

# Measurement of silicon-sensor prototypes for the CMS High-Granularity Calorimeter Upgrade for HL-LHC



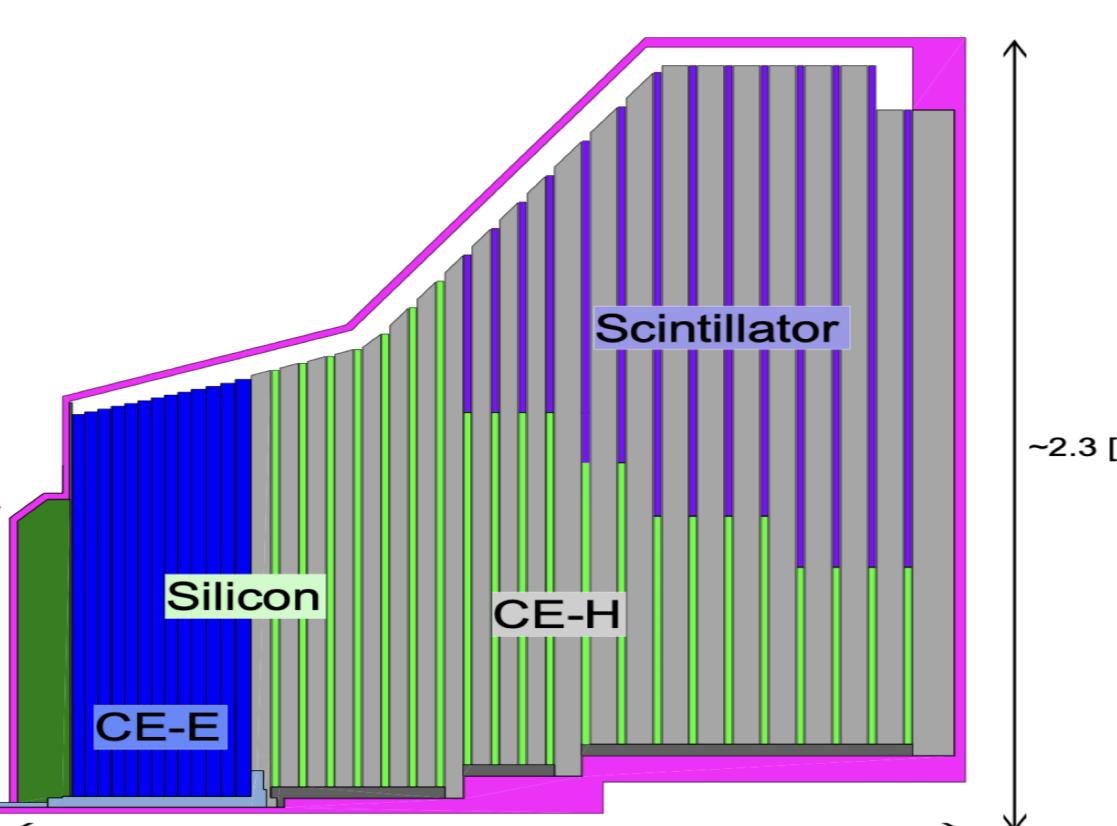
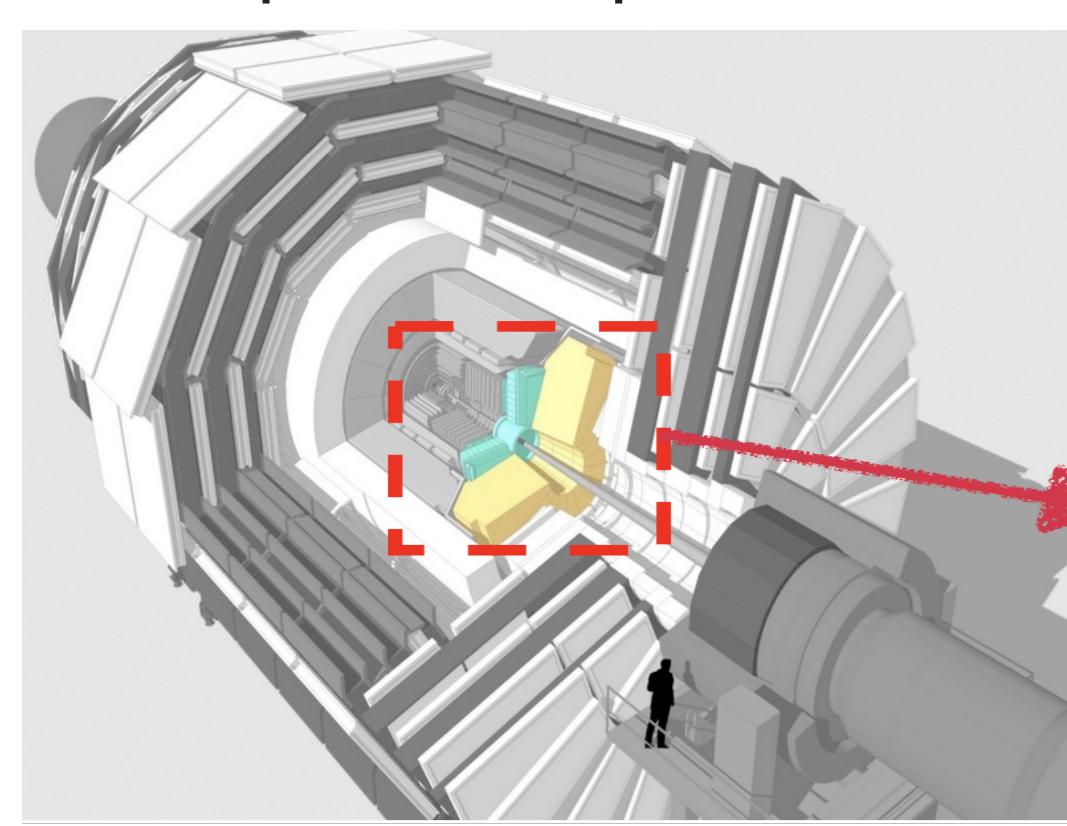
Chaochen Yuan, Eva Sicking, Philipp Zehetner, Huijing Hua, Kourosh Sarbandi, Marta Krawczyk, Pedro Almeida, Filip Moortgat, Thorben Quast on behalf of the CMS Collaboration



