



Automating accelerators

evolution since last year

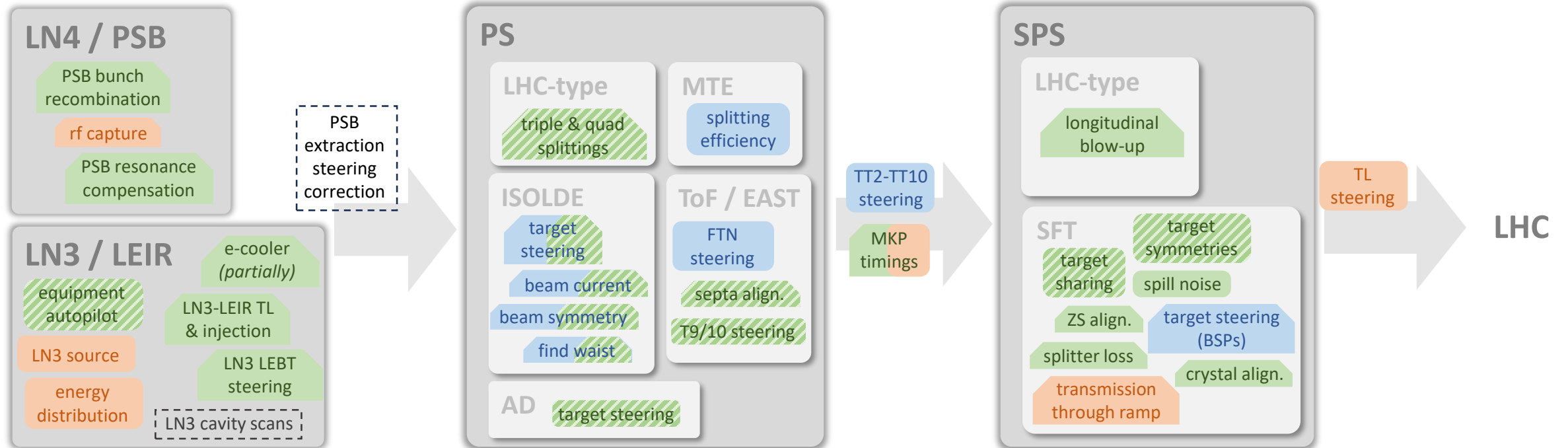
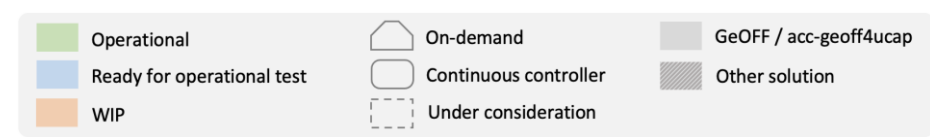
M. Schenk with input from: P. Arrutia, D. Banerjee, G.P. Di Giovanni, Y. Dutheil, F. Follin, M. Fraser, M. Hostettler, A. Huschauer, V. Kain, D. Krefta, A. Lasheen, K. Li, A. Lu, N. Madysa, J. McCarthy, B. Mikulec, H. Pahl, K. Papastergiou, R. Scrivens, P. Skowronski, G. Trad, F. Velotti, E. Veyrunes,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

Contents

- **Auto-pilots, optimizers, and frameworks** *(EPA WP3)*
- **Hysteresis compensation** *(EPA WP4)*
- **Automated LHC filling** *(EPA WP2)*
- **Conclusions**

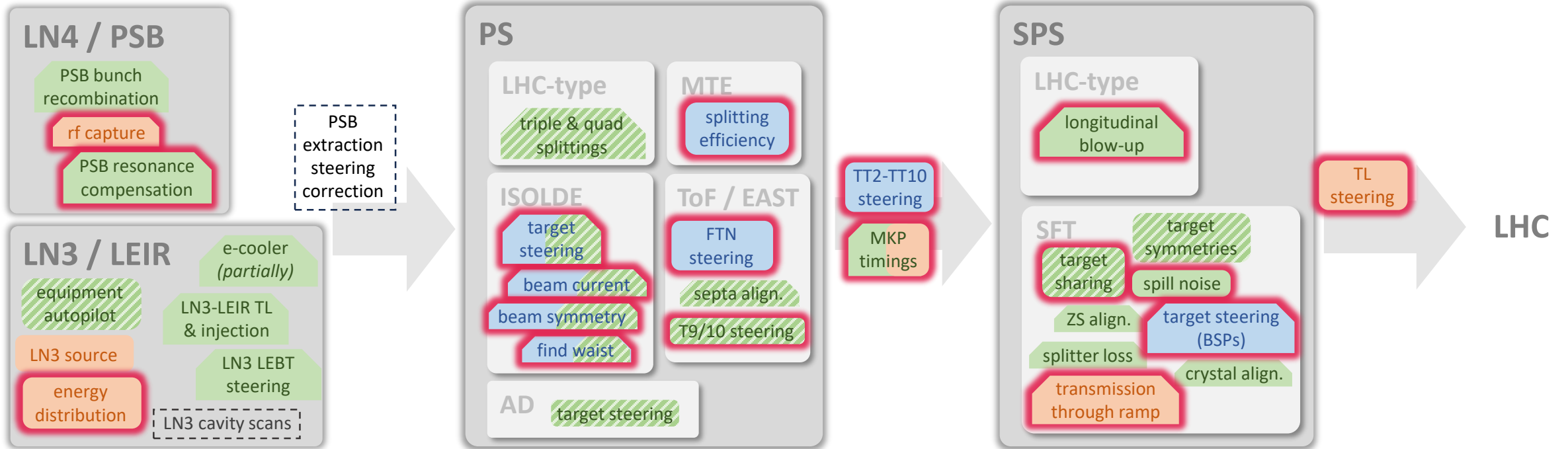
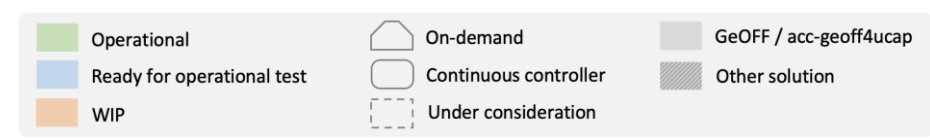
Auto-pilots, optimizers, and frameworks

An incomplete overview ...



Auto-pilots, optimizers, and frameworks

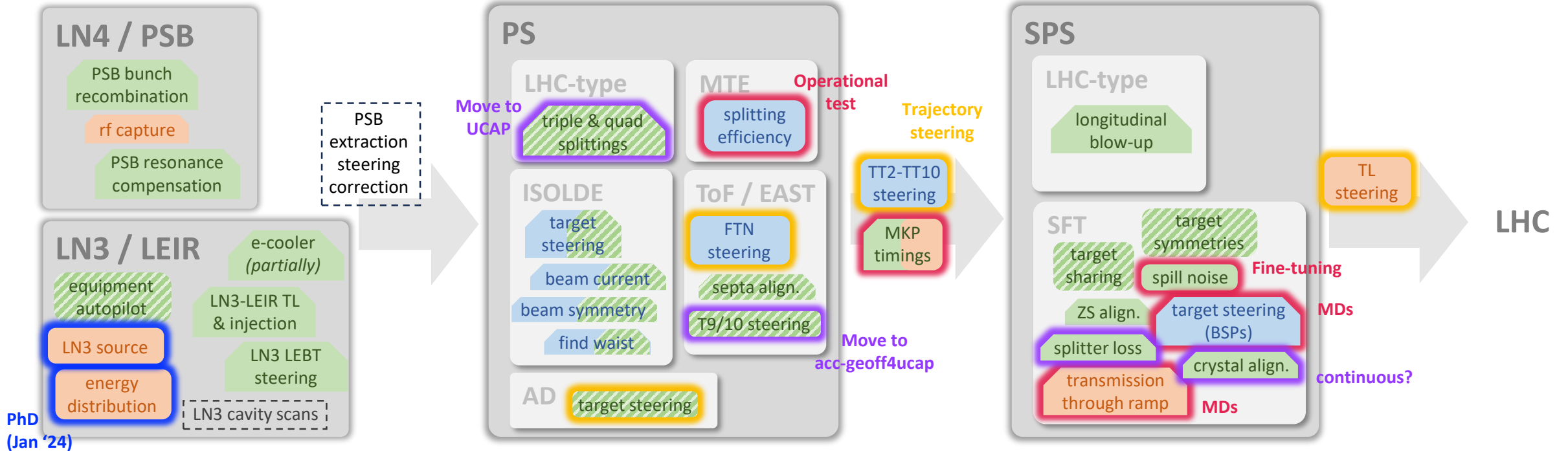
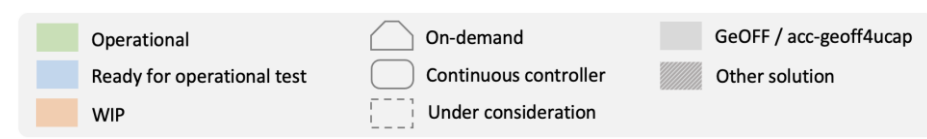
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- **Status 2023:** multiple new auto-pilots / optimizers under development – several used operationally
N.B. not all regularly used by OP: some expert tools, some for beam commissioning, some require more tuning / MD time, etc.

Auto-pilots, optimizers, and frameworks

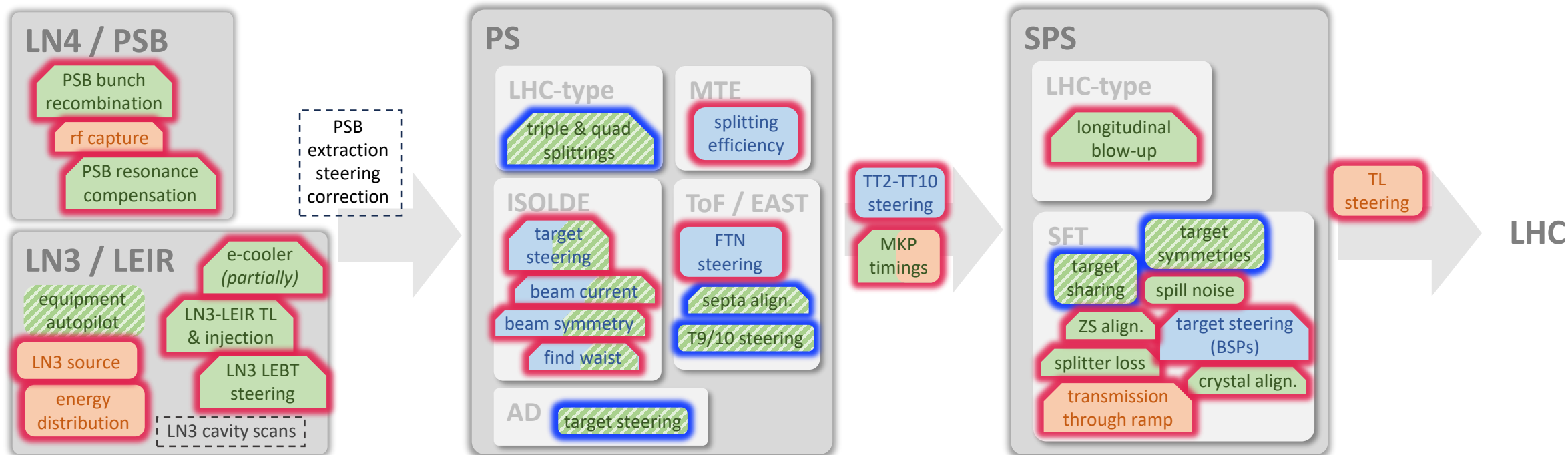
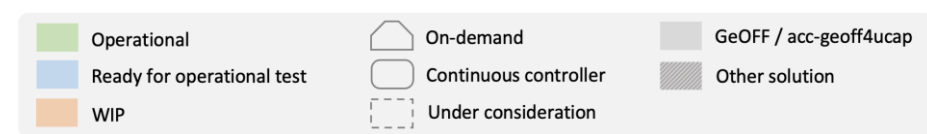
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Be aware of concurrency between controllers / humans & controllers, monitoring

Auto-pilots, optimizers, and frameworks

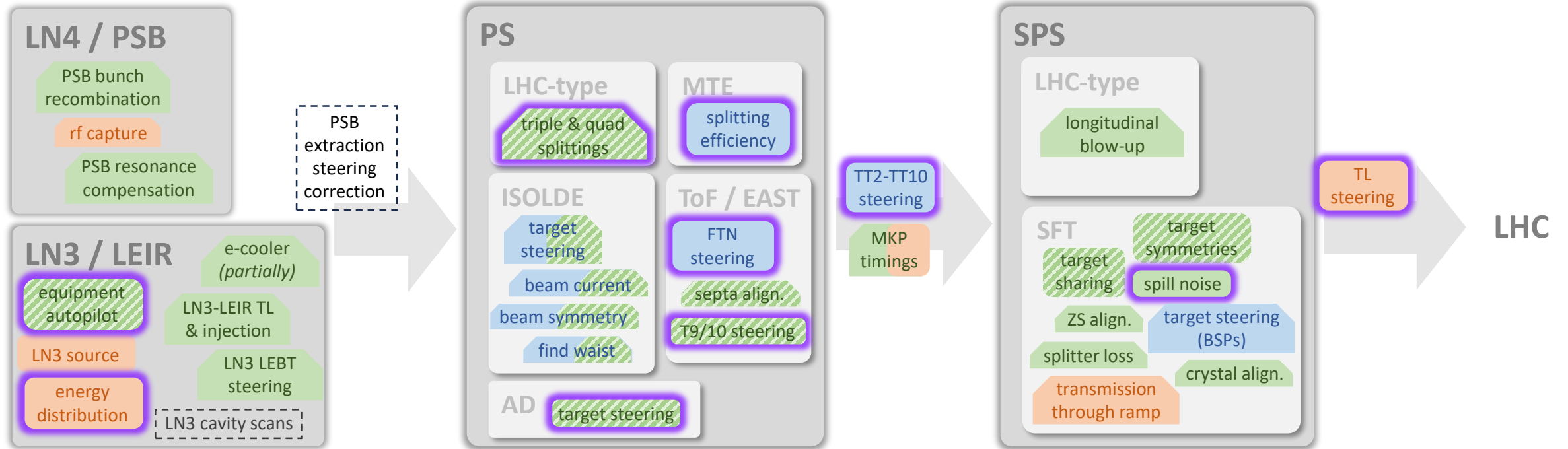
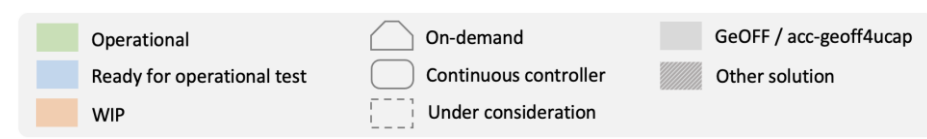
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- **Frameworks:** GeOFF (local & UCAP) | other solutions

Auto-pilots, optimizers, and frameworks

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

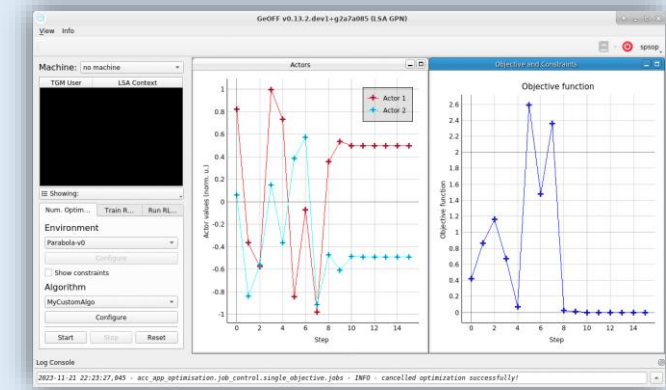
Auto-pilots, optimizers, and frameworks

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



UcapOptimizationProblem
(objective, x_0 , trigger, ...)

UcapControllerPublications
(action parameters, ...)

UcapOptimizer



UcapOptimizerConverter

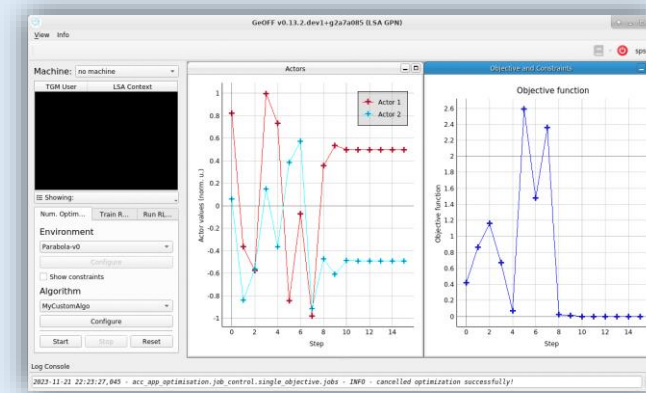
Auto-pilots, optimizers, and frameworks

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

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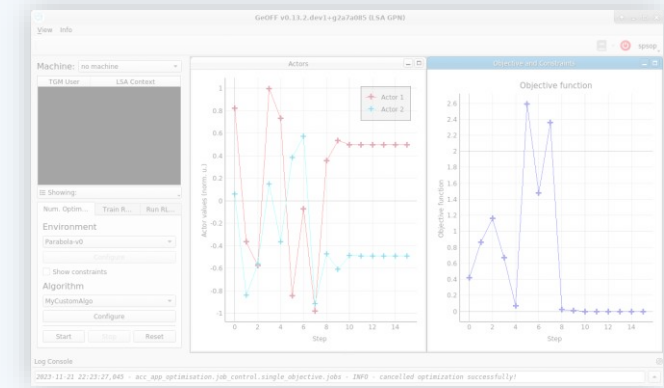
Auto-pilots, optimizers, and frameworks

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

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Auto-pilots, optimizers, and frameworks

Some news & highlights

SPS NA

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

PS

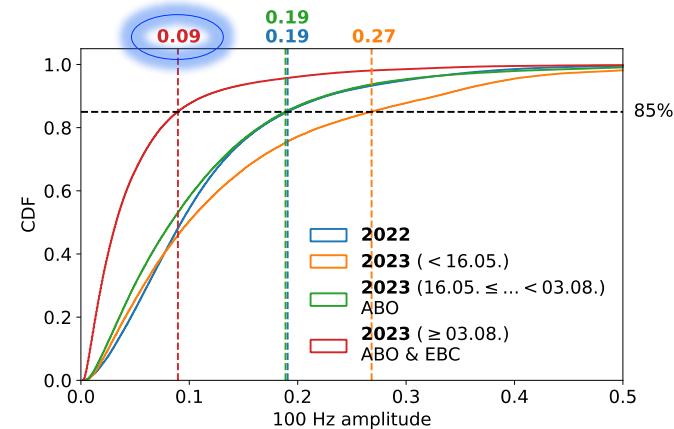
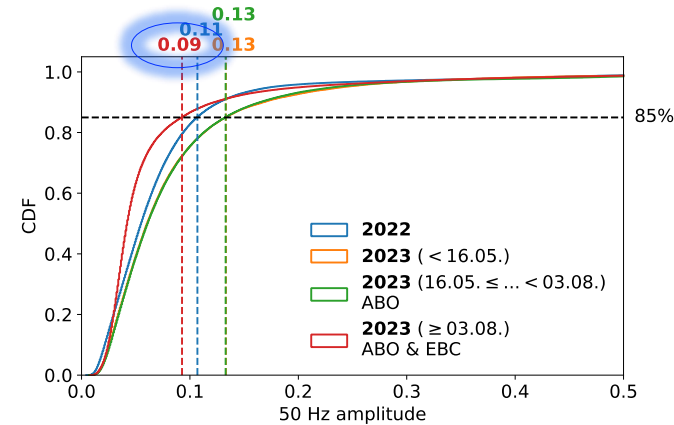
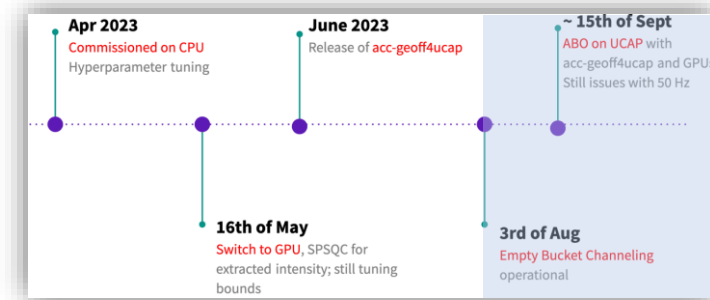
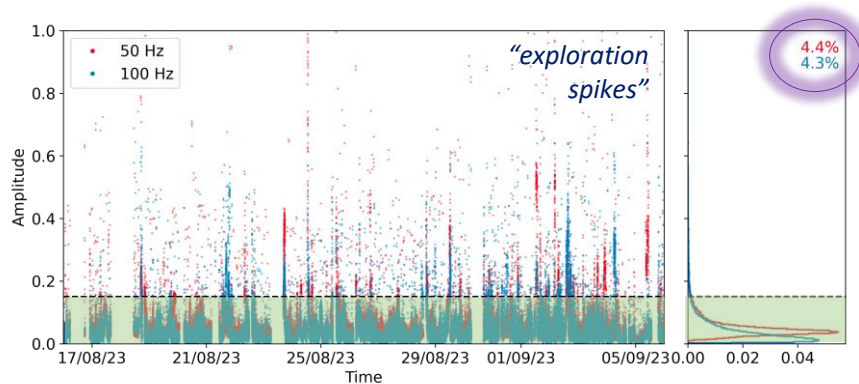
- EAST T9 / T10 steering
- **MTE efficiency**

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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Trajectory steering framework

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

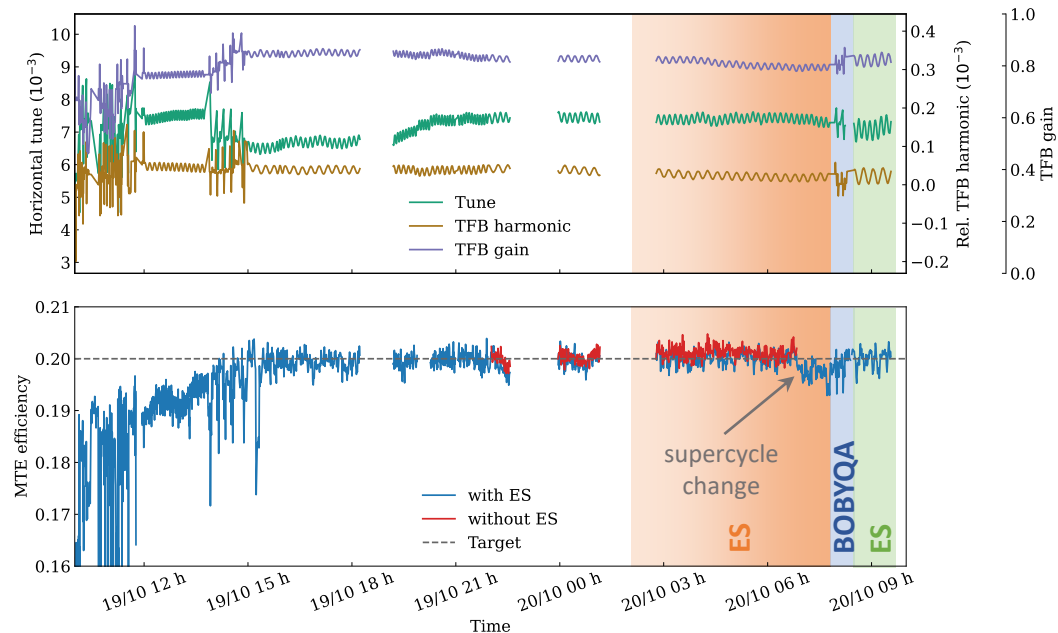
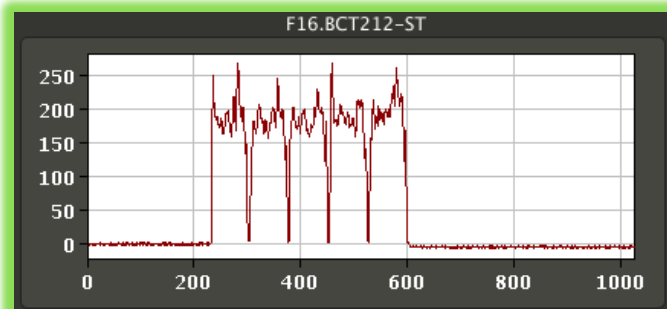
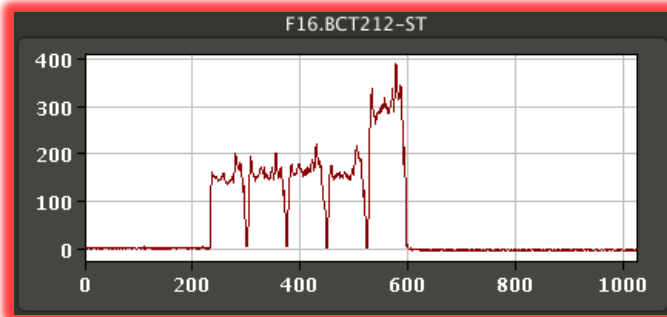
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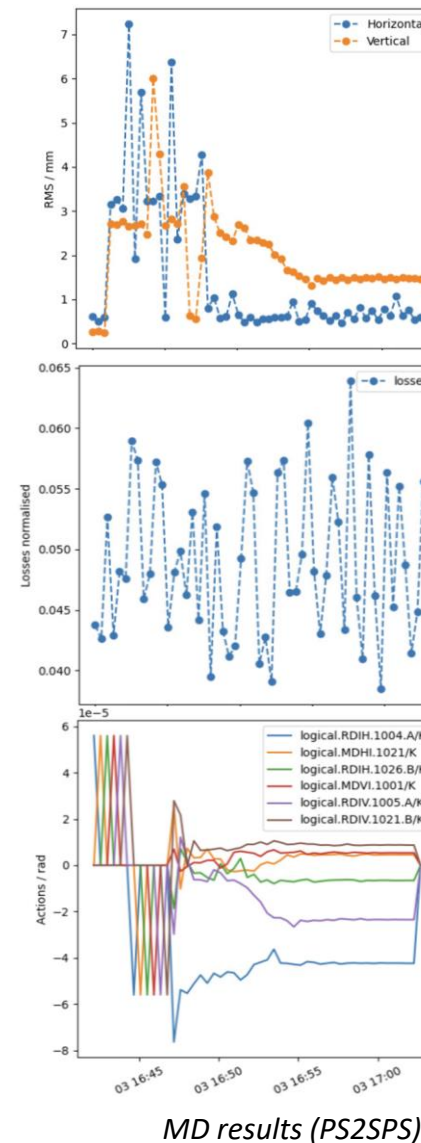
Trajectory steering framework



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



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Trajectory steering framework

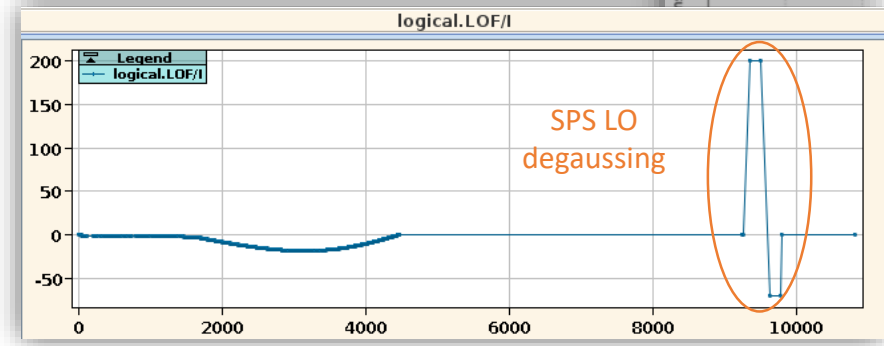
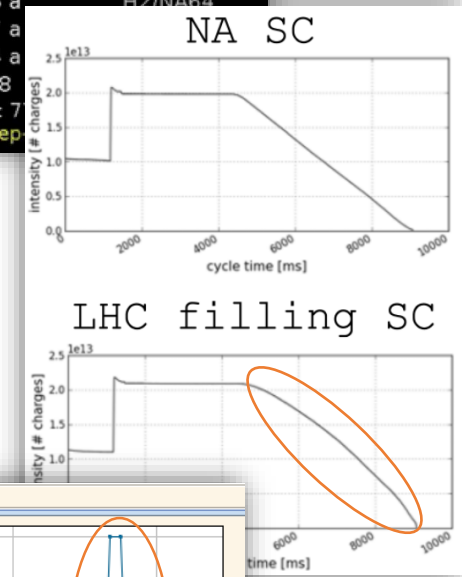
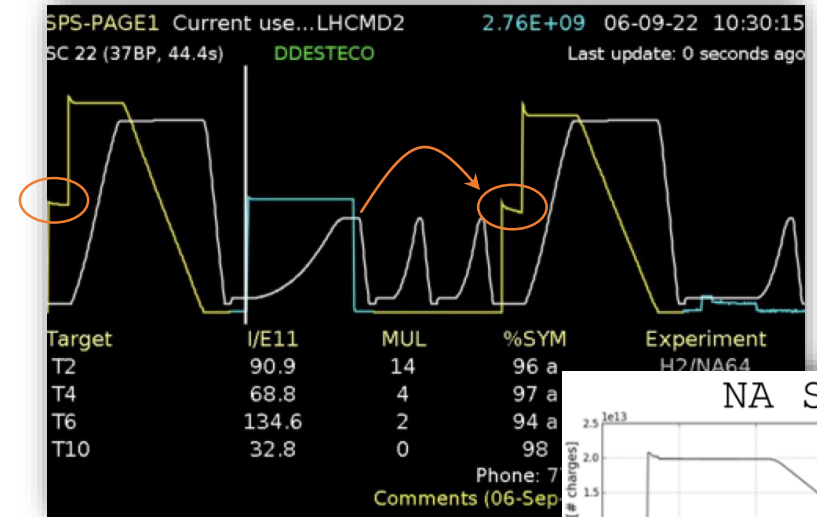
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Hysteresis compensation

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**

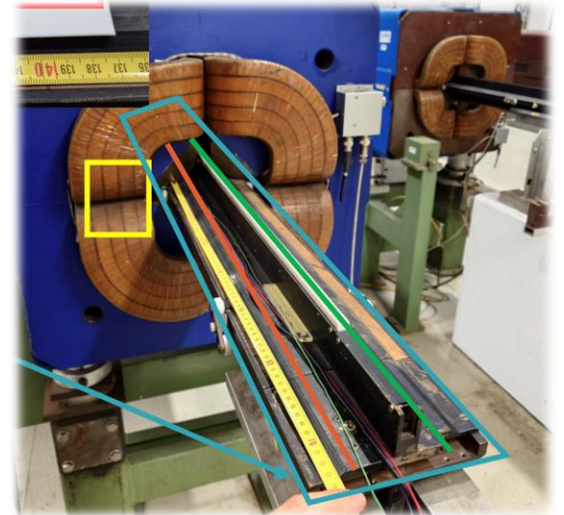
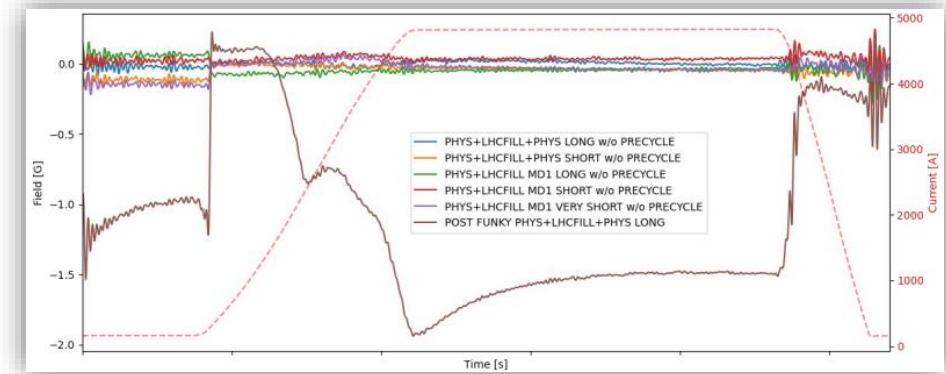
- **Parasitic to OP:** abundant, but lacking variability
- **Dedicated:** 2 h slot exploring supercycle variations
 - ➡ *Very valuable for dipole model training*
 - ➡ *New insights to hysteretic and eddy-current behaviour*

- **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



Hysteresis compensation

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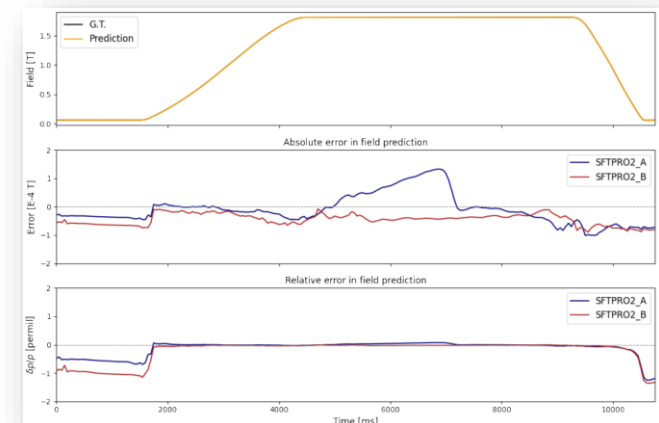
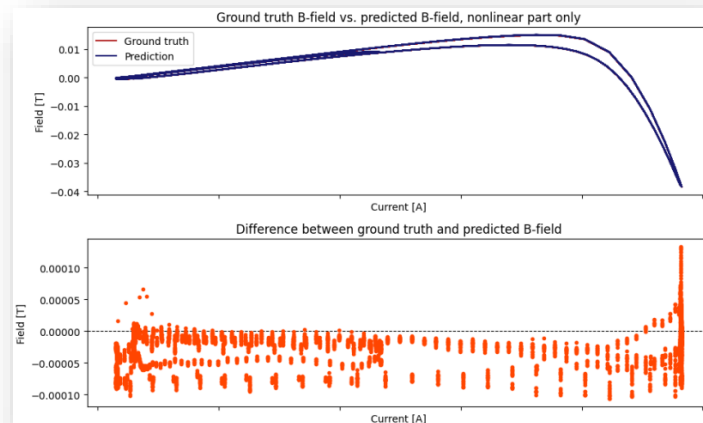
Model deployment, feed-
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- **Two time-series models under study**

- **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**



Hysteresis compensation

Status & progress in 2023

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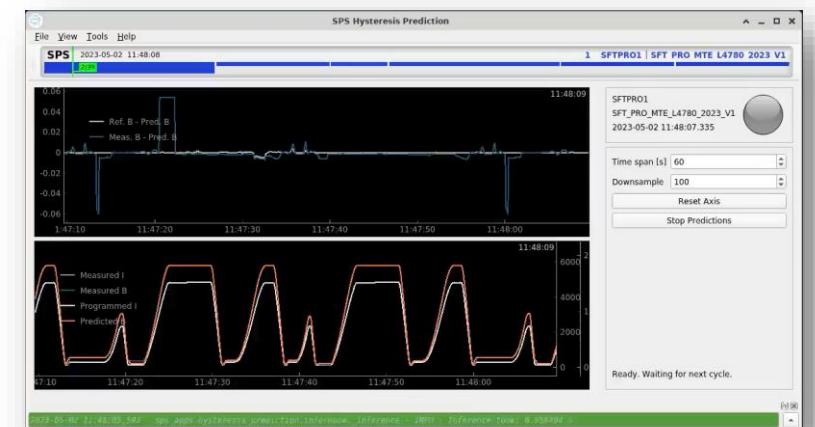
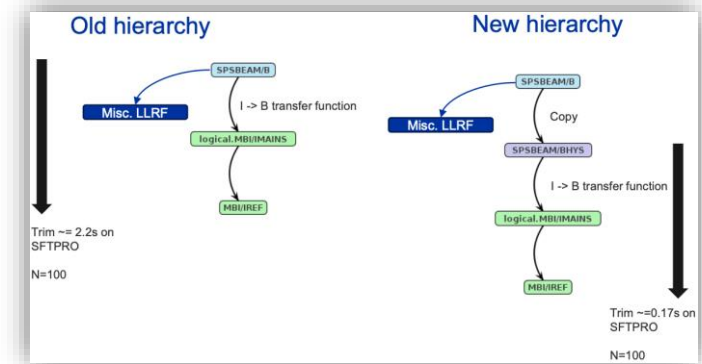
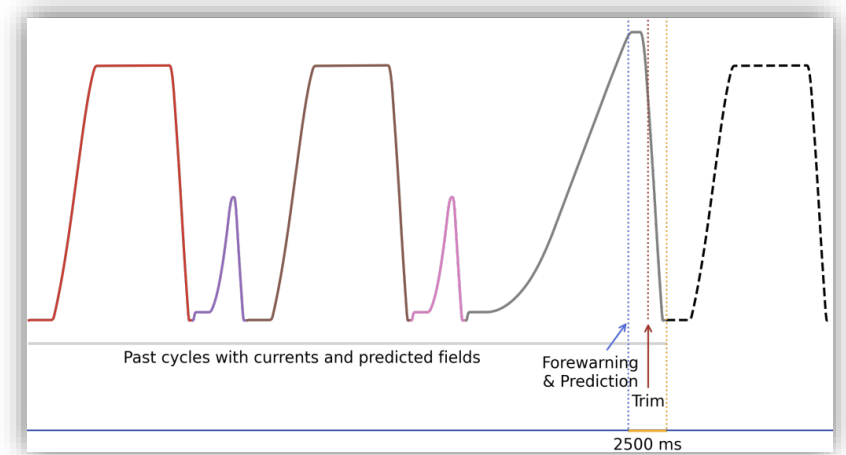
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Integration

Model deployment, feed-
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- **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



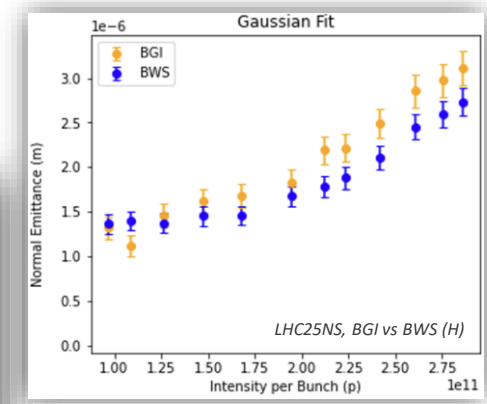
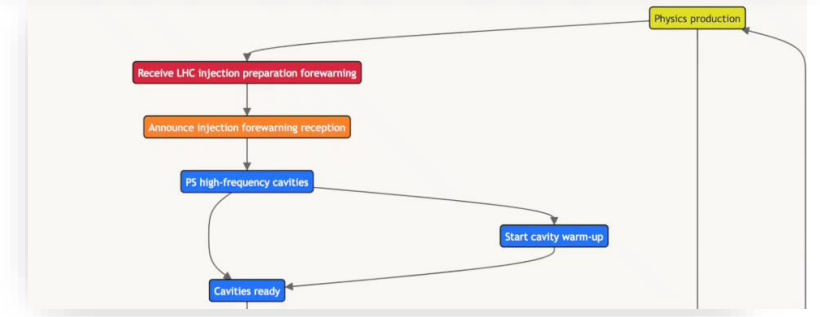
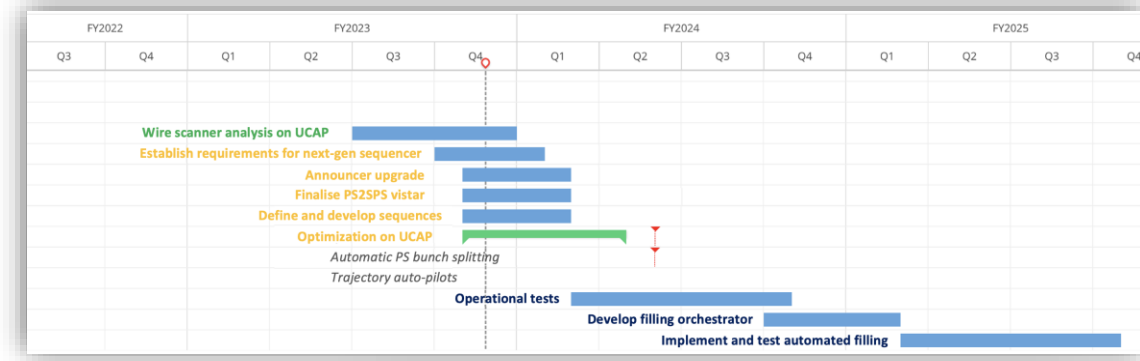
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Automated LHC filling

Status & progress in 2023

- EPA WP2
- Progress on various fronts in 2023
 - Established **event sequence**, defined **tasks & timeline**
 - **Ongoing:** beam observation, quality metrics & vistar, trajectory auto-pilots & bunch splitting automation
- PS beam observations
 - Transverse emittances
 - **Wiresscanner 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**

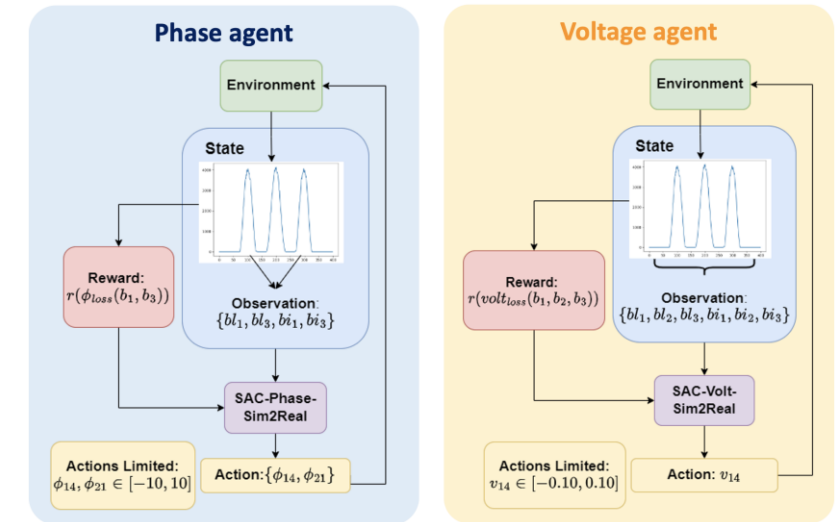


Automated LHC filling

Status & progress in 2023

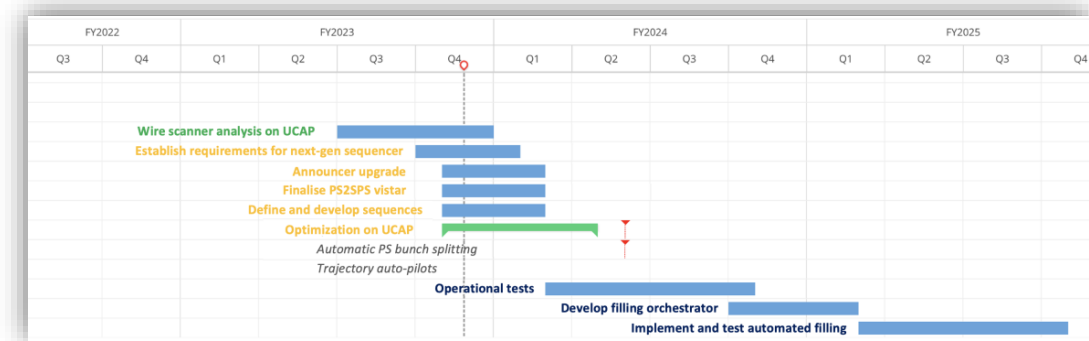
- **Optimization on UCAP**

- **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

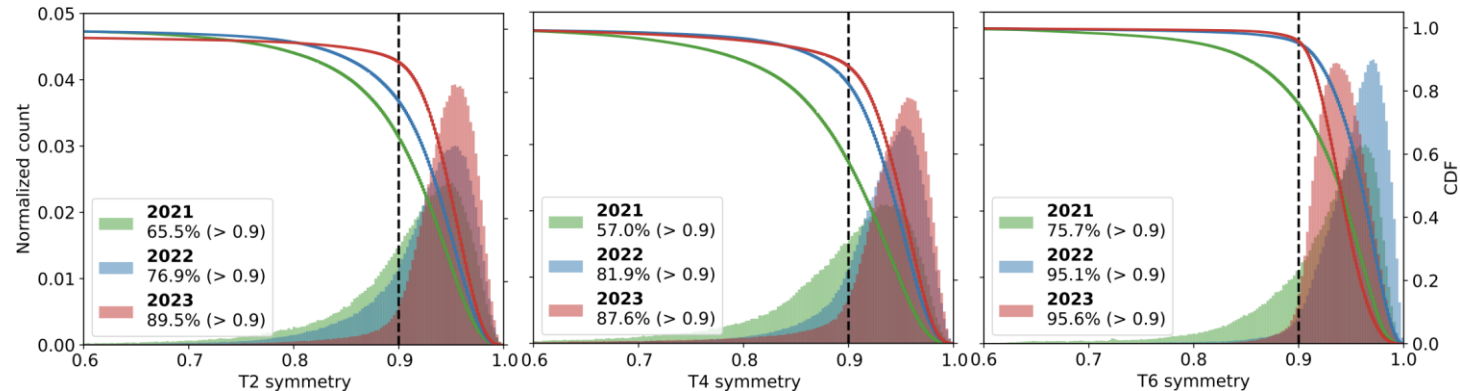
Some news & highlights

- **Target sharing**

- PID controller in place since August '23

- **Target symmetries**

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



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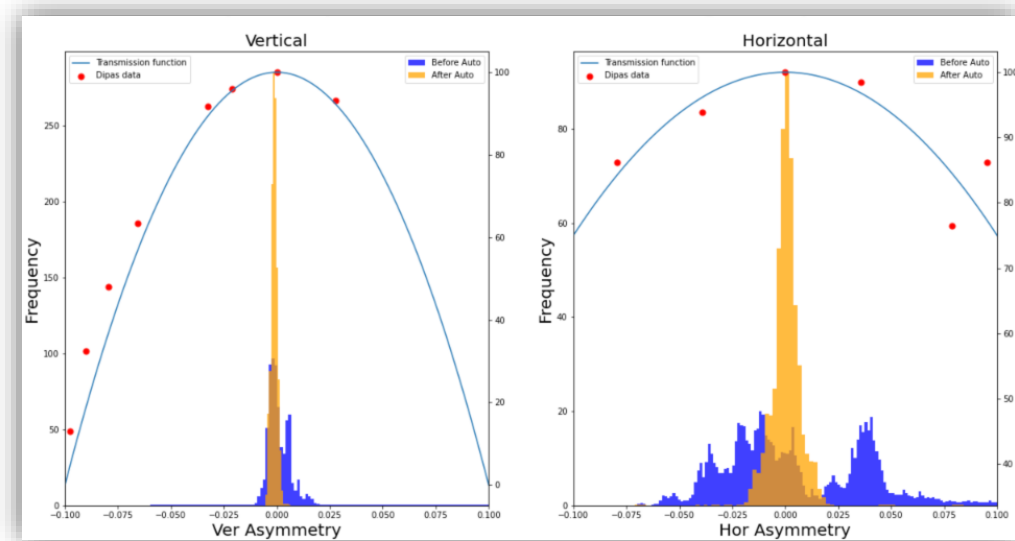
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Transfer line steering framework

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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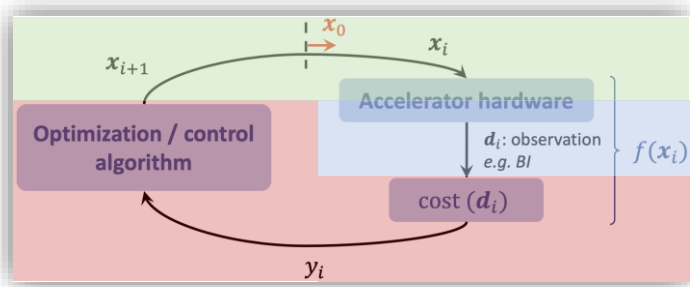
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Auto-pilots, optimizers, and frameworks

acc-geoff4ucap – an example: PS MTE controller



Transformation: PS_SFTPRO_SPILL_CONTROLLER -> MteOptimizerConverter

rmi://virtual_ps/PA.TFB-DSPU-H/BlowupCtrl#excDDS1gain @ CPS.USER.SFTPRO2 SUBSCRIBED / OK Values: 81 Errors: 0	<p>GROUP_TRIGGERED_CYCLE_STAMP_GROUPED</p> <p>Last Event: 2023-10-19 14:38:06 Events: 81 Timeouts: 1</p> <p>MteOptimizerConverter Type: EVENT_TO_MANY Language: PYTHON Converter: converter</p> <p>RUNNING since 2023-10-19 14:01:10 Issues: 0 Queue: 0 / 32 (0 discarded) Converter Calls: 81 (0 failed)</p>	PS_SFTPRO_SPILL_CONTROLLER/LoggingOutput Last Published: 2023-10-19 14:38:06 Published Values: 81 Published Errors: 0
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PS_INFO/AcquisitionReady#basicPeriodInstance @ CPS.USER.SFTPRO2 SUBSCRIBED / OK Values: 81 Errors: 0		
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rmi://virtual_ps/PsMteSpillController/ActionParameterSettings @ CPS.USER.SFTPRO2 SUBSCRIBED / OK Values: 1 Errors: 0		
PS_SFTPRO_SPILL_MONITOR/SftproSpillQuality#splittingEfficiency @ CPS.USER.SFTPRO2 SUBSCRIBED / OK Values: 81 Errors: 0		

Optimizer thread

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relative_actions_normalized (double[1:3]) -> -0.07469191097383468, -0.03258328251790222,
-0.13246424318436223
timestamp (String:1) -> 10/19/2023 14:36:26
total_objective (double:1) -> 4.640444904204367
--- Received: 2023-10-19 14:36:57.269293 (acqStamp: 2023-10-19 14:36:55.850000) ---
Header(acqStamp:1697719014700000000) cycleStamp:1697719014700000000 selector(CPS.USER.SFTPRO2)]
actions_hw (double[1:3]) -> 6.250046, 0.2923, 0.0288138042
c_gta (double:1) -> 0.008248270954559017
c_flat (double:1) -> 0.0539545919006634
c_he (double:1) -> 1.0
Iteration (int:1) -> 77
relative_actions_normalized (double[1:3]) -> -0.11053278419329438, 0.0035867533018342918,
-0.13336828791312896
timestamp (String:1) -> 10/19/2023 14:36:57
total_objective (double:1) -> 4.743599712103252
```

```
Monitoring rda3://UCAP-NODE-PS/PS_SFTPRO_SPILL_CONTROLLER/LsaOptimizerActions @ no-selector
value1 (double:1) -> 0.2923
value2 (double:1) -> 0.0288138042
--- Received: 2023-10-19 14:36:57.268624 (acqStamp: 2023-10-19 14:36:55.850000) ---
Header(acqStamp:1697719014700000000) cycleStamp:1697719014700000000 selector(CPS.USER.SFTPRO2)]
context (String:1) -> CPS.USER.SFTPRO2
customSettingPart0 (String:1) -> VALUE
customSettingPart1 (String:1) -> VALUE
customSettingPart2 (String:1) -> VALUE
description (String:1) -> Trim by UCAP device: PS_SFTPRO_SPILL_CONTROLLER
incorporationTime2 (int:1) -> 825
parameter0 (String:1) -> PA.TFB-DSPU-H/BlowupCtrl#excDDS1harmonic
parameter1 (String:1) -> PA.TFB-DSPU-H/BlowupCtrl#excDDS1gain
parameter2 (String:1) -> PSBEAM/QX_LEQ
relative (boolean:1) -> false
transient (boolean:1) -> true
value0 (double:1) -> 6.250043
value1 (double:1) -> 0.2923
value2 (double:1) -> 0.0288696735
```

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

Converter
triggers run, handles
optimization loop

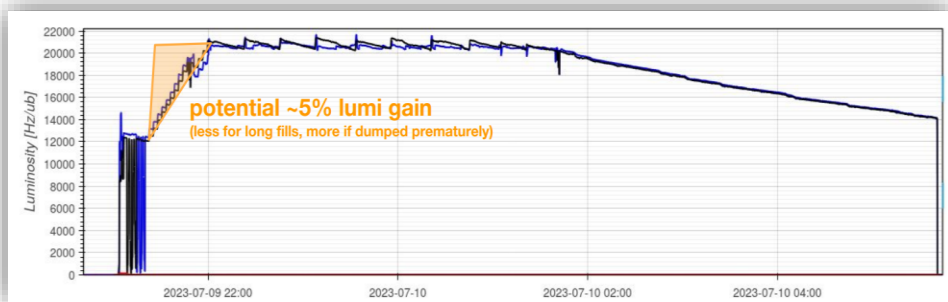
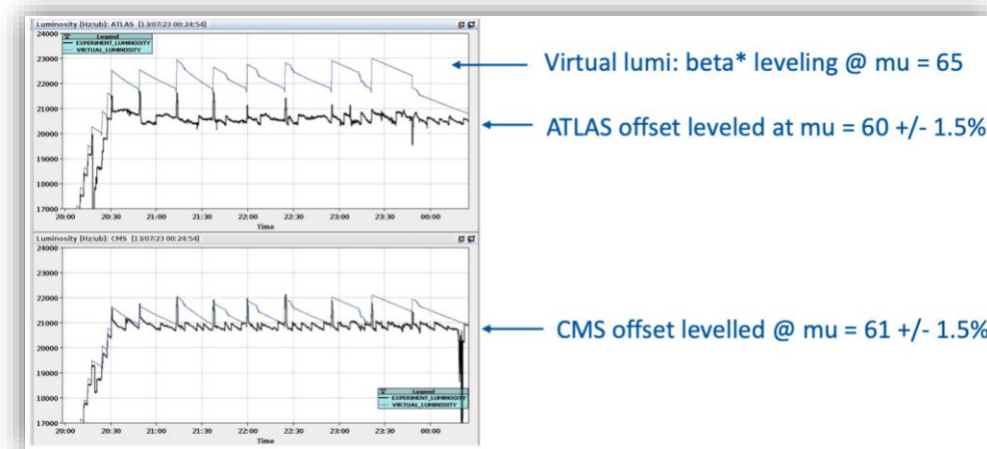
Publications
parameter sets
(PyJapc, LSA),
diagnostics

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 $\beta^* = 120$ cm optimized for $N_b = 1.8 \times 10^{11}$ ppb
 - ➔ But, limited to $N_b = 1.6 \times 10^{11}$ 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