# New readout electronics for Ultra fast Silicon Detectors

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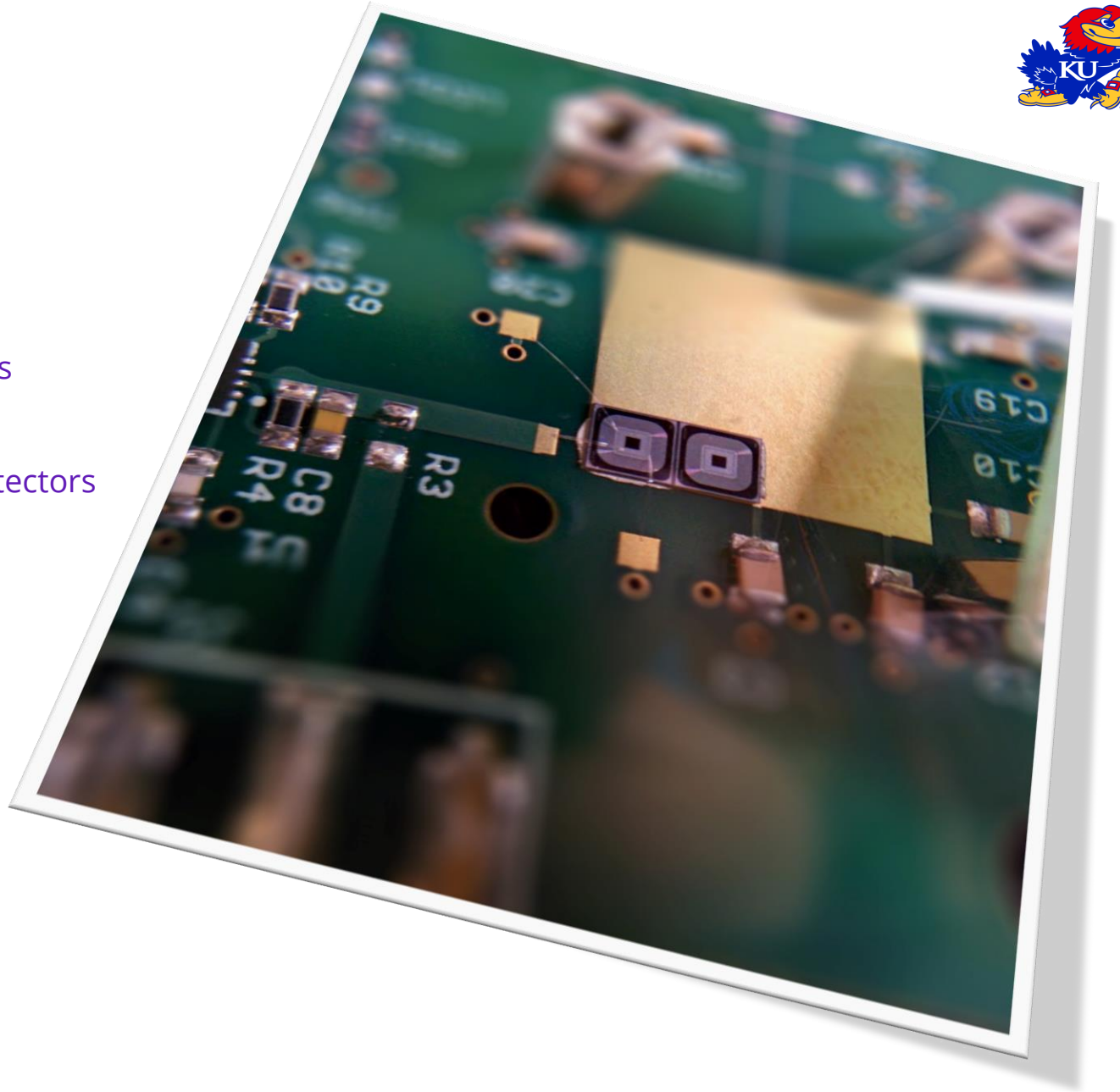
Workshop on picosecond timing detectors for physics and medical applications, Kansas City 15-18 September 2016

# Outline

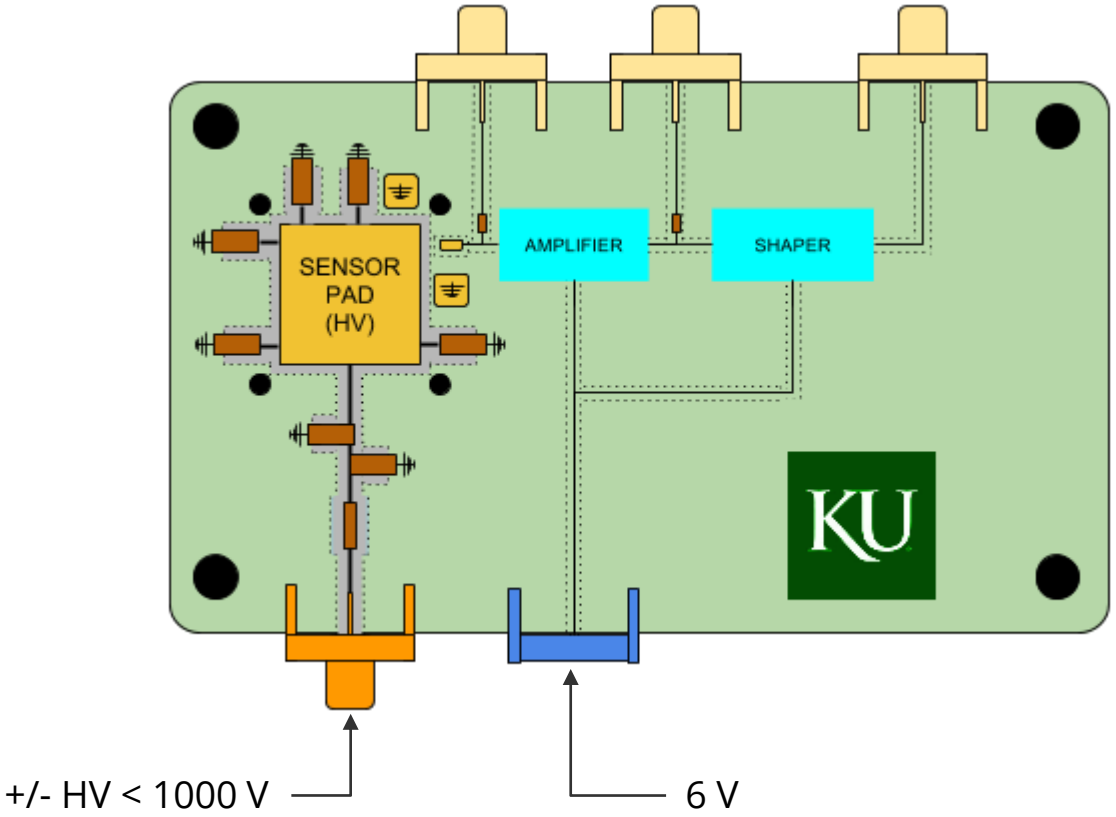
- The idea for a new amplifier
- Different read-out techniques for solid state detectors
- Optimization of the amplifier for Ultra Fast Silicon Detectors
- Experimental results



# Multi purpose board for a silicon/diamond detector

A one channel board that can be use for the characterization of different solid state detectors.

- Sensors can be read-out using an external amplifier
- The amplifier can be characterized injecting an external signal
- The 0 Ω resistor can be removed during normal operation




- The first stage is a Charge Sensitive Amplifier
- The second stage is optimizing the output for timing measurements

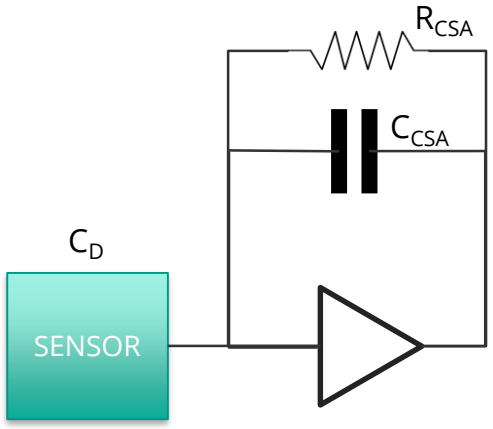
Sensors up to 20x20 mm$^2$ can be glued and bonded.

The components can be easily changed 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

# Charge Sensitive Amplifier

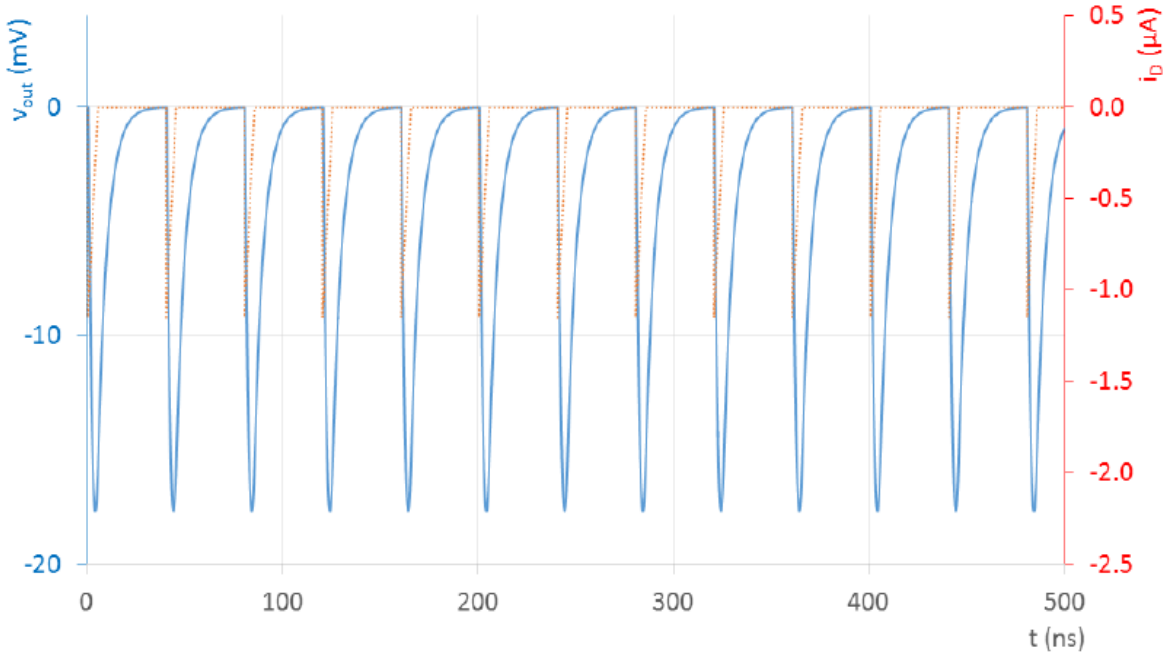
The output of a Charge Sensitive Amplifier (CSA) is proportional to the charge injected by the sensor.




$$v_{out} = -\frac{C_D}{C_{CSA}} \frac{1}{1 + \frac{C_D}{C_{CSA}}} Q_{gen}$$

$Q_{gen} = \int i_{gen}\, dt \rightarrow$ Good solution for:

- *Large* SNR
- *Slow* signal

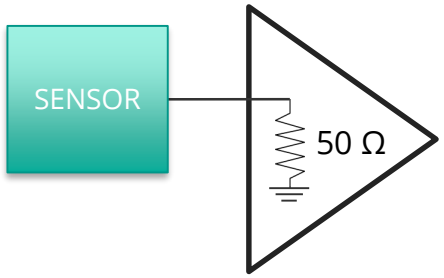



Simulation of a diamond detector read-out using a ideal Charge Sensitive Amplifier

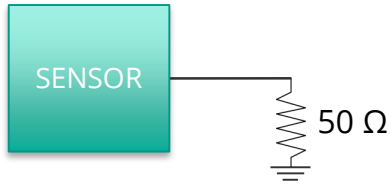
More details: Sec. 4.5 of Development of a timing detector for the TOTEM experiment at the LHC

# Broadband amplifier

A Broadband Amplifier (BDA) can take advantage of a fast signal.



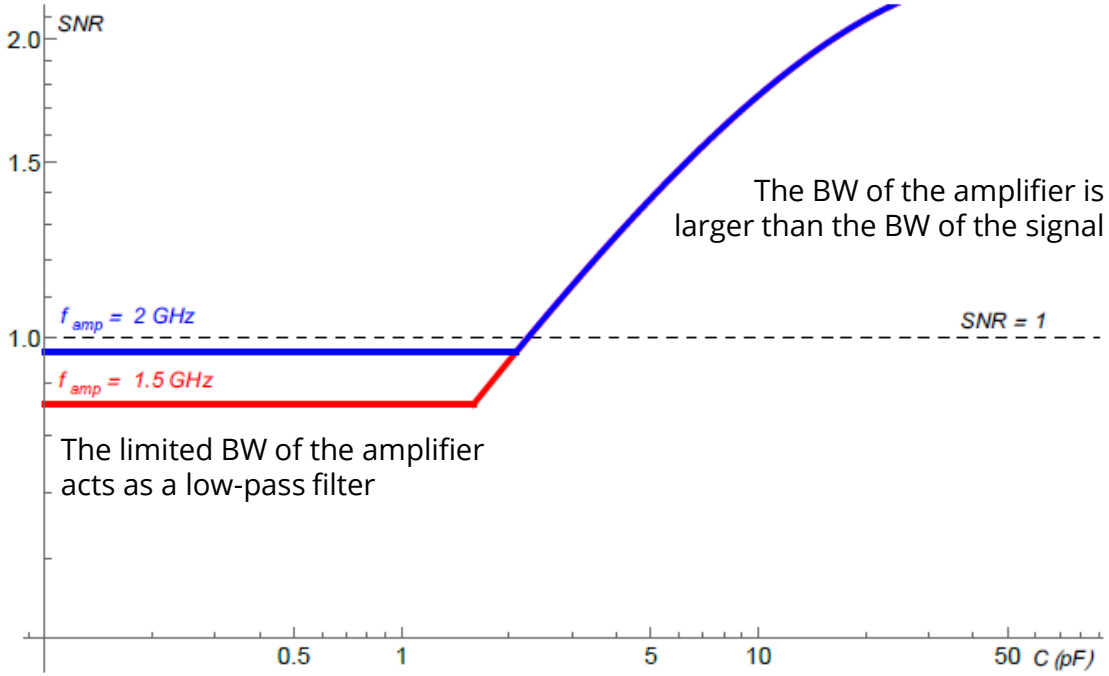

SNR for the ideal case of a read-out resistor:




$$SNR = \frac{SNR_B}{\sqrt{F}} = \frac{k_0}{\sqrt{F}} \frac{R_i C}{\sqrt{k_B T C}} \left( t_{tr} + R_i C \ln \left( \frac{R_i C}{R_i C + t_{tr}} \right) \right)$$

F: Noise Factor
only contribution from the amplifier

Good solution for *large* and *fast* signals.

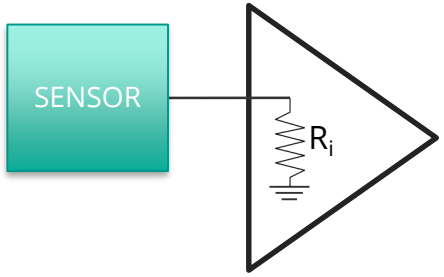



Simulated diamond detector read for F ~ 1.5 at T = 300K.


More details: Sec. 4.4 of Development of a timing detector for the TOTEM experiment at the LHC

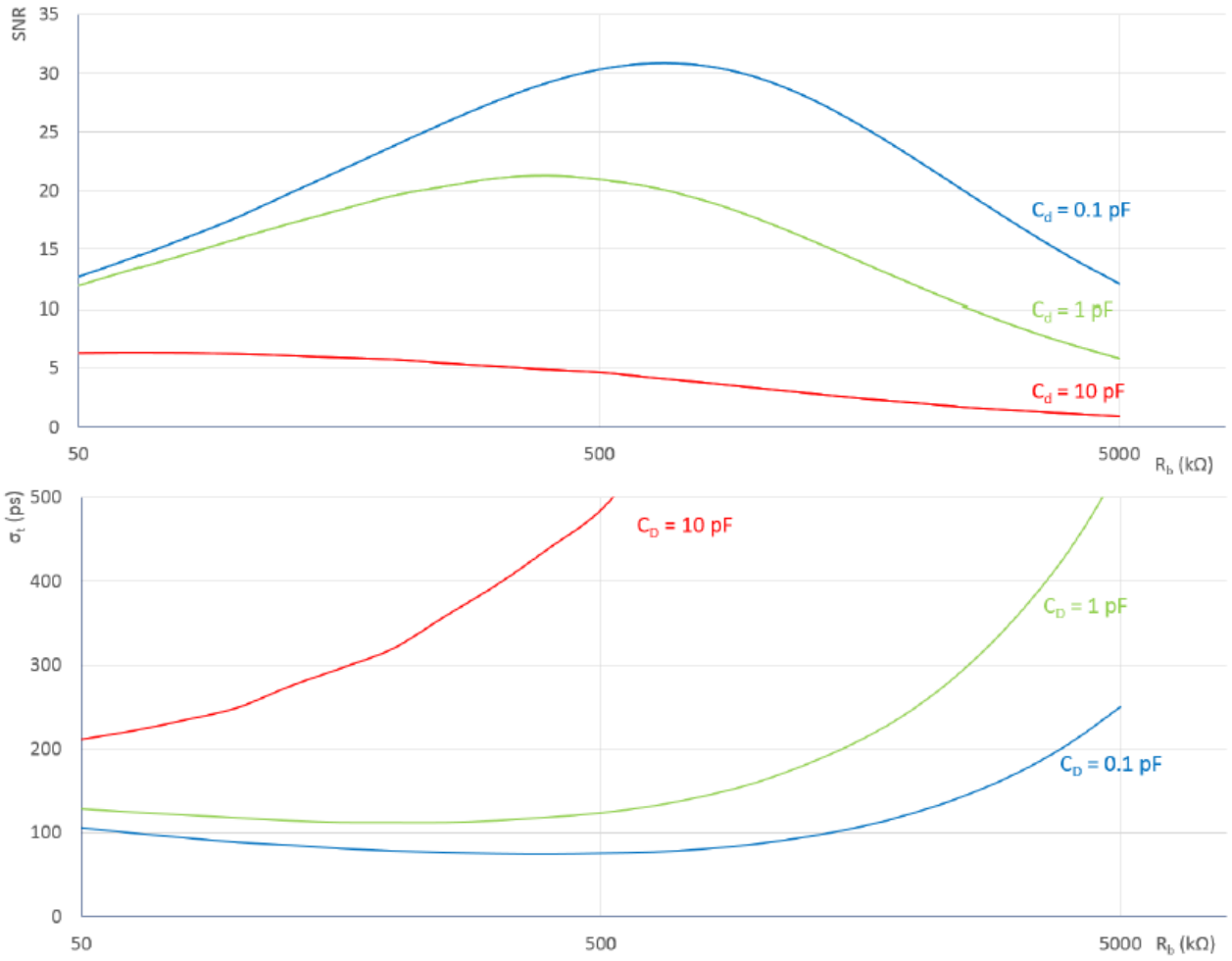
# Amplifier with high input impedance

A different approach that has some advantage of a BDA and some of the CSA is an amplifier with High Input impedance (Himp).




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!

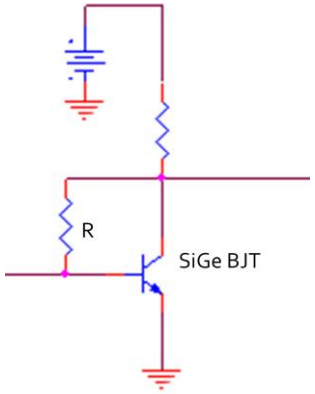



Simulated SNR and time resolution for a diamond detector.

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

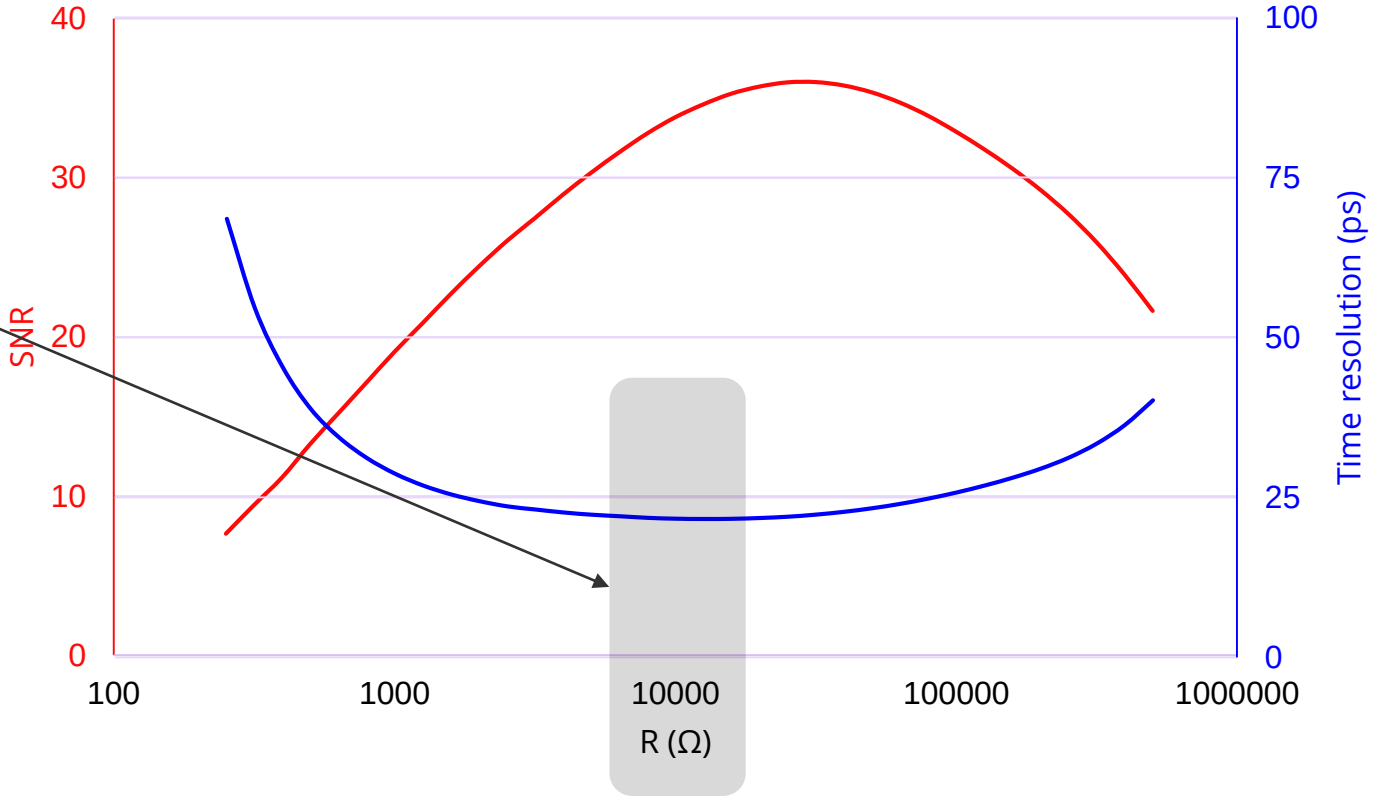
# Amplifier with high input impedance

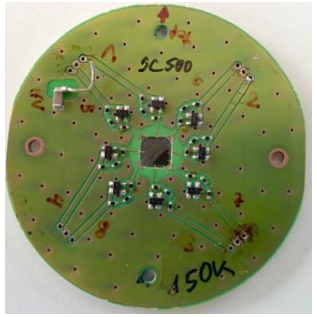
One implementation of a HImp amplifier is using a common emitter with a feedback resistor.



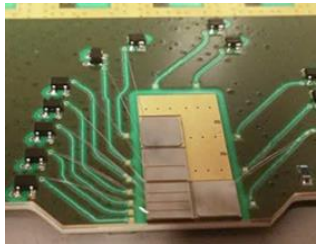

The best value of R for timing has to be optimized according to the sensor:

- 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 yesterday talk

# Optimization for UfSD

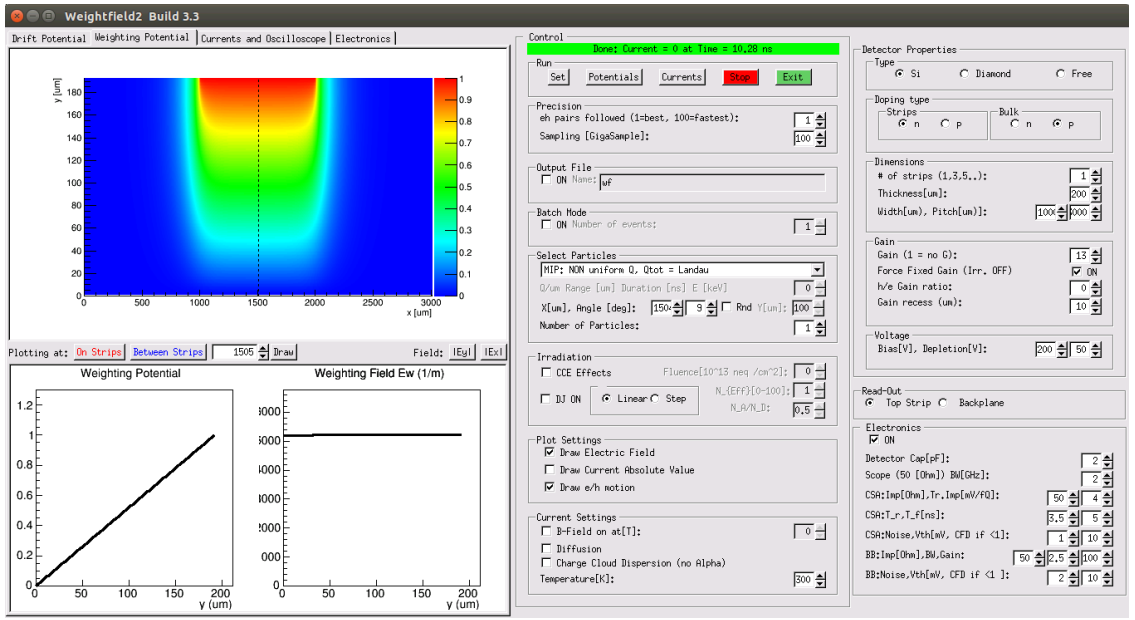
The signal generated at the passage of a MIP by a 50 μm UfSD can be simulated using Weightfield2*.

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

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

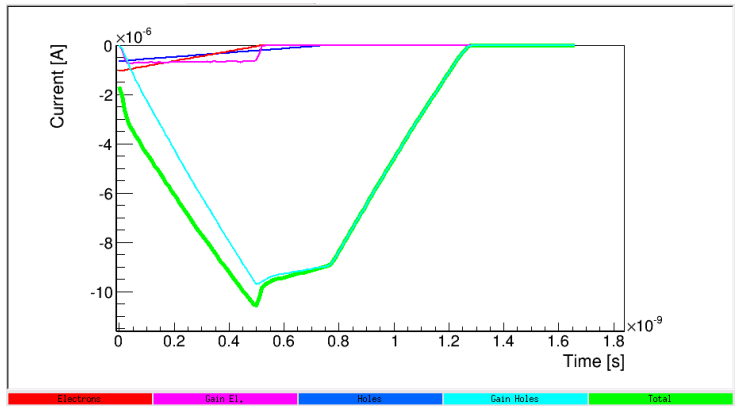
arXiv:1608.08681

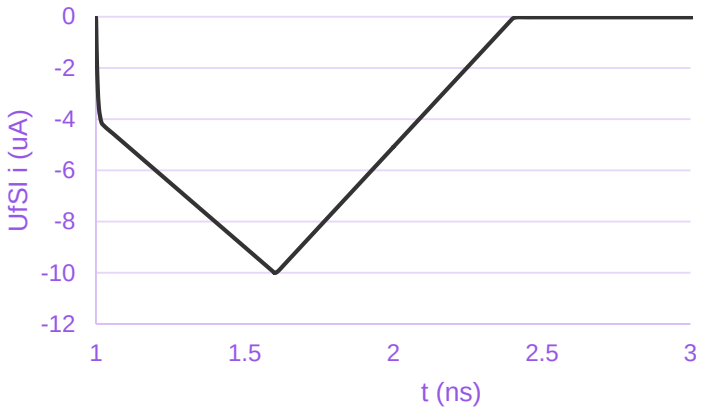
Timing capabilities of Ultra-Fast Silicon Detector




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

50 μm UfSD at 200V with a gain 15

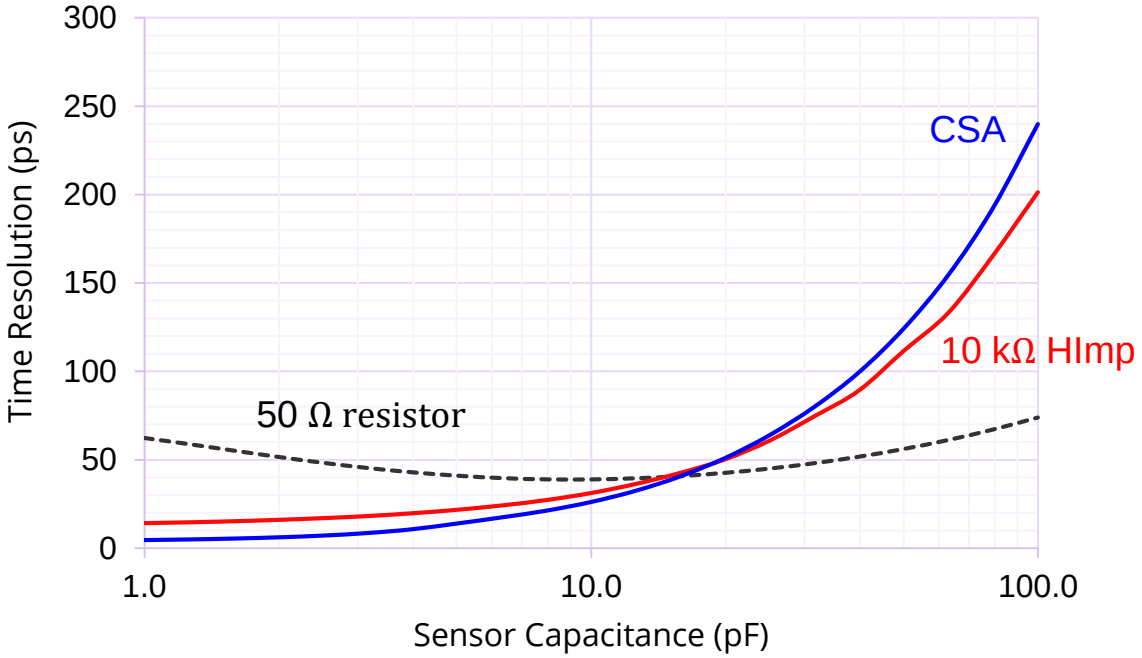


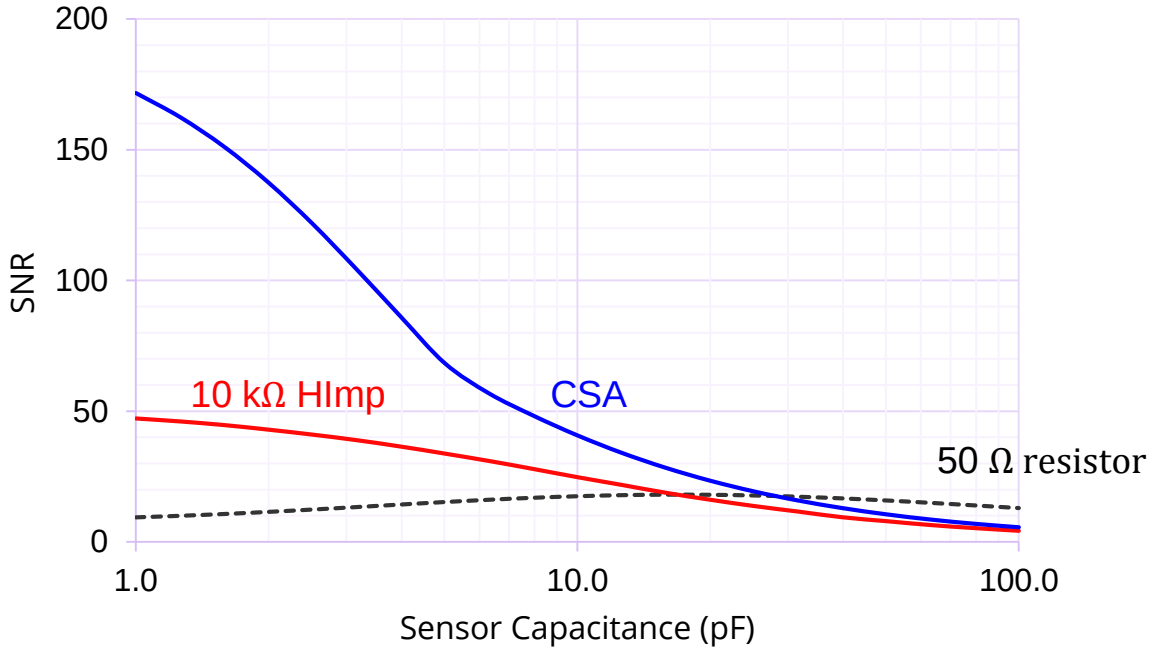




*: http://personalpages.to.infn.it/~cartigli/Weightfield2/Main.html

# 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.

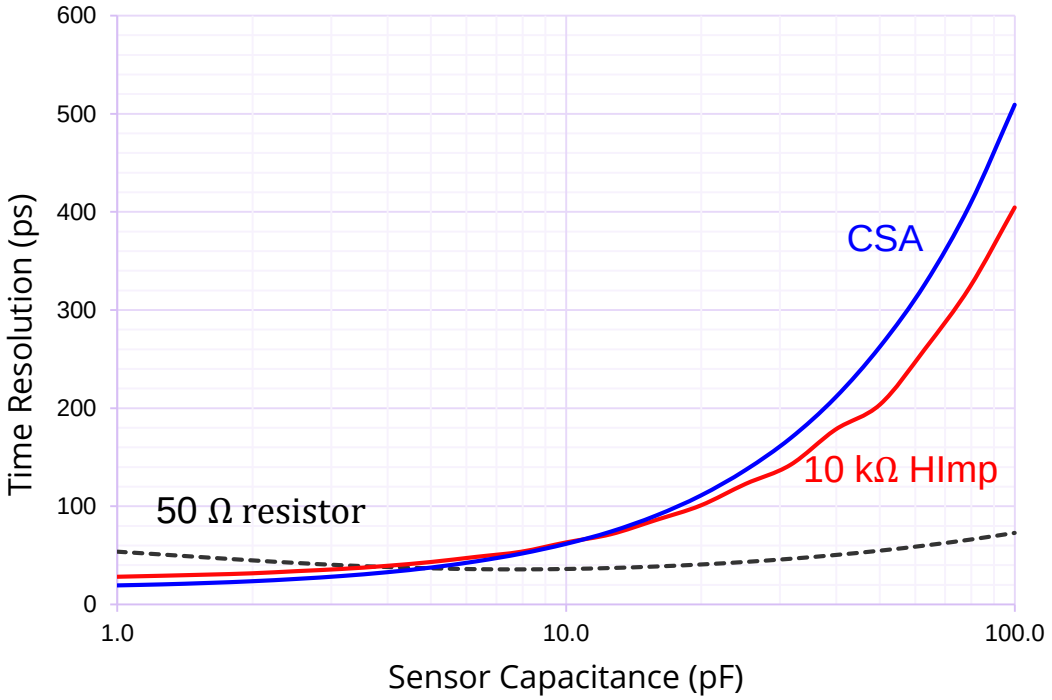


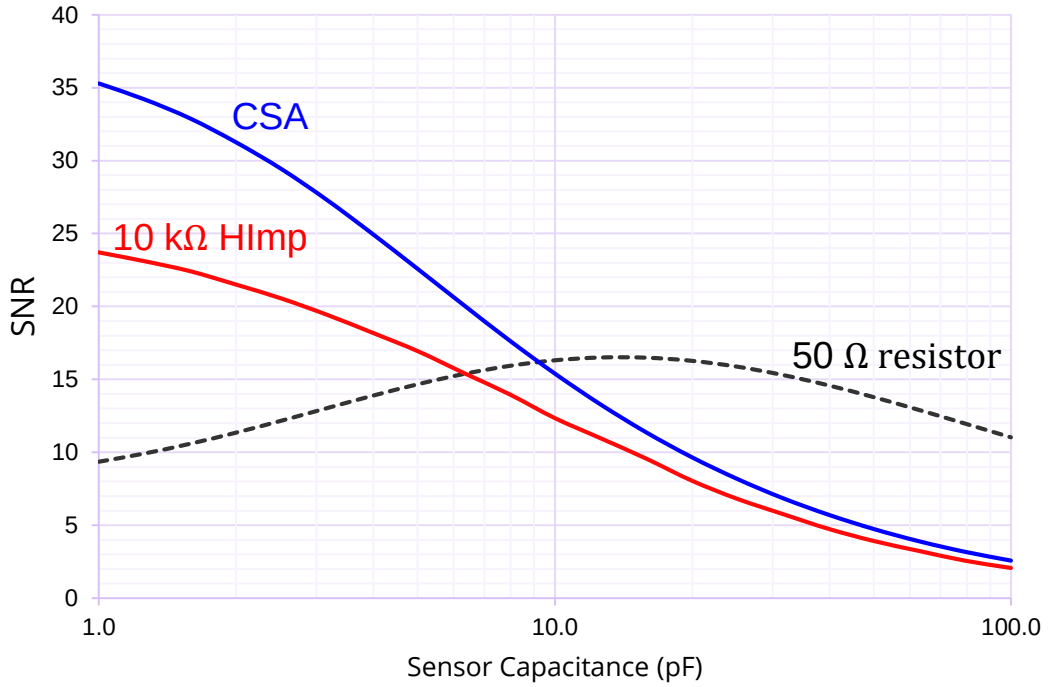




Below 15 pF the CSA is the amplifier with the best time resolution

# Performance with damaged sensors

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



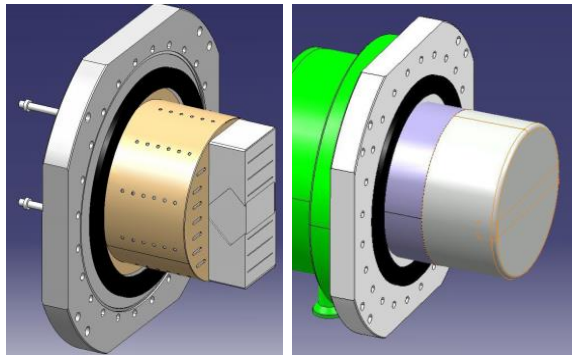

Below 10 pF the CSA is the amplifier with the best time resolution.

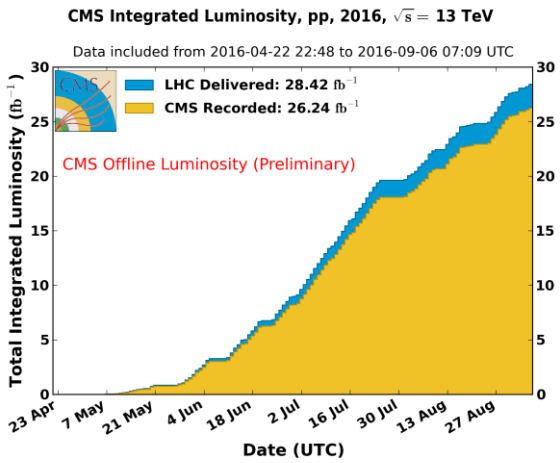
# The timing detector for CT-PPS

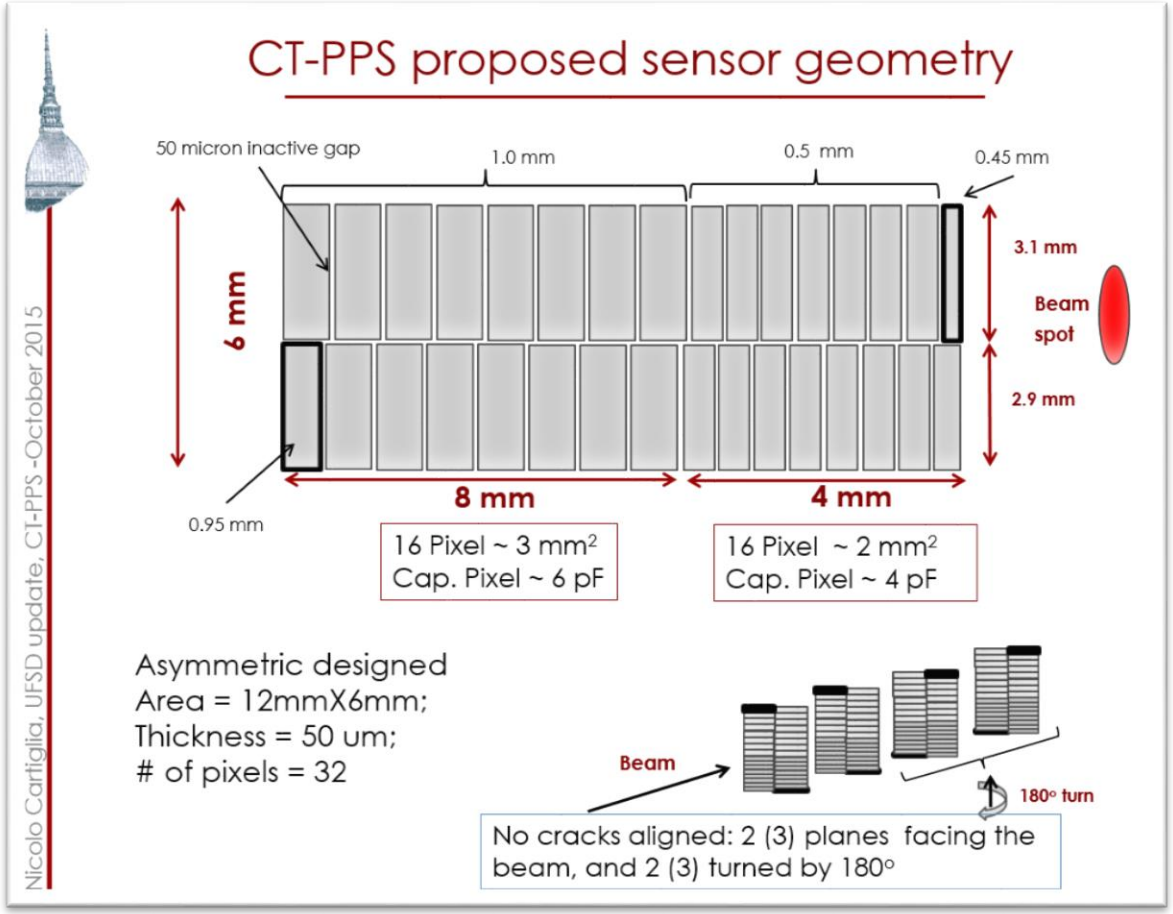
CMS TOTEM Proton Precision Spectrometer (CT-PPS) adds precision proton tracking and timing detectors in the very forward region on both sides of CMS to study central exclusive production (CEP) in proton-proton collisions.

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 $5 \times 10^{15}$ $cm^{-2}$ per 100 $fb^{-1}$ )
- Time resolution of 10-30 ps.





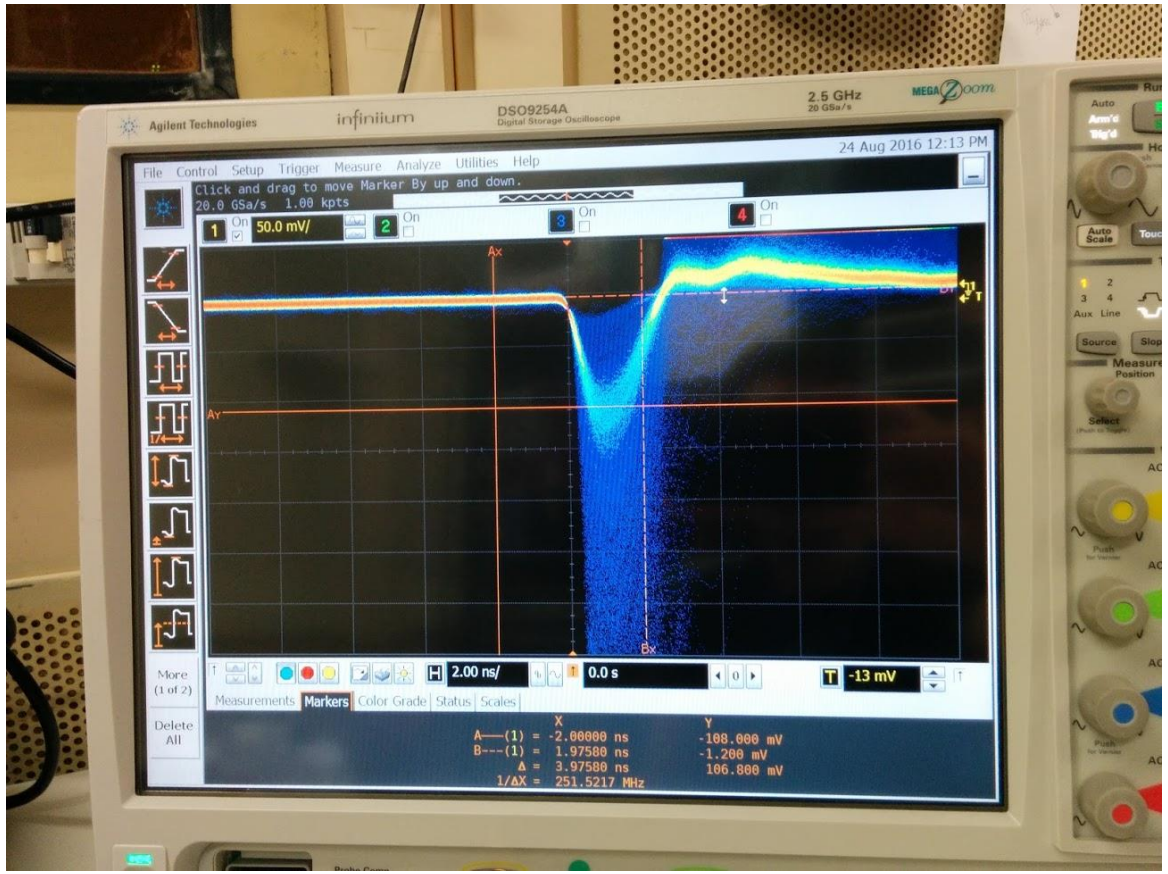




Simulations suggest CSA as the best approach.

More details: CT-PPS project a the LHC, L. Forthomme

# Test of the amplifier

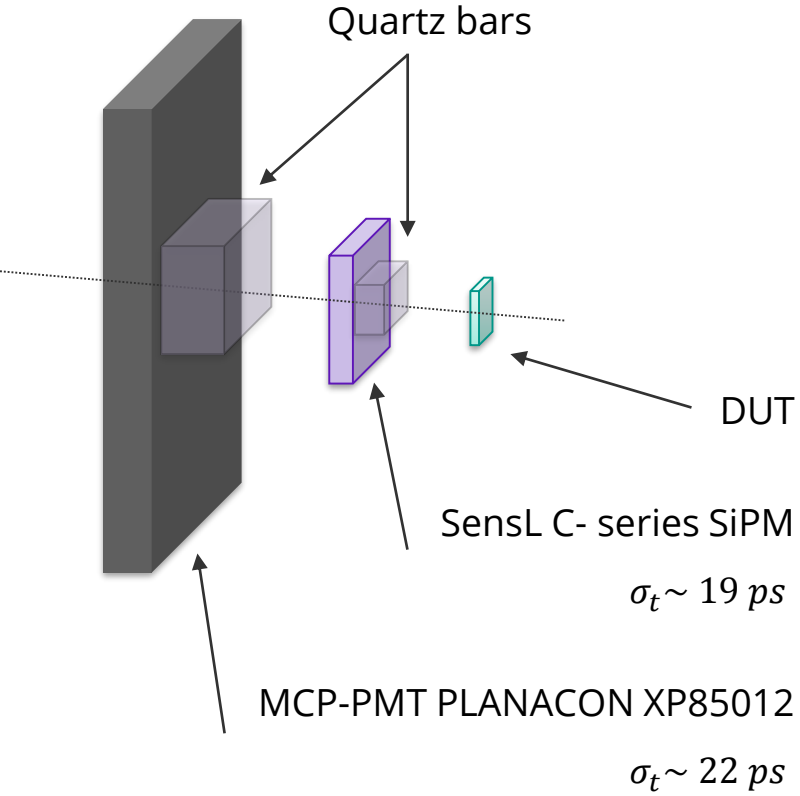
The amplifier was first test using a radioactive source ($Sr^{90}$).

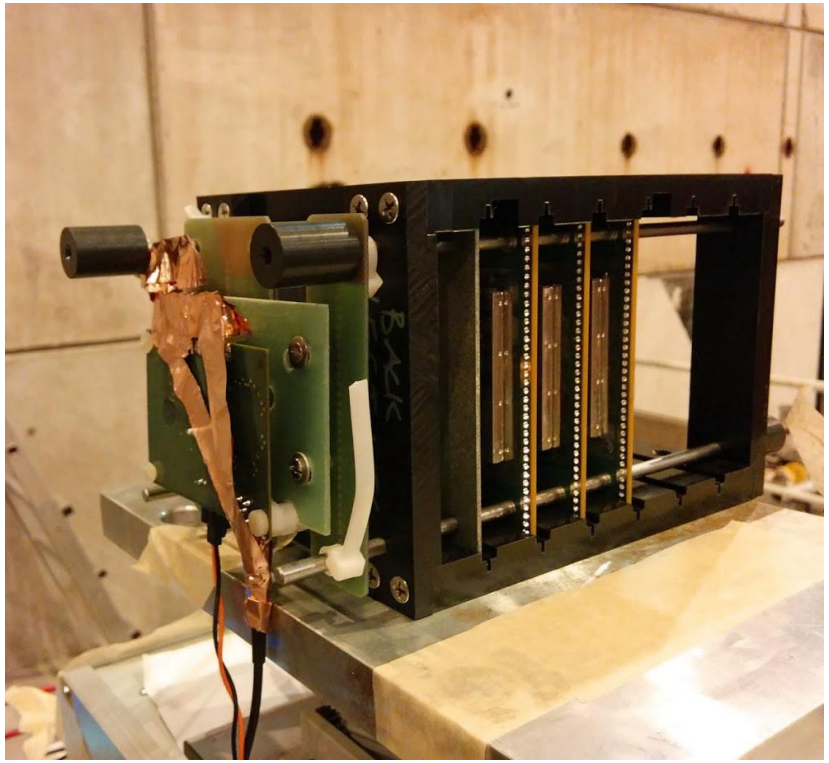



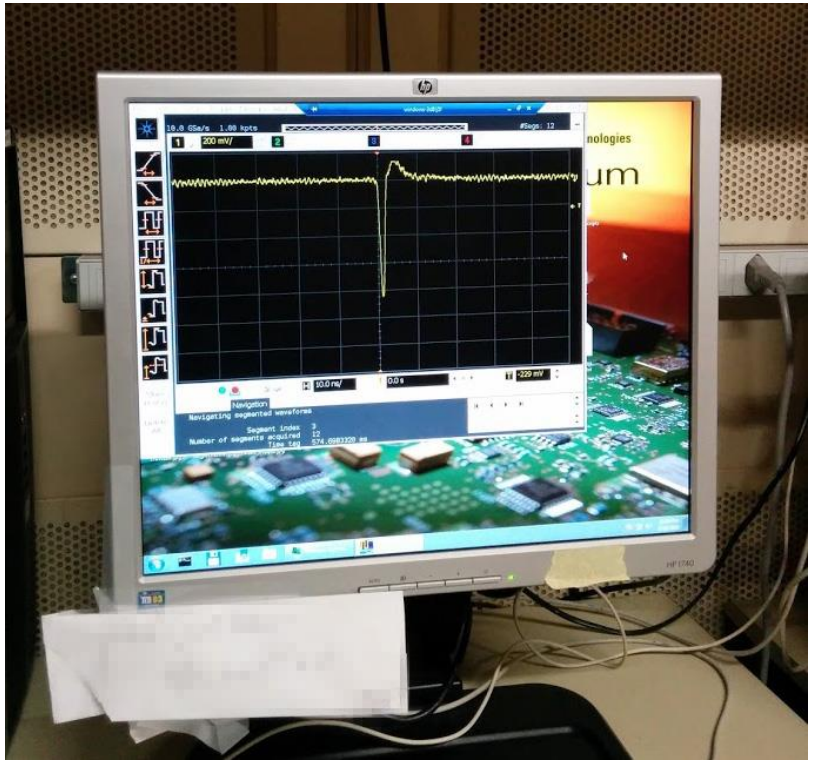

The amplifier and the acquisition chain can be optimized for different scenarios; in this case, they were optimized to have the noise at the output of the amplifier at ~ 1 mV RMS: the same order of the noise added by the digitization process i.e. 500 mV / $2^8$

# Test Beam in the CERN North Area

The time resolution was measured using a SiPM and a MCP-PMT with Cerenkov bars as time reference





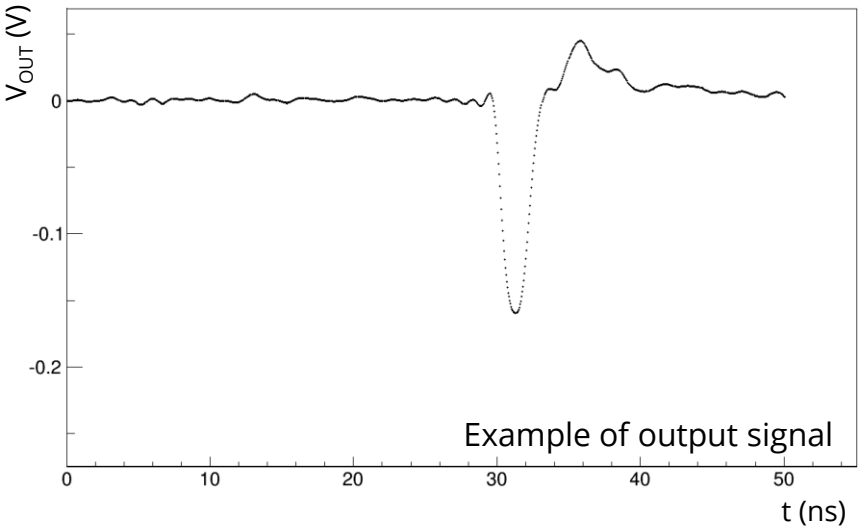
The detector was installed on the beam in the H8 area[1] using a pre-aligned structure[2] and was acquired using a remote controlled oscilloscope: Agilent DSO9254A, 8 bit at 20 Gsa/s

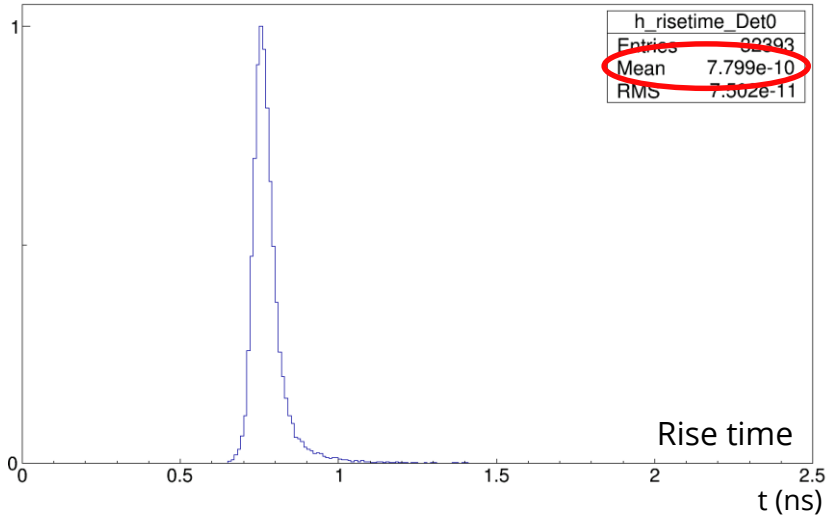
All the tests were conducted at room temperature.

1: Thanks to the TOTEM Collaboration
2: Thanks to N. Cartiglia et al. : arXiv:1608.08681

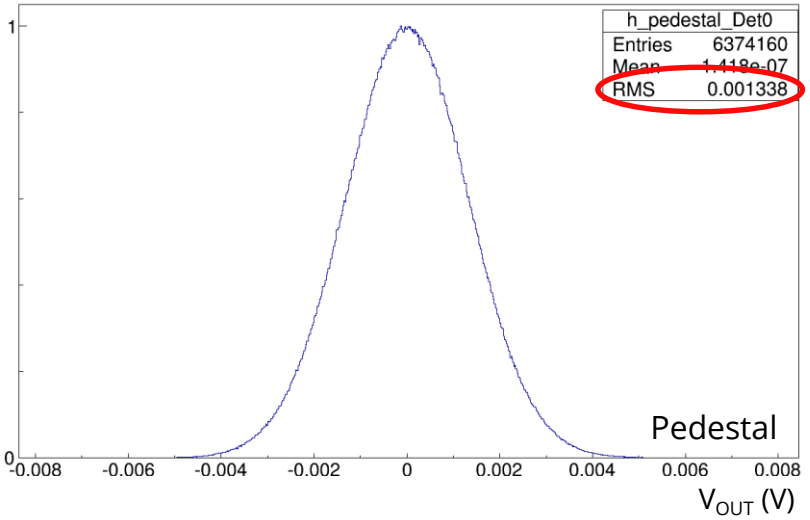
# Measurements on the amplifier

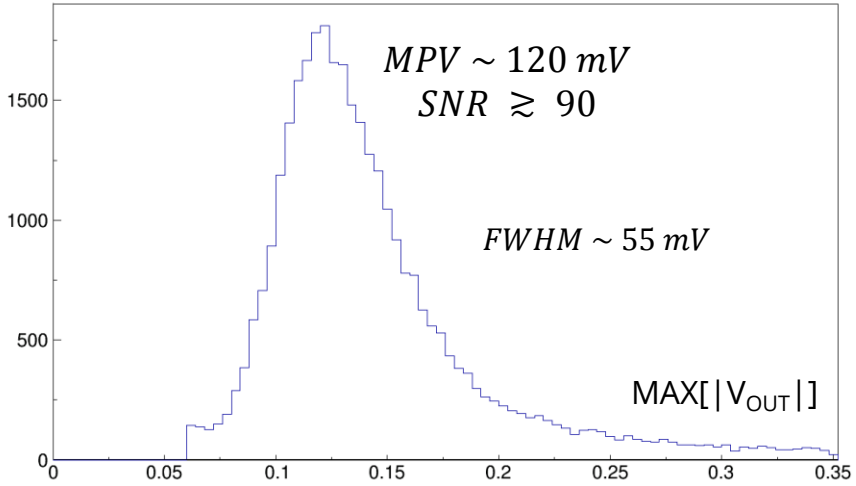
The pedestal, the rise time and the output amplitude have been measured using a beam of MIPs.




The performance measured with the beam test were compatible with what expected from the simulations



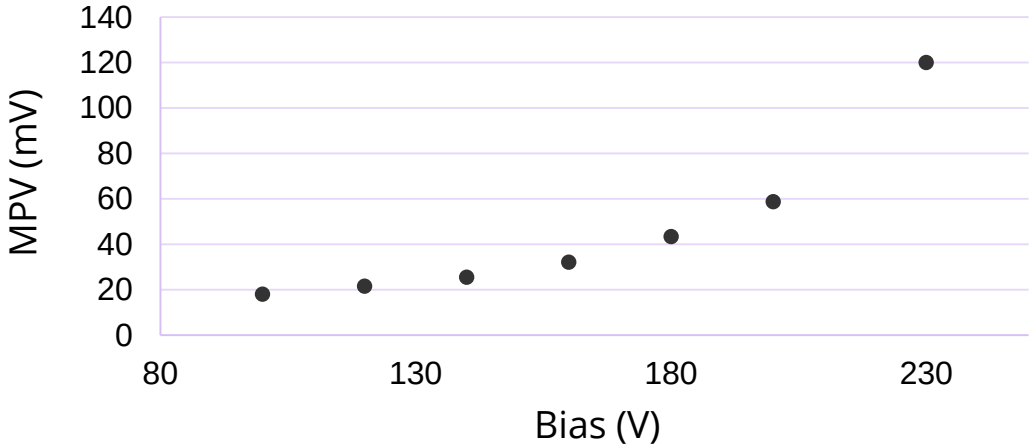



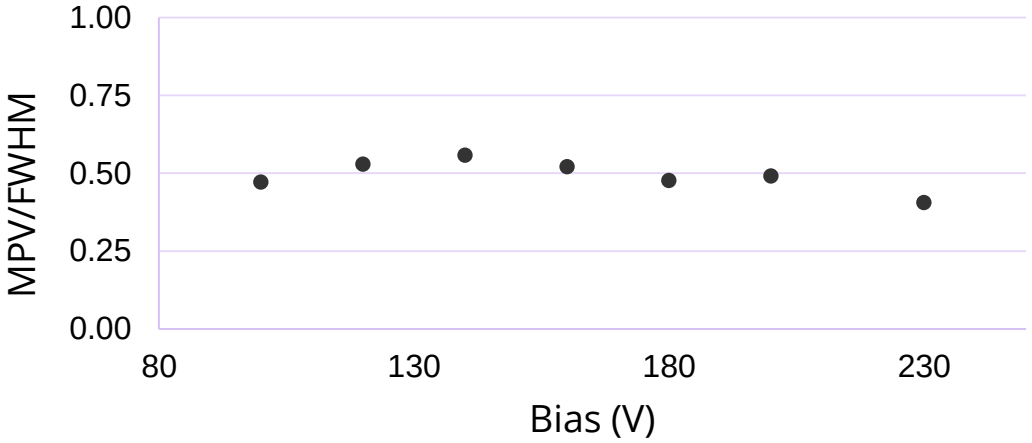

Beam: 180 GeV $\pi^+$

The sensor was biased at 230 V

# Performance vs bias voltage

A time resolution below 30 ps was obtained, in stable running conditions, using an off-line Constant Fraction Discriminator.