## Overview of HGCal

### Key parameters for the HGCal:

- HGCal covers  $1.5 < \eta < 3.0$
- Full system maintained at  $-30^\circ\text{C}$
- $\sim 31000$  Si modules
- Power at end of HL-LHC:  $\sim 110$  kW per endcap
- $\sim 640 \text{ m}^2$  of silicon sensors
- $\sim 370 \text{ m}^2$  of scintillators
- 6M Si channels,  $0.5$  or  $1.1 \text{ cm}^2$  cell size

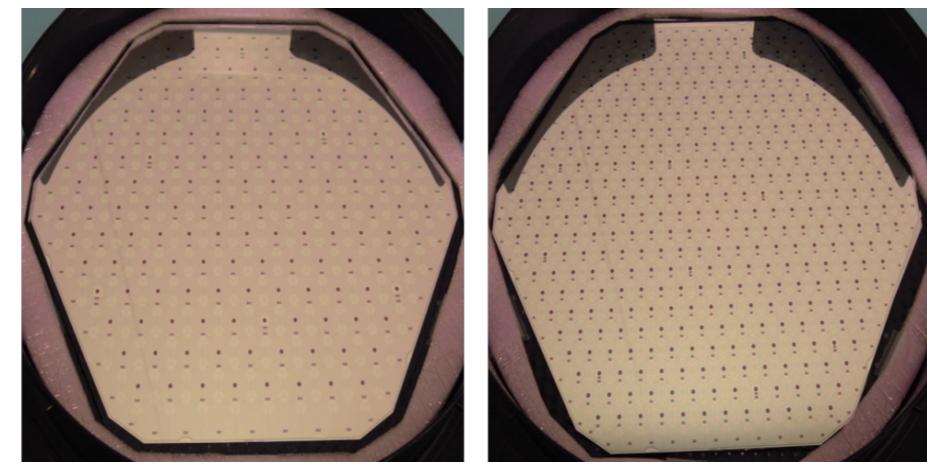
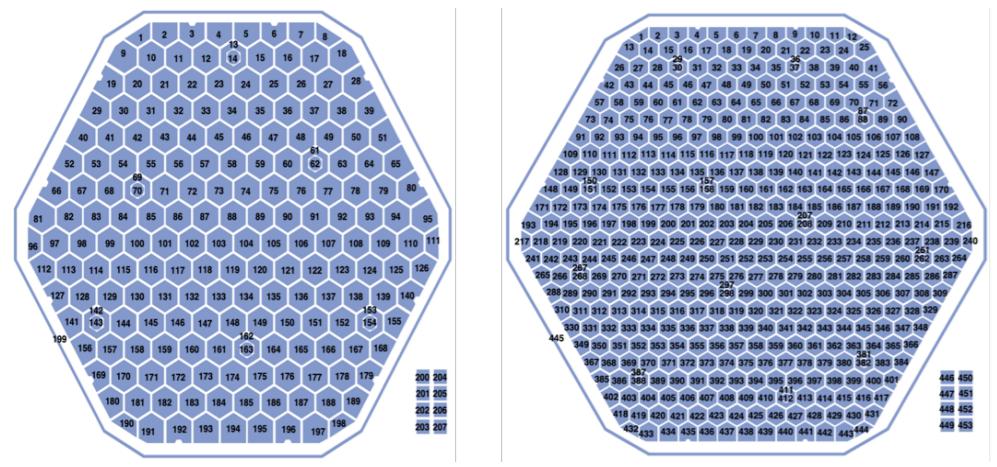


- Endcap Electromagnetic calorimeter (CE-E): Si, Cu & CuW & Pb absorbers, 28 layers,  $25.5 X_0$ .
- Hadronic calorimeter(CE-H):Si & scintillator, steel absorbers, 22 layers,  $\sim 9.5 \lambda$
- First 5D imaging calorimeter to operate in a collider experiment

