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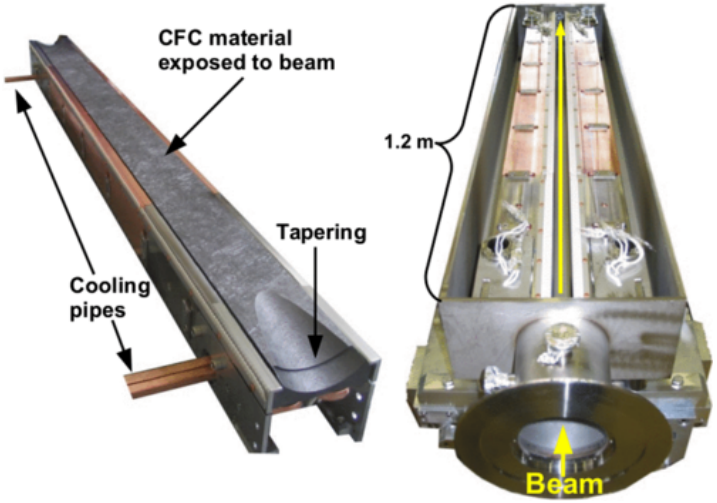
Collimation commissioning JAPW ’22

F.F. Van der Veken, A. Abramov, G. Azzopardi, G. Broggi, R. Bruce, M. D’Andrea, D. Demetriadou, K. Dewhurst, A. Frasca, P. Hermes, B. Lindström, D. Mirarchi S. Redaelli, M. Solfaroli, F. Ziliotto

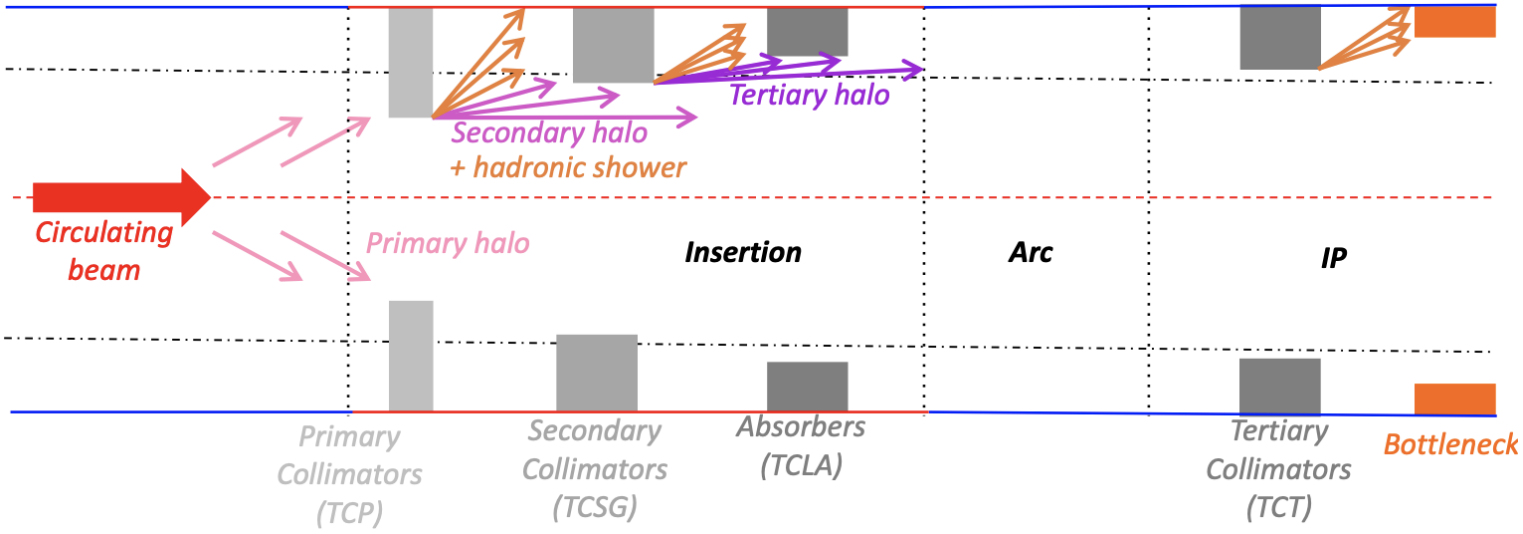
with many thanks to the LHC OP, STI, CEM, BI, and GM teams

Outline

- Collimation system essential to protect machine against quenches
- Run 2: stored energy $\sim$ 300MJ
  Run 3: increased to $\sim$ 400MJ
- Collimators follow strict hierarchy



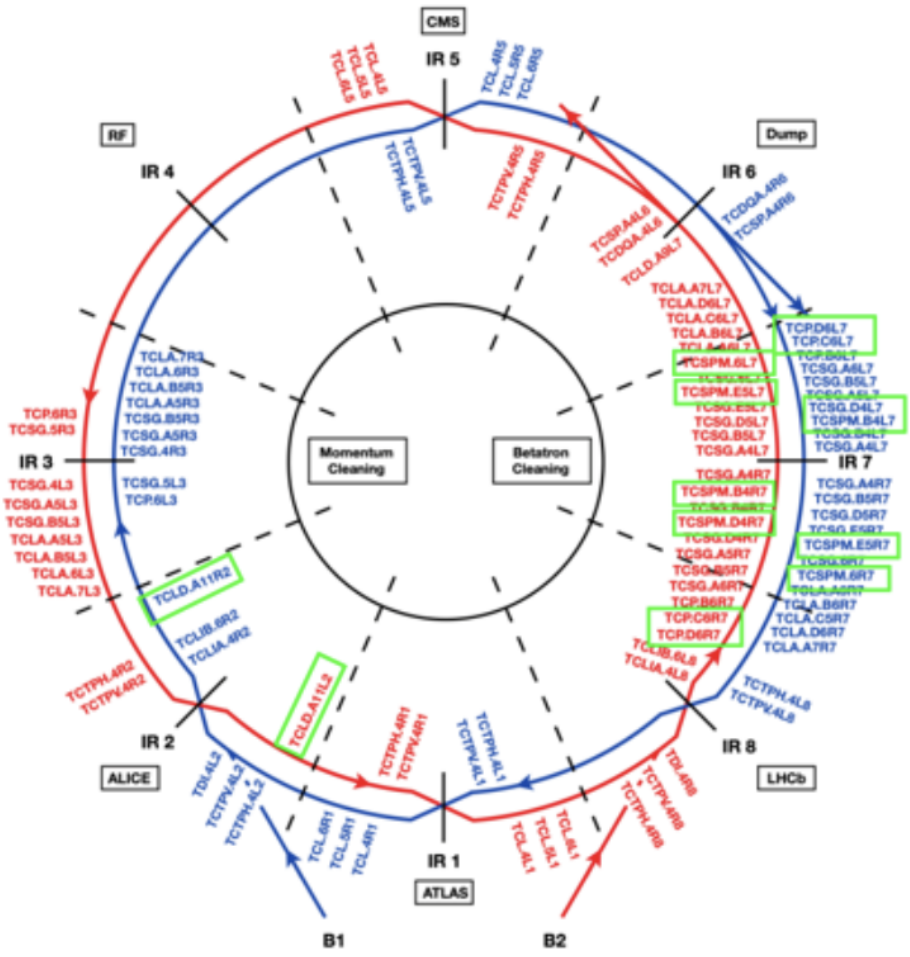
courtesy of R. Bruce



courtesy of 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

  $\Rightarrow$ **coarse settings** initially (few collimators only, more open)

  $\Rightarrow$ 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 β^*=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

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

Aperture Results

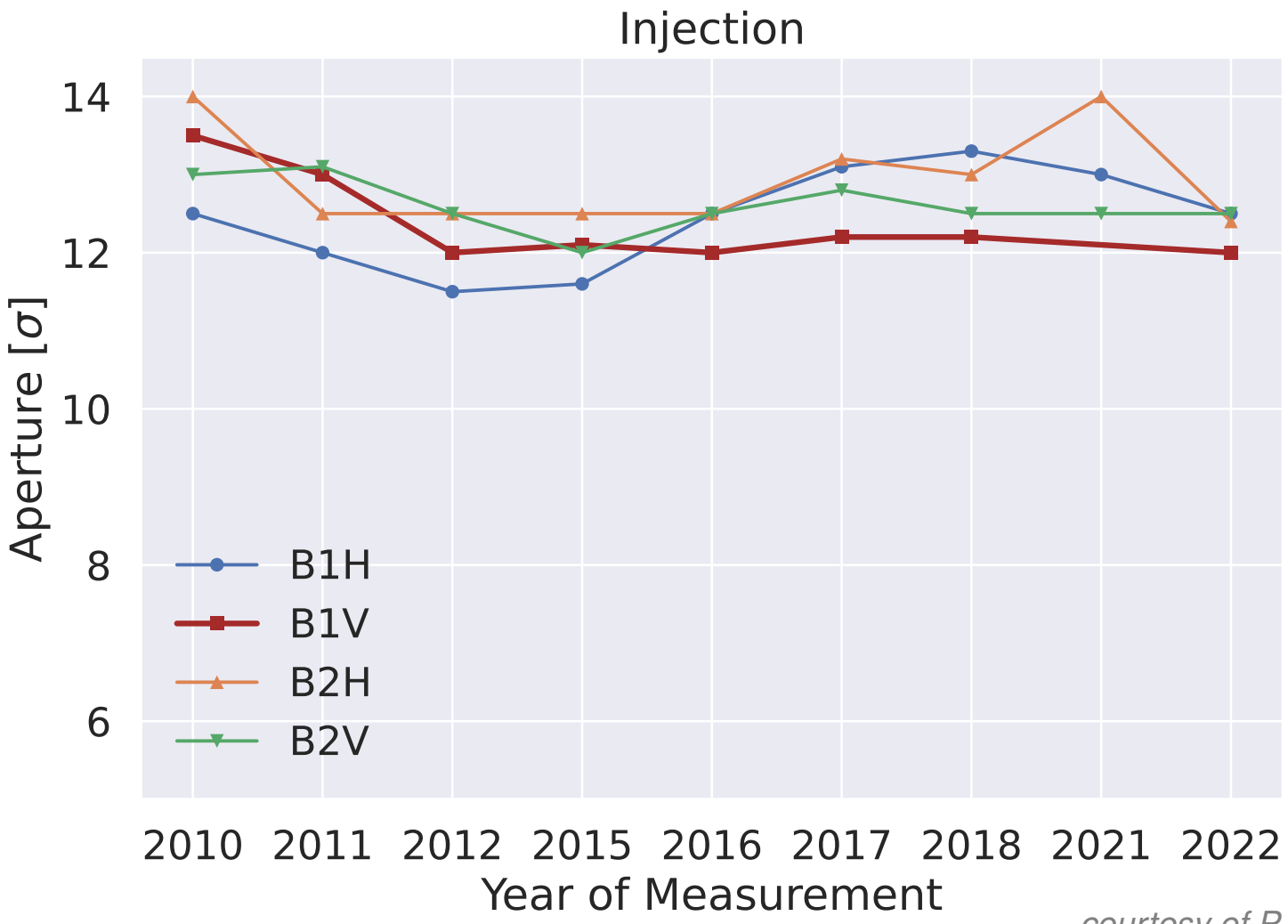
- Settings from Run 2 confirmed by aperture measurements
- No showstopper found for $\beta^* = 30$ cm (at 160μrad crossing)

Plane	CS (σ)	BBA (σ)	Bottleneck
B1H	11.5-12.1	>10.5	Q2L5
B2H	11.0-11.5	12.5-13.0	Q2R5
B1V	9.2-10.0	9.3-10.5	Q3L1
B2V	9.4-10.1	>9.7	Q3R1

2022: Aperture measured at β*=30cm

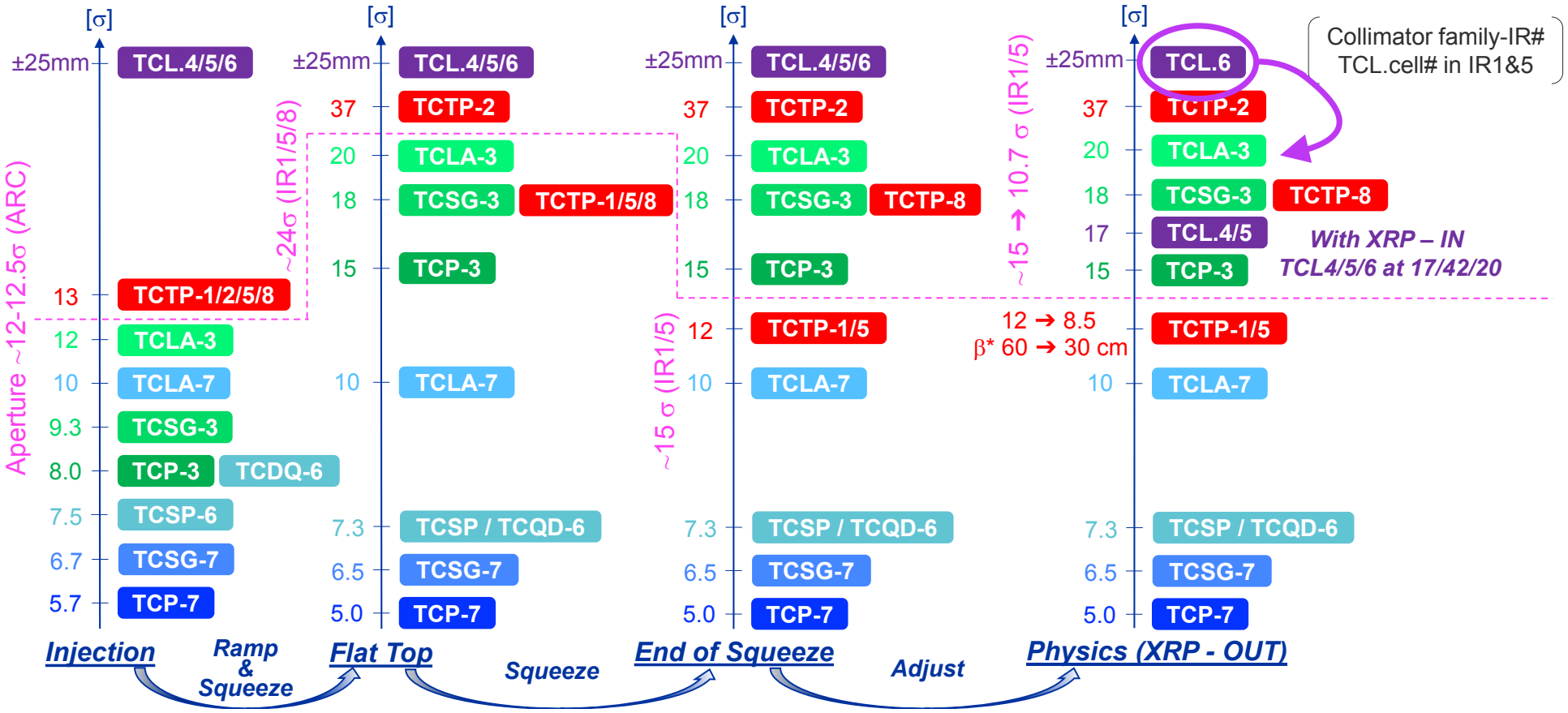
courtesy of P. Hermes (see also talk by R. Bruce at LMC #452)

Aperture over the Years



courtesy of P. Hermes

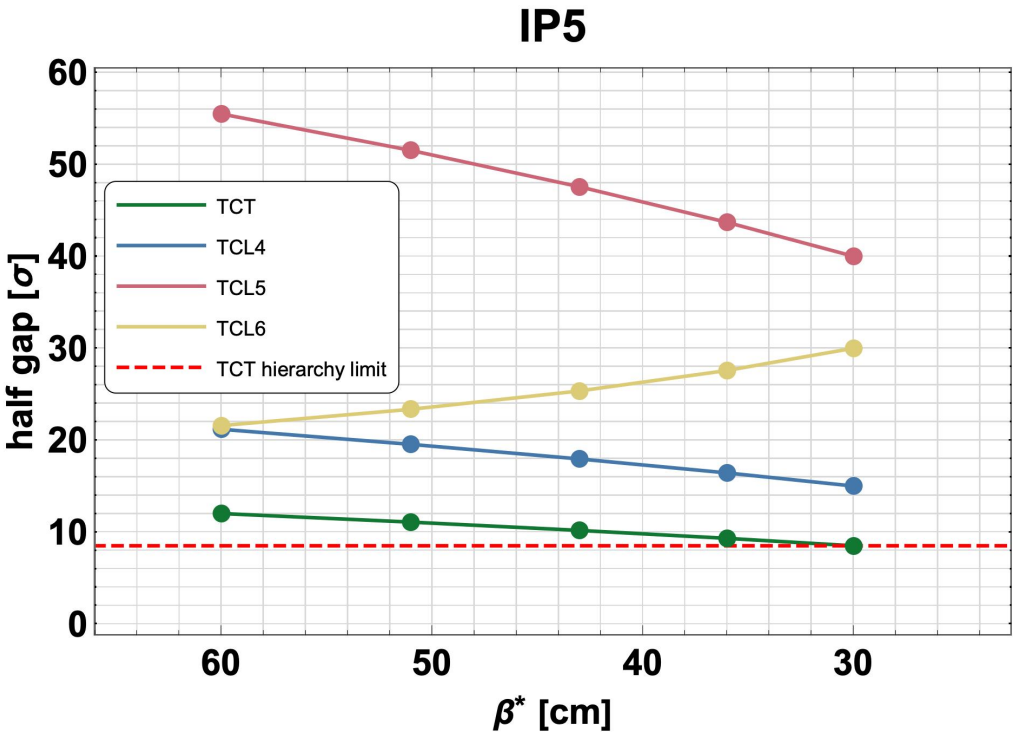
Collimator Settings 2022



courtesy of D. Mirarchi

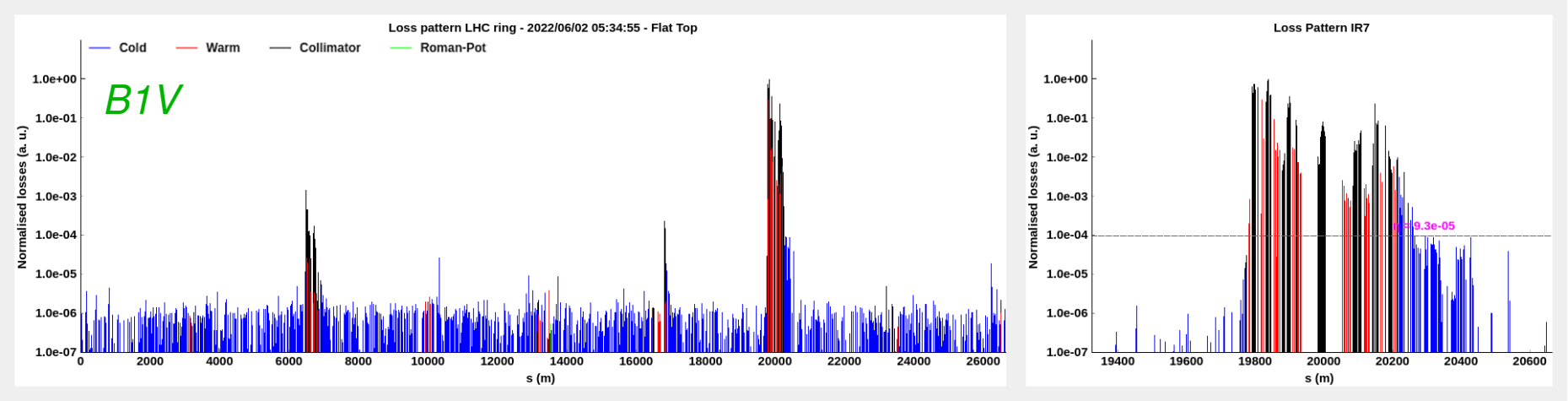
TCT Strategy During Levelling 2022

- 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?

Outline

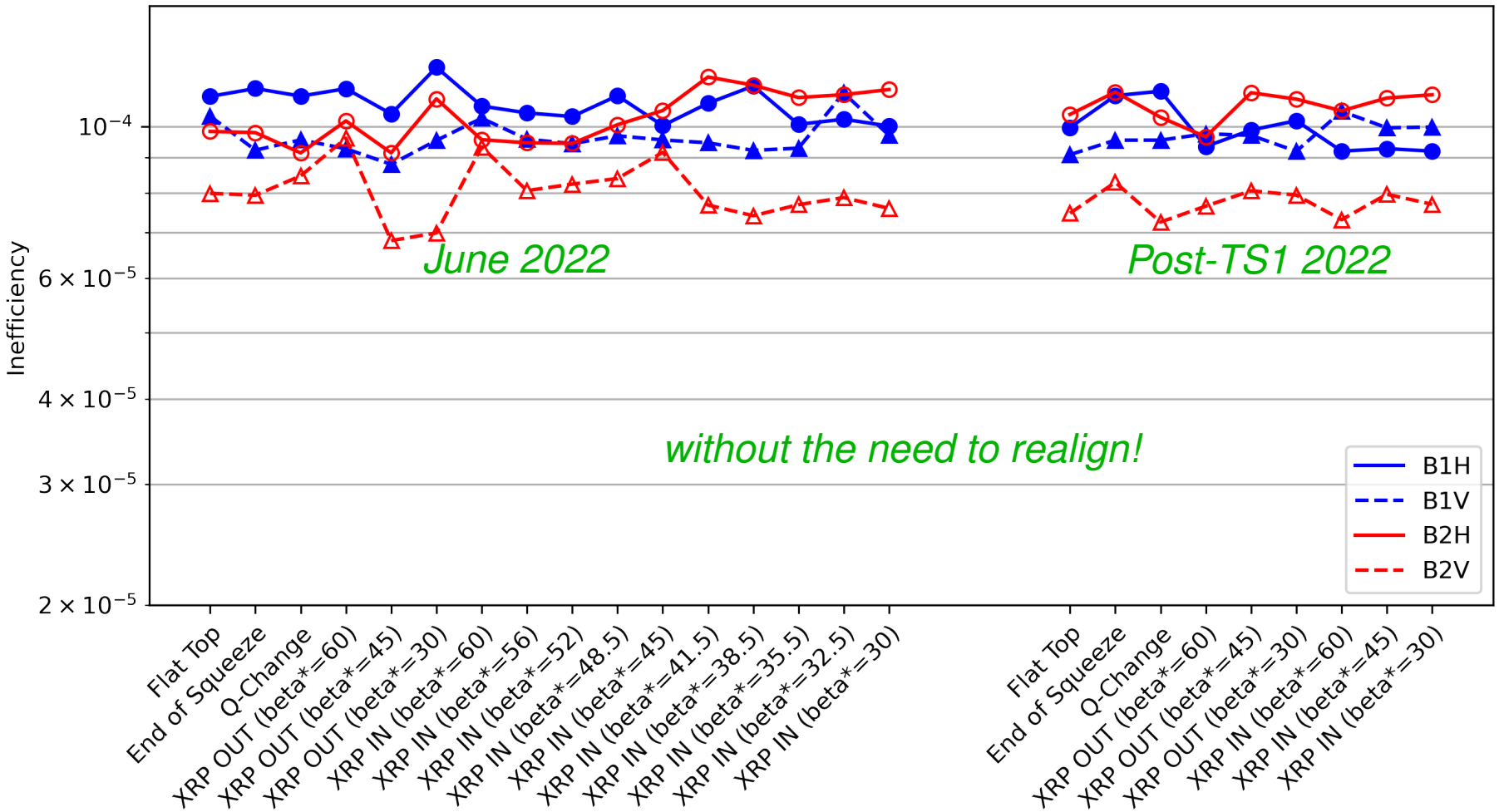
Performance

- Machine is well protected during the full cycle

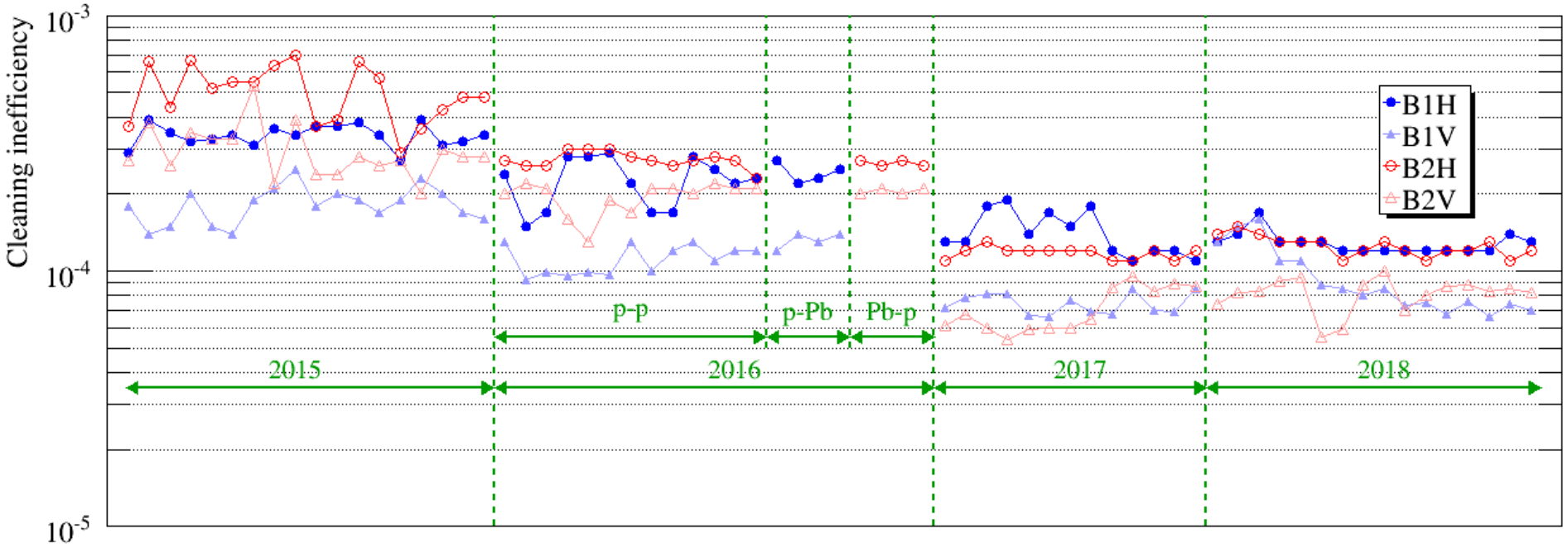
  up to $\beta^* = 30\,\text{cm}$
- As expected, losses on TCTs increase with smaller β^*

  Background still under good control
- Collimation system performs in line with previous years

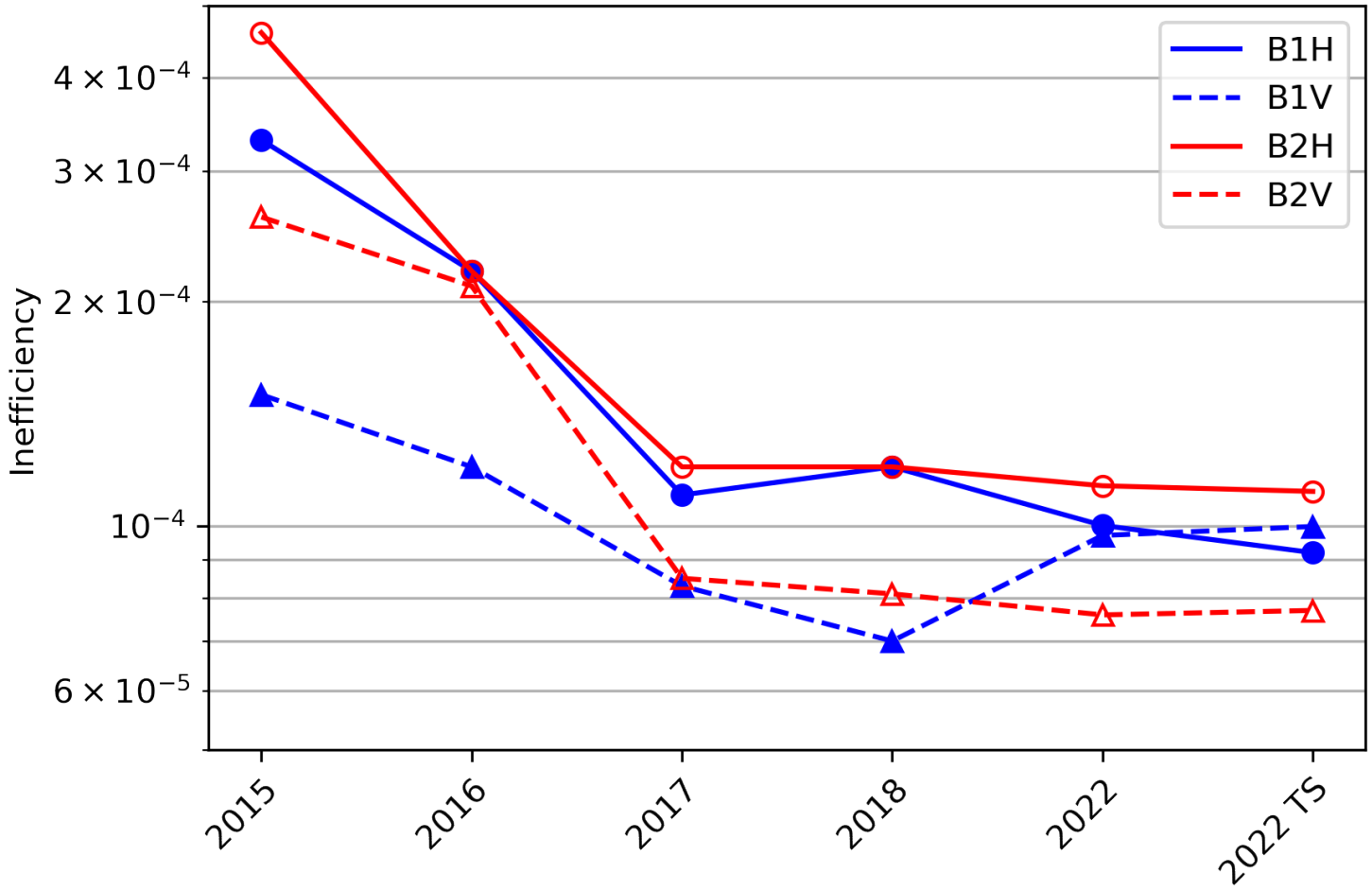
Cleaning Inefficiency During the Year



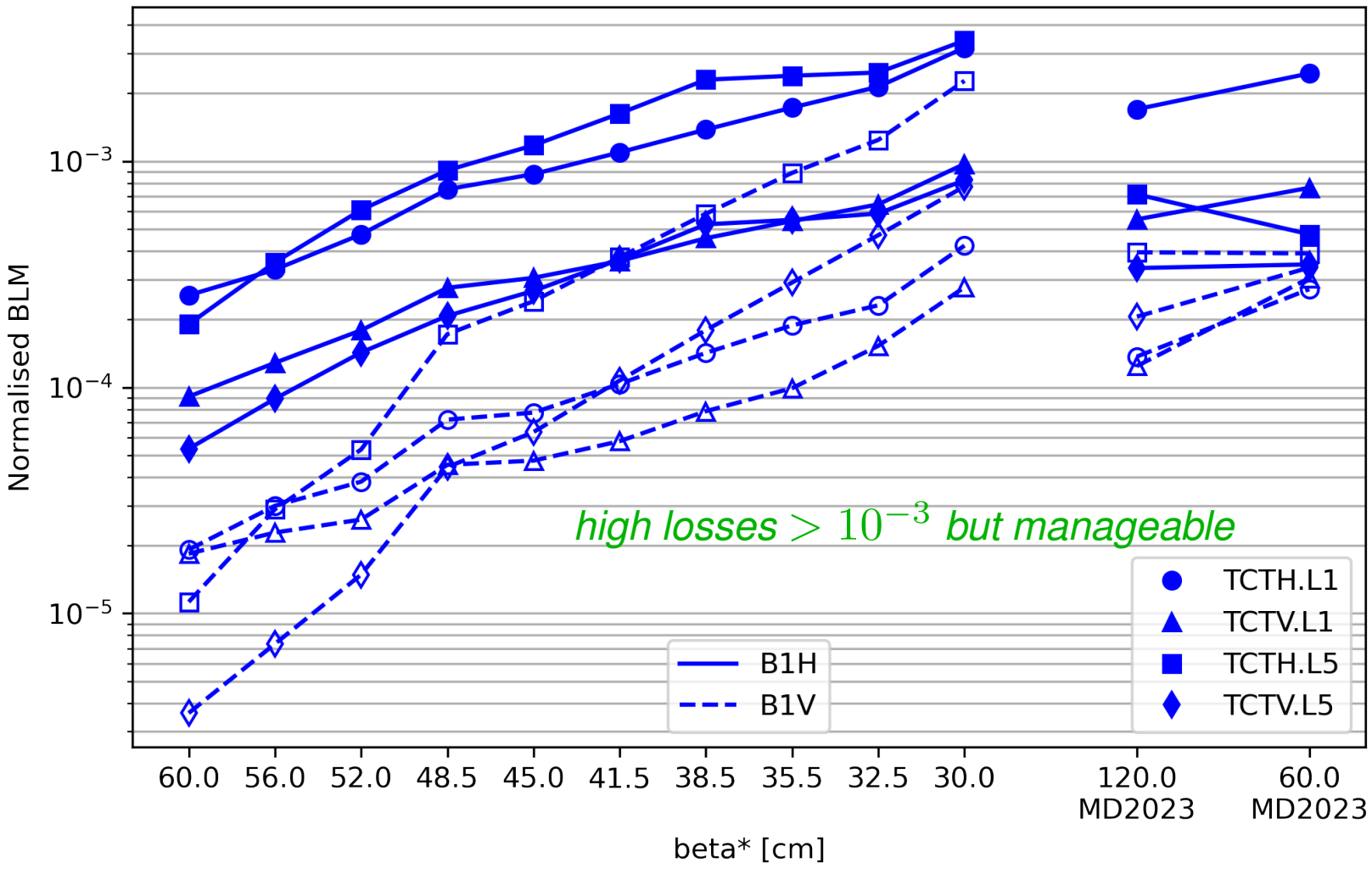
Comparison: Inefficiency over Run 2



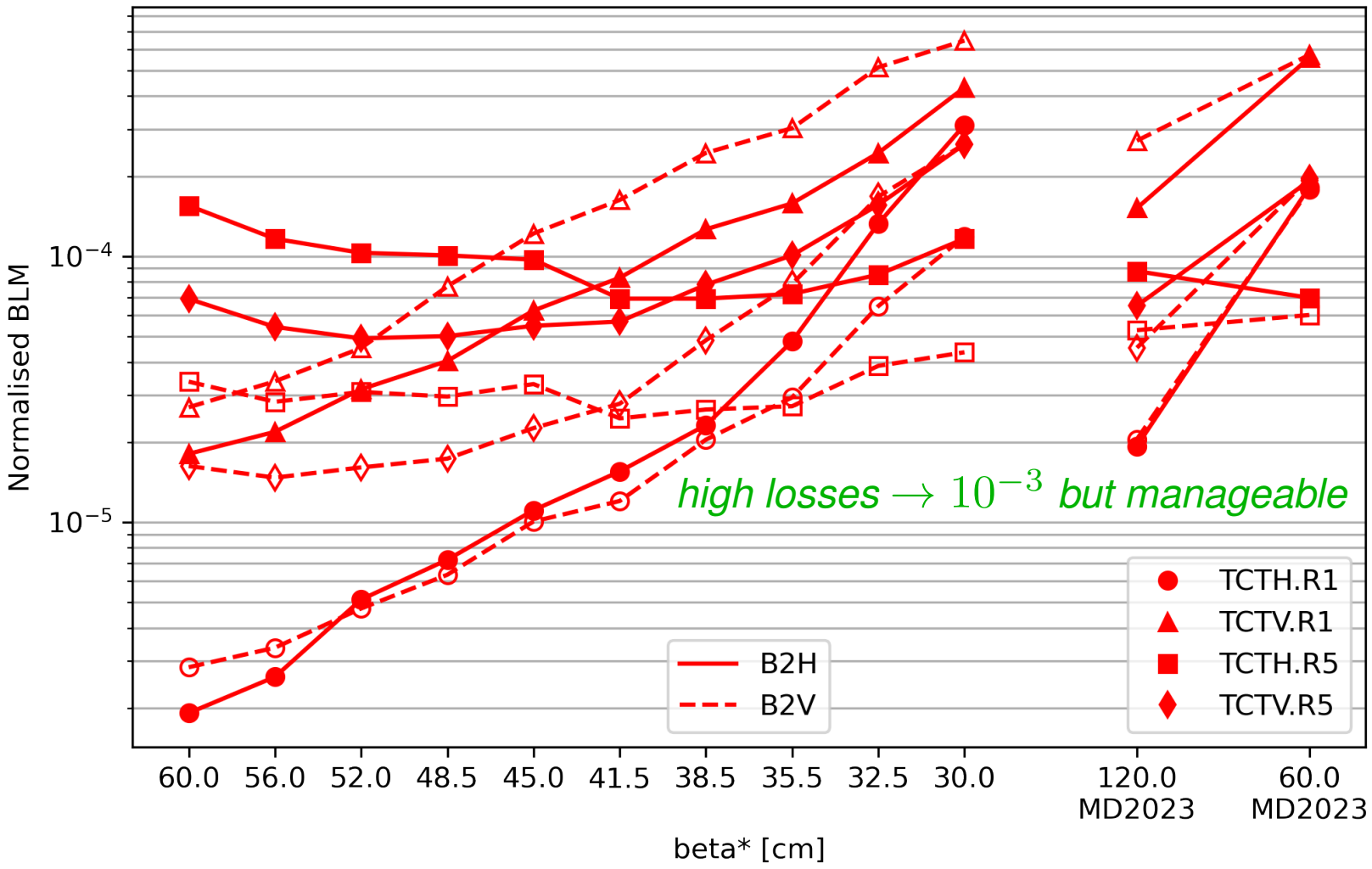
Inefficiency over the Years



TCT Inefficiency during Levelling in 2022



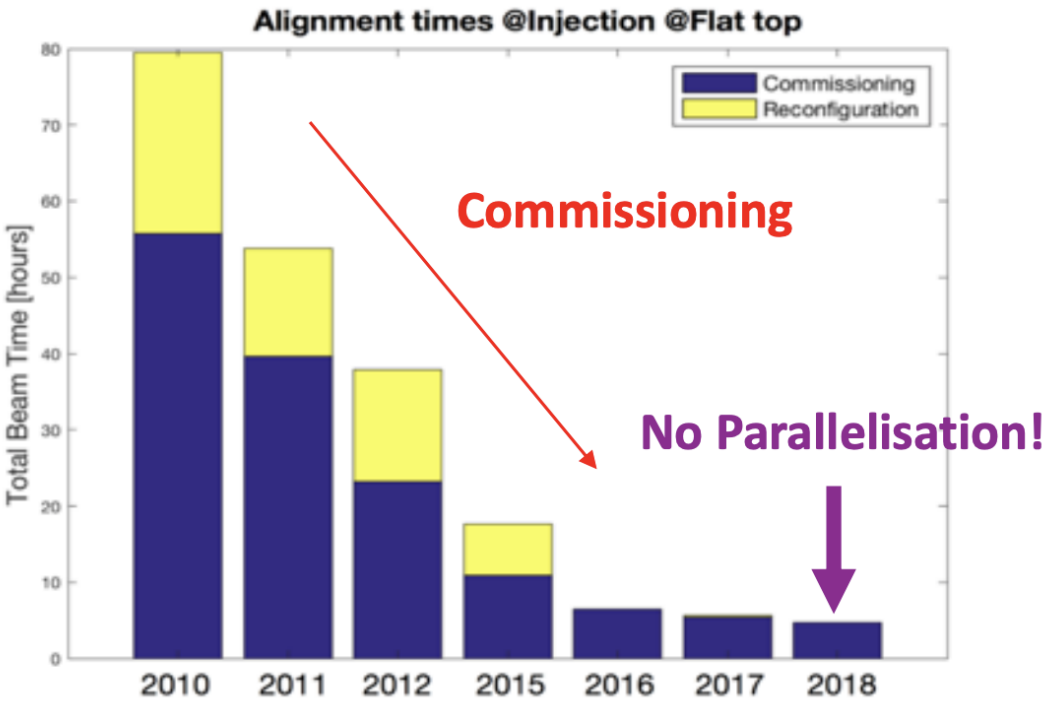
TCT Inefficiency during Levelling in 2022



Outline

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!)



courtesy of N. Fuster-Martínez

First Alignment of 2022

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

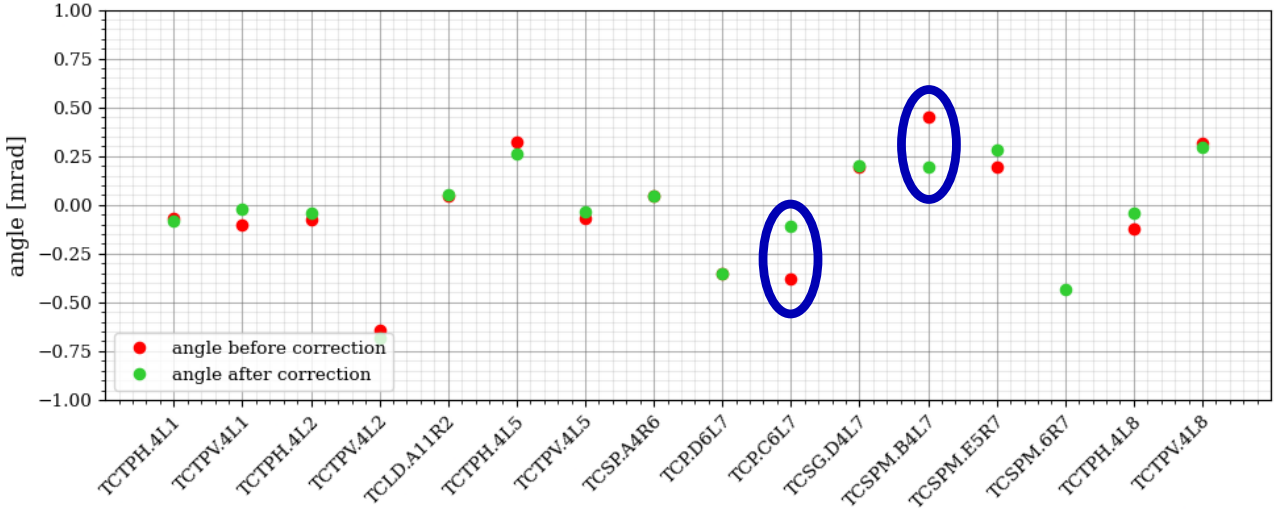
  Not strictely necessary, but useful to confirm adequateness of fully-automatic alignment in presence of tilts

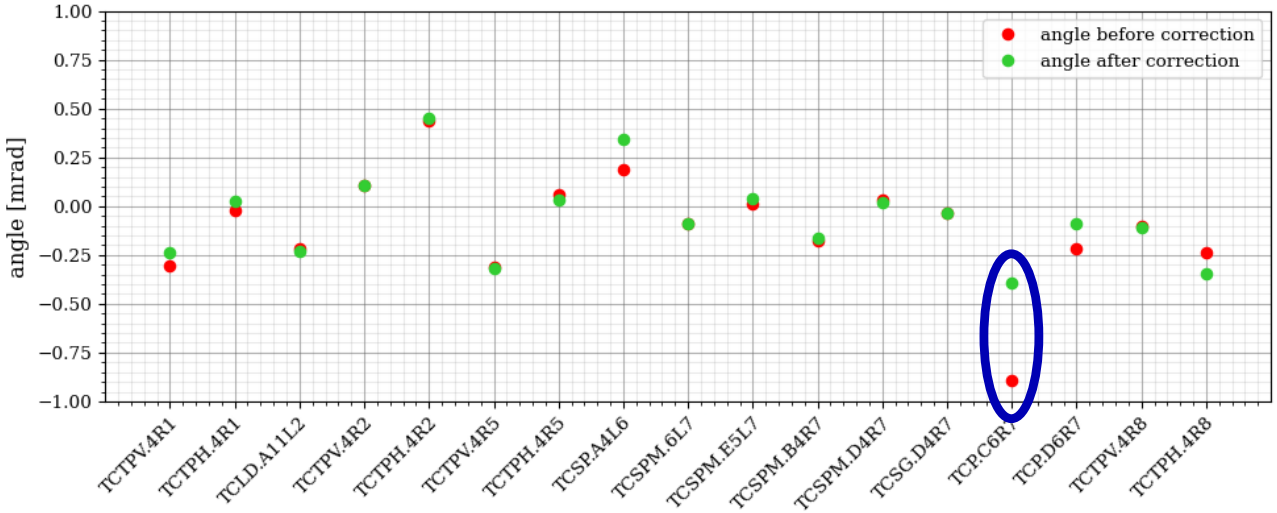
- Several large collimator tilts were found

  Three were deemed too large

  $\Rightarrow$ 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

Outline

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 *($\sim$1 min per LM)*:

  Essentially only limited by number of fills needed for ASDs!

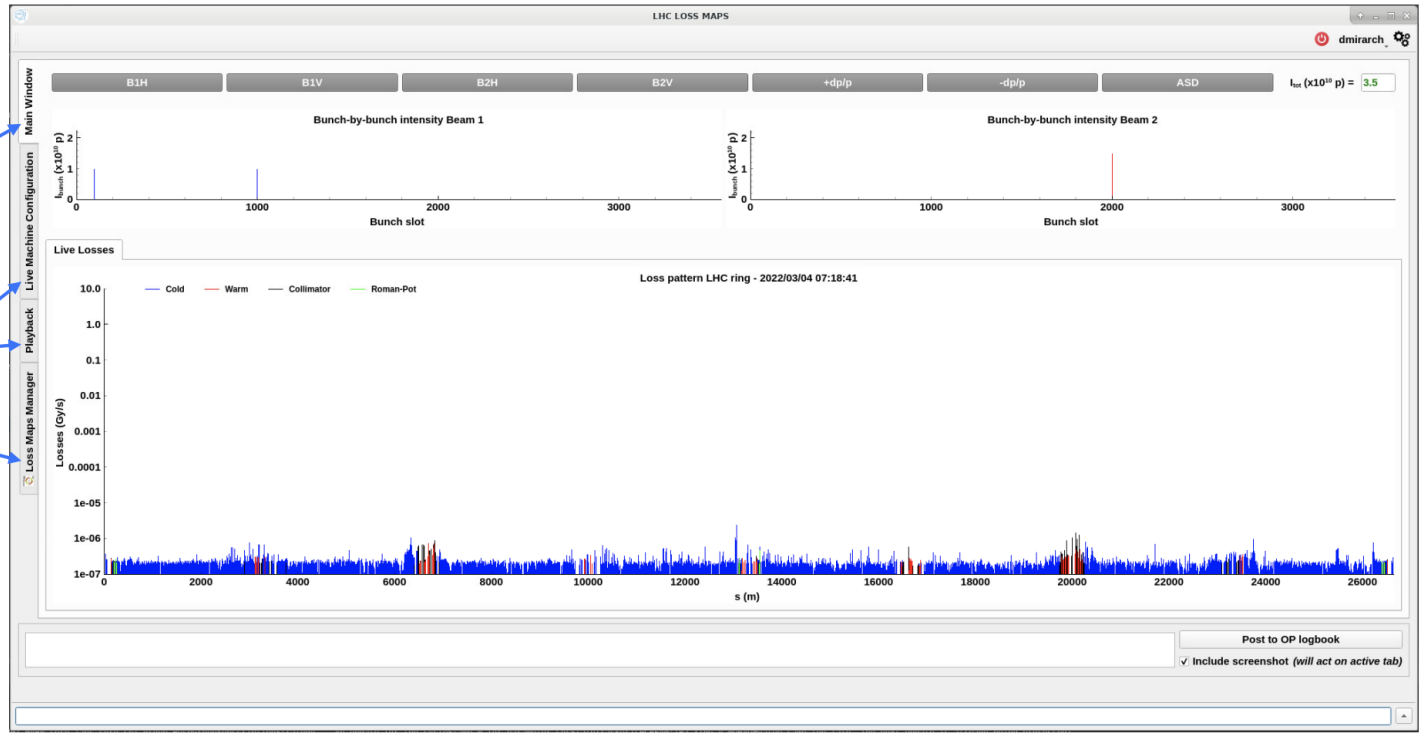
Loss Maps Matrix

	450 GeV		6.8 TeV															
			Non colliding			Colliding – XRP IN										Colliding – XRP OUT		
	Inj Prot IN	Inj Prot OUT	FT	EoS	Q change	60 cm	56 cm	52 cm	48.5 cm	45 cm	41.5 cm	38.5 cm	35.5 cm	32.5 cm	30 cm	60 cm	45 cm	30 cm
B1H	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
B1V	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
B2H	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
B2V	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
+dp/p	✓	✓	✓		✓	✓									✓			
-dp/p	✓	✓	✓		✓	✓									✓			
ASD	✓	✓	✓		✓	✓									✓			

pyLossMaps

Four main tabs:

- Main Window
- Live Machine Configuration
- Playback
- Loss Maps Manager



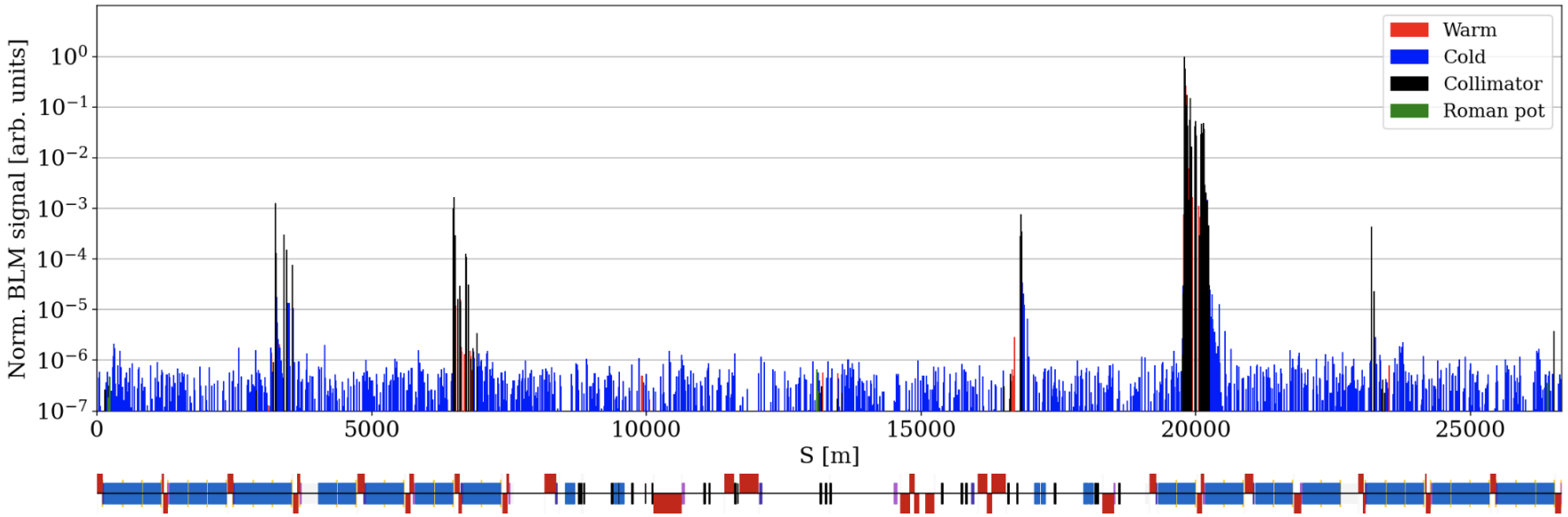
- Easy to use
- Much more flexible
- Preliminary online analysis
- Faster (especially off-momentum and ASD)

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')
lm.plot_lossmap(B2H_InjIN,   timestamp=None, label_fake_spikes=False, outfile='plots/InjProtIN_B2H.pdf')
lm.plot_lossmap(B2V_InjIN,   timestamp=None, label_fake_spikes=False, outfile='plots/InjProtIN_B2V.pdf')
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')
```

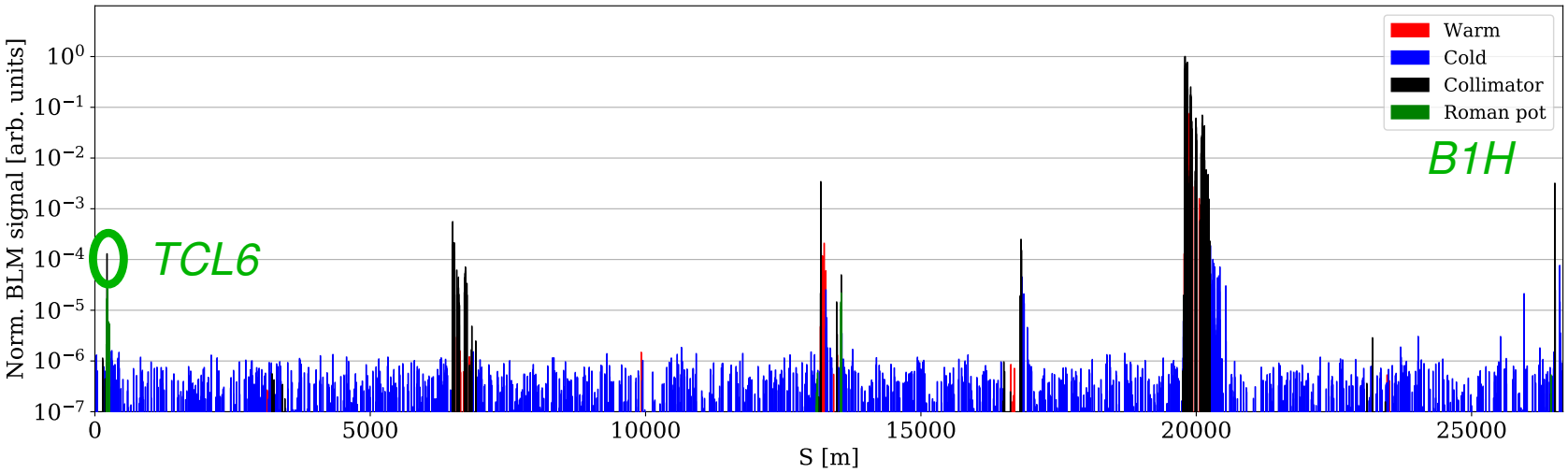
```
pymadx.Tfs.Load> zipped file
```

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



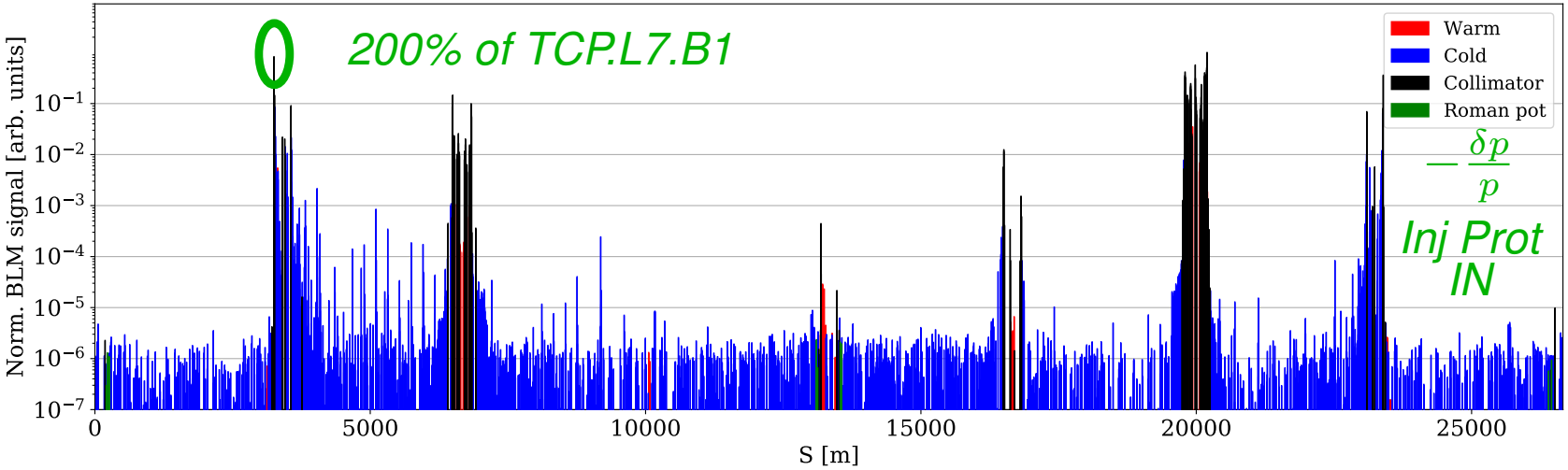
Large Losses on TCL6

- 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 sensitvity to non-linearities
- No issue for machine safety, but raises questions
  $\Rightarrow$ Need to review 2023 strategy, also for top energy



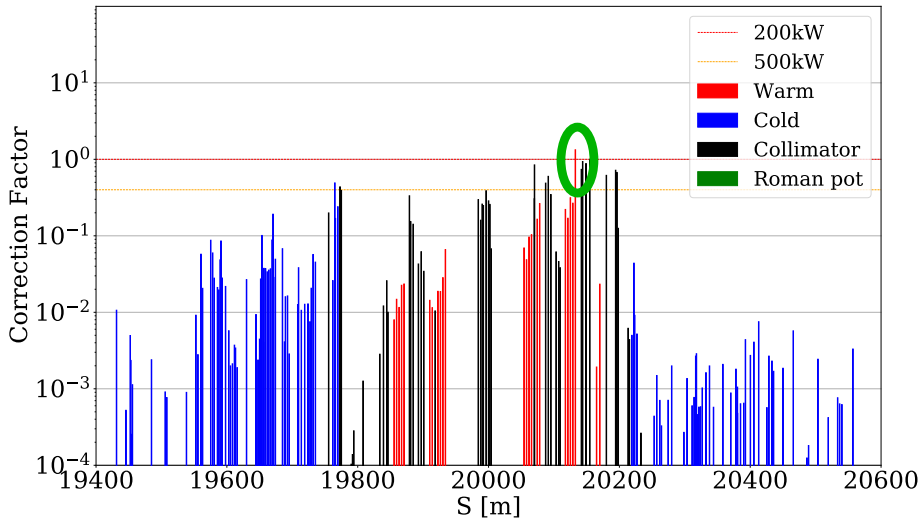
Tuning BLM Thresholds

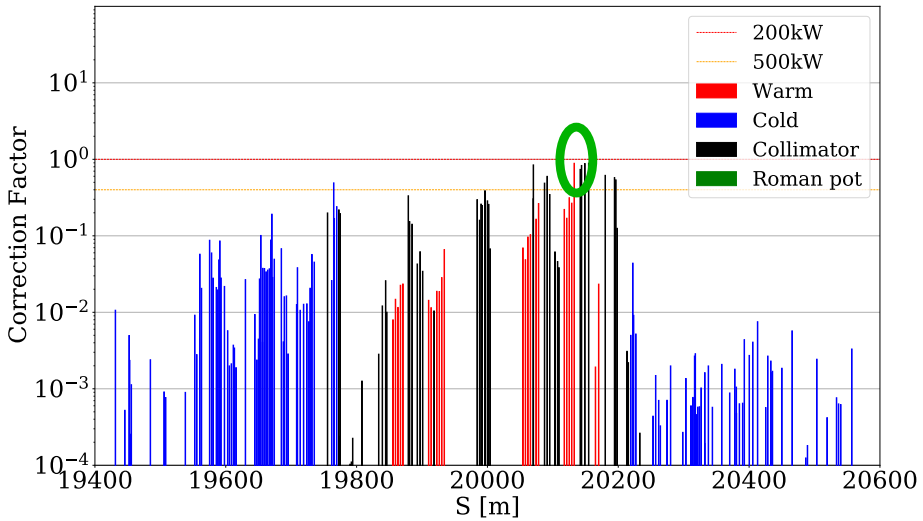
loss maps used to calibrate BLMs by updating thresholds

⇒ offline `lossmaps` tool includes functionality to simplify this

s	name	losses_type	Th_old	Th_new	F
20132.68	BLMQI.05R7.B2I10_MQWA.D5R7	Losses.WARM	0.111035	0.134235	1.208952

s	name	losses_type	Th_updt	Th_new	F
20132.68	BLMQI.05R7.B2I10_MQWA.D5R7	Losses.WARM	0.160148	0.134235	0.838205





thanks also to the BLM threshold working group

courtesy of F. Ziliotto

Outline

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

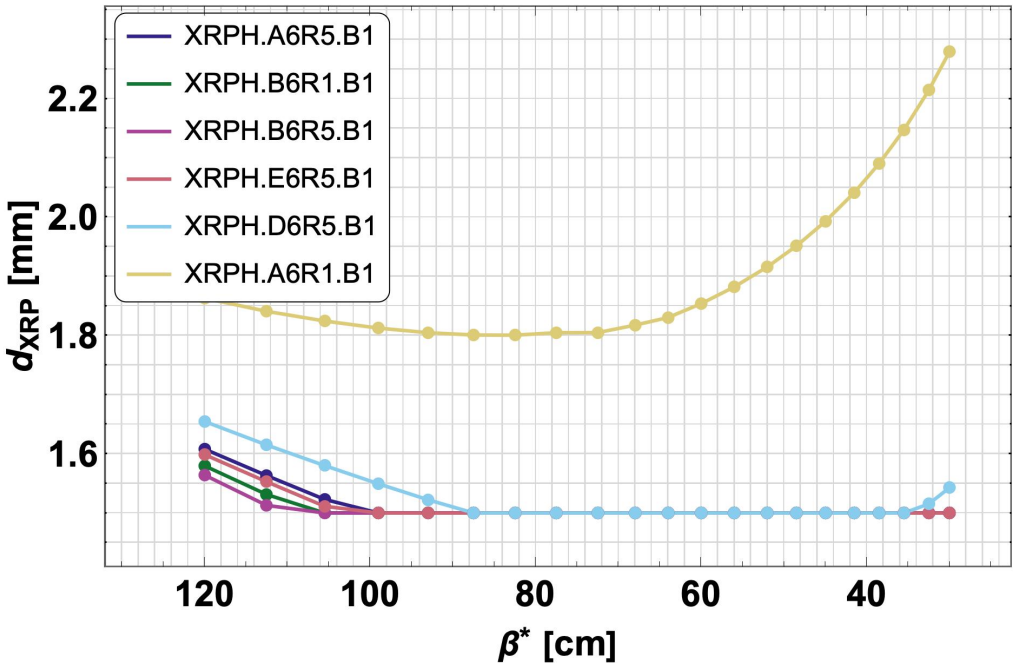
    depending on available resources
  - Loss Maps: discuss strategy for non-linearities

Many thanks for your attention!

Backup Slides

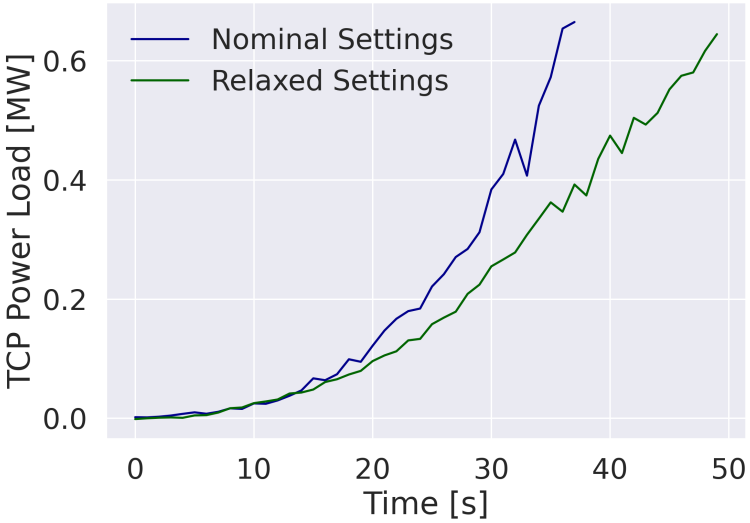
TCT Strategy During Levelling 2023

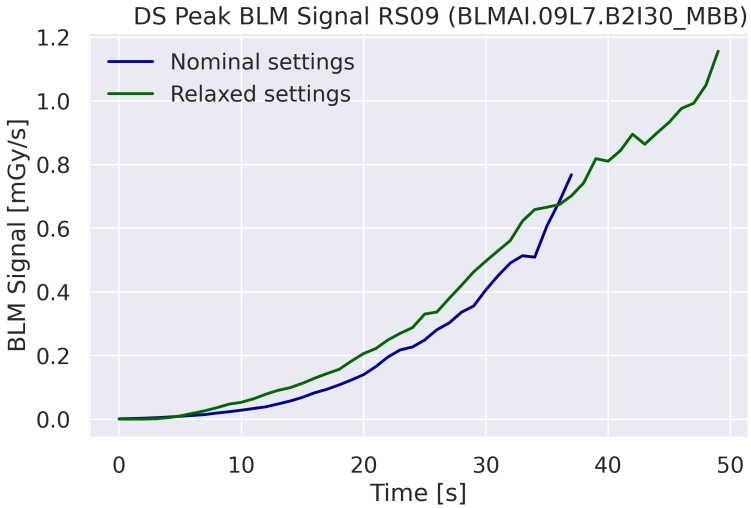
- During levelling, beam sizes and orbit at TCTs/TCLs change!
- Need strategy to allow Roman pots to get in close enough
- 2023: TCT gap fixed at 8.5σ for $\beta^* = 60 \ldots 30$ cm
  decreasing from 9.3σ for $\beta^* = 120 \ldots 60$ cm



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 β^* interlock (7857, 7961, 7968)

  FEC overload (from collimation vistar) $\rightarrow$ hardware replaced (new FEC)
- Four dumps due to UFOs (8045, 8056, 8108, 8111)

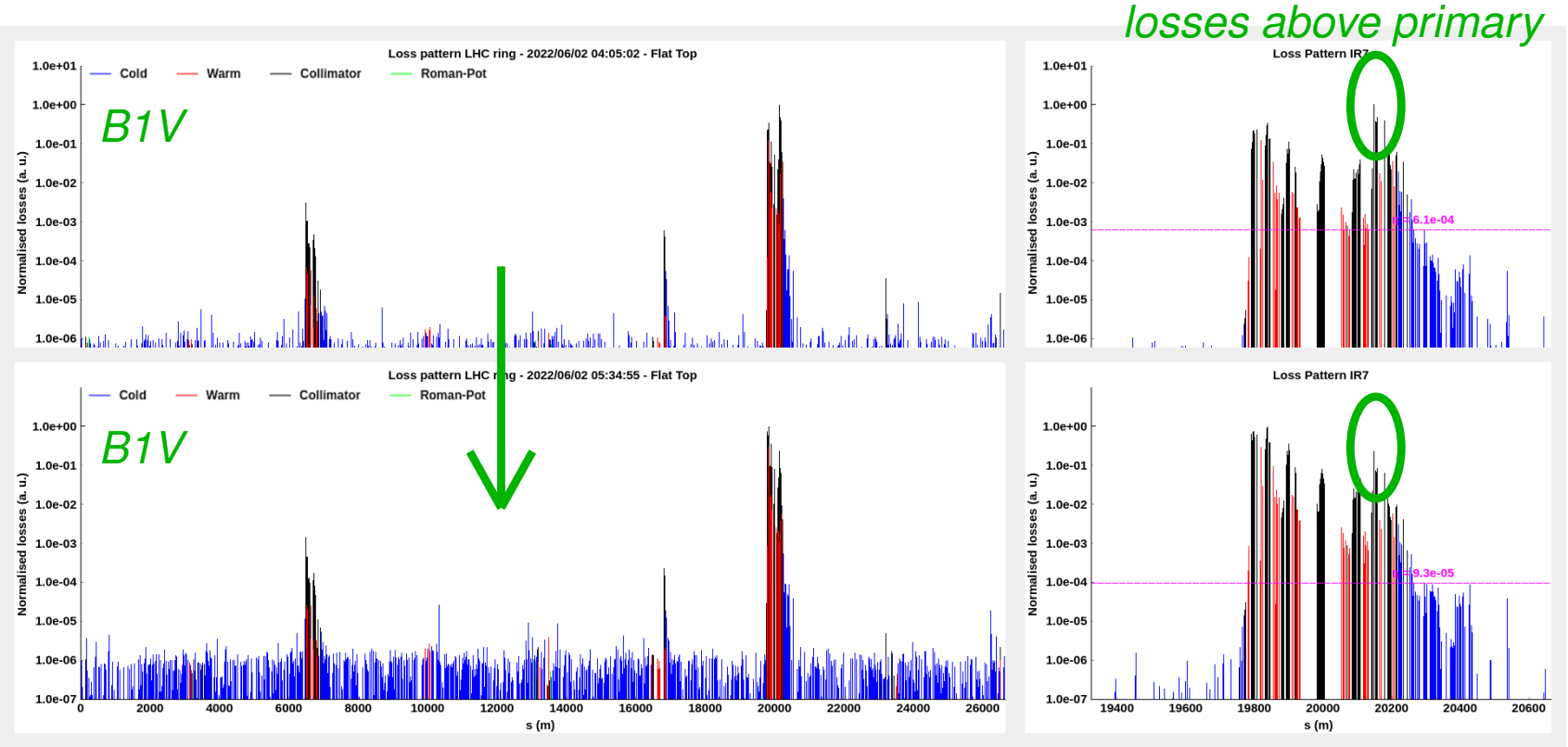
  BLM thresholds adapted
- Four dumps due to collimator temperatures (7796, 8127, 8150, 8251)

  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



Off-Momentum Loss Maps

- Easier to perform, and more reliable, thanks to `pyLossMaps`
- Only one dump in 2022!

  $\Rightarrow$ during +dp/p with collision tunes

  $\Rightarrow$ large chroma (20) sent beams on 3rd order resonance

  $\Rightarrow$ with ~ 100 Hz trim that gives a large tune shift ($> 1e-2$)

  - Can be addressed by lowering chromaticity

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