New Measurements of Lorentz angle in (irradiated) silicon-strip-detectors

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What is new?

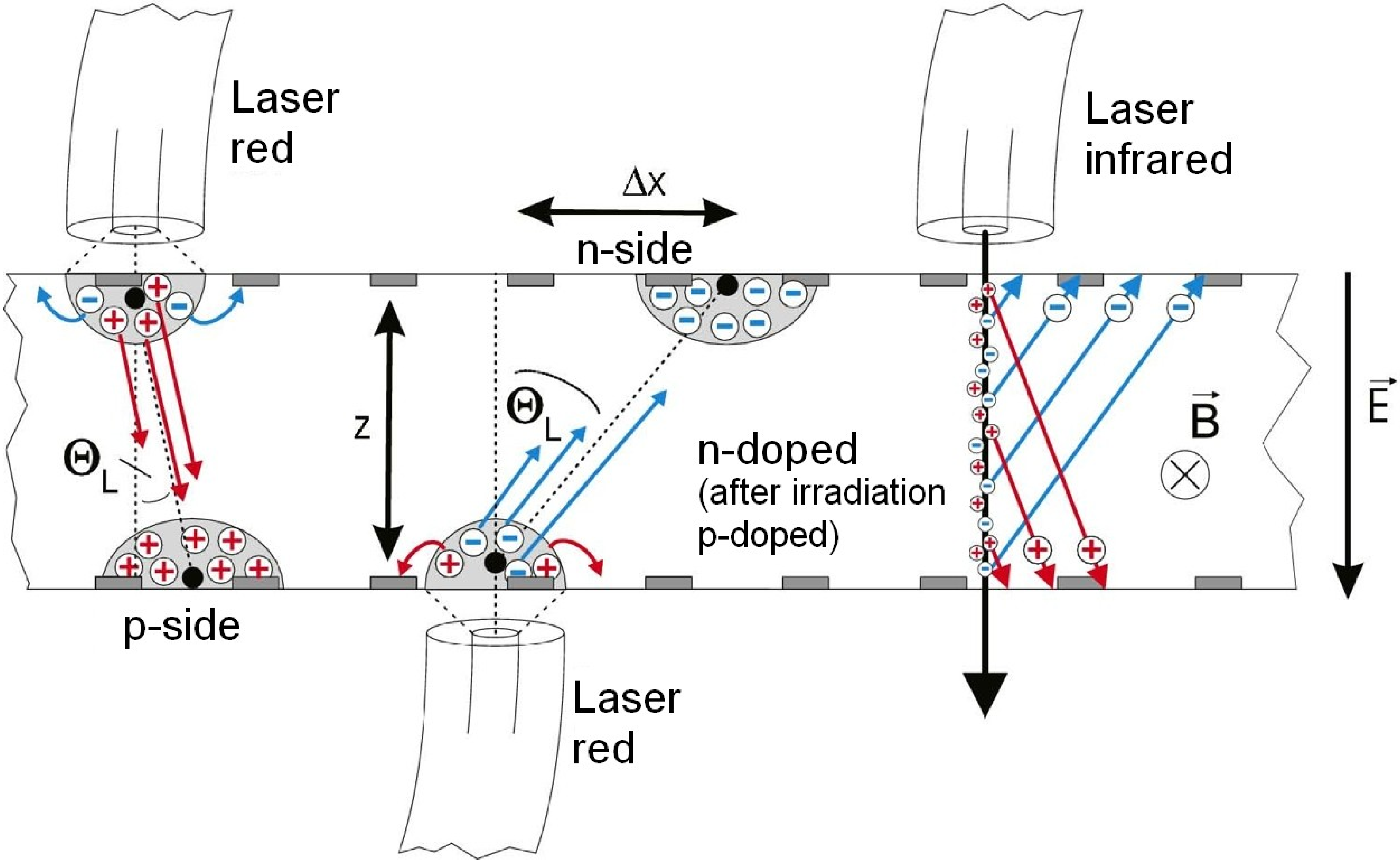
- Measured real CMS ministrip sensors

  (instead of ministrips from HERA-B, which had smaller pitch)
  CMS sensors allowed to measure to much higher bias voltages, use 500 μm for better sensitivity
- Measured RD50 n-in-p sensors to get much better Lorentz angle measurements for electrons
- Measured Lorentz angle in highly irradiation sensors

Outline

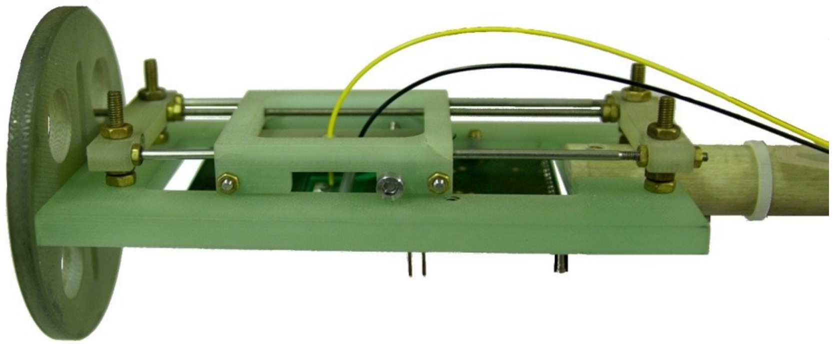
- Experimental Setup
- Sensors
- Model for calculating the Lorentz angle
- Results
- Lorentz angle over fluence
- Comparison with CMS data
- Summary

Experimental Setup (1)



Experimental Setup (2)

- Sensor with readout-chip PreMux (=APV w.o. Pipeline) on hybrid
- Hybrid mounted on structure for magnet
- Optical fibers for laser
  - red laser for best signal
  - infrared laser for MIP-like signal