### Silicon-sensor plays a crucial role

## Overview of the sensor

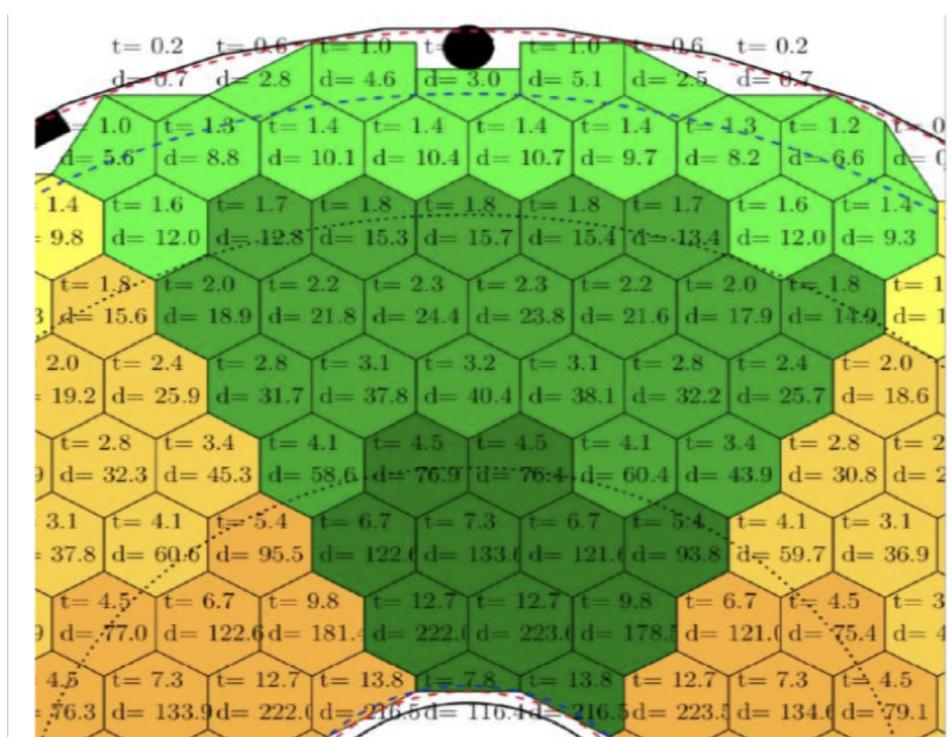
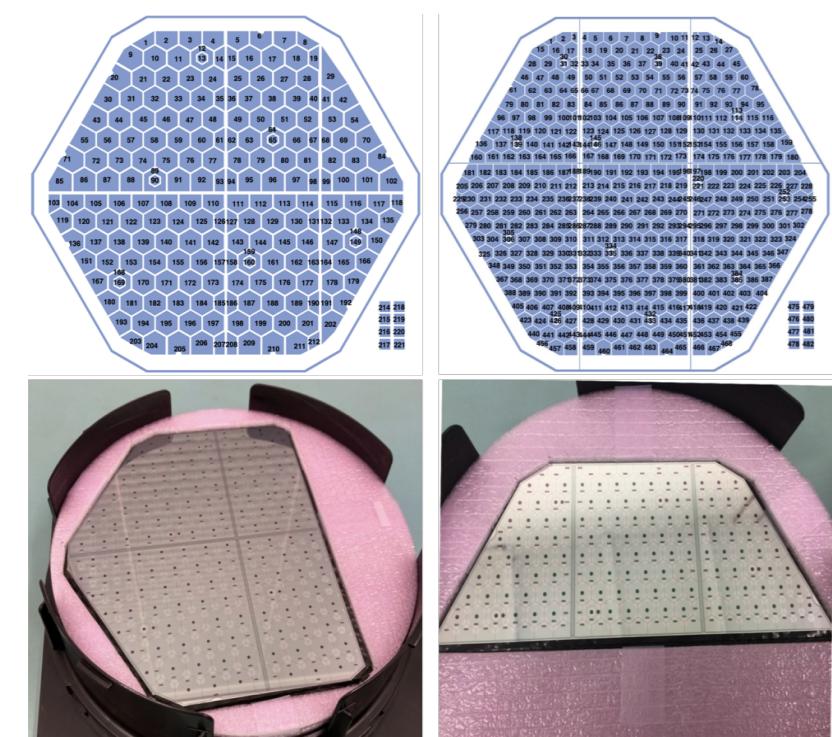
### Overview of full-sized sensors



- 8" full-sized sensors with different number of channels
- 3 different oxide quality: B, C, D

- 3 different thicknesses  $120\mu\text{m}, 200\mu\text{m}, 300\mu\text{m}$
- Some of them have been irradiated up to around  $10^{16} \text{ neq/cm}^2$

