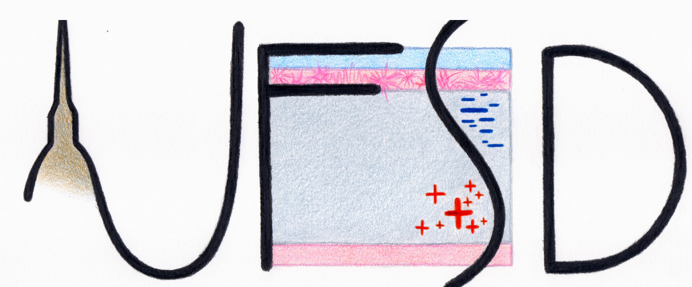
UNIVERSITA
DEGLI STUDI
DI TORINO

UNIVERSITÀ DEGLI STUDI
DI TRENTO

Ministero degli Affari Esteri
e della Cooperazione Internazionale

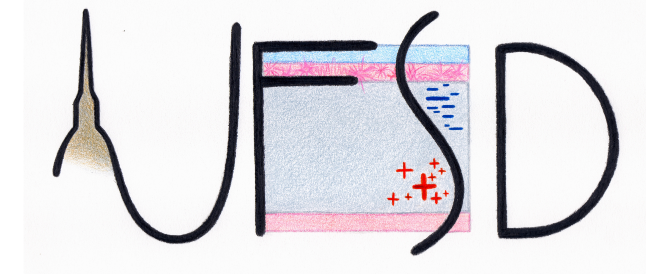
33rd RD50 Workshop, CERN, Geneva, 27th November 2018



Performances of the third UFSD production at FBK

Tornago M., Arcidiacono R., Borghi G., Boscardin M., Cartiglia N., Dalla Betta G.F., Ferrero M., Ficorella F., Mandurrino M., Pancheri L., Paternoster G., Siviero F., Sola V., Staiano A.

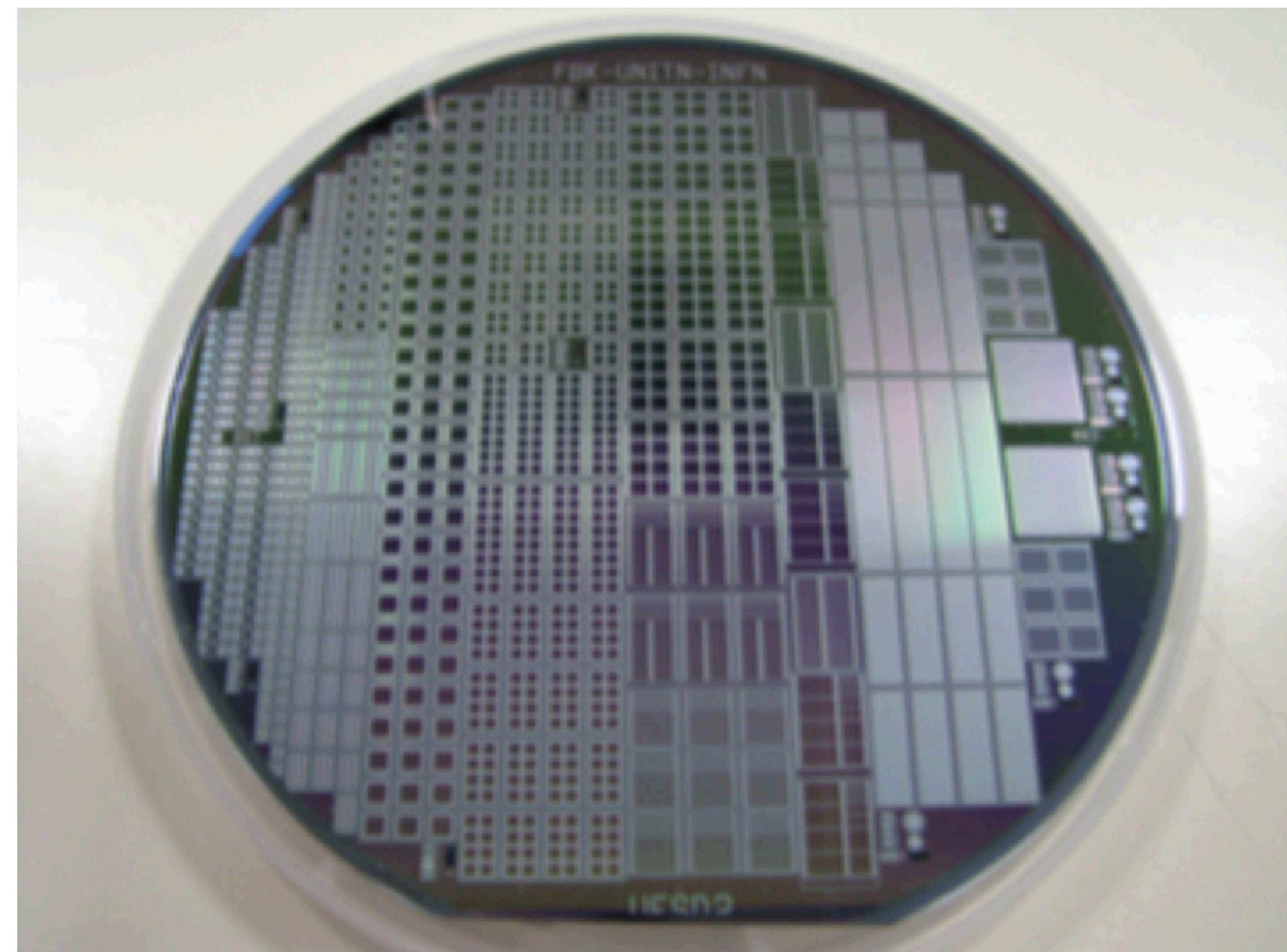
UFSD2 PRODUCTION (2017)



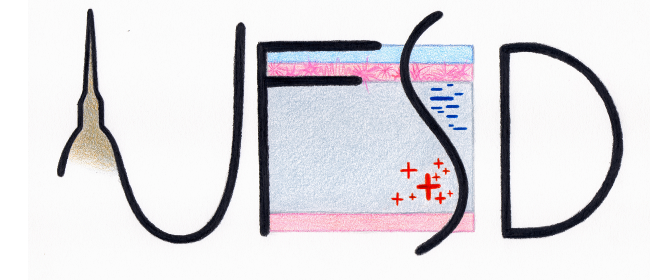
Focused on validation of doping element and profile

*First production with **Carbon**, measurements show improved radiation hardness* → ***UFSD3***

Wafer #	Dopant	Gain dose	Carbon	Diffusion
★1	Boron	0.98		Low
2	Boron	1.00		Low
3	Boron	1.00		HIGH
4	Boron	1.00	Low	HIGH
5	Boron	1.00	HIGH	HIGH
★6	Boron	1.02	Low	HIGH
7	Boron	1.02	HIGH	HIGH
★8	Boron	1.02		HIGH
9	Boron	1.02		HIGH
10	Boron	1.04		HIGH
11	Gallium	1.00		Low
14	Gallium	1.04		Low
15	Gallium	1.04	Low	Low
16	Gallium	1.04	HIGH	Low
18	Gallium	1.08		Low



UFSD3 PRODUCTION



Wafer #	Dose Pgain	Carbon	Diffusion
★ 1	0.98		L
2 *	0.96		L
3	0.96	A	L
4 *	0.96	A	L
5	0.98	A	L
6	0.96	B	L
7	0.98	B	L
8	0.98	B	L
9	0.98	C	L
10	1.00	C	L
11	1.00	D	L
★ 12	1.02		H
13 *	1.00		H
★ 14	1.02	A	H
15 *	1.00	A	H
16	1.02	B	H
17	1.02	B	H
18	1.04	B	H
19	1.02	C	H
20	1.04	C	H

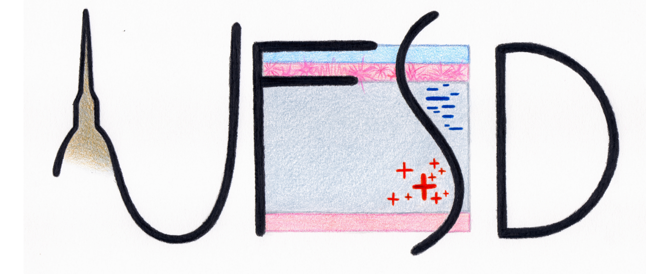
***Requirements** for CMS and ATLAS:*

- ***Higher radiation resistance***
- *Narrower **no gain area***
- *Demonstrate **uniformity of large sensors***

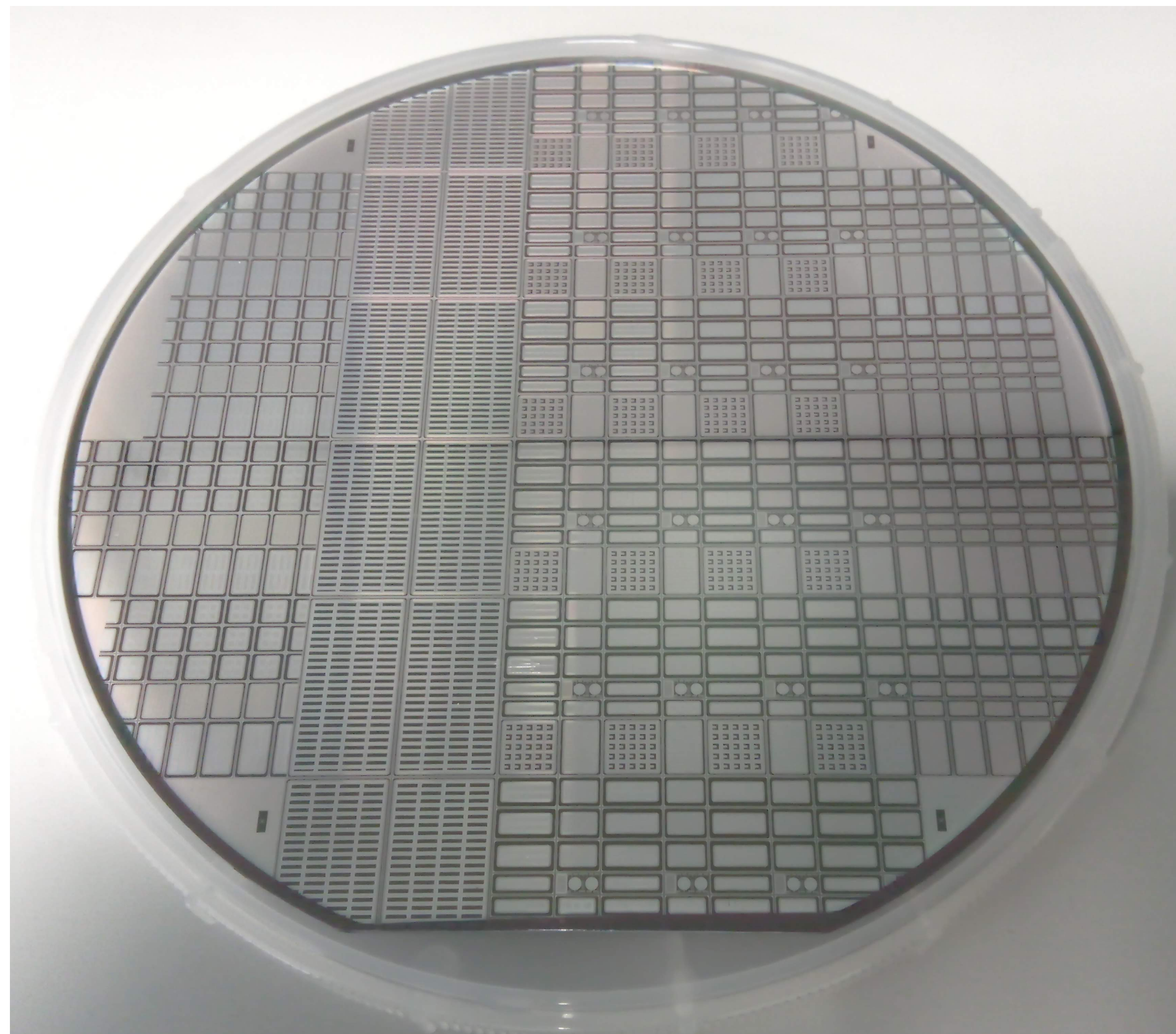
*New production **characteristics**:*

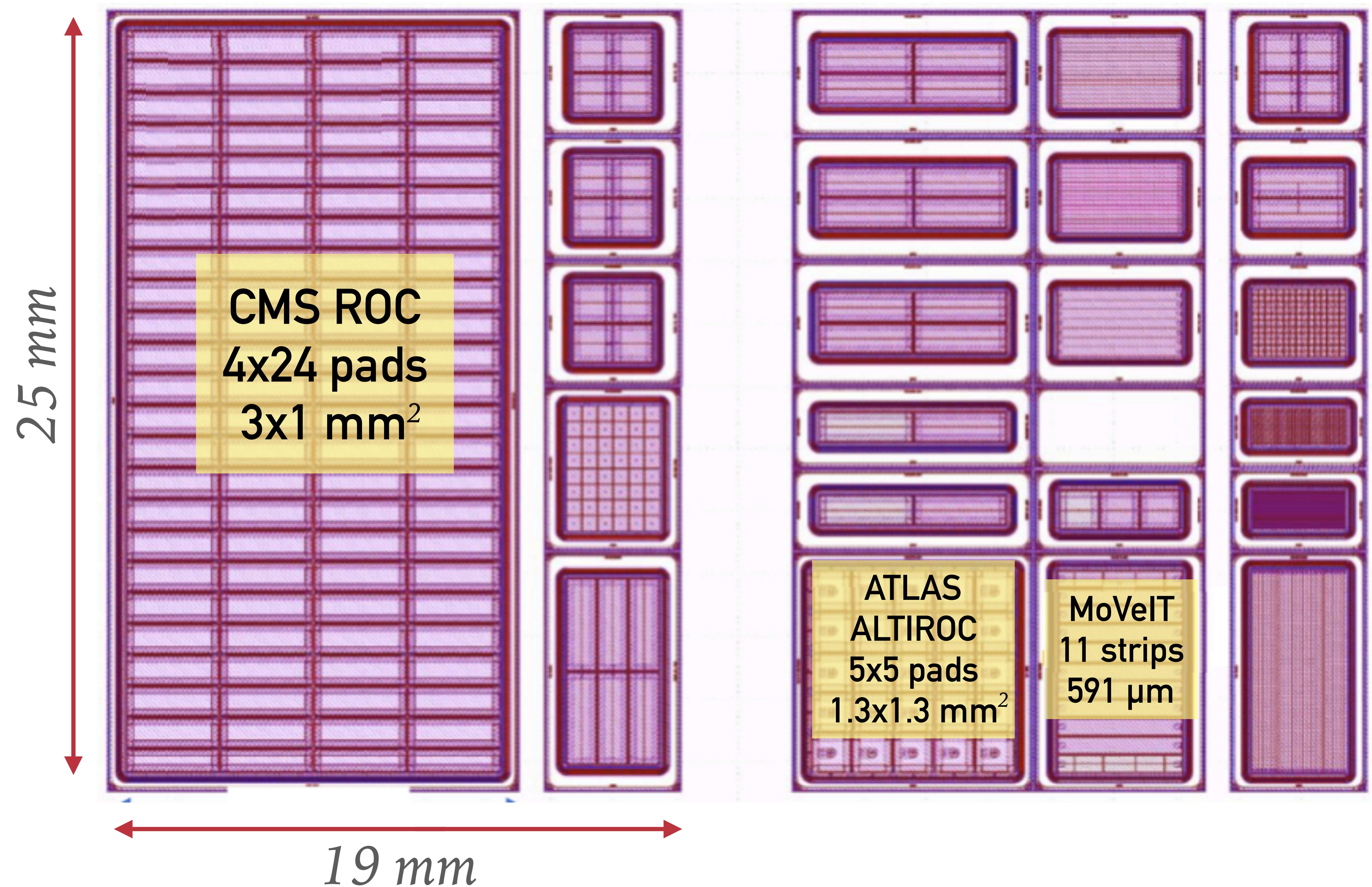
- *Low and High gain layer diffusion profiles*
- *4 splits of Carbon doses*
- *5 splits of gain layer doses*
- ***Epitaxial** * and Floatzone wafers*

UFSD3 PRODUCTION

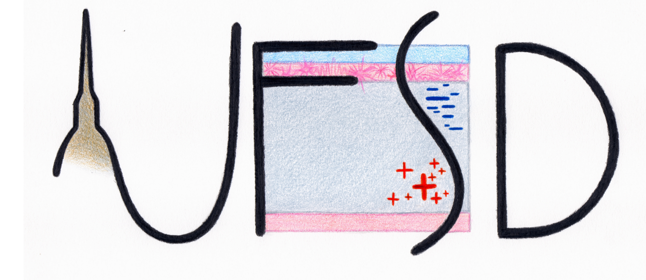


- *Produced by **FBK** with the **stepper**, on two full reticles (19x25 mm²)*
- *Introduction of **photocomposed** devices (needed to produce the full-size CMS sensor!)*





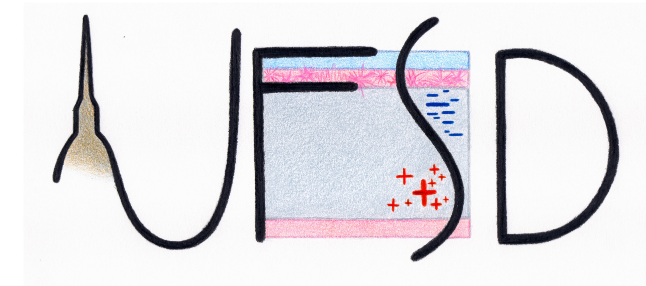
OVERVIEW



In this presentation one of the three requirements for UFSD3 will be discussed:

- ***Uniformity** studies on wafer and cut structures: CMS, MoVeIT and ALTIROC*
- ***Radiation resistance** (talk by Marco Ferrero)*
- ***Interpad and breakdown studies** with TCT (talk by Federico Siviero)*

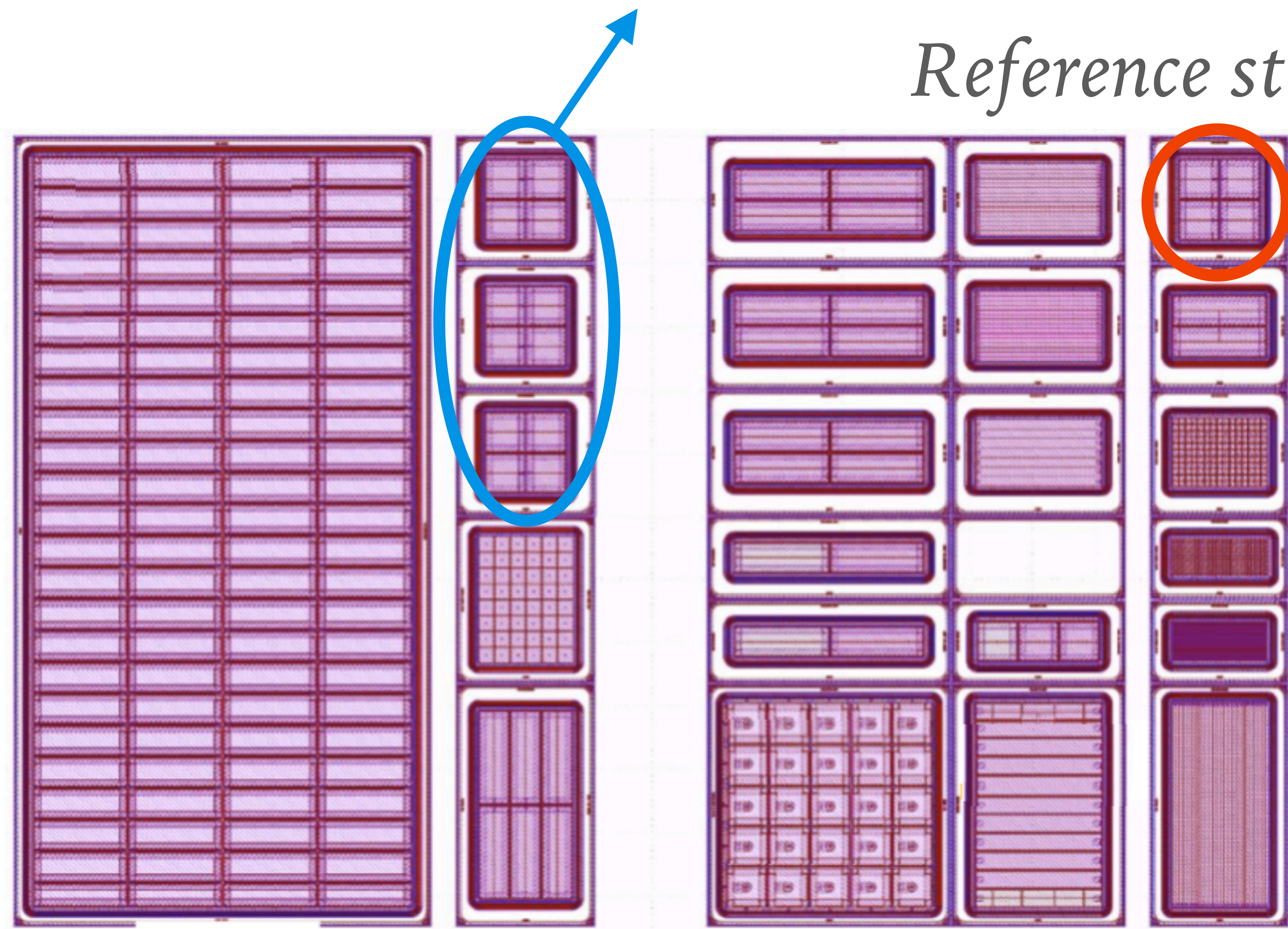
PHOTOCOMPOSITION

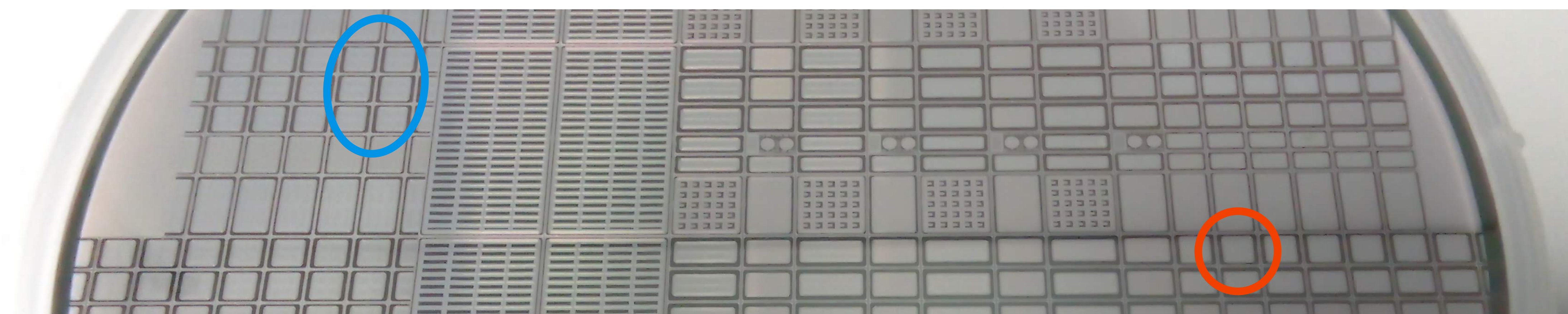


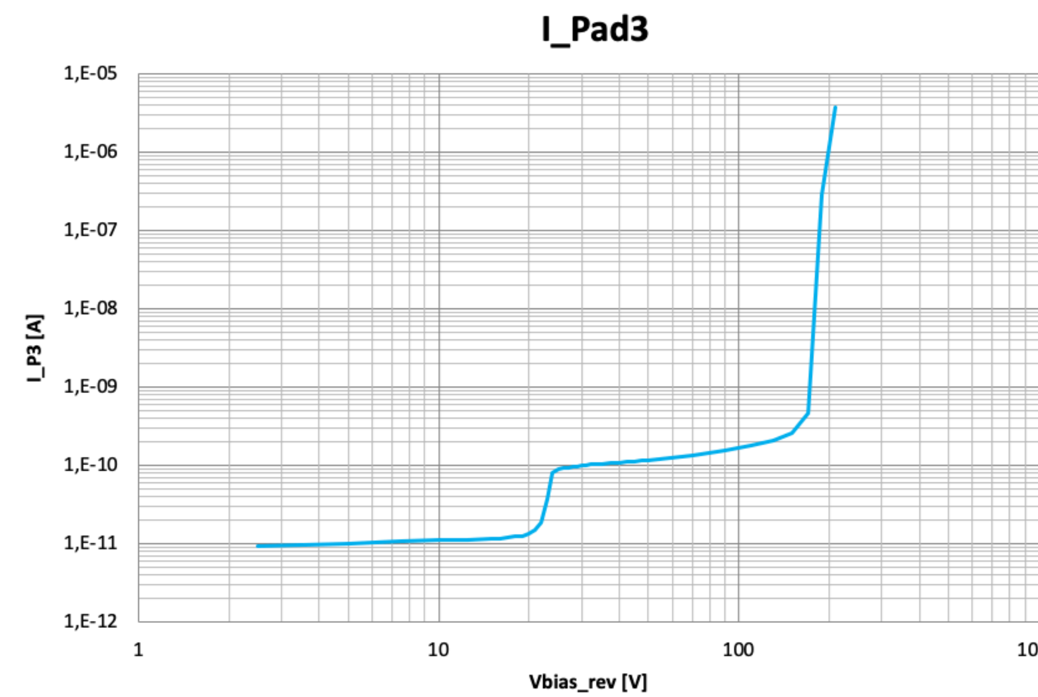
*Fundamental to **produce large sensors** with the stepper*

