Automating accelerators

evolution since last year

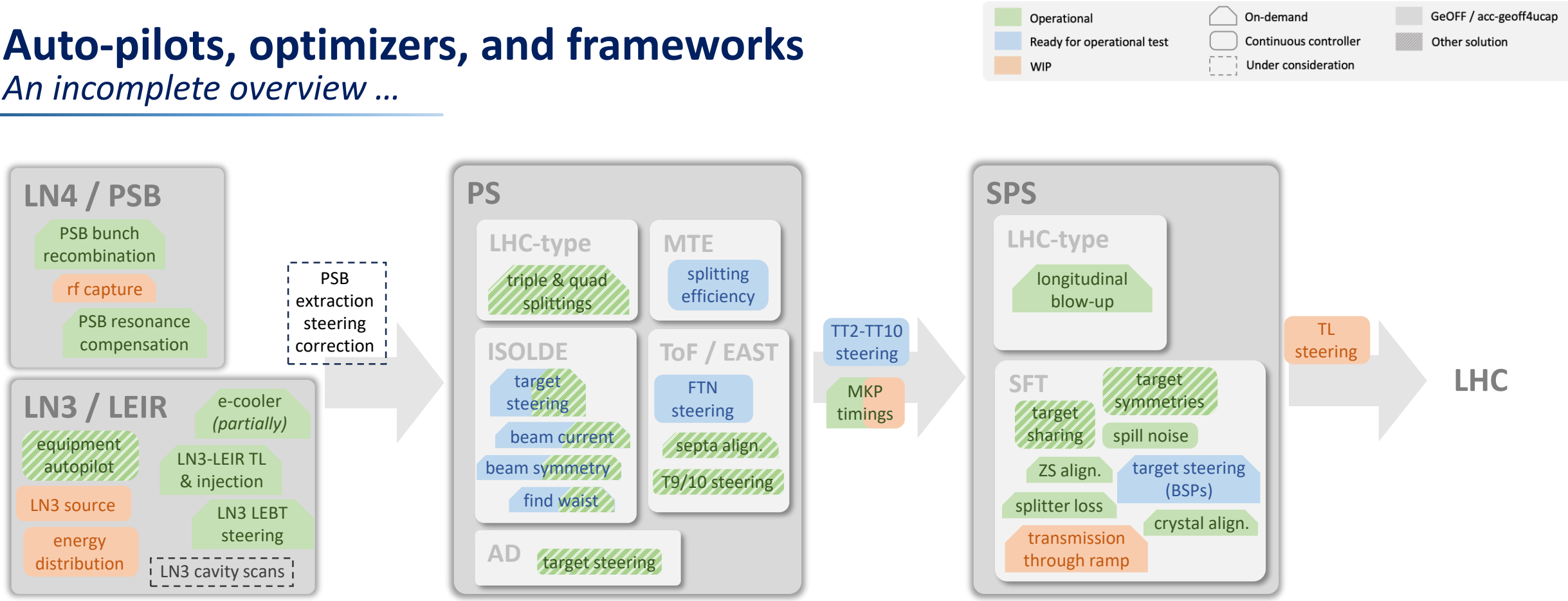
M. Schenk with input from: P. Arrutia, D. Banerjee, G.P. Di Giovanni, Y. Dutheil, F. Follin, M. Fraser, M. Hostettler, A. Huschauer, V. Kain, D. Krefta, A. Lasheen, K. Li, A. Lu, N. Madysa, J. McCarthy, B. Mikulec, H. Pahl, K. Papastergiou, R. Scrivens, P. Skowronski, G. Trad, F. Velotti, E. Veyrunes, J. Wulff, and many more

JAPW'23, Montreux, Switzerland *07. December 2023*

Contents

Auto-pilots, optimizers, and frameworks

An incomplete overview …



Auto-pilots, optimizers, and frameworks

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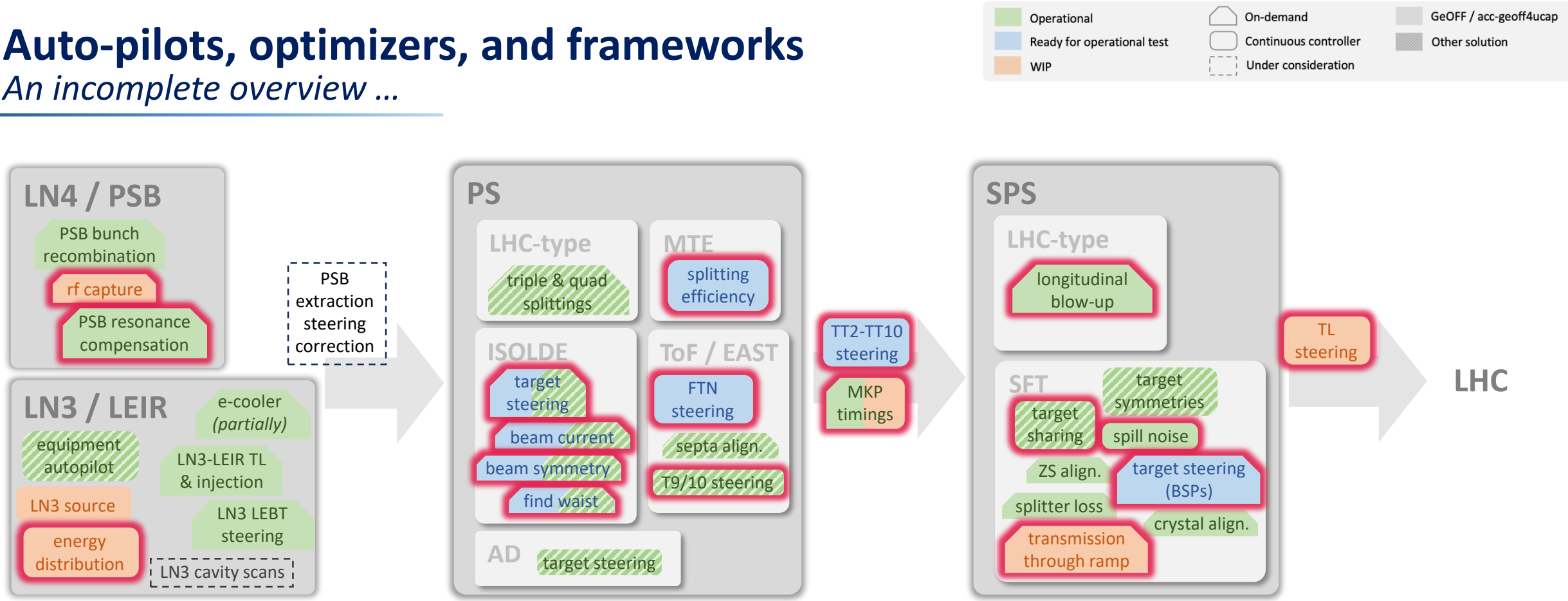

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Auto-pilots, optimizers, and frameworks

