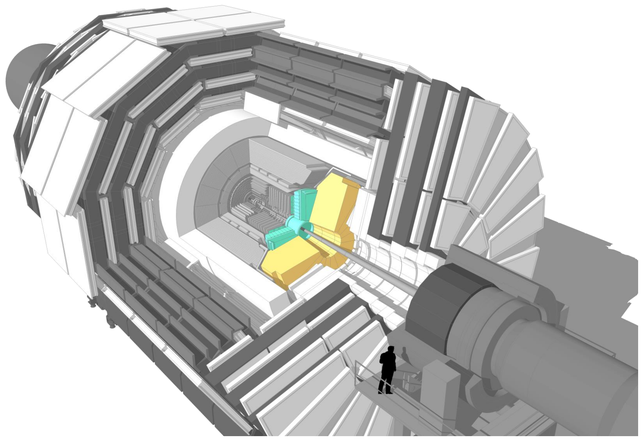
The Silicon Sensors for the High Granularity Calorimeter of CMS

Peter Paulitsch on behalf of the CMS collaboration

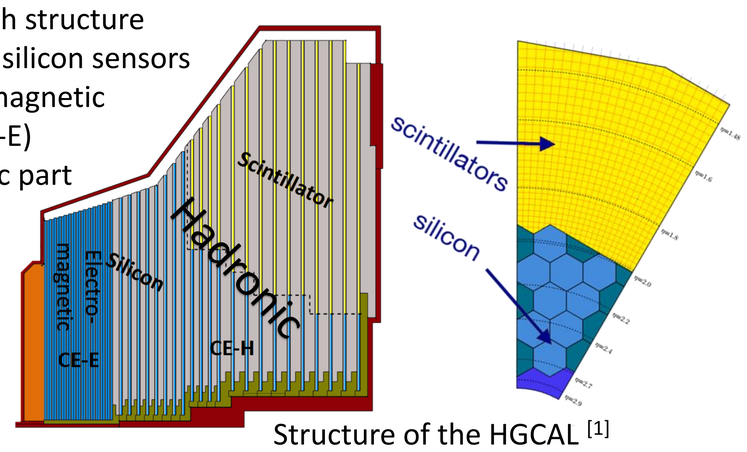
Background

The High Luminosity LHC (HL-LHC) will have a factor 5 higher instantaneous luminosity compared to the end of LHC operation, resulting in a proportionally higher event rate and a factor 10 increase of integrated luminosity (3000 fb^{-1}). Therefore, unprecedented levels of radiation and particle shower densities will affect experiments such as CMS. To address these challenges, the CMS collaboration will replace the existing endcap calorimeters with a new High Granularity Calorimeter (HGCAL) during the Phase-II Upgrade, around 2024-2026, which will include more than 600m² of silicon sensors to allow efficient mitigation of pileup and facilitate particle-flow calorimetry.



Location of the HGCAL at the CMS experiment [1]

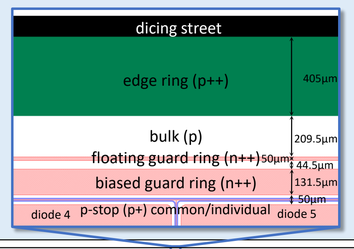
- Sandwich structure
- >**600m²** silicon sensors
- Electromagnetic part (CE-E)
- Hadronic part (CE-H)



Structure of the HGCAL [1]

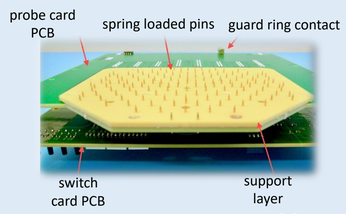
Sensor design

- **8" wafers**, two cell densities (LD/HD)
- Thicknesses 120, 200, 300µm to cope with different levels of radiation
- 8" process is a **new experience** in HEP, important differences from well-known 6": oxide charges, oxygen concentration of bulk, and fragile thin metal backside of 8"
- **Hexagonal shape**: A hexagon is the largest tileable, regular shape on a circular wafer
- Sensing elements are hexagonal, n-in-p, **DC-coupled** diodes
- Additional smaller, circular calibration diodes with lower capacitance to maintain MIP sensitivity after 3000 fb^{-1}
- Two guard rings (biased+floating)

