Timing capabilities of Ultra-Fast Silicon Detector

- Aide memoire of time resolution
- UFSD Timing capabilities
- Alternative design
- LHC interests

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With

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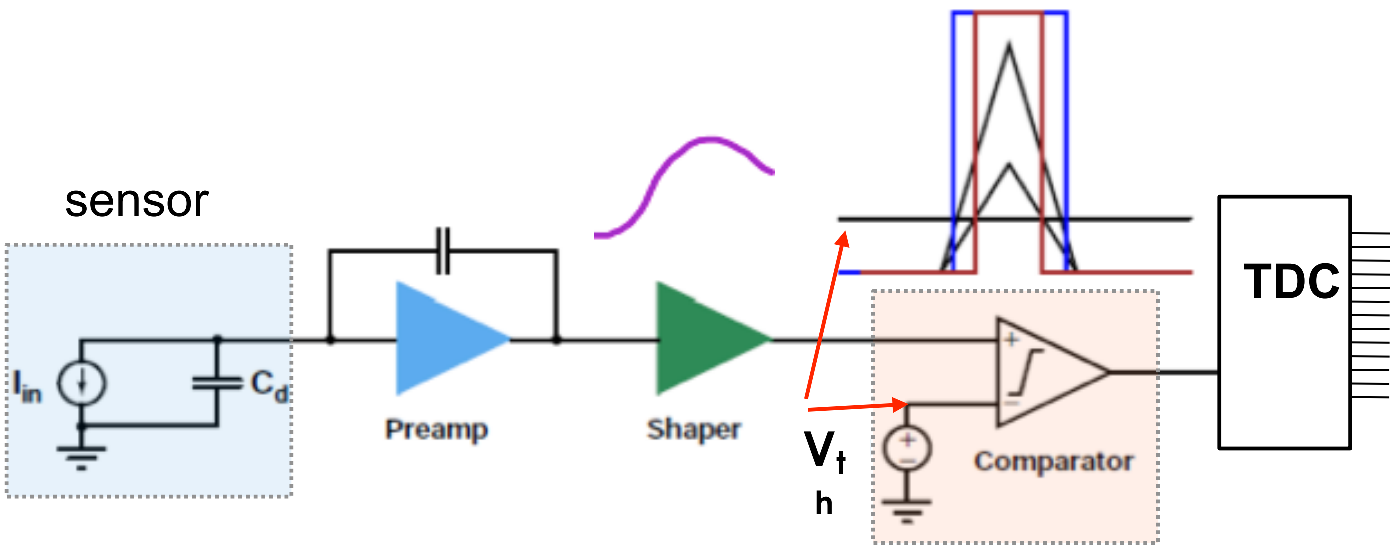
Time Tagging



The time is measured here

The timing capabilities are determined by the characteristics of the signal at the entrance of comparator and by the TDC binning:

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

Parameterization of Time Resolution

In a simple model approximation, we can write

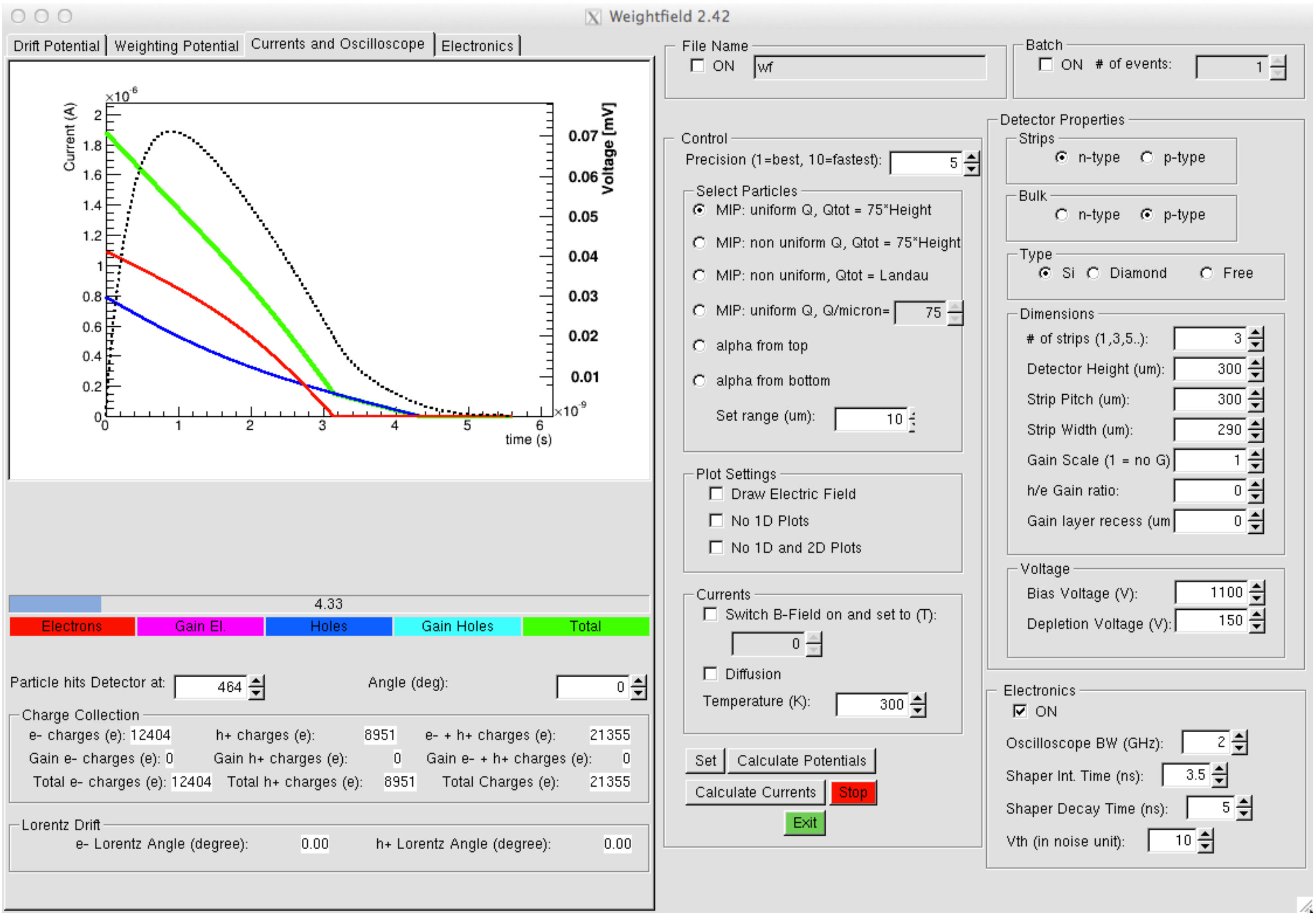
$$\sigma_t^2 = ([\frac{V_{th}}{S/t_r}]_{RMS})^2 + (\frac{N}{S/t_r})^2 + (\frac{TDC_{bin}}{\sqrt{12}})^2$$

