Controls review follow-up

Ralph C. Bär, Acc. Controls Project Leader

28th FAIR Machine Advisory Committee Meeting

Presentation Outline

- **Brief overview of present controls activities**
  - General Controls Status w.r.t. Early Science and First Beam Event
  - Replacement of the UNILAC Control System
  - Preparation to move operation to FCC
- **Recommendations addressed**
  - LSA framework and setting generation
  - SFRS data exchange
  - Archiving system
  - Digitisation of analog signals
- **Summary**

General Status Control System

General Status

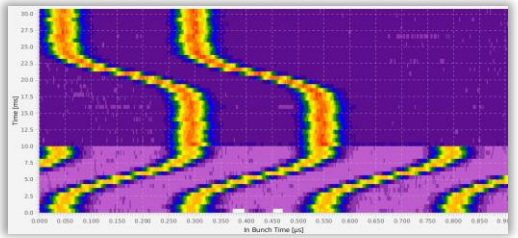
- FAIR CS now operated since 2018, 6th physics beam time in 2025
- Stable & reliable operation on SIS18, ESR, CRYRING and GSI-HEBT
- CS architecture has shown to be stable & adequate for ES
- SIS100 already operated virtually and for SIS100 string test

Highlights 2025

- B2B phase shift method successfully tested, FAIR Beam Interlock System (BIS) master interlock processor installed & commissioned
- Successful tests of UNILAC control system upgrade/replacement
- Completion of Slovenian in-kind contract for (control & BI systems): final acceptance ceremony on 21.10.2025, work with SLO partner ongoing

Readiness for First Beam Event (12/2026)

- All controls hardware for FBI ready for installation
- Vacuum control system fully delivered (cabinets, software)
- Installations technical networks in FAIR buildings ongoing (G017A complete)



General Status Control System

Work still to be done for Early Science

- Improvement of LSA setting generation trim performance (CO-R02)
- Implementation of SFRS ACC-EXP data exchange interfaces (CO-R05)
- Improvement and upgrade of Archiving System (CO-R06)
- Open Digitizer Digitizer systems integration (CO-R04)

- Production of SCU v4.1 and v5 equipment controllers (2026)
- Machine protection system → separate talk by K. Fuchsberger

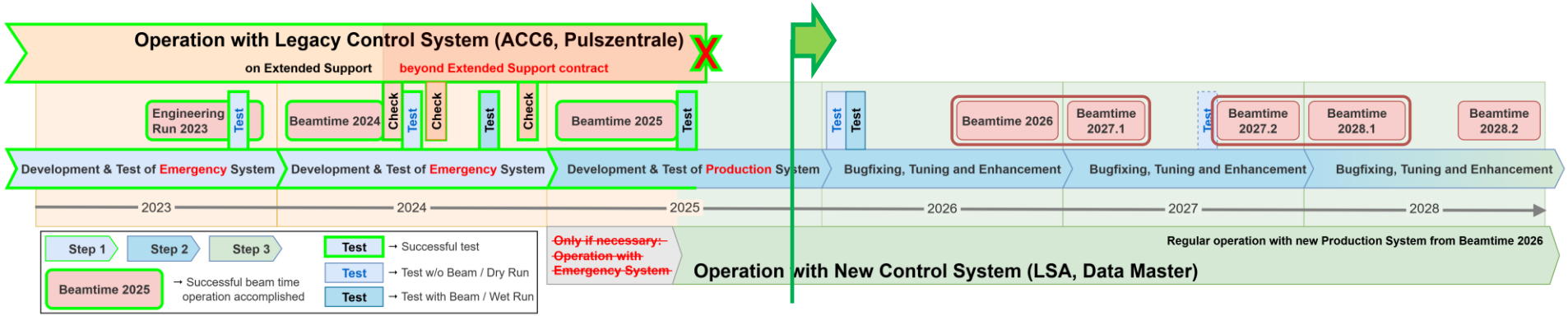
Controls Installations and Commissioning

- Installation of industrial controls cabinets has started, central systems completed
- Commissioning of first components started (technical networks)

Injector Controls Upgrade [1/3] – Timeline

Modernizing the legacy control system for UNILAC using sustainable technologies and integrating it into the FAIR standard architecture

