Injector Controls Upgrade Project

Peter Gerhard/PSU, Hanno Hüther/ACO

Operator School 2025

Outline

- Introduction
  - Project overview: general strategy, CS architecture , project organization
  - A brief history of the Injector Controls Upgrade (ICU) project
  - Timeline: were are we
  - Major changes and progress since wet run 2024

- Report on wet run July 2025
  - Overview and statistics
  - Program and results
    - Basic, mandatory, and advanced topics
    - The icing on the cake
    - Remaining major tasks
  - MCR modernization overview and status July ’25
  - Conclusions regarding the project status wrt. the upcoming beamtimes

- Outlook
  - ICU major milestones, project planning and agenda
  - Wet run 2026
  - Forecast beamtime 2026 & 2027/1 – deliverables and limitations

Outline

- Introduction
  - Project overview: general strategy, CS architecture , project organization
  - A brief history of the Injector Controls Upgrade (ICU) project
  - Timeline: were are we
  - Major changes and progress since wet run 2024

- Report on wet run July 2025
  - Overview and statistics
  - Program and results
    - Basic, mandatory, and advanced topics
    - The icing on the cake
    - Remaining major tasks
  - MCR modernization overview and status July ’25
  - Conclusions regarding the project status wrt. the upcoming beamtimes

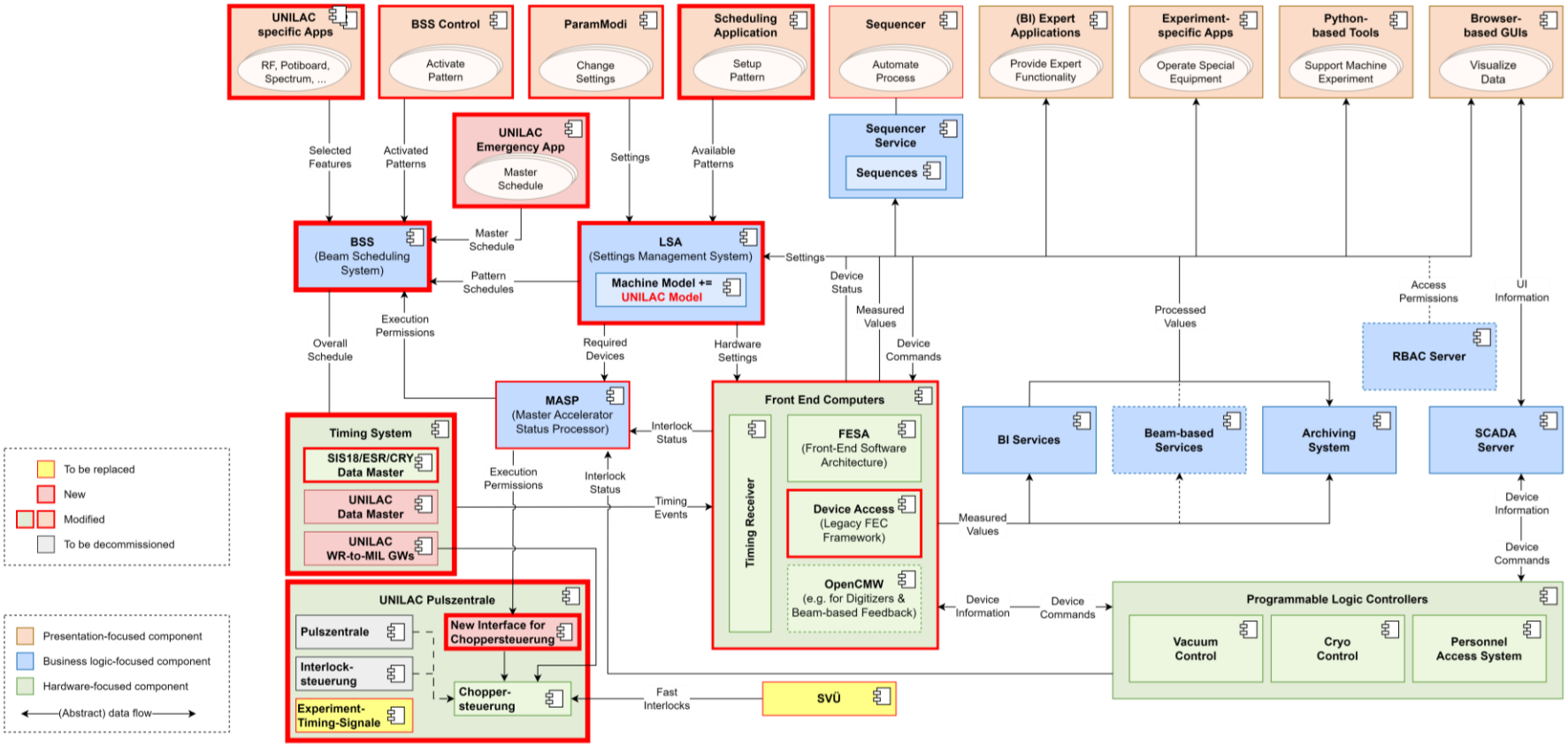
- Outlook
  - ICU major milestones, project planning and agenda
  - Wet run 2026
  - Forecast beamtime 2026 & 2027/1 – deliverables and limitations