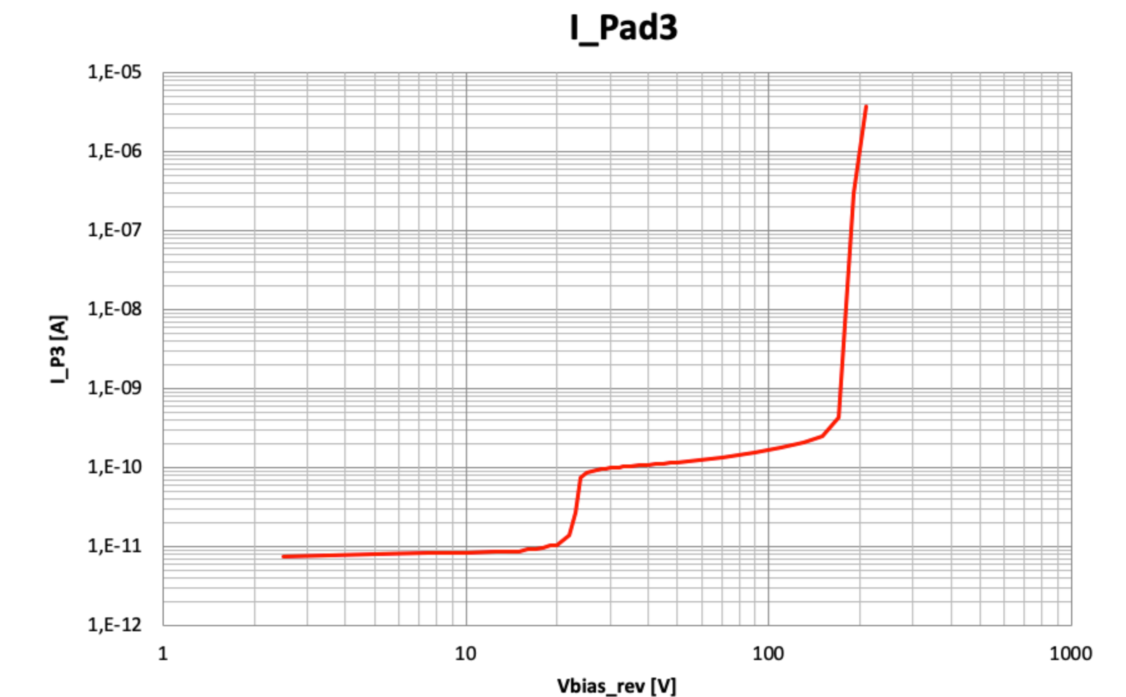
*ATLAS 2x2 **photocomposed** with 3 different overlaps*

Reference structure

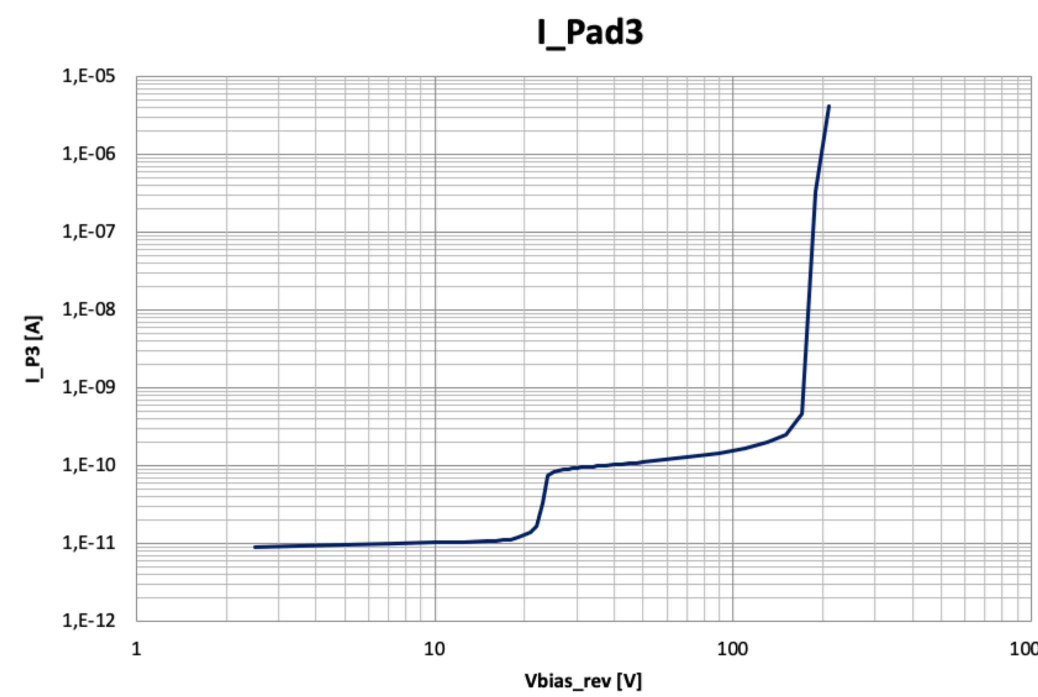


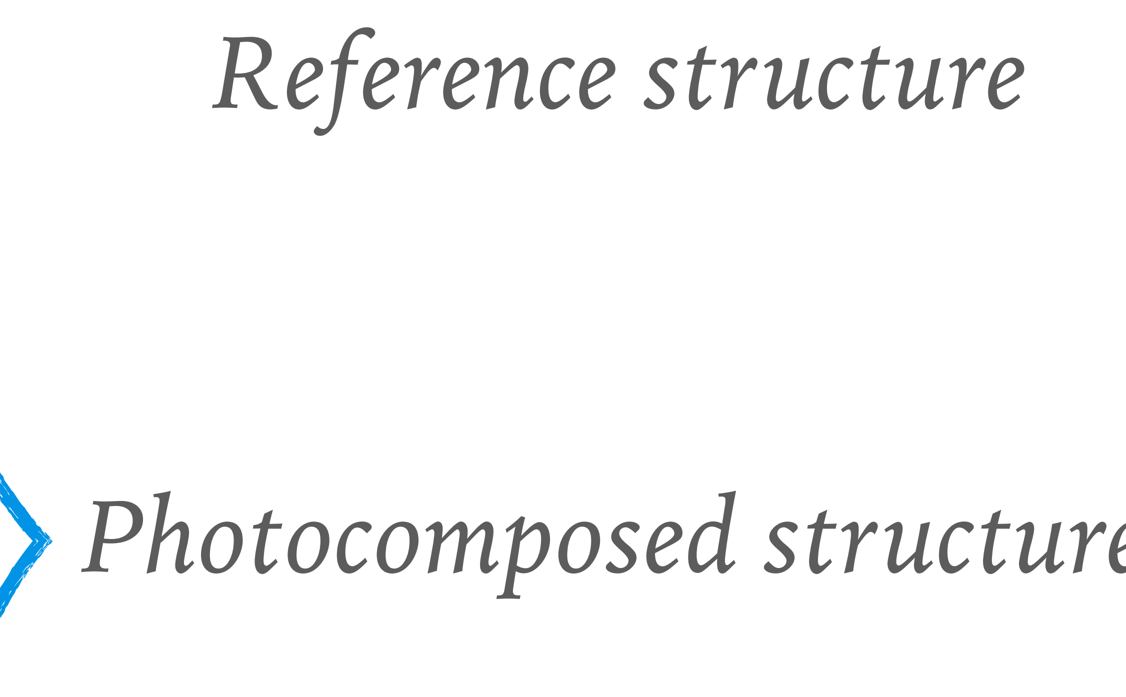




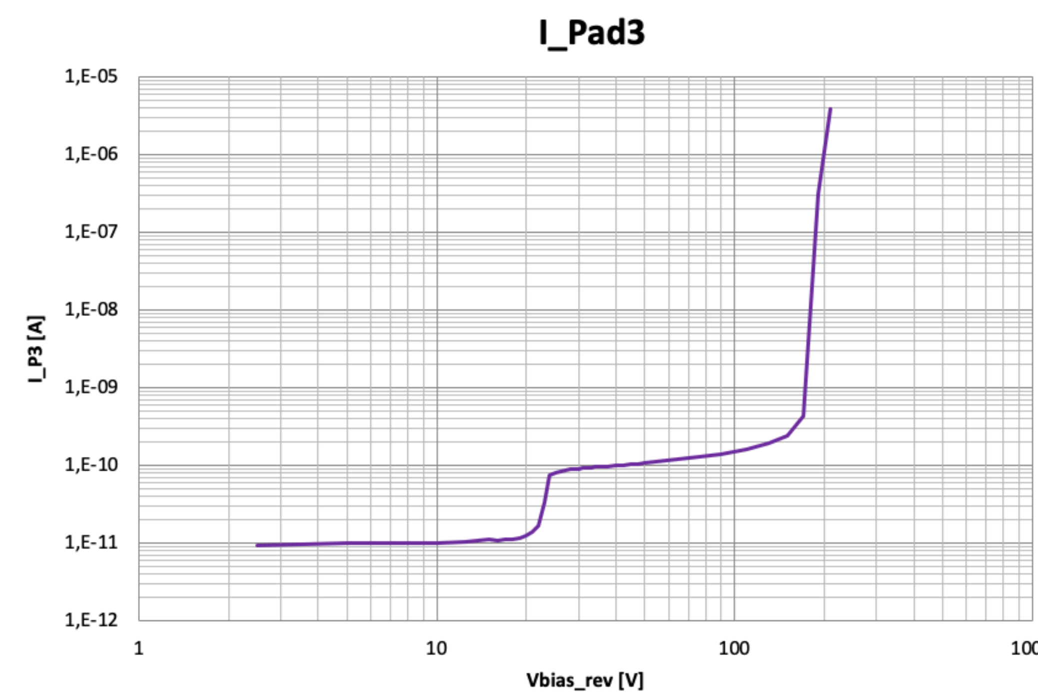


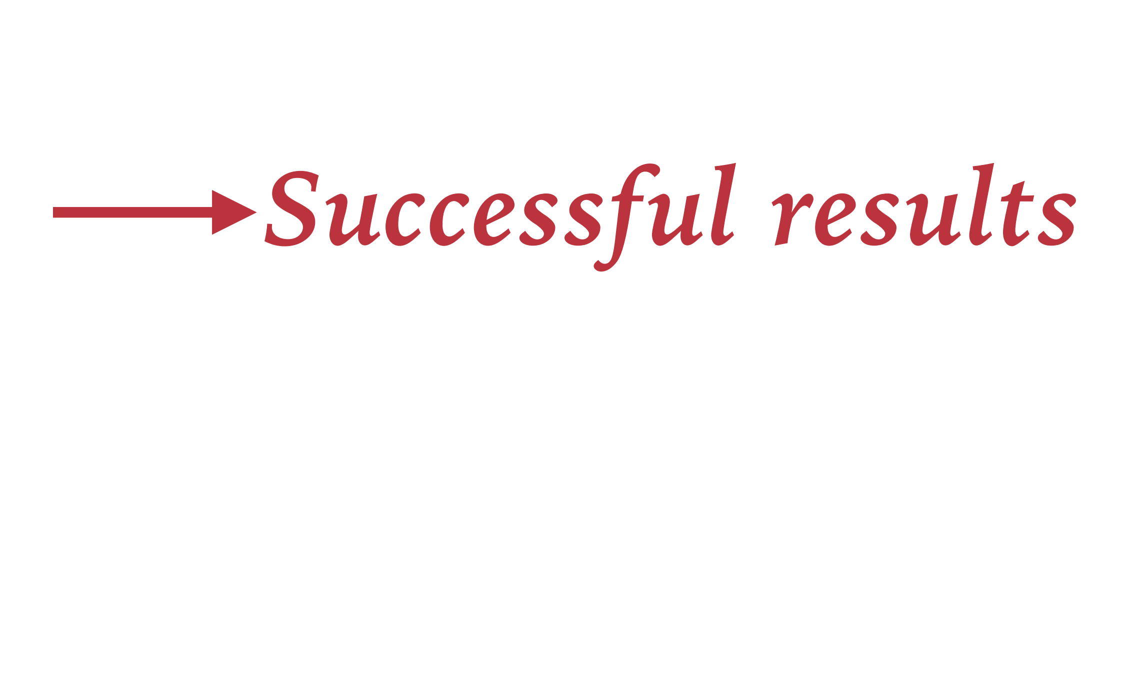
Reference structure





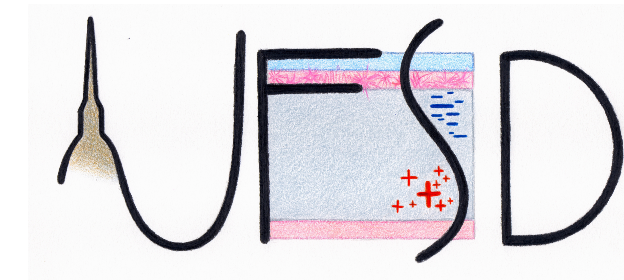
Photocomposed structures





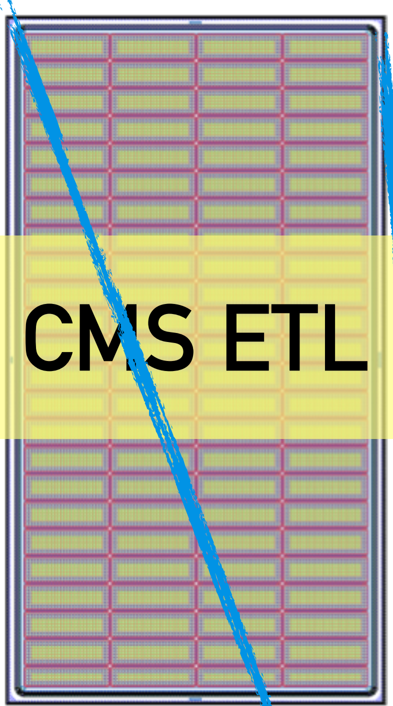
→ ***Successful results***

METHOD FOR UNIFORMITY STUDIES – CMS STRUCTURE

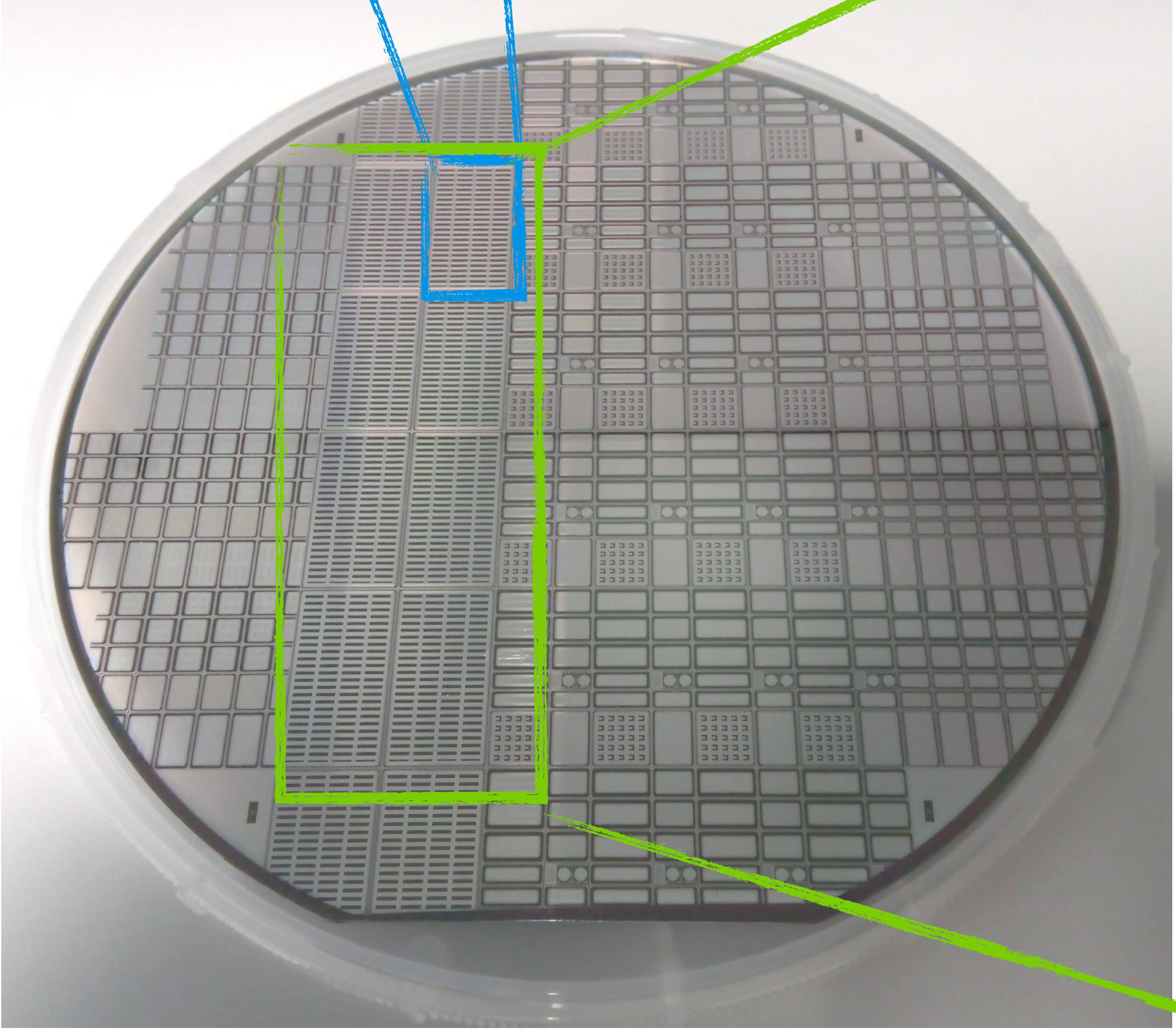


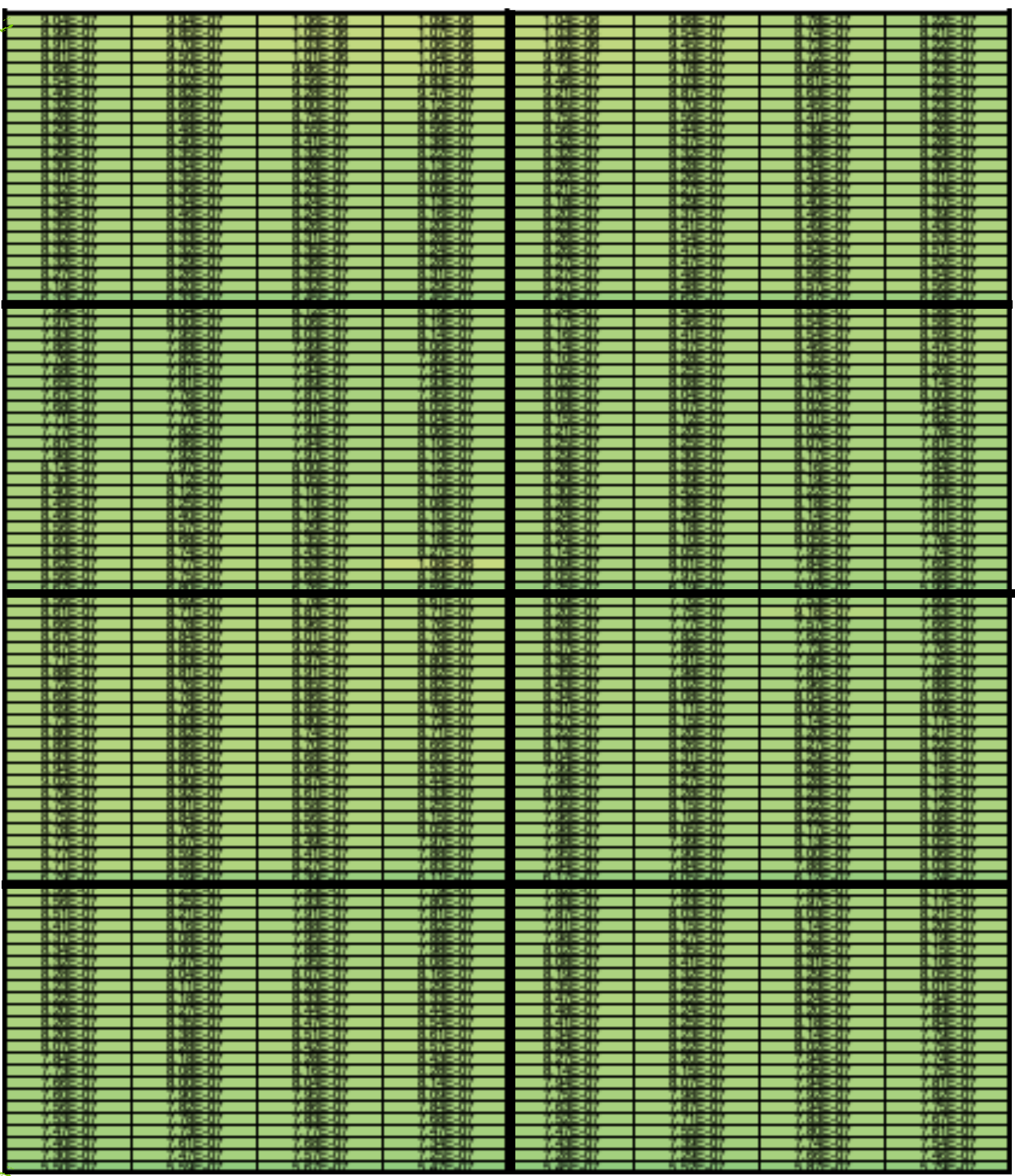
Measurements with probe card with automatic movement performed at ***FBK***

Maps of ***leakage current*** *values @****100V*** *for each pad of every CMS ROC in a wafer*

