Multi-turn Losses and Cleaning in 2011 and 2012


OP-Team, BLM-Team
Outline

• Introduction

• Collimator Setup
  ▪ Collimator Beam-Based Alignment
  ▪ Setup Highlights: Accuracy and Beam Time Required
  ▪ Setup Stability
  ▪ Collimator Misalignments

• Collimation Qualification
  ▪ Loss maps performed in 2011 and Beam Time Required
  ▪ Proton and Ion Cleaning Inefficiency in 2010 and 2011
  ▪ Online Loss Maps

• Improvements and Outlook for 2012
  ▪ Fully Automatic Collimator Setup
  ▪ Alignment and Qualification Requirements

• Summary
Introduction – LHC Collimation System

- Multi-stage cleaning and multi-turn losses.
- Momentum cleaning in IR3, betatron cleaning in IR7.
- No beam-induced quenches so far!
- Jaw gaps of $\sim 3 - 4 \text{ mm}$ maintained throughout 2011:
Collimator Beam-Based Alignment

- **Aim of Beam-Based Collimator Alignment**
  - Determine the beam centres and sizes at the collimators
  - Maintain the correct collimation hierarchy

- **Jaw moved to the beam until a BLM loss spike is observed**

- **Semi-Automatic Setup Algorithm for 2011** (G. Valentino et al., IPAC 2011)
  - Jaw moves automatically and stops when BLM signal exceeds user-defined threshold
  - Parallel setup speeds up alignment

- **BLM Data Rate: 1 Hz**

- **Collimator Movement: 5 – 20 μm every second**
Setup Highlights of 2010 and 2011

2010: Manual alignment

Jaw Step Size: 10 – 40 µm

2011: Semi-Automatic Alignment

Total Time incl. Ramp, Squeeze, ...

3 more 3.5 TeV setups in 2011

Jaw Step Size: 5 – 20 µm

Number of Beam Dumps during setup at 3.5 TeV

2010: Manual alignment
2011: Semi-Automatic Alignment
Collimation Hierarchy and Tolerances

- Overview of the different collimator settings and the corresponding TCP-TCSG margins:

<table>
<thead>
<tr>
<th>Collimator</th>
<th>Relaxed 3.5 TeV</th>
<th>Tight 3.5 TeV</th>
<th>Tight 4 TeV</th>
<th>Nominal 7 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP IR7</td>
<td>5.7</td>
<td>4</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>TCSG IR7</td>
<td>8.5</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Margin [σ]</td>
<td>2.8</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Margin [µm]</td>
<td>1050</td>
<td>750</td>
<td>728</td>
<td>274</td>
</tr>
</tbody>
</table>

Margin between TCP and TCSG

Currently operational

Tested in Tight Settings MD

2012?
Setup Stability (1) – TCP Hor & Ver

Beam Centres found from beam-based alignment

Orbit variation affects loss rates but not cleaning efficiency due to dual jaw collimator structure
Setup Stability (2) – IR3 collimators

IR3 Beam Centre Change over 4 months (March to July 2011)

Average: 0.088 mm
Max: 0.243 mm

Maximum change 243 µm
ALICE Polarity Inversion: Beam-Based Alignment vs Orbit Model

- Polarity of ALICE dipole and solenoid switched from negative to positive for ions.

- Beam-based alignment re-done for vertical TCTs in IR2.

<table>
<thead>
<tr>
<th>Collimator</th>
<th>Change in Centre (mm)</th>
<th>Difference between Alignment &amp; Model (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Orbit Model</td>
<td>Beam-Based Alignment</td>
</tr>
<tr>
<td>TCTV IR2 B1</td>
<td>- 4.698</td>
<td>- 4.805</td>
</tr>
<tr>
<td>TCTV IR2 B2</td>
<td>- 4.824</td>
<td>- 4.840</td>
</tr>
</tbody>
</table>

Orbit model data provided by J. Wenninger

- **Good comparison** between measured and predicted beam centre shifts.
Collimator Misalignments


• Misalignments corrected in March Technical Stop > 1.6 mrad found (O. Aberle, P. Bestmann et al.)

