

## IV+CV Results for HGCAL Proto A Sensors

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CMS HGCAL Si Sensor Meeting

# Outline

1 Introduction

2 IV Results

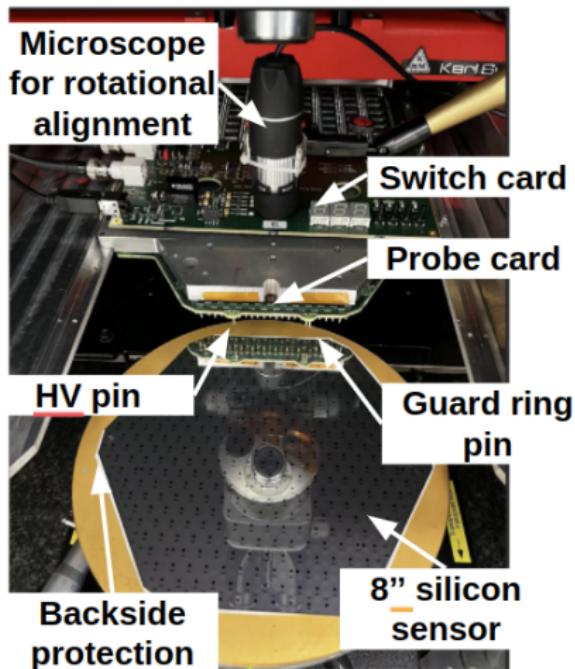
3 CV Results

4 Additional Measurements

# Proto A sensors and their properties

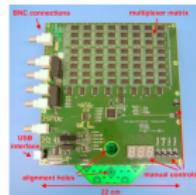
- Have measured 43 sensors in about 6 months
- 120 um:
  - ▶ 19 HD Sensors: 5 oxide type B, 8 oxide type C (3 common p-stop), 6 oxide type D
- 200 um:
  - ▶ 12 LD Sensors: 2 oxide type A, 3 oxide type B, 5 oxide type C (3 common p-stop), 2 oxide type D
- 300 um:
  - ▶ 12 LD Sensors: 2 oxide type A, 3 oxide type B, 4 oxide type C (common p-stop), 5 oxide type D

# Measurement Setup



- Measurement at room temperature
- Humidity: 40% – 50%
- Voltage up to -850V
- Voltage provided through the HV pin to the backside

# General Remarks



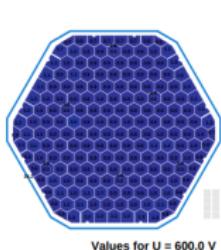
picture of a discharge

- Vulnerability to switch card breaks
- No discharges has been observed for proto A sensors
- Test throughput max. 20 per week

