Comments on electron/hole mobility

Reisaburo Tanaka (LAL-Orsay)

SCT Digitization Taskforce Meeting
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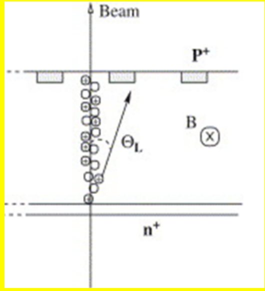
Lorentz (Hall) angle model

$$\tan\theta_L = \mu_H B = r\mu_d B$$

μ_H : Hall mobility

r : Hall factor ≈ 1



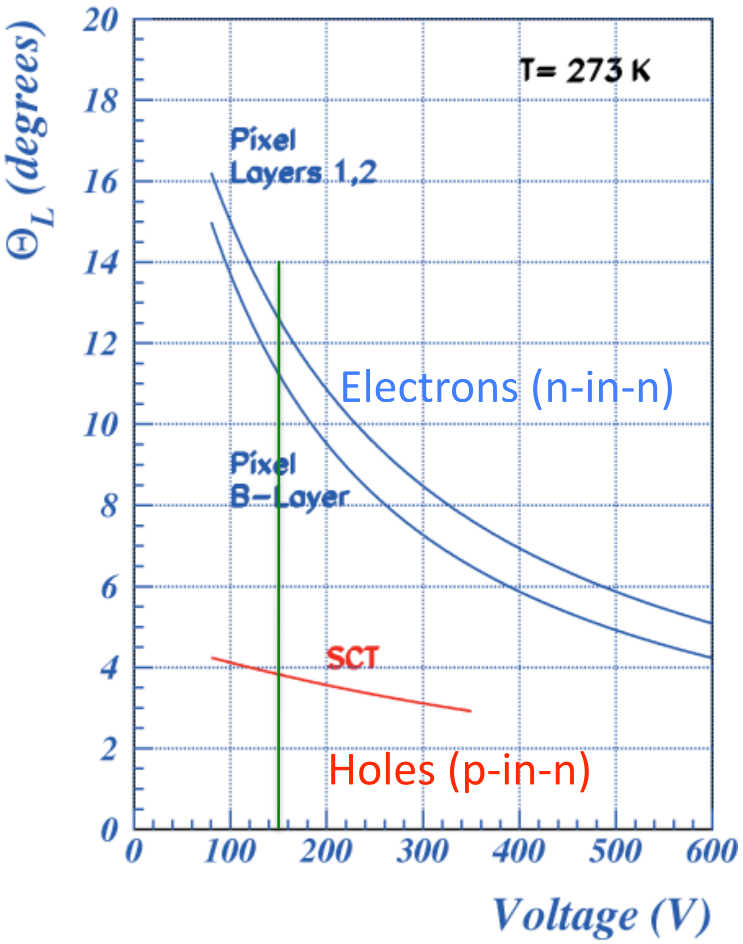
$$\mu_d = \frac{v_s/E_c}{\left[1+\left(E/E_c\right)^{\beta}\right]^{1/\beta}} \quad \text{(drift mobility)}$$

	Electrons	Holes
$v_s(\mathrm{cm\ s^{-1}})$	$1.53 \cdot 10^{9} \cdot T^{-0.87}$	$1.62 \cdot 10^{8} \cdot T^{-0.52}$
$E_c(\mathrm{V\ cm^{-1}})$	$1.01 \cdot T^{1.55}$	$1.24 \cdot T^{1.68}$
β	$2.57 \cdot 10^{-2} \cdot T^{0.66}$	$0.46 \cdot T^{0.17}$
r	$1.13 + 0.0008 \cdot (T - 273)$	$0.72 - 0.0005 \cdot (T - 273)$

