A grazing angle technique to measure the charge collection efficiency for CMOS active pixel sensors

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2018/2/23

Grazing angle technique:

- The most direct way to accomplish the measure of the CCE profile is to generate a known amount of electron/hole pairs at a given depth and then to measure the pixel response.
- This is not an easy measurement because it requires an accurate and complex setup.

➢ Modified grazing angle approach

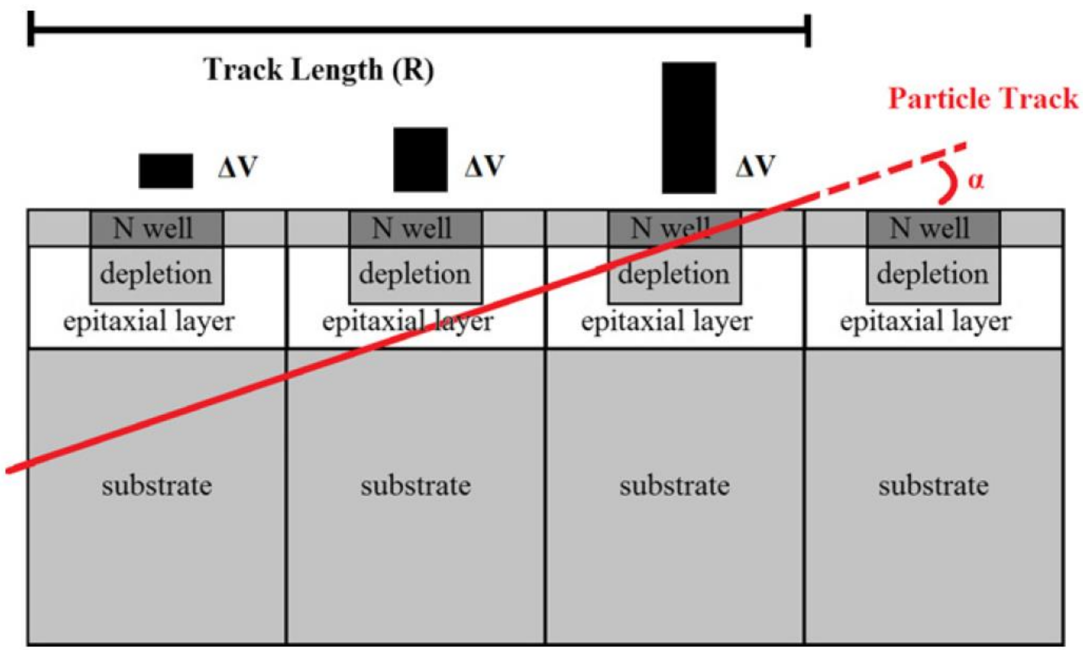

Fig. 1. Schema of grazing angle method: several pixels are hit by the same track.

The incident angle(α) is strictly related to the track length(R) by the expression:

$$R=d/\tan(\alpha)$$

where d is the sensitive layer of the sensor, often unknown.

- The track will be detected with a sharper definition near the sensor surface and **a more unfocused one in depth(worse S/N and worse spatial resolution)**

