A Measurement of the Radiation Field in the CDF Tracking Volume

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(CDF Radiation Monitoring Group)
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Why Measure Radiation?

Motivation

- Correlate information w/ beam
- Predict radiation damage to inner devices

Method: Thermal Luminescent Dosimeters

- TLD features
  + Continuously integrates radiation
  + Passive
  + Large dynamic range 1mRad – 200kRad
  + On-site TLD reader “fast turn around”
  + Industry standard
- Requires harvesting + reading individual dosimeters
- Large amount of handling
Thermal Luminescence

Ionizing radiation

\[ \text{Detection of ionization from } ^3\text{H} \]

Neutron absorption

\[ ^6\text{Li} + n \rightarrow ^3\text{H} + \alpha \]

Detect ionization from \(^3\text{H}\)
Measurement Technique

“The Devil is in the details…”

Considerations:
- Redundancy multiple measurements
- Low mass light materials
- Low profile thin materials
- $\gamma$, n meas. 2 types of dosimeters

Implementation

- 2 types of dosimeters in a holder
  - TLD-700 $^7$LiF $\gamma$ sensitive
  - TLD-600 $^6$LiF $\gamma$, n sensitive
- 3 TLD chips of each type per holder

0.8mm thick FR-4
TLD Locations

<table>
<thead>
<tr>
<th>Location</th>
<th># φ</th>
<th># z</th>
<th># r</th>
<th>Total # Holders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug faces</td>
<td>8</td>
<td>2</td>
<td>5</td>
<td>80</td>
</tr>
<tr>
<td>SVX</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>ISL</td>
<td>8</td>
<td>5</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td><strong>Total # TLD chips</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>916</strong></td>
</tr>
</tbody>
</table>

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TLD Locations

How do we install holders?
Magnet Bore

Finding the leaders in CDF
Calibration

All dosimeters of each type from a single batch
- Chip to chip response variation ~3%

All dosimeters γ response calibrated w/ 1 Rad exposure to a $^{137}$Cs source
- Reproducibility <1% variation
- Absolute scale ~1% uncertainty

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Neutron Calibration

- 10 mRad exposure to $^{252}$Cf
  - 15% variation
  - 10% scale uncertainty
TLD Non-linearity

LiF exhibits super linearity $\sim 100\text{Rad}$

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**Dosimetry**

**Ionizing Radiation Dosimetry**

\[
D_\gamma = C(kR)kR - D_c
\]

- **R**  TLD reading (nC)
- **k**  \(1/(1 \text{ Rad response}) \) (Rad/nC)
- **C(kR)**  non-linearity correction
- **D_c**  control dose (Rad)

**Neutron Radiation Dosimetry**

\[
D_n = \{C(kR)kR - D_c\} - D_\gamma
\]

- **R**  TLD reading (nC)
- **k**  \(1/(1 \text{ Rad response}) \) (Rad/nC)
- **C(kR)**  non-linearity correction
- **D_c**  control dose (Rad)
- **D_\gamma**  ionizing radiation dose (Rad)
Beam Monitoring

Losses (beam shower counters)
- Scintillation counters

Radiation (beam loss monitors)
- Ionization chambers
- Wagon wheel (TLDs)
- BLMs
- Luminosity Monitor
Exposure Statistics

Beam Statistics

<table>
<thead>
<tr>
<th></th>
<th>Feb. - May</th>
<th>May - Oct.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>0.0703</td>
<td>1.56</td>
<td>$10^{19}$</td>
</tr>
<tr>
<td>Pbar</td>
<td>0.0082</td>
<td>0.137</td>
<td>$10^{19}$</td>
</tr>
<tr>
<td>P-losses</td>
<td>1.06</td>
<td>2.84</td>
<td>$10^9$</td>
</tr>
<tr>
<td>Pbar-losses</td>
<td>0.14</td>
<td>0.71</td>
<td>$10^9$</td>
</tr>
<tr>
<td>$\int L dt$</td>
<td>0.058</td>
<td>10.7</td>
<td>$pb^{-1}$</td>
</tr>
</tbody>
</table>

Beam Loss Monitors

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inner</td>
<td>Outer</td>
</tr>
<tr>
<td>Proton</td>
<td>7.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Pbar</td>
<td>241</td>
<td>224</td>
</tr>
</tbody>
</table>

