Characterization of silicon sensors for high-granularity calorimeters at CERN

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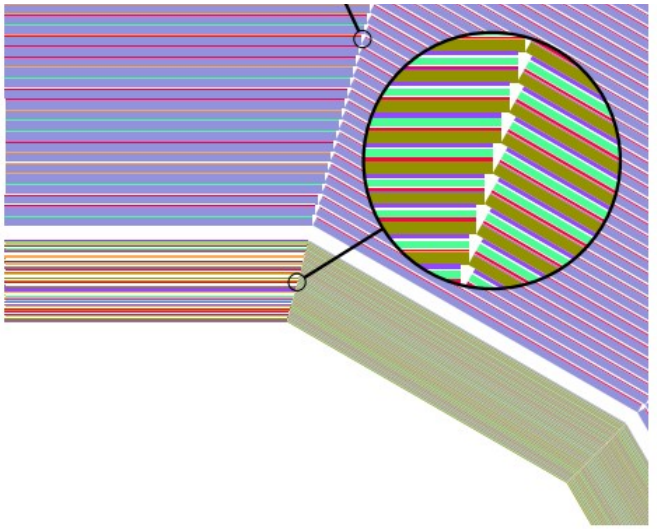
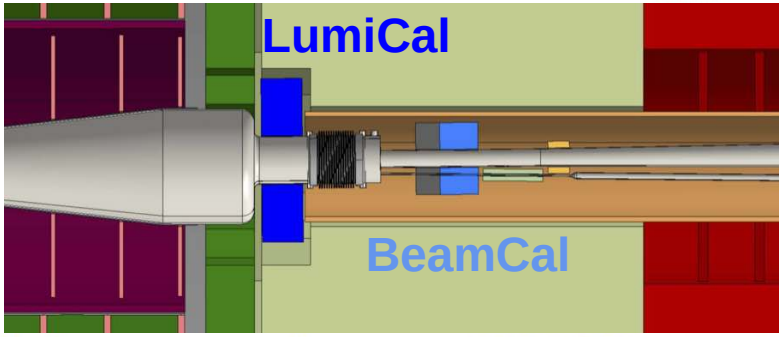
CLIC Detector and Physics Collaboration Meeting
29th August 2018

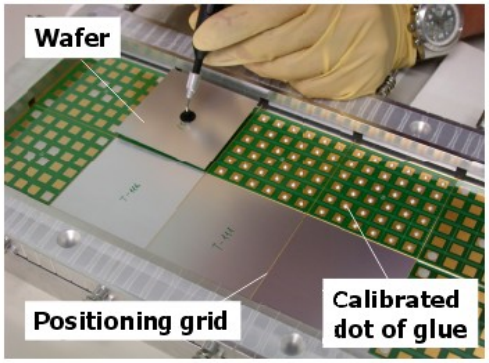
CLICdet Calorimeters

- Jet energy resolution drives the design of CLIC calorimeters → Particle Flow Analysis → Highly granular calorimeters
- **CLICdet calorimeters** (active material): **ECAL** (Si), **HCAL** (Scint), **LumiCal** (Si) and **BeamCal** (GaAs or Diamond)
- Hardware R&D by **CALICE and FCAL** collaborations
- Synergy with **ILC** (ILD/SiD) and **CMS HGCal**
- In this talk, only Si-based calo

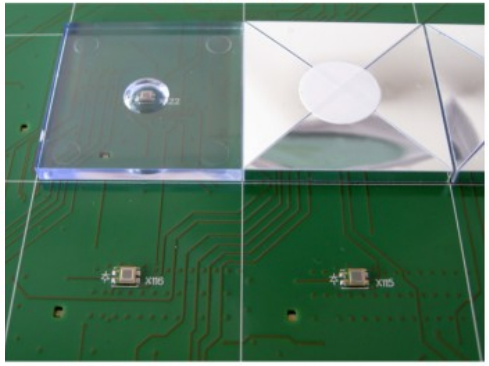




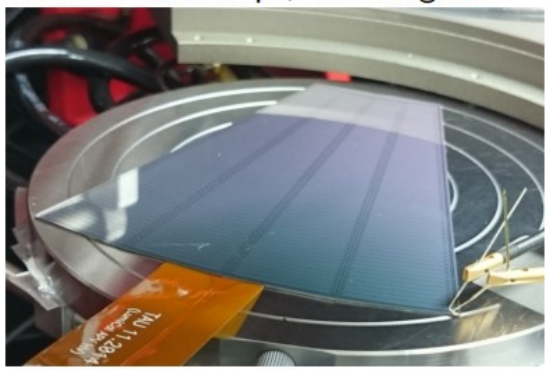
CALICE silicon PIN diodes
$1 \times 1\,\mathrm{cm}^2$ in 6×6 matrices



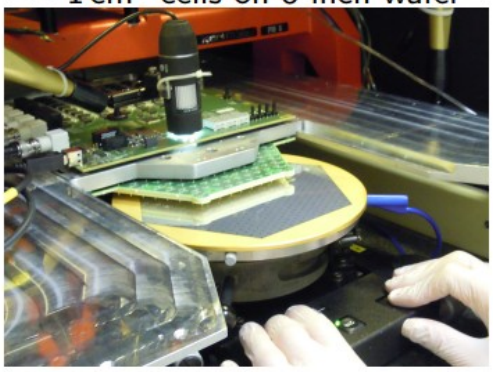
CALICE scint. tiles + SiPMs
$3 \times 3\,\mathrm{cm}^2$



LumiCal silicon sensor petal
1.8 mm wide strips, diff. lengths



CMS HGCal silicon diodes
$\sim 1\,\mathrm{cm}^2$ cells on 8-inch wafer



CMS-CLIC synergies

The CMS HGCal upgrade

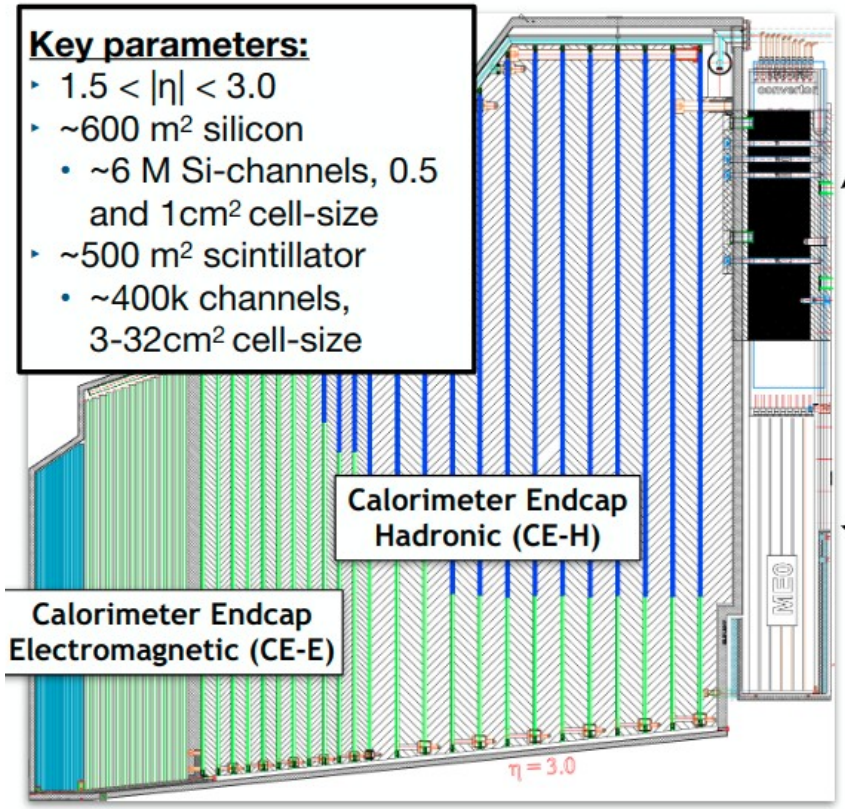
TDR link

Calorimeters designed for radiation dose equivalent to 500fb^{-1}.

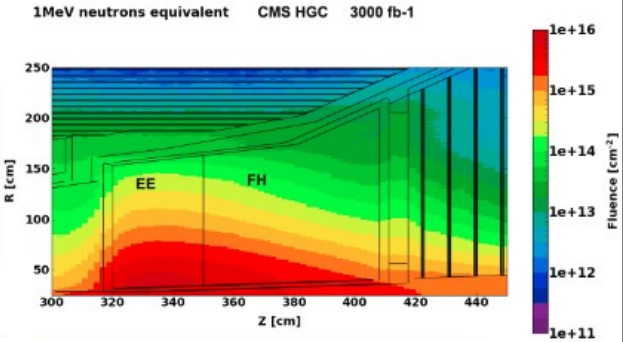
➡ Replacement of CMS' complete endcap calorimeter during HL-LHC upgrade.

