Development of Electronics for Ultra Fast Silicon Detectors

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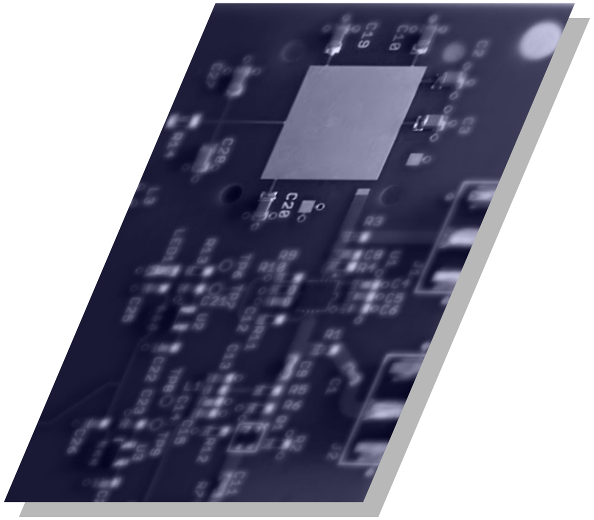
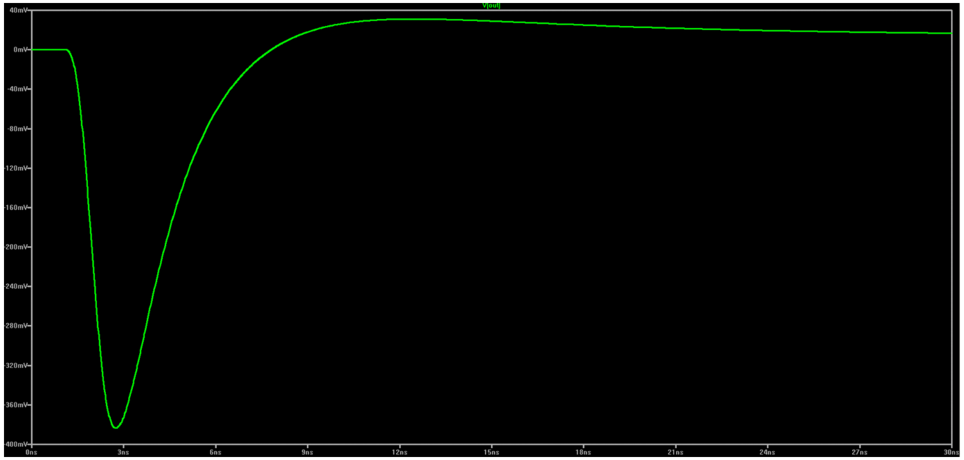


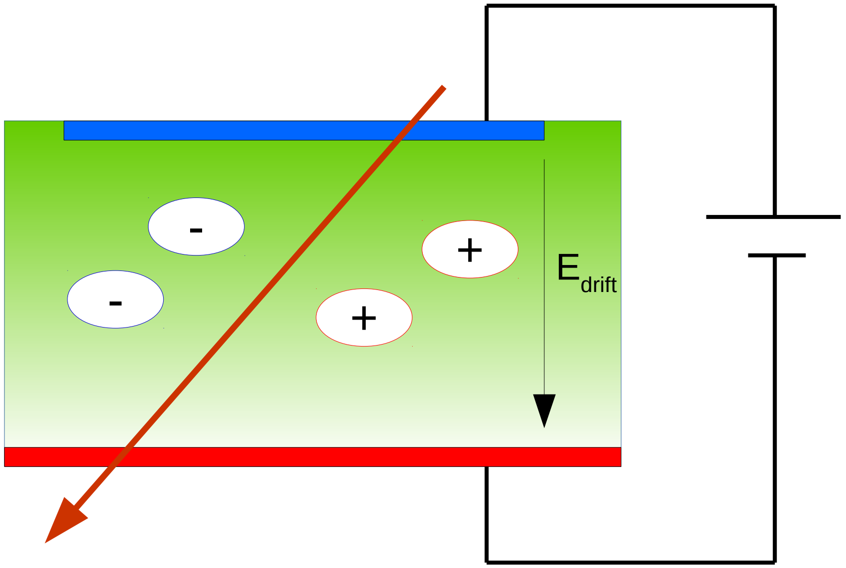
Outline

- Silicon Detectors
- Signal Amplifiers
- New Amplifier Concept of Development
- Final Tests



Silicon Detectors

How do common silicon detectors work?

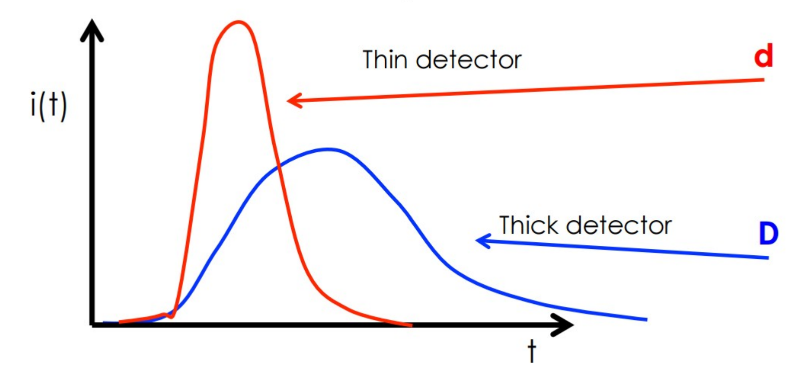


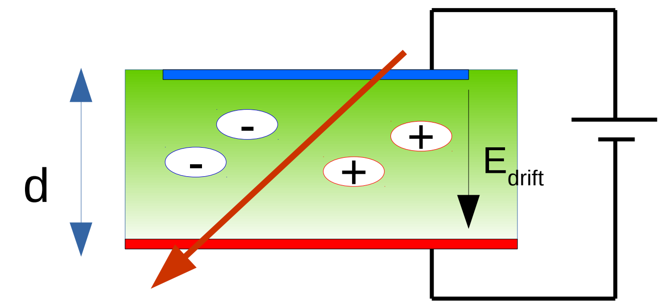
- Charges start moving under the influence of the electric field.
- Motion of the charges induces a current on the electrodes.
- Signal ends when the charges reach the electrodes.

Silicon Detectors

Does the sensor's thickness matter?

