CERN

Collimation MPP-related software and settings generation

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Outline

- Introduction
- Settings generation, testing and verification
- Collimator alignment
- XRPs
- Temperature interlocks
- Wish list of changes
- Conclusions

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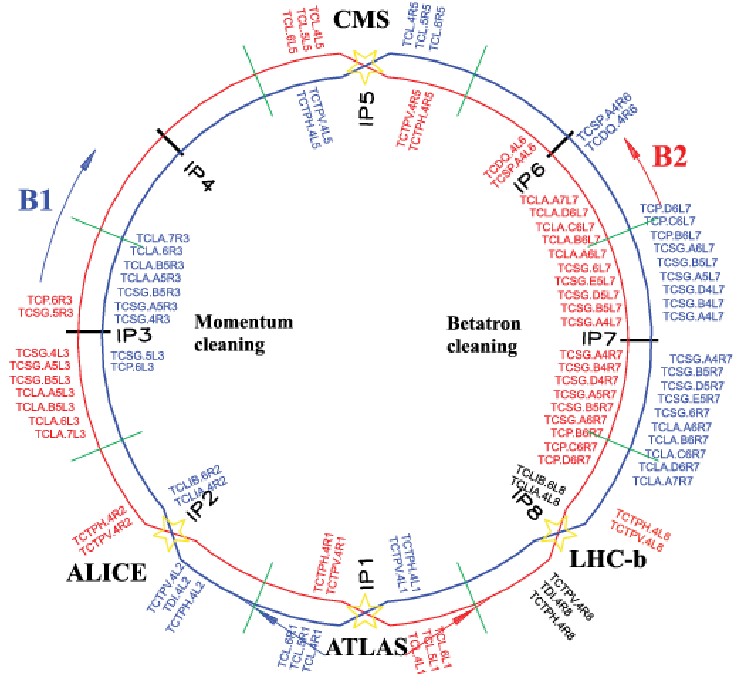
Overview of the Collimation System

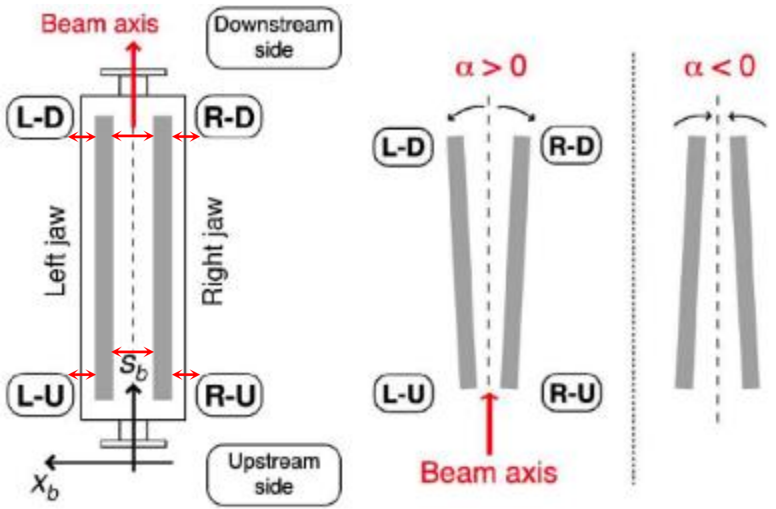
- The multi-stage LHC collimation system is aimed at reducing risks of quench from circulating beam in case of regular and abnormal losses;
- No quenches from circulating beam recorded during Run II, with up to 300 MJ stored energy and 6.5 (Z) TeV beams (see D. Mirarchi's talk);
- Overall system performance depends critically on correct collimator positioning wrt the beam;



System is complex, with >100 movable devices: control functions must be reliably played *at the same time*, with adequate interlocking;

