

# Biweekly GBP meeting

Frascati data analysis



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## **Frascati test beam**

# Status of the analysis

Few points to account

1. MC estimate to be improved (~ **30%**)
  - Detailed geometry
  - Beam misalignment and/or profile smearing
2. Data points must be corrected (min<CH>, 8-bit, pickup noise) (**<15%**)
3. Fit model must be revised
4. Allpix<sup>2</sup> simulation for the charge collected

## Current status

MC improved with all the details of the geometry. Data biasing (min<CH>, 8-bit) studied in detail and error constrained to 15%. Analysis of the BTF data ongoing, data correction to be accounted yet. Fit model worked out in the general case of uniform initial charge distribution, moving in an arbitrary  $E(z) = E_0 + E_1 z + E_2 z^2$  field; implementation of the fit model in ROOT ongoing.

# Status of the analysis

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- ✓ MC estimate improved (~ **30%**)
  - Detailed geometry
  - Beam misalignment and/or profile smearing
- ✓ Data points corrected (min<CH>, 8-bit, pickup noise) (**<15%**)
- ✓ ~~Fit model must be revised~~
- 🧱 Allpix<sup>2</sup> simulation for the charge collected

## Current status

MC improved with all the details of the geometry. Data biasing (min<CH>, 8-bit) studied in detail and error constrained to 15%. Data corrections accounted.

Analysis of the BTF data completed. Fit model worked out in the general case of uniform initial charge distribution. Fit results for uniform E in the next slides.

Allpix<sup>2</sup> simulation under development.

# Overview of 'data corrections'

1. Mostly accounted to fix the bias we introduced when measuring the signal using the <min(CH)> function. More details will be available in a report of the Frascati testbeam I'm writing

**3 Measurement procedure**

The test beam in Frascati was mainly devoted to investigate the efficiency of the signal detector to detect the signal radiation. The aim of the measure was to determine the charge collection efficiency (CCE)

$$CCE = \frac{Q_{col}}{Q_{tot}} \quad (1)$$

defined as the ratio between the charge collected by the detector ( $Q_{col}$ ) over the total amount of charge produced in the material  $Q_{tot}$ , i.e. by incident radiation ionizing energy deposit.

The main reference is an investigation performed at DESY using a 5 GeV electron beam [1]. The authors managed to measure the characteristics of a stack of 500 silicon samples, in the form of the  $\langle \mu \rangle$  product for each charge number  $z = e^-, \mu^+, \pi^+$  for different bias. It is useful to start from that study:

$$\langle \mu \rangle = 28 \text{ ns} \cdot \text{cm}^2 \cdot \text{V}^{-1} \quad \langle \mu \rangle = 4.0 \text{ ns} \cdot \text{cm}^2 \cdot \text{V}^{-1}$$

for the product of charge-carrier mobility  $\mu$  (in  $\text{cm}^2 \cdot \text{V}^{-1}$ ). These values are to be considered as a reference point for our measurements.

*(comment about variability in first paper)*

**Purpose of the test beam.** The main objective is to measure the  $\langle \mu \rangle$  product characterizing the charge transport in silicon, and compare this result with what has been in the literature. Second, it is to investigate the behavior of the detector efficiency of electron, muon and positron radiation effects on the collection efficiency to the range over of operation (in the LXI experiments).

The measure consisted in the following:

- CCE as a function of the biasing voltage  $V_{bias}$  (forward and reverse)
- CCE as a function of the beam intensity  $N_b$  (with PPS off)
- CCE as a function of the beam intensity  $N_b$  (with PPS off)

The measures were performed using a digital oscilloscope (DSO) connected by the beam test facility control system. The specific DSO model is a LeCroy Waveform 480i 1ch, 4GB and 400MS/s.

**TODD: further description of the experimental apparatus**

**4 Overview of the acquisition procedure using the DSO**

For each size of the samples, two channels corresponding to small and large pad are connected to the oscilloscope. The interesting physical quantity is the waveform amplitude, which is directly proportional to the amount of charge collected by the device by means of field  $E$ . Also, it is interesting to measure the duration of the detector pulse when different biasing voltage and/or beam intensity are used. The fastest (PS) is measured using the time-to-digital converter (TDC) function of the oscilloscope. The latter (PS) is evaluated in a given window of two decades, when the detector has not reached the detector  $\mu$ . Given fixed external conditions (beam characteristics and  $V_{bias}$ ), an acquisition is considered to occur in about a minute corresponding to a statistics of about 5000 triggers.

**Scope setup.** The first input channels of the scope were set to high impedance AC-coupled. The former being a requirement of the amplifier circuitry, the latter is useful to ensure any DC component. The sampling rate was set to 100 MS/s, high for convenience in data processing and to improve scope responsiveness – i.e. time resolution (10 ns much smaller than shaping time). The vertical resolution was kept to default value dictated by the 8-bit ADC resolution. This corresponds to 25.25 mV for the given 1 V/div scale – consequence of the 10-bit data points will be discussed later. External triggering was beam's clock signal, a delay of  $\sim 20$  ns is measured between trigger gate and beam detector from the data stream had after measurement. A typical waveform series is shown in the Fig. 6.

Scope/PS	Logic/PS	Min/PS	Logic/PS
4	1	2	1
100 MS/s	252	192	220
100 MS/s	32	32	32

Table 1: Comparison factor for each of the amplifiers and average detector RMS noise.

*(comment about variability in first paper)*

**4.1 Correction for the <min(CH)>**

The proposed vertical scale was of a 100 mV/div, which accounts for the best signal (sampling rate) and vertical (ADC resolution) quantization. The effect of horizontal vertical distribution can be seen by looking at the Fig. 6. It is clear that depending upon the number of samples in the peak box, there is accordingly a certain probability that the number of samples will shift the measured value by 1, 2, ..., N times the RMS noise.

**4.1.1 Correction for RMS**

The limited 8-bit vertical resolution (which on the scale corresponds to 25.25 mV) is comparable with previous measure of the detector noise in the amplification circuitry. This is likely to have two independent impacts:

the first which is the noise spectral in the amplifier to the power supply unit (PSU), the second which is the noise spectral in the detector. The latter is expected to have a constant component, essentially characterized by the temperature, and is likely to depend on the amount of the detector bias. The measurement will be investigated in further detail later. For now, let us focus on quantifying the total noise. It is important to understand the effect of quantization on the measure of the detector noise. This is simple if compared to storing a decadal number of random numbers, distributed around zero with  $\sigma_{rms}$ . After quantizing the vertical distribution of the ADC by

$$B_{rms} = \text{round}(\text{true}(x)) \cdot \sigma_{rms} \quad (2)$$

What value to use for the detector's noise RMS?

For any trigger, the RMS noise was measured in a gate 2-de wide before the signal

**4.2 min(CH) & 8-bit ADC**

Structure of the subtraction: • explanation of the problem; • proposed solution; • comparison of the 8-bit ADC with the waveform; • conclusion.

