THPV012

LHC COLLIMATION CONTROLS FOR RUN III OPERATION

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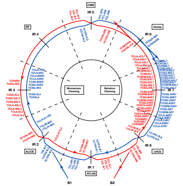
ICALEPCS 2021

Introduction

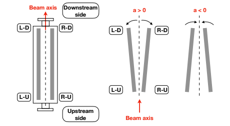
- The LHC operates towards a centre-of-mass energy of 14 TeV with 300 MJ of stored beam energy planned for Run 3.
- A collimation system safely disposes of beam losses, providing a cleaning efficiency of 99.998% of halo particles.
- 123 movable collimators in the LHC for Run 3 in 2022. Newly installed/replaced: 14 betatron, 6 injection protection, 12 transfer line and 2 crystal collimators planned to be replaced.



The Run 3 LHC ring collimation system layout.

Background

- A collimator is made up of two parallel absorbing blocks, referred to as jaws.
- Each jaw is controlled by two stepping motors to adjust the jaw position/angle.
- The tightest settings (5 σ / ~1 mm gaps), require ~20 μm position accuracy.
- A system of threshold functions is implemented to keep the jaw positions within safe operational windows.
- The collimation controls are used for all LHC ring and transfer line collimators.

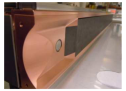


(a) Jaw coordinate system (b) Jaw angular tilt convention

Collimator Alignments

- Commissioning before each operational year ensures correct collimator set-up, i.e. alignment campaigns required at all machine states, to set-up the hierarchy.
- Different setups needed for different machine parameters, and if orbit shifts.
- 2 types of devices; Beam Loss Monitor (BLM) and in-jaw collimator Beam Position Monitor (BPM).
  - A BLM installed downstream per collimator, outside beam vacuum.
  - 33 collimators have BPM pick-up buttons installed in each jaw.

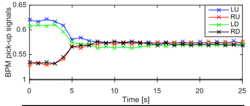
BLM detector



BPM pick-up button

BPM Alignments

- BPM collimators are aligned using a successive approximation algorithm.
- **Purpose:** Find the jaw positions/angles, centring the beam orbit at up-/down-stream sides of the collimator (see Figure).
- **Monitor:** BPM electrodes, beam position.
- **Inputs:** Min. coll. gap (mm), target align error (μm) for precise electrode equalizing, time interval (s) between steps.
- **Procedure:** Move both jaws in steps, keeping the same gap, until the signals from electrodes are equalized.
- **Performance:** Automatically aligns a collimator at the optimal angle in ~10-20 s.
  - All alignments can be done in parallel.



BPM electrode signals during alignment.

BLM Alignments

- BLM collimators are aligned by moving parallel jaws towards the beam, with a 0 tilt angle w.r.t. the collimator frame.
- **Monitor:** BLM signal, jaw positions.
- **Inputs:** The list of collimators to be aligned.
- **Procedure:**
  1. Move collimator towards the beam, ignoring spurious BLM spikes, until a clear alignment spike. (ML used for automatic spike classification in 2018.)
  2. Align collimator by centring the jaws around beam after touching beam halo.
- **Performance:** Automatically aligns a collimator in ~1-2 minutes
  - Max. 2 collimators aligned in parallel, one per beam (avoiding any cross-talk).

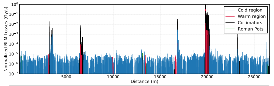
- Automating BLM alignments allows:
  - More complex alignment techniques
  - Changing the collimation hierarchy more frequently for tighter settings.

Angular Alignments

- Introduce tilt angles in collimator jaws.
- **Purpose:**
  - Allow for tighter collimator settings
  - Correct tank misalignments that could jeopardize system performance.
- **Monitor:** BLM signals, individual positions of 4 collimator jaw corners.
- **Inputs:** Start and end angles (μrad) of angular range, angle step size (μad) to tilt between alignments, selection of one of 3 procedures depending on the error.
- **Procedure:** Perform the standard BLM alignments at different angles, to find the most optimal one. (Automated in 2018.)
- **Performance:** At injection, 2 methods require ~13 minutes per collimator, the other requires ~3 minutes.
  - Angular alignments rely on BLMs, thus cross-talk must be considered to align collimators in parallel.

Loss map Analysis

- Loss maps (LM) show the spatial distribution of losses along the LHC ring, to validate the collimator setup (see Figure).
- **Purpose:** New framework developed for Run 3, to automatically validate loss maps generated throughout the year.
- **Inputs:** LM metadata; start date/time, plane info, beam energy, and loss map type (betatron or off-momentum).
- **Procedure:** Automatically extract the loss map data logged in NXCALS to:
  - Plot individual loss maps across the full ring or in specific IRs.
  - Plot multiple loss maps at a particular IR, stacked for comparison
  - Calculate the collimation hierarchy inefficiency by analysing losses in DS.



Proton full ring loss map @ Injection B1H plane.

Settings Generation

- After hierarchy validation, the collimator settings must be generated for operation.
- **Purpose:** New application developed for Run 3 to create a central and homogeneous procedure for settings' generation.
- **Inputs:** The alignment results file, the list of collimators, the LSA parameters to be updated, the collimator settings to be used.
- **Procedure**: Automatically extract the relevant data to calculate then import the settings into the LSA control system.