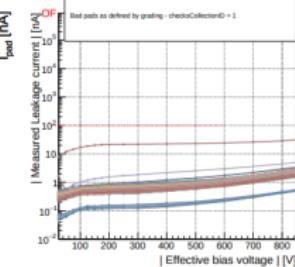
# Proto-A: example IV+CV results

CERN IV  
N4791\_6

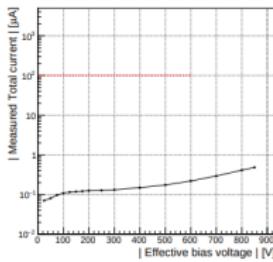
Cell current at 600 V



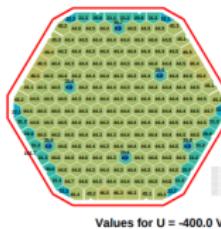
Channel IV curve



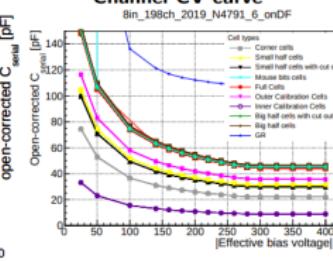
Total current curve

CERN CV  
N4791\_6

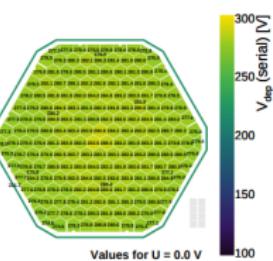
Capacitance at -400 V



Channel CV curve



Depletion voltage



# Outline

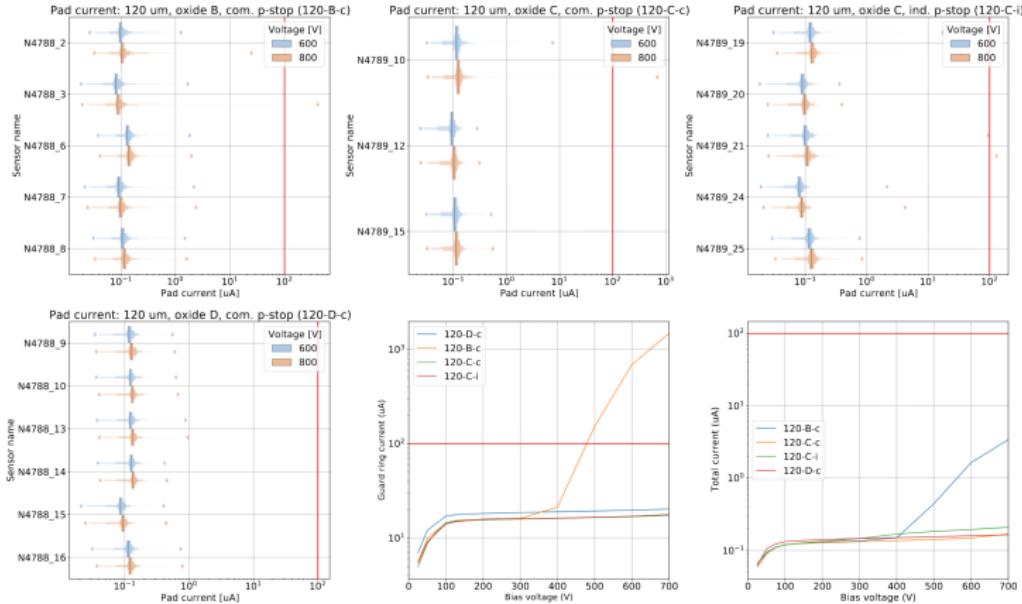
1 Introduction

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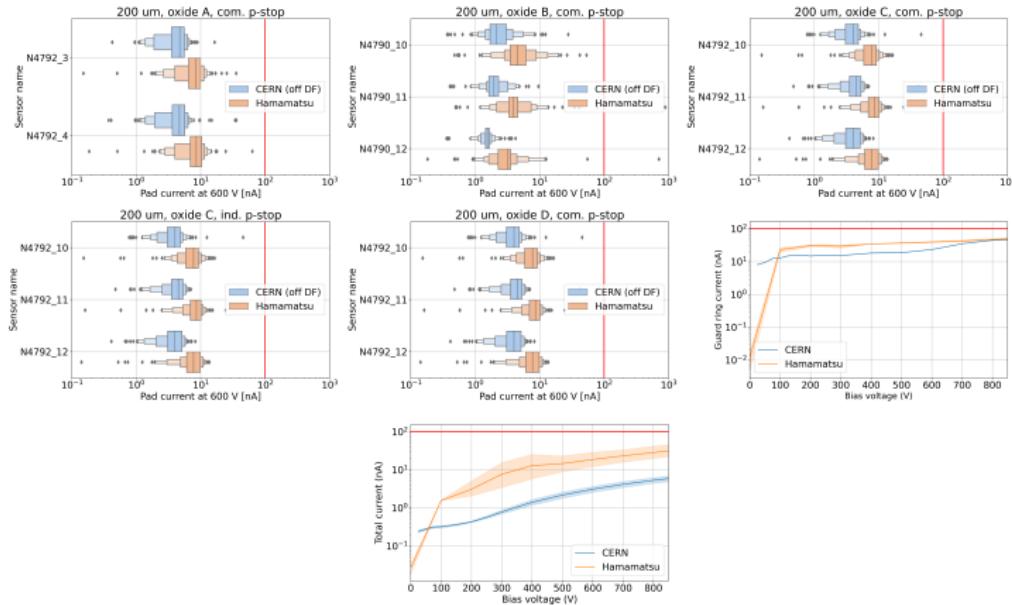
# Proto-A, 120 um, IV results: HPK and CERN (on DF)



