Latest results of RD50 collaboration

Development of radiation hard sensors for very high luminosity colliders

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on behalf of RD50 collaboration

http://www.cern.ch/rd50
Development of Radiation Hard Semiconductor Devices for High Luminosity Colliders

250 Members from 48 Institutes

41 European and Asian institutes
- Belarus (Minsk), Belgium (Louvain), Czech Republic (Prague (3x)), Finland (Helsinki), Germany (Dortmund, Erfurt, Freiburg, Hamburg, Karlsruhe, Munich), Italy (Bari, Bologna, Florence, Padova, Perugia, Pisa, Torino, Trento), Lithuania (Vilnius), Netherlands (NIKHEF), Norway (Oslo (2x)), Poland (Warsaw(2x)), Romania (Bucharest (2x)), Russia (Moscow, St.Petersburg), Slovenia (Ljubljana), Spain (Barcelona, Valencia), Switzerland (CERN, PSI), Ukraine (Kiev), United Kingdom (Glasgow, Lancaster, Liverpool)

8 North-American institutes
- Canada (Montreal), USA (BNL, Fermilab, New Mexico, Purdue, Rochester, Santa Cruz, Syracuse)

1 Middle East institute
- Israel (Tel Aviv)

Detailed member list: http://cern.ch/rd50
Motivation:

Signal degradation for LHC Silicon Sensors

Pixel sensors:
max. cumulated fluence for LHC

Strip sensors:
max. cumulated fluence for LHC

FZ Silicon Strip and Pixel Sensors

- n-in-n (FZ), 285μm, 600V, 23 GeV p
- p-in-n (FZ), 300μm, 500V, 23GeV p
- p-in-n (FZ), 300μm, 500V, neutrons

References:
Motivation:

Signal degradation for LHC Silicon Sensors

Pixel sensors:
max. cumulated fluence for LHC and SLHC

Strip sensors:
max. cumulated fluence for LHC and SLHC

FZ Silicon Strip and Pixel Sensors

- n-in-n (FZ), 285μm, 600V, 23 GeV p
- p-in-n (FZ), 300μm, 500V, 23GeV p
- p-in-n (FZ), 300μm, 500V, neutrons

References:
[1] p/n-FZ, 30μm, (-30°C, 25ns), strip [Casse 2008]

SLHC will need more radiation tolerant tracking detector concepts!

Boundary conditions & other challenges:
Granularity, Powering, Cooling, Connectivity, Triggering, Low mass, Low cost!
RD50 approaches to develop radiation harder tracking detectors

- **Material Engineering -- Defect Engineering of Silicon**
  - Understanding radiation damage
    - Macroscopic effects and Microscopic defects
    - Simulation of defect properties & kinetics
    - Irradiation with different particles & energies
  - Oxygen rich Silicon
    - DOFZ, Cz, MCZ, EPI
  - Oxygen dimer & hydrogen enriched Silicon
  - Influence of processing technology

- **Material Engineering-New Materials** (work concluded)
  - Silicon Carbide (SiC), Gallium Nitride (GaN)

- **Device Engineering (New Detector Designs)**
  - p-type silicon detectors (n-in-p)
  - thin detectors
  - 3D detectors
    - Simulation of highly irradiated detectors
    - Semi 3D detectors and Stripixels
    - Cost effective detectors

- Development of test equipment and measurement recommendations

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**Radiation Damage to Sensors:**

- **Bulk damage due to NIEL**
  - Change of effective doping concentration
  - Increase of leakage current
  - Increase of charge carrier trapping
- **Surface damage due to IEL**
  (accumulation of positive charge in oxide & interface charges)

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**Related Works – Not conducted by RD50**

- “Cryogenic Tracking Detectors” (CERN RD39)
- “Diamond detectors” (CERN RD42)
- Monolithic silicon detectors
- Detector electronics
### RD50 Reminder: Silicon Materials under Investigation