Experimental Setup - Magnet

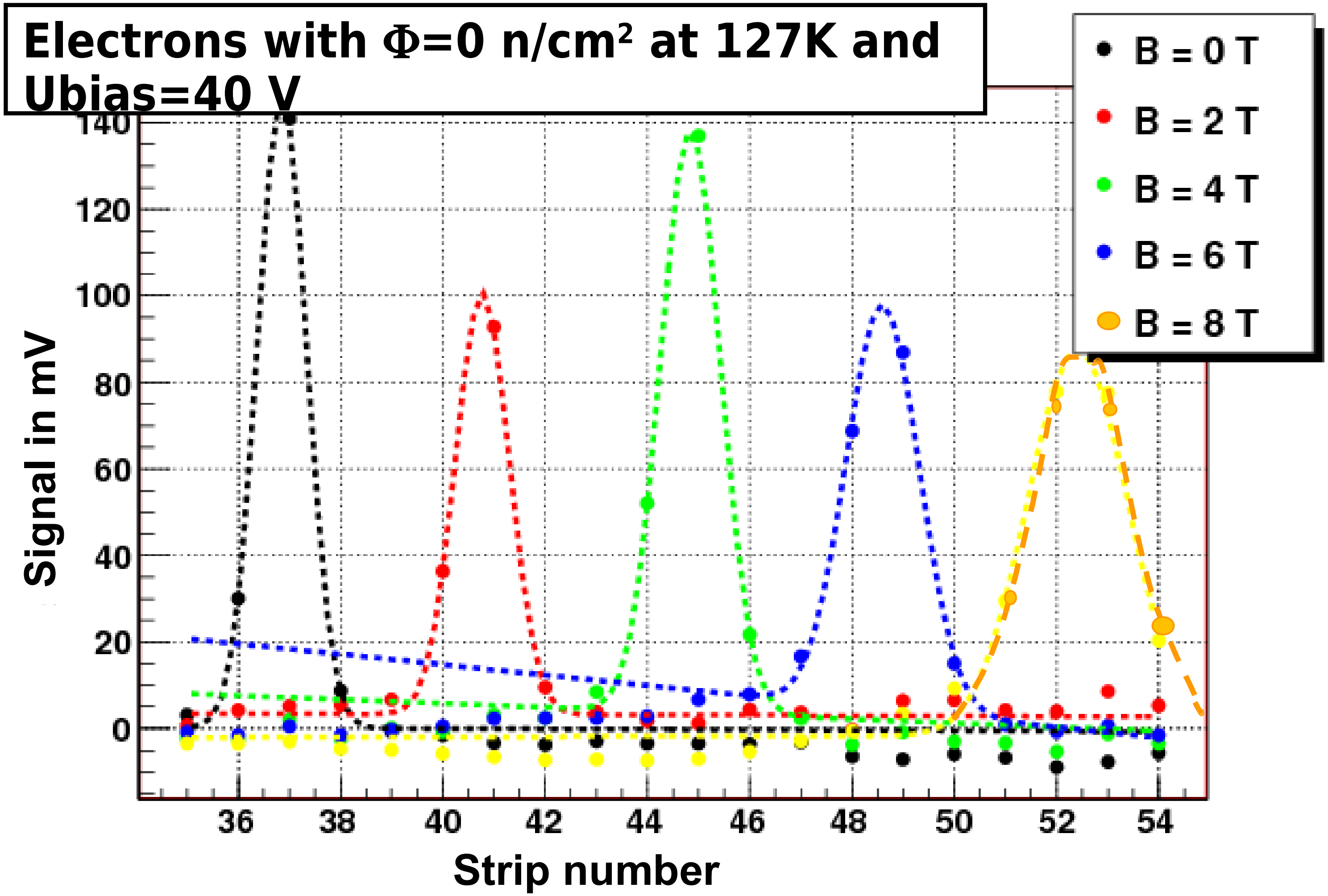
- Magnet lab of ITP at Forschungszentrum Karlsruhe
- Measurements of Lorentz shift up to 8T

Sensors

Sensorname	Manufacturer	Material	Thickness [μm]	U_{dep} [V]	Fluence [$\frac{n_{eq}}{cm^2}$]	Pitch[µm]
FZ-p-in-n-0-h-154-CMS	ST Microelectronics	FZ n-type	500	154	0	120
FZ-n-in-p-0-e-12	Micron / RD50	FZ p-type	300	12	0	80
FZ-n-in-p-1E15-e-1000	Micron / RD50	FZ p-type	300	≈ 1000	$1 \cdot 10^{15}$	
FZ-n-in-p-9.8E15-e-1000	Micron / RD50	FZ p-type	300	> 1000	$9.8 \cdot 10^{15}$	
MCz-p-in-n-7.1E14-h-169	HIP	MCz n-type	300	169	$7.1 \cdot 10^{14}$	50
MCz-p-in-n-7.1E14-h-272	HIP	MCz n-type	300	272	$7.1 \cdot 10^{14}$	
MCz-p-in-n-7.2E15-h-1000	HIP	MCz n-type	300	> 1000	$7.2 \cdot 10^{15}$	
MCz-p-in-n-0-h-347	HIP	MCz n-type	300	347	0	

- Measurement of depletion voltage by finding the knee in the $1/C^2$ over U plot
- Irradiated at Karlsruhe Kompaktzyklotron with 23 MeV protons
- Hardness factor 1.9

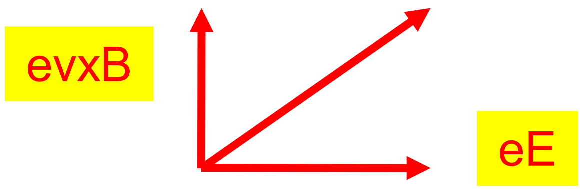
Signals of unirradiated sensors



Model for calculating the Lorentz angle

An Algorithm for calculating the Lorentz angle in silicon detectors.
V. Bartsch, W. de Boer, J. Bol, A. Dierlamm,
E. Grigoriev, F. Hauler , S. Heising, L. Jungermann.
Nucl.Instrum.Meth.A497:389-396,2003.
e-Print: **physics/0204078**

$\tan\theta_L = evB/eE = v/E\ B = r_H \mu B$



r_H=Hall factor, depends on scattering mechanism

$$E(z) = \frac{U_{Bias} - U_{Dep}}{d} + 2\frac{U_{Dep}}{d}\left(1 - \frac{z}{d}\right)$$

mobility

$$\mu(E) = \frac{\mu_0}{\left(1 + \left(\frac{\mu_0 E}{v_{sat}}\right)^\beta\right)^{\frac{1}{\beta}}}$$

C. Jacoboni, C. Canali, 1977

possible fit of 4 parameters:

- **shaping exponent β**
- **temperature exponents**

Electrons (μ_0 valid for T>200K)