HL-LHC Conditions (~2025-2035)

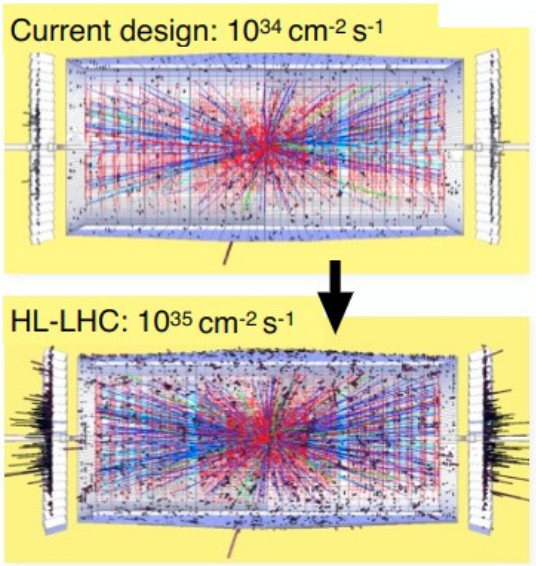
Key parameters:
- 1.5 < |η| < 3.0
- ~600 m^2 silicon
  - ~6 M Si-channels, 0.5 and 1cm^2 cell-size
- ~500 m^2 scintillator
  - ~400k channels, 3-32cm^2 cell-size



Radiation hardness



Increased pileup



Thorben Quast - 29.08.2018 2

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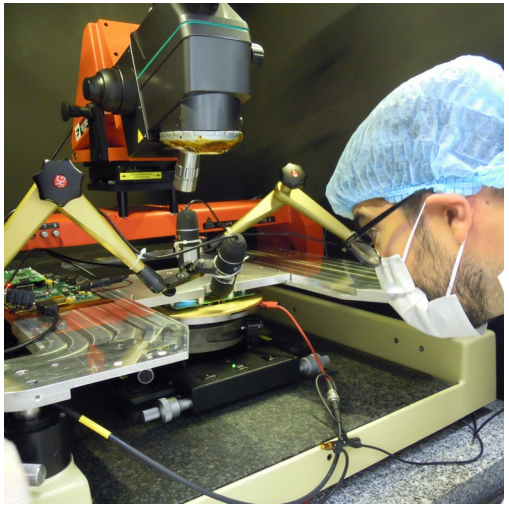
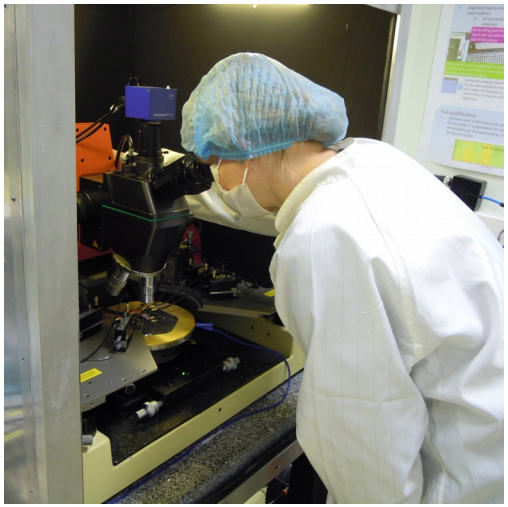
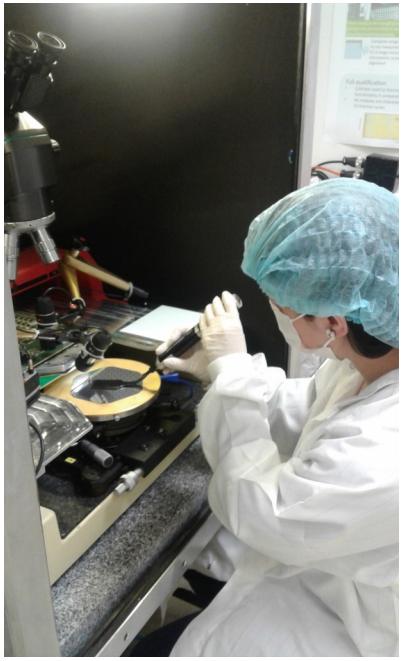
CMS-CLIC synergies

- Similar high granularity calorimeter **concept** and sensor **technology** foreseen
  - CMS HGCal: Silicon cells with size ~0.5 – 1 cm^2
  - CLICdet ECAL: Silicon cells with size ~5 x 5 mm^2
- Some CLICdet challenges (ex. power pulsing, cooling) are not covered by CMS HGCal, but are addressed within CALICE
- **Both CLIC and CMS members** take part in the sensor testing activity at CERN
- **Outside CERN:**
  Sensor testing for HGCAL on-going also at HEPHY (Vienna) and Fermilab (US)







Sensor characterization

- **On-going/future activities:**

  - Electrical sensor characterization (IV+CV): Study voltage dependence of leakage current, capacitance, inter-pad capacitance and resistance
  - Study noise behavior and charge collection efficiency
  - Development and characterization of measurement setups for studying radiation effects on full sensors
  - Software development and analysis of sensor data

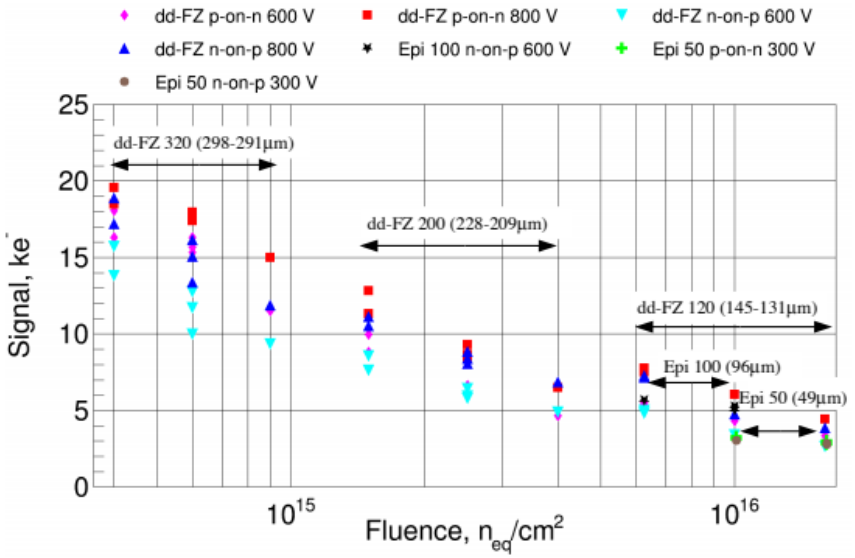


Figure 2.1: Signal (ke^-) versus neutron fluence, extracted from transient current technique measurements, described in Section 7.1.3. The range of fluences includes the maximum expected exposure after 3000 fb^{-1}. The arrows indicate the thickness of the different samples, the corresponding MIP charge yield before irradiation. The charge collection results are shown at 600 V and 800 V for the ddFZ diodes of 300 μm, 200 μm and 120 μm nominal thickness, at 600 V for the 100 μm epitaxial, and at 300 V for the 50 μm epitaxial diodes.

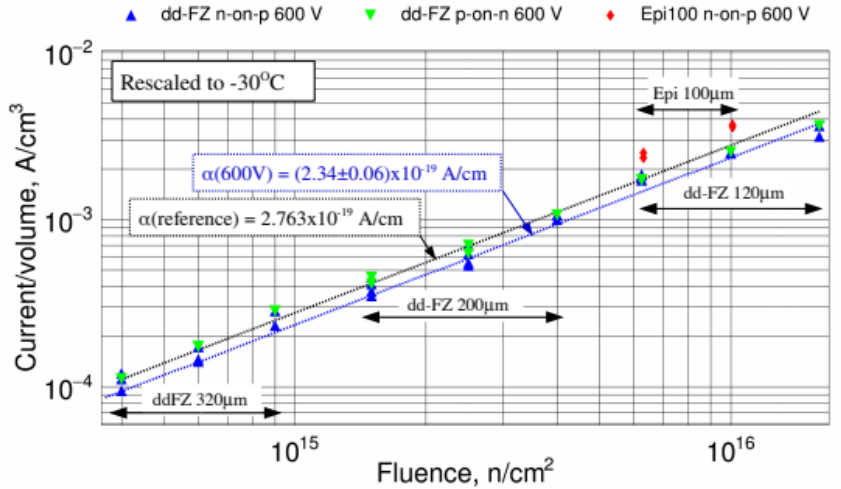


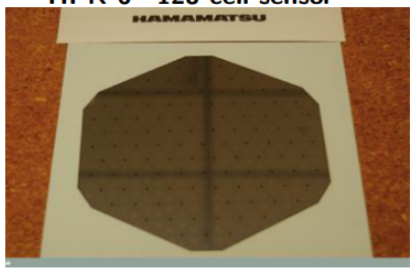
Figure 2.2: Leakage currents, as a function of neutron fluence, measured at −20 °C and rescaled to −30 °C at a bias voltage of 600 V. The arrows indicate the thickness of the different samples, and the range of fluences to which each sample was exposed.

Diodes irradiation results (TDR link, Curras PhD Thesis)

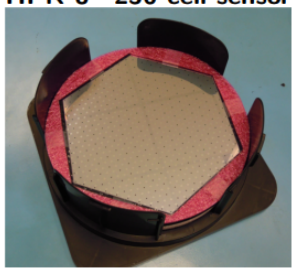
Sensor prototypes

- **Silicon sensors available for testing:**

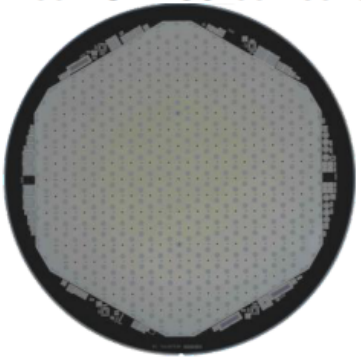
HPK 6'' 128-cell sensor



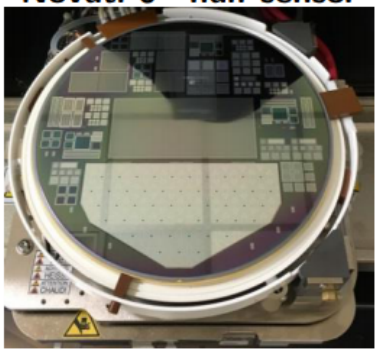
HPK 8'' 256-cell sensor



Infineon 8'' 256-cell sensor



Novati 6'' half-sensor



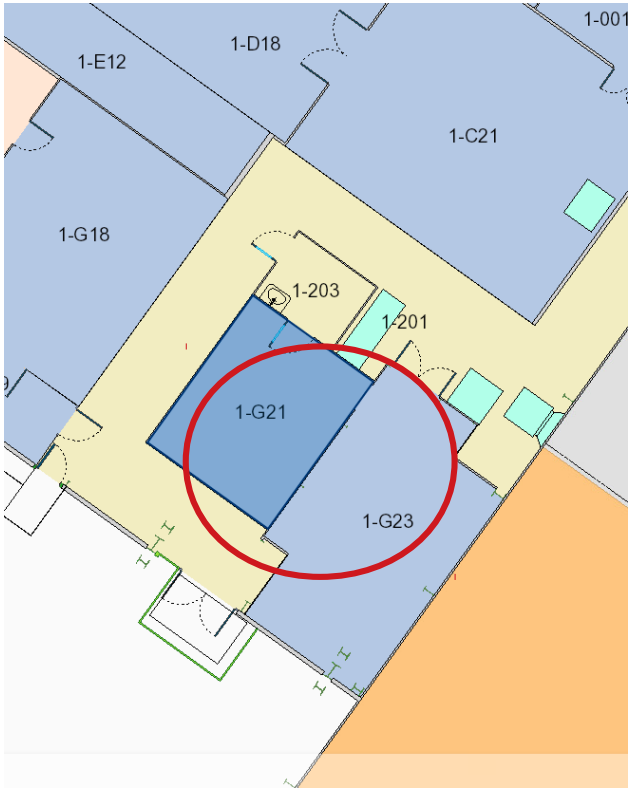
- **Hamamatsu (HPK), Japan**
  - several 6'' with different diffusion techniques, thicknesses, n- and p-types, geometries, p-stop options
  - several 8'' prototypes
  - electrical sensor characterization on-going (or complete) for ~40 sensors
  - 18 6'' sensors sent for irradiation campaign to Ljubljana