General Strategy of the Injector Controls Upgrade

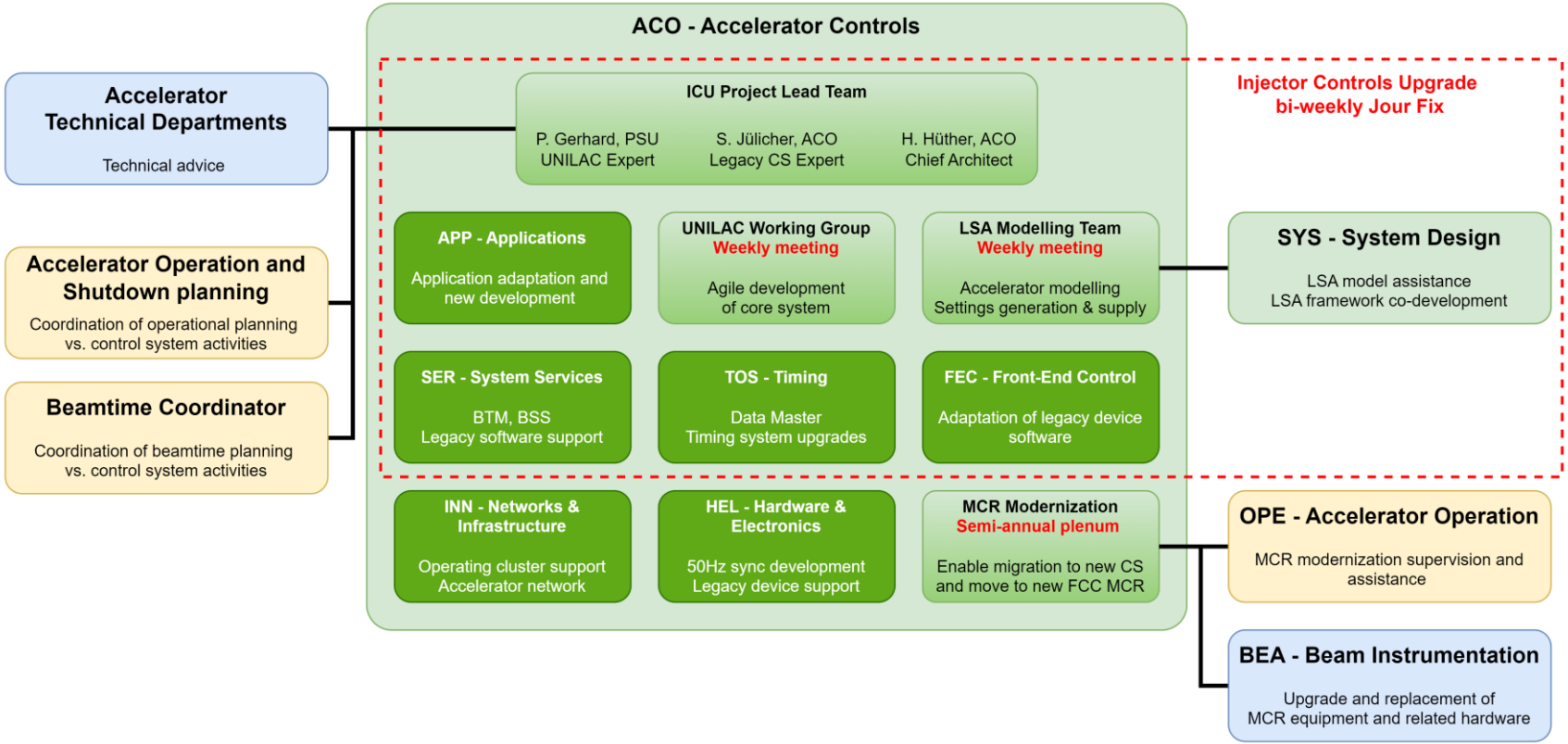
14th July 2023

- Step 0: **Secure UNILAC beam operation** through beamtime 2025 ✓
  - Replace existing operating cluster with virtual machines, replace terminals in MCR
  - Implement IT security measures for operation extension
- **MCR modernization project**: replace/upgrade hardware devices in control room
- Step 1: Develop **emergency control system** ✓
  - First viable version of new control system with reduced and simplified feature set
  - Replace existing MIL timing system by White Rabbit-based system
  - Serves as emergency backup for beamtime 2025
- Step 2: Develop **production control system** ... in progress ...
  - Based on emergency control system
  - **Replace simplifications made by fully fledged solutions, implement full feature set**
  - Enhance operability and efficiency during beamtimes 2026 and 2027
- End of ICU project, transition of UNILAC into regular control system maintenance and development
- Step 3: Further development, include other linear accelerators

Control System Architecture Changes for ICU



Project Organization



A Brief History of the Injector Controls Upgrade (ICU) Project

- Project kick-off November 2019

- Step 0: Secure UNILAC operation through beamtime 2025 ✓
  - 2019: decision to prolong operation of ACC6 cluster, Red Hat 6 and UNILAC consoles until 2024
  - 2021: change from server cluster to virtual machines ⇒ decommission obsolete hardware
  - 2023: **general transition strategy fixed**, exchange terminal consoles in MCR and console monitors
  - operation with legacy control system on extended support for Red Hat operating system until 2024
  - final operation of user beamtime 2025 with legacy control system beyond extended support ⇒ IT security
  - **legacy control system decommissioned August 2025**

- MCR modernization project
  - replace/upgrade hardware devices in legacy control room in preparation of move to FCC
  - 2019: MCR survey, 100+ single features identified
  - 2021: 14 work packages defined, including ACO, BEA and OPE, 365k€ budget allocated in 2023
  - 1st meeting December 2021, 8th meeting September 2025

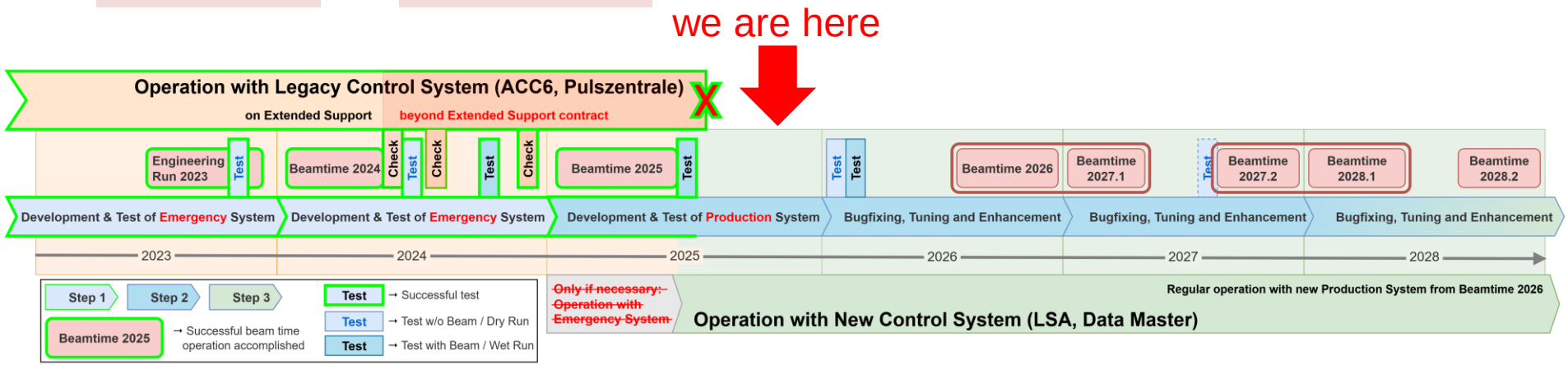
A Brief History of the Injector Controls Upgrade (ICU) Project

- Step 1: emergency system ✓
  - 2020: Development started
  - Dry run November 2023: first test of **basic fragments** of the FAIR control system @ UNILAC
  - Dry run July 2024: test of **incomplete emergency system**, core functionality complete
  - Wet run November 2024: feature **complete emergency system**
  - **First test of new control system with beam** but only at UNILAC, not at SIS18 (not available)
  - **Emergency system not needed for beamtime 2025**

