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Weightfield2
A friendly simulator for silicon detectors

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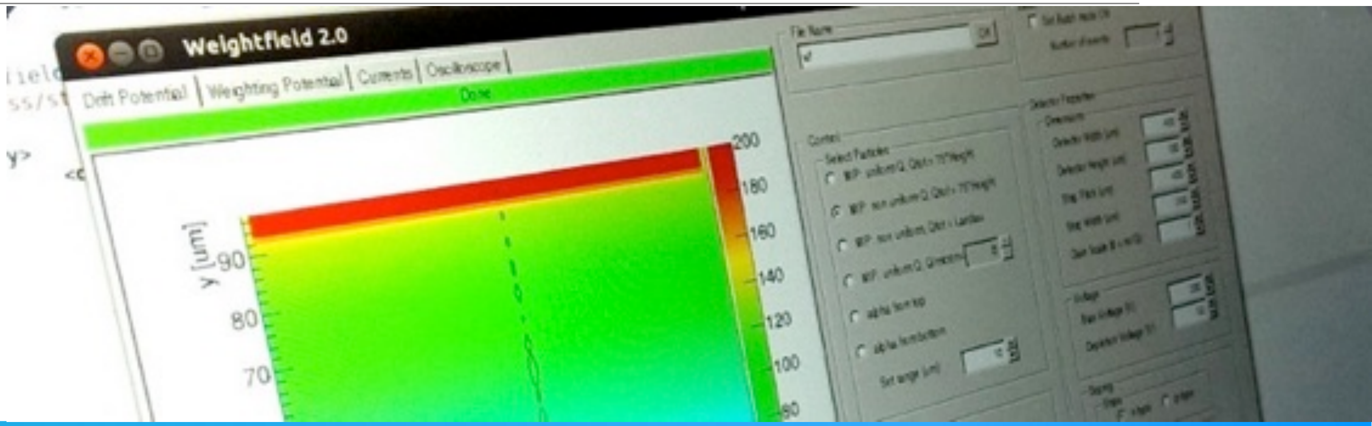
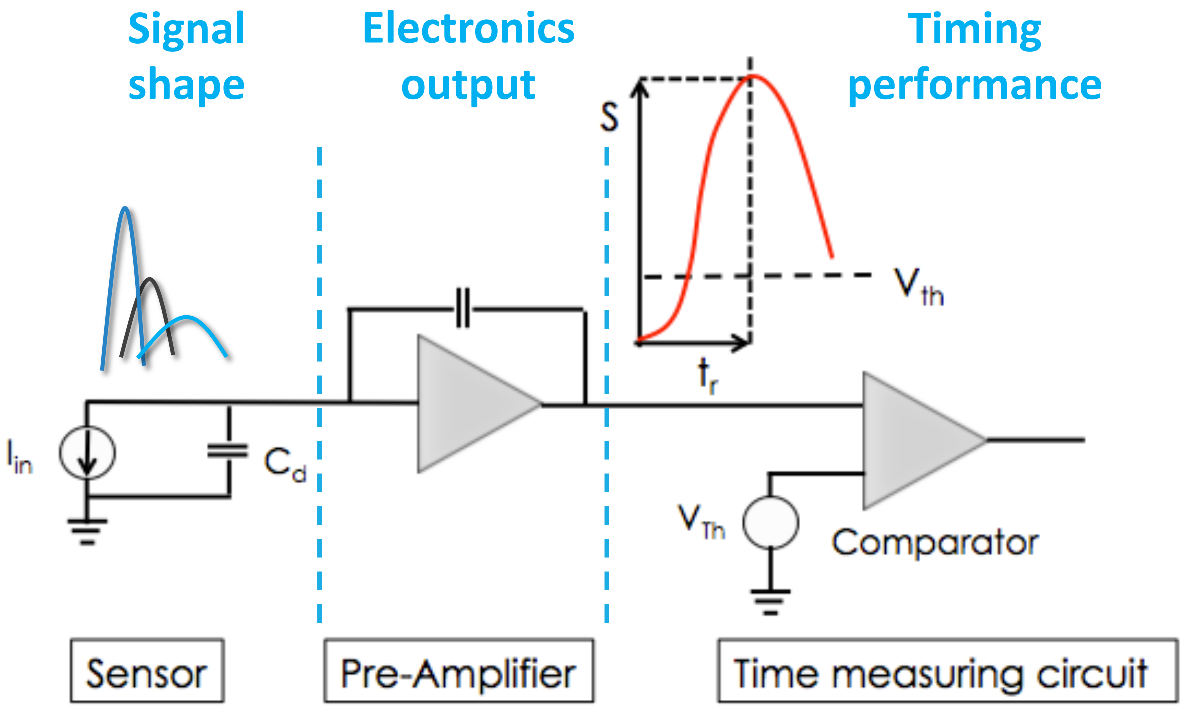


Weightfield2 at a Glance

- A fast simulator program to study the performance of silicon and diamond detectors
- It simulates the entire signal chain

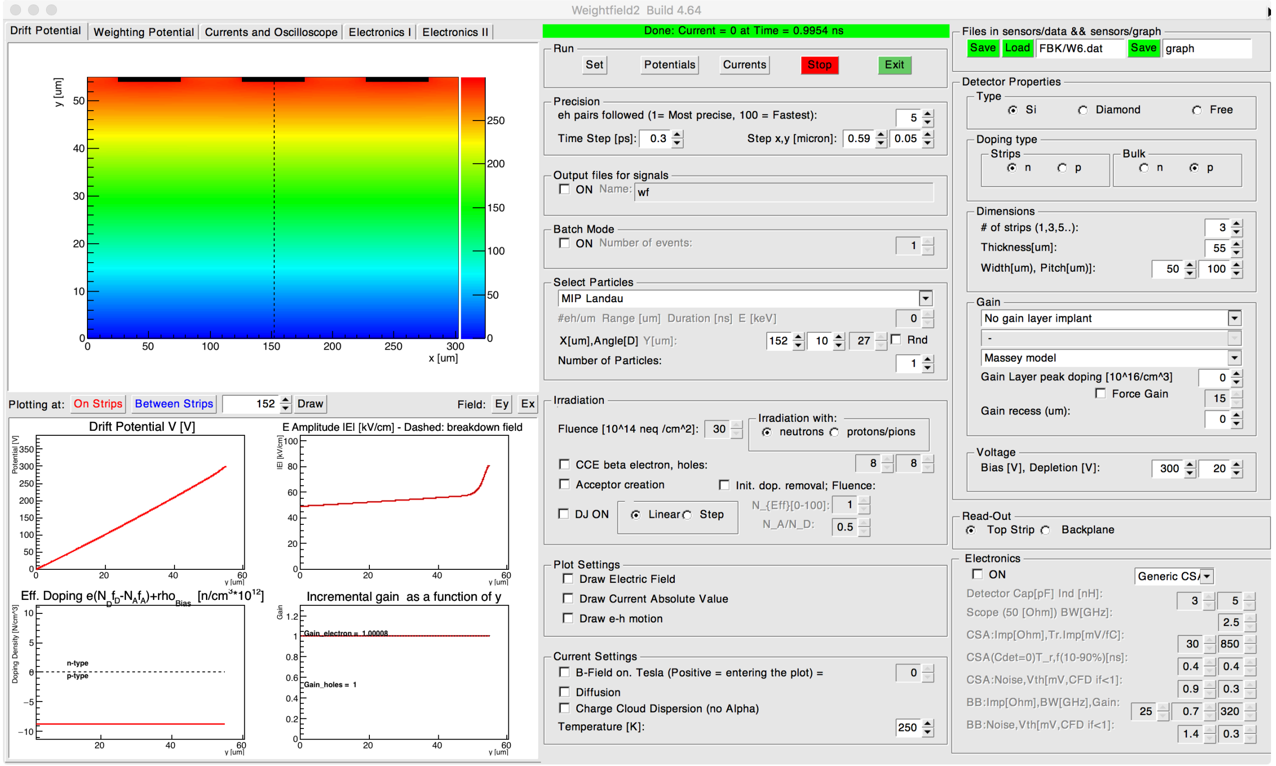


Weightfield2 at a Glance

Available at l.infn.it/wf2

It requires root(.cern.ch) build from source, it is for Linux and Mac-OS

It does not replace TCAD, but it helps in understanding the sensors response



Weightfield2 Highlights

- It is open source
- It is fast
- It generates the signal from several sources (MIP, alpha, lasers..)
- It runs in batch mode writing output file
- It loads/save configurations
- It performs basics electronics simulation

How to get it

1. Obtain the last version from l.infn.it/wf2
2. Unzip it
3. In a terminal, type "make” or "make -f Makefile_MacOS10.10_root6"
4. In the same terminal, type "./weightfield"

The Manual page explains the basic features of the program

Weightfield2 Layout

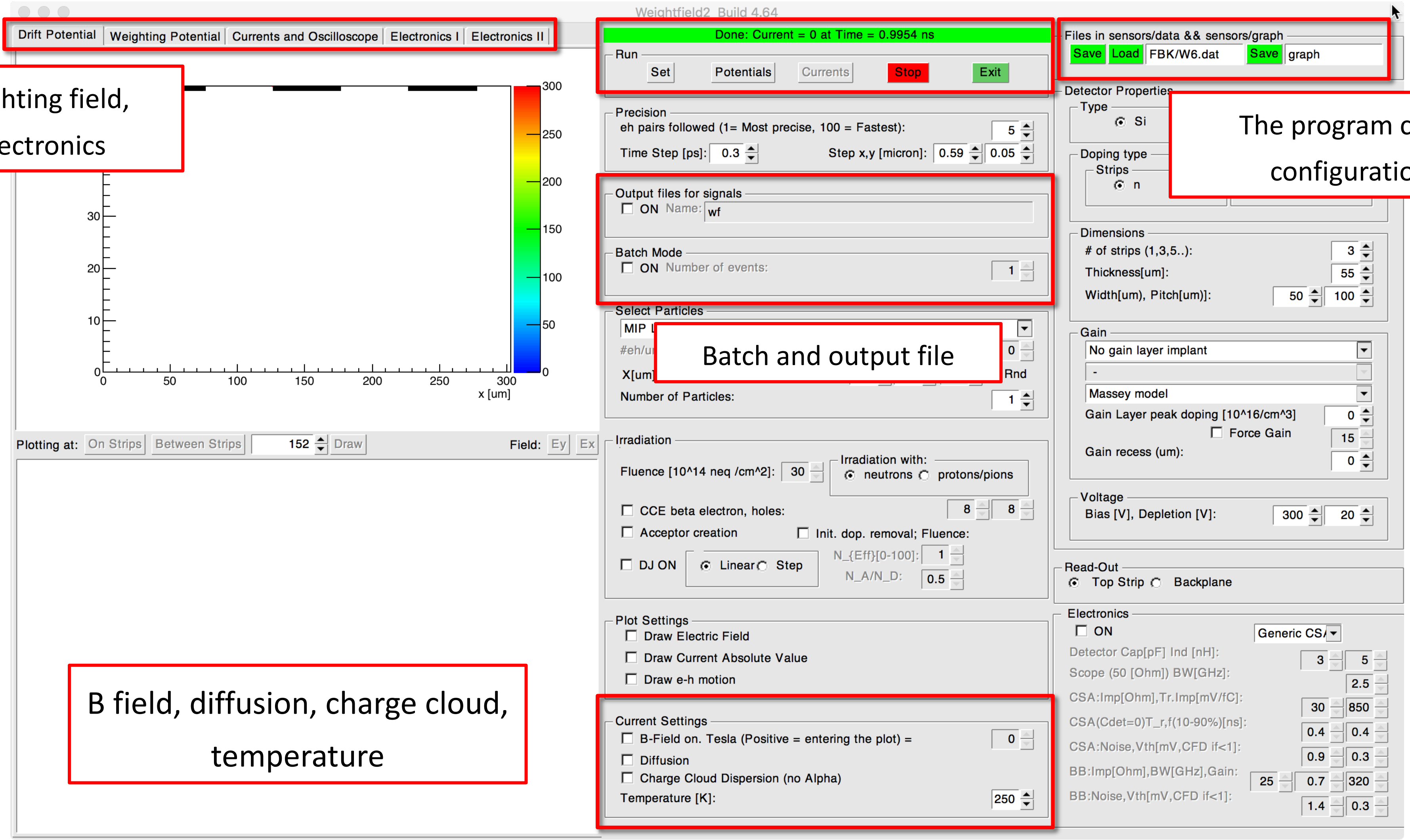
Controls

4 tabs: field, Weighting field, currents, and electronics

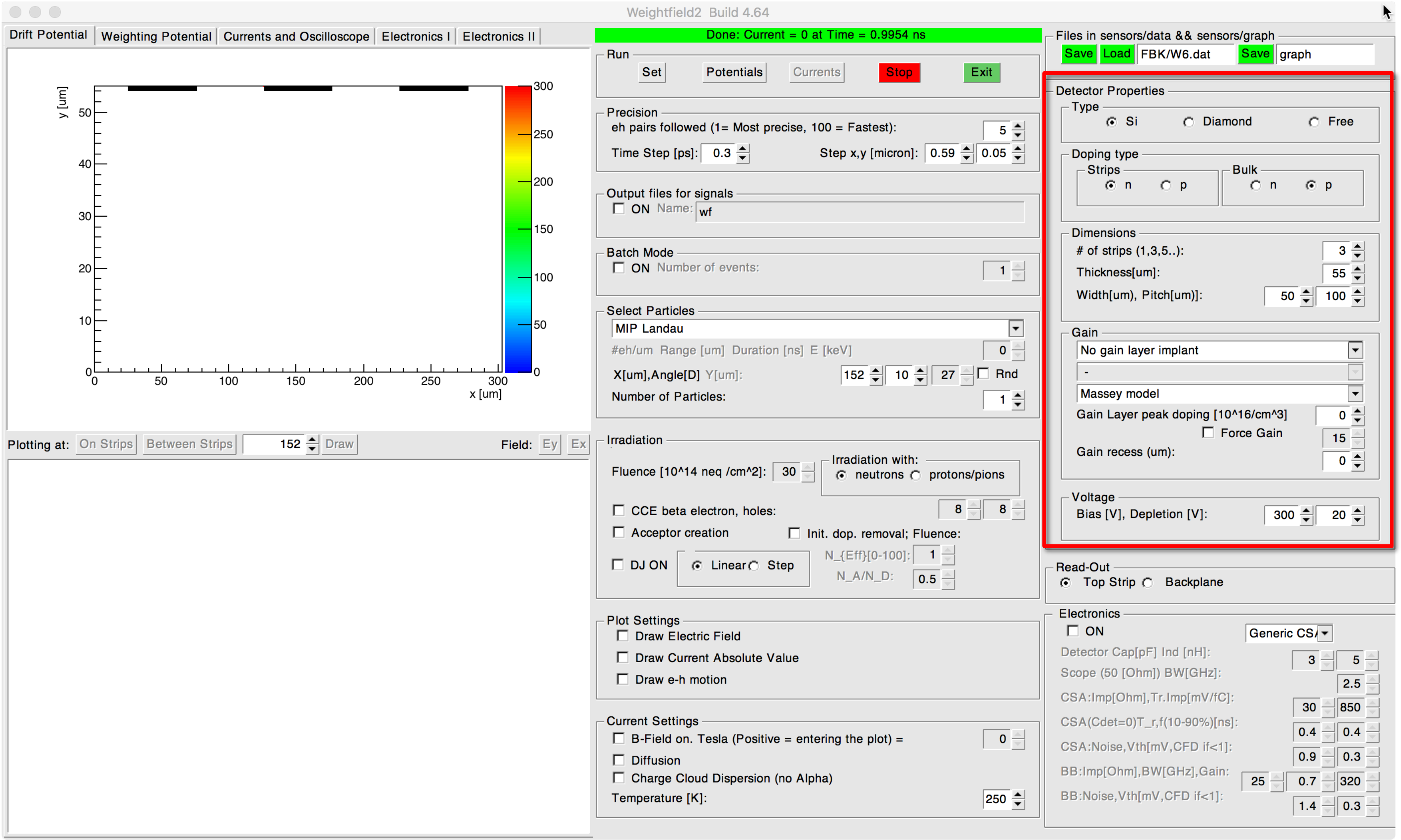
The program can save/load your configuration and the plots

Batch and output file

B field, diffusion, charge cloud, temperature



Step 1: Select your sensor



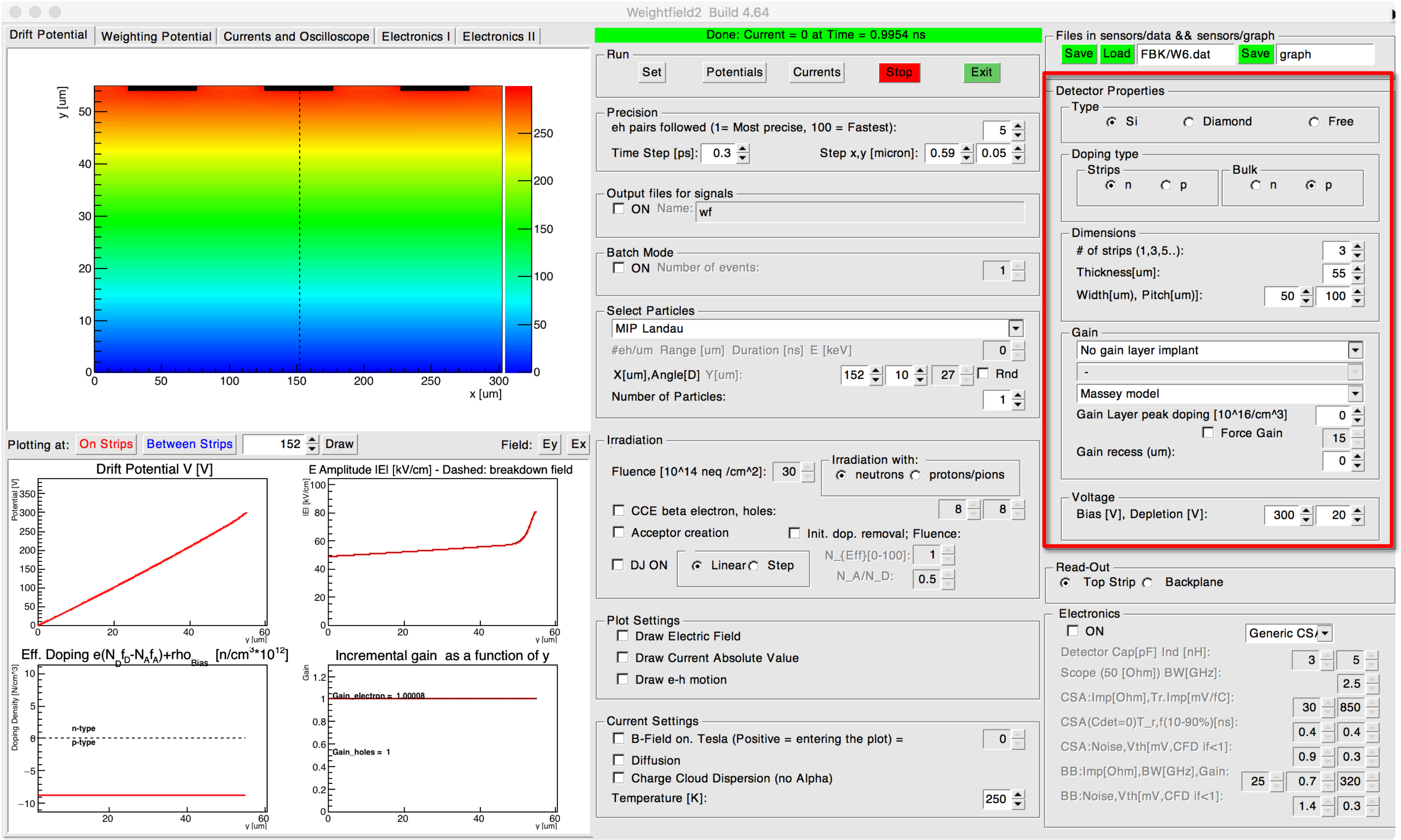
Fields Computation

- ▻ The program loads your geometry
- ▻ It compute the silicon resistivity from the depletion voltage
- ▻ It uses an iterative method to compute:

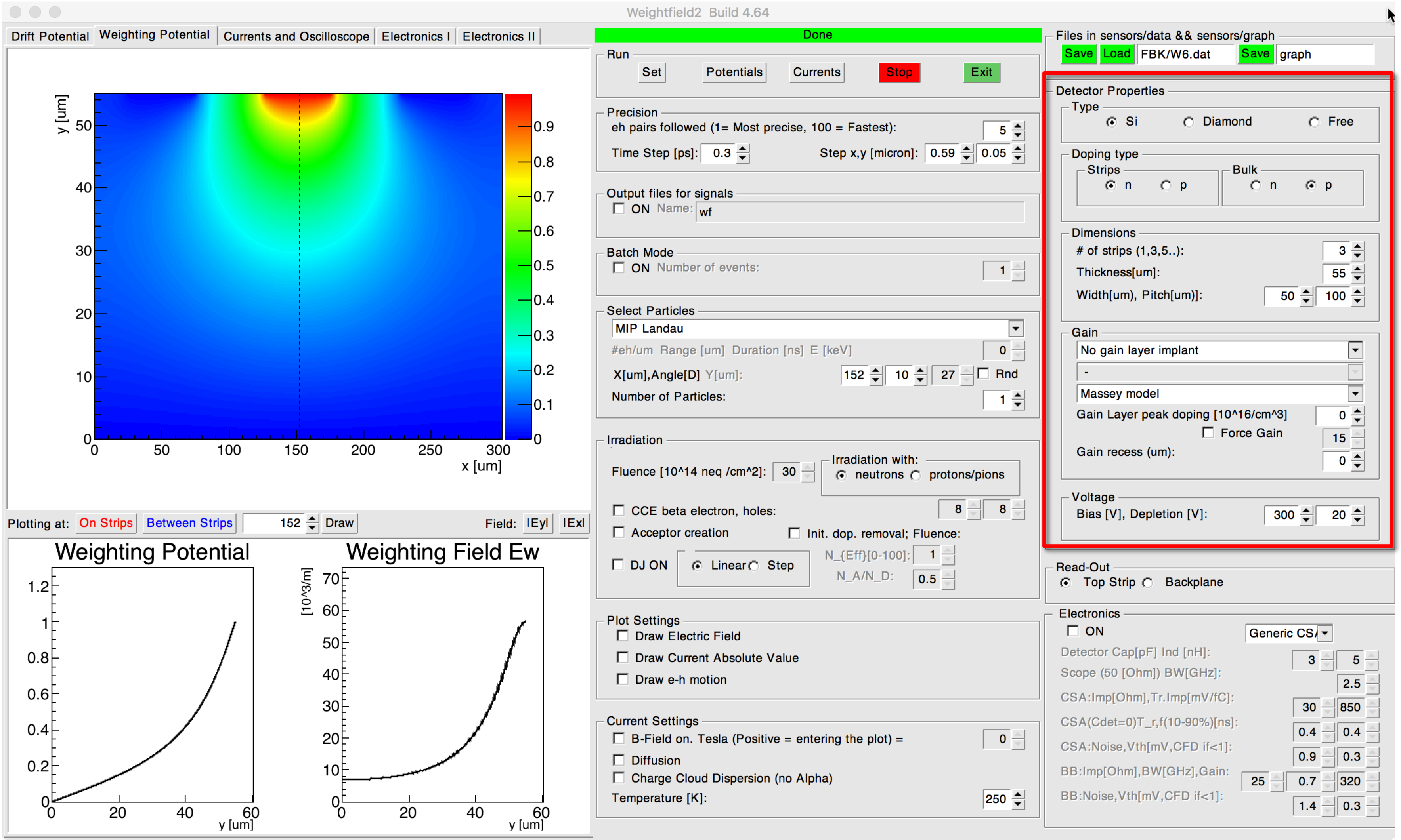
→ The electric field

→ The weighting field

Step 1: E field

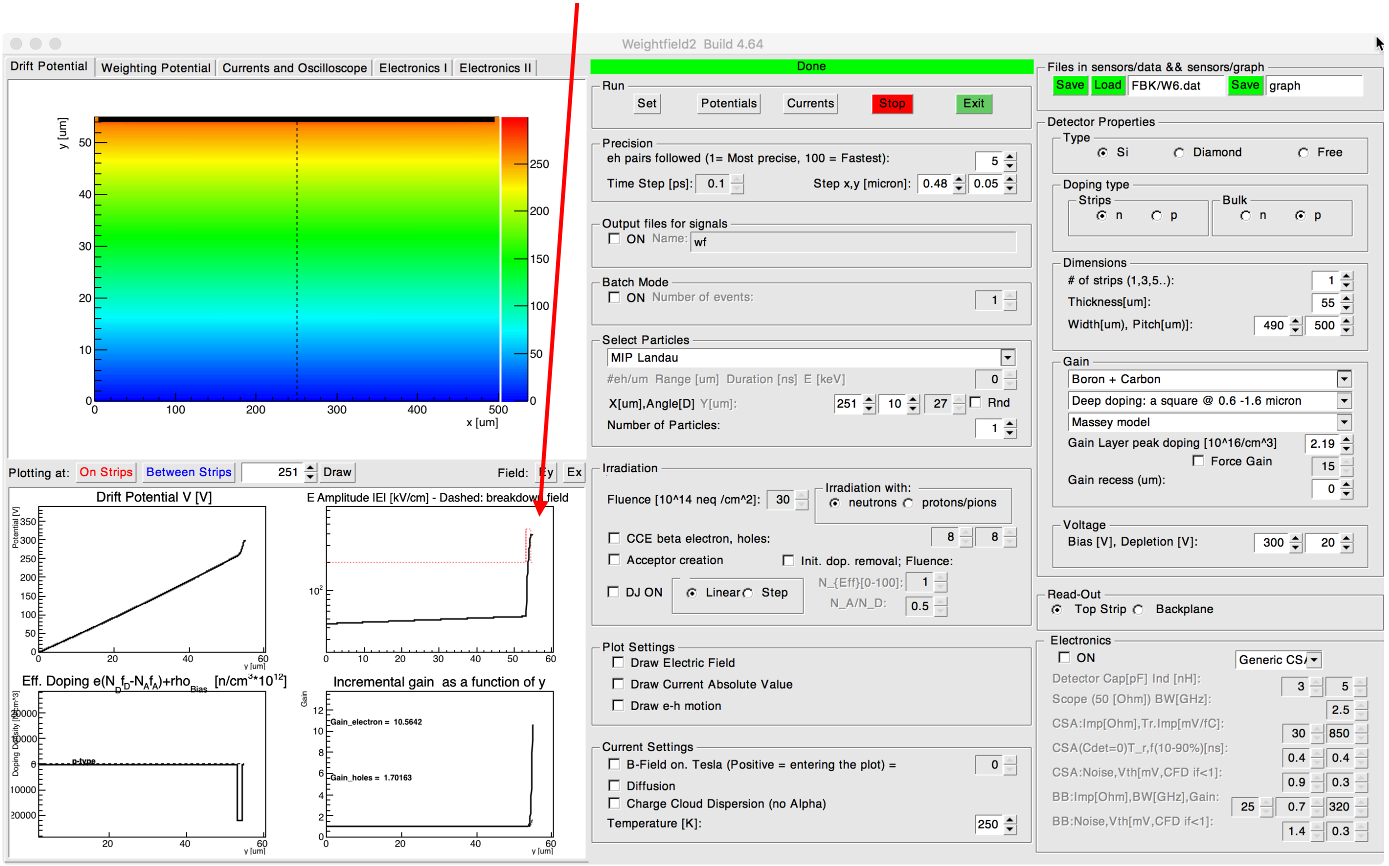


Step 1: W field

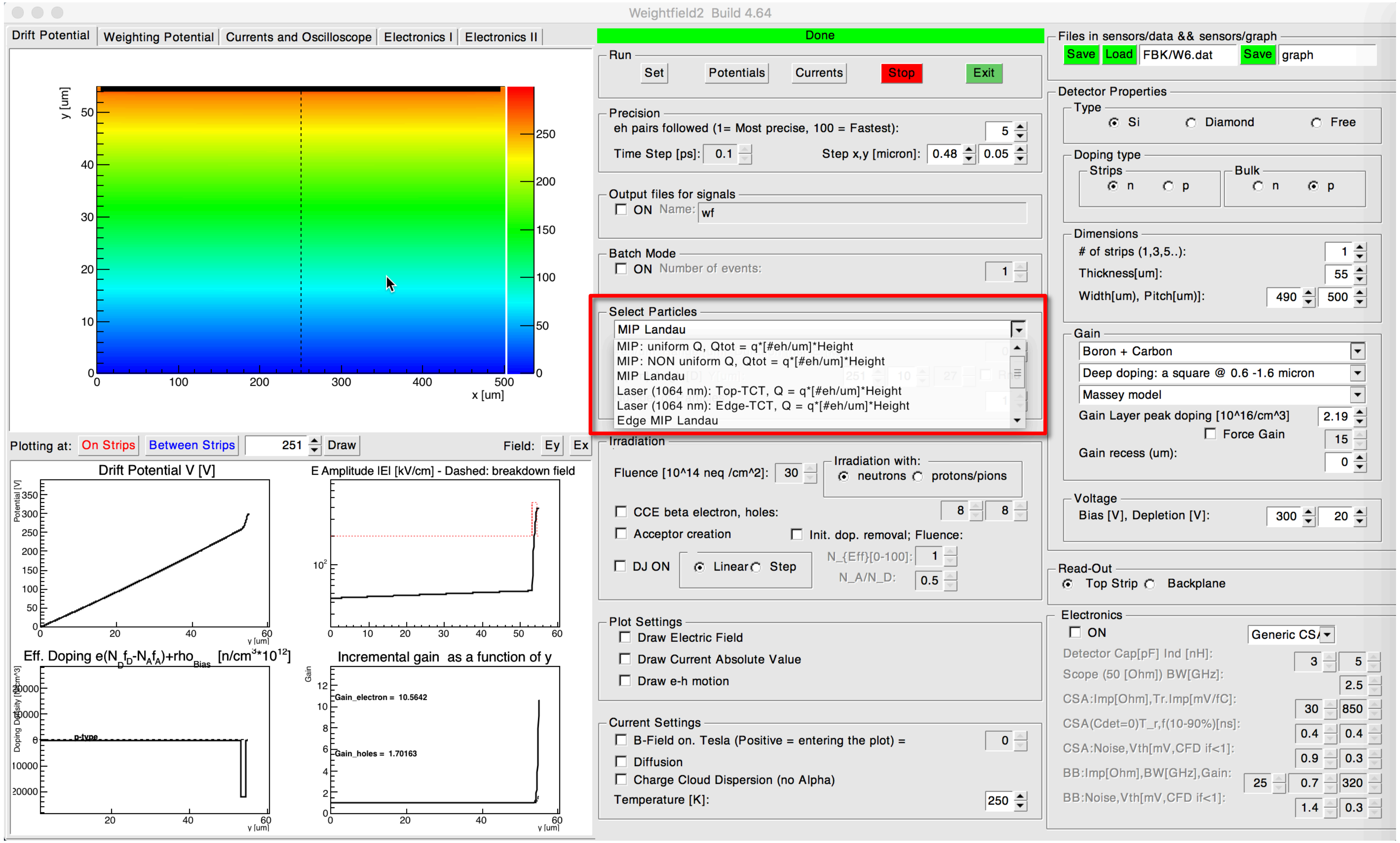


Select your sensor: does it have gain?

- The program implements a gain layer – LGAD design
- It computes the contribution from the additional doping to the electric field

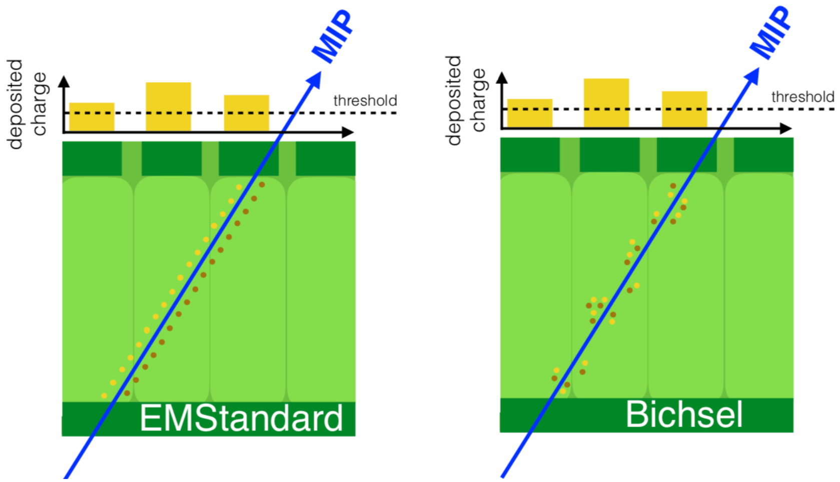


Step 2: Select the particle



Step 2: Charge deposition – Landau

The program uses GEANT4 with the photo-absorption ionization (PAI) model to generate non-uniform charge depositions



Results cross-checked with several publications, for example:
The Impact of Incorporating Shell-corrections to Energy Loss in Silicon
F. Wang, D. Su, B. Nachman, M. Garcia-Sciveres, and Q. Zeng
`arXiv:1711.05465v2 [physics.ins-det]`

“The ionization energy loss fluctuation in very thin silicon sensors significantly deviates from the Landau distribution. Therefore, we have developed a charge deposition setup that implements the Bichsel straggling function, which accounts for shell-effects.”

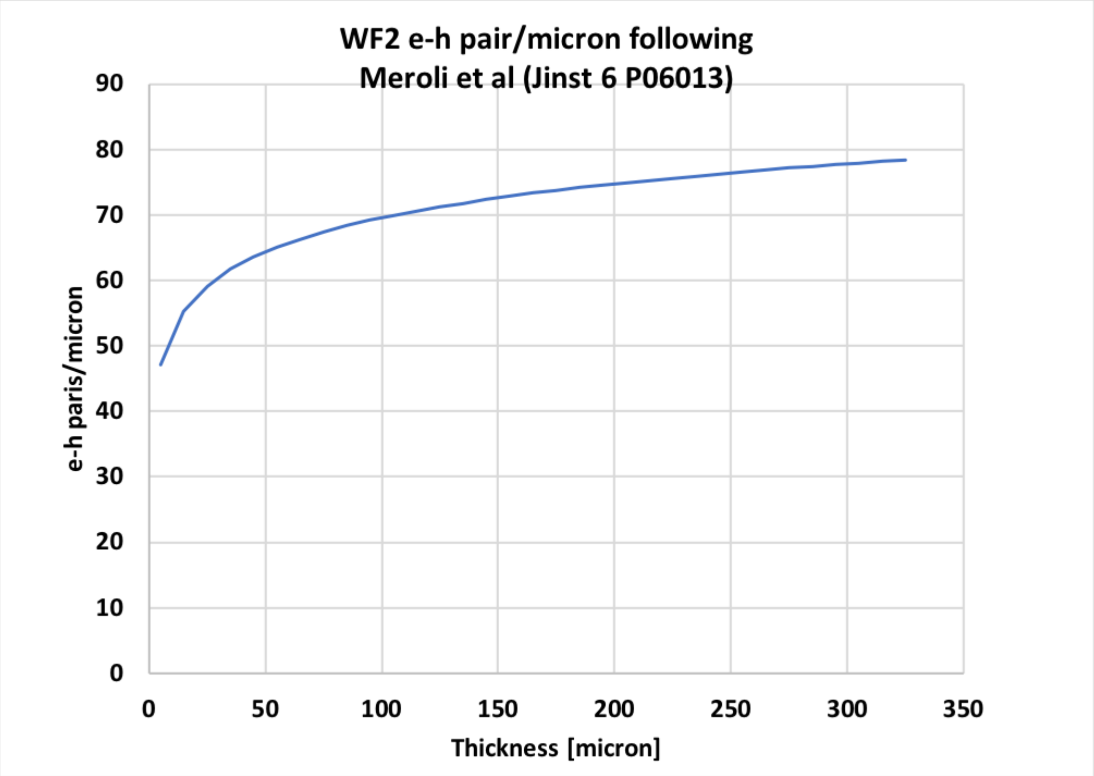
Step 2: Charge deposition – Landau

Landau distribution

$$MPV = d*[\ 0.027*\ln(d)+0.126]$$

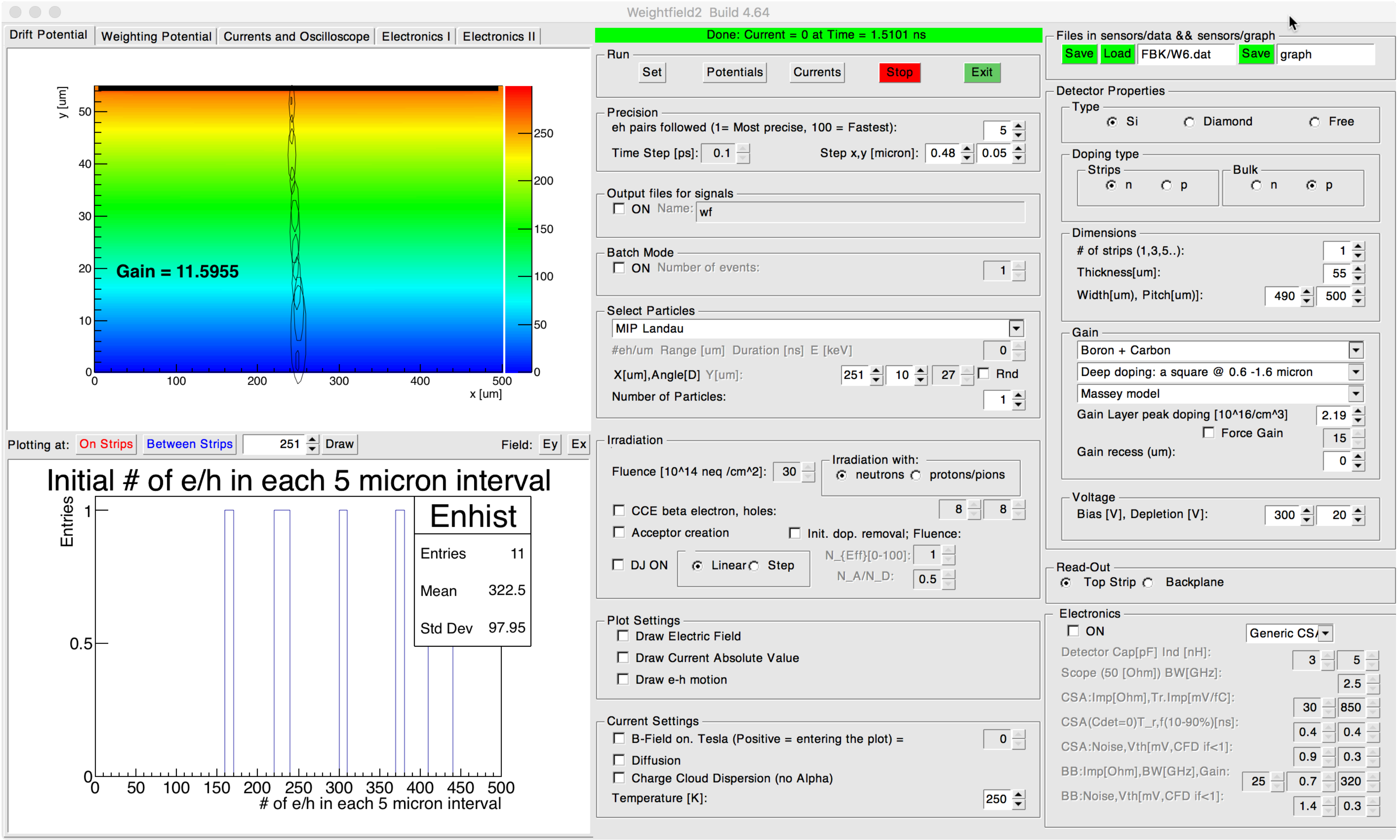
$$FWHM = 0.31*d^{0.81}$$

$$\frac{FWHM}{MPV} = 2.1*d^{-0.3}$$



Following Meroli et al (Jinst 6 P06013), these are the parameterizations of the MPV and FWHM as a function of the sensor thickness d for the Landau distribution in silicon

Step 2: Charge carriers drift



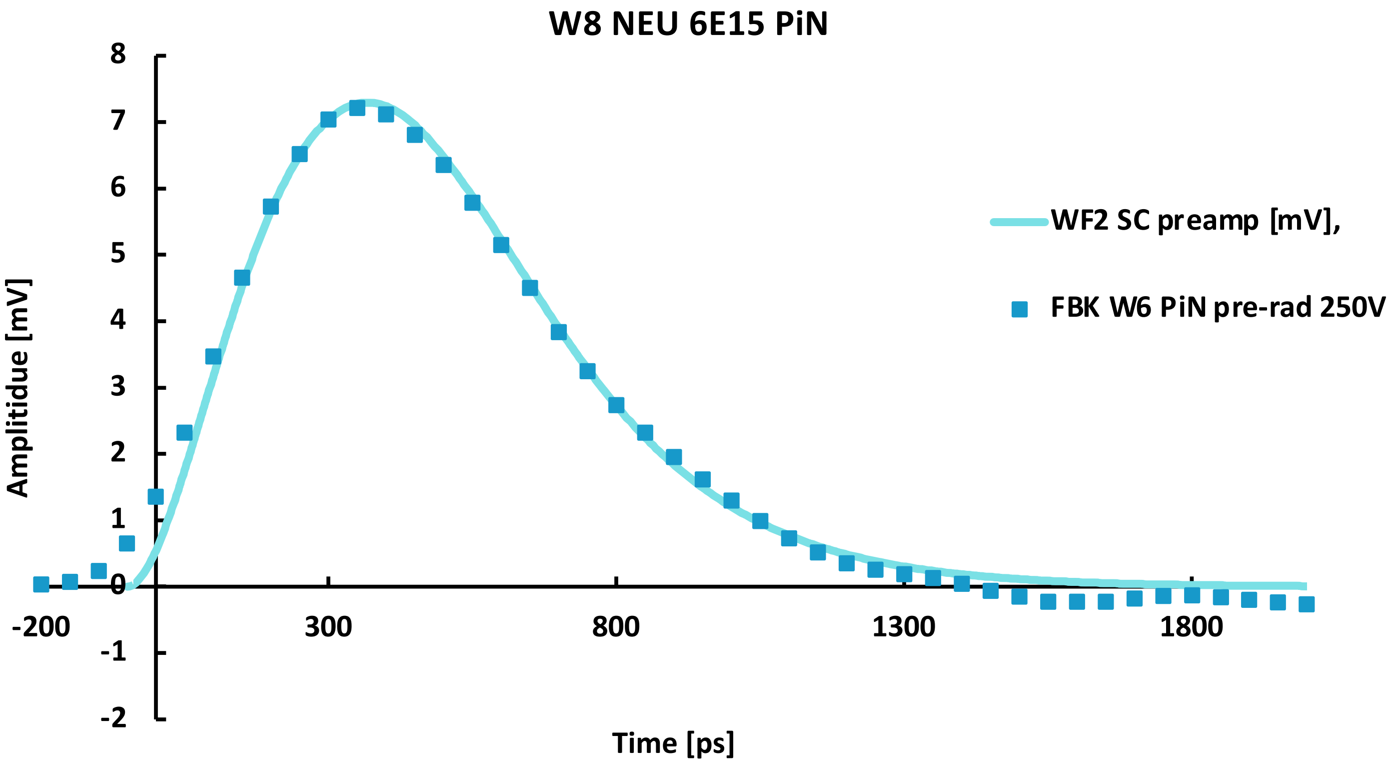
Drift of the charge carriers – Ramo's theorem

Current is generated using Ramo's theorem: i(t) = qv(t)E_w

$$I_{tot}(t_j) = \sum_{k=1}^{n} I_k(t_j) = -\text{q} \sum_{k=1}^{n} \overrightarrow{v_k(t_j, x_k)} \cdot \overrightarrow{E_w}(x_k)$$

	Electrons	Holes
$\mu(T)\ \left[{}^{m^2}/_{Vs}\right]$	$0.1414\left(\frac{T}{300K}\right)^{-2.5}$	$0.0470\left(\frac{T}{300K}\right)^{-2.2}$
$\beta(T)$	$1.09\left(\frac{T}{300K}\right)^{0.66}$	$1.213\ (\frac{T}{300K})^{0.17}$
$v_{Sat}(T)\ [{}^{m}/_{s}]$	$1.07e5\left(\frac{300K}{T}\right)^{0.87}$	$8.35e4\left(\frac{300K}{T}\right)^{0.52}$
$v(\text{x, T})\ [{}^{m}/_{s}]$	$\frac{\mu_e(T)E_d(x)}{\sqrt[1/\beta_e(T)]{1+(\frac{\mu_e(T)E_d(T)}{v_{e,Sat}(T)})^{\beta_e(T)}}}$	$\frac{\mu_h(T)E_d(x)}{\sqrt[1/\beta_h(T)]{1+(\frac{\mu_h(T)E_d(x)}{v_{h,Sat}(T)})^{\beta_h(T)}}}$

WF2 – Data: current in PiN



Gain modelling

If the electric field is high enough, carriers generate secondary ionization along the drift path

$$N_e(x) = N_e e^{\beta x} \qquad N_h(x) = N_h e^{\alpha x}$$

$$\alpha = A_n \exp\left\{-\frac{B_n}{E}\right\}$$

$$\beta = A_p \exp\left\{-\frac{B_p}{E}\right\}$$

$$B_{n,p}(T) = C_{n,p} + D_{n,p}\, T$$

Different impact ionisation models can be selected:

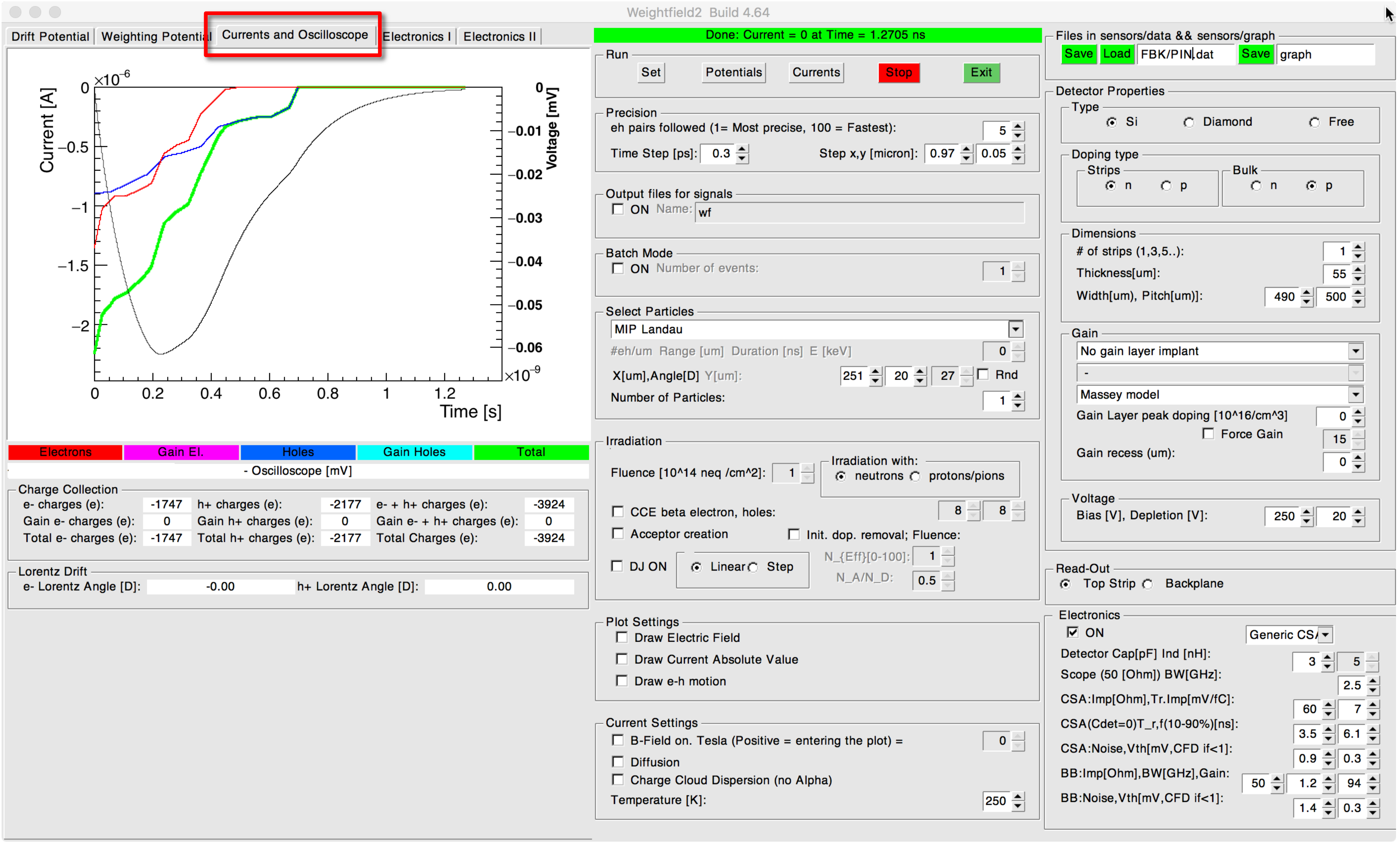
– Massey

– van Overstraeten-de Man

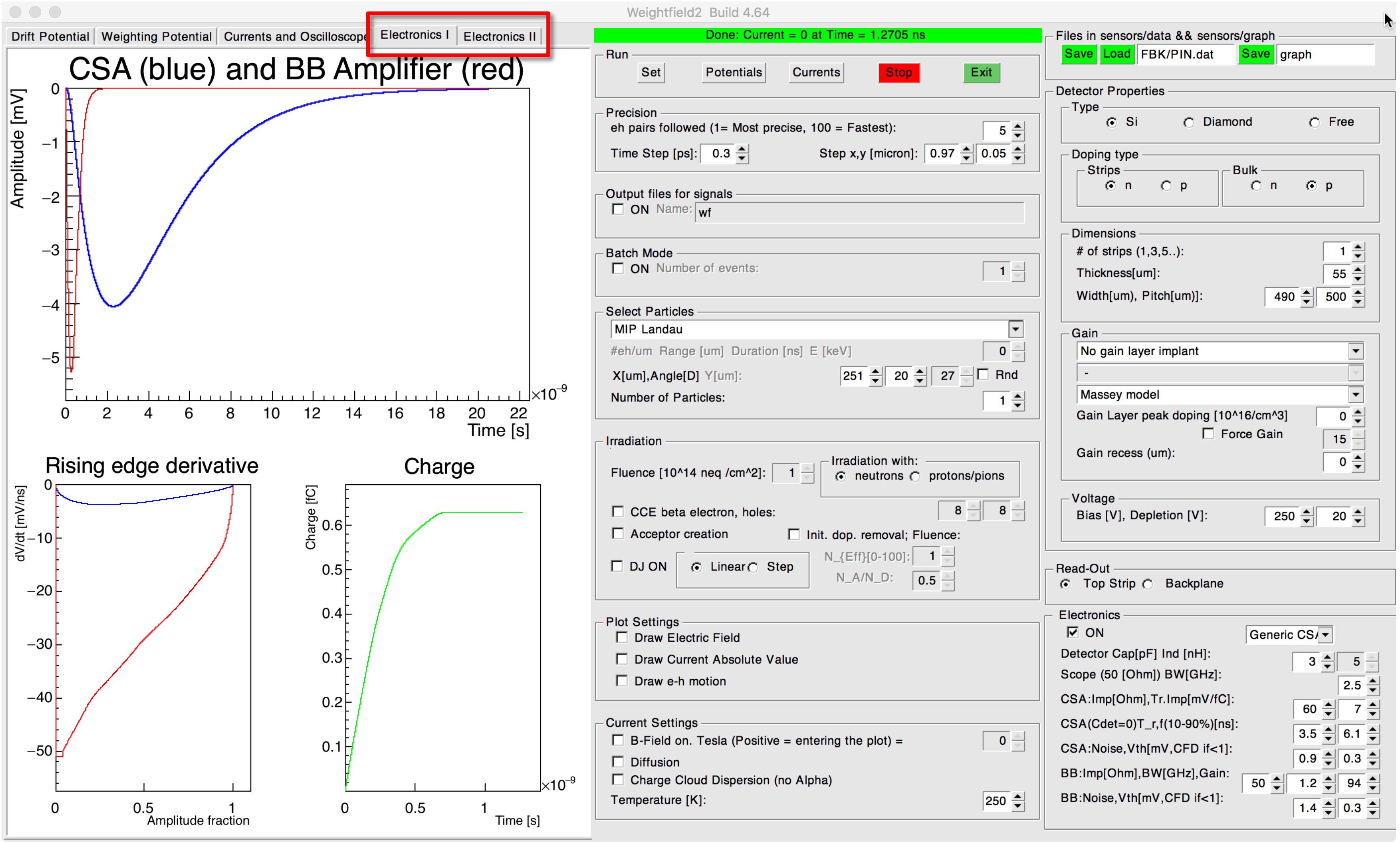
– Okuto-Crowell

– Bologna

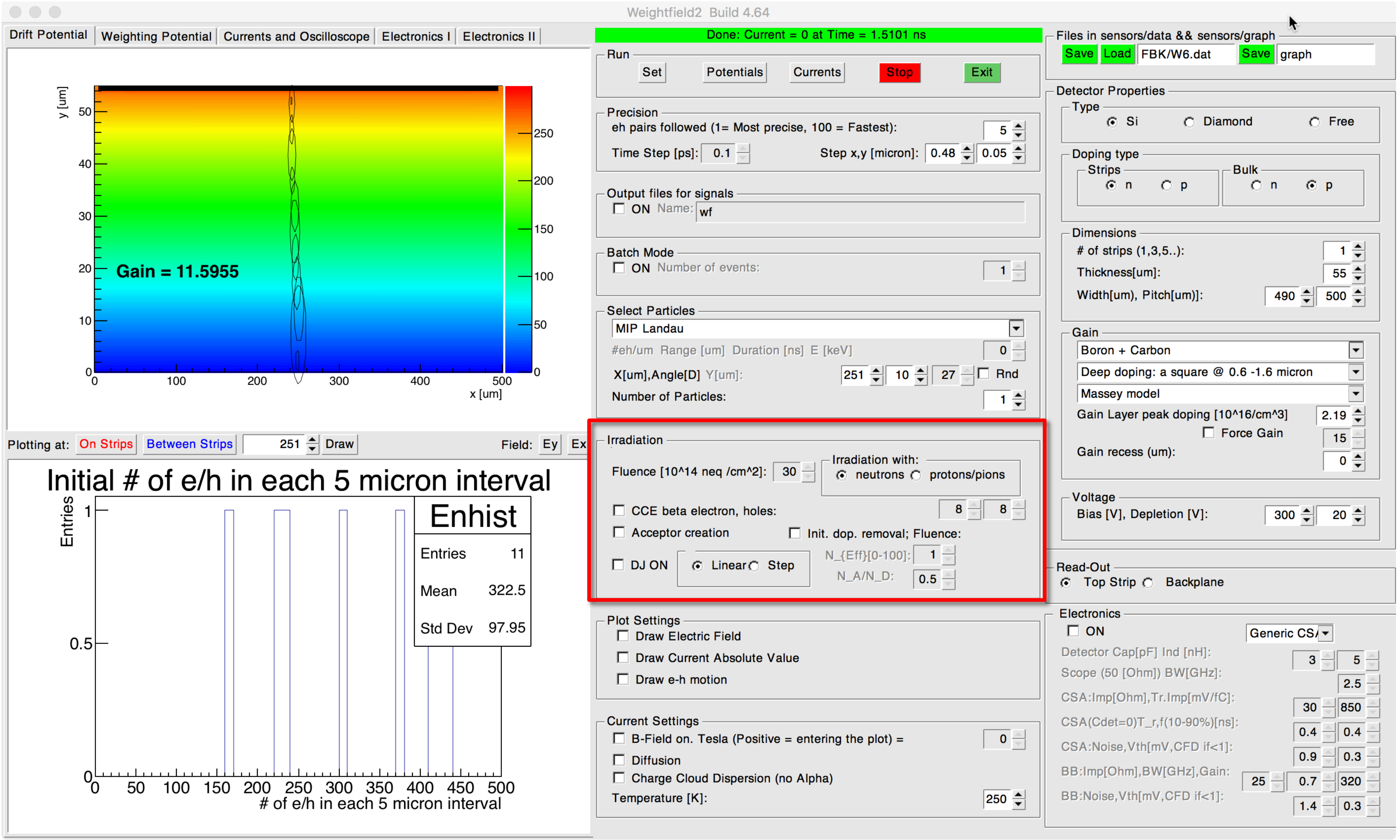
WF2 – Currents



WF2 – Electronics



Step 4: Radiation damage



Radiation damage effects

Charge trapping with fluence phi:

$$\mathbf{i}(\boldsymbol{t}) = \boldsymbol{i}(\boldsymbol{t})_{\boldsymbol{new}}\boldsymbol{e}^{-\boldsymbol{t}/\boldsymbol{\tau}}$$

$$\boldsymbol{\tau} = \boldsymbol{\beta}\emptyset$$

Acceptor removal:

$$\boldsymbol{N}(\emptyset) = \boldsymbol{N}(\mathbf{0}) * \boldsymbol{e}^{-\boldsymbol{c}\emptyset}$$

Acceptor creation:

$$\boldsymbol{N}(\emptyset) = \boldsymbol{\beta}\emptyset$$

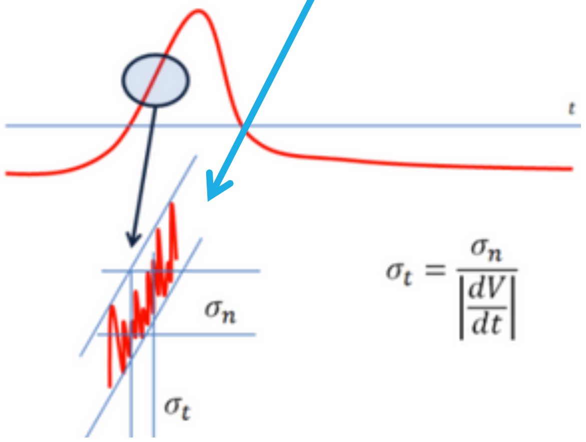
Time resolution

$$\sigma_t = \left(\frac{N}{dV/dt}\right)^2 + (\text{Landau Shape})^2 + \text{TDC}$$

Usual "Jitter" term

Here enters everything that is "Noise"

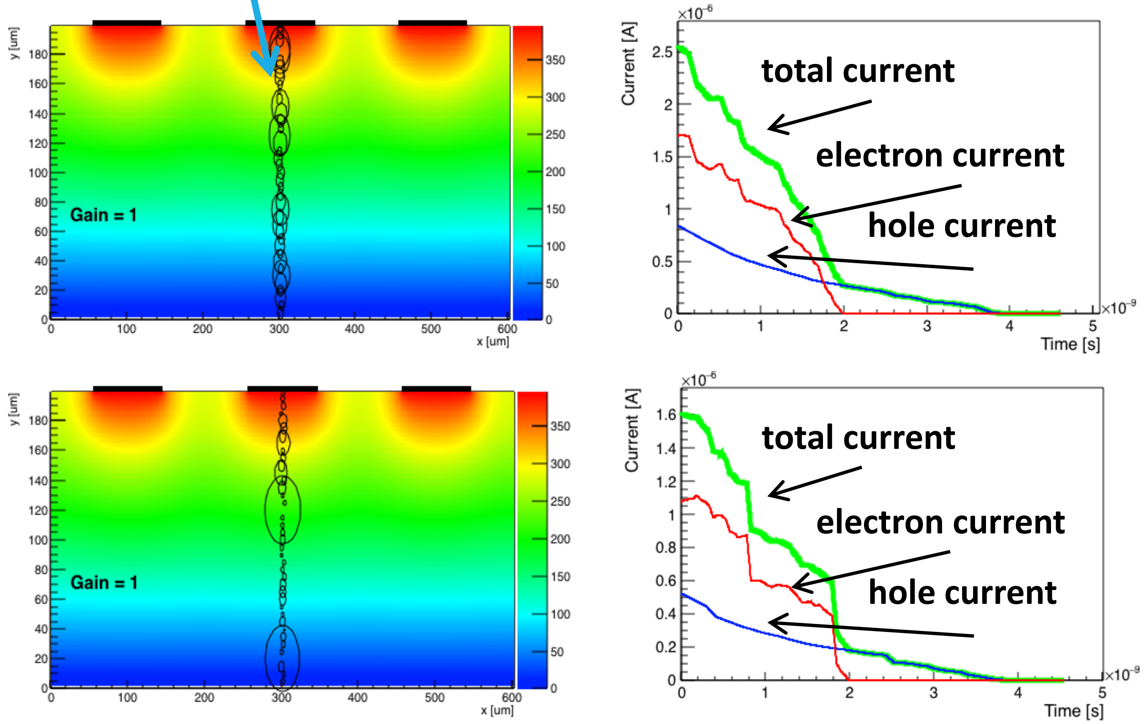
and the steepness of the signal



Need large dV/dt

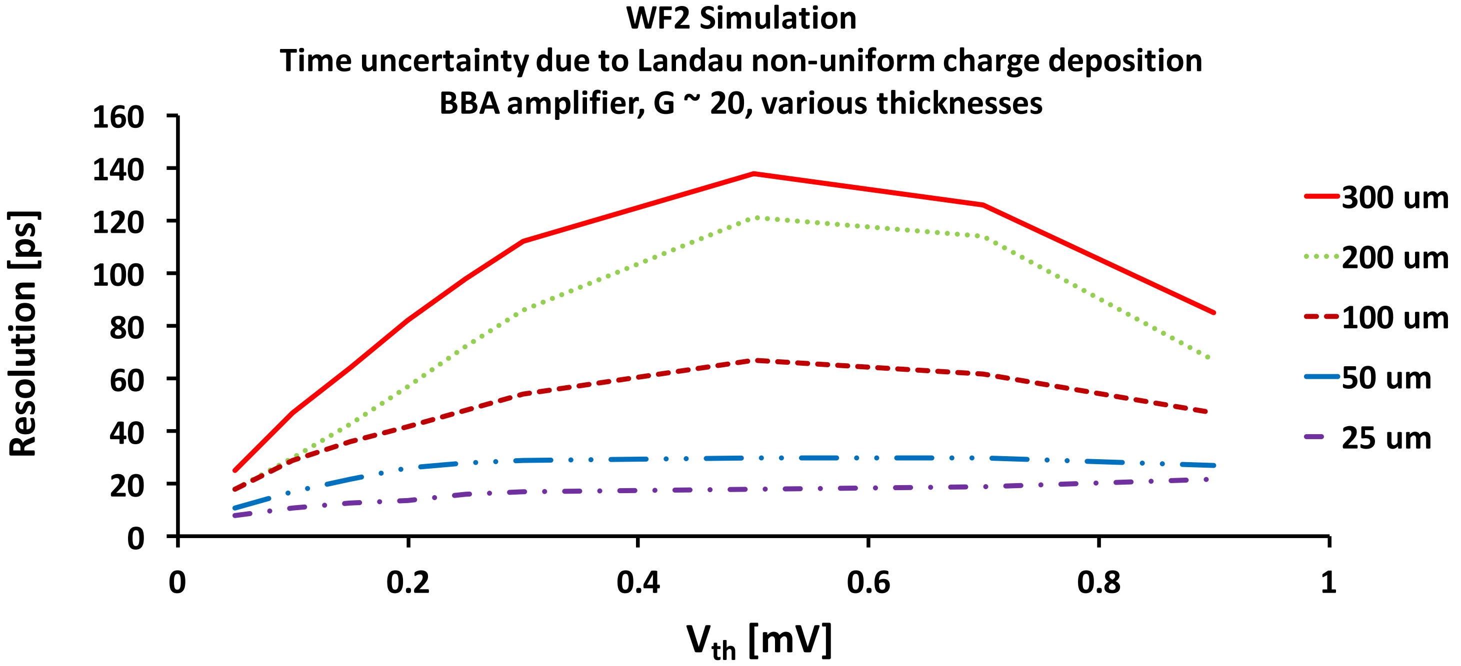
Time walk: Amplitude variation, corrected in electronics

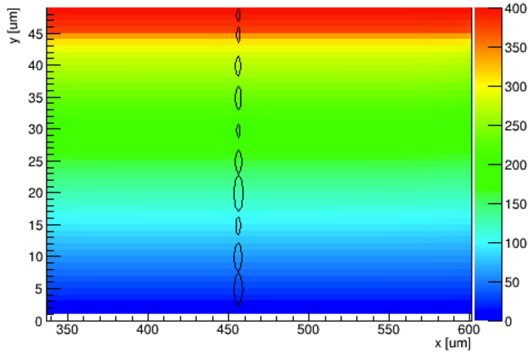
Shape variations: non-homogeneous energy deposition



Non-uniform charge deposition

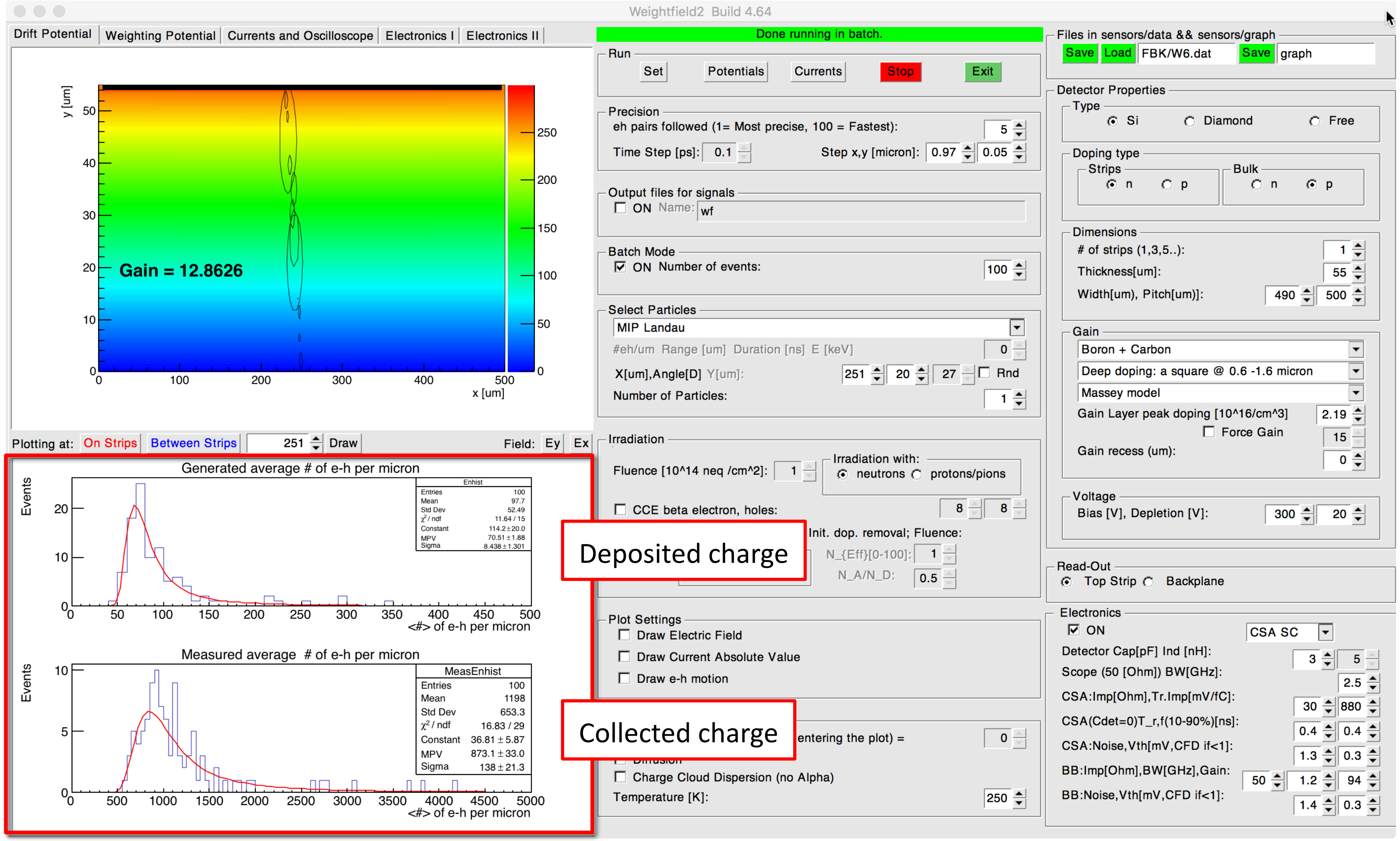
This is a physical limit to time resolution
Need to use thin detectors and low comparator threshold



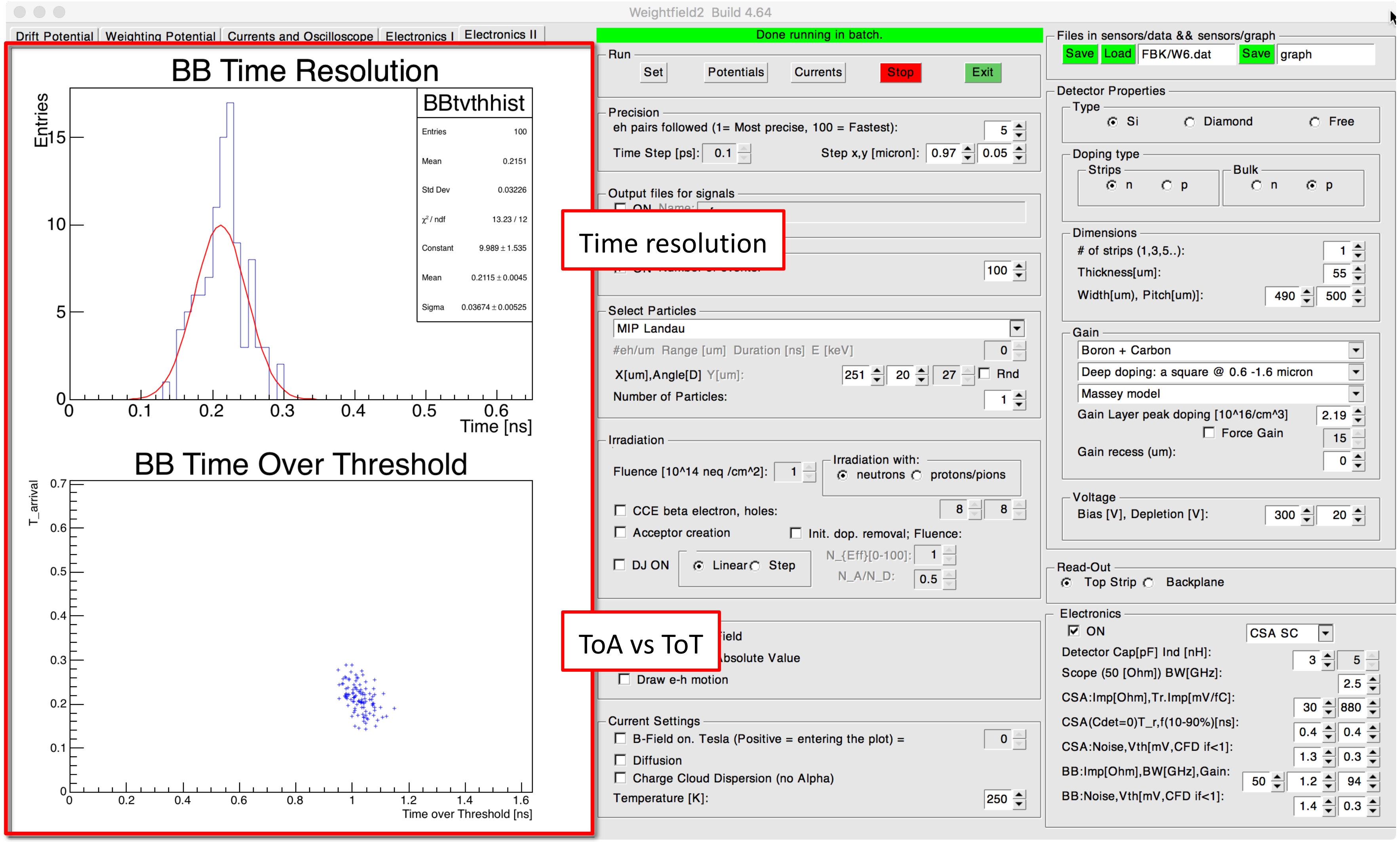


→ Set the comparator threshold as low as you can
→ Use thin sensors

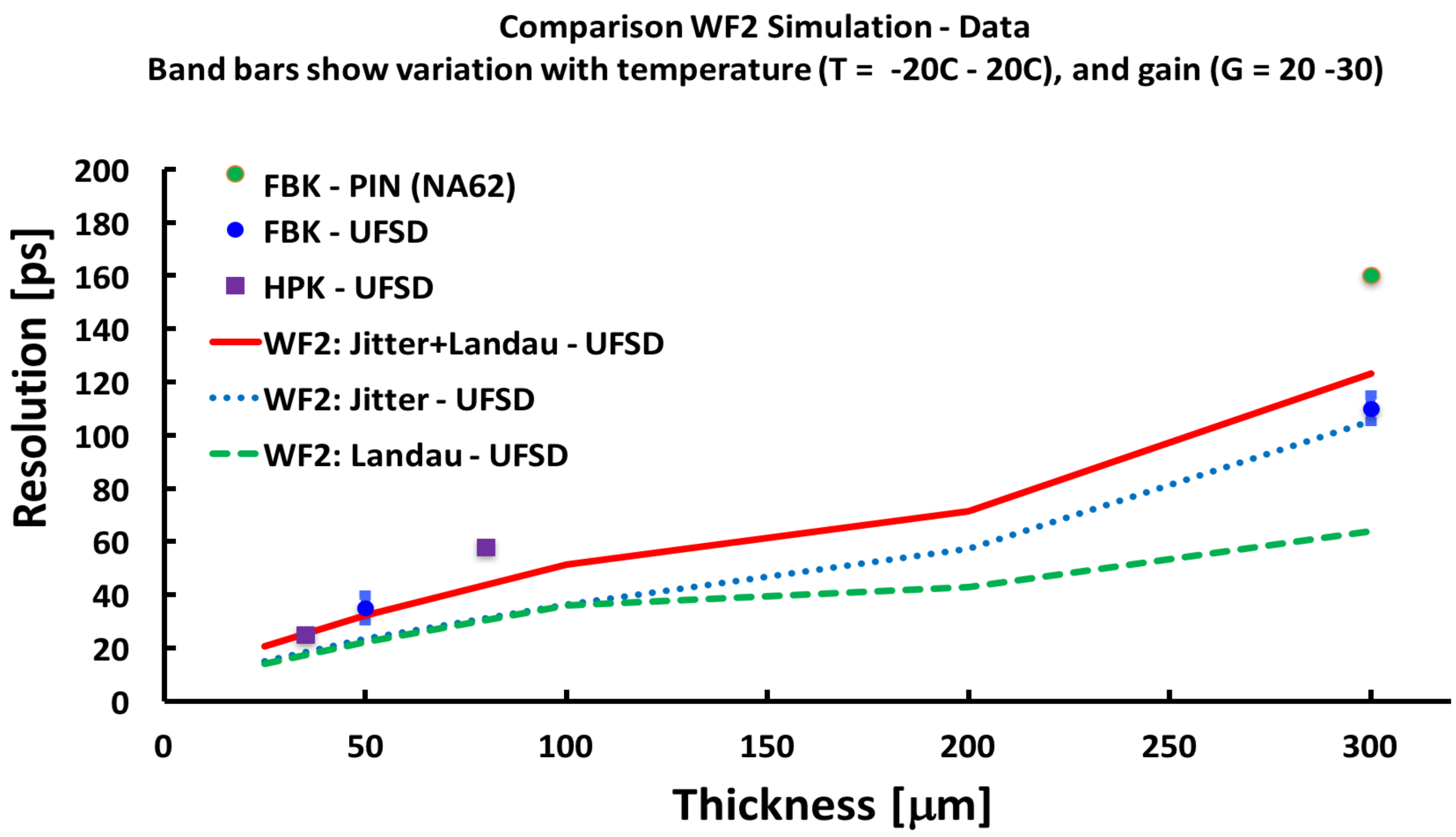
Batch mode: deposited & collected charges



Batch mode: time resolution



Time resolution vs thickness

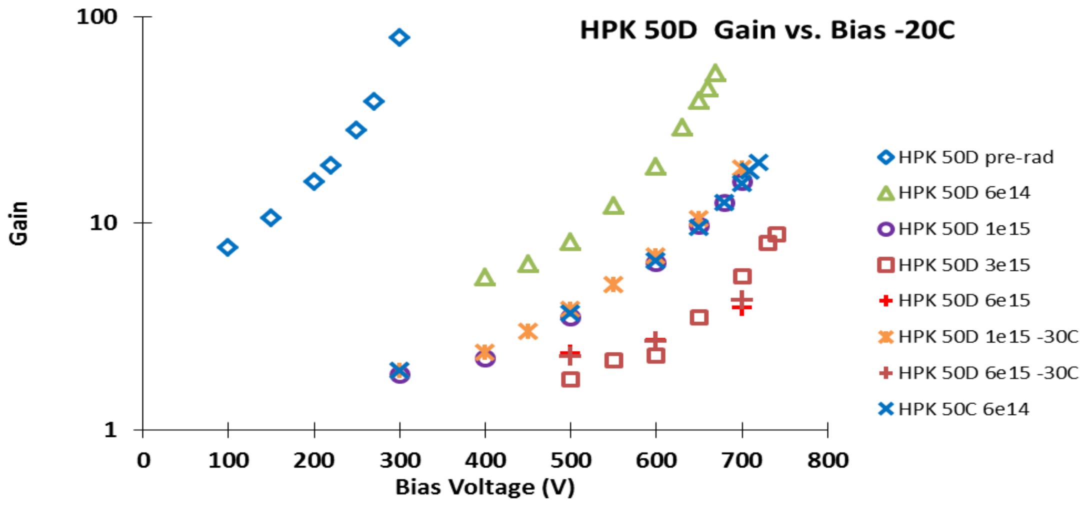


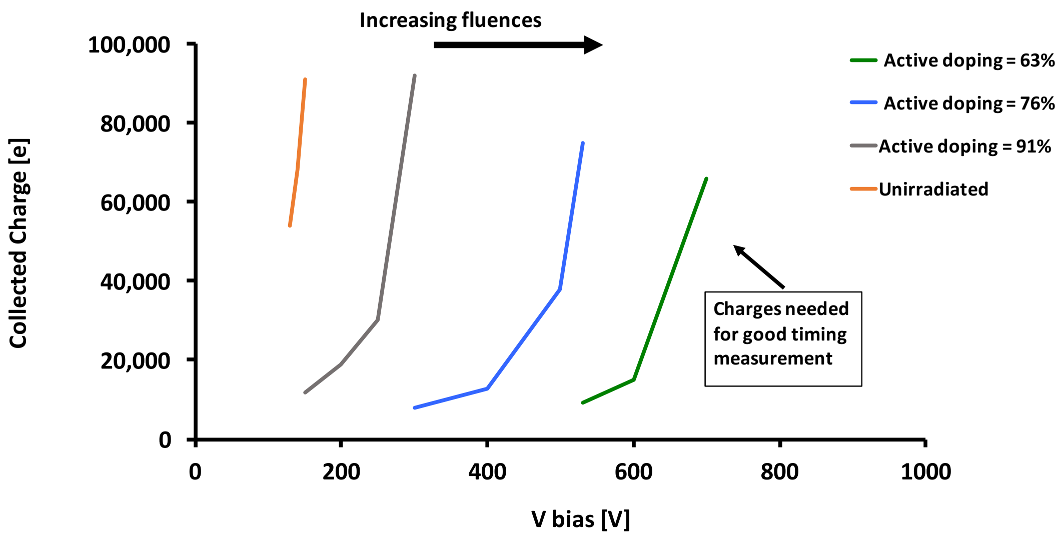
Compensation with V_{bias}

Due to irradiation, the gain layer atoms get deactivated (acceptor removal)

The necessary field can be recovered by increasing the external Vbias:

proven to work up to $5{\cdot}10^{15}\ n_{eq}/cm^2$

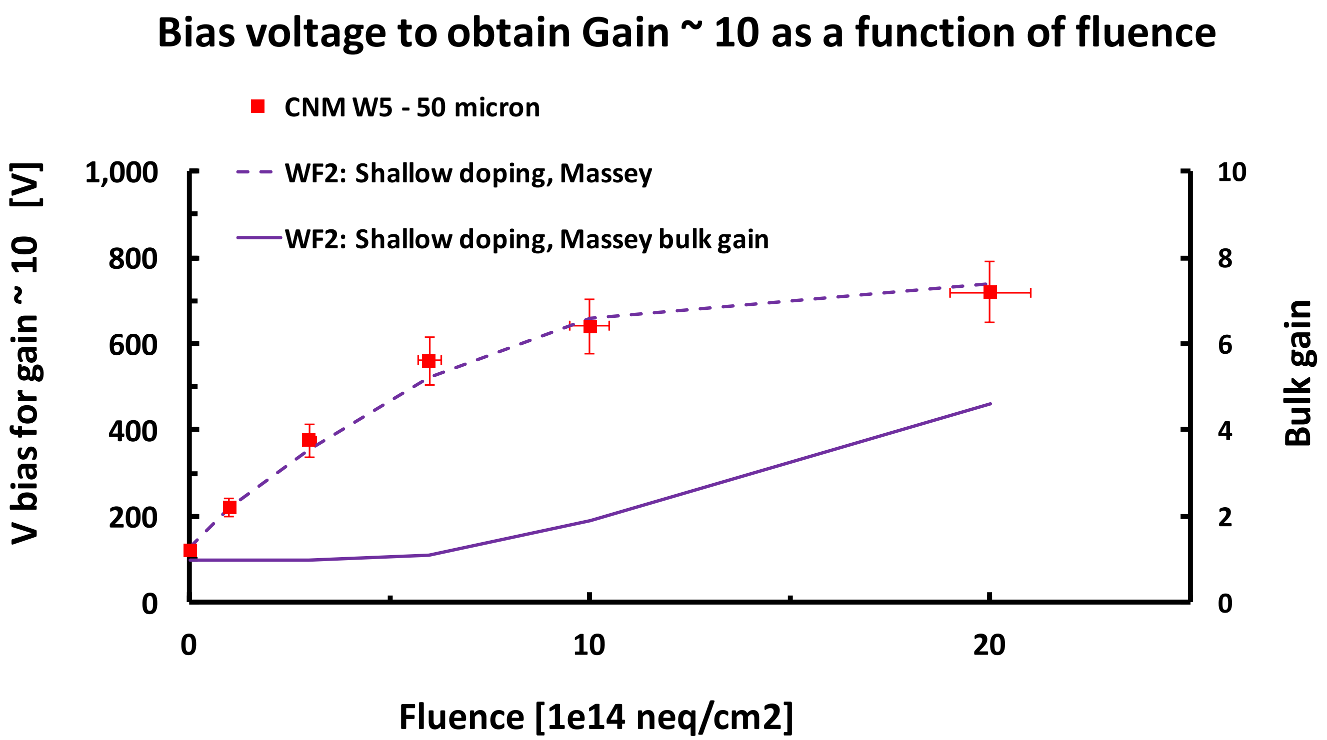




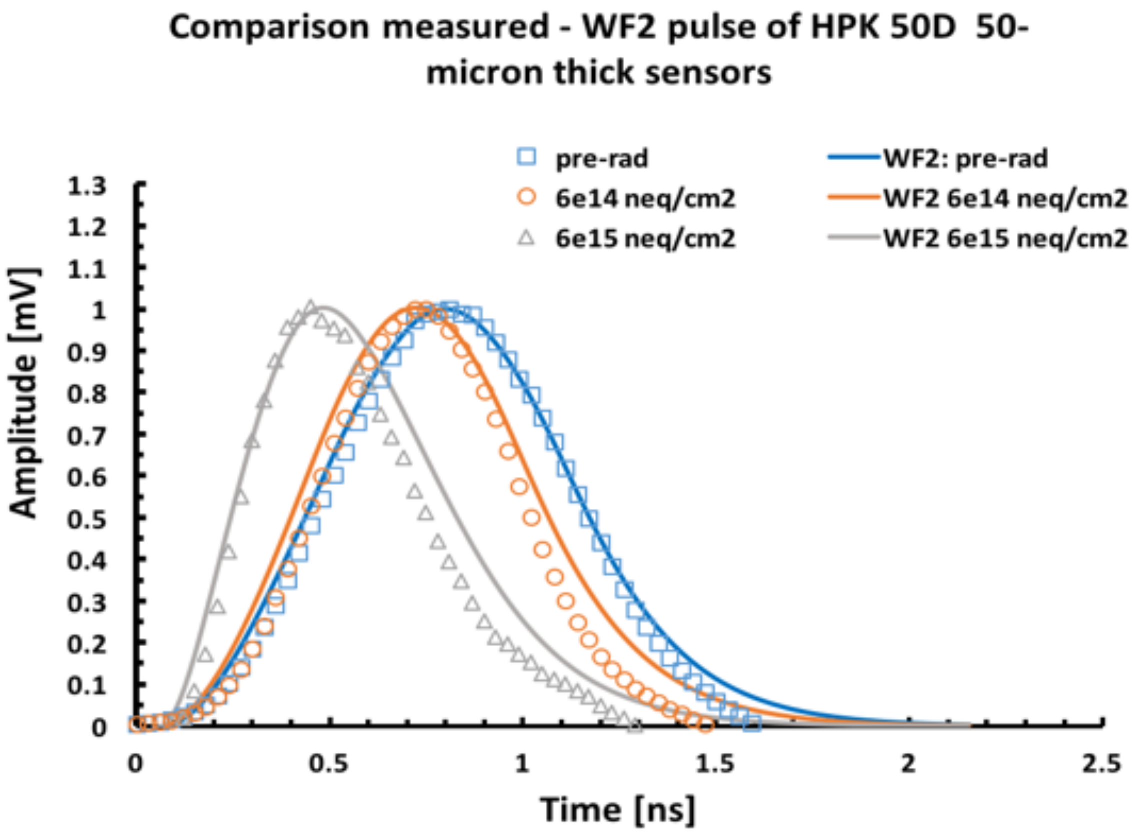
Compensation with V_{bias}

As the gain layer density decreases, we need to increase the external voltages to create the E_{field} needed for multiplications

In so doing, the gain moves from the gain layer to the bulk



Pulse shape in irradiated sensors



With irradiation the signal changes: it becomes shorter and steeper

Summary

- Weightfield2 is a rather easy to use simulator for silicon sensors
- It can help the user's intuition in deciding the best solutions
- It is fully configurable by the user

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Ministero degli Affari Esteri
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Unità per la cooperazione scientifica
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