CMS HGCAL

Status at HEPHY

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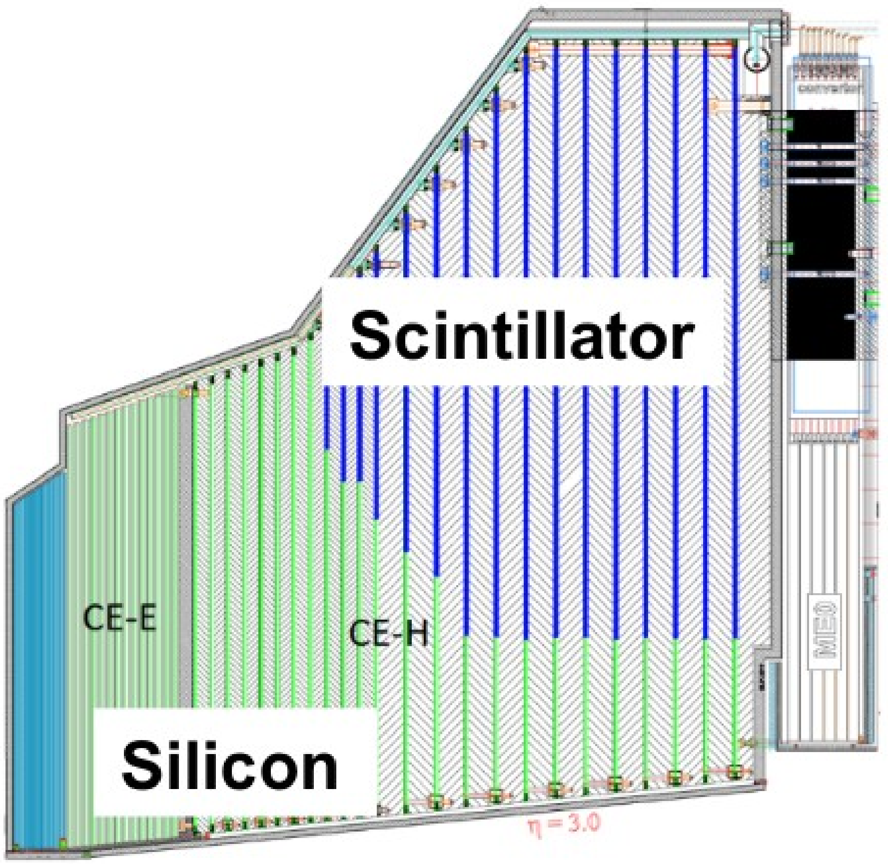
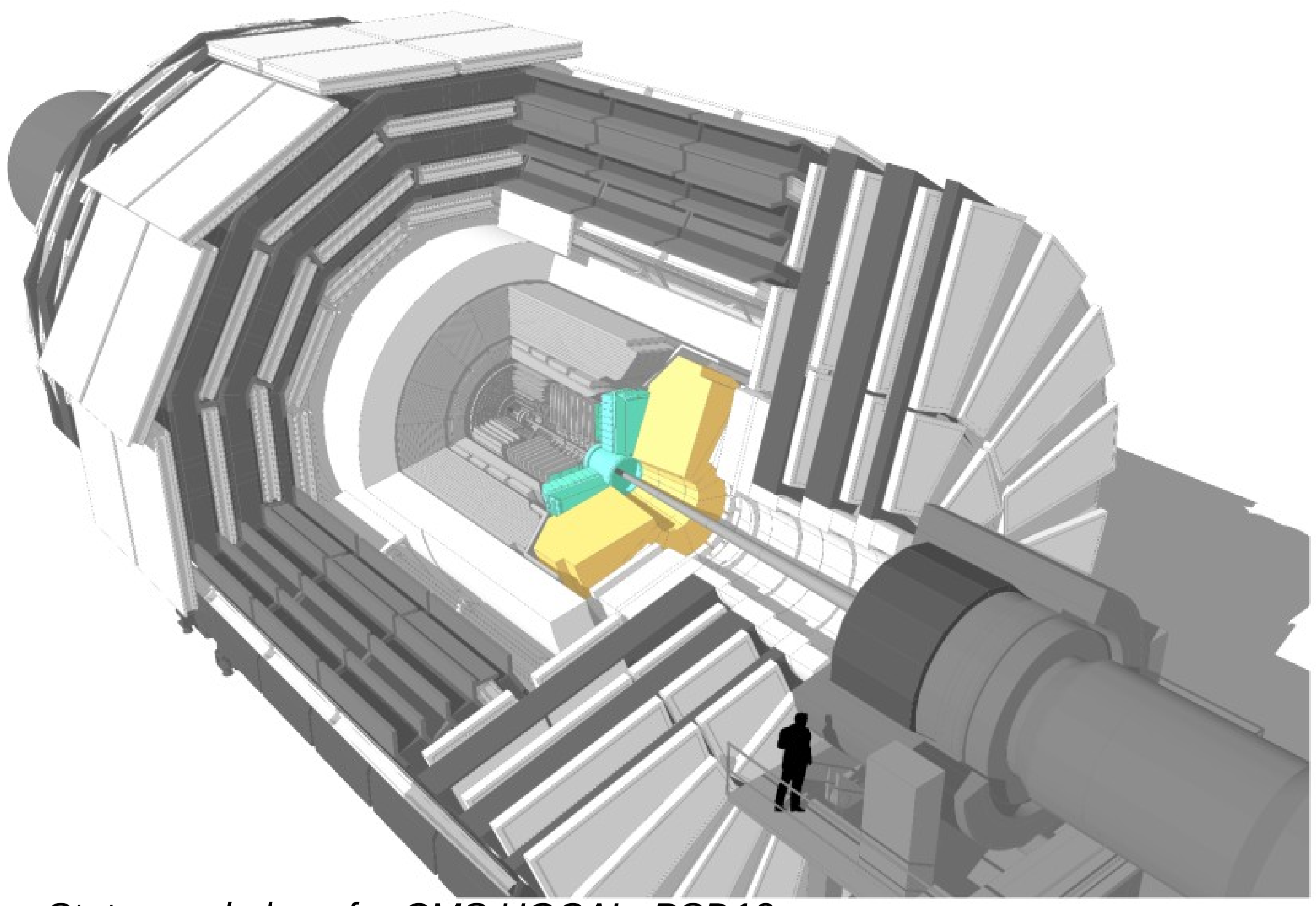
HEPHY
3.12.2021

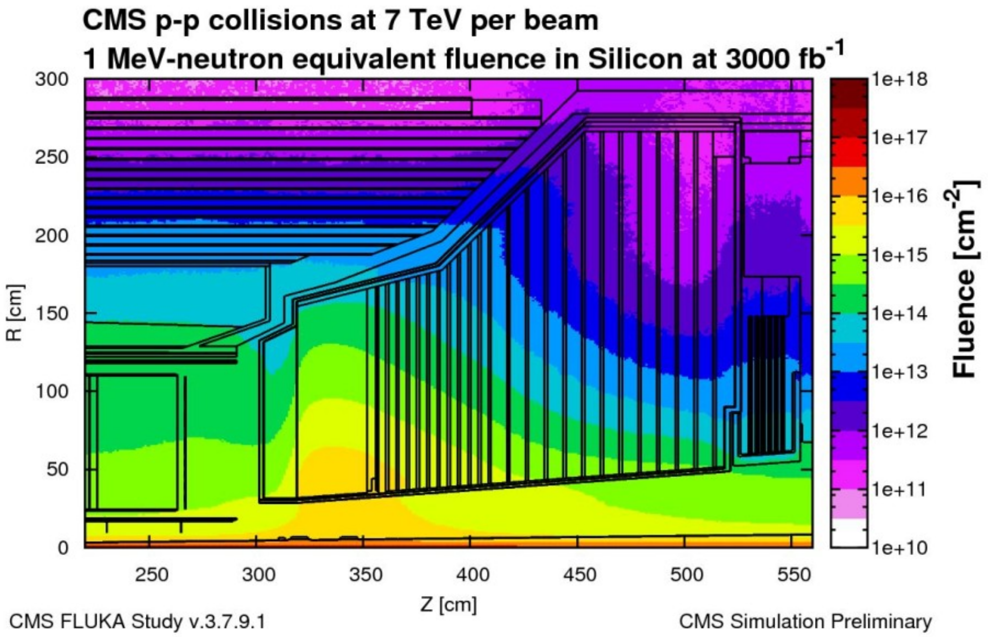
CMS High Granularity Calorimeter

Calorimeter endcaps:
- Coverage 1.5< | η | <3.0
- radiation tolerant
- high granularity
- precise hit/cluster timing
- Enhanced capability for particle flow reconstruction

- El.-mag. section CE-E: Si, Cu, CuW, Pb absorbers, 26 layers,
- Hadronic section CE-H: Si+scintillator+SiPM, steel absorbers, 21 layers