- **Proof of concept achieved**, fundamental components deployed and tested
  - New Data Master- and White Rabbit-based timing system, adapted to UNILAC-specific requirements
  - LSA-based Settings Management System enhanced, machine model designed specifically for UNILAC
  - JavaFX- and Web-based standard operating applications adapted for UNILAC
- **Transition to new control system complete**, rollout of unified architecture ongoing
  - **Successful wet runs** (full stack control system tests in production environment with beam) in Oct/Nov 2024 and Jul 2025
  - Upcoming Dry/Wet Run for UNILAC/SIS18/ESR/CRYRING in Jan/Feb 2026
- Current milestone: Operational readiness for beamtime 2026/2027.1



Injector Controls Upgrade [2/3] – Deliverables

Complex project involving all Controls Department teams

- Significant contributions also from Beam Instrumentation, System Design and Operations
  - New FESA-based BI systems
  - Digitizers required for move to FCC
  - Legacy CS features moved to Sequencer
- New/unified control system will not be feature-complete for BT 2026/27.1, but experiment schedule has been adapted accordingly for this run
  - Thanks to close cooperation with beamtime coordinator and operations manager
- Limited personnel for software development remains an issue, but project is still on track
  - Mitigation actions are being implemented

Injector Controls Upgrade [3/3] – Highlights & Outlook

Several major goals achieved during the last Wet Run at UNILAC and SIS18

- Delivered multiple UNILAC beams in parallel to different destinations, including different beams in transfer channel and high duty cycle beams (50 Hz)
- Injected three different UNILAC beams into three different SIS18 chains in complex operation scenario
  - UNILAC and SIS18 integrated into one consistent timing schedule
  - Beam transfer directly synchronized between Data Masters
  - Successfully tested advanced operation scenarios including multi-multiturn injection and dual beam

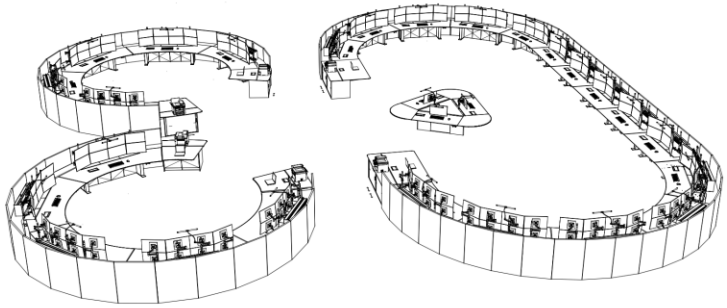
Operation scenarios for the beamtime will be tested during the upcoming wet run

- Operating UNILAC and all rings during a period of seven weeks, empowering operators as a main goal
- First productive beamtime will be challenging, but progress achieved has been positively acknowledged

FAIR Control Centre

Move of operation to new FCC control room

FCC building progressing well (on schedule for MCR installation in 12/2025)



Planned Milestones

- 08.12.2025: Consoles installation works start
- 02/2026: Cabling & network installations completed
- 02/2026: Installation of console IT (workstations, screens, periphery)
- 23.02.2026: Test of first consoles during engineering run
- 04/2026: Installation of fixed LED matrix displays
  →presently under tender

- 05/2026: Completion of MCR installation, start of MCR operation
- 08/2026: Start of regular operation from FCC control room

FCC Console view

Recommendations addressed (CO-R2)

CO-R2: LSA Framework and LSA Setting Generation

"The committee recommends ensuring adequate resources for managing the ORACLE database. As more rings and transfer lines are added and automated feedback systems are introduced, existing performance issues with parameter trims are likely to become more pronounced."

Status and Activities

- Continuous support of Oracle DB engineer needed to monitor the performance, optimize the database and mitigate latency problems
- Position for DB engineer approved by management, but difficulties to find adequate candidates
- **Position filled** recently **01.10.2025**, **experienced DB engineer** w/ background in Oracle

- First steps: analysing specific daily problems
- Q1/26: **Performance analysis** during wet/engineering run with predefined scenarios planned
- Q1/26: Setup detailed **DB performance monitoring**
- Q3/26: Close contact with CERN LSA DB experts foreseen, with regular visits and information exchange

- 2026: DB hardware update → use monitoring to assess performance gains of HW upgrades

Recommendations addressed (CO-R5)

