Characterization of a large LGAD sensor for proton counting in particle therapy

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Outline

- **Motivation**
- **Laboratory characterization**

  -> MoVEIT 2020 FBK's production

  -> Static characterization of LGAD sensors (current-voltage, capacitance-frequency, and capacitance-voltage)

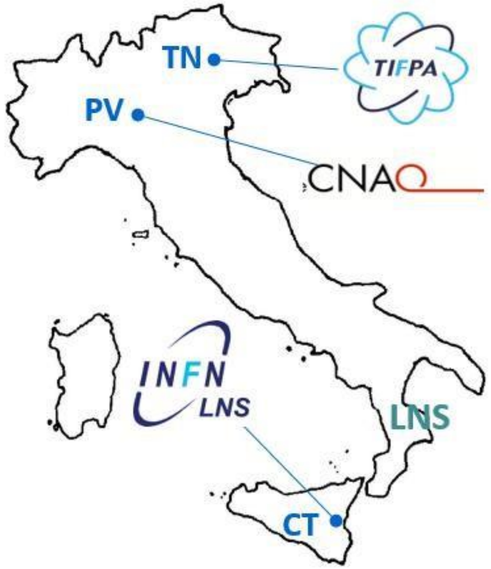
  -> Summary

  -> Transient Current Technique (TCT) test
- **Conclusions**

Motivation

MoVe IT :Modeling and Verification for Ion beam Treatment planning (INFN)

Implementation of advanced radiobiological models in ion TPS, experimental verification in-vitro and in-vivo



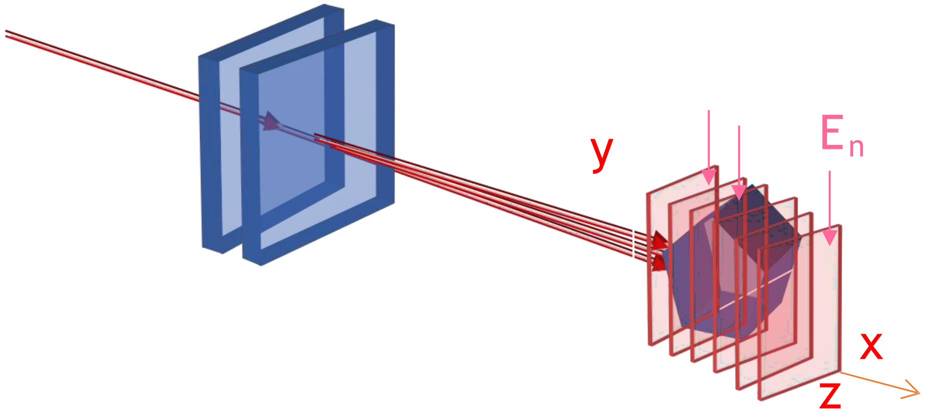
One device is being developed based on Ultra Fast Silicon Detectors:

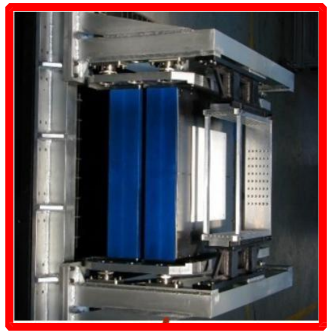
1. to **directly count** individual protons
   - area 3x3 cm^2;
   - up to fluence rate of 10^8 p/s*cm^2 (with error < 2% : clinical requirement);
   - segmented in strips (beam projections in two orthogonal directions).

For additional details https://www.tifpa.infn.it/projects/move-it/

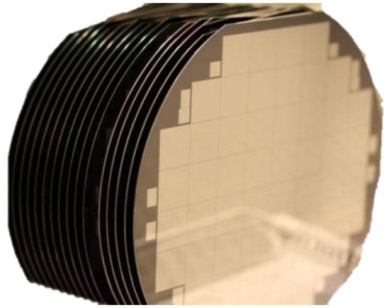
Motivation (Cont.)

Monitor System





vs.



IONIZATION CHAMBER

✓
- Robust
- Simple construction and readout
- Large sensitive area allowed
- Radiation resistance

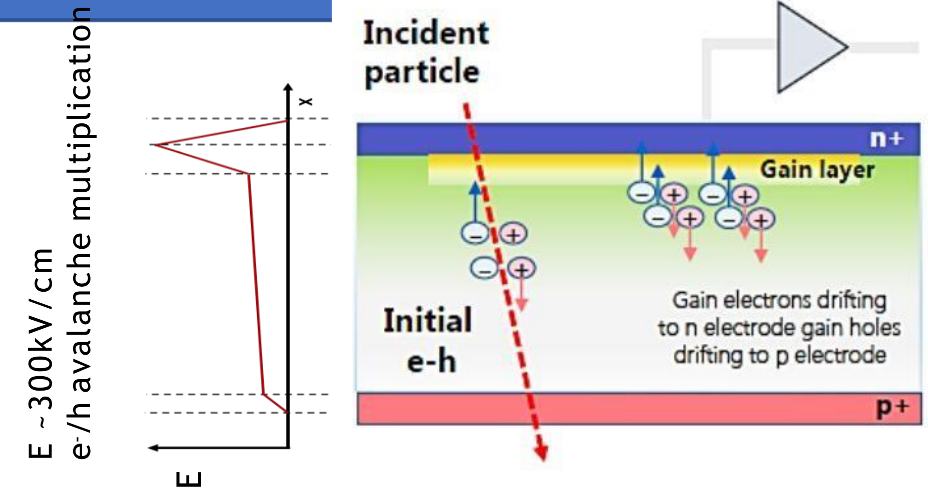
✗
- Slow collection time (~100 μs)
- Low sensitivity (10^4 protons/s)
- Dependance on beam energy and environmental parameters

SOLID STATE DETECTORS

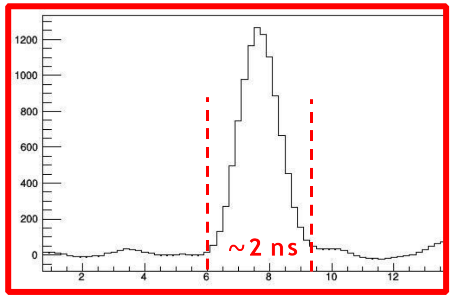
✓
- Fast collection time (~ns)
- Excellent time resolution (<100 ps)
- Good sensitivity (single protons)

✗
- **Radiation resistance**
- **Pile-up effects**

Low Gain Avalanche Detectors (LGADs)



