Development of AC-LGADs for Large-Scale High-Precision Time and Position Measurements

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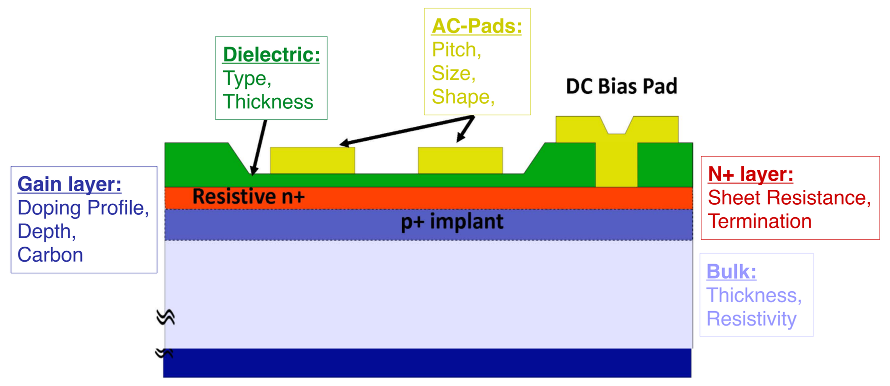
Introduction

AC-LGADs are a version of the LGAD which has been shown to provide spatial resolution on the 10's of micrometer scale

- AC-LGADs are designed with an un-segmented (p-type) gain layer and (n-type) resistive N+ layer, and a dielectric layer separating the metal readout pads
- High spatial precision is achieved by using information from multiple pads, exploiting the intrinsic charge sharing capabilities of the AC-LGAD provided by the common N+ layer



Using focused IR-laser scans, the following detector parameters have been investigated in RSD produced by FBK: sheet resistance of the n-layer, dielectric thickness, and pitch and size of the readout pads

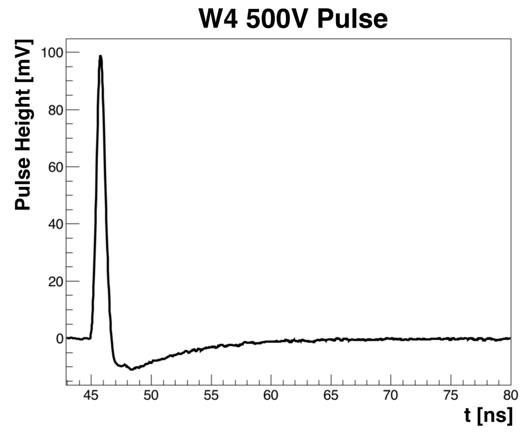
Tested wafers include # 3, 4, 8, 10, 13 and 15

Split table (with breakdown voltage)

wafer #	*n* -plus dose	*p* -gain dose	dielectric thickness	*p* -stop dose	substrate	Vbd
1	A	0.92	L	B	Si-Si	480
2	A	0.94	L	A	Si-Si	440
3	A	0.92	L	B	Epi	460
4	A	0.94	H	B	Si-Si	440
6	B	0.92	L	B	Epi	525
7	B	0.94	L	A	Si-Si	460
8	B	0.94	L	B	Si-Si	460
10	B	0.96	H	B	Si-Si	430
11	C	0.92	L	B	Si-Si	515
12	C	0.94	L	B	Epi	490
13	C	0.94	L	B	Si-Si	465
15	C	0.96	H	C	Si-Si	445

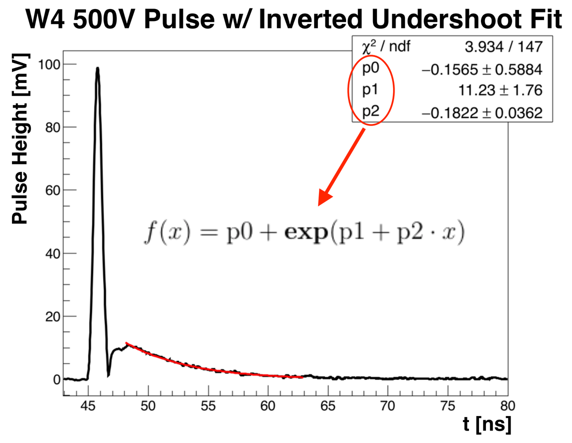
Calculating the RC time constant of a pulse undershoot

W4 500V Pulse



To calculate the RC time constant the undershoot is inverted and fit with an exponential

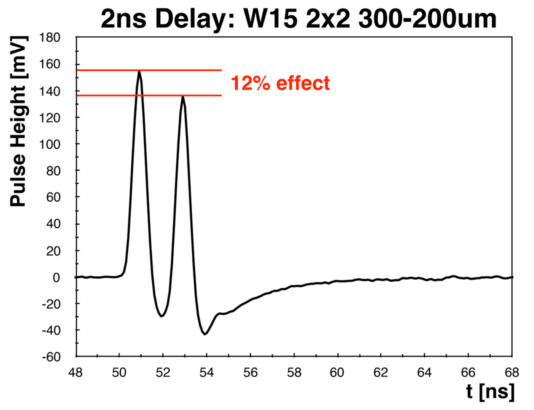
W4 500V Pulse w/ Inverted Undershoot Fit



Adding pulses back-to-back in time

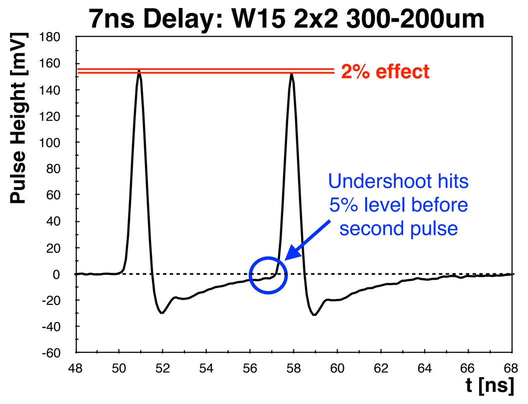
If we want a < 5% contribution from the undershoot, how close can a secondary pulse be?

2ns Delay: W15 2x2 300-200um



2ns delay: The primary pulse is at its deepest point in the undershoot and therefore the secondary pulses a large reduction in P-max. What does the combined effect look like if we have many pulses back-to-back?

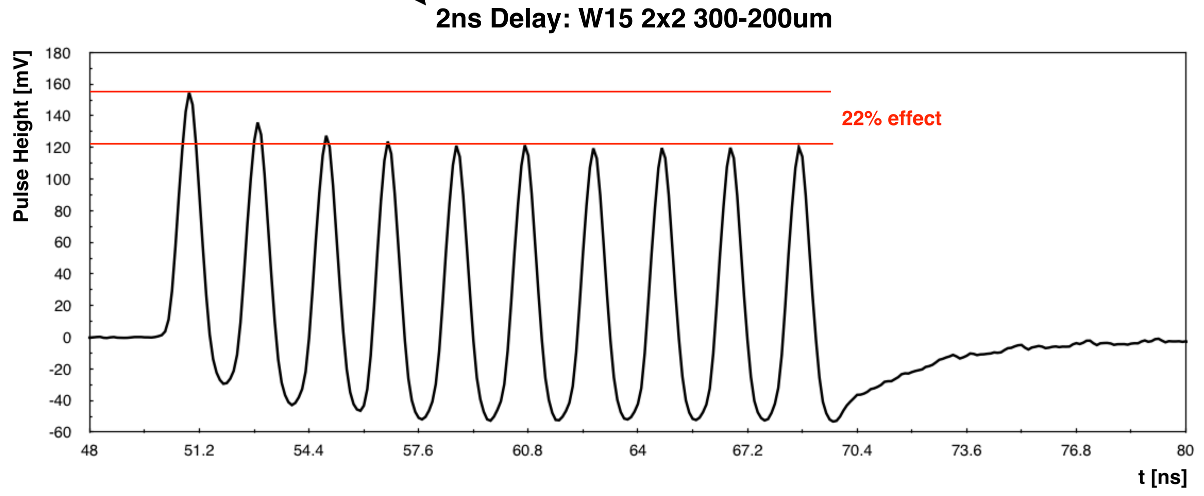
7ns Delay: W15 2x2 300-200um



7ns delay: The primary pulse has enough time for its undershoot to return to below the 5% level before the secondary pulses comes. As a result, there is minimal effect on the secondary pulse shape.

- a 7ns delay corresponds to a pulse repetition rare of ~0.14 GHz
- Higher repetition rates will likely cause deformation of subsequent pulses

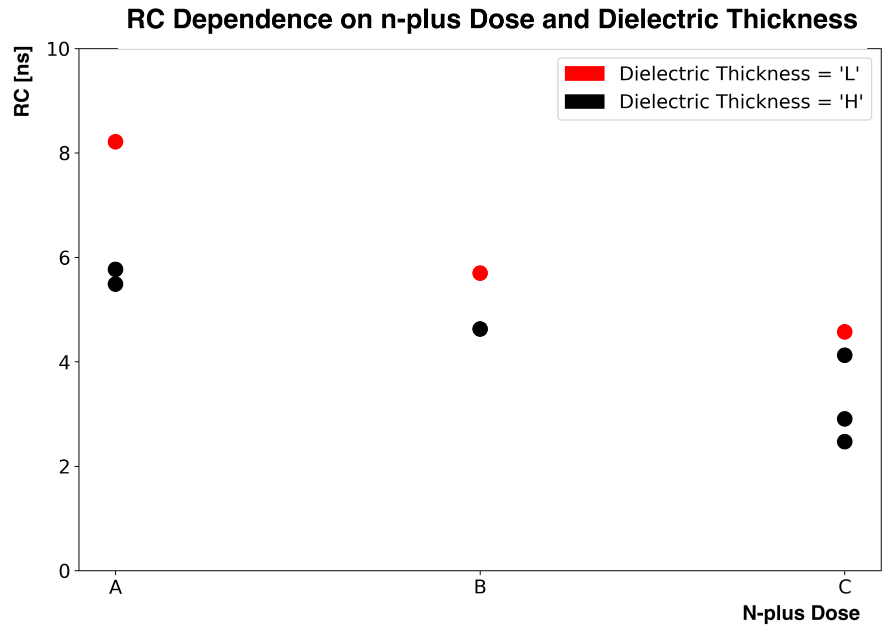
2ns Delay: W15 2x2 300-200um



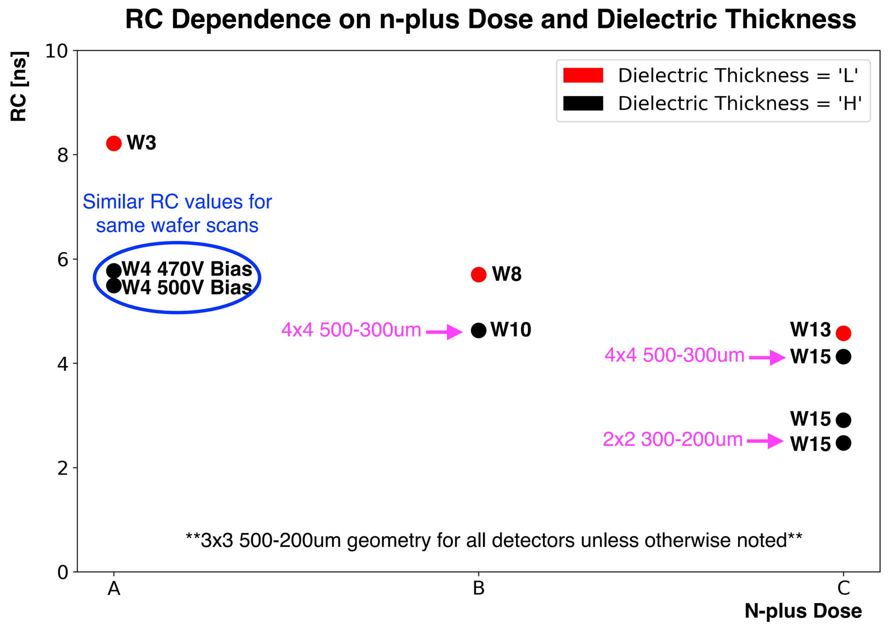
The reduction in P-max appears to level off after the 4th pulse with a ~22% reduction on the P-max of the initial pulse.

How is the pulse undershoot RC time content influenced by n-plus dose and dielectric thickness?

RC Dependence on n-plus Dose and Dielectric Thickness



RC Dependence on n-plus Dose and Dielectric Thickness



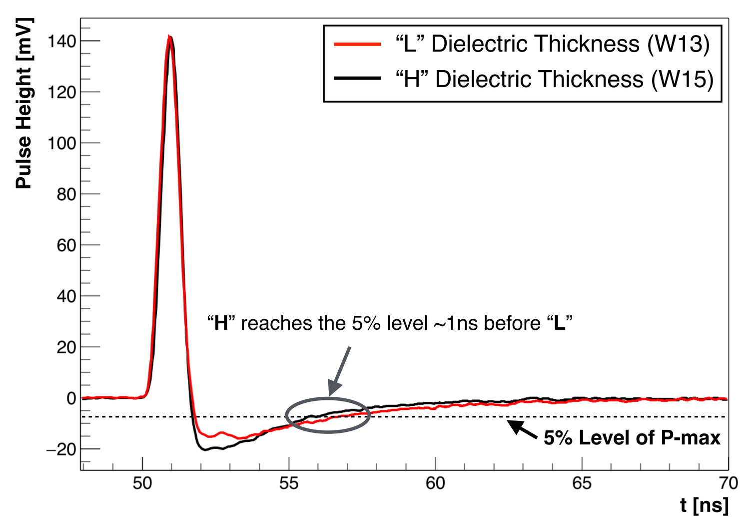
n-plus dose nomenclature:
"A" = 1/2 x Standard Dose
"B" = Standard Dose
"C" = 2 x Standard Dose

The Standard Dose "B" is approximately 1/10 of the usual LGAD doping density.

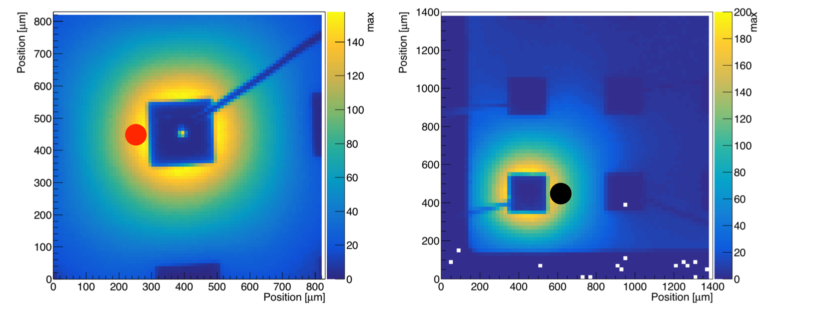
- RC depends on n-plus dose and dielectric thickness:
  - Larger n-plus dose -> smaller RC value
  - Higher dielectric thickness -> smaller RC value (as big an effect as n-plus dose)
- Pad size has a larger influence on RC value than pitch:
  - 300um pad size has larger RC than 200um pad size for same n-plus dose (expected to be larger by a factor of 9/4)
  - 300um pitch has slightly smaller RC to 500um pitch for same n-plus dose
- Consistent RC values measured for multiple scans of the same wafer at similar bias voltages

How does dielectric thickness effect RC?

Pulse Shapes - n-plus Dose "C" (Normalized)



W13 3x3 500-200um W15 3x3 500-200um

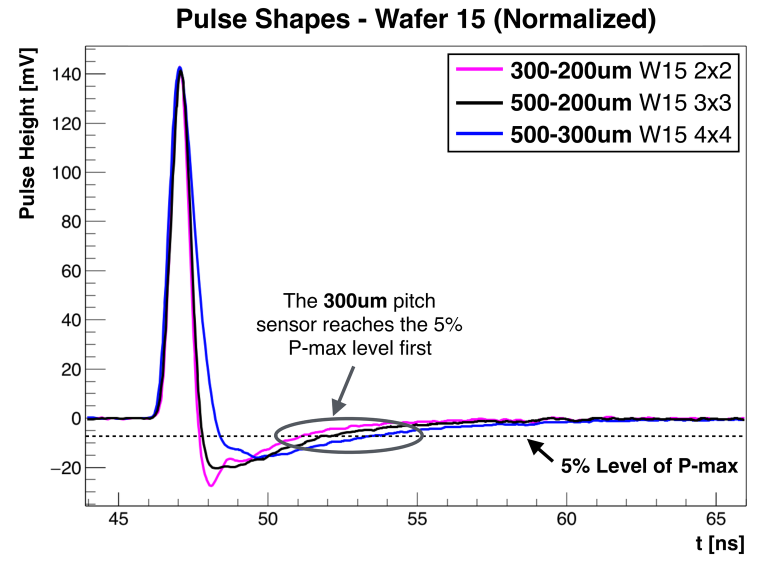


Colored circles on the 2D P-max profiles indicate the location of the pulses shown in the left plots

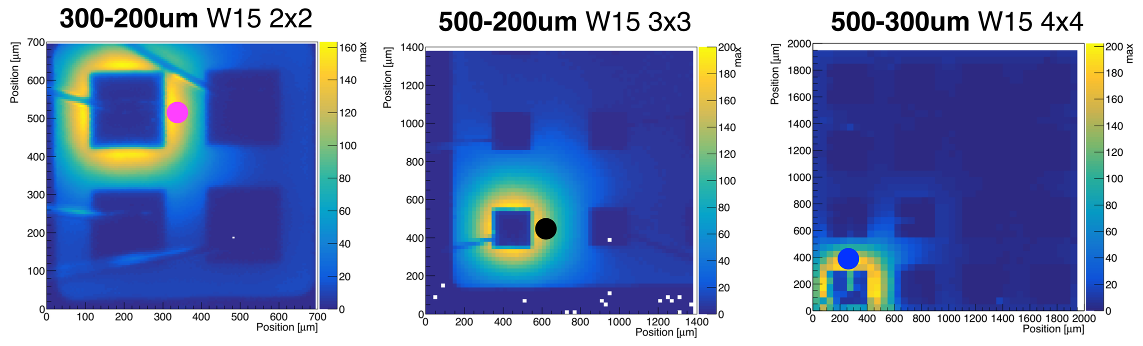
Normalized pulses are identical except for in the undershoot. Pulses for sensor with the larger dielectric thickness has bigger undershoot but then returns to backline quickest
- Larger undershoots return to baseline faster because integral is the same!

How does geometry effect RC?

Pulse Shapes - Wafer 15 (Normalized)



300-200um W15 2x2 500-200um W15 3x3 500-300um W15 4x4



Colored circles on the 2D P-max profiles indicate the location of the pulses shown in the left plots

The **300-200um** W15 2x2 sensor has the largest undershoot and returns to the 5% of P-max level the quickest at ~5ns (compared to ~6ns for the **500-200um** W15 3x3 sensor and ~7.5ns for the **500-300um** W15 4x4 sensor).
- Smallest pitch sensor has the smallest RC and quickest return to baseline
- Largest pad size sensor has the largest RC and slowest return to baseline
- Keep RC small by minimizing the pitch and the pad size -> best for high repetition rate experiments

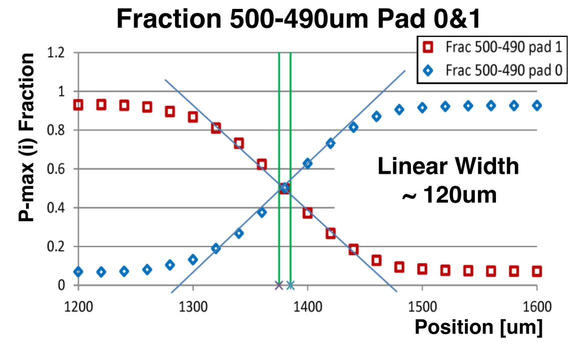
P-max Fractions

To determine the position of a signal we need a linear correlation between p-max fraction and position on detector

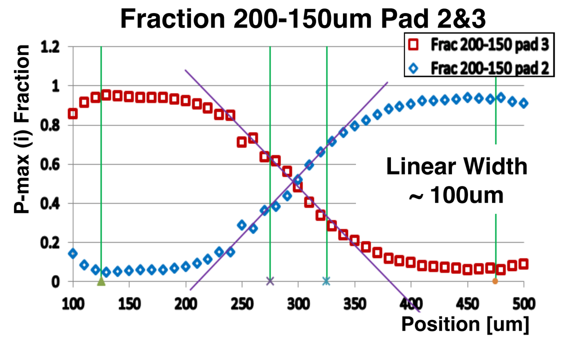
For **500-490um** and **200-150um** geometries there is a linear region between the pads which extends beyond the gap
- At some distance under the pad, the line becomes horizontal and the correlation is lost so no position information is available

More geometries should be measured in order to determine if we can extend the linear region farther under the metal pad

