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Thin Silicon Detectors for Tracking in High Radiation Environments

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OUTLINE:

Silicon detectors offer high resolution, speed and granularity for Vertexing and Tracking tracking in High Energy and, increasingly, Nuclear Physics experiments.

The request for reducing the mass of these sensors, for a number of Physics reasons in the various application fields, get more and more pressing. Radiation tolerance is one of the aspects that these lower mass sensors will need.

A sensitive thickness of 50 μm will be desirable for several applications: here we study the radiation tolerance properties of such a thin silicon sensors.

Low mass: a real need

Future Vertex and Tracker detectors at the HL-LHC

e^+-e^- colliders

LHeC colliders

Nuclear physics experiments

B-factories ....

All these experiments would benefit (and some strictly require) very low mass sensors.

The quest for low mass detectors!

Old ATLAS Barrel Module
12 ASIC of 300µm thickness for double-sided module read-out
(*ie* just 6 read-out chips per side)

New ATLAS HL-LHC-Tracker Module will need to have 80 ASICs in two hybrids for each side.
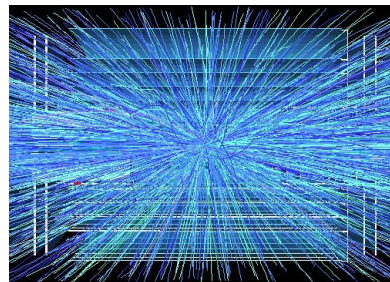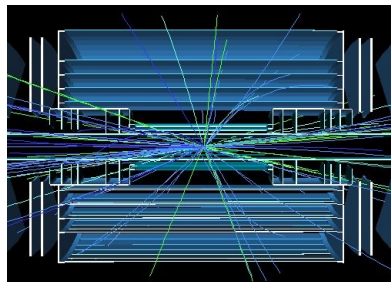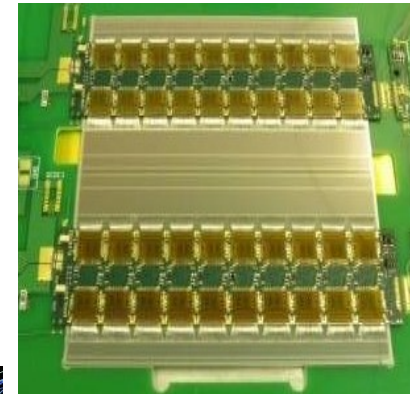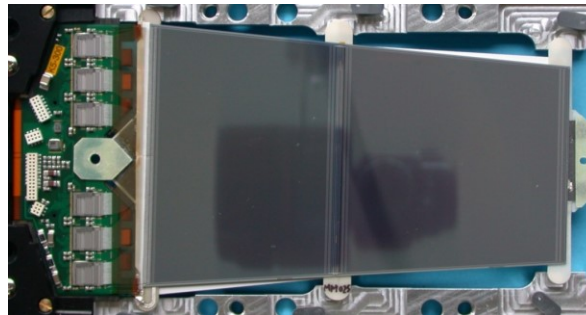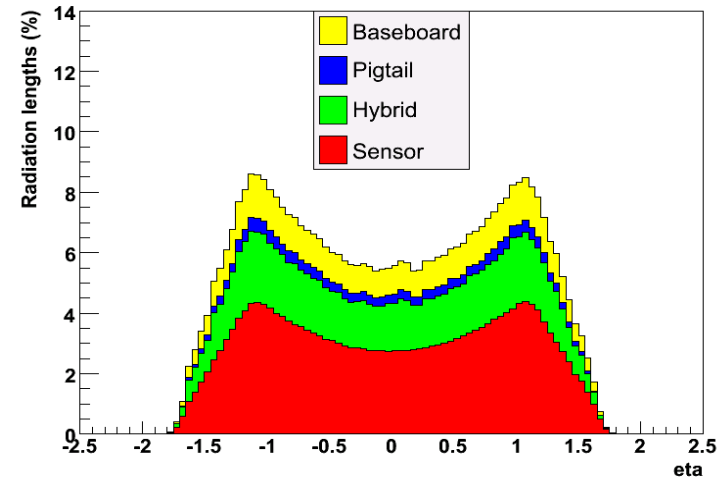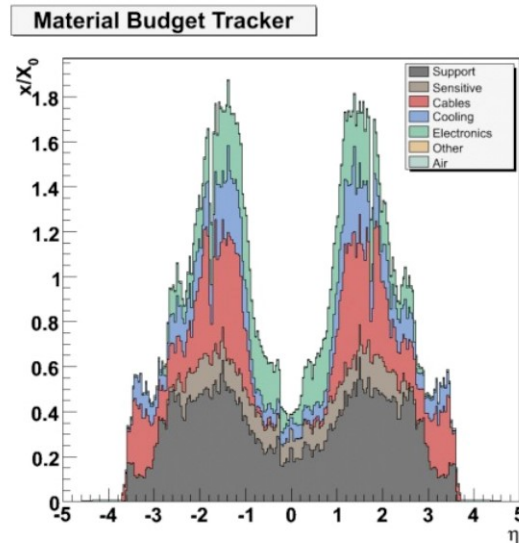
Reducing mass is hard. In certain experiments will be extremely demanding:
••• ILC target material budget is ~0.1% X_0 per layer ••• (< 100 µm silicon).

The radiation hardness challenge

The expected doses in HL-LHC go up to 1×10^{16} n_{eq} cm^{-2}.
The fluences vary in intensity and particle composition as a function of the radial distance from the beam axis. The qualification doses are different at any different radius, but for qualification the sensors for the ATLAS innermost pixel layer are required to operate after 2×10^{16} n_{eq} cm^{-2} (attaching a safety factor x2 to the anticipated dose). In addition, a better than binary resolution is desired for vertexing, therefore Time over Threshold (ToT) information is envisaged for increased resolution. The charge collection with bias voltage (CC(V)) and charge sharing (CS) need to be estimated as a function of fluence.

Could it be that the requirement for low mass and radiation hardness are compatible?

The method

Sensors made by Micron Semiconductor on 4" wafers with thicknesses 50, 100, 140, 300 μm. 1x1 cm², 80 μm pitch, n-in-p devices. The 50 μm thick would break (mechanically) when permanently glued to the cooling block due to the different CTE. Using silver conductive paint (only at 1 point) is sufficient to perform measurements.
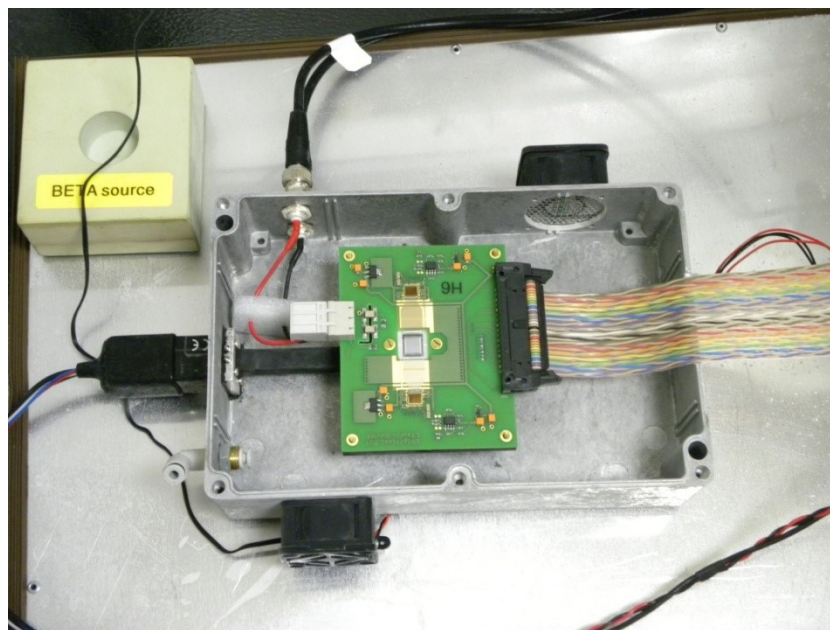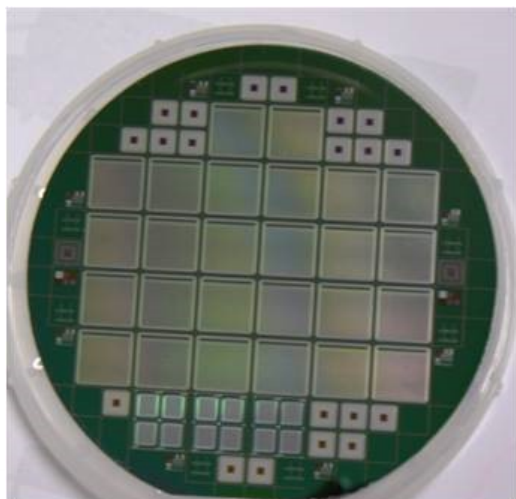
Analogue information from the Alibava board (equipped with Beetle chip)
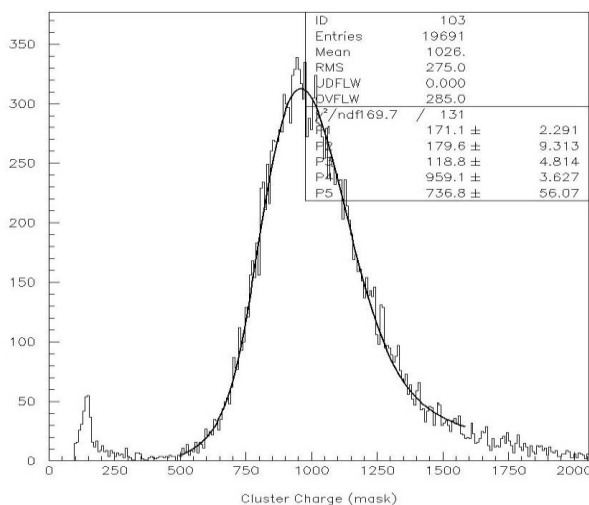
Mip signal from ^{90}Sr source in 300 μm thick sensors.