### Overview of multi-geometry sensors

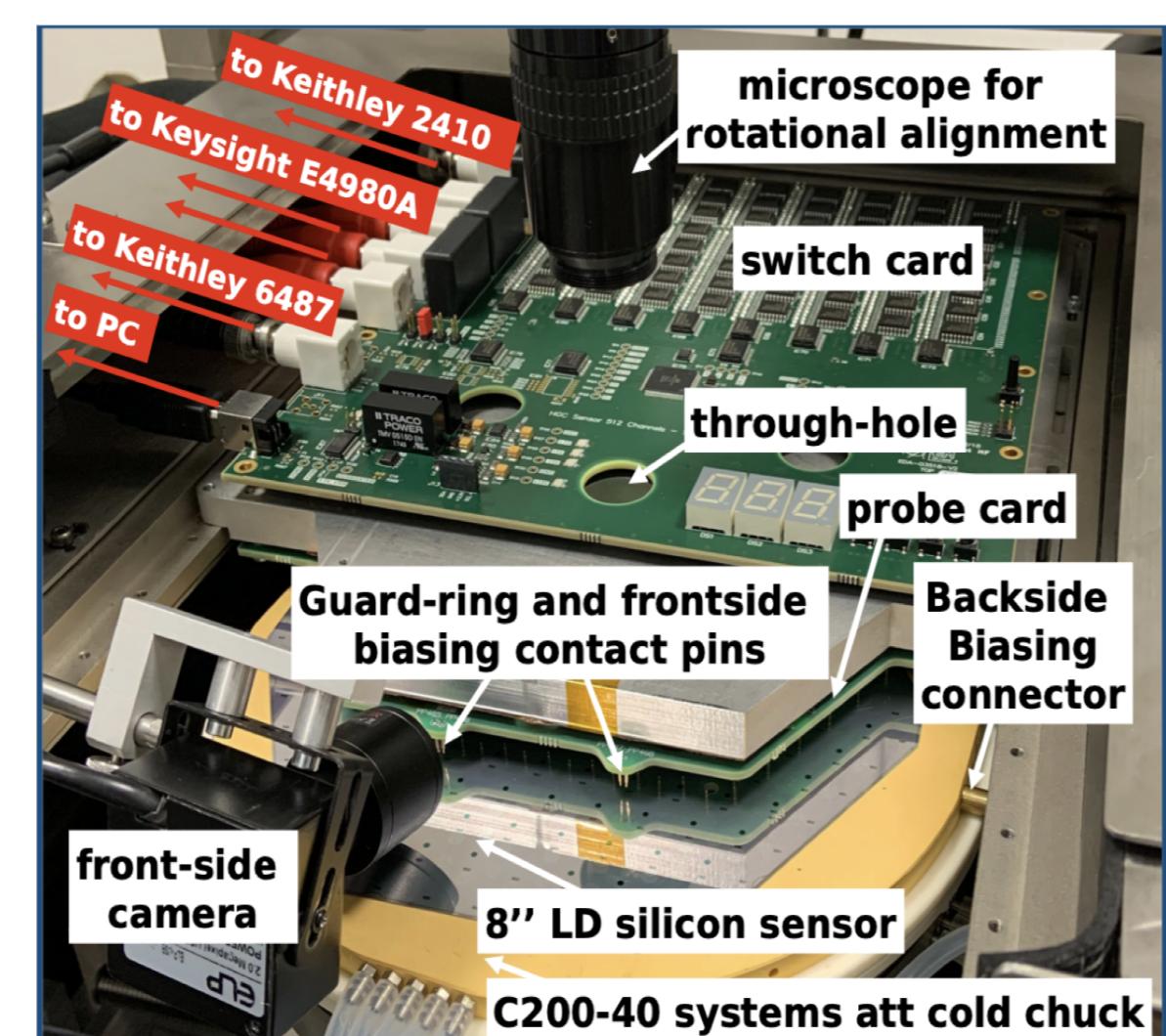
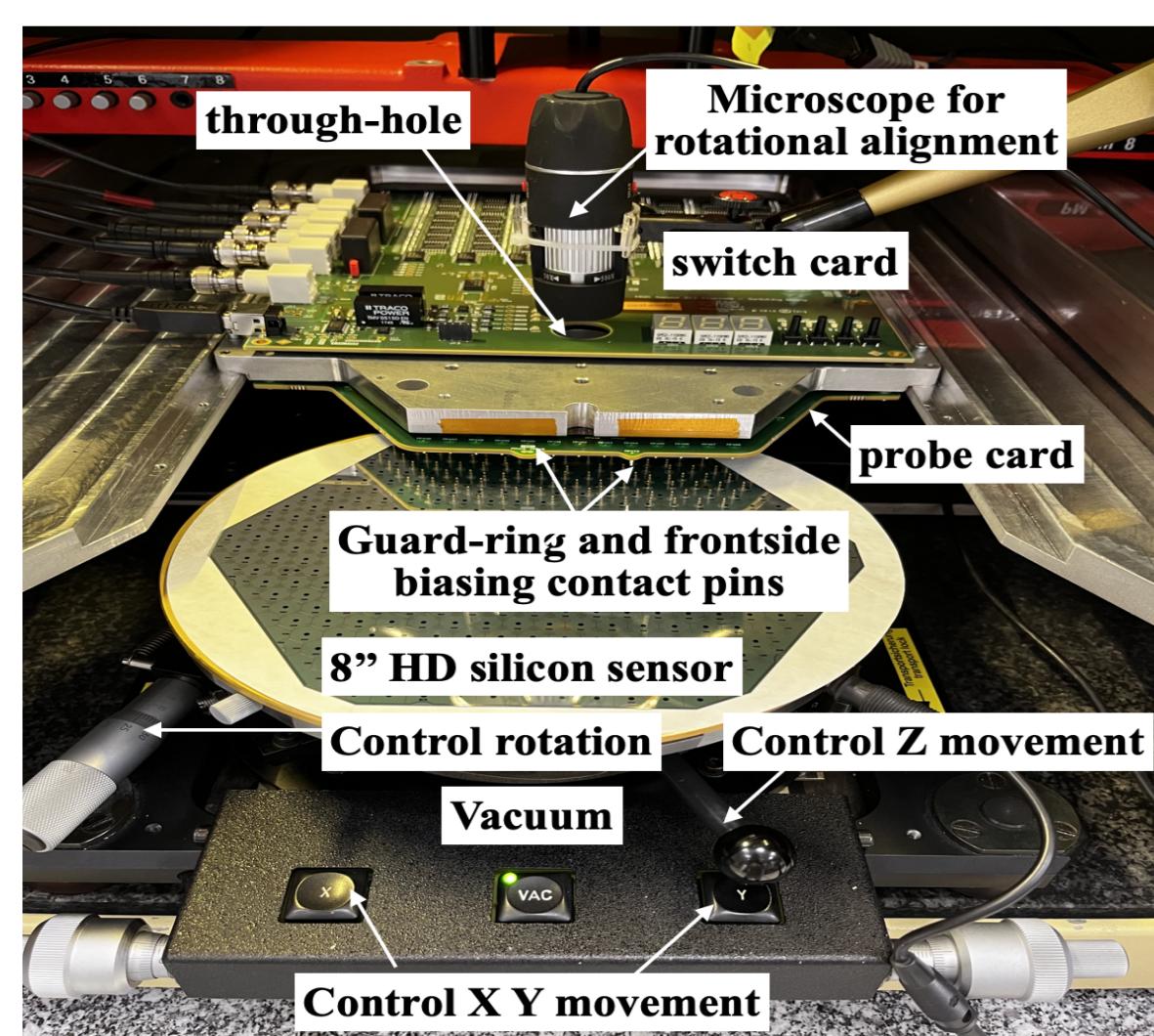


- 8" multi-geometry sensors with different number of channels
- 3 types of thicknesses