Fraction 500-490um Pad 0&1

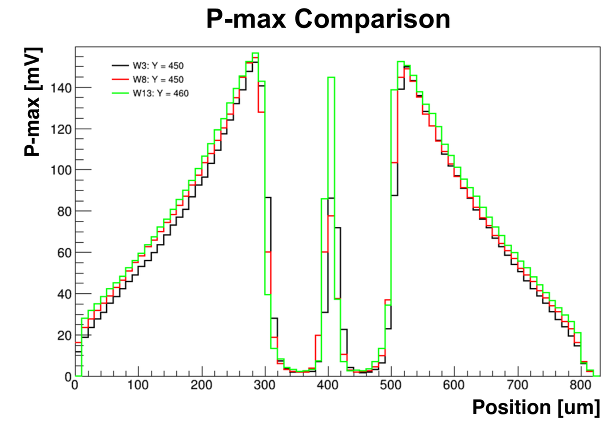


Fraction 200-150um Pad 2&3



N-plus effect on p-max and jitter

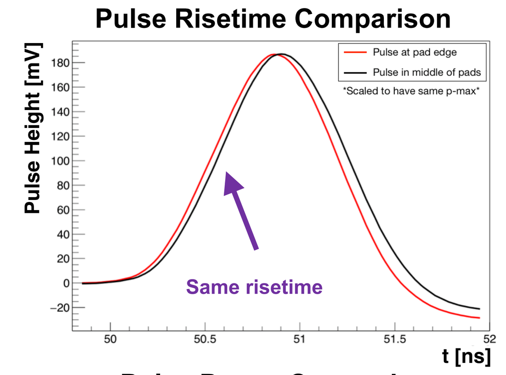
P-max Comparison



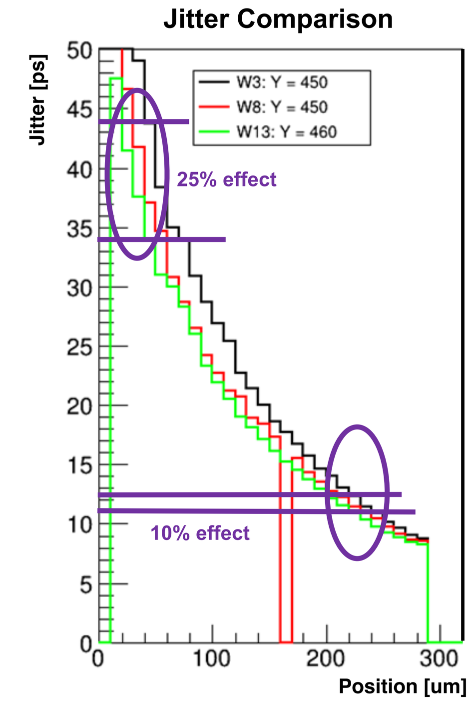
wafer	*n* -plus dose	*p* -gain dose	dielectric thickness	*p* -stop dose	substrate	Vbd
3	A	0.92	L	B	Epi	460
8	B	0.94	L	B	Si-Si	460
13	C	0.94	L	B	Si-Si	465

Pmax:
small differences
W3 slightly smaller close to adjacent pad

Pulse Risetime Comparison



Jitter Comparison



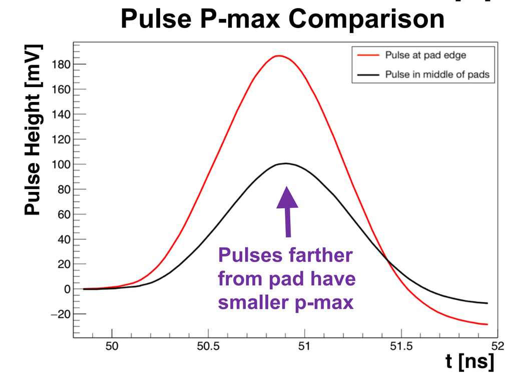
Jitter:
large differences growing toward adjacent pad
W3 larger

What causes the increase in the jitter as you go away from the pad?

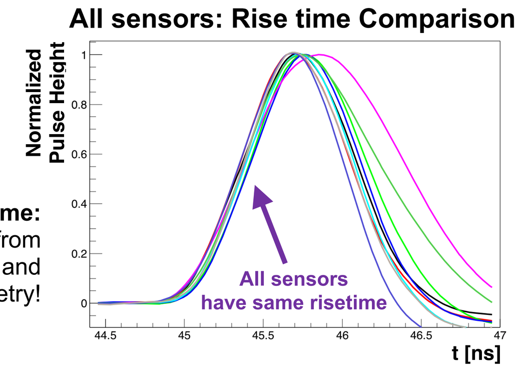
$$\mathrm{Jitter} = \frac{\mathrm{risetime}}{\mathrm{SNR}}$$

The risetime stays constant when moving away from the pad, so the jitter increases as a result of the reduction in p-max