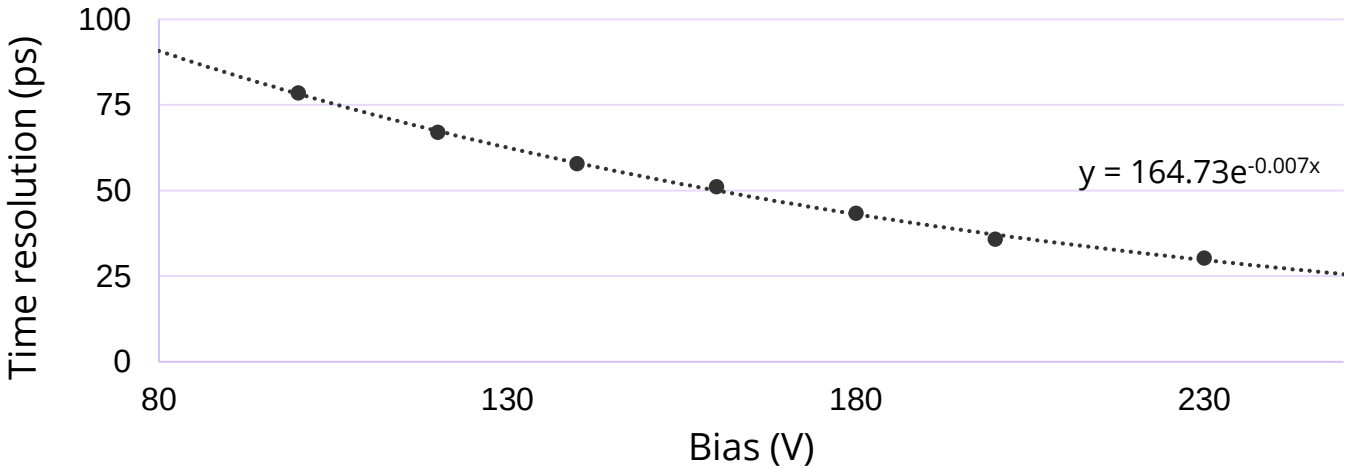


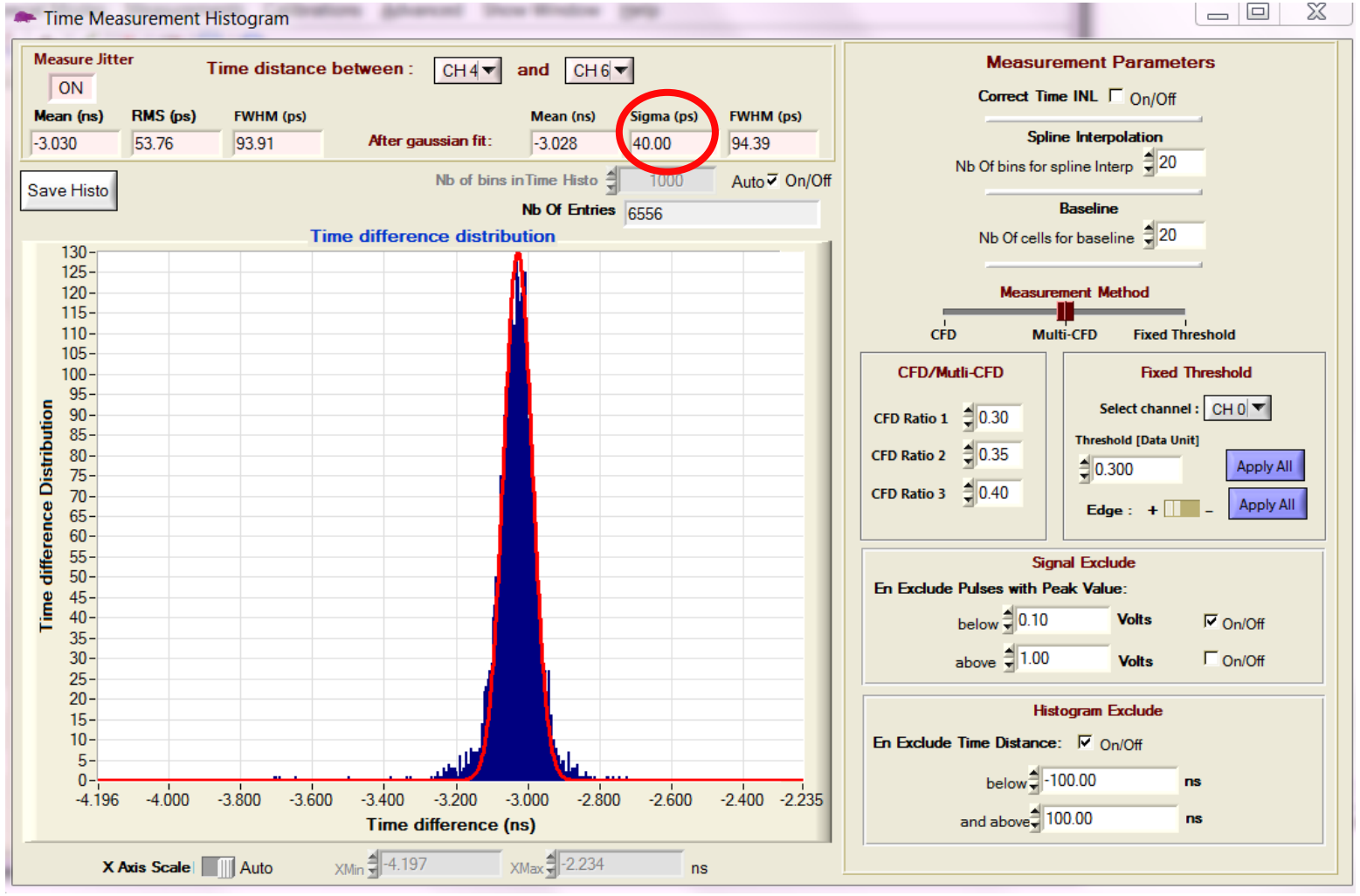

There is a clear increase of the gain of the sensor increasing the biasing voltage.

Above 230 V the sensor dark current was > 1 μA.

Clear benefit for the time resolution!



# Measurement using SAMPIC




The SAMPIC requires a calibration procedure, a preliminary result suggest that the performance are 1% worse than the oscilloscope:

$$\sqrt{(19+1\%)^2+(35+1\%)^2} \sim 40.2 \text{ ps}$$

SiPM UfSD

# New readout electronics for Ultra fast Silicon Detectors

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Workshop on picosecond timing detectors for physics and medical applications, Kansas City 15-18 September 2016

# Front-end electronics: amplifier

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

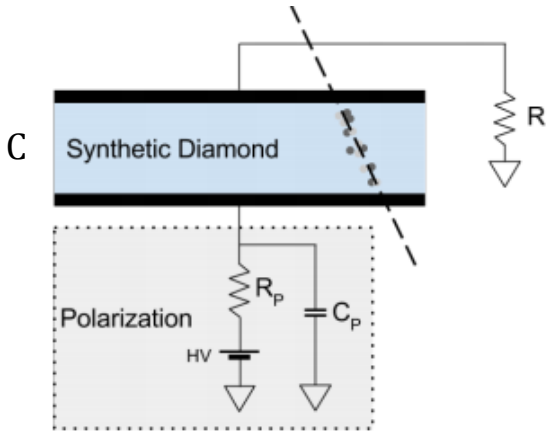
For $R < \sim 100\,\Omega$ the signal is not separated from the noise ( $SNR \sim 1$ ) also for $C \sim 0.1$ pF.

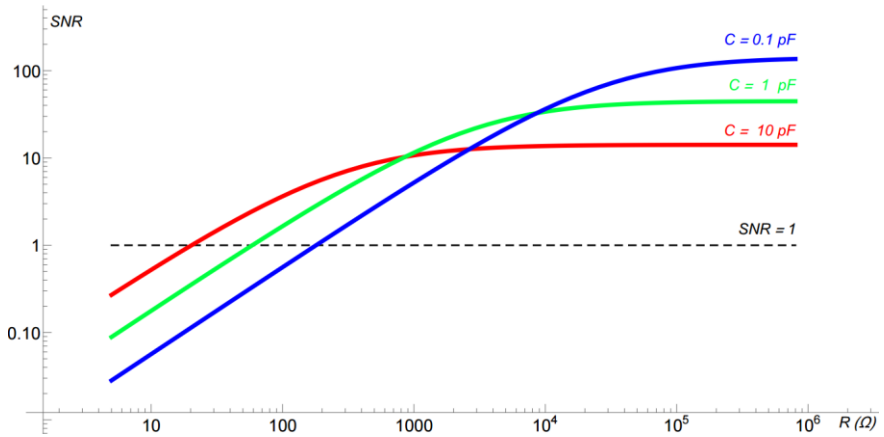
The only way to have a SNR > 1 is to increase the value of the read-out resistor.

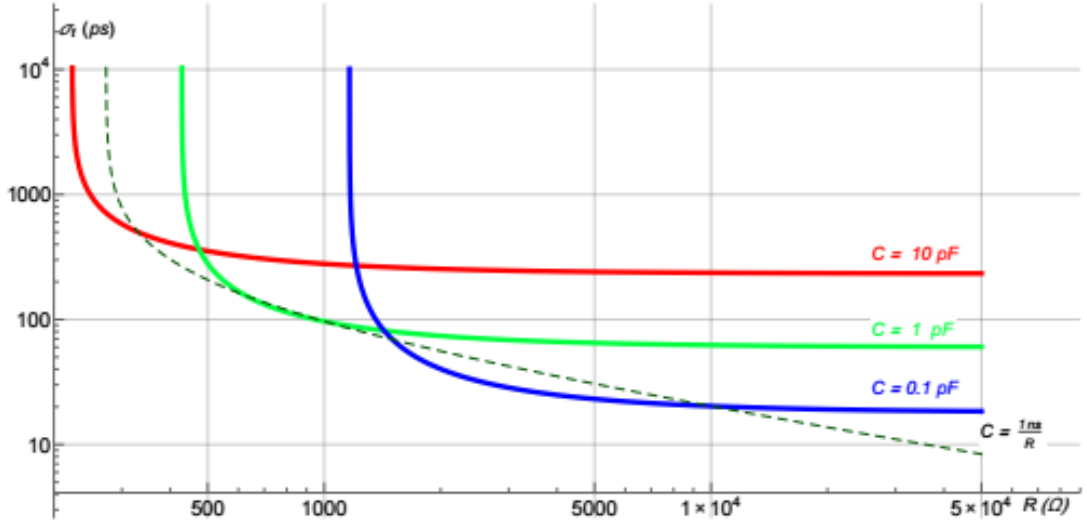
However, the time resolution is given by:

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

And higher R means slower signal:



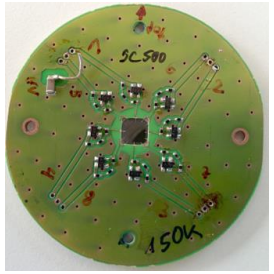



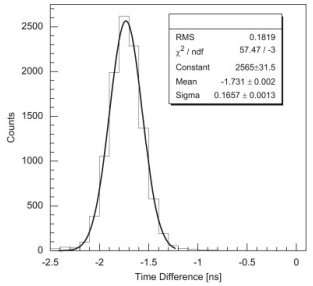




A useful rule of thumb: **minimize C and use R ~ 1 ns/C**

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

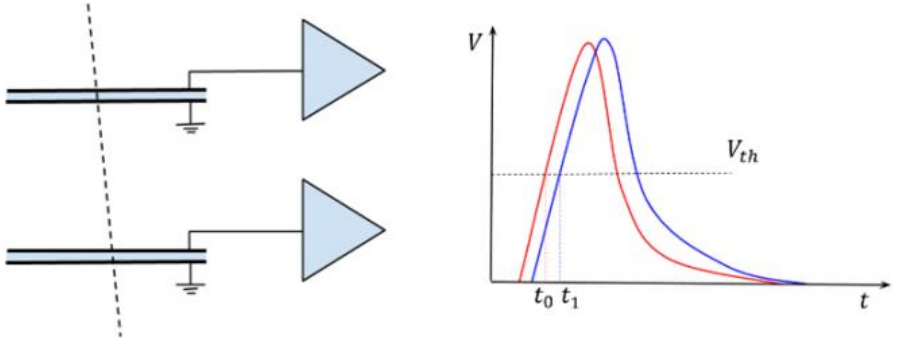
Strategy suggested by HADES @ GSI
10.1016/j.nima.2010.02.113





# 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.

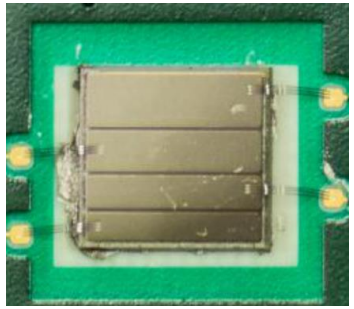



The measured time difference will be distributed around the true value because of the limited resolution of the detectors:

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

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 mm$^2$ (~1.7 pF) and sensors of different size