# Proto-A, 120 um, IV grading comparison

tbd

# Proto-A, 200 um, IV results: HPK and CERN (on DF)



# Proto-A, 200 um, IV grading comparison

Proto-A: CERN IV grading, 12/12 passed



CMS full probe card (off dicing frame)									
Sensor ID	Thick-ness	P- Stop	Oxide type	I_tot_600V <100uA	I_tot_800V < 2.5* I_tot_600V	1) Ncell with I600 > 100nA	2) Ncell with I800 > 2.5 * threshold    I800>25nA & I600<10nA	3) More than 8 bad cells: requirement, 1) and 2)	4) More than two neighbour cells, bad: requirement, 1) and 2)
N4792_3	200	com	A	Passed	Passed	0	0	Passed	Passed
N4792_4	200	com	A	Passed	Passed	0	0	Passed	Passed
N4790_10	200	com	B	Passed	Passed	0	1	Passed	Passed
N4790_11	200	com	B	Passed	Passed	0	0	Passed	Passed
N4790_12	200	com	B	Passed	Passed	0	0	Passed	Passed
N4792_10	200	com	C	Passed	Passed	0	0	Passed	Passed
N4792_11	200	com	C	Passed	Passed	0	0	Passed	Passed
N4792_12	200	com	C	Passed	Passed	0	0	Passed	Passed
N4792_22	200	ind	C	Passed	Passed	0	0	Passed	Passed
N4792_23	200	ind	C	Passed	Passed	0	0	Passed	Passed
N4790_22	200	com	D	Passed	Passed	0	0	Passed	Passed
N4790_23	200	com	D	Passed	Passed	0	0	Passed	Passed

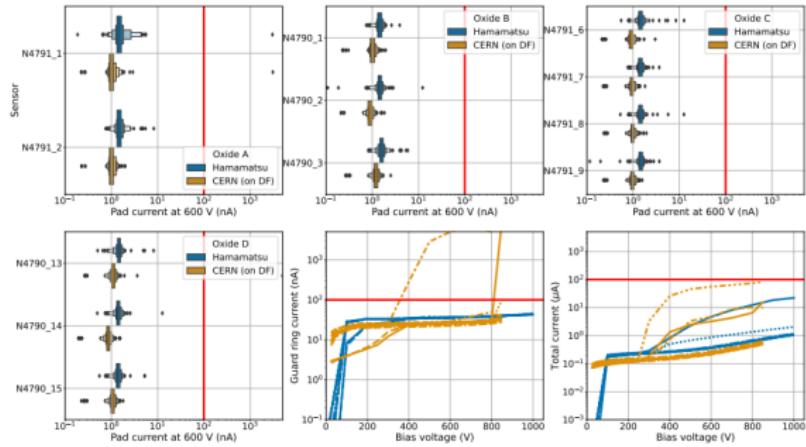
All sensors passed the grading at Hamamatsu as well

March 1, 2022

Marta Krawczyk, Low Density proto-A sensors

4

# Proto-A, 300 um, IV results: HPK and CERN (on DF)

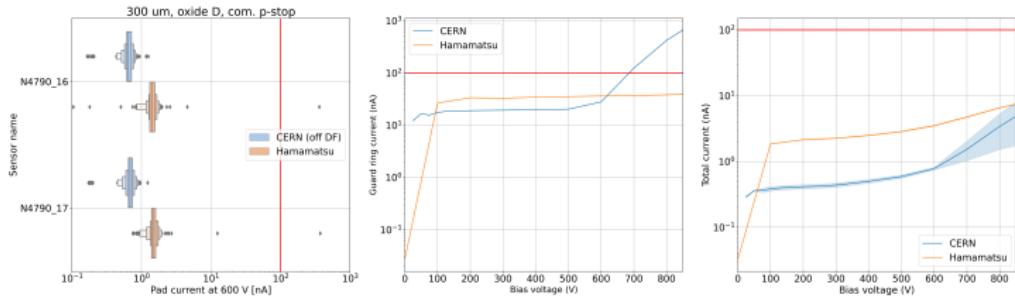


- ▶ N4791\_1 (oxide type 'A') also fails at CERN. Other 11 sensors also pass IV criteria at CERN
- ▶ Guard ring current tends to be higher at CERN than at HPK

