A Collimation perspective on the commissioning


10th LHC Operations "Evian" Workshop
Introduction

- Several HW and SW upgrades during LS2 on one of the most critical LHC systems (see G. Azzopardi)

Collimator settings and cleaning performance tightly linked to:

Available aperture that must be protected at any time

Machine performance reach

Very useful to have feedback on HW and SW before 2022 run for an educated perspective on commissioning
Outline

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VII. Looking at the future
VIII. Conclusions
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Collimation activities during test beam

Sequential automatic alignment of entire system Global aperture measurements with nominal Loss Maps

Global aperture with pilot BPM checks

Threading

25.10 Validation of new loss map application

24.10 26.10

21L3 local aperture

21L3 local aperture

29.10

IT1&5 local aperture

31.10

21L3 local aperture

21L3 local aperture

30.10

IT2 local aperture

21L3 mitigations

Tested crystals

Tested new fully-automatic and angular alignment features

Tested new direct settings trim generation

Tested new settings check application

Quite exciting and intense two weeks, which provided plenty of inputs!
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Get beams circulating

- Beam left “circulating” step-by-step: collimators used to stop the beam in each IR (except IR4…)
  
  *a.k.a. Threading*

<table>
<thead>
<tr>
<th>Beam 1</th>
<th>Beam 2</th>
</tr>
</thead>
</table>

Ring coll. at: LD = 0.5mm, LU = -1mm, RD = -1mm, RU = -2.5mm
TDIS[A|B] at: L = [4.0|-2.5], D = [2.5|-4.0]

BP and sequences used to handle collimators worked smoothly, ready for 2022
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Aperture measurements

Consistent with 2018 and gained in B2H
Without considering bottleneck in 21L3

Consistent with expectations, to be confirmed in 2022

Complete overview and summary of previous years in: N. Fuster et al. arXiv:2106.09656 (Sub to EPJ Plus)
Impacts on 2022 settings ($\varepsilon^* = 3.5\ \mu m$)

Collimator family-IR#
TCL.cell# in IR1&5

Collimator family-IR#
TCL.cell# in IR1&5

With XRP – IN
TCL4/5/6 at 17/42/20

Injection
Ramp & Squeeze
Flat Top
Squeeze
End of Squeeze
Adjust

Physics (XRP - OUT)
Settings strategy during $\beta^*$ and Xing leveling in 2022

- Settings strategy **agreed with forward physics experiments** at LHC Collimation WG #256 and #260
  - Keep TCTs and TCLs at constant mm gap corresponding to requested $\sigma$ at $\beta^*$=30 cm
  - Small XRPs movement to keep adequate hierarchy margins within discrete limits

- Still needed to **follow closed orbit**
  - Problematic to use discrete limits

**Solution for Run3:**

- Interlock limit functions sliced at matched points
- Segments stored in LSA as function list and signature generated for every segment

More flexible solution envisaged for Run 4, where new collimator controls will be deployed (SAMBUCA)
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Alignment and settings

Several milestones achieved during test beam:

- Entire system aligned sequentially:
  - Demonstrated max 2h in worst conditions
  - Collected data for parallel alignment of new collimators

- All BPMs tested:
  - Minor issues identified only on 2 collimators that will be fixed during YETS

- New app functionality for direct trims:
  - Centres can be trimmed right after alignment without file exchange
Impacts on 2022 commissioning

- **Expected time** to align full system at different stages:
  - ✓ **Reconfigurations** along the year *not an issue* thanks to BPMs
  - ✓ ~1.5h needed in 2018 with **sequential alignment** (79 colls)
  - ✓ **Parallel alignment** also **validated** along 2018

Expected ~1h/2h with parallel/parallel+sequential alignment at Injection/Flat Top in 2022 (85/81 colls) thanks also to data for new collimators collected in 2021

- **Quicker and easier generation** of settings:
  - ✓ **Direct trims of centres** from main application
  - ✓ **Direct generation in LSA** of setting functions

*No need* of external settings generation and file exchange (time consuming and error prone)

*First estimation of integrated time needed for alignment and validation: ~4 shifts*
Crystals

- Bent crystals will be used as **primary collimation stage during 2022 ion run**
  - ✓ Requested to validate their **status after LS**
  - ✓ Two crystals to be replaced during YETS

- Dynamic schedule and priorities pushed test at the **end of the test beam**
  - ✓ Managed to test **B2 crystals**
  - ✓ **Channelling successfully observed** and consistent with 2018 measurements
  - ✓ Confident that crystals in beam 1 should be as left in 2018 as well
## Additional time requests in 2022 commissioning

<table>
<thead>
<tr>
<th>Activity</th>
<th>Estimated time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BPM scan</strong> for 33 collimators</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Align with BPMs</strong> the 3 missing collimators post-beam test</td>
<td>0.5</td>
</tr>
<tr>
<td>Test of <strong>new ML model</strong> under development that promises up to 50% time reduction for beam based alignment</td>
<td>1.5</td>
</tr>
<tr>
<td>Test <strong>new parallel alignment</strong> implemented for <strong>Flat Top</strong></td>
<td>0.5</td>
</tr>
<tr>
<td>Sequential alignment of entire system at <strong>Flat Top</strong> to collect missing <strong>crosstalk data</strong></td>
<td>2</td>
</tr>
<tr>
<td>Validation of <strong>new crystals</strong> installed during <strong>YETS</strong></td>
<td>12</td>
</tr>
</tbody>
</table>
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Performance validation in 2022

Same approach extensively used in Run II

Initial commissioning

Static points & dynamic phases

Both signs at static points

After TS / expired validity

Static points

Alternated signs at static points

Example from 2016:

Small bump building up toward IR7-TCLAs (~100 um) during squeeze revealed by unexpected B1H cleaning behaviour

After correction during TS1 comm. back to 2.0e-4

96 loss maps!
New tool for Loss Maps and online analysis

New unique application for $\beta$ and $\delta p/p$ LM to ease and speed up performance validation

✓ Integrated definition of LM matrix and storing in LSA

✓ Live machine configuration
✓ Automatic loading of requested LM
✓ Status of LM advancement

✓ On-line feedback of LM quality

✓ Preliminary analysis for quick feedback during intensity ramp up

Deployed and fully compliant with acc-py guidelines/environment
New tool for offline analysis

Main features

- Uses **NXCALS** for *data extraction* and **SPARK** for distributed *data analysis*
- Designed for **Jupyter notebooks** running on the **SWAN** cloud service
- Possibility to *store* a catalogue of analysed loss map scenarios on **HDFS**

Latest developments

- Compatible with the **latest logging** structures
- Modular design for improved analysis **flexibility**
- **Interactive** loss map plotting
- Improved **efficiency**

https://gitlab.cern.ch/collteam/lossmaps/

Python package originally developed by A. Gorzawski

Example from 2021
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21L3 identification

- **Puzzling** observations during initial global aperture measurements
  - Losses observed at 21L3 but never became larger than at primary collimators
  - Usual signature of secondary halo lost locally

- **Alarming losses** observed during performance validation with single stage

OK given for stable beams with three bunches, but **local aperture measurements requested**
21L3 local aperture measurements

1) **Beam shaped** with primary collimators to have the desired beam probe

2) 3/4-Correctors **local orbit bump** matched in H/V plane at Q21L3

3) Local aperture probed systematically with 2/0.5 mm steps in H/V plane

4) **Max bump excursion in H of ±10 mm** defined by arising of losses at Q20/Q22

5) **Measurements** performed on 29/10 and 30/10 after Fast Power Abort at 3.5 TeV

*Measurements used to match a local orbit bump that could restore >11σ global aperture from ~7σ*
21L3 mitigations

- **Primary collimator** in V plane closed from $8\sigma$ to $6\sigma$ during test beam to alleviate losses in first minutes of SB
- **Other mitigations** were tested to probe possibility to cope with high intensity beams in 2022:
  - Primary opened to $8\sigma$ and local orbit bump of (5, 2.5) mm
  - Entire IR7 closed to nominal injections settings for high intensity beams

Both worked well: feeling that we could have handled without major performance limitation from losses/collimation

*Tests possible also thanks to the complete system alignment and new SW tools validated during test beam, allowing a quick parameter generation for entire IR7*
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Performance of the Run 3 system

- **Detailed assessment in simulations:**

  Machine configuration 2023, $\beta^* = 30\text{cm}$

- ✓ Layouts updated with “as-built” lattice
- ✓ Performance evaluated with the **new collimator design/materials**
- ✓ **Gain of 20-25% cleaning performance** due to new materials
  (A. Waets @ [ColUSM #138](#))

F. Van Der Veken
Settings for $\beta^*$ leveling in 2023 – 2024

Main changes on collimation strategy w.r.t. 2022:

- Keep constant TCT-TCL settings in units of $\sigma$ (instead of mm)

Significant changes in optics (see R. Tomas):

- Not constant $\Delta \mu$ MKD - TCDQ for $\beta^* > 60$ cm

Proposed solution:

- Adapt TCT settings to be in TCDQ shadow while protecting IT

To be validated by dedicated asynchronous dump study

Change of effective TCDQ gap

Potential breakage of hierarchy
Impact of 1 year extension

• **No impacts** on collimation performance if same 2024 machine parameters are kept

  Detailed assessment needed if machine **performance pushed** further

• **Complete renewal** of entire control system foreseen for **LS3** because of reached **end of life**

  Study in progress to address failure rate in the additional year of Run 3
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Conclusions

• Several upgrades HW and SW during LS2 on one of the most critical LHC systems

• Quite exciting and intense test beam providing plenty of inputs:
  ✓ Threading worked smoothly and ready for 2022
  ✓ Aperture in agreement with expectations (provided no other 21L3-like events)
  ✓ Settings along the cycle and strategy during levelling defined along Run III
  ✓ Alignment and new tools tested promising faster setup and validation

• Impact of 1 year extension:
  ✓ No impacts on cleaning performance if same 2024 machine parameters are kept
  ✓ Study in progress to address failure rate of controls at end of life in the additional year
Outline

BACKUP
## Summary global aperture measurements

From N. Fuster et al. arXiv:2106.09656 (Sub to EPJ Plus)

Table 4. Summary of the measured global aperture bottlenecks per beam and plane at injection energy. The aperture measurements are expressed by the reference collimator half-gap before and after exposing the bottleneck. All values are given in units of beam size $\sigma$, for $\sigma_{\text{b}} = 3.5$ $\mu$m. The bottleneck location is also indicated for each beam and plane and the beam-based aperture measurement method used.

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy [TeV]</th>
<th>Method</th>
<th>B1H $\sigma$</th>
<th>B1V $\sigma$</th>
<th>B2H $\sigma$</th>
<th>B2V $\sigma$</th>
<th>Bottleneck</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0.450</td>
<td>Tune resonance blow-up + coll. scan</td>
<td>12.5-13.0 (Q6R2)</td>
<td>13.5-14.0 (Q4L6)</td>
<td>14.0-14.5 (Q3R6)</td>
<td>13.0-13.5 (Q4R6)</td>
<td>TCDSA</td>
</tr>
<tr>
<td>2011</td>
<td>0.450</td>
<td>Tune resonance blow-up + coll. scan</td>
<td>12.0-12.5 (Q6R2)</td>
<td>13.0-13.5 (Q4L2)</td>
<td>12.5-13.0 (Q4R6)</td>
<td>13.1-13.6 (Q4R6)</td>
<td>MQY 4L6</td>
</tr>
<tr>
<td>2012</td>
<td>0.450</td>
<td>Controlled white noise emittance blow-up + coll. scan</td>
<td>11.5-12.0 (Q6R2)</td>
<td>12.0-12.5 (Q4L6)</td>
<td>12.5-13.0 (Q5R6)</td>
<td>12.5-13.0 (Q4R6)</td>
<td>MQY 4R6</td>
</tr>
<tr>
<td>2015</td>
<td>0.450</td>
<td>Controlled white noise emittance blow-up + coll. scan</td>
<td>11.6-12.1 (MBRC.4R8)</td>
<td>12.1-12.6 (Q6L4)</td>
<td>12.5-13.0 (Q6L6)</td>
<td>12.0-12.5 (Q4R6)</td>
<td>MQY 4L6</td>
</tr>
<tr>
<td>2016</td>
<td>0.450</td>
<td>Controlled white noise emittance blow-up + coll. scan</td>
<td>12.5-13.0 (MBRC.4R8)</td>
<td>12.0-12.5 (Q6L4)</td>
<td>12.5-13.0 (TCDQM.4L6)</td>
<td>12.5-13.0 (Q4R6)</td>
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<tr>
<td>2017</td>
<td>0.450</td>
<td>Controlled white noise emittance blow-up + coll. scan</td>
<td>13.1-13.6 (Q6R2)</td>
<td>12.2-12.7 (Q4L6)</td>
<td>13.2-13.7 (Q6L8)</td>
<td>12.8-13.3 (Q4R6)</td>
<td>MQY 4R6</td>
</tr>
<tr>
<td>2018</td>
<td>0.450</td>
<td>Controlled white noise emittance blow-up + coll. scan</td>
<td>13.3-13.8 (Q4R6)</td>
<td>12.2-12.7 (Q4L6 &amp; Q6L8)</td>
<td>13.5-13.5 (Q4R6)</td>
<td>12.5-13.0 (Q4R6)</td>
<td>MQY 4R6</td>
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## Summary IT aperture measurements

From N. Fuster et al. arXiv:2106.09656 (Sub to EPJ Plus)

The aperture measurements are given by the reference collimator half gap before and after exposing the bottleneck. All values are given in units of beam size $\sigma$, for $\sigma_0 = 3.5$ mm. The bottleneck location is also indicated for each beam and plane.