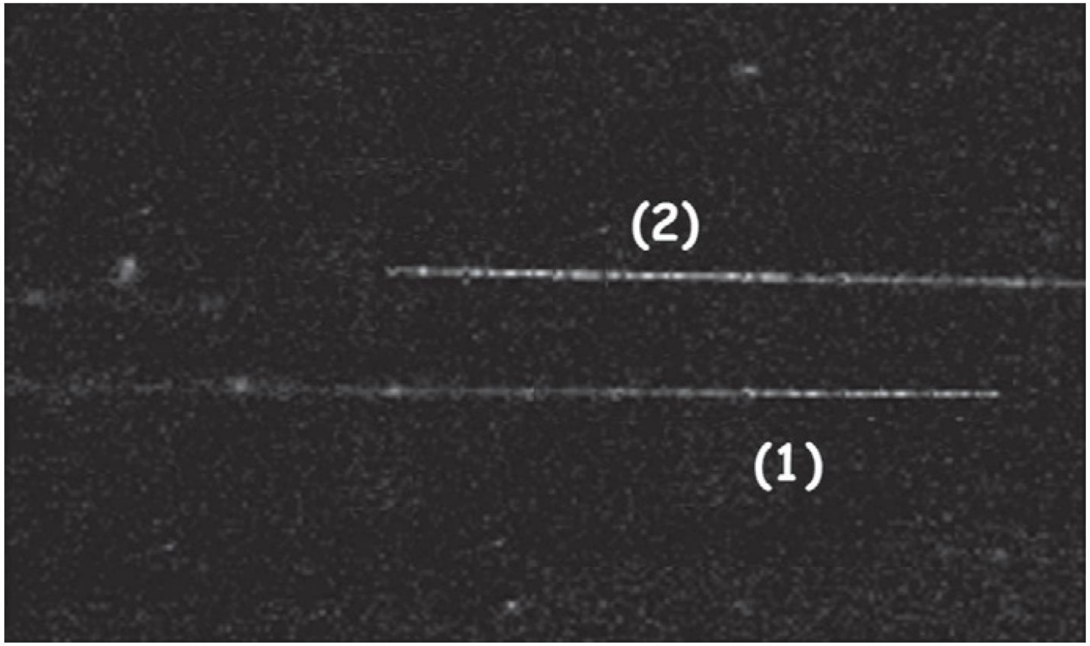

Fig. 2. Online display of two simultaneous tracks entering the sensor from opposite sides (100 MeV electrons coming from the right). Track entering from sensor surface (1) and from sensor back (2).

- Brightest pixel at the right hand side of track1 could be ascribed to closer-to-the-surface charge generation and therefore greater charge collection efficiency.

Test setup:

- The sensor was exposed to100–500 MeV electron beam and 12 GeV protons . To have tracks lengths up to 100 pixels a small incidence angle was used.
- The maximum sensitive region could be guessed , as a first approximation , at about twice the epitaxial layer thickness.
- A track finding algorithm has been implemented to select good tracks and to reject background signals

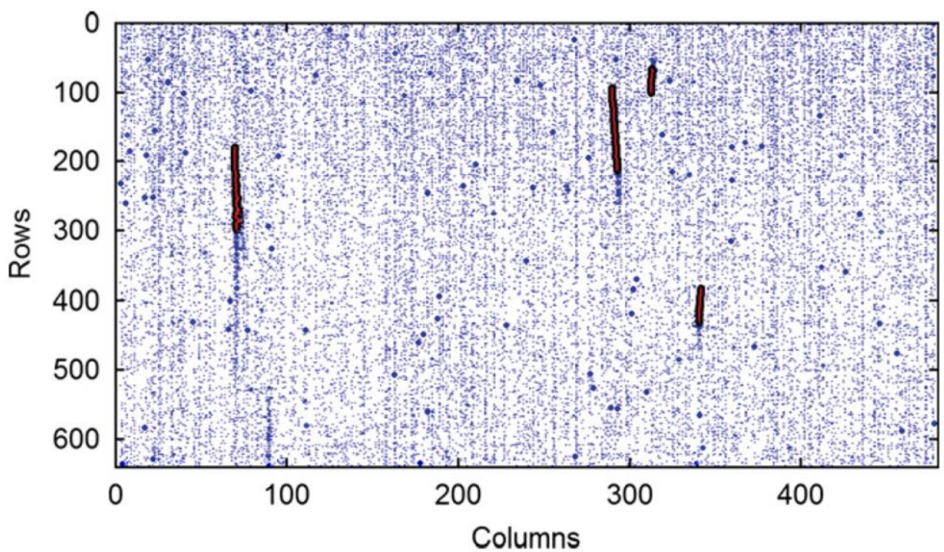

Fig. 5. Frame with four identified tracks.

✓ A very good track separation capability has been obtained . Two different tracks with a distance of only few pixels , can be actually recognized (Fig. 5).