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness [μm]</th>
<th>Symbol</th>
<th>( \rho ) (Ωcm)</th>
<th>([O_i]) (cm(^{-3}))</th>
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</thead>
<tbody>
<tr>
<td><strong>Standard FZ</strong> (n- and p-type)</td>
<td>50, 100, 150, 300</td>
<td>FZ</td>
<td>1–30(\times10^3)</td>
<td>&lt; 5(\times10^{16})</td>
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<tr>
<td><strong>DOFZ silicon</strong></td>
<td>300</td>
<td>DOFZ</td>
<td>1–7(\times10^3)</td>
<td>≈ 1–2(\times10^{17})</td>
</tr>
<tr>
<td><strong>Diffusion oxygenated FZ</strong> (n- and p-type)</td>
<td>100, 300</td>
<td>MCz</td>
<td>(~1\times10^3)</td>
<td>(~5\times10^{17})</td>
</tr>
<tr>
<td><strong>Czochralski Si, Sumitomo, Japan</strong> (n-type)</td>
<td>300</td>
<td>Cz</td>
<td>(~1\times10^3)</td>
<td>(~8-9\times10^{17})</td>
</tr>
<tr>
<td><strong>Magnetic Czochralski Si, Okmetic, Finland</strong> (n- and p-type)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Epitaxial layers on Cz-substrates, ITME, Poland</strong> (n- and p-type)</td>
<td>25, 50, 75, 100, 150</td>
<td>EPI</td>
<td>50 – 100</td>
<td>&lt; 1(\times10^{17})</td>
</tr>
<tr>
<td><strong>Diffusion oxyg. Epitaxial layers on CZ</strong></td>
<td>75</td>
<td>EPI–DO</td>
<td>50 – 100</td>
<td>(~7\times10^{17})</td>
</tr>
</tbody>
</table>

- **DOFZ silicon** - Enriched with oxygen on wafer level, **inhomogeneous** distribution of oxygen
- **CZ/MCZ silicon** - high O\(_i\) (oxygen) and O\(_{2i}\) (oxygen dimer) concentration (**homogeneous**)
  - formation of shallow Thermal Donors possible
- **Epi silicon** - high O\(_i\), O\(_{2i}\) content due to out-diffusion from the CZ substrate (**inhomogeneous**)
  - thin layers: high doping possible (low starting resistivity)
- **Epi-Do silicon** - as EPI, however additional O\(_i\) diffused reaching **homogeneous** O\(_i\) content

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- standard for particle detectors
- used for LHC Pixel detectors
- “new” silicon material
WODEAN project (initiated in 2006, 10 RD50 institutes, guided by G.Lindstroem, Hamburg)

- **Aim:** Identify defects responsible for Trapping, Leakage Current, Change of $N_{eff}$
- **Method:** Defect Analysis on identical samples performed with the various tools available inside the RD50 network:
  - C-DLTS (Capacitance Deep Level Transient Spectroscopy)
  - I-DLTS (Current Deep Level Transient Spectroscopy)
  - TSC (Thermally Stimulated Currents)
  - PITS (Photo Induced Transient Spectroscopy)
  - FTIR (Fourier Transform Infrared Spectroscopy)
  - RL (Recombination Lifetime Measurements)
  - PC (Photo Conductivity Measurements)
  - EPR (Electron Paramagnetic Resonance)
  - TCT (Transient Charge Technique)
  - CV/IV

- ~ 240 samples irradiated with protons and neutrons
- first results presented on 2007 RD50 Workshops, further analyses in 2008 and publication of most important results in Applied Physics Letters

... significant impact of RD50 results on silicon solid state physics – defect identification
Summary – defects with strong impact on the device properties at operating temperature

**Point defects**

- $E_i^{BD} = E_c - 0.225 \text{ eV}$
- $\sigma_n^{BD} = 2.3 \times 10^{-14} \text{ cm}^2$

- $E_i^1 = E_c - 0.545 \text{ eV}$
  - $\sigma_n^1 = 2.3 \times 10^{-14} \text{ cm}^2$
  - $\sigma_p^1 = 2.3 \times 10^{-14} \text{ cm}^2$

**Cluster related centers**

- $E_i^{116K} = E_v + 0.33 \text{ eV}$
- $\sigma_p^{116K} = 4 \times 10^{-14} \text{ cm}^2$

- $E_i^{140K} = E_v + 0.36 \text{ eV}$
- $\sigma_p^{140K} = 2.5 \times 10^{-15} \text{ cm}^2$

- $E_i^{152K} = E_v + 0.42 \text{ eV}$
- $\sigma_p^{152K} = 2.3 \times 10^{-14} \text{ cm}^2$

- $E_i^{30K} = E_c - 0.1 \text{ eV}$
- $\sigma_n^{30K} = 2.3 \times 10^{-14} \text{ cm}^2$
Point defects

