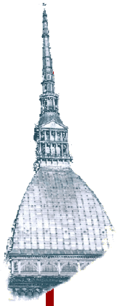
Ultra-Fast Silicon Detector

This report is a summary of what was shown at IEEE.

Nicolo Cartiglia

With
LGAD group of RD50

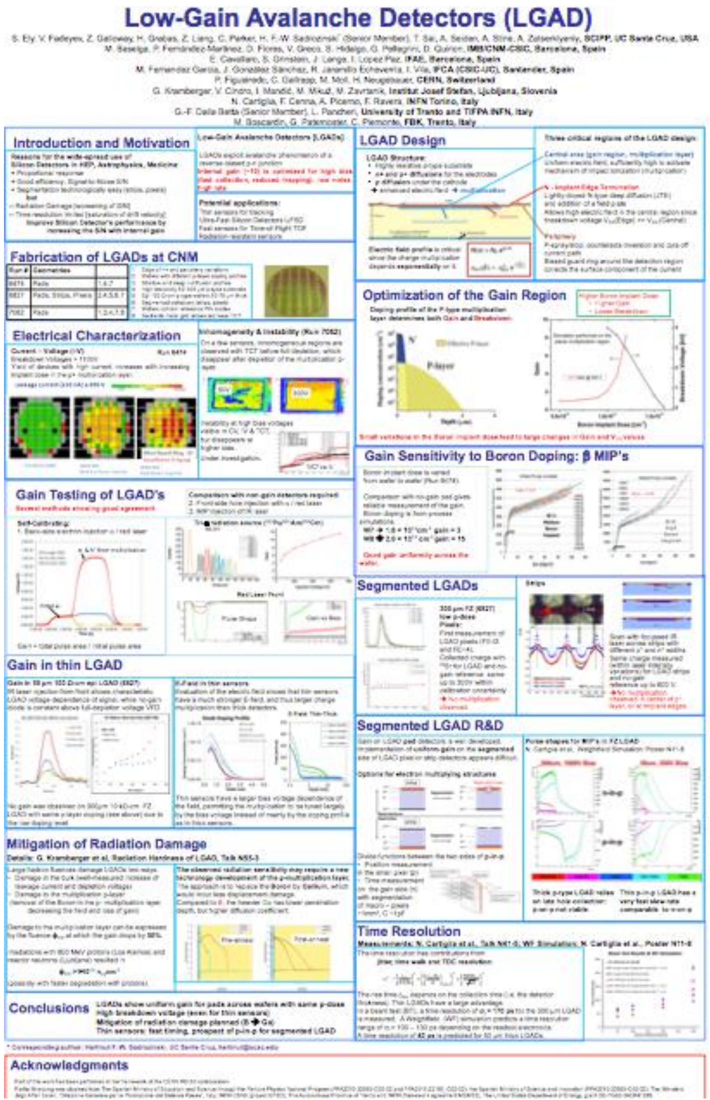


The "Low-Gain Avalanche Detector" project

Is it possible to manufacture a silicon detector that looks like a normal pixel or strip sensor, but

with a much larger signal (RD50)?

- 730 e/h pair per micron instead of 73 e/h
- Finely segmented
- Radiation hard
- No dead time
- Very low noise (low shot noise)
- No cross talk



Low-Gain Avalanche Detectors (LGAD)

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Introduction and Motivation

LGAD Design

Fabrication of LGADs at CNM

Optimization of the Gain Region

Electrical Characterization

Gain Sensitivity to Boron Doping: β MIP's

Gain Testing of LGAD's

Segmented LGADs

Gain in thin LGAD

Segmented LGAD R&D

Mitigation of Radiation Damage

Time Resolution

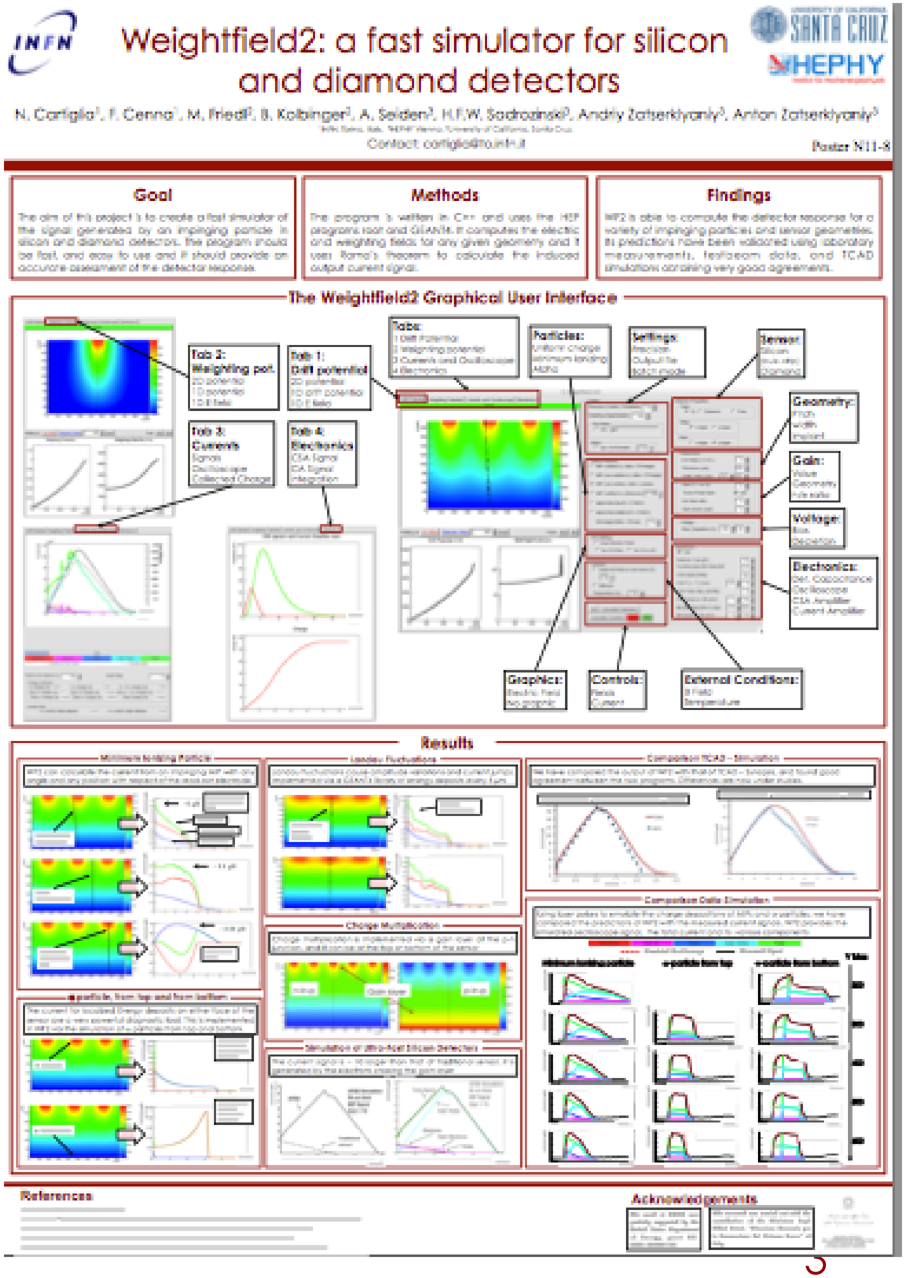
Conclusions

Acknowledgements

Poster Session IEEE N26-13

How can we progress? Need simulation

We developed a full simulation program to optimize the sensor design, WeightField2, (http://cern.ch/weightfield2)



Weightfield2: a fast simulator for silicon and diamond detectors

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Poster N11-8

Goal

The aim of this project is to create a fast simulator of the signal generated by an impinging particle in silicon and diamond detectors. The program should be fast, and easy to use and it should provide an accurate assessment of the detector response.