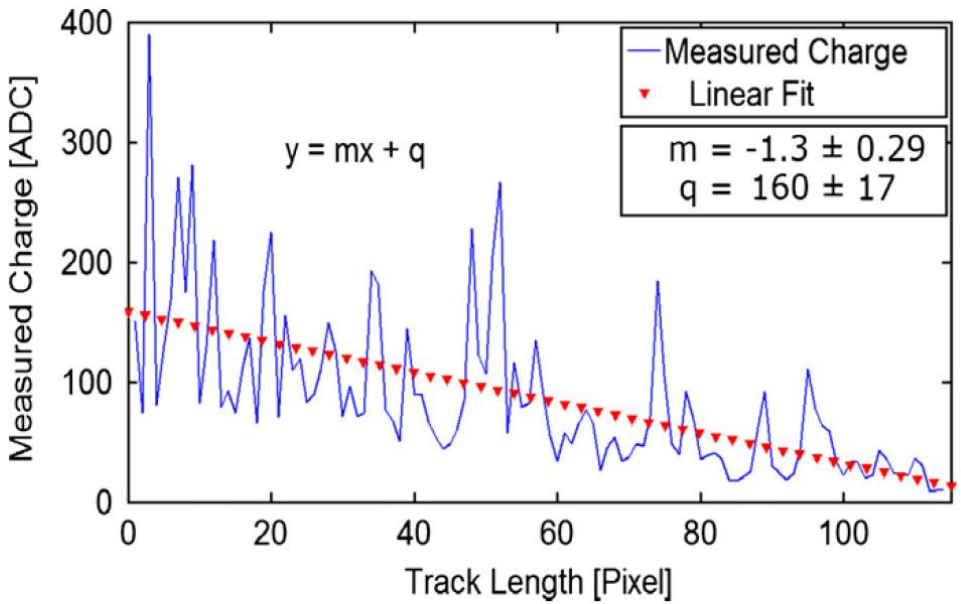

Fig. 6. Pixel response of one track entering from the surface with linear fit.

- The slope of the linear fit is the pixel response slope

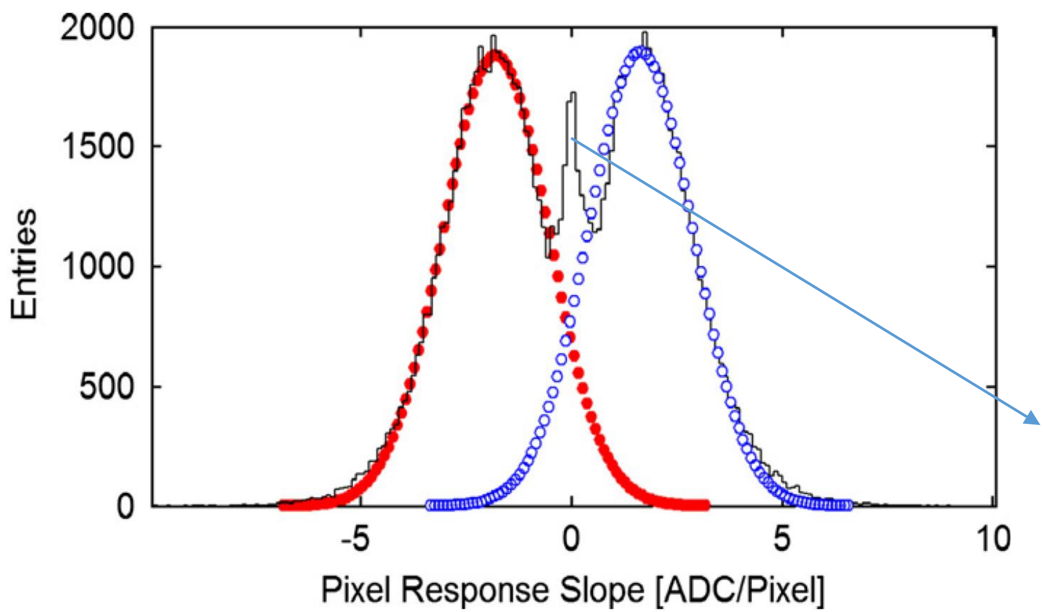

Fig. 7. Distribution of the Pixel Response Slope measured with tracks entering form the sensor surface (filled circle) and from the sensor back (open circle).

- In Fig. 7. It is possible to notice the two fitted Gaussian distributions , which represent the two different directions of incoming tracks.

- The peak around zero represents all the incoming tracks parallel to the sensor surface , not selectable for the following analysis.

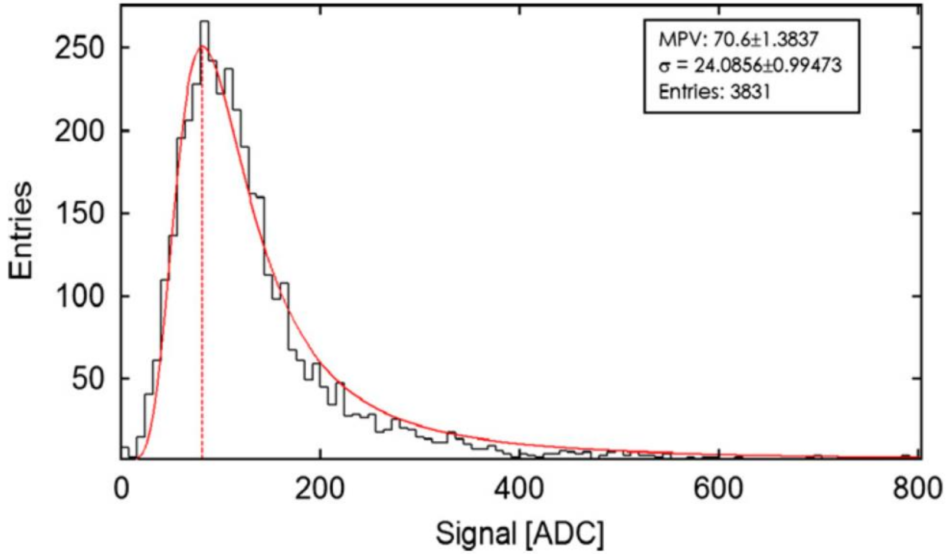

Fig. 8. Signal distribution of the all 1st pixels.

- In Fig. 8 is shown the signal distribution for the 1st pixel , well modeled by the Landau–Vavilov distribution.

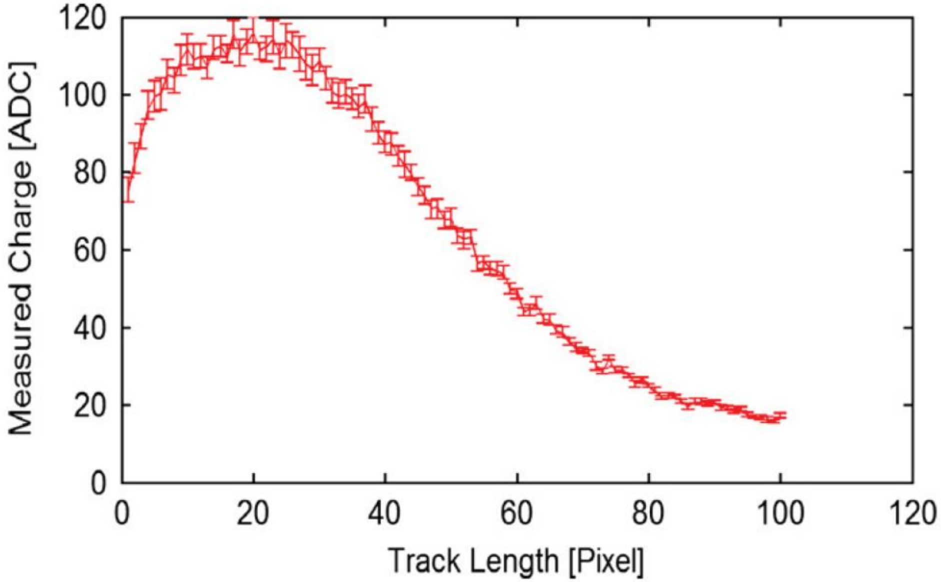

Fig. 9. Charge collection efficiency profile for MT9V011 sensor.