- \( E^{BD}_{i} = E_{c} - 0.225 \text{ eV} \)
- \( \sigma_{n}^{BD} = 2.3 \cdot 10^{-14} \text{ cm}^{2} \)

- \( E^{I}_{i} = E_{c} - 0.545 \text{ eV} \)
  - \( \sigma_{n}^{I} = 2.3 \cdot 10^{-14} \text{ cm}^{2} \)
  - \( \sigma_{p}^{I} = 2.3 \cdot 10^{-14} \text{ cm}^{2} \)

Cluster related centers

- \( E^{116K}_{i} = E_{v} + 0.33 \text{ eV} \)
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- \( E^{152K}_{i} = E_{v} + 0.42 \text{ eV} \)
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- \( E^{30K}_{i} = E_{c} - 0.1 \text{ eV} \)
- \( \sigma_{n}^{30K} = 2.3 \cdot 10^{-14} \text{ cm}^{2} \)

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Reverse annealing

- leakage current (current after \( \gamma \) irradiation)
- positive charge (higher introduction after proton irradiation than after neutron irradiation)
- positive charge (high concentration in oxygen rich material)

l.Pintilie, NSS, 21 October 2008, Dresden
RD50 Test Sensor Production Runs (2005-2008)

- **Recent production of Silicon Strip, Pixel and Pad detectors (non exclusive list):**
  - **CIS Erfurt, Germany**
    - 2005/2006/2007 (RD50): Several runs with various epi 4” wafers only pad detectors
  - **CNM Barcelona, Spain**
    - 2006 (RD50): 22 wafers (4”), (20 pad, 26 strip, 12 pixel), (p- and n-type), (MCZ, EPI, FZ)
    - 2006 (RD50/RADMON): several wafers (4”), (100 pad), (p- and n-type), (MCZ, EPI, FZ)
  - **HIP, Helsinki, Finland**
    - 2006 (RD50/RADMON): several wafers (4”), only pad devices, (n-type), (MCZ, EPI, FZ)
    - 2006 (RD50): pad devices, p-type MCz-Si wafers, 5 p-spray doses, Thermal Donor compensation
    - 2006 (RD50): full size strip detectors with 768 channels, n-type MCz-Si wafers
  - **IRST, Trento, Italy**
    - 2004 (RD50/SMART): 20 wafers 4” (n-type), (MCZ, FZ, EPI), mini-strip, pad 200-500μm
    - 2004 (RD50/SMART): 23 wafers 4” (p-type), (MCZ, FZ), two p-spray doses 3E12 amd 5E12 cm⁻²
    - 2005 (RD50/SMART): 4” p-type EPI
    - 2008 (RD50/SMART): new 4” run
  - **Micron Semiconductor L.t.d (UK)**
    - 2006 (RD50): 4”, microstrip detectors on 140 and 300μm thick p-type FZ and DOFZ Si.
    - 2006/2007 (RD50): 93 wafers, six inch wafers, (p- and n-type), (MCZ and FZ), (strip, pixel, pad)
  - **Sintef, Oslo, Norway**
    - 2005 (RD50/US CMS Pixel) n-type MCZ and FZ Si Wafers
  - **Hamamatsu, Japan [ATLAS ID project – not RD50]**
    - In 2005 Hamamatsu started to work on p-type silicon in collaboration with ATLAS upgrade groups
      (surely influenced by RD50 results on this material)

Hundreds of samples (pad/strip/pixel) recently produced on various materials (n- and p-type).
n-in-p microstrip detectors

- n-in-p microstrip p-type FZ detectors (Micron, 280 or 300μm thick, 80μm pitch, 18μm implant)
- Detectors read-out with 40MHz (SCT 128A)

- CCE: ~7300e (~30%) after ~ $1 \times 10^{16}$ cm$^{-2}$ 800V
- n-in-p sensors are strongly considered for ATLAS upgrade (previously p-in-n used)

- no reverse annealing in CCE measurements for neutron and proton irradiated detectors
Signal comparison for various Silicon sensors