Where:
- $S/t_r = dV/dt$
- N = system noise
- $V_{th} = 10$ N

To minimize the time resolution
we need to maximize the S/t_r term
(i.e. the slew rate dV/dt of the signal)

Weightfield2

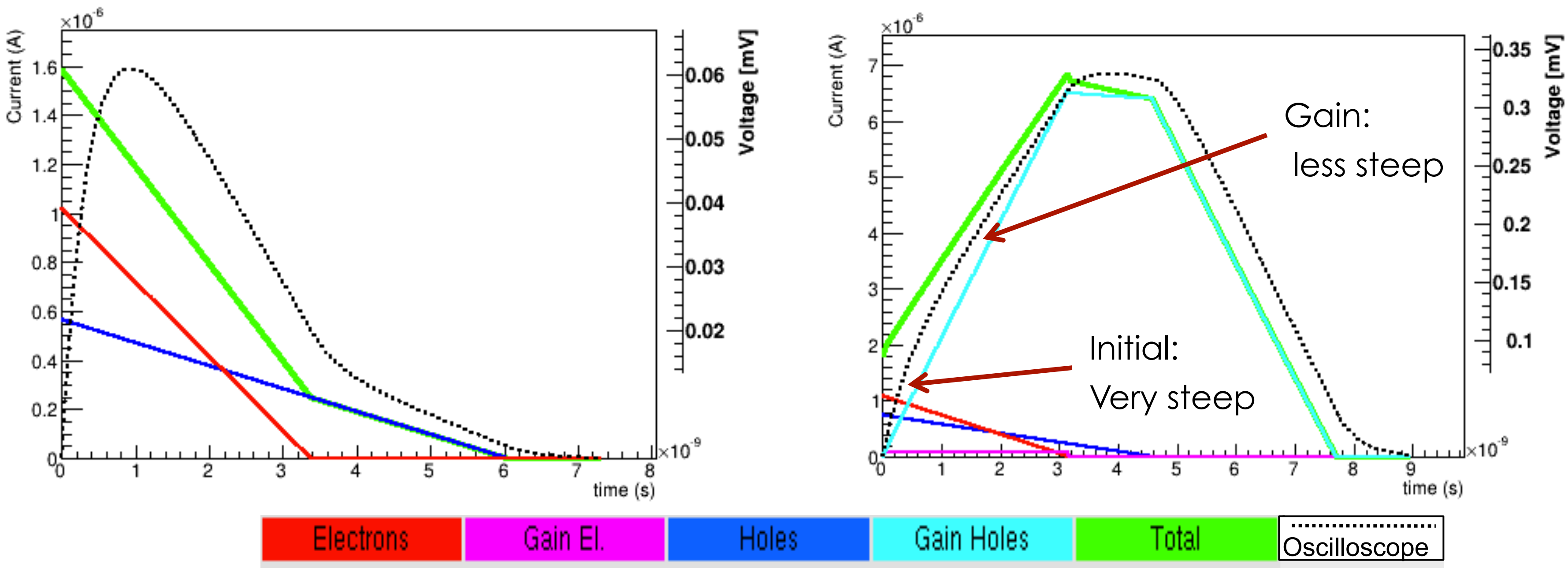
We use **Weightfield2** to simulate various configurations, and study how time resolution is affected by gain, geometry, fields…



Available at http://personalpages.to.infn.it/~cartigli/Weightfield2/

Signal shape: how to maximize dV/dt

Contributions to the total current as simulated by Weightfield2



Pads with no gain

Current only decreasing.
Rise time limited by electronics

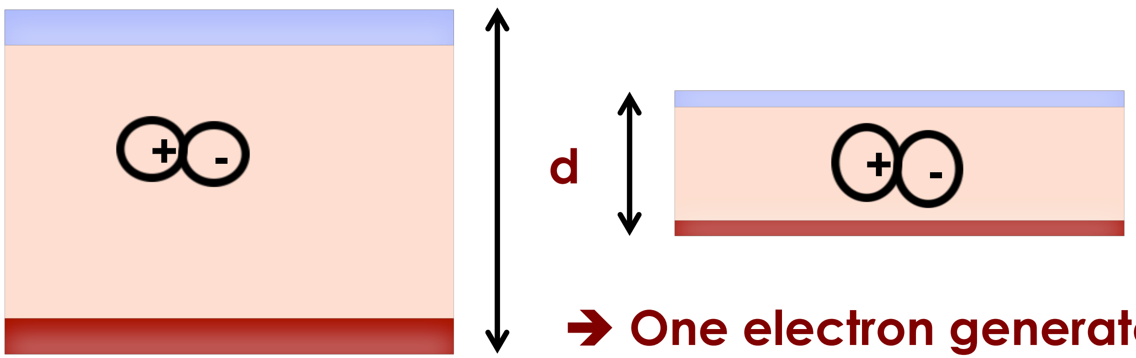
Pads with gain

Electrons entering the gain layer produce *e-h* pairs.
Current due to holes creates a longer and higher signal
Rise time limited by physics

dV/dt, gain and sensor thickness - I

(Simplified model for pad detectors)

1) The amplitude of the current generated **by a single e** (h) depends on the thickness *d* of the detector (via the weighting field):



$$i \propto qv\frac{1}{d}$$

➔ **One electron generates higher current in thin detectors** (while the integral is a constant = q)

