REFINING LONGITUDINAL BEAM PARAMETERS ALONG THE CHAIN

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REFINING REQUIRES DEFINING

August 25, 2017 – Beam parameters at injection of each accelerator

PSB (H^- injection from Linac4)

		N (10^{11} p)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs)	B_l (ns)	$\delta p/p_0$ (10^{-3})	$\Delta Q_{x,y}$
Achieved	Standard	17.73	2.14	0.05	1.0	1100	2.4	(0.51, 0.59)
	BCMS	8.48	1.15	0.05	0.9	1000	2.2	(0.46, 0.56)
LIU target	Standard	34.21	1.72	0.16	1.4	650	1.8	(0.58, 0.69)
	BCMS	17.11	1.36	0.16	1.4	650	1.8	(0.35, 0.43)

PS (Standard: 4b+2b – BCMS: 2× 4b)

		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$ (10^{-3})	$\Delta Q_{x,y}$
Achieved	Standard	16.84	2.25	1.4	1.2	180	0.9	(0.25, 0.30)
	BCMS	8.05	1.20	1.4	0.9	150	0.8	(0.24, 0.31)
LIU target	Standard	32.50	1.80	2.0	3.00	205	1.5	(0.18, 0.30)
	BCMS	16.25	1.43	2.0	1.48	135	1.1	(0.20, 0.31)

SPS (Standard: 4 × 72b – BCMS: 5 × 48b)

		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$ (10^{-3})	$\Delta Q_{x,y}$
Achieved	Standard	1.33	2.36	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.05, 0.07)
	BCMS	1.27	1.27	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.07, 0.12)
LIU target	Standard	2.57	1.89	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.10, 0.17)
	BCMS	2.57	1.50	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.12, 0.21)

LHC (≈10 injections)

		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)	bunches/train
Achieved	Standard	1.20	2.60	450	0.47 (0.48)	1.65 (1.21)	288
	BCMS	1.15	1.39	450	0.40 (0.41)	1.50 (1.13)	96
LIU target	Standard	2.32	2.08	450	0.56 (0.58)	1.65 (1.24)	288
	BCMS	2.32	1.65	450	0.56 (0.58)	1.65 (1.24)	240

https://edms.cern.ch/ui/file/1296306/2/LIU-table-protons_v3.pdf

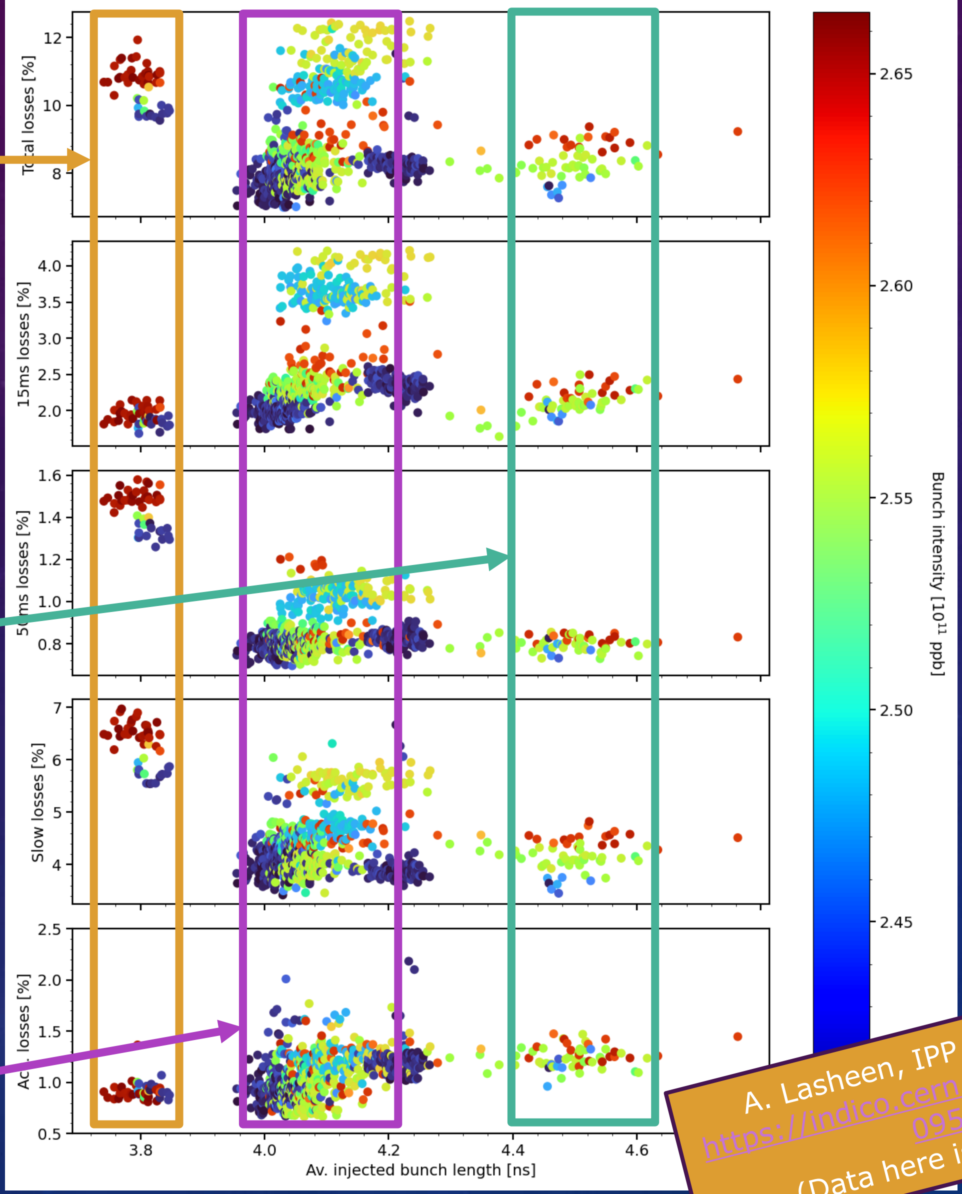
- Parameter tables (e.g. LIU protons) provide guidance for “correct” beam parameters
- For experimental facilities, the specifications are generally only at extraction from the last accelerator
- Where specifications are given, they will often be adapted during commissioning and optimization