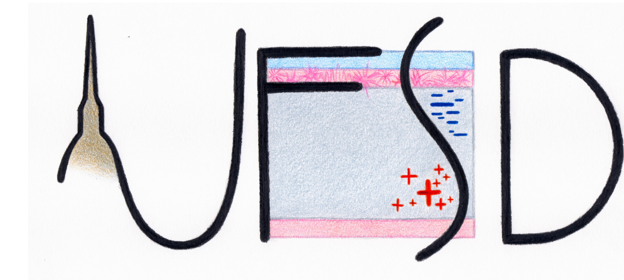


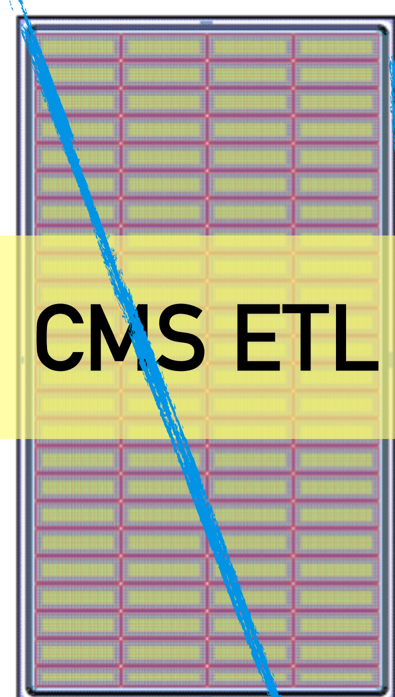
CMS ETL



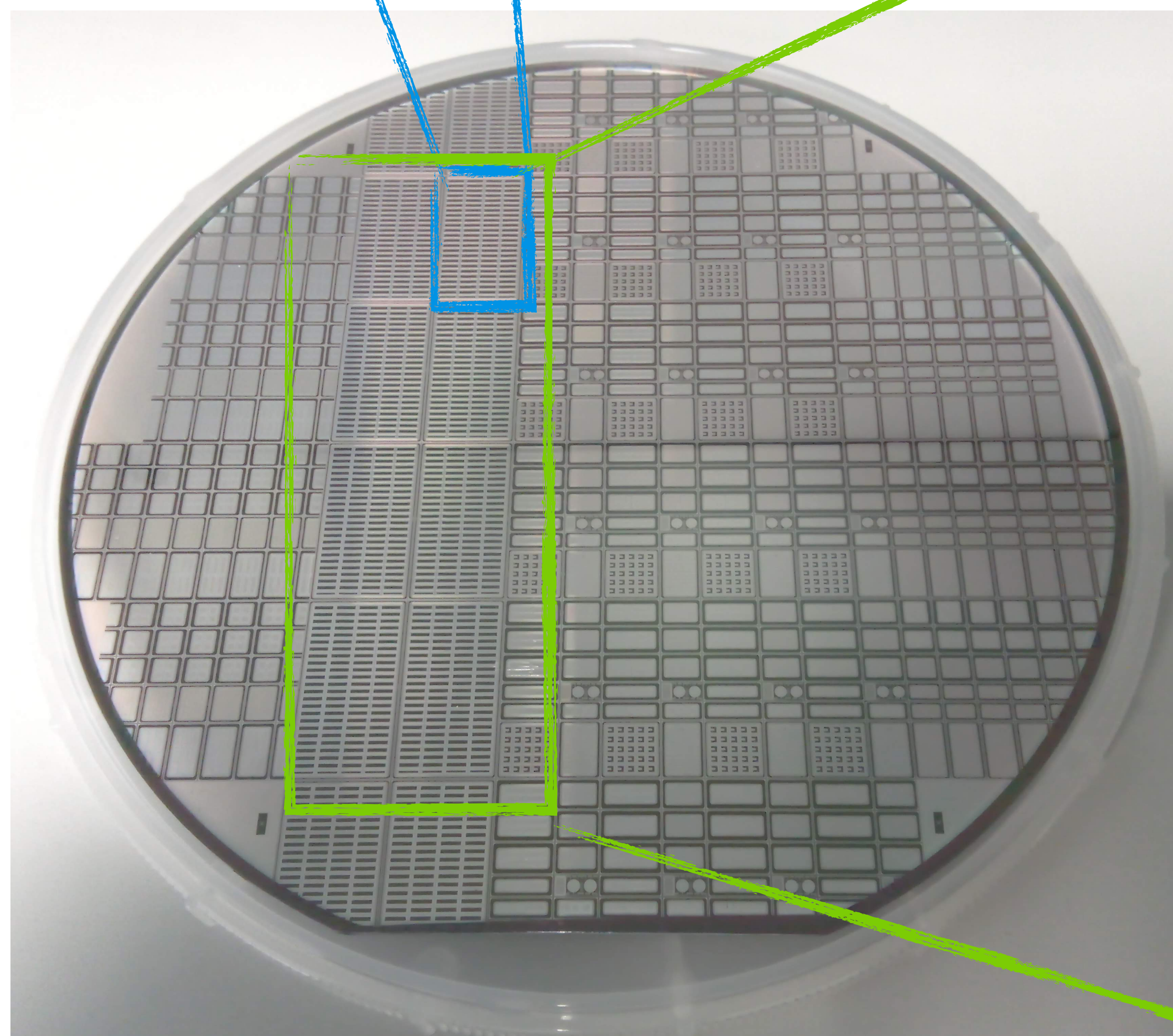


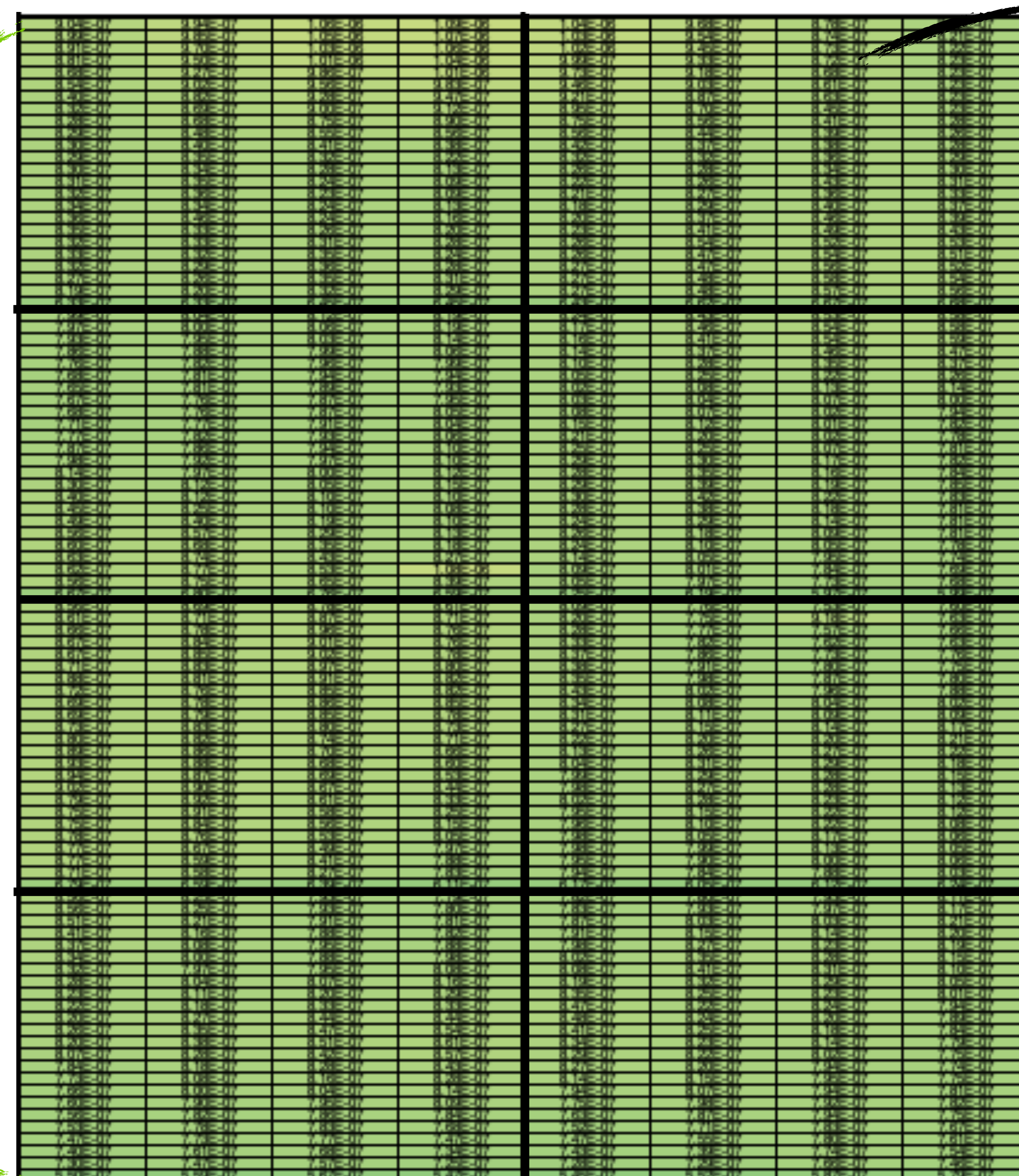
UNIFORMITY STUDIES - AN EXAMPLE OF CMS STRUCTURE

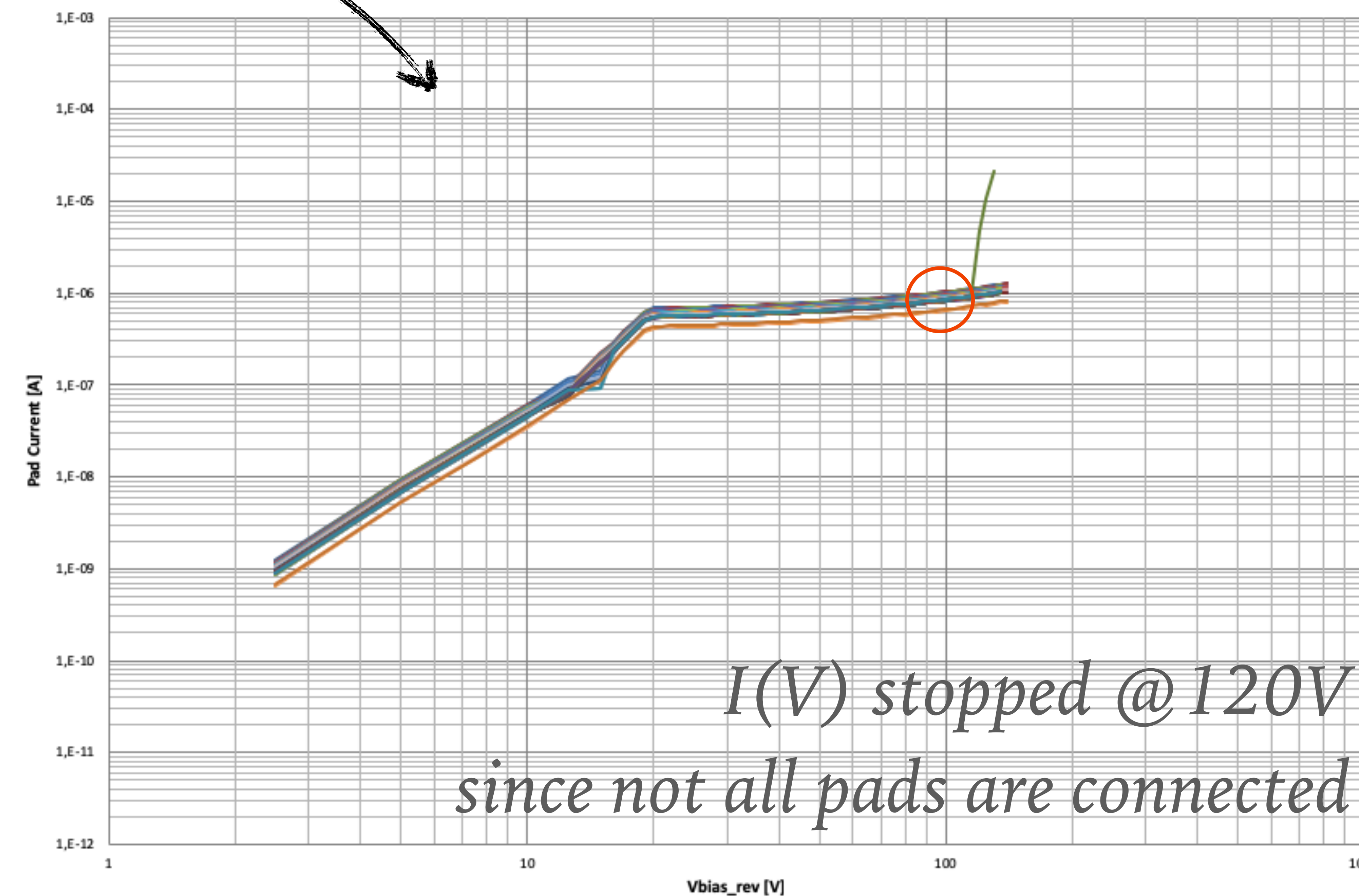




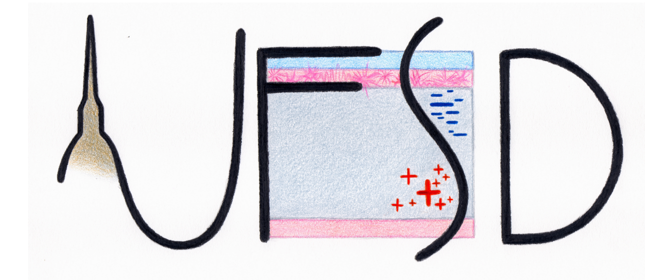
Maps of ***leakage current*** *values @****100V*** *for each pad of every CMS ROC in a wafer*

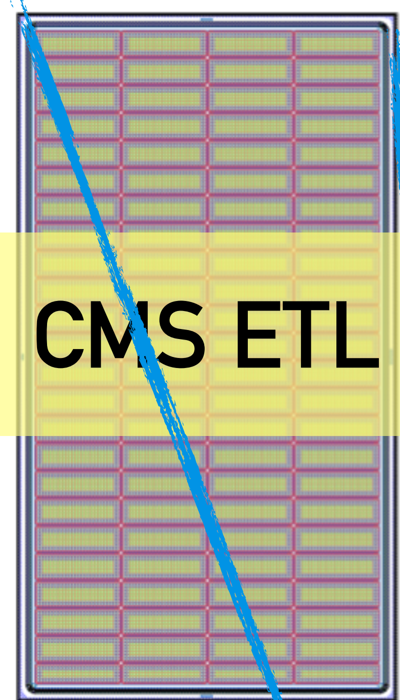






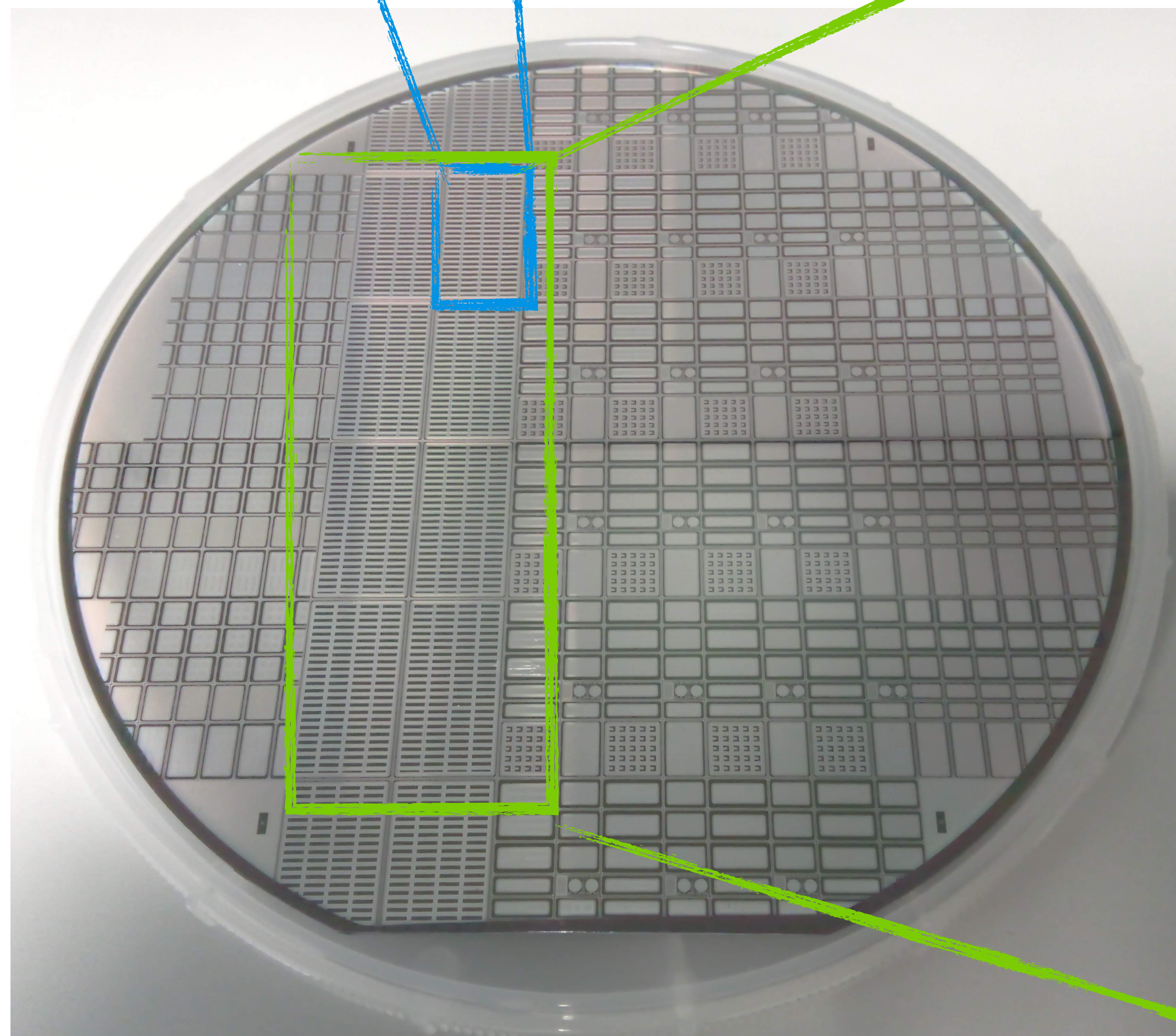
UNIFORMITY STUDIES - MASK DEFECT

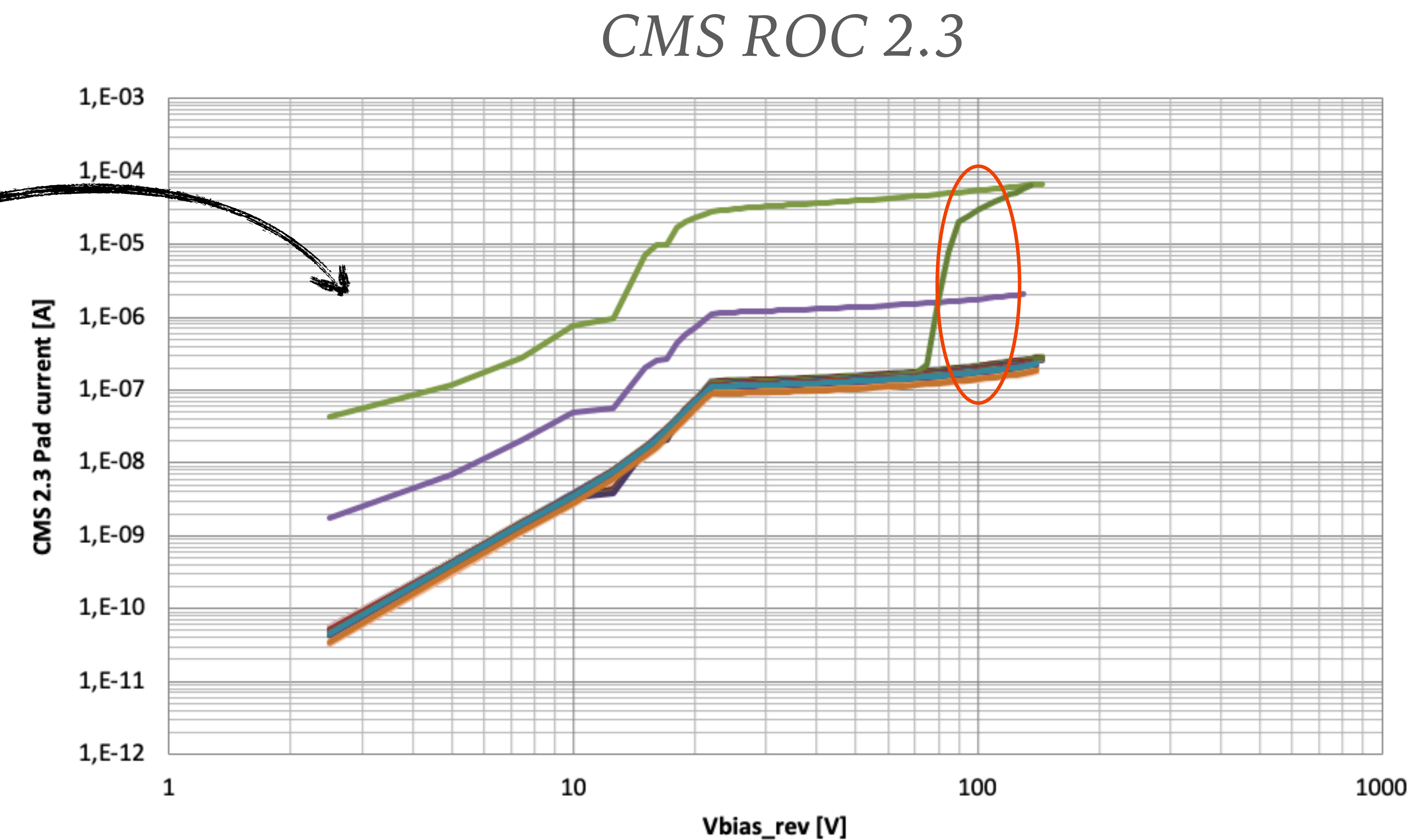




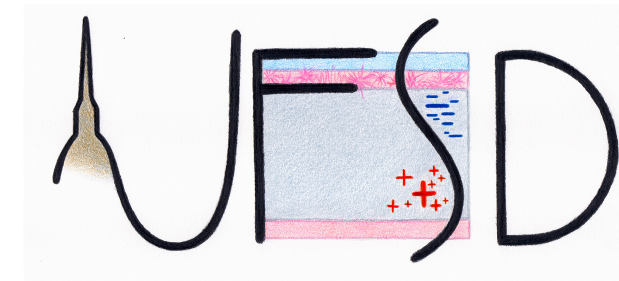
*Maps of **leakage current** values @**100V** for each pad of every CMS ROC in a wafer*

Mask defect: appears with high gain (excluded in uniformity analysis)



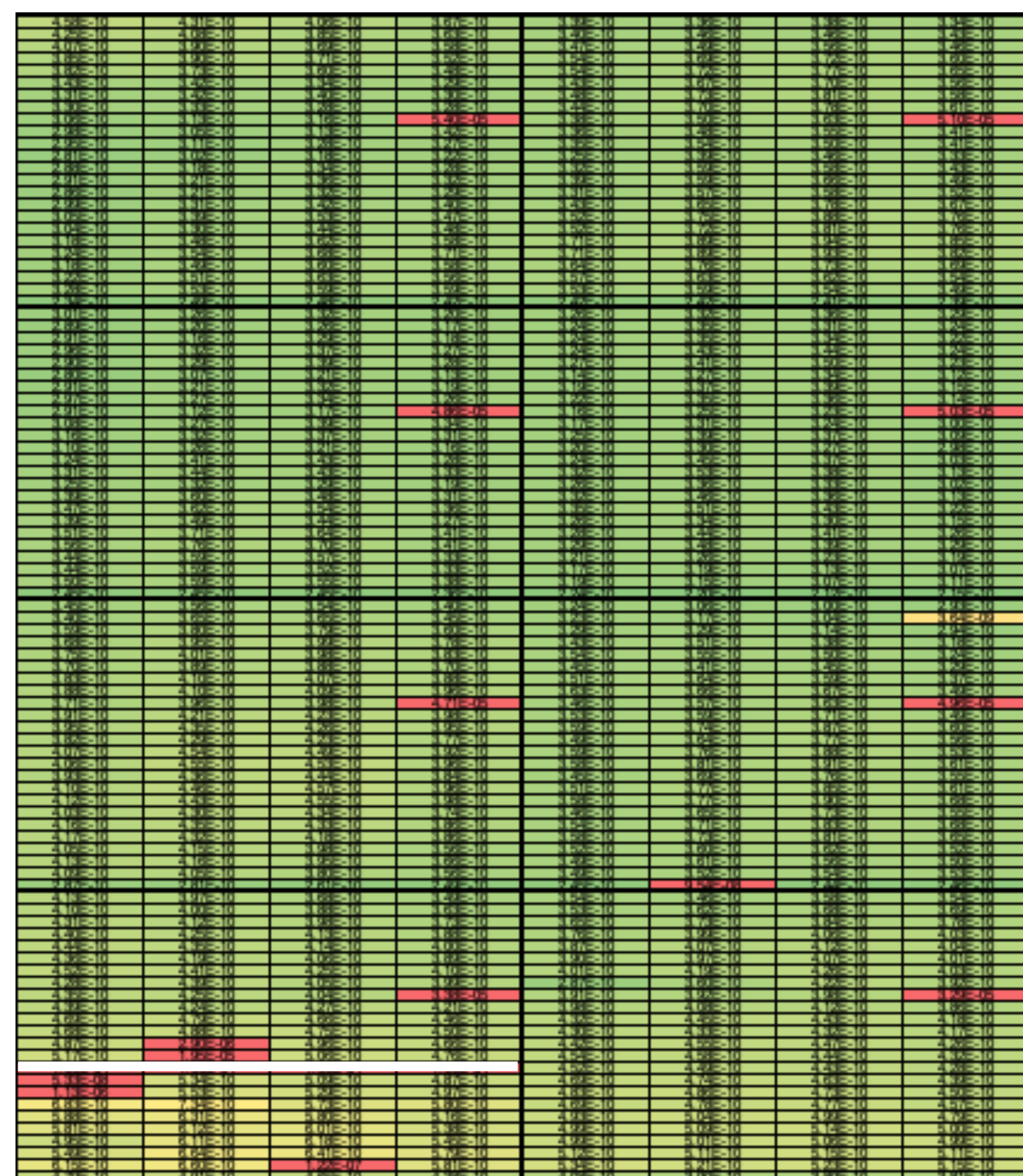


UNIFORMITY STUDIES - CMS STRUCTURE



Wafers without carbon

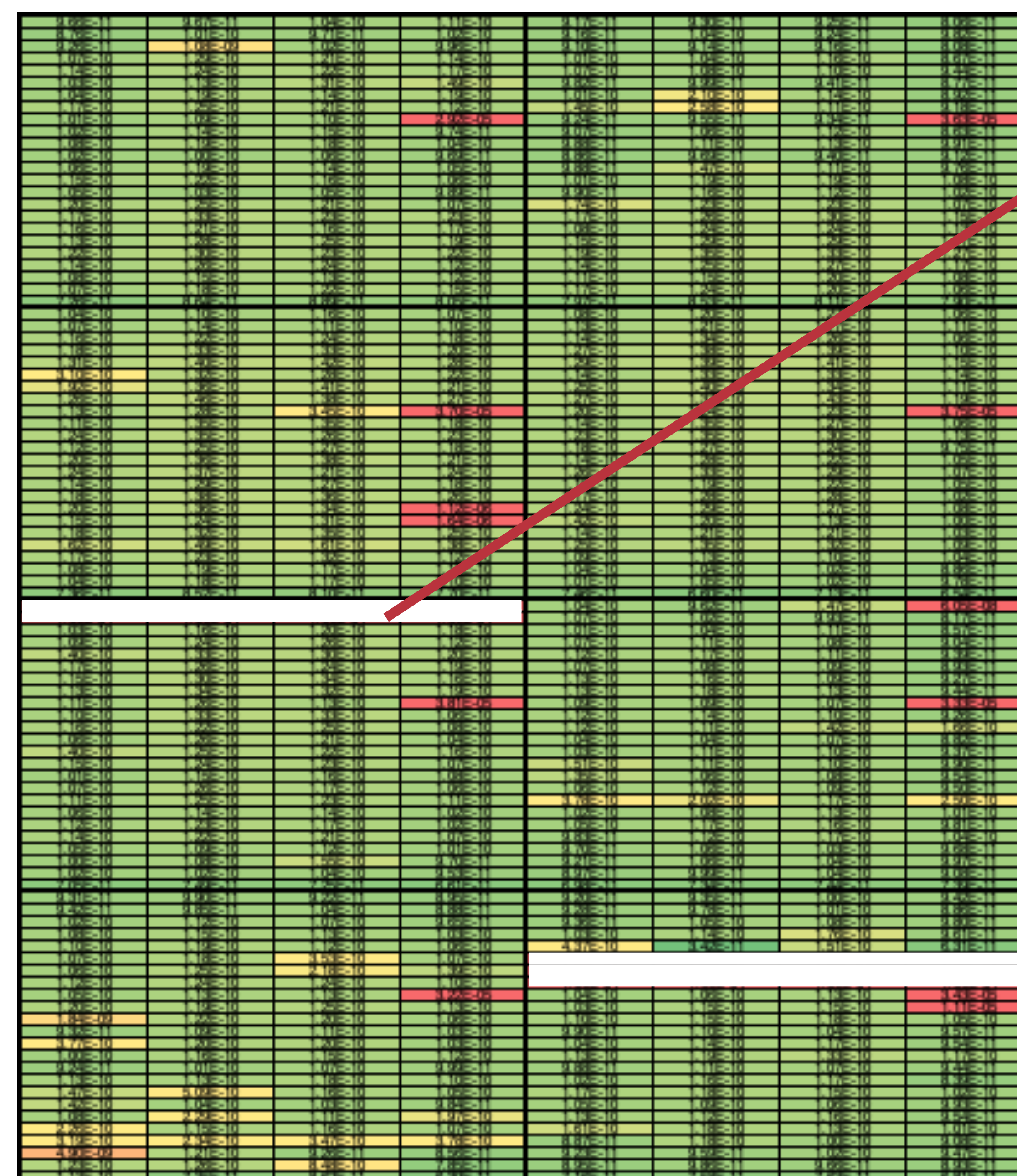
Values not acquired due to software issue