Methods

The program is written in C++ and uses the HEP programs root and GEANT4. It computes the electric and weighting fields for any given geometry and it uses Ramo's theorem to calculate the induced output current signal.

Findings

WF2 is able to compute the detector response for a variety of impinging particles and sensor geometries. Its predictions have been validated using laboratory measurements, testbeam data, and TCAD simulations obtaining very good agreements.

The Weightfield2 Graphical User Interface

Results

References

Acknowledgements

It includes:

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

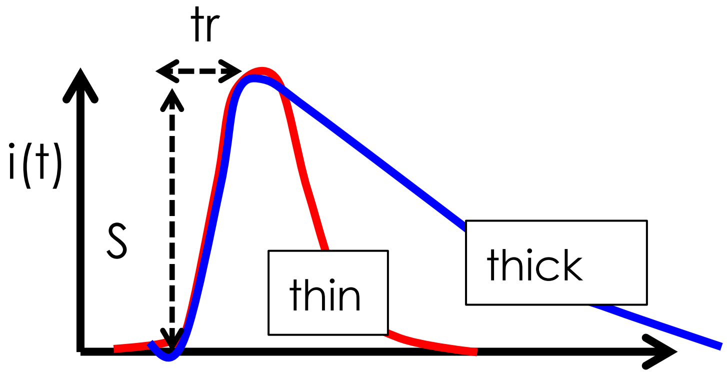
Poster Session IEEE N11-8

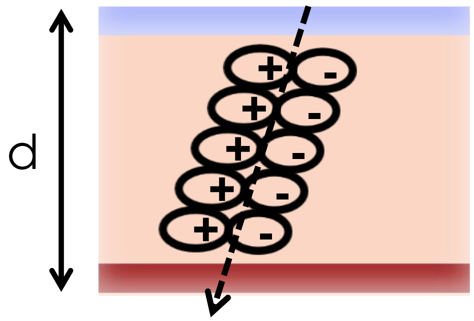
Signals in no-gain diode and LGAD sensors

(Simplified model for pad detectors)

No-gain diode: fix slew rate

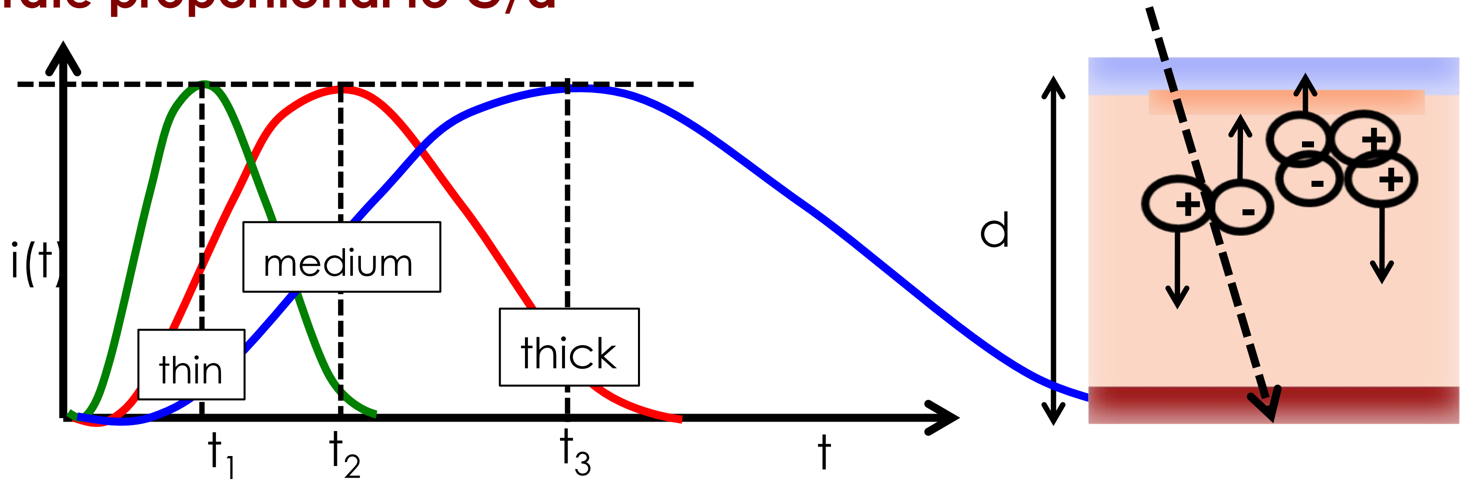
$$\frac{dV}{dt} \sim \frac{S}{t_r} \sim const$$





