

Automated equipment monitoring: status and evolution

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Overview

- **Introduction**
 - Purpose of monitoring
 - Systems in place across the complex
- **EPA WP8 – towards smart equipment**
 - OP monitoring
 - Status and plans for generic framework
- **Conclusions**

Purpose of monitoring

- **Avoid and reduce downtime** of our accelerators and facilities
- Provide a **snapshot** of the status of an entity, a family of equipment, an accelerator, ...
- Basis for **interlocking** (BIS, SIS, external conditions, etc.)
- **Distribute** critical and non-critical **information** to various clients (OP teams, users, exchange between machines, AFT, equipment owners, etc.)
- **Trigger** manual and automatic **actions** (recovery of equipment, beam steering, etc.)
- **Predict** future equipment **behavior**

Systems in place across the complex

- Various solutions are being used across the chain

- Differences are based on **criticality of interlocking, know-how of available tools, cycle length, number of users, and history**

- **LHC and SPS**

- Operation relies on **BIS** and **SIS**, with critical hardware being direct input to the interlock system

- machine protection: equipment failure needs to trigger beam dump asap
- equipment monitoring used to understand the dump cause in a second stage
- SIS (GUI and logic) tailor made for LHC and also well suitable for SPS due to cycle lengths

- **Post-Mortem system** an additional asset for (online) fault analysis (PM-triggered UCAP AFT actor)

- **LHC IQC** and **SPS QC** for beam quality monitoring, **BigSister** as second SIS instance to announce alarms


The screenshot shows the 'bic_eventseq' software interface. It features a header with system information (System: BIC, Class: EVENT_SEQ, Source: IA, Session time: 11:54:56.041 27/11/23, Version: 3.6.0, Encoder: BIC/EVENT_SEQ, Qualifier: Analysis flags (NORMAL)). Below the header is a table with columns: Index, Loc. Permit, Time, Delta(us), Description, and BIC name. The table contains multiple rows of event data, such as '05:28:03+178968 0 USER_PERMIT: Ch 8-RF-B2: A T => F' and '05:28:03+179020 52 USER_PERMIT: Ch 6-CBDS Beam 2: B T => F'. A filter bar at the bottom allows for selecting various permit types like 'Beam_Permit', 'Local_Permit', 'User_Permit', etc.

The screenshot shows the 'Permits Tree' interface. It displays a hierarchical tree structure of system permits. The root node is 'Permits Tree'. Underneath, there are several main categories, each with a status indicator (e.g., 'L [OK]', 'X [L]', 'P [AND]', 'I [COD]'). These categories include: 'BUNCH_LENGTH_RAMP_B1', 'RING_B1_PERMIT', 'COLLBPB_B1', 'ORBIT_PHYS_B1', 'ORBIT_INTERLOCK_B1', 'ORBIT_REF_ORBIT_CHECK', 'ORBIT_REF_VOLTAGE_FT_B1', 'ENERGY_BELOW_3400GEV', 'RF_VOLTAGE_MIN_FT_B1', 'RING_PHYS_B1', 'ORBIT_PHYS_B1', 'BEAM_MODE_NOT_STABLE', 'ORBIT_READING_PHYS_HV_B1', and 'ORBIT_READING_PHYS_HV_B1'. The tree is expandable and collapsible.

The screenshot shows the 'PM PLAYBACK PRO GUI' interface. It displays event sequence details and machine protection features. The 'Event sequence' section shows event timestamp, fill number, filling pattern, and event description. The 'Machine protection features' section shows a list of features with their status (e.g., 'BIC IPQC: [OK]', 'FMCHSA: [OK]', 'PC IPQC: [OK]', 'XPOC B1: [OK]', 'XPOC B2: [OK]', 'REQUIRED INTERLOCK: [OK]', 'PM Overl: [OK]', 'BEAM LOSS ANALYSIS: [OK]', 'SAFE FOR INJECTION: [OK]'). The interface also includes a 'Dump context' section and a 'Comments' section.

Systems in place across the complex


- SPS




SIS : Tree-like structure, exporter, time of the evaluation

- SIS monitors ~ 1045 devices, ~ 9498 logics inputs, states and settings covering the SPS and its transfer lines.
- The acquired values are analysed (tested) and converted into a logical state (**TRUE** or **FALSE**).
- The logical states are grouped into tree-like structures and combined using logical operators (AND or OR). In the simplest case an 'AND' of all conditions is performed.
- The top of the tree corresponds to a **SOFTWARE PERMIT (SW_PERMIT)** which itself is either **TRUE** or **FALSE**:
 - ☐ **TRUE** : OK for beam operation.
 - ☐ **FALSE** : one or more tests indicate an abnormal situation.

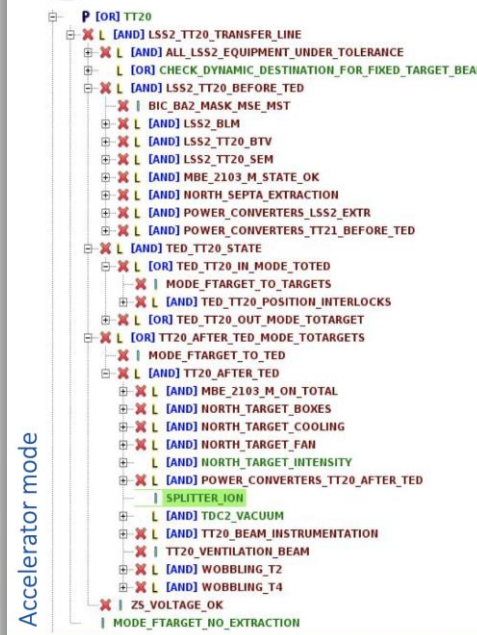
>> the status of the SW_PERMIT is exported to HW interlock and timing systems.




