Characterization after neutron irradiation of Silicon Diodes for the CMS High Granularity Calorimeter (HGCAL)

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Outline

- High Granularity Calorimeter (HGCAL)
- HGCAL silicon sensors
- Results of the characterization after neutron irradiation
- Summary and future activities

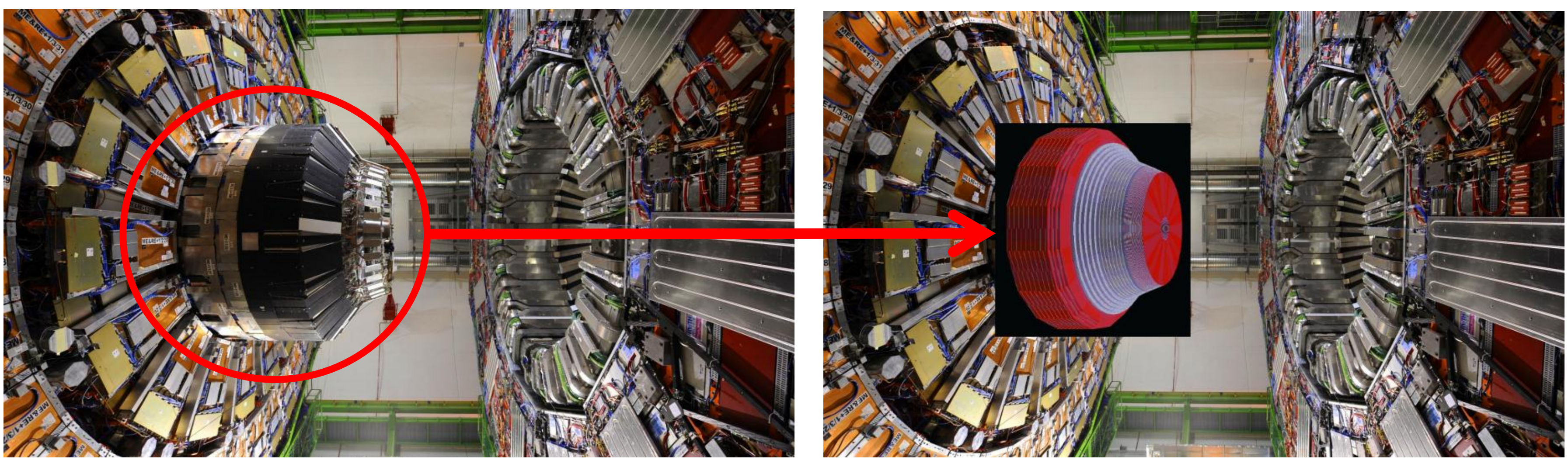
High Granularity Calorimeter (HGCAL)

CMS needs to replace End-cap Electromagnetic and Hadronic calorimeters for Phase II due to radiation damage. This opens new possibilities for Calorimeter design.

We are investigating in detail the possibility of using a high granularity calorimeter with ~9M channels of silicon pads, integrating EE and HE functions (CALICE concept) with a Back HE to capture energy tails.

We expect that with such detailed information from the calorimeter, coupled with a precision silicon tracker, we will be able to measure physics objects with high precision.

Current detector **An Si Based HGC CMS at the HL-LHC**



High Granularity Calorimeter (HGCAL)

Major Engineering Challenges

600 m2 of Silicon in a high radiation environment.

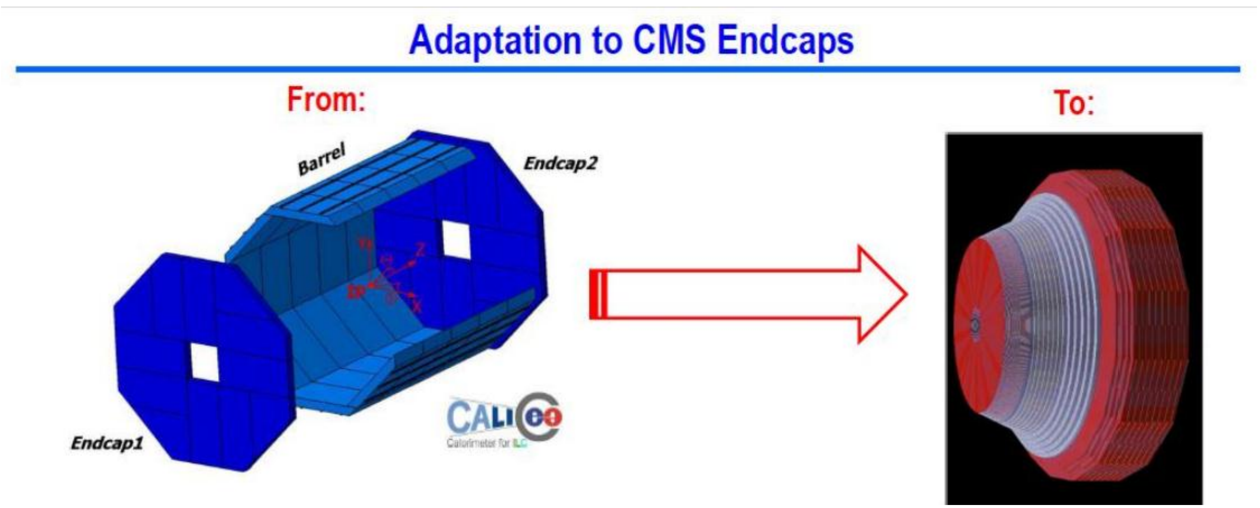
- ✓ Cost.
- ✓ Very high radiation levels – need to plan for 3×10^{16} neutrons/cm^2 in the highest

Cooling.

- ✓ We need a compact calorimeter with small gaps between absorber plates.
- ✓ We need to operate at – 30°C
- ✓ Total power is ~ 100 kW.

Data and Trigger

- ✓ Channel count is 9M. Producing a prodigious amount of data.
- ✓ Data used in the Level- 1 CMS event trigger.