Collimation Positions and Settings

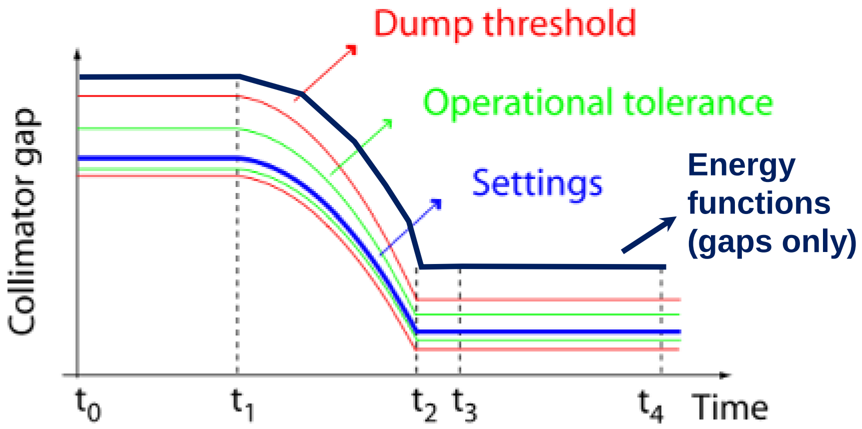
- Jaw positioning is achieved by 4 stepping motors, one per jaw corner;
  - Motors equipped with resolvers and LVDT sensors (Linear Variable Differential Transformer);
  - LSA settings (LHC Application Softare): *requiredAbsolutePosition* (sent to the hardware), determined by means of higher level parameters (eg: optics functions, emittance, Nσ, …);
- Jaw positions determine:
  - Collimator gaps:
    - these are the actual collimator settings desired/required for operation
    - 2 settings: gap upstream and downstream;
    - equipped with LVDTs;
  - Collimator centering and jaw angle: necessary for optimum performance;
- Discrete and time-dependent (function) settings;



Hardware is driven by single corner jaws which determine operational gaps;

Collimation Interlocking

- Inner and outer thresholds as a function of time:
  - Applied to each collimator motor axis (4) and gap (2);
  - Encompass the operational tolerance (warnings) and the dump tolerance on the inside and on the outside;
  - ➔ Total of 24 functions per collimator;
- Redundancy interlocking (on gaps only):
  - Max allowed gap vs E_b (2 per collimator);
  - Max and min allowed gap vs β^* (4 per collimator);
- Temperature interlocks:
  - 4+1 independent inputs per collimator;



Interlocks on: single corner jaws (driver of hardware) and gaps (actual operational settings);
… + independent temperature checks;

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Generation of Collimator Settings

- Jaw corner positions and gaps (mm) are generated based on:
  - Local beam-based parameters (i.e. collimator centres and beam σ) → alignment campaigns;
  - Normalised half-gaps (nσ settings) → aperture measurements and MADX (optics) / SixTrack (cleaning performance) simulations;
  - LVDT offsets;
- Input info is collected at static points (e.g. inj., FT, EoSqueeze, coll.);
  - Time functions are generated offline, saved in .csv files that are then imported into LSA via TRIM editor / LSA app suite;

Beam Mode	Beam Process	
Injection	Ramp@start	← Alignment (All colls)
Ramp	Ramp function	← f(γ, t)
Flat Top	Ramp@end / Squeeze@start	← Alignment (All except inj. prot.)
Squeeze	Squeeze function	← f(β*, t)
Adjust	Squeeze@end / Collisions@start	← Alignment (TCTs)
Adjust	Collisions function	← f(Xing/Sep, t)
Stable Beams	Collisions@end	← Alignment (TCTs + TCLs)
Levelling	Multi-instances of collisions	

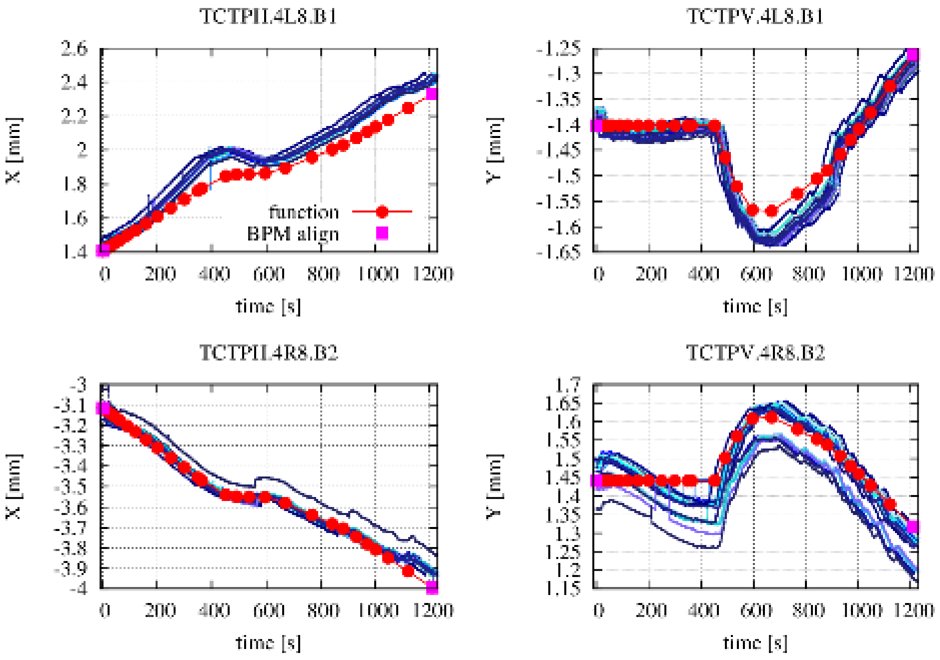
Collimator settings generation is a complex concatenation of measured data and expectations from simulation;

Example: TCT Centre Function

- Functions at TCTs must accommodate all the changes in crossing conditions at the collision IPs, e.g. β* and shape of collision bumps;
- Jaw corner positions (mm):

  $$Pos_{jaw} = C_{coll} \pm n_{(E_b|\beta^*)} \times \sigma_{(E_b|\beta^*)}$$

- Generation:
  - Evolution with time of closed orbit at TCTs as from MADX simulations;
  - Centre from (BPM-based) alignment at extremes of time functions (static points);
  - A good recipe used throughout Run 2 and MDs requiring specific TCT setup!
- Verification by comparing coded functions against BPM readouts during commissioning fills



2018 R&S functions (IR8), fills from initial commissioning with beam with nominal bunches [6544:6569]

Function generation at the best of the present knowledge

Settings Generation, Testing and Verification

- Settings automatically generated with dedicated software:
  - Flexible and reproducible way to generate complex functions;
  - Energy and β^* limits generated in LSA, based on the input functions;
  - Software uses standardized I/O files, e.g. .csv, .tfs, set-up sheet;
  - Alignment results automatically stored in standardized set-up sheet;
  - Mathematica / Python / LSA;
- Settings imported in LSA via .csv files:
  - Minimizes human intervention;

- Testing and Verification:
  - *Without beam*: manual verification of generated settings by experts:
    - Within functions: graphical cross-checks;
    - Between functions: LSA compare settings;
    - Automated setting checker by G. Valentino;
  - *With beam*:
    - Low-intensity fills to validate sequencer operation or looking at various setting displays in shade of fills for LMs or other commissioning activities;
    - Machine configurations verified with LMs, with cross-checks against similar configurations or simulations;

Generation of settings done such that human errors are at minimum;

Testing and verification of settings done in multiple ways

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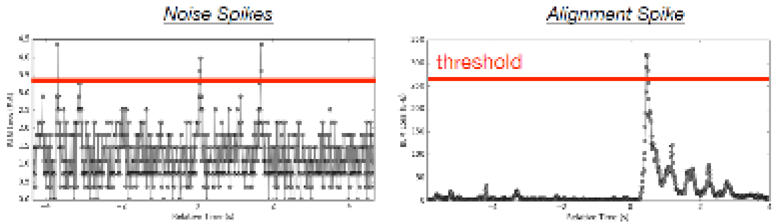
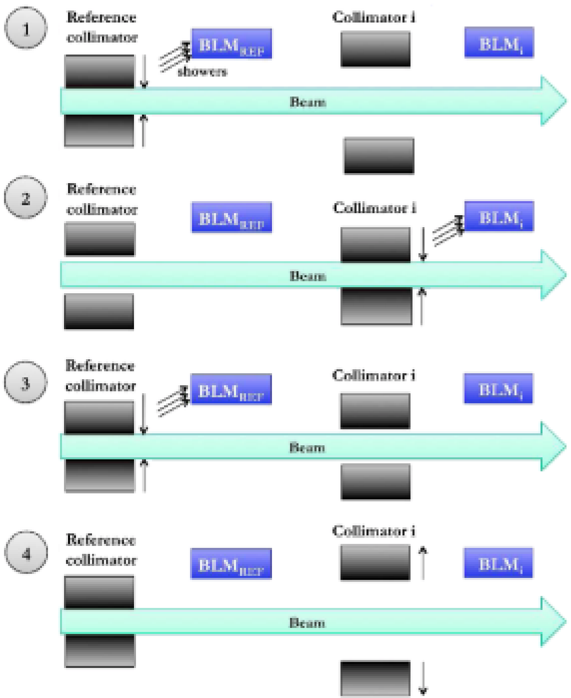
Collimator Alignment

- Recap of BLM-based alignment:
  - A collimator is aligned when both jaws touch the beam envelop;
  - Allows to centre the collimator around the beam;
  - Reference collimator: possibility to estimate the local beam size;
- Starting from 2011: semi-automatic collimator alignment:
  - The collimator moves until the BLM signal exceeds a threshold;
- Roles of collimation expert during alignment:
  - Set threshold and recognize alignment spikes;
  - Cycle alignment procedure on the desired collimators and acknowledge results of alignment;

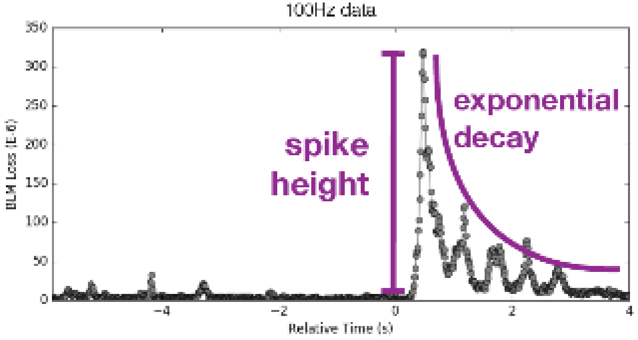


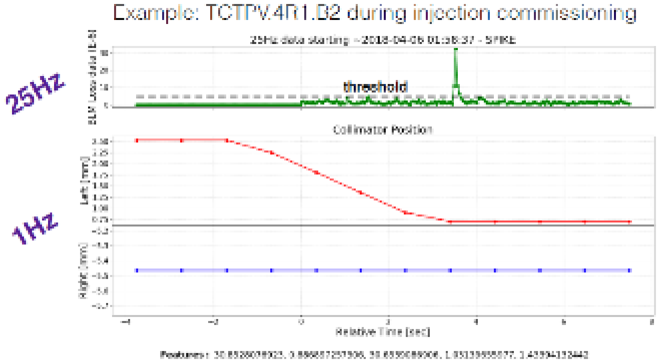


Alignment procedure long and requiring 4/5 collimation experts in the CCC

Fully Automatic Collimator Alignment

- Fully automatic BLM-based alignment:
  - A controller FESA class cycles the alignment among collimators;
  - BLM spike recognition done via Machine Learning (ML):
    - 6 ML models trained independently are used;
    - The majority vote among all models is used;
    - 95% of precision;
  - Single jaw alignment repeated twice:
    - 1st one: to get both jaws actually touching the beam;
    - 2nd one: to make sure jaw is at contact with beam;
  - Automatic BLM threshold selection (for stopping moving jaw):
    - max: 2E-04;
    - Start with latest BLM signals at collimators and then increased in steps until jaw can move;
  - Automatic saving of settings;
  - Suitable also for angular alignment!





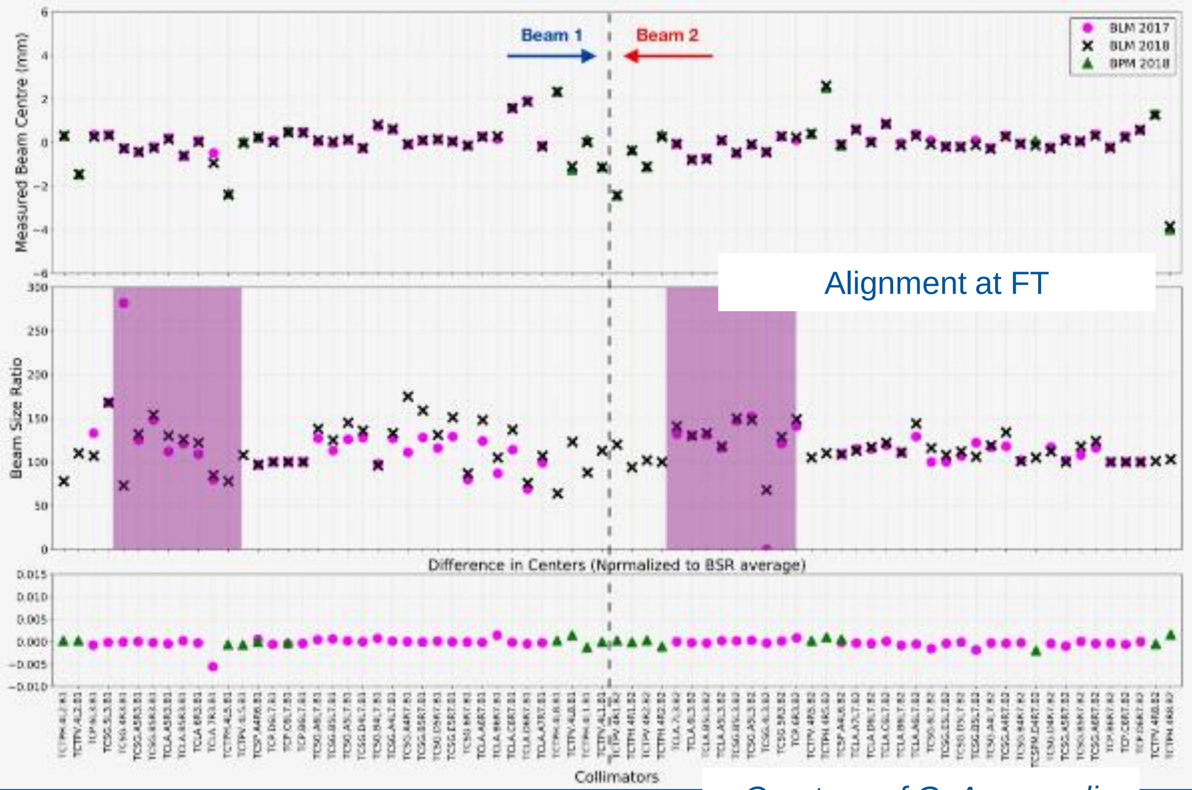
Automatic collimator alignment faster than the semi-automatic + requiring only a collimation experts in the CCC

Courtesy of G. Azzopardi

Collimator Alignment: 2018

- 2018 Collimator alignment campaign carried out only with fully automatic collimator alignment;
  - Centres deployed for operation!
- Very good reproducibility wrt 2017 alignment results, especially in IR3 & IR7, where no changes in optics occurred;

Fully automatic alignment is reliable.



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TOTEM & PPS XRPs before LS2

Run 1:

- XRPs (almost) exclusively used in low-lumi special runs (as designed)
- End of run 1: extension of physics programme to include operation in standard runs
  → first insertion tests in 2012 revealed serious impedance problems (temperature, vacuum)

LS1:

Upgrade of the XRP system:

- Total number of jaws: 12 → 26, addition of new cylindrical pots (impedance-friendly design)
- Impedance mitigation:
  exchange of ferrites, new ferrites with better geometry, RF shields to avoid cavities

Run 2:

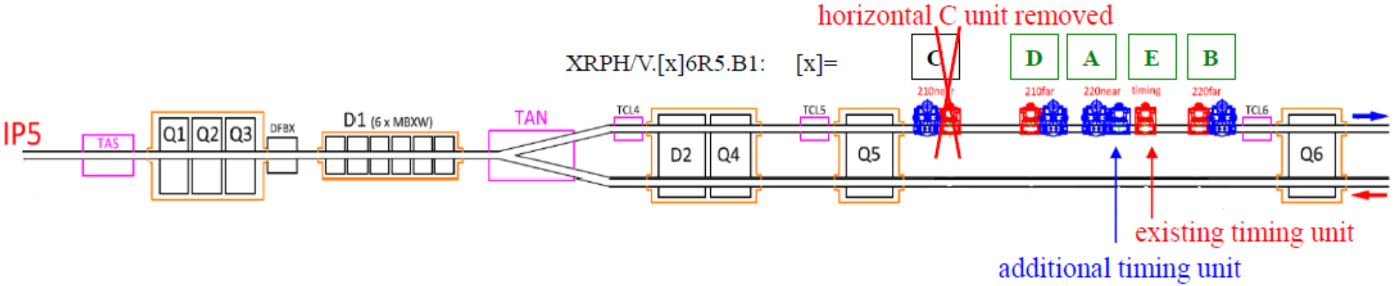
- Successful intensity ramp-up to the highest LHC luminosities without problems
  (monitoring of BLM rates, temperatures, vacuum, beam stability)
- Insertion in almost all standard fills
- Initial stability problems in PXI software, solved within first year of Run 2, then very stable.
- Very rare problems with LVDT readout amplifiers (O(1 per year))
  → spiky signal exceeds warning limit → XRP extraction with springs,
  in 1 case (2017): spurious dump
  → implementation of filter in LVDT FPGA code (interlock after 3 readings = 30 ms over limit),
  internal post-mortem file generated if any limit is crossed even once.
- Occasional (O(1 per year)) connectivity problems with microswitches (broken solderings)
  → OUT-stopper and IN-stopper position signals wrong
  → no danger, but can block operation.

TOTEM & PPS: LS2 Interventions

LS2:

- vertical beamline levelling in LSS5 by -3 mm including Roman Pots
- New detector packages for all tracking and timing Roman Pots
- Move RF shield from unused unit XRPH.C6 to empty unit XRPH.A6 ,
  C6 removed (replaced with beampipe),
  A6 to be equipped with diamond timing detectors

→ Full metrological survey of all Roman Pots needed



- Movement system change as proposed by EN-SMM (and discussed in TREX, 12.12.2018)
  - communication between CCC and PXI directly with CMW, no DIM anymore
  - simplified internal communication between the two PXIs

Commissioning after LS2:

- Movement and **full** interlock tests (incl. beam-mode dependent tests)
- Beam-based alignment

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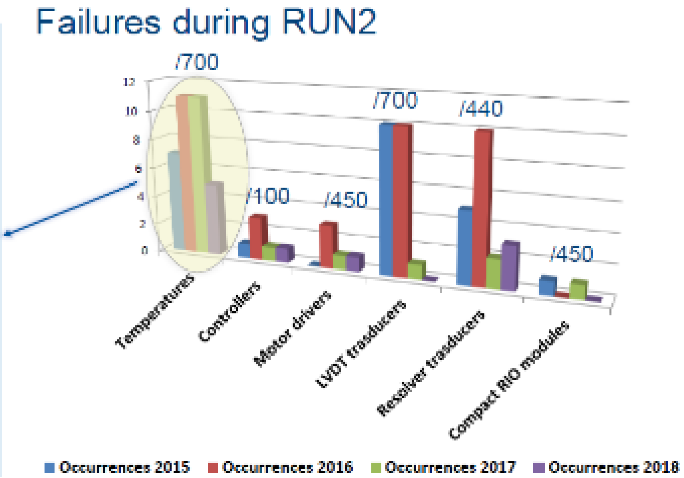
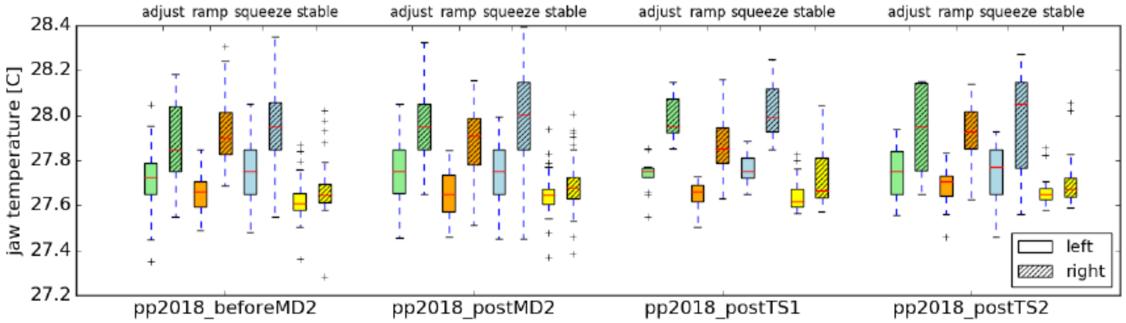
Temperature Interlocks

- Jaw temperatures reflect the load on collimators due to slowly varying drops of beam lifetime;
- Temperature of jaws (4) and cooling water (1) are monitored and interlocked;
- 2 sensors per jaw:
  - Warning: >45°C;
  - Dump: >50°C;
- 1 sensor on the outgoing cooling channel
  - Warning: >30°C;
  - Dump: >35°C;

10 blocked during RUN1 and 34 blocked during RUN2.
+ 20 blocked on the TDI.
During LS2 "intelligent" algorithm will mitigate this effect recognizing broken temperature in real-time avoiding unwanted beam dumps



Courtesy of M. Di Castro



- In Run 1 and Run 2, issues with faulty temperature readings led to disabling the sensors;
- Only 1 dump in Run 2!
- Upgrade to intelligent algorithm for faulty sensors on-going;

TCSPM.D4R7.B2 (2018) - Courtesy of M. Patecki

Wish List of Changes

- We have enough maturity in generating collimator settings outside LSA to try the implementation in LSA;
  - do not depend on specific experts (e.g. R. Bruce for nσ function, A. Mereghetti for TCT centre functions);
- Full deployment of ML and fully automatic alignment in Run 3;
- Ramp functions to crystal control system;
- Proposed changes in automatic disabling temperature sensors with erratic readouts;
- First online LM analysis in CCC before final validation (see D. Mirarchi's presentation) + possibility to collect reference LMs per machine and beam mode;
- Considering improvements in settings checker;

A large set of improvements;
Their achievement heavily depends on actual man-power available!

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Conclusions

- The LHC collimation system is at the forefront of LHC protection during every phase with beams;
  - Reliability and safety are essential ingredients for the excellent performance achieved so far;
  - System with unprecedented complexity and amount of degrees of freedom;
- Settings generation and interlocking are activities essential to grant reliability and safety;
  - The collimator settings and interlocks were recalled;
  - Their generation and verification cycle was presented;
- 2018 alignment campaigns carried out with fully automatic alignment;
  - Results safely deployed in 2018 in operation;
  - Comparison with human BLM-based alignment shows full reliability of results;
- Temperature interlocks worked fine in Run 2;
  - On-going development to automatic identification and disabling of faulty sensors;
- XRPs will undergo an important upgrade in the movement control system;
  - As discussed in TREX meeting (12 Dec 2018);
  - Full survey of XRPs + movement and interlock tests in initial commissioning with beam;
- A wish list of software changes has been drafted;
  - Actual achievements will depend on available man-power;

Thanks for your attention!

…questions?