Simulation of Ultra-Fast Silicon Detectors

- Explanation of the program
- 3 examples of simulated signal: ideal MIP, real MIP, alpha from bottom
- Comparison laboratory measurements/simulation

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with

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A. Picerno, F. Ravera, H. Sadrozinski, A. Seiden, A. Solano

Weightfield 2.0

- Our goal is to develop a tool to study signals in UFSD

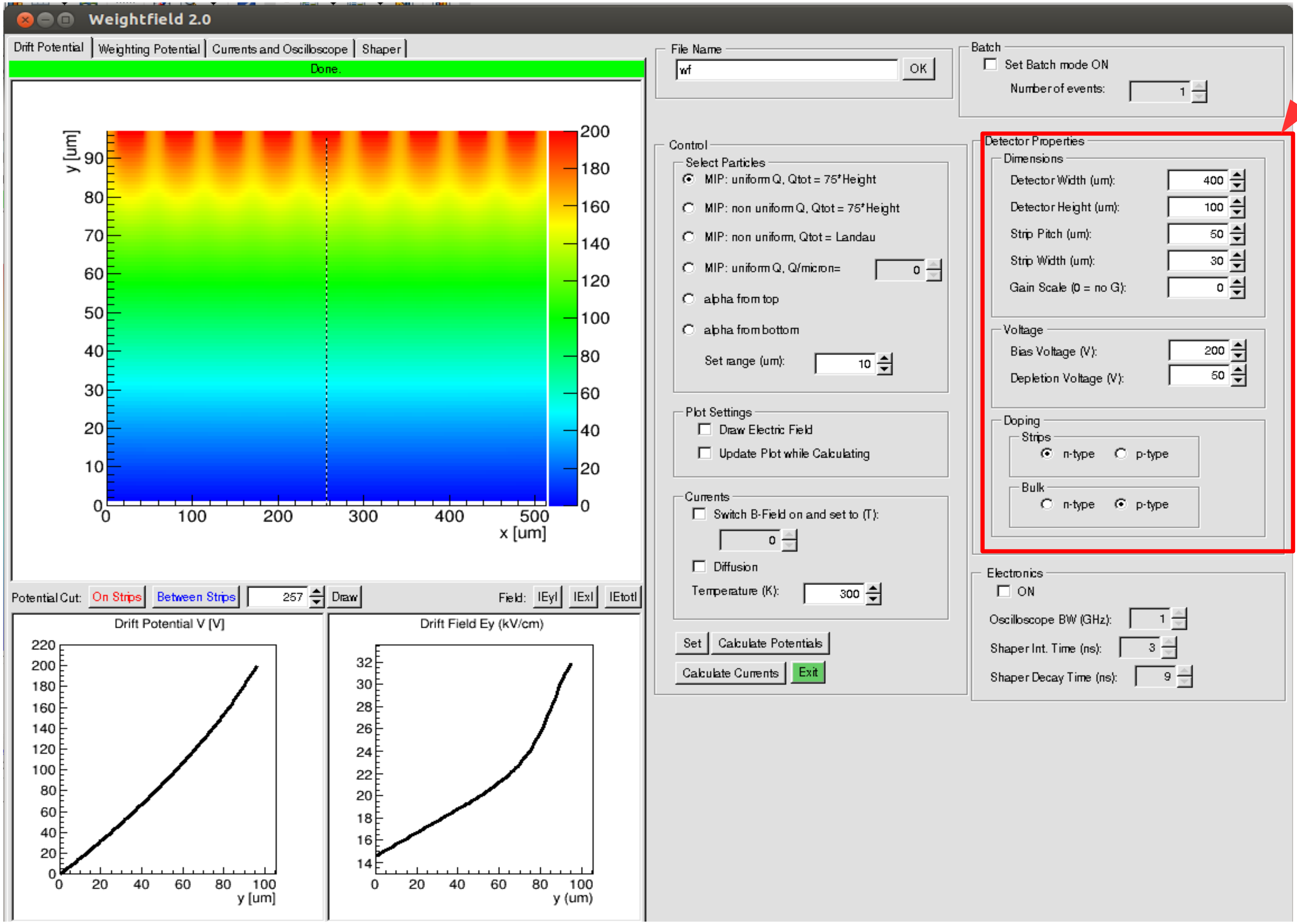
- Weightfield 2.0 is based on *Weightfield* by M. Friedl and B. Kolbinger
  http://www.hephy.at/en/research/departments/semiconductor-detectors/detector-simulation

- Written in C++ language, uses ROOT graphical interface TGUI

- Program features:
  - calculates induced currents with Ramo's Theorem $I=-e\,v(x)\,E_w$
  - solves Poisson's equation using Vdep (not from doping)
  - draws electric field
  - allows to set temperature
  - allows to simulate non uniform charge deposition
  - allows to set gain “by hand”

Graphical Interface

Detector Geometry



Potential Cut: On Strips | Between Strips | 257 | Draw

Field: |Ey| |Ex| |Etot|

File Name: wf OK

Batch
- ☐ Set Batch mode ON
- Number of events: 1

Control

Select Particles
- ● MIP: uniform Q, Qtot = 75*Height
- ○ MIP: non uniform Q, Qtot = 75*Height
- ○ MIP: non uniform, Qtot = Landau
- ○ MIP: uniform Q, Q/micron= 0
- ○ alpha from top
- ○ alpha from bottom
- Set range (um): 10

Plot Settings
- ☐ Draw Electric Field
- ☐ Update Plot while Calculating

Currents
- ☐ Switch B-Field on and set to (T): 0
- ☐ Diffusion
- Temperature (K): 300

Set | Calculate Potentials | Calculate Currents | Exit

Detector Properties

Dimensions
- Detector Width (um): 400
- Detector Height (um): 100
- Strip Pitch (um): 50
- Strip Width (um): 30
- Gain Scale (0 = no G): 0

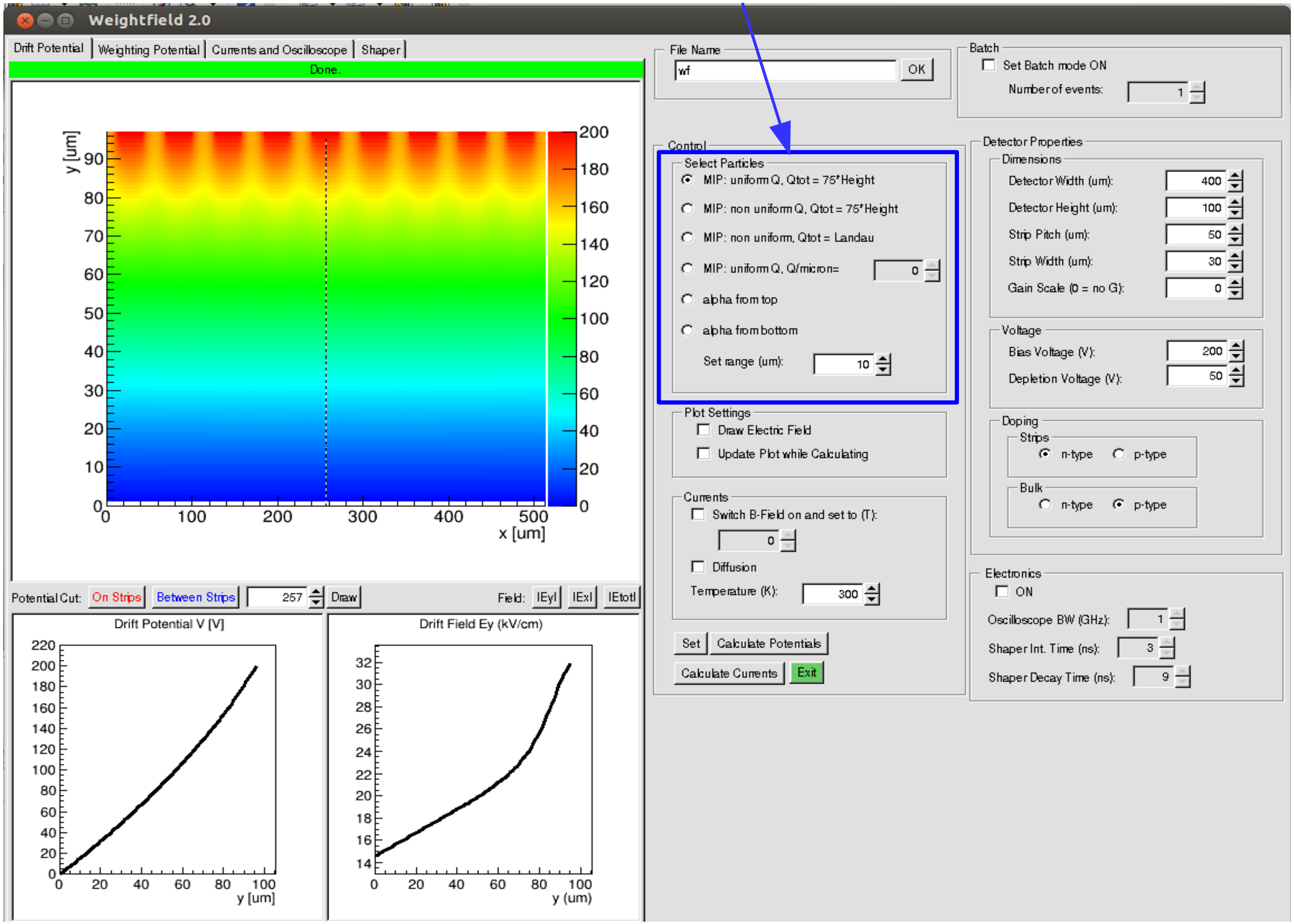
Voltage
- Bias Voltage (V): 200
- Depletion Voltage (V): 50

Doping
- Strips: ● n-type ○ p-type
- Bulk: ○ n-type ● p-type

Electronics
- ☐ ON
- Oscilloscope BW (GHz): 1
- Shaper Int. Time (ns): 3
- Shaper Decay Time (ns): 9

Graphical Interface

Select Particles



Potential Cut: 257

File Name: wf

Batch

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Number of events: 1

Control

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- ○ alpha from top
- ○ alpha from bottom

Set range (um): 10

Plot Settings

- ☐ Draw Electric Field
- ☐ Update Plot while Calculating

Currents

- ☐ Switch B-Field on and set to (T): 0
- ☐ Diffusion

Temperature (K): 300

Detector Properties

Dimensions

Detector Width (um): 400
Detector Height (um): 100
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Gain Scale (0 = no G): 0

Voltage

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Depletion Voltage (V): 50

Doping

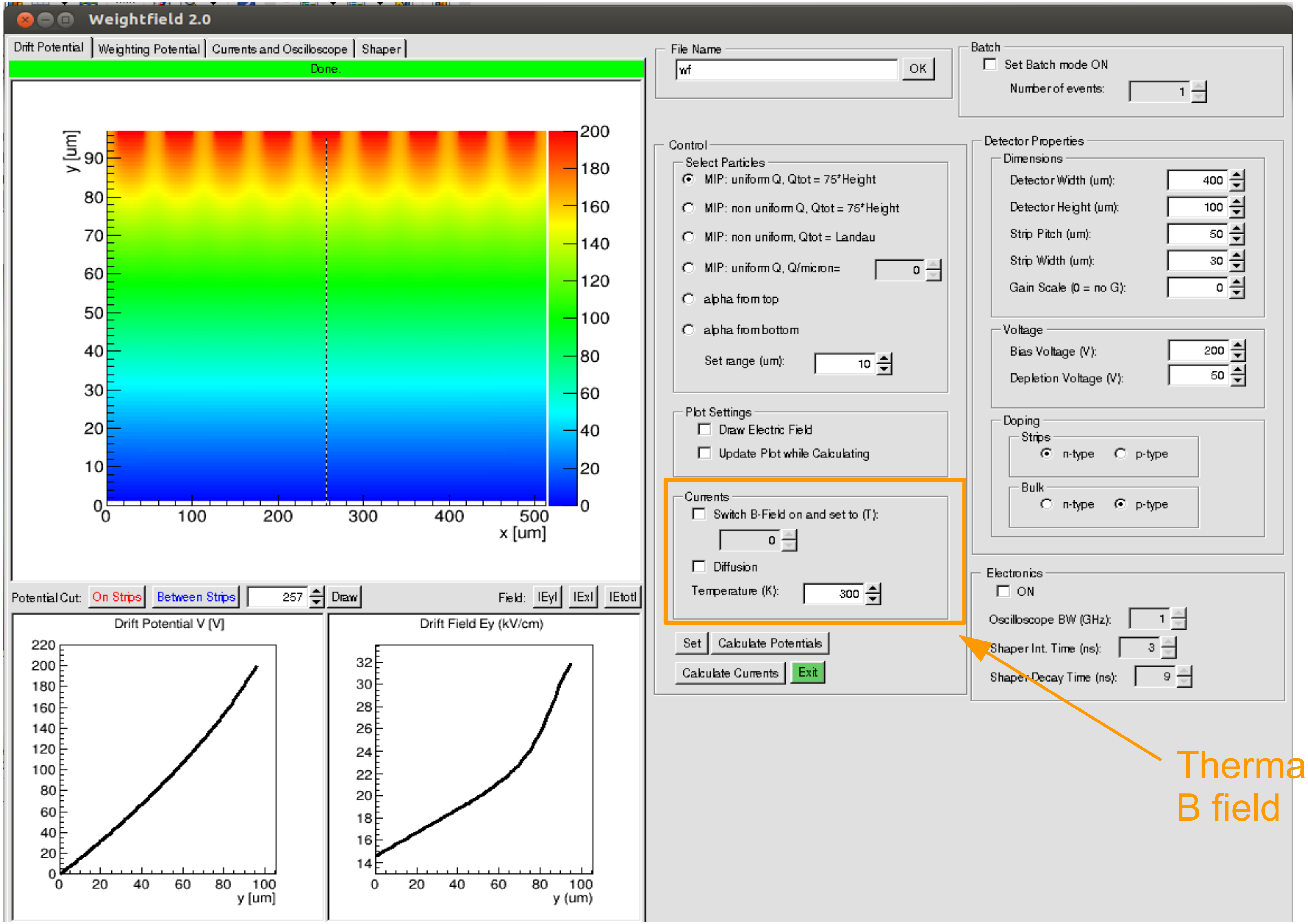
Strips: ● n-type ○ p-type
Bulk: ○ n-type ● p-type

