2024 TIDC Annual Meeting

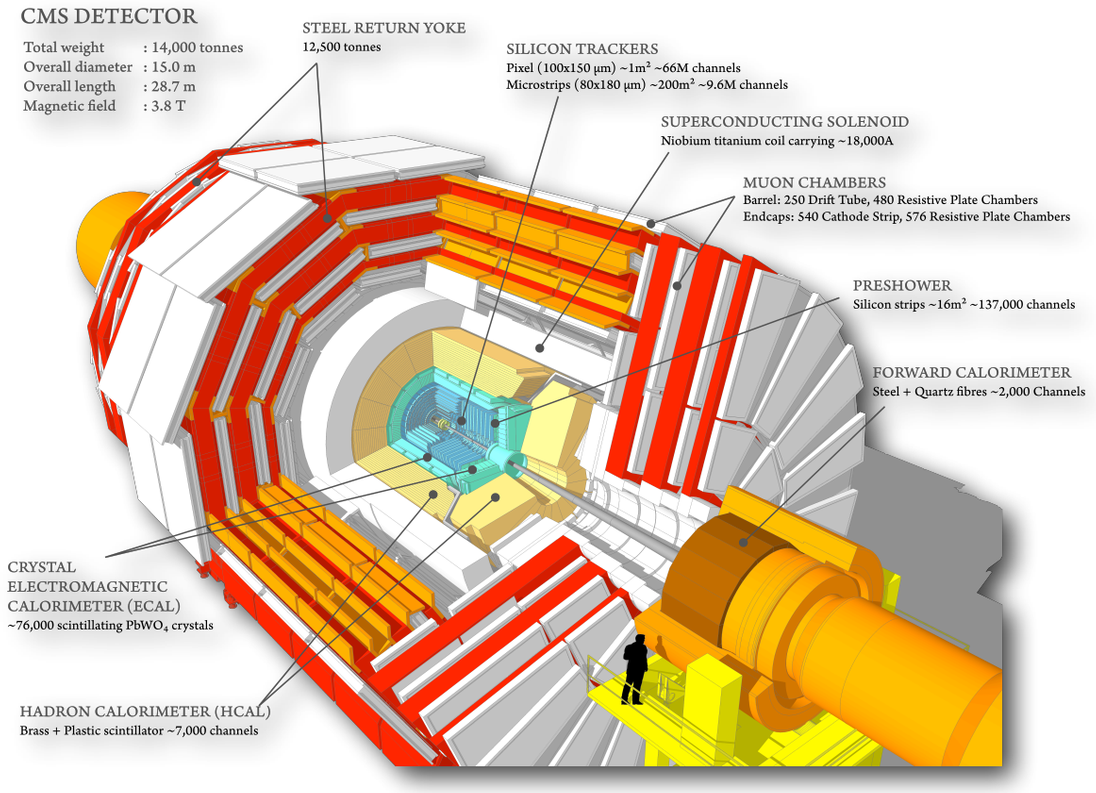
Status of HGCAL SQC at NCU

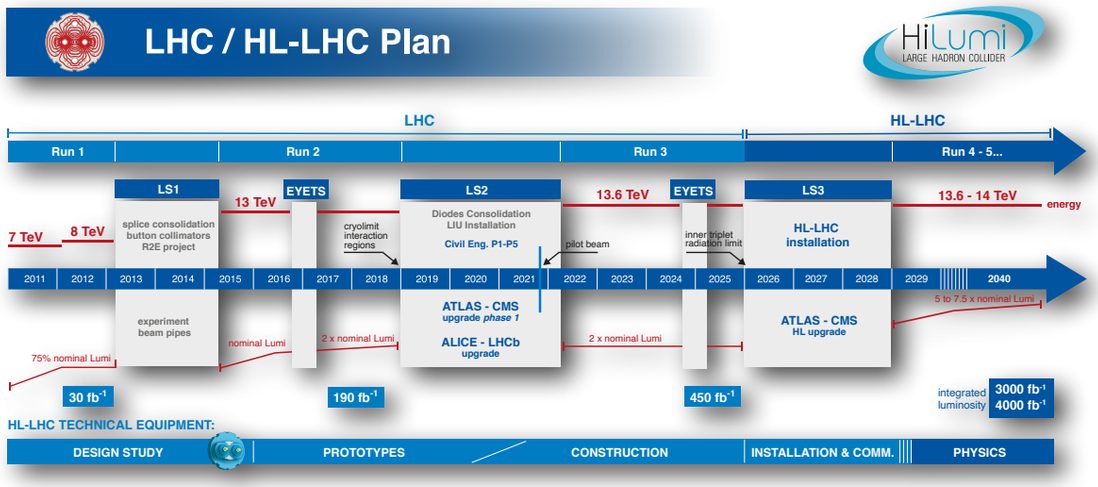
Chia-Ming Kuo, Debabrata Bhowmik, Kai-Yu Cheng, Wei-Che Tang
National Central University, Taiwan

2024/11/22 TIDC Annual Meeting

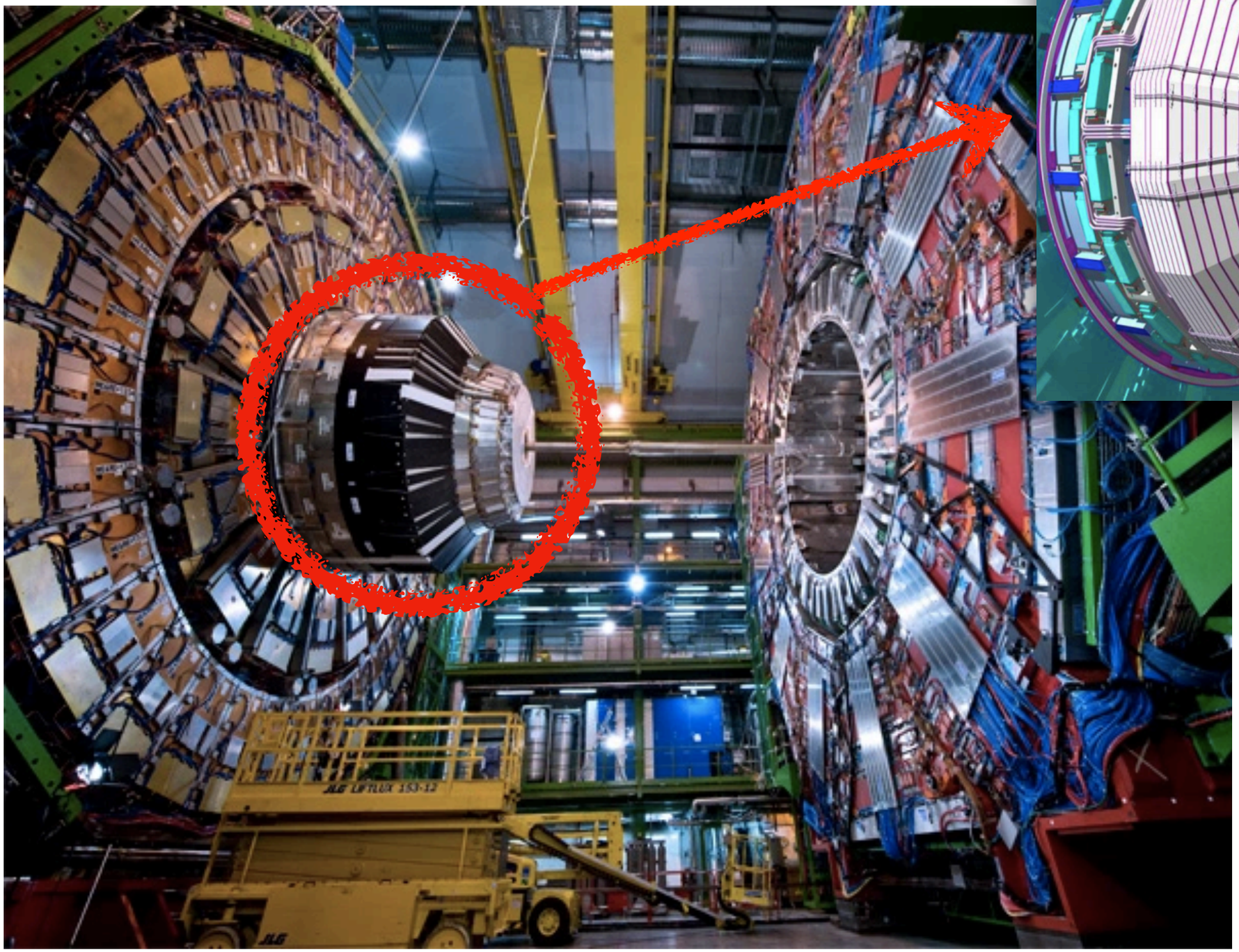
Introduction

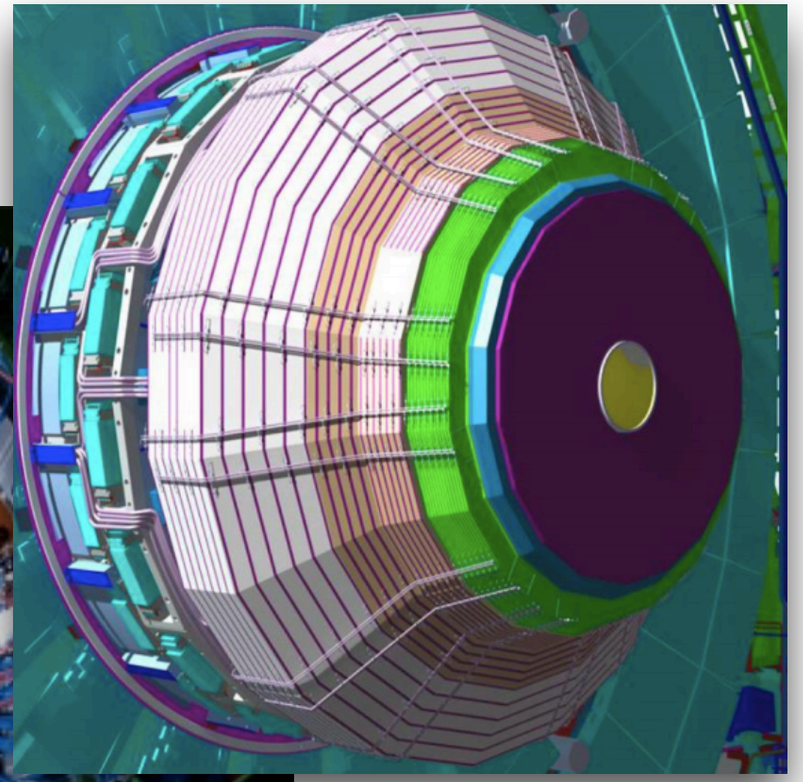
- High luminosity LHC(HL-LHC): Expected to start operation in 2029.
- ~10 times integrated luminosity.
- High pile up rate.
- High radiation levels : dose ~2 MGy
- CMS collaboration is designing a new high granularity calorimeter (HGCAL) which will be built and replace existing End-cap calorimeters in around 2026.