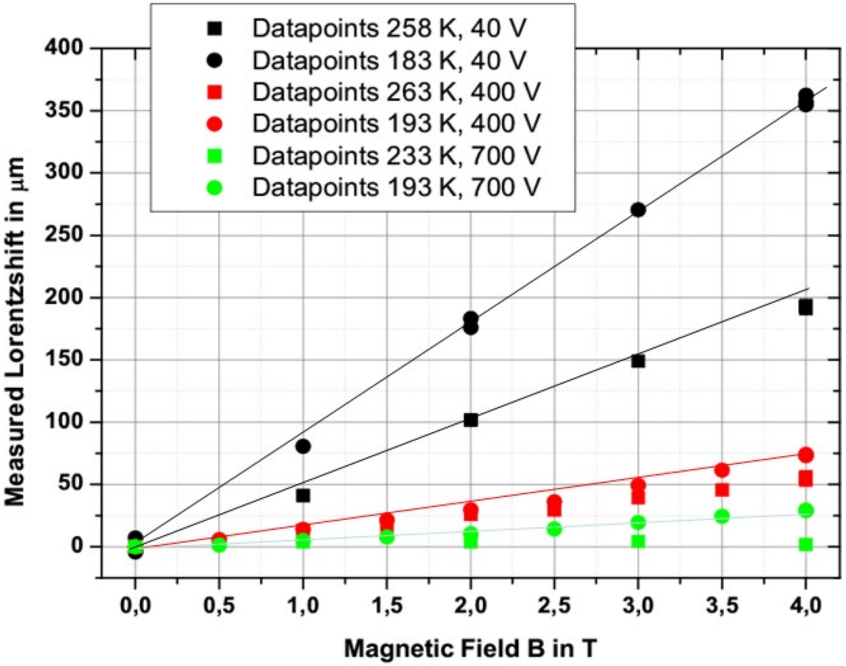
$$\mu_0 = 1417\frac{cm^2}{Vs}\cdot\left(\frac{T}{300}\right)^{-2.42};\ \beta = 1.109\cdot\left(\frac{T}{300}\right)^{0.66};\ v_{sat} = 1.07\cdot 10^7 cm/s\cdot\left(\frac{T}{300}\right)^{-0.87}$$

Holes (μ_0 valid for T>50K)

$$\mu_0 = 470.5\frac{cm^2}{Vs}\cdot\left(\frac{T}{300}\right)^{-2.2};\ \beta = 1.213\cdot\left(\frac{T}{300}\right)^{0.17};\ v_{sat} = 8.37\cdot 10^6 cm/s\cdot\left(\frac{T}{300}\right)^{0.52}$$

Results (1) Lorentz-shift of unirradiated sensors

B field linearity of the CMS sensor

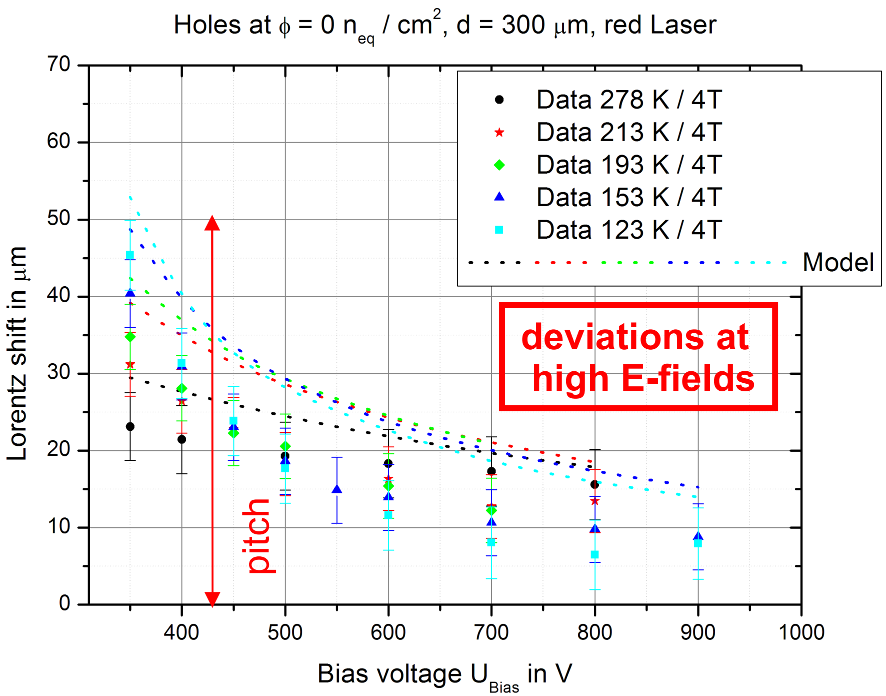


The new data shows a linear dependence on the magnetic field, which confirms the Lorentz-shift dependence:

$$\Delta x = r_H \cdot \mu \cdot B \cdot \Delta d$$

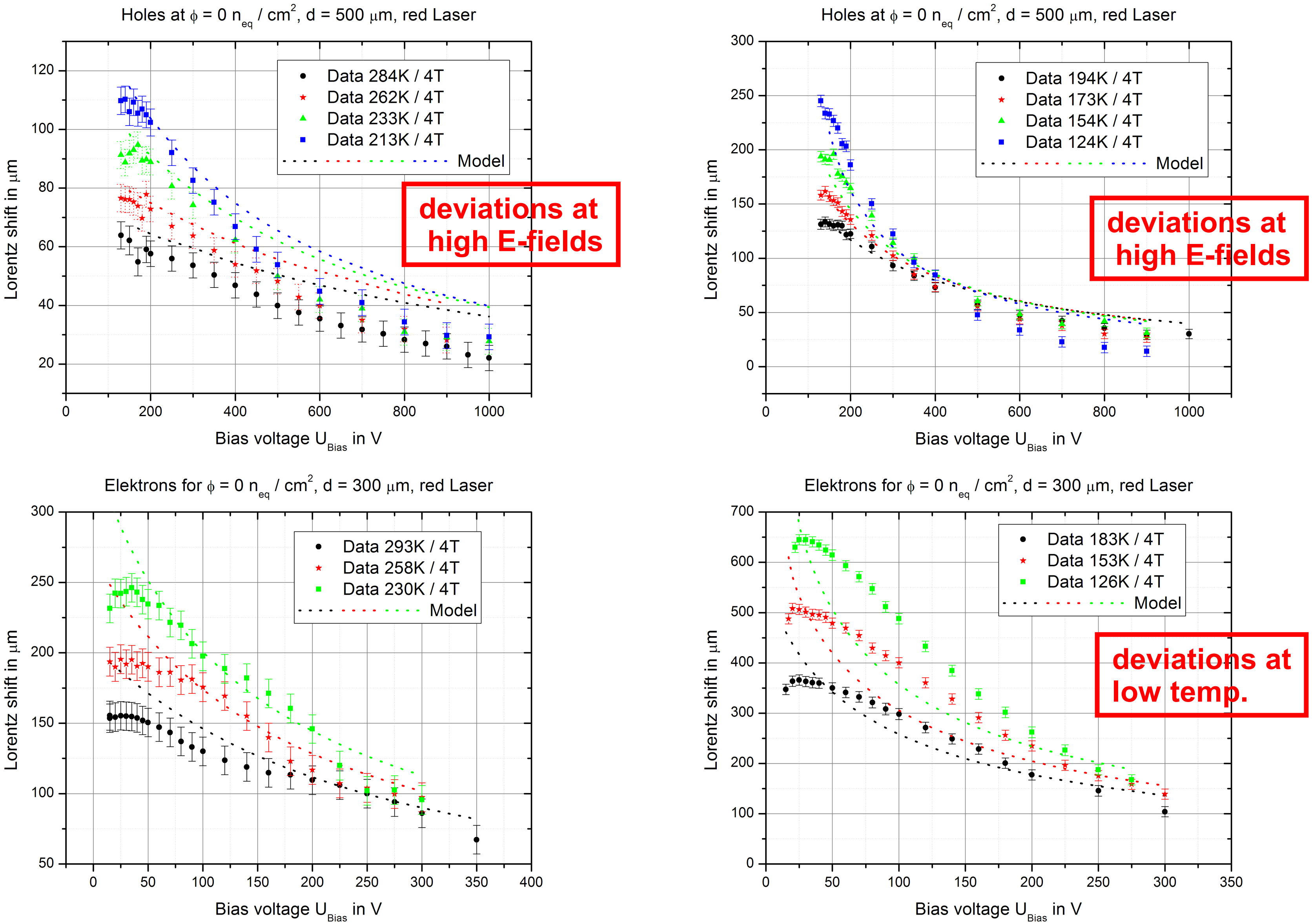
used by the model.