CO-R5: SFRS specific controls

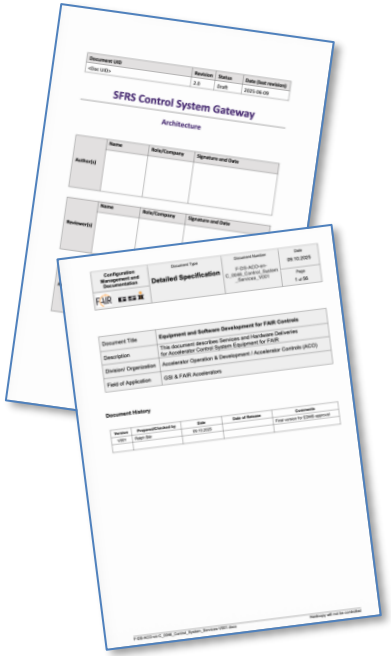
"Discuss between the teams how data from the technical network can be accessed from NUSTAR (and the reverse)."

Activities

- Detailed **specification paper** for data exchange worked out (use cases, data types and qualities, performance)
  - Bi-directional exchange of data between ACC and Campus/SFRS
  - Access to LSA server and ACS equipment
  - Exchange of non-structured data objects (to be defined by the developers of SFRS-specific Applications w.r.t. data protocol/format)

- **Conceptual design completed**
  Implementation of 3 dedicated REST gateway services bridging networks and bridge to EPICS slow controls

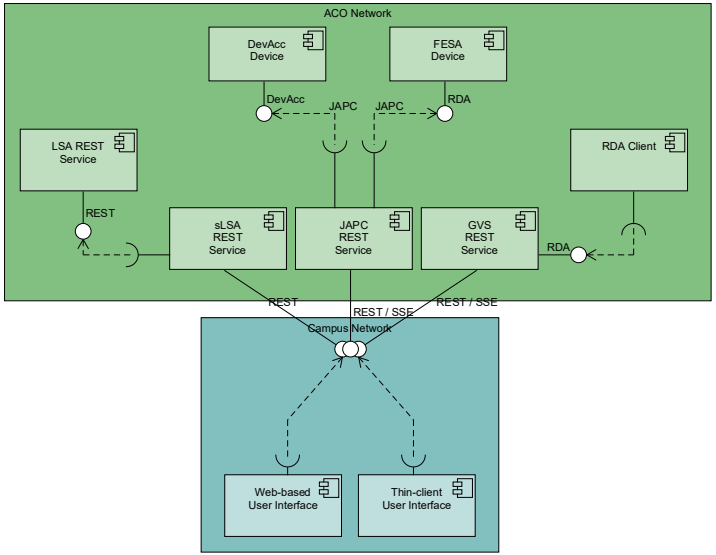
- Software **implementation** approach
  outsourced (presently tendered as part of comprehensive tender)



Data exchange interface ACC-SFRS

Design

- Data exchange services comprise 3 dedicated REST services
  - JAPC REST Service (JAPC) →already existing, needs modification
  - Global Variable Store (GVS) REST service
  - simplified LSA REST Service (sLSA)
- EPICS accelerator/experiment bridge/data exchange for SFRS
  - exchange of CA EPICS process variables
  - synergy with **CROME** (radiation dose monitoring system) and other experiment interface (CBM, HADES, …) planned



Planned Schedule – aligned with SFRS team

- 01/2026: Development contract awarded, technical kick-off
- 03/2026: Prototype REST gateways implemented (basic read functionality)
- 04/2026: Prototype EPICS bridge
- 10/2026: Full Implementation REST gateways completed for SFRS/LSA tests
- 11/2026: Full EPICS bridge completed
- 06/2027: Gateways operational for commissioning

Recommendations addressed (CO-R6)

CO-R6: General Archiving System

"The committee considers that the resources allocated to data archiving are not sufficient given the importance of archived data to fully exploit and understand modern machines. The committee considers that this system needs attention, the need for data storage and the list of data sources and performance limitations may be underestimated."

