Plan for Collimator Commissioning

R. Assmann, CERN/AB
7/12/2007
for the Collimation Project
LHC MAC

RWA, LHC MAC 12/07
1) Installation Planning and Performance Reach

- Collimation is an **performance-driven system**: Low energy and low intensity requires much less collimators.

- Several systems defined for initial installation (160 DB locations):
  - **Full system** [as defined in LHC-LJ-EC-0002 (IR3/7), LHC-LJ-EC-0003 (tertiary collimators), LHC-LJ-EC-0010 (active absorbers), LHC-LJ-EC-0014 (passive absorbers) and LHC-T-EC-0001 (injection protection)] ➔ **116 collimators**
  - Minimal system 7 TeV (only required collimators) ➔ **70 collimators**
  - Minimal system for 450 GeV (Oct 2006) ➔ **36 collimators**
  - Starting system for 7 TeV (June 2007-now) ➔ **92 collimators**

- Every installation plan adapted to LHC performance goals, LHC schedule and collimator production schedule.

- Formalized in ECR. Ahead of planning since September!
Staged Installation Phase 1

June/Sep 2007

Installation until Apr08
92 collimators
29 vacuum sectors affected

Beam

Installation 2008/9 shutdown
24 collimators

Ready for 7 TeV physics in May 2008!

1. Luminosity up to $10^{33}$ cm$^{-2}$ s$^{-1}$.
2. Total stored intensity of up to $1 \times 10^{14}$ p per beam.
3. Maximum injection of up to $1.7 \times 10^{13}$ p per pulse.
4. Minimum $\beta^*$ in IR1/IR5/IR8 of 2 m. (or less)
5. Minimum $\beta^*$ in IR2 of 10 m. (or less)

Intensity reach at ~50% of full phase 1 system.
2) Progress: Industrial Production

**Industry:** 94% of production for 7 TeV initial ring installation has been completed (75/80).

All collimators for initial installation should be at CERN by end of the year.

Total production of 110 collimators should be completed in April.
Installation: Status and IR1 Example

• We are installing presently about 4 collimators per week.
• At this time: 64 installed \(\rightarrow \sim 70\%\) of total installation completed.
CERN Production

- In total 15 special collimators produced at CERN.
- Last for initial installation will arrive in week 11.
- Fully on track with production.

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<th>Quantity</th>
<th>Availability</th>
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<td>TCLIA #2</td>
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<td>week 15</td>
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</table>

Two-beam collimator

Passive Absorber
3) Hardware Commissioning & Cold Checkout

**System commissioning:**
- R. Assmann, T. Weiler  
- S. Redaelli  
- M. Jonker, M. Sobczak  
- R. Losito, A. Masi + team  
- O. Aberle, R. Chamizo, Y. Kadi + team

<table>
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<th></th>
<th>AB-ABP</th>
<th>AB-OP</th>
<th>AB-CO</th>
<th>AB-ATB (low-level)</th>
<th>AB-ATB (hardware)</th>
</tr>
</thead>
</table>

**Special functionalities**

(protection, physics,...)

- Injection team, Dump team, (with beam only)
- Ion collimation team, TOTEM, ...

⇒ Collaborative effort between several teams and groups.
HWC Procedure Defined and in MTF

HWC procedures specified (EDMS document by T. Weiler): cover all production phases.

HW commissioning in preparation of beam operation MTF structures.

Close collaboration: ABP, ATB, OP, CO, HCC

Profile Workflow

Final validation of single collimator functionalities!
**Machine Protection Commissioning Being Formally Defined**

**MPS Commissioning Procedure**

**THE COMMISSIONING OF THE LHC MACHINE PROTECTION SYSTEM**

**MPS ASPECTS OF THE COLLIMATION SYSTEM COMMISSIONING**

Abstract
This document describes the set of tests which will be carried out to validate for operation the machine protection aspects of the LHC collision system. The area concerned by these tests extends over 7 out of the 8 long straight sections.

These tests include the Hardware Commissioning, the machine check-out and the tests with beam, to the extent that they are relevant for the machine protection functionality of collision.

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- Heike Landerer
- Elena Pardilla
- Rudiger Schmidt
- Benjamin Treib
- Rolf Weininger
- Marco Zschiedrich

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**Example of collimator settings**

- **Dump threshold**
- **Operational tolerance**
- **Settings**

**Collimator gap**

- **t₀, t₁, t₂, t₃, t₄**

**Time**

- Injection
- Ramp
- Squeeze

All machine protection functionality based on interlocks on position readings (redundancy).

Can be commissioned without beam.

Foreseen for March/April.
HWC: Tracking Jaw Positions

S. Redaelli

Generally excellent resolution and performance.
In the tunnel at some locations pickup noise.
Being analyzed.

S. Redaelli
Deliverables

- **Outcome of the collimator hardware commissioning:**
  - Validation of single collimator, all relevant functionality
  - Settings and sensor readouts (position, temperature, switches,...) verified
  - Control of each collimator from CCC is declared “safe”
  - Machine protection functionality (without beam) partially established

- **Cold checkout** focused on:
  - Control an ensemble of collimators
  - Address timing and synchronization issues
  - Function-driven motion, “tracking” tests with other equipment
  - Establish full machine protection functionality without beam
  - Verify interfaces to other accelerator systems
    - Beam loss monitors: configuration/acquisition of distributed system
    - Sequencer driven commands, machine modes
    - Verify logging of distributed systems (big data sets!)
  - Consistency and sanity checks; global system status
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3) Beam Commissioning

- Beam commissioning of collimators will involve many aspects:
  - Proton losses around the ring.
  - Energy deposition in accelerator devices, including SC magnets.
  - Quenches induced by beam loss.
  - Activation.
  - Radiation.
  - Background in the experiments.
  - Vacuum and heating in the collimation regions.
  - Cooling capacity.

- All has been addressed over the last 5 years (CWG web site).

- These issues are all driven by collimator settings (~500 degrees of freedom) and performance.

- In this talk, focus on how to get to nominal settings and performance.
Set-up of single collimator

Calibrated center and width of gap, if beam extension is known (e.g. after scraping).

Advance with experience! Rely on BLM system...
SPS Test for LHC Collimator: BLM-based Calibration

\[ \sigma_x \approx 0.7 \text{ mm} \]

Required time < 1h; Centring repeated at every new coast: \(~15\text{ minutes}\)
Learning from Tevatron

• We do now have our own guns at CERN (collimators)!

• Tevatron has the bullets (knowledge how to make collimation work).

• Visits to Fermilab, especially by younger members of the collimation project:
  • S. Readelli (EIC)
  • V. Previtali (PhD)

• Several visits from FNAL experts to CERN.

• Also contacts with BNL on this.
• Two collimation activities ongoing in parallel last Friday in the Tevatron control room: main injector and Tevatron.

• Must get used to this at CERN…

• Tevatron collimation system is the second system (other less powerful system was used for run I).
A Look at Tevatron

~ factor 2 improvement per year
My Tevatron Lessons

• Collimation can perform very well if effort is spent.
• Tevatron collimation is only set up by experts (actually ONE expert: Dean Still). Operators only execute pre-defined automatic sequences.
• In order to tune up collimator positions, the beam is touched and small amounts of beam are lost:
  – During collimator tuning the target losses in magnets go up to ~80% of quench threshold.
  – If something goes wrong in collimator tuning a magnet can and will quench.
  – BLM’s are bypassed due to excessive rate of false beam dumps.
  – Tevatron has a stable algorithm with a peak maximum loss rate of $6 \times 10^{-3} \text{s}^{-1}$.
  – Stability is achieved by stopping BLM-based tuning when reaching maximum intensity loss, indicated by fast intensity measurement (kind of cut off at the $3\sigma$ point of the Gaussian beam intensity distribution - less stable halo).

6 times the specified maximum beam loss rate at the LHC with collimation fully set up!
For LHC Collimation

- Train and keep **collimation experts for commissioning** the LHC system:
  - **S. Redaelli**, 4 years collimation work (fellow + EIC), staff in operations group.
  - **C. Bracco**, 3 years collimation work (PhD), start fellowship in June 08.
  - **V. Previtali**, 1 year collimation work (PhD).
  - **T. Weiler**, 2 years collimation work (present fellow).
  - **M. Jonker**, 3 years collimation work (staff).
  
  *Connected: G. Robert-Demolaize (PhD on LHC collimation).*

- **Automatic procedures** must be in place: Work ongoing (see presentation by M. Jonker at last MAC).

- The **intensity information** must be added with good rate (100 Hz). To be done.

- Collimator set up in the LHC must work differently than in Tevatron:
  - Nominal LHC at 7 TeV has **200 times higher stored energy** than Tevatron.
  - For same quench threshold and set up method, can only **allow for 0.5% of LHC beam** (14 bunches out of 2808). Note: LHC quench thresholds are even lower!
  - Collimator set up in LHC is foreseen with a **few nominal bunches** (determined from simulation results on single stage cleaning efficiency – consistent with Tevatron).
Principle for Collimator Set-up at 7 TeV

Inject 5 nominal bunches
- Collimator set up 450 GeV (1-4 batches)
  - Ramp
- Collimator set up at 7 TeV (build on Tevatron scheme)
  - Record beam parameters and collimator settings
  - Beam Dump

Inject high intensity
- Collimator set up 450 GeV (1-4 batches)
  - Ramp
  - Restore beam conditions and collimator settings
  - Good?
    - NO
      - Beam Dump
    - YES
      - Physics

Inject high intensity
- Collimator set up 450 GeV (1-4 batches)
  - Ramp
  - Restore beam conditions and collimator settings
  - Good?
    - NO
      - Beam Dump
    - YES
      - Physics
Set Up Strategy

- Rely on **reproducibility of the machine** for the baseline.
- This is helped by only working with bunches of ONE intensity – **only change number of bunches, not bunch intensity**.
- Good **reproducibility and stability** is crucial for the LHC!
- Feedback from **orbit measurements** to collimator settings, if orbit is not stabilized as specified or not reproducible.
- In parallel work on more **advanced methods**:
  - Understand changes from 450 GeV to 7 TeV ➔ adjust 7TeV collimator settings with 450GeV data?
  - Do 7 TeV collimator set-up on **secondary halo or pattern of beam loss** measurement?
  - Phase 2: **buttons in jaws** for deterministic setup of collimators (center around beam by equalizing pick up signal of two buttons, coupled to jaws).
- Reproducibility is not evident. However, advanced methods challenging!
Definition of “Good” and “Bad”

- Collimation efficiency will be measured after every set-up.
- Measurement method:
  - Generate diffusive beam losses in one plane (will always end up on primary collimator after collimator setup). Can be done with transverse feedback, tunes, kicker, ...
  - Measure intensity loss rate (p/s).
  - Record beam loss monitor readings.
  - Increase diffusion speed until the target loss rate (efficiency) is reached.
  - For example with phase 1 we should reach $1 \times 10^{11}$ p/s (conclusion: efficiency OK).
  - **Performance reach**: Increase diffusion speed while recording intensity loss rate. Push up to quench or BLM generated abort.
Measured Cleaning Efficiency

- Measure \((dI/dt)_{\text{max}}\) at the abort limit of the BLM or until we quench.

\[
(dI / dt)_{\text{max}} = \frac{R_q}{\tilde{\eta}_{\text{ineff}}} \quad \Rightarrow \quad \tilde{\eta}_{\text{ineff}} = \frac{R_q}{(dI / dt)_{\text{max}}}
\]

- Deliverable of the collimation system: Target cleaning efficiency (support DC betatron beam losses of up to \(1.6 \times 10^{11}\) p/s at 7 TeV – 200 kJ/s).
- Once design has been reached, the collimation is commissioned.
- Can be achieved, once full phase 1 is installed: 2009. Should be able to reach \(0.8 \times 10^{11}\) p/s with 2008 system.
Commissioning Preparations: Start with Less Collimators and Relaxed Tolerances

![Graph with data points and trend lines showing the relationship between beam population and the number of collimators per beam, along with tolerance values for different beta-star values.]

- Tolerance: $[\beta^* = 2\text{m}]$ for a specific beam population.
- Tolerance: $[\beta^* = 0.55\text{m}]$ for another beam population.

Number of collimators per beam increases as the beam population decreases.
### Commissioning Preparations: 7 TeV Settings for Various Intensities

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<th>Intensity</th>
<th>$\beta^*$ [m]</th>
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<th>$n_2$ [σ]</th>
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<td>8.3</td>
<td>7.5</td>
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Commissioning Preparations: Efficiency and Quench Limit During the Ramp

C. Bracco

Two observations:  
1) Quench limits go down.  
2) Local losses in DS go up because collimator not closed!
Commissioning Preparations: Triplet Aperture During Squeeze

T. Weiler

Beam 1, left

Beam 1, right

Beam 2, left

Beam 2, right

\( n_\gamma \) [c]

\( \beta \) [m]

aperture limit arcs
Transient in Collimation Insertion vs. Squeeze Step
- moderate global orbit correction only (commissioning)

\[ \beta^* = 17 \rightarrow 9 \text{ m} \quad \text{and} \quad \beta^* = 1.5 \rightarrow 1.1 \text{ m} \]

will be toughest for keeping orbit collimation requirements

(further mitigated by controller)
Commissioning Preparations: Collimation During the Squeeze

End of Ramp
- Correct machine
- Verify coll settings
- Switch off FB (transv)
- Switch on octupoles
- Correct machine
- Check feedbacks
- Squeeze to $\beta^*=6$ m all relevant IR’s
- Correct machine

Measure tail population to 6 $\sigma$
- Scraping of tails
- Set absorbers for physics debris (TCLP)
- Put beams into collision
- Switch off octupoles?
- Correct machine
- Check losses and background

Adjust coll IR3/7 for $n_1$ of next $\beta^*$ step (apply 1 $\sigma$ margin)
- Adjust dump protection (TCDQ+TCS)
- Adjust triplet collimators (TCT)
- Squeeze each IR to next $\beta^*$ step (maybe track TCT’s with crossing bumps)
- Correct machine
- Correct machine

YES
- End of squeeze?

NO
- Physics
Commissioning Preparations: Collimation During the Squeeze (Low Intensity)

- **End of Ramp**
  - Correct machine
  - Verify coll settings
  - Switch off FB (transv)
  - Correct machine
  - Check feedbacks?
  - Squeeze to $\beta^* = 6$ m all relevant IR’s
  - Correct machine

- **Measure tail population to 6 $\sigma$**
  - Scraping of tails
  - Put beams into collision
  - Correct machine
  - Check losses and background

- **Low**
  - Adjust coll IR3/7 for n1 of next $\beta^*$ step (apply 1 $\sigma$ margin)
  - Adjust dump protection (TCDQ+TCS)
  - Adjust triplet collimators (TCT)
  - Squeeze each IR to next $\beta^*$ step (maybe track TCT’s with crossing bumps)
  - Correct machine

- **High**
  - End of squeeze?

- **YES**
  - Correct machine
  - End of squeeze?

- **NO**
  - Correct machine
Commissioning Preparations:
Squeeze Routine Operation Procedure

End of Ramp
- Correct machine
- Verify coll settings
- Switch off FB (transv)
- Switch on octupoles
- Correct machine

Automated scraping
- Set absorbers for physics debris (TCLP)
- Put beams into collision
- Switch off octupoles
- Correct machine
- Check losses and background

Physics

Automated squeeze, crossing changes and collimator closing (function-driven)
- Correct machine
Summary

- LHC collimation on track for beam in May 2008.
- Thorough hardware commissioning and cold checkout is establishing known collimators with safe position monitoring.
- Results look very promising with some issues being addressed.
- All results from production, HWC and cold checkout documented on project website (easily accessible from the control room).
- A strong team has been trained for collimator commissioning. Try to learn as much as possible from Tevatron and RHIC. PhD on commissioning: May 2008.
- Collimation set-up is necessarily different from Tevatron! Procedures have been worked out, based on detailed LHC simulations (number of collimators versus performance, ramp, squeeze, …).
- ‘Phase 1’ collimation commissioning must be supported by ‘phase 2’ implementation, such that performance can be continuously improved (Tevatron: factor 2 per year over 6 years).