Single Event Effects and Their Mitigation at the Collider Detector at Fermilab

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for the CDF Radiation Monitoring Group
CDF-II Detector (G-rated)

\[ E_{cm} = 1.96 \text{ TeV} \]
CDF Detector (Adults Only)

Readout, control and support electronics located on the detector:

- 5kW custom low voltage (LV) switching power supplies
- Commercial remotely operated high voltage (HV) switching power supplies
- Custom digitizing and readout electronics
  - 9U VME crate (FPGA based)
  - 1 kW custom low voltage (LV) linear power supplies.
- Custom digitizing and readout electronics
  - 6U VME crate (FPGA based)
Operational Problems

Custom low voltage switching power supplies
- catastrophic component failure only with beam present
- average ~3 failures/week
- 12 failures in single day (St. Catherine’s day massacre)
- single event burnout (SEB) of power MOSFET

Commercial high voltage switching power supplies (CPU controlled)
- “soft” failure when beam present
- loss of communication/cpu hang
- loss of calibration constants
- 10% of non-accelerator down time due to problem+recovery

Custom detector readout electronics (Shower Maximum, SMX, system)
- soft failure when beam present
- only systems near beam line fail
- communication interrupt/hang
- 6% of non-accelerator down time due to problem+recovery
Low Voltage Power Supply Failures

Failure Characteristics
- **Position Dependent**
- **Beam Related**

Experiments show focusing quads are a line source of radiation.

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Failure Locations

*SVX Readout*

- **West**
- **East**

*COT Readout*

- **West**
- **East**

- **N** = north
- **S** = south
- **T** = top
- **B** = bottom

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Silicon detector readout
Central tracker readout

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protons
antiprotons

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NORTH
Low Voltage Power Supply Failures

Power Factor Corrector Circuit

Most failures were associated with high beam losses or misaligned beam pipe

> Power MOSFET SEB (radiation induced)

epoxy covering fractured

silicon in MOSFET sublimated during discharge through single component
Single Event Burnout (SEB)

SEB Features
- catastrophic
- beam related
- damage at low doses
- depends on bias voltage

SEB cross section measurement

Solution (lower Vbias)
- Factor of 50 reduction in radiation sensitivity
- No failures in > 2 years operation

What about radiation?

Test beam data, 200 MeV protons

*Indiana Cyclotron*

R.J. Tesarek, C. Rott, R. Napora, C. Rivetta
High Voltage Power Supplies

Commercial system (CAEN SY527 mainframe)

Only system in collision hall fail

Failure Modes:

<table>
<thead>
<tr>
<th>Observed Failure</th>
<th>Recovery Action</th>
<th>Likely Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Communication lost</td>
<td>CPU reset</td>
<td>SEU in CPU/EPROM</td>
</tr>
<tr>
<td>b. Power supply modules spontaneously turn off</td>
<td>turn on HV</td>
<td>SEU in KILL logic (FPGA)</td>
</tr>
<tr>
<td>c. Garbled information from crate (ie, voltage reads 10.0V, nominal 150.0V)</td>
<td>CPU reset</td>
<td>SEU in RAM memory</td>
</tr>
</tbody>
</table>

Assistance from manufacturer: **modify firmware to shorten recovery time**

- enable CPU watchdog
- enhance error checking

Anticipate order of magnitude reduction of down time
Shower Maximum (SMX) Readout

Custom designed system

Communication lost in system

- only occurs for systems in highest radiation areas
- requires power cycle to recover
- ram based calibrations must be restored (re-calibration)
- 30 minute recovery time
- failed component not yet identified (2700 FPGAs)

Modify procedures to always write calibrations to non-volatile (FRAM) memory

- recovery time reduced to few minutes.
Radiation Shielding?
Scintillation counter measurements show low beta quadrupoles form a line source of charged particles.

Power supply failure analysis shows largest problem on the west (proton) side of the collision hall.