- Produce "partial sensors" to tile inner and outer edges
- 7 cut types, oxide quality: C

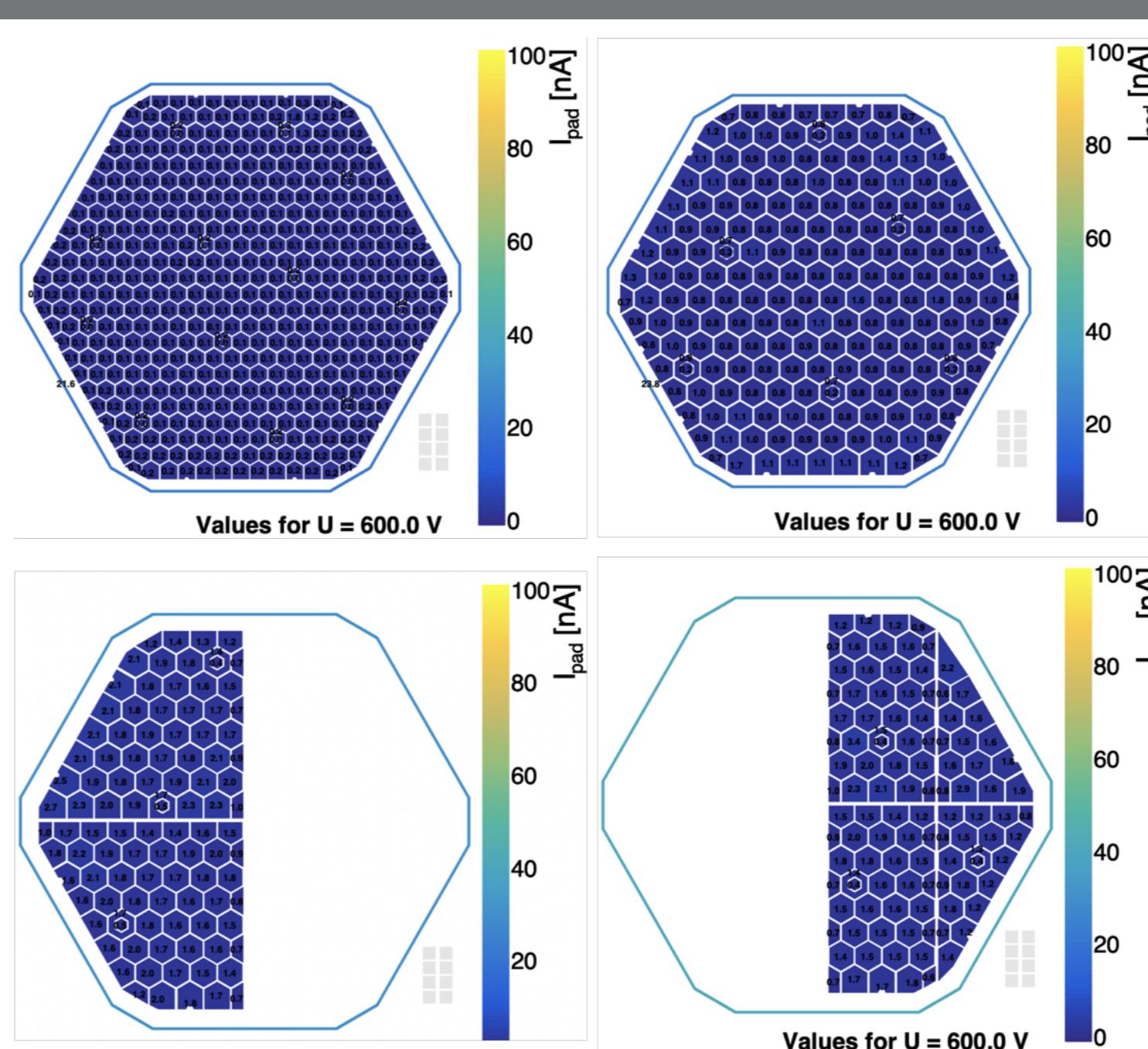
## Measurement setup

### Measurement setup



- Sensors on chuck with backside protection
- Temperature: room temperature; humidity: 4%-8%
- Voltage up to  $-850\text{V}$
- Only used for non-irradiated sensors
- Sensors on chuck without backside protection
- Temperature:  $-40^\circ\text{C}$ ; humidity: 4%-8%
- Voltage up to  $-850\text{V}$  from backside
- Annealing at  $60^\circ\text{C}$ , target time of 80 mins

## Leakage current measurement before irradiation



- Measure full-sized sensors, and multi-geometry-sensors.
- Leakage current less than  $100\mu\text{A}$  at  $600\text{V}$ , all passed

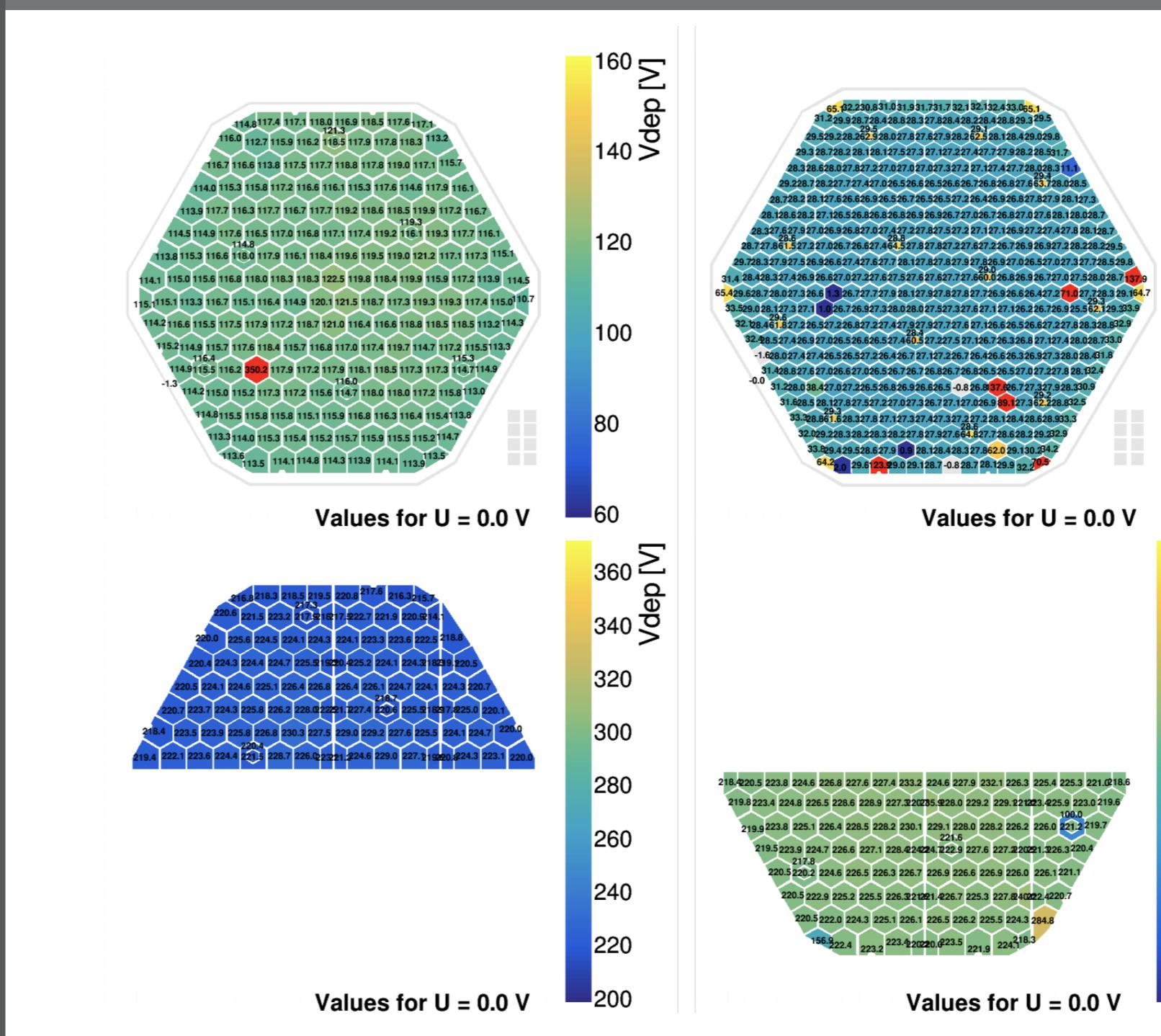
### Grading

- Total current at  $600\text{V}$  ( $I_{600}$ )  $< 100\mu\text{A}$
- $I_{800} < 2.5 * I_{600}$
- Bad pads number  $\leq 8$ (full-sized)
- Adjacent bad pads number  $\leq 2$

### Define bad pads:

- Pad current at  $600\text{V}$   $> 100 \text{ nA/pad}$

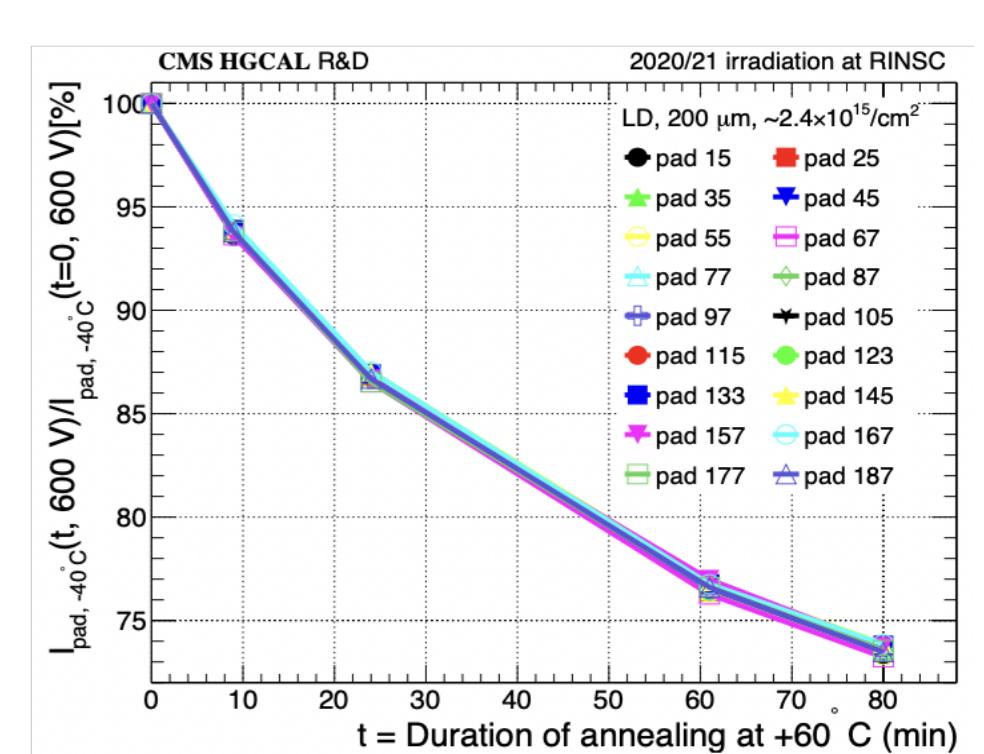
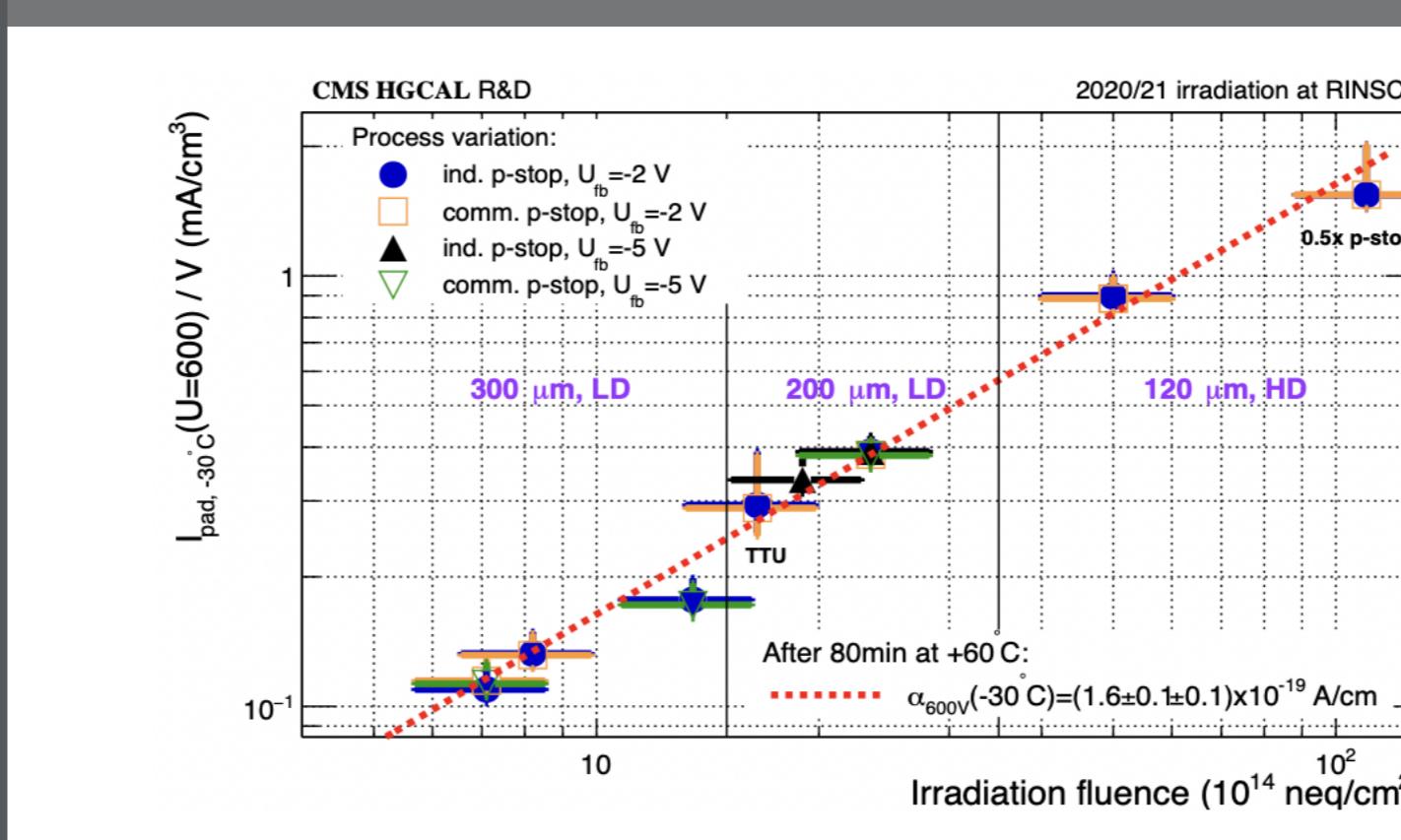
## Depletion voltage measurement before irradiation



