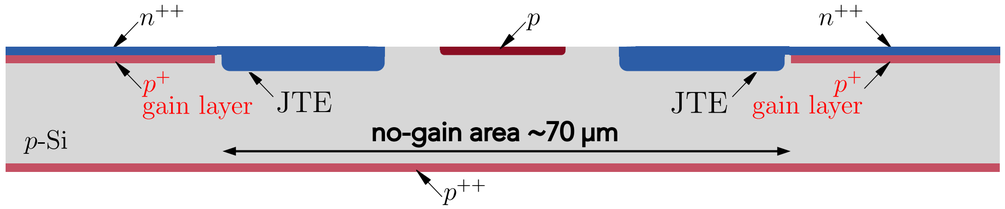
35th RD50 Workshop, CERN, Geneva, 19th November 2019

Characterization of the first RSD production at FBK

Tornago M., Mandurrino M., Arcidiacono R., Borghi G., Boscardin M., Cartiglia N., Centis Vignali M., Dalla Betta G.F., Fernandez Garcia M., Ferrero M., Ficorella F., Moll M., Pancheri L., Paternoster G., Siviero F., Sola V.

4D TRACKING WITH 100% FILL FACTOR

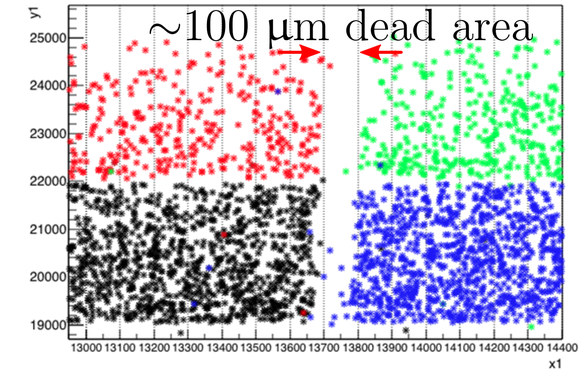
In the current UFSD design, isolation structures between readout pads represent a no-gain area for signal collection

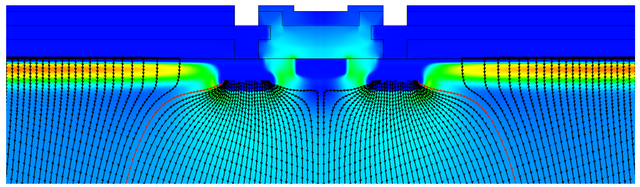


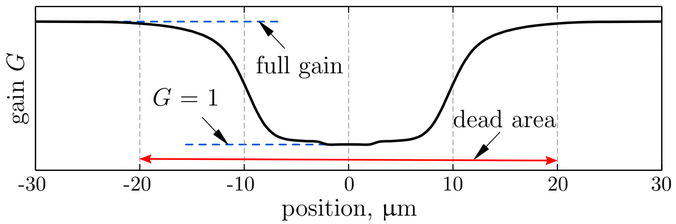
present limit of no-gain area in the UFSD design 40-100 µm

Beam-test results *confirm the presence of a non-gain space between active regions:*

- *HPK: 100 µm (2018)* ⟶ ***70 µm (2019)***
- *FBK: 70 µm (2018)* ⟶ ***40 µm (2019)***
- *CNM: 70 µm*

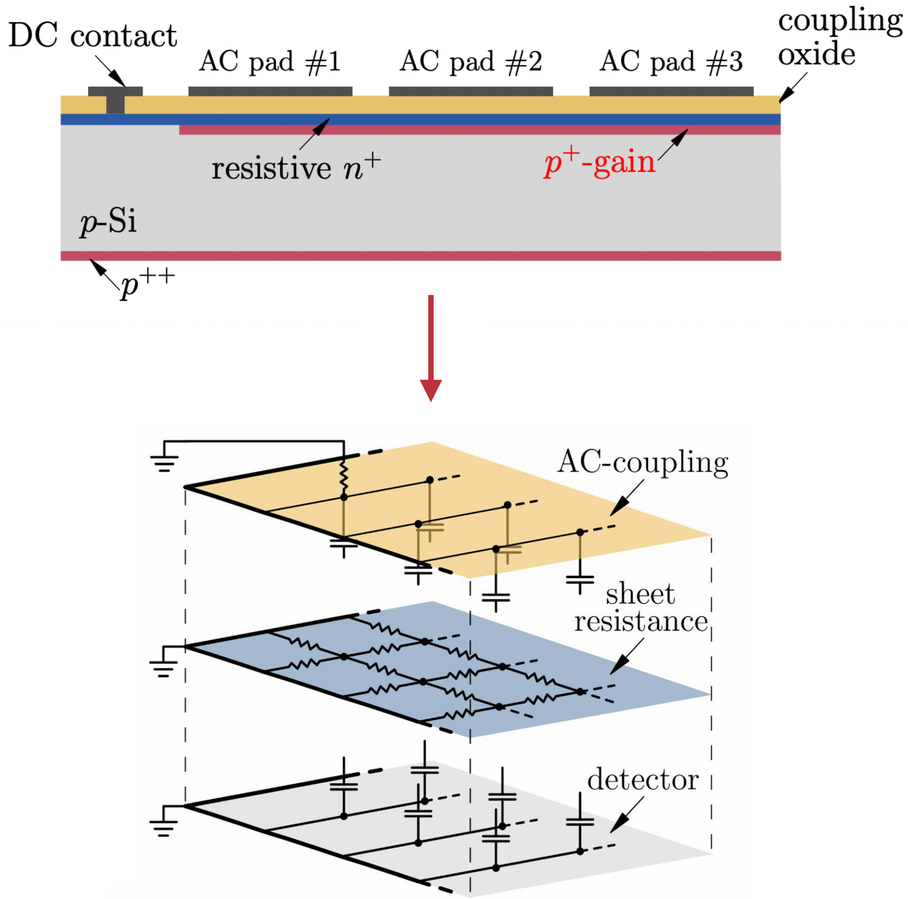






TCAD simulations *performed on 50-µm UFSD show that a no-gain area of about 20 µm could be reached with aggressive designs*

RSD PROJECT



Resistive AC-coupled LGAD (RSD) *are designed as detectors with 100% fill factor*

- ***One continuous gain layer***
- *Segmentation of* ***read-out pads*** *defines spatial resolution*
- *Easy structure with a reduced number of edges, more resistant*

See Marco Mandurrino presentation @ TREDI 2018: https://indico.cern.ch/event/666427/contributions/2885020/

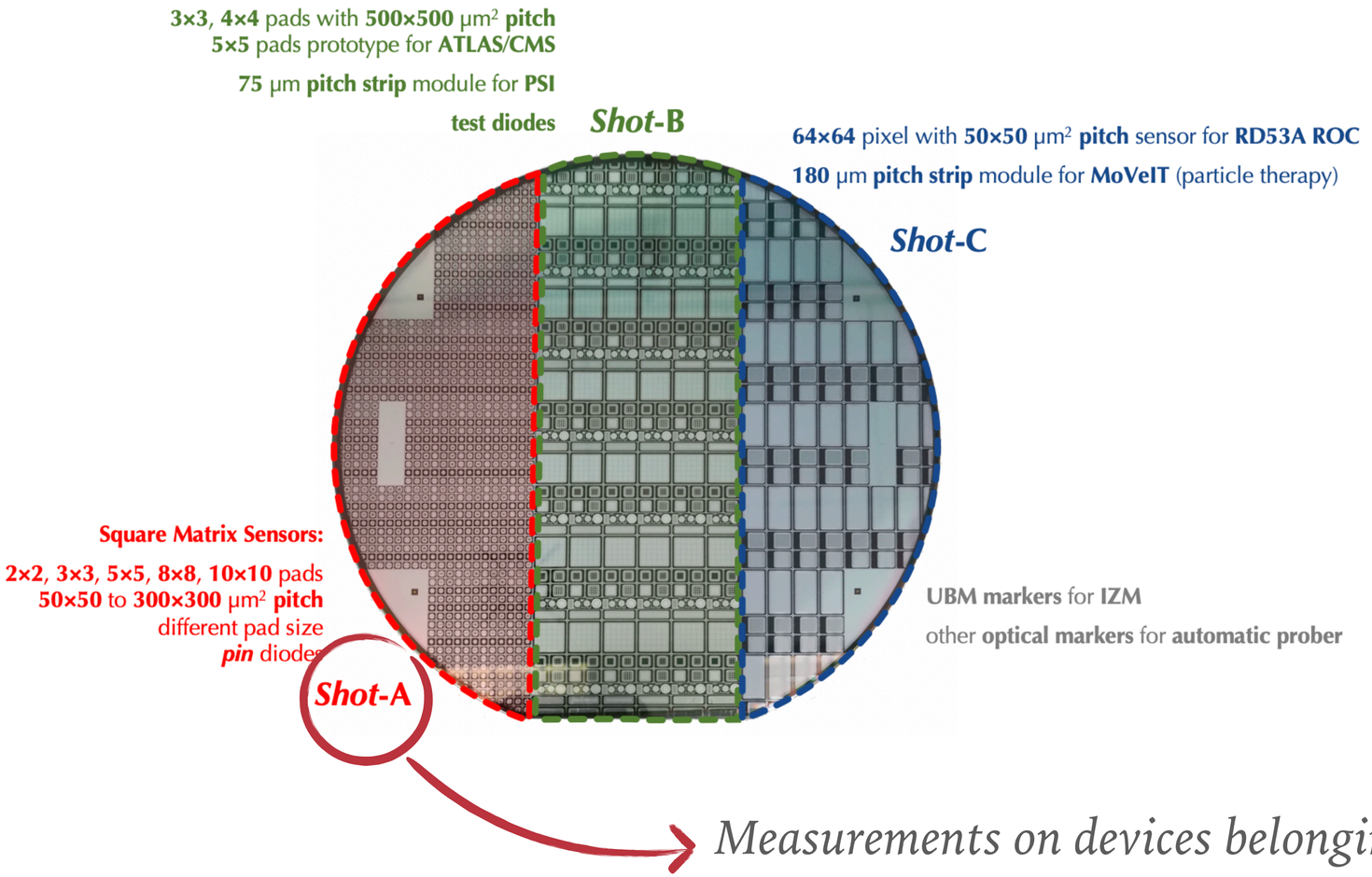
RSD PROJECT: SIGNALS

Negative component: *signal induced on AC pad by charges drifting towards the surface, same shape as the equivalent DC sensor*

Positive component: *signal induced by discharge along the resistive layer, depends on the sensor RC*

RSD PROJECT: RSD1 PRODUCTION

See Marco Mandurrino presentation @ 34th RD50 https://indico.cern.ch/event/812761/contributions/3459062/



wafer	*n-plus dose*	*p-gain dose*	dielectric thickness	*p-stop dose*	substrate
1	A	0.92	L	B	Si-Si
2	A	0.94	L	A	Si-Si
3	A	0.94	L	B	Epi
4	A	0.94	H	B	Si-Si
6	B	0.92	L	B	Epi
7	B	0.94	L	A	Si-Si
8	B	0.94	L	B	Si-Si
10	B	0.96	H	B	Si-Si
11	C	0.92	L	B	Si-Si
12	C	0.94	L	B	Epi
13	C	0.94	L	B	Si-Si
15	C	0.96	H	C	Si-Si

Measurements on devices belonging to this shot are presented

OUTLINE

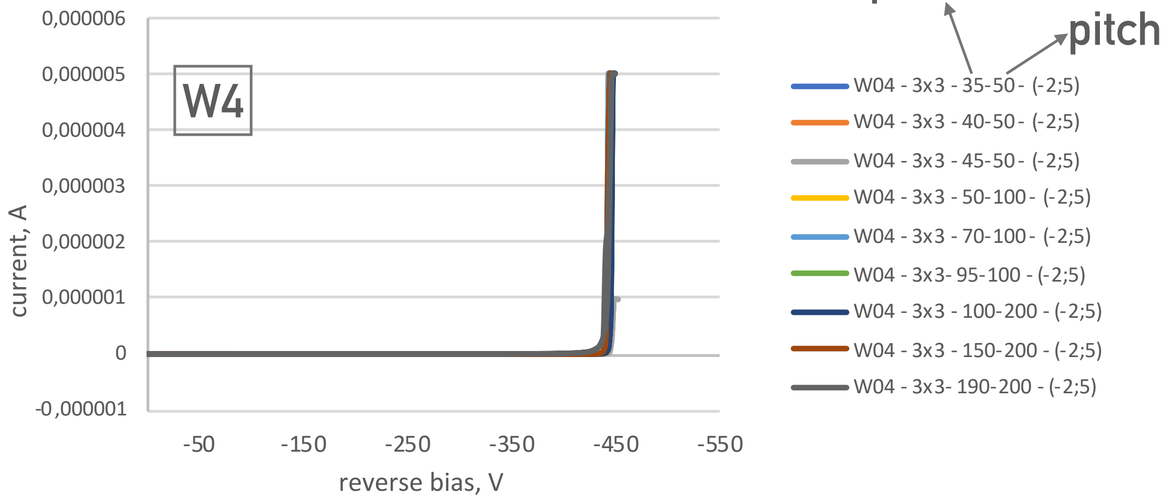
- *Initial RSD1 lab characterization*
- ***Capacitance** measurements*
- ***Dynamic characterization**: charge, signals properties* ⟶ ***spatial resolution***
- ***Time resolution** measurements*

