LGAD modeling and production points

This talk covers two topics:

- Important R&D points for the next production of LGAD
- Do we have a model that fits the LGAD data collected so far?

Structures for AIDA production - I

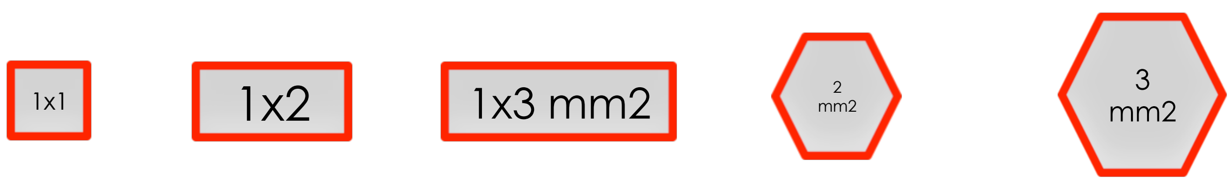
Thicknesses: 50 micron, 25 micron

Array of diodes: with various sizes 1x1 mm^2, 2x2 mm^2 pads to study edge termination.

➔ Very important to study the electrical properties of structures with many pads

➔ Very important to increase the fill factor, need to reach > 95% active area

30 μm dead area



Dead area:	**12%**	**9%**	**8%**	**9%**	**6%**

Structures for AIDA production - II

Using p-spray instead of p stops?

Short/long strips: can we design small pitch strips? What is the minimum from design consideration?

AC coupling strips: can we use polysilicon resistors?

PIN diodes with gain: Can we do it? PIN diode going to 800V when irradiated?

Breakdown after irradiation (to compensate for loss of gain layer):

How we can reach very high voltages after irradiation?

➔ Does it matter the guard rings/number geometry?

Modeling the properties of LGAD

In the last two years we achieved a good understanding of the LGAD design

- Do we have a single models that fits LGAD - PiN data?
  - Gain vs Vbias, Gain vs Temperature

Models for gain in LGADs

- Parameterization of acceptor removal
- Pulse shape in irradiated LGAD
- Discussion points in LGAD production

Models for gain in LGAD

We compared several models with measurements

Two models:

- **Van – Overstraeten**
- **Massey [2]**

use the standard Chynoweth law for the impact ionization rate

while two other models

- **Bologna**
- **Okuto**

use their own parameterization

[1] TDAC Sentaurus manual
[2] Massey, D. J., J. P. R. David, and G. J. Rees, Temperature dependence of impact ionization in submicrometer silicon devices., IEEE Transactions on Electron Devices 53.9 (2006) 2328

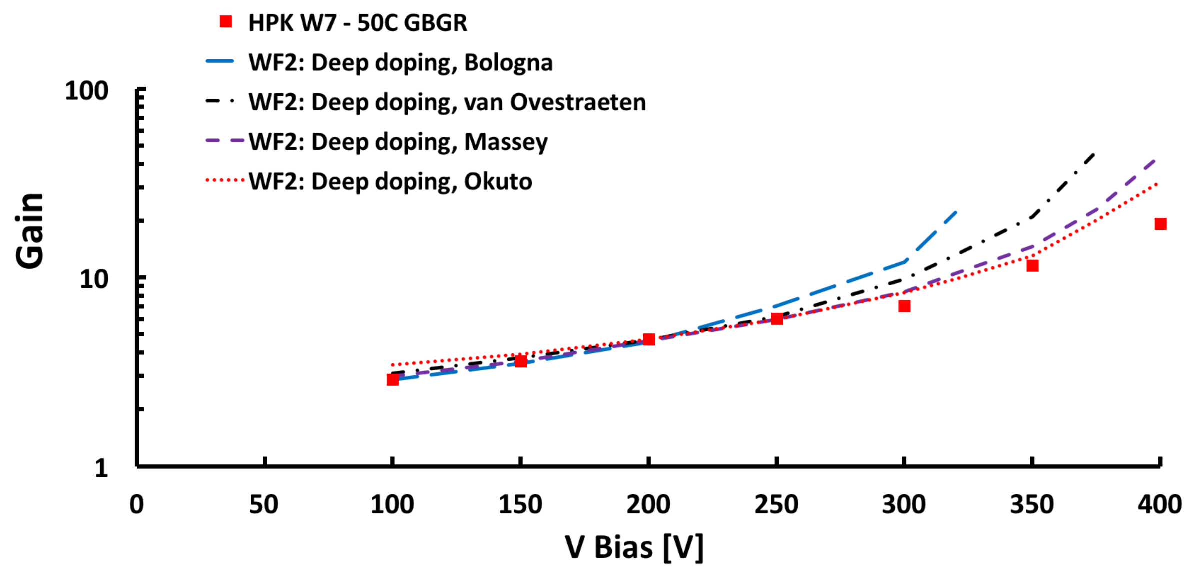
Note: models are taken with default parameters from the TCAD manual

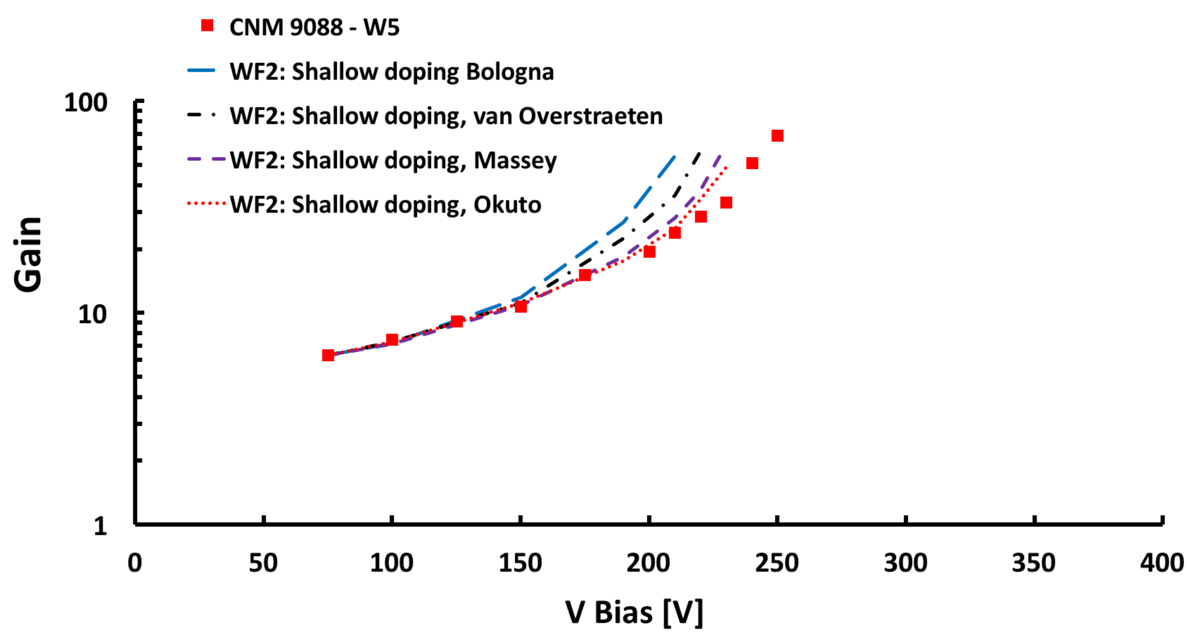
50 micron Gain vs Bias Voltage: CNM - HPK

WF2 reproduces fairly well the Gain vs Bias behavior.

Overall, the gain is rather “flat” with Vbias.

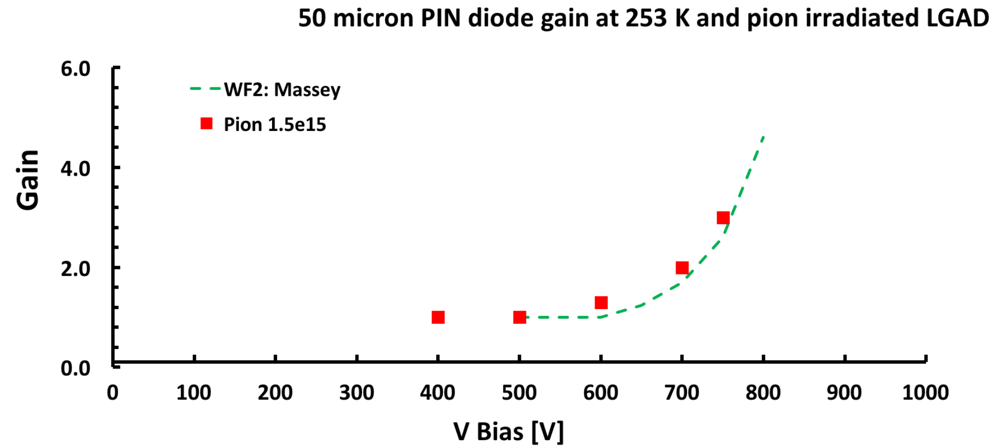
Okuto and Massey models provide a good fit to the data (using default settings)

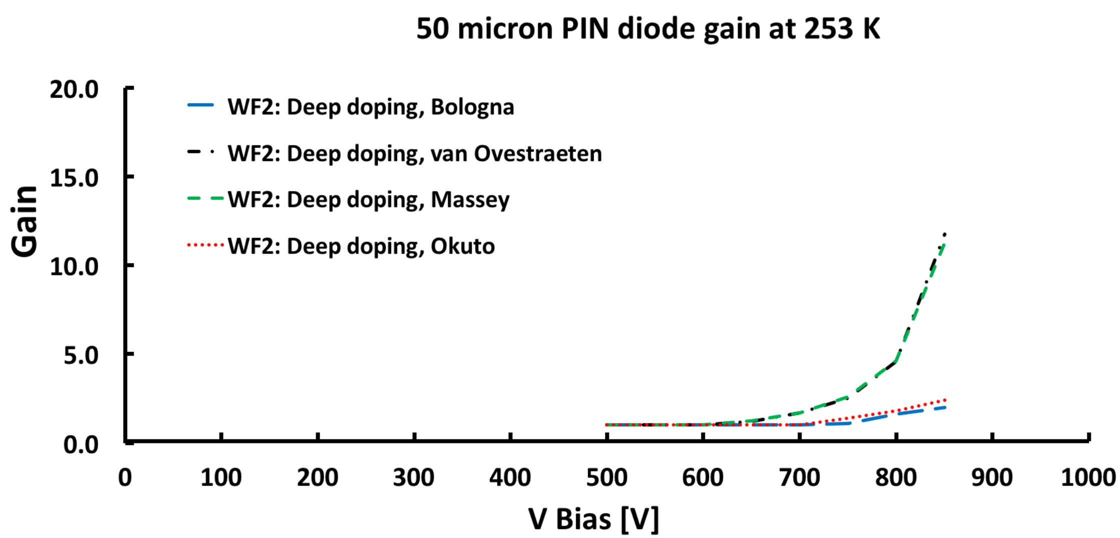




50 micron PIN diode gain

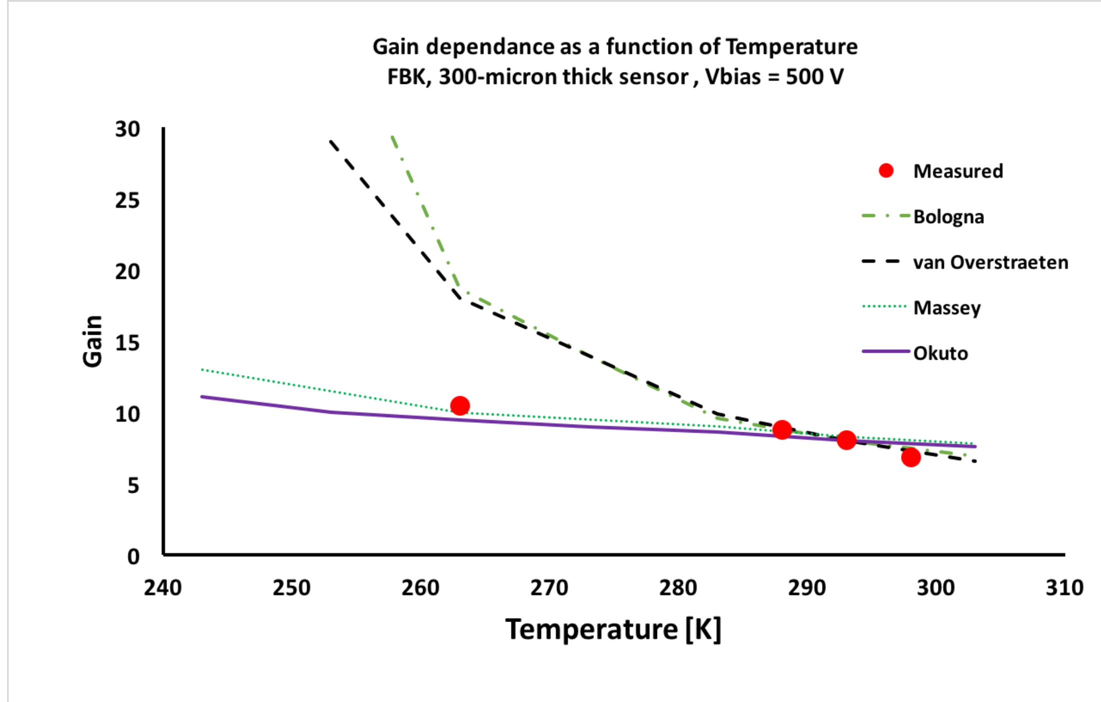
Gain model should also reproduce PiN behavior

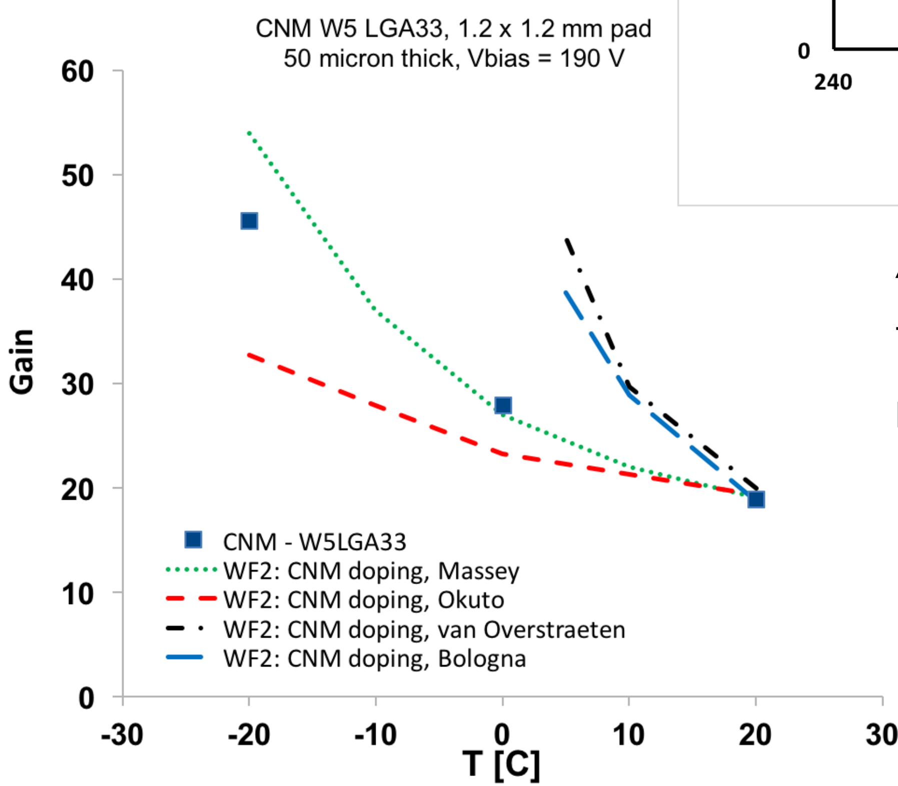




Interestingly, only two models, **Massey**, **van Overstreaten**, predict the onset of internal multiplication up to 850 V in PIN diodes at 253 K

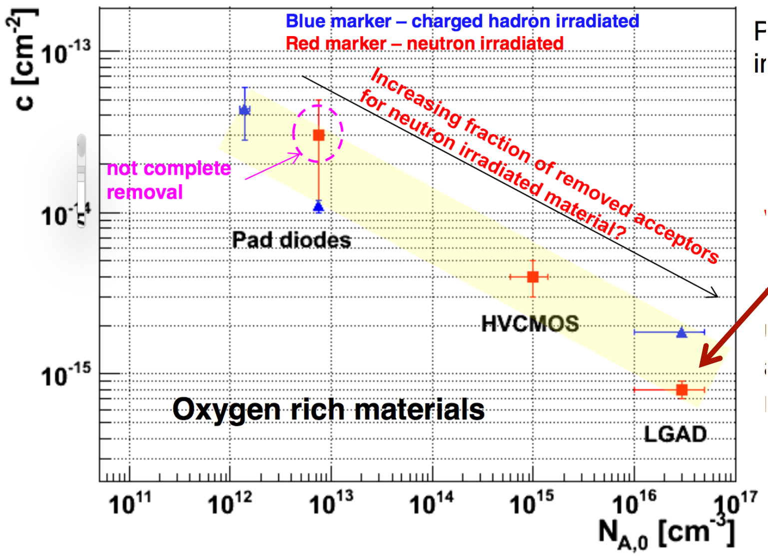
Gain vs Temperature





Also in the prediction of Gain vs temperature **Okuto and Massey** models provide a good fit to the data

WF2 model for Initial acceptor removal

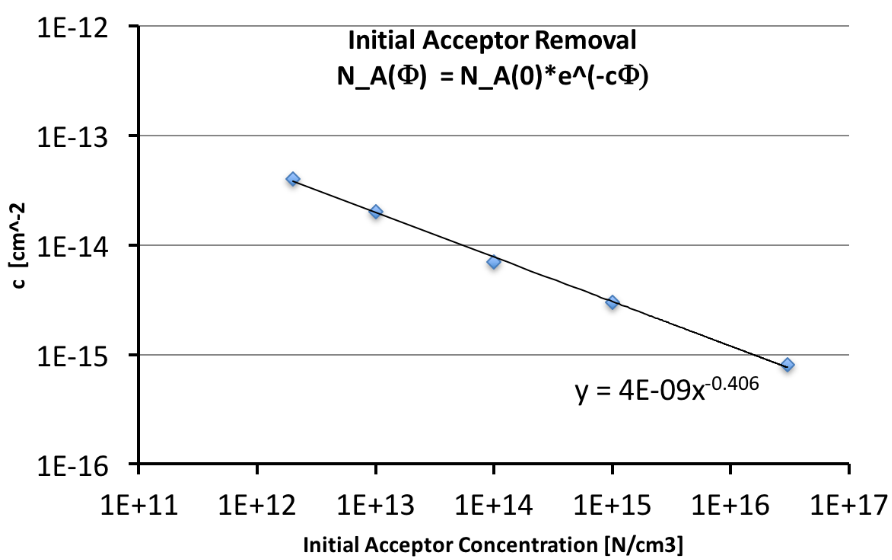


Gregor's data

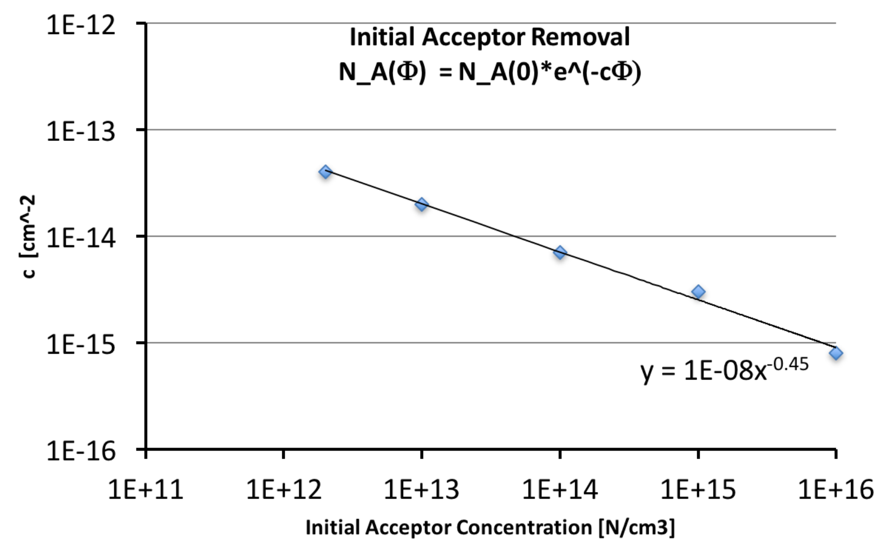
The key element for this parameterization is the x-axis value of this point : at doping 10^{16}/cm3 or at 3 10^{16}/cm3?

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

Old WF2 model: use 3 10^{16} ➔ too rapid removal



New WF2 model: use 10^{16} ➔ good fit

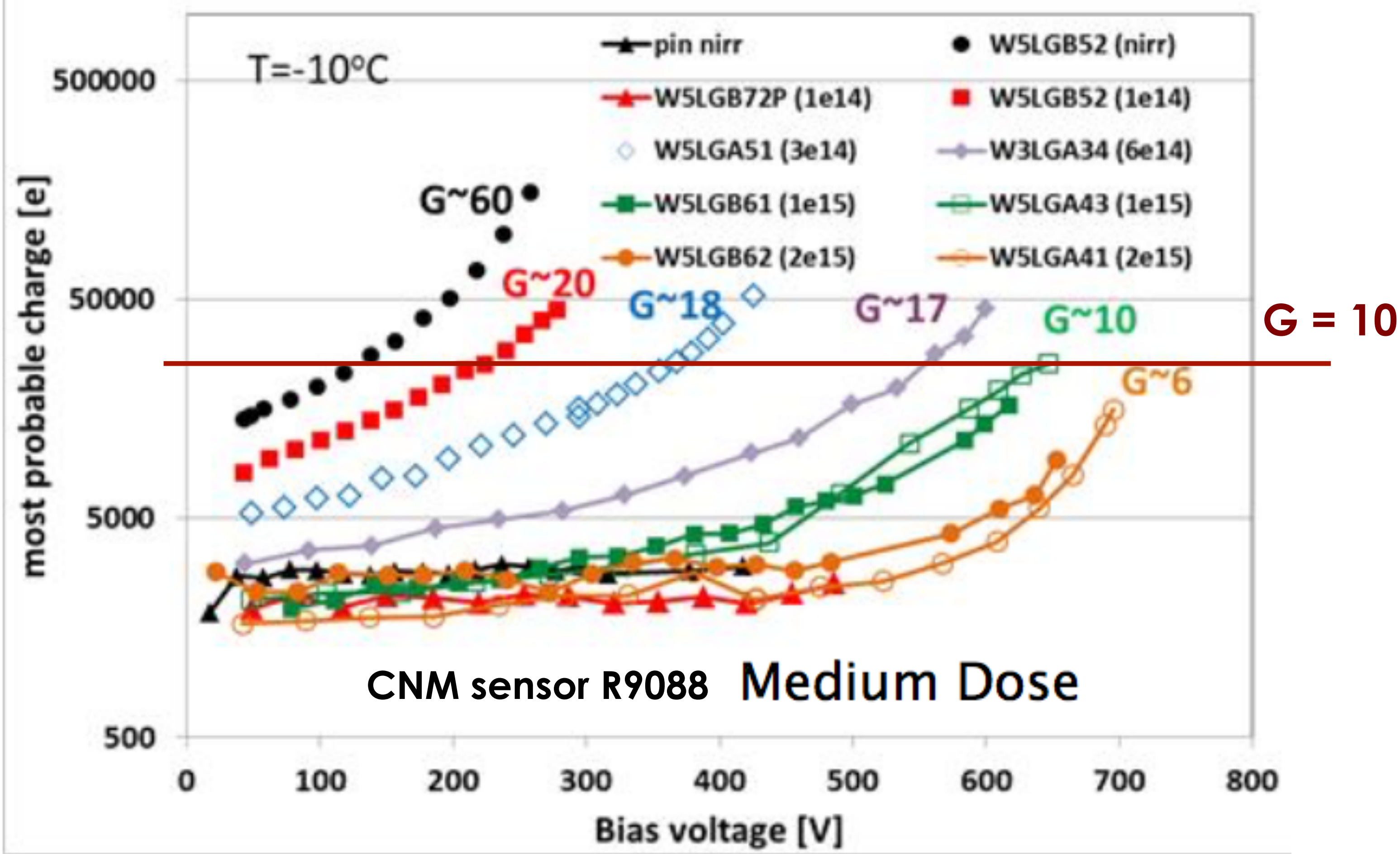


Gain vs Irradiation - neutron

This plot contains a massive amount of information (CNM R9088).

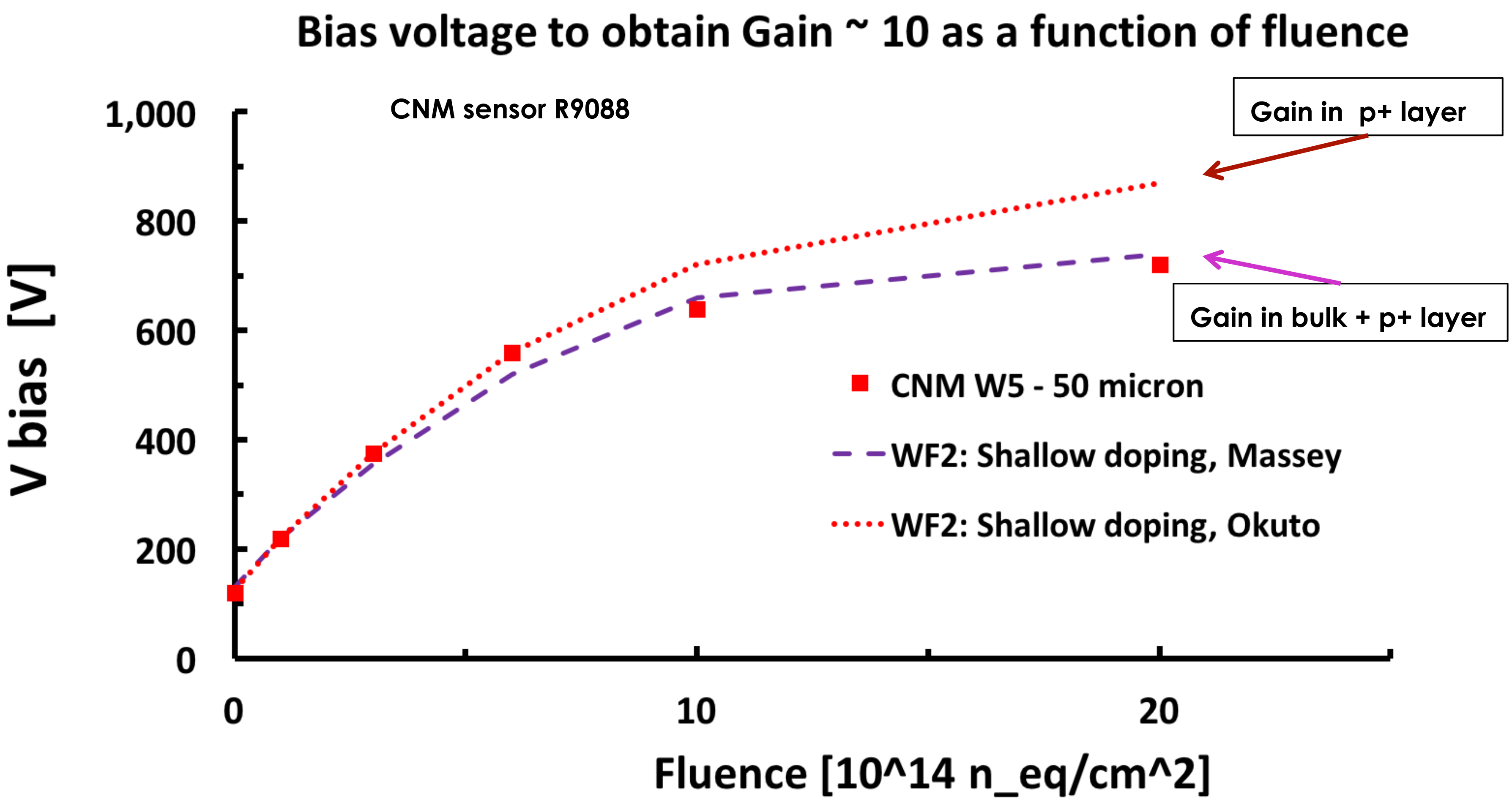
Can we have a model for this?

Can we explain the evolution of Vbias @ gain = 10 as a function of radiation?



Nicolo Cartiglia, INFN, AIDA2020, April 5th 2017

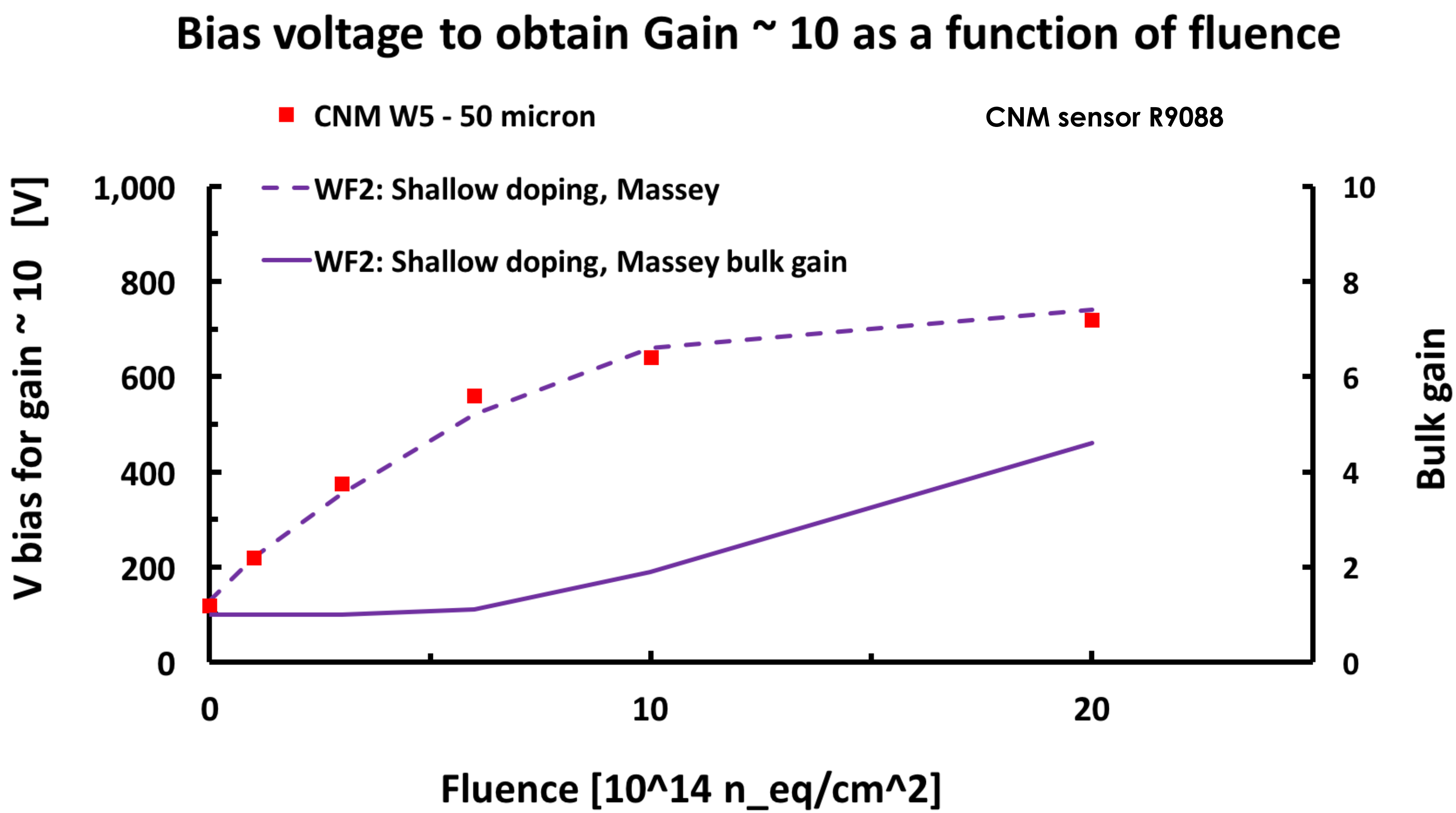
WF2 prediction for Vbias to have gain = 10



Okuto's model: good fit when bulk gain is not important

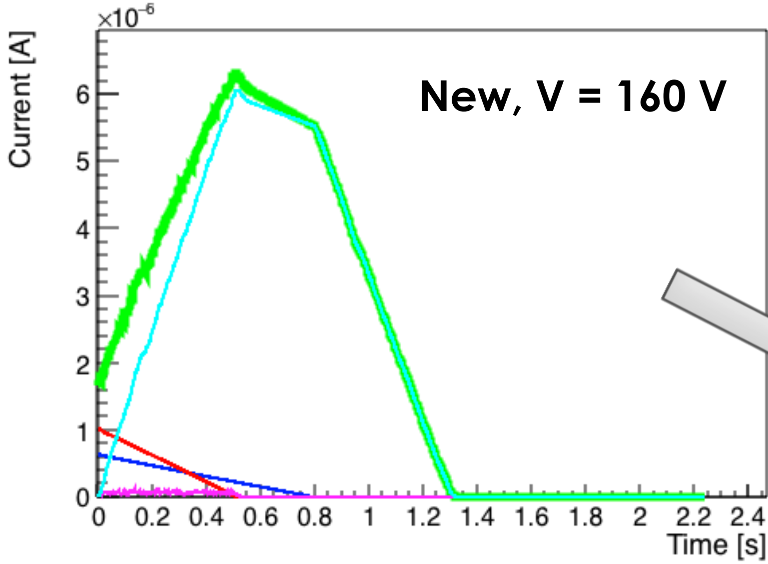
Massey: correct mix of gain from bulk and p+ layer

Massey's model: contribution from bulk gain



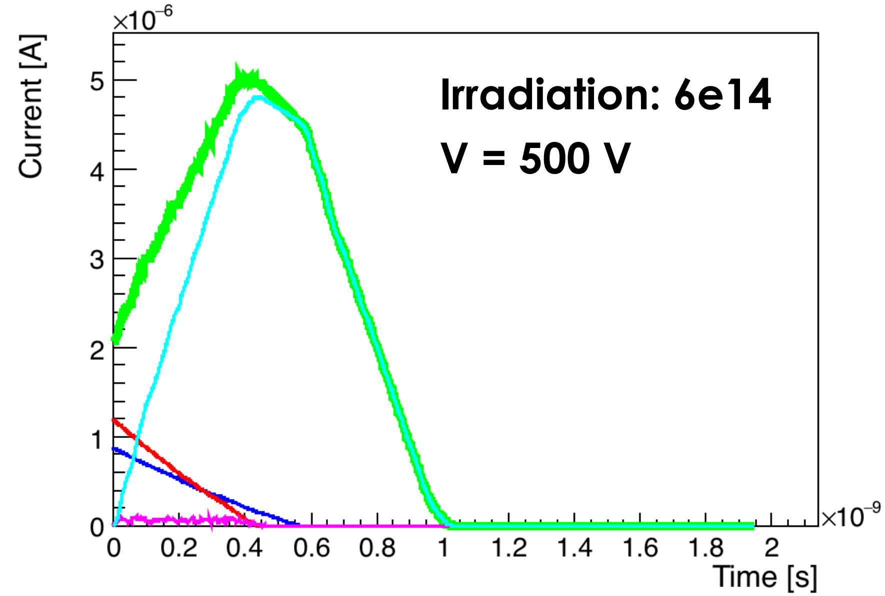
At fluences >~ 10^{15} neq/cm^2, bulk gain becomes important

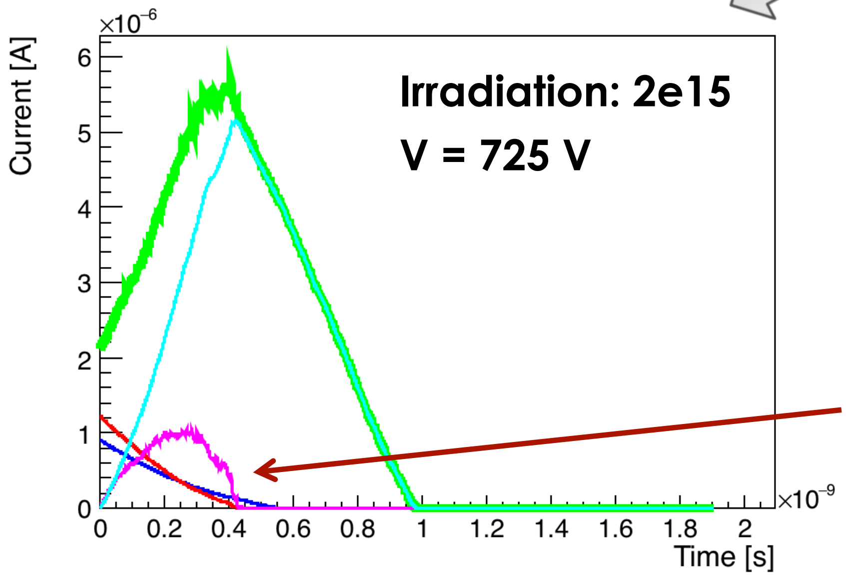
Signal shape in irradiated sensors



As we go to highly irradiated sensors, the gain in bulk becomes important.

Does it matter?



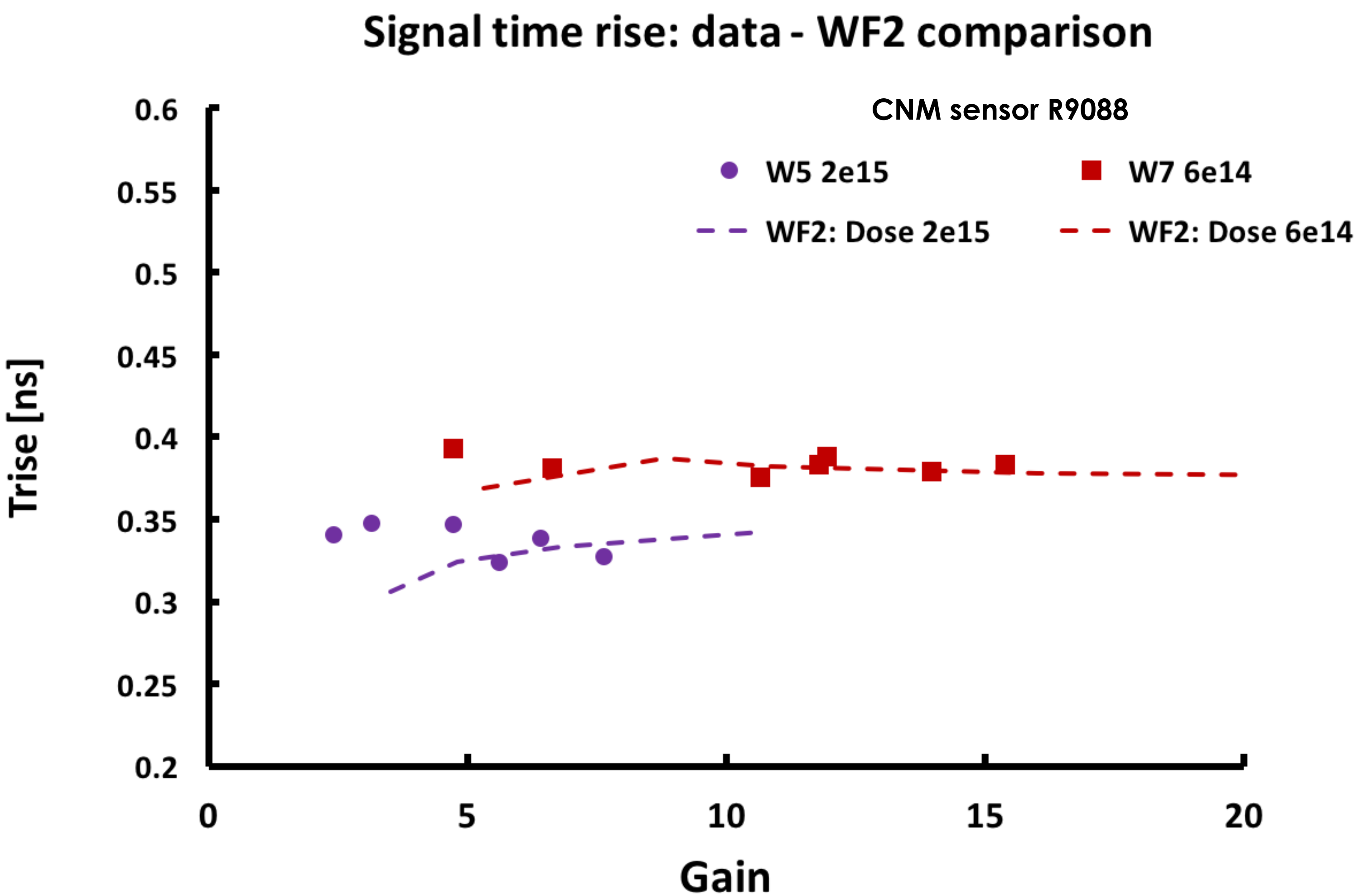


The signal shape does not change much:

- The rise time becomes a bit shorter
- Gain electrons (generated in the bulk) are contributing

Signal rise time in irradiated sensors

Remarkably, the decrease of signal rise time with increasing fluence has been measured (UCSC), and it compares well with WF2 (WF2 rescaled by 0.9 as the amplifier simulation is not perfect)



Conclusion

We have compared measured data with 4 simulation models for 3 quantities: (i) Gain vs Vbias (LGAD), (ii) vs Temperature (LGAD) and (iii) vs Vbias (PIN) and found that only the Massey model is able to fit correctly all of them.

WF2 with a parameterization using Gregor's data on Initial Acceptor removal rate is able to correctly simulate the evolution of gain vs fluence.

The evolution of the pulse shape with fluence is well explained by CCE, the onset of gain in the bulk and the decrease of gain in the gain layer.

The contribution of charge non uniformity to time resolution decreases with increasing gain in the bulk.