MCz data for holes

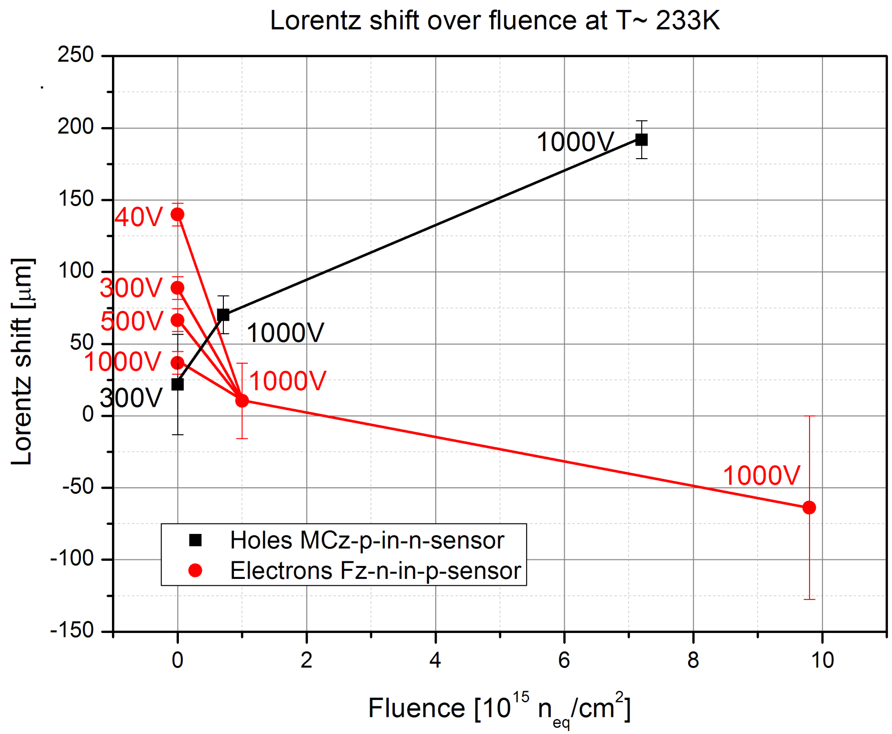


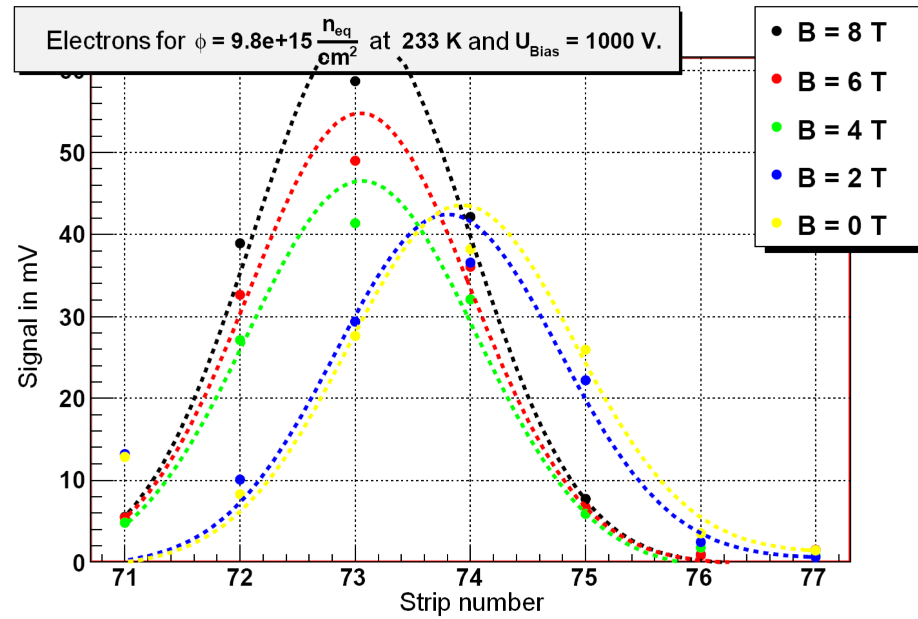
The data taken with the MCz-sensor has quite large deviations to the model, due to large deviations of the model at high voltages and measured Lorentz-shifts below the sensor pitch.