Settings Check

- The generated settings must be validated.
- **Inputs:** LSA configuration, start/end times, list of collimators to check their settings.
- **Procedure:** Automatically compare settings:
  - In the selected LSA configuration.
  - Calculated based on the data in LSA.
  - In NXCALS logged during selected time.
  - The real-time collimator positions.

MP Sequence

- The precise control of the jaw positions versus time and beam position has important relevance for machine protection (MP) of the LHC.
- **Purpose:**
  - Ensure correct behaviour of interlocks to guarantee beam abort in case of critical situations, i.e. if a collimator moves beyond the safe limit.
  - Used when new collimators are installed/replaced, and after long shutdowns to test all collimators before starting a new LHC run.
- **Input:** Select collimator to be tested.
- **Procedure:** The collimator is moved sequentially to each of its limits to ensure the interlocks are correctly triggered.
- **Performance:** Typically takes less than 10 minutes per collimator.
  - Parallel sequences can be started in for collimators not connected to the same interlock units (typically one interlock unit per IR).

BPM Calibration

- Automatic scan to measure the beam position at different collimator gaps and offsets, to ensure proportionate centre.
- **Pre-requisites:** Align the collimator with BLMs, to centre the jaws around the beam.
- **Inputs:** Max. offset (μm) to avoid beam scraping, jaw step size (μm), gap step size (μm), initial/final gaps (μm) defining the range, wait time (s) between movements.
- **Procedure**:
  1. Open the jaws to the starting gap.
  2. Continuously shift the jaws by the predefined jaw step size, waiting the requested time between movements.
  3. When the predefined limit is reached, move jaws back to the starting point and reduce the jaw gap by the predefined gap step size.
  4. Repeat until the minimum jaw gap is reached. Save jaw positions and BPM electrode signals for offline analysis.

Crystal Controls

- Bent crystals replace primary collimators to channel beam halo particles and deflect them onto a single secondary collimator per beam and plane, further downstream.
- **Purpose:** Improve the overall cleaning inefficiency for heavy-ion beams.
- **Monitor:** Signals of neighbouring BLMs, linear crystal position.
- **Procedure:**
  1. Align crystal linearly using the BBA.
  2. Perform Angular scan to determine optimal channelling angle.
- **Linear Performance:** A linear crystal alignment is not automated, requiring ~5-10 minutes, depending on machine state.
  - Relies on BLMs thus cross-talk must be considered for parallel alignments.
- **Angular Performance:** The largest angular scan of 20 mrad requires > 1 hour.
  - Not done in parallel, as any cross-talk inhibits determining the optimal channelling angle in post-analysis.

Global Monitoring

- **Purpose:** Given the numerous collimators, various global monitoring displays are available to provide an overview of their status.
- **Monitor:** Four dedicated fixed displays are available to monitor:
  - Collimators in beam 1.
  - Collimators in beam 2.
  - Transfer line collimators.
  - Crystal collimators.
- **Monitor:** Display for collimator settings is available to monitor the collimation hierarchy in case of incorrect settings.
- **Future Monitor:** A dedicated display for BPM collimators is being developed to monitor their overall status. It will compare the collimator centre and the beam centre measured by the BPMs in real-time.

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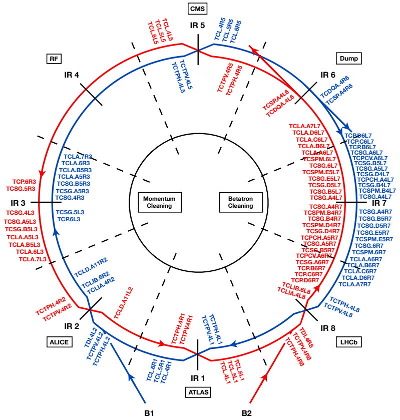

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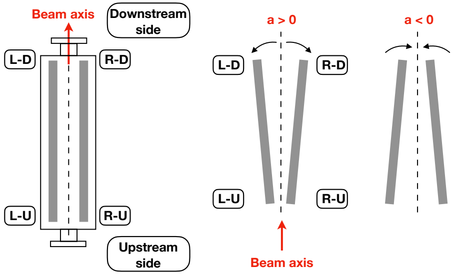

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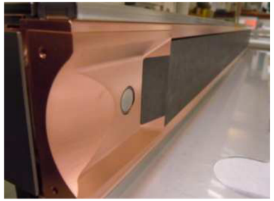

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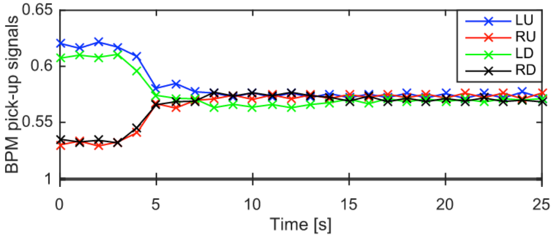

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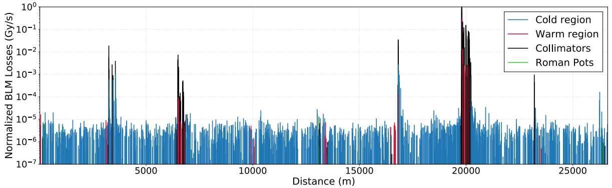

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