Beam Induced Backgrounds: CDF Experience and LHC

R.J. Tesarek
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Beam Induced Backgrounds: CDF Experience and LHC
or
Where Did That Come From?

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Outline

Tevatron and CDF
Instrumentation/Measurements
  • Losses
  • DC Beam

Effects Observed at CDF (sources/cures)
  • Single event effects (SEE)
  • Chronic radiation damage
  • Physics Backgrounds

Accelerator Improvements
  • Measurements
  • Instrumentation

Summary

Work by many machine and experiment people
Tevatron Beam Structure

Beam Parameters

- Interaction regions: 2
- Beam energy: 980 GeV
- # bunches: 36
  (3 trains of 12 bunches)
- Bunch length: 1 ns
- Bunch spacing: 396 ns
- Abort gap: 2.6 μs
- Protons/bunch: 30x10^{10}
- Pbars/bunch: 8x10^{10}
- Luminosity: 2.8x10^{32} cm^{-2}s^{-1}
- RF frequency: 53 MHz

Both beams in same vacuum pipe

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CDF-II Detector (G-rated)

$E_{cm} = 1.96 \text{ TeV}$
Measuring Beam Losses/Halo at CDF

Losses/Halo rates measure beam conditions/risk

Beam Losses all calculated in the same fashion

- Detector signal in coincidence with beam passing the detector plane.
- ACNET variables differ by detector/gating method.
- Gate on bunches and abort gaps

Definitions:
lost particles: close to beam
halo particles: far from beam
Beam Monitors

BSC counters: monitor beam losses
Halo counters: monitor beam halo and abort gap

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Beam Halo Loss Detectors

Halo Counters

Beam Shower Counters

ACNET variables:

- **B0PHSM**: beam halo
- **B0PBSM**: abort gap losses
- **B0PAGC**: 2/4 coincidence abort gap losses
- **B0PLOS**: proton losses (digital)
- **LOSTP**: proton losses (analog)
Activated quadrupole steel
- Periods of sustained high losses
- Large beam “accident”
- $\beta$ radiation mostly
  - Lose timing info
  - Contaminate measurement

Majority 2/4 coincidence
- Reduces contamination
- Reduces overall rate
- Insensitive to single particles

$^{48}\text{K}(\tau = 9.6\text{ sec})$

$^{46}\text{K}(\tau = 2.5\text{ min})$

$^{38}\text{K}(\tau = 11\text{ min})$
Beam Structure (from losses)

Not all beam is in bunches!
beam in abort gaps => dirty aborts

Abort Gap
2.6μs

"DC Beam"

Note: detector reset cycles during abort gaps susceptible to abort gap losses.
Monitor Experience

“Typical Good Store”

proton beam current
proton abort gap halo
proton halo
proton losses
Abort Gap Monitors

“DC” Beam in Abort Gap
- Risk to detectors on abort (acute radiation damage)

Abort Gap Halo (losses)
- fast
- VERY sensitive
- sensitive to ANY problem in Tevatron
  - good canary for experiment
  - bad debugging tool for accelerator

Sync. Light Measurements
- “direct” measure of beam in abort gap
- slow
Abort Gap Beam & Losses

- Abort gap beam (sync. light)
- Abort gap losses (counters)
“DC Beam”

Notes:
- Losses from “DC” or un-captured beam only increase
- “Cleaning” of abort gaps necessary for detector safety

Possible Sources
- Noise in RF systems
- Inter Beam Scattering (IBS)

LHC:
- Care taken in RF system design
- Rate of “DC” beam production at LHC unknown
Beam Radiation Measurements

TLDs installed in tracking volume
3 exposure periods
- 0.06 pbarn\(^{-1}\) (p-loss dominated)
- 12.3 pbarn\(^{-1}\)
- 167 pbarn\(^{-1}\)

![Diagram showing a cross-section of the tracking volume with labeled components and dose measurements.]