Results (1) Lorentz shift of unirradiated sensors



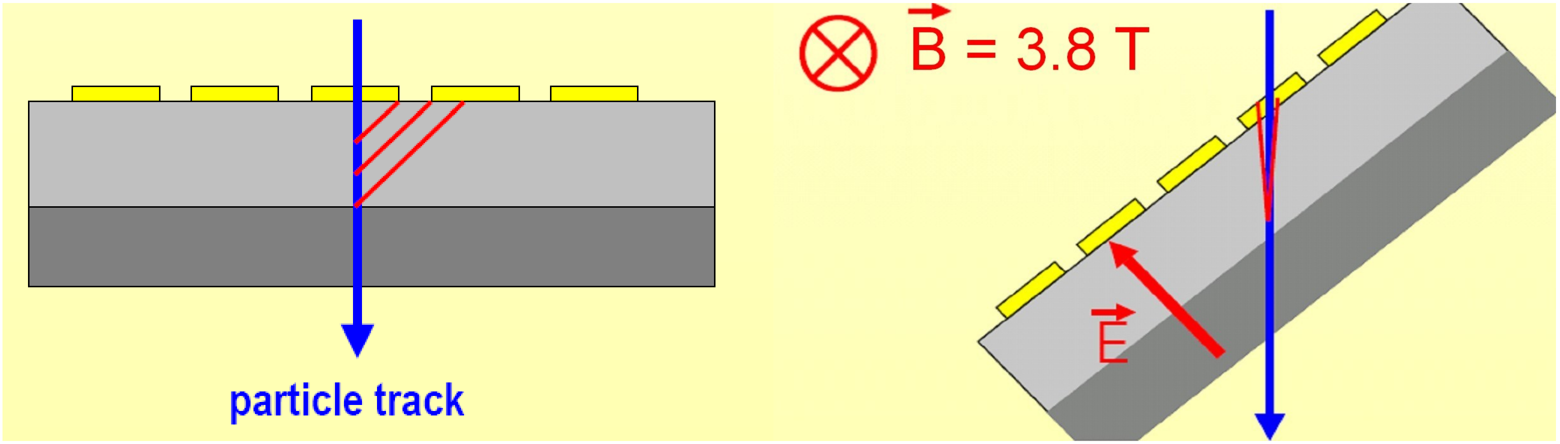
Lorentz angle versus fluence

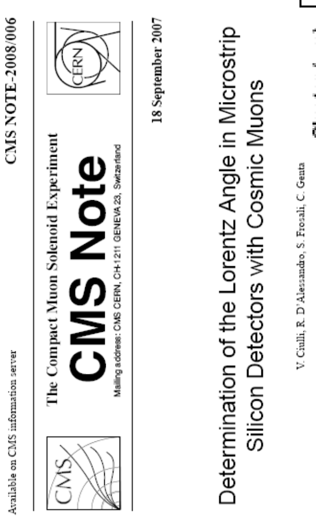




- •Strong dependence of Lorentz shift for holes on fluences above $1*10^{15}$ n/cm^2?
- •Vanishing Lorentz shift for electrons above$1*10^{15}$ n/cm^2?
- •Change of sign at high fluences for electrons?? But strange binary effect for this measurement!

Lorentz angle from cluster width in CMS





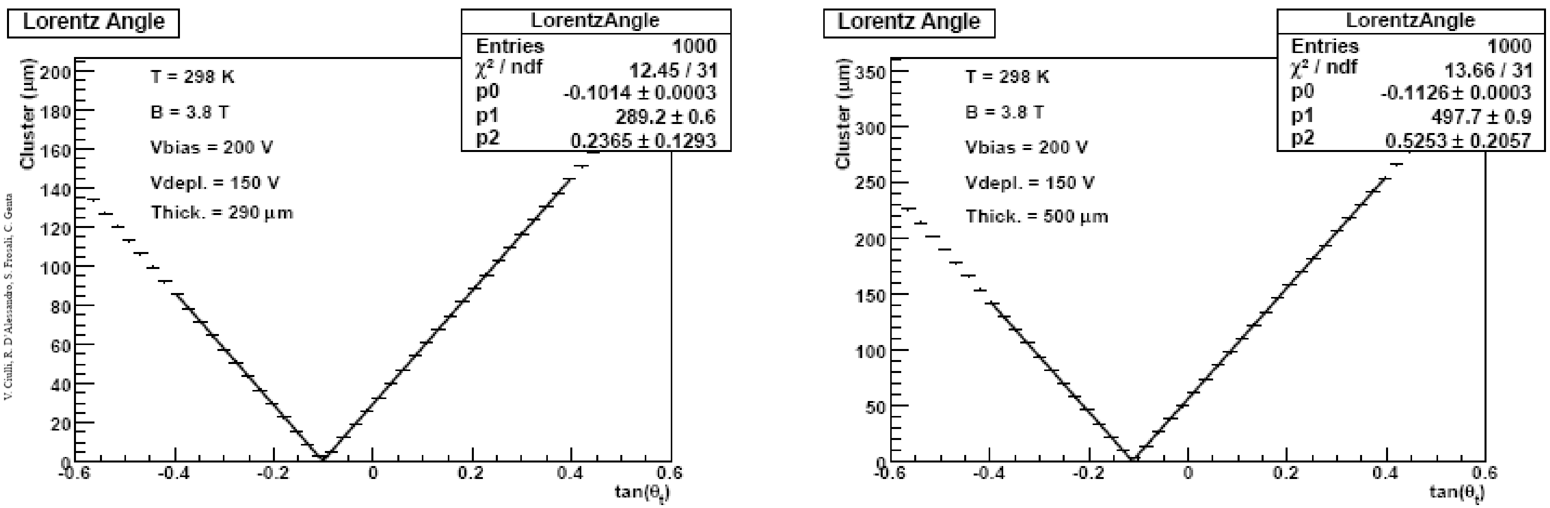
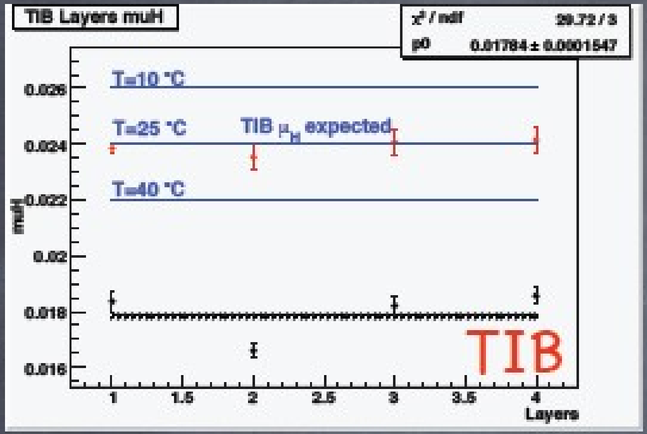


