Tests of Ultra Fast Silicon Detectors

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LHC Working Group on Forward Physics and Diffraction, CERN

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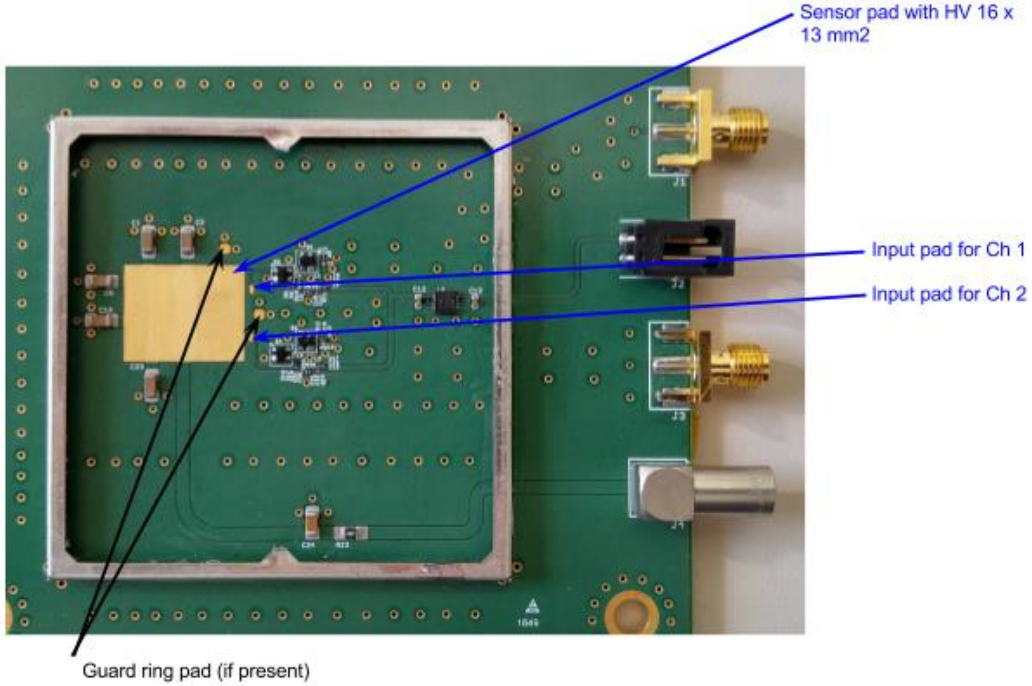
Multi purpose board for a silicon/diamond detector

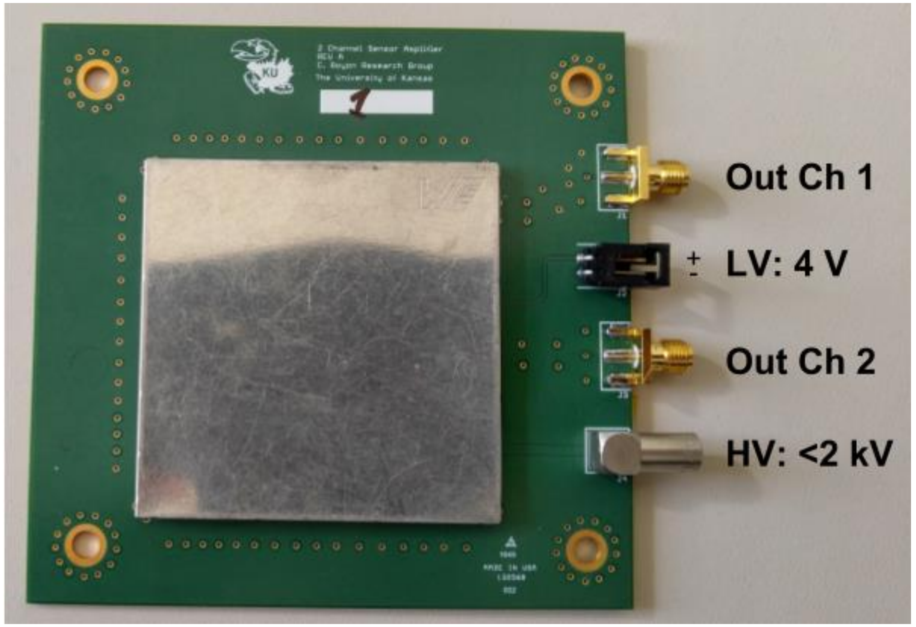
A two channels board that can be use for the characterization of different solid state detectors.



Sensors up to 16x13 mm^2 can be glued and bonded.

The components can be easily adapted to accommodate:

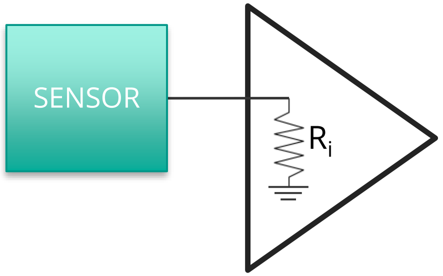
- Diamond sensors: ~1 nA bias current, both polarities, small signal
- Silicon detectors: ~100 nA bias current, small signal
- UfSi: ~100 nA bias current, ~ larger signal
- SiPM: ~ 5 uA bias current, large signal

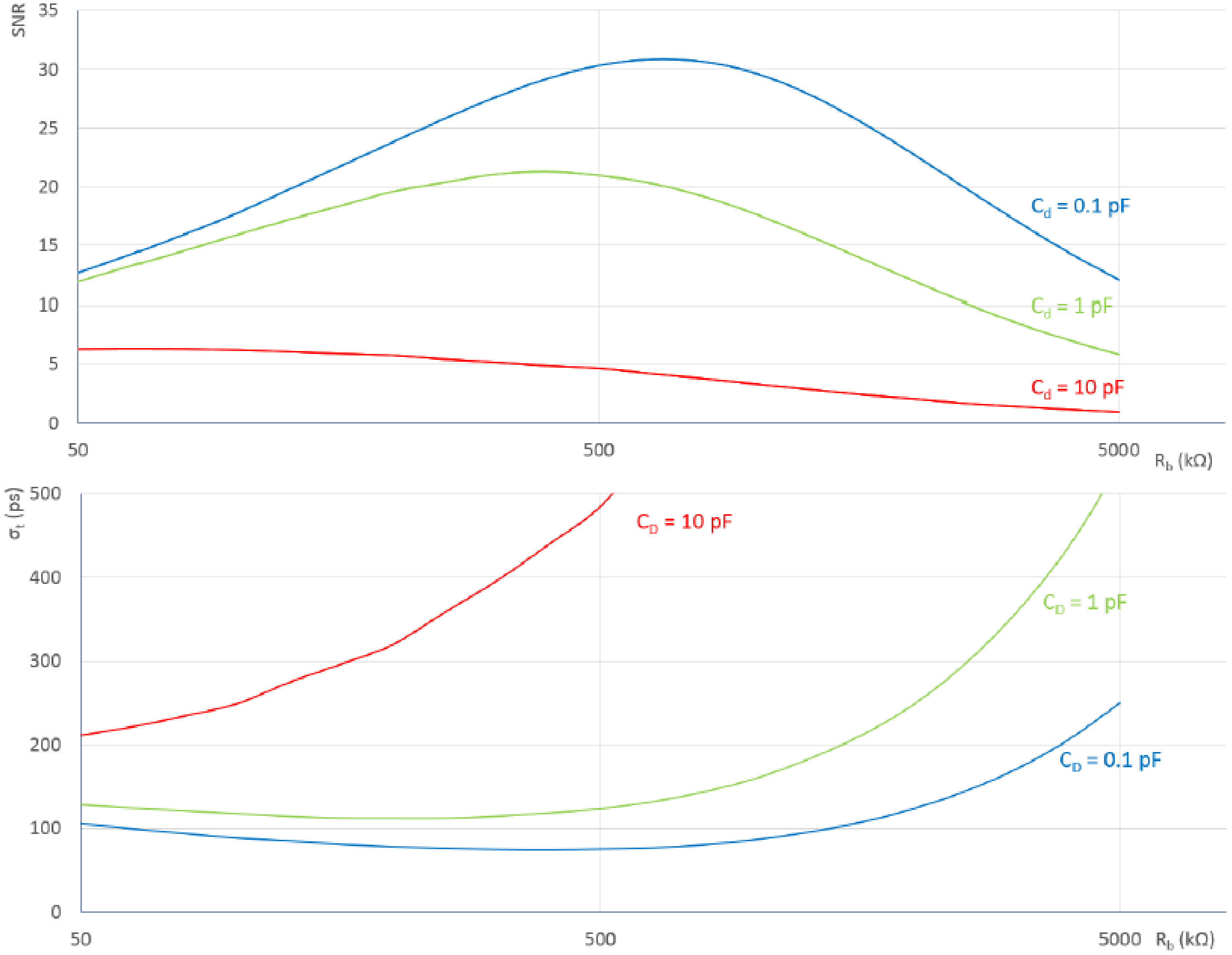


< 200 USD per board
(10 produced)

Amplifier with high input impedance

An amplifier with High Input impedance has some advantage of a Broadband Amplifier (50 Ω) and some of the Charge Sensitive Amplifier





Simulated SNR and time resolution for a diamond detector.

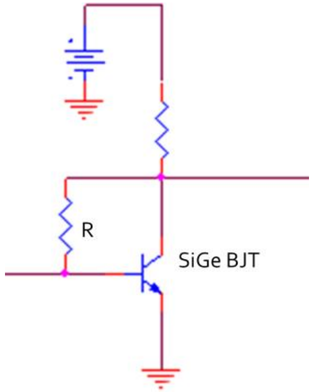
The input impedance has to be selected according to the characteristics of the sensor.