W1

Iave=4.6E-10 A

7 bad pads



***W2**, Epi*

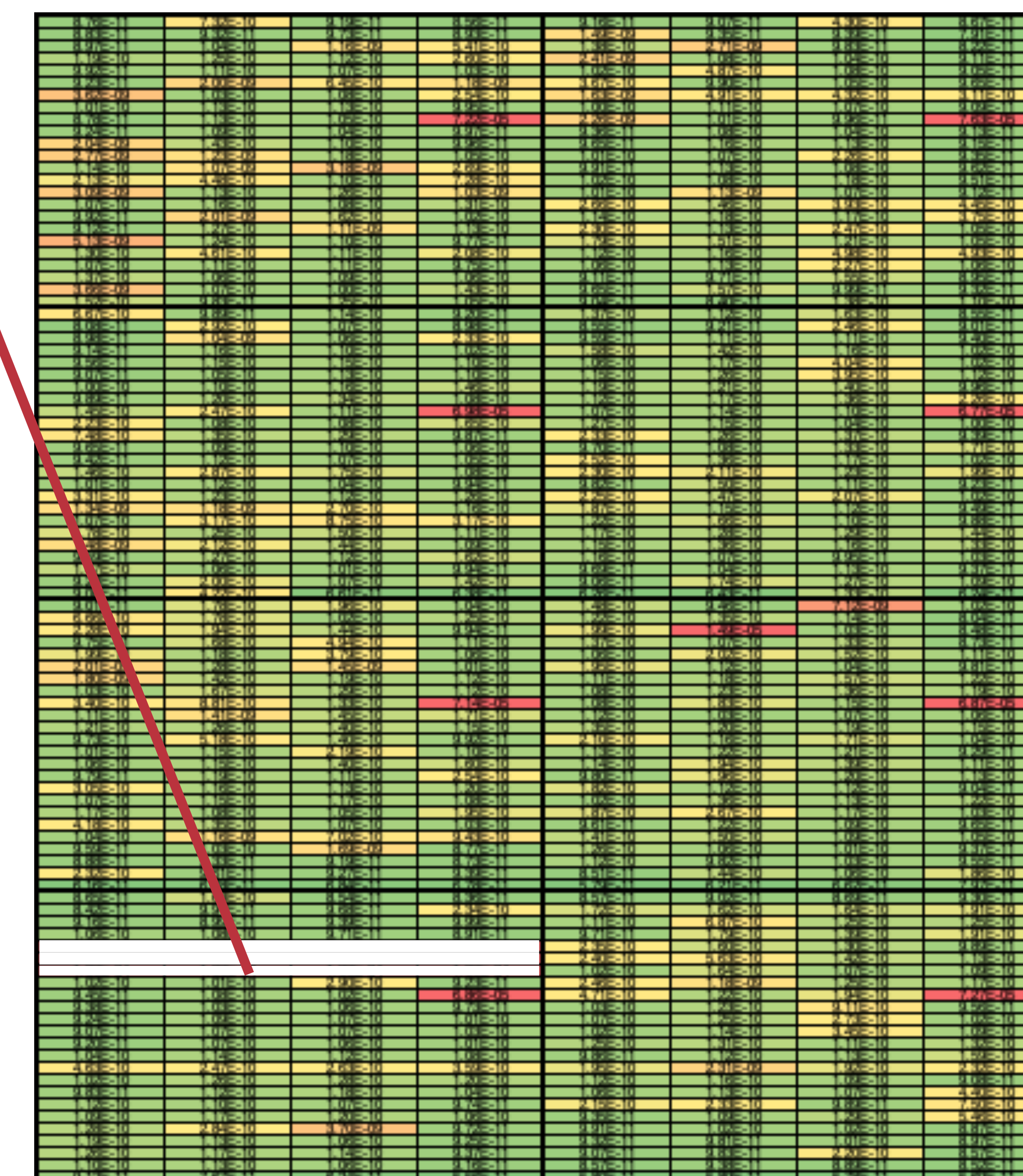
Iave=1.2E-10 A

2 bad pads

W12

Iave=2.7E-10 A

3 bad pads

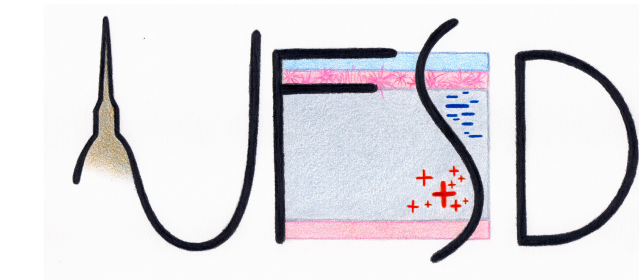


***W13** Epi*

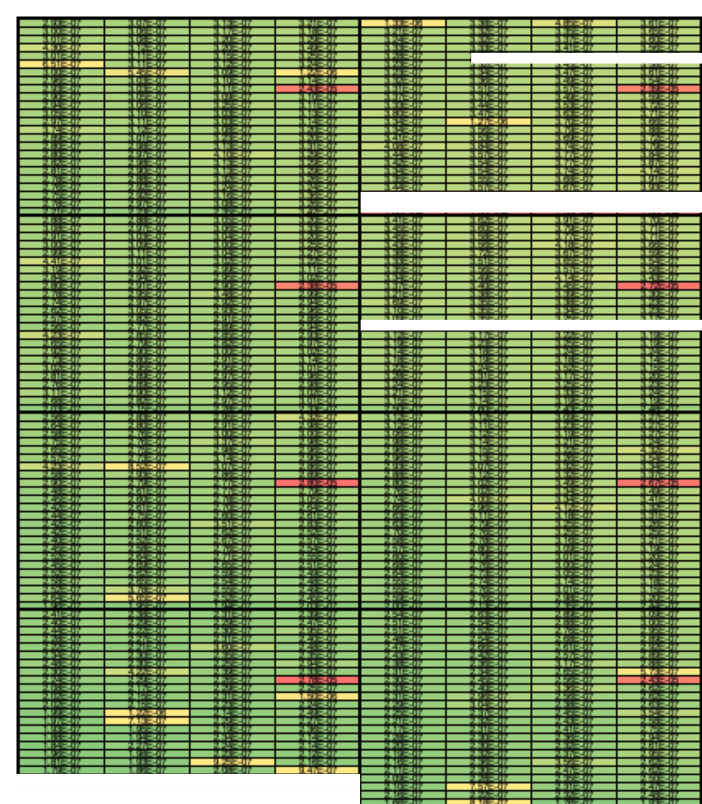
Iave=1.4E-10 A

1 bad pad

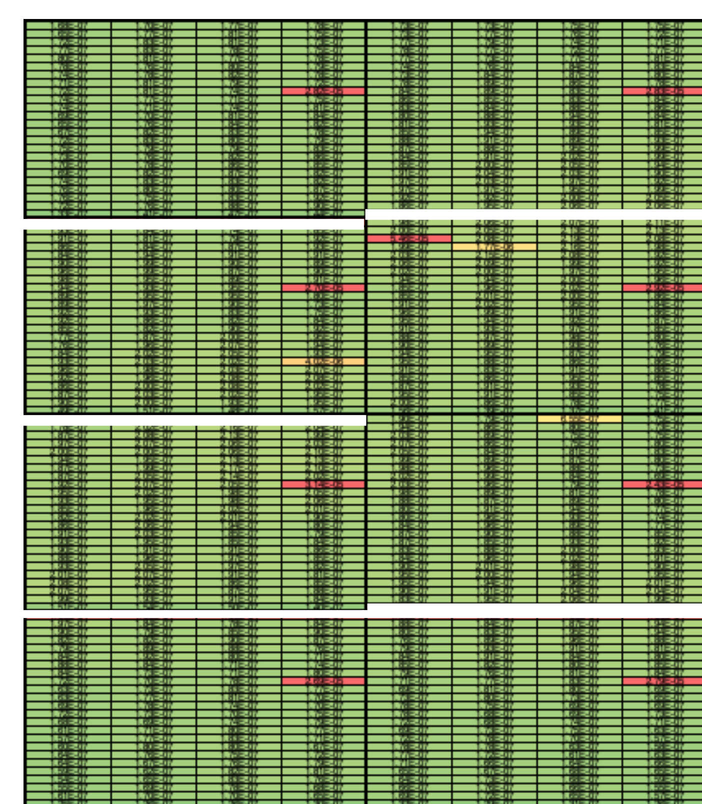
UNIFORMITY STUDIES – CMS STRUCTURE



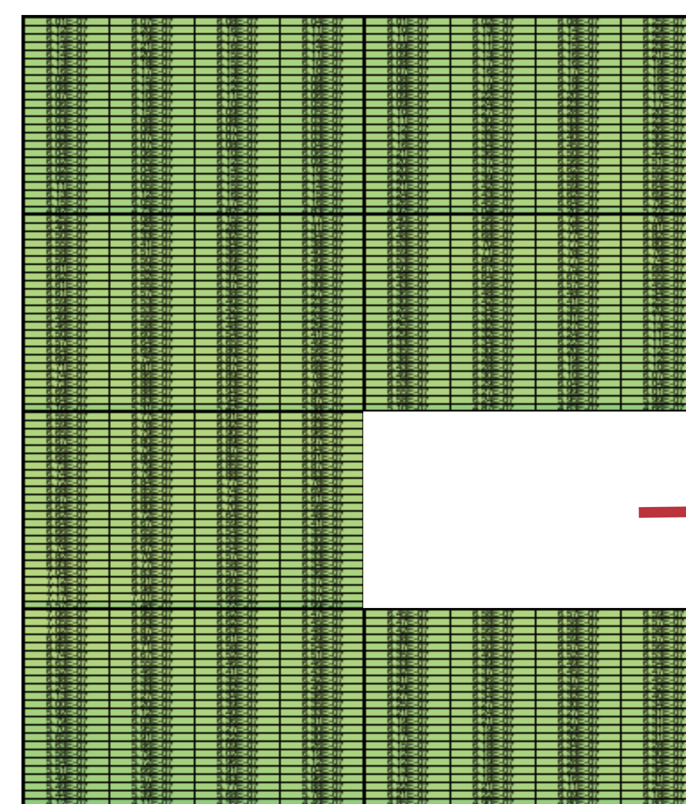
Wafers with carbon



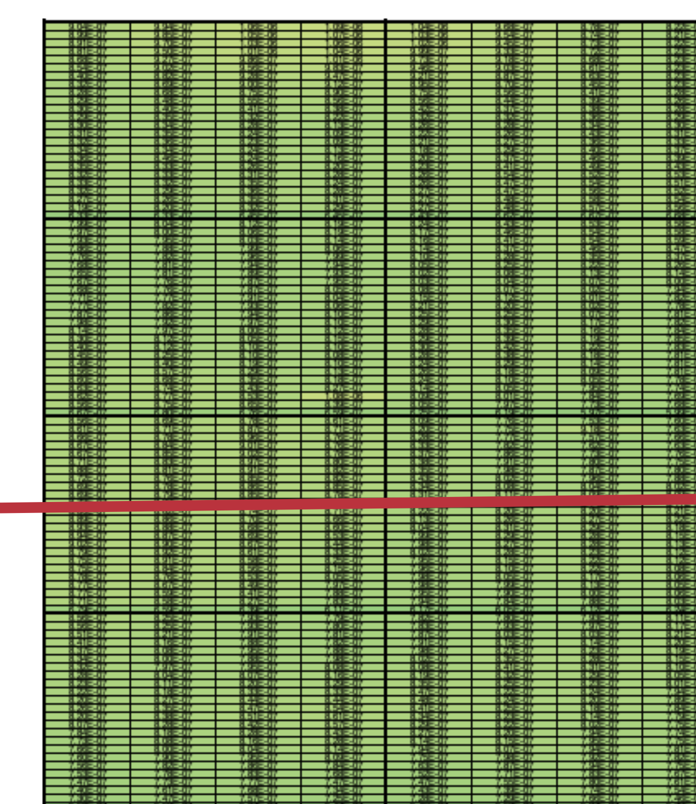
W3, I_{ave}=3,0E-7 A



W4, Epi, I_{ave}=1.9E-7 A, 1 bad pad

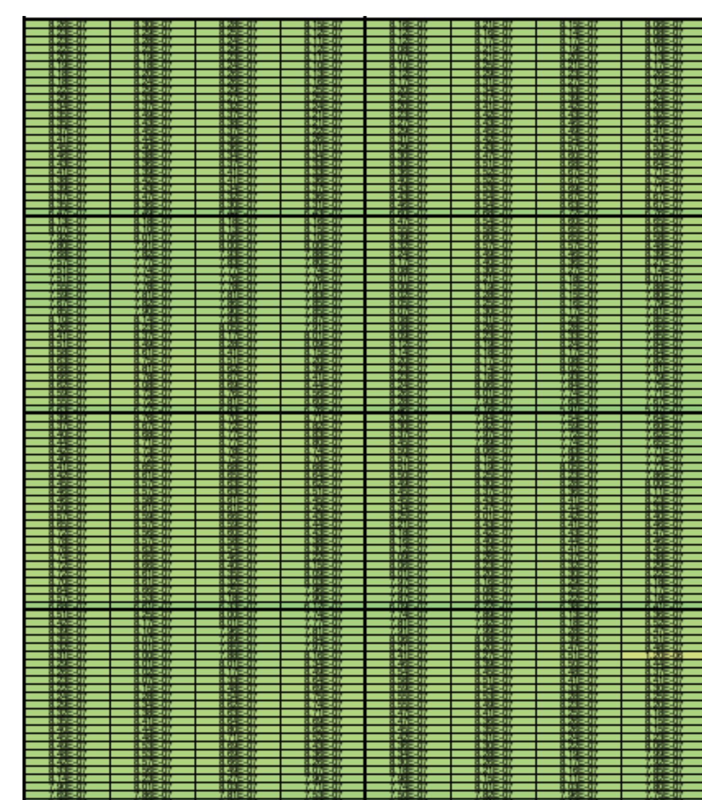


W6, I_{ave}=6.3E-7 A

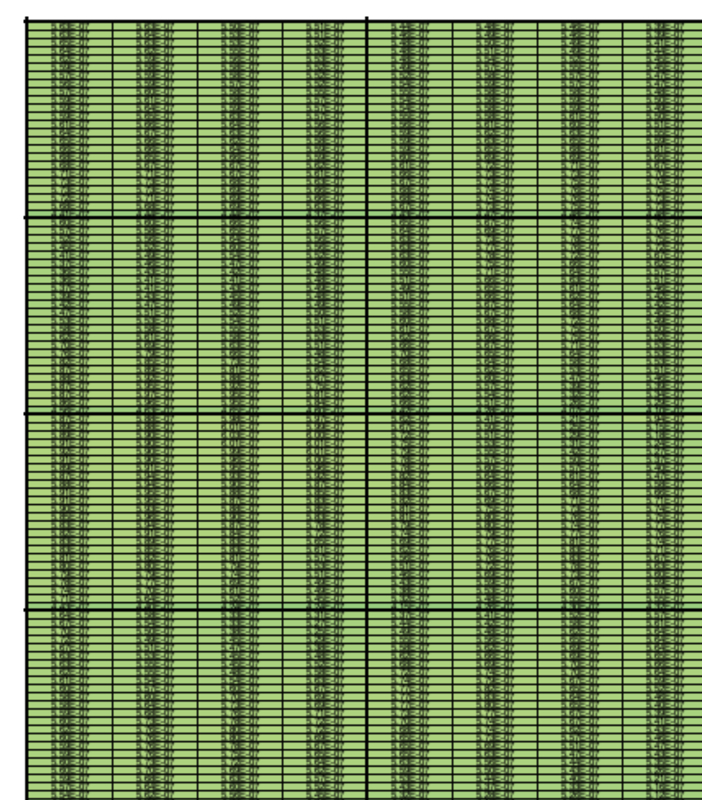


W7, I_{ave}=8.0E-7 A

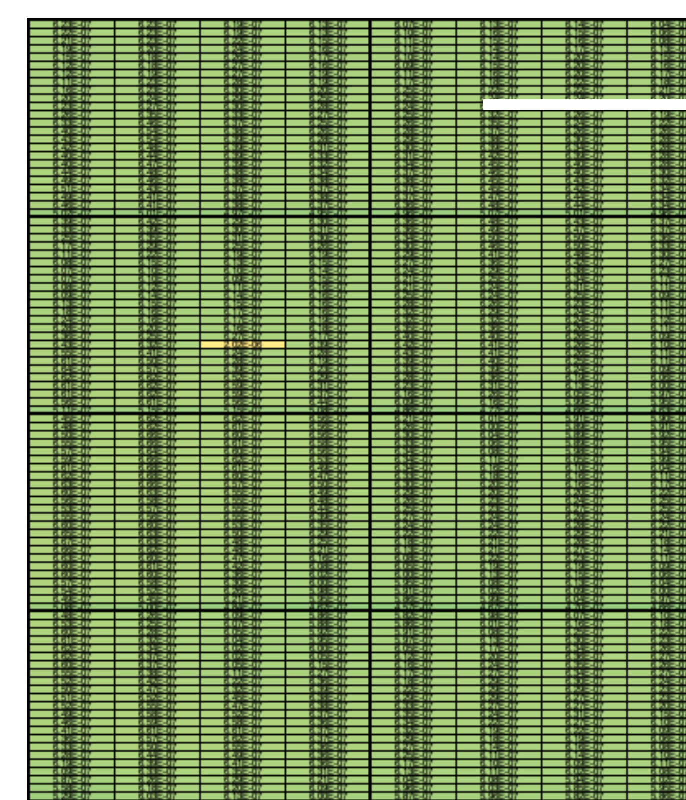
Values not acquired due to software issue



