
CERN

Setting the scene
Follow-up from last year's workshop

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and many more colleagues

08/12/22

Joint Accelerator Performance Workshop
CERN, 4-8 December 2022

Outline

- Introduction
- Efficiency
  - Beam scheduling and exploitation
- Automation and reproducibility
  - Optimization and machine learning
- Optimization of injector complex operation
  - Timing system flexibility
  - Tools, setting management
- Summary

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Introduction

Efficiency

Aggressive commissioning

Energy-efficient operation

Less time for same result

- **Expertise**
- **Software tools**

→ **Settings management**

→ **Optimizers**

→ **Machine learning**

Scheduled: optimize usage of facilities

- **Maximize beam for users**
- **Avoid any idling without beam**

→ **Beam destinations**

→ **Optimized cycling**

More with less?

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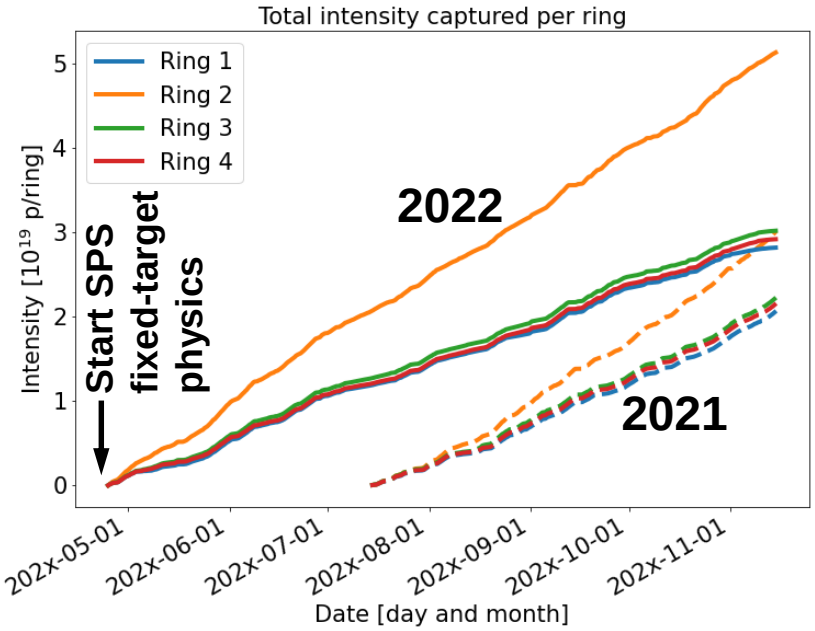
Scheduled efficiency – PSB

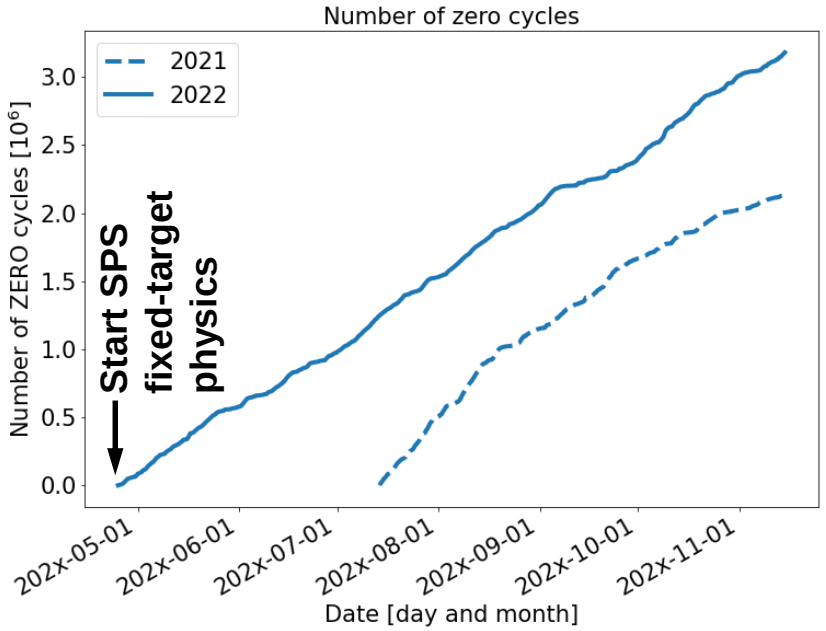
- **Different intensities from four ‘identical’ PSB rings***

→ **Ring 2 delivers 40 % more protons: bunch for nTOF**

→ **Rings 1, 3 and 4 could technically also deliver more**

***Commissioning not included**

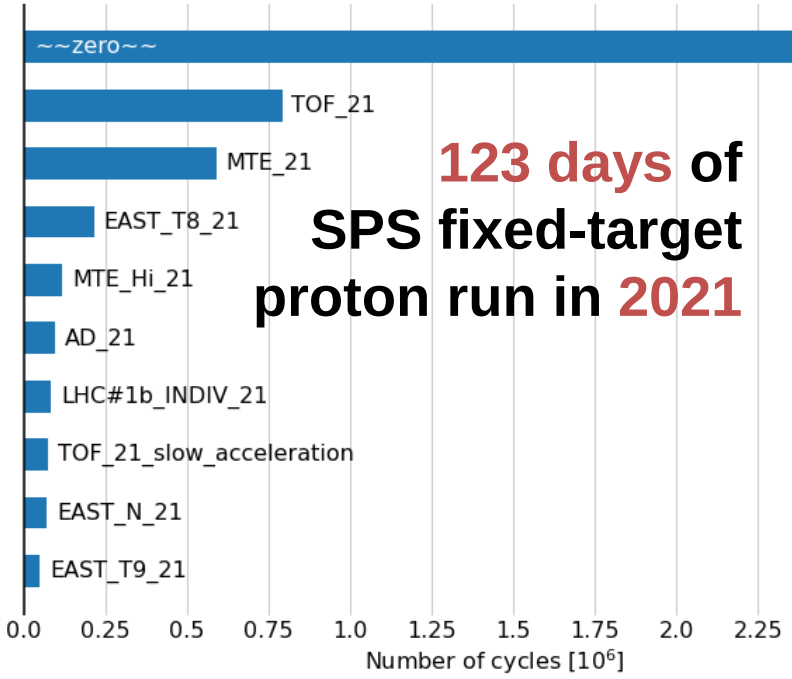




- **Combined extraction to PS (TOF) and ISOLDE?**
- **Idling facility which could produce beam for physics: many zero cycles → limited by beam destinations?**