2) The initial current for a silicon detector does not depend on how thick (d) the sensor is:

$$i = Nq\frac{k}{d}v = (75dq)\frac{k}{d}v = 75kqv \sim 1-2*10^{-6}A$$

Number of e/h = 75/micron

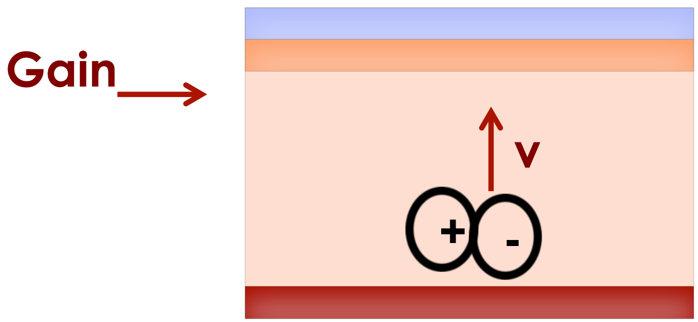
Weighting field

velocity

➔ **Initial current = constant**

dV/dt, gain and sensor thickness - II

3) The rate of particles produced by the gain does not depend on *d* (assuming saturated velocity v_{sat})



$$\frac{dN_{Gain}}{dt} \propto 75 G v_{sat}$$

Particles per micron

Gain

➔ Constant rate of production

4) The gain current depends on d (via the weighting field)

$$i_{gain} \propto \frac{dN_{Gain}}{dt} \frac{kq}{d} v_{sat}$$

➔ Gain current ~ 1/d

dV/dt, gain, and sensor thickness - III

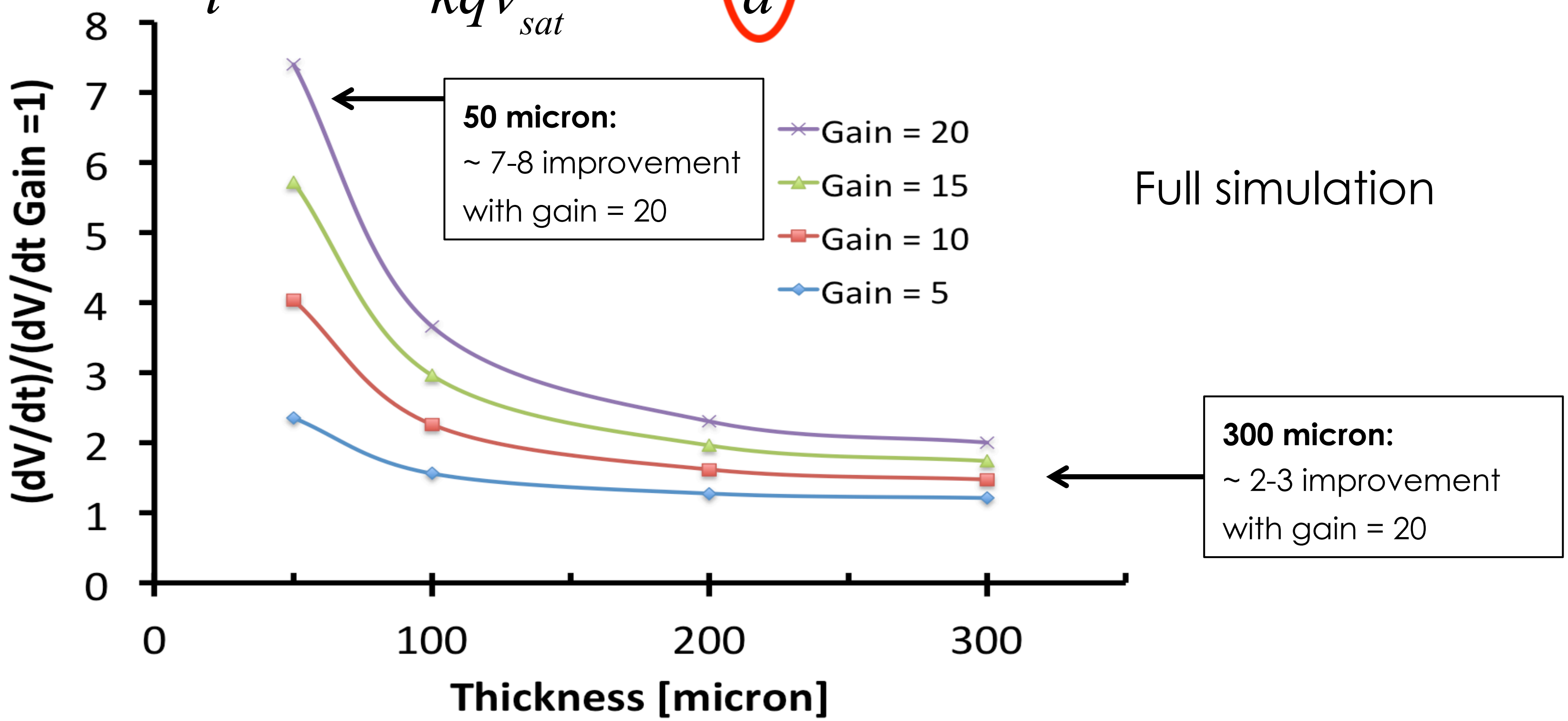
5) A given value of gain has much more effect on thin detectors:

$$\frac{i_{gain}}{i} \propto \frac{\frac{dN_{Gain}}{dt}\frac{kq}{d}v_{sat}}{kqv_{sat}} = \frac{G}{d}$$

!!!

➔ **Go thin!!**

(Real life is a bit more complicated, but the conclusions are the same)



Full simulation

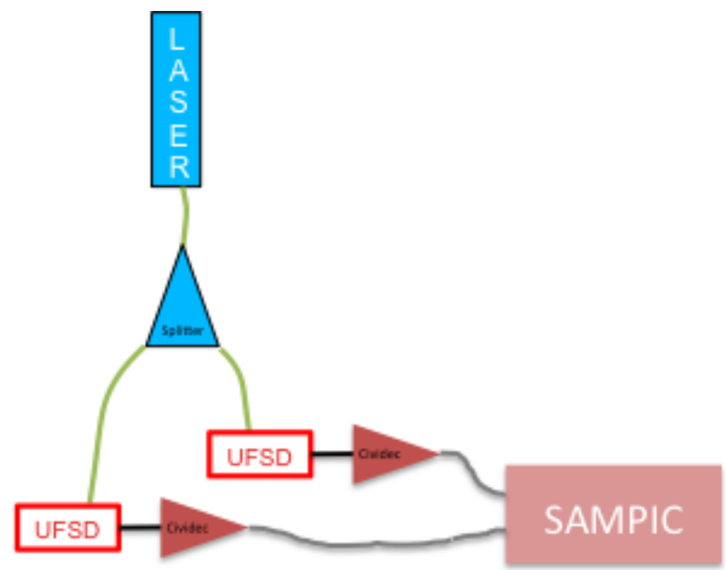
Significant improvements in time resolution require thin detectors

