CHARACTERISATION OF UFSD4 PRODUCTION BY FBK

Marta Tornago

Università degli Studi and INFN Torino

17th (Virtual) "Trento" Workshop in Advanced Silicon Radiation Detectors

2-4 March 2022

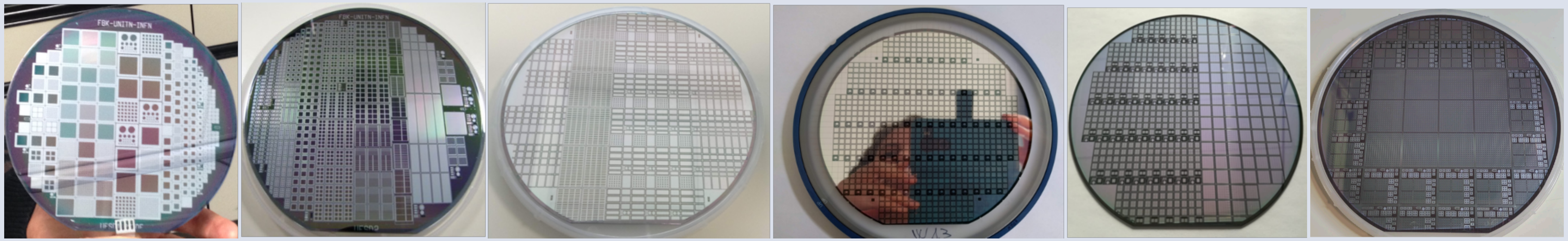
Arcidiacono R., Borghi G., Boscardin M., Cartiglia N., Centis Vignali M., Costa M., Dalla Betta G.F., Ferrero M., Ficorella F., Gioachin G., Mandurrino M., Menzio L., Pancheri L., Paternoster G., Siviero F., Sola V., Staiano A.

HISTORY OF UFSD PRODUCTIONS

FONDAZIONE BRUNO KESSLER

UFSD4 is the latest UFSD production, featuring **prototypes for the sensor of CMS Endcap Timing Layer**
It bears within itself the experience gained with the UFSD R&D productions

- **UFSD2**: first 50-μm thick batch, focus on **gain layer design** and **radiation hardness**
- **UFSD3**: studies on **carbon doses** and **gain layer termination structures**, production of **first large multipad structures**
- **UFSD3.1**: exploration of various **interpad layouts**, optimisation of **p-stop doping**
- **UFSD3.2**: optimisation of **carbon level**, study of different **gain layer depths** and **wafer thicknesses**, refinement of **interpad design**

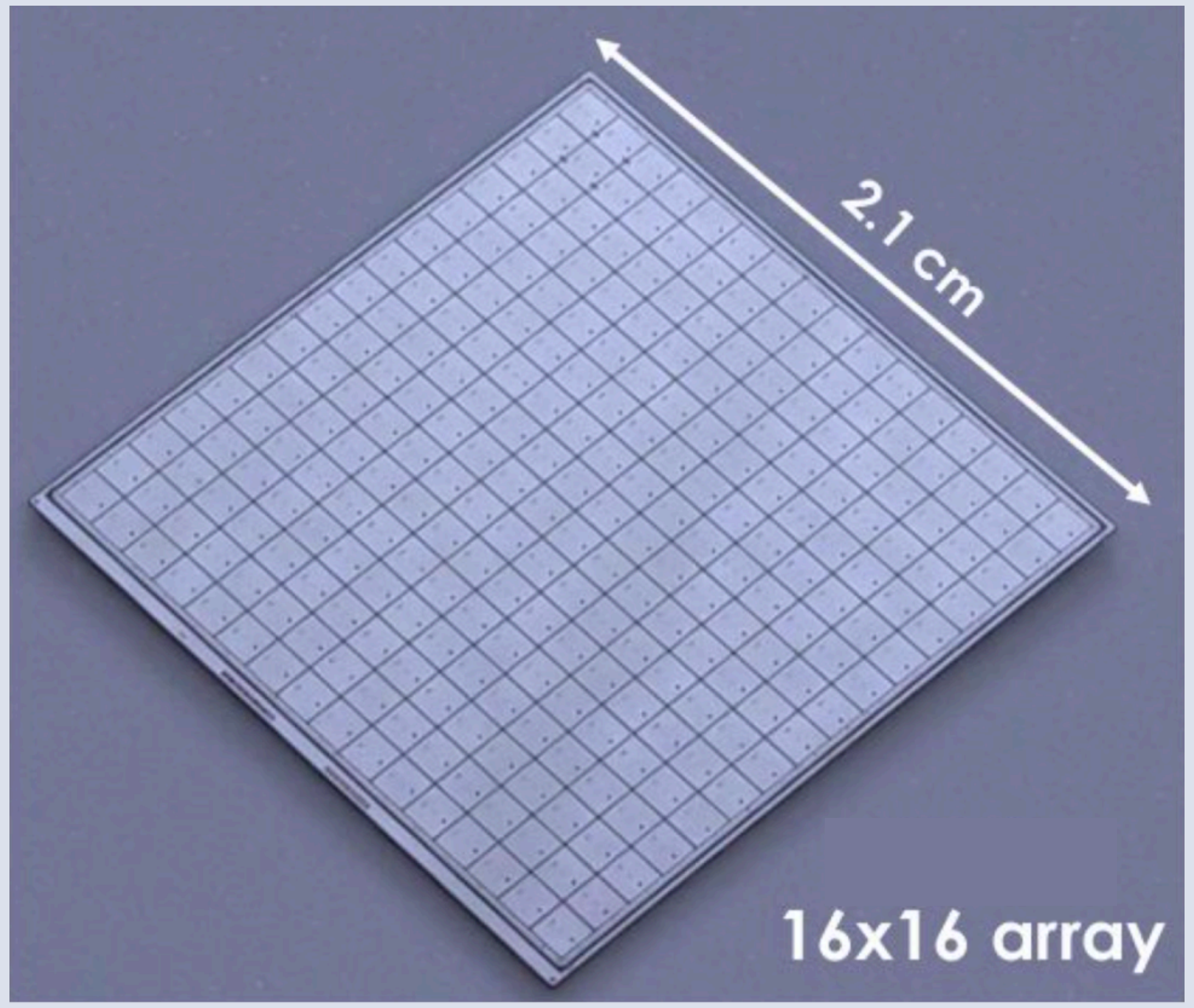


UFSD1 UFSD2 UFSD3 UFSD3.1 UFSD3.2 UFSD4

A SENSOR FOR THE CMS ENDCAP TIMING LAYER

Sensor requirements for the CMS Endcap Timing Layer:

- **Timing resolution** of $\sigma_t = 30$ ps up to $\phi \sim 1.5 \times 10^{15} n_{eq}/cm^2$
- **Gain uniformity** better than 1% within a sensor
- **Low leakage current** to limit power consumption and noise
- Provide **large and uniform signals**, >8 fC up to $\phi \sim 1.5 \times 10^{15} n_{eq}/cm^2$
- Minimized “no-gain” area, **interpad distance between 50-70 µm**
- Pad size $1.3 \times 1.3\ mm^2$, determined **occupancy** and **read-out electronics**



The final sensor will be a 50 µm-thick 16×16 pad array

UFSD4 PRODUCTION

Wafer #	DI	Gain Layer Dose	Carbon	Diffusion
1	Shallow	0.98	0.8	CH-BL
2	Shallow	1.00	1	CH-BL
3	Shallow	0.98	1	CH-BL
4	Shallow	0.98	1	CH-BL
5	Shallow	0.98	0.8	CH-BL
6	Shallow	0.98	0.8	CH-BL
7	Shallow	0.98	0.8	CH-BL
8	Shallow	0.98	0.8	CH-BL
9	Shallow	0.98	0.8	CH-BL
10	Shallow	0.98	0.8 + C0.6	CH-BL
11	Shallow	0.98	0.8 + C0.6	CH-BL
12	Deep	0.75	0.6	CL-BL
13	Deep	0.77	0.6	CL-BL
14	Deep	0.77	0.6	CL-BL
15	Deep	0.77	0.6	CL-BL
16	Deep	0.79	0.6	CL-BL
17	Deep	0.79	0.6	CL-BL
18	Deep	0.79	0.6	CL-BL

UFSD4 includes 18 wafers with:

- **Shallow and deep gain layer**
- **6 Boron doses**
- **4 different Carbon implants**
- **2 diffusion types**

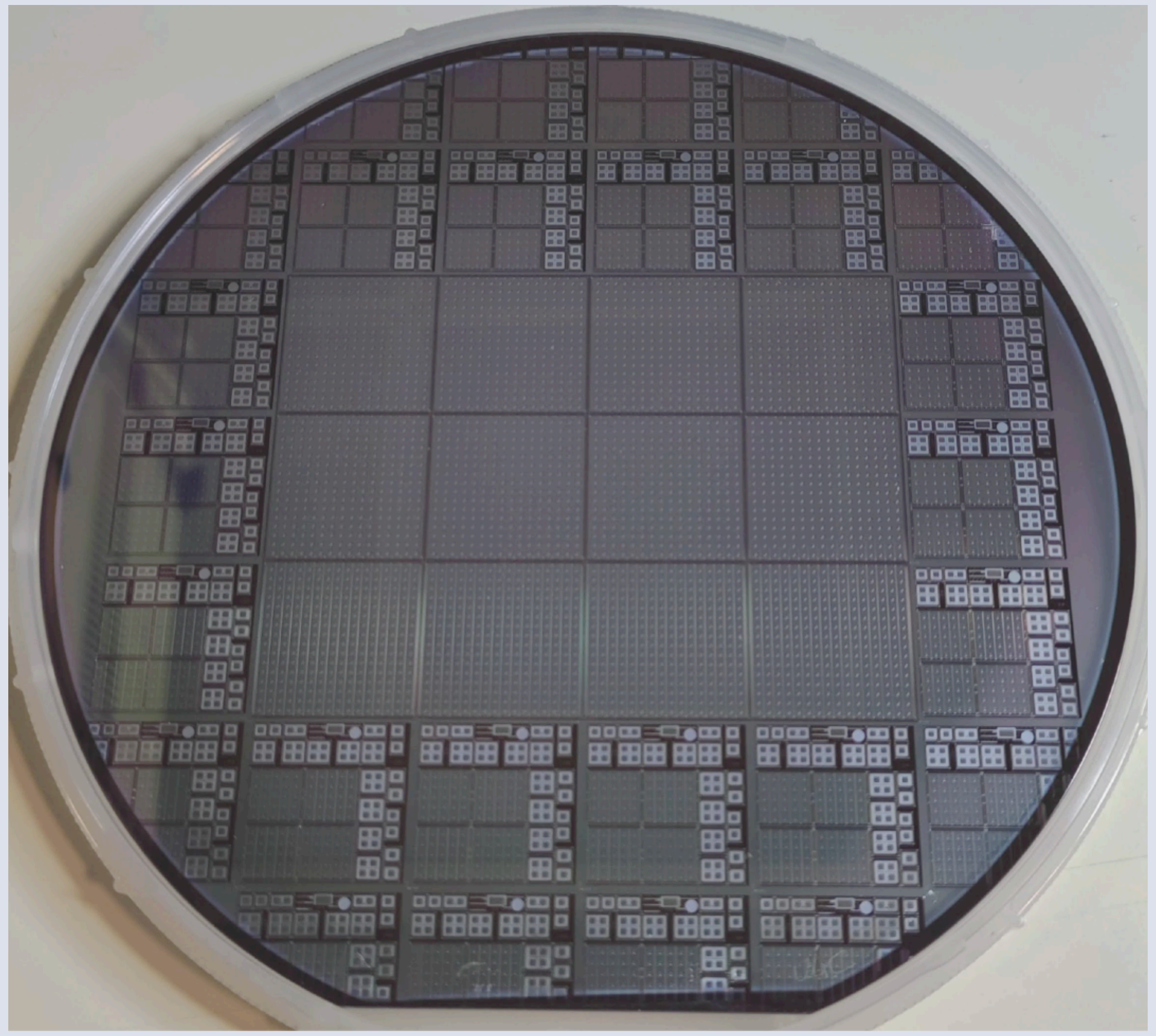
Goals of this production:

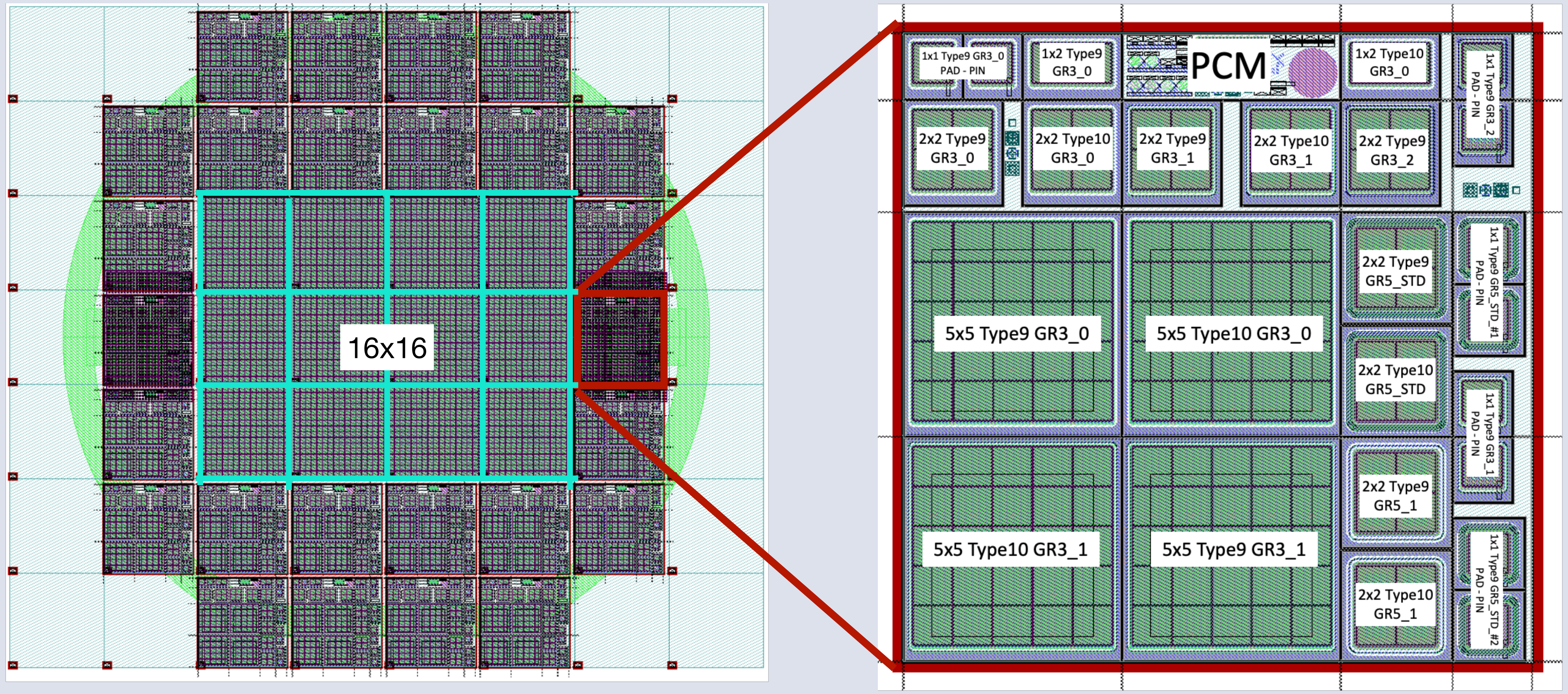
- **design optimisation**
- production **uniformity**
- demonstrate ability of **producing large sensors with same characteristics**

UFSD4 PRODUCTION

UFSD4 includes single pads, 1x2, 2x2, 5x5 and 16x16 pad arrays with:

- 2 layouts for interpad regions, Type 9 and 10
- 5 different guardring designs: GR3_0, GR3_1, GR3_2, GR5_1, GR5_STD





CHARACTERISATION OF UFSD4 PRODUCTION

FONDAZIONE BRUNO KESSLER

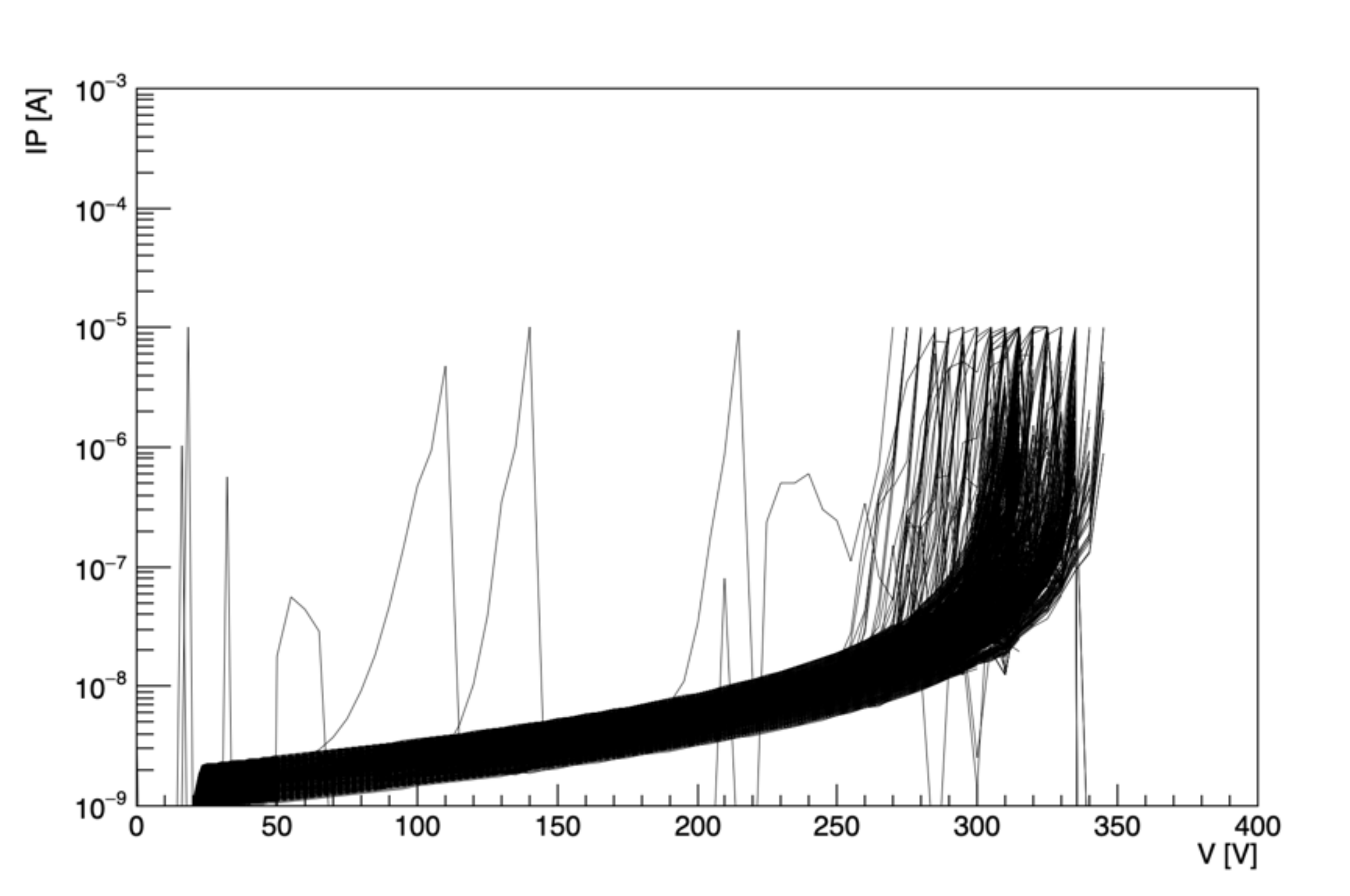
Measurements of all structures performed on wafer by FBK (Trento)
A few diced structures have been measured in the Laboratory for Innovative Silicon Sensors in Torino