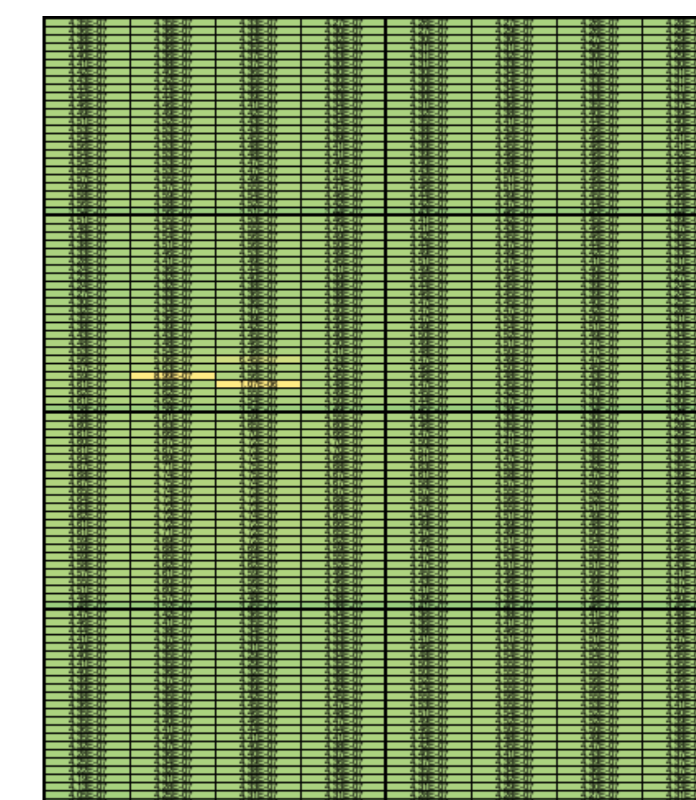
W8, I_{ave}=8.2E-7 A



W9, I_{ave}=5.6E-7 A

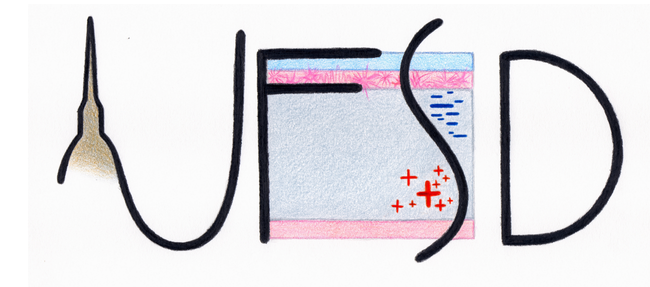


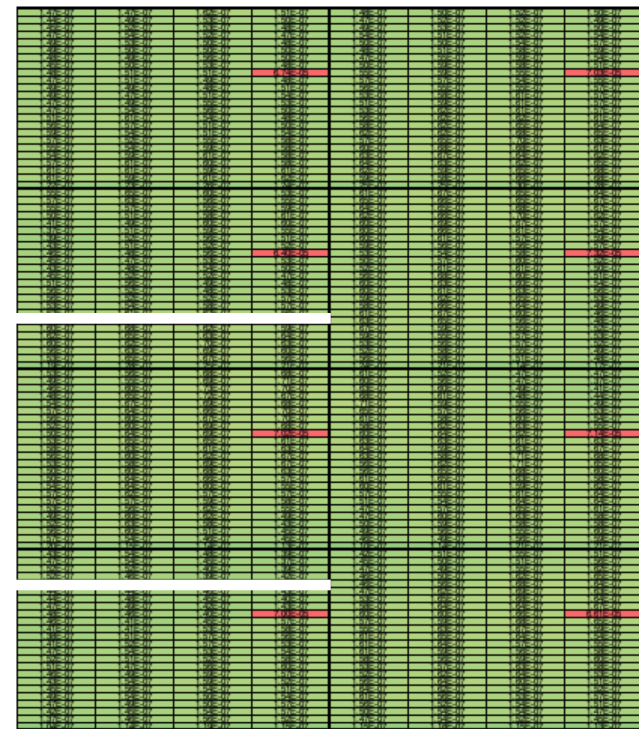
W10, I_{ave}=6.2E-7 A



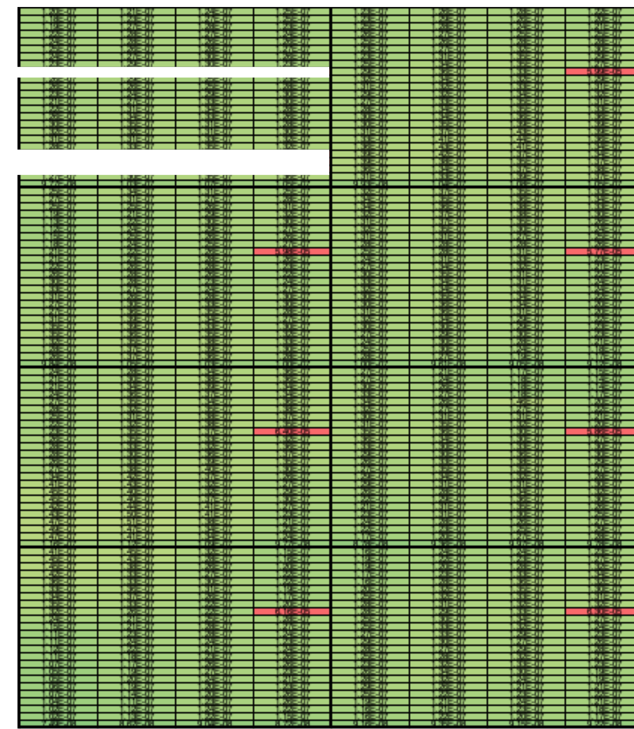
W11, I_{ave}=4.4E-7 A

UNIFORMITY STUDIES - CMS STRUCTURE

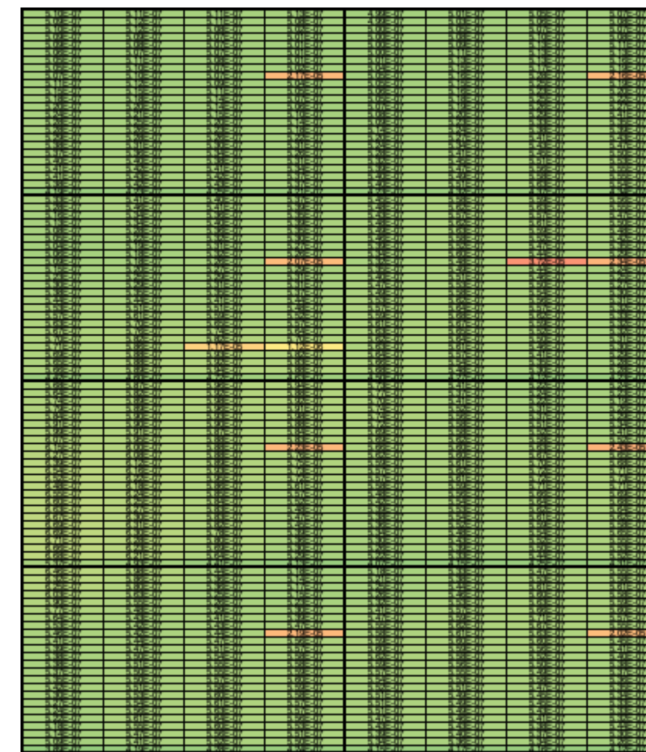




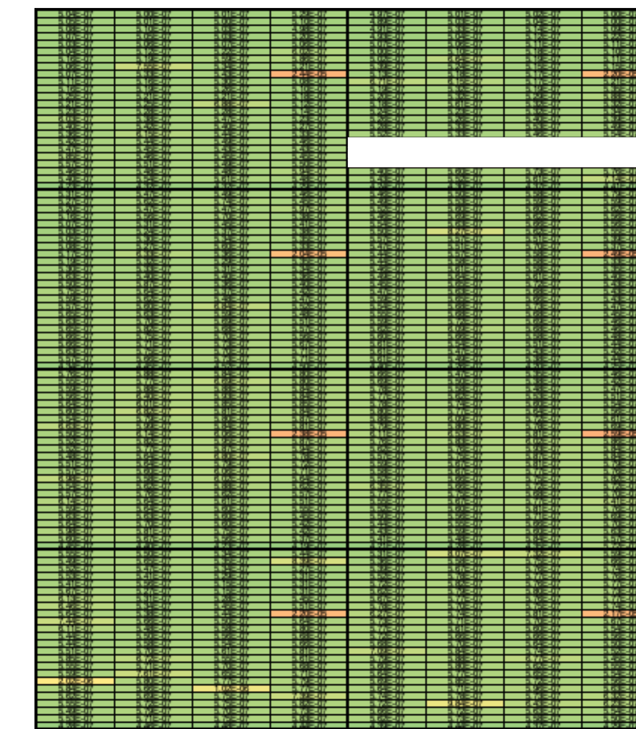
W14, I_{ave}=1.6E-7 A



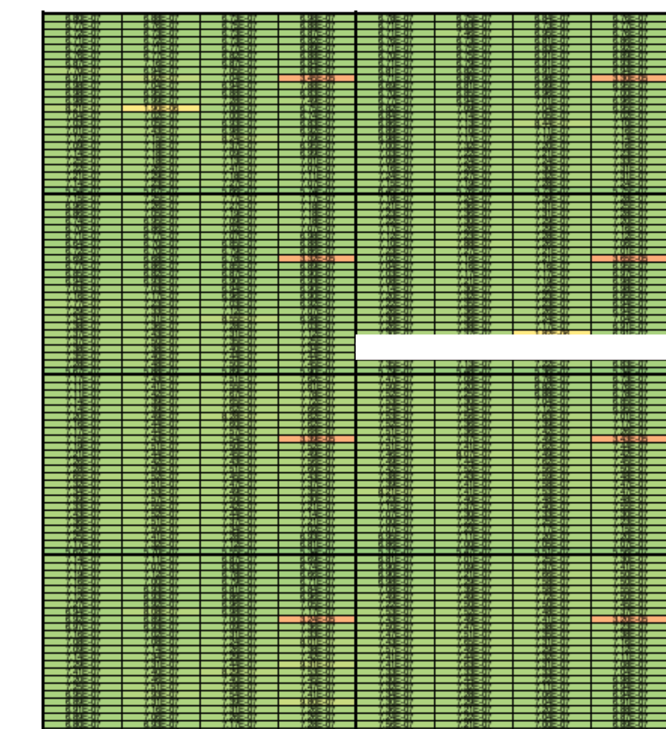
W15, Epi, I_{ave}=1.3E-7 A



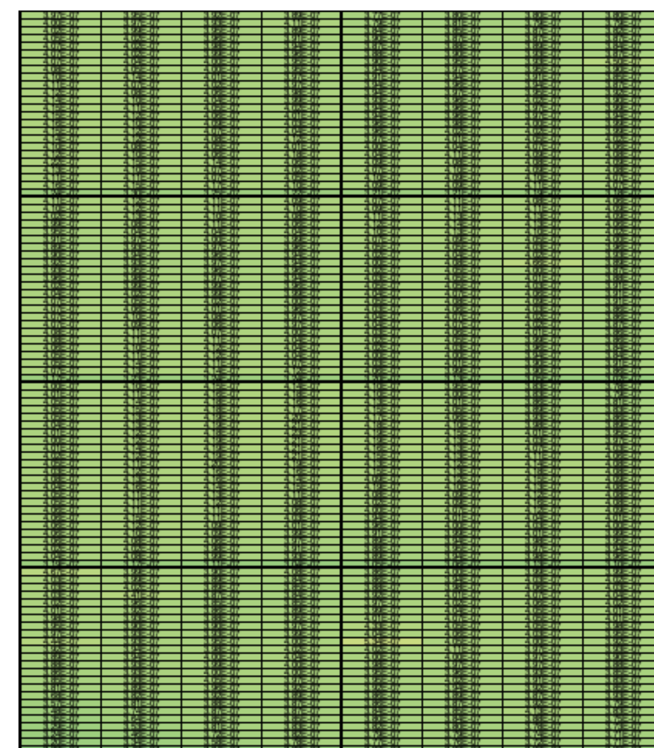
W16, I_{ave}=5.5E-7 A



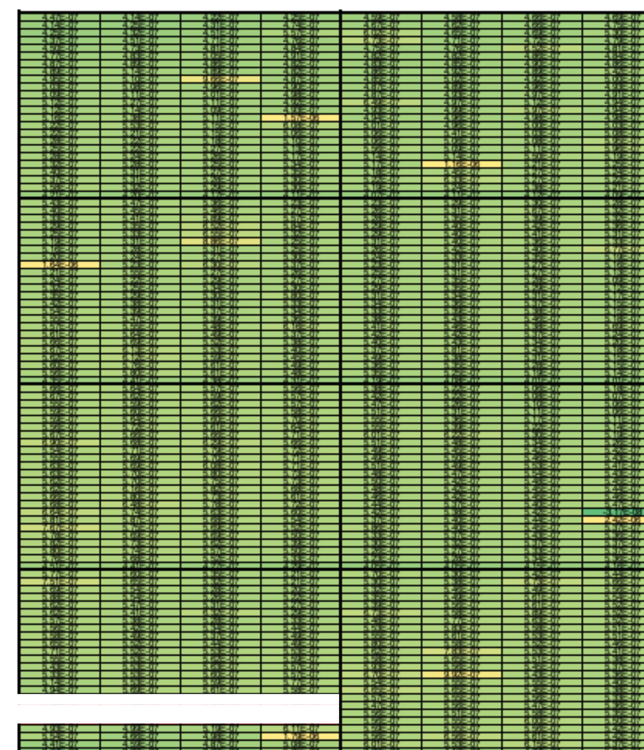
W17, I_{ave}=5.6E-7 A



W18, I_{ave}=7.2E-7 A



W19, I_{ave}=4.0E-7 A



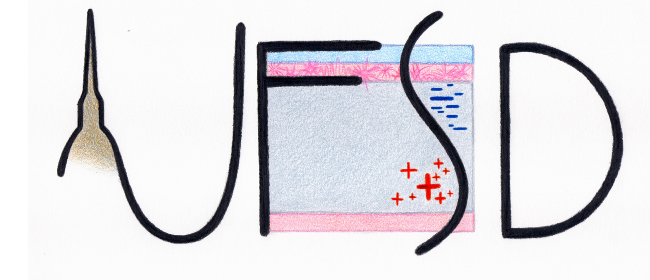
W20, I_{ave}=5.4E-7 A

14 bad channels out of 15.100 ***~0.1%***

→ *(64 bad pads due to mask defect)*

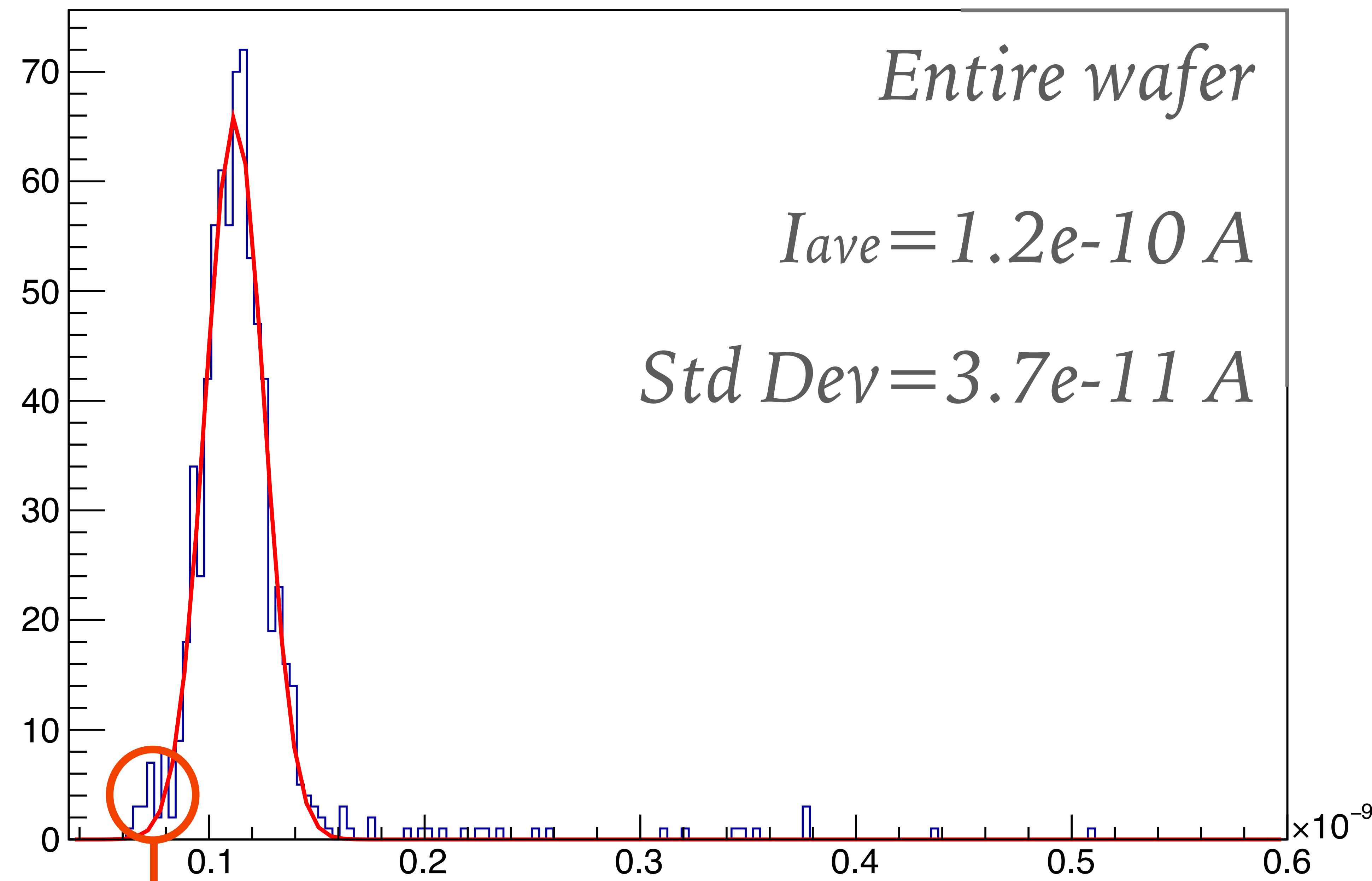
High gain (no Carbon + Carbon A): 14 bad channels out of 6000 ***~0.2%***

UNIFORMITY STUDIES - CMS STRUCTURE W2



*Leakage current distribution @**100V***

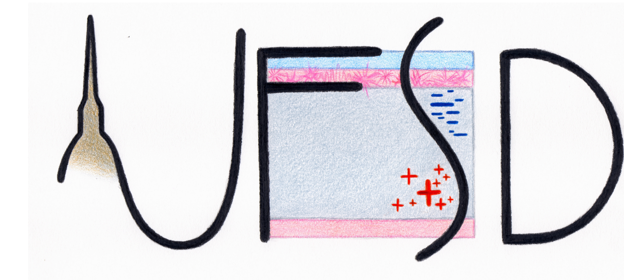
current



last row of pads with smaller area

Pad	Iave	Std Dev
1.4	1.1e-10 A	1.0e-11 A
2.4	1.1e-10 A	2.5e-11 A
1.3	1.3e-10 A	3.3e-11 A
2.3	1.2e-10 A	1.2e-11 A
1.2	1.2e-10 A	1.1e-11 A
2.2	1.1e-10 A	3.6e-11 A
1.1	1.4e-10 A	7.4e-11 A
2.1	1.1e-10 A	4.1e-11 A

UNIFORMITY STUDIES – CMS STRUCTURE



*Leakage current distribution @**100V***

current

W1

No Carbon

Iave=4.6e-10 A
Std Dev=6.2e-11 A

current

W2

No Carbon

Iave=1.2e-10 A
Std Dev=3.7e-11 A

current

W4, Epi

Carbon A

Iave=1.9e-7 A
Std Dev=2.2e-8 A

current

W6

Carbon B

Iave=6.3e-7 A
Std Dev=3.7e-8 A

current

W7

Carbon B

Iave=8.0e-7 A
Std Dev=3.2e-8 A

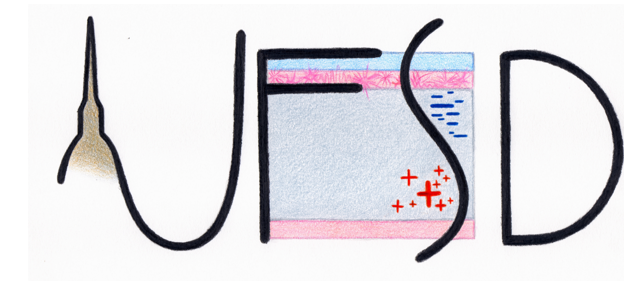
current

W9

Carbon C

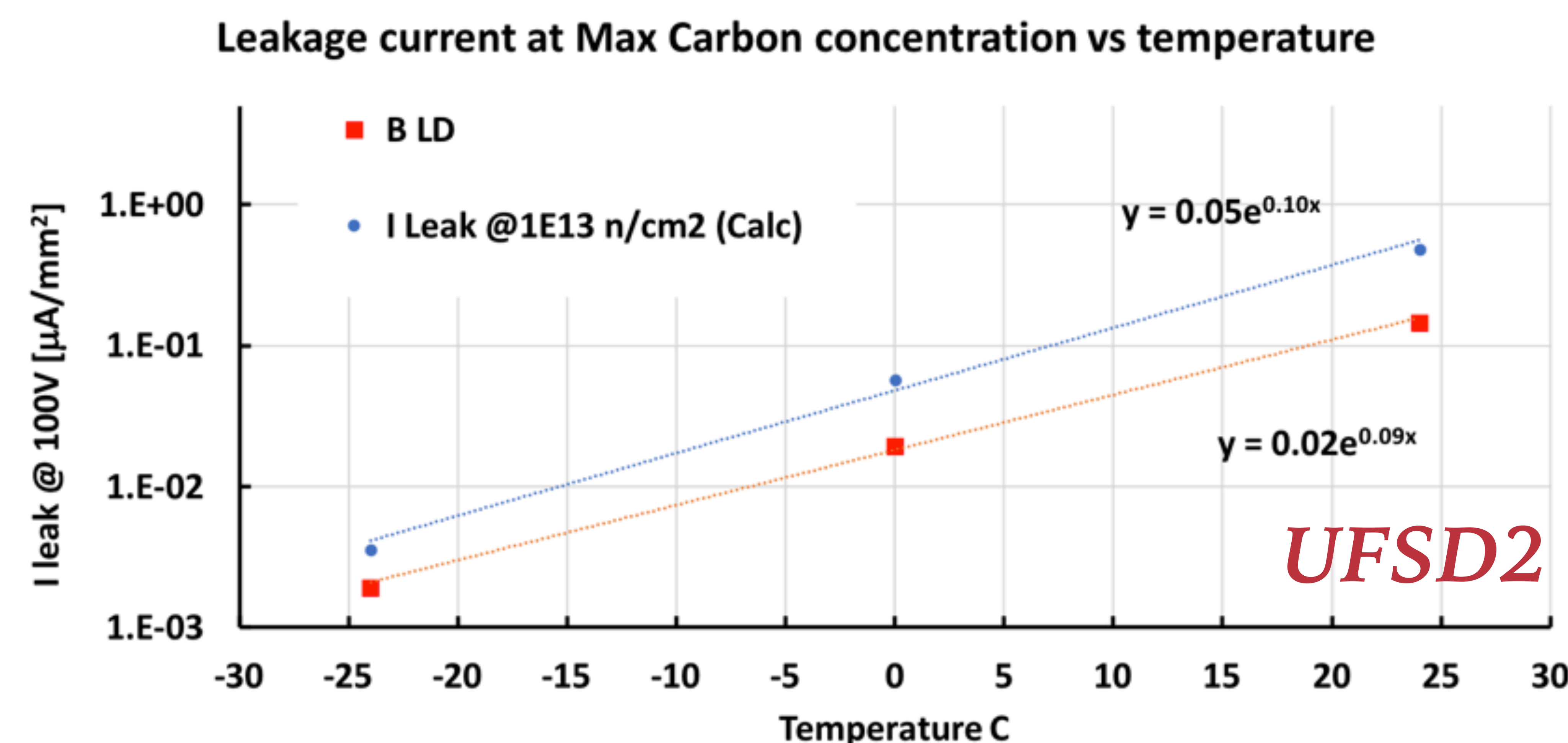
Iave=5.6e-7 A
Std Dev=2.7e-8 A

UNIFORMITY STUDIES – CMS STRUCTURE

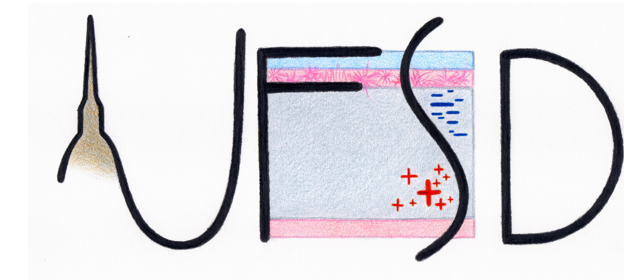


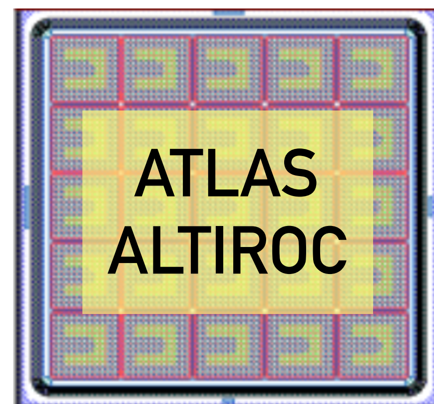
Wafer #	Dose Pgain	Carbon	Diffusion	Leakage current mean (A)	Std Dev (A)	Ratio (%)
1	0.98		L	4,6E-10	6,2E-11	13
2	0.96		L	1,2E-10	3,7E-11	31
3	0.96	A	L	3,0E-07	7,0E-08	23
4	0.96	A	L	1,9E-07	2,2E-08	12
5	0.98	A	L	*diced before measurements*		
6	0.96	B	L	6,3E-07	3,7E-08	6
7	0.98	B	L	8,0E-07	3,2E-08	4
8	0.98	B	L	8,2E-07	4,2E-08	5
9	0.98	C	L	5,6E-07	2,7E-08	5
10	1.00	C	L	6,2E-07	3,1E-08	5
11	1.00	D	L	4,4E-07	3,6E-08	8
12	1.02		H	2,7E-10	5,4E-11	20
13	1.00		H	1,4E-10	7,7E-11	56
14	1.02	A	H	1,6E-07	9,4E-09	6
15	1.00	A	H	1,3E-07	8,6E-09	7
16	1.02	B	H	5,5E-07	4,1E-08	8
17	1.02	B	H	5,6E-07	5,0E-08	9
18	1.04	B	H	7,2E-07	4,2E-08	6
19	1.02	C	H	4,0E-07	2,0E-08	5
20	1.04	C	H	5,4E-07	5,6E-08	10

- *Carbon implant* ***increases leakage current***, *equivalent to* $\phi = 10^{13} n_{eq}/cm^2$
- *Leakage current weakly increases with Carbon dose*
- *Carbon-wafer's leakage current has the* ***same behaviour with temperature of standard leakage current***