Update on Activities

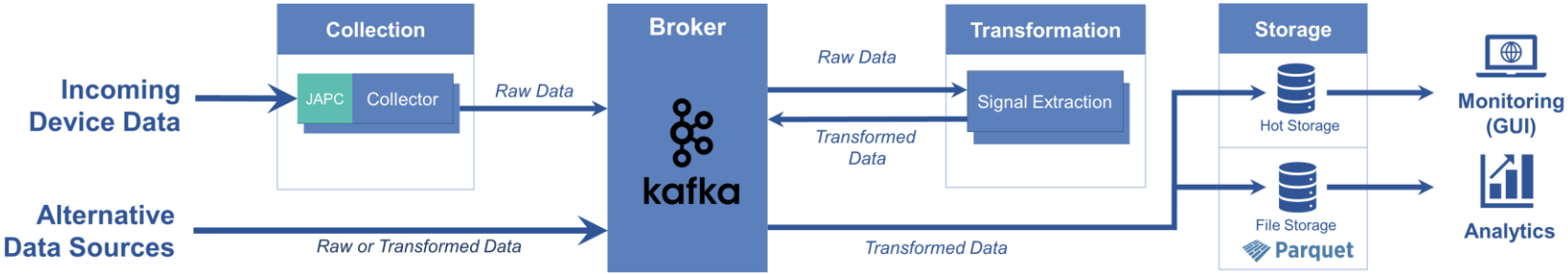
- Position for dedicated developer approved by management after MAC review
- **New developer joined the team in 03/2025**
- Polish in-kind partner supports Archiving system development
- Present system is in use for 5y now, Grafana in use, current ingestion rate 70-150 GB/day (gross)


FROM TERABYTES TO PETABYTE:
SCALING OF THE ARCHIVING SYSTEM FOR FAIR

- **Expert workshop** with major stakeholders was held (update/determine use cases, w.r.t. ML/AI)
- → **Present system is being re-worked and optimized to handle the required scale and performance, minimize technical dept, improve stability and maintainability**
- Concepts presented and discussed with experts during ICALEPCS 2025 Conference (Chicago, 09/2025)
- Presented and approved in CSG (Controls Steering Group) in 10/2025
- Revised technical specification under preparation

Archiving System [2/3]

NXAR (NeXt generation Archiving)



Main architectural changes

- Central **kafka** broker (data injest, transformation, cache storage → performs well and is being extended
- Normalize (transform) incoming data to basic **time-series format**
- Store data in **Apache Parquet files** → easy integration/use with modern analytical, ML/AI tools
- Use GSI central IT **lustre storage installation** (multi-PB capacity)
- Use **time-series DB** as **hot storage** and **monitoring (Grafana)** → proven solution, low barrier for user access
- **No disruptive changes** → smooth transition by implementing new storage in parallel

Archiving System [3/3]

Planned Milestones

- 12/2025: Working **prototype** available
- 03/2026
  - Configuration data is migrated to NXAR
  - All user side components are adapted (proxy, extractor)
- 06/2026
  - Web GUI for basic operations is ready
  - Basic **context data from LSA** is available in the new system
- 07/2026
  - Data from the current system is **exported to Parquet files**
- 08/2026 (Beamtime)
  - Using existing Opensearch cluster, but storing the **data in new time series format**
  - Existing Grafana dashboards are migrated
  - Writing **parquet files to Lustre** (if achievable by that time)
- 2027
  - Introduction of a powerful tool set to analyze and query the data e.g. Jupyter Notebook (or similar)
  - Extending the available context information e.g. LSA Trim Settings, Timing Data etc.
  - Integration with OPC UA and WinCC OA data (industrial Controls systems)
  - Introduction of a new time-series DB for hot storage and monitoring

Follow-up on CO-R04

CO-R4: OpenDigitizer, OpenCMW, GNU Radio, Control Apps

"Evaluating how this system integrates into the control infrastructure, […]"

Strategy and Status

- Decision presented at MAC27: continuation of OpenDigitizer implementation
  - Gain in functionality and accessibility due to innovative approach outweighs integration efforts
- Implementation in three phases: **(1) prototype, (2) basic CS integration**, (3) full CS integration
  - **Prototype** digitizers targeted in phase 1 include **signals essential for operation** of SIS18 and ion sources
  - Phase 2 comprises deployment on all digitizers of GSI and **provides access to digitized signals during operation from FCC**
  - Coordination of basic **CS integration** with ACO: JAPC plugin clarified, establishing of configuration database ongoing
  - Full integration (phase 3) not required for operation from FCC and FAIR commissioning
- Project follow-up by CSG (Controls Steering Group)

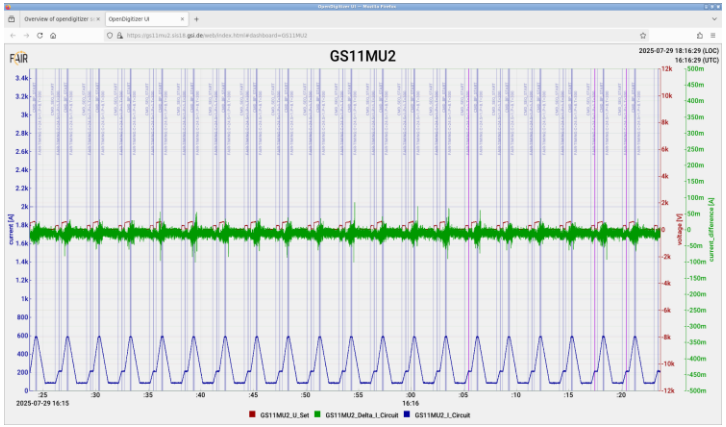
Planned Milestones

- 11/2025: Roll-out of SIS18 **prototype digitizers completed** (resp. SYS)
- 12/2025: Roll-out of **ion source prototype digitizer completed** (resp. SYS)
- 02/2026: **OPE tests** of SIS18 and ion source digitizers **during engineering/wet run completed** (resp. SYS)
- 02/2026: ACO **tests of JAPC plugin** during engineering/wet run completed (resp. SYS)
- 04/2026: **Configuration DB** for deployment of all digitizers available (resp. SYS, ACO)
- 08/2026: All digitizers rolled out and **ready for operation from FCC** (resp. ACO, SYS, technical groups)

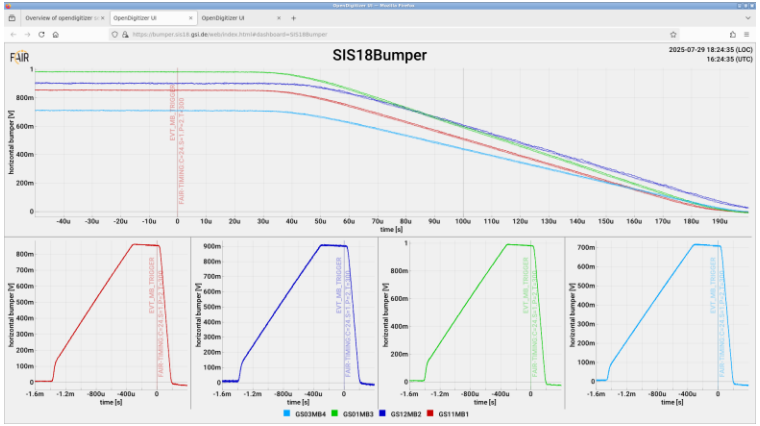
Digitizer Status

- **Technology stack** for acquisition and displaying of device signals **implemented and verified**
  - *Picoscope 4000* digitizers rolled out and tested at SIS18 in **both continuous and triggered acquisition mode** (07/2025)
  - Unified integration comprising *Picoscope 3000* and *6000* close to completion, roll-out for chopper and kickers in 11/2025
  - All digitizers essential for operation of SIS18 from FCC will be deployed by 12/2025, to be tested in 02/2026

- Implementation of **JAPC plugin prepared** in collaboration with ACO
  - Realization based on existing OpenCMW Java client with minor adaptations
  - Implementation will start immediately after completion of Picoscope integration and roll-out



Continuous acquisition of SIS18 main dipole PC signals



Triggered acquisition of SIS18 bumper magnet currents

Summary

- Control system development is generally on good track.
- Controls department is fully focused on control system development for ES (FBE) and the control system upgrade of the UNILAC injector chain.
- Substantial progress has been made on the modernisation and upgrade of the UNILAC control system with several major goals achieved during two successful beam runs at UNILAC and SIS18.
- Operation are due to move into new FCC control room for the next beam time in mid-2026. Control system installation and software is aligned accordingly and appears well prepared from today's perspective.
- Recommendations have been addressed and activities are ongoing, in particular:
- LSA setting management: Experienced DB engineer hired, performance monitoring and analysis started. Close cooperation with CERN LSA DB experts has been agreed upon.
- SFRS data exchange: Data exchange gateways have been specified and conceptually designed. Development will be carried out externally, roadmap defined and aligned with SFRS team.
- Archiving system: System design fundamentally revised including ML/AI requirements and implementation has begun, planning use GSI's central lustre fs mass storage system.
- OpenDigitizer development strategy is continued, prototypes demonstrated. Control system middleware (JAPC) integration and roll-out aligned with FCC commissioning, follows a strict schedule and monitored by CSG.