Collimation

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On behalf of the LHC Collimation team

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Chateau de Bossey, Bogis-Bossey, VD, Switzerland

Outline

I. Run 2 overview
II. Near misses in Run 2
III. Looking at Run 3
IV. Conclusions

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I. **Run 2 overview**
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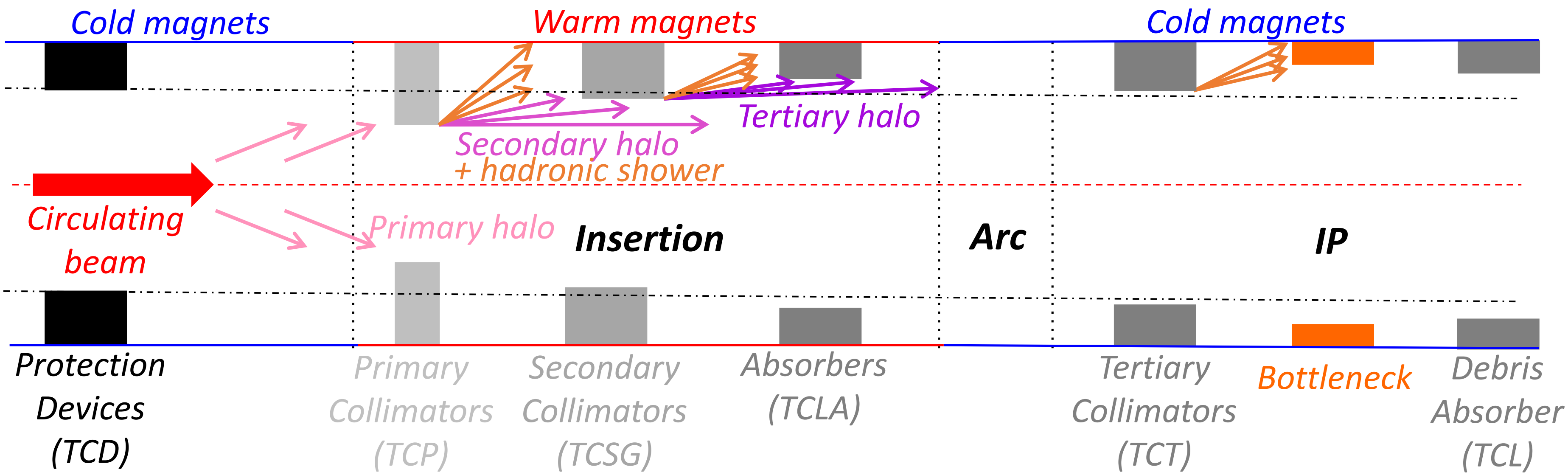
Introduction

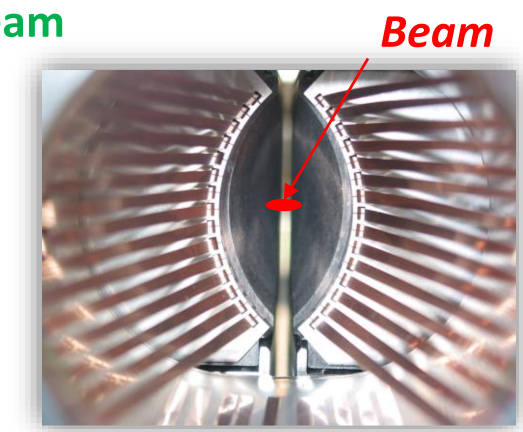


- **Multi-stage cleaning** with about **50 movable collimators per beam**

  → Ensure required performance along the entire cycle

- **Two dedicated insertions**: IR7 β and IR3 $\delta p/p$ cleaning

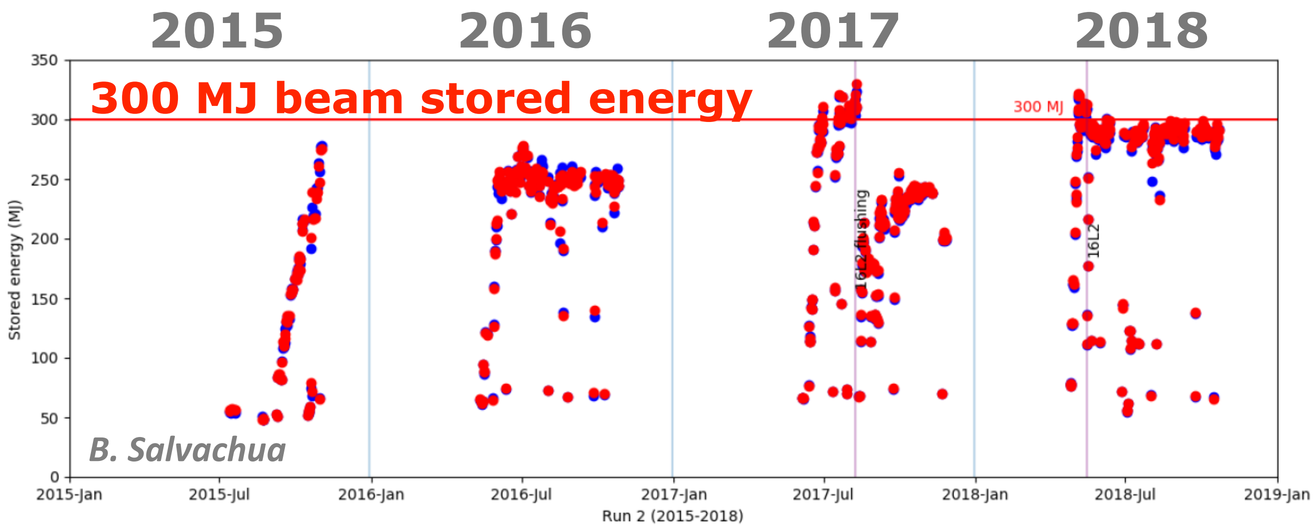
- **First line of machine protection** against ultra fast loss scenario



At 6.5 TeV: ~2 mm gap with 5 μm resolution!

Operations in Run 2

- **No quench** from circulating beam losses with **up to > 300 MJ stored energy!**



- Very good **beam lifetime** and **orbit stability**, **plus**:
  - ✓ **Alignment** of the entire system during **commissioning**
  - ✓ Deployment of **settings along the entire cycle** based on aperture measurements
    - ⇨ **Dedicated functions** for each collimator related to every beam process
  - ✓ System **validation** through betatron and off-momentum **loss maps**
    - ⇨ **YETS**, each **TS**, and **changes** of machine **parameters** (i.e. Xing ➔ TCTPs centre)

Main changes during Run 2

2016

- **Interlocked phase advance MKD→TCT close to 0˚**

2017

- **BPMs** in TCTs jaws **used for alignment**
- **Collimator movement in Stable Beams** during Xing change

2018

- **Interlock on BPMs** in TCTs jaws
- **Collimator movement in Stable Beams** during Xing & β^* change
- Collimator alignment using **machine learning** (see Alessio's talk)
- **Jaw tilt**

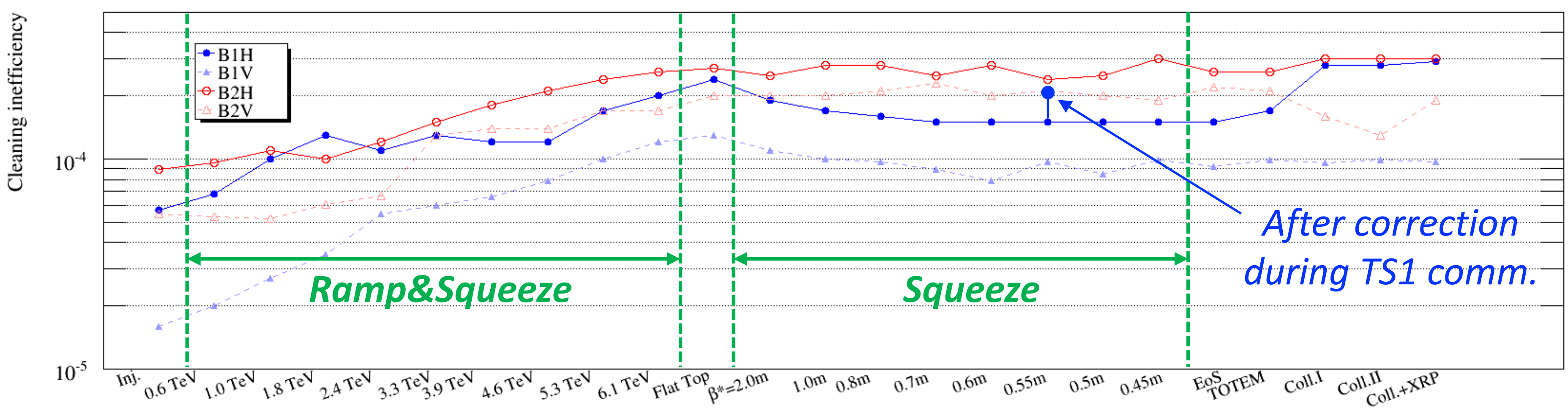
System performance validation

- **Controlled high losses** generated in the transverse and longitudinal planes: **Loss Maps (LM)**
  - → **Powerful probe of potential issues** during operations

- *Two examples for Run 2:*

1. First set of **LM done after alignment**
   - → **Jaw tilt not incorporated** correctly in setting generation/import
     - → **Hierarchy breakage** found in **final validation** using operational sequ. and BP

2. First time of **continuous LM during cycle**
   - → **Found and corrected small bump** (~100 um – 0.5 σ) building up toward IR7-TCLAs



Validation strategy

Very efficient methods to generate controlled high losses developed along the years

✓ **ADT** for **betatron** LM
✓ **Feedback on losses** during faster RF phase shift for **off-momentum** LM

More configurations can be validated with fewer fills required

More LM to be analysed

- Validation strategy:

Commissioning

- Both **betatron and off-momentum** LM at **every static point** of the cycle
- **Betatron** LM during **dynamic phases**

After Technical Stops or 3 months

- **Betatron** LM at **every static point**
- **Alternated off-momentum** LM

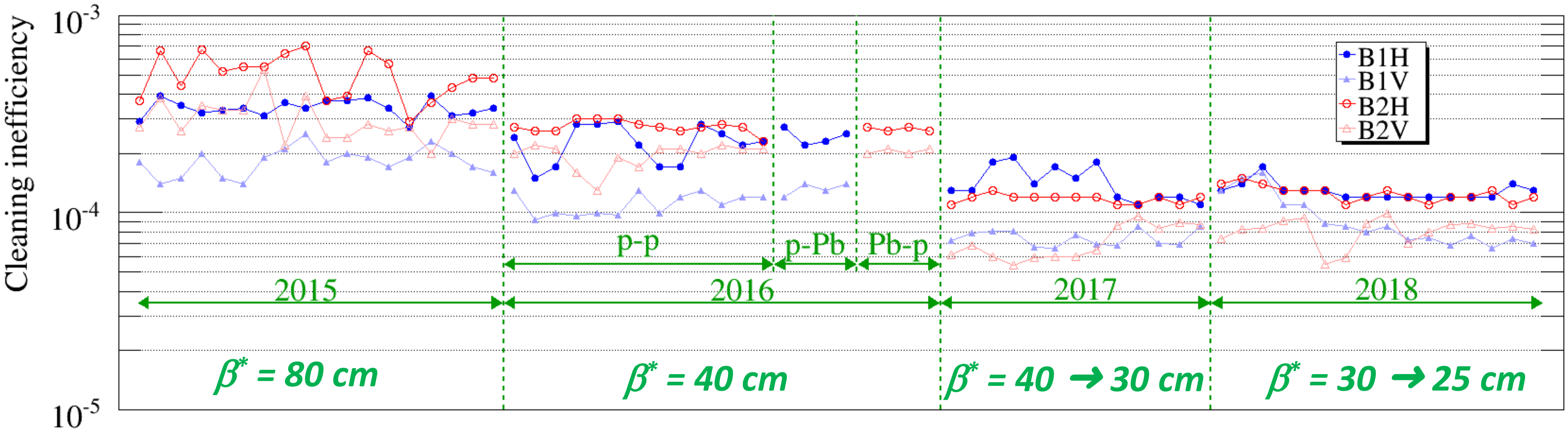
IR7 settings and cleaning evolution

- **Constant evolution** of settings along the years to **push β* reach**

  → Tight connection between protected aperture and IR7 settings

  → ***The smaller the β*, the tighter the IR7 hierarchy***

2015	TCLA = 14 σ	TCSG = 8.0 σ	TCP = 5.5 σ
2016	TCLA = 11 σ	TCSG = 7.5 σ	TCP = 5.5 σ
2017 & 2018	TCLA = 10 σ	TCSG = 6.5 σ	TCP = 5.0 σ



***Clear improvement** with **tighter hierarchy** and **stable performance** along the years*

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Potential concerns

- *Very smooth and safe operations during Run 2*
- **Only three potentially dangerous events involving collimators:**

1. β^* **squeeze** levelling step performed **before end Xing** anti-levelling
   → **Collimators would have not protect the aperture**, beam dump on pos. limits
     → **Redundancy avoided potentially dangerous condition**

2. **MD** with asymmetric **Xing allowed to scan the range ±12-17 μrad** with orchestration tool
   → Scan extended to a range of **±30 μrad without moving collimators**
     → **Safety of the collimators not guaranteed** in case of async. dump

3. **Crystals during high β^* run**

Crystals during high β^* run

- **Highly non-standard collimation schemes with low intensity beams at injection in 2018**

- **Crystal collimation: from a brainstorming** in a meeting **to operations in about 1 month**
  - ✓ Intense **simulation** studies to optimize performance
  - ✓ Preparation of operational **sequences** and **beam process** for OP use

- ***Accidental scenario: crystals left into beam position after last physics fill***
  - → Dumped on injection losses when setting up VdM cycle

- **Main lesson** learnt: highly non-standard operations need **even better preparation/checks**
  - → **Smooth operations of crystal collimation with ion beams in 2018**
    - → Agreed implementation for crystal operations in 2018 was OK if used properly

More details can be found at MPP meeting #117

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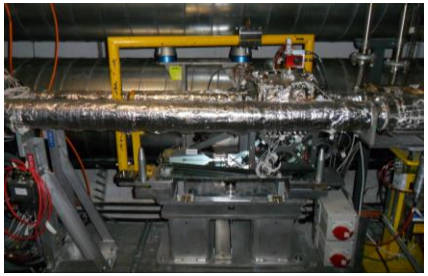
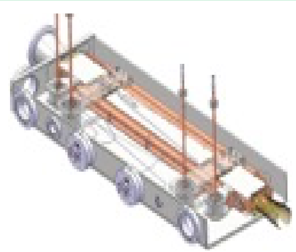
System upgrade & HW changes in LS2

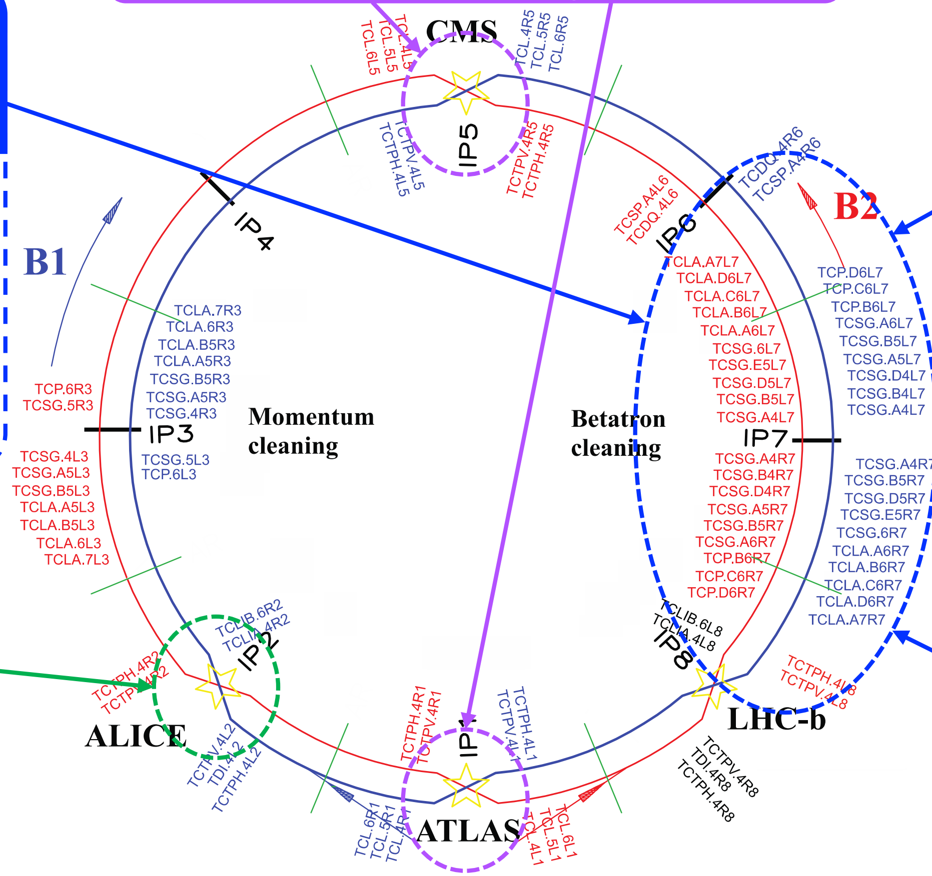
Re-arrangement of TCTs-TCLs with wires for LRBB compensation

Replacement of one goniometer plus crystal assembly

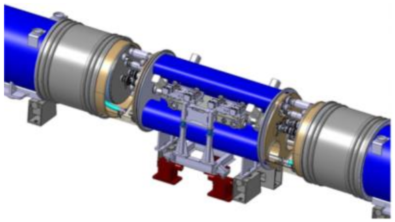


Ion physics debris: DS collimator

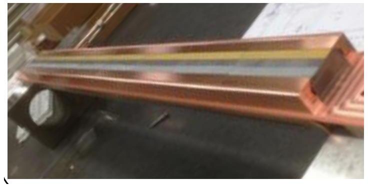




Cleaning perf.: 11 T dipoles + DS coll.



Impedance and robustness: 2 TCPs (MoGr) 4 TCSGs (Mo coated)



16 new collimators, all with BPMs!

Significant hardware upgrade during LS2: **thorough commissioning** and **new logging** required

Operations with new collimators

- **New DS collimators** (TCLD) made of 60 cm long jaws of **W**

  → High absorption power at expense of robustness

  → To be applied all considerations as of present TCTs

- **Important feature of new collimators: BPMs!**

  → **Interlock** on local orbit **desirable**, with **same logic** used for **TCTs in Run2**

  - Robustness of TCLD
  - Avoid grazing impacts on coated secondary collimators

Working hypothesis for operations Run 3

- **Excellent and very stable system performance** along the years
  - **Baseline settings** at restart in **2021**: **same as 2018** for similar β^* reach
    - Final decision once 2021 optics stabilised

- How much are the **losses** going to **increase in Run3?**
  - **Reproducible cleaning** performance as function of IR7 settings expected
  - **Main uncertainty: lifetime** scaling with larger bunch population

- Any impact on performance of **operation at 7 TeV?**
  - **Negligible change in cleaning** between 6.5 TeV and 7 TeV
  - **System designed for operations at 7 TeV**

Analysis automatization for Run 3

- Full analysis of validation loss maps performed by collimation experts during Run 1 & 2

- Possible future development:

→ Automated tool for a first performance evaluation directly by OP

Performance evaluation based on pattern recognition

Automatic storage of loss maps for collimation experts

Brainstorming already started: many ideas, poor manpower

- Possible Run 3 validation flow:

  1. Preliminary validation by OP provided on-line by automated tool
  2. Place holder fills with low intensity to be scheduled while final checks carried out
  3. Final validation by collimation experts looking at pre-analysed loss maps

On-going studies

- **Possible running scenario** at Run 3 restart: **β^* levelling from 1.5 m to 30 cm**

Constraints

- $\Delta\mu$ MKD-TCT < 30˚
- Fixed β at TCDQ

Drawback

- $\Delta\mu$ MKD-TCDQ ~ 115˚ in the range 1.5 m < β^* < 0.8 m

More leakage in case of Asynchronous dump!

✓ **No problems expected for TCTs** due to their settings at those β^*

✓ **Asynchronous dump simulations for impacts on TCSGs-TCLAs** in IR7 on-going

- **Wires in TCTs/TCLs for LRBB** compensation will become **operational in Run 3**:

→ Best strategy for **interlock logic** and **maintenance** is **being addressed**

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Conclusions

- ***Very smooth and safe operations during Run 2***
  - ✓ **No quench** from circulating beam losses with **up to > 300 MJ stored energy!**

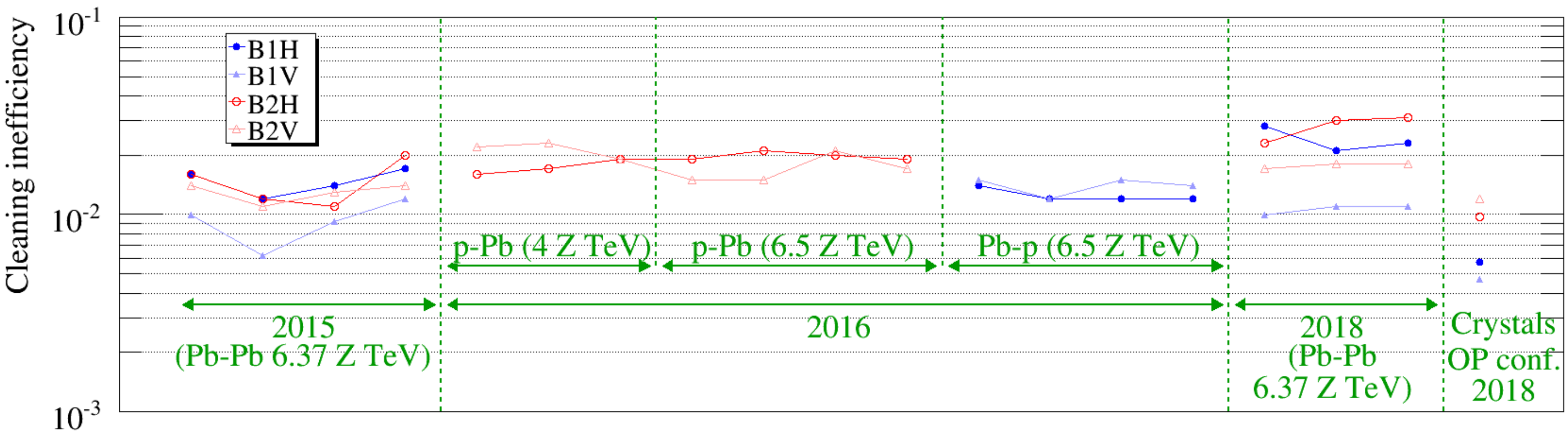
- ***Only 3 potentially dangerous events involving collimators***
  - ✓ Thanks to **redundancy** nothing bad happened
  - ✓ Even better **preparation/check** of non-standard operations

- ***Looking at 2021 – Run 3***
  - ✓ Same **settings as 2018 for similar β^* reach**
  - ✓ **Lifetime** scaling with larger bunch population **main uncertainty for expected losses**
  - ✓ **No problems** to run at **7 TeV**
  - ✓ **Simulation** studies **on-going** to freeze **running scenario**
  - ✓ **Several ideas** on how to **speed-up** performance **validation**, but poor manpower
  - ✓ **New interlock on BPMs** in TCLDs and TCSPMs **desirable**

Thanks for your attention!

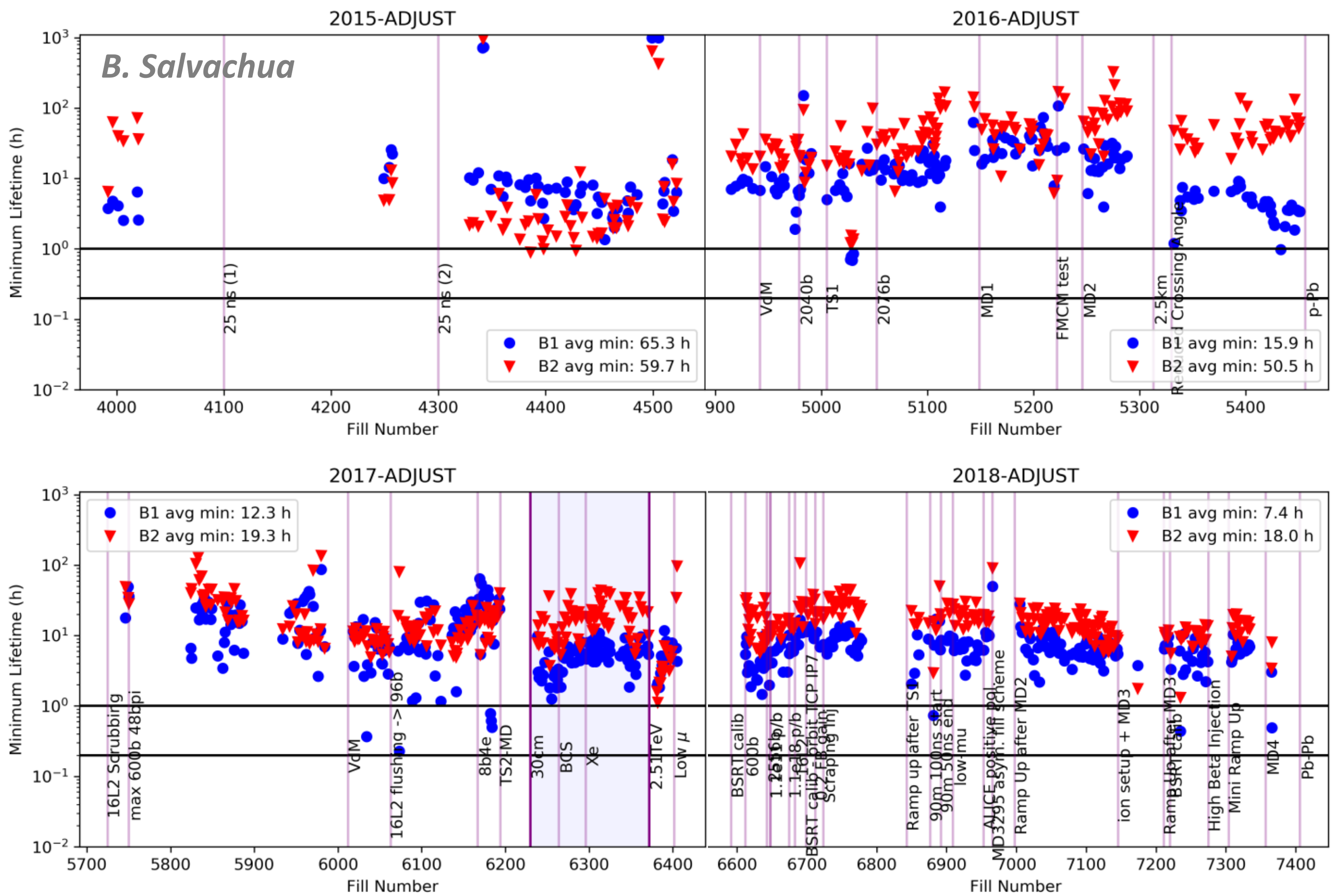
Operations with heavy ions

- **Heavy ions** collimation much more **challenging**
  → **Cleaning very stable** along the years in Run 2, but about **x100 worse than with protons**



- Two possible solutions to **improve cleaning performance in Run 3**:
  → ✓ **TCLD** collimators installed in IR7-DS during LS2 (baseline)
  ✓ **Crystal** collimation (backup)
    → **Smooth operations** with up to **648 Pb bunches** in 2018
    Main change for Run 3: deployment of **limit functions**

Lifetime in Run 2



Issue of injection losses

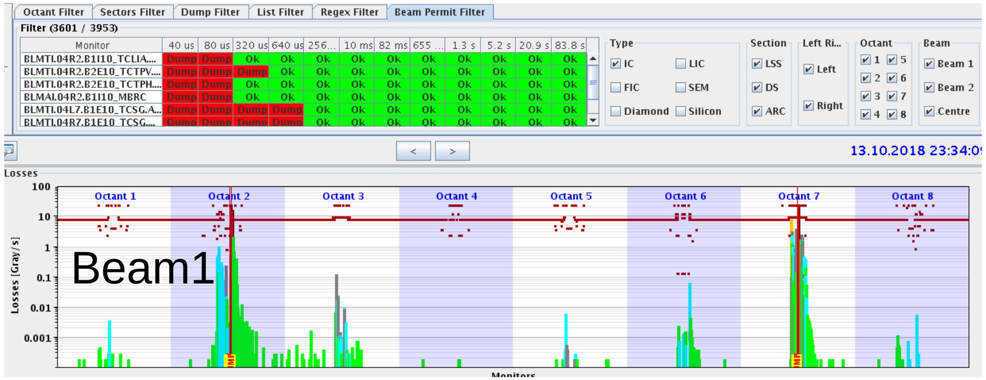
After last fill at high-beta, vertical crystals were left into beam position.

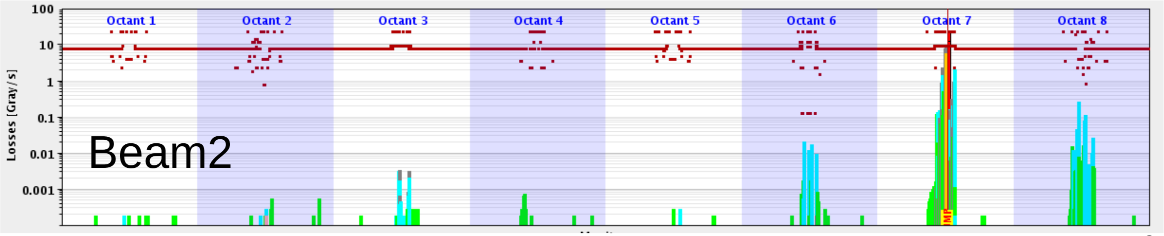
Observed high losses with trains of 8b/12b when setting up VdM cycle.

About 8 dumps before realising this. Dumped on injection losses.

Temporarily increased intensity to check nominal 25ns configuration.

A fraction of the injected beam was channeled and safely intercepted by the standard collimators (correctly driven to nominal positions).





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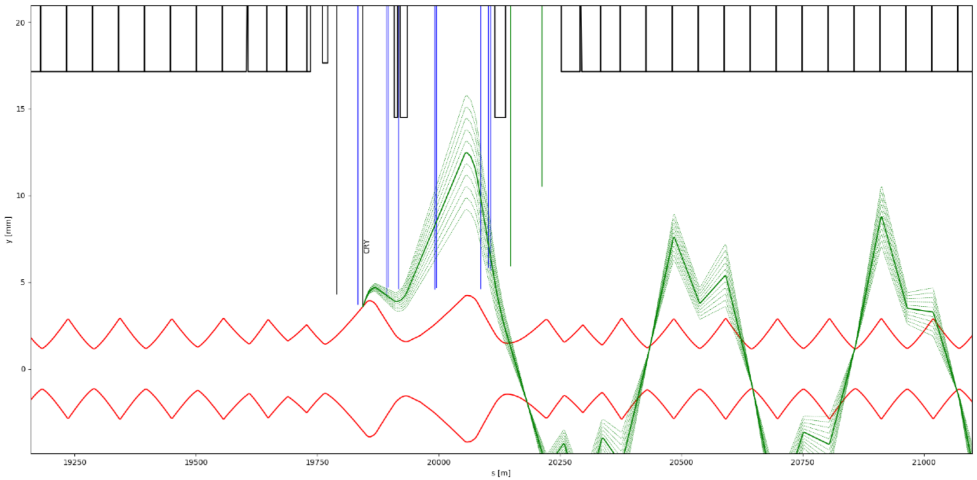
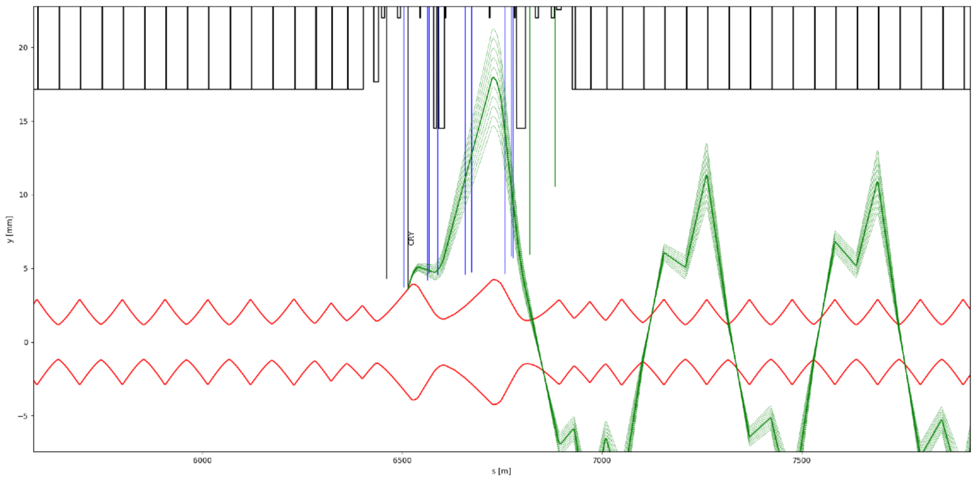
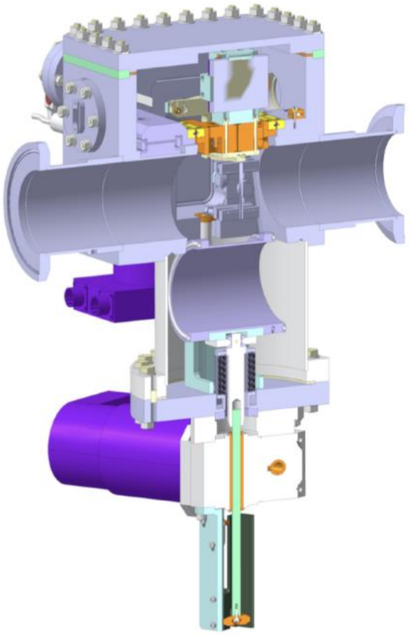

y [mm]
s [m]
CRY
19250
19500
19750
20000
20250
20500
20750
21000


y [mm]
s [m]
CRY
6000
6500
7000
7500

Crystal interlocking

- Key design feature: a replacement "O"-shape chamber moves into the beam to hide the goniometer.
- 2018 operational mode (for high intensity):
  1) Hardware interlock while moving OUT IN
  2) Software interlock prevents injection if IN
     To be masked to inject with crystals seeing the beam: only in MDs and for high-β* run.
  3) Time position limits, like other collimators
     Not used yet operationally, deployed to allow EoF tests with ion beams

  High intensity operation so far relied on 1+2.
- High-beta*
  — Used in "MD mode" [SIS masked]
  — New specific high-beta* sequence for settings crystal positions (in and out) and angles



All infrastructure for interlocking available, but transition from safe to unsafe operations was not properly handled.

Events

- Collimation experts had left before last fill's end, leaving crystals IN for data taking.
  Note that no formal procedures were prepared for this complex and short run. Only oral *consigne* left to the shift crew.
- Events sequence while recovering high-intensity operation:
  1) New specific crystal sequence to take crystals out was not executed
     Crystals remained IN below 3 σ, in channeling orientation
  2) Experts did not check (remotely) explicitly that the sequence was run, as they were not call for any problem/anomaly
  3) Nominal sequence for standard fill played — no error as crystals not part of it
     Re-established injection conditions for the rest of systems
  4) Repeated several injections, suspecting issues with the ADT with new bunch spacing for the VdM, intensity even increased
- Why it was noticed late that crystals were left in
  — Losses with injected single bunches too small to dump, issue visible with trains
  — Injected with SIS mask still active
  — Systematic look al loss patterns at injection around the ring (IQM ?)
  — Inner limits for crystal positions (discrete) not set
- Events after
  1) Thorough check of PM to confirm that only collimators were hit.
  2) Simulation of channeled beam trajectory for injection configuration
  3) Check with beam of crystal hardware to exclude apparent damage
  4) Tightened procedures / sequence (see SR presentation at LMC, Oct. 31st, 2018)

Lessons learnt

- All test devices should have a **recovery task** in the nominal sequence, or at least a check task, to make sure that they are in the desired configuration for nominal fills.
- Non-standard operations need better preparation/checks, and should not rely only on procedures.
- In particular, long operation periods spanning over several shifts should be automatised through sequences.
  - — Even if it costs some overhead to operations. Can we enforce this?
- Additional (personal) thoughts
  - — How can we resist the pressure to do everything?
  - — Can we maintain in the logbook a list of critical masks/problems/recovery procedures?
  - — Is it possible to have more sophisticated loss checks in the IQM?
- Smooth operation with ion beams with crystals properly handled by the sequencer: clearly the agreed implementation for 2018 was OK if used properly

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