Sensors for the CMS High Granularity Calorimeter

INSTR17 at BINP, Novosibirsk

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on behalf of the CMS Collaboration

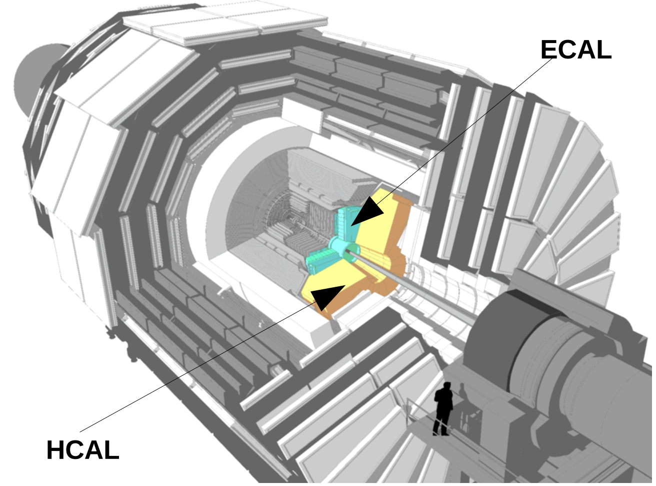
Wed, March 1, 2017

The CMS HGCAL project

Answer to HL-LHC challenges:

- **Pile-up:** up to μ=200
  - timing information valuable for mitigation
- **Radiation exposure:** up to 10^{16} neq/cm^2
  - Si well studied and under control for high fluences

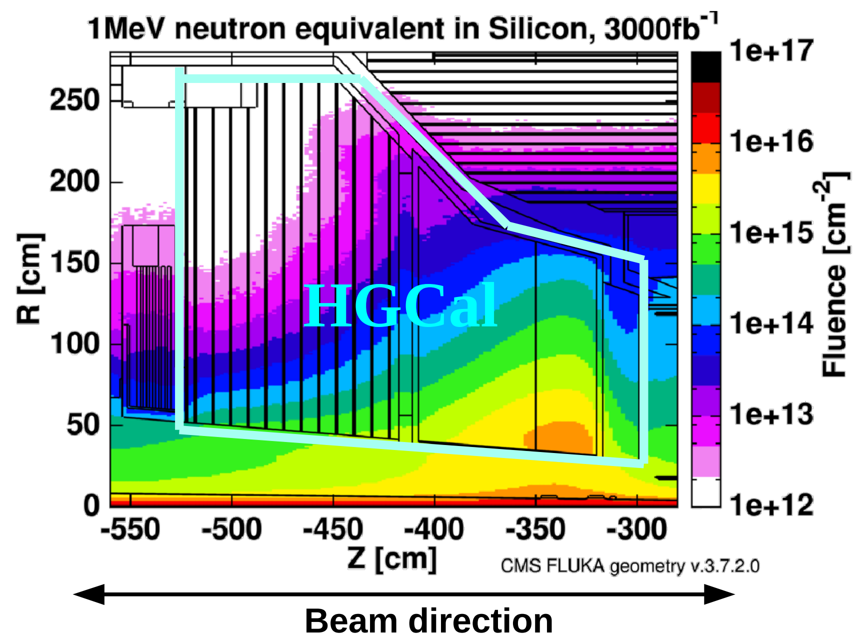
➔ replace entire endcap calorimeter, with a radiation-hard, fast timing, **High Granularity Calorimeter (HGCAL)**



Project details:

- High granularity sampling calorimeter for particle flow (as studied by CALICE)
- Active development in
  - TDAQ
  - electronics architecture
  - particle flow reconstruction and physics performance
- TDR by end of 2017

Technical proposal: https://cds.cern.ch/record/2020886/files/LHCC-P-008.pdf



ECAL: Electromagnetic CALorimeter HCAL: Hadronic CALorimeter neq: 1 MeV neutron equivalent	CALICE: CAlorimeter for Linear Collider Experiment TDR: Technical Design Repori TDAQ: Trigger and Data AcQuisition

The CMS HGCAL layout

Active Elements:

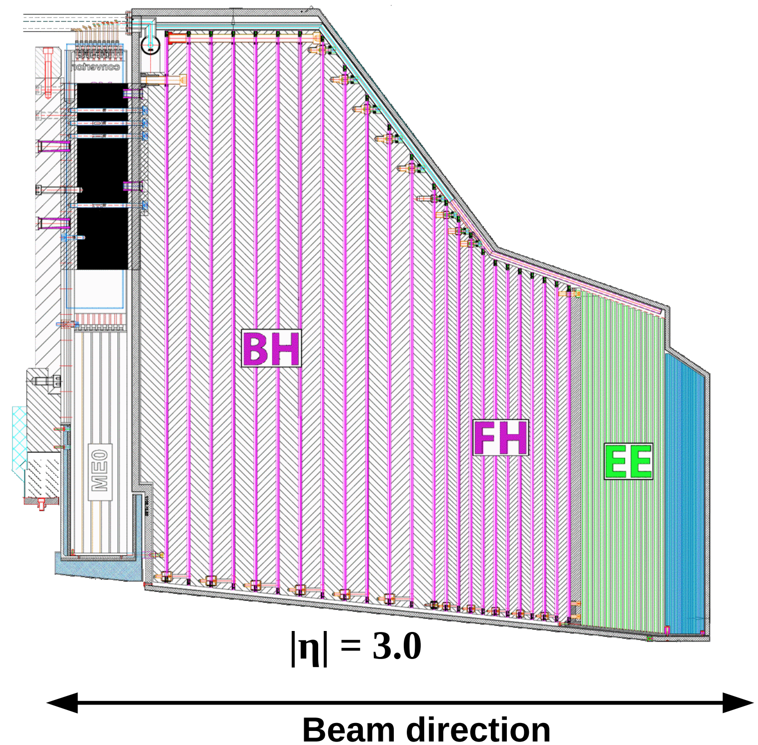
- Hexagonal Si sensor modules consisting of several 100 hexagonal sensor cells
- “Cassettes”: multiple modules mounted on cooling plates with electronics and absorbers
- Scintillating tiles with SiPM readout in low-radiation regions