The main advantage/disadvantage is that there are no general purpose commercial solutions!

More details: Sec. 4.6 of Development of a timing detector for the TOTEM experiment at the LHC

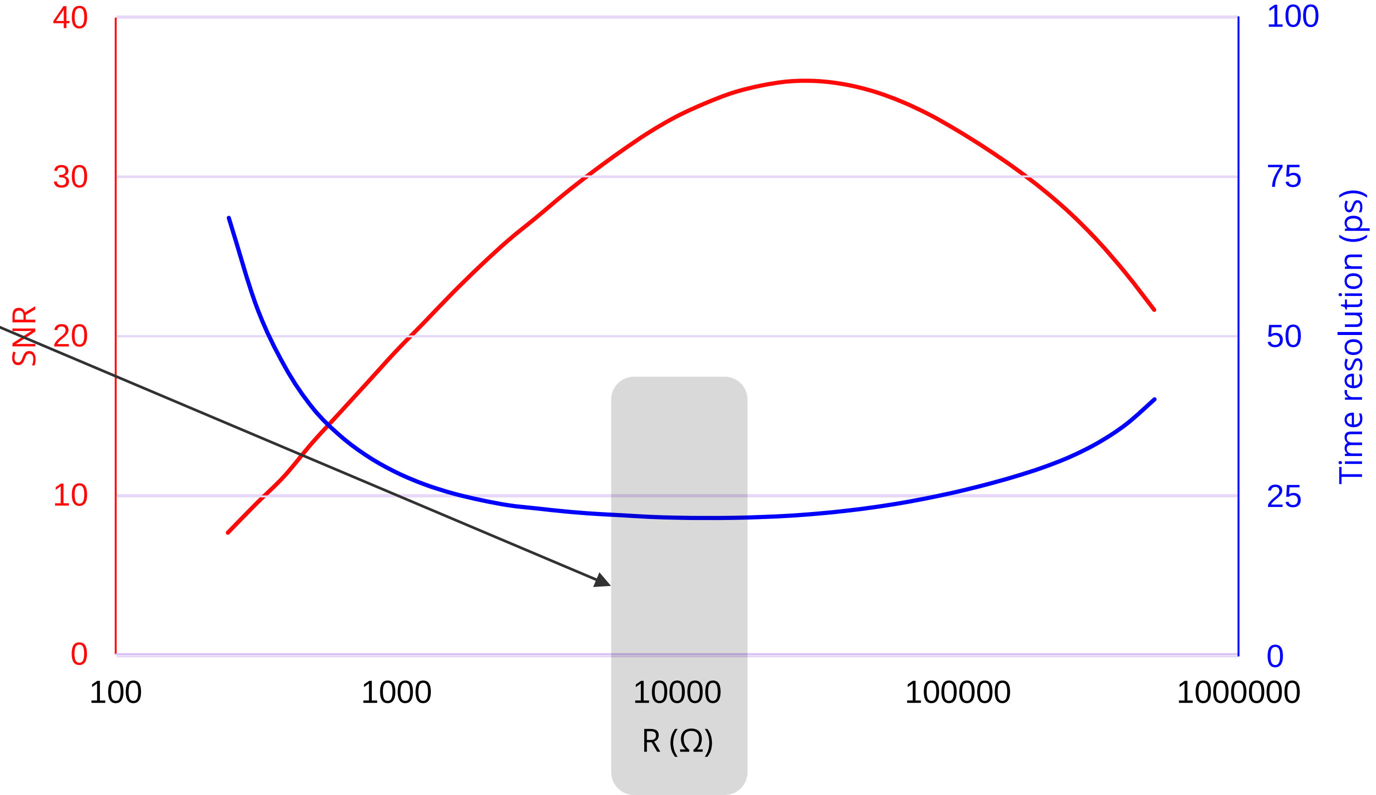
Amplifier with high input impedance

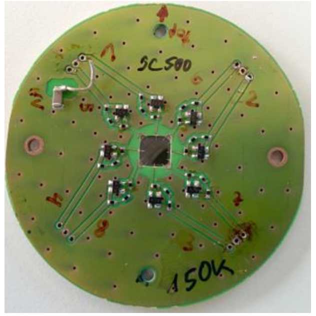
One implementation of a HImp amplifier is using a common emitter with a feedback resistor



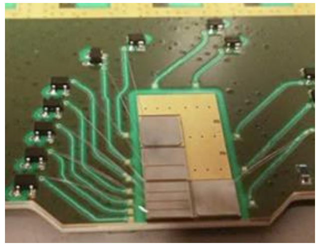
The best value of R for timing has to be optimized according to the sensor:

- High for diamonds (R ~ 300 kΩ)
- Lower for thick UfSD (R ~ 30 kΩ)
- Low for 50 µm UfSD





HADES @ GSI
10.1016/j.nima.2010.02.113



TOTEM @ CERN
See talks tomorrow

Optimization for UfSD

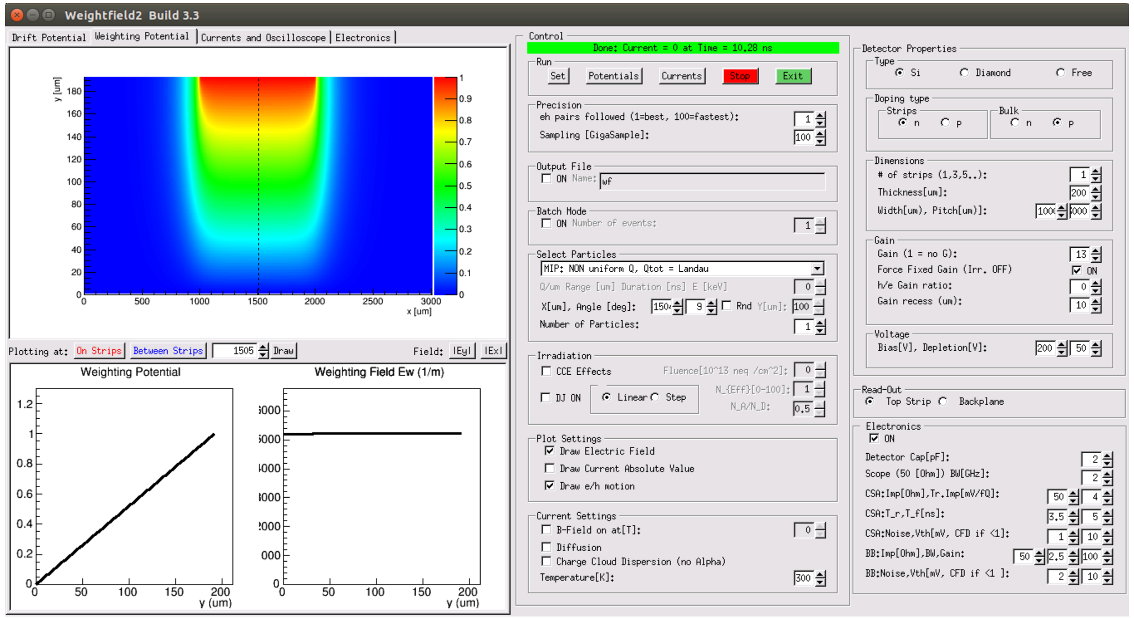
The signal generated at the passage of a MIP by a 50 µm UfSD can be simulated using Weightfield2*

Using Weightfield2 it is possible to simulate different detectors, in different configurations.

The reliability of the simulations have been proved in several occasions.

arXiv:1608.08681

Timing capabilities of Ultra-Fast Silicon Detector



Control

Done: Current = 0 at Time = 10.28 ns

Precision
eh pairs followed (1=best, 100=fastest): 1
Sampling [GigaSample]: 100

Output File
☐ ON Name: wf

Batch Mode
☐ ON Number of events: 1

Select Particles
MIP: NON uniform Q, Qtot = Landau
Q/um Range [um] Duration [ns] E [keV] 0
X[um], Angle [deg]: 150 9 ☐ Rnd Y[um]: 100
Number of Particles: 1

Irradiation
☐ CCE Effects Fluence[10^13 neq /cm^2]: 0
☐ DJ ON ● Linear ○ Step 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 at[T]: 0
☐ Diffusion
☐ Charge Cloud Dispersion (no Alpha)
Temperature[K]: 300

Detector Properties
Type: ● Si ○ Diamond ○ Free
Doping type
Strips: ● n ○ p
Bulk: ○ n ● p

Dimensions
# of strips (1,3,5..): 1
Thickness[um]: 200
Width[um), Pitch[um)]: 100 000

Gain
Gain (1 = no G): 13
Force Fixed Gain (Irr. OFF) ☑ ON
h/e Gain ratio: 0
Gain recess (um): 10