- In Fig. 9 is plotted the distribution of MPV as a function of the pixel position along the track

➢ **It is evident the modulation of the response as a function of the pixel position along the depth of the track.**

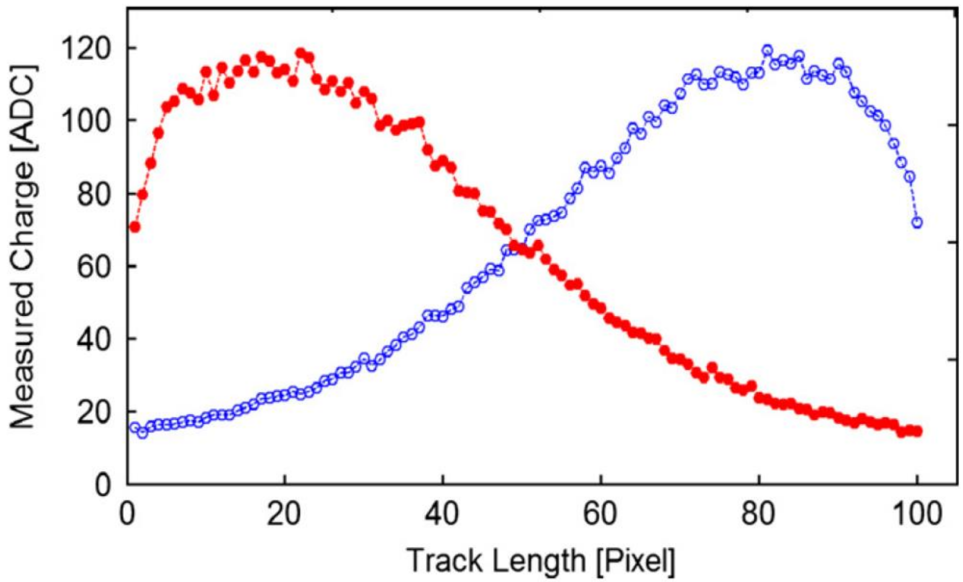

Fig. 10. Charge collection efficiency profiles measured with tracks entering form the sensor surface (filled circle) and from the sensor back (open circle).

In Fig. 10 are reported the two profiles obtained using the tracks coming from the sensor surface (filled circle) and from the sensor backside (open circle) .

- **The high symmetry shows that the track finding algorithm is working very well.**

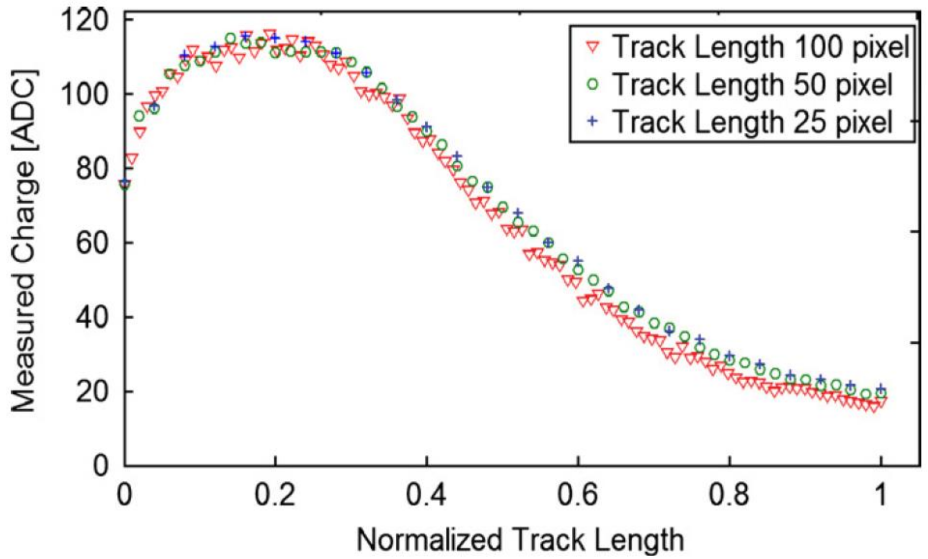

Fig. 11. Charge collection efficiency profiles measured with different track lengths.

- In Fig. 11 are shown three profiles normalized to the track length , obtained with three different tracklength values (25,50 and100 pixels). The curves overlap very well .

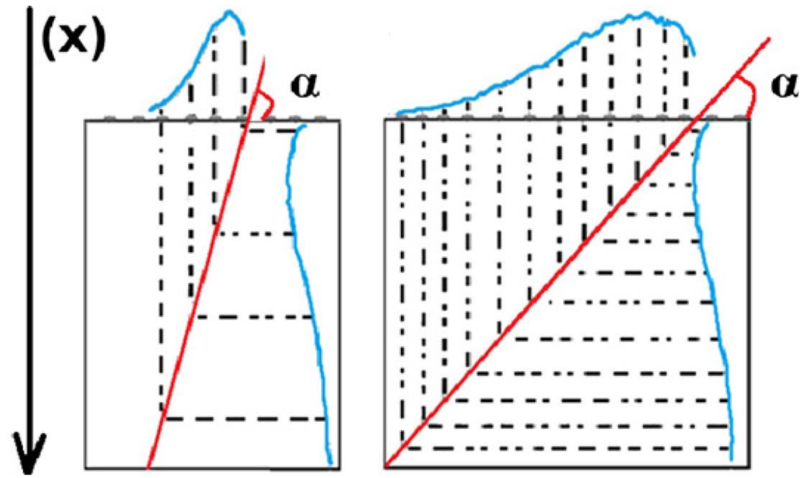

Fig. 12. Scheme of charge collection efficiency profile measurement using grazing particles.

- Fig. 12 illustrates how using longer tracks yields a finer sampling of the CCE, allowing a more detailed measurement.

Results:

The result for sensor MT9V011 (4 mm epi-layer) is shown in Fig. 13.

The profile could be divided roughly in three parts:

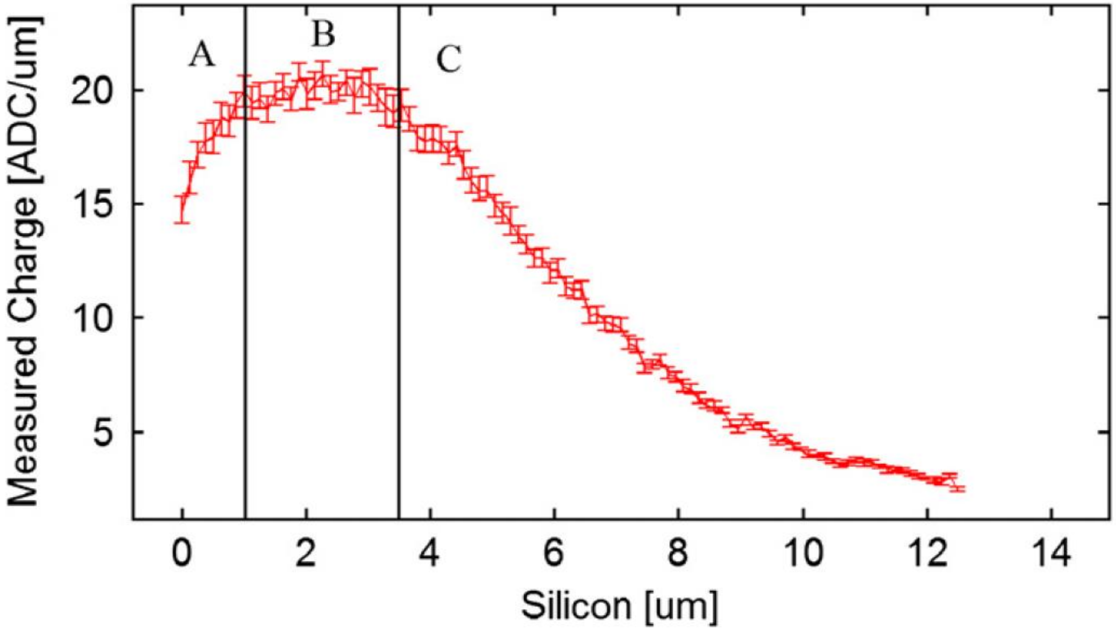

Fig. 13. Charge collection efficiency profile for MT9V011 sensor.

A. The first 1 mm, where the charge collection efficiency is not complete , most likely due to the presence of the pixel architecture and p-wells regions (hosting the pixel transistors);

B. From 1 to3.5 mm, where there is a plateau in efficiency , corresponding to the epitaxial region;

C. From 3.5 to 12 mm where the efficiency decreases due to the increasing distance of the charge creation region from the epitaxial region.