<table>
<thead>
<tr>
<th>E</th>
<th>$\beta^*$</th>
<th>$\phi$</th>
<th>Method</th>
<th>B1H</th>
<th>B1V</th>
<th>B2H</th>
<th>B2V</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>4</td>
<td>100</td>
<td>-145</td>
<td>Controlled white noise emittance blow-up+coll. scan</td>
<td>11.5-12.0 (Q2L5)</td>
<td>11.0-11.5 (D1/Q3L1)</td>
<td>11.5-12.0 (D1/Q3R1)</td>
</tr>
<tr>
<td>2015</td>
<td>6.5</td>
<td>80</td>
<td>-145</td>
<td>Controlled white noise emittance blow-up+coll. scan</td>
<td>18.2-18.7 (D1/Q3R5)</td>
<td>15.7-16.2 (D1/Q3L1)</td>
<td>16.2-16.7 (D1/Q3R1)</td>
</tr>
<tr>
<td>2016</td>
<td>6.5</td>
<td>40</td>
<td>-185</td>
<td>Controlled white noise emittance blow-up+coll. scan</td>
<td>10.6-11.1 (D1/Q3R5)</td>
<td>9.9-10.4 (D1/Q3L1)</td>
<td>11.5-12.0 (D1/Q3R1)</td>
</tr>
<tr>
<td>2017</td>
<td>6.5</td>
<td>40</td>
<td>+185</td>
<td>Controlled white noise emittance blow-up+coll. scan</td>
<td>10.9-11.4 (D1/Q3R5)</td>
<td>12.0-12.5 (D1/Q3L1)</td>
<td>12.9-13.4 (Q2R5)</td>
</tr>
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<td>30</td>
<td>+150</td>
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<td>10.6-11.1 (D1/Q3L1 &amp; D1/Q3R5)</td>
<td>11.1-11.6 (Q2R5 &amp; D1/Q3L1)</td>
<td>10.9-11.4 (D1/Q3R1)</td>
</tr>
<tr>
<td>2018</td>
<td>6.5</td>
<td>30</td>
<td>+160</td>
<td>Controlled white noise emittance blow-up+coll. scan</td>
<td>10.5-11.0 (D1/Q3L1)</td>
<td>10.5-11.0 (D1/Q3L1)</td>
<td>10.0-10.5 (D1/Q3R1)</td>
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<tr>
<td>2018</td>
<td>6.5</td>
<td>25</td>
<td>+145</td>
<td>Controlled white noise emittance blow-up+coll. scan</td>
<td>9.2-9.7 (D1/Q3L1)</td>
<td>9.2-9.7 (D1/Q3L1)</td>
<td>&gt;12</td>
</tr>
</tbody>
</table>

### 2021 test beam

<table>
<thead>
<tr>
<th>IT - plane</th>
<th>Positive</th>
<th>Negative</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - H</td>
<td>23.3/23.9</td>
<td>-23.3/-23.9</td>
<td>24</td>
</tr>
<tr>
<td>1 - V</td>
<td>28.4/28.7</td>
<td>-27.7/-28.0</td>
<td>28.9</td>
</tr>
<tr>
<td>5 - H</td>
<td>29.9/31.1</td>
<td>-29.1/-29.5</td>
<td>28.9</td>
</tr>
<tr>
<td>5 - V</td>
<td>24.4/24.7</td>
<td>-25.3/-25.7</td>
<td>24</td>
</tr>
<tr>
<td>2 - H</td>
<td>18.0/19.5</td>
<td>-18.5/-19.5</td>
<td>19</td>
</tr>
<tr>
<td>2 - V</td>
<td>27.4/28.9</td>
<td>-28.9/-30.4</td>
<td>28.9</td>
</tr>
</tbody>
</table>

All at Q2, except IT2-H at Q1