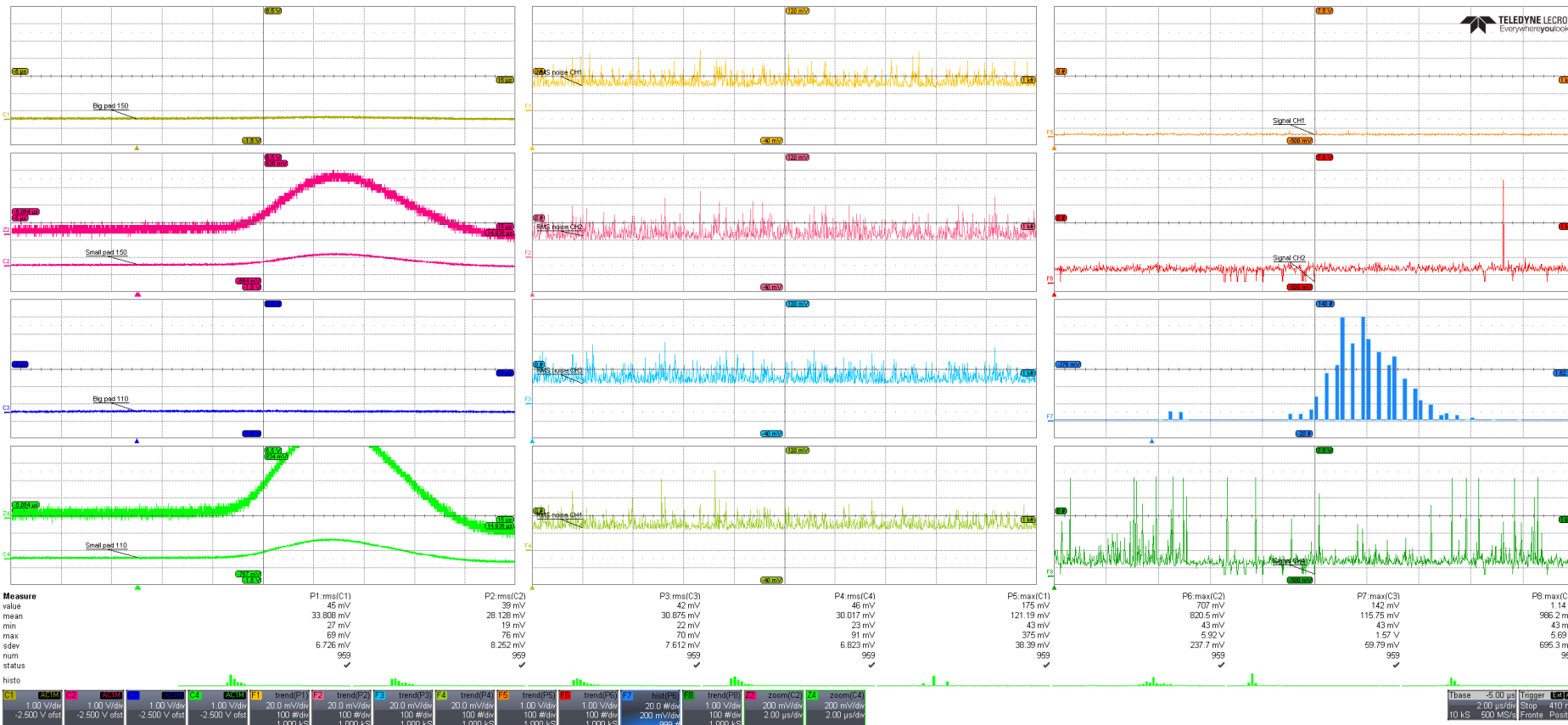
This subsection will address the main issues presented above, namely the noise to correct the acquired <min(CH)> data to obtain the actual charge.

2. At very high HV, many acquisitions were polluted by internal discharges. In these cases it is recorded a saturation signal of the amplifier, which clearly affects the average over N triggers. In an ensemble of 0.8-1k triggers, this matters and these signals have to be removed in order to read an accurate value of the average signal.



# Overview of 'data corrections'

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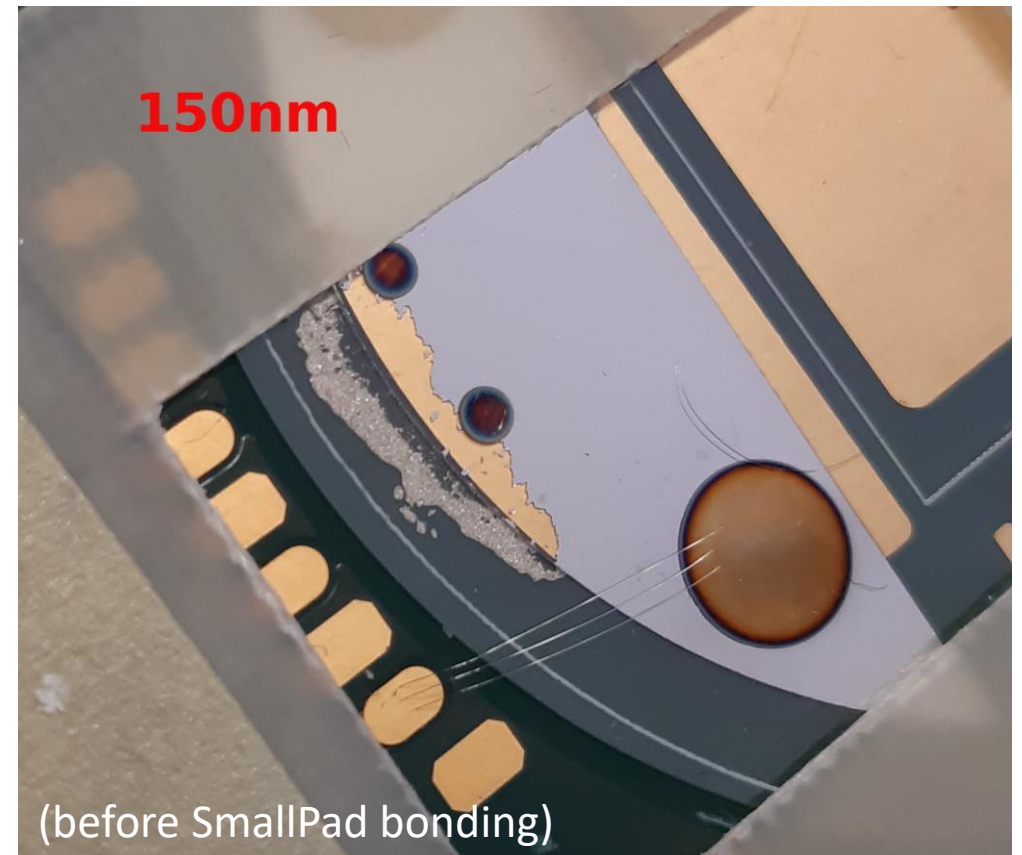
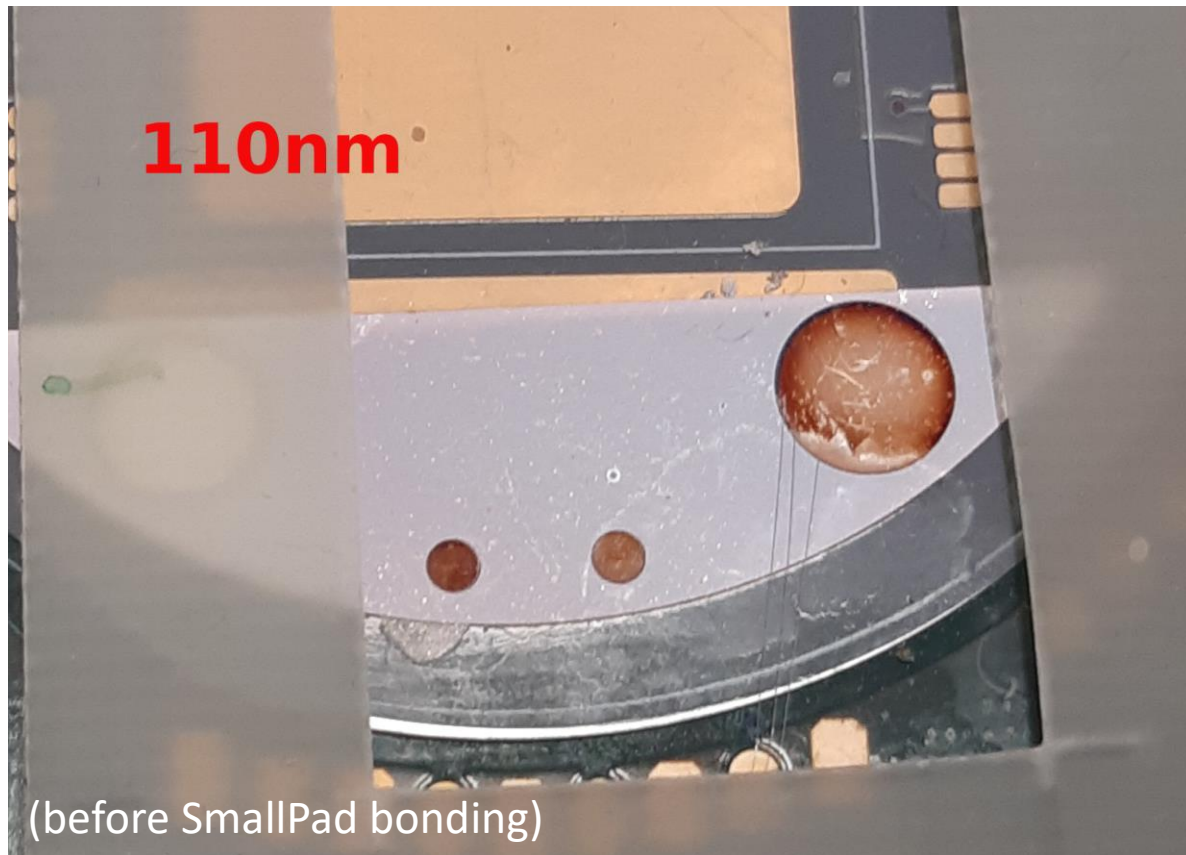


**SmallPad**  
**HV = 800V**



# Overview of 'data corrections'

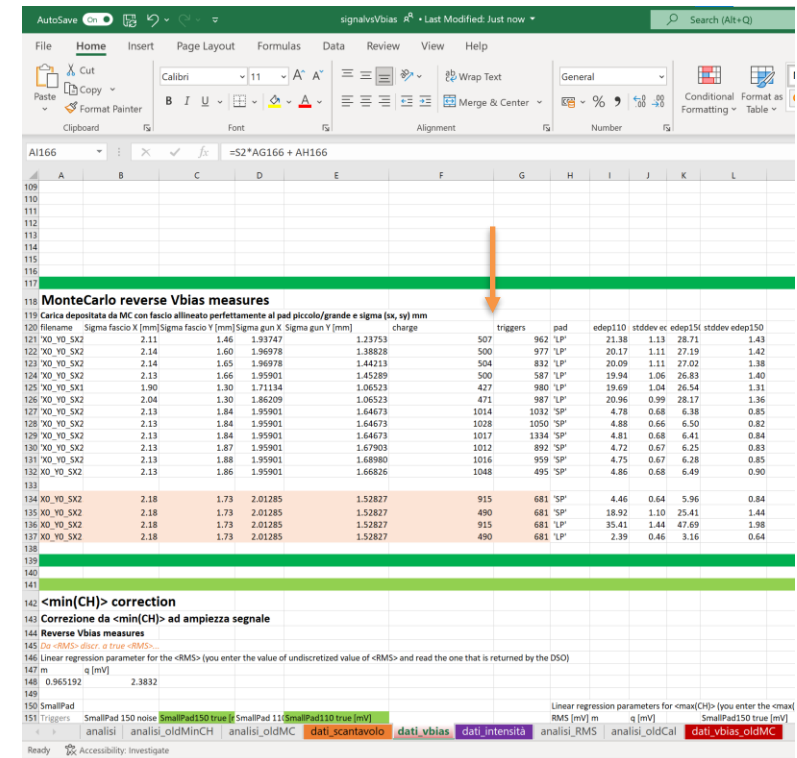
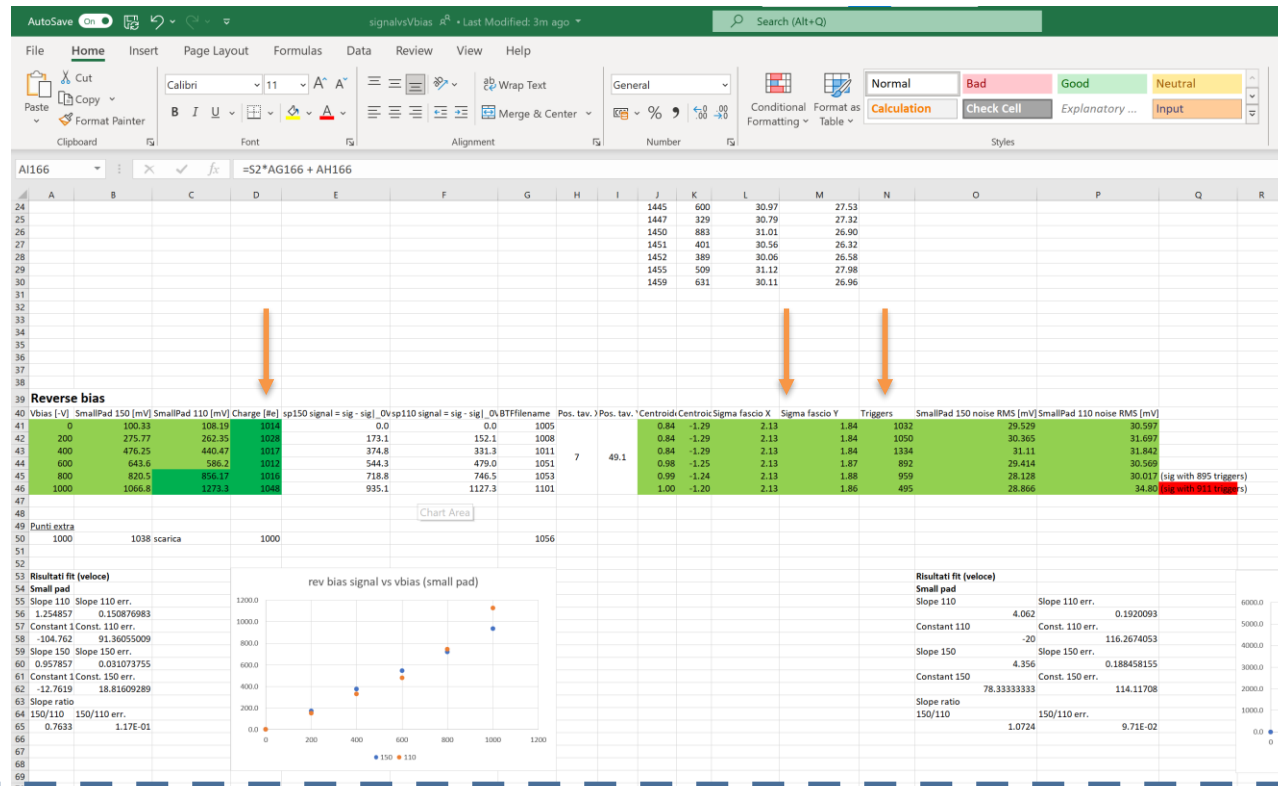
2. At very HV, many acquisitions were polluted by internal discharges. In these cases it is recorded a saturation signal of the amplifier, which clearly affects the average over  $N$  triggers. In an ensemble of 0.8-1k triggers, this matters and these signals have to be removed in order to read an accurate value of the average signal.





# Overview of 'data corrections'

3. Charge multiplicity has been corrected using recorded average data by the lead-glass calorimeter (BTF data).
4. Beam characteristics (sigma X, sigmaY) variations have been accounted in the estimate of deposited charge.



analisi | analisi\_oldMinCH | analisi\_oldMC | dati\_scantavolo | dati\_vbias | dati\_intensita | analisi\_RMS | analisi\_oldCal | dati\_vbias\_oldMC

# Fit model

→  $\text{CCEAvgE}[k\_ , V\_ ] := \text{Abs} \left[ k V \left( 1 - k V \left( \text{Exp} \left[ \frac{1}{k V} \right] - 1 \right) \right) \right];$

$\text{CCEAvgH}[k\_ , V\_ ] := \text{Abs} \left[ k V \left( 1 - k V \left( 1 - \text{Exp} \left[ -\frac{1}{k V} \right] \right) \right) \right];$

$\text{Hecht}[k\_ , V\_ ] := \text{Abs} \left[ k V \left( 1 - \text{Exp} \left[ \frac{1}{k V} \right] \right) \right];$

Energy deposited  
uniformly over  
thickness  $d^{(\text{MIP})}$

Carriers generation  
( $Q = E / 27\text{eV}$ )

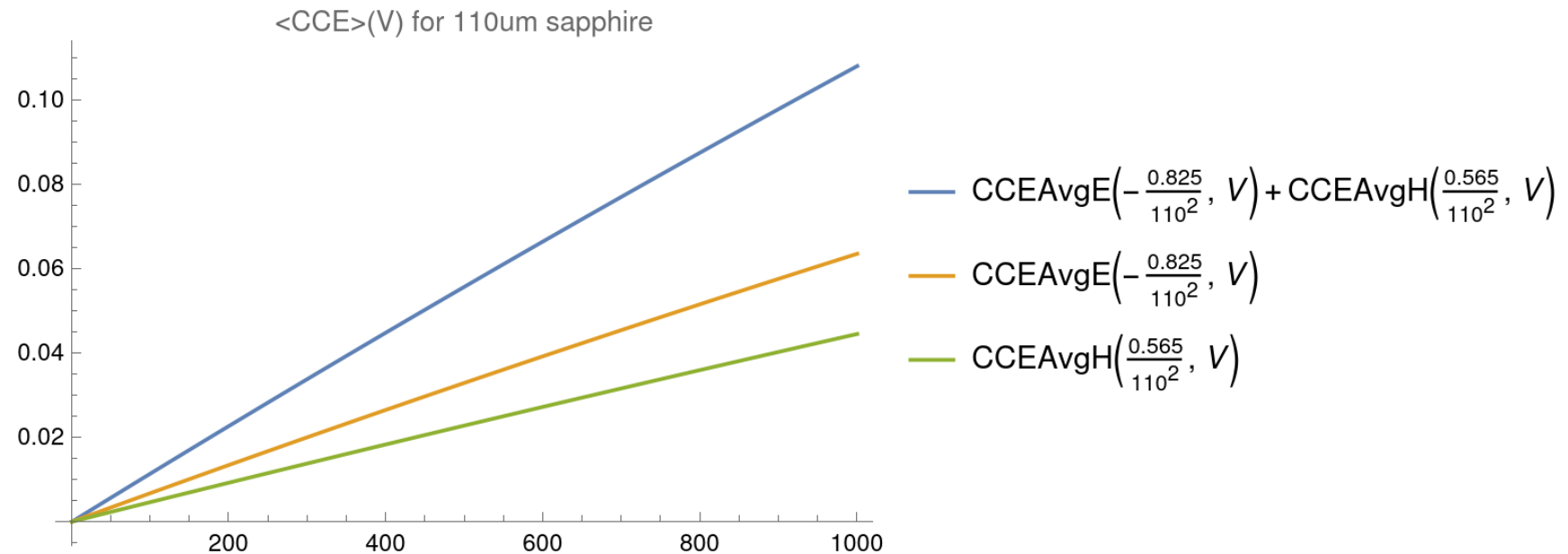
Propagation in  
uniform field  $E = V/d$

## Problem

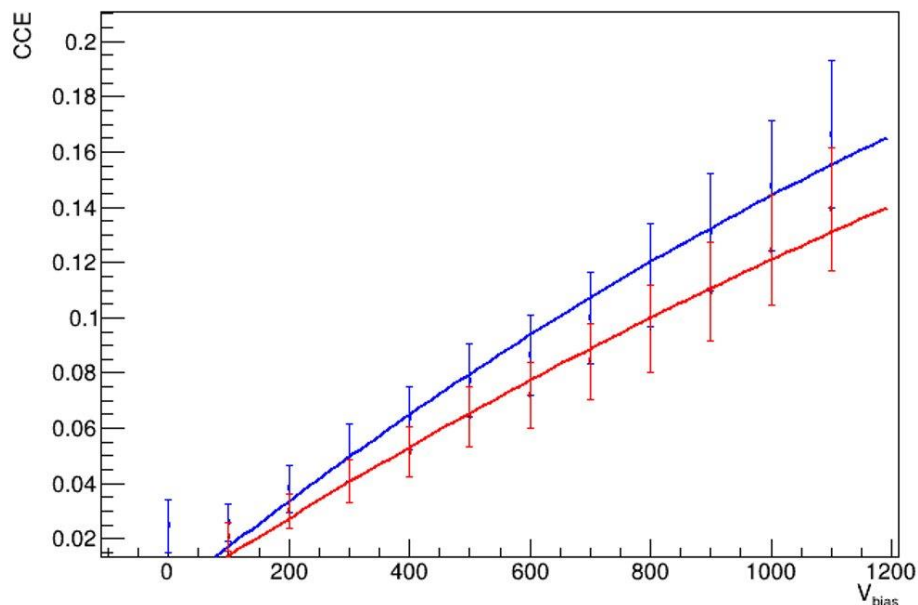
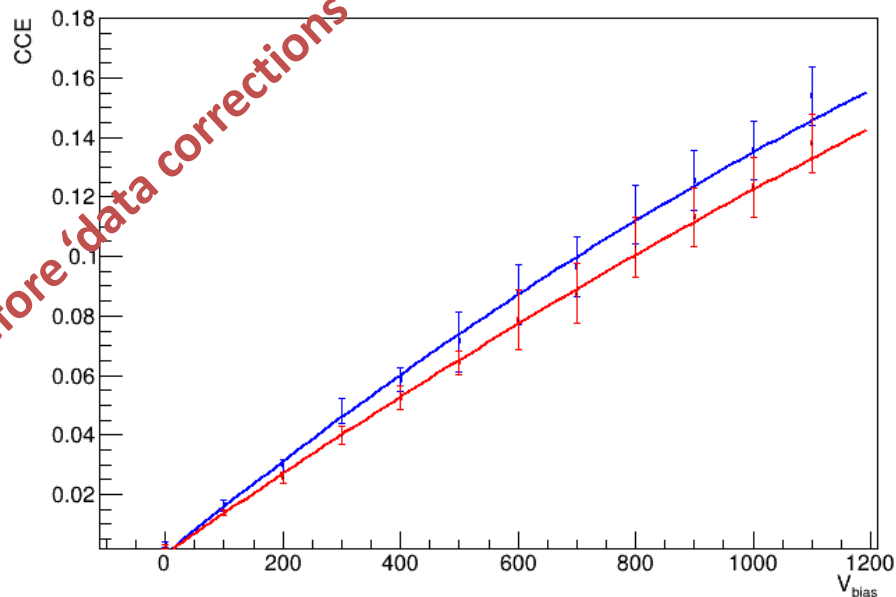
The hole contribution cannot be clearly distinguished from the electron one.

Fitting data, by assuming hole's contribution is negligible, can give an idea of the  $(\mu\tau)_e$  product.

Comparison with both alpha experiments parameter and literature can be useful to test the Hecht assumptions for the internal field.



before 'data corrections'



## 2. Fitting $\langle CCE(V) \rangle$

Forward bias

### LargePad

#### 110 um wafer

Giving for the mutau product:  
 $1.94 \pm 0.05 \text{ um}^2/\text{V}$

#### 150 um wafer

Giving for the mutau product:  
 $3.16 \pm 0.08 \text{ um}^2/\text{V}$

before 'data corrections'

### SmallPad

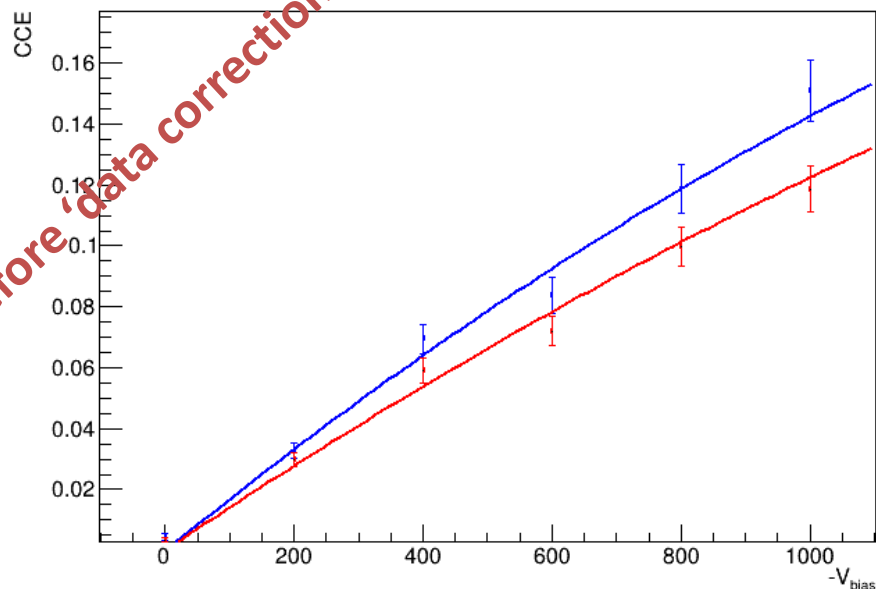
#### 110 um wafer

Giving for the mutau product:  
 $2.11 \pm 0.13 \text{ um}^2/\text{V}$

#### 150 um wafer

Giving for the mutau product:  
 $3.2 \pm 0.2 \text{ um}^2/\text{V}$

before 'data corrections'



## 2. Fitting $\langle CCE(V) \rangle$

Reverse bias

### LargePad

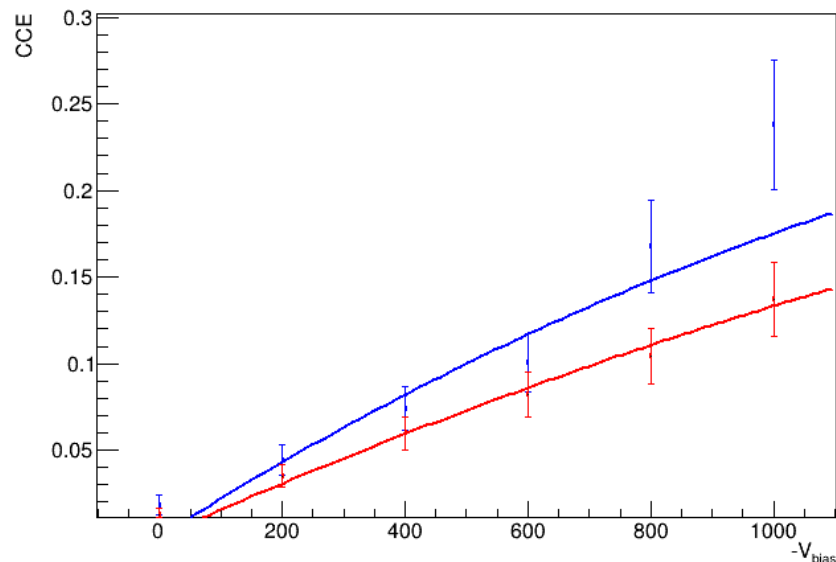
#### 110 um wafer

Giving for the mutau product:  
 $2.08 \pm 0.07 \text{ um}^2/\text{V}$

#### 150 um wafer

Giving for the mutau product:  
 $3.22 \pm 0.11 \text{ um}^2/\text{V}$

before 'data corrections'



### SmallPad

#### 110 um wafer

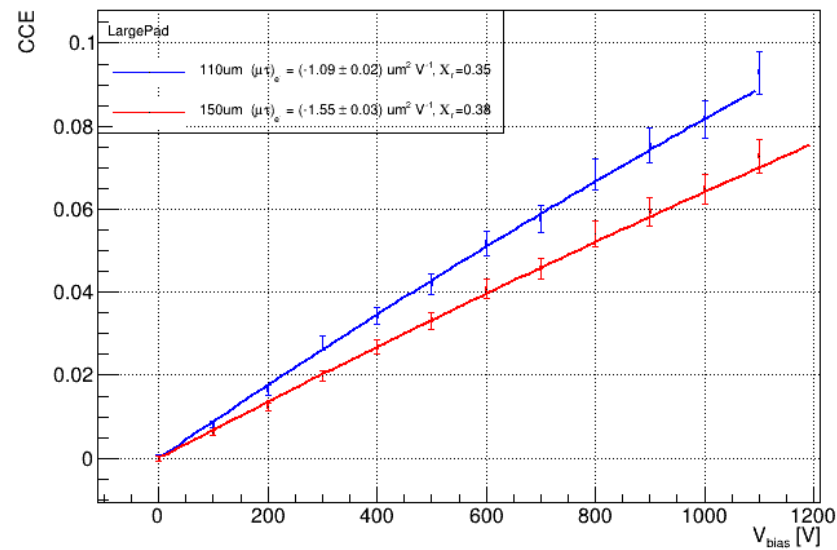
Giving for the mutau product:  
 $2.7 \pm 0.2 \text{ um}^2/\text{V}$

#### 150 um wafer

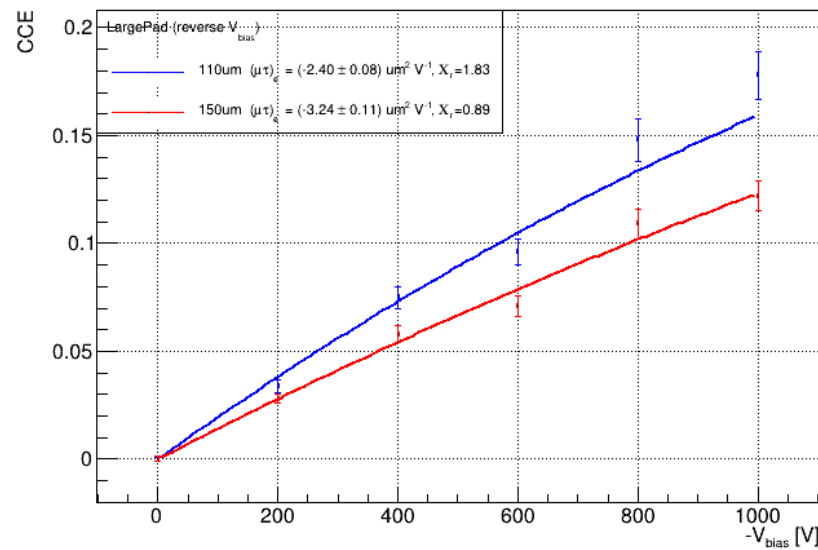
Giving for the mutau product:  
 $3.3 \pm 0.3 \text{ um}^2/\text{V}$

# Fit results

CCE( $V_{\text{bias}}$ ) for 110um



CCE( $V_{\text{bias}}$ ) for 110um (reverse bias)

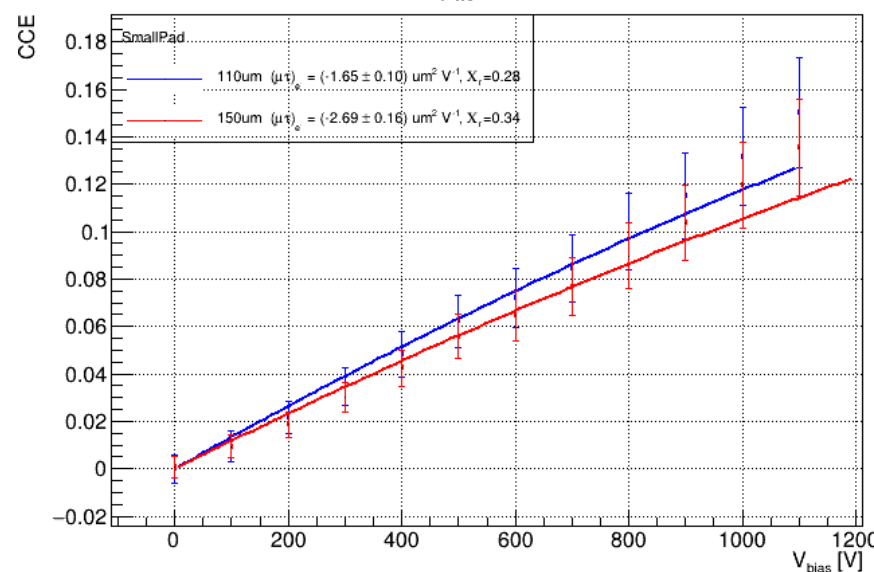


$-\mu\tau$ [um <sup>2</sup> V <sup>-1</sup> ]	110um	150um
LargePad	1.09 +/- 0.02	1.55 +/- 0.03
-HV	2.40 +/- 0.08	3.24 +/- 0.11
SmallPad	1.65 +/- 0.10	2.69 +/- 0.16
-HV	2.07 +/- 0.18	(fit failed)

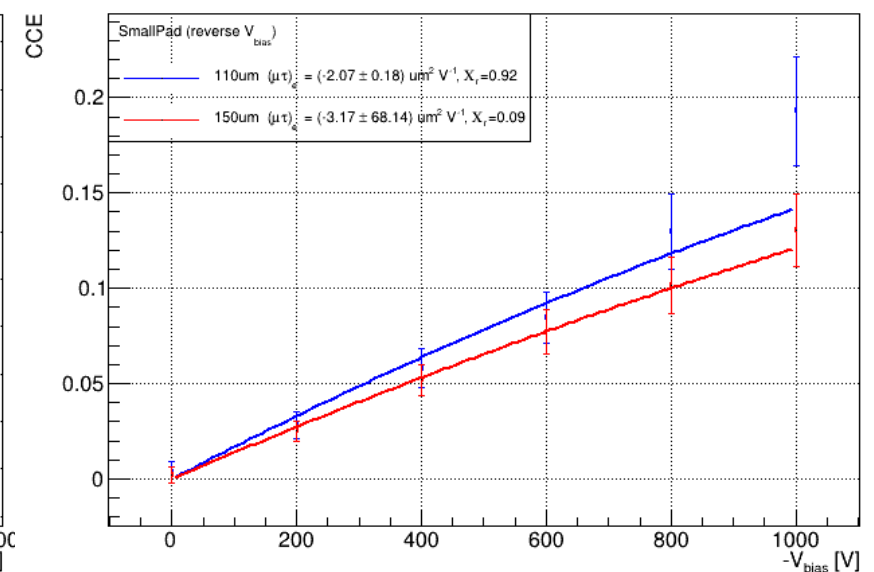
Reverse bias measures are believed to be most accurate given

1. the availability of calorimeter data and LeCroy notebooks data;
2. the 1k triggers statistics

CCE( $V_{\text{bias}}$ ) for 110um

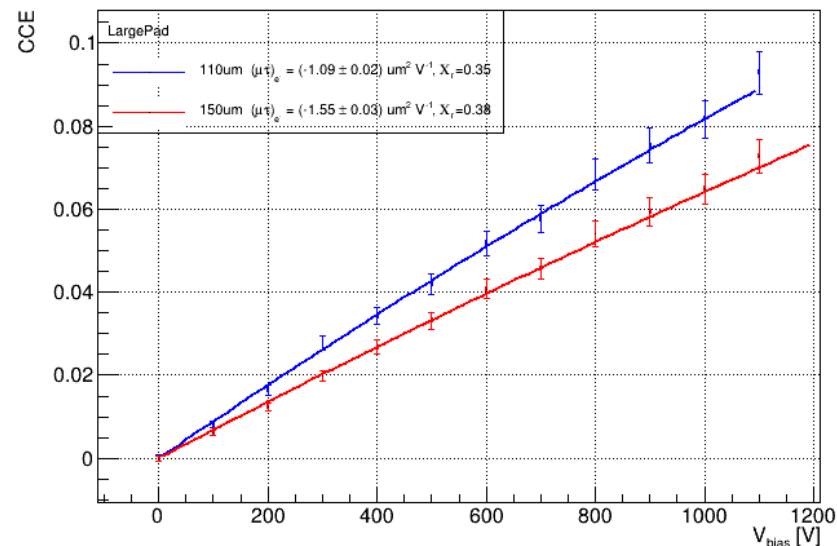


CCE( $V_{\text{bias}}$ ) for 110um (reverse bias)

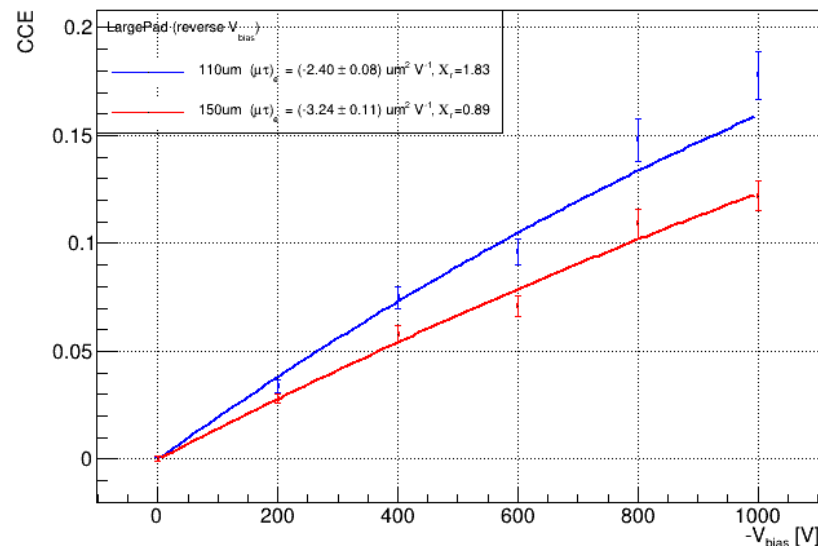


# Fit results

CCE( $V_{bias}$ ) for 110um



CCE( $V_{bias}$ ) for 110um (reverse bias)



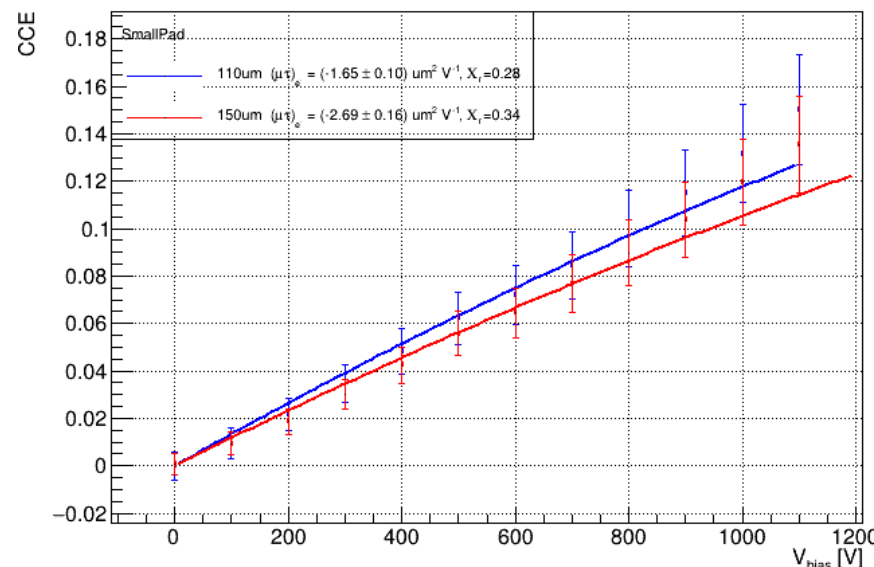
$-\mu\tau$ [ $\mu\text{m}^2 \text{V}^{-1}$ ]	110um	150um
LargePad	1.09 +/- 0.02	1.55 +/- 0.03
-HV	2.40 +/- 0.08	3.24 +/- 0.11
SmallPad	1.65 +/- 0.10	2.69 +/- 0.16
-HV	2.07 +/- 0.18	(fit failed)

Fit results confirmed the preliminary analysis with a

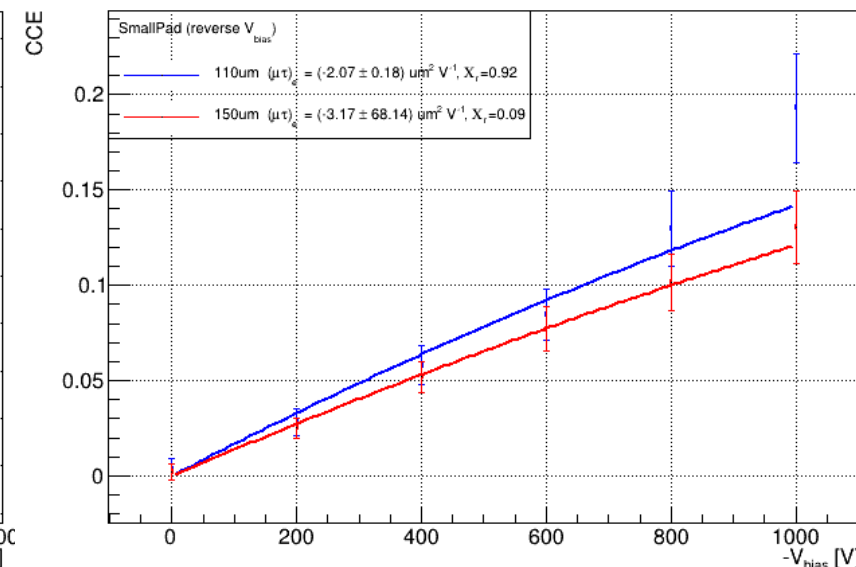
$$\mu\tau = 1.0 \div 3.3 \mu\text{m}^2 \text{V}^{-1}$$

However, data points have large uncertainties due to the lack of statistics and auxiliary data (fitpix) for deposited charge reconstruction.

CCE( $V_{bias}$ ) for 110um

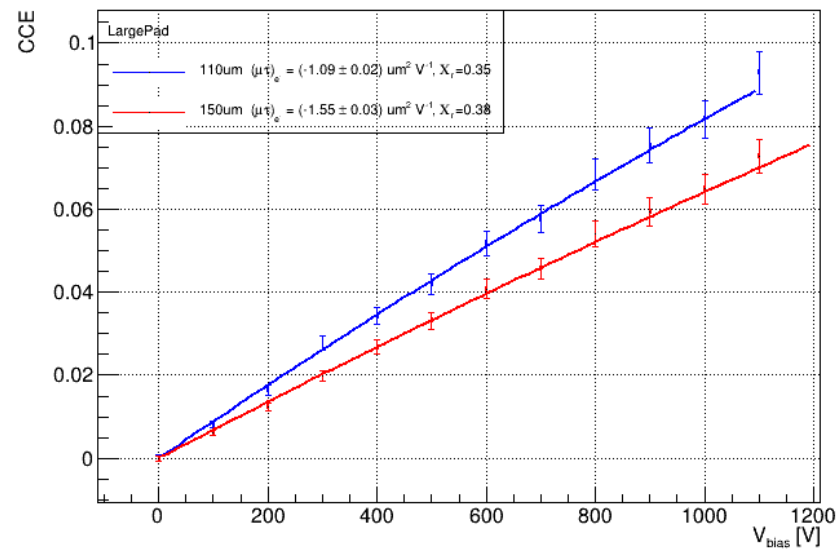


CCE( $V_{bias}$ ) for 110um (reverse bias)

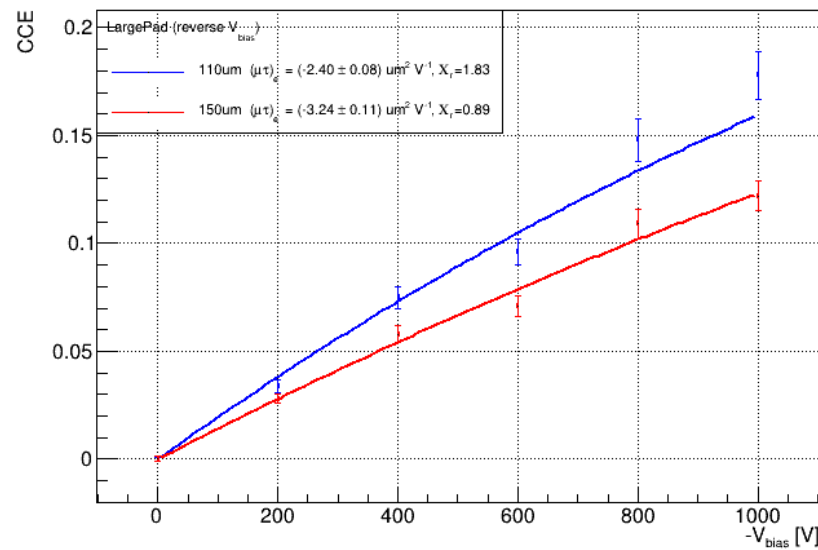


# Fit results

CCE( $V_{bias}$ ) for 110um



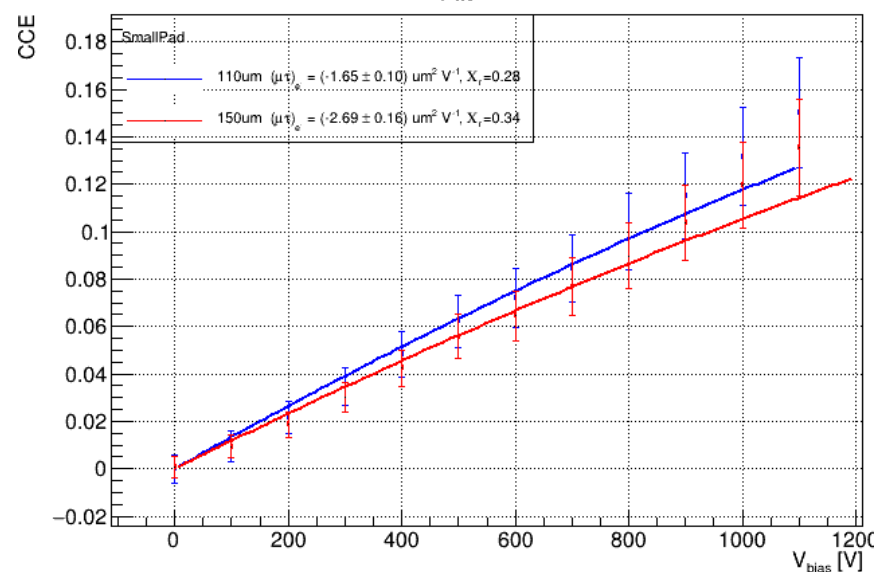
CCE( $V_{bias}$ ) for 110um (reverse bias)



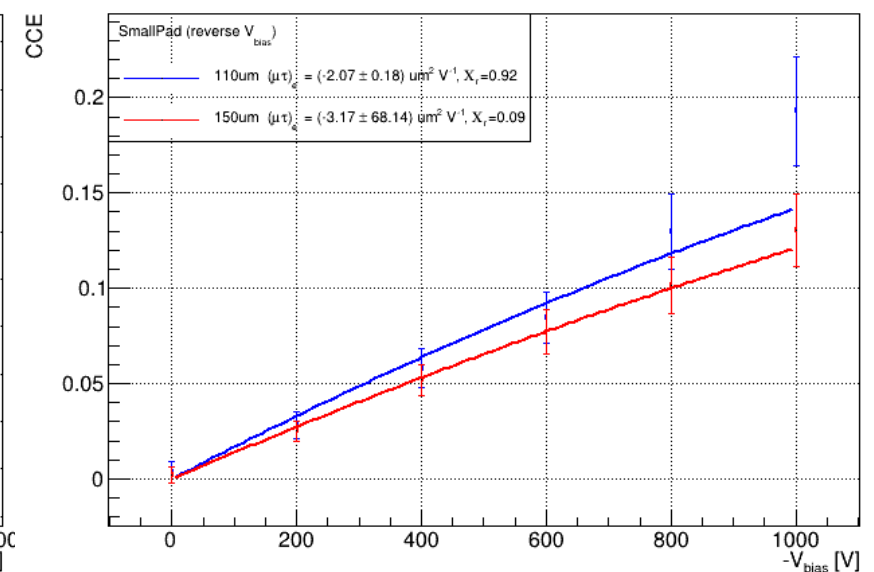
$-\mu\tau$ [um² V⁻¹]	110um	150um
LargePad	1.09 +/- 0.02	1.55 +/- 0.03
-HV	2.40 +/- 0.08	3.24 +/- 0.11
SmallPad	1.65 +/- 0.10	2.69 +/- 0.16
-HV	2.07 +/- 0.18	(fit failed)

- Consistent higher detection efficiency for the 110um detector.
- Unable to determine if Small/Large pad difference is physical or not.

CCE( $V_{bias}$ ) for 110um



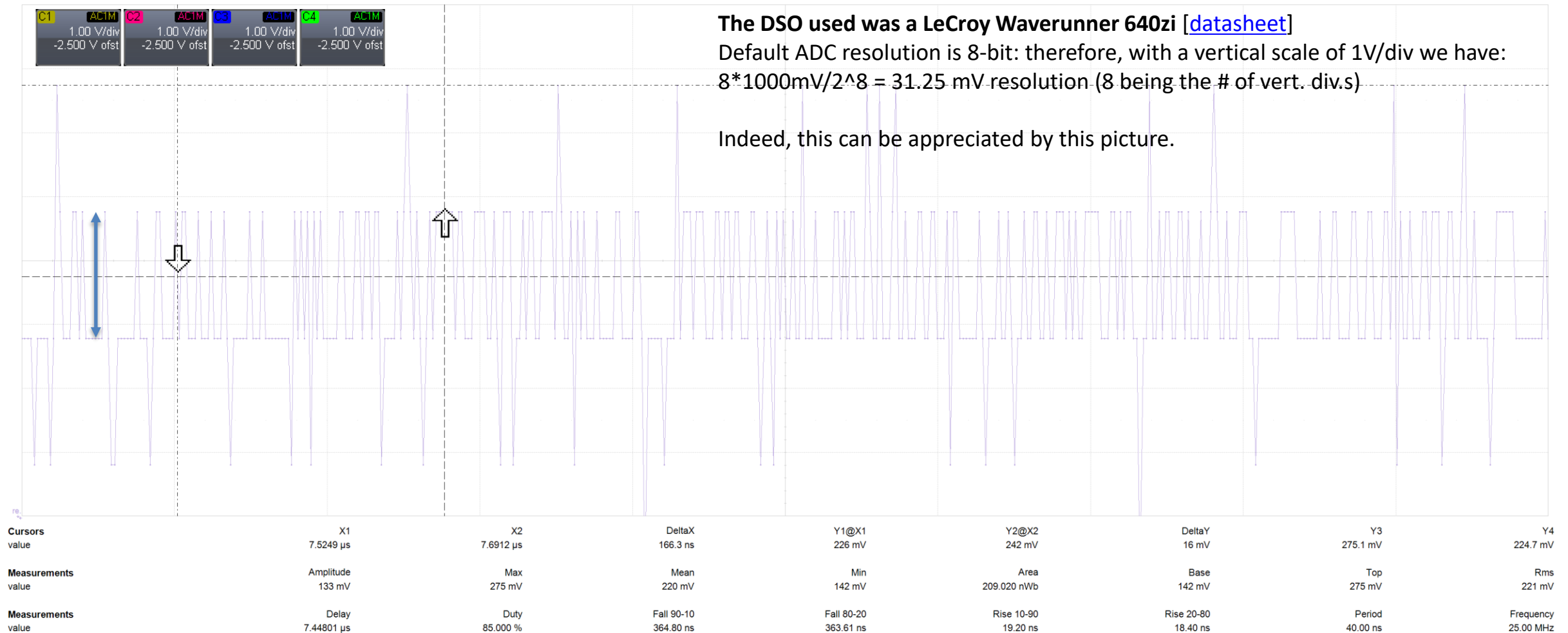
CCE( $V_{bias}$ ) for 110um (reverse bias)





**backup**

# DSO ADC resolution

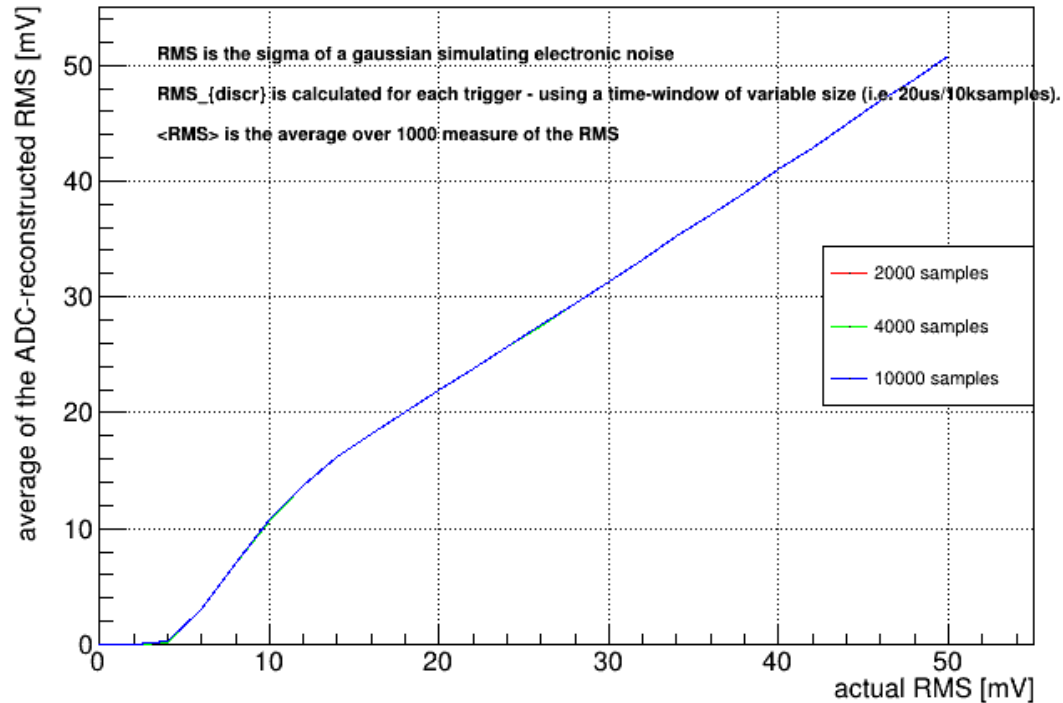


This matter for the measurement of

- the electronic noise
- the signal, which we measured using  $\langle \min(\text{CH}) \rangle$  and which is a function of  $f(\langle \min(\text{CH}) \rangle)$

# ADC biasing with an example 1/2

## The electronics noise

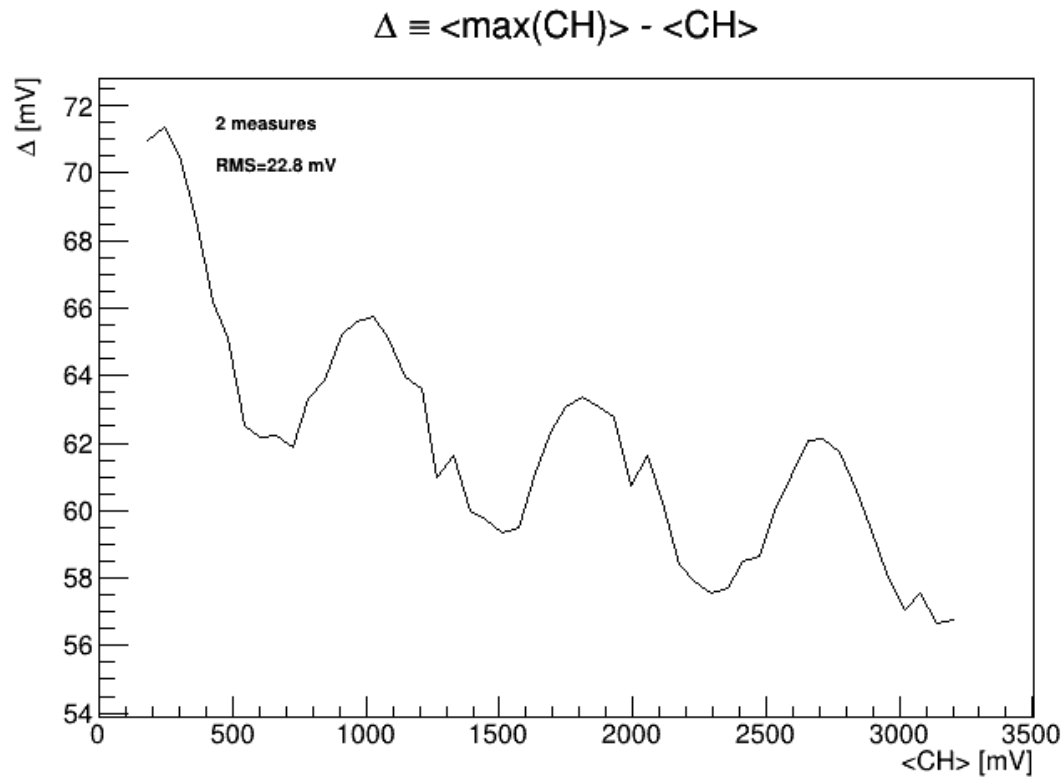


- Assume that the electronics noise is completely random, and it's normally distributed with a certain sigma ('actual RMS').
- This noise overlays the actual signal, and this waveform is then fed in the DSO front-end where the analog signal is quantized over the 8-bit resolution (31.25 mV)
- Dithering from signal+noise sampling make the measure of the RMS noise meaningful, as illustrated here

The Fig. shows that if we read  $\langle \text{RMS} \rangle = 32 \text{ mV}$  – e.g. the RMS is calculated in a 2k sample window (2 $\mu\text{s}$ ) and the average over 1k triggers – the true unbiased RMS value is  $32 - 2.67 = 29.3 \text{ mV}$ .

## ADC biasing with an example 2/2

### The electronics noise



- Incidentally, this toy model shows that dithering allows to measure the  $\langle \text{RMS} \rangle$  noise with a precision smaller than the ADC resolution.
- However, to the pure electronics noise we have to add another noise disturbing the signal measure: the noise from the environment
  - Waveforms (right)
  - Trace of RMS noise (left)

The difference  $\Delta$  depends from the intensity of the  $\langle \text{CH} \rangle$  itself, given that the sampling rate is fixed and the shaping time determines the temporal width of the peak.