Key parameters:

- 600 m^2 of silicon
  - hexagonal shape saves space on wafer
- Power at end of life ~60 kW per endcap
  - 25% due to leakage current
- CO_2-cooled operation at -30°C

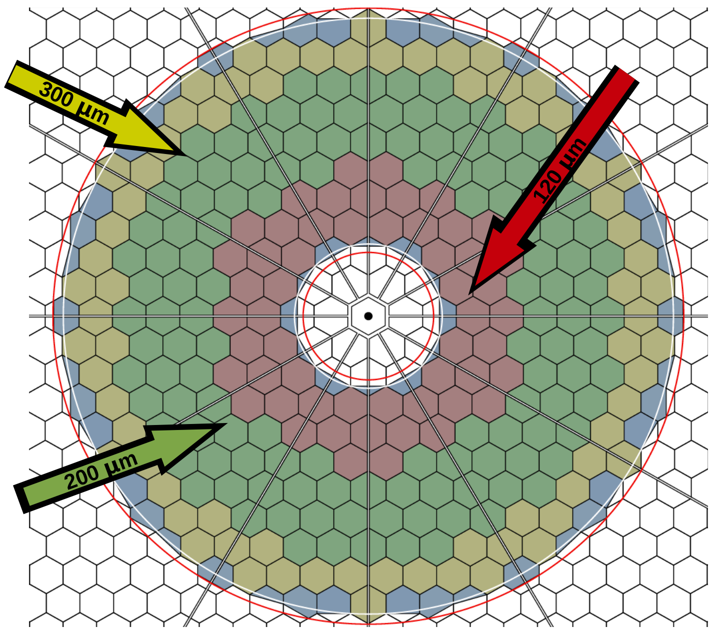
Main components:

- EE – Si, Cu & CuW & Pb absorbers
  - 28 layers: 25 X_o + ~1.3 λ
- FH – Si & scintillator, steel absorbers
  - 12 layers: ~3.5 λ
- BH – Si & scintillator, steel absorbers
  - 11 layers: ~5.5 λ

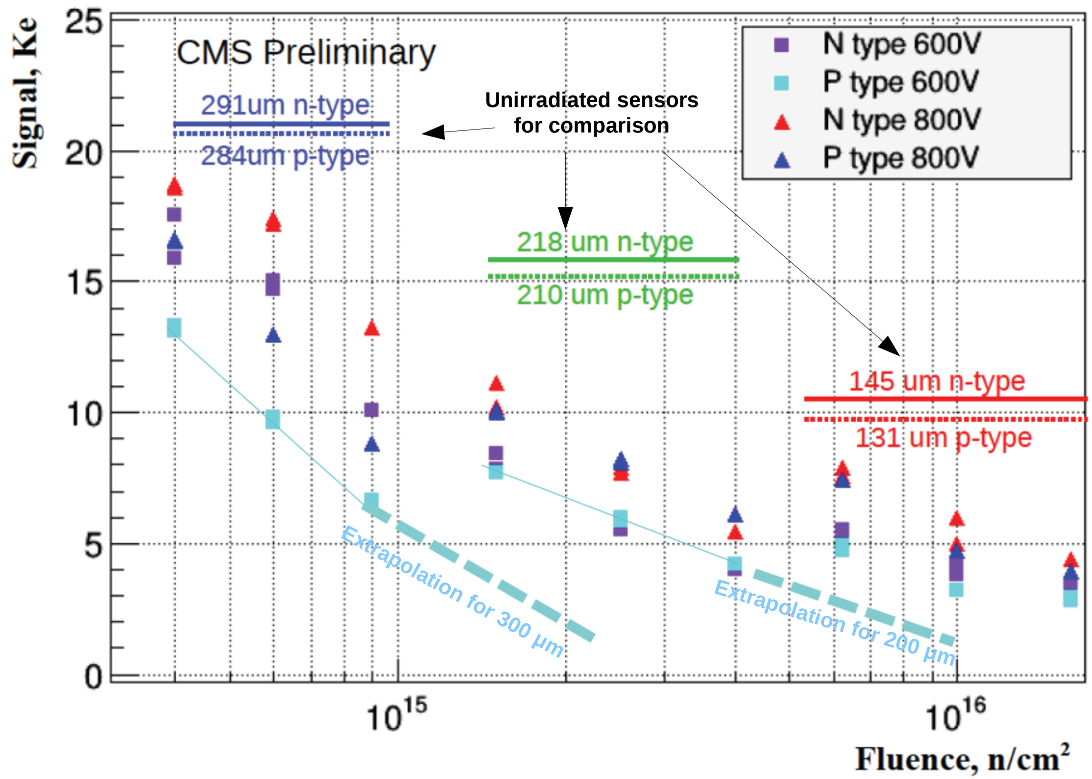


SiPM: Si PhotoMultiplier
BH: Backing HCAL
FH: Front HCAL
EE: Endcap ECAL
ASIC: Application-Specific Integrated Circuit

