

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

Francesca Cenna

with

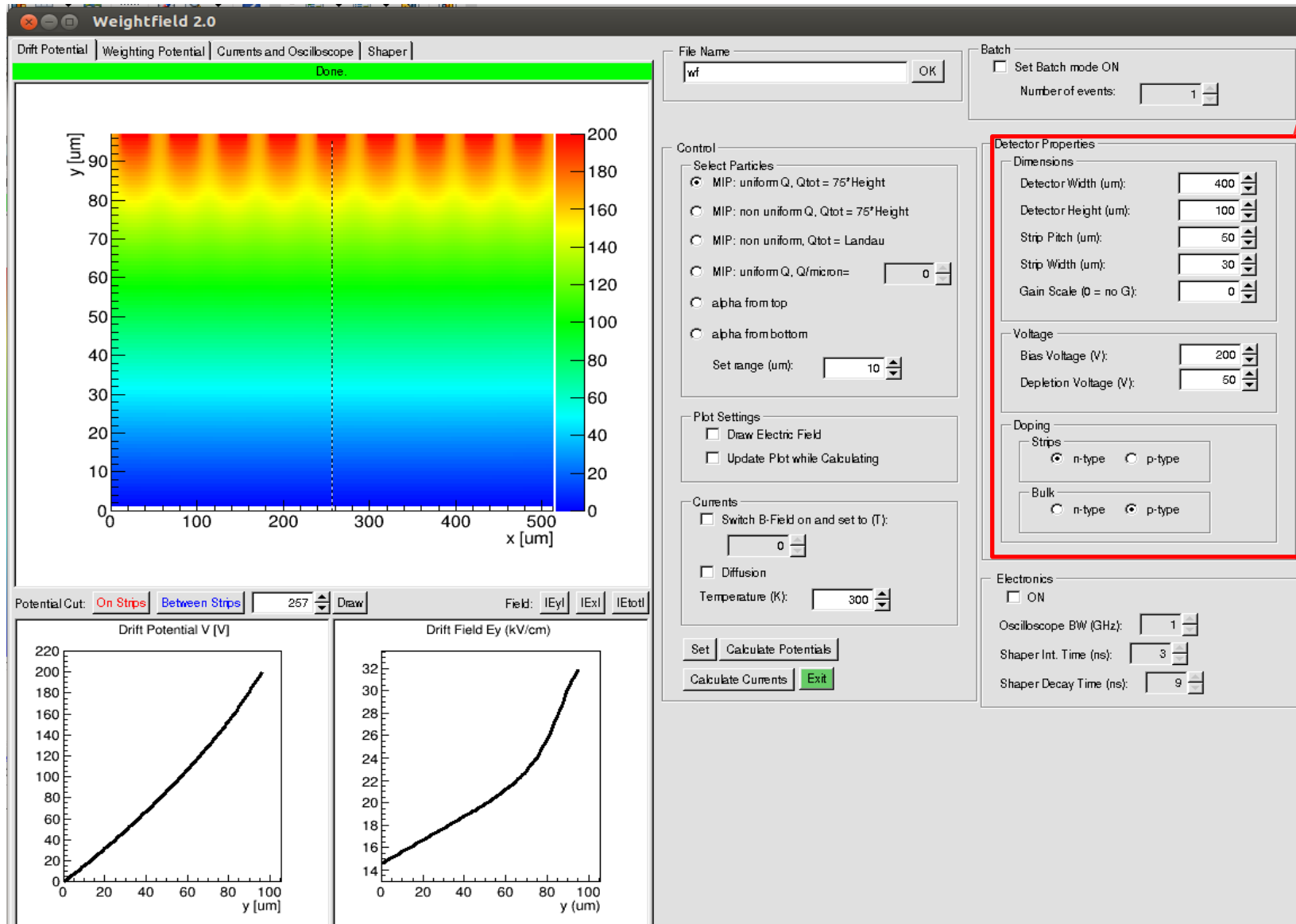
**N. Cartiglia, V. Fadeyev, M. Friedl, B. Kolbinger, F. Marchetto,
A. Picerno, F. Ravera, H. Sadrozinski, A. Seiden, A. Solano**

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”