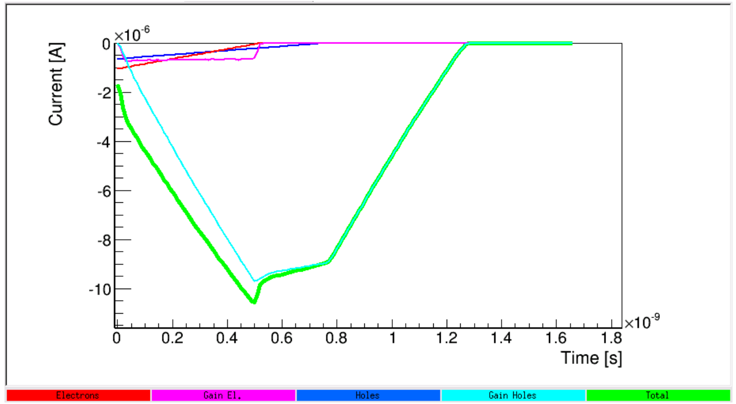
Voltage
Bias[V], Depletion[V]: 200 50

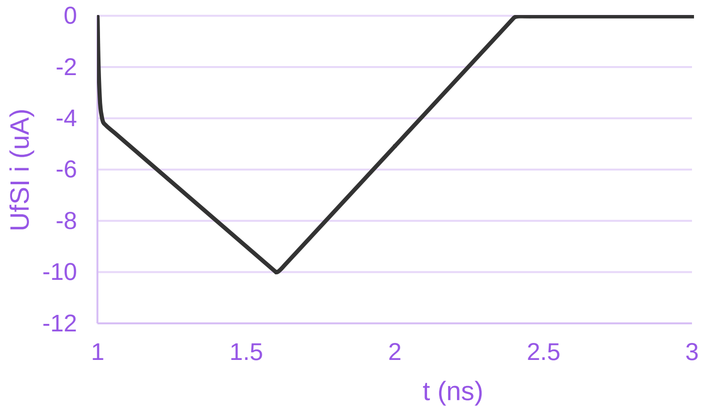
Read-Out
● Top Strip ○ Backplane

Electronics
☑ ON
Detector Cap[pF]: 2
Scope (50 [Ohm]) BW[GHz]: 2
CSA:Imp[Ohm],Tr.Imp[mV/fQ]: 50 4
CSA:T_r,T_f[ns]: 3.5 5
CSA:Noise,Vth[mV, CFD if <1]: 1 10
BB:Imp[Ohm],BW,Gain: 50 2.5 100
BB:Noise,Vth[mV, CFD if <1]: 2 10

A simplified signal can be used to simulate the behavior of several types of amplifiers.

50 µm UfSD at 200V with a gain 15





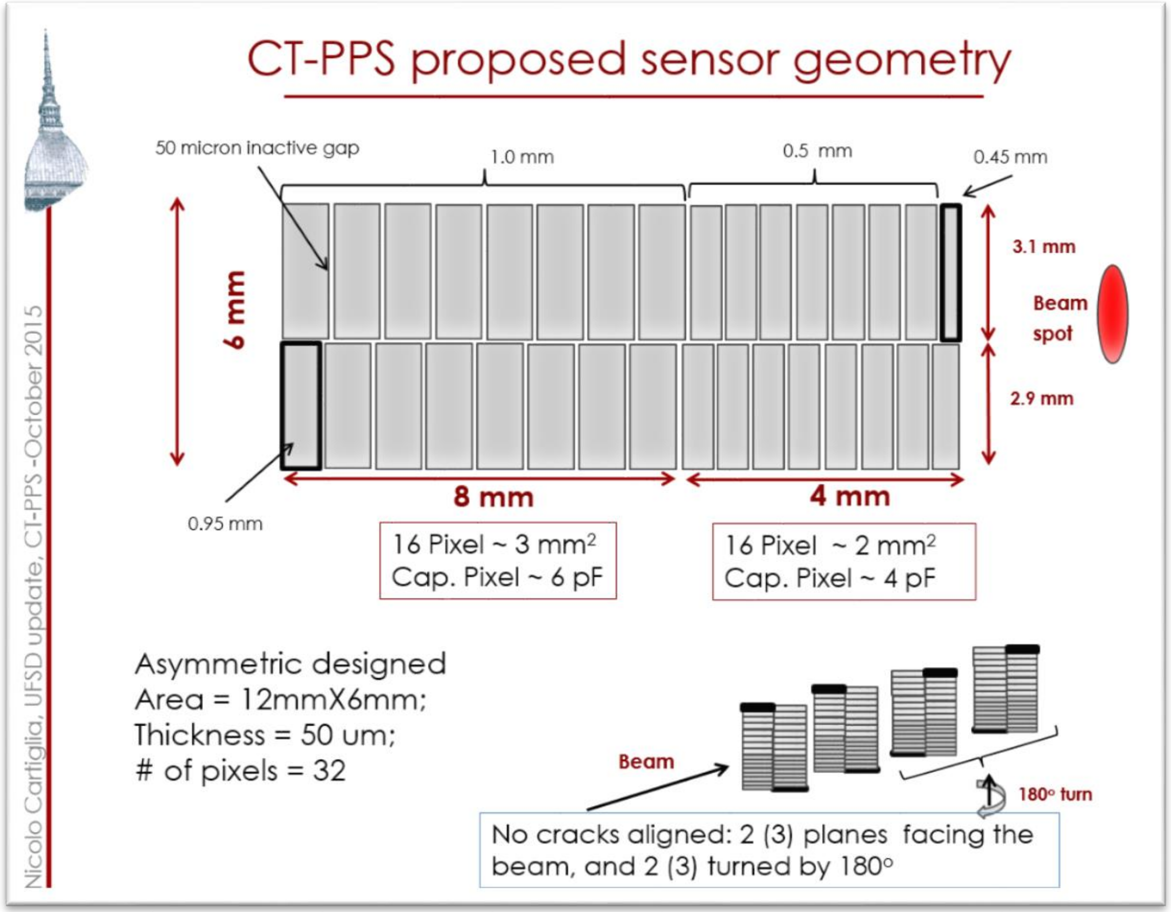
*: http://personalpages.to.infn.it/~cartigli/Weightfield2/Main.html

The timing detector for CT-PPS

CMS TOTEM Proton Precision Spectrometer (CT-PPS) adds precision proton tracking and timing detectors in the very forward region on both sides of CMS to study central exclusive production (CEP) in proton-proton collisions.

Requirement of the timing detector:

- Small active area (~ 4 cm^2)
- Small dead region at the edge and between channels
- Low power consumption and low material budget
- Radiation hard (proton flux of $5 \times 10^{15}\ \mathrm{cm}^{-2}$ per 100 fb^{-1})
- Time resolution of 10-30 ps.