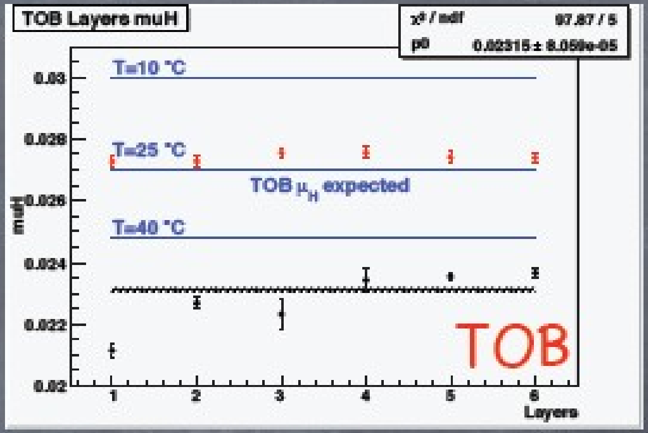
Figure 4: *Estimate of the tangent of the Lorentz angle (p_0) provided for the model, for TIB (left) and TOB (right) modules, at the MTCC working conditions.*

Comparison of CRAFT data to the model

Slide from „ Lorentz angle calibration. CRAFT data. Cosmic MC.“ S. Frosali, V. Ciulli, 17 March 2009

CRAFT REPRO





- **Black:** (μ_H)measured ; **Red:** (μ_H)expLy ;
  Blue line: (μ_H)expected (TIB/TOB)
- In the plots the mean and the error on the mean obtained from the gaussian fit for each layer are shown
- We measure μ_H values lower than the expected ones, ~25% for TIB and ~14% for TOB

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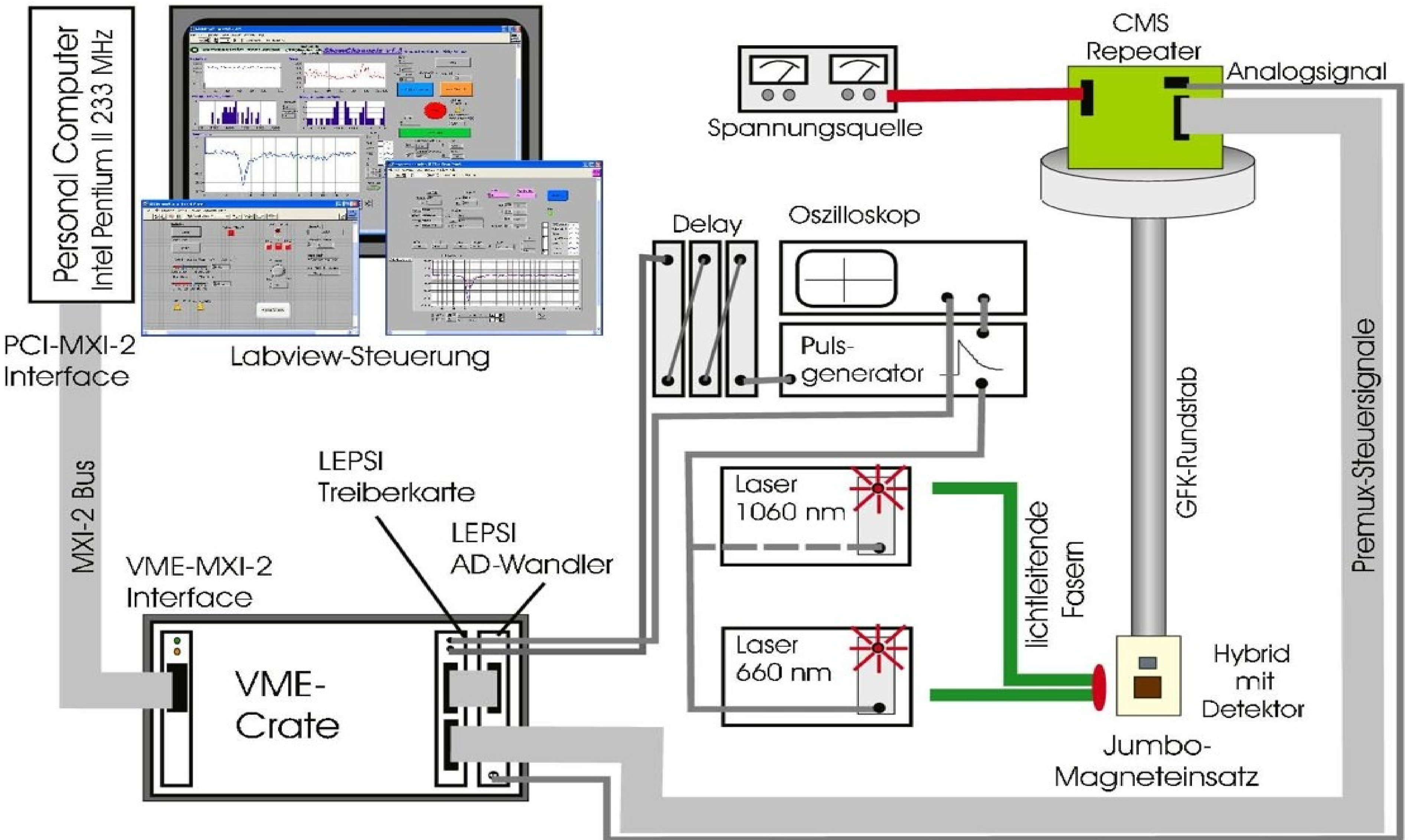
Summary

- New Lorentz measurements for holes with real mini-CMS sensors (100 orientation, previous partially 111)
- Strong difference for the Lorentz of holes and electrons at high fluences compared to lower ones
- Since Lorentz angle varies with fluence, in situ measure-ment by analog read out is needed for SLHC
- Slide changes for the new data, but still incompatible with CMS minimal cluster width method

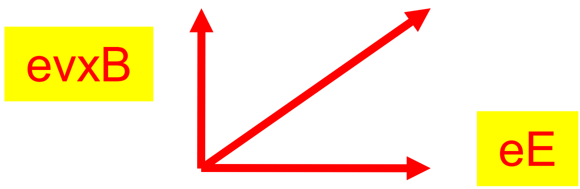
Experimental Setup (3)



Parametrization of Lorentz angle model

An Algorithm for calculating the Lorentz angle in silicon detectors.
V. Bartsch, W. de Boer, J. Bol, A. Dierlamm,
E. Grigoriev, F. Hauler , S. Heising, L. Jungermann.
Nucl.Instrum.Meth.A497:389-396,2003.
e-Print: **physics/0204078**

$\tan\theta_L = evB/eE = v/E\ B = r_H \mu B$



r_H=Hall factor, depends on scattering mechanism

$$E(z) = \frac{U_{Bias} - U_{Dep}}{d} + 2\frac{U_{Dep}}{d}\left(1 - \frac{z}{d}\right)$$

mobility

$$\mu = \frac{\mu_0}{\left(1 + \left(\frac{E\mu_0}{v_s}\right)^{\beta}\right)}$$

New fit of the 4 parameters:

- **shaping exponent β**
- **temperature exponents**

electrons

$$\mu_0 = 1417 \frac{cm^2}{VS} (T/300K)^{-1.76\pm0.08}$$

$$\beta = (1.247 \pm 0.054)$$

$$v_{sat} = 1.0 \cdot 10^7 \frac{cm}{s} (T/300K)^{0.89\pm0.10}$$

holes

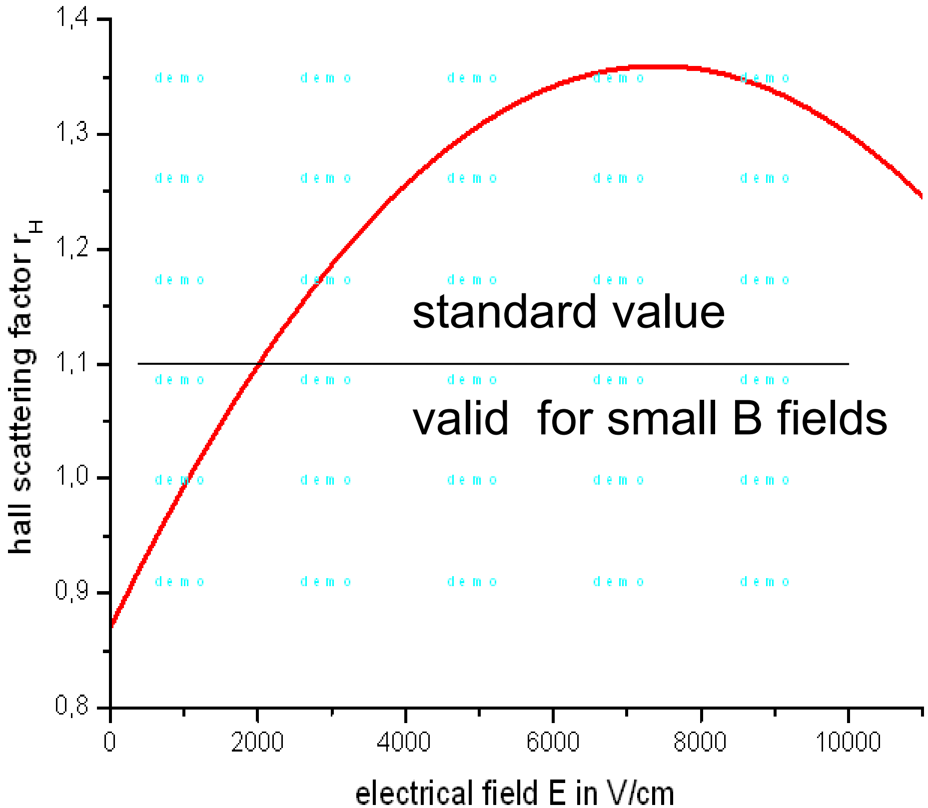
$$\mu_0 = 470.5 \frac{cm^2}{VS} (T/300K)^{-2.60\pm0.03}$$

$$\beta = (1.383 \pm 0.052)(T/300K)^{0.07\pm0.05}$$

$$v_{sat} = 8.37 \cdot 10^6 \frac{cm}{s}$$

New: Parametrization of hall scattering factor

$$r_H = (0.87 \pm 0.02) + (1.32 \pm 0.09) \cdot 10^{-4} \cdot E - (0.89 \pm 0.09) \cdot 10^{-8} \cdot E^2$$

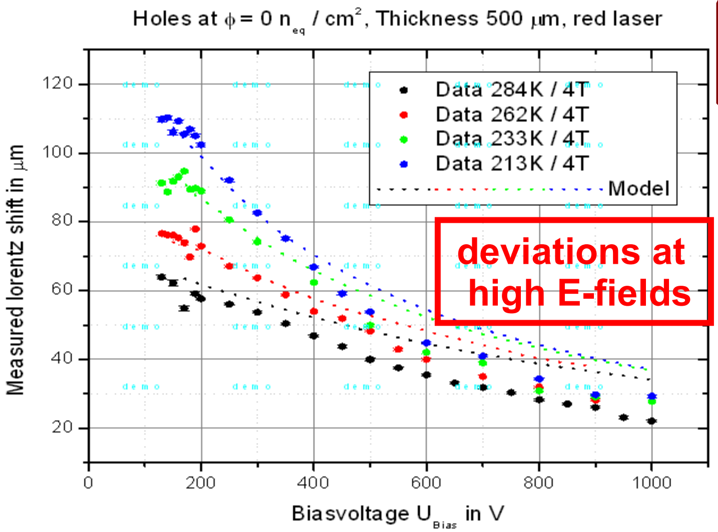


- Parabolic dependence of hall scattering factor on electric field
- Good description of data
- A constant r_H seems not appropriate (1.1 expected for small fields (i.e. small Lorentz angles, implying little curvature between scatterings)

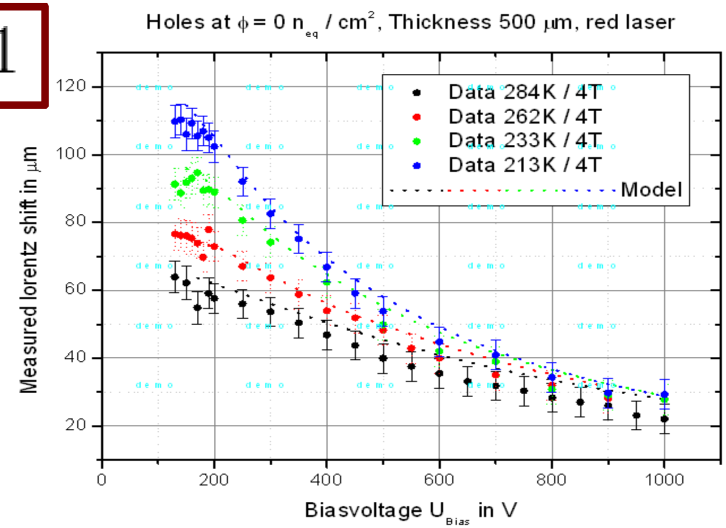
Results (1) holes CMS sensor (p-in-n)