# Proto-A, 300 um, IV grading comparison

Sensor ID	HPK full probe card				CMS full probe card (on dicing frame)				CMS full probe card (off dicing frame)			
	I_tot, 800V <100nA	I_tot, 800V <2.5°	I_tot, 600V	I_tot, 600V >100nA	I_tot, 800V <100nA	I_tot, 800V <2.5°	I_tot, 600V	I_tot, 600V >100nA	I_tot, 800V <100nA	I_tot, 800V <2.5°	I_tot, 600V	I_tot, 600V >100nA
N4791_1	Passed	Failed	1	0	Passed	Passed	Passed	Passed	1	1	Passed	Passed
N4791_2	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4790_1	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4790_2	Passed	Passed	0	0	Passed	Passed	Passed	Passed	1	0	Passed	Passed
N4790_3	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_4	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_5	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_6	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_7	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_8	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_9	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_10	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_11	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_20	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_21	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_22	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4790_13	Passed	Passed	0	0	Passed	Passed	Passed	Passed	1	0	Passed	Passed
N4790_14	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4790_15	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed

# Proto-A Batch 2, 300 $\mu\text{m}$ , IV results: HPK and CERN (on DF)



# Proto-A Batch 2, 300 um, IV grading comparison

HPK full probe card									
Sensor ID	Thickness	P- Stop	Oxide type	I_tot_600V <100uA	I_tot_800V < 2.5* I_tot_600V	1) Ncell with I600 > 100nA	2) Ncell with I800 > 2.5 * I600 & I600>10nA threshold    I800>25nA & I600<10nA	3) More than 8 bad cells: requirem. 1) and 2)	4) More than two neighbour cells bad: requirem. 1) and 2)
N4790_16	300	com	D	Passed	Passed	0	0	Passed	Passed
N4790_17	300	com	D	Passed	Passed	0	0	Passed	Passed

CMS full probe card (off dicing frame)									
Sensor ID	Thickness	P- Stop	Oxide type	I_tot_600V <100uA	I_tot_800V < 2.5* I_tot_600V	1) Ncell with I600 > 100nA	2) Ncell with I800 > 2.5 * I600 & I600>10nA threshold    I800>25nA & I600<10nA	3) More than 8 bad cells: requirem. 1) and 2)	4) More than two neighbour cells bad: requirem. 1) and 2)
N4790_16	300	com	D	Passed	Failed	0	1	Passed	Passed
N4790_17	300	com	D	Passed	Passed	0	0	Passed	Passed

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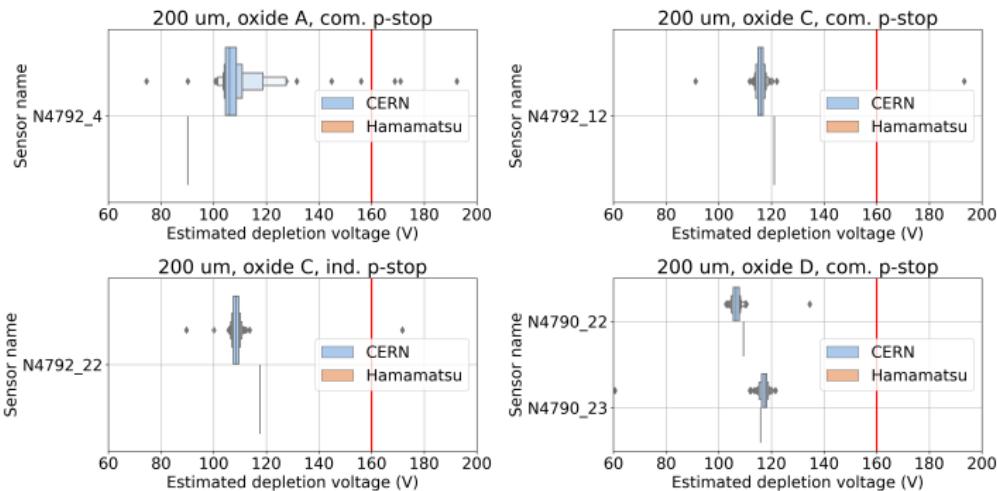
# Proto-A, 120 um, CV results: HPK and CERN (on DF)

