Collimator Settings Generation, Management and Verification

G. Valentino, R. Bruce, S. Redaelli

with input from:
Outline

• Introduction and Motivation
• Recap of Collimator Settings
• Settings Generation Cycle
• Review of Collimator Status Monitoring
• Errors encountered and Measures taken
• MAD-X Online
• Results and Status of BPM Collimator Operation
• Summary
Introduction and Motivation
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- In the LHC, collimation is required at all phases (injection, ramp + squeeze, physics) due to high beam energy.
- The collimator settings depend on key beam parameters e.g. energy, orbit and $\beta$-functions as a function of time, energy and/or $\beta^*$. 
- OP team must be able to change critical parameters (unlike the kicker, BLM master tables ...).
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• Overall system performance depends critically on the correct positioning w.r.t. the beam.

• Unprecedented complexity: function-based settings, redundant interlocking strategy that change with time.

• Monitoring of settings and comparison to the “desired” values is critical.
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- Overall system performance depends critically on the correct positioning w.r.t. the beam.
- Unprecedented complexity: function-based settings, redundant interlocking strategy that change with time.
- Monitoring of settings and comparison to the “desired” values is critical.

Scope of the talk:

- To review the settings generation, the errors that occurred and measures taken
- To review the present collimator status monitoring system, including MAD-X online
- To present the current status of achieving operability of the new BPM collimators
Recap of Collimator Settings

- The jaw corner positions in mm for any point in the operational cycle are determined from the local beam-based parameters and half-gap opening in beam $\sigma$ units at each collimator.
Recap of Collimator Settings

- The jaw corner positions in mm for any point in the operational cycle are determined from the **local beam-based parameters** and **half-gap opening in beam σ units** at each collimator.

- Typically, the **BB Params** are measured at 4 points: Injection, Flat Top, End of Squeeze, Collisions.

- Functions are generated for a smooth transition of the jaw positions from one point to another.

- The jaw positions are interlocked at all times (typically ± 400 µm or 1 σ):
  (a) inner/outer limits for each jaw corner (actual/fn BP)
  (b) inner/outer β* limits on the jaw gap (discrete BP)
  (c) energy limits on the jaw gap (discrete BP)

- Exceeding the limits triggers a beam dump.
Settings Generation Cycle
Settings Generation Cycle

Collimator Alignment

Beam

\[\text{Jaw} \downarrow \text{Jaw} \uparrow\]
Settings Generation Cycle

Collimator Alignment

Beam

Jaw

Potential Errors!

Excel Setup Sheet

Saved on CCC machines after every alignment
Settings Generation Cycle

Collimator Alignment

Beam

Potential Errors!

Excel Setup Sheet

Potential Errors!

Saved on CCC machines after every alignment
### Settings Generation Cycle

#### Collimator Alignment

- **Beam**
- **Jaw**

![Potential Errors!]

#### Excel Setup Sheet

- **As of 2012**: setup sheet now generated automatically by alignment application.

#### Saved on CCC machines after every alignment

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**Beam Process Settings**

- **Preparation**
  - **System**: CERN
  - **Parameters**: MC, BEAM, LHC

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**Potential Errors!**

Gianluca Valentino
Settings Generation

- Alignments are done at four points to measure the beam centers and beam sizes.
- Functions during squeeze or collisions determined from simulations, and are created with Mathematica or LSA.

<table>
<thead>
<tr>
<th>Beam Mode</th>
<th>Beam Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection</td>
<td>Ramp@start</td>
</tr>
<tr>
<td>Ramp</td>
<td>Ramp function</td>
</tr>
<tr>
<td>Flat Top</td>
<td>Ramp@end / Squeeze@start</td>
</tr>
<tr>
<td>Squeeze</td>
<td>Squeeze function</td>
</tr>
<tr>
<td>Adjust</td>
<td>Squeeze@end / Collisions@start</td>
</tr>
<tr>
<td>Adjust</td>
<td>Collisions function</td>
</tr>
<tr>
<td>Stable Beams</td>
<td>Collisions@end</td>
</tr>
</tbody>
</table>

- \( f(\gamma, t) \)
- \( f(\beta^*, t) \)
- \( f(Xing/Sep, t) \)
- \( f(Xing/Sep, t) \)
- \( f(\gamma, t) \)
Settings Generation

- Collimator beam-based alignment procedure:

Collimator -> BLM -> Beam
Settings Generation

- Collimator beam-based alignment procedure:

![Diagram showing beam, collimator, and BLM with a graph of Gy/s vs. t [s]]
Settings Generation

- Collimator beam-based alignment procedure:
Settings Generation

- Collimator beam-based alignment procedure:

  - $N$ is the number of beam $\sigma$ of the jaw half gap.
  - Depends on the collimator family, e.g. TCP IR7, TCSG IR7, TCLA IR7, TCT, TCP IR3....

  \[
  \Delta x_i = \frac{x_{i}^{L,m} + x_{i}^{R,m}}{2}
  \]

  \[
  \sigma_{i}^{\text{inf}} = \frac{x_{i}^{L,m} - x_{i}^{R,m}}{n_{i}^{k-1} + n_{i}^{k}}
  \]

  \[
  x_{i}^{L,\text{set}} = \Delta x_i + N_i \sigma_{i}^{\text{inf}}
  \]

  \[
  x_{i}^{R,\text{set}} = \Delta x_i - N_i \sigma_{i}^{\text{inf}}
  \]
Settings Generation

- Collimator beam-based alignment procedure:

  - $N$ is the number of beam $\sigma$ of the jaw half gap.
  - Depends on the collimator family, e.g. TCP IR7, TCSG IR7, TCLA IR7, TCT, TCP IR3....
  - At injection: the measured beam size is used.
  - At top energy: collimator gaps are smaller in mm and beta-beat $< 10\%$, hence the nominal beam size is used.
  - In 2011-2012, several algorithms were introduced to speed up and automate the alignment.
  - Time for full alignment: 30 hours (2010) $\rightarrow$ 5 hours (2012).
Settings Verification

- Manual verification of generated values by experts.
- Systematic checks of the settings transitions (e.g. ramp to squeeze).
- Low-intensity fill to validate sequencer operation in shade of fills for loss maps or Q/OFB checks.
- All machine configurations are validated by loss maps.
- Online tool to verify the gaps in mm and beam $\sigma +$ limits:
### Review of Collimator Status Monitoring

(a) Online vistar and CCC overhead display

#### LHC Collimators | Beam: B1 | Set: HW Group: LHC COLLIMATORS

<table>
<thead>
<tr>
<th>L(mm) MDC</th>
<th>PRS R(mm)</th>
<th>Collimator Status</th>
<th>LVDT Jaw Positions in mm</th>
<th>Indication of Gap Opening</th>
<th>MDC Status</th>
<th>PRS Status</th>
<th>Collimator Status</th>
<th>Loss Map Expiry Status</th>
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<tbody>
<tr>
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</table>

**Quick View of:**
- LVDT jaw positions in mm
- Indication of gap opening
- MDC status
- PRS status
- Collimator status
- Loss map expiry status
Review of Collimator Status Monitoring

(b) Collimator display for detailed view of the MDC/PRS warnings/errors (S. Redaelli)

(c) Higher-level collimator display, settings in $\sigma$ units, limits + $\beta$-functions (D. Jacquet)
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Settings errors in the 2010-2013 run
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   - **Error:** TCTVA.4R1.B2 center shifted by 1.8 $\sigma$ at a gap of 26 $\sigma$
     - TCTVA.4R2.B2 center shifted by 3.8 $\sigma$ at a gap of 12 $\sigma$
   - **Action:** trimmed in the new values

2. **March 2012:** 2 IR3 collimators (ramp function)
   - **Error:** when calculating functions, centers set to 0
   - **Action:** no action necessary (errors small compared to IR3 gap openings, no need to repeat loss maps)
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   - **Error:** TCTVA.4R1.B2 center shifted by $1.8\,\sigma$ at a gap of $26\,\sigma$
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   - **Error:** when calculating functions, centers set to 0
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   - Belen will discuss the beam-based validation of the settings in greater detail.

   - For 1097 collimators aligned in 41 alignment campaigns $\rightarrow$ error $= 0.36\%$
Measures taken to avoid similar errors

- Following the settings errors in March 2012, a **tool** was developed for post-alignment checks.
- Used systematically since, although no further errors were detected.

**Tool operation:**

1. Reads the centers from the setup sheet.
2. Automatically calculates the centers at the time of alignment from the MDB.
3. Exports the LSA settings used by the operational sequence for the appropriate beam process.
4. Compares the different values.

**Future work:**

- Comparison also between the jaw corner positions (“external parameters”) that are sent to the hardware.
- Possibility to select MDB or LDB (for previous fills).
- Could be used to compare LSA and Timber jaw settings after power cuts.
Possible Improvements in Collimator Status Monitoring

- **LHC Alarms SERvice (LASER):** should be used more by the OP crews for diagnostic purposes, e.g. for identifying warnings (orange colour) in collimator status display.

- Assign actions to be taken by OP for the different collimator errors / warnings.

- Plan to **develop further the post-mortem collimation buffer** so that expert does not need to dig through the data when called by OP in case of errors.

- **Better interlock colour-coding:** e.g. energy interlocks for injection protection collimators should not show up in red after the start of the ramp.

- The **State Machine** checks that the TCTs are at the correct stable beams settings, i.e. make sure that the collision functions were executed correctly
  - could be possibly improved to detect any problems at the start of collisions process.

- Acquisition of the measured $\beta$-functions in the collimator settings display.
MAD-X Online

• The online model provides an environment to support:
  • the use of MAD-X simulations and calculations as control system inputs
  • operators while coping with the complexity of the machine
  • simulation of machine manipulations

❖ How does it work? ⇒ Online Model System Overview

G. Müller, Gentner Day’10
LHC Aperture Meter

Usage:

• online acquisition of BPM-interpolation to speed up collimator alignment (see HB 2012 paper)
• playback of settings during ramp and squeeze, possibility to catch settings errors (work in progress)
• orbit checks (incl. ATS, 90 m) and aperture measurements:

minimal aperture evolution (beam 1 horizontal) during triplet aperture scan in IP5 (CMS) to determine the maximal available aperture before the decision was taken to further reduce the β* to 1.0m

Gianluca Valentino
LHC Aperture Meter

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G. Müller, ICALEPCS’11

Useful tool which was unfortunately not followed up recently...
Now taken over by G. Roy
TCP Aperture Evolution

- Aperture calculation not accurate to $< 1 \sigma$, but can provide an independent check of the settings.
- **Inputs:** orbit, current collimator positions and optics (**NOT** LSA collimator settings).

![TCP Aperture Evolution during Ramp + Squeeze](image)

courtesy of G. Müller
Results and Status of BPM Collimator Operation
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- Collimators with embedded BPM buttons will replace current TCTs and IR6 TCSGs in LS1.
**Results and Status of BPM Collimator Operation**

• Collimators with embedded BPM buttons will replace current TCTs and IR6 TCSGs in LS1.

After proof-of-principle SPS tests in 2010-2011, automatic alignment algorithm tested in 2012.

### Collimator Coordinate System

The collimator coordinate system is shown in Fig. 1. Jaw positions on the left of the zero-axis are positive, while jaw positions on the right are negative.

**Figure 1: Collimator Coordinate System**

### Definitions

- **J_A**: The left jaw position.
- **J_B**: The right jaw position.
- **d**: The jaw gap, equivalent to \( J_A - J_B \), which is always > 0.
- **b**: The button distance, or aperture, equivalent to \( d + 10mm \).
- **V_X**: The voltage on electrode X, where \( V_A \) is the voltage on the left jaw button and \( V_B \) is the voltage on the right jaw button.

