Intensity Ramp-Up 2024

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Outline

- **Introduction and ramp-up strategy**
- **Intensity ramp-up(s) in 2023**
- **Proposal for 2024 proton intensity ramp-up**
  - Reminder: ramp-up scenarios after stops of nominal operation
- **Conclusions**

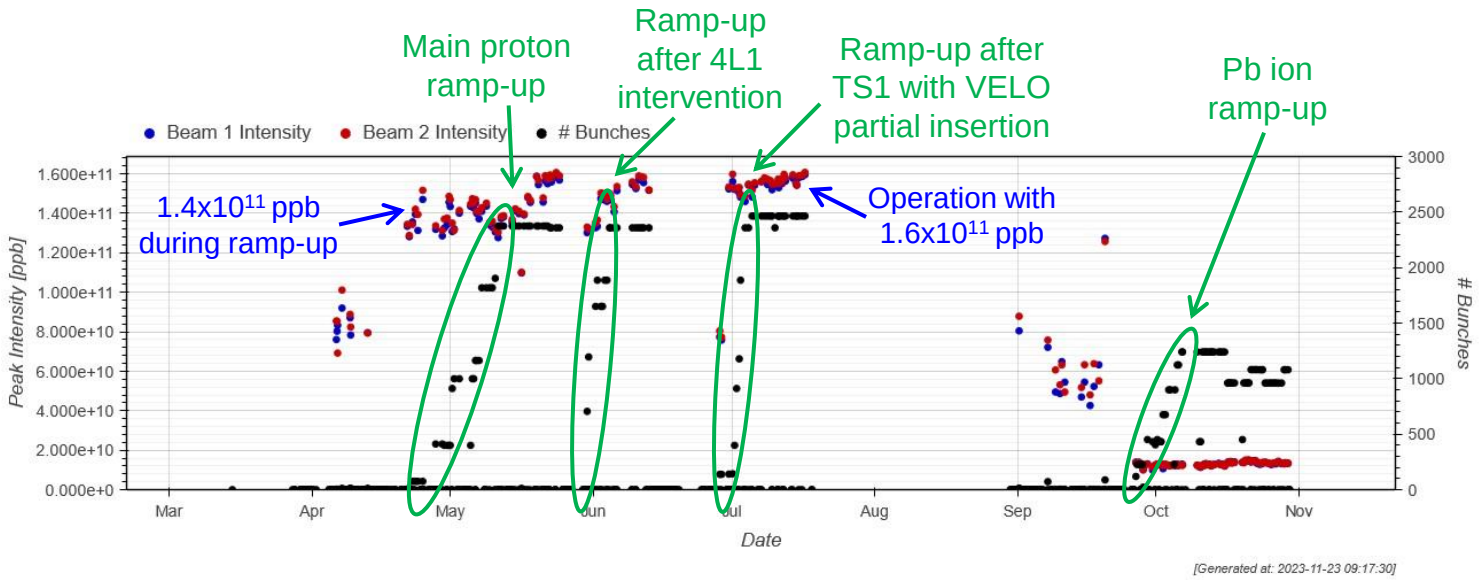
Introduction and general strategy

- **Intensity ramp-up is based on step-wise increase of injected and stored beam energy after YETS/LS to:**
  - establish operational cycle
  - identify and mitigate issues in machine-protection-relevant systems that are remaining after individual system tests and hardware and beam commissioning with as low as possible stored beam energy
  - identify issues related to stored beam intensity and other beam related parameters and establish mitigation measures
- **Monitor behavior and validate correct functioning of machine-protection system using checklist before advancing to the next intensity step**
  - Centralising and formalising the check process reduces the risk to overlook a check task and provides a common holding point, where the state of all systems is evaluated simultaneously, allowing for an efficient decision taking on the readiness to advance to the next intensity step

For more details see LMC, 9.11.2022, 217th MPP and 10th “Evian” workshop

Intensity ramp-up(s) 2023: overview

- **Intensity ramp-ups 2023**
  - Main proton ramp-up performed in April/May 2023
  - Additional ramp-ups required after 4L1 intervention, after TS1 with VELO partial insertion, and for Pb ion operation
- **Bunch intensity**
  - Kept around 1.3-1.4x10^{11} ppb during ramp-up
  - Then slowly ramped up to 1.6x10^{11} ppb
  - Reached record stored energy of ~430 MJ per beam
- **No beam-loss induced damage occurred in 2023**
  - However, bunch intensity limited to 1.6x10^{11} ppb after 4L1 event



Machine-protection checklists 2023

- 17 checklists issued in 2023 (compared to 11 in 2022)
- Important tool to analyse and document correct functionality and performance of machine protection critical systems
- Includes ~100 check tasks for nine relevant systems
- Great *thank you* to all the system experts for their commitment, dedication and flexibility!

Pb ion operation

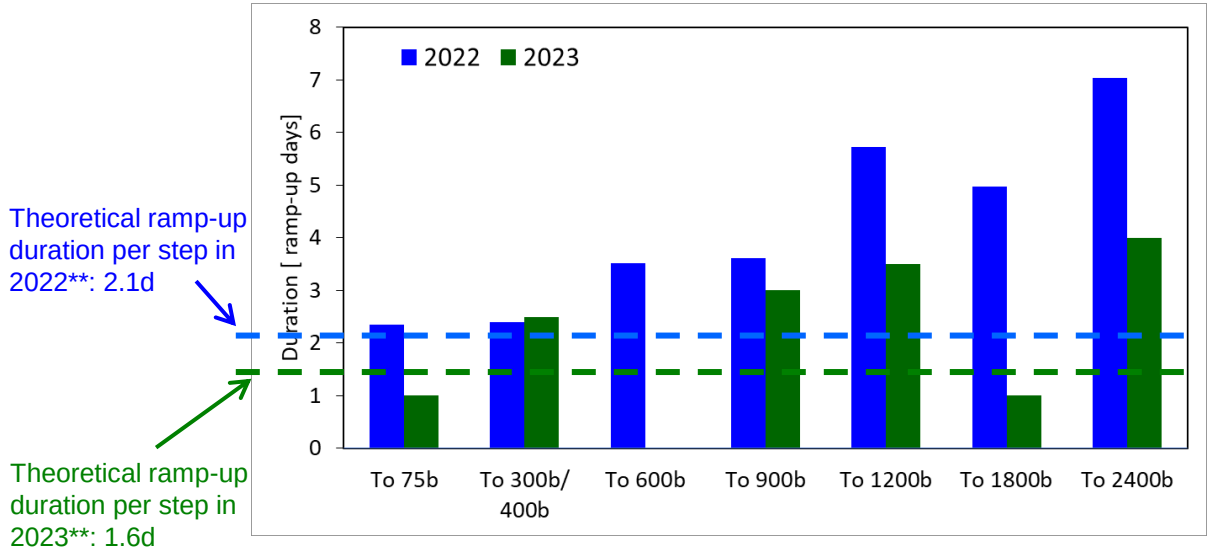
Checklist type	Intensity step	Checklist (EDMS)
Intensity ramp-up	From 80b to 250b	#2956830
	From 250b to 450b	
	From 450b to 850b	
Cruise Oct. I	Intensity cruise	#2975964
Cruise Oct. II	Intensity cruise	#2975967

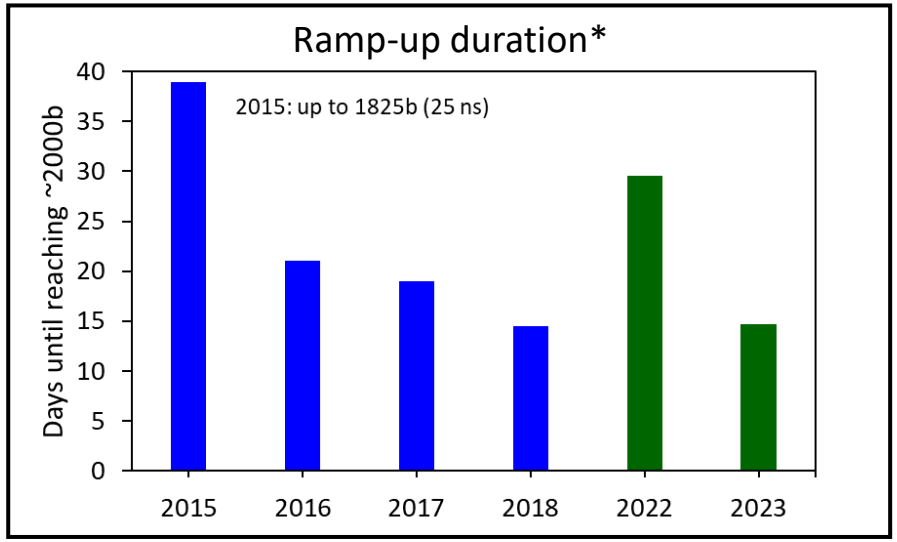
Proton operation

Checklist type	Intensity step	Checklist (EDMS)
Intensity ramp-up	From 3/12b to 75b	#2887282
	From 75b to 400b	
	From 400b to 900b	#2888331
	From 900b to 1200b	#2891262
	From 1200b to 1800b	#2892600
	From 1800b to 2400b	#2893111
Scrubbing	Beyond 500 bunches	#2887415
	End of scrubbing	#2933511
Bunch intensity	Beyond 1.6×10^{11} ppb	#2897728
Cruise May/June	Intensity cruise	#2933512
Ramp-up after TS1 (dedicated checklists for VELO partial insertion)	From 75b to 400b	#2911909
	From 400b to 900b	
	From 900b to 1200b	#2911910
	From 1200b to 1800b	#2911912
	From 1800b to 2400b	#2911913
Cruise June/July	Intensity cruise	#2975994

Ramp-up duration 2023

- ***Ramp-up time***
  - Reached 1200b in 10 ramp-up days*
    - Compared to 18 ramp-up days* in 2022
  - Reached full machine in ~15 ramp-up days*
    - Compared to ~30 ramp-up days* in 2022
  - Average duration per step decreased from 4.2d (2022) to 2.5d (2023)
- **Required time in SB for each intensity step**
  - In 2023, performed ≥ 2 fills with ≥15h in SB (going through the full luminosity levelling process)
    - Compared to ≥ 3 fills with ≥20h in SB for previous ramp-ups
  - Propose to keep this approach for 2024
  - De-facto duration of steps largely influenced by machine status and encountered issues



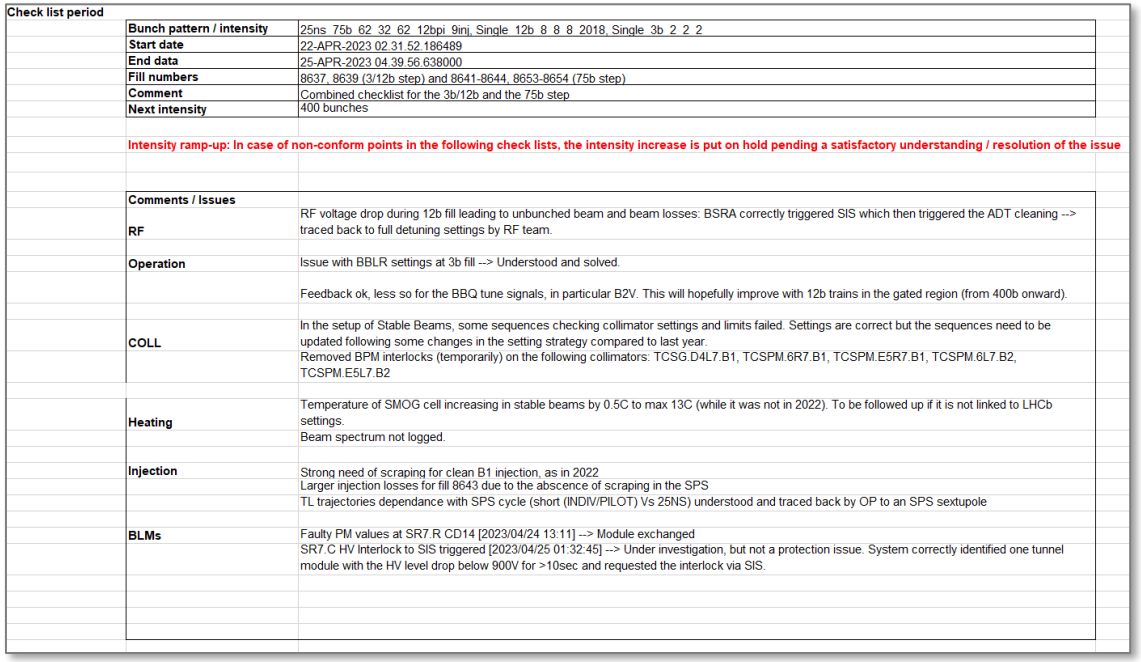


Excludes time for scrubbing, commissioning left-overs, crossing-angle change (2023), long faults

***Assuming 60% availability, 3h turn-around time, and 10h to fill and validate the checklist*

Intensity ramp-up 2023: Observations

- **Important number of issues found and followed up**
- **Issues distributed over all intensity steps, e.g.:**
  - RF voltage drop leading to unbunched beam and beam losses → solved by adjusting RF settings (12b)
  - High injection losses → limited injection to 144 bpi for B1→ realignment of transfer line collimator (scrubbing, 500b)
  - BTVDD image saturated → followed up by BI (400b)
  - Higher leakage from collimation losses in Beam 1 → retraction of TCSPM.E5R7.B1 to 8.2 sigma and revalidation (900b)
  - BPM calibration for trains not correctly applied (not new…) → SIS interlock implemented (1800b)



Check list period	
Bunch pattern / intensity	25ns_75b_62_32_62_12bpi_9inj, Single_12b_8_8_8_2018, Single_3b_2_2_2
Start date	22-APR-2023 02.31.52.186489
End data	25-APR-2023 04.39.56.638000
Fill numbers	8637, 8639 (3/12b step) and 8641-8644, 8653-8654 (75b step)
Comment	Combined checklist for the 3b/12b and the 75b step
Next intensity	400 bunches

Intensity ramp-up: In case of non-conform points in the following check lists, the intensity increase is put on hold pending a satisfactory understanding / resolution of the issue

Comments / Issues	
RF	RF voltage drop during 12b fill leading to unbunched beam and beam losses: BSRA correctly triggered SIS which then triggered the ADT cleaning --> traced back to full detuning settings by RF team.
Operation	Issue with BBLR settings at 3b fill --> Understood and solved. Feedback ok, less so for the BBQ tune signals, in particular B2V. This will hopefully improve with 12b trains in the gated region (from 400b onward).
COLL	In the setup of Stable Beams, some sequences checking collimator settings and limits failed. Settings are correct but the sequences need to be updated following some changes in the setting strategy compared to last year. Removed BPM interlocks (temporarily) on the following collimators: TCSG.D4L7.B1, TCSPM.6R7.B1, TCSPM.E5R7.B1, TCSPM.6L7.B2, TCSPM.E5L7.B2
Heating	Temperature of SMOG cell increasing in stable beams by 0.5C to max 13C (while it was not in 2022). To be followed up if it is not linked to LHCb settings. Beam spectrum not logged.
Injection	Strong need of scraping for clean B1 injection, as in 2022 Larger injection losses for fill 8643 due to the abscence of scraping in the SPS TL trajectories dependance with SPS cycle (short (INDIV/PILOT) Vs 25NS) understood and traced back by OP to an SPS sextupole
BLMs	Faulty PM values at SR7.R CD14 [2023/04/24 13:11] --> Module exchanged SR7.C HV Interlock to SIS triggered [2023/04/25 01:32:45] --> Under investigation, but not a protection issue. System correctly identified one tunnel module with the HV level drop below 900V for >10sec and requested the interlock via SIS.

Example: combined checklist for the 3b/12b and 75b steps

Proposal for 2024 intensity ramp-up (1/2)

- **Continue successful strategy applied during Run 2 and in 2022/23**
- **Intensity steps:**
  - Use steps of 3/12 - 75 - 400 - **800** - 1200 - 1800 - 2400 - full machine* (≥2 fills with ≥15h in SB)
  - Compared to 3/12 - 75 - 400 - 900 - 1200 - 1800 - 2400 bunches in 2023 (≥2 fills with ≥15h in SB)
  - Compared to 3/12 - 75 - 300 - 600 - 900 - 1200 - 1800 - 2400 bunches in 2022 (≥3 fills with ≥20h in SB)
- **For each step:**
  - Monitor behavior during >15h in stable beams with at least 2 fills that go through the full luminosity levelling process (reaching the smallest beta*) using the operational tool
  - Validate correct functioning of machine-protection systems via checklist
    - Before going from 12 to 75 bunches: verbal verification with all concerned teams and combined checklist for 3/12/75b fills after the 75b step
  - CT-PPS, AFP roman pots to be inserted to agreed settings before the first levelling step for all fills at each intensity step
  - VELO to be moved to its nominal position during ramp-up steps
    - Dedicated check tasks to be included in the ramp-up checklist
  - No simultaneous increase in the total number of bunches and the injected train length in the same fill

**exact number of bunches depends on agreed filling schemes*

Proposal for 2024 intensity ramp-up (2/2)

- **Bunch intensity**
  - Perform ramp-up with bunch intensities established in 2023 (1.6e11 ppb)
  - Bunch intensity will be limited to 1.6e11 ppb in 2024
- **Scrubbing:**
  - Verify heating of critical elements before going to next intensity step
  - Intermediate scrubbing checklist after ~500 bunches
  - Final checklist at the end of scrubbing to be integrated into the first proton cruise checklist
- **During the Run**
  - Issue Cruise Checklists covering ~8 weeks (e.g. between TS) to check behaviour of machine-protection systems

Update of checklist tasks

- **New check tasks:**
  - Dedicated tasks for VELO
  - “No unexplained beam dumps and no unexpected behaviour from the BCCM”
  - Bunch length evolution?
- **For all system responsibles: Please contact us in case of any proposed changes of the check tasks and/or a change of responsibility**

System	Responsible persons
Magnet powering (MP3)	Arjan Verweij, Zinur Charifoulline
Interlocks	Ivan Romera Ramirez, Jan Uythoven
RF	Wolfgang Hofle, Andy Butterworth
Beam Instrumentation	Belen Salvachua Ferrando, Christos Zamantzas, Stefano Mazzoni
Collimation	Stefano Redaelli, Roderik Bruce, Frederik Van Der Veken, Björn Lindström
Operation, orbit and feedbacks	Jörg Wenninger, Matteo Solfaroli Camillocci
Beam dump	Yann Dutheil, Chiara Bracco
Injection	Yann Dutheil, Chiara Bracco
Heating of Equipment	Benoit Salvant

Reminder: Ramp-up scenarios after stops of nominal operation

Stop >48 h with massive HW + SW interventions	Stop >48 h without massive HW + SW interventions	Triplet events with non-reversible position changes**
One fill with either pilot bunches or max. 2-3 nominal bunches into SB (cycle revalidation, etc.)	One fill with 2-3 nominal bunches into SB (cycle revalidation, etc.)	One fill with 2-3 nominal bunches into SB (re-adjust orbit in IP)
One fill with ~50 bunches and about 1-2 hours of stable beams		
One fill with 400 bunches and min. 2 hours of stable beams*	One fill with 400 bunches and min. 2 hours of stable beams*	
If > 2000 bunches have been reached, one fill with about half max. number of bunches and about 5 hours of stable beams		
Back to pre-stop intensities	Back to pre-stop intensities	Back to pre-stop intensity
In total, 3-4 fills for ramp-up	**In total, 2 fills for ramp-up**	**In total, 1 fill for ramp-up**

Note: All fills need to go through the full luminosity levelling.

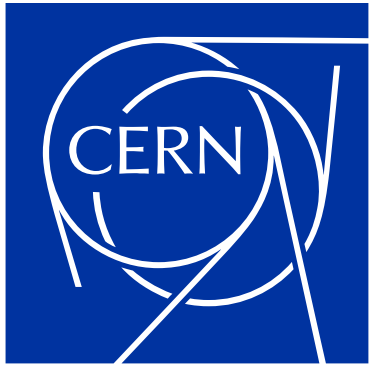
*known intensity step to disentangle wrong settings, de-conditioning, etc. from intensity dominated effects at full intensity

**E.g. triplet quench, warm up of triplet region, cryo stop in triplet region, …

LMC #460, 2023-04-05

Conclusions

- **Intensity ramp-up 2023 accomplished in a safe and efficient manner**
  - Reached 1200b in 10 ramp-up days
  - Reached 2400b in 15 ramp-up days
  - No beam-loss induced damage occurred
  - Important number of issues identified and tackled at the different intensity steps
- **Proposal for 2024 intensity ramp-up**
  - Based on the existing successful strategy
  - Includes:
    - Bunch steps of 3/12 - 75 - 400 - 800 - 1200 - 1800 - 2400 – full machine
    - For each step: ≥15h in Stable Beams with ≥2 fills that go through the full luminosity levelling, to be validated with checklist
    - Perform ramp-up with bunch intensity of 1.6×10^{11} ppb
  - Considers the operational scenario, the maturity of the systems and the balance between machine efficiency and risks



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Issues encountered during 2022 intensity ramp-up

- Examples:
  - Unexpected high beam losses at TDIS*
  - Unexpected high beam losses at TCLIA**
  - Issue with creation of PM event causing XPOC to latch
  - Sporadic missing of BLM data in XPOC and PM
  - Intermittently missing BBQ data in PM event
  - BLMLHC FESA server exiting due to low memory
  - Need to adapt BLM thresholds
  - Miscalibration of BSRA B2 by factor 4
- Intermittent issues with BQM and FBCT that prevented IQC from confirming that an injection took place
- One MKI2 main switch showing higher erratic rate
- Dumps on TCLIA temperature probe leading to threshold adaption
- LVDT reading of TCTPV.4R1.B2 drifting and reaching the dump limit
- Difficulties in using the QFB due to working point with high Q' and octupoles

*See D. Wollmann, LMC,#450, 12.10.2022
** See C. Bracco, LBOC #142, 1.11.2022

See checklists for details

Note that the 2022 ramp-up could profit from issues found and solved during the beam test in Oct 2021, in particular the aperture restriction in 21L3.

Issues discovered during ramp-ups (Run 2) - Selection

- **Establish cycle/beam commissioning:**
  - PM/XPOC: data missing or misaligned
  - BIS timing mis-aligned
  - Direct dump BLMs (IR6) – connected to LBDS of wrong beam
- **MP dominated:**
  - Orbit feedback: offsets due to BPM calibrations
  - UFO – 16L2 events causing beam dumps & quenches
  - Abort Gap cleaning not properly functioning
  - Screen unintentionally left in dumpline
- **Intensity dominated:**
  - TDI – vacuum issues and heating
  - Insufficient cooling of a collimator
  - Instabilities
- **Random occurrence:**
  - MKD and MKB erratics
  - Un-physical BLM readings in PM
  - PM event builder stuck

For full list: see D. Wollmann, Evian'19 and checklists for intensity ramp-up