The HGCAL design

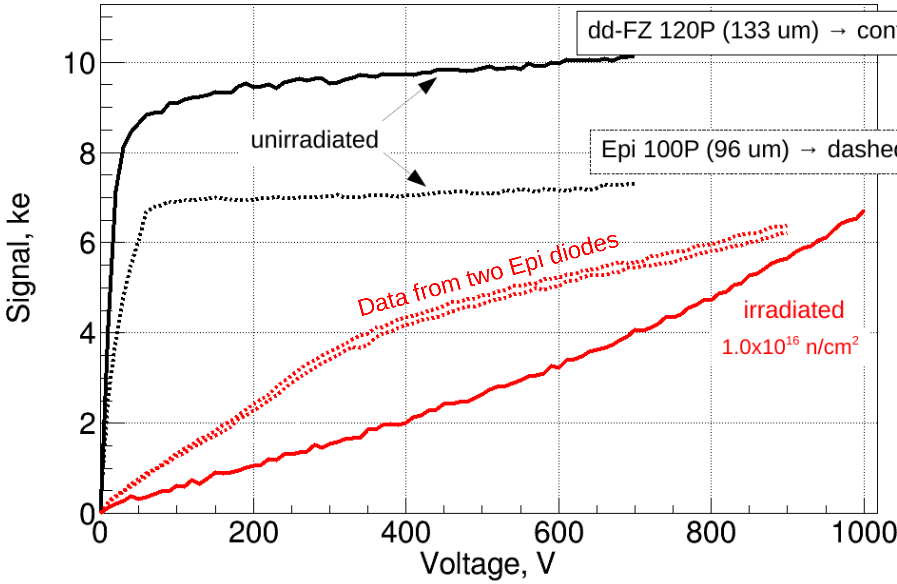


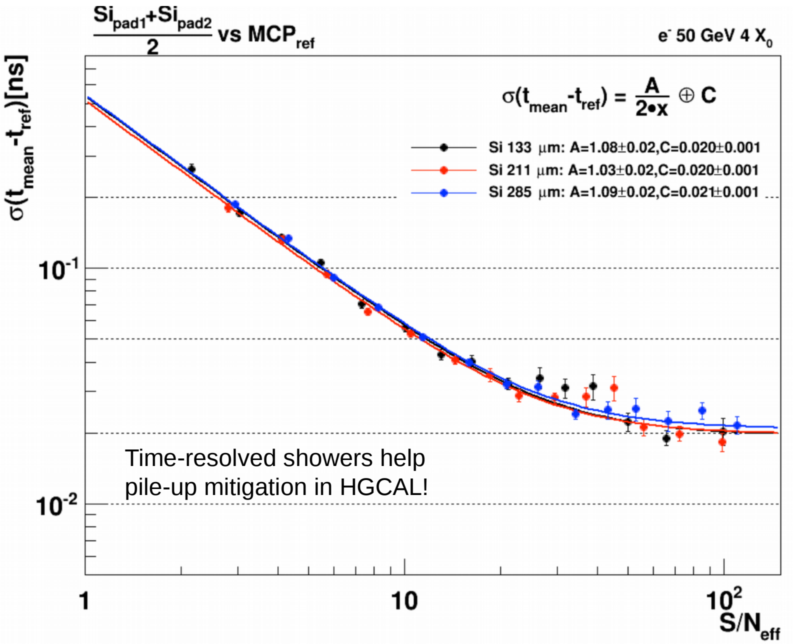
Full HGCAL cut in x-y plane



- Thinner Si sensors for high fluence regions → better signal at high fluence
  - high-η region: sensors with **120 µm** active thickness
  - lower-η regions: **200 µm** & **300 µm** active thickness
- Smaller cell size in central region → less occupancy, less noise

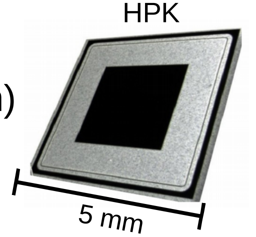
Single diode tests





Measured properties:

- Bulk current → power consumption, noise
- Capacitance
- CCE with laser signal
- MIP studies with beta source
- Timing performance (test beam)
- Effects of annealing



First irradiation results:

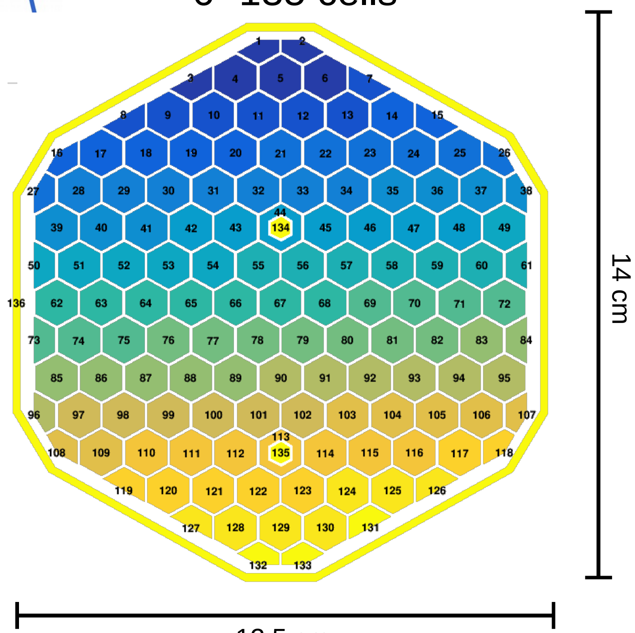
- Good signal at 1x10[16] neq/cm[2] within voltage range!
- Single MIP signal is resolvable from noise
- Intrinsic timing resolution of
  - < 50 ps for S/N > 10
  - ~20 ps for S > 20 MIPs

dd: deep diffusion
FZ: Float Zone
EPI: Epitaxial growth
CCE: Charge Collection Efficiency
HPK: Hamamatsu
MIP: Minimum Ionizing Particle
MCP: Micro-Channel Plate
S: Signal
N: Noise

See Esteban Curras Rivera's contribution for the IPRD16 conference for more details on the diode tests