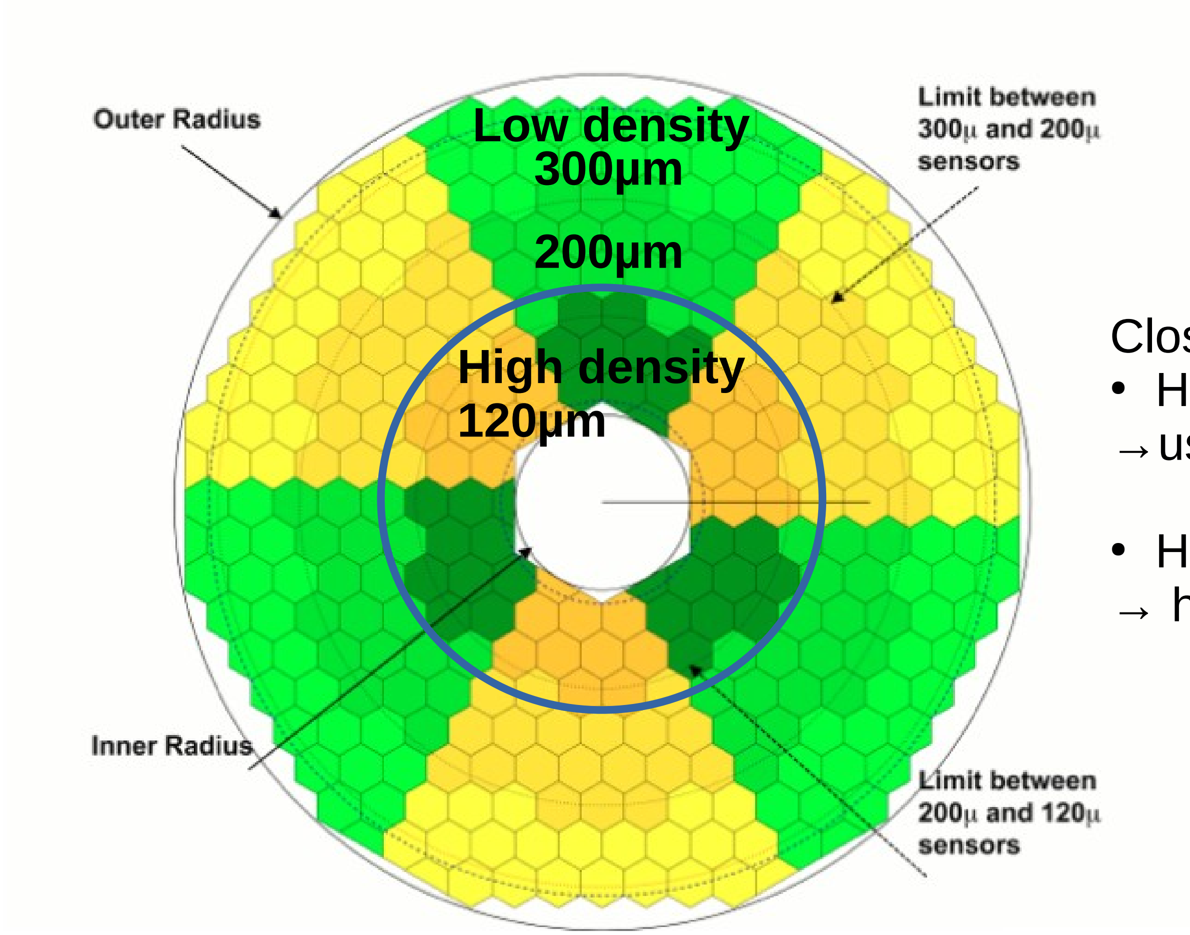






Eva Sicking: Status and plans for CMS HGCAL, PSD12
CMS HGCAL TDR

Silicon sensors for HGCAL



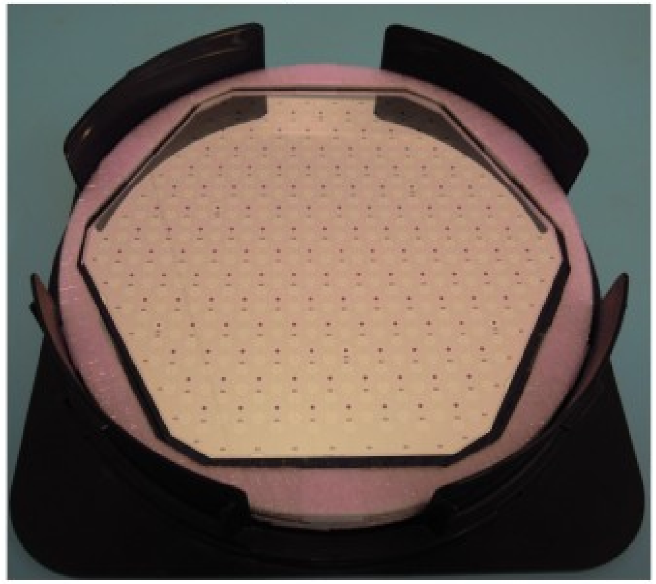
Close to the beam axis :
- Higher radiation fluence
→ use of thin detectors

