A Collimation perspective on the commissioning

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10th LHC Operations "Evian" Workshop

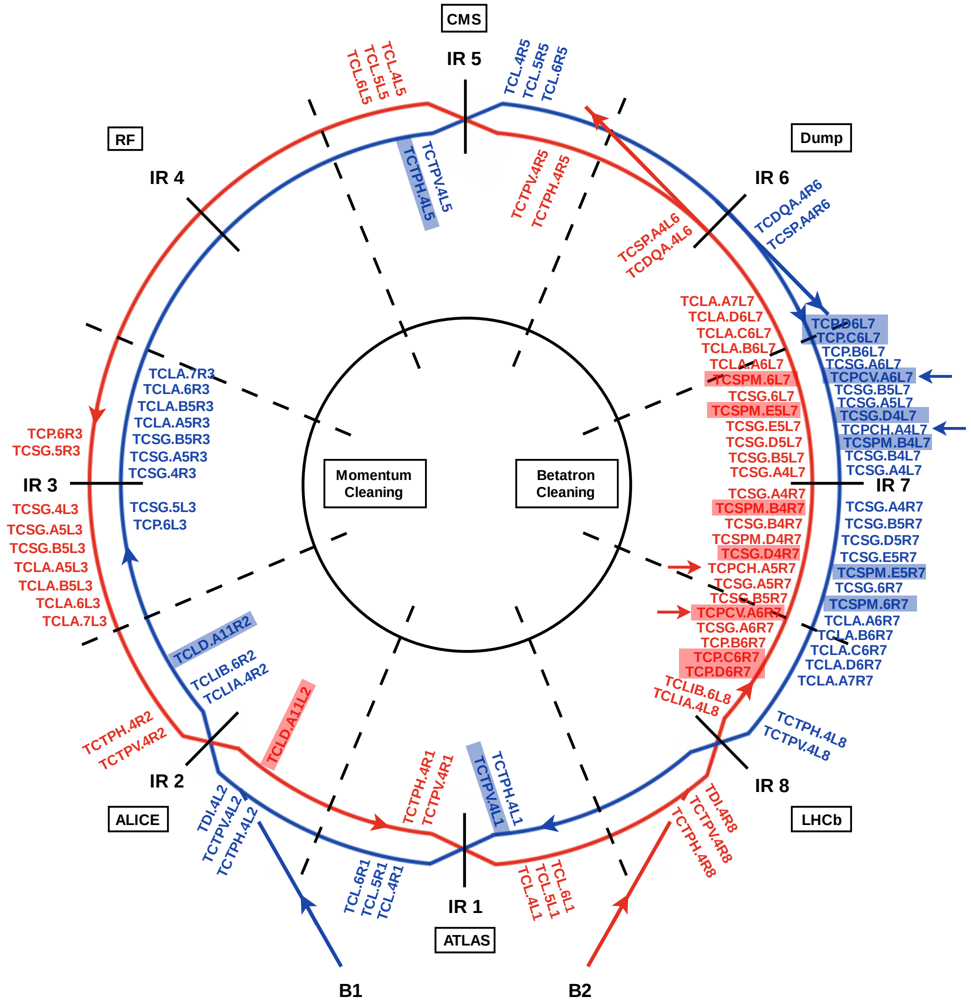
Introduction

- **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

I. Overview of activities in 2021 beam test
II. Threading
III. Available aperture
IV. Collimator setup
V. Performance validation
VI. Collimation experience with 21L3
VII. Looking at the future
VIII. Conclusions

Outline

Collimation activities during test beam

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

Global aperture with pilot
BPM checks

IT1&5 local aperture
21L3 local aperture

Threading

21L3 local aperture

19.10 | 23.10 | 24.10 | 25.10 | 26.10 | 28.10 | 29.10 | 30.10 | 31.10

Validation of
new loss map application

21L3 local aperture

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!

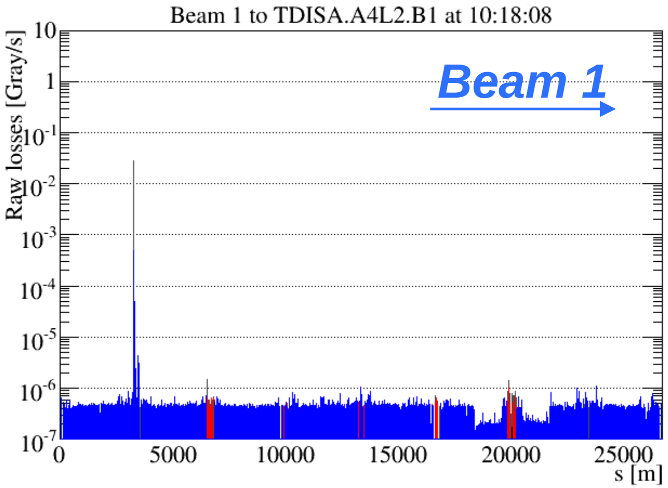
Outline

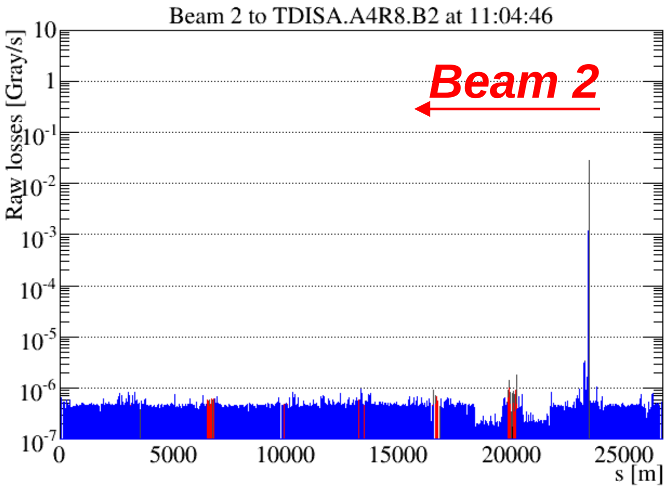
Get beams circulating

- Beam left "circulating" step-by-step: collimators used to stop the beam in each IR (except IR4…)

a.k.a. Threading

Beam 1	Beam 2
TDIS[A|B].A4L2.B1	TDIS[A|B].A4R8.B2
TCP.6L3.B1	TCP.B6R7.B2
TCTPV.4L5.B1	TCSP.A4L6.B2
TCSP.A4R6.B1	TCTPV.4R5.B2
TCP.B6L7.B1	TCP.6R3.B2
TCTPH.4L8.B1	TCTPH.4R2.B2
TCTPH.4L1.B1	TCTPH.4R1.B2





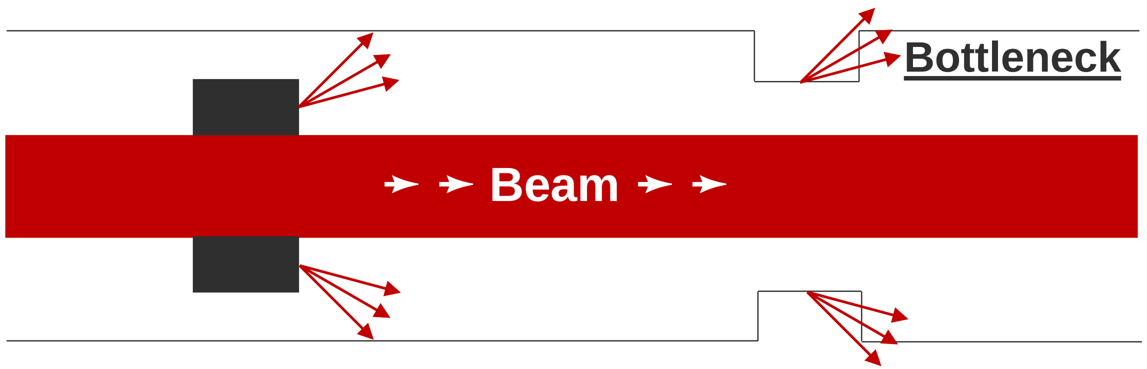
Ring coll. at: LD = 0.5mm, LU = -1mm, RD = -1mm, RU = -2.5mm
TDIS[A|B] at: L = [4.0|-2.5], D = [2.5|-4.0]

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

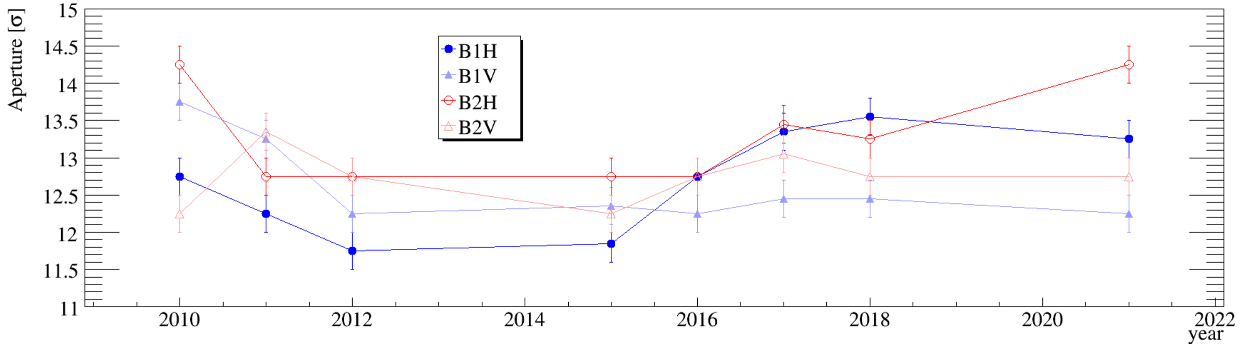
Outline

Aperture measurements

Global

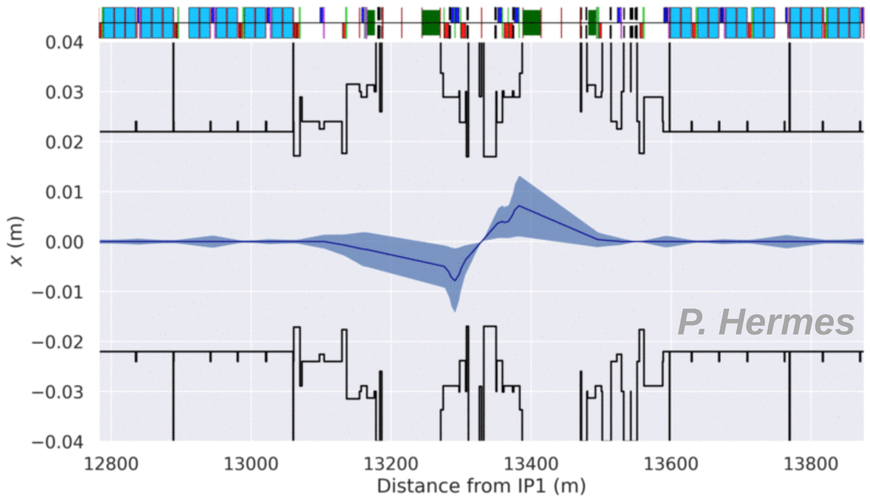


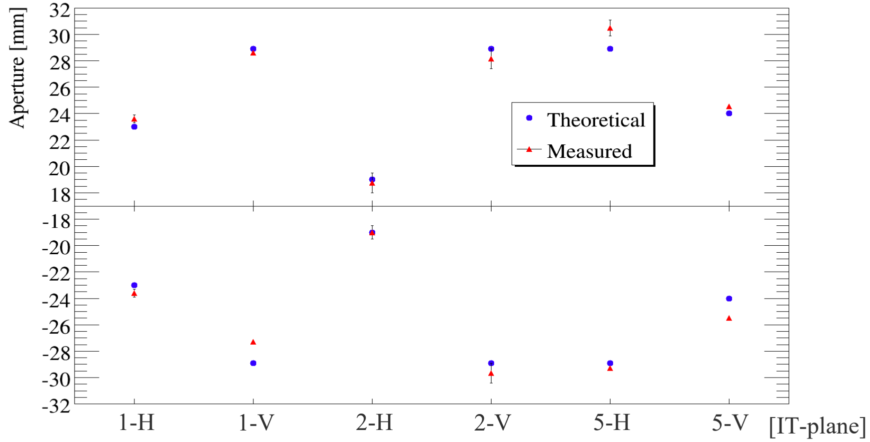
Primary collimator



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

Local

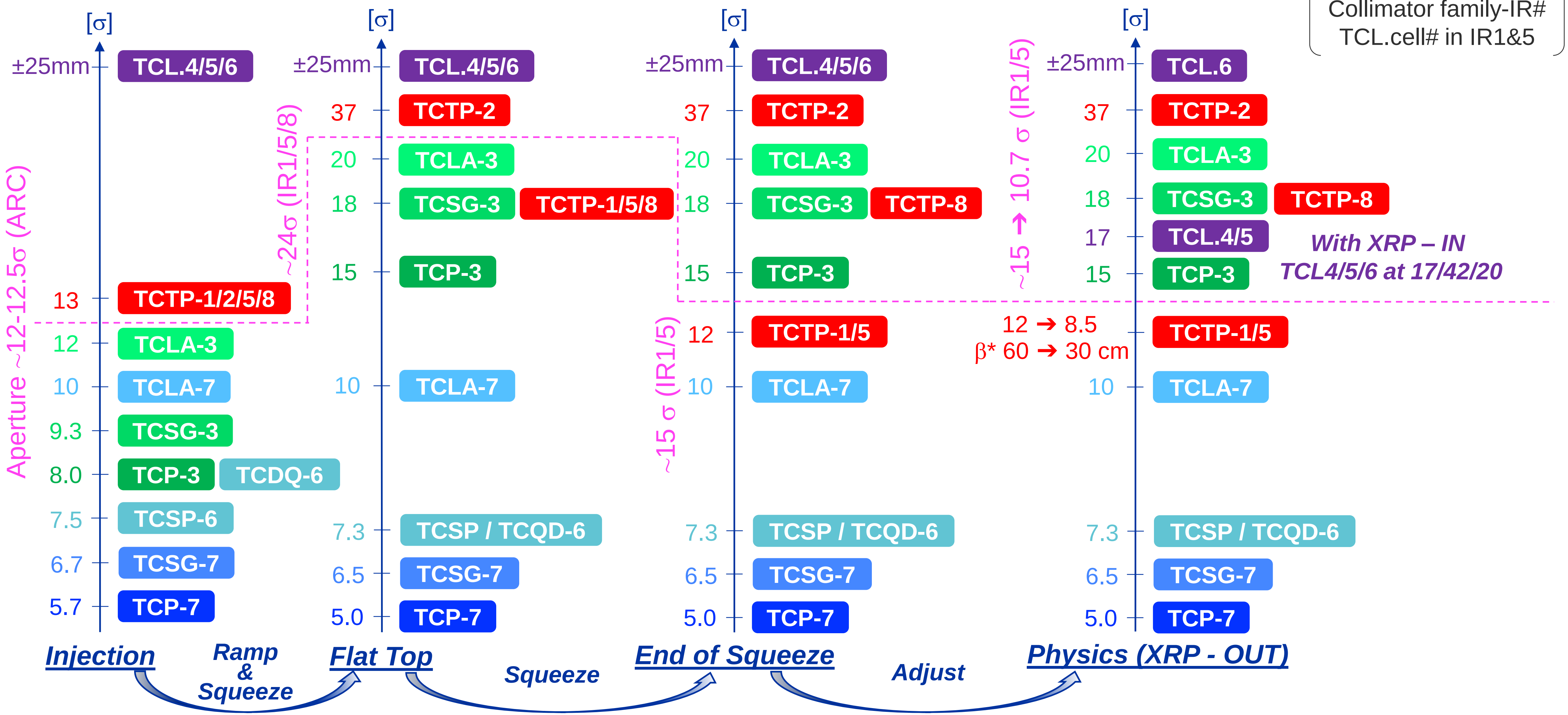




Consistent with expectations, to be confirmed in 2022

Complete overview and summary of previous years in: N. Fuster et al. arXiv:2106.09656 (Sub to EPJ Plus)

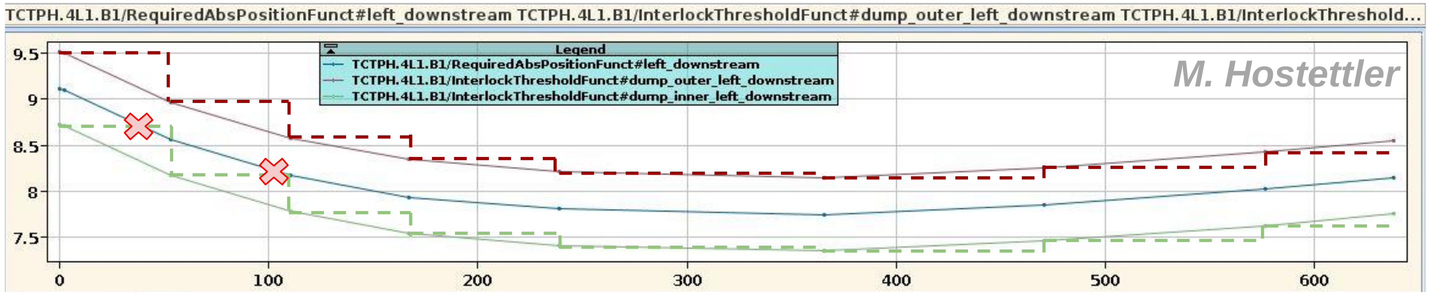
Impacts on 2022 settings (ε* = 3.5 μm)



Settings strategy during β* 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 σ at β*=30 cm
  - ✓ Small **XRPs movement** to keep adequate hierarchy margins **within discrete limits**

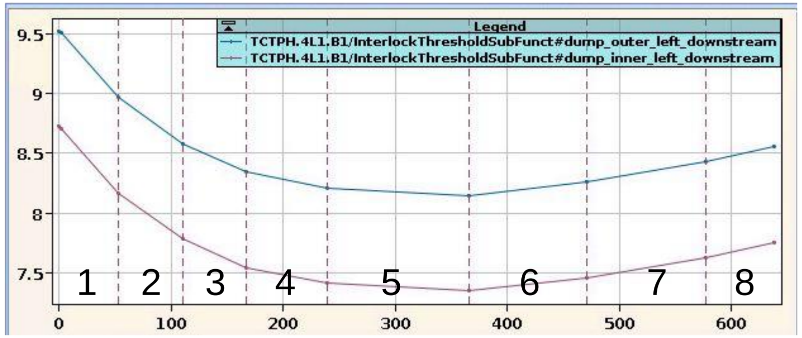
- Still needed to **follow closed orbit**
  - Problematic to use discrete limits



Solution for Run3:

✓ Interlock **limit functions sliced** at matched points

✓ Segments **stored in LSA** as function list and **signature generated for every segment**

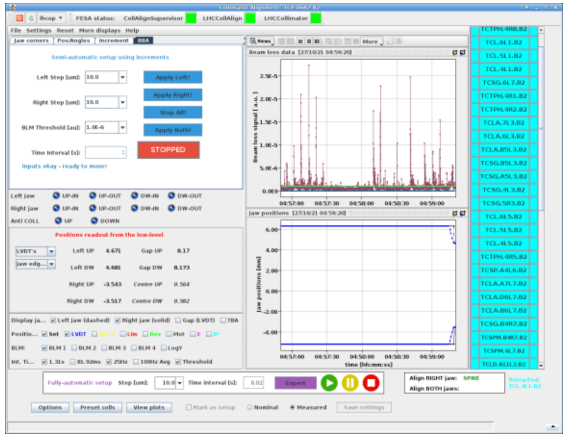


#	
1	3623a9201248778d829522474a529541fe3c2b
2	689d8ff9d9c3a5cccb36da72e64afe17696a50
3	214cf2dd45e43065765e6eba3d9b5f64234bb
4	606bda074c945eaf8b816c60a245e60f8ac484
5	6e01551f1040ba3ceff9ccc6b74cc759e6dd5e8
6	47f0050a12ba1d05547d91a25d393553fef3b0
7	9b35dec3d8d09c8890f6d9595b0406d05d4c0
8	88924aacfd5571bd910595599b3469f31fd619

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

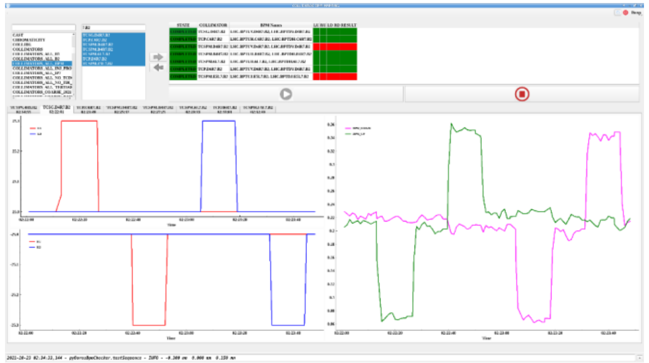
Outline

Alignment and settings



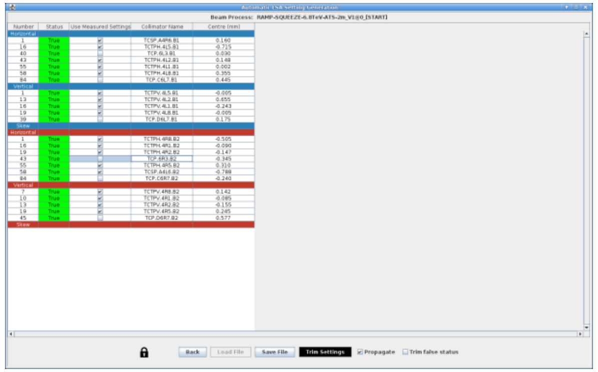
Several milestones achieved during test beam:

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



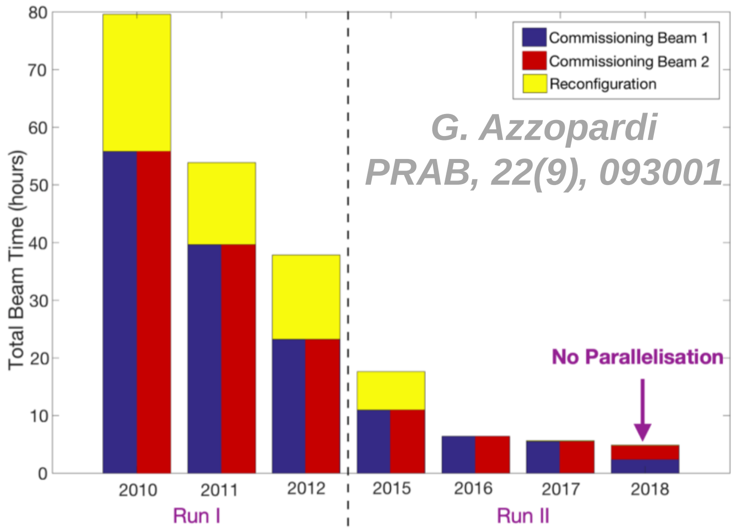
- **All BPMs tested**:
  - ✓ **Minor issues** identified **only on 2** collimators that will be fixed during YETS

- **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** (85/81colls) 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

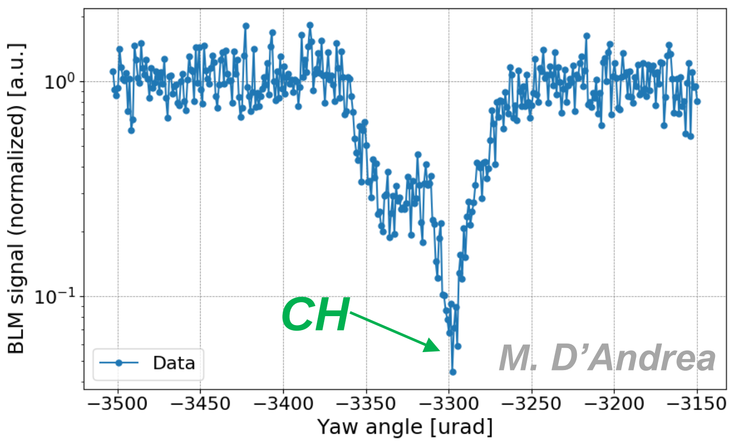
No need of external settings generation and **file exchange** (time consuming and error prone)

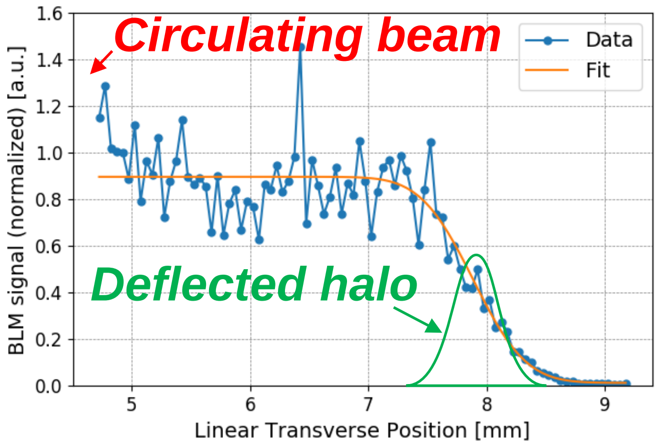
First estimation of integrated time needed for alignment and validation: ~4 shifts

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

Activity	Estimated time (h)
• **BPM scan** for 33 collimators	1.5
• **Align with BPMs** the 3 missing collimators post-beam test	0.5
• Test of **new ML model** under development that promises up to 50% time reduction for beam based alignment	1.5
• Test **new parallel alignment** implemented for **Flat Top**	0.5
• Sequential alignment of entire system at **Flat Top** to collect missing **crosstalk data**	2
• Validation of **new crystals** installed during YETS	12

Outline

Performance validation in 2022

Same approach extensively used in Run II

	Initial commissioning	After TS / expired validity
β	Static points & dynamic phases	Static points
δp/p	Both signs at static points	Alternated signs at static points
ASD	Static points	Static points

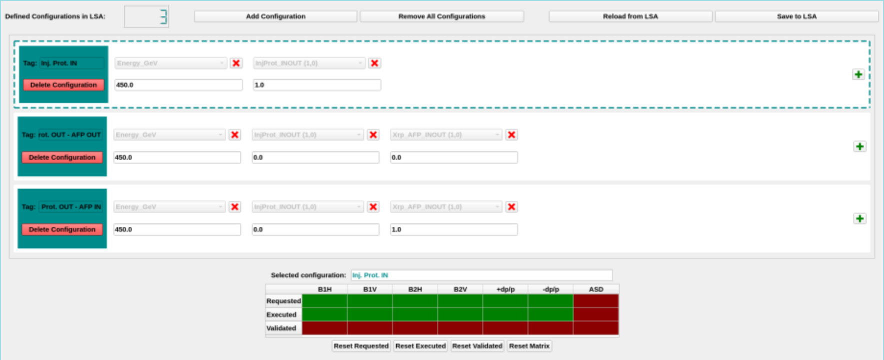
Example from 2016:

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

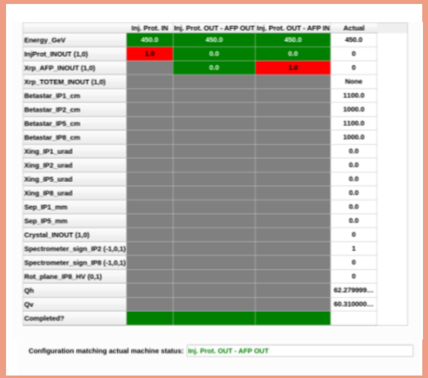
New tool for Loss Maps and online analysis

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

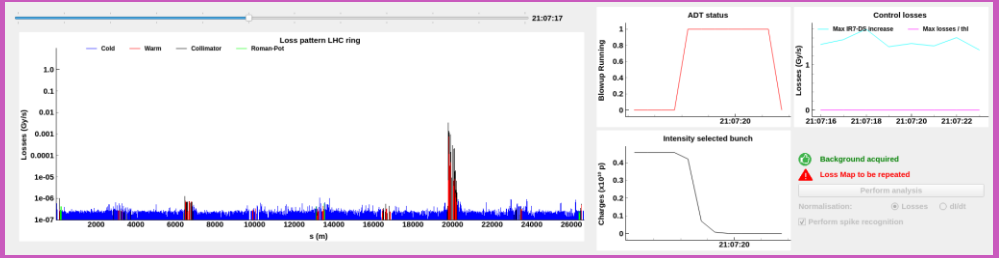
- ✓ Integrated definition of LM matrix and storing in LSA



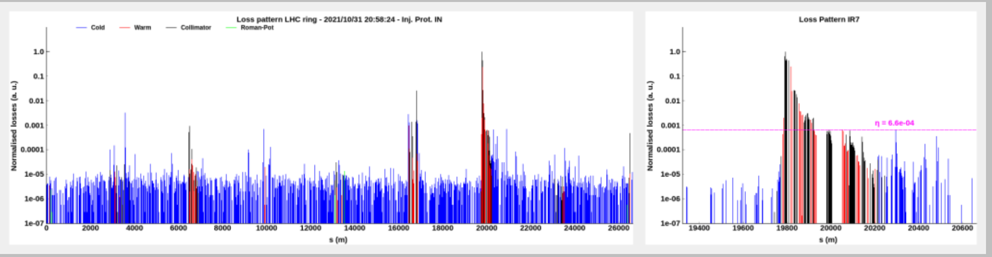
- ✓ Live machine configuration
- ✓ Automatic loading of requested LM
- ✓ Status of LM advancement



- ✓ 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

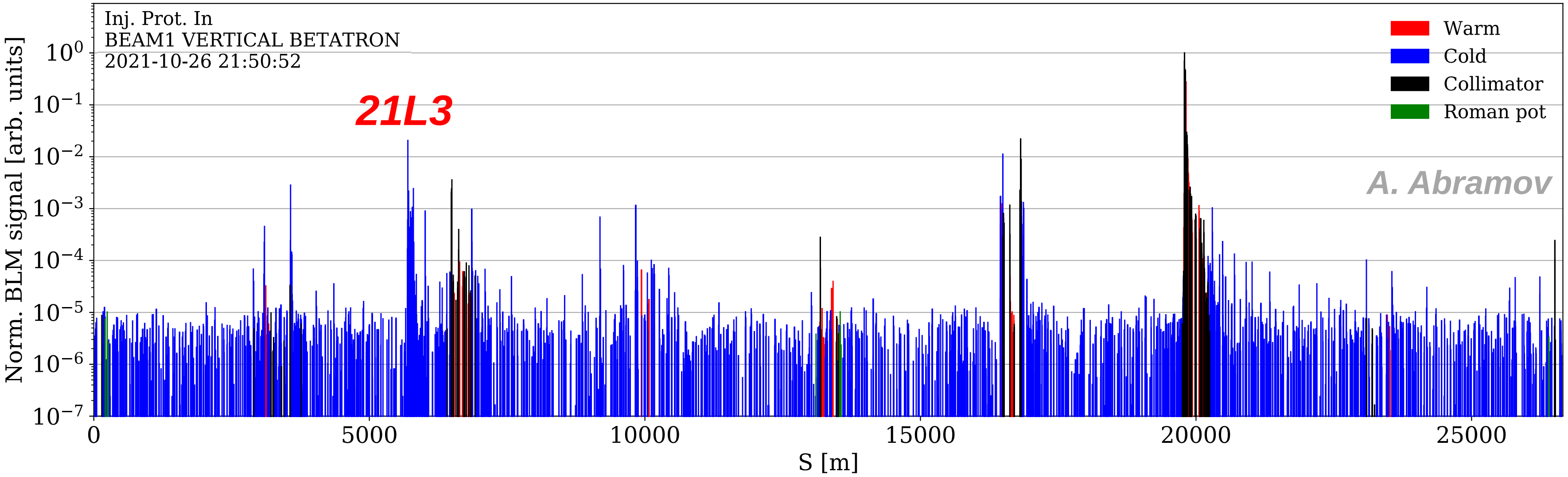
- Compatible with the **latest logging** structures
- Modular design for improved analysis **flexibility**
- **Interactive** loss map plotting
- Improved **efficiency**

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

Outline

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

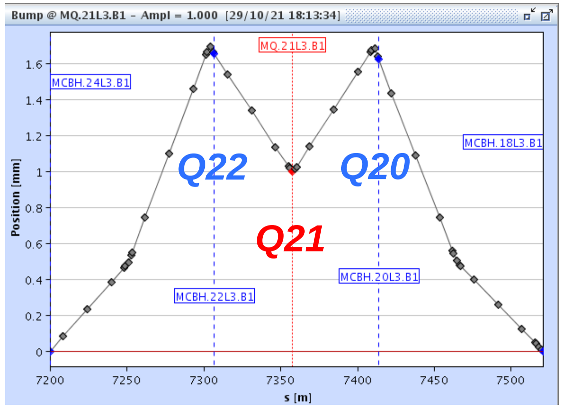


OK given for stable beams with three bunches, but **local aperture measurements requested**

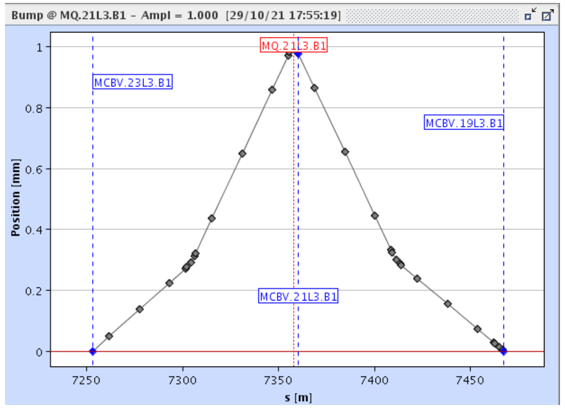
21L3 local aperture measurements

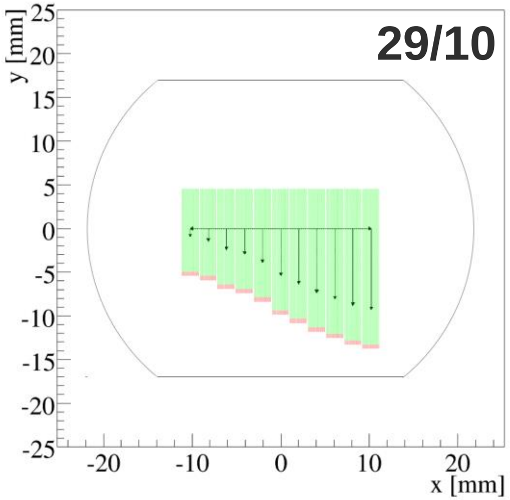
1) **Beam shaped** with primary collimators to have the desired beam probe
2) 3/4-Correctors **local orbit bump** matched in H/V plane at Q21L3
3) Local aperture probed systematically with **2/0.5 mm steps in H/V plane**
4) **Max bump excursion in H of ±10 mm** defined by arising of losses at Q20/Q22
5) **Measurements** performed on **29/10** and **30/10 after Fast Power Abort at 3.5 TeV**

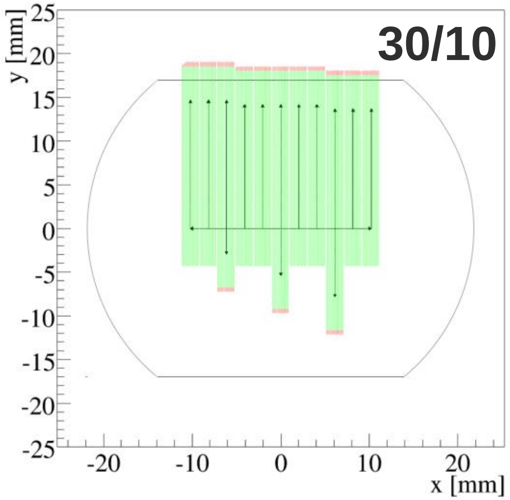
4-Correctors in H



3-Correctors in V





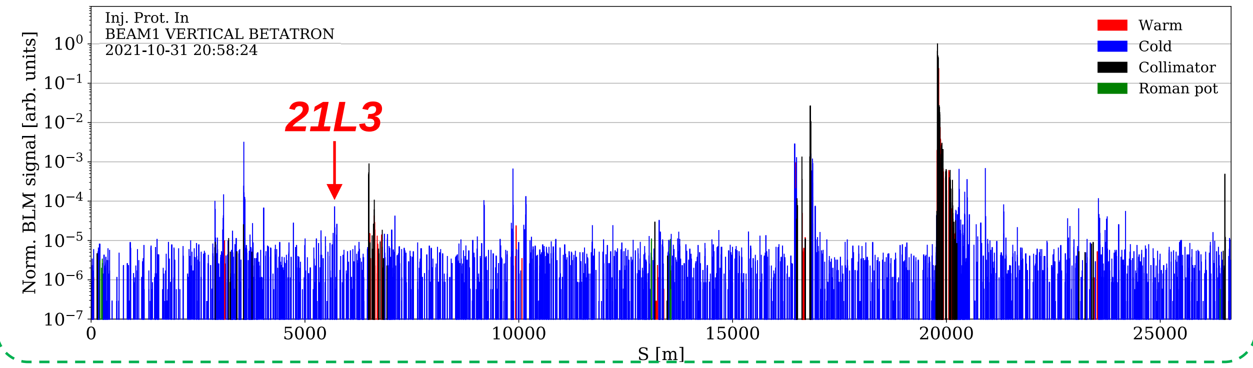


Measurements used to match a local orbit bump that could restore >11σ global aperture from ~7σ

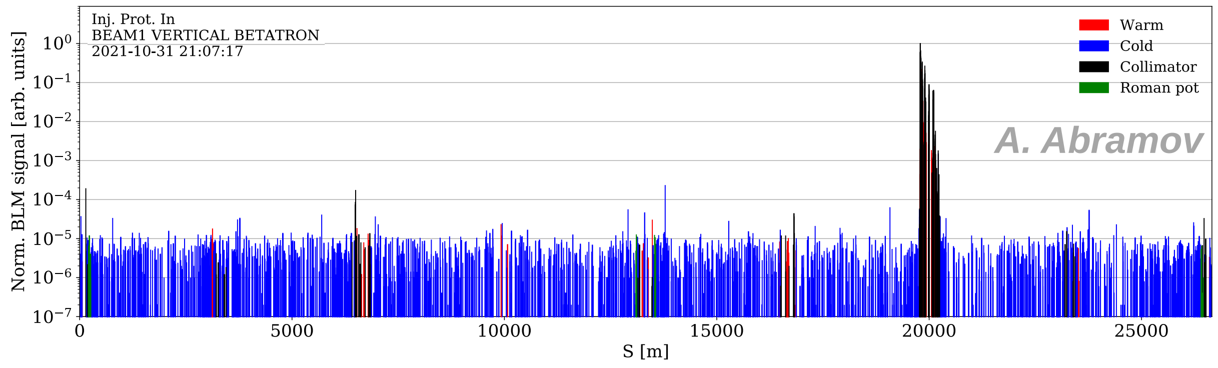
21L3 mitigations

- **Primary collimator** in V plane closed **from 8 σ to 6 σ 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 8σ 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

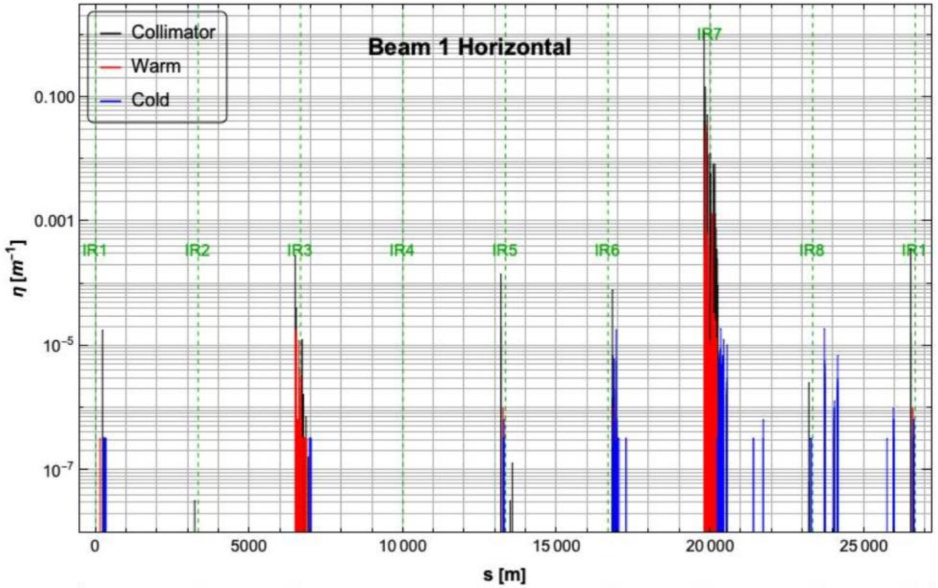
Outline

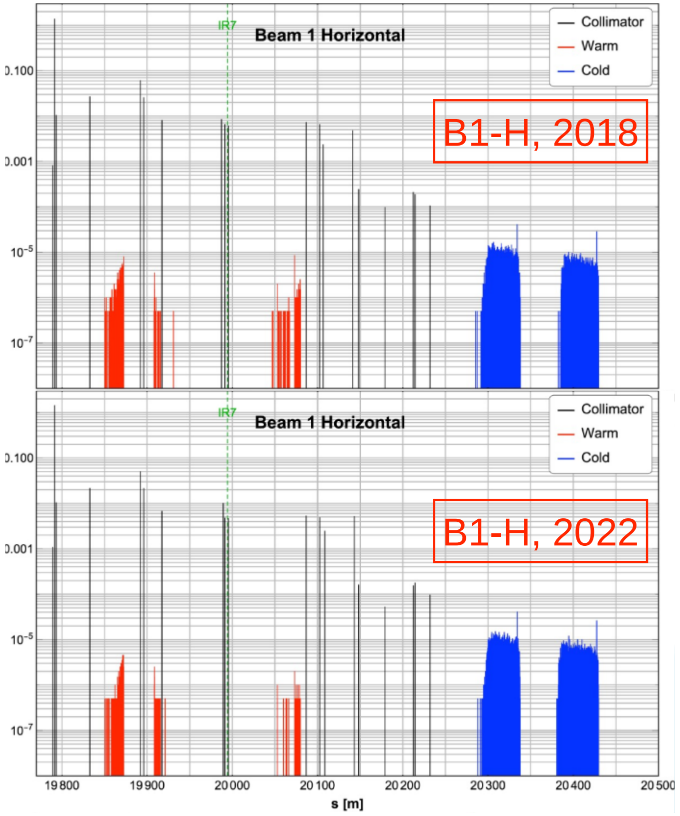
Performance of the Run 3 system

- ***Detailed assessment in simulations:***

F. Van Der Veken

Machine configuration 2023, β* = 30cm





- ✓ **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)

Settings for β* leveling in 2023 – 2024

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

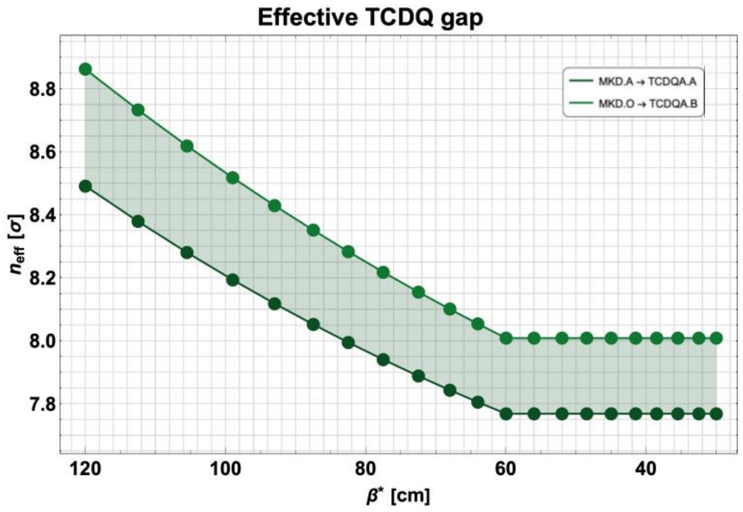
Keep **constant TCT-TCL settings in units of σ** (instead of mm)

Significant changes in optics (see R. Tomas):

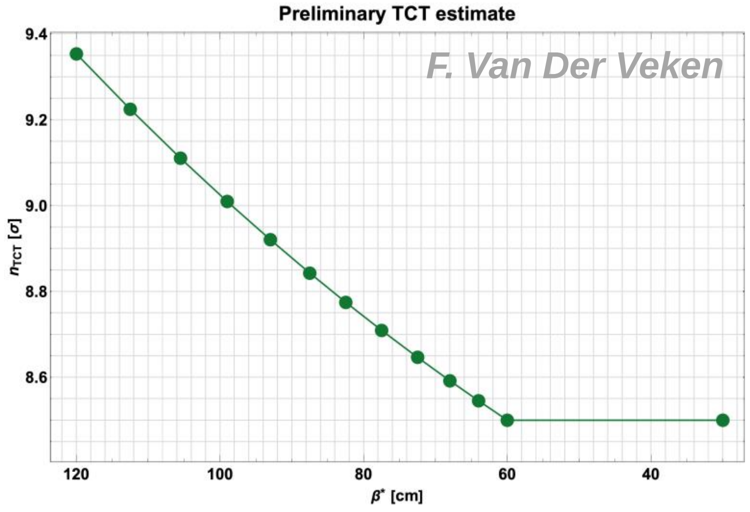
Not constant Δμ MKD - TCDQ for β* > 60 cm

Change of effective TCDQ gap

Potential **breakage of hierarchy**



Proposed solution



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

To be validated by dedicated asynchronous dump study

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

Outline

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 σ, for ϵ_n =3.5 μm. The bottleneck location is also indicated for each beam and plane and the beam-based aperture measurement method used.

	E [TeV]	Method	B1H	B1V	B2H	B2V
2010	0.450	Tune resonance blow-up +coll. scan	12.5-13.0 (Q6R2)	13.5-14.0 (Q4L6)	14.0-14.5 (Q5R6)	13.0-13.5 (Q4R6)
2011	0.450	Tune resonance blow-up +coll. scan	12.0-12.5 (Q6R2)	13.0-13.5 (Q4L2)	12.5-13.0 (Q5R6)	13.1-13.6 (Q4R6)
2012	0.450	Controlled white noise emittance blow-up+coll. scan	11.5-12.0 (Q6R2)	12.0-12.5 (Q4L6)	12.5-13.0 (Q5R6)	12.5-13.0 (Q4R6)
2015	0.450	Controlled white noise emittance blow-up+coll. scan	11.6-12.1 (MBRC.4R8)	12.1-12.6 (Q6L4)	12.5-13.0 (Q6L6)	12.0-12.5 (Q4R6)
2016	0.450	Controlled white noise emittance blow-up+coll. scan	12.5-13.0 (MBRC.4R8)	12.0-12.5 (Q6L4)	12.5-13.0 (TCDQM.4L6)	12.5-13.0 (Q4R6)
2017	0.450	Controlled white noise emittance blow-up+coll scan	13.1-13.6 (Q6R2)	12.2-12.7 (Q4L6)	13.2-13.7 (Q6L8)	12.8-13.3 (Q4R6)
2018	0.450	Controlled white noise emittance blow-up+coll scan	13.3-13.8 (Q4R6)	12.2-12.7 (Q4L6)	13-13.5 (Q4L6 & Q6L8)	12.5-13.0 (Q4R6)

2021 test beam

Plane	Aperture [σ]	Bottleneck
B1H	13.0 – 13.5	TCDSA
B1V	**12.0 – 12.5**	**MQY 4L6**
B2H	14.0 – 14.5	MQY 4L6
B2V	12.5 - 13.0	MQY 4R6

Summary IT aperture measurements

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

Table 6. Summary of measured global aperture bottlenecks per beam and plane in Run 1 and Run 2 for physics configuration 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 σ, for ϵ_n =3.5 μm. The bottleneck location is also indicated for each beam and plane.

	E [TeV]	β^* [cm]	ϕ [μrad]	Method	B1H	B1V	B2H	B2V
2012	4	100	-145	Controlled white noise emittance blow-up+coll. scan	11.5-12.0 (Q2L5)	11.0-11.5 (D1/Q3L1)	11.5-12.0 (D1/Q3R1)	11.0-11.5 (D1/Q3R1)
2015	6.5	80	-145	Controlled white noise emittance blow-up+coll. scan	18.2-18.7 (D1/Q3R5)	15.7-16.2 (D1/Q3L1)	16.2-16.7 (D1/Q3R1)	15.7-16.2 (D1/Q3R1)
2016	6.5	40	-185	Controlled white noise emittance blow-up+coll. scan	10.6-11.1 (D1/Q3R5)	9.9-10.4 (D1/Q3L1)	11.5-12.0 (D1/Q3R1)	10.4-10.9 (D1/Q3R1)
2017	6.5	40	+185	Controlled white noise emittance blow-up+coll. scan	10.9-11.4 (D1/Q3R5)	12.0-12.5 (D1/Q3L1)	12.9-13.4 (Q2R5)	11.4-11.9 (D1/Q3R1)
2017	6.5	40	+150	Controlled white noise emittance blow-up+coll. scan	11.5-12.0 (D1/Q3R5)	12.4-12.9 (D1/Q3L1)	14.0-14.5 (Q2R5)	12.0-12.5 (D1/Q3L1)
2017	6.5	30	+150	Controlled white noise emittance blow-up+coll. scan	10.6-11.1 (D1/Q3L1 & D1/Q3R5)	11.1-11.6 (Q2R5 & D1/Q3L1)	10.9-11.4 (D1/Q3R1)	10.5-11.0 (D1/Q3R1)
2018	6.5	30	+160	Controlled white noise emittance blow-up+coll. scan	10.5-11.0 (D1/Q3L1)	10.5-11.0 (D1/Q3L1)	10.0-10.5 (D1/Q3R1)	10.5-11.0 (D1/Q3R1)
2018	6.5	25	+145	Controlled white noise emittance blow-up+coll. scan	9.2-9.7 (D1/Q3L1)	9.2-9.7 (D1/Q3L1)	>12	10.5-11.0 (D1/Q3R1)

2021 test beam

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

All at Q2, except IT2-H at Q1

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