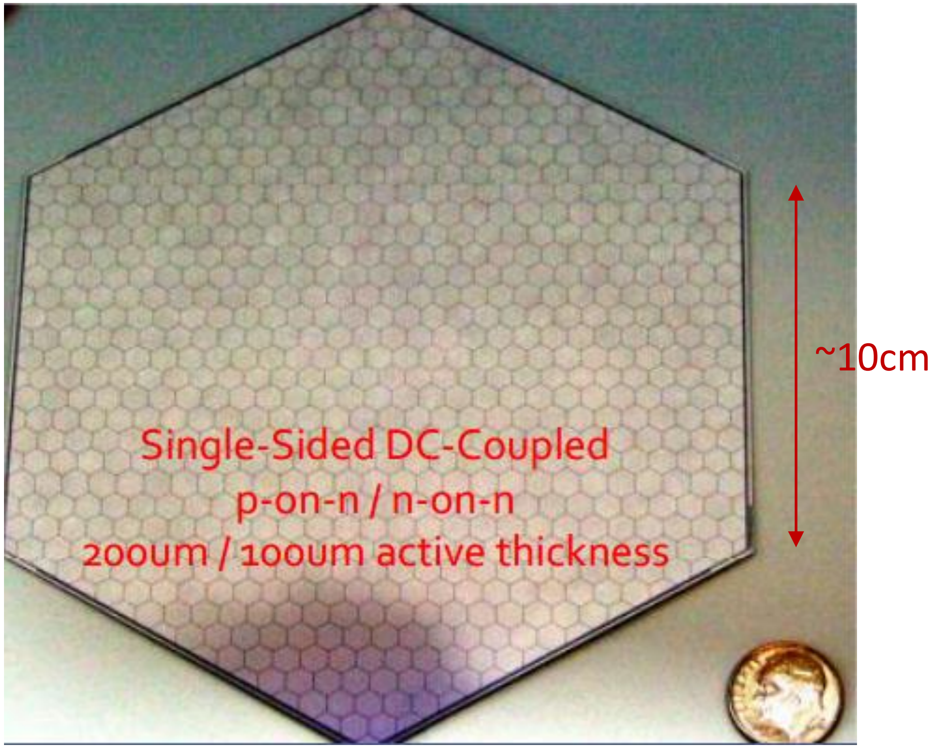
HGCAL Silicon sensors

Tolerance study of large area pad diodes as active sensor for a High Granularity Electromagnetic Endcap Calorimeter for PhaseII Upgrade

Investigate sensor performance after **neutron irradiation** with neutron equivalent fluences up to $1 \cdot 10^{16} n/cm^2$

Sensors under investigation:

- ✓ Silicon growth technique (Epi: epitaxial layer, FZ: floating zone)
- ✓ Polarity: n-on-p (p-type), p-on-n (n-type)
- ✓ Active thickness:
  - FZ: 320, 200 and 120 um
  - Epi: 100 and 50 um
- ✓ Size:
  - Large diodes : 5×5 mm^2
  - Small diodes : 2×2 mm^2



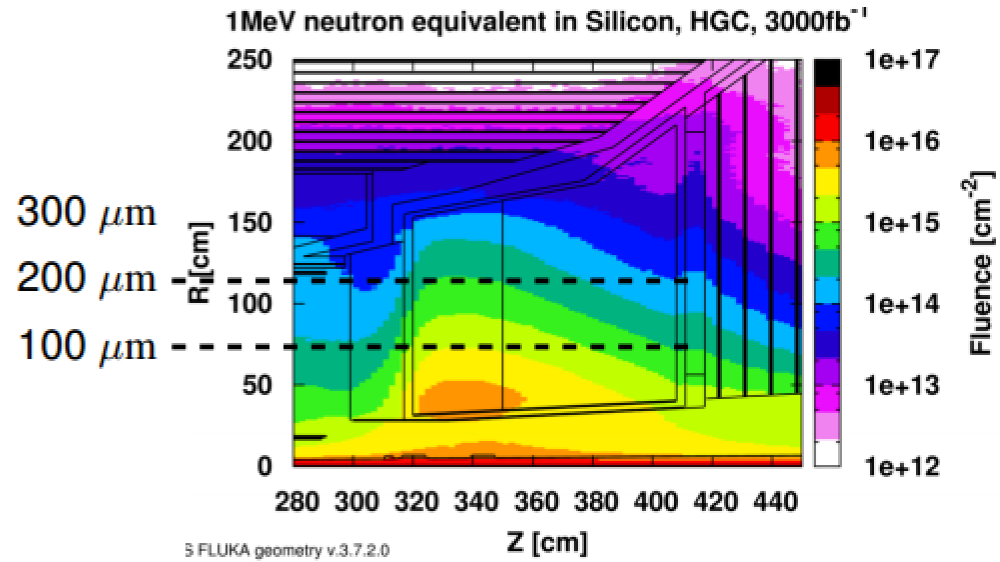
HGCAL operating conditions:

- ✓ Temperature (T) < −30◦C: ∼ −35◦C
- ✓ Bias voltage (U): 600 ÷ 1000 V

HGCAL Silicon sensors

Available sensors

- ✓ Sensors irradiated in Ljubljana
- ✓ Sensors now at Hamburg University
- ✓ 2 identical sensors for each type and each fluence
- ✓ P: bulk P (n-on-p)
- ✓ N: bulk N (p-on-n)



List of sensors:

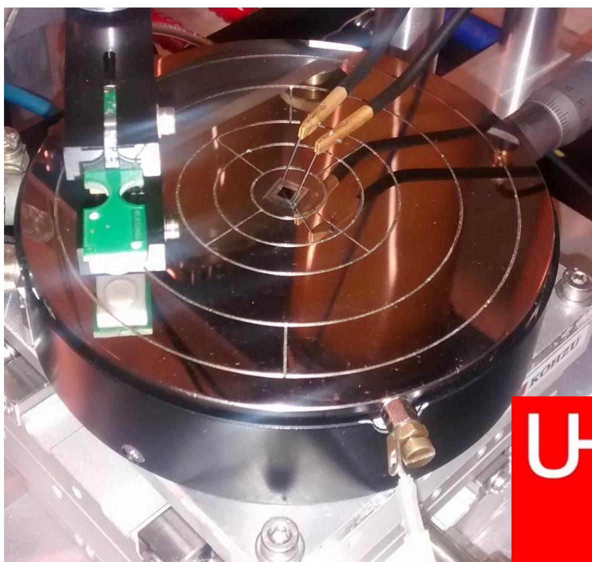
Fluence (Φ) $[n/cm^{-2}]$	Thickness $[\mu m]$ 320	200	120	50
4e14	2 FZ-P, 2 FZ-N			
→ 6e14	2 FZ-P, 2 FZ-N			
1.5e15		2 FZ-P, 2 FZ-N		
→ 2.5e15		2 FZ-P, 2 FZ-N		
6.25e15			2 FZ-P, 2 FZ-N, 1Epi-P	
→ 1.0e16			2 FZ-P, 2 FZ-N, 2Epi-P	2 Epi-P, 2Epi-N
1.6e16			2 FZ-P, 2 FZ-N	2 Epi-P, 2Epi-N

Characterization after neutron irradiation

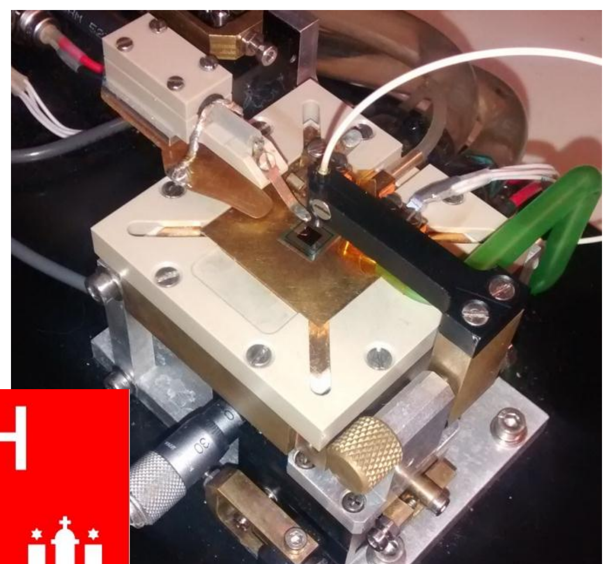
Properties to be measured:

- ✓ Bulk current I(U, Φ, h) → power consumption, noise
- ✓ Capacitance (1 MHz signal): C(U, Φ, h) → capacitance seen by electronics (below ~50pF)
- ✓ Charge collection efficiency CCE(U, Φ, thickness) → signal
- ✓ MIP sensitivity with beta source → for calibration purpose and S/N
- ✓ Effect of annealing on the properties (up to 3 months at room temperature)

IV/CV set-up



TCT set-up for CCE
IR laser (1063 nm)

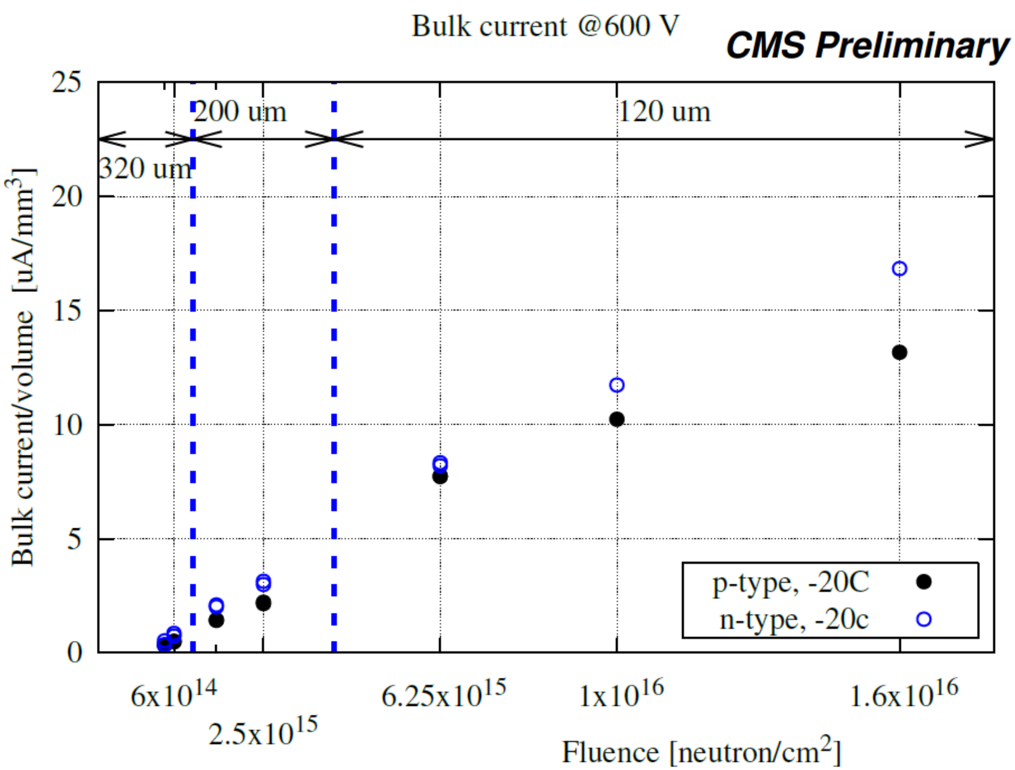


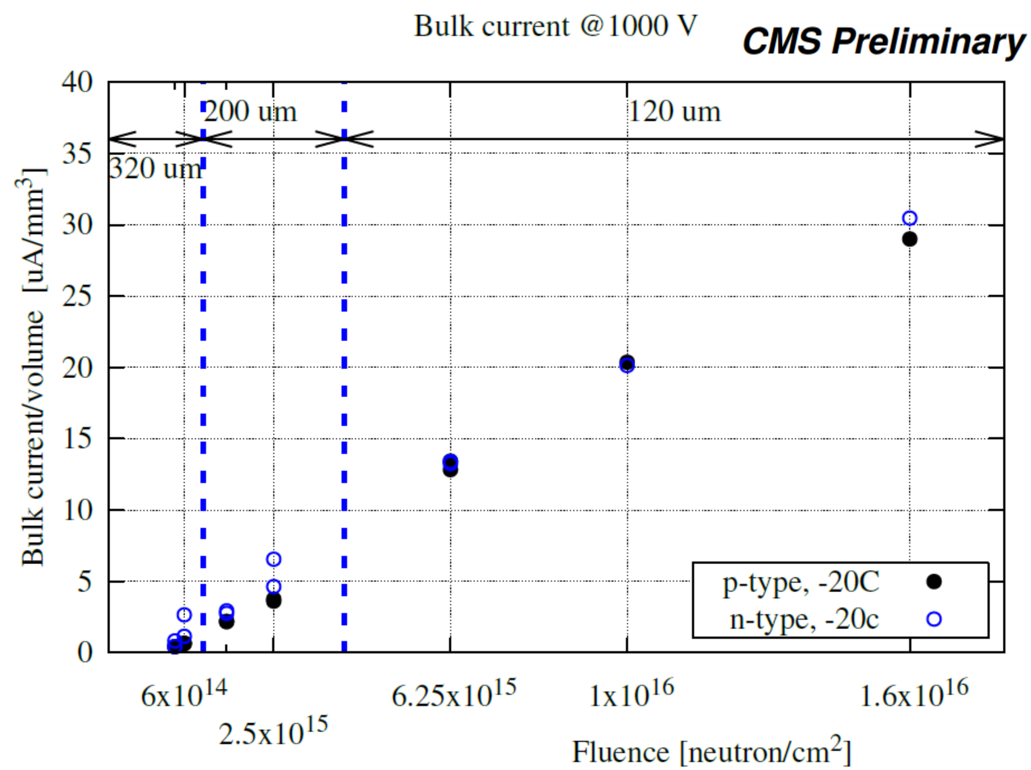
U: bias voltage (V)
Φ: neutron fluence (cm^{-2})
T: operating temperature
h: sensor thickness (μm)

