The Final LHC Collimation System

R. Assmann, CERN/AB for the LHC Collimation Team
EPAC 2006
Edinburgh
The LHC Collimation Team

Collimation team:
About 60 CERN technicians, engineers and physicists… in various groups and departments.

⇒ Several at EPAC06

+ collaborators in various laboratories…
The LHC Challenge


High stored energy and stored energy density!

Small collimation gaps!

![Graph showing the relationship between beam momentum and stored beam energy for various accelerators, including LHC, ISR, SPS, HERA, and TEVATRON. The graph illustrates the high stored energy and stored energy density of the LHC compared to other accelerators.]

![Diagram showing small collimation gaps: injection jaw opening ~12 mm, top energy ~3 mm.]
Preventing Quenches

- Shock beam impact: \(2 \text{ MJ/mm}^2\) in \(200 \text{ ns}\) \((0.5 \text{ kg TNT})\)

- Maximum **beam loss at 7 TeV**: 1% of beam over 10 s

- **Quench limit** of SC LHC magnet: \(8.5 \text{ W/m}\)

\[
\text{500 kW}
\]
Phased LHC Collimation System

- In total 8 different types of collimators plus masks and absorbers.
- In total 138 ring and 28 transfer line locations for LHC collimators and absorbers:

<table>
<thead>
<tr>
<th>Phase</th>
<th># collimators</th>
<th>Intensity limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>88</td>
<td>≤ 40% of nominal</td>
</tr>
<tr>
<td>Upgrade 1</td>
<td>34</td>
<td>&gt; 100% of nominal</td>
</tr>
<tr>
<td></td>
<td>(all prepared)</td>
<td></td>
</tr>
<tr>
<td>Upgrade 2</td>
<td>16</td>
<td>ultimate efficiency</td>
</tr>
</tbody>
</table>

- Series production ongoing for 125 ring and transfer line collimators.
"Phase 1"

"Final" system:
Layount is 100% frozen!

RWA, EPAC06
Multi-Stage Betatron Cleaning

Effectively 4-stage cleaning process at 7 TeV to triplets!
Performance Reach

Simulations: 5 million halo protons
200 turns
realistic interactions in all collimator-like objects
LHC aperture model

⇒ Multi-turn loss predictions
Beam1 and Beam 2 Loss Simulations

**Beam1, 7 TeV**
Betatron cleaning
Ideal performance

**Beam2, 7 TeV**
Betatron cleaning
Ideal performance

**Quench limit**
*(nominal I, $\tau=0.2h$)*

Local inefficiency: 
#p lost in bin over total #p lost over length of aperture bin! New!
Effect of Closed Orbit (Static & Beam1)

IR7
Betatron collimation

Higher inefficiency (factor 2) ➔ Less performance!

Impact on machine design: Allocation of ring BLM’s!

Quench limit (nominal I, $\tau=0.2h$)

Ideal case

With orbit error

RWA, EPAC06
Energy Deposition (FLUKA)

IR7 Betatron collimation

High activation!

Mean values ± 2m horizontally and ± 1m vertically.
Impedance

- Increase from collimators (nominal settings) for the imaginary part of the effective vertical impedance:
  - 8 kHz:
    - factor 3 for injection
    - factor 69 for 7 TeV
  - 20 kHz:
    - factor 3 for injection
    - factor 145 for 7 TeV
- Large increase in impedance must be actively counteracted by transverse feedback and octupoles!
- Phase 2 collimators to overcome impedance and improve efficiency!

*Phase 1 is limited from collimator-induced impedance!*
Hardware: Water Cooled Jaw

- Up to 500 kW impacting on a jaw (< 7 kW absorbed in jaw)...

Advanced material: Fiber-reinforced graphite (CFC)
The Collimator Tank Assembly

360 MJ proton beam
Collimator General Layout
(vertical and skew shown)
Base Support and Lower Plug-In

Guides

Lower plug-in

Base support

Water plugs

Electrical plugs

RWA, EPAC06
First LHC collimators installed…

10 minutes installation: checking on quick-plugs…

First ring collimator in 8L. (triplet protection for beam 1)

- June 14th -
First LHC collimators installed…

Injection protection: Transfer line collimators in the ring, just before injection 8R.

