Radiation Environment and Damage in the CDF Tracking Volume

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Outline

• Introduction
  – Accelerator environment
  – Detector environment
  – Why these measurements

• TLD Radiation Measurements
  – Thermal Luminescent Dosimeters
  – Exposure statistics
  – Data
  – Model

• Diode Radiation Measurements
  – PIN diodes
  – Calibration with TLD data

• Summary & Conclusions
Experiment Environment

Accelerator:
- 980 GeV proton(p)/antiproton(pbar) beams
- 36 bunches ~$10^{10}$ part/bunch
- Beam currents p:pbar = 10:1
- Radiation from beam halo
  - Beam-gas collisions
  - Interactions in collimators
Experiment Environment

Detector:
Cylindrically symmetric detector at collision point.
- Collisions can occur every 396ns
- ~10 charged particles/collision
- Radiation from collisions
  - Ionizing radiation ($\gamma$, charge particles)
  - Neutrons
Radiation Measurement

Goal:

Accurately measure radiation field
⇒ Predict silicon detector’s useful lifetime

Considerations:

Redundancy
Absolute Calibration
Accuracy

Detector Technologies:

**Thermal Luminescent Dosimeters (TLDs)**

+ Industry standard
+ Good precision
+ Large dynamic range: \((10\mu\text{Gy} - 2\text{kGy})\)
+ Calibrate with \(^{137}\text{Cs}(\gamma), \text{~}^{252}\text{Cf}(n)\)
- Harvest & read each chip
- Large amount of handling

**PIN Diodes**

+ Large dynamic range: \((10\text{Gy} - 10\text{MGy})\)
+ Remote readout
- Temperature history
- In-situ calibration
Measurement Technique

**TLDS:** (~1000 dosimeters in 145 locations)

- **2 types of dosimeters**
  - TLD-700 ($^7$LiF): ionizing radiation
  - TLD-600 ($^6$LiF): ionizing radiation & low energy neutrons ($E_n < 200$ keV)

- **Calibration**
  - 1% reproducibility, 3% chip-to-chip variation
  - **Ionizing radiation:** 10 mGy exposure to $^{137}$Cs
  - **Neutrons:** 10 mGy exposure to $^{252}$Cf

**PIN Diodes:** (12 diodes in 10 locations)

Cross calibrated with TLDs

Portland, OR
Exposure Conditions

Beam conditions:

- **Collisions (luminosity at CDF):**
  - Measured by Cherenkov radiation counters (A. Sukhanov N11-1)

- **Losses of incoming p and pbar:**
  - Monitored by scintillator counters near beam pipe on either side of CDF

### Three TLD exposure periods

<table>
<thead>
<tr>
<th>Period</th>
<th>Beam ($x10^{18}$)</th>
<th>Losses ($x10^9$)</th>
<th>Ldt (pbarn$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb.– May 2001</td>
<td>0.702</td>
<td>15.3</td>
<td>0.058</td>
</tr>
<tr>
<td>May– Oct. 2001</td>
<td>15.6</td>
<td>40.9</td>
<td>12.3</td>
</tr>
</tbody>
</table>

Feb. – May: p-loss/collision=$264x10^9$/pbarn$^{-1}$
May – Oct.: p-loss/collision=$3.3x10^9$/pbarn$^{-1}$
Oct. – Jan.: p-loss/collision=$1.6x10^9$/pbarn$^{-1}$

**NOTE:** 1 pbarn$^{-1}$ ~ 5x$10^{10}$ p-pbar collisions
TLD Data (Ionizing Radiation)

Loss dominated
20% collisions

Collision dominated
82% collisions

Collision dominated
91% collisions

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TLD Data (Neutrons)

Loss dominated data

Collision dominated data

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Separating Collision/losses

Assume radiation is a linear superposition of collisions and losses

\[ D_1(x,y,z) = l_1 L(x,y,z) + c_1 C(x,y,z) \]
\[ D_2(x,y,z) = l_2 L(x,y,z) + c_2 C(x,y,z) \]
A Simple Model

Use previous experience to build a simple model of the radiation field.*


- Assumptions:
  - Radiation has cylindrical symmetry about the beam
  - Field follows power law: \( D \sim A r^{-\alpha} \)
    \( \alpha = \) power law exponent
    \( A = \) Normalization
Ionizing Radiation Fields

Collisions

Proton Losses

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PIN Diodes

- TLDs → Radiation field
- PIN diodes scale radiation

![Graph showing the relationship between bias voltage and current for different diodes.](image1)

![Graph showing the relationship between bias voltage and current for different r values.](image2)
Comparison with Si Data

• Si bias current increase rate measurements
  - Correct for temperature (8→20°C)
  - Include $\alpha_{\text{damage}} = 3.0 \times 10^{17}$ A/cm
  - Extrapolate TLD results 17cm→1.7cm
Summary

• Installed ~1000 TLDs, 12 diodes in CDF.
  – Photon & neutron measurements.
  – Bias current increase calibrated with TLDs.

• TLDs yielding accurate measurements of radiation environment in CDF.
  – $\gamma$ radiation $\sim$5% uncertainty.
  – Multiple measurements internally consistent
  – Separate fields from collisions and losses.

• New details
  – Predict radiation for given beam conditions
  – PIN diodes to scale radiation field
  – Early prediction of detector lifetime

• Quantitative agreement between Si detectors and TLD data.
Si Bias Current Data

Si detector bias current vs collisions

- Calculate $I_{bias}$/volume of each sensor
- Correct to 20°C
TLD Calibrations

- TLD non-linearity calibration
Neutron Calibration

$^6\text{Li}(n,t)^4\text{He}$

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Neutron Calibration

- 252 Cf Spectrum

![Graph showing the 252 Cf spectrum](image)

\[\frac{dN}{dE} \text{ (neutrons/MeV)}\]

\[^{252}\text{Cf} \text{ spontaneous fission}\]

\[N_{cf}/\text{fission} = 20\]