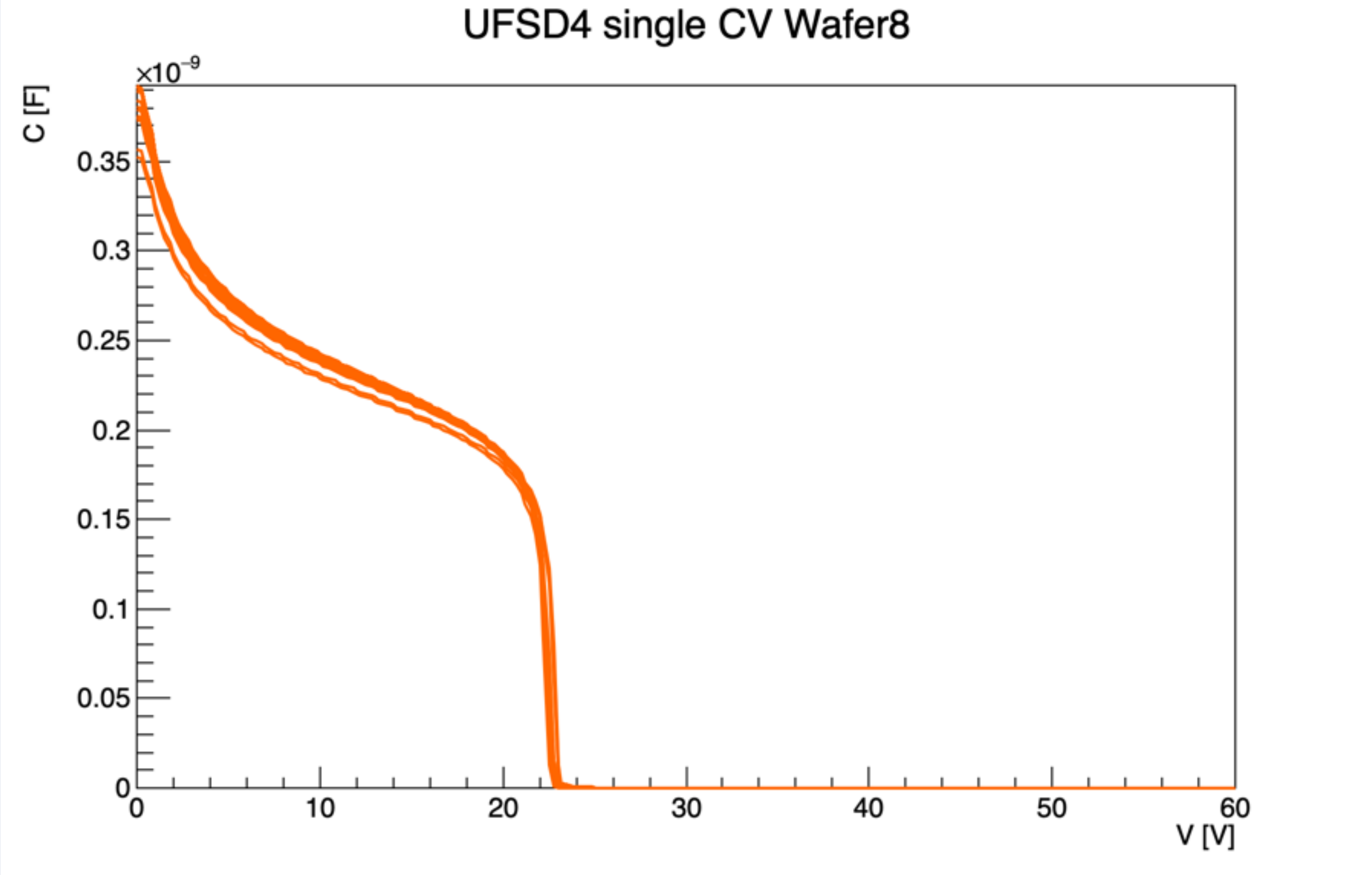
IV studies

- **Breakdown voltage** maps
- Structures and pads are considered broken if $V_{BD} < 150V$ or $I_{structure,pad}\ (V < 80\,\%\ V_{BD}) > I_{Thr}$
  → **Production yield** evaluation
- Maps and distributions of **current @100V** for all pads for each wafer
  → **Production disuniformity** evaluation

CV studies

- **Depletion voltage** maps and distribution for each wafer
  → **Gain uniformity** evaluation