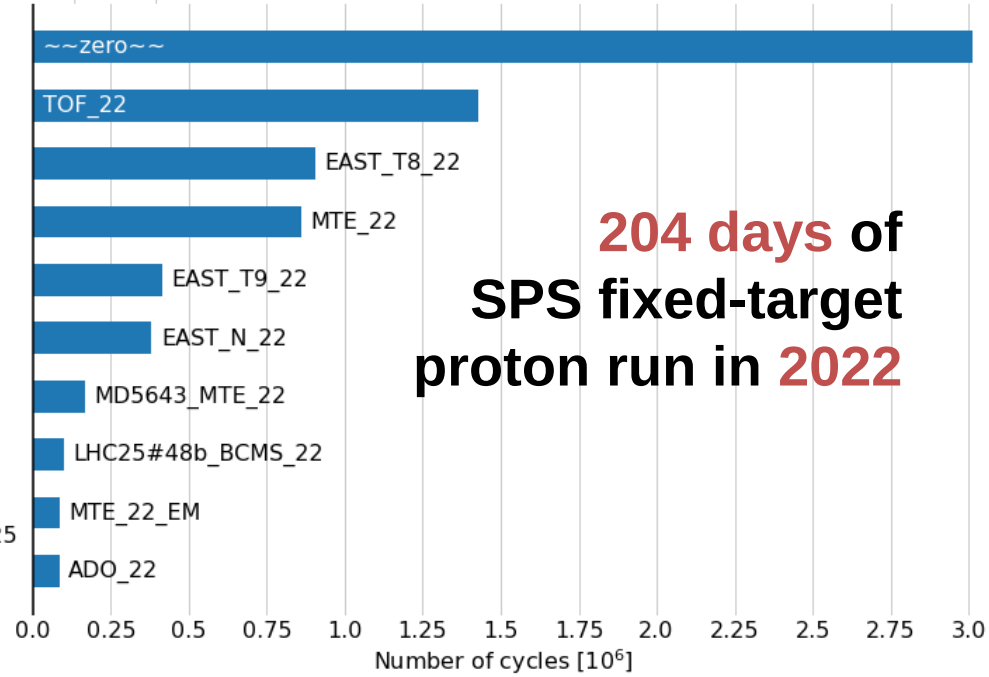
Scheduled efficiency – PS

- **Cycles played during 2021 and 2022 runs* with SPS taking beam**



123 days of SPS fixed-target proton run in 2021

***Commissioning not included**



204 days of SPS fixed-target proton run in 2022

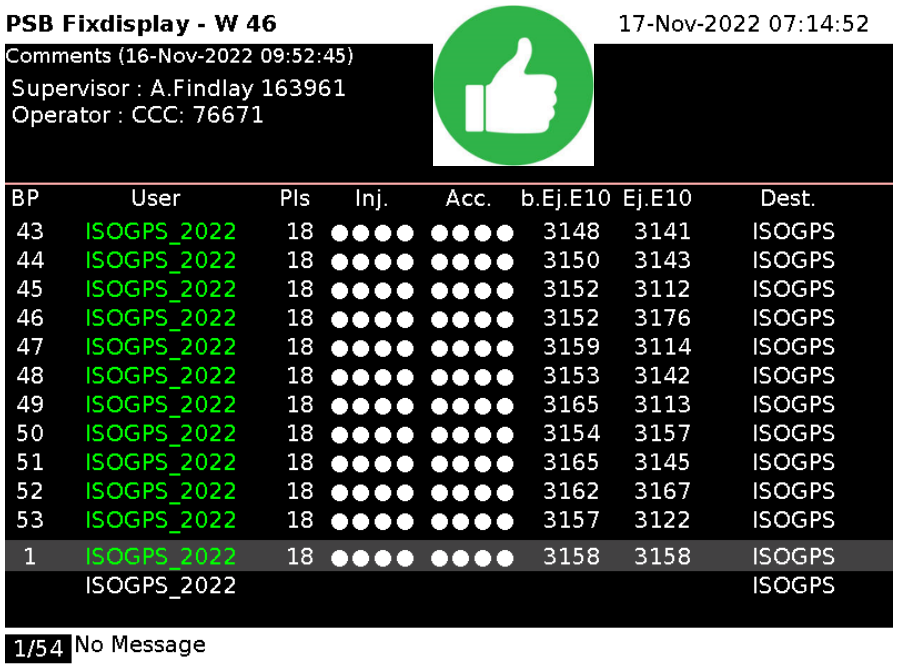
→ **PS spent many days playing ZERO cycles in 2022**

→ **Lots of constraints for cycle combination due to hardware**

→ **Possible upgrades to (partially) remove limitations?**

Scheduled efficiency

- **Cycles played during 2021 and 2022 runs with SPS taking beam**

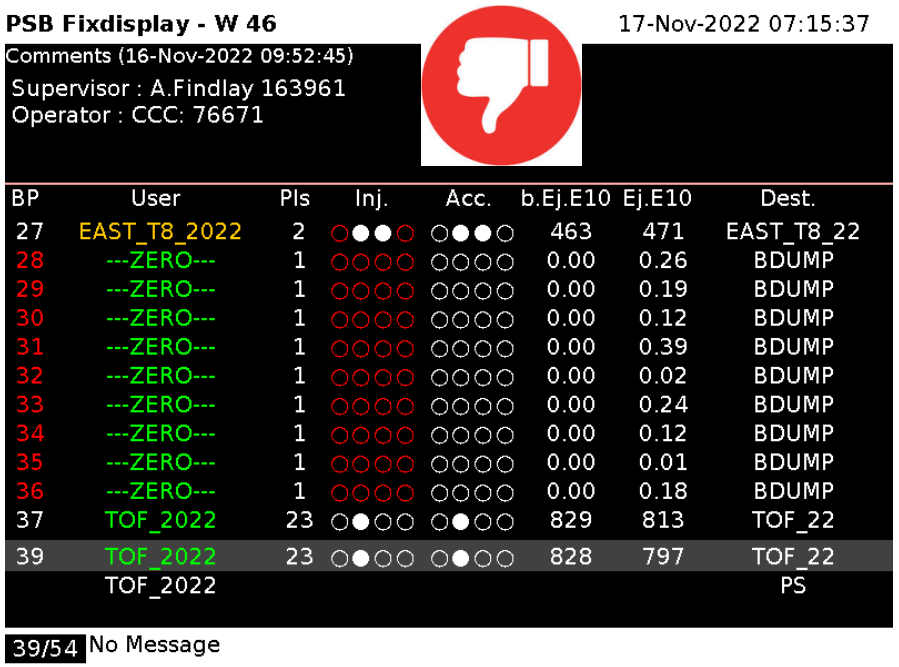


PSB Fixdisplay - W 46 17-Nov-2022 07:14:52

Comments (16-Nov-2022 09:52:45)
Supervisor : A.Findlay 163961
Operator : CCC: 76671

BP	User	Pls	Inj.	Acc.	b.Ej.E10	Ej.E10	Dest.
43	ISOGPS_2022	18	●●●●	●●●●	3148	3141	ISOGPS
44	ISOGPS_2022	18	●●●●	●●●●	3150	3143	ISOGPS
45	ISOGPS_2022	18	●●●●	●●●●	3152	3112	ISOGPS
46	ISOGPS_2022	18	●●●●	●●●●	3152	3176	ISOGPS
47	ISOGPS_2022	18	●●●●	●●●●	3159	3114	ISOGPS
48	ISOGPS_2022	18	●●●●	●●●●	3153	3142	ISOGPS
49	ISOGPS_2022	18	●●●●	●●●●	3165	3113	ISOGPS
50	ISOGPS_2022	18	●●●●	●●●●	3154	3157	ISOGPS
51	ISOGPS_2022	18	●●●●	●●●●	3165	3145	ISOGPS
52	ISOGPS_2022	18	●●●●	●●●●	3162	3167	ISOGPS
53	ISOGPS_2022	18	●●●●	●●●●	3157	3122	ISOGPS
1	ISOGPS_2022	18	●●●●	●●●●	3158	3158	ISOGPS
	ISOGPS_2022						ISOGPS

1/54 No Message



PSB Fixdisplay - W 46 17-Nov-2022 07:15:37

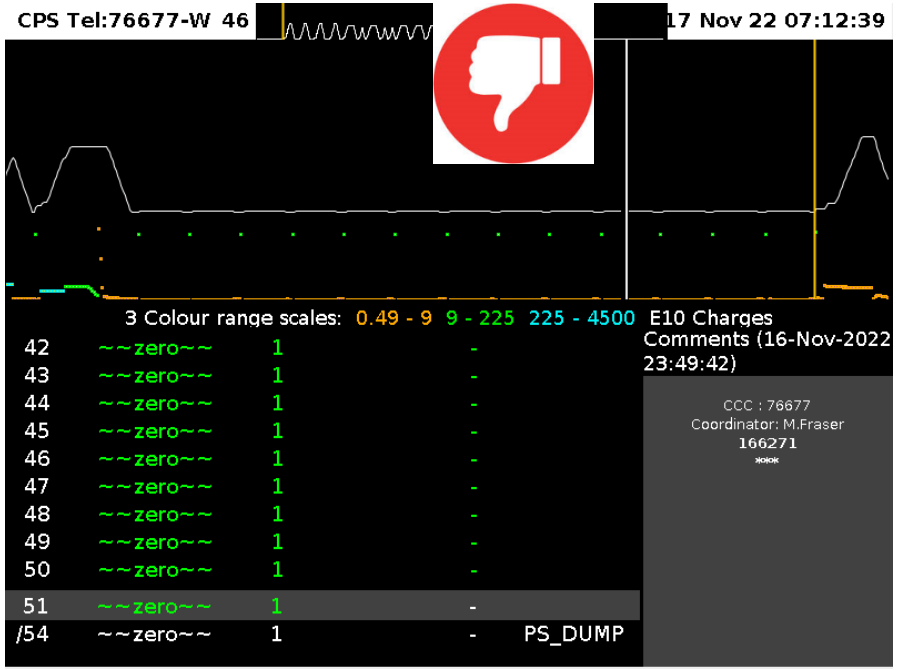
Comments (16-Nov-2022 09:52:45)
Supervisor : A.Findlay 163961
Operator : CCC: 76671

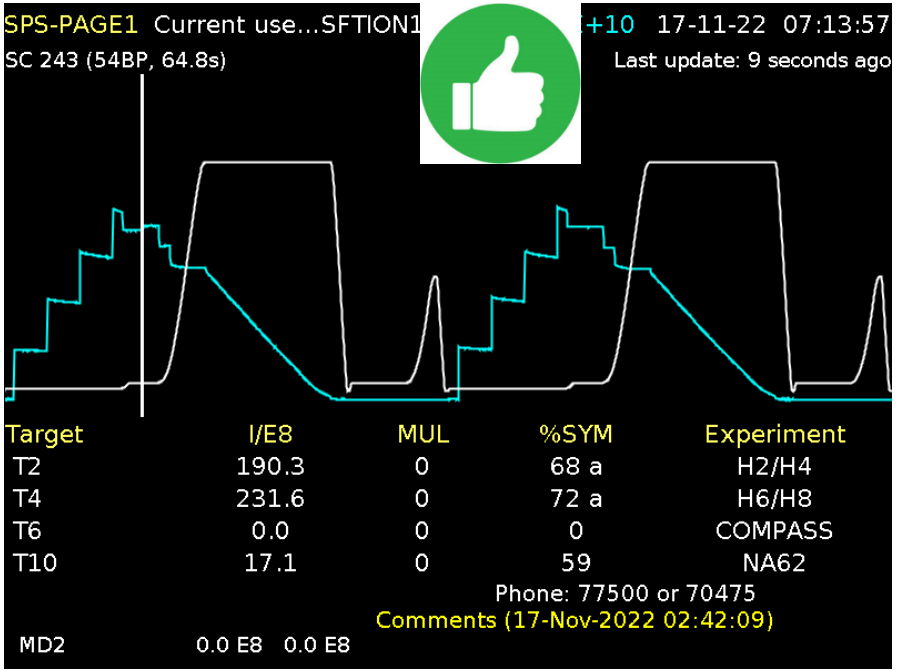
BP	User	Pls	Inj.	Acc.	b.Ej.E10	Ej.E10	Dest.
27	EAST_T8_2022	2	○●●○	○●●○	463	471	EAST_T8_22
28	---ZERO---	1	○○○○	○○○○	0.00	0.26	BDUMP
29	---ZERO---	1	○○○○	○○○○	0.00	0.19	BDUMP
30	---ZERO---	1	○○○○	○○○○	0.00	0.12	BDUMP
31	---ZERO---	1	○○○○	○○○○	0.00	0.39	BDUMP
32	---ZERO---	1	○○○○	○○○○	0.00	0.02	BDUMP
33	---ZERO---	1	○○○○	○○○○	0.00	0.24	BDUMP
34	---ZERO---	1	○○○○	○○○○	0.00	0.12	BDUMP
35	---ZERO---	1	○○○○	○○○○	0.00	0.01	BDUMP
36	---ZERO---	1	○○○○	○○○○	0.00	0.18	BDUMP
37	TOF_2022	23	○●○○	○●○○	829	813	TOF_22
39	TOF_2022	23	○●○○	○●○○	828	797	TOF_22
	TOF_2022						PS