LGAD: slew rate proportional to G/d

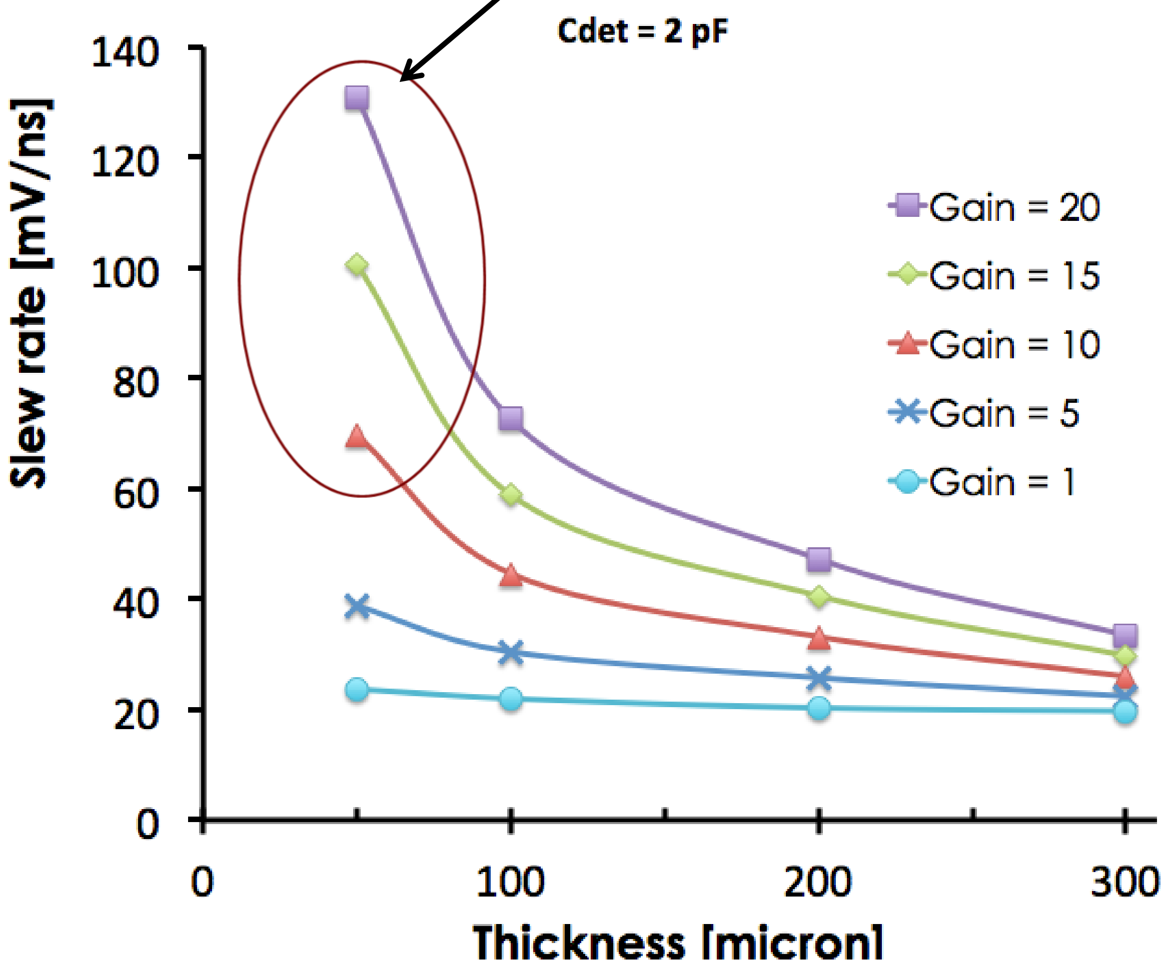
$$\frac{dV}{dt} \mu \frac{G}{d}$$



Slew rate as a function of sensor thickness

Large slew rate, good time resolutions

Weightfield2 simulation



300 micron:
~ 2-3 improvement with gain = 20

Significant improvements in time resolution require thin detectors

First Measurements and future plans

LGAD laboratory measurements

- Gain
- Time resolution measured with laser signals

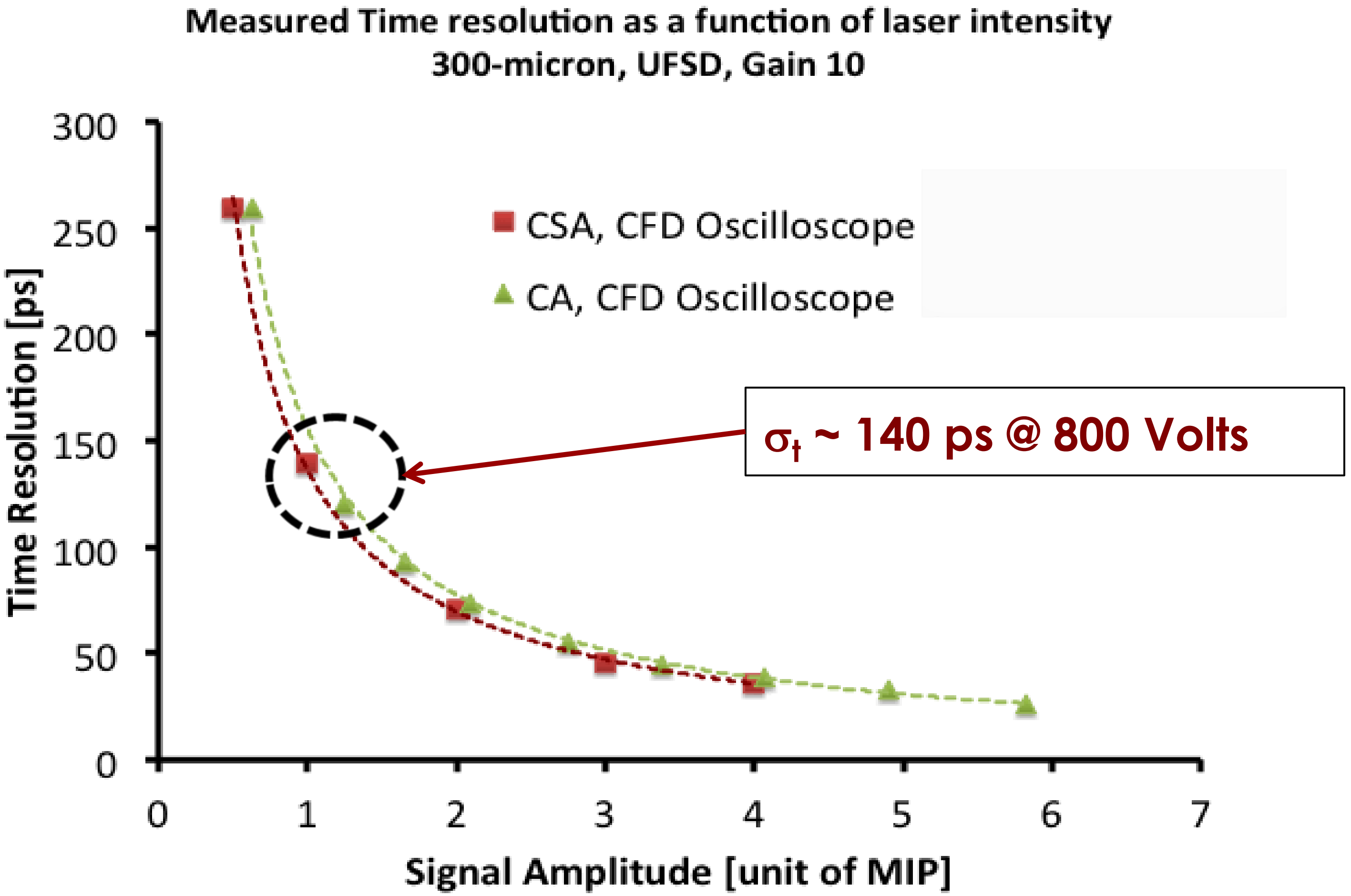
LGAD Testbeam measurements

- Landau shape at different gains
- Time resolution measured with MIPs

Laser Measurements on CNM LGAD

We use a 1064 nm picosecond laser to emulate the signal of a MIP particle (without Landau Fluctuations)

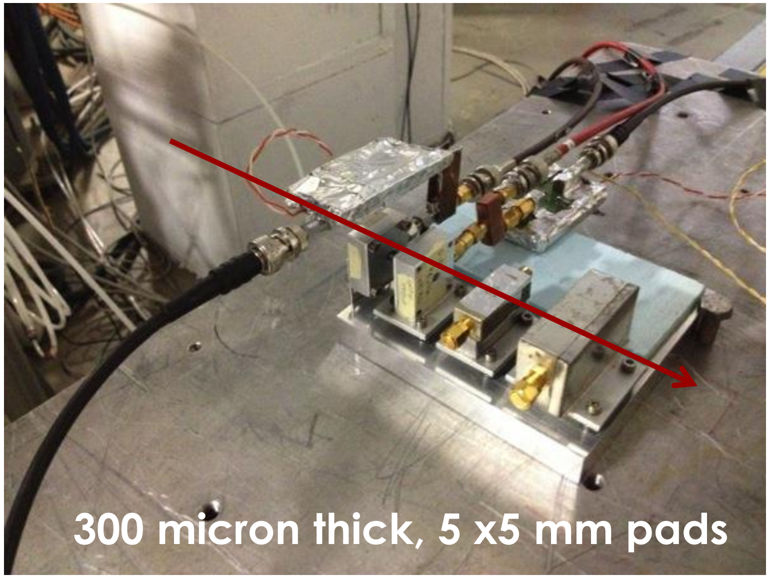
The signal output is read out by either a Charge sensitive amplifier or a Current Amplifier (Cividec)


Measured Time resolution as a function of laser intensity
300-micron, UFSD, Gain 10

