Timing performance of LGAD-UFSD

1. New results from the last CNM LGAD runs
2. A proposal for LGAD segmentation

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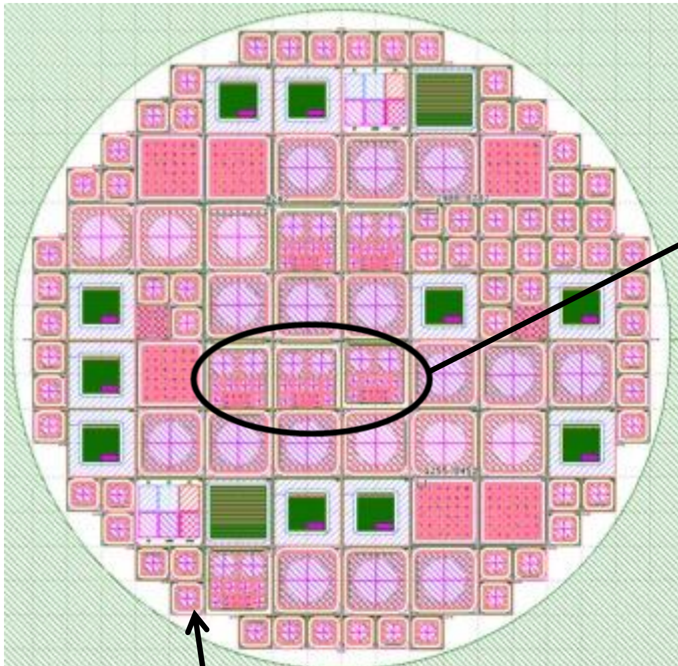
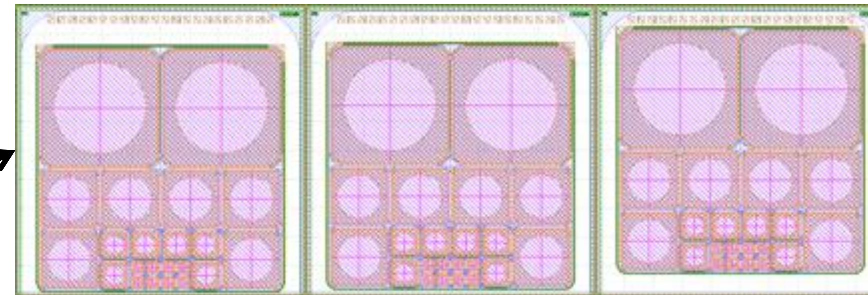
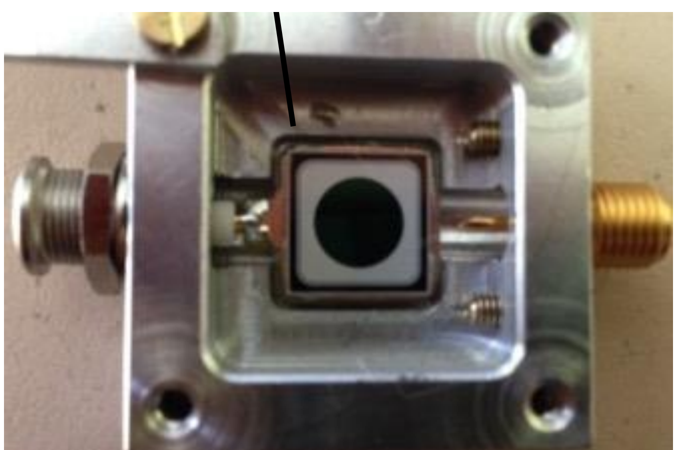
Structures from the last LGAD CNM Run (7509-7589)



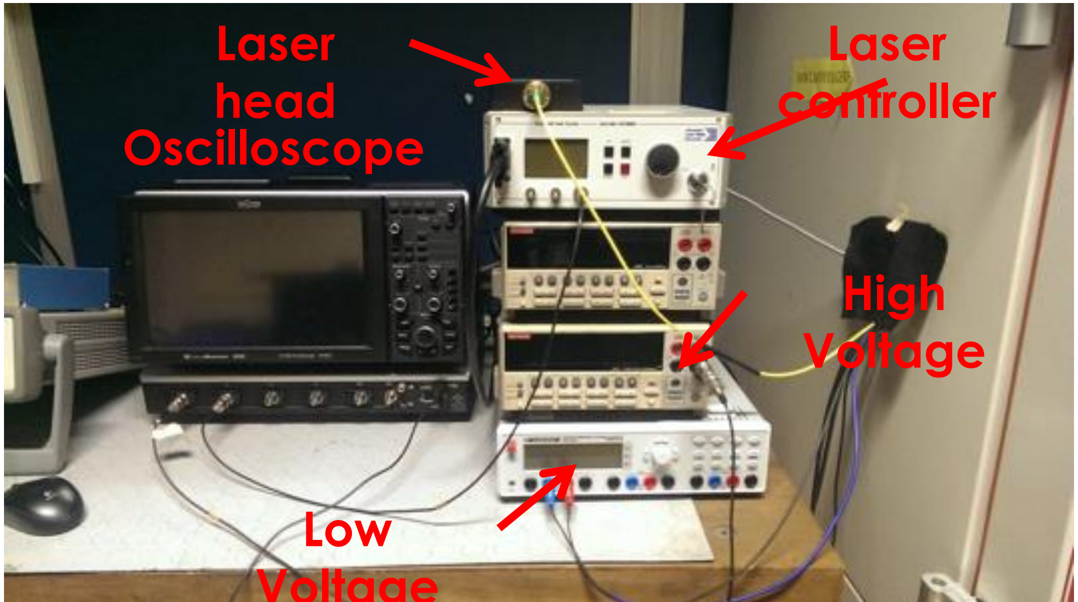


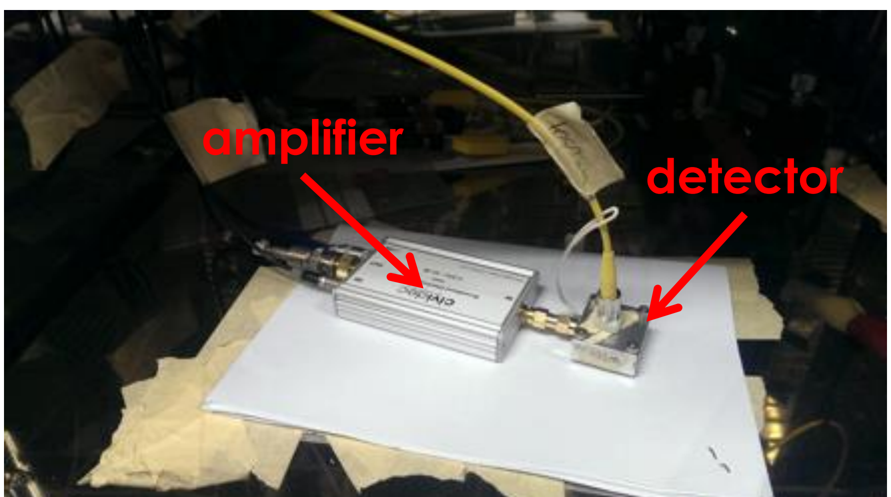
Multipad structures with different distances from bottom edge

Single pad, 3x3 and 8x8 mm



Laboratory Setup for signal acquisition



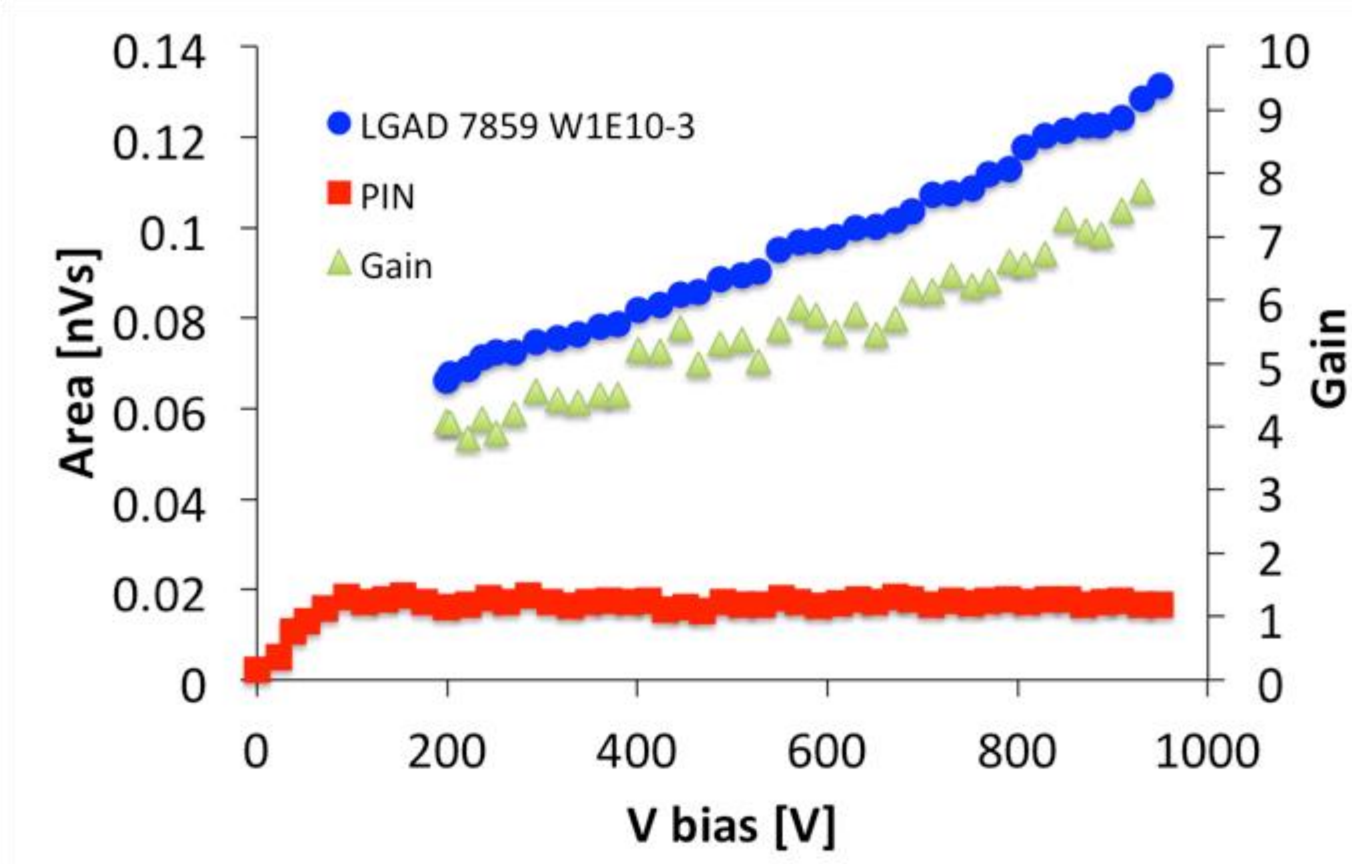


- Picosecond Diode Laser;
- Laser head (1064 nm 400nm);
- Voltage Source Keithley 2410 (High Voltage);
- Power supply Rohde & Schwarz HMP2030 (low Voltage);
- Broadband amplifier Cividec, 40 dB, 2 GHz BW;
- SMA amplifier Cividec;
- Oscilloscope LeCroy Waverunner 2.5 Ghz BW;
- Detector;

New results from the last LGAD CNM Run

(laser data)

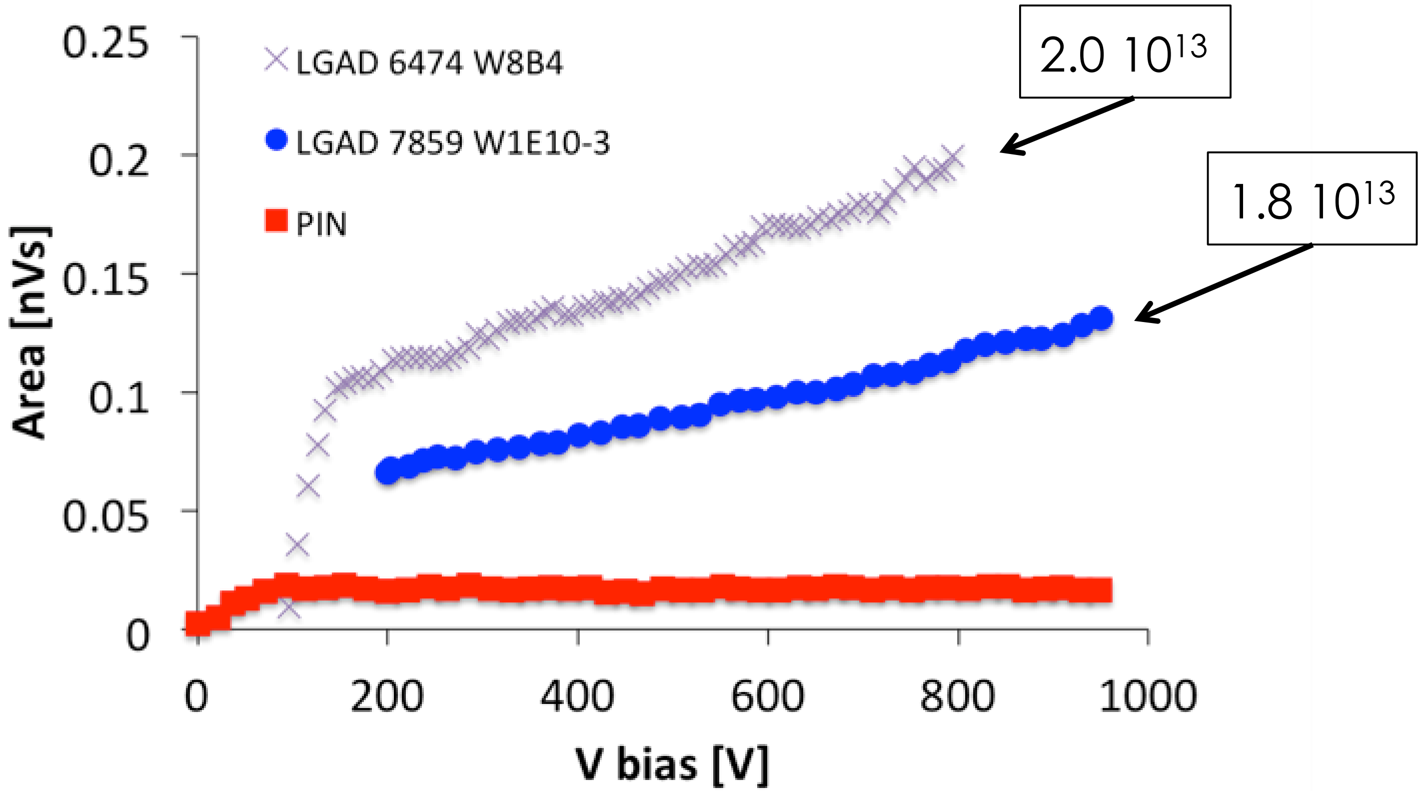
CNM run 7859: 3 different gain doping: 1.8, 2.0, 2.2 *10^{13} cm^2



- This device belongs to the lowest gain production.
- Gain value in line with expectations
- Linear gain with Vbias

LGAD diodes from CNM Run 6474 and 7589

(laser data)

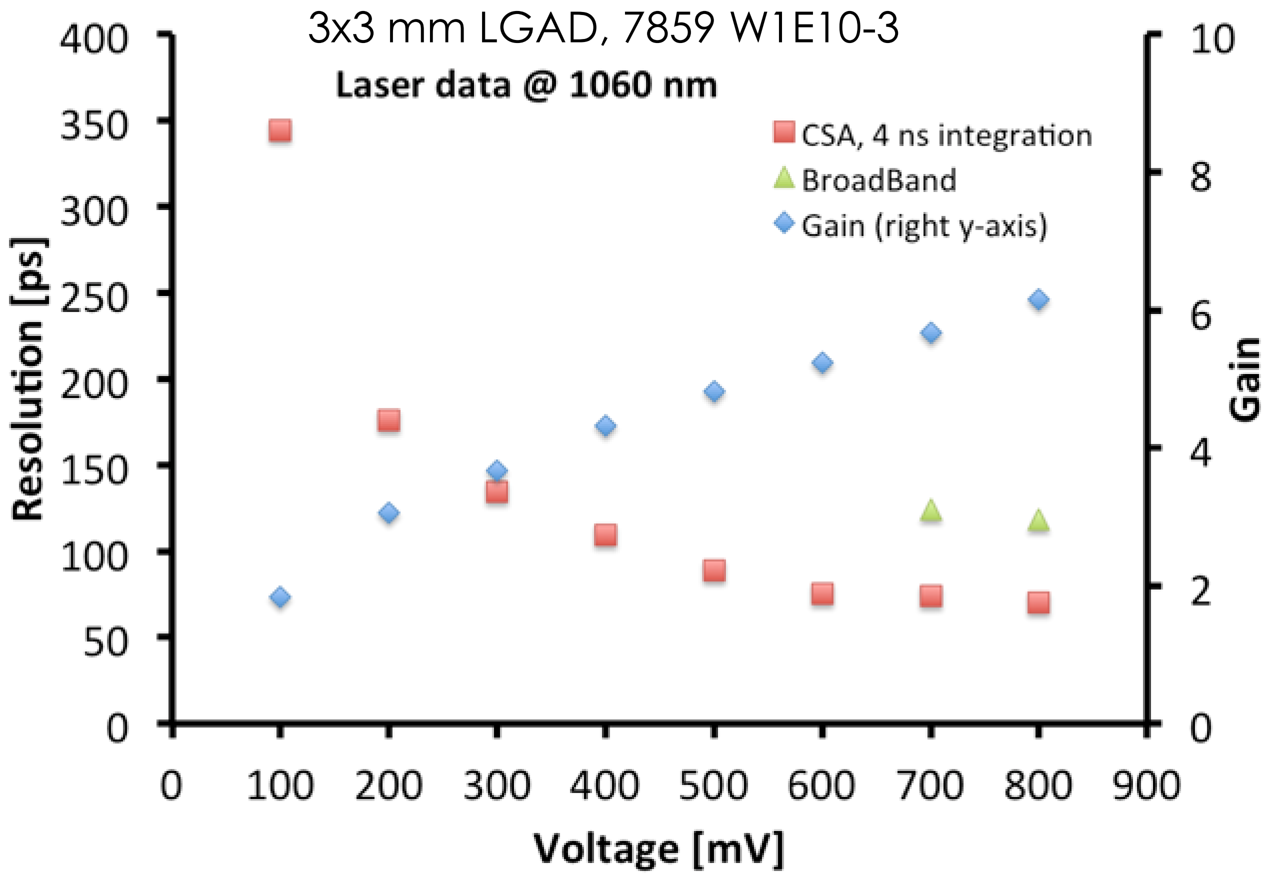


The two devices, from two different runs, show good consistency in the gain value with respect of the implanted boron dose

Time resolution vs gain

(laser data)

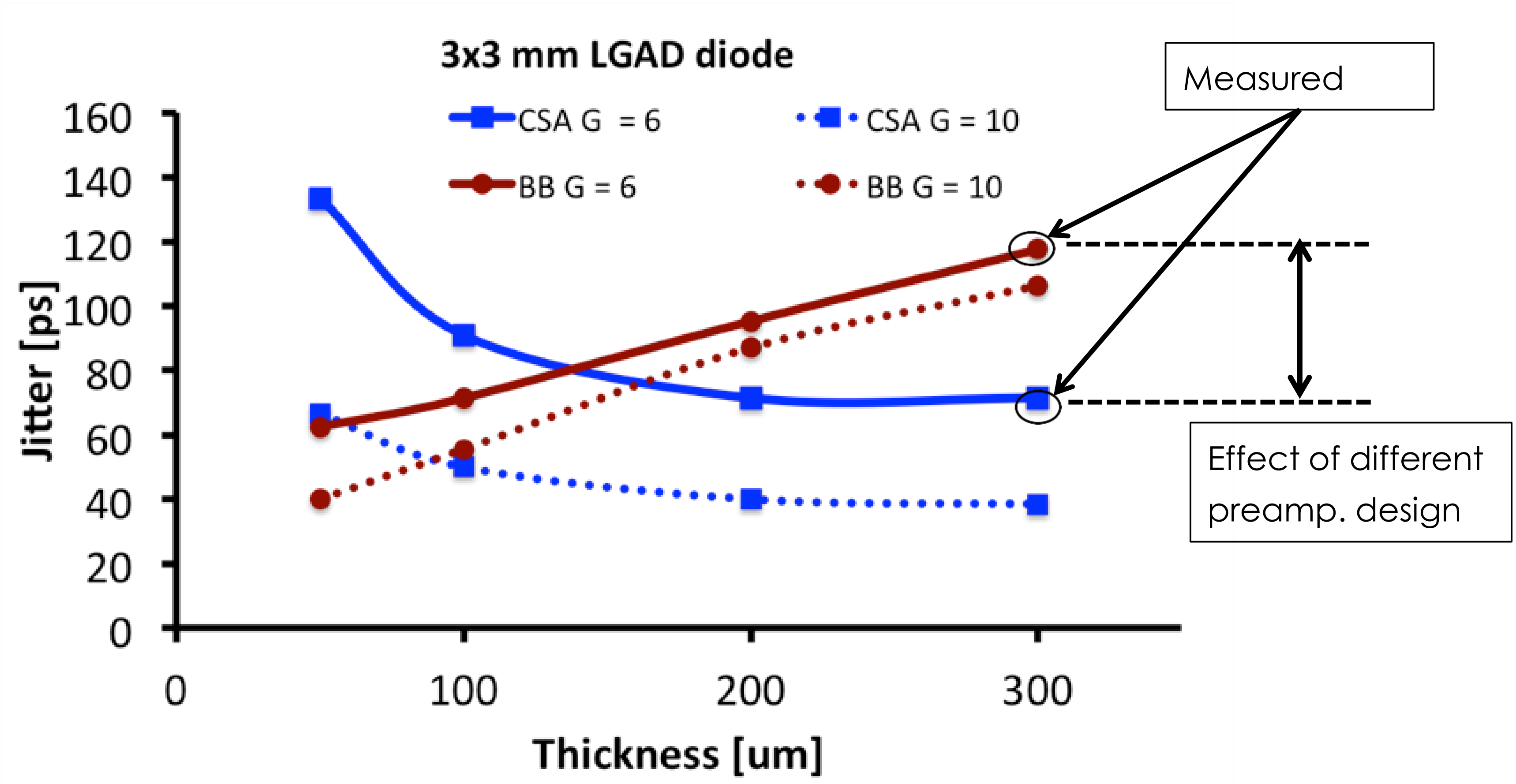
$$s_t \ \mu \ \frac{\text{Noise}}{\text{dV/dt}}$$



Achieved ~ 70 ps resolution with laser pulses

Extrapolation to thinner sensors and higher gain

Assuming the same electronics, and 3 mm^2 LGAD pad with gain 6 and 10 , we can predict the timing capabilities of the next sets of sensors.



Prediction: 3x3 mm pad, 300micron thick with gain 10 should have ~ 40 ps resolution

Why the time resolution is so much better than before?

CNM first production: **$\sigma_t \sim$ 150 ps**

300 micron thick, 5x5 mm, no guard ring, gain 10

CNM second production: **$\sigma_t \sim$ 70 ps**

300 micron thick, 3x3 mm, guard ring, gain 6

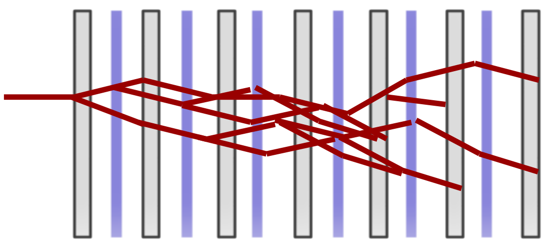
Why so much improvement, even with a diode with lower gain?

$$\boxed{\sigma_t \propto \frac{\text{Noise}}{\text{dV/dt}}}$$

The secret is in the noise: these small sensors have very low leakage current and much smaller capacitance → very low noise

Timing in a "many particles" environment

Is it possible to do precise timing measurements in a calorimeter using silicon pads?



CMS decision:

Tungsten – silicon calorimeter

What is the best shower depth to do timing?

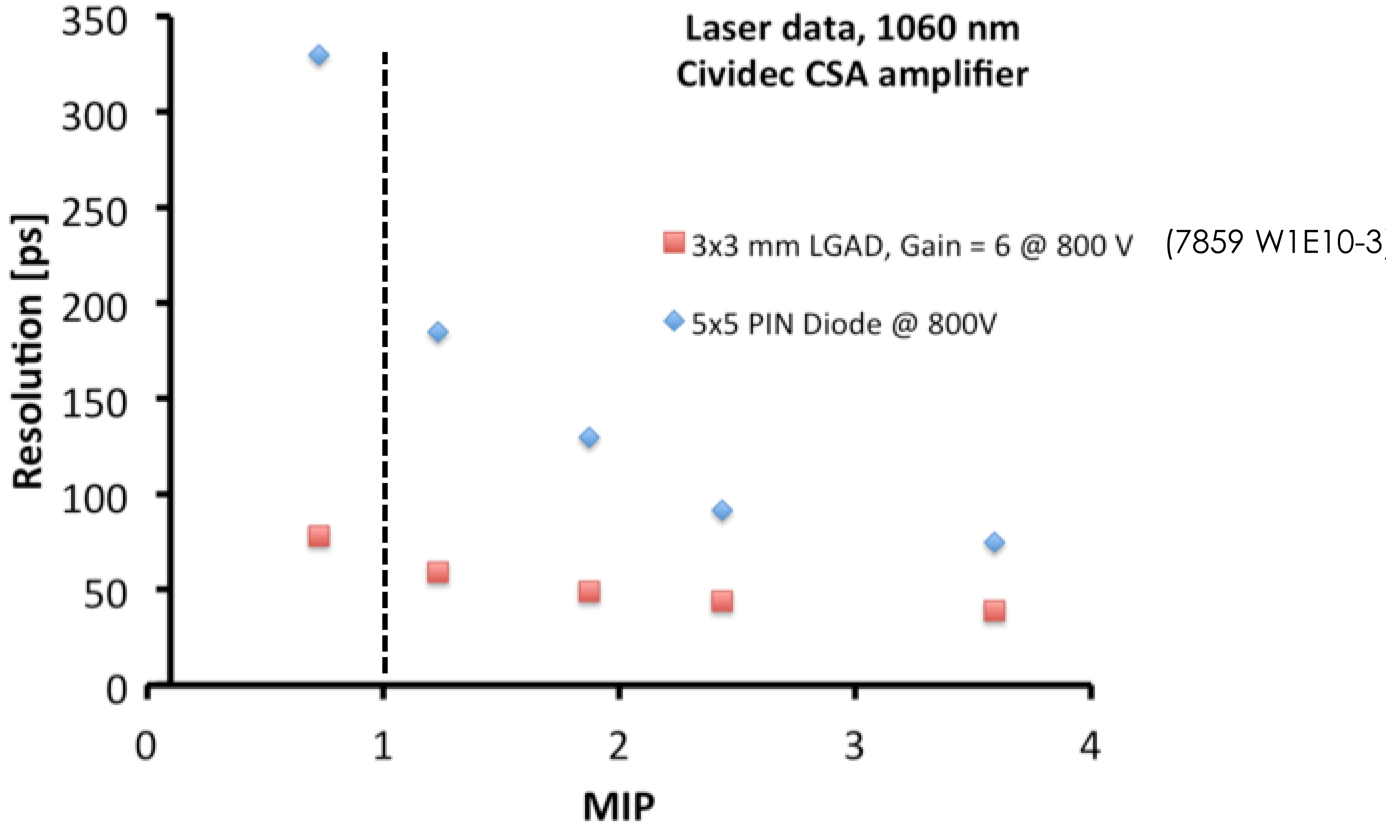
Shallow timing layer:

- ☹ Less particles
- ☺ No time dispersion of the particles
- ☺ Lower radiation damage

Deep timing layer

- ☺ A lot of deposited charge right away (up to 100 particles)
- ☹ Intrinsic time dispersion of particles in a single silicon pad
- ☹ High radiation damage

Time resolution of UFSD and PIN diodes
(laser pulses)



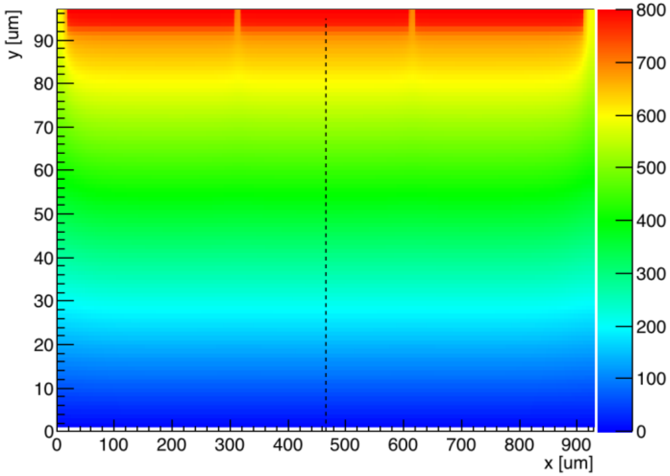
For 1 MIP, A UFSD with gain ~ 6 shows a factor of 3 better time resolution than PIN diodes: 70 ps vs 200 ps

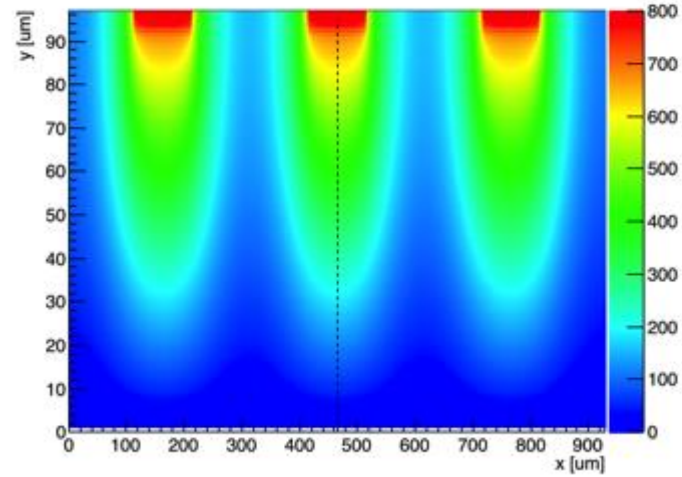
For many MIPS the difference is becoming less and less

A proposal for LGAD segmentation

Uniform multiplication in segmented detectors

Electrode segmentation makes the E field very non uniform, and therefore ruins the gain and timing properties of the sensor





Non uniform E field and Weighting field

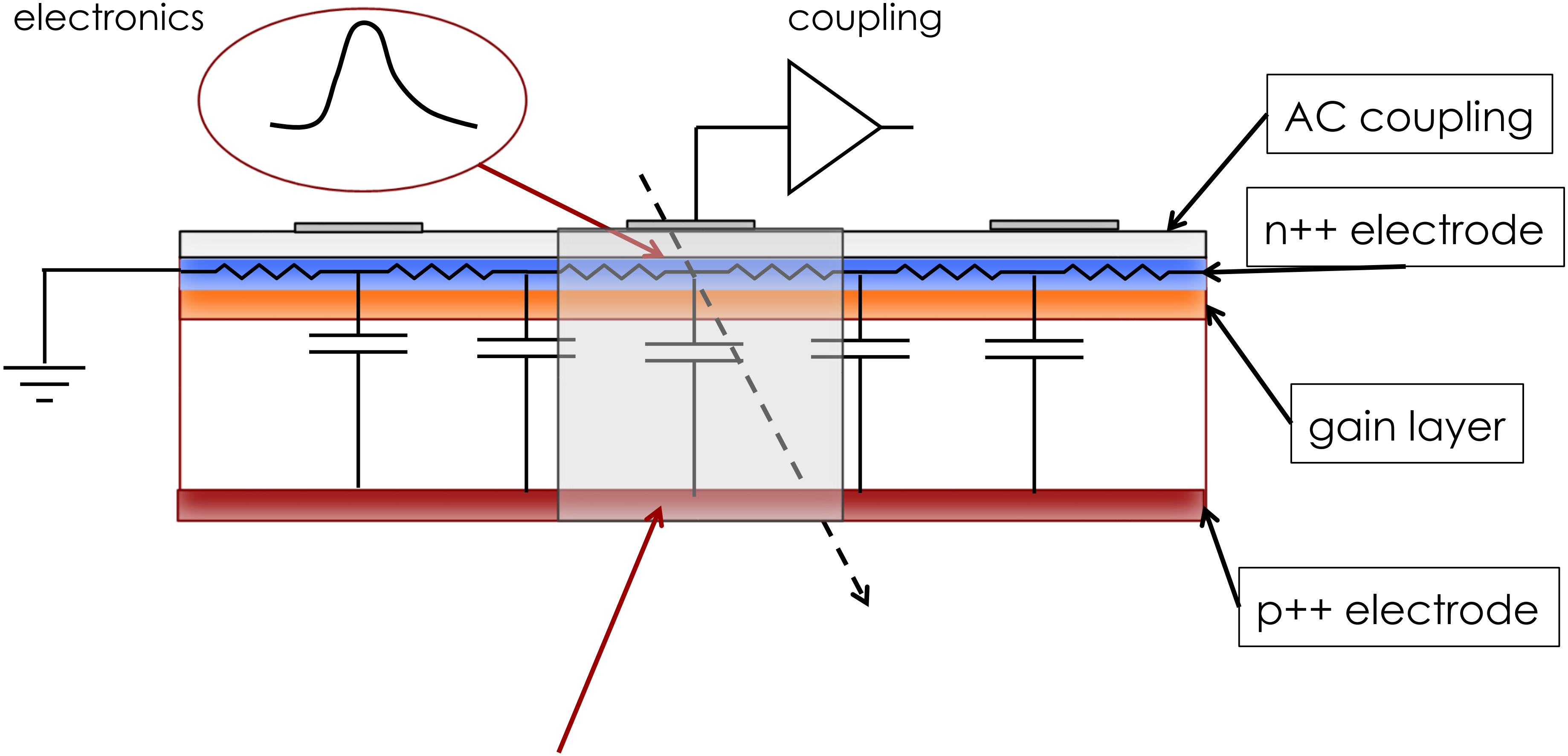
We need to find a design that produces very uniform E field, while allowing electrode segmentation.

LGAD with a resistive n++ electrode

The signal is frozen on the resistive sheet, and it's AC coupled to the electronics

➔ E and E_w fields are very regular

➔Segmentation is achieved via AC coupling



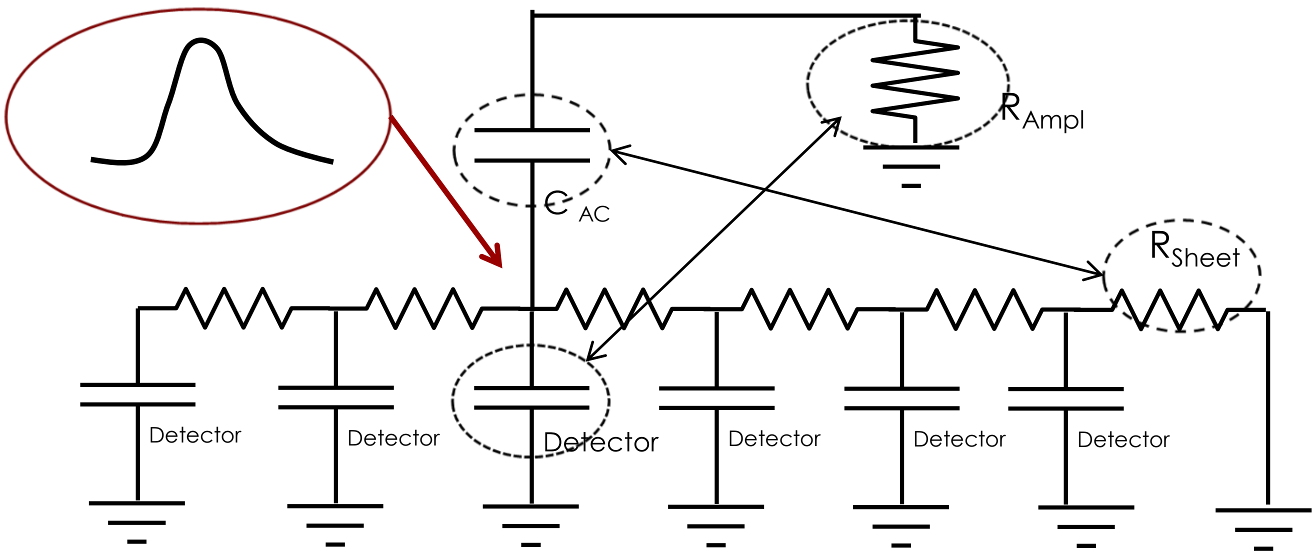
The AC read-out sees only a small part of the sensor:

small capacitance and small leakage current.

Details of AC coupling - I

Additional Rise time

$R_{Ampl} * C_{detector} \sim 100\ \Omega * 1pF \sim$ **100 ps**

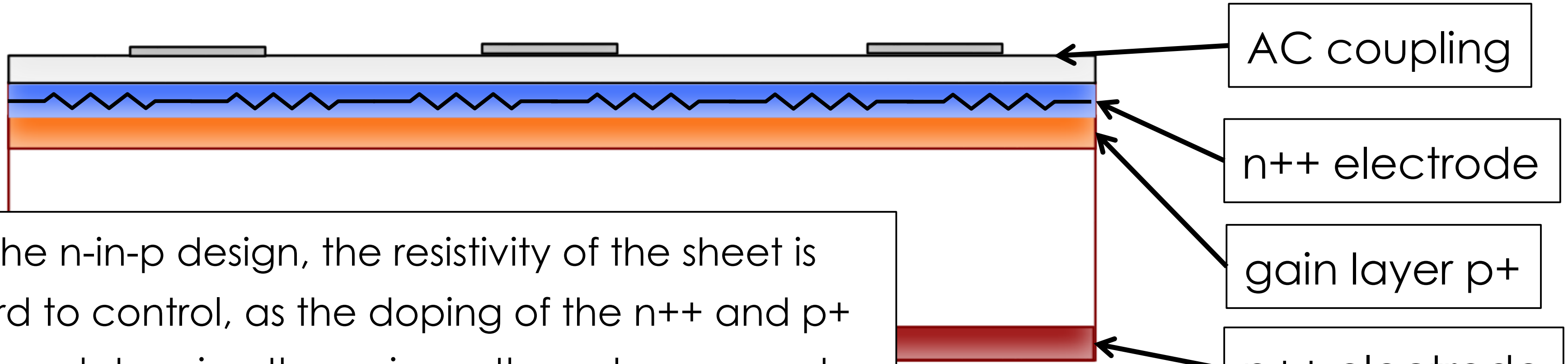


Freezing time

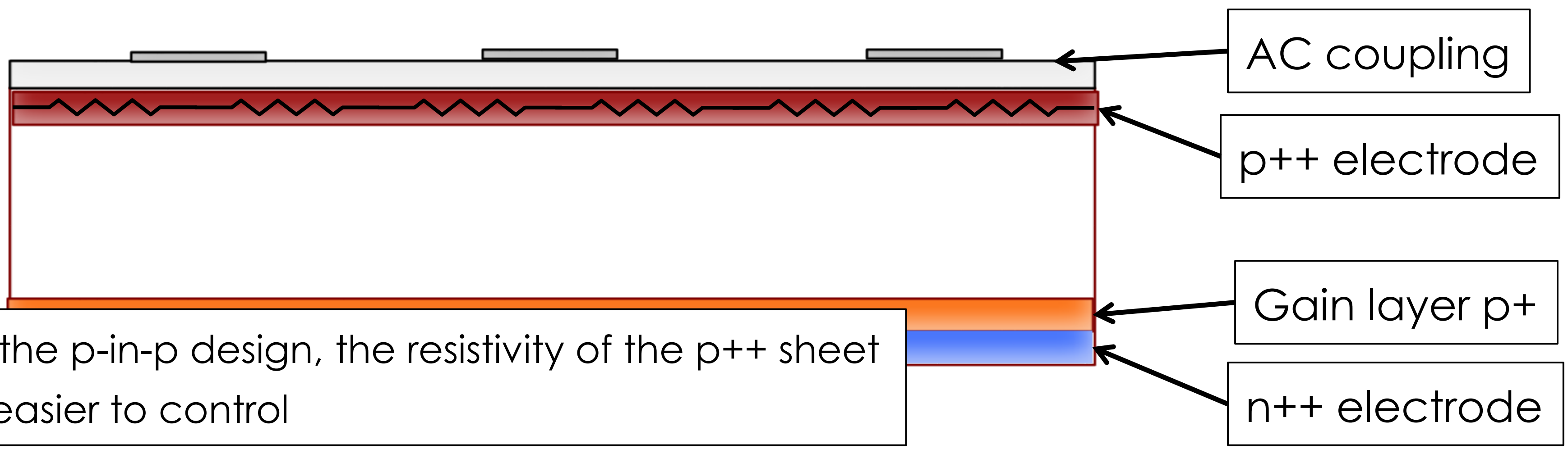
$R_{Sheet} * C_{AC} \sim 1k\Omega * 100pF \sim 100$ ns

Only a small part of the detector is involved

Details of AC coupling - II



In the n-in-p design, the resistivity of the sheet is hard to control, as the doping of the n++ and p+ layers determine the gain, so the values cannot be chosen as we like.



In the p-in-p design, the resistivity of the p++ sheet is easier to control

Summary

Timing performance of LGAD

1) We tested the new CNM production of LGAD
2) Very good timing performances due to the reduced noise
3) Testing of additional pads soon
4) Testbeam coming in the next weeks
5) Timing for calorimeters using silicon pads

LGAD Segmentation

1) We propose to use the resistivity of the n++ electrode to achieve AC segmentation.
2) For appropriate values of R_{Sheet} and C_{AC} , the signal is frozen in place for ~ 100 ns

Extra

New results from the last LGAD CNM Run

We received samples from two runs: 7509 and 7859.