Electronics

☐ ON

Oscilloscope BW (GHz): 1
Shaper Int. Time (ns): 3
Shaper Decay Time (ns): 9

Graphical Interface



Potential Cut: 257

File Name: wf

Batch
☐ Set Batch mode ON
Number of events: 1

Control

Select Particles
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○ MIP: non uniform Q, Qtot = 75*Height
○ MIP: non uniform, Qtot = Landau
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○ alpha from top
○ alpha from bottom
Set range (um): 10

Plot Settings
☐ Draw Electric Field
☐ Update Plot while Calculating

Currents
☐ Switch B-Field on and set to (T): 0
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Temperature (K): 300

Detector Properties

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Detector Width (um): 400
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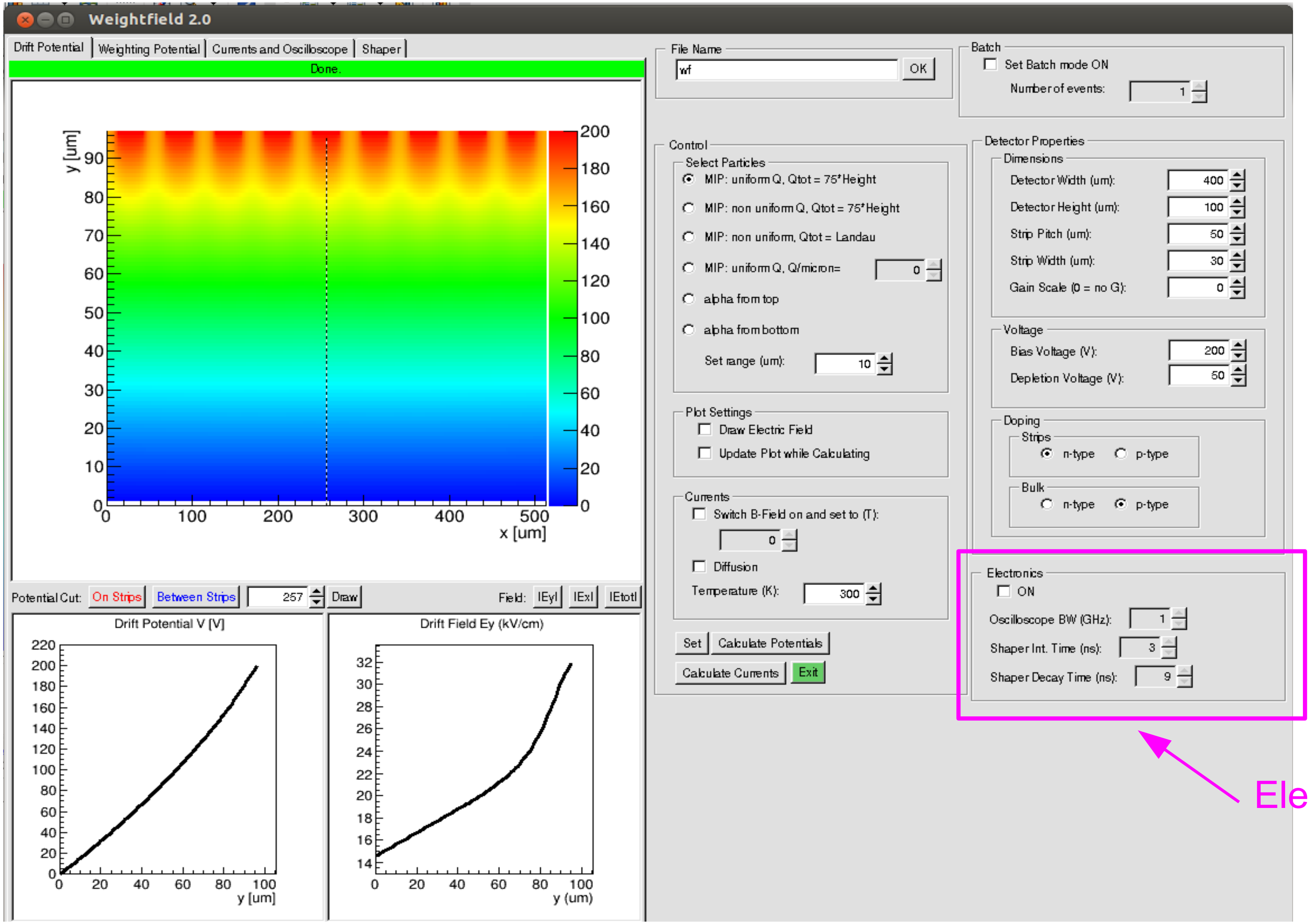
Voltage
Bias Voltage (V): 200
Depletion Voltage (V): 50

Doping
Strips: ● n-type ○ p-type
Bulk: ○ n-type ● p-type

Electronics
☐ ON
Oscilloscope BW (GHz): 1
Shaper Int. Time (ns): 3
Shaper Decay Time (ns): 9

Thermal Diffusion
B field

Graphical Interface



Potential Cut: On Strips Between Strips 257 Draw

Field: |Ey| |Ex| |Etot|

File Name: wf OK

Batch

☐ Set Batch mode ON

Number of events: 1

Control

Select Particles

● MIP: uniform Q, Qtot = 75*Height

○ MIP: non uniform Q, Qtot = 75*Height

○ MIP: non uniform, Qtot = Landau

○ MIP: uniform Q, Q/micron= 0

○ alpha from top

○ alpha from bottom

Set range (um): 10

Plot Settings

☐ Draw Electric Field

☐ Update Plot while Calculating

Currents

☐ Switch B-Field on and set to (T): 0

☐ Diffusion

Temperature (K): 300

Detector Properties

Dimensions

Detector Width (um): 400

Detector Height (um): 100

Strip Pitch (um): 50

Strip Width (um): 30

Gain Scale (0 = no G): 0

Voltage

Bias Voltage (V): 200

Depletion Voltage (V): 50

Doping

Strips ● n-type ○ p-type

Bulk ○ n-type ● p-type

Electronics

☐ ON

Oscilloscope BW (GHz): 1

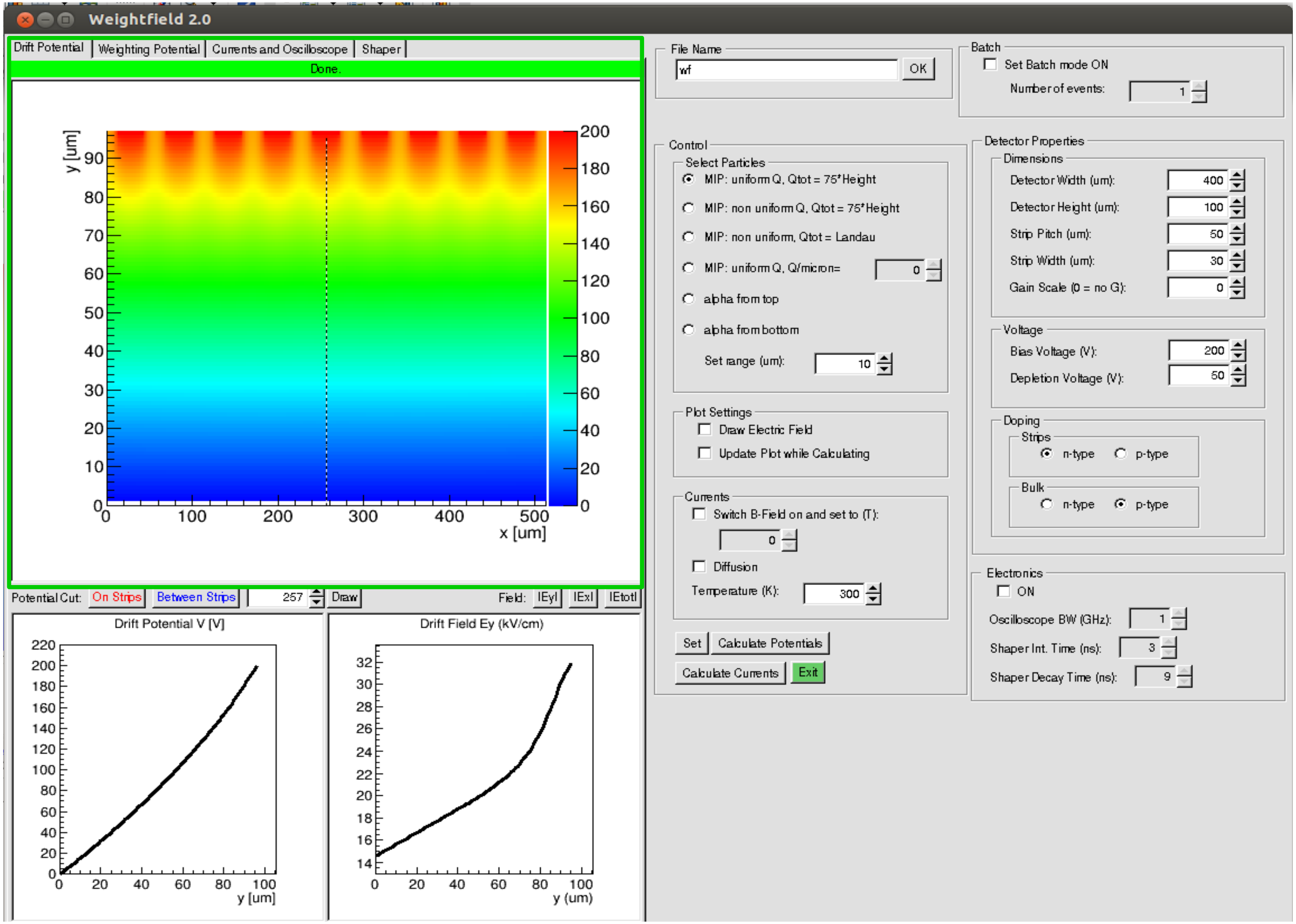
Shaper Int. Time (ns): 3

Shaper Decay Time (ns): 9

Electronics

Graphical Interface

4 Tabs:



File Name: wf

Batch

☐ Set Batch mode ON

Number of events: 1

Control

Select Particles

- ● MIP: uniform Q, Qtot = 75*Height
- ○ MIP: non uniform Q, Qtot = 75*Height
- ○ MIP: non uniform, Qtot = Landau
- ○ MIP: uniform Q, Q/micron= 0
- ○ alpha from top
- ○ alpha from bottom