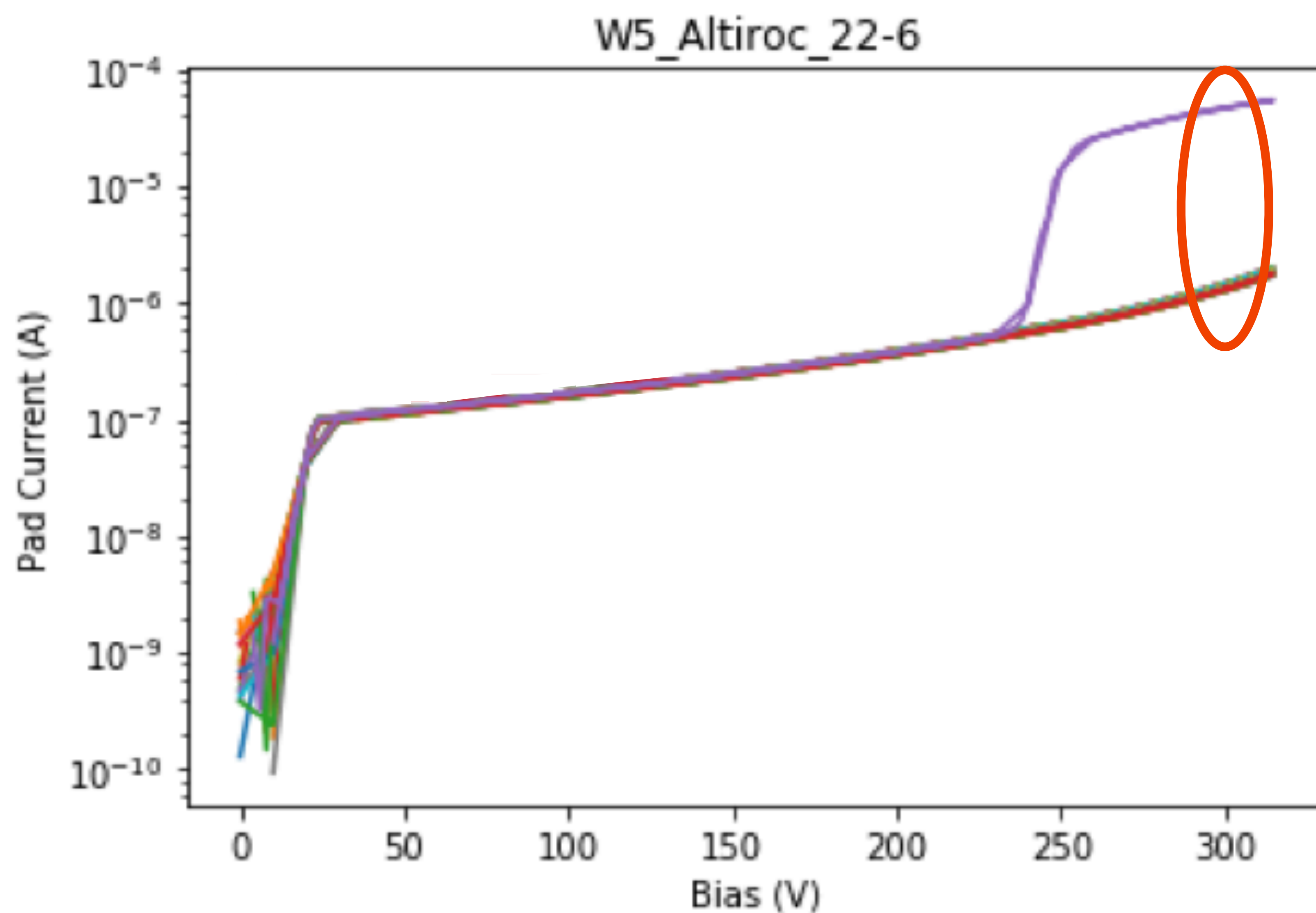
UNIFORMITY STUDIES – ALTIROC STRUCTURE W5

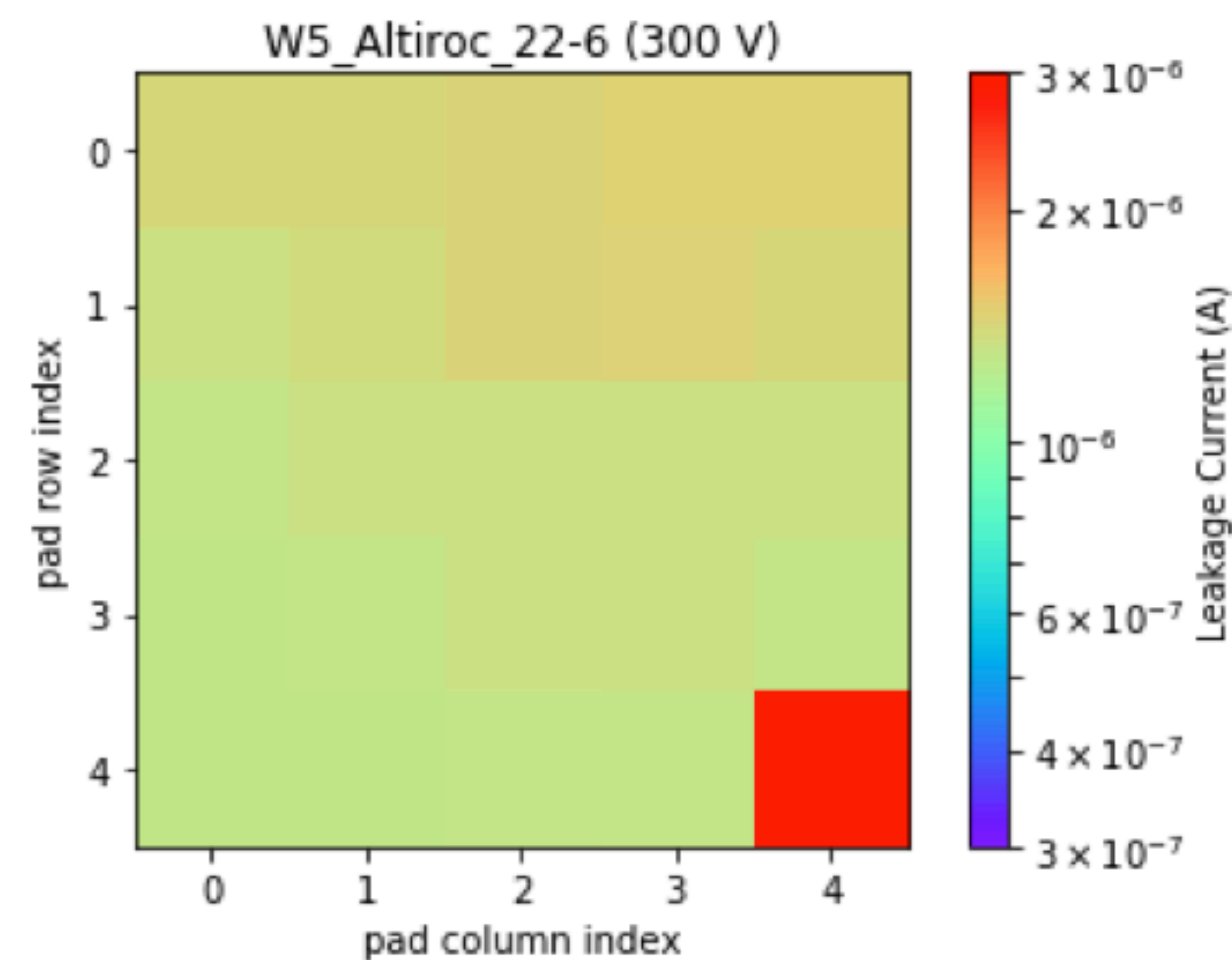


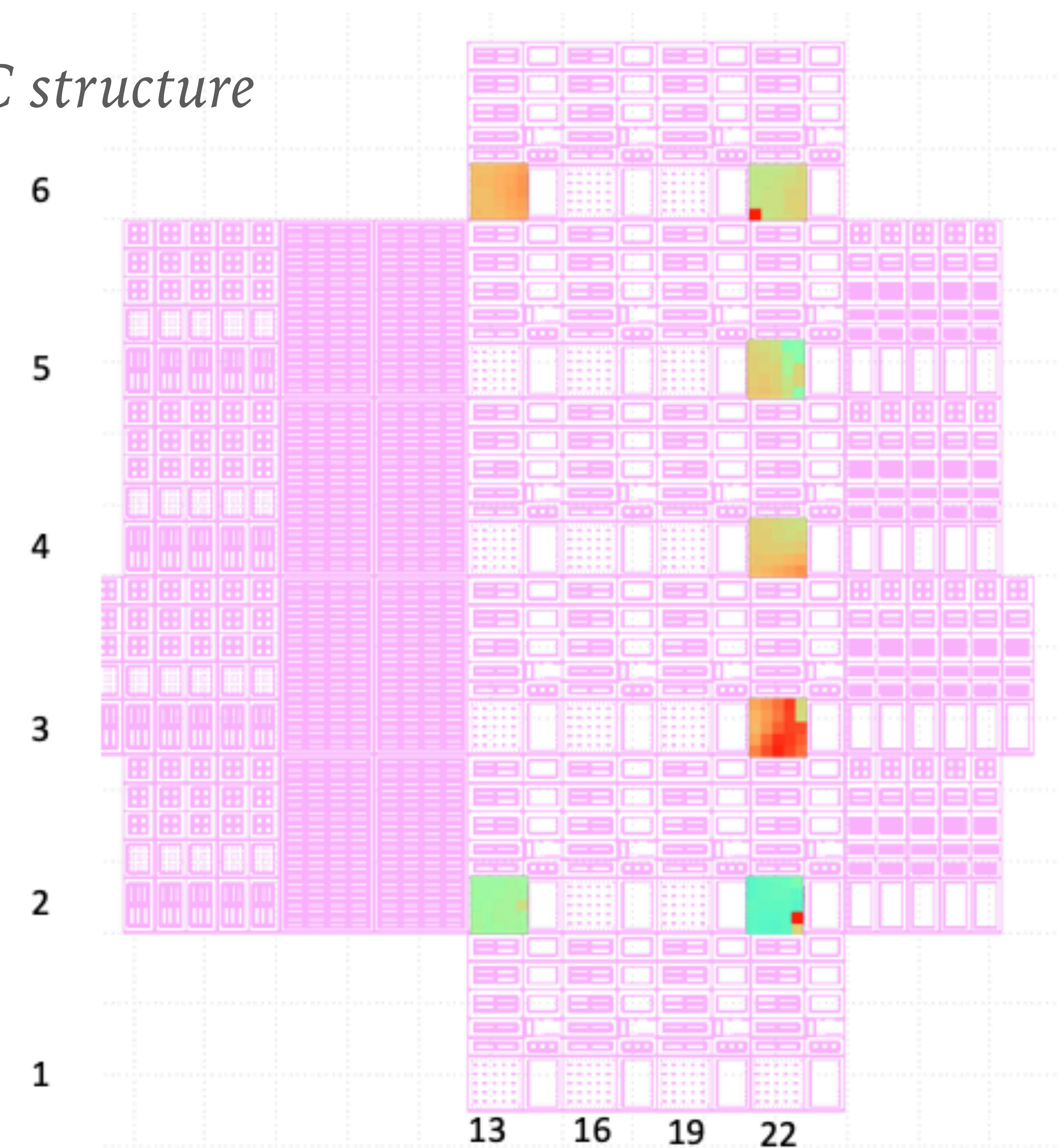


Every pad is connected, higher voltage reached

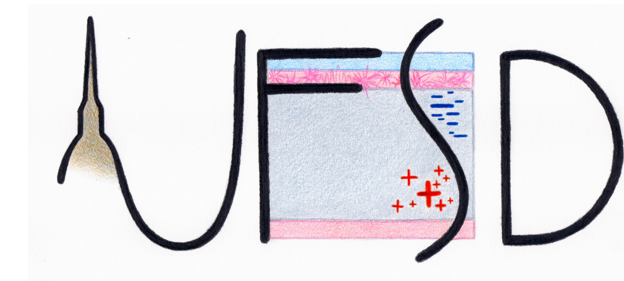
*Leakage current @**300V** for each pad of **W5** ALTIROC structure*