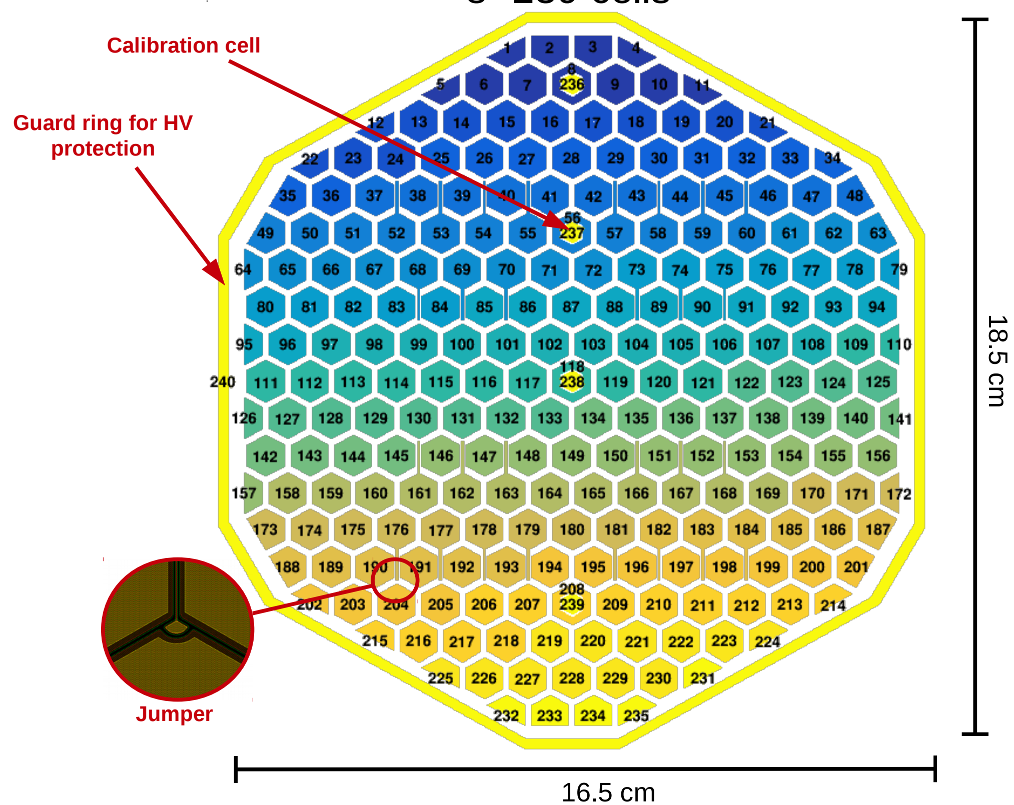
Sensors for HGCAL

6” 135 cells



Shown here: HPK layout for 200/300 µm wafers. The 120 µm versions have about twice the number of cells.

8” 239 cells



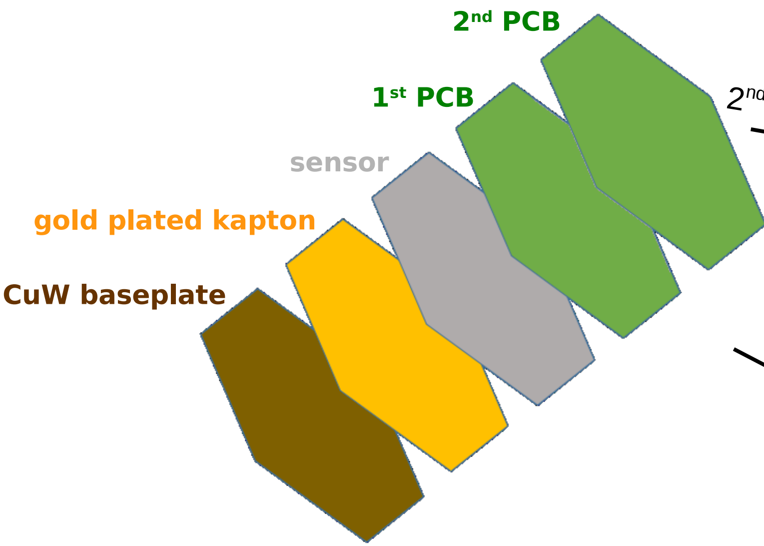
Detector optimization ongoing:

- Wafer size (6” or 8”)
- Contact pad layout for wire bonding (e.g. jumper cells)
- Sensor type (n-in-p or p-in-n)
- Interpad distance

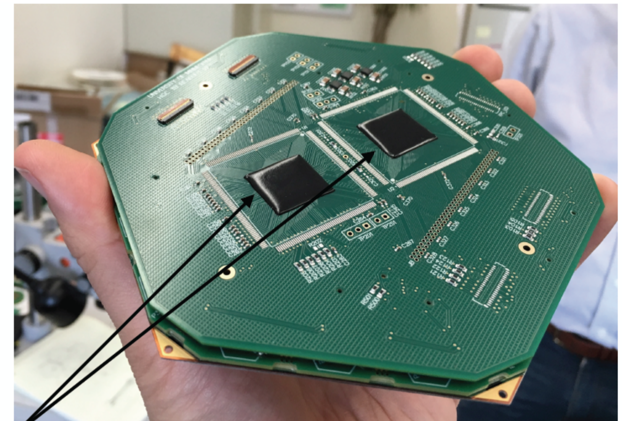
Ongoing activities:

- (Automated) sensor tests
- Design studies for TDR
- p-stop layout validation
- Radiation testing

Modules for HGCAL

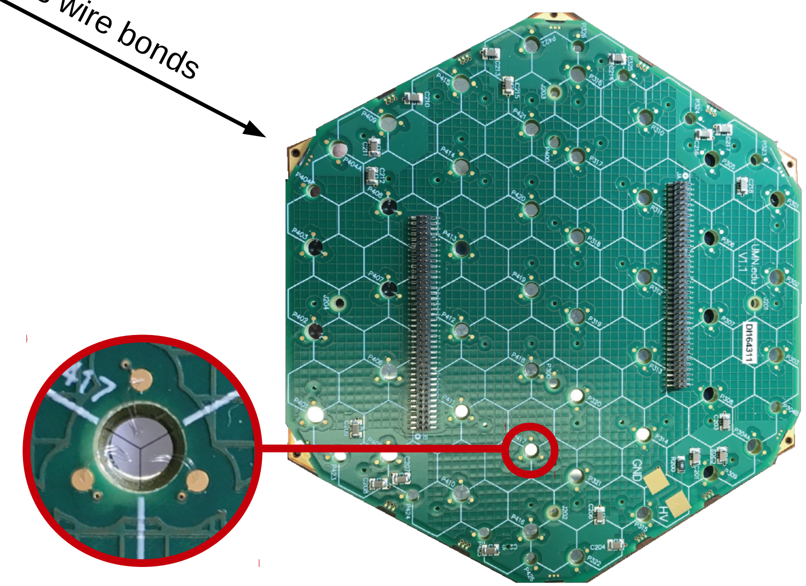


2nd PCB holds readout chips



SKIROC 2 ASIC will be replaced by SKIROC2-CMS chip for future production

1st PCB holds wire bonds



- Two PCB design chosen for 2016 for beam tests
  - different chips can easily be mounted
  - ~700 deep wire bonds on 6” module
- New SKIROC2-CMS hexabord is on a single PCB