continue with measures at CERN

Characterization after neutron irradiation

Bulk current vs fluence ⇨ **N-type vs P-type diodes**

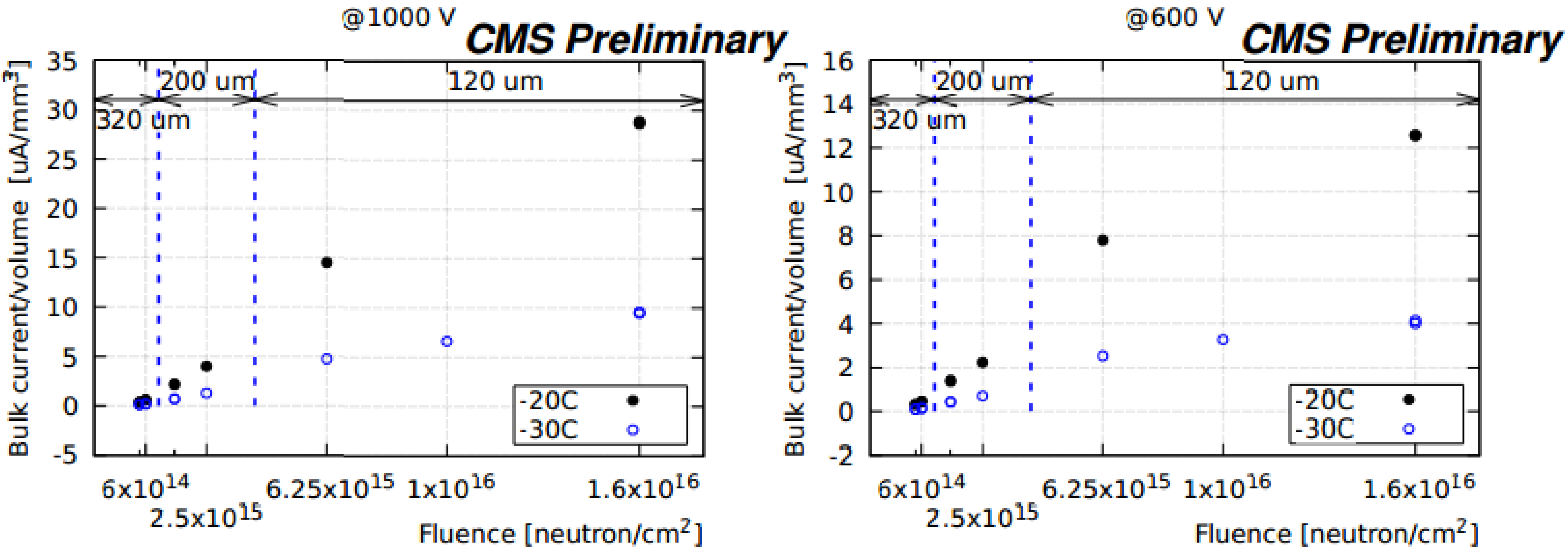




- ✓ Bulk current normalized by the volume of the diode
- ✓ Bulk current compatible between P and N type diodes