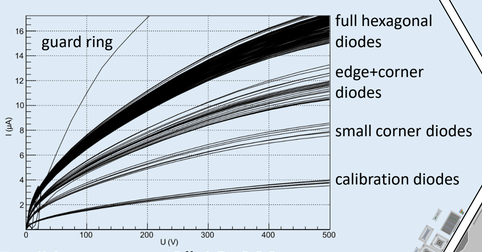


Sensor testing

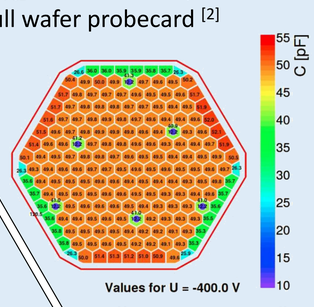
- Laser-TCT for charge collection efficiency
- Sensors DC-coupled, no common biasing
- ☹ Single, consecutive diode measurements do not represent IVCV situation on module
- ☺ **Full wafer probecard with spring-loaded pins**



Full wafer probecard [2]



IV curves on 8", LD-300µm, p-stop common, $\Phi_{eff} = 1.23*10^{15}\ n_{eq}\ cm^{-2}$, T = -20°C

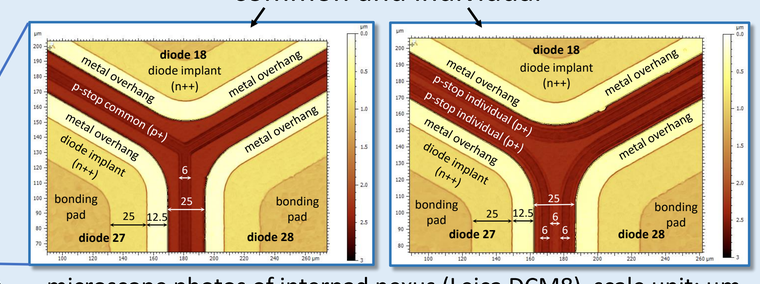


Cell capacitance 8", 300µm, p-stop individual

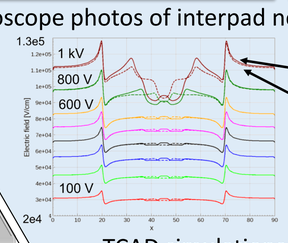
Test structures to be diced off (talk by V. Hinger [3])

Interpad structure

- **Metal overhang** to move peaks in E fields into oxide
- p+ implants (**p-stops**) to increase interpad resistance
- Two p-stop geometries under investigation: common and individual



microscope photos of interpad nexus (Leica DCM8), scale unit: µm



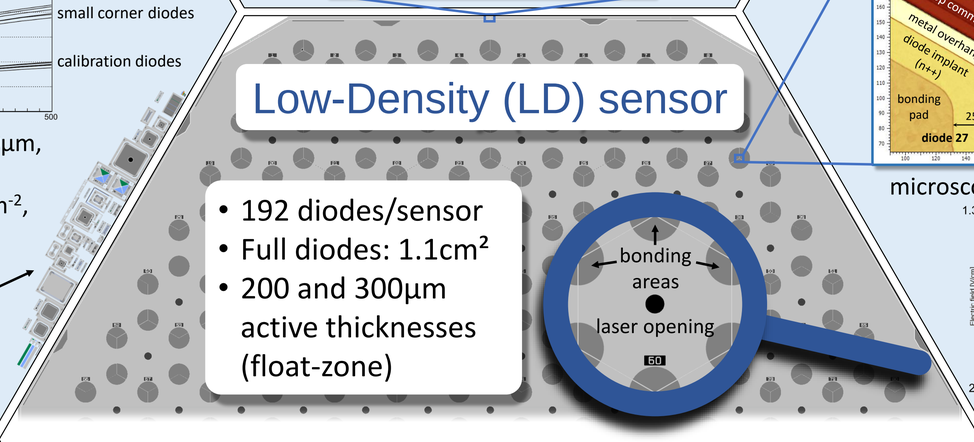
solid line: p-stop individual
dashed line: p-stop common

$\Phi_{eff} = 10^{15}\ n_{eq}\ cm^{-2}$
$N_{ps} = 10^{16}\ cm^{-3}$
$d_{pstop} = 1\ \mu m$

