Timing capabilities of Ultra-Fast Silicon Detector

- A parameterization of time resolution
- A program to calculate Time resolution
- UFSD Timing capabilities

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With
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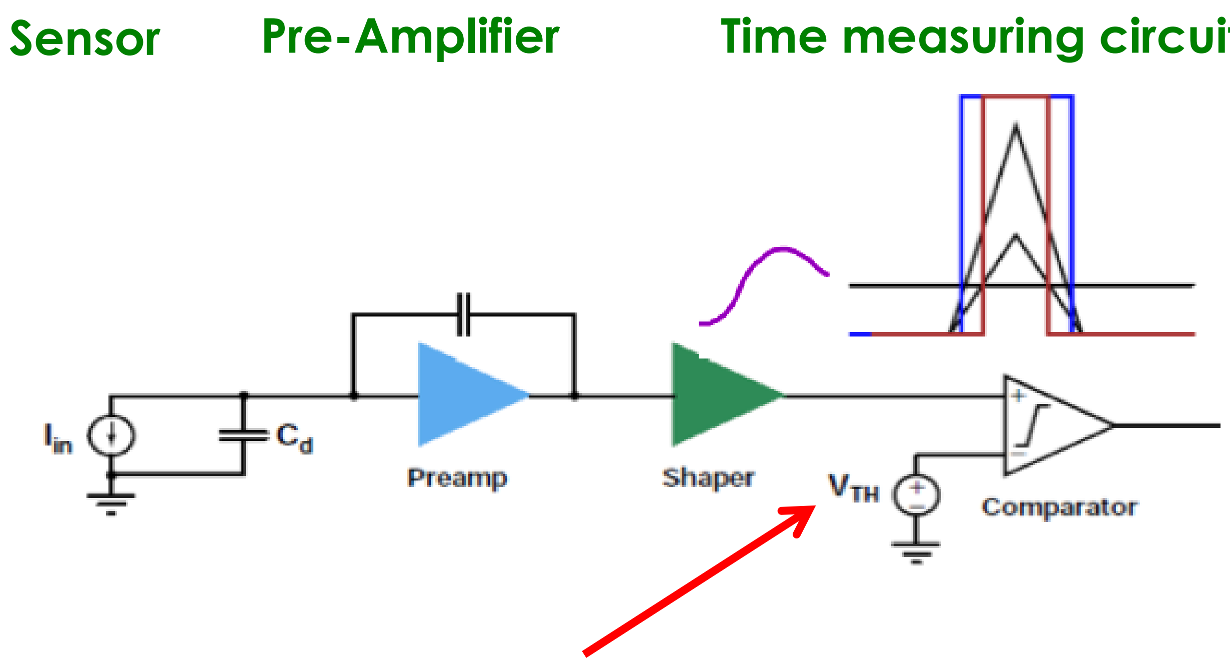
UFSD: a time-tagging detector



Time is set when the signal crosses the comparator threshold

The timing capabilities are determined by the characteristics of the signal at the output of the pre-Amplifier and by the TDC binning:

$$\sigma_{Total}^2 = \sigma_{Jitter}^2 + \sigma_{Time\ Walk}^2 + \sigma_{TDC}^2$$

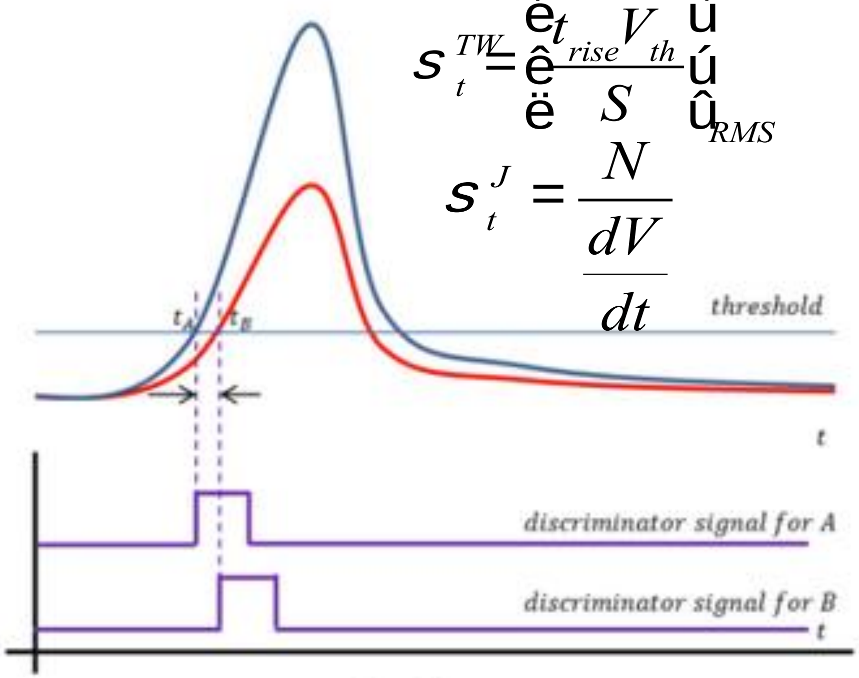
Time walk and Time jitter

Time walk: the voltage value Vo is reached at different time for signal of different amplitudes

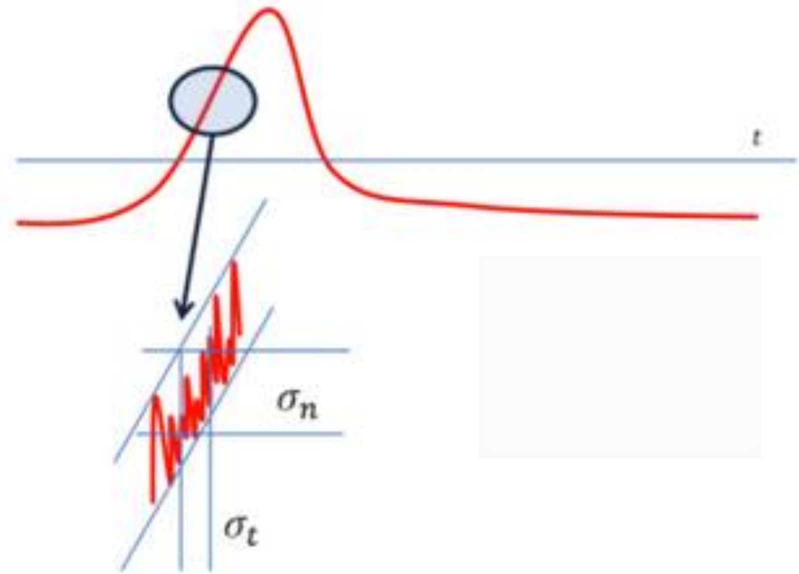
Jitter: the noise is summed to the signal, causing amplitude variations

$$\sigma_t^{TW} = \left[\frac{t_{rise} V_{th}}{S}\right]_{RMS}$$

$$\sigma_t^{J} = \frac{N}{\frac{dV}{dt}}$$



Time walk effect



Jitter effect

Due to the physics of signal formation

(see backup slides for full calculation and reduction techniques)

Mostly due to electronic noise

(see backup slides for capacitance and noise values used)

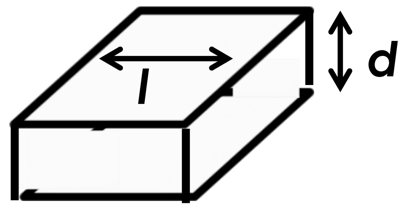
A parameterization of σ_t

$$\sigma_t^2 = \left(\frac{t_{rise}}{S/N}\right)^2 + \left(\left[\frac{t_{rise} V_{th}}{S}\right]_{RMS}\right)^2 + \left(\frac{TDC_{bin}}{\sqrt{12}}\right)^2 \qquad \textbf{(1)}$$

Jitter

Time Walk

TDC



d: **detector thickness** [micron]

l: **pitch** [micron]

C: **Detector capacitance [fF]**
Depends on the pitch and thickness

N: **Noise at preamp.**
Dominated by the voltage term

S: **Signal**

t_{rise}: Pre-Amp Shaping time

V_{th}: Comparator threshold
Depends on the noise level

TDC:Width of the TDC LSB [ps]

$$C_{Det} = \varepsilon\varepsilon_o \frac{l*l}{d} + 0.2*4l + 50$$

$$N \propto \frac{C_{Det}}{\sqrt{t_{rise}}}$$

$$V_{th} = 10*N$$

$$LSB = 20$$

What is the best shaping time (t_{rise}) ?

$$N \propto \frac{C_{Det}}{\sqrt{t_{rise}}}$$

$$S \propto \begin{cases} t_{rise} \xrightarrow{if} t_{rise} \leq t_{col} \\ Const \xrightarrow{if} t_{rise} > t_{col} \end{cases}$$

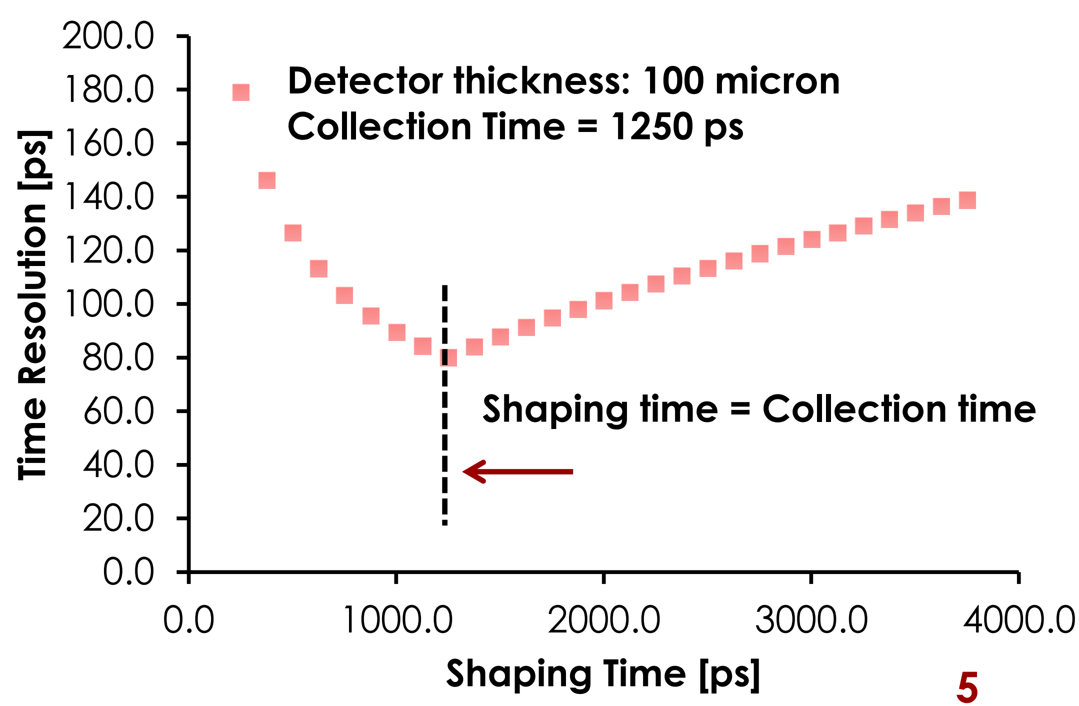
$$V_{th} \propto N$$

$$\Rightarrow s_t \propto \begin{cases} \frac{C_{det}}{\sqrt{t_{rise}}} \xrightarrow{if} t_{rise} \leq t_{col} \\ C_{det} * \sqrt{t_{rise}} \xrightarrow{if} t_{rise} > t_{col} \end{cases}$$

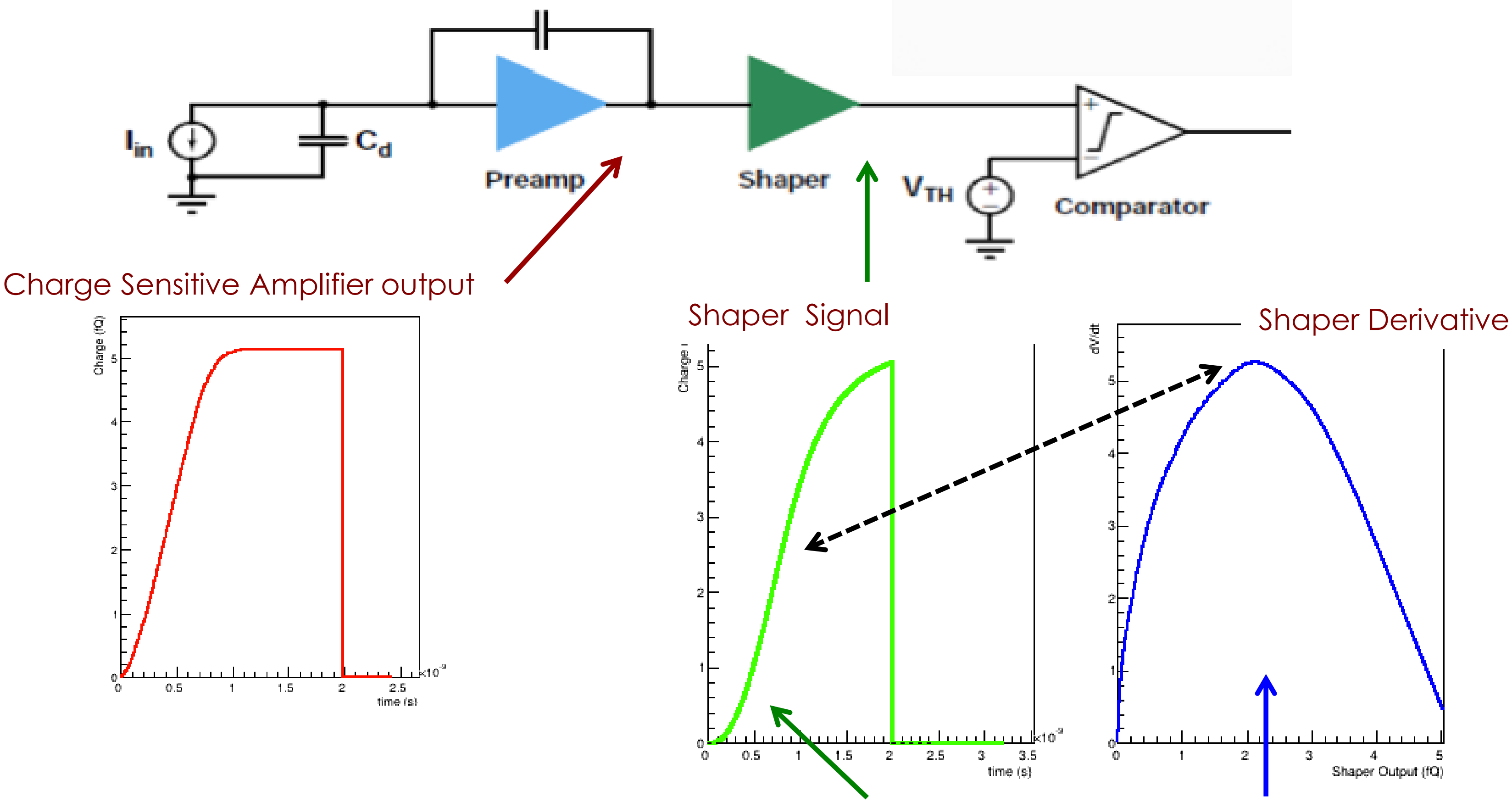
To minimize time resolution:

$$t_{rise} \sim t_{col}$$

Note: This value also minimizes fake signals in neighboring pixels.



Where to set the threshold



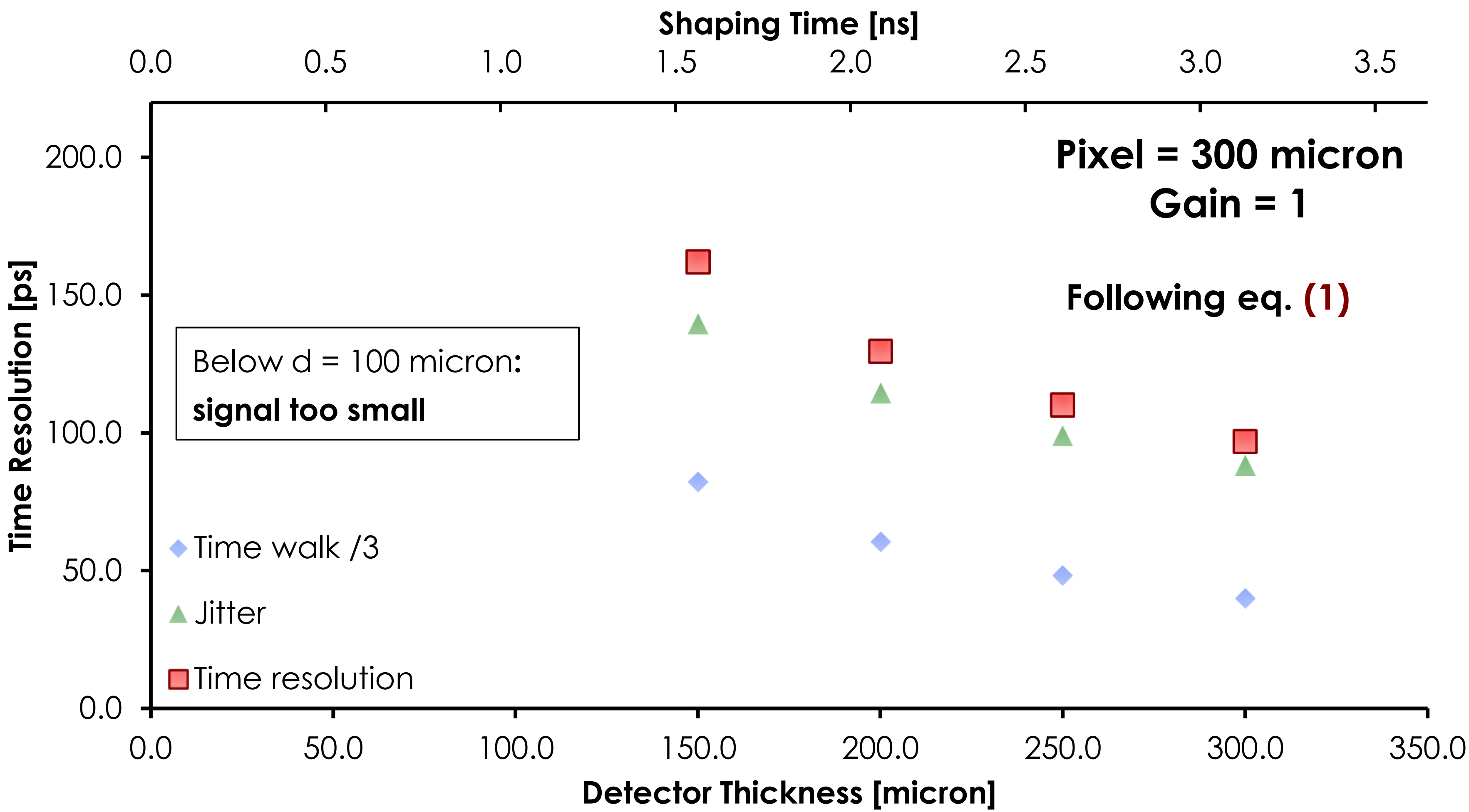
How to minimize Time Walk and Jitter: **Compromise!**

Time Walk: set the threshold at the minimum possible value

Jitter: set the threshold at the maximum derivative

$$\sigma_t^J = \frac{N}{dV/dt}$$

State of the Art



Best resolution achievable: ~ 100 ps

(assuming Time Walk reduction of ~ 3)

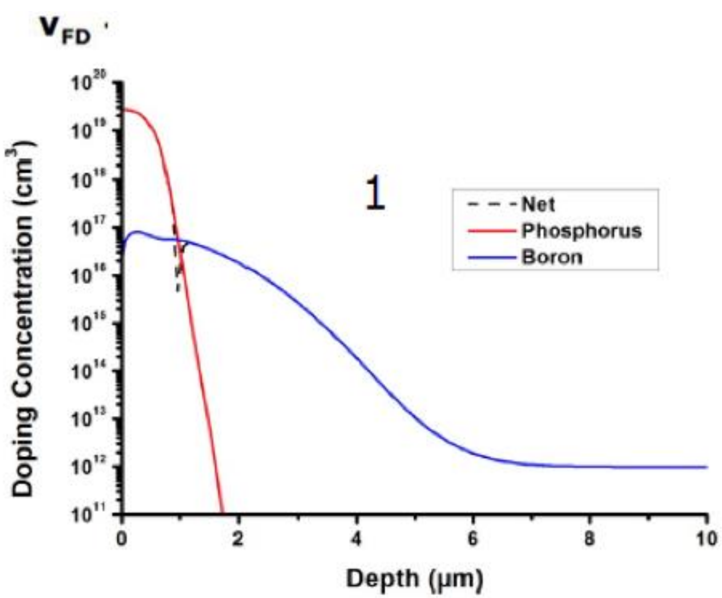
Sensor: Ultra-Fast Silicon Detector

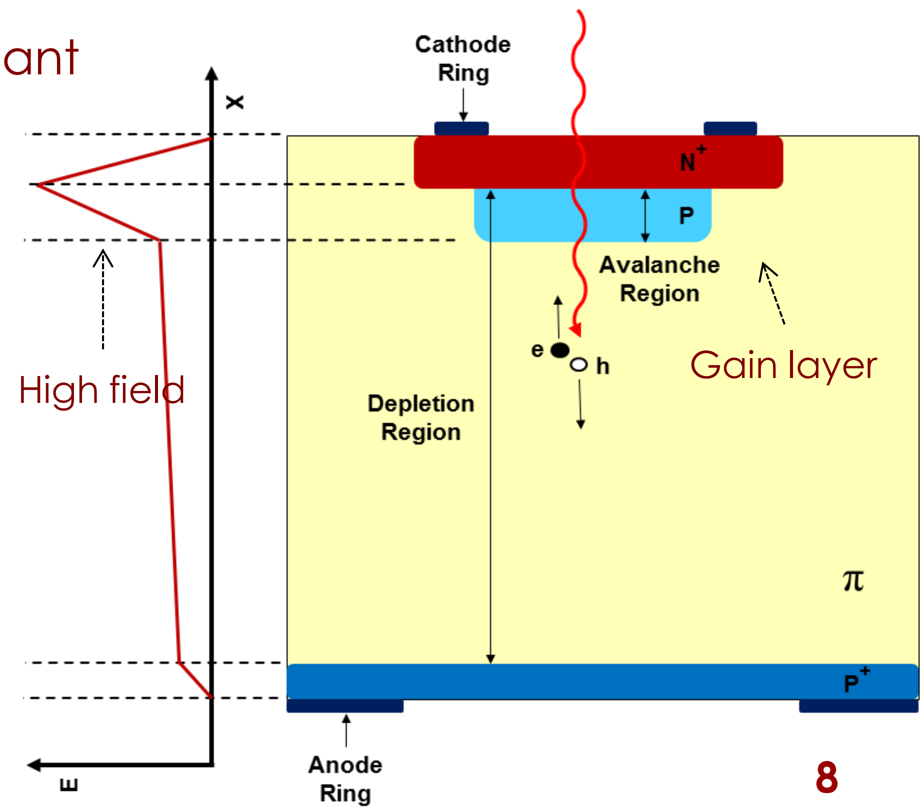
UFSD: pixelated silicon detector with internal gain

Main point: boost the signal

- Minimize jitter and TW
- Allows for very thin detector

UFSD gain: Add an extra deep p+ implant





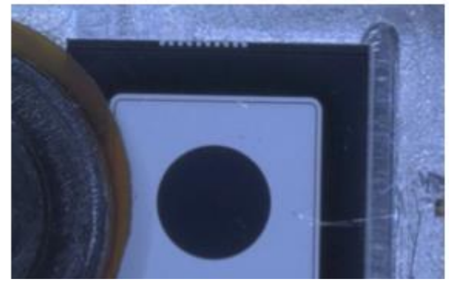
Sensor: Status

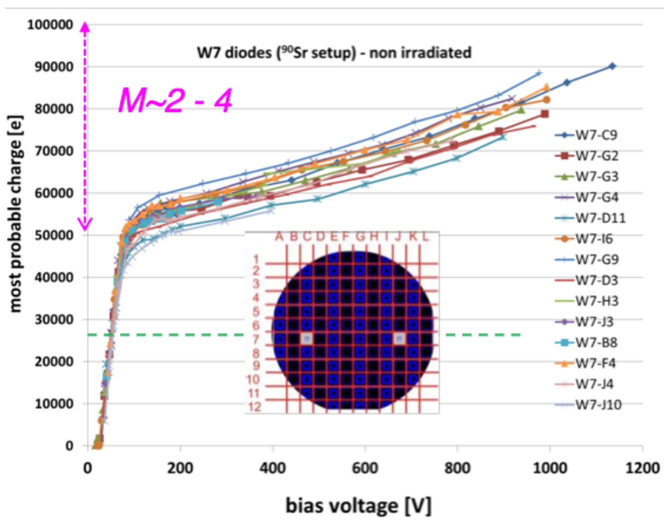
Presented at the 9th

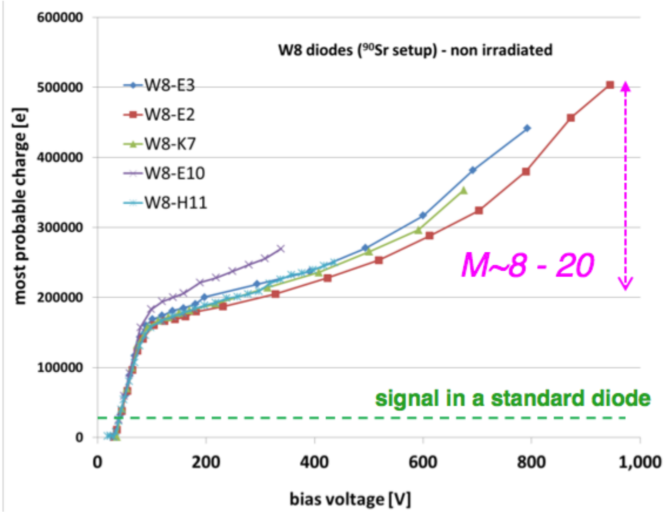
Trento Workshop, 2014 Genova

Measured Gain: 2-10

The LGAD diodes processed by CNM exhibit good gain M_Q~3-10 and uniform multiplication over the diode surface.







Wafers have different gains:

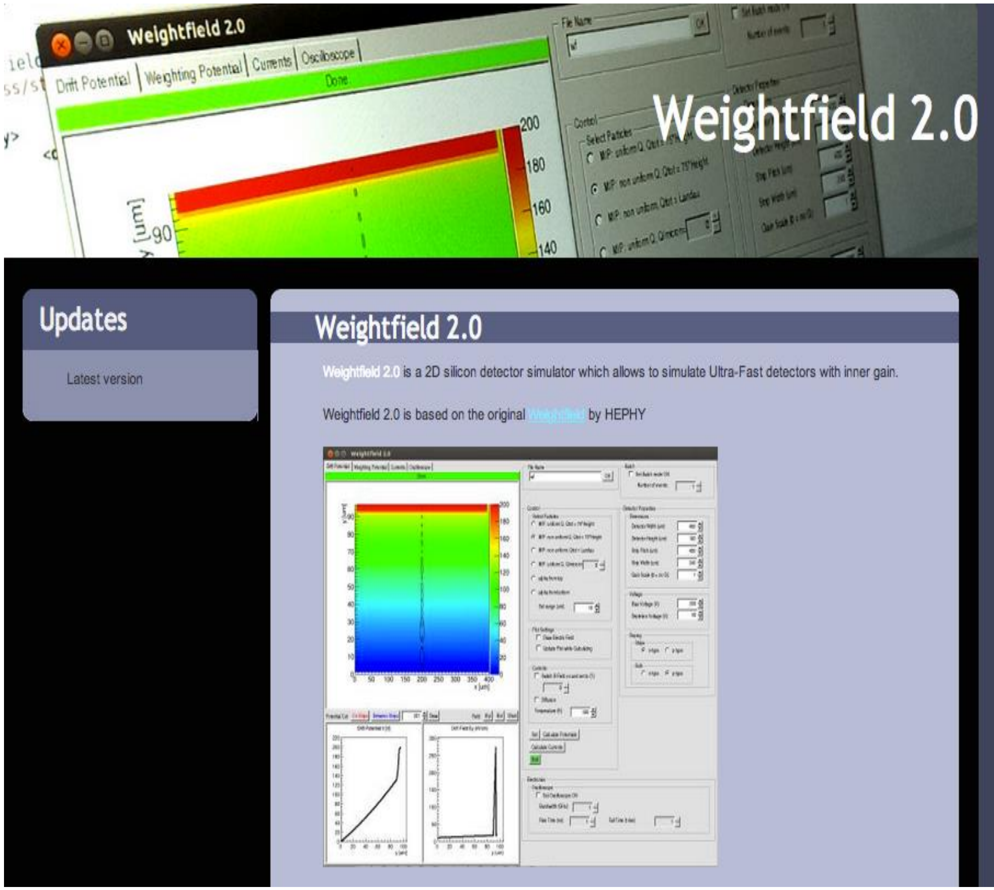
- Good uniformity of gain over the wafer
- Very good stability of some diodes up to >1000 V.
- For W8 samples the gain at >900 V is difficult to measure – amplifier saturates due to too large signals – note steeper increase of gain for U>500V.

Sensor: Simulation

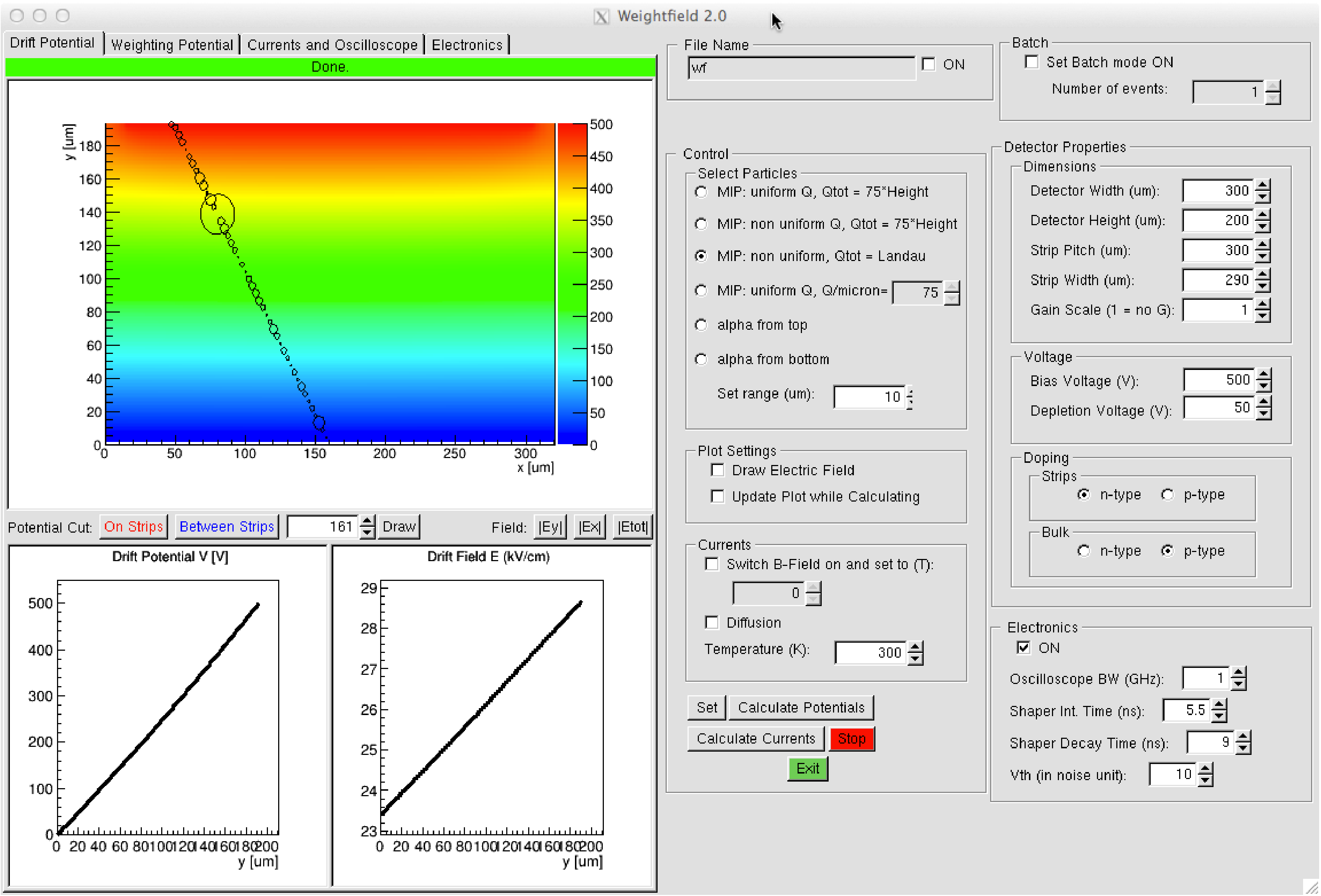
We developed a full sensor simulation (WeightField2, F. Cenna, 9th Trento workshop) avalilable at http://personalpages.to.infn.it/~cartigli/weightfield2

It includes:

- Custom Geometry
- Calculation of drift field and weighting field
- Currents signal via Ramo's Theorem
- Gain
- Diffusion
- Temperature effect
- Non-uniform charge deposition
- Electronics



WeightField2: a program to simulate silicon detectors



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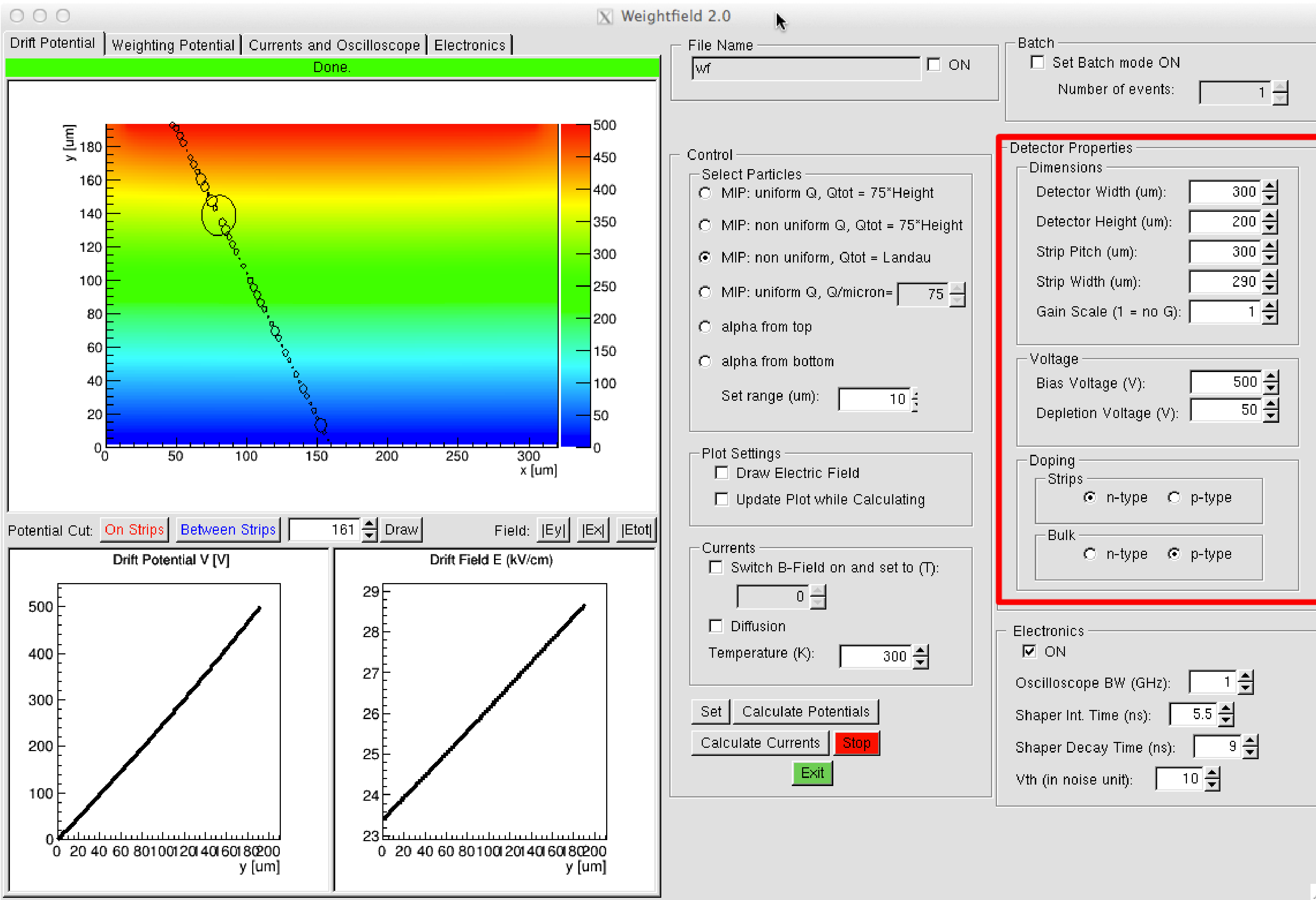

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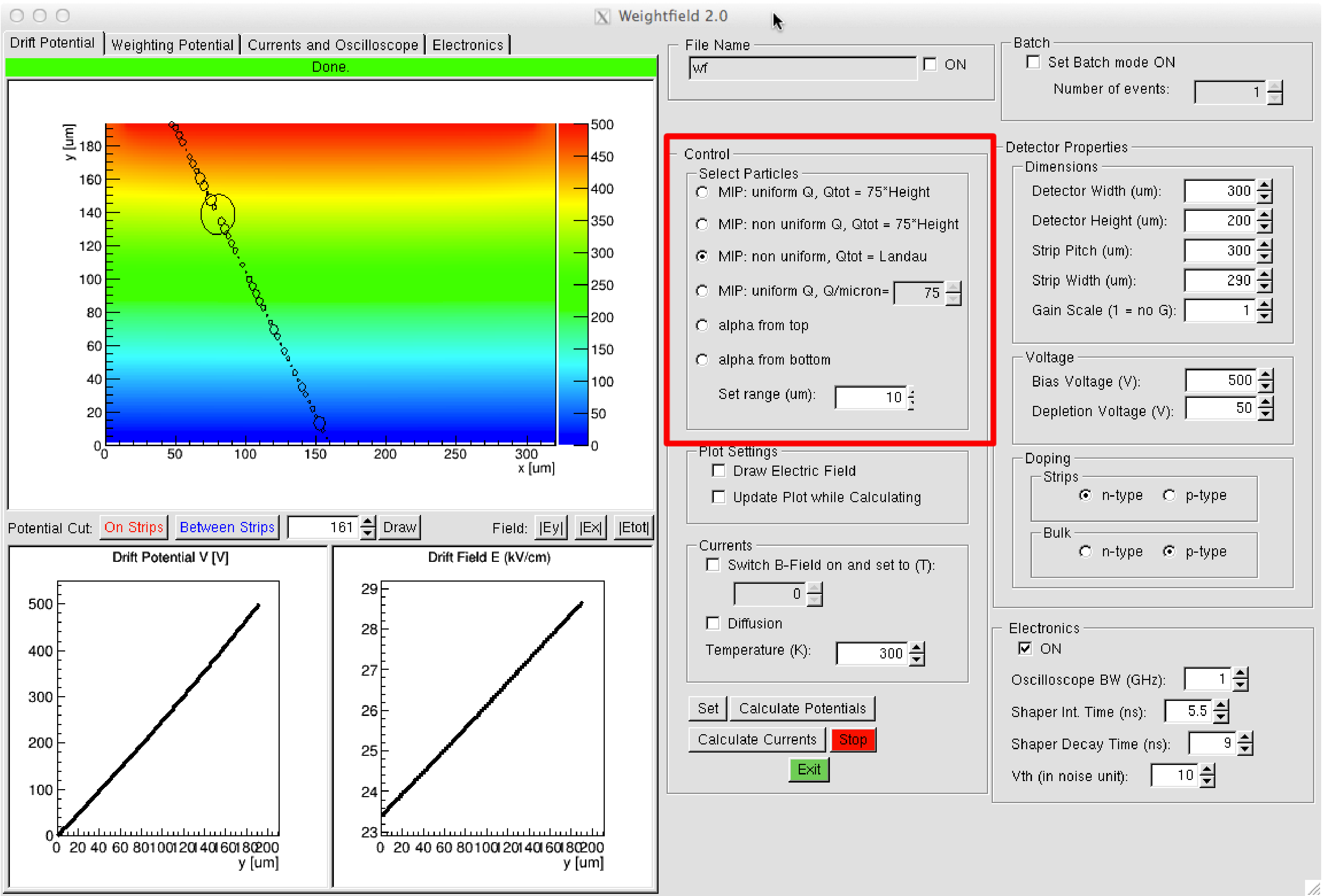

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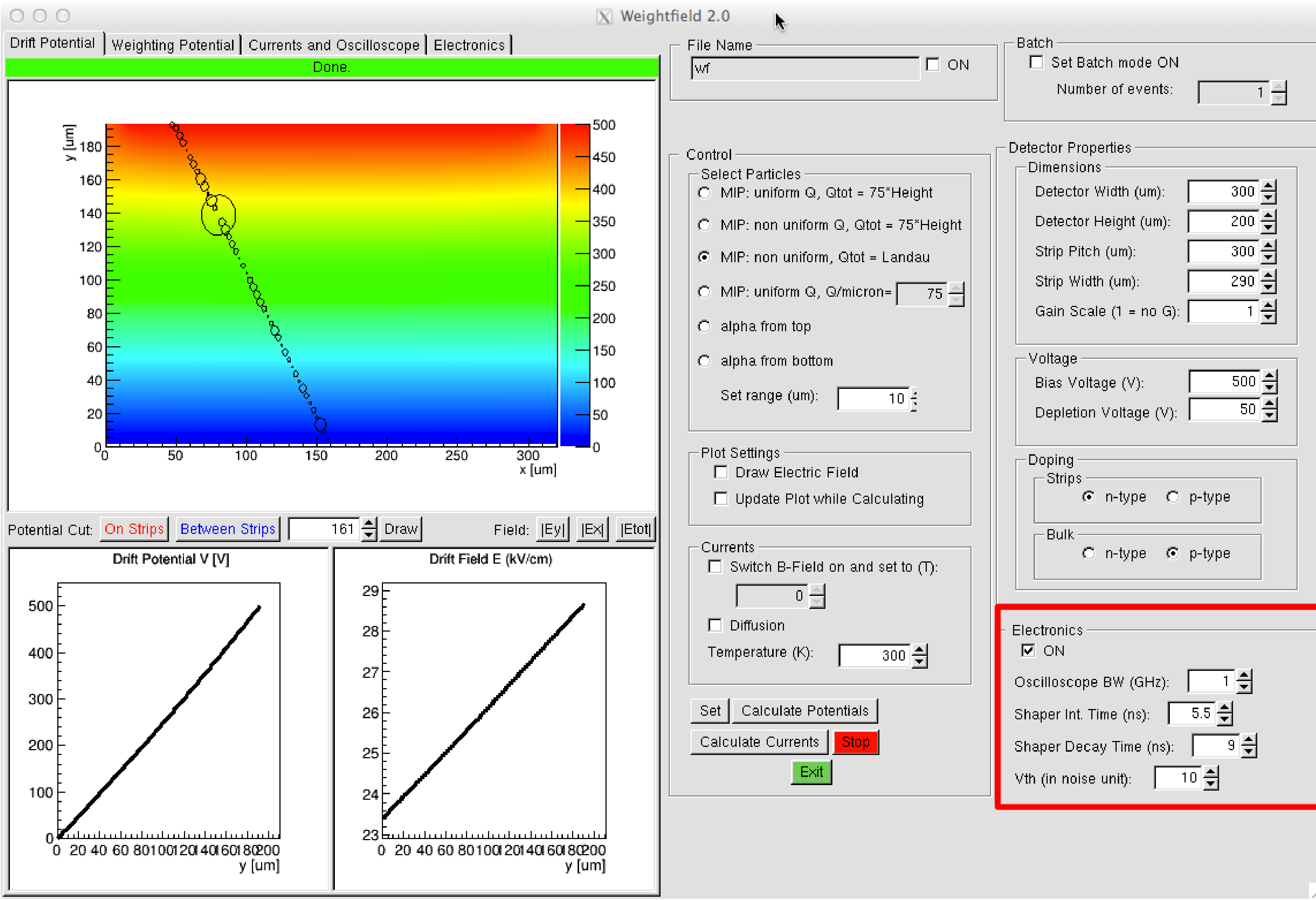

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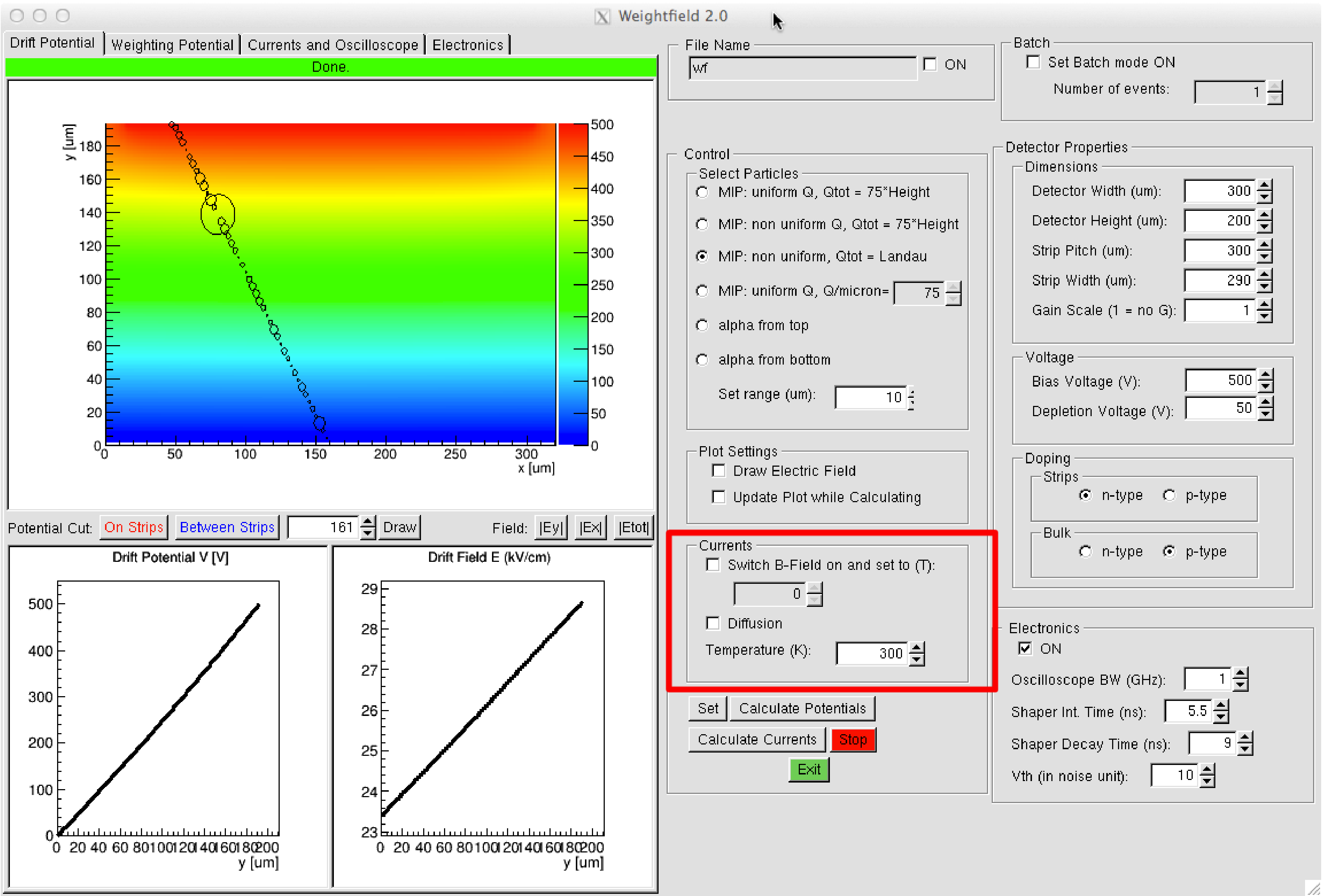

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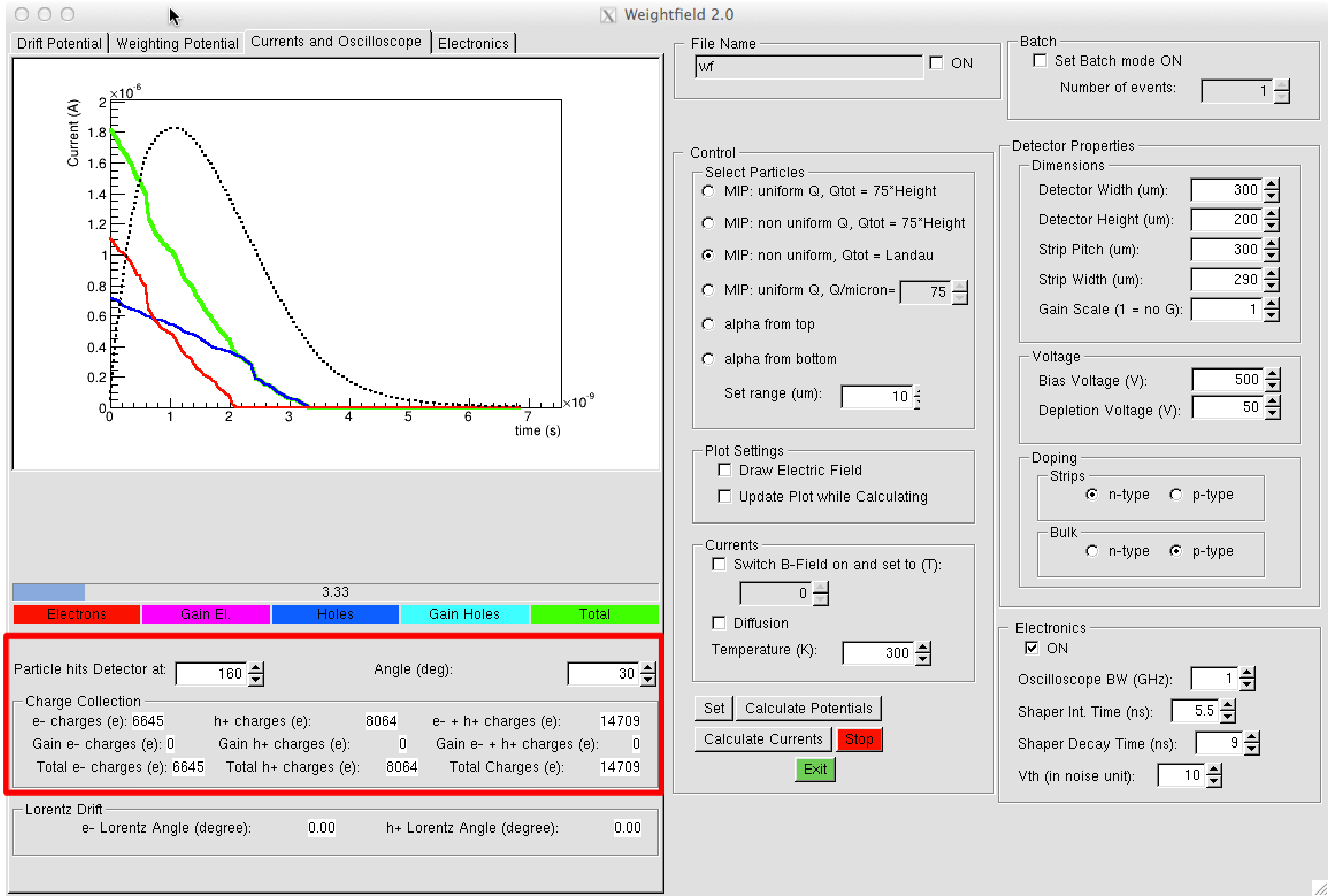
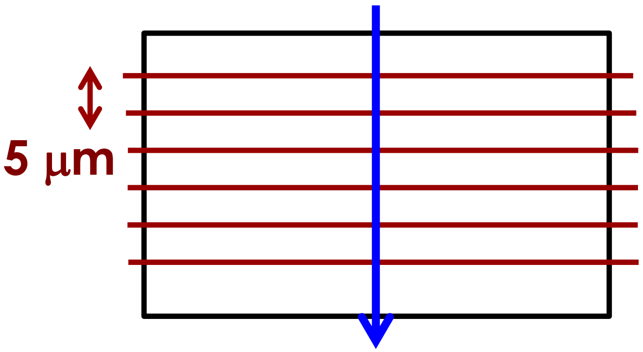
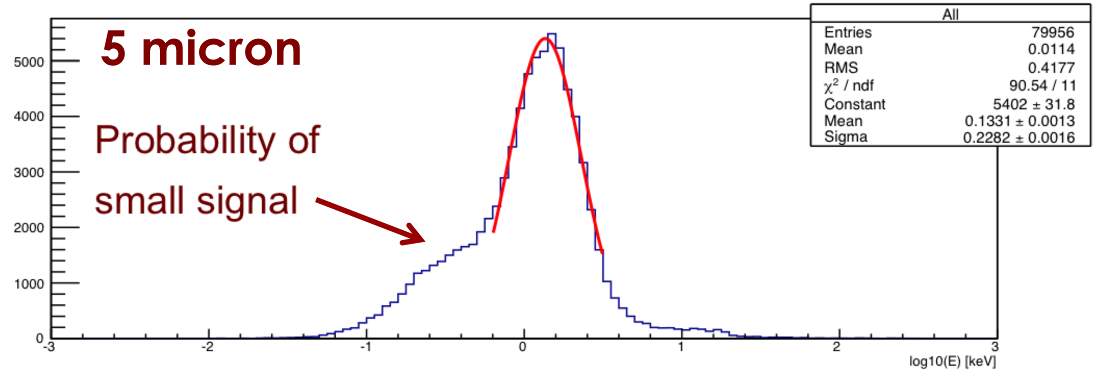


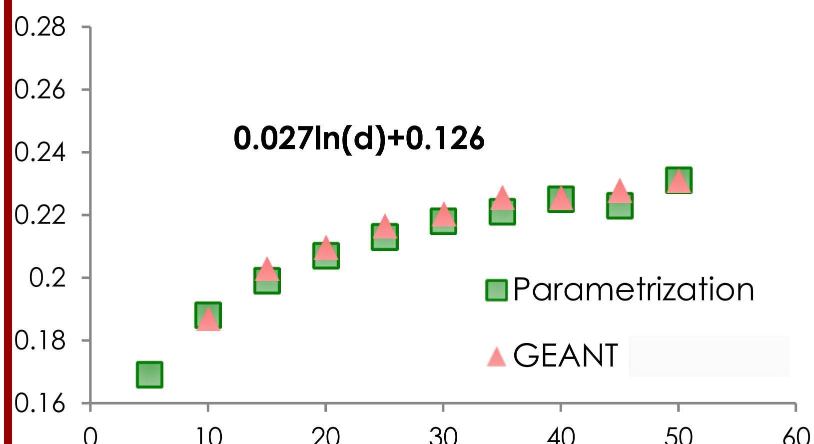
Aside: Non-Uniform Energy deposition

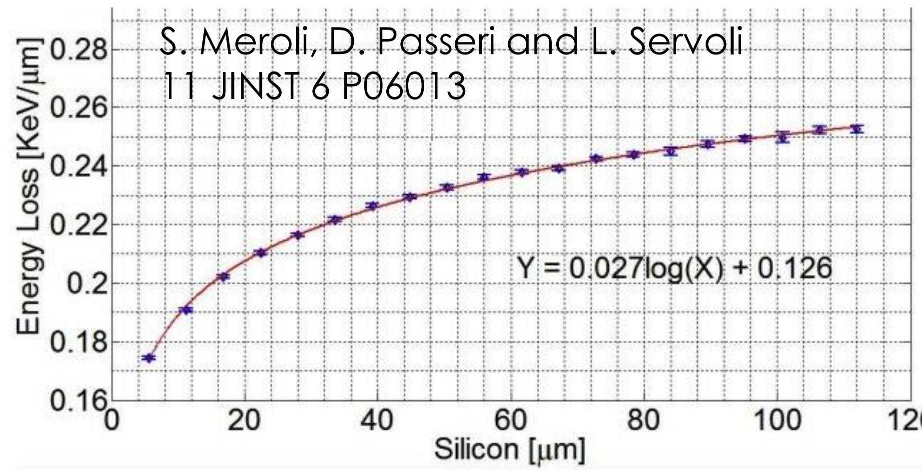




We have created, using GEANT4, a library of the energy depositions of a MIP in silicon, every 5 micron. Using this library, we can predict the value in any thickness

Comparison with the measurement presented in 2011 JINST 6 P06013

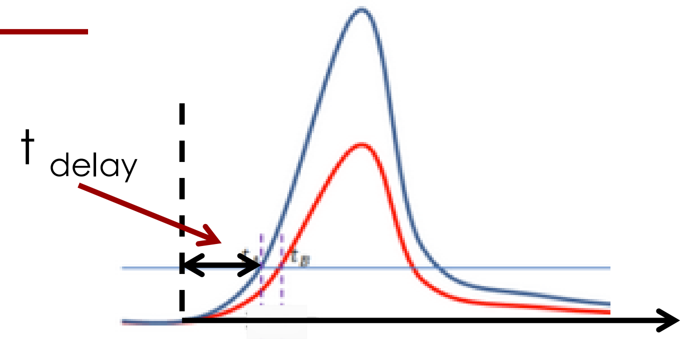




Time walk

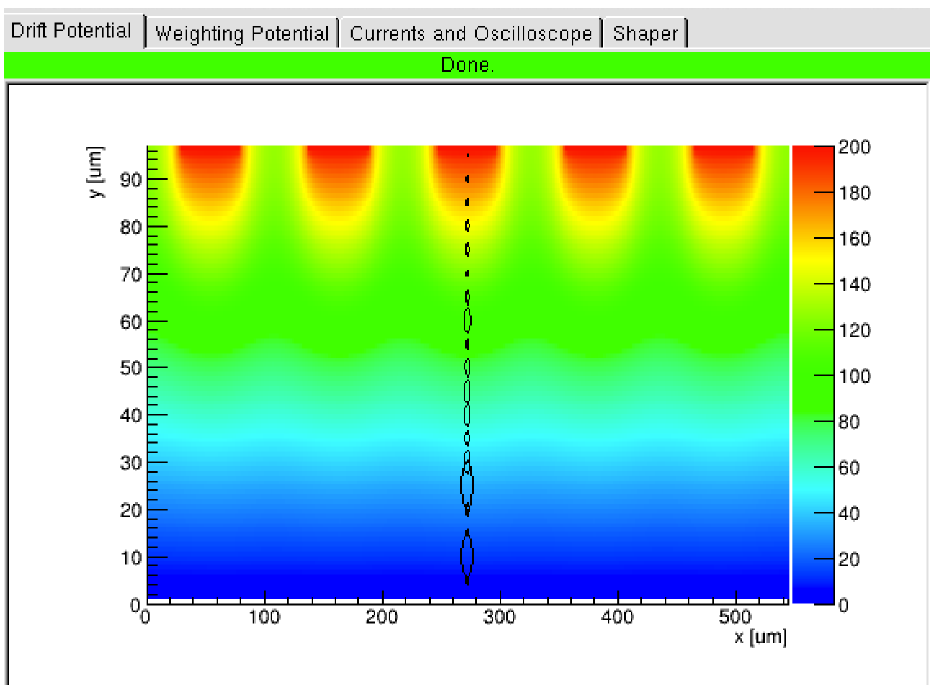
Signals cross a given threshold with a delay that depends on their amplitude, on the rise time and on the value of the threshold:

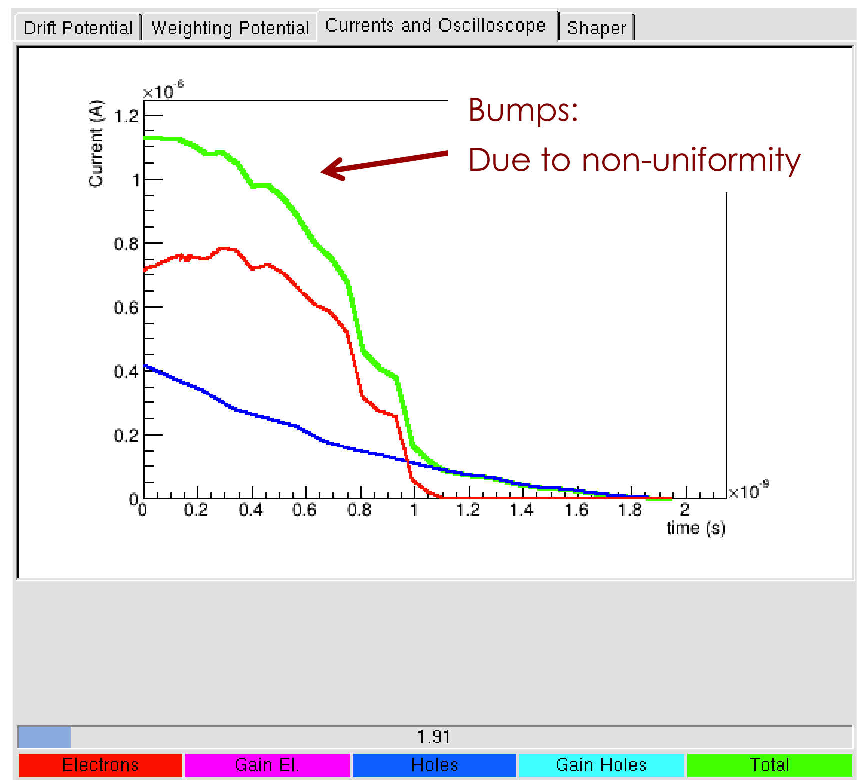
$$t_{delay} = t_{rise} \frac{V_{th}}{V}$$



Time walk has 2 different source:

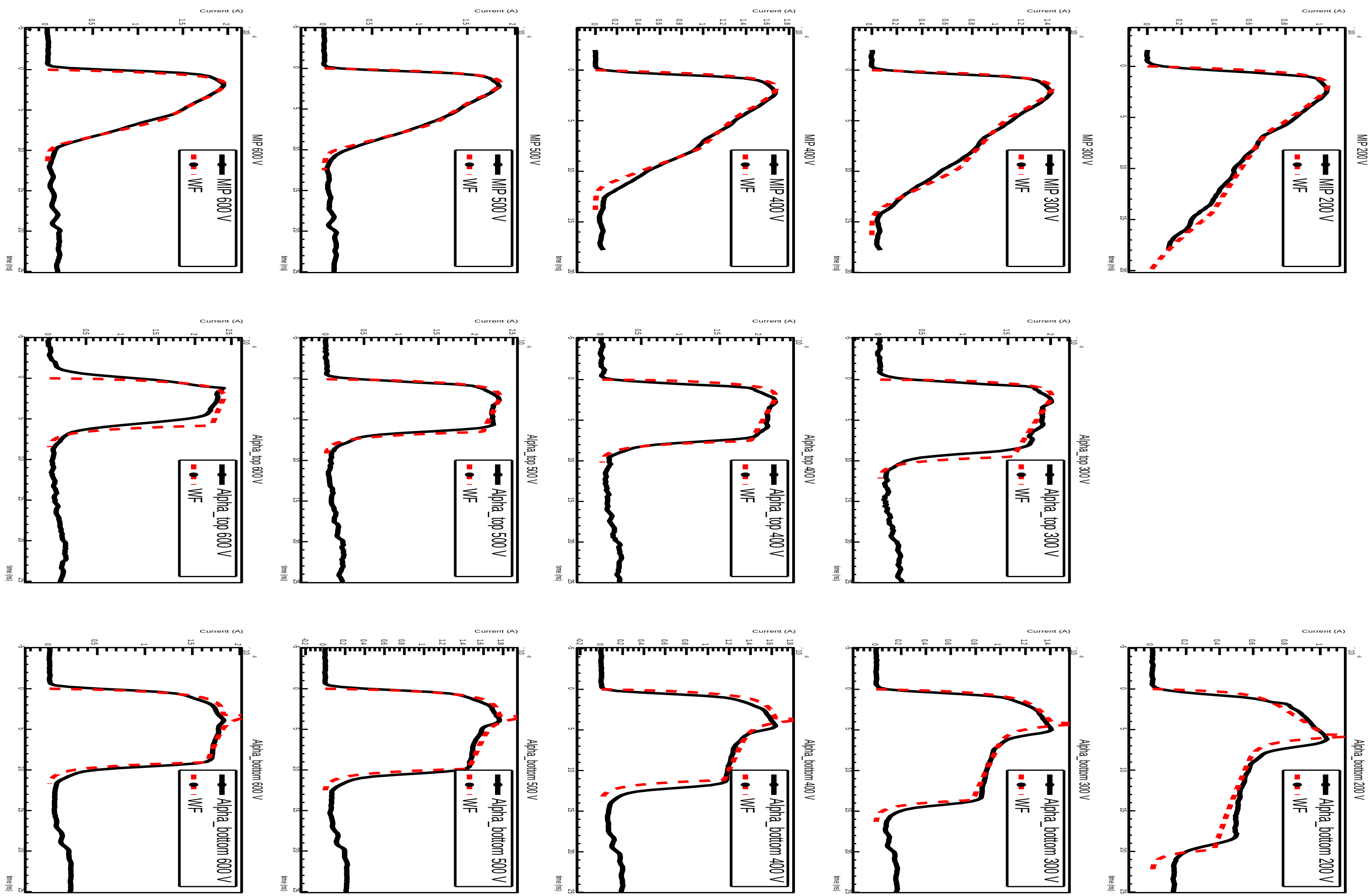
1. Amplitude variation (Landau distributed)
2. Non-uniformity charge deposition





Comparison Data-Simulation

MIP **Alpha from Top** **Alpha from bottom**



Comparison Data Simulation

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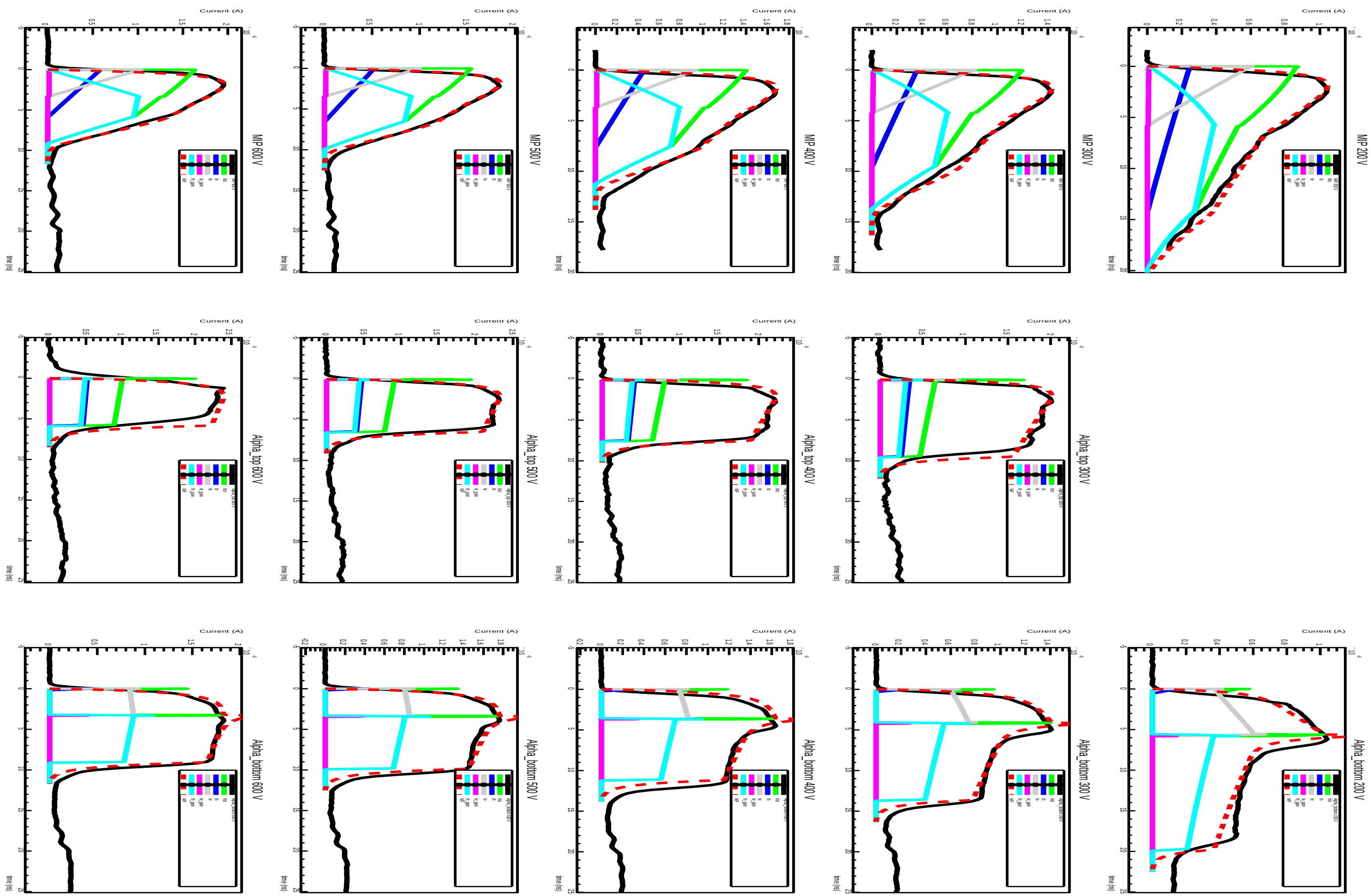
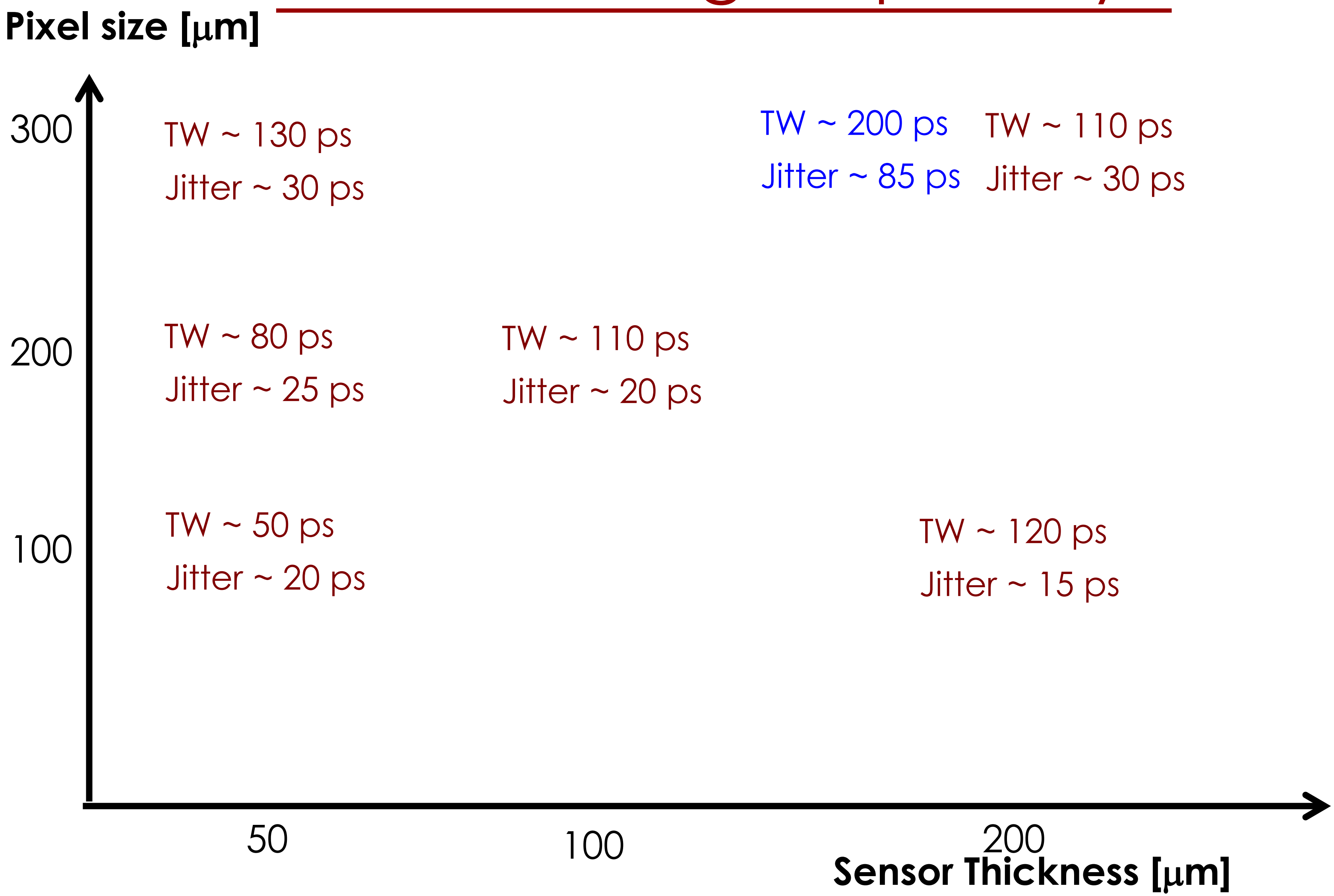


Simulation prediction

Using Weightfield we are able to simulate many geometries, and to predict the timing capabilities of UFSD.

NOTE: We simulate the value of TimeWalk without any correction. Constant Fraction Discriminator and Time-Over-Threshold circuits are able to reduce this component by a large fraction (3-10)

UFSD – Timing Capability



UFSD with Gain = 10

Blue = NA62

UFSD – Summary

We are just starting to understand the timing capability of UFSD

The internal gain of UFSD makes them ideal for accurate timing studies

We developed a program, **Weightfield2.0**, that is able to reproduce accurately the output response of UFSD
(available at http://personalpages.to.infn.it/~cartigli/Weightfield2.0/)

Many geometries allow for small jitter (~20 ps) and TimeWalk (~ 100 ps)

10 ps looks really difficult, 20 ps looks 1/4 as difficult, 30 ps 1/9 …

References

Several talks at the 22nd and 23rd RD50 Workshops:

23rd RD50: https://indico.cern.ch/event/265941/other-view?view=standard
22nd RD50: http://panda.unm.edu/RD50_Workshop/

9Th Trento Workshop, Genova, Feb 2014.

F. Cenna "**Simulation of Ultra-Fast Silicon Detectors**"

N. Cartiglia "**Timing capabilities of Ultra-Fast Silicon Detector**"

Papers:

[1] N. Cartiglia, **Ultra-Fast Silicon Detector**, 13th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD13), 2014 JINST 9 C02001, http://arxiv.org/abs/1312.1080

[2] H. Sadrozinski, N. Cartiglia et al., **Ultra-fast Silicon Detectors**, NIM-A, RESMDD12 proceeding (2012), Firenze, http://dx.doi.org/10.1016/j.nima.2013.06.033