First Timing Measurement on CNM LGAD

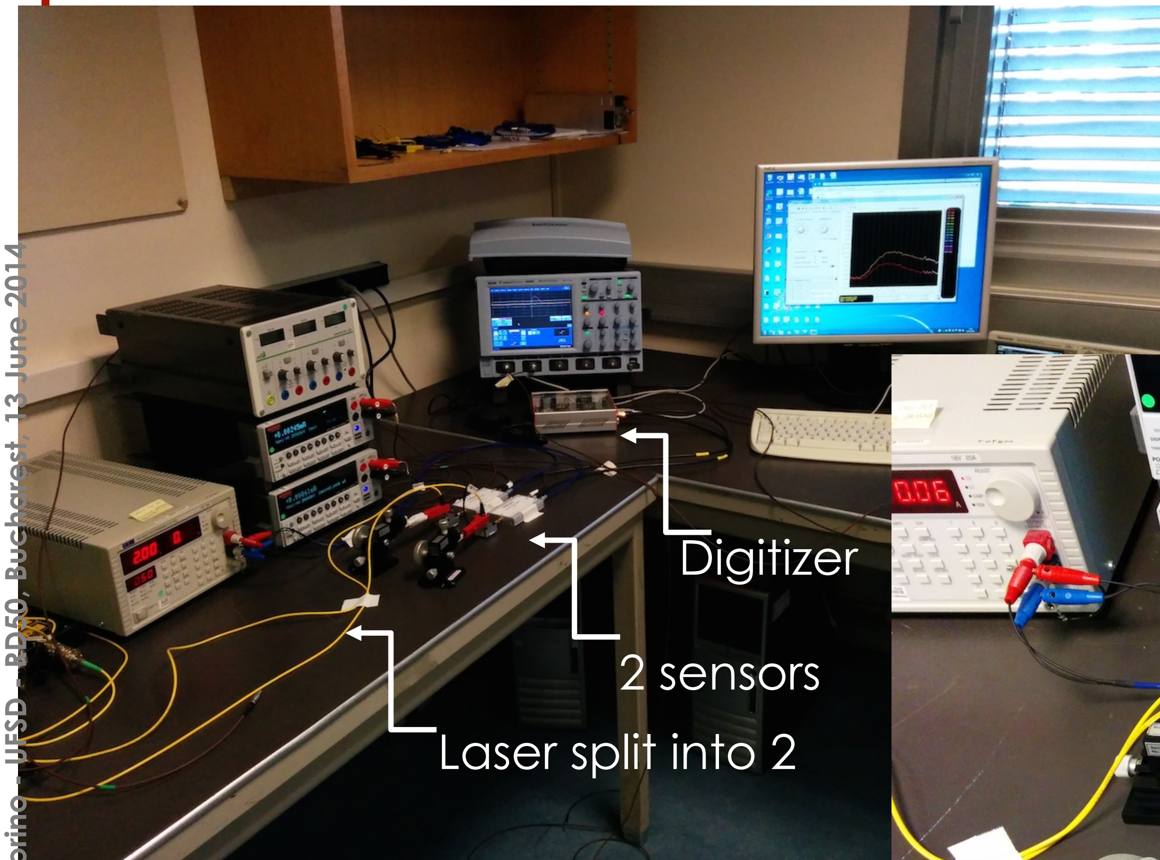
- First test organized at CERN: a very fruitful collaboration among TOTEM, ATLAS and CMS, aimed at evaluating the timing performance of UFSD, diamond detector and a custom read-out chip (SAMPIC).
- Two LGAD sensors have been illuminated with a split laser signal (wl =1064 nm), and the time difference has been measured

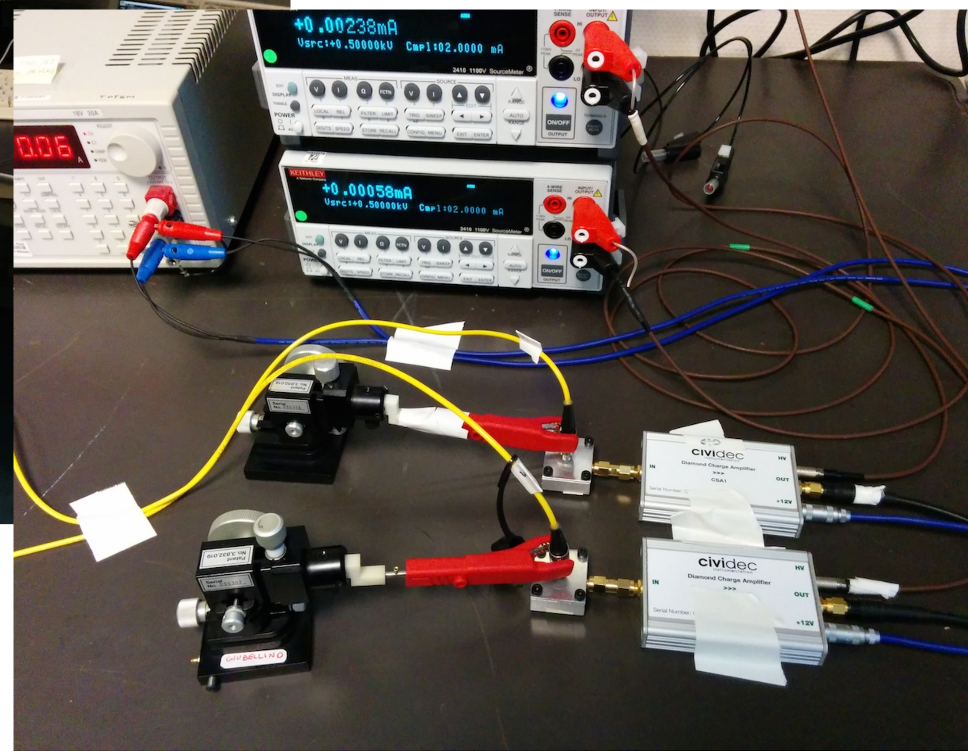
→ estimate of time jitter

The setup comprised of:
- 2 UFSD sensors (LGAD pad 5x5 mm^2 – 300 micron thick)
- 2 CIVIDEC broadband amplifiers , 2 GHz (180 ps rise time), 2 mV of noise
- waveform digitizer: SAMPIC – a **SAM**pler for **PIC**osecond time measurement