Valid for T>250K,

E along <111> crystallographic direction

ATL-INDET-2001-004



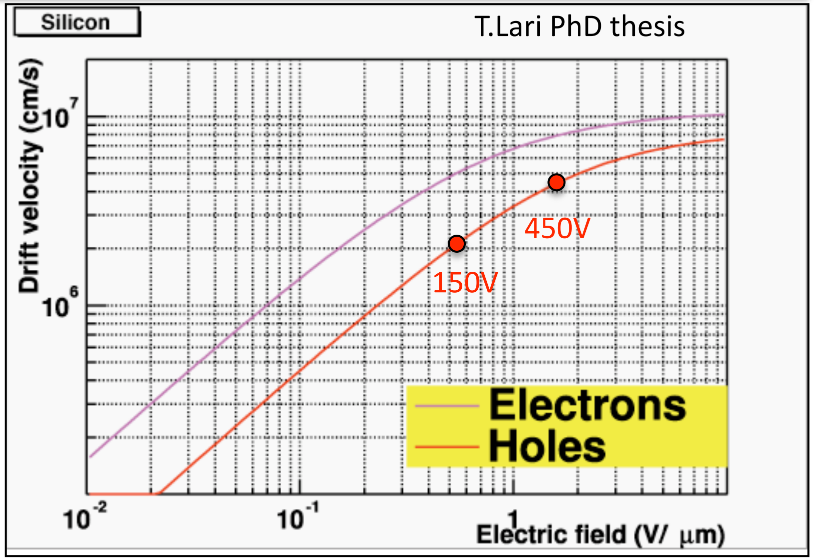
Parametrization: C. Jacoboni *et al.*, Solid-State Electronics 20 (1977) 77-89.
T. Lari, ATL-INDET-2001-004

Implemented into SCT Digitization S.Gadomski, ATL-SOFT-2001-005

Bias voltage dependence

$$\tan\theta_L = \mu_H B = r\mu_d B$$

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


T.Lari PhD thesis

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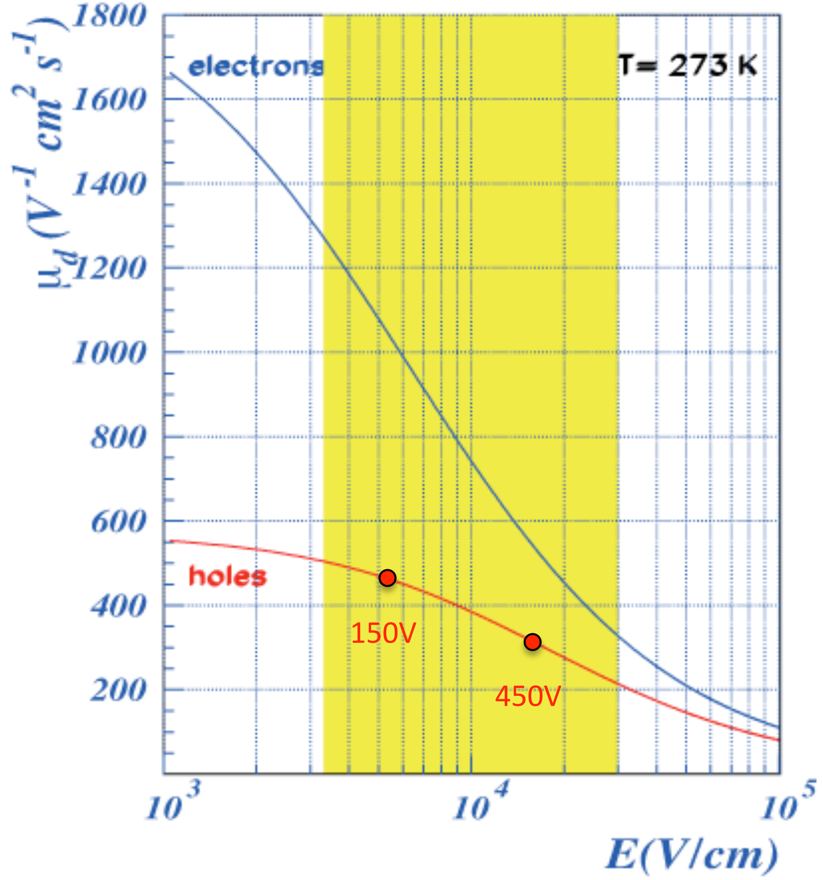


drift velocity saturation at high electric field
→ drop of "mobility" =*v*/E
→ drop of Lorentz angle

$$\left.\frac{\partial\theta_L(V,T)}{\partial V}\right|_{150V,273K} \approx -0.005^\circ/V$$

Doping and Temperature dependence

$$\tan\theta_L = \mu_H B = r\mu_d B$$

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

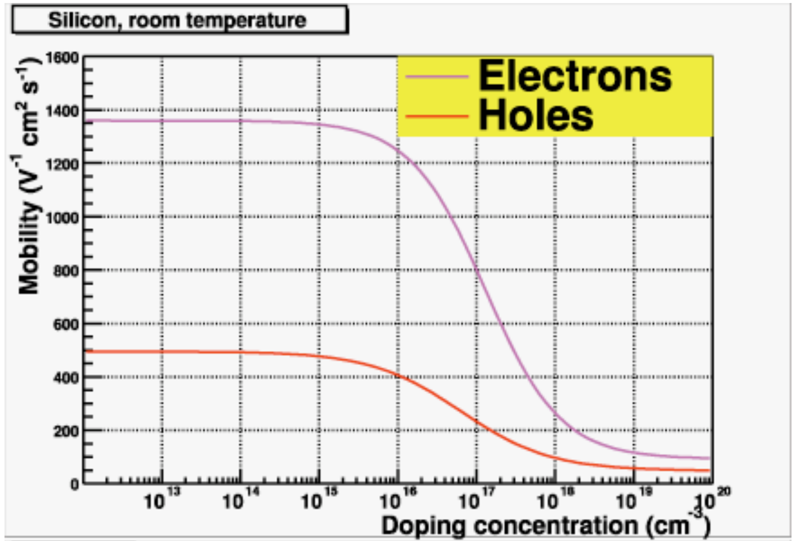
- LHC is not supposed to give effects on mobility due to doping concentration increase by radiation.

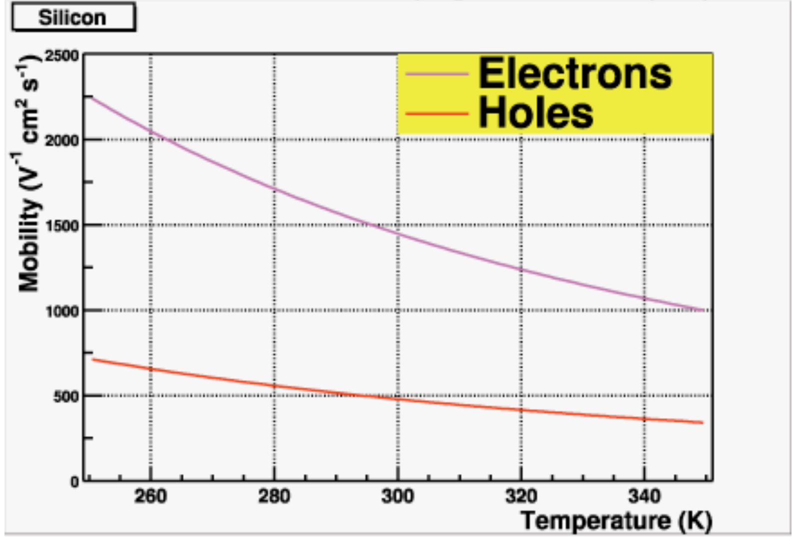
10^{12} cm^{-3} at the beginning of LHC.

- Mobility depends on temperature.

$$\left.\frac{\partial\theta_L(V,T)}{\partial T}\right|_{150V,273K} \approx -0.027^{\circ}/K$$

T.Lari PhD thesis





C Jacoboni et al., Solid-State Electronics 20 (1977) 77-89

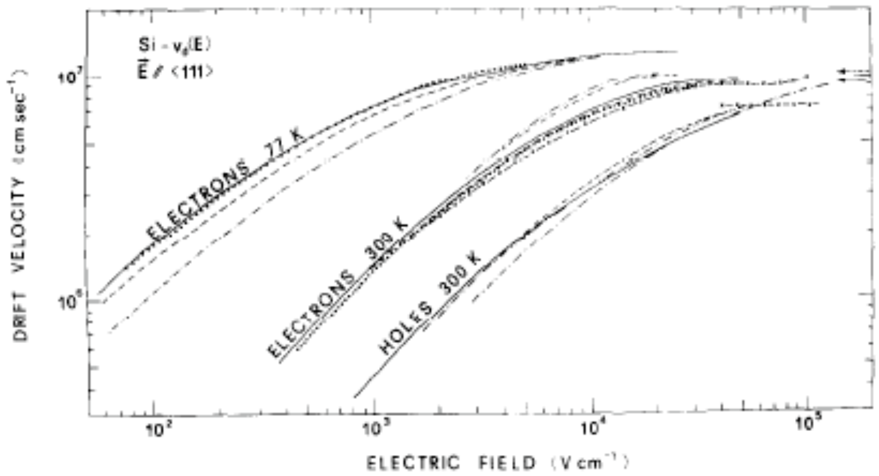


Fig. 2. Comparison of some experimental results, obtained with different techniques, on electron- and hole-drift velocities as functions of electric field **E** applied parallel to a ⟨111⟩ crystallographic direction.

Holes, T = 300 K: (——) Canali *et al.*[28], ToF; (– – –) Norris and Gibbons[26], ToF; (··–··–) Sigmon and Gibbons[30], ToF; (x—x—x) V. Rodriguez *et al.*[35], I(V) in space charge limited current (SCLC) regime; (–·–·–·) Seidel and Scharfetter[37], I(V); (→) extrapolated value for the saturated hole drift velocity by the same authors[37].

Electrons, T = 300 K: (——) Canali *et al.*[28], ToF; (—·—) Norris and Gibbons[26], ToF; (–––––) Sigmon and Gibbons[30], ToF; (··–··) Rodriguez and Nicolet[36], I(V) in SCLC regime; (······) Boichenko and Vasetskii[41], I(V); (–x–x–) A. C. Prior[19], I(V); (- - - →) saturated electron-drift velocity from Duh and Moll[38], I(V) in avalance diodes.

Electrons, T = 77 K; (——) Canali *et al.*[28], ToF; (– – – –) Jørgensen *et al.*[42], I(V); (–·–·–) Asche *et al.*[43], I(V); (· · · · · ·) Nash and Holm-Kennedy[44] I(V).

____solid line	Canali et al. [28]	ToF method
------dashed line	Norris and Gibbons [26]	ToF method
.. _ .._two dot dashed line	Sigmon and Gibbons [30]	ToF method
x---x ---x dashed line	Rodriguez et al. [35]	Conductivity method
. __ . __dot dashed line	Seidel and Scharfetter [37]	Conductivity method

The three ToF method measurements agree perfectly at 150V/285micron = 5263V/cm,
while conductivity method of Seidel and Scharfetter shows 10% lower values than ToF method for holes at 300K
(Rodoriquez et al. even lower by 25%).

Drift –velocity measurements in silicon

1) Conductivity technique

- Measure current density $j(E) = nqv_d(E)$
- First measurement of v_d(E) thanks to its simplicity.
  - n (determined by the Hall-effect measurement) is carrier density and q is the charge
  - Assumption is that n is constant, but can depend on E as a result of Joule heating, carrier injection at the contacts or impact ionization.
  - First two effects can be avoided by applying very short-pulse, but this requires low resistivity material.

2) Microwave technique

- Heat up charge carriers by pulsed electric field, then measure mobility via attenuation of a low microwave field or via low d.c. electric field.
  - High field measurement is difficult to interpret and today rarely used for the determination of v_d.

3) Time-of-flight (ToF) technique

- Measure tile T_R by charge carriers to travel across W under E, $v_d = W/T_R$
- V_d(E) characteristics can be obtained in the same sample for both type carriers.
  - i) Material must have a sufficiently high resistivity to keep Joule heating negligible, and afford a dielectric relaxation time ρε longer than T_R.
  - ii) The mean lifetime of the carriers must not be short compared with T_R.

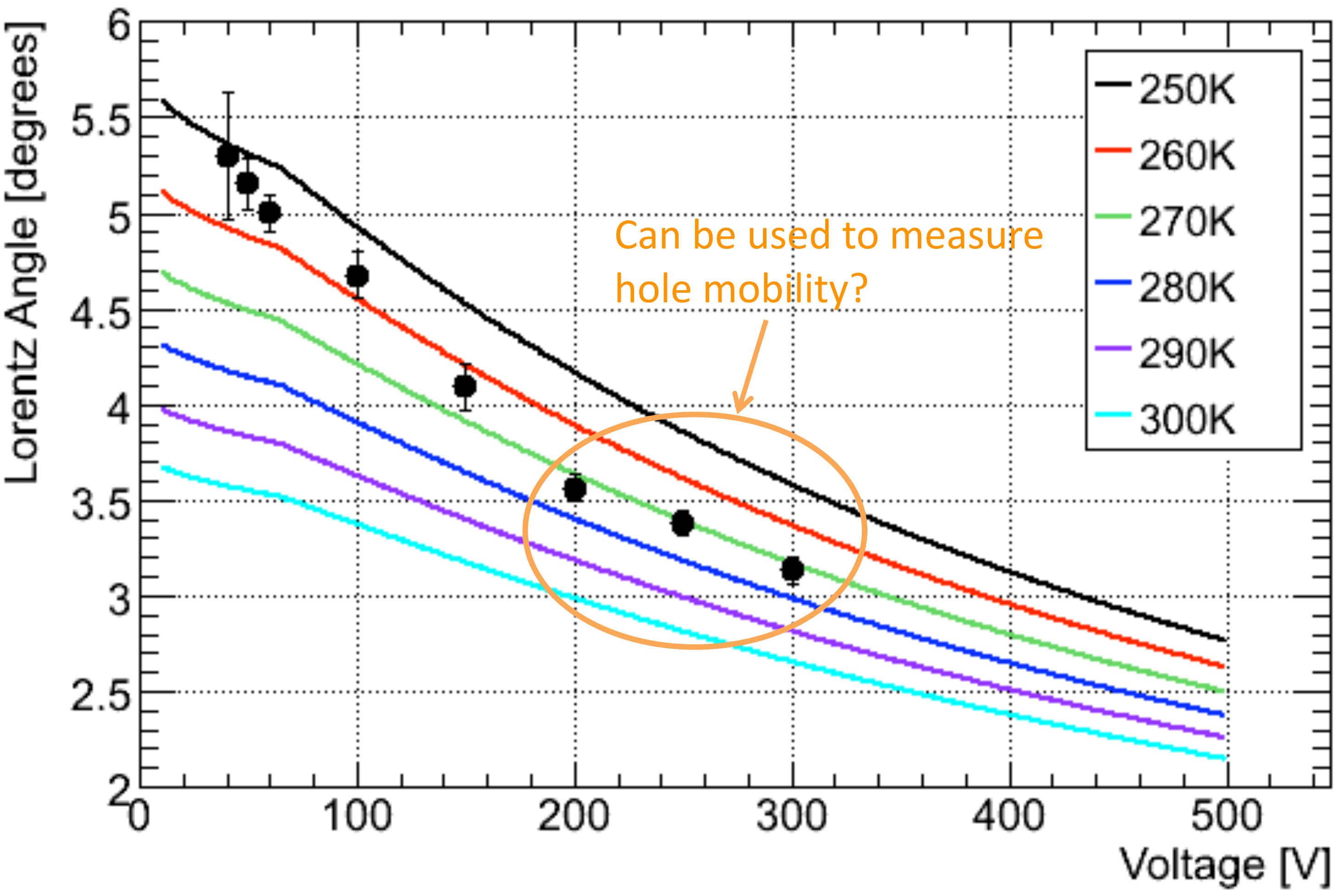
Drawbacks of Conductivity and Microwave techniques

1) Only be applicable to material with relatively low resistivity.
2) Indirect measurement of v_d
3) Only the drift velocity of the majority carriers can be measured.

➪ Thus we relied on ToF measurement on hole drift-velocity.