### Equations

The measured beam position, which is not the 'absolute' beam position, is given by:

\[
J_i = \frac{\text{Gap}_{BPM}}{4} \times \frac{V_A - V_B}{V_A + V_B} + J_{i-1}
\]

As during the MD, the beam is kept stationary and the jaws are moved around it, the actual beam position is defined as:

\[
x_{\text{beam}} = -J_A + J_B
\]

Note the usage of the '-' sign. This is because of the following:

1. < 30 s alignment time!
2. Successive approximation algorithm

---

*Courtesy A. Dallocchio, A. Bertarelli, O. Aberle et al.*
Results and Status of BPM Collimator Operation
Results and Status of BPM Collimator Operation

• 1 hour is currently required for an alignment of 16 TCTs → factor 120 improvement!
• In 1 year of operation (e.g. 2012): gain of 8 hours (8 TCT alignments).
• Gain in $\beta^*$ reach (see talk by Roderik for more details).
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- Gain in \( \beta^* \) reach (see talk by Roderik for more details).

Alignment accuracy:

- BPM non-linearities are a function of the jaw gap and beam center.
- Correction polynomial developed by A. Nosych based on CST Particle Studio simulations (for more details see my talk in Collimation Working Group, 26.11.2012).
- Accuracy of \(< 1\%\) of the BPM aperture for beam offsets of up to 50 \% and jaw gaps from 2 - 60 mm.
- Tested during SPS MDs and cross-checked with standard BLM-based alignment.
Results and Status of BPM Collimator Operation

• **Main goal:** elimination of all orbit-related settings errors at the TCTs and IR6 TCSGs!

• BPMs will **improve collimator operation** by providing:
  – online monitoring of beam centres
  – possibility of interlocks on orbit measurements (should always be 0 with centered jaws)
  – fast fill-to-fill TCT alignments, or as frequently as required

• Possible future usage for **transfer line collimators** (SPS measurements done with single pass).

• **Better monitoring in IR6:**
  – find out earlier on possible problems rather than waiting for the infrequent loss maps
  – can also be used for the SIS interlock of the TCDQ centering/retraction (J. Wenninger)

• **Commissioning with beam** will be required to ensure calibration of electronics for correction of noise and BPM non-linearities.

• **Engineering specification** to be drawn up in collaboration with BI team.
Summary

• The collimator settings generation and verification cycle was presented.

• **Potential error locations** in the cycle and tools developed to verify the settings were identified.

• The different components of the present top-level collimator monitoring system were discussed, highlighting the different layers of abstraction.

• A settings error occurred in 4 out of 1097 (0.36 %) cases in 4 years of operation. A tool was developed to ensure consistency between alignment measurements and LSA settings.

• Possible improvements in the current collimator status monitoring and the status of MAD-X online tools was reviewed.

• Test results for a fast alignment in < 30 sec with an accuracy of < 10 µm, and the status of current work towards maximizing the operational potential with BPM button collimators were presented.
Reserve Slides
# Collimator Settings 2010-2013

<table>
<thead>
<tr>
<th>Coll Family</th>
<th>Injection [σ]</th>
<th>Physics Relaxed [σ]</th>
<th>Physics Tight [σ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP IR3</td>
<td>8</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>TCSG IR3</td>
<td>9.3</td>
<td>15.6</td>
<td>15.6</td>
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<tr>
<td>TCLA IR3</td>
<td>10</td>
<td>17.6</td>
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<td>TCL</td>
<td>20</td>
<td>out</td>
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</tr>
</tbody>
</table>
LHC Aperture Meter

Solution / Design

The Aperture Meter as a fixed display in the Control Room

Calculate the available free space for the beam by merging measurements and online simulation data

LHC Software Architecture (LSA) 

Machine Setting

- (active) beamprocess
- knob settings
- active optics
- parameter trims

LHC Measurement

- Collimator Jaw Positions
- Beam Positions
- Beam Emittance
- Beam Energy

Aperture Meter

Theoretical Model

- JMad (Java API for MAD-X)
- LHC Linear Model Definition
- SFS / TIX / ...
- Model Definition

Display

G. Müller, ICALEPCS’11