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**February 25, 2001 - May 2, 2001**
- SVX spacetube (r = 18 cm)
- ISL spacetube (r = 35 cm)
- 20% collisions
- 0.06 pbarn\(^{-1}\)

**May 2, 2001 - October 18, 2001**
- SVX spacetube (r = 18 cm)
- ISL spacetube (r = 35 cm)
- 82% collisions
- 12.3 pbarn\(^{-1}\)

**October 18, 2001 - January 13, 2003**
- SVX spacetube (r = 18 cm)
- ISL spacetube (r = 35 cm)
- 91% collisions
- 167 pbarn\(^{-1}\)

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Radiation from Collisions

TLD measurements + model

$r$ measured transverse to the beam

$$\text{Dose} = \frac{A}{r^\alpha} \quad \alpha \sim 1.5; \quad |z| < 100\text{cm}$$
Radiation from Beam Losses

TLD measurements + model

\[ \text{Dose} = \frac{A}{r^\alpha} \quad \alpha \sim 1.8; \ |z| < 100\text{cm} \]
Silicon Detector Dose (Damage)

Measure $I_{\text{bias}}$

- correct Temp. to 20°C
- $\alpha_{\text{damage}} = 3.0 \times 10^{17} \text{A/cm}$

Early comparison with TLD Data

- Assume $r^{-\alpha}$ scaling
- $1 \text{Gy} = 3.8 \times 10^9 \text{MIPS/cm}^2$

Temp profile of SVX sensors poorly understood.

Note: Beam offset 5mm from detector axis

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Simulated Ionizing Radiation

MARS simulation of CDF
- collisions simulated by DPMJET
- absolute normalization from first principles
+ Quantitative understanding of collision dose (dominant)
- Losses not understood!

Possible issues
- source of losses?
- forward material distribution?

L. Nicolas, N.V. Mokhov
Neutron Measurements

TLD Measurements sensitive to low energy neutrons
- $E_n < 2$ keV

Low Energy Measurements
- flat spacial distribution
- albedo from calorimeters

Distributions consistent with expectations
Conversion Factors

\[ \gamma: \ 1 \text{ Gy} = 3.8 \times 10^9 \text{ MIPS/cm}^2 \]
\[ n: \ 1 \text{ Gy} = 3.2 \times 10^{10} \text{ n/cm}^2(\text{thermal}) \]

Assumptions

- scale CDF measurements
- collision dominated radiation
- luminosity = $10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- $10^7 \text{ sec/year}$

Expected tracker dose/year

Inner detectors ($r = 4.3\text{cm}$)

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

Measurement based projections consistent with predictions


Radiation dose calculator
CDF Ionizing Radiation Field
TLD + model (similar to tracking volume)

\[ Dose = \frac{A}{\rho^\alpha} \]


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Neutron Spectrum Measurement

Evaluate Neutron Energy Spectrum

- Bonner spheres + TLDs
- ~1 week exposures
- Shielding in place

Measuring neutrons is hard
Work in progress...

Polyethylene “Bonner” spheres

Bonner sphere locations

protons

antiprotons
Neutron Data

Compare data with $^{252}$Cf

- spontaneous fission
- $\sim$20 n/decay
- $<E_n> \sim 2$ MeV

Data show average $E_n < 2$ MeV

To do:
- understand $E_n$ distribution
- neutron fluence

Collision hall data

$^{252}$Cf (calibration)

W. Schmitt, et al.

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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 commercial low voltage (LV) linear power supplies.
- Custom digitizing and readout electronics
  - 6U VME crate (FPGA based)

This space for rent
Contact: R.Roser
roser@fnal.gov
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
12 switching power supplies failed in an 8 hour period.

