Radiation Detectors Group

Soft X-Ray Low Gain Avalanche Detectors with 55 µm pitch for Imaging Applications using the Timepix4 ASIC.

Centro Nacional de Microelectrónica IMB

CSIC Consejo Superior de Investigaciones Científicas

The 39th RD50 Workshop

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Introduction

- Why small pixel LGAD's?
- Issue with Small Pixel LGADs
- AC-LGAD – Solving the problem of small pixel LGAD's
- P-SPICE Model
- TCAD Model
- Conclusion

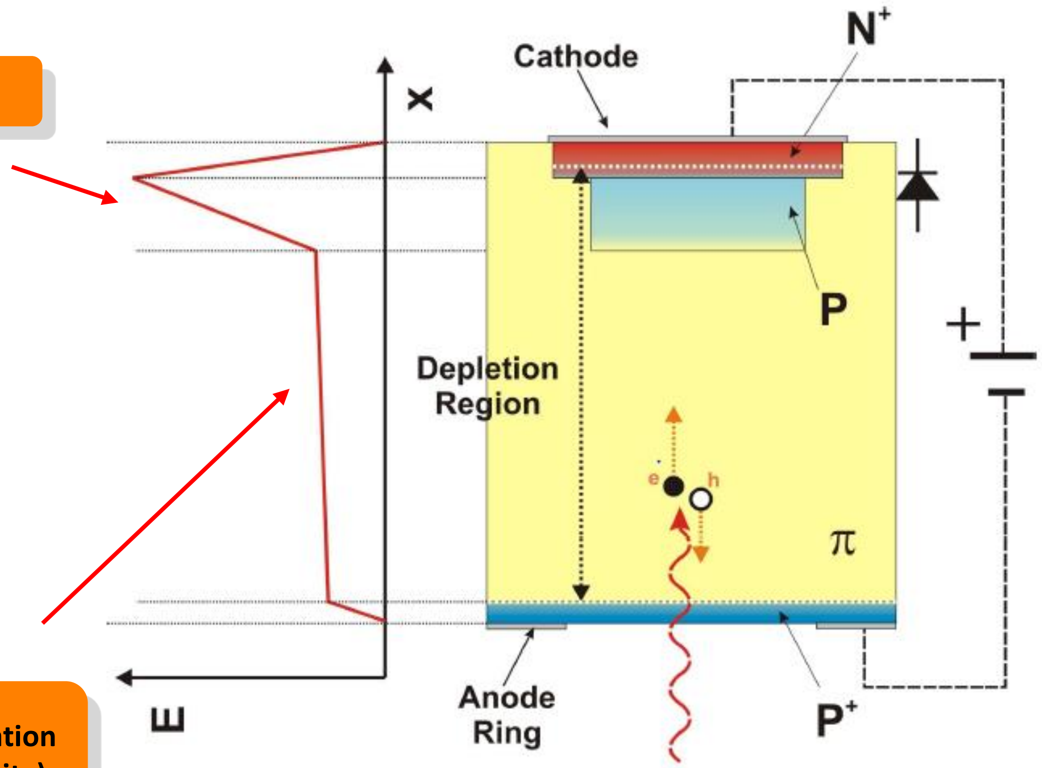
Why Small Pixel LGAD’s?

- Small pixels provide a very good spatial resolution.
- We want to benefit from the excellent capabilities of the Timepix3/Timepix4 ASIC.
- Synchrotron Applications
  - Timepix4 timing bin of 195 ps is well below the typical interbunch spacing of synchrotron electron bunches of a few ns.
  - **Material Science** -to look at the absorption edges of transition metals, important for magnetic domain studies in the context of storage media. This would be in **the 700 - 900 eV** range
  - **Biological samples studies**: LGADs with a charge gain somewhat higher than 20 would be needed to reach the so-called “water window”, between the Carbon and Oxygen edges (282 eV to 533 eV – Carbon and Oxygen being present in all biological samples).
  - For all these studies, at photon energies below 1 keV **the insensitive layer** at the photon entrance side of the LGAD must be minimized.
- High energy Physics
  - LHCb –Velopix
- Medical Physics
  - Analysing biopsy's –typically thin, more information gathered by using “soft” Xrays

LGAD Basic Structure

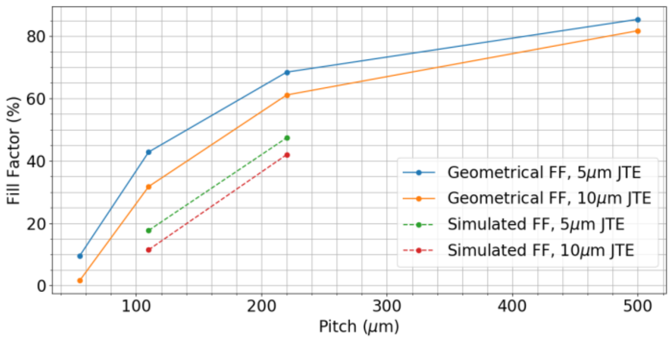
Impact ionisation region

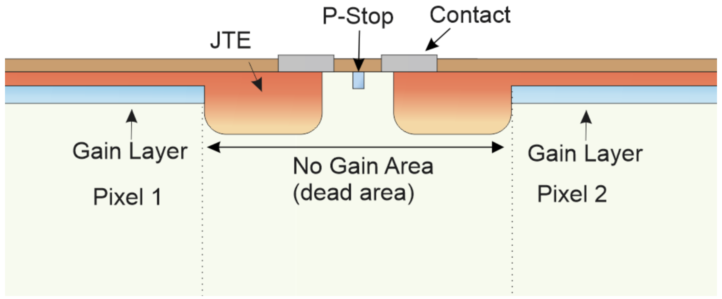
Electrons traveling at their saturation velocity (good for signal uniformity)

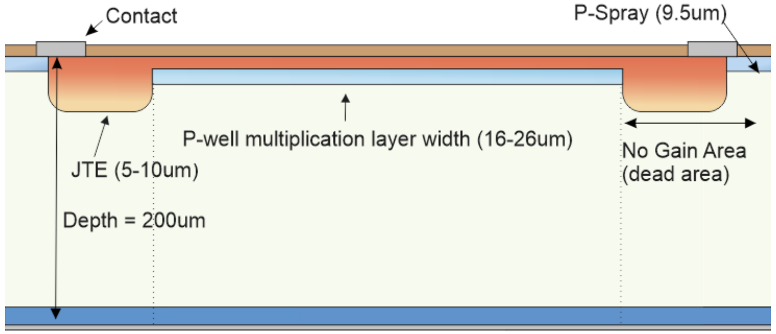


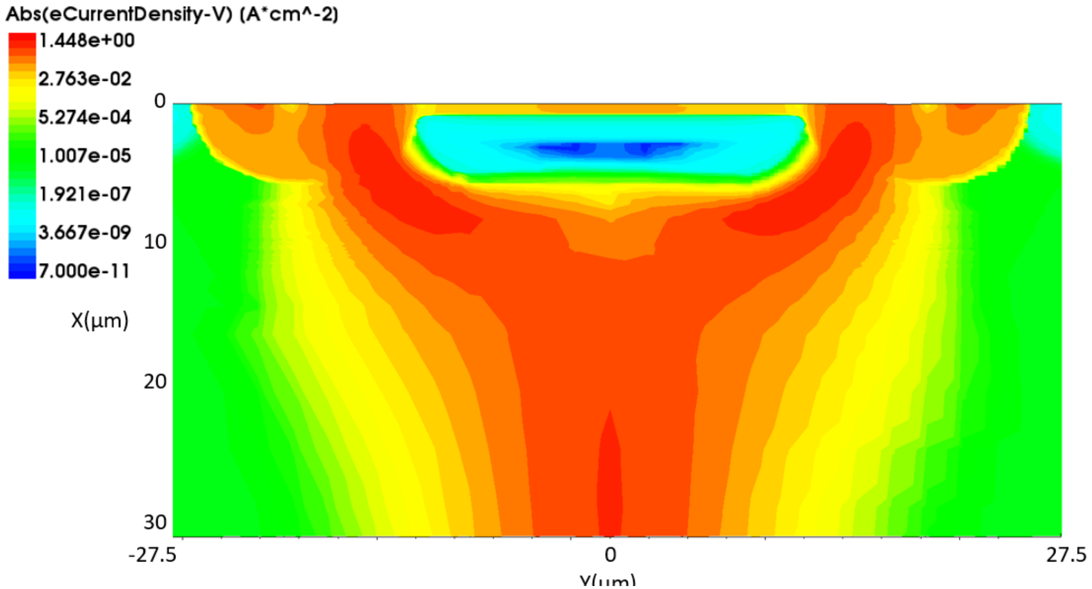
Small Pixel Problem

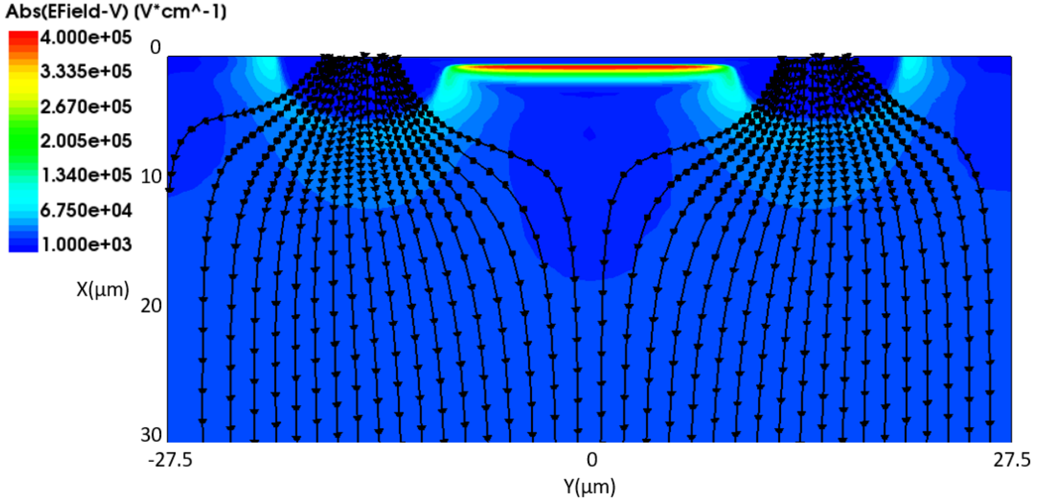
https://doi.org/10.1016/j.nima.2021.165746





