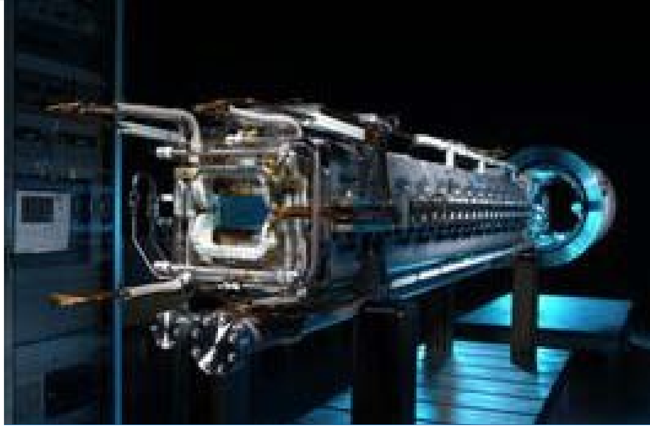


FAIR Commissioning & Control: Status and Outlook until 2025

Ralph J. Steinhagen

(FC^2-PL, 2.14.17 & 2.14.10.10)

FAIR Experiment and Accelerators Workshop

December 14th, 2018, Darmstadtium, Darmstadt, Germany

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

GSI HELMHOLTZ ASSOCIATION FAIR

Overview

- Main aim of this talk:
  - Setting the Stage
    - Boundary Constraints & Challenges
    - Primary FC2-Strategy
  - Update on Commissioning & Controls Activities
    - Boundary Constraints & Challenges
  - Brief update on FAIR Control Centre Activities

- references & previous talks (strategies & concepts still valid)
  - HIC4FAIR'15 (Hamburg):
    - *"Options for Parallel Operation"* → link
  - HIC4FAIR'16 (Rheingau):
    - *"FAIR Commissioning & Control WG - Status & Strategy Update"* → link
    - *"Machine Experiment Interface - 2nd Iteration"* → link
  - Special FC2WG & FCC Projectgroup Info-Meeting'17
    - *"FCC – FAIR Control Centre -- Concepts, Requirements & Next Steps"* → link
    - K. Berkl: *"Neubau - FAIR Control Centre – FCC"* → link
  - MAC'18 - Machine Advisory Committee: *"FAIR Commissioning & Control WG Status"* → *link*
  - … more documentation (Google: 'FC2WG'): FC2-WG Homepage, Presentations & Minutes