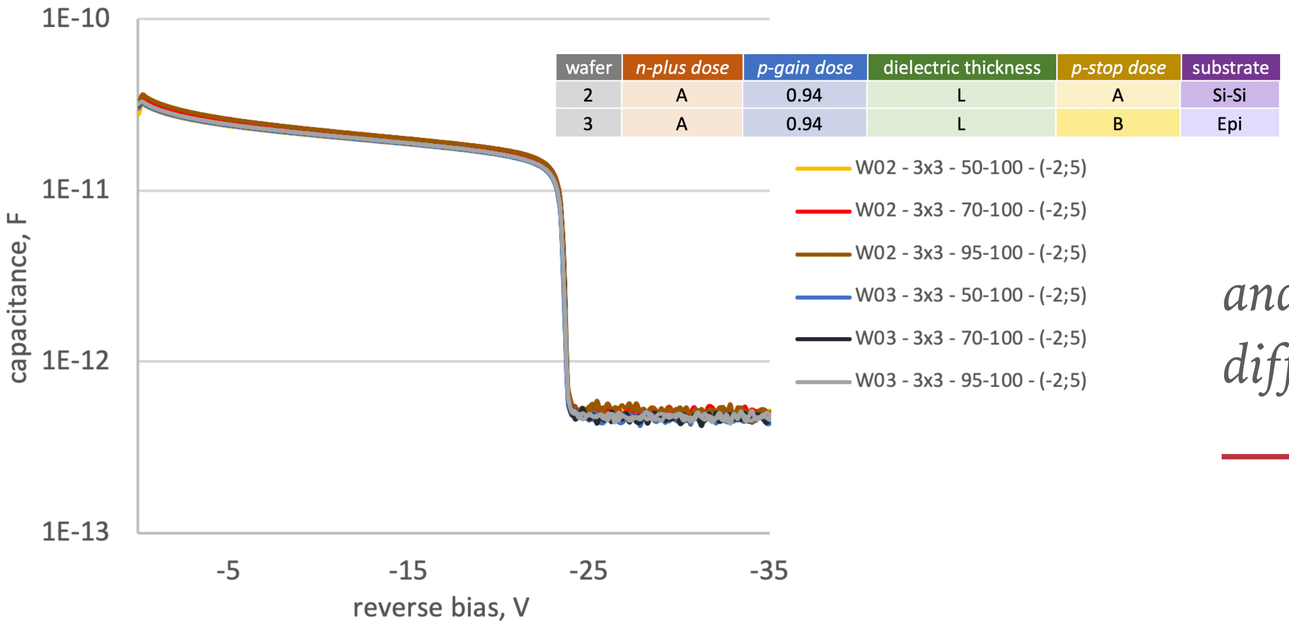
FIRST TESTS IN TORINO

I(V) and C(V) measurements

Characterization of different devices from each wafer

→ *Excellent homogeneity within the wafer*





wafer	*n-plus dose*	*p-gain dose*	dielectric thickness	*p-stop dose*	substrate
2	A	0.94	L	A	Si-Si
3	A	0.94	L	B	Epi

and measurements of samples with the same geometry from different wafers with same pgain dose

→ *Excellent homogeneity among wafers*

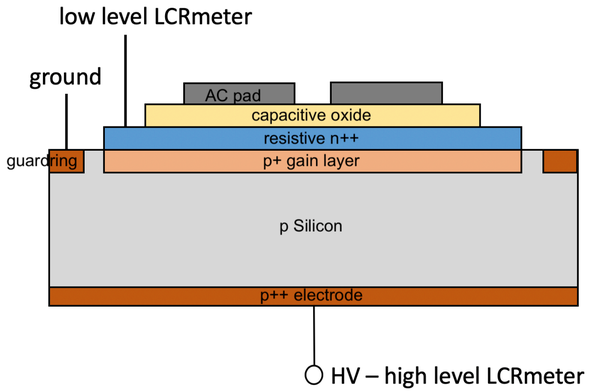
CV MEASUREMENTS @CERN SSD LAB

Study of pads and interpad ***capacitance***

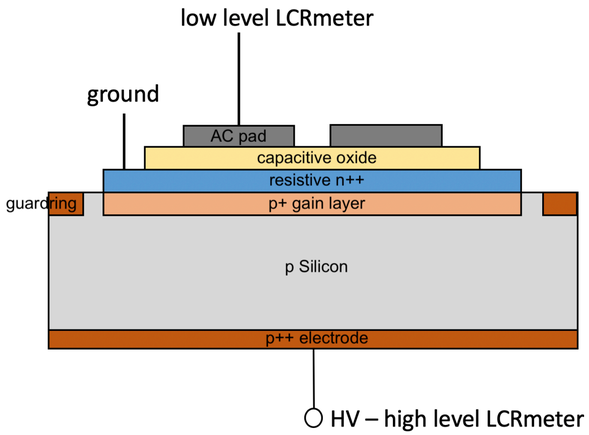
DC*: sinusoidal signal on DC pad, guardring grounded, f=1 kHz*

AC*: sinusoidal signal on AC pad, DC grounded, guarding floating, f=200 kHz*

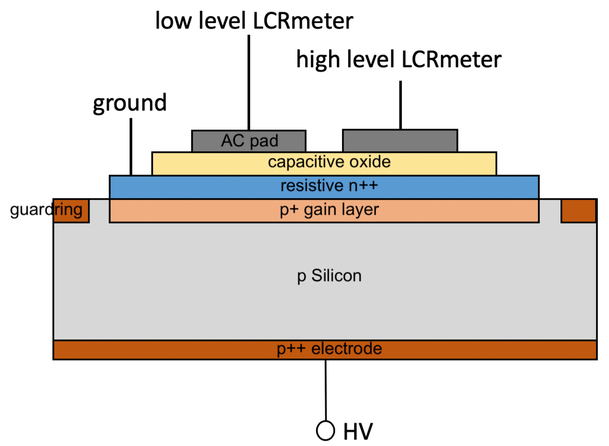
AC AC*: AC pads connected to high and low level of LCRmeter, DC grounded, guarding floating, f=200 kHz*



DC setup

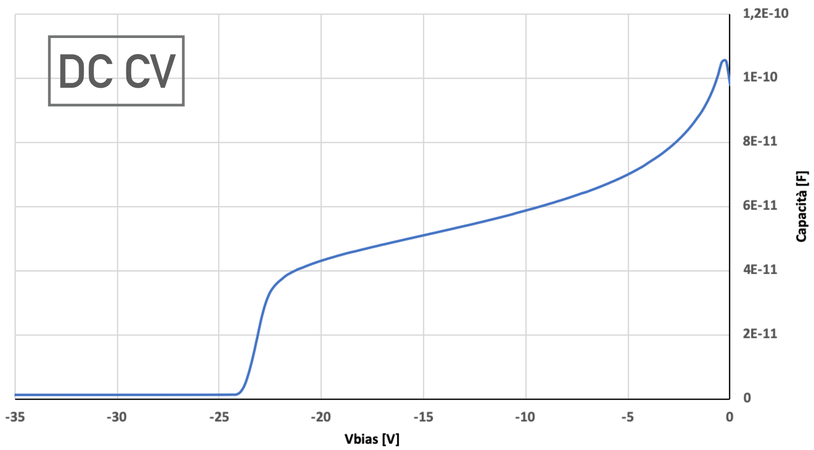


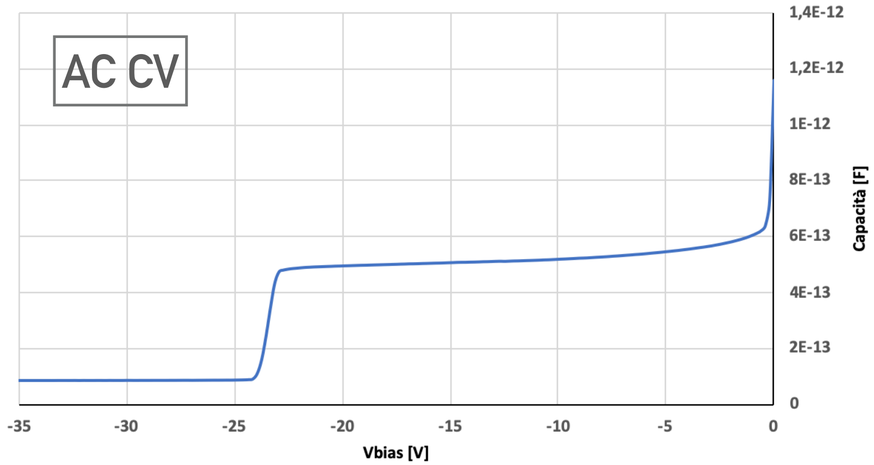
AC setup

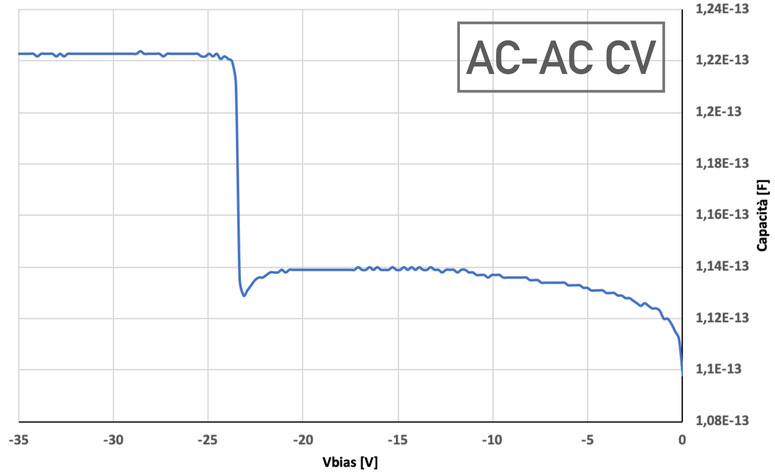


AC AC setup

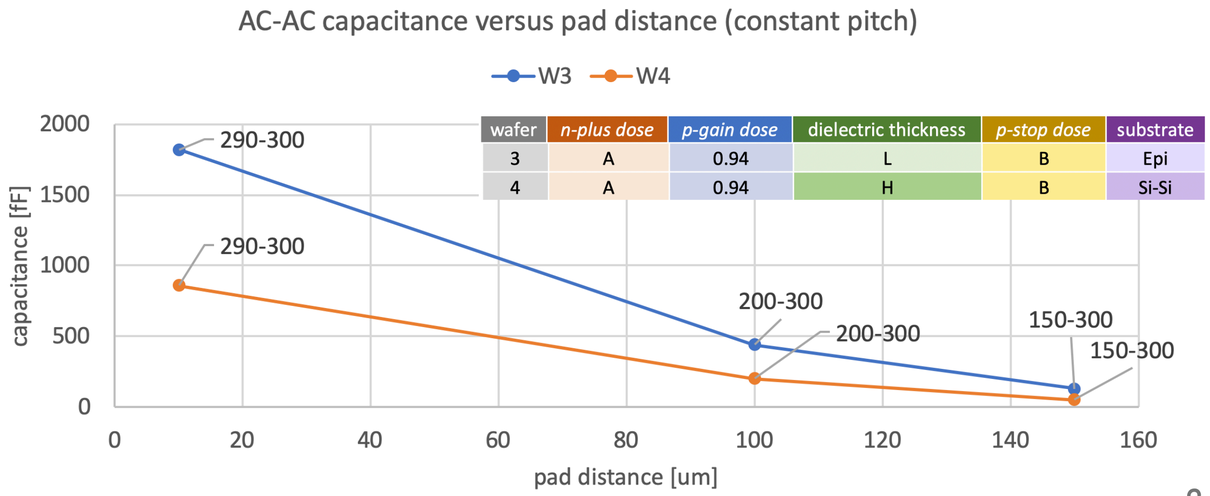
CV MEASUREMENTS: EXAMPLES FROM W4



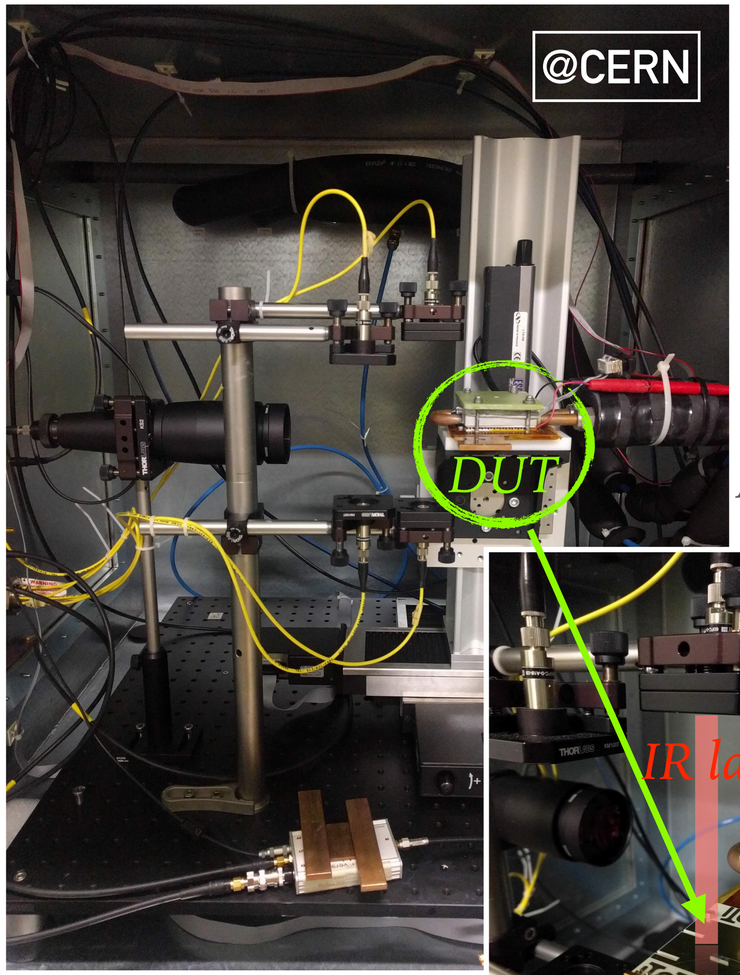


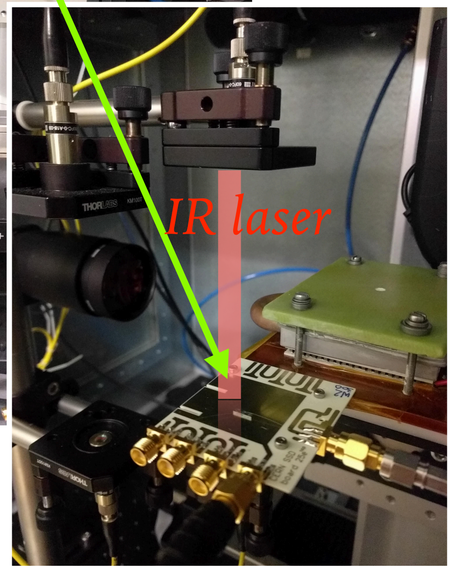


- *Gain layer and bulk depletion visible for all the curves*
- *Capacitance values after depletion in agreement with theoretical ones*
- *AC-AC capacitance depends on AC pad dimension*