TCAD simulations of interpad fields

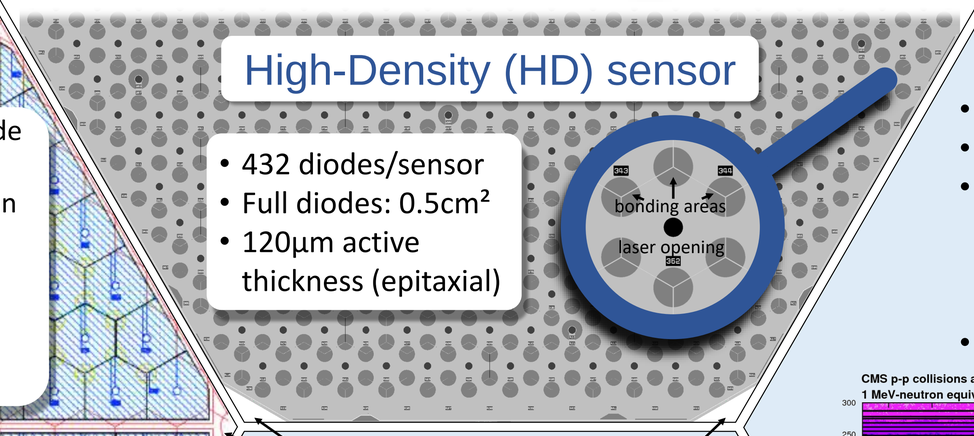
Low-Density (LD) sensor

- 192 diodes/sensor
- Full diodes: 1.1cm²
- 200 and 300µm active thicknesses (float-zone)



High-Density (HD) sensor

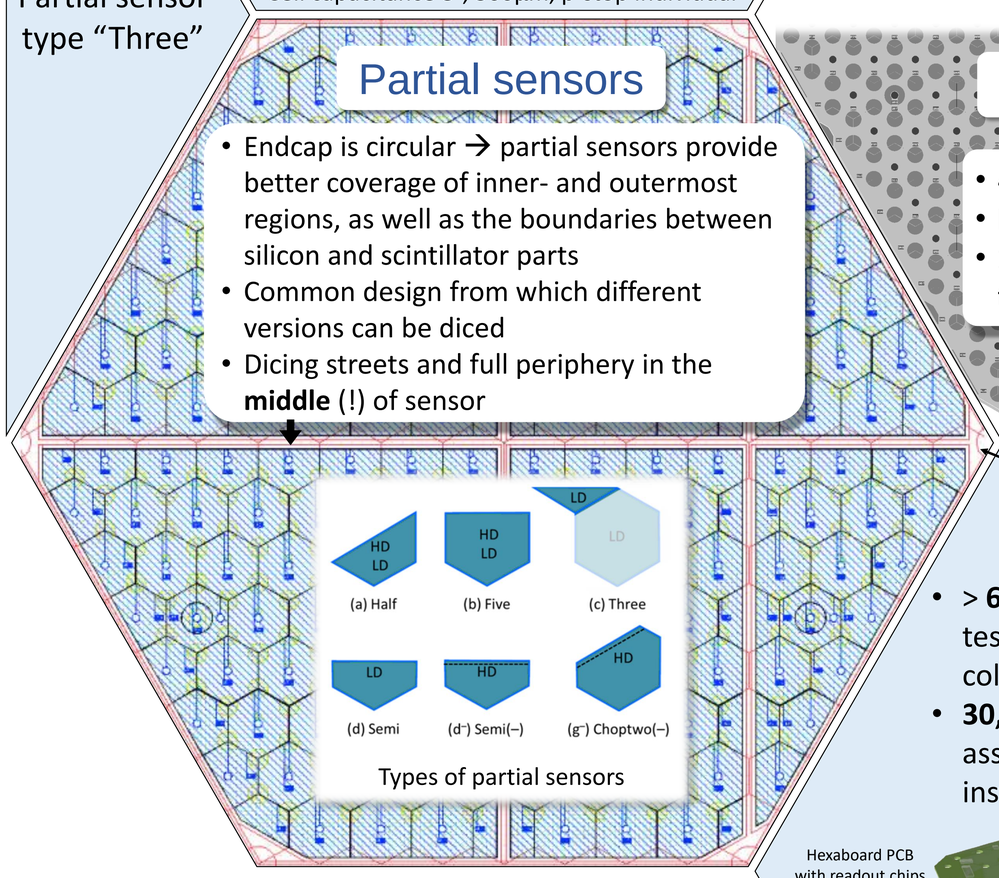
- 432 diodes/sensor
- Full diodes: 0.5cm²
- 120µm active thickness (epitaxial)