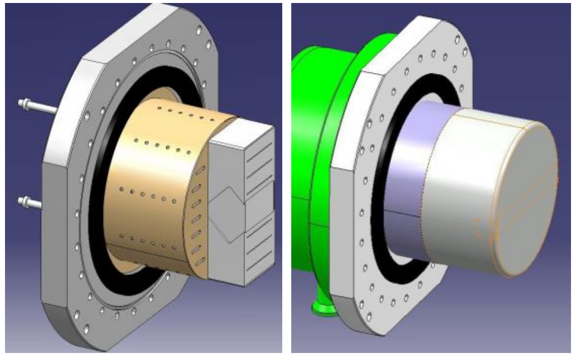
CT-PPS proposed sensor geometry

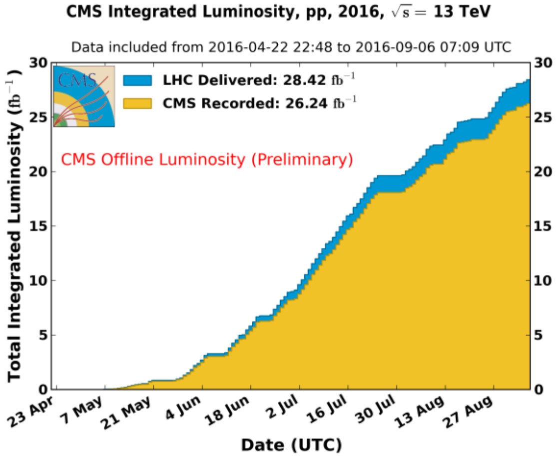
16 Pixel ~ 3 mm^2
Cap. Pixel ~ 6 pF

16 Pixel ~ 2 mm^2
Cap. Pixel ~ 4 pF

Asymmetric designed
Area = 12mmX6mm;
Thickness = 50 um;
# of pixels = 32

No cracks aligned: 2 (3) planes facing the beam, and 2 (3) turned by 180°



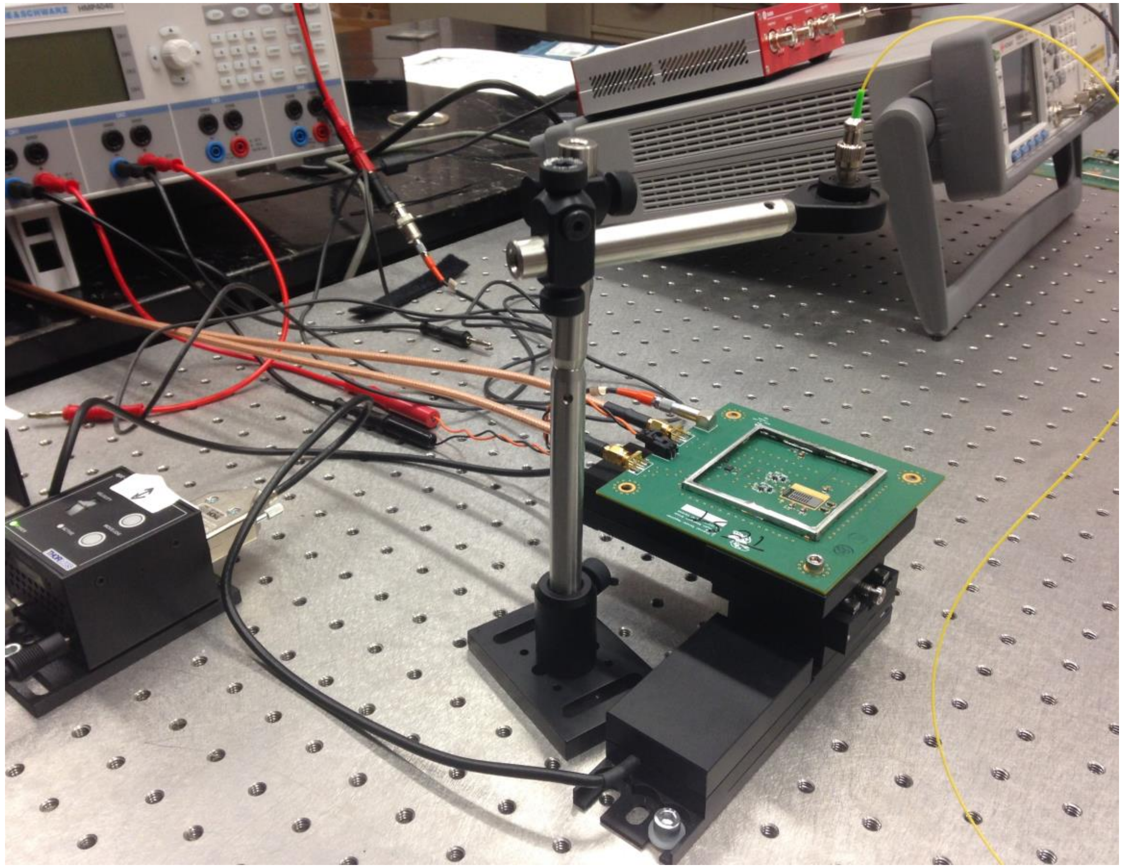


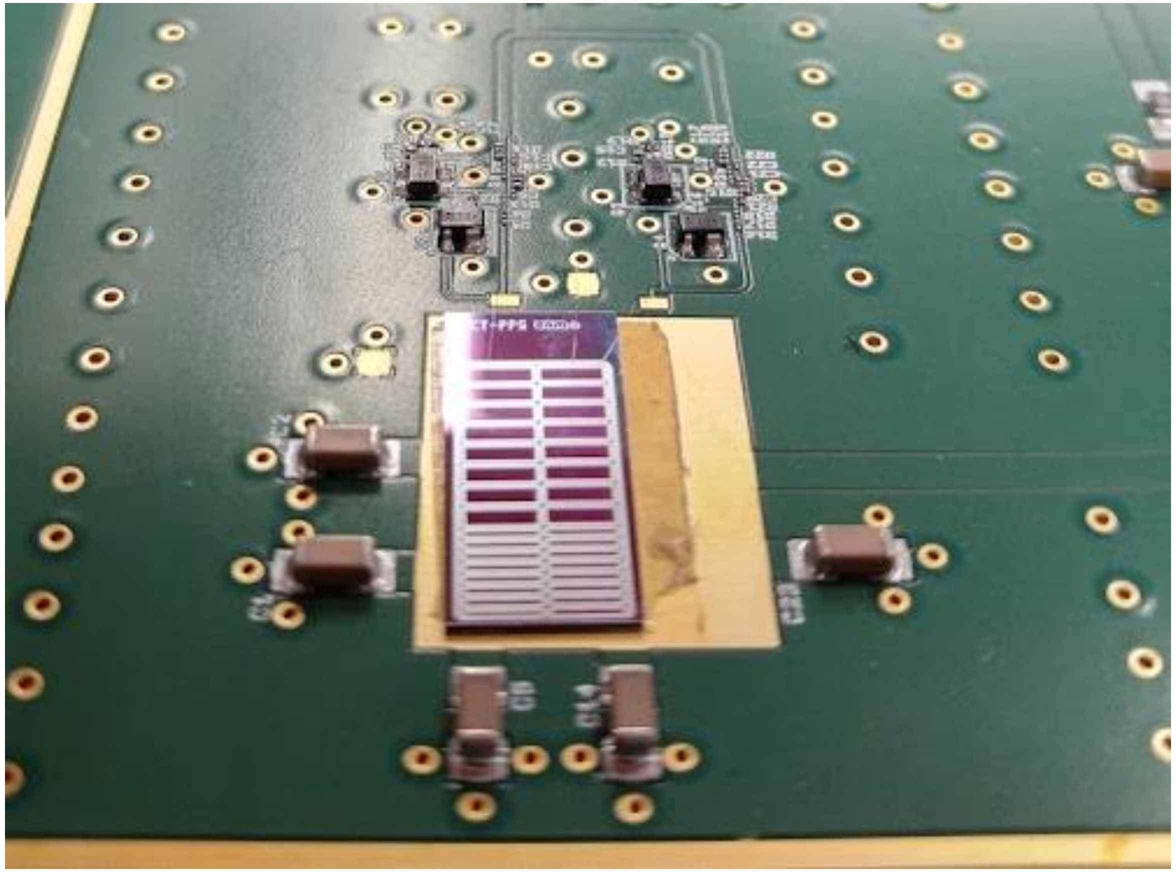
CMS Integrated Luminosity, pp, 2016, $\sqrt{s} =$ 13 TeV

Data included from 2016-04-22 22:48 to 2016-09-06 07:09 UTC

Test of the amplifier in KU

The amplifier was first test using a laser pulse to measure the behaviour with sensors of different capacitance





1080 nm picosecond laser, 50 ps wide pulses with peak power > 100 mW set at 10 cm away from the sensor board
The support can be moved XY with micrometric accuracy

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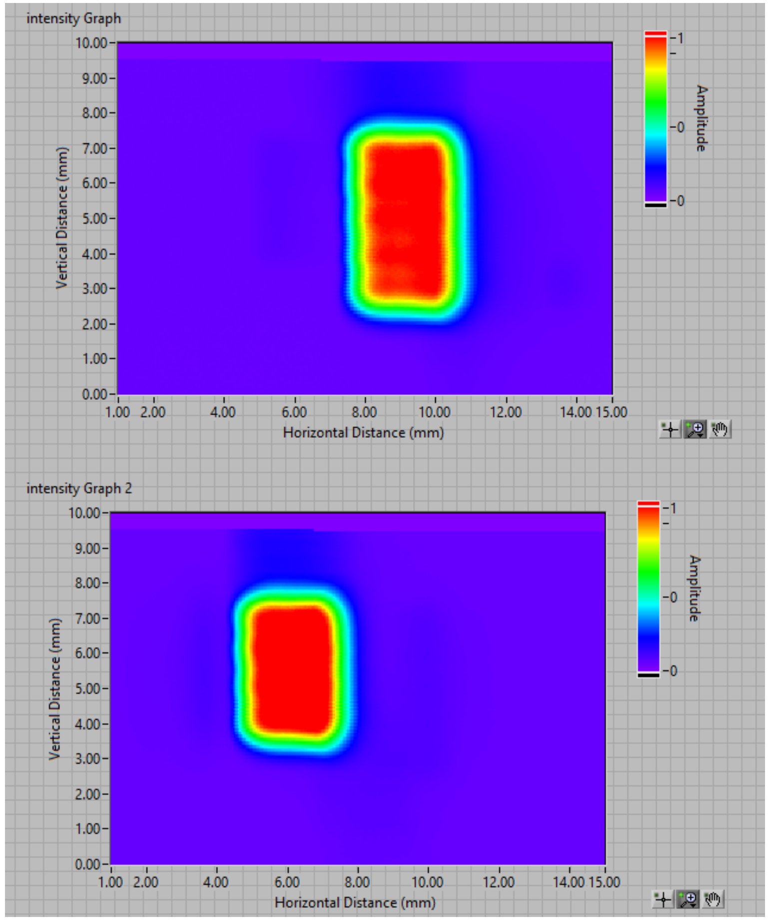
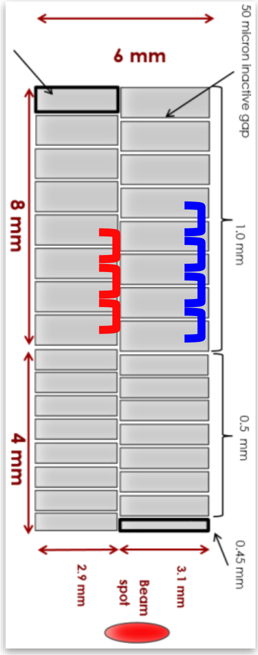
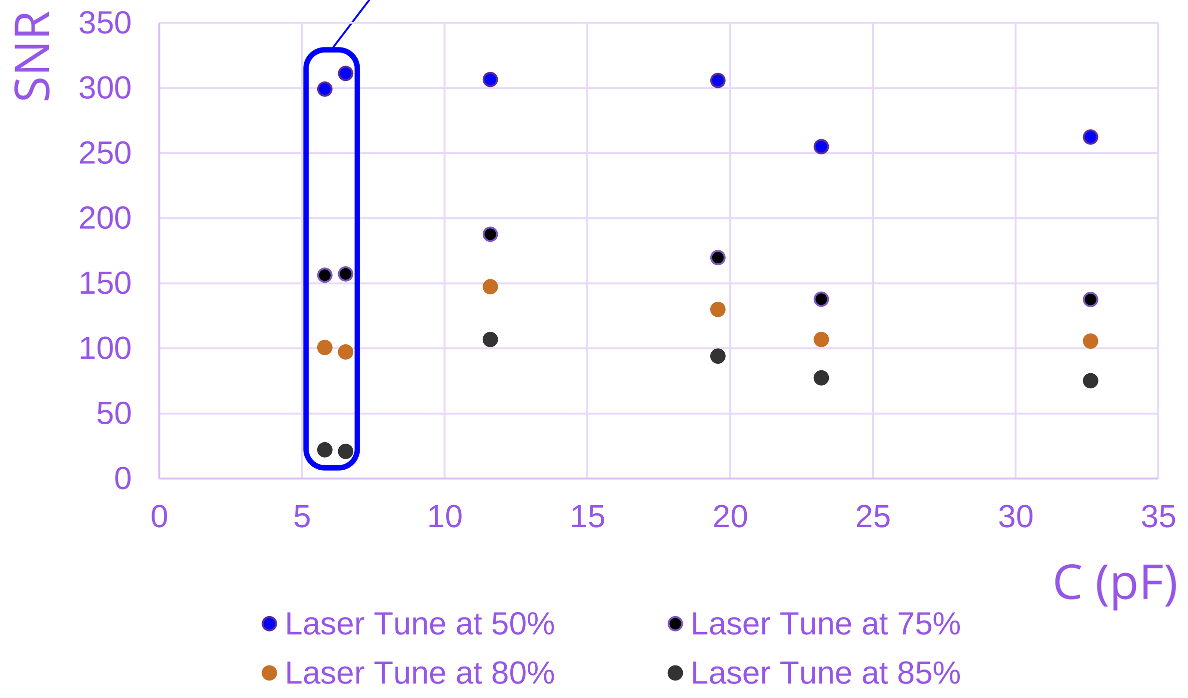