Silicon Sensors
- p-in-n (EPI), 150 μm [7,8]
- p-in-n (EPI), 75 μm [6]
- n-in-p (FZ), 300 μm, 500 V, 23 GeV p [1]
- n-in-p (FZ), 300 μm, 500 V, neutrons [1]
- n-in-p (FZ), 300 μm, 500 V, 26 MeV p [1]
- n-in-p (FZ), 300 μm, 800 V, 23 GeV p [1]
- n-in-p (FZ), 300 μm, 800 V, neutrons [1]
- n-in-p (FZ), 300 μm, 800 V, 26 MeV p [1]
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Other materials
- SiC, n-type, 55 μm, 900 V, neutrons [3]

References:
[5] 3D, double sided, 250 μm columns, 300 μm substrate [Pennicard 2007]

Note: Measured partly under different conditions!
Lines to guide the eye (no modeling)!
**RD50 Silicon materials for Tracking Sensors**

- **Signal comparison for various Silicon sensors**

![Graph showing signal comparison for various Silicon sensors](image)

- **Silicon Sensors**
  - p-in-n (EPI), 150 μm [7,8]
  - p-in-n (EPI), 75μm [6]
  - n-in-p (EPI), 300μm, 500V, 23GeV p [1]
  - n-in-p (EPI), 300μm, 500V, neutrons [1]
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- **Other materials**
  - SiC, n-type, 55 μm, 900V, neutrons [3]

**Note:** Measured partly under different conditions! Lines to guide the eye (no modeling!)

- Highest fluence for strip detectors in LHC: The used p-in-n technology is sufficient

- **SLHC**
  - n-in-p technology should be sufficient for Super-LHC at radii presently (LHC) occupied by strip sensors

**References:**

[5] 3D, double sided, 250μm columns, 300μm substrate [Pennicard 2007]
LHC Experiments radiation field is a mix of different particles
(in particular: charged hadrons ↔ neutrons)

MCZ silicon has shown an interesting behavior:
- build up of net negative space charge after neutron irradiation
- build up of net positive space charge after proton irradiation

Question:
- What happens when (MCZ) detectors are exposed to a ‘mixed’ radiation field?
Micron diodes irradiated with protons first and then with 2e14 n cm⁻² (control samples p-only, open marker)

- FZ-p,n: increase of $V_{fd}$ proportional to $\Phi_{eq}$
- MCz-n: decrease of $V_{fd}$, due to different signs of $g_{c,n}$ and $g_{c,p}$
- MCz-p at larger fluences the increase of $V_{fd}$ is not proportional to the added fluence – as if material becomes more “n-like” with fluence – same as observed in annealing plots
Both FZ and MCz show “predicted” behaviour with mixed irradiation:

- FZ doses add
  - $|N_{\text{eff}}|$ increases
- MCz doses compensate
  - $|N_{\text{eff}}|$ decreases

Needs further study with both nMCz and pMCz substrates and differing mixed doses

[T.Affolder 13th RD50 Workshop, Nov.2008]
**RD50**

**Development of 3D detectors**

- **“3D” electrodes:**
  - narrow columns along detector thickness,
  - diameter: 10μm, distance: 50 - 100μm

- **Lateral depletion:**
  - lower depletion voltage needed
  - thicker detectors possible
  - fast signal
  - radiation hard

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**From STC to DTC**

- **DDTC:** “double-sided double type columns”
  
  - Columnar electrodes of both doping types are etched into the detector from both wafer sides

- Columns are not etched through the entire detector
  
  - Charge collection expected to be similar to “full 3D” detectors, but the fabrication process is much simpler
1. CNM Barcelona (2 wafers fabricated in Nov. 2007)
   - Double side processing with holes not all the way through
   - n-type bulk
   - Next step: - dice and test 1 wafer
     - bump bond 1 wafer to Medipix2 chips
   - Further production (n and p-type) to follow

2. FBK (IRST-Trento)
   - very similar design to CNM
   - 2 batches under production (n-type and p-type)

- First tests on irradiated devices performed (CNM devices, strip sensors, 90Sr, Beetle chip, $5 \times 10^{15} n_{eq}/cm^2$ with reactor neutrons): 12800 electrons
Two microstrip 3D DDTC detectors tested in testbeam (CMS/RD50)
- One produced by CNM (Barcelona), studied by Glasgow
- One produced by FBK-IRST (Trento), studied by Freiburg

- Readout: APV25, as used in CMS tracker
  - Analogue readout (40 MHz), 50 ns shaping time
  - Trigger accepted during the entire 25 ns clock window (no TDC), but sampling of the signal always at the same time
    - Average detected signal expected to be ≈ 10% lower