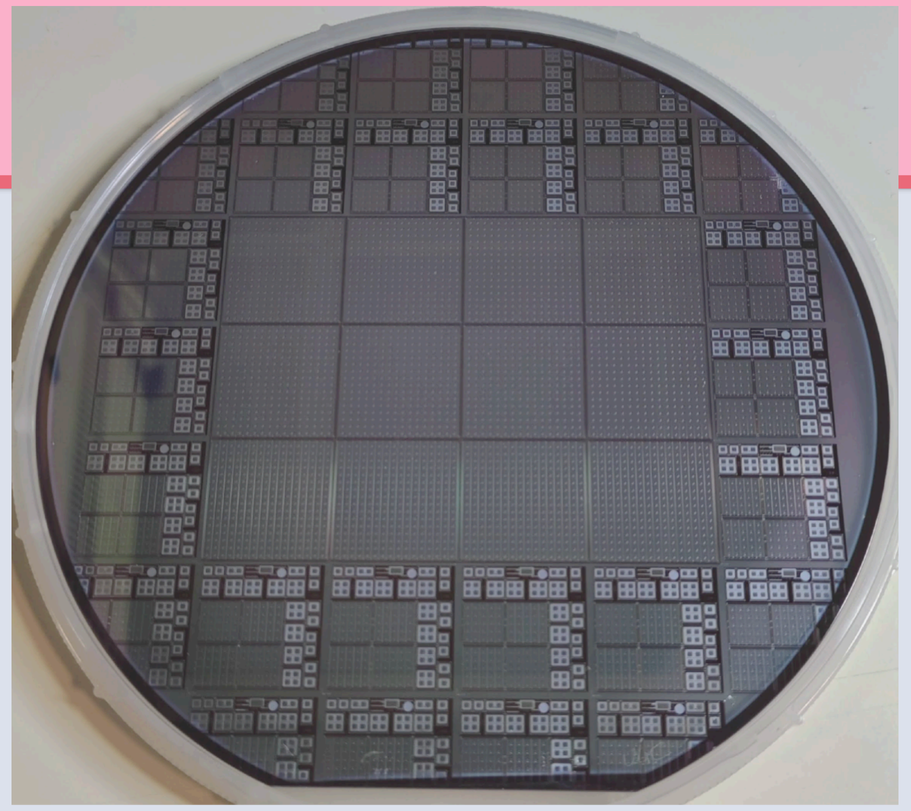


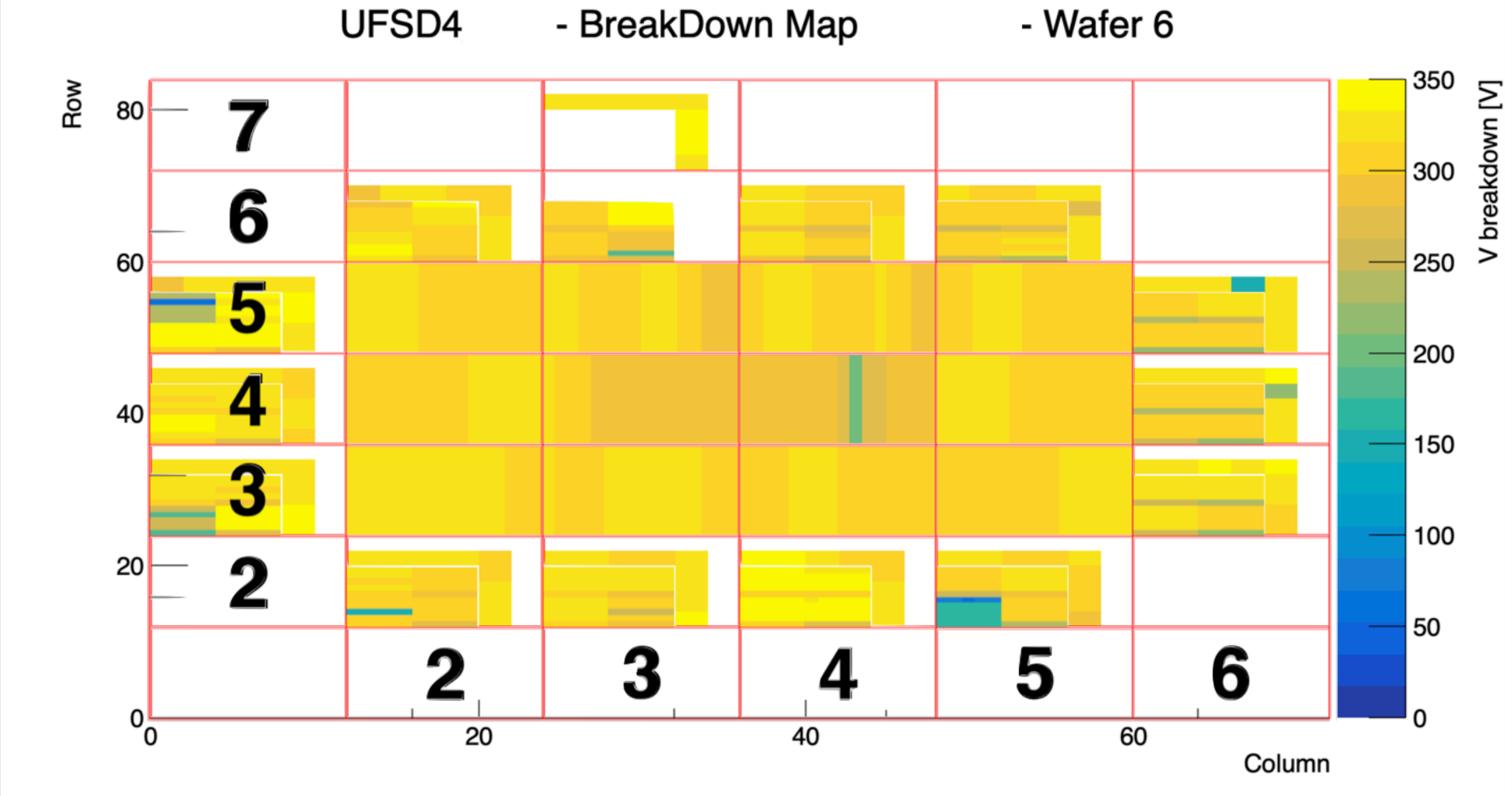


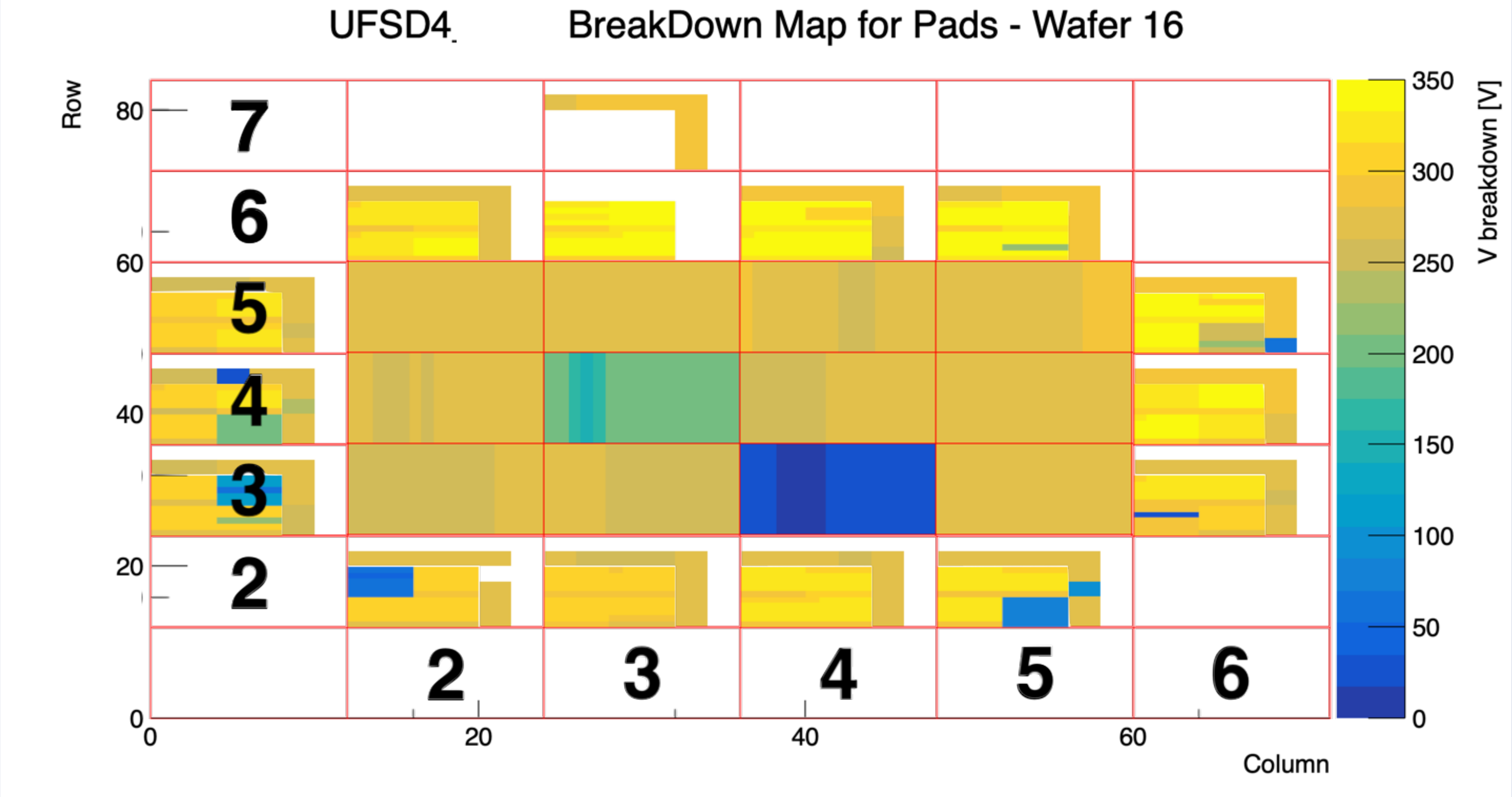
PRODUCTION YIELD STUDIES

Maps of **breakdown voltage** for pads used to evaluate **production yield** as **ratio between working and total structures and pads**

We have a single value for the breakdown voltage of 5-pads lines in 5x5 and 16-pads columns in 16x16 due to measurements setup