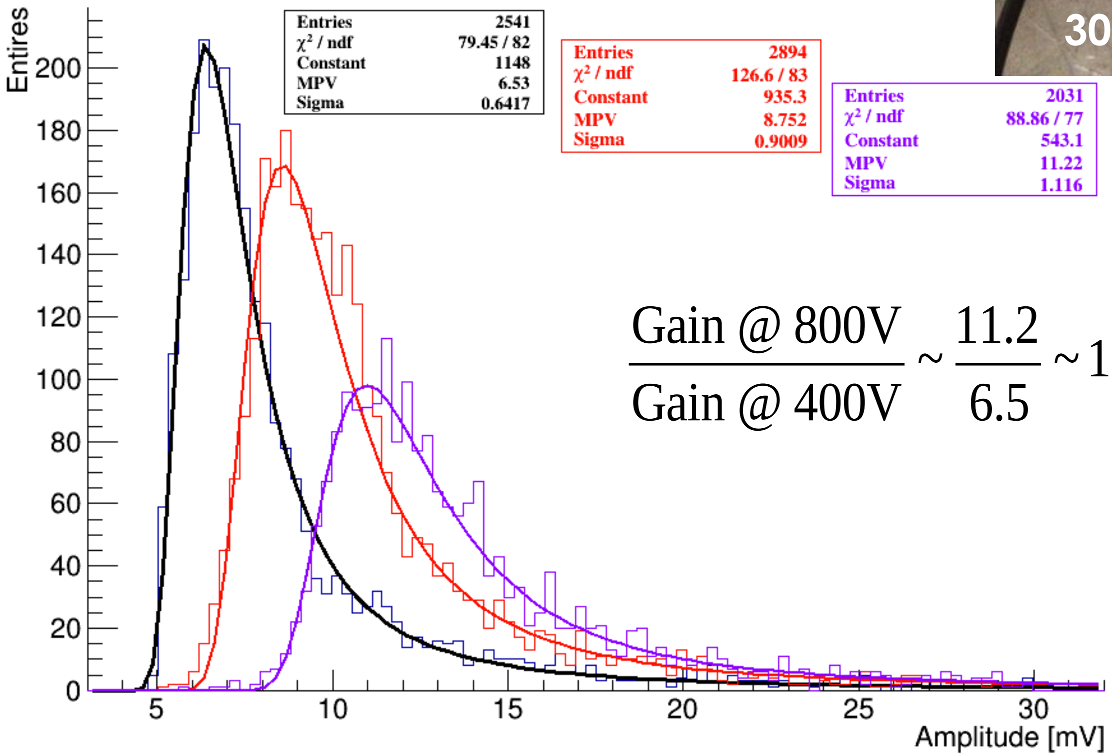
σ_t ~ 140 ps @ 800 Volts

Testbeam Measurements on CNM LGAD

In collaboration with Roma2, we went to Frascati for a testbeam using 500 MeV electrons


300 micron thick, 5 x5 mm pads

As measured in the lab, the gain ~ doubles going from 400 -> 800 Volt.



$$\frac{\text{Gain @ 800V}}{\text{Gain @ 400V}} \sim \frac{11.2}{6.5} \sim 1.7$$

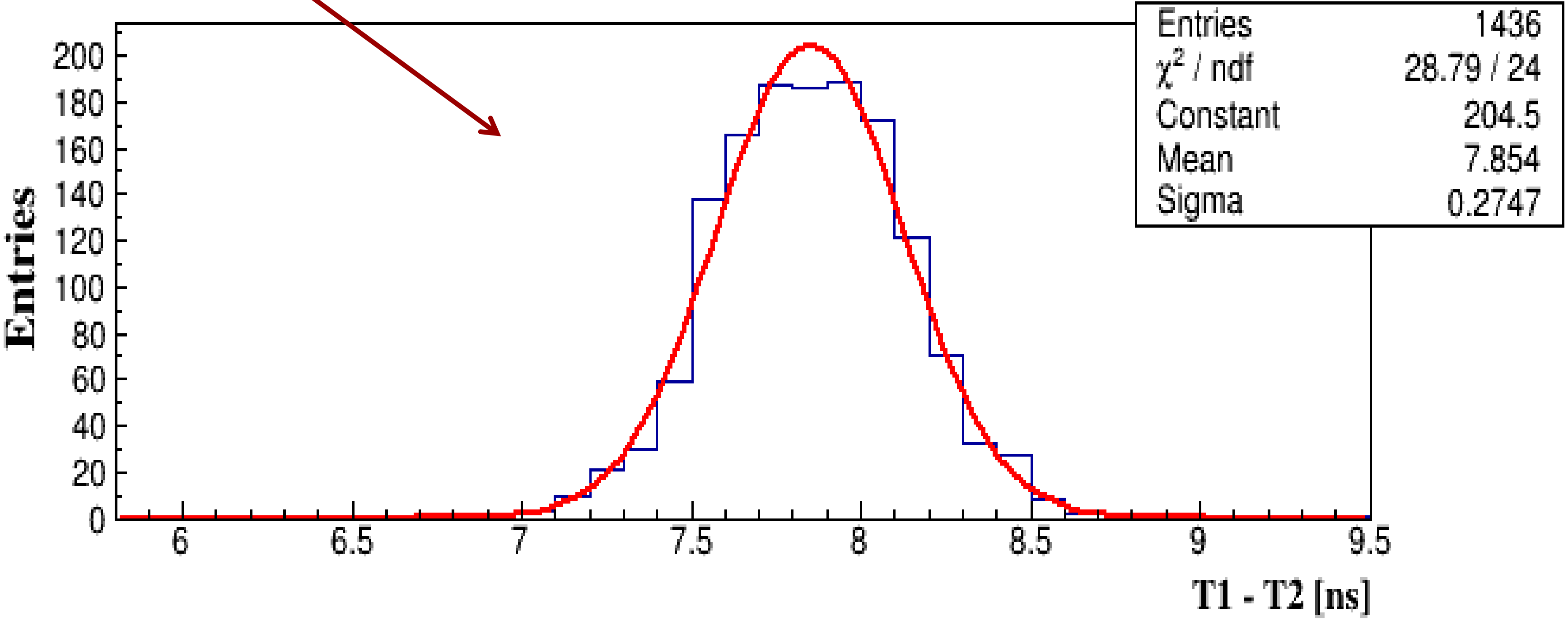
The gain mechanism preserves the Landau amplitude distribution of the output signals

Testbeam Measurements on CNM LGAD

Time difference between two LGAD detectors crossed by a MIP

Tested different types of electronics (Rome2 SiGe, Cividec),
Not yet optimized for these detectors