"mousebites" for mounting purposes

Partial sensors

- Endcap is circular → partial sensors provide better coverage of inner- and outermost regions, as well as the boundaries between silicon and scintillator parts
- Common design from which different versions can be diced
- Dicing streets and full periphery in the **middle** (!) of sensor



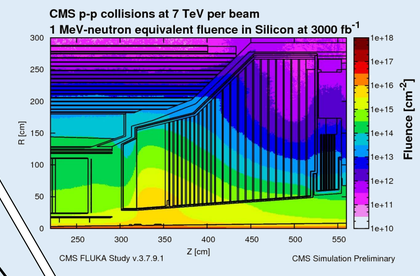
Types of partial sensors

Partial sensor type "Three"

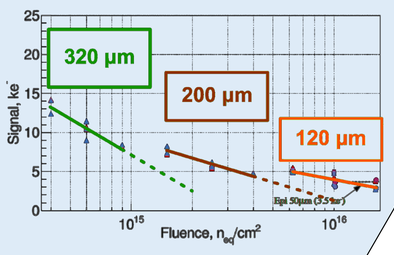
Partial sensor type "Three"

Radiation hardness

- Total Ionizing Dose up to 2 MGy
- Fluence Φ dominated by neutrons (90%)
- Three sensor types for different Φ regions
  - 120µm (HD): $1x10^{16}\ n_{eq}/cm^2$
  - 200µm (LD): $2.5x10^{15}\ n_{eq}/cm^2$
  - 300µm (LD): $5x10^{14}\ n_{eq}/cm^2$
- A full campaign was done on 6" sensors



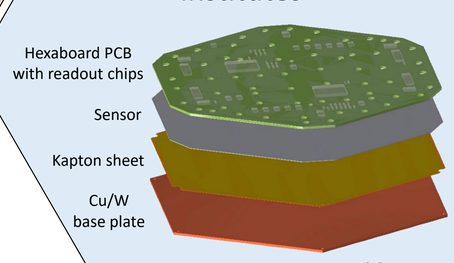
FLUKA study on expected hadron fluences during 10-year operation of the HGCAL [1]



Signal (ke⁻) from TCT measurements for different sensor thicknesses and fluences, 600V [4]

Outlook

- > **600m²** sensors will be produced and tested by **Hamamatsu Photonics**, CMS collaboration will test 2-5%
- **30,000 modules** will be assembled by CMS institutes



Module stack [1]

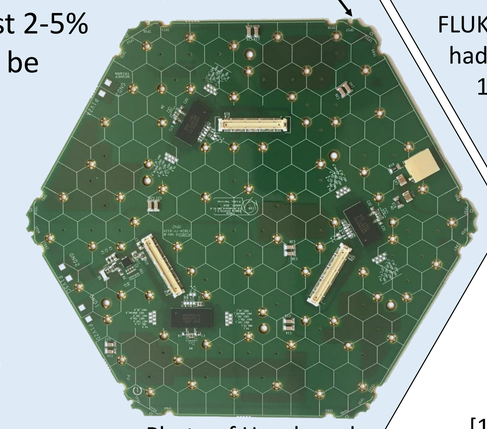


Photo of Hexaboard PCB

Production schedule for HGCAL sensors

About the author

Peter Paulitsch
Institute of High Energy Physics
of the Austrian Academy of Sciences
Nikolsdorfer Gasse 18, A-1050 Vienna
peter.paulitsch@cern.ch
Tel.: +43 (1) 5447328 - 41

References

[1] CMS Collaboration, *The Phase-2 Upgrade of the CMS Endcap Calorimeter, Technical Design Report*, 2017
[2] E. Brondolin et al., *ARRAY: An open source, modular and probe-card based system with integrated switching matrix for characterisation of large area silicon pad sensors*, Nucl. Instrum. Methods A A940 (2019) pages 168-173
[3] V. Hinger, *Process quality control strategy for the Phase II upgrade of the CMS tracker and endcap calorimeters*, HSTD12, 2019
[4] M. Valentan, *The CMS high granularity calorimeter for the high luminosity LHC*, Nucl. Instrum. Methods A A936 (2019) , page 103