Feb. - May loss dominated
May - Oct. collision dominated
BLMs insensitive to collisions
**Data**

**Feb - May 2001 Exposure**

- \( r = 34 \text{ cm} \) (ISL space tube)
- \( r = 17 \text{ cm} \) (SVX space tube)

**May - Oct 2001 Exposure**

- \( r = 34 \text{ cm} \) (ISL space tube)
- \( r = 17 \text{ cm} \) (SVX space tube)

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Neutrons

Feb. – May 2001

Loss dominated

May – Oct. 2001

Collision dominated

protons antiprotons

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Collisions & Losses

Motivation:
- Dose different for collisions/losses
- Collisions should dominate losses even more in the future
  ⇒ Better prediction of radiation field

Method: Linear model

\[ D_1 = L_1 d_L + C_1 d_C \]
\[ D_2 = L_2 d_L + C_2 d_C \]

- \( L_i \): measured losses
- \( C_i \): measured collisions (luminosity)
- \( d_L \): dose/unit losses
- \( d_C \): dose/unit luminosity

Solve for \( d_L \) and \( d_C \)
  ⇒ Unnecessary for neutrons
Collisions & Losses

Collisions

- SVX space tube (r=17.7cm)
- ISL space tube (r=34.7cm)
- p-Loss Scale Uncertainty

Proton Losses

- SVX space tube (r=17.7cm)
- ISL space tube (r=34.7cm)

May - Oct: $L/C = 3.9 \times 10^9 / pb^{-1}$

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Finding the Beam w/ TLDs

Beam and Detector cylindrically symmetric

Beam Axis
Detector Axis
Radiation Field

\[ \phi \text{ (Radians)} \]

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Data ($\Phi$)

Fit $\text{Acos}(\phi - \phi_0) + D_{\text{avg}}$  \hspace{1cm} $\phi_0$: 1.7–2.0

Measured beam offset  
$\phi_0=1.81$ radians  
$d_0=4.1$ mm
Modeling

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


Assumptions

- Radiation has cylindrical symmetry about the beam.
- Field follows a power law in $1/r$.

Fit the data to the following form:

$$D(x,y) = A \{ (x-x_0)^2 + (y-y_0)^2 \}^{-\alpha/2}$$

- $D(x,y)$: radiation dose
- $A$: absolute normalization
- $(x_0, y_0)$: beam position offset
- $\alpha$: power law exponent

Note: Run I radiation damage profile yields $\alpha = 1.6 - 1.7$. 
Results

Statistical uncertainties only!

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Ionizing Radiation Map

10.7 pb\(^{-1}\) delivered luminosity
Silicon Leakage Currents

- Leakage Si current increase rate measurements
  - Correct for temperature (8 → 20 C)
  - Include $\alpha_{\text{damage}} = 3.0 \times 10^{-17}$ A/cm

![Graph showing fluence vs. $\phi$ (radians)](image)

- Si $I_{\text{leak}}$ data ($r = 1.7$ cm)
- TLD + Model prediction

Preliminary
CMS Projections

Conversion Factors

\[ \gamma: \text{1 rad} = 3.8 \times 10^7 \text{MIPs/cm}^2 \]
\[ n: \text{1 rad} = 3.2 \times 10^8 \text{n/cm}^2 \text{ (thermal)} \]

Assumptions:

- Scaling of CDF measurements
- \( L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \)
- \( 10^7 \text{ sec/year} \)

CMS expected dose/year

Inner PIXEL detector (r=4.3cm)

\[ \gamma: \ 6.6 \times 10^{14} \text{ MIPs/cm}^2 \]
\[ n: \ 1.9 \times 10^{14} \text{n/cm}^2 \text{ (thermal)} \]
Summary

• Installed ~1000 TLDs in CDF
  - Photon and neutron measurements

• TLDs yield accurate measurements of radiation environment in CDF
  - $\gamma$ radiation ~5% uncertainty
  - Separate fields from collisions and losses
  - N radiation ~20% uncertainty

• Qualitative agreement with expectations
  - Beam losses & collisions
  - Neutrons field

• New details emerging
  - Predict radiation for given beam conditions
  - Early prediction of detector lifetime
  - Naïve model from early experience (Tevatron Run I) needs update

• Semi quantitative agreement with Si data