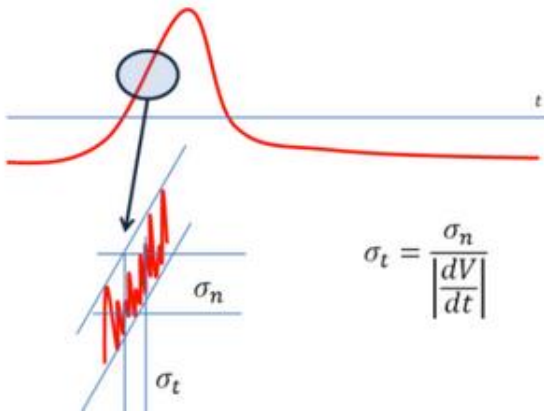


# Signal formation and intrinsic time resolution

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

Usual "Jitter" term

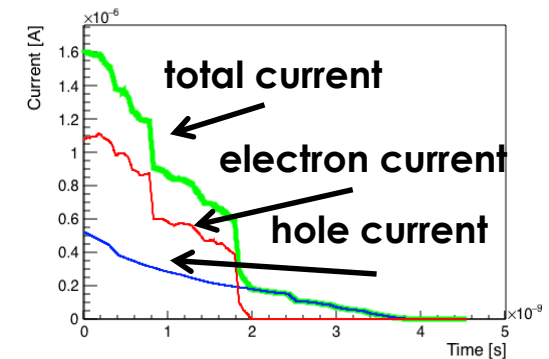
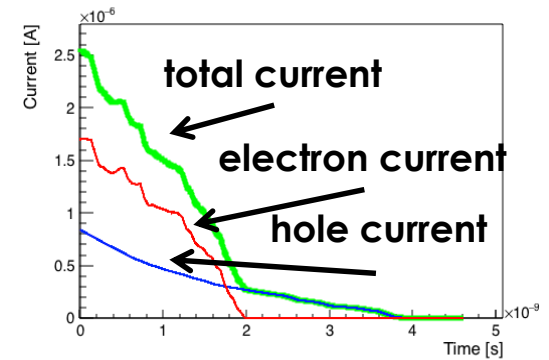
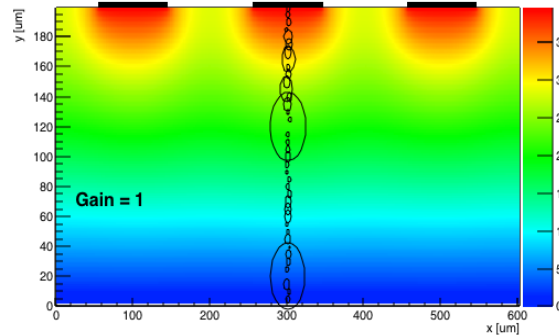
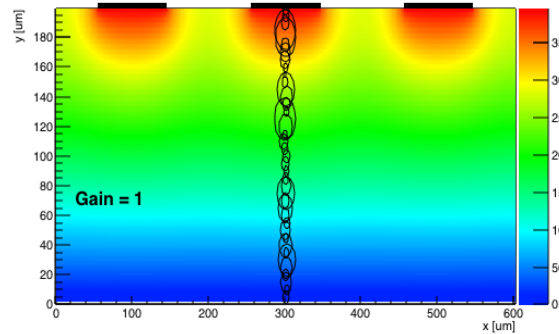
Here enters everything that is "Noise" and the steepness of the signal



**Need large dV/dt**

**Time walk:** Amplitude variation, **corrected in electronics**

**Shape variations:** non homogeneous energy deposition

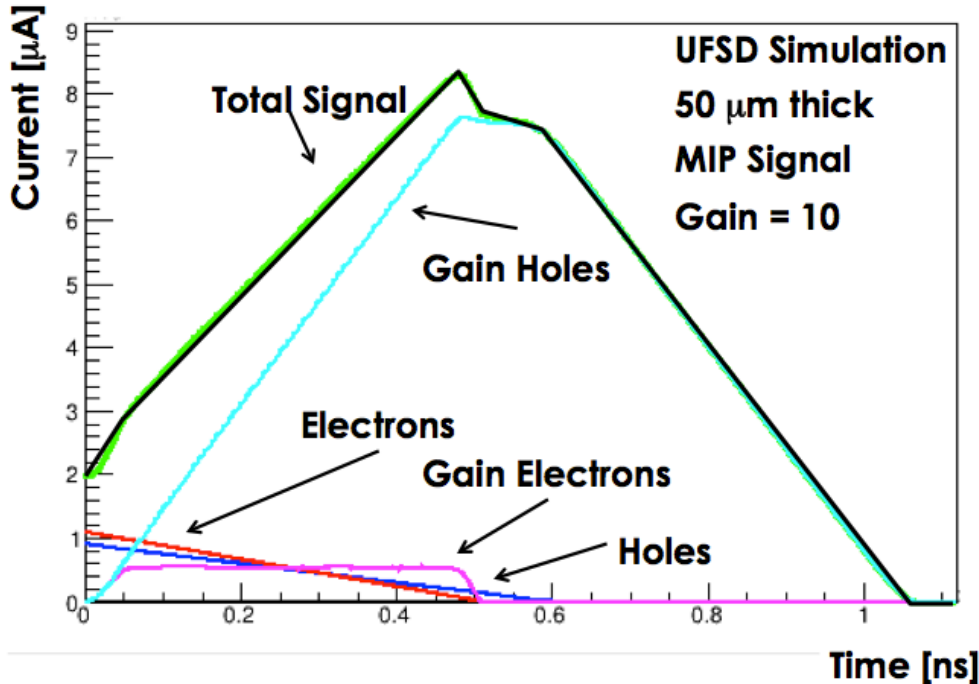
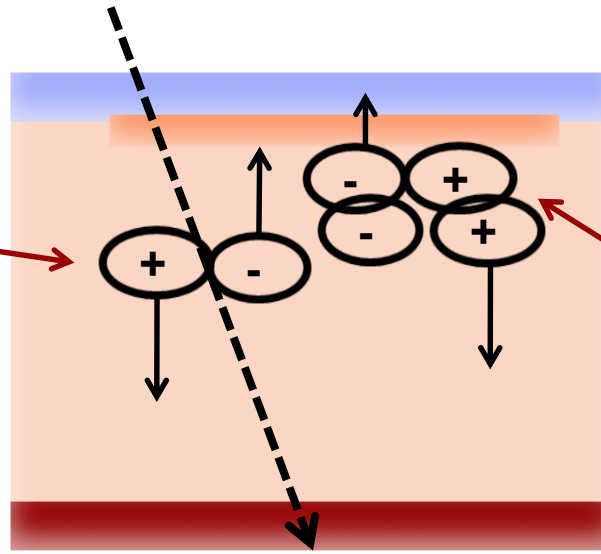


# How gain shapes the signal

**Gain electron:**  
absorbed immediately

**Gain holes:**  
long drift home

Initial electron, holes

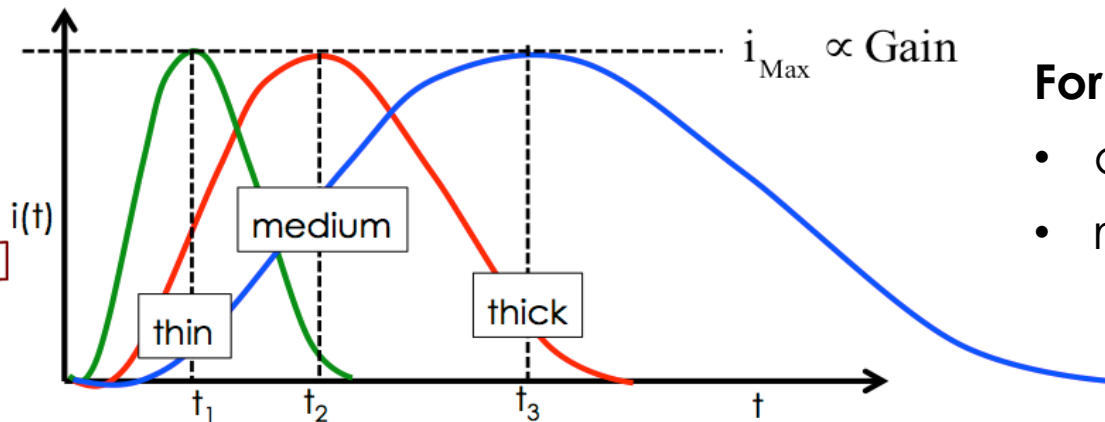


Electrons multiply and produce additional electrons and holes.

- **Gain electrons have almost no effect**
- **Gain holes dominate the signal**

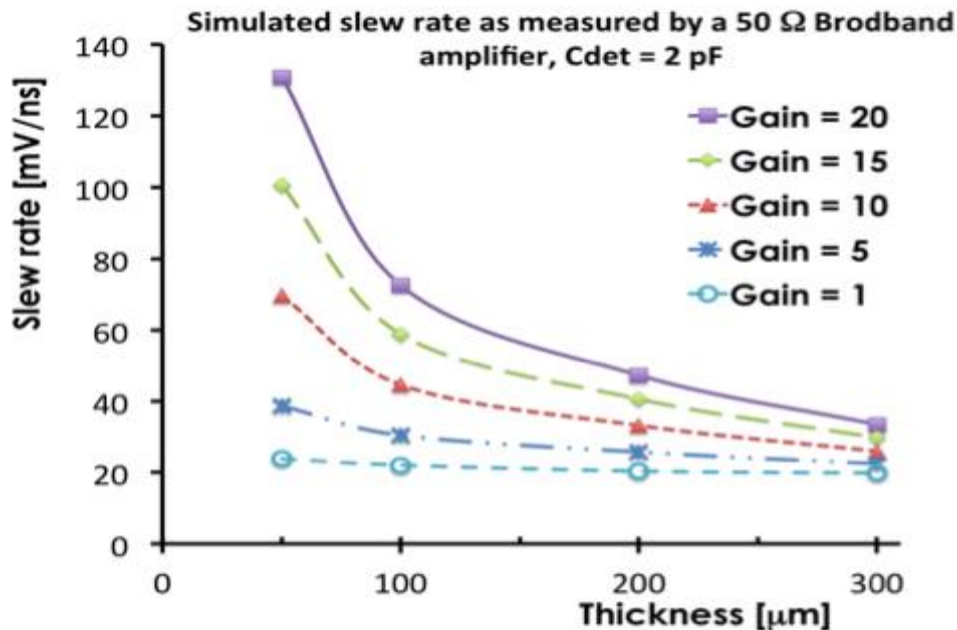
➔ **No holes multiplications**

# Gain and slew rate vs thickness



**For a fixed gain:**

- amplitude = constant
- rise time  $\sim 1/\text{thickness}$



**The slew rate:**

- Increases with gain
- Increases  $\sim 1/\text{thickness}$

**→ Go thin!!**

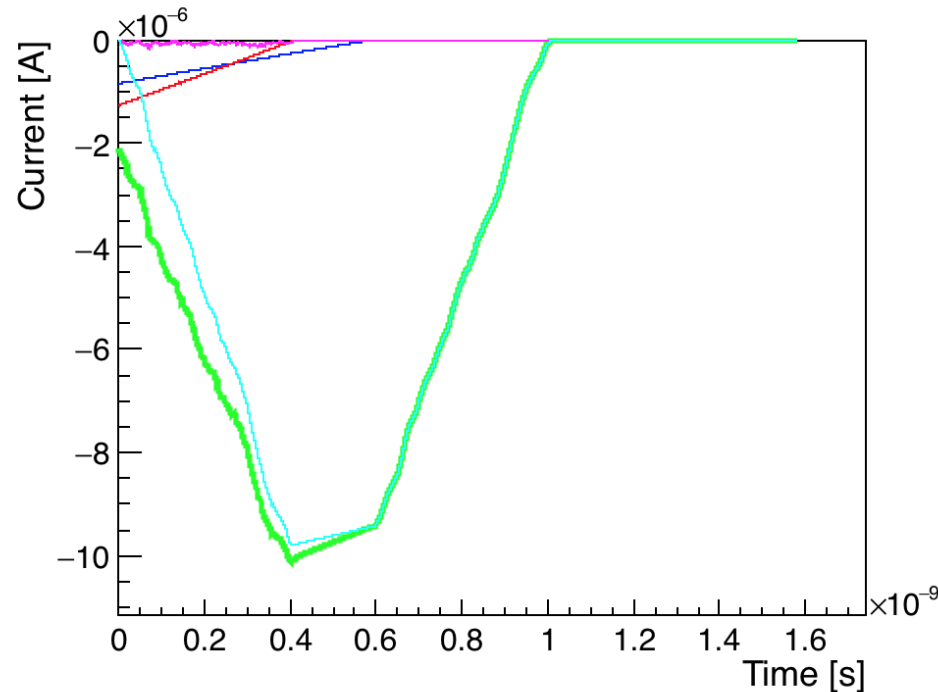
**Significant improvements in time resolution require thin detectors**

# Evolution of LGAD signal shape in ETL

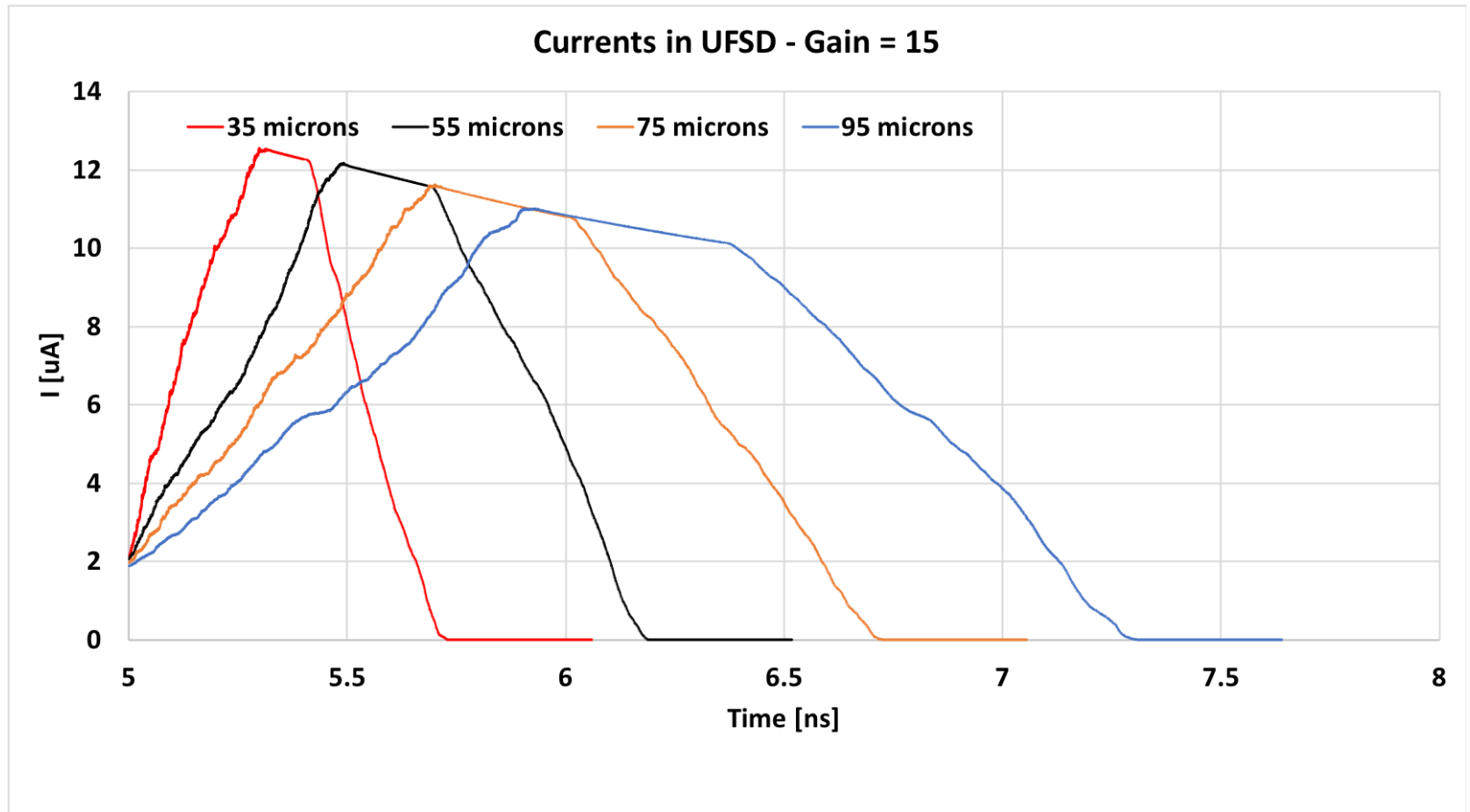
The signal from an LGAD is short and reaches  $\sim 10 \mu\text{A}$   
(gain = 13 in the plot)

**Gain = 10  $\rightarrow$  Q = 5 fC**

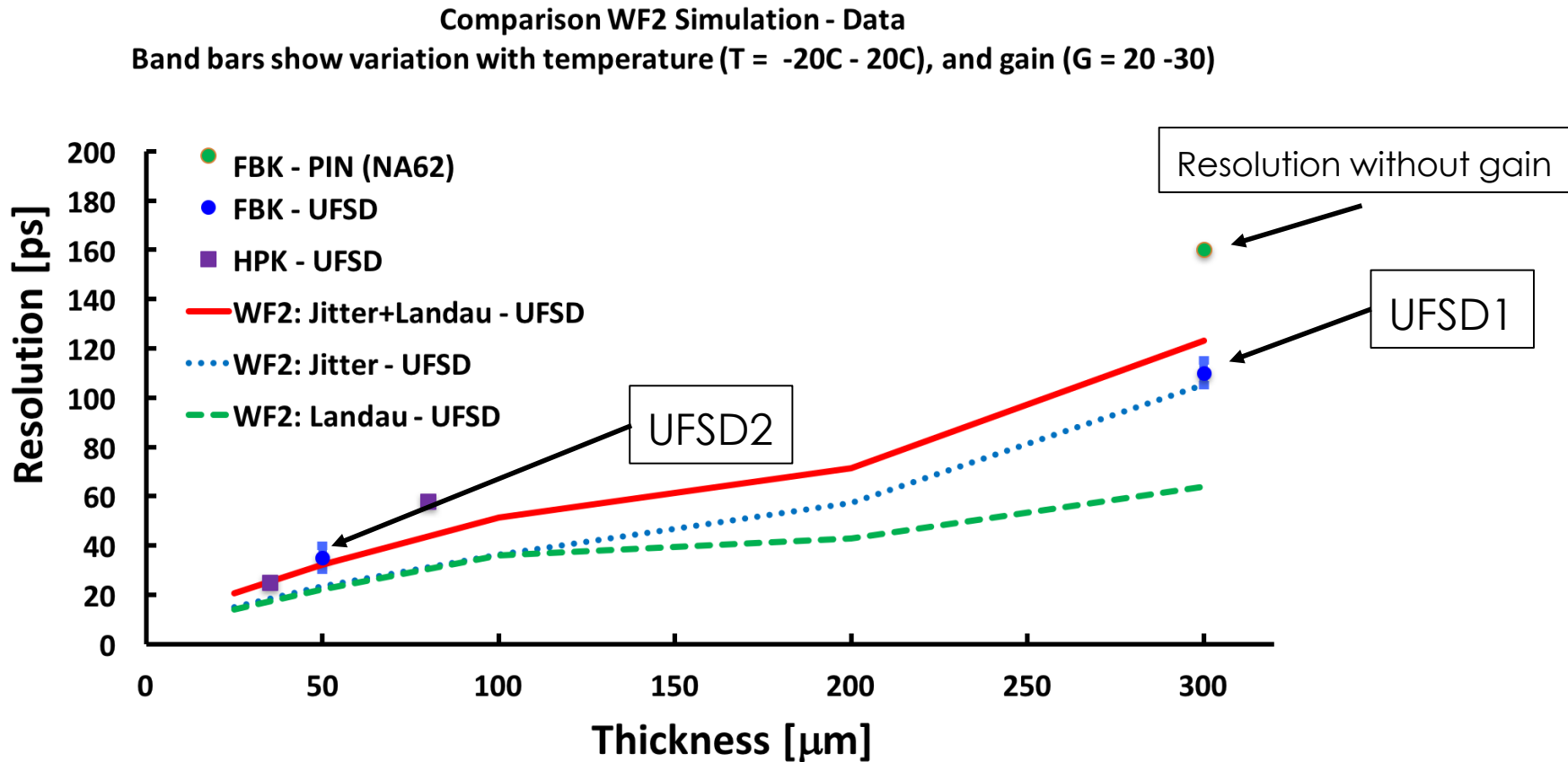
The electronics needs to exploit it: needs to follow the rising edge.



# Currents for different thicknesses



# UFSD time resolution summary

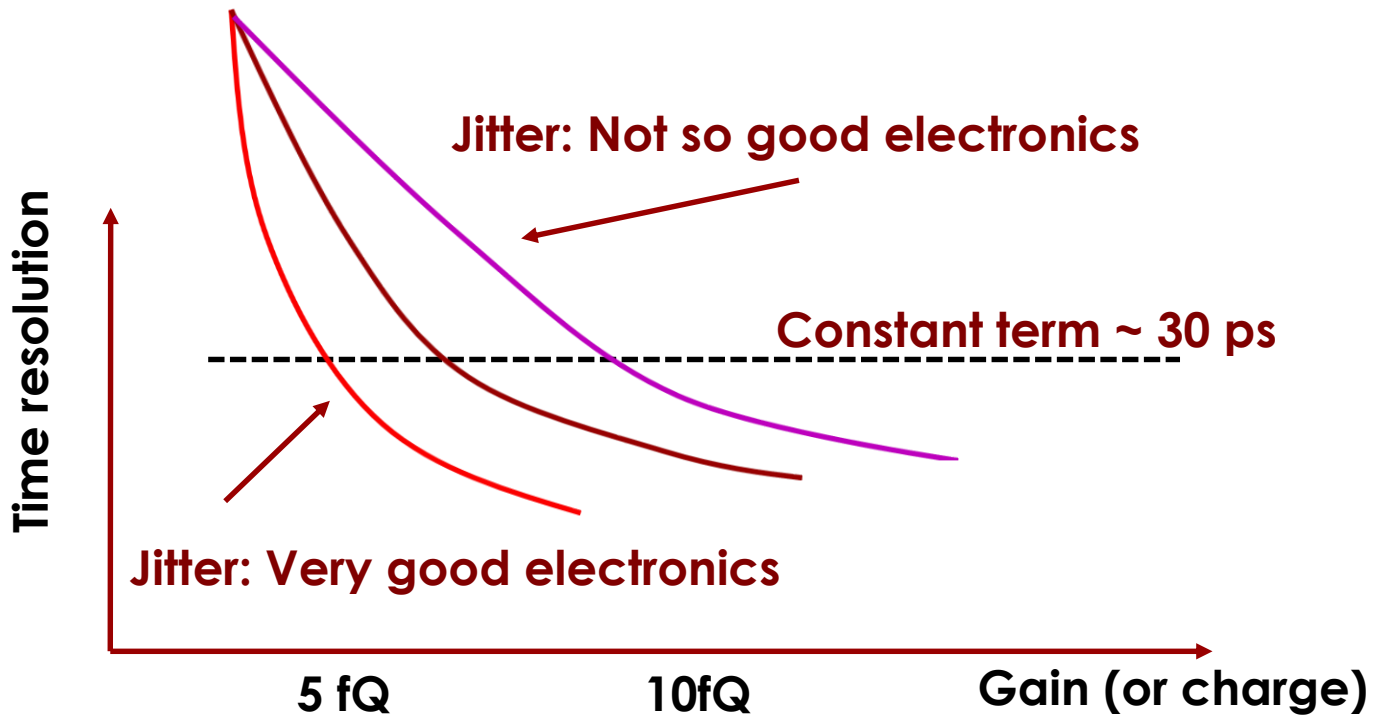


**Message:** the time resolution is limited by charge non uniformity

➔ Be aware: this is not time walk, it is the variability of the current pulse

# Time resolution at 50 micron

$$\sigma_t^2 = \left( \frac{N}{dV/dt} \right)^2 + \sigma_{\text{Non-uniform charge dep.}}^2$$

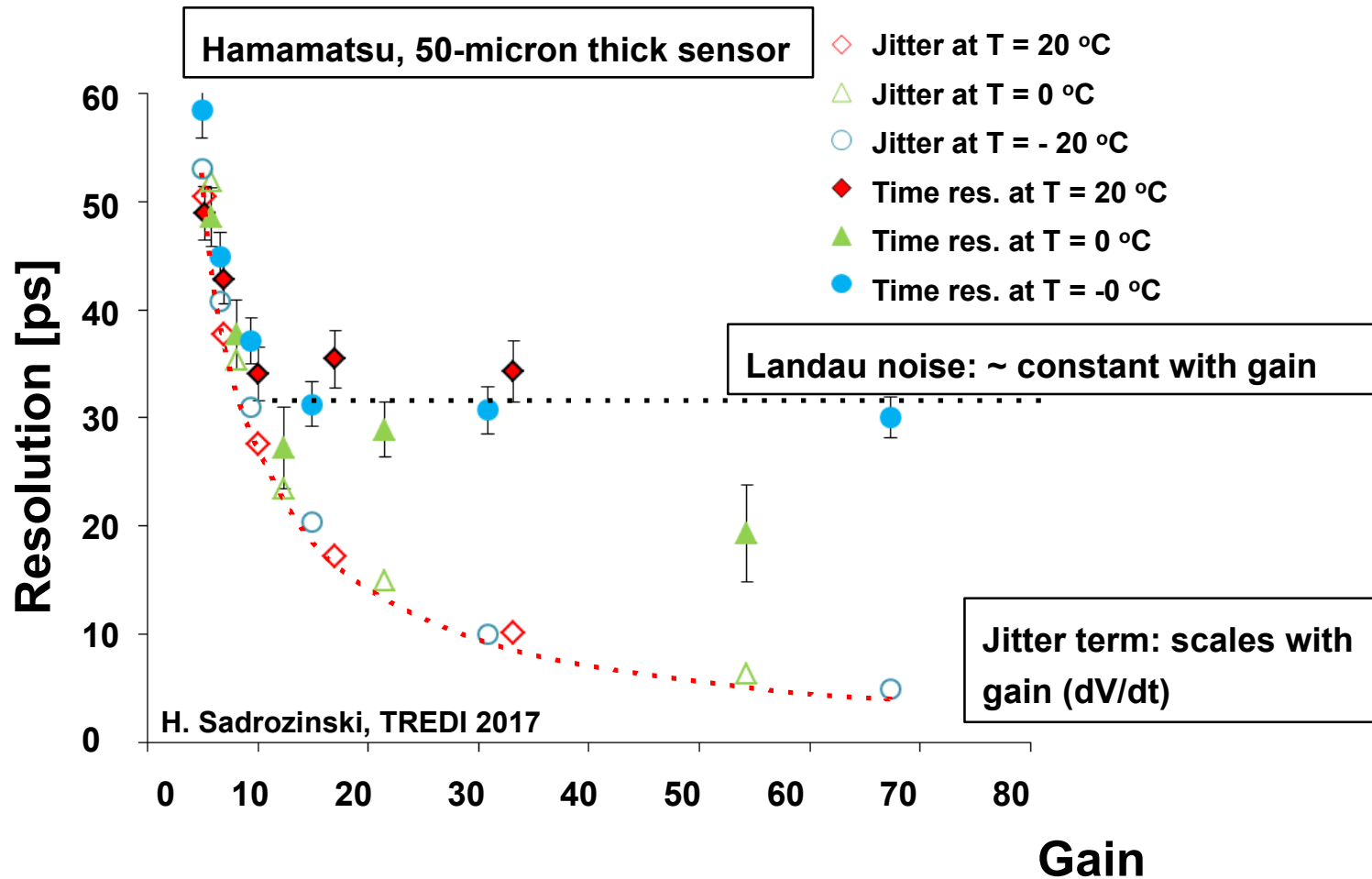


**Two components determine the time resolution:**

- Non uniform charge deposition → ~ constant term 25 – 30 ps
- Jitter contribution =  $N/(dV/dt) \sim 1/\text{Gain}$  **(controlled by electronics)**

# UFSD: time resolution

UFSD from Hamamatsu confirm our simulation: 30 ps time resolution,  
Value of gain  $\sim 20$





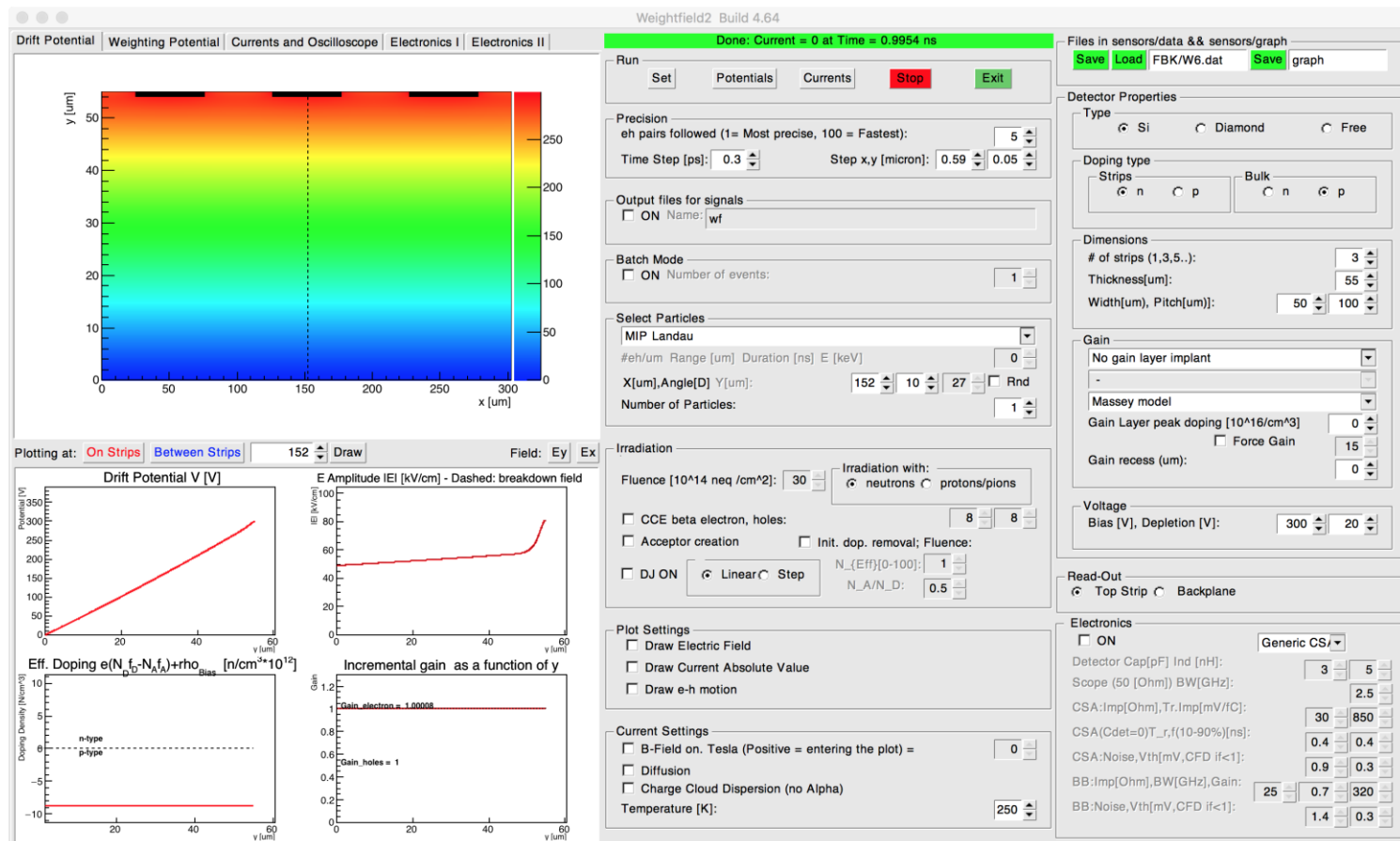
# Weightfield2

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



# WF2: Currents

Current tabs

The screenshot displays the Weightfield2 software interface, version 4.64. The main window is titled "Currents and Oscilloscope" and shows a plot of Current [A] (left y-axis,  $\times 10^{-6}$ ) and Voltage [mV] (right y-axis) versus Time [s] (x-axis,  $\times 10^{-9}$ ). The plot shows several curves representing different components: Electrons (red), Gain El. (magenta), Holes (blue), Gain Holes (cyan), and Total (green). A status bar at the top indicates "Done: Current = 0 at Time = 1.2705 ns".

Below the plot is a legend for the current components:

Electrons	Gain El.	Holes	Gain Holes	Total
-----------	----------	-------	------------	-------

Below the legend is a table for Charge Collection:

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

Below the charge collection table is a table for Lorentz Drift:

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

The interface also includes several control panels:

- 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<sup>2</sup>): 1; Irradiation with: neutrons; CCE beta electron, holes: 8, 8; Acceptor creation; Init. dop. removal; Fluence: DJ ON; Linear; N\_{Eff}[0-100]: 1; 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
- Detector Properties:** Type: Si; 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<sup>3</sup>): 0; Force Gain; 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/IC]: 60, 7; CSA(Cdet=0)T\_r,(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

# WF2: Electronics

Electronics tabs

The screenshot displays the Weightfield2 software interface, version Build 4.64. The main window is titled "Electronics I" and contains several plots and control panels.

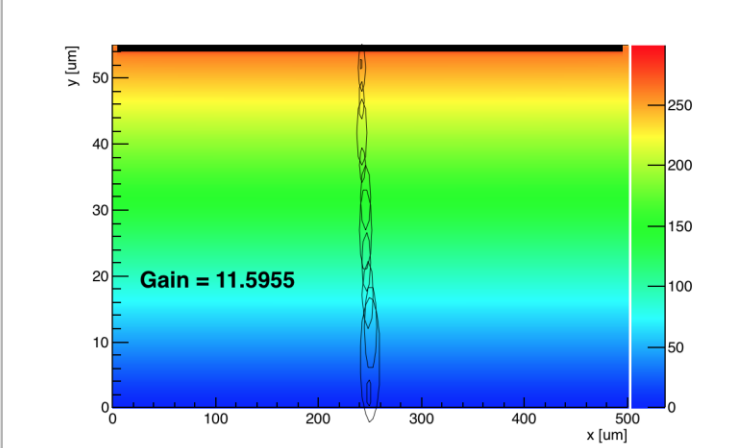
**Plots:**

- CSA (blue) and BB Amplifier (red):** A plot of Amplitude [mV] vs Time [s] (scaled by  $10^{-9}$ ). The blue curve (CSA) shows a smooth, rising edge, while the red curve (BB Amplifier) shows a sharp, oscillating response.
- Rising edge derivative:** A plot of  $dV/dt$  [mV/ns] vs Amplitude fraction. The blue curve (CSA) shows a smooth, rising edge, while the red curve (BB Amplifier) shows a sharp, oscillating response.
- Charge:** A plot of Charge [C] vs Time [s] (scaled by  $10^{-9}$ ). The green curve shows a smooth, rising edge.

**Control Panels:**

- Run:** Includes buttons for Set, Potentials, Currents, Stop, and Exit. A status bar indicates "Done: Current = 0 at Time = 1.2705 ns".
- Precision:** Includes settings for "eh pairs followed" (1= Most precise, 100 = Fastest), Time Step [ps], and Step x,y [micron].
- Output files for signals:** Includes a checkbox for "ON" and a text field for "Name" (set to "wf").
- Batch Mode:** Includes a checkbox for "ON" and a text field for "Number of events" (set to "1").
- Select Particles:** Includes a dropdown for "MIP Landau", "#eh/um", "Range [um]", "Duration [ns]", "E [keV]", "X[um], Angle[D]", "Y[um]", "Rnd", and "Number of Particles".
- Irradiation:** Includes "Fluence [10<sup>14</sup> neq /cm<sup>2</sup>]", "Irradiation with:" (neutrons, protons/pions), "CCE beta electron, holes", "Acceptor creation", "Init. dop. removal", "Fluence:", "DJ ON", "Linear/Step", "N\_{Eff}[0-100]", and "N\_A/N\_D".
- Plot Settings:** Includes checkboxes for "Draw Electric Field", "Draw Current Absolute Value", and "Draw e-h motion".
- Current Settings:** Includes checkboxes for "B-Field on. Tesla (Positive = entering the plot)", "Diffusion", "Charge Cloud Dispersion (no Alpha)", and "Temperature [K]".
- Detector Properties:** Includes "Type" (Si, Diamond, Free), "Doping type" (Strips: n, p; Bulk: n, p), "Dimensions" (# of strips, Thickness, Width, Pitch), "Gain" (No gain layer implant, Massey model, Gain Layer peak doping, Force Gain, Gain recess), and "Voltage" (Bias, Depletion).
- Read-Out:** Includes "Top Strip" and "Backplane".
- Electronics:** Includes "ON" checkbox, "Generic CS/" dropdown, "Detector Cap[pF] Ind [nH]", "Scope (50 [Ohm]) BW[GHz]", "CSA:Imp[Ohm],Tr.Imp[mV/IC]", "CSA(Cdet=0)T\_r,(10-90%)[ns]", "CSA:Noise,Vth[mV,CFD if<1]", "BB:Imp[Ohm],BW[GHz],Gain", and "BB:Noise,Vth[mV,CFD if<1]".

# WF2: Radiation damage



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

Done: Current = 0 at Time = 1.5101 ns

Run:

Precision: eh pairs followed (1= Most precise, 100 = Fastest):

Time Step [ps]:  Step x,y [micron]:

Output files for signals:  ON Name:

Batch Mode:  ON Number of events:

Select Particles: MIP Landau

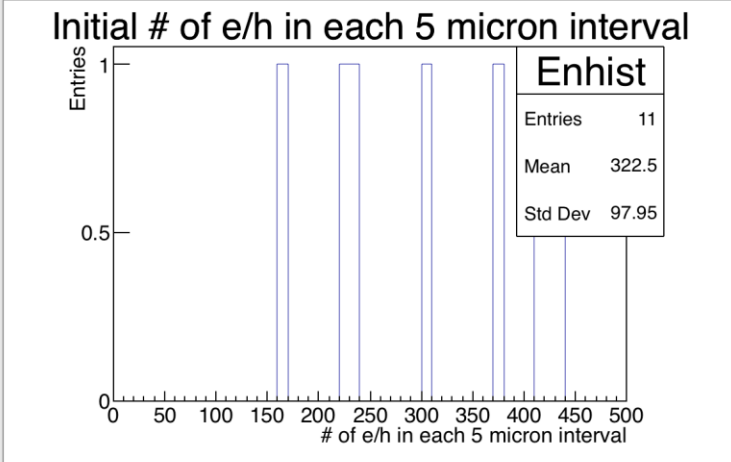
#eh/um Range [um] Duration [ns] E [keV]:

X[um], Angle[D] Y[um]:     Rnd

Number of Particles:

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

Initial # of e/h in each 5 micron interval



Enhist	
Entries	11
Mean	322.5
Std Dev	97.95

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

Detector Properties

Type:  Si  Diamond  Free

Doping type: Strips  n  p Bulk  n  p

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

Gain: Boron + Carbon Deep doping: a square @ 0.6 -1.6 micron Massey model Gain Layer peak doping [ $10^{16}/\text{cm}^3$ ]:  Force Gain  Gain recess (um):

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

Read-Out:  Top Strip  Backplane

Electronics:  ON Generic CS/ Detector Cap[pF] Ind [nH]:   Scope (50 [Ohm]) BW[GHz]:  CSA:Imp[Ohm], Tr.Imp[mV/fC]:   CSA(Cdet=0)T\_r,f(10-90%)[ns]:   CSA:Noise,Vth[mV,CFD if<1]:   BB:Imp[Ohm],BW[GHz],Gain:    BB:Noise,Vth[mV,CFD if<1]:

Irradiation: Fluence [ $10^{14}$  neq /cm<sup>2</sup>):  Irradiation with:  neutrons  protons/pions

CCE beta electron, holes:    Acceptor creation  Init. dop. removal; Fluence:   DJ ON  Linear  Step N\_A/N\_D:

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

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

# Evolution of the signal with fluence

The UFSD signal becomes

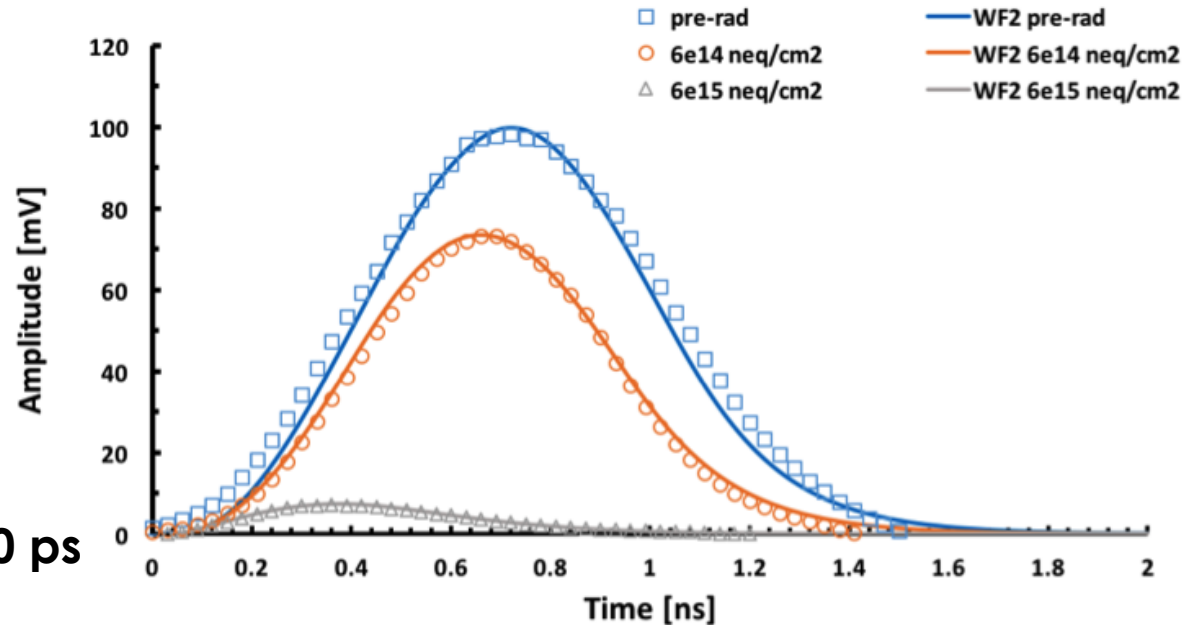
- Faster
- Shorter
- Smaller

Q: 10 fC  $\rightarrow$  2 fC

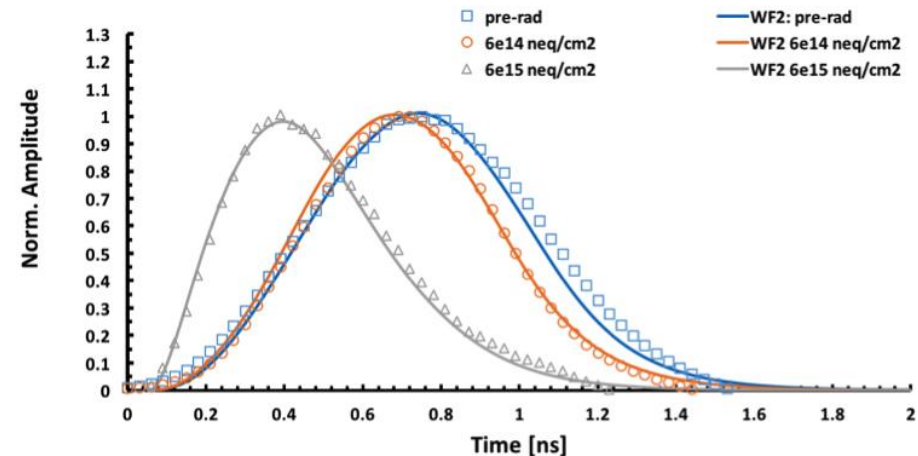
Rise time: 400 ps  $\rightarrow$  200 ps

**Be aware of ToT:** the signal tail changes dramatically with irradiation,  
**ToT might not work without constant calibration**  
 **$\rightarrow$  Use CFD**

Comparison measured - WF2 pulse of HPK 50-micron thick sensors



Comparison measured - WF2 pulse of HPK 50D 50-micron thick sensors



# Summary

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- The signal of UFSD for gain = 10 is 5 fC
- ➔ The range we need to consider is about 3 – 15 fC
- With 50-micron thick sensors we have ~ 30 ps intrinsic resolution
- Smaller intrinsic terms require thinner sensors