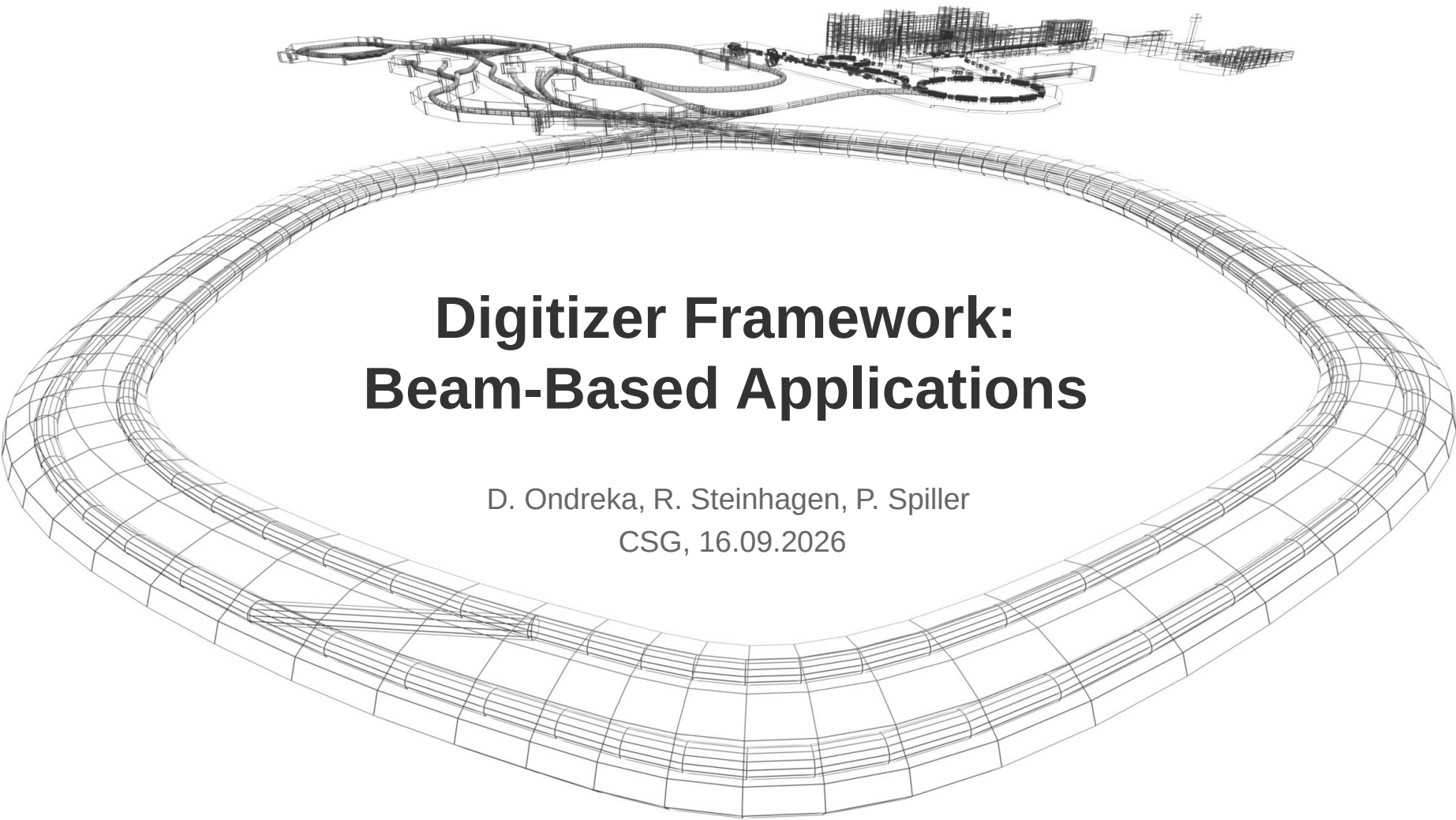


A detailed wireframe model of a particle accelerator, showing a large, curved ring structure with multiple internal components and a smaller, more complex structure in the background.

Digitizer Framework: Beam-Based Applications

D. Ondreka, R. Steinhagen, P. Spiller

CSG, 16.09.2026

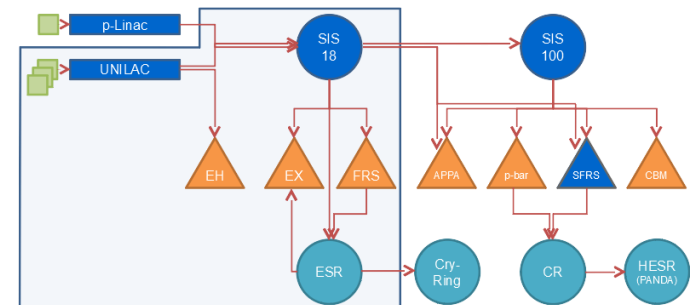
- Beam-based applications
 - Motivation
 - Relation to digitizer framework
 - Status of digitizer implementation
 - Responsibilities for beam-based applications
 - Planned extension of framework for beam-based applications
- Resources and schedule
 - Resource constraints and inclusion of external resources
 - Frame contract for framework extensions

Need for beam-based tools

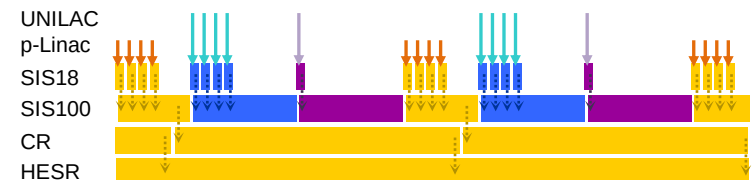
- Operators' job gets harder in FAIR
 - Few operators for very complex facility
 - Pushing for **intensity limits with tight loss budgets**
 - Damage potential of high intensity beams**
- Present way of machine control suboptimal
 - Manual tuning time-consuming and error prone
 - No time-dependent corrections possible
 - No derived beam quality signals available
- Operators **need better tools**
 - Monitoring of transmission and beam quality
 - Beam based feedback** for set-up and stability
 - Protection against** inadvertent **dangerous trims**
 - Usage of **automation** where possible

Presented at CSG Meeting on digitizer framework (05/2021) and MAC26 (12/2023)