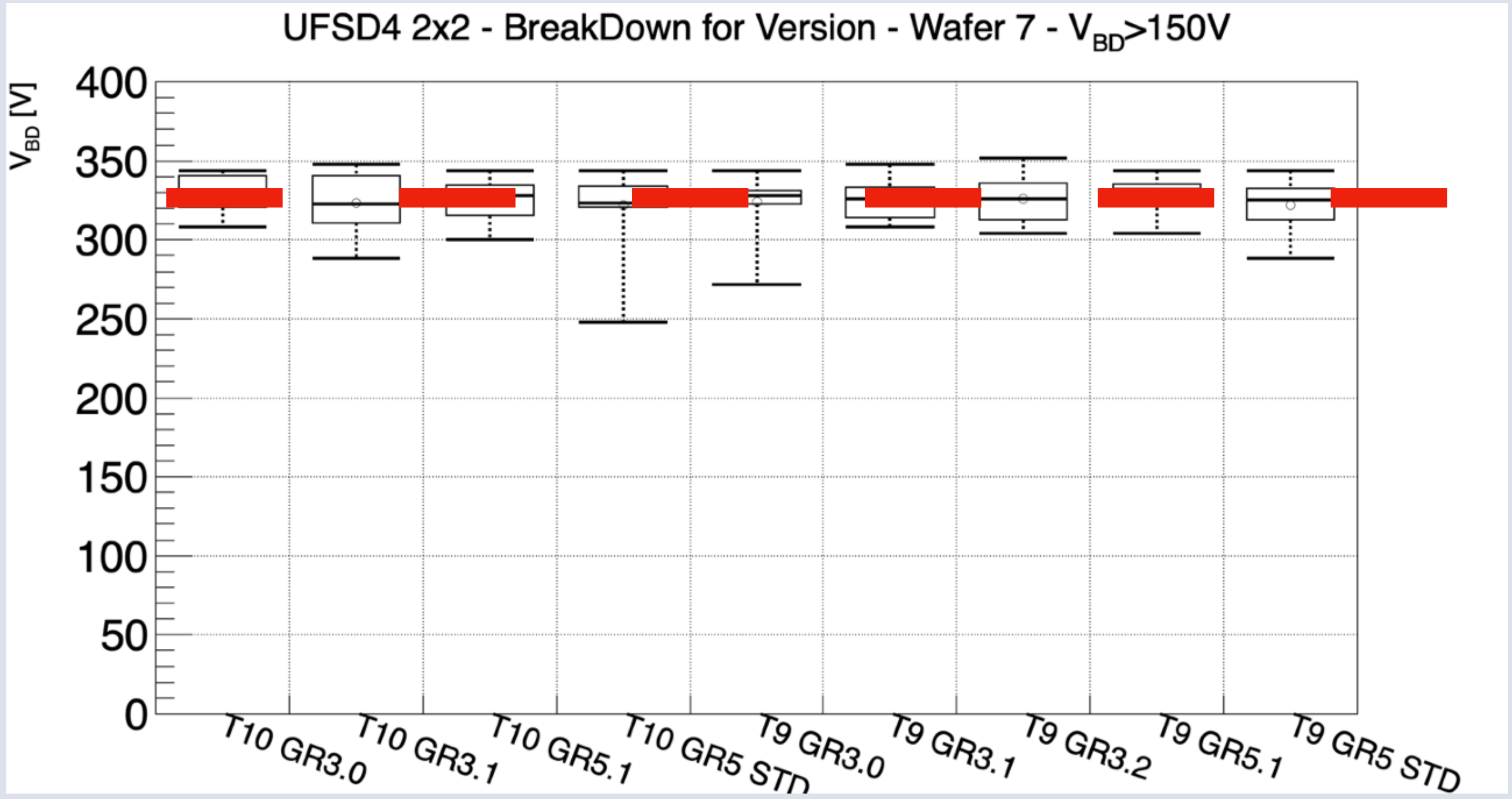


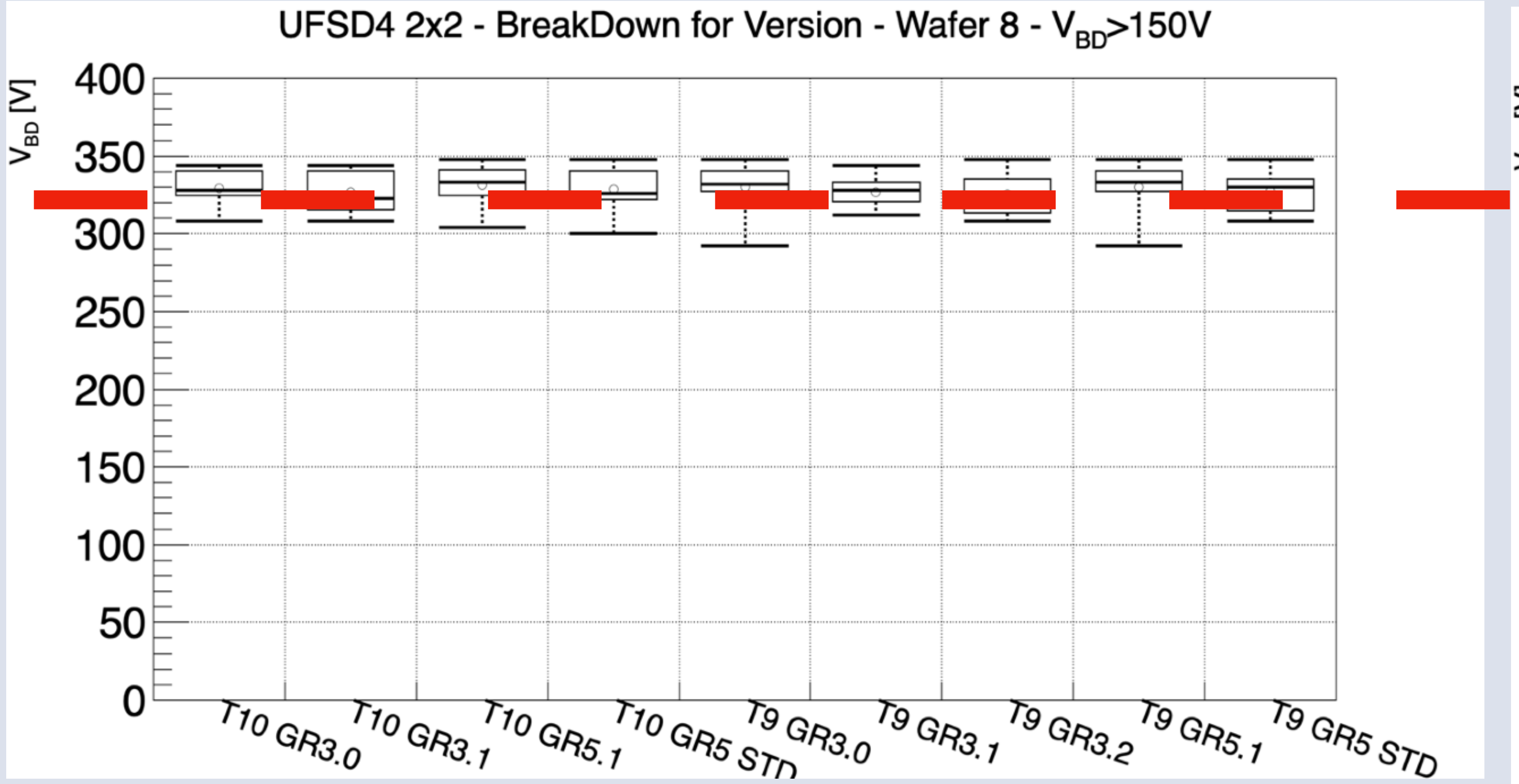


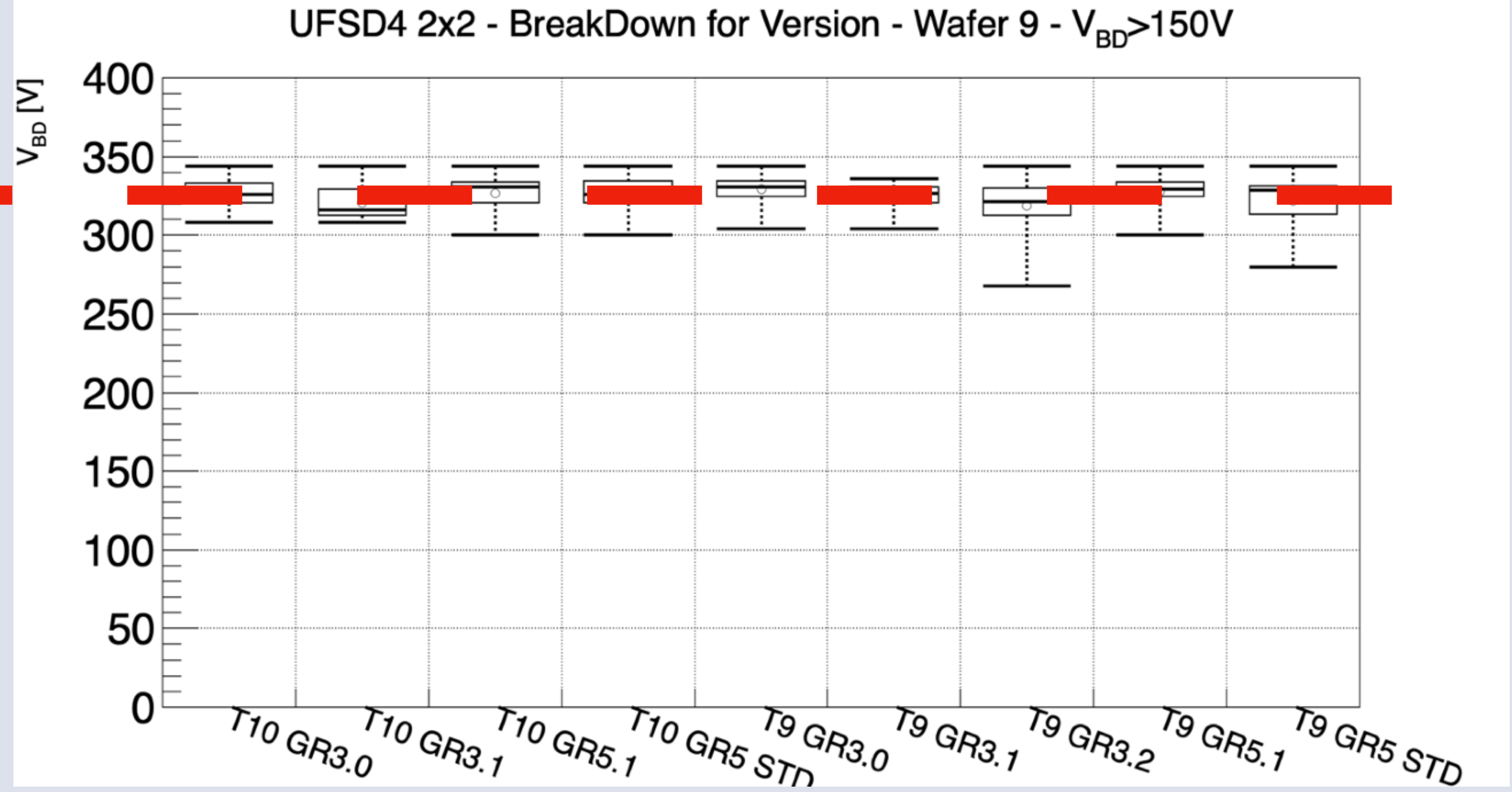
PRODUCTION YIELD STUDIES

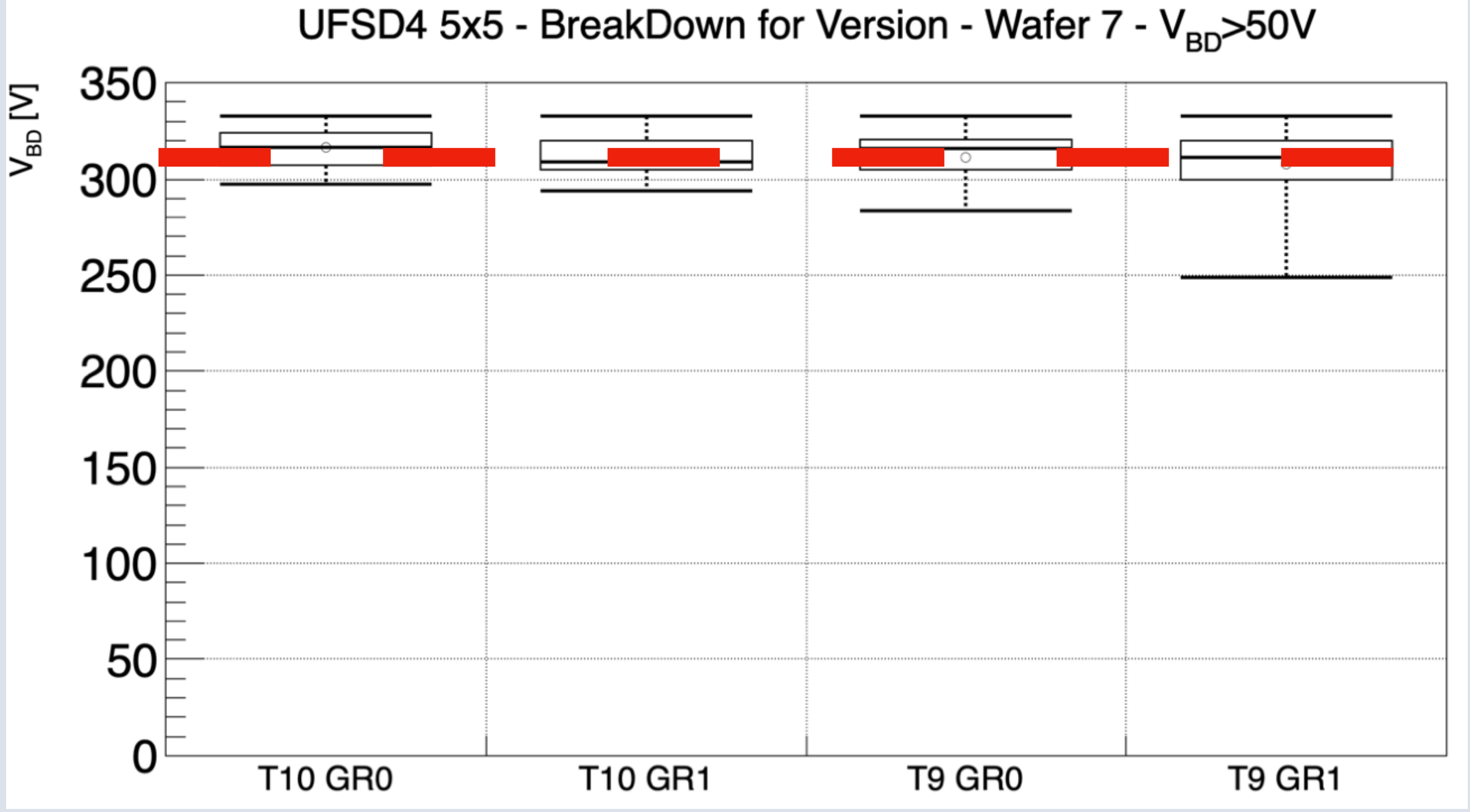
FONDAZIONE BRUNO KESSLER

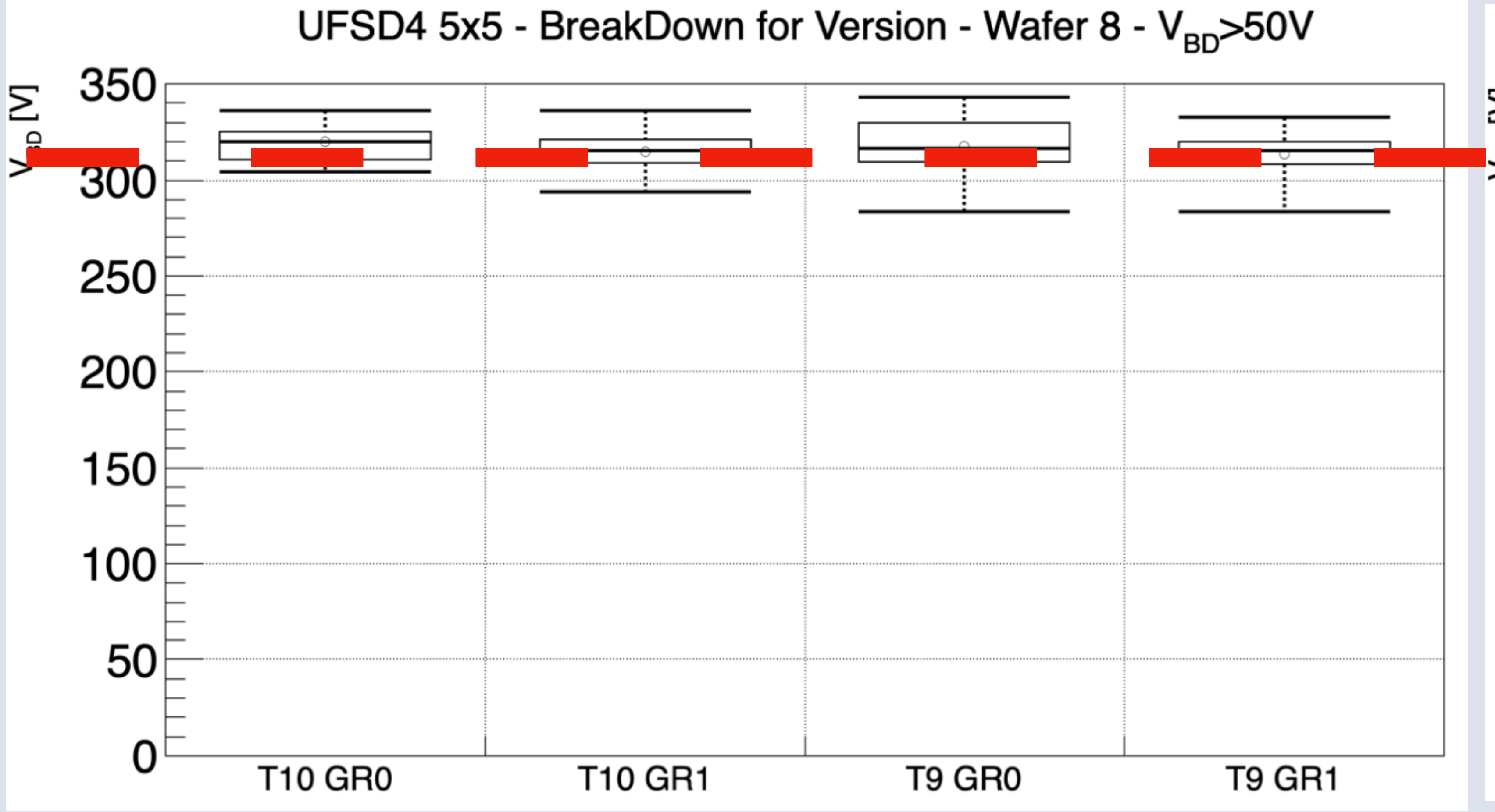
Breakdown distributions **do not depend on the interpad or guardring layout** of the measured structure
Designs seem equally performing