REFINING REQUIRES DEFINING

Short bunches, area of interest (work in progress)

Good transmission but too long

“target” bunch length



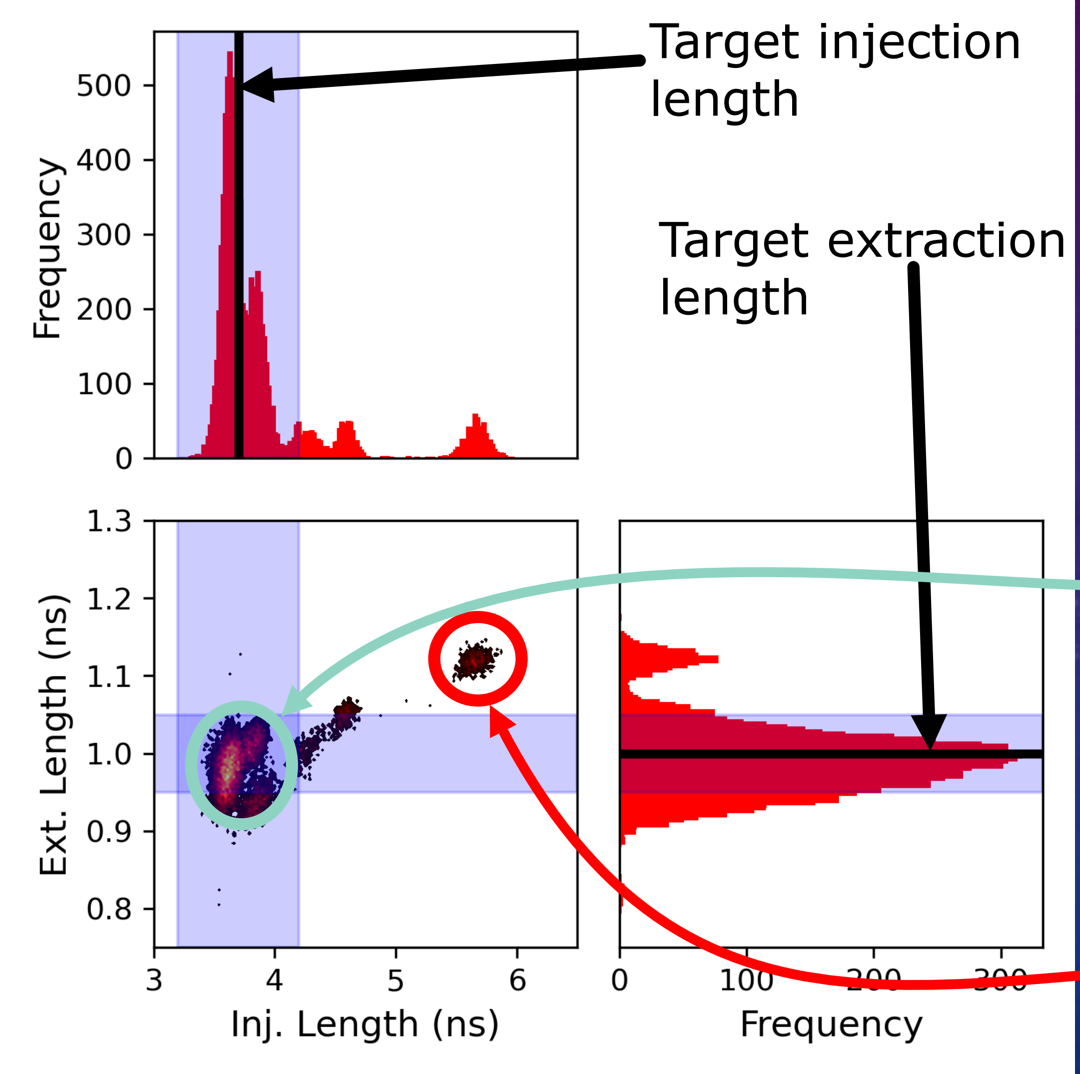
A. Lasheen, IPP 3/11/2023
https://indico.cern.ch/event/1340095/
(Data here is updated)

- LIU parameter table specifies 4.0 ns at SPS injection
- 4.0 ns to 4.2 ns typically accepted in operation*
- Shorter bunches are promising, but require more work
- Better observation through the complex required to define optimum parameters