39/54 No Message

Scheduled efficiency

- **Cycles played during 2021 and 2022 runs with SPS taking beam**





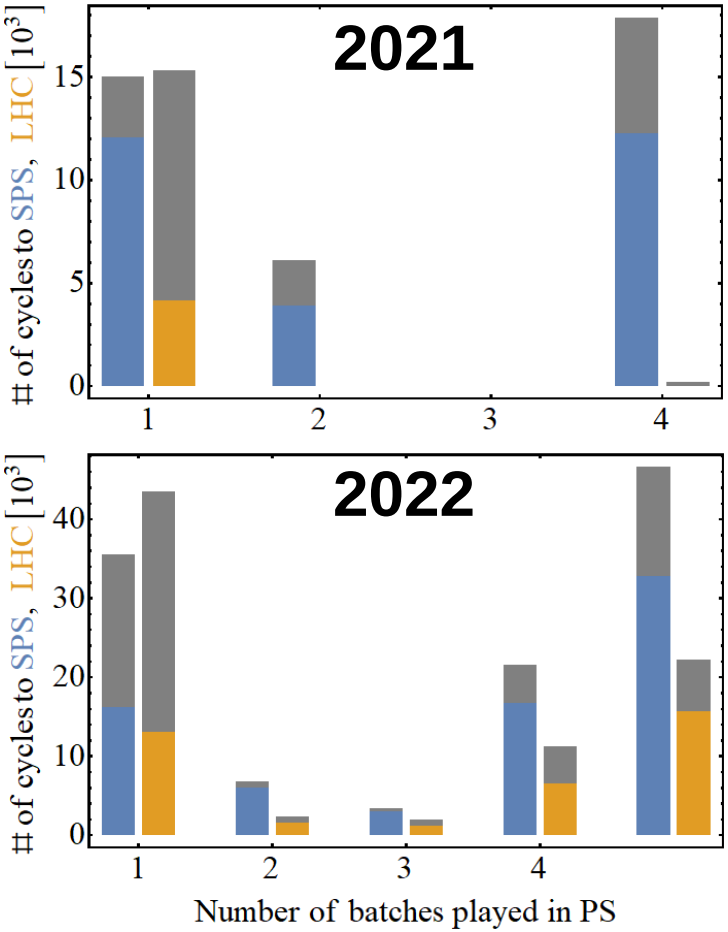
- **Physics requirements cause idling of downstream accelerators**

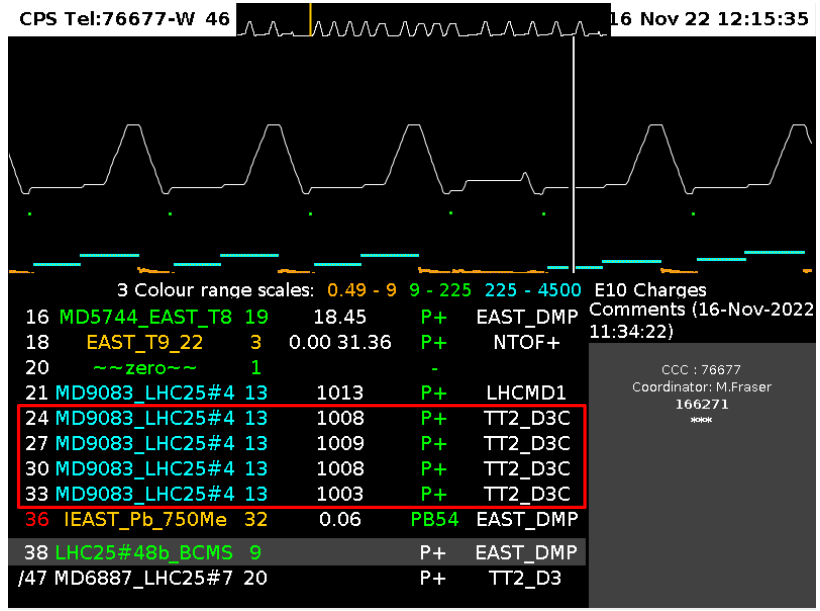
→ **Scheduled inefficiency difficult to avoid in many cases**

→ **Carefully check potential of remaining zero cycles**

Scheduled efficiency: PS-SPS with LHC beams

- **LHC cycles played in L4-PSB-PS, but not requested → dump**





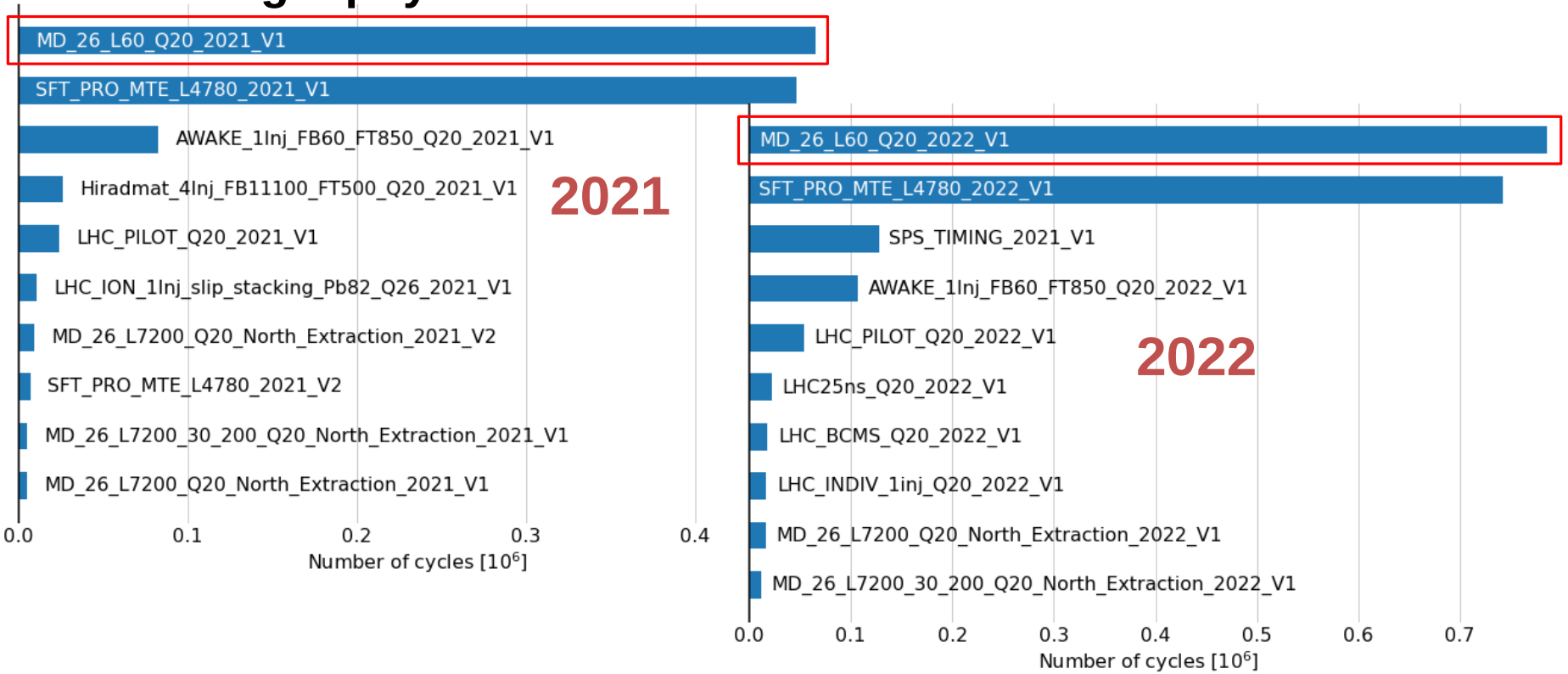
- **22 kcyles (2021), 82.7 kcycles (2022) executed uselessly**

→ **Corresponding 3.44 days (out of 204 days) in 2022**

→ **Timing system upgrade needed to dynamically play requested cycles**

Scheduled efficiency - SPS

- **Fixed target physics takes more than 96% of beam**



- **Slow extraction required remanence clearing afterwards (‘MD1’)**
- **Hysteresis prediction: avoid cycling without beam and save energy**
  - → **Push to RMS limit and potentially save time (save basic periods)**
  - → **Needs advanced machine learning techniques**