TCT MEASUREMENTS @CERN SSD LAB AND @TORINO





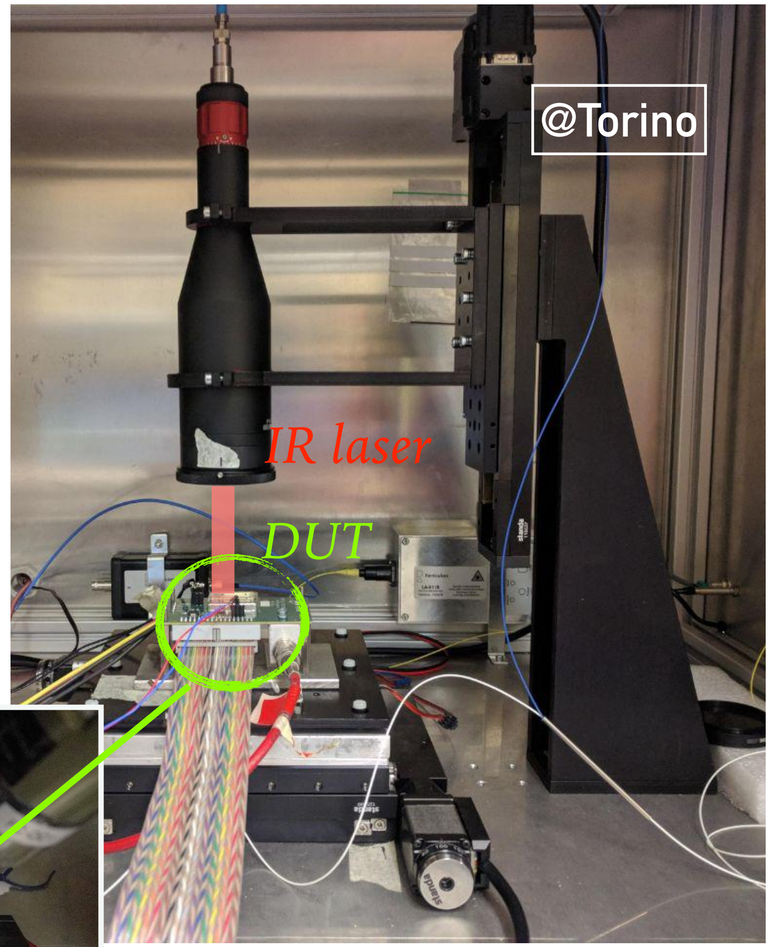
Analysis of current signal produced by a laser

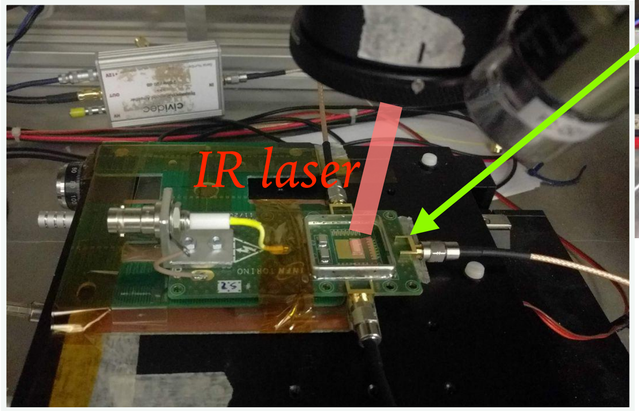
Laser 1064 nm, spot 10 μm

Stages with micrometrical precision

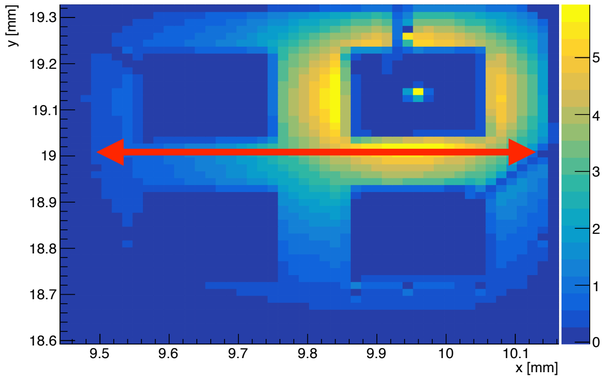
DAQ with LabView softwares

Measurements performed in similar conditions





TCT MEASUREMENTS: RESULTS FROM CHARGE SCANS

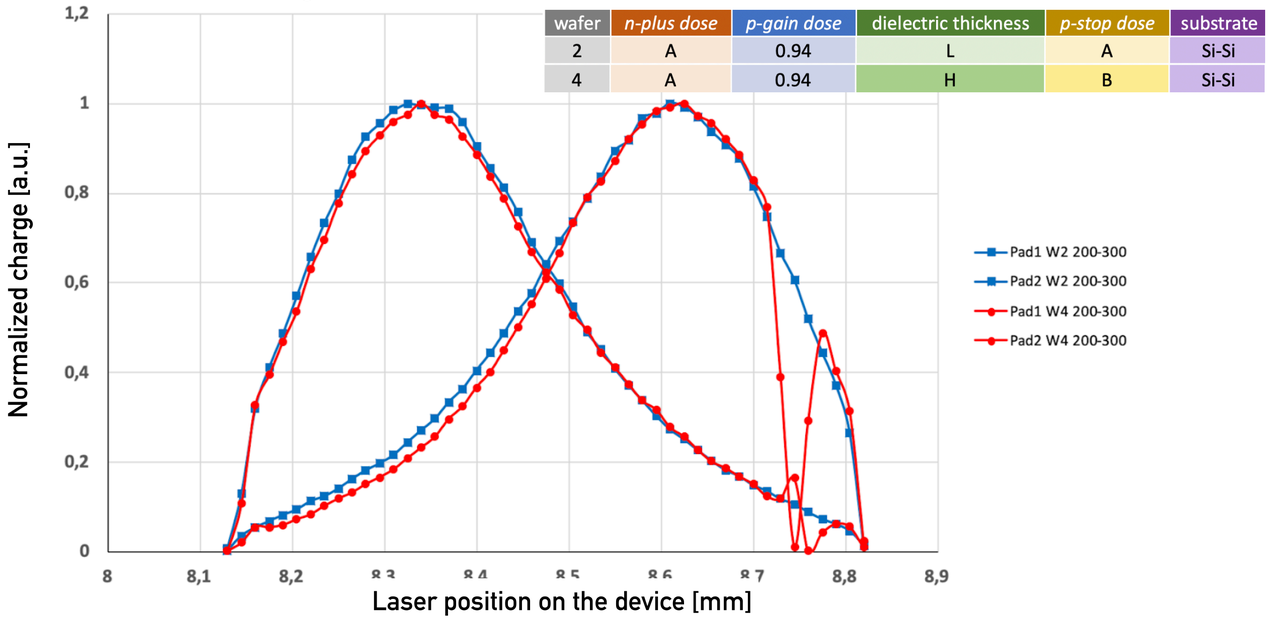


Study of charge projections along a scan line (in red) for two neighboring pads

The induced charge shape doesn't depend on the oxide thickness or on the n+ dose

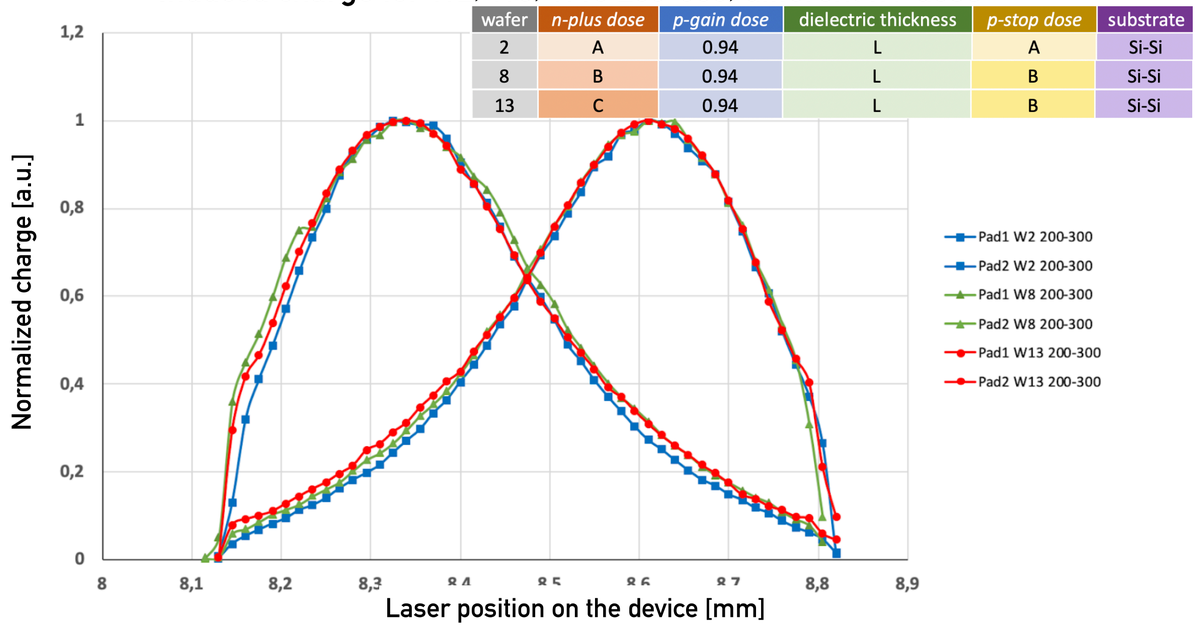
Induced charge for W2, W4 200-300, different oxide thickness

wafer	*n-plus dose*	*p-gain dose*	dielectric thickness	*p-stop dose*	substrate
2	A	0.94	L	A	Si-Si
4	A	0.94	H	B	Si-Si



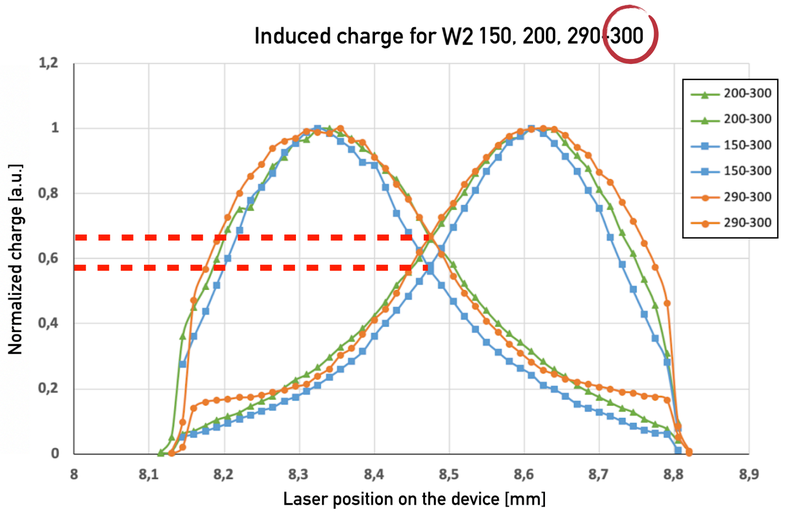
Induced charge for W2, W8, W13 200-300, different n+ dose

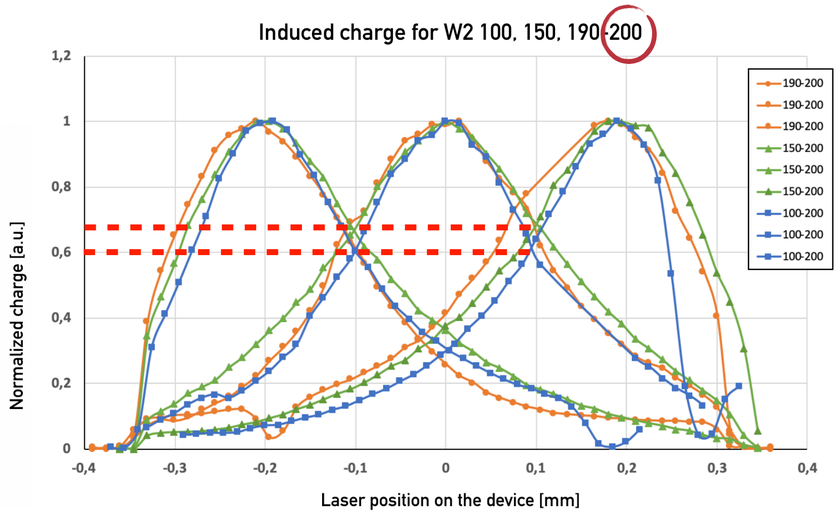
wafer	*n-plus dose*	*p-gain dose*	dielectric thickness	*p-stop dose*	substrate
2	A	0.94	L	A	Si-Si
8	B	0.94	L	B	Si-Si
13	C	0.94	L	B	Si-Si

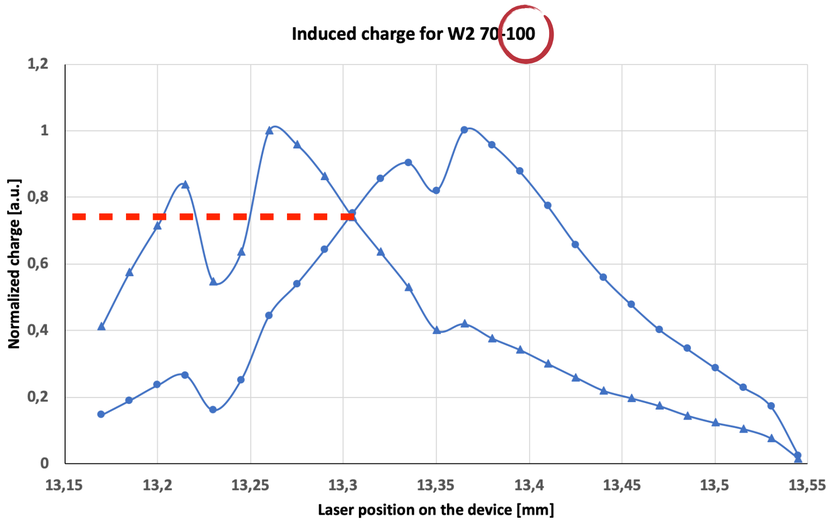


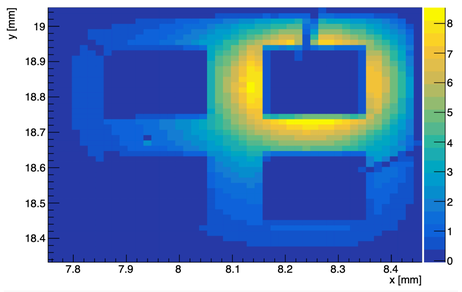
TCT MEASUREMENTS: RESULTS FROM CHARGE SCANS

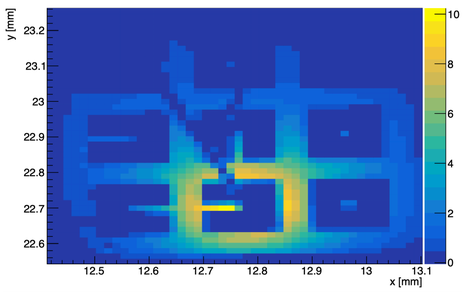
The induced charge shape depends on the pitch and the AC pad size in the DUTs