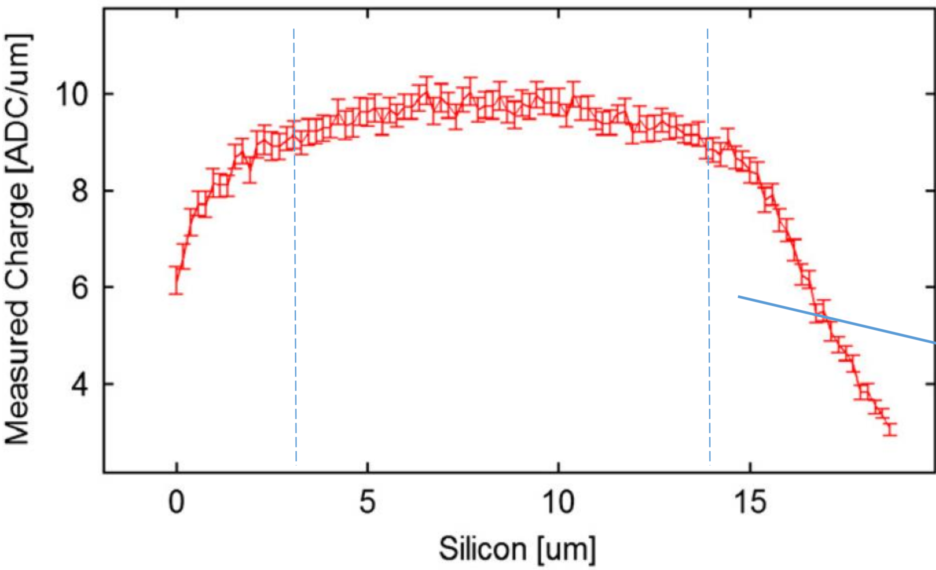

Fig. 14. Charge collection efficiency profile for MT9V032 sensor.

- Another Micron sensor (MT9V032) featuring different epi-layer thicknesses (12 mm) has been tested and preliminary results are shown in Fig. 14.

The wider plateau due to the thicker epitaxial layer

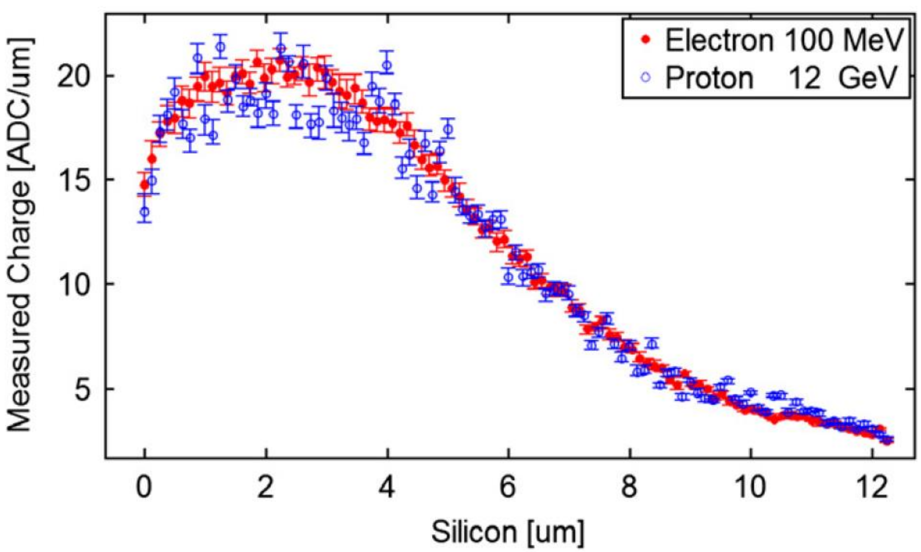

Fig. 15. Charge collection efficiency profile for MT9V011 sensor using 100 MeV electrons (filled circle) and 12 GeV Protons (open circle).

- In Fig. 15 , using different particle beams , with different energies , the profile does not change.

It shows how multiple scattering does not significantly affect the measure of the CCE profile and therefore both high or medium energy facilities can be used for this measurement.