• Beam-based alignment re-done after correction.

• Before tunnel alignment:

<table>
<thead>
<tr>
<th>Collimator</th>
<th>$\Delta \sigma_{icoll}$ (mm)</th>
<th>$n_1$</th>
<th>$\alpha$ (mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCTH.4L2.B1</td>
<td>0.424</td>
<td>3.63</td>
<td>1.5</td>
</tr>
<tr>
<td>TCLA.A7L7.B1</td>
<td>0.400</td>
<td>4.40</td>
<td>1.7</td>
</tr>
<tr>
<td>TCSG.A5L3.B2</td>
<td>0.442</td>
<td>3.68</td>
<td>1.6</td>
</tr>
</tbody>
</table>

• After tunnel alignment:

<table>
<thead>
<tr>
<th>Collimator</th>
<th>$\Delta \sigma_{icoll}$ (mm)</th>
<th>$n_1$</th>
<th>$\alpha$ (mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCTH.4L2.B1</td>
<td>0.144</td>
<td>4.38</td>
<td>0.6</td>
</tr>
<tr>
<td>TCLA.A7L7.B1</td>
<td>0.064</td>
<td>4.64</td>
<td>0.27</td>
</tr>
<tr>
<td>TCSG.A5L3.B2</td>
<td>0.080</td>
<td>4.56</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Without $\beta$-beat effect (~ 5% to 10%)

$\alpha_{icoll} = \tan^{-1}\left(\frac{2n_1\Delta \sigma_{icoll} - \Delta icoll}{2L_{icoll}}\right)$

$\Delta \sigma_{icoll}$ : error in measured gap w.r.t. nominal
$\Delta icoll$ : measured position vs actual position error
$\alpha_{icoll}$ : misalignment angle
$L_{icoll}$ : length of collimator
$n_1$ : cut of TCP in units of sigma
Collimation Hierarchy Breakdown?

- Hierarchy breakdown observed on 02/04/2011 from loss map.
- Problems with the TCSG.D5R7.B1 (losses only factor 2 below TCP).
- B1 skew collimators re-aligned as a precautionary measure but same centres found (± 80 µm).
- Causes: BPM filling pattern dependent shift + lost margin (power cut) + ver. loss map before hor. loss map (see D. Wollmann and R. W. Assmann LMC talk for detailed analyses)

TCSG: ~0.7

TCTH L8: ~ 8.4e-3

DS < 6e-5

factor 260 times higher losses into IR8!

Courtesy of D. Wollmann

450 GeV B1 h IR 7–8 Zoom

TCTH L8: ~ 8.4e-3

DS < 6e-5

factor 260 times higher losses into IR8!

Courtesy of D. Wollmann

Gianluca Valentino
Collimation Qualification

• Collimation system hierarchy regularly qualified by creating multi-turn losses.

• **Betatron Losses:** cross a third integer tune resonance to create horizontal and vertical losses.

• **Momentum Losses:** change the RF frequency by ± 1000 Hz for positive and negative momentum offsets.

• Performed with one nominal bunch at 450 GeV and 3.5 TeV.

• Requires two dedicated fills: 30-50% of the beam is lost in 1-2s.

• Collimators are re-aligned to correct any anomalies in the hierarchy.

• The local cleaning inefficiency at any point in the ring is determined from the ratio to the highest loss:
  
  – E.g. cold aperture:

  \[ \eta_c = \frac{\text{Highest Leakage in Cold Aperture}}{\text{Highest Losses in TCP}} \]
Beam Time needed for Qualification

- **26 qualifications at injection** (450 GeV)
- Different settings: injection protection collimators IN / OUT (now doing both)
- 6 loss maps performed as EOF, 20 loss maps required dedicated fill
- **Total: 21.5 hours in 2011** (including overhead for dedicated fills)

- **33 qualifications at 3.5 TeV**
- Different settings: flat top, squeezed, colliding, crossing angle, …
- 15 loss maps performed as EOF, 18 loss maps required dedicated fill
- **Total: 31.5 hours in 2011** (including overhead for dedicated fills)