Detectors made by Micron, designed by Liverpool. Irradiation at the Triga reactor of Ljubljana (many thanks!!!).

Issue with thin sensors

Thin sensors yield small signals (4 ke⁻ for 50μm thick sensors). The electronics we use here is optimised for higher signals having typically a ENC of 450 + 45*pF .

This creates an issue after irradiation, with a degraded signal, it is hardly possible to separate low signal values from noise.

A method for subtracting the noise when substantial overlap between noise and signal distribution has to be implemented.

Method 1 (standard):

- Fit convoluted Landau-Gauss to peak

Method 2:

- Fit Gauss distribution to noise peak.
  Subtract noise (from distribution) form total data set
  Fit convoluted Landau-Gauss to subtracted data
- Subtract signal (from Landau-Gauss) from total data set.
  Fit Gauss to remaining data.
  Subtract this new noise from total data set.
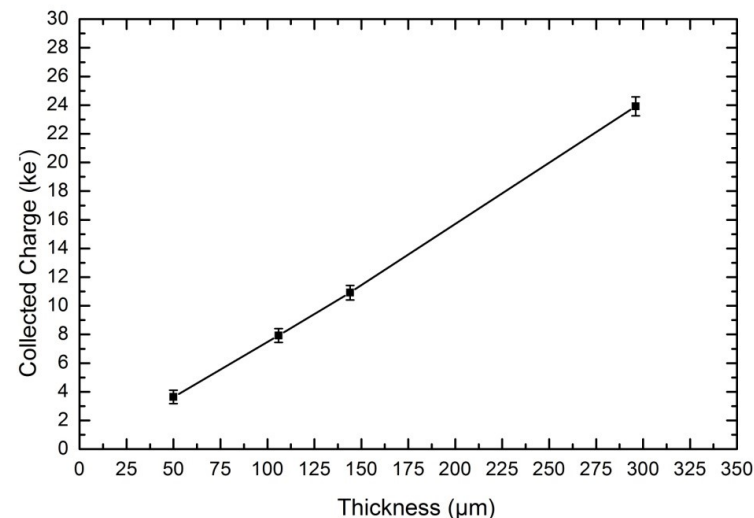 Fit Landau-Gauss to remaining data.

Method 3:

- Fit total dataset with a function that is composed of a Gaussian distribution and a Landau-Gauss distribution.
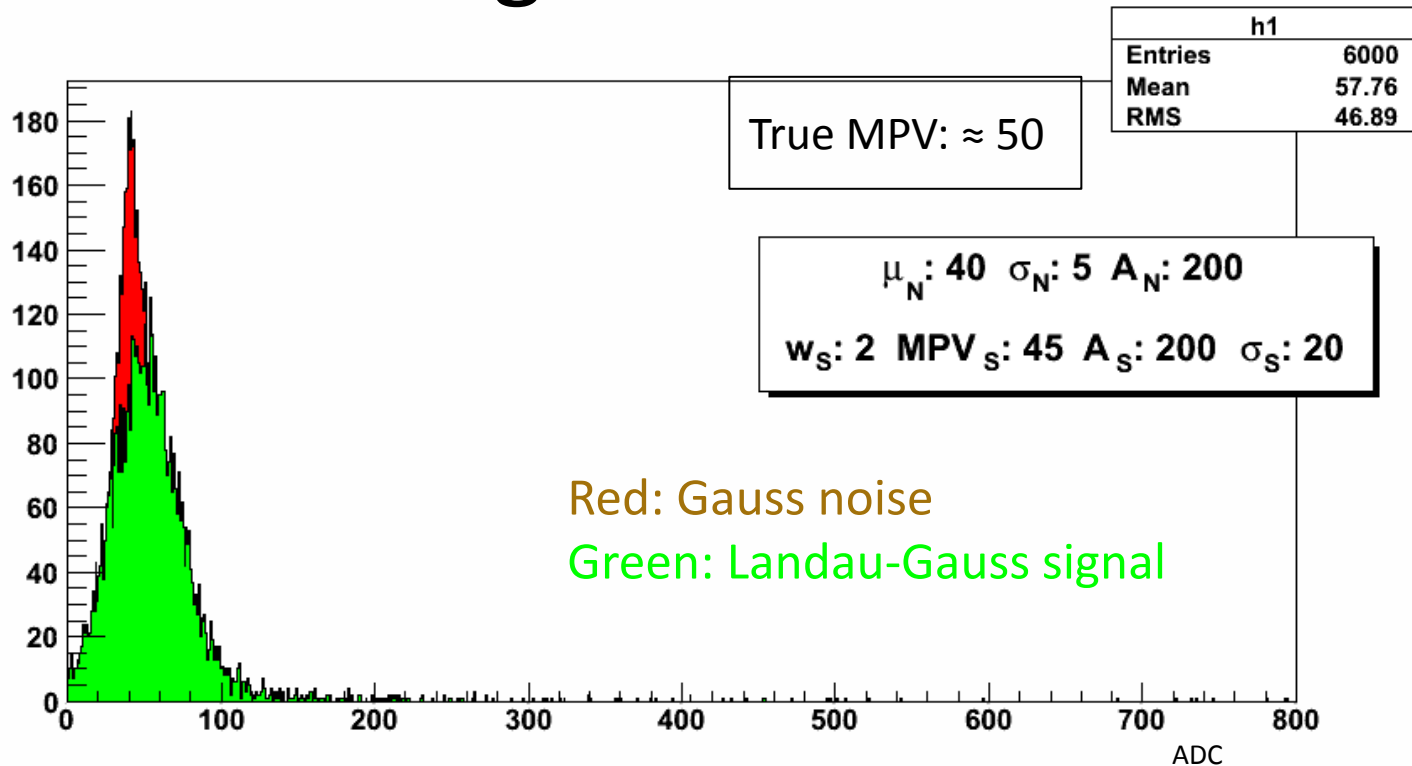
Problems:

In the overlap region, if the fit is not accurate enough and allows some of the signal to be subtracted , the MPV estimate is larger than true MPV.

The DAQ uses a noise cut for seeding the signals (if not used the number of noise hits dominated the distribution). Method 3 is sensitive to this cut and it proves to be unstable.
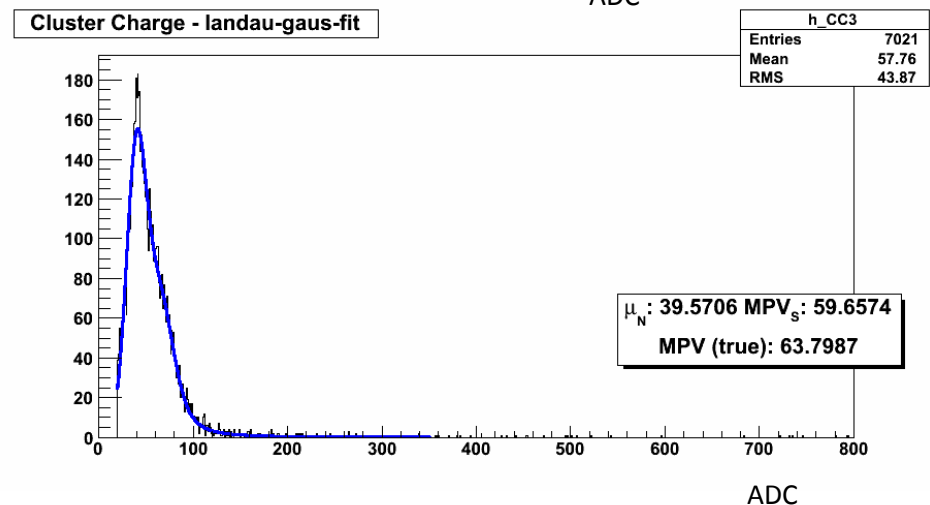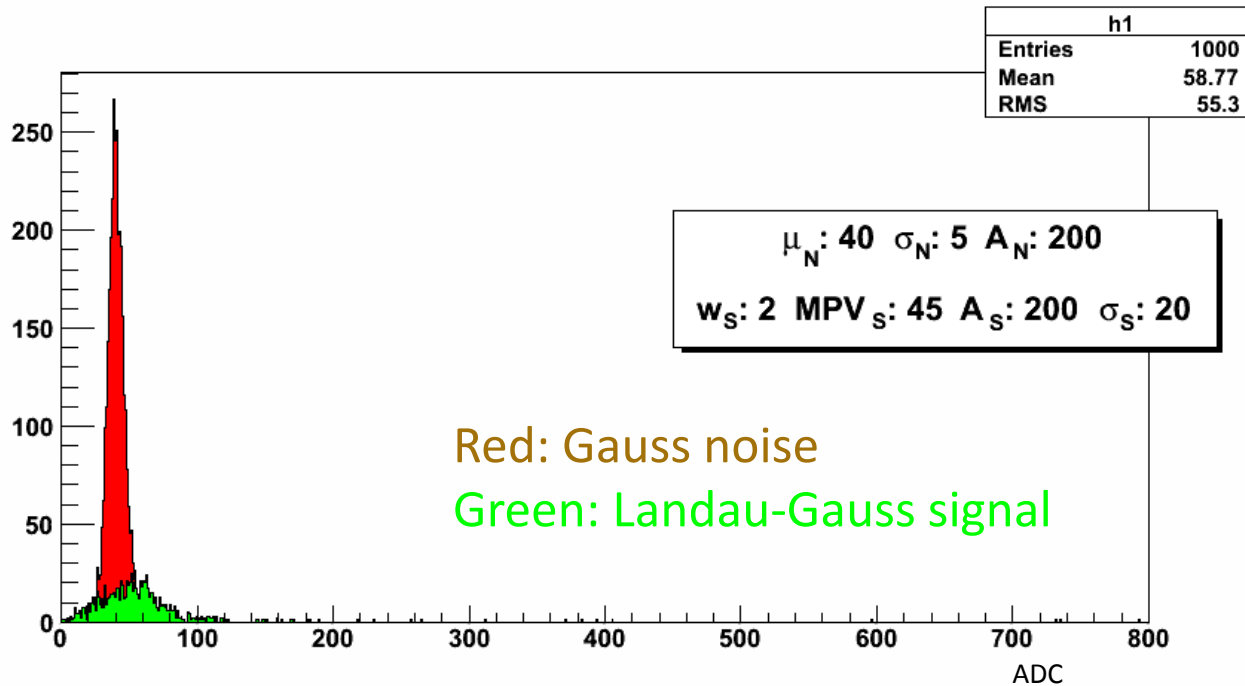
Low signal and noise

True MPV: ≈ 50

h1	
Entries	6000
Mean	57.76
RMS	46.89

μ_N: 40 σ_N: 5 A_N: 200

w_S: 2 MPV_S: 45 A_S: 200 σ_S: 20

Red: Gauss noise

Green: Landau-Gauss signal

ADC

Simulation of noise and signal

Fit with standard convoluted Landau-Gauss

Cluster Charge - landau-gaus-fit

h_CC3	
Entries	7021
Mean	57.76
RMS	43.87

μ_N: 39.5706 MPV_S: 59.6574

MPV (true): 63.7987

ADC

Low signal and noise

h1	
Entries	1000
Mean	58.77
RMS	55.3

μ_N: 40 σ_N: 5 A_N: 200

w_S: 2 MPV_S: 45 A_S: 200 σ_S: 20

Red: Gauss noise
Green: Landau-Gauss signal

ADC

Simulation of noise and signal

Fit with standard convoluted Landau-Gauss

Cluster Charge - landau-gaus-fit

h_CC3	
Entries	4021
Mean	42.94
RMS	10.87

μ_N: 40.0889 MPV_S: 44.7191

MPV (true): 47.7654

ADC

Test the methods

Test 1:

keep the MPV of the signal and the <N> of the noise constant and change the number of noise events.

Test 2:

keep number of events constant, <N> at same position and change the MPV of the signal (move the signal peak "out of" the noise).

Test 1

Measured Value – True MPV

Test the methods

Test 1:

keep the MPV of the signal and the <N> of the noise constant and change the number of noise events.

Test 2:

keep number of events constant, <N> at same position and change the MPV of the signal (move the signal peak "out of" the noise).

Measured Value – True MPV

Test 2

Issues with method 3

- Dependent on seed cut

- Usually set to 3.5

- For two sensors (1E15 and 2E16) the cut has been varied between 0 and 5 and the MPV was determined using Method 3
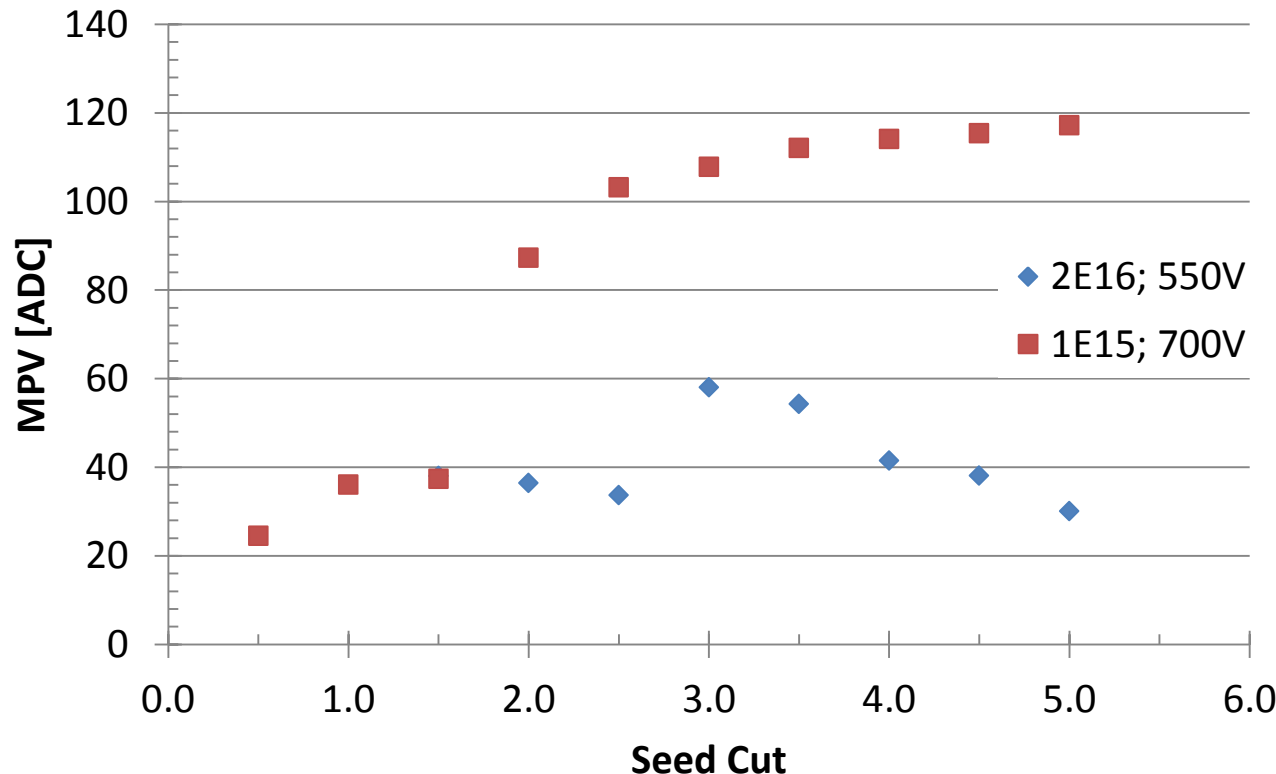
For the low fluence it is possible to apply a higher seed cut . But for high fluences this is not possible.

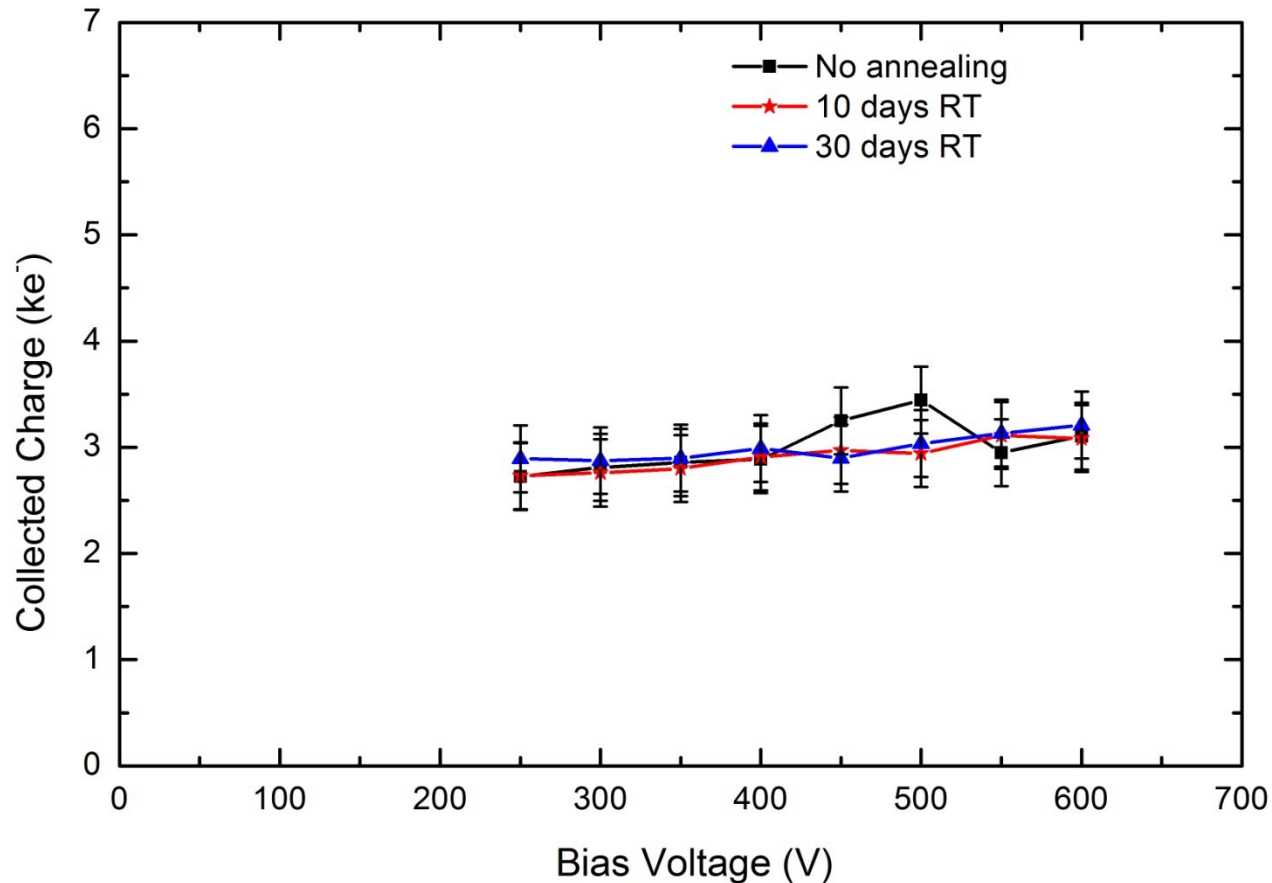# CC(V) of 50 μm sensors after various fluences
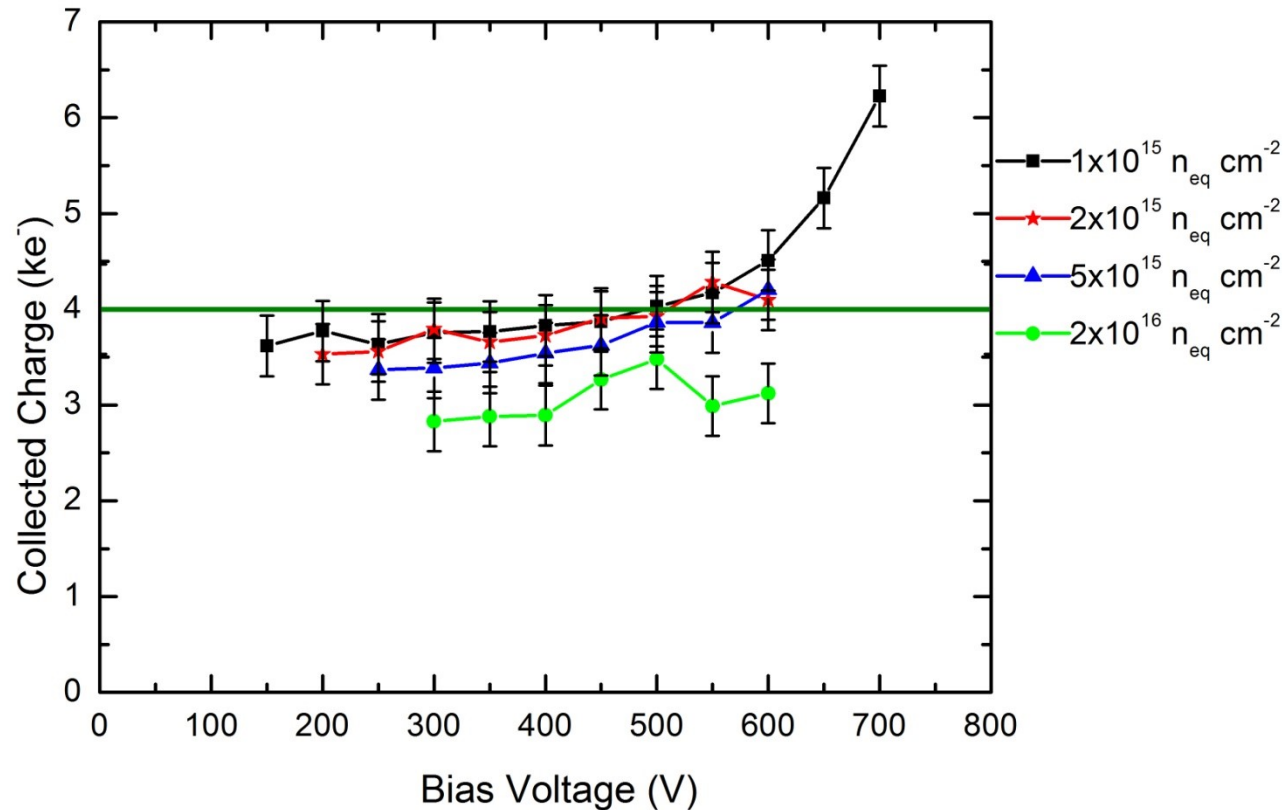
Method 2

Degradation of the CC(V) with fluence at 600 and 1000V
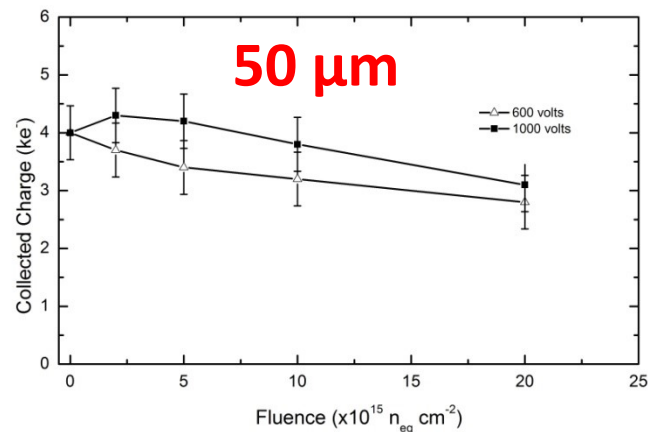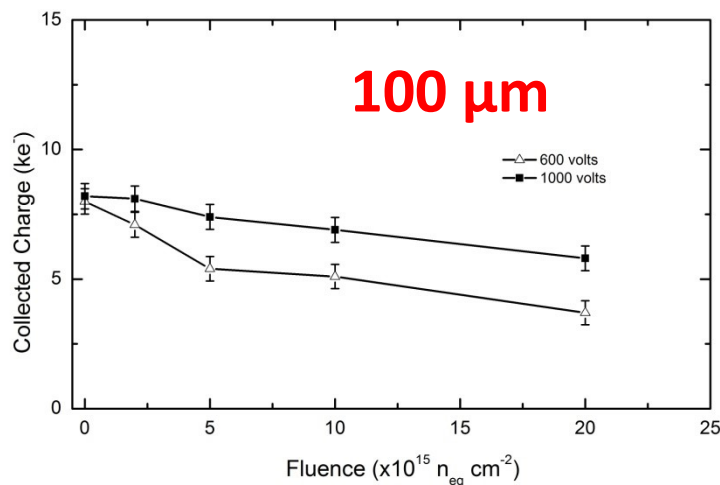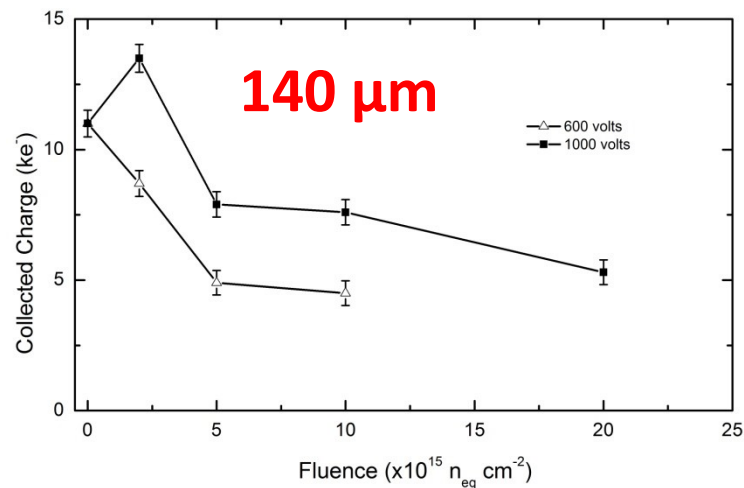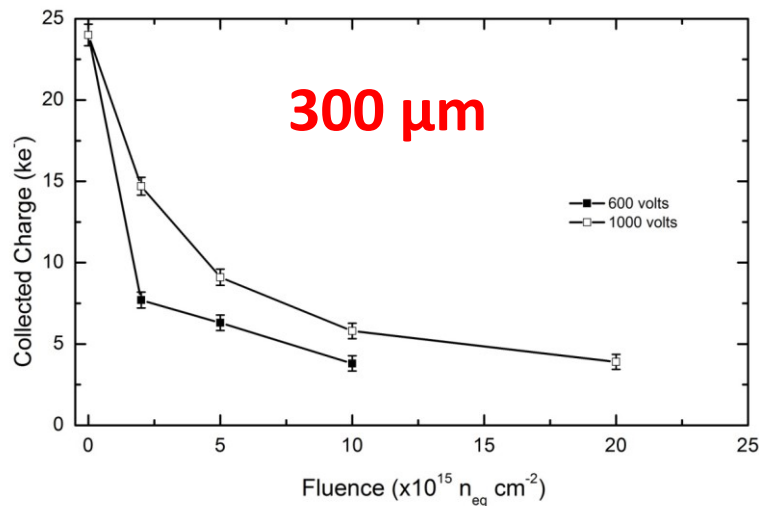
Why no/small multiplication after 2×10^{16} n_{eq} cm^{-2}?
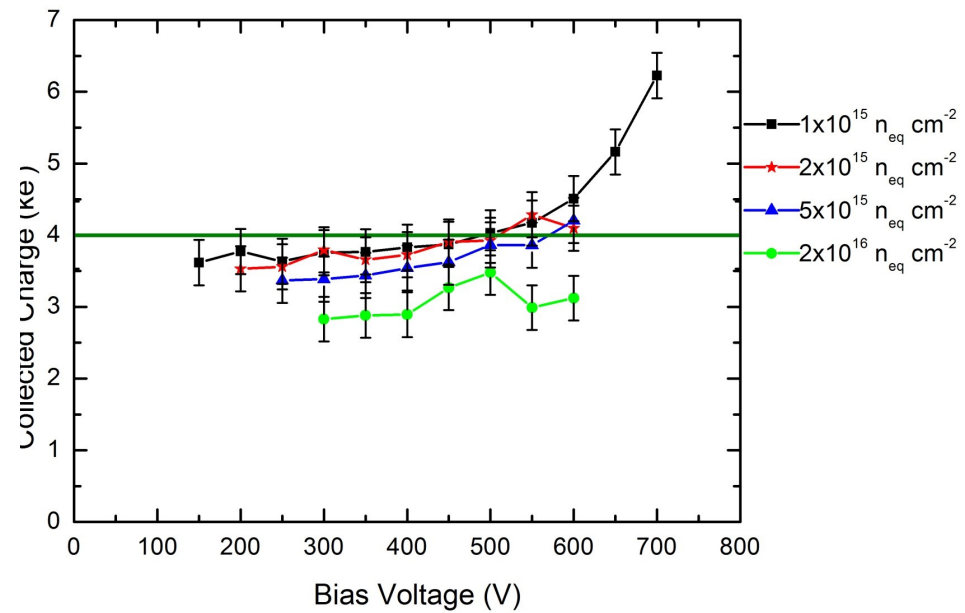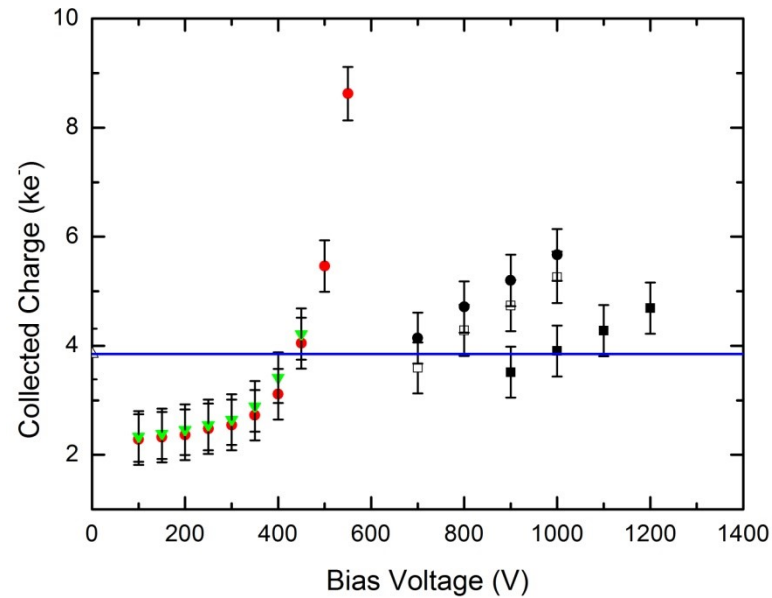
Annealing of CC(V) of the 50 μm sensor after 2×10^{16} n_{eq} cm^{-2}

CONCLUSIONS

Thin silicon sensors is an available technology. Pixel and microstrip sensors can be produced down to at least 50μm thickness.

The study of the charge collection as a function of the applied bias voltage with 50μm thick microstrip sensors show a degradation of about 25% of the collected signal after 2×10^{16} n_{eq} cm^{-2} (after neutron irradiation). This in a bias regime where there is no direct evidence of charge multiplication. The ability to create CM is not yet under control (similar sensors processed a few years ago showed evidence of CM after this dose).

Anyhow these results show that with a different detector technology where small electrode sizes with much lower noise can be implemented (like HV-CMOS sensors), the CCE at (relatively) moderate bias voltages is degraded only by ~ 25%, making reliable performance possible after this very high fluence. HV-CMOS can be operated with high signal to noise with thinner sensitive volumes (e.g. 20 μm thick) where it is possible to envisage an even lower degradation of the CCE, opening the attractive scenario that performances does not degrade with fluence (at least up to 2×10^{16} n_{eq} cm^{-2}). A caveat: this is after neutron irradiations, proton irradiation might cause a larger signal loss also with this sensors.

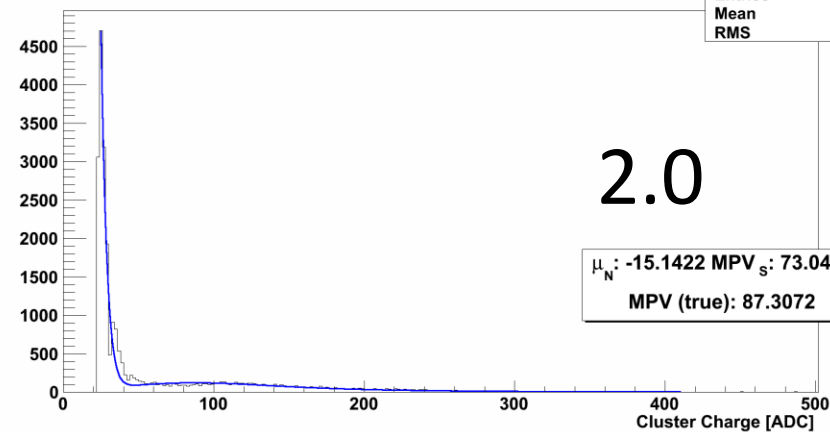We irradiated thin sensors up to 3×10^{16} n_{eq} cm^{-2} but no distinguishable signal was measured.

SPARE SLIDES

1E15
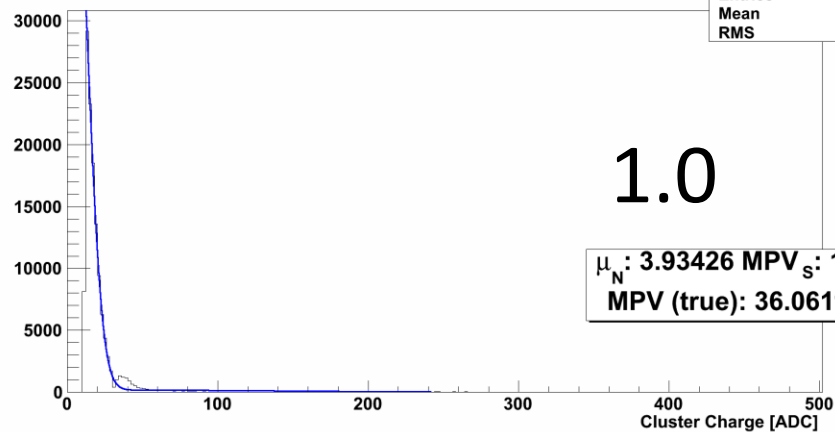
2E16

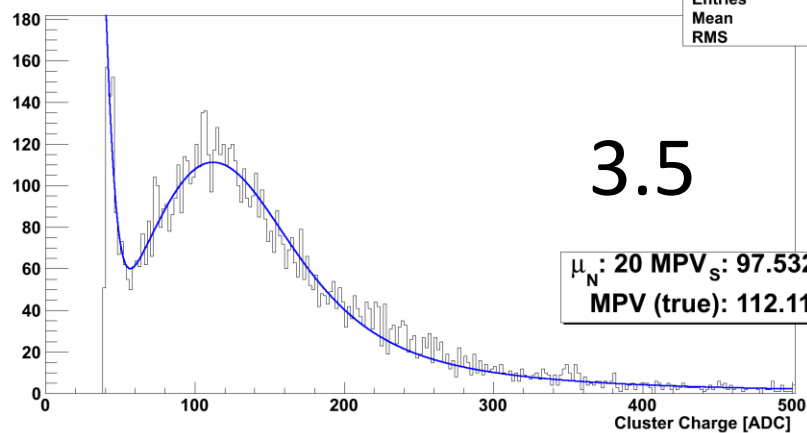S. Wonsak, RD50, 02-04 Dez. 2015, CERN   20
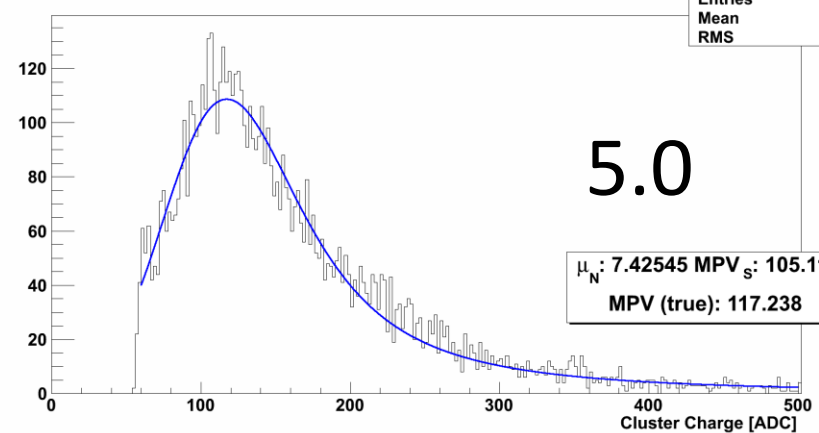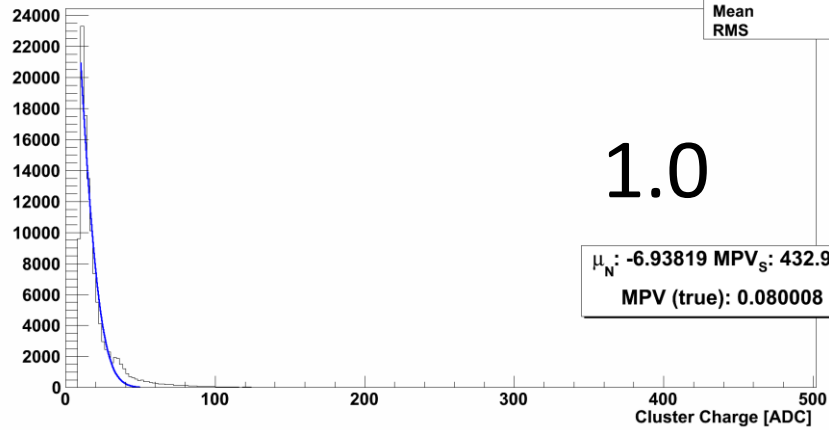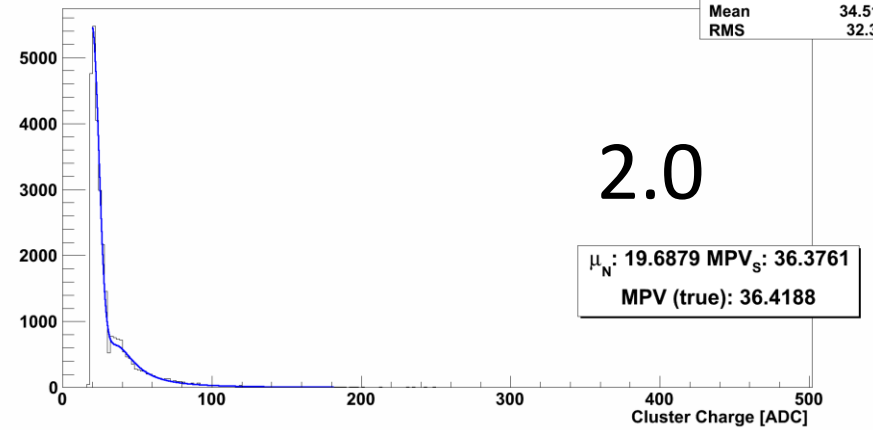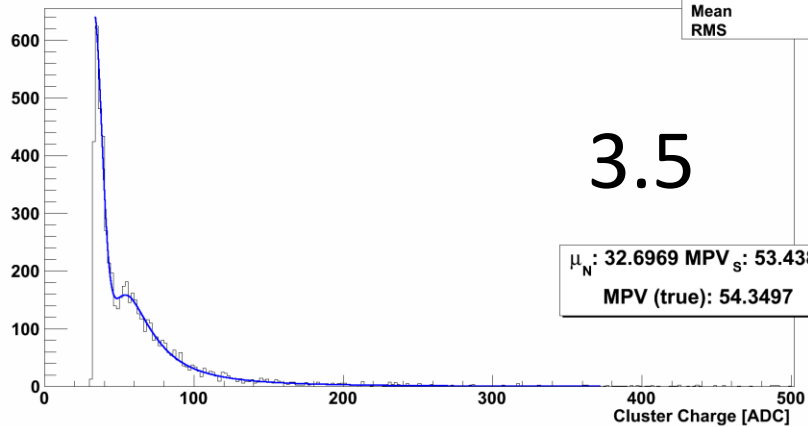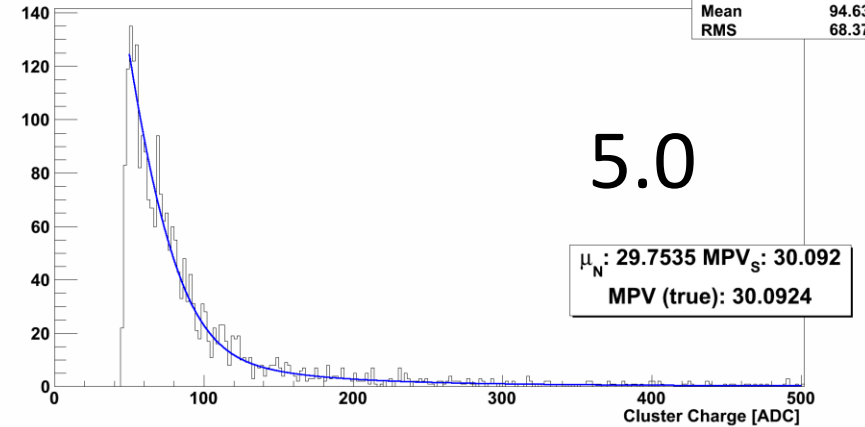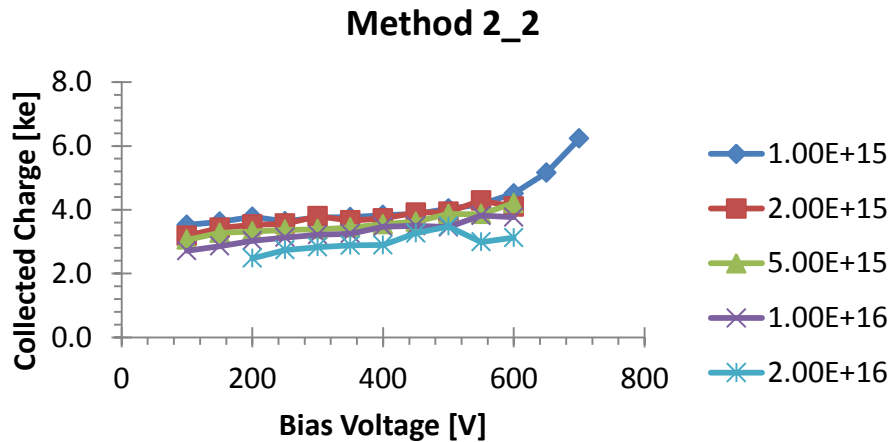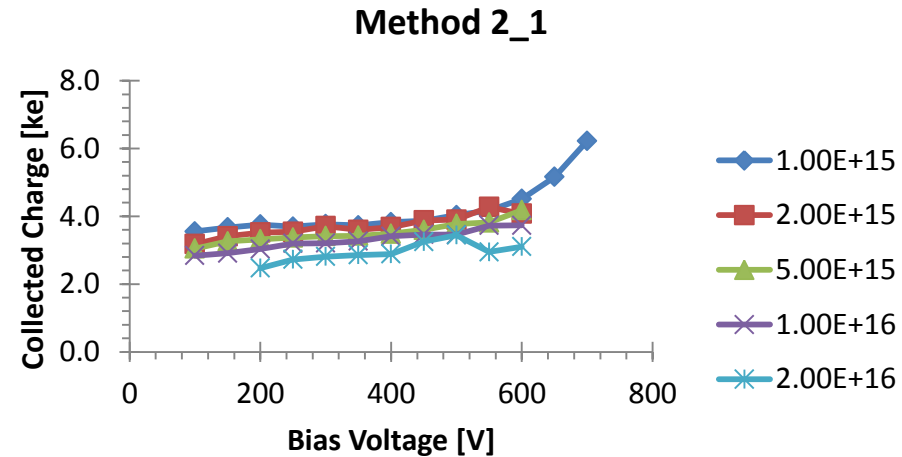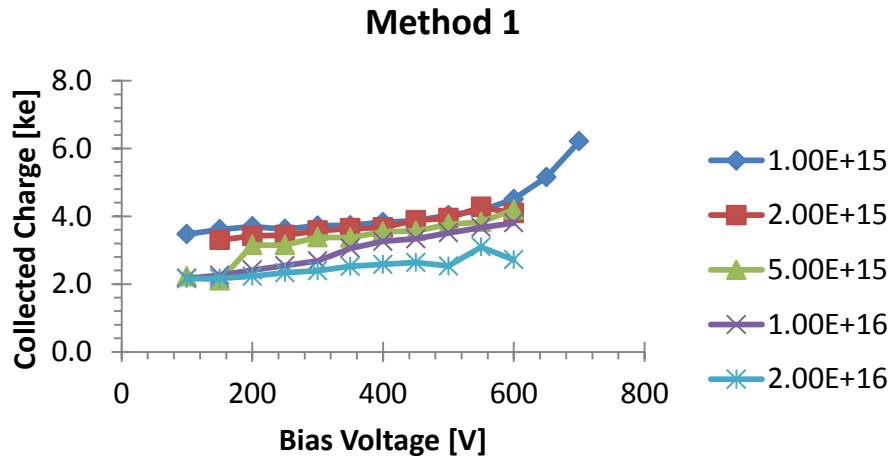
Collected Charge

- The raw data of several 50um sensors, irradiated from 1E15 to 2E16 have been analysed with the three methods

- Method 2 will give two MPV values
  - Method 2_1: after the initial noise subtraction
  - Method 2_2: after second noise subtraction

- For comparison the MPV value of Method 1 has been subtracted from the other MPV values
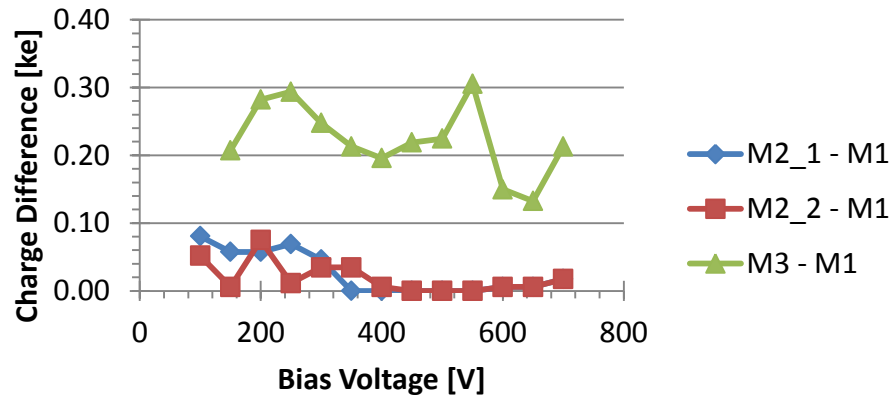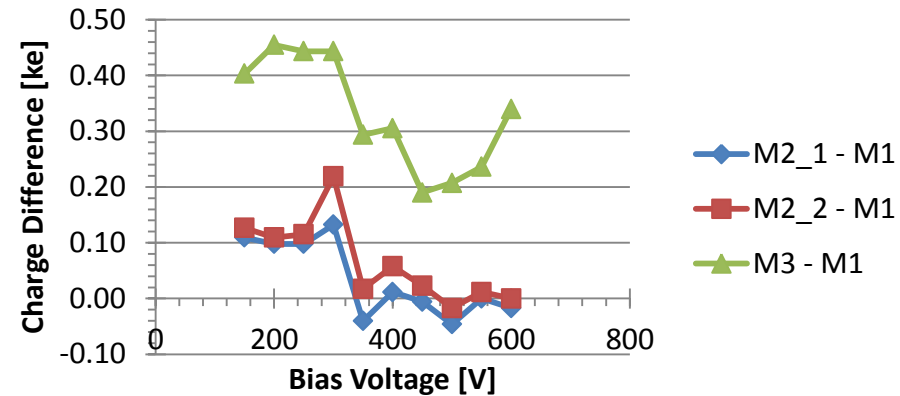
Collected Charge
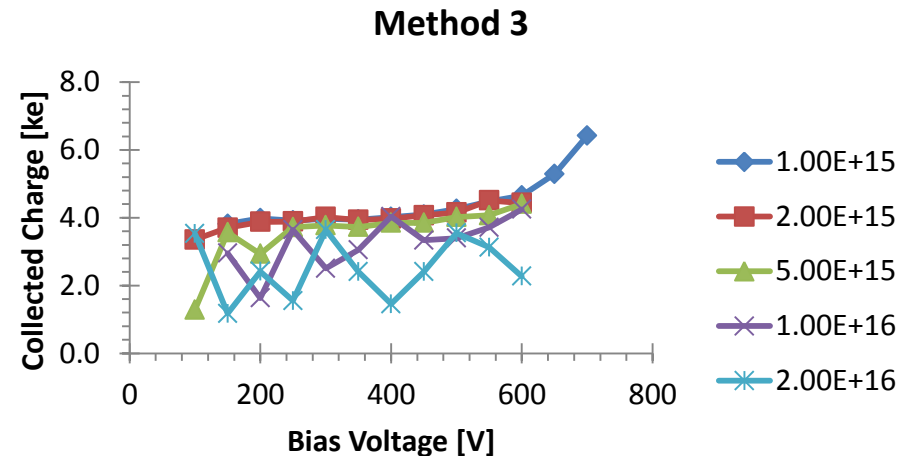
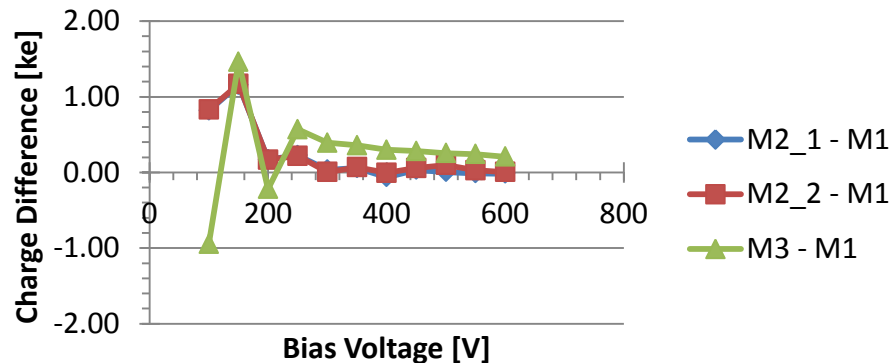Method 3 is not reliable for high fluences (1E16 and 2E16)

