Properties of LGAD

- Models for gain in LGADs
- Parametrization of acceptor removal
- Gain vs Vbias, Temperature, fluence for LGAD sensors
- Gain vs Vbias for PIN sensors
- Pulse shape in irradiated LGAD
- Effect of pulse shape variation with irradiation on time resolution
- Discussion points in LGAD production

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WF2 Models for gain in LGAD

We implemented in Weightfield2 4 models [1] of impact ionization.

Two models:

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

use the standard Chynoweth law for the impact ionisation rate

while two other models

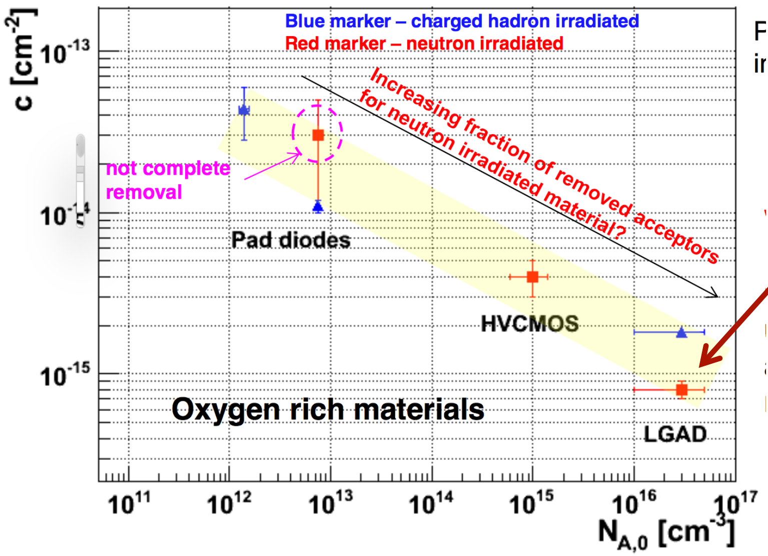
- **Bologna**
- **Okuto**

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

WF2 model for Initial acceptor removal

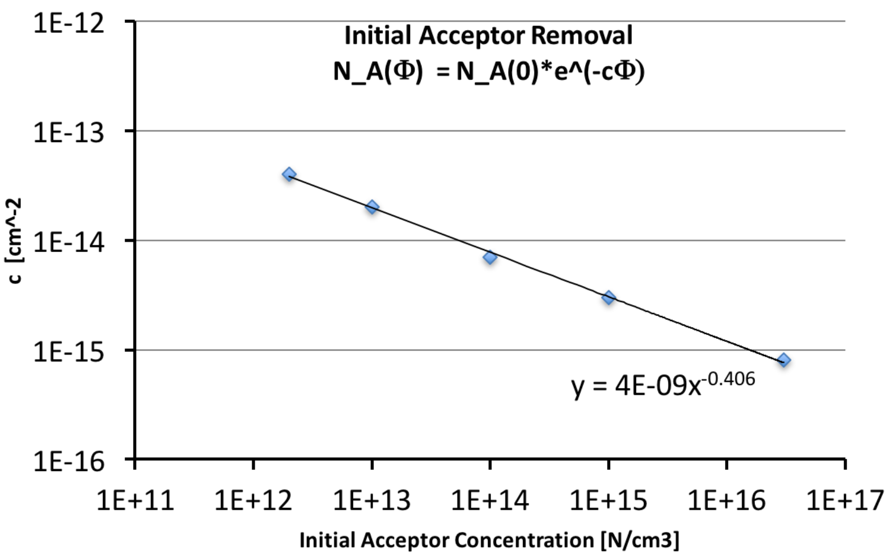


Gregor's data

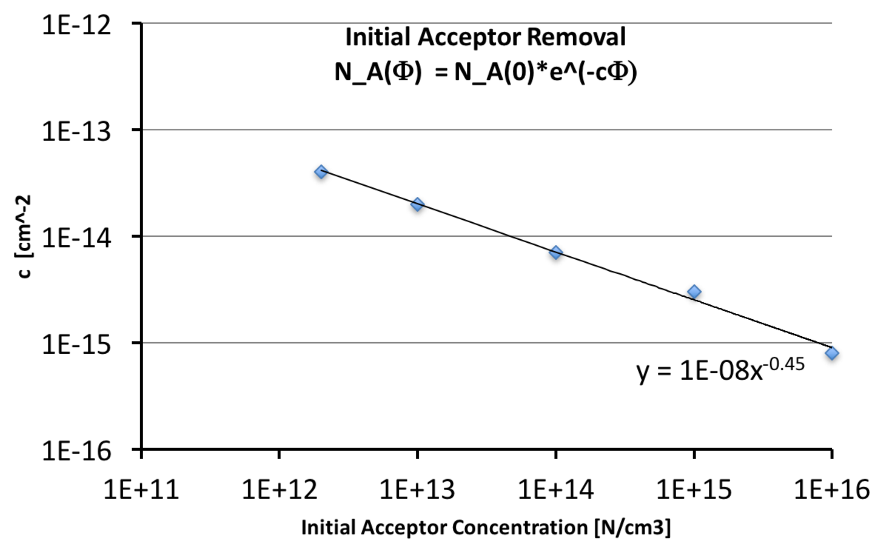
The key element for this parameterization is the x-axis value of this point : at doping 10^{16}/cm3 or at 3 10^{16}/cm3?

