Updating automatic RF triple splitting optimizations in the PS

Injector performance Panel MD days 2025

Presenter: Joel Wulff

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Acknowledgements:
A. Lasheen, A. Beeckman
G. Trad, H. Pahl, M. Schenk,
PS Operators and coordinators

Introduction

Main activites

- Updating the CNN + RL based **optimization of RF triple splittings in the PS** for autonomous operation
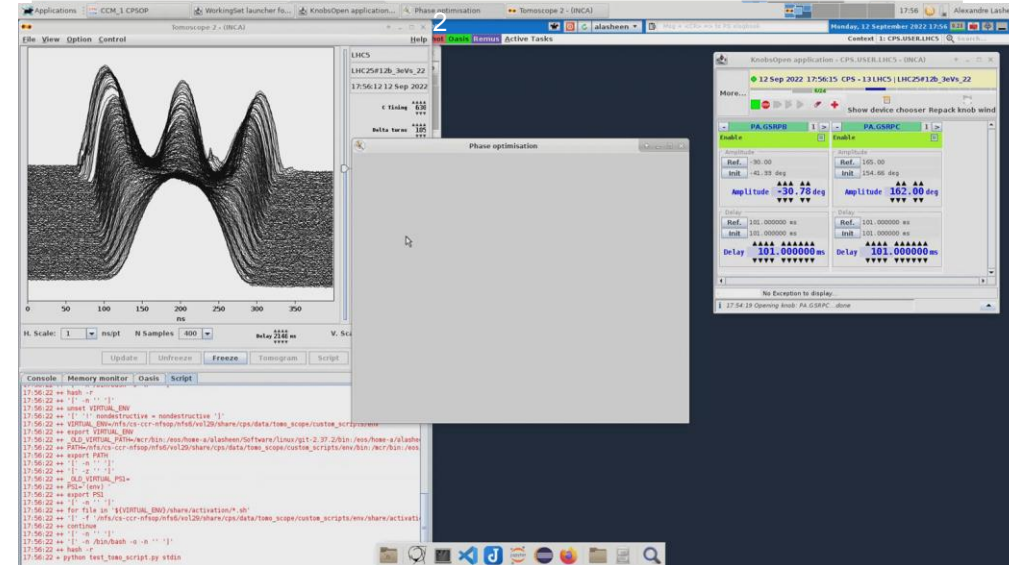- Continued on work from 2022/23: IPP MD days 2023

Motivation

1. **Solution from 2023 very limited:**
   a. Script launched from tomoscope application: codimd
   b. Useful for MDs, but inflexible. Several key issues,

User instructions for running Automatic Splitting Optimization scripts

Step 1: Open the Tomoscope Next app

- Make sure you have opened CCM on the USER of your beam.
- You will find the tomoscope Next app on CCM under Test/Tomoscope Next (see in gif).

Introduction

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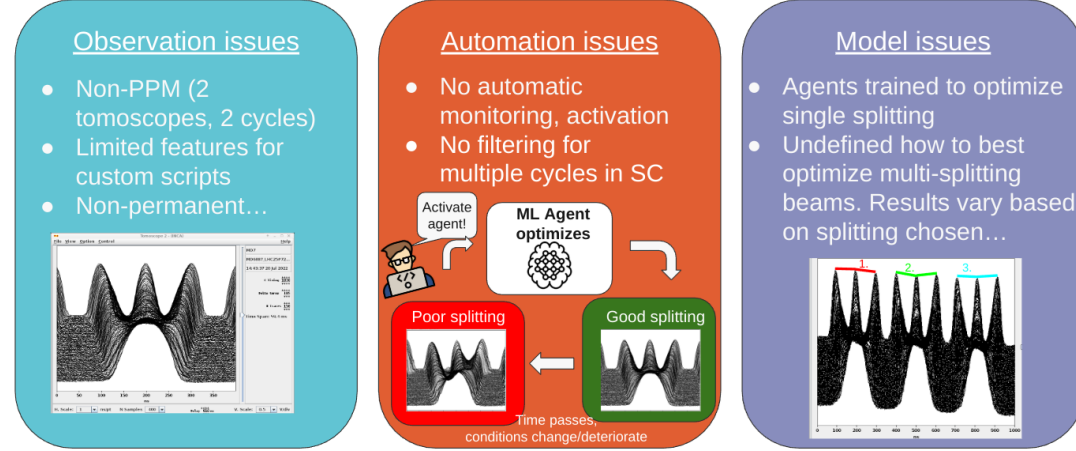## Motivation

1. **Solution from 2023 very limited:**
   a. Script launched from tomoscope application: codimd
   b. Useful for MDs, but inflexible. Several key issues,

   - Non-permanent, non-ppm observations
   - No automatic triggering, monitoring
   - Inconsistent performance for high transient beam loading regimes, e.g. 36b BCMS.

Solving these issues **necessary** for automated splitting optimizations
→ **Needed for automated LHC fillings (EPA WP2)**
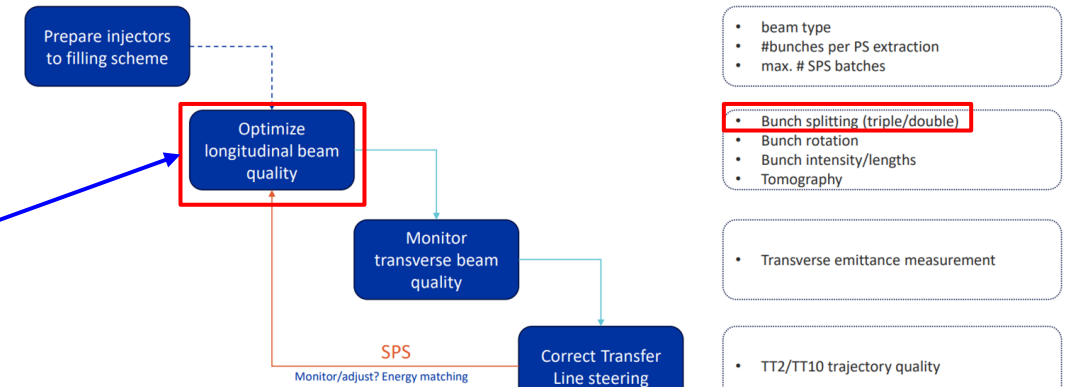
Blockers for automatic triple splitting adjustments:

Observation issues	Automation issues	Model issues
• Non-PPM (2 tomoscopes, 2 cycles) • Limited features for custom scripts • Non-permanent…	• No automatic monitoring, activation • No filtering for multiple cycles in SC	• Agents trained to optimize single splitting • Undefined how to best optimize multi-splitting beams. Results vary based on splitting chosen…

In 2024, do we have solutions for these? Yes!

PS MPC #157, Triple splitting on LHC type beam, J. Wulff

Automated LHC Filling PS

- beam type
- #bunches per PS extraction
- max. # SPS batches
- Bunch splitting (triple/double)
- Bunch rotation
- Bunch intensity/lengths
- Tomography
- Transverse emittance measurement
- TT2/TT10 trajectory quality

Dynamic beam scheduling and automated LHC filling, A. Beeckman, JAPW2024

# Main 2024 developments

More info in talk from A. Beeckman, PS Co. Meeting #144

❖ **Observation:**
➢ Migration from tomoscope → BCWLBO
  ■ PPM, Permanent
❖ **Automation:**
➢ UCAP + LSA implementation replacing script
➢ Automatically monitor, activate optimization, PPM

❖ **Performance:**
➢ Optimize the average splitting rather than splitting of interest
➢ Updated optimization criterion

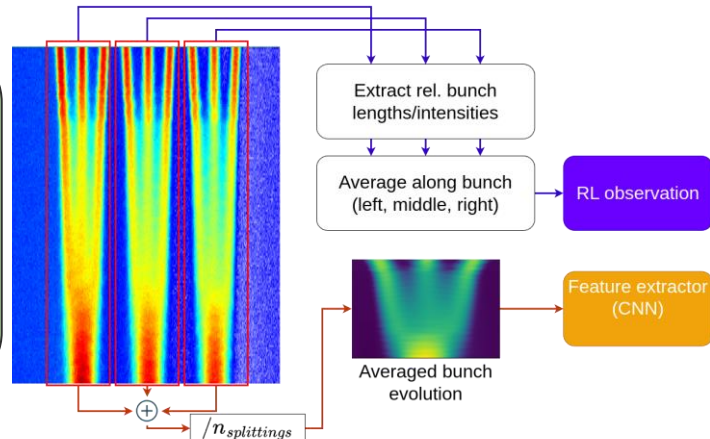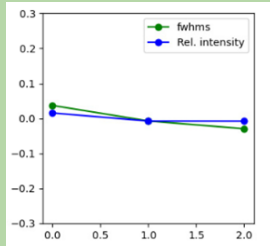*Observation per USER*
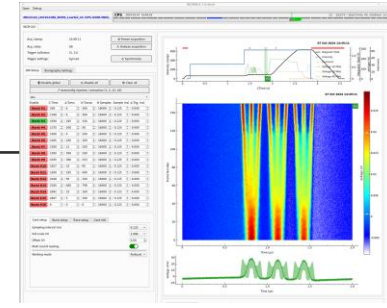
Act on cavities

RF Cavities

LSA

Check if enabled and above criterion

$$Loss_{rel.bl,bi} = \left(\frac{|bi_1|+|bi_2|+|bi_3|}{3} + \frac{|bl_1|+|bl_2|+|bl_3|}{3} \right)/2$$

Extracted features → **less sensitive** to alignment **More interpretable**!

Extract rel. bunch lengths/intensities

Average along bunch (left, middle, right)

RL observation

Averaged bunch evolution

Feature extractor (CNN)

$/n_{splittings}$

Transpose table				0	Add delta		Table/Function
PARAMETER				MD13143_LHC25#48b_BCMS_LowTail_24$PSRING_3BP$BP0			
CPS.RF.SPLITTING.SETTINGS/TripleSplittingControl#enabled				☑			
CPS.RF.SPLITTING.SETTINGS/TripleSplittingThresholds#phaseCriterion				0.038			
CPS.RF.SPLITTING.SETTINGS/TripleSplittingThresholds#voltageCriterion				0.018			

LSA settings (PPM)

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2024 MD purpose and experience

Goals and purpose

❖ **Test and aid in development of new software implementations**
  ➢ UCAP + LSA setup
❖ **Check performance on 36b BCMS**
  ➢ Did averaging/updated criterion improve it?

Availability and support

❖ Good availability, **many successful MDs!**
  ➢ Only a few lost hours due to LHC filling and LHC ION beams
  ➢ **Very good support from PSOP**
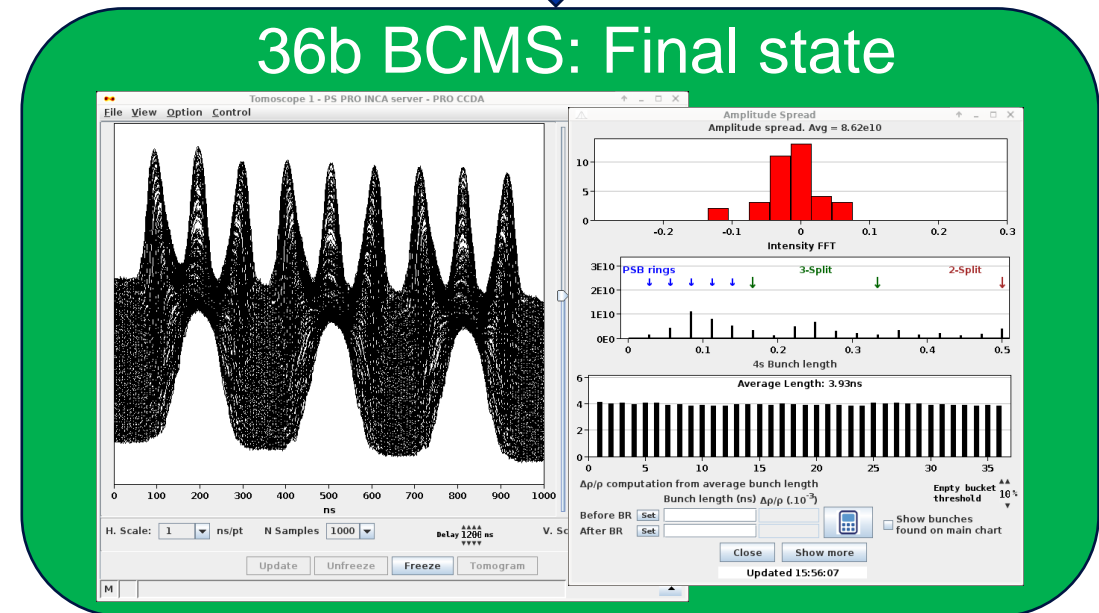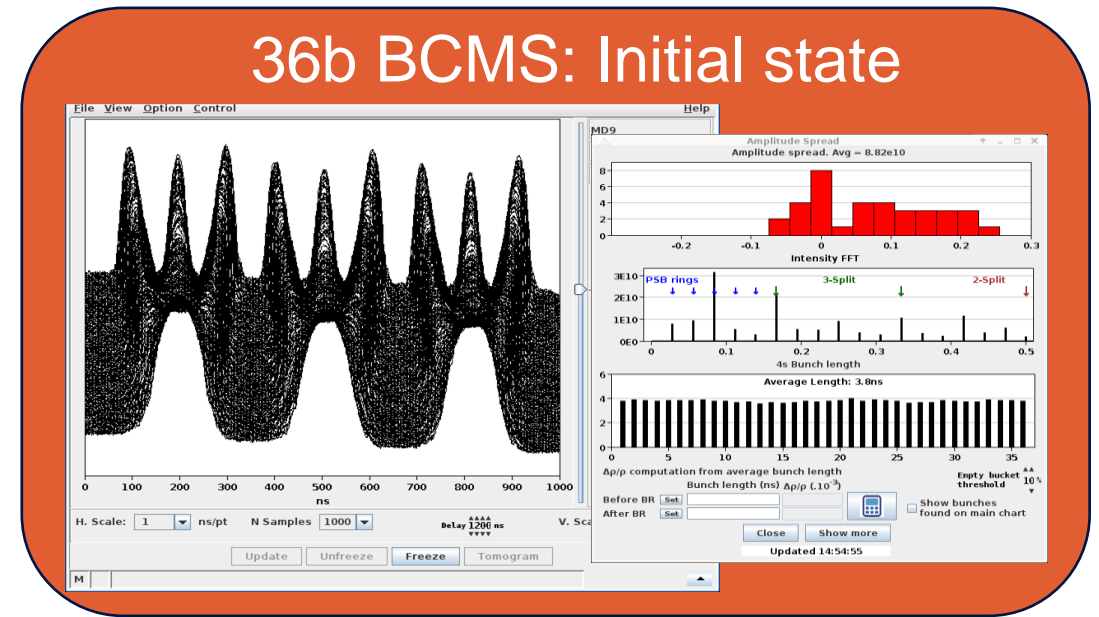
MD results and takeaway

36b BCMS:

❖ 6/6 test runs on operational beam successful (varying initial conditions).
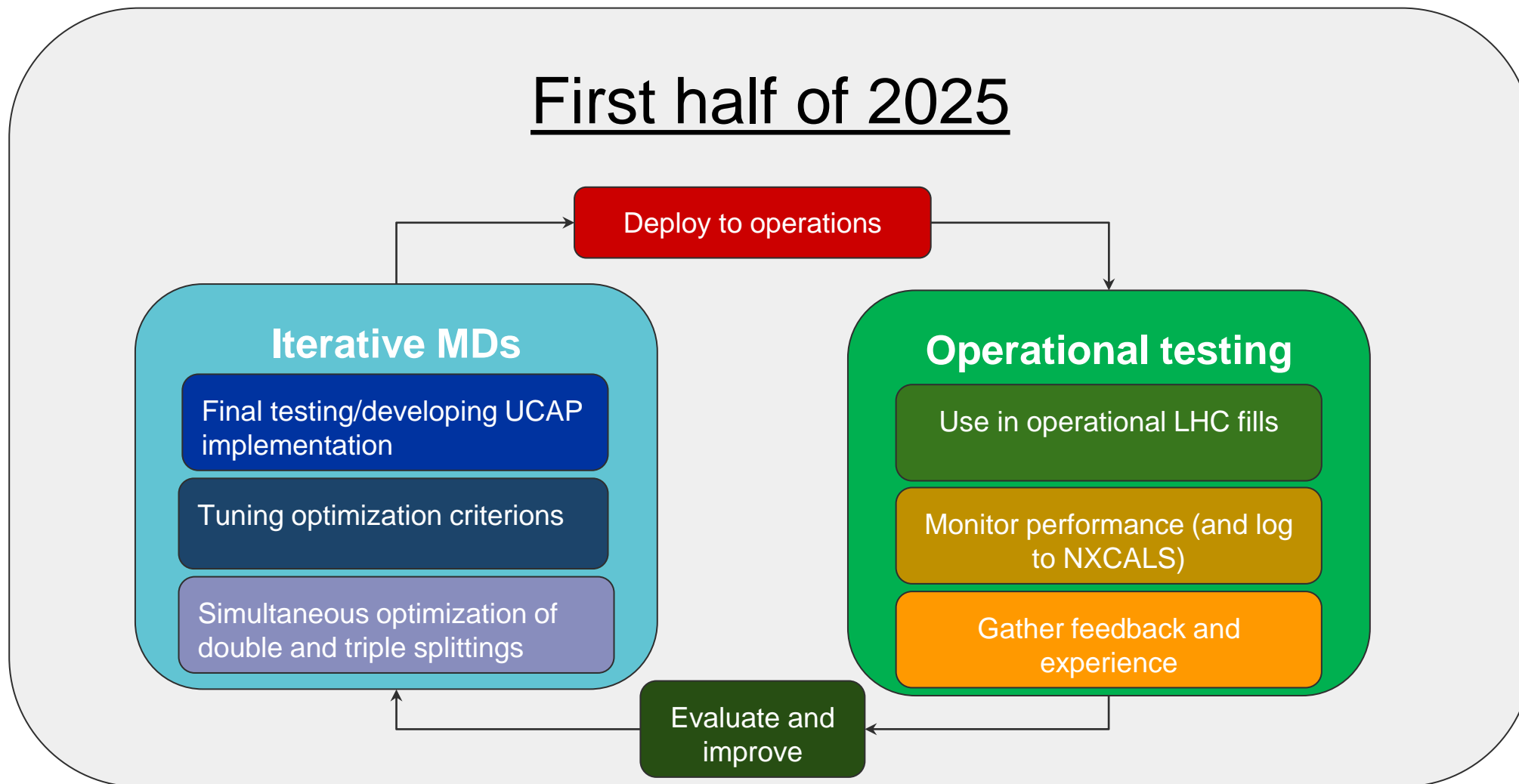 ➢ Logbook entry

72b Nominal (HL-LHC intensity):

❖ 11 episodes run, all successful.
  ➢ Logbook example

Main takeaways

❖ Current implementation shows promise
❖ Main blockers from 2023 solved
❖ Well poised for operational testing in 2025!

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36b BCMS: Initial state

36b BCMS: Final state

Looking forward in 2025: Operational testing

First half of 2025

Deploy to operations

Iterative MDs
- Final testing/developing UCAP implementation
- Tuning optimization criterions
- Simultaneous optimization of double and triple splittings

Operational testing
- Use in operational LHC fills
- Monitor performance (and log to NXCALS)
- Gather feedback and experience

Evaluate and improve

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Thank you for listening! Questions?

Links and contact information

Additional information available in:

- [Triple splitting on LHC type beam, J. Wulff, PS Coordination Meeting #157, 2024](#)

- [Reinforcement Learning applied to RF manipulation optimization in the PS. J. Wulff, 2023 RF Seminar](#)

- [Reinforcement Learning Applied to Optimization of LHC Beams in the CERN Proton Synchrotron, J. Wulff, 3rd ICFA Beam Dynamics Mini-Workshop on Machine Learning Applications for Particle Accelerators](#)

- [Progress with RL for controlling RF manipulations in the PS, J. Wulff, 2022 ML community forum](#)

- [Reinforcement learning applied for RF manipulations in the PS, J. Wulff, 2021 ML Coffee](#)

Contact information

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Example performance: MD results for 36b BCMS

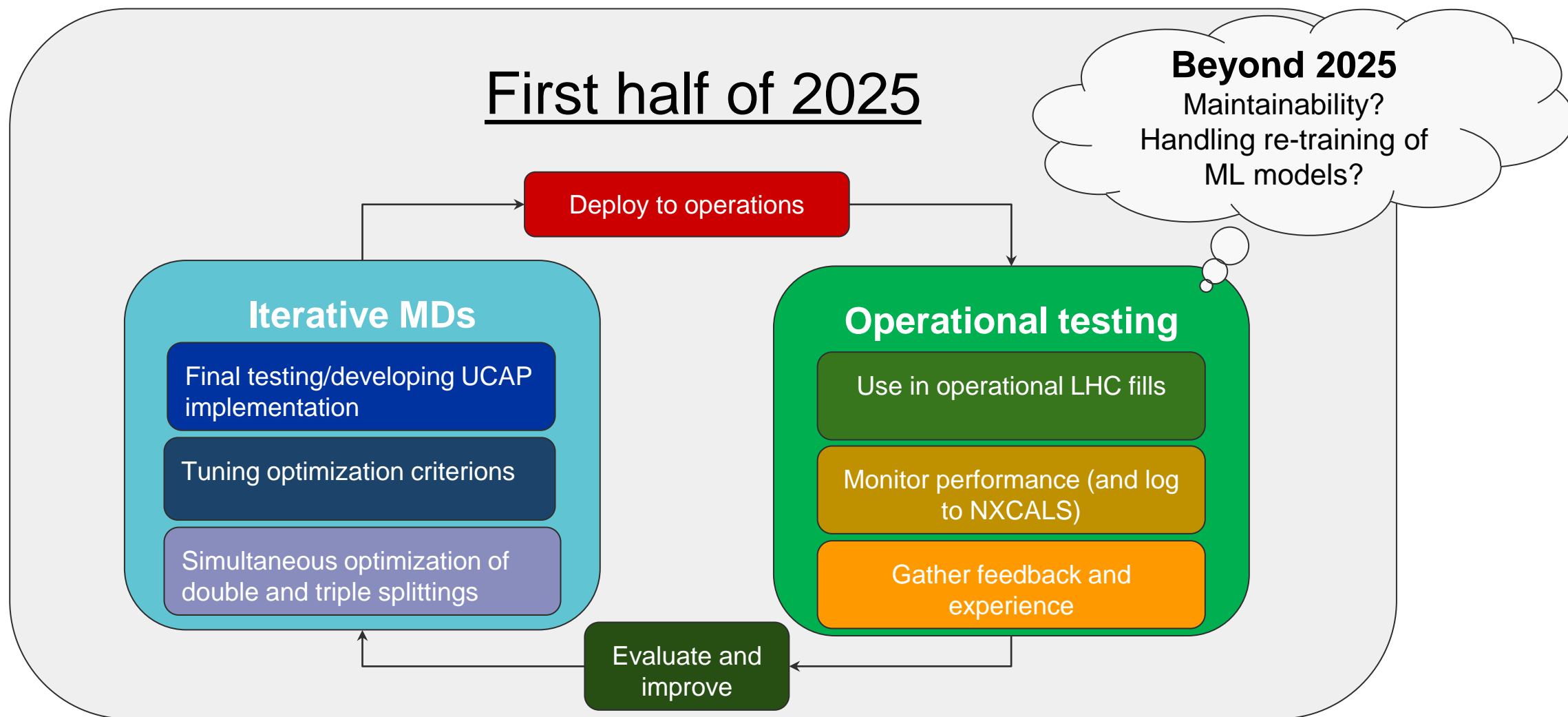Final bunch-by-bunch parameters differ depending on which splitting is observed:

- First splitting often ~±5% intensity spread
- Splitting 2 and 3 intensity/length spread < ±2 %

Is it good enough? Needs operational testing to truly determine… but probably.

Episode	First splitting		Splitting 2 and 3			
	Rel. BI spread	Rel. BL spread	Rel. BI spread	Rel. BL spread	Phase opt. steps	Volt. opt. steps
1.	± 5%	± 3%	± < 3%	± < 3%	14	2
2.	± 3%	± < 2%	± < 2%	± < 2%	14	2
3.	± < 2%	± < 2%	± < 2%	± < 2%	11	7
4.	± 6%	± 4%	± < 2%	± < 2%	1	16
5.	± 5%	± 3%	± < 2%	± < 2%	22	3
6.	± 5%	± 2%	± < 2%	± < 2%	5	5

Note: Spread estimations based on plots from logbook, since raw data was not saved during this MD

Looking forward in 2025: Operational testing