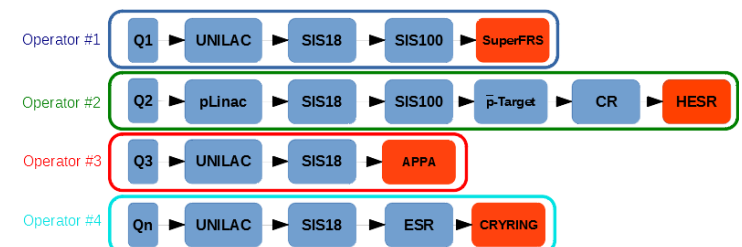
Increased complexity of FAIR over GSI



Parallel Operation in the FAIR facility



New paradigm: "One operator per FAIR-chain"

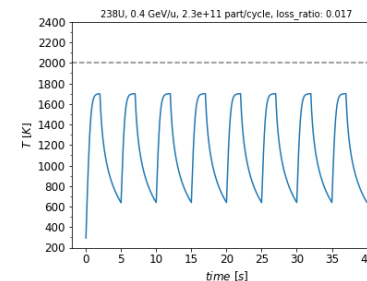
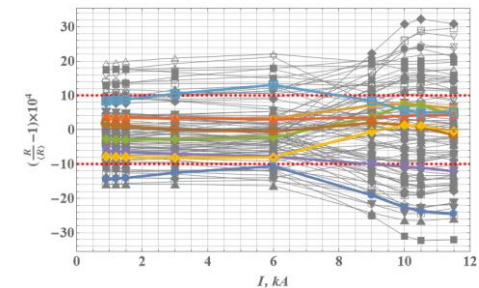
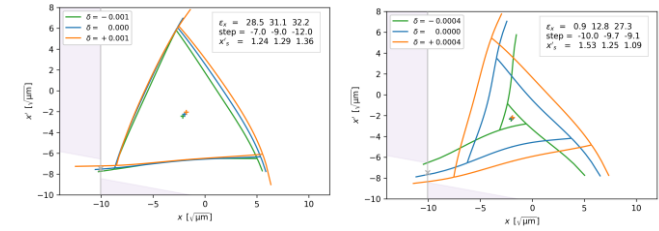


Tools for high-intensity: SX from SIS100

- Challenges for SX from SIS100
 - Highly non-linear dynamic
 - Dependence on many beam parameters
 - Significant impact of expected field errors
 - Tight loss budget (5%) with high-intensity beams
 - Intensity limits of electrostatic septum (ES)

- Protection of ES critical
 - Limits intensity of U28+ ($\sim 2.5 \times 10^{11}$ /spill with 2s/5s)
 - Quantitative control of beam size necessary
 - Erroneous trim can lead to serious damage

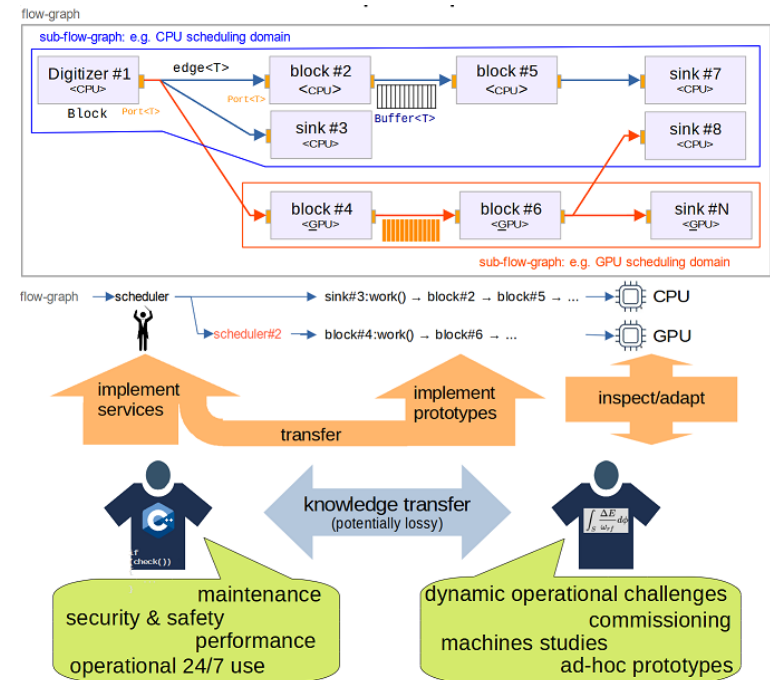
- Safe operation within loss budget requires tools
 - Control of orbit, tune, chromaticity
 - Optics measurements and beta beating correction
 - Monitoring of losses and beam size at ES



Path to beam-based tools: OpenDigitizer Framework



- Goal: facilitate creation of beam based tools
 - Provide common functionalities centrally
 - Communication, aggregation and **signal processing**
 - Scientific charting for **visualization**
 - **Enable domain experts** with little software expertise
 - Focus on signal extraction and physics
 - Support **high bandwidth** applications
 - **Minimize maintenance** effort
- Key framework features
 - Signal processing through integrated **GNU Radio**
 - **Flow-graphs** built from processing block library
 - Seamless moving of processing between layers
 - Fast prototyping at UI level e.g. during commissioning
 - Processing for approved tools moved to service
- Framework used for both **digitizer frontends** and **beam-based applications**



*Presented at MAC26 (12/2023)
and MAC Controls Review (06/2024)*

References

<https://github.com/fair-acc/opencmw-cpp>
<https://github.com/fair-acc/opendigitizer>

Software technologies



R. Steinhagen et al, ICALEPCS'21
 R. Steinhagen et al, IPAC'23



CSG Software Activity Matrix: Digitizers & Beam Based Applications



- CSG acknowledged need of tools for monitoring and control
 - Digitizers
 - Beam-based applications
 - Added to matrix very early (07/2021)
- Priorities approved by CSG
 - Unchanged since 02/2023
 - High-intensity presently not considered in priority!
- Activities with Prio 1 in production
 - Visualization (ChartFX): maintenance mode
 - OpenDigitizer: status according to agreed strategy
- Realization of beam-based applications in SYS
 - Implementation based on digitizer framework
 - Extensions needed for beam-based tools

*Presented at CSG Meeting (05/2021),
MAC26 (12/2023), and MAC Review (06/2024)*

Framework aspects

Activity		Priority* (without Intensity priority)
1	(misleading, refers to digitizer framework)	
94	PicoScope Digitizer (DAQ) System + GUI control App	1
199	Data visualisation / charting libraries (Java)	1

Beam-based applications

Activity		Priority* (without Intensity priority)
1		
20	Schottky (measurement & injection matching)	2
24	Closed-orbit and radial-loop control	2
27	Inj./extr. Trajectory control (BPM-based)	2
31	Slow extraction spill form/structure optimisation	3
38	Status & Overview SIS18	3
78	Status & Overview SIS100	3
79	Beam-Quality-Monitoring Applications	3
98	Beam-cooling optimisation	3
99	RF bunch gymnastics	3
179	Collimator/Cleaning set-up (SIS-100)	4
182	Q/Q' control	4
211	Multi-Turn-Injection	4
217	Optics measurement & correction	4
219	Slow extraction parameter setup and optimization	4
220	Measurement & control of long. emittance (Rings)	4
221	Measurement & control of transv. emittance (ring/HEBT)	4

Latest status: 24.05.2025

Status Digitizer Project

- Agreed strategy (CSG, MAC): three phases

- Phase 1: working prototype
- Phase 2: features for operation (scheduled as needed)
 - JAPC plugin, LSA settings, RBAC
- Phase 3: final integration into CS

Strategy for Integration of Digitizer Modules into the FAIR Control System

Authors:

R. Bär, Head Department Control Systems (ACO)

D. Ondreka, Head Department System Design SIS100/SIS18 (SYS)

Date: 01.11.2024

Involved ORG Units and their Roles

Department ACO (Control Systems) has overall responsibility for the FAIR control system and, in particular, defines its system architecture and system environment and common standards. Additionally, ACO develops, maintains, and operates a large part of the components of the FAIR control system.

Department SYS (System Planning) is involved in the development of components of the FAIR control system that serve to control the accelerators and monitor accelerator components. Specifically, SYS implements physical machine models and develops applications for beam-based monitoring and control of the accelerators at GSI and FAIR.

Presented at MAC27 (11/2024)

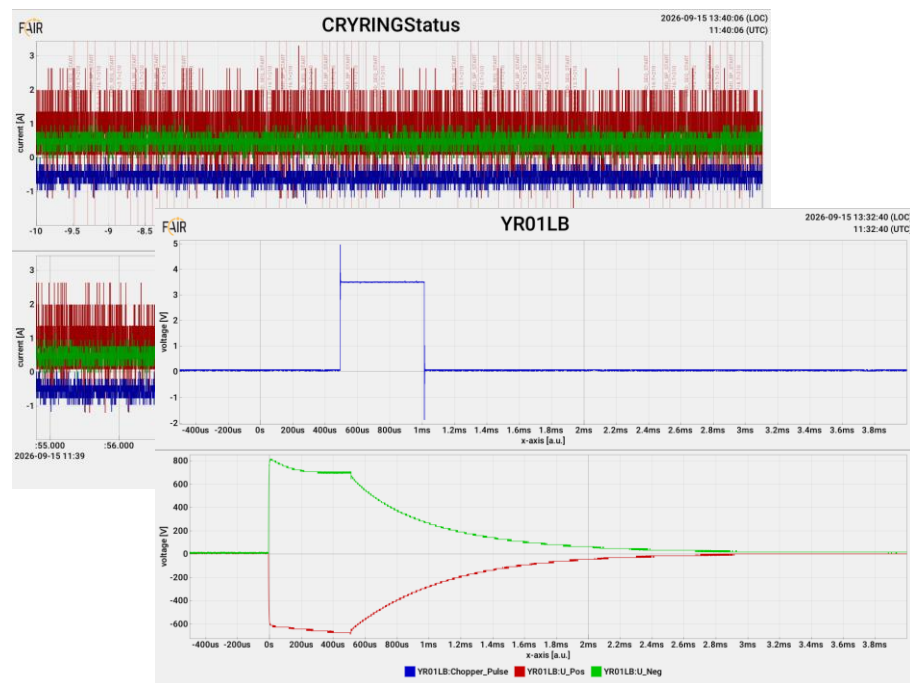
into the FAIR control system with the aim of providing all users with uniform access through standard interfaces.

- Present Status

- Phase 1: completed
 - Prototype demonstrated and accepted 05.03.2026
- Phase 2: in line with strategy
 - JAPC plugin available since 31.01.2026
 - Other functionalities presently not required
- Important digitizers deployed and running
 - CRYRING: 5, SIS18: 14
- Significant performance and stability upgrades

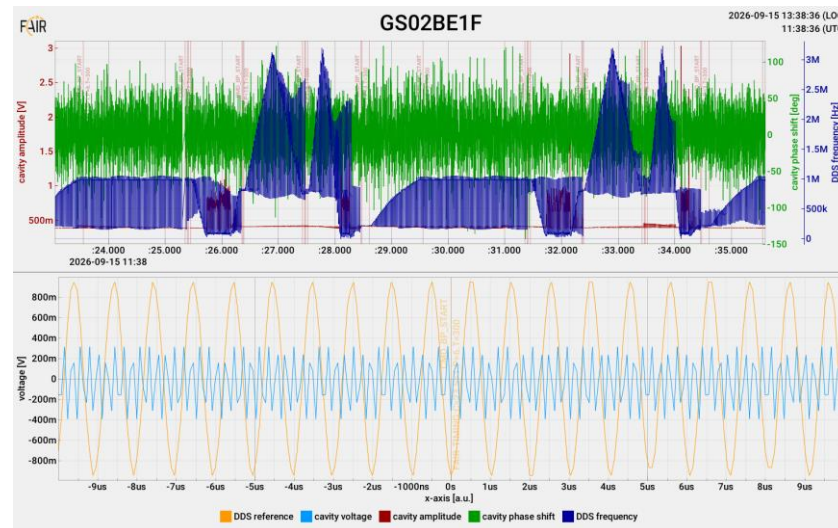
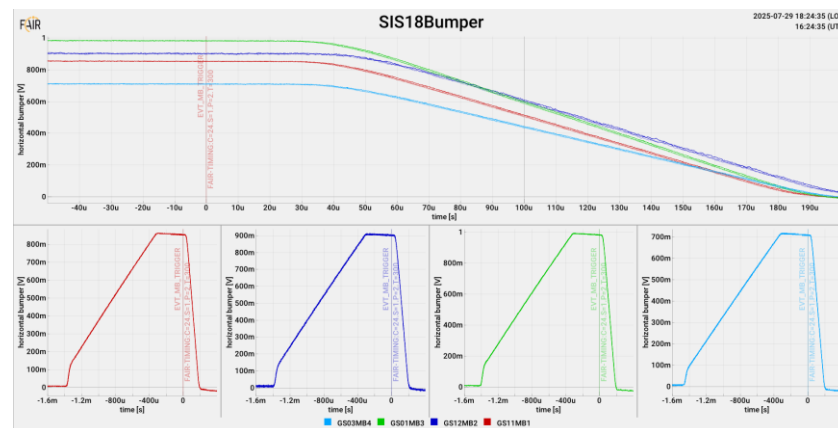
- Further integration activities (ACO, SYS)

- Temporarily on hold due to consequences of fire
- Definition of next steps soon to be continued
 - E.g. deployment tools, channel directory service



Digitizers at SIS18

- Most important digitizers deployed
 - Main power converters
 - Electrostatic septa
 - Bumpers
 - Chopper and TK beam pulses
 - RF systems (cavities + reference DDS)
- Added value for operation
 - Display of **all 4 bumpers** (prev. just 1)
 - Display of cavity signals for **all cavities** (prev. just 1)
 - **New: demodulation** (amplitude, frequency, phase)



Beam-Based Applications: Responsibilities



- Subproject SIS100/SIS18 has responsibility for
 - design, functioning, and upgrades of SIS18 and SIS100
 - assuring FAIR design performance can be achieved
 - assuring FAIR radiation protection limits are not violated
 - defining the measures for a safe operation of SIS18 and SIS100
- Fulfilling performance and safety goals requires beam-based tools
- Subproject lead has delegated development of these tools to SYS
 - Required expertise (physics and control) gathered in SYS department
 - Expert knowledge of machine functionalities, constraints, and hazards
 - Development of physics-based machine models for settings management
 - Proficiency in software for signal processing and beam-based feedback systems
- SYS now works on extension of framework for beam-based applications

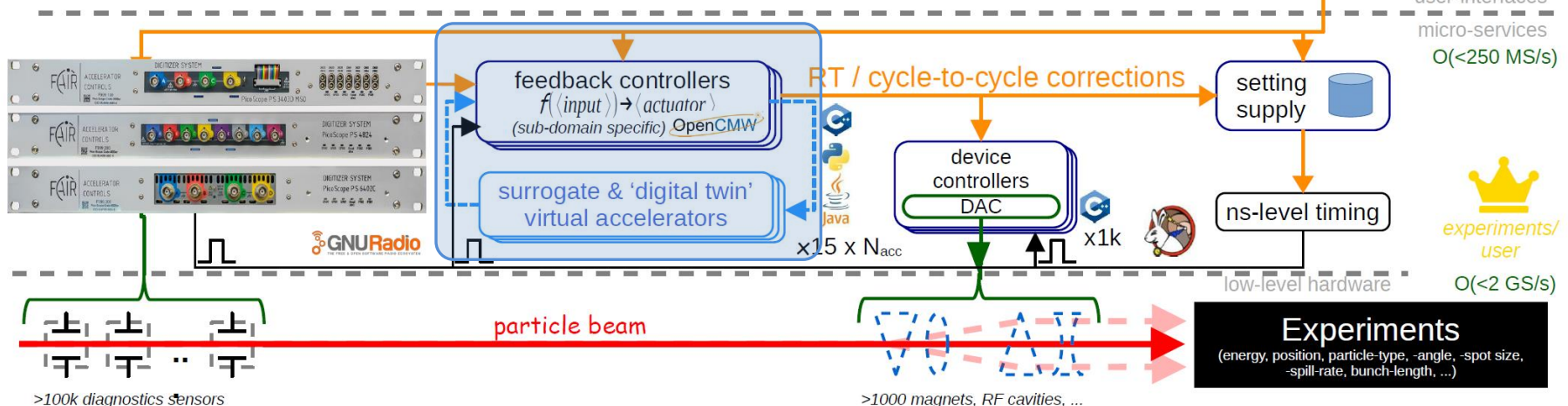
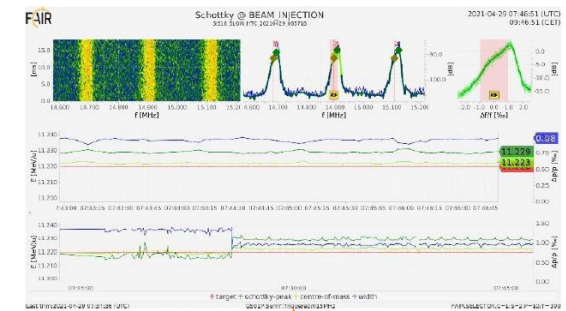
Framework Extensions for Beam-Based Applications



- Simulation environment ('digital twin')
 - Testing of applications independent of availability of accelerator
 - Imitation of high intensity conditions not yet reachable with SIS18
 - Analysis of errors observed during operation by replaying stored data
 - Reproduction of dangerous machine states in a safe environment
- Readout adapter for archived data
 - Performant readout of data from archiving system, files, or other sources
 - Reproduction of data streams like in operational conditions

Presented at MAC Review (06/2024)

beam-based controls applications
(interactive, expert. & monitoring/web-type)

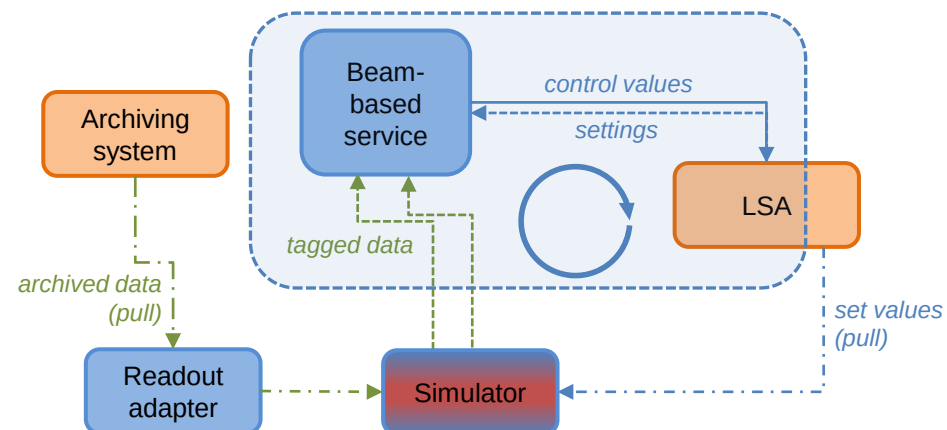
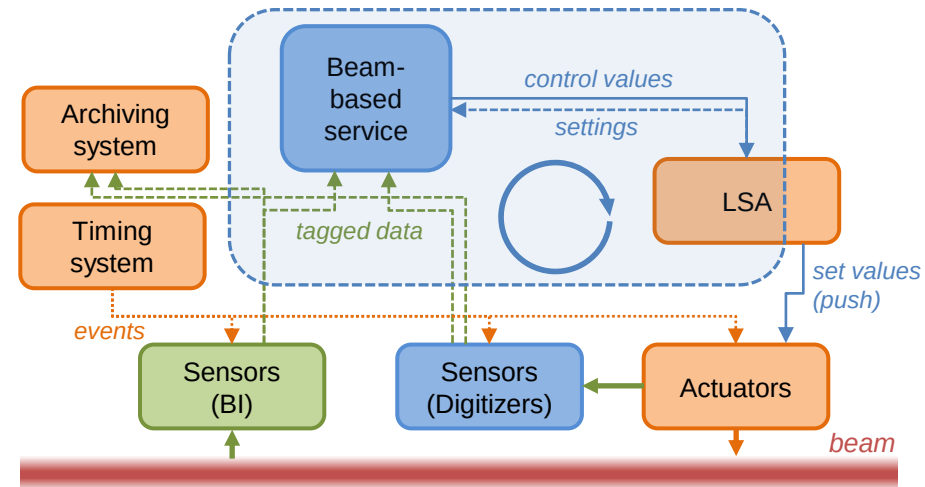


Simulation Environment

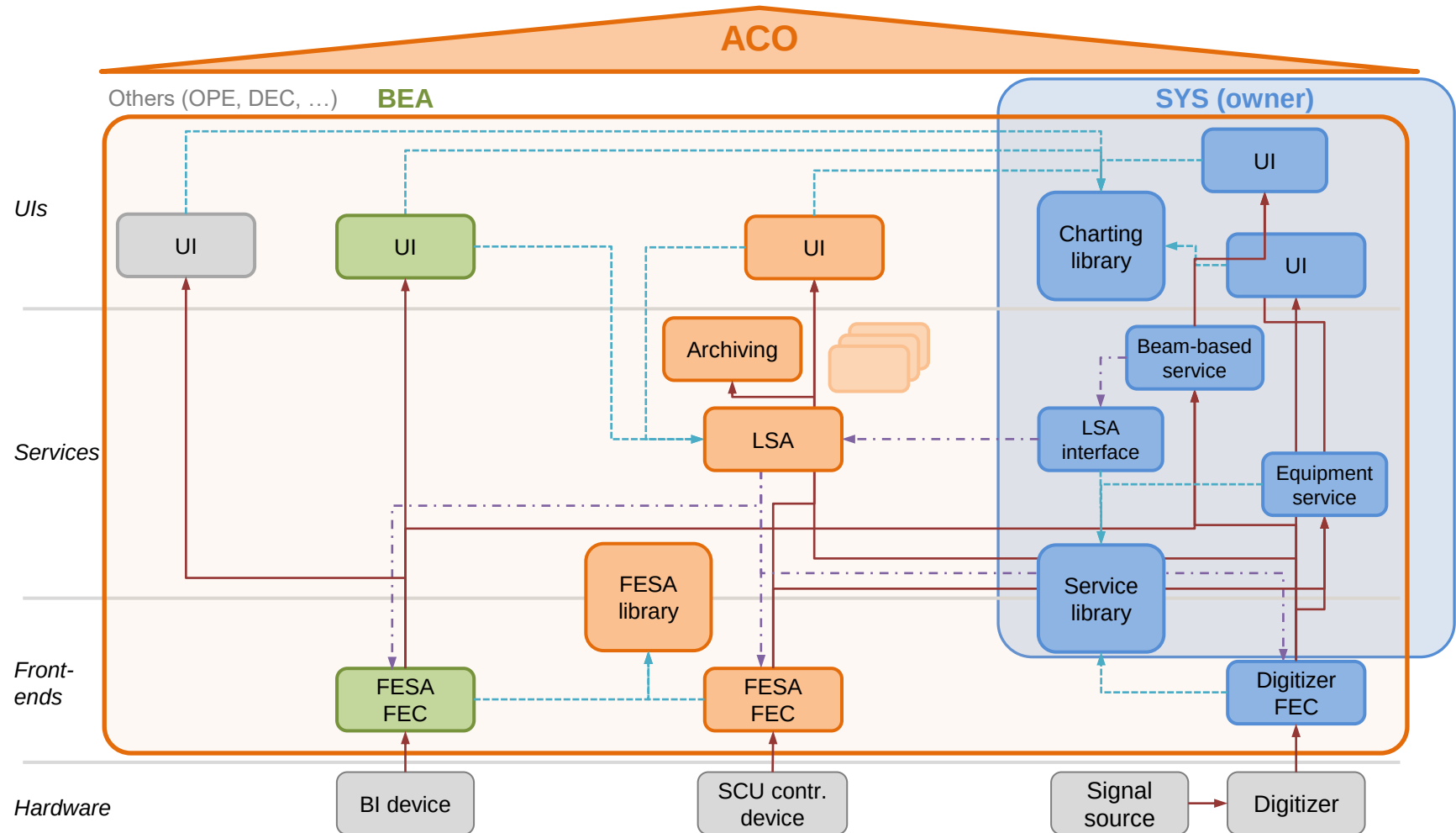
- Beam-based application during operation
 - Machine executed by timing system through events
 - Service
 - receives sensor data tagged by timestamps
 - processes data through GR flowgraph
 - sends control values to machine via LSA
 - Feedback loop (if any) over machine repetitions
 - Effect of control values seen by sensors

- Beam-based application in simulation mode
 - Archived data provided via readout adapter
 - Adapter combines real data and stored timestamps
 - Simulator
 - sends data to service in identical way to operation
 - can emulate erroneous and corrupted data
 - provides hooks for simulation of beam response
 - Service oblivious to difference

- **No effort created in other departments**
 - Only existing or specified systems will be used
 - No requests on BI beyond defined FESA classes
 - No requests on ACO beyond specified archiving



Digitizers and Beam-Based Applications within the FAIR Control System



Presented at CSG Meeting (05/2021)

- Framework development resource limited
 - 3 developers in SYS with required skill set
 - 1 FTE for framework development, 1 FTE for SYS specific development
 - Known to be insufficient for realization of framework
 - Inclusion of external resources in accord with demand by management (TGF)
- Strategy pursued by SYS
 - Focus internal resources on FAIR-specific parts
 - Outsourcing of all other task to external resources
 - Applied during implementation of digitizer software via frame contract (RV1)
 - Attract additional resources through participation in EU projects
- Multiplication of internal resources once framework is mature enough
 - SYS: 7 accelerator physicists expected to develop tools with at least 0.5 FTE each
 - Will lead to significant ramp-up of tool creation

External Resources: EU Project iRIS-GREMLIN



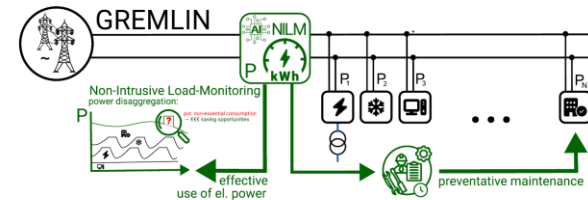
- iRIS
(Intelligent Research Infrastructure Sustainability)
 - EU project concerned with sustainable design and operation of accelerators
 - GSI is part of consortium

- SYS participates with GREMLIN
(Green Energy Monitoring for Large INfrastructure)
 - Project goals
 - Non-intrusive load monitoring
 - Preventative maintenance
 - Based on signal processing of digitized data
 - Will employ and extend digitizer framework

- Significant resource gain
 - Project funds 2 x 3 FTE for software development

- Requires planned framework extensions

 **iRIS-GREMLIN is a diagnostic layer, not an energy controller**
<https://github.com/fair-acc/gremlin>



... turns electrical noise into a facility-scale diagnostic layer for energy monitoring and predictive maintenance

A) Non-Intrusive-Load-Monitoring (NILM)

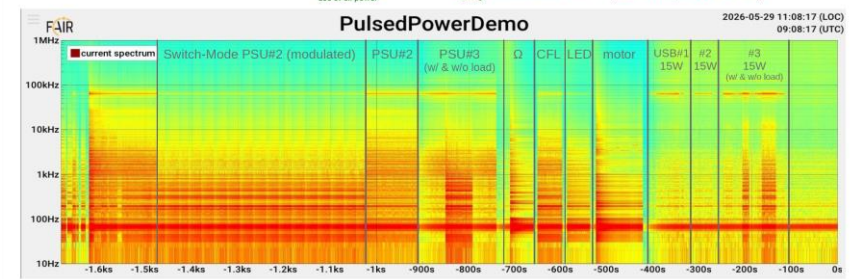
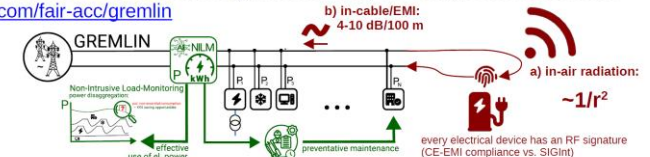
- GREMLIN: **cost-effective & robust** – single high-bandwidth DAQ (free- and open-HW/SW designs, modelling, upgradability, ...)
- others: instrumenting 1000+ individual devices (infrastructure costs, calibration, reliability, maintenance, ...)

B) Preventative Maintenance

- monitor device efficiency drifts comparing primary-(to-secondary) RF signature and power consumption
- facility availability and **cost saving through pro-active grouping of maintenance and repairs** rather than re-active repairs (e.g. during weekends, nights, single-point-failures, ...)



 **iRIS GREMLINs — Green Energy Monitoring for Large INfrastructure**
<https://github.com/fair-acc/gremlin>

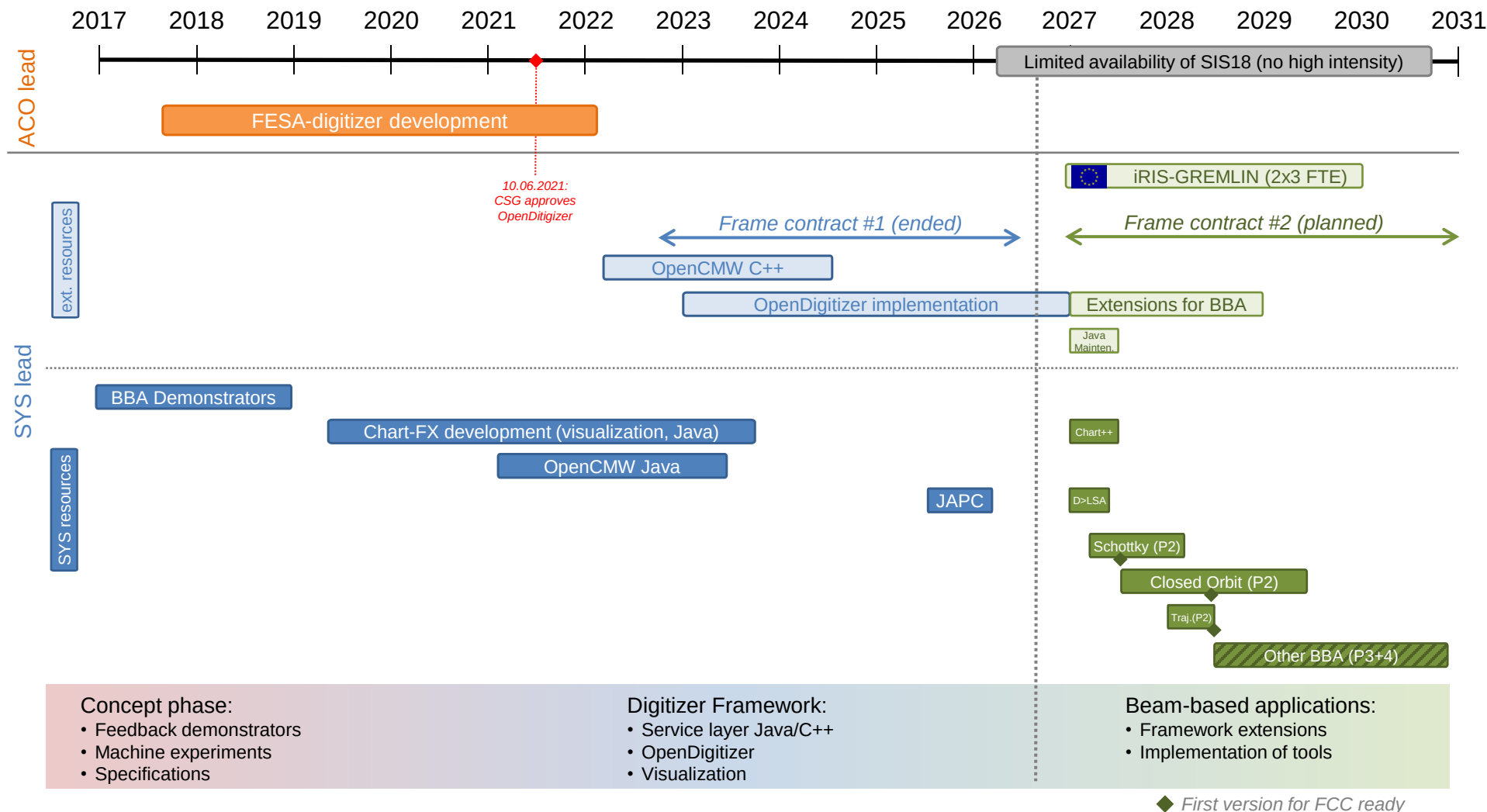


R. Steinhagen, FCC Week'26 – iRIS Project Kick-Off



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101275935 (iRIS – Intelligent Research Infrastructure Sustainability).

Beam-Based Applications: Schedule Overview

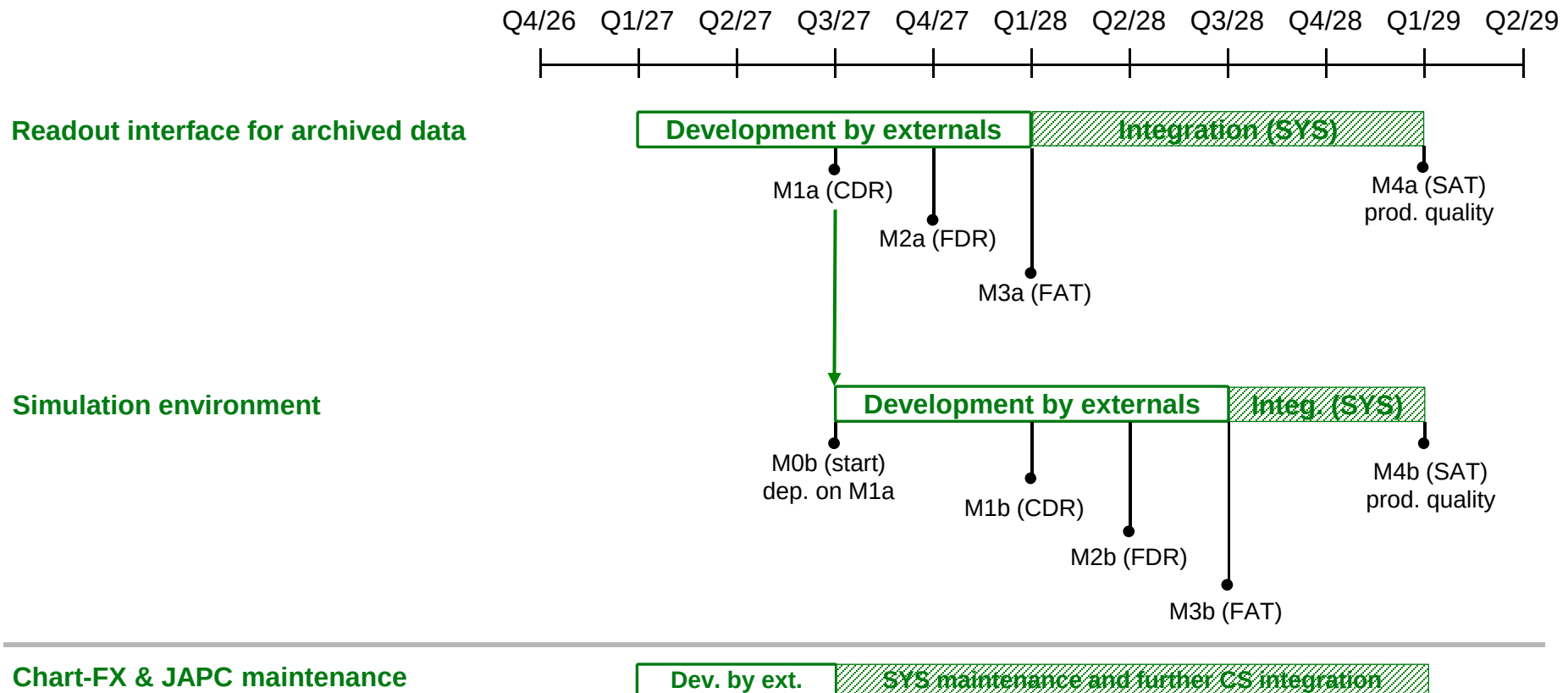


Frame Contract #2 (RV2): Resources

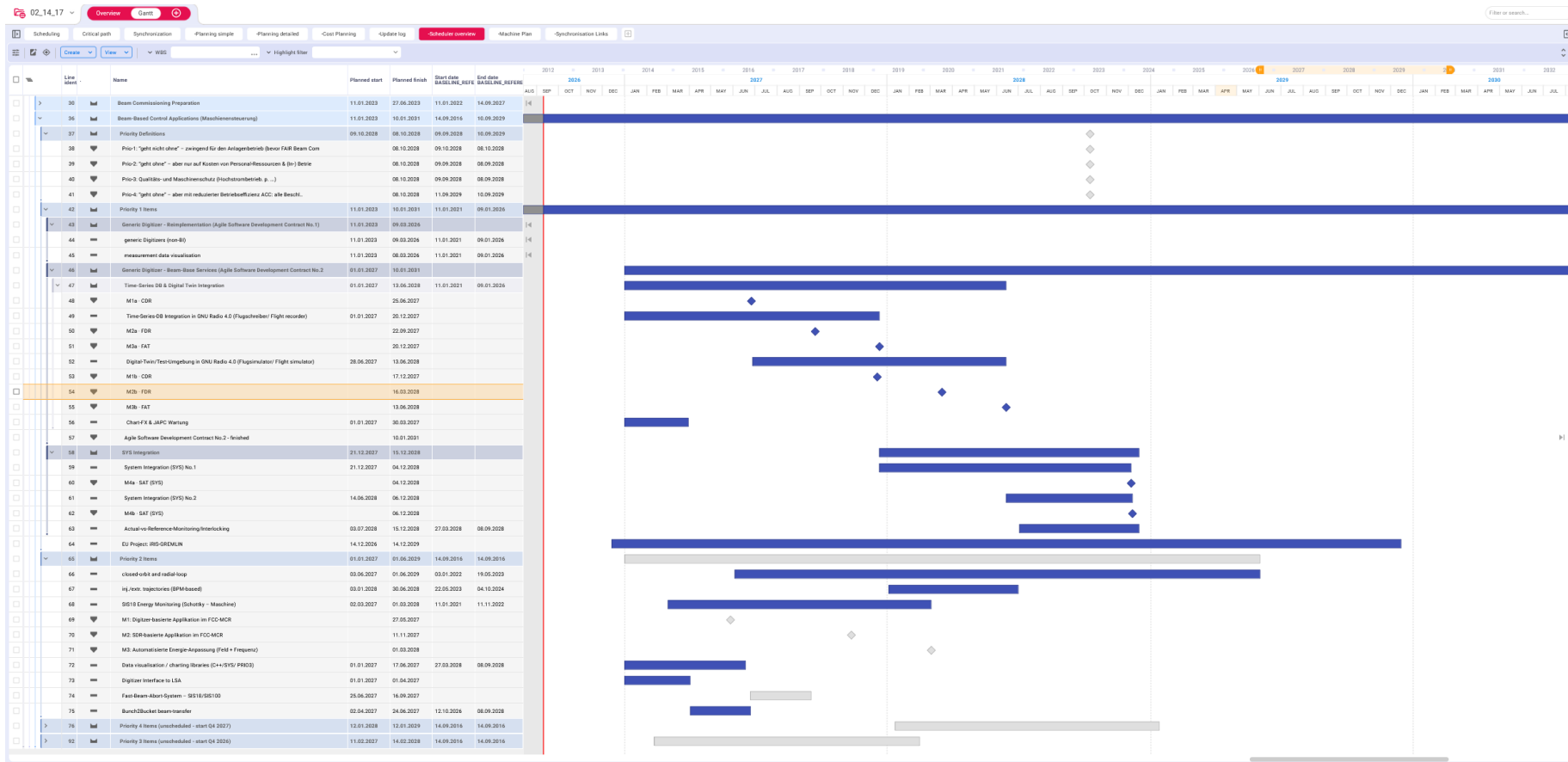


- Scope
 - Adapter to data storage systems
 - Simulation environment ('digital twin')
 - Smaller maintenance work
- Resource requirements (external resources)
 - Minimal feature set for start of BBA implementation and GREMLIN: 1 FTE
 - Full feature set including hedging of risk of unexpected effects: + 5 FTE
 - Translated into budget requirements with 240kEUR/FTE
- Frame contract defined with corresponding boundaries
 - Time limit: 4 years (max. possible duration)
 - Budget limit: 1.5 MEUR

New Frame Contract: First Planned Activities

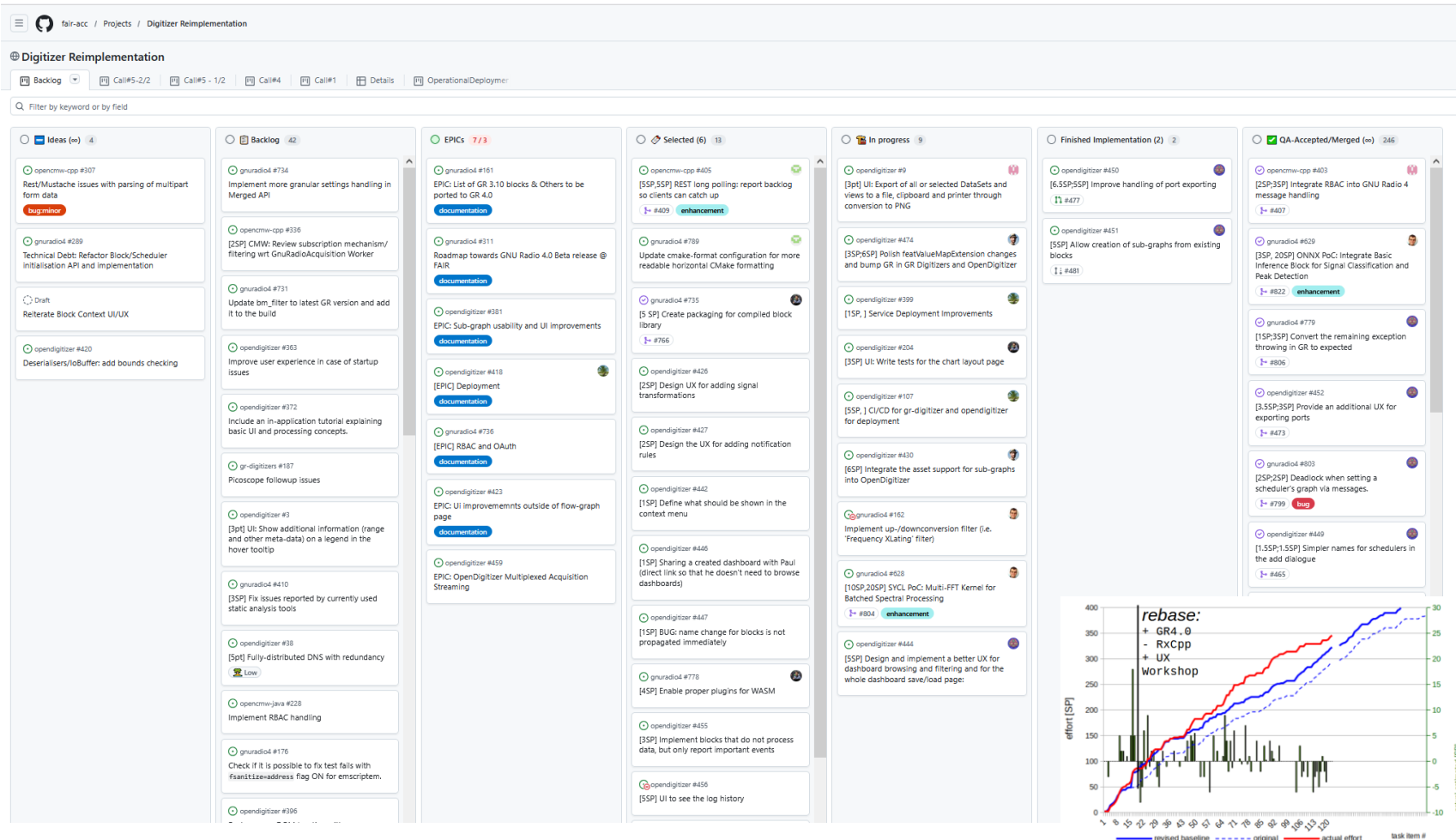


Framework & Beam Based Applications: Planisware Schedule



- All activities related to beam-base applications with Prio 1 and 2 scheduled until end of 2028
- Activities with Prio 3 and 4 not yet scheduled

Framework & Beam Based Applications: Kanban Project Board



- Estimate of effort on average within 30% of original estimate

- SYS develops framework for realization of beam-based applications (BBA)
 - Basis for 10+ tools planned in SYS for high-intensity operation in FAIR
 - Such tools are essential for reaching FAIR design parameters efficiently and safely
 - Based on OpenDigitizer, extensions for data replay and accelerator response simulations
 - Designed for low maintenance overhead (< 1 FTE for long-term maintenance)
 - Enabling technology with a large multiplication factor
 - Realization of tools for commissioning and operation by non-programmers
 - Allows physicists and engineers to contribute their domain knowledge easily (+7 in SYS)
- Outsourcing of framework extensions for BBA to spare internal resources
 - 1 FTE effort for minimal functionality
 - Potential for additional 5 FTE for full functionality and unexpected effects (risk)
 - Integration work done within SYS with available 2 FTE
- Frame contract planned for implementation of framework extensions for BBA
 - Time duration 4 years, price cap at 1.5 MEUR (corresponding to 6 FTE)
 - First tranche for minimal functionality to be contracted immediately (240 kEUR)