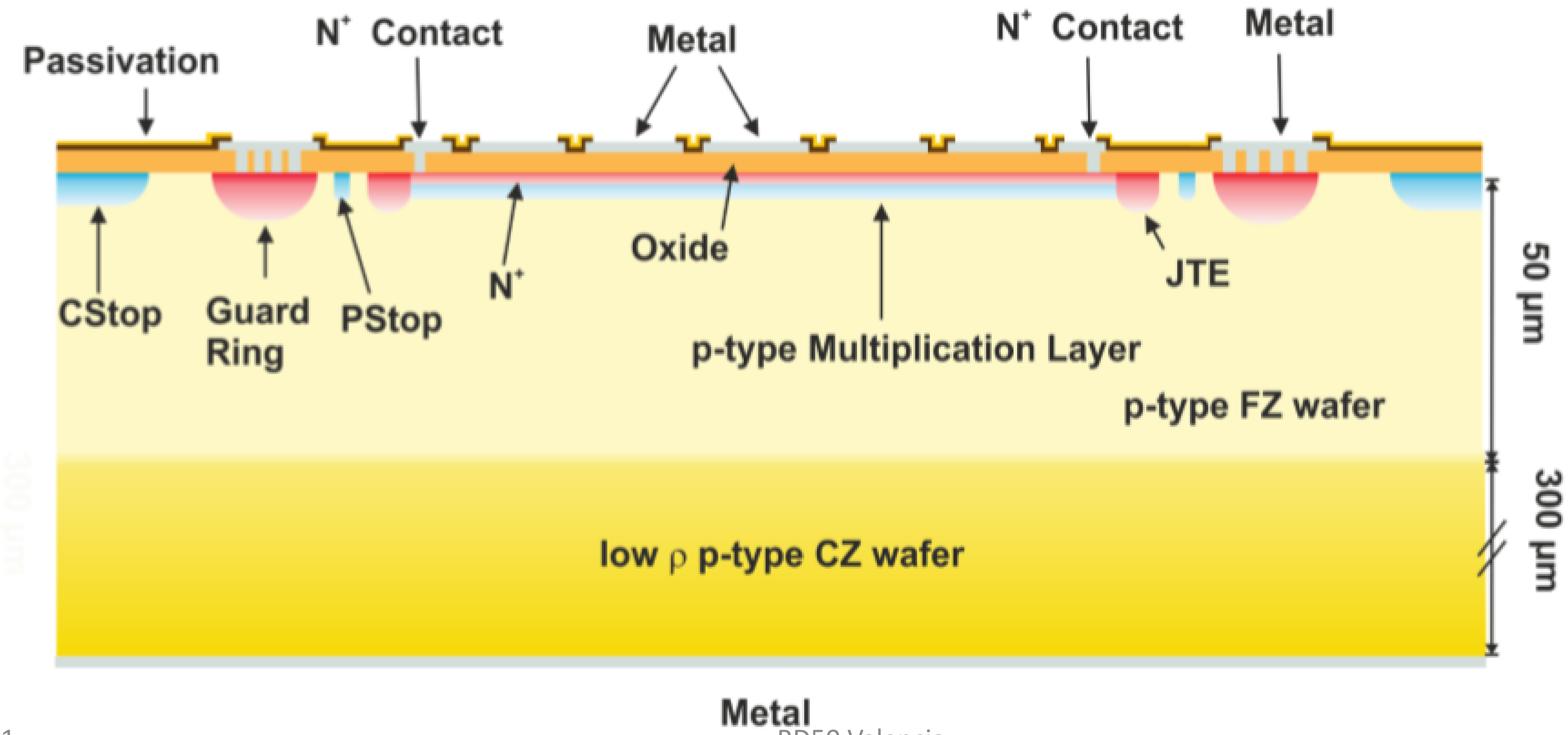






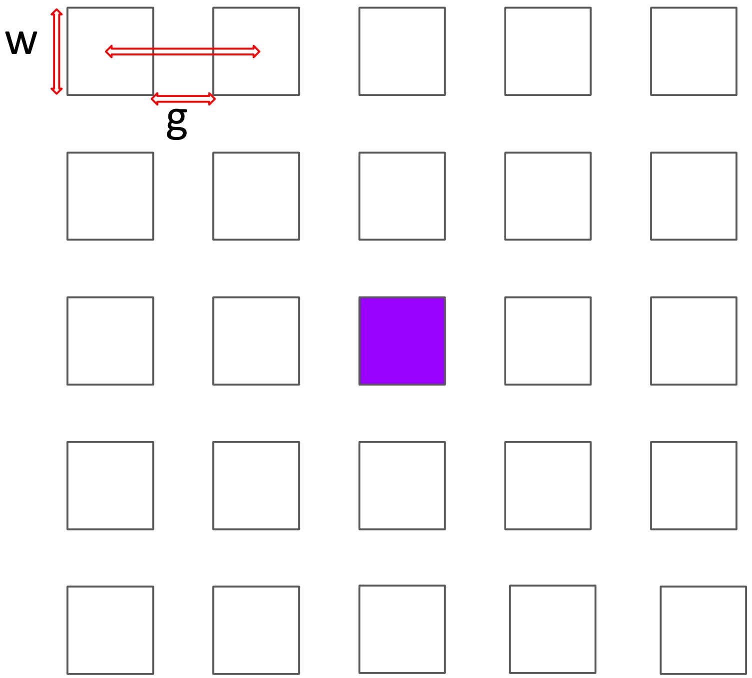
AC-LGAD Basics

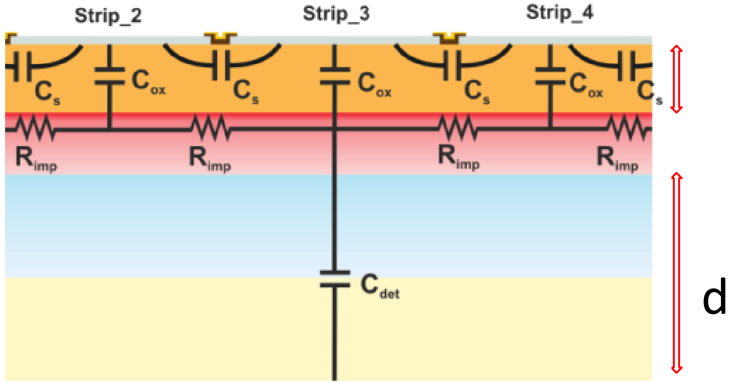
- AC-LGAD replaces the segmentation of the pad implants into continuous sheets of multiplication layer and n+ layer and only segments the metal connected to the readout
- The signal is AC-coupled into the metal pads by another continuous sheet of coupling oxide.



P-SPICE Model

PSPICE Model

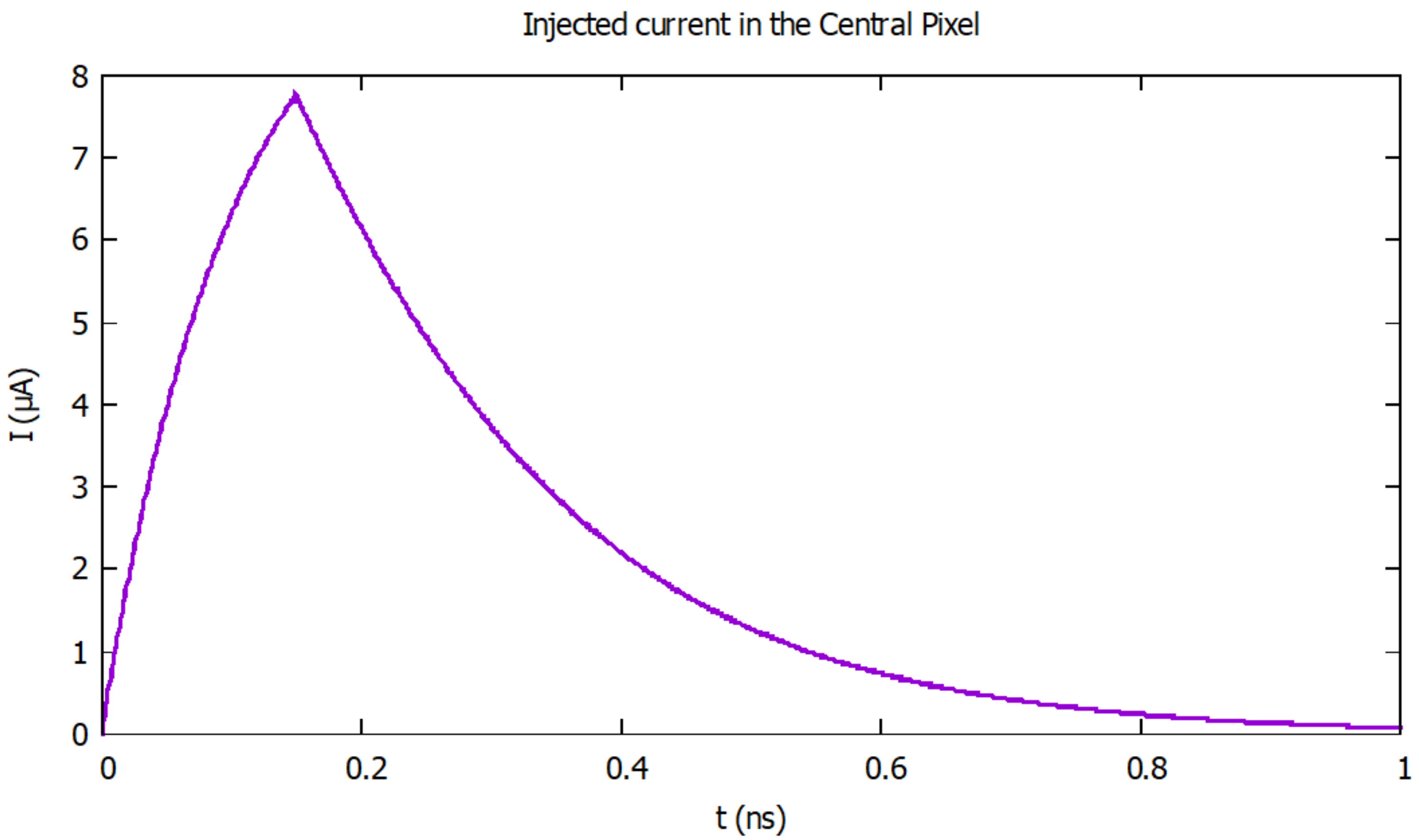




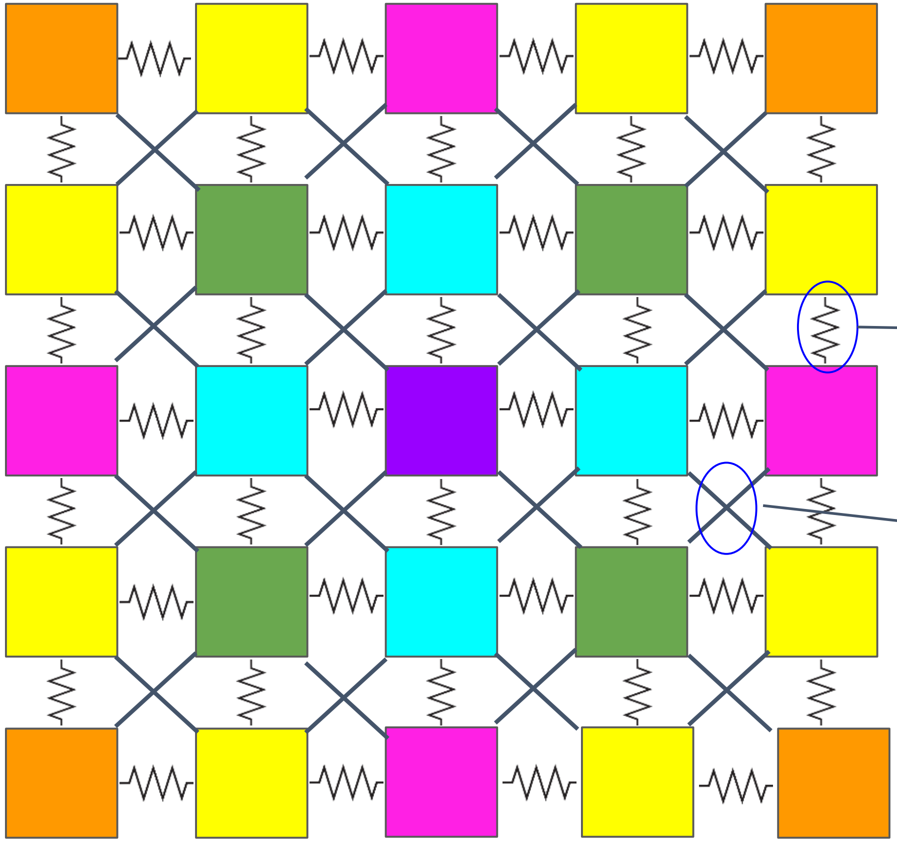
25 square pixels ⟹ 256x256 square pixels

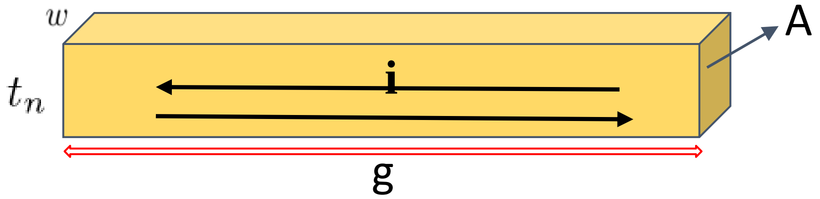
Timepix3 LGAD Standard values	
w(μm)	32
p(μm)	55
g=w-p(μm)	23
d(μm)	50