25-01-23 Eric VEYRUNES/Serge MASSOT 3



FTARGET mode



- No Extraction – seen before
- TT20-TED mode:
 - Test/check all elements before TED TT20.
 - Mask/ignore all elements after TED TT20
 - Mode of the MBE_2103 has to be PARTIAL (TBD)
 - Access possible in BA80 and downstream
 - (EIS to be safe for access – TBSE, TED, MBE Partial mode)
- To Target mode:
 - Test/check all elements up to targets.
 - Mode of the MBE_2103 has to be TOTAL
 - No access possible in BA80 and BA81



25-01-23 Eric VEYRUNES/Serge MASSOT 11

S. Massot, E. Veyrunes, [Interlocks SPS, OP shutdown lecture, 2023](#)

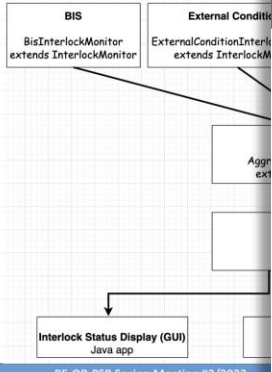
Systems in place across the complex

- **Linac4 and PSB**

- SIS limitations for fast cycling machines → **UCAP developments**

Interlock detection

- The presented solution aims to solve 2 problems at the same time
 - For the operations: displaying the root cause for beam interruptions
 - The initial one in the series, the ongoing ones and the last one that was already cleared
 - For RAWG¹: automatic registration of the faults in



1: RAWG: Reliability and Availability Working Group
aft.cern.ch

2: AFT: Accelerator Fault Tracking, aft.cern.ch

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BE-OP-PSB Section Meeting #2/2023

Status and plans

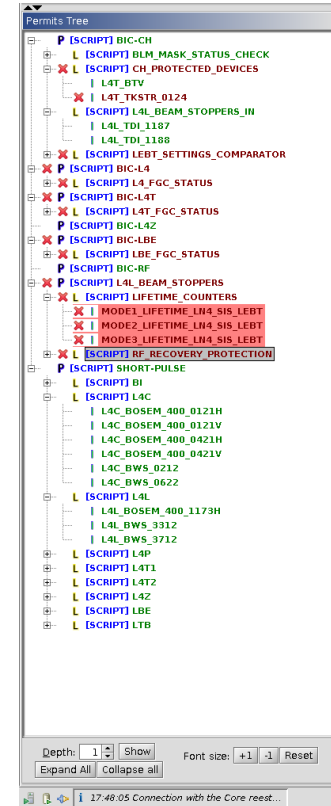
- It is still in beta version: many issues to fix and improvements to implement
 - Detection of faulty System
 - Rather straight forward: each interlock name can be directly linked with system name
 - Detection of faulty Element
 - More complicated, requires dedicated monitoring of all hardware devices
 - Determination of impacted destinations
 - AFT actor change from Tibor's to Michi's version
 - After Tibor departure Michi continues this actor development in a new repository
- Many corner cases still to be understood and correctly programmed

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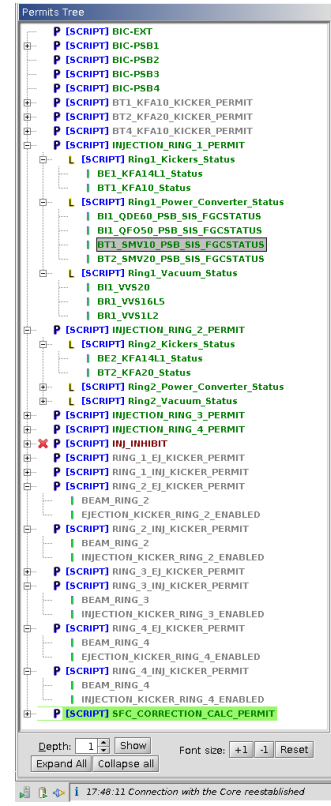
BE-OP-PSB Section Meeting #2/2023