- only during beam
- only switching supplies
- failures on detector east side
- shielding moved out
- new detector installed
- beam pipe misaligned

**Conclusion:** Albedo radiation from new detector
L.V. Power Supply Failures

Power Factor Corrector Circuit

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

Power MOSFET Single Event Burnout (SEB)

silicon in MOSFET sublimated during discharge through single component

epoxy covering fractured
Low Voltage Power Supply Failures

Failure Characteristics
- Position Dependent
- Beam Related

Experiments show focusing quads are a line source of radiation

Failure Locations

SVX Readout

COT Readout

Silicon detector readout
Central tracker readout

protons
antiprotons

NORTH

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Detected configuration different in Run II

- Run I detector “self shielded”
- Additional shielding abandoned (forward muon system de-scoped).
- Shielding installed surrounding beam line.
Radiation and 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

Thermal luminescent dosimeter (TLD) measurements
Shielding installed on proton side only.
25% reduction in radiation confirmed with measurements.

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

Active Dosimeters

SEU counters (memories) >20 MeV hadrons
PIN diodes 1 MeV n equivalent

Thijs Wijnands, Christian Pignard
Located near sensitive electronics
Readout at ~0.1 Hz
LHC prototype

v2 Now installed around LHC

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CDF Radiation Field
(ionizing radiation)

Exposure Period: 27 April - 28 September 2005
Jet/Missing $E_T$ Backgrounds

W trigger requires energy imbalance in calorimeters.

Trigger: Missing $E_T > 25$ GeV

$\phi = \pi$ : muon bremsstrahlung

$\phi = \frac{n\pi}{2}$ : peak/background $\sim$ beam current
“Jet/MET” Background Events

Events show “track” in calorimeter
- High energy muon
- Beam “halo” hitting Roman pot detectors

Calorimeter Schematic

Particle “tracks”
Plug Calorimeter Backgrounds

Gaps in shielding aligned with backgrounds

"Fin" to plug 2" gap between torroid halves

5cm gap
W Decay: \( W^+ \rightarrow e^+ \nu \)
- Require energy matched to track
- signal:halo >358:1 (95%CL)

Graviton search: \( \bar{p}p \rightarrow G\gamma \)
- Require good EM shower shape
- Require no contiguous energy in \( \phi \) slice.
- Limited by Standard Model processes: \( Z^0 \rightarrow \nu\bar{\nu}\gamma \)
- Z background:halo >16:1 (68%CL)

Advances in selection criteria give halo suppression >1000
Halo (Beam Loss) Reduction

Vacuum problems identified in 2m long straight section of Tevatron (F sector ~ 1km from detector!)

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

Collaborative effort between experiment and accelerator

R. Moore, V. Shiltsev, N. Mokhov, A. Drozdhin
Collimators in Action

- E0 collimator
- Proton beam current
- Proton halo
- Proton losses
“Poor Collimation” Example

antiproton abort gap losses
Dzero Roman Pot position
antiproton losses
Improvements

2004 shutdown
- adjust low beta quads/magnet unroll
- dipole coil lift (skew quad component)
- Added separators (wider separation of beams)
- Moved Dzero separators

2005 shutdown
- adjust low beta quads/magnet unroll

2006 shutdown
- adjust low beta quads/magnet unroll

2007 shutdown
- adjust low beta quads/magnet unroll
Typical Store (2004)

Beam Parameters:

Protons: 5000 - 9000 $10^9$ particles

Antiprotons: 500-1500 $10^9$ particles

Luminosity: 30 - 70 $10^{30} \text{cm}^{-2}\text{s}^{-1}$

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.
Typical Store (2005)

Beam Parameters:

<table>
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<tr>
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<th>Limit (kHz)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>5000 - 10000</td>
<td>10^9 particles</td>
<td></td>
</tr>
<tr>
<td>Antiprotons</td>
<td>500-1800</td>
<td>10^9 particles</td>
<td></td>
</tr>
<tr>
<td>Luminosity</td>
<td>50 - 170</td>
<td>10^30 cm⁻²s⁻¹</td>
<td></td>
</tr>
<tr>
<td>P Losses</td>
<td>0.1 - 0.5</td>
<td>25</td>
<td>chambers trip on over current</td>
</tr>
<tr>
<td>Pbar Losses</td>
<td>0.1 - 3.0</td>
<td>25</td>
<td>chambers trip on over current</td>
</tr>
<tr>
<td>P Halo</td>
<td>15 - 18</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Pbar Halo</td>
<td>20 - 100</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Abort Gap Losses</td>
<td>0.1 - 15</td>
<td>25</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>