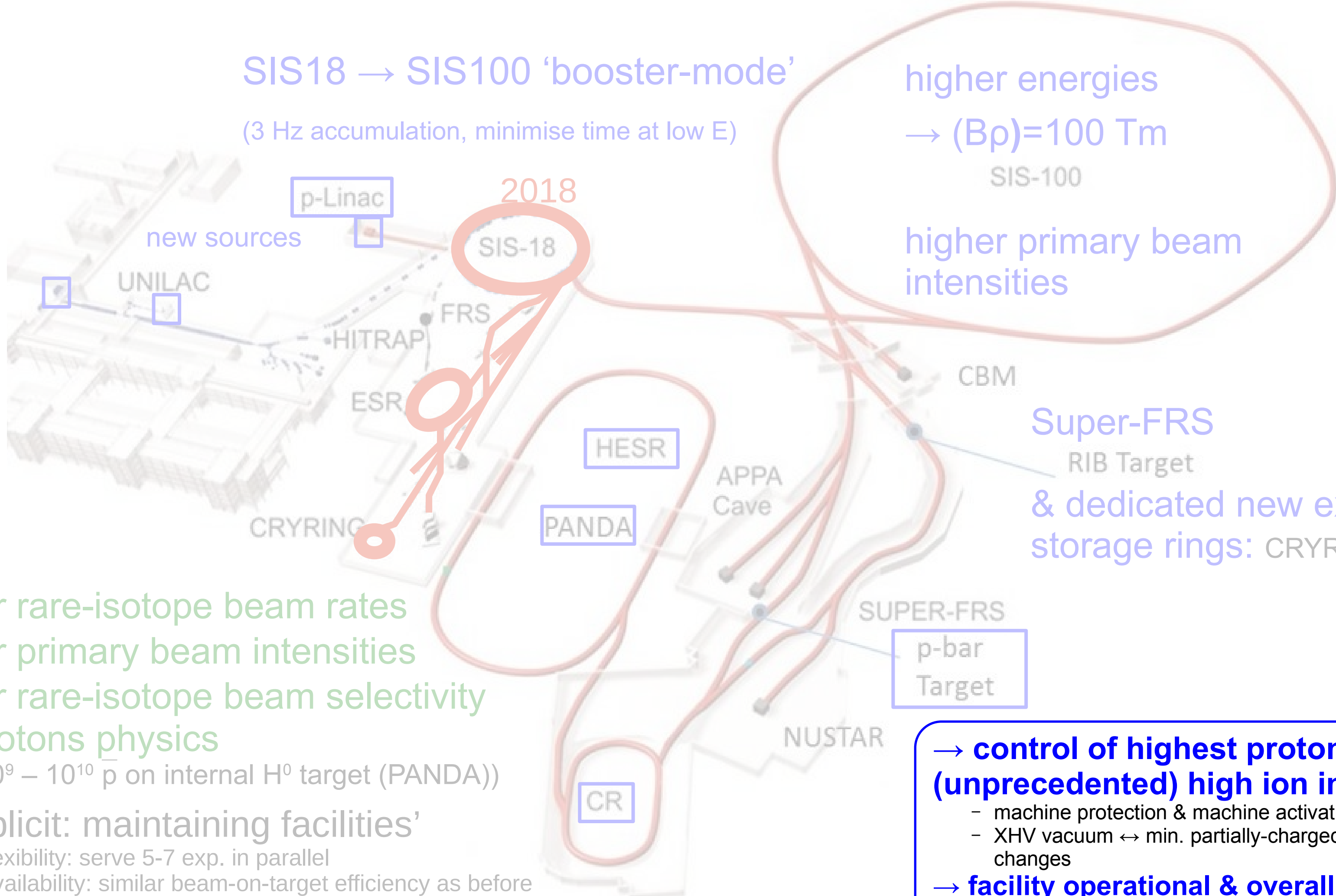
Setting the Scene….

GSI → FAIR Transition in 2018, 2022 → 2025 (SIS100)

experiments' requirements → **consequences for the accelerator facility**

SIS18 → SIS100 'booster-mode'

(3 Hz accumulation, minimise time at low E)



higher energies

→ (Bρ)=100 Tm

higher primary beam intensities

Super-FRS

& dedicated new experimental storage rings: CRYRING, CR, HESR

higher rare-isotope beam rates

higher primary beam intensities

higher rare-isotope beam selectivity

antiprotons physics

(N.B. $10^9 - 10^{10}$ $\bar{p}$ on internal H^0 target (PANDA))

… implicit: maintaining facilities'