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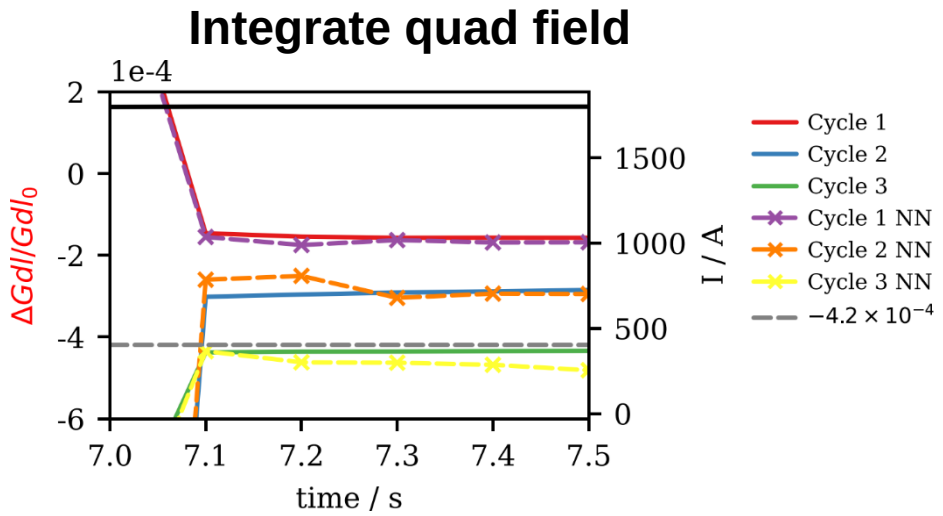
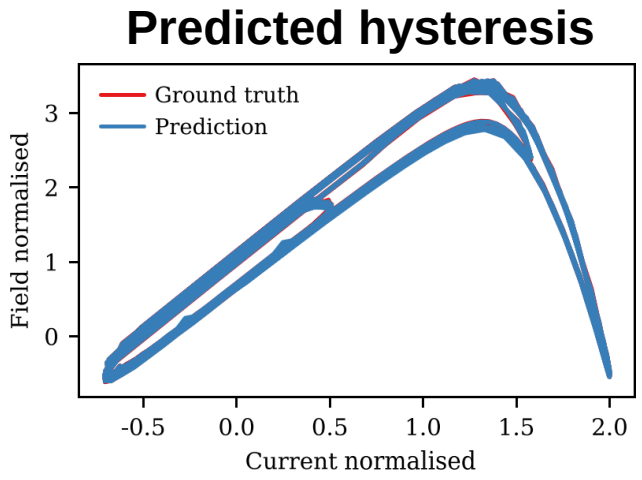
Reproducibility

- **MD1 purely present to reset magnetic hysteresis**
- **Huge reward to remove**

→ **Conventional machine learning approach would require vast amount of training → cost in terms of MD time**





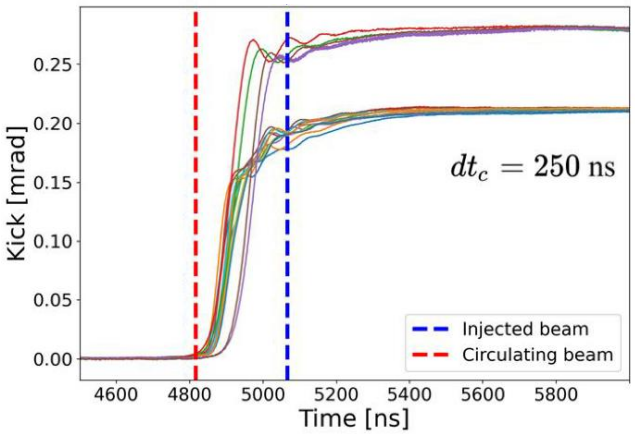
https://indico.cern.ch/event/1019698/

→ **Initial studies based on advanced machine learning concepts: Physics informed neural networks (PINN)**

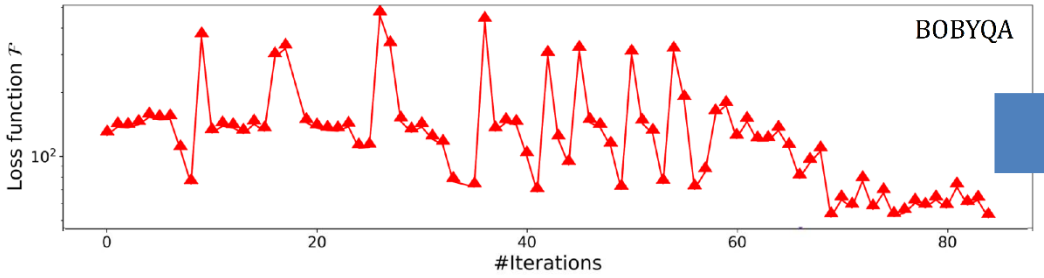
SPS injection kicker (MKP) risetime minimization

- **Alignment of 8 kicker modules (2022: conventional opt., then ML)**
- **Minimize impact on circulating and freshly injected beam**