- Higher track density
→ higher density of sensor pads

8-inch Low-Density sensor

∼ 200 cells of 1.1 cm^2 size

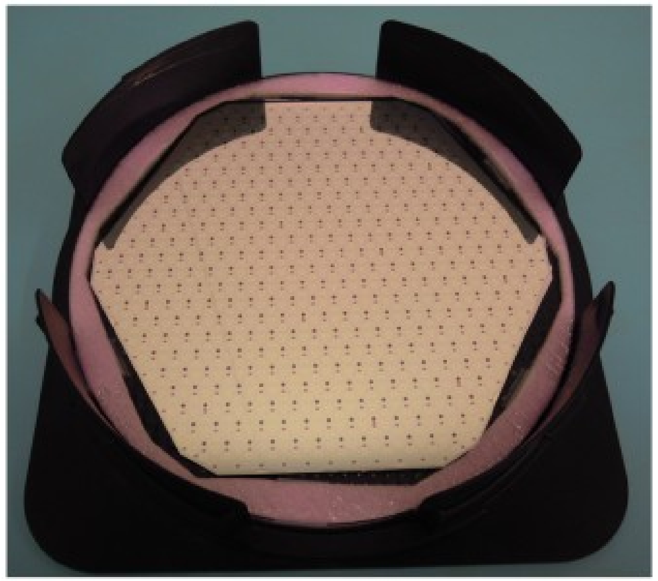
300 µm & 200 µm active thickness

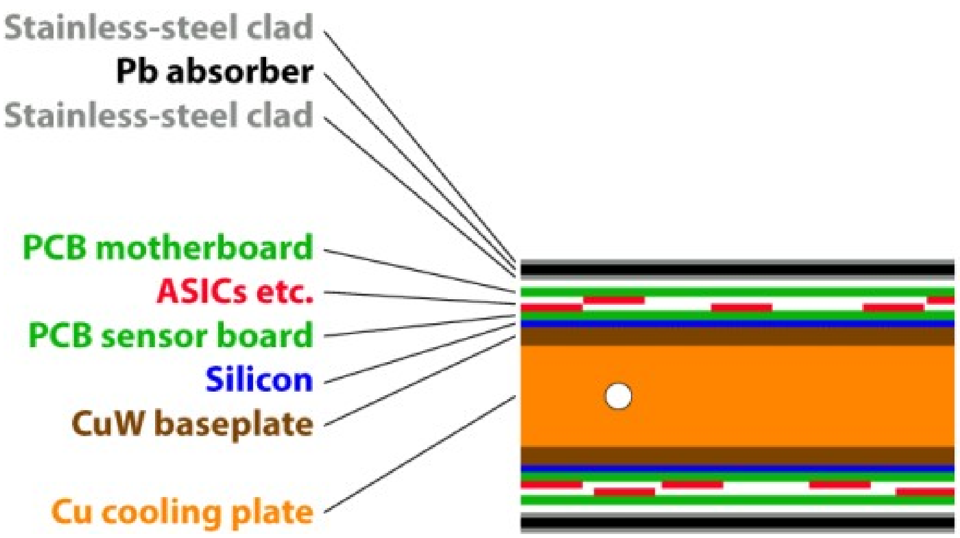


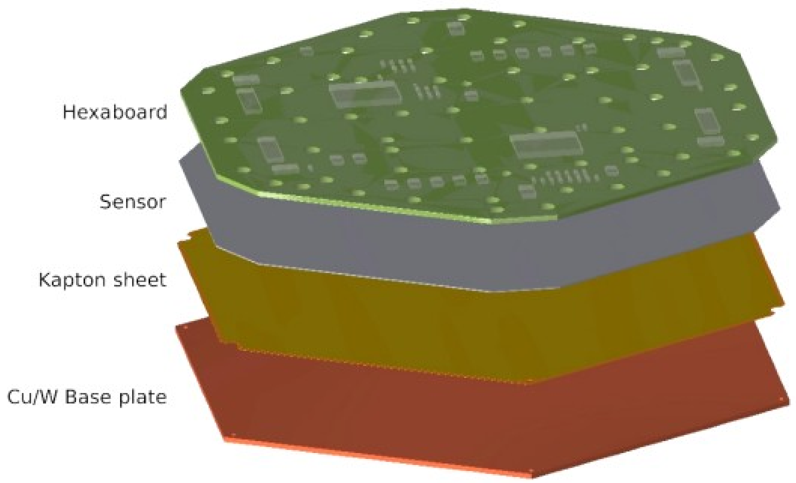
8-inch High-Density sensor

∼ 450 cells of 0.5 cm^2 size

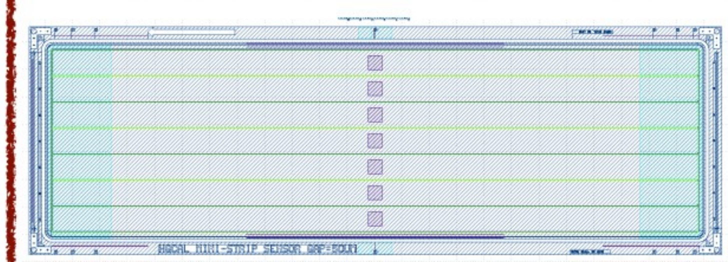
120 µm active thickness







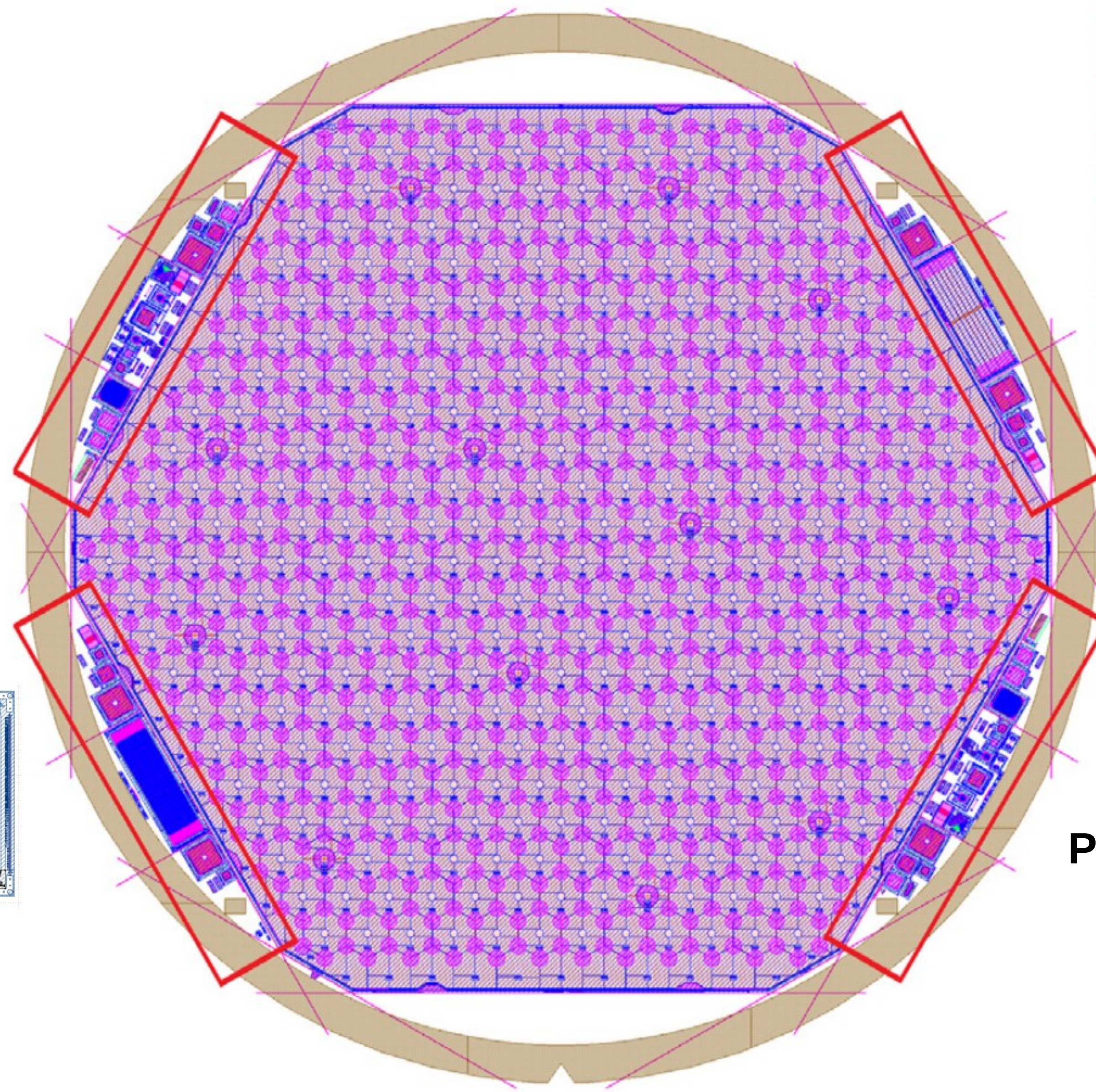
Test structures on HGC wafer



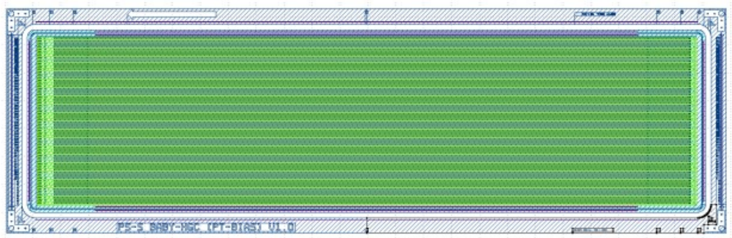
HGC-like Ministrip Sensor

- 7 DC coupled strip
- Direct bias
- 0.95 mm pitch
- 23.541 mm length
- Resembles HGC sensor

PQC Upper Left (UL)



PQC Lower Right (LR)

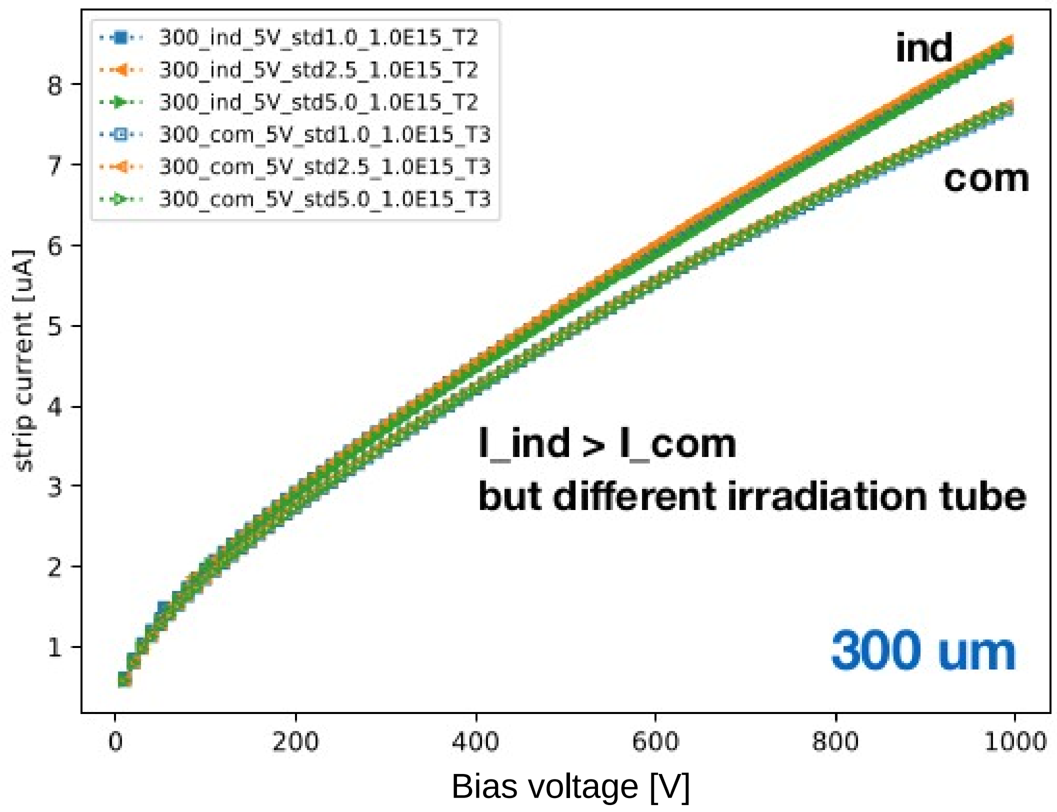


Tracker-like Microstrip Sensor

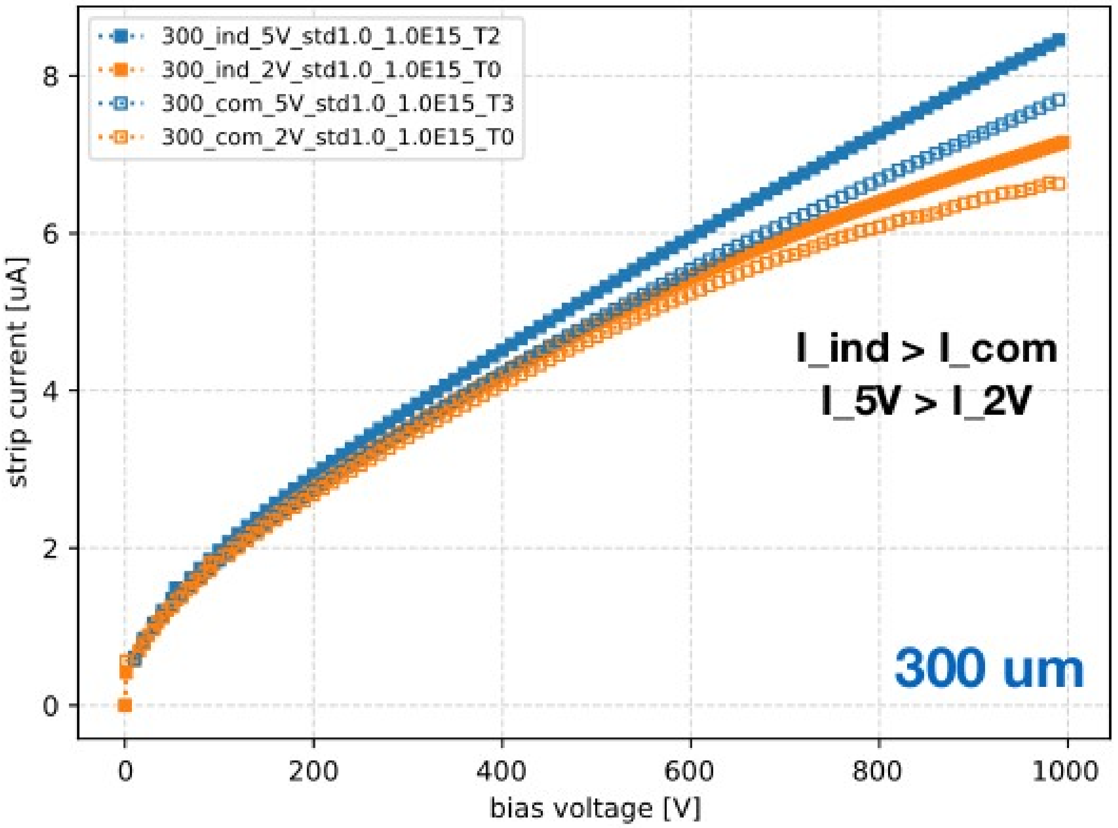
- 60 AC coupled strips
- Punch through bias
- 0.1 mm pitch
- 23.526 mm length
- Resembles tracker sensor (though no poly silicon bias)

Electrical characterization of irradiated sensors

Variation of the p-stop layout



Variation of the flatband voltage (oxide quality)



A large parameter space has been investigated:
- Variations in p-stop dose, p-stop geometry, flatband voltage (+ thickness)
- Fluences: 6.5E14, 1E15, 1.5E15, 2.5E15, 1.0E16

This study is now being repeated with new Proto-A sensors for different oxide variants. Measurements ongoing..