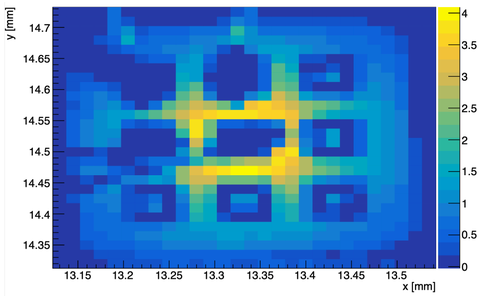




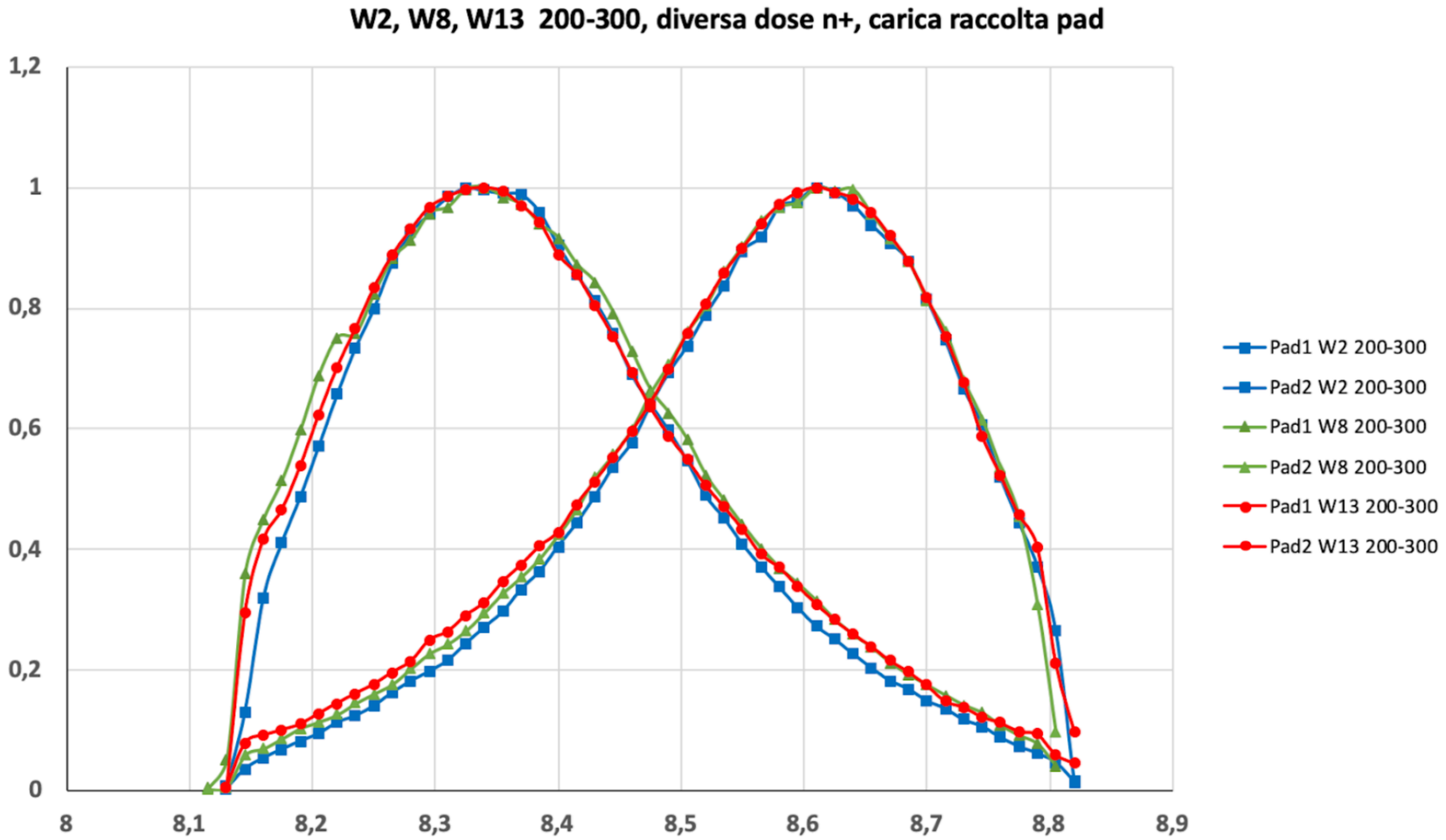








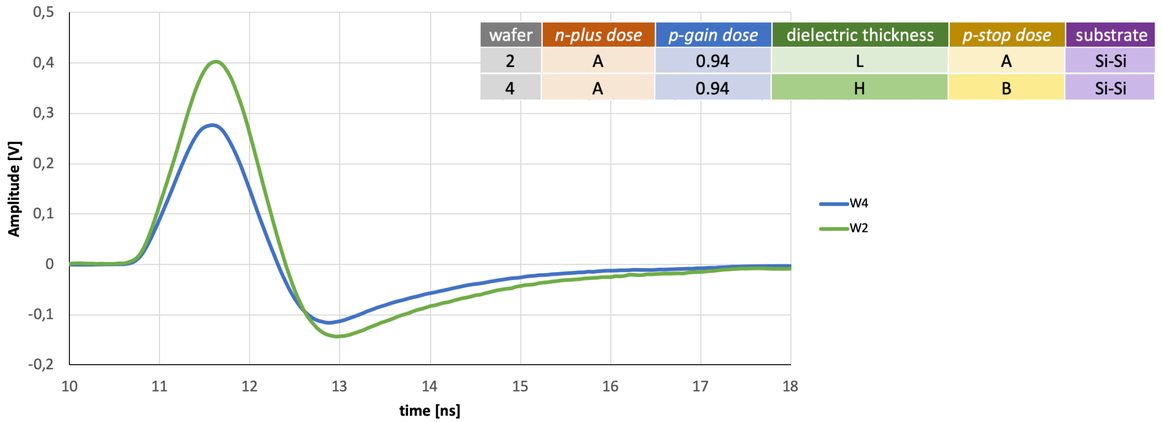
TCT MEASUREMENTS: RESULTS FROM CHARGE SCANS



TCT MEASUREMENTS: WAVEFORMS

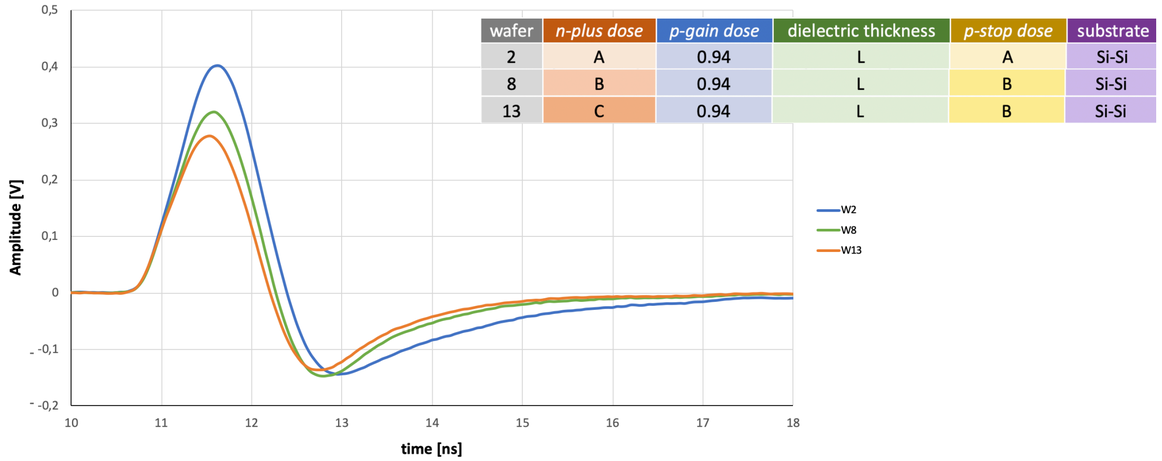
Waveforms change with the sensors RC, depending on n+ dose, oxide thickness and also AC pad size and pitch

Signal RSD 70-100 different oxide thickness



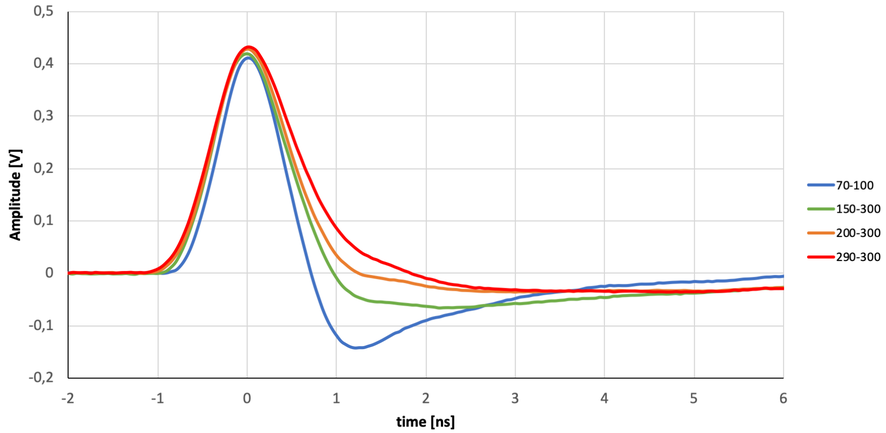
wafer	*n-plus dose*	*p-gain dose*	dielectric thickness	*p-stop dose*	substrate
2	A	0.94	L	A	Si-Si
4	A	0.94	H	B	Si-Si

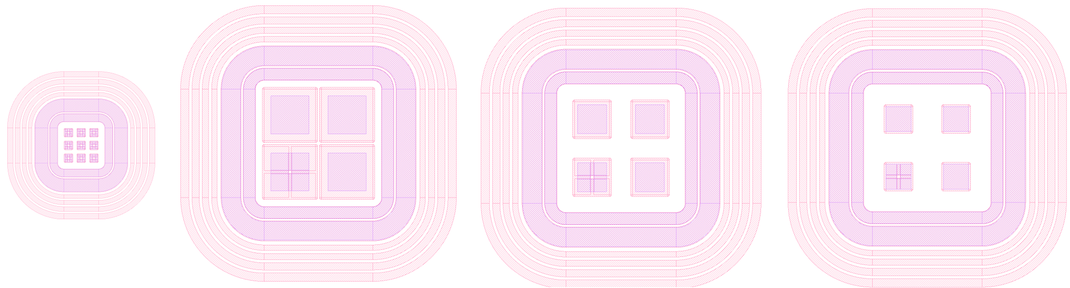
Signals RSD 70-100 different n+ dose



wafer	*n-plus dose*	*p-gain dose*	dielectric thickness	*p-stop dose*	substrate
2	A	0.94	L	A	Si-Si
8	B	0.94	L	B	Si-Si
13	C	0.94	L	B	Si-Si