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Typical Store (2007-8)

**Beam Parameters:**

- **Protons:** 5000 - 10000 $10^9$ particles
- **Antiprotons:** 1000-3000 $10^9$ particles
- **Luminosity:** 50 - 300 $10^{30}$ cm$^{-2}$s$^{-1}$

**Losses and Halo:**

<table>
<thead>
<tr>
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<th>Rate (kHz)</th>
<th>Limit (kHz)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Losses</td>
<td>0.05 - 15*</td>
<td>25</td>
<td>chambers trip on over current</td>
</tr>
<tr>
<td>Pbar Losses</td>
<td>0.02 - 3.0*</td>
<td>25</td>
<td>chambers trip on over current</td>
</tr>
<tr>
<td>P Halo</td>
<td>3 - 100*</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Pbar Halo</td>
<td>40 - 100*</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Abort Gap Losses</td>
<td>0.5 - 1.5*</td>
<td>25</td>
<td>avoid dirty abort (silicon damage)</td>
</tr>
<tr>
<td>L1 Trigger</td>
<td>0.1-0.5</td>
<td>10</td>
<td>two track trigger (~1 mbarn)</td>
</tr>
</tbody>
</table>

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

*High losses for first 2 hrs of store (decreasing rapidly) nearly steady state at lower value thereafter.*
Observations

Accelerator Backgrounds at CDF (Losses)

- Beam is not always where you think it is (abort gaps)
- Beam losses may cause operational problems/physics backgrounds
- Origins of backgrounds may be far from detectors
  + Understanding losses $\Longleftrightarrow$ understand detector and accelerator
  + dialog between experiment and accelerator crucial
- Real time beam monitoring important
- Measurement of backgrounds early helps identify potential problem areas

Accelerator Backgrounds at LHC

- Many backgrounds anticipated (workshops,)
- Some surprises at CDF/Tevatron $\Longrightarrow$ Evaluation at LHC
- DC (un-captured) beam
- Effect of Roman Pot detectors
- Dialog between Accelerator/Experiments beginning now
“If you know the enemy and know yourself, you need not fear the result of a hundred battles”
-- Sun Tzu, “The art of War” (6th century B.C.)
Summary

Control of backgrounds important at CDF

- Detector operations
- Physics backgrounds

Backgrounds from

- Focusing triplet is a line source
- Local aperture restrictions
- “Incomplete collimation”

Solutions

- Shielding + Experiment (Accelerator)
- Collimation + Accelerator (Experiment)
- Alignment + Accelerator (Experiment)
- Monitoring of beam conditions + Accelerator/Experiment
- Analysis selection (physics) + Experiment

Exchange between experiment and accelerator
References (Incomplete List)

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

Single Event Effects:

Beam Quality and Instrumentation:
• http://www-cdfonline.fnal.gov/acnet/ACNET_beamquality
• A. Bhatti, et al., CDF internal note, CDF 5247.
• A. Drozdhin, et al., Proceedings: Particle Accelerator Conference(PAC03), Portland, OR, 12-16 May 2003.

Radiation:
• http://ncdf67.fnal.gov/~tesarek/radiation
Backup/Supplemental Slides
Simulated Radiation Environment

Detailed MARS simulation of:

- accelerator & beam transport
- collision hall & detector

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**Neutrons**

**Charged Hadrons**

**Gammas**

**Muons**

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Electron Lens Abort Gap Cleaning

Proton Info...

Proton beam current
Lost P
Proton Halo
Proton Halo in abort gap
Electron Lens current
RF Glitch

Abort Gap

Losses

Sum RF voltage