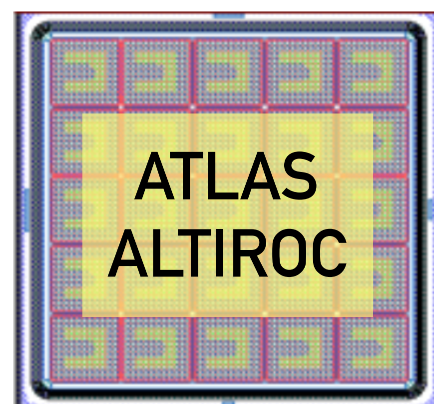






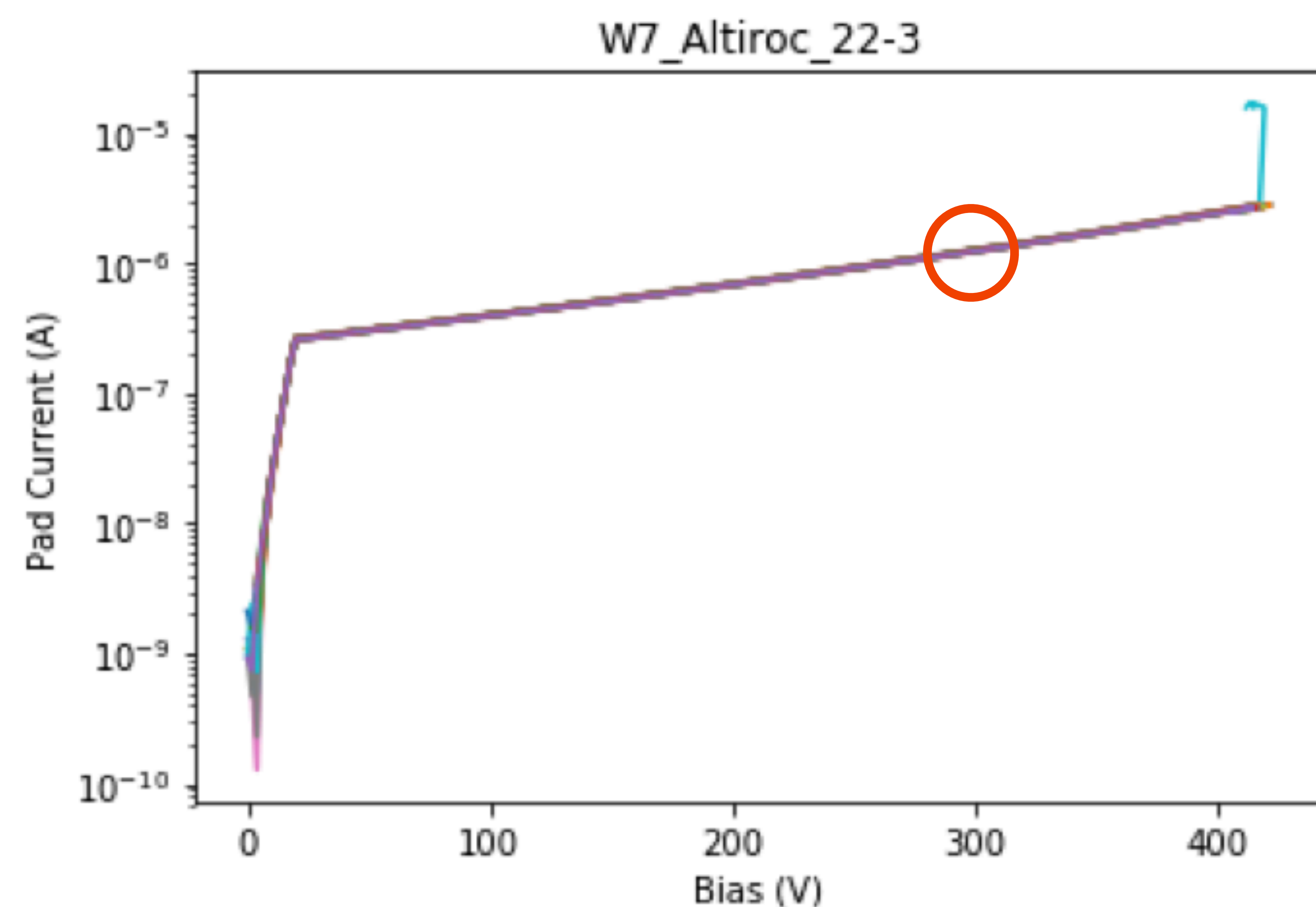
UNIFORMITY STUDIES – ALTIROC STRUCTURE W7

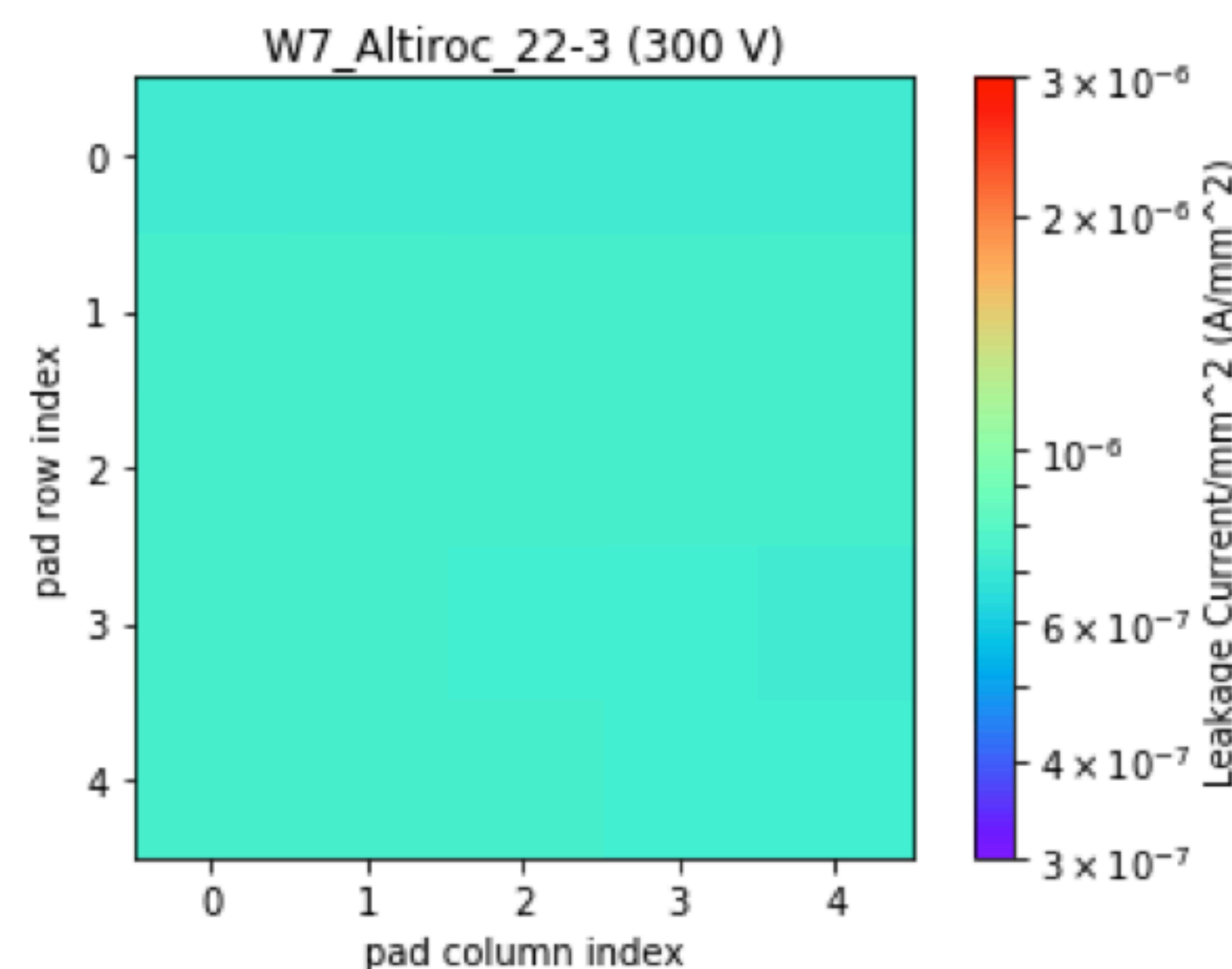


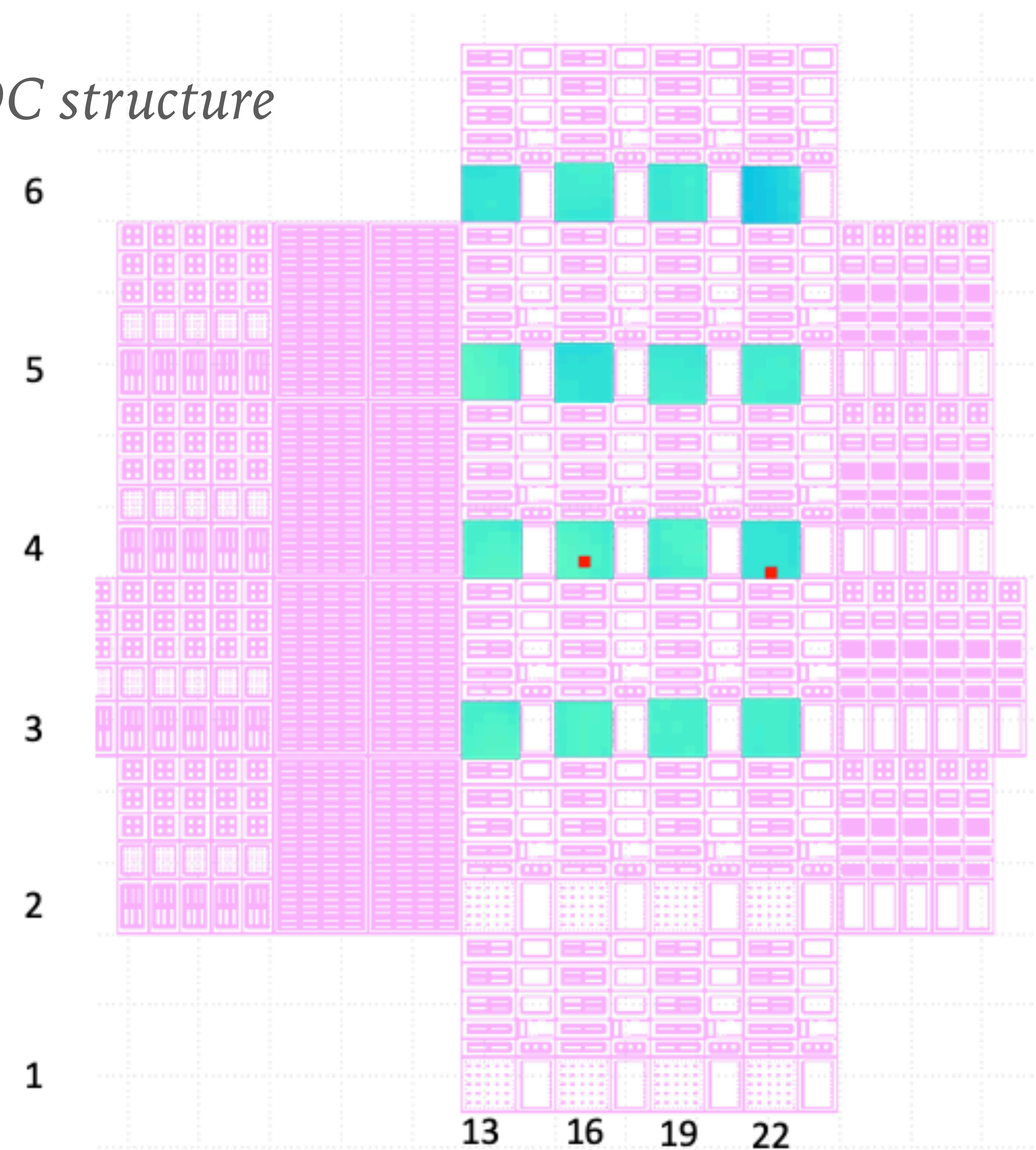


Every pad is connected, higher voltage reached

*Leakage current @**300V** for each pad of **W7** ALTIROC structure*

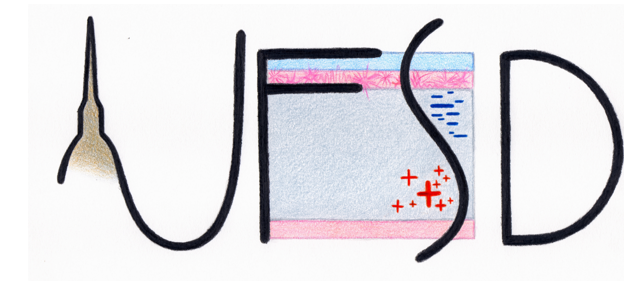


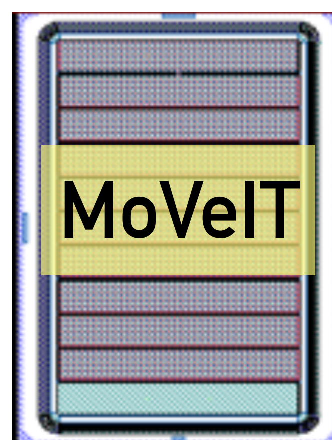




→ *In total 4 bad pads out of 575 ~ **0.7%***

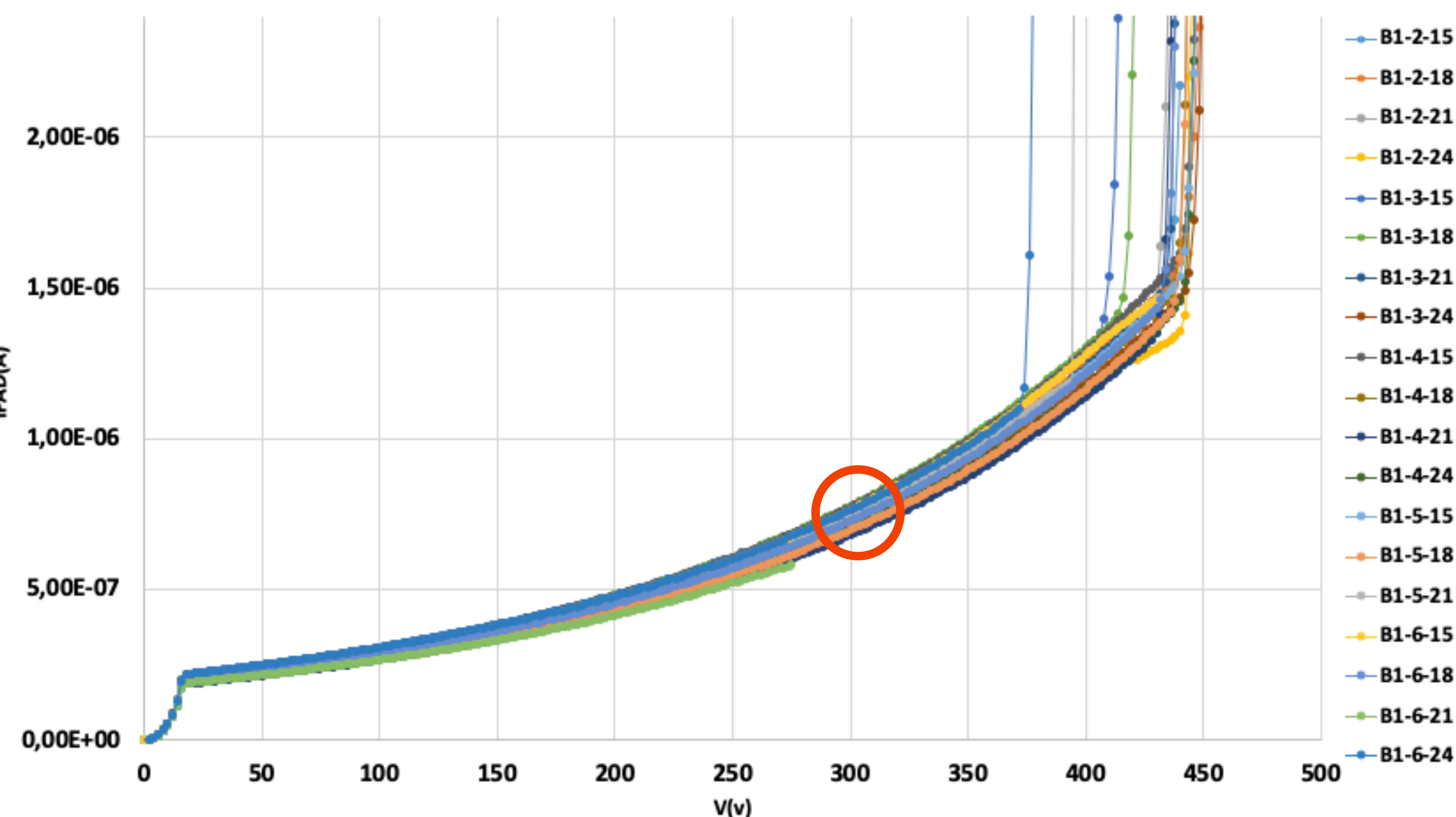
UNIFORMITY STUDIES – AN EXAMPLE OF MOVEIT STRUCTURE

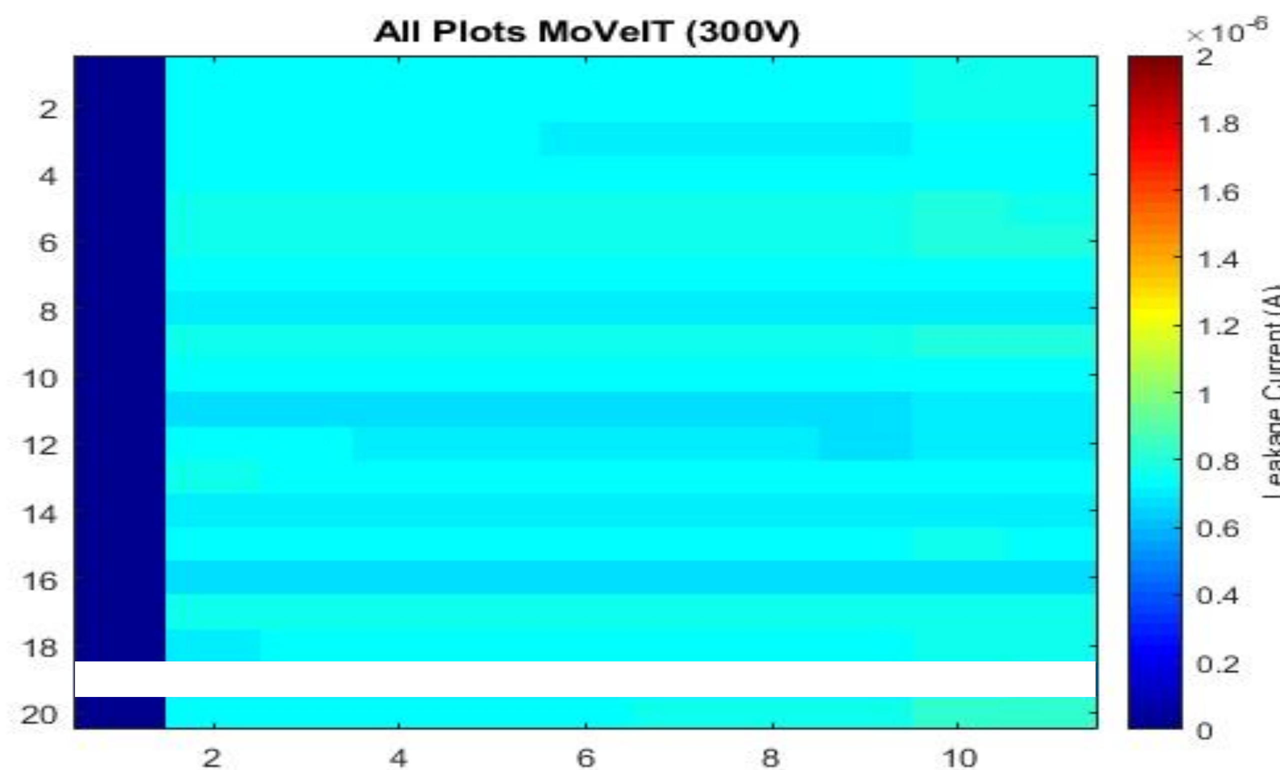


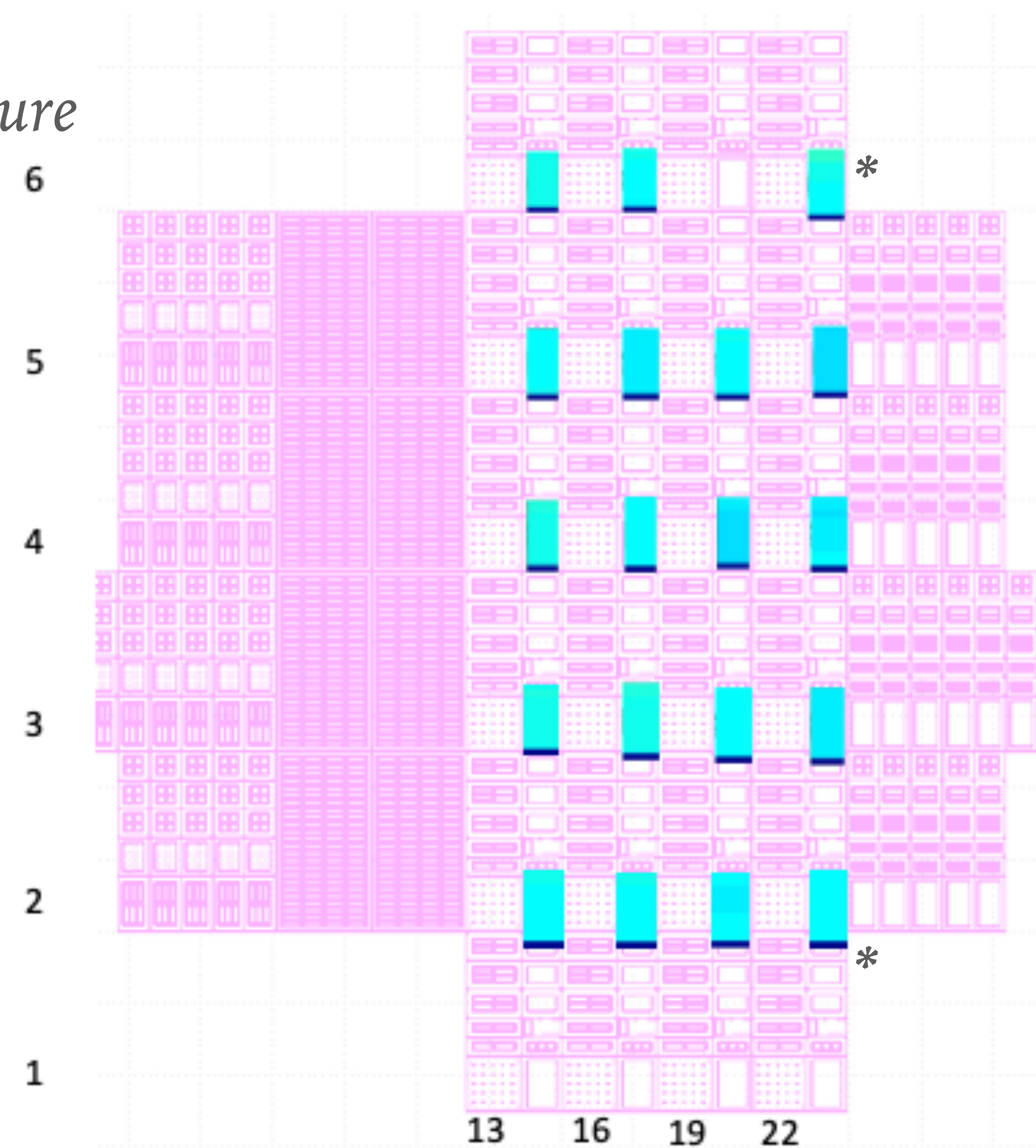


Every pad is connected, higher voltage reached

*Leakage current @**300V** for each strip of **W9** MoVeIT structure*



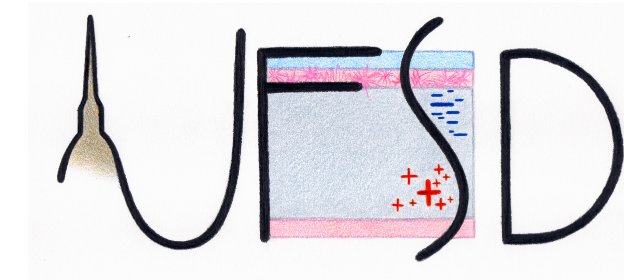




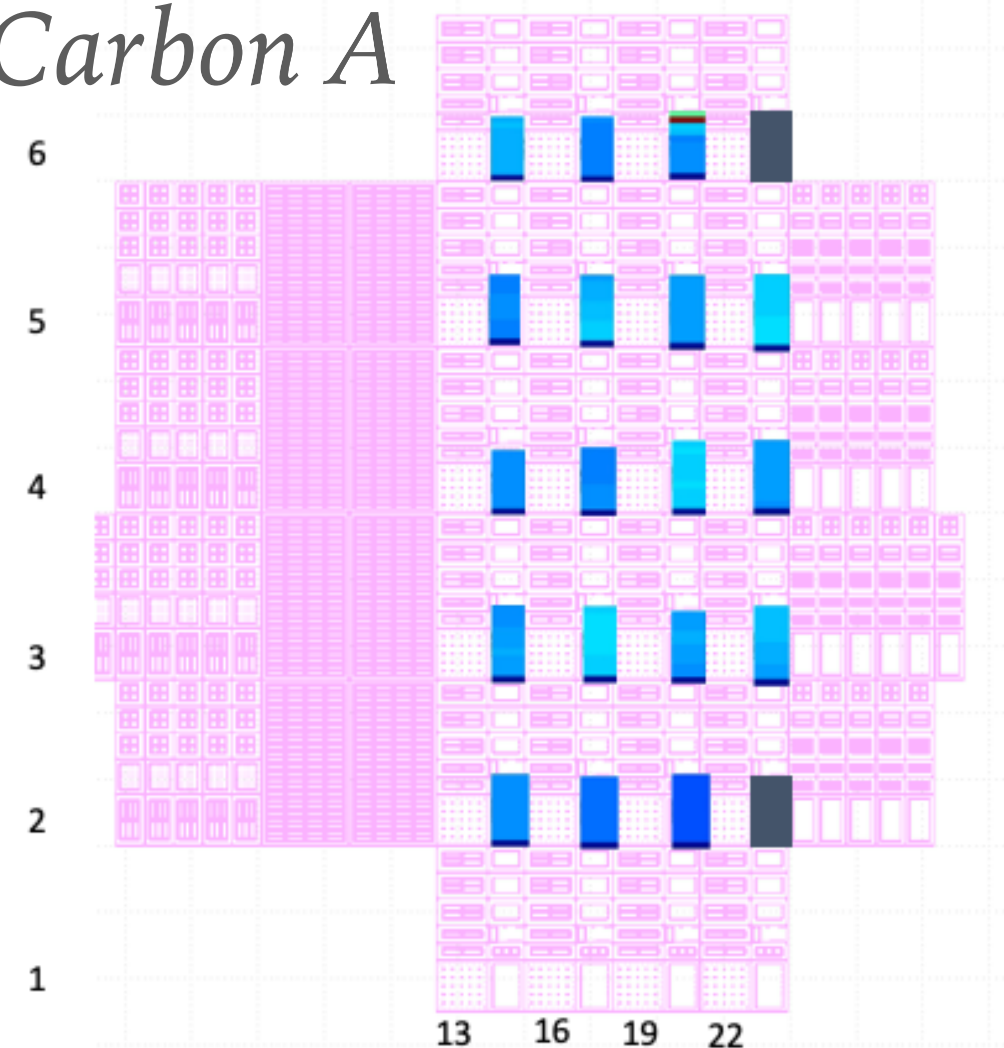
Measurements performed by MoVeIT group:
S. Giordanengo, O. Hammad, V. Monaco, R. Sacchi, Z. Shakarami, A. Vignati

**on the edge of fiducial area*

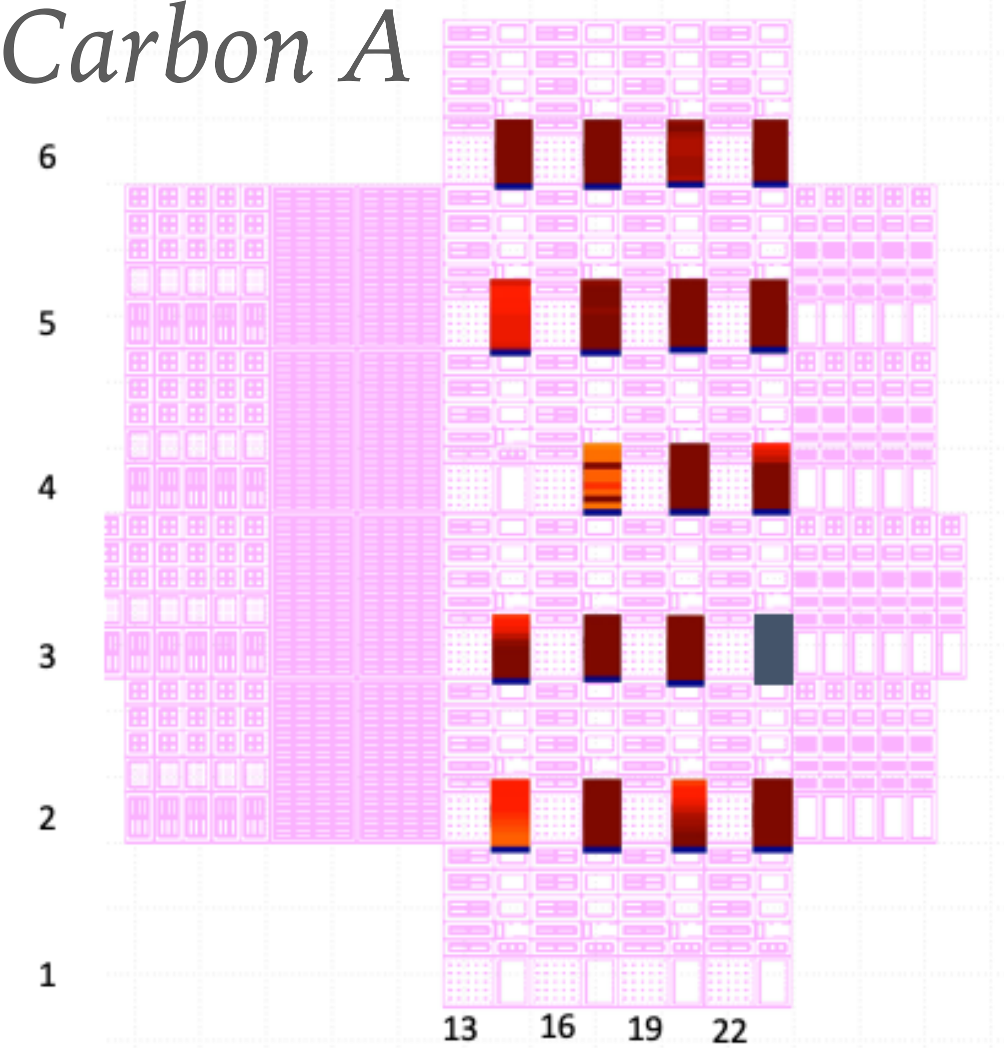
UNIFORMITY STUDIES – MOVEIT STRUCTURE



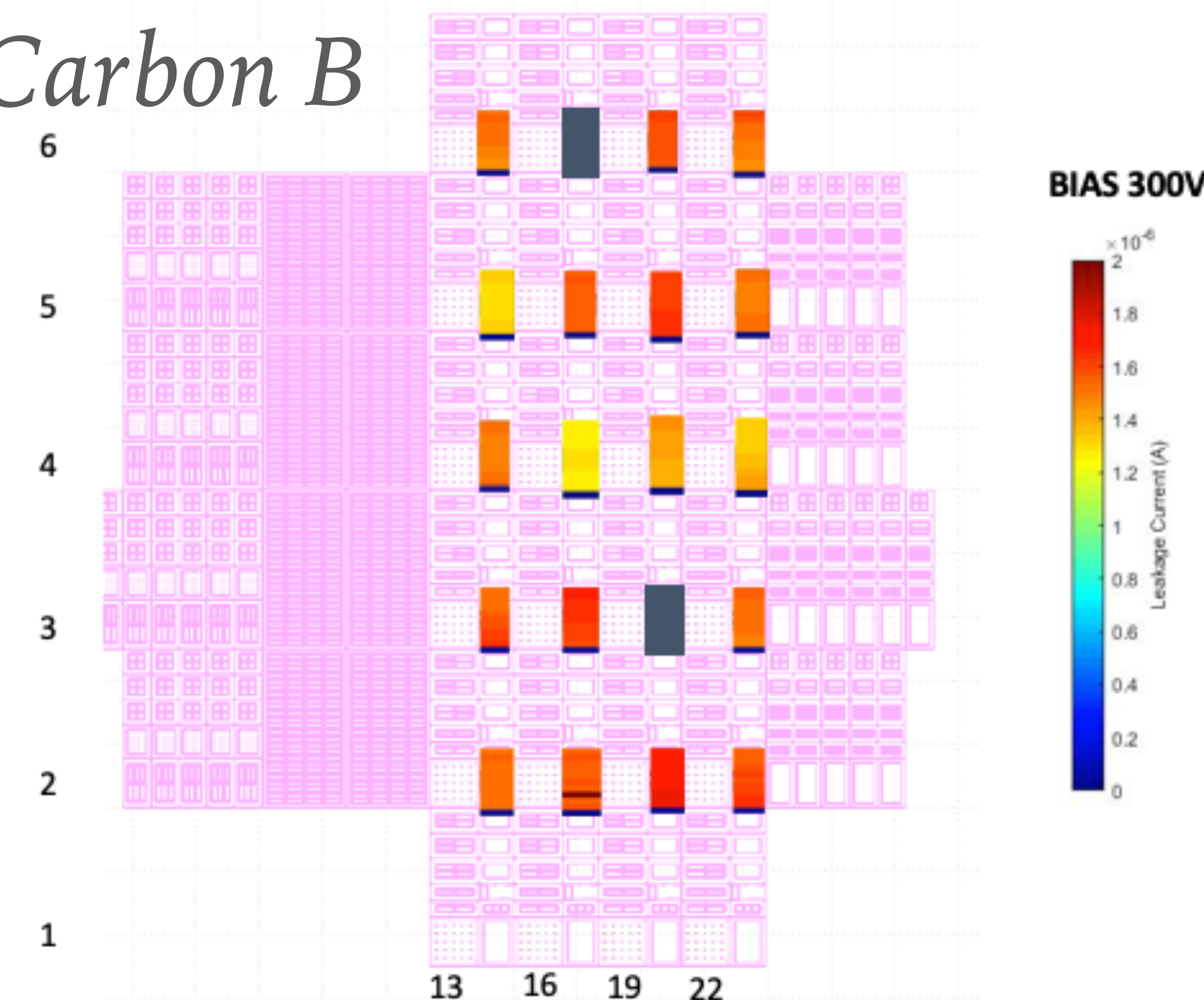
W4, Epi, Carbon A



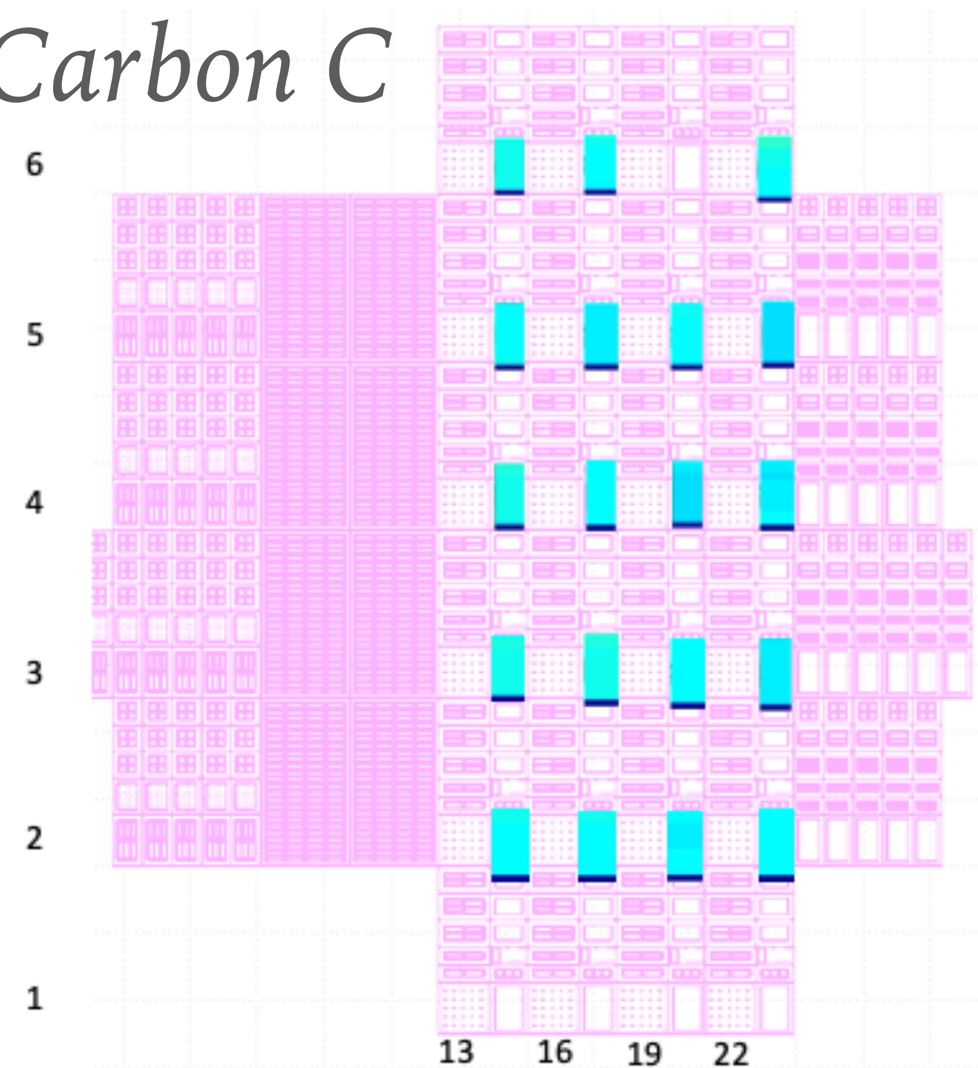
W5, Carbon A



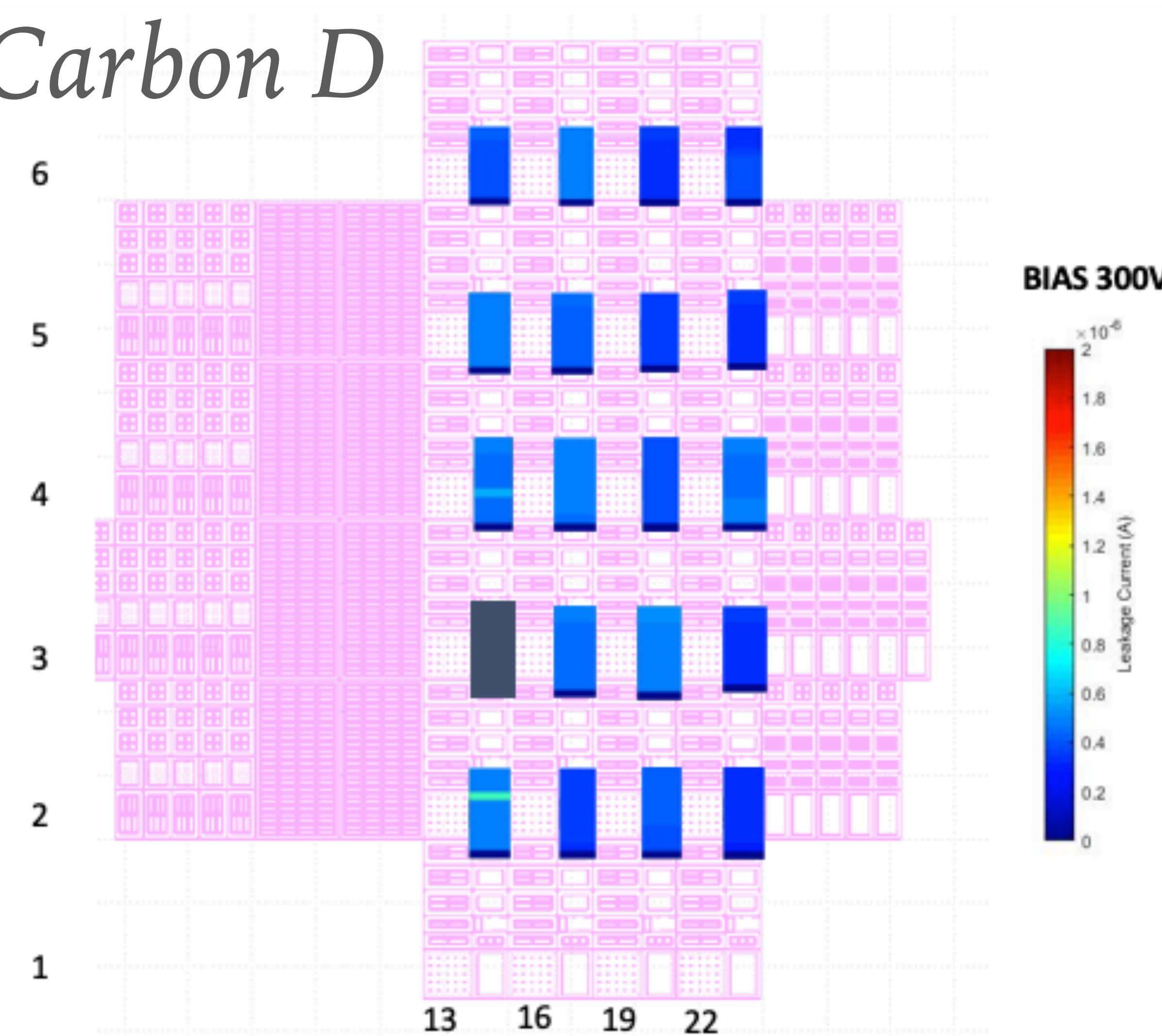
W7, Carbon B



W9, Carbon C



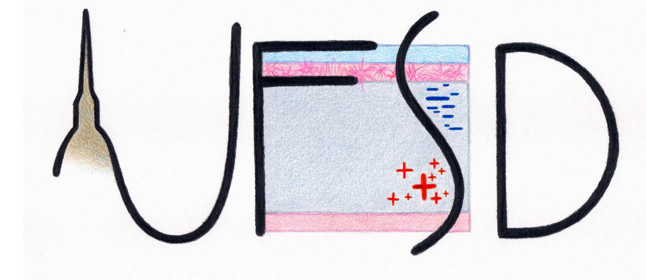
W11, Carbon D



4 devices out of 84 in breakdown

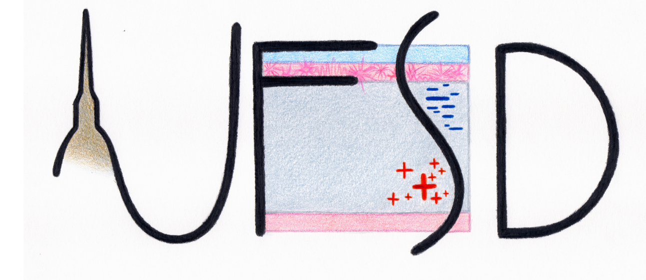
2 bad strips out of 880 for the good devices ~ ***0.2%***