3.1 x 5 mm^2 ~ 33 pF



2.9 x 4 mm^2 ~ 24 pF

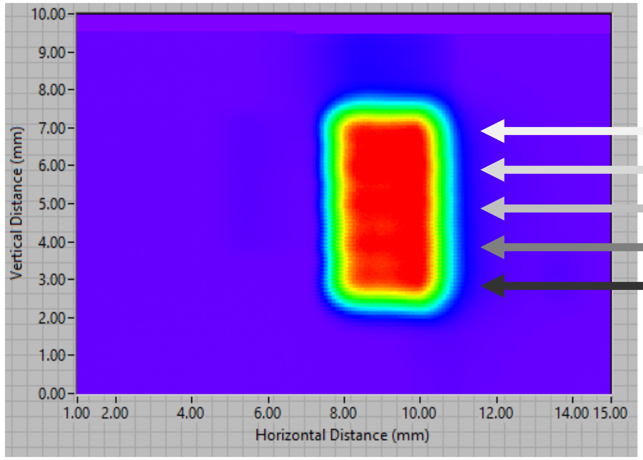
Laser spot larger than the pad: partial light collection

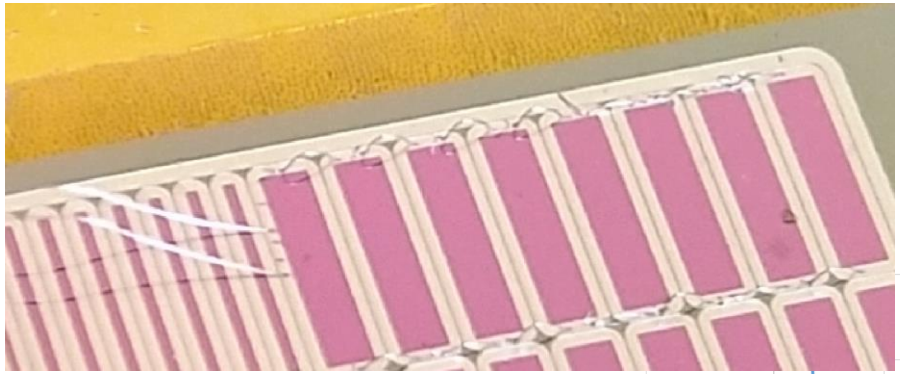


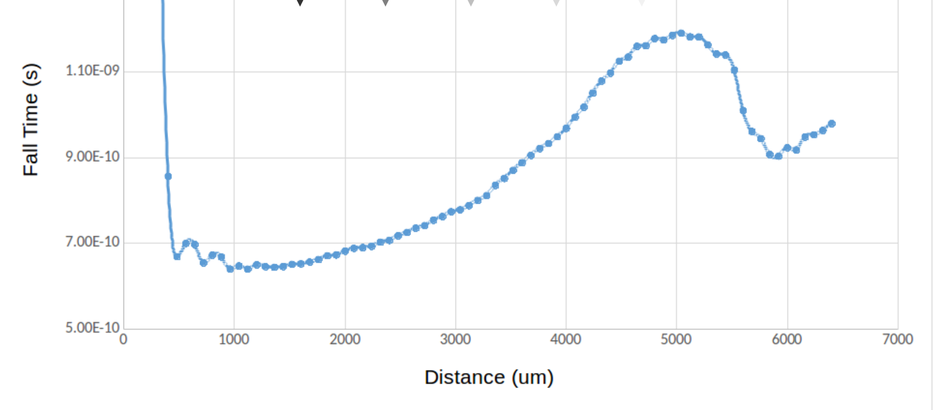
To test the amplifier with sensors of increasing capacitance, more than one pad were connected to the same amplifier

Test of the amplifier in KU

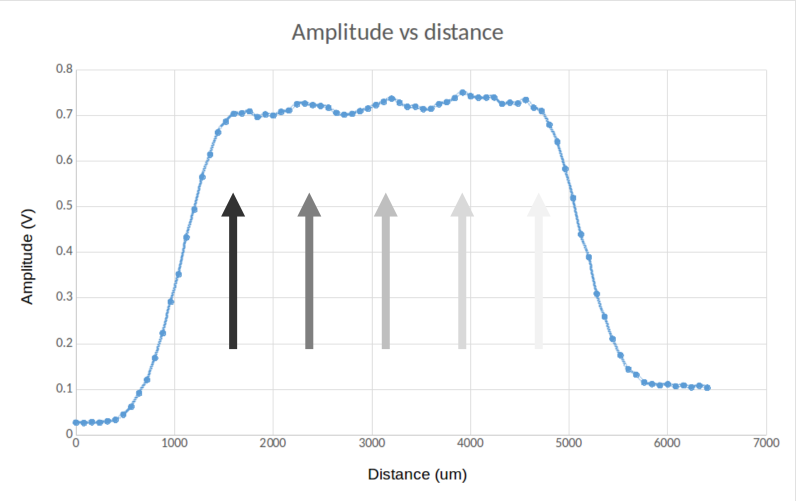
The amplifier was first test using a laser pulse to measure the behaviour with sensors of different capacitance







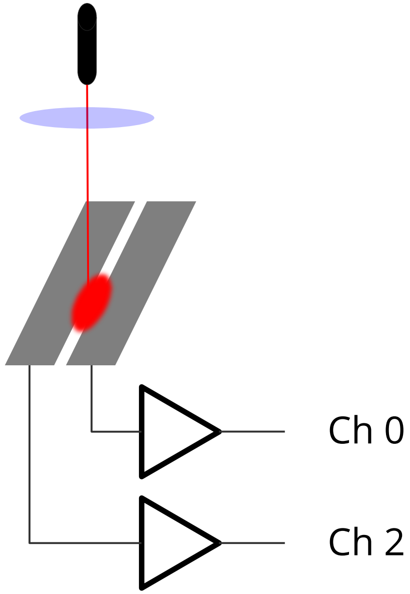
However, the fall-time shows a strong dependency



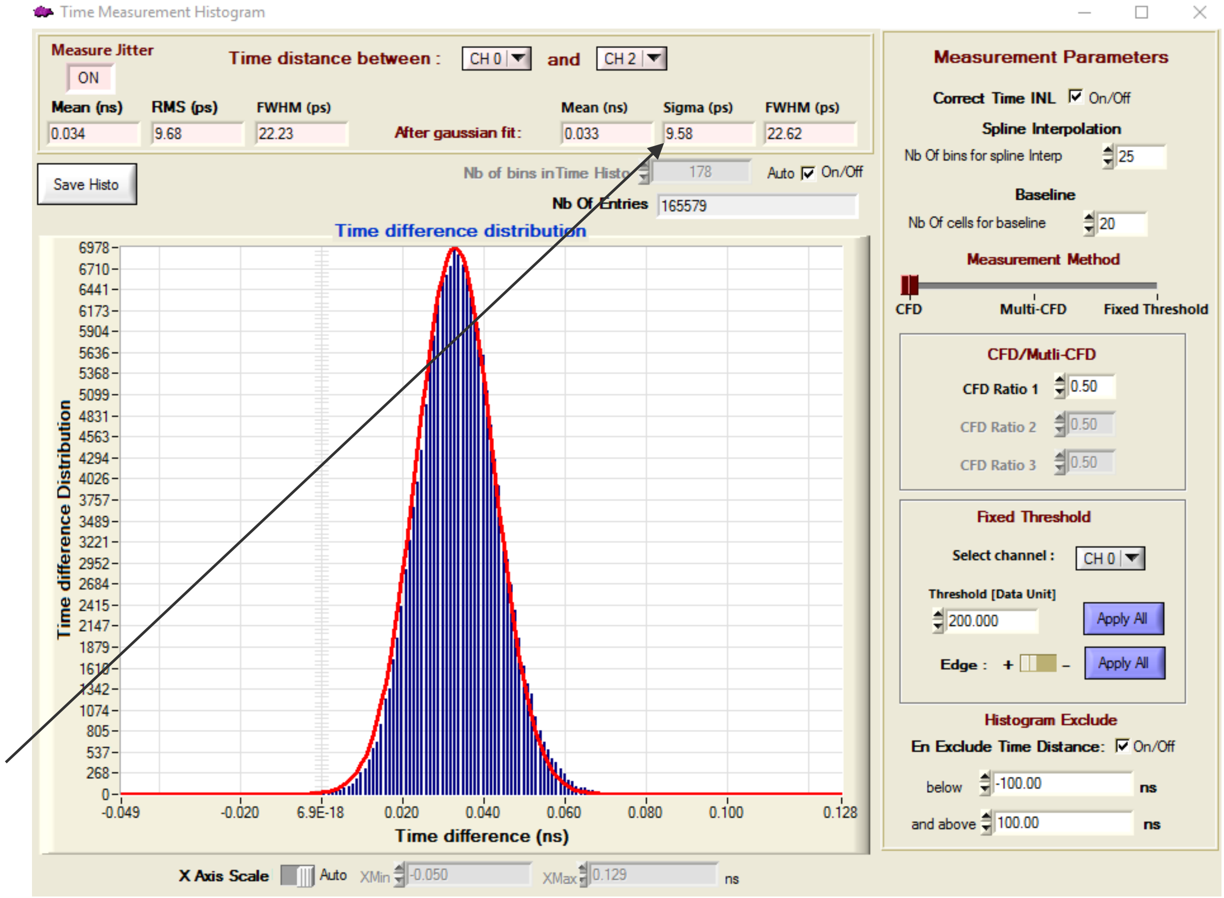
The amplitude of the signal has a week dependence on the position of the laser spot

Test of the amplifier in KU

The amplifier was first test using a laser pulse to measure the behaviour with sensors of different capacitance



σ ~ 10ps



Measure Jitter: ON

Time distance between : CH 0 and CH 2

Mean (ns)	RMS (ps)	FWHM (ps)		Mean (ns)	Sigma (ps)	FWHM (ps)
0.034	9.68	22.23	After gaussian fit :	0.033	9.58	22.62

Nb of bins in Time Histo: 178 Auto ☑ On/Off

Nb Of Entries: 165579

X Axis Scale: Auto XMin -0.050 XMax 0.129 ns

Measurement Parameters

Correct Time INL ☑ On/Off

Spline Interpolation

Nb Of bins for spline Interp: 25

Baseline

Nb Of cells for baseline: 20

Measurement Method: CFD / Multi-CFD / Fixed Threshold

CFD/Mutli-CFD

CFD Ratio 1: 0.50

CFD Ratio 2: 0.50

CFD Ratio 3: 0.50

Fixed Threshold

Select channel : CH 0

Threshold [Data Unit]: 200.000

Edge : + –

Histogram Exclude

En Exclude Time Distance: ☑ On/Off

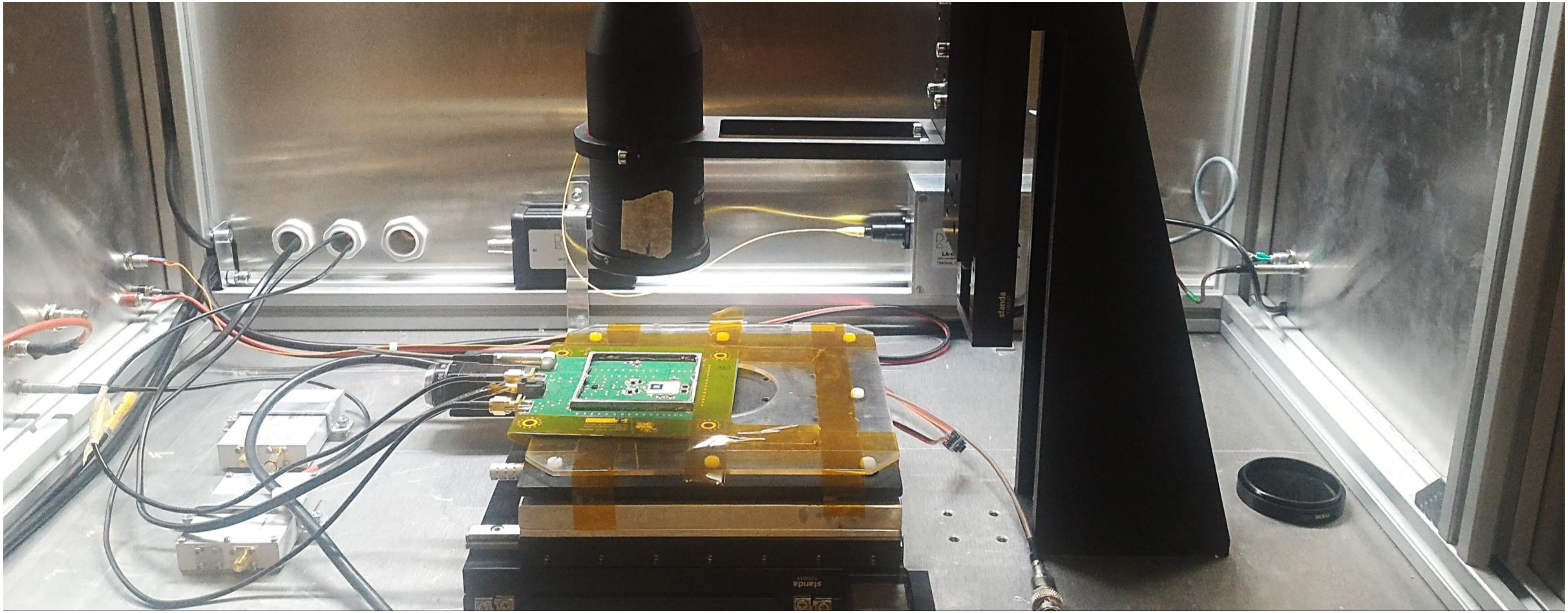
below -100.00 ns

and above 100.00 ns

Time difference between two neighboring pixels with the laser, measured using the SAMPIC evaluation board

Test of the amplifier in Turin

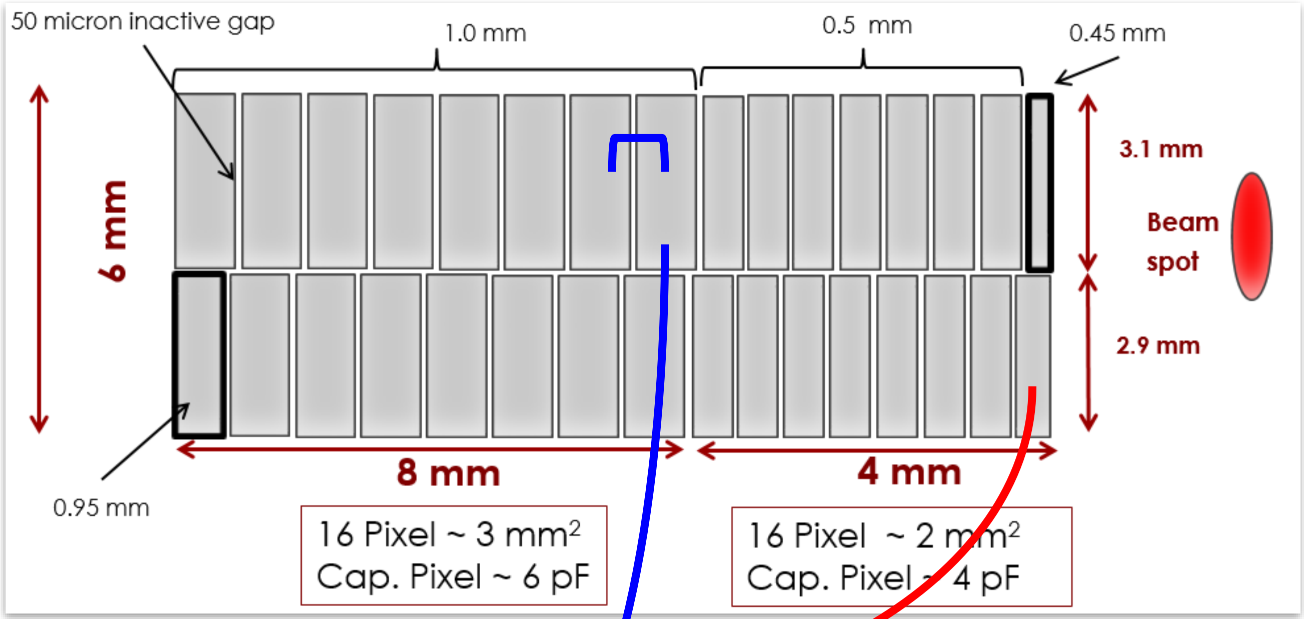
The amplifier was first test using a laser pulse, calibrated using cosmic rays and a radioactive source (Sr^{90})



The laser pulse was focused on $\sim 50\ \mu m$ spot; the power was calibrated using a Sr^{90} and

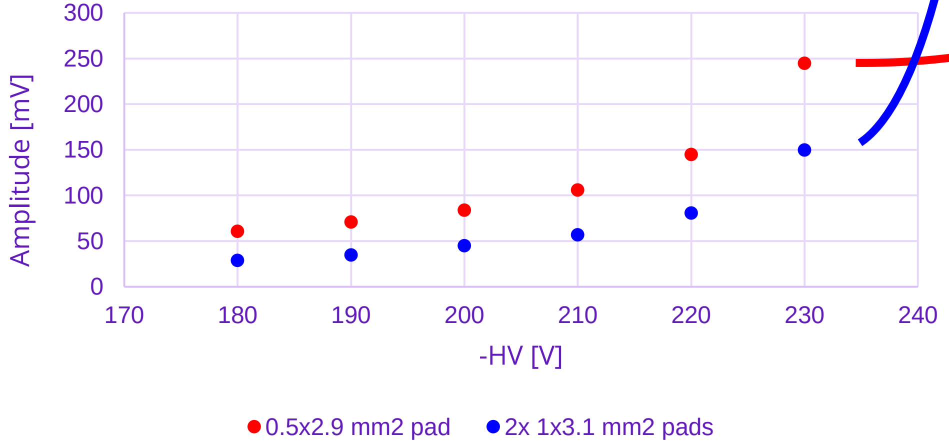
UFSD for CT-PPS

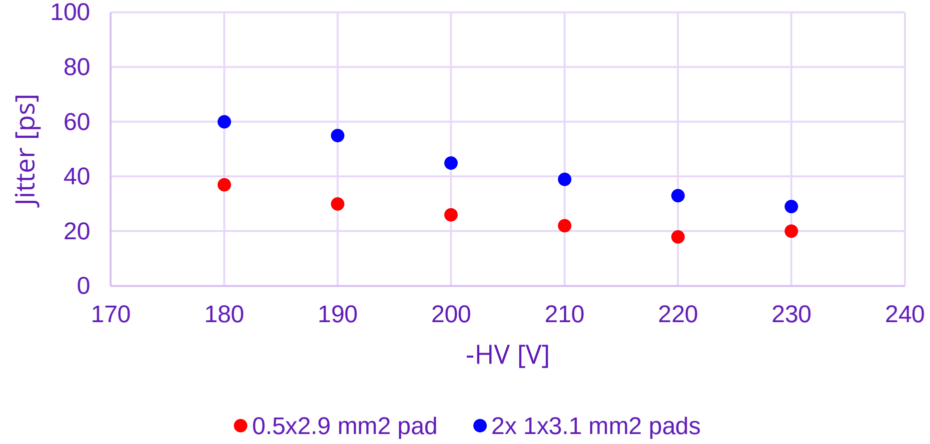
The CT-PPS sensor was used to test the amplifier with a pad of ~3 pF and one of ~12 pF



16 Pixel ~ 3 mm^2
Cap. Pixel ~ 6 pF

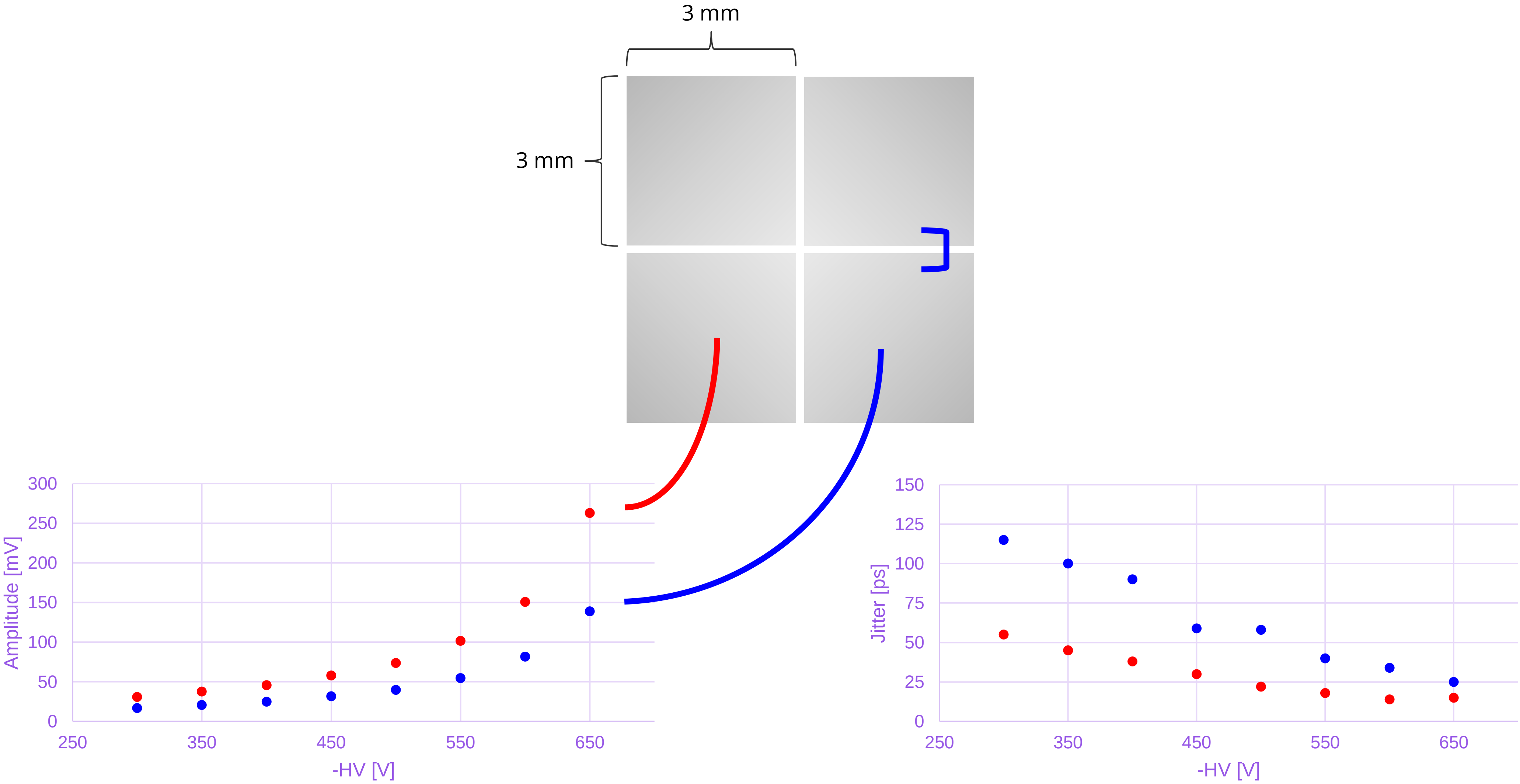
16 Pixel ~ 2 mm^2
Cap. Pixel ~ 4 pF





UFSD produced by Hamamatsu

Hamamatsu produced some 50 µm thick LGADs, a sample with gain ~10 at 600V was tested



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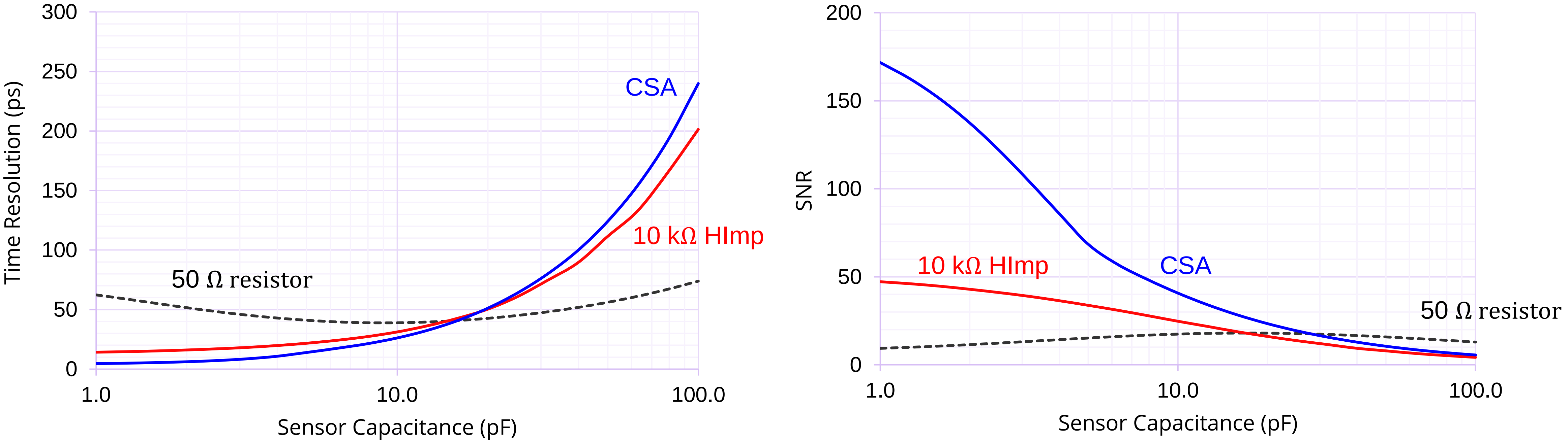
Performance with different sensor capacitances

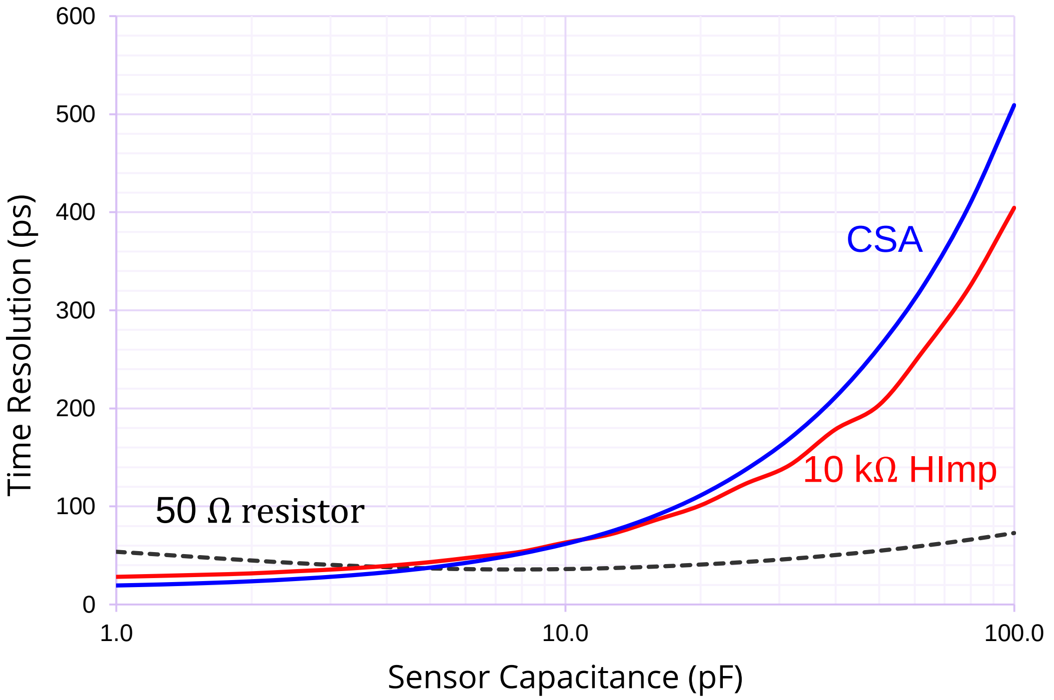
The behaviour of the different approaches using 50 µm UfSD can be simulated for several values of the sensor capacitance.