Current from one e/h pair: $i \propto qv\frac{1}{d}$



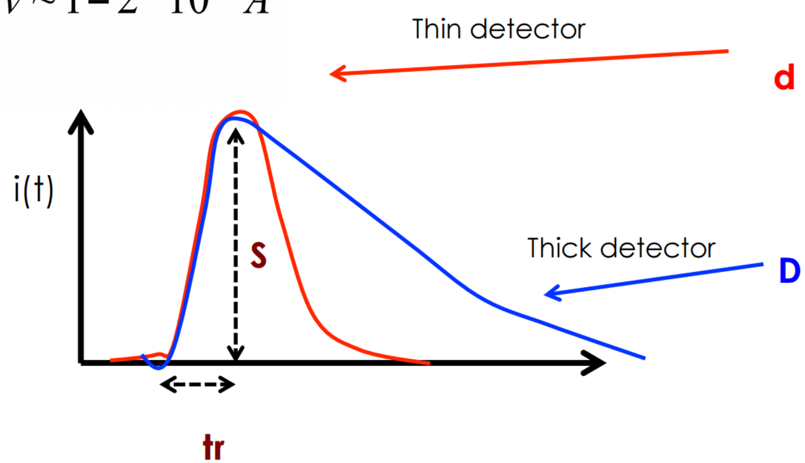


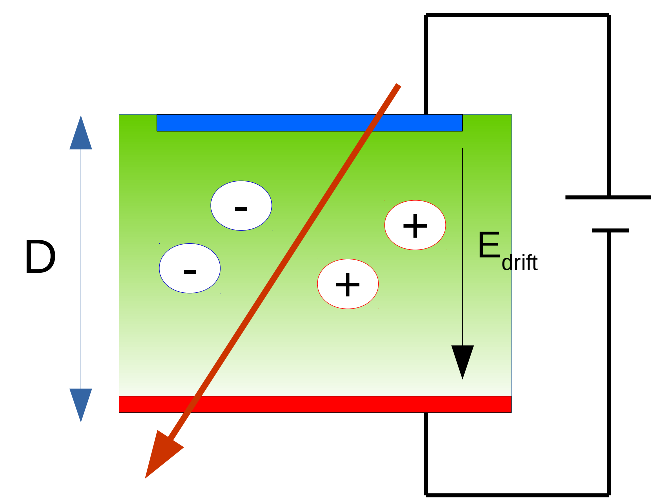
Higher number of charges in thick detectors:

$Q_{tot} \sim 75\ q*d$

Total initial current:

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

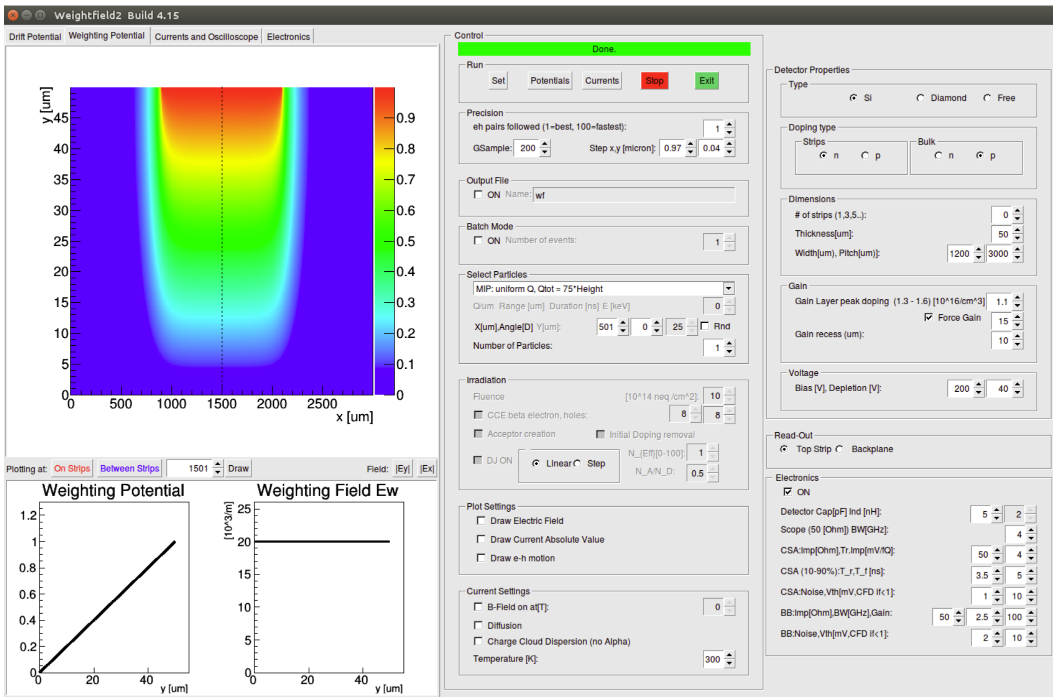




S and tr are independent of thickness!

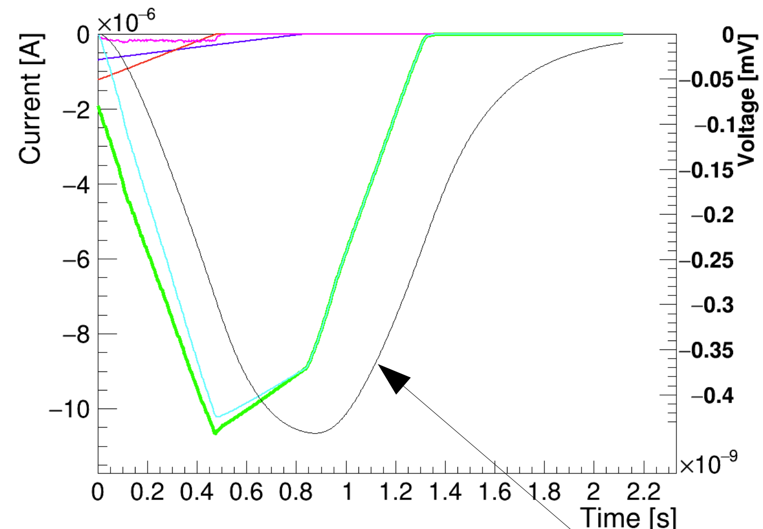
Silicon Detectors

Simulating a Silicon detector



arXiv:1608.08681 Timing capabilities of Ultra-Fast Silicon Detector

50um 2pF UFSD at 200V with gain=15



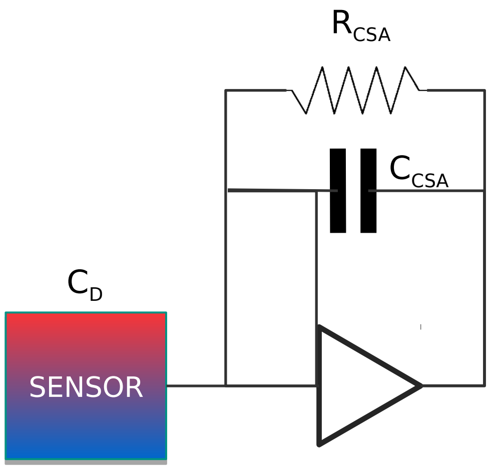
Electronics response

- Using weightfield2 it is possible to simulate different detectors with different technologies.
- Electronics response can also be simulated with a charge sensitive amplifier

Signal Amplifiers

Charge Sensitive Amplifier

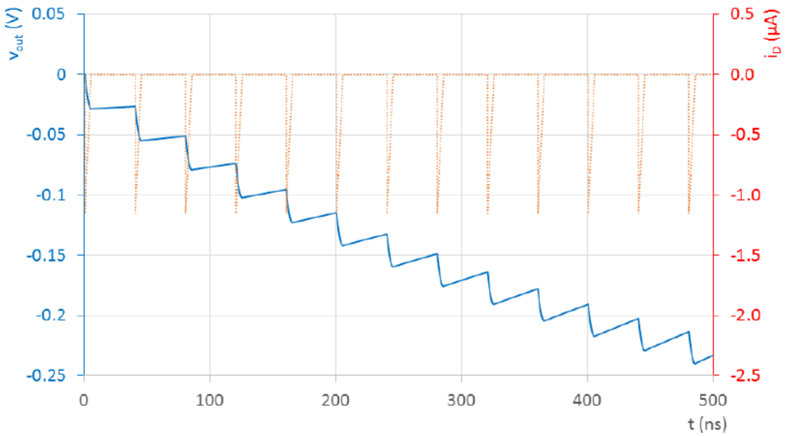
The output of a Charge Sensitive Amplifier (CSA) is proportional to the charge injected by the sensor.

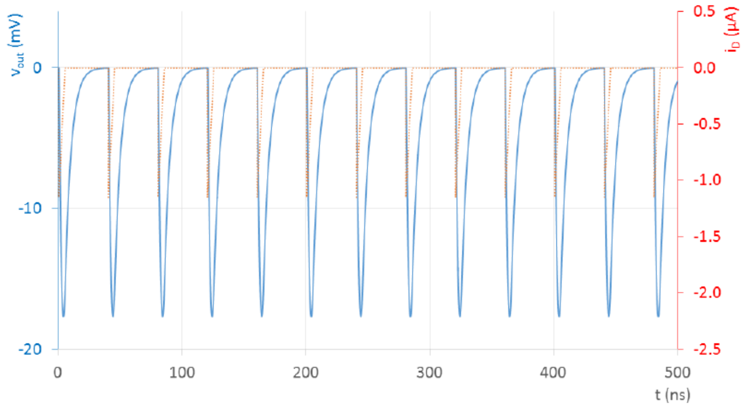


$$v_{out} = -\frac{C_D}{C_{CSA}} \frac{1}{1+\frac{C_D}{C_{CSA}}} Q_{gen}$$

Good solution for:

- *Large* SNR
- *Slow* signal





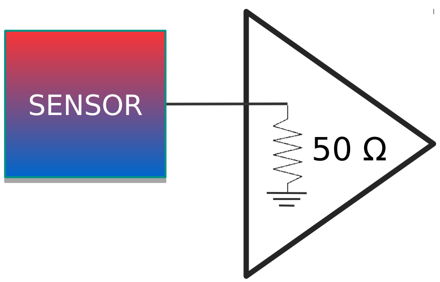
Simulation of a diamond detector read-out using a ideal Charge Sensitive Amplifier

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

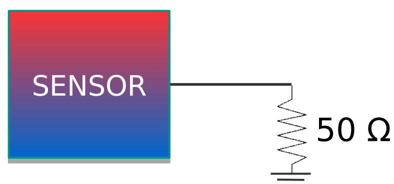
Signal Amplifiers

Broadband Amplifier

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



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

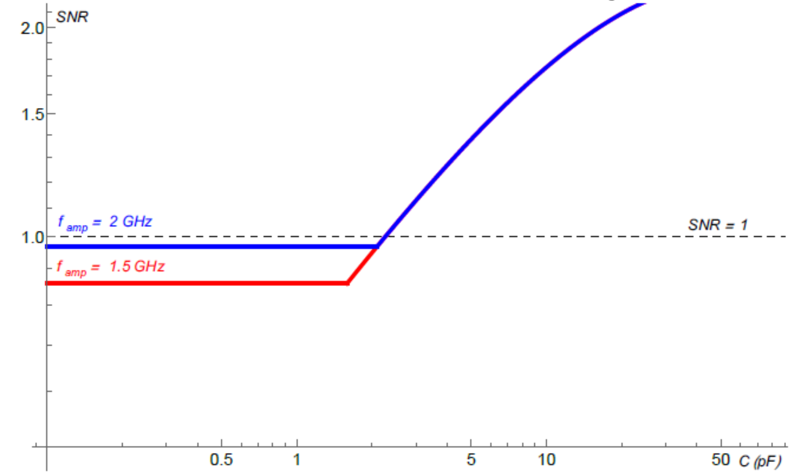


$$SNR = \frac{SNR_B}{\sqrt{F}} = \frac{k_0}{\sqrt{F}} \frac{R_i C}{\sqrt{k_B T C}} \left(t_{tr} + R_i C \ln \left(\frac{R_i C}{R_i C + t_{tr}} \right) \right)$$

F: Noise Factor
only contribution from the amplifier

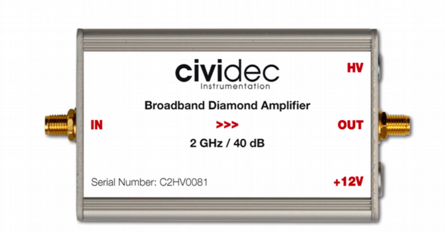
Good solution for *large* and *fast* signals.

The BW of the amplifier is larger than the BW of the signal



The limited BW of the amplifier acts as a low-pass filter

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

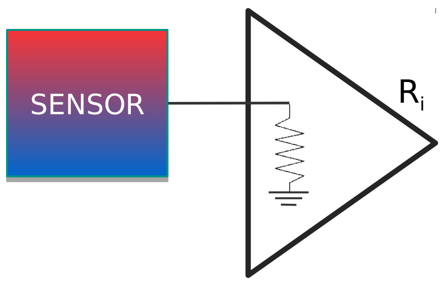


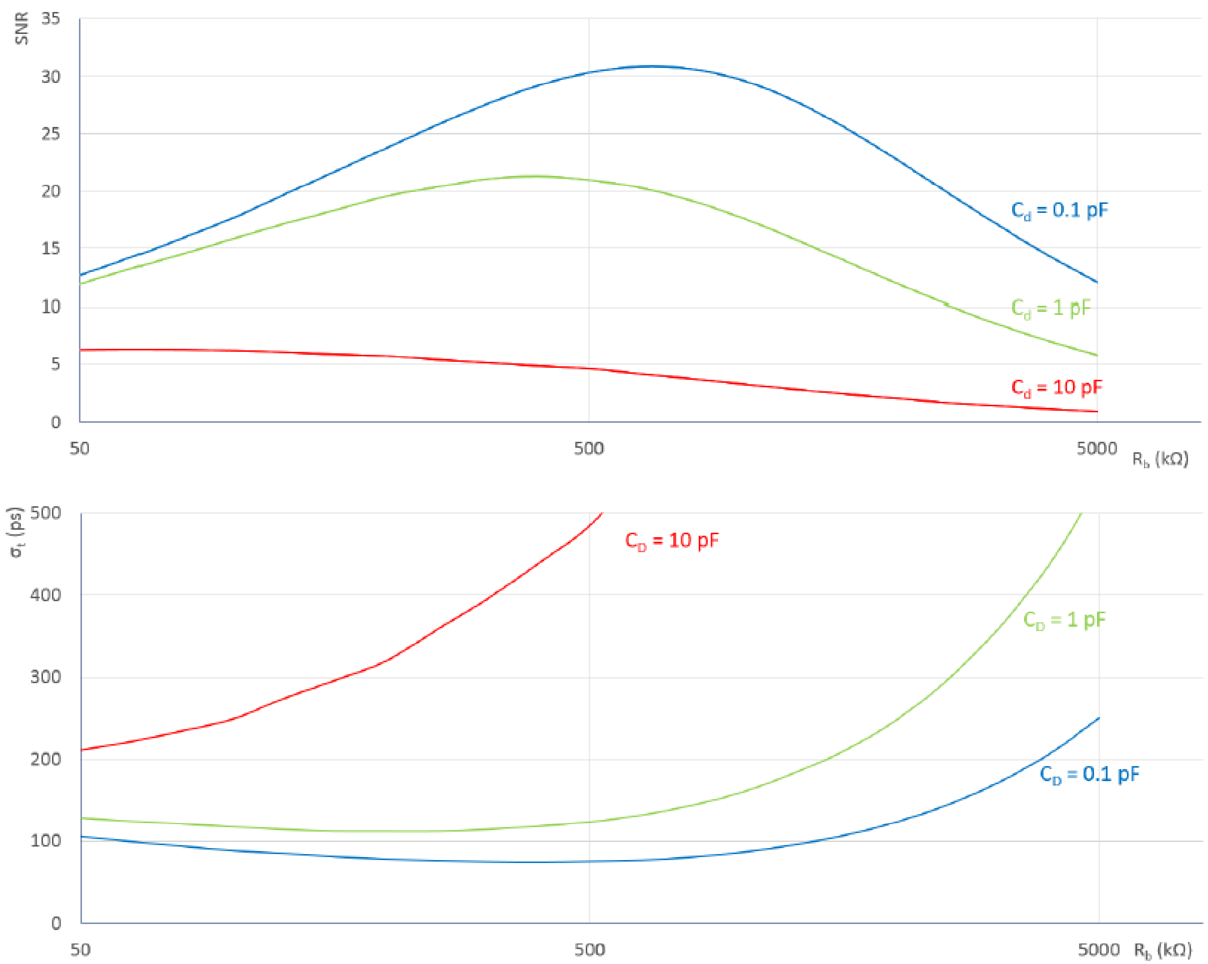
More details: Sec. 4.4 of
Development of a timing detector for the TOTEM experiment at the LHC

Signal Amplifiers

High Impedance Amplifier

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





Input impedance is highly dependent on the characteristics of the sensor.

No general purpose commercial solutions!

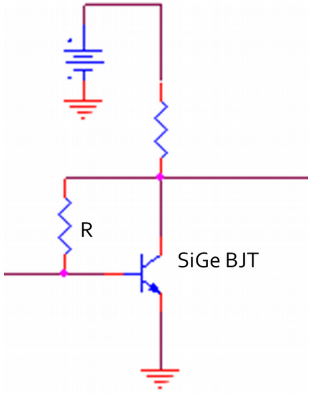
Simulated SNR and time resolution for a diamond detector.

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

Signal Amplifiers

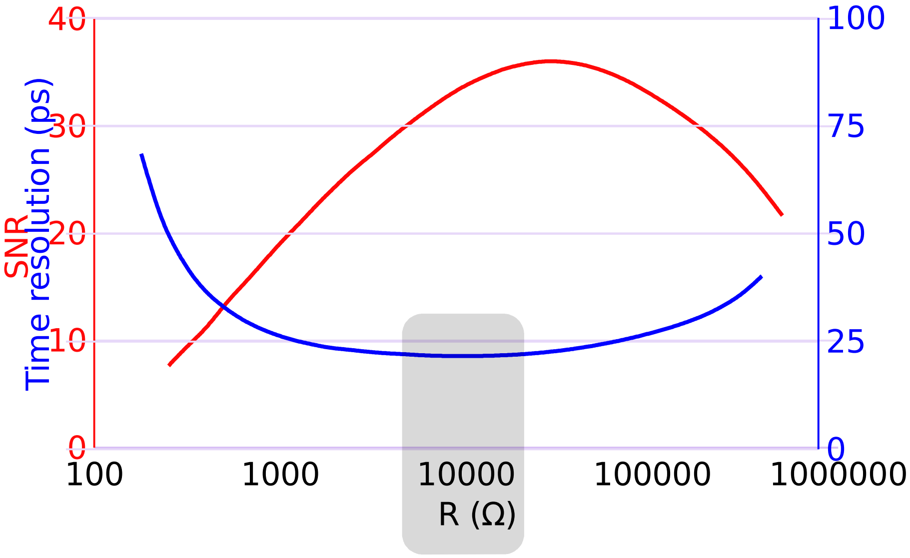
Choice of R for High Impedance Amplifier

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:

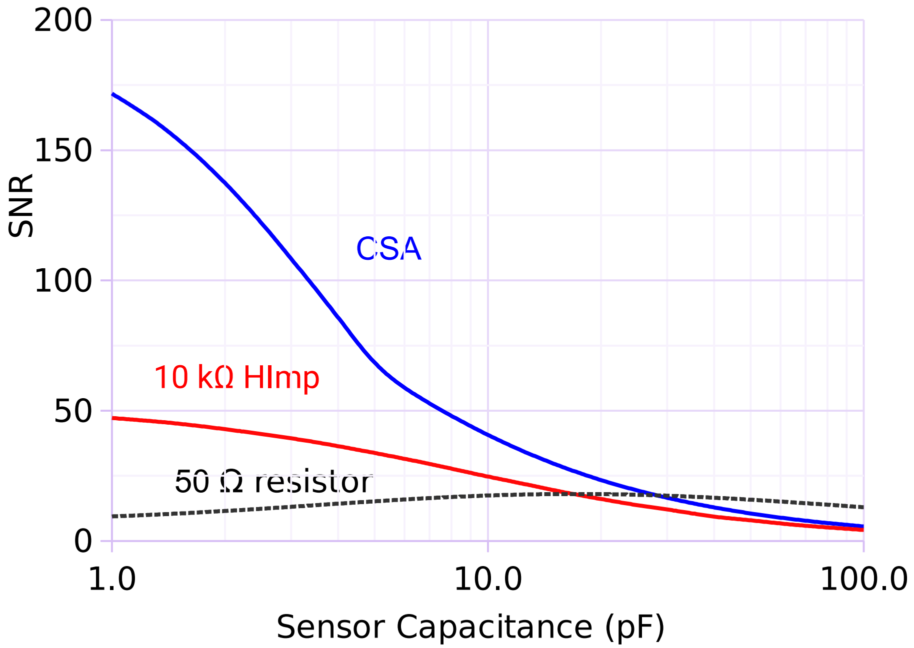
- High for diamonds (R ~ 300 kΩ)
- Lower for thick UfSD (R ~ 30 kΩ)
- Low for 50 µm UfSD

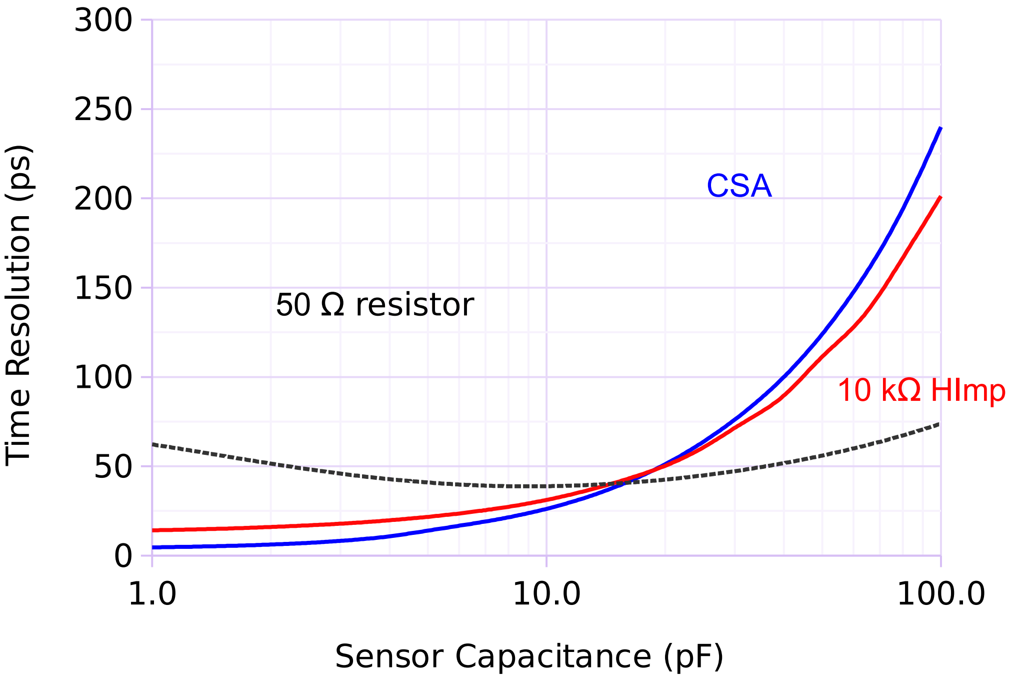


Signal Amplifiers

Amplifiers performances VS sensor capacitance

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



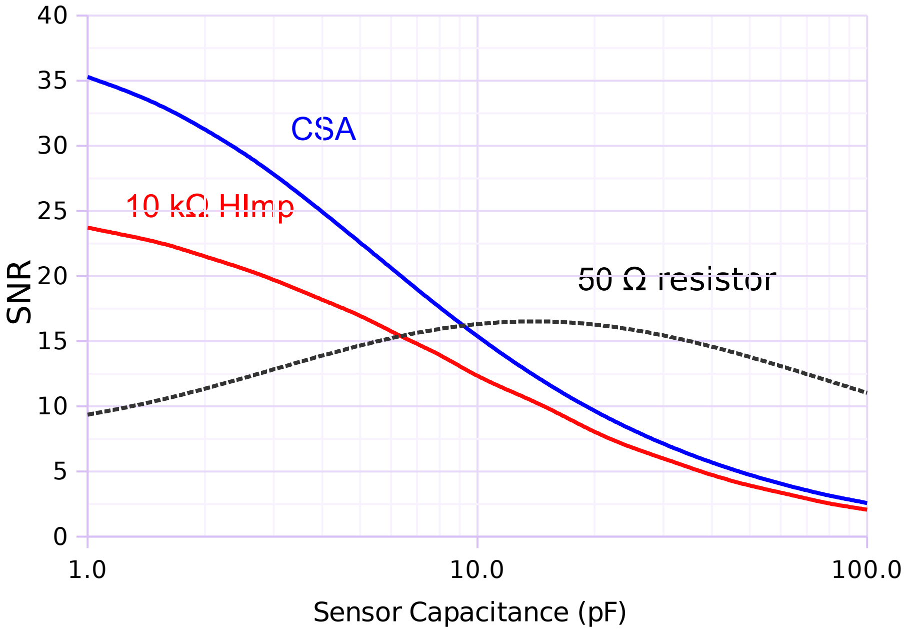


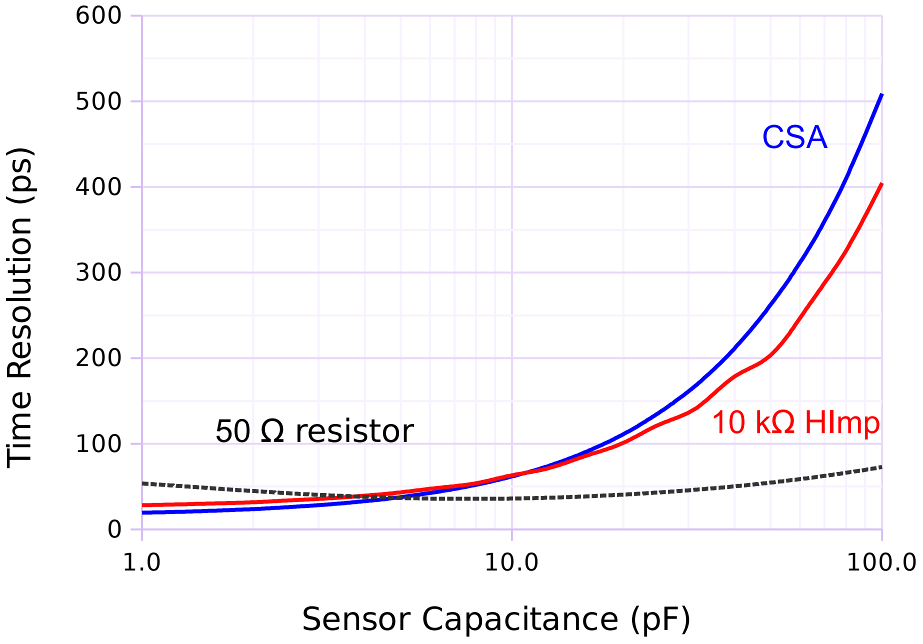
Below 15 pF the CSA is the amplifier with the best time resolution

Signal Amplifiers

Amplifiers performances VS sensor capacitance: Radiation Damage

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





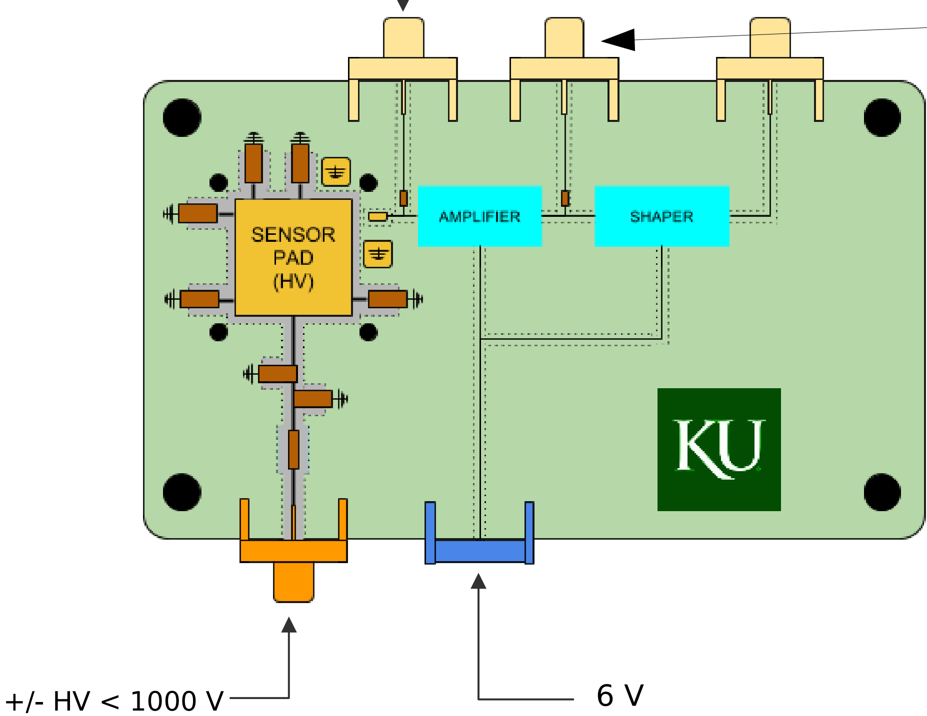
Below 10 pF the CSA is the amplifier with the best time resolution.

New Amplifier Concept

Original Design

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 by injecting an external signal
- The 0 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.