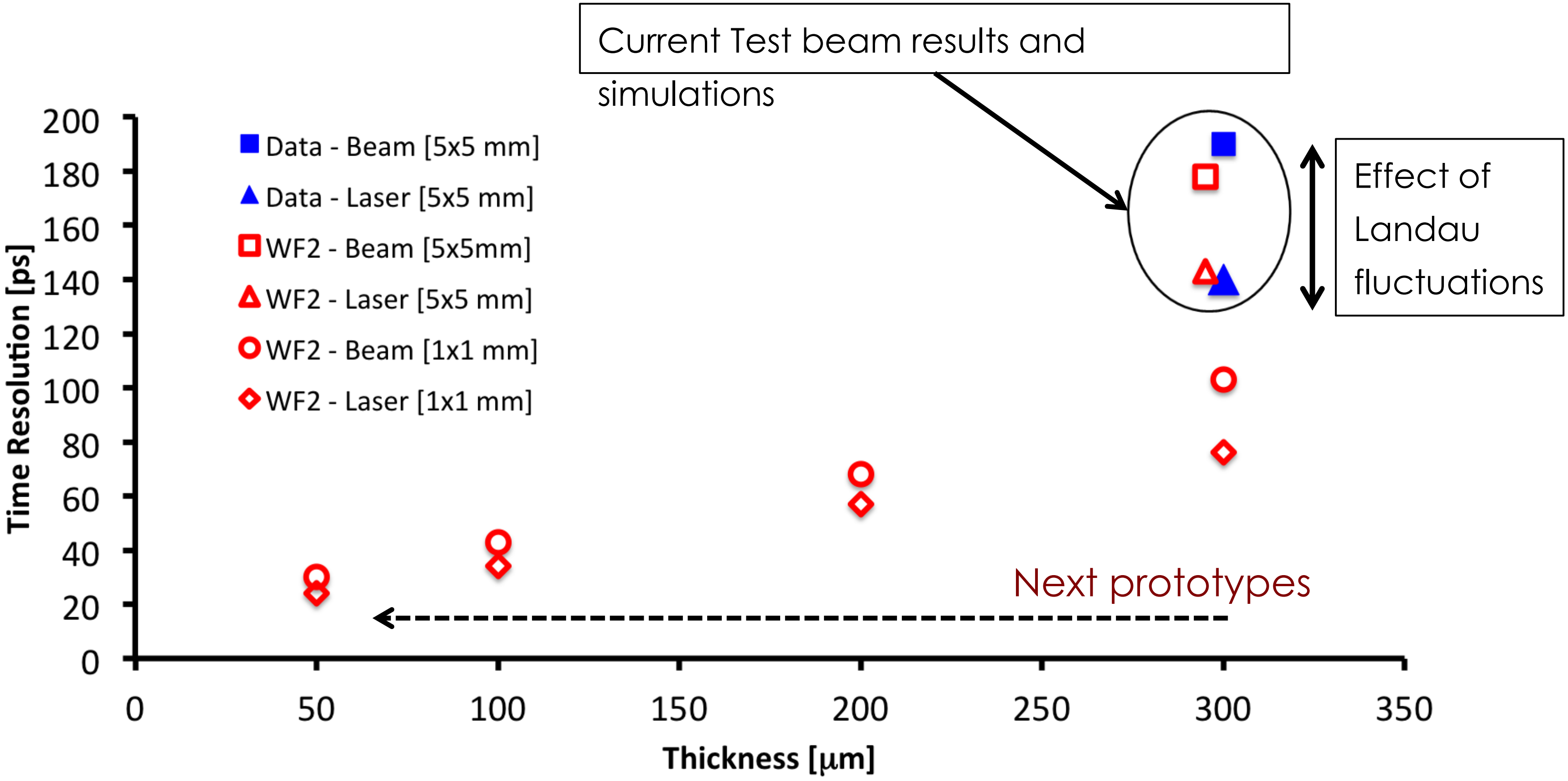
σ_t ~ 190 ps @ 800 Volts



Present results and future productions

With WF2, we can reproduce very well the laser and testbeam results.

Assuming the same electronics, and 1 mm^2 LGAD pad with gain 10, we can predict the timing capabilities of the next sets of sensors.



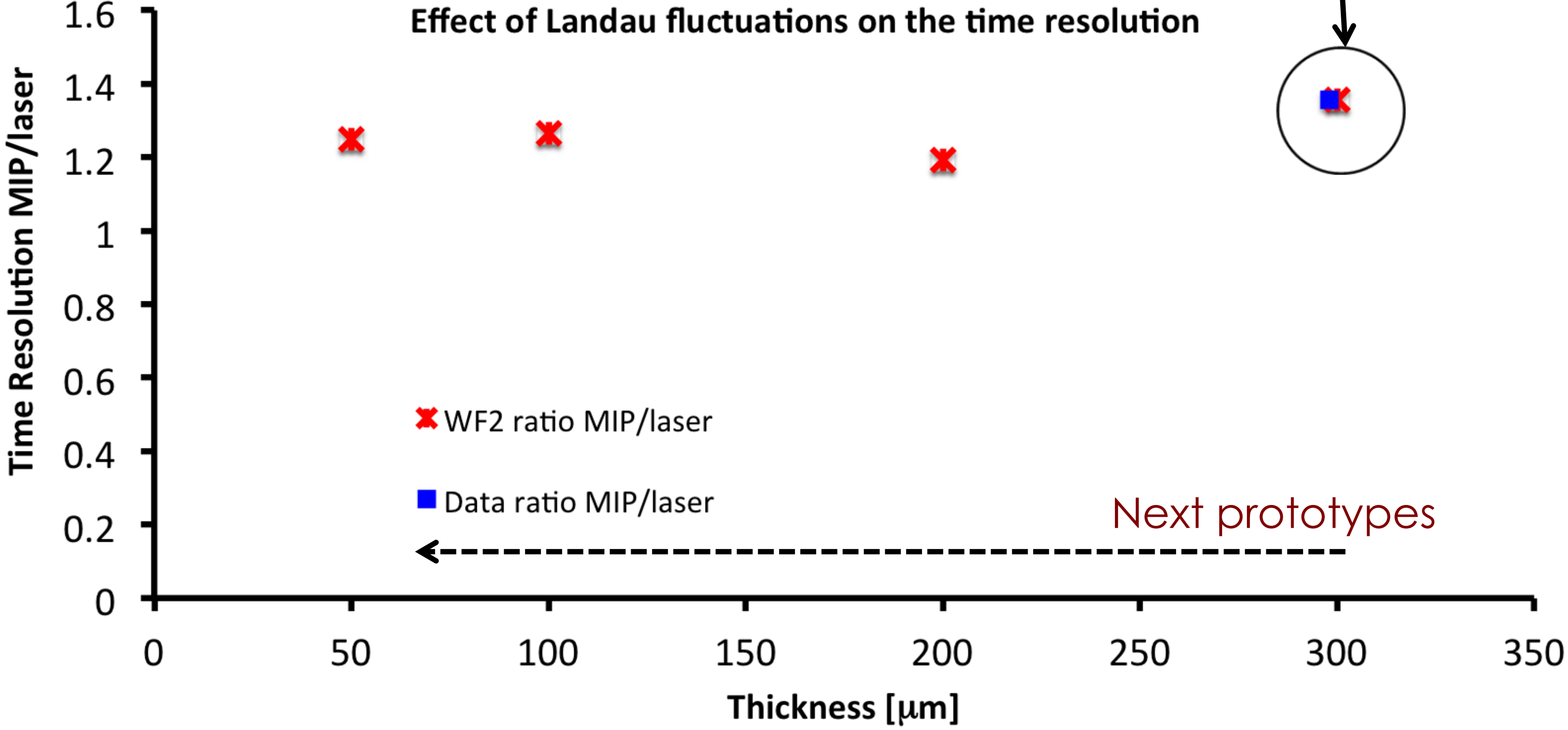
Current Test beam results and simulations

Effect of Landau fluctuations

Next prototypes

Effect of Landau Fluctuations on the time resolution

The effect of Landau fluctuations in a MIP signal are degrading the time resolution by roughly 30 % with respect of a laser signal