Compare Methods

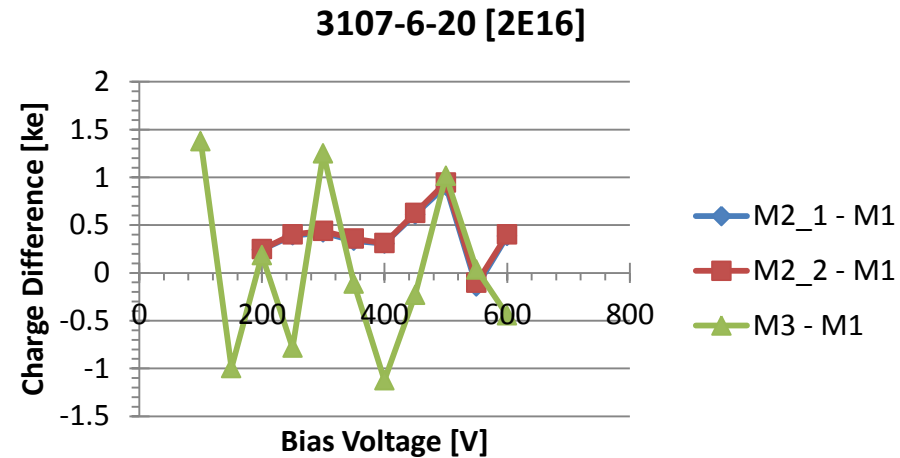**3107-3-13 [1E15]**
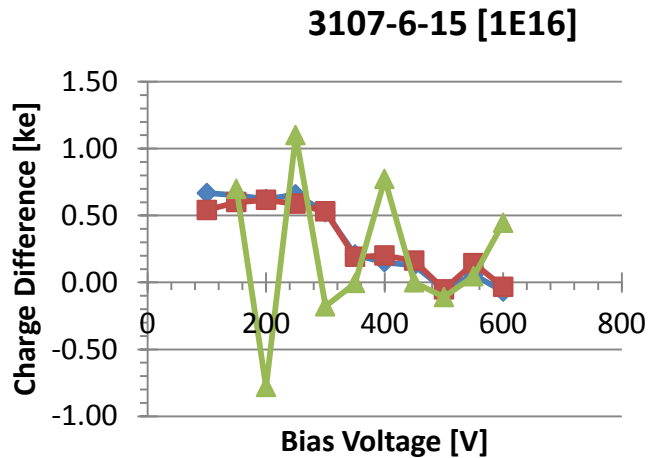

3107-3-19 [2E15]

3107-6-12 [5E15]

- For low fluences the value obtained with Method 3 is higher than with other methods

- Method 1 and 2 have a small deviation, especially for higher voltages

Compare Methods

- At high fluences the difference in the methods increase.
- At 2E16 Method 3 is clearly not reliable, while Method 2 produces a value that is higher than Method 1

Conclusion

- There is no reliable method to obtain the collected charge for thin sensors

- Fitting the data only with the Landau-Gauss distribution (Method 1) will result in a value, that is too small due to noise contributions

- Using Method 2 will result in a signal that is too high due to misidentification of signal as noise

- Method 3 should be more reliable and the MPV value should be the true MPV, but fitting high noise / low signal graphs is also not fitting the true MPV value

- The true signal value is in-between the values obtained with these methods
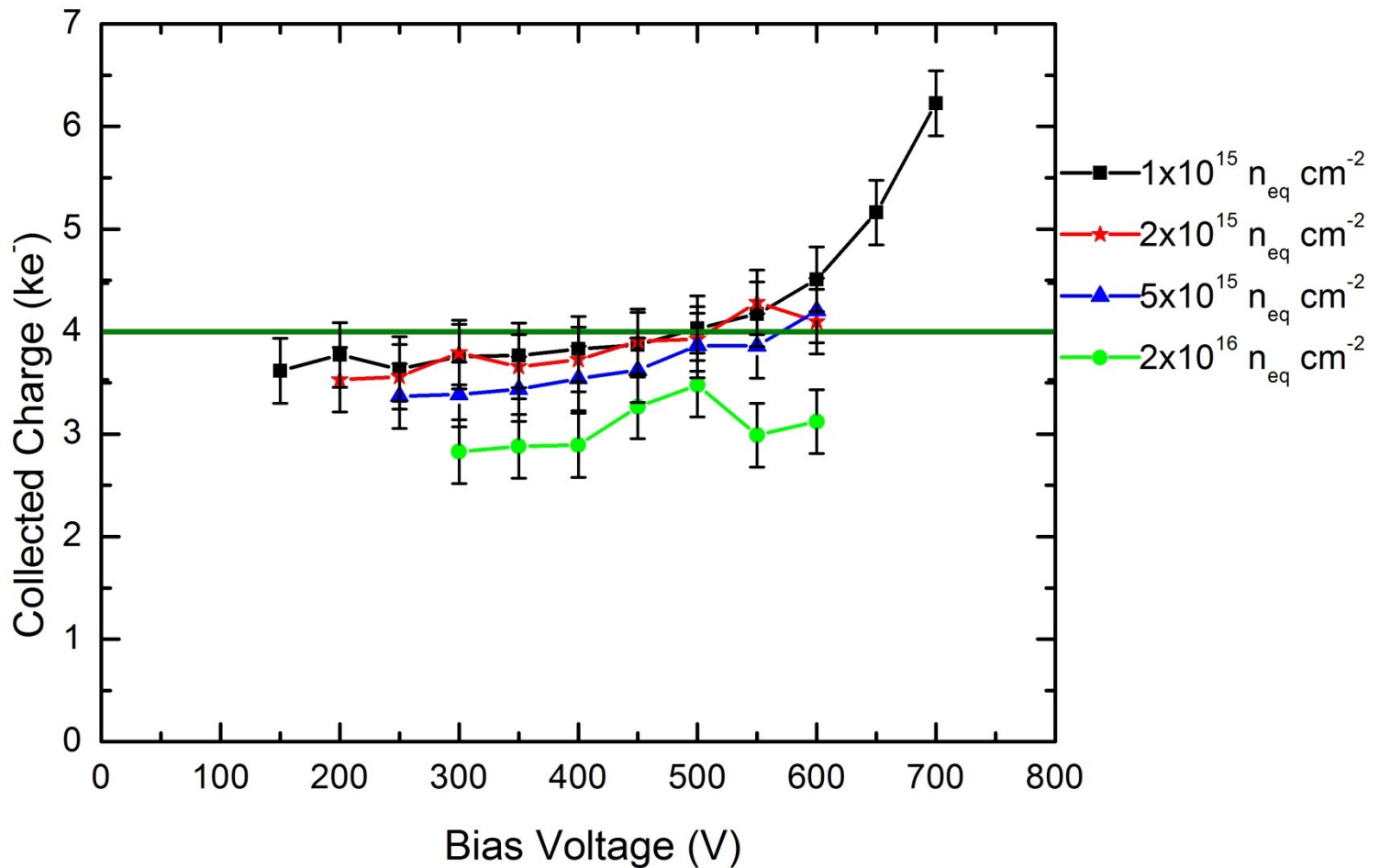
Degradation of the CC(V) with fluence

2×10^{15} n$_{eq}$ cm^{-2}

Notice that the CC(V) for the 140μm thick sensor exceeds the expected charge ionised by a mip in that thickness of silicon.
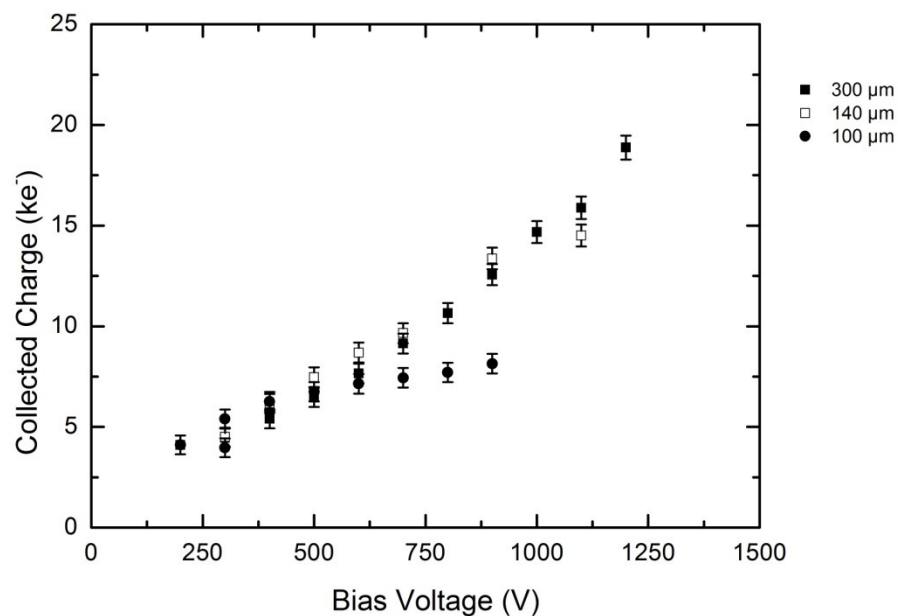
CC(V) of 50 μm at various fluences
With method 2

Noise of 50 µm thick sensors after various fluences