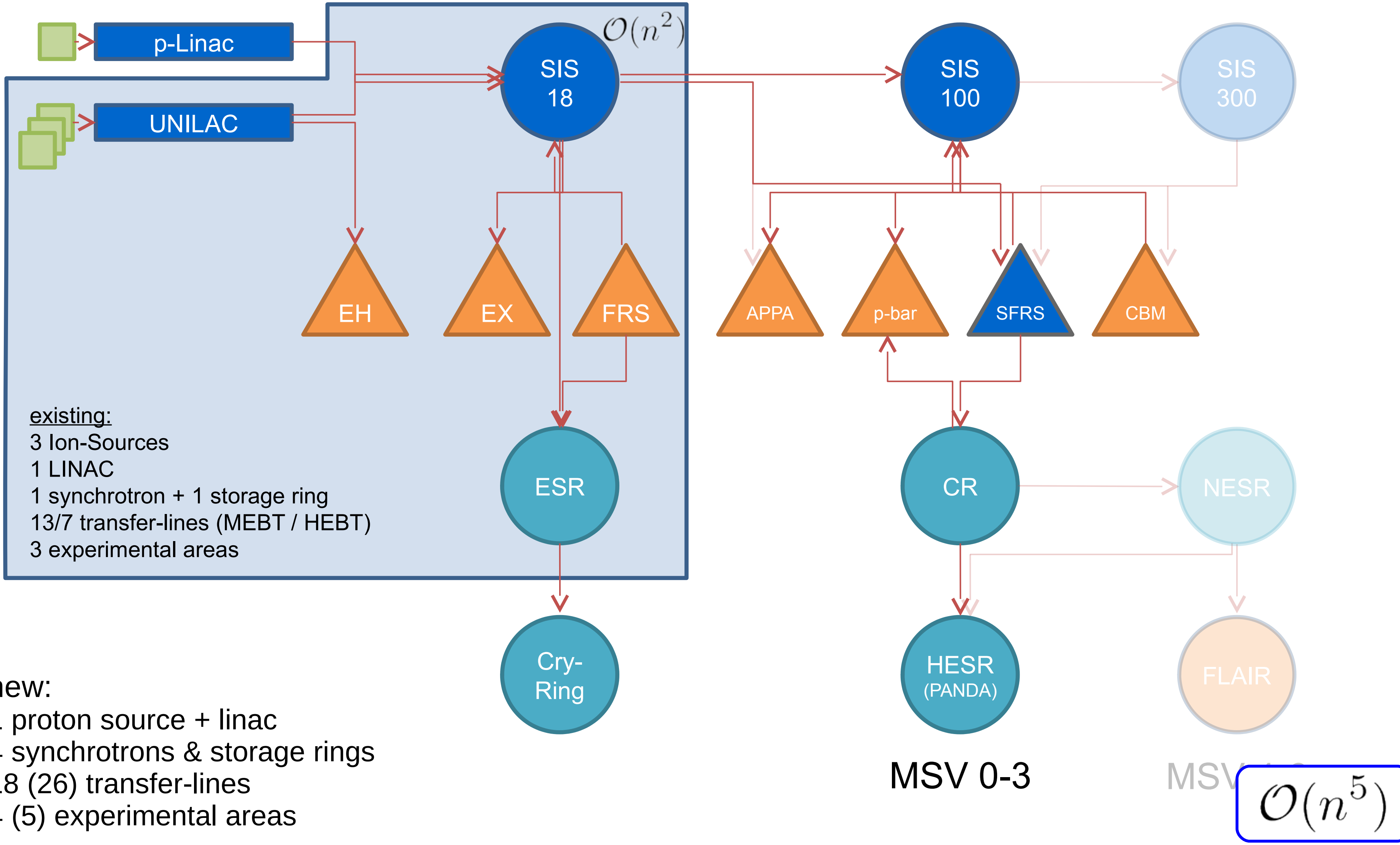
- flexibility: serve 5-7 exp. in parallel
- availability: similar beam-on-target efficiency as before

→ control of highest proton and (unprecedented) high ion intensities
- machine protection & machine activation
- XHV vacuum ↔ min. partially-charged ion charge state changes