RSD signals W2 150, 200, 290-300, 70-100

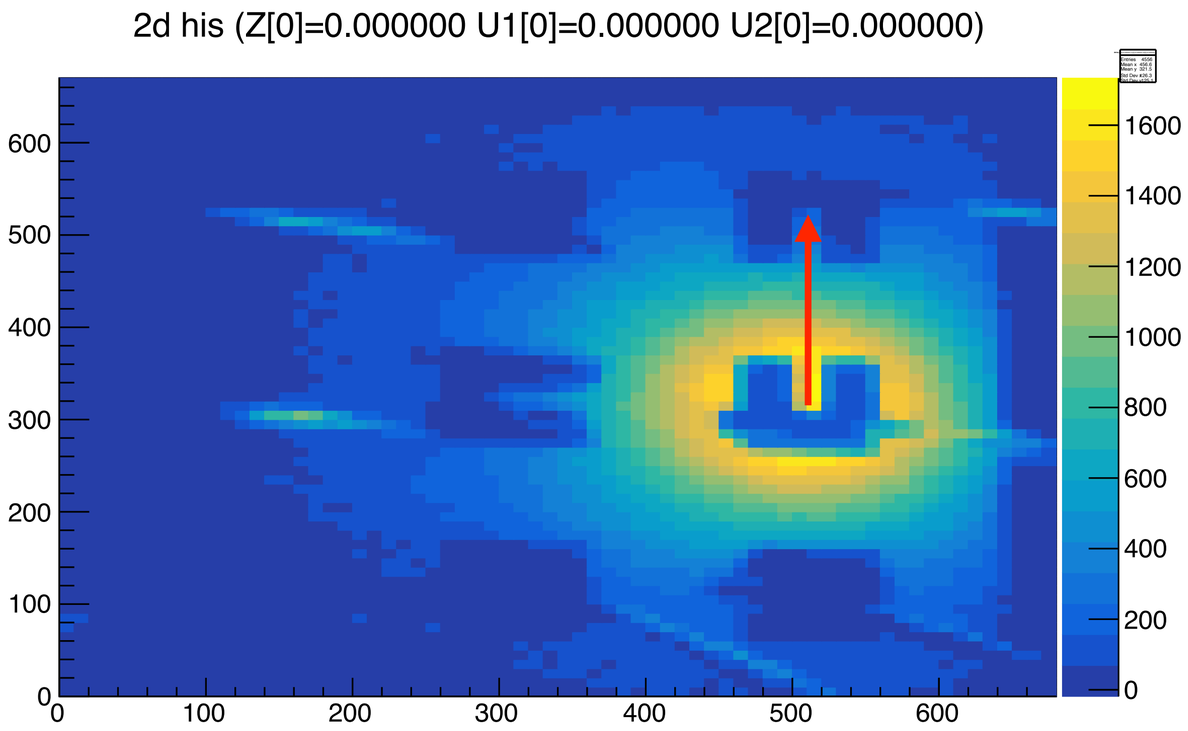


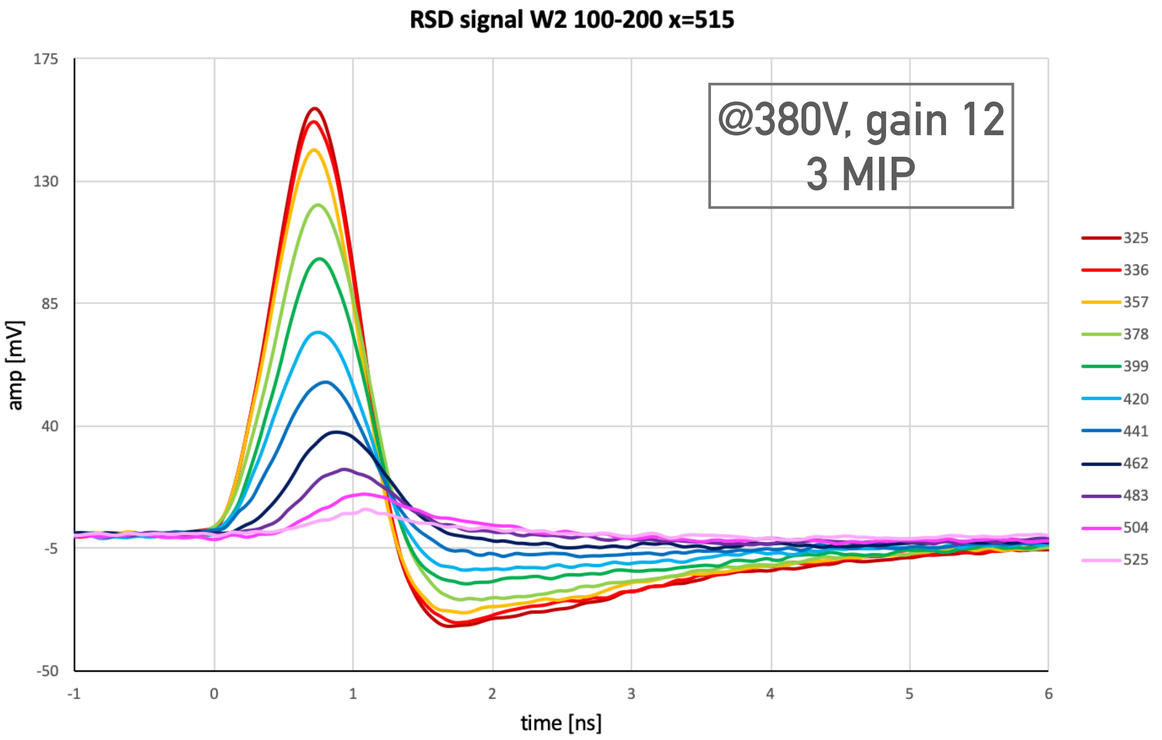


SPATIAL RESOLUTION: MEASUREMENTS

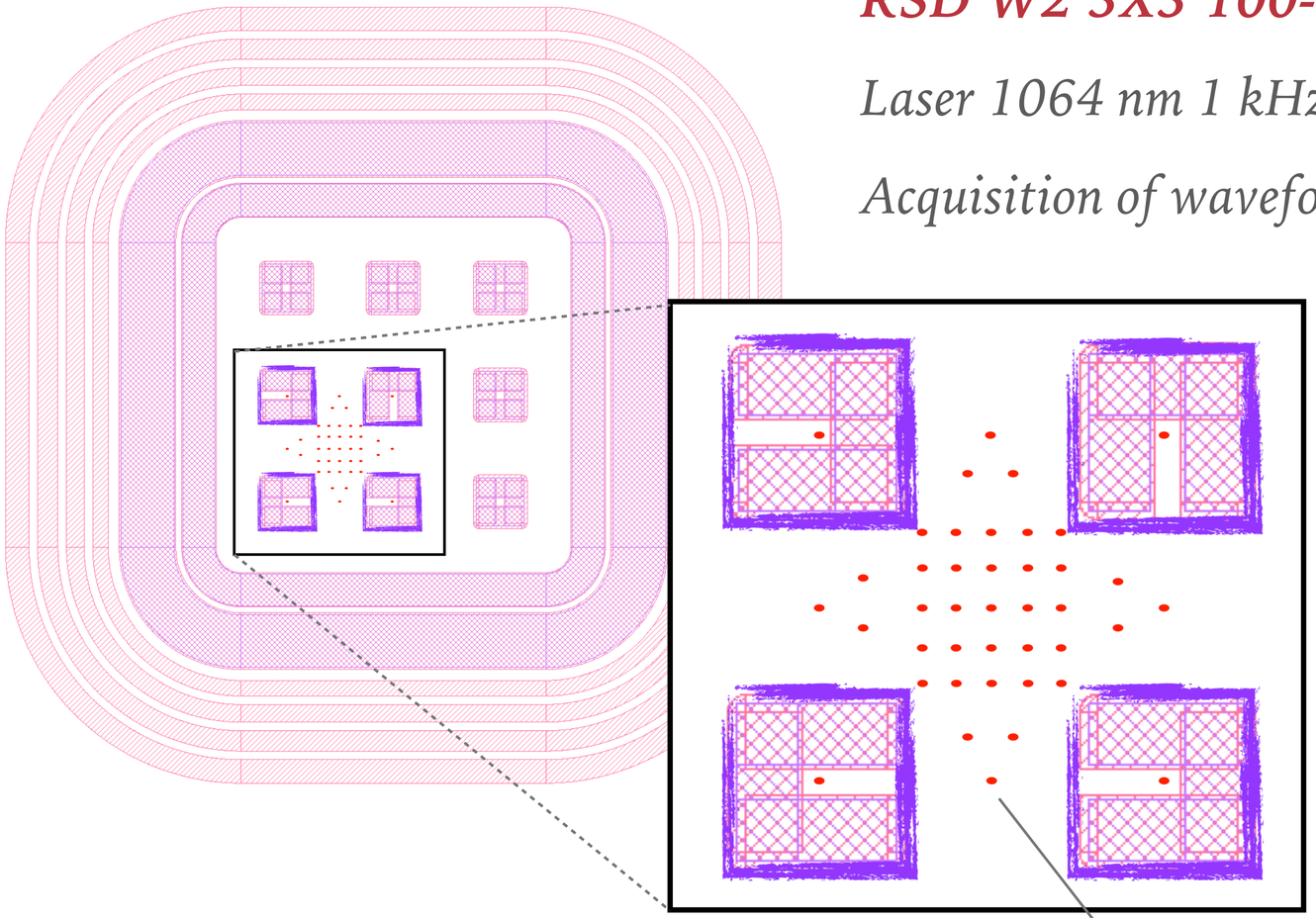
RSD signals reach their maximum in the middle of the AC pad and get smaller moving towards neighboring pads

→ *We can use this feature to obtain a* ***spatial resolution better than the sensors pitch***





SPATIAL RESOLUTION EXTRACTION



***RSD W2 3X3 100-200**, 380 V (gain=12) on FNAL board*

Laser 1064 nm 1 kHz, spot ~10 μm, intensity ~ 3 MIP

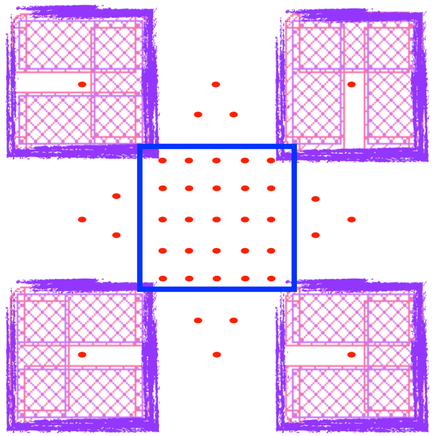
Acquisition of waveforms from 4 AC pads, ~500 triggers in each point

Reconstruction of hit position:

- *Centroid using signal **amplitude***
- *Centroid using signal **area***
- *Intersection of three **circumferences** using the three largest amplitudes*

Laser shot on red dots

SPATIAL RESOLUTION EXTRACTION

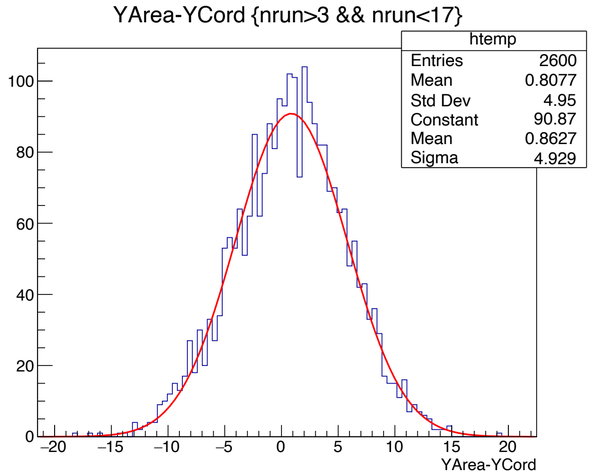


Spatial resolution is obtained as the sigma of the gaussian distribution of

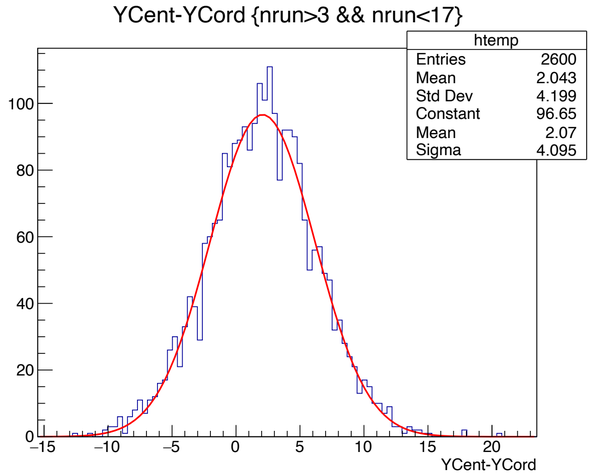
$x - x_{reco}$ *and* $y - y_{reco}$

Considering the points in the most central area (blue square), where you have a good signal from at least 3 pads, a ***spatial resolution of ~5μm*** *is obtained with each method*

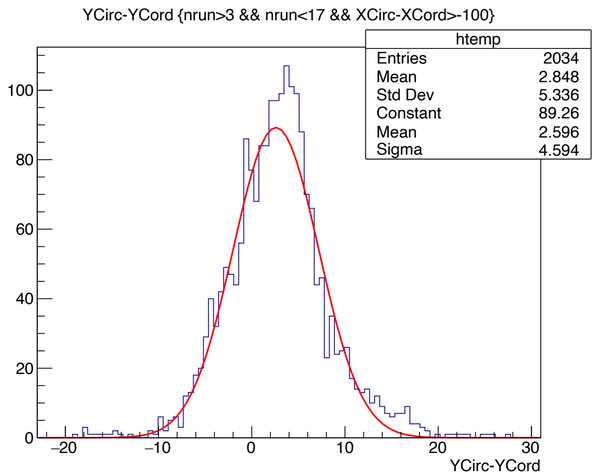
Centroid (area)



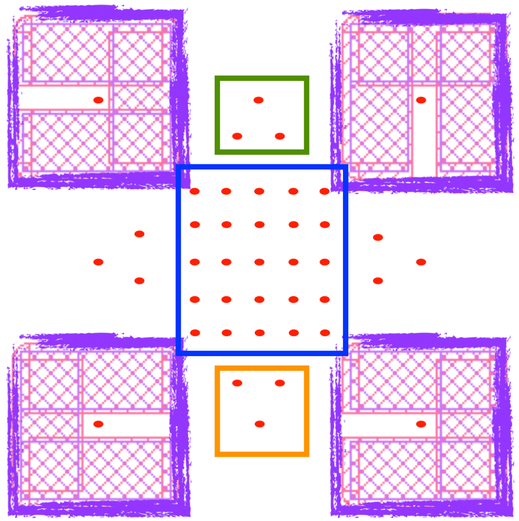
Centroid (amplitude)



Circles intersection

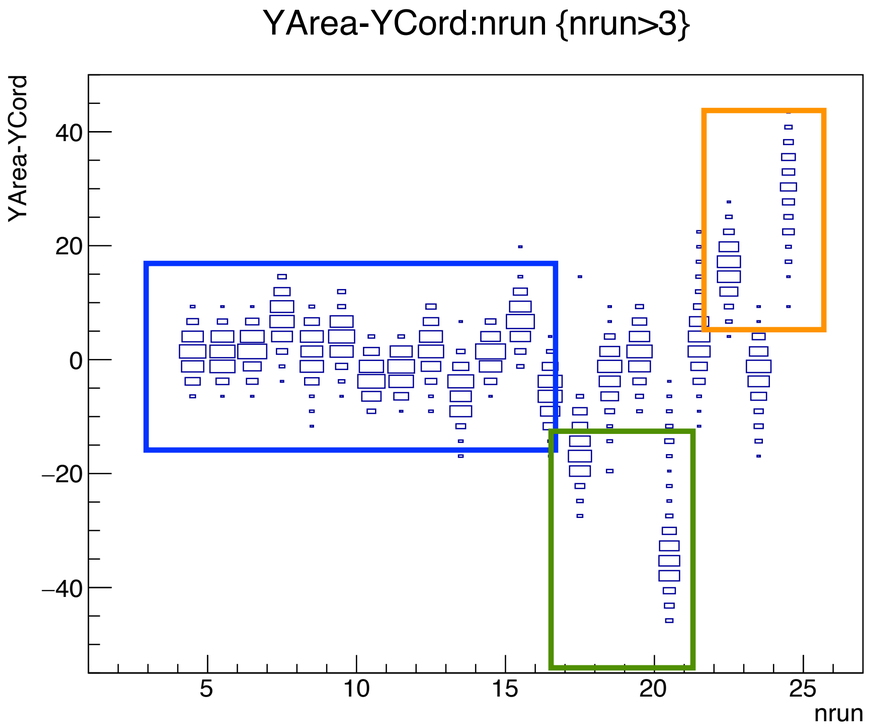


SPATIAL RESOLUTION EXTRACTION



Spatial resolution is obtained as the sigma of the gaussian distribution of

$x - x_{reco}$ *and* $y - y_{reco}$

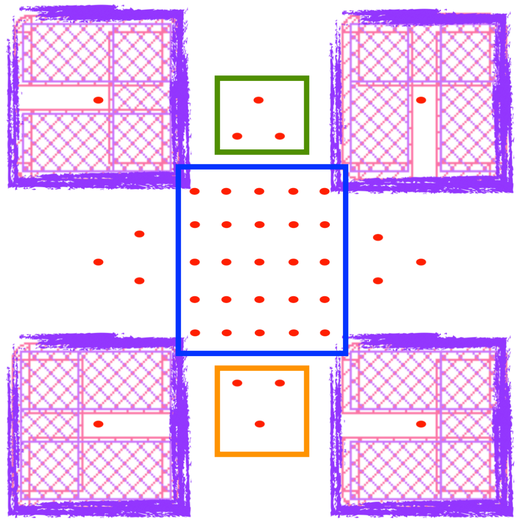


Signals between two pads (green and orange square) miss part of the information to calculate the centroid (2 more pads would be needed - not read in this setup)

A similar problem affects the reconstruction of the position for the middle points of AC pads

→ *Next: study the dependence of the position resolution on the input signal size, gain and metal pad size*