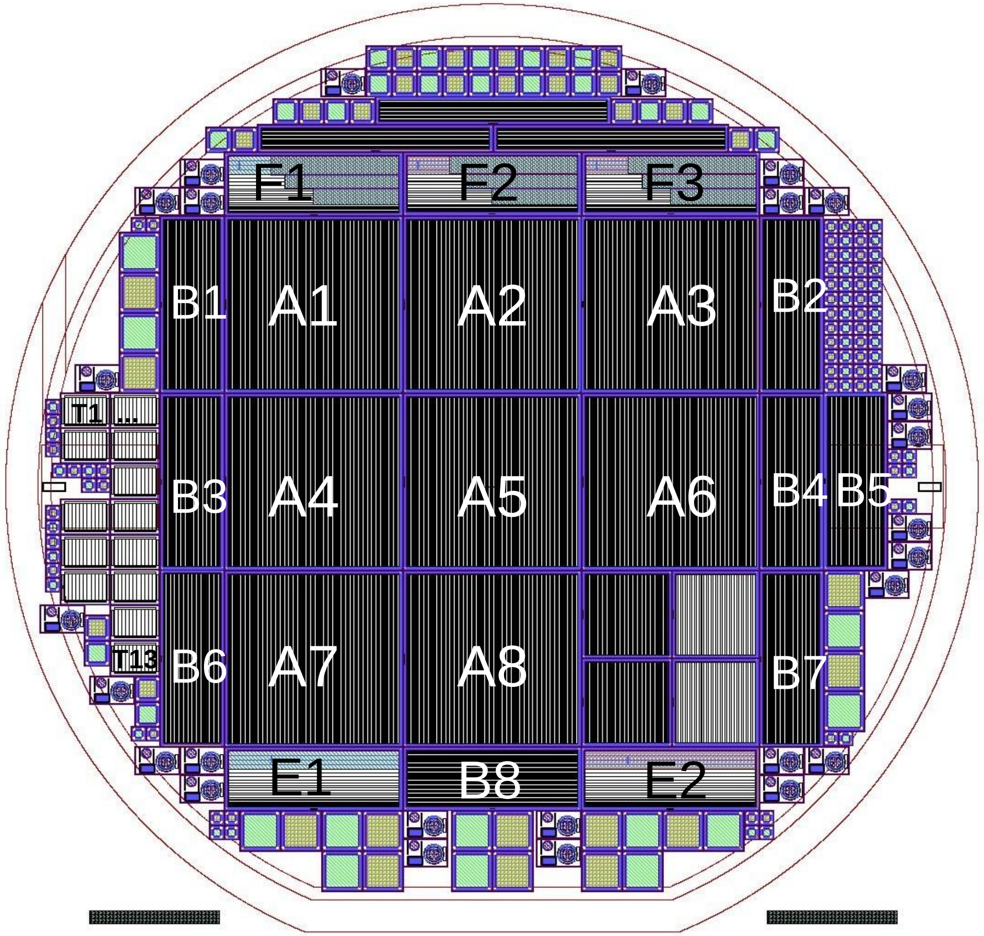
- **fast signal duration (1-2 ns)**
  Single particle detection capability



- **Excellent time resolution (tens of ps)**
  Optimal for Energy measurement using ToF techniques

Laboratory characterization

MoVEIT 2020 FBK's production



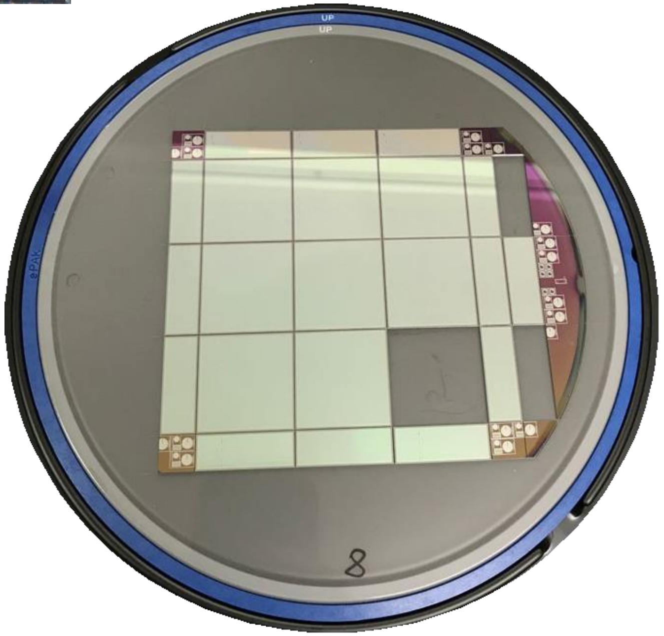
Wafer n.	Dopant	Substrate	Dose Pgain	Carbon	Diffusion	Thickness (μm)
1	Boron	Epi	2.4	YES	L	45
2	Boron	Epi	2.4	YES	L	45
3	Boron	Si-Si	2.4	YES	L	55
4	Boron	Si-Si	2.4	YES	L	55
5	Boron	Si-Si	2.4	YES	L	55
6	Boron	Si-Si	2.4	YES	L	55
7	Boron	Si-Si	2.4	YES	L	55
8	Boron	Si-Si	2.45	YES	L	55
9	Boron	Si-Si	2.45	YES	L	55
10	Boron	Si-Si	2.45	YES	L	55
11	Boron	Si-Si	2.45	YES	L	55
12	Boron	Si-Si	2.45	YES	L	55
13	Boron	Si-Si	2.45	YES	L	55
14	Boron	Epi	2.4	YES	L	45

Detectors used for proton counting

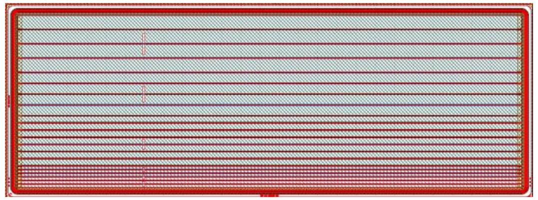
not to scale

Type A
-> Large area: 2.74 x 2.74 cm^2
-> 146 strips

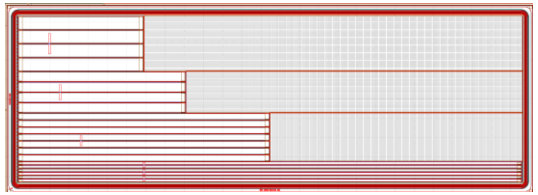
Dimension of the metal:
(NG) Strip 1,2(160 μm x 26260 μm)
(G) Strip 3 - 1 4 6 (160 μm x 26260 μm)
Pitch: 180 μm



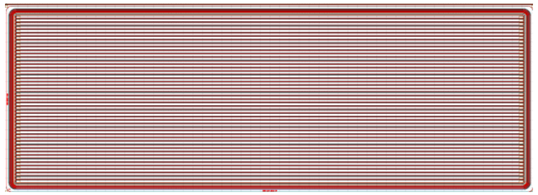
Detectors used for testing



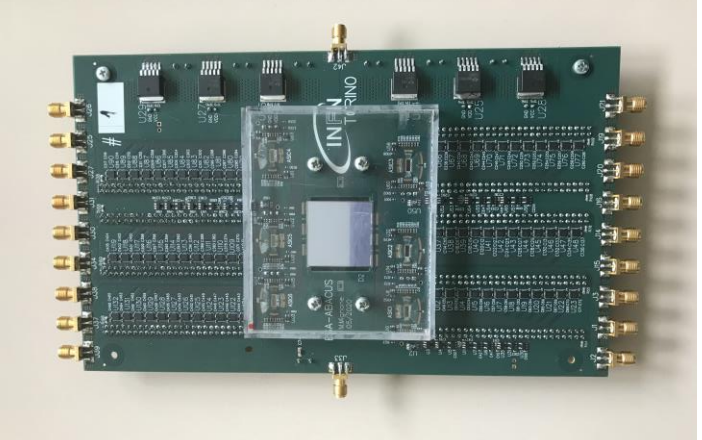
Type E



Type F



Type B



ESA_ABACUS frontend board + Detector Type A
Final counter prototype

Experimental setup

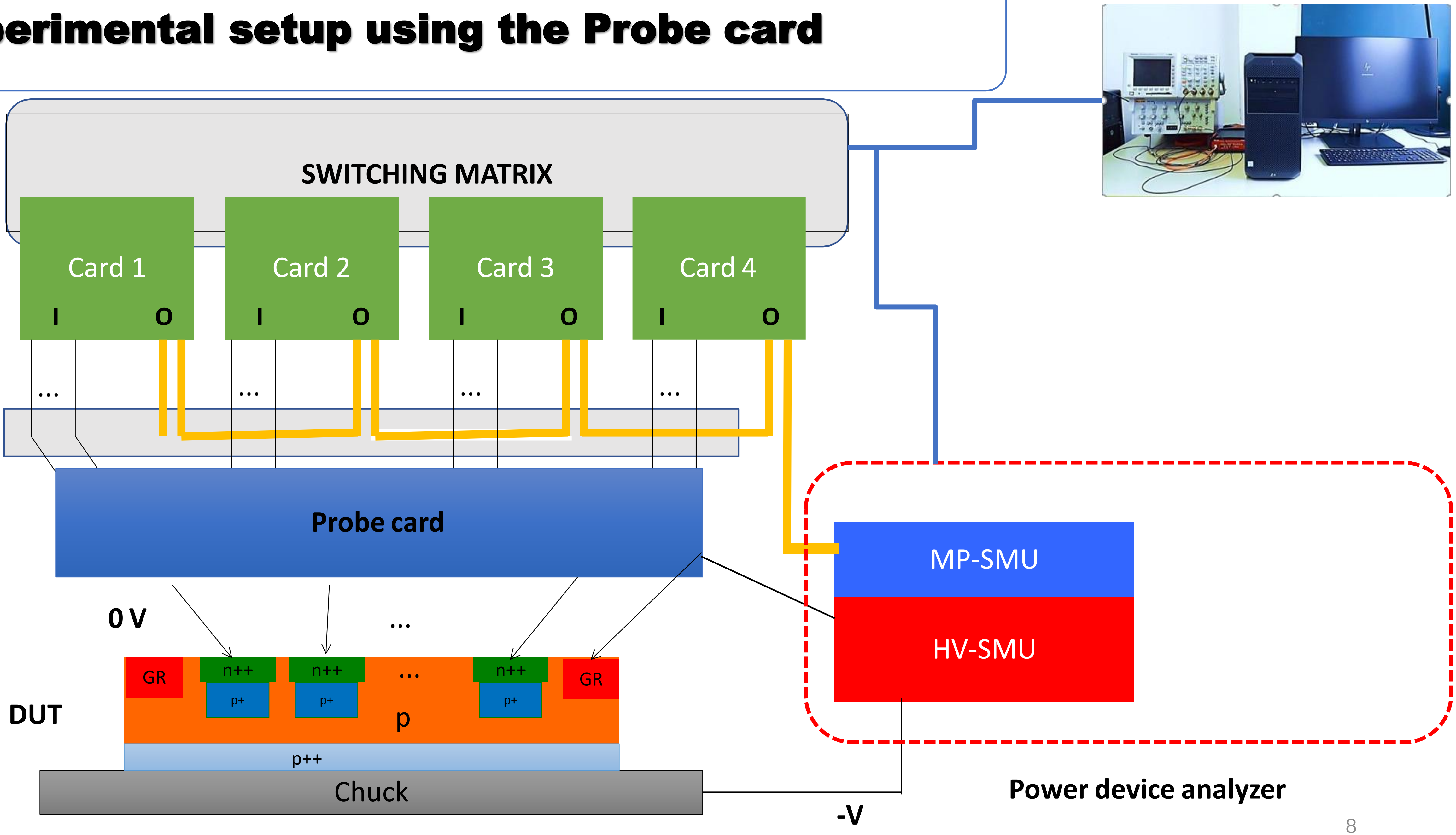
-> Switching MATRIX and a dedicated probe card (current-voltage)

-> Manipulators (capacitance-frequency and capacitance-voltage)

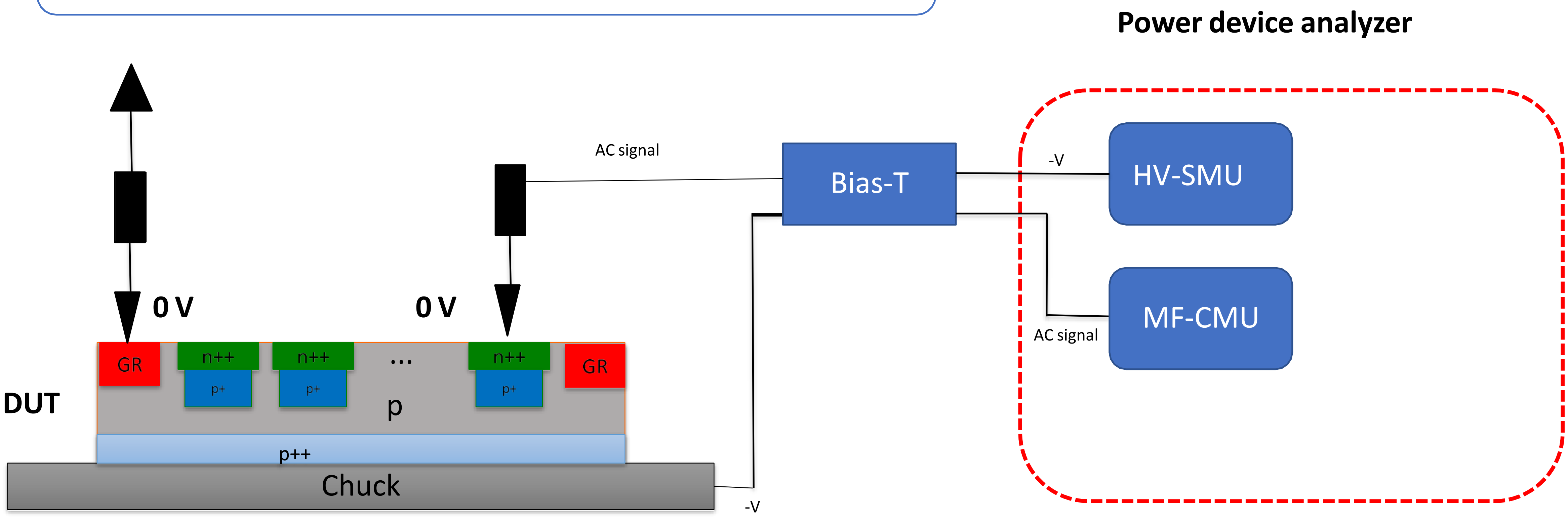
-> Elastomer (current-voltage)

-> Transient Current Technique (TCT) test (interstrip distance)

Experimental setup using the Probe card



CV/Cf measurement in LAB

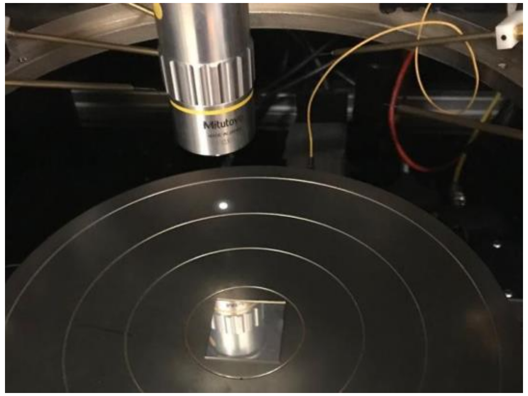


The neighboring strips+GR to the strip that we are measuring were grounded.

Experimental setup using the elastomer

Process

1



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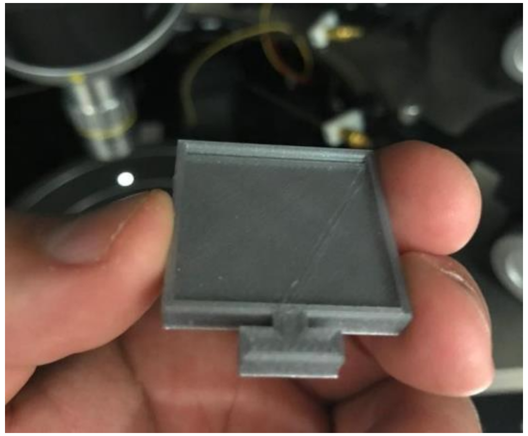

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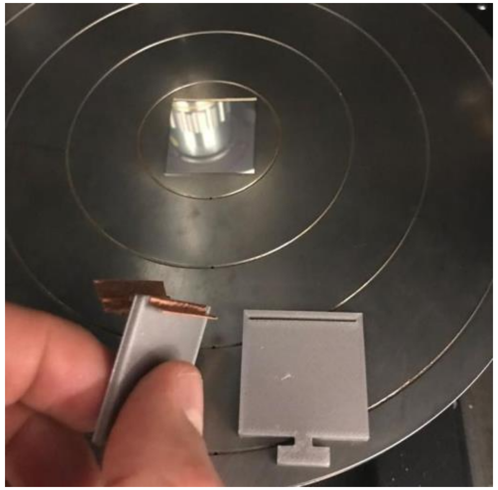

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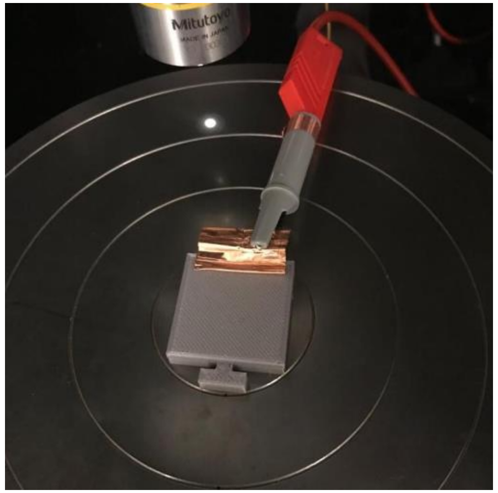

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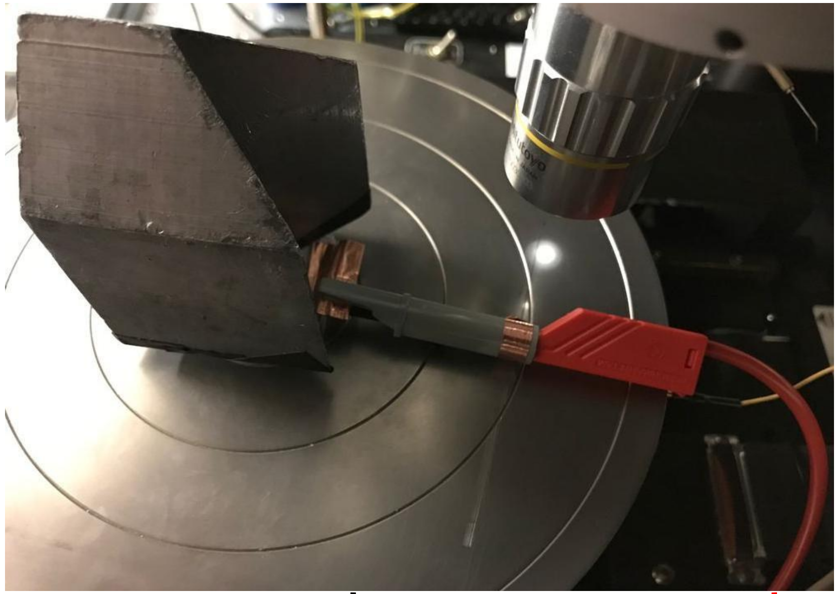


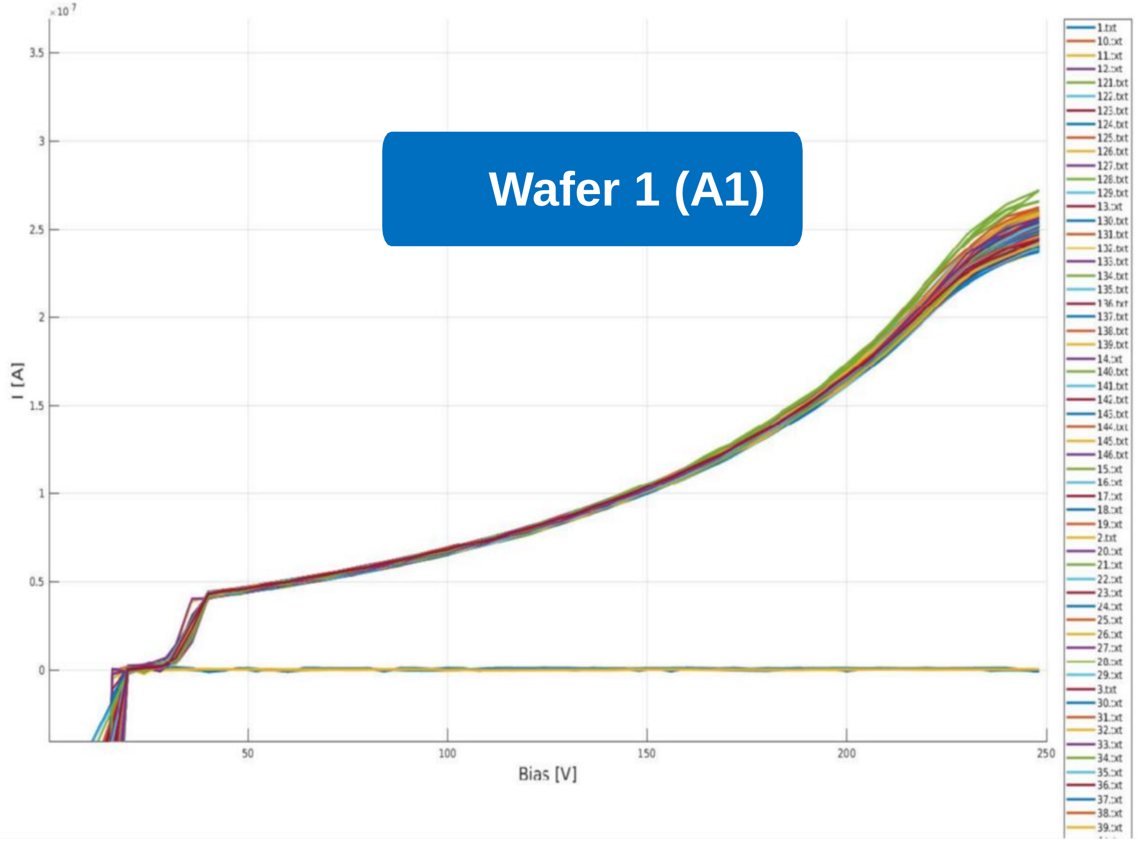
0 V

Power device analyzer

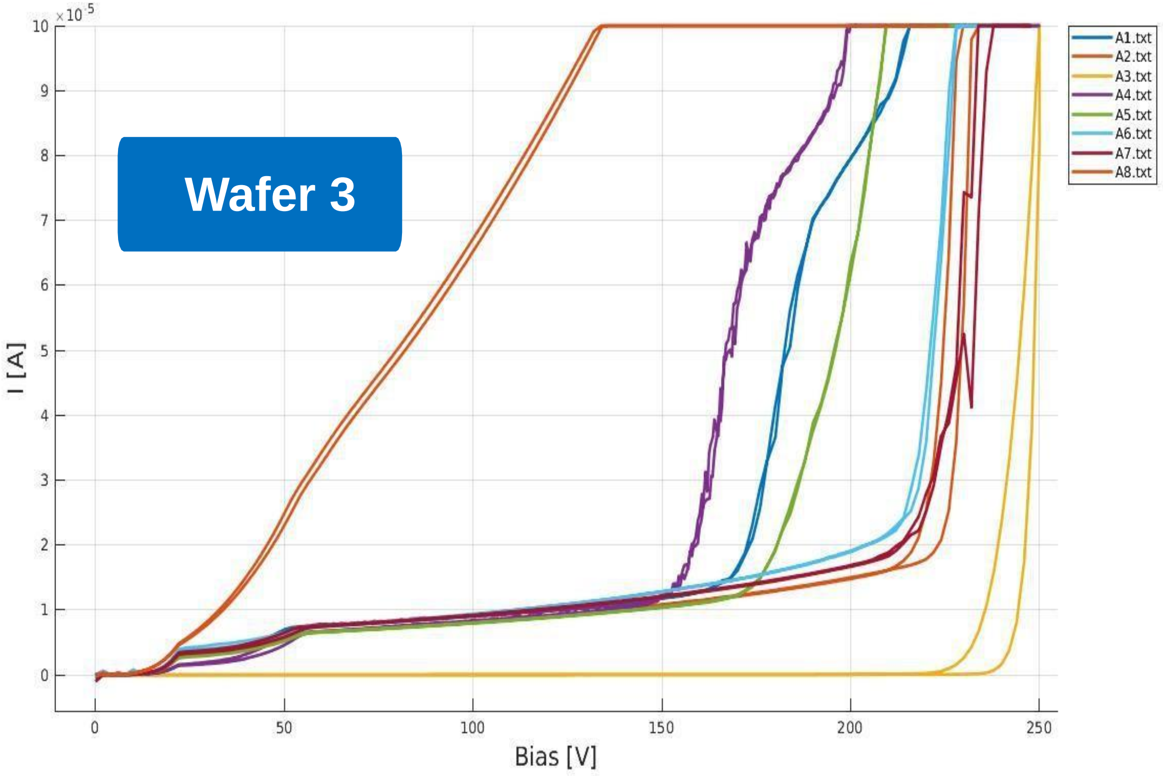
-V

Example of some IV

Probe card measurements

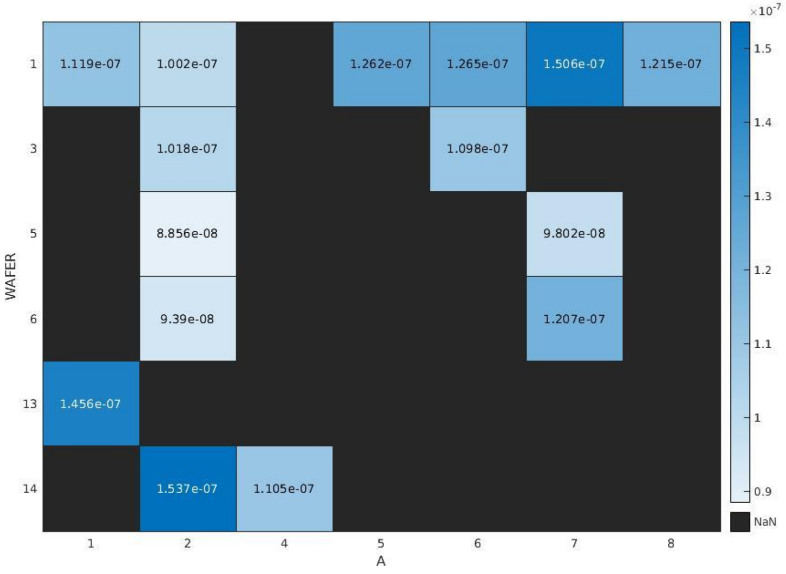


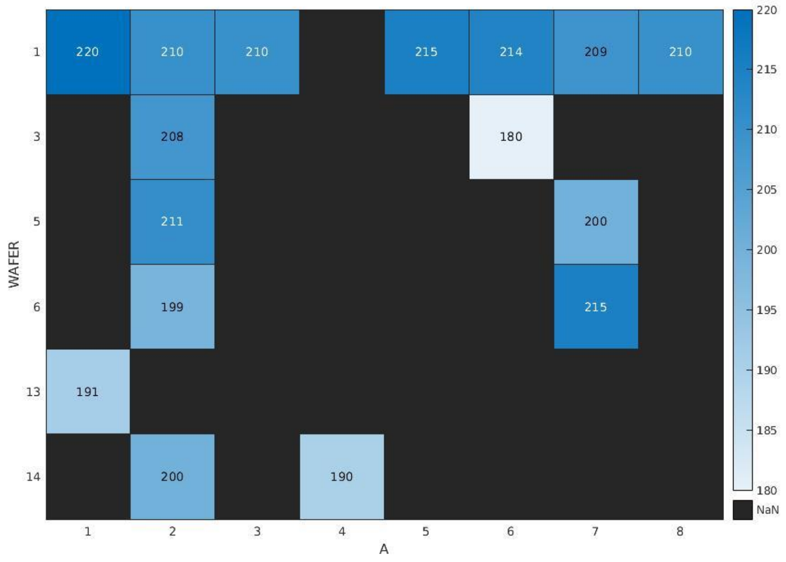
Elastomer measurements

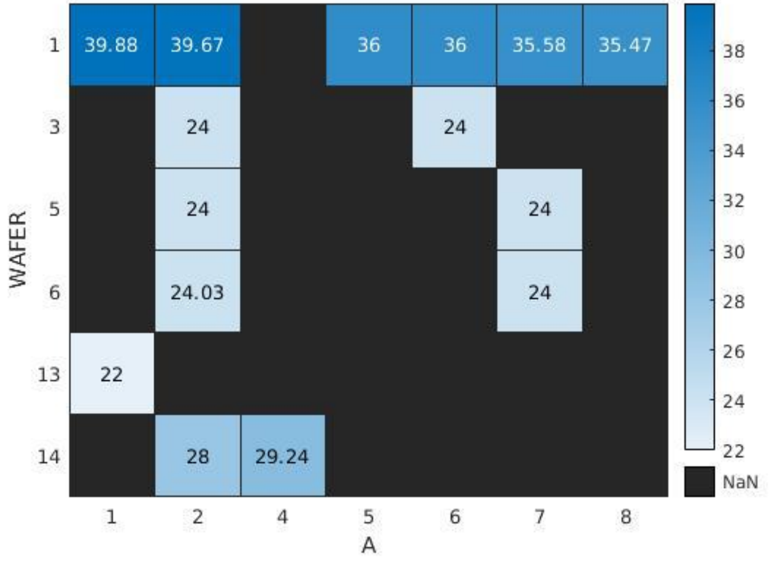


Leakage current (A) at 160 V | Breakdown Voltage (V) | Depletion Voltage (V)

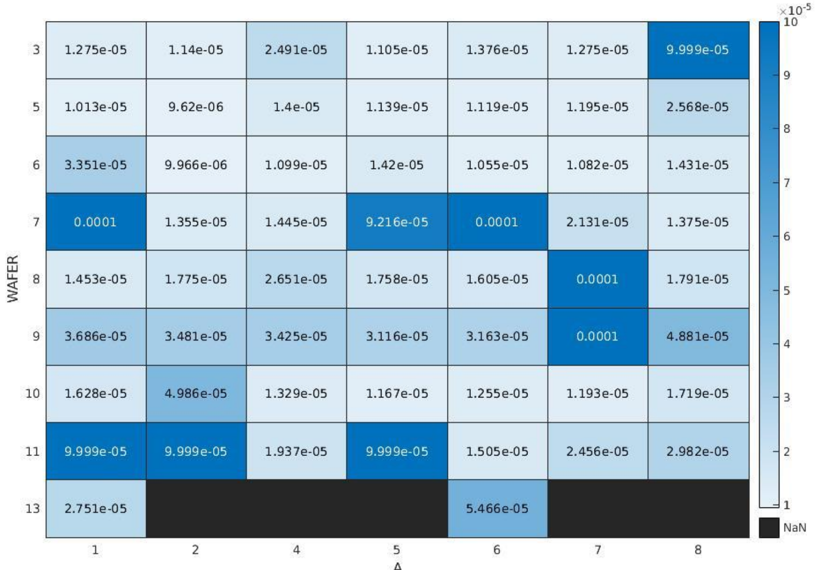
Probe card measurements

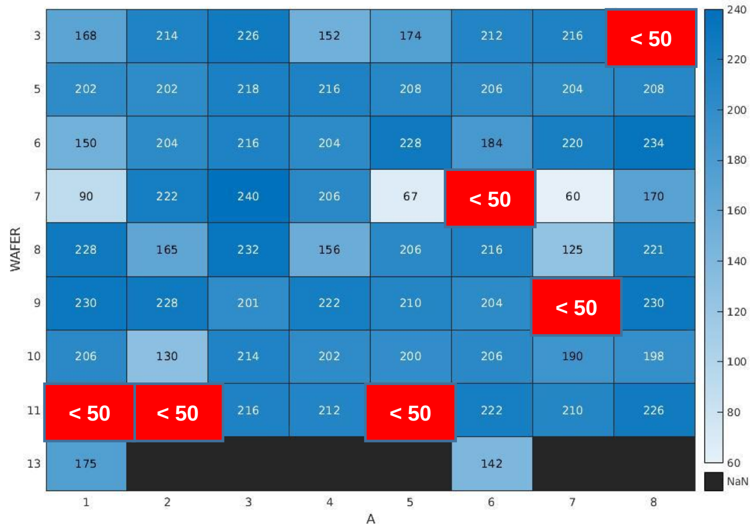


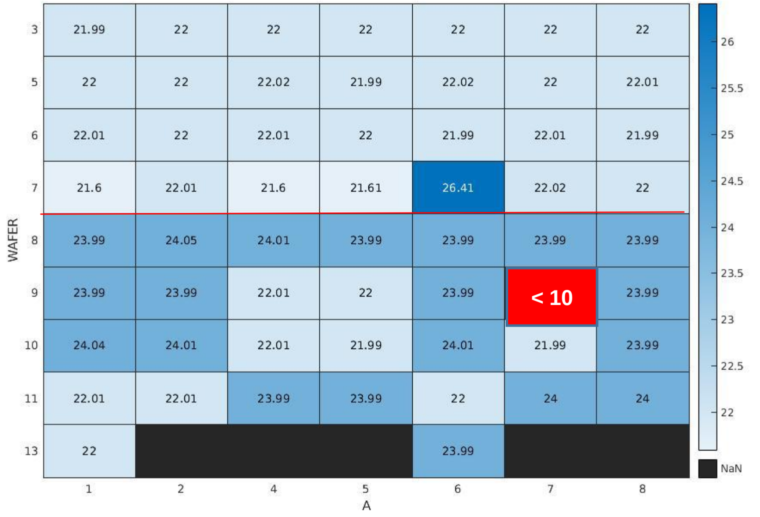




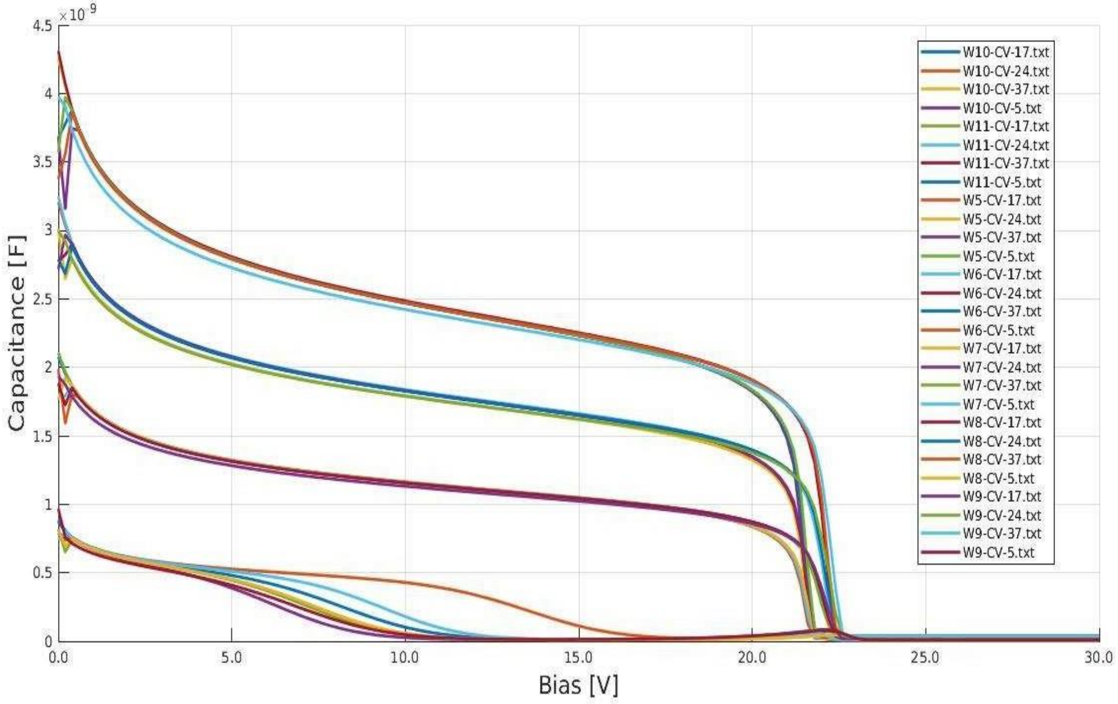
Elastomer measurements

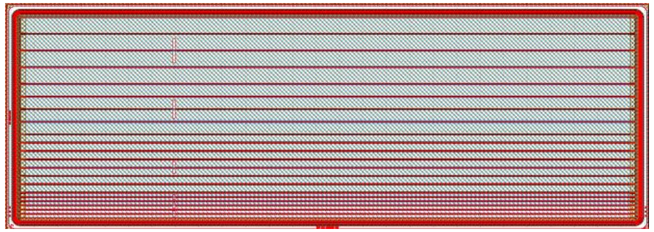




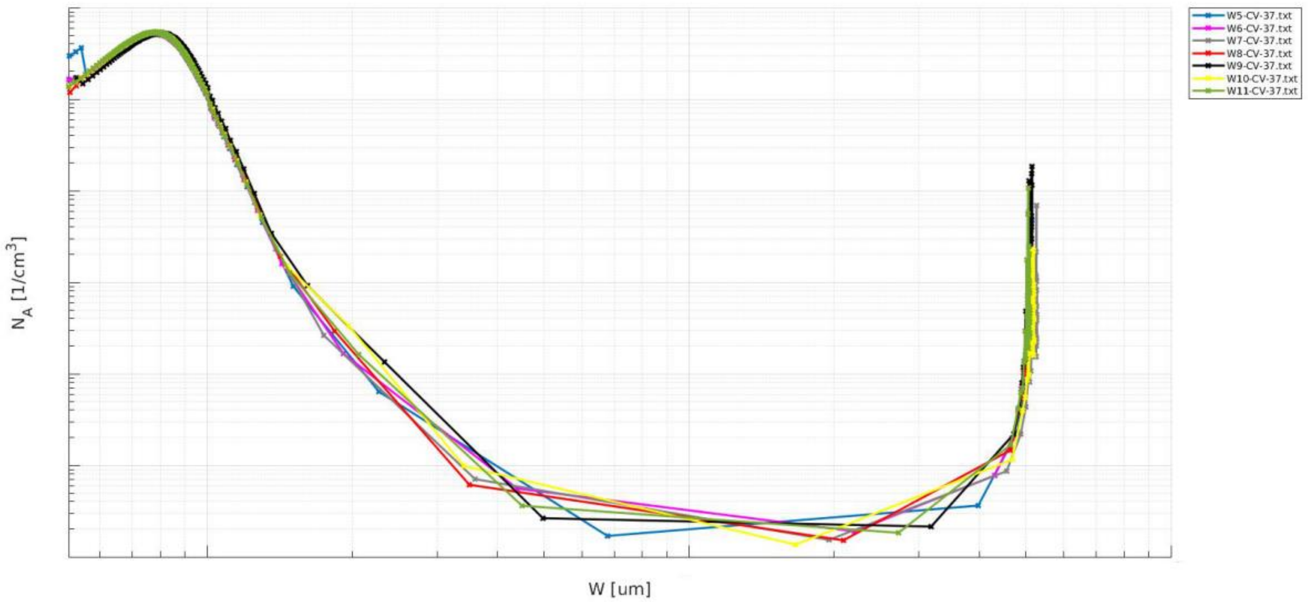


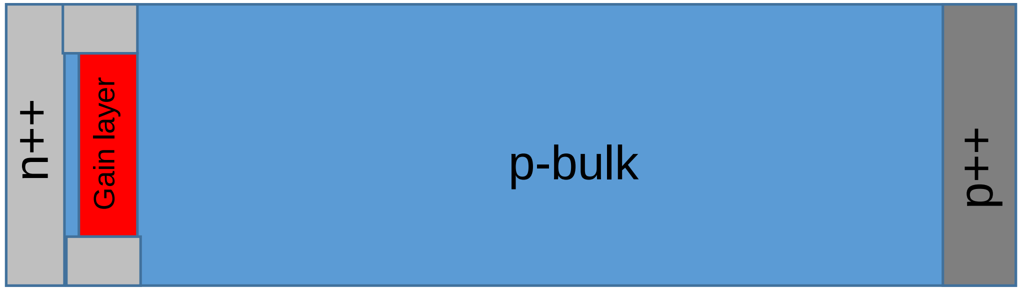
Capacitance vs. Bias Voltage





Doping Profile





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Summary

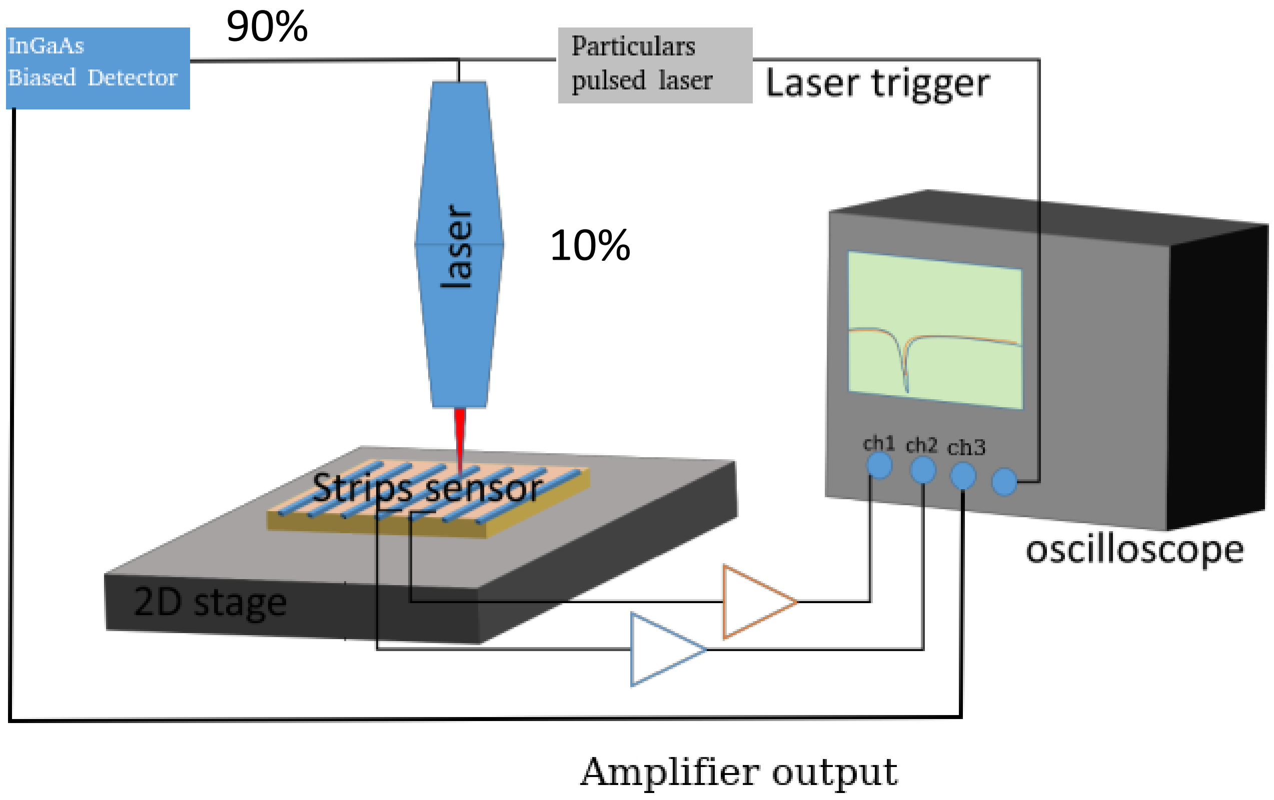
Elastomer

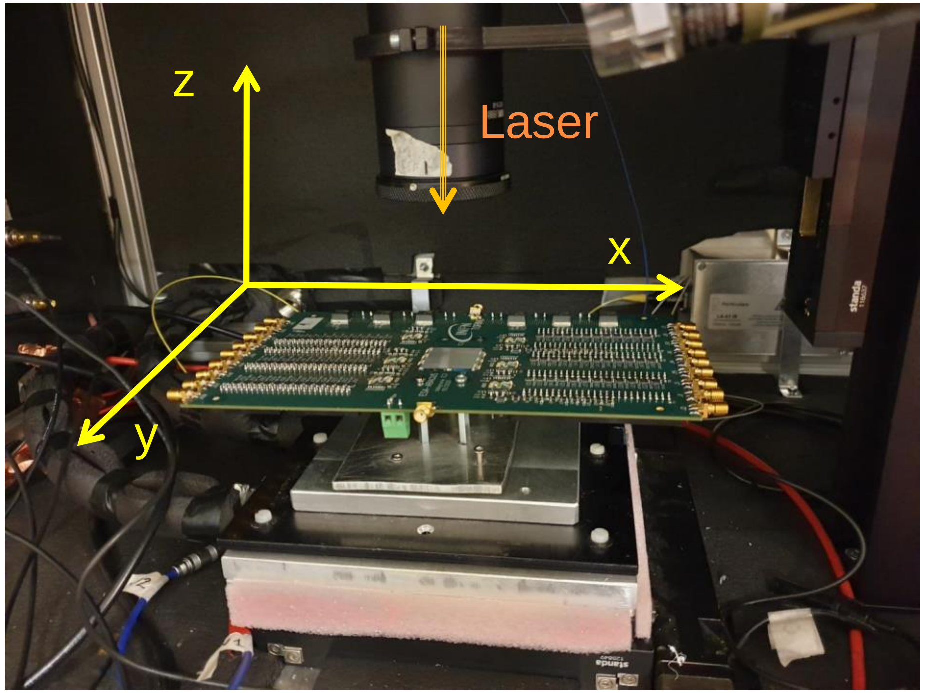
Bad sensors	Total sensors Tested	% Bad sensors
22	66	33.33

Probe Card

Sensor	Bad Strips (UNITO)	Bad Strips (FBK)
W1-A1	/	/
W1-A2	/	/
W1-A3	/	/
W1-A5	83	82,83
W1-A6	/	/
W1-A7	/	/
W1-A8	/	/
W3-A2	/	/
W3-A6	/	/
W5-A2	/	/
W5-A7	/	/
W6-A2	/	/
W6-A7	/	/
W13-A1	12,22,23	12,22,23
W14-A2	70	70
W14-A4	/	/
Yield	99.79	99.74
Yield (All production)	-	89.40

Experimental setup scheme

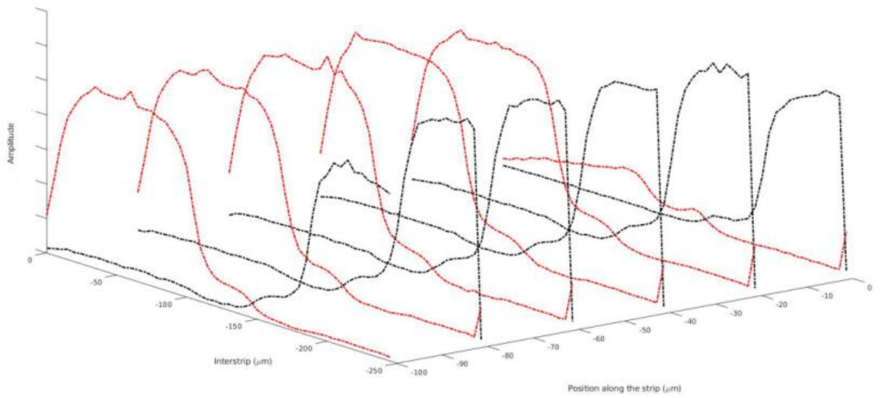


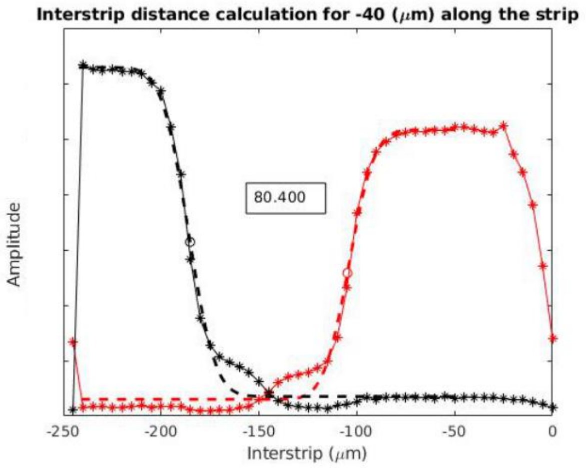


TCT measurements

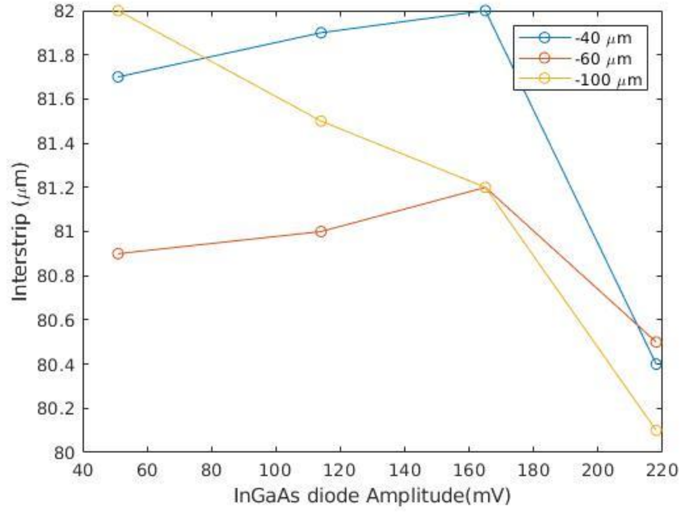
Interstrip measured for a fixed bias voltage

12th International Conference on POSITION SENSITIVE DETECTORS
Hosted by UNIVERSITY OF BIRMINGHAM

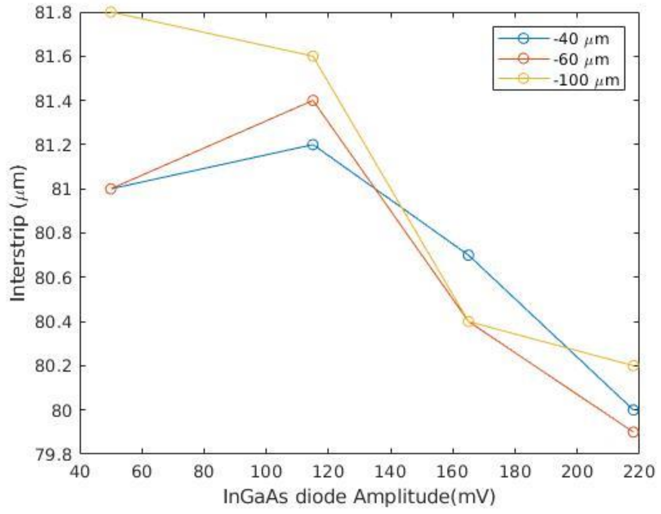




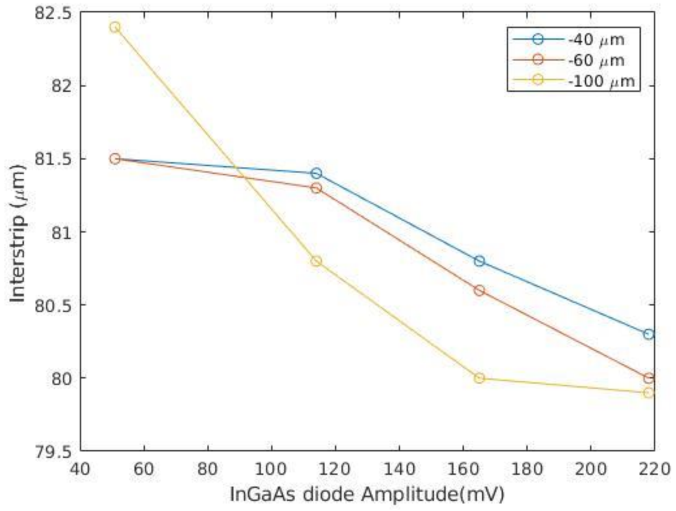
174.6 V



199.5 V



224.6



[1]Paternoster, G., et al. "Novel strategies for fine-segmented Low Gain Avalanche Diodes." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 987 (2021): 164840.

Conclusions

- A global yield ratio between working stips over the total number of strips measured in the entire production of 89.4% were found;

- The average full depletion voltage obtained was 22.12-23.47 V and 34.98 V for Si-Si and Epi wafer, respectively and a mean breakdown voltage for good sensors measured on the backplance of about 212 V were found;

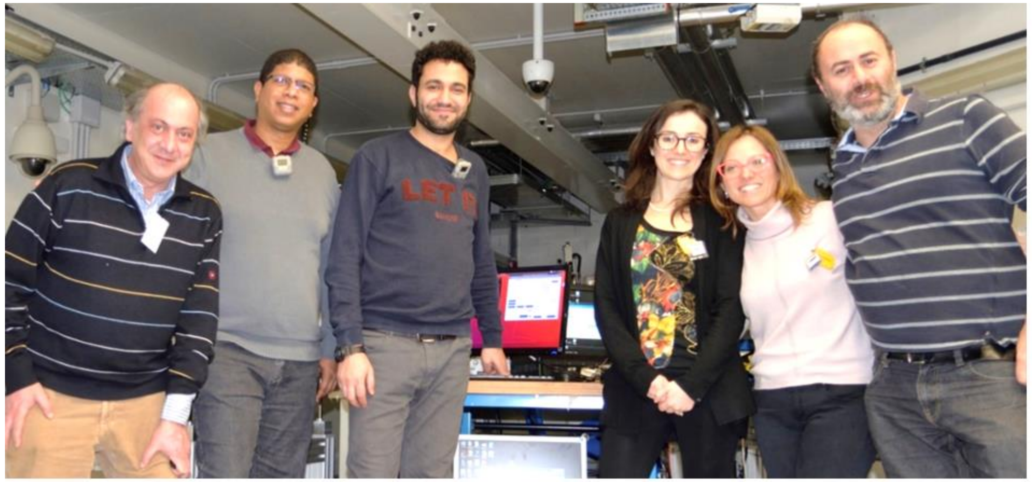
- From the selection of 16 sensors from differents wafers we found a consistently between the measurements taken at FBK and at the University of Torino, where the yields were 99.74% and 99.79% respectively;

- The inter-strip distance measured was 80.8 μm, 22 % larger than the nominal no-gain distance and has a small dependence on bias voltage or the signal amplitude;

- The laboratory characterization showed good results and prepared the groundwork for the selection of the best set of sensors to be tested on clinical proton beams.

Acknowledgments

This work was financed by the INFN CSN V (MoVe-IT project), Ministero della Ricerca, PRIN 2017, project "4DInsiDe" (MIUR PRIN 2017L2XKTJ) and by the European Union's Horizon 2020 Research and Innovation funding program (Grant Agreement no. 669529-ERC UFSD669529). In addition, it has been supported by MIUR Dipartimenti di Eccellenza (ex L.232/2016, art.1, cc. 314, 337). We kindly acknowledge the dedicated collaboration of FBK and the UFSD group in this research.



Thank you!