→ facility operational & overall complexity

FAIR Operational Challenge

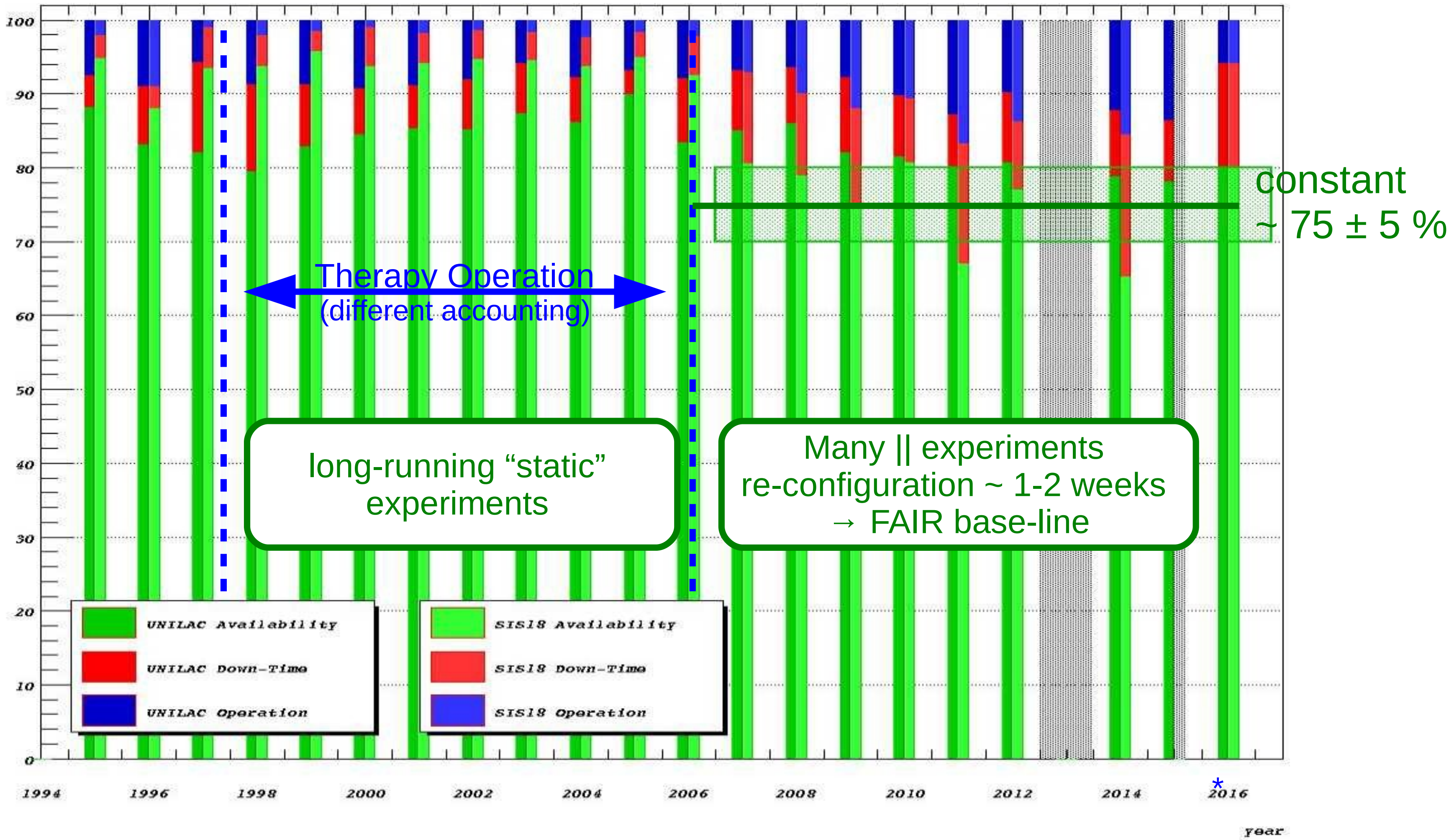
Transition from 3 → 8½ (11+) accelerator(-like) Machines



new:
1 proton source + linac
4 synchrotrons & storage rings
18 (26) transfer-lines
4 (5) experimental areas

Accelerator Experience & Efficiency

1995-2016: U. Scheeler, S. Reimann, P. Schütt et al.