SPATIAL RESOLUTION EXTRACTION



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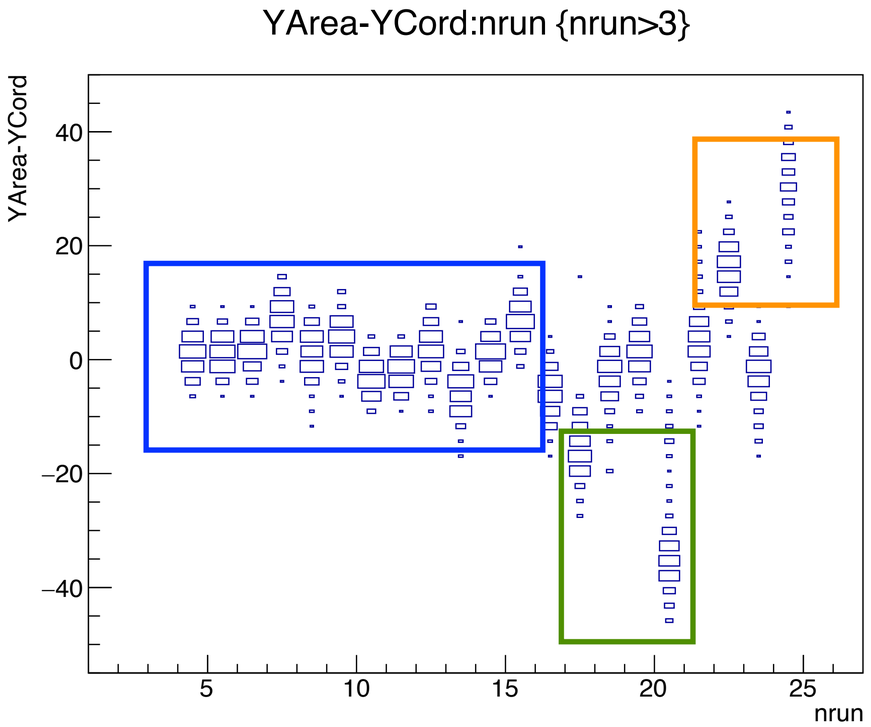

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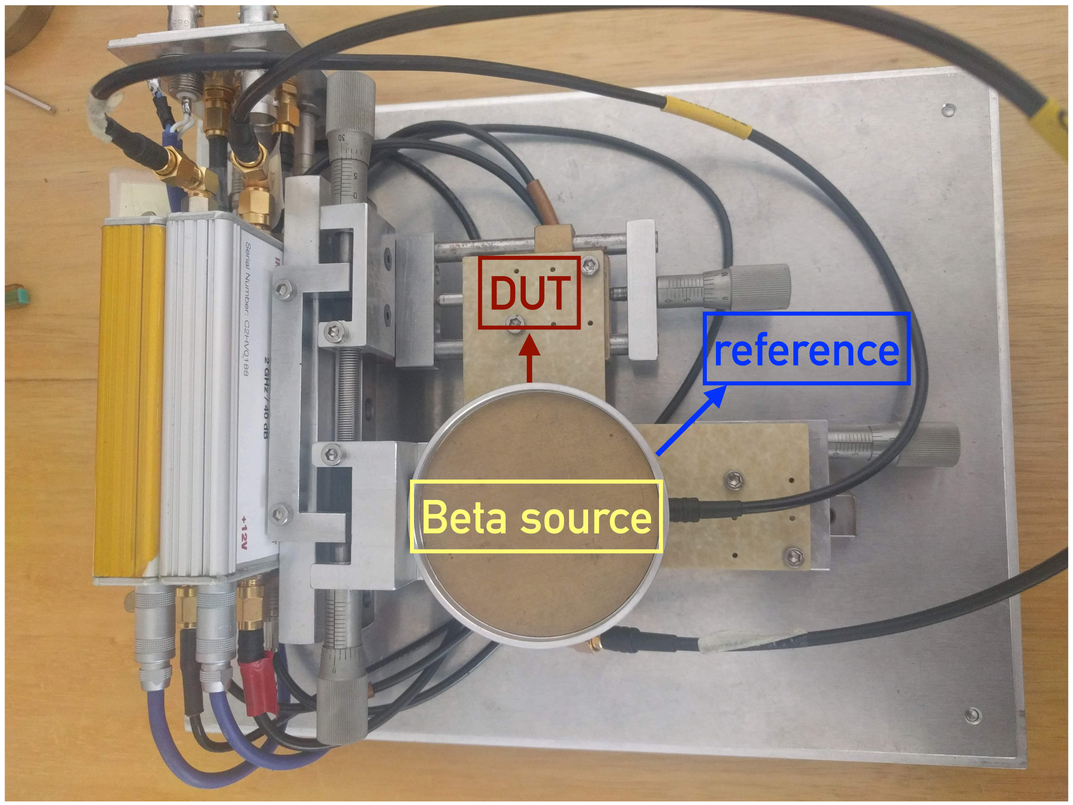
A similar problem affects the reconstruction of the position for the middle points of AC pads

→ *Next: study the dependence of the position resolution on the input signal size, gain and metal pad size*

TIME RESOLUTION @CERN SSD LAB

New beta setup @SSD lab



Measurements @20°C for three pairs of sensors with Sr90 (22.6 MBq):

- ***RSD W10 290-300*** *(400 V) - CNM LGAD 2 (215 V)*
- ***RSD W10 290-300*** *(400 V) - CNM LGAD 3 (205 V)*
- *CNM LGAD 2 (215 V) - CNM LGAD 3 (205 V)*

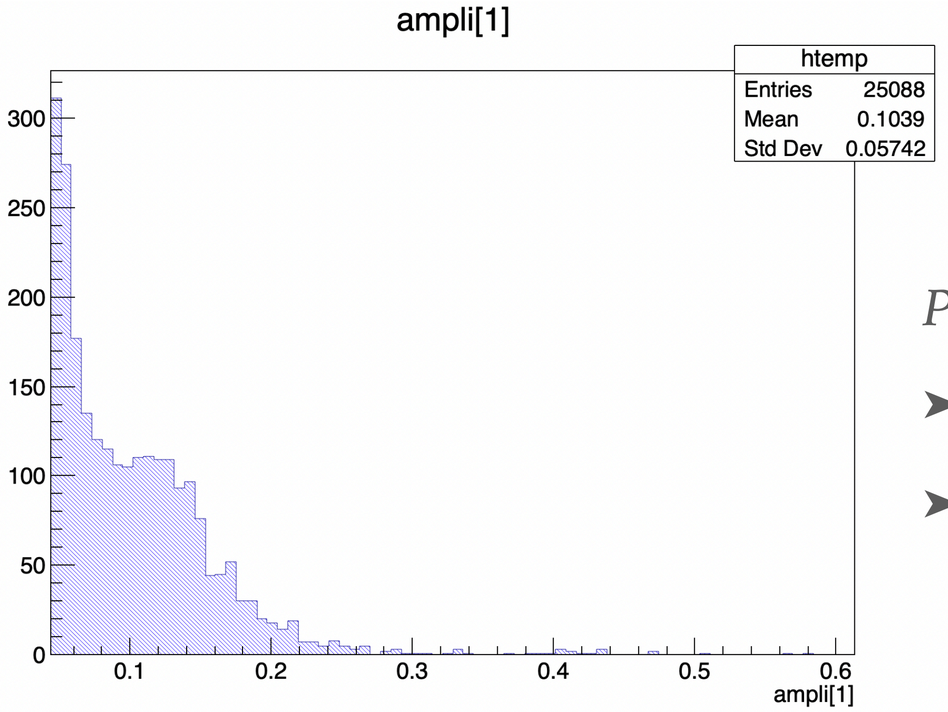
Analysis performed with CERN timing scripts

$$\sigma_{LGAD2} = 40ps \quad \sigma_{LGAD3} = 53ps$$

$$\sigma_{system} = t_{DUT} - t_{ref} = \sqrt{\sigma_{DUT}^2 + \sigma_{ref}^2}$$

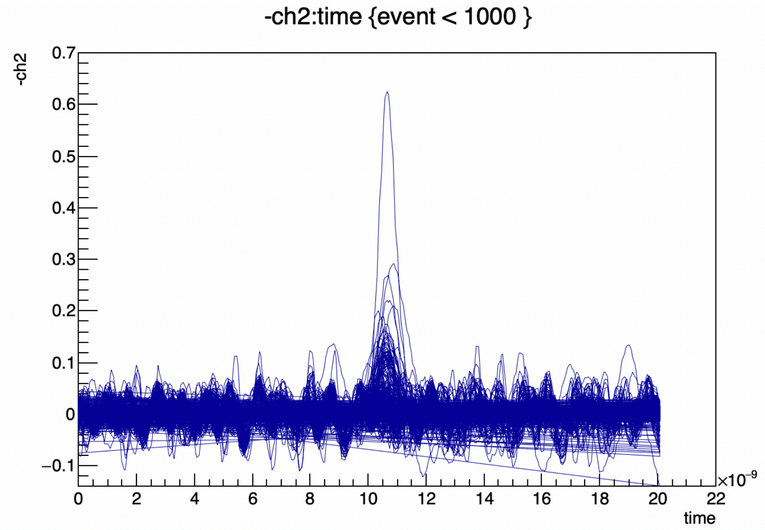
TIME RESOLUTION @CERN SSD LAB

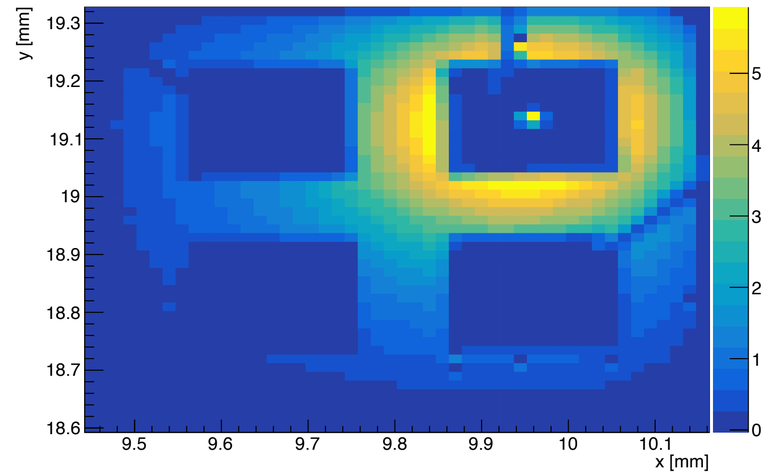
RSD Landau distribution can't be clearly distinguished from the noise



Possible reasons:

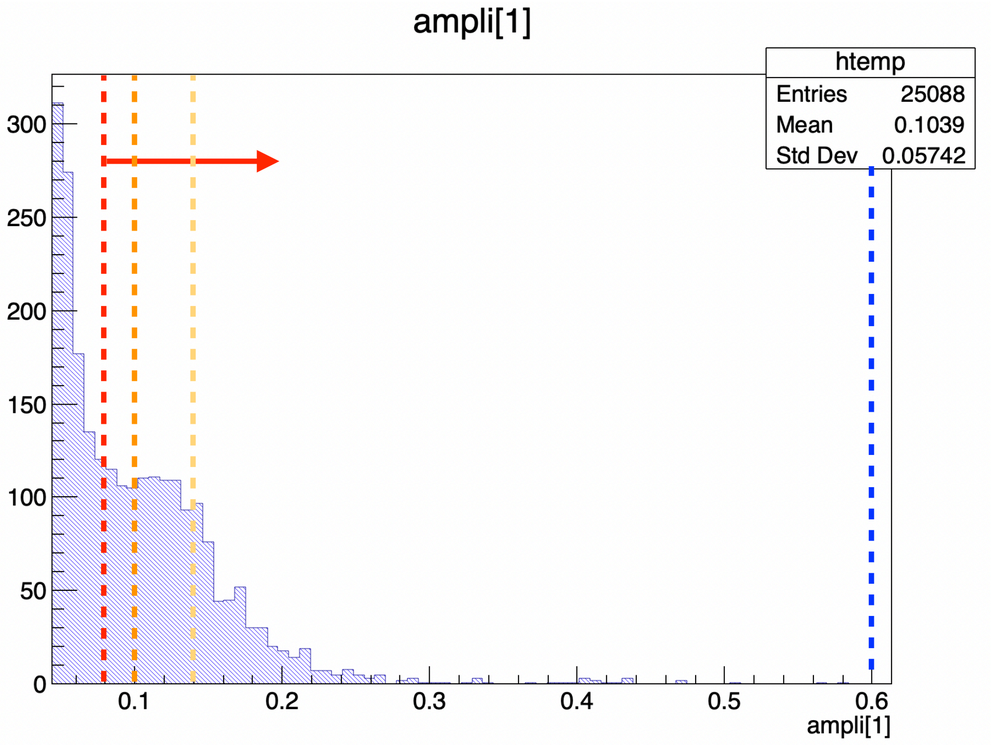
- *Noise from the setup*
- *Small signals produced when particles hit neighbouring pads*





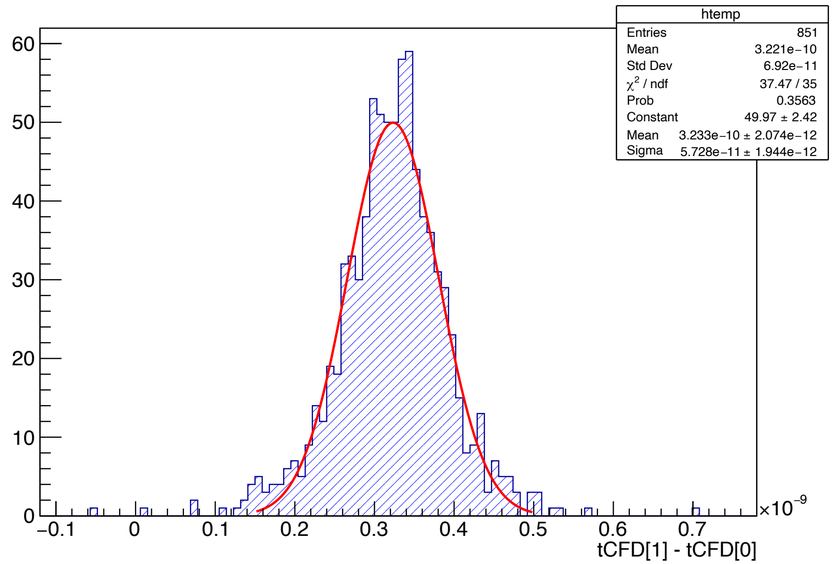
→ *In multichannel readout, the time resolution would be obtained always using the largest signal. This analysis uses only one pad, so time resolution is not optimal.*

TIME RESOLUTION @CERN SSD LAB



Time resolution calculated in different amplitude intervals:

- $amp(DUT) > 0.08\ V\ and\ < 0.6\ V \longrightarrow \sigma_{RSD} = 48ps$
- $amp(DUT) > 0.1\ V\ and\ < 0.6\ V \longrightarrow \sigma_{RSD} = 45ps$
- $amp(DUT) > 0.14\ V\ and\ < 0.6\ V \longrightarrow \sigma_{RSD} = 45ps$



CONCLUSIONS AND FUTURE PLANS

- ***Excellent production uniformity*** *for the RSD1 production by FBK within a wafer and among wafers*
- *Preliminary measurements show that* ***spatial resolution*** *is about* ***5 μm*** *(gain 12, ~3MIP) in 200 μm pitch devices*
- *First measurements give promising results for* ***time resolution***

