Collimation commissioning
JAPW ’22


with many thanks to the LHC OP, STI, CEM, BI, and GM teams
Outline

1. Overview
2. Performance
3. Alignment
4. Loss Maps
5. Conclusion
- Collimation system essential to protect machine against quenches
- Run 2: stored energy $\sim 300$MJ
- Run 3: increased to $\sim 400$MJ
- Collimators follow strict hierarchy

![Collimation System Diagram](image)

*Courtesy of R. Bruce and N. Fuster-Martínez*
Collimation @ LHC

- 101 collimators in the LHC
- 14 new collimators, many in IR7:
  - new materials for lower impedance
  - all with BPMs embedded
  - DS cleaning around IR2 to enable x6 lumi after update
- 2 new crystal primary collimators
Collimation Commissioning

- Three pillars of collimation: to ensure safe and efficient operation
  - **Alignment**: center collimators around beam
  - **Loss Maps**: verify distribution of losses around the ring
  - **Aperture**: verify bottleneck location and magnitude, and that it is protected

- Need set-up and validation at every step in the cycle
  - injection, flat top, squeeze, Q-change, physics, collisions XRP IN/OUT

- Keep machine protected during commissioning phases
  - ⇒ **coarse settings** initially (few collimators only, more open)
  - ⇒ validate with **nominal settings**
Beam Time for Commissioning

- **Core Commissioning:**
  - Full system alignment (coarse, and later nominal): 3 shifts
    *including one repetition due to an operational mistake*
    *not counted: Roman pot alignment*
  - Aperture measurements: 4.5 shifts
    *including explicit check at flat top due to BSRT mirror*
    *performed twice at $\beta^*=30$ cm because of steady-state losses*

- **Machine Validation (OP+COLL/ABT):**
  - Loss Maps: 5 shifts
    *performed over 6 fills because of requested ASDs*

- **First commissioning**
  *(some steps repeated: special runs, 450 GeV physics, and post-TS1)*
Beam Time for Commissioning

- Time shown includes time spent on:
  - beam availability, operational set up, and cycling the fill
  - *These are typically the main driving factor to the time spent!*
  - often cycle is combined with OP or optics tasks

- Many more shifts done:
  - checks and commissioning of new hardware
  - support for other teams
  - MDs & special fills

- Commissioning was a long period in 2022:
  - increased complexity (new hardware, more involved cycle)
  - needed to ensure machine was protected during every phase
Aperture Results

- Settings from Run 2 confirmed by aperture measurements
- No showstopper found for $\beta^* = 30$ cm (at $160 \mu$rad crossing)

<table>
<thead>
<tr>
<th>Plane</th>
<th>CS ($\sigma$)</th>
<th>BBA ($\sigma$)</th>
<th>Bottleneck</th>
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<tr>
<td>B1H</td>
<td>11.5-12.1</td>
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2022: Aperture measured at $\beta^* = 30$ cm

courtesy of P. Hermes (see also talk by R. Bruce at LMC #452)
Aperture over the Years

courtesy of P. Hermes
TCT Strategy During Levelling 2022

- During levelling, beam sizes and orbit at TCTs/TCLs change!
- 2022: TCT aperture fixed in mm (different strategy for 2023)
Loss Map Example

- Two types of collimation loss maps: betatron and off-momentum
- Losses in aperture are normalised to primary losses
- Things to check:
  - hierarchy preserved?
  - no unexplained peaks in cold aperture?
  - maximum inefficiency in dispersion region
- Losses in DS suppressed by a factor $10^4$!
General Outcome

- Collimation system performed very well:
  - complex cycle in 2022: excellent performance at every step!
  - no quenches, not even in quench test
  - few dumps on losses are only due to BLM threshold tuning
  - no need to realign after TS
  - loss maps performed much faster than Run 2 (automation)

- Potential improvements for 2023:
  - much more complex cycle, more loss maps will be needed
  - can do 20 betatron per fill, but limited to 1 ASD
  - assuming 12 probes
  - consider including Roman pot alignment in automatic tool?
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Performance

- Machine is well protected during the full cycle up to $\beta^* = 30$ cm
- As expected, losses on TCTs increase with smaller $\beta^*$

Background still under good control

- Collimation system performs in line with previous years
Cleaning Inefficiency During the Year

without the need to realign!
Comparison: Inefficiency over Run 2
Inefficiency over the Years
TCT Inefficiency during Levelling in 2022

high losses $> 10^{-3}$ but manageable
TCT Inefficiency during Levelling in 2022

high losses $\rightarrow 10^{-3}$ but manageable

Collimation commissioning 2022 17/30
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First Full System Alignment of 2022

- First use of parallel alignment in operation
- Very smooth and fast: 1h25m for full system
- BPM alignment reliable and fast (7m for 16 collimators!)

![Alignment times @Injection @Flat top graph](image)

*courtesy of N. Fuster-Martínez*
First Alignment of 2022

- This alignment was performed twice (with and without tilts)

  *Not strictly necessary, but useful to confirm adequateness of fully-automatic alignment in presence of tilts*

- Several large collimator tilts were found
  
  Three were deemed too large
  
  ⇒ many thanks to Survey team to realign!
BPM Alignments and Survey

courtesy of B. Lindström
General Outcome of Alignment

- BPM alignment very fast and reliable
- Semi-automatic BBA reliable and easy to use
- Found issue with fully-automatic BBA during parallelisation
  
  *looks like communication problem with the middleware*
  
  *currently followed up, to be improved for 2023*

- Very reliable alignment overall
  
  *no system realignment needed during the year*

- Special care needed when aligning TCL6
  
  *due to small beam size*
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Loss Maps

- LM matrix larger than Run 2, but still minimum required
  
  *This is due to many extra steps while levelling*

- Reduced LM matrix used after TS

- Extra LMs done for detailed investigations and special fills

- New tools to simplify operation and analysis:
  - `pyLossMaps` for operation in the CCC
  - `lossmaps` for offline analysis

- Huge speed-up compared to Run 2 (~1 min per LM):
  
  Essentially only limited by number of fills needed for ASDs!
## Loss Maps Matrix

### 450 GeV

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<th>EoS</th>
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### 6.8 TeV

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### Colliding – XRP OUT

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**Also:** continuous LM during the energy ramp.

**Morning:** plan to test LMs for different XRP/TCL6 conditions.
pyLossMaps

- Easy to use
- Much more flexible
- Preliminary online analysis
- Faster (especially off-momentum and ASD)
lossmaps

```
In [7]:  
  
  lm.plot_lossmap(B1H_InjIN, timestamp=None, label_fake_spikes=False, outfile='plots/InjProtIN_B1H.pdf')
  lm.plot_lossmap(B1V_InjIN, timestamp=None, label_fake_spikes=False, outfile='plots/InjProtIN_B1V.pdf')
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  lm.plot_lossmap(DPpos_InjIN, timestamp=None, label_fake_spikes=False, outfile='plots/InjProtIN_DPpos.pdf')
  lm.plot_lossmap(DPneg_InjIN, timestamp=None, label_fake_spikes=False, outfile='plots/InjProtIN_DPneg.pdf')
  
  pymadx.Tfs.Load> zipped file

Out[7]:  
  
  (<Figure size 1440x864 with 3 Axes>,
   array([<AxesSubplot:xlabel='S [m]', ylabel='Norm. BLM signal [arb. units]'>,
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          dtype=object))
```
Large Losses on TCL6

- Originally not sure if losses originate from TCL6 or XRP
- Spent extra time to investigate with dedicated LMs
- Not unexpected: predicted by simulations
- No issue for machine safety
Large Losses on TDIS at Injection

- High peak on TDIS was already observed in previous years
- But still higher now (after TS)
- Using optics for trains uncovered a sensitivity to non-linearities
- No issue for machine safety, but raises questions

⇒ Need to review 2023 strategy, also for top energy

200% of TCP.L7.B1
Tuning BLM Thresholds

loss maps used to calibrate BLMs by updating thresholds

⇒ offline loss maps tool includes functionality to simplify this

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thanks also to the BLM threshold working group
courtesy of F. Ziliotto
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Conclusion

- Very reliable performance of the collimation system
- Overall smooth commissioning
- Many developments made on the coding front
  vastly simplifying operation and analysis

TODO for 2023:

- Alignment: understand parallelisation issue
- Alignment: consider adding XRP to automatic BBA
  depending on available resources
- Loss Maps: discuss strategy for non-linearities
Many thanks for your attention!
Backup Slides
TCT Strategy During Levelling 2023

- During levelling, beam sizes and orbit at TCTs/TCLs change!
- Need strategy to allow Roman pots to get in close enough
- 2023: TCT gap fixed at $8.5\sigma$ for $\beta^* = 60 \ldots 30$ cm
  decreasing from $9.3\sigma$ for $\beta^* = 120 \ldots 60$ cm
Quench Test 2022

- Collimation system too performant: did not manage to quench
- Reached 650kW twice, did not reach 1MW
- No quench even if collimation system artificially downgraded
- Post-processing ongoing to draw conclusions for HiLumi
Faults Related to Collimation

- No dumps due to collimator movement
- Two dumps due to drifting LVDT (8001, 8332)
- Three dumps due to glitch in $\beta^*$ interlock (7857, 7961, 7968)
  
  *FEC overload (from collimation vistar) → hardware replaced (new FEC)*

- Four dumps due to UFOs (8045, 8056, 8108, 8111)
  
  *BLM thresholds adapted*

- Four dumps due to collimator temperatures (7796, 8127, 8150, 8251)
  
  *threshold increased in some cases*

- One dump due to vacuum spike at the TDIS (7779)
  
  *still being followed up*
(Mis)Alignment at Flat Top

- Operational mistake during training of new people:
- Performed another alignment shift to (manually) correct losses above primary B1V
Off-Momentum Loss Maps

- Easier to perform, and more reliable, thanks to pyLossMaps
- Only one dump in 2022!
  - during $+dp/p$ with collision tunes
  - large chroma (20) sent beams on 3rd order resonance
  - with $\sim 100$ Hz trim that gives a large tune shift ($> 1e^{-2}$)
- Can be addressed by lowering chromaticity