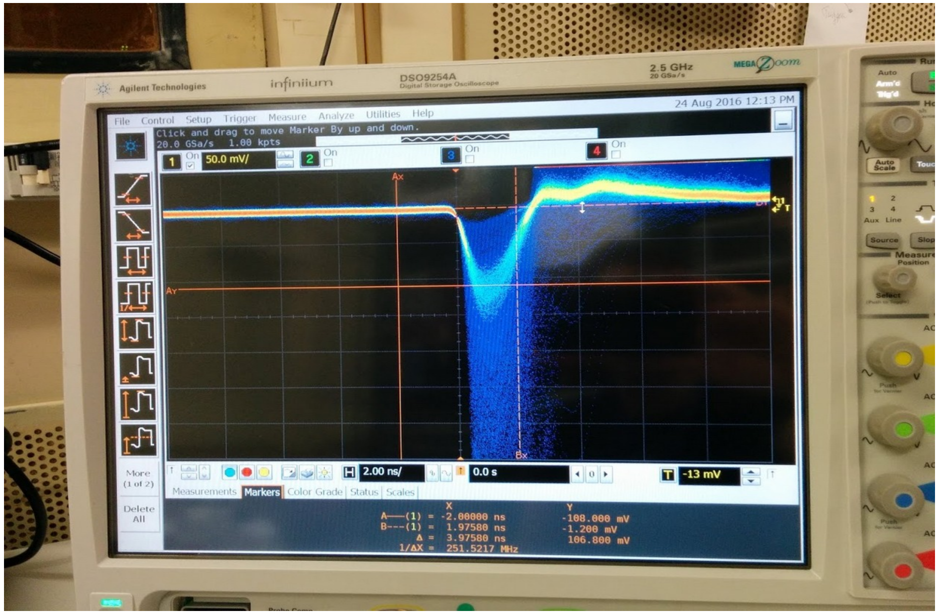
The components can be easily changed to accommodate:

- 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

New Amplifier Testing

Amplifier Testing

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

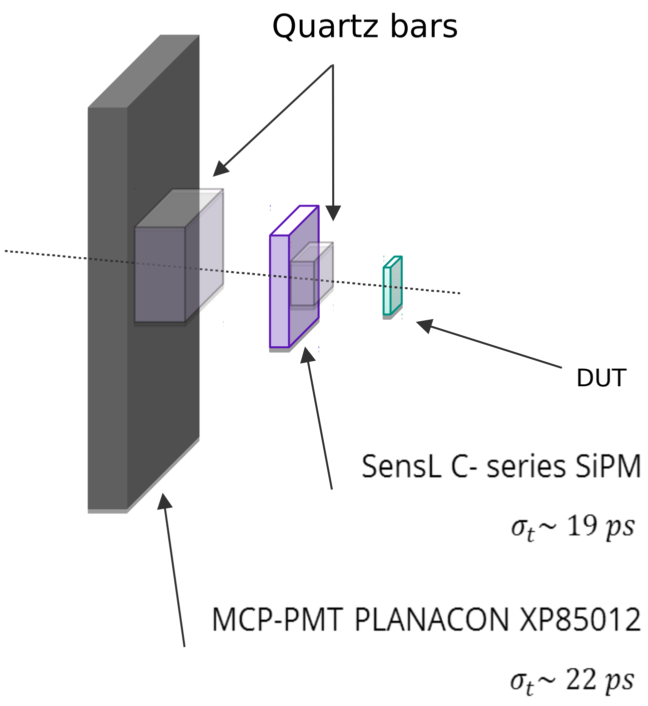


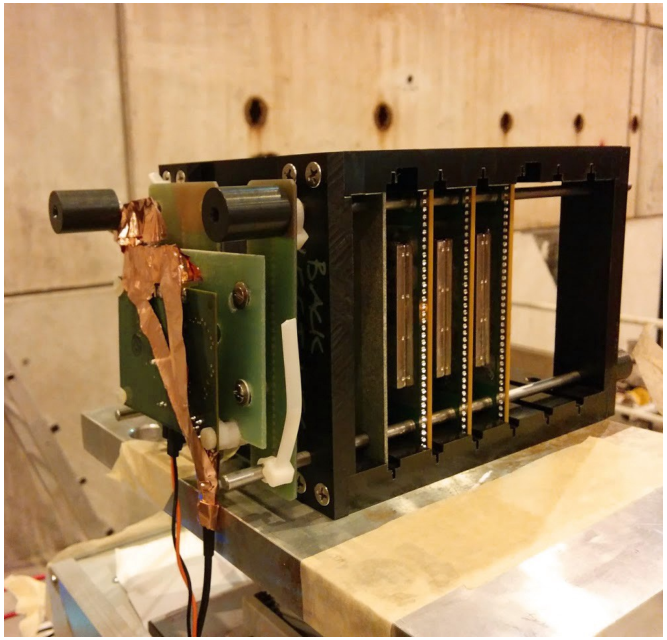
The amplifier and the acquisition chain can be optimized for different scenarios; in this case, they were optimized to have the noise at the output of the amplifier at ~ 1 mV RMS.

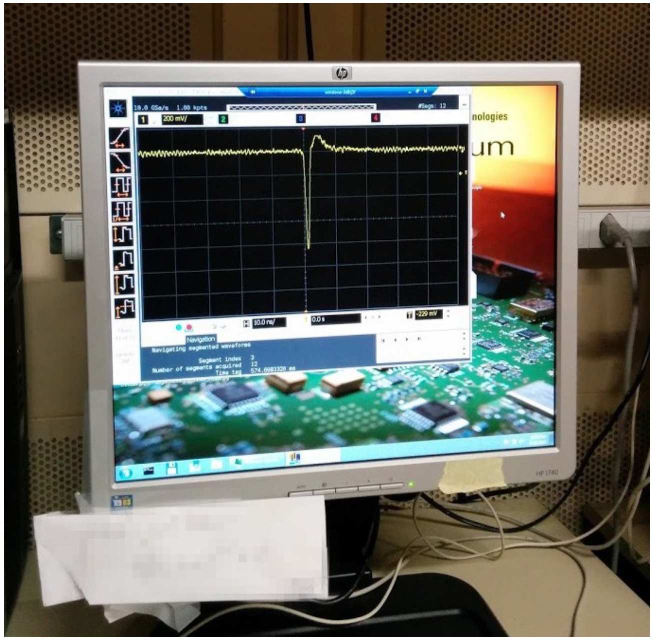
New Amplifier Testing

Test beam in the north CERN 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

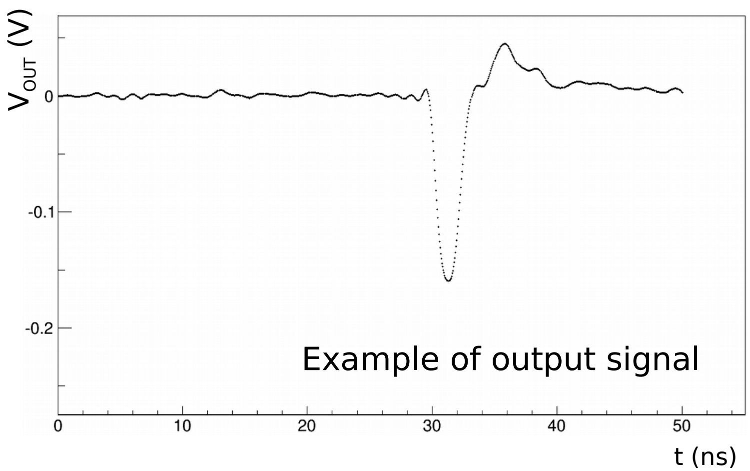
All the tests were conducted at room temperature.

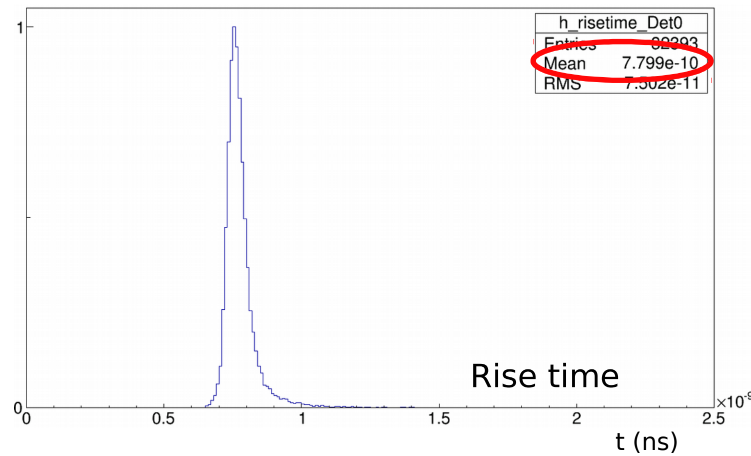
1: Thanks to the TOTEM Collaboration
2: Thanks to N. Cartiglia et al. : arXiv:1608.08681

New Amplifier Testing

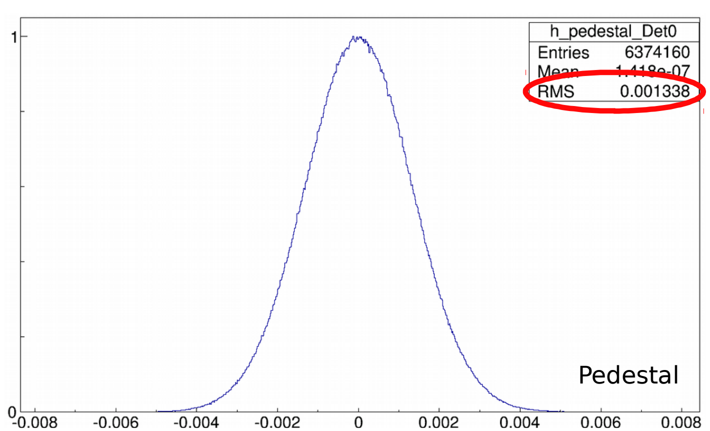
Amplifier measurements

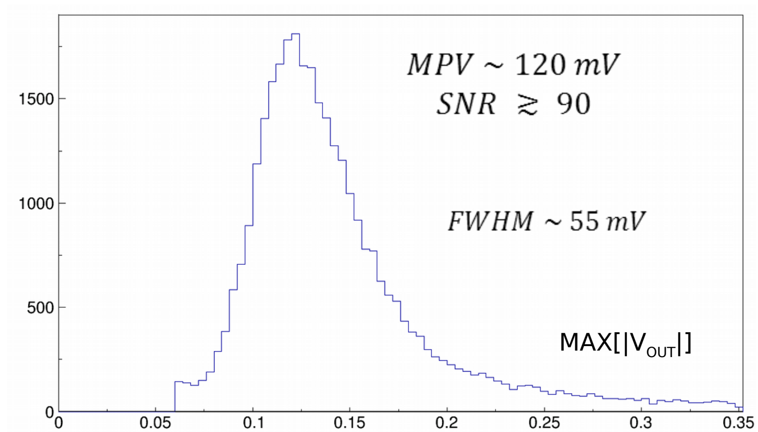
The pedestal, the rise time and the output amplitude have been measured using a beam of MIPs.





