

Dynamic beam scheduling and automated LHC filling Status of the EPA WPs

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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

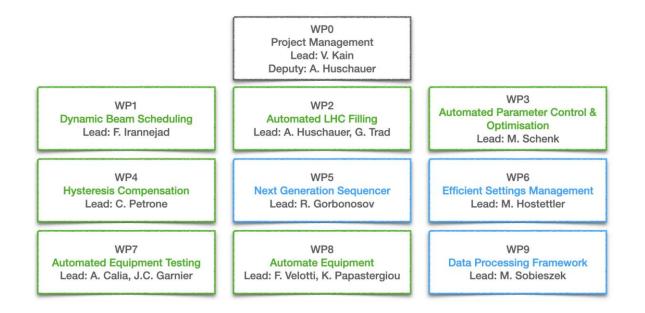


Introduction

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

irrent hardware status Played super	cycle Dynamic Beam Sche	duling			
Dynamic Beam Scheduling					
AD Beam Scheduling					
BCD Template: bcd_template	*				
Available Beams:			Selected Beams:		
	T.		Beam	min	max
[CPS]:AD_23_2E13		•	[PSB]:EAST_T8_2024+[CPS]:EAST_T8_24	2	4
[CPS]:AD_24			[PSB]:EAST N 2024+[CPS]:EAST N 24	2	4
[CPS]:AD_4BSW16_23 [CPS]:AD_4BSW16_23_ejBLM		1	[PSB]:TOF 2024+[CPS]:TOF 24 AutoSteer	4	5
[CPS]:AD_4Heiko			[PSB]:ISOHRS 2024		4
CPS]:AD_degauss CPS]:DEGAUSS 1BP			-	2	-
[CPS]:DEGAUSS_EAST			[PSB]:AD_5b_2024+[CPS]:AD_24	0	0
[CPS]:DoubleTOF_24					
[CPS]:EAST_1.4GeV_23_new [CPS]:EAST_15GeV_24					
[CPS]:EAST_LI_24		>>			
[CPS]:EAST_N_23					
[CPS]:EAST_N_24 [CPS]:EAST_N_SE_tests		<<)			
[CPS]:EAST_N_SE_tests [CPS]:EAST_T8_23					
[CPS]:EAST_T8_24					
[CPS]:EAST_T9_23					
[CPS]:EAST_T9_24					
[CPS]:HW_TEST_23					
[CPS]:HW_TESTS					
[CPS]:IEAST_Pb_1GeV_24					
[CPS]:IEAST_Pb_1GeV_HighFlux_24					
[CPS]:IEAST_Pb_23 [CPS]:IEAST_Pb_500MeV_24					
[CPS]:IEAST_PD_500Mev_24 [CPS]:IEAST_tests_24					
[CPS]:ILHC#1b Mg7 24					
[CPS]:ILHC#1b_Ng7_24		-			
4	•				

Hardware Settings Panel

Dynamic Beam Scheduling

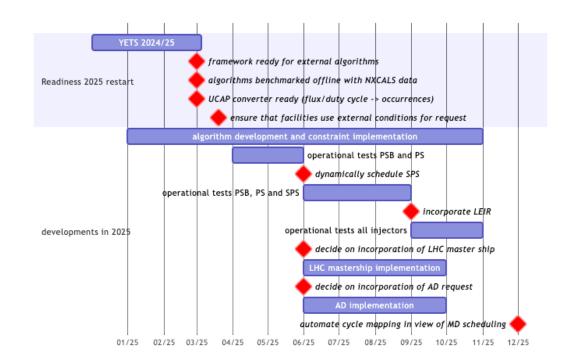
First stage: automated scheduling of PSB and PS beams based on an SPS template

ral Beams Beams Compositions 🖌 Rules	Dynamic Beam Scheduling											Duty C	ycle			
able Beams:	-,			Selected Be	3000							Dom	in Destination		Duty Cyc	le
Ole Beams:				Selected Be	Beam	min max						PS	B ISO_[HRS/GPS	J.	0 %	
:DoubleTOF 24				[PSB]:EAST	N 2024+[CPS]:EAST N							CF	S EAST_T8		21 %	
TOF 44ns 24 EAST BigTof 2024					T8 2024+[CPS]:EAST T							CF	S EAST T9		0 %	
EAST BigTof 2024+[CPS]:EAST N 24					2024+[CPS]:TOF_24_Aut	-							-		28 %	
TOF_2024 TOF_2024+[CPS]:TOF_24_AutoSteer													-			
OF_2024+[CPS]:TOF_44ns_24												SF	S FTARGET		32 %	
				>>												
				<<								Flux				
												Dom	in Destination		Relati	tive Flux
												PS	B ISO_[HRS/GPS] 0.00e+00		
												CF	S EAST_T8	4.29e+10		
												CF	S EAST_T9	0.00e+00		
												CF	S EAST N	2.86e+10		
													-	7.14e+10		
			Sci	nedule Beams								CF				
ods: 28 🗘 Q												CF	S NTOF	1.72e+12	10	02 %
	3 4 3	6 7		9 10	11	12 13	14	15	16	17	10	19	20	21	22 23	
SPS	SFT_PRO_MTE_L47	80_2024_V1									inj_Nom_48b_Q20_	2024_V1				
SPS	SFT_PRO_MTE_L47	80_2024_V1						LH	IC_PILOT_020_2024	_V1						
	4 5				11 12	13			16 13			19 20	21	22	23	24
	EAST_N_24 EAST_N_2	24 EAST_T8_24	TOF_24oStee	-	.HC25#12b_3eVs_24	EAST_N_24	•	EAST_T8_24	TOF_24	.oSteer TOF_24	oSteer	EAST_N_24	EAST_	18_24	TOF_24oSteer	
CPS MTE_BBlgh_24	4			DEGAUSS_1BP	LHC#1b_PILOT_24		15	10	17							
E HI 2024 MTE HI 2024 EAST N 2024	4 5 0 EAST_N_2024	7 8 EAST_T8_2024	TOF 2024	LHC25s_2024		13 14 N_2024	EAST_T8_2024	10	TOF 2024	18 TOF 2024	19 EAST_N_2024	20 EAS	21 2 T_T8_2024		23 24 F 2024	
E_Hi_2024			-	LHC PILOT 2024					-	-					-	
1 2 3	4 3	6 7 8	9	10 11	12	13	14 15	16	17	18	19	20	21	22	23	24
				3P 2024 NOMINAL V1		EARLY_V1 Pb5	4_2BP_2024_EARLY_V1		Pb54_3BP_2024_NC			Pb54_3BP_2024_NOMIN		Pb54_2BP_2024		Pb54

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





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

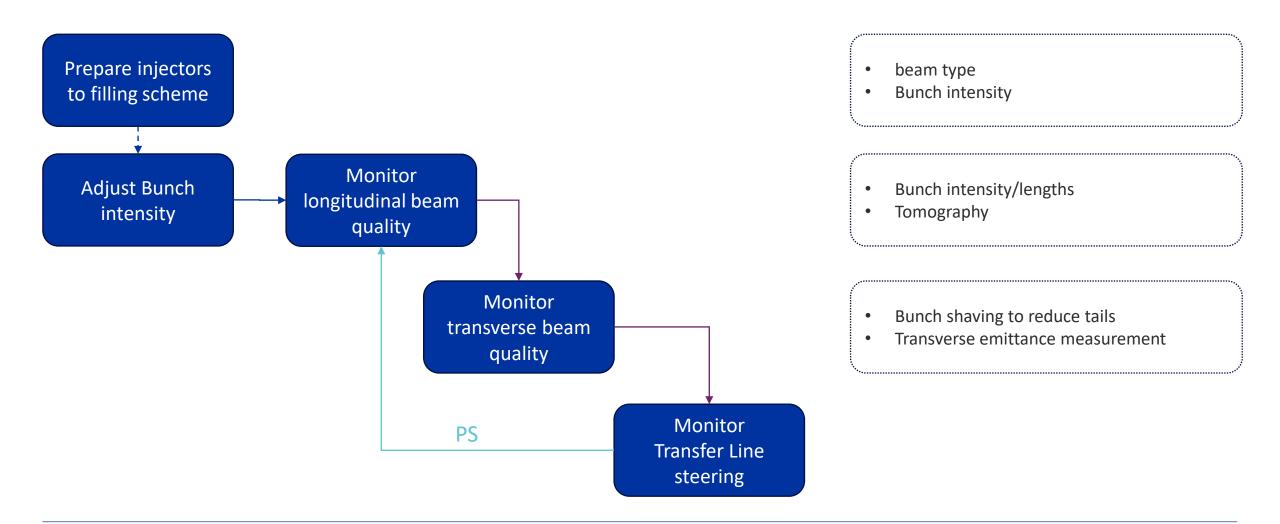
Class details								
Class version Class	s name	Responsible	De	Description				
1.4.0 🛊 Lhc	BeamPreparation	Delphine Ja	cquet			VIRTUAL		
Properties Devices	RBAC							
Class Properties								
Property Name 🔺 🔹	y Visibility V	Get 🗸	Set ~	Monitorab ~	Multiplexe 🗸	Cycle Bour 🗸		
FillingSchemeInfo	operational	~	×	~	×	×		
InjectorPreparationStage	operational	~	×	~	×	×		
RequestedBeams	operational	~	×	~	×	×		
RequestedBunchIntensity	operational	~	~	~	×	×		
RequestedTrainType	operational	~	~	~	×	×		

(@M. Hostettler & D. Jacquet)

EXTRACTION	CAVITIES 10 MHz	CAVITIES SINGLE	CAVITIES MULTI	SPS FREQ
LHC FILLING:		PREPARATION	II	MMINENT

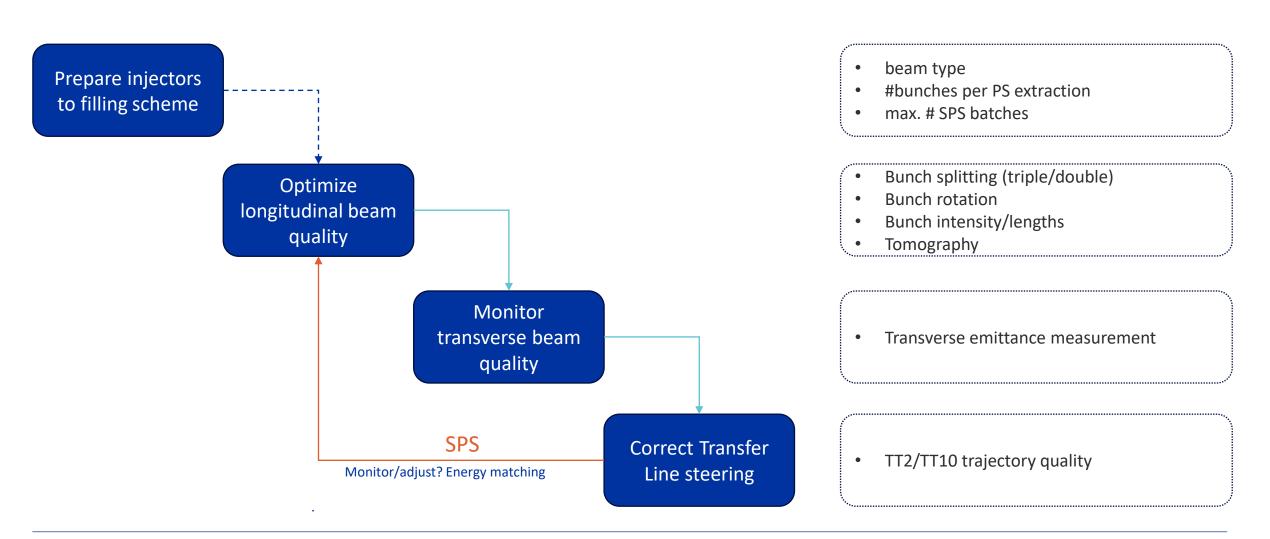


Automated LHC Filling Booster

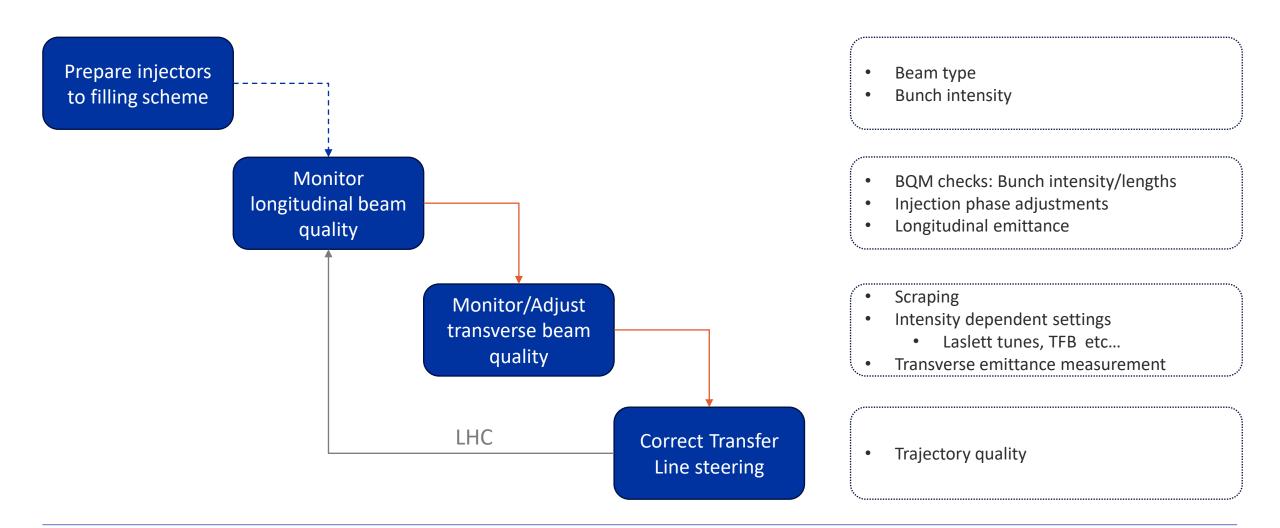


CÉRN

Automated LHC Filling PS



LHC filling flowchart SPS



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Observable and metrics

Focus on online metrics computation



New longitudinal acquisition layer needed

Prepare injectors

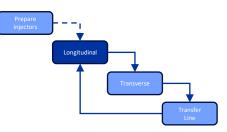
- Previously no common framework for online monitoring (BQM @SPS, OASIS @PSB/PS)
- Difficult to update the BQM to the other injectors
- Measurement and adjustment longitudinal beam characteristics with OASIS
 - Only manual and on-demand measures; effort required to automate
 - No PPM acquisition
- PS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

... CPS MD564...TE 22 MD564...TE 22 TOF 22 MD7464 LHC25#48b BC ADO 22 LHC#16 INDIV 22 MD7464 LHC25#48b BCM CPS EAST TB 22 LHC#1b INDIV 22 MD7464 LHC25#48b BCM5 MD564...22 **ISOHRS 2022** PS8 ISOHRS 2022 ISOHRS 2022 LHCINDIV 2022 MD746 2022 MD746 2022 150HRS 2022 **ISOHRS 2022**

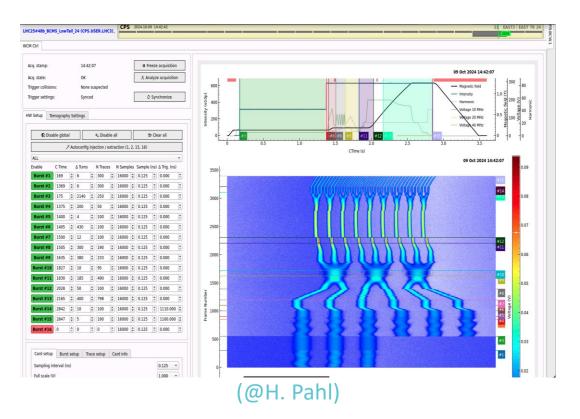


Enabler of longitudinal beam quality monitoring and optimization

- 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



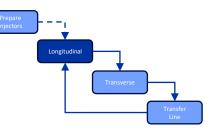
(PS) Longitudinal BQM app



IPP Meeting Slides



PS – LHC Double/Triple splitting



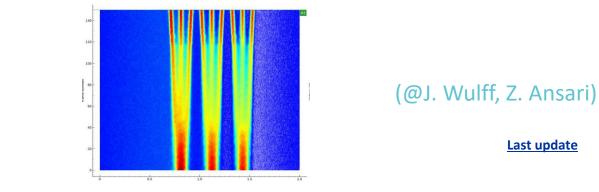
Triple Splitting

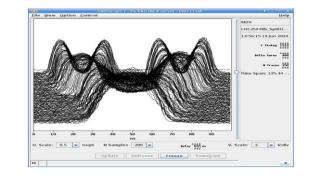
- Data coming from BCWLBO class
- Measure + monitoring •
 - Bunch intensity & bunch length after splitting •
 - Act on the Phase & Voltage of the cavities ۲
- Current CNN/RL implementation flexible ۲ enough to be tested operationally

Double Splitting

Last update

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



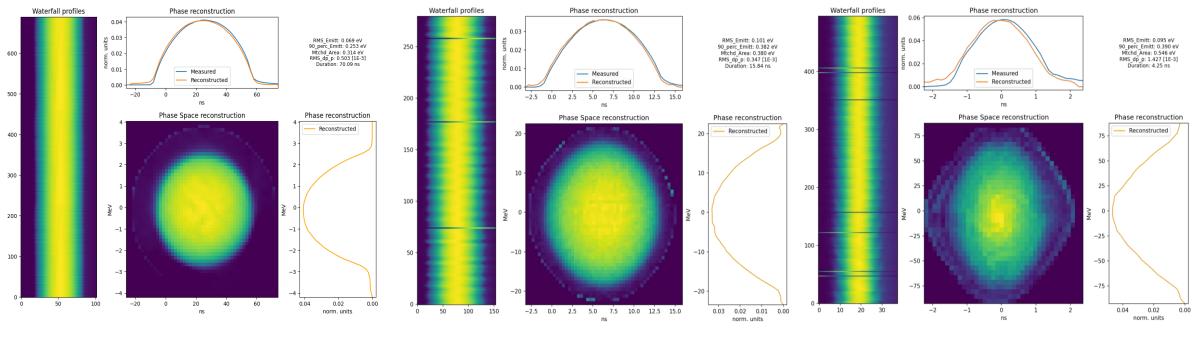




Last update

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

PSB



PS

Extraction

Bef. Rotation

Injection

Longitudin

SPS

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



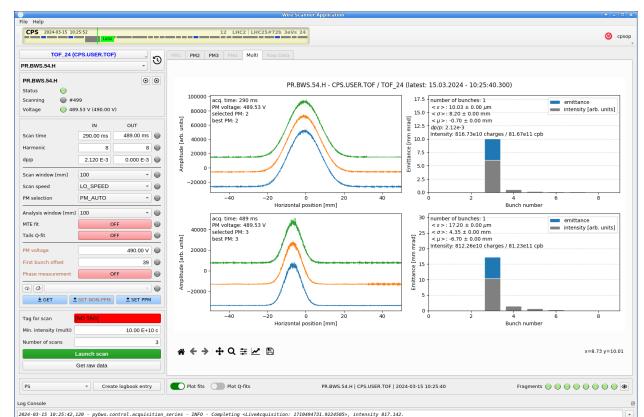
Amaury Beeckman | Automated beam scheduling and setup for LHC fillings

Wire scanner application

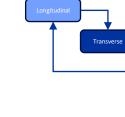
- Automation of wire scans for emittance measurements
 - Regular beam quality measurements (BPT)
 - Beam preparation and qualification during automated LHC filling
- Backend on UCAP; Permanent logging (NXCALS)
- Low-effort, repeatable measurements
 - Use of prepared ("tagged") acquisition and analysis parameters
 - Recovery & filtering of historical data based on tags
- Next step:

Wire scanner functionalities slides

- 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



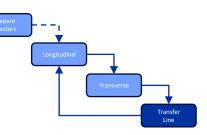
(@H. Pahl, G. Trad)



11 December 2024



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: <u>Results and plans for integration of</u> <u>automation and optimization in operation</u>



Online Monitoring

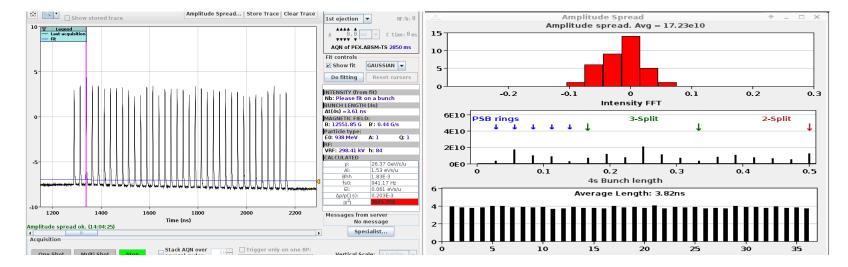
Ensure high beam quality 24/7

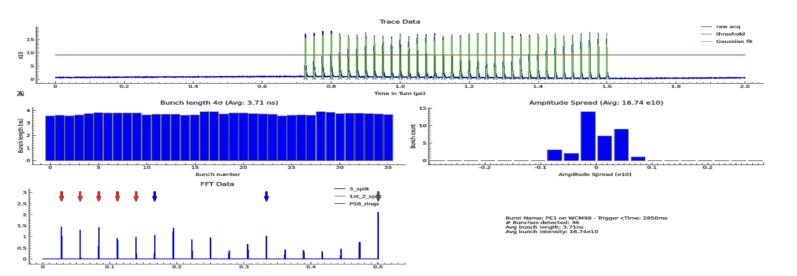


PS – Bunch Shape Measurement

"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
 - <u>https://op-webtools.web.cern.ch/vistar/?usr=PS2SPS1</u>
 - <u>https://op-webtools.web.cern.ch/vistar/?usr=PS2SPS2</u>
- 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

st cycle: coupled T_PRO_MTE_L4780_2024_V1		SFT	PRO1	Wednesday, May 15 2024 - 11:14 Showing cycle: 11:14		
PS	PSR / E10	% TT2	% TT10	% SPSR	% MTE EFF	
SFTPR01	1164.0	98.9	98.7	92.3	20.29	
SFTPRO1	1159.5	99.0	98.7	91.7	19.82	
0.5 10.4 0.3 0.3 0.2			% 22 /j 20 JJ W 18			
	400 600	800	Particular Setting / Arrent Control of Contr	08:11 09:40	11:09 11:14	
EXTRACTIC	N MI	JLTIPOLES	CAVITIES 10	MHz	SPS FREQ	

t cycle: coupled _SCRUB_26_FB11100	_FT4820_EXTR_	Q20_2024_V1	LHCMD2		r 13 2024 - 21:35 wing cycle: 21:35
PSR / E10	% TT2	% TT10	% SPSR	B.INT / E11	B.LEN / ns
1672.1	102.6	101.5	96.6	2.32 ± 0.09	3.65 ± 0.12
1674.6	102.7	101.6	95.9	2.33 ± 0.13	3.60 ± 0.09
1672.8	102.6	101.5	95.8	2.32 ± 0.18	3.65 ± 0.11
1674.9	102.6	101.6	95.4	2.33 ± 0.11	3.60 ± 0.12
2.0 1.5 1.0 0.5		— TT2 — TT10 — T110 — #11 — #2 — #3 — #4	Bunch Len / ns Bunch Int / E11		i .
0.00 200	400 600	800	53 3 15:36 16:4	48 18:00 19:12	20:24 21:36
EXTRACTION	CAN	TIES SINGLE	CAVITIES M	ULTI S	SPS EREO

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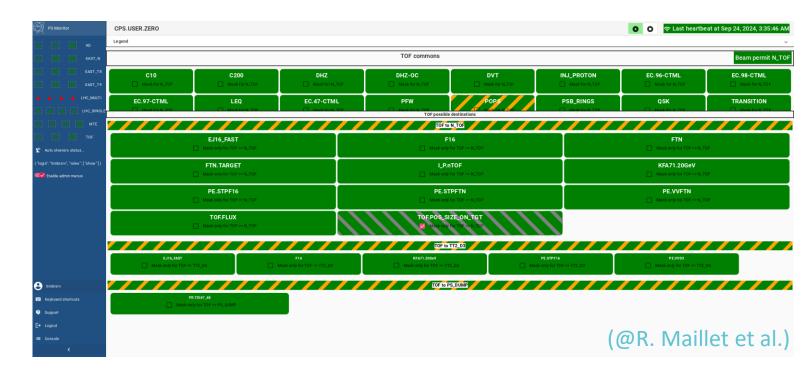
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(@H. Pahl)

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



Status of PS performance monitoring

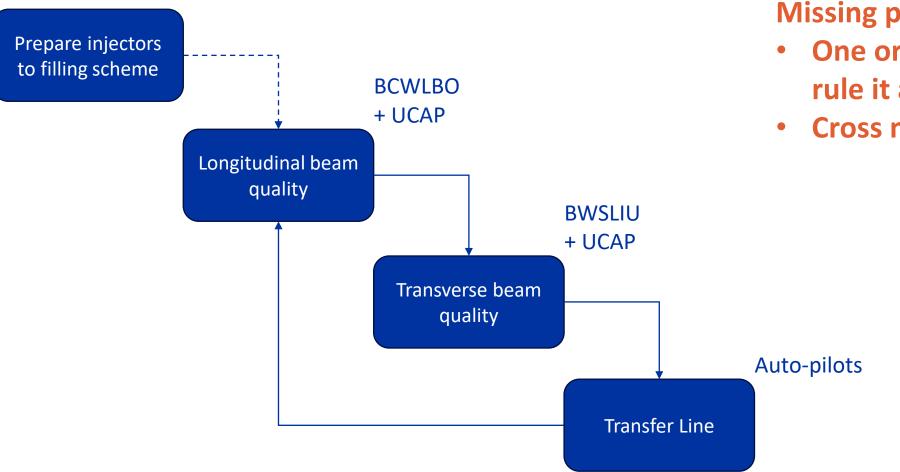


Outlook

Future plans and missing pieces across complex



Putting things together



Missing pieces:

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

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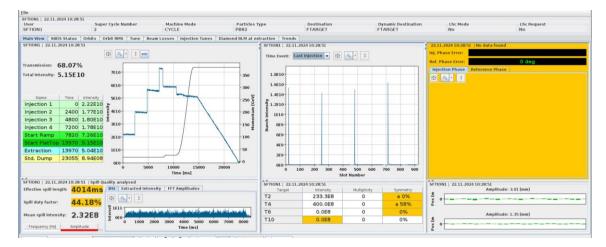
Cross machines metrics: quality control

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

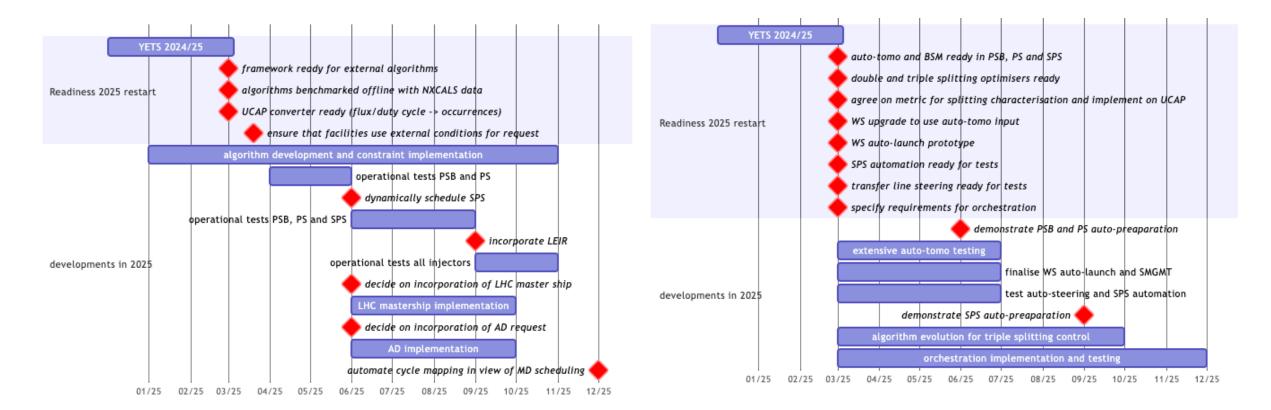
- Instance on top of all machines (state machine)
 - This the "Brain" of the procedure
 - Knows all the optimization steps required
 - Keep track on where it is on the sequence of tasks
- Launch UCAP/scripts/auto-reset processes on the fly
- Launch task in
 - Parallel
 - Sequentially
- Beam coupling 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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