

# Areas with elevated cell currents in HPK IV data of CMS HGCAL Pad sensors

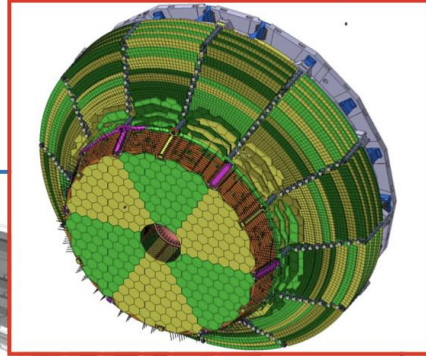
**Ebru Simsek** (Yildiz Technical University & Bogazici University)

Ufuk Guney Tok (Cukurova University)

on behalf of the HGCAL Silicon Sensor Team

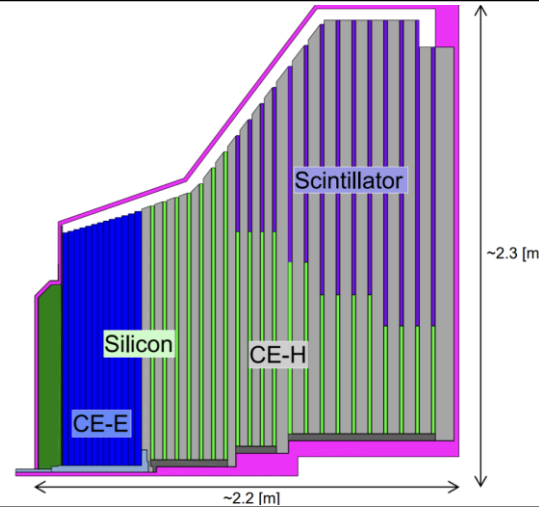
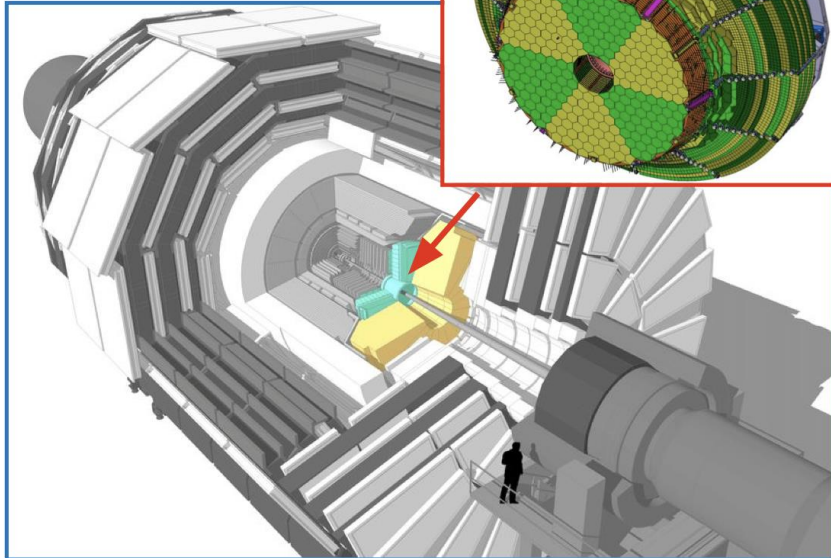
# Transition to the HL-LHC Era: CMS HGCAL

## New Calorimeter Endcap (CE)

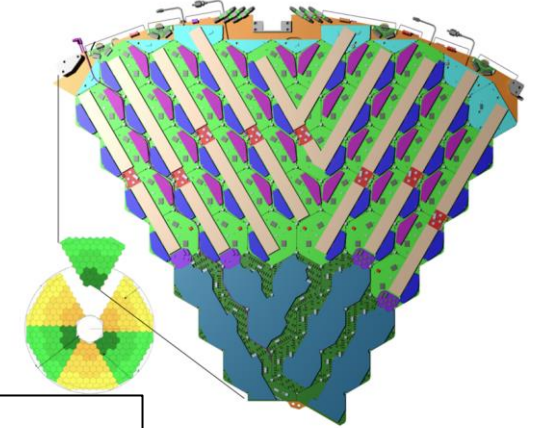


- ❑ Silicon sensors in CE-E (Electromagnetic Endcap) and high-radiation CE-H (Hadronic Endcap)
- ❑ Scintillator tiles + SiPM in lower-radiation CE-H

## Current CMS detector



## Slices of HGCAL : Cassettes



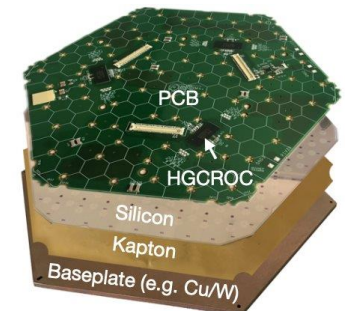
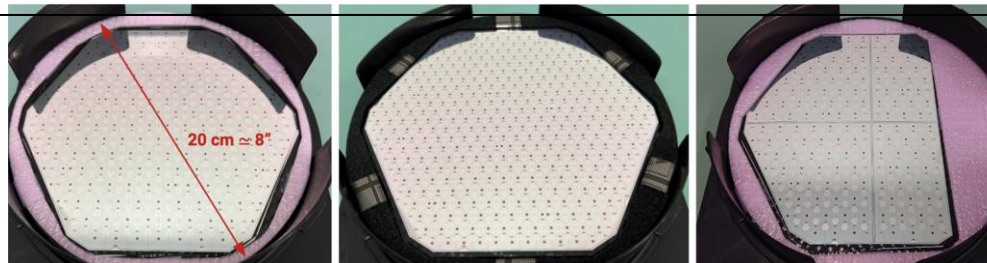
## Silicon sensors

- ❑ Radiation-hard, fast-response
- ❑ 300, 200, and 120 $\mu$ m thickness, depending on radiation field
- ❑ Low Density (LD): 198 channels, mostly 1.26 cm<sup>2</sup>
- ❑ High Density (HD): 444 channels, mostly 0.56 cm<sup>2</sup>
- ❑ Partial sensors to fill the perimeter of the detector

~26 000 silicon modules

## HGCAL Overview:

- ❑ Coverage:  $1.5 < \eta < 3.0$
- ❑ 10x more integrated luminosity
- ❑ ~6 million readout channels
- ❑ ~620 m<sup>2</sup> silicon in 26'000 8-inch sensors
- ❑ ~500 m<sup>2</sup> scintillator tiles
- ❑ Operation temperature: -35 °C



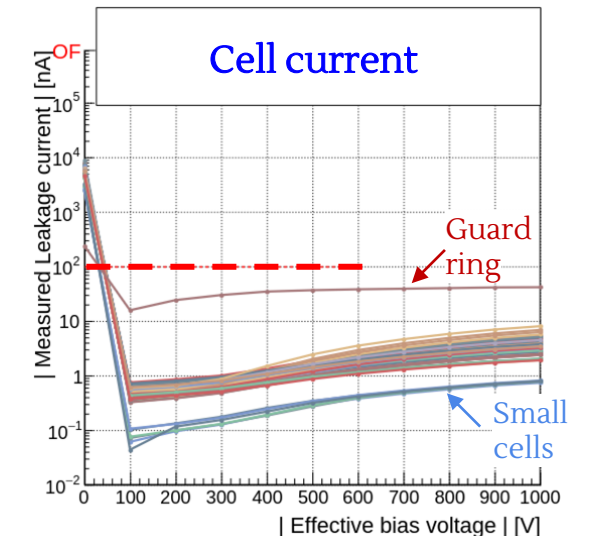
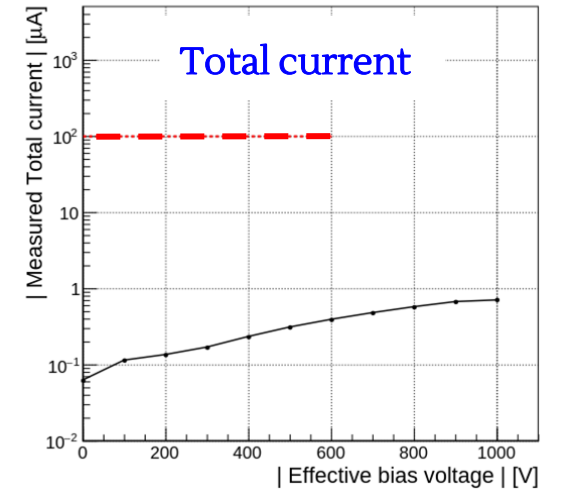
# HGCAL Silicon Sensors - Acceptance Criteria

- ~25'000 silicon sensors delivered by Hamamatsu Photonic K.K. in 2023–2025
- Vendor Quality Control included
  - IV of all cells from 0-1000V
  - CV of single test diode from 0-400V

- Sensor is rejected if
  - The sensor's **total current**
    - Is above **100 $\mu$ A** at 600V
    - Increases by more than a factor 2.5 between 600V and 800V
  - The sensor has
    - $\geq 8$  “bad” cells
      - A cell is considered “bad” if the **cell current**
        - Is above **100nA** at 600V
        - Increases by more than a factor 2.5 between 600V and 800V
    - $\geq 2$  neighbouring bad cells

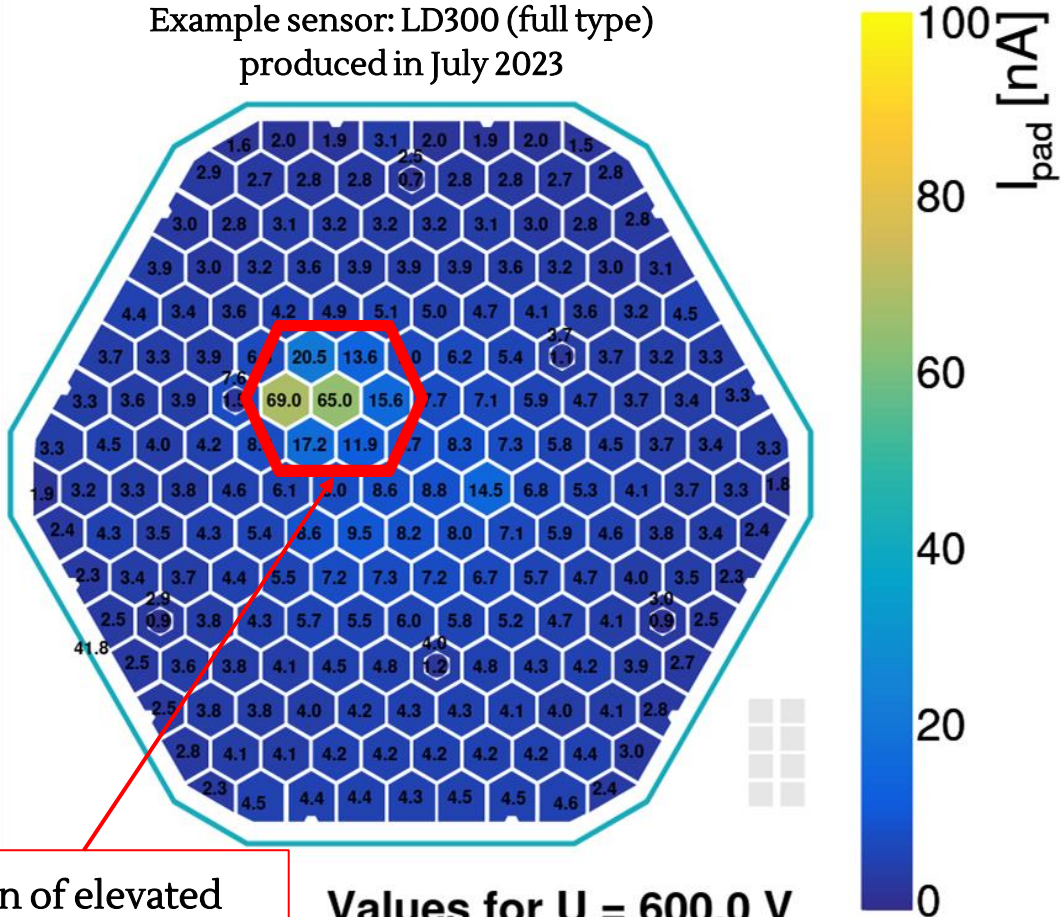
- Current limits chosen to detect manufacturing defects
- Avoid **early break down** and **micro discharges**
  - Avoid being in **range of MIP**

Example HPK measurement



# Motivation

Example sensor: LD300 (full type)  
produced in July 2023



Region of elevated  
by still technically  
acceptable currents

**Observation:** Many sensors exhibit elevated but mostly moderate leakage current ( $<100\text{nA}$  at  $600\text{V}$ ), e.g. located just to the upper left of the geometrical center.

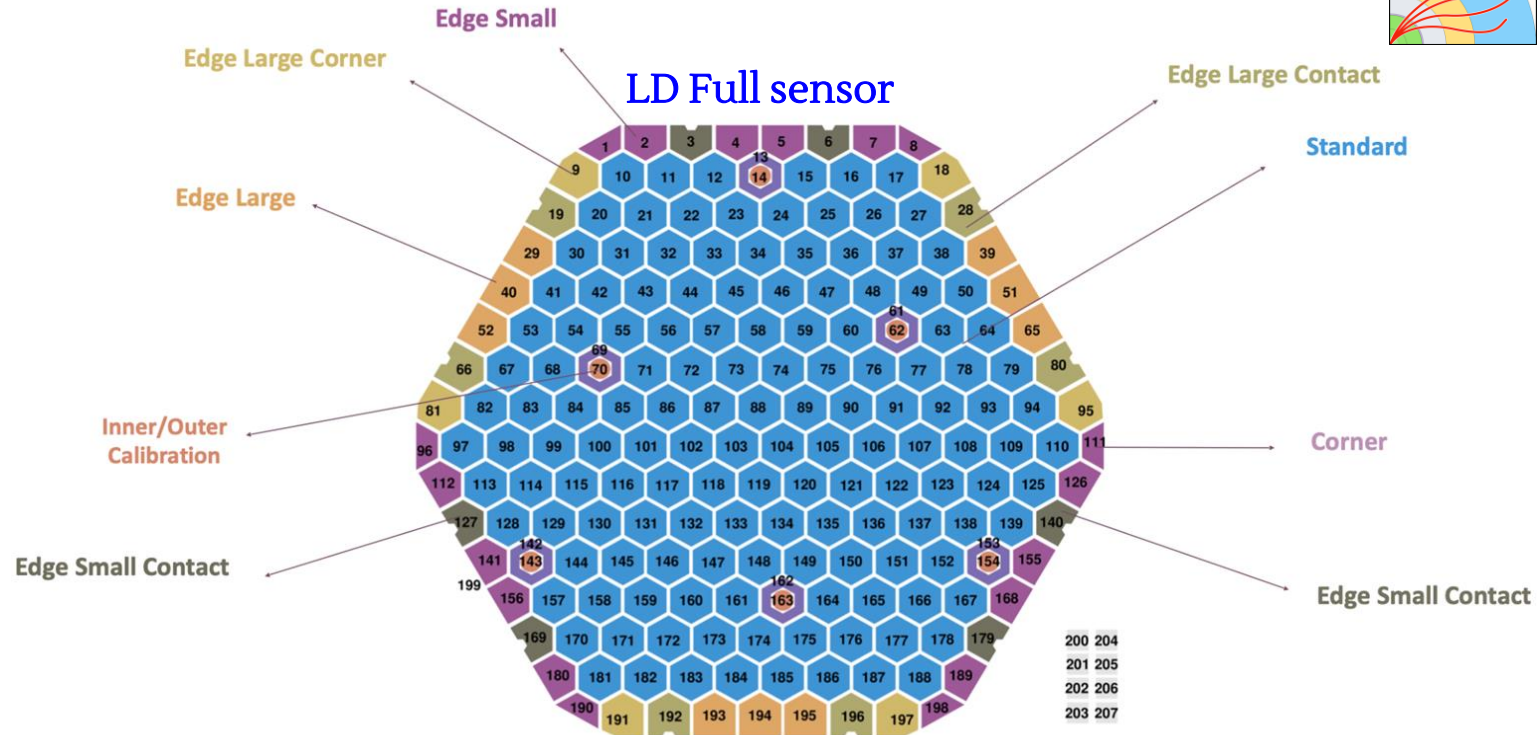
**Goal:** Understand the origin of these “hot regions” by evaluating their occurrence frequency across all sensor types and deliveries.

**Hot cell:** Leakage current well above average but below  $100 \text{ nA @ } 600 \text{ V}$ , so not failing quality criteria.

**Data source:** Per-cell IV measurements by HPK at  $25 \text{ }^\circ\text{C}$ . Hot-cell frequency derived from these data.

# “Hot cell” thresholds

- Use volume-current thresholds that make structures already seen in bare IV data best visible
- Test with 3 thresholds for large sensitivity
  - Tight: 0.4 nA/mm<sup>3</sup>
  - Medium: 0.2 nA/mm<sup>3</sup>
  - Loose: 0.1 nA/mm<sup>3</sup>



Sensor Type	Material	Standard Cell Volume (mm <sup>3</sup> )	Tight (nA):	Medium (nA)	Loose (nA)
LD 300μm	FZ	37.416	15.00	7.50	3.75
LD 200μm	FZ	24.944	10.00	5.00	2.50
HD 200μm	FZ	11.012	4.41	2.20	1.10
HD 120μm	Epi	6.607	2.64	1.32	0.66

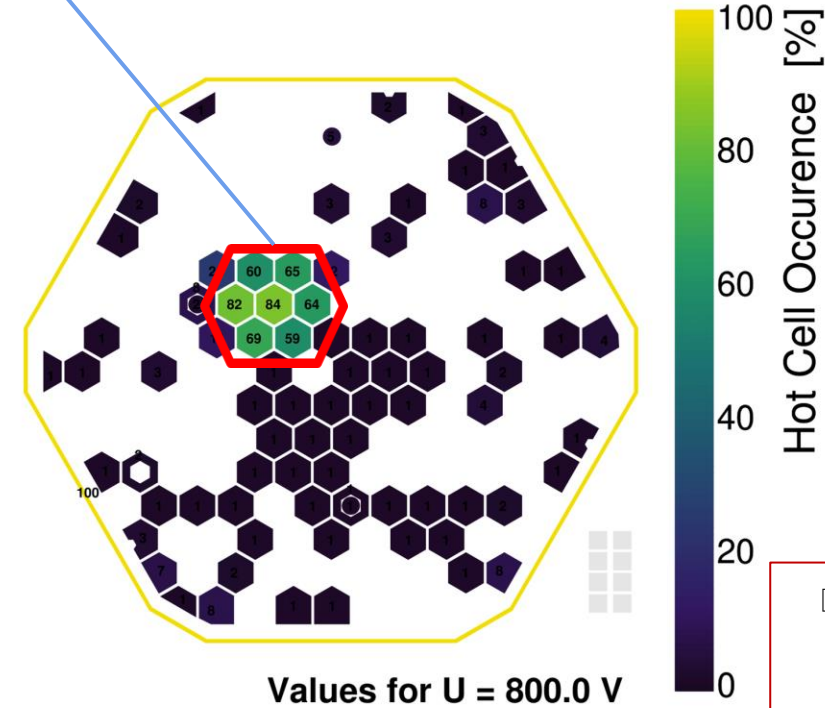
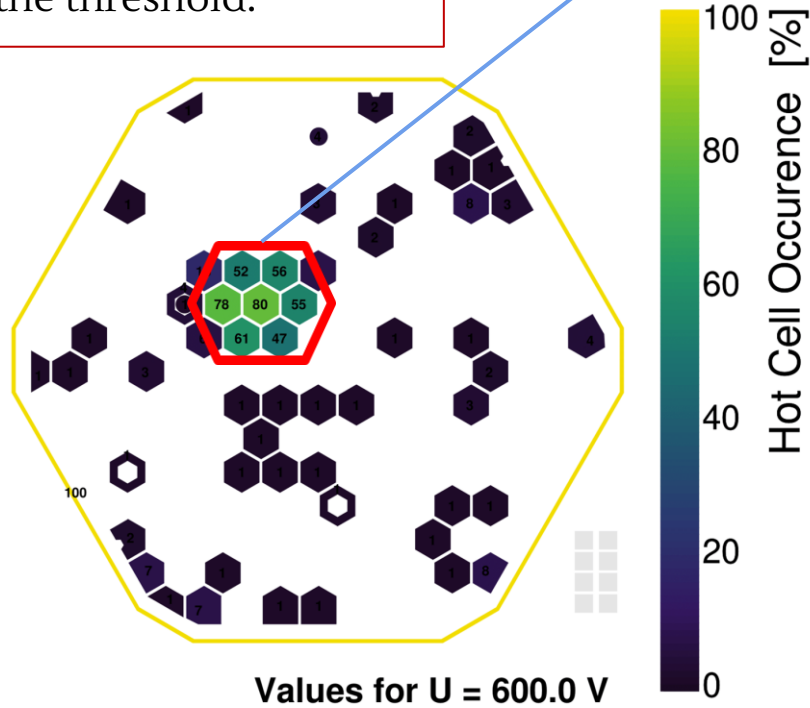
- Threshold defined for **standard cell**, adjusted for all other cells by cell area scaling
- Cell area taken from sensor GDS design files, approximated by n-implant area

# Examples: LD-Full 300um - April 2024 delivery (medium thr.)

**Hot cell occurrence:**  
 Fraction of sensors in the given delivery in which the given cell is above the threshold.

**Hot cell cluster around cell 72**

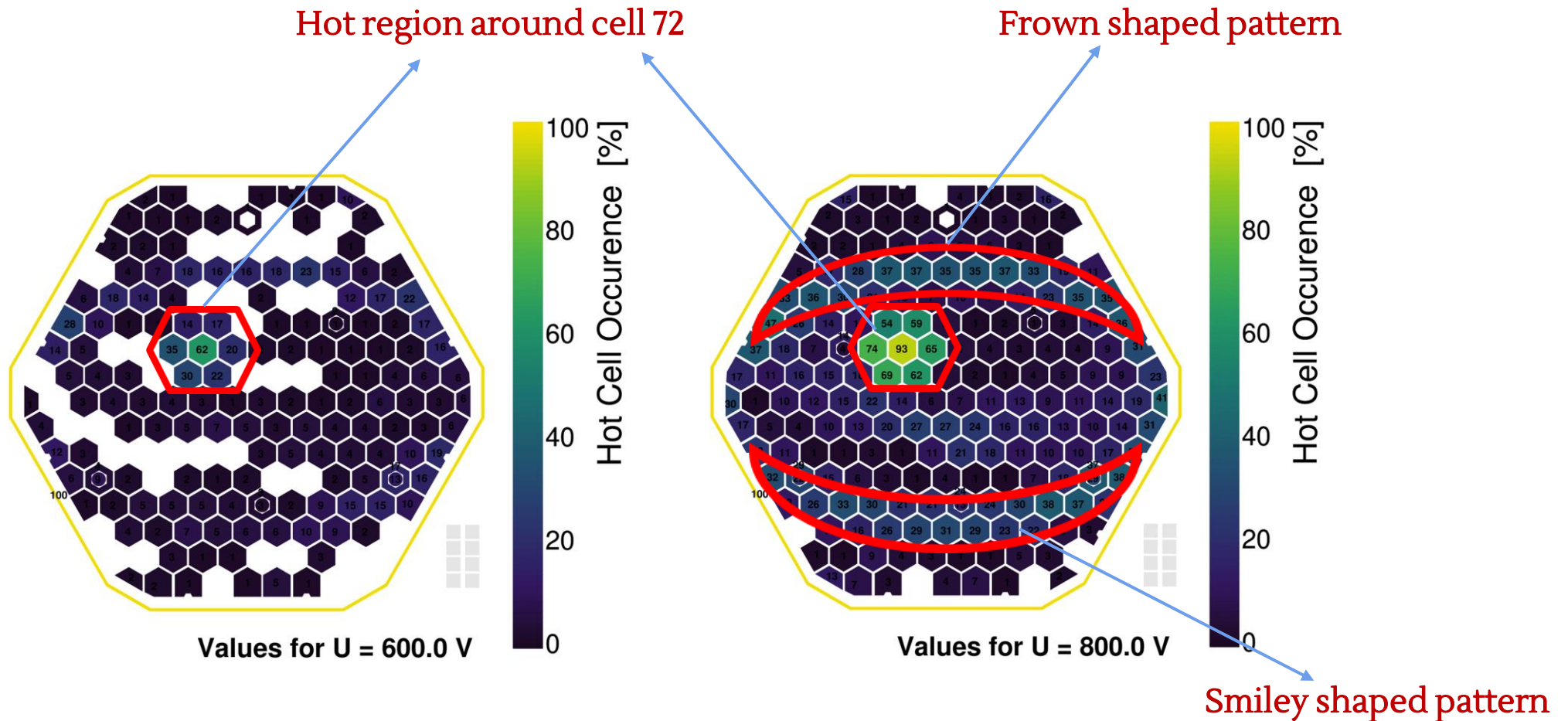
□ White: no data (0%)  
 □ Dark blue: >0%



□ Each plot represents all sensors in one delivery, not a single sensor.

- Around cell 72 and its surrounding region, the occurrence rises up to 85%.
  - Note: Medium threshold for a standard cell in LD300 sensors is 7.5 nA.

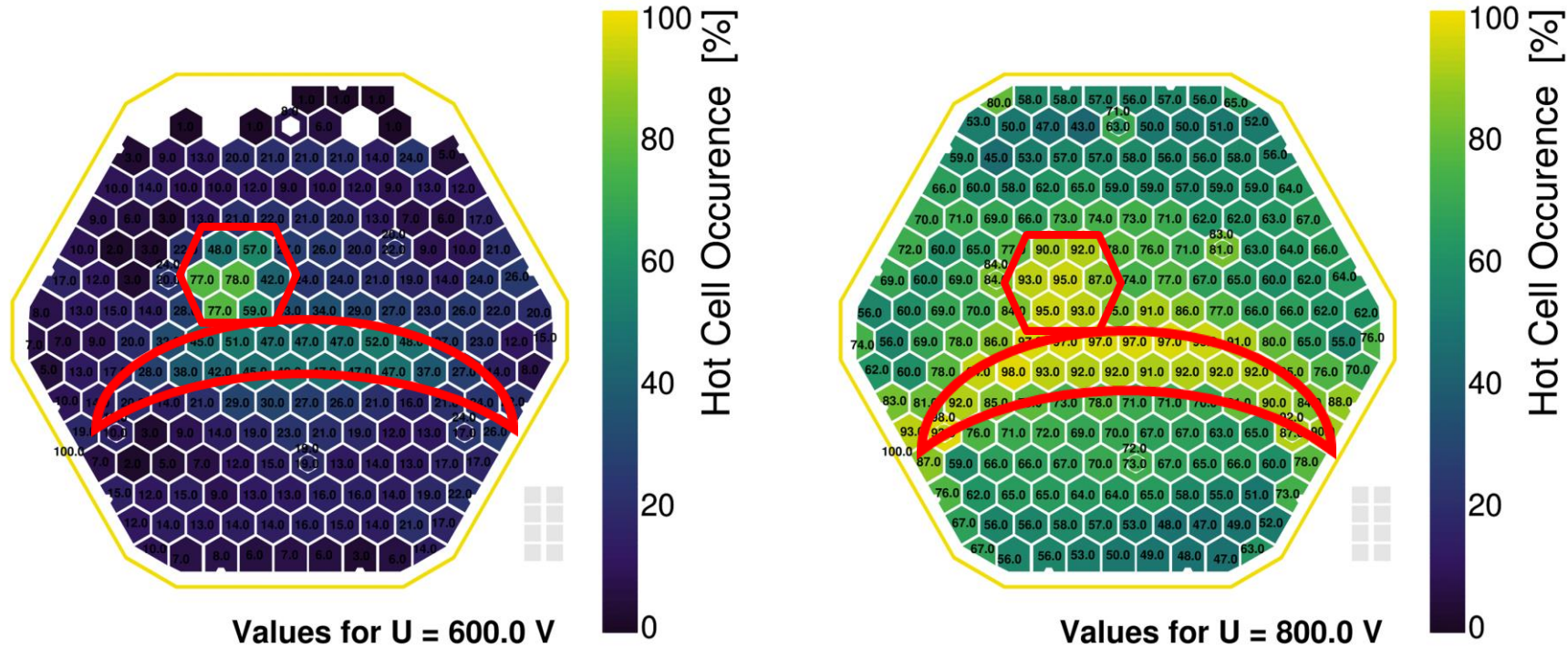
# Examples: LD-Full 200um - October 2024 delivery (medium thr.)



- Apart from cell 72, hot regions appear in smiley and frown-shaped patterns.

# Examples: LD-Full 200um - August 2024 delivery (medium thr.)

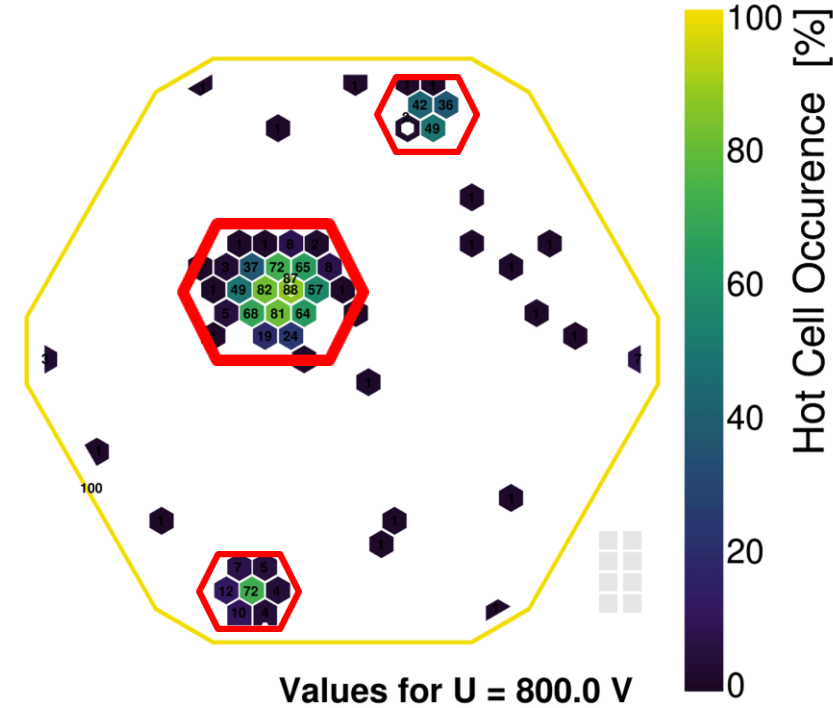
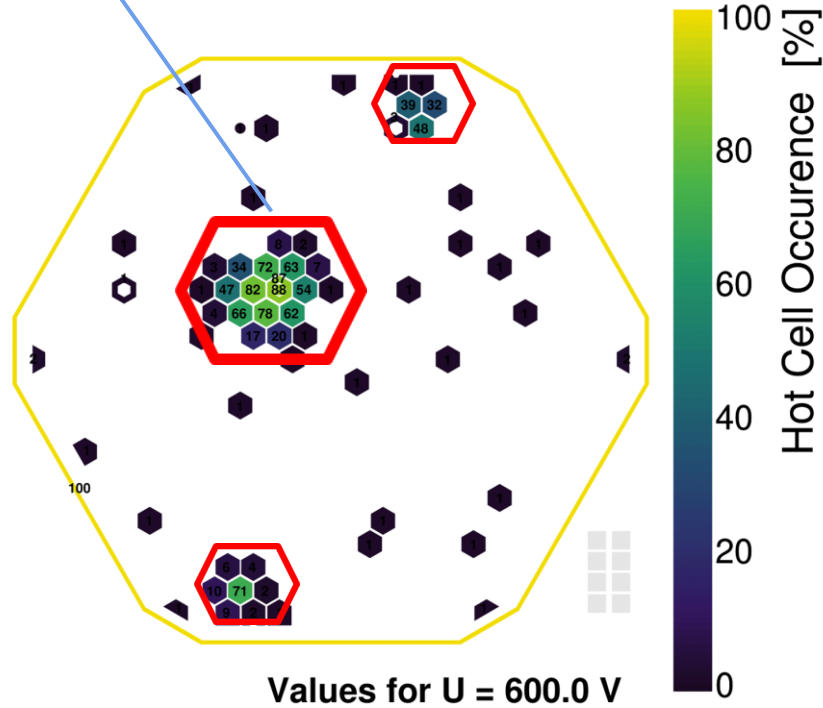
- Around cell 72, occurrence up to 80% at 600 V and 95% at 800 V.



- A frown-shaped hot-cell cluster along the sensor's midline.

# Examples: HD-Full 120um - July 2024 delivery (loose thr.)

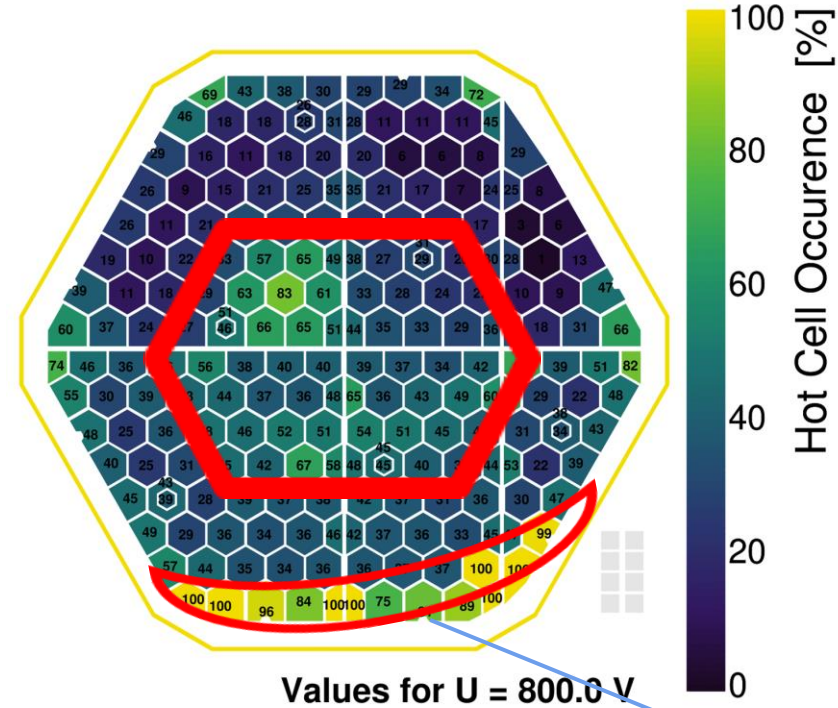
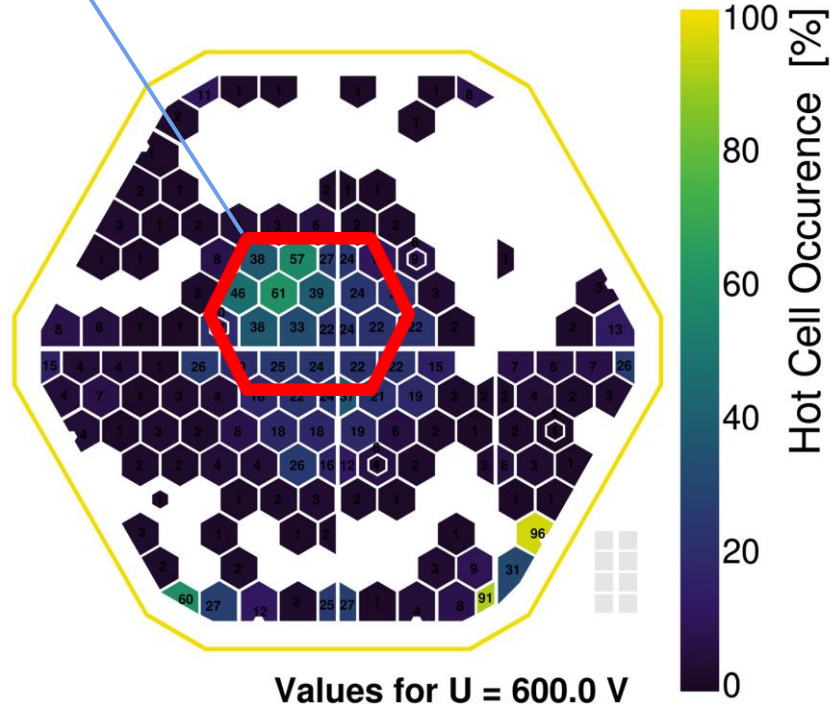
Hot region around cell 156



- In addition to cell 156 (72 for LD full), two small clusters appear in the left and right corners.

# Examples: LD-Partial 300um - July 2024 delivery (tight thr.)

Hot cluster around cell 76 (72 for LD full)

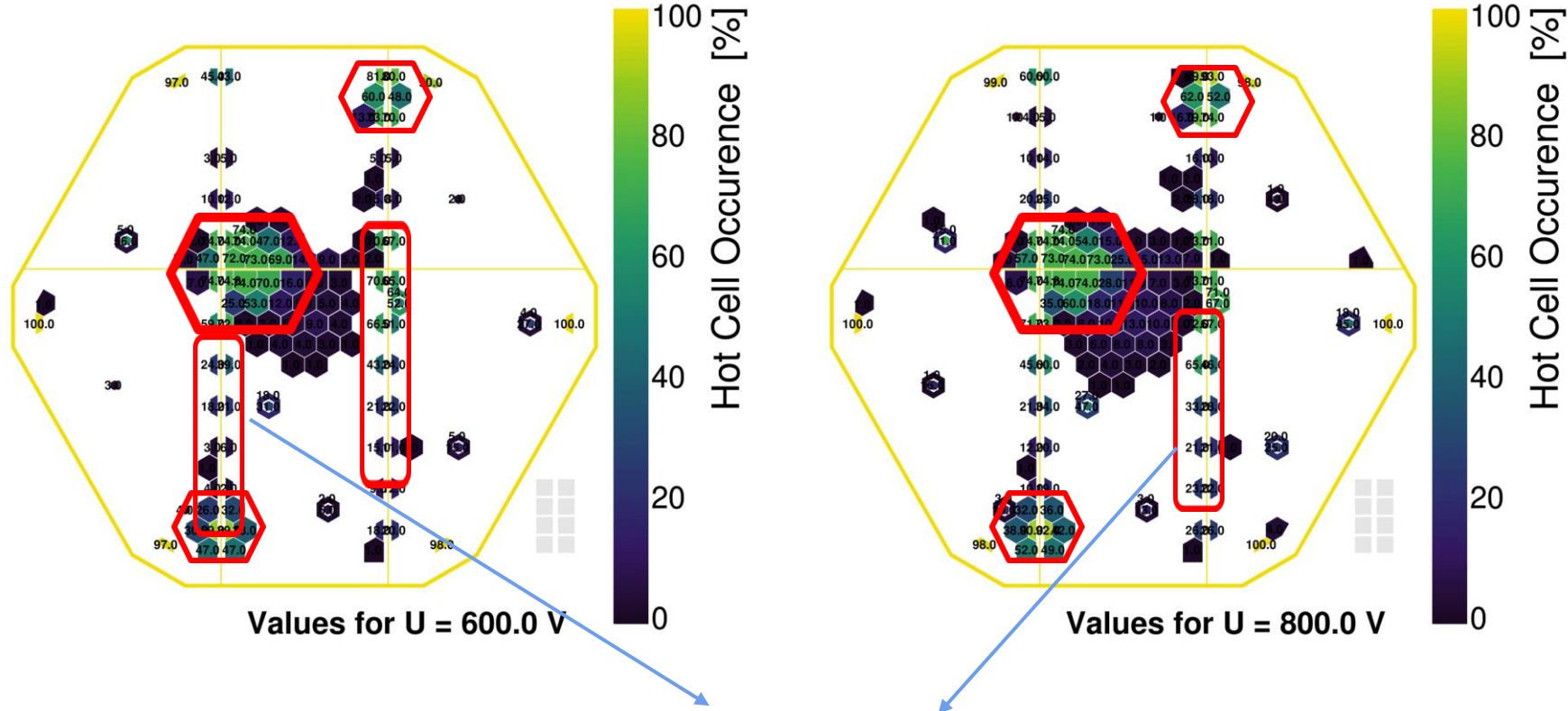


Hot cell cluster close to guard ring

- Hot cells are observed around cell 76 and near the guard ring.

# Examples: HD-Partial 120um - August 2024 delivery (medium thr.)

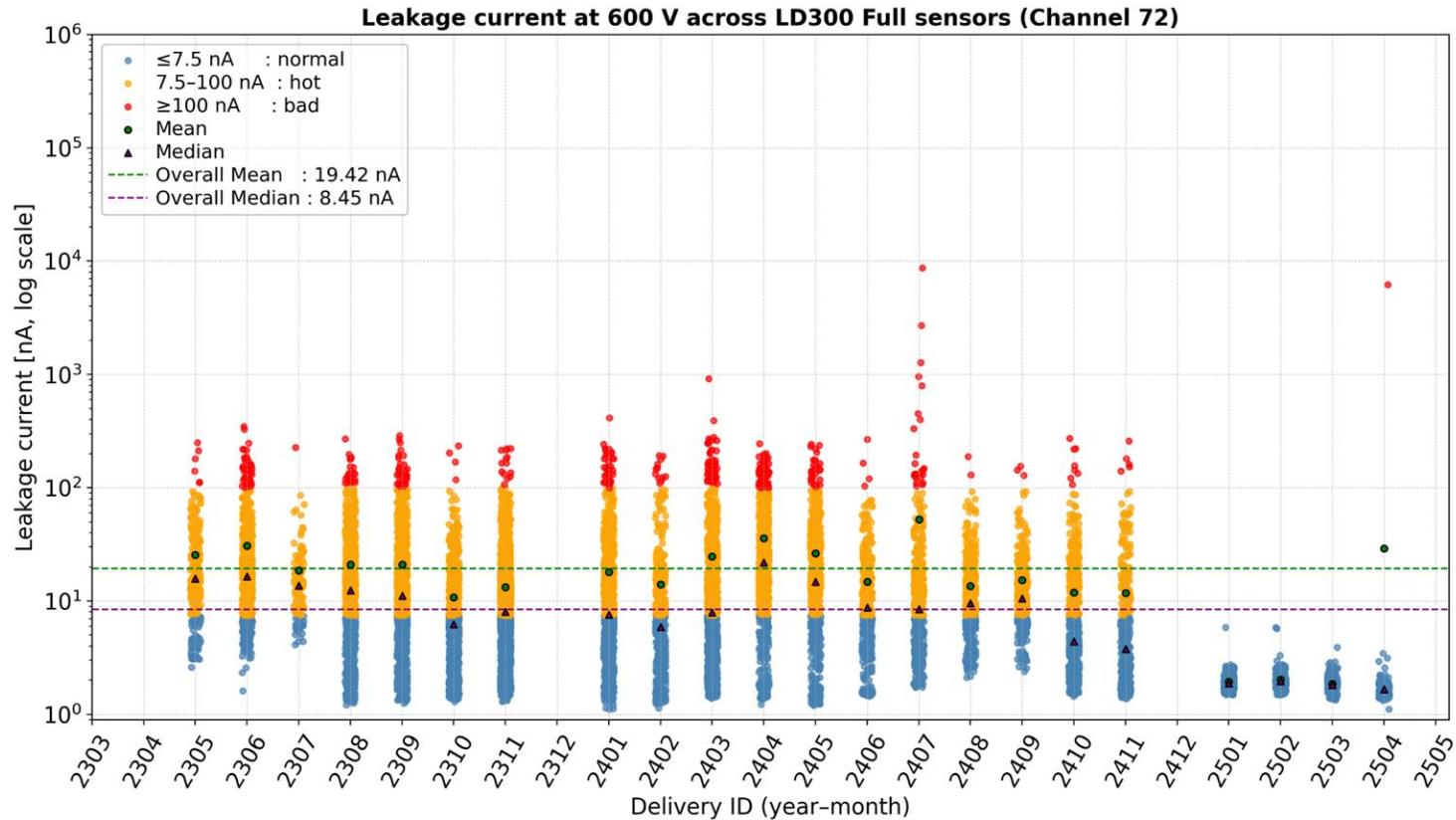
- Same pattern as HD120 full, but with hot-cell clusters on the inner guard rings.
  - HPK performs measurements on partial sensors before dicing.



Hot cell clusters on inner guard rings

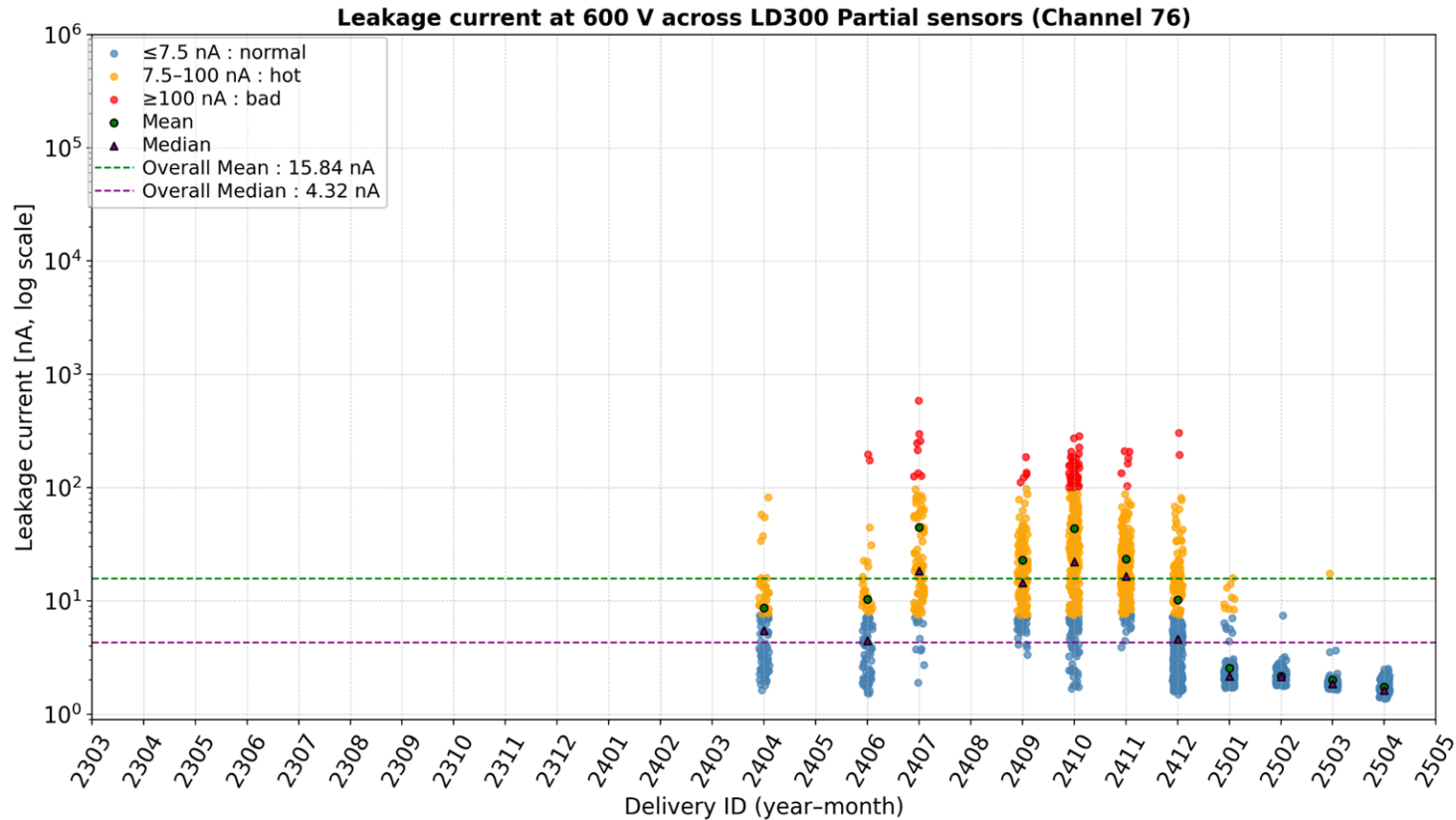
- Note: Medium threshold for a standard cell in HD120 sensors is 1.32 nA.

# Evolution of hot spot around cell 72 in LD300um Full sensors



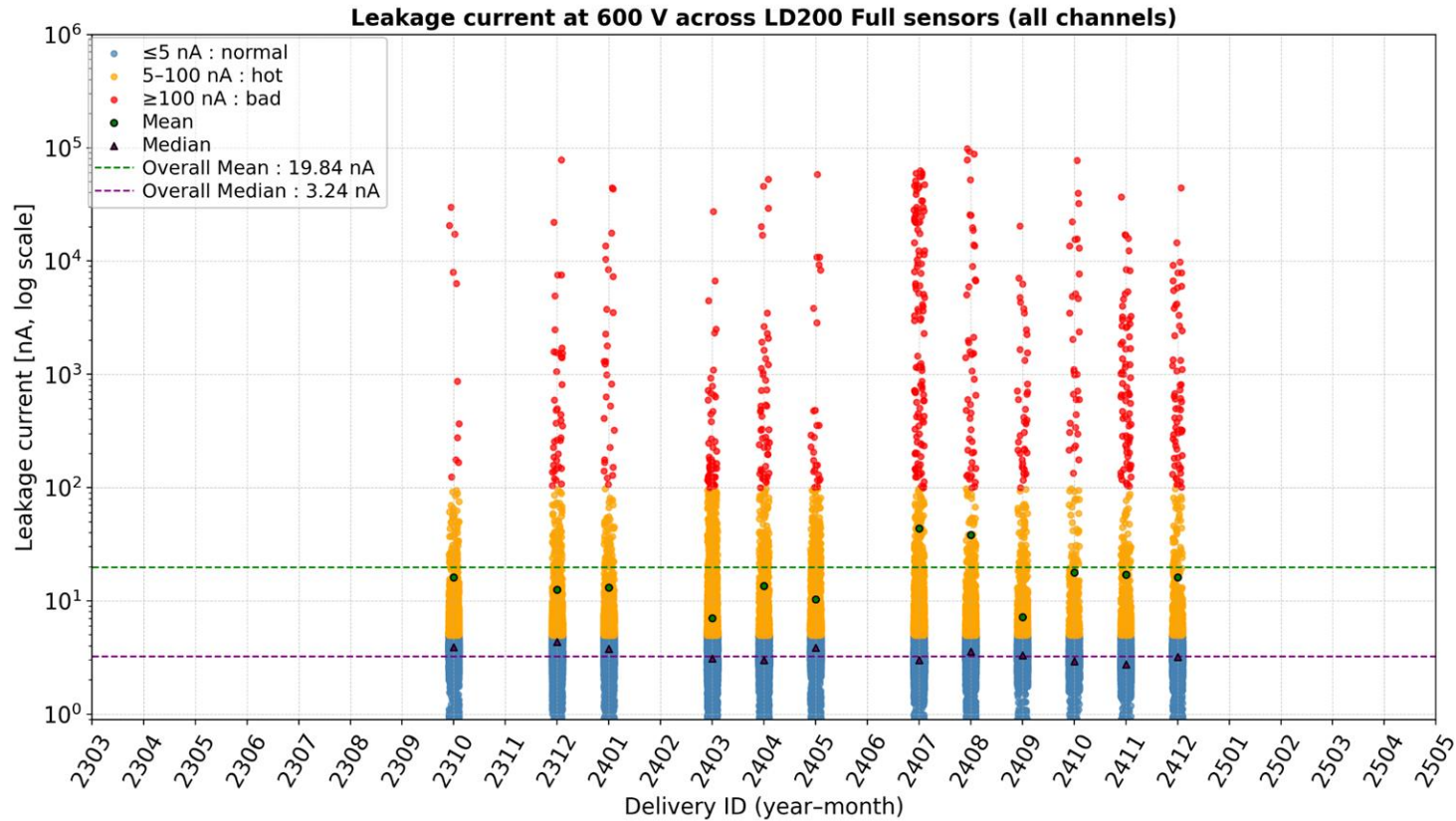
- Frequent elevated currents in 2023–2024.
- Extra high outliers in July 2024.
- Cell current improved drastically in 2025.

# Evolution of hot spot around cell 76 in LD300um Partial



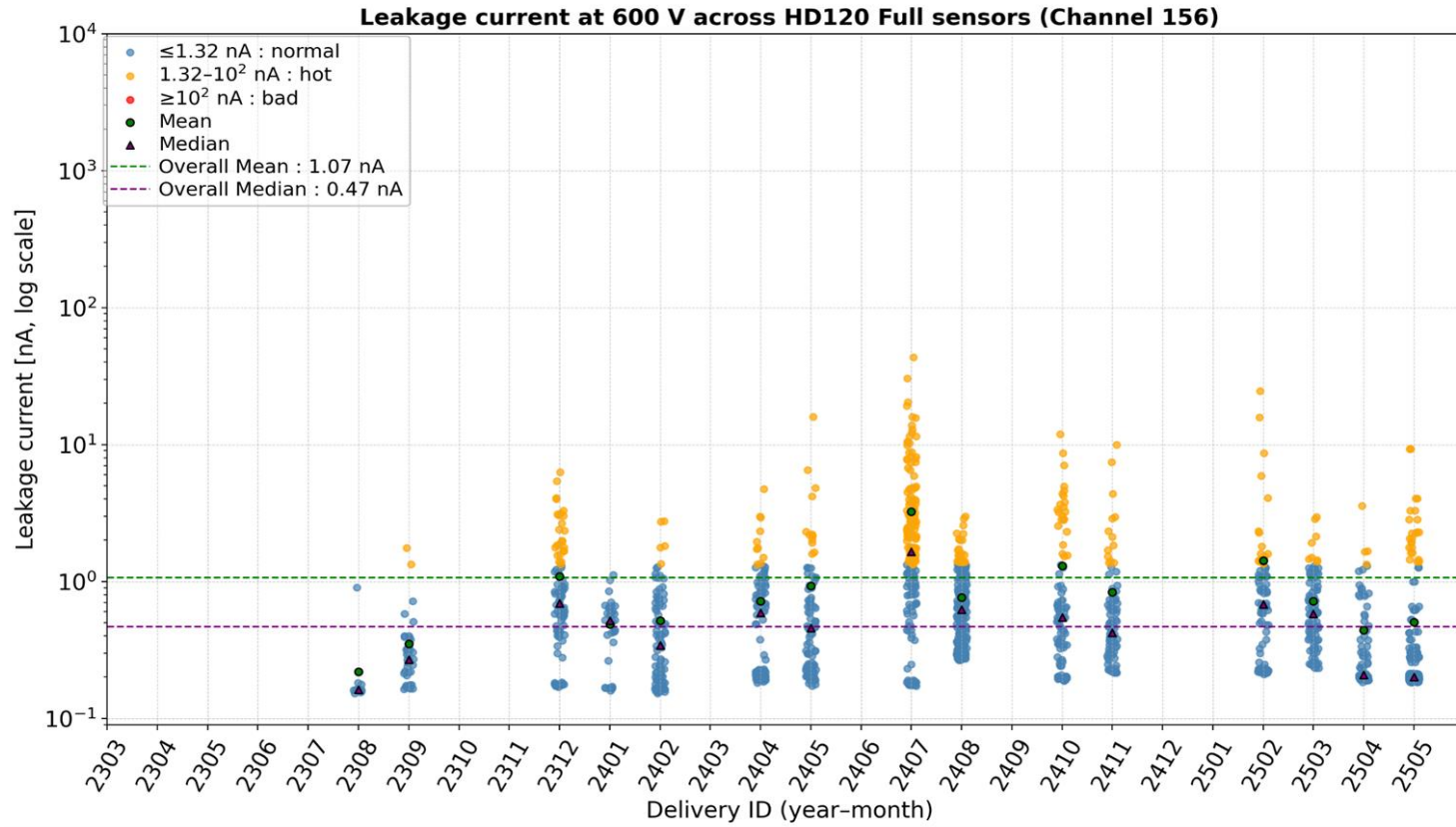
- Cell current improved drastically in 2025, the same as for other LD300 types.
- Hot cells are frequent in the 2024 deliveries, and there are even bad cells, but in 2025 there are a few hot cells and no bad cells.

# Evolution of cell current in LD200 Full sensors for all channels



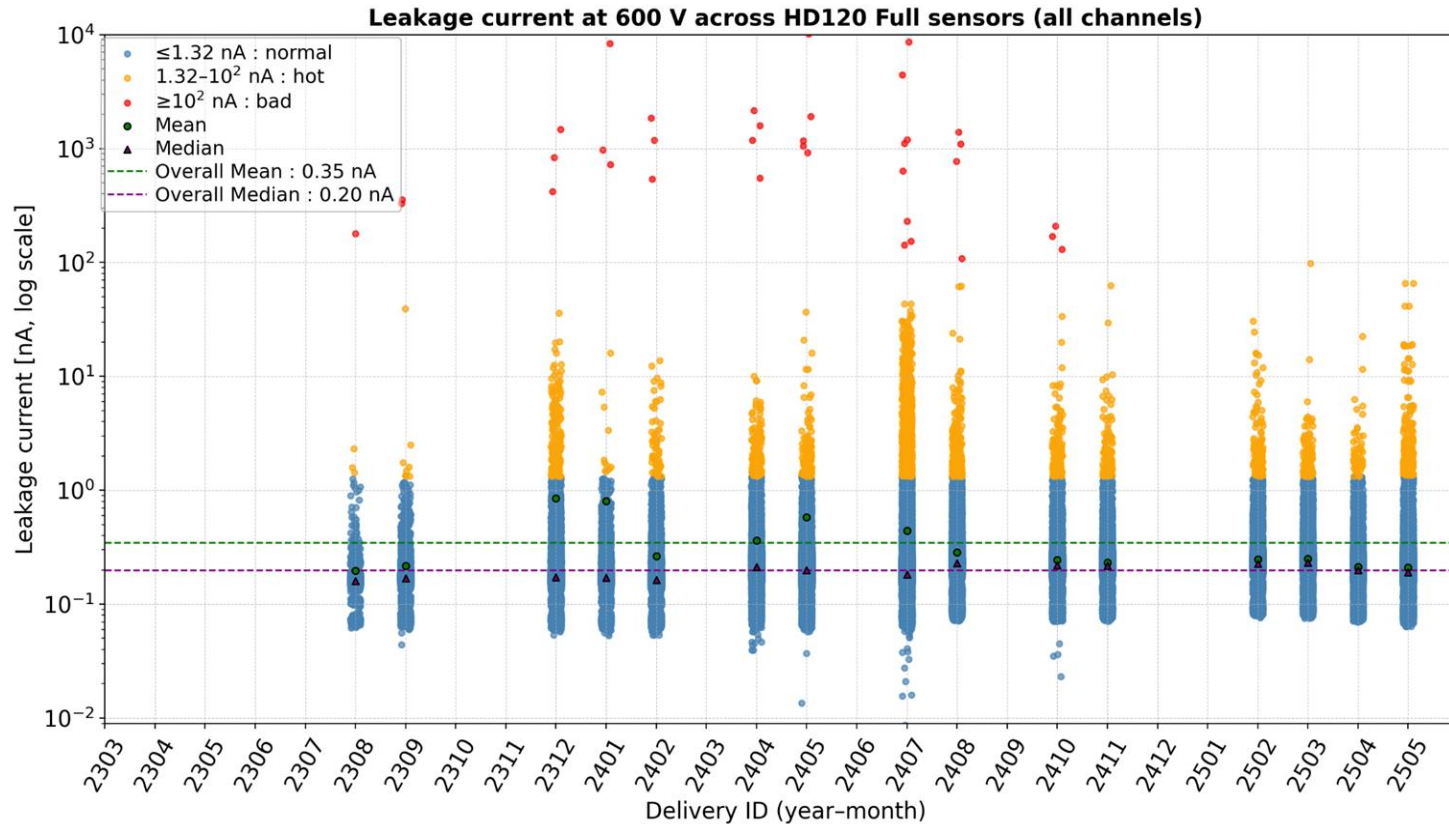
- LD200 generally exhibits elevated leakage current.
- The average current exceeds that of LD300.

# Evolution of hot spot around cell 156 in HD120um Full sensors



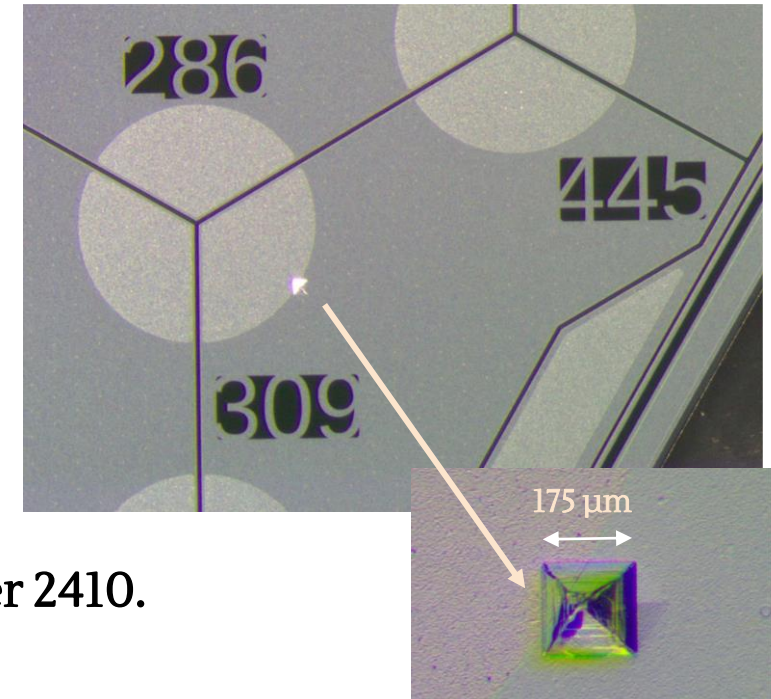
- No bad measurements ( $\geq 100$  nA) occurred.
- A clear increase in current is visible in delivery 2407.

# Evolution of cell current in HD120 Full sensors for all channels



- Up to 2410: outliers above 1000 nA.
  - After 2410: none above 100 nA.
- HPK stopped sending sensors with cells  $>100\text{nA}$  @ 600V after 2410.
  - This is consistent with cells with stacking faults.

Microscope view of stacking fault



# RESULTS

- **Hot spot above the centre, observed in 2023-2024, no longer seen in 2025 FZ sensors.**
  - We are following up with HPK to understand the cause.
- **Smile/frown patterns visible in 200  $\mu\text{m}$  FZ sensors (LD + HD).**
  - Further clarification is being discussed with HPK.
- Slide 25 shows the presence and type of pattern for each delivery (backup table).
- **Cells with high currents ( $>100$  nA) in epitaxial sensors disappear after delivery 2410.**
  - This is consistent with the discontinued shipment of sensors suspected to have a stacking fault.
- **Increased cell currents in delivery 2407.**
  - Seasonal temperature variation may play a role, although the pattern is not consistent.

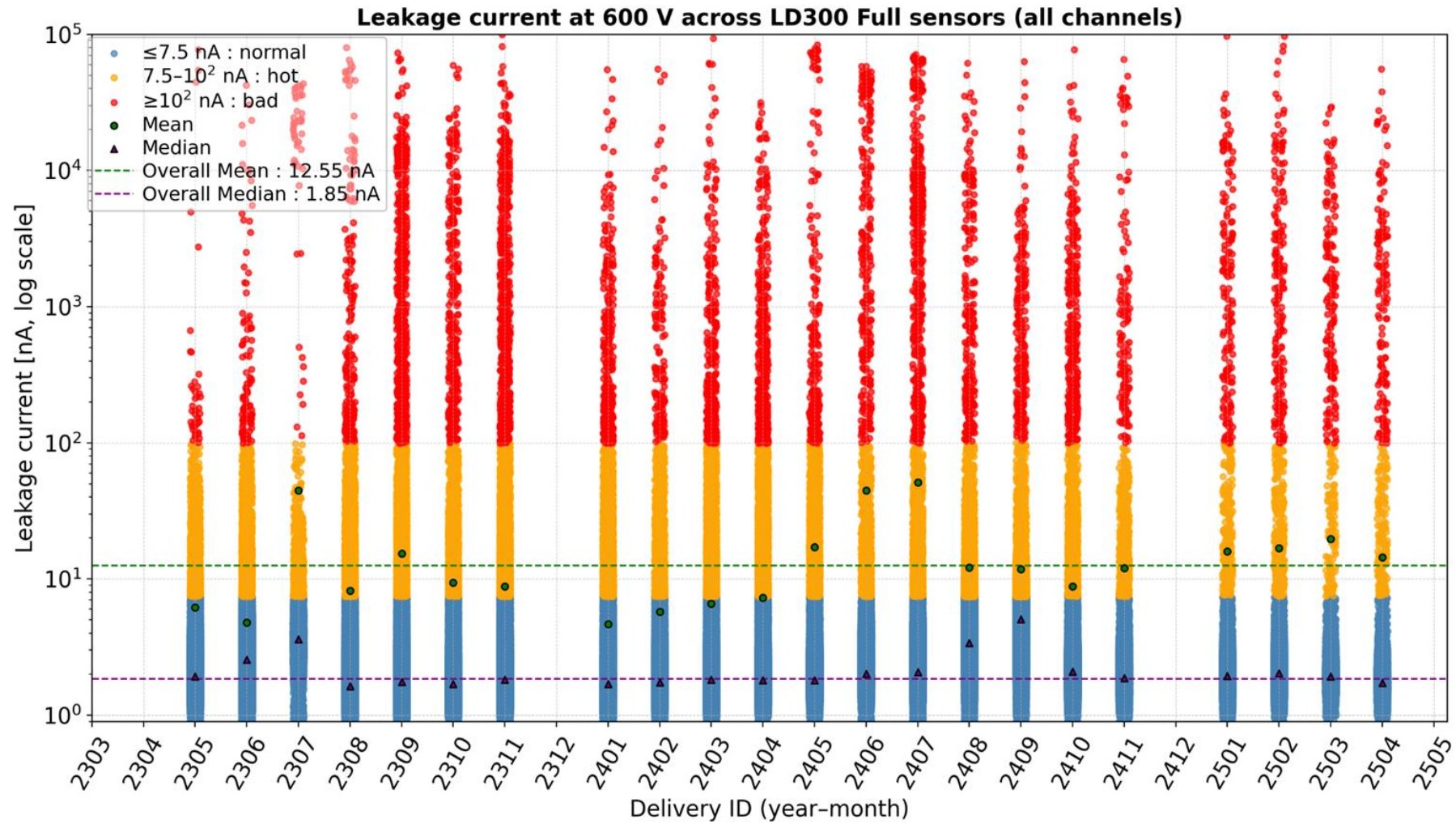


**THANK YOU  
FOR YOUR ATTENTION!**

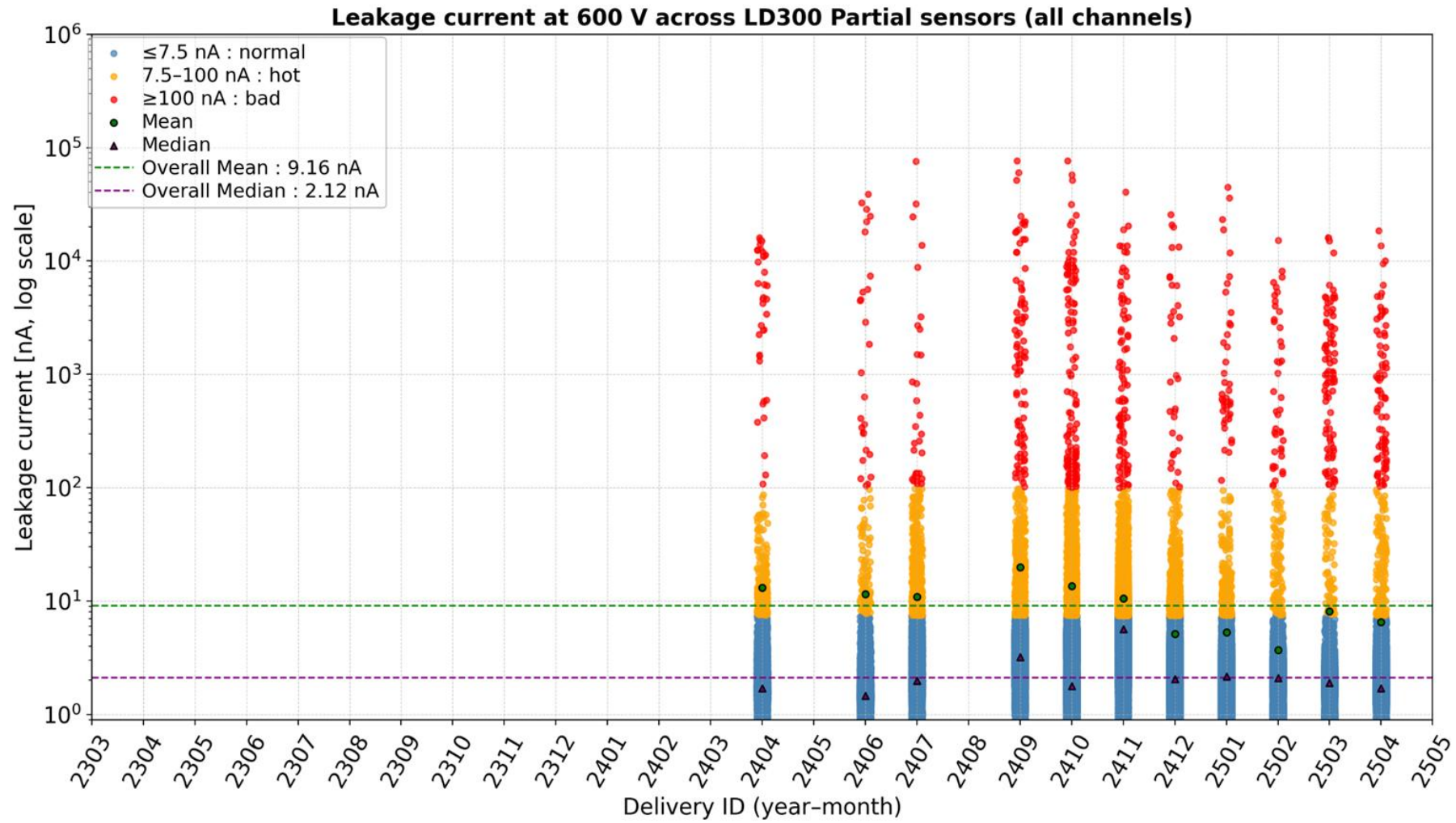


# BACKUP

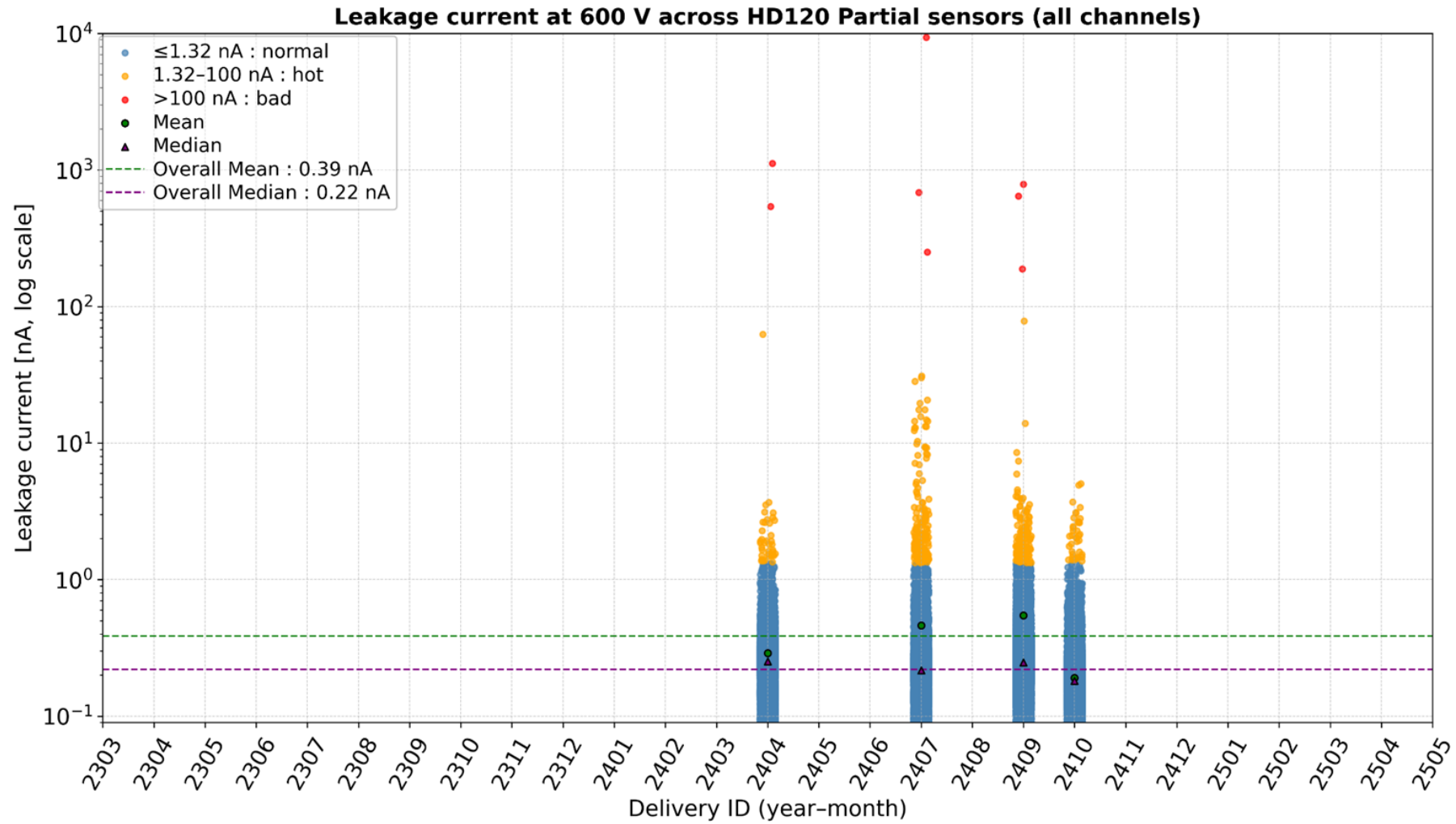
# Evolution of cell current in LD300 Full sensors for all channels



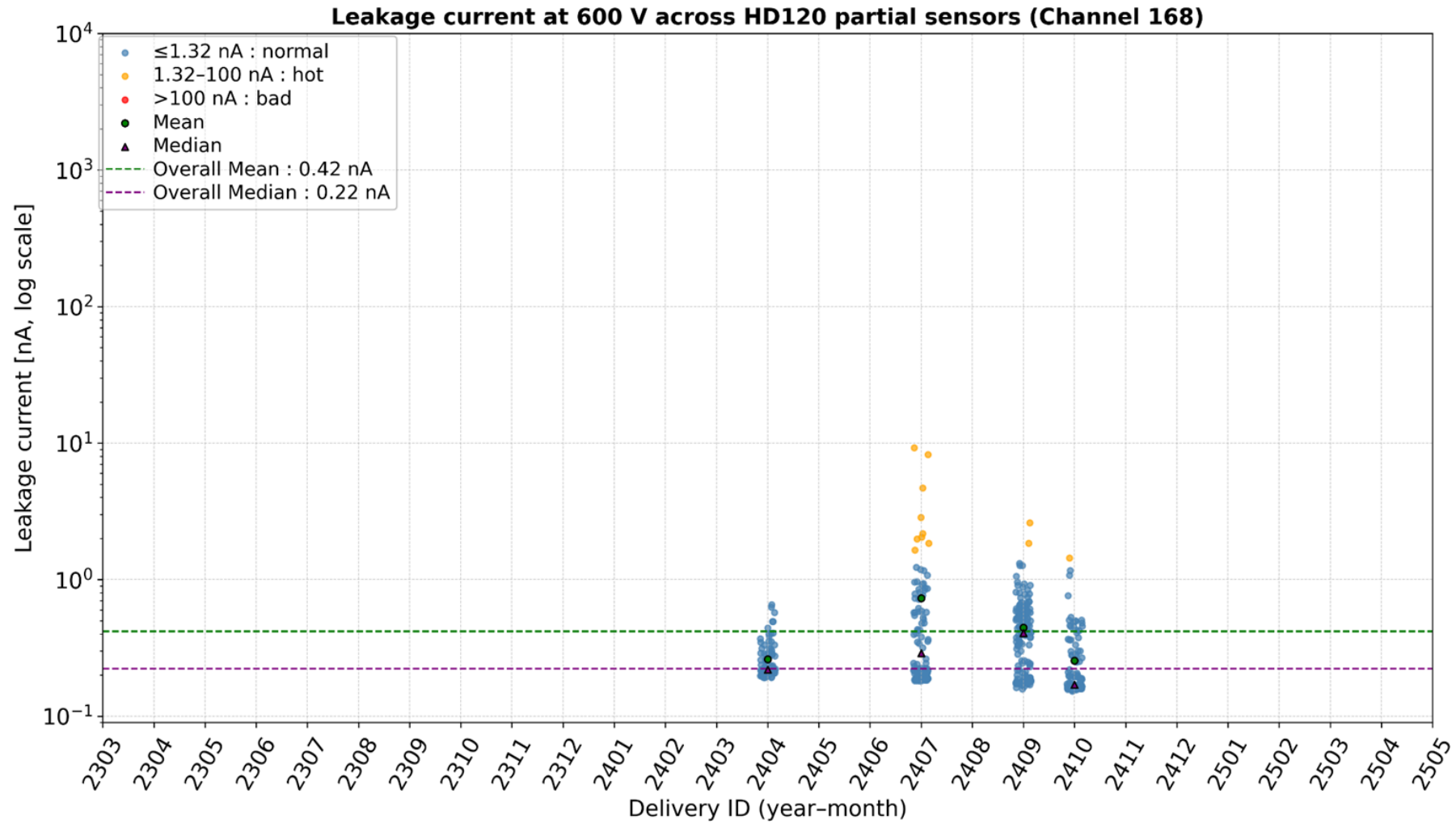
# Evolution of cell current in LD300um Partial sensors for all channels



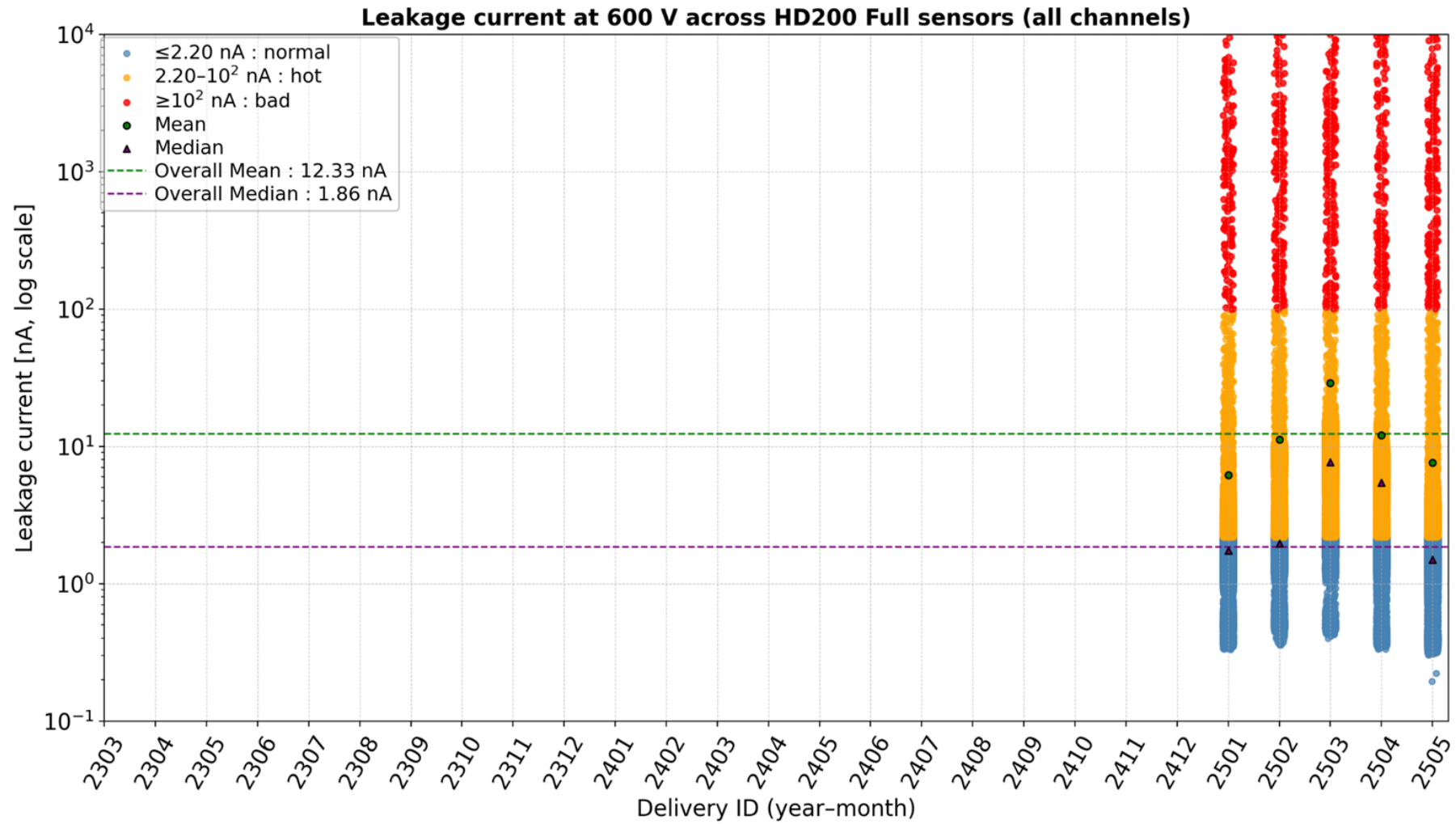
# Evolution of current in around in HD120 Partial sensors for all channels



# Evolution of current in around cell 168 in HD120 Partial



# Evolution of cell current in HD200 Full sensors for all channels



# Main patterns per delivery and type

## ~Central hot spot (e.g. cell 72 in full LD, 156 in full HD)

	Quarter	Q1'23			Q2'23			Q3'23			Q4'23			Q1'24			Q2'24			Q3'24			Q4'24			Q1'25			Q2'25			
		Month (shipping date !)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Full	S15591-01 (FULL 300LD)		Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No		
	S15591-02 (FULL 200LD)	Yes										Yes	Yes		Yes	Yes		No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes						
	S15591-04 (FULL 200HD)																	No						No	No	No	No	No	No	No	No	No
	S15591-03 (FULL 120HD)											Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Partial	PAD-MGS-300-LD																	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	x		
	PAD-MGS-200-LD																				No			No	Yes							
	PAD-MGS-120-HD														Yes			Yes		Yes	Yes			Yes								

### YES:

The pattern was seen consistently throughout the month.

## Bottom left hot spot

	Quarter	Q1'23			Q2'23			Q3'23			Q4'23			Q1'24			Q2'24			Q3'24			Q4'24			Q1'25			Q2'25			
		Month (shipping date !)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Full	S15591-01 (FULL 300LD)		No	No		No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No		
	S15591-02 (FULL 200LD)								No	No		No	No		No	No		No	No		No	No		No	No							
	S15591-04 (FULL 200HD)														No			Yes			No	No	No	No	No	No	No	No	No	No	No	No
	S15591-03 (FULL 120HD)											Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Partial	PAD-MGS-300-LD														No	No		No	No		No	No	No	No	No	No	No	No	No	x		
	PAD-MGS-200-LD																	No			No			No	No							
	PAD-MGS-120-HD														Yes			Yes		Yes	Yes			Yes								

### NO:

The pattern was not seen consistently over the month.

## Smiles and frowns

	Quarter	Q1'23			Q2'23			Q3'23			Q4'23			Q1'24			Q2'24			Q3'24			Q4'24			Q1'25			Q2'25			
		Month (shipping date !)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Full	S15591-01 (FULL 300LD)		No	No		No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No		
	S15591-02 (FULL 200LD)								Yes	Yes		Yes	Yes		Yes			Yes			Yes	Yes	No	Yes	Yes	Yes						
	S15591-04 (FULL 200HD)														No									Yes	No	Yes	No	No	No	No	No	No
	S15591-03 (FULL 120HD)											No	No	No	No	No	No	No	No		No	No		No	No		No	No	No	No	No	No
Partial	PAD-MGS-300-LD														No	No		No	No		No	No	No	No	No	No	No	No	No	x		
	PAD-MGS-200-LD																				Yes			No	Yes							
	PAD-MGS-120-HD														No	No		No	No		No	No		No								

### NOTE:

Patterns can still appear in individual sensors (e.g. smile/frown shapes in single LD300 sensors).