Tests of silicon sensors for the CMS pixel detector

D.Bortoletto\textsuperscript{1}, V.Chiochia\textsuperscript{2}, S.Cucciarelli\textsuperscript{3}, A.Dorokhov\textsuperscript{2,4}, M.Konecki\textsuperscript{3}, K.Prokofiev\textsuperscript{2,4}, C.Regenfus\textsuperscript{2}, T.Rohe\textsuperscript{4}, S. Son\textsuperscript{1}, T.Speer\textsuperscript{2}, M.Swartz\textsuperscript{5}

\textsuperscript{1}Purdue University, USA, \textsuperscript{2}University of Zürich, CH, \textsuperscript{3}Institut für Physik der Universität Basel, CH, \textsuperscript{4}Paul Scherrer Institut, Villigen, CH, \textsuperscript{5}Johns Hopkins University, Baltimore, USA.

3\textsuperscript{rd} RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders
CERN, 3-5 November, 2003

Slides available at http://cern.ch/chiochia/pixel/
## Contents

- The CMS Pixel Detector
- Sensor designs under study
- The test beam setup

### Results:
- Lorentz angle
- Depletion and CCE
- Charge sharing
- S/N ratio and track detection efficiency

### Conclusions
The CMS Pixel Detector

- 3 barrel layers (at least 2 at startup)
- 2 endcap disks (at least 1 at startup)
- 720 barrel modules, 672 endcap modules and 66 M channels
- Pixel size $100\times150\ \mu m^2$ thanks to the 0.25 \(\mu m\) technology of the front-end chip
- innermost layer: 47 mm radius
- annual fluence: $\sim3\times10^{14}\ n_{eq}/cm^2$ in the innermost layer at full luminosity
Sensor designs

- **p-spray**
  - medium p-spray dose
  - punch-through bias grid
  - 125x125 $\mu$m$^2$ cell, 20 $\mu$m gap

- **p-stop**
  - $n^+$ surrounded by $p^+$ ring implants
  - resistive path through openings
  - 125x125 $\mu$m$^2$ cell

---

285±15 $\mu$m thick wafer, oxygen enriched starting material
Test beam setup

- Full analog readout with no zero suppression, unirradiated read out chip
- Cooling with Peltier elements down to -30° C
The grazing angle method

- Lorentz charge drift used to enhance the spatial resolution
- Low values of the Lorentz angle and the partial sensor depletion degrade the spatial resolution
- The direct measurement of the Lorentz angle and of the depletion is performed using the grazing angle method

The incoming particle crosses the sensor with a shallow angle $\alpha = 15^\circ$

The deposited charge drifts according to the Lorentz force

we measure the deflection angle $\beta$
Lorentz angle measurement (1)
The Lorentz angle decreases with the bias voltage.
At lower temperature the mobility increases and the Lorentz angle as well.
Depletion in irradiated devices

Averaged cluster, projection

- Depleted
- Undepleted

Depletion in irradiated devices

integrated charge

Y position (μm)

ADC counts

Total collected charge

percentage (%)

Bias voltage (V)

V. Chiochia et al. - Tests of silicon sensors for the CMS Pixel Detector
Charge collection

Charge collected on the hit pixel

**p-spray**

![Grayscale image of charge collection in p-spray configuration]

**p-stop**

![Grayscale image of charge collection in p-stop configuration]

- Charge collected on the hit pixel
- unirradiated
- $\phi = 8 \times 10^{14} \text{ n}_{eq} / \text{cm}^2$
S/N ratio and efficiency

- **p-spray:**
  - before irradiation S/N~65
  - after irradiation 35<S/N<45
- **p-stop:**
  - before irradiation S/N~30
  - large sharing between neighboring pixels
  - after irradiation 22<S/N<40

- **p-spray:**
  - inefficient in the punch-through dot
  - slow increase with threshold
- **p-stop:**
  - inefficient close to the detector borders
  - fast increase with threshold
Conclusions

- The performance of two pixel designs (implementing a p-stop or p-spray pixel isolation) have been measured with a test beam setup using unirradiated and irradiated samples.
- The Lorentz angle is ~26° at low bias voltage and decreases with increasing bias. The dependence on the irradiation/temperature is weak.
- The CCE is >60% for both designs after $8 \times 10^{14}$ n$_{eq}$/cm$^2$ and $V_{bias} > 350$ V.
- The S/N is ~65 for p-spray sensors and ~30 for p-stop sensors (because of the large charge sharing). After irradiation can still achieve a S/N > 30 for $V_{bias} > 350$ V.
- Efficiency >98% for a threshold of 65 ADC counts (~2000 e⁻).
- Most inefficient region of the p-spray sensor is the punch-through dot and metal line, the p⁺ rings for the p-stop detector.