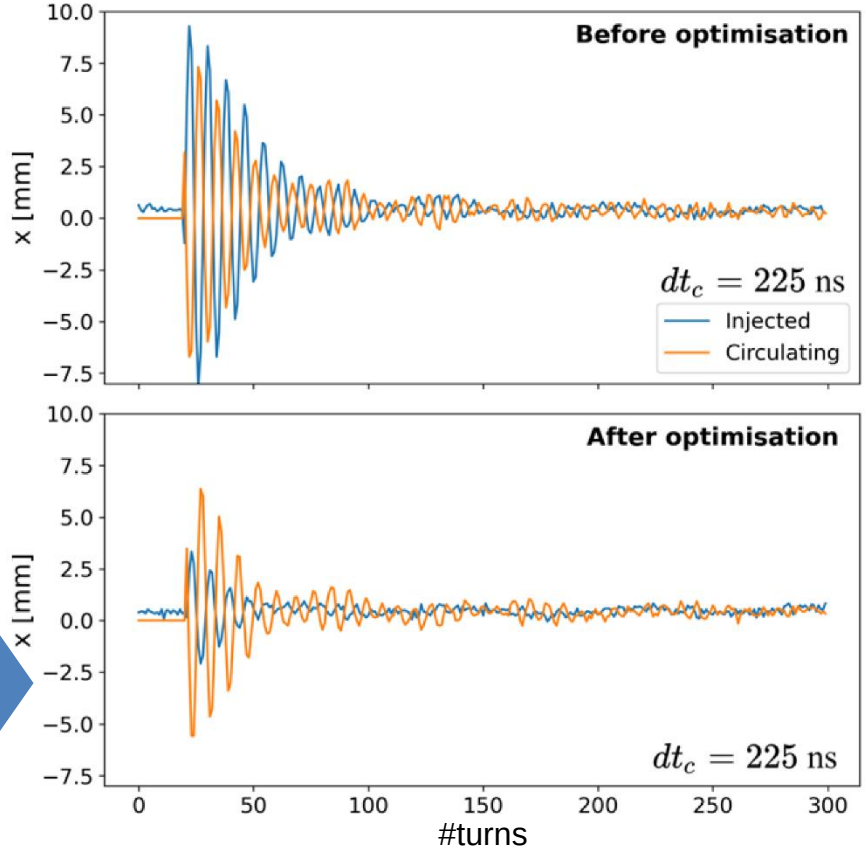
Kicker field rise



Loss function evolution



Horizontal oscillations



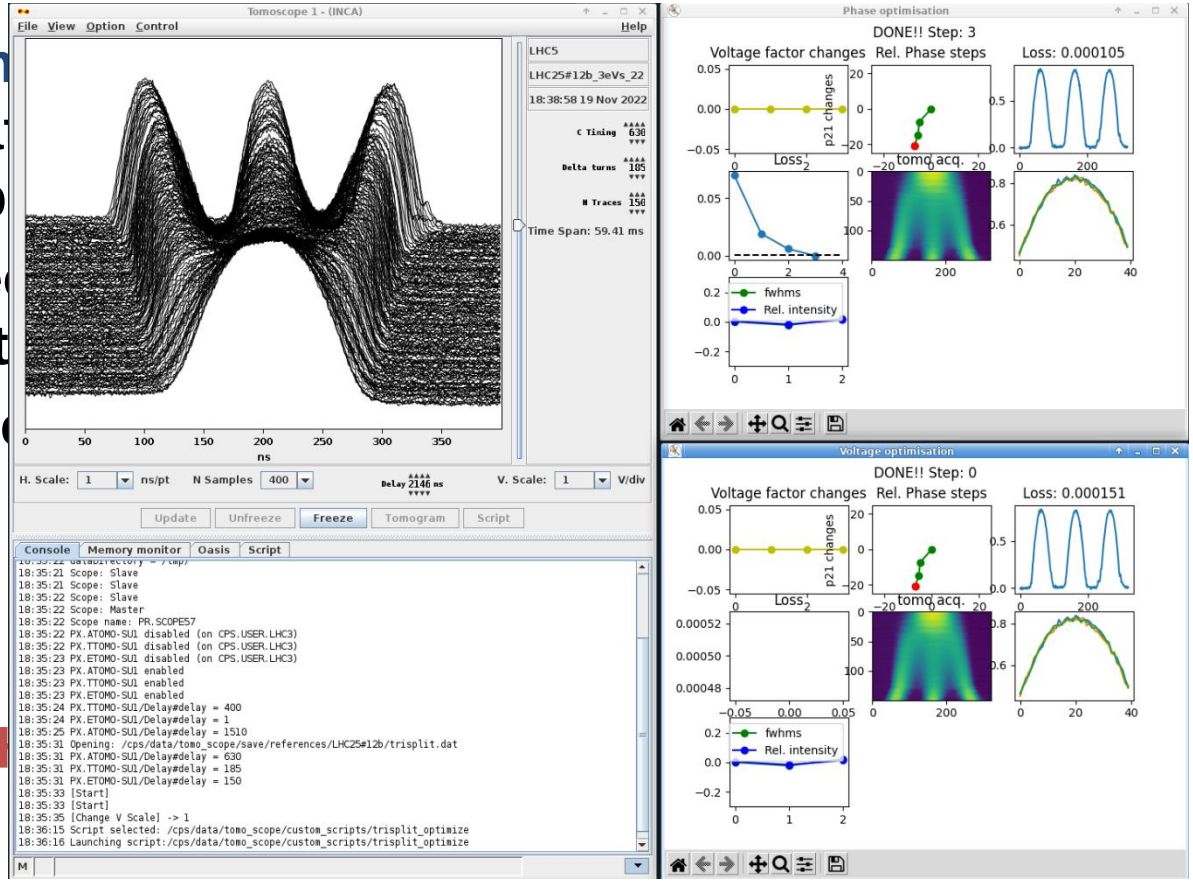
E. Waagaard

→ **Automated optimization is only path to consistent results**

Automatic bunch splitting adjustments

- **Reinforcement learnin**
  application to automat
  optimize PS bunch sp
- → **Now faster than a spe**
  or experienced operat
- → **Reproducible outcom**

→ **Well advanced on patl**
MDs to operation



Automation strategy

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Flexible cycle length

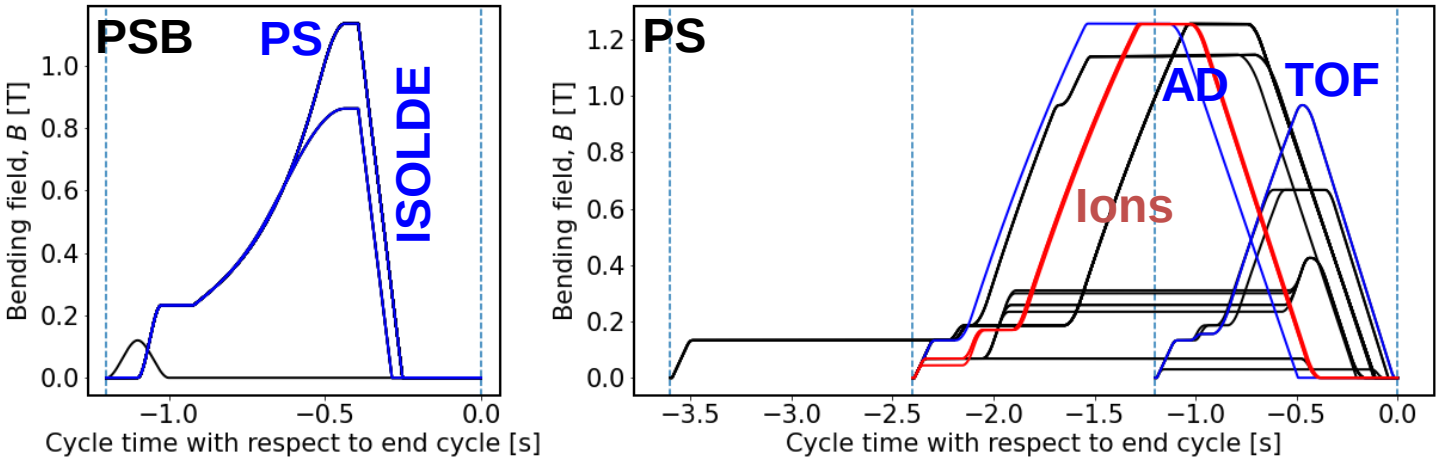
- **Basic period → basic heartbeat: 1.2 s**
- **Typical cycle length in injectors: *n* · 1.2 s, *n* < O(10)**

→ **Most important time loss for PS complex accelerators with cycles of 1, 2 and 3 basic periods**

→ **Present beam parameters/cycles are designed around this basic period constraint**

→ **What are the consequences?**

Bending field of operational users aligned to end of cycle



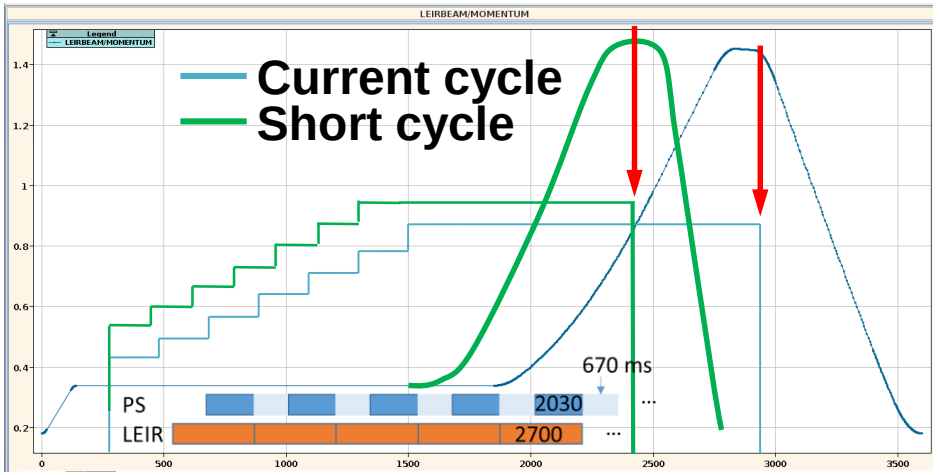
Flexible cycle length – example of ions

- Without 1.2 s basic period
- Shorter ion cycle in LEIR
- Faster filling with less losses at in SPS

→ 5% gain in intensity per beam

→ Smaller transverse emittance

→ 8 min shorter turnaround time



→ Combined impact of three improvements is 7-10% in integrated luminosity for a 1-month run

→ Automated super-cycle generation essential to profit from flexible cycle length

→ Just too complex for human beings

Flexible cycle length

- **Paradigm change to remove concept of basic period?**
  - → **More physics in less time**
- **Run accelerators at limit of hardware capabilities**
- **Potential impact well beyond just timing system**

→ **Define time-limited project to evaluate consequences**

→ **Prepare decision on implementation**

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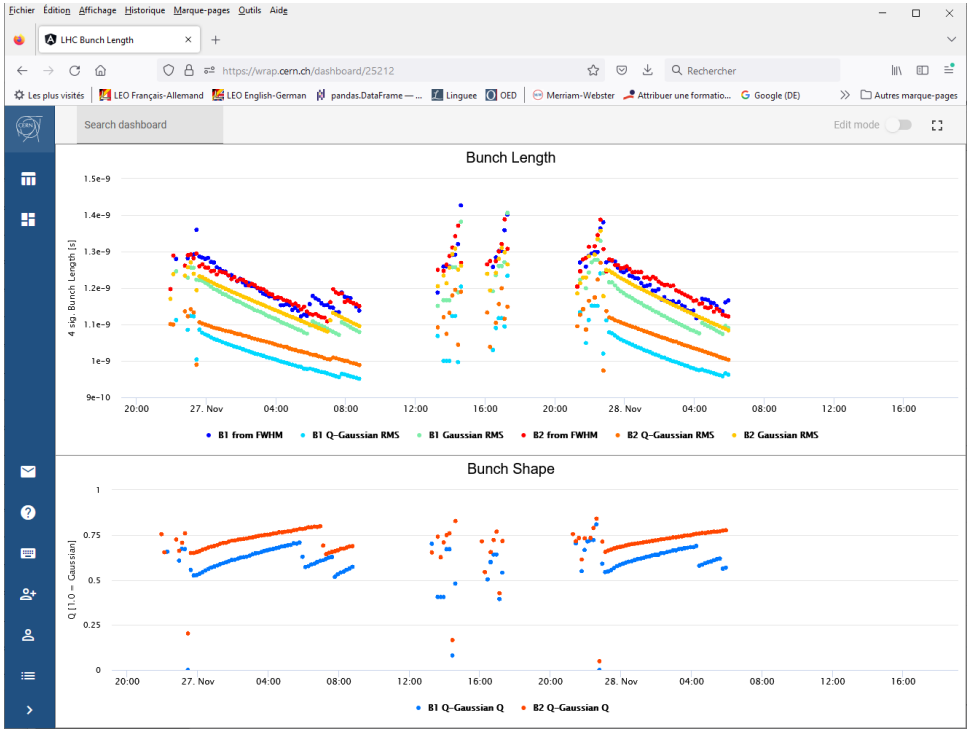
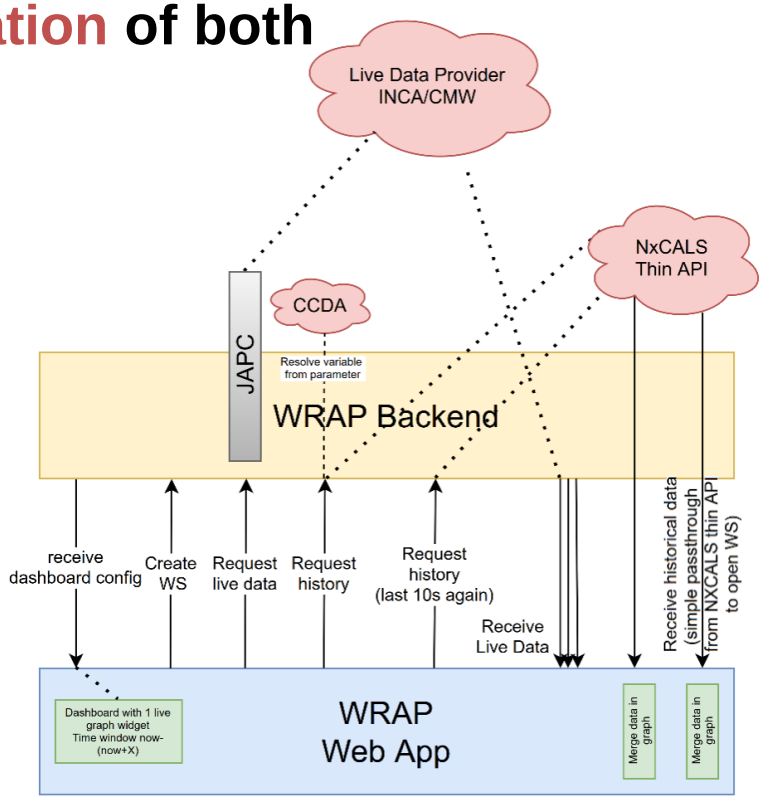
Complexity HW → SW

