Beam Loss Patterns at LHC Collimators

Presentation of Master Thesis by Till Boehlen

Supervised by Prof. Pietralla
Threat of Damage to LHC

- Max. energy: 7 TeV -> 7 times higher than present-day accel.
- Nominal Intensity N: $3 \times 10^{14}$ prot. per beam
  -> 35 times higher than present-day prot. accel.
- Energy stored: 360MJ per beam -> Melts 500kg copper

Critical beam losses:
- Damage: $\sim 3 \times 10^{-6} \times N$ in one turn
- Quench: $\sim 3 \times 10^{-9} \times N$ in one turn

Protection of LHC Components needed!
Protection Systems of the LHC

Beam Losses
- Exceptional Losses
- Unavoidable Losses
  - Failure Scenarios
  - Nominal Losses
- Grouped by Loss Duration
  - Single Turn – Fast – Constant

LHC Protection System
- Passive Protection
- Active Protection

Collimation System
- Absorbers in front of magnets
  - etc.

Failure Scenario
- Damage to Superconducting Magnet
- Downtime of several Month

Beam Loss Monitoring (BLM) System
- Quench Protection System
  - etc.

Beam Interlock & Dump System
- Save Extraction of the Beam
Collimator Types & Locations

Types of Collimators

<table>
<thead>
<tr>
<th>Name</th>
<th>Active Jaw</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP</td>
<td>60cm</td>
<td>C</td>
</tr>
<tr>
<td>TCSG</td>
<td>100m</td>
<td>C</td>
</tr>
<tr>
<td>TCLA(TCT)</td>
<td>100m</td>
<td>W in Cu</td>
</tr>
</tbody>
</table>

Locations

Exemplary Setup

Courtesy of C. Bracco

IR3 & 7
Beam Loss Monitoring System (BLM)

**Task**
Measure Secondary Particles from Beam-Induced Showers

**Detectors**
- ~3700 Ionization Chamber (IC)
- ~280 Secondary Emission Monitors (SEM)

**Prevent**
Beam-Induced Damage & Quenching of Sensitive Equipment
  e.g.: Magnets, Collimators

**Damage & Quench Level**
- transient: \( \frac{E}{V} \) µsecs
- steady-state: \( \frac{E}{P} \) Several secs

**Reaction Time**
- Detection: one turn (~89µs)
- Beam Extraction: 3-4 turns (~350µs)

**Detector Threshold**
Must be Assessed! Relation of Energy Deposited in Equipment to Detector Signal
Contents of Master Thesis

Part 1: Reproduction of BLM detector measurements by simulation
Part 2: Prediction of BLM detector signal for the actual LHC setup

Measurement vs. Simulation for LHC-like Setup in SPS
(pre-accelerator of the LHC)

- Setup: LHC collimator, 2 IC's, and 1 SEM detector
- Simulation tool: Monte Carlo particle code FLUKA
- Goal: determine accuracy of predicting BLM signals by simulations for an LHC collimation scenario

Prediction of BLM Signals for LHC Collimation Setup

- Implementation: a cell consisting of a (exchangeable) collimator and IC-SEM detector pair
- Prediction:
  - BLM signal per beam proton (=normalized dose)
  - BLM signal per total and peak energy deposition in the collimator
- Focus: variation of BLM signals and energy dep. in collimator due to BLM misalignment & beam impact scenario
Losses at the LHC collimator in the SPS

Setup Experiment

FLUKA Implementation

Focus on:
- Collimator
- BLM Detectors
- Beam Tube

Sensitivity study:
- Misalignment
- Geom. Simplification
- Impact scenarios

=>Max. change 15%

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Measurements in the SPS

Data Acquisition

☆ 3 sessions: circulating mode @ 26 GeV (cycle = 20 sec)
☆ Injected intensities: 10-90x10^{10}, 900x10^{10}, 1300x10^{10} protons
☆ Acquisition: beam intensity (beam current converters), BLM detector signals, collimator jaw positions wire scanner (transversal beam intensity distribution)

First Method: “Direct Dumping”

![Graph showing jaw positions and injected circulating intensities over time.](image)
Measurements in the SPS

Second Method: “Continuous Scraping”