- **Infineon (IFX), Austria**
  - 25 8'' p-type prototypes
  - Currently tested at HEPHY, Vienna

- **Nhanced (Novati/Tezzaron), US**
  - 6'' half sensors on 8'' wafers
  - several 8'' prototypes
  - Currently tested in US

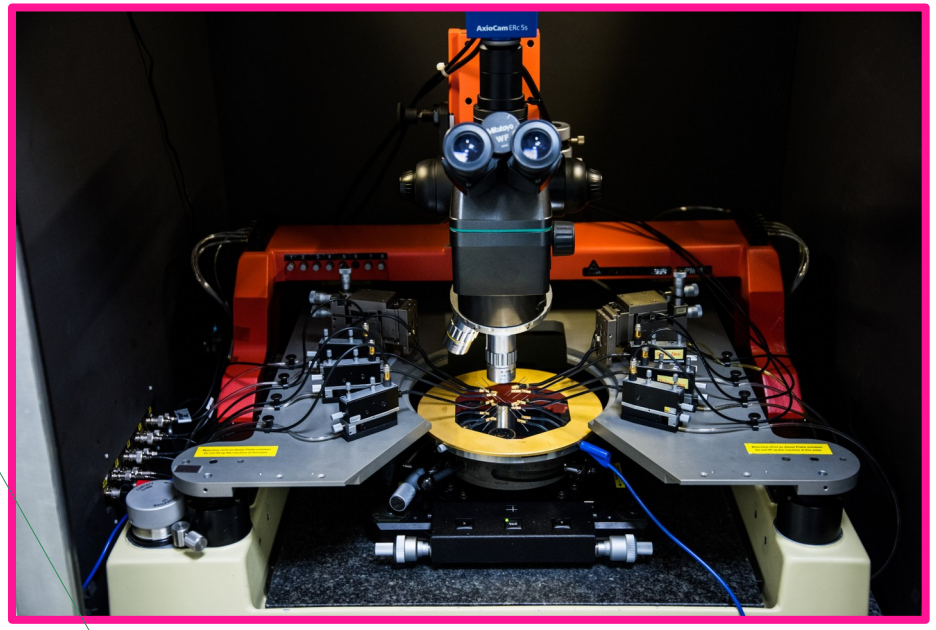
Setup at CERN

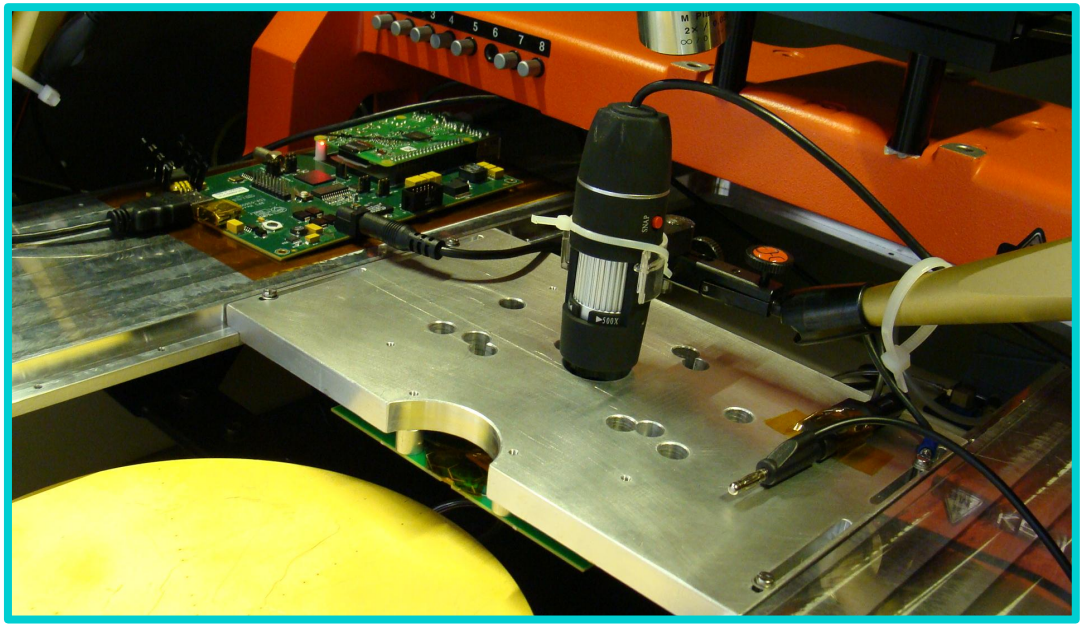
- New lab from June 2018 (Class: 10’000, Location: 186/1-G21+G23)
- **Started measurements on 10th August**
- Time needed between first discussion and first measurements: ~2.5 years
- Fully refurbished:
  New AC system, converted room G21 from tent into proper room, asbestos removal, new conductive floor, installed sink in SAS, partially new furniture , etc.

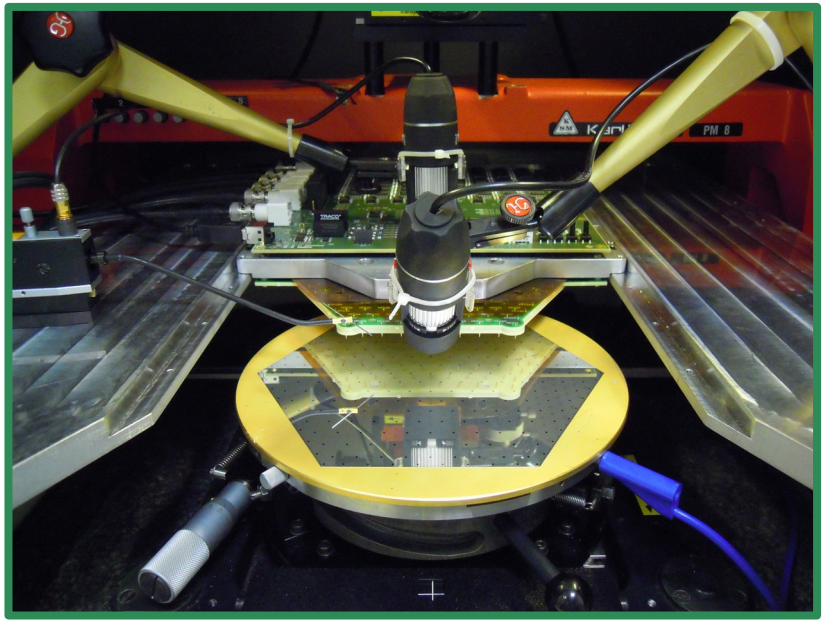


Setup at CERN

- **Tests have been made so far with a manual probe station**
  - single/multi-needle measurements
  - probe-cards + switch card for electrical characterization
  - readout PCB (Hexabord) for noise and charge collection measurements
- **HexDAQ: LabView / python-based DAQ**







