Pixel2000

A Measurement of Lorentz angle of rad-hard pixel sensors

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for the ATLAS Pixel Collaboration

Partecipating Institutes

- Canada
  - University of Toronto
- Czech Republic
  - Academy of Sciences - Institue of Physics of Prague, Charles University of Prague, Czech Technical University of Prague
- France
  - CPPM, Marseille
- Germany
  - Bonn University, Dortmund University, Siegen University, Bergische University - Wuppertal, MPI Munich (R&D only)
- Italy
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- Netherlands
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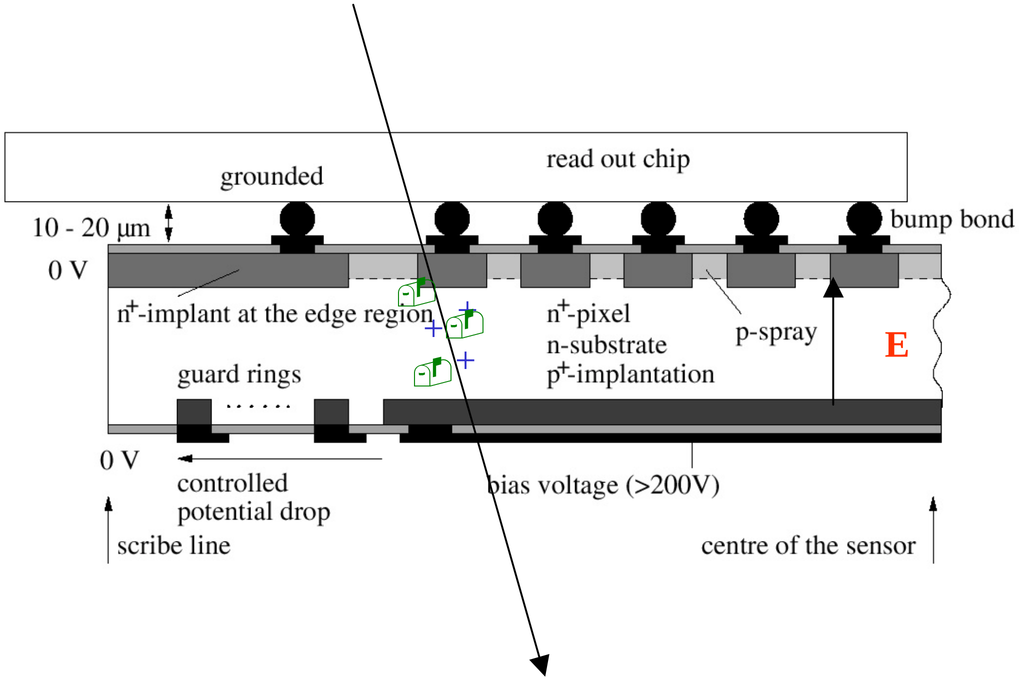
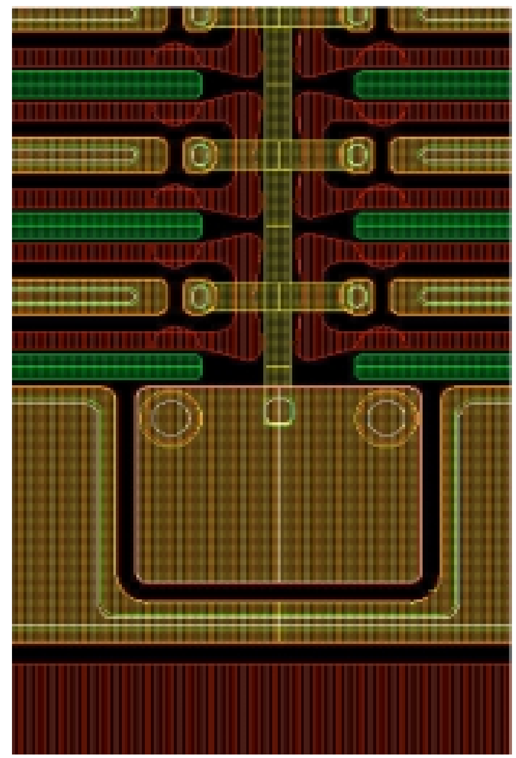


Test sensors are irradiated at a fluence of $5\times10^{14} n_{eq}/cm^2$ and $1\times10^{15}\ n_{eq}/cm^2$.

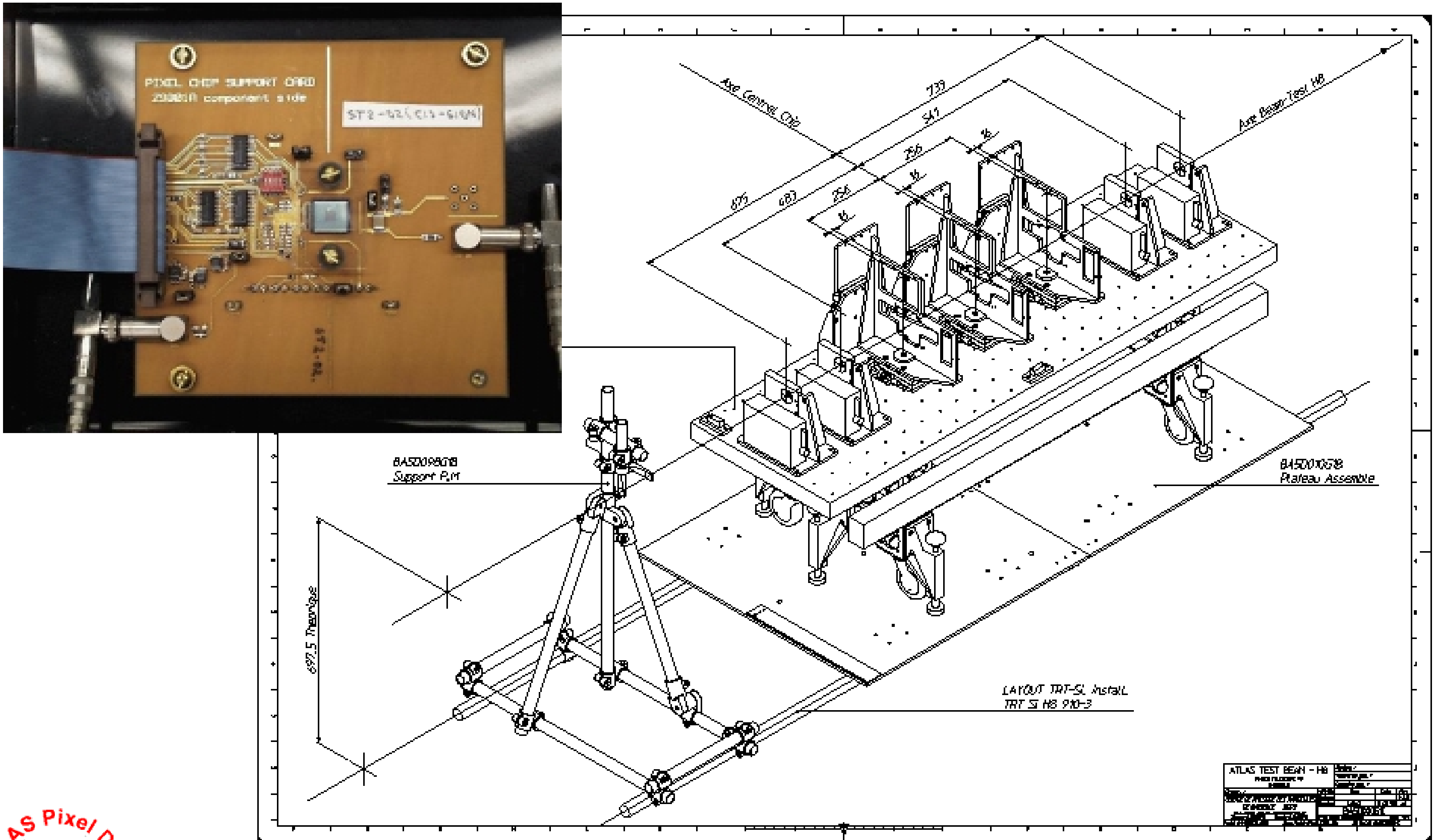


Every chip is a matrix of 18 columns and 160 rows

Pixel size is 50 µm × 400 µm

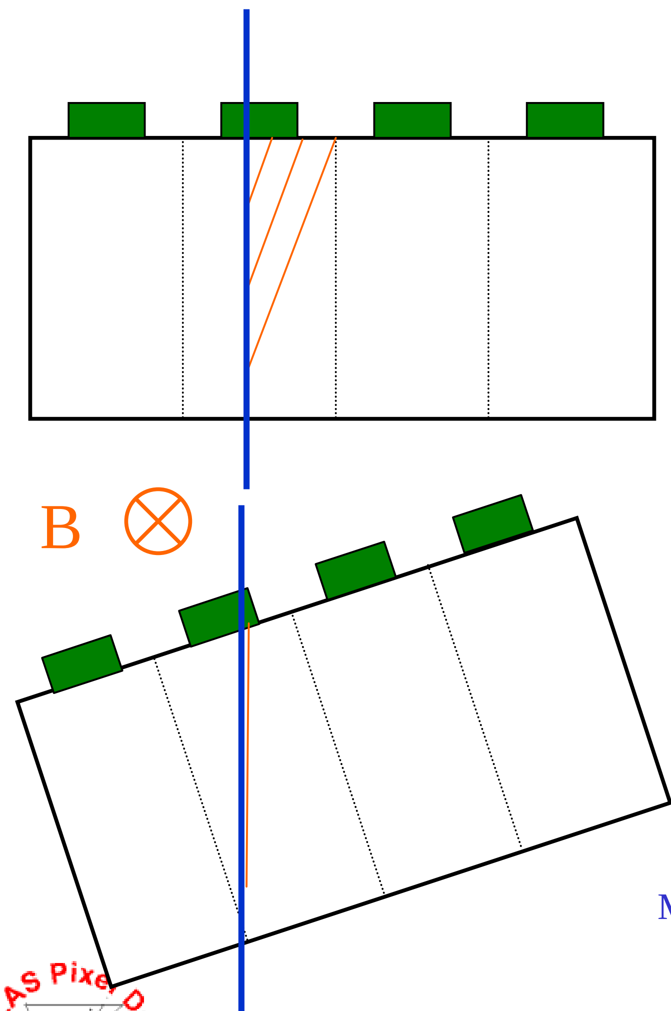
Thickness 280 µm

Testbeam setup



The importance of the Lorentz angle measurement

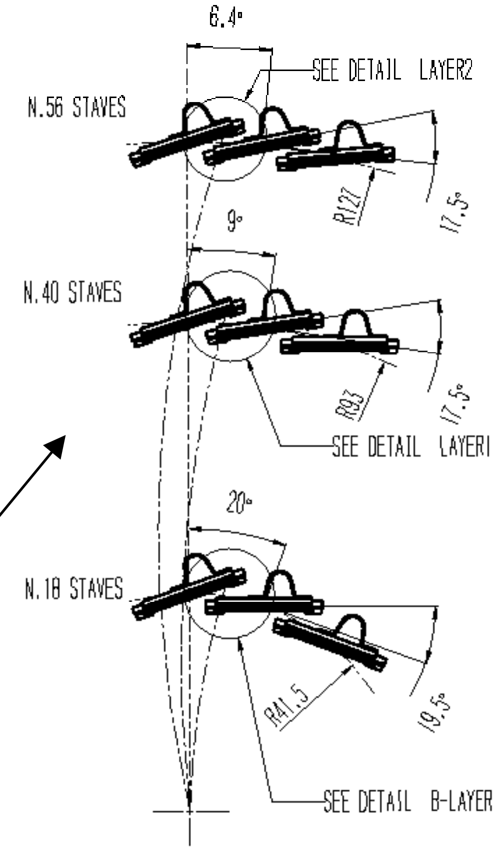
Charge drifts with an angle θ_L respect to the direction of the Electric field in presence of a Magnetic field



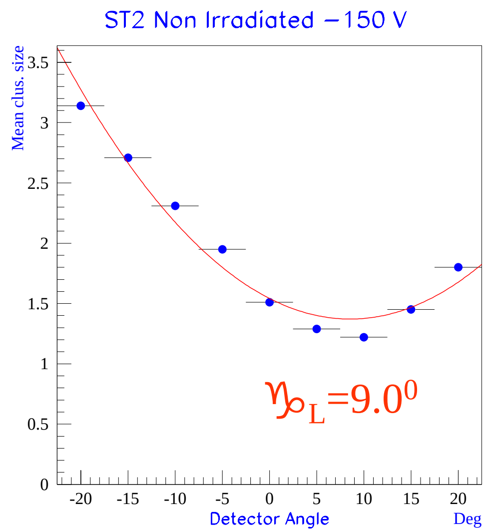
Charge sharing depends upon the Lorentz angle.

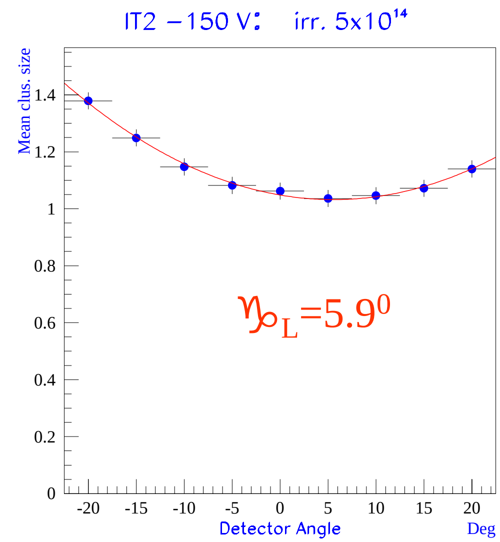
This affects detector performances: space resolution, efficiency and occupancy.

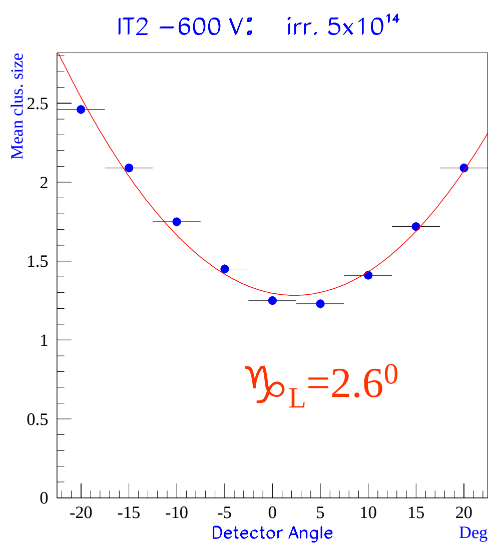
Modules are tilted to take into account the effect of Lorentz angle on the charge drift.

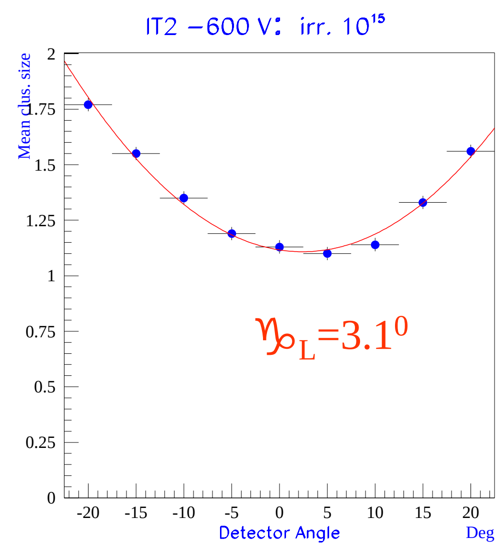


Measurement of the mean cluster size as a function of the angle


ST2 Non Irradiated −150 V
Mean clus. size
Detector Angle
Deg
$\vartheta_L=9.0^0$


IT2 −150 V: irr. 5x10^14
Mean clus. size
Detector Angle
Deg
$\vartheta_L=5.9^0$


IT2 −600 V: irr. 5x10^14
Mean clus. size
Detector Angle
Deg
$\vartheta_L=2.6^0$

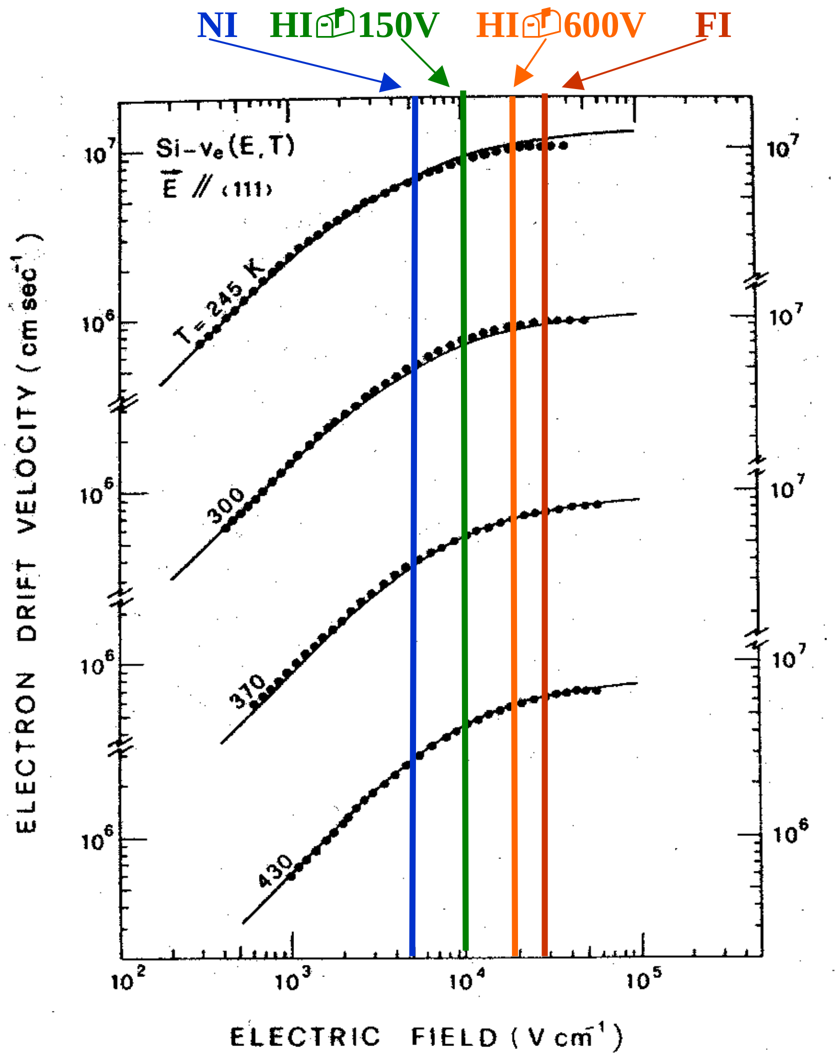

IT2 −600 V: irr. 10^15
Mean clus. size
Detector Angle
Deg
$\vartheta_L=3.1^0$

$$\mathrm{tg}(\gamma_L) = r \cdot B \cdot \mu_d$$

$$r = \langle \tau^2 \rangle / \langle \tau \rangle^2$$

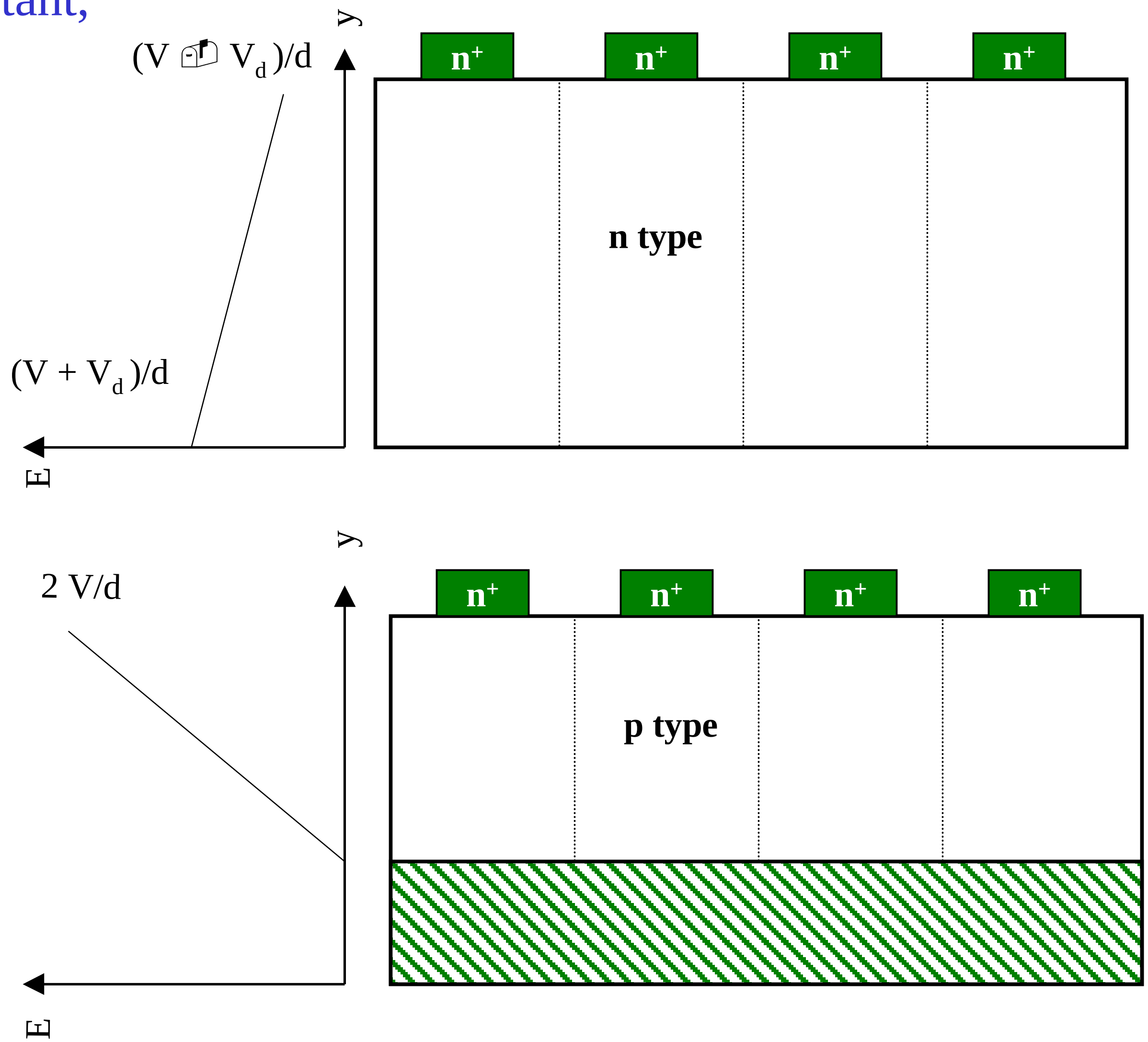
$$\mu_d = \frac{v_s/E_c}{\left[1 + (E/E_c)^{\beta}\right]^{1/\beta}}$$

$$\begin{cases} v_s = 1.53 \cdot 10^9 \cdot T^{-0.87} \mathrm{cm\ s^{-1}} \\ E_c = 1.01 \cdot T^{1.55}\ \mathrm{Vcm^{-1}} \\ \beta = 2.57 \cdot 10^{-2} \cdot T^{-0.66} \mathrm{cm\ s^{-1}} \end{cases}$$



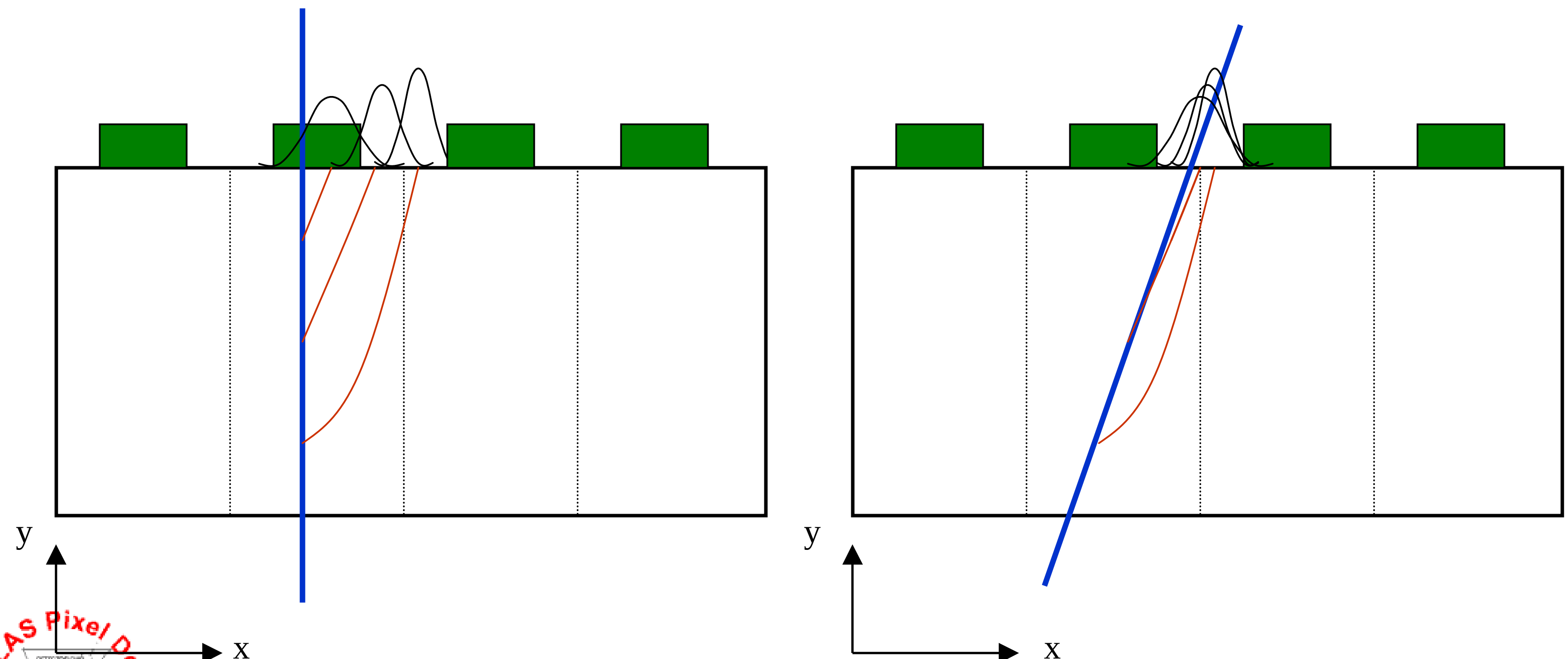
The Electric field is not constant,
due to the spatial charge.

The charge distribution
is assumed to be uniform.



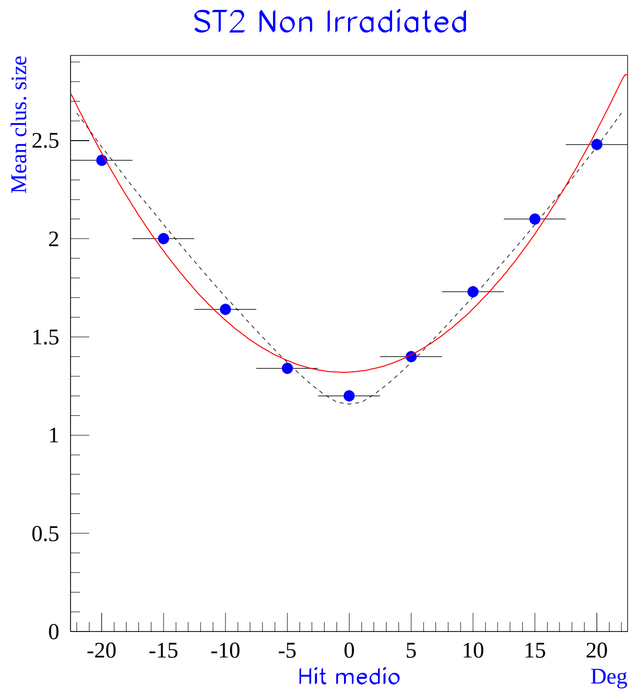
$$\mathrm{tg}(\gamma_{\mathrm{L}}) = \frac{dx}{dy}(y) = r\ B\mu_d\left(E(y),T\right)$$

An effective Lorentz angle has been defined as the angle corresponding to the minimum cluster size.



Lorentz angle measurement

- Measured mean cluster size for different angles with B_{on} (1.4 Tesla) and B_{off}
- Data with B_{off} are used to check systematic effects
- Fits with a parabola
- Comparison with results obtained with the model:
  - Depletion taken from data
  - Threshold fitted from data taken with B_{off}

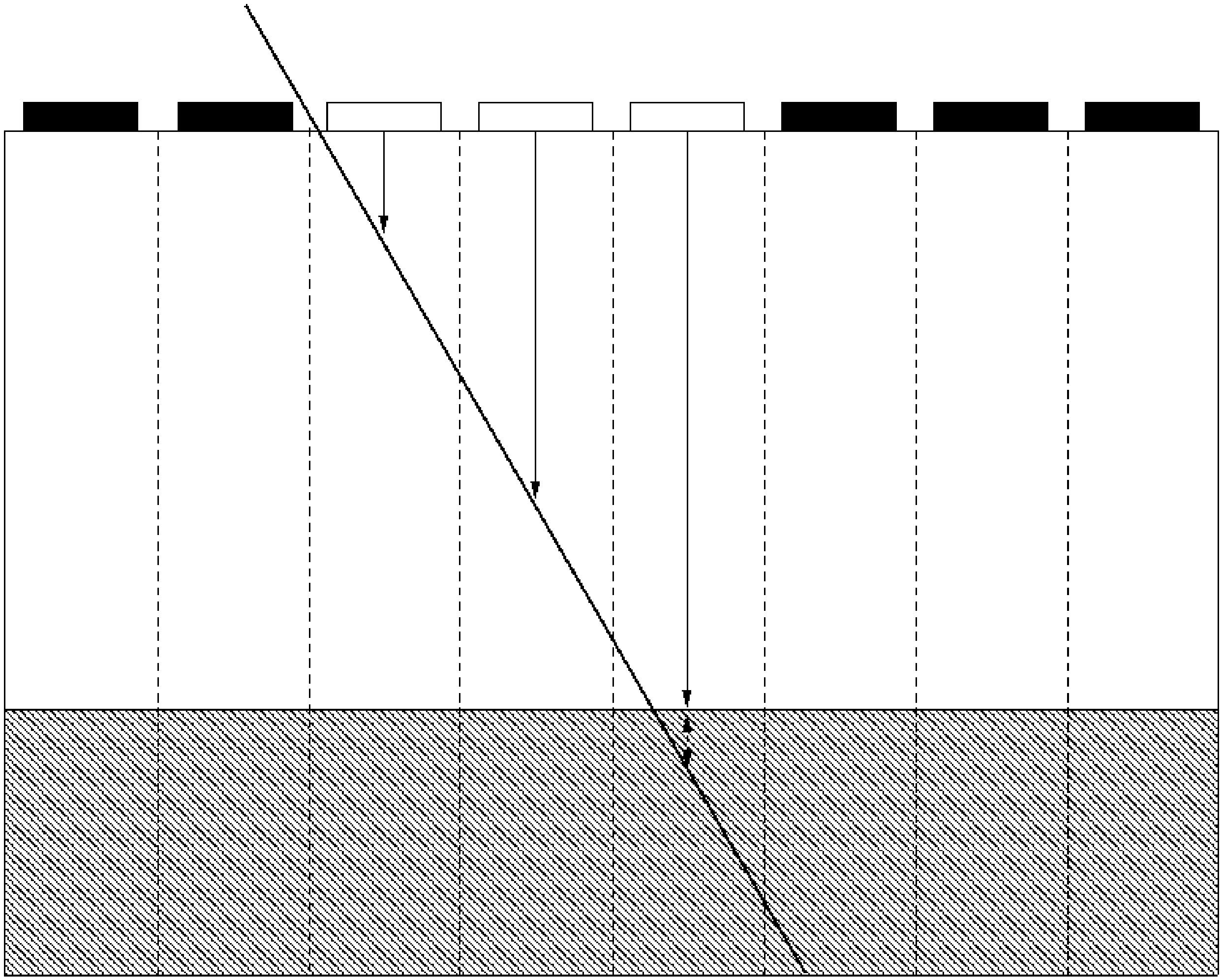


Depletion depth measurement

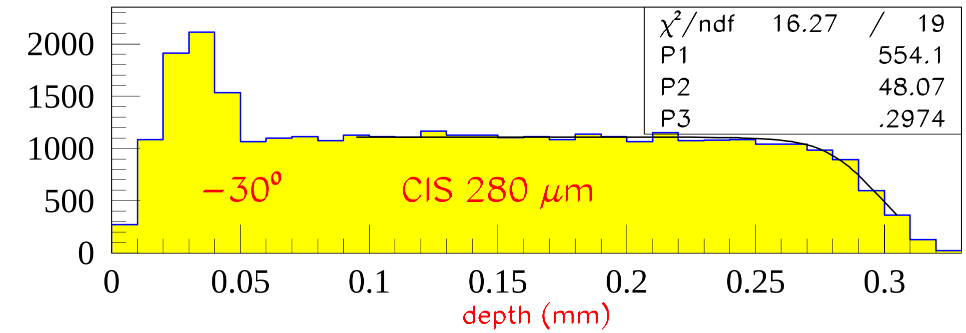
• Performed rotating the sensor around the pixel axis parallel to the long size of pixels.

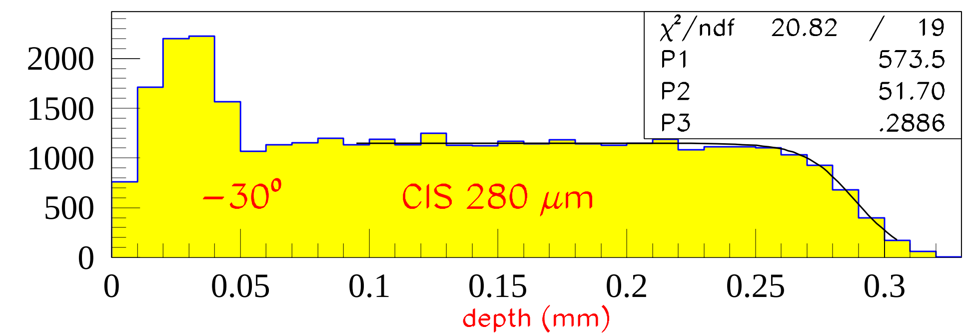
• Strategy based on the determination of the entrance and exit points of tracks

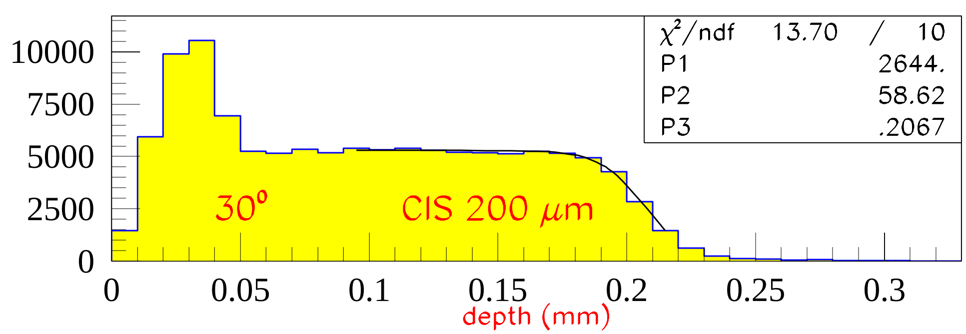
• Charge segment depth plots



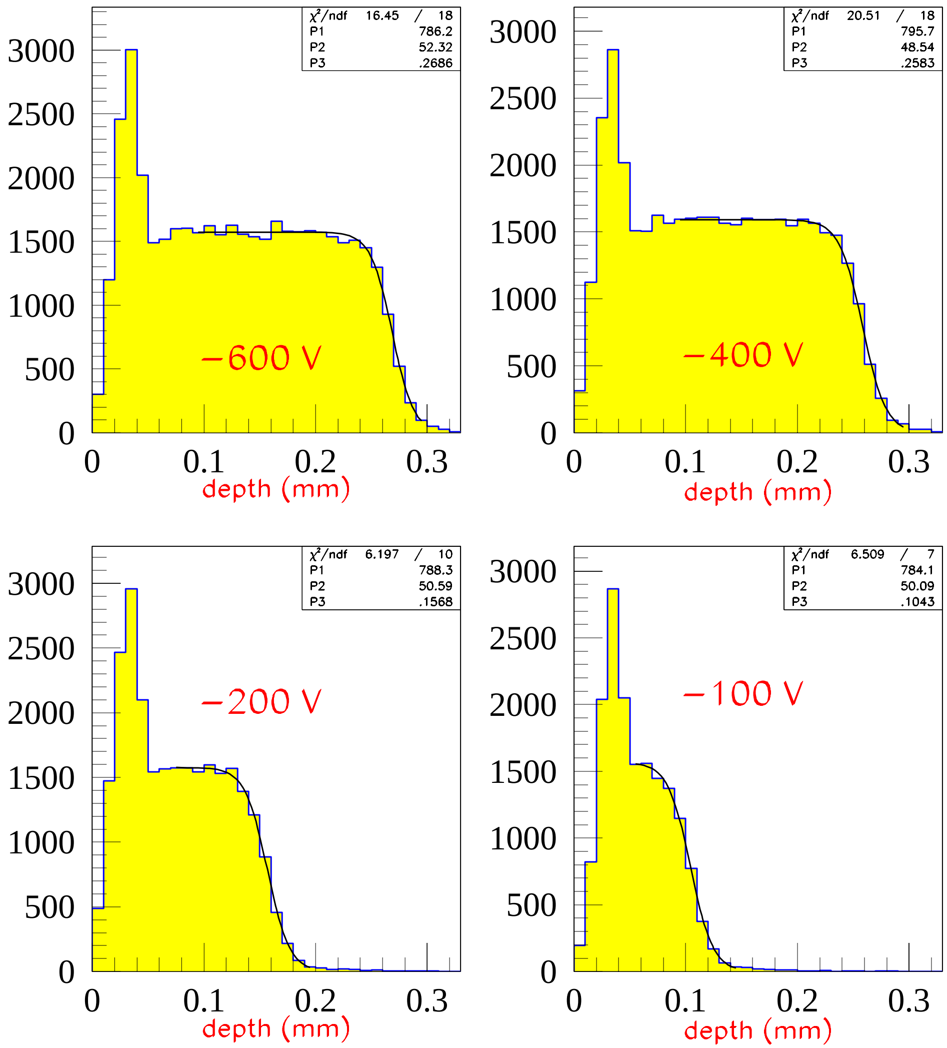
ST2 non irradiated







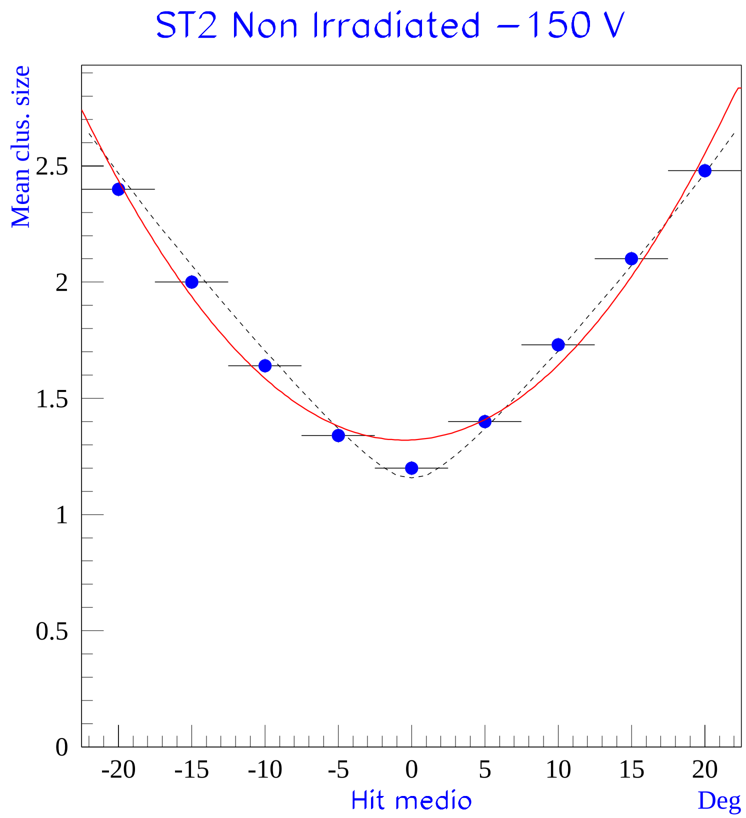
IT2 at -30^{0} irr. $5x10^{14}$

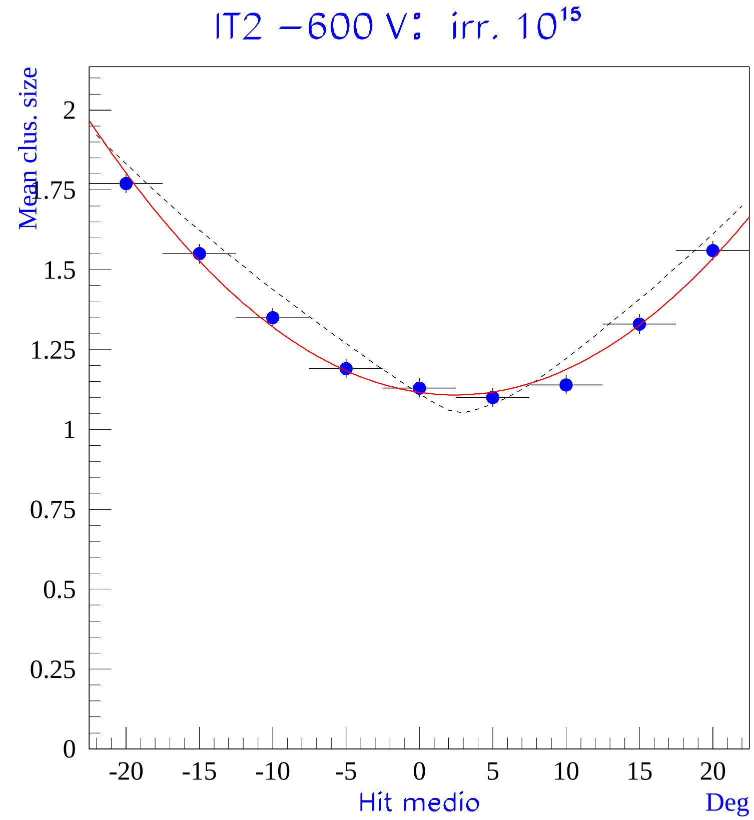


Depletion depth results

Fluence	Thickness [μm]	Bias Voltage [V]	Angle [^{0}]	Depletion depth [μm]
0	280	150	-30	284 ± 7
0	280	150	$+30$	280 ± 10
0	200	150	$+30$	190 ± 7
5×10^{14}	280	600	-30	261 ± 8
5×10^{14}	280	400	-30	252 ± 10
5×10^{14}	280	200	-30	147 ± 7
5×10^{14}	280	150	-30	123 ± 11
5×10^{14}	280	100	-30	100 ± 7
10^{15}	280	600	-30	186 ± 14
10^{15}	280	600	$+30$	198 ± 24
10^{15}	280	300	-30	111 ± 10
10^{15}	280	600	-20	216 ± 16
10^{15}	280	600	$+20$	219 ± 22

Lorentz angle fits





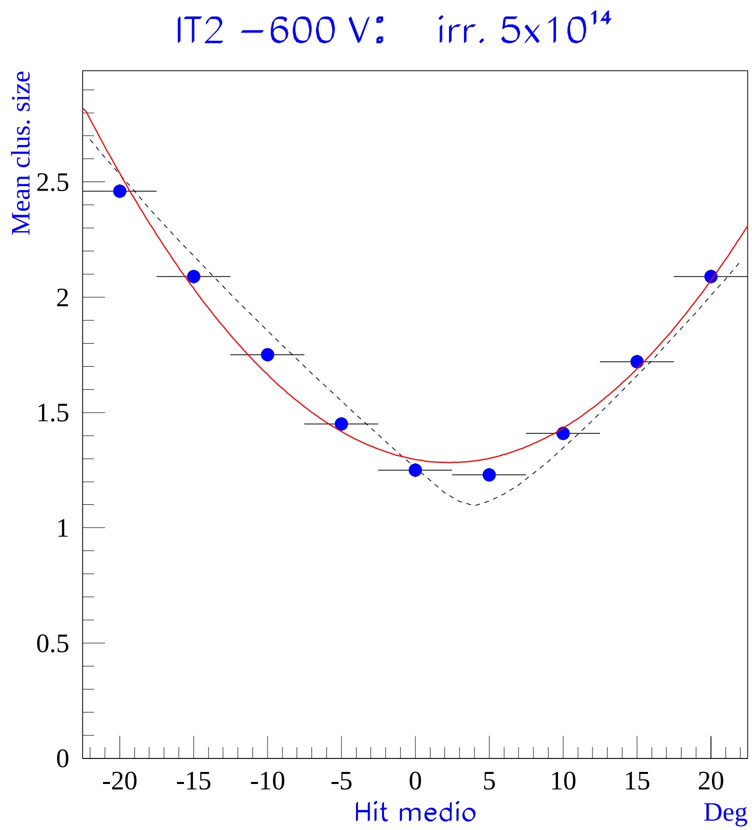
Measured value $\theta_L=9.0^0 \oplus 0.4^0 \oplus 0.5^0$

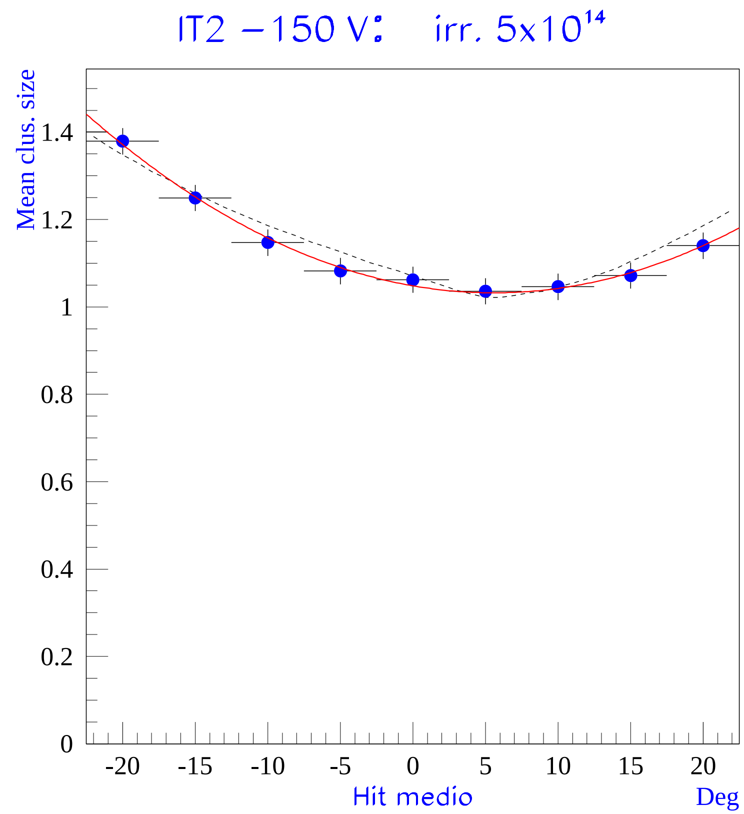
Predicted value $\theta_L=8.6^0 \oplus 0.4^0$

Measured value $\theta_L=3.1^0 \oplus 0.4^0 \oplus 0.6^0$

Predicted value $\theta_L=2.9^0 \oplus 0.2^0$

Lorentz angle fits





Measured value $\theta_L = 2.6^0 \oplus 0.2^0 \oplus 0.3^0$

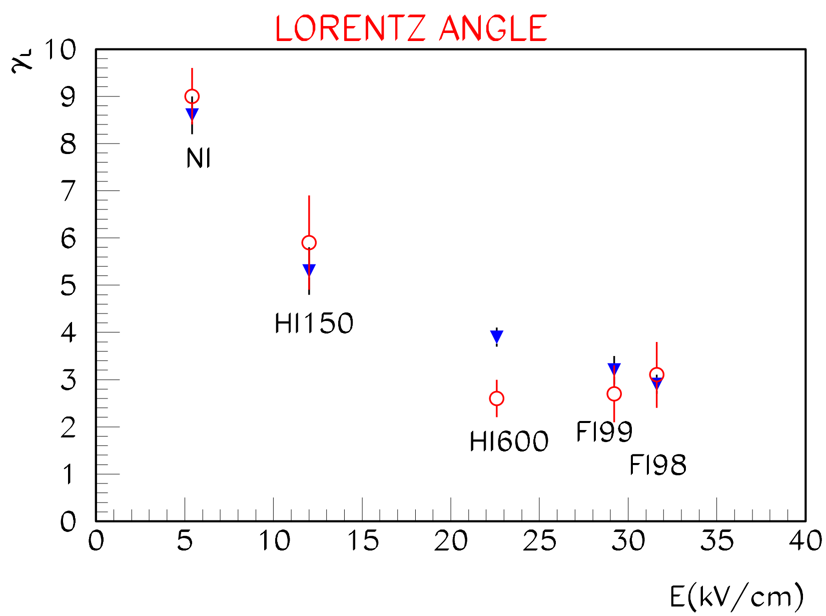
Predicted value $\theta_L = 3.9^0 \oplus 0.2^0$

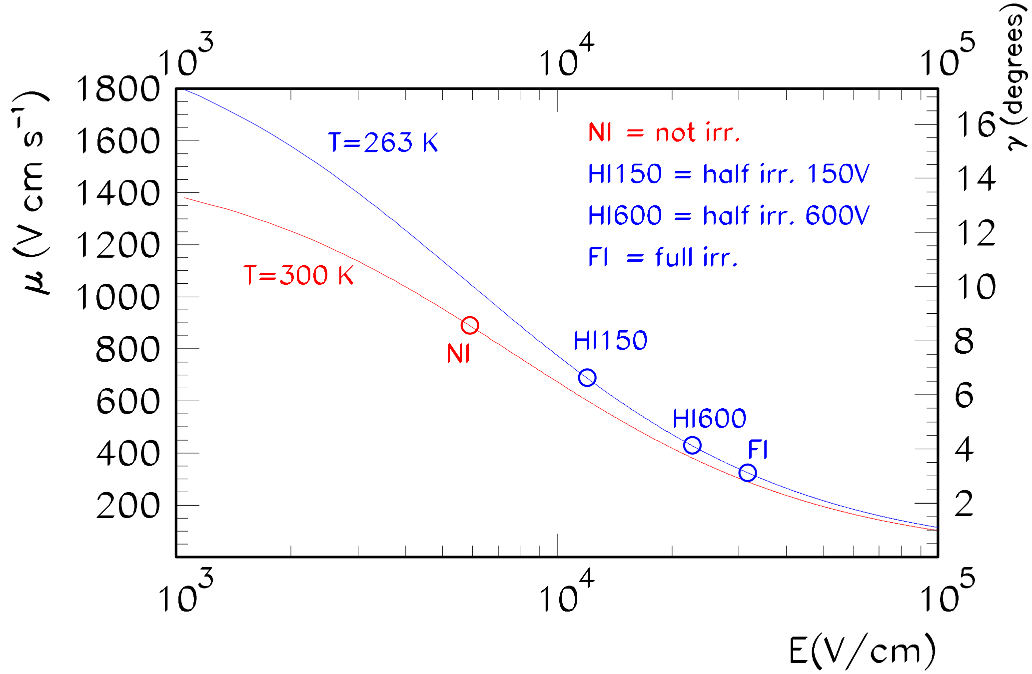
Measured value $\theta_L = 5.9^0 \oplus 1.0^0 \oplus 0.3^0$

Predicted value $\theta_L = 5.3^0 \oplus 0.5^0$

Lorentz Angle Results

Fluence	Bias Voltage V	Depletion depth [μm]	$\theta_L[^0]$(Parabola)	$\theta_L[^0]$ (Model)
0	150	283 ± 6	$9.0 \pm 0.4 \pm 0.5$	9.0 ± 0.4
5×10^{14}	150	123 ± 11	$5.9 \pm 1.0 \pm 0.3$	5.7 ± 0.5
5×10^{14}	600	261 ± 8	$2.6 \pm 0.2 \pm 0.3$	4.1 ± 0.2
10^{15} ('98)	600	189 ± 12	$3.1 \pm 0.4 \pm 0.6$	3.0 ± 0.2
10^{15} ('99)	600	217 ± 13	$2.7 \pm 0.4 \pm 0.4$	3.4 ± 0.3





Conclusions

- Lorentz angle of ATLAS Pixel rad-hard sensors has been measured.
- The observed behavior is well explained by a model based on charge drift in silicon.
- The Lorentz angle (through the mobility) depends upon the Electric field inside sensors.
- At the operating conditions for ATLAS pixel sensor we expect a Lorentz angle of 13^0 at the beginning of data taking. After 10 years we expected a Lorentz angle of 4^0.
- Depletion depth of sensors irradiated at two different fluences has been measured and characterized as a function of the operation voltage.