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





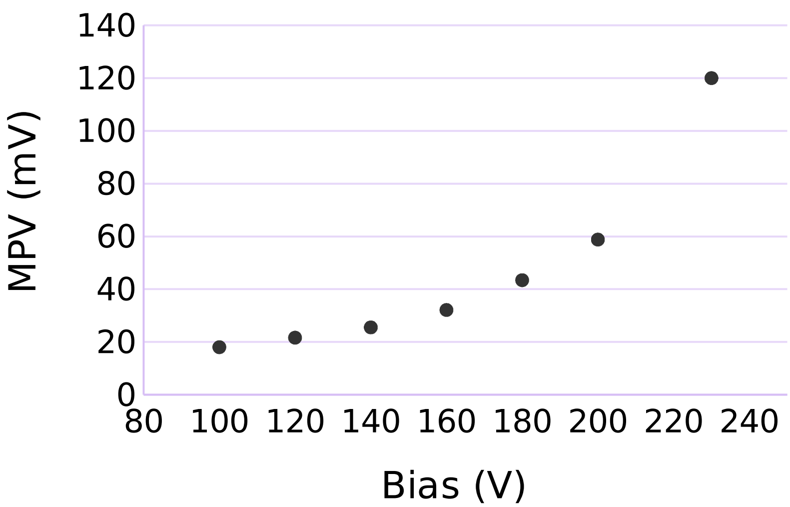
Beam: 180 GeV pions

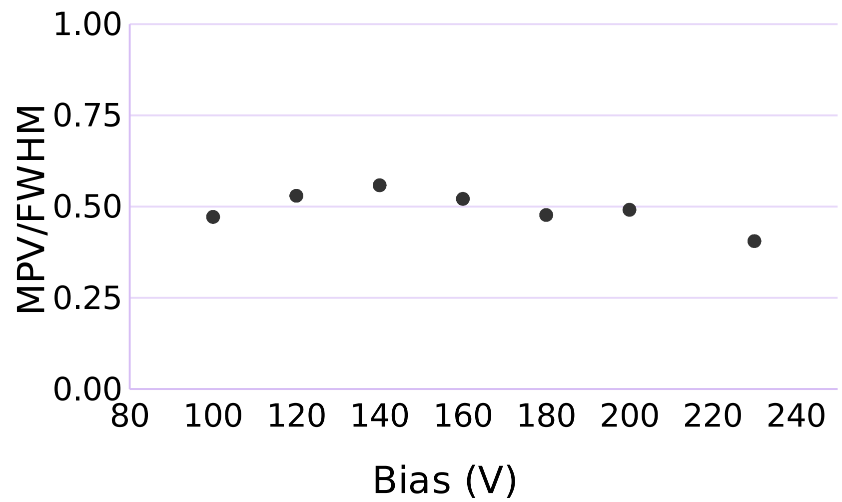
The sensor was biased at 230 V

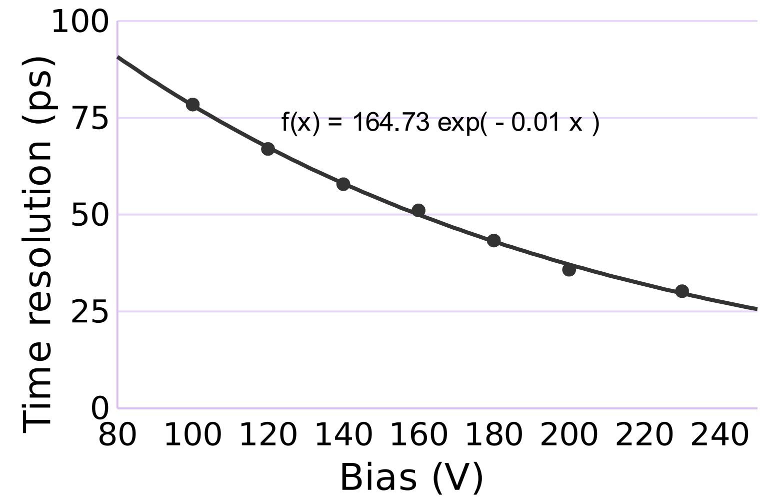
New Amplifier Testing

Performance VS Bias voltage

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





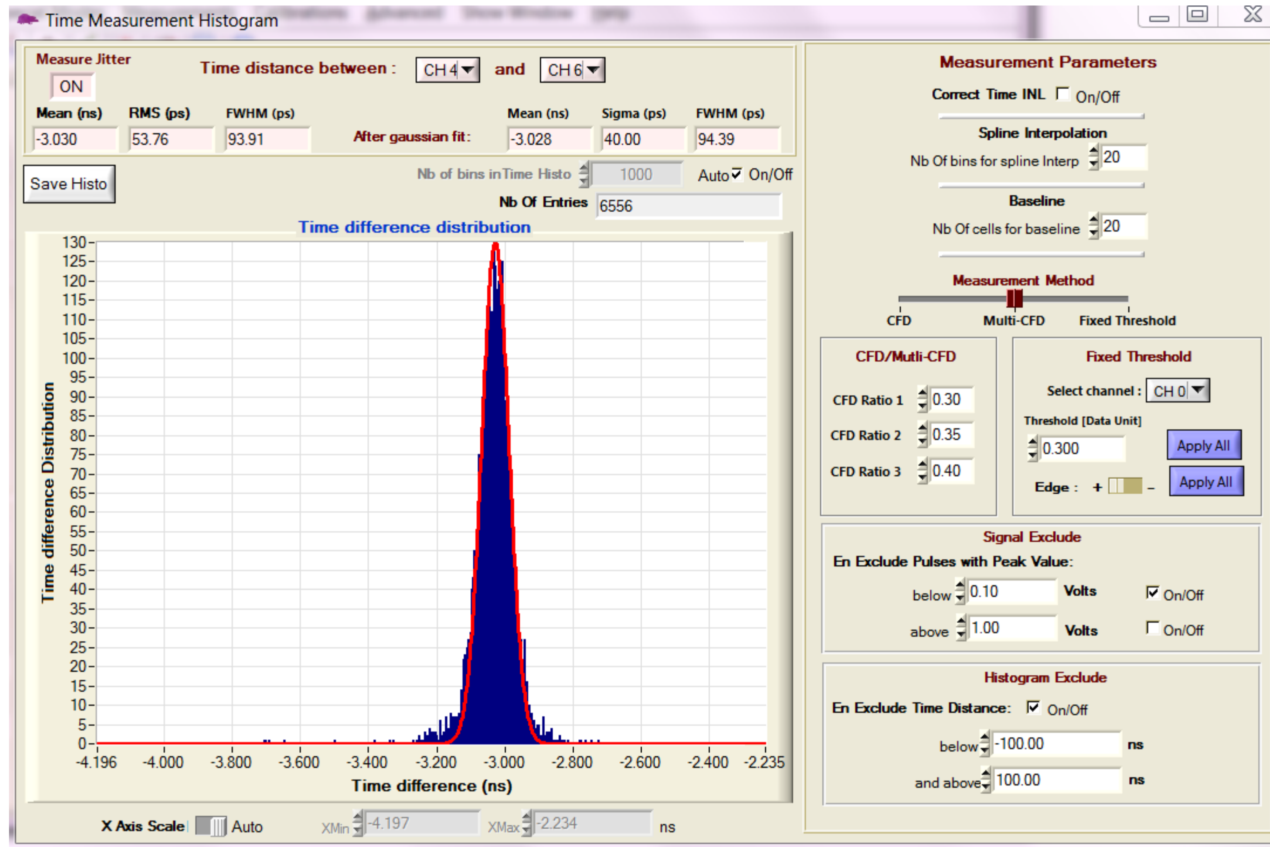


The sensor's gain clearly increases when the bias voltage is increased

The sensor's dark current is above > 1uA when the bias voltage is above 230V

New Amplifier Testing

Time difference measurements using a SAMPIC



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

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

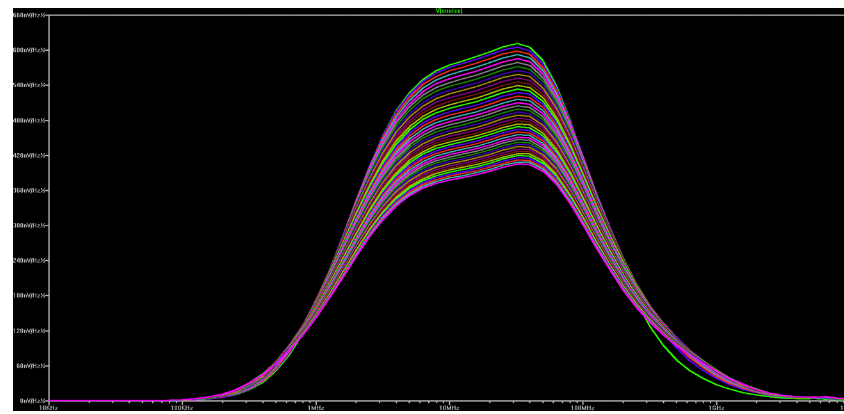
SiPM

UfSD

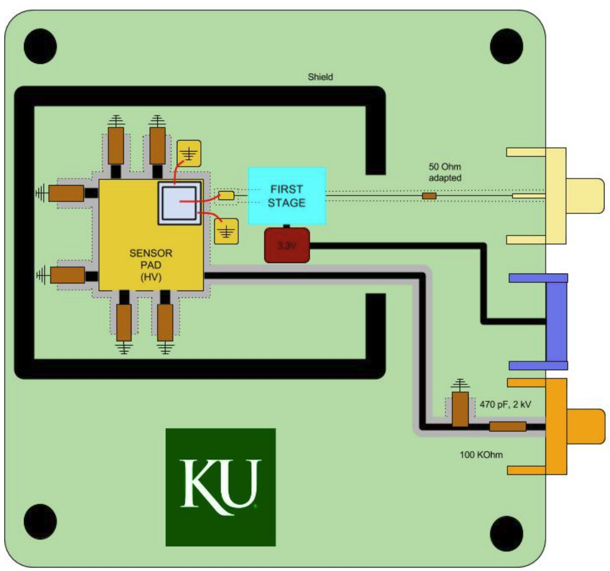
Outlook

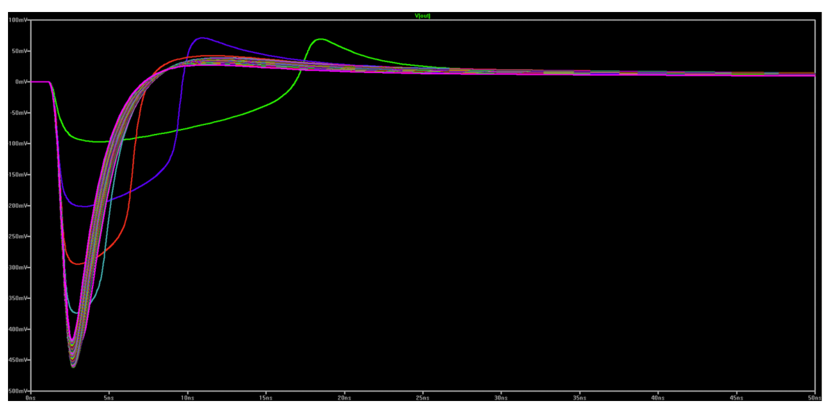
Design changes

- The original design is in the process of being modified to become more compact and power efficient
- Mostly small components are to be used switching from 0402 to 01005
- Currently simulating the latest circuit with LtSpice to ensure highest SNR and lowest power consumption



SNR=60 for a 10uA signal
Power Consumption =140mW





Outlook

Comments/Suggestions ?