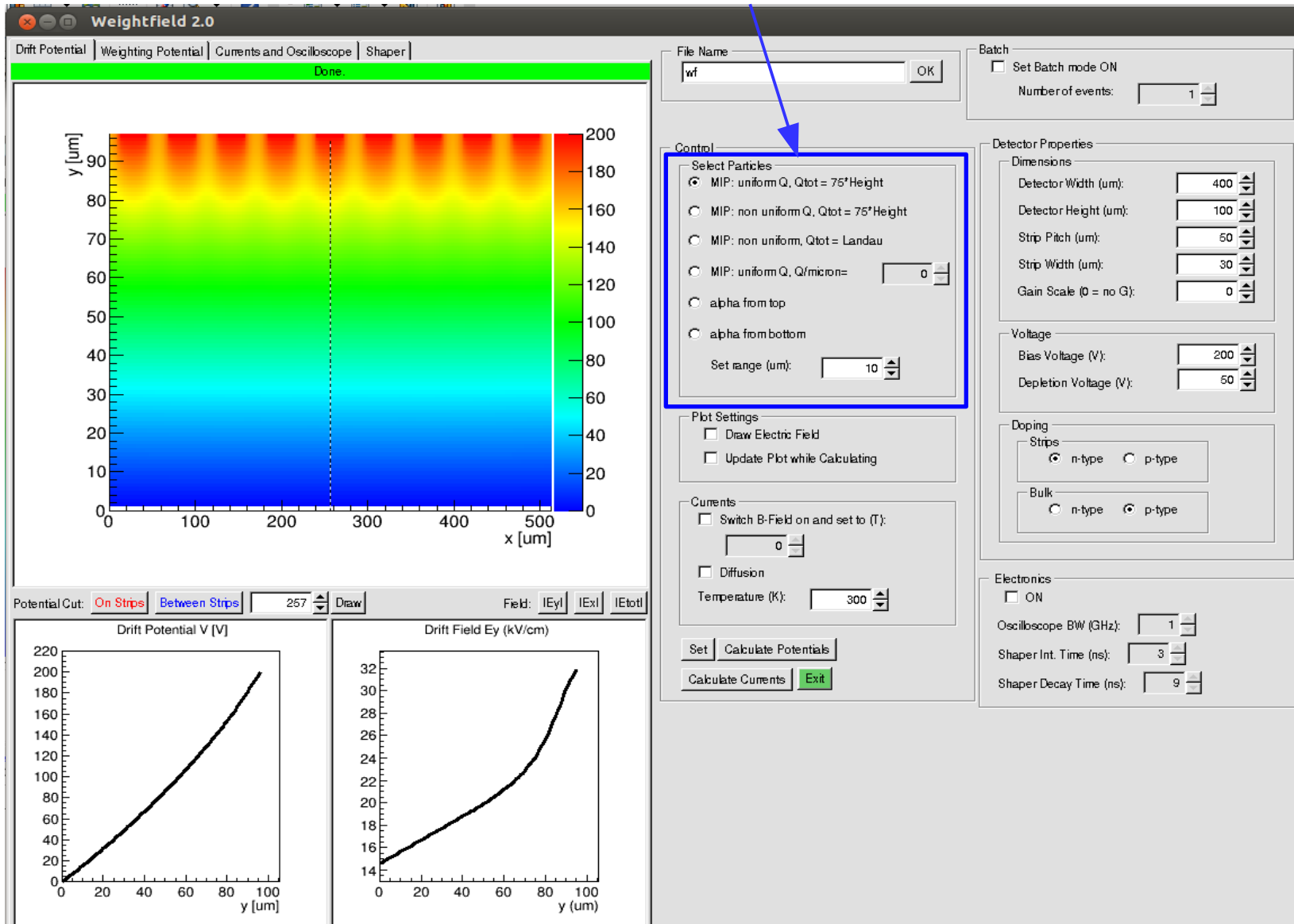
Graphical Interface

Detector Geometry

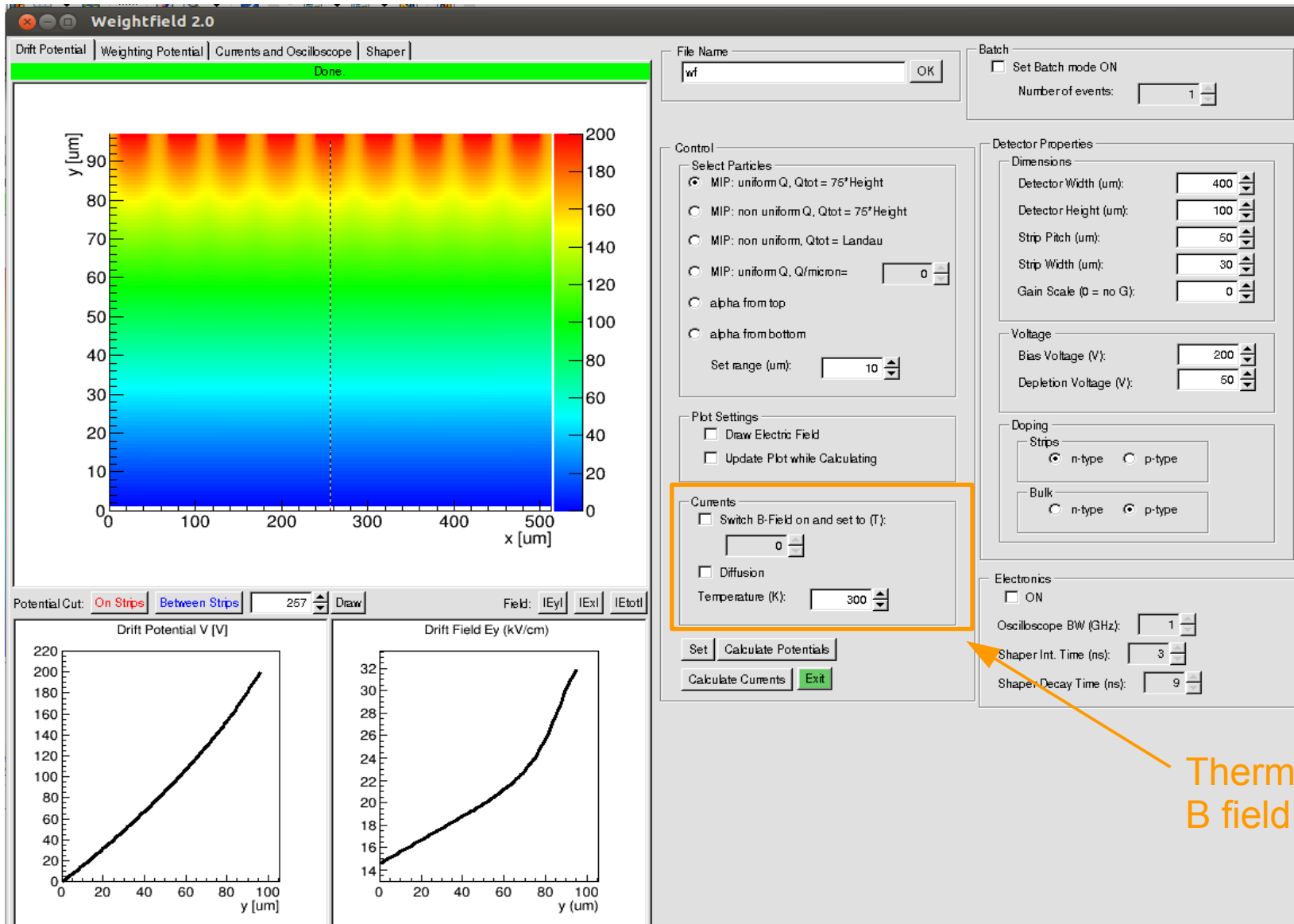


Graphical Interface

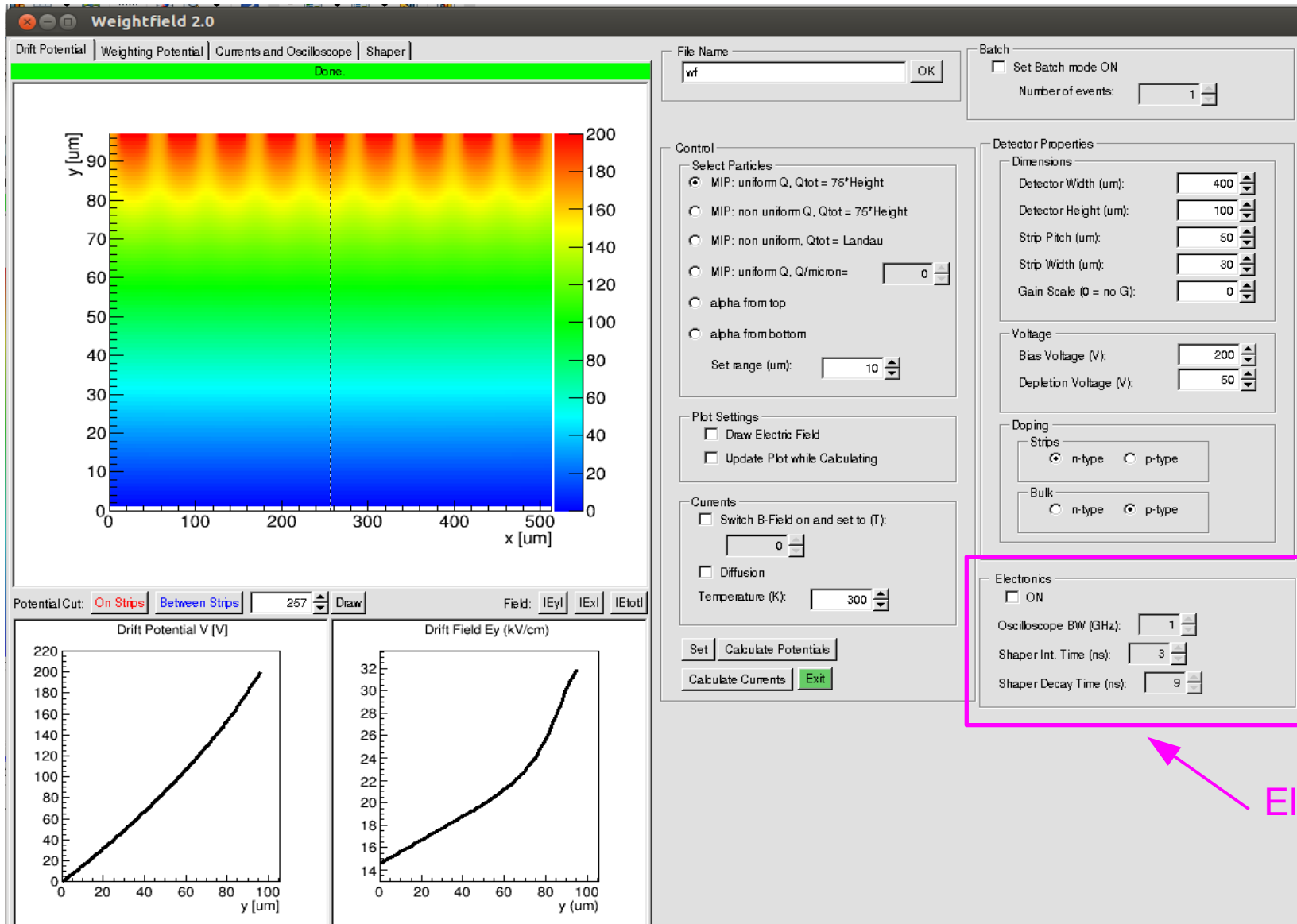
Select Particles



Graphical Interface

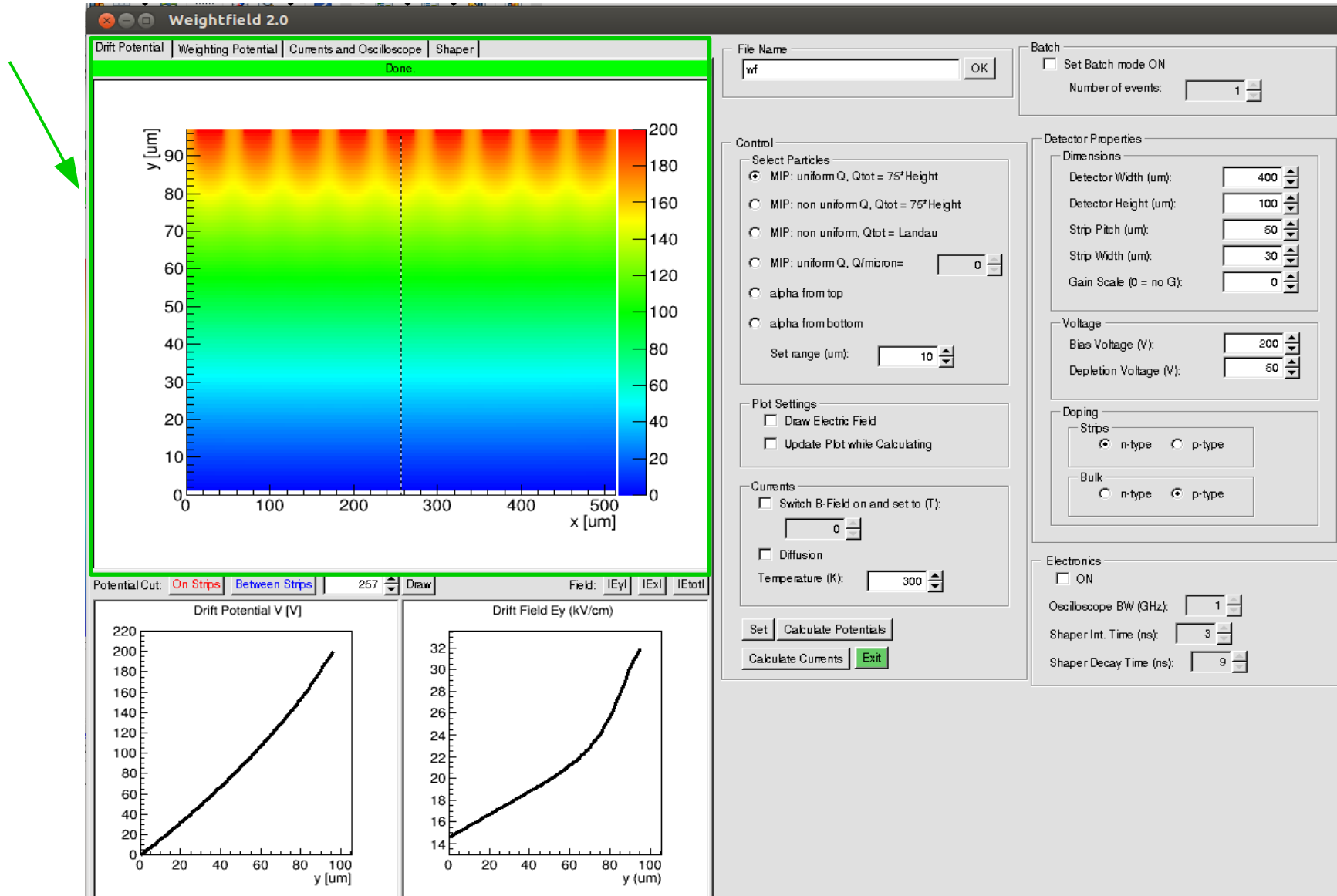


Graphical Interface



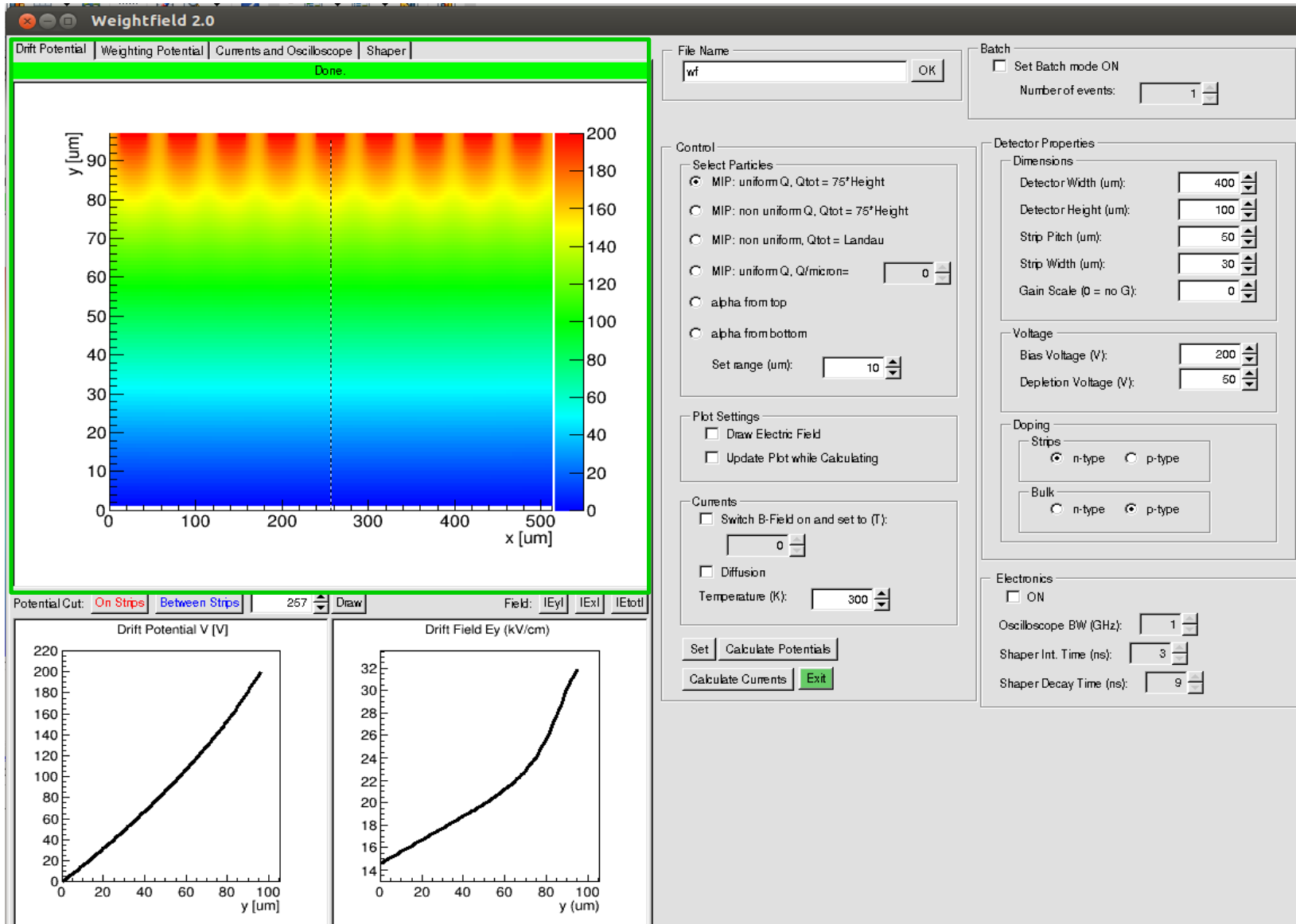
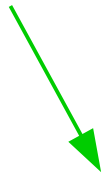
Graphical Interface

4 Tabs:



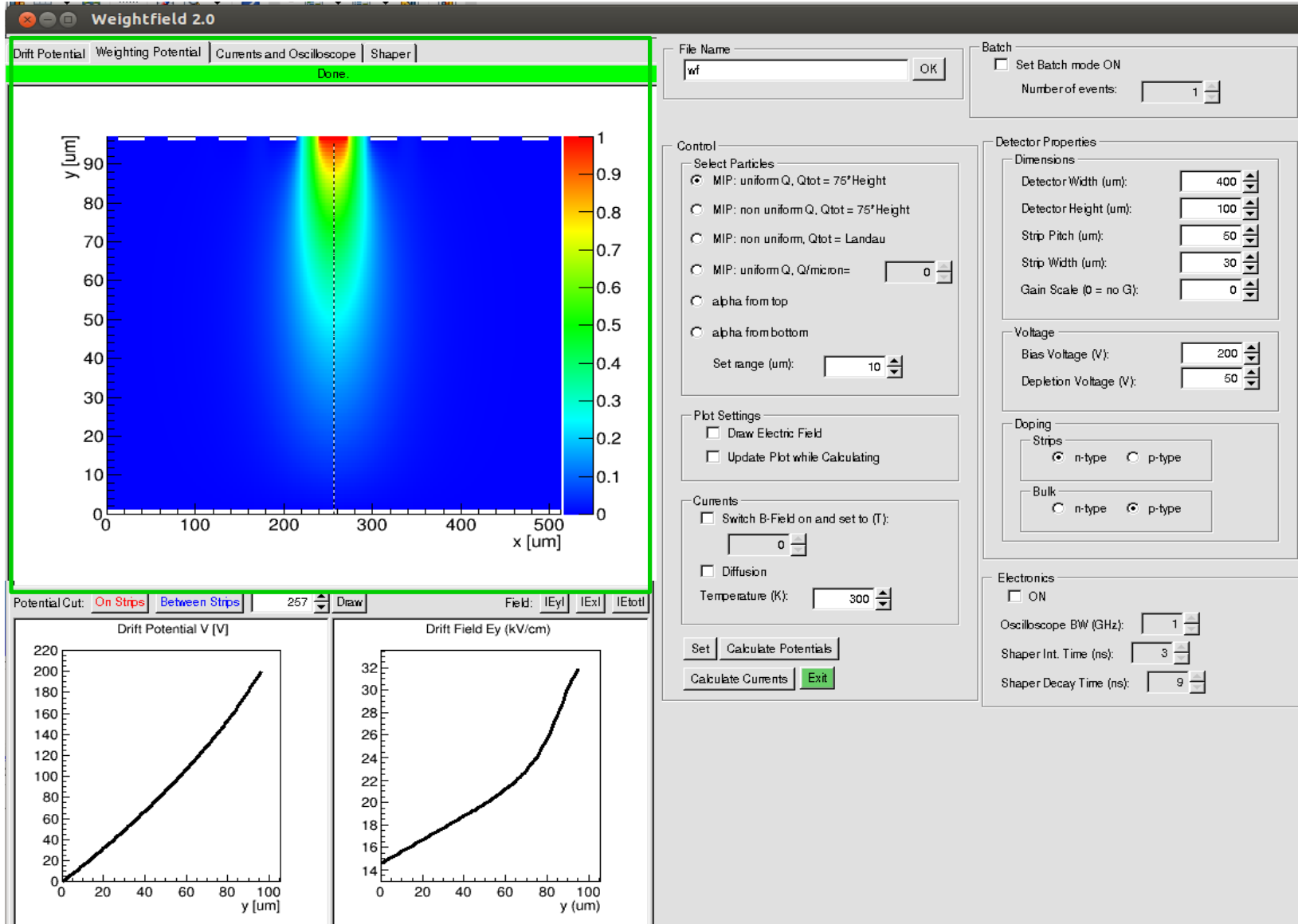
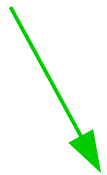
Graphical Interface

4 Tabs:
Drift Potential



Graphical Interface

4 Tabs:
Drift Potential, Weighting Potential



Graphical Interface

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

The screenshot shows the 'Currents' tab of the Weightfield 2.0 software. A green arrow points to the 'Currents' tab label. The main window contains a graph of Current (A) versus time (s). The y-axis is labeled 'Current (A)' and has a multiplier of $\times 