- Step 2: **production system**
  - Wet run July 2025: **Test of** first version of **initial production system at UNILAC and SIS18** with beam ✓
  - Development ongoing, major conceptual changes
  - Wet run February 2026: 2nd test of initial production system
  - Beamtime 2026 & 2027.1: First user operation with new (initial production) control system
  - Further completion, enhancement, optimization and bug fixing
  - Beamtime 2027.2 & 2028.1 with production system
  - End of ICU project

Updated Timeline for Development and Test Strategy

- Planning basis adapted to new strategic planning 2027 + 2028
- Control system for beamtime 2026 will not be feature complete
- Beamtime 2026 and 2027.1 constitute a single, continuous beamtime
  ⇒ No major control system upgrades possible before 2027.2!
- Development of production control system (Step 2) covers 2 beamtimes
  ⇒ 2026 – 2027.1 and 2027.2 – 2028.1



Step 2: Initial production system
Major Changes and Progress Since Wet Run 2024

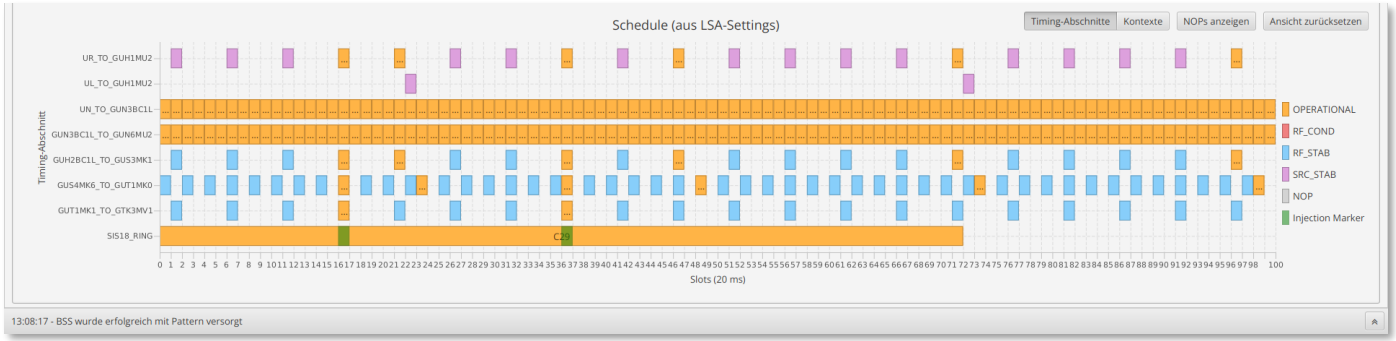
- **Control system architecture for UNILAC and SIS18 unified**
  - November 2024: Separate data supply concepts as temporary (emergency) solution
    - For UNILAC implemented as intermediate Standalone-Pattern-Chains
    - SIS18 still running on (previous state of) Pattern implementation
  - New FAIR standard: control the whole facility (injectors and rings) via the same control system structures, components and applications
  - In addition to LSA and BSS, applications had to be adapted
  - **Consolidation of Pattern concept necessary for integrating UNILAC**
    - All machines now run on **Stand-alone Chains**
    - Features added for UNILAC **benefit other machines**, too (e.g. it's now possible to schedule SIS chains multiple times in arbitrary order, non-mux contexts)
    - Also prerequisite for FAIR (Booster Mode)
  - **Pattern Group** replaced by **Patterns able to schedule multiple Chains**, includes SIS18 and UNILAC chains

⇒ Big step for the implementation of the Pattern Concept as originally intended

⇒ see Talk "Control System Design & Architecture Changes I: Patterns & Chains" for more details

Step 2: Initial production system
Major Changes and Progress Since Wet Run 2024

- **UNILAC and SIS18 integrated into one consistent timing schedule**
  - **No more requesting** beam from UNILAC by SIS18, i.e. no more waiting for beam



- **Beam transfer directly synchronized between Data Masters** (UNILAC and SIS18 DMs)
  - **Communication between UNILAC-DM and Ring-DM implemented**
  - Master Schedule (equivalent to Super Cycle) for both accelerators runs in UNILAC DM
  - SIS18 chains run in Ring DM, triggered by special events in Master Schedule in UNILAC DM
  - UNIPZ-DM gateway between Ring-DM and UNILAC Pulszentrale decommissioned

⇒ see Talk “Control System Design & Architecture Changes II: Scheduling” for more details

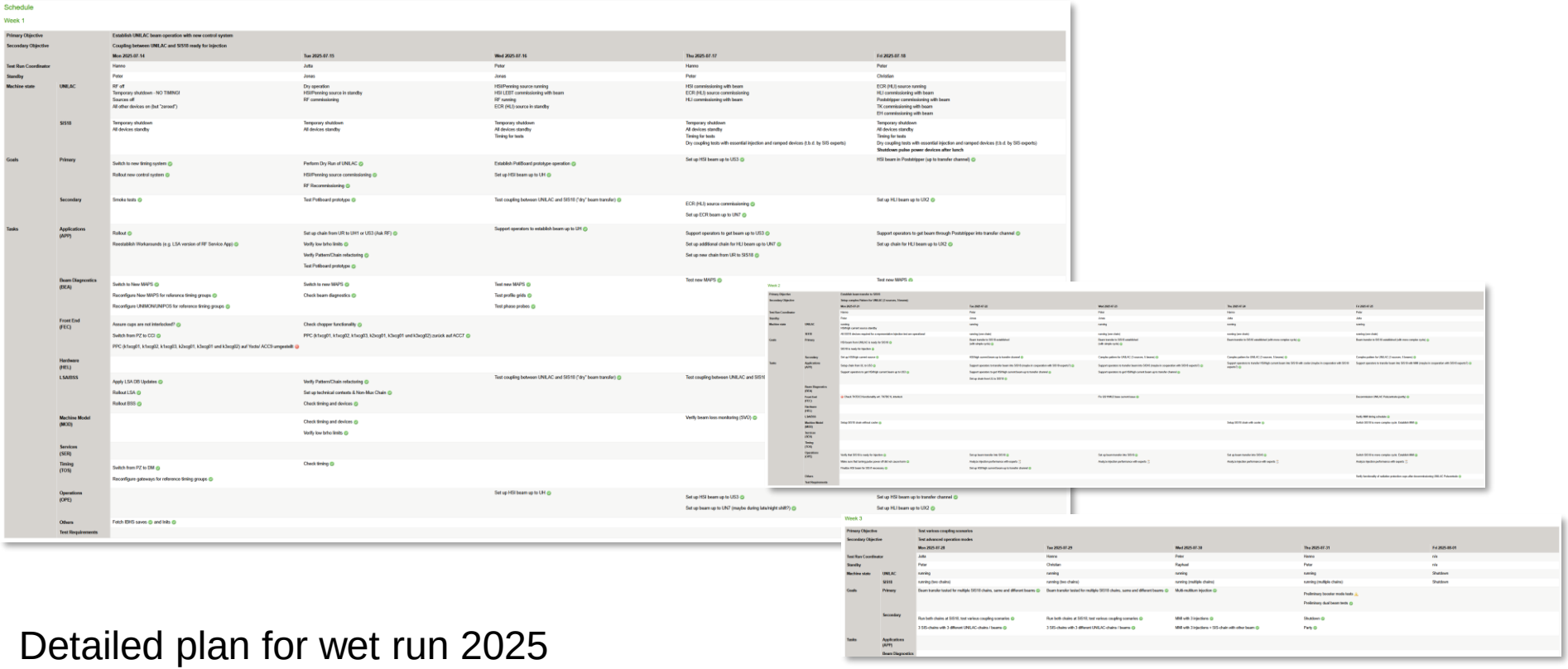
Outline

- Introduction
  - Project overview: general strategy, CS architecture , project organization
  - A brief history of the Injector Controls Upgrade (ICU) project
  - Timeline: were are we
  - Major changes and progress since wet run 2024

- Report on wet run July 2025
  - Overview and statistics
  - Program and results
    - Basic, mandatory, and advanced topics
    - The icing on the cake
    - Remaining major tasks
  - MCR modernization overview and status July ’25
  - Conclusions regarding the project status wrt. the upcoming beamtimes

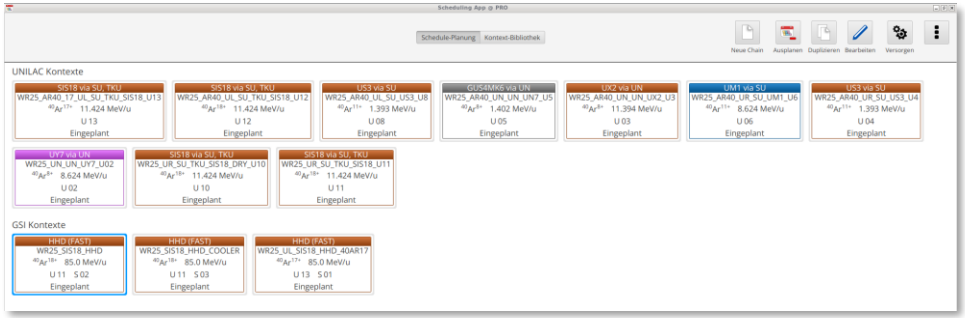
- Outlook
  - ICU major milestones, project planning and agenda
  - Wet run 2026
  - Forecast beamtime 2026 & 2027/1 – deliverables and limitations

Wet Run July 2025: Overview and Statistics



Detailed plan for wet run 2025

Wet Run July 2025: Overview and Statistics



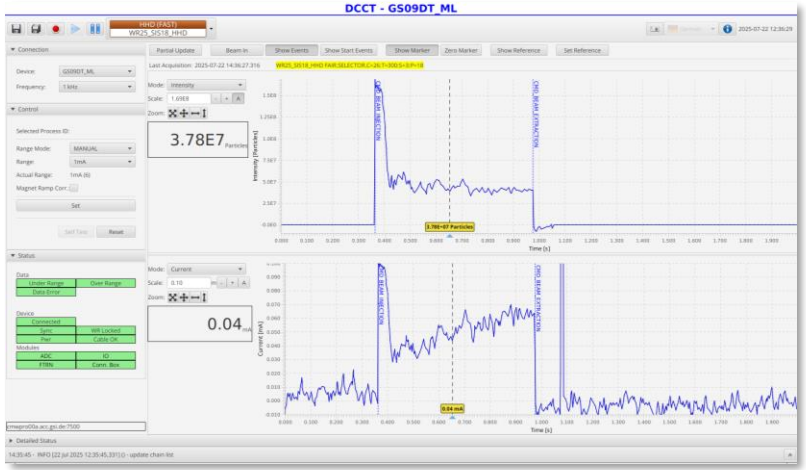
- Full operation of UNILAC and SIS18
- 14 weekdays, 2 weekends
- Extensive planning (see wiki)
- Daily coordination meetings
- Coordination zoom and on-call service
- 18 UNILAC chains created, up to 8 scheduled in the same Pattern
- 9 SIS18 chains created, max. 3 SIS chains available at the same time
- 4 principle beams from all 3 sources established to 6 destinations
- Parasitic beam delivered to X2 (master thesis), Y7 (machine investigations), beam used in SIS18 by BEA (machine investigations)
- Operators performed tasks at night and on weekends successfully
- 73 test cases in 7 categories tracked, performed and documented (see wiki)

Planned Tests and Results
Week 1: The Basics

- Switch UNILAC to new control system and new timing system ✓
  - Including full decommissioning of UNILAC Pulszentrale (except for Choppersteuerung and related parts) in week 2
- Get all necessary apps and tools running ✓
  - Took until week 3
- Introduce operators to new control system ✓
- Verify safety functions and changes made since last Wet Run ✓
- Ramp up and establish UNILAC beam operation ✓
  - Starting with single beam from Penning source
  - Establish beam along machine
  - First time HLI operated with new control and timing system ✓
  - Add beam from ECR ion source, establish second beam ✓

Planned Tests and Results
Week 2: The Mandatory

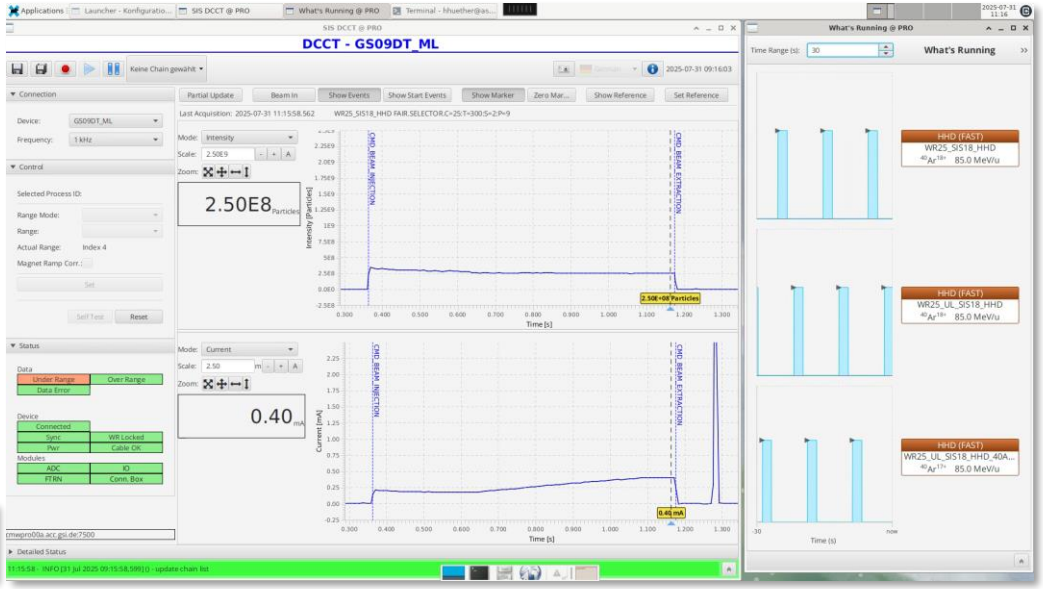
- Add beam from high current source ⇒ beams from all three sources ✓
- Deliver several UNILAC beams in parallel to different destinations, including different beams in transfer channel and high duty cycle beams (50 Hz) ✓
  - Verify transfer channel preparation ✓
- Inject beam into SIS18 for the first time with the new control system at UNILAC ⇒ successful ✓



First beam injected into SIS18 with new control system at UNILAC

Planned Tests and Results
Week 3: Advanced Topics

- Inject beam into two SIS18 chains from one UNILAC chain
  ⇒ successful ✓
- Use SIS cooler ✓
- Inject three different beams (three different UNILAC chains) into three different SIS18 chains
  ⇒ successful ✓

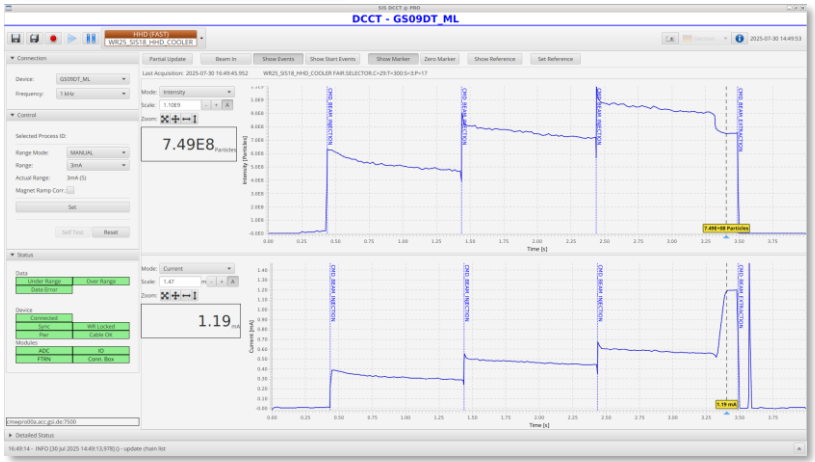


3 beams injected (movie)

The Icing on the Cake

- Multi-Multiturn-Injection ⇒ successful ✓
- Dual Beam and Booster Mode
  ⇒ partly successful ✓

Multi-Multiturn



Dual Beam

MCR Modernization Overview and Status

Work package	Dept.	Description	Status
MAPS	BEA	Beam current measurement and display	**Operational, enhancements?**
UNIMON	BEA	RF cavity display	**Operational**
PHAS	BEA	Phase probe control, bunch shape and energy measurement	**Commissioning**
Cupid	BEA	Integrated video monitoring system	**Operational, full installation pending**
UNIPOS	BEA	Beam position measurement and display	**Operational**
BIF	BEA	Beam Induced Fluorescence monitor	**Operational, strategic upgrade pending**
Chopper display	ACO	Status display for beam chopper requests	**In progress**
PG/EMI protection	ACO	Control and status display for SEM grid protection	**In progress**
Cup control	ACO	Control and status display for faraday cups	**In progress**
Interlock/beamloss display	ACO	Interlock and beamloss status display	**Advanced, in progress**
Experiment signal display	ACO	Display any detector feedback from beam users	**Postponed**
WR-Snoop@UNILAC	ACO	WR timing diagnostic tool	**Operational**
BTM	ACO	Beam Transmission Monitoring	**In progress, pending**
Experiment timing	ACO	Trigger, sync and gate signals for beam users	**In progress, pending**
Gas stripper	PSU	Pulsed hydrogen gas stripper	**Operational (limited), full installation in progress**
Potiboard	ACO/OPE	Realtime accelerator (magnet) adjust	**Operational, upgrade planned**
Oscilloscopes	ACO/IQU	Signal display for ion sources	**Operational (limited), upgrade pending**

Conclusions: Status of the project wrt. to the upcoming beamtimes

- All compulsory tests were successful:
  Basic operation of UNILAC and SIS18 together has been verified
- Advanced features – the freestyle part of the wet run:
  - MMI also worked out of the box
  - Booster Mode and Dual Beam operation worked technically,
    but beam injection was not successful
- Operating efficiency of UNILAC was greatly enhanced wrt. emergency system in wet run 2024
- Operating efficiency for SIS18 nearly as usual for basic operation, handling of more complex injection schemes still needs to be improved

⇒ **Viability of fundamental integrated operation mechanisms has been demonstrated and can now be built upon**

Outline

- Introduction
  - Project overview: general strategy, CS architecture , project organization
  - A brief history of the Injector Controls Upgrade (ICU) project
  - Timeline: were are we
  - Major changes and progress since wet run 2024

- Report on wet run July 2025
  - Overview and statistics
  - Program and results
    - Basic, mandatory, and advanced topics
    - The icing on the cake
    - Remaining major tasks
  - MCR modernization overview and status July ’25
  - Conclusions regarding the project status wrt. the upcoming beamtimes

- Outlook
  - ICU major milestones, project planning and agenda
  - Wet run 2026
  - Forecast beamtime 2026 & 2027/1 – deliverables and limitations

Deliverables Completed and Remaining (since Wet Run November 2025)

- new activity
- achieved
- in progress
- pending
- cancelled
- to be clarified
- critical

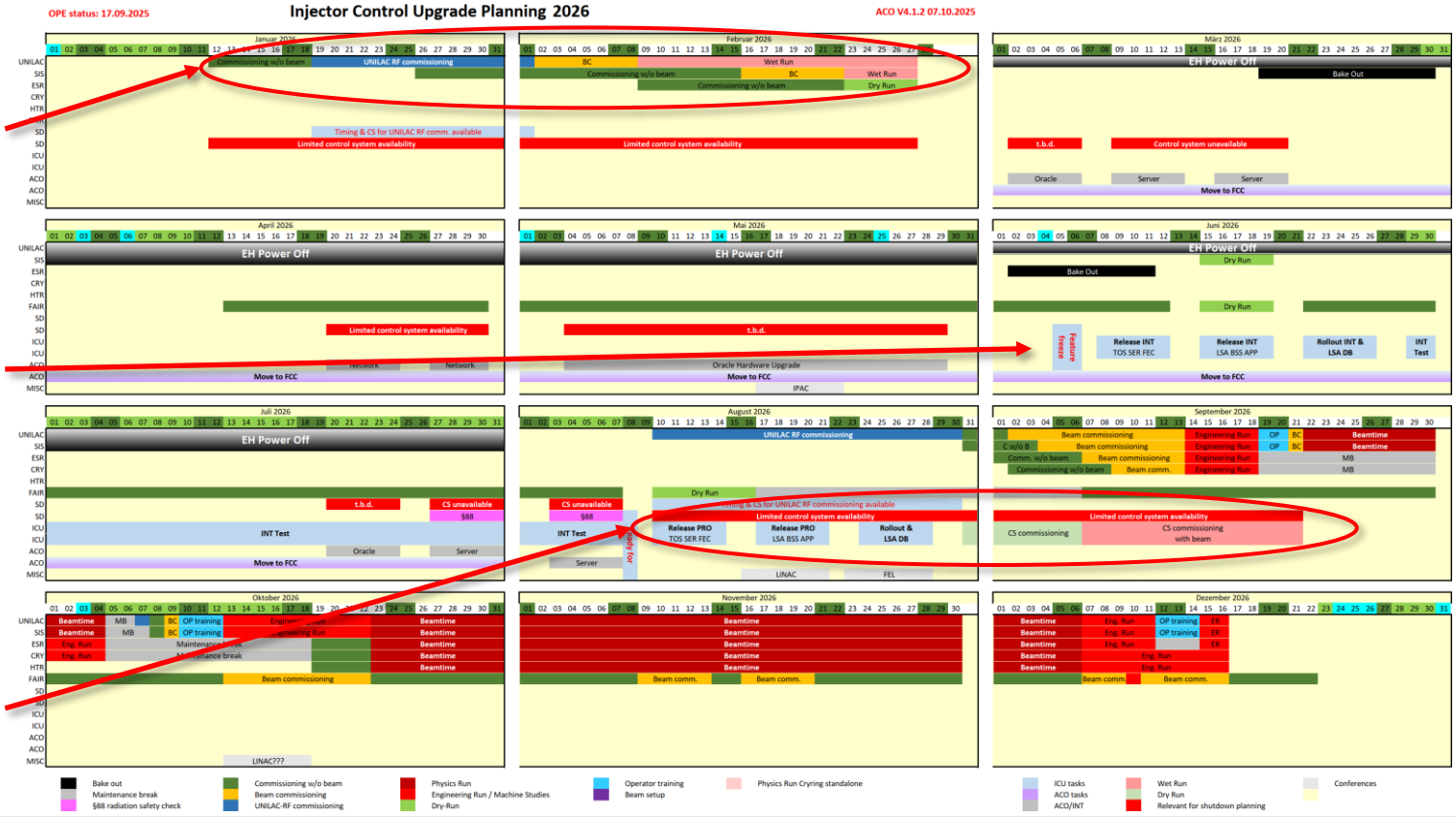
For details, see ICU wiki

Project Planning 2026

Wet run Feb ‘26:
during shutdown,
SIS18 open,
UNILAC+SIS18
+ESR +Cryring?

CS integration test

Beamtime ‘26:
CS release, rollout and commissioning for first regular user beamtime



ICU Agenda until Wet Run and BT 2026

- Consolidate
  - Review results from Wet Run
  - Follow up changes, fixes and workarounds made during Wet Run
  - Solve issues for currently critical deliverables
  - Complete rollout of unified control system, reestablish full functionality for storage rings
  - Revise and clean up code base
- Complete
  - Implement missing features (e.g. SelectBeamLine, RF app, FC panel)
  - Finalize provisional/intermediate software
    (e.g. PHAS, Bottle app, Emergency App, schedule planning algorithm)
  - Replace remaining MCR hardware (e.g. profile grid switches, experiment timing signals)
  - Some tasks identified during Wet Run are out of ICU scope
- Coach
  - Introduce operators and related staff to new control system at UNILAC
  - First course planned for end of the year: general introduction, concepts
  - Hands-on training during Wet Run February 2026
  - Second course planned for spring 2026
  - Hands-on training during commissioning and beamtime 2026

Wet Run February 2026: Planning Status

- Draft coarse planning:
  - Dry commissioning of control system, UNILAC, SIS18, ESR (tentatively Cryring) 2-3 weeks each
  - Beam commissioning of UNILAC and SIS18 1 week each
  - Wet Run UNILAC 3 weeks, SIS18 1 week
  - Extensive restrictions for beam operation at SIS18 due to open ceiling, no extraction allowed, no beam operation at ESR
  - Small ICU team, long test run ⇒ stronger involvement of shift crews in test run, include training of operators (and others)

	12.01.	13.01.	14.01.	15.01.	16.01.	17.01.	18.01.	19.01.	20.01.	21.01.	22.01.	23.01.	24.01.	25.01.	26.01.	27.01.	28.01.	29.01.	30.01.	31.01.	01.02.	02.02.	03.02.	04.02.	05.02.	06.02.	07.02.	08.02.	09.02.	10.02.	11.02.	12.02.	13.02.	14.02.	15.02.	16.02.	17.02.	18.02.	19.02.	20.02.	21.02.	22.02.	23.02.	24.02.	25.02.	26.02.	27.02.
	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr
General Plan UNILAC	Commissioning without Beam							LINAC-RF commissioning														Beam Commissioning							Engineering Run																				
General Plan SIS18															Commissioning without Beam																						Beam Commissioning							Engineering Run				
General Plan ESR																													Commissioning without Beam															Dry Run				
ICU	Dry run UNILAC							School	Debugging						Dry run UNILAC+SIS							Wet Run UNILAC							Dry run ESR							Wet Run UNILAC+SIS							Dry run UNILAC+SIS+ESR				
OPE								School	Tutorial						Hands-on training							Wet Run UNILAC						UNILAC operation														UNILAC+SIS operation								

Wet Run February 2026: Major topics

- New synchronization UNILAC↔SIS18 directly between UNILAC and Ring Data Masters
- Re-established Storage Ring Mode and Coupling (ESR, Cryring?)
- Beam Operation Scenarios as requested for Beamtime 2026/2027.1, derived from beamtime schedule: MMI, Dual Beam, single request (PP), slow extraction
- Other improvements (LSA model, Applications, HKR modernization, removed workarounds)
- Preparation for move to FCC

	12.01.	13.01.	14.01.	15.01.	16.01.	17.01.	18.01.	19.01.	20.01.	21.01.	22.01.	23.01.	24.01.	25.01.	26.01.	27.01.	28.01.	29.01.	30.01.	31.01.	01.02.	02.02.	03.02.	04.02.	05.02.	06.02.	07.02.	08.02.	09.02.	10.02.	11.02.	12.02.	13.02.	14.02.	15.02.	16.02.	17.02.	18.02.	19.02.	20.02.	21.02.	22.02.	23.02.	24.02.	25.02.	26.02.	27.02.
	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr
General Plan UNILAC	Commissioning without Beam							UNAC-RF commissioning														Beam Commissioning							Engineering Run																				
General Plan SIS18															Commissioning without Beam																						Beam Commissioning							Engineering Run				
General Plan ESR																													Commissioning without Beam															Dry Run				
ICU	Dry run UNILAC							School	Debugging						Dry run UNILAC+SIS							Wet Run UNILAC							Dry run ESR							Wet Run UNILAC+SIS							Dry run UNILAC+SIS+ESR				
OPE								School	Tutorial						Hands-on training							Wet Run UNILAC							UNILAC operation															UNILAC+SIS operation					

Forecast Beamtime 2026 & 2027/1 – deliverables

- Based on results from wet run July 2025: no show stoppers encountered

- Basic operation from UNILAC together with SIS18 can be expected
  - UNILAC: multiple beams to EH users and SIS18 in parallel
  - SIS18: multiple beams to EX users, including MMI

- Ongoing: restore ring operation from restrictions imposed for/by wet run
  - Full ability to trim SIS18
  - General operation for rings other than SIS18
    ⇒ Implementation of stand-alone Chains for ESR, CRYRING, HITRAP in autumn 2025
  - Storage ring mode and coupling
    ⇒ testing in wet run February 2026

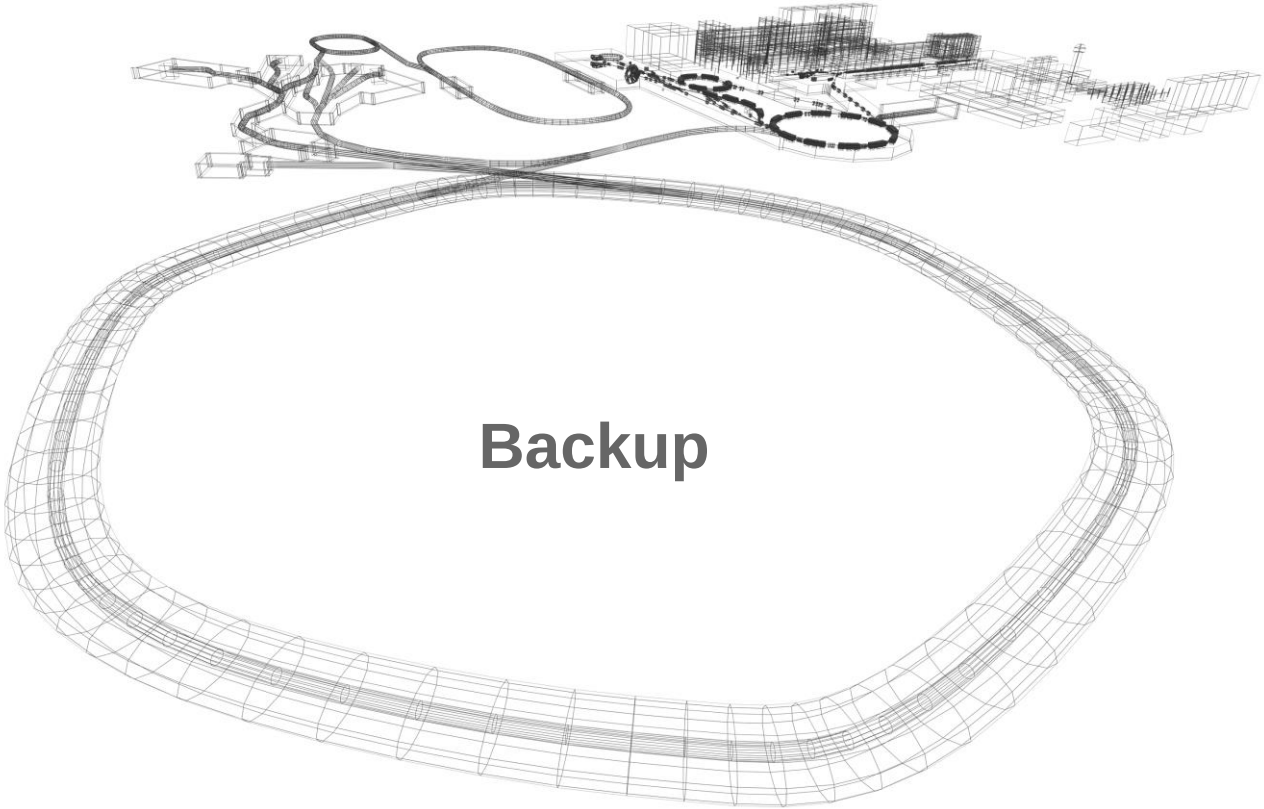
Forecast Beamtime 2026 & 2027/1 – limitations

- **Anticipated limitations for beamtime 2026**
  ⇒ Communicated to, discussed with and acknowledged by D. Severin in March 2025
  ⇒ Will be accounted for in beamtime planning
  - (UNILAC) operating efficiency will generally be (much) lower than usual
    - Operators will have to get used to new control system
    - Expert support will be needed more often
    - **Expected teething problems** will lead to delays and interruptions, ad-hoc workarounds may be necessary

    ⇒ **Some setups may need much more time than usual/expected**
  - No long Master Schedules / Super Cycles
    ⇒ No complex SIS18 operation with many chains including long slow extraction
  - To be prioritized (may not both be realizable):
    - Switching of BSS patterns for infrequent beam delivery to storage rings
    - Multiple-chain operation for BIO experiments
- Possible mitigations / workarounds have been discussed

Thank You for Your Attention!

- Thanks a lot to all who contributed the project and the wet run!
  - To all colleagues from controls for the preparation, testing, debugging, hot fixing, documenting, ...
  - To the colleagues from beam diagnostics and the synchrotron experts for their great support
  - To the RF colleagues for their attention
  - To operations and all specialists for keeping it running smoothly for another three weeks
  - To the shutdown planners (and affected colleagues) for accepting the cut in shutdown time
  - To ACO's INN group for keeping ACC6 running for so long
  - Special thanks to all operators on shift during the wet run for their interest, motivation, commitment, questions, feedback and (nearly endless) patience



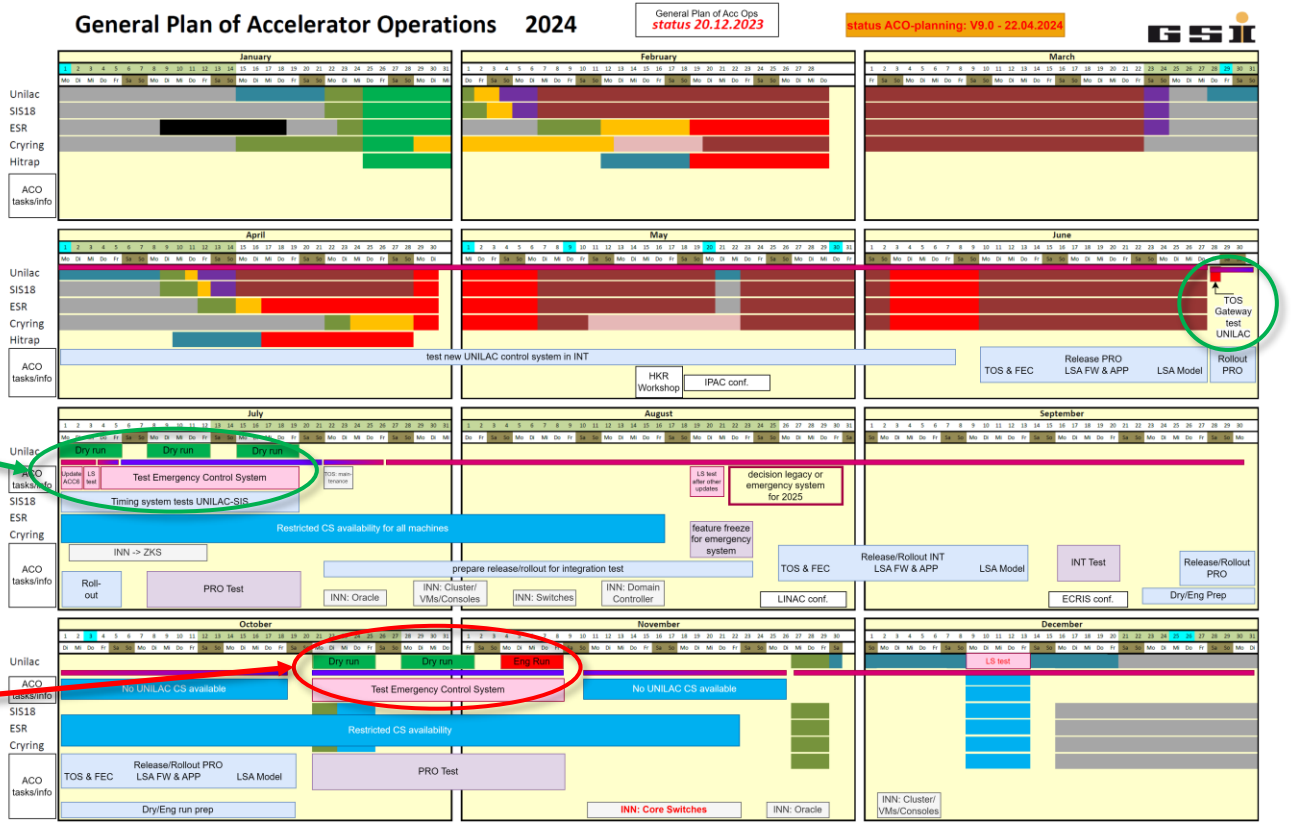
Backup

Project Planning 2024

Extremely dense shutdown

Dry run July ‘24: directly following beam time

Wet run Nov ‘24: **only UNILAC**, not SIS18



Project Planning 2025

Wet run July ‘25: directly following beam time, **UNILAC+SIS18** for the first time

Preparation for wet run Feb ’26 starts in Nov ‘25

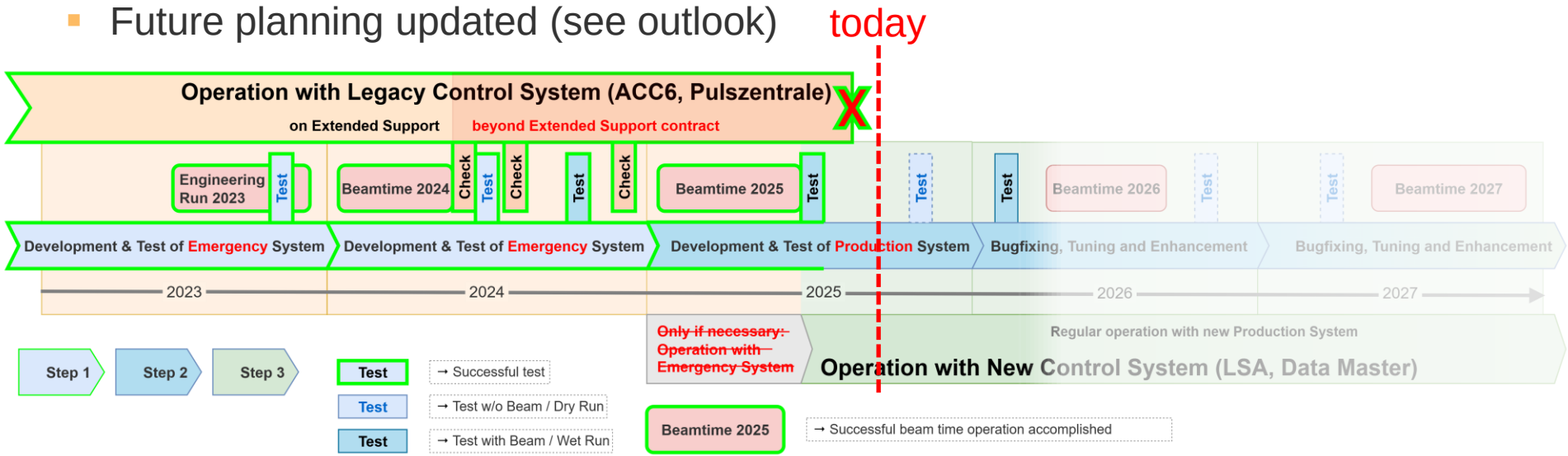
Project Planning 2027 (draft)

Pre-(INT)-testing starts June 2027

Beamtime ’27.2: CS release, rollout and commissioning

Timeline for development and test strategy

- Beamtime 2025: Last beamtime operated with legacy control system ✓
- Final decommissioning of legacy control system after 30+ years ✓
- Development of production version of new control system ongoing
- Future planning updated (see outlook)



Step 2: develop production control system - milestones

- Complete and finalize implementation of initial production control system
  - starting point: emergency system
  - fully fledged White Rabbit-based timing system, new FAIR pattern scheduling concept
  - enhanced settings generation and data supply
  - full set of operating tools and applications
  - bugfixes, essential tuning and necessary enhancements
- Engineering Run 2025
  - test initial production control system with beam
  - first test of beam injection into SIS18 solely with new control system
- Dry Run / Engineering Run 2025/26
  - in between testing of further developments before first beamtime operation
- Beamtime 2026
  - initial production control system
  - first regular operation with new control system
- Beamtime 2027
  - improved production control system
  - first regular operation of **user beam time** with new control system