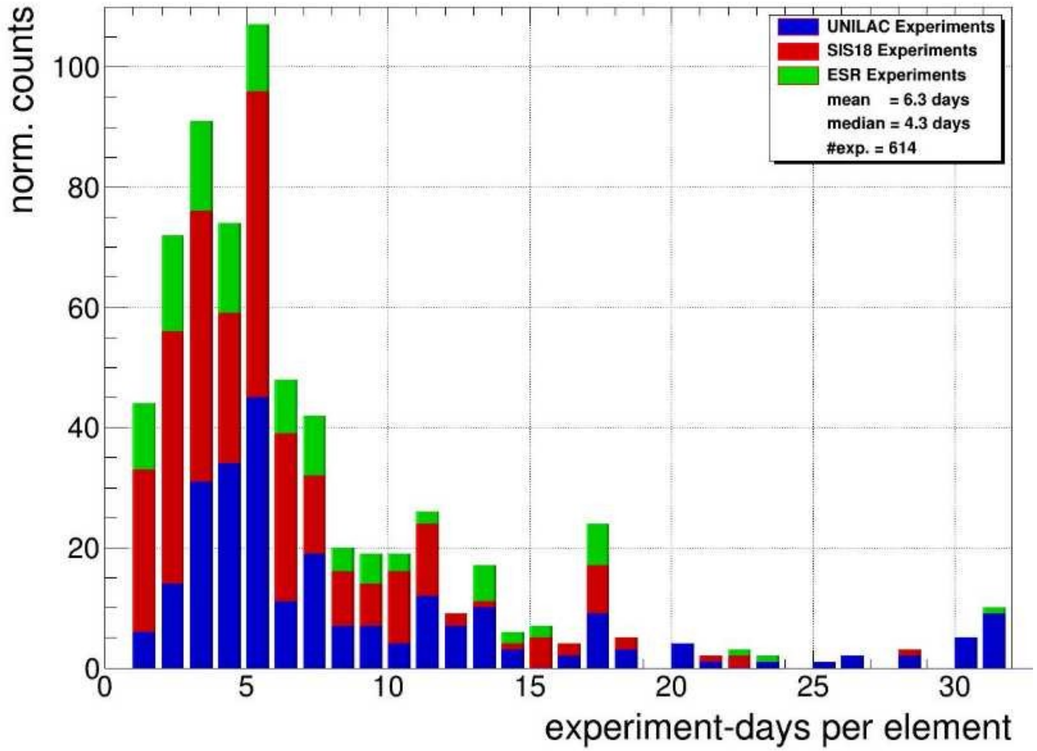


Based on: U. Scheeler, S. Reimann, P. Schütt et al., “Accelerator Operation Report”, GSI Annual Scientific Reports 1992 – 2015 + 2016 (D. Severin)
https://www.gsi.de/en/work/research/library_documentation/gsi_scientific_reports.htm
N.B. ion source exchanges are factored out from UNILAC & SIS18 data (~ constant overhead)
Availability: *experiments + detector tests + machine development + beam to down-stream accelerators;*
Down-time: *unscheduled down-time + standby;* Operation: *accelerator setup + re-tuning*

* 2018 operation limitations:
- only ½ UNILAC (w/o A3 & A4)
- only 1 element in SIS18

Accelerator Experience & Efficiency

or: .. how to move/transform accelerator operation from 3 (GSI) → 9 (FAIR) machines



bottom line (1st order):

A) an 'average' GSI/FAIR experiment lasts about 5 days

B) FAIR will accommodate about 5-6 parallel experiments

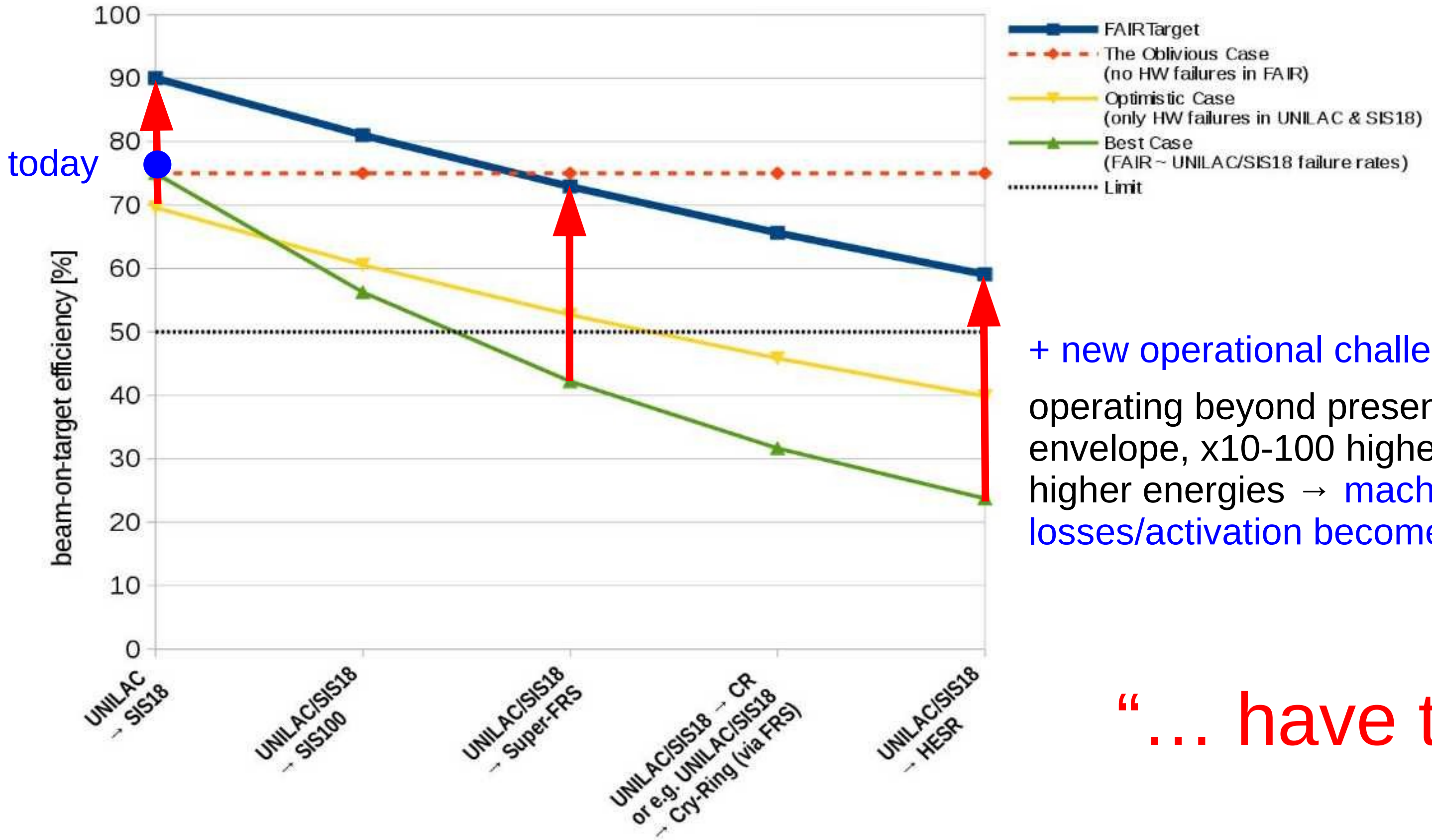
→ expect:

- setup of new beam-production-chain (BPC) about once per day
- longer BPCs (↔ number of sequential acc.) → larger complexity

FAIR Challenges & Constraints
… SIS18 Operation Experience & Efficiency

- Beam-on-Target figure of merit (FoM) of ~75% → FAIR-BoT (efficiency ε_{FAIR}):

$$\varepsilon_{\mathrm{FAIR}} := \prod_{i}^{n_{machines}} \varepsilon_i = \varepsilon_{\mathrm{UNILAC}} \cdot \varepsilon_{\mathrm{SIS18}} \cdot \varepsilon_{\mathrm{SIS100}} \cdot \varepsilon_{\mathrm{SuperFRS}} \cdot \varepsilon_{\mathrm{CR}} \cdot \varepsilon_{\mathrm{HESR}} \cdot \ldots$$

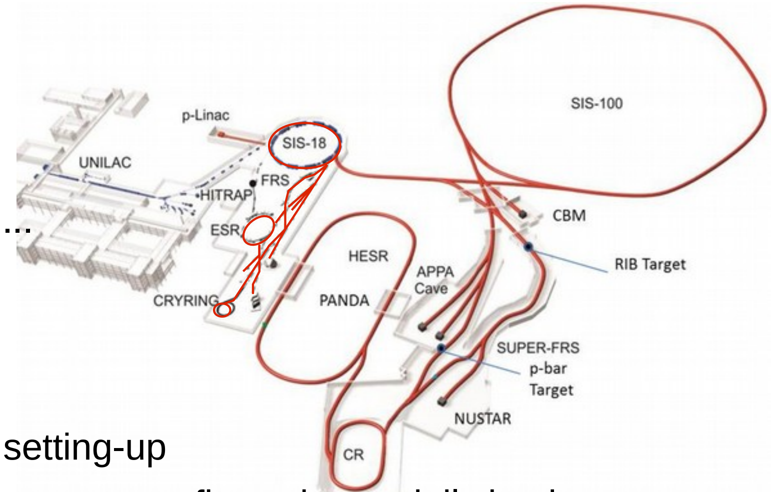


+ new operational challenges:

operating beyond present beam parameter envelope, x10-100 higher intensities, x10 higher energies → machine protection & losses/activation become an issue

"… have to improve!"

Setting the Scene….



- FAIR ~4 x the size of existing GSI facility
  - non-linear operational complexity increase $O(n^2) \rightarrow O(n^5)$
  - efficiency scalling $\varepsilon_{FAIR} = \varepsilon_{UNILAC} \cdot \varepsilon_{SIS18} \cdot \varepsilon_{SIS100} \cdot \varepsilon_{Super\text{-}FRS} \cdot \varepsilon_{CR} \cdot \varepsilon_{HESR} \cdot \ldots$
- parallel operation of 5-7 distributed experiments
  - lasting typically only 4-5 days, few long-runners
  - large potential for cross-talk between users especially while setting-up
  - world-wide unique requirement: facility and key beam parameters reconfigured on a daily basis
    - energy, ion species, intensity, extraction type/length, …
- new challenges w.r.t. GSI:
  - operating beyond present beam parameter envelope, x10-100 higher intensities, x10 higher energies → machine protection & losses/activation become an important issue
  - high-intensity and higher-order feed-down effects require machine and beam parameter control well below the sub-percent level →beyond feed-forward-only (open-loop) modelling and machine reproducibility
  - need to operate FAIR with reduced skeleton crew consisting of only ~5-6 operators (nights & weekends)
    - minimise putting unnecessary stress on crews ↔ ergonomics, human-centric design, (semi-)automation (this talk)