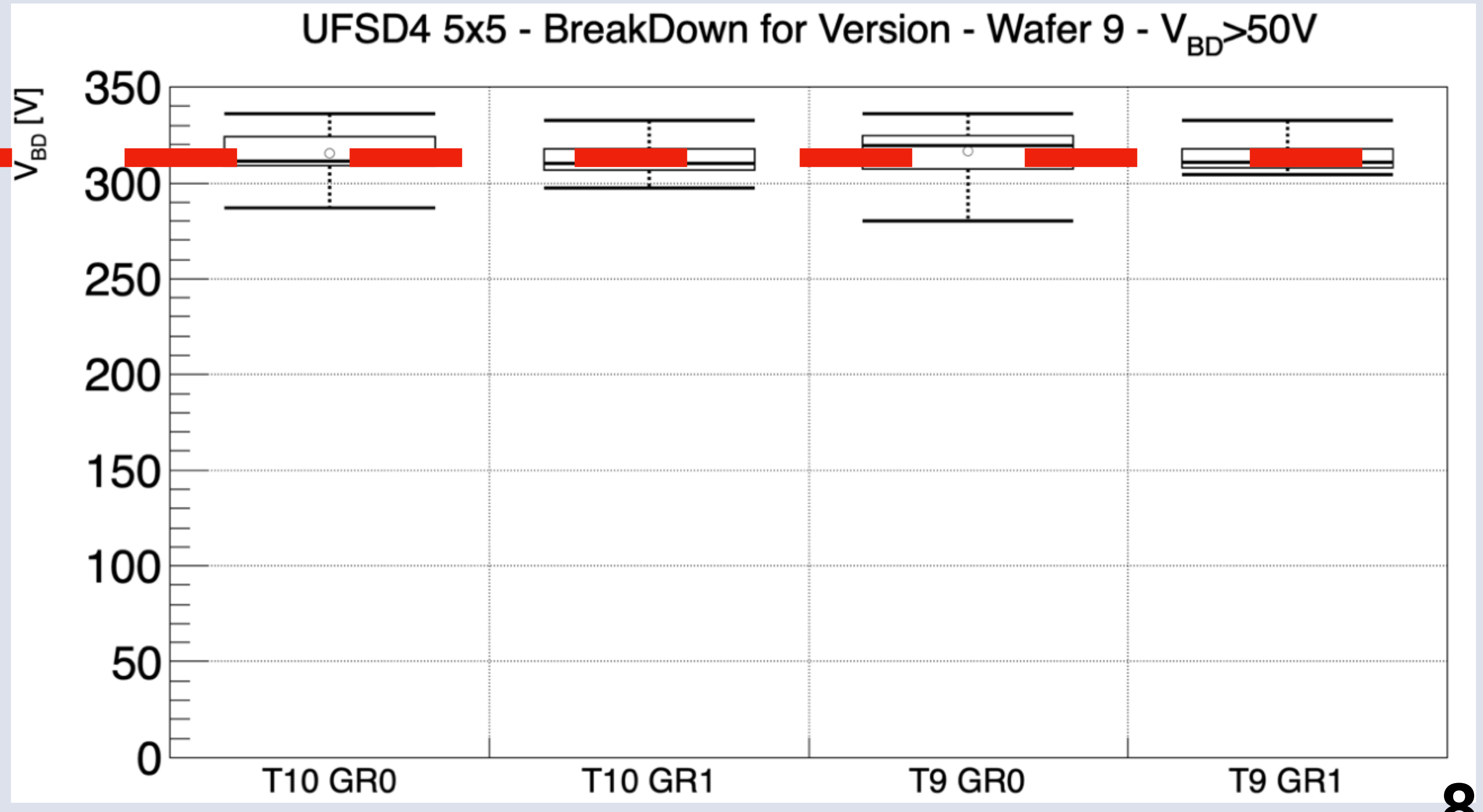




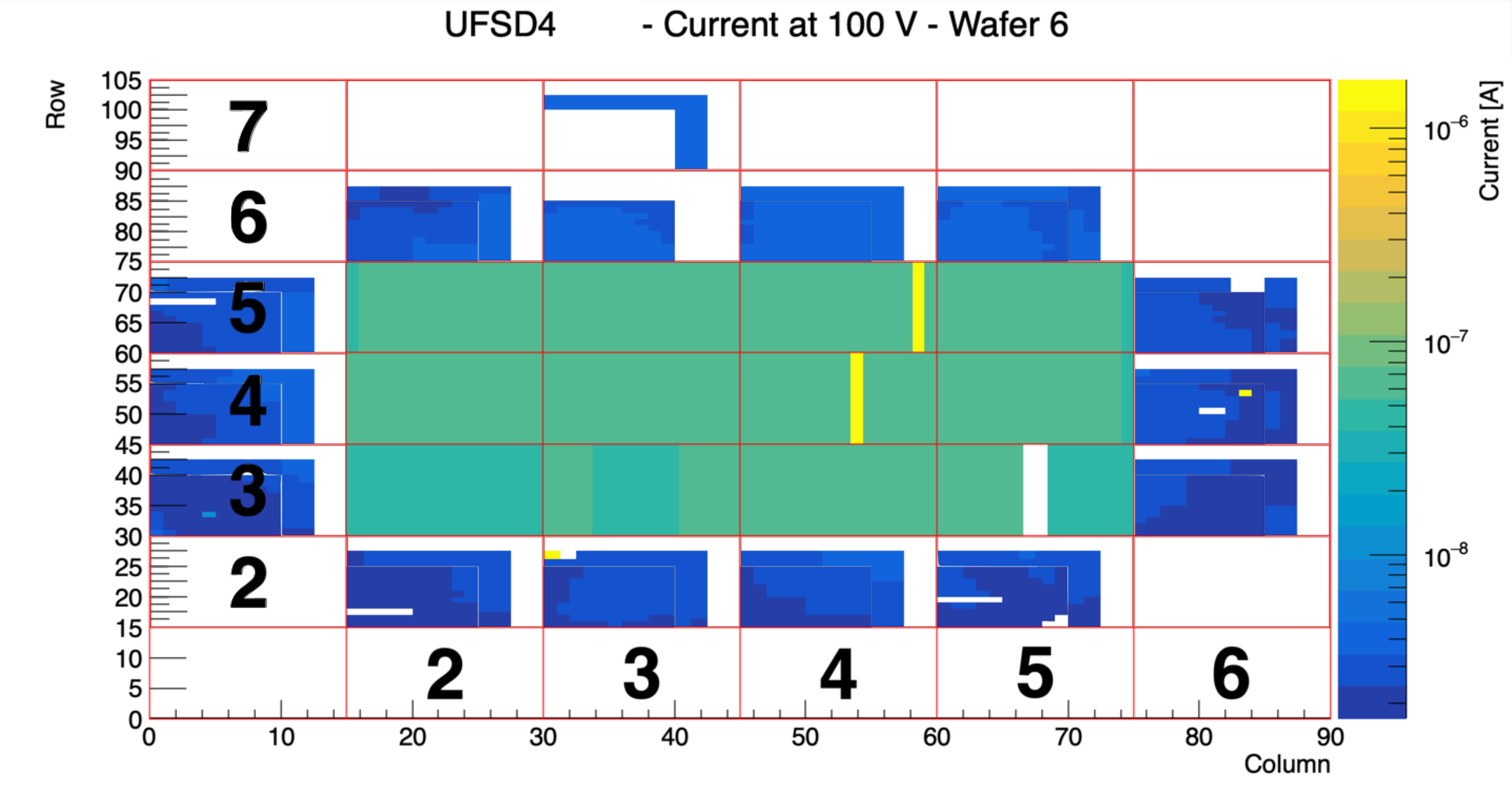


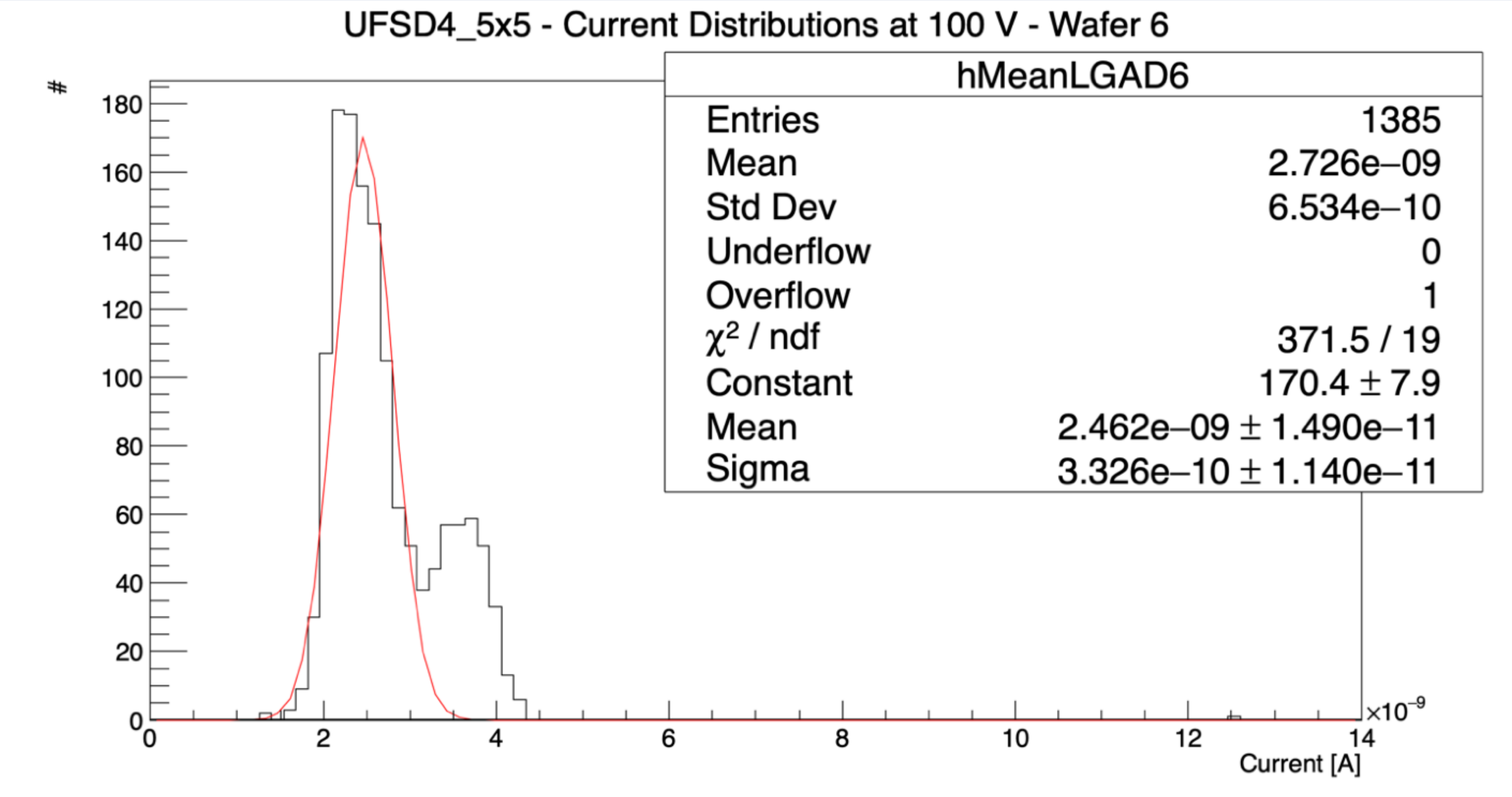






Maps of leakage **current @100V** for pads provide indication of **production quality and uniformity** as **ratio between sigma and mean of leakage current distributions**