[M.Koehler 13th RD50 Workshop, Nov.2008]
Landau distribution

- ADC distribution with fit of a **convoluted Landau and Gaussian**
- Bias voltage: 40 V, SNR ≥ 10
- Result: Landau MP = (33.32±0.02) ADC counts
- Calibration ADC counts → charge so far not available
- Histogram contains data from all bonded strips (**not position resolved**)

[M.Koehler 13th RD50 Workshop, Nov.2008]
Test beam results of heavily irradiated magnetic Czochralski silicon (MCz-Si) strip detectors

Telescope setup

- The telescope reference planes + detectors under test are housed inside a cold chamber, in which the temperature can be adjusted by two water cooled 350 W Peltier elements.
- Reference planes are installed to ±45 degrees (due to the height limitation)
- Reference detectors are D0 Run IIb HPK sensors with:
  - 60 micron pitch and intermediate strips
  - size 4 cm x 9 cm
  - 639 channels
- Readout electronics: CMS 6-APV chip Tracker Outer Barrel hybrids (5 chips bonded)
- DAQ software: a modified version of the CMS Tracker data acquisition software XDAQ
Telescope setup

- An additional cold box was designed for operating very heavily irradiated detectors in cold temperature.
- The box can reach a temperature of $-52^\circ C$. 
MCz-Si detectors

- Detector processing was done at the clean room of Helsinki University of Technology (TKK) Micro and Nanofabrication Centre (MINFAB)

- Materials: n-type Magnetic Czochralski (Okmetic Ltd., Finland) wafers and n-type Float Zone wafers (Topsil, RD50 common order)

- Detector characteristics:
  - AC-coupled
  - 4.1×4.1 cm² area
  - 50 µm pitch
  - strip width 10 µm, strip length 3.9 cm
  - 768 strips per detector (=6*128)
  - Designed for CMS (APV) readout

- MCz detectors depleted with 330 V, Fz sensors with 10 V prior to the irradiation.
The detectors were irradiated to the fluences ranging from $2 \times 10^{14}$ to $3 \times 10^{15}$ 1 MeV n$_{eq}$/cm$^2$ with 26 MeV protons in Karlsruhe and 3 MeV – 45 MeV neutrons (average spectrum 20 MeV) in Louvain.

<table>
<thead>
<tr>
<th>Material</th>
<th>Fluence</th>
<th>n/p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCz</td>
<td>$6.1 \times 10^{14} \pm 20%$</td>
<td>n/p mix</td>
</tr>
<tr>
<td>MCz</td>
<td>$1.1 \times 10^{15} \pm 20%$</td>
<td>n/p mix</td>
</tr>
<tr>
<td>MCz</td>
<td>$1.6 \times 10^{15} \pm 20%$</td>
<td>n/p mix</td>
</tr>
<tr>
<td>MCz</td>
<td>$2.8 \times 10^{15} \pm 20%$</td>
<td>p</td>
</tr>
<tr>
<td>MCz</td>
<td>non-irradiated</td>
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</tr>
<tr>
<td>Fz</td>
<td>$2.4 \times 10^{14} \pm 20%$</td>
<td>p</td>
</tr>
<tr>
<td>Fz</td>
<td>non-irradiated</td>
<td></td>
</tr>
</tbody>
</table>
Test beam results (results from 2007 included)
Detector resolutions (2007 data)

- The resolution doesn’t seem to change much with the irradiation.
- This is most probably due to so-called double junction effect.
Conclusions

- N-type MCz-Si strip detectors have an acceptable S/N at least up to the fluence of $1 \times 10^{15}$ 1 MeV $n_{eq}/cm^2$.

- Thus, n-type MCz-Si detectors are a feasible option for the outer strip layers of the SLHC CMS tracker.