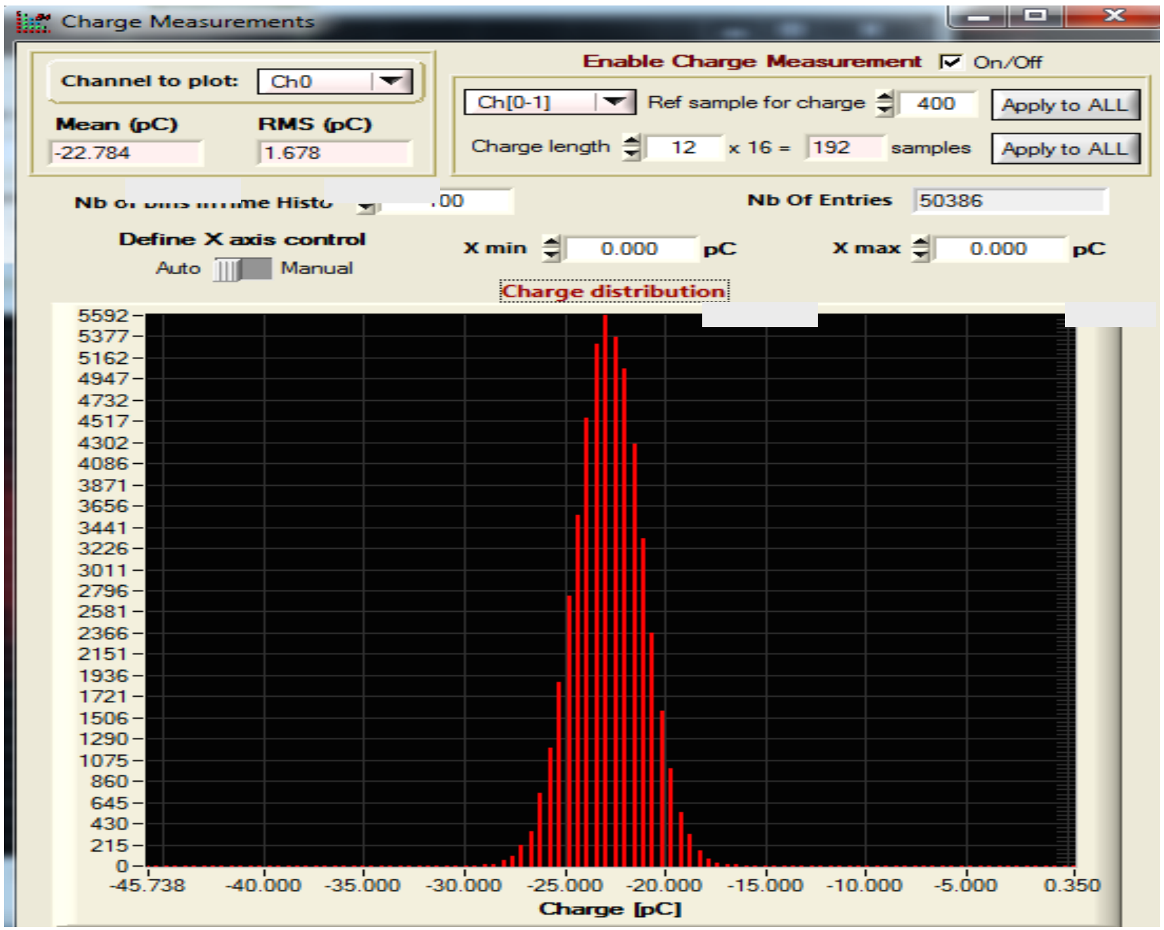
Experimental Setup





Timing Measurements: signal stability

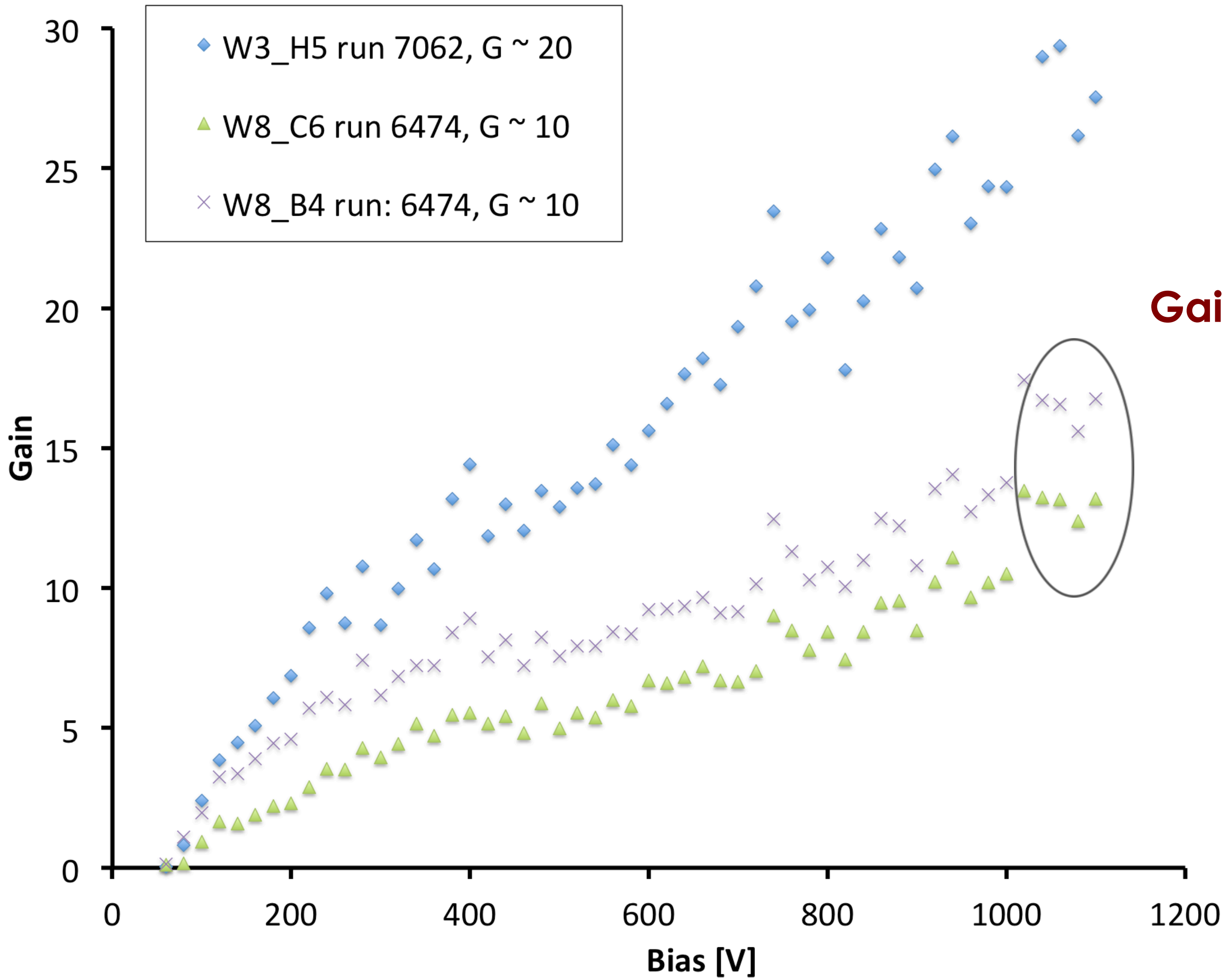
Is the gain mechanism stable?



Mean 22.784 fC
RMS 1.678 fC

Very stable multiplication mechanism ~ 7%

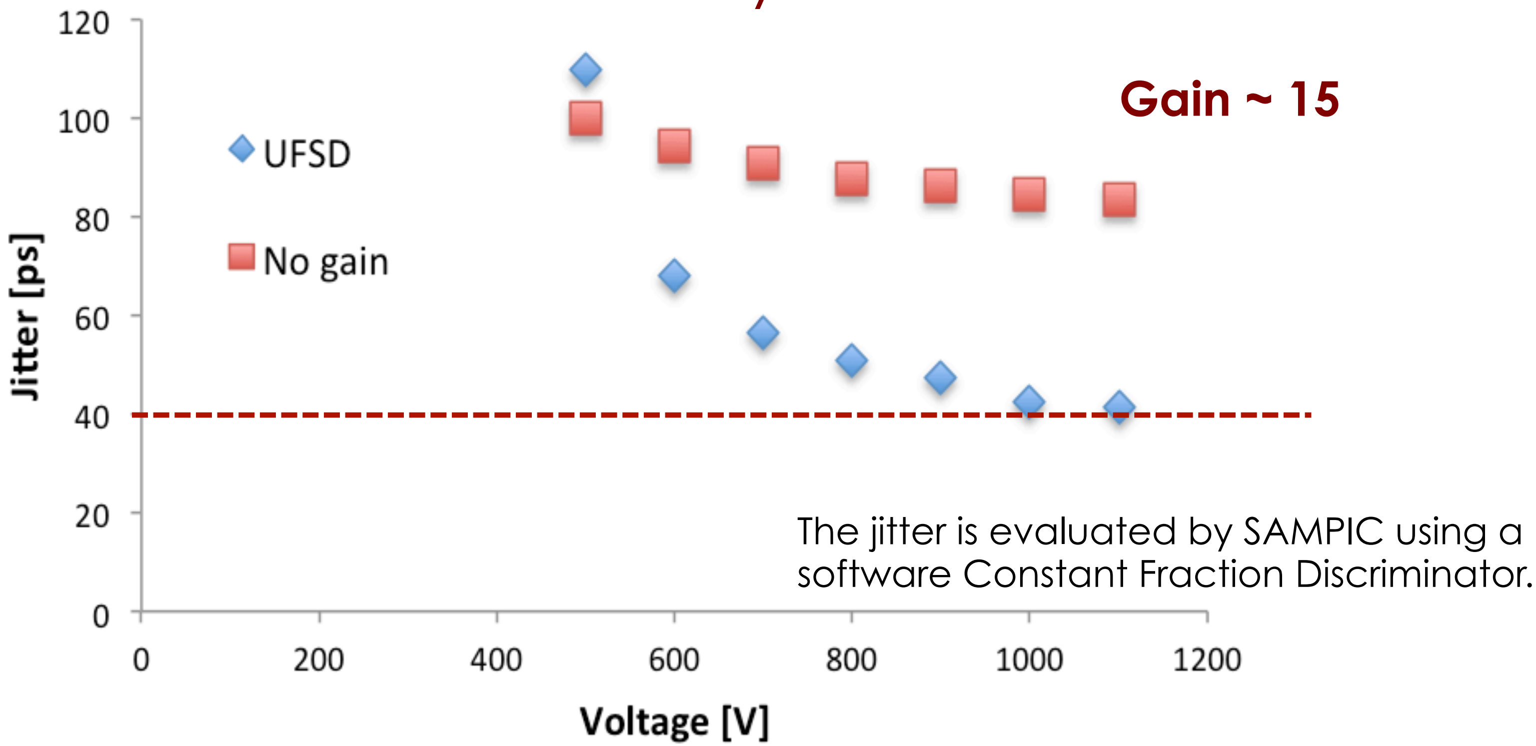
Sensors used



Gain ~ 15

Time Resolution vs Vbias

Laboratory Results



This result is consistent with the simulation predictions:

300-micron thick UFSDs with gain of ~ 15 improve by ~ 2 the timing resolution

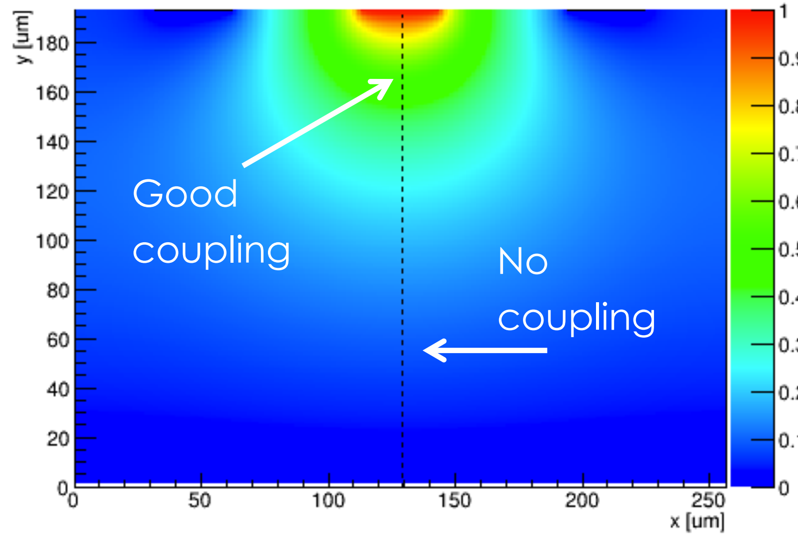
Geometry optimization

The weighing field favors geometries in which multiplication happens near the read-out electrode, unless:

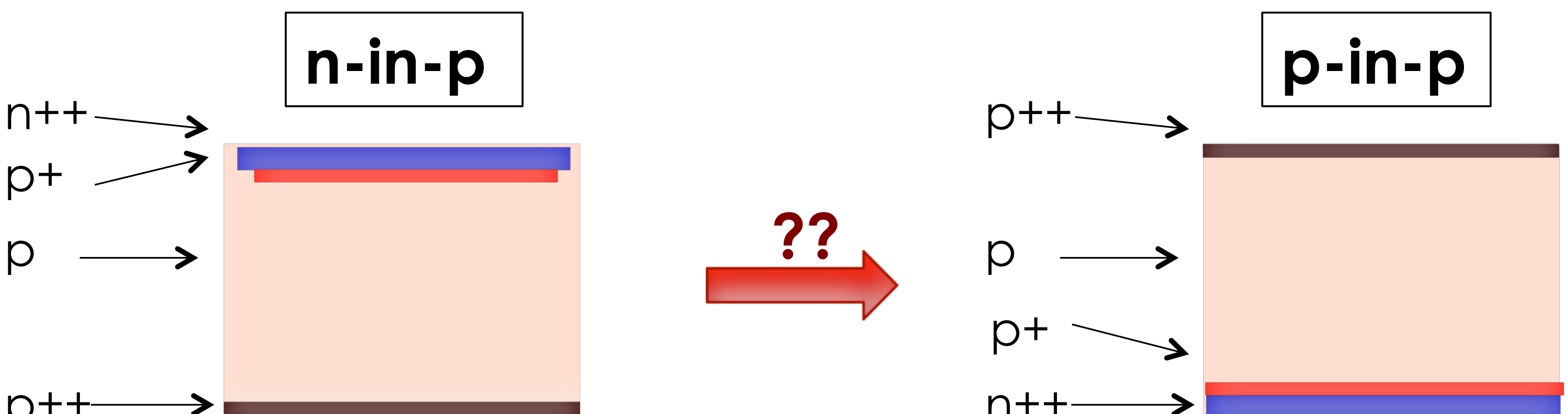
- The detectors are very thin

  or

- They are large pads



Under these conditions, can we use for timing applications p-in-p instead of n-in-p ?



dV/dt for large pads n-in-p vs p-in-p

n*dV/dt	d	Gain n-in-p	Gain p-in-p	Ratio
2	50	3.9	6.	1.5
2	100	8.4	10	1.2
2	200	16.1	19	1.2
2	300	20	27	1.3

n*dV/dt	d	Gain n-in-p	Gain p-in-p	Ratio
4	50	9.4	14	1.5
4	100	23.5	26	1.1
4	200	47	52	1.1
4	300	~100	-	-

p-in-p needs more gain: ~ 1.2 times that of n-in-p

LHC interest

Very strong interest from LHC experiments:

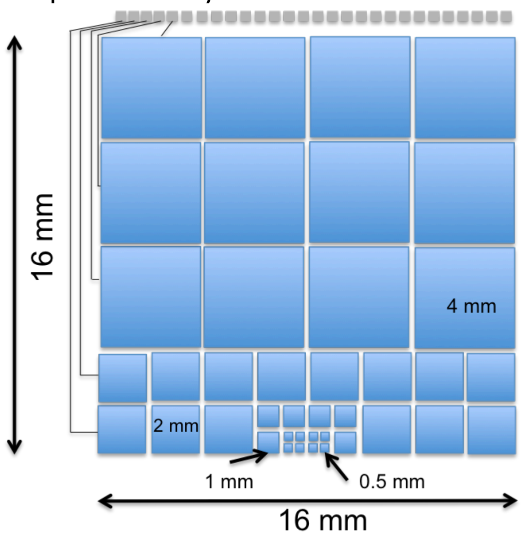
good fit for TOTEM, ATLAS-AFP and CMS-PPS needs.

Necessary steps for deployment:

- Need rad-hard version, ~10^{15} neq/cm^2
- Realization of multipad geometries
- Production of thinner detectors
- Tests with real beams
- Optimized read-out scheme

TOTEM, AFP, PPS geometry

(simplified layout, not the real one)



Summary

- **We measured a jitter of 40 ps** for a 300-micron thick pad LGAD detectors
- Extrapolations indicate that a resolution of ~ 20 ps can be achieved: thin detectors require much smaller gain

A breakthrough in timing capabilities requires

thicknesses ~< 100 micron

- p-in-p design needs 20-30% higher gain
- Testbeams:
  - Now @ PSI
  - end of July (PS)
  - October (SPS)
  - Requested Micro Ion Beam at Legnaro, (step of 1 micron)

Acknowledgement

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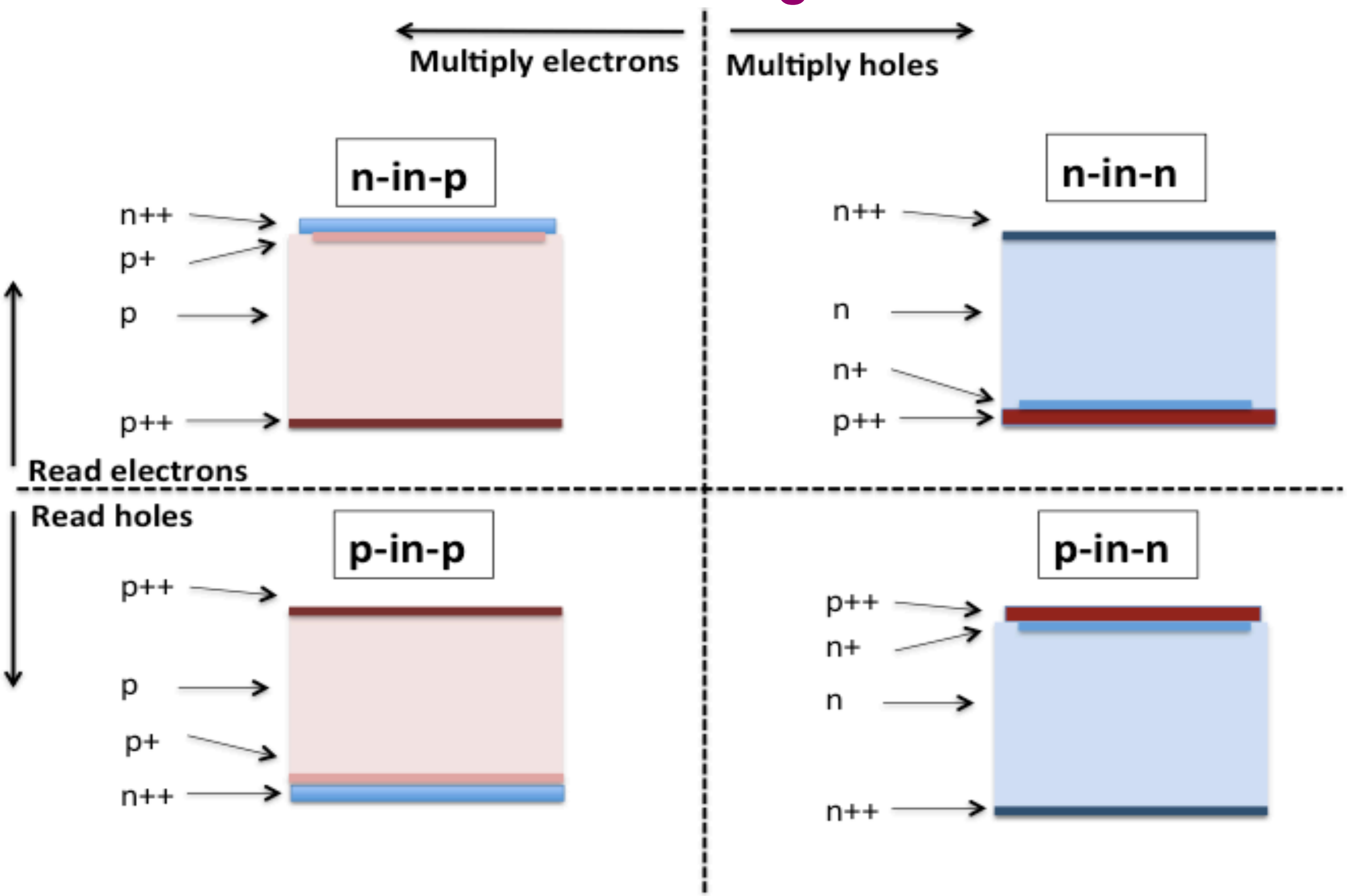
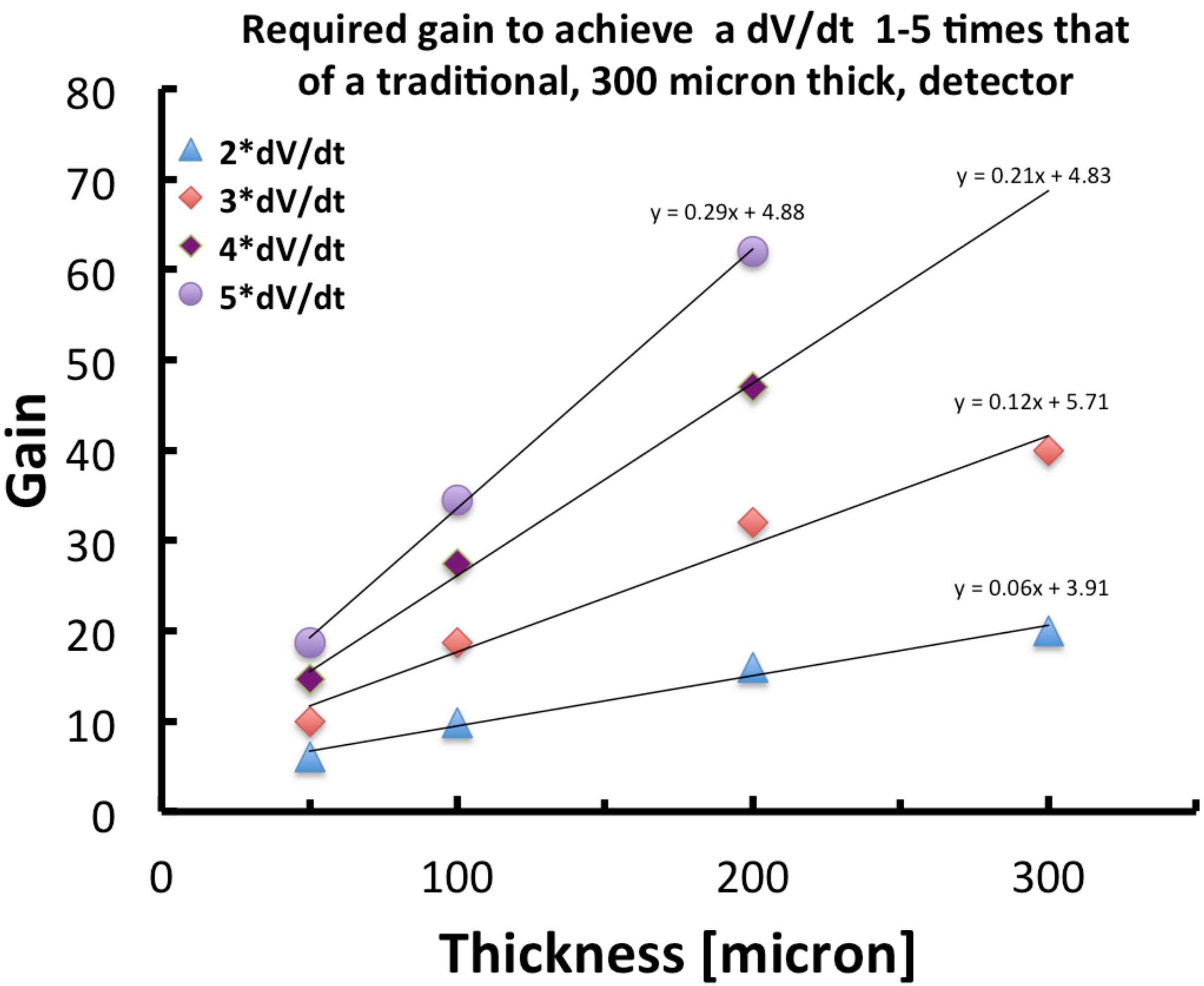
Backup

New directions

- **New designs for the gain layer position/doping under investigation**



Full Simulation Results



n*dV/dt	d	Gain
2	50	3.9
2	100	8.4
2	200	16.1
2	300	20

n*dV/dt	d	Gain
4	50	9.4
4	100	23.5
4	200	47
4	300	~100

Gain extraction comparing gain/no gain