The injected pulse



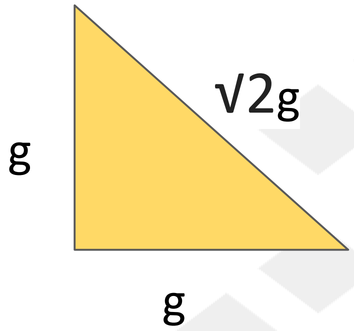
PSPICE - Resistances



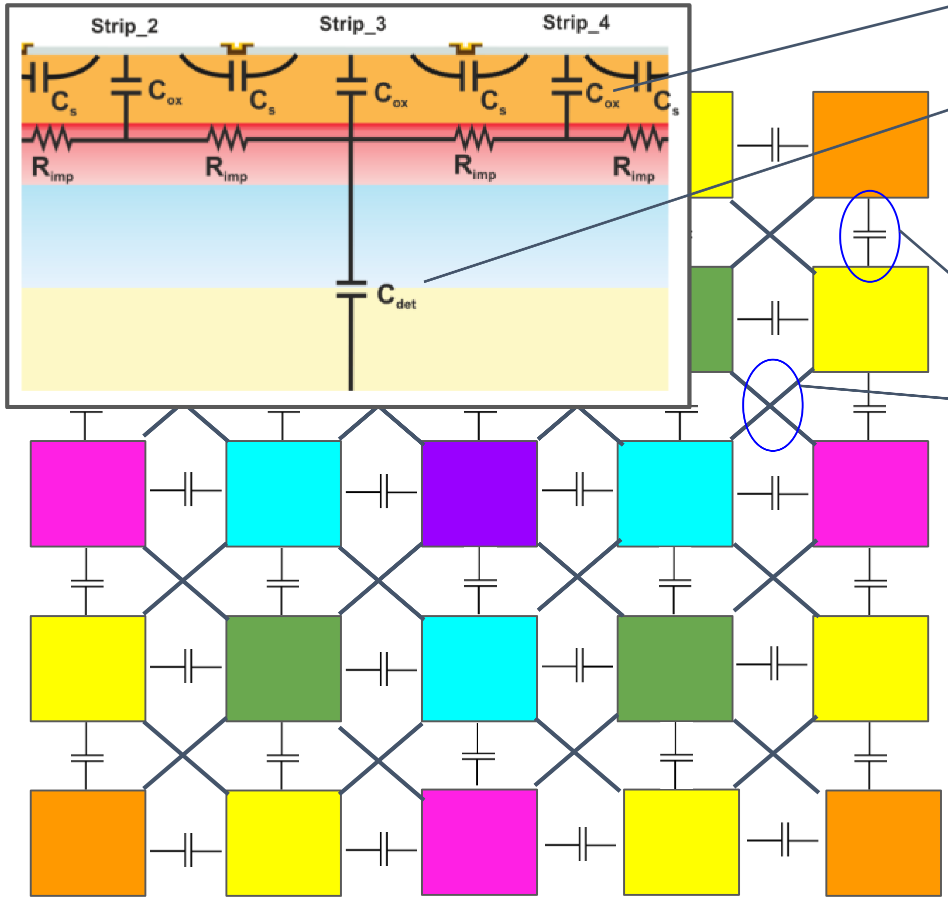


$$R_i = \rho L/A = (\rho/t_n) g/w = R_S (g/w)$$

$$R_{diag} = \sqrt{2} R_i$$



PSPICE - Capacitances



$C_{det}=\epsilon_s w/d$ $C_{ox}=\epsilon_{ox} w/t_{ox}$

$C_s=[0.23(d/w)^{0.75}/(g/d+0.18)-0.07d/w]\mathbf{C_d}$

$C_{diag}=(0.1)^{w/d}[1-1.15(g/w)(7/(g/d+3)-1]\mathbf{C_d}$

A.Cerdeira, IEEE Transactions on Nuclear Science 44(1): 63-66, 1997

PSPICE - Noise

Pspice calculates the **noise spectral distribution** in every part of the circuit due to all contributions of the entire device

- Flicker noise
- Shot noise
- Thermal noise

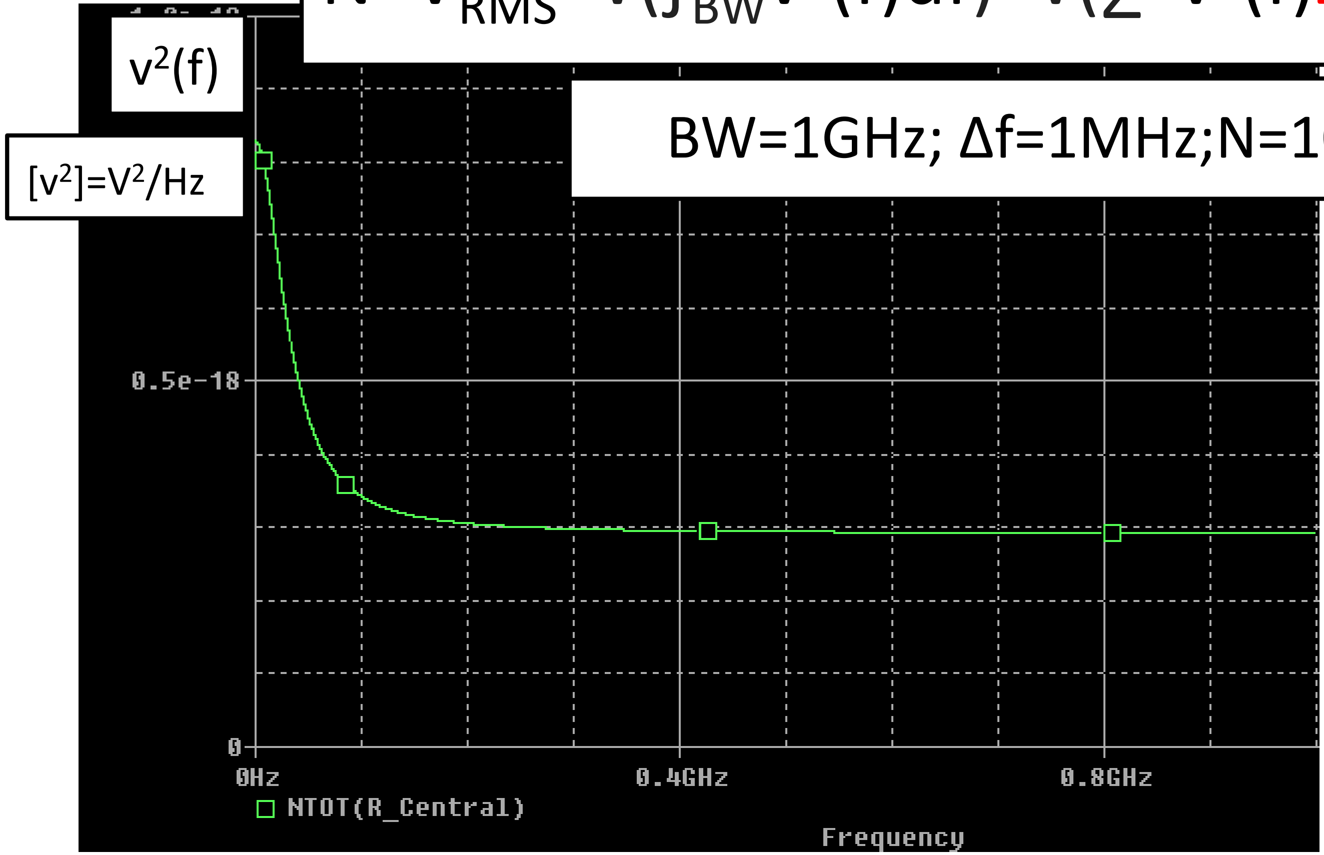
$v^2(f)$

$[v^2]=V^2/Hz$

PSPICE - Noise

$$N=V_{RMS}=\sqrt{\left(\int_{BW} v^2(f)df\right)}=\sqrt{\left(\sum^{N} v^2(f)\Delta f\right)}$$

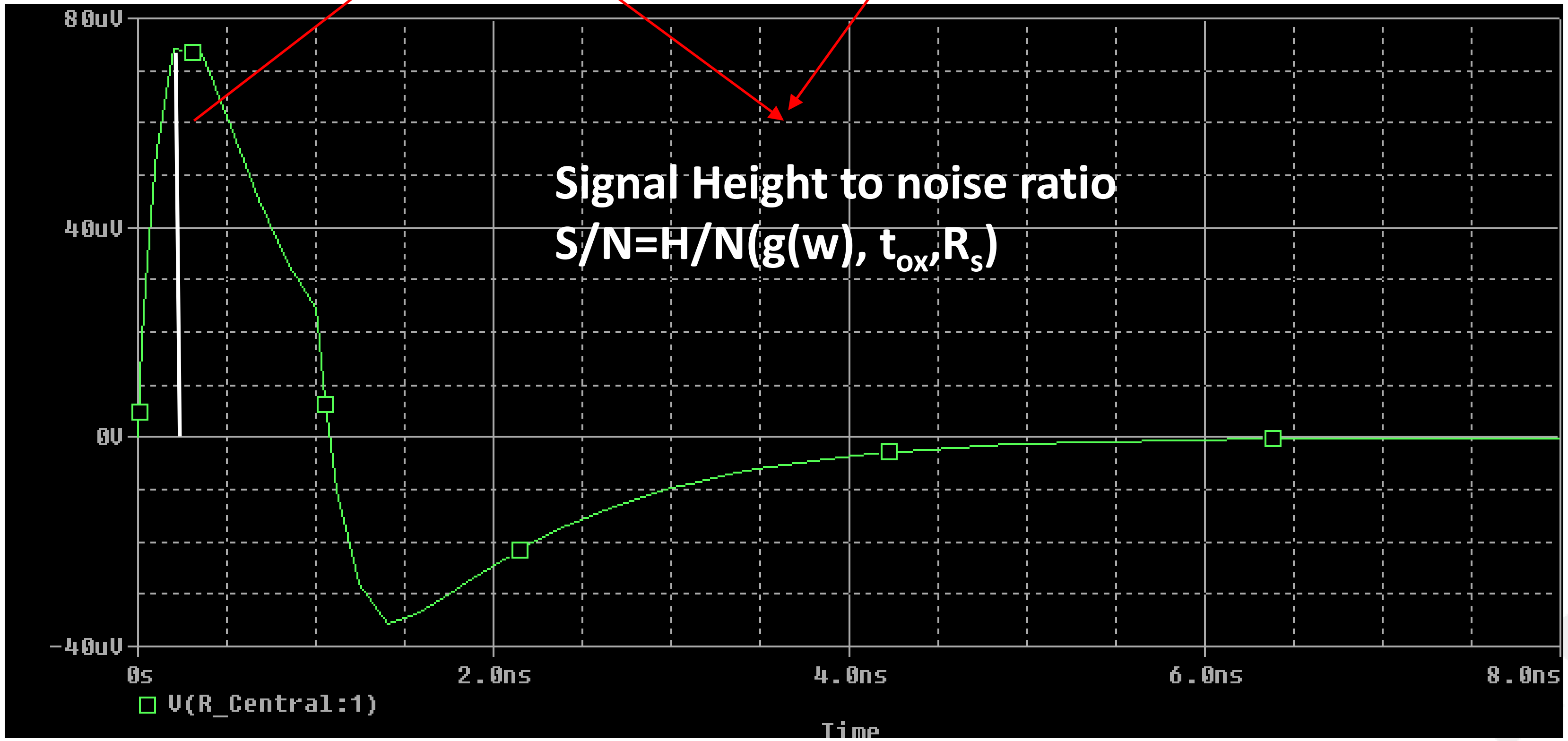
BW=1GHz; Δf=1MHz;N=1000



PSPICE - Signal

$H=V_{max}$

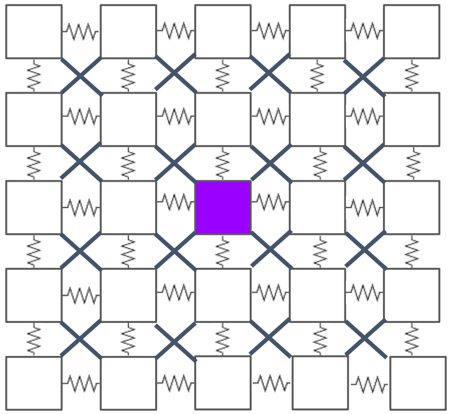
$N=V_{RMS}=\sqrt{\int_{BW} v^2(f)df}=\sqrt{\sum^N v^2(f)\Delta f}$