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

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



New WF2 model: use 10^{16} ➔ good fit

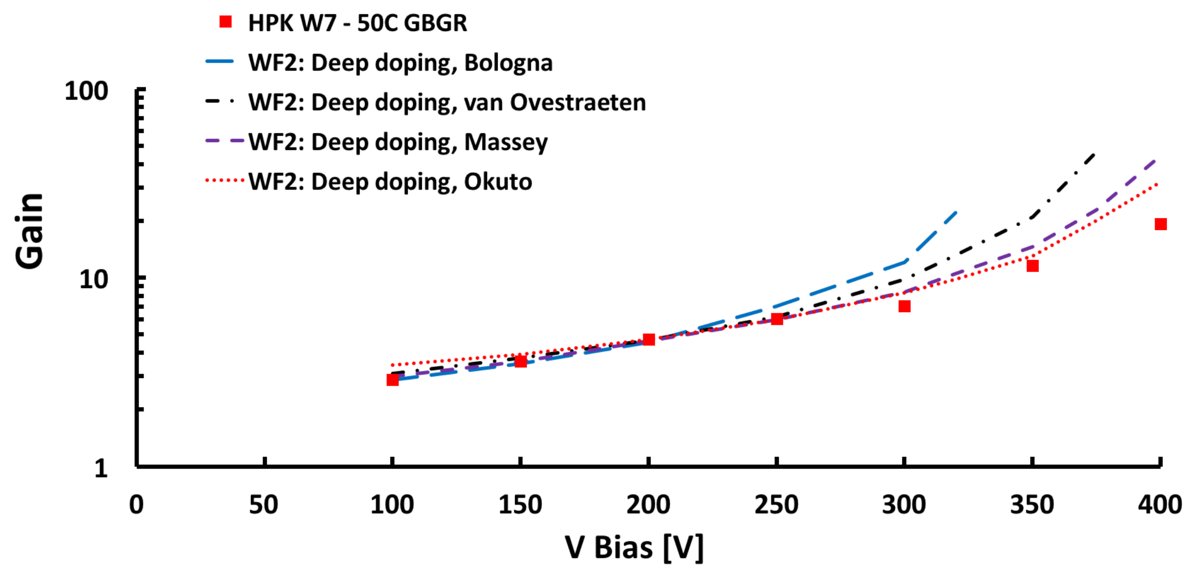


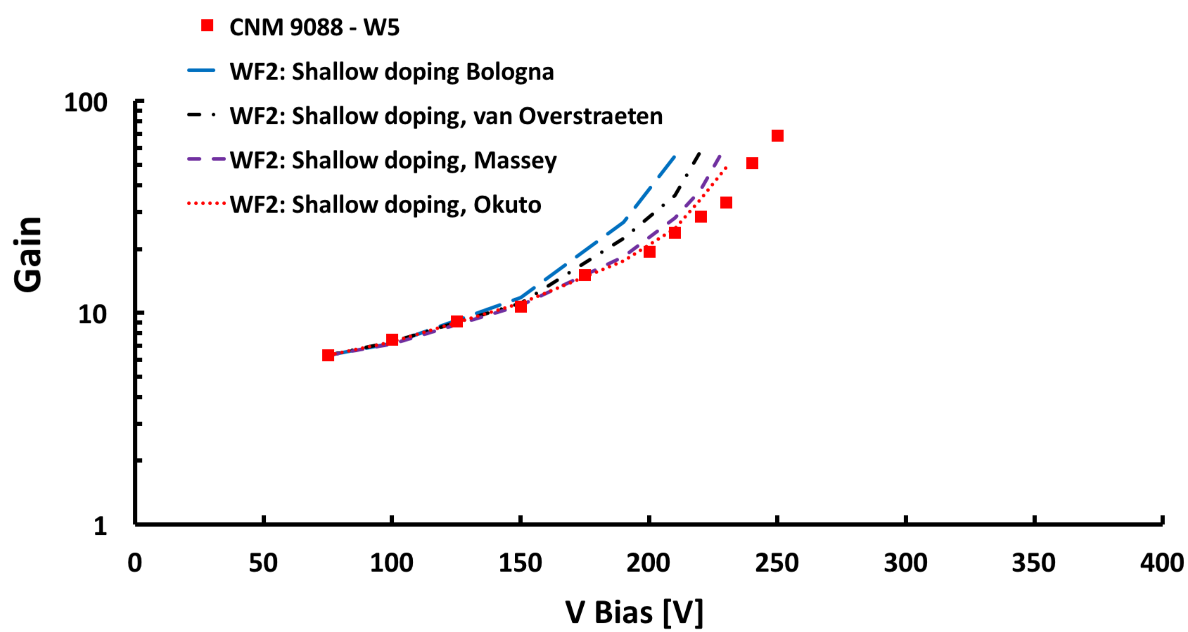
50 micron Gain vs Bias Voltage: CNM - HPK

WF2 reproduces fairly well the Gain vs Bias behavior.

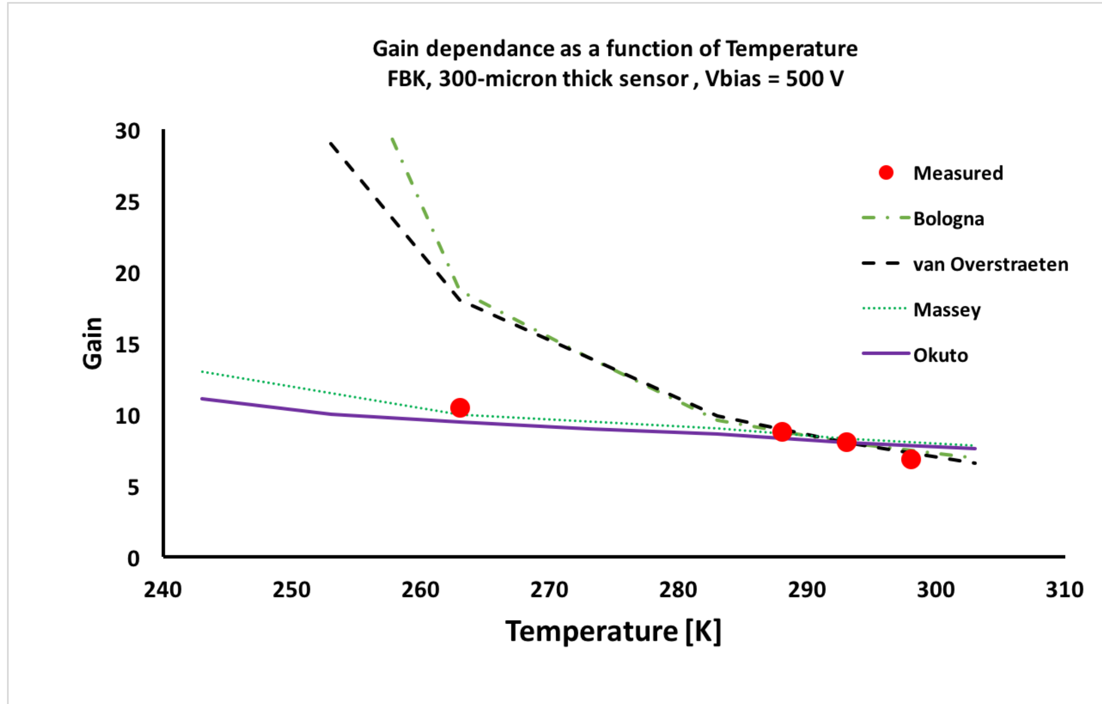
Overall, the gain is rather "flat" with Vbias.

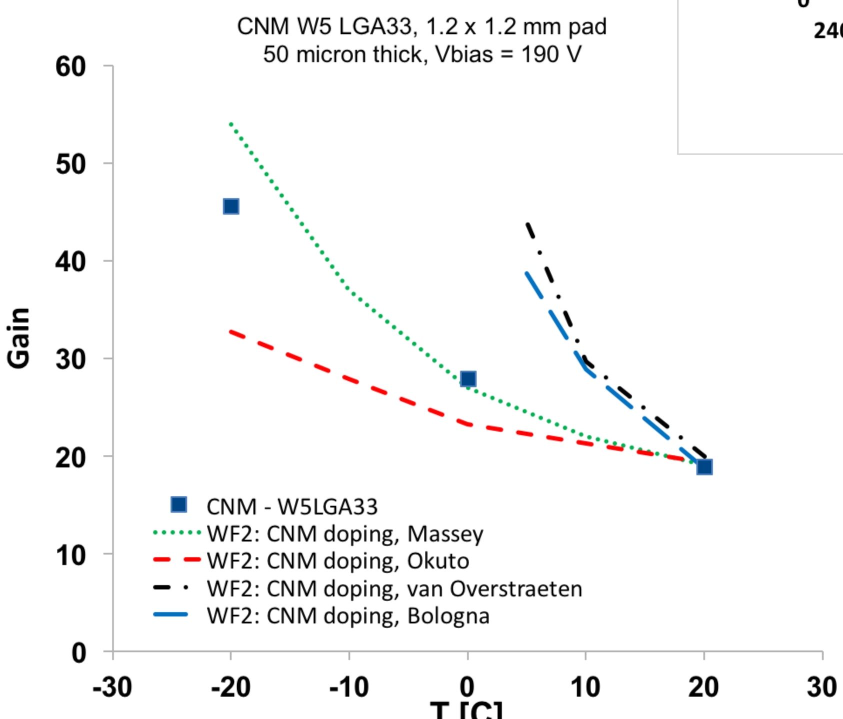
Okuto and Massey models provide a good fit to the data (using default settings)





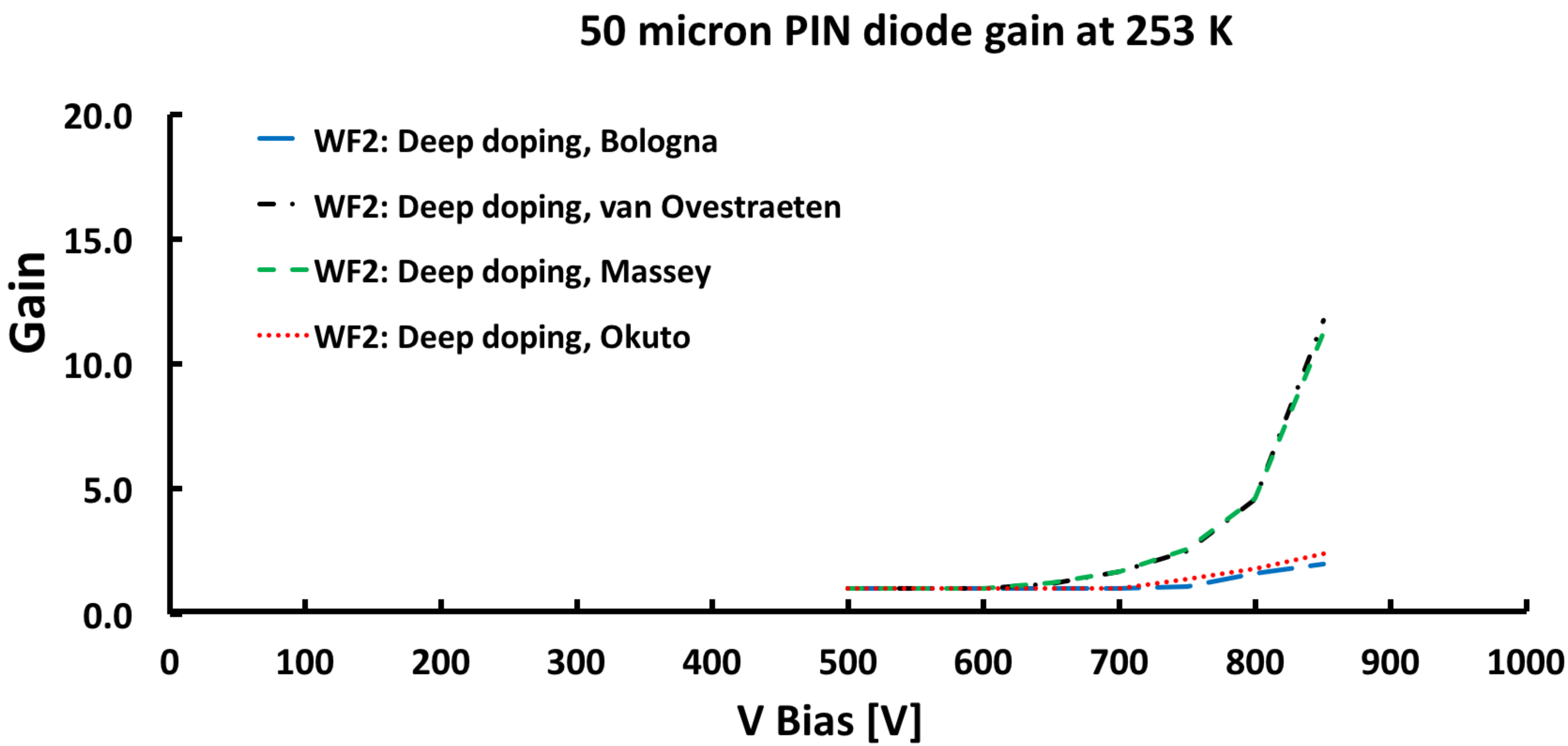
Gain vs Temperature





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

50 micron PIN diode gain



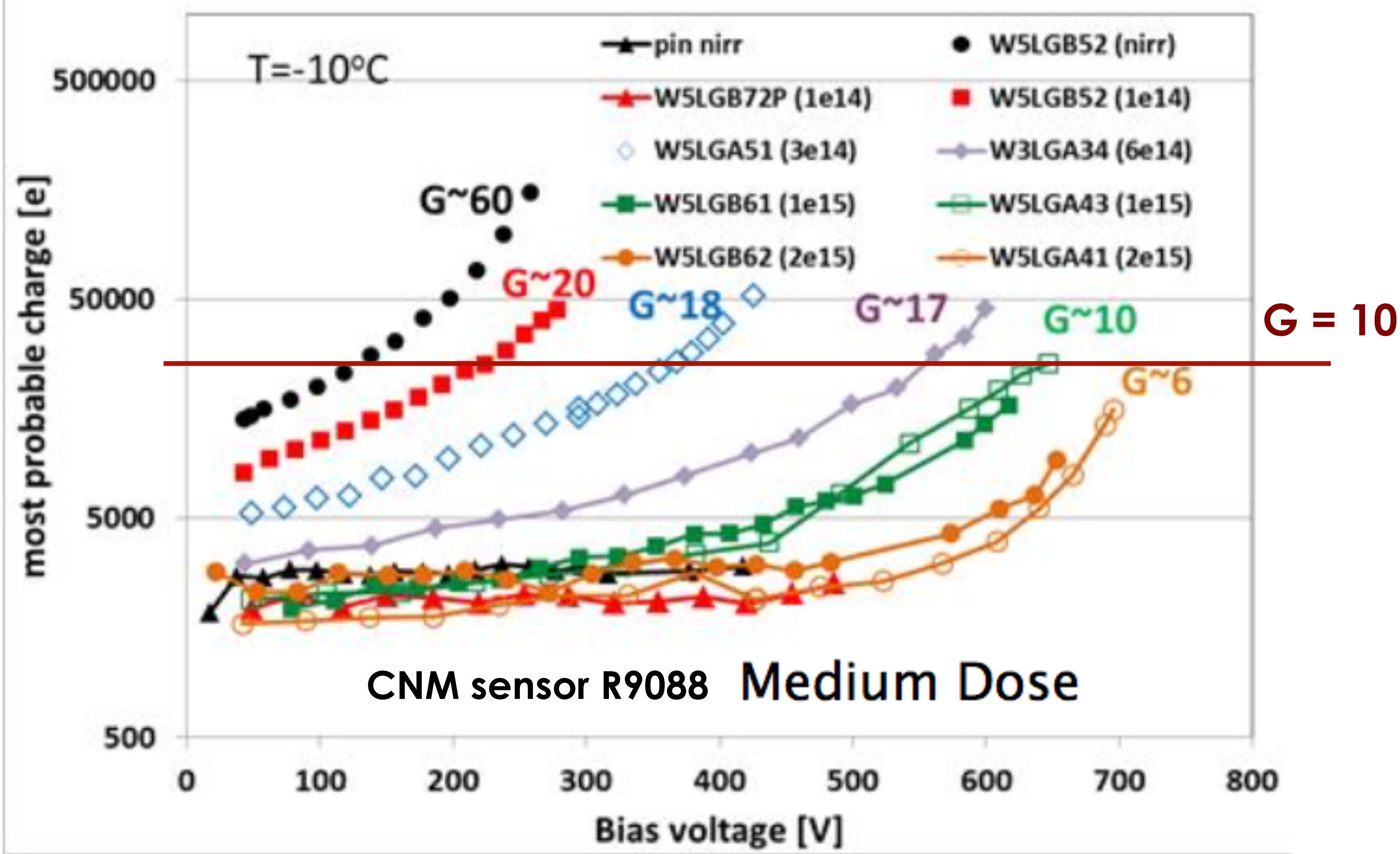
Interestingly, only two models, **Massey, van Overstreaten**, predict the onset of internal multiplication up to 850 V in PIN diodes at 253 K

Gain vs Irradiation - neutron

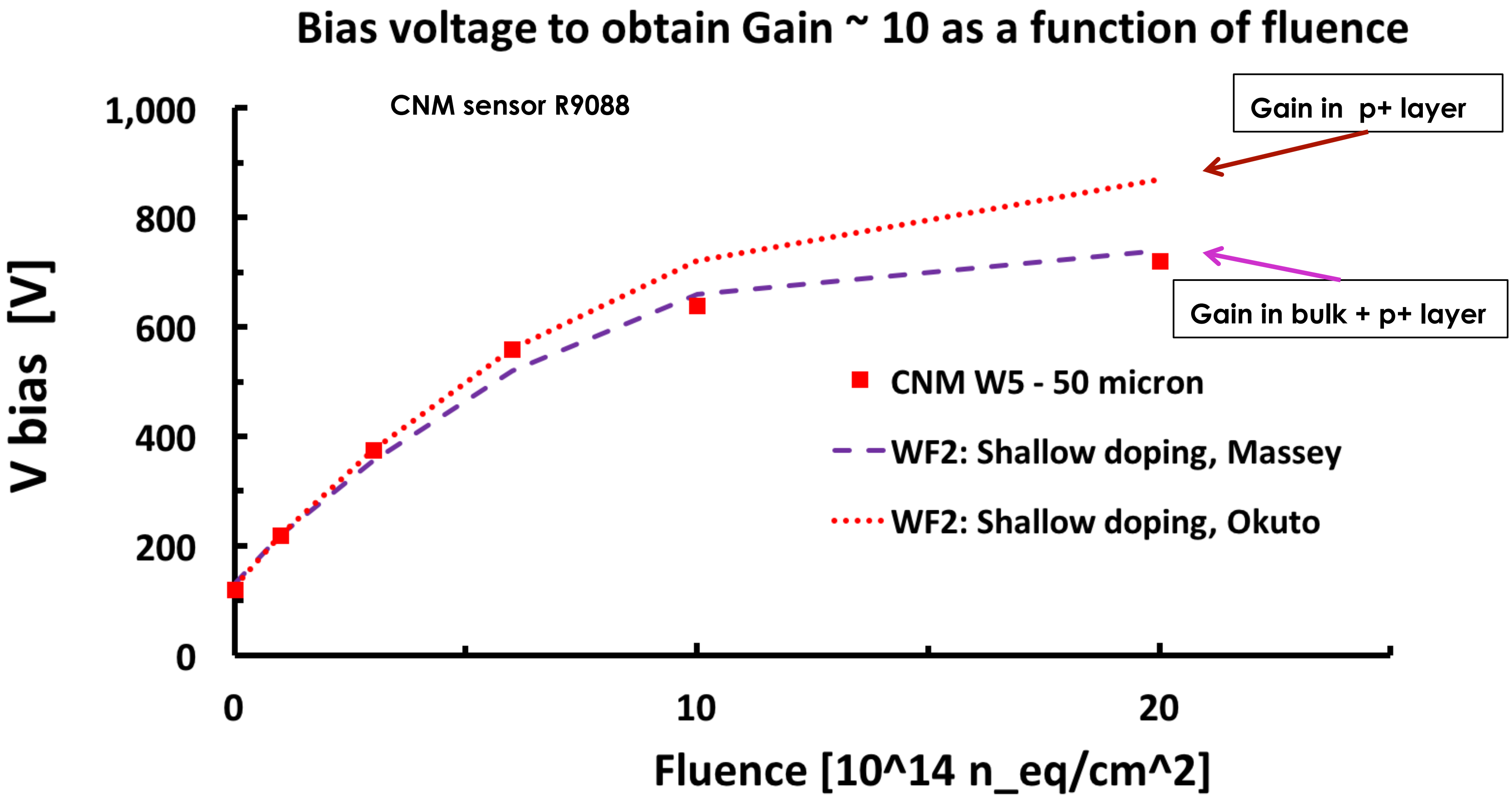
This plot contains a massive amount of information (CNM R9088).

Can we have a model for this?

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



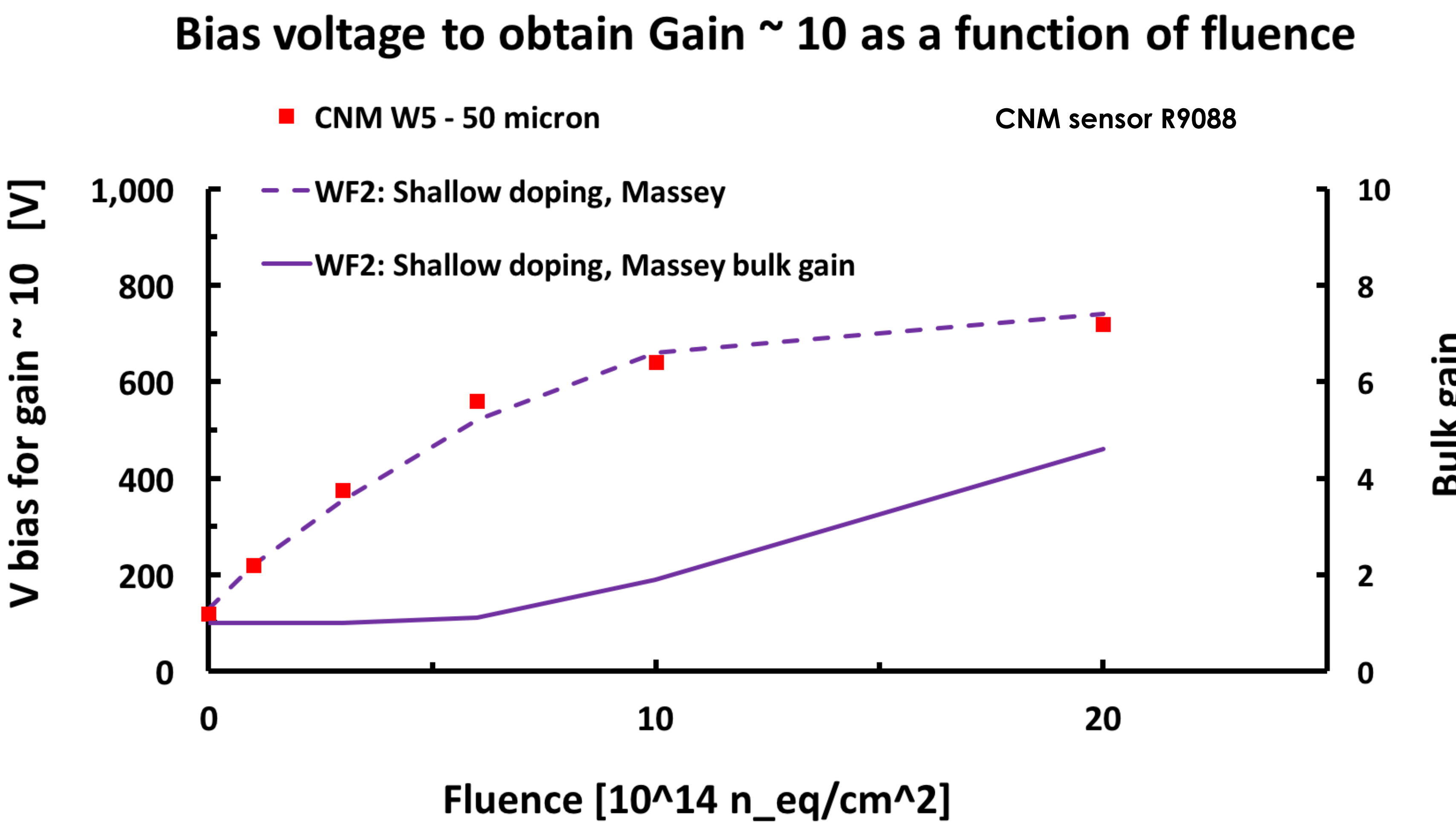
WF2 prediction for Vbias to have gain = 10



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

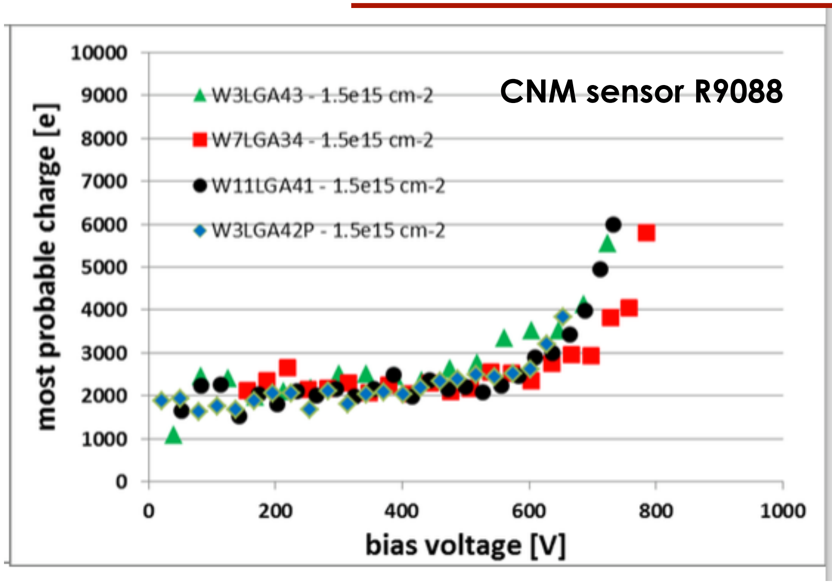
Massey: correct mix of gain from bulk and p+ layer

Massey's model: contribution from bulk gain

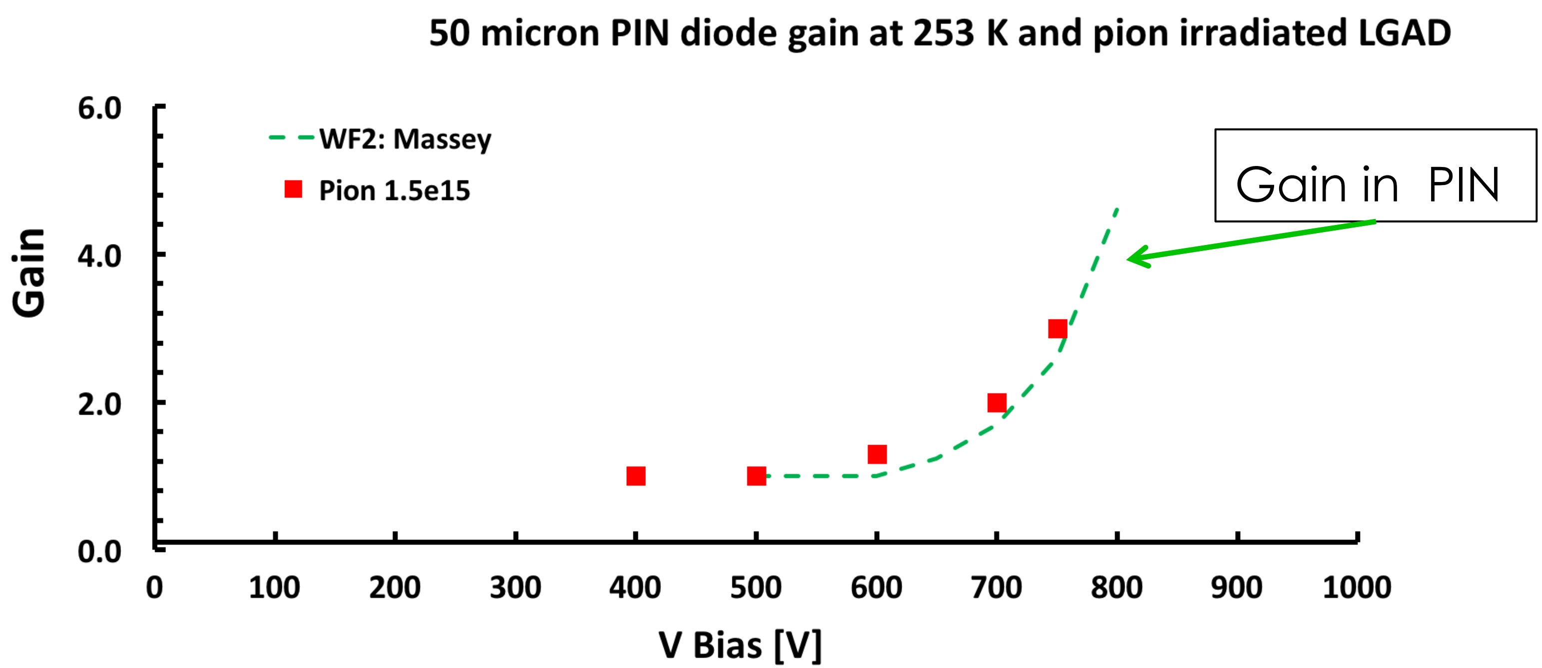


At fluences >~ 10^{15} neq/cm^2, bulk gain becomes important

Gain vs irradiation – 1.5e15 pions/cm^2



Gain is consistent with no contribution from gain layer

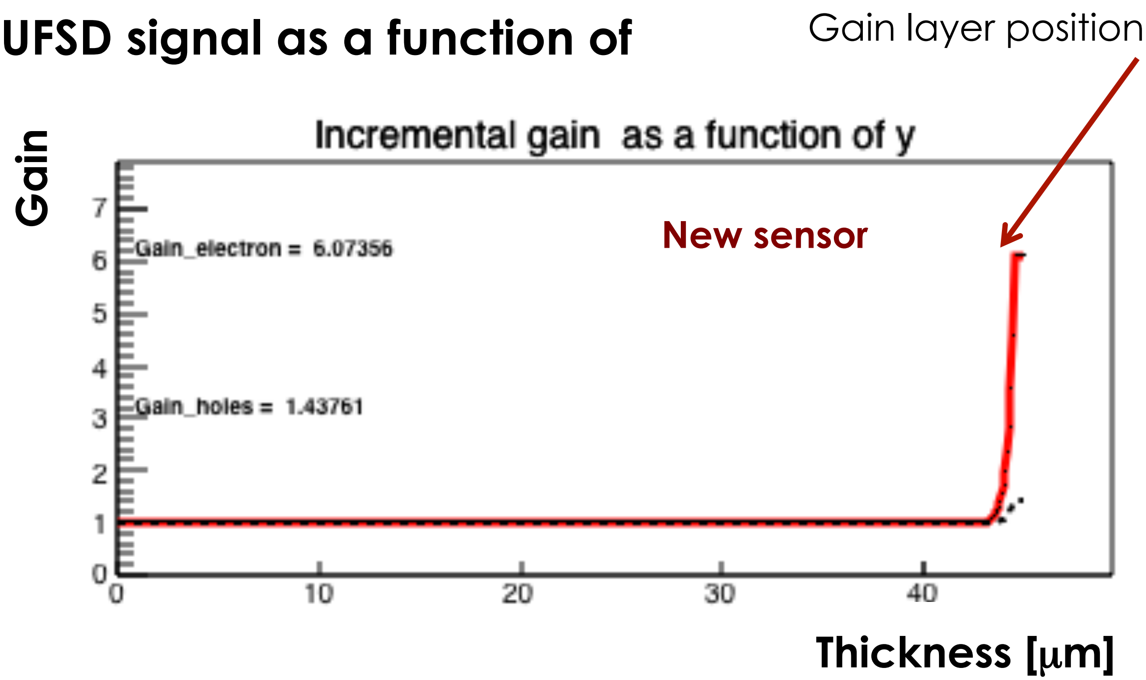


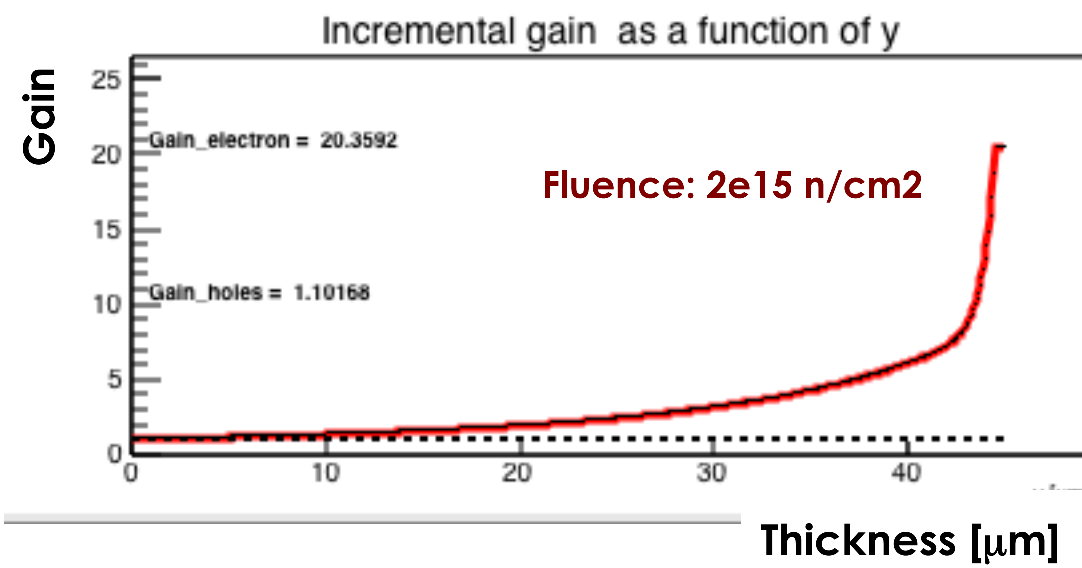
LGAD Signal as a function of fluence

What does happen to the UFSD signal as a function of irradiation?

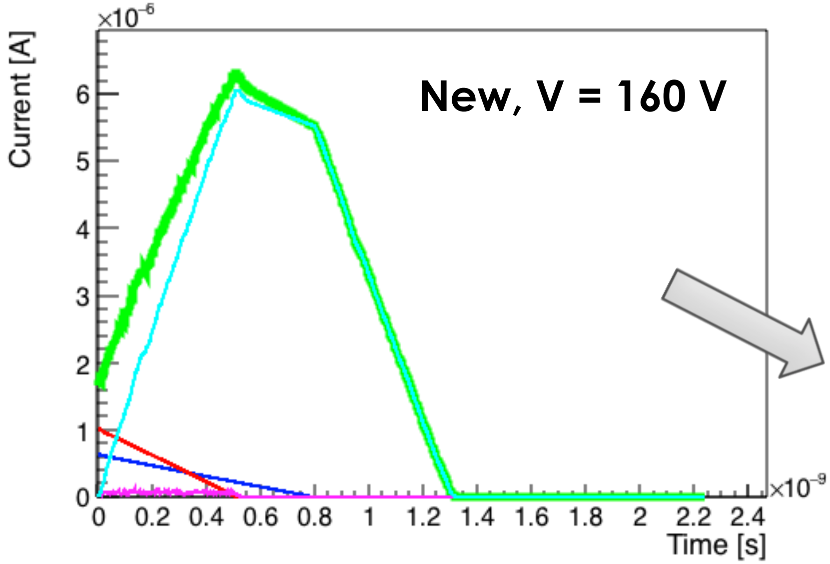
<ins>The gain moves from the gain layer to the bulk</ins>

<ins>Is this affecting the signal?</ins>



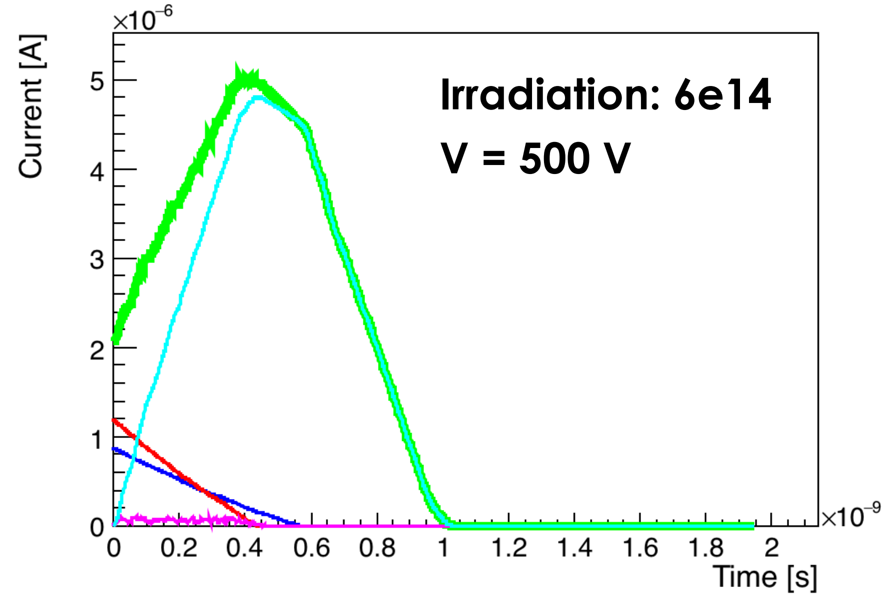


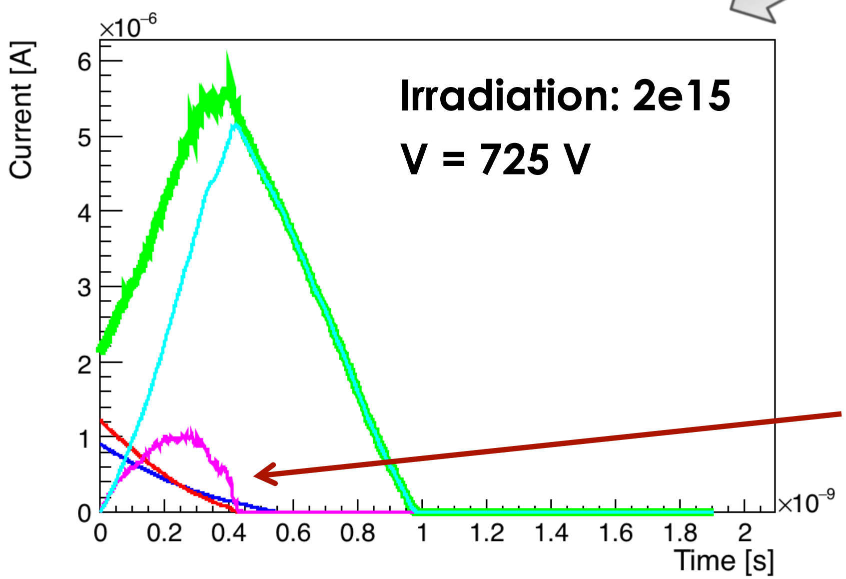
Signal shape in irradiated sensors



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

Does it matter?



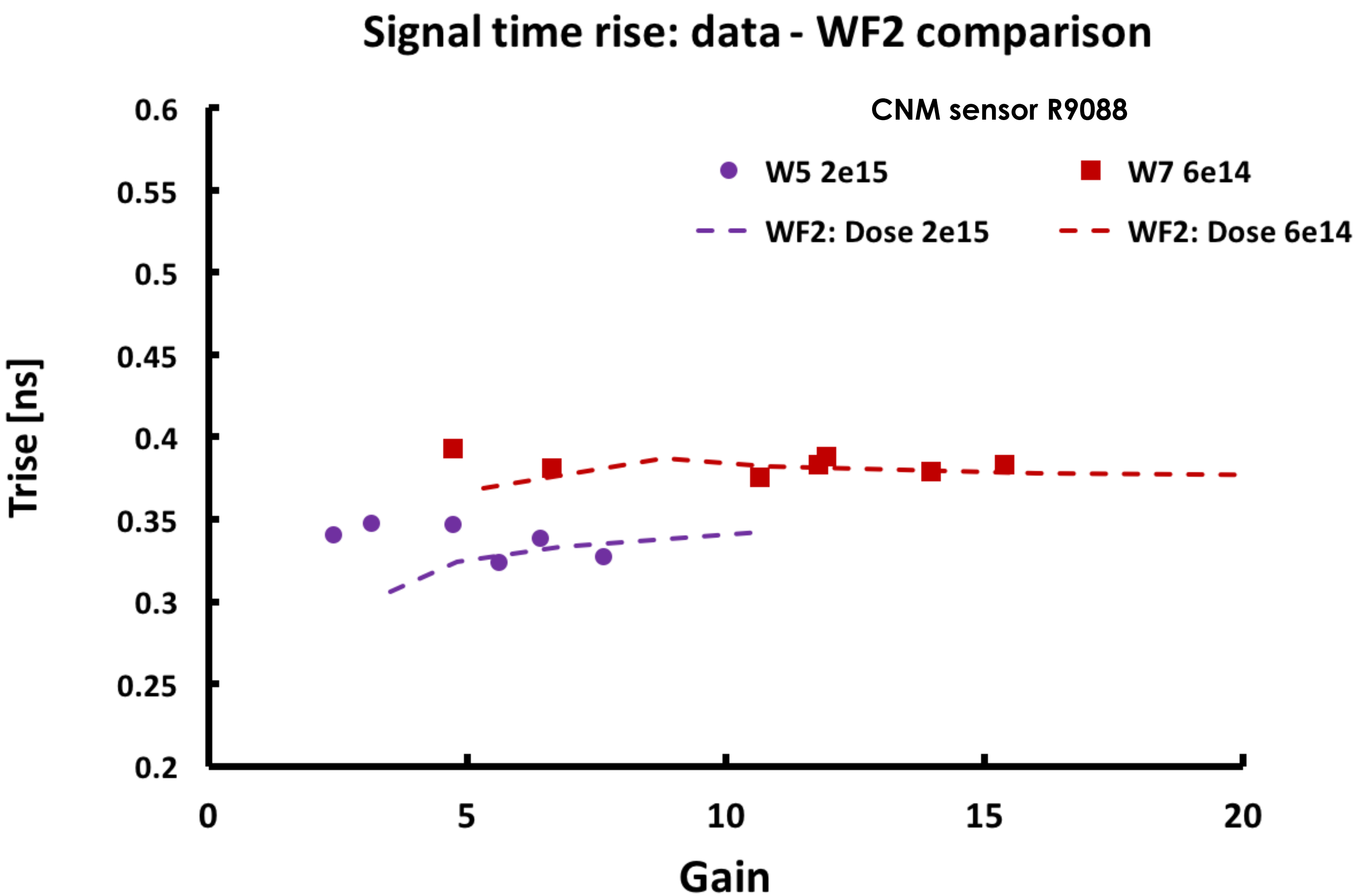


The signal shape does not change much:

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

Signal rise time in irradiated sensors

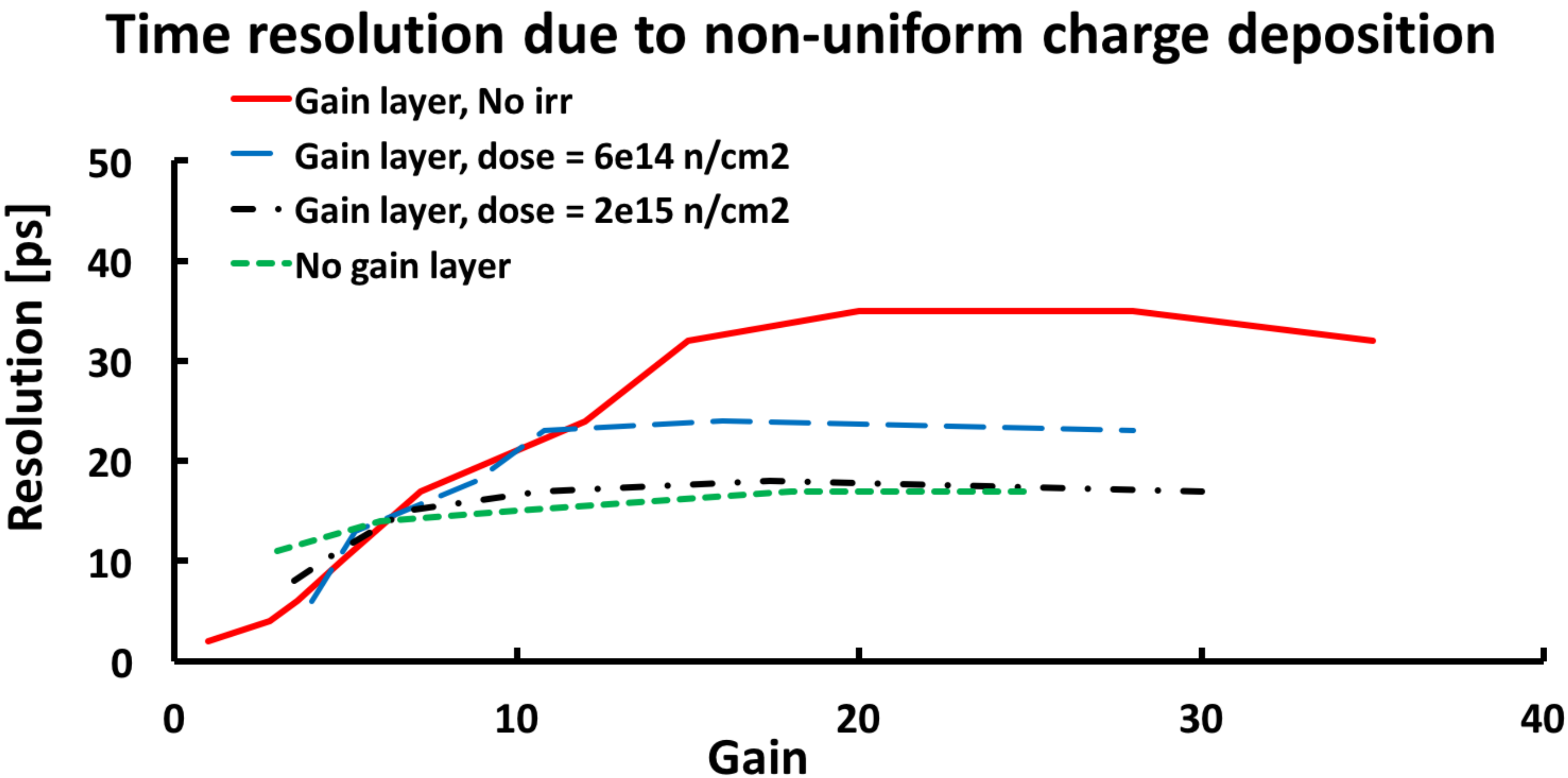
Remarkably, the decrease of signal rise time with increasing fluence has been measured (UCSC), and it compares well with WF2 (WF2 rescaled by 0.9 as the amplifier simulation is not perfect)



Non Uniform charge deposition

Non uniform charge deposition is currently limiting time resolution to ~ 30 ps in new sensors.

Interestingly, as the multiplication starts to happen in bulk, this contribution decreases to ~ 20 ps



Discussion point for LGADs

CNM 300, 50 micron, epi and FZ substrates.

FBK 300 micron

HPK 50, 80 micron

What are the consequences of these differences?

Best Solution?

Borders:

Number of guard rings, p-stops, edge termination

Gain layer implant type:

Shallow, deep, very deep, epi

Bulk-Support Wafer:

SOI, Si-Si, mostly very high resistivity bulk, few epi substrate

Leakage current:

Why is higher than we expect? Silicon quality? Support wafer?

Gain:

Sensor gain is very "power efficient", we need to keep it ~ 20, otherwise the electronics will require too much power

Dimension

1mm2, 2 mm2 diodes

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- U.S. Department of Energy grant number DE-SC0010107
- CNM, Barcellona
- RD50, CERN

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.

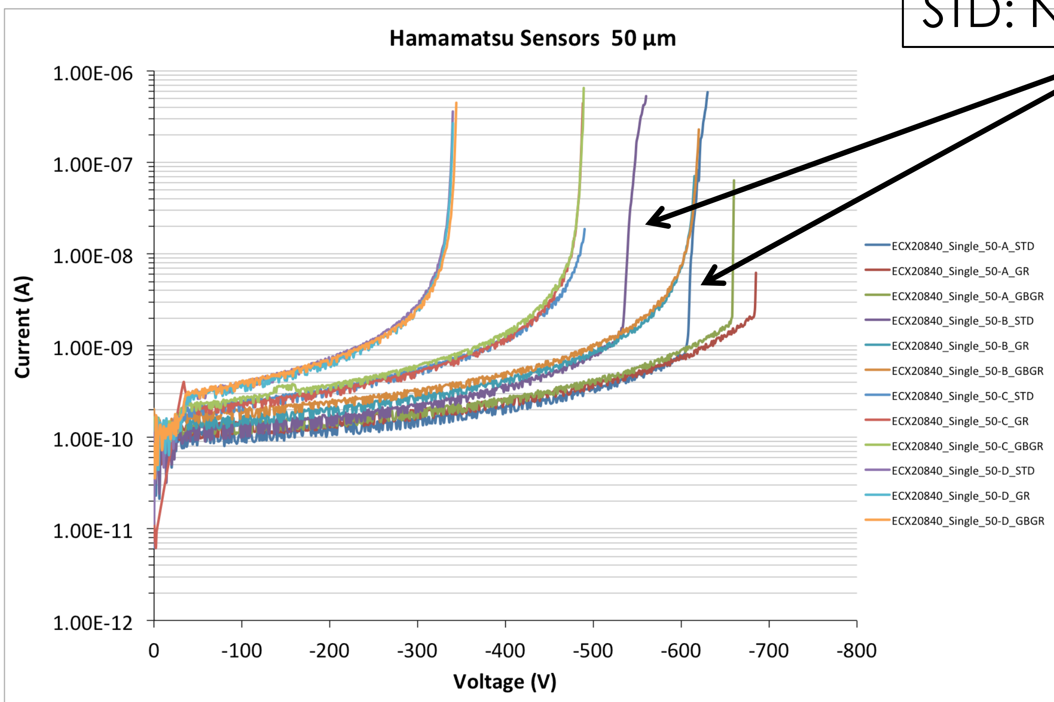
The contribution of charge non uniformity to time resolution decreases with increasing gain in the bulk.

Extra

Edge termination, guard rings - I

The issue: if the gain layer disappears, we need to compensate with the external Vbias

➔ Need to bias in excess of 700V after a fluence of 10^{15} n/cm^2



STD: No guard ring

3 types of sensors

STD: No guard ring
GR: Guard ring
GBGR: Guard ring + xxx

See presentation from M. Ferrero

HPK production, "no guard ring" breaks down earlier

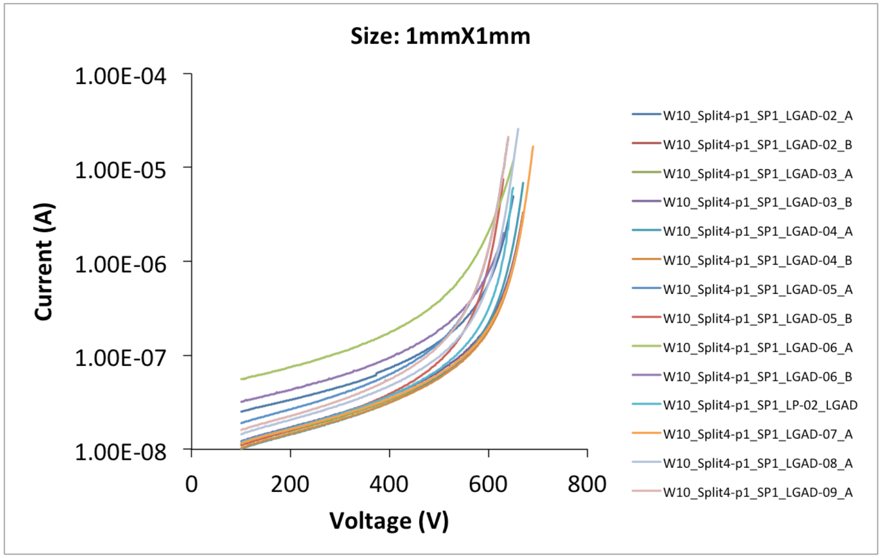
Edge termination, guard rings - II

FBK production,

JTE - like in each pad

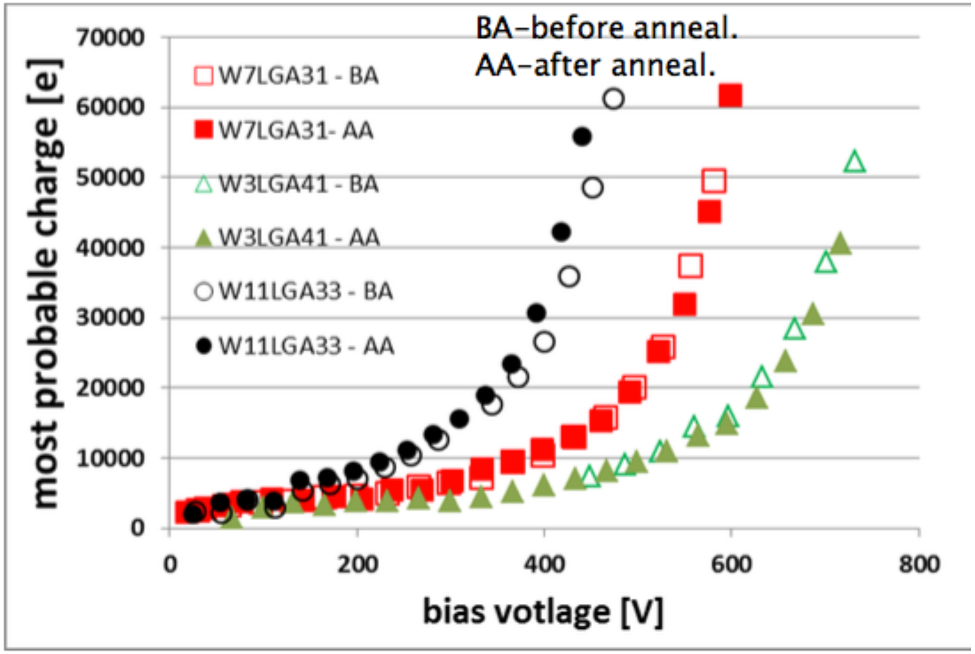
CNM production,

JTE- like in each pad



FBK production : large statistics of well behaving pads

Gain vs irradiation: 3.5e14 pions/cm^2



Use this data to define the initial acceptor removal rate