PCB: Printed Circuit Board

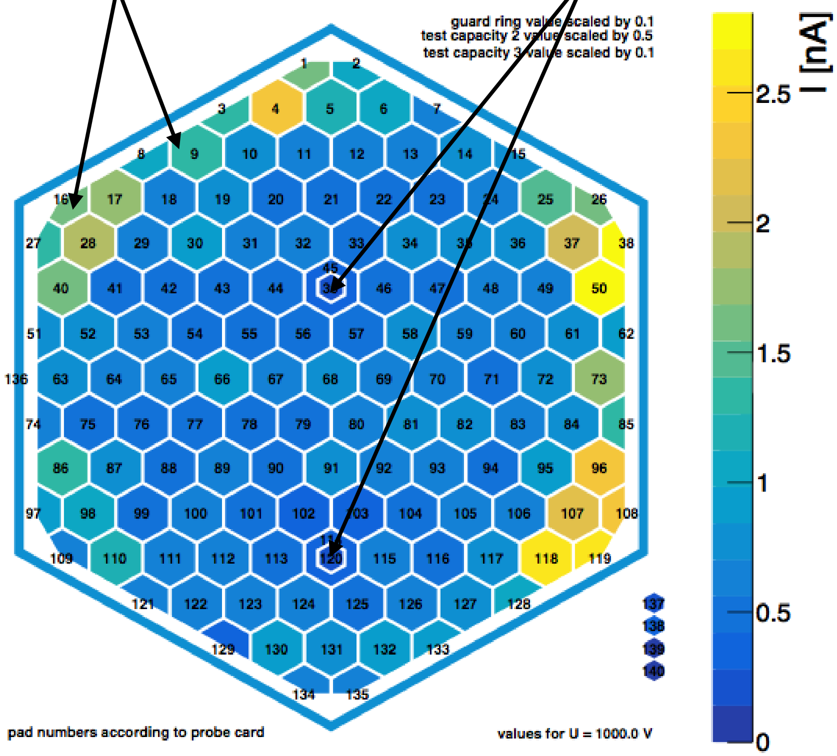
Full wafer measurements

6“ 135 pad HPK sensors measured at FNAL

Leakage current

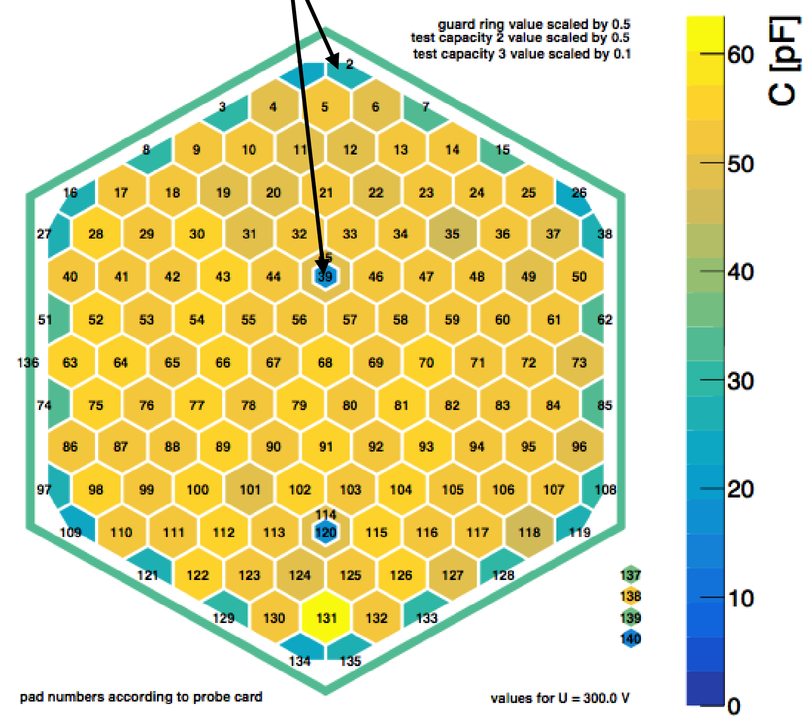
Higher leakage currents in the edge region

Lower leakage currents in the calibration cells



Capacitance

Mouse bites & calibration cells show lower capacitances than full cells (smaller size)

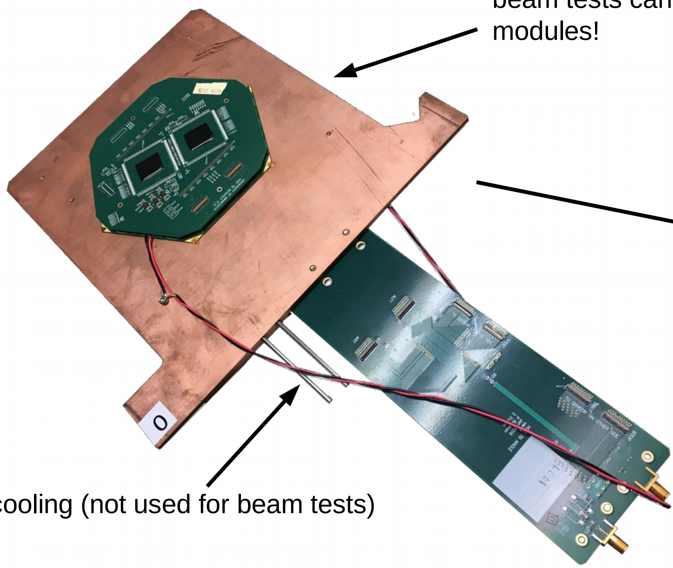


- Detector conditions: all cells biased by probe card
- Excellent performance of the tested wafers
  - behavior as expected for IV and CV measurements
  - no breakdown until 1000 V bias voltage observed among all tested sensors