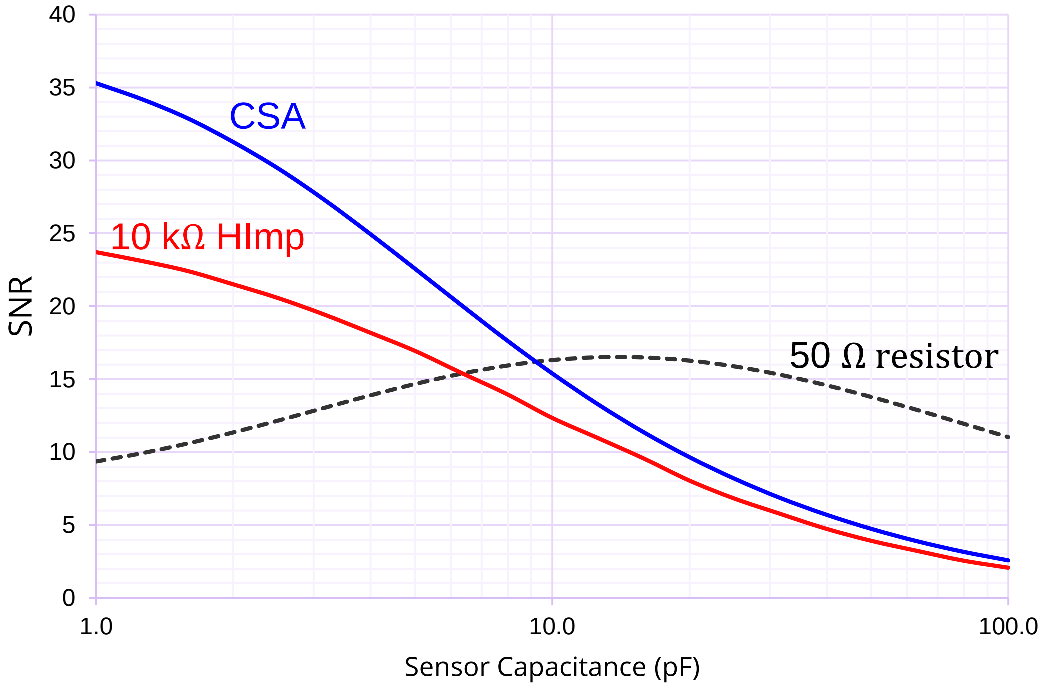


Below 15 pF the CSA is the amplifier with the best time resolution

Performance with damaged sensors

Supposing that the gain become 50% lower because of radiation damage, the CSA is still the best approach.





Below 10 pF the CSA is the amplifier with the best time resolution.

Front-end electronics: amplifier

It is useful to analyse the simplest possible case: a diamond detector read using a simple resistor.

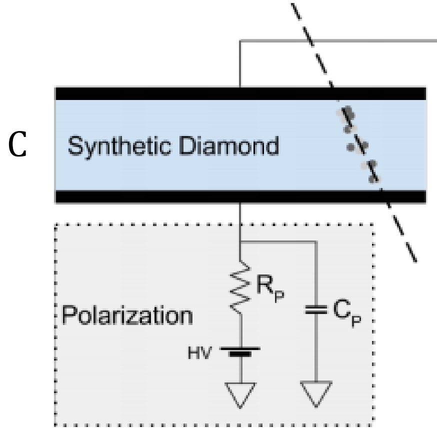
For $R < \sim 100\ \Omega$ the signal is not separated from the noise ($SNR \sim 1$) also for $C \sim 0.1$ pF.

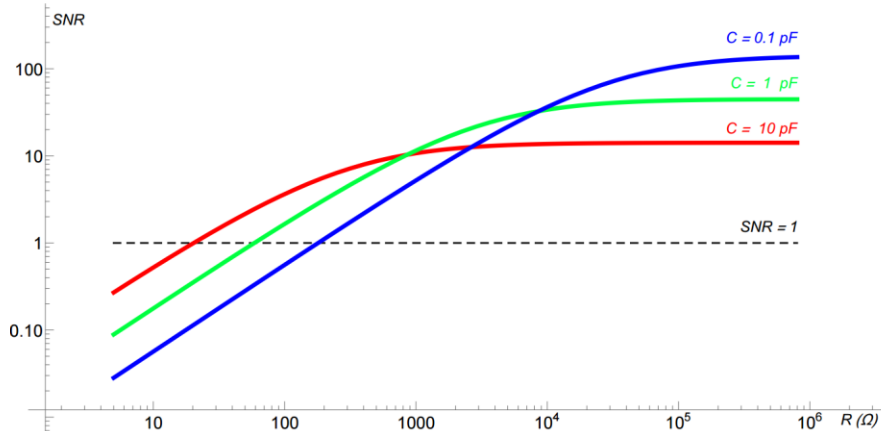
The only way to have a SNR > 1 is to increase the value of the read-out resistor.

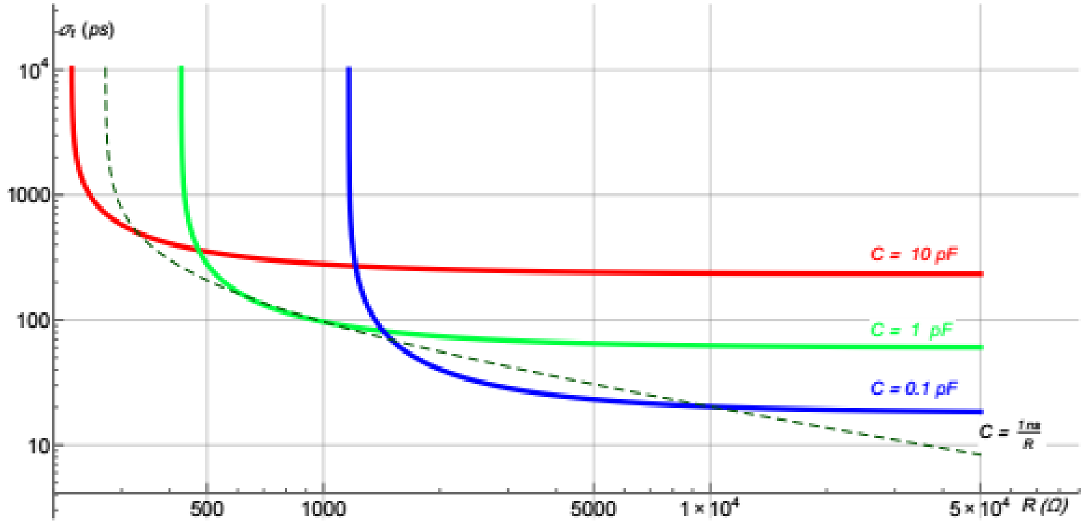
However, the time resolution is given by:

$$\sigma_t \sim \frac{\sigma_V}{MAX[\frac{dV}{dt}]}$$

And higher R means slower signal:



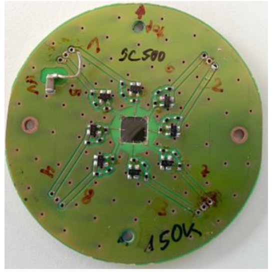


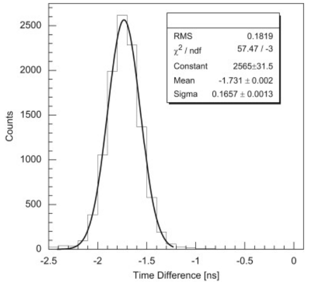


A useful rule of thumb: **minimize C and use R ~ 1 ns/C**

Amplifier as close as possible to the sensor (minimize C)
First stage with input resistor ~ kΩ

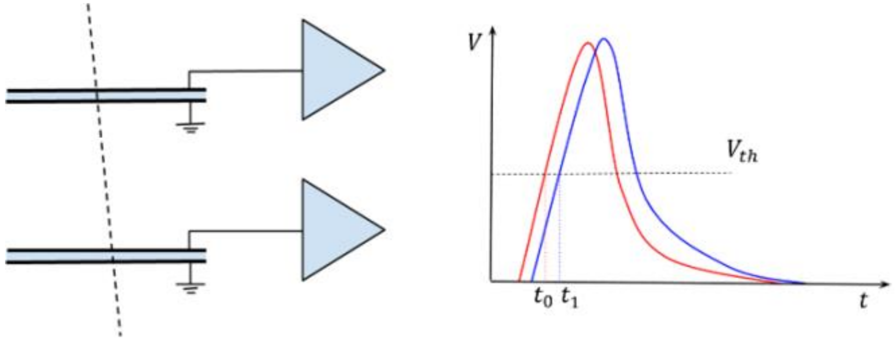
Strategy suggested by HADES @ GSI
10.1016/j.nima.2010.02.113





The TOTEM timing detector: timing performance

To measure the time resolution of two identical detectors it is possible to measure the arrival time of a particle crossing both sensors.

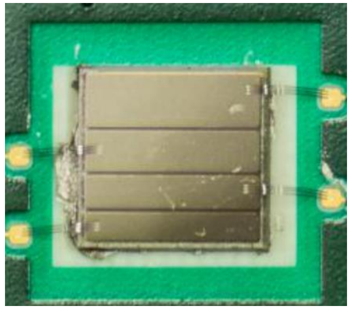


The measured time difference will be distributed around the true value because of the limited resolution of the detectors:

$$\sigma^2_{TOT} \sim \sigma^2_{det1} + \sigma^2_{det2} \sim 2\sigma^2_{det1} \longrightarrow \sigma_{meas} \sim \sqrt{2}\sigma_{det}$$

However, the time resolution depends on the capacitance of the detector!

A series of tests were done using a sensor with pads of different surface, i.e. capacitance.



Time difference between a sensor of 17.6 mm² (~1.7 pF) and sensors of different size