RiseTime : $T_r=T(V=90\%H)-T(V=10\%H)$

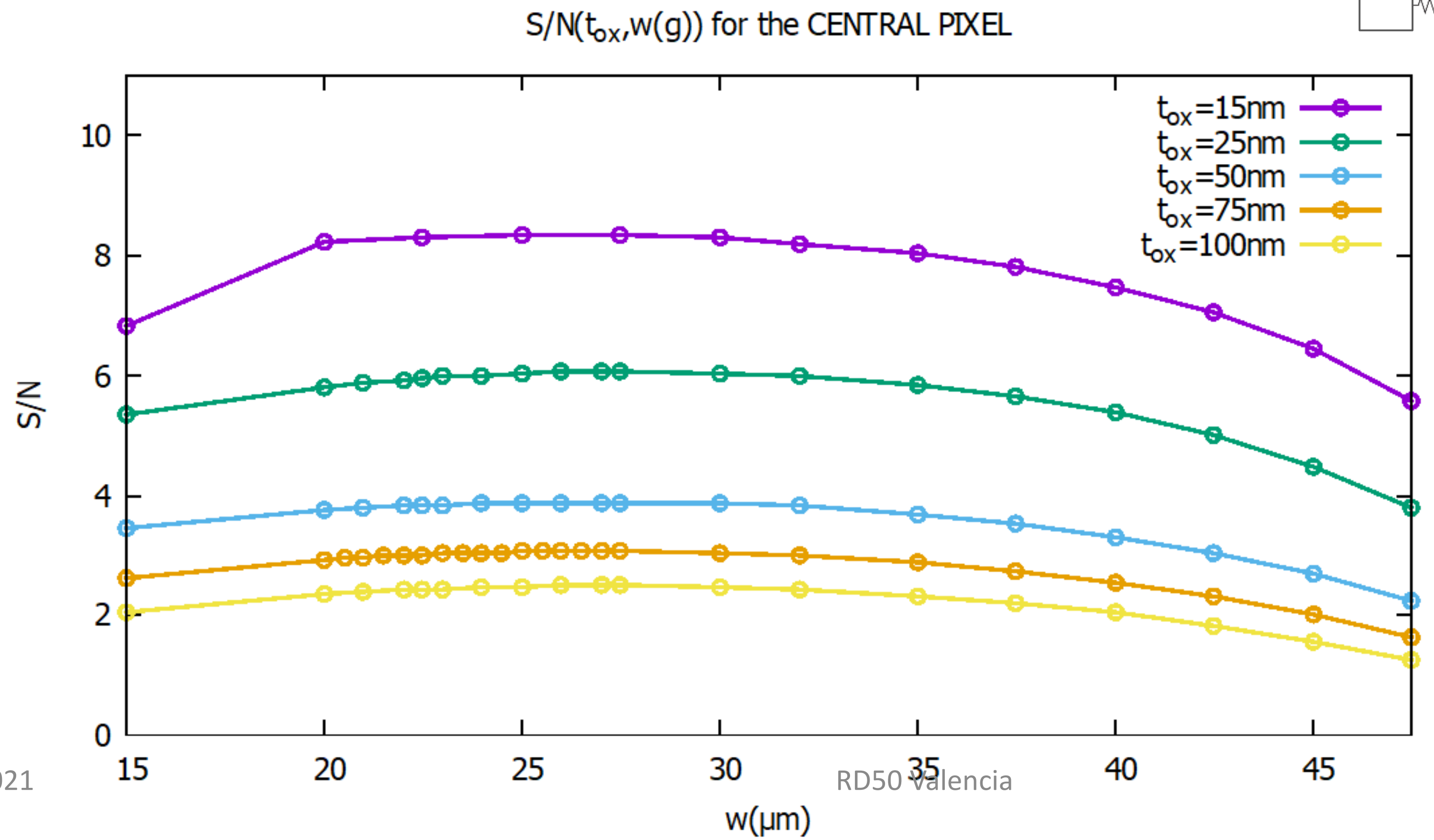
Jitter : $\sigma_{jitter}(g(w),t_{ox},R_s) \approx T_r/(S/N)$ → To be minimized

PSPICE – Some Results



TCAD:

- **Decreasing oxide thickness tox improves S/N.**
- **Decreasing pad size w (increasing interpixel gap=p-w) improves S/N.**

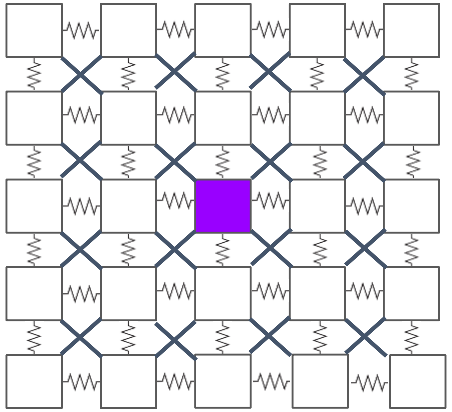


Rs=696Ω
d=50um

$w_{standard}$=32um

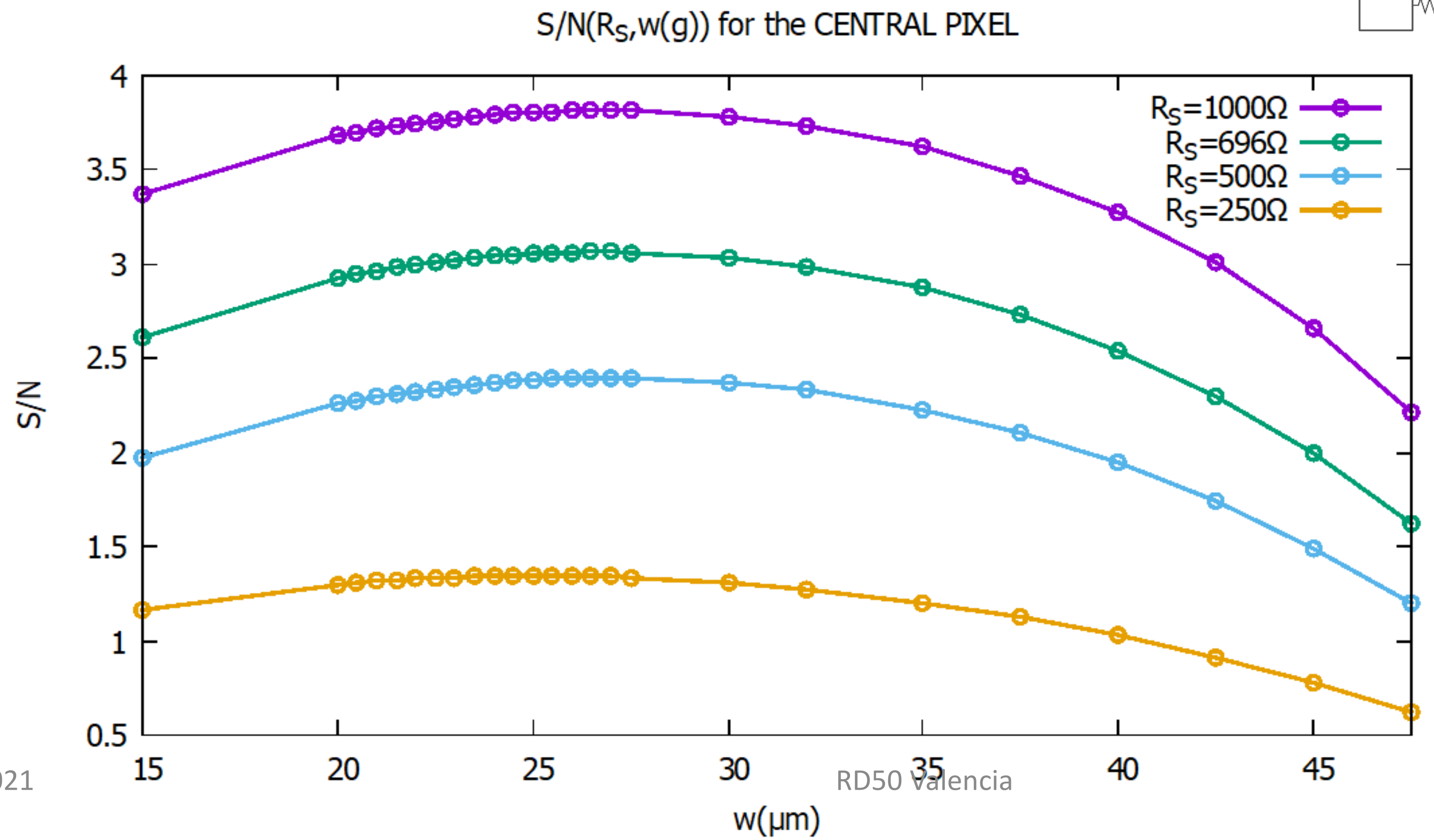
$w_{optimal}$≈27.5um

PSPICE – Some Results



TCAD:

- **Increasing sheet resistance Rs improves S/N.**
- **Decreasing pad size w (increasing interpixel gap=p-w) improves S/N.**