Shielding reduces ionizing radiation by 25%

CDF Detector w/ additional shielding
Collision Hall Ionizing Radiation Field

Thermal luminescent dosimeter (TLD) measurements
Shielding installed on proton side only.

\[ \text{Ratio} = \frac{R_{\text{shielding}}}{R_{\text{no shielding}}} \]


R.J. Tesarek
IEEE-NSS/MIC El Conquistador Resort, Puerto Rico
24-30 October 2005
Simulated Radiation Environment

Detailed MARS simulation of:

- accelerator & beam transport
- collision hall & detector

![Graphs showing simulated radiation environment with various fluxes for Neutrons, Charged Hadrons, Gammas, and Muons.](image-url)
Halo (Beam Loss) Reduction

Vacuum problems identified in 2m long straight section of Tevatron (F sector)

Improved vacuum (TeV wide)

Commissioning of collimators to reduce halo

> Halo/proton reduced by factor of 10.

> Physics backgrounds reduced by ~40% in some triggers

Requires good beam quality monitoring

R. Moore, V. Shiltsev, N.Mokhov, A. Drozdhin
Summary

Single event effects (S.E.E.) observed at CDF in multiple systems/components

At present ~16% of down time traced to S.E.E.

Attack problems on multiple fronts:

- identify problem component
- modify operating conditions
- understand radiation and shield where possible
- reduce radiation from accelerator (collimation, improved operation)
- modify software/firmware to make system failure tolerant
- modify system/procedures to reduce recovery time after failure

Work continues...
References (Incomplete List)

General:
- http://ncdf67.fnal.gov/~tesarek

CDF Instrumentation:
- A.Bhatti, et al., *CDF internal note*, CDF 5247.

Beam Halo and Collimation:

Radiation:
Active Dosimeters

SEU counters (memories) >20 MeV hadrons

PIN diodes 1 MeV n equivalent

Thijs Wijnands, Christian Pignard

Located near sensitive electronics

Readout at ~1 Hz

LHC prototype

RadFETs γ–e dose
CDF Detector (Adults Only)

Power Supplies on the CDF Detector

- 36 switching supplies (5kW)
  - 28 “shielded”
- 38 linear supplies (1kW)
  - all “shielded”
- ~200 linear supplies (0.3kW)
  - all “shielded”

“shielded” means no line of sight to beam.

- Switching Power Supplies (5kW)
- Linear Power Supplies (1kW, 0.3kW)
- HV Mainframe
Typical Store

Beam Parameters:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Rate (kHz)</th>
<th>Limit (kHz)</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>5000 - 9000</td>
<td>$10^9$ particles</td>
<td></td>
</tr>
<tr>
<td>Antiprotons</td>
<td>100-1500</td>
<td>$10^9$ particles</td>
<td></td>
</tr>
<tr>
<td>Luminosity</td>
<td>10 - 50</td>
<td>$10^{30}$ cm$^{-2}$s$^{-1}$</td>
<td></td>
</tr>
</tbody>
</table>

Losses and Halo:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Rate (kHz)</th>
<th>Limit (kHz)</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Losses</td>
<td>2 - 15</td>
<td>25</td>
<td>chambers trip on over current</td>
</tr>
<tr>
<td>Pbar Losses</td>
<td>0.1 - 2.0</td>
<td>25</td>
<td>chambers trip on over current</td>
</tr>
<tr>
<td>P Halo</td>
<td>200 - 1000</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Pbar Halo</td>
<td>2 - 50</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Abort Gap Losses</td>
<td>2 - 12</td>
<td>15</td>
<td>avoid dirty abort (silicon damage)</td>
</tr>
<tr>
<td>L1 Trigger</td>
<td>0.1-0.5</td>
<td></td>
<td>two track trigger (~1 mbarn)</td>
</tr>
</tbody>
</table>

Note: All number are taken after scraping and HEP is declared.