Tools – dashboards → WRAP*

*Web Rapid Application Platform

- Aggregate historic (NXCALS) and live data
- WRAP service offers seamless integration of both





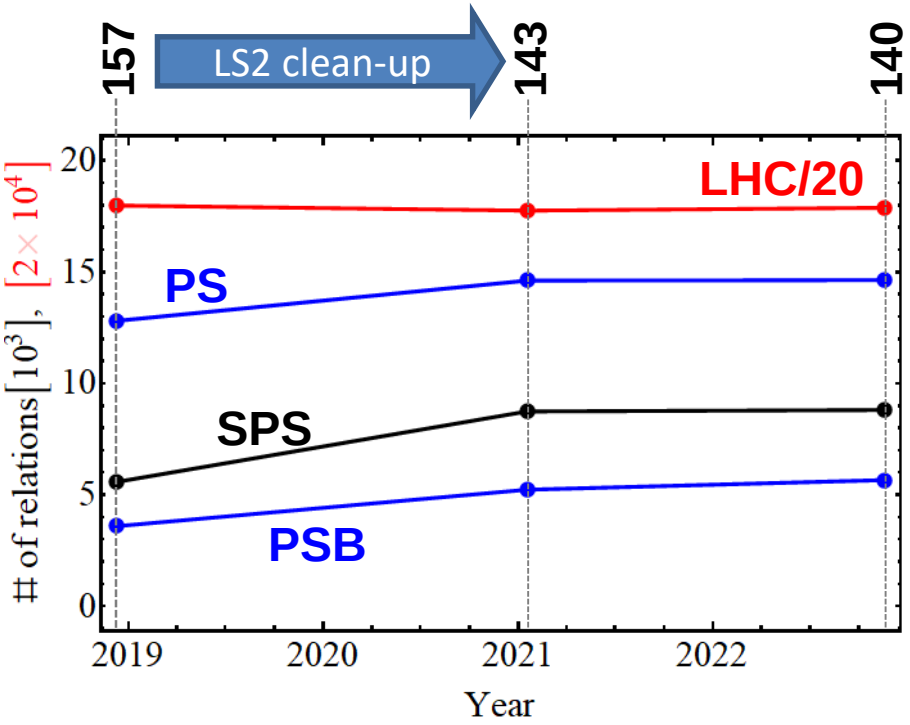
→ Integration with other tools, like beam performance tracking?

→ Add-hoc logging for improved data storage

High-level knobs, MakeRules and relations

- **High-level knobs to trim and optimize physics parameters**
  - → **MakeRules to propagate to low-level settings for hardware**

MakeRules and device relations



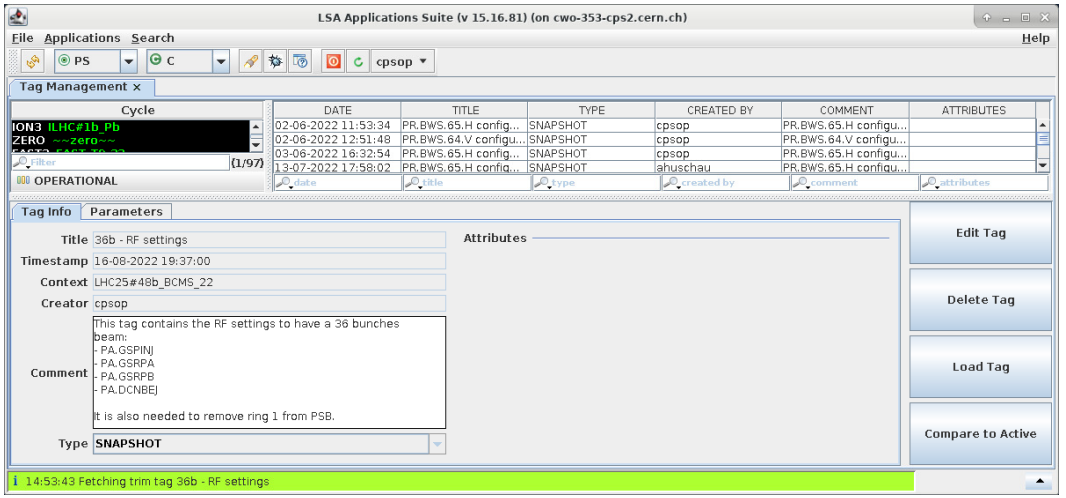
→ **Small increase → First phase implementing parameters easily 'MakeRuleable' completed**

→ **All systems 'MakeRuled' at similar level? Next steps to high-level knobs?**

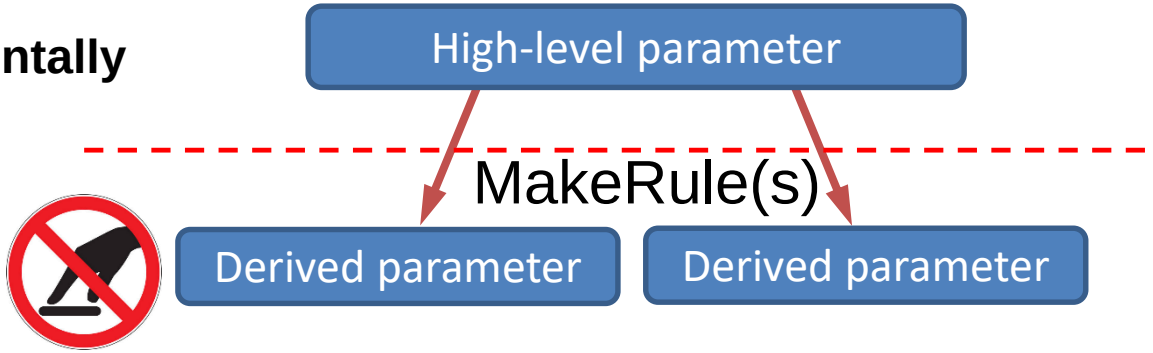
→ **Simplifying MakeRule development process would be appreciated: rapid prototyping**

Moderate improvement → relevant impact

- **Trim tags**
  - **Manage settings for very similar beams**
  - → **Switch number of bunch configurations: 36 or 48 bunches for LHC**
  - → **Beam parameter configurations for MDs**



- **Destination settings of MakeRules non-trimmable**
  - **Derived settings configured non-trimmable**
  - → **Prevents from accidentally breaking MakeRules**
  - → **Few issues remain**
  - → **Improved setting stability in 2022**



Examples of setting inconsistencies

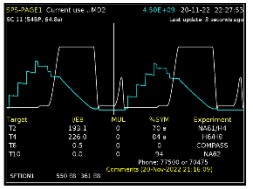
- **Settings in LSA ≠ settings in hardware**
  - **Found some TL quads not pulsing […]**
  - → **After 'redriving functions', much improved with nominal spill duration**

Activities & status I

FOM, 22/11/2022

SFTION

- Mon
  DSO tests, setting up SX, beam permit (TT20 TED out)
  First steering attempts to T2 & T4 – challenging. Beam ~OK, but not great.
- Tue
  Found some **TL quads not pulsing** (spill duration ~3 s).
  After **"redriving functions"**, much improved with nominal spill duration.
- Since
  Stable on targets *(symmetry, sharing)*. Some downtime due to LEIR & L3 faults. L3 source required tuning every now and again. SPS BSI calibration recorrected on Wed.



LHC

- Protons for physics: until Thursday 12:00, and again from Saturday. **Not an easy return for LHC** – frequent refills.
- Ions: with some adjustments and workarounds: **slip-stacked beam & trains of up to 3 EARLY bunches successfully transferred to LHC.** Between Thursday and Saturday, **several fills** took place with both beam types.

- **Manually trigger MakeRule re-establishes correct settings**

24-07-2022 04:05:29 3596264

```
High beam losses at transition, for TOF and EAST (not for MTE and AD).
Cavities show beam loading.
Call RF-LL piquet
```

  - → **At 8h14: […] rewrote the PA.MHSCRSJPC10 setting […]. The values shown were correct but a send to hardware was necessary**

→ **Having diagnostics tools is important, but one needs to use them**

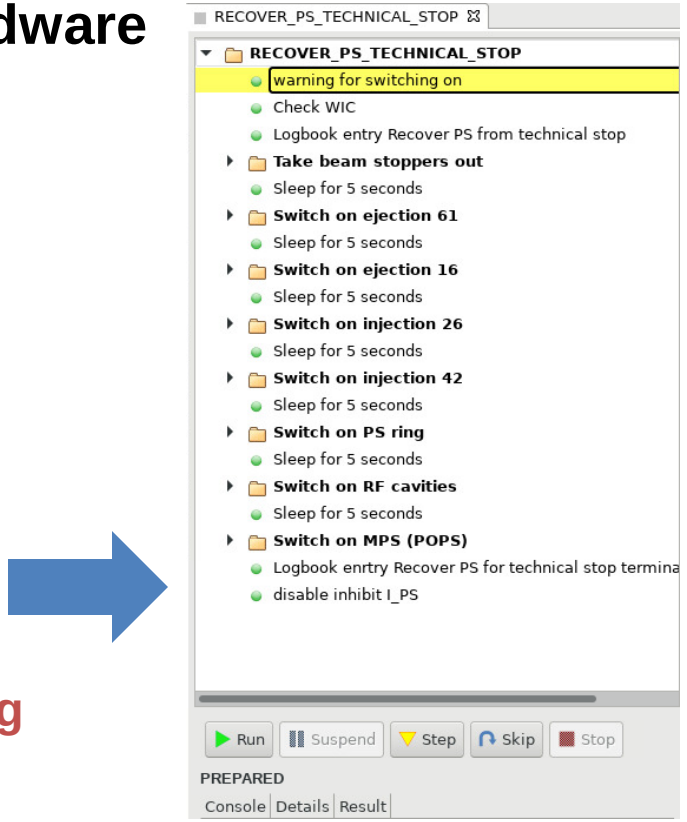
→ **Periodic, automatic checks would support trouble-shooting**

Tools – moderate improvement → relevant impact

- **Settings management working group**
  - → **Progress slowed down due to insufficient manpower**

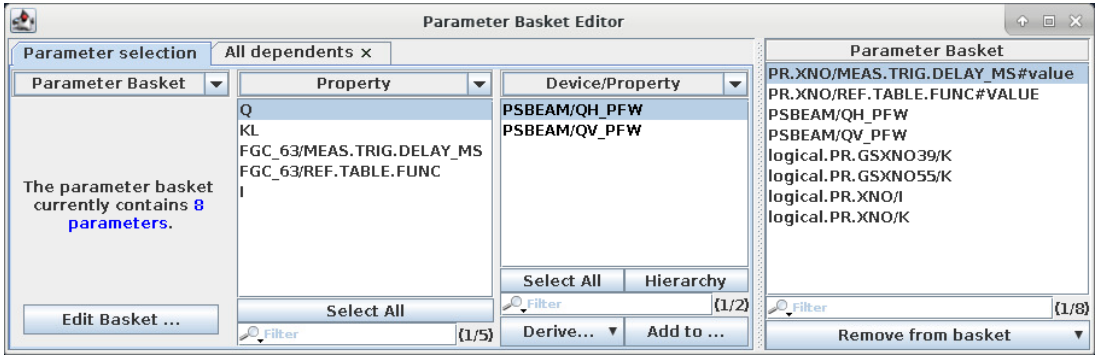
- **Online-check: LSA settings versus hardware**
  - → **Important effort to clean up → ignore certain parameters**
  - → **First step towards automated ‘online’ online-check**

- **Sequencer**
  - → **Large scale deployment in PSB, PS, SPS**
  - → **Faster change of configuration, e.g., before/after technical stops**
  - **Next: automated hardware commissioning**
  - → **Needs modifications planed by BE-CSS**



Tools – moderate improvement → relevant impact

- **New parameter basket**
  - → Facilitate selection of parameters for hierarchy or for common trims



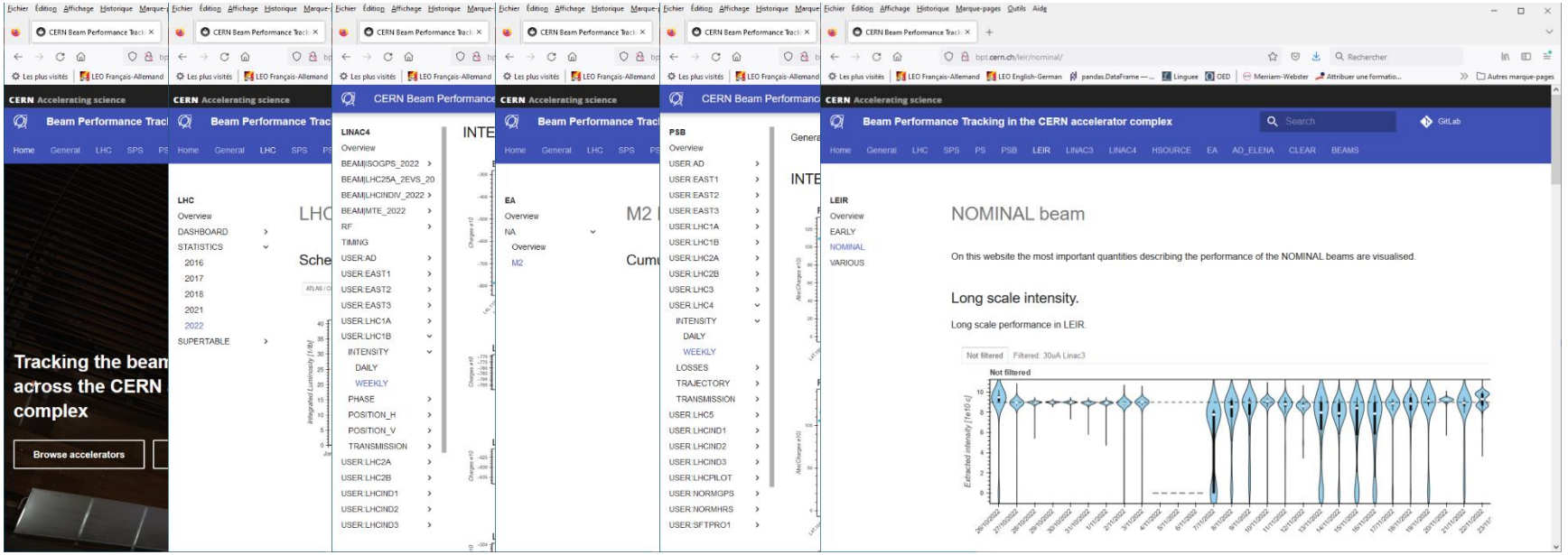
- **Important activities on hold**
  - → Consistency check for parameters hierarchies by running MakeRules to detect inconsistencies
  - → Generation parameters for multiple contexts at once
  - → Consistency check between cycles of the same ‘family’: huge project missing resources

→ Many new features to ease operation, but still long way to go

→ Resource allocation on top of SMWG unclear

Beam performance tracking (BPT)

- **Tracking per accelerator**
  - → **Very flexible, impressive list of plots: weekly to yearly**
  - → **May lead to different choices for different accelerators**

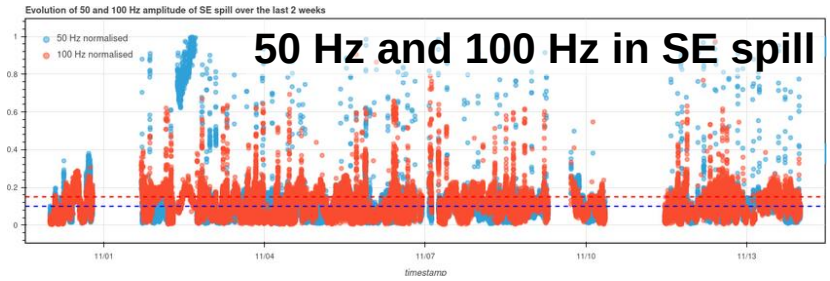


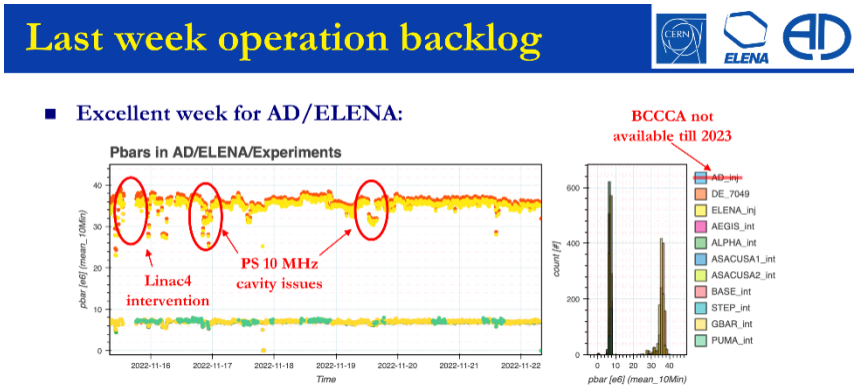
→ **Tracking by beam across accelerators still to come**

→ **Future extension to 'System Performance tracking'?**

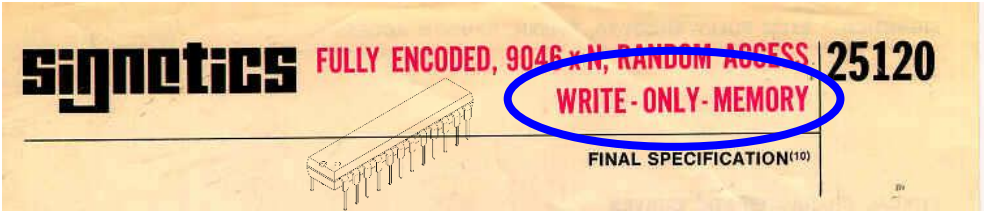
Beam performance tracking (BPT)

- **Some BPT plots have evolved to key references to qualify and quantify performance**





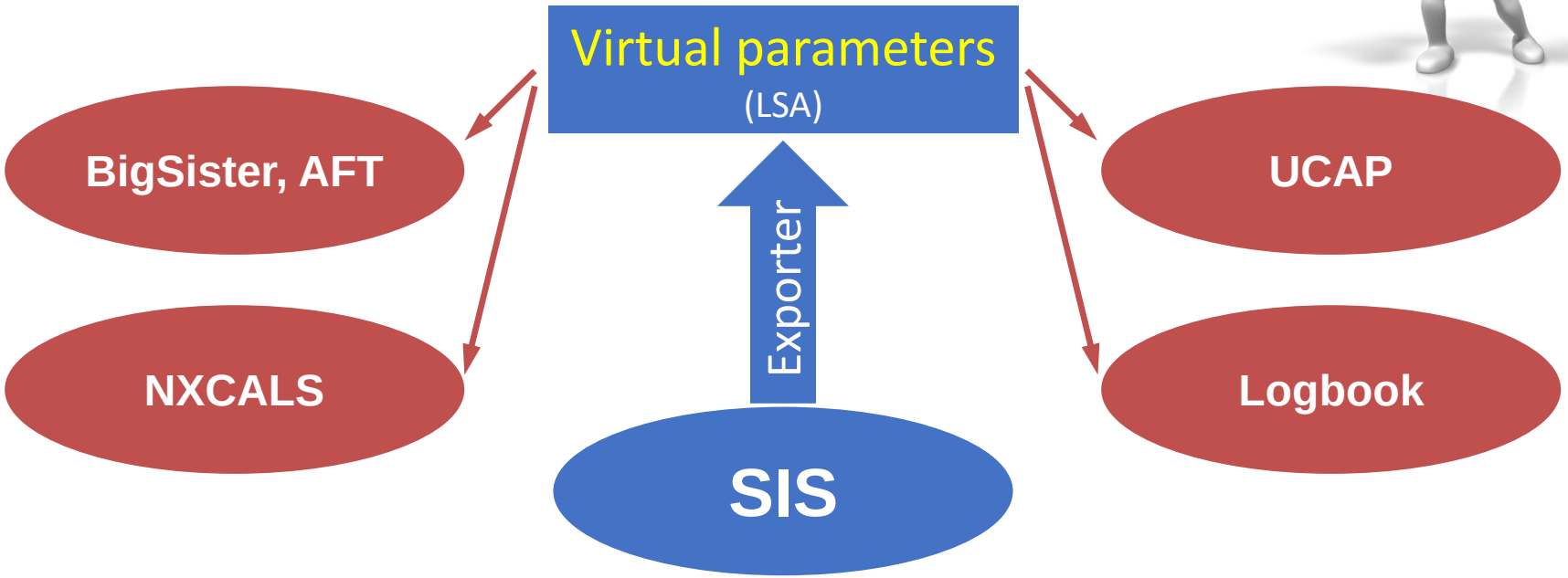
- **Others seem to be generated but never looked at**



- **How to link to KPIs and references? → Need references in LSA**
- **Next steps:** **→ Trigger actions to automatically recover KPI**
  → Online BPT, but how to combine with e.g. WRAP

Interlocking Super Agent

- **Set of tools to facilitate diagnostics of operation, logbook MASK entry, NXCALS, Accelerator Fault Tracking (AFT) across all machines.**



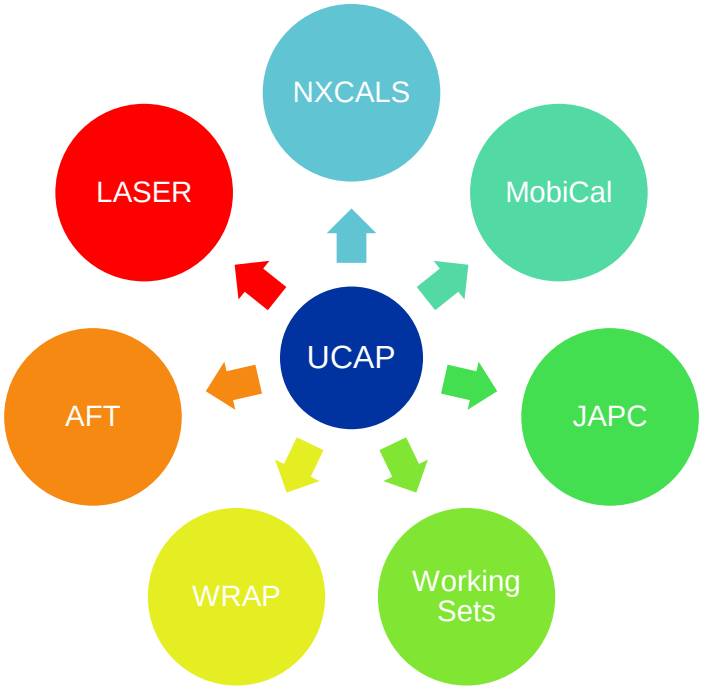
E. Veyrunes

→ **In operation since 2022 → Offloads dump tasks in SPS and LHC**

→ **Generic virtual parameters: usable by any application in complex**

Task automation framework for Linac4 and PSB

Built around UCAP micro services



Functions to support operations

Alarming and Monitoring	• BIS Mask monitors • H0HM Dump Monitor • LN4 Source Downtime
Automatic Operation	• Stray Field Compensation
Event Management	• Automatic AFT

T. Bukovics

→ **Interlock monitoring agent is in preparation, should be operational for 2023 run**

Outline

- Introduction
- Efficiency
  - Beam scheduling and exploitation
- Automation and reproducibility
  - Optimization and machine learning
- Optimization of injector complex operation
  - Timing system flexibility
  - Tools, setting management
- **Summary**

Summary

- **Remarkable operational improvements on all fronts**
- **However, 2022 operation still felt like previous years**
  - → **Settings, consistency**
  - → **Some known issues still open**

- **Still large potential for future optimization**

→ **Deliver more beam with ~~less~~ equal effort**

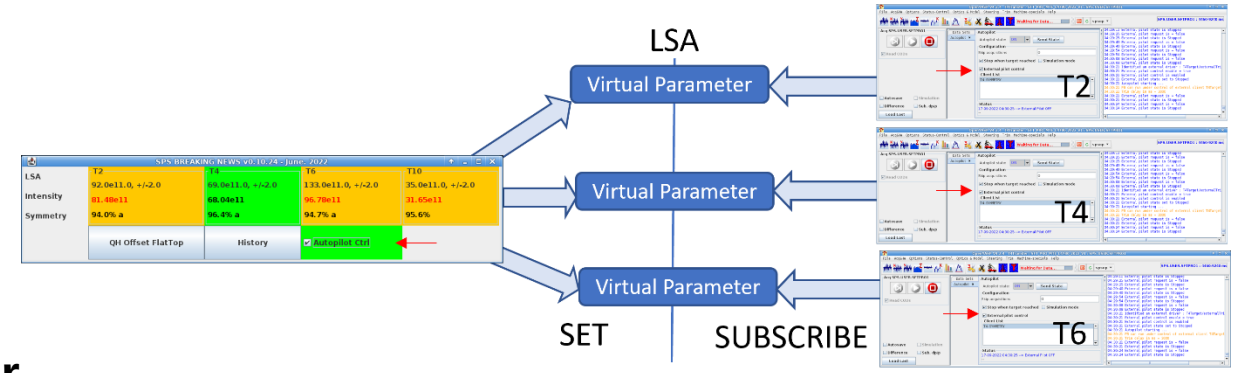
- **Automation with extensive optimizer and machine learning applications key towards autonomous operation**
- **Choices not consistent between accelerators → Replace duplication by exchange**

Exploiting synergies

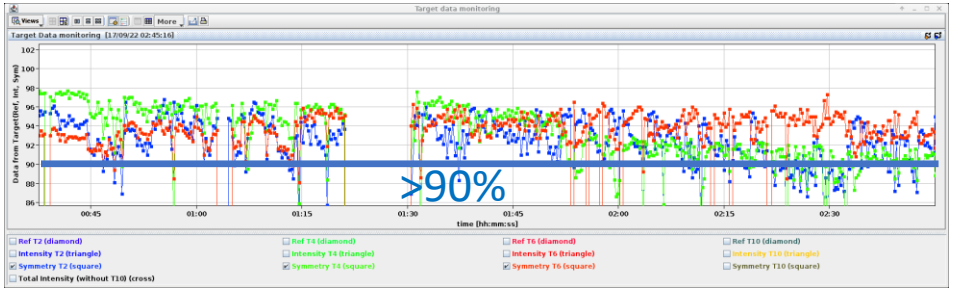
www.cern.ch

Automatic target steering

- **SPS Target autopilot application is monitoring LSA References, Target intensities and symmetries**
- **Symmetry drop below 90 % on a target, a correction request is activated via YASP**



- **Variation of intensities or symmetries for T2, T4 and T6 target**
- **No correction if no beam (symmetry < 10%)**
- **Delay of 3 s before YASP triggers correction**



→ **In operation since 2022**

Automation strategy