tbd

# Proto-A, 120 um, CV grading comparison

tbd

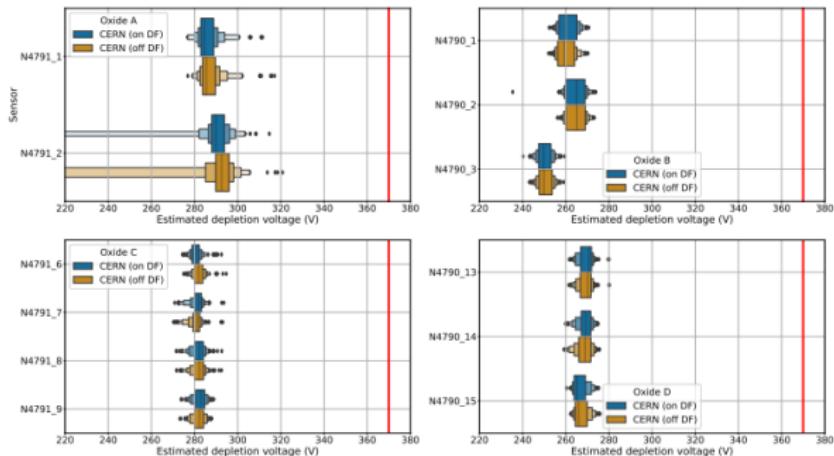
# Proto-A, 200 um, CV results: HPK and CERN (on DF)



# Proto-A, 200 um, CV grading comparison

CMS full probe card (off dicing frame)						
Sensor ID	Thick-ness	P- Stop	Oxide type	V dep corresponding to thickness	Maximum variation of Vdep across sensor of $\pm 10\%$	Thickness variation < 10 $\mu\text{m}$
N4792_4	200	com	A	passed: 94.5V < 160V	passed: 7.9%	passed: 0.5% = 1.0um
N4792_12	200	com	C	passed: 117.2V < 160V	passed: 0.9%	passed: 0.4% = 0.8um
N4792_22	200	ind	C	passed: 109.4V < 160V	passed: 0.8%	passed: 0.4% = 0.8um
N4790_22	200	com	D	passed: 106.9V < 160V	passed: 0.7%	passed: 0.6% = 1.2um
N4790_23	200	com	D	passed: 116.2V < 160V	passed: 0.5%	passed: 0.6% = 1.2um

# Proto-A, 300 um, CV results: HPK and CERN (on DF)

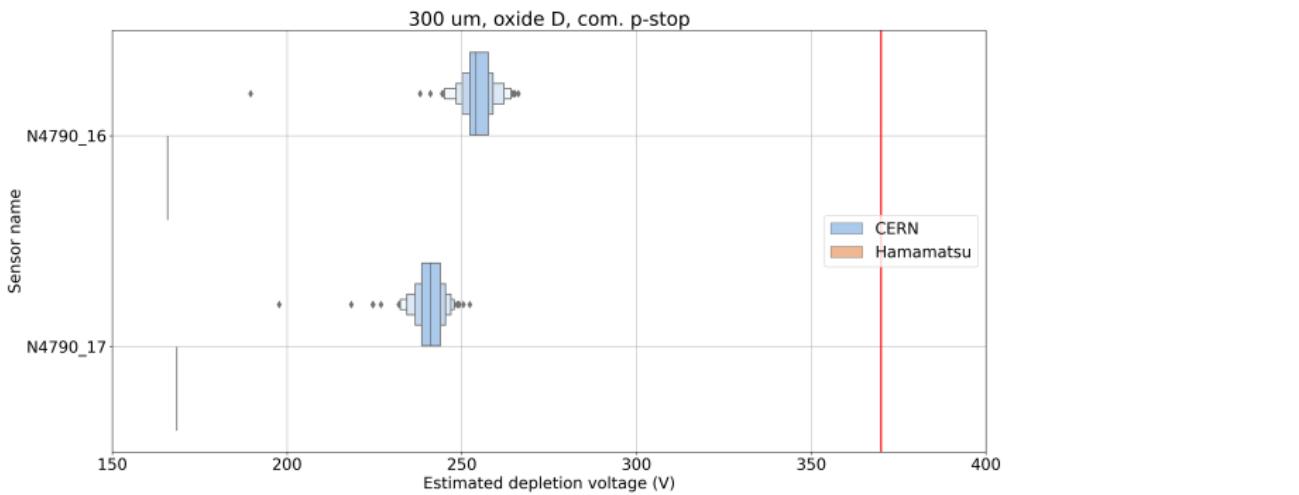


- ▶ Note difference in depletion voltage between oxide types
- ▶ Oxide types B-D pass CV criteria
- ▶ Oxide type A also pass CV criteria, but many pads with spurious C-readings