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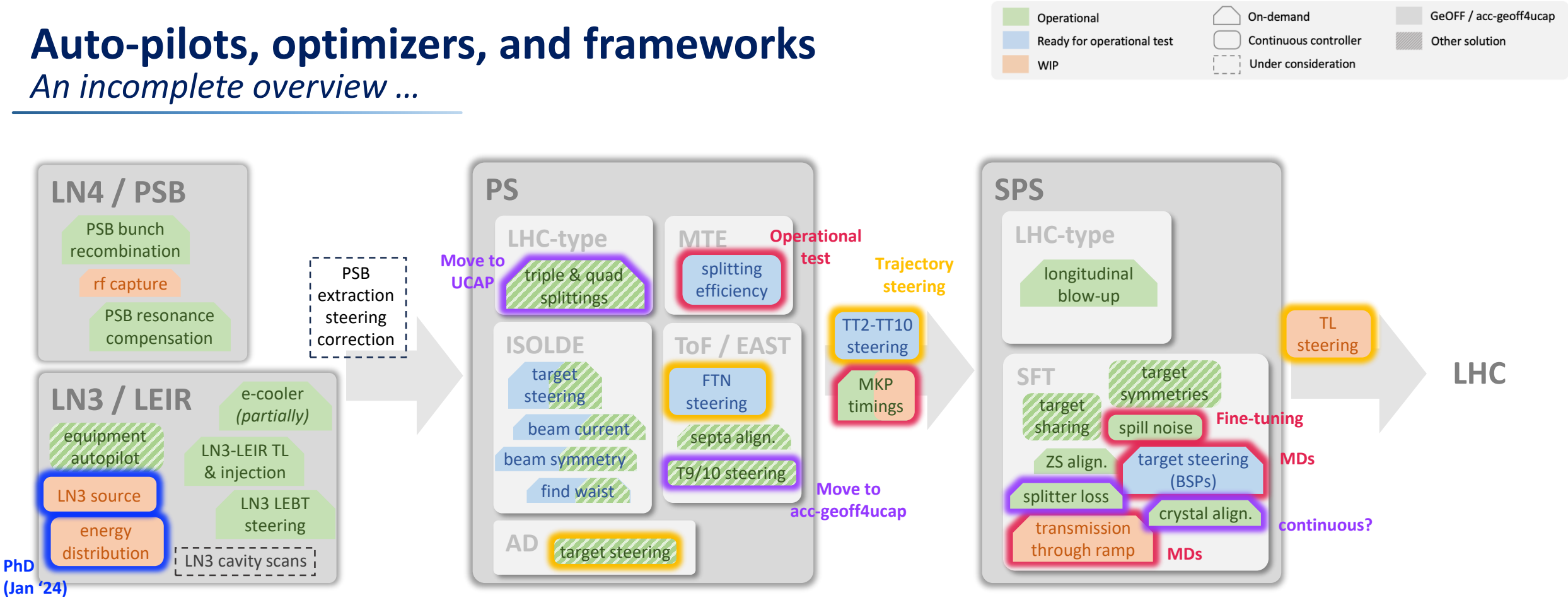

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  Be aware of concurrency between controllers / humans & controllers, monitoring

Auto-pilots, optimizers, and frameworks

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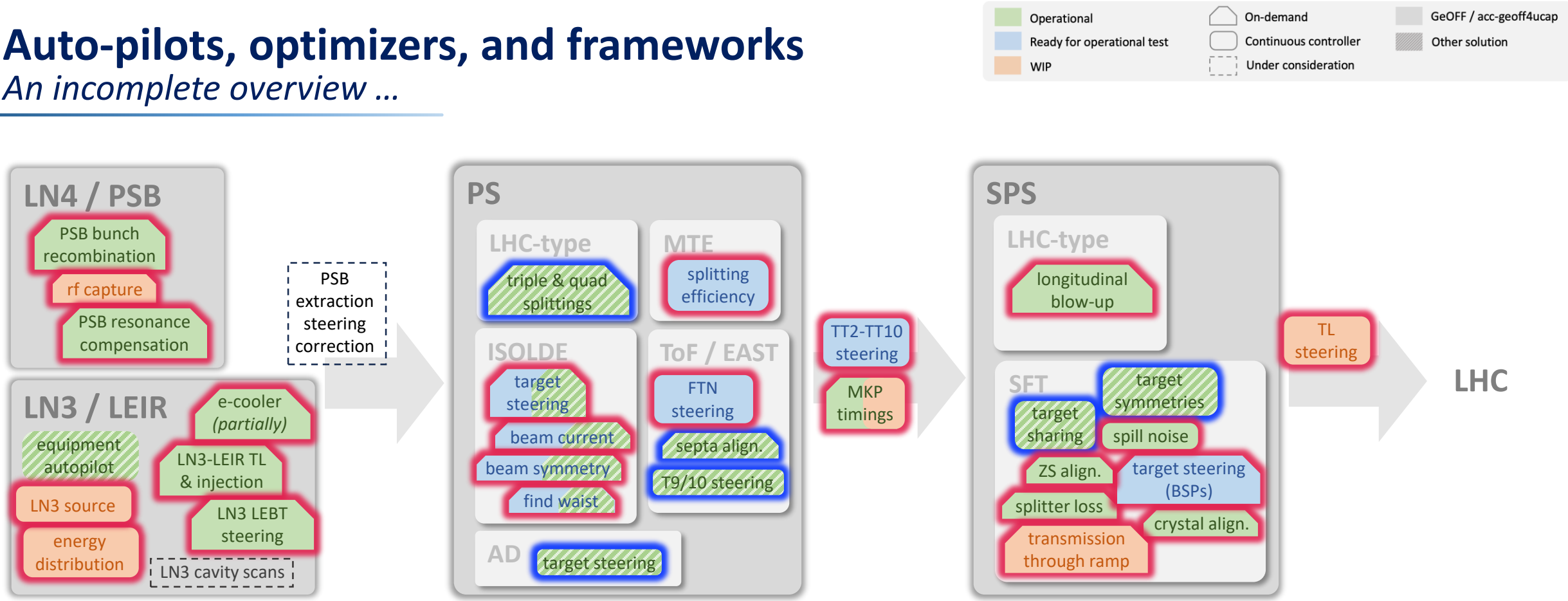

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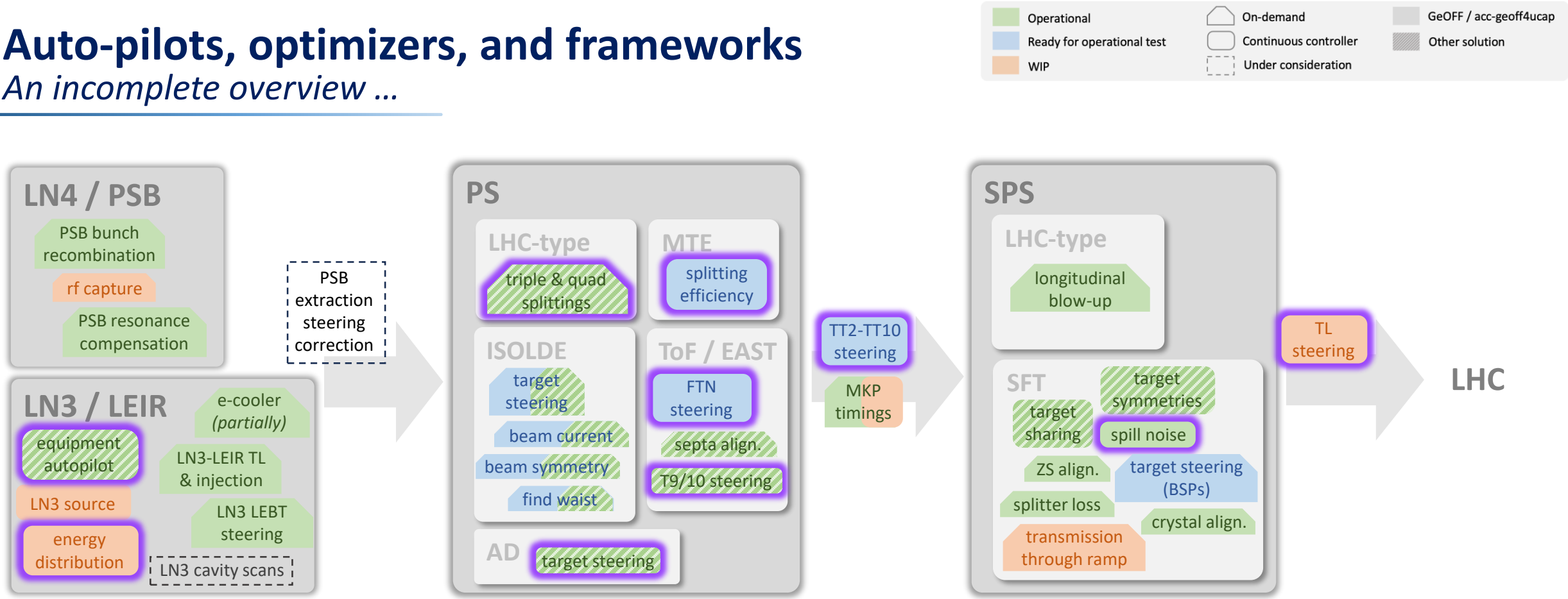

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- **Frameworks:** GeOFF (local & UCAP) | other solutions | frequent use of UCAP actors

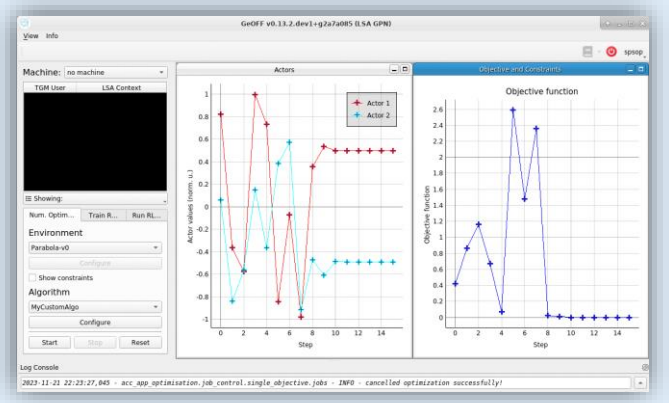
Auto-pilots, optimizers, and frameworks

Frameworks

- **Purpose**
  - **Facilitate** realization of new controllers
  - Be **generic and flexible** to meet requirements for different use cases
  - **Exploit & expose features** of control architecture
  - Maintain **uniformity** across machine complex
- BE-CSS maintains **GeOFF, acc-geoff4ucap,** and **Machine Learning Platform**
- **Other frameworks** or **dedicated solutions** also in use

GeOFF

Generic Optimization Framework and Frontend



acc-geoff4ucap

Python framework for optimization & continuous control via UCAP

NEW

UcapOptimizationProblem
(objective, x_0, trigger, …)

UcapControllerPublications
(action parameters, …)

UcapOptimizer

UcapOptimizerConverter

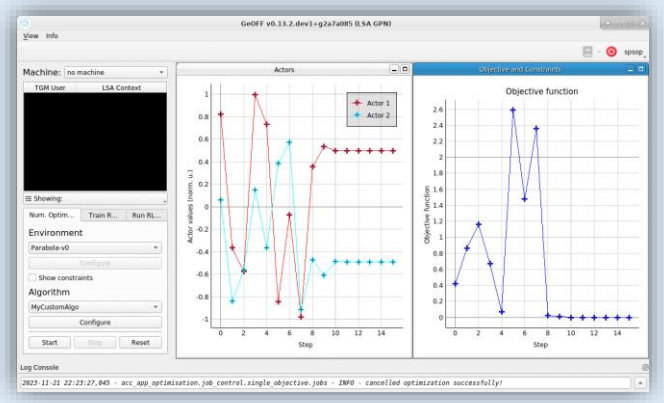
Auto-pilots, optimizers, and frameworks

Frameworks

- **What's new in GeOFF?**
  - **Features:** use your own problem-specific customizable algorithms, integration of TransientTrims
  - **Standalone optimizers** package
  - **Support & announcement service**
- **Plans 2024**
  - **Decouple** GUI from **optimization problem releases**
    ➡ developers **more independent**
  - **Features:** on-the-fly function incorporation, reset to specific iteration, data logging
  - **Maintenance:** keep up with dependency changes, explore integration with **PyDA**

GeOFF

Generic Optimization Framework and Frontend



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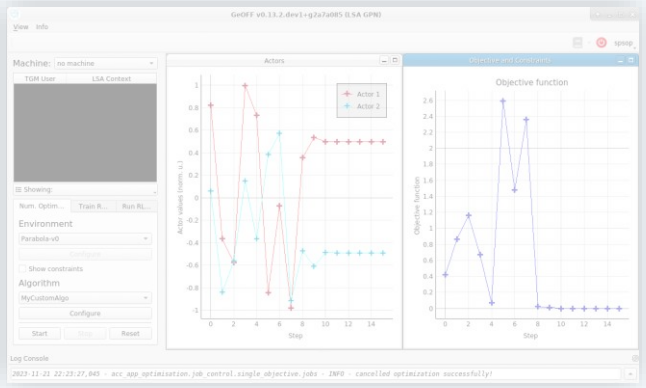
Auto-pilots, optimizers, and frameworks
Frameworks

- **acc-geoff4ucap:** reported as missing piece (JAPW'22)
- **First release in June '23**
  Following code review with feedback from early adopters
- **Similar to GeOFF**
  - **User-code in problem formulation & publications**
  - Use **built-in optimizers** or **your own**
  - GeOFF environments **not directly transferable**
    PyJapc vs UCAP event builders
- **Project still evolving**
  - **Integrate user feedback**
  - **UCAP-related**
    - Exploit device set-commands once available
      pilot on / off, parameter adjustments, etc.
    - Officialize LsaActor
  - **GeOFF GUI as monitoring display**

GeOFF
Generic Optimization Framework and Frontend



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Auto-pilots, optimizers, and frameworks

Some news & highlights

SPS NA

- Target sharing
- Target symmetries
- **Spill noise cancellation**

PS

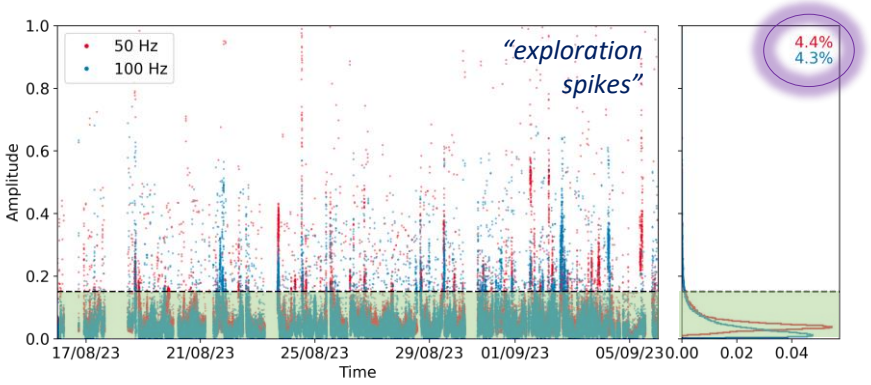
- EAST T9 / T10 steering
- **MTE efficiency**

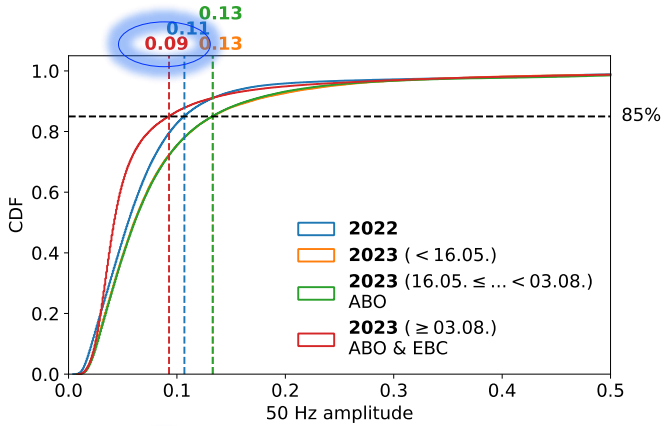
Trajectory steering framework

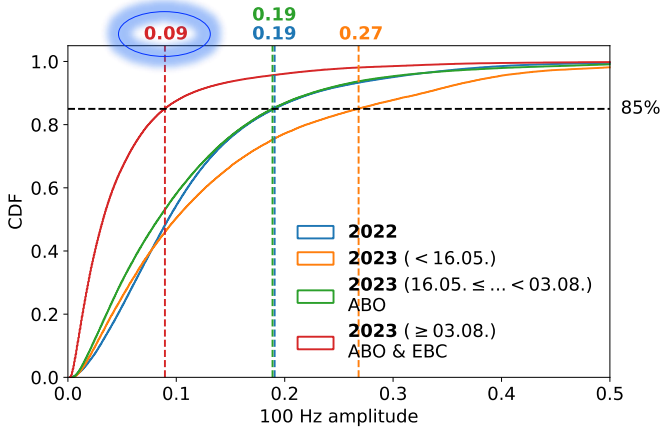
Auto-pilots, optimizers, and frameworks

Some news & highlights

- **50 Hz & 100 Hz noise from power converter ripple**
- **2022:** auto-launch numerical optimizer
  - Effective for 50 Hz, but **not for 100 Hz**
  - Phases of **strong exploration**
- **2023:** continuous control & EBC
  - **Adaptive Bayesian optimization** (ABO): feed-forward spatio-temporal model
  - **Changes & improvements throughout the run**
  - **Tracks well** except for **"exploration spikes"** *follow up with simulations during YETS'23*
  - Treat like **expert equipment** with **on-call service**







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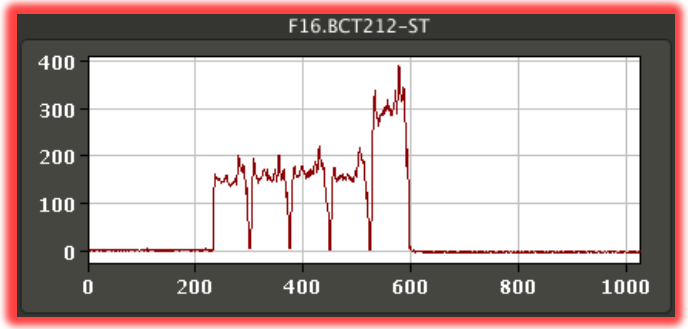
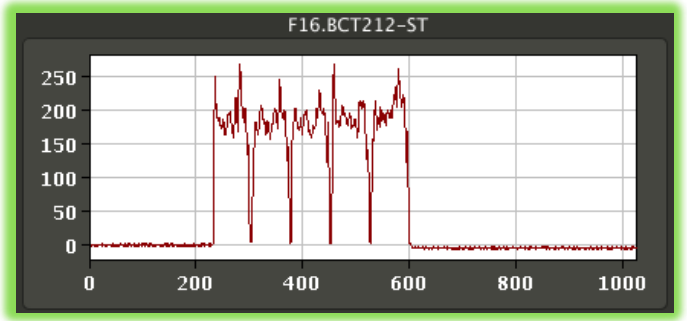
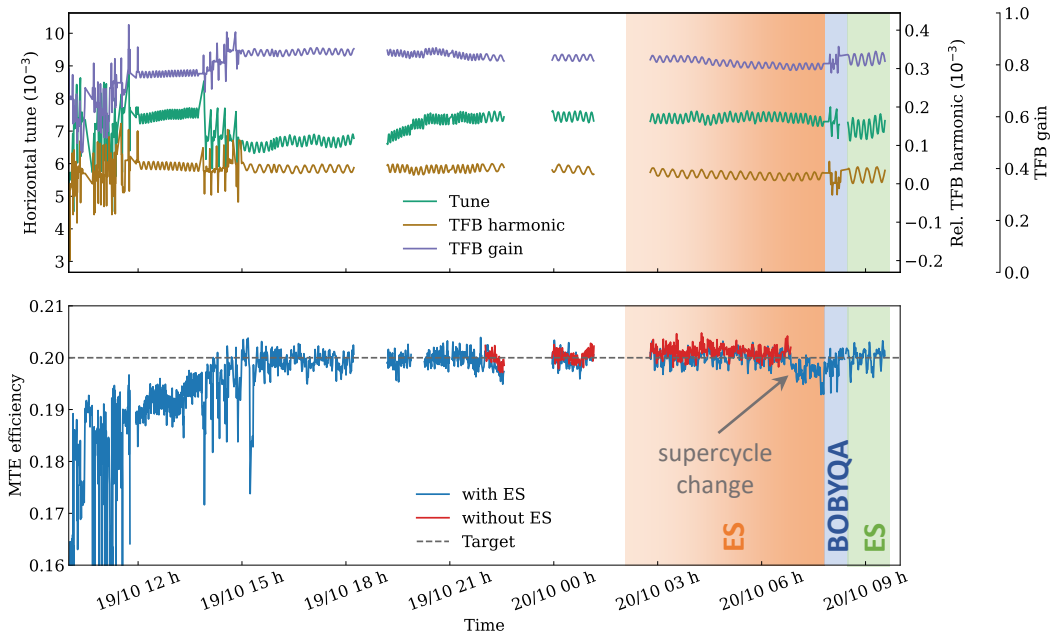
Auto-pilots, optimizers, and frameworks

Some news & highlights

- **PS MTE efficiency**
  - **Automatic drift compensation** studies started in **2022**
  - This year: GeOFF implementation **ported to acc-geoff4ucap**
  - **Successfully tested** and tuned in MDs (~15 h)
  - **Hybrid agent:** continuous controller interleaved with optimizer when far off target
    here: switching manually
  - **Operational test** beginning of 2024 run







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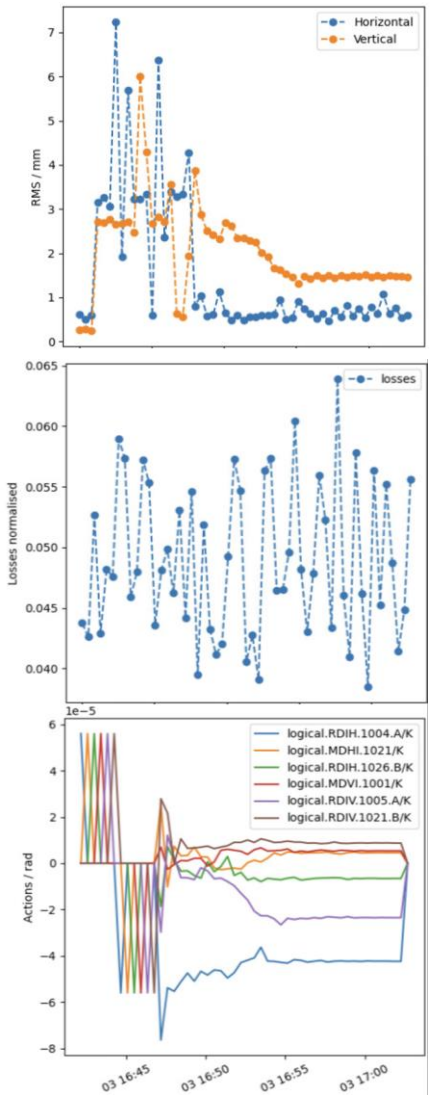
Auto-pilots, optimizers, and frameworks

Some news & highlights

- **Trajectory steering framework** using acc-geoff4ucap
  - **Versatile objective**
    Transmission, rms beam position, beam loss, etc.
  - **Generic settings management & actors**
  - **Data source:** adapt to case
    ALPS, BLMs, etc.
  - **Various algorithms**, incl. Micado / SVD

- **Status & plans**
  - **PS2SPS:** MDs in ‘23. Final test during commissioning ‘24, followed by operational run
  - **SPS2LHC:** implementation & tests to be planned
  - **FTN / FTA:** potentially optimize on transmission & position on target



MD results (PS2SPS)

SPS NA
- Target sharing
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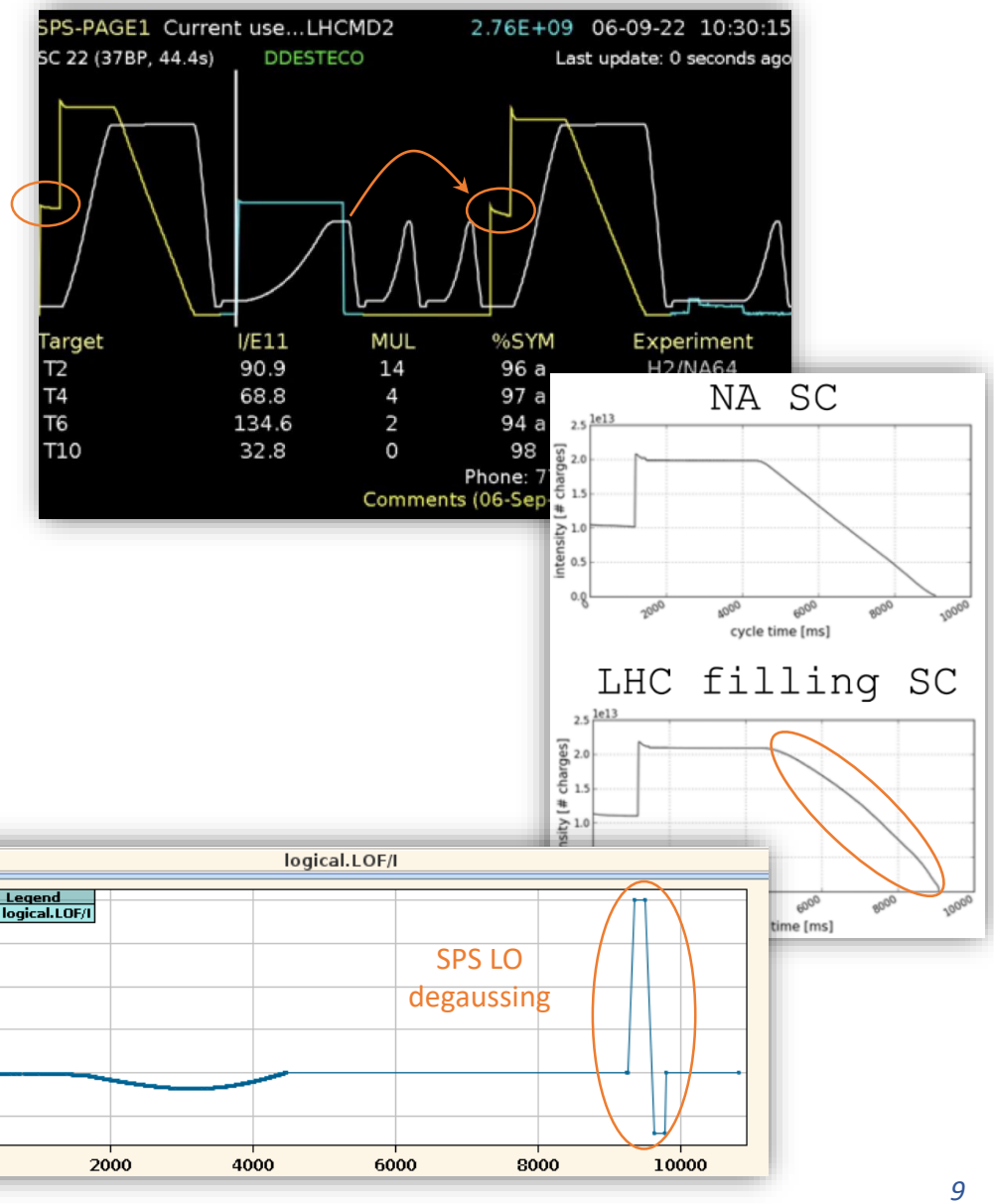
Trajectory steering framework

Contents

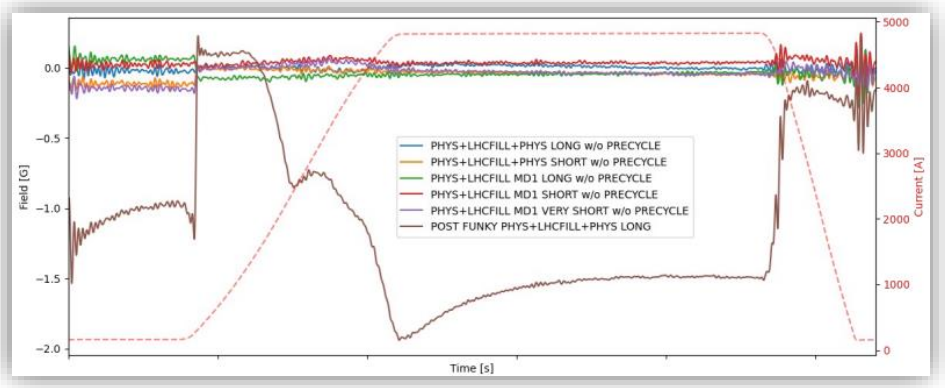
Hysteresis compensation
Overview

- **EPA WP4**
- **Motivation & goals**
  - **Feed-forward correction for reproducible magnetic field strengths**
    - **Saving** cost & time
    - **Reproducible** beams & SX spills
    - **Flexibility:** dynamic beam scheduling *(EPA WP1)*
- **Status & progress 2023**
  - PoC at SPS: **PhD project** since March ‘23
  - **Progress on all fronts:**
    data collection, model, integration



Hysteresis compensation

Status & progress in 2023



Data

SPS B-Train (dipoles) & Lab (other multipoles)

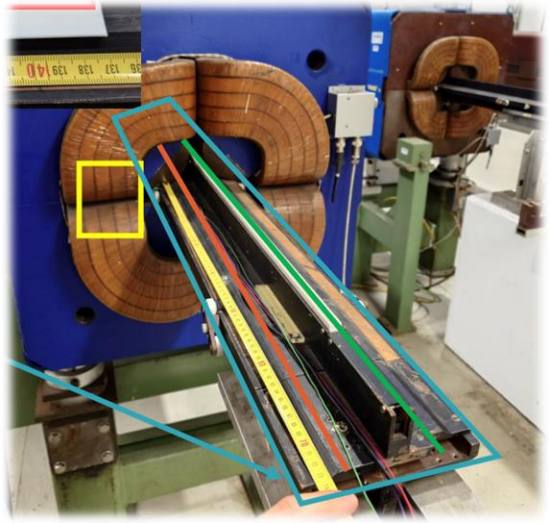
Model

Prediction of hysteresis & eddy-current effects based on historical measured and future set currents

Integration

Model deployment, feed-forward correction in controls infrastructure, and tests with beam

- **SPS B-Train**
  - **Parasitic to OP:** abundant, but lacking variability
  - **Dedicated:** 2 h slot exploring supercycle variations
    - *Very **valuable** for dipole **model training***
    - ***New insights** to hysteretic and eddy-current behaviour*
- **Lab**
  - **Quadrupole campaign** has started
  - **Sensor fusion:** Hall probe & flux meter
  - **Plans 2024:** measure sextupoles & octupoles, improve setup for quadrupoles?
- **Challenges**
  - Securing adequate **data variability**
  - **Lab:** baseline drift correction for flux meter data



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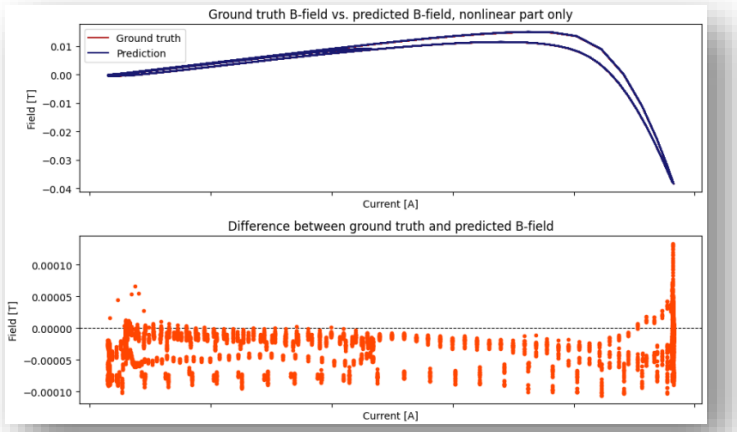
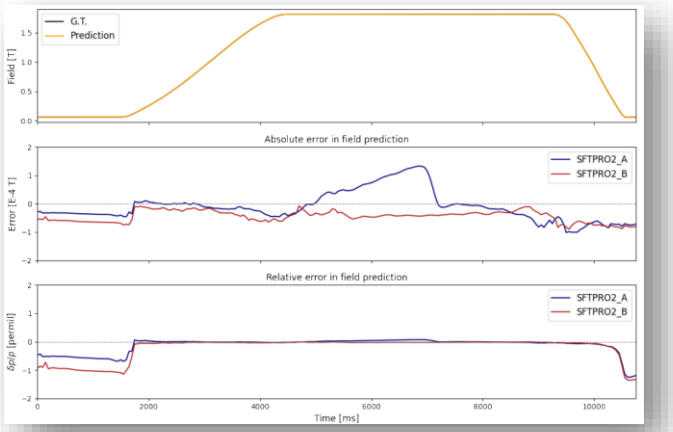
- **Two time-series models under study**
  - **PhyLSTM:** physics-inspired loss function
  - **Temporal Fusion Transformer**
    - ***Powerful**, but **data hungry** and **compute-intensive** training*
  - **Plans 2024:** explore **alternatives**, exploit **new data sets**
- **Challenges**
  - **Achieving sub-Gauss accuracy:** crucial at low beam energies
  - **Tracking hysteretic state**





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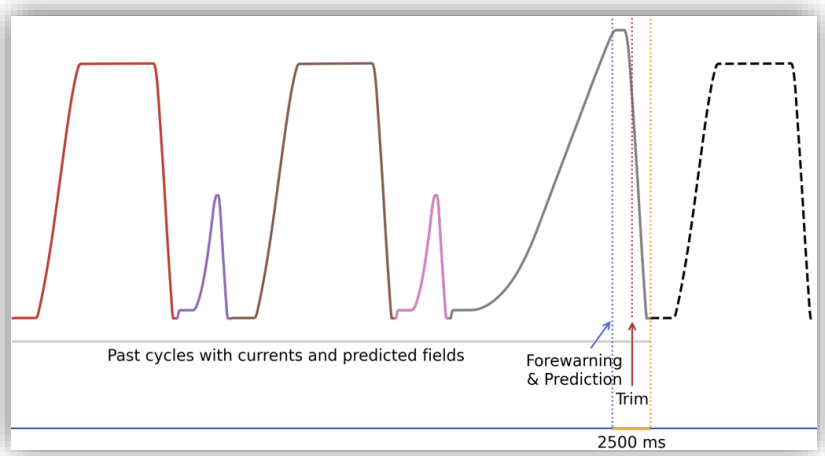
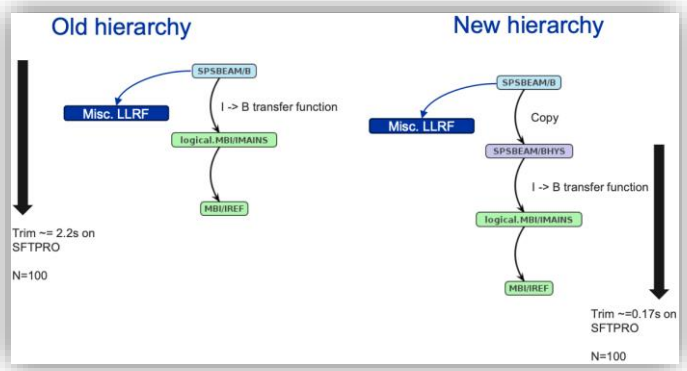
Model deployment, feed-forward correction in controls infrastructure, and tests with beam

- **Feed-forward correction**
  - **Reproducible magnetic fields** for every timing user
  - **2.5 s** to **calculate & apply ΔB trim** before next cycle starts
    GPU on TN VM
- **Tests with beam**
  - **Works conceptually:** ΔB is applied in time
  - **Issue with < 2 BP cycles:** new LTIM during YETS'23
  - **Plans 2024:** dedicated MDs to evaluate new models

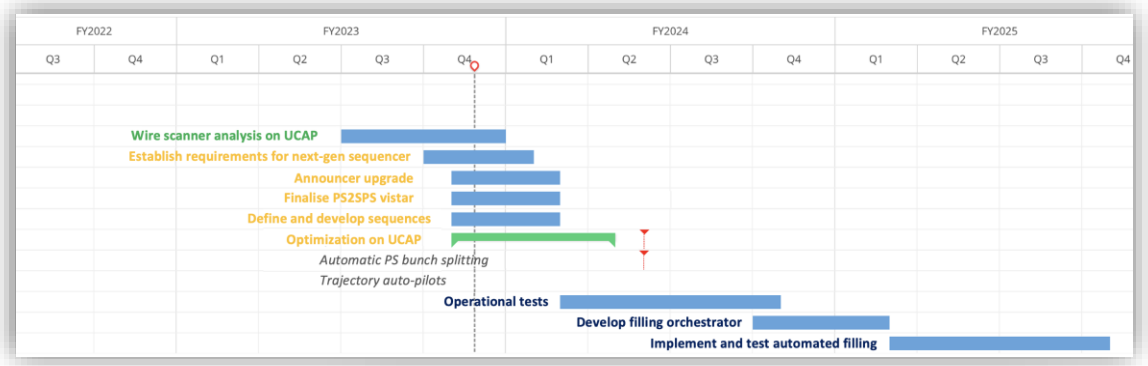




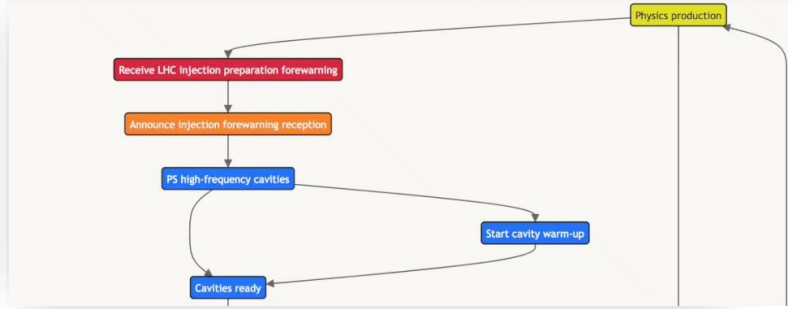
Contents

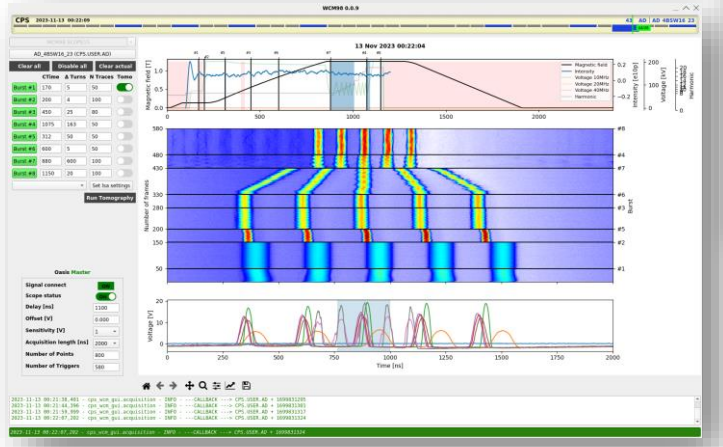
Automated LHC filling

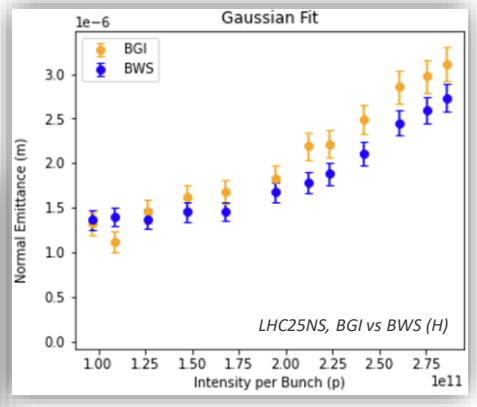
Status & progress in 2023



- **EPA WP2**
- **Progress on various fronts in 2023**
  - Established **event sequence**, defined **tasks** & **timeline**
  - **Ongoing:** beam observation, quality metrics & vistars, trajectory auto-pilots & bunch splitting automation
- **PS beam observations**
  - **Transverse emittances**
    - **Wirescanner analysis** on UCAP (PSB, PS, SPS)
    - **BGI benchmarking** campaign *(see Clara's talk)*
  - **Longitudinal**
    - **New wall current monitor** since YETS'22
    - **Developed GUI:** burst acquisition, visualization, OASIS integration, tomographic analysis
    - Implemented **last-turn logging**



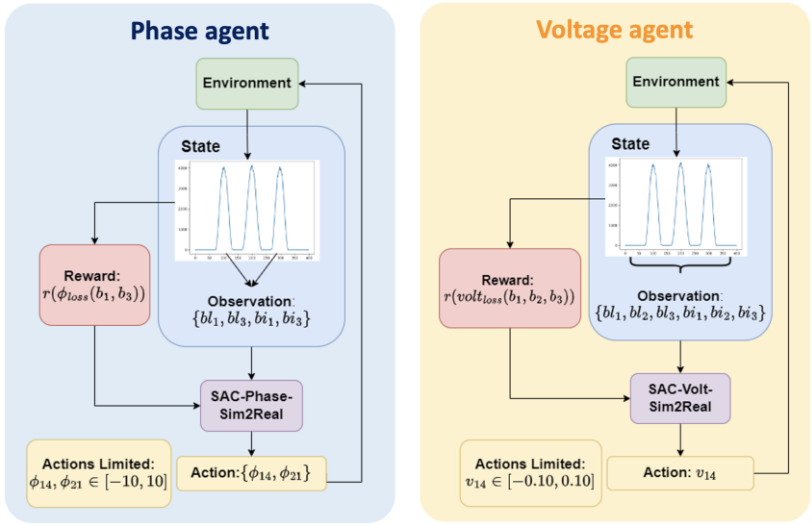




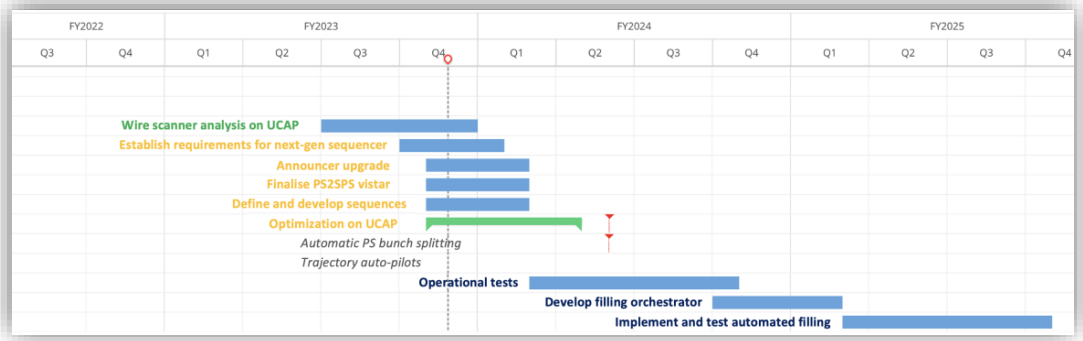
Automated LHC filling

Status & progress in 2023

- **Optimization on UCAP**
  - **Trajectory auto-pilots:** based on steering framework
  - **Automatic bunch splitting**
    - **Triple splitting**
      RL agents + CNN: operational with manual procedure
      ➡ **transfer to UCAP** during YETS'23
    - **Double splittings:**
      develop new approach and move to UCAP



- **Plans 2024**
  - **Semi-automatic** filling tests & define **Sequencer v2.0** requirements *(EPA WP5)*
  - Continue **online monitoring** efforts and define **beam quality metrics**



Conclusions

- **Auto-pilots, optimizers and frameworks**
  - **Trends:** from **on-demand to continuous**, from **local to server**, extensive use of **UCAP**, some **new controllers**
  - **Frameworks:** maintain **uniformity**
  - Controller tuning **requires beam time:** MDs & operational tests
    - ➡ **worthy investment:** various examples with **beam quality improvements for users**
- **Hysteresis compensation**
  - Progress on **data collection, modeling, and integration**
  - First **tests with beam & dedicated data collection:** very insightful
  - **Main challenges:** data variability, sub-Gauss accuracy, tracking hysteretic state
- **LHC automated filing**
  - Defined **concept & strategy**
  - Progress on **beam observations** and **transfer line auto-pilots**

Thank you

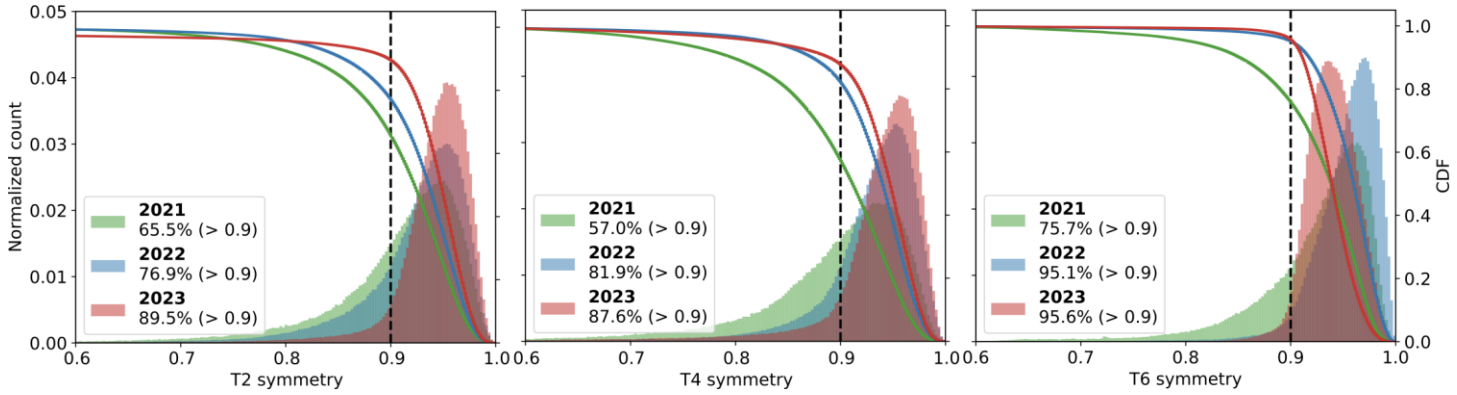
Backup

Auto-pilots, optimizers, and frameworks

Some news & highlights

- **Target sharing**
  - PID controller in place since August ’23

- **Target symmetries**
  - Continous control via YASP *(since 2022)*
  - KPI has been increasing over the years
  - Thanks to line resteering no longer face issue with corrector dipole polarity change reported at JAPW’22



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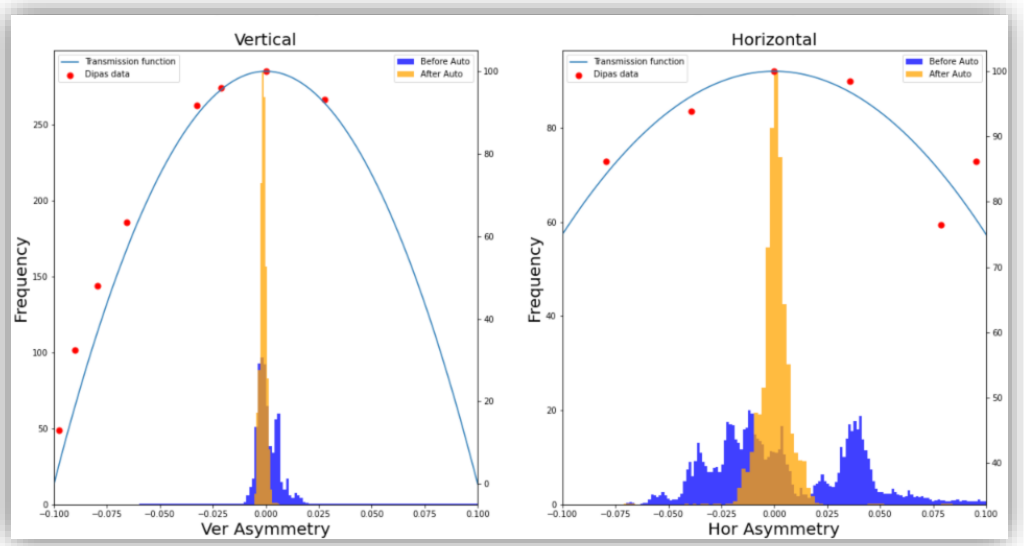
- EAST T9 / T10 steering
- **MTE efficiency**

Transfer line steering framework

Auto-pilots, optimizers, and frameworks

Some news & highlights

- **T9 / T10 steering**
  - P[ID]-regulator **on UCAP**
  - **Very effective**
  - **Integrate with acc-geoff4ucap** during YETS'23



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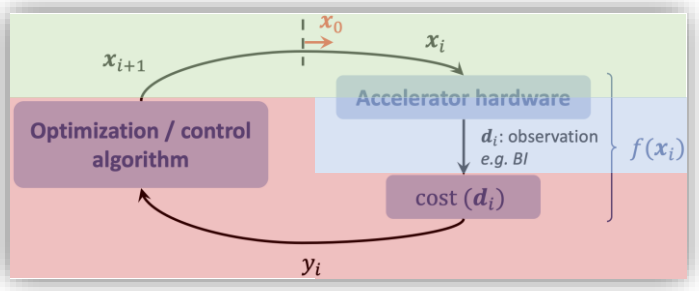
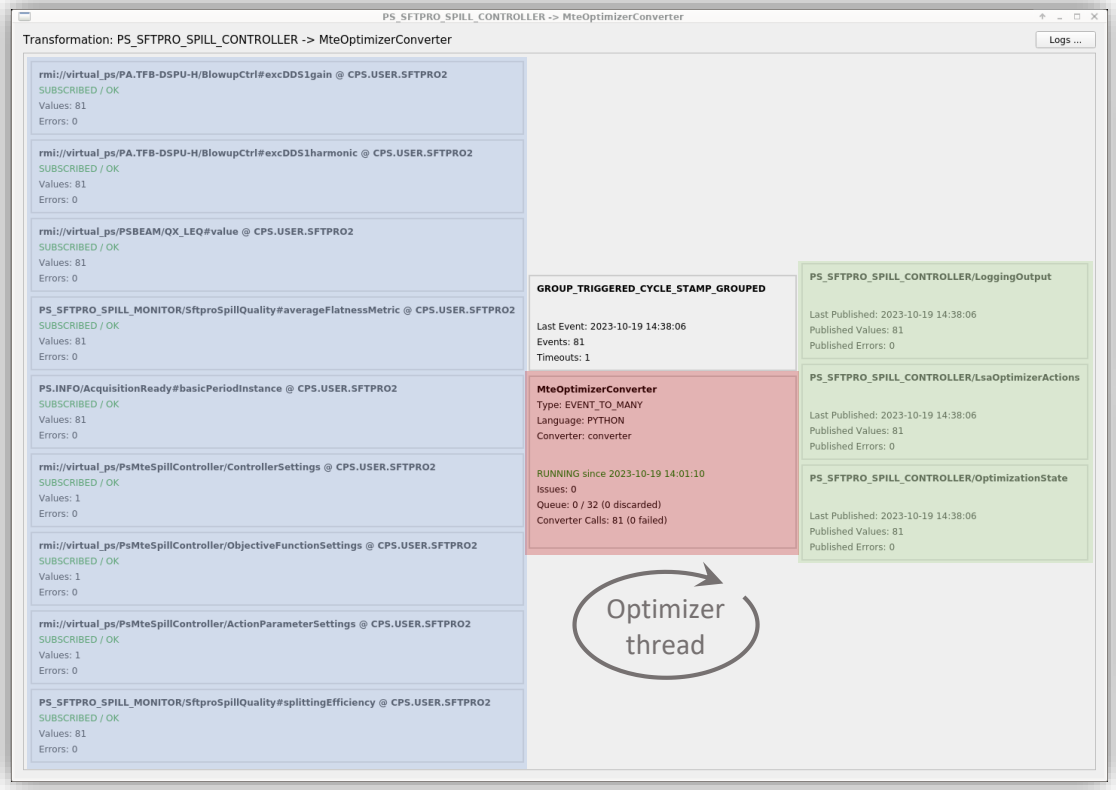
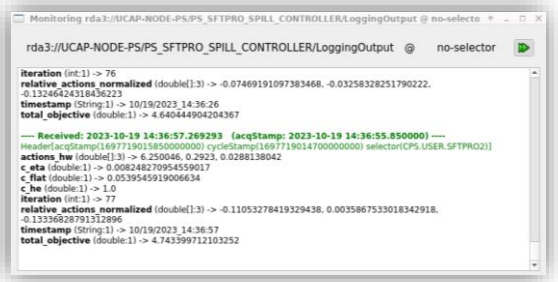
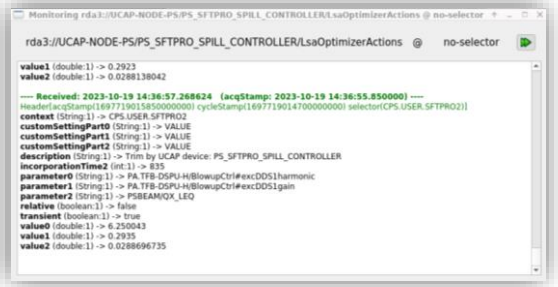
acc-geoff4ucap – an example: PS MTE controller









Subscriptions
data sources to calculate objective, change hyperparameters, etc.

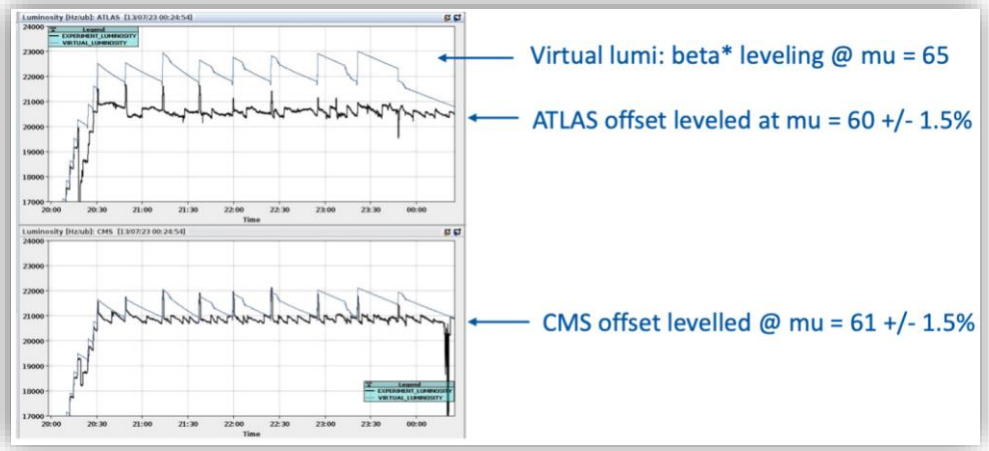
Converter
triggers run, handles optimization loop

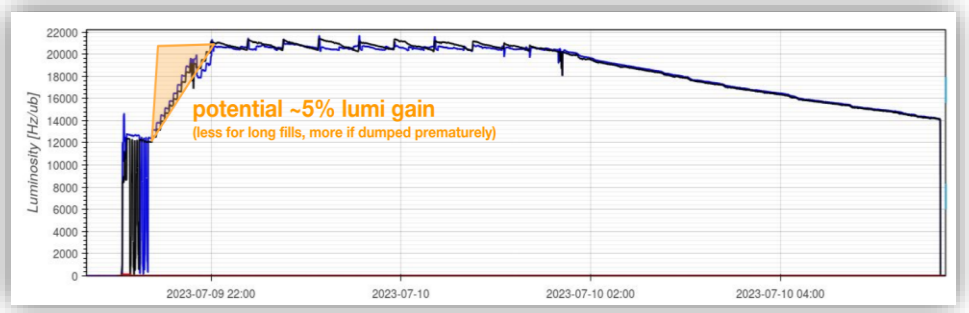
Publications
parameter sets (PyJapc, LSA), diagnostics

LHC: lumi-leveling
What's new in 2023?

Virtual lumi-leveling

- **β^* leveling:** discrete optics sets implying $\pm$2.5 % lumi steps
- **Offset leveling:** preferred by ATLAS & CMS
  - **Combine:** β^*-leveling for "virtual experiment" plus offset leveling for ATLAS & CMS
  - **Running automatically** during the **last 2 weeks** of the **2023 p run**





Faster β^* steps

- **2023:** squeeze ends at β^* = 120 cm
  optimized for N_b = 1.8 x 10^{11} ppb
  - But, limited to N_b = 1.6 x 10^{11} ppb: **45' to reach target lumi**
- **Potential reduction to < 10'**
  - **Segmented collimation limits** prevent skipping steps
  - Introduced **cumulative limit functions, tested** with setup beam
  - **MPP approved to go ahead:** dry-test, followed by small jumps, and gradual increase by fill