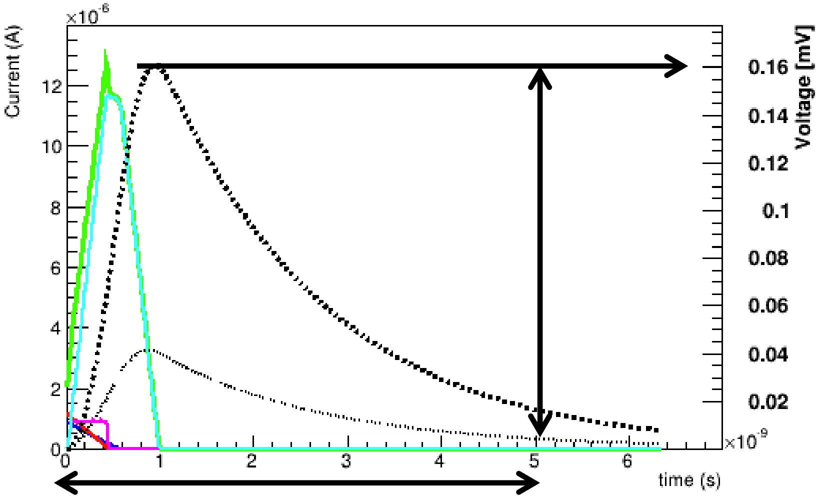
Current Test beam results and simulations

Next prototypes

Signal from a 50 micron-epi LGAD

WF2, 50 micron, 550V

Needs gain = 14!

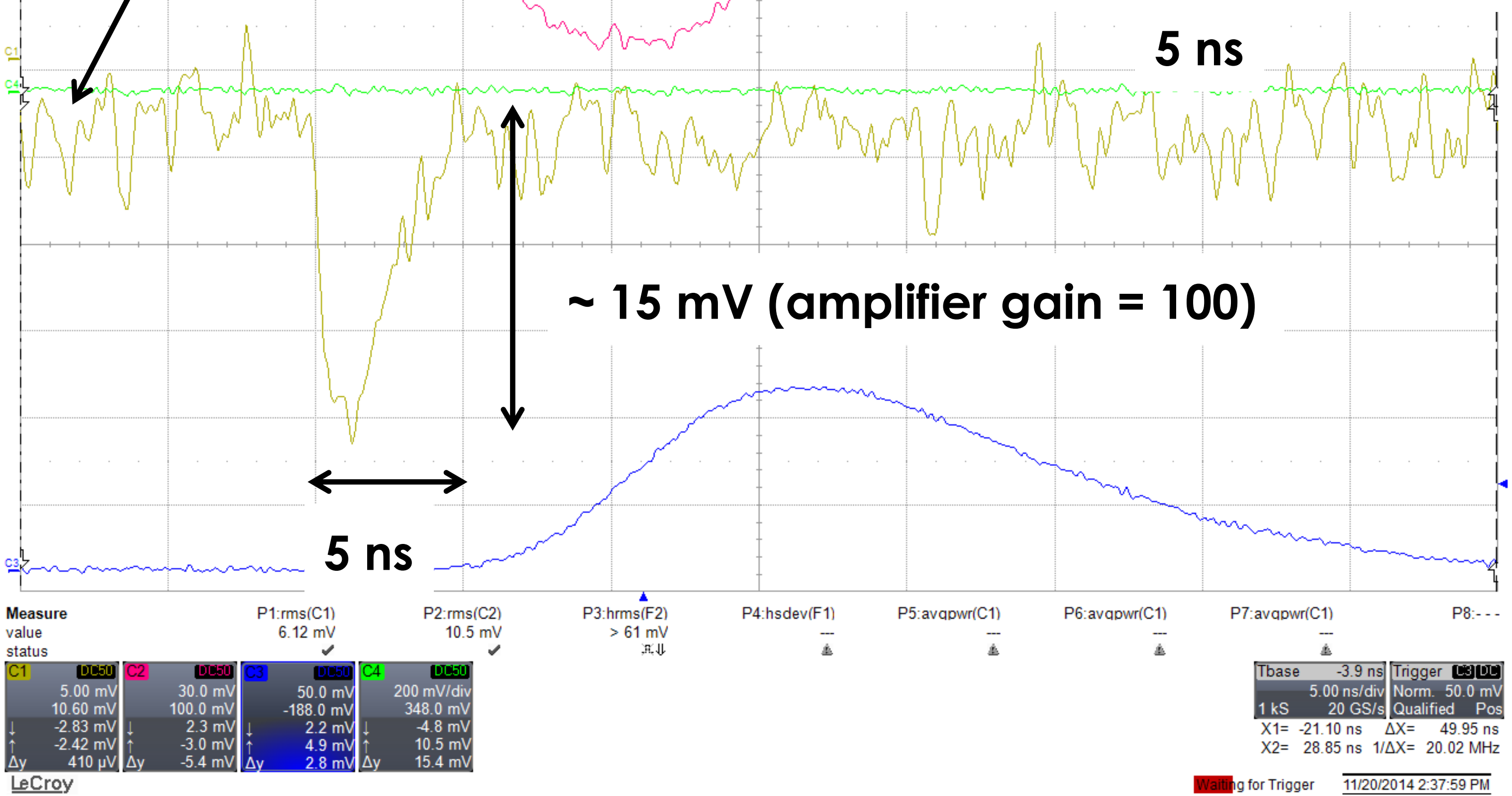


5 ns

Trace from a 50 micron epi

~ 15 mV (amplifier gain = 100)

5 ns



Measure	P1:rms(C1)	P2:rms(C2)	P3:hrms(F2)	P4:hsdev(F1)	P5:avgpwr(C1)	P6:avgpwr(C1)	P7:avgpwr(C1)	P8:- - -
value	6.12 mV	10.5 mV	> 61 mV	---	---	---	---	
status	✓	✓						

	C1 DC50	C2 DC50	C3 DC50	C4 DC50
	5.00 mV	30.0 mV	50.0 mV	200 mV/div
	10.60 mV	100.0 mV	-188.0 mV	348.0 mV
↓	-2.83 mV	2.3 mV	2.2 mV	-4.8 mV
↑	-2.42 mV	-3.0 mV	4.9 mV	10.5 mV
Δy	410 µV	-5.4 mV	2.8 mV	15.4 mV