Characterization after neutron irradiation

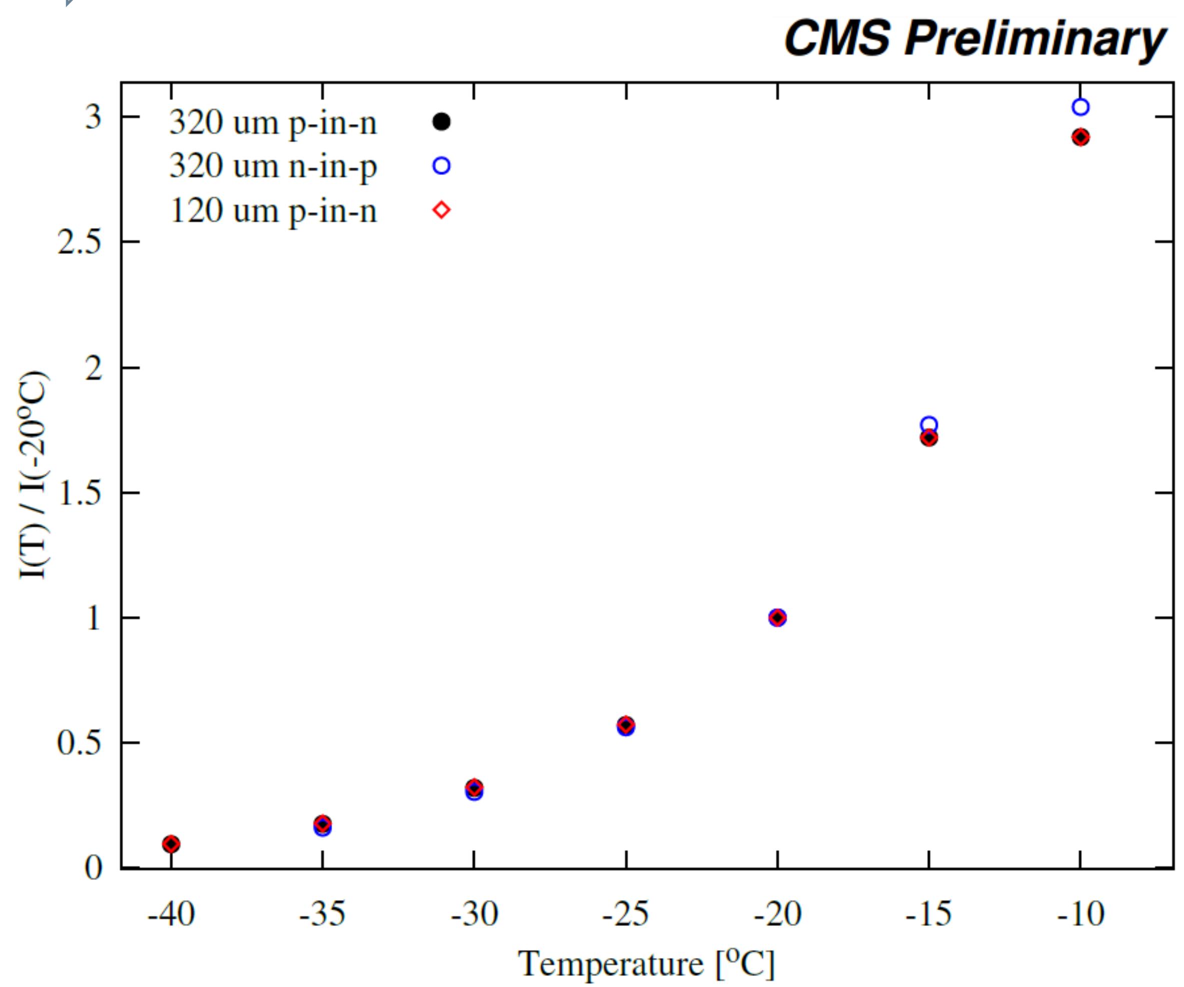
Bulk current vs fluence ⇨ **Temperature dependence**



- ✓ Bulk current normalized by the volume of the diode
- ✓ $I(-20^\circ C) \sim 3 \cdot I(-30^\circ C)$

Characterization after neutron irradiation

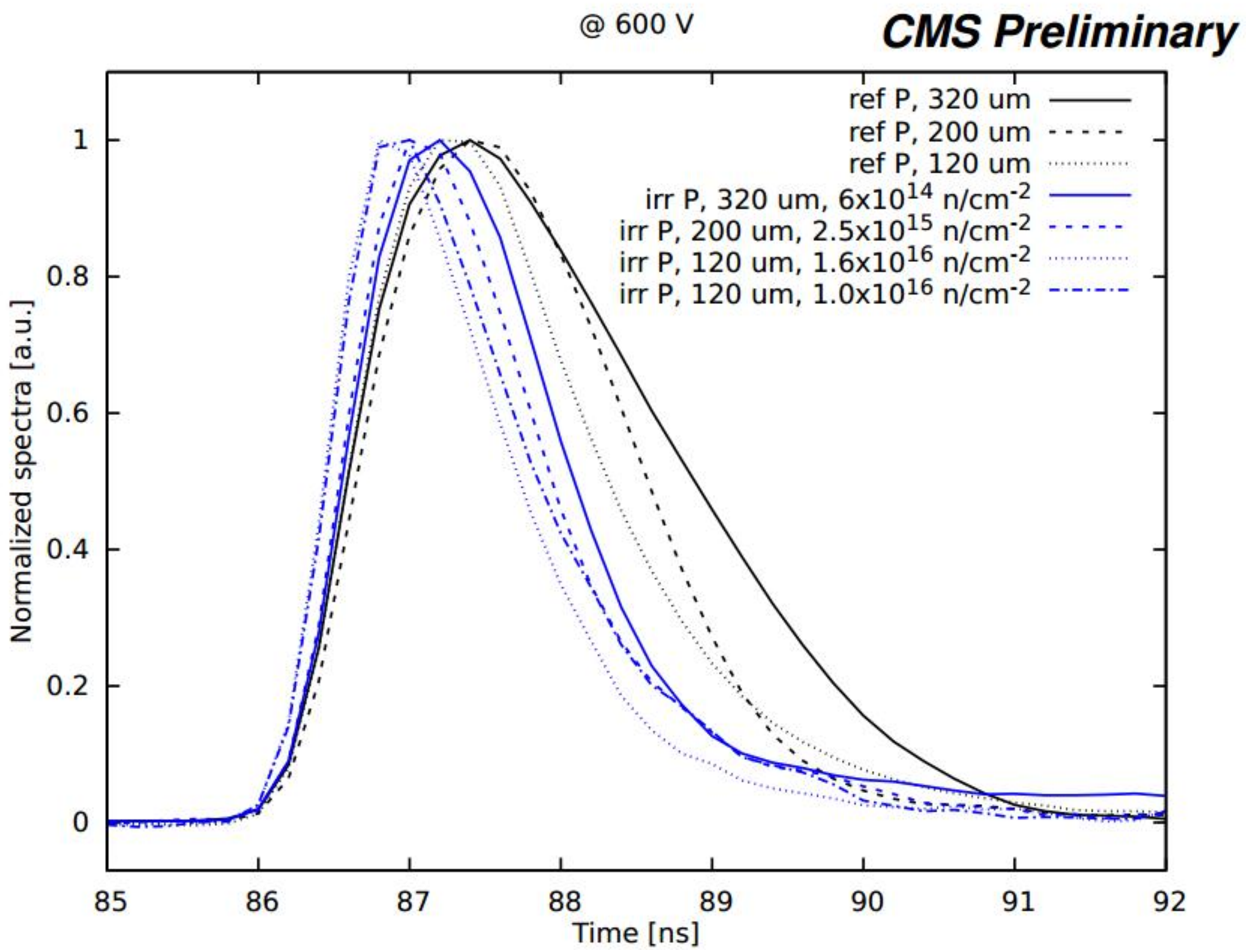
Calibration curve ⇨ **from -10°C to -40°C**



- ✓ measurement of bulk current vs bias voltage (IV) as function of temperature (from -10 to −40◦C) for few diodes
- ✓ Results are compatible between p-type and n-type
- ✓ Also compatible between different active thickness

Characterization after neutron irradiation

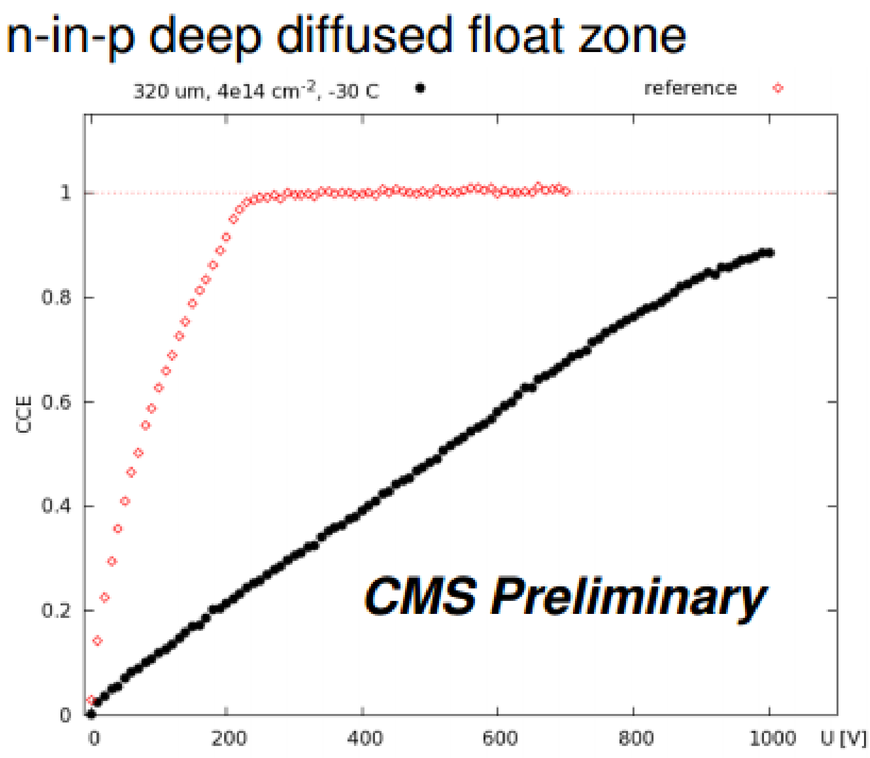
TCT spectra ⇨ **600 V (normalized amplitude)**

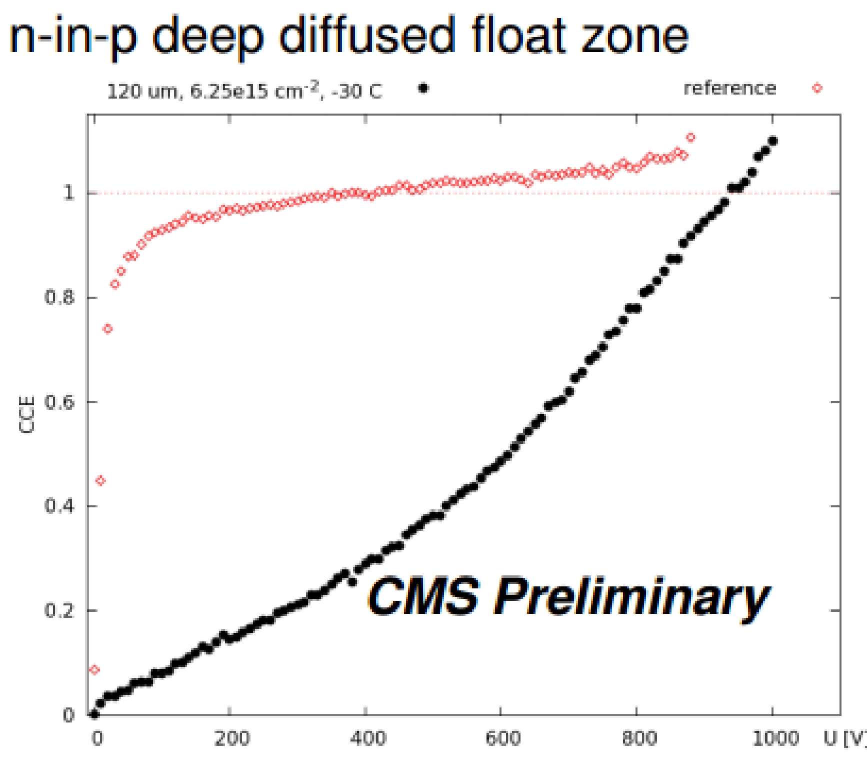


- ✓ IR laser (1060 nm) pulse width: 50 ps
- ✓ TCT pulse width < 10ns
- ✓ Shorter pulse and raise time after irradiation → relevant for timing

Characterization after neutron irradiation

Charge collection efficiency measurement ⇨ **TCT IR laser**

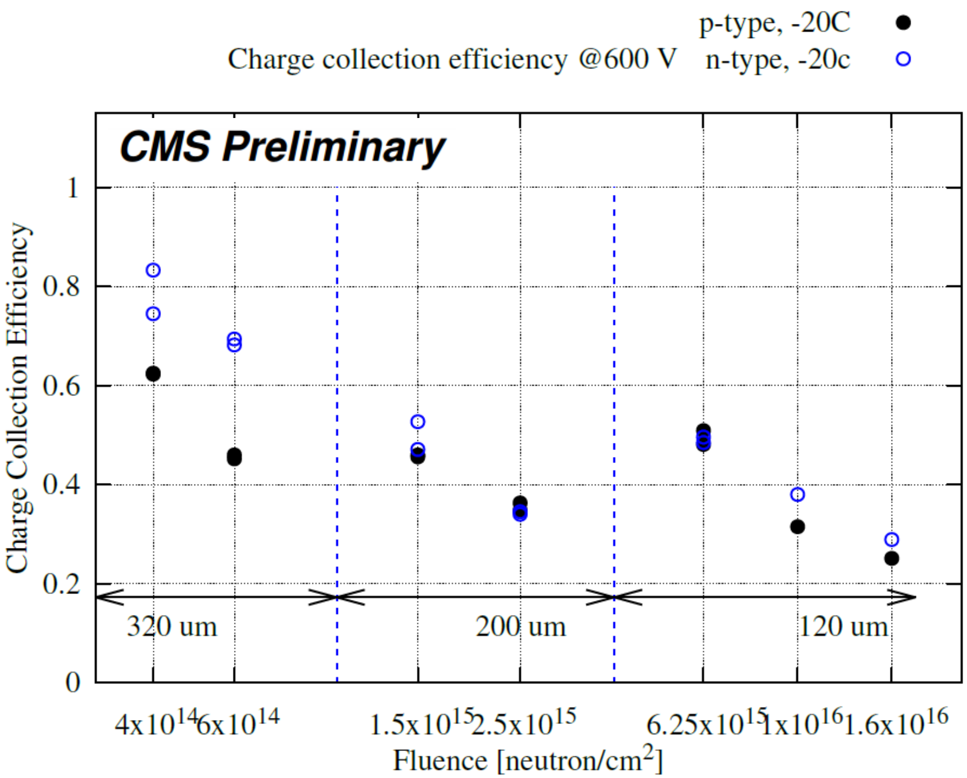


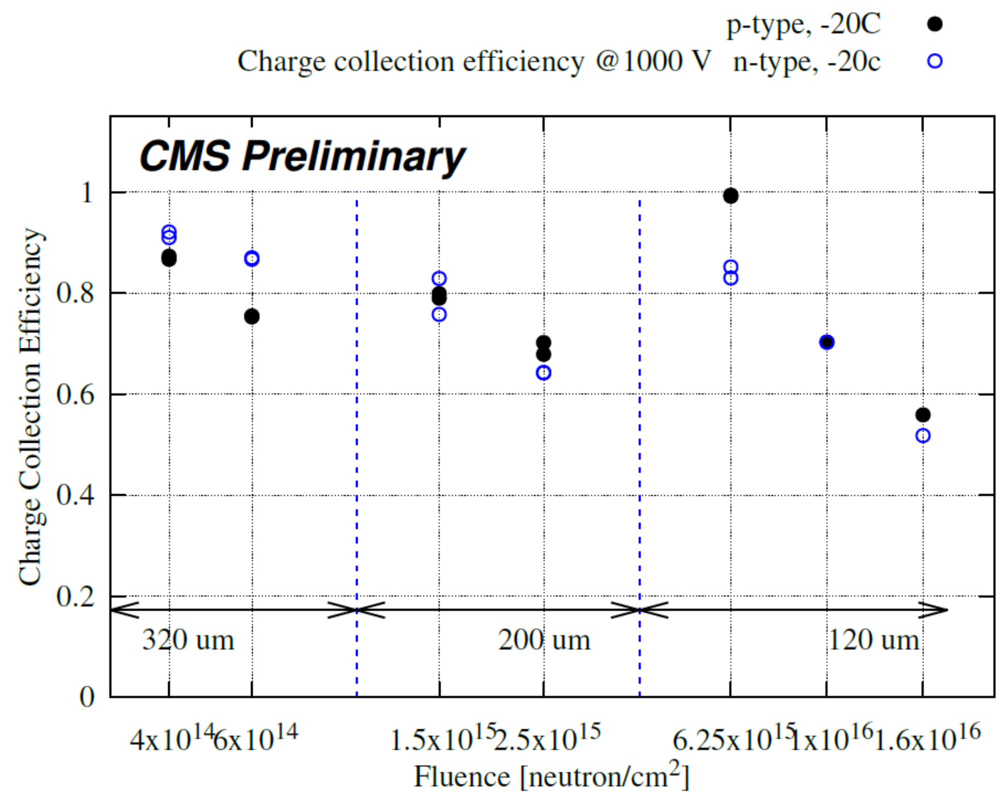


- ✓ Measure the charge Q_{ref} for unirradiated diode (reference) integrating spectrum from TCT
- ✓ Q_{ref} is defined for fully depleted diode at U = 400 V
- ✓ Q = integrated charge for irradiated diode
- ✓ CCE = $^{Q}/_{Q_{ref}(400V)}$

Characterization after neutron irradiation

Charge collection efficiency ⇨ n-type vs p-type

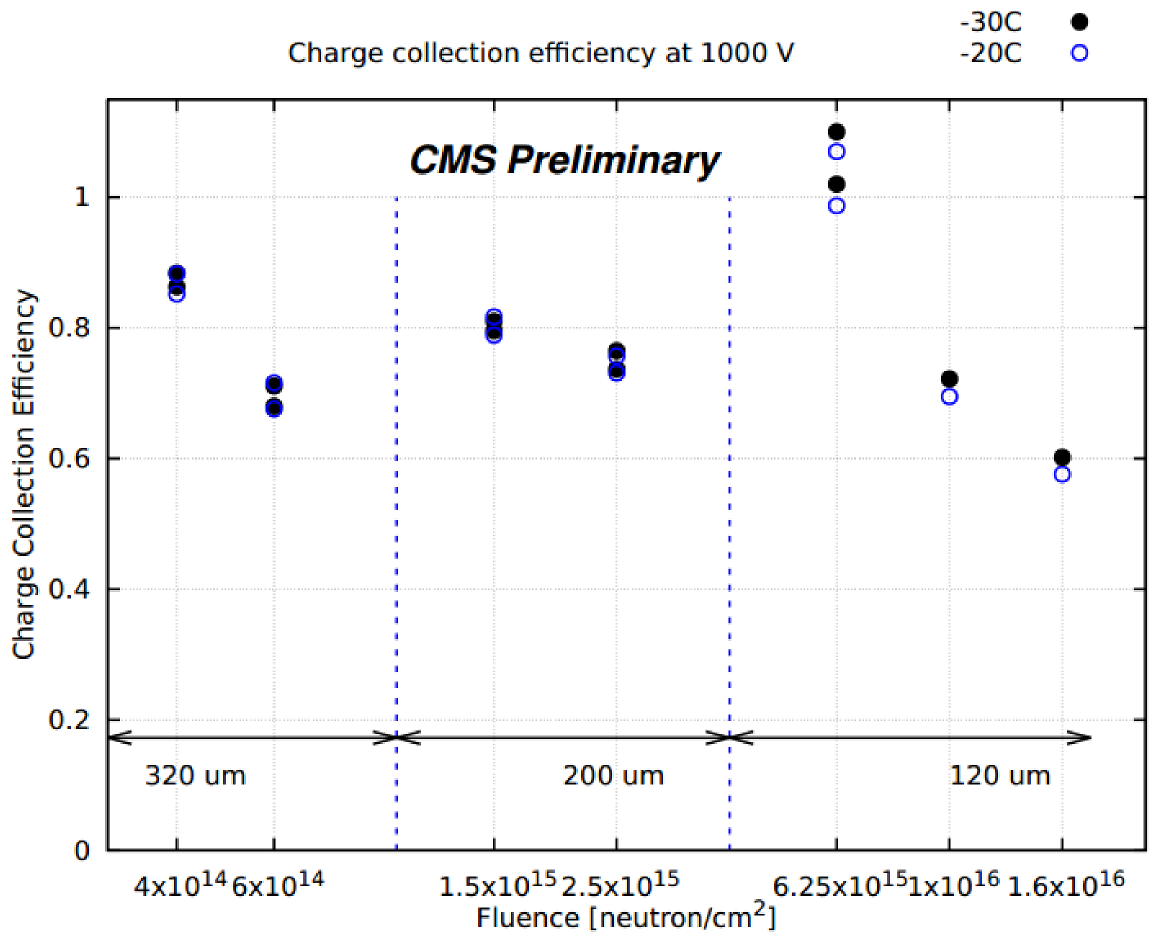




- ✓ For a low bias voltage CCE for n-type diodes is higher than for the p-type
- ✓ For a higher bias voltage p-type and n-type have similar CCE values.

Characterization after neutron irradiation

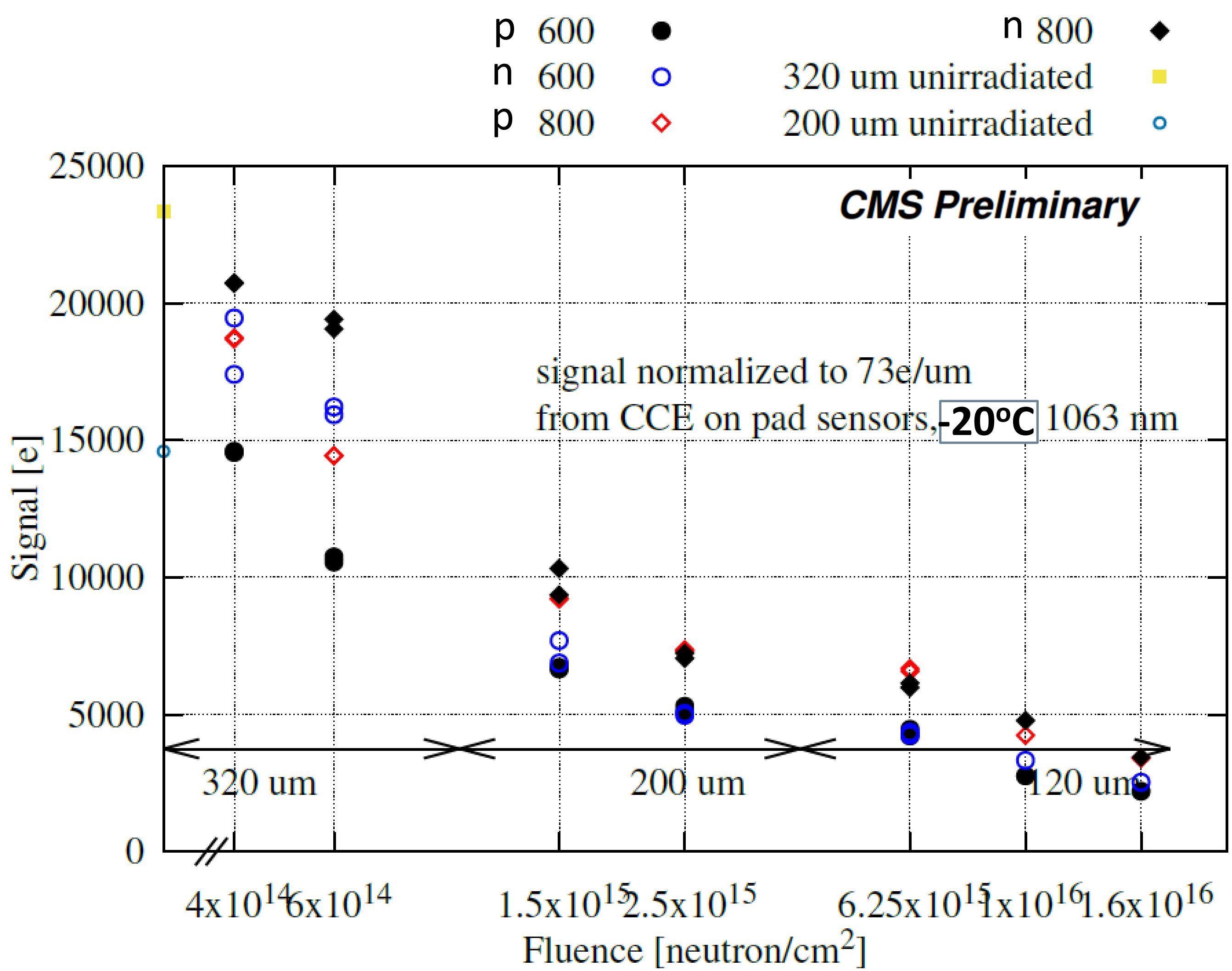
Charge collection efficiency vs temperature ⇨ p-type diodes



✓ We have the same result for the CCE at -20°C and -30°C

Characterization after neutron irradiation

Charge collection efficiency ⇨ **in electrons (21.900 e^- for 300um of Si)**



Summary and future activities

- ✓ Charge collection efficiency (CCE) measured at -20°C and at -30°C:
  $\rightarrow$ CCE measurement at -20°C can be used for lower temperatures
- ✓ Signal pulse shorter than 10 ns (from TCT measurement)
- ✓ To do:
  - ✓ perform 80 min at 60°C additional annealing on half of the diodes (two weeks at room temperature) $\rightarrow$ repeate measurements
  - ✓ Re-irradiation of other half of the sensors (those not annealed) to have estimate for +50% fluence with respect to the nominal one
  - ✓ compare against data of HPK campaign (lower fluence neutrons, but also protons...)
  - ✓ Continue with the measurement at CERN after the annealing and Re-irradiation of the sensors
  - ✓ Measurement with beta source to be performed $\rightarrow$ for MIP sensitivity

Questions …