16x16 are featured with larger values of current as each bin is the sum of leakage current from 16 pads of a column of the device

FINAL RESULTS ON YIELD AND CURRENT UNIFORMITY

FONDAZIONE BRUNO KESSLER

Results for **structures yield** and for **pad current disuniformity** in each group of similar wafers

Small arrays

Wafer group	Sensor Yield [%]	Mean Leakage Current @100 V [A]	Sigma [A]	Disuniformity [%]
1	97.22	2.73E-09	4.22E-10	15.5
2	97.85	2.42E-08	3.79E-09	15.6
3	99.15	2.20E-08	2.98E-09	13.6
4	97.08	2.65E-09	4.55E-10	17.2
5	98.51	1.44E-08	1.53E-09	10.7
6	99.15	2.17E-09	1.37E-10	6.33
7	98.54	2.51E-09	3.15E-10	12.5
8	99.52	2.99E-09	3.16E-10	10.6
9	95.97	3.93E-09	3.79E-10	9.64

16x16

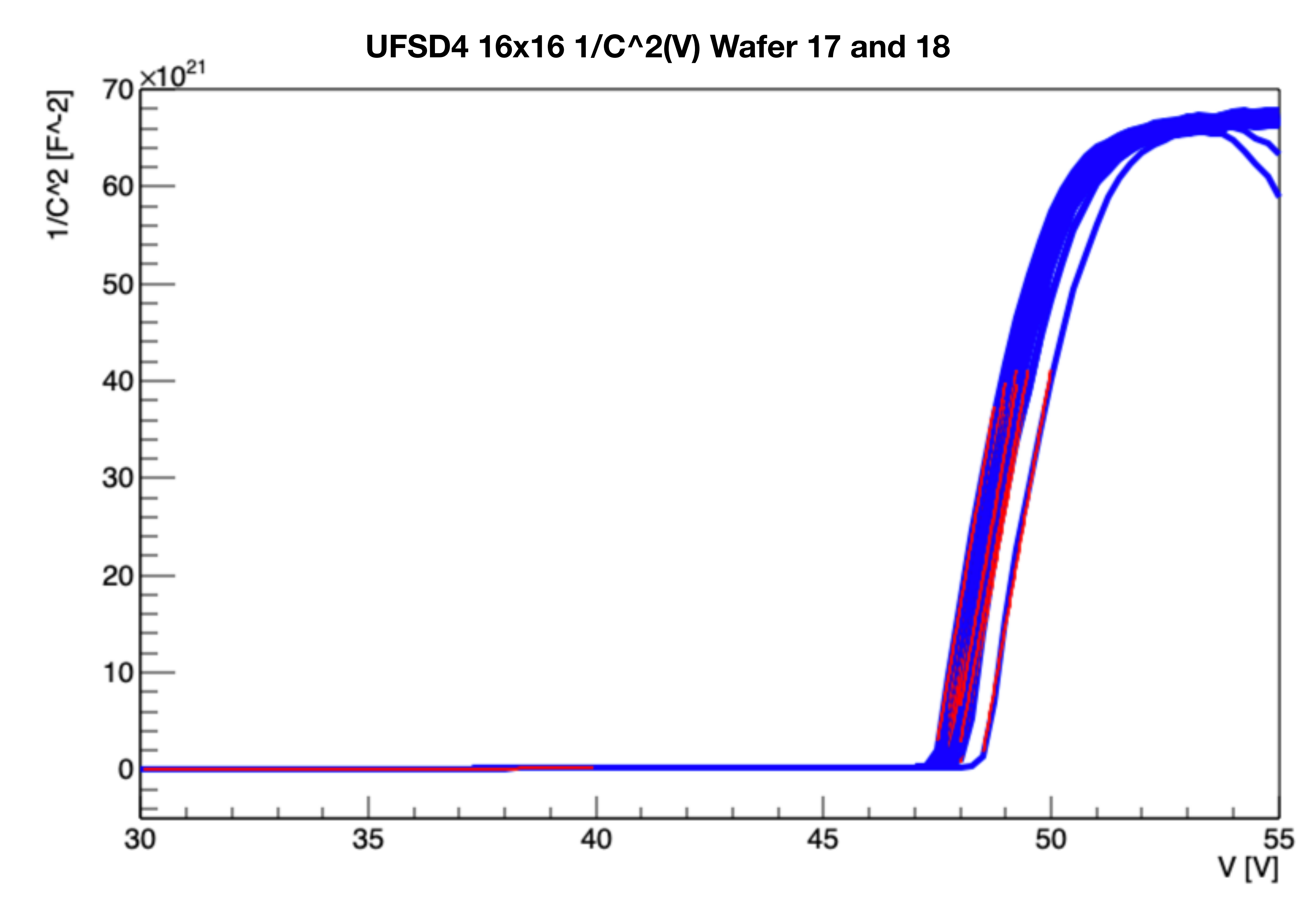
Wafer group	Sensor Yield [%]	Mean Leakage Current @100 V [A]	Sigma [A]	Disuniformity [%]
1	83.33	4.92622E-08	3.71298E-09	7.54
2	100.00	4.52762E-07	5.15744E-08	11.39
3	91.67	4.04945E-07	3.92497E-08	9.69
4	80.00	5.5461E-08	5.95051E-09	10.73
5	87.50	2.71854E-07	2.50953E-08	9.23
6	66.67	3.73805E-08	7.3242E-10	1.96
7	91.67	4.38402E-08	2.58748E-09	5.90
8	100.00	5.16091E-08	1.77389E-09	3.44
9	66.67	6.9986E-08	3.71148E-09	5.30

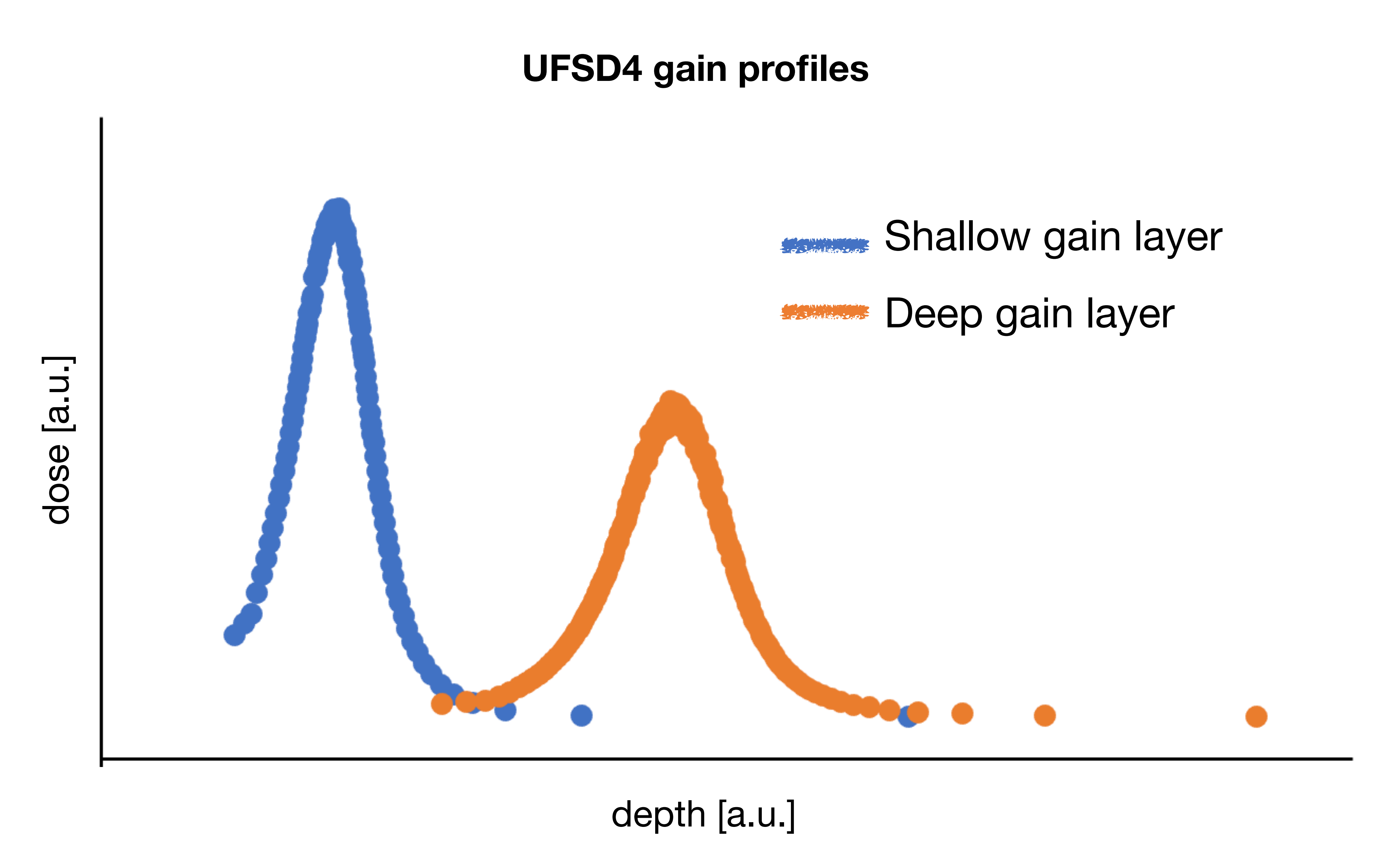
Wafer Group	Wafer #	DI	Gain Layer Dose	Carbon	Diffusion
1	1	Shallow	0.98	0.8	CH-BL
2	2	Shallow	1.00	1	CH-BL
3	3	Shallow	0.98	1	CH-BL
3	4	Shallow	0.98	1	CH-BL
4	5	Shallow	0.98	0.8	CH-BL
4	6	Shallow	0.98	0.8	CH-BL
4	7	Shallow	0.98	0.8	CH-BL
4	8	Shallow	0.98	0.8	CH-BL
4	9	Shallow	0.98	0.8	CH-BL
5	10	Shallow	0.98	0.8 + C0.6	CH-BL
5	11	Shallow	0.98	0.8 + C0.6	CH-BL
6	12	Deep	0.75	0.6	CL-BL
7	13	Deep	0.77	0.6	CL-BL
8	14	Deep	0.77	0.6	CL-BL
8	15	Deep	0.77	0.6	CL-BL
9	16	Deep	0.79	0.6	CL-BL
9	17	Deep	0.79	0.6	CL-BL
9	18	Deep	0.79	0.6	CL-BL

GAIN LAYER UNIFORMITY STUDIES

Measurements performed on 16x16 diced structures in the Laboratory for Innovative Silicon Sensors in Torino to extrapolate gain layer uniformity