- May 31st -
Preparing Commissioning at 7 TeV

0.8 mm at a typical collimator

0.2 mm at a typical collimator

Phase 1

Commissioning is being prepared: Controls, tools, scenarios, ...

Tolerance $[\beta^* = 2\text{m}]$

Tolerance $[\beta^* = 0.55\text{m}]$

Number of collimators per beam

Beam population [p]
Conclusion

- The LHC collimation system layout is finalized and performance reach is evaluated.

- Simulations: Performance can reach \(\sim 10^{-40}\%\) of nominal intensity for phase 1 after initial and full commissioning (up to 100 times TEVATRON/HERA stored energy). Imperfections and quench limits are critical!

- Production is now running for all major parts in the tunnel. Last collimator for 2007 installation will arrive end of January 2007.

- Installation has started in IR8. All of infrastructure under way in the seven IR’s with collimators (also for first upgrade).

- A relatively powerful LHC collimation system will be available for the LHC start-up. It can be upgraded in performance (around 2010).

- Commissioning and operation is being prepared…

- Phase 2 R&D program under preparation (FP7 collaboration).
Collimation-Related Papers

- **MOPCH091** An Alternative **Nonlinear Collimation** System for the LHC
  Javier Resta (IFIC, Valencia; CERN, Geneva), Ralph Assmann, Stefano Redaelli, Guillaume Robert-Demolaize, Daniel Schulte, Frank Zimmermann (CERN, Geneva), Angeles Faus-Golfe (IFIC, Valencia)

- **MOPLS003** Tertiary Halo and Tertiary **Background** in the Low Luminosity Experimental Insertion IR8 of the LHC
  Vadim Talanov (IHEP Protvino, Protvino, Moscow Region), Ralph Assmann, Daniela Macina, Keith Michael Potter, Stefano Redaelli, Guillaume Robert-Demolaize, Emmanuel Tsesmelis (CERN, Geneva)

- **MOPLS008** Beam Halo on the **LHC TCDQ Diluter System** and Thermal Load on the Downstream Superconducting Magnets
  Brennan Goddard, Ralph Assmann, Andrew Presland, Stefano Redaelli, Guillaume Robert-Demolaize, Lucia Sarchiapone, Thomas Weiler, Wim Weterings (CERN, Geneva)

- **TUPLS013** Protection of the LHC against **Unsynchronised Beam Aborts**
  Brennan Goddard, Ralph Assmann, Etienne Carlier, Jan Uythoven, Jorg Wenninger, Wim Weterings (CERN, Geneva)

- **TUPLS017** Optics Study for a Possible **Crystal-based Collimation** System for the LHC
  Ralph Assmann, Stefano Redaelli, Walter Scandale (CERN, Geneva)

- **TUPLS018** **LHC Collimation Efficiency** during Commissioning
  Chiara Bracco, Ralph Assmann, Alfredo Ferrari, Stefano Redaelli, Guillaume Robert-Demolaize, Mario Santana-Leitner, Vasilis Vlachoudis, Thomas Weiler (CERN, Geneva)

- **TUPLS019** Critical **Halo Loss Locations** in the LHC
  Guillaume Robert-Demolaize, Ralph Assmann, Chiara Bracco, Stefano Redaelli, Thomas Weiler (CERN, Geneva)

- **TUPLS130** Comparison between **Measured and Simulated Beam Loss Patterns** in the SPS
  Stefano Redaelli, Gianluigi Arduini, Ralph Assmann, Guillaume Robert-Demolaize (CERN, Geneva)

- **THPCH061** Tune Shift Induced by Nonlinear Resistive Wall **Wake Field of Flat Collimator**

- **TUPLS131** **LHC Collimation Efficiency** as a Function of Collimator Jaw Flatness
  Stefano Redaelli, Ralph Assmann, Chiara Bracco, Guillaume Robert-Demolaize (CERN, Geneva)