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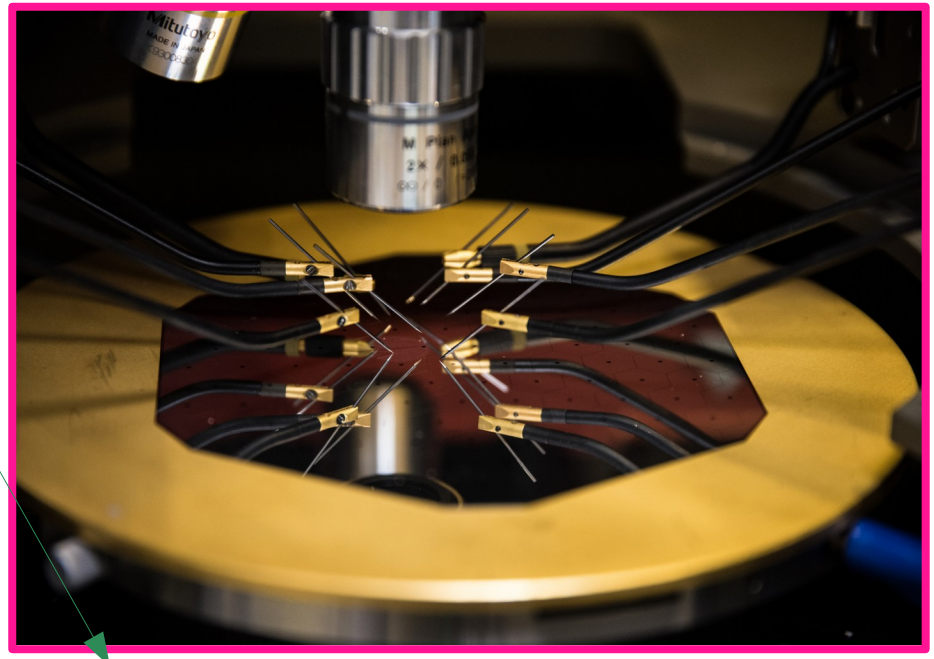
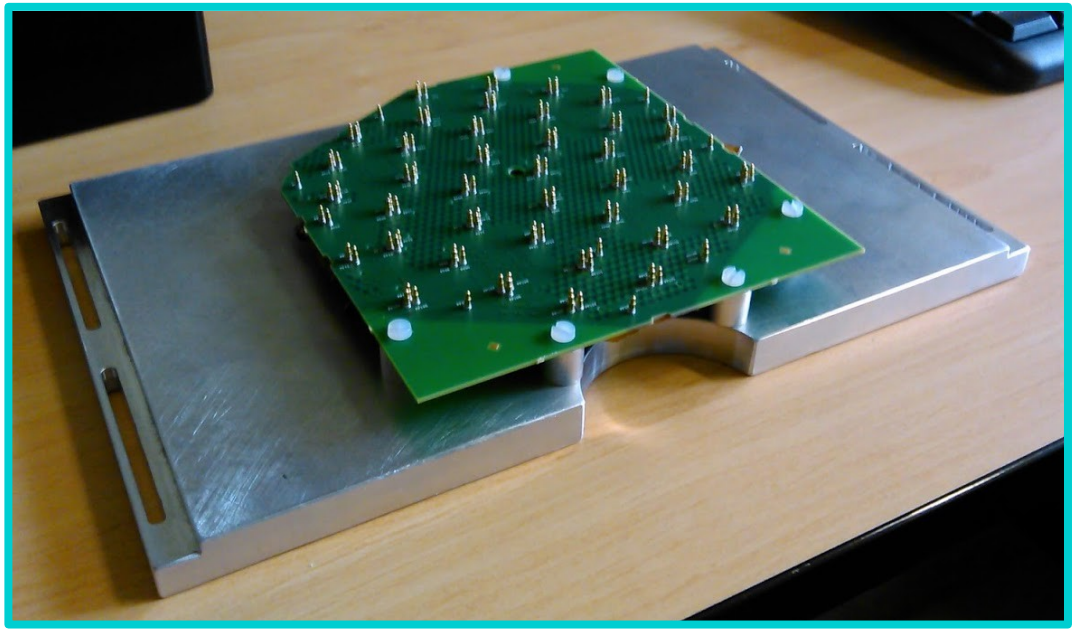
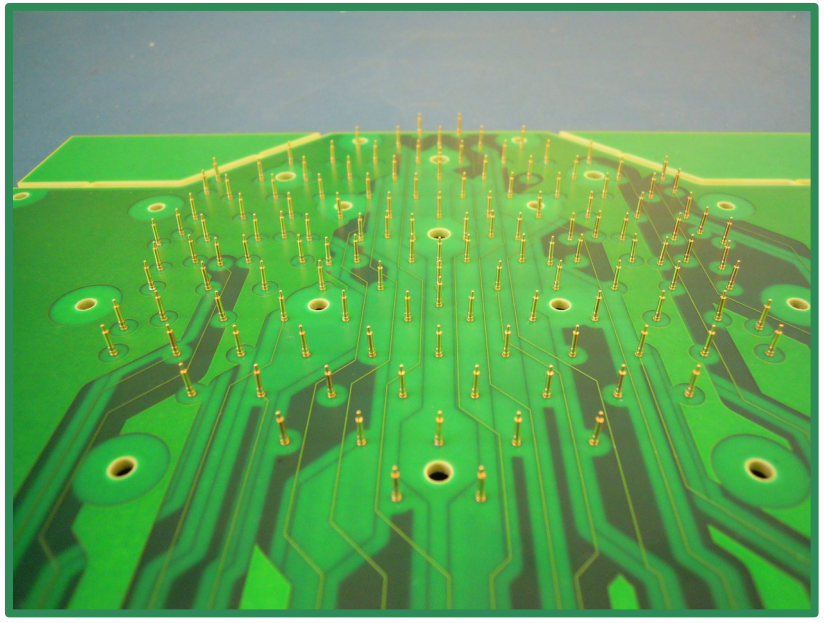


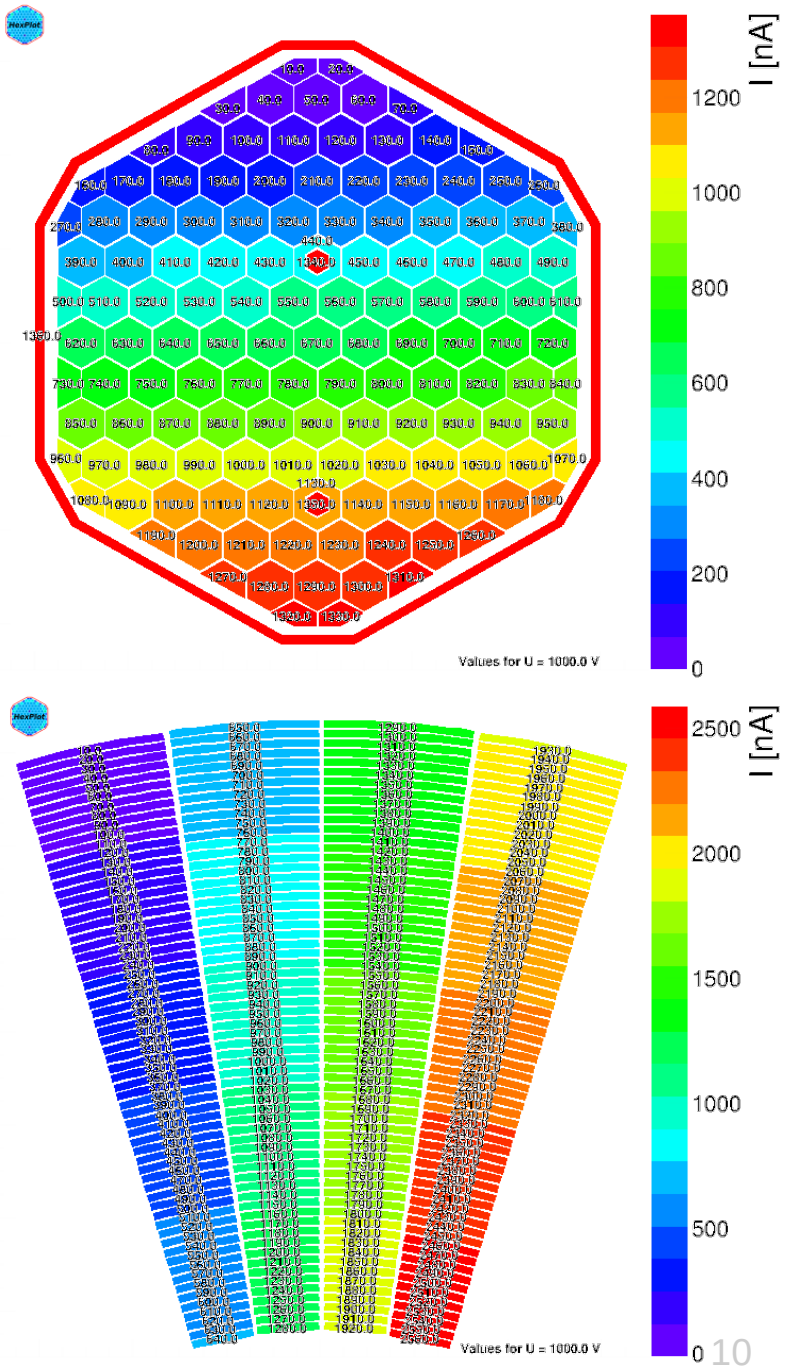




Analysis tools

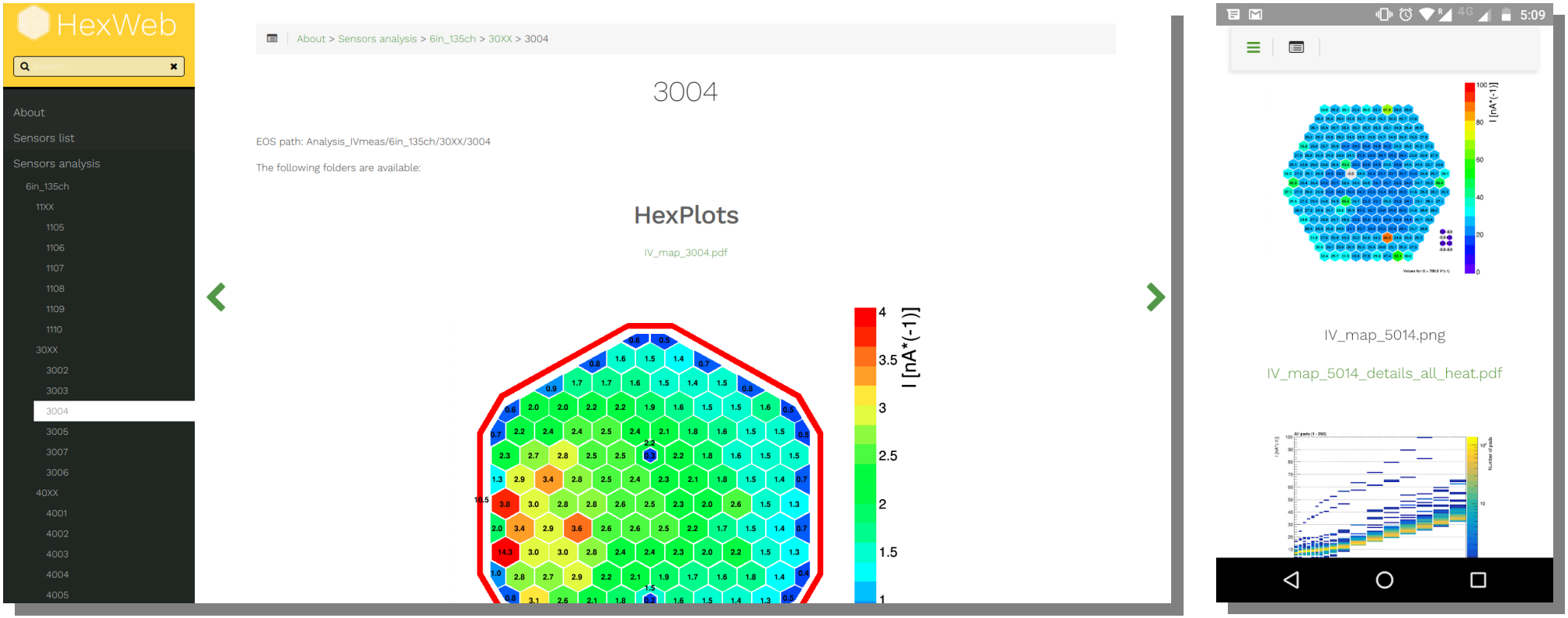
- **HexPlot**
  - A program to display data in geometrical shapes (HGCal sensors).
  - Possibility to plot maps and single cells graphs
  - Completely developed within the group, now used also at HEPHY
  - **GitLab repo**
  - Example:

  HexPlot -i examples/test_data.txt -g geo/hex_positions_HPK_128ch_6inch.txt -o example.pdf –IV



Database

- **HexWeb** (local database at for CERN group)
  - based on open-source static site generators Hugo

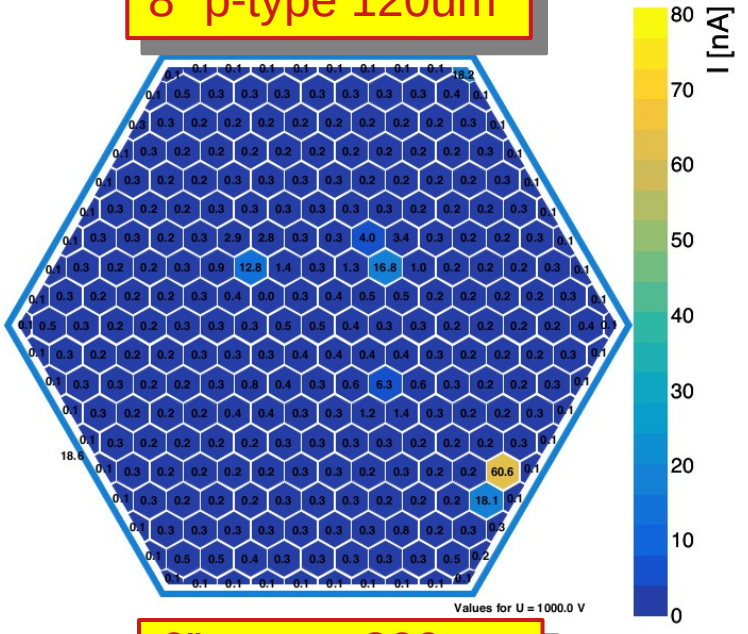


- Work on-going in global oracle-based database for all CMS HGCal sub components

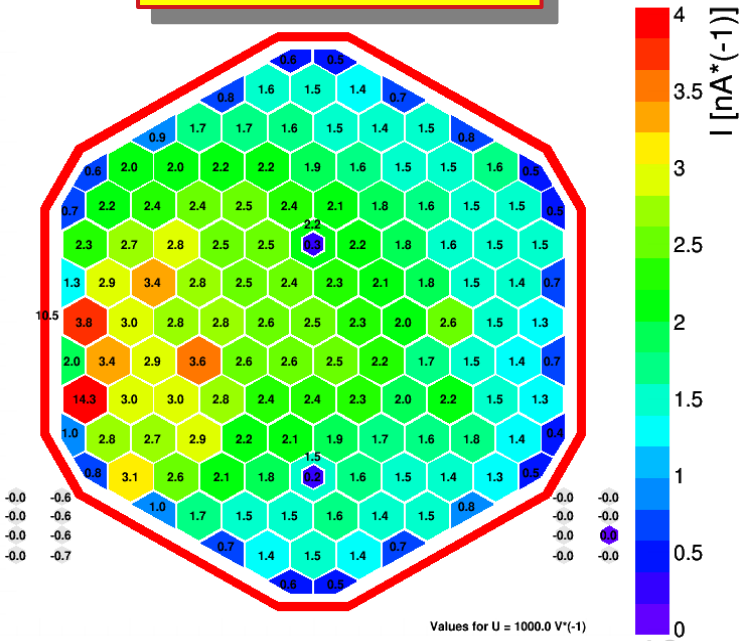
Measurements results

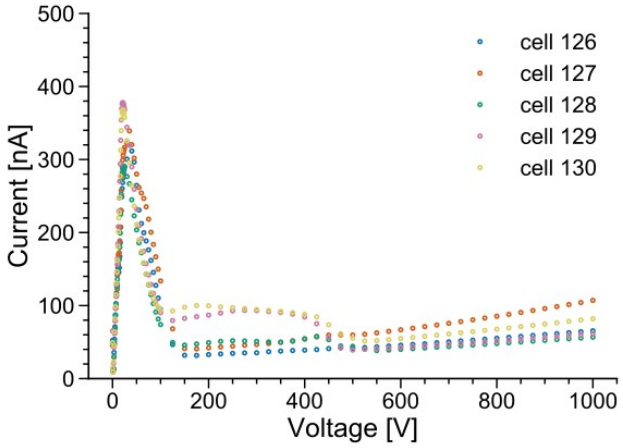
- Many different sensor types and thicknesses tested
  - 120, 200, 300 um active thickness via epitaxial growth and deep diffusion
  - n- and p- type
  - Different p-stop geometries
- Importance of biasing full sensor to get full picture
  - Weird effects especially with individual (atoll) p-stop geometry observed
  - Huge speed up in measurement time

8” p-type 120um

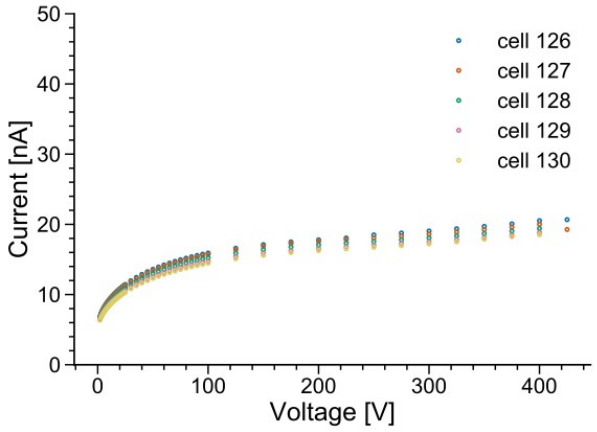


6” p-type 300um





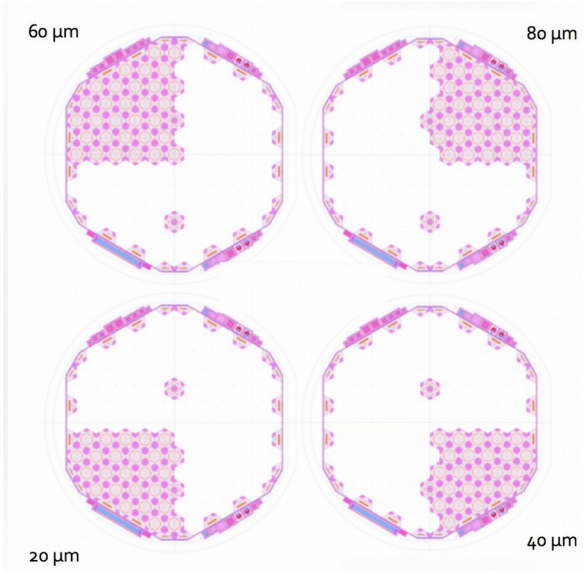
7-needle measurement

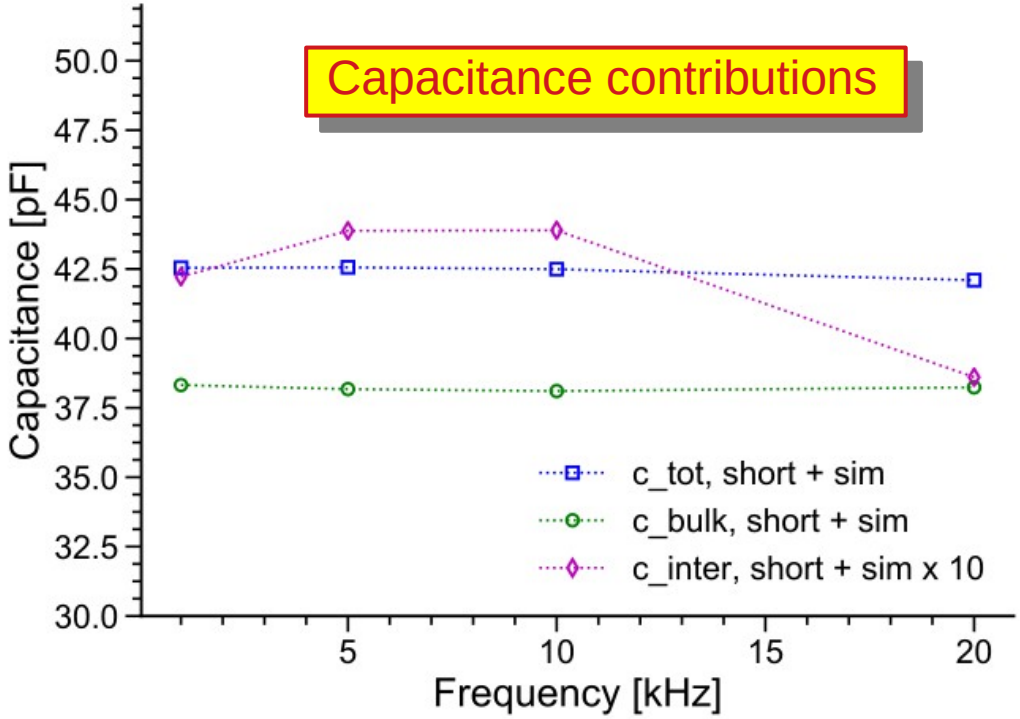


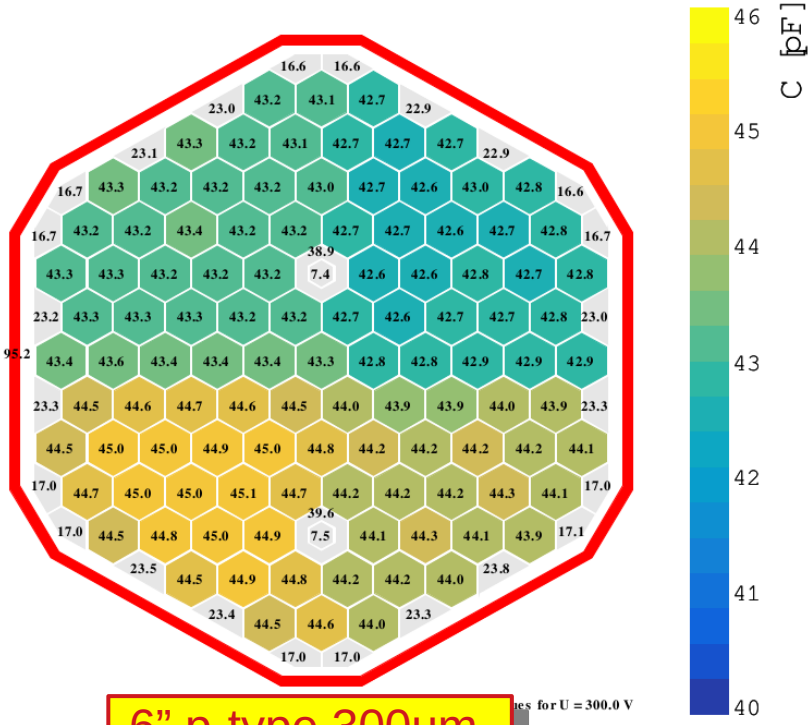
switch/probacard meas

Measurements results

- Initial design bug limited CV measurements but is now fixed
- Precision of about 0.5 pF is now possible
  - Need open and short corrections necessary
  - SPICE simulation can be used to further improve the result
  - Can separate bulk and edge contributions (inter-pad) by looking at cells with different size but same pad-to-pad gap
  - Extract active thickness







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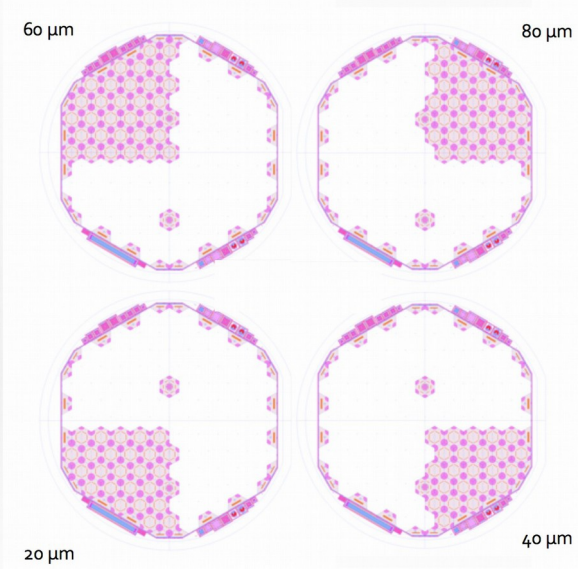
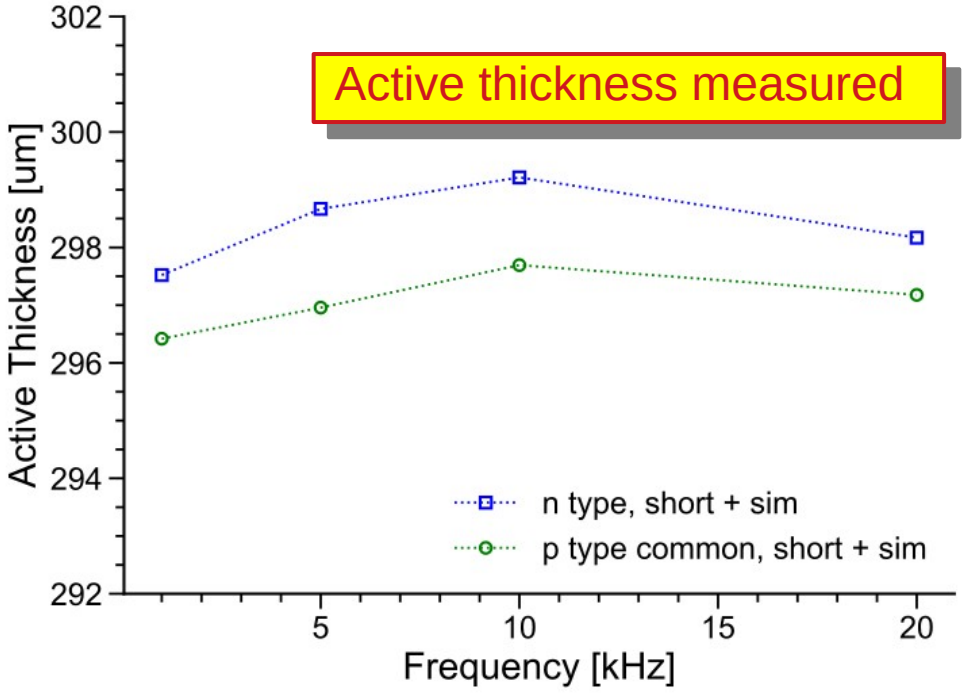
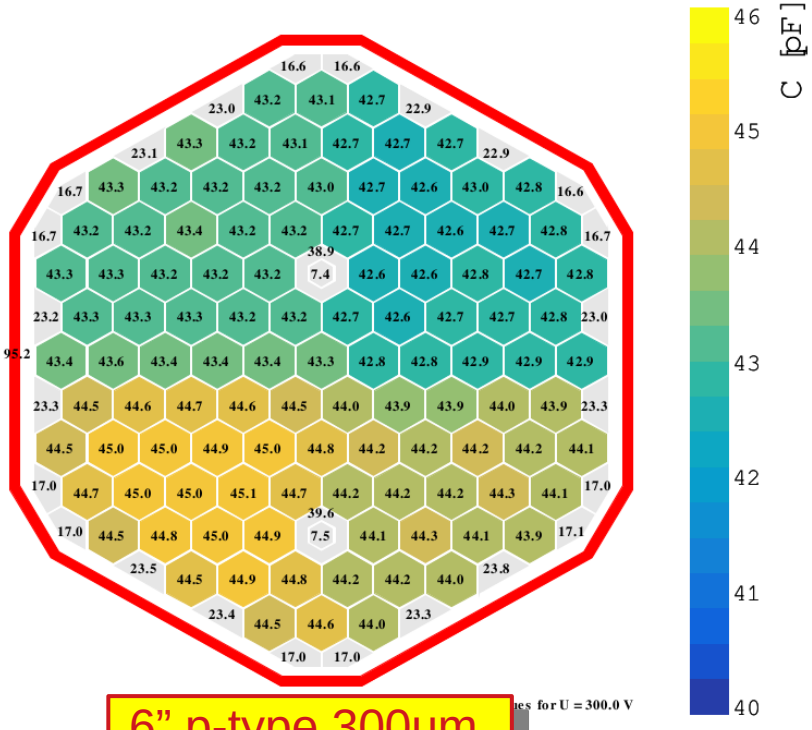
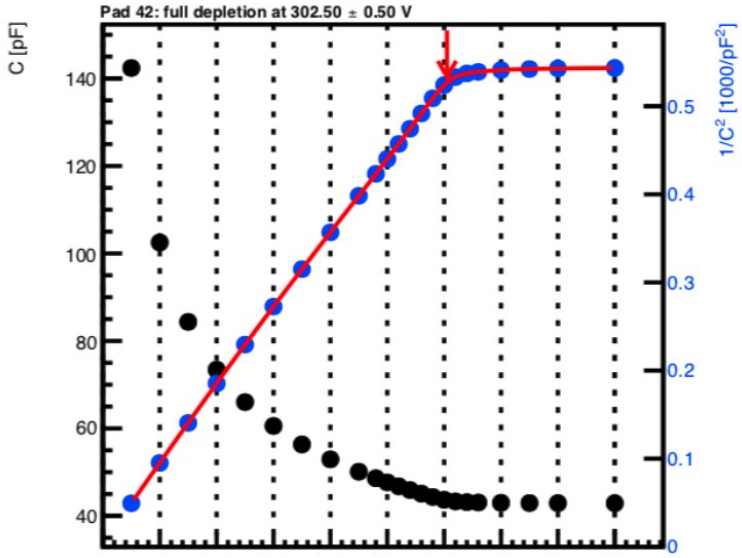


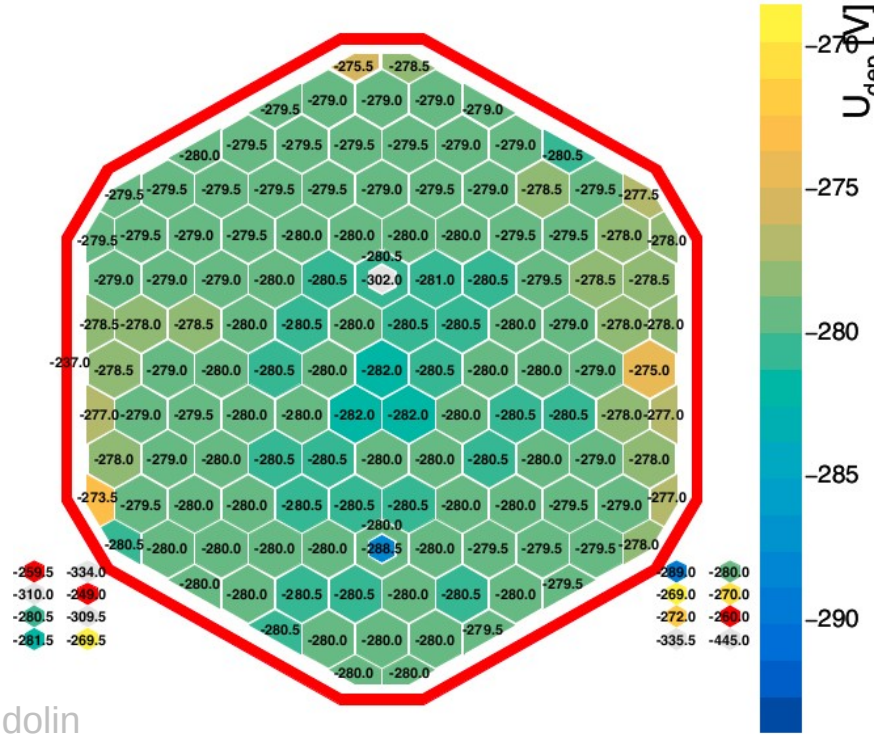


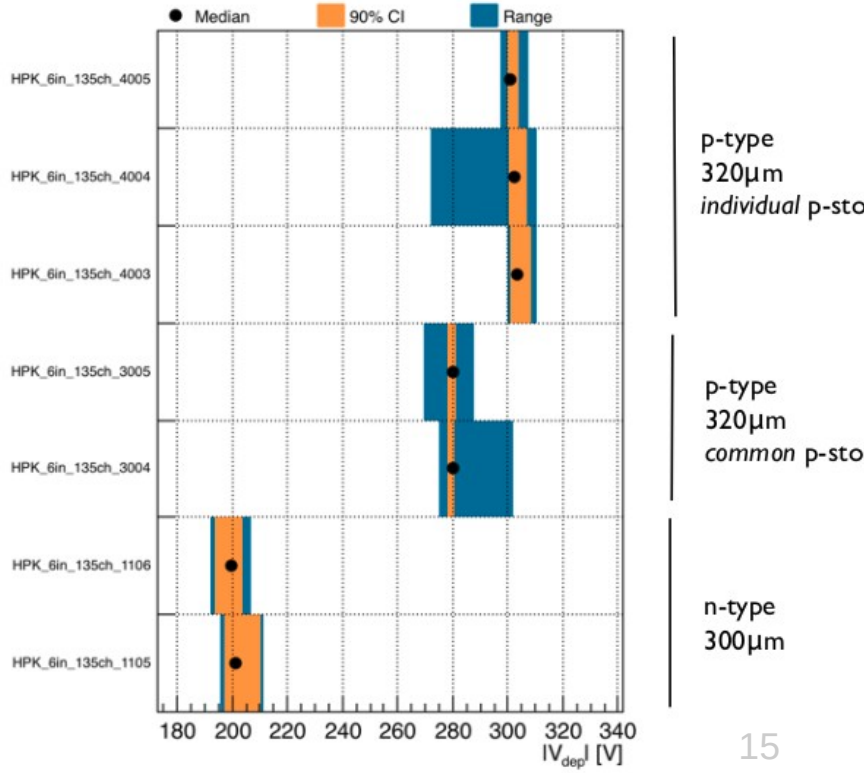


Measurements results

- Study depletion voltage in curves of $1/C^2$ versus V
- Extract depletion voltage via spline fits and point of largest curvature
- Study uniformity over individual multi-pad sensors, compare different sensor-production parameters
- Challenge: Exclude parasitic capacitances from measurement circuit via open and short correction
- Open items: Separate contributions from bulk capacitance and inter-pad capacitance

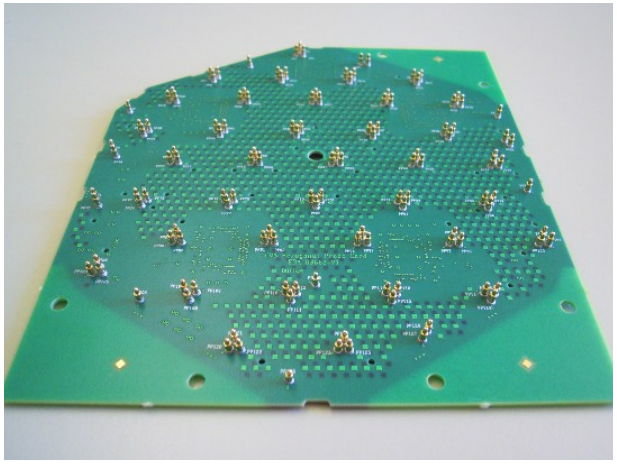


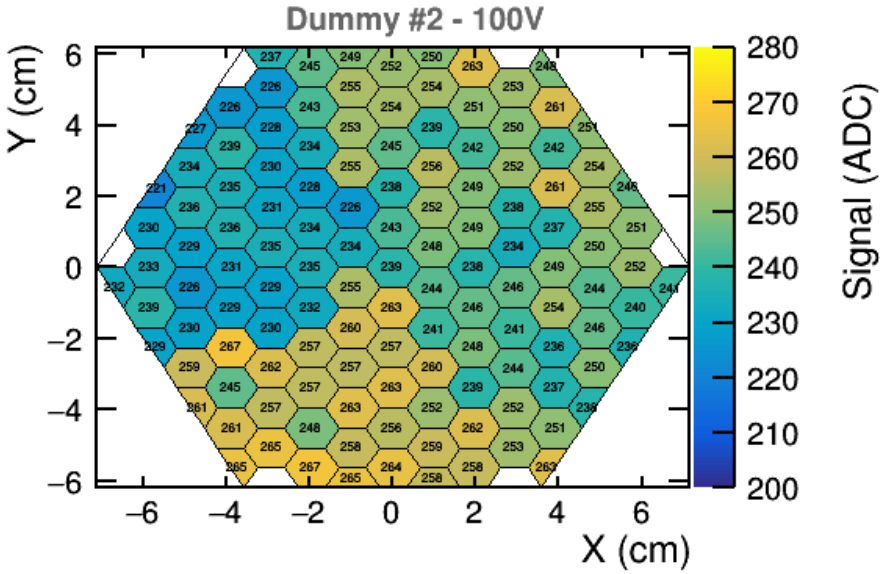


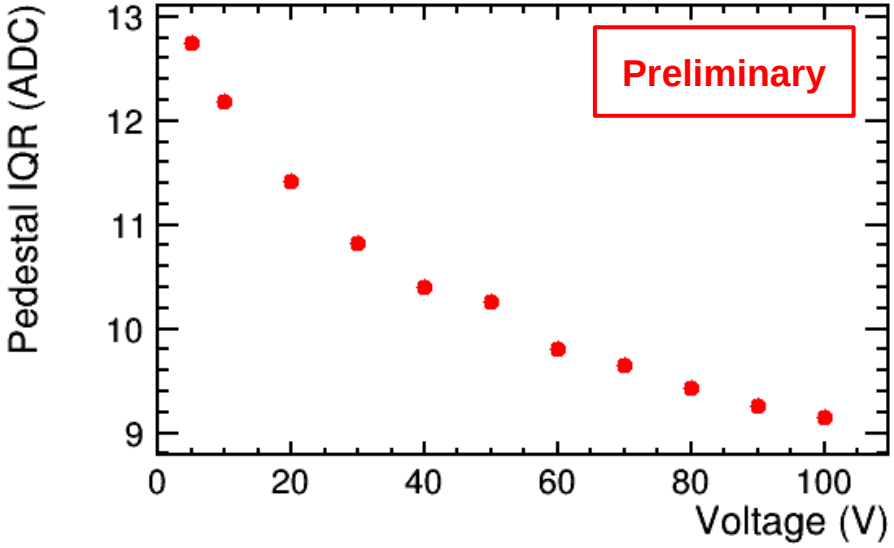


Charge collection measurement

- Setup under development for charge collection measurement of multiple sensors (using pogo pins).
- Inspired on setup used for test beam (Thorben's talk)
- Status and next steps:
  - Noise measurements for setup validation ✔
  - Test and validate all features of the setup
  - Sensor noise measurements
  - Implementation of IR laser system in new cold probestation for CCE measurements for irradiated sensors