November 22 2023

Linac4 SIS



PSB SIS

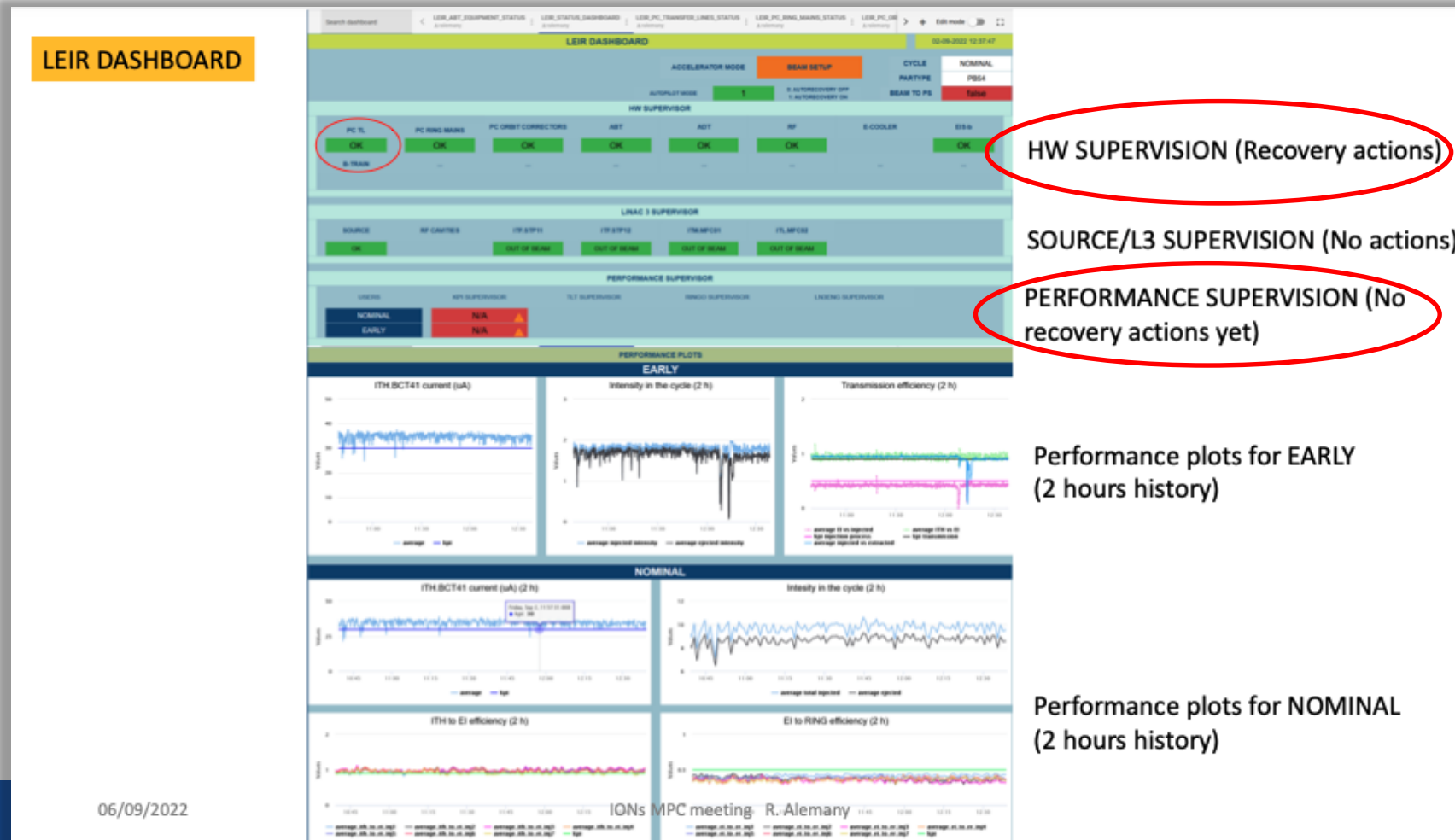


P. Skowronski, [Linac4 Interlocking and AFT](#)



Systems in place across the complex

- LEIR autopilot (UCAP-based, WRAP display)

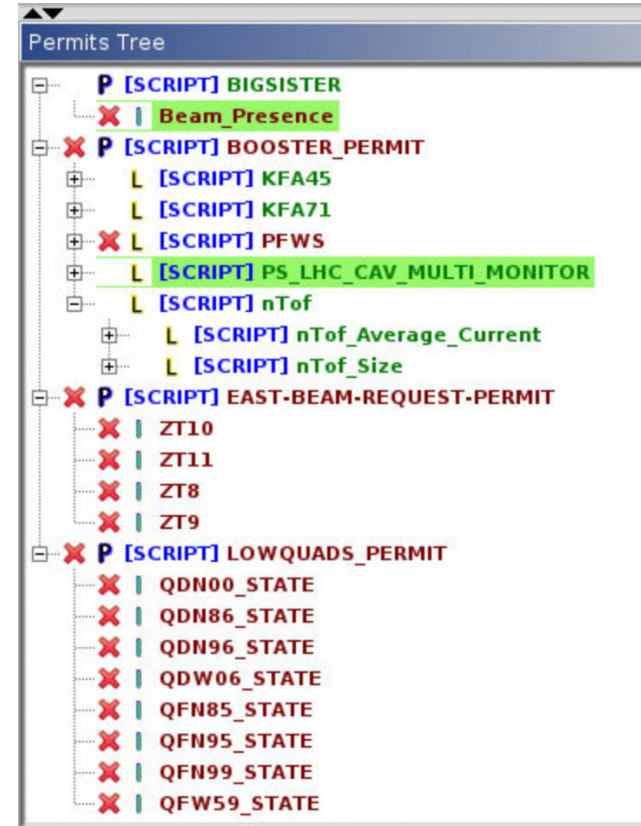


R. Alemany,
[LEIR Autopilot](#)



Systems in place across the complex

- PS
 - **SIS** in PS far **less developed** than in other machines
 - **Interlocking PSB beam production** in case of failure of major equipment (after first bad shot)
 - **Beam quality monitoring** for nTOF via SIS (flux and beam size checks)
 - **BigSister** as AFT actor
 - Based on BCT reading, **requiring manual completion** of AFT entry (*Downtime to be updated*)



Towards smart equipment

- **Large fraction of downtime in our accelerators due to resettable equipment faults**
 - Significant amount of time spent to understand situation and, eventually, reset
- **Equipment issues can very often be predicted and planned stops can be targeted for maintenance to avoid unforeseen stops**
- **Beam characteristics can be important input to proper equipment functioning**
- **EPA project includes WP8 – Automate Equipment to streamline the management of equipment**
 - Equipment **configuration, monitoring, fault analysis** and **recovery**
 - Automating equipment must become a **common effort**
 - **Common vision and strategy** being defined together with equipment groups
 - Details and timeline can be found [here](#)

Towards smart equipment

- **WP8 aims at**

- the development of a **unified way of reporting equipment status**
- providing **intervention assistance** with suggestions, leads, and analytics
- equipment that **self-analyses the source of an issue** and communicates it clearly
- **early identification** of upcoming **failures** to allow for scheduled maintenance
- development of **self-configuring equipment** given the operational conditions

- **Activities being carried out in parallel**

- Implementation of **general equipment monitoring, automatic fault recording and auto-resets** by OP
- WP8 implementation of **automatic fault monitoring, recovery and prevention, and beam-based configuration** on the **equipment side**
 - Definition of **pilot projects** in different equipment groups (see Kostas' talk)
 - Definition of **interface and architecture for data analysis and automatic recovery frameworks**

UCAP-based PS performance monitoring system

- **Performance monitoring == equipment and beam quality monitoring**

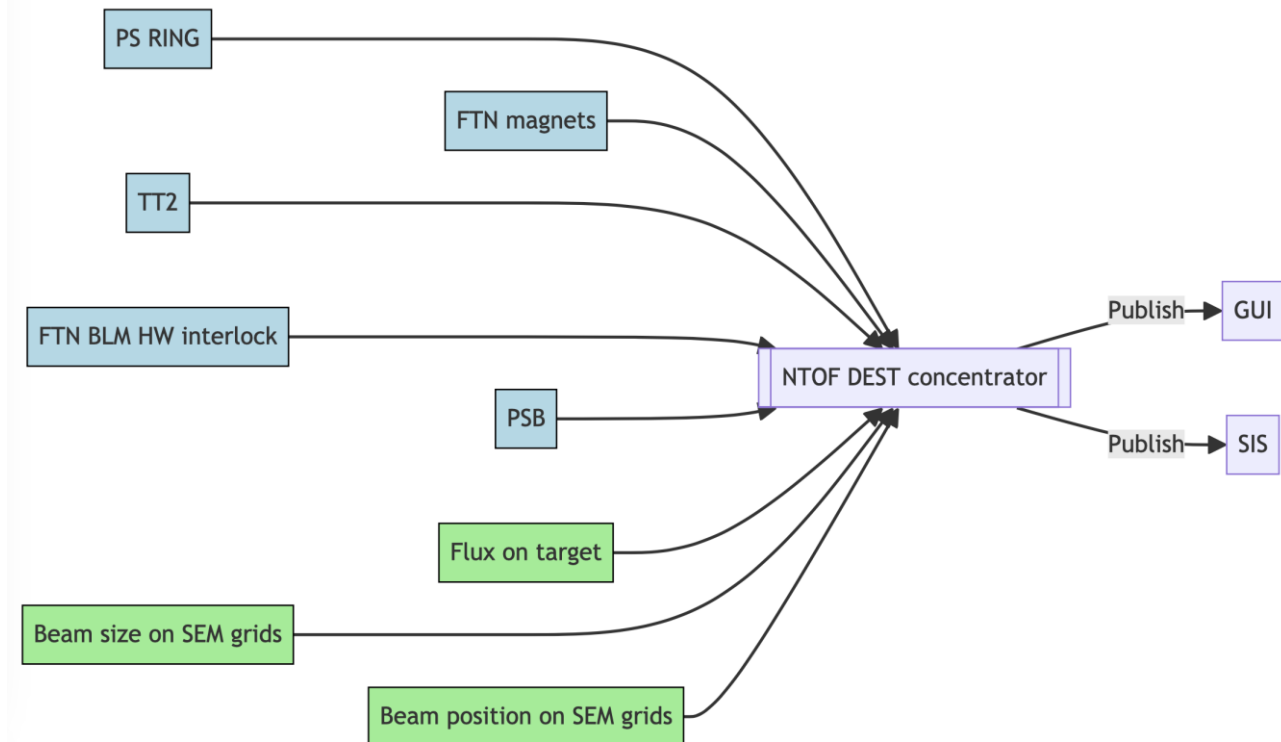
- Crucial in the **PS as multi-user facility** with many different requirements in terms of beam characteristics
- Java on UCAP: equipment monitoring
- Python on UCAP: beam quality monitoring

- **Monitoring the health of the different destinations**

nTOF monitoring

Open Created 1 year ago by Rodolphe Maillet

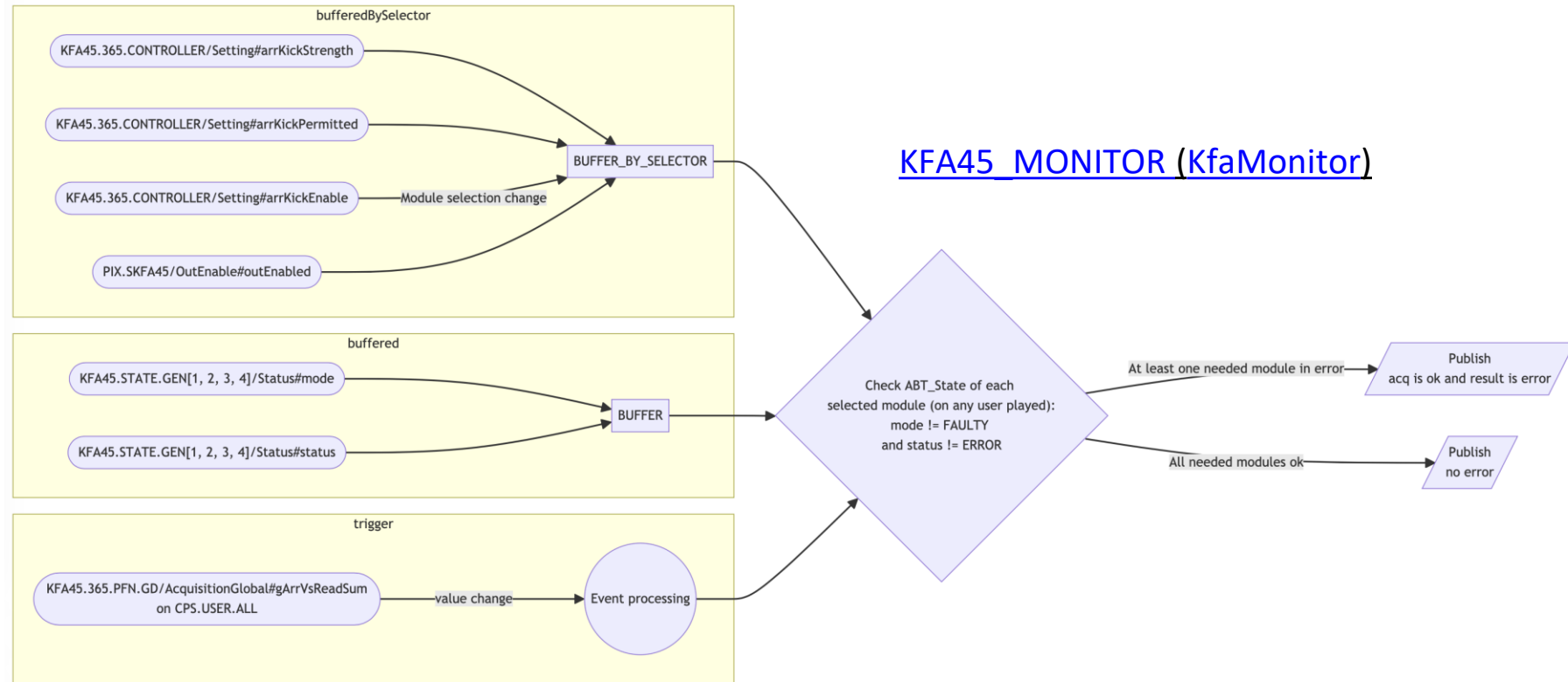
- Monitor all HW devices needed to produce nTOF beam up to the nTOF target
 - FTN, TT2 power supplies (devices following their CCV correctly)
 - Same for PS ring including only devices needed for TOF
 - exclude ions, mte, east dedicated hardware
 - include all devices to inject, accelerate and extract the beam
 - FTN, TT2 BLMs
- Monitor beam quality
 - beam position on target
 - beam size on target
 - FTN trajectories (looking for drifts and/or wrong setting)