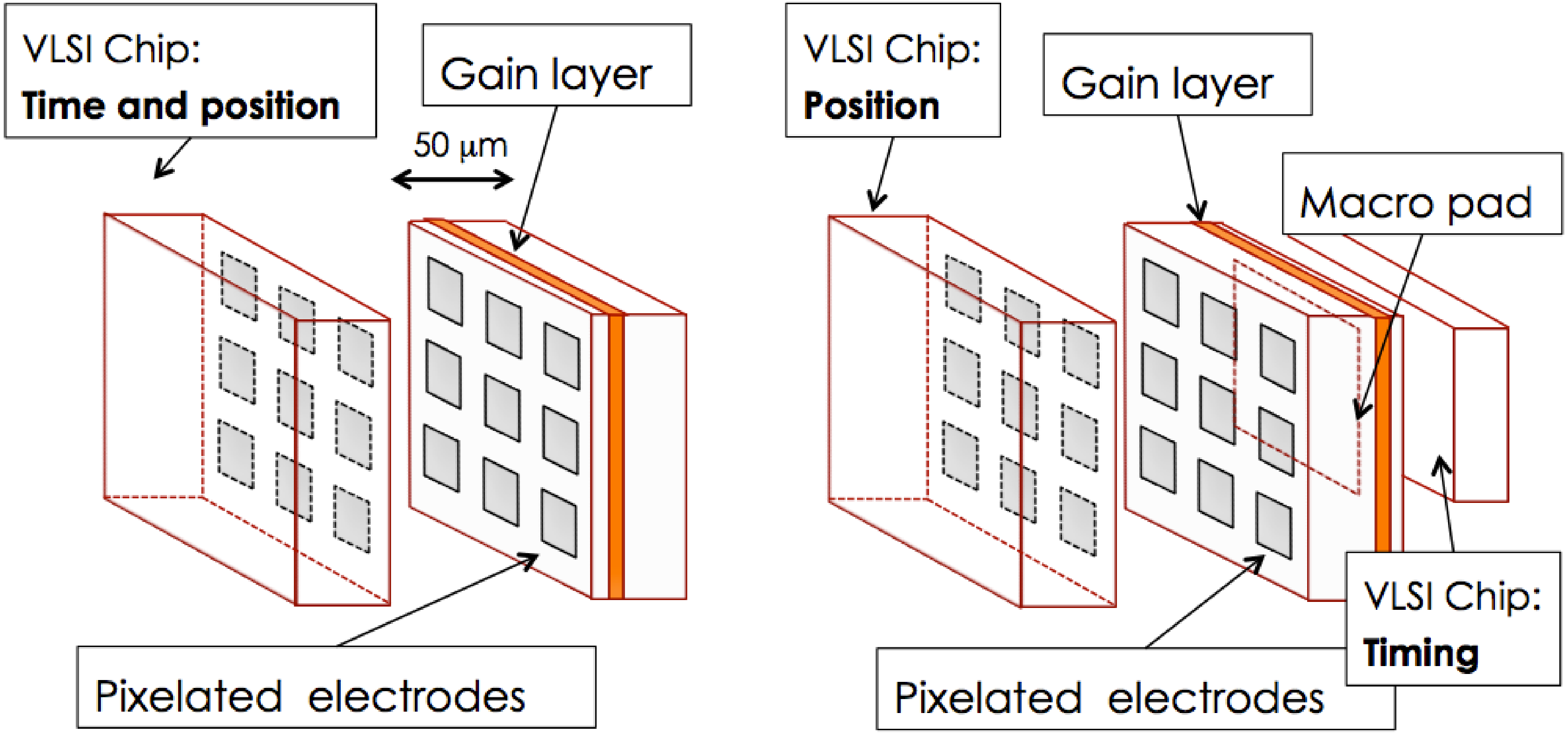
Tbase	-3.9 ns	Trigger	C3 DC
	5.00 ns/div	Norm.	50.0 mV
1 kS	20 GS/s	Qualified	Pos

X1= -21.10 ns ΔX= 49.95 ns

X2= 28.85 ns 1/ΔX= 20.02 MHz

Waiting for Trigger 11/20/2014 2:37:59 PM

Splitting gain and position measurements



VLSI Chip:
Time and position

Gain layer

50 µm

Pixelated electrodes

VLSI Chip:
Position

Gain layer

Macro pad

VLSI Chip:
Timing

Pixelated electrodes

The ultimate time resolution will be obtained with a custom ASIC.

However we might split the position and the time measurements

UFSD – Summary

- The internal gain makes them ideal for accurate timing studies

- **We measured 140 ps resolution with laser and 190 ps with MIPS** (300 μm sensors)

- We are manufacturing thin LGAD optimized for time resolution. With non-optimized electronics we predict **<50 ps resolution for a 50 μm thick, 1 mm^2 pad.**

- Ultimate time resolution (~10-20 ps) requires custom ASIC design.

Timescale:
300- and 200- micron sensors: Winter 2014
100- and 50- micron sensors: Summer 2015

Acknowledgement

This research was carried out with the contribution of the Ministero degli Affari Esteri, "Direzione Generale per la Promozione del Sistema Paese" of Italy.

Ministero degli Affari Esteri
e della Cooperazione Internazionale

DIREZIONE GENERALE
PER LA PROMOZIONE DEL SISTEMA PAESE
Unità per la cooperazione scientifica
e tecnologica bilaterale e multilaterale

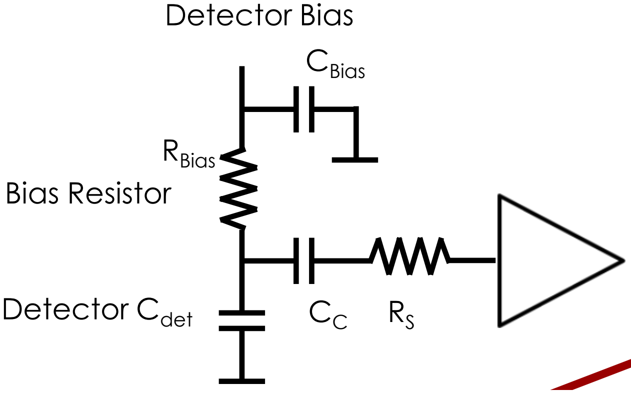
This work was developed in the framework of the CERN RD50 collaboration and partially financed by the Spanish Ministry of Education and Science through the Particle Physics National Program (F P A2010−22060−C 02−02 and FPA2010 − 22163 − C02 − 02).

The work at SCIPP was partially supported by the United States Department of Energy, grant DE-FG02-04ER41286.

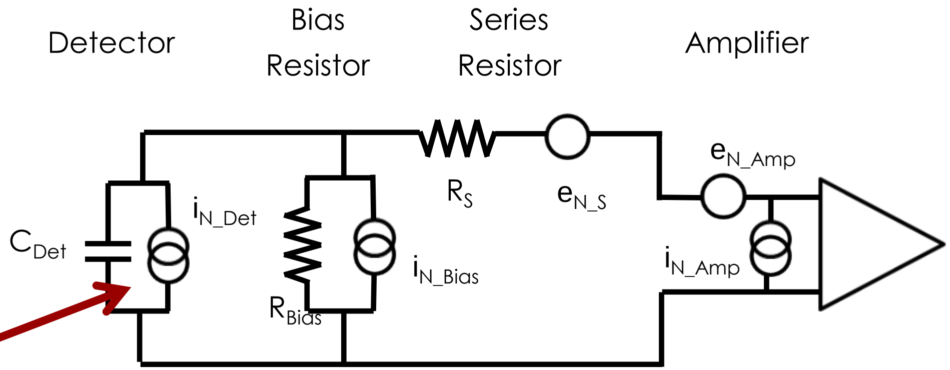
Backup

Noise

Real life



Noise Model



This term, the detector current shot noise, depends on the gain

$$Q_n^2 = (2eI_{Det} + \frac{4kT}{R_{Bias}} + i^2_{N\_Amp})F_i T_s + \underbrace{(4kTR_s + e^2_{N\_Amp})F_v \frac{C^2_{Det}}{T_S}}_{\text{This term dominates for short shaping time}} + F_{vf} A_f C^2_{Det}$$

$$\boxed{2eI_{Det} * \mathrm{Gain}}$$

Shot noise:

low gain

This term dominates for

short shaping time

$$ENF = kG + (2 - \frac{1}{G})(1 - k)$$

k = ratio h/e gain

Excess noise factor:

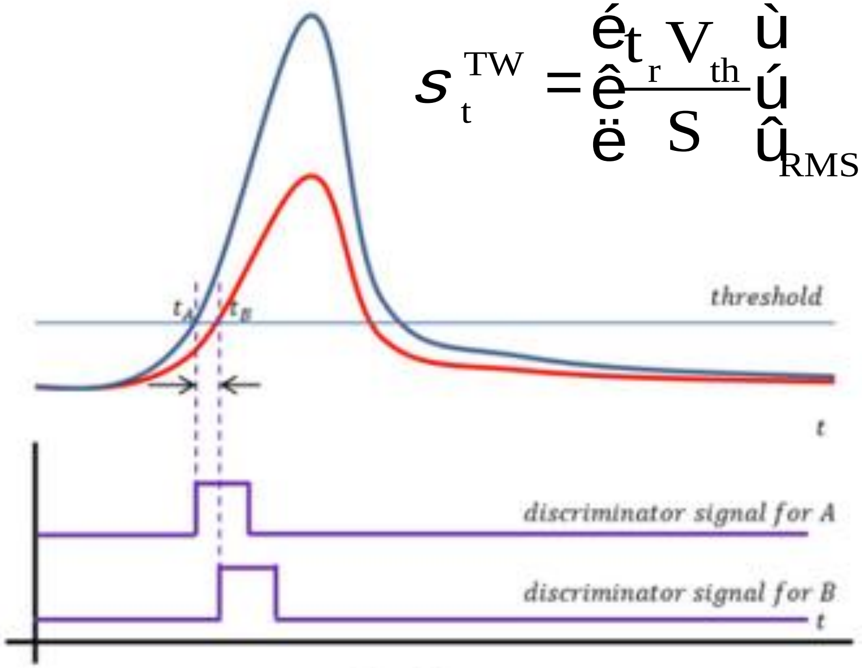
low gain, very small k

Time walk and Time jitter

Time walk: the voltage value V_{th} is reached at different times by signals of different amplitude

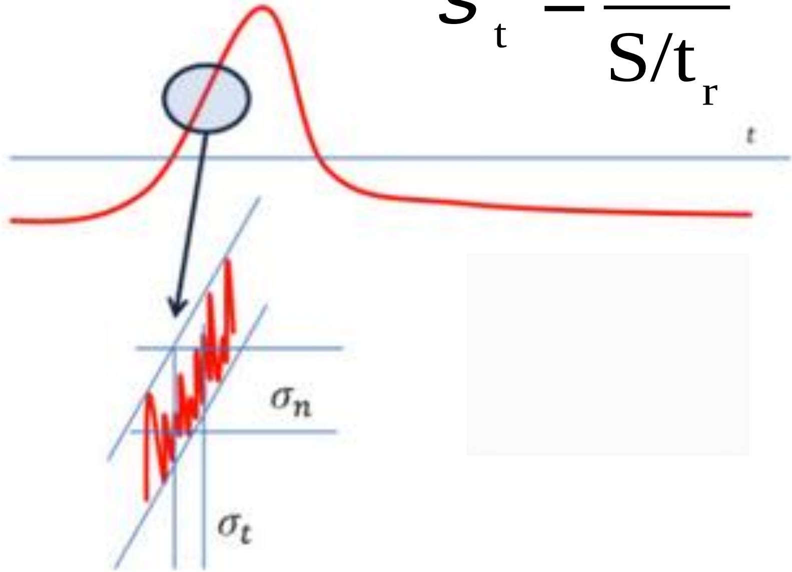
Jitter: the noise is summed to the signal, causing amplitude variations

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



Time walk effect

$$\sigma_t^{J} = \frac{N}{S/t_r}$$



Jitter effect

Due to the physics of signal formation

Due to Landau fluctuations

Mostly due to electronic noise

Sum of noise sources

How to make a **good** signal

Signal shape is determined by Ramo's Theorem:

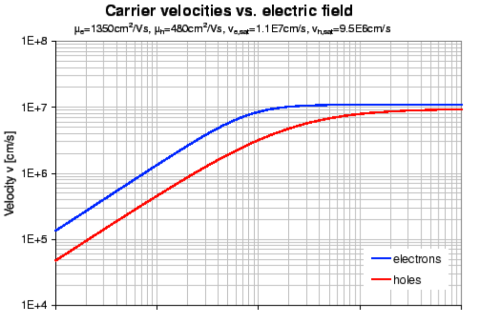
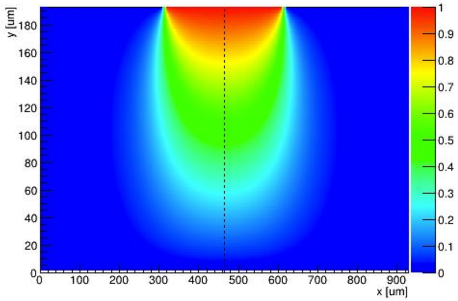


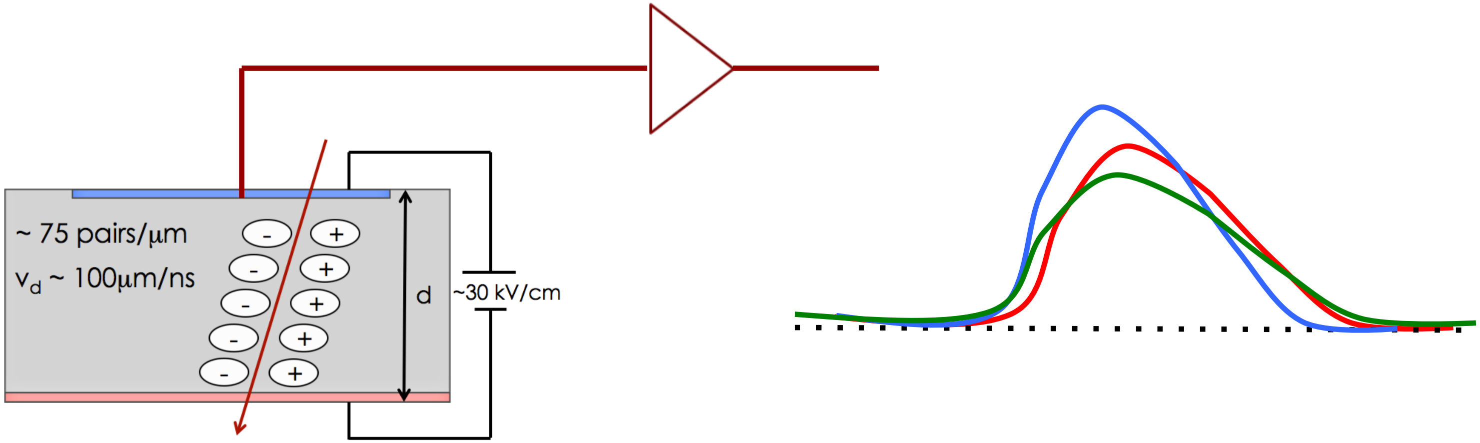
Figure: Electron and hole velocities vs. the electric field strength in silicon.

$$i \propto qvE_w$$



Drift velocity

Weighting field



A key to good timing is the uniformity of signals:

Drift velocity and **Weighting field** need to be **as uniform as possible**

Non-Uniform Energy deposition

Landau Fluctuations cause two major effects:

- Amplitude variations, that can be corrected with time walk compensation
- For a given amplitude, the charge deposition is non uniform.

These are 3 examples of this effect: