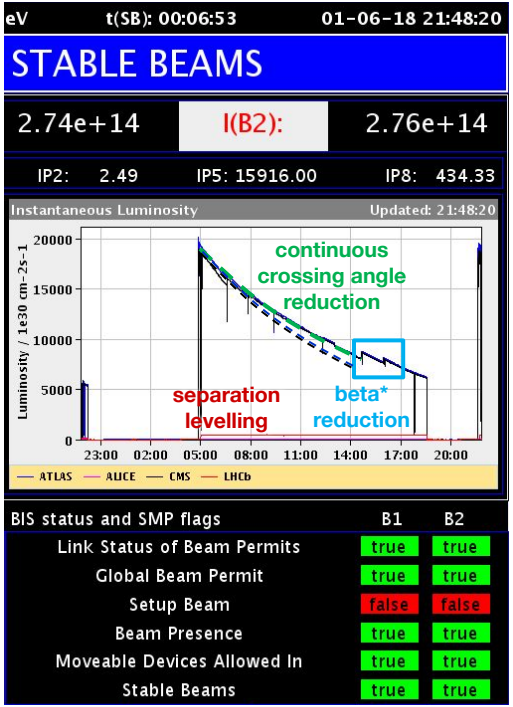
plans for luminosity levelling in 2022 and outlook for 2023

(with emphasis on MP aspects)

M. Hostettler, A. Calia, S. Fartoukh, D. Jacquet,
S. Kostoglou, D. Mirarchi, M. Solfaroli,
J. Wenninger, D. Wollmann

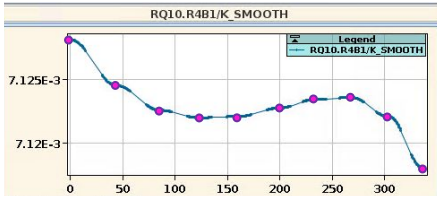
recap: what was done in run 2

- **separation levelling in IP 2 / 8**
- **as of 2017: crossing angle reduction with intensity**
  - 160urad → 130urad
  - TCT centres following crossing angle, open limits (discrete)
- **as of 2018: operational beta* levelling @ end-of-fill**
  - 30cm → 27cm → 25cm (ATS), triggered by OP
  - collimators fixed
- **levelling mechanics & procedures well established**
  - levelling orchestrated by LHC Luminosity Server
  - settings & corrections fine-tuned to minimize transients
- ➜ **run 3 beta* levelling is nothing fundamentally new**
  - larger levelling range - some additional requirements



beta* levelling: settings management

- **settings are stored in a "repository BP" that spans the full levelling range**
  - e.g. 60cm → 30cm for 2022
- **optics match points in BP = possible levelling targets**
  - identified by position (seconds) in the BP

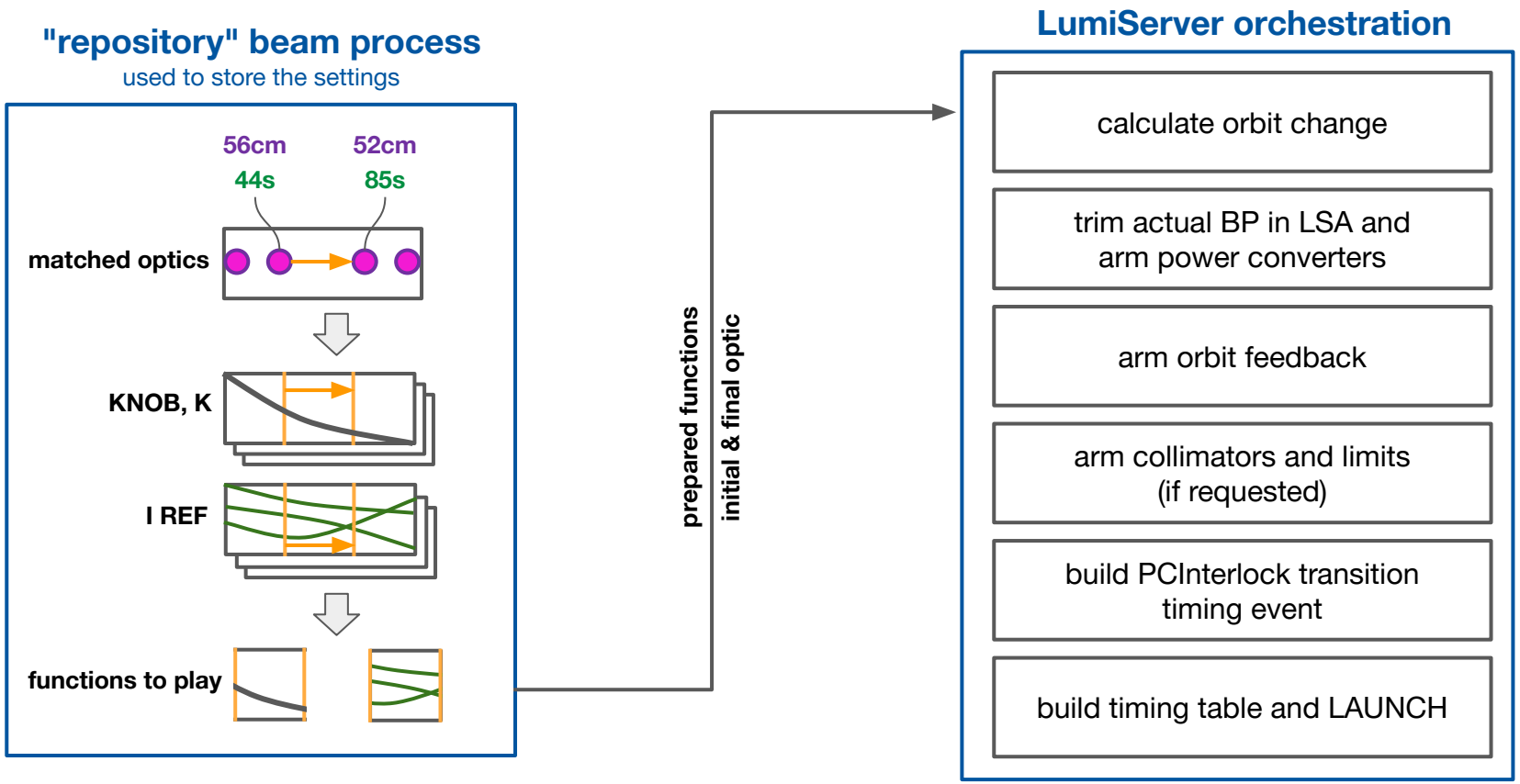


60cm → 30cm repository BP

0.600	0.560	0.520	0.485	0.450	0.415	0.385	0.355	0.325	0.300
0s	44s	85s	123s	161s	199s	233s	268s	304s	337s

- **high-level levelling logic or OP decides to execute a step to a particular target**
- **lumi server identifies start and end point (seconds in BP)**
- **functions to play are sliced by lumi server**
  - similar to the squeeze in steps
  - start point of the functions are required to match actual settings (except corrections)

beta* levelling: mechanics



beta* levelling: machine protection aspects

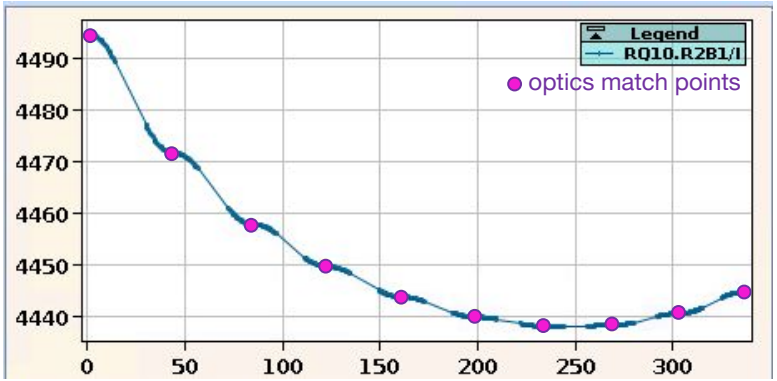
- **beta* levelling is more dynamic than a "standard squeeze"**
  - the situation in SB is less static than the cycle before: knobs, corrections
  - tight requirements on orbit control in collisions: few um @ IPs
  - OFB reference, collimator centres calculated from orbit response
  - magnet kick & PC current functions automatically "incorporated" for corrections
    - orbit, tune, chroma, coupling = relative corrections
  - in general, the "orchestration" steps are equivalent to the sequencer squeeze