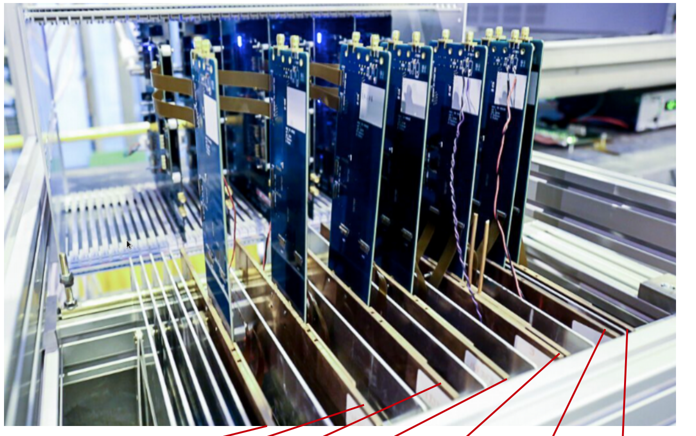
For more information on the probe card, see backup

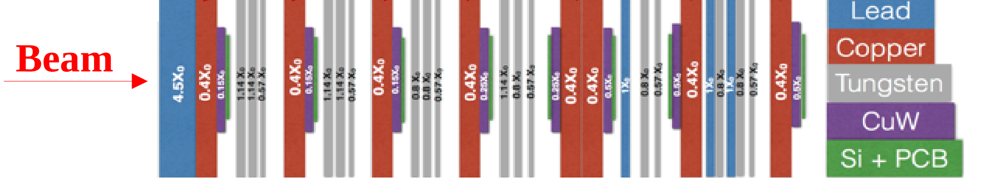
2016 beam tests

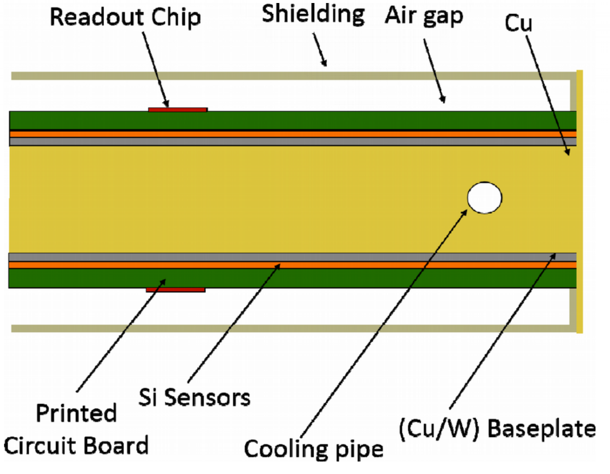
This double casette for beam tests carries two modules!



CO_2 cooling (not used for beam tests)







- Cassettes consist of
  - one ore two modules mounted
  - on absorber plates with electronics and cooling
- Can be easily stacked and removed from frame
- Mechanics as well as DAQ is designed scalable

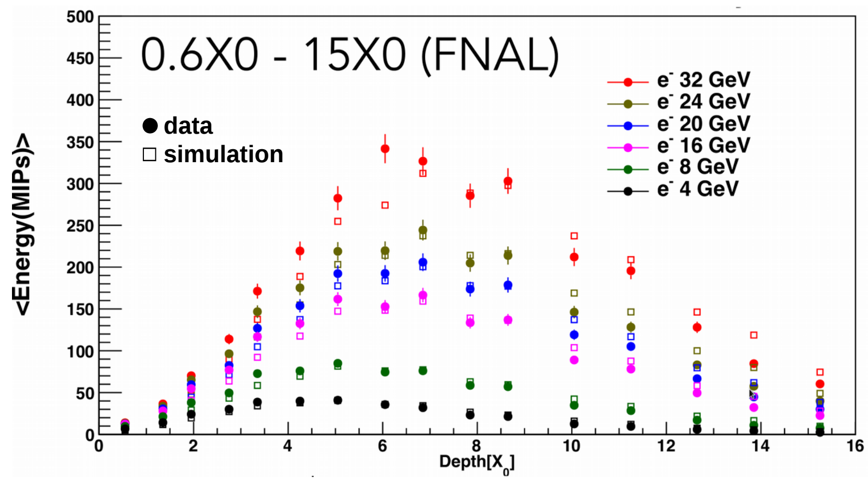
The test beam setup

FNAL

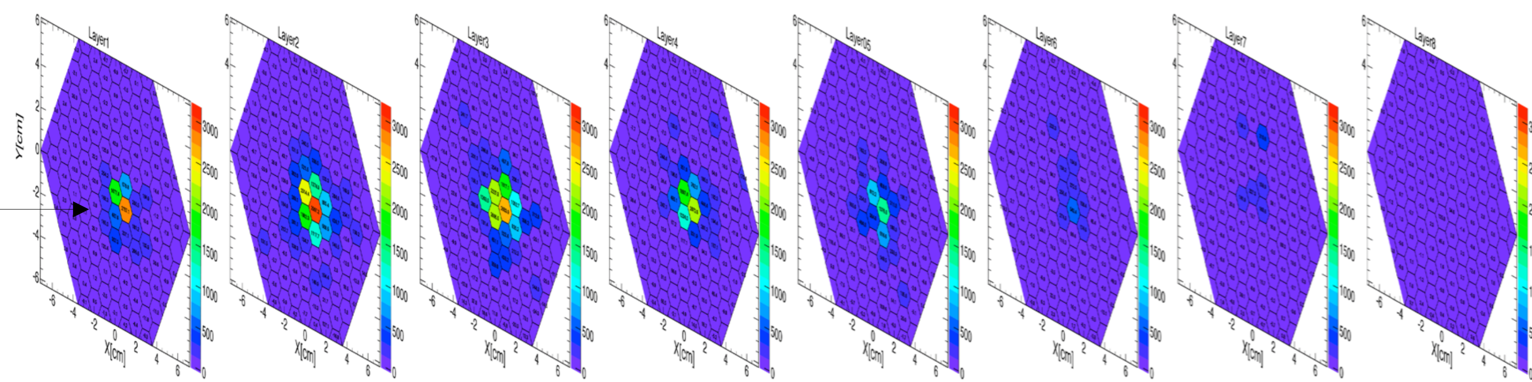
- Up to 16 HGCAL modules tested
- e^- beam at 4-32 GeV
- Protons at 120 GeV
- 0.6-15 X_0 absorber configuration