CONCLUSIONS



- *We consider as "bad" pads or devices the ones that show breakdown before the bias at which the measurement is performed*
- ***@100V*** *all pads of every CMS ROC have been measured on wafer:*
  bad channels are 0.1% *of the total*
- ***@300V*** *we measured cut structures with a lower number of pads, ALTIROC and MoVeIT:*
  bad channels are 0.7% *of the measured pads for ALTIROC*
  bad strips are 0.2% *of the working structures measured for MoVeIT*
- *We can conclude that we observe an* ***excellent uniformity*** *on UFSD3 sensors by FBK*

ACKNOWLEDGEMENTS



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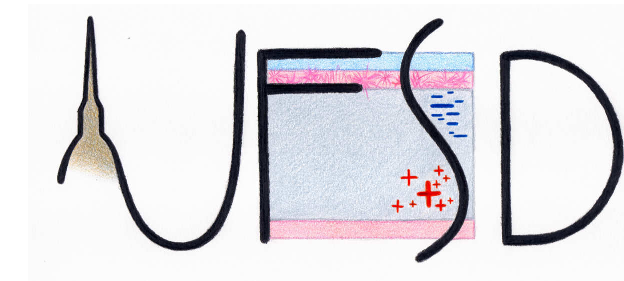
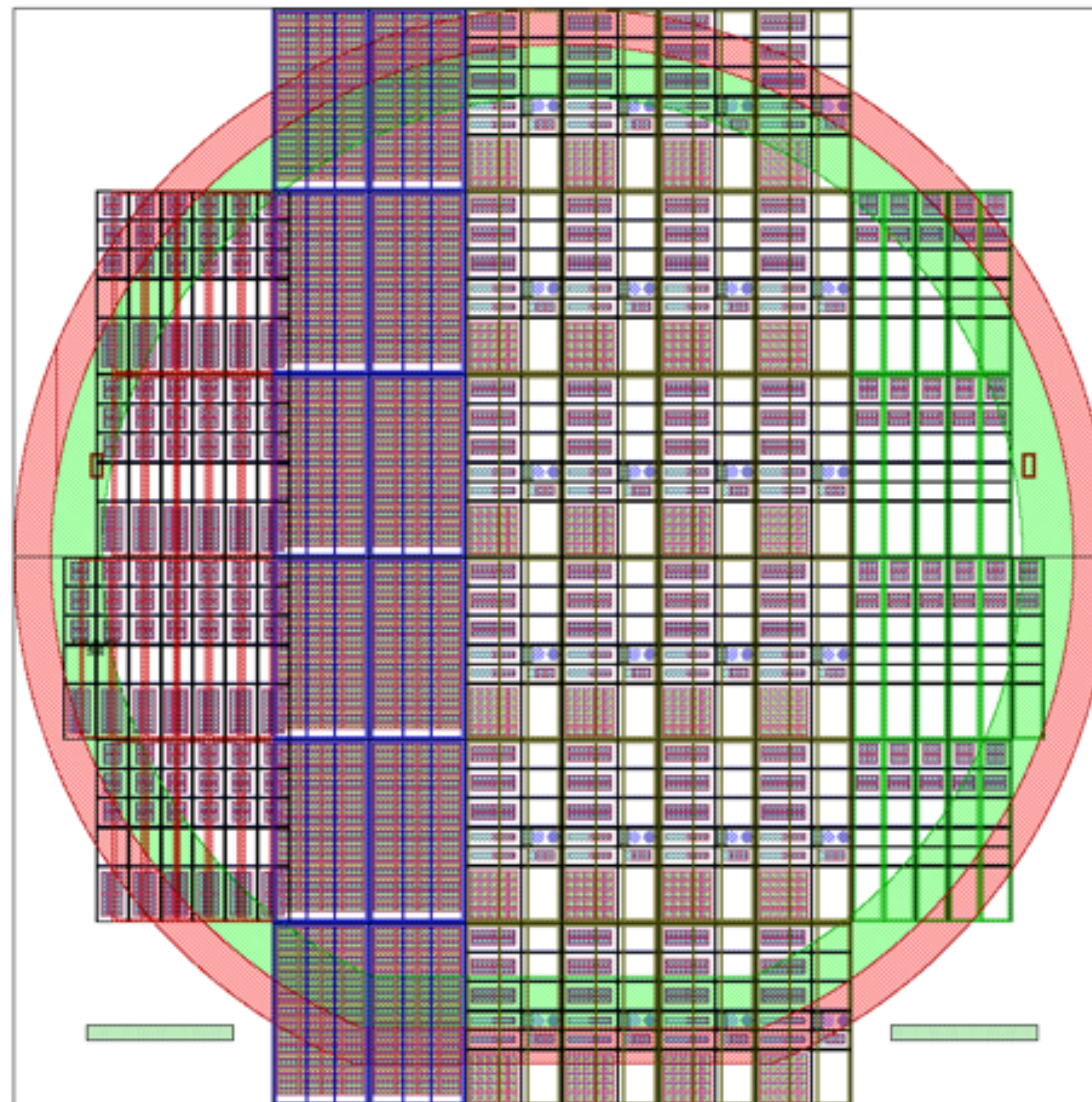
- ***INFN - Gruppo V***
- *Horizon 2020, ERC - Advanced* ***Grant*** *UFSD*
- *Horizon 2020, MSCA -* ***INFRAIA Grant AIDA2020***
- ***Ministero degli Affari Esteri****, Italia, MAE, “Progetti di Grande Rilevanza Scientifica”*

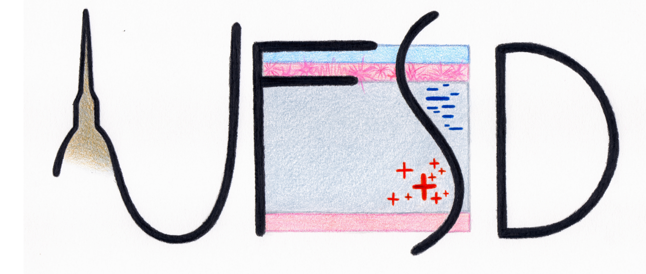
BACKUP

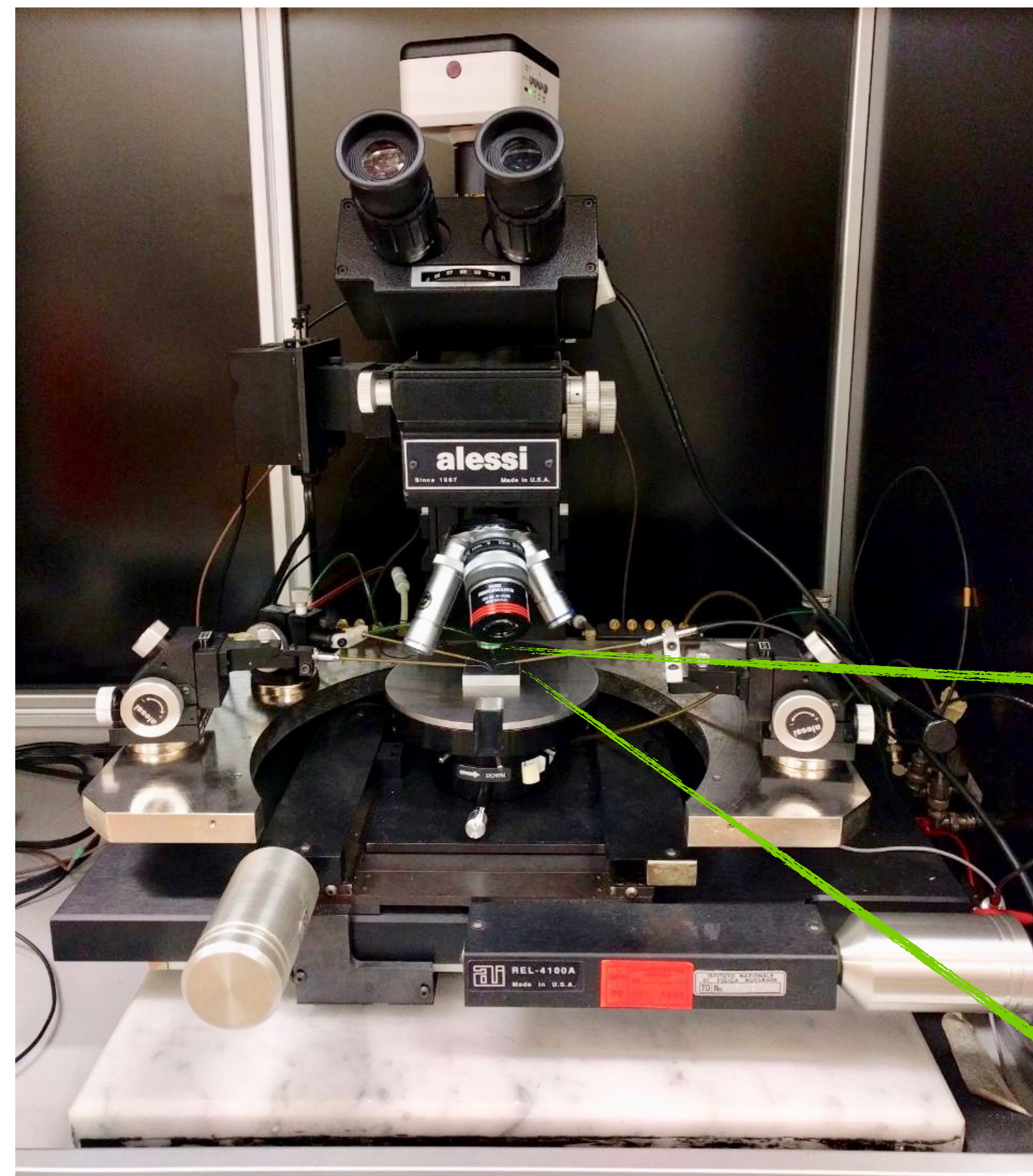
WAFER FIDUCIAL AREA



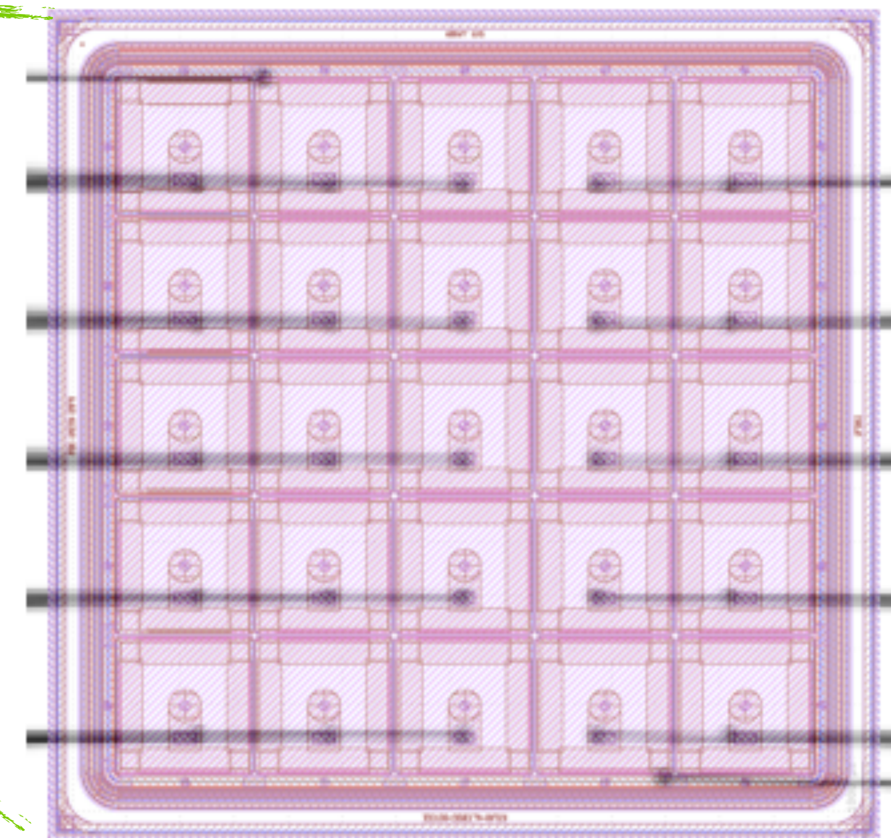


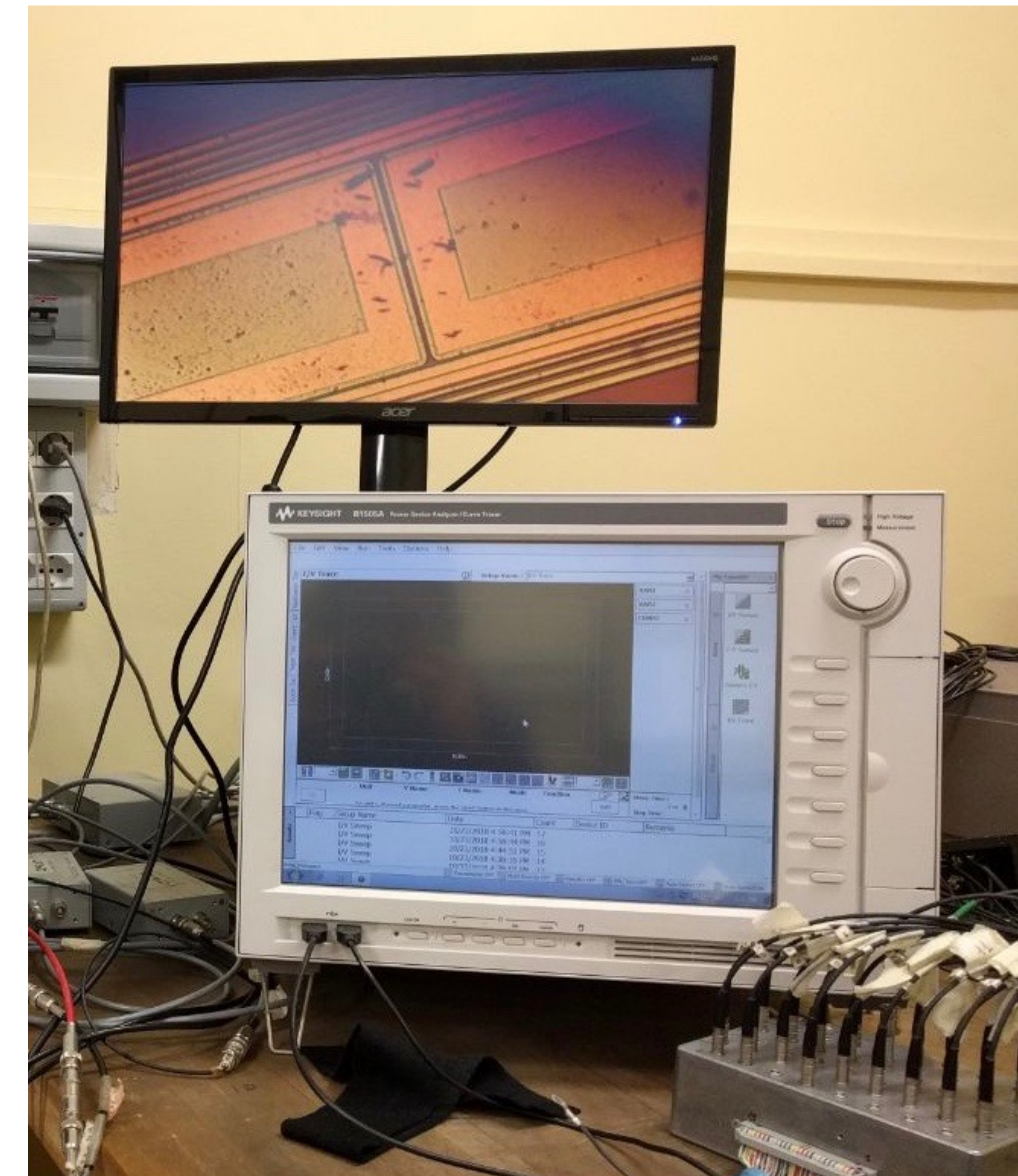
SPERIMENTAL SETUP FOR ALTIROC AN MOVEIT MEASUREMENTS



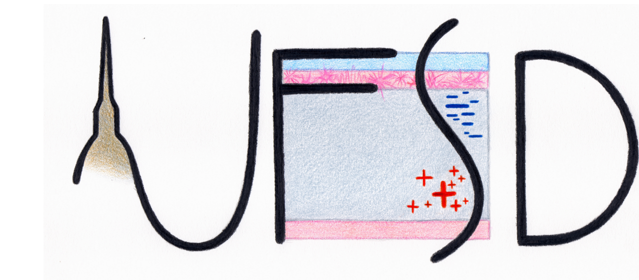


- ***Probe card*** *used to contact all the pads or strips of the device*
- ***CV Analizer*** *Keysight B1505A with SMU High Voltage and Medium Power and CMU*
- ***Switching matrix***

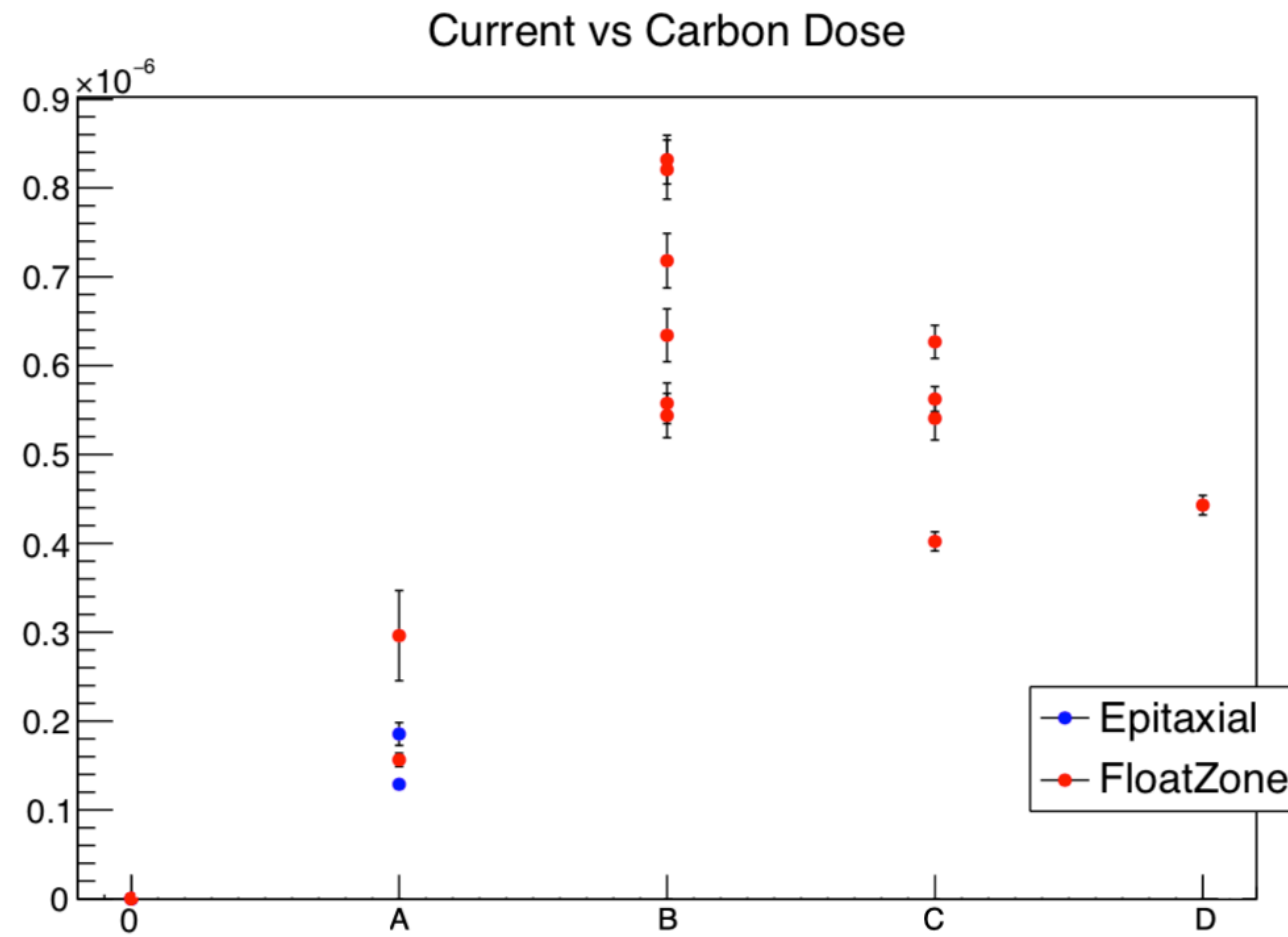




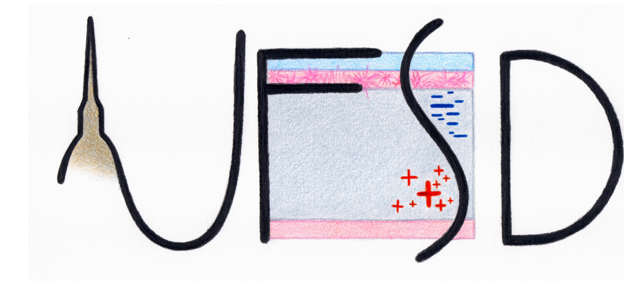
UNIFORMITY STUDIES – CMS STRUCTURE



Wafer #	Dose Pgain	Carbon	Diffusion
1	0.98		L
2	0.96		L
3	0.96	A	L
4	0.96	A	L
5	0.98	A	L
6	0.96	B	L
7	0.98	B	L
8	0.98	B	L
9	0.98	C	L
10	1.00	C	L
11	1.00	D	L
12	1.02		H
13	1.00		H
14	1.02	A	H
15	1.00	A	H
16	1.02	B	H
17	1.02	B	H
18	1.04	B	H
19	1.02	C	H
20	1.04	C	H



UNIFORMITY STUDIES – CMS STRUCTURE W11



Leakage current distribution RMS as function of ROC position