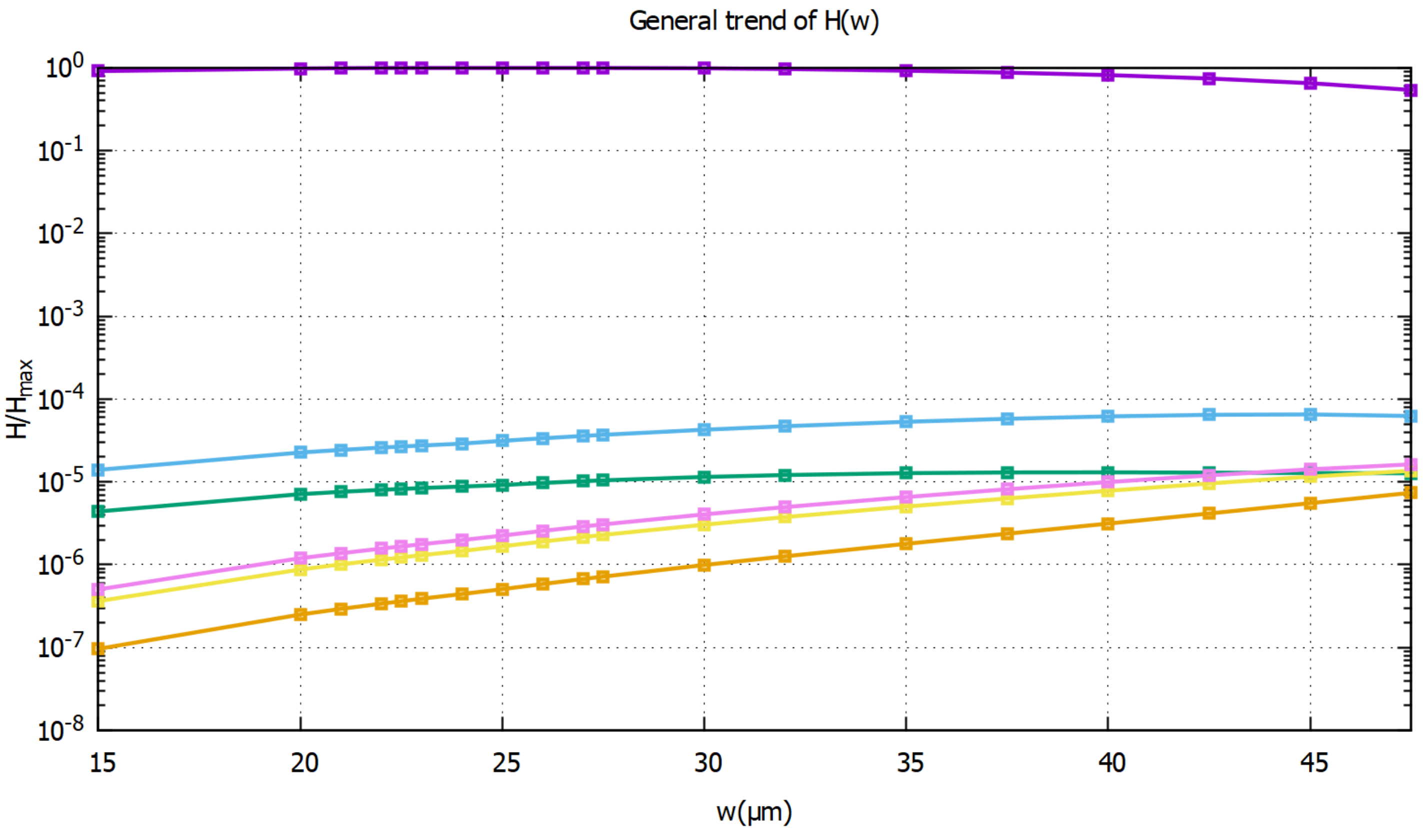


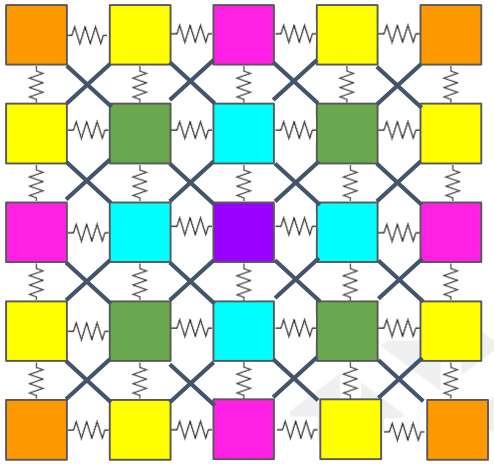
tox=75nm
d=50um

$w_{standard}$=32um

$w_{optimal}$≈27.5um

Neighboring pixels → General trend of H(w) **(tox=75nm and Rs=696Ω)**



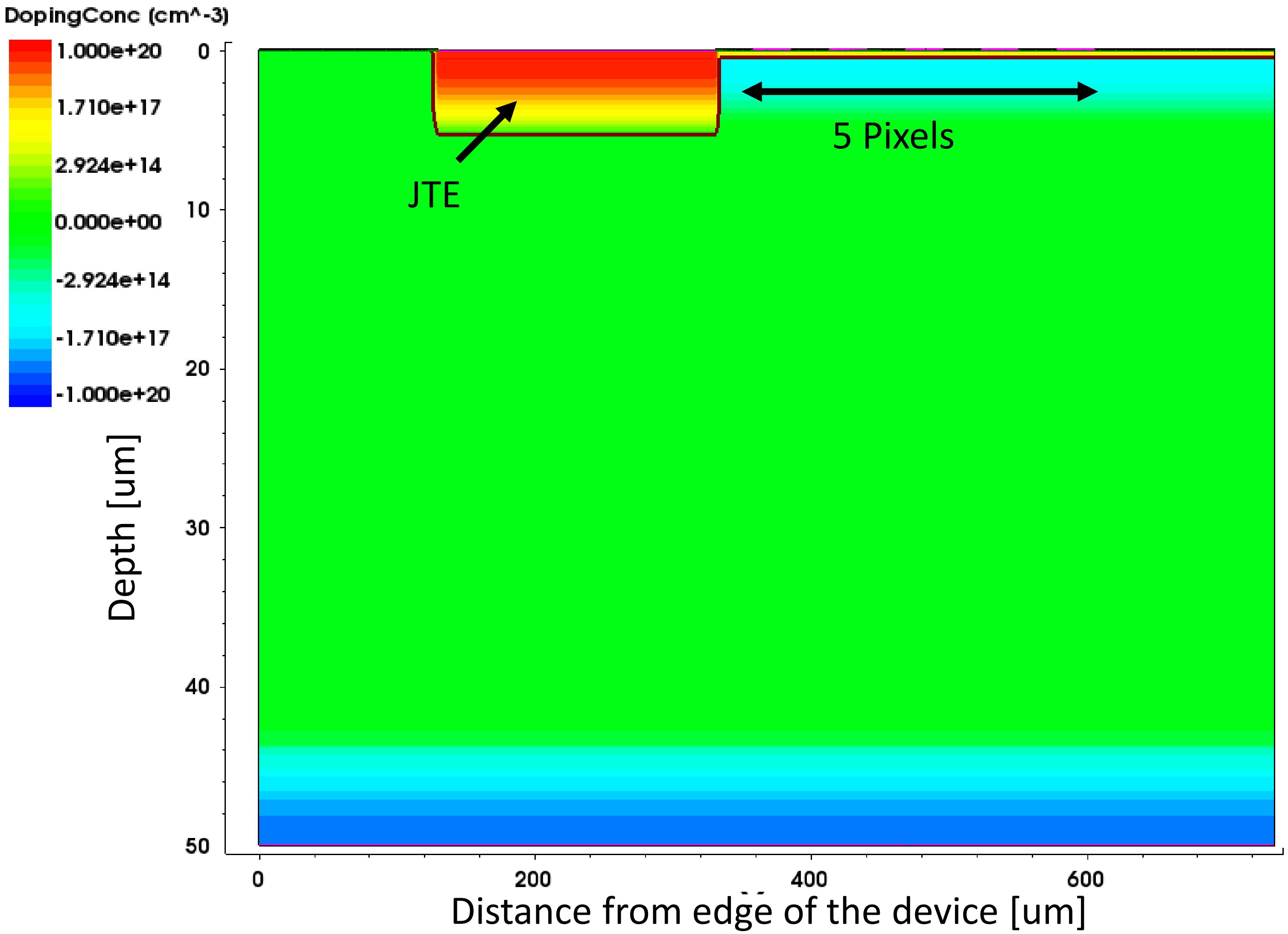


PSPICE preliminary Results

- **Increasing sheet resistance Rs improves S/N.**
- **Decreasing oxide thickness tox improves S/N.**
- **PSPICE model optimised to reduce charge sharing between pixels.**

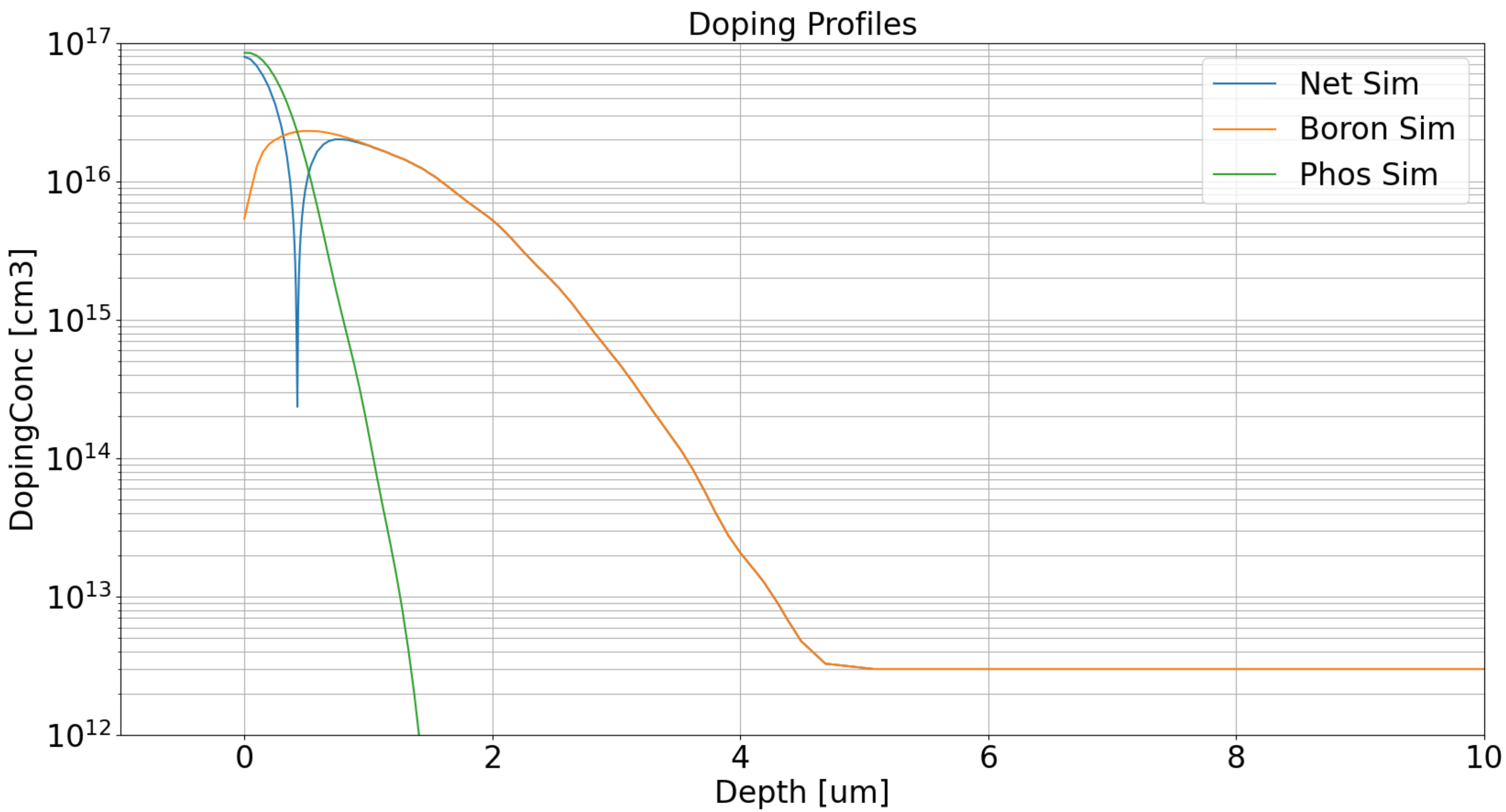
TCAD Model

AC-LGAD structure for TCAD.