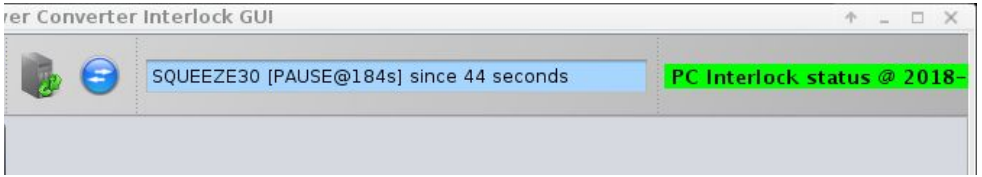
- **principle: lumi server shall NOT become critical for machine protection**
  - safe envelope guarded by external systems:
    - collimators: pre-programmed limits checked by the PRS
    - magnets: PCInterlock (orbit, quads including optics)
  - within these safe envelopes, lumi server can calculate settings
  - ➜ moving the limits during levelling needs to be carefully considered

PCInterlock limits

- **moved during beta* levelling since 2018**
- **dedicated PCInterlock reference BP**
  - clone of beta* repository BP, functions for full levelling range
- **lumi server sends timing event to advance PCInterlock in steps**
  - PCInterlock held in "PAUSE" state during the step plateau

2022 60cm → 30cm squeeze PC interlock ref

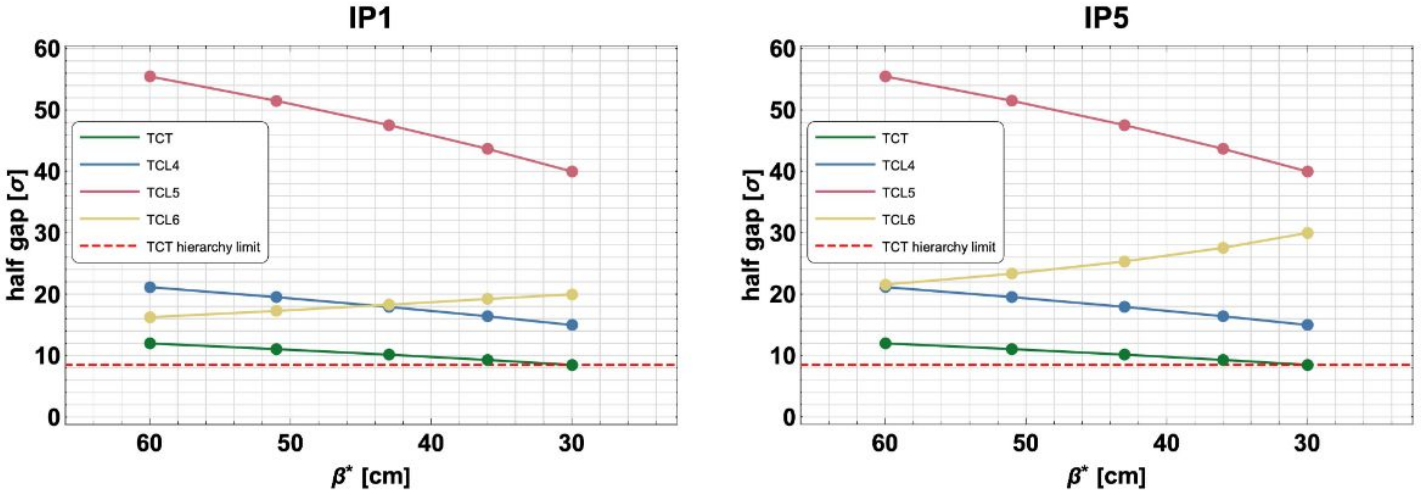




first test from 2018
(used operationally throughout the year)

outcome from the Collimation WG - 2022

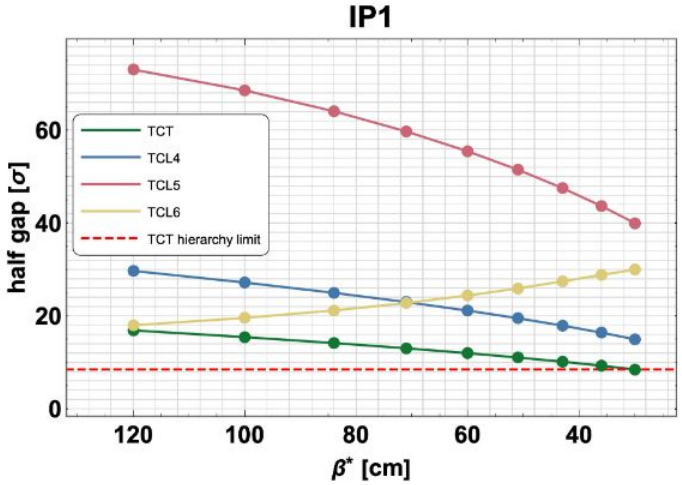
- **strategy for levelling discussed at collimaton WGs #256, #260**
- **2022: 60cm → 30cm beta*, no crossing angle change**
  - ➜ TCT/TCL positions & limits can be kept constant (in mm)

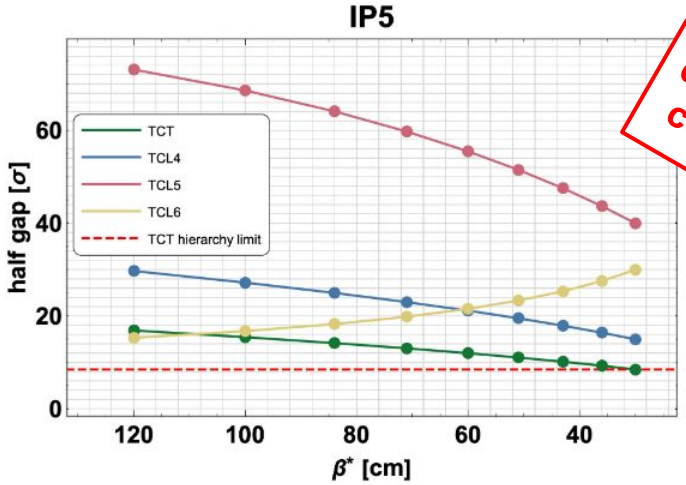


F.F. Van der Veken, CollWG #256

outcome from the Collimation WG - 2023

- **strategy for levelling discussed at collimaton WGs #256, #260**
- **2023: 1.2m → 30cm beta*, crossing angle 130 urad → 160 urad**
  - ➜ TCT/TCLs need to move to preserve hierarchy & allow XRP insertion



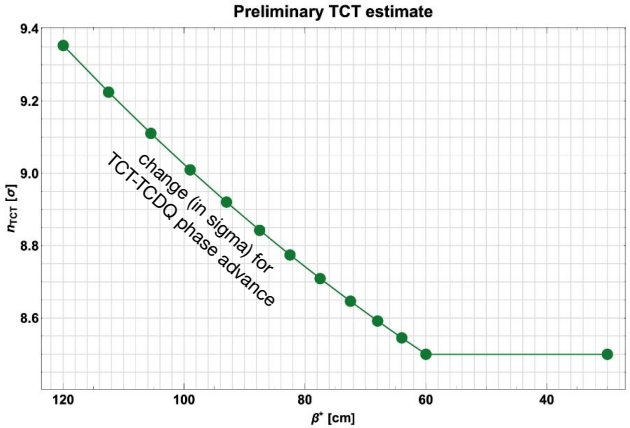


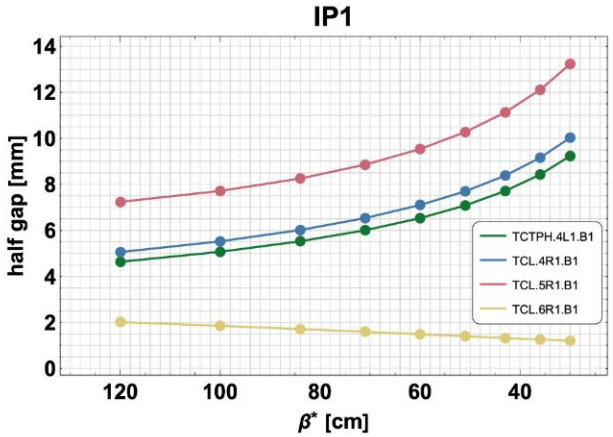
discarded scenario: constant positions

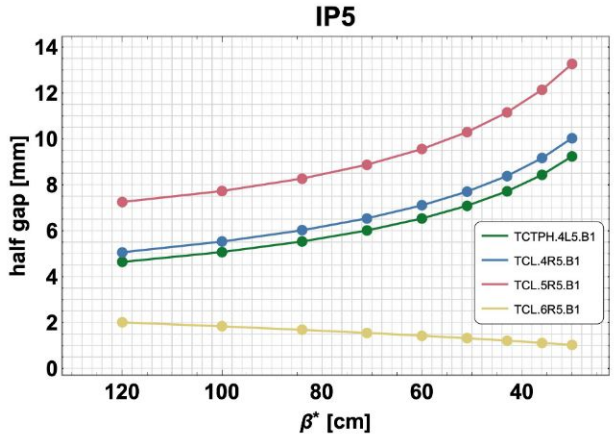
F.F. Van der Veken, CollWG #256

outcome from the Collimation WG - 2023

- **scenario for 2023+ with changing TCT/TCL gaps**
  - centre will also move due to crossing angle change
- **changes of several mm: discrete limits can not ensure protection**
  - e.g. run 2 crossing angle levelling: discrete limits opened by ~300 um
  - ➜ need to play limit functions around expected displacements







PRELIMINARY ESTIMATES

F.F. Van der Veken, CollWG #256 & #260

moving TCT/TCL jaws

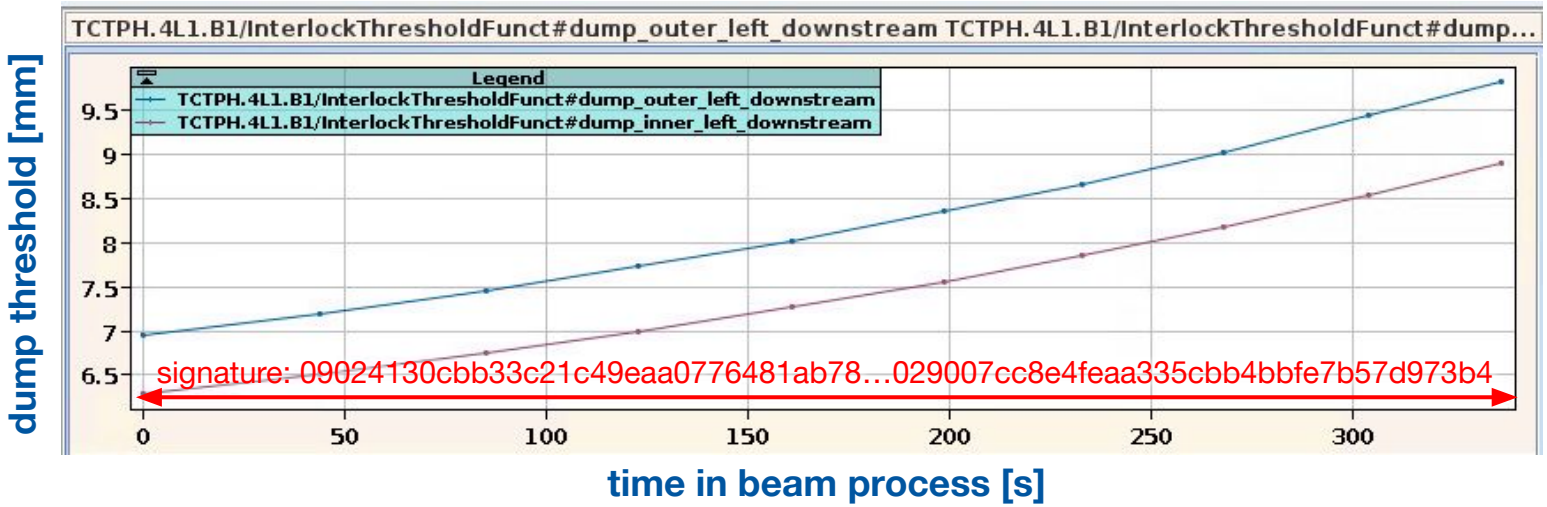
- **TCTs/TCLs moved during crossing angle levelling in run 2**
  - centres calculated from expected bump changes
- **beta* levelling reusing the same logic**
  - centres calculated from orbit changes
    - same approach (and largely the same code) now also used for TCT settings generation throughout the cycle
  - gaps from pre-programmed functions
- **"best effort" pre-flight check of interlock limits**
  - not 100% reliable due to LVDT offsets
  - not for protection - avoid dumps due to mistakes
- **tested in 2018 MDs (MD 2427 and MD 3349)**

```
java.lang.IllegalArgumentException:  The
set value violates the limits on Collimator
[element=TCL.5R5.B1, beam=BEAM1, plane=H]:
...
 ---- TIME PT1M1S ----
  Motor [DOWNSTREAM, RIGHT]:
     InnerLimit =  -6.3763
     OLD Position = -6.77
     NEW Position =  -6.3556
     OuterLimit = -25.407

...
```

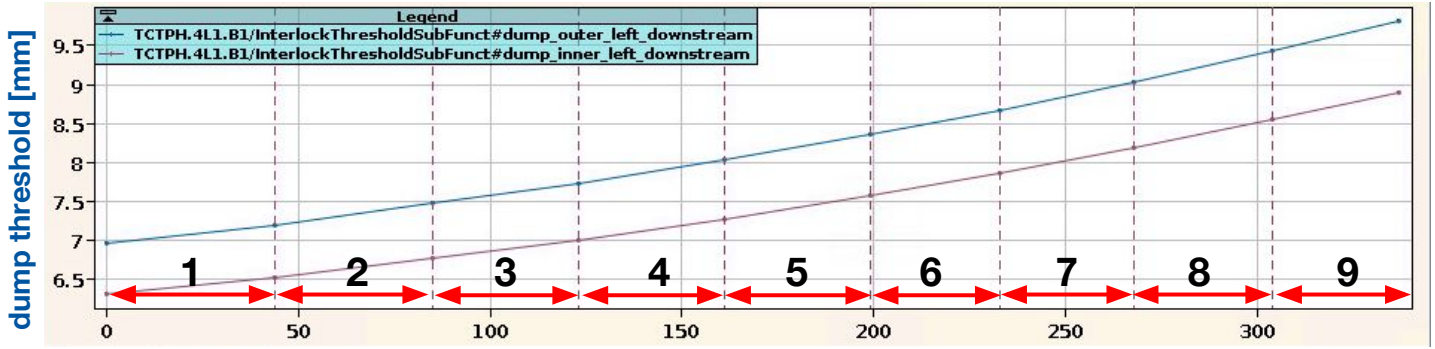
moving TCT/TCL limits: MCS

- **unlike jaw positions, collimator limits are Machine Critical Settings (MCS)**
  - can only be changed by experts (MCS-Collimation role)
  - digitally signed on creation
  - after creation, can not be altered but only loaded & played as a whole



moving TCT/TCL limits: run 3 proposal

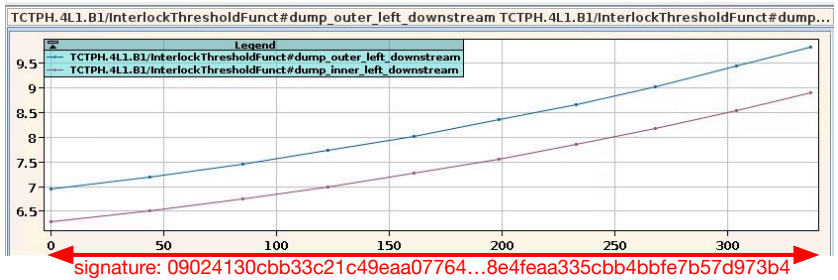
- **proposed approach for run 3:**
  - at generation time, split the TCT/TCL limt functions at the optics match point
  - generate MCS signature for every segment
  - store segments & signatures in LSA
  - lumi server retrieves segment (by BP time) & signature and sends it to the HW



PARAMETER	#	
TCTPH.4L1.B1/InterlockThresholdSubFunct#sub_signatures	1	1bfb078e4790391b448d16c70b5fefed47d7c7aeff37a7ee587e17eafeb288657dc3004baa85048d946cb683490f0ce4b72dbe7f296a48b8947e9ae1768acc6e
	2	8ae20eb075e7fd3656881987e44e1f3c302840da2830518b212267cea82944acf9dba0a14bc0cdd9f5ded02b19d3bce21910c0c70a980d661335e572723a2d36
	3	86277cf8eb0f35053f693ed1fd57be0397254c2963d21f4afdd67e7f2c3a70ef52874be2e71c172acaccdfb826b0fd7ccc0c82eb4ec0cf8e9e9f00e2b92ed220
	4	32da1c173506b7d763684bc947f8d23f8f40effd6bb5a5247c047547c1c390f77b6f5f624debfc745845a433fedb0cee38f88208e0fc7b096fd5e06dd20cfc12
	5	3754dd217752c2765231d86709a55ee7eb347a1fbc7395c8a532ba4fcf7c521de8428e0b7e9cb7f79828ab9af1c5ab5b6e2a1e2881c407fe225e63c660ffca5e
	6	5deabab2cbd1b726d13efebbd4a9276be63898de6d818443c45b8f662eb9aec7552c20d64b4310b8ae8586357558f534882a78a3cbfe268fcd6bc1b27099f00c
	7	23bfb6b2d5d917d717adff41903a2ec01632c7ba1c53694de900f146f43af7160c656c9fad8394afed2d5ffcde0286c72a9af4884d6d40b05d4e3311993aecaa
	8	4af5cc176063e4859e4538d21acb1ca16ba77efe76ea512687ee99167af549aa1a176ae0a955293154fa5ad48b2fb457cbf30d187a5fd0d0954a273670a89860
	9	6650b5b7caf948568801db991ad2e63b03e503ba3e8d8dc909dd8f89646fe6f20cdadb0868537d677c92487af606fa252957bbf59522c7229a05b8705c18a23c

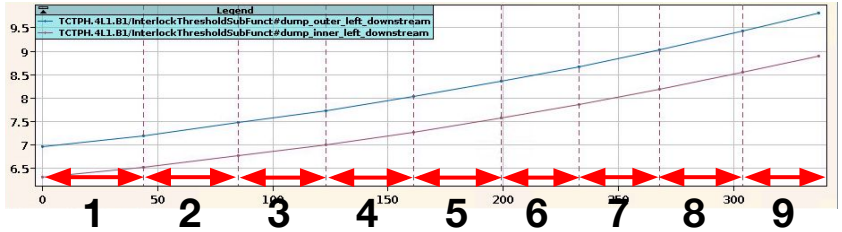
"segmented" limits: generation time

standard interlock functions



trim/generation with MCS-Collimation role

LSA MakeRule



"segmented" interlock functions

LSA MakeRule

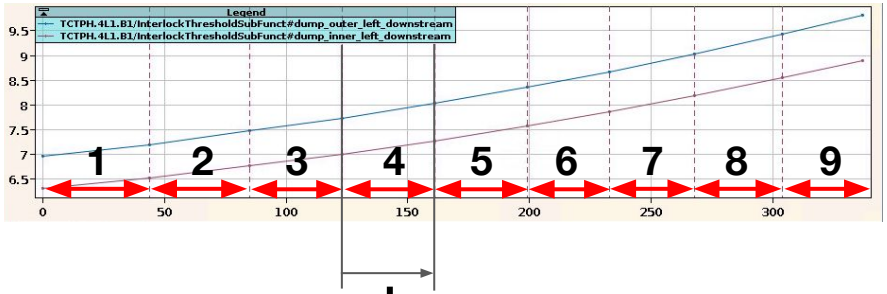
pre-generated signature table

#	
1	1bfb078e4790391b448d16c70b5fefed47d7c7aeff37a7ee587e17eafeb288657dc3004baa85048d
2	8ae20eb075e7fd3656881987e44e1f3c302840da2830518b212267cea82944acf9dba0a14bc0cdd9
3	86277cf8eb0f35053f693ed1fd57be0397254c2963d21f4afdd67e7f2c3a70ef52874be2e71c172aca
4	32da1c173506b7d763684bc947f8d23f8f40effd6bb5a5247c047547c1c390f77b6f5f624debfc74584
5	3754dd217752c2765231d86709a55ee7eb347a1fbc7395c8a532ba4fcf7c521de8428e0b7e9cb7f79
6	5deabab2cbd1b726d13efebbd4a9276be63898de6d818443c45b8f662eb9aec7552c20d64b4310b
7	23bfb6b2d5d917d717adff41903a2ec01632c7ba1c53694de900f146f43af7160c656c9fad8394afed
8	4af5cc176063e4859e4538d21acb1ca16ba77efe76ea512687ee99167af549aa1a176ae0a9552931
9	6650b5b7caf948568801db991ad2e63b03e503ba3e8d8dc909dd8f89646fe6f20cdadb0868537d67

1 signature per function segment

"segmented" limits: use time

pre-generated function segments



pre-generated signature table

#	
1	1bfb078e4790391b448d16c70b5fefed47d7c7aeff37a7ee587e17eafeb288657dc3004baa85048d
2	8ae20eb075e7fd3656881987e44e1f3c302840da2830518b212267cea82944acf9dba0a14bc0cdd9
3	86277cf8eb0f35053f693ed1fd57be0397254c2963d21f4afdd67e7f2c3a70ef52874be2e71c172aca
4	32da1c173506b7d763684bc947f8d23f8f40effd6bb5a5247c047547c1c390f77b6f5f624debfc74584
5	3754dd217752c2765231d86709a55ee7eb347a1fbc7395c8a532ba4fcf7c521de8428e0b7e9cb7f79
6	5deabab2cbd1b726d13efebbd4a9276be63898de6d818443c45b8f662eb9aec7552c20d64b4310b
7	23bfb6b2d5d917d717adff41903a2ec01632c7ba1c53694de900f146f43af7160c656c9fad8394afed
8	4af5cc176063e4859e4538d21acb1ca16ba77efe76ea512687ee99167af549aa1a176ae0a9552931
9	6650b5b7caf948568801db991ad2e63b03e503ba3e8d8dc909dd8f89646fe6f20cdadb0868537d67

calculated knob effects (centres)

programed gaps

signed interlock limit segment

calculated jaw positions segment

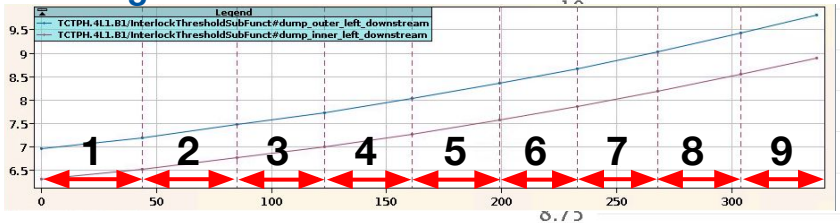
TCLs

TCTs

lumi server orchestration

dry run results

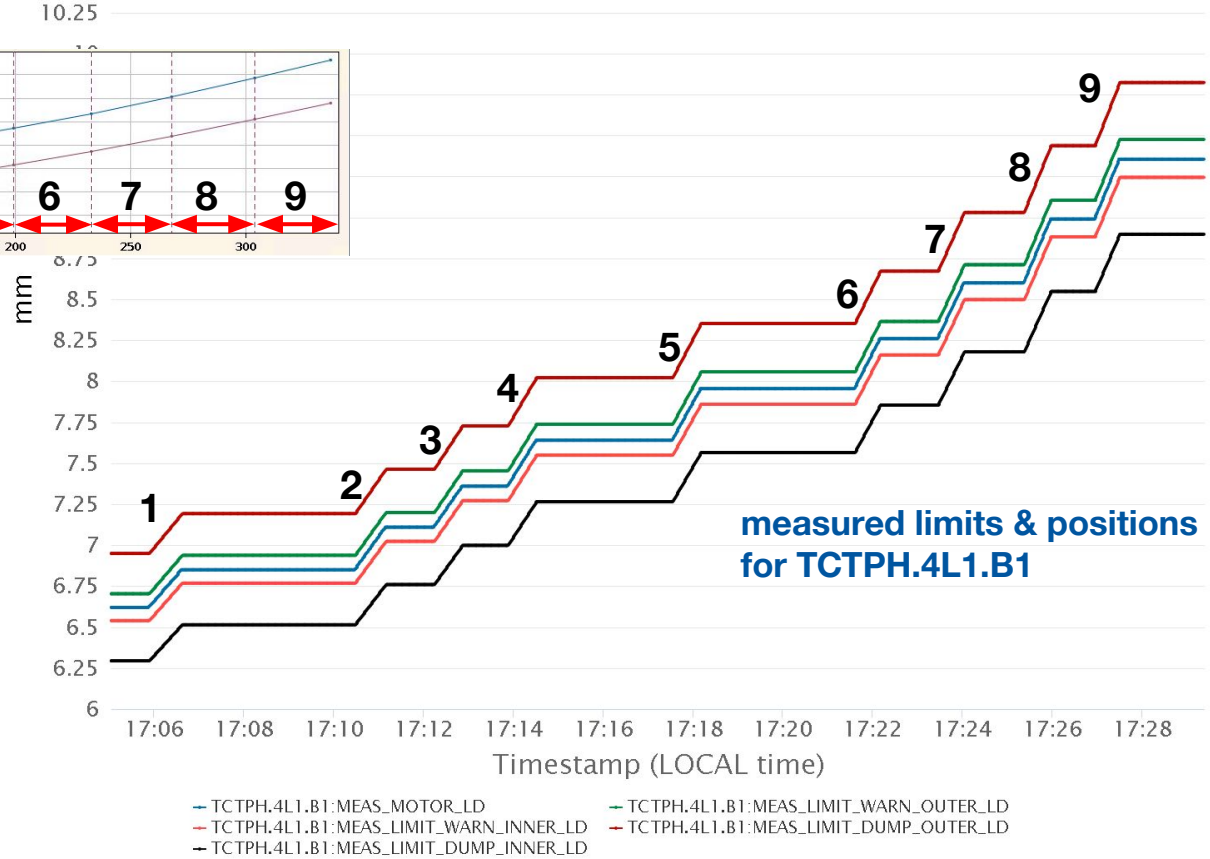
settings for TCTPH.4L1.B1



first full beta* levelling dry run performed on 3 March 2022

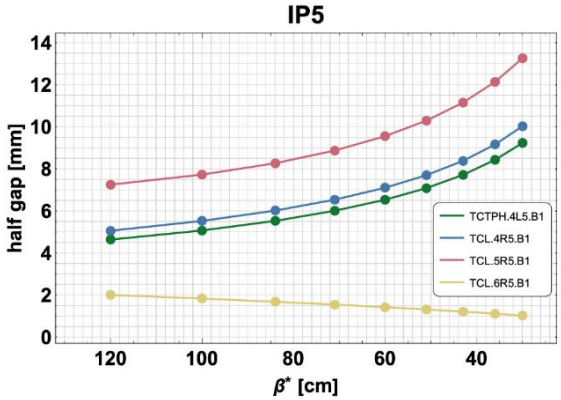
PC currents (simulated), orbit feedback reference, TCT gaps, centres & limits moved as expected

[details in LHC OP e-logbook]



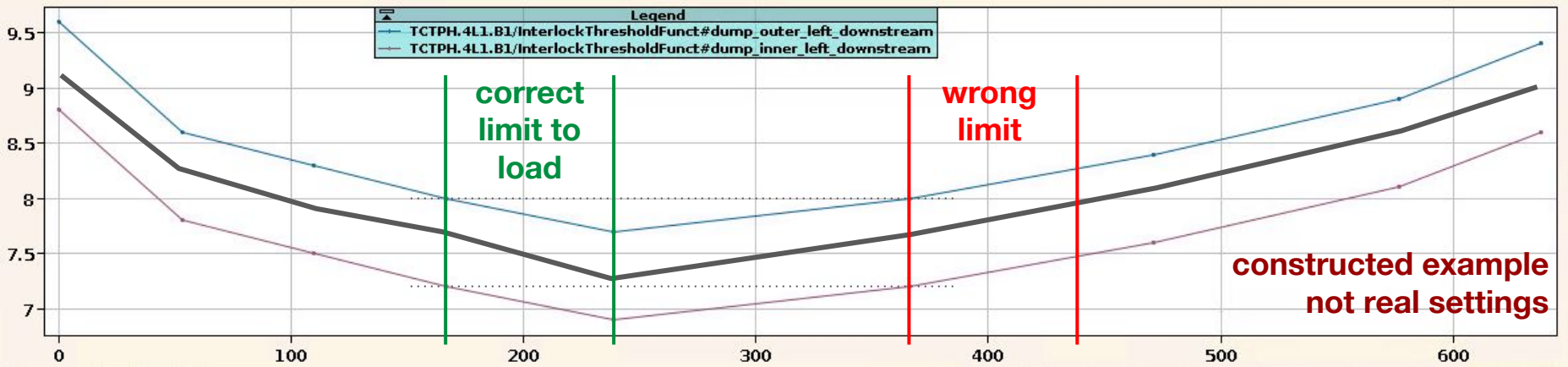
failure case: wrong limit function loaded

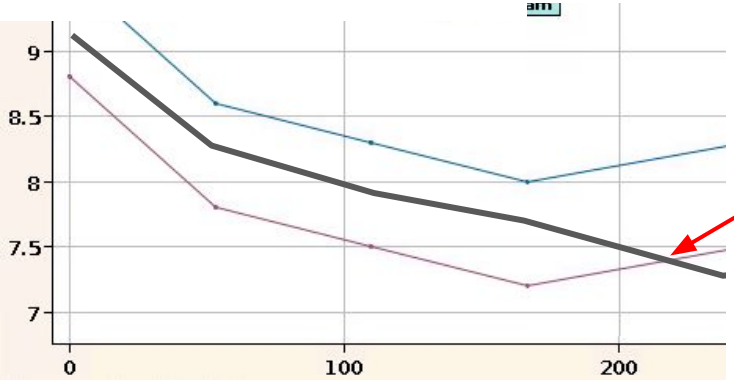
- **in principle, lumi server can load any collimator limit function segment**
  - what if the wrong segment is picked, e.g. due to bug?
- **collimator PRS checks continuity**
  - start point mismatches actual limits → exception
- **driven jaw positions & limits must match**
  - "best effort" pre-flight check should trigger if not
  - failing that → dump on limits



- **problem only if segments start exactly at the same point and driven jaw positions are consistent with wrong limits**
  - preliminary 2023 limits are monotonous
  - 2 segments starting at the same point could be prevented in the LSA MakeRule

failure case: wrong limit function loaded



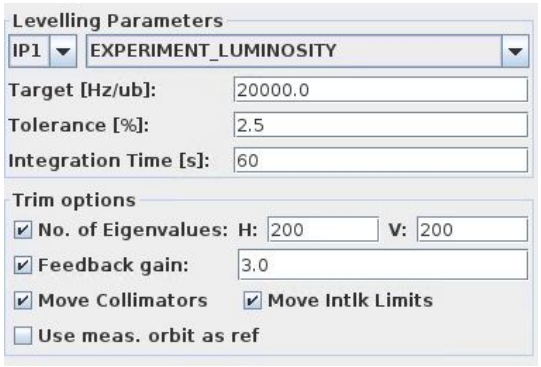


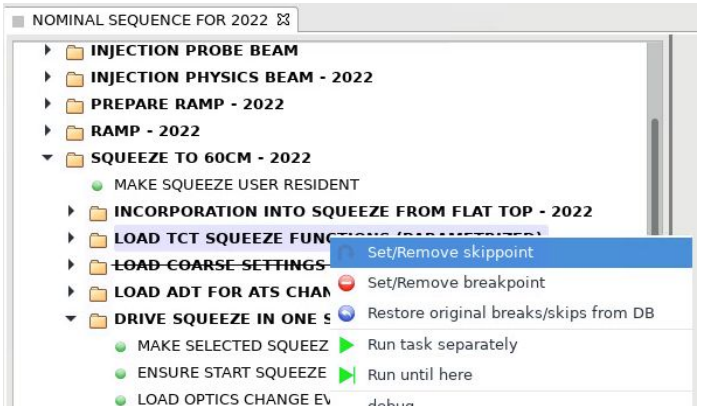
dump since jaw position outside of limit

(should be detected by best-effort pre-flight check)

failure case: collimators not driven

- **moving collimators & limits can be deselected in the LumiServer GUI**
  - not much different from sequencer: task can be skipped
- **collimator jaw positions & limits will be consistently wrong**
- **guarded by collimator beta* interlock → will dump when out of tolerance**
- **should the option in the GUI be (soft) protected to avoid mistakes?**





commissioning of TCT/TCL movements

- **TCTs/TCLs need to move in 2023 (positions & limits)**
- **proposal: commission & validate the mechanics in 2022**
  - drive collimator positions & limits like needed for 2023
  - jaw positions: program flat gap, centre from orbit response (almost flat)
  - limits: program almost flat (~10-20um changes)
  - validate logged data in NXCALS

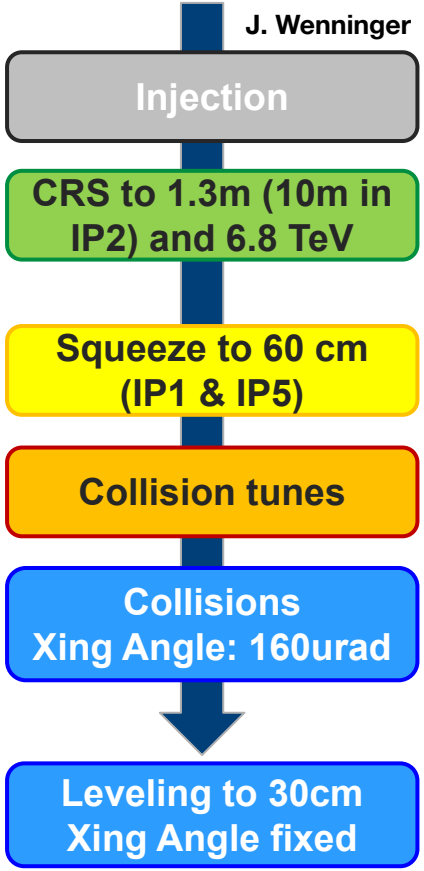
conclusions

- **crossing angle & beta* levelling not fundamentally new**
  - moving PCs, feedback, TCT/TCL positions, PCInterlock reference done in run 2
- **new for run 3: moving TCT/TCL limits**
  - not required for 2022
  - required for 2023 (1.2m → 30cm with crossing angle change)
  - based on pre-sliced limit functions, MCS signature per segment
    - lumi server picks function segment & corresponding signature
  - first dry run successful
- **proposal: commission & validate full procedure in 2022**
  - move collimators & limits already, with almost flat functions
  - validate behavior based on logged data

thanks for your attention!

2022: a simplified scenario

- **"run 2 like" scenario to ease commissioning**
- **IP 1 / 5**
  - constant crossing angle: **160urad**
  - beta* levelling: **60cm → 30cm**
  - **roman pots fixed during levelling**
  - **TCT and TCL positions, gaps & limits can stay constant**
  - if we exceed $2 \cdot 10^{34}$ cm^{-2} s^{-1} @ 60cm - apply separation
    - cryo limitation has ~15 min of inertia: not a hard limit
- **IP 2 / 8**
  - crossing angle: 200urad
  - separation levelling
  - LHCb not rotated (ext. H crossing)

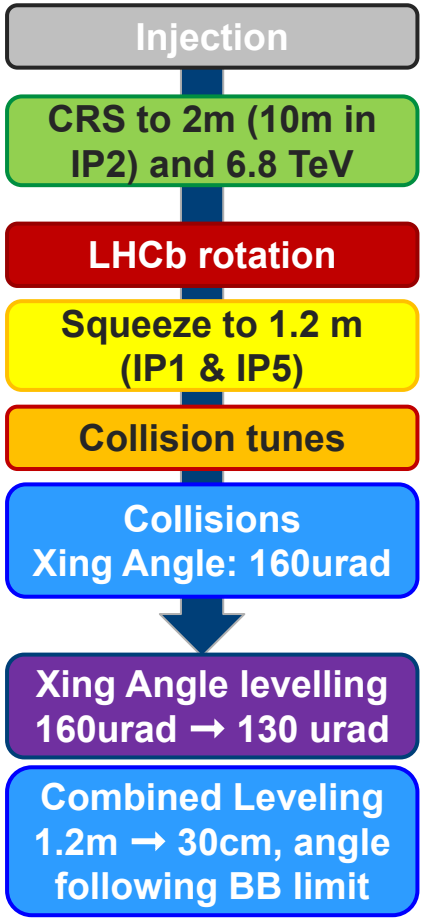


2023 and beyond: full-range levelling

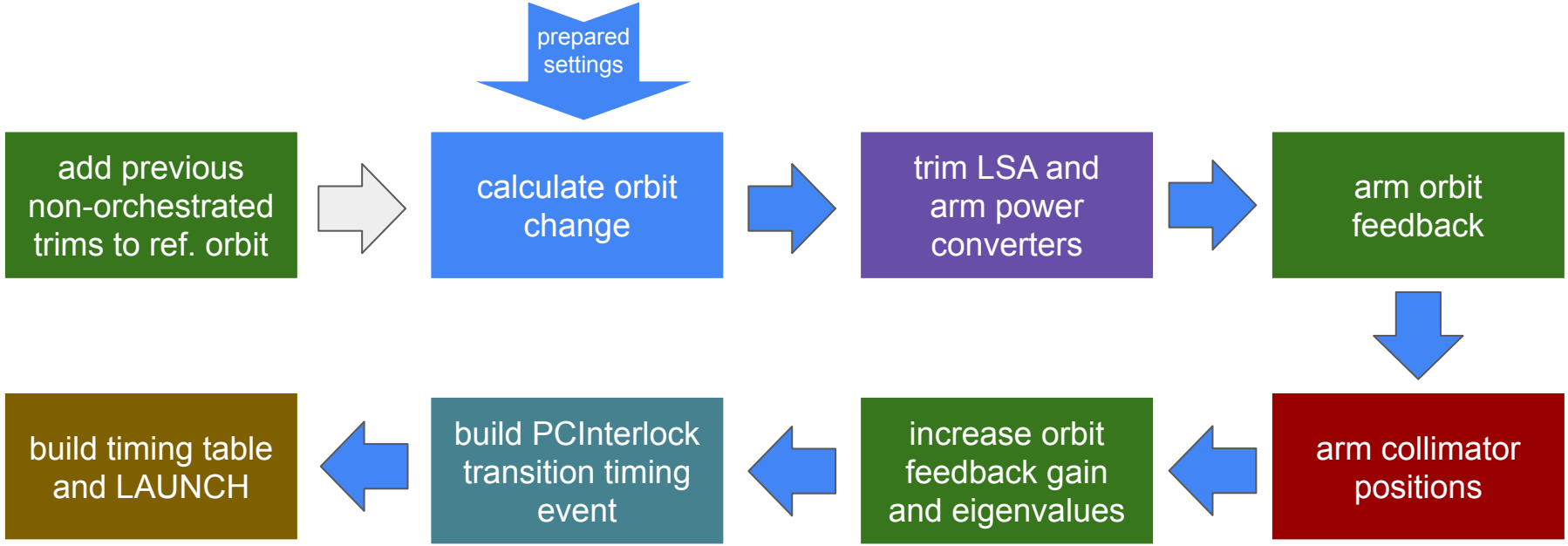
- **IP 1 / 5**
  1. crossing angle levelling to beam-beam limit:
     160urad → 130urad
  2. combined beta* + crossing angle levelling:
     1.2m → 30cm, 130urad → 160urad (beam-beam limit)
  - **TCTs and TCLs moving during levelling**
    - **centres following crossing angle**
    - **gaps following squeeze**
    - **limits following expected movements**

- **IP 2 / 8**
  - crossing angle 200urad
  - separation levelling
  - LHCb rotated (ext. V crossing)

➜ **preliminary: to be confirmed based on 2022 experience**



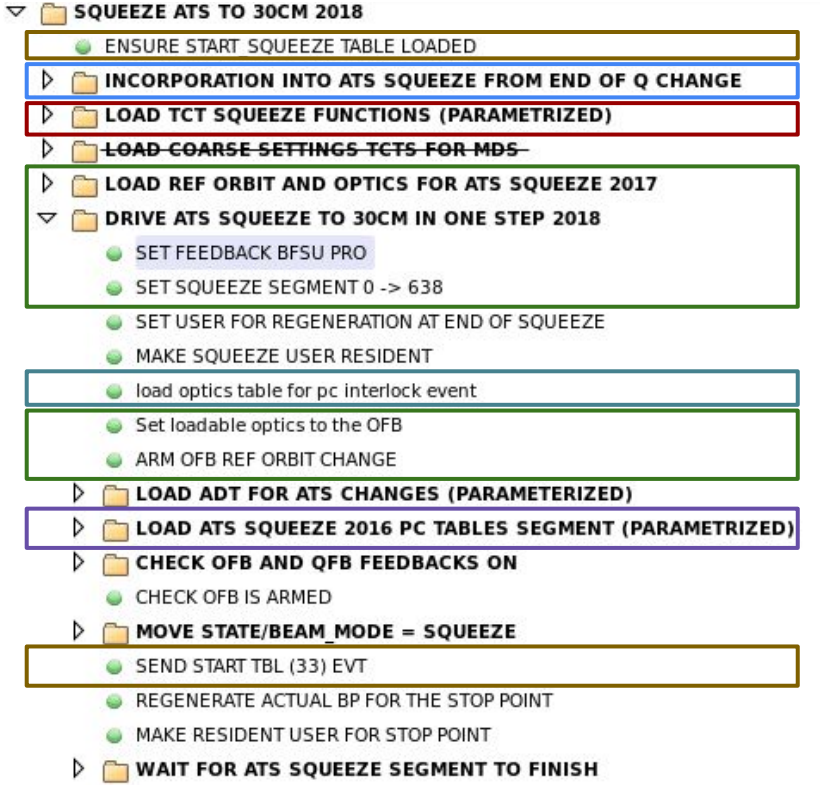
beta* levelling orchestration sequence

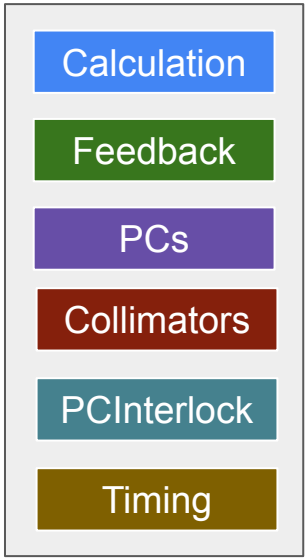


comparison: squeeze by the sequencer

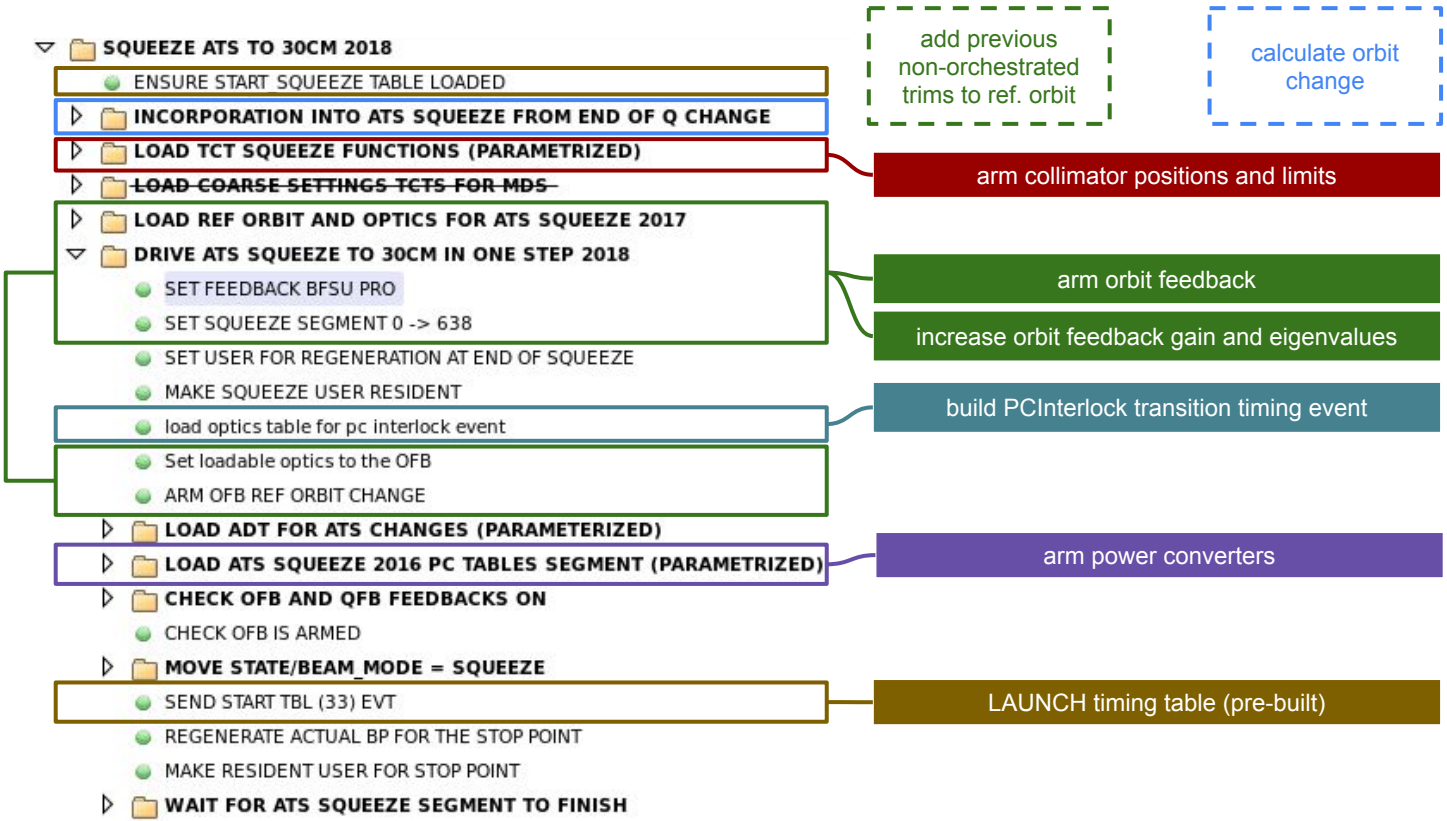
- **SQUEEZE ATS TO 30CM 2018**
  - ENSURE START_SQUEEZE TABLE LOADED
  - **INCORPORATION INTO ATS SQUEEZE FROM END OF Q CHANGE**
  - **LOAD TCT SQUEEZE FUNCTIONS (PARAMETRIZED)**
  - ~~**LOAD COARSE SETTINGS TCTS FOR MD5**~~
  - **LOAD REF ORBIT AND OPTICS FOR ATS SQUEEZE 2017**
  - **DRIVE ATS SQUEEZE TO 30CM IN ONE STEP 2018**
    - SET FEEDBACK BFSU PRO
    - SET SQUEEZE SEGMENT 0 -> 638
    - SET USER FOR REGENERATION AT END OF SQUEEZE
    - MAKE SQUEEZE USER RESIDENT
    - load optics table for pc interlock event
    - Set loadable optics to the OFB
    - ARM OFB REF ORBIT CHANGE
    - **LOAD ADT FOR ATS CHANGES (PARAMETERIZED)**
    - **LOAD ATS SQUEEZE 2016 PC TABLES SEGMENT (PARAMETRIZED)**
    - **CHECK OFB AND QFB FEEDBACKS ON**
    - CHECK OFB IS ARMED
    - **MOVE STATE/BEAM_MODE = SQUEEZE**
    - SEND START TBL (33) EVT
    - REGENERATE ACTUAL BP FOR THE STOP POINT
    - MAKE RESIDENT USER FOR STOP POINT
    - **WAIT FOR ATS SQUEEZE SEGMENT TO FINISH**

comparison: squeeze by the sequencer



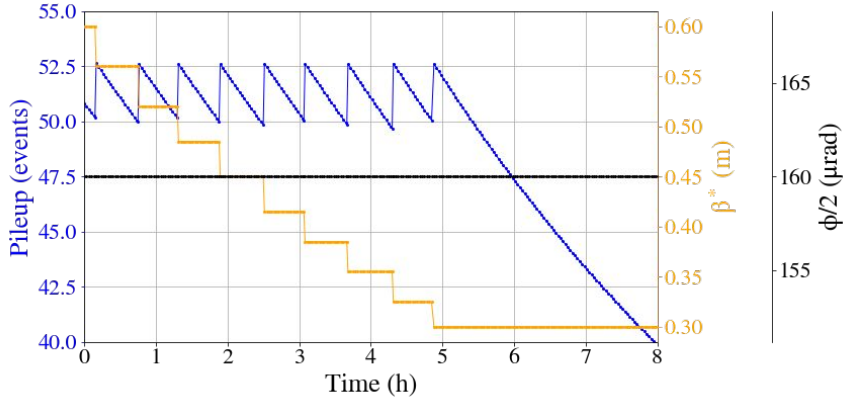


comparison: squeeze by the sequencer



beta* levelling: step granularity

- **pre-matched optics**
  - ➜ fixed steps
  - ➜ IP 1 / 5 fully coupled
- **number of steps is a compromise**
  - experiments
    - small, regular steps
    - max. ~5% lumi / pile-up jump
  - operation & commissioning
    - max. 1 step every ~30 min
    - 2022: max. 10 optics *(OMC foreseen at 60cm & 30cm)*
    - 2023: re-use 60cm ➞ 30cm part



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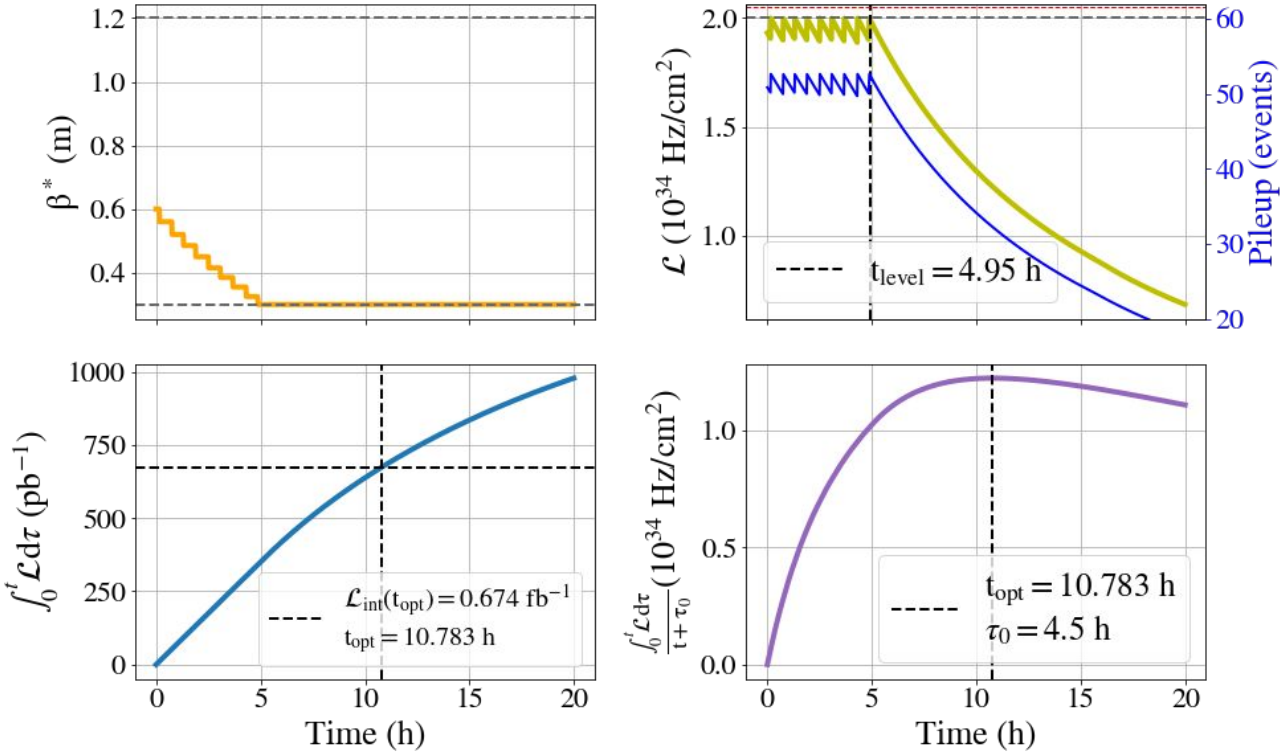
1.200	1.125	1.055	0.990	0.930	0.875	0.825	0.775	0.725	0.680	0.640	0.600	0.560	0.520	0.485	0.450	0.415	0.385	0.355	0.325	0.300

2023+: 1.2m ➞ 30cm (11+10 steps)

2022: 60m ➞ 30cm (10 steps)

2022 levelling scenario



bunches	2736
emittance	2.0 um
intensity	1.4 ppb
energy	6.8 TeV
xing angle	160 urad
β* steps	10

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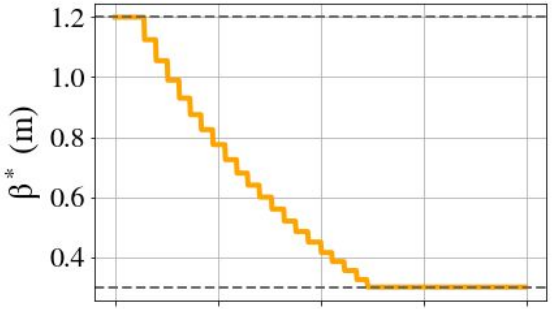
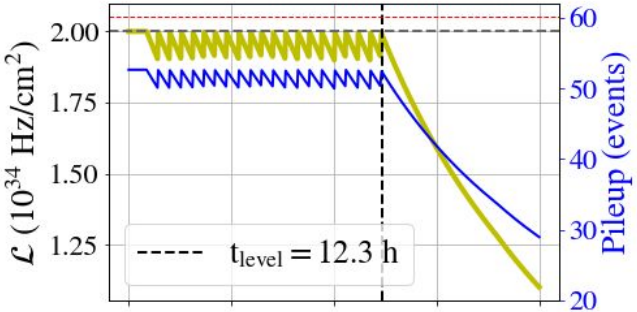
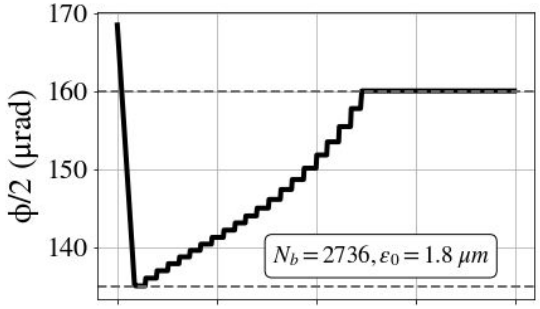
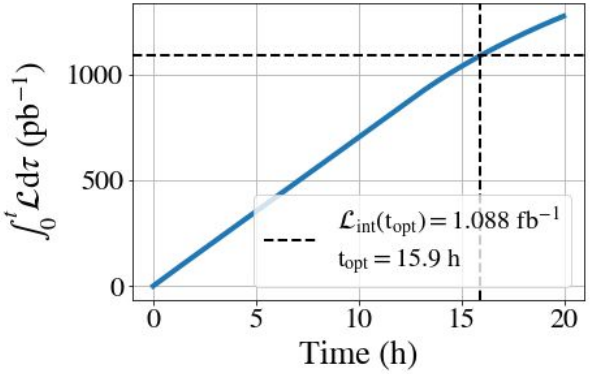
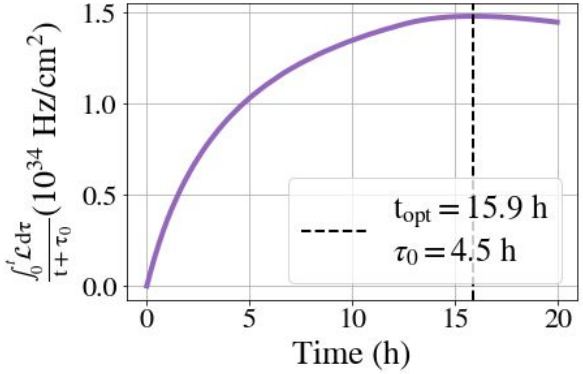
2023+ levelling scenario











bunches	2736
emittance	1.8 um
intensity	1.8 ppb
energy	6.8 TeV
β* steps	21

S. Kostoglou & Run 3 WG

commissioning beta* levelling with beam

- **first commissioning with beam**
  - execute all steps with manual trigger, check mechanics
  - commission the 60cm → 30cm squeeze in collisions
  - move collimators with (almost) flat functions?
- **fine-tuning & automation: during intensity ramp-up**
  - test automatic triggering - manual as fall-back
  - tune feed-forward corrections & feedback gains
  - run through the full squeeze to 30cm in all fills - level at initial luminosity first