# Proto-A, 300 um, CV grading comparison

	CERN full probe card (on dicing frame)			CMS full probe card (off dicing frame)		
Sensor ID	V dep corresponding to thickness	Maximum variation of Vdep across sensor of ± 10%	Thickness variation < 10 µm	V dep corresponding to thickness	Maximum variation of Vdep across sensor of ± 10%	Thickness variation < 10 µm
N4791_1	passed: 284.9V<370V	passed: 0.9%	passed: 0.8% = 2.4 um	passed: 285.8V<370V	passed: 0.9%	passed: 0.9% = 2.7 um
N4791_2	passed: 280.3V<370V	passed: 0.7%	passed: 0.8% = 2.4 um	passed: 293.1V<370V	passed: 0.7%	passed: 0.8% = 2.4 um
N4790_1	passed: 262.7V<370V	passed: 1.2%	passed: 0.4% = 1.2 um	passed: 261.8V<370V	passed: 1.2%	passed: 0.4% = 1.2 um
N4790_2	passed: 267.7V<370V	passed: 1.1%	passed: 0.4% = 1.2 um	passed: 267.6V<370V	passed: 1.2%	passed: 0.4% = 1.2 um
N4790_3	passed: 251.0V<370V	passed: 0.9%	passed: 0.6% = 1.8 um	passed: 251.2V<370V	passed: 0.9%	passed: 0.6% = 1.8 um
N4791_6	passed: 281.2V<370V	passed: 0.4%	passed: 0.4% = 1.2 um	passed: 282.7V<370V	passed: 0.5%	passed: 0.4% = 1.2 um
N4791_7	passed: 282.3V<370V	passed: 0.9%	passed: 0.3% = 0.9 um	passed: 281.6V<370V	passed: 0.9%	passed: 0.4% = 1.2 um
N4791_8	passed: 283.0V<370V	passed: 0.4%	passed: 0.5% = 1.5 um	passed: 283.0V<370V	passed: 0.4%	passed: 0.5% = 1.5 um
N4791_9	passed: 283.5V<370V	passed: 0.4%	passed: 0.4% = 1.2 um	passed: 283.0V<370V	passed: 0.4%	passed: 0.5% = 1.5 um
N4791_18	Not available			passed: 281.1V<370V	passed: 0.2%	passed: 0.4% = 1.2 um
N4791_19				passed: 281.2V<370V	passed: 0.3%	passed: 0.6% = 1.8 um
N4791_20				passed: 281.5V<370V	passed: 0.4%	passed: 0.8% = 2.4 um
N4791_21				passed: 276.2V<370V	passed: 0.5%	passed: 0.6% = 1.8 um
N4790_13	passed: 271.3V<370V	passed: 0.4%	passed: 0.5% = 1.5 um	passed: 271.0V<370V	passed: 0.4%	passed: 0.5% = 1.5 um
N4790_14	passed: 269.8V<370V	passed: 0.5%	passed: 0.4% = 1.2 um	passed: 269.6V<370V	passed: 0.7%	passed: 0.4% = 1.2 um
N4790_15	passed: 266.8V<370V	passed: 0.9%	passed: 0.3% = 0.9 um	passed: 267.4V<370V	passed: 1.0%	passed: 0.3% = 0.9 um
N4790_7				passed: 111.4V < 160V	passed: 2.9%	passed: 0.2% = 0.4um
N4790_8	passed: 111.0V< 160V	passed: 1.7%	passed: 0.3% = 0.6um			
N4790_9	passed: 111.3V< 160V	passed: 1.7%	passed: 1.0% = 2.0um			
N4792_6				passed: 126.6V < 160V	passed: 2.2%	passed: 0.3% = 0.6um
N4792_7				passed: 124.6V < 160V	passed: 2.7%	passed: 0.3% = 0.6um
N4792_9	passed: 121.7V< 160V	passed: 2.4%	passed: 2.2% = 4.4um			
N4792_18				passed: 121.2V < 160V	passed: 2.7%	passed: 0.3% = 0.6um
N4792_19				passed: 111.3V < 160V	passed: 2.7%	passed: 0.3% = 0.6um
N4792_20				passed: 118.5V < 160V	passed: 2.9%	passed: 0.3% = 0.6um
N4792_21				passed: 119.3V < 160V	passed: 2.4%	passed: 0.3% = 0.6um
N4790_19				passed: 115.3V < 160V	passed: 1.9%	passed: 0.3% = 0.6um
N4790_20	passed: 115.5V< 160V	passed: 2.0%	passed: 0.9% = 1.8um			
N4790_21	passed: 110.3V< 160V	passed: 2.6%	passed: 0.4% = 0.8um			

# Proto-A Batch 2, 300 $\mu\text{m}$ , CV results: HPK and CERN (on DF)



# Proto-A, Batch 2, 300 um, CV grading comparison

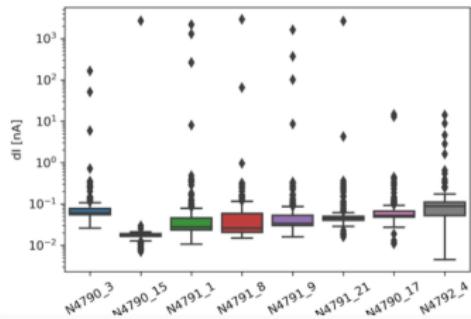
CMS full probe card (off dicing frame)						
Sensor ID	Thickness	P- Stop	Oxide type	V dep corresponding to thickness	Maximum variation of <u>Vdep</u> across sensor of $\pm 10\%$	Thickness variation < 10 $\mu\text{m}$
N4790_16	300	com	D	passed: 258.0V<370V	passed: 1.2%	passed: 0.4% = 1.2 $\mu\text{m}$
N4790_17	300	com	D	passed: 240.2V<370V	passed: 0.9%	passed: 0.4% = 1.2 $\mu\text{m}$

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# Longterm Leakage current stability

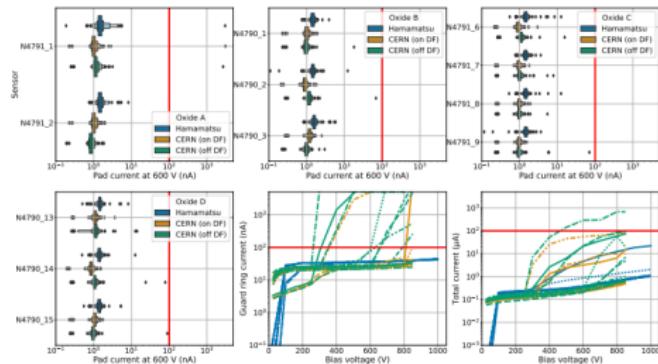
## Ranges of current variations



Most channels show small variations. The outliers show current in the range of uA.

# Dicing Frame removal at CERN

## Proto-A: Our DF removal worsened IV



- ▶ 6/11 previously good sensors now fail at least one of the total current requirements
- ▶ Guard ring and total current (driven by guard ring) higher.

# Summary

- Vulnerability to switch card breaks
- No discharges has been observed for proto A sensors
- Test throughput max. 20 per week

# Backup

backup

# List of ProtoA Sensors

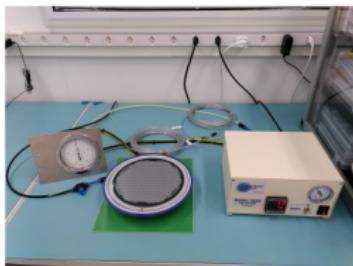
# Dicing Frame removal at CERN

## Backup

### Dicing frame removal

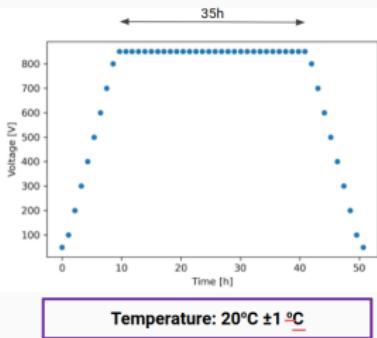
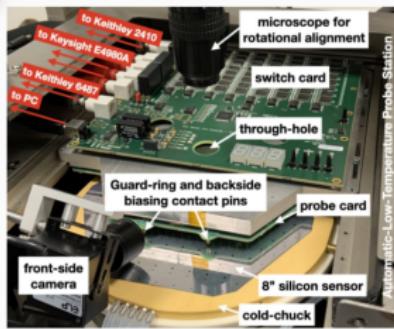


- ▶ UV illumination
- ▶ Heating up to 50°C
- ▶ 600 mbar vacuum



# Longterm Leakage current stability

## Measurement in ALPS probe station



Courtesy of T. Quast