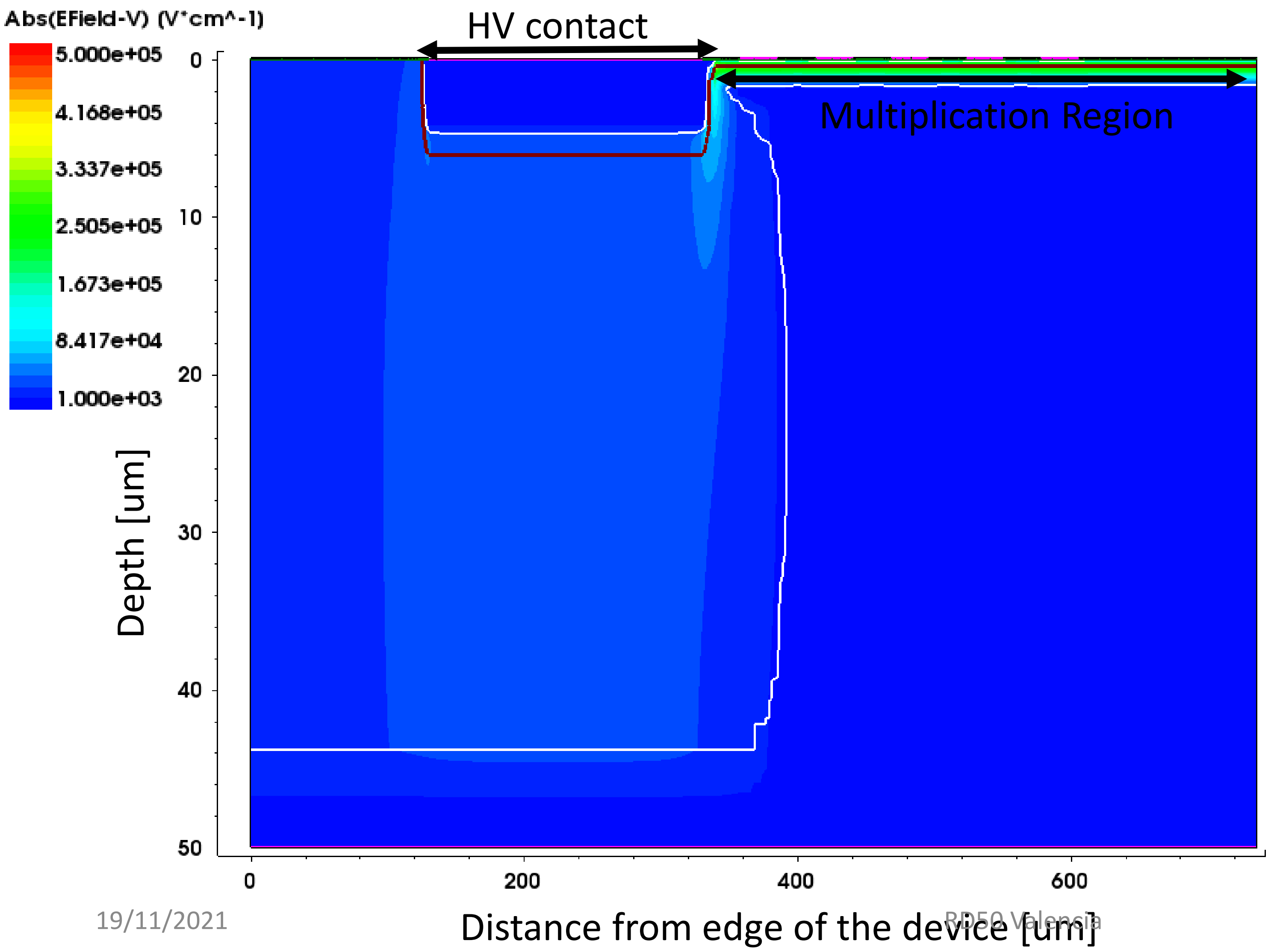
- 55um Pitch Pixels
- Pixel size of 27.5um
- 5 pixels.
- High resistive N+ Implant.
- Implant doping profiles generated in sprocess.

Doping Profiles



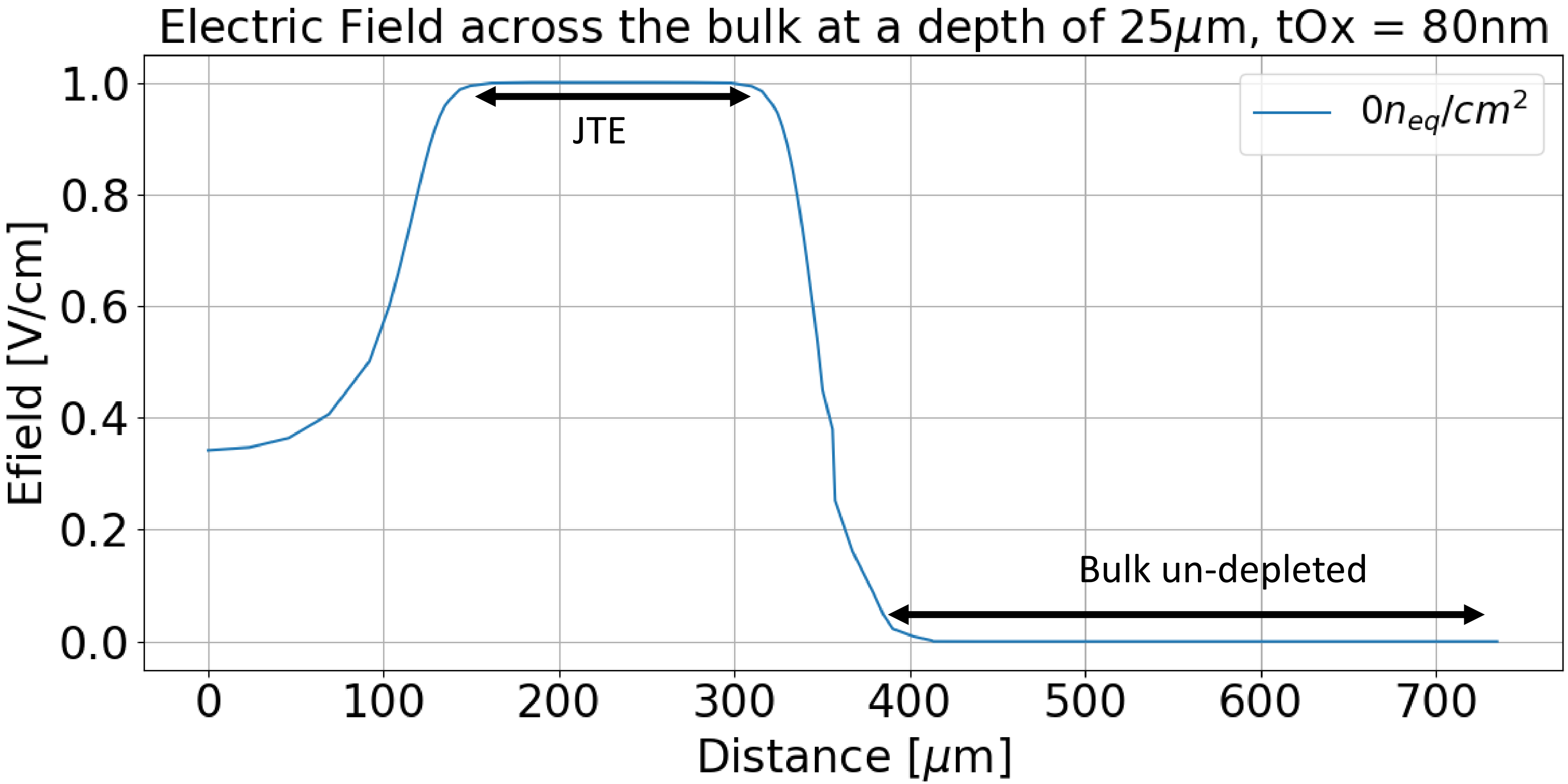
- Low resistive implant – Lower doping concentration of junction implant.
- Doping profiles generated using an analytical function with SDE

Efield at 180V of AC-LGAD



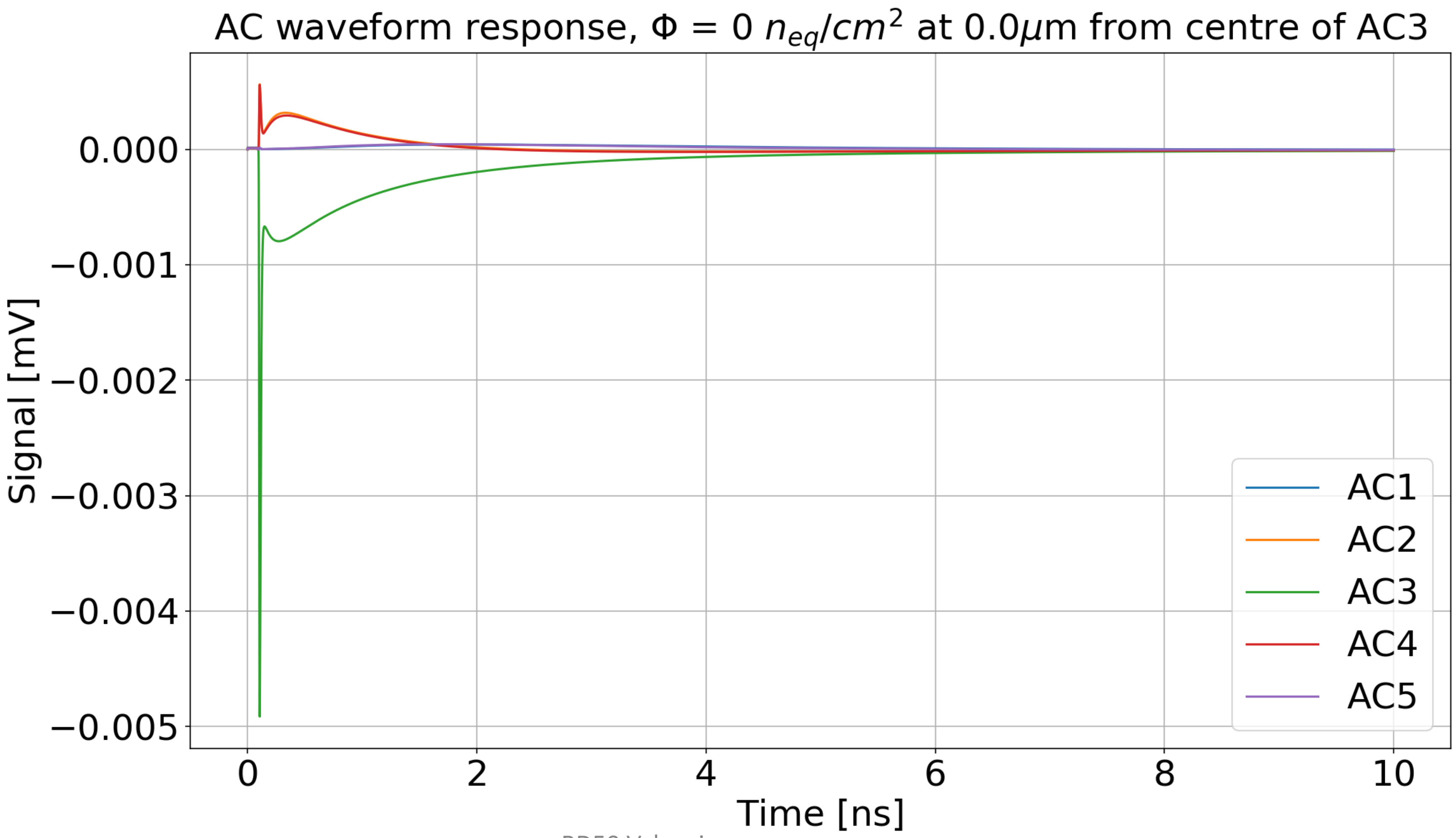
- High field seen at the junction – Multiplication
- Bulk does not deplete as expected.
- Depletion region extends into the bulk only in the region below the N++ region.
- Bulk does not deplete below the multiplication region
- **N++ Resisitive implant too resisitive**

Efield Across device at a depth of 25um at 180V.



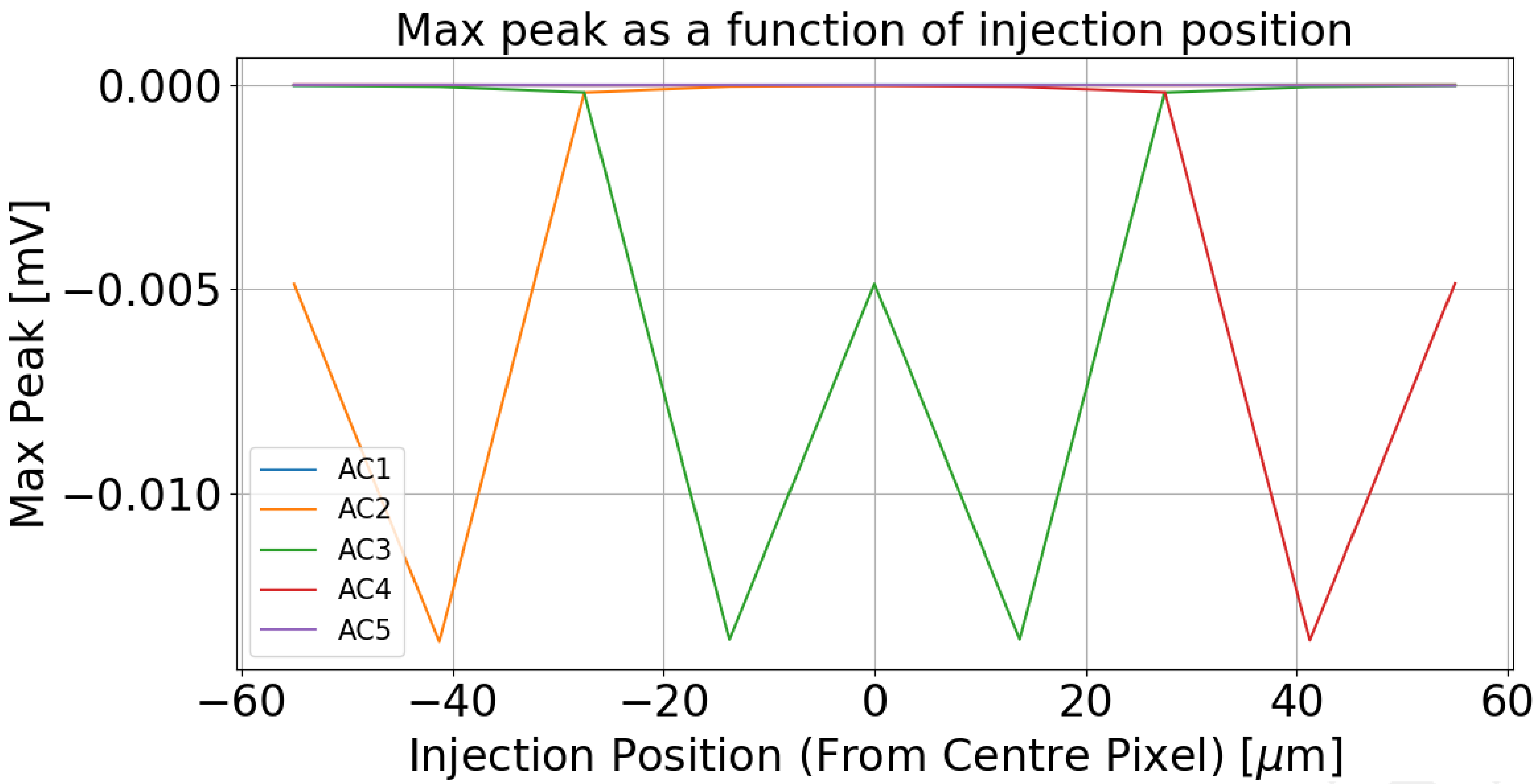
TCAD Results – Waveforms – 80nm Oxide

Rs=696Ω
Pitch=55um

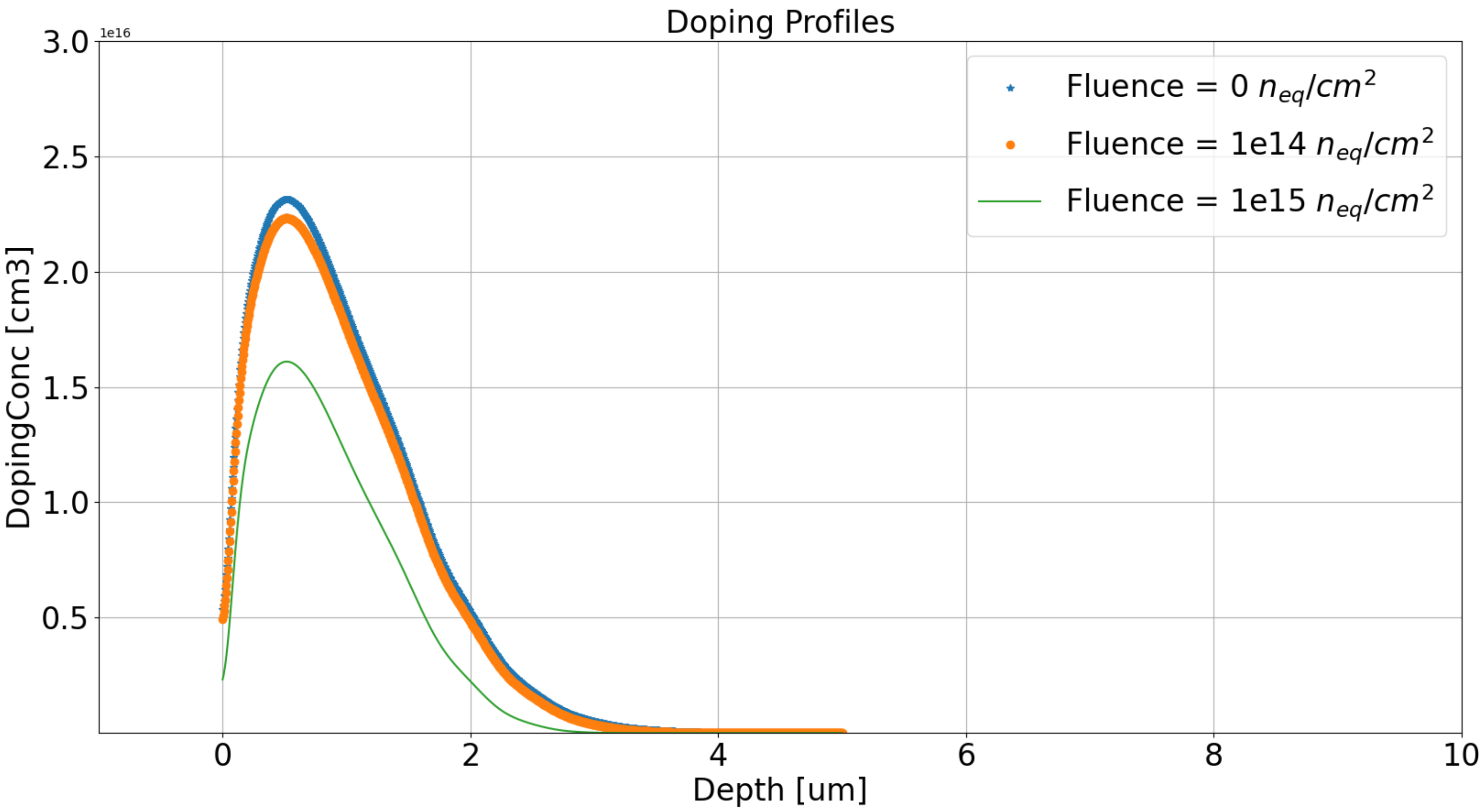


TCAD Results – Peak at each channel as a function of injection position – 80nm Oxide

Rs=696Ω
Pitch=55um



Doping Profiles - Irradiated



Acceptor removal mechanism

$$N_{GL}(\phi) = N_A(0)e^{-c\phi}$$

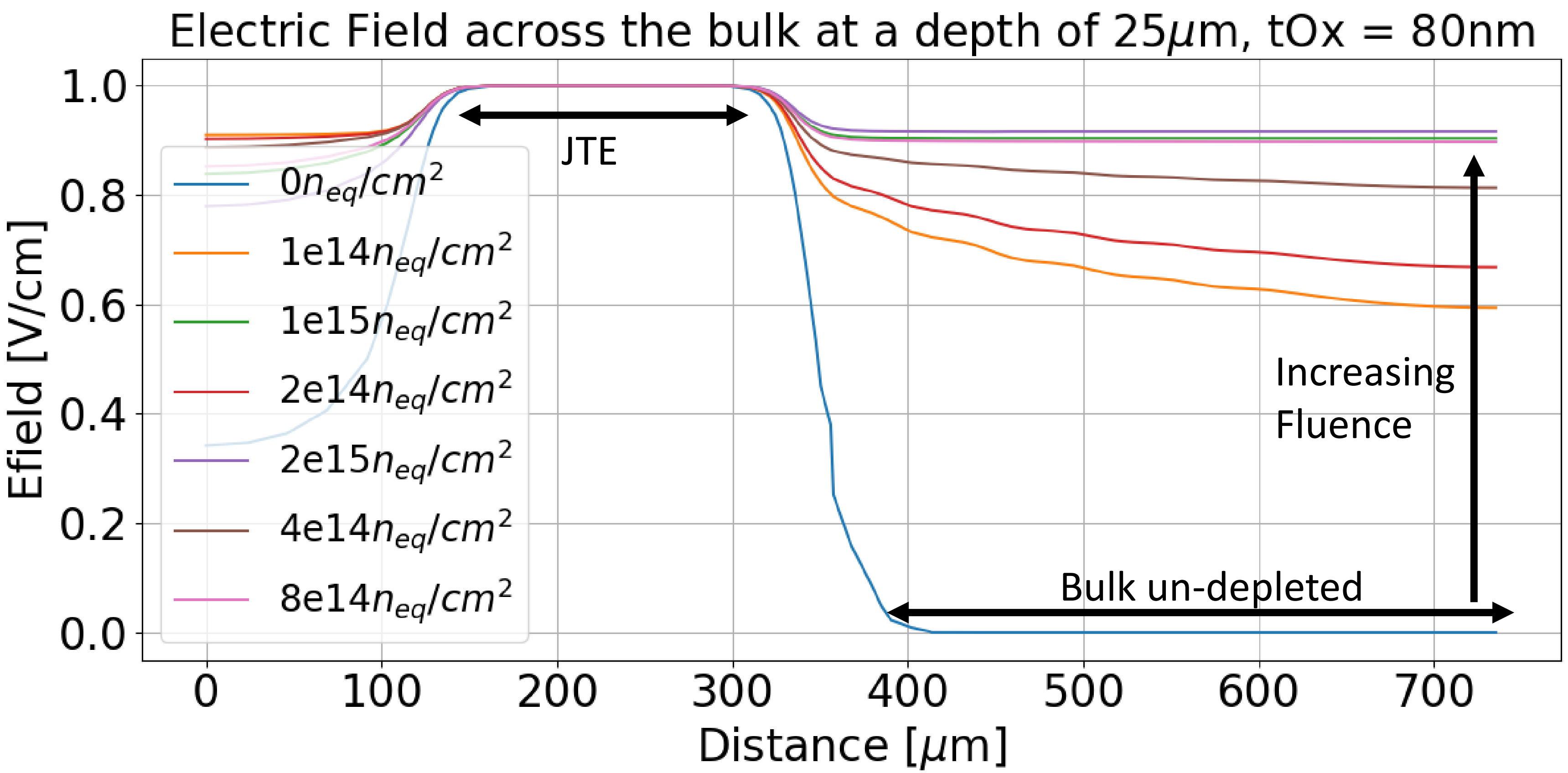
Radiation Model based on the AIDA deliverable for Radiation models and the RD50 talk given by Marco Mandurrino

[AIDA Deliverable (cern.ch)]

[PowerPoint Presentation (cern.ch)]

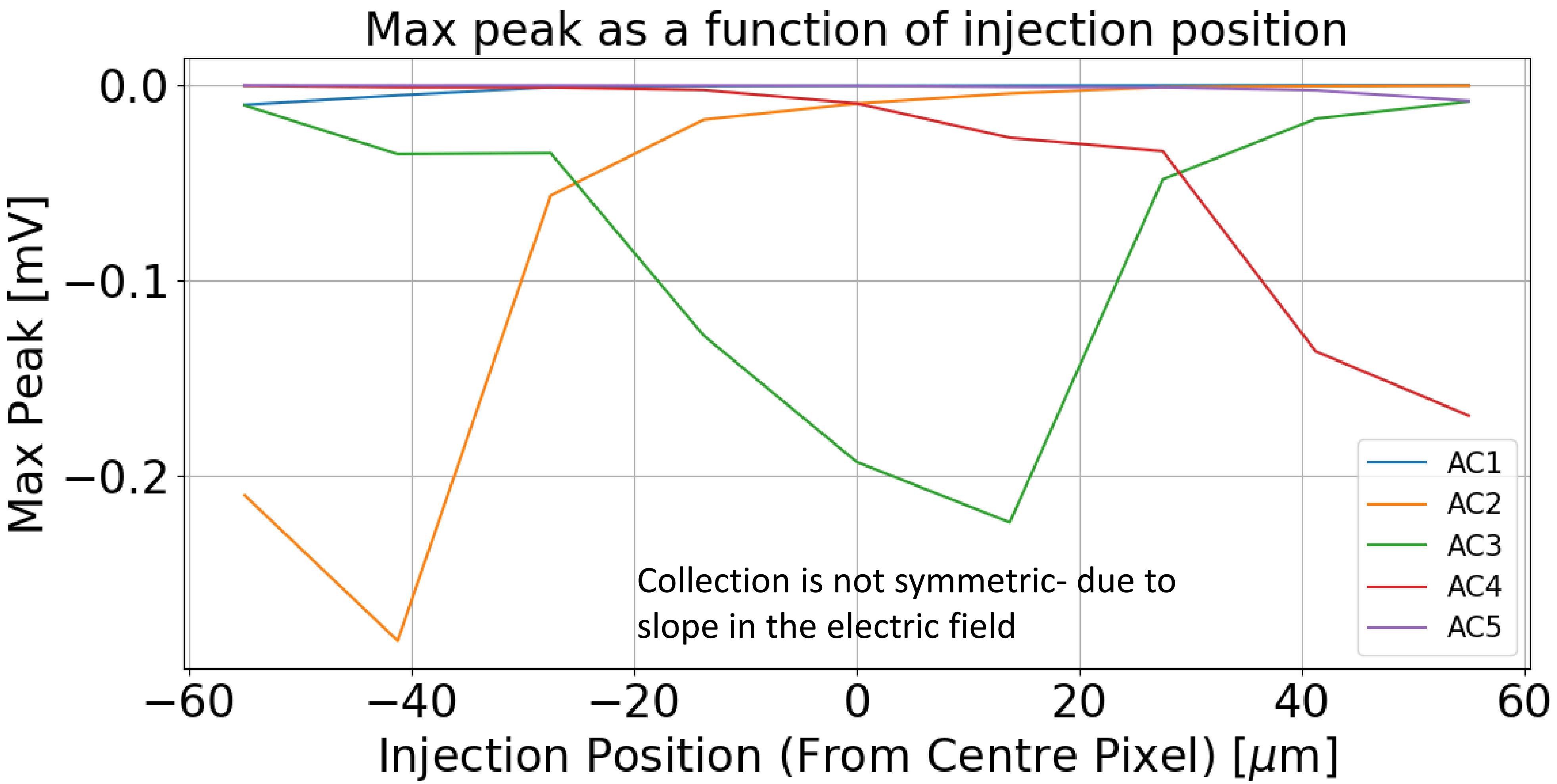
[Microsoft PowerPoint - 2017Mandurrino_30thRD50.pptx (cern.ch)]

Efield Across device at a depth of 25um



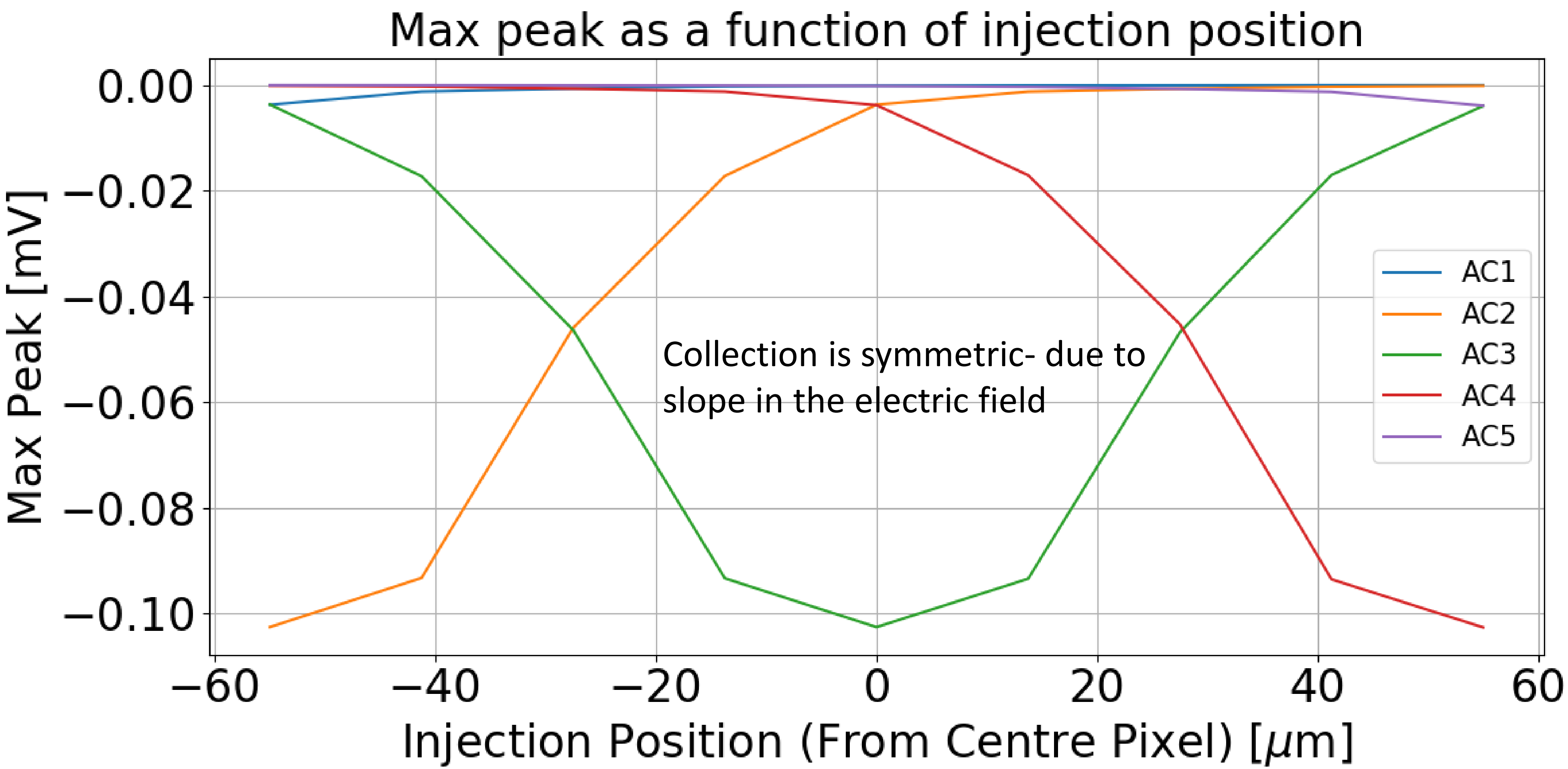
TCAD Results – Peak at each channel as a function of injection position – 80nm Oxide – 1e14

Rs=696Ω
Pitch=55um

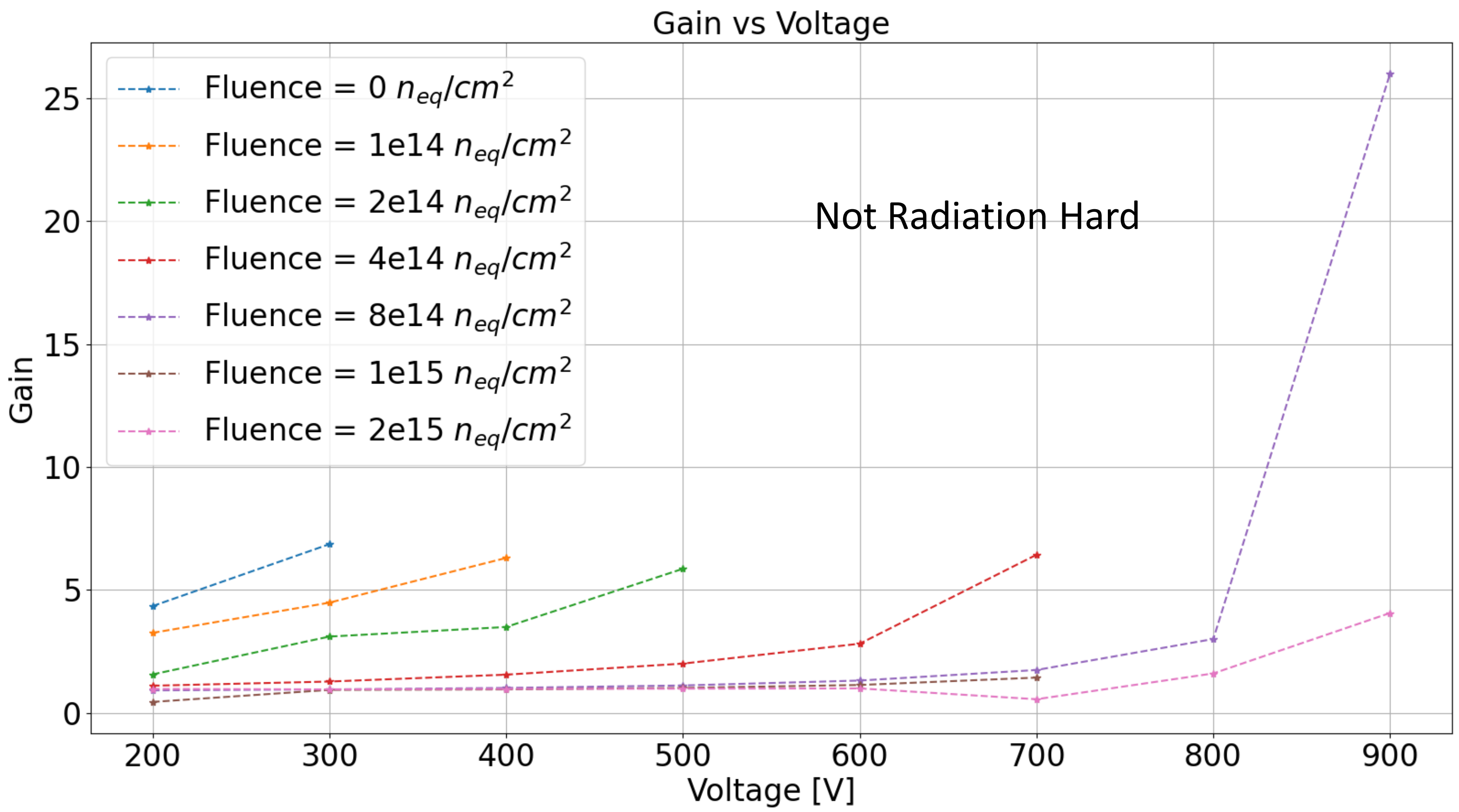


TCAD Results – Peak at each channel as a function of injection position – 80nm Oxide – 1e15

Rs=696Ω
Pitch=55um



Gain of Irradiated AC-LGAD



Main Points to Takeaway from TCAD

- **Design not Radiation Hard**
  - ➢ **Implement deep multiplication junction, higher dose boron.**
- **Detector does not deplete**
  - ➢ **Modify high resistive (n+) implant, i.e less resistive.**
- **At high fluence, the AC-LGAD works well, we see a uniform charge collection at the neighbouring pixels.**
- **Not much charge is shared between neighbouring pixels. Good for HEP?**

Conclusion

- **Look at adapting profiles to make them more radiation hard –deep junction.**
- **Junction implant may be to high resistivity, need to study the effect of reducing this resistivity.**
- **The effect of the oxide thickness was also studied but the same effect was seen, this will be optimized after the Resistance is changed.**
- **PSPICE modelled developed to optimize AC-LGAD to reduce charge sharing between pixels.**
- **Can also model the detector to optimize for charge sharing (Good for position resolution)**
- **Next steps to optimize design for Soft-Xrays**

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Project references: SPID202000X118404SV1

Thanks for your attention!