10^{-6}$, ranging from 0 to 1.8. The x-axis is labeled 'time (s)' and has a multiplier of $\times 10^{-9}$, ranging from 0 to 2. Three curves are shown: a green curve starting at ~1.7 and decaying to 0; a red curve starting at ~1.0 and decaying to 0; and a blue curve starting at ~0.6 and decaying to 0. Below the graph is a legend with colored bars: Electrons (red), Gain EL (magenta), Holes (blue), Gain Holes (cyan), and Total (green). The 'Total' bar is highlighted with a value of 1.88. Below the legend is a table of charge collection statistics.

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		

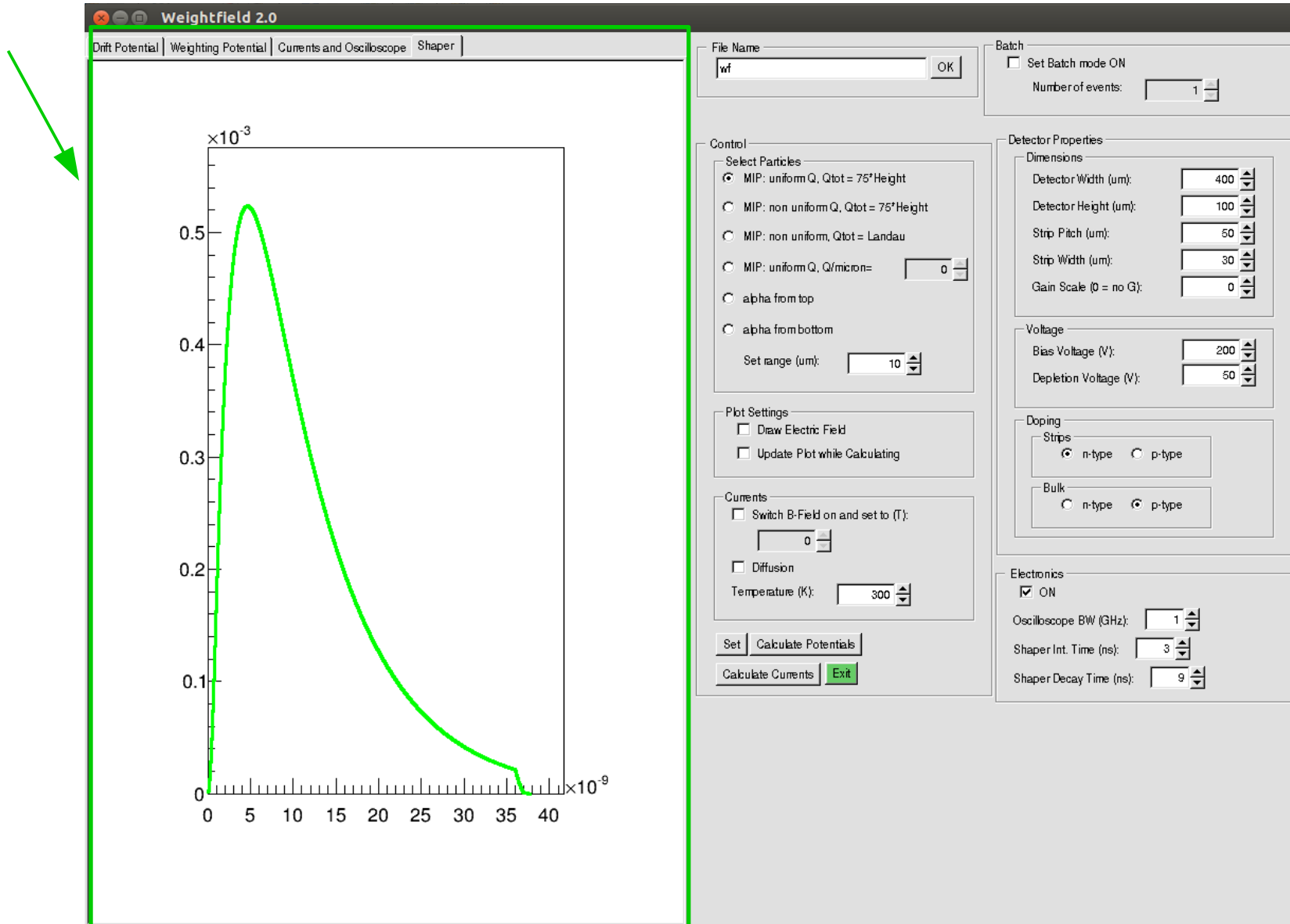
The right side of the interface contains several control panels:

- 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 Q, 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

Buttons at the bottom right include 'Set', 'Calculate Potentials', 'Calculate Currents', and 'Exit'.

Graphical Interface

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



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 dependence with E
 - small gain (~ 2)

$$G \propto C_0 \cdot E$$

C_0 = gain scale factor → selectable by user

The image shows a software interface titled "Detector Properties" with several sections for configuration:

- Dimensions:** Includes five input fields with spinners: "Detector Width (um)" set to 400, "Detector Height (um)" set to 100, "Strip Pitch (um)" set to 400, "Strip Width (um)" set to 390, and "Gain Scale (0 = no G)" set to 0.
- Voltage:** Includes two input fields with spinners: "Bias Voltage (V)" set to 200 and "Depletion Voltage (V)" set to 50.
- Doping:** Contains two sub-sections: "Strips" with radio buttons for "n-type" (selected) and "p-type", and "Bulk" with radio buttons for "n-type" and "p-type" (selected).

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 dependence 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

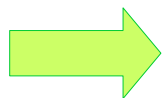
Doping

Strips

n-type p-type

Bulk

n-type p-type



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, $Q_{tot} = 75 \cdot \text{Height}$

MIP: non uniform Q, $Q_{tot} = 75 \cdot \text{Height}$

MIP: non uniform, $Q_{tot} = \text{Landau}$

MIP: uniform Q, $Q/\text{micron} =$

alpha from top

alpha from bottom

Set range (um):

Choosing Particles

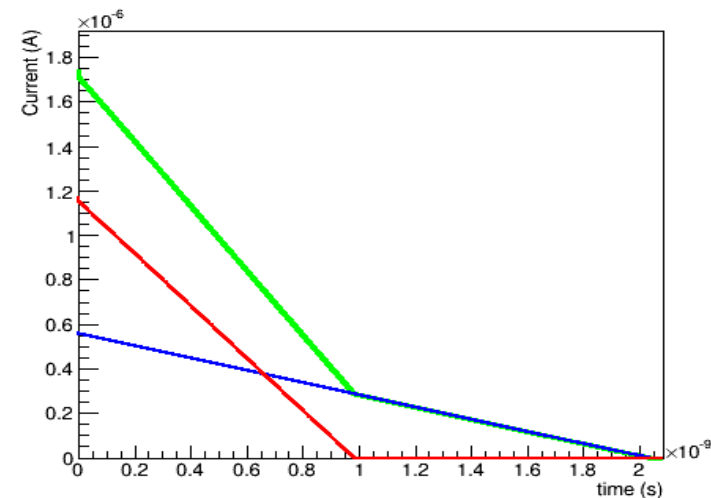
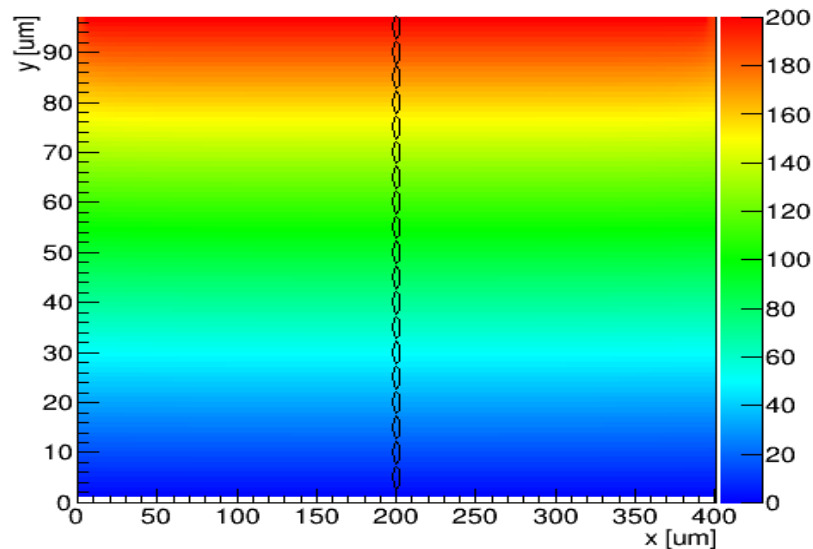
- MIP with uniform charge deposition (75 pairs/ μm)
- MIP with non uniform charge deposition
- MIP with Landau-distributed charge deposition
- α particle from top/bottom

Select Particles

- MIP: uniform Q, $Q_{\text{tot}} = 75 \cdot \text{Height}$
- MIP: non uniform Q, $Q_{\text{tot}} = 75 \cdot \text{Height}$
- MIP: non uniform, $Q_{\text{tot}} = \text{Landau}$
- MIP: uniform Q, $Q/\mu\text{m} =$
- alpha from top
- alpha from bottom

Set range (μm):

Pad, Gain Scale=0



Choosing Particles

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

Select Particles

MIP: uniform Q, $Q_{\text{tot}} = 75 \times \text{Height}$

MIP: non uniform Q, $Q_{\text{tot}} = 75 \times \text{Height}$

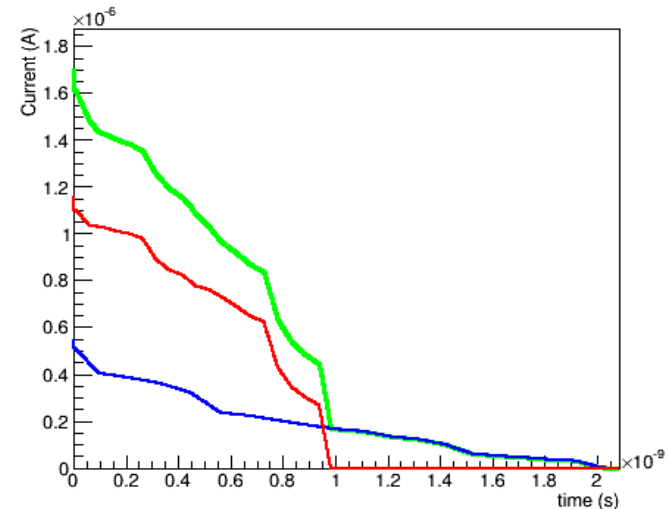
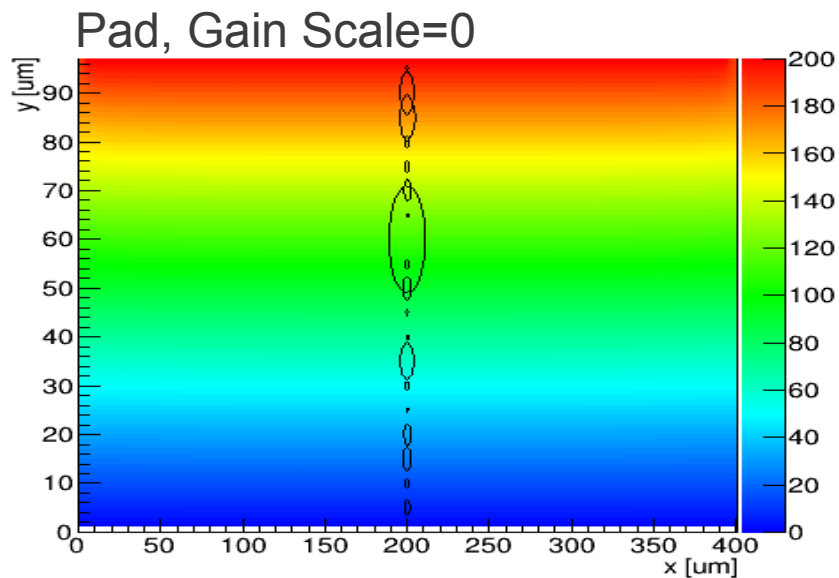
MIP: non uniform, $Q_{\text{tot}} = \text{Landau}$

MIP: uniform Q, Q/micron=

alpha from top

alpha from bottom

Set range (μm):



Choosing Particles

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

Select Particles

MIP: uniform Q, $Q_{\text{tot}} = 75 \cdot \text{Height}$

MIP: non uniform Q, $Q_{\text{tot}} = 75 \cdot \text{Height}$

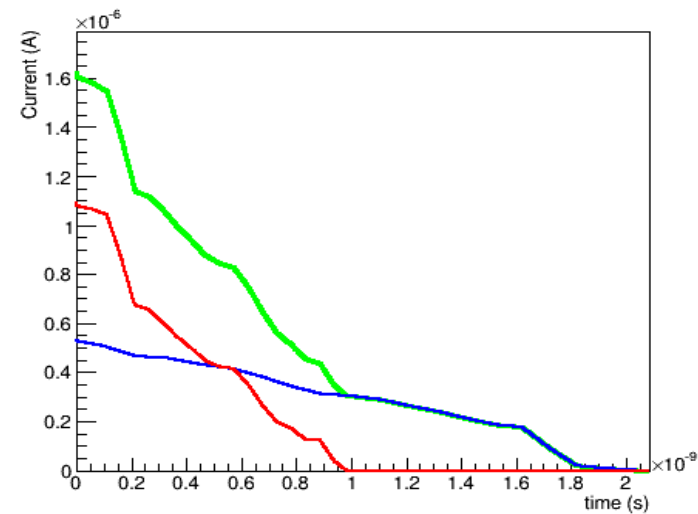
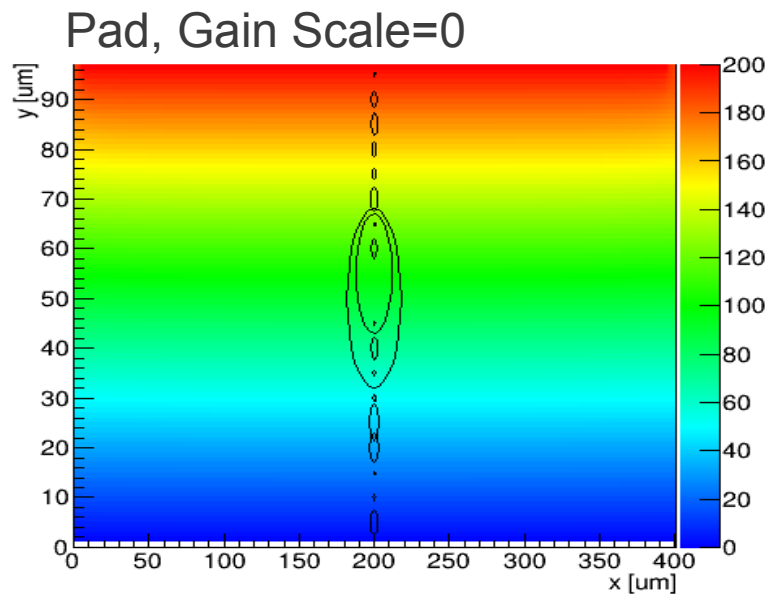
MIP: non uniform, $Q_{\text{tot}} = \text{Landau}$

MIP: uniform Q, $Q/\text{micron} =$

alpha from top

alpha from bottom

Set range (μm):



Choosing Particles

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

Select Particles

MIP: uniform Q, $Q_{\text{tot}} = 75 \cdot \text{Height}$

MIP: non uniform Q, $Q_{\text{tot}} = 75 \cdot \text{Height}$

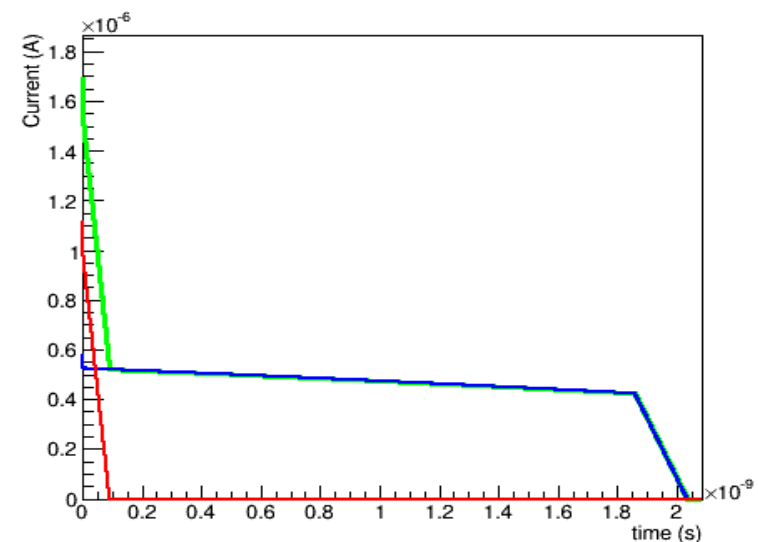
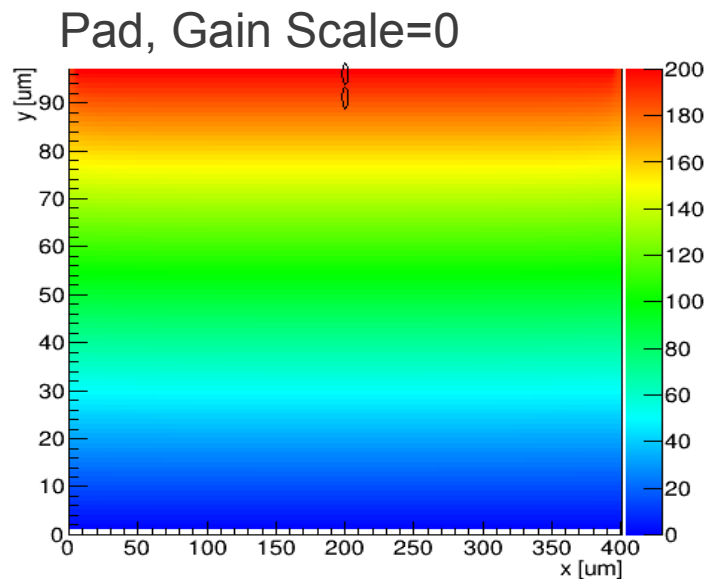
MIP: non uniform, $Q_{\text{tot}} = \text{Landau}$

MIP: uniform Q, Q/micron=

α from top

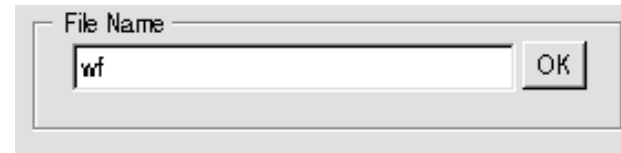
α from bottom

Set range (μm):



Additional Features

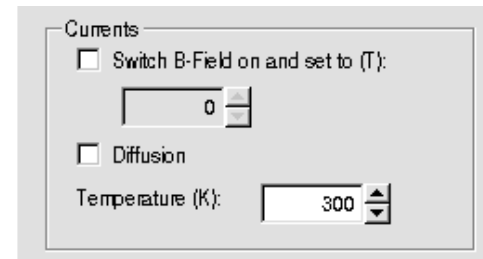
- **Output file** →
- **B field:** drift in magnetic field
- **Thermal diffusion** given a T value
- **Electronics:** simulates an oscilloscope and a shaper
- **Batch mode:** loop of selectable n events



File Name

wf

OK



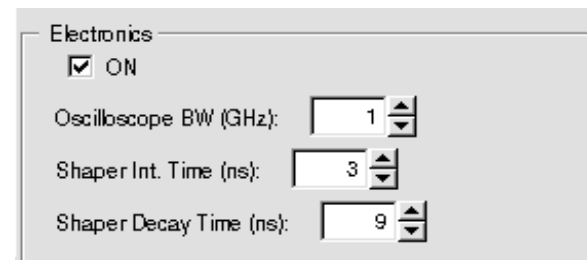
Currents

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

0

Diffusion

Temperature (K): 300



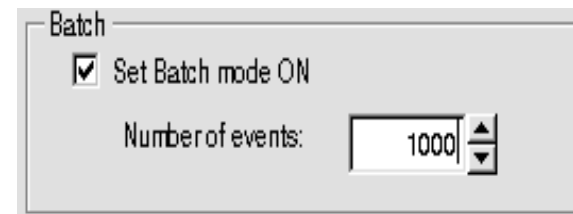
Electronics

ON

Oscilloscope BW (GHz): 1

Shaper Int. Time (ns): 3

Shaper Decay Time (ns): 9



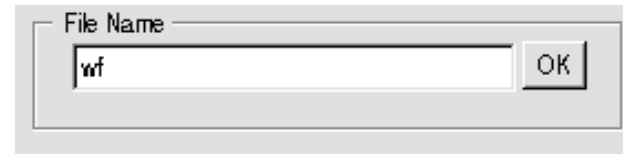
Batch

Set Batch mode ON

Number of events: 1000

Additional Features

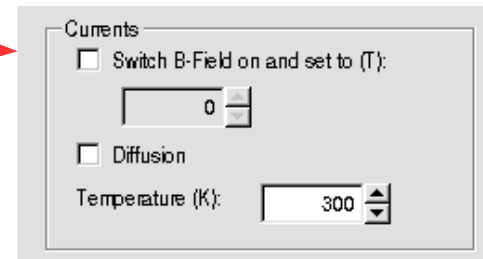
- **Output file**
- **B field:** drift in magnetic field
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File Name

wf

OK



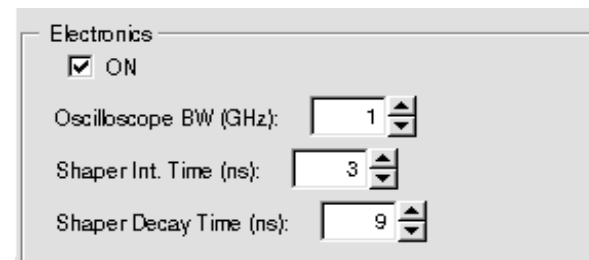
Currents

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

0

Diffusion

Temperature (K): 300




Electronics

ON

Oscilloscope BW (GHz): 1

Shaper Int. Time (ns): 3

Shaper Decay Time (ns): 9



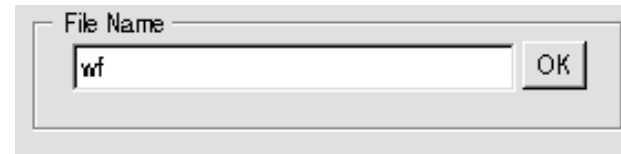
Batch

Set Batch mode ON

Number of events: 1000

Additional Features

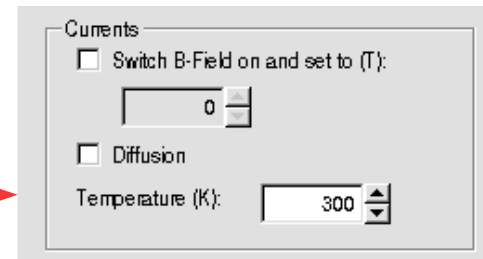
- **Output file**
- **B field:** drift in magnetic field
- **Thermal diffusion given a T value** →
- **Electronics:** simulates an oscilloscope and a shaper
- **Batch mode:** loop of selectable n events



File Name

wf

OK



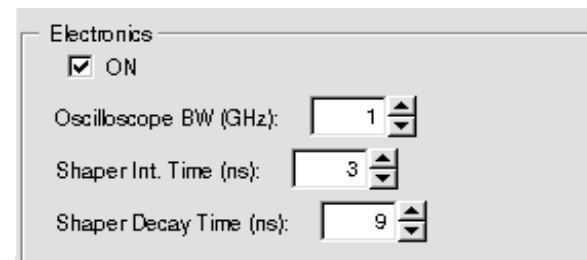
Currents

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

0

Diffusion

Temperature (K): 300



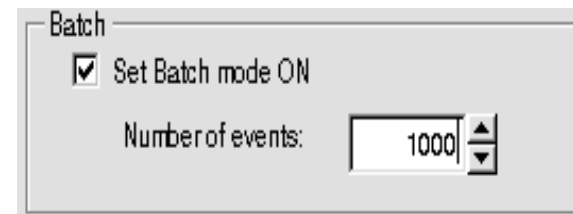
Electronics

ON

Oscilloscope BW (GHz): 1

Shaper Int. Time (ns): 3

Shaper Decay Time (ns): 9



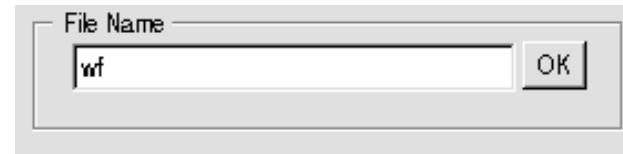
Batch

Set Batch mode ON

Number of events: 1000

Additional Features

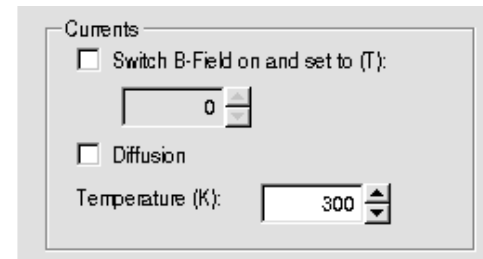
- **Output file**
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File Name

wf

OK



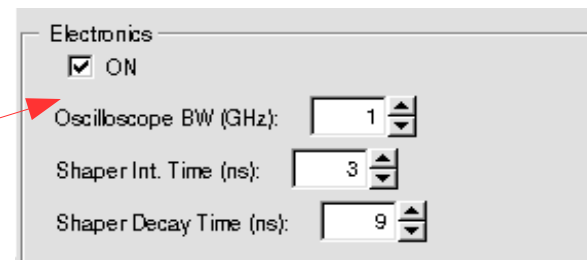
Currents

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

0

Diffusion

Temperature (K): 300




Electronics

ON

Oscilloscope BW (GHz): 1

Shaper Int. Time (ns): 3

Shaper Decay Time (ns): 9



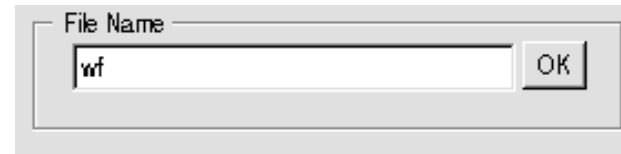
Batch

Set Batch mode ON

Number of events: 1000

Additional Features

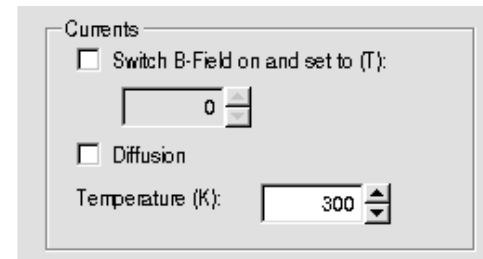
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File Name

wf

OK



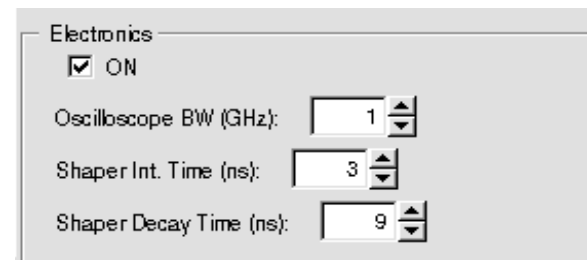
Currents

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

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Diffusion

Temperature (K): 300




Electronics

ON

Oscilloscope BW (GHz): 1

Shaper Int. Time (ns): 3

Shaper Decay Time (ns): 9



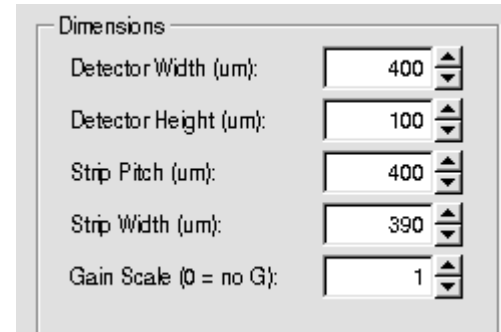
Batch

Set Batch mode ON

Number of events: 1000

Potentials and Currents with Gain

Now we set the gain...

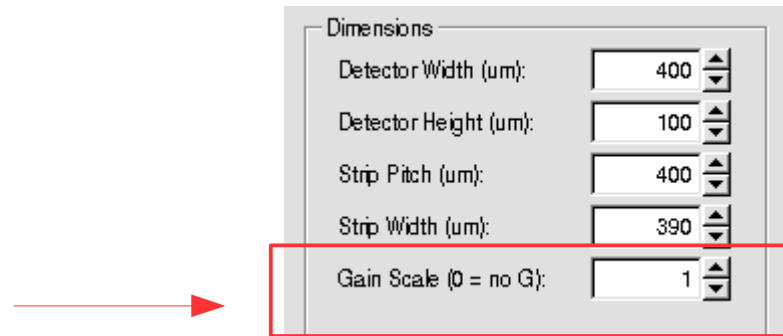


The image shows a software control panel titled "Dimensions" with five adjustable parameters, each with a numerical input field and a vertical slider:

Parameter	Value
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

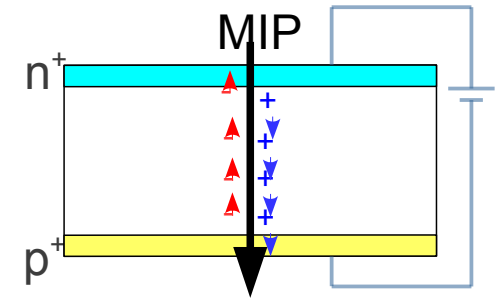
Now we set the gain...



Potentials and Currents with Gain

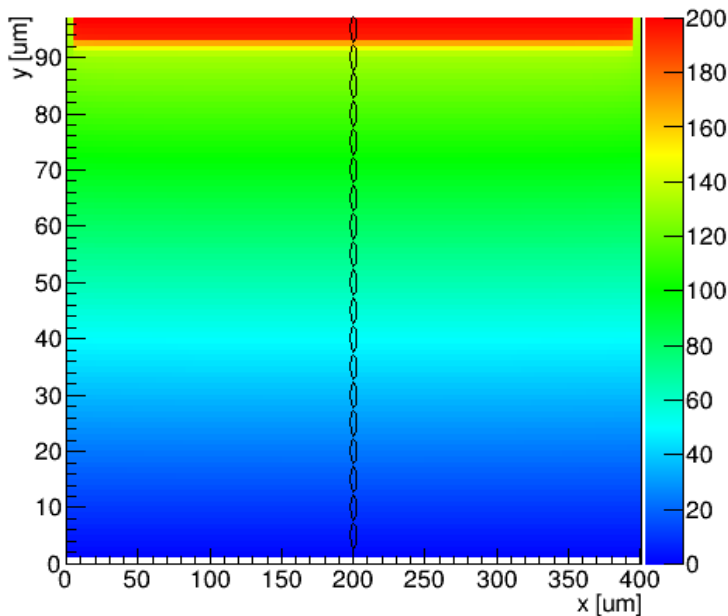
Now we set the gain...

Dimensions	
Detector Width (um):	400
Detector Height (um):	100
Strip Pitch (um):	400
Strip Width (um):	390
Gain Scale (0 = no G):	1

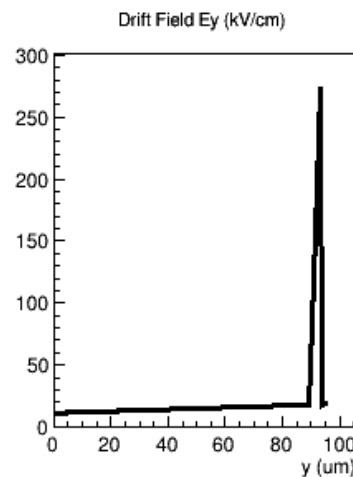


Case: MIP with uniform Q

Drift potential with Gain

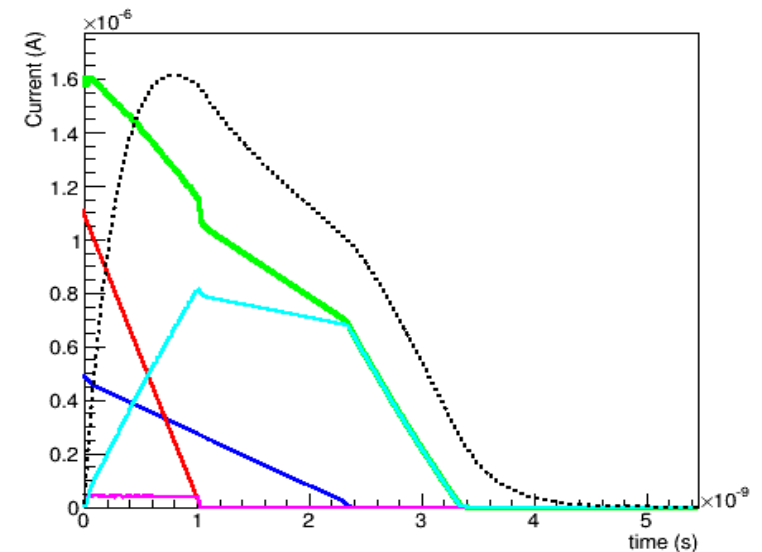


$V_{bias} = 200 \text{ V}$
 $V_{dep} = 50 \text{ V}$



Currents with Gain

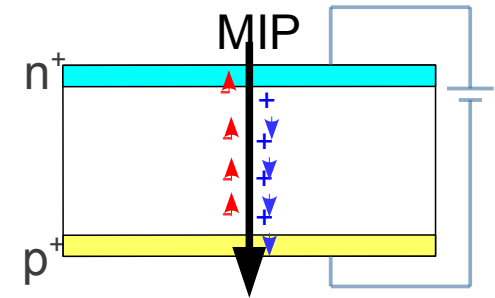
...and with oscilloscope on



Potentials and Currents with Gain

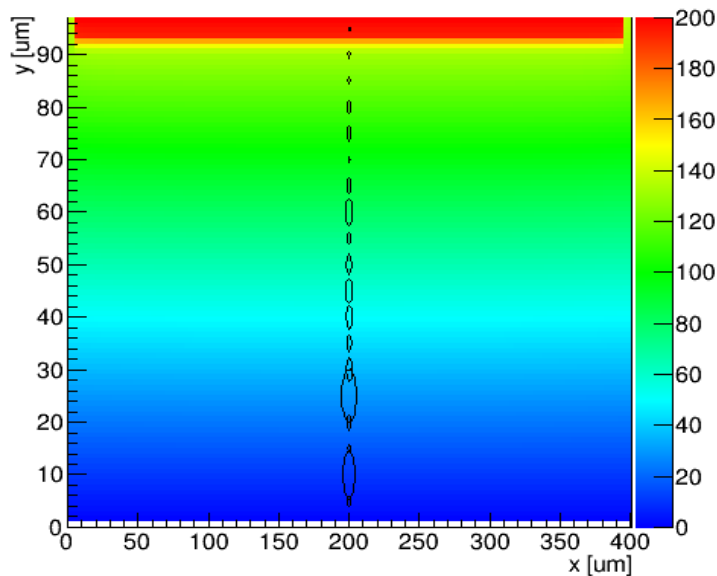
Now we set the gain...

Dimensions	
Detector Width (um):	400
Detector Height (um):	100
Strip Pitch (um):	400
Strip Width (um):	390
Gain Scale (0 = no G):	1



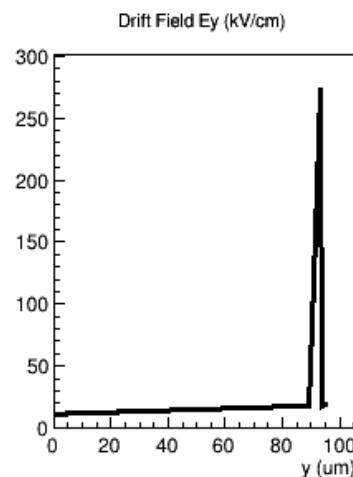
Case: MIP with Landau distributed Q

Drift potential with Gain



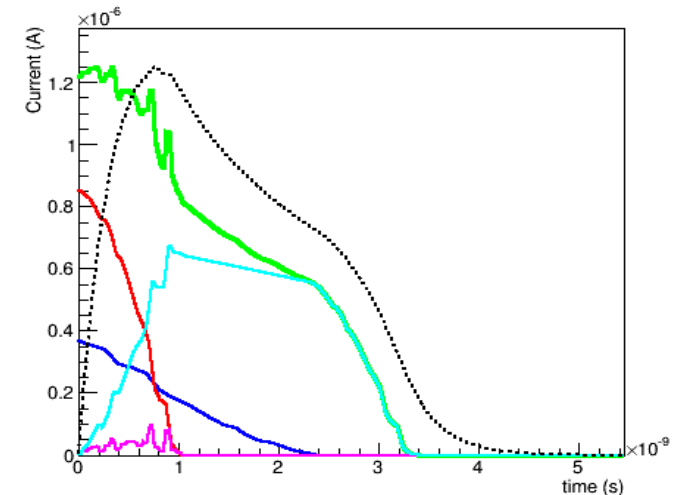
$$V_{\text{bias}} = 200 \text{ V}$$

$$V_{\text{dep}} = 50 \text{ V}$$



Currents with Gain

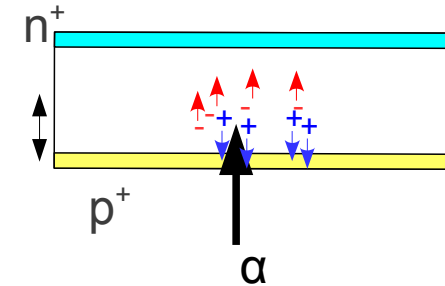
...and with oscilloscope on



Potentials and Currents with Gain

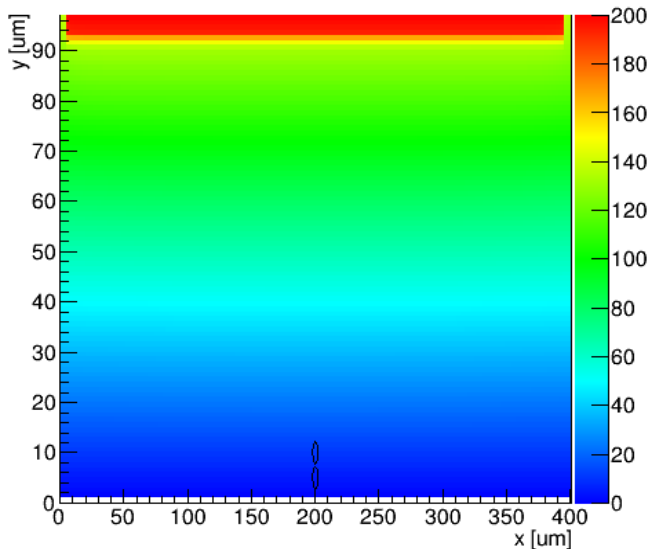
Now we set the gain...

Dimensions	
Detector Width (um):	400
Detector Height (um):	100
Strip Pitch (um):	400
Strip Width (um):	390
Gain Scale (0 = no G):	1



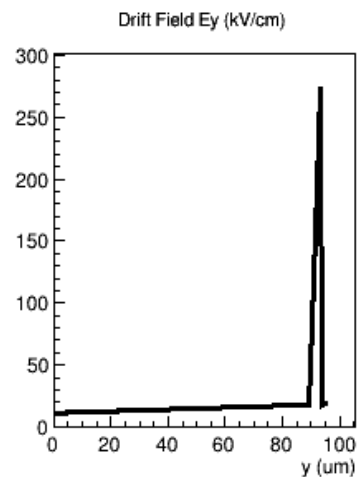
Case: Alpha particle from bottom

Drift potential with Gain



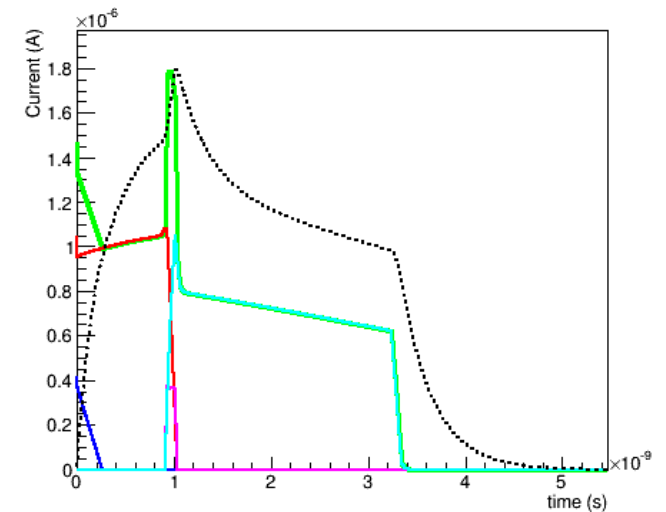
$$V_{\text{bias}} = 200 \text{ V}$$

$$V_{\text{dep}} = 50 \text{ V}$$

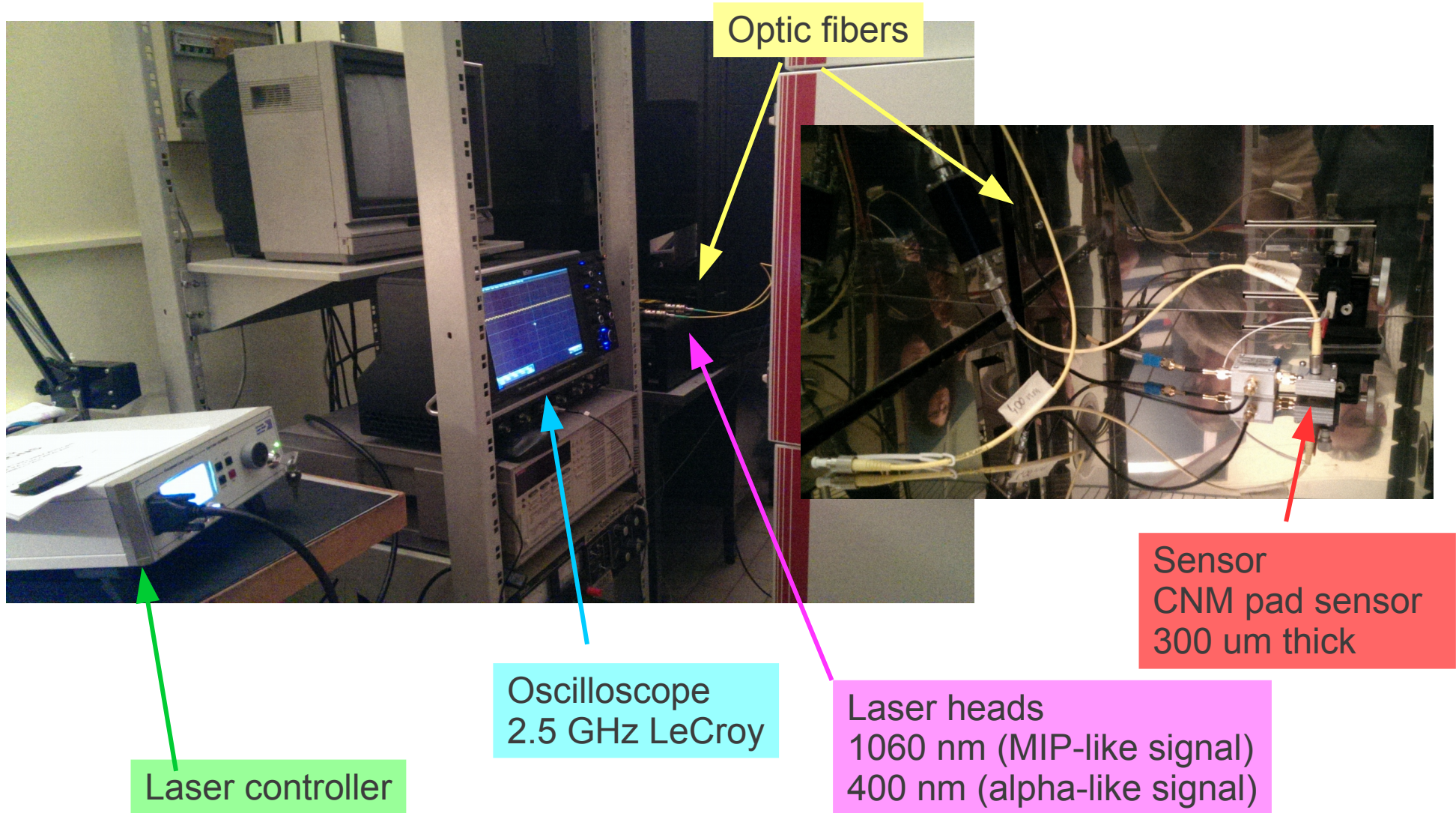


Currents with Gain

...and with oscilloscope on



Laboratory Setup



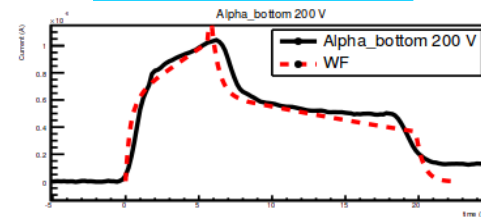
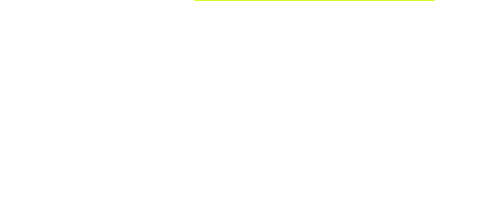
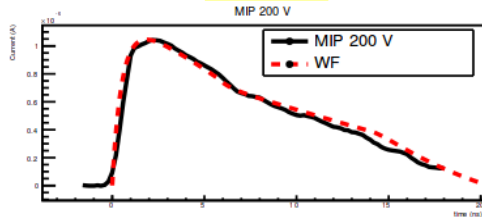
Laboratory Measurements

MIP

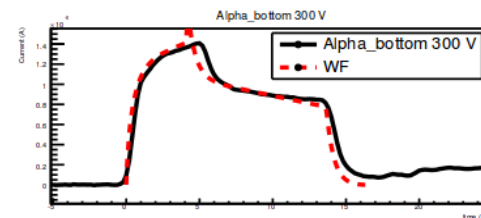
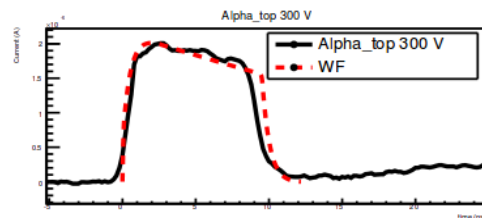
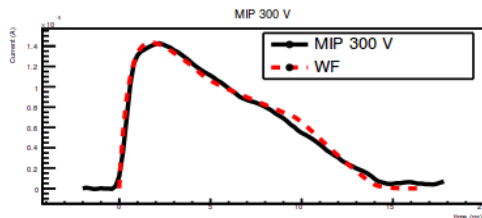
Alpha top

Alpha bottom

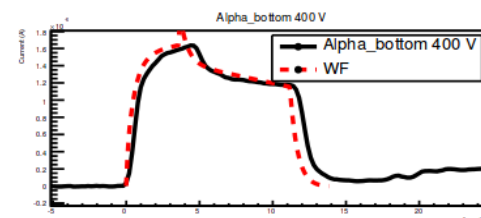
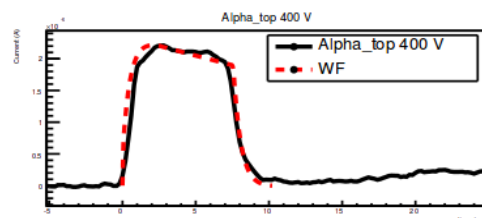
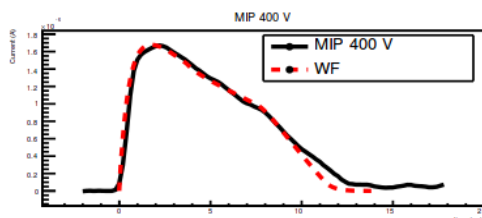
Voltage



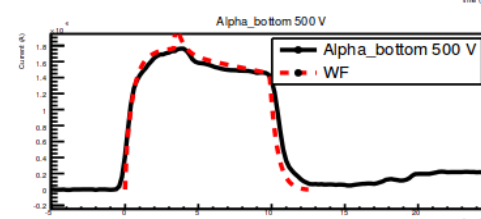
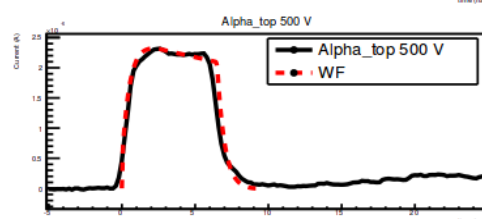
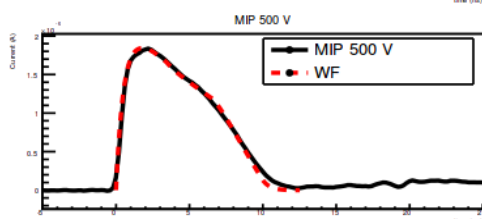
200 V



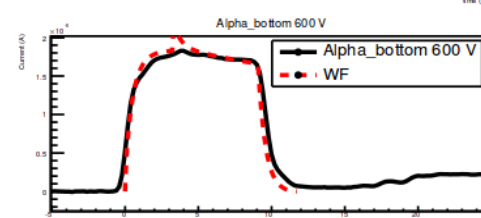
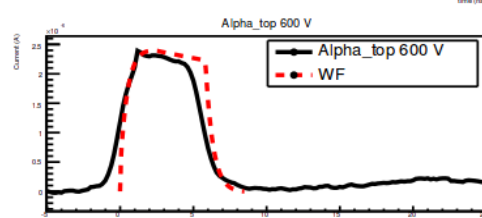
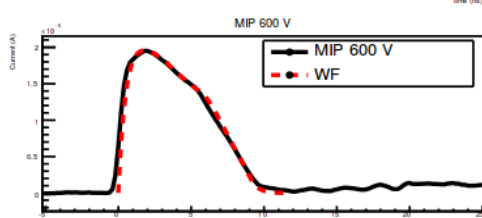
300 V



400 V

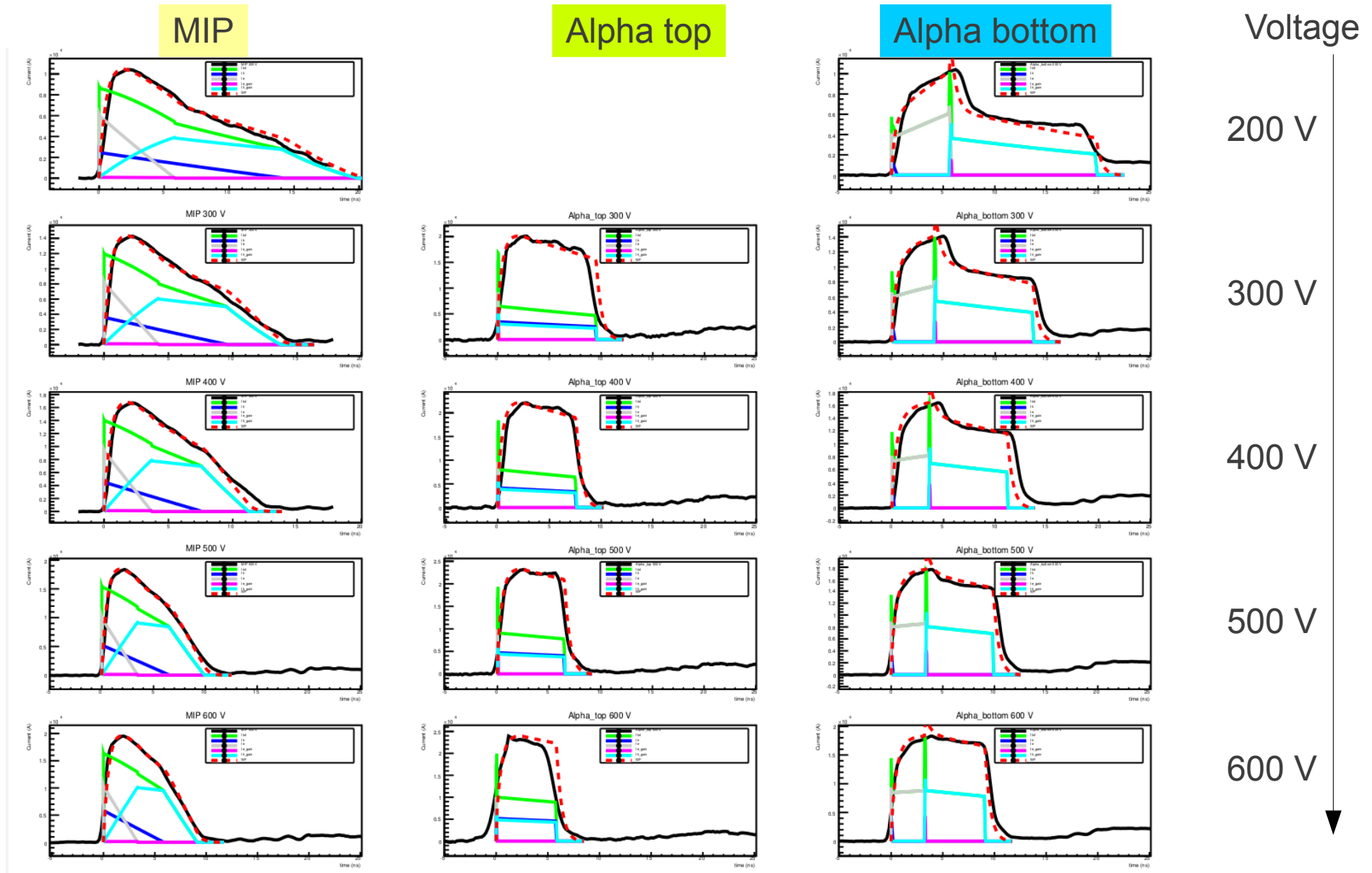


500 V



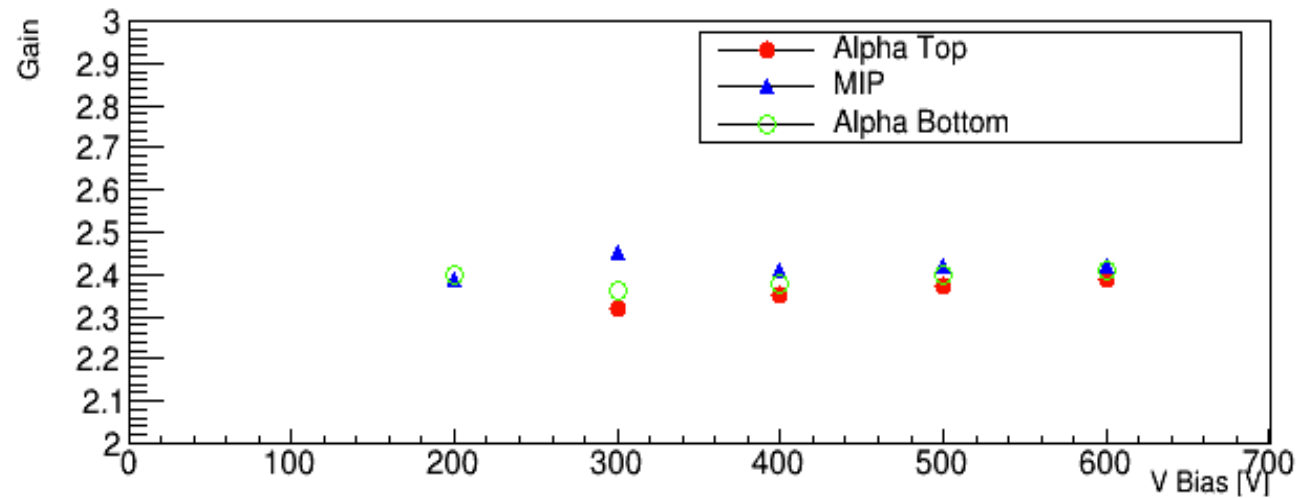
600 V

Laboratory Measurements



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>