Florian Pitters

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Proto-A Samples

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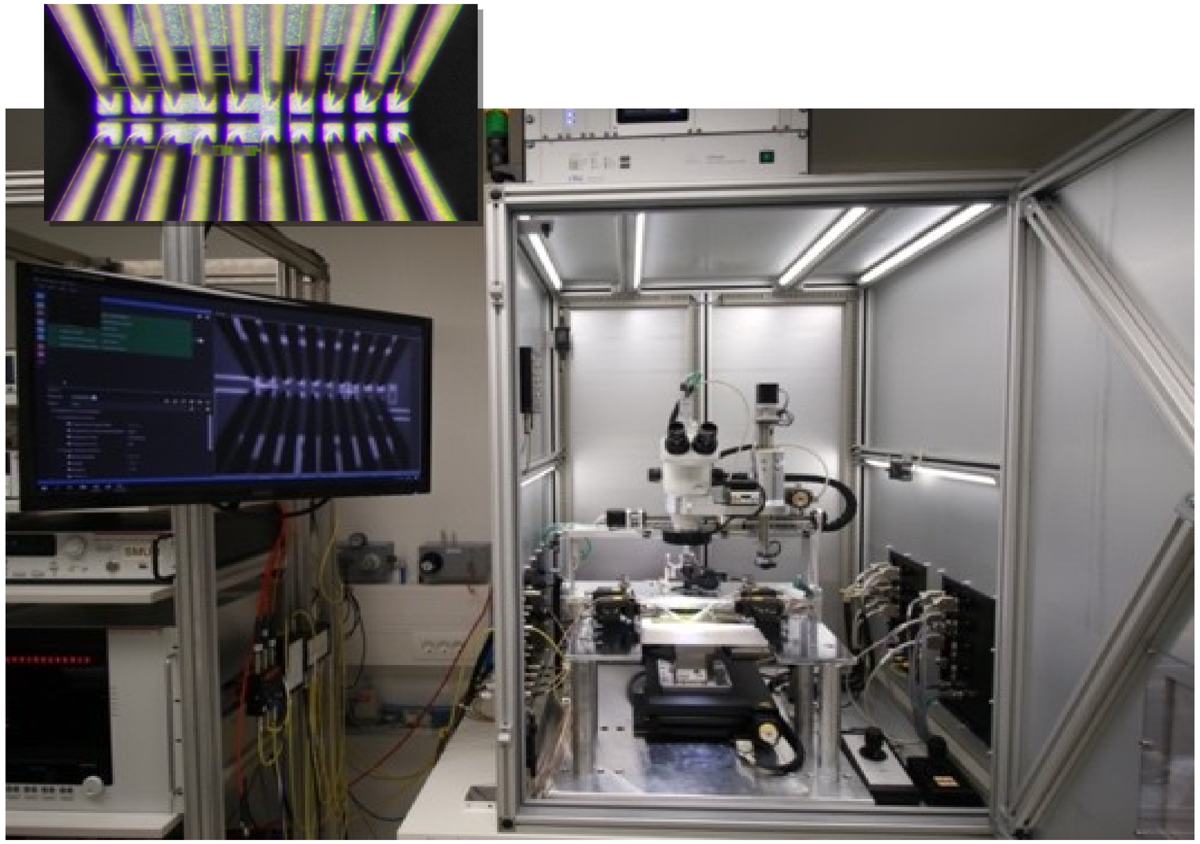
Sensor ID	Scratch pad ID	Thick-ness	P-Stop	Oxide type	Flat band volt. (V)	P-Stop conc.	Proc.
N4788_2	300001	120	com	B	-2	STD	epi
N4788_3	300002	120	com	B	-2	STD	epi
N4788_4	300003	120	com	B	-2	STD	epi
N4788_5	300004	120	com	B	-2	STD	epi
N4788_6	300005	120	com	B	-2	STD	epi
N4788_7	300006	120	com	B	-2	STD	epi
N4788_8	300007	120	com	B	-2	STD	epi
N4789_10	300032	120	com	C	-2	STD	epi
N4789_12	300034	120	com	C	-2	STD	epi
N4789_13	300035	120	com	C	-2	STD	epi
N4789_14	300036	120	com	C	-2	STD	epi
N4789_15	300037	120	com	C	-2	STD	epi
N4789_19	300041	120	ind	C	-2	STD	epi
N4789_20	300042	120	ind	C	-2	STD	epi
N4789_21	300043	120	ind	C	-2	STD	epi
N4789_24	300046	120	ind	C	-2	STD	epi
N4789_25	300047	120	ind	C	-2	STD	epi
N4788_9	300008	120	com	D	-2	STD	epi
N4788_10	300009	120	com	D	-2	STD	epi
N4788_11	300010	120	com	D	-2	STD	epi
N4788_12	300011	120	com	D	-2	STD	epi
N4788_13	300012	120	com	D	-2	STD	epi
N4788_14	300013	120	com	D	-2	STD	epi
N4788_15	300014	120	com	D	-2	STD	epi
N4788_16	300015	120	com	D	-2	STD	epi

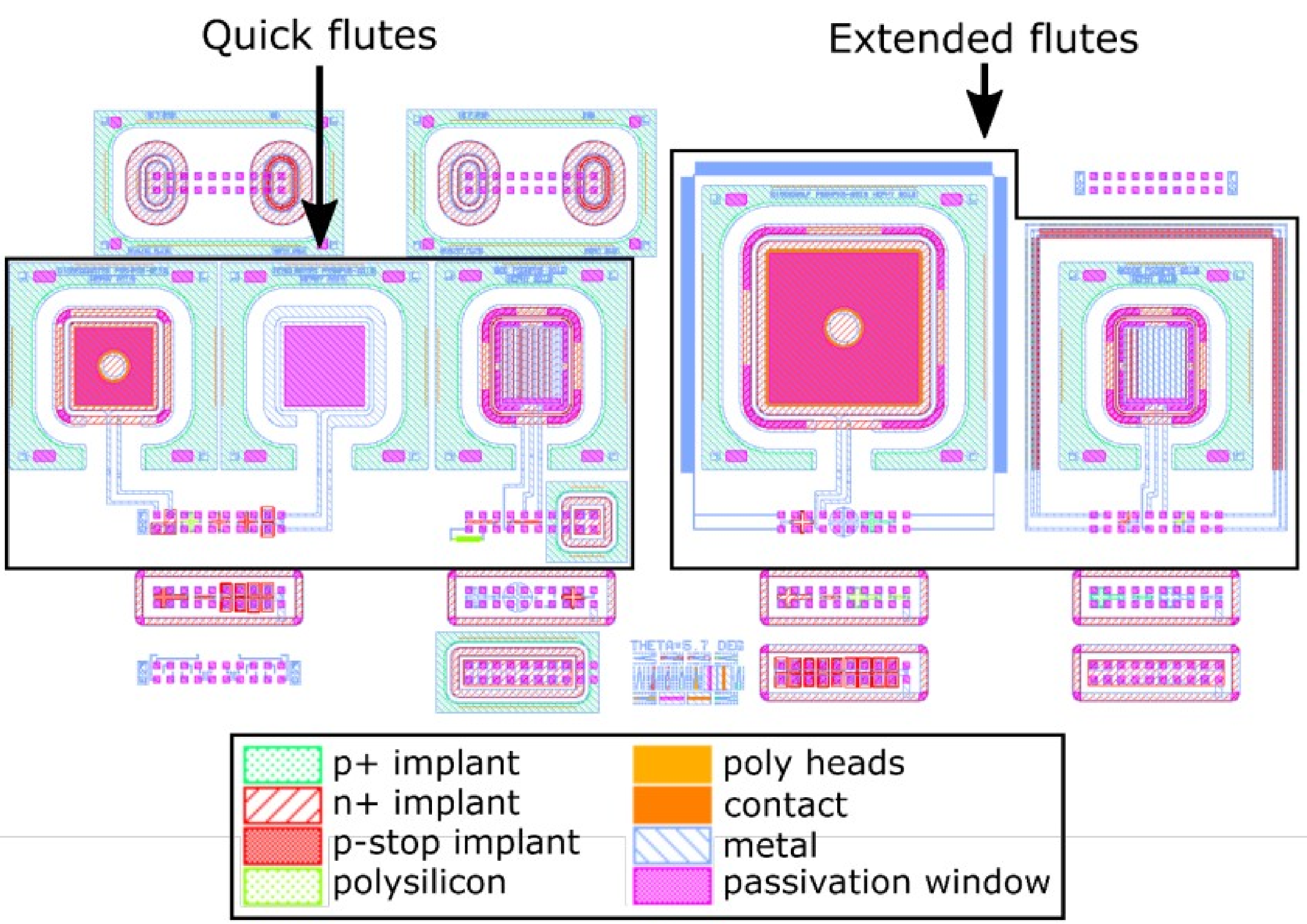
- 50 PQC structures from 25 wafers
- Unirradiated, measured at room temperature