R. Maillet, [nTOF monitoring on Gitlab](#)

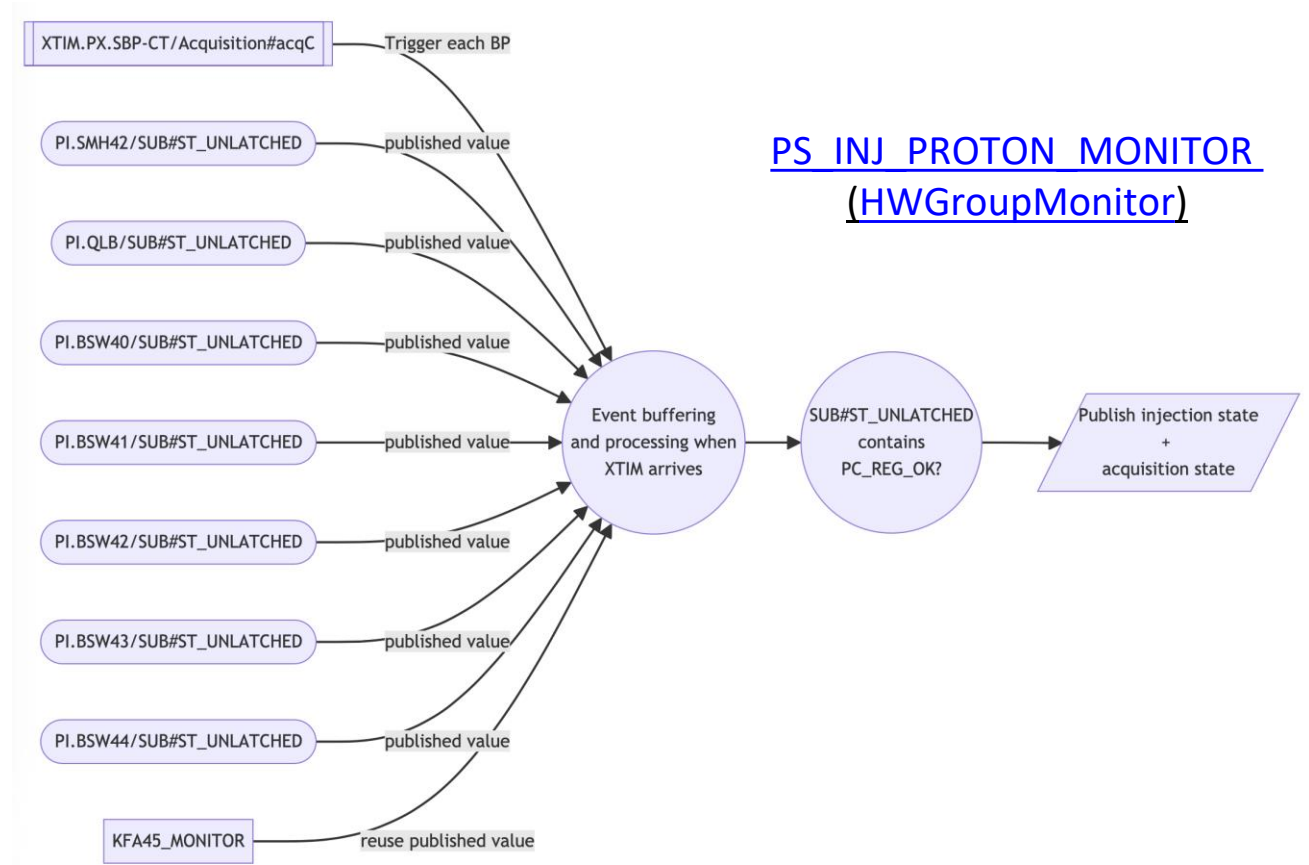
UCAP-based PS performance monitoring system

- **Status of monitoring**
 - **reusing infrastructure** from PSB for FGCs (covering ~80% of the equipment)
 - **PS-specific developments** for kickers and RF cavities
 - publication of generic simple Boolean flags
 - collaboration with equipment experts to define logic
- **Developments eventually to be taken over by equipment experts**



UCAP-based PS performance monitoring system

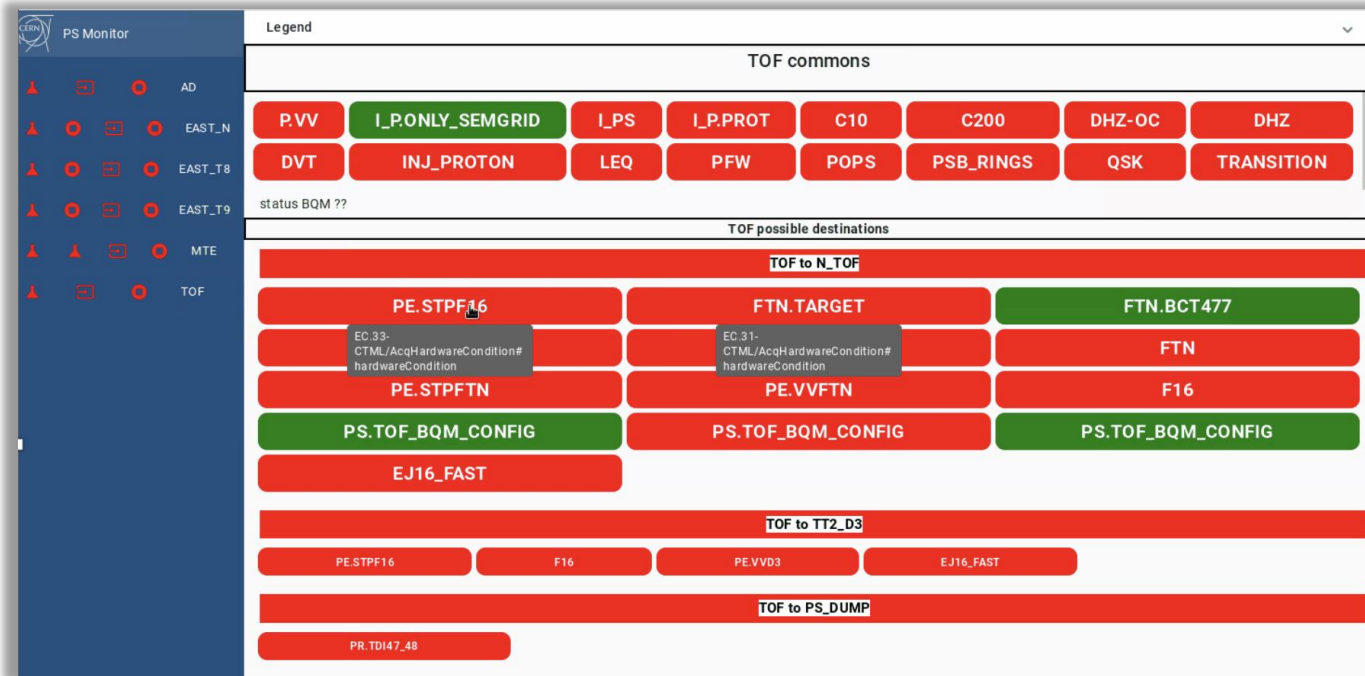
- Concentrating similar equipment as hardware groups
 - Avoids the creation of 100s of additional virtual devices
 - Generic class implementation (HWGroupMonitor) for various applications
 - To be used as input for destination concentrator
- Destination concentrator
 - “Can beam be sent to <DEST>?”
 - Publishing PSB user and **number of turns** in a given ring to be set to **zero** (action on BIX.NT0)
 - **health of destination checked every cycle (in contrast to SIS)**
 - Virtual UCAP device per PS destination



UCAP-based PS performance monitoring system

- **Development of a monitoring GUI**

- Choice of **web-based solution** for convenient access to global machine status parameters
- **Prototype GUI** based on accsoft-web-seed
 - supported by BE-CSS
 - initially tested with WRAP, but functionality not mature enough
- Planning to **add** important **beam quality information**
 - TOF bunch length, steering and beam size on target
 - LHC bunch-by-bunch variation of intensity, length
 - MTE splitting efficiency
 - ...

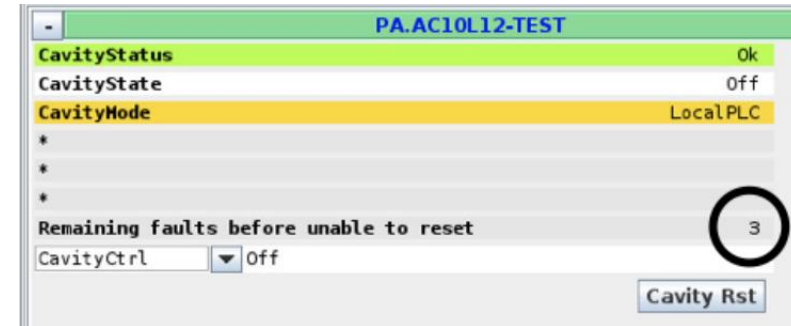


- **Could imagine simplified GUI for the users**

UCAP-based PS performance monitoring system

• Auto-reset

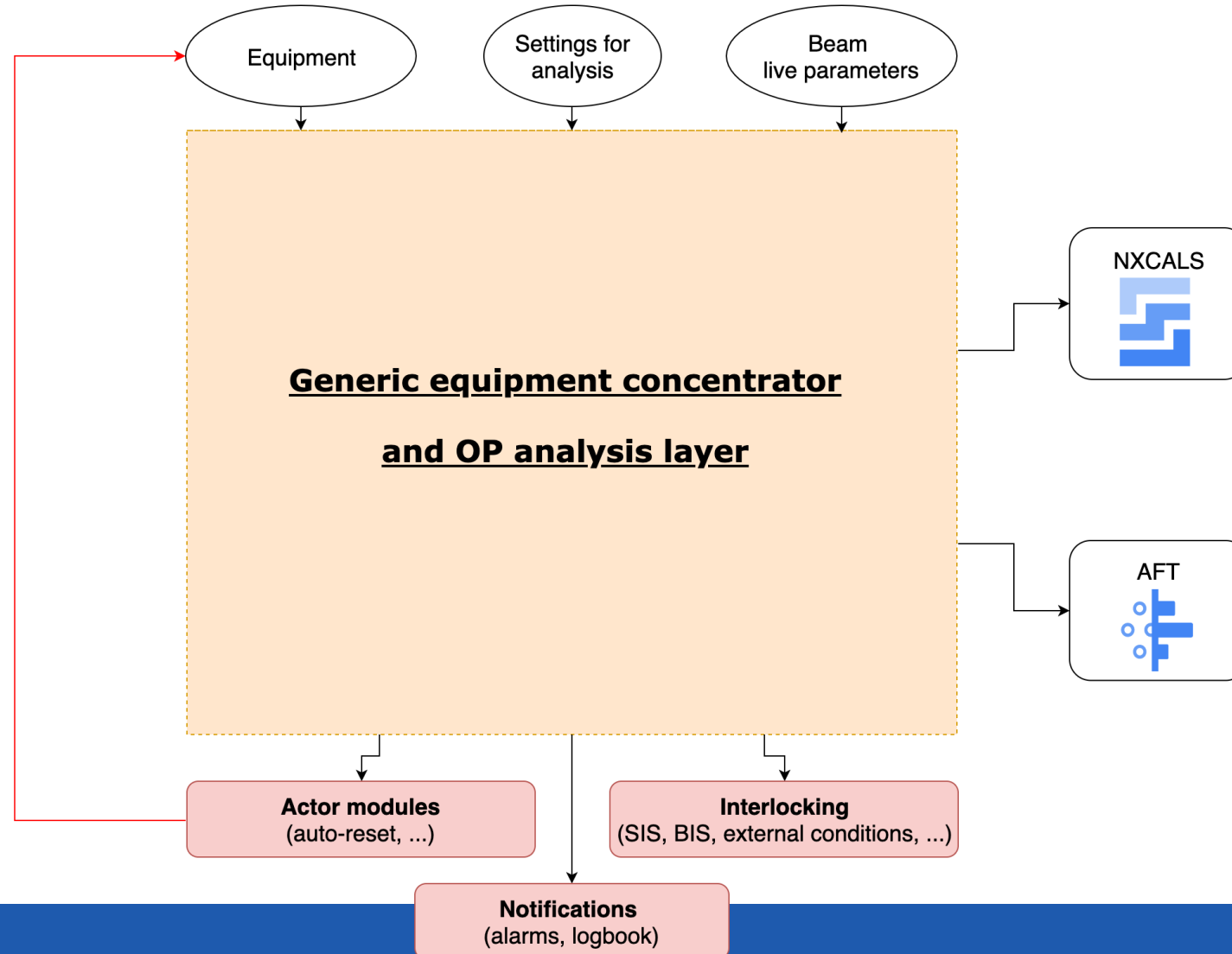
- **Protoype development** started on PS 10 MHz cavities
- Discussed and agreed with SY-RF group
 - cavity **PLC counts the number of resets** in a given time window
 - **Maximum number of resets** after which cavity becomes **unresetable** and expert/piquet needs to be called
- **Benefits:**
 - Potential to **avoid radiation alarms** due to early resets
 - **Avoiding too many** (manual) **resets** with negative implications on the hardware
 - **Automatic AFT** of single cavity faults
- **To be extended** to other equipment **in agreement with experts**



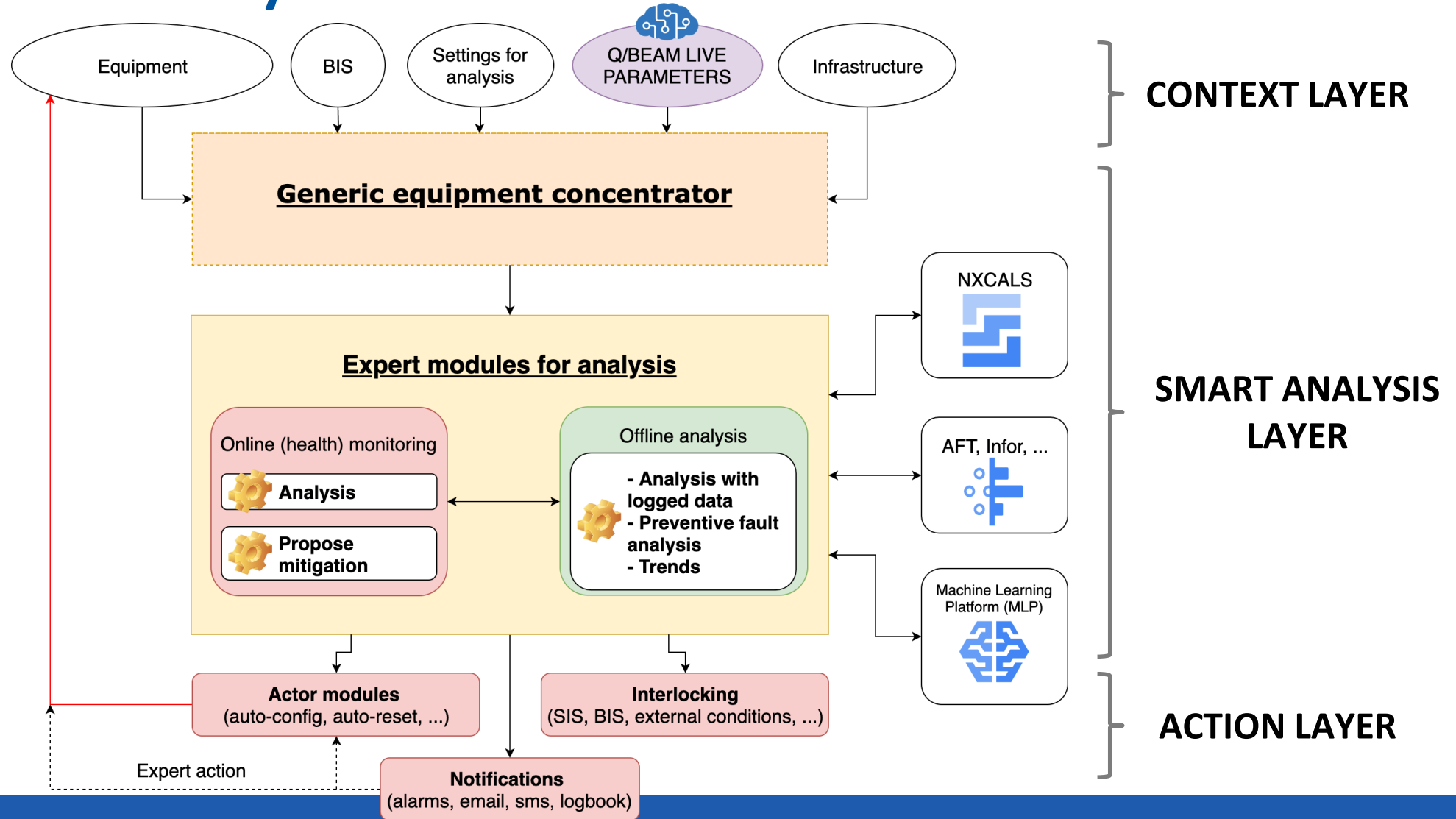
• Other related developments

- Defining a **clear and generic naming convention** for OP-UCAP developments (large number of new developments with an increasing trend)
- Developing a **reference GUI** to acquire and average data, and save references in virtual devices
- Implementation of the **AFT actor** on the hardware group monitor niveau
- Use the **announcer** to inform about performance issues

From the UCAP-based PS performance monitoring system ...



... to the WP8 data analysis framework



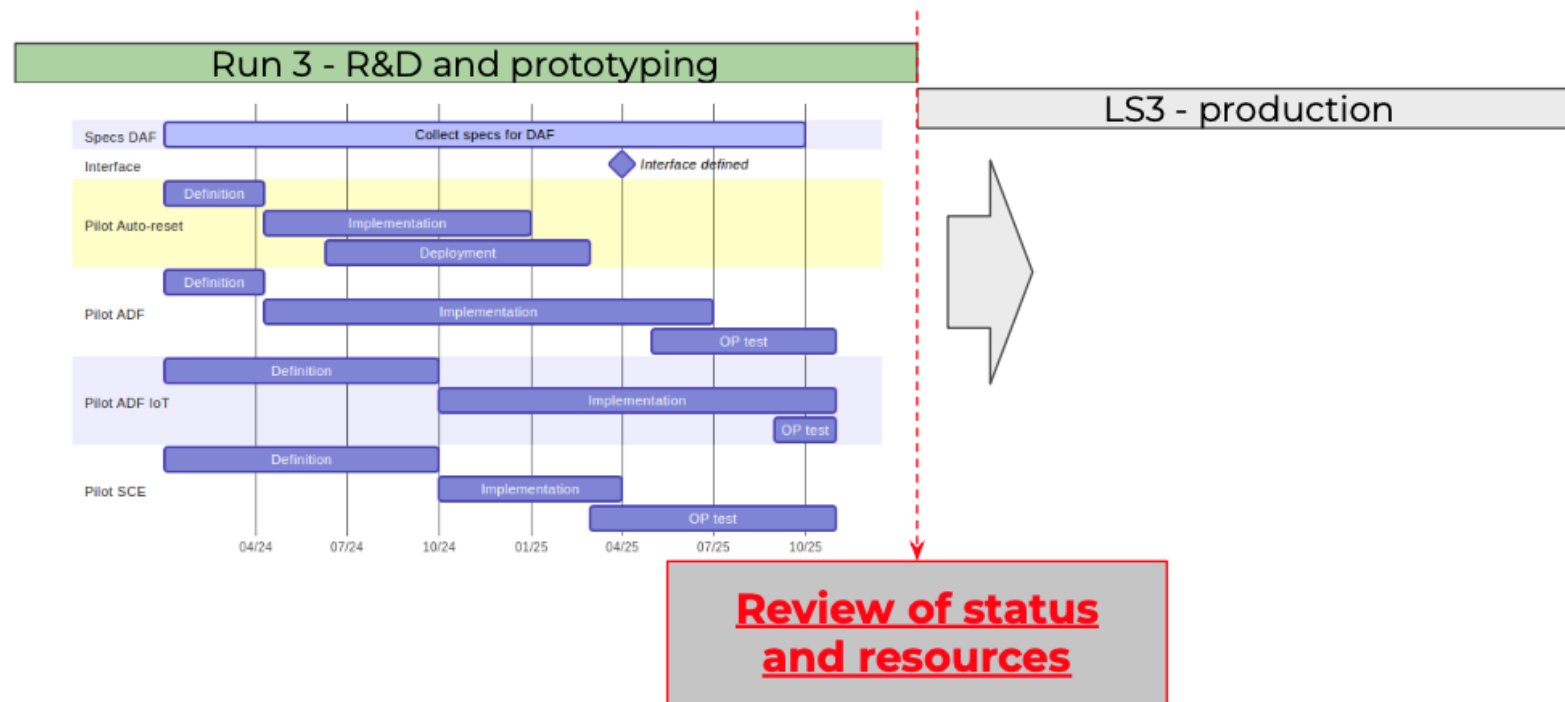
Conclusions

- **Large effort ongoing to bring performance monitoring to a next level in the PS**
 - **Concentrating** equipment and beam **information** to alert, act and interlock
- **EPA WP8 paving the way for future autonomous equipment management**
 - **Preparing pilot projects** as presented by Kostas
 - PS performance monitoring system as **additional pilot project**
 - **Testing** of monitoring **GUI** solutions, destination-based **interlocking, alerting and announcing, automatic fault tracking**, etc.
 - Defining (and eventually implementing) a **generic data analysis framework** based on the various existing solutions and collecting all requirements
 - to ease maintainability and development, and to share knowledge
 - framework allows to implement monitoring, recovery, alerting and fault tracking **directly by the equipment owners**, who know their systems best
- **Common effort between equipment groups, controls groups and OP needed to make this happen**

Backup

Proposed timeline

- Initial phase of definition of pilot projects, interface for equipment and tools to use for pilots
 - ◆ Approval via CTTB for interfaces
- Work on all pilots in parallel and feedback to specs for DA framework and specs for future interface of equipment and the upper layers
- All this deliverable by end of Run3 (if extended to 2026) ⇒ LS3 dedicated to deployment to all equipment



Main deliverables - **only to end of 2026**



- Define scope and requirements with all equipment groups Q4 23
- Define KPIs to quantify performance gain during the execution of the WP: Q1 2024
- Define interface for clear equipment status labelling: Q2 2024
- Pilots projects (with graduate resources attached)
 - ◆ Self-recovery from faults (automate what is now done manually)
 - ◆ Auto-recovery based on advanced algorithms and failure prediction
 - ◆ Multi-sensor Internet-of-Things (IoT) devices applications:
 - Automatic commissioning sequences
 - Diagnostics and failure prediction
 - ◆ Pilot project on self-configuring equipment
 - Define, develop and deploy pilot project: Q3 2026
- Define automatic recovery tool interface and architecture: Q4 2026 (throughout)
- Define requirements for data analysis tool: Q4 2024 and Q4 2025