- **Grand Total: 53 hours** (including overhead for dedicated fills)
Proton Cleaning Inefficiency 2010/2011
3.5 TeV, 1.3s integration time (Q8 IR7)

2010 Average: 2.57E-04 ± 6.69E-05
2011 Average: 3.39E-04 ± 1.22E-05

Cleaning Inefficiency in 2011 consistent with 2010

See also Evian 2010 talk by D. Wollmann and MD Note on tight settings
Leakage into horizontal tertiary collimators
3.5 TeV, 1.3s integration time

2010 Average: 2.02E-04 ± 5.75E-05
2011 Average: 1.04E-03 ± 3.12E-04

Sum over all horizontal TCTs

Increased BLM signal due to closer TCT settings

See also Evian 2010 talk by D. Wollmann
Ion Cleaning Inefficiency in 2011
3.5 TeV, 1.3s integration time

Simulated Efficiency: 99.3%
98% measured efficiency

Cleaning Inefficiency in 2011 consistent with 2010

See also IPAC’11 paper by G. Bellodi
Online Loss Maps

- Work in progress for online loss map display (BLM team, F. Follin).

- Attempt to decompose the losses observed during stable beams into separate horizontal and vertical B1 and B2 components with Singular Value Decomposition.

- Technique described in IPAC’11 paper (A. Marsili et al.)

- **Goal:** continuous monitoring of cleaning efficiency without need for dedicated fills.

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**B1 hor loss map (1/3 tune resonance), IR7**

**Integrated losses during stable beams, IR7**
Fast Automatic Collimator Setup

Faster alignment:

- Ongoing work to improve BLM data and collimator movement rates by factor $\approx 10$
  (thanks to R. W. Assmann, B. Dehning, A. Masi, S. Redaelli, C. Zamantzas)

Automatic alignment:

- Pattern recognition of BLM loss spikes during setup (up till now $\approx 90\%$ accuracy)
- Learning algorithm will be trained on simulator to make decisions taken by expert during alignment.
- Decisions include: Loss threshold selection, jaw step size, step repetition rate
  
  \[ \text{decisions based on BLM signal} \]
Alignment and Qualification Requirements for 2012

• Collimator Alignment:
  • Required frequency: once per year (except alignments due to change in optics).
  • Beam time required for a full collimator alignment (86 collimators) expected to decrease from ~18 hours to ~6 hours.
  • Aim for tight settings in 2012.

• Collimation Qualification
  • In 2011: 7 full qualifications (~1 per month).
  • Tight settings: valid over full year (as verified in MD).
  • In 2012: 3 full qualifications (e.g. April / July / October) + online loss maps.
  • ADT blow up method: MD requested, see IPAC’12 paper (W. Höfle et al.)

• Further Work & Info
  • See talks at Chamonix 2012: R. W. Assmann (intensity limits), R. Bruce (tight collimator settings), S. Redaelli (upgrade needs).
Summary


• Semi-automatic tool has improved collimator operation during alignment (reduced setup time and eliminated beam dumps during setup).

• Collimator misalignments can be detected from beam-based setup.

• Aim for \textbf{tight collimator settings in 2012}: should improve efficiency by \textbf{factor \~8}, but reduce TCP-TCSG margin by \textbf{factor \~1.5} at 4 TeV.

• Aim for \textbf{qualifications every 3 months}, complemented by online monitoring.

• Work in progress: - Faster and fully automatic setup procedure (\~6 hours)
  - Online loss maps
  - ADT blow up qualification method
RESERVE SLIDES
BPM Interpolation Comparison

Interpolated BPM data extracted with Aperture Meter (G. Mueller)
Leakage into vertical tertiary collimators
3.5 TeV, 1.3s integration time

2010 Average: 5.05E-04
2011 Average: 1.11E-03

Increased BLM signal due to closer TCT settings

Full setup

Sum over all vertical TCTs

Gianluca Valentino