CV are performed on 25 pads for each of the 6 16x16 structures under test





GAIN LAYER UNIFORMITY STUDIES

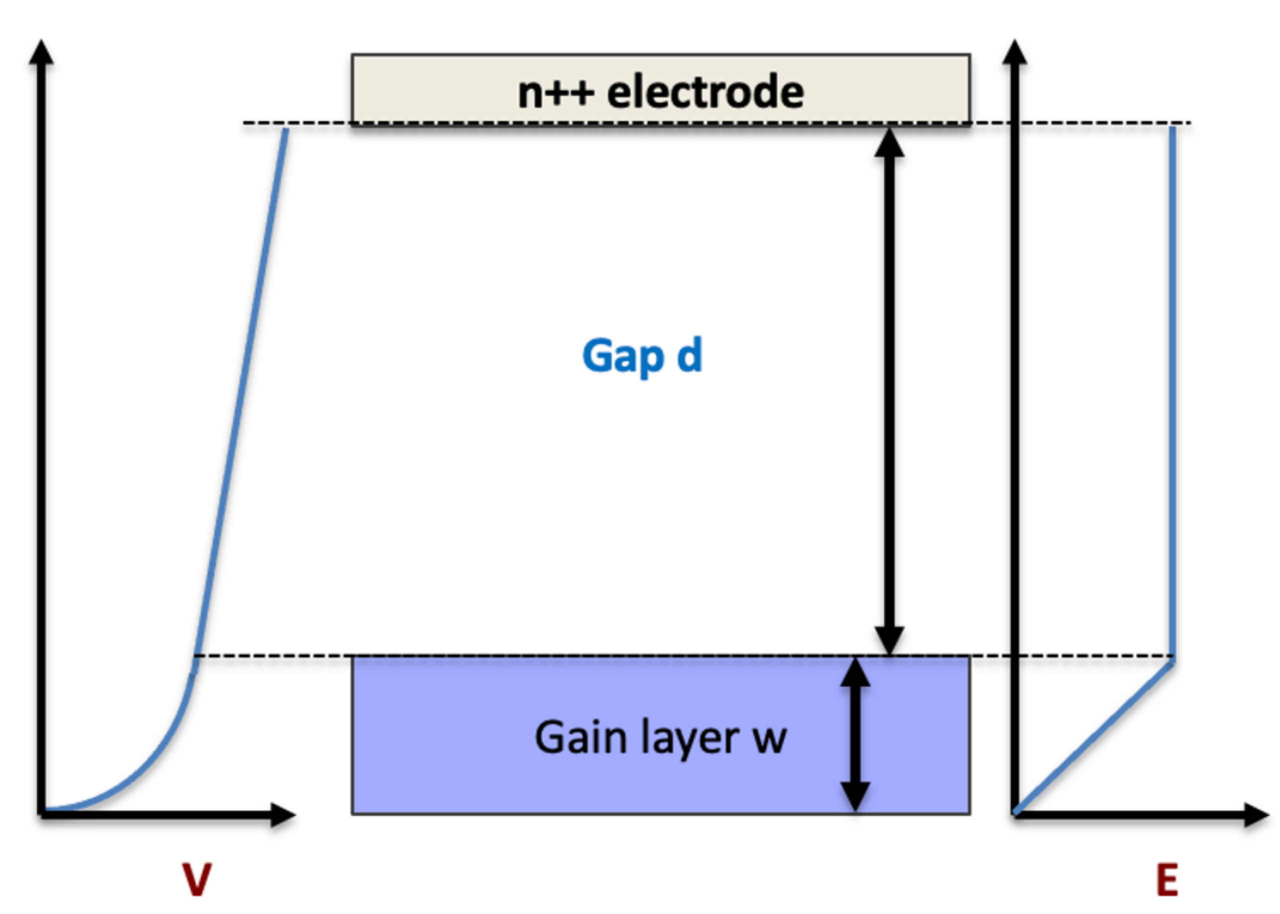
Measurements performed on 16x16 diced structures in the Laboratory for Innovative Silicon Sensors in Torino to extrapolate gain layer uniformity

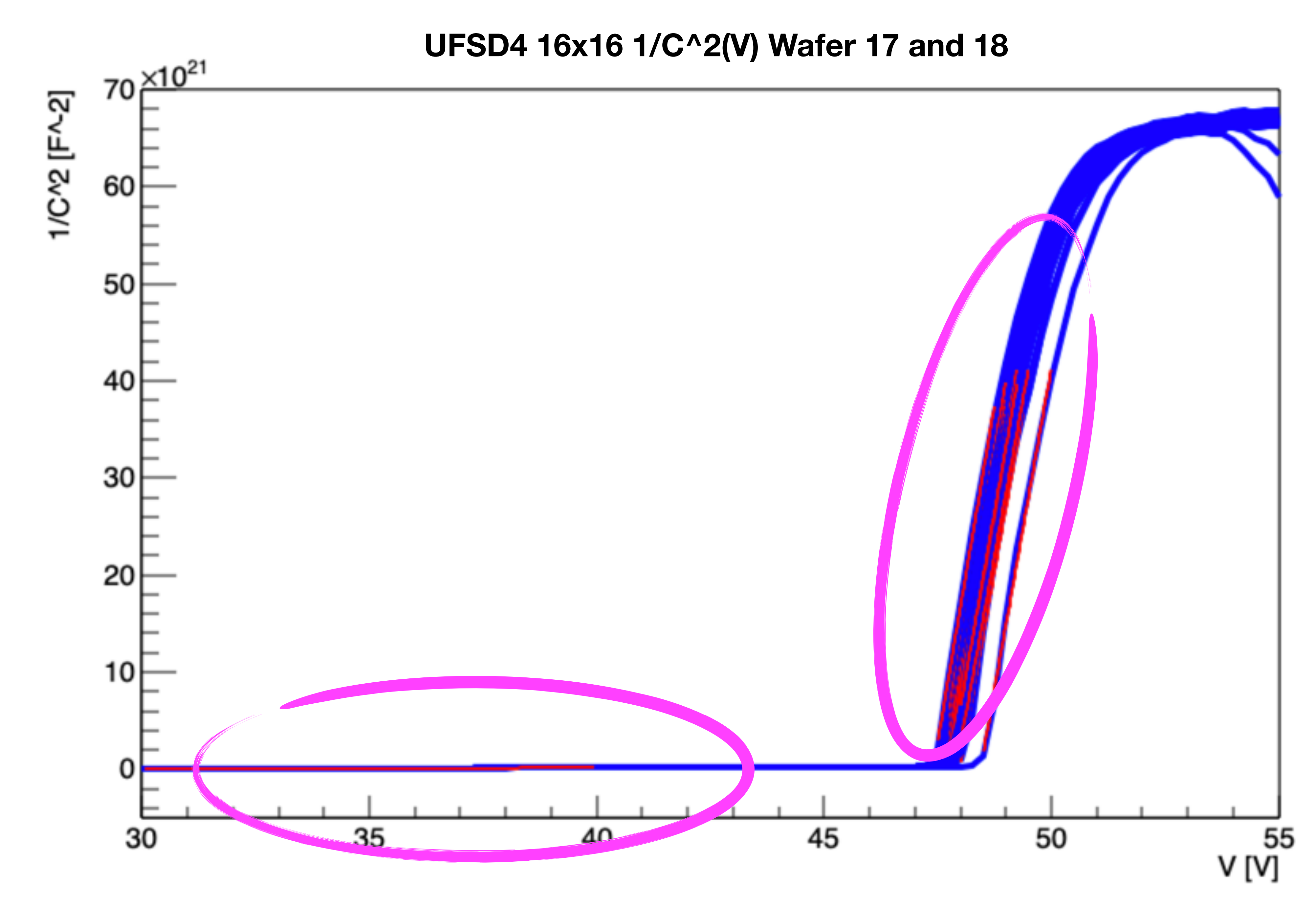
V_{foot} is the intersection point of the two lines fitting C(V) curves in the regions corresponding to gain layer and full depletion

V_{GL} is calculated as:

$$V_{GL} = \frac{V_{foot}}{1 + 2\frac{d}{w}}$$

d: gap between n+ and gain layer
w: gain layer width





GAIN LAYER UNIFORMITY STUDIES

Gain layer disuniformity measured on 3 sensors for each group
Obtained as **ratio between sigma and mean values of $V_{depletion}$ distributions**

Wafer group	V_foot [V]	Sigma V_foot [V]	V_foot disuniformity [%]	V_GL [V]	Sigma V_GL [V]	V_GL disuniformity [%]
4	22.53	0.20	0.89	3.76	0.03	0.89
8	47.66	0.10	0.22	4.77	0.01	0.22

Same results for V_{foot} and V_{GL} disuniformities

Wafer Group	Wafer #	DI	Gain Layer Dose	Carbon	Diffusion
1	1	Shallow	0.98	0.8	CH-BL
2	2	Shallow	1.00	1	CH-BL
3	3	Shallow	0.98	1	CH-BL
3	4	Shallow	0.98	1	CH-BL
4	5	Shallow	0.98	0.8	CH-BL
4	6	Shallow	0.98	0.8	CH-BL
4	7	Shallow	0.98	0.8	CH-BL
4	8	Shallow	0.98	0.8	CH-BL
4	9	Shallow	0.98	0.8	CH-BL
5	10	Shallow	0.98	0.8 + C0.6	CH-BL
5	11	Shallow	0.98	0.8 + C0.6	CH-BL
6	12	Deep	0.75	0.6	CL-BL
7	13	Deep	0.77	0.6	CL-BL
8	14	Deep	0.77	0.6	CL-BL
8	15	Deep	0.77	0.6	CL-BL
9	16	Deep	0.79	0.6	CL-BL
9	17	Deep	0.79	0.6	CL-BL
9	18	Deep	0.79	0.6	CL-BL

CONCLUSIONS

UFSD4 is the latest UFSD production by FBK including prototypes of the CMS ETL sensor
The aim is to demonstrate the capability of producing **the large sensors with similar characteristics and good yield**

The whole production has been characterised with **measurements** performed both **on wafer by FBK**
A few diced structures have been tested at the Laboratory for Innovative Silicon Sensors **in Torino**
More measurements will come in the next months

Results on yield and current uniformity:

- Percentage of **working devices >96% in small arrays and >67% in 16x16 matrices**
- **Low mean values for leakage current @100 V**
- **Maximum current disuniformity is 17% in small devices and 11% in 16x16 arrays**

Results on gain layer uniformity:

- **Spread of gain layer depletion voltage lower than 1%** for both wafers with shallow and deep gain implants

ACKNOWLEDGMENTS

We kindly acknowledge the following funding agencies and collaborations:

- MIUR, **Dipartimenti di Eccellenza** (ex L. 232/2016, art. 1, cc. 314, 337)
- Ministero della Ricerca, Italia, **PRIN 2017, progetto 2017L2XKTJ – 4DinSiDe**
- Ministero della Ricerca, Italia, **FARE, R165xr8frt_fare**

BACKUP

MEASUREMENT REPRODUCIBILITY

Wafer	Good columns ratio A [%]	Good columns ratio B [%]	Good columns ratio C [%]
5	84.375	84.375	84.375
6	100	100	100