Dynamic beam scheduling and automated LHC filling

Status of the EPA WPs

Amaury Beeckman with input from A. Huschauer, A. Lasheen, M. Schenk, V. Kain, G. Trad, H. Pahl, M. Jaussi, D. Lampridis, M. Cejp, Z. Ansari, D. Cotte, G. Papotti, T. Argyropoulos, S. Albright, F. Irannejad, J. Wulff, R. Maillet and many others…

11th December 2024

Outline

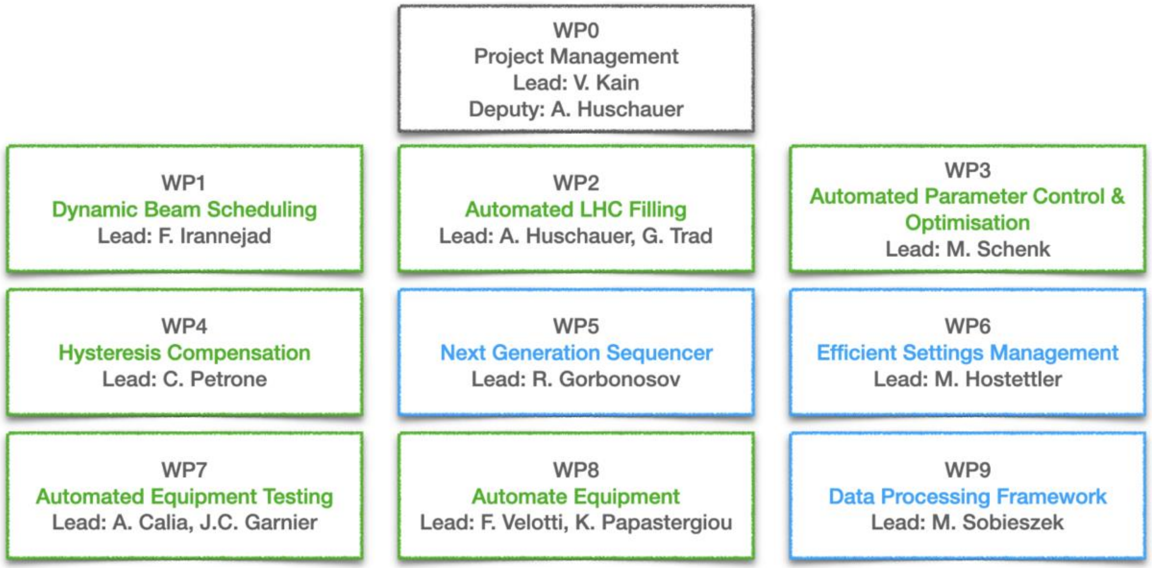
- **Introduction on EPA**
- **Dynamic Beam Scheduling**
- **Automated LHC filling**
- **Progress across the injector complex**
  - Transverse
  - Longitudinal
  - Transfer lines
- **Outlook & Next steps**

Introduction

Main progress coming from the Efficient Particle Accelerator project (EPA):

The focus is on automation to increase efficiency, reproducibility, flexibility, and margins for operation

- **WP1** - Dynamic Beam Scheduling
- **WP2** - Automated LHC Filling
- **WP5** - Next Generation Sequencer



EPA Mini-Workshop

Dynamic allocation of cycles in the super-cycle

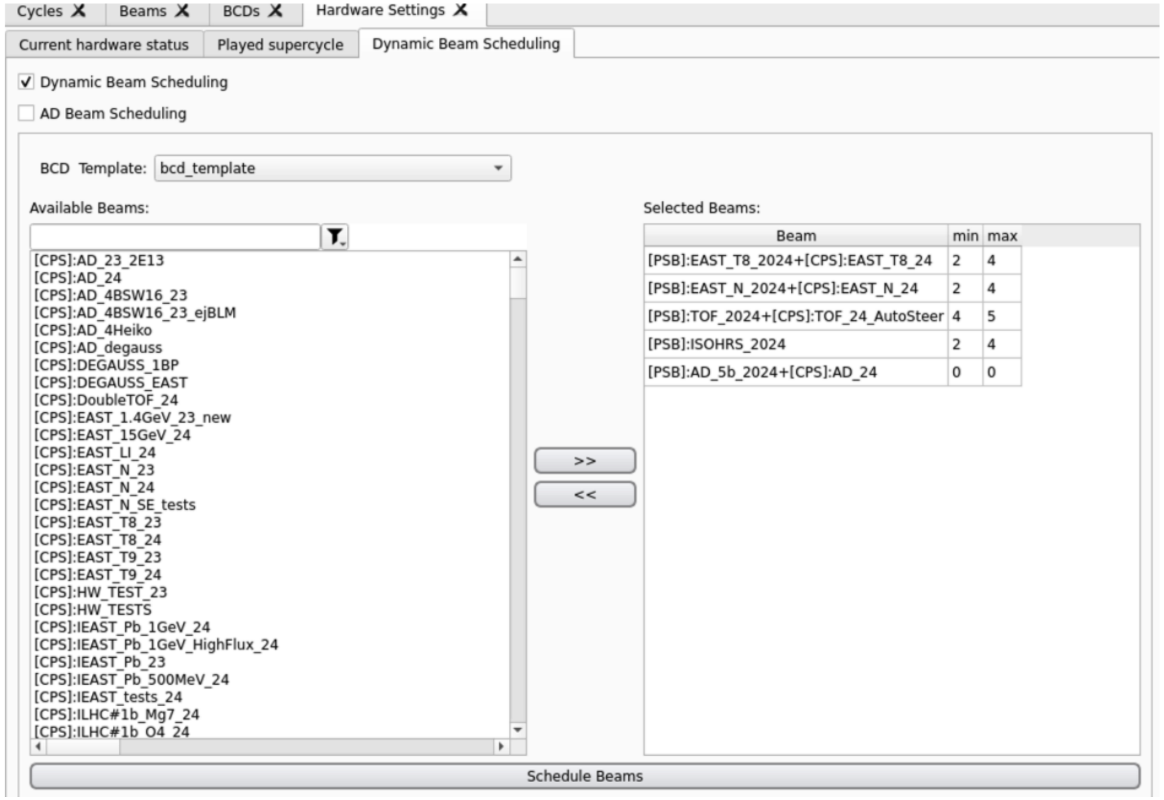
Optimize beam delivery for "physics" users

Dynamic Beam Scheduling

Automatic configuration of the super-cycle composition to optimize physics

- Schedule beams based on user requests
  - Trigger a new BCD proposition at change of requests
- Incorporate constraints according to the needs
  - Flexible algorithm with the aim of providing stable and reproducible performance for physics users

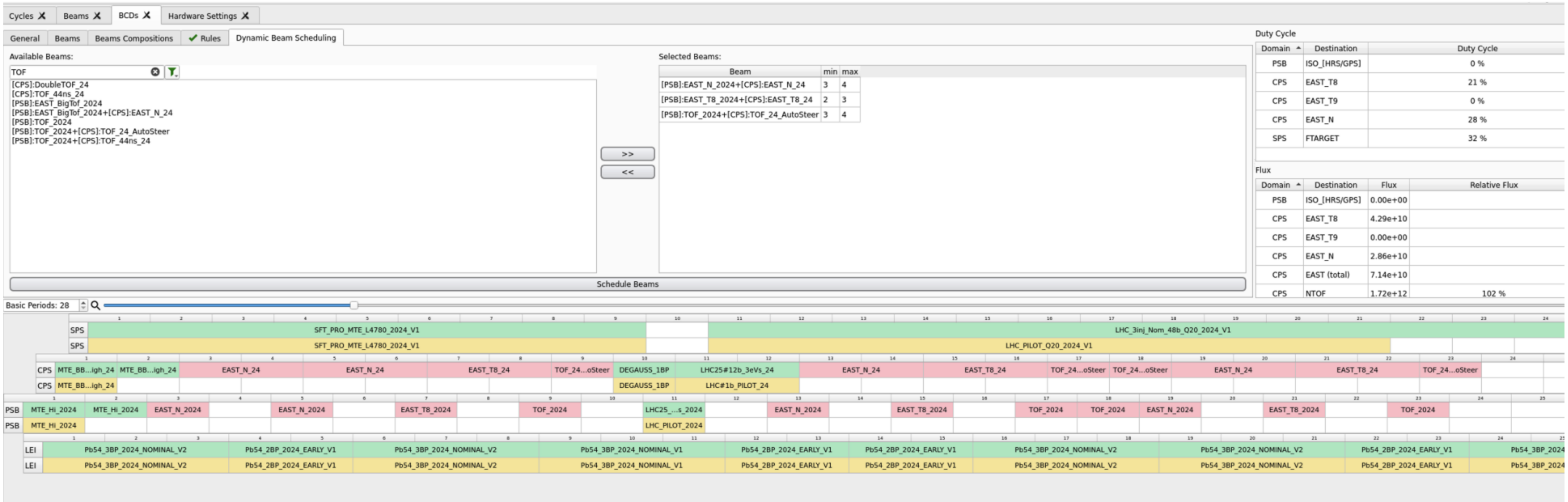
Hardware Settings Panel



Reference Link @F. Irannejad

Dynamic Beam Scheduling

First stage: automated scheduling of PSB and PS beams based on an SPS template

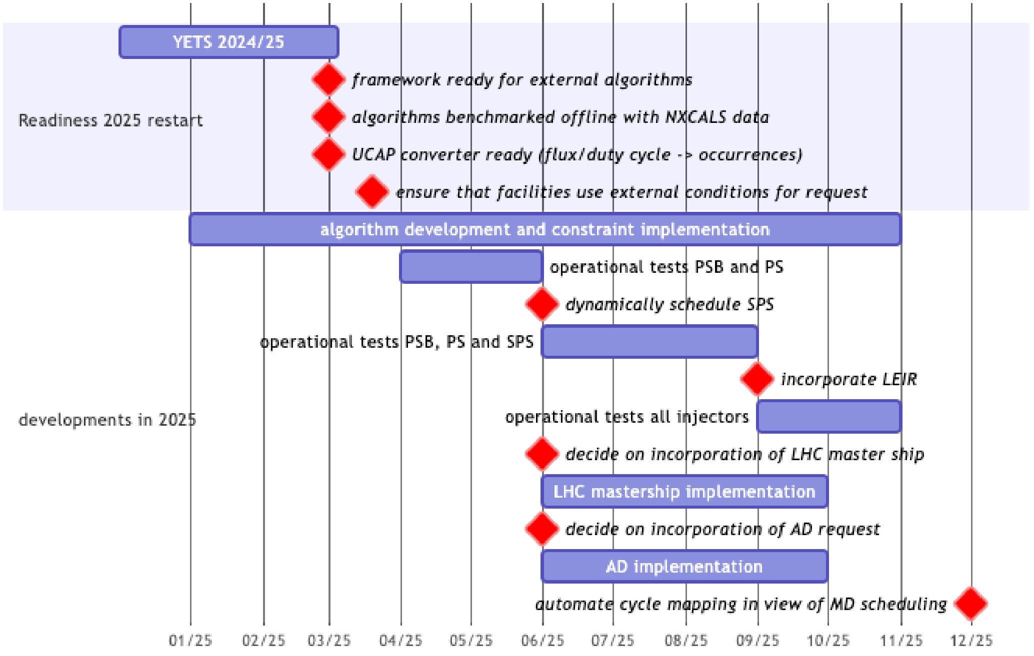


Reference Link @F. Irannejad

Dynamic Beam Scheduling

Next steps

- Evolve framework and test algorithm
  - Launch in operation early 2025 to gain experience
- Adding constraints in the current solution
  - Exploring constraint programming
  - In terms of accepted previous cycles / requests for equidistant spacing in supercycle
- Add SPS & LEIR in the dynamic scheduling
- Deal with AD request and discuss concept of LHC mastership



Reference Link @F. Irannejad

Automated LHC Filling

What are the key components

What is the aim of automated LHC Filling

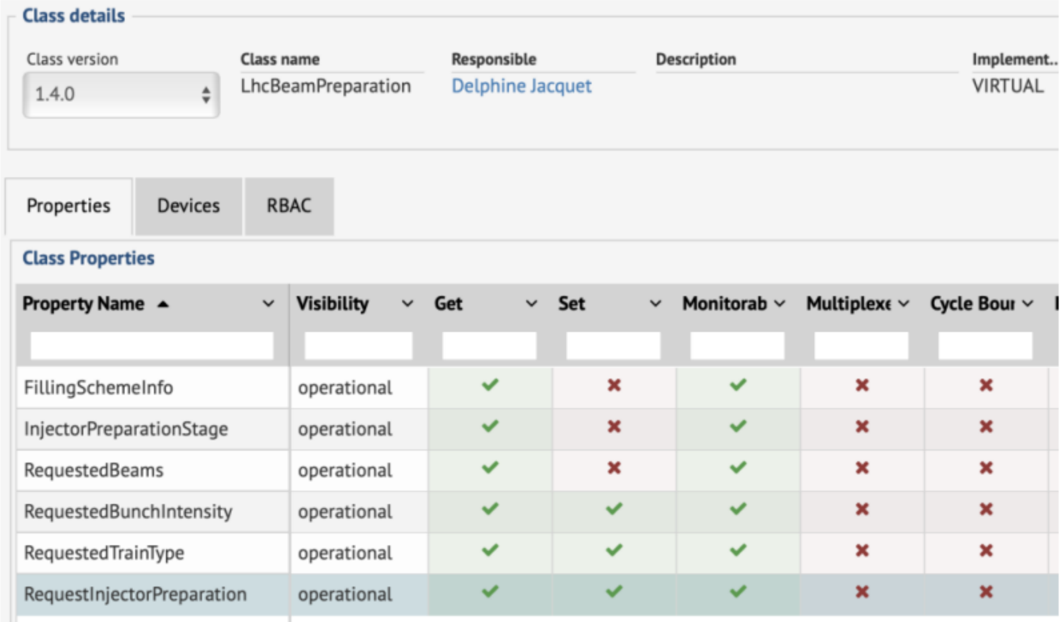
The ability to fill the LHC without human intervention to improve efficiency, reproducibility and performance

- Dynamic allocation of dedicated cycles in the super-cycle
  - Make room for LHC cycles during the preparation stage in the injectors and the actual filling
- Continuous monitoring of beam quality
  - Longitudinal & transverse beam quality metrics in the synchrotrons and transfer lines
  - Equipment status
- Implementation of automatic procedures for orchestration, optimization and recovery
  - Improvement of beam and equipment performance

Information/forewarning from the LHC

LHC Beam Preparation Server

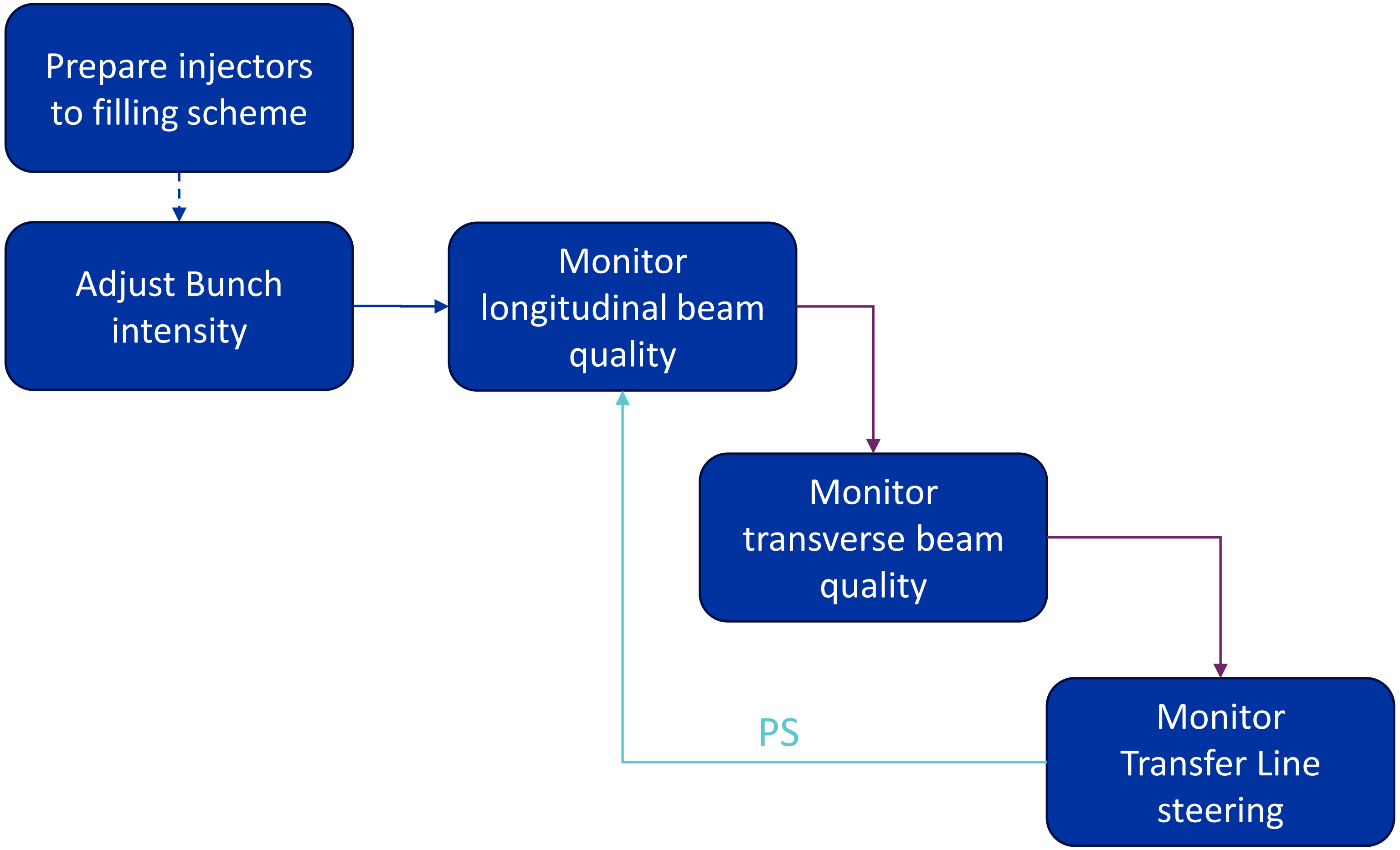
- Injector Preparation Stage:
  - “beamPreparationRequested”
  - “injectionImminent”
- Information displayed on PS2SPS transfer vistar
- Dynamic Beam scheduling should change BCD
  - Progressively filling cycles to avoid blocking SPS while optimizing beam



Property Name	Visibility	Get	Set	Monitorab	Multiplexe	Cycle Bour
FillingSchemeInfo	operational	✔	✖	✔	✖	✖
InjectorPreparationStage	operational	✔	✖	✔	✖	✖
RequestedBeams	operational	✔	✖	✔	✖	✖
RequestedBunchIntensity	operational	✔	✔	✔	✖	✖
RequestedTrainType	operational	✔	✔	✔	✖	✖
RequestInjectorPreparation	operational	✔	✔	✔	✖	✖

(@M. Hostettler & D. Jacquet)

Automated LHC Filling
Booster



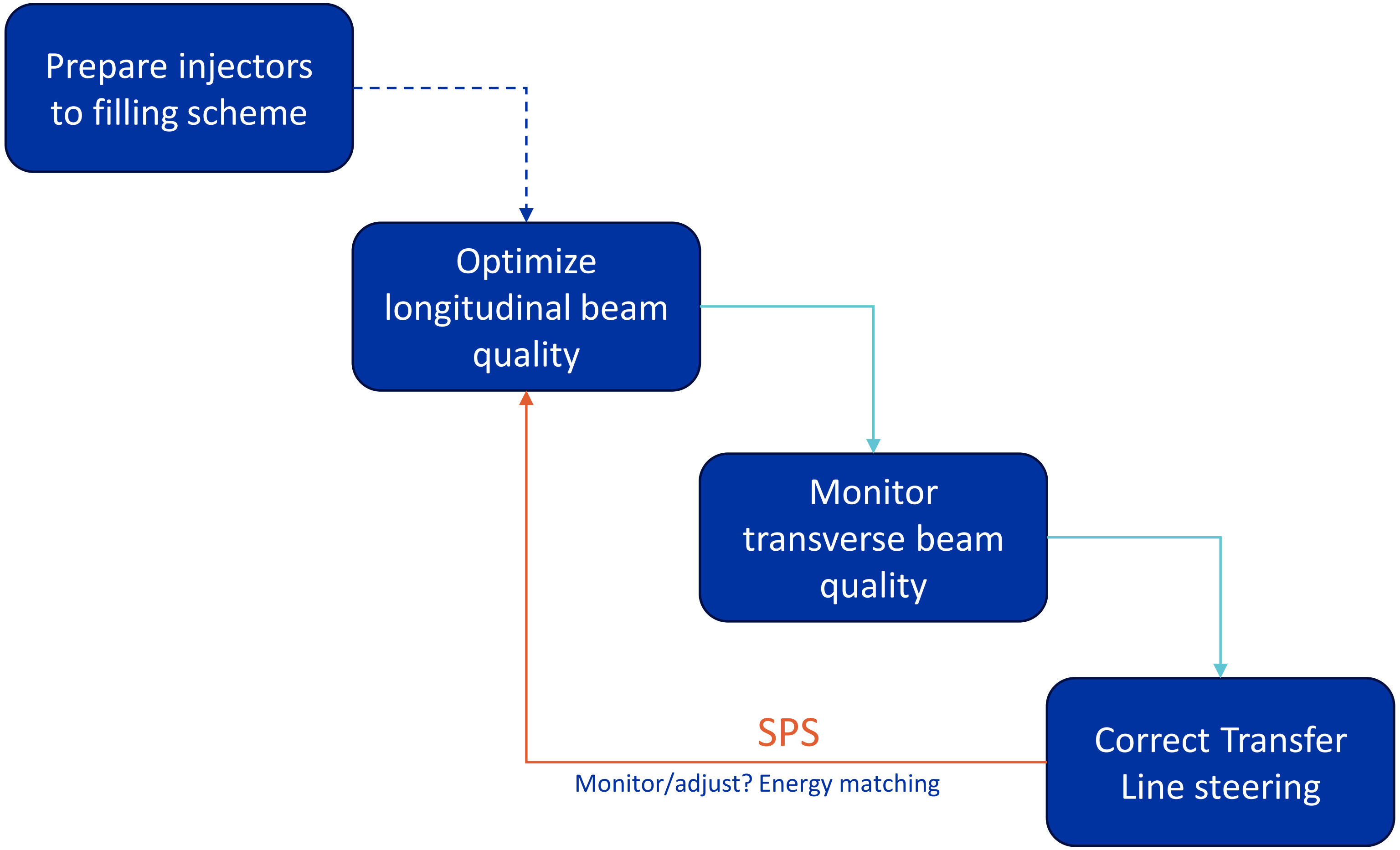
- beam type
- Bunch intensity

- Bunch intensity/lengths
- Tomography

- Bunch shaving to reduce tails
- Transverse emittance measurement

Automated LHC Filling

PS



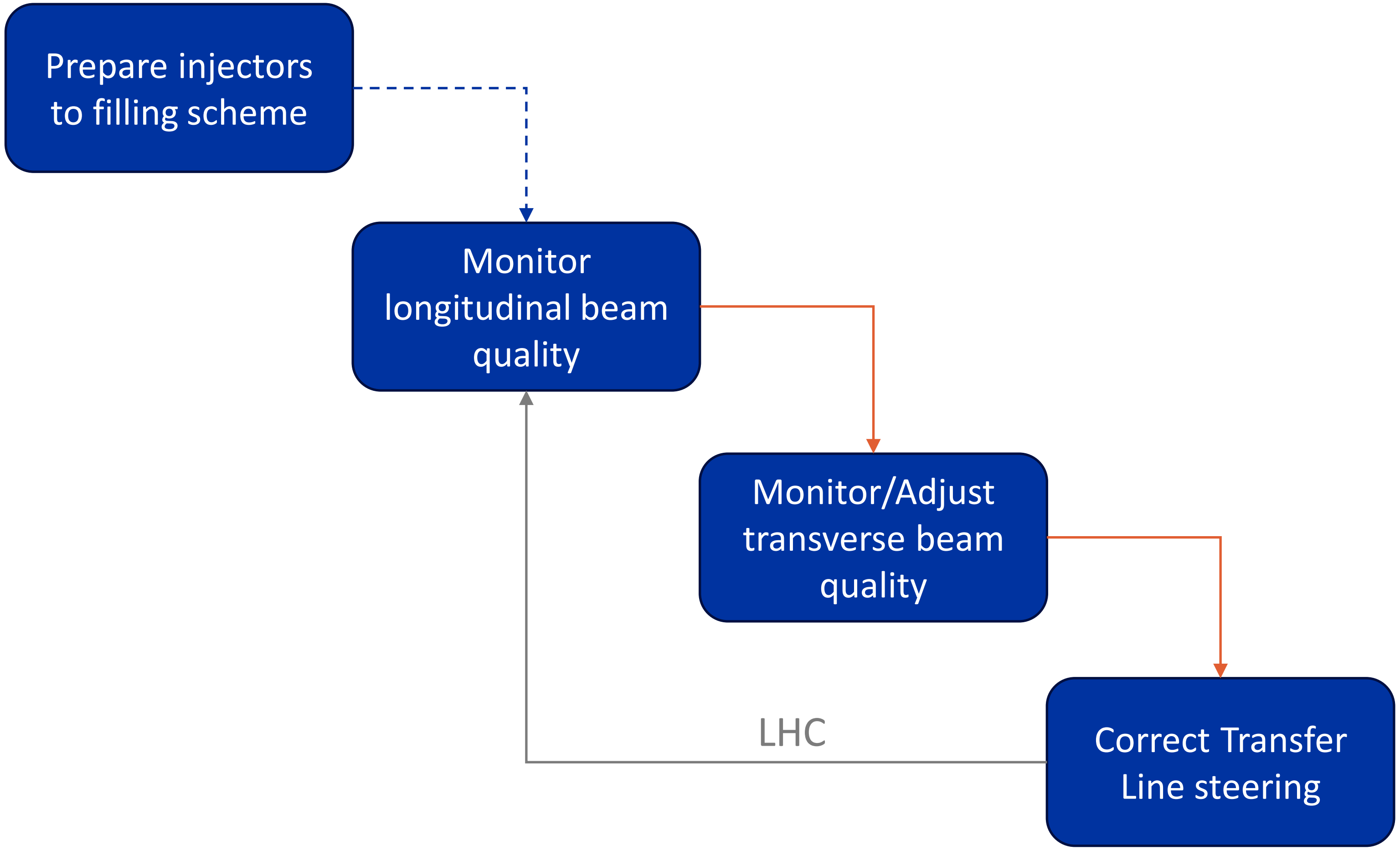
- beam type
- #bunches per PS extraction
- max. # SPS batches

- Bunch splitting (triple/double)
- Bunch rotation
- Bunch intensity/lengths
- Tomography

- Transverse emittance measurement

- TT2/TT10 trajectory quality

LHC filling flowchart
SPS



- Beam type
- Bunch intensity

- BQM checks: Bunch intensity/lengths
- Injection phase adjustments
- Longitudinal emittance

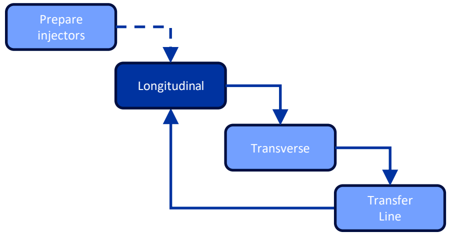
- Scraping
- Intensity dependent settings
  - Laslett tunes, TFB etc…
- Transverse emittance measurement

- Trajectory quality

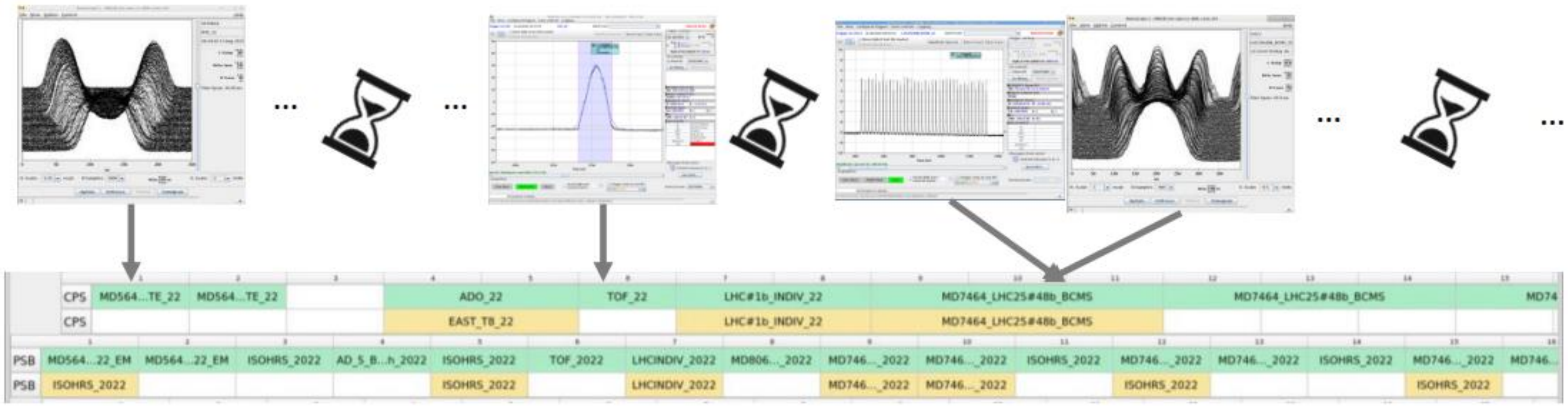
Observable and metrics

Focus on online metrics computation

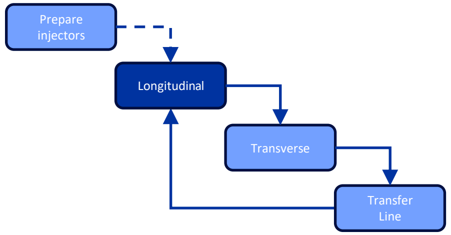
New longitudinal acquisition layer needed



- **Previously no common framework for online monitoring (BQM @SPS, OASIS @PSB/PS)**
- **Difficult to update the BQM to the other injectors**
- **Measurement and adjustment longitudinal beam characteristics with OASIS**
  - Only manual and on-demand measures; effort required to automate
  - No PPM acquisition
- **PS Longitudinal characterization based on Tomoscope and bunch shape measurement (BSM)**
  - Single acquisition on a single user, only two channels available

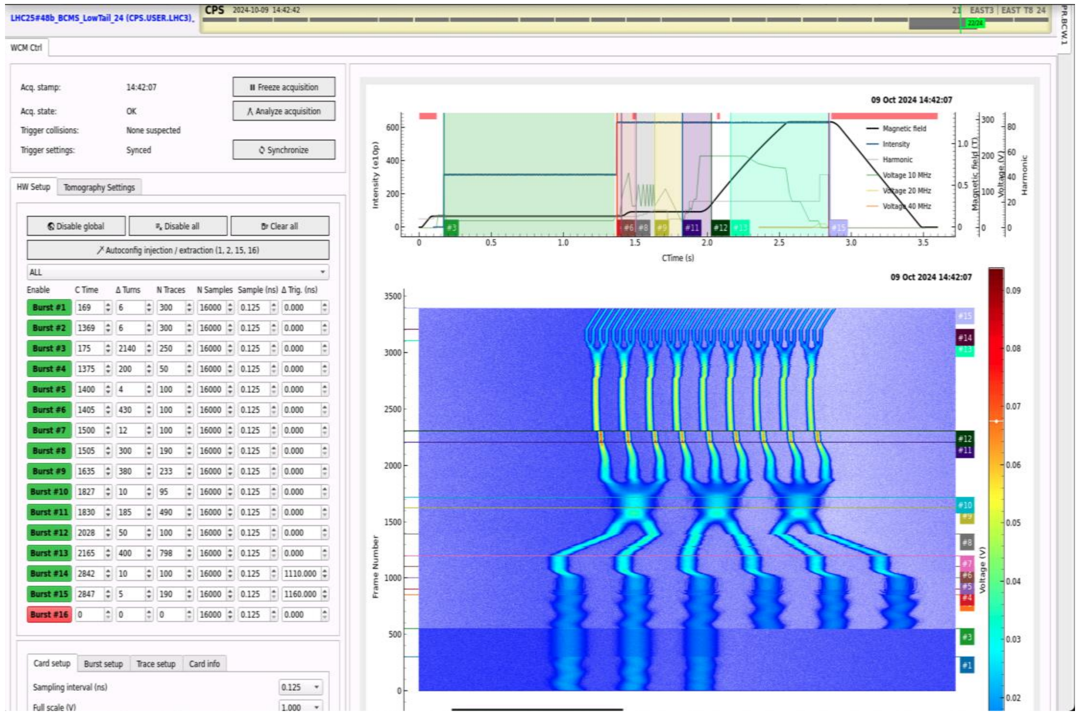


Enabler of longitudinal beam quality monitoring and optimization



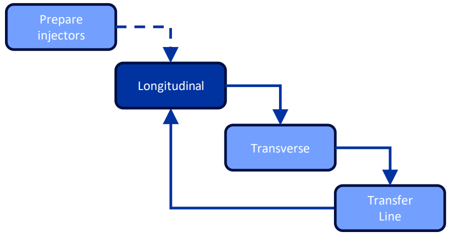
- **New longitudinal acquisition layer – FESA class BCWLBO**
- **FESA - Fully multiplexed class**
  - Settings can be changed between cycles
  - Every trace can be set differently (even inside a burst)
- **Start Acquisition Event**
  - Timing / On-demand event that starts one acquisition
- **End Acquisition Event**
  - Timing / On-demand event from which we abort the “wait” acquisition
- **The device publishes as soon as data is available**
- **Generic implementation for all synchrotrons**
  - Enables online beam monitoring and optimization for multiple users at once and along the full cycle
    - permanent PPM acquisition

(PS) Longitudinal BQM app



(@H. Pahl)

IPP Meeting Slides

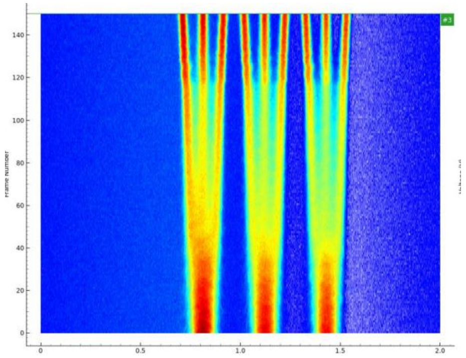


PS – LHC Double/Triple splitting

Triple Splitting

- Data coming from BCWLBO class
- Measure + monitoring
  - Bunch intensity & bunch length after splitting
  - Act on the Phase & Voltage of the cavities
- Current CNN/RL implementation flexible enough to be tested operationally

Last update

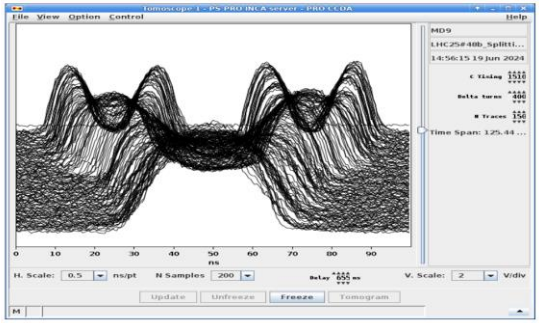


Double Splitting

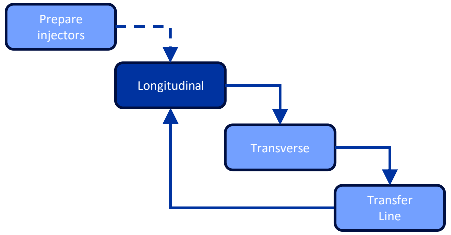
- Data coming from BCWLBO class
- Measure + monitoring
  - intensity after each double split
  - Act on the Phase of the cavities
- Current implementation: PID controller

(@J. Wulff, Z. Ansari)

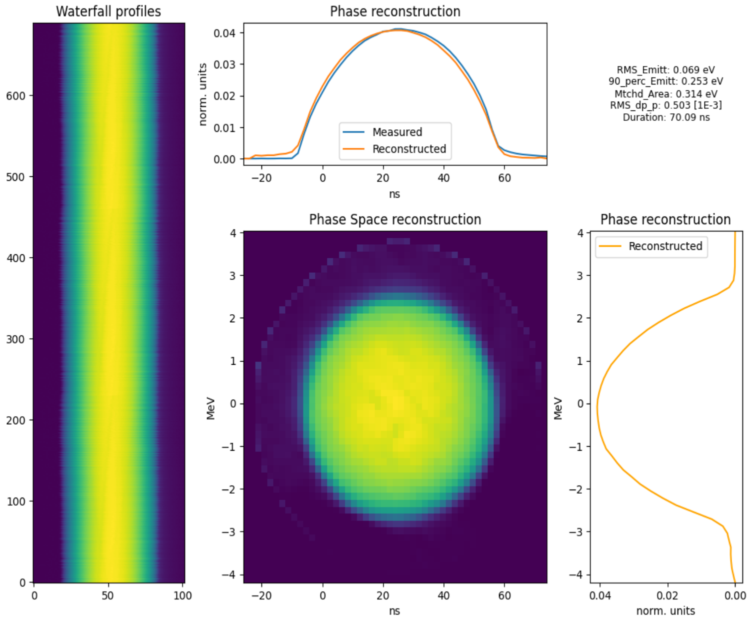
Last update



Monitoring all along the injector's chain LHC INDIV beam – automated tomography

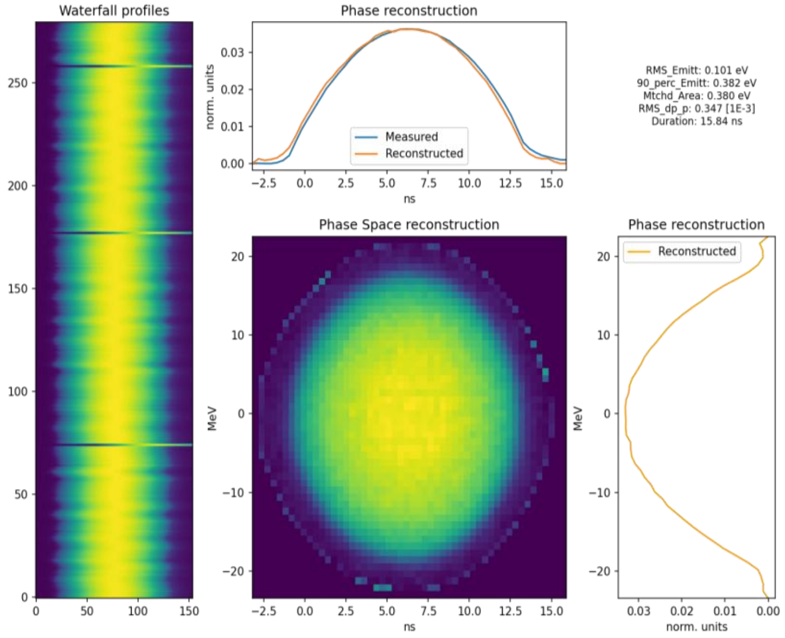


PSB



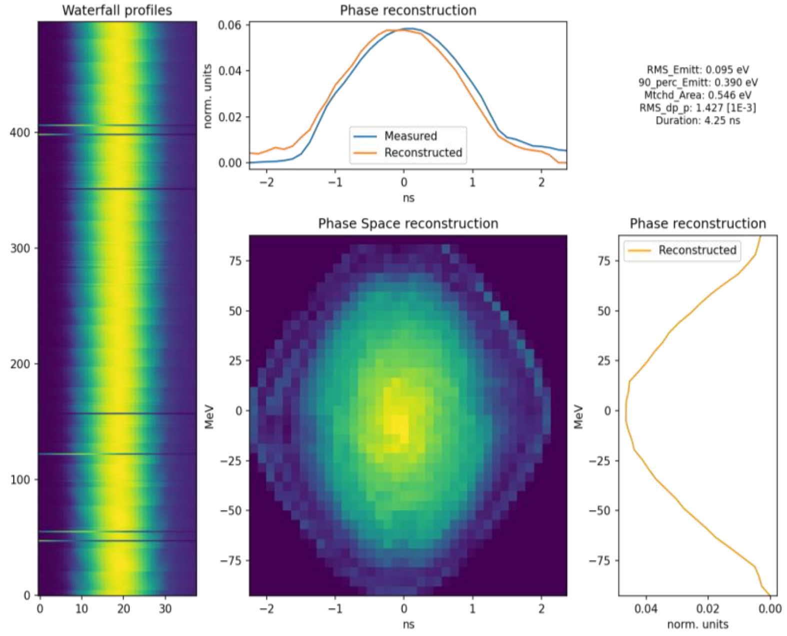
Extraction

PS



Bef. Rotation

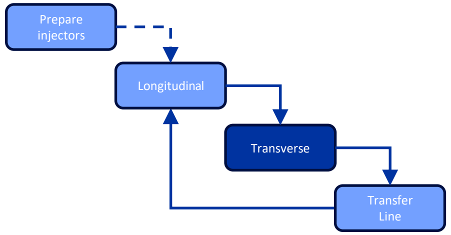
SPS



Injection

Automated multi-bunch tomography based on several UCAP devices for every machine at different timings in the cycle.
Permanent logging (NXCALS) for the PS

Wire scanner application

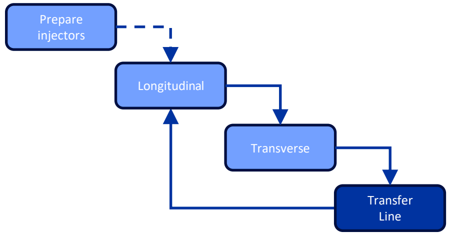


- **Automation of wire scans for emittance measurements**
  - Regular beam quality measurements (BPT)
  - Beam preparation and qualification during automated LHC filling
- **Backend on UCAP; Permanent logging (NXCALS)**
- **Low-effort, repeatable measurements**
  - Use of prepared (“tagged”) acquisition and analysis parameters
  - Recovery & filtering of historical data based on tags
- **Next step:**
  - Incorporate bunch-by-bunch dp/p from auto-tomo
  - Auto-launch emittance measurements
  - Ensure measurement only at allowed moments in the cycle
    - Especially important in the SPS

(@H. Pahl, G. Trad)

[Wire scanner functionalities slides]

Trajectory auto-pilot



Steering framework "YASP steering on UCAP" (@G. Trad, F. Velotti)

- Generic solution, easy to extend, add measured response matrix
  - Reduce rms trajectory, losses and optimize transmission
- GUI for monitoring trajectories & corrector changes
- Request to make trim sanity checks possible for MUXin

Lots of initiatives:

- Target steering, FTN line steering etc.

Next step:

- PS-SPS & SPS-LHC tests to follow next year

More info in next talk:
Results and plans for integration of automation and optimization in operation

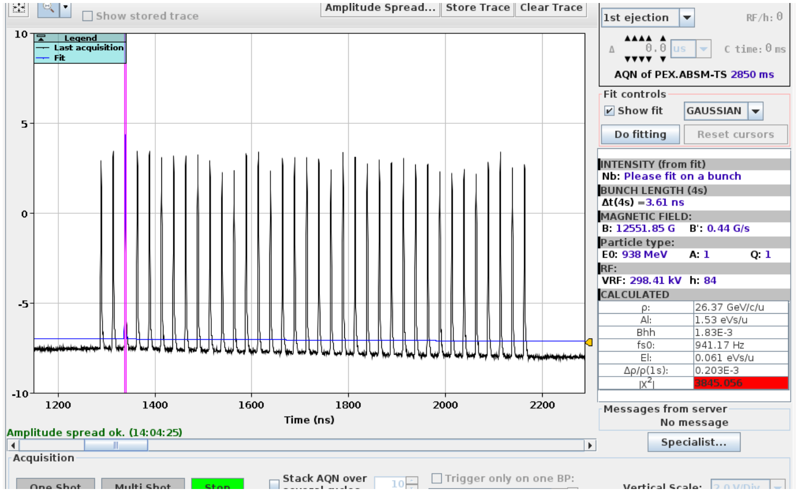
Online Monitoring

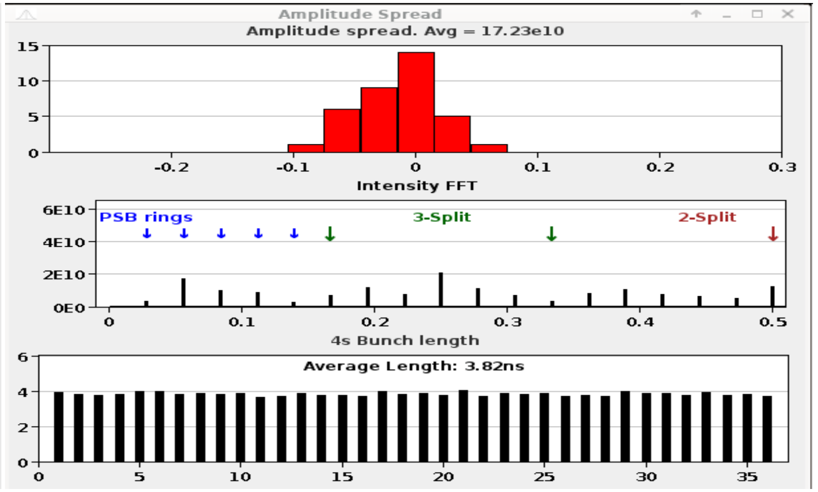
Ensure high beam quality 24/7

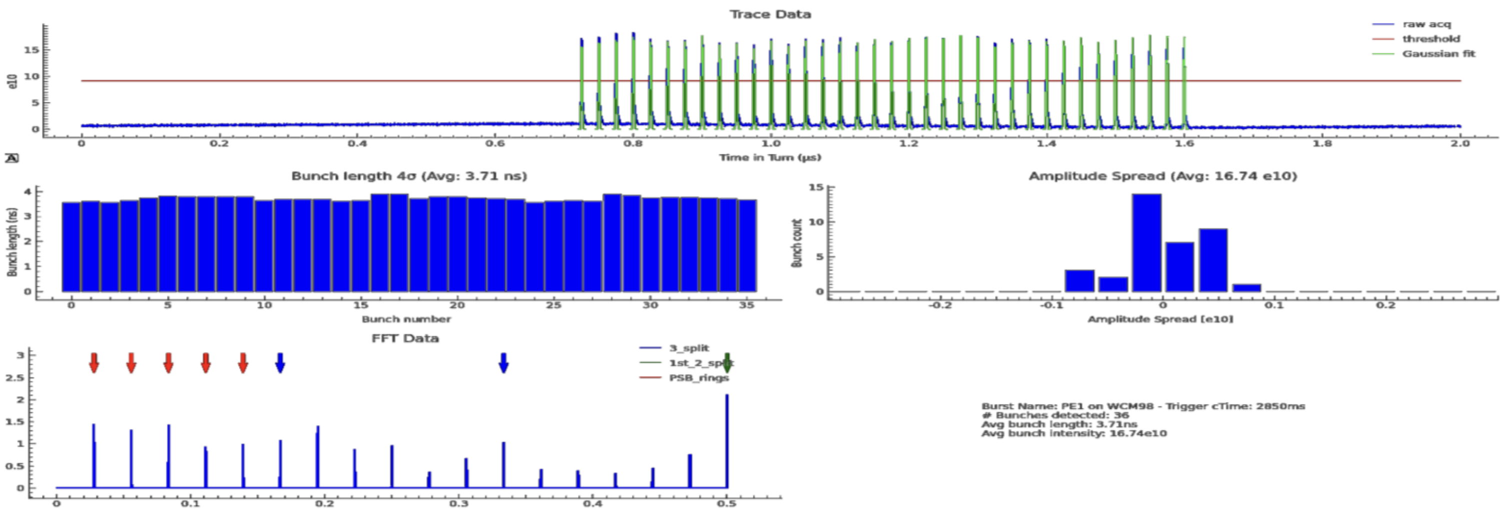
PS – Bunch Shape Measurement

"BSM" bunch-by-bunch analysis

- On-demand analysis
- OASIS based - Non-PPM
- OP application based





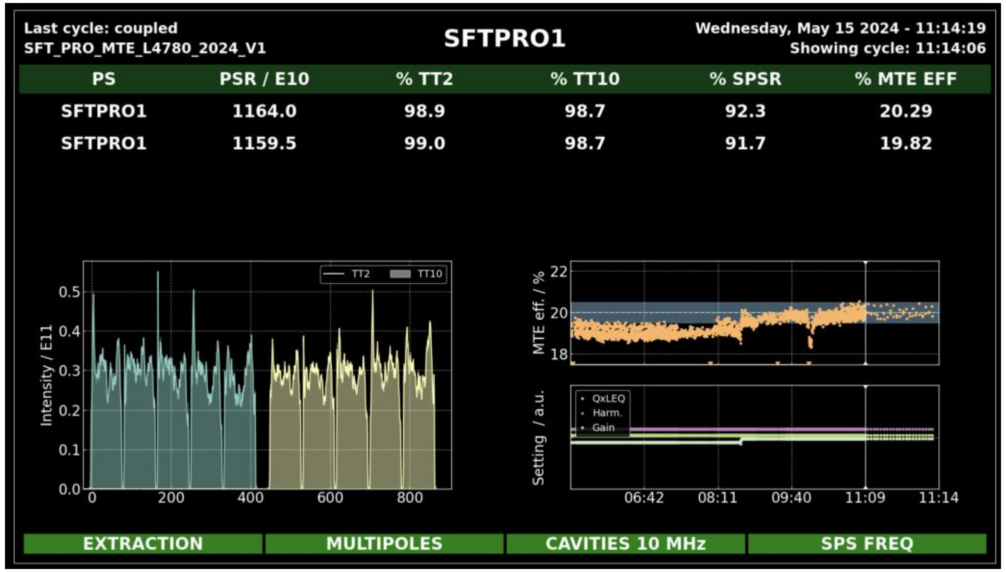


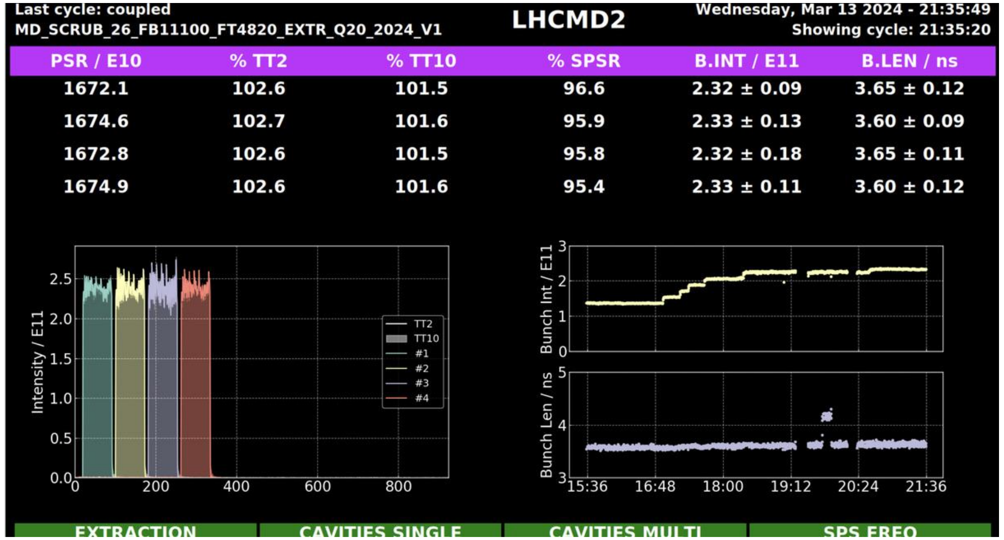
New "BSM"

- Online analysis (permanent)
- BCWLBO - PPM
- UCAP based (@M. Coly) + GUI

PS – SPS vistar

- Two instances available in the OP webtools
  - https://op-webtools.web.cern.ch/vistar/?usr=PS2SPS1
  - https://op-webtools.web.cern.ch/vistar/?usr=PS2SPS2
- Currently two modes available
  - SFTPRO and LHC
  - Will add additional mode for ion beams
- Triggering on SPS cycle, user selection from PS non-multiplexed LSA setting
- Backend including cross-machine event building on UCAP
  - Good feedback from operations
  - Allowed to spot drifting MTE efficiency, incorrect bunch lengths on LHC beams



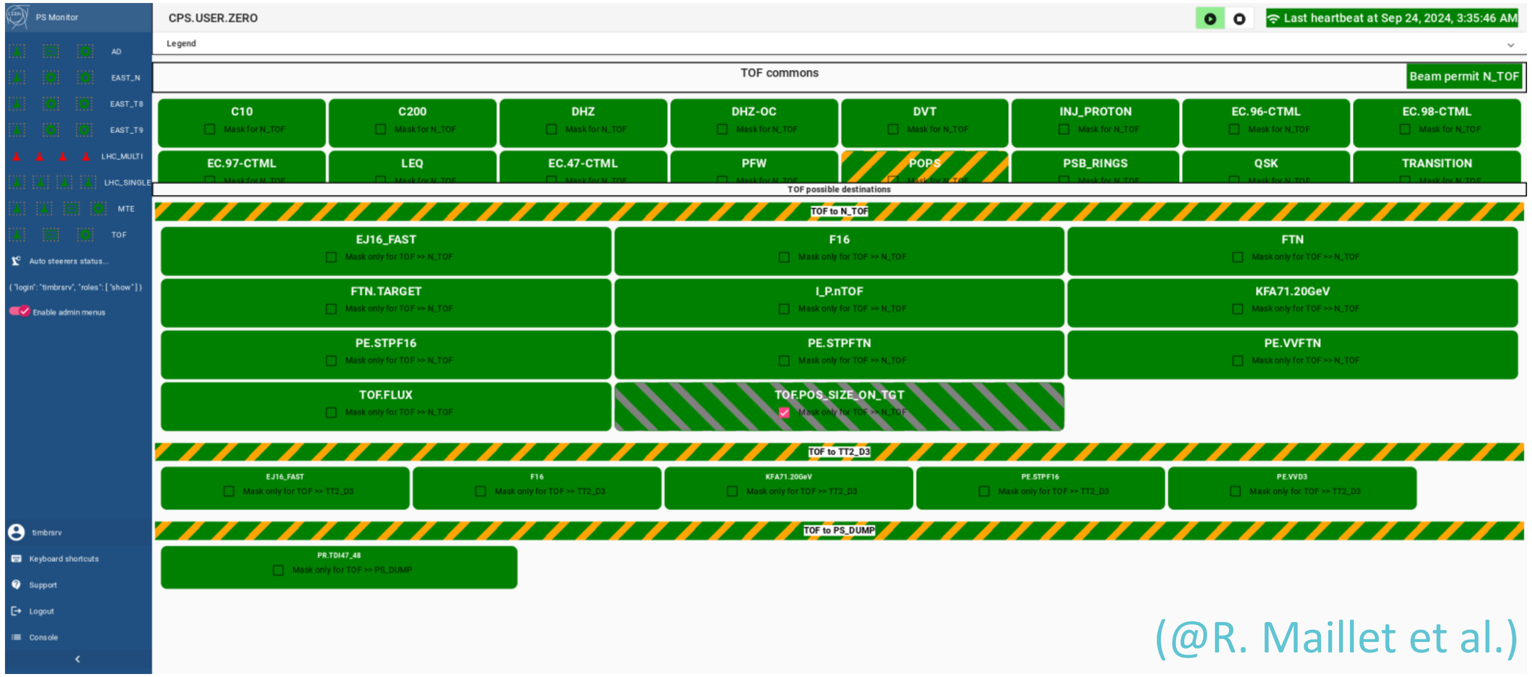


(@H. Pahl)

PS performance monitoring

PS performance monitoring developments

- Cavities, magnets, kickers, etc. status monitored via UCAP
- Auto-resets in place for 10, 20, 40 and 80 MHz systems and KFA71 modules
  - Fruitful collaboration with RF and ABT experts
- Auto-start in place for 20 MHz system
  - Triggered by LHC forewarning or presence of LHC type beam in the super cycle



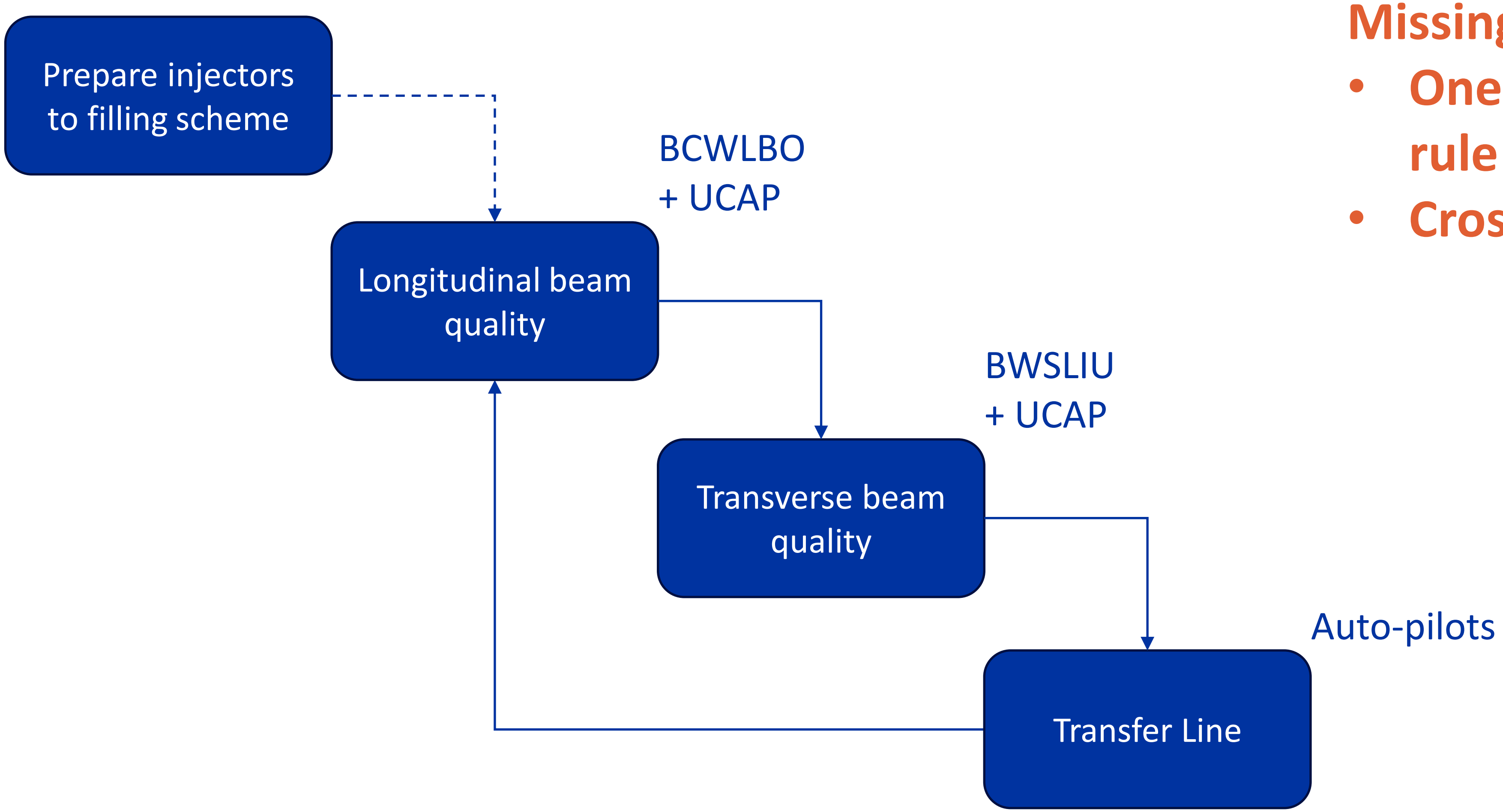
(@R. Maillet et al.)

Status of PS performance monitoring

Outlook

Future plans and missing pieces across complex

Putting things together



Missing pieces:

- **One orchestrator to rule it all!**
- **Cross machines metrics**

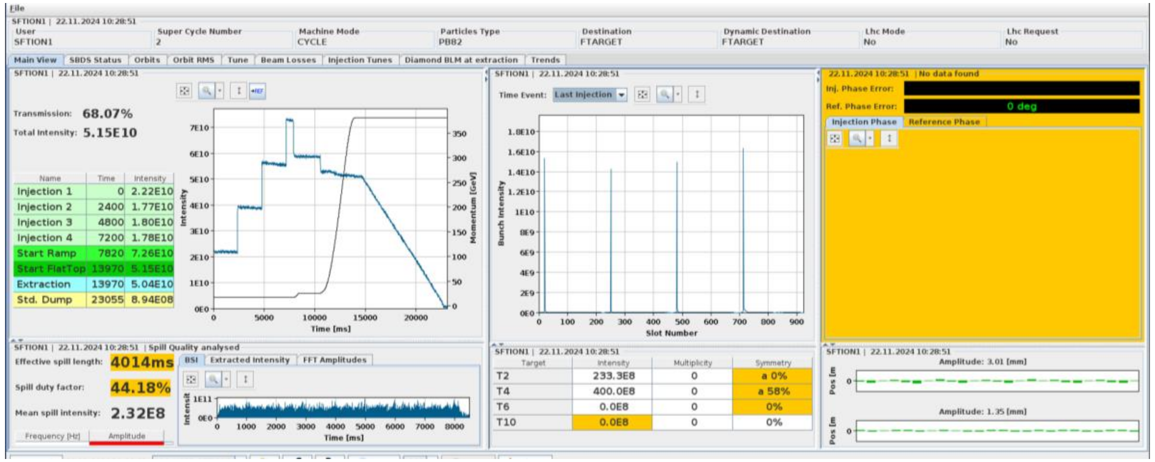
Cross machines metrics: quality control

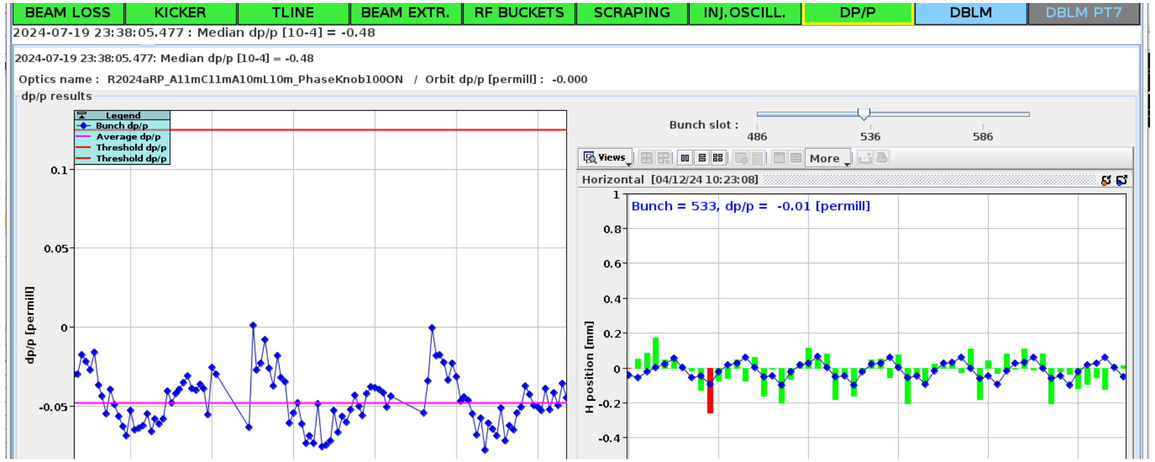
Current setup (SPS QC | LHC IQC) not suitable enough for PS/PSB

- Link to post-mortem
- Be able to reload data and reprocess it

There is a need for a generic solution where we can collect information on the beam quality metrics across machines!

- **Online** / NXCALS for data recovery
  - One shot every ~ 1BP
- Event collector **via identifier management**
  - Should be a dynamic set of input
- Data processing & analysis could be done anywhere
- Visualize data from different machines on the same app (from PSB – LHC, PSB – North area, …)
- Ideally be able to reload data and reprocess it



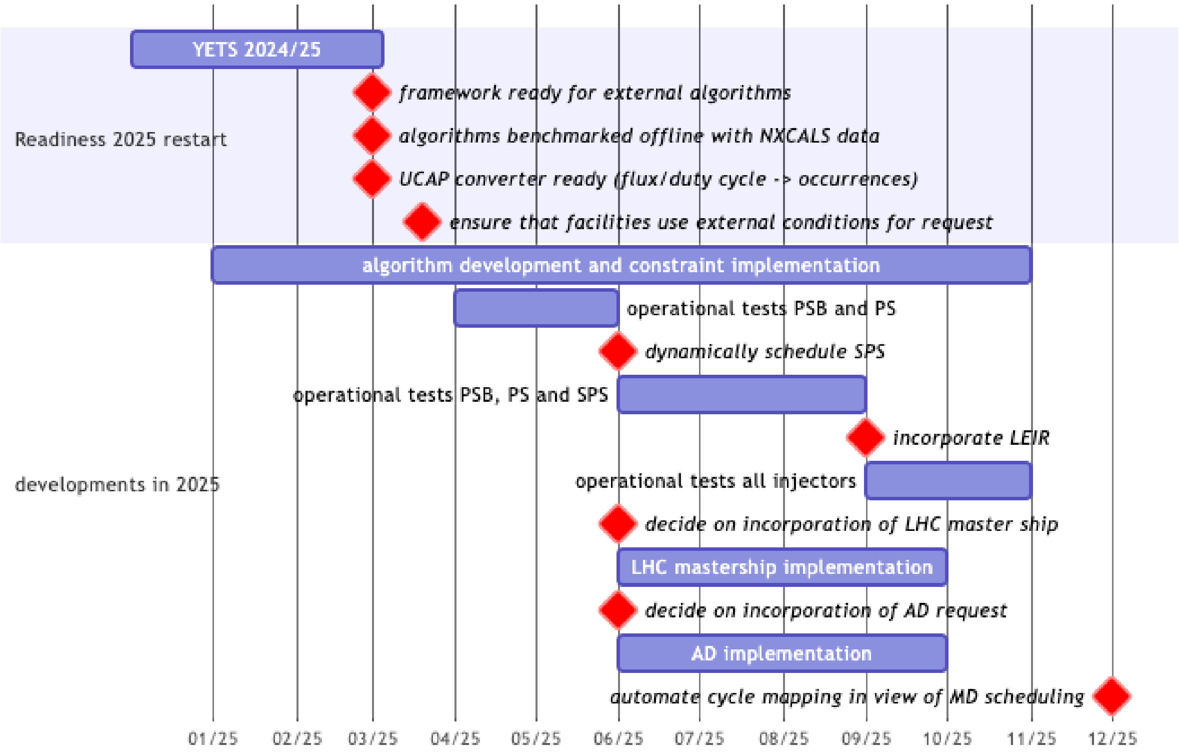


Orchestrator

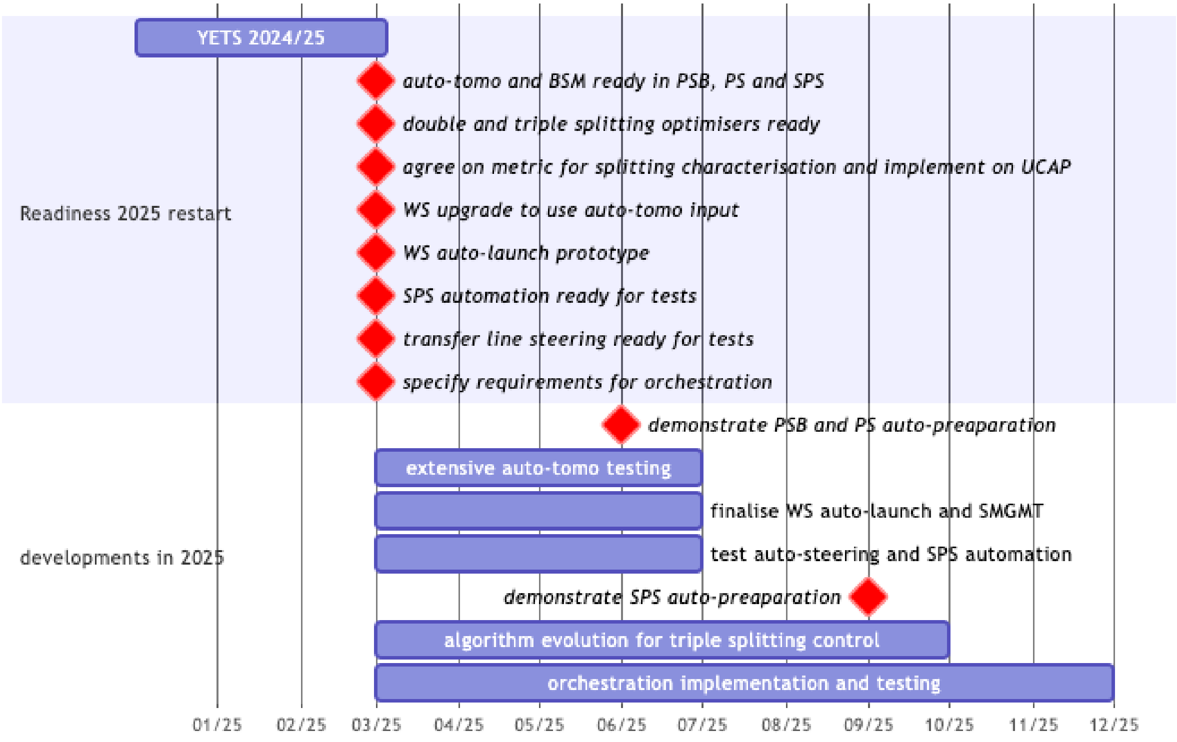
- Instance on top of all machines (state machine)
  - This the “Brain” of the procedure
    - Knows all the optimization steps required
    - Keep track on where it is on the sequence of tasks
- Launch UCAP/scripts/auto-reset processes on the fly
- Launch task in
  - Parallel
  - Sequentially
- Beam coupling to the next machine once success criteria
  - Able to **restart processes** if conditions are degraded
  - Inhibit beam production
- Have its own GUI to monitor the optimization advancements

Next steps

WP1 - Dynamic Beam Scheduling



WP2 - Automatic LHC Filling



Thank you for listening
Any questions ?

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