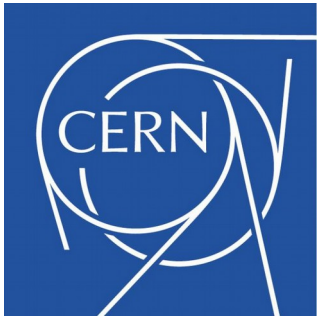




Summary and next steps

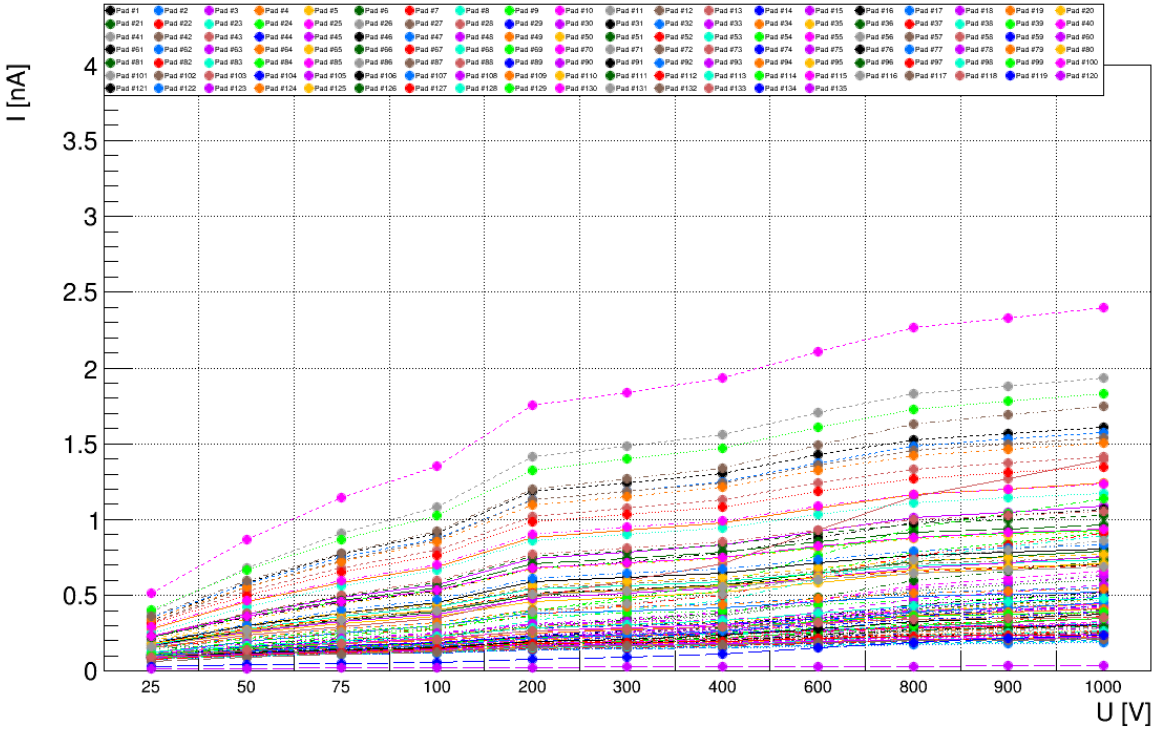
- **Summary**
  - Lots of progress in the last year:
    - Infrastructure → new lab is now operative
    - Local database → easy way to access to measurements and analysis
    - Analysis tools → flexible and used also by other institutes
    - Very successful collaboration with other institutes
  - Complete electrical sensor characterization for several 6 inch sensors
  (- Including Hamamatsu comparison)
  - Electrical sensor characterization for several 8 inch sensors on-going

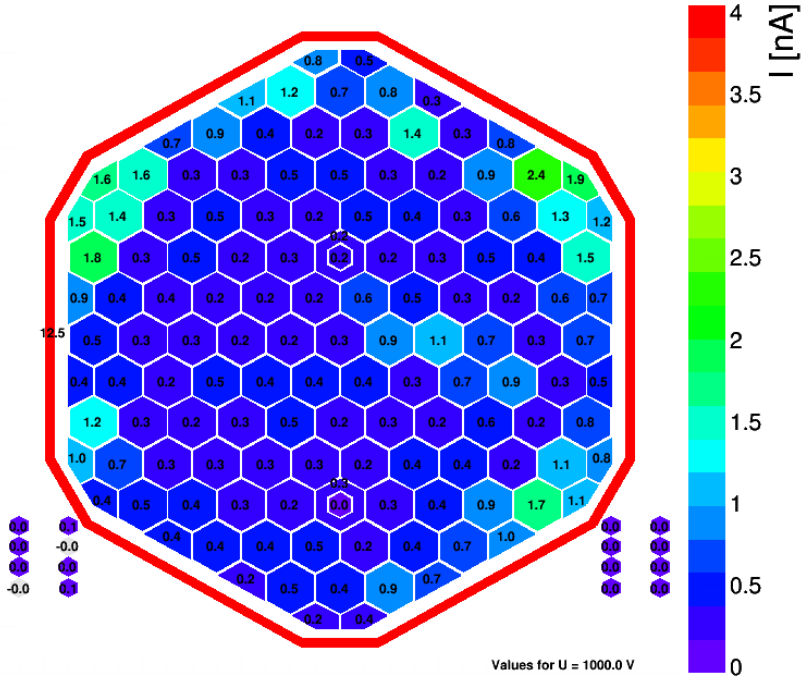
- **Next steps**
  - Noise and charge collection efficiency
    - Some steps were already done (ith preliminary, but very encouraging results)
    - Design of mechanical support for laser system started
    - Automatized DAQ / analysis on-going
  - Measurement of irradiated sensors
    - Part of the 6 inch sensors already sent to irradiation
    - Purchase of new probe station with cold environment on its way



Thank you for the attention!

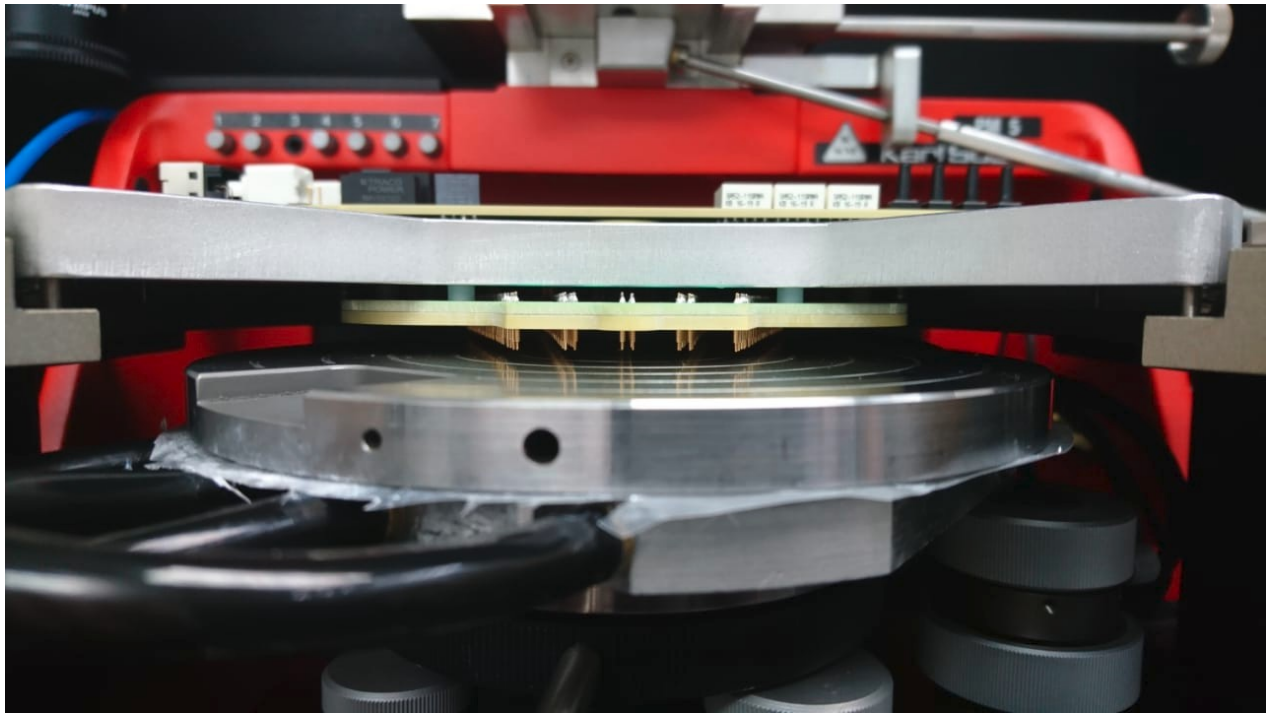
Measurements results (n-type)

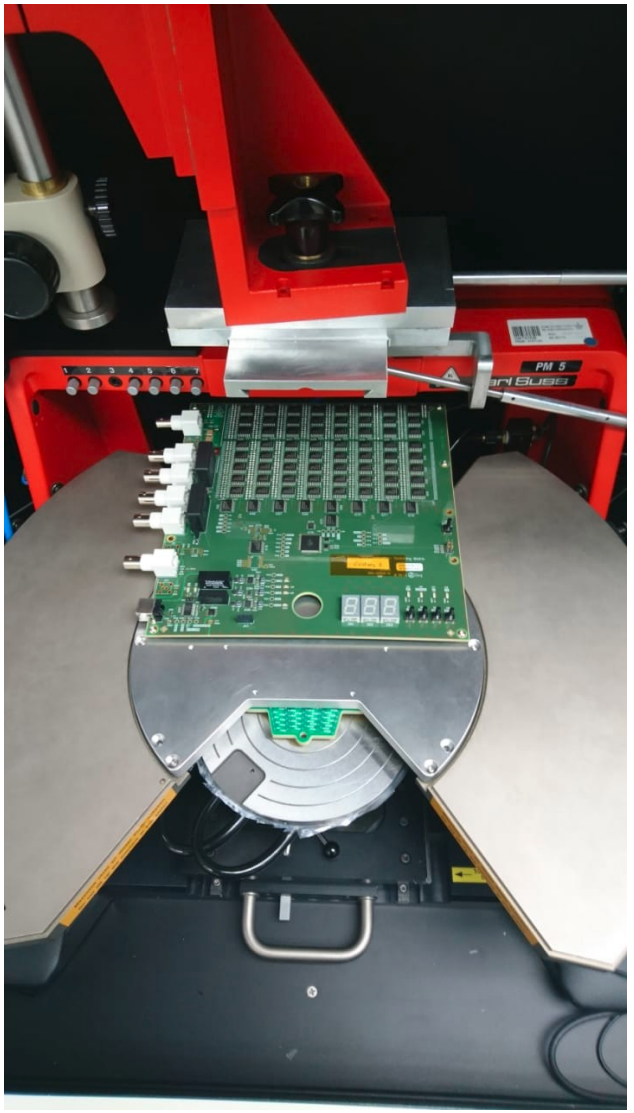




LumiCal sensor testing

- **Similar setup will be also used for LumiCal sensors testing**
- **Same DAQ / analysis tools can be used**
- **Strong collaboration already in place**





Switch/probecards

- **Switch/probecard for testing multi pads sensors**
  - probe cards available for several sensor design (6 in total)
  - some of them also used by other institutes