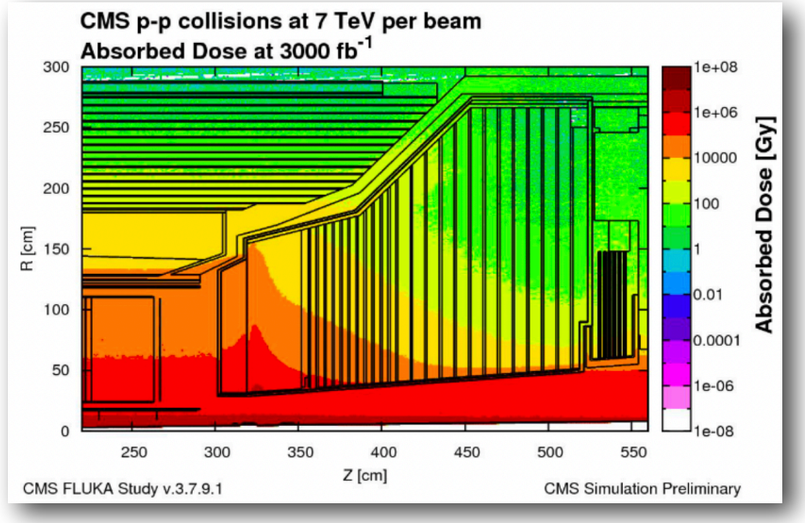
HGCAL



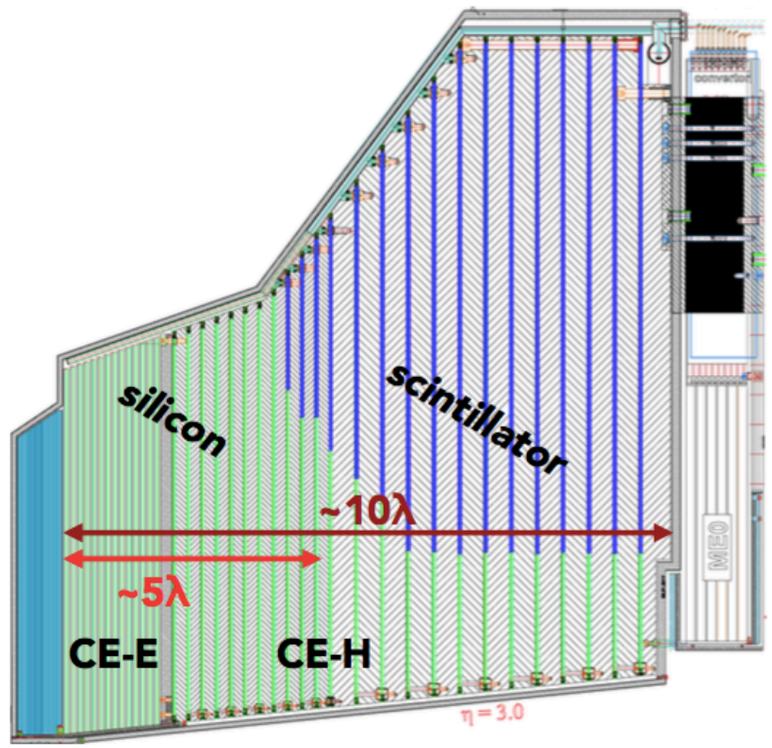


HGCAL sensors

- HGCAL
  - Active layers :
    - CE-E - silicon
    - CE-H - mixed layers of silicon & scintillator
  - Key parameters :
    - ~600 m^2 silicon sensors produced on 8-inch wafers
    - There are three different thicknesses : 300 μm, 200 μm and 120 μm

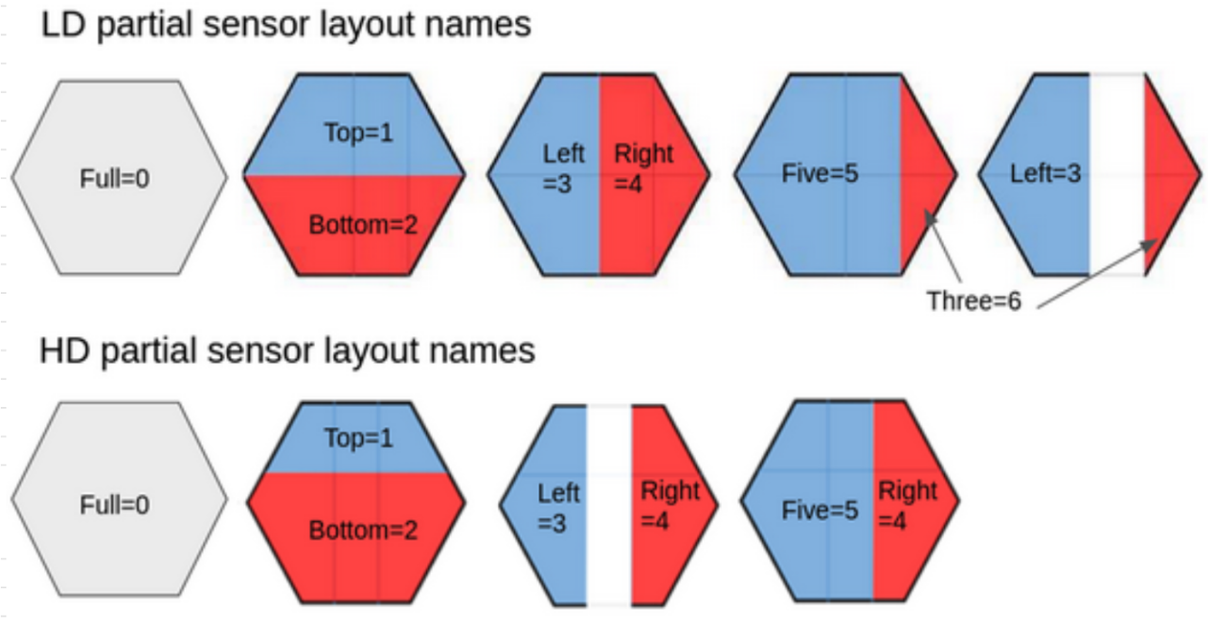


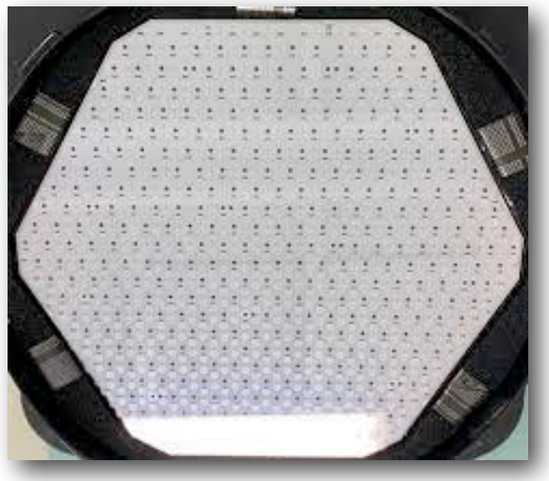
	Silicon	Scintillators
Area	~600 m^2	~500 m^2
Channel size	0.5 - 1.0 cm^2	4 - 30 cm^2
Modules	~30000	~4000
Channles	~6 M	~240 k



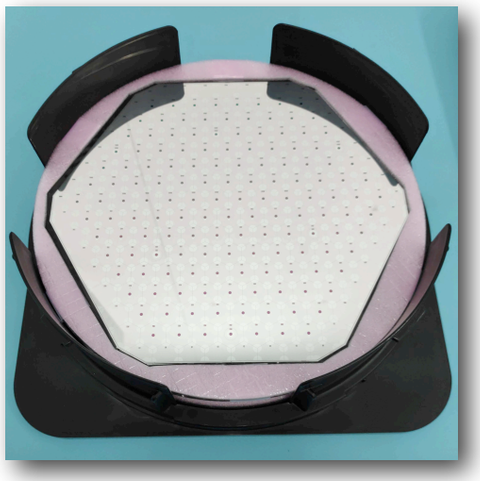
HGCAL SQC

- HGCAL sensors quality control (HGCAL SQC) :
  - There are 4 HGCAL SQC centers : CERN, FSU, NCU, TTU.
- There are different types of silicon sensors according to the silicon shape and its channel number.
  - NCU currently only received LD full sensors and HD full sensors.
- HGCAL SQC steps :
  - Sensor Alignment (along with contact test)
  - IV measurement & CV measurement





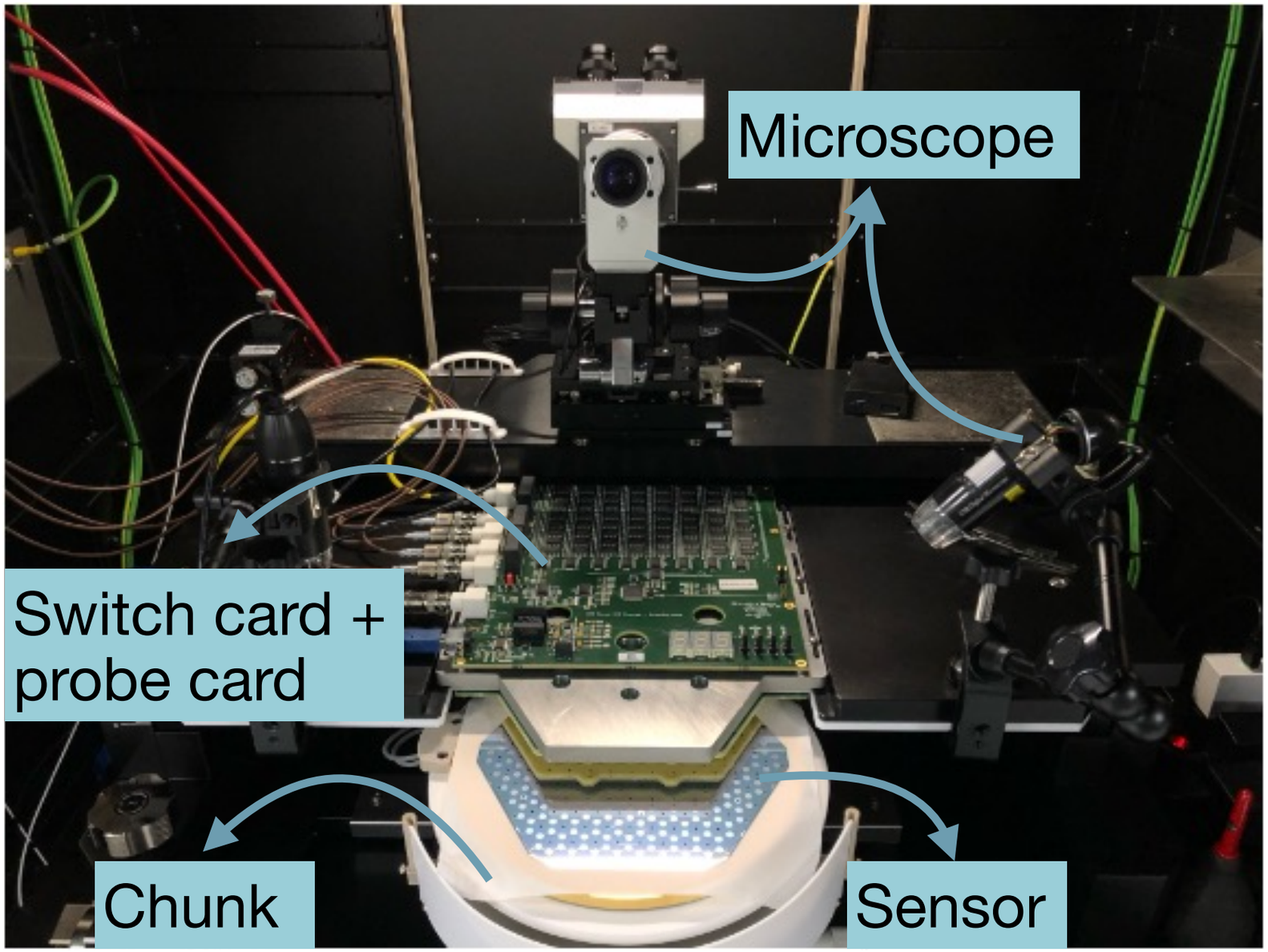
HD full sensor



LD full sensor

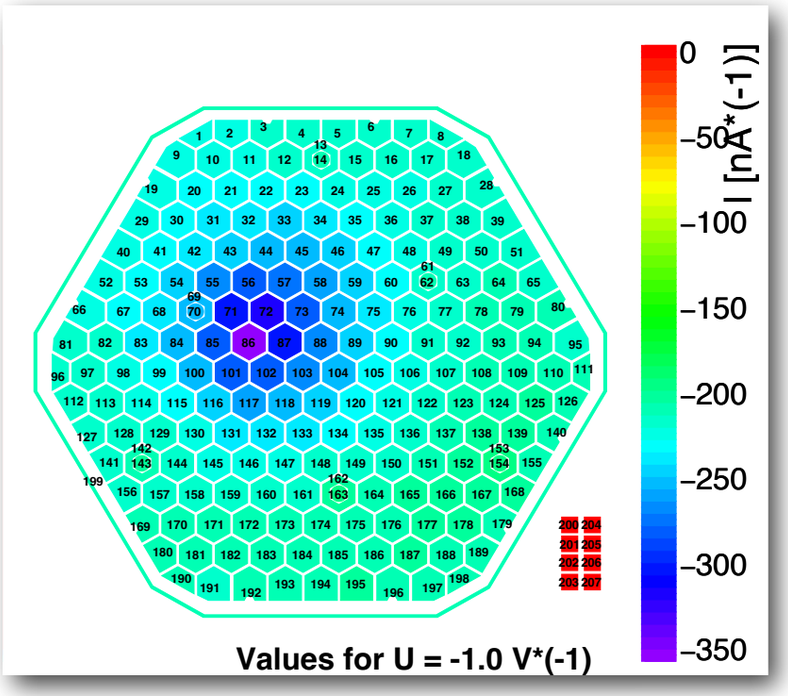
Setup

- The microscope is used for the sensor alignment.
- To ensure the good sensor alignment, the contact test is performed.