Set range (um): 10

Plot Settings

- ☐ Draw Electric Field
- ☐ Update Plot while Calculating

Currents

☐ Switch B-Field on and set to (T): 0

☐ Diffusion

Temperature (K): 300

Detector Properties

Dimensions

Detector Width (um): 400

Detector Height (um): 100

Strip Pitch (um): 50

Strip Width (um): 30

Gain Scale (0 = no G): 0

Voltage

Bias Voltage (V): 200

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Doping

Strips: ● n-type ○ p-type

Bulk: ○ n-type ● p-type

Electronics

☐ ON

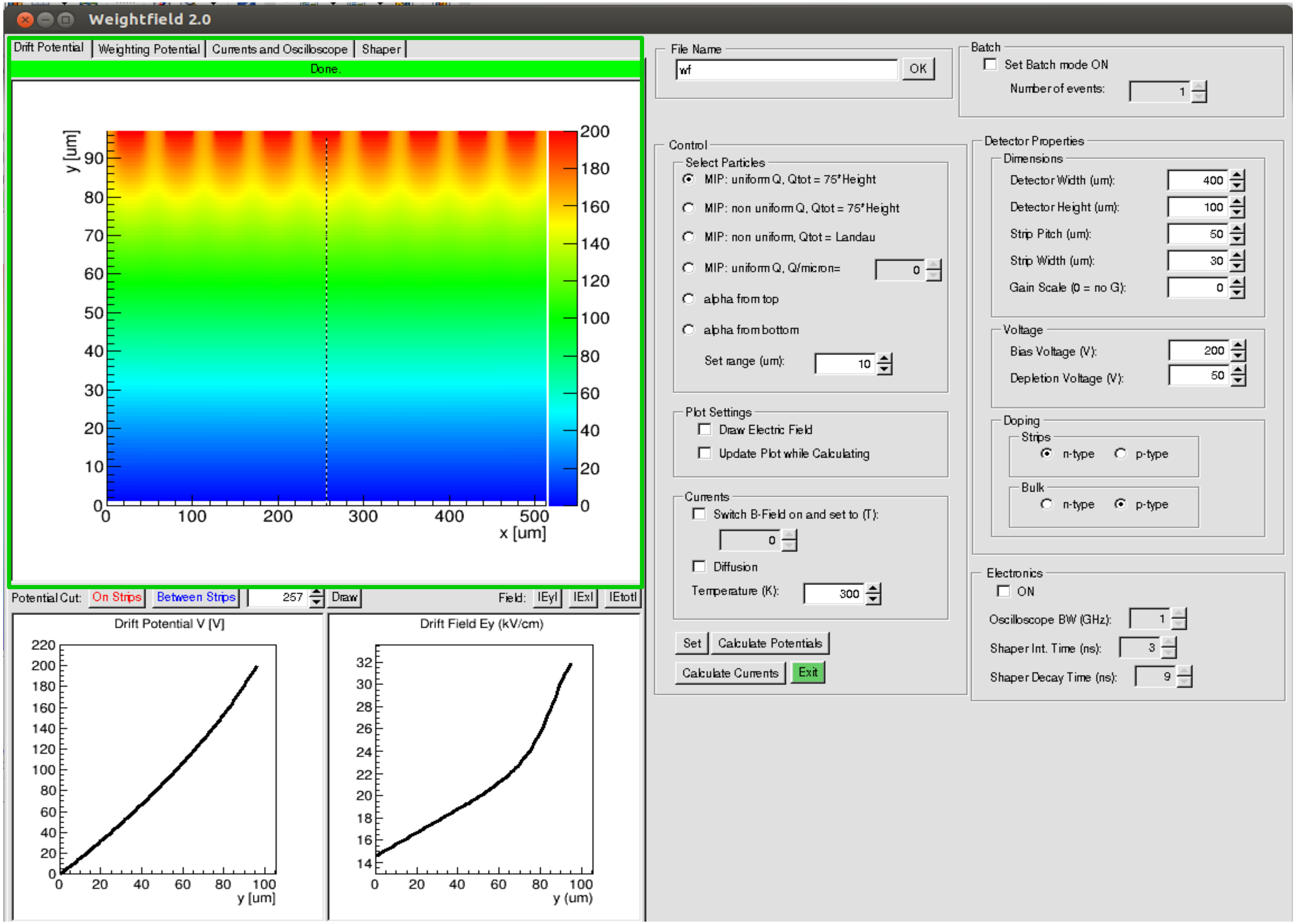
Oscilloscope BW (GHz): 1

Shaper Int. Time (ns): 3

Shaper Decay Time (ns): 9

Graphical Interface

4 Tabs:
Drift Potential



Potential Cut: 257

File Name: wf

Batch
- ☐ Set Batch mode ON
- Number of events: 1

Control

Select Particles
- ● MIP: uniform Q, Qtot = 75*Height
- ○ MIP: non uniform Q, Qtot = 75*Height
- ○ MIP: non uniform, Qtot = Landau
- ○ MIP: uniform Q, Q/micron= 0
- ○ alpha from top
- ○ alpha from bottom
- Set range (um): 10

Plot Settings
- ☐ Draw Electric Field
- ☐ Update Plot while Calculating

Currents
- ☐ Switch B-Field on and set to (T): 0
- ☐ Diffusion
- Temperature (K): 300

Detector Properties

Dimensions
- Detector Width (um): 400
- Detector Height (um): 100
- Strip Pitch (um): 50
- Strip Width (um): 30
- Gain Scale (0 = no G): 0

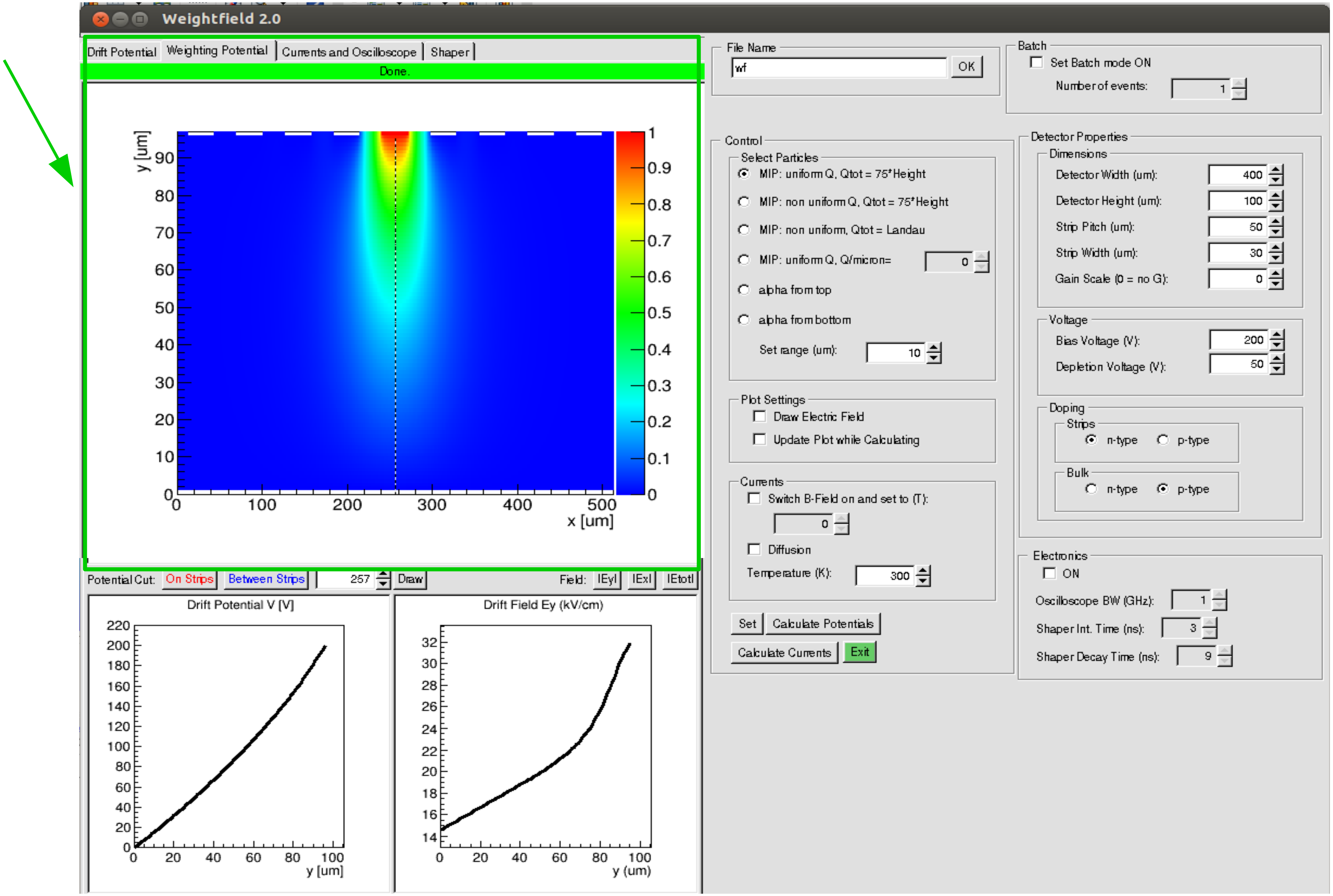
Voltage
- Bias Voltage (V): 200
- Depletion Voltage (V): 50

Doping
- Strips: ● n-type ○ p-type
- Bulk: ○ n-type ● p-type

Electronics
- ☐ ON
- Oscilloscope BW (GHz): 1
- Shaper Int. Time (ns): 3
- Shaper Decay Time (ns): 9

Graphical Interface

4 Tabs:
Drift Potential, **Weighting Potential**



Potential Cut: 257

File Name: wf

Batch
- ☐ Set Batch mode ON
- Number of events: 1

Control

Select Particles
- ● MIP: uniform Q, Qtot = 75*Height
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- ○ MIP: non uniform, Qtot = Landau
- ○ MIP: uniform Q, Q/micron= 0
- ○ alpha from top
- ○ alpha from bottom
- Set range (um): 10

Plot Settings
- ☐ Draw Electric Field
- ☐ Update Plot while Calculating

Currents
- ☐ Switch B-Field on and set to (T): 0
- ☐ Diffusion
- Temperature (K): 300

Detector Properties

Dimensions
- Detector Width (um): 400
- Detector Height (um): 100
- Strip Pitch (um): 50
- Strip Width (um): 30
- Gain Scale (0 = no G): 0

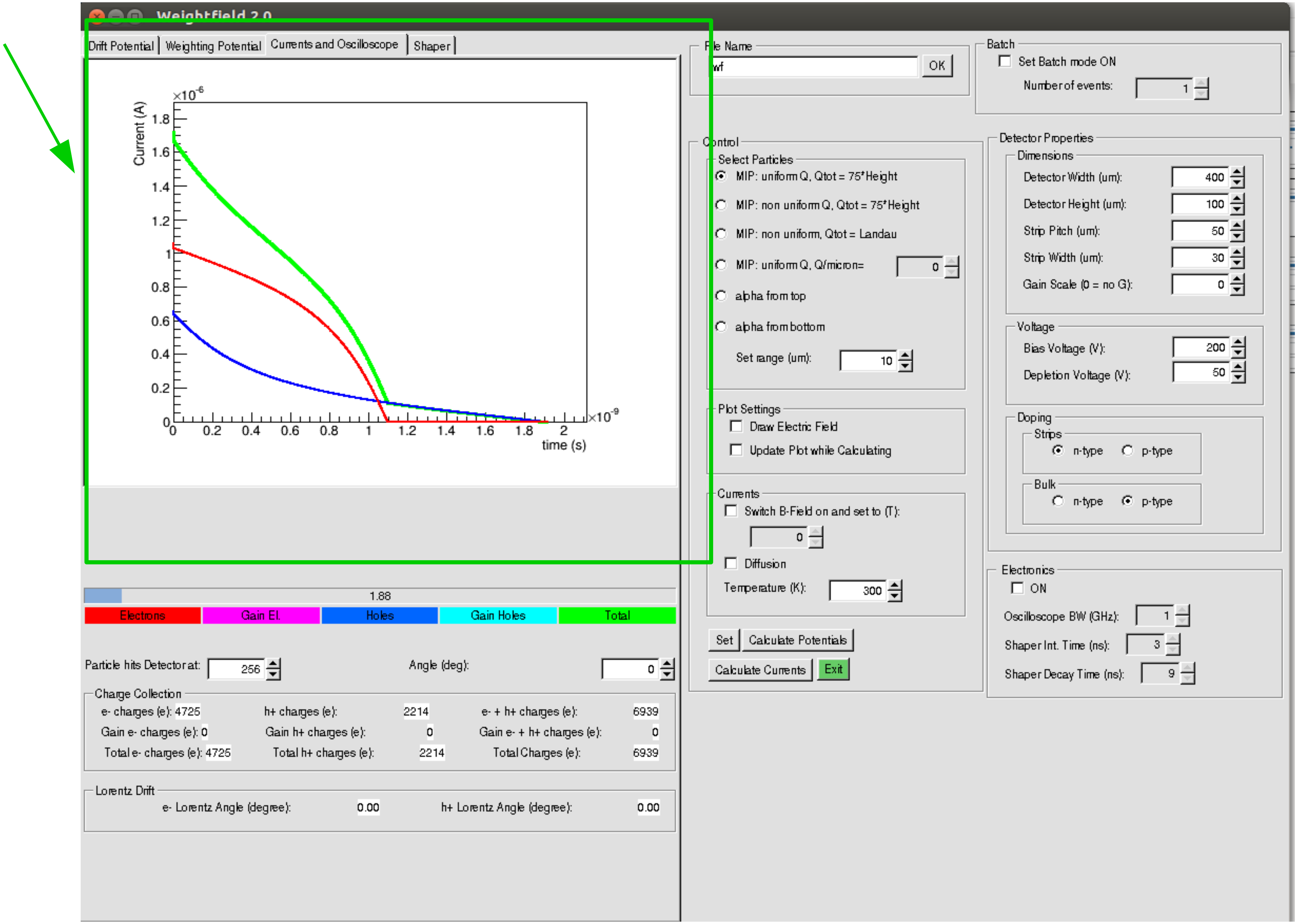
Voltage
- Bias Voltage (V): 200
- Depletion Voltage (V): 50

Doping
- Strips: ● n-type ○ p-type
- Bulk: ○ n-type ● p-type

Electronics
- ☐ ON
- Oscilloscope BW (GHz): 1
- Shaper Int. Time (ns): 3
- Shaper Decay Time (ns): 9

Graphical Interface

4 Tabs:
Drift Potential, Weighting Potential, **Currents**



Particle hits Detector at: 256

Angle (deg): 0

Charge Collection

e- charges (e):	4725	h+ charges (e):	2214	e- + h+ charges (e):	6939
Gain e- charges (e):	0	Gain h+ charges (e):	0	Gain e- + h+ charges (e):	0
Total e- charges (e):	4725	Total h+ charges (e):	2214	Total Charges (e):	6939

Lorentz Drift

e- Lorentz Angle (degree): 0.00

h+ Lorentz Angle (degree): 0.00

File Name: wf

Batch

☐ Set Batch mode ON

Number of events: 1

Control

Select Particles

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○ MIP: non uniform, Qtot = Landau
○ MIP: uniform Q, Q/micron= 0
○ alpha from top
○ alpha from bottom

Set range (um): 10

Plot Settings

☐ Draw Electric Field
☐ Update Plot while Calculating

Currents

☐ Switch B-Field on and set to (T): 0
☐ Diffusion

Temperature (K): 300

Detector Properties

Dimensions

Detector Width (um): 400
Detector Height (um): 100
Strip Pitch (um): 50
Strip Width (um): 30
Gain Scale (0 = no G): 0

Voltage

Bias Voltage (V): 200
Depletion Voltage (V): 50

Doping

Strips: ● n-type ○ p-type

Bulk: ○ n-type ● p-type

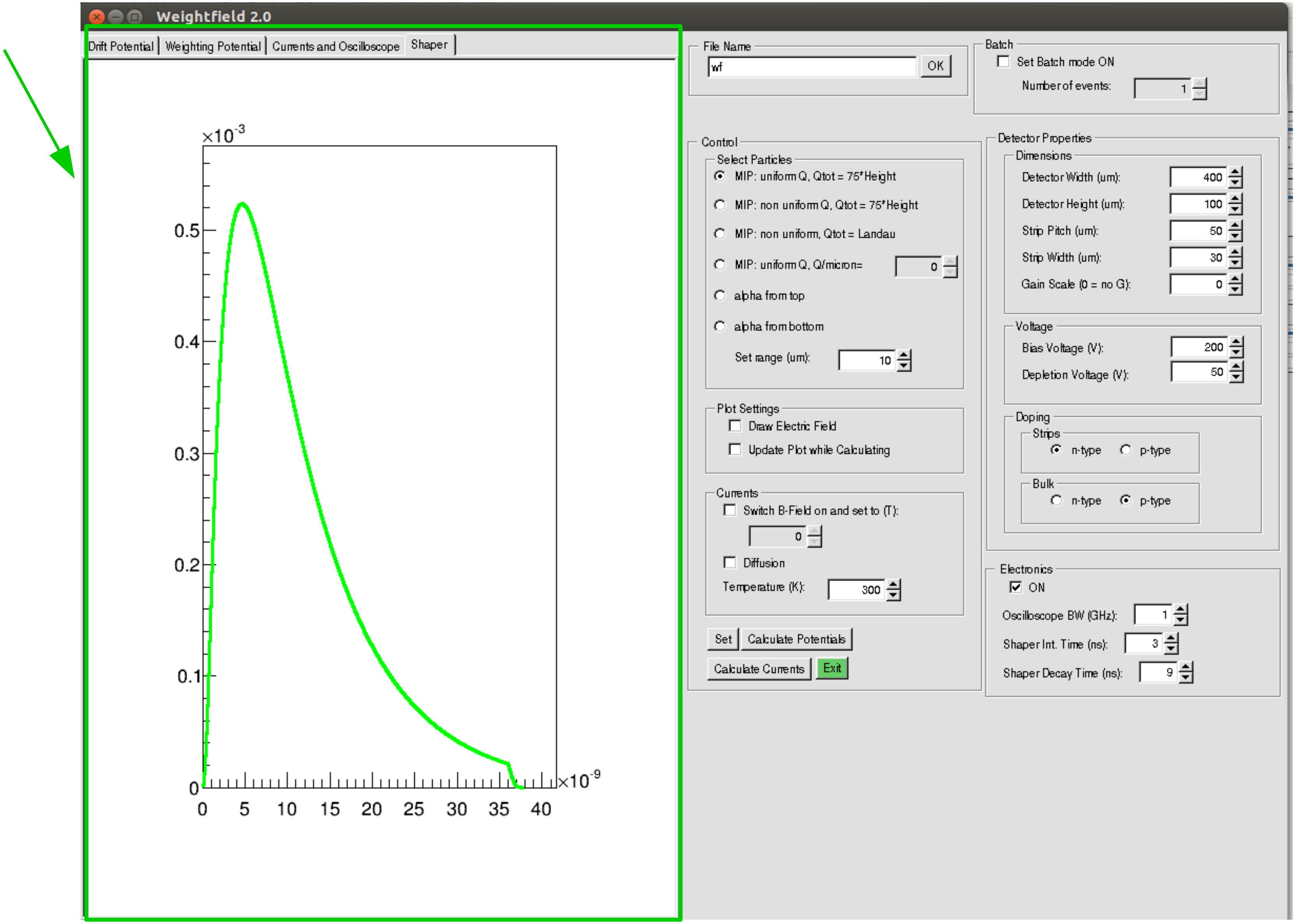
Electronics

☐ ON

Oscilloscope BW (GHz): 1
Shaper Int. Time (ns): 3
Shaper Decay Time (ns): 9

Graphical Interface

4 Tabs:
Drift Potential, Weighting Potential, Currents, **Shaper**



File Name: wf

Batch
☐ Set Batch mode ON
Number of events: 1

Control
Select Particles
● MIP: uniform Q, Qtot = 75*Height
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○ alpha from bottom
Set range (um): 10

Plot Settings
☐ Draw Electric Field
☐ Update Plot while Calculating

Currents
☐ Switch B-Field on and set to (T): 0
☐ Diffusion
Temperature (K): 300

Detector Properties
Dimensions
Detector Width (um): 400
Detector Height (um): 100
Strip Pitch (um): 50
Strip Width (um): 30
Gain Scale (0 = no G): 0

Voltage
Bias Voltage (V): 200
Depletion Voltage (V): 50

Doping
Strips
● n-type ○ p-type
Bulk
○ n-type ● p-type

Electronics
☑ ON
Oscilloscope BW (GHz): 1
Shaper Int. Time (ns): 3
Shaper Decay Time (ns): 9

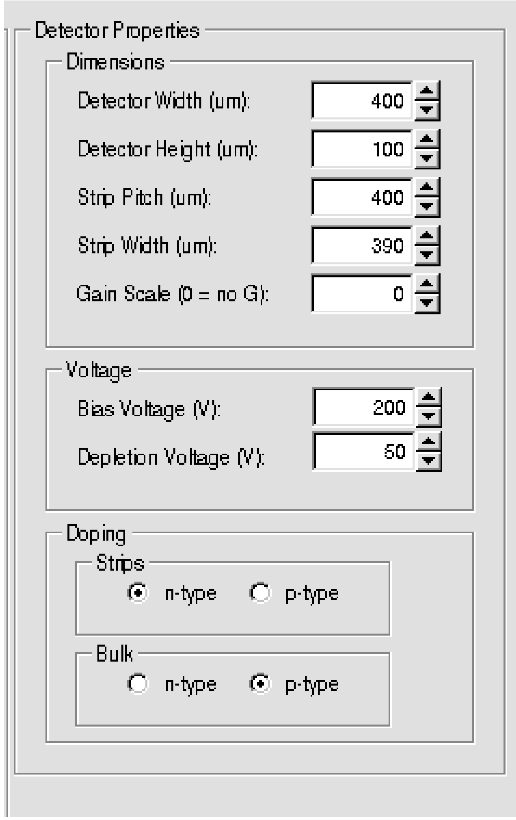
Choosing a Detector Geometry

Detector Properties

- detector geometry (width, thickness, strip pitch/width...)
- depletion and bias voltages
- electrodes and bulk doping
- We simulate the gain value G according to what we measure:
  - linear dipendence with E
  - small gain (~2)

$$G \propto C_0 \cdot E$$

C_0 = **gain scale factor** → selectable by user



Detector Properties

Dimensions

Detector Width (um): 400

Detector Height (um): 100

Strip Pitch (um): 400

Strip Width (um): 390

Gain Scale (0 = no G): 0

Voltage

Bias Voltage (V): 200

Depletion Voltage (V): 50

Doping

Strips

● n-type ○ p-type

Bulk

○ n-type ● p-type

Choosing a Detector Geometry

Detector Properties

- detector geometry (width, thickness, strip pitch/width...)
- depletion and bias voltages
- electrodes and bulk doping
- We simulate the gain value G according to what we measure:
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$$G \propto C_0 \cdot E$$

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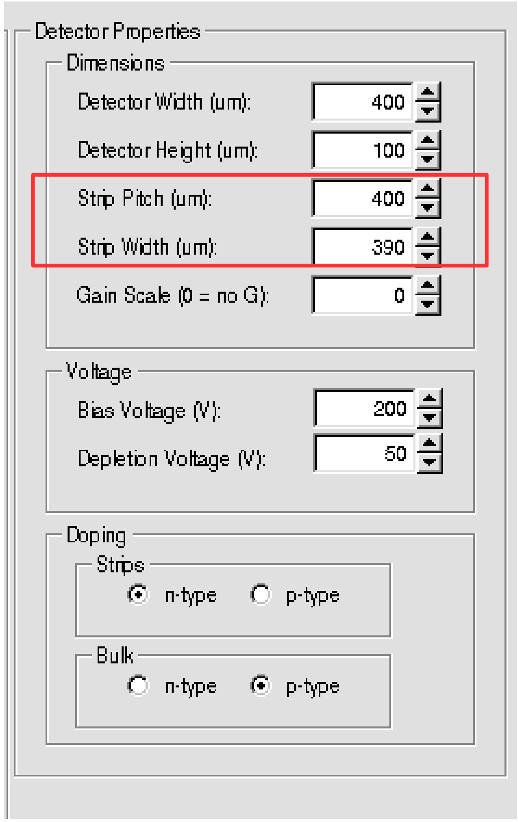


Detector Properties

Dimensions

Detector Width (um): 400

Detector Height (um): 100

Strip Pitch (um): 400

Strip Width (um): 390

Gain Scale (0 = no G): 0

Voltage

Bias Voltage (V): 200

Depletion Voltage (V): 50

Doping

Strips

● n-type ○ p-type

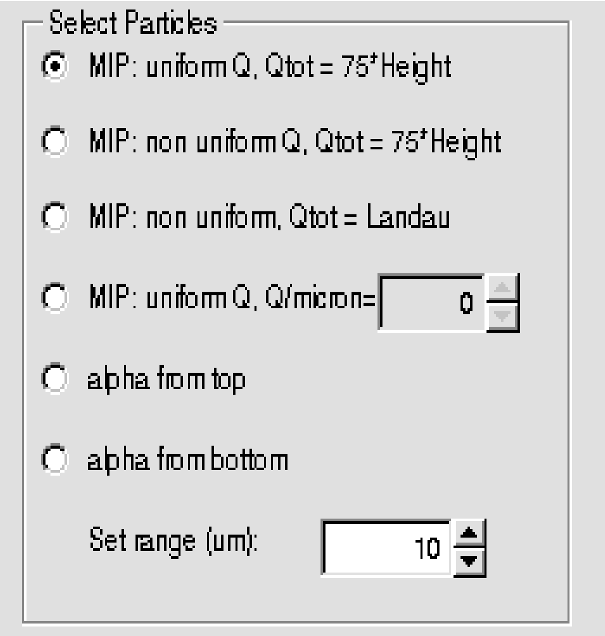
Bulk

○ n-type ● p-type

For example we select a simple **pad geometry** without gain

Choosing Particles

- MIP with uniform charge deposition (75 pairs/um)
- MIP with non uniform charge deposition
- MIP with Landau-distributed charge deposition
- α particle from top/bottom



Select Particles

● MIP: uniform Q, Qtot = 75*Height

○ MIP: non uniform Q, Qtot = 75*Height

○ MIP: non uniform, Qtot = Landau

○ MIP: uniform Q, Q/micron= 0

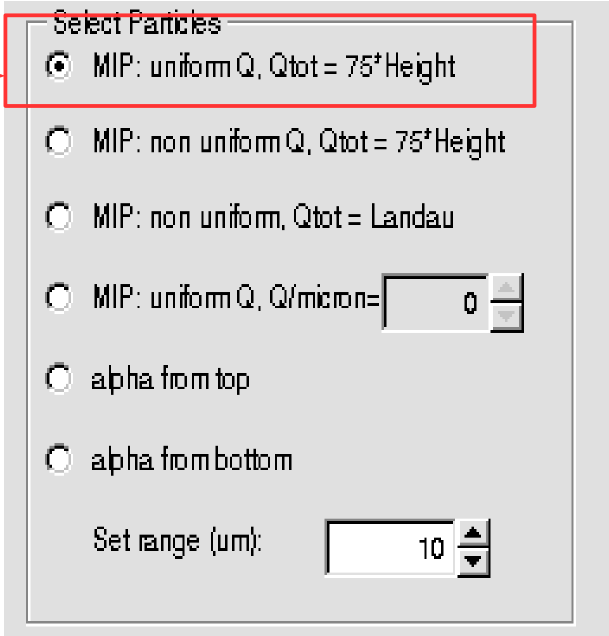
○ alpha from top

○ alpha from bottom

Set range (um): 10

Choosing Particles

- MIP with uniform charge deposition (75 pairs/um)
- MIP with non uniform charge deposition
- MIP with Landau-distributed charge deposition
- α particle from top/bottom



