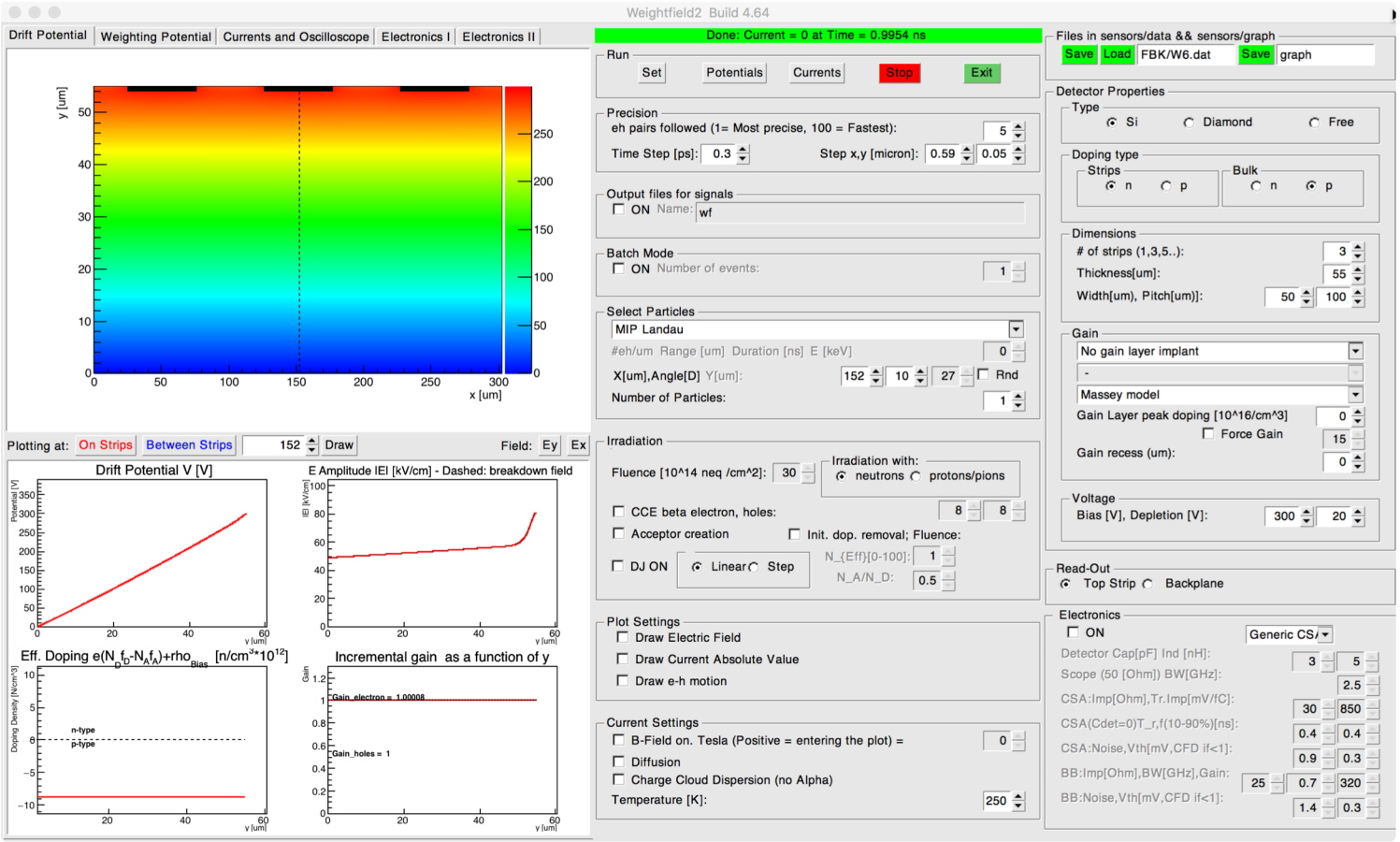
Weightfield2

Available at:

http://personalpages.to.infn.it/~cartigli/Weightfield2/Main.html

It requires Root build from source, it is for Linux and Mac.

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

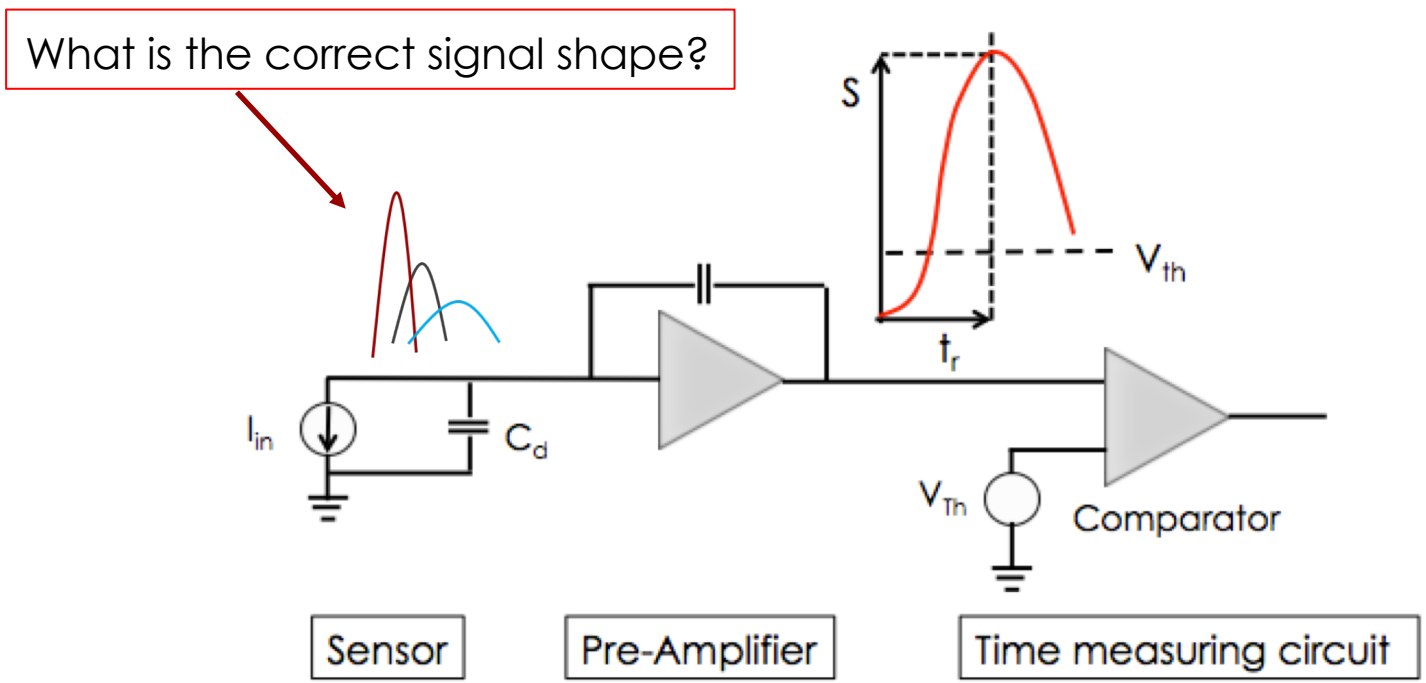


Nicolo Cartiglia, INFN, Torino

Why did we design WF2?

From Angelo's keynote talk:

- Electronics for ps timing is (in principle) already there!
- **But what about sensors?**
- Sensor and front-end codesign essential to achieve best possible timing



Weightfield2

Highlights:

- It is completely open source
- it's fast
- It generates the signal from several sources (MIP, alpha, lasers..)
- Runs in batch mode writing output files
- It loads/save configurations
- It has basics electronics simulation

It crashes occasionally

How to use it:

Obtain the last version from

http://personalpages.to.infn.it/~cartigli/Weightfield2/Main.html

1)From the download page, get the latest version
2)Unzip it and then type:
3)Make or 3-bis) make -f Makefile_MacOS10.10_root6
4)./weightfield

WF2 layout

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

Controls

The program can save/load your configuration and the plots

Batch and output file

B field, diffusion, charge cloud, temperature

Weightfield2 Build 4.64

Drift Potential | Weighting Potential | Currents and Oscilloscope | Electronics I | Electronics II

Done: Current = 0 at Time = 0.9954 ns

Run: Set | Potentials | Currents | Stop | Exit

Files in sensors/data && sensors/graph: Save | Load | FBK/W6.dat | Save | graph

Precision: eh pairs followed (1= Most precise, 100 = Fastest): 5; Time Step [ps]: 0.3; Step x,y [micron]: 0.59 0.05

Output files for signals: ON Name: wf

Batch Mode: ON Number of events: 1

Select Particles: MIP Landau; #eh/um Range [um] Duration [ns] E [keV] 0; X[um],Angle[D] Y[um]: 152 10 27 Rnd; Number of Particles: 1

Irradiation: Fluence [10^14 neq /cm^2]: 30; Irradiation with: neutrons / protons/pions; CCE beta electron, holes: 8 8; Acceptor creation; Init. dop. removal; Fluence: N_{Eff}[0-100]: 1; N_A/N_D: 0.5; DJ ON; Linear / Step

Plot Settings: Draw Electric Field; Draw Current Absolute Value; Draw e-h motion

Current Settings: B-Field on. Tesla (Positive = entering the plot) = 0; Diffusion; Charge Cloud Dispersion (no Alpha); Temperature [K]: 250

Detector Properties: Type: Si / Diamond / Free; Doping type: Strips n / p; Bulk n / p

Dimensions: # of strips (1,3,5..): 3; Thickness[um]: 55; Width[um], Pitch[um]: 50 100

Gain: No gain layer implant; Massey model; Gain Layer peak doping [10^16/cm^3] 0; Force Gain; Gain recess (um): 15 0

Voltage: Bias [V], Depletion [V]: 300 20

Read-Out: Top Strip / Backplane

Electronics: ON; Generic CS/; Detector Cap[pF] Ind [nH]: 3 5; Scope (50 [Ohm]) BW[GHz]: 2.5; CSA:Imp[Ohm],Tr.Imp[mV/fC]: 30 850; CSA(Cdet=0)T_r,f(10-90%)[ns]: 0.4 0.4; CSA:Noise,Vth[mV,CFD if<1]: 0.9 0.3; BB:Imp[Ohm],BW[GHz],Gain: 25 0.7 320; BB:Noise,Vth[mV,CFD if<1]: 1.4 0.3