- All wafers:
  120µm epi,
  standard p-stop concentration,
  -2V flatband voltage

- Oxide types B, C, D
- P-stop layout: com, ind (only type C)



PQC measurements



PQC measurements for development:
- Establish differences between production processes
- Evaluate impact of design parameters on sensor performance
- Correlate PQC measurements with sensor tests after irradiation

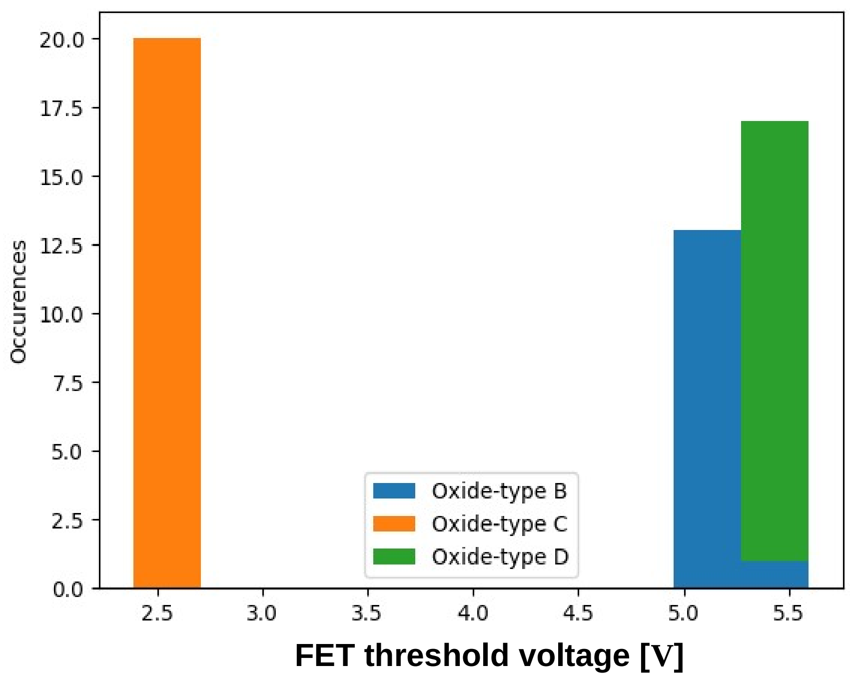
PQC measurements during production:
- Continuously monitor design parameters to identify irregularities / changes in the production process
- Prevent bad sensors from being used for the experiment

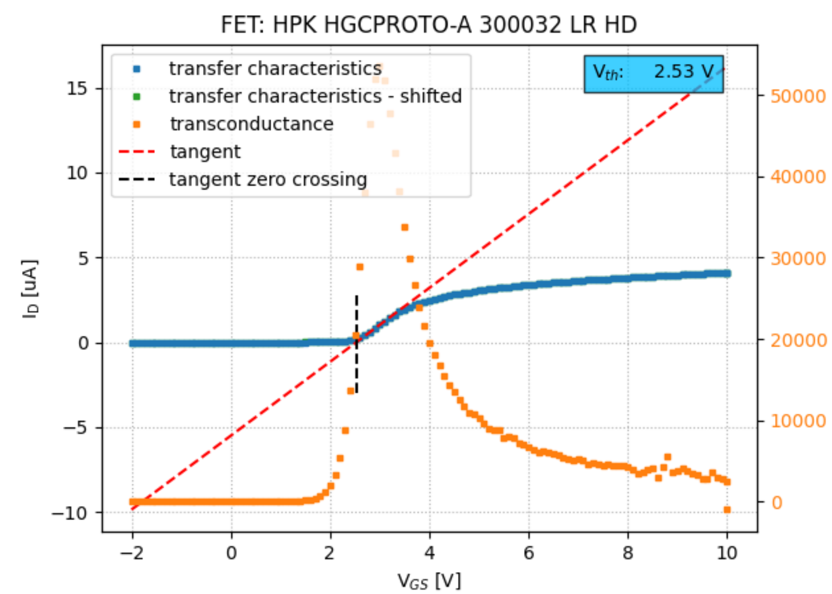
Different structures to asses design parameters
- Diode: Current and Capacitance characteristics, Full-depletion voltage
- Gate-Controlled-Diode (GCD): Surface current, surface generation velocity, Si-SiO2 interface quality, interface traps
- Field-Effect-Transistor (FET): Threshold voltage is sensitive to p-stop doping and interstrip resistance
- Metal-Oxide-Semiconductor (MOS) Capacitor: Oxide thickness and quality (amount of fixed oxide charges)
- Van-der-Pauw structures: Sheet resistance of various materials / implants

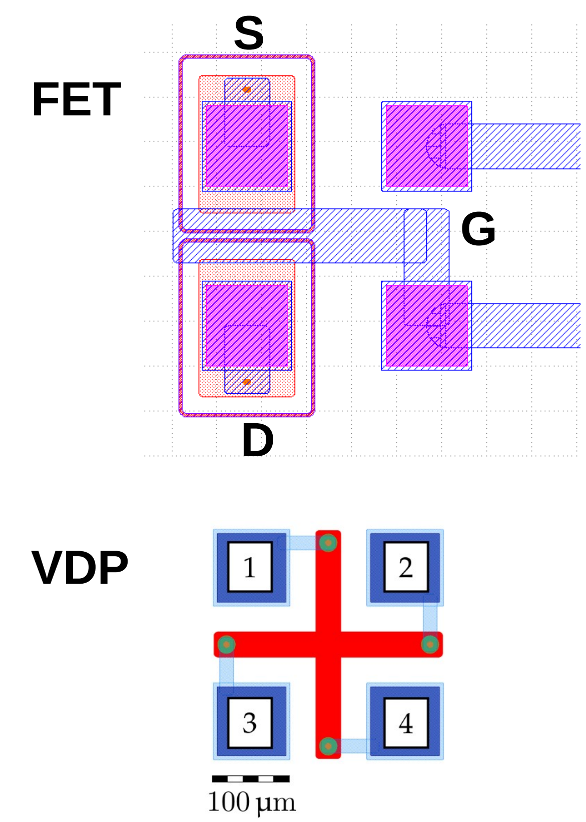
Florian Pitters

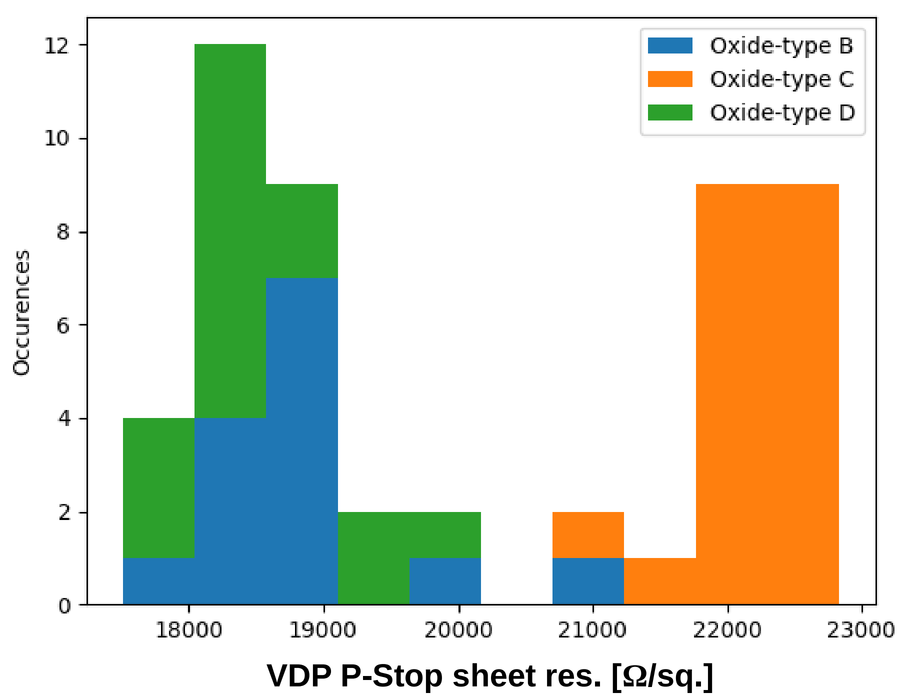
P-stop resistivity + FET

- FET threshold voltage is sensitive to the p-stop and interpad resistance
- Type B/D are more similar to tracker FET V_{th} and p-stop res.

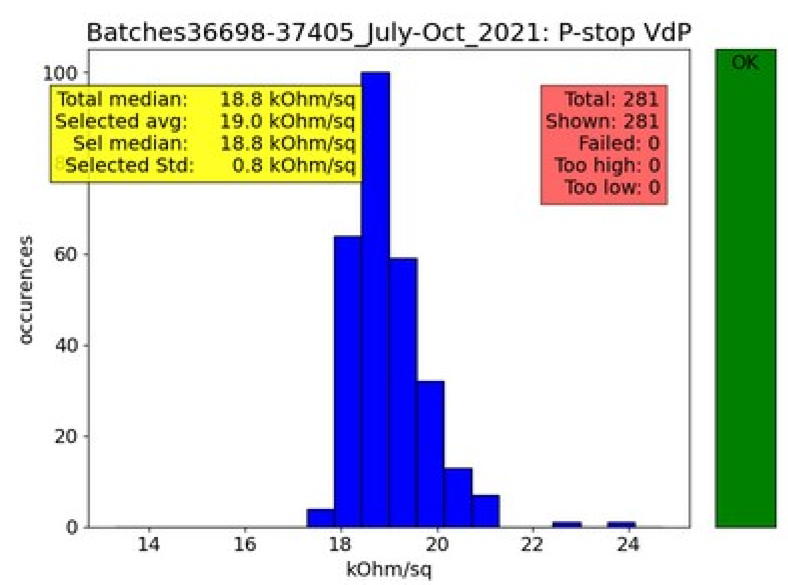


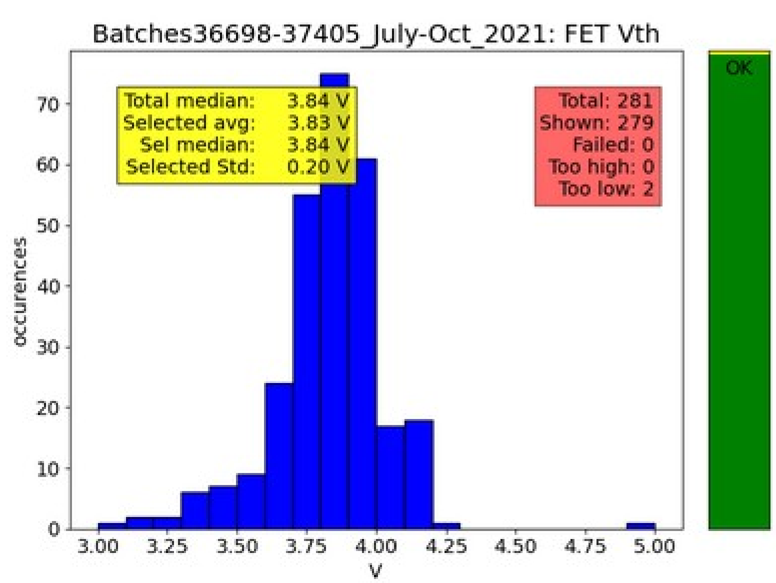






Tracker PQC:



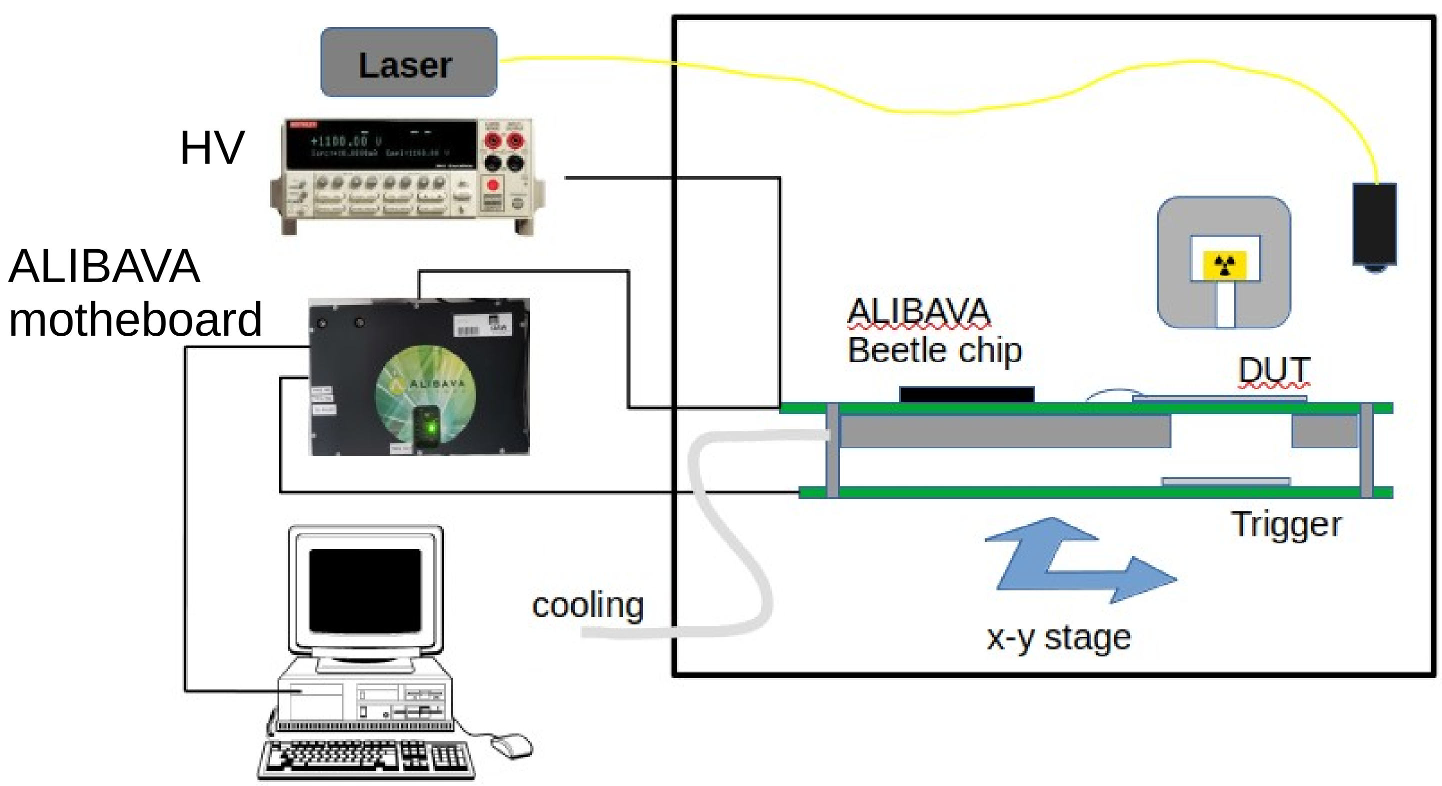


ALIBAVA measurements

ALIBAVA is a read-out system for microstrip sensors

- The Beetle chip is an analogue readout chip used in the LHCb experiment
- Read-out based on LHC 25ns clock
- up to 256 channels
- Can be used with a radioactive source or a laser to generate signals

- Possibility to study noise / charge collection of unirradiated and irradiated sensors
- Complementary to electrical characterization

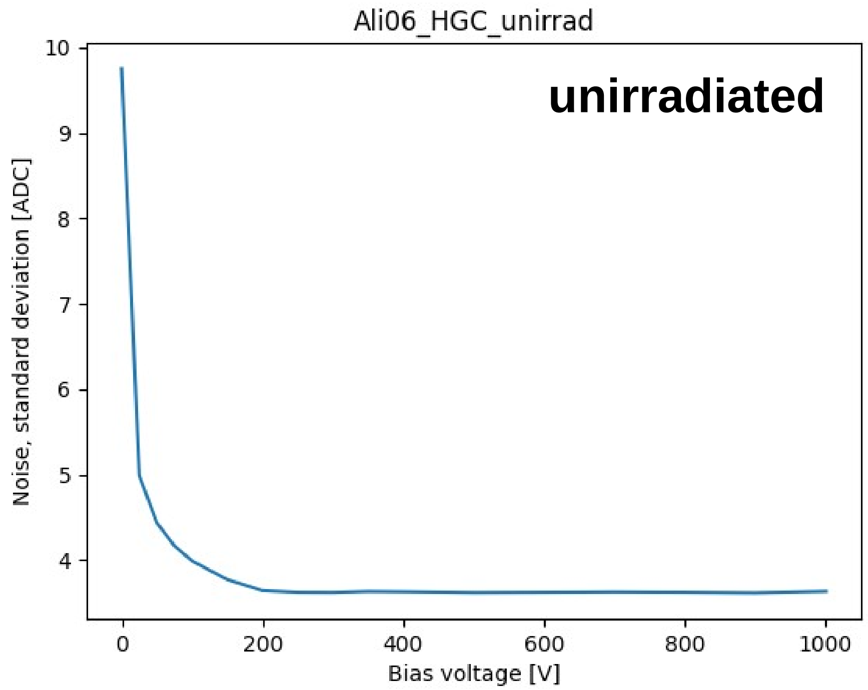


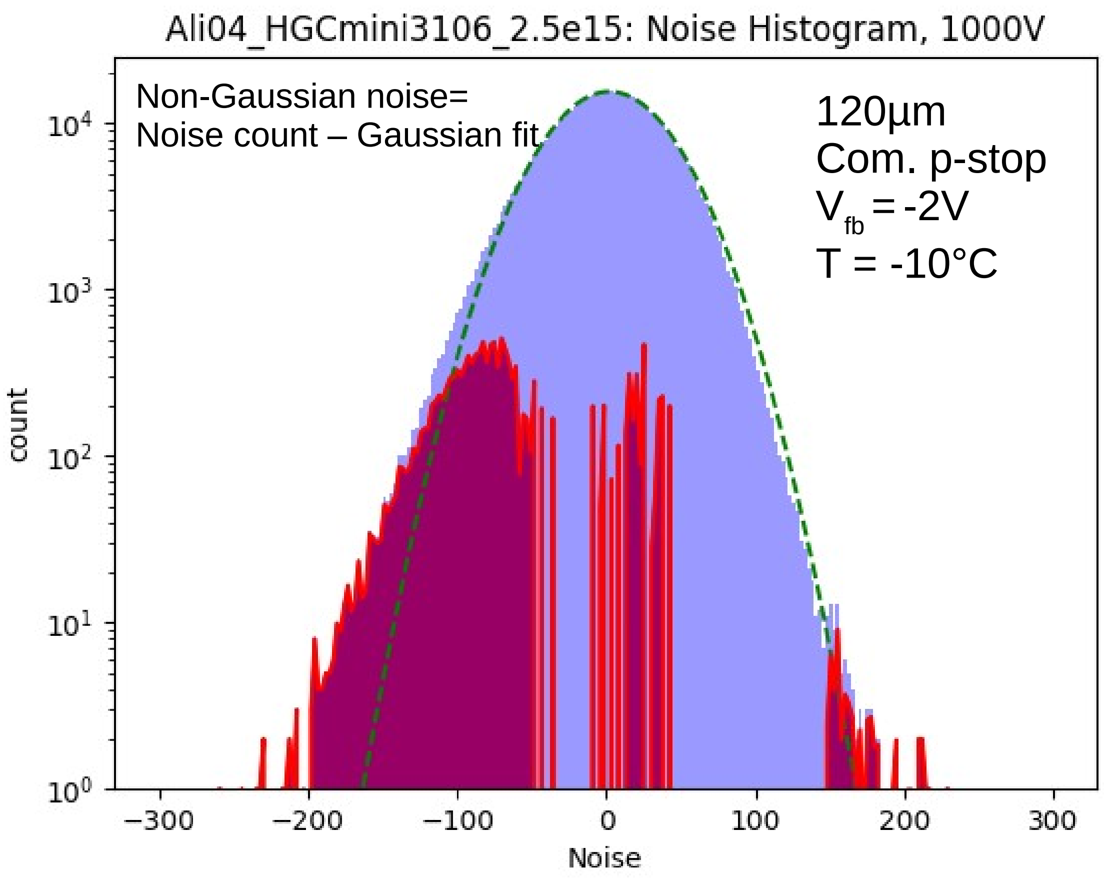
Excess noise in HGC mini sensors

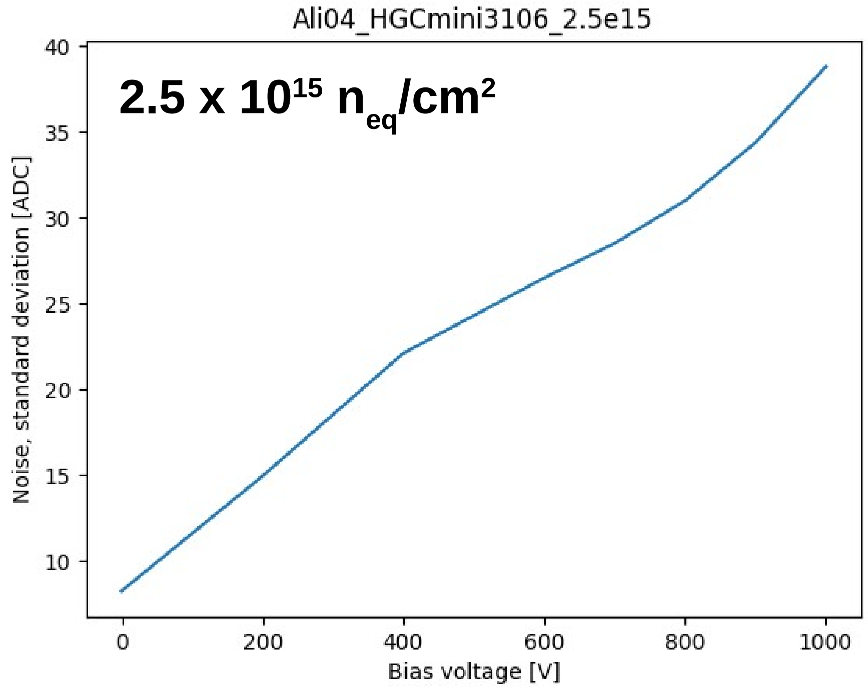
Non-Gaussian noise contribution observed in HGC-mini sensors after irradiation

Study ongoing..

- Also visible in tracker sensors?
- Related to sensor design parameters?
- Is the performance / signal-noise discrimination affected?





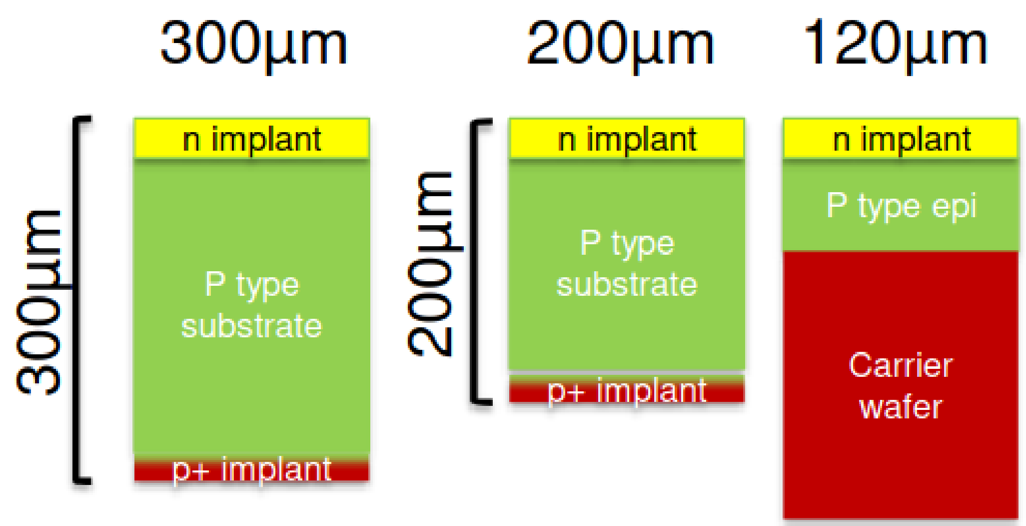


Backside protection

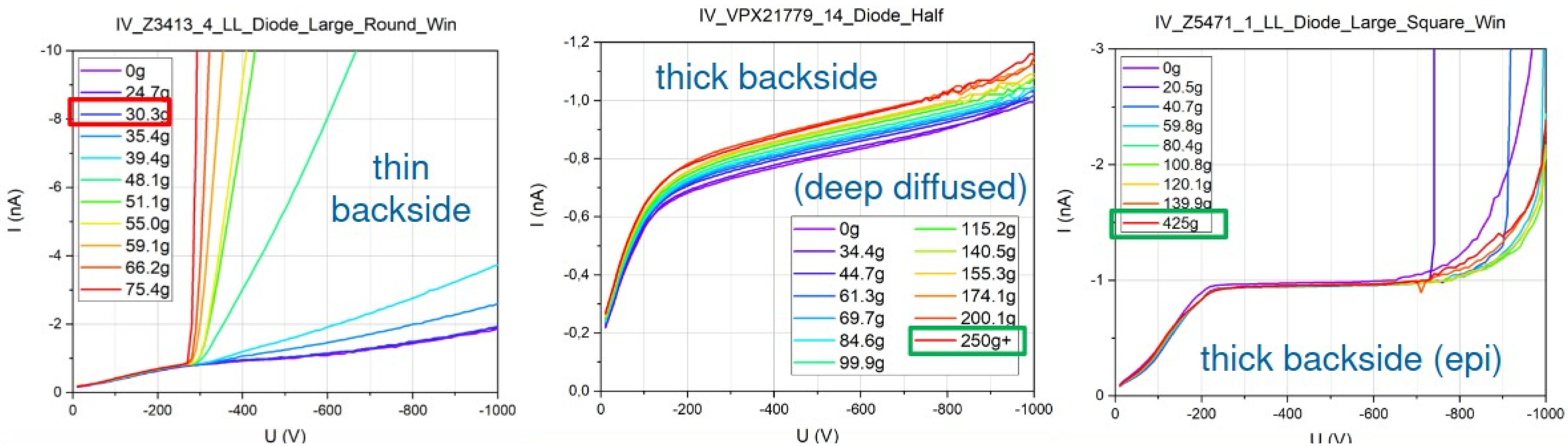
Production process of 8” sensors for HGCal is substantially different to 6” tracker sensors

– **300µm and 200µm float-zone (FZ) sensors:**
  - – Front side processed on thick wafers (presumably >600µm)
  - – Back side grinded and polished down
  - **– Backside implant ~0.7 µm**
  - – Backside metallization

– 120µm sensors no issues due to thick carrier wafer



Scratch test 2019



Thomas Bergauer, HGC sensor Pre-series readiness review

HGC scratch study 2021

Setup:

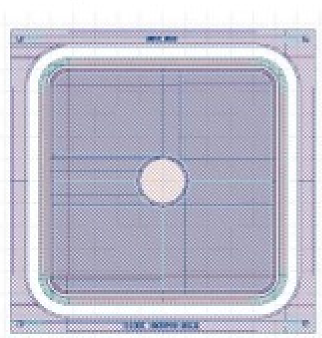
Scale with aligned top plate

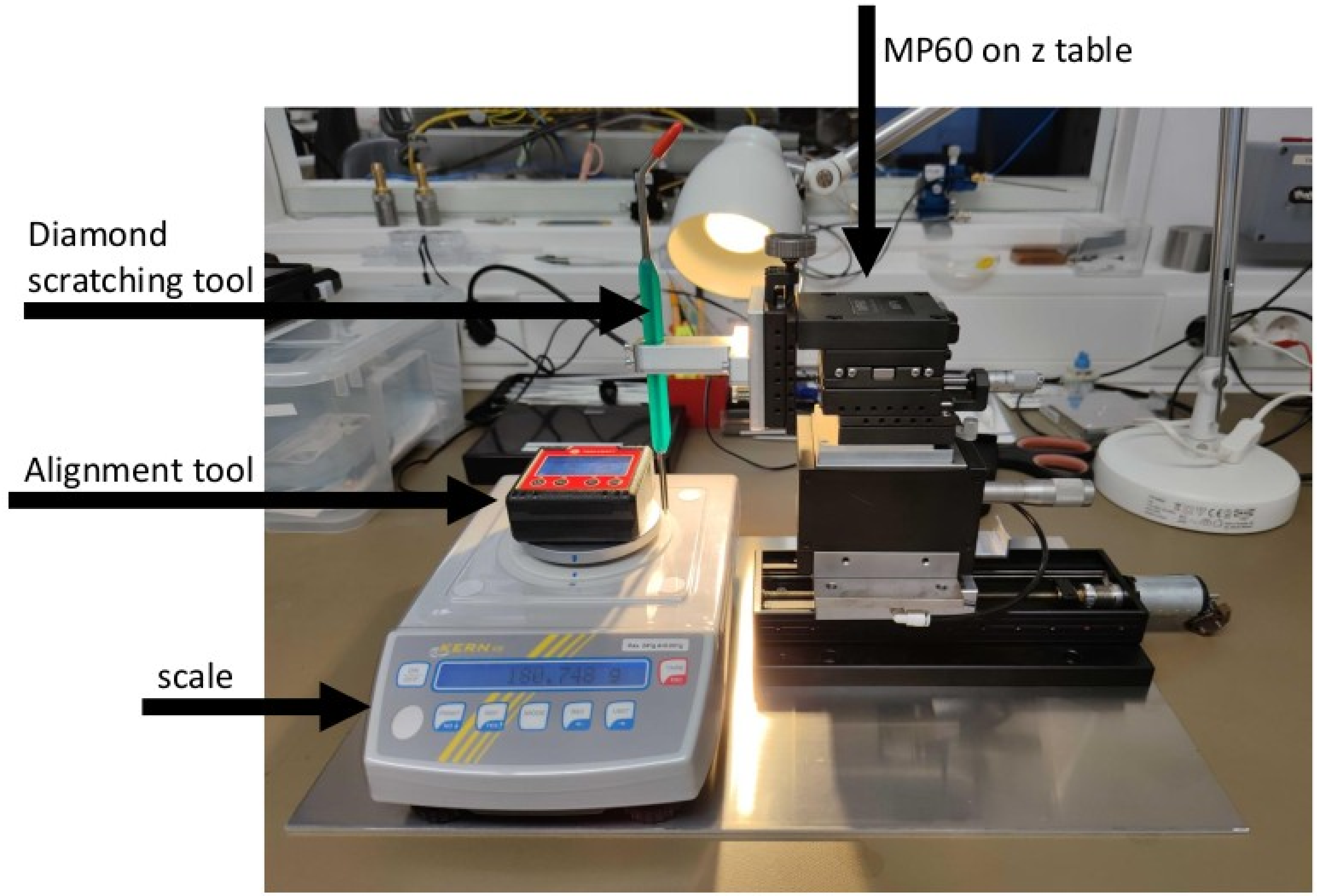
Linear table, Z table and MP60 Positioner with special holder for diamond scratching tool

Teststructure is placed on plate using Kapton tape as stopper

Scratching tool is placed with < 1g accuracy

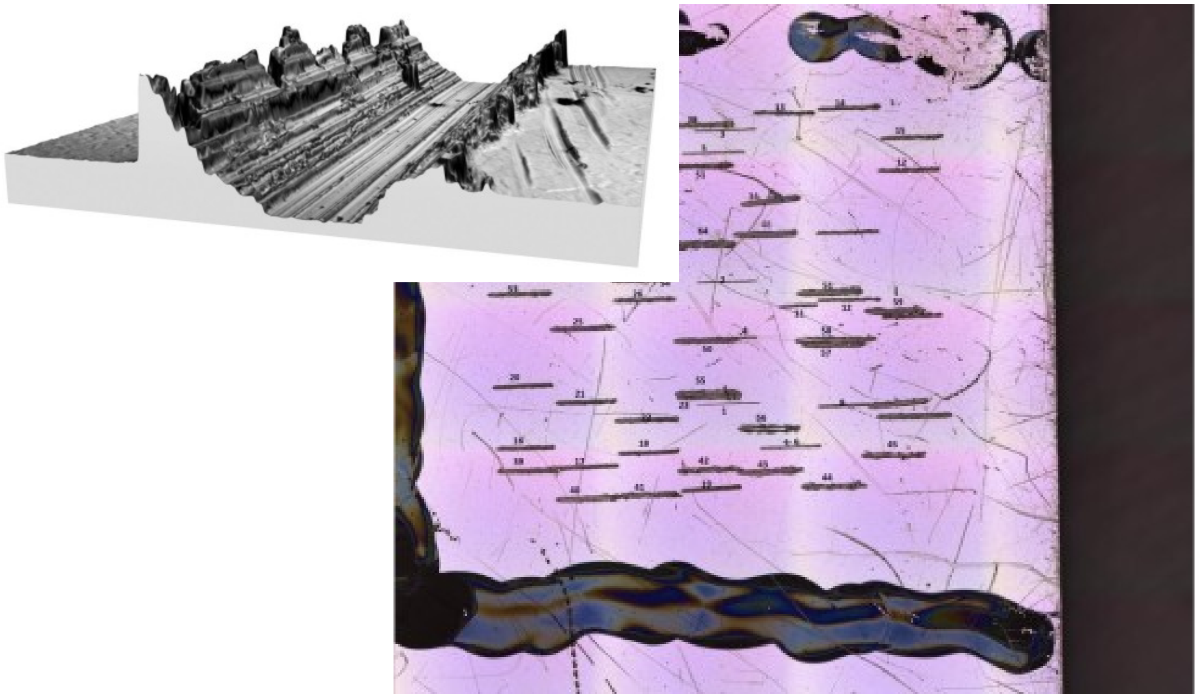
No spring like behaviour of setup with oscillating weight measurements -> large improvement

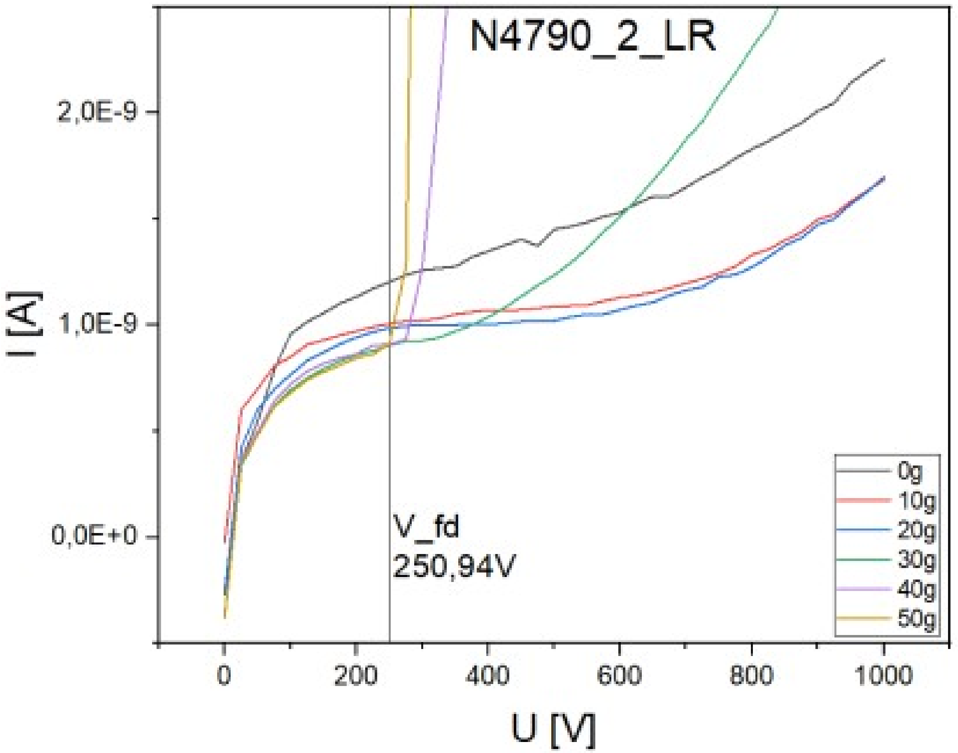




Stefan Schultschik

HGC scratch study 2021





Current measurements are carried out after repeatedly scratching the sensor backside with varying force.

Depending on the force applied an early breakdown can be observed at the full depletion voltage.

Shown is the worst case sensor, three more were tested with much higher force (~ 230 to 250g) required to cause early breakdown.

Maximum depth of scratches is about 2.5µm at 250g.

First measurements indicate improved backside hardness compared to V0 (2019) prototypes.

Possible solutions:

- Delivery / testing on dicing foil: backside protected, increased risk of damage during removal
- Delivery in coin stack, test on soft material as chuck cover (lint free paper, Delrin, Teflon)

Outlook

1. ☑ R&D – Stepper layout
   - 25 LD (delivered in 2018)
     - First full 8-inch wafers, testing
2. ☐ Prototypes – Full lithography
   - ☑ Version 0: 42 LD (delivered in 2019)
     - Design, simulation, testing, and first full-wafer irradiation
   - ☑ Version 1: 56 LD, 32 HD (delivered in 2020)
     - Updated design for front side biasing (backside damage mitigation)
     - Many process splits imposed by HPK, identify best production process (flat band voltage, oxide quality, p-stop concentration, material, p-stop layout)
     - Full radiation hardness study (neutron, X-ray)
   - ☐ Version 2: 72 LD, 44 HD (expected at CERN in Sept. 2021) (V2 Prototype Series: common p-stop baseline design, includes 3 oxide process variants)
     - Sensor design updates for improved HV stability
     - Best candidates for production process parameters from Version 1 prototypes
   - ☐ Multi-geometry wafers for partial sensors: (expected at CERN in fall 2021)
3. ☐ Pre-series (Delivery in Q2, 2022, common p-stop design, single oxide process (“type c”) variant)
4. ☐ Pre-production (Start Mid-2022)
5. ☐ Production

Eva Sicking, P2UG review, May 2021

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Summary

HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

- For the High Luminosity upgrade of the LHC a High Granularity Calorimeter is under development
- Sensors are produced by Hamamatsu on 8” wafers, posing new challenges to development, handling and testing
- HEPHY is playing a leading role in the development of silicon sensors for HGCAL:
  - PQC measurements
  - Noise / Signal measurements
  - Electrical characterization of Mini- and Full-size sensors
- Pre-production will commence in 2022