More studies to be performed on both spatial and time resolution to define the characteristics of the next RSD production

ACKNOWLEDGEMENTS

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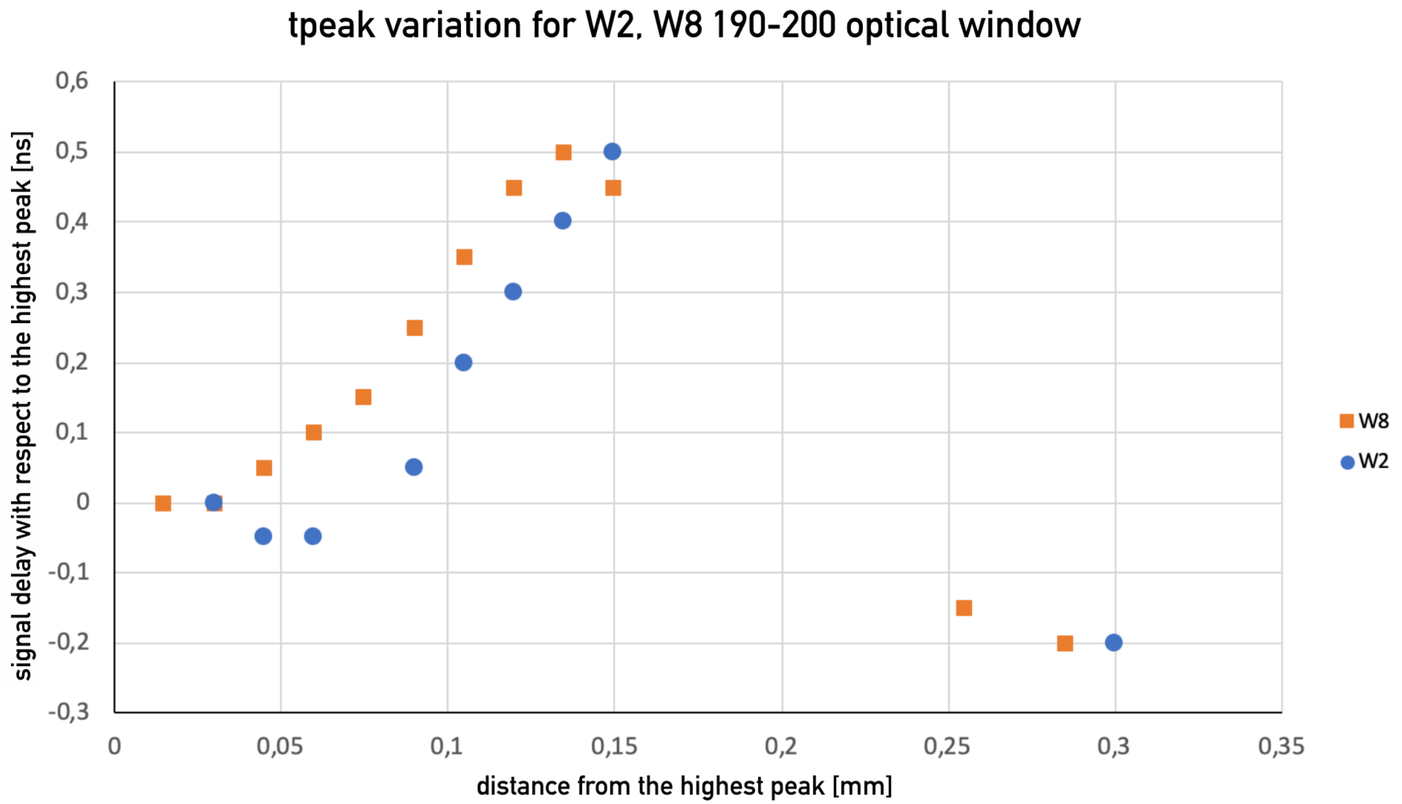
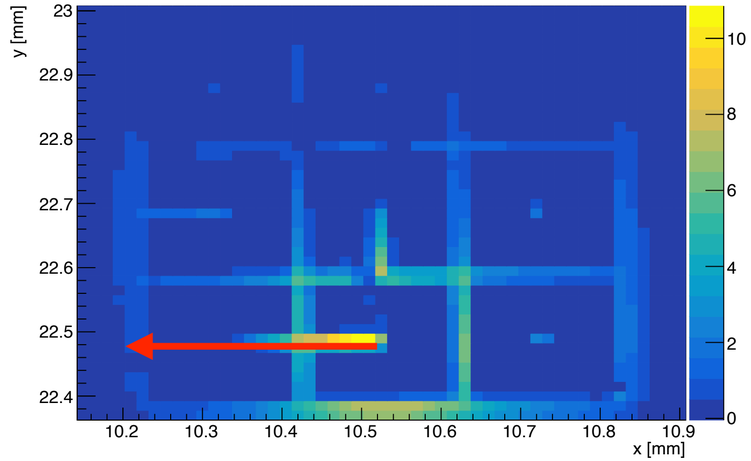
- ***INFN - Gruppo V***
- ***FBK-INFN*** *collaboration framework*
- *Horizon 2020, ERC - Advanced* ***Grant*** *UFSD*
- *Horizon 2020, MSCA -* ***INFRAIA Grant AIDA2020***
- ***Ministero degli Affari Esteri****, Italia, MAE, "Progetti di Grande Rilevanza Scientifica"*
- ***Dipartimenti di Eccellenza****, University of Torino (ex L. 232/2016, art. 1, cc. 314, 337)*

Backup

TCT MEASUREMENTS: WAVEFORMS – SIGNALS DELAY

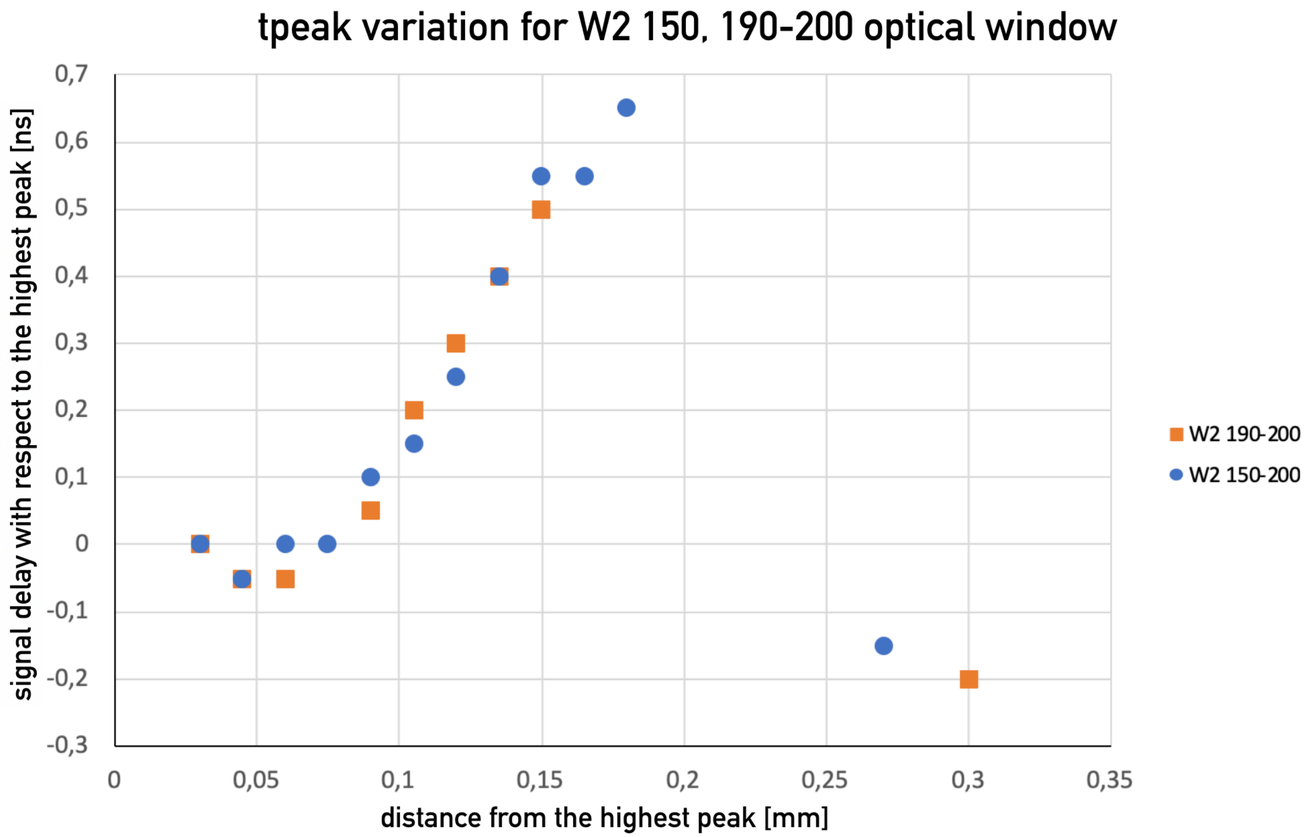
Signals peak delay with respect to the largest signal as function of the distance in mm from the largest signal for W2, W8 190-200 in the optical window

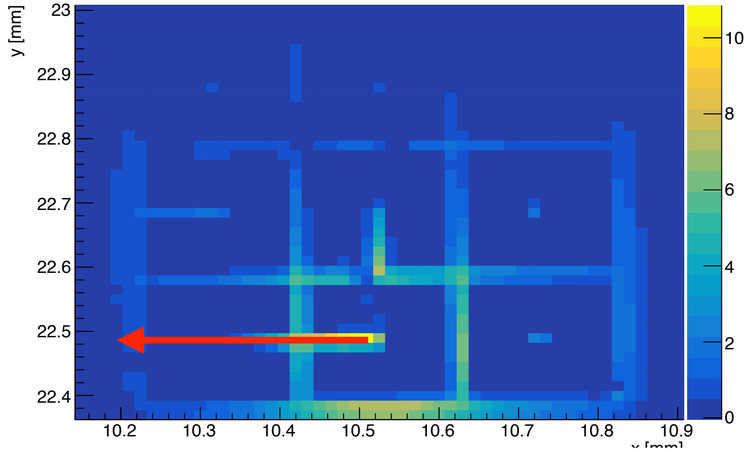


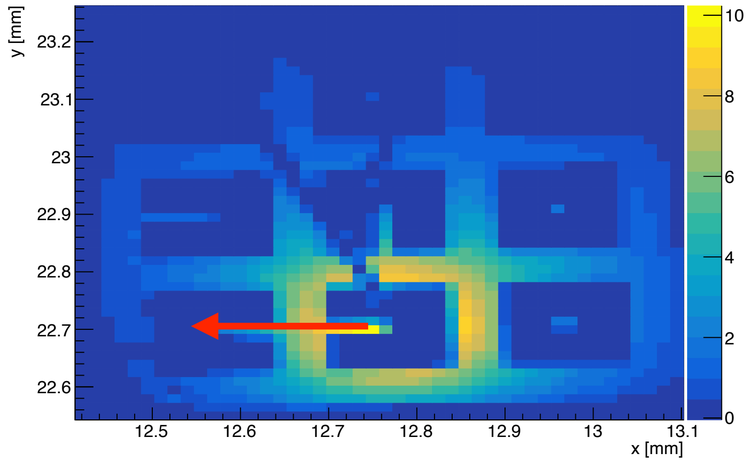


TCT MEASUREMENTS: WAVEFORMS – SIGNALS DELAY

Signals peak delay with respect to the largest signal as function of the distance in mm from the largest signal for W2 150 and 190-200 in the optical window

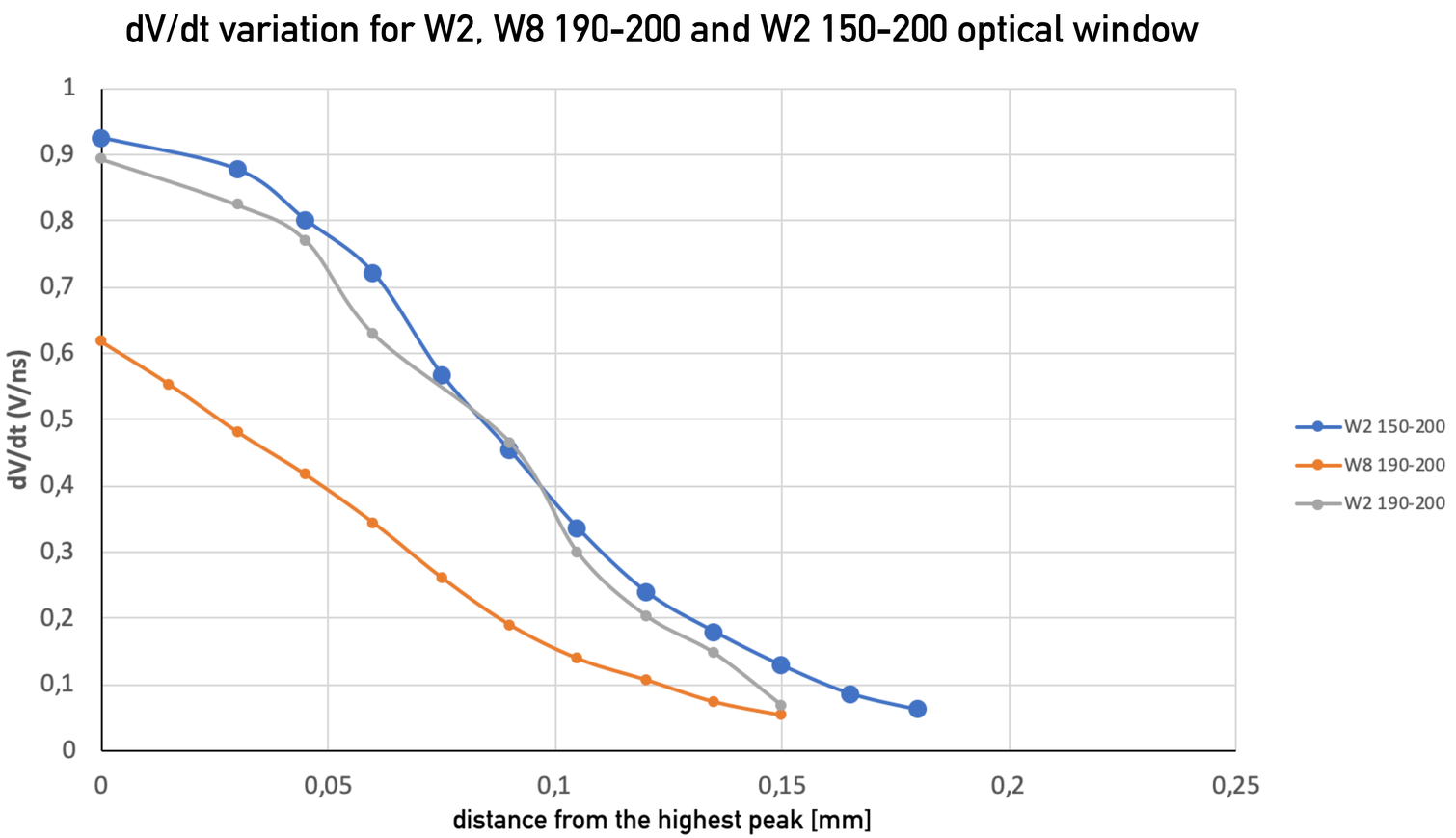


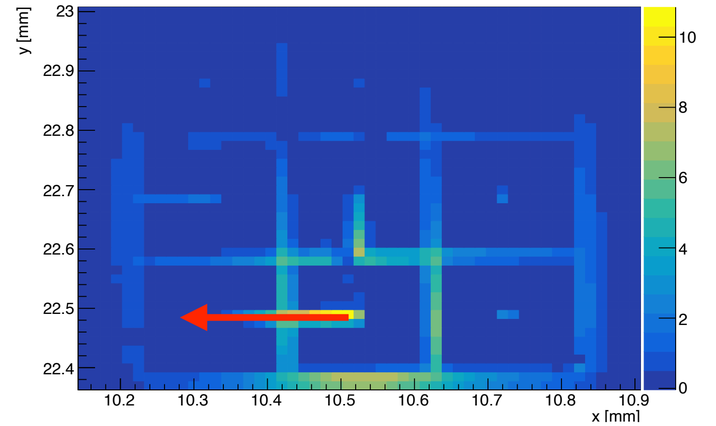


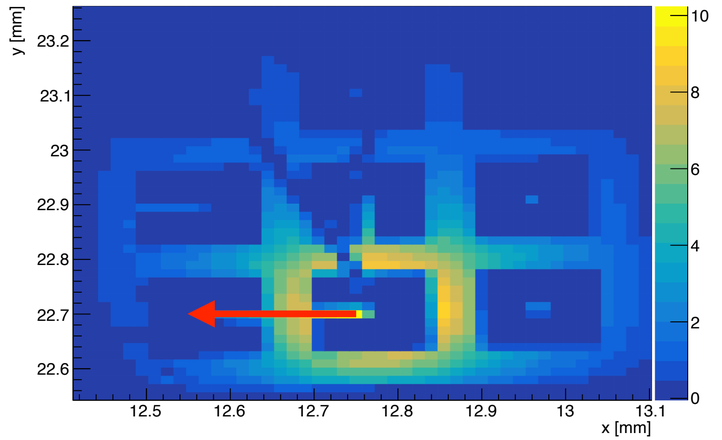


TCT MEASUREMENTS: WAVEFORMS – DV/DT

Signals dV/dt as function of the distance in mm from the largest signal for W2 150 e 190-200 e W8 190-200 in the optical window





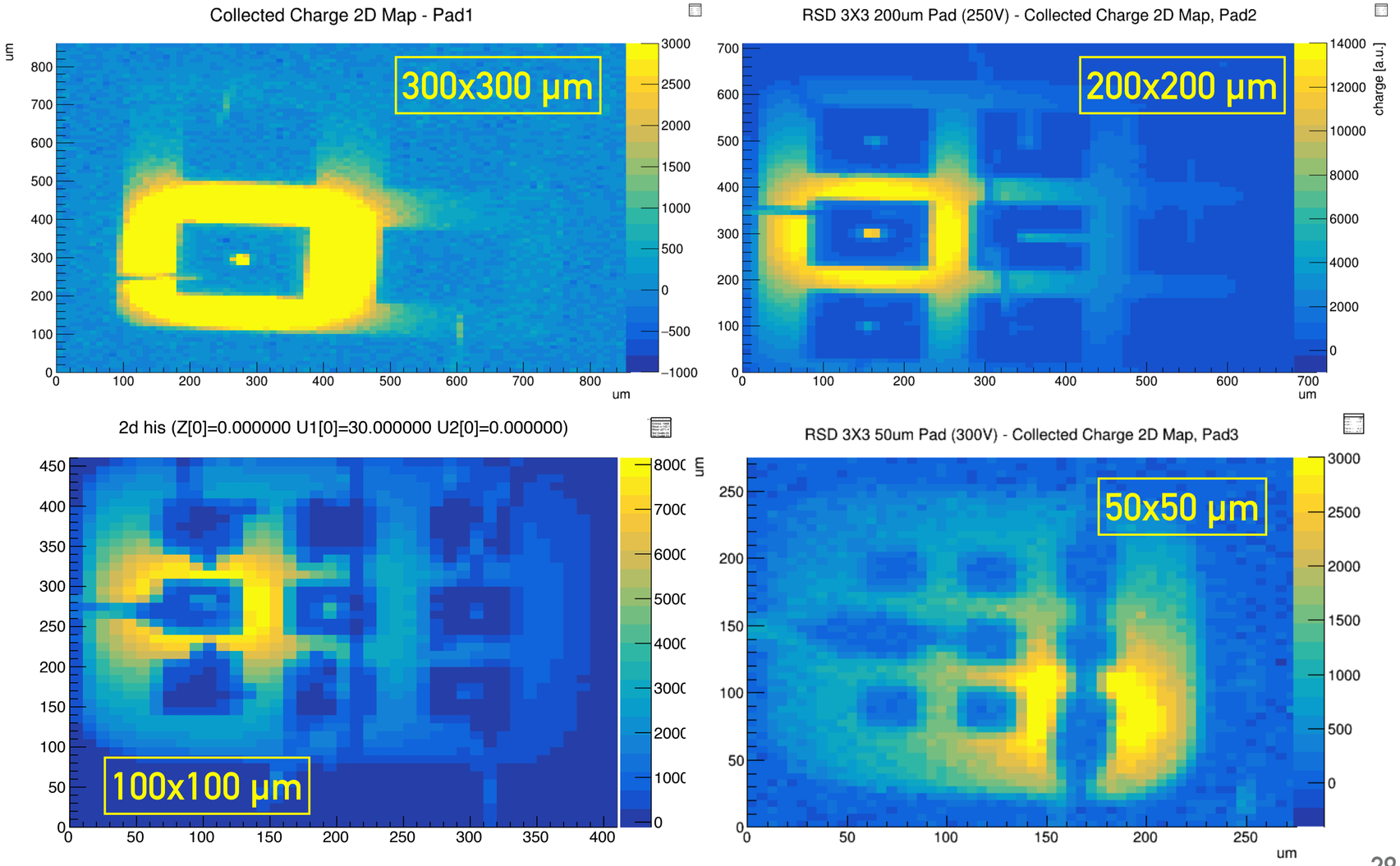


SPATIAL RESOLUTION

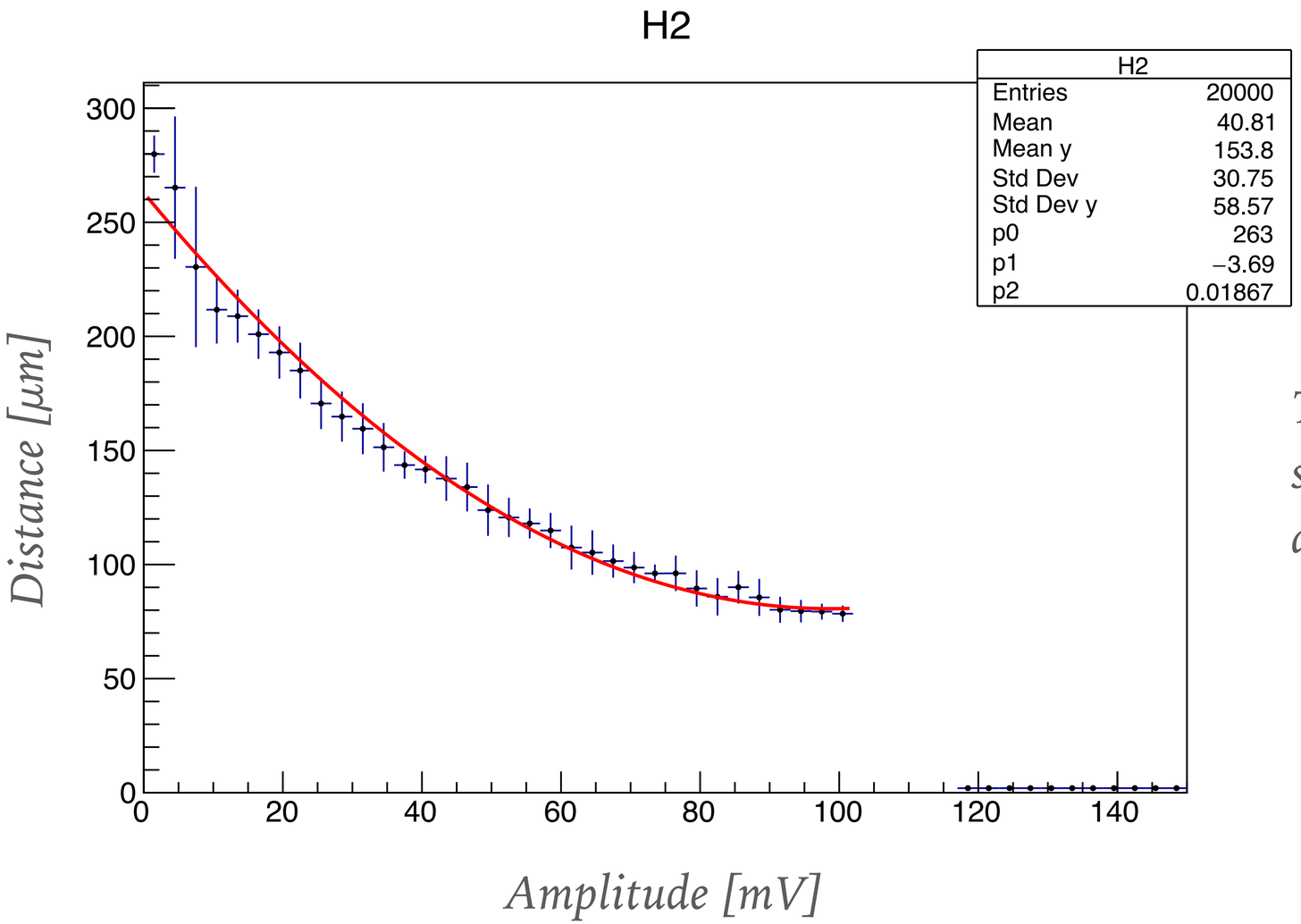
2D charge maps

Nominal RSD spatial resolution corresponds to the devices pitch

$\longrightarrow \sigma_{RSD} \geq 50\ \mu m$

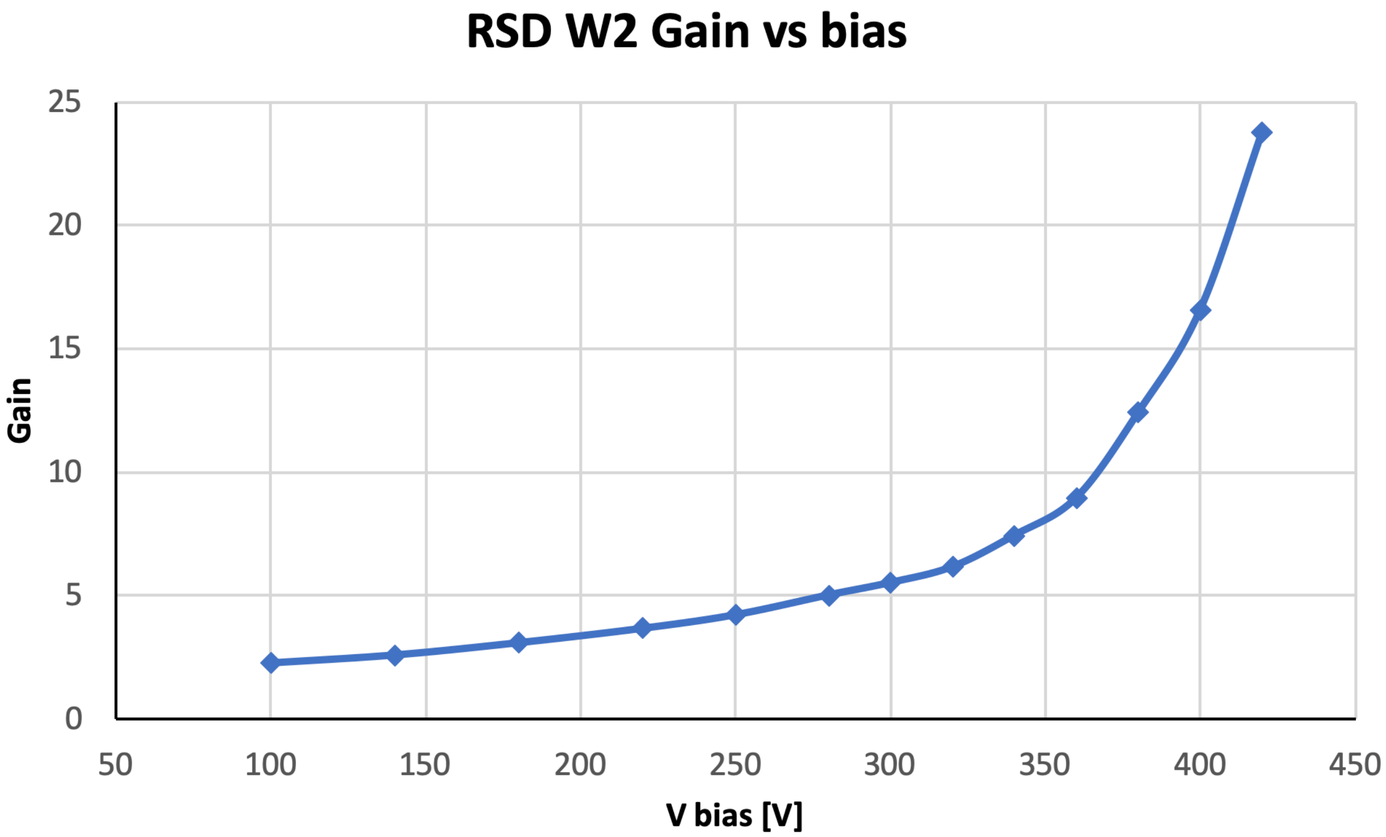


SPATIAL RESOLUTION EXTRACTION



The relationship between shot distance and signal amplitude can be extracted from data and it's very similar for each pad

SPATIAL RESOLUTION EXTRACTION



Gain is obtained as the ratio between the area of the DC signal in an LGAD and in a PiN device at each bias step