Product Lifecycle: 'Power-of-10 Law'
also 'lean principle'

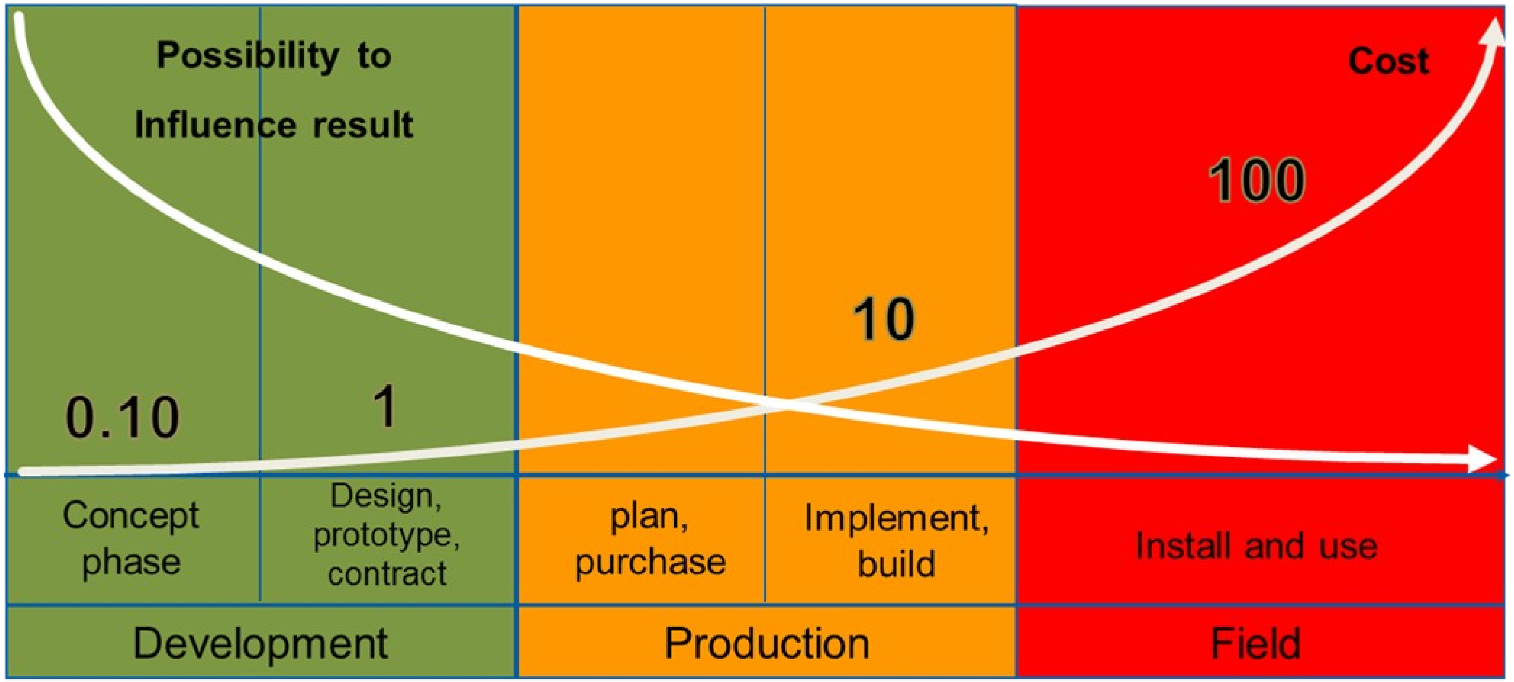


image courtesy Andrea Apollonio, CERN

- The earlier constraints are included in the design, the more effective the resulting measures
- Drives FC²-strategy:
  - Continuous improvement → right processes to produce right results & for getting it right the first time
    - commissioning procedures as evolving operation and commissioning standard
    - system integration: determine of what, how and when is needed
  - Prevention of inefficiencies, inconsistencies & wastes by design → 'poka-yoke'/'error proofing' principