Lorentz angle measurements in Silicon detectors

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Outline

- Motivation
- Definitions
- Results

\textsuperscript{a}Talk at: http://home.cern.ch/~deboerw
KEY QUESTIONS:
1) Should I rotate detectors to compensate Lorentz angle?
2) Should I readout p- or n-side, i.e. electrons or holes?

Holes: Cheaper and smaller Lorentz angle
Electrons: Larger signal after strong irradiation and better charge sharing, but Lorentz angle large and more dependent on irradiation.

(CMS: strip detectors: holes. Pixel detectors: electrons)
3) How does Lorentz angle depend on temperature? (Detectors absolutely radiation hard below 150 K (LARUS effect))
Lorentz Angle

Lorentz angle $\theta$:

$$\tan \theta = \frac{F_y}{F_x} = \frac{e\nabla_x B}{e\overline{E}} = \frac{vB}{E} \equiv \mu B$$

Drift mobility: $\mu = \frac{v}{E}$.

Second order effects:

$$F_x \equiv m\dot{v}_x = -eE_x + ev_y B_z$$

$$F_y \equiv m\dot{v}_x = ev_x B_z$$

These coupled differential equations can be solved. Results for Lorentz angle as above.
Hall Scattering Factor

In magnetic field: curved trajectories $\rightarrow$ different effective drift velocity $\rightarrow$ different Lorentz angle

\[ \tan \theta = r_H \mu B \equiv \mu_H B \text{ (Master Formula)} \]

$r_H$ is called Hall scattering factor.

Measure $r'_H \approx 2$ at 77 K for electrons??

From Landolt-Börnstein, (17a), Springer Verlag, Berlin, 1982.
The 10T JUMBO Magnet (FZ Karlsruhe)

Hybrid with Premux chips, pitch adapter and double-sided Sintef “baby” sensor (thanks to Iris Abt, MPI-Munich) mounted under 45° in order to measure angles of both, electrons and holes.
Lorentz shift LINEAR with magnetic field up to 10 T
Simulation needs temperature dependent $r_H$
Hall Scattering factor vs Temperature

Increase from Coulomb scattering on ionized impurities, but needed concentration much larger than expected??

According to Wacker NO other impurities in their material, but they got very interested in the results.

Published theoretical formulae not valid for our high fields. Theory being modified for full depletion (no screening).
Lorentz shift at low temperatures can be reduced by OVERDEPLETION.
Hall scattering factor is TWO at low temperatures.
$r_H \approx 2$ is expected from ionized impurity scattering.
**Simulation of Lorentz shift**

Simple simulation using $\tan \theta_L = r_H \mu B$ with:

$$\mu = f(E, T) : (C. Canali et al., IEEE, ED-22 (1975) 1045)$$

$$\mu(E) = \frac{\mu_{low}}{1 + (\frac{\mu_{low} E}{v_{sat}})^\beta} \cdot \left(\frac{T}{300}\right)^{-2.5}$$  \hspace{1cm} (1)

For holes the values are: $\mu_{low} = 470.5 \text{ cm}^2 \text{ V}^{-1} \text{s}^{-1} \cdot \left(\frac{T}{300}\right)^{-2.5}$

$\beta = 1.213 \cdot \left(\frac{T}{300}\right)^{0.17}$ \hspace{0.5cm} $v_{sat} = 8.37 \cdot 10^6 \text{ cm/s} \cdot \left(\frac{T}{300}\right)^{0.52}$

For electrons the values are: $\mu_{low} = 1417 \text{ cm}^2 \text{ V}^{-1} \text{s}^{-1} \cdot \left(\frac{T}{300}\right)^{-2.2}$

$\beta = 1.109 \cdot \left(\frac{T}{300}\right)^{0.66}$ \hspace{0.5cm} $v_{sat} = 1.07 \cdot 10^7 \text{ cm/s} \cdot \left(\frac{T}{300}\right)^{0.87}$

\[E - \text{field} = f(U_{bias}, U_{depl}, \text{detector thickness } d) :\]

\[E(z) = \frac{U_{bias} - U_{depl}}{d} + \frac{2 \cdot U_{depl}}{d} \cdot \left(1 - \frac{z}{d}\right)\]

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**Simple formula** $\tan \theta_L = r_H \mu B$ still works after irradiation, if $\mu_{low}$ for electrons is reduced by up to 30%.
Sim. of Lorentz shifts in pixel detectors

After strong irradiation only partial depletion. Simple algorithm still works, if non-linearity of mobility is taken into account by “slicing” detector.

Fluence n/cm² | $U_{bias}$ in V | Depl. in μm | $\Theta_{meas}$ | $\Theta_{sim}$ | $\Theta_{sim}$
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<td>261</td>
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<td>189</td>
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<td>600</td>
<td>217</td>
<td>2.7°</td>
<td>3.2°</td>
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Data from Atlas irradiated pixel detector (M. Aleppo, Pixel2000, Genua). $V_{depl} = 1100V$. $\Theta_{sim}$ with the reduced mobility fits the data $\Theta_{meas}$ better.
Summary

- The Lorentz shift for electrons (ca. 200\(\mu m\) for 280 \(\mu m\) thick detectors at 4 T) is 4 to 5 times the Lorentz shift for holes at room temperature.

- At liquid nitrogen temperatures the Lorentz shift for electrons increases dramatically by a factor 2 to 8.

- Overdepletion can reduce this Lorentz shift.

- The Hall scattering factor \(r_H\) at low temperatures measured to be about 2, as expected from Coulomb scattering on ionized impurities. However, no quantitative agreement with theory yet.

- Irradiation reduces the mobility at room temperature and correspondingly the Lorentz shift. Below 200 K the mobility after irradiation increases.

- A simple algorithm based on \(\tan(\Theta_L) = \Delta x / d = \mu_H B = r_H \mu B\) can be used to calculate the Lorentz angle before and after irradiation, if mobility \(\mu_e\) is reduced after irradiation (\(\mu_h\) within errors not effected by irrad., more data to come).