Plotting at: On Strips | Between Strips | 152 | Draw Field: Ey Ex

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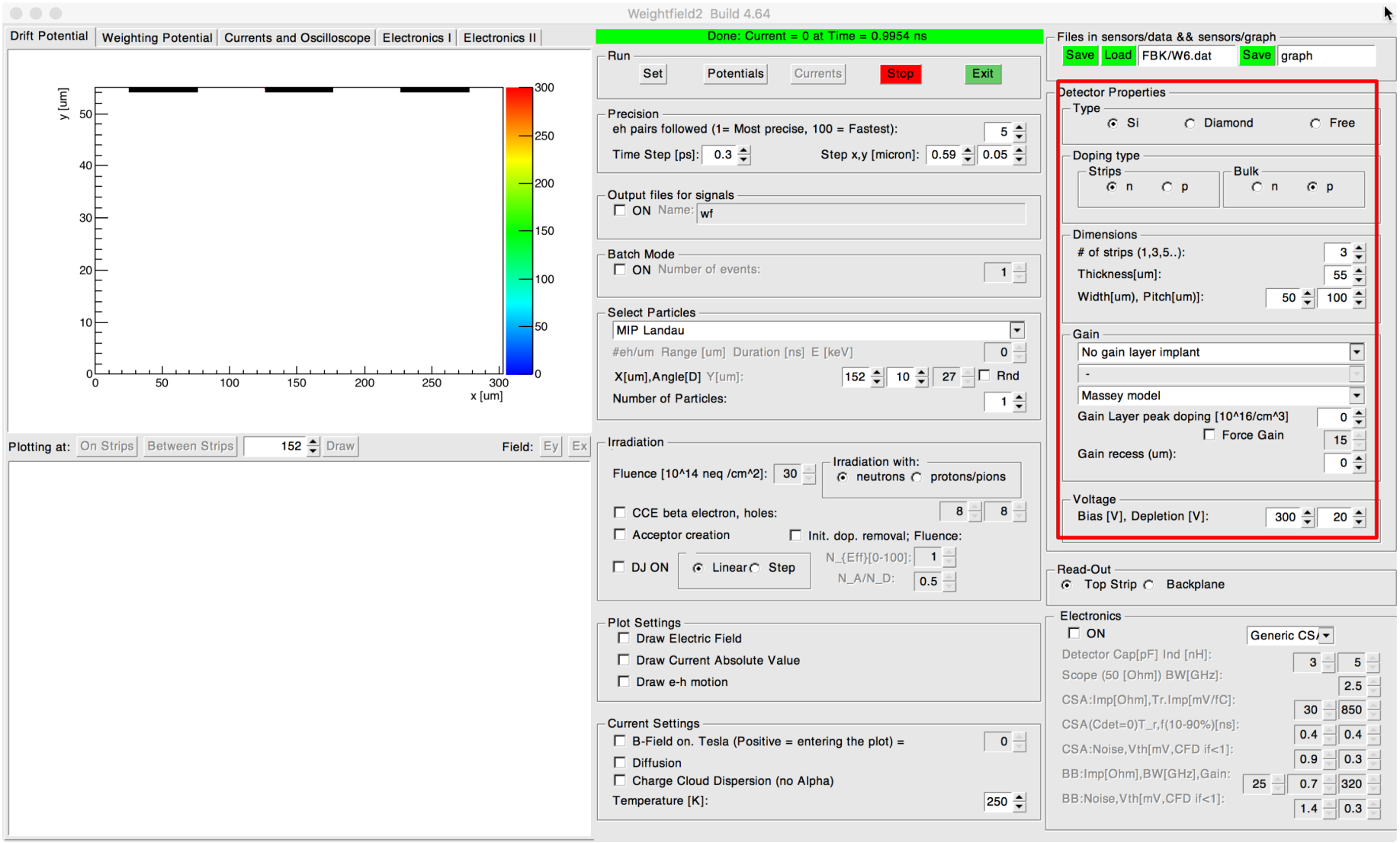
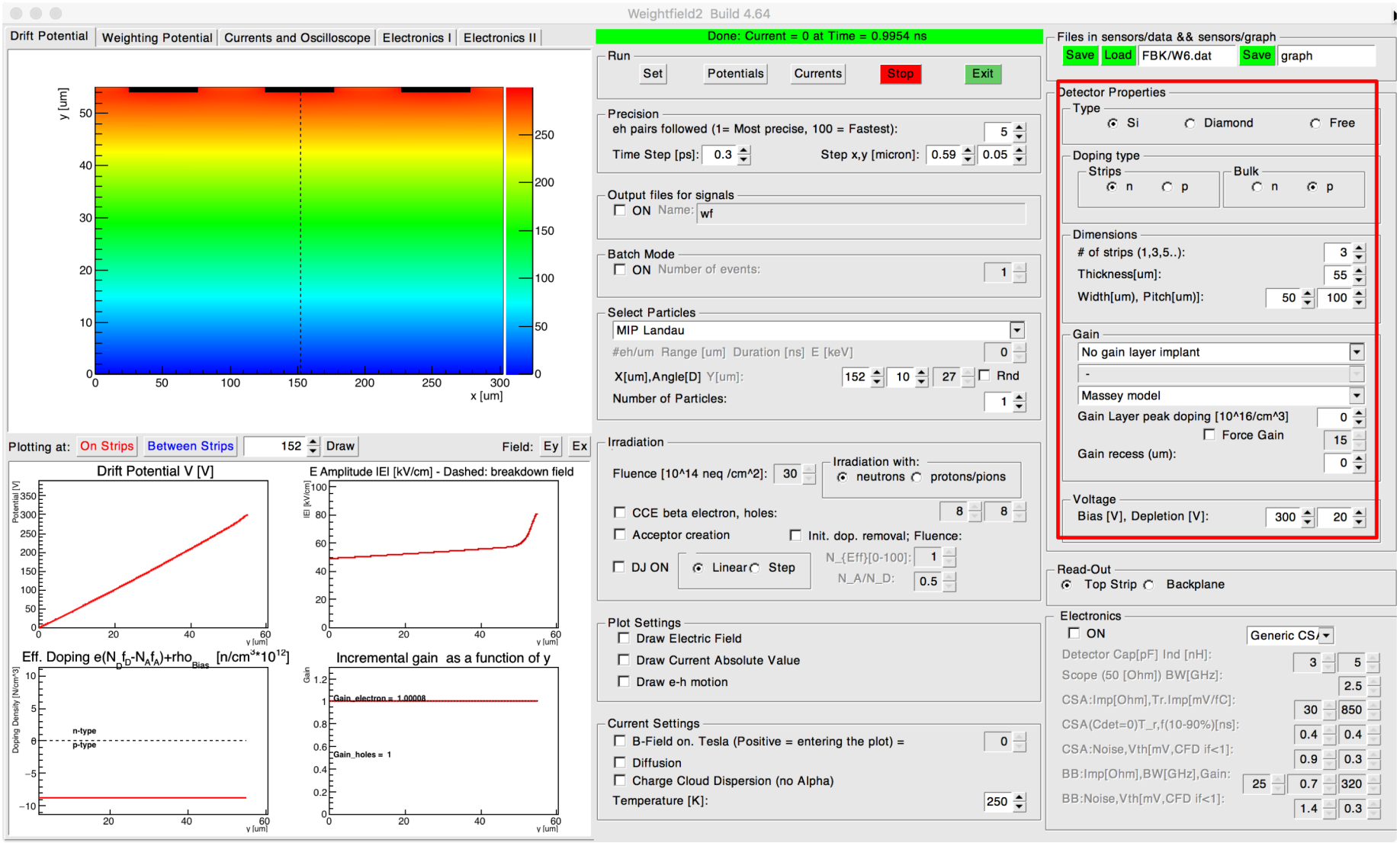
Step 1: select your sensor



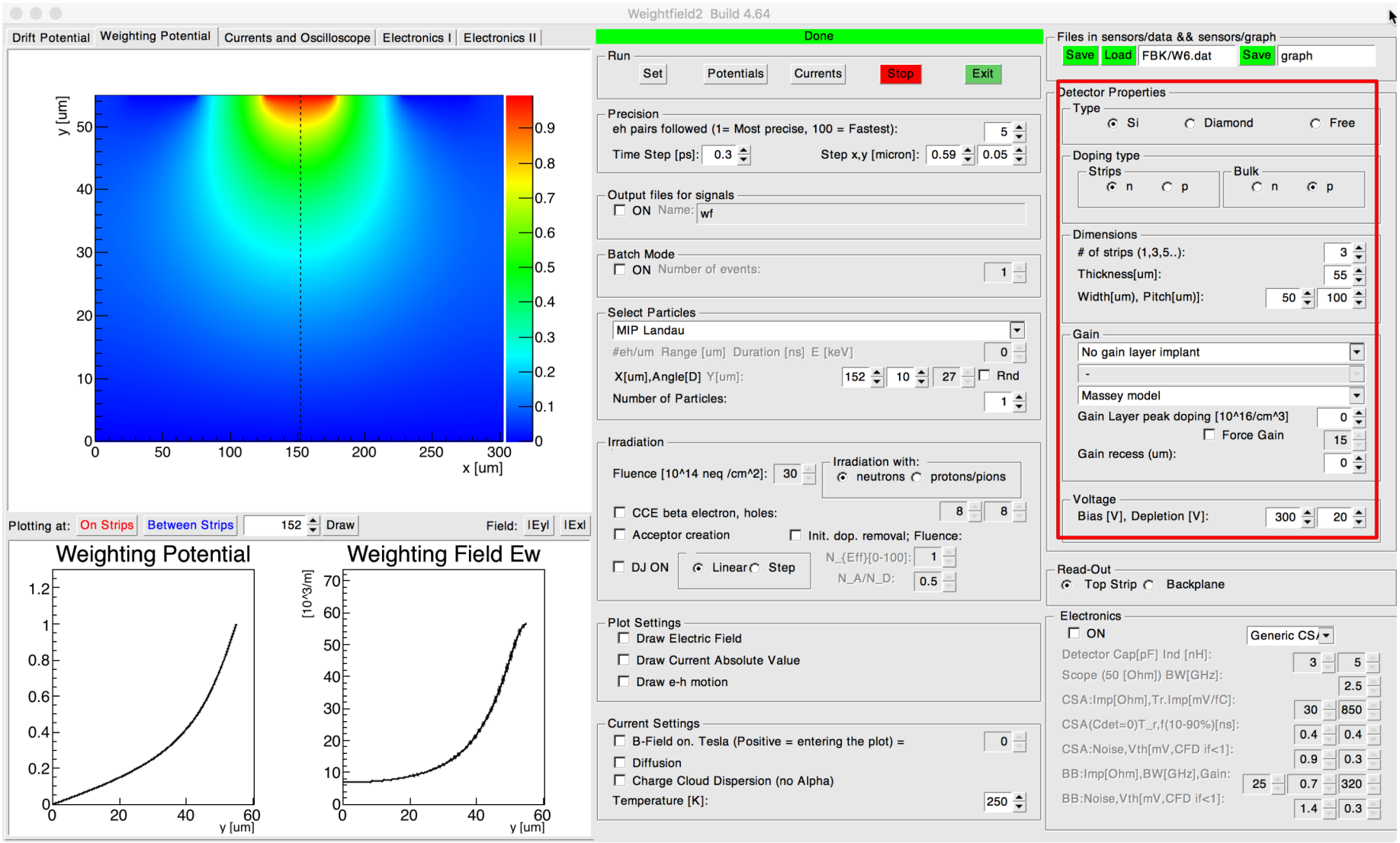
Fields: under the hood

- The program loads your geometry
- 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

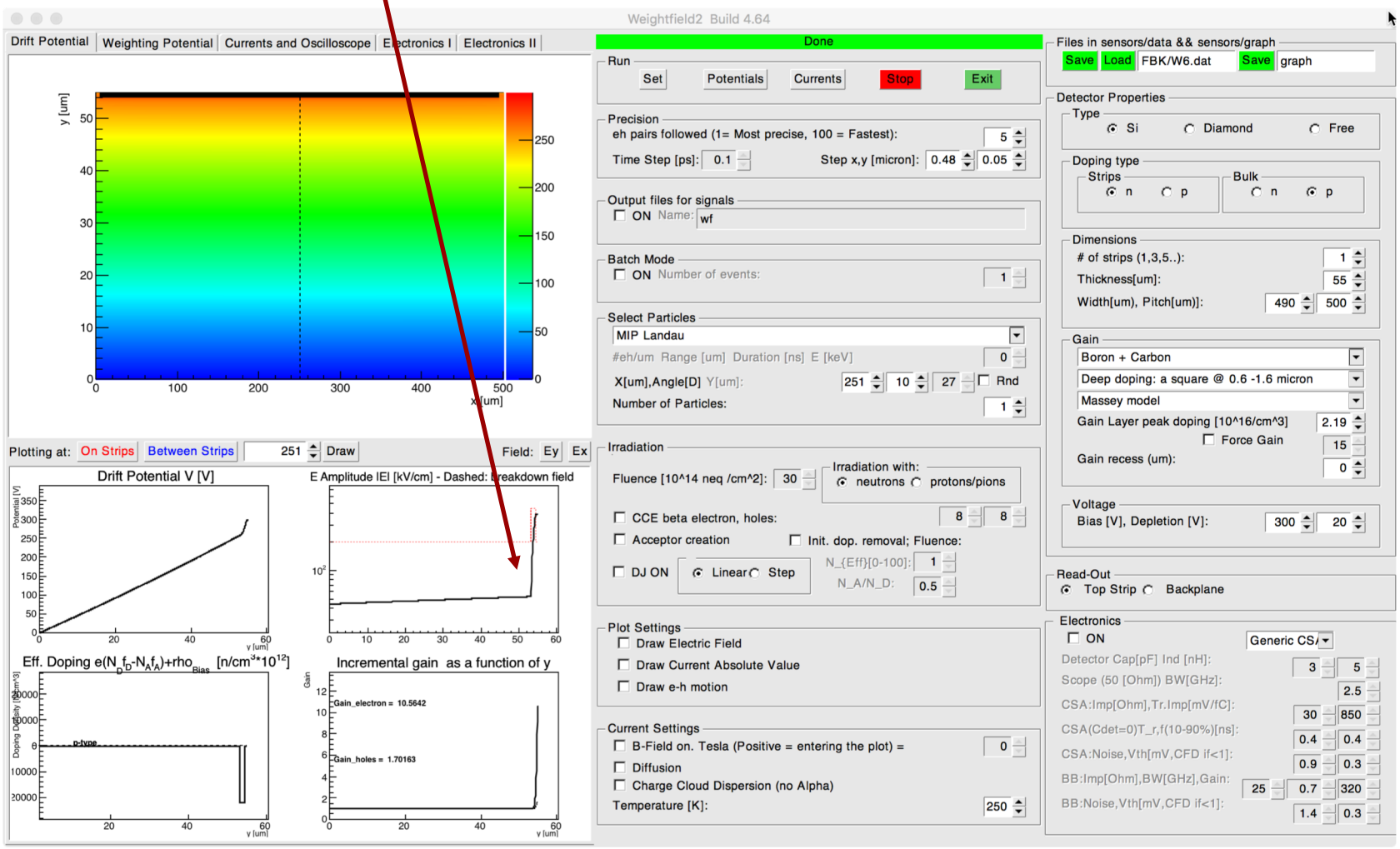


Step 1: W field

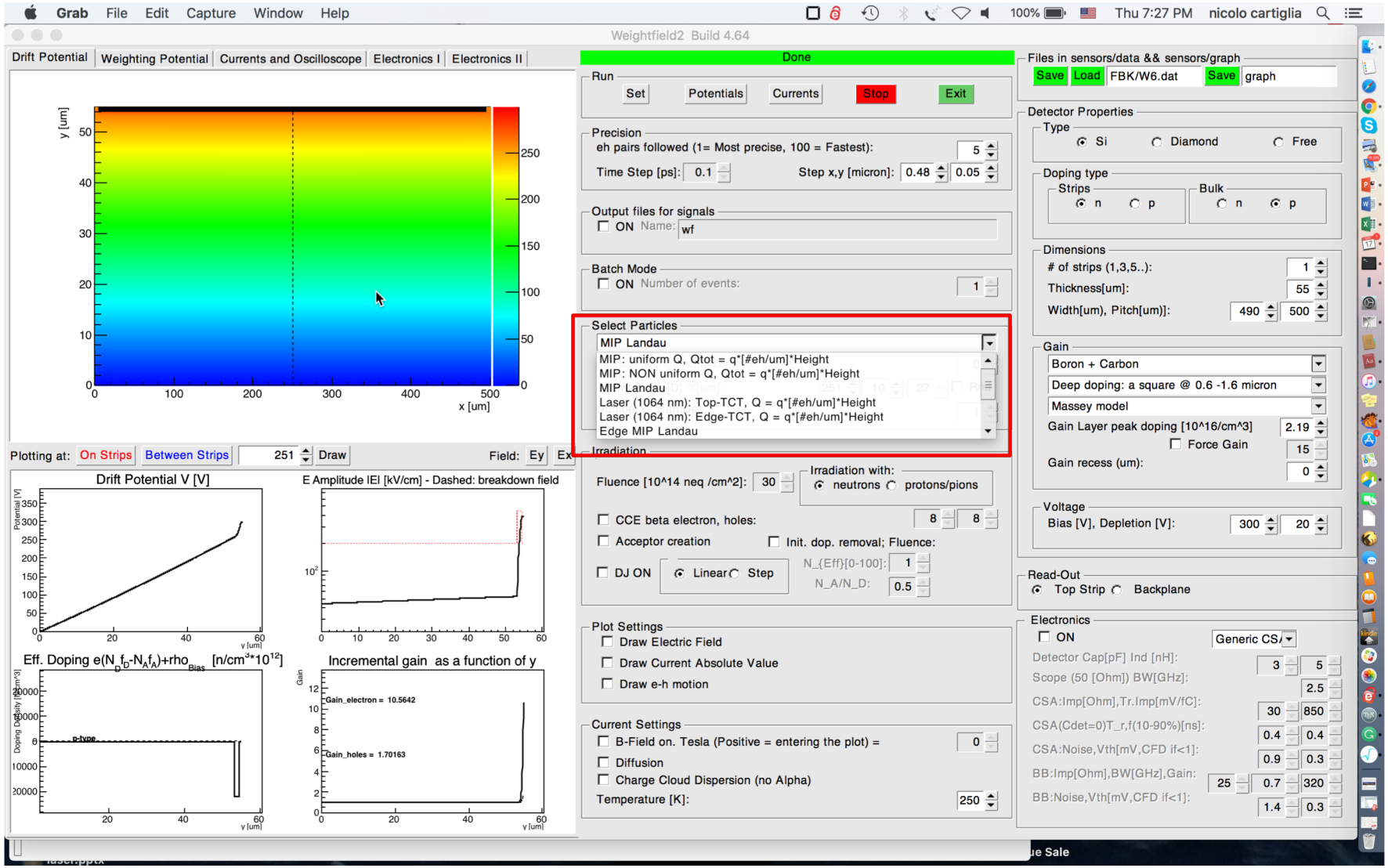


Select your sensor: does it have gain?

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

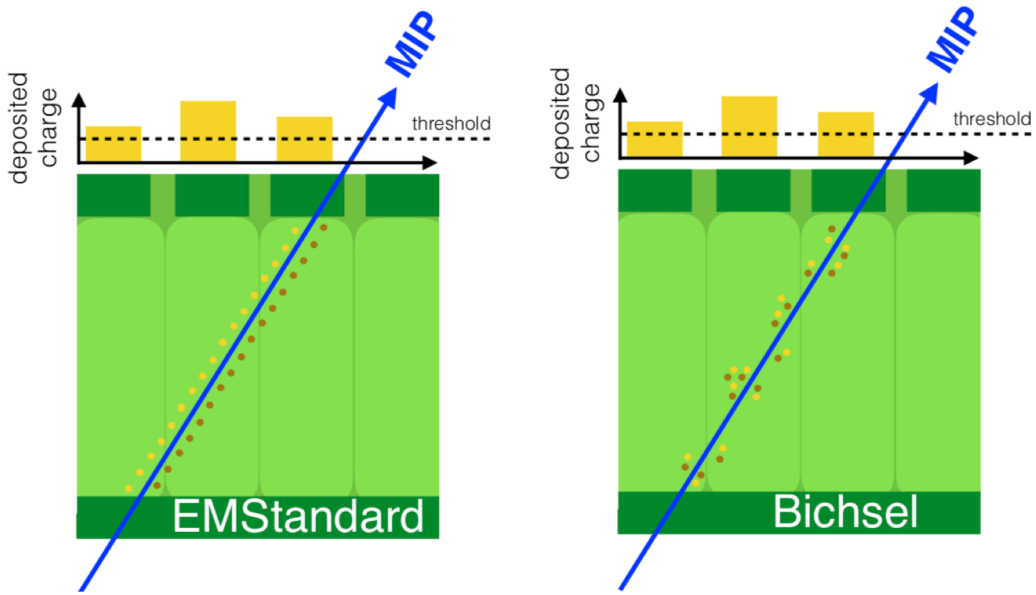


Step 2: select the particle



Landau: under the hood

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
Fuyue Wang, Dong Su, Benjamin Nachman, Maurice Garcia-Sciveres, and Qi 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. "

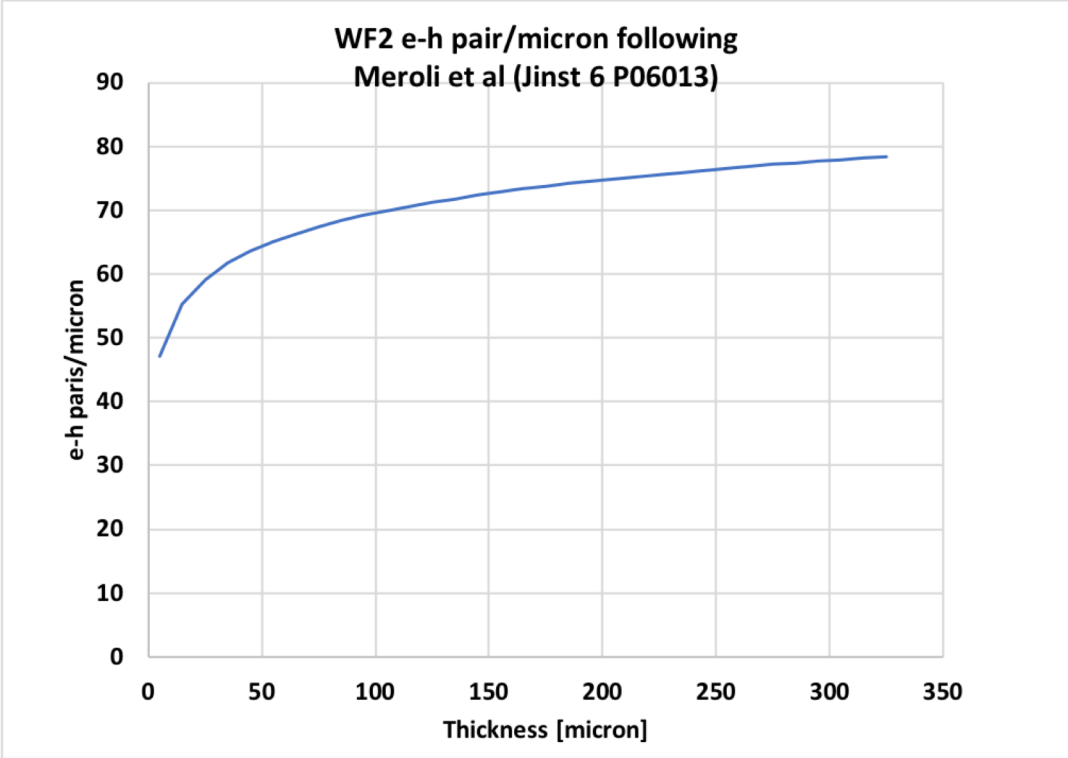
Landau: under the hood

Landau distribution

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

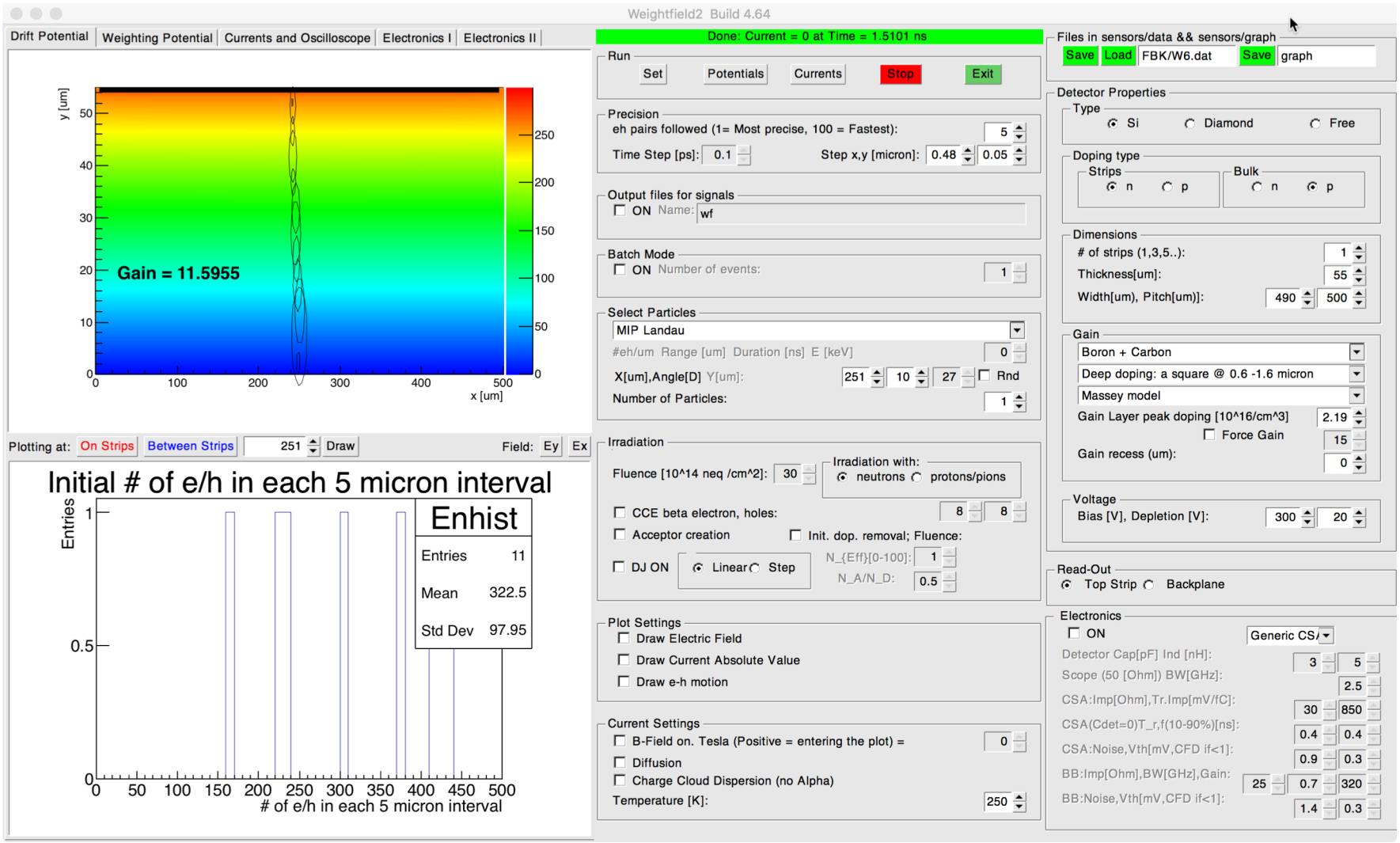
$$FWHM = 0.31*d^{0.81}$$

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



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 3: charge carriers drift



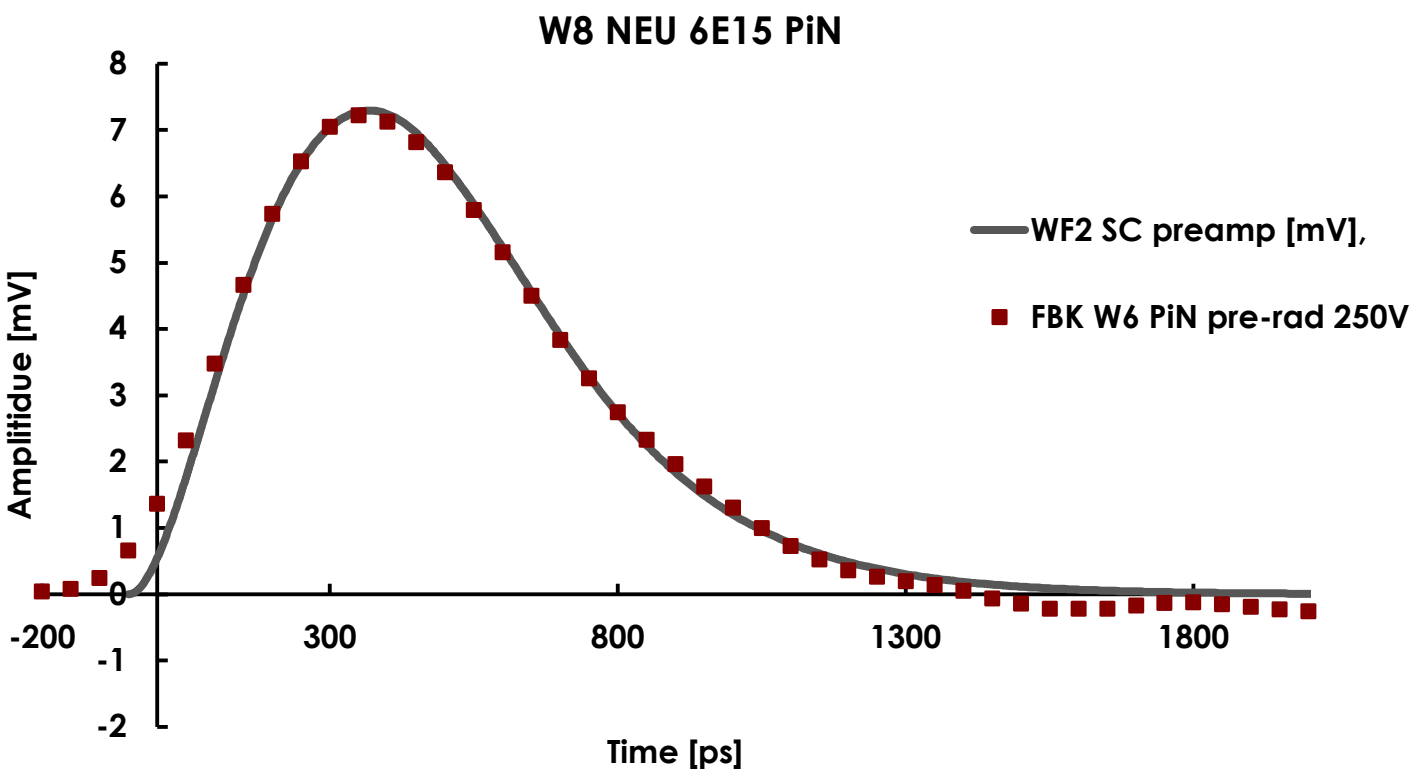
drift: under the hood

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

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

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

WF2 – Data: current in PiN



gain: under the hood

If the electric field is high enough, carriers multiply

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

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

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

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

Currents

Current tabs

Weightfield2 Build 4.64

Drift Potential | Weighting Potentia | Currents and Oscilloscope | Electronics I | Electronics II

Current [A] — Voltage [mV] — Time [s]

Electrons | Gain El. | Holes | Gain Holes | Total

- Oscilloscope [mV]

Charge Collection

e- charges (e):	-1747	h+ charges (e):	-2177	e- + h+ charges (e):	-3924
Gain e- charges (e):	0	Gain h+ charges (e):	0	Gain e- + h+ charges (e):	0
Total e- charges (e):	-1747	Total h+ charges (e):	-2177	Total Charges (e):	-3924

Lorentz Drift

e- Lorentz Angle [D]: -0.00 h+ Lorentz Angle [D]: 0.00

Done: Current = 0 at Time = 1.2705 ns

Run: Set | Potentials | Currents | Stop | Exit

Precision: eh pairs followed (1= Most precise, 100 = Fastest): 5; Time Step [ps]: 0.3; Step x,y [micron]: 0.97 0.05

Output files for signals: ON Name: wf

Batch Mode: ON Number of events: 1

Select Particles: MIP Landau; #eh/um Range [um] Duration [ns] E [keV] 0; X[um],Angle[D] Y[um]: 251 20 27 Rnd; Number of Particles: 1

Irradiation: Fluence [10^14 neq /cm^2]: 1; Irradiation with: neutrons protons/pions; CCE beta electron, holes: 8 8; Acceptor creation; Init. dop. removal; Fluence: N_{Eff}[0-100]: 1; DJ ON; Linear Step; N_A/N_D: 0.5

Plot Settings: Draw Electric Field; Draw Current Absolute Value; Draw e-h motion

Current Settings: B-Field on. Tesla (Positive = entering the plot) = 0; Diffusion; Charge Cloud Dispersion (no Alpha); Temperature [K]: 250

Files in sensors/data && sensors/graph: Save Load FBK/PIN.dat Save graph

Detector Properties

Type: Si Diamond Free

Doping type: Strips n p; Bulk n p

Dimensions: # of strips (1,3,5..): 1; Thickness[um]: 55; Width[um], Pitch[um]): 490 500

Gain: No gain layer implant; -; Massey model; Gain Layer peak doping [10^16/cm^3] 0; Force Gain 15; Gain recess (um): 0

Voltage: Bias [V], Depletion [V]: 250 20

Read-Out: Top Strip Backplane

Electronics: ON Generic CS/; Detector Cap[pF] Ind [nH]: 3 5; Scope (50 [Ohm]) BW[GHz]: 2.5; CSA:Imp[Ohm],Tr.Imp[mV/fC]: 60 7; CSA(Cdet=0)T_r,f(10-90%)[ns]: 3.5 6.1; CSA:Noise,Vth[mV,CFD if<1]: 0.9 0.3; BB:Imp[Ohm],BW[GHz],Gain: 50 1.2 94; BB:Noise,Vth[mV,CFD if<1]: 1.4 0.3

Electronics

Electronics tabs

Weightfield2 Build 4.64

Drift Potential | Weighting Potential | Currents and Oscilloscope | Electronics I | Electronics I

CSA (blue) and BB Amplifier (red)

Amplitude [mV]

Time [s]

Rising edge derivative

dV/dt [mV/ns]

Amplitude fraction

Charge

Charge [fC]

Time [s]

Done: Current = 0 at Time = 1.2705 ns

Run: Set | Potentials | Currents | Stop | Exit

Precision: eh pairs followed (1= Most precise, 100 = Fastest): 5; Time Step [ps]: 0.3; Step x,y [micron]: 0.97 0.05

Output files for signals: ON Name: wf

Batch Mode: ON Number of events: 1

Select Particles: MIP Landau; #eh/um Range [um] Duration [ns] E [keV] 0; X[um],Angle[D] Y[um]: 251 20 27 Rnd; Number of Particles: 1

Irradiation: Fluence [10^14 neq /cm^2]: 1; Irradiation with: neutrons protons/pions; CCE beta electron, holes: 8 8; Acceptor creation; Init. dop. removal; Fluence: N_{Eff}[0-100]: 1; DJ ON; Linear Step; N_A/N_D: 0.5

Plot Settings: Draw Electric Field; Draw Current Absolute Value; Draw e-h motion

Current Settings: B-Field on. Tesla (Positive = entering the plot) = 0; Diffusion; Charge Cloud Dispersion (no Alpha); Temperature [K]: 250

Files in sensors/data && sensors/graph: Save Load FBK/PIN.dat Save graph

Detector Properties: Type: Si Diamond Free; Doping type: Strips n p; Bulk n p; Dimensions: # of strips (1,3,5..): 1; Thickness[um]: 55; Width[um], Pitch[um]): 490 500

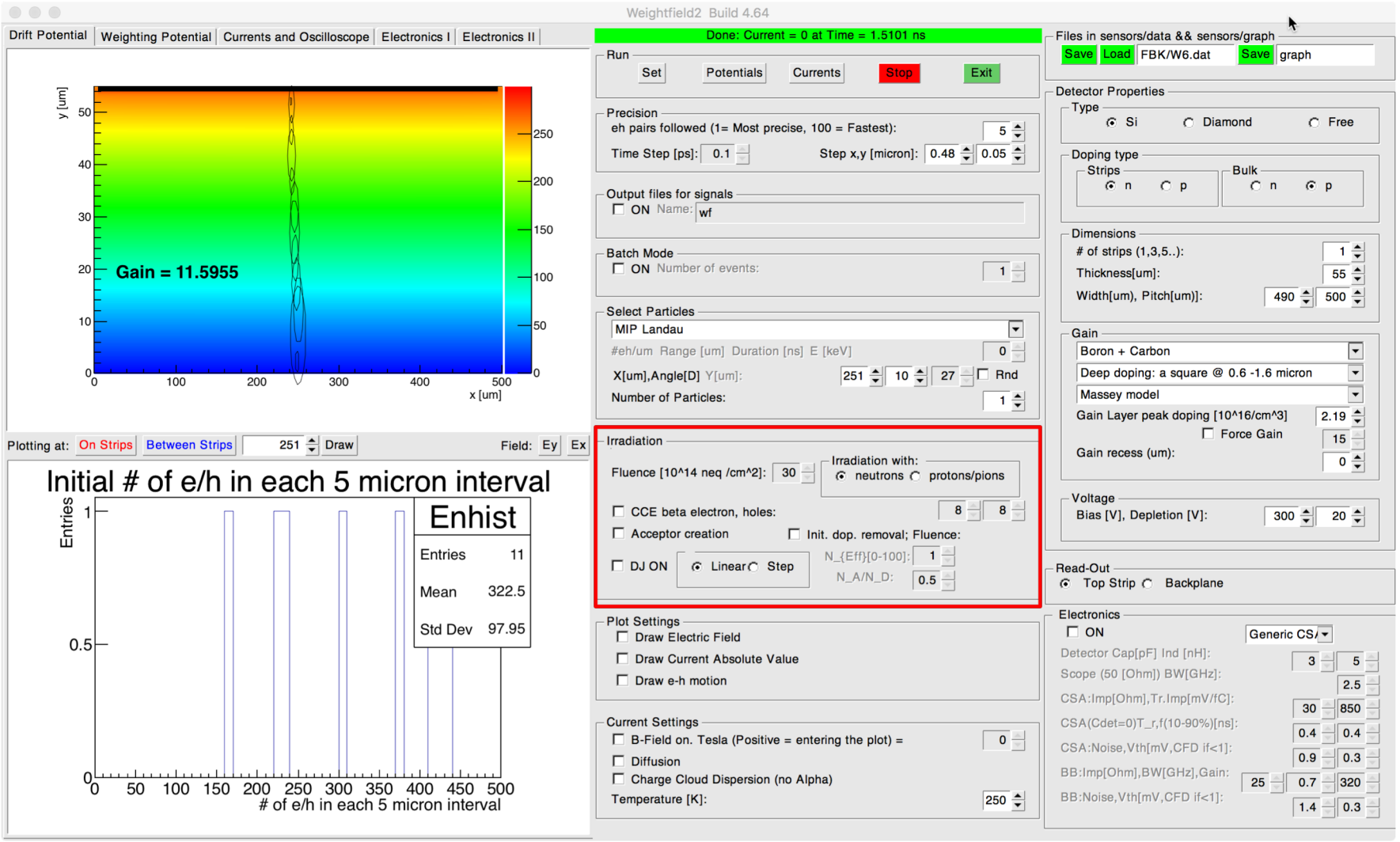
Gain: No gain layer implant; Massey model; Gain Layer peak doping [10^16/cm^3] 0; Force Gain 15; Gain recess (um): 0

Voltage: Bias [V], Depletion [V]: 250 20

Read-Out: Top Strip Backplane

Electronics: ON; Generic CS/; Detector Cap[pF] Ind [nH]: 3 5; Scope (50 [Ohm]) BW[GHz]: 2.5; CSA:Imp[Ohm],Tr.Imp[mV/fC]: 60 7; CSA(Cdet=0)T_r,f(10-90%)[ns]: 3.5 6.1; CSA:Noise,Vth[mV,CFD if<1]: 0.9 0.3; BB:Imp[Ohm],BW[GHz],Gain: 50 1.2 94; BB:Noise,Vth[mV,CFD if<1]: 1.4 0.3

Step 4: radiation damage



Step 4: under the hood

Charge trapping with fluence phi:

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

$\tau = \beta\emptyset$ ← model under discussion

Acceptor removal:

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

Acceptor creation:

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

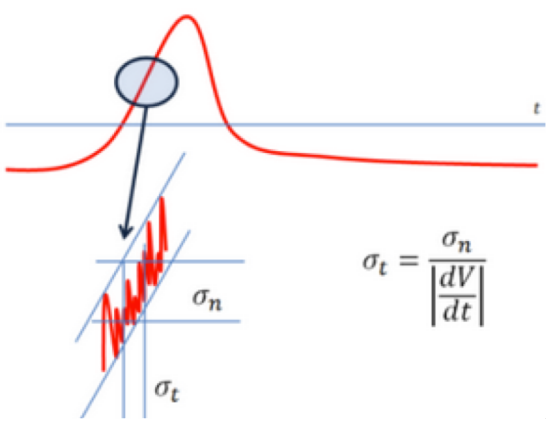
WF2: predictions

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

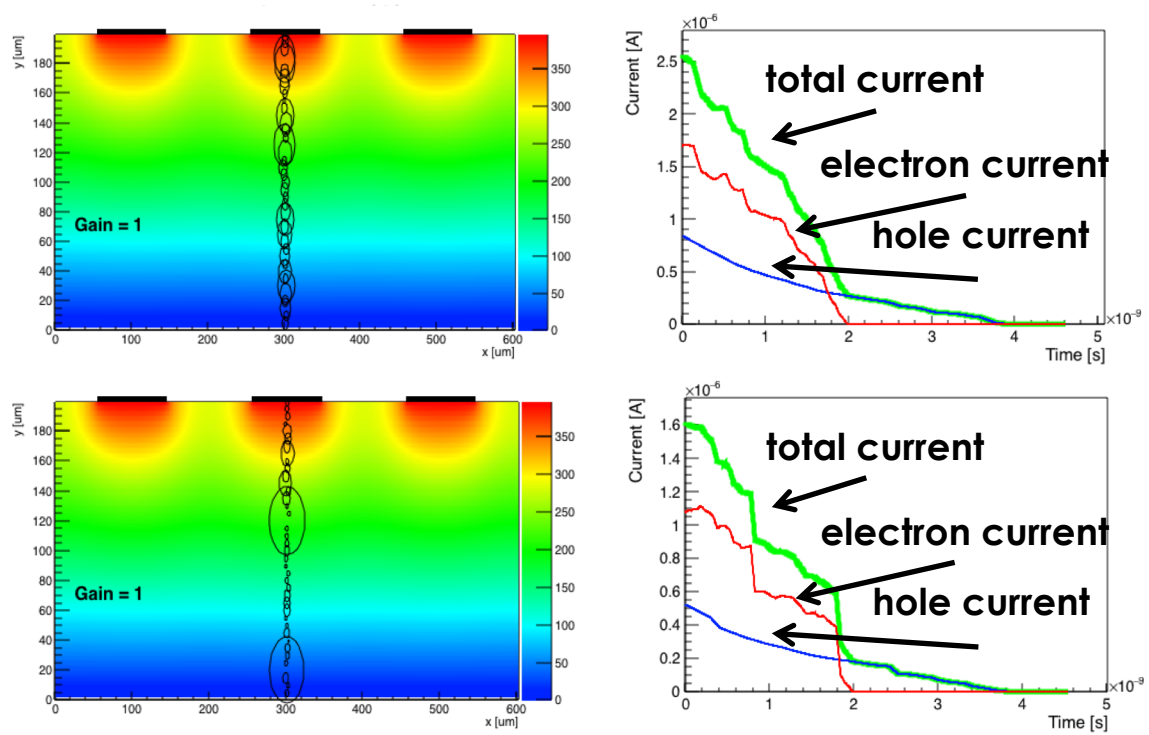
Usual "Jitter" term
Here enters everything that is "Noise" and the steepness of the signal

Time walk: Amplitude variation, corrected in electronics

Shape variations: non homogeneous energy

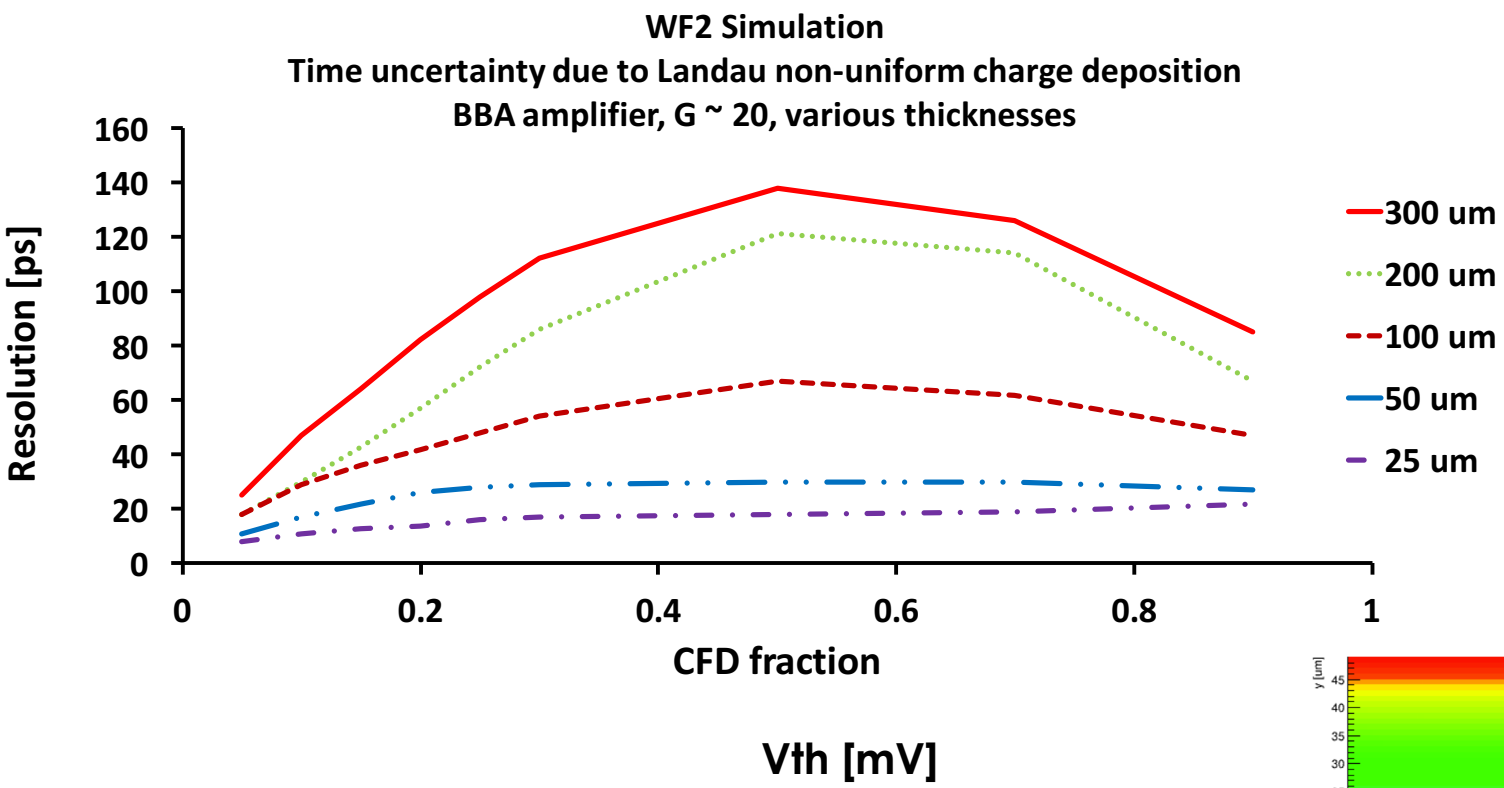


Need large dV/dt

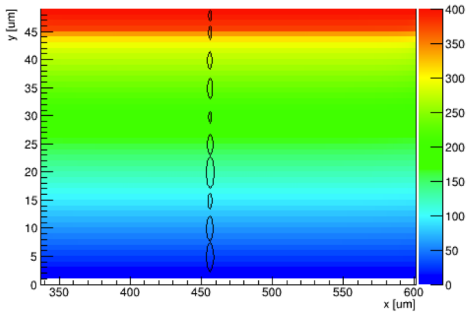


Non uniform charge deposition along the track

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

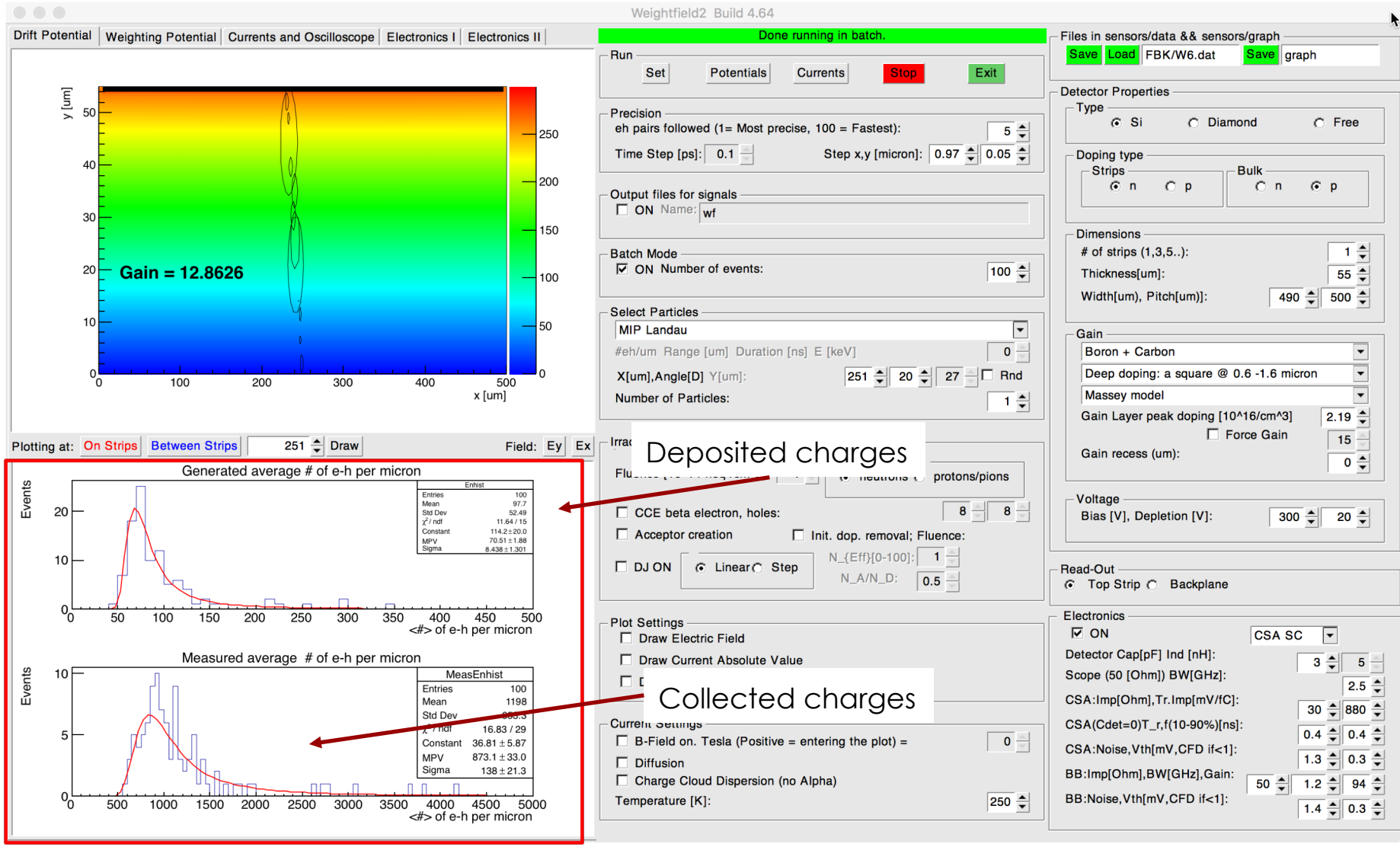


Vth [mV]

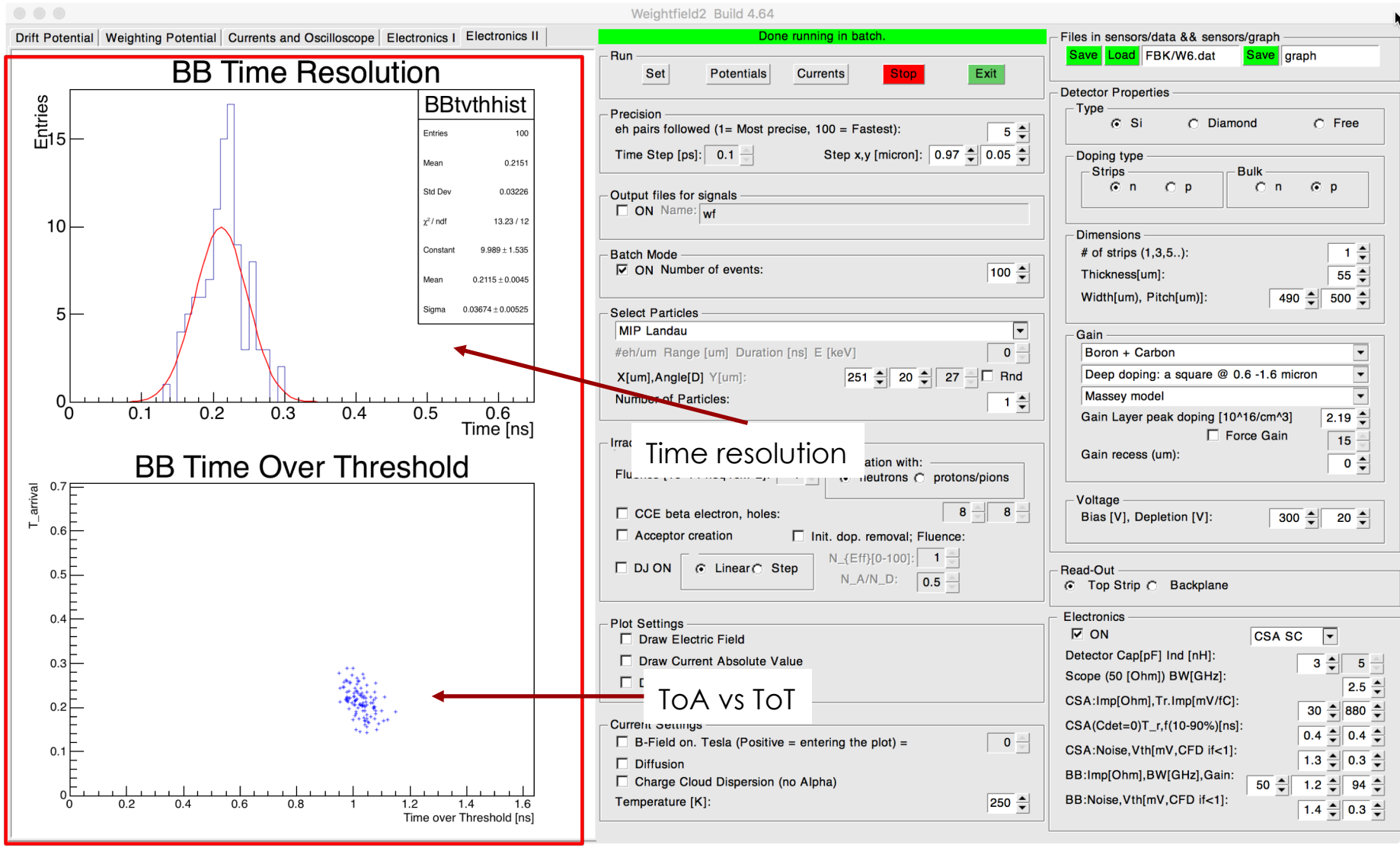


➔ Set the comparator threshold as low as you can
➔ Use thin sensors

Batch mode: deposited & collected charges

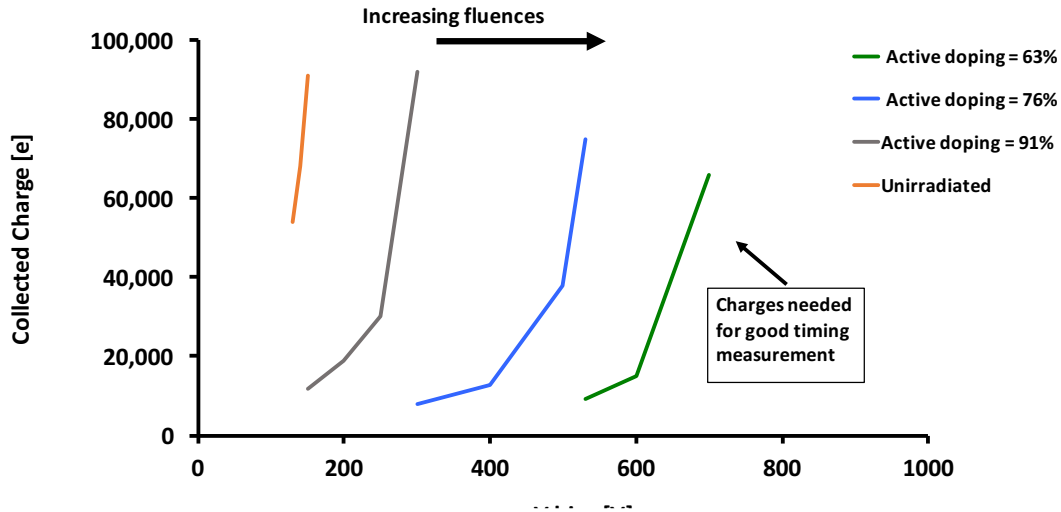


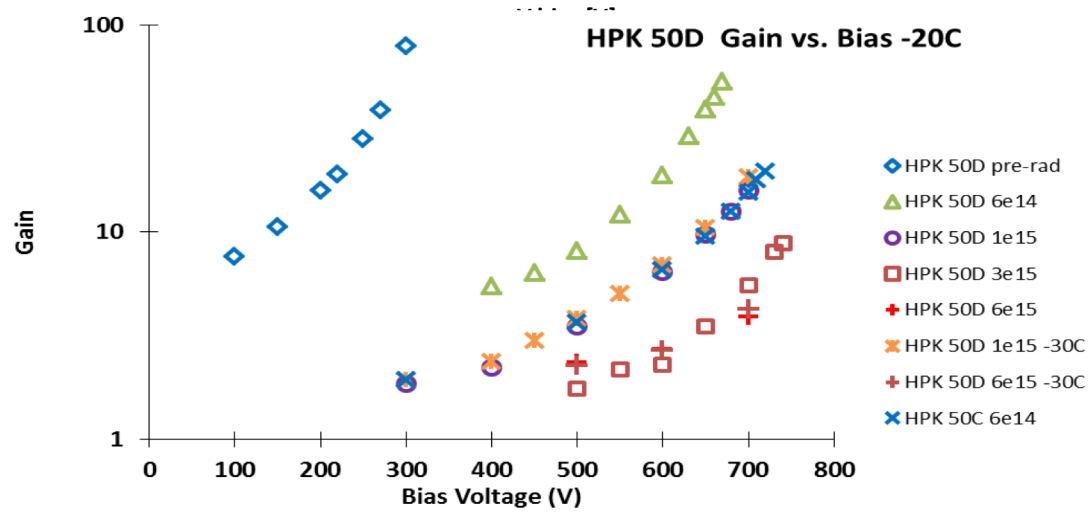
Batch mode: time resolution



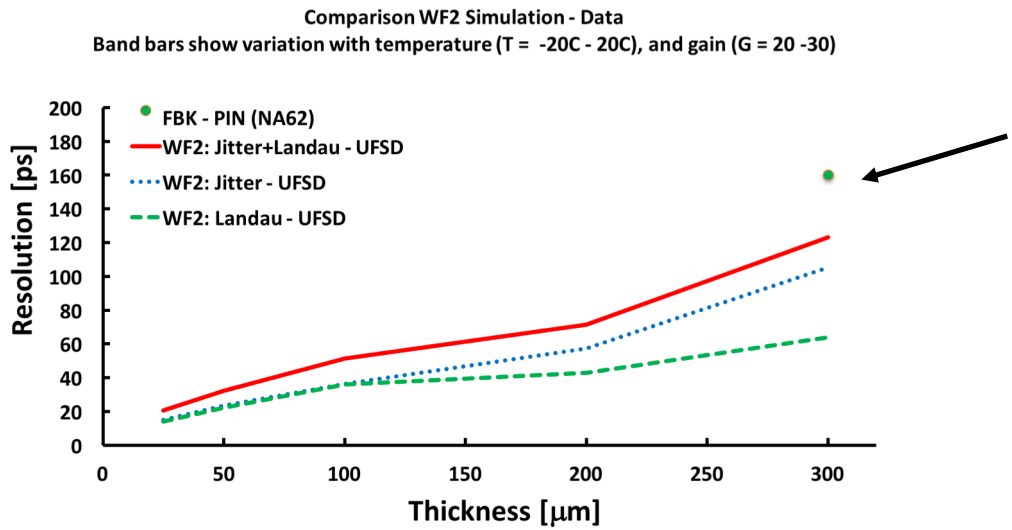
Compensation with Vbias

The necessary field can be recovered by increasing the external Vbias: proven to work up to 5 10^{15} n^{eq}/cm^2

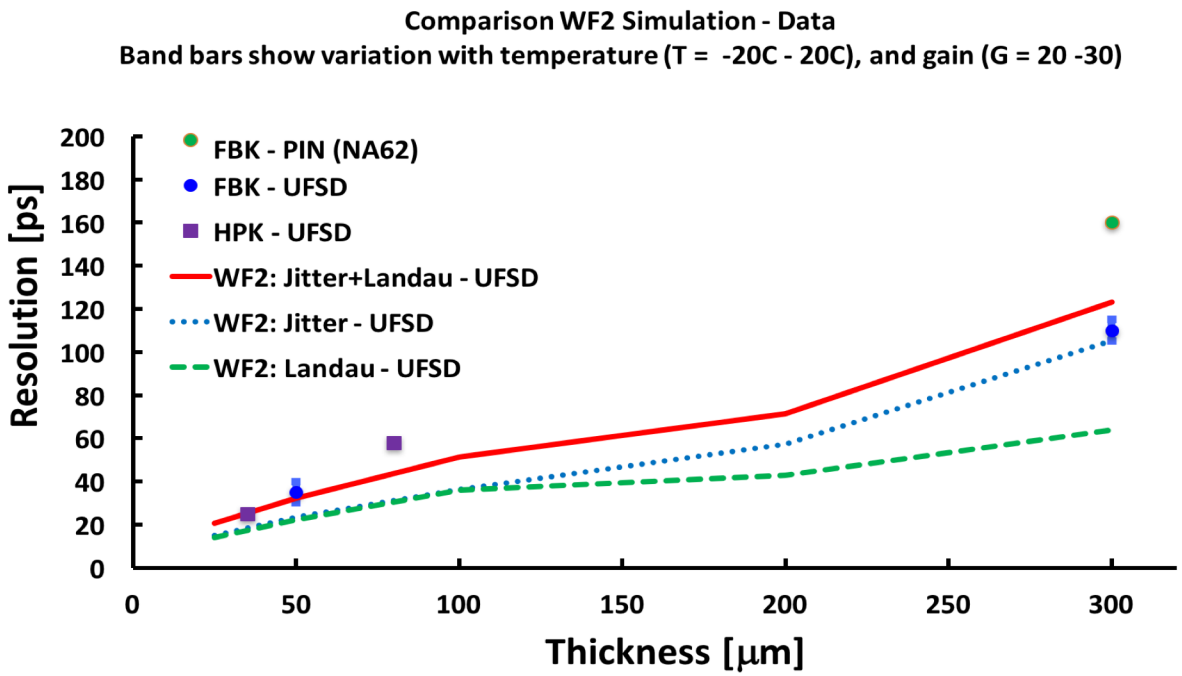




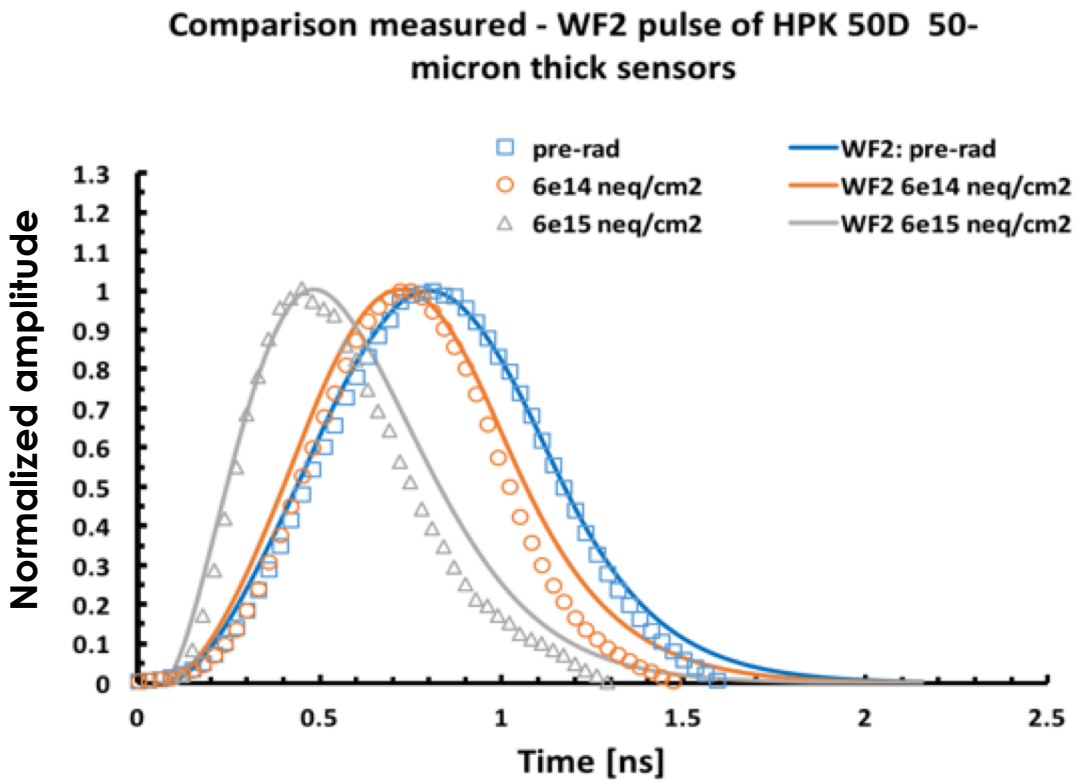
Time resolution vs thickness



Initial condition



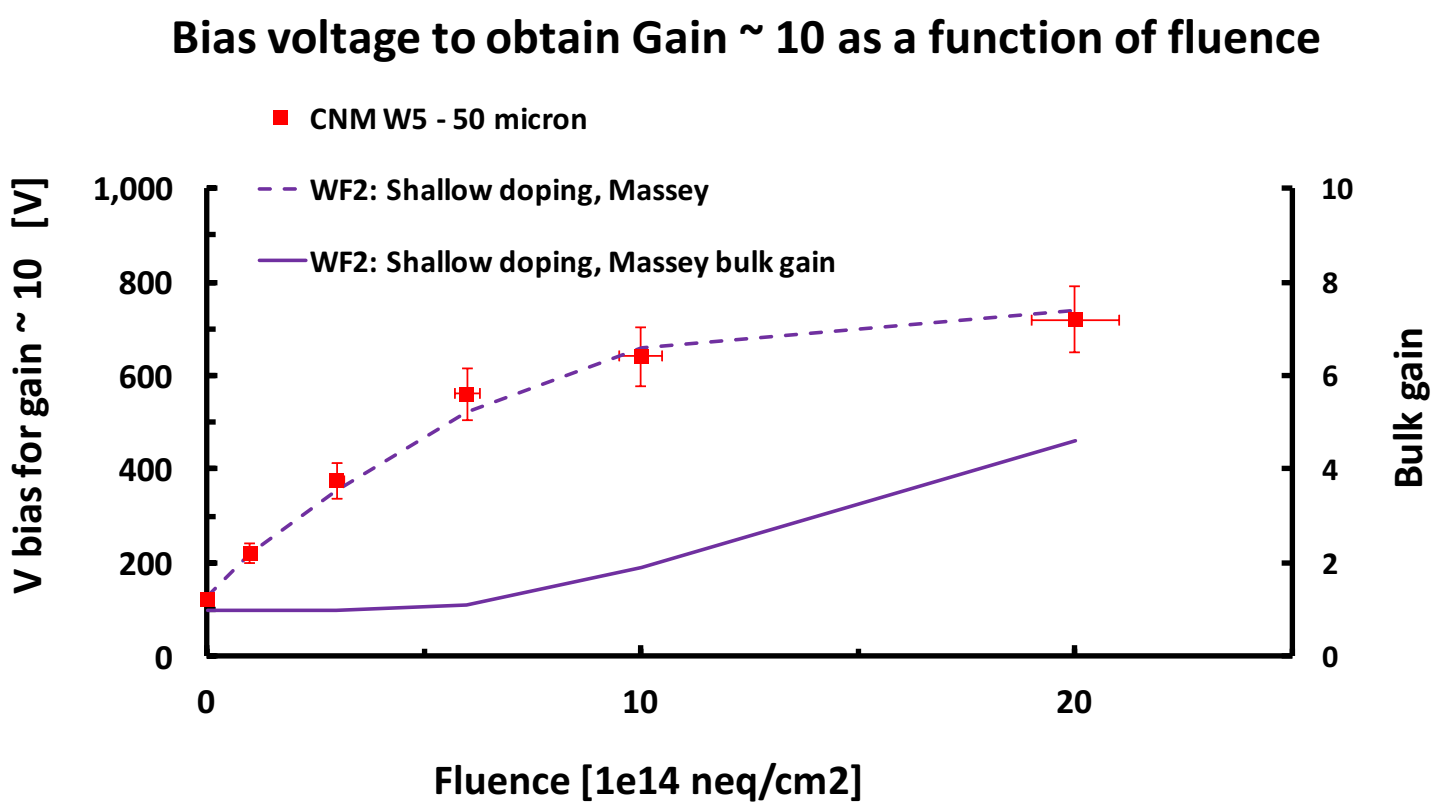
Pulse shape in irradiated UFSD



With irradiation the signal changes: it becomes shorter and steeper

How to use UFSD up to 5~10^{15} n_{eq}/cm^2

As the gain layer density decreases, we need to increase the external voltages to create the Efield needed for multiplications. In so doing, the gain moves from the gain layer to the bulk



Conclusion

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

Acknowledgement

This research was carried out with the contribution of the Ministero degli Affari Esteri, "Direzione Generale per la Promozione del Sistema Paese" of Italy.

Ministero degli Affari Esteri
e della Cooperazione Internazionale

DIREZIONE GENERALE
PER LA PROMOZIONE DEL SISTEMA PAESE
Unità per la cooperazione scientifica
e tecnologica bilaterale e multilaterale

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