### Grading

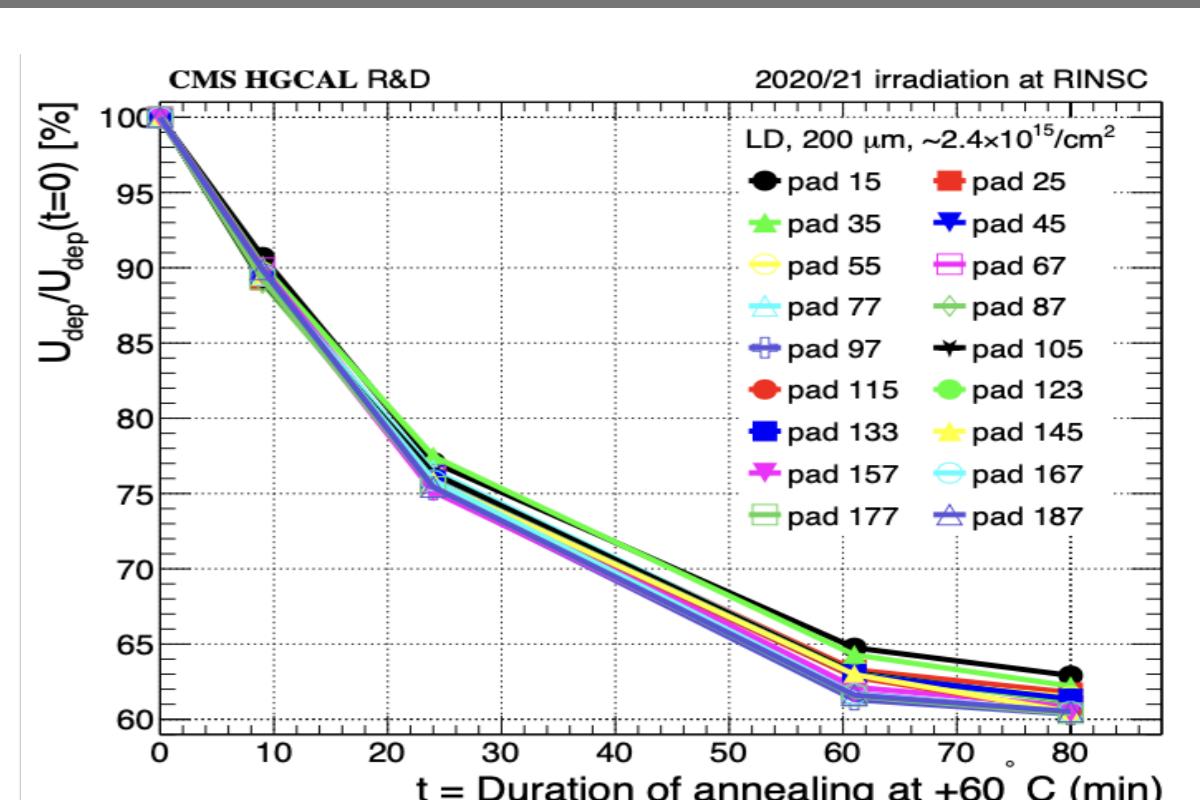
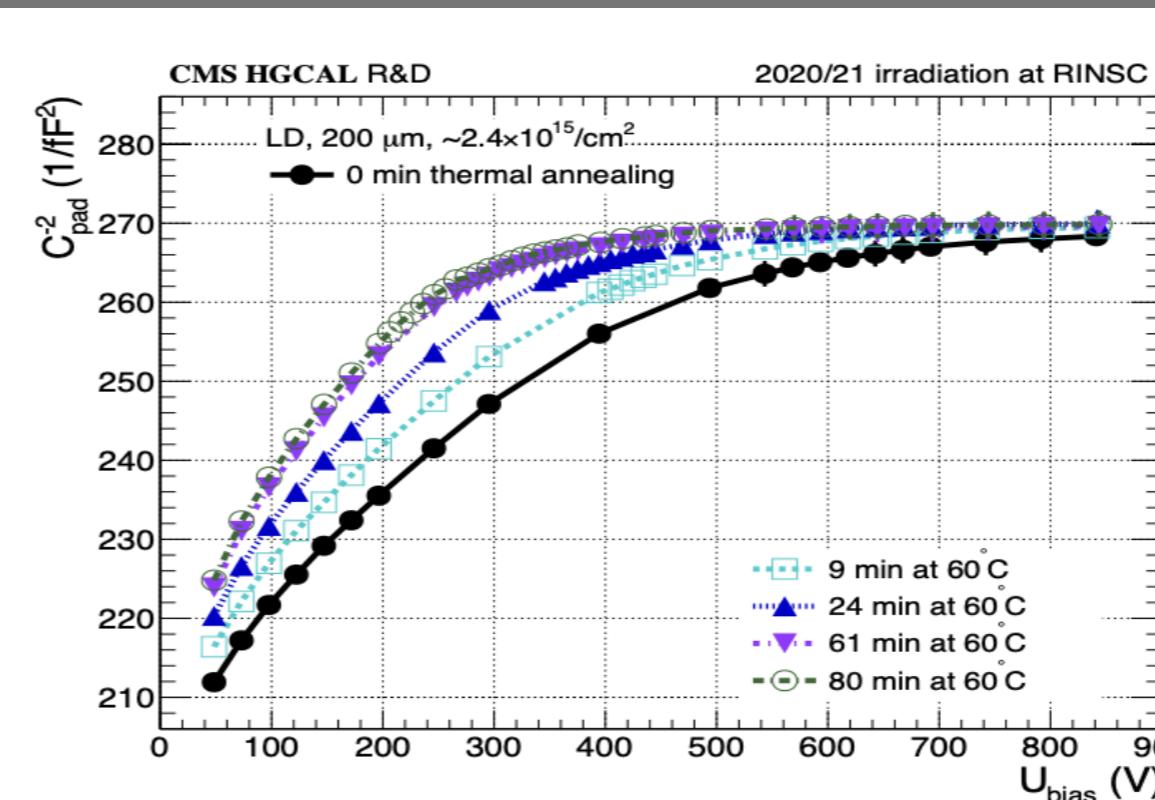
- Full depletion voltages  $V_{dep}$ : median of depletion voltages across cells
- $V_{dep} < 370\text{V}$  for  $300\mu\text{m}$  thickness
- $V_{dep} < 160\text{V}$  for  $200\mu\text{m}$  thickness
- $V_{dep} < 70\text{V}$  for  $120\mu\text{m}$  thickness
- Depletion voltage sensitive to thickness
- Depletion voltage all passed the grading

## Leakage current measurement after irradiation



- $\frac{\Delta I}{V} = \alpha * \Phi_{eq}$  ( $\Delta I$ : change of leakage current,  $\alpha$ : current related damage rate,  $\Phi_{eq}$ : irradiation fluence, V: volume)
- Linear relationship between leakage current and irradiation fluence
- $\frac{\Delta I(t)}{\Delta I(0)} = b e^{-\frac{t}{\tau}}$  (b: corresponding amplitude, t: annealing time,  $\tau$ : time constant)
- Leakage current drop with annealing

## Depletion voltage measurement after irradiation



- The change of depletion voltage is dominated by short annealing term  $N_A = \Phi_{eq} * g * e^{-\frac{t}{\tau}}$  (g: introduction rate)
- Depletion voltage decreases with annealing time

## Next step

- Start the irradiation test for multi-geometry sensors with higher fluence
- Measure pre-series sensors
- Prepare measurement infrastructure and procedure for mass measurement