Pulse P-max Comparison



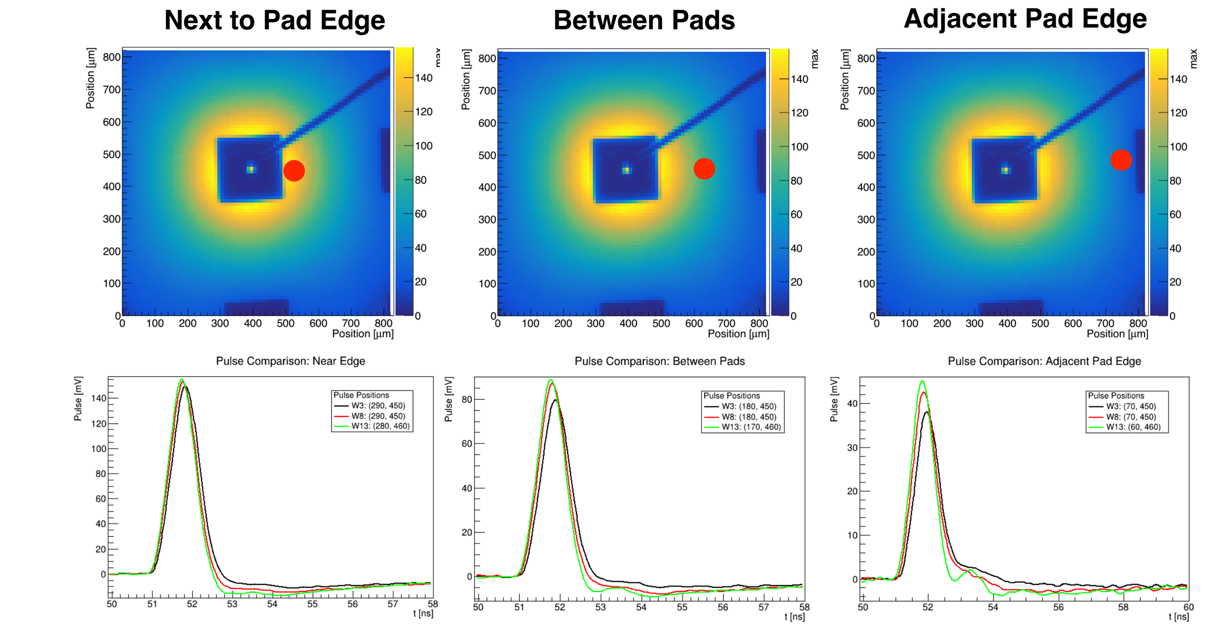
All sensors: Rise time Comparison



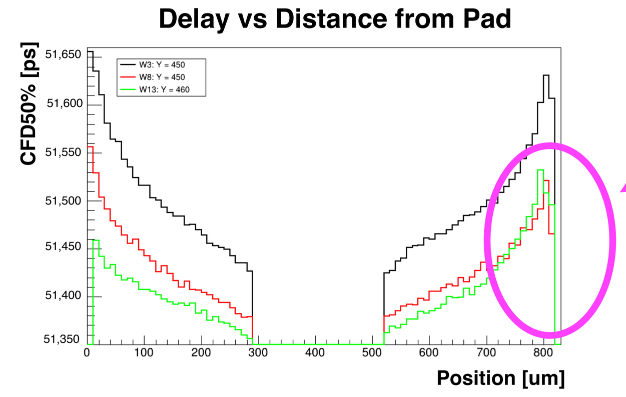
Risetime:
Not only is rise time independent of distance from pad, is is also independent of wafer type and geometry!

CFD50% (delay) from n-plus and distance from readout pad

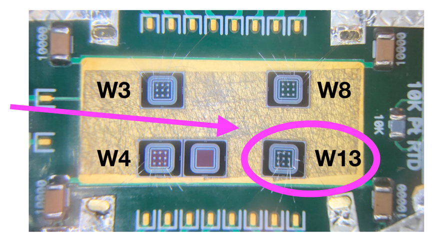
Next to Pad Edge Between Pads Adjacent Pad Edge



Delay vs Distance from Pad



The large asymmetry we see in the W13 data is an effect of the rotation of the W13 sensor, relative to the W3 and W8 sensors, on the readout board.



- The CFD50% (delay) depends on n-plus dose and on distance from the readout pad
  - Lower n-plus dose corresponds to larger delay
  - Delay increases with distance from the pad

Conclusions

- Pulse undershoot RC decay varies from **2.5ns** to **8.2ns** and depends on detectors parameters including *n*-plus dose and dielectric thickness:
  - RC is *larger* for less doped sensors with a thicker dielectric
  - RC is *smaller* for higher doped sensors with a thinner dielectric
- Pulse shape in first nanosecond was constant for all parameters measured -> stable risetimes means that time resolution is consistent for these sensors
- Jitter depends on 1/p-max as expected