OLD → **NEW**

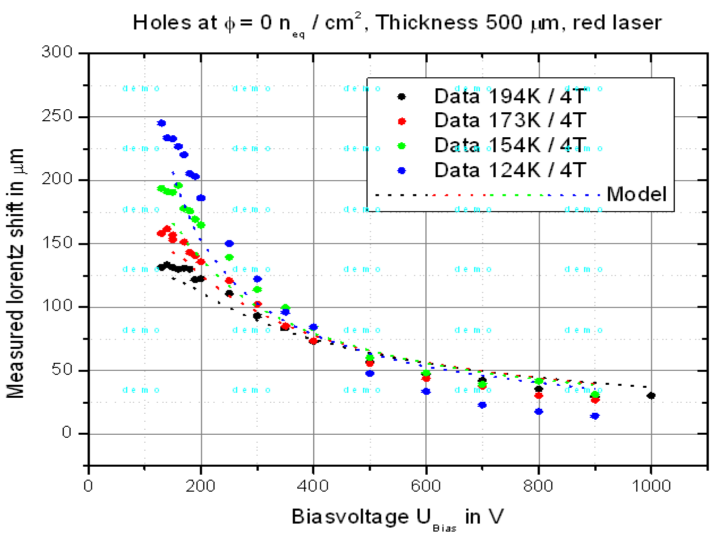
$$\chi^2/NDF = 1.1$$



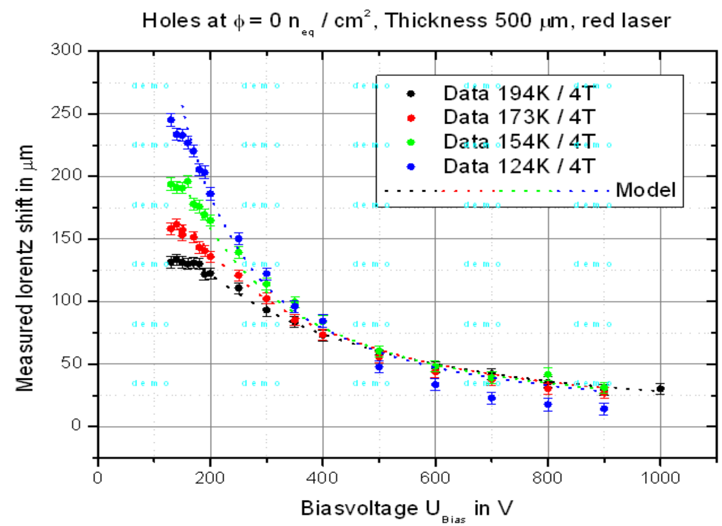
Fit →



holes

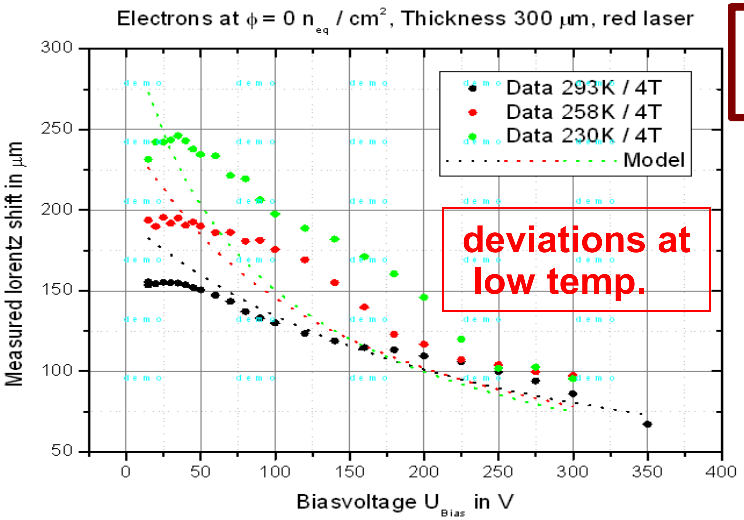


Fit →



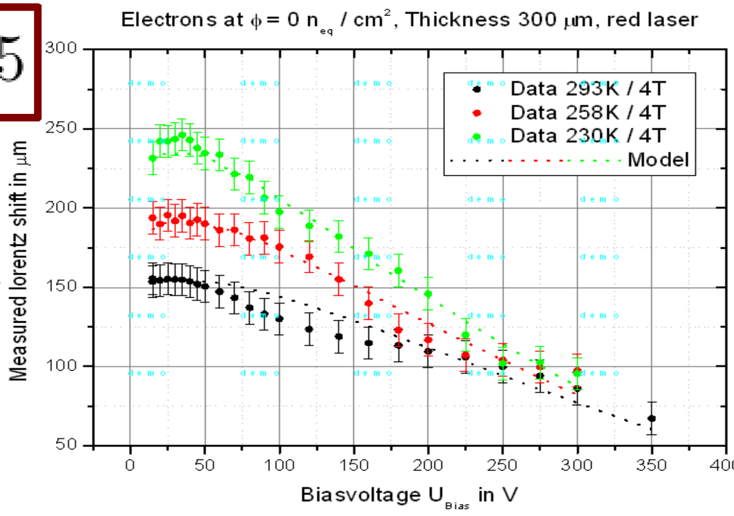
Results (2) electrons n-in-p (float zone)

OLD → **NEW**

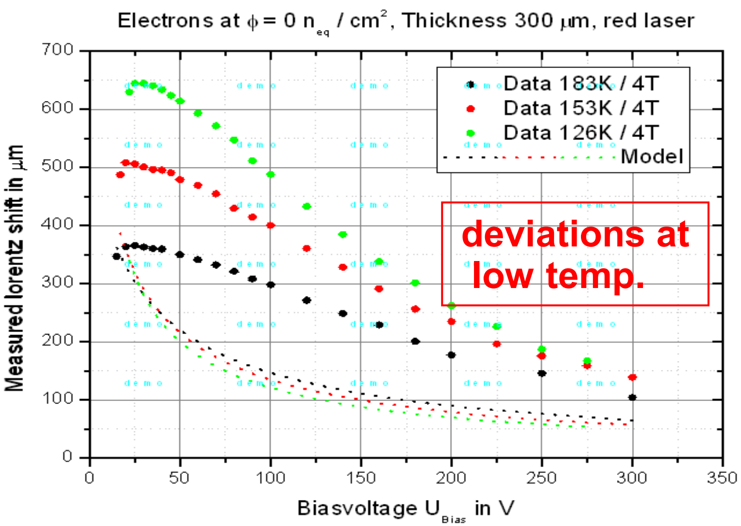


$$\chi^2/NDF = 0.5$$

Fit →



electrons



Fit →