



Limitation to the resolution of solid-state detectors.

M. Boronat , C. Marinas, A. Frey, I. Garcia, B. Schwenker, M. Vos, F. Wilk

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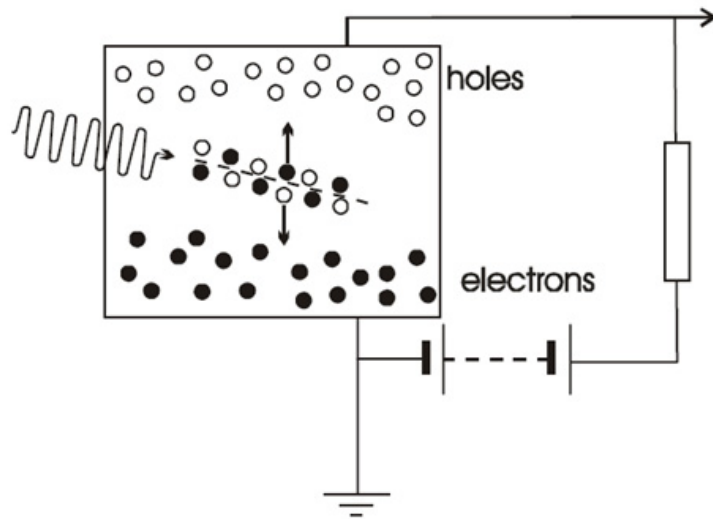
Introduction:

Physical limitations to the spatial resolution of solid-state detectors

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Solid-State Detectors



Operation: Consists of a full depleted p-n junction across which a pulse of current develops when a particle of ionizing radiation traverses it.

Position-Sensitivity: The key is the segmentation of the silicon wafer*.

Signal collected by a single strip or pixel, resolution σ :

$$\sigma = \frac{p}{\sqrt{12}}$$

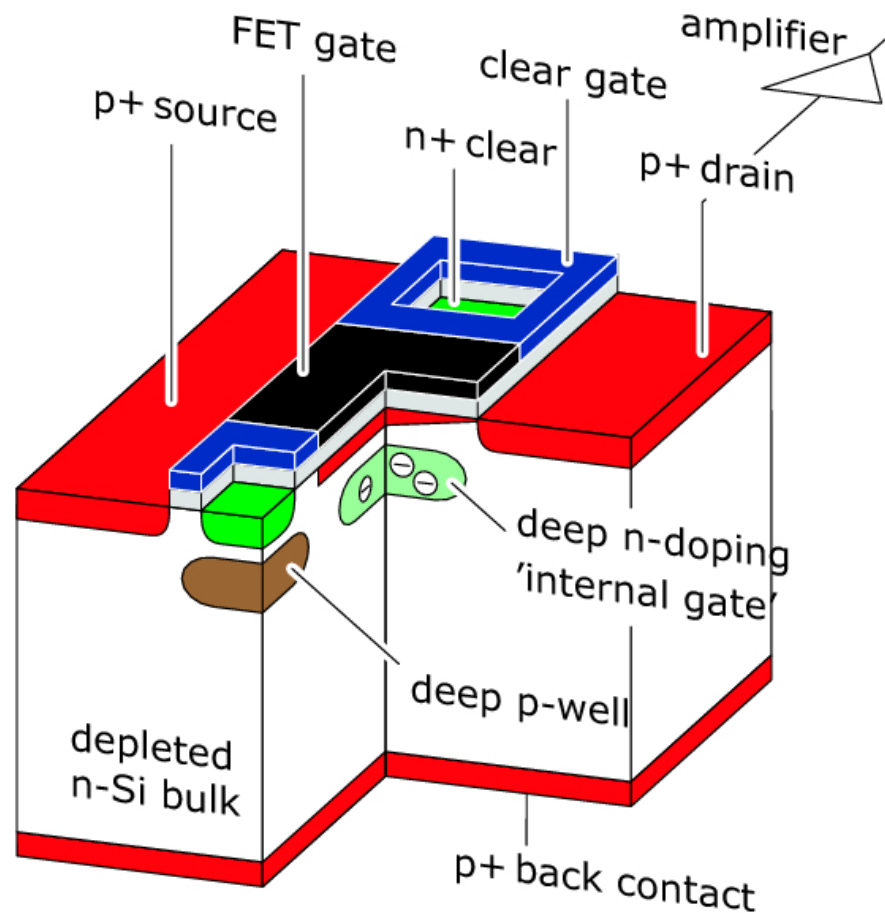
Interpolating the position on the basis of the signal measured on two neighbouring strip or pixel:

$$\sigma \propto \frac{p}{S/N}$$

Question:

What is the ultimate position resolution that can be obtained with solid-state devices that rely on charge sharing between neighbouring cells?

The Study:



Study made using:

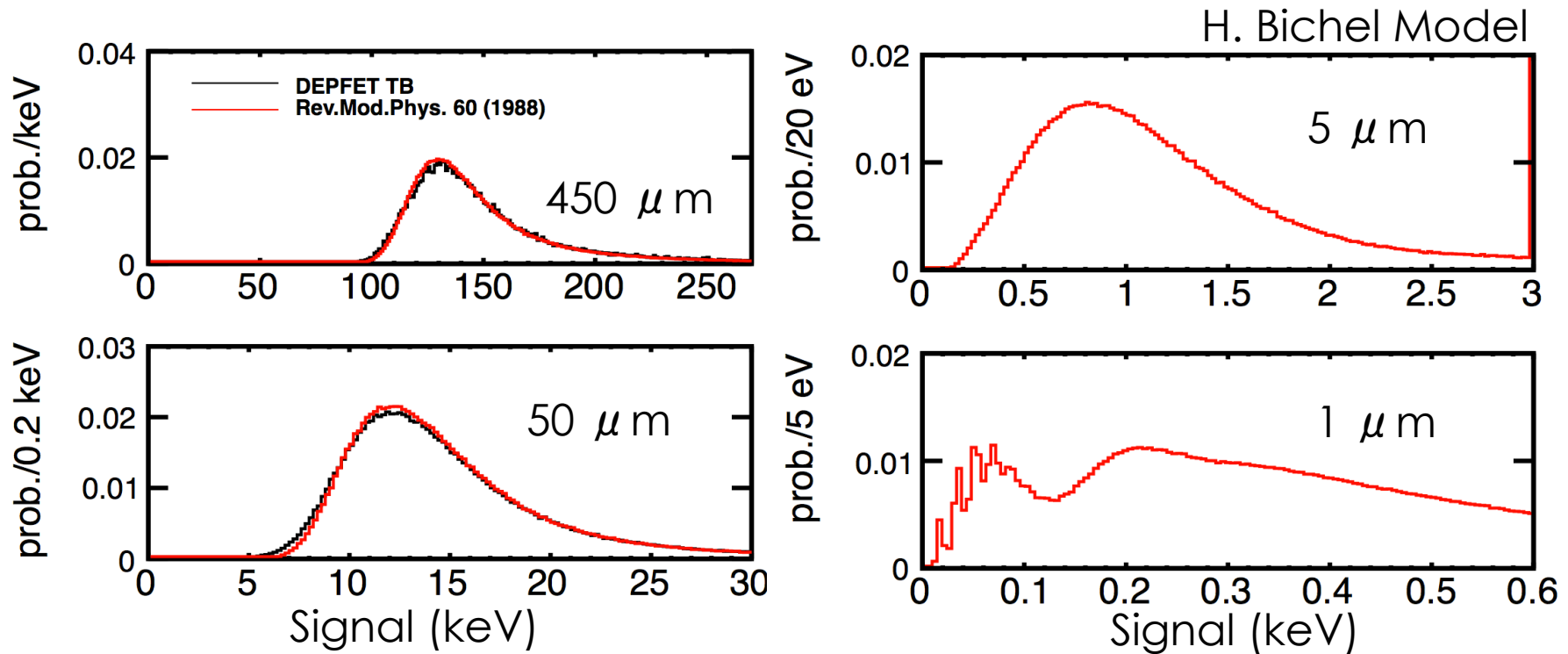
- Monte Carlo Simulations.
- Measurements in beams of particles at CERN and DESY.

Data used were from the DEPFET active pixel detector:

- Excellent S/N ration – well over 100.
- Small pixel size – down to $20 \times 20 \mu\text{m}^2$.

But the conclusions apply quite generally to position sensitive devices based on silicon

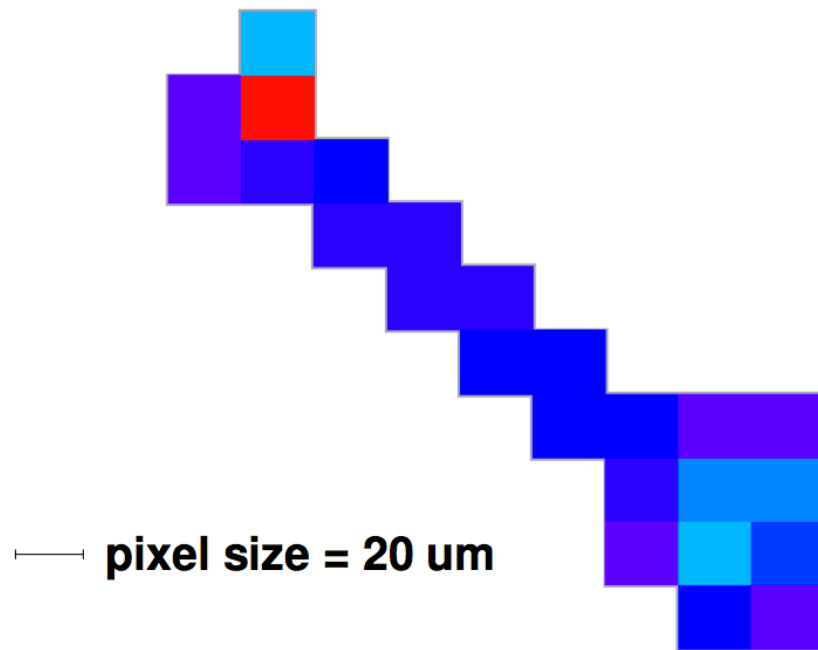
Straggling Functions



The probability of energy deposition by charged particles in thin layers of silicon is described by straggling functions (*landau distributions*).

The distributions show a pronounced tail with large energy deposition. This becomes more prominent as the thickness of the sensor decreases.

δ - electrons



Charge particles traversing material ionize atoms along the trajectory.

Occasionally the momentum transferred to the electron is large enough that a secondary track is formed.

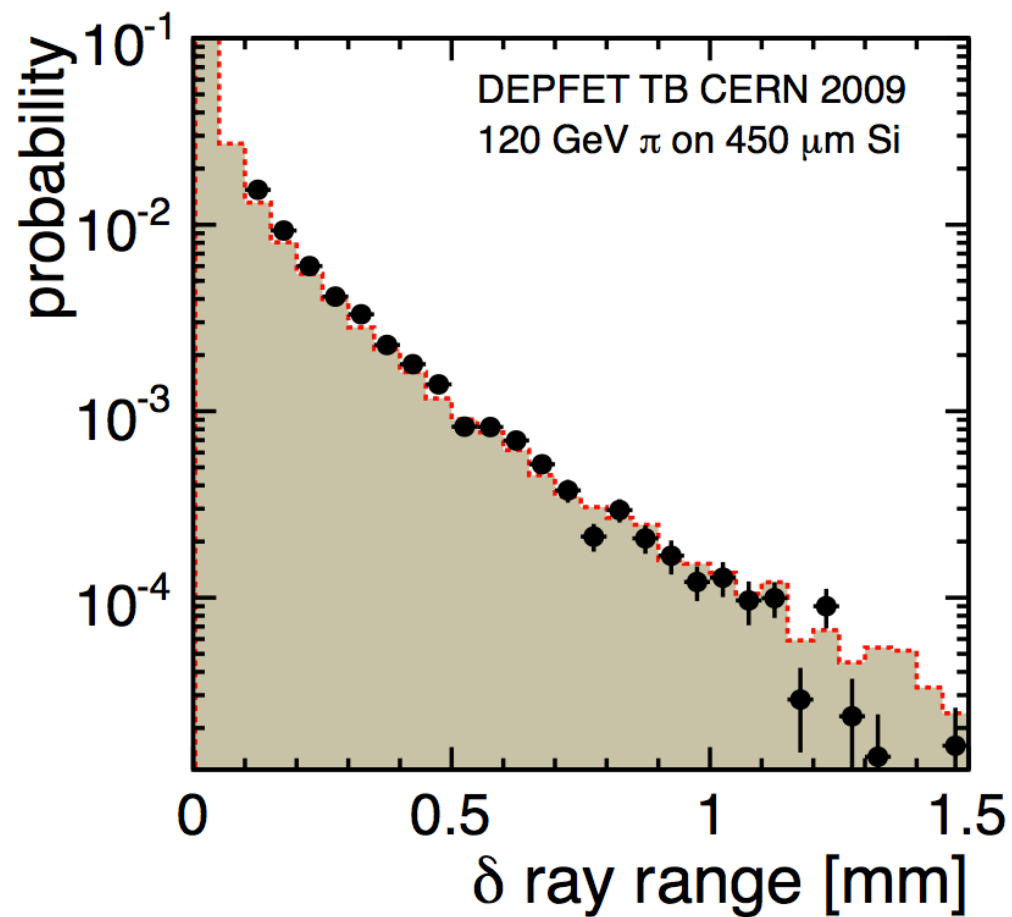
Center of Gravity of the signal is a poor estimation of the position of the primary pion.

δ - electrons

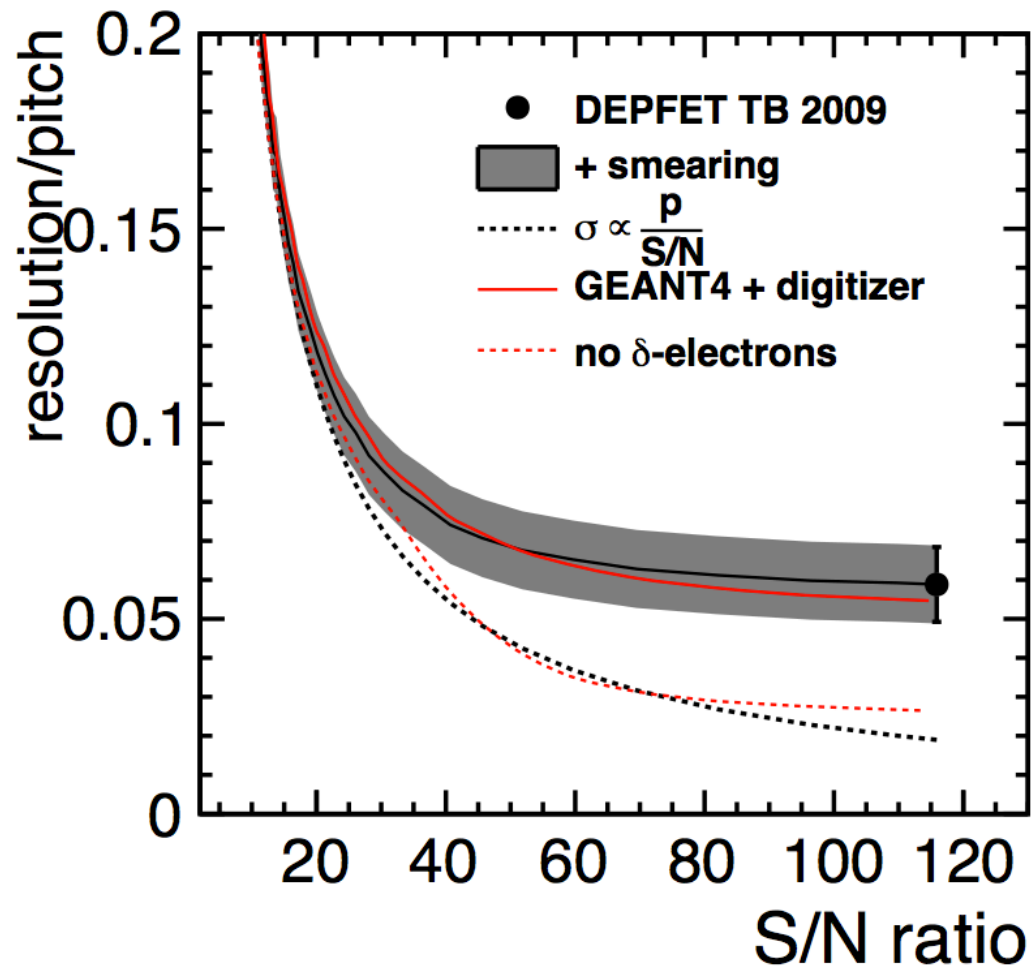
Probability that 120 GeV pion emits a δ - electron when traversing a 450 μ m of silicon sensor versus electron range.

Low probability of long range electrons: 5.4% probability of secondary track with at least 100 μ m.

But shorter range δ - electron are exceedingly common.



Perpendicular incidence

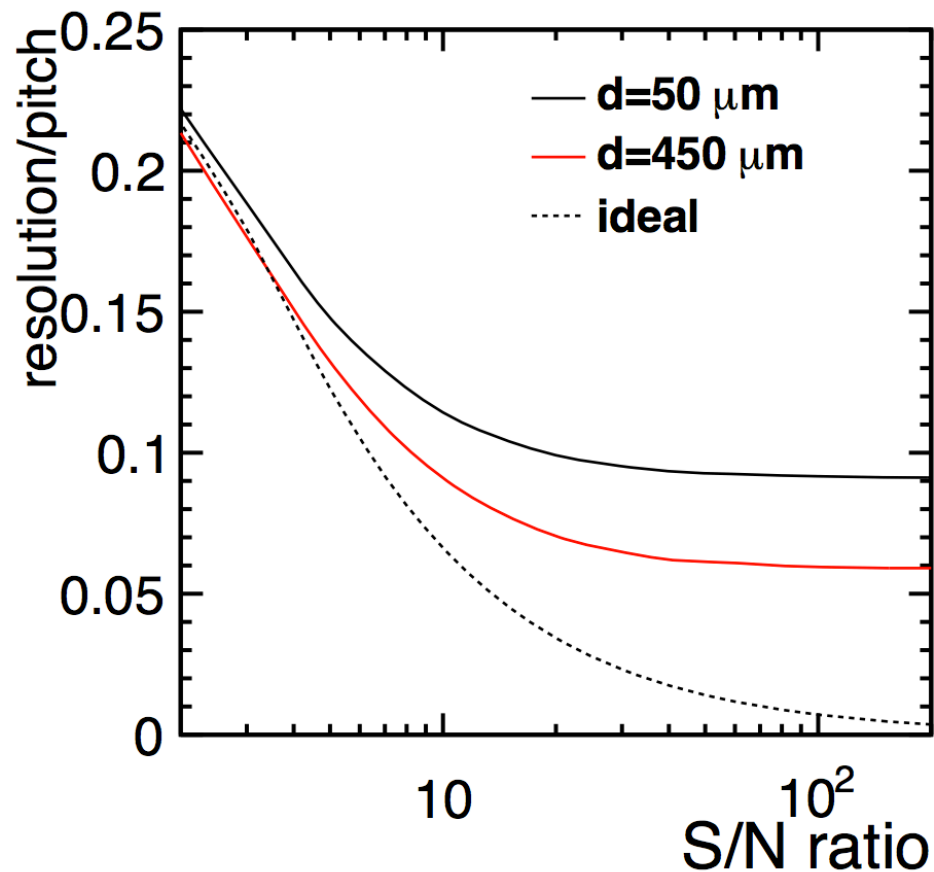


Impact of δ - electron in the spatial resolution.

Black solid point – spatial resolution on a DEPFET device, the grey band is obtained by smearing the signal.

The δ - electron play an important role in the region with large S/N ratio.

Incidence under an angle: signal fluctuations.

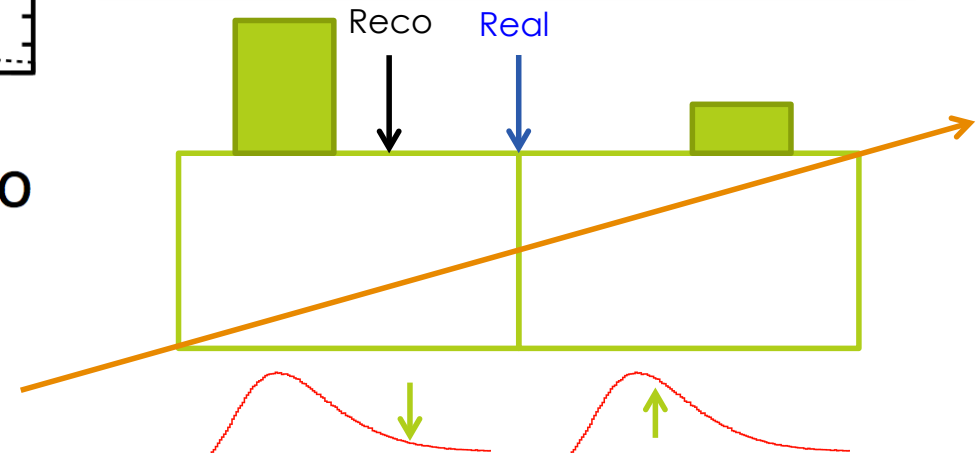


Non perpendicular incidence – signal fluctuation must be considered.

On average the signal deposited is proportional to the path, but in each segment fluctuates strongly.

Ideal detector improves with the inverse of the S/N ratio.

The realistic model reaches an asymptotic value – 9% ($50\ \mu\text{m}$ thick).

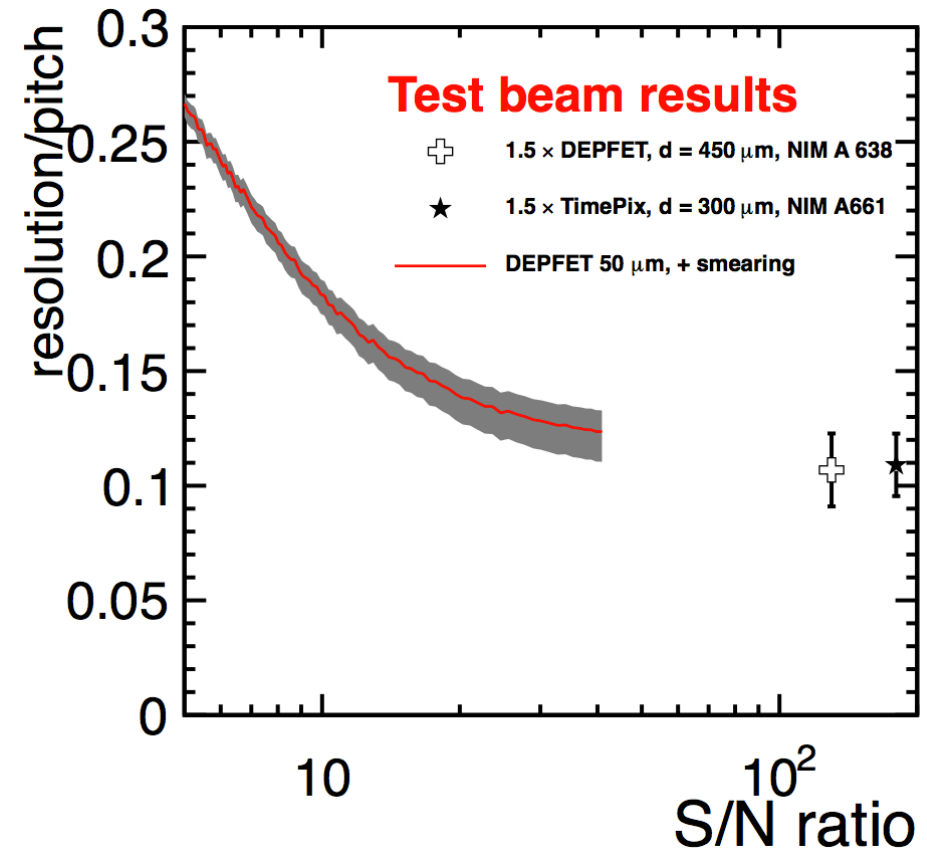


Incidence under an angle: signal fluctuations.

Empirical demonstration of the signal fluctuation.

Curve – 50 μm thick DEPFET device + smearing.

Further measurements – devices with 450 and 300 μm thick multiplied by a factor 1.5, obtained from the simulation.



Summary and Discussion

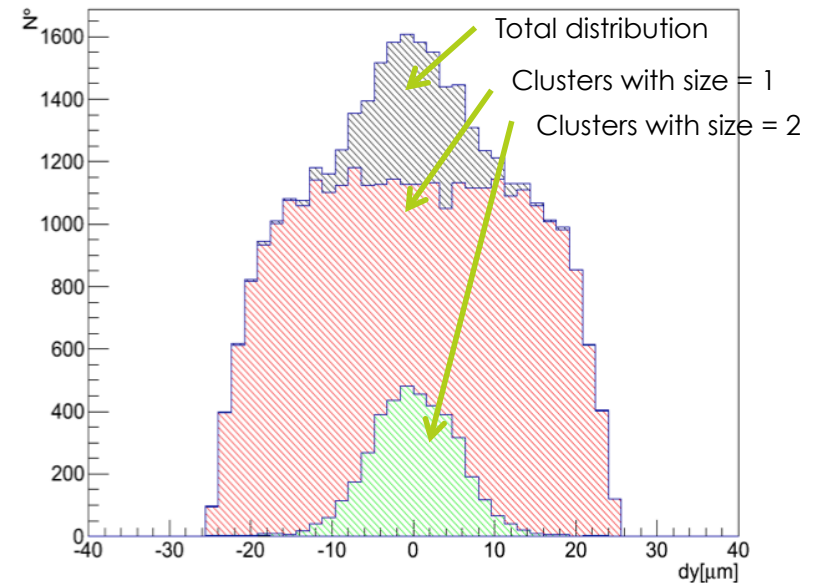
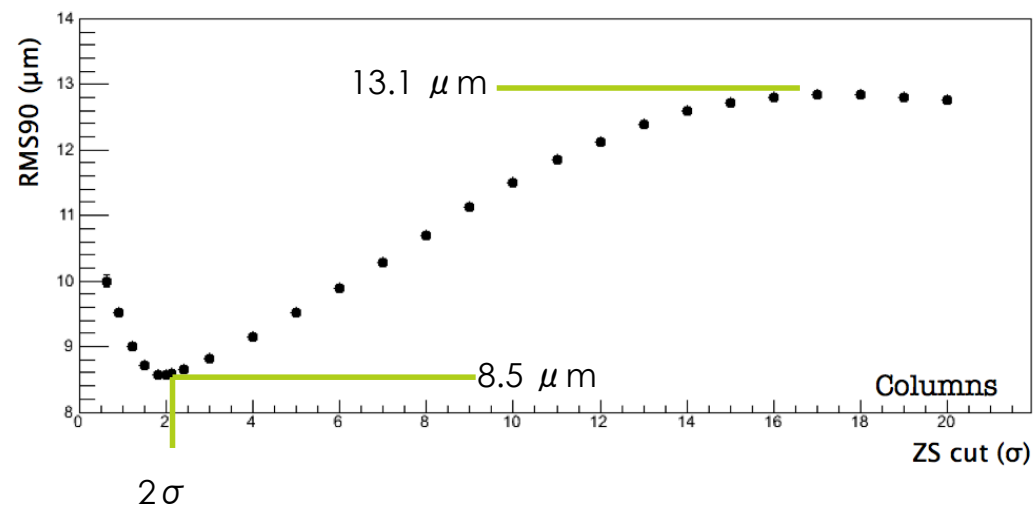
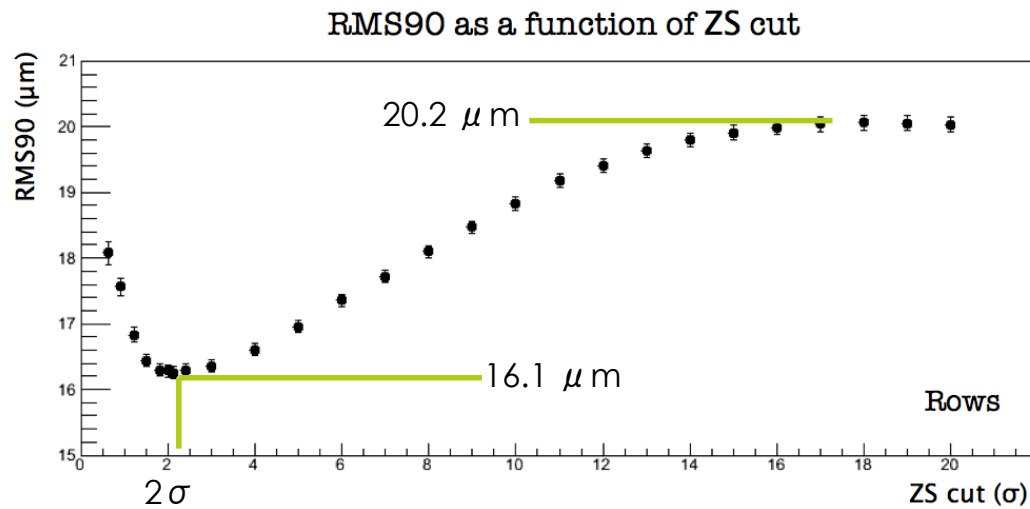
We find several limitations inherit in the physical process that is responsible for the ultimate resolution that can be obtained with this scheme.

Using combinations of Monte Carlo simulations and test beam data:

- We establish that energetic electrons forming secondary tracks knows as δ - electrons limit the resolution to the level of approximately $1 \mu\text{m}$.
- For particles that traverse the silicon under an angle, fluctuations of the signal have an impact on the spatial resolution that becomes more important as devices get thinner.

Thanks for you attention.

DEPFET Test Beam, Sensor Resolution



- Resolution limit: 8.5 (16.1) μm to the side with 50 (75) μm . (Pixel size: 50x75 μm on 50 μm thick)
- Using DEPFET sensor on 450 μm tick and 20x20 μm of pitch: Resolution limit $\approx 1 \mu\text{m}$.

Reconstruction Method: CoG

Binary limit

3.- La distribución uniforme.

La distribución uniforme describe una variable aleatoria para la cual, la densidad de probabilidad es constante

$$f(x) = \frac{1}{b-a}, \quad a \leq x \leq b$$
$$f(x) = 0, \quad \text{otros valores}$$

Función cumulativa

$$F(x) = \int_a^x f(x') dx' = \int_a^x \frac{1}{(b-a)} dx' = \frac{(x-a)}{(b-a)}; \quad a \leq x \leq b$$

Valor esperado

$$E[x] = \int_a^b x f(x) dx = \frac{1}{(b-a)} \left[\frac{x^2}{2} \right]_a^b = \frac{b^2 - a^2}{2(b-a)} = \frac{(a+b)}{2}$$

Varianza

$$V[x] = E[x^2] - E[x]^2 = \int_a^b (x - E[x])^2 f(x) dx = \frac{(b-a)^2}{12}$$

Skewness

$$\gamma_1 = 0$$

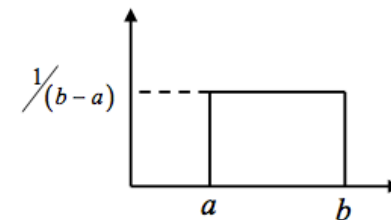
Kurtosis

$$\gamma_2 = -1.2$$

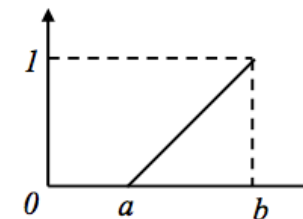
18/11/2010

Función característica

$$\phi(t) = \frac{e^{itb} - e^{ita}}{it(b-a)}$$



Distribución uniforme



Función cumulativa