Select Particles

● MIP: uniform Q, Qtot = 75*Height

○ MIP: non uniform Q, Qtot = 75*Height

○ MIP: non uniform, Qtot = Landau

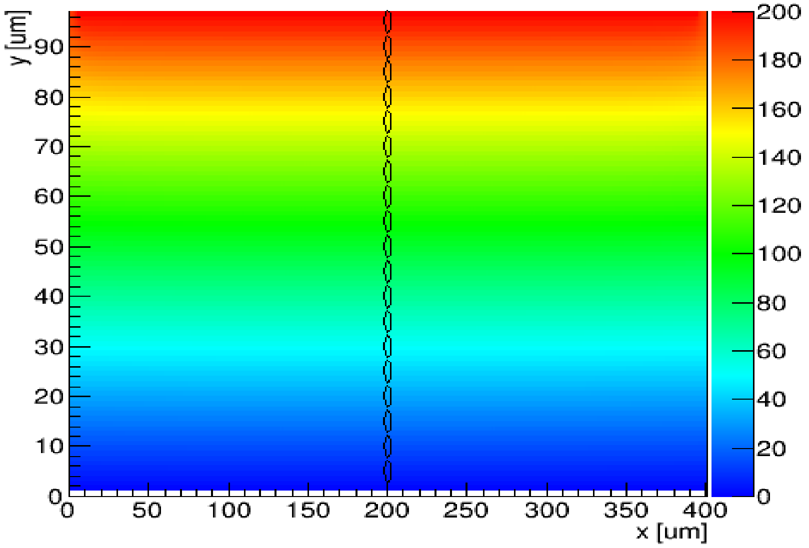
○ MIP: uniform Q, Q/micron= 0

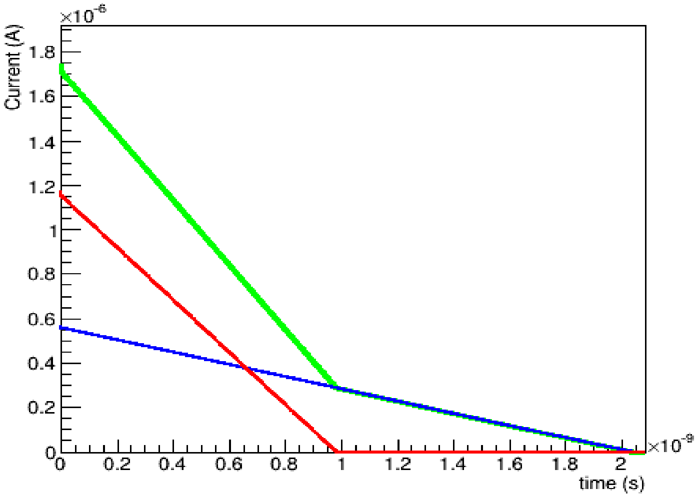
○ alpha from top

○ alpha from bottom

Set range (um): 10

Pad, Gain Scale=0





Choosing Particles

- MIP with uniform charge deposition (75 pairs/um)
- MIP with non uniform charge deposition
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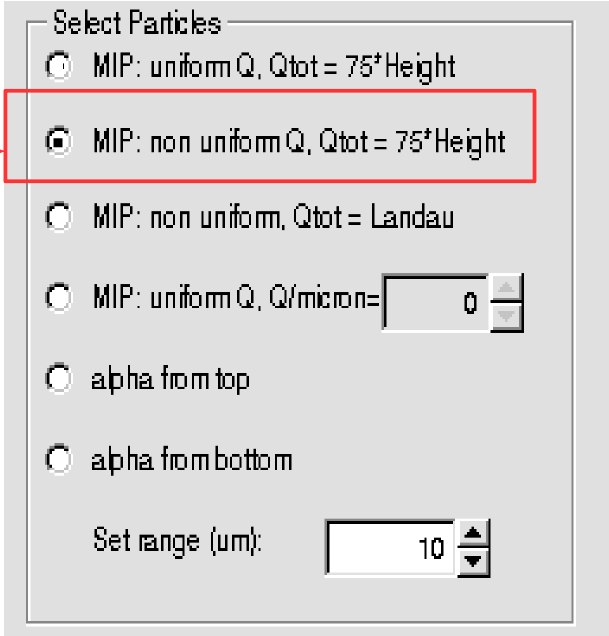


Select Particles

○ MIP: uniform Q, Qtot = 75*Height

● MIP: non uniform Q, Qtot = 75*Height

○ MIP: non uniform, Qtot = Landau

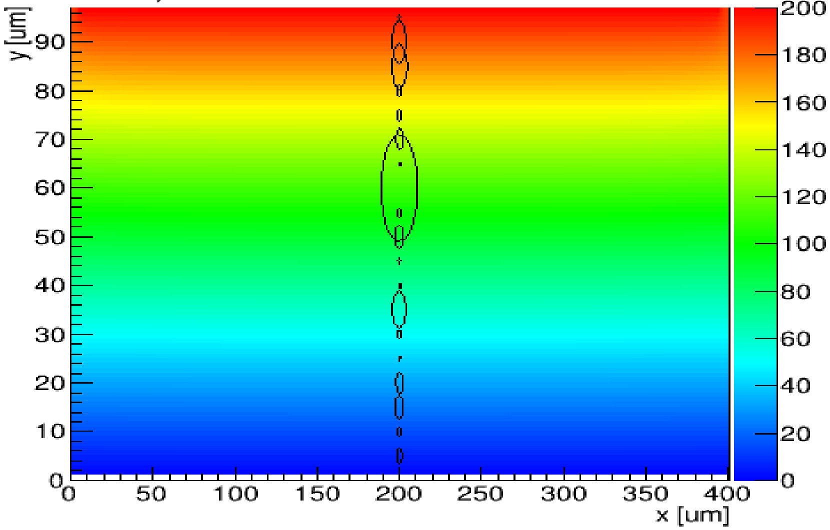
○ MIP: uniform Q, Q/micron= 0

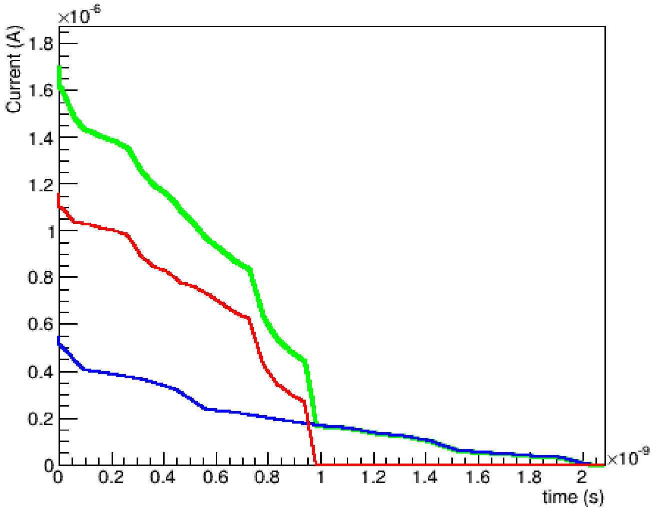
○ alpha from top

○ alpha from bottom

Set range (um): 10

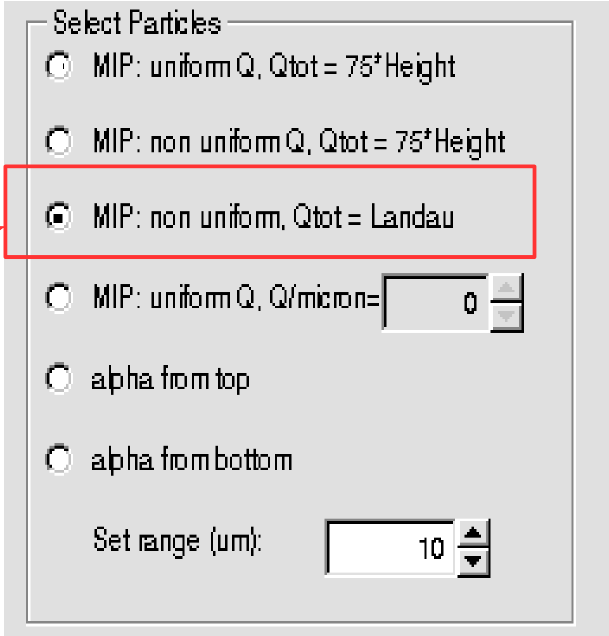
Pad, Gain Scale=0





Choosing Particles

- MIP with uniform charge deposition (75 pairs/um)
- MIP with non uniform charge deposition
- MIP with Landau-distributed charge deposition
- α particle from top/bottom



Select Particles

○ MIP: uniform Q, Qtot = 75*Height

○ MIP: non uniform Q, Qtot = 75*Height

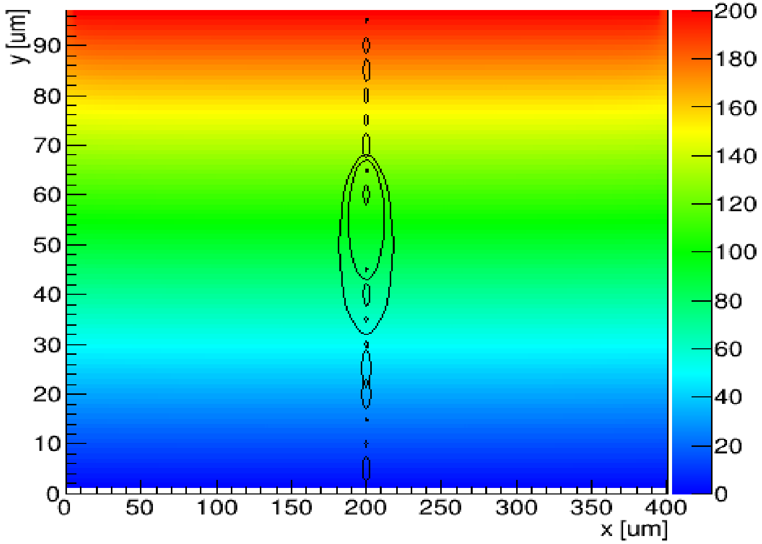
● MIP: non uniform, Qtot = Landau

○ MIP: uniform Q, Q/micron= 0

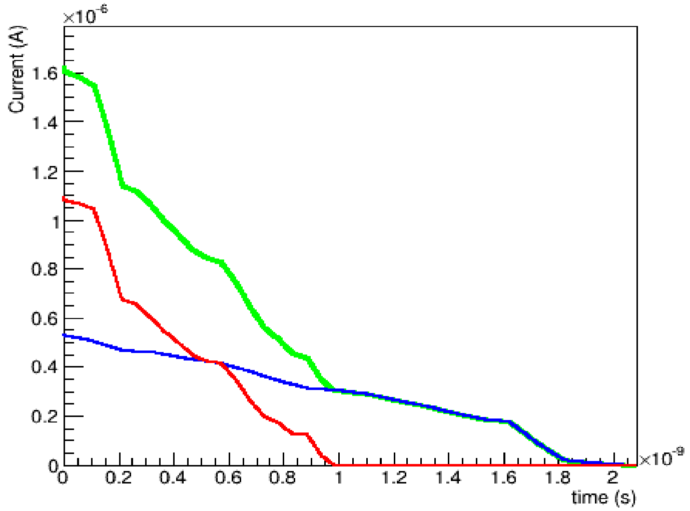
○ alpha from top

○ alpha from bottom

Set range (um): 10

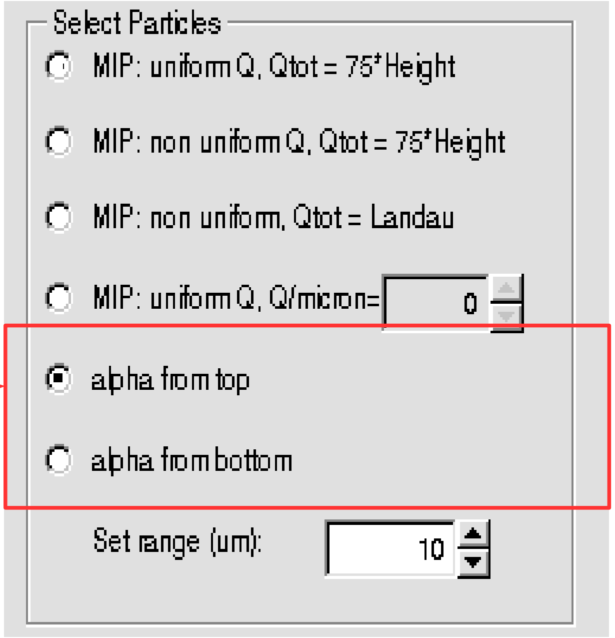


Pad, Gain Scale=0



Choosing Particles

- MIP with uniform charge deposition (75 pairs/um)
- MIP with non uniform charge deposition
- MIP with Landau-distributed charge deposition
- α particle from top/bottom



Select Particles

○ MIP: uniform Q, Qtot = 75*Height

○ MIP: non uniform Q, Qtot = 75*Height

○ MIP: non uniform, Qtot = Landau

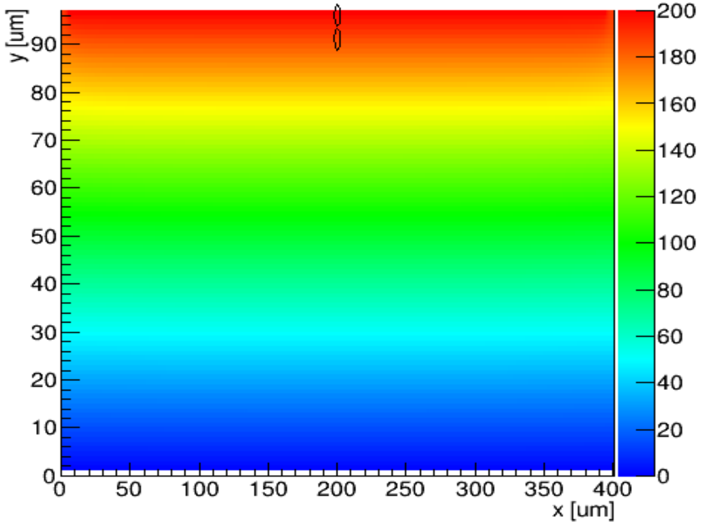
○ MIP: uniform Q, Q/micron= 0

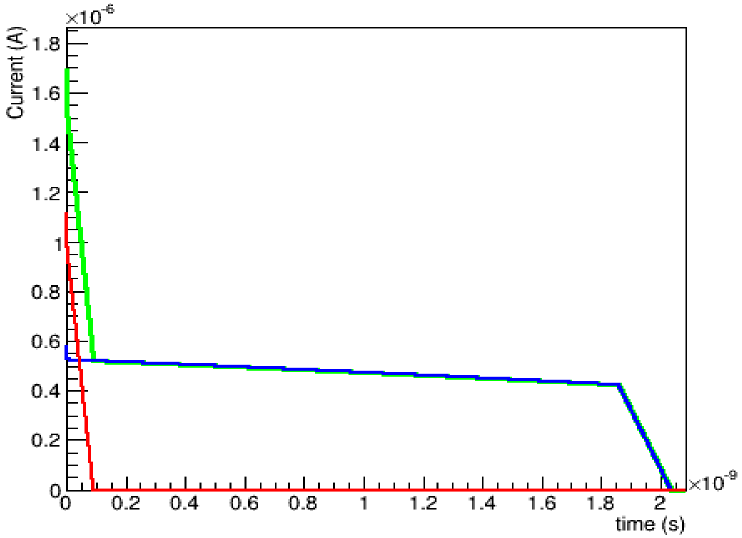
● alpha from top

○ alpha from bottom

Set range (um): 10

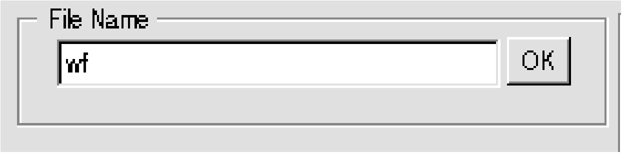
Pad, Gain Scale=0





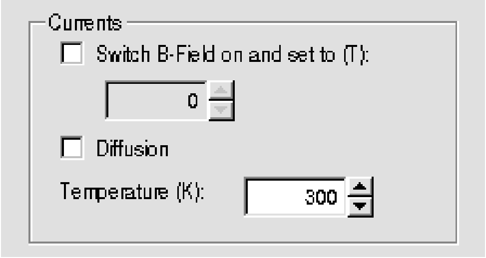
Additional Features

- **Output file**



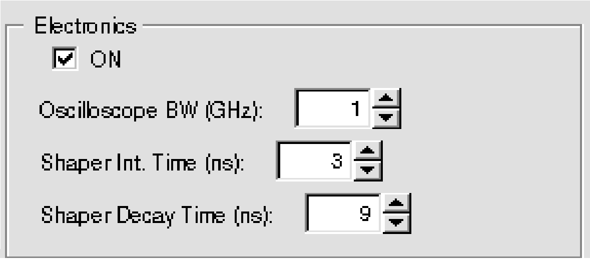
File Name
wf

- **B field:** drift in magnetic field
- **Thermal diffusion** given a T value



Currents
☐ Switch B-Field on and set to (T): 0
☐ Diffusion
Temperature (K): 300

- **Electronics:** simulates an oscilloscope and a shaper



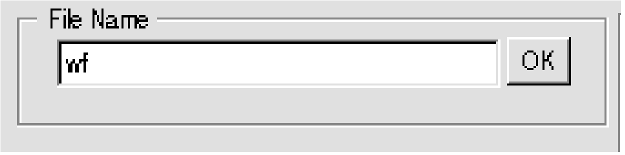
Electronics
☑ ON
Oscilloscope BW (GHz): 1
Shaper Int. Time (ns): 3
Shaper Decay Time (ns): 9

- **Batch mode:** loop of selectable n events

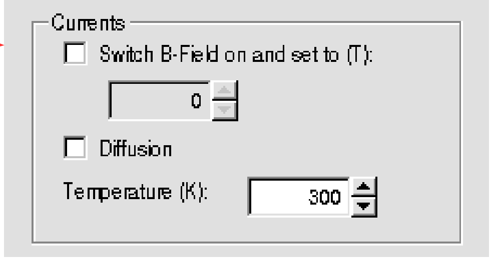
Batch
☑ Set Batch mode ON
Number of events: 1000

Additional Features

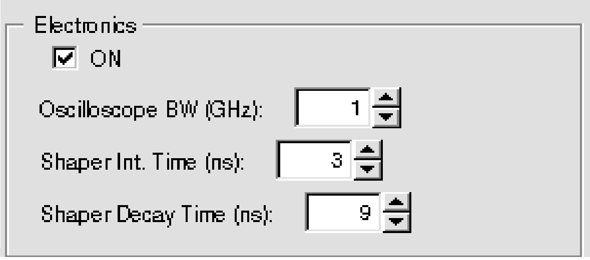
- **Output file**


File Name
wf

- **B field:** drift in magnetic field


Currents
☐ Switch B-Field on and set to (T): 0
☐ Diffusion
Temperature (K): 300

- **Thermal diffusion** given a T value


Electronics
☑ ON
Oscilloscope BW (GHz): 1
Shaper Int. Time (ns): 3
Shaper Decay Time (ns): 9

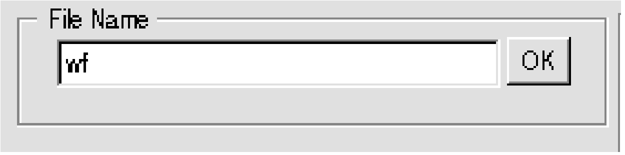
- **Electronics:** simulates an oscilloscope and a shaper


Batch
☑ Set Batch mode ON
Number of events: 1000

- **Batch mode:** loop of selectable n events

Additional Features

- **Output file**


File Name
wf

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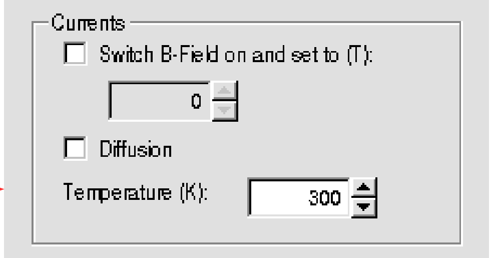
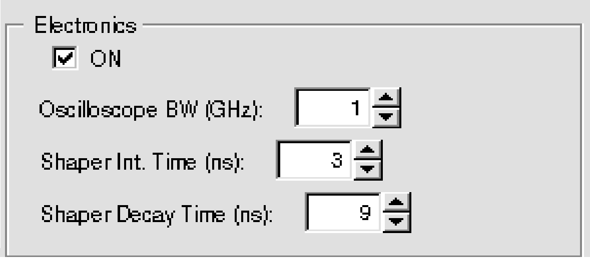

Currents
☐ Switch B-Field on and set to (T):
0
☐ Diffusion
Temperature (K): 300

- **Thermal diffusion** given a T value

- **Electronics:** simulates an oscilloscope and a shaper


Electronics
☑ ON
Oscilloscope BW (GHz): 1
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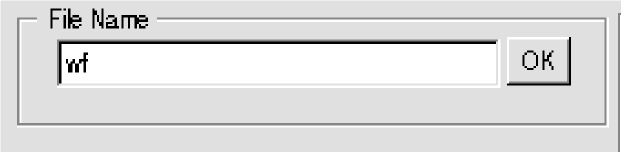
Number of events: 1000

Additional Features

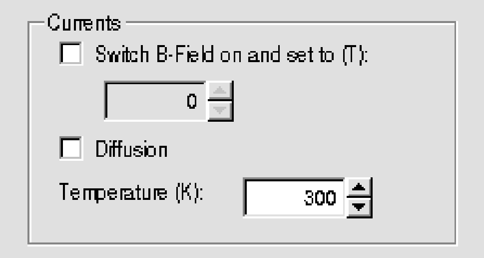
- **Output file**



File Name

wf

- **B field:** drift in magnetic field
- **Thermal diffusion** given a T value



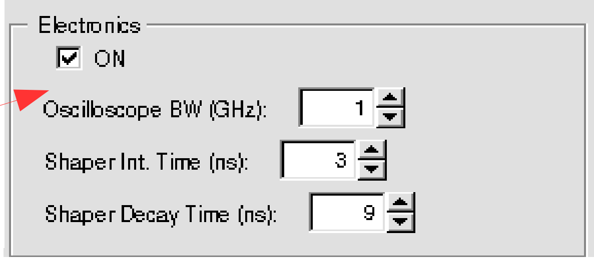
Currents

☐ Switch B-Field on and set to (T): 0

☐ Diffusion

Temperature (K): 300

- **Electronics:** simulates an oscilloscope and a shaper



Electronics

☑ ON

Oscilloscope BW (GHz): 1

Shaper Int. Time (ns): 3

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- **Batch mode:** loop of selectable n events

Batch

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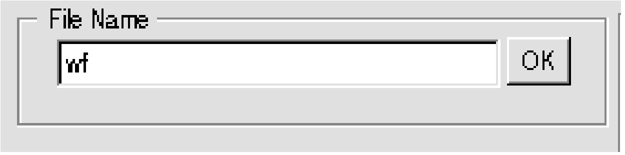
Additional Features

- **Output file**

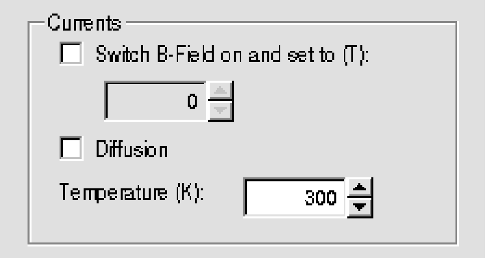


File Name

wf

- **B field:** drift in magnetic field

- **Thermal diffusion** given a T value



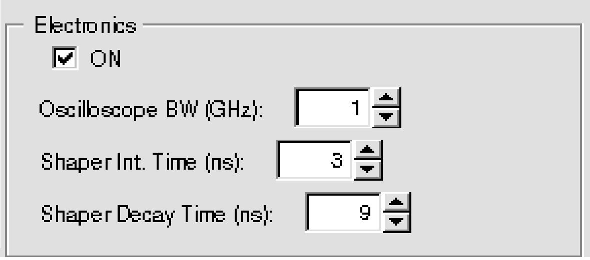
Currents

☐ Switch B-Field on and set to (T): 0

☐ Diffusion

Temperature (K): 300

- **Electronics:** simulates an oscilloscope and a shaper



Electronics

☑ ON

Oscilloscope BW (GHz): 1

Shaper Int. Time (ns): 3

Shaper Decay Time (ns): 9

- **Batch mode:** loop of selectable n events

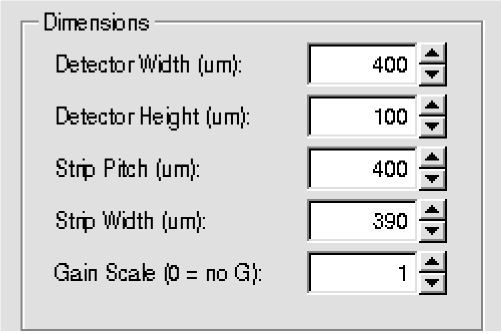
Batch

☑ Set Batch mode ON

Number of events: 1000

Potentials and Currents with Gain

Now we set the gain...



Dimensions

Detector Width (um): 400

Detector Height (um): 100

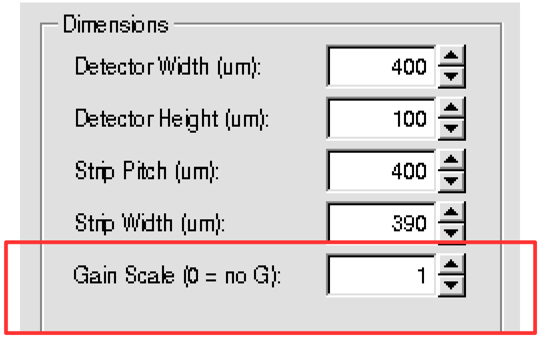
Strip Pitch (um): 400

Strip Width (um): 390

Gain Scale (0 = no G): 1

Potentials and Currents with Gain

Now we set the gain...



Dimensions

Detector Width (um): 400

Detector Height (um): 100

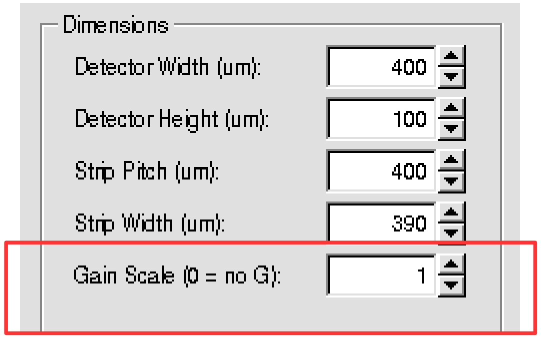
Strip Pitch (um): 400

Strip Width (um): 390

Gain Scale (0 = no G): 1

Potentials and Currents with Gain

Now we set the gain...



Dimensions

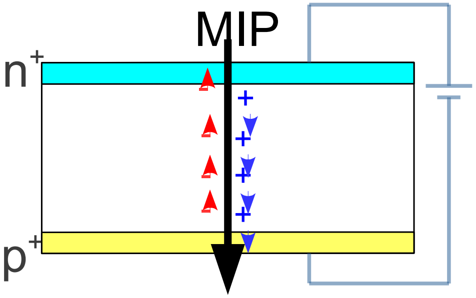
Detector Width (um): 400

Detector Height (um): 100

Strip Pitch (um): 400

Strip Width (um): 390

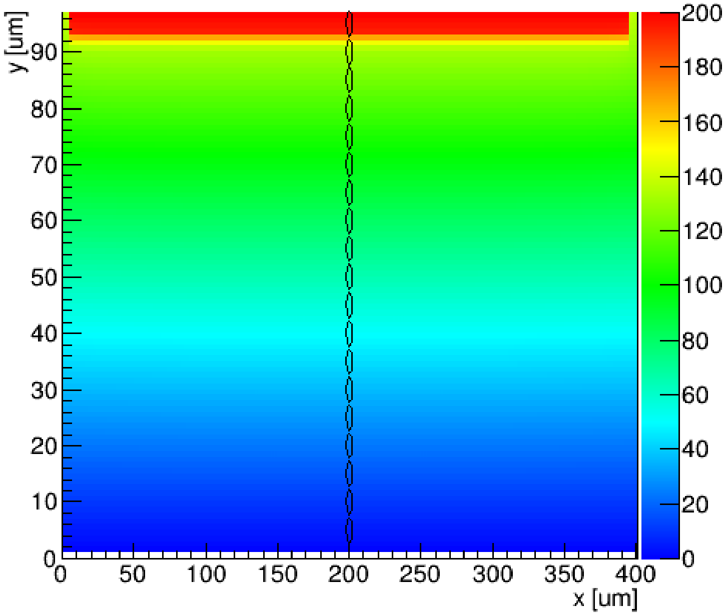
Gain Scale (0 = no G): 1

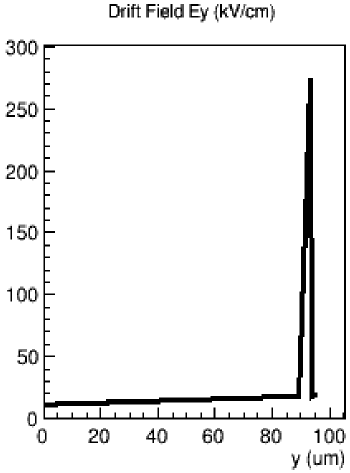


Case: MIP with uniform Q

Drift potential with Gain

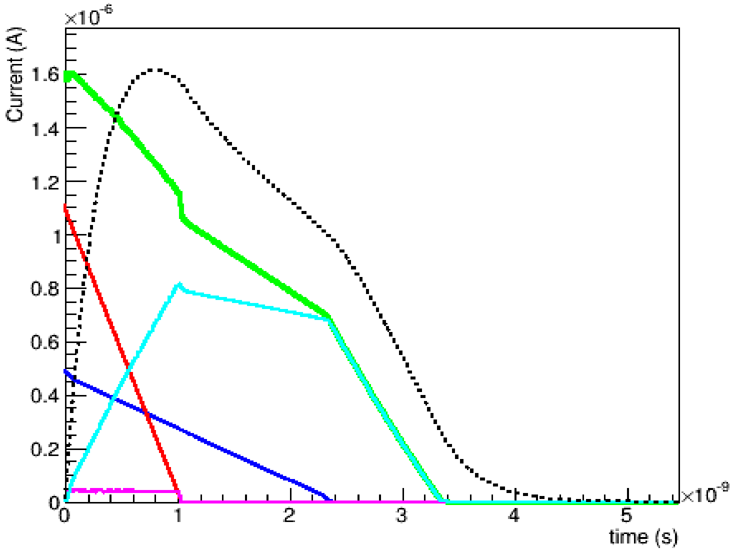
V_{bias} = 200 V
V_{dep} = 50 V





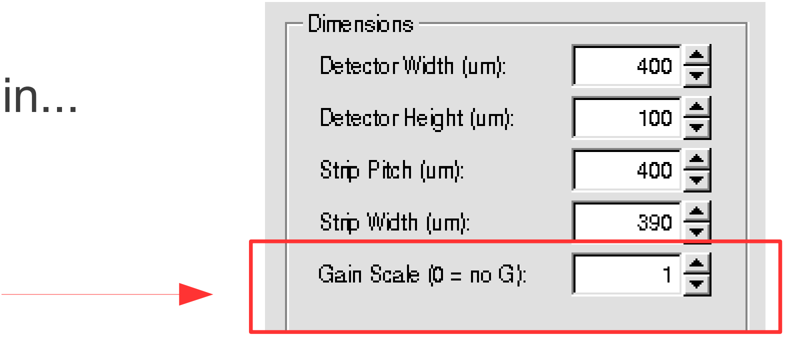
Currents with Gain

...and with oscilloscope on



Potentials and Currents with Gain

Now we set the gain...



Dimensions

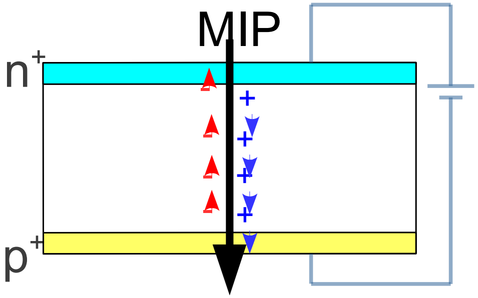
Detector Width (um): 400

Detector Height (um): 100

Strip Pitch (um): 400

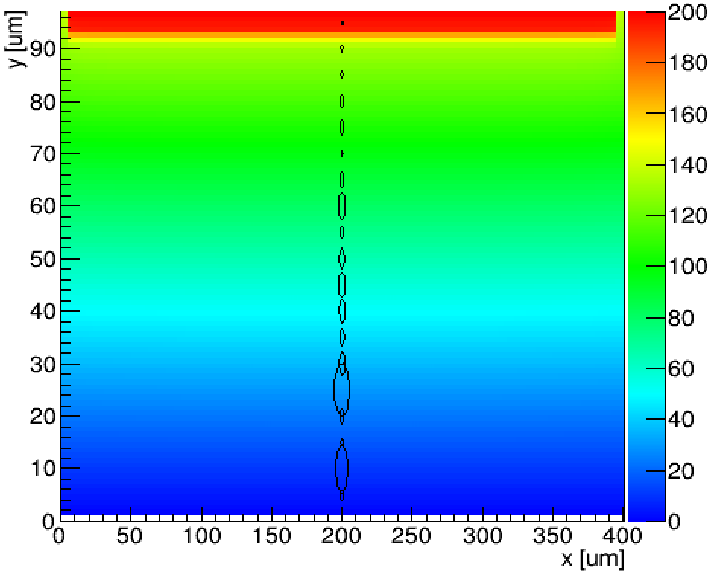
Strip Width (um): 390

Gain Scale (0 = no G): 1



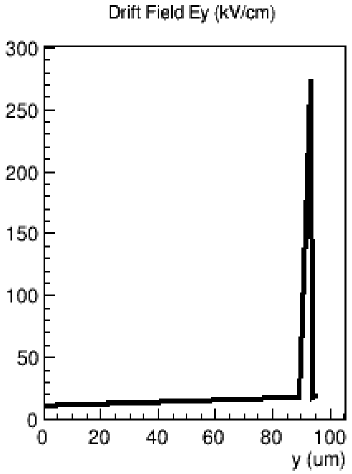
Case: MIP with Landau distributed Q

Drift potential with Gain



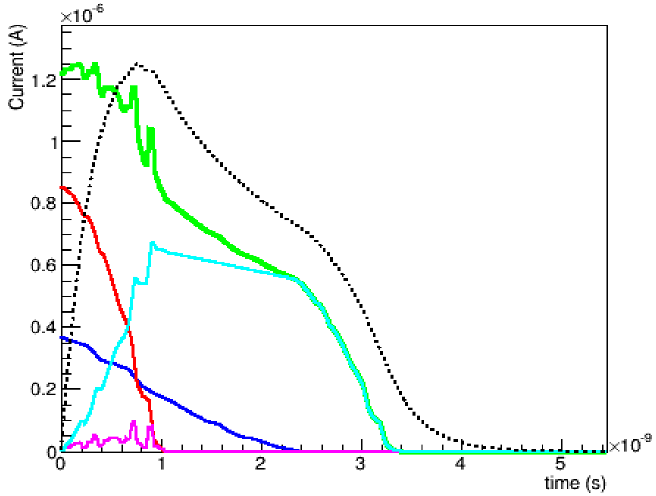
$V_{bias} = 200$ V

$V_{dep} = 50$ V



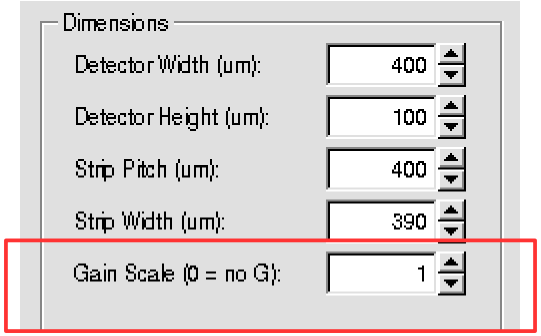
Currents with Gain

...and with oscilloscope on



Potentials and Currents with Gain

Now we set the gain...



Dimensions

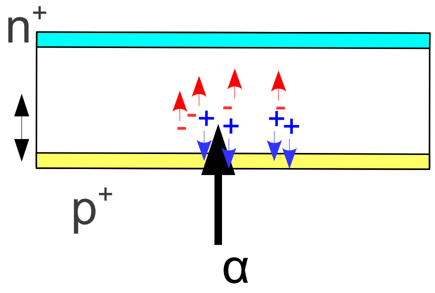
Detector Width (um): 400

Detector Height (um): 100

Strip Pitch (um): 400

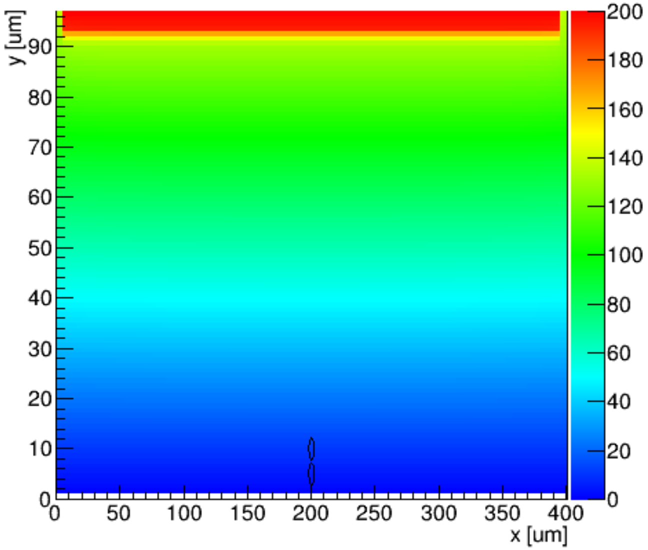
Strip Width (um): 390

Gain Scale (0 = no G): 1

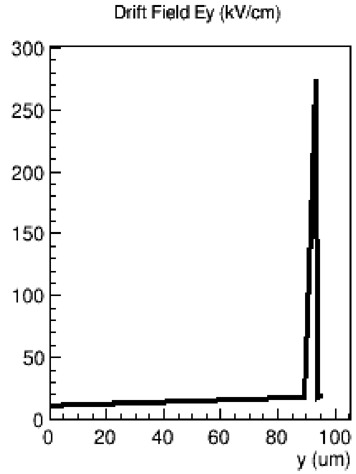


Case: Alpha particle from bottom

Drift potential with Gain

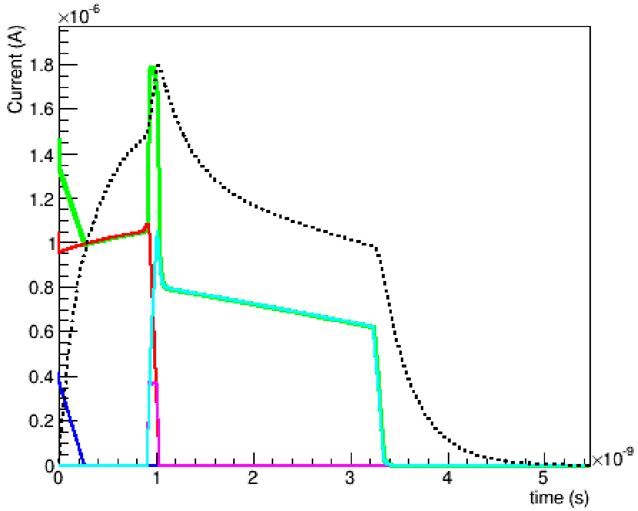


V_{bias} = 200 V
V_{dep} = 50 V

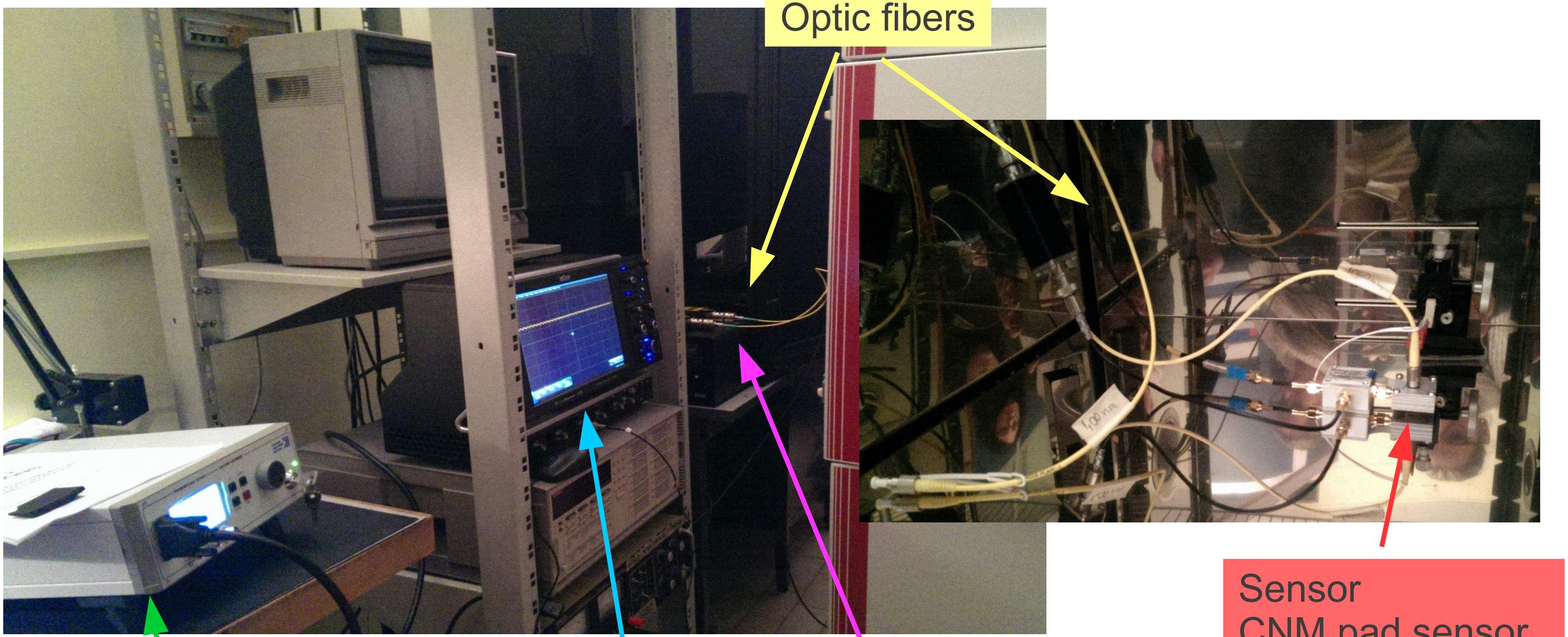


Currents with Gain

...and with oscilloscope on



Laboratory Setup



Optic fibers

Sensor
CNM pad sensor
300 um thick

Oscilloscope
2.5 GHz LeCroy

Laser heads
1060 nm (MIP-like signal)
400 nm (alpha-like signal)

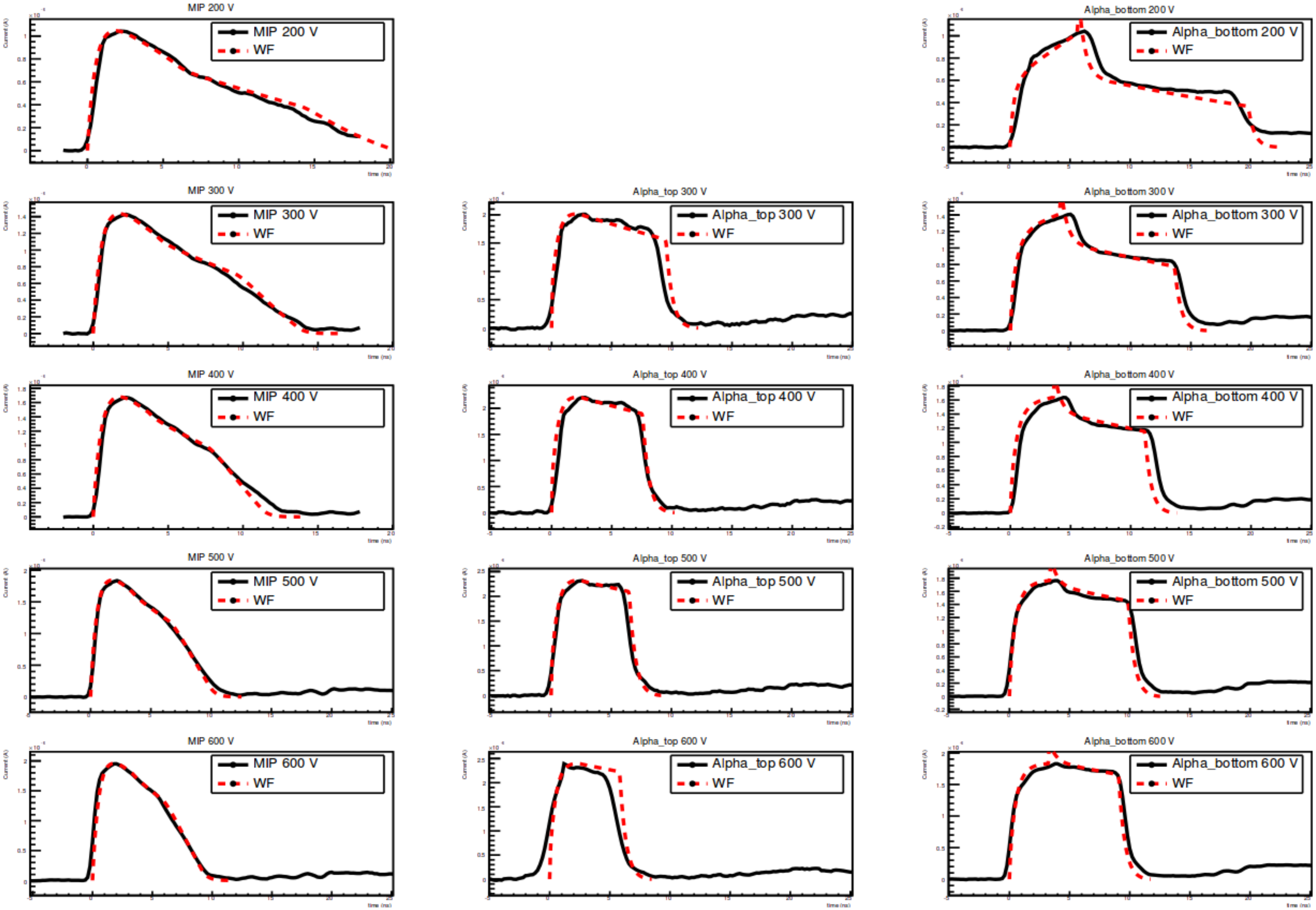
Laser controller

Laboratory Measurements

MIP

Alpha top

Alpha bottom



Voltage

200 V

300 V

400 V

500 V

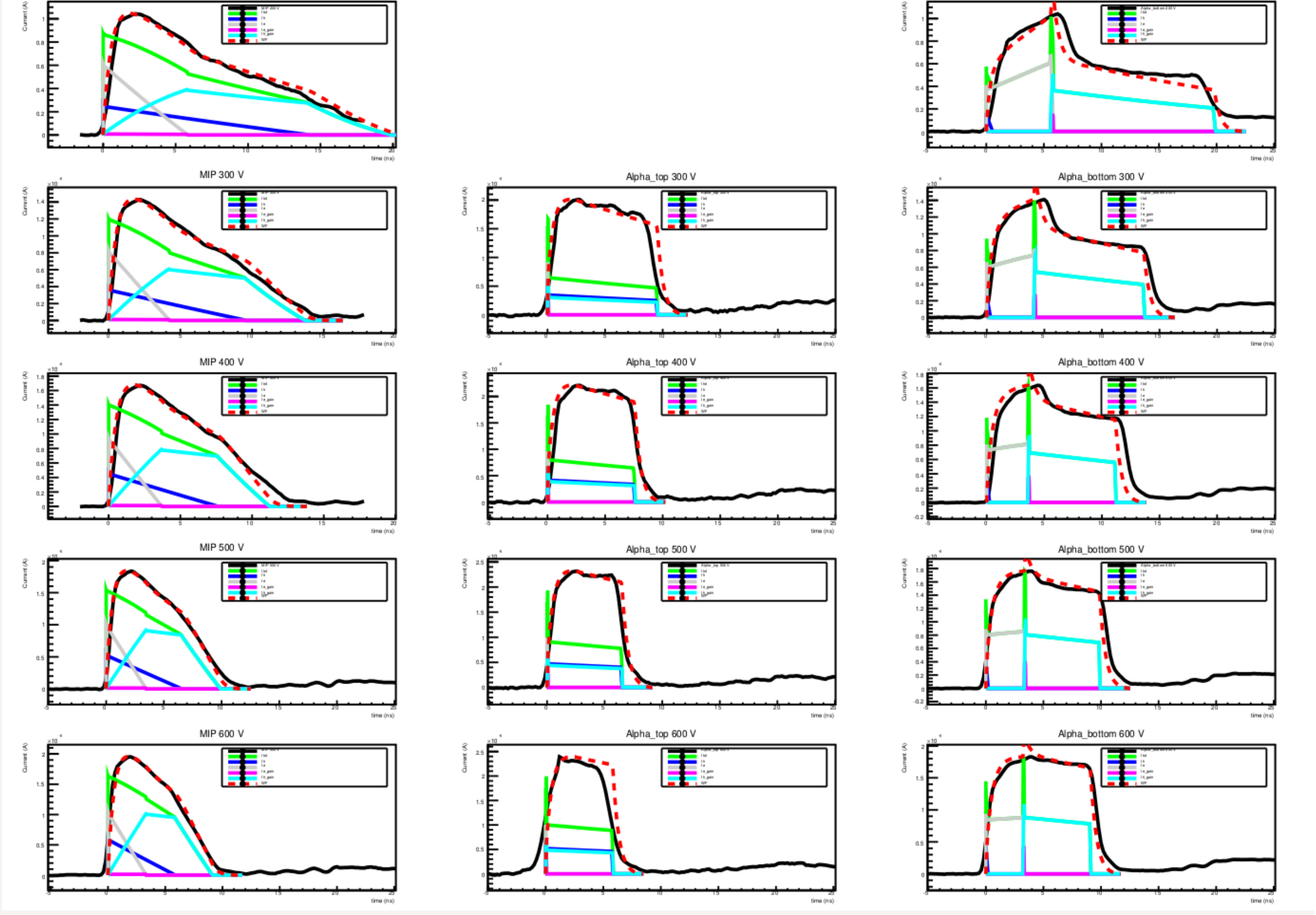
600 V

Laboratory Measurements

MIP

Alpha top

Alpha bottom



Voltage

200 V

300 V

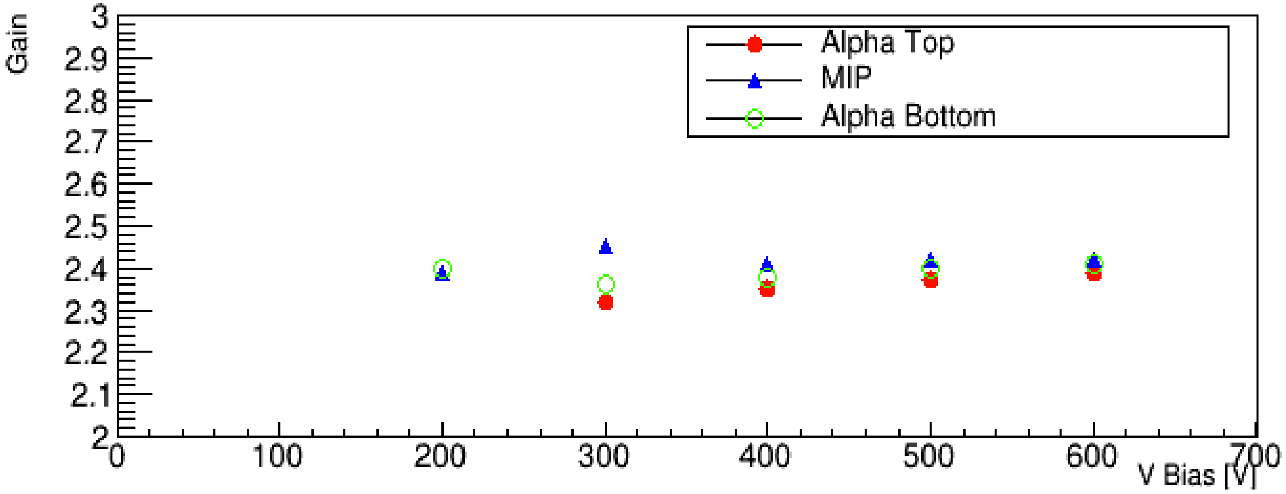
400 V

500 V

600 V

Gain Measurements

Gain estimate using our measurements and fits



Conclusions and Outlook

- We developed a tool to simulate Ultra-Fast Silicon Detectors
- We obtained good agreement between the simulated pulses and the measured signals for MIP, alpha top, alpha bottom
- The program is available at http://personalpages.to.infn.it/~cartigli/weightfield2