supported by the Italian National Institute for Nuclear Physics (INFN), Projects ATLAS, CMS, RD-FASE2 (CSN1):

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✓Many thanks to all ITk pixel testbeam community specially LAL group(Dmytro&Anestasia).