*4.2 ns measured at SPS injection requires 4.0 ns measured at PS extraction

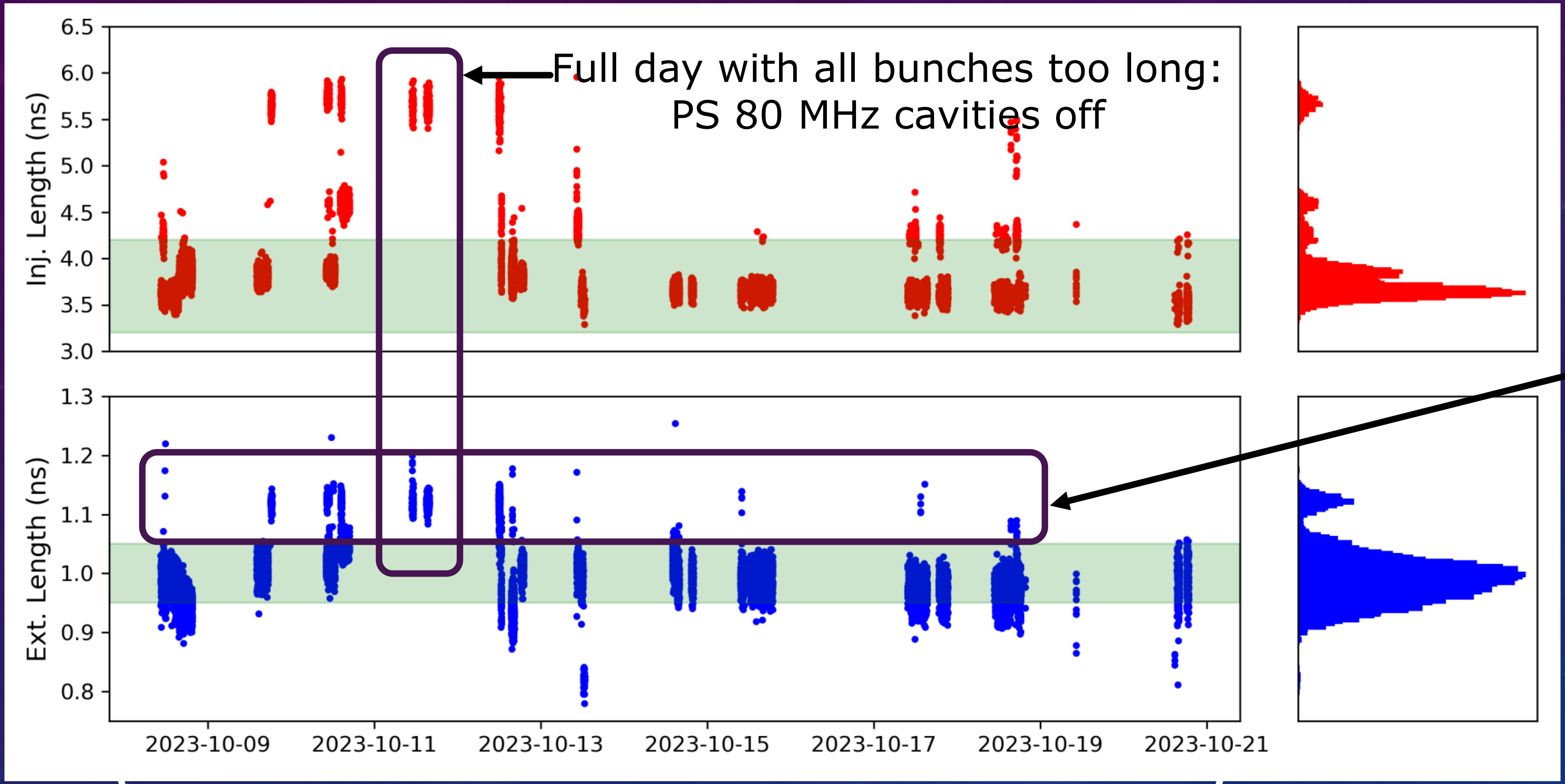
CASE STUDIES

BUNCH LENGTH TO AWAKE



- Typical bunch length range during the last run of 2023:
  - Extraction: τ_l = 1 ns ± 5%
  - Injection: 3.2 ns < τ_l < 4.2 ns
- Most bunches meet the required specifications
- A cluster of points can be seen with:
  - Extraction: τ_l ≈ 1.15 ns
  - Injection: τ_l ≈ 5.5 ns

BUNCH LENGTH TO AWAKE

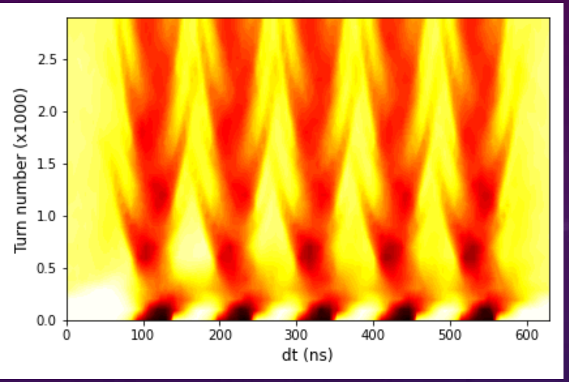


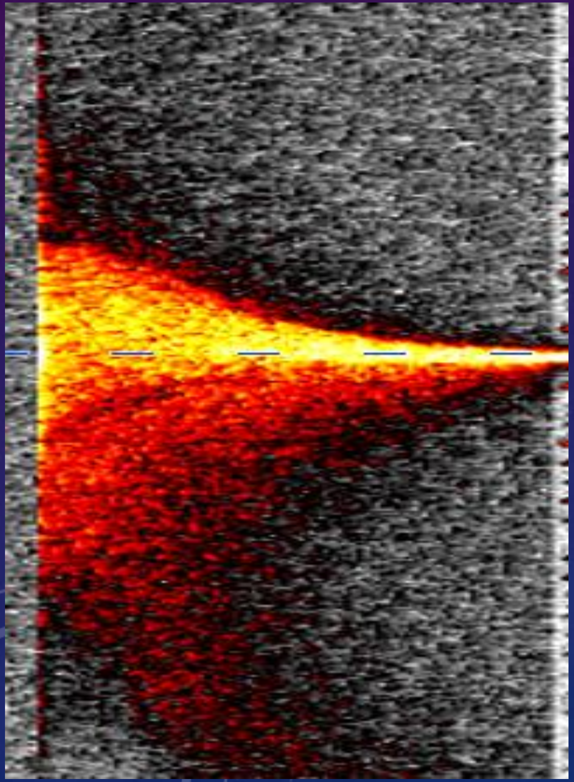
Long bunches appear intermittently throughout the run, but are generally transient or get corrected

Last AWAKE run of 2023

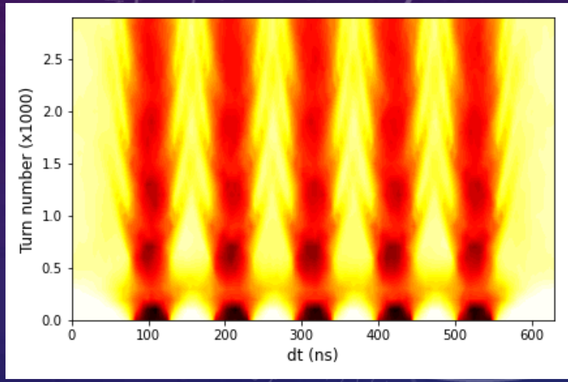
Details presented at SPS MPC #50:
https://indico.cern.ch/event/1349652/

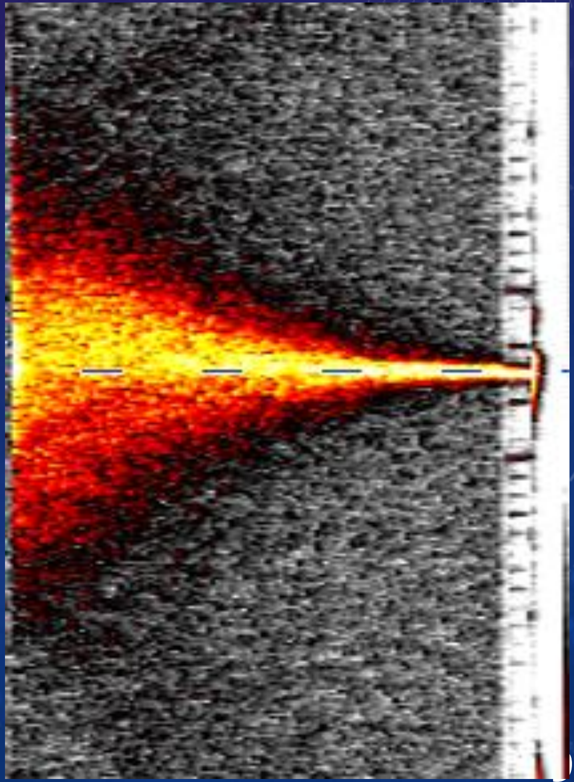
AD BUNCH ROTATION



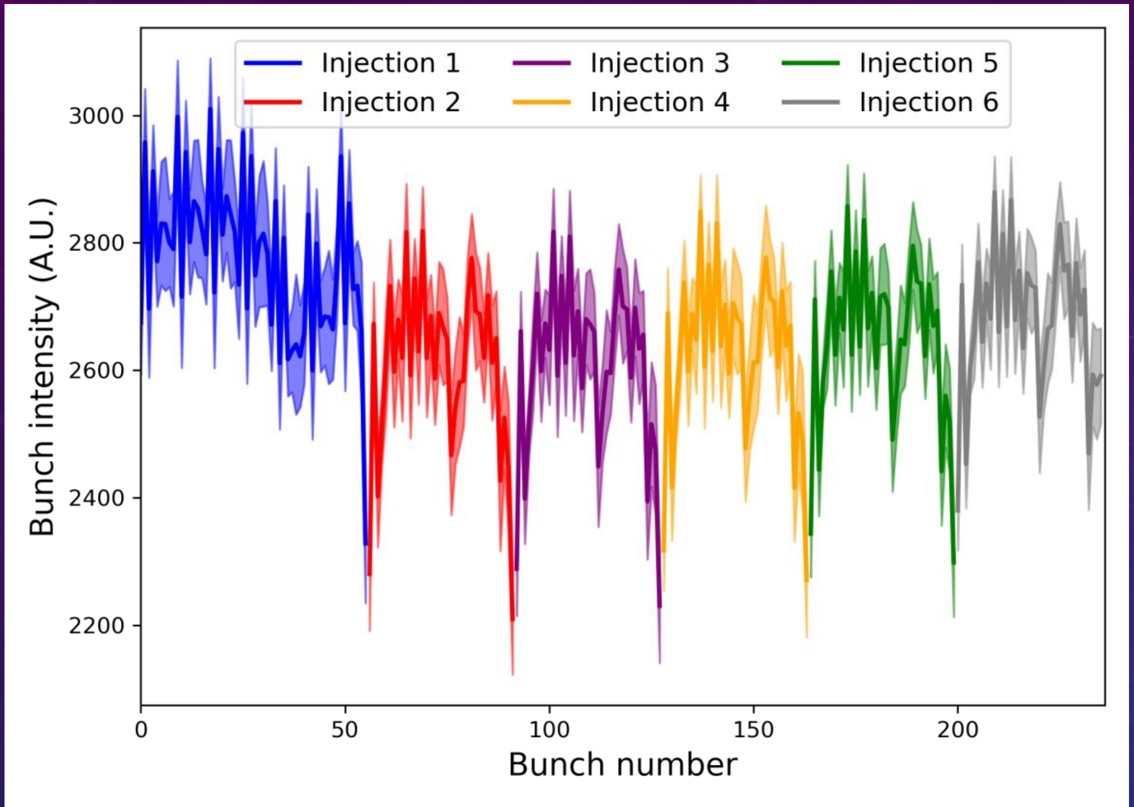


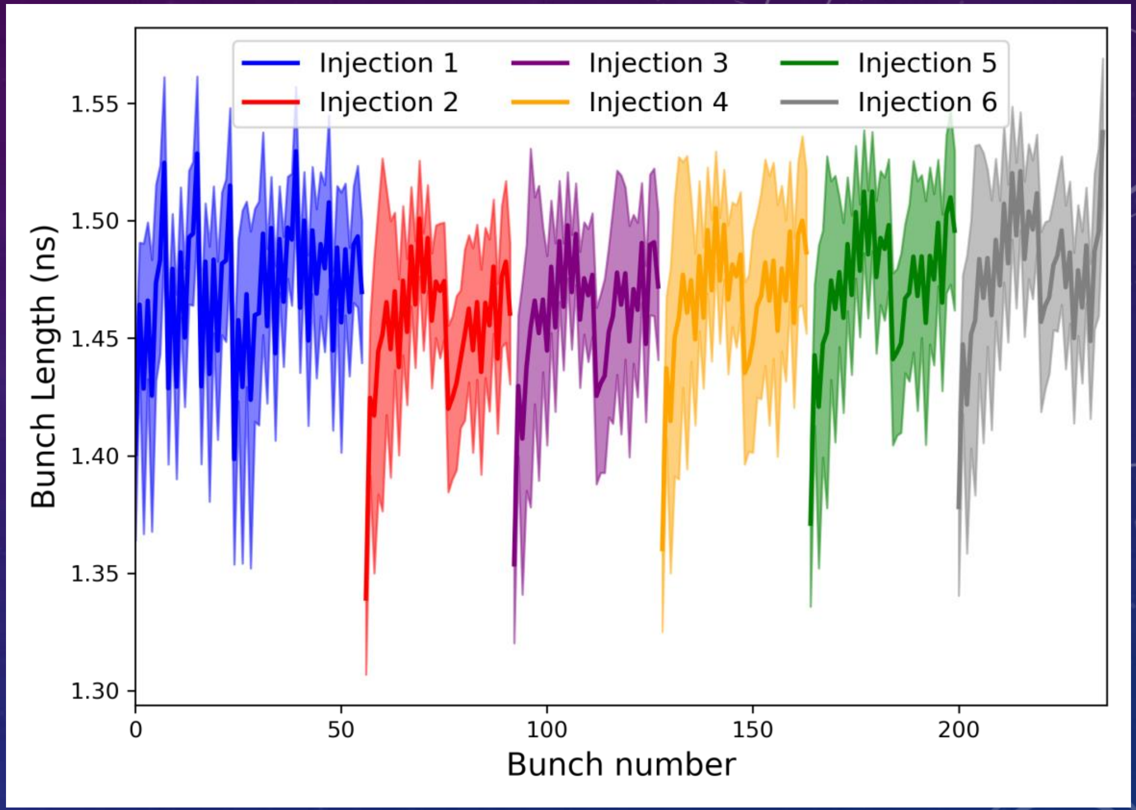
- Bunch rotation at injection is required to quickly reduce the momentum spread for effective stochastic cooling
- If the bunch rotation is incorrect, the cooling will be degraded and transmission will drop
- **If** a problem is identified, debugging can be difficult:
  - AD or PS?
  - Energy or phase?
  - Bunch length or bunch spacing?
- No automatic system to identify bad cycles





LHC 25NS PARAMETER SPREAD

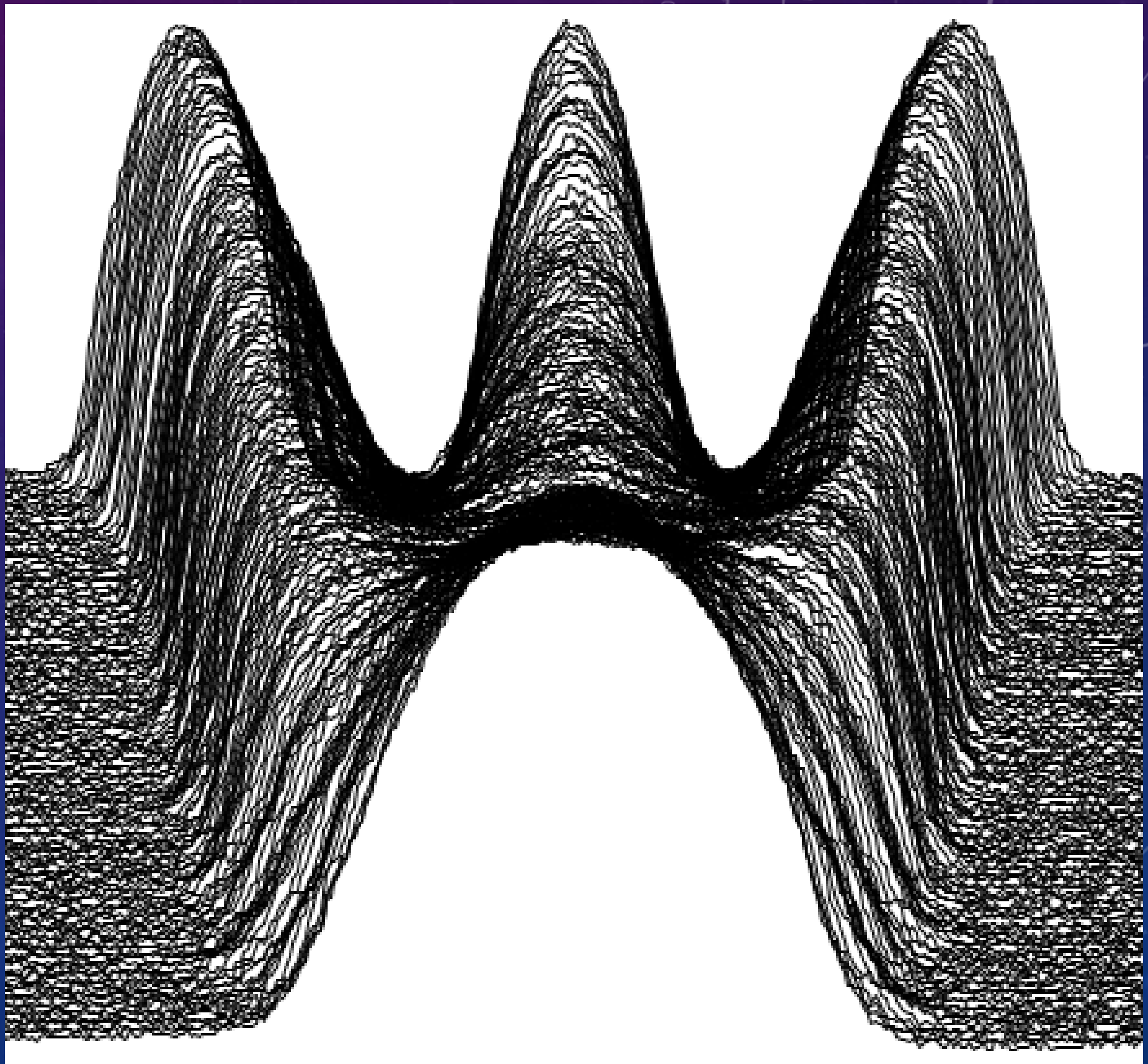




- Bunch-by-bunch intensity and length spreads at SPS extraction for one day of operational LHC filling cycles (121 cycles with *SPS.BQM:BEAM_OK = True,* 15th July 2023)
- Some contributing factors:
  - Ring-by-ring and cycle-by-cycle differences at PSB extraction
  - Kicker timing in the SPS
  - **Splitting imperfections in the PS**
  - …

LHC 25NS PARAMETER SPREAD

- Triple splitting requires precise voltage and phase control of three RF harmonics, drifts with time lead to unbalanced splitting
- A ML tool developed in RF (J. Wulff https://indico.cern.ch/event/1195988/) can automatically optimise the splitting
- The optimisation is launched manually once a problem is identified
- Feedback loop from splitting to correction is still very human

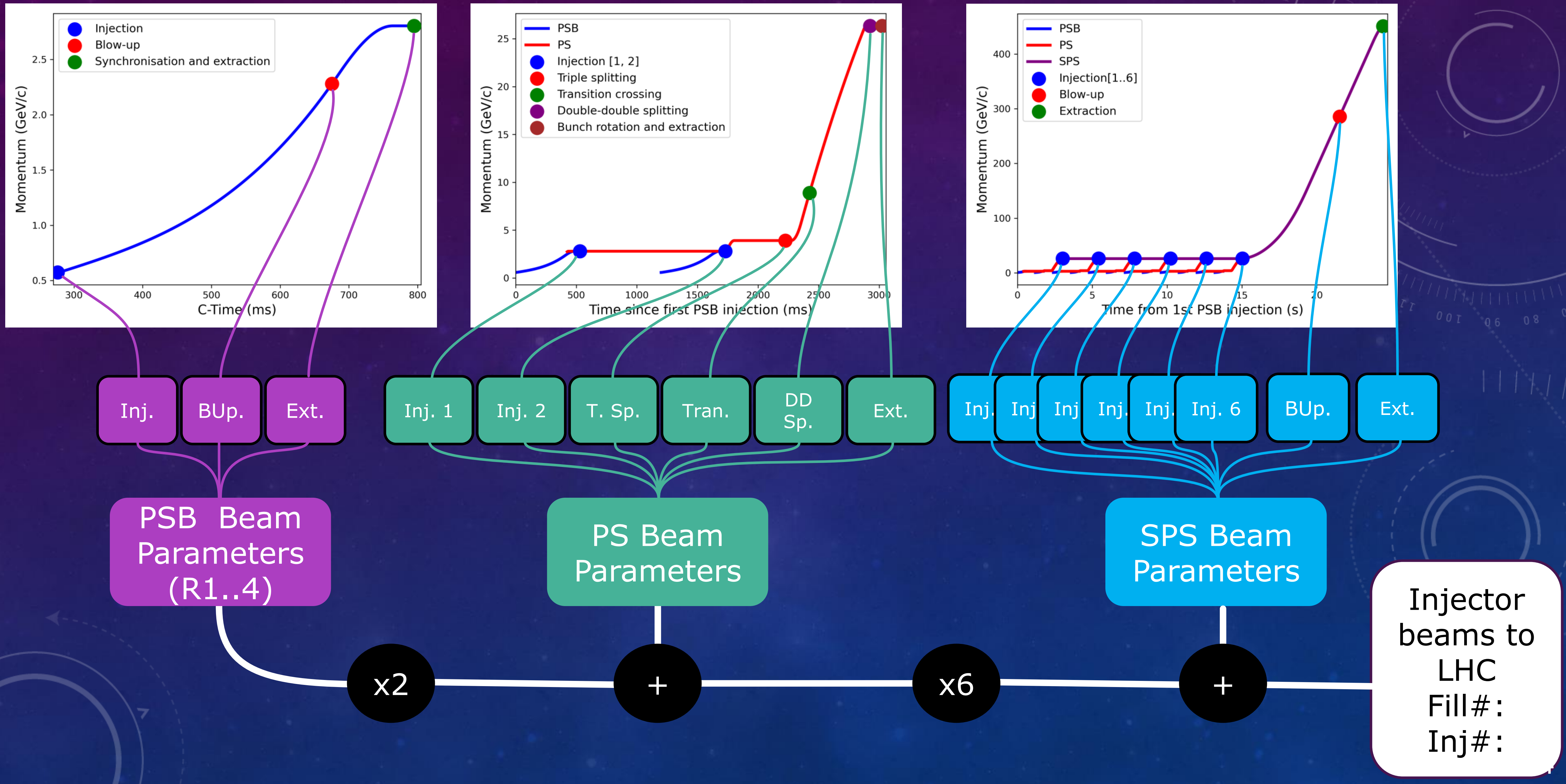


IDEAL SITUATION (LHC 25NS)

OBSERVATIONS

- For each machine and cycle, continuously monitor beam parameters at key times
- Ensure parameter definitions are sufficient to cover all features of interest:
  - Bunch shape as well as bunch length
  - Phase and energy errors
  - …
- Make better use beam instance tracking to determine effect of upstream parameter drifts on downstream performance
- Identify discrepancies between different measurement sources and control for them:
  - Bunch length between PS and SPS
  - Longitudinal emittance between PSB and PS
  - …
- Create a standardised connection between cycles in the injectors and timing data for the LHC (and experimental facilities)

EXAMPLE: PARAMETER MONITORING 2023 LHC 25NS



IMPLEMENTATION

CURRENT SITUATION

Good:

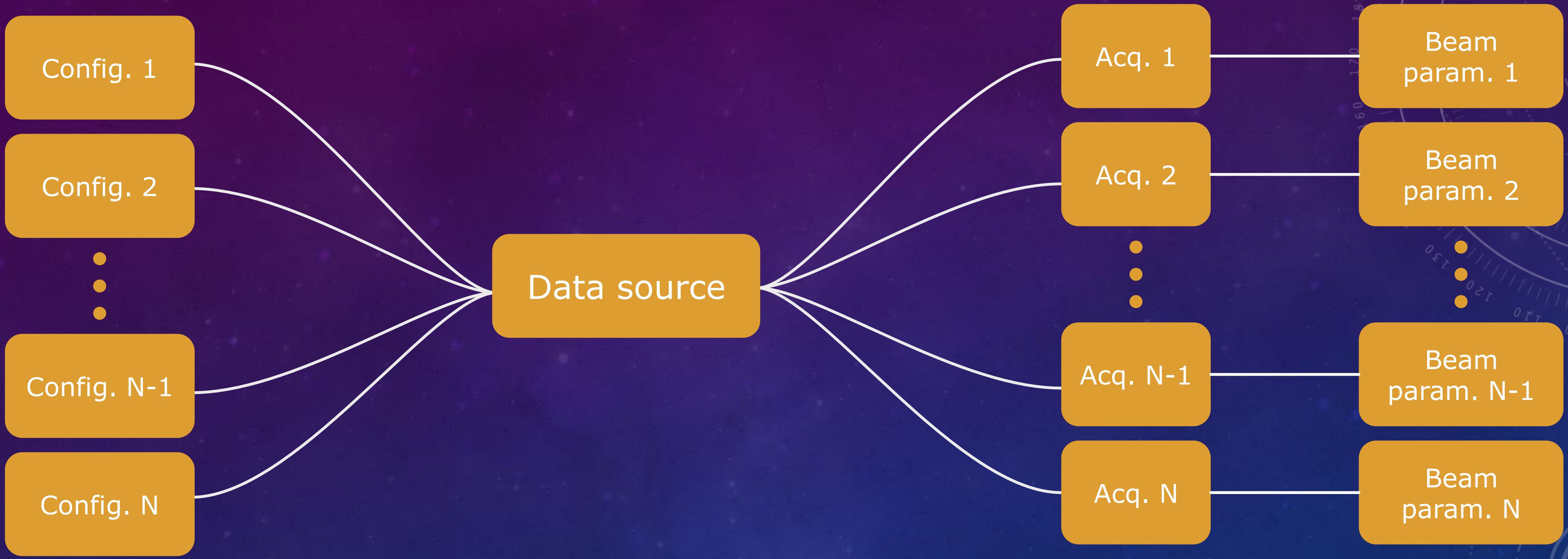
- Beam instance tracking is available for the injectors
- UCAP converters provide efficient and reliable live data analysis
- SPS has a lot of required functionality already:
  - BQM identifies good/bad cycles
  - ABWLM can give measurements through a full cycle
- LHC IQC qualifies beam injection

Bad:

- Beam instance tracking is difficult online
- No easy way to identify which bunches
  - Enter which LHC bucket
  - Get sent to experiments
- Very little automatic measurement

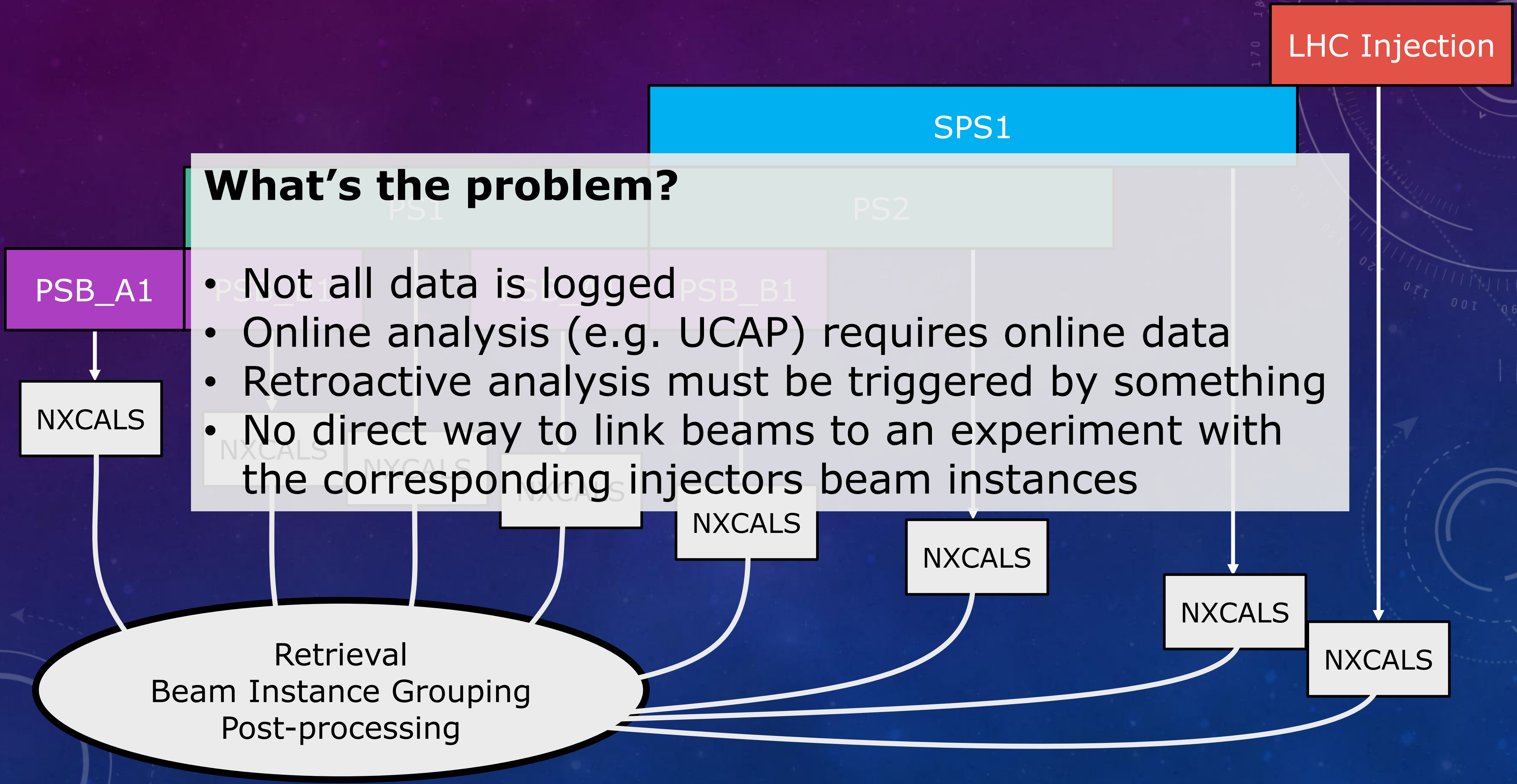
ADDITIONAL NEEDS/DESIRES

CONTINUOUS MONITORING



- PSB proof-of-principle:
  - OASIS interface to beam profile digitizer
  - Custom FESA class provides multi-PPMness
  - UCAP converter chain to separate acquisitions and perform analysis
- PS proof-of-principle:
  - OASIS interface to beam profile digitizer
  - Python application to get and post-process data

AUTOMATIC BEAM INSTANCE TRACKING: OFFLINE

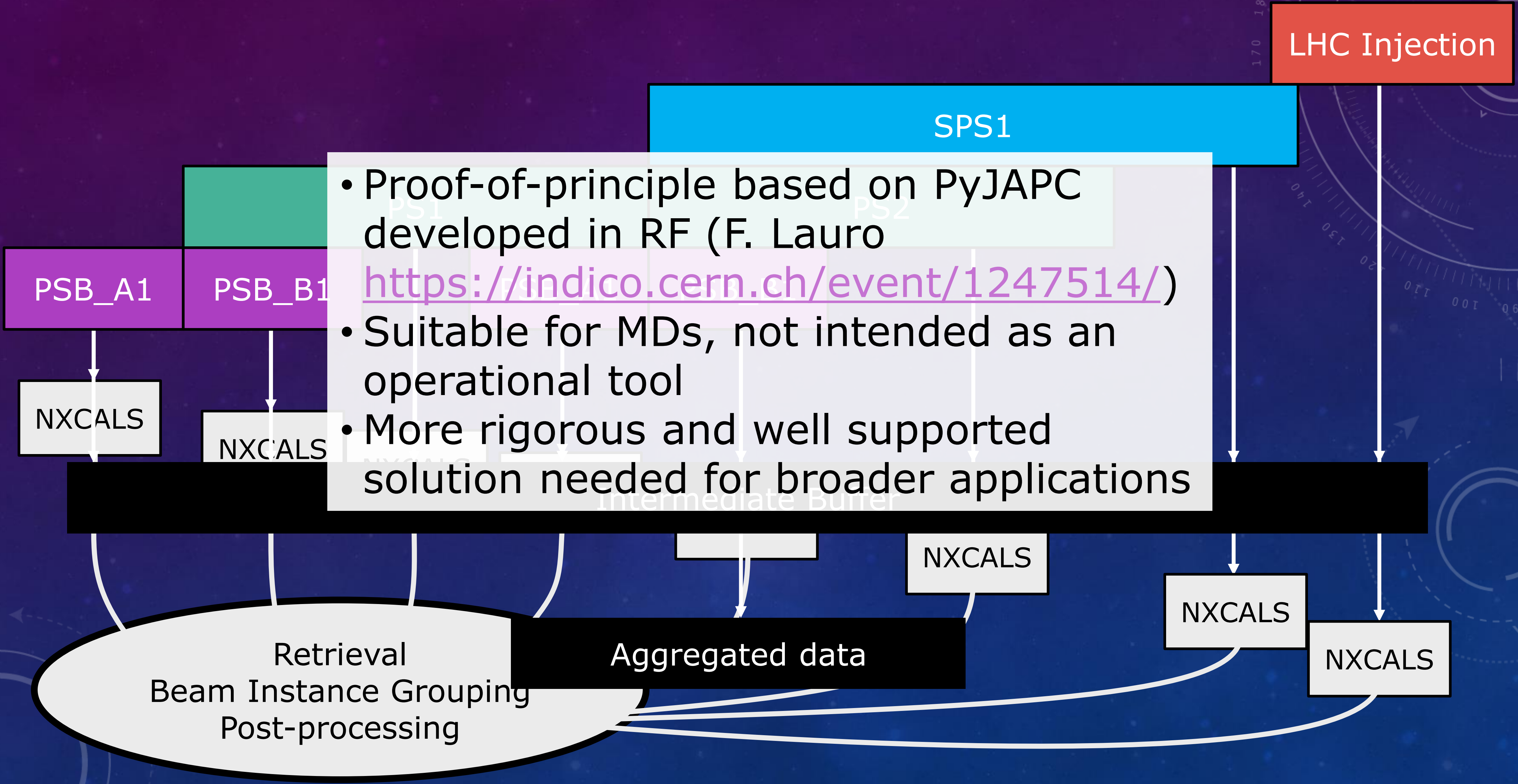


What's the problem?

- Not all data is logged
- Online analysis (e.g. UCAP) requires online data
- Retroactive analysis must be triggered by something
- No direct way to link beams to an experiment with the corresponding injectors beam instances

AUTOMATIC BEAM INSTANCE TRACKING: ONLINE

- Proof-of-principle based on PyJAPC developed in RF (F. Lauro https://indico.cern.ch/event/1247514/)
- Suitable for MDs, not intended as an operational tool
- More rigorous and well supported solution needed for broader applications



CONCLUSION

- Definition of optimal beam parameters is still ongoing
- Before we can refine beam parameters, we must be able to reliably determine their impact
- Punctual measurements are adequate for reaching specification, but not for tracking performance
- Multi-PPM data acquisition is essential for continuous monitoring
- A rigorous link between injector cycles and downstream facilities is required
- Automatic online beam instance tracking is needed to improve correlation of beam parameters through the complex