CERN

- Up to 8 HGCAL modules tested
- π/μ at 125 GeV
- e^- beam at 20-250 GeV
- 6-15 X_0 and 5-27 X_0 absorber configurations



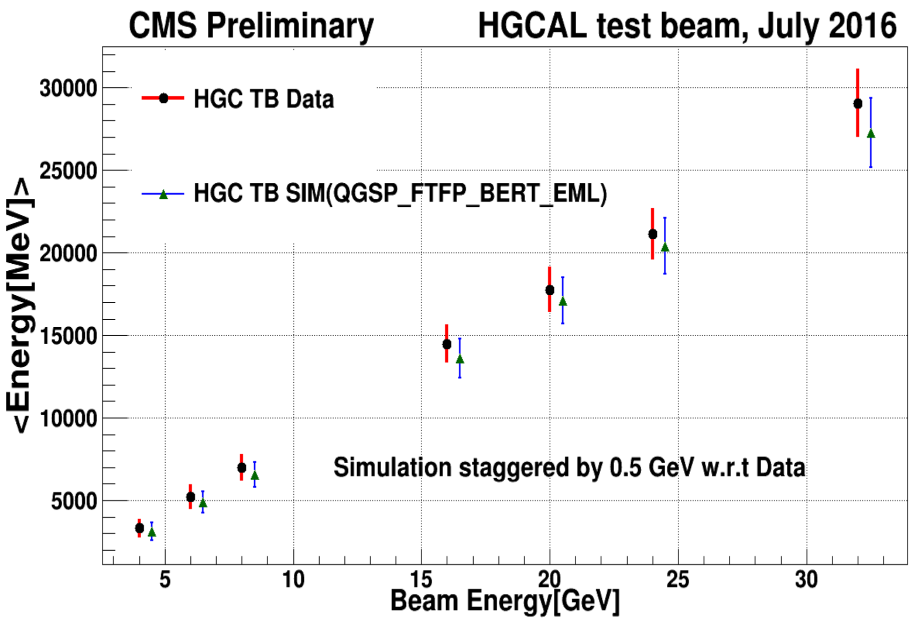
250 GeV e^-

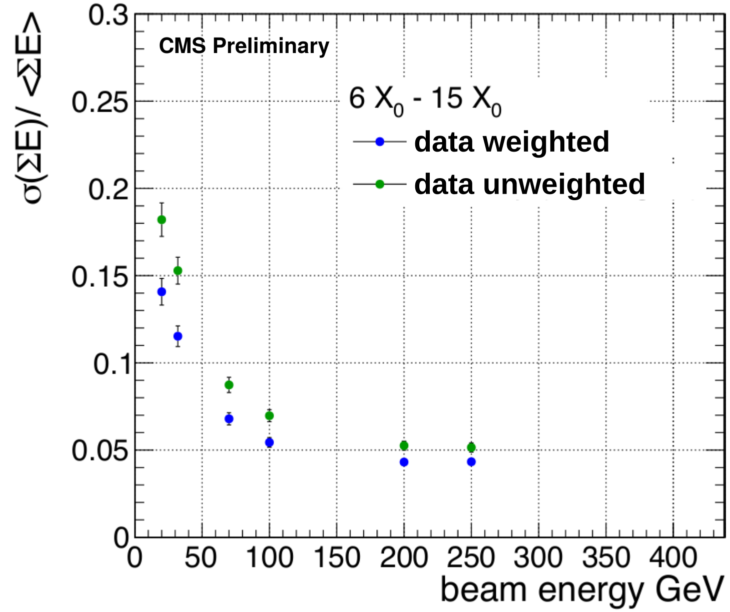


$5X_0$ $8.5X_0$ $12X_0$ $15X_0$ $17X_0$ $19X_0$ $21X_0$ $27X_0$

Electron showers passing through 8 layers (27 X_0)

Test beam results





Results

- Energy response is linear
- Shower profile and energy resolution agree well with simulation
- dE/dx weighting improves energy resolution by ~20%

Series of beam tests planned for 2017

TB: Test Beam
FTFP_BERT_EMM: A fast electromagnetic shower model optimised for CMS HCAL

Conclusions

- Good progress on the way to a full HGCAL
- Series of beam tests to understand and demonstrate detector performance
- Sensor testing ongoing
- Potential timing precision of < 50 ps
- Main design decisions in the coming months leading to TDR end of 2017

Thank you for your attention!