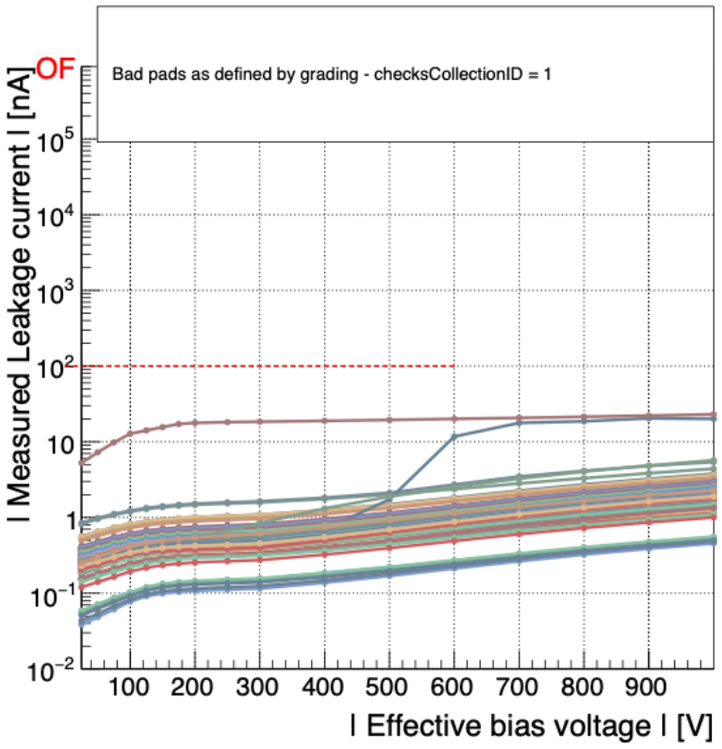
IV @ 1V forward bias: to test if all pins have contact.

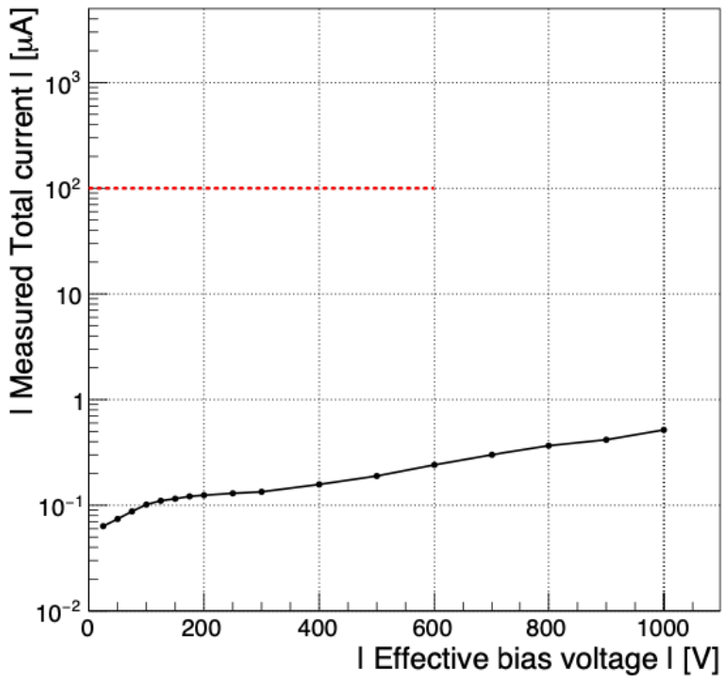
All cells have ~200nA forward bias current

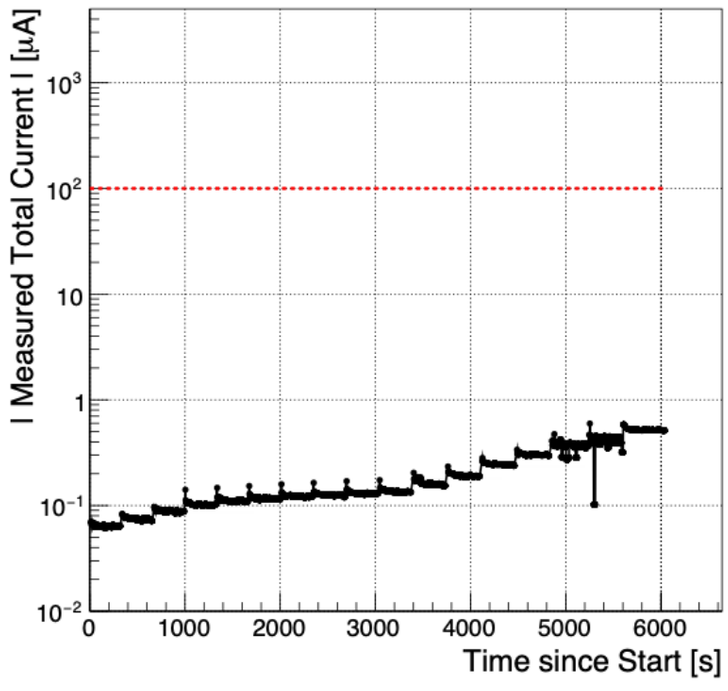


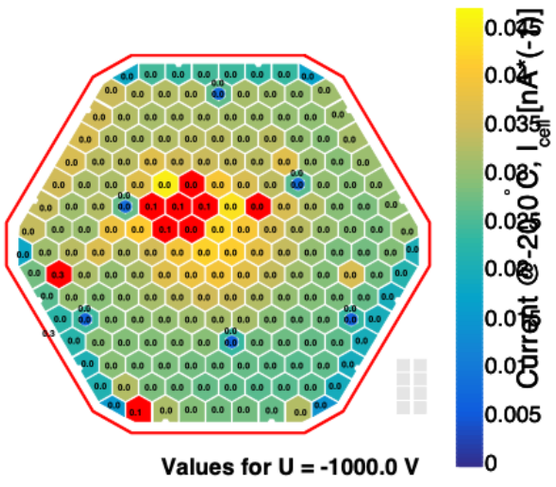
IV measurement results

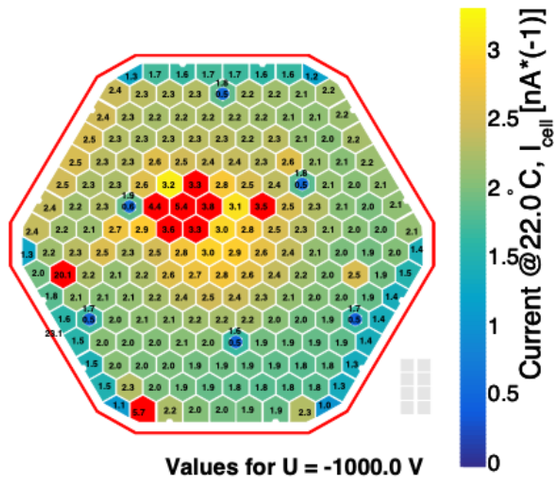
Sensor: 102004, 300μm LD











Grading:

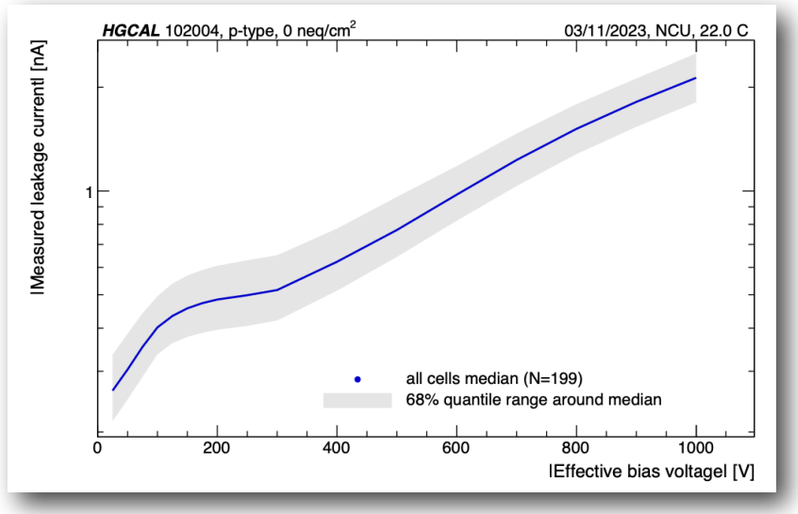
- Sensor has been graded with checksCollectionID 1.
- Global characteristics:
  - Current at 600V I600 (normalised to 20 deg Celsius): <= 100 μA integrated over the sensor and guard rings: Passed
  - I800 < 2.5 x I600: Passed
  - Number of bad pads 0 <= 8 for full-sized sensors: Passed
  - Allowed number of adjacent bad pads <= 2: Passed
- Per-pad characteristics used to define bad pads if any of the following are met:
  - Current at 600V I600 (normalised to 20 deg Celsius) > 100 nA/pad: **0** pads, namely **[]**
  - I600 > 10 nA and I800 > 2.5 x I600: **0** pads, namely **[]**
  - I600 $\leq$ 10 nA and I800 > 25 nA: **0** pads, namely **[]**

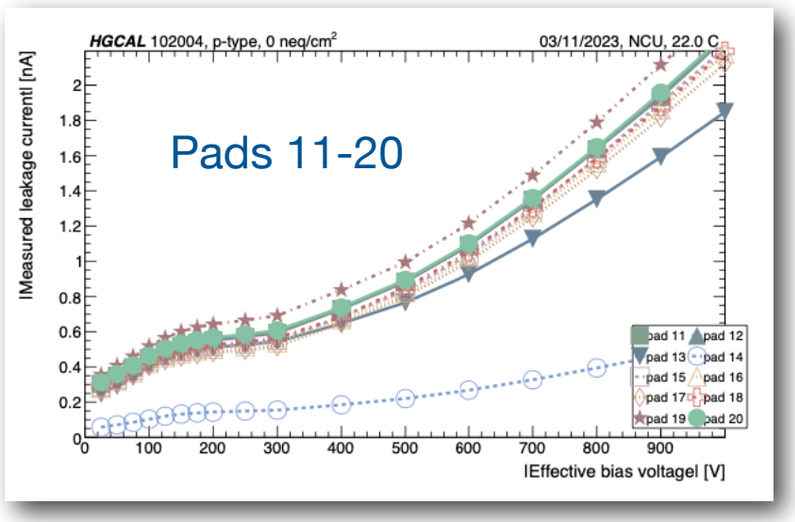
Sensor has PASSED the requirements.

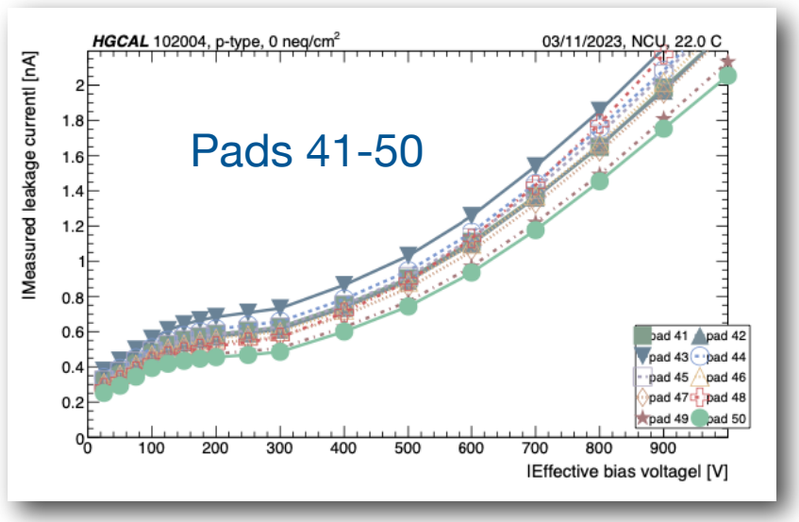
IV measurement results

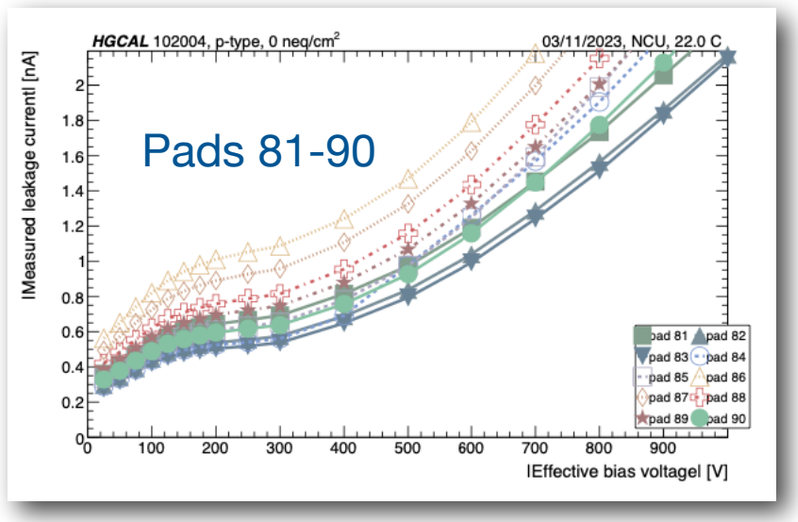
Sensor: 102004, 300μm LD

- IV curve per cell results.
- The individual cell currents show expected trend with increasing voltage.
- Looking particularly at the hot regions also confirms that the voltage dependency of the currents are of the same characteristic as for the other cells.



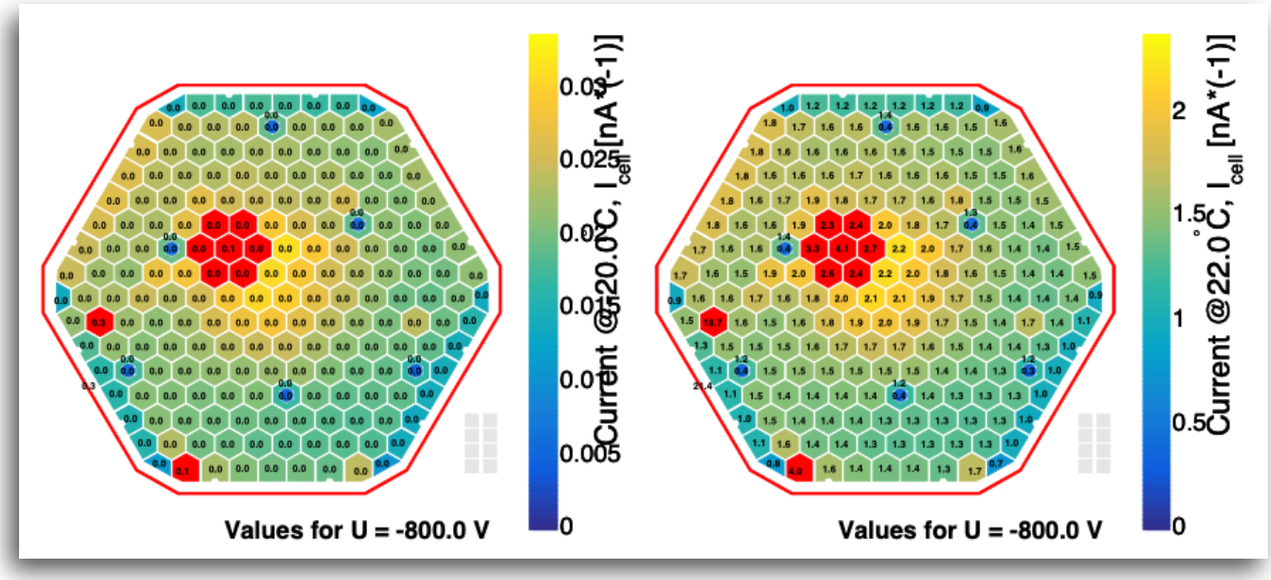






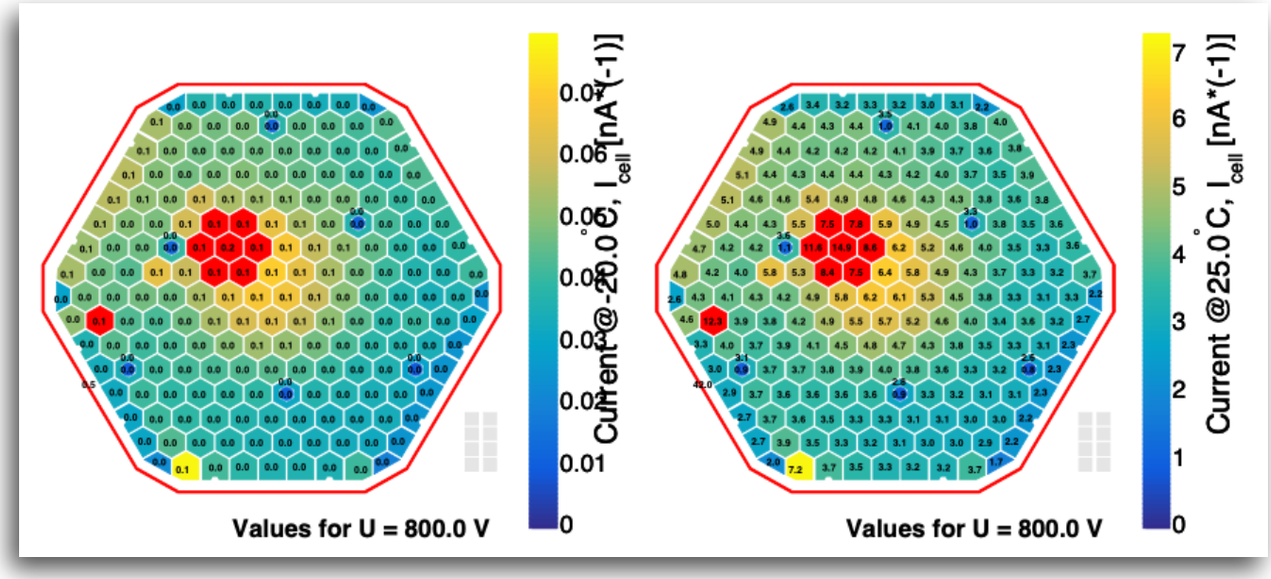
Compare results to Hamamatsu

- We compared the results of the same sensor measured at Hamamatsu.
- The testing results are similar to our results.



Sensor: 102004, 300μm LD

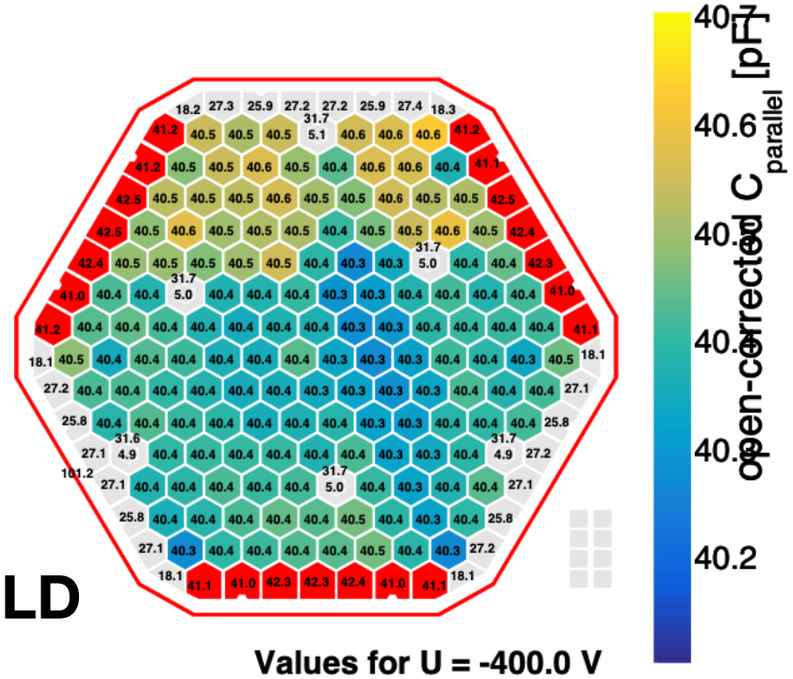
@ NCU



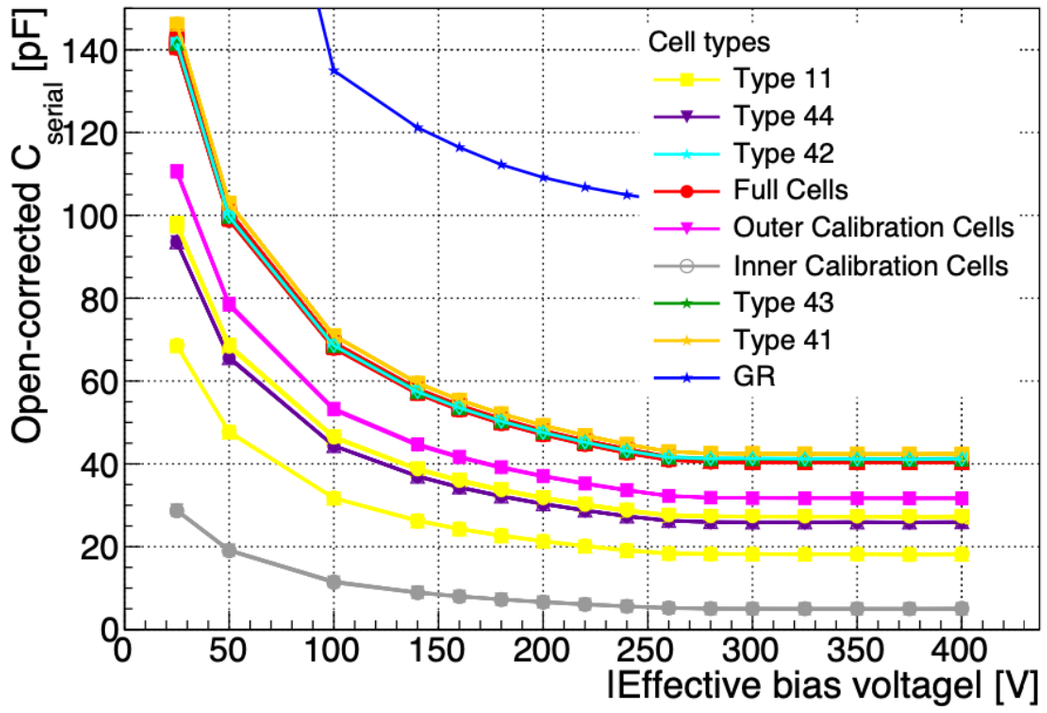
@ Hamamatsu

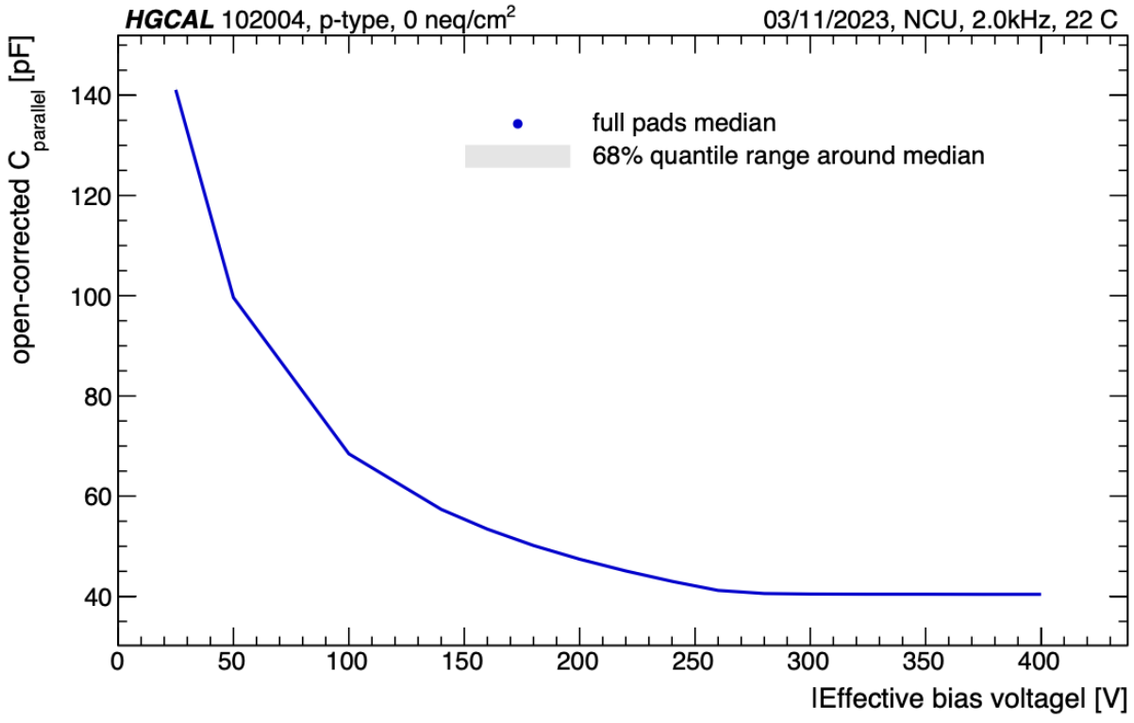
CV measurement results

- The CV characteristic also has been checked.
- The CV characteristic behaved as expected.



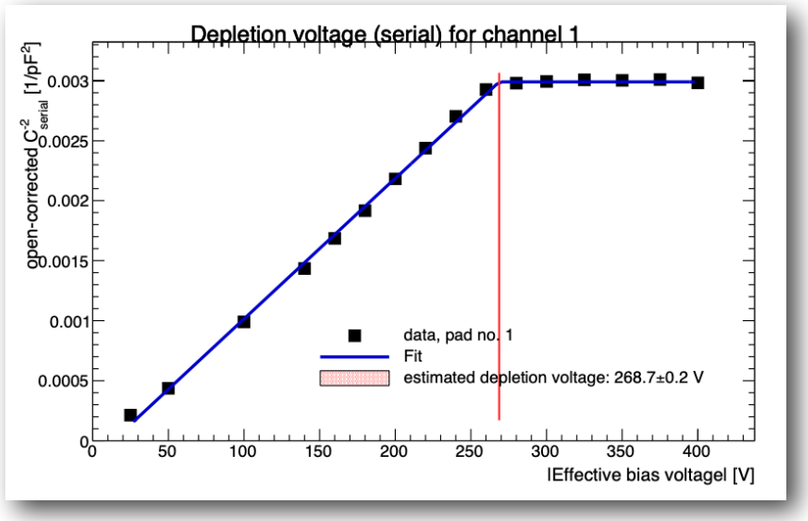
Sensor: 102004, 300μm LD

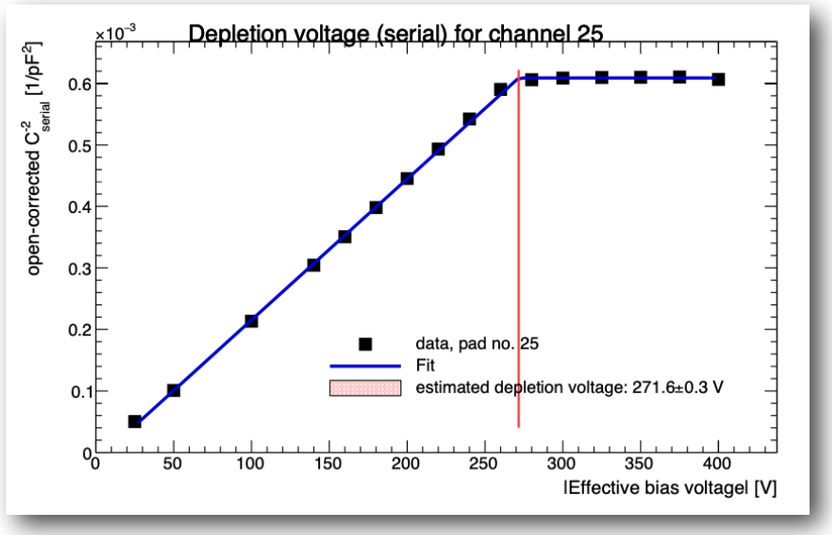


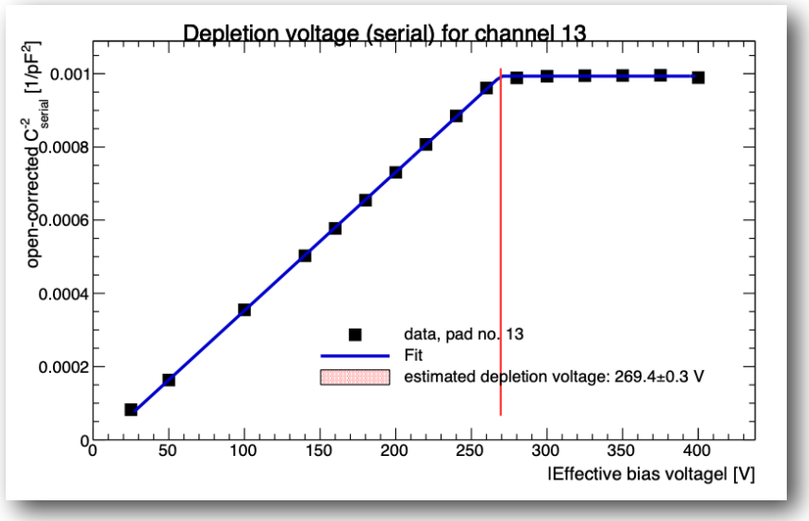


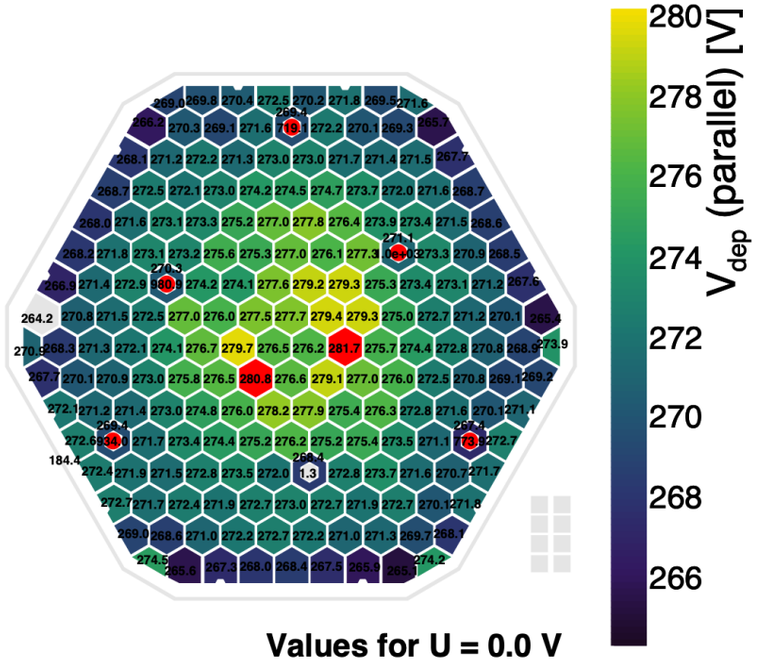
CV measurement results

Sensor: 102004, 300μm LD









- Global characteristics using FULL cells only:
  - Full depletion voltage V_{dep} = 273.0 V calculated as the median of depletion voltages across cells, after removing outliers outside quantile 16-84%.
  - V_{dep} < 370 V for sensor of **assumed thickness** of 300 μm: Passed
  - Variation across sensor ΔV_{dep} = 0.7 %
  - ΔV_{dep} <= Maximum variation across sensor of ± 10% for sensor of V_{dep} = 273.0 V: Passed
- Per-pad characteristics using FULL cells only:
  - C_{meas_mean} = 40.461 pF, computed as the measured open corrected serial capacitance averaged over cells
- Thickness uniformity across sensor using FULL cells only:
  - Relative thickness variation $\Delta thickness$ = 0.2 % < 10 / 300: Passed

Sensor has PASSED the requirements.

SQC status

- In total we received **3325** LD sensors and **322** HD sensors.
- In total **168** LD sensors and **32** HD sensors were tested and passed the criteria.

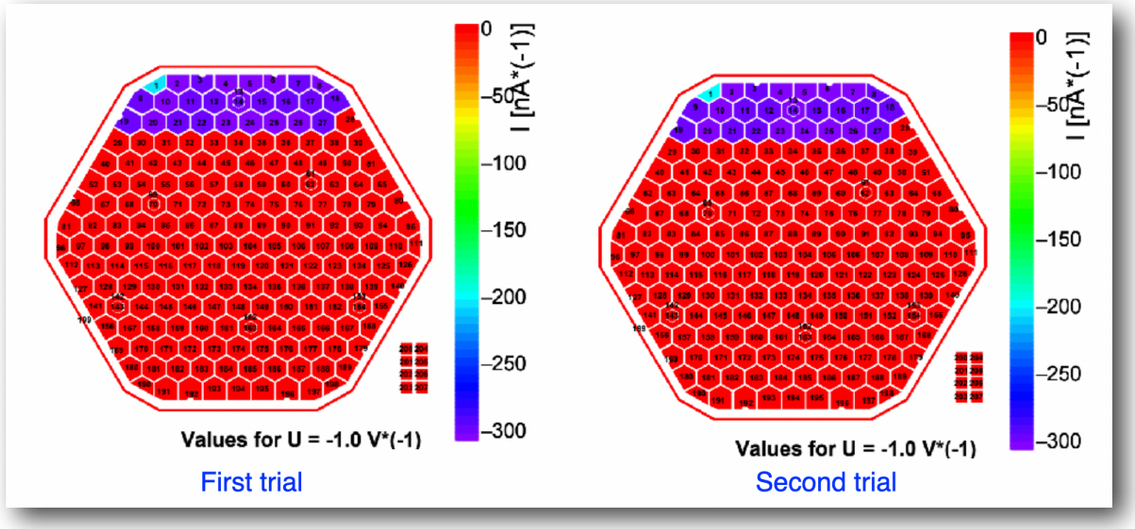
Shipping date	Production round	Thickness	Number of sensors	Number of sensors to be measured (5%)	Number of sensors	IV passed	CV passed
March, 2023	Production	300 um	73	~4	4	4	4
July, 2023	Production	300 um	1142	~57	57	57	57
November, 2023	Production	300 um	1443	~73	73	73	73
January, 2024	Production	120 um	132	~7	16	16	16
April, 2024	Production	120 um	96	~5	8	8	8
May, 2024	Production	300 um	667	~33	38	38	38
May, 2024	Production	120 um	94	~5	8	8	8
July, 2024	Production	120 um	191	~10	On going	NaN	NaN

SQC measurement rate : ~3 /working days

Contribution in software

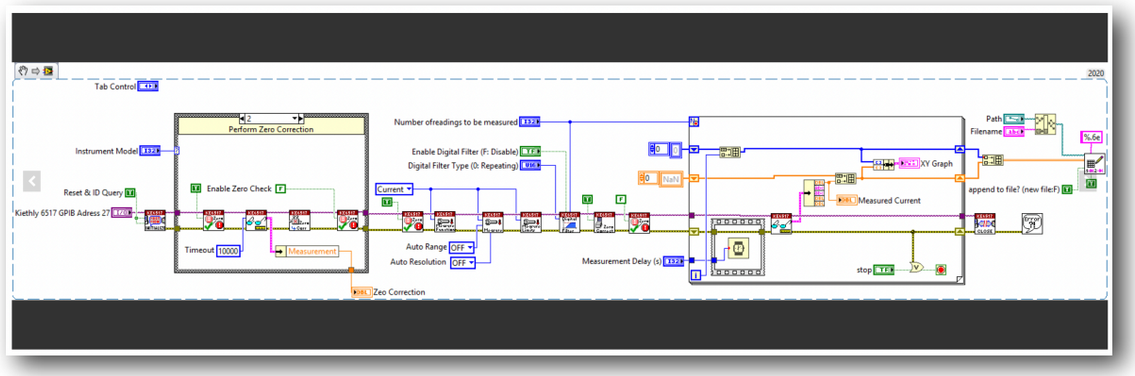
- The LabView control system setup for the picometer *Keithly 6517* was not properly developed as CERN or any other sensor testing station doesn't use it.
  - We contributed in updating the LabView software setup to correctly incorporate *Keithly 6517* in the testing system.

Contact test before software development

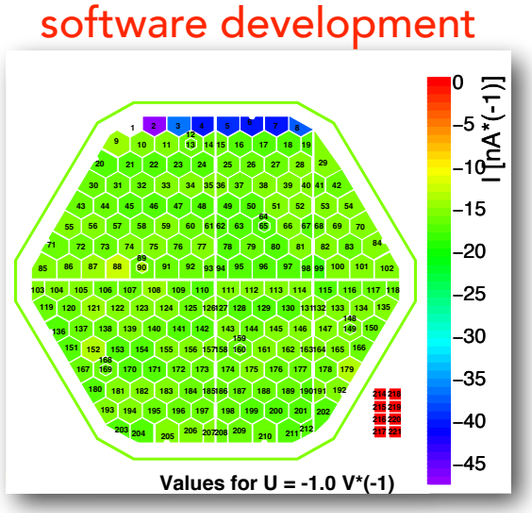


First trial

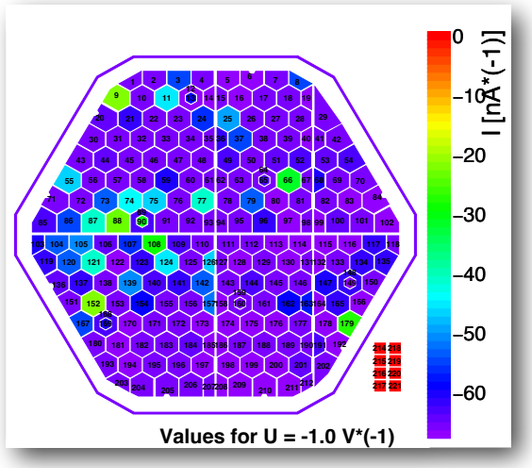
Second trial



Contact test comparison after software development



Measurements with picometer 6517b (The one NCU used)



Measurements with picometer 6487 (Standard one CERN uses)

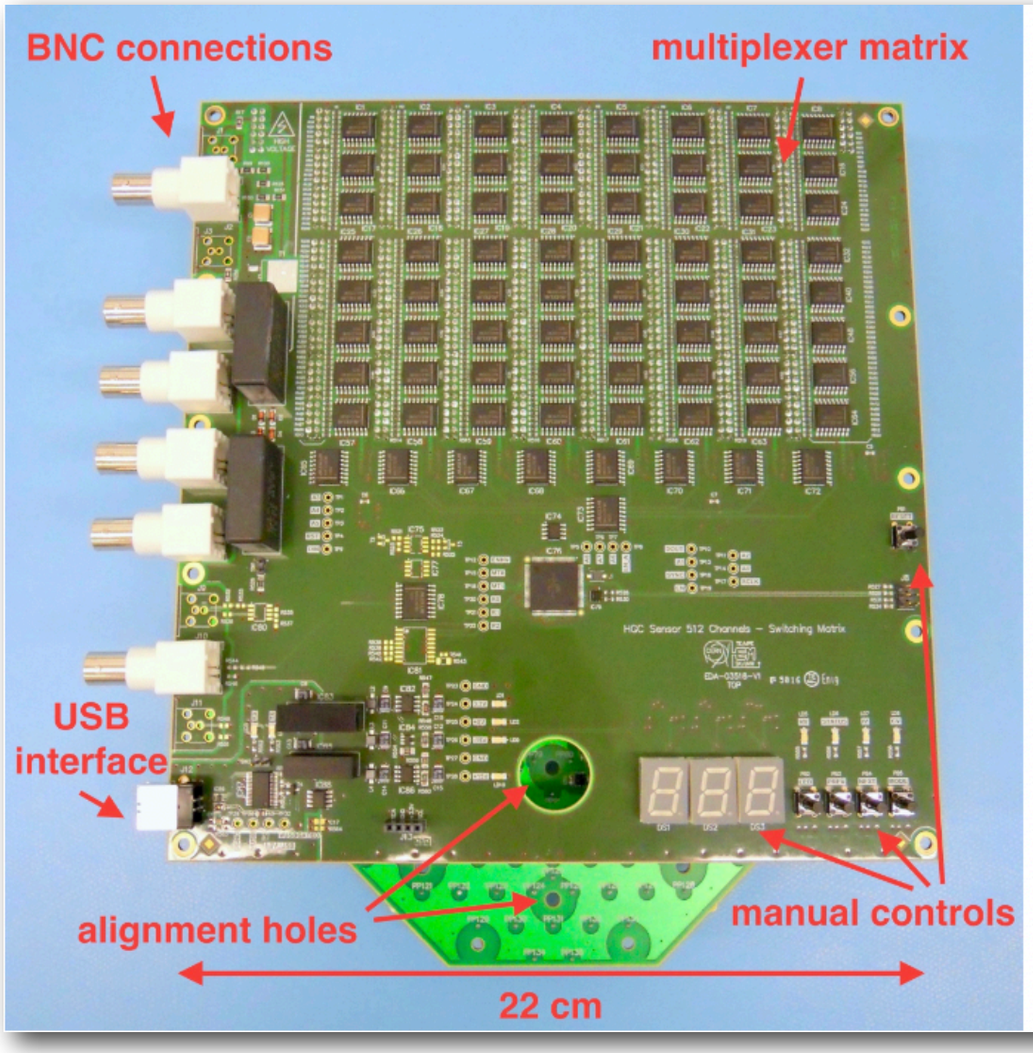
Summary

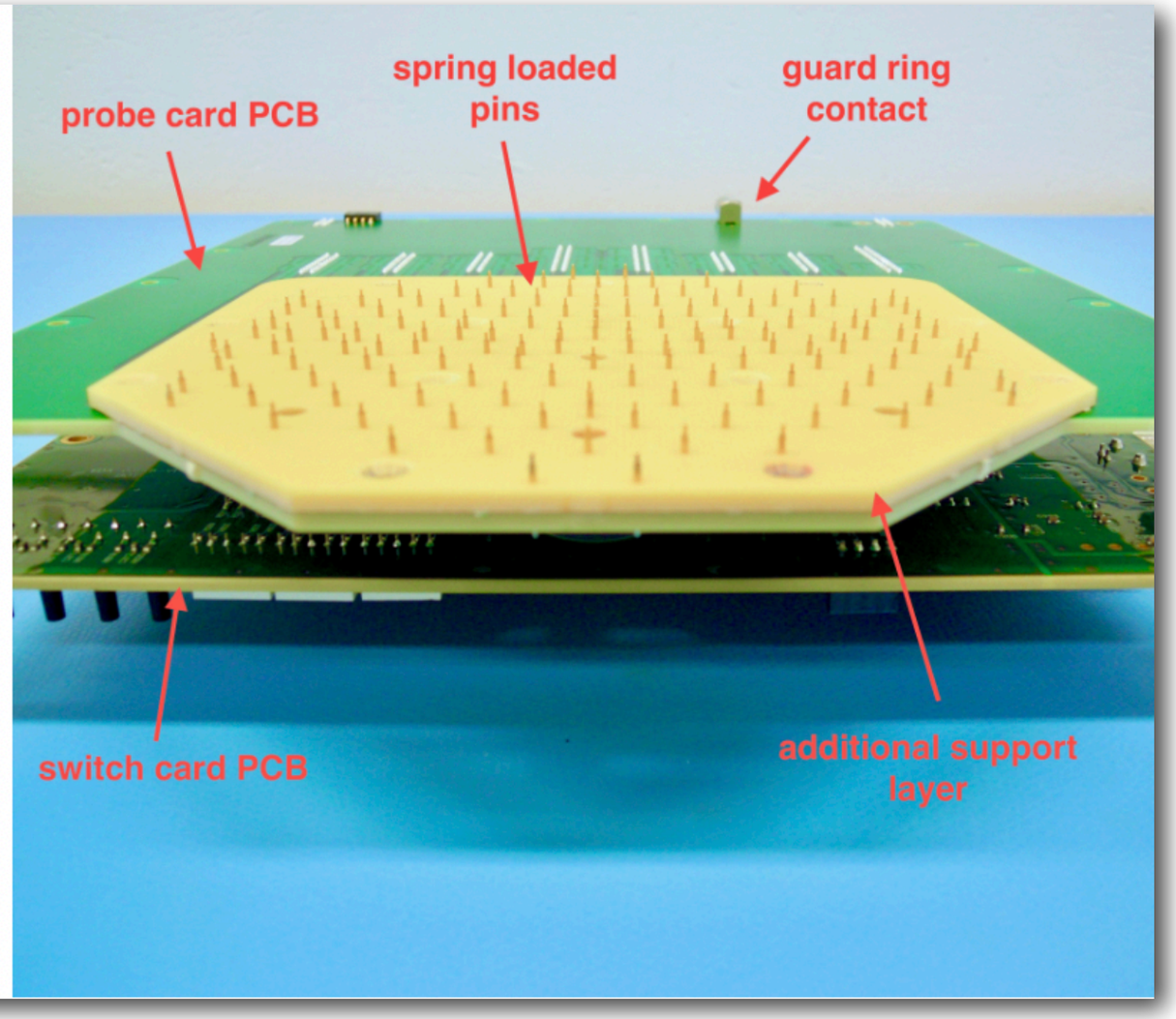
- NCU is fully functional in HGCAL SQC now.
- From production campaign we received ***3325*** *300 μm LD full sensors* and ***322*** *120 μm HD full sensors* at NCU.
- Measured ~5% of all the sensors.
- Average measurement rate : ~2 sensors per day
- Contributed in the testing system software for the measurement instruments.
- Future work :
  - 563 *300 μm LD full sensors* & 94 *120 μm HD full sensors* will arrive at NCU in recent future.
  - Raise the measurement rate up to 8%.

Back up

Testing platform

- We used a probe card (right figure) as a probing tool to the sensor and use a switch card (left figure) as readout controller board.

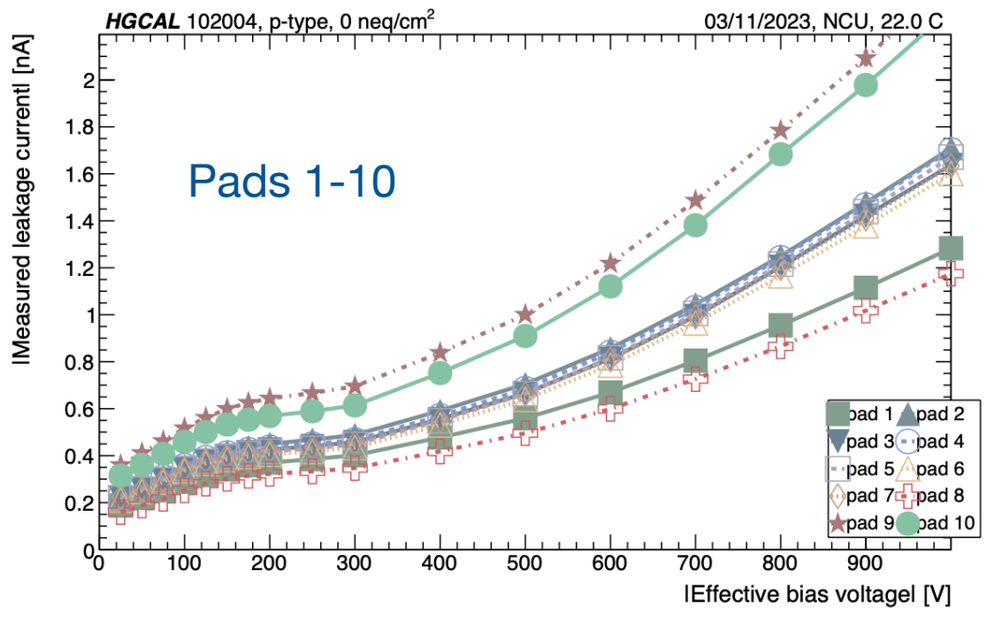


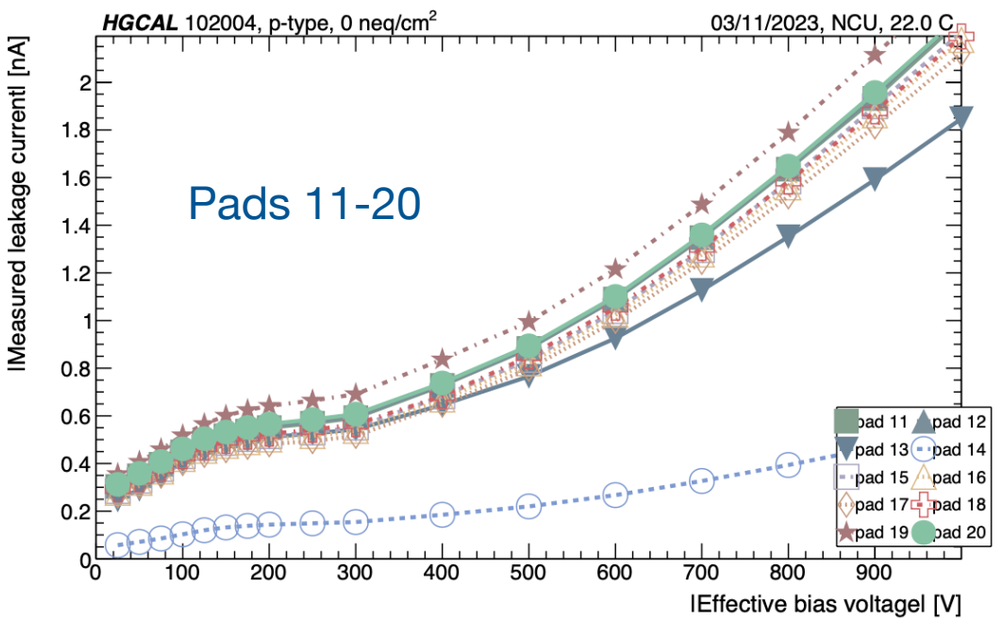


Comparison with Hamamatsu

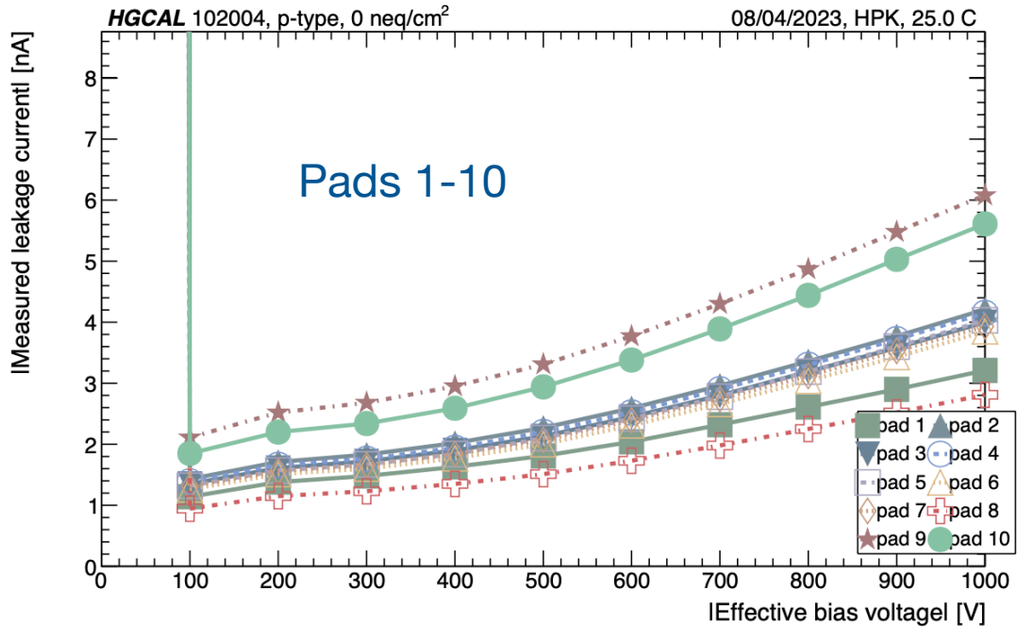
Sensor: 102004, 300μm LD

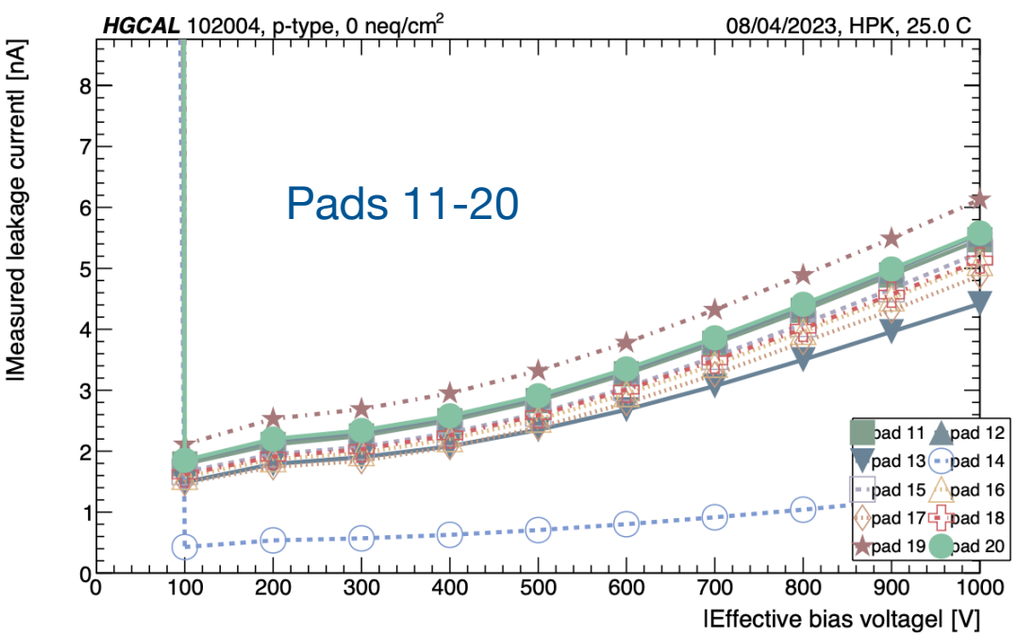
@ NCU





@ Hamamatsu





Analysis framework

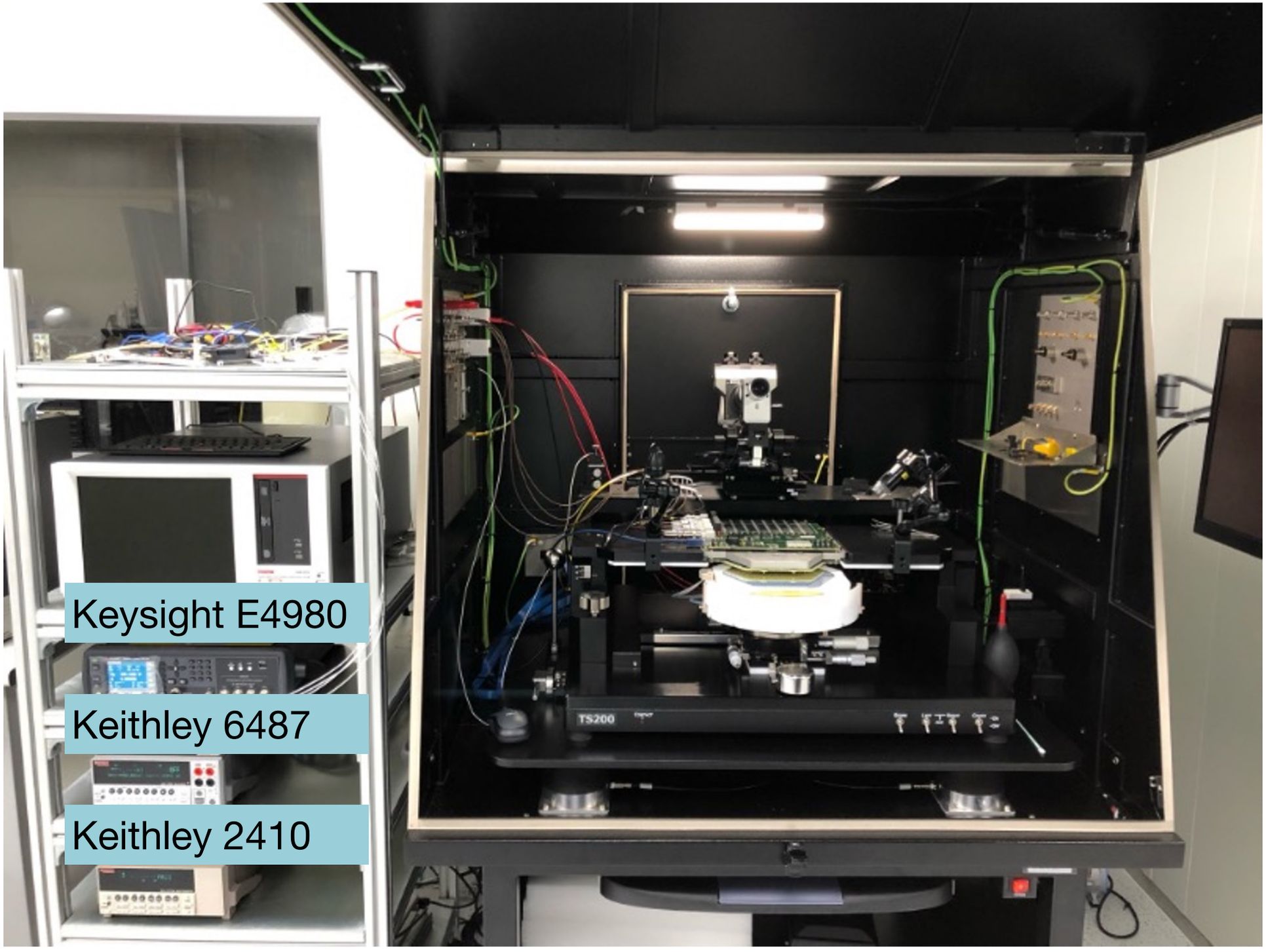
- Gitlab link for IVCV analysis framework:
  - https://gitlab.cern.ch/CLICdp/HGCAL/lcd_hgcal_analysisworkflows
- The requirements for non-irradiated sensors:

ChecksCollectionID 1

The vendor specifications for non-irradiated HGC silicon sensors.

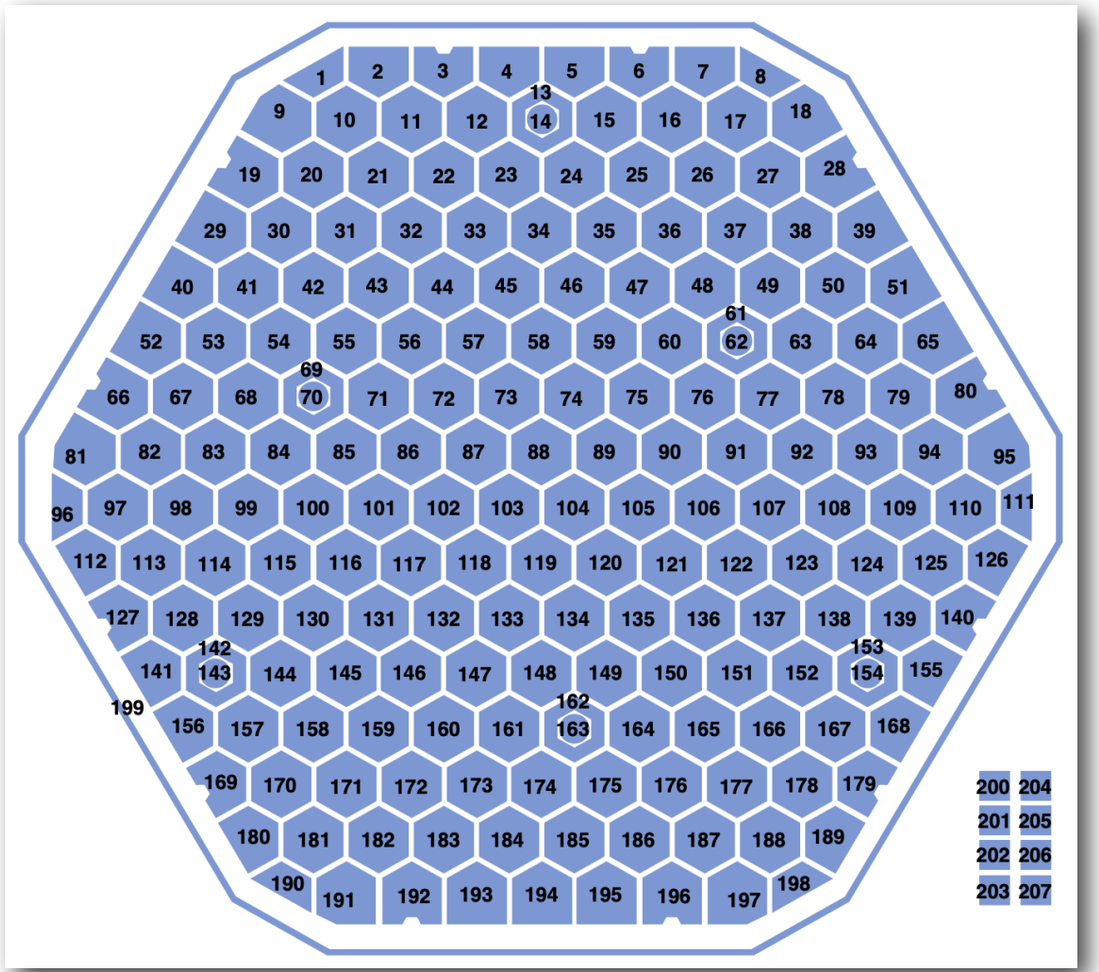
- All pads (full hexagons and special geometries), I_pad_increase requirement with 10nA threshold, different increase requirements for pads with more or less than 10nA of leakage current.
- Global characteristics based on total leakage current:
  - Current 600V I600 (normalised to 20 deg Celsius): <= 100 uamp integrated over the sensor and guard rings
  - I800 < 2.5 x I600
- Per-pad characteristics for all (i.e. full hexagons and special geometries) pads:
  - Current @600V I600 (normalised to 20 deg Celsius): <= 100 nA/pad
  - if I600 > 10 nA: I800 < 2.5 x I600
  - else if I600<=10 nA: I800 < 25nA
- Location of bad pads and clustering:
  - <= 8 bad pads for full-sized sensors
  - not more than two adjacent bad pads

Setup & Instruments

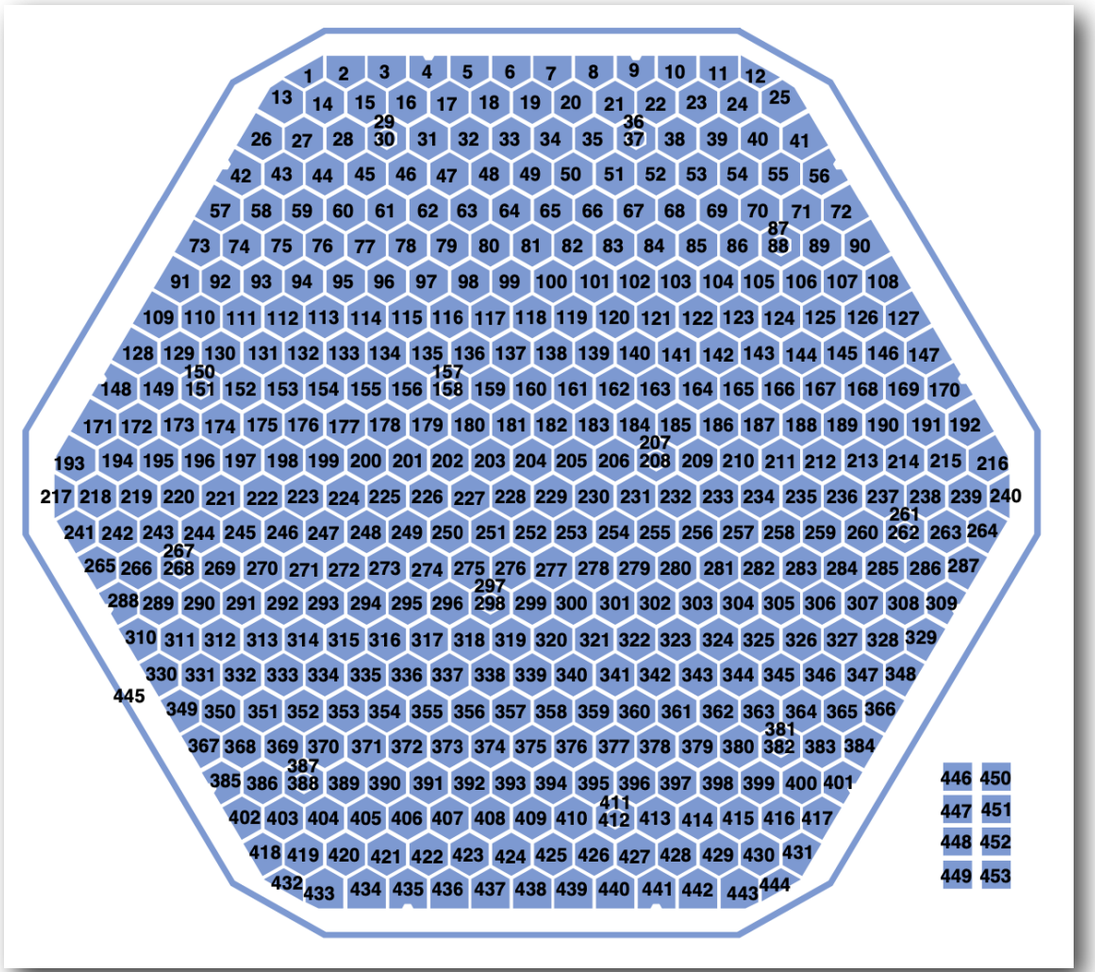


Channel mapping

LD full sensor channel map

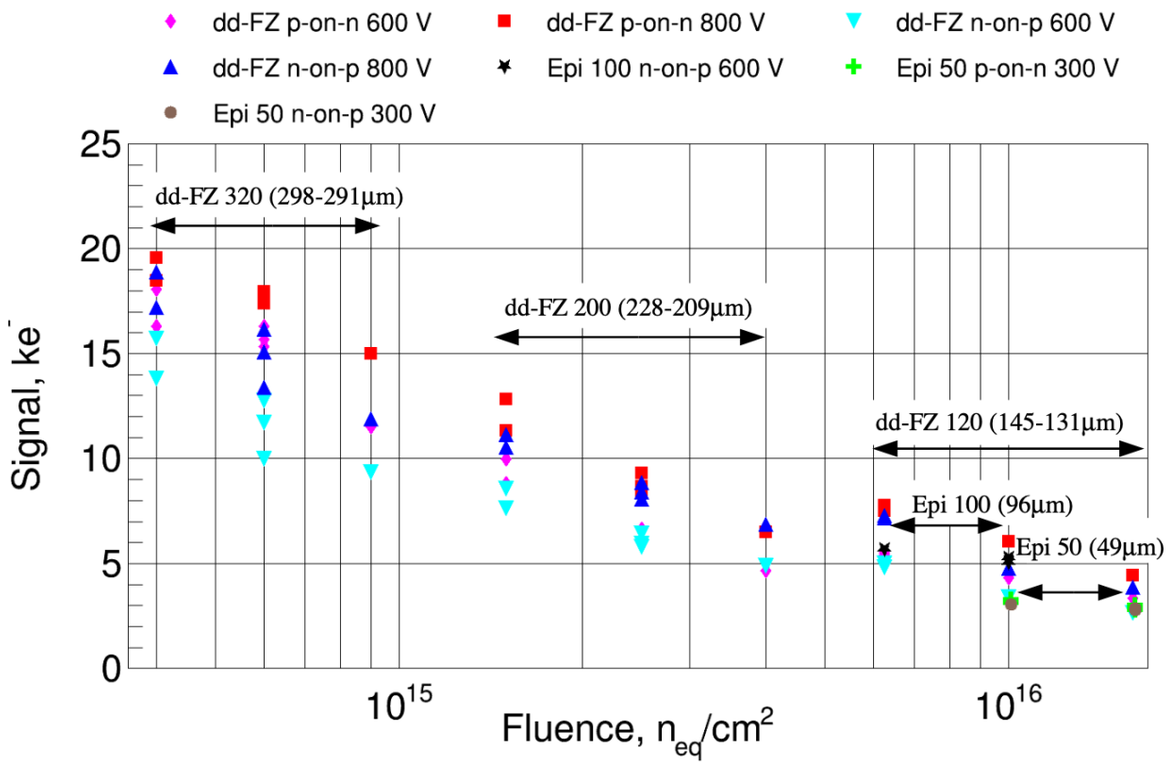


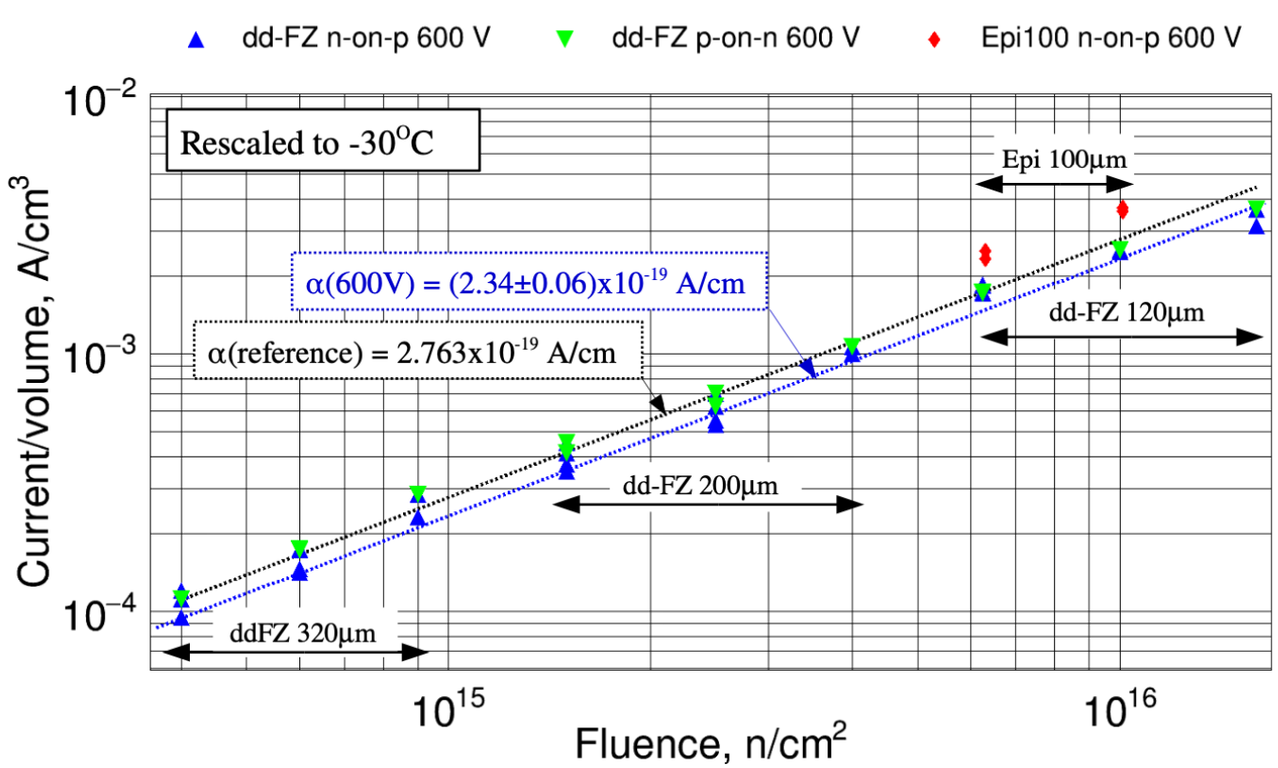
HD full sensor channel map



Silicon sensors tolerance

The Phase-2 Upgrade of the CMS Endcap Calorimeter.





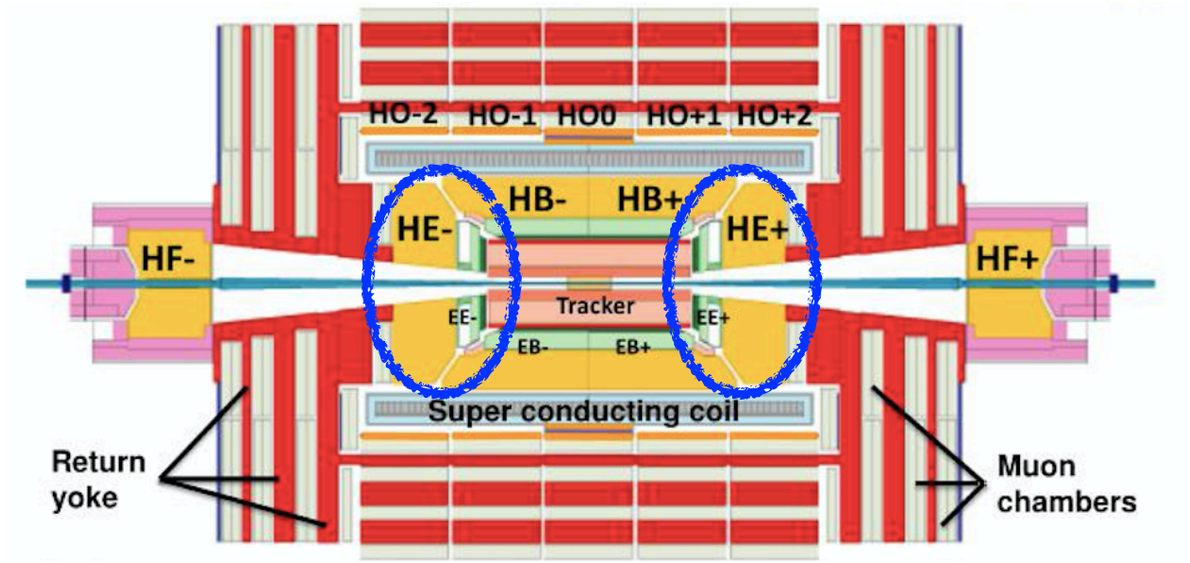
Silicon sensors property

The Phase-2 Upgrade of the CMS Endcap Calorimeter.

Active thickness (μm)	Cell size (cm^2)	Cell capacitance (pF)	Bulk polarity	Expected range of fluence ($\times 10^{15}\, n_{eq}/cm^2$)	Number of wafers	Number of partial wafers
300	1.18	45	p / (n)	0.1–0.5	13 164	1284
200	1.18	65	p	0.5–2.5	8 712	144
120	0.52	50	p	2–7	3 000	324
				Total:	24 876	1752

Active thickness (μm)	**300**	**200**	**120**
Area (m^2)	245	181	72
Largest lifetime dose (Mrad)	3	20	100
Largest lifetime fluence (n_{eq}/cm^2)	0.5×10^{15}	2.5×10^{15}	7×10^{15}
Largest outer radius (cm)	≈180	≈100	≈70
Smallest inner radius (cm)	≈100	≈70	≈35
Cell size (cm^2)	1.18	1.18	0.52
Initial S/N for MIP	11	6	4.5
Smallest S/N(MIP) after 3000 fb^{-1}	4.7	2.3	2.2

HGCAL


HO-2
HO-1
HO0
HO+1
HO+2
HB-
HB+
HE-
HE+
HF-
HF+
Tracker
EE-
EE+
EB-
EB+
Super conducting coil
Return yoke
Muon chambers