Jaw speed ~ 2mm/s

- 5.2 s integration time

- Dose rate [Gy/s]
- Jaw pos. [mm]
- part/10^10

Injected  Circulating
Measurements in the SPS

Determination of the Impact Distributions on the Collimator

Definition of impact parameter:

★ Beam center position w.r.t. the collimator jaws
★ Beam size at the collimator
★ Beam impact distribution for continuous scrapings

Input for reproduction of measurements by simulations
Comparison: Measurement vs. Simulation

First Method: “Direct Dumping”
- High intensities in short time
- IC detectors: space-charge effects
- Similar to LHC failure scenario

Max. deviation (Meas./Sim.):
IC: +9%
SEM: -30% (FLUKA+Geant4: -40%)

Second Method: “Continuous Scraping”
- Intensities are integrated over ~3sec
- Bigger uncertainties of BLM signals due to:
  ☆ Returning protons
  ☆ Impact distribution/beam-jaw angle
- Similar to LHC nominal scenario

Max. deviation (Meas./Sim.):
IC: +/-20%
SEM: +73% (FLUKA+Geant4: +/-40%)
Simulations for LHC Setup

Implementation of “Collimator-Detector Cell”

Aim:
Predicting ratios of BLM signal to total and peak energy deposition (ED) in collimators

Focus:
Dependency of these ratios on different parameters:
- detector misalignment
- impact parameter
- beam-jaw angle
- higher order particle halos from upstream

Cross-checks

SPS simulation:
- Particle fluxes through BLM detectors are comparable

Implementation by FLUKA team:
- BLM signals agree within 5%
Simulations for LHC Setup

Definition Impact Parameter

Impact Parameter Scan

Jaw Roughness & Flatness

Factor 3

nearly constant
Simulations for LHC Setup

Illustration: Beam-Jaw Angle

a) negative beam-jaw angle

b) positive beam-jaw angle

Save estimation for protons when setting to lowest signal-to-energy deposition ratio.

Beam-Jaw Angle Scan

2-3 orders of magn.

Factor 4
Simulations for LHC Setup

Peak Energy deposition

Assumes Gaussian tails as particle distributions on collimator (typical distributions for failure scenarios calculated by A. Gómez Alonso)

Higher Particle Order Halos

Mixed particle spectra hitting downstream collimators

Simulations for 3 “collimator-detector cells”

★ Beam protons impacting on Cell 1
★ Particles exiting through beam pipe propagated through Cell 2 and Cell 3

Results:
★ Ratio of BLM signal to total energy dep. in jaw for Cell 3 is 25% of Cell 1!
=> Systematic studies needed
Summary & Conclusions

Part 1: Comparison Measurement-Simulation: Experimental Setup in the SPS

- Max. deviation Meas./Sim. for IC detectors: ±21%
- Max. deviation Meas./Sim. for SEM detectors: ±40% (FLUKA+Geant4), 73% (FLUKA)
- Final determined discrepancy between meas.-sim. Interpreted as systematic uncertainty for assessment of BLM detector thresholds by simulations

Part 2: Simulation Studies for the LHC Collimation Scenario

- Investigating ratios of BLM signal to (total and peak) energy deposition (ED) in collimator jaws
- Signal-to-total ED ratio:
  - about constant for different impact parameter,
  - only increasing for different beam-jaw angles,
  - decreasing for mixed particle spectra from upstream=> systematic calculation needed!
- Signal-to-peak ED ratio:
  -
Thanks for attentive ...

Comments and questions welcome!
OLD: Summary & Outlook

- Implementation of experimental setup in FLUKA
- Several scans of model parameters => max. systematic error of 15%
- Measurements: few data usable: space-charge effects, missing logging data (software)
- First comparisons between meas. and sim. => agreement within 5% (but low statistics!)
  - Agreement of other meas.-model comparisons 10-50%

- Final determined discrepancy of meas.-model as systematic uncertainty for assessment of LHC BLM detector thresholds by simulations
- Impact parameter studies will be continued at LHC energies
  - Further systematic error for determining thresholds
- Inclusion of determination of peak energy and total energy deposition in collimator
- More measurements in May 2008 – optimizing conditions
  - Lower intensities (no saturations), improved calibration of impact parameter
Preliminary Results (Add.)

- IC signal ratio Right/Left Sim: $0.73 \pm 0.05$  
  Exp: $0.71 \pm 0.09$

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