- After the fluence of $3 \times 10^{15}$ 1 MeV $n_{eq}/cm^2$ the collected signal is approximately 20% of the signal of a non-irradiated device.
Latest results of RD39 collaboration

1. Trapping effect on Charge Collection Efficiency (CCE) in Super-LHC
2. Operation of current-injected-detectors (CID)
4. Beam test results of CID strip detectors
5. Summary

Trapping effect on CCE in S-LHC

\[
CCE = \frac{Q}{Q_0} = CCE_{GF} \times CCE_t = \frac{w}{d} \times \left[ \frac{\tau_t}{t_{dr}} \cdot (1 - e^{-t_{dr}/\tau_t}) \right]
\]

Depletion term

Trapping term

Overall CCE is product of
- CCE\(_t\) is trapping factor
- \(CCE_{GF}\) is geometrical factor

For fluence less than \(10^{15}\) neq/cm\(^2\), the trapping term CCE\(_t\) is not significant

For fluence \(10^{16}\) neq/cm\(^2\), \(\frac{\tau_t}{t_{dr}} \ll 1\) the trapping term CCE\(_t\) is a limiting factor of detector operation!

\[
Q = Q_0 \cdot CCE \approx Q_0 \cdot \frac{w}{d} \cdot \frac{\tau_t}{t_{dr}} = q_{MIP} \cdot d \cdot \frac{w}{d} \cdot \frac{v_{dr} \cdot \tau_t}{v_{dr} \cdot t_{dr}} = q_{MIP} \cdot v_{dr} \cdot t_{dr} = q_{MIP} \cdot d_t
\]

- \(d_t\) is trapping distance, and it is about \(20\) \(\mu m\) at \(10^{16}\) neq/cm\(^2\) for non-CID detectors
- \(q_{MIP}\) is unit charge/ \(\mu m\) for MIP in Si = \(80\) e's/ \(\mu m\)
Current injected detector
(principle of operation)

\[ J_p = e \rho \mu E \]
\[ \text{div} J = 0 \]
\[ \text{div} E = p_{tr} \]
\[ E(x=0) = 0 \quad (\text{SCLC mode}) \]

The key advantage:

The shape of \( E(x) \) is **not affected** by \( N_{mgl} \) and **stable** at any fluence.
CCE of strip detectors as a function of fluence

Pitch = 80 μm, width = 20 μm

Larger $\tau_t$ used to fit CID data less trapping in CID
Expected CCE of CID at -50°C

- Simulation takes into account linear dependence of trapping probability on fluence
- \( \beta = 0.01 \text{ cm}^{-1} \)
- \( \sqrt{x} \) E-field distribution is assumed

\[
E_{\text{pin}} \propto \left(1 - \frac{x}{W}\right) \\
E_{\text{CID}} \propto \sqrt{x}
\]
CID, irradiated up to $3 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$

- MCz-Si AC-coupled strip detector with 768 channels
- APV25 readout
- Fabrication of detector and pitch adapter by HIP @ Helsinki University of Technology, Micronova
- Irradiation with 26 MeV protons @ University of Karlsruhe
- Bonding @ University of Karlsruhe
CID strip detector test beam results – CCE at -52°C

Charge Injected Detector (CID) vs reverse biased MCz-Si at -52°C

- MCz-Si non-irradiated
- CID $3 \times 10^{15}$ $n_{eq}/cm^2$
- MCz-Si $3 \times 10^{15}$ $n_{eq}/cm^2$ reverse

Fluence ($n_{eq}/cm^2$):
- $3 \times 10^{15}$ → $1 \times 10^{16}$
- 75% → 22.5% (5400 e's)
- 20% → 6% (1440 e's)

Collected charge [counts] vs Voltage [V]
Noise of CID and non-irradiated detector

CID noise at -40 °C
Little change with T (-53 to -40 °C)

Reference detector noise at -20°C
Fz-Si p+/n-/n+, same design, same processing, $V_{fd} \sim 10V$
Tracking efficiency of CID vs reference

CID at -53°C

Reference Fz-Si at -20°C

Tracking efficiency = probability that DUT measures the same track as the reference telescope
Conclusions

• CID offers: full depletion and less trapping
• At least two times greater CCE is expected from CID than in reverse biased detectors according to measurements and simulations.
• Normal detector operation possible with 300μm MCz-Si up to 1-2×10^{15} \text{n}_{eq}/\text{cm}^2 fluence, i.e. strip layers in Super-LHC trackers.
• CID was measured at -40°C, -45°C and -53°C (768 channels AC-coupled MCz-Si strip detector) in test beam.
• Test beam results reveal >70% CCE, and S/N >10 after 3×10^{15} \text{n}_{eq}/\text{cm}^2 irradiation.
• Test beam was performed with CMS electronics and DAQ (SiBT).
• CID operation possible up to 1×10^{16} \text{n}_{eq}/\text{cm}^2 fluence.
• Collected charge equals \approx 7000e^{-} and 30% at this fluence.