Elias Coniavitis, Preliminary

SCT bias voltage scan

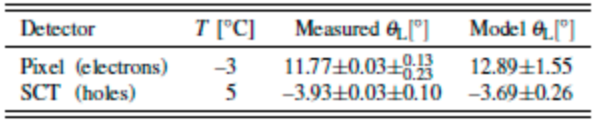


Can be used to measure hole mobility?

Lorentz angle can be a thermometer !

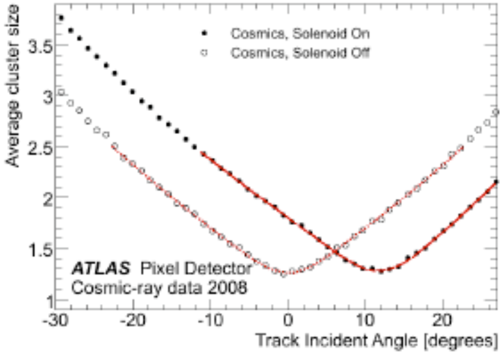
Pixel Lorenz angle measurement

The ATLAS Inner Detector commissioning and calibration
arXiv:1004.5293v2

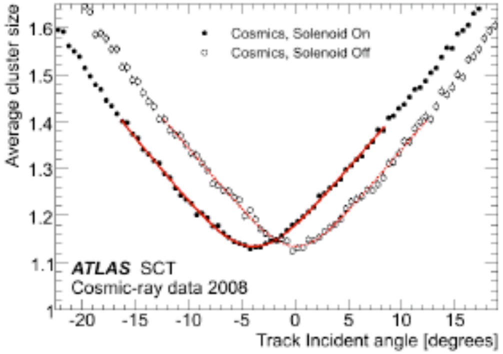


Detector	T [°C]	Measured θ_L[°]	Model θ_L[°]
Pixel (electrons)	–3	$11.77\pm0.03\pm^{0.13}_{0.23}$	12.89±1.55
SCT (holes)	5	–3.93±0.03±0.10	–3.69±0.26

Table 5. Measured values of the Lorentz angle in 2 T magnetic field at the average operational temperature in 2008, compared with model expectations [46]. For the measurements, the first error is statistical and the second systematic. The error on the model prediction arises from uncertainties in the charge-carrier mobility.



(a) Pixel Detector mean cluster width



(b) SCT mean cluster width

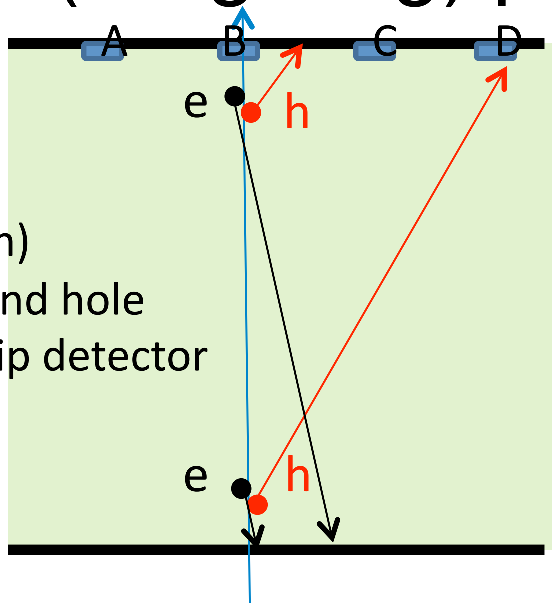
Fig. 17. Cluster-size dependence on the particle incident angle for the Pixel Detector (a) and the SCT (b). The displacement of the minimum for the data with solenoid on is a measurement of the Lorentz angle θ_L.

Matilde Teixeira Dias Castanheira
SCT Offline Software Meeting
Aug. 5, 2010

Detector	Model Prediction	Cosmic Data	Recent Coll. data (7 TeV)
Pixel	200 ± 14 mrad *(a)*	$205.5 \pm 0.5(\text{stat})^{+2.3}_{-4.0}(\text{syst})$ mrad *(a)*	211.3±1.6 mrad *(b)*
SCT	3.69 ± 0.26 degrees	3.93 ± 0.03(stat) ± 0.10(syst) degrees	4.24 ± 0.02 degrees

Extra slides

Ramo (weighting) potential and induced current



SCT (p-in-n)
electron and hole
drift in strip detector

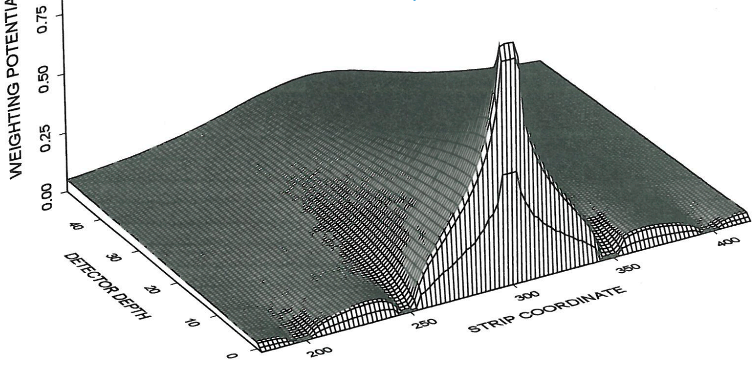


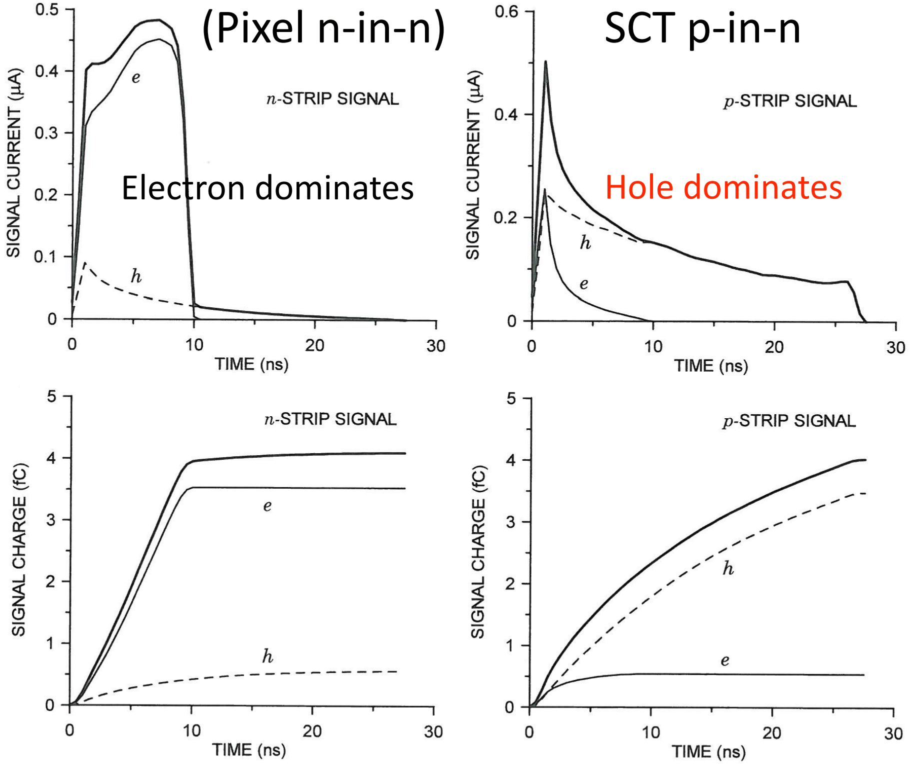
FIG. 2.29. Weighting potential for a 300 μm thick strip detector with strips on a pitch of 50 μm. The central strip is at unit potential and the others at zero. Only 50 μm of depth are shown.

H. Spieler

- V. Radeka, "Low Noise Techniques in Detectors," Ann.Rev.Nucl.Part.Sci.38 (1988) 217-277.
- H. Spieler "Semiconductor Detector Systems," Oxford Univ Press, 2005.

Strip detector signal for n-bulk device

V_D=60V, V_{bias}=90V



(Pixel n-in-n)

SCT p-in-n

Electron dominates

Hole dominates

Total charge is the same.