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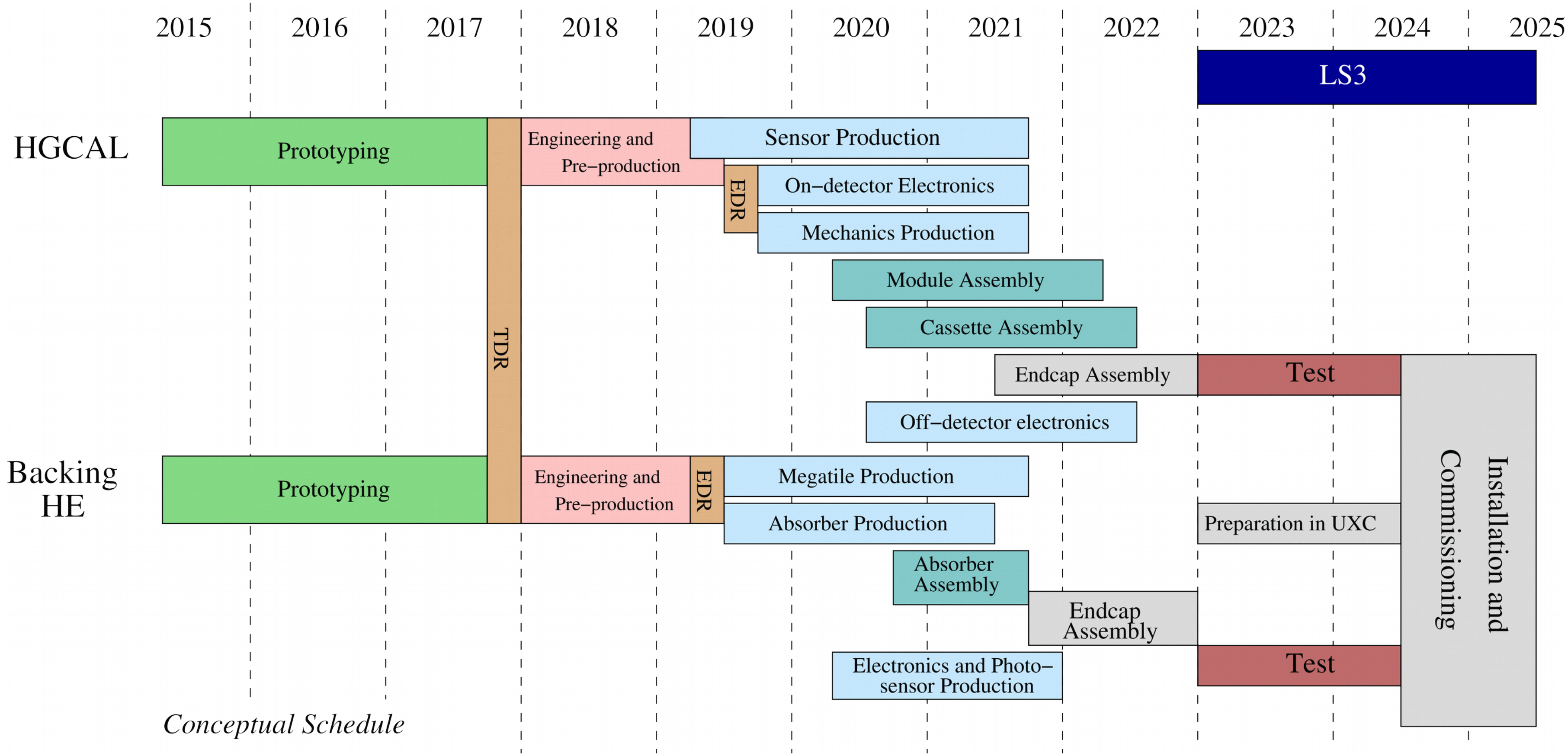
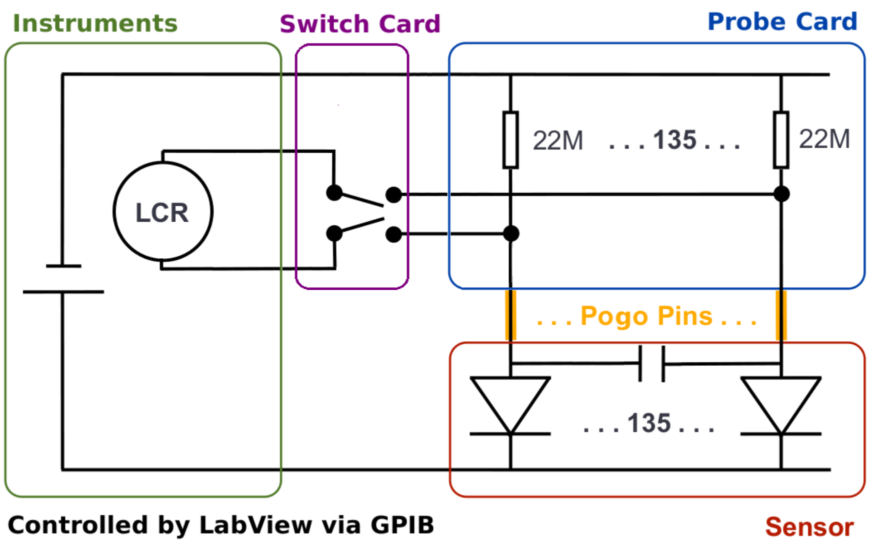
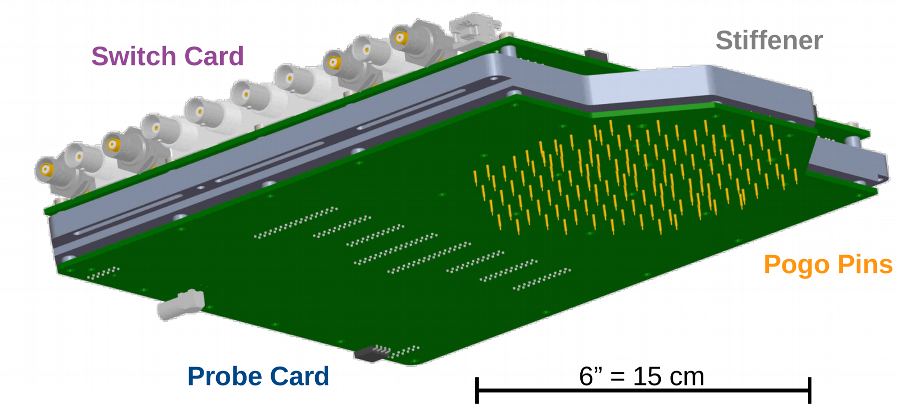
Backup - The HGCAL schedule



Backup - Full wafer test setup





- Bias all sensor cells during the tests at the same time for realistic test conditions
  - contact and bias all cells at the same time using probe card
  - spring-loaded pins (pogo pins) for uniform contact over whole plane
- Depending on the sensor layout, test 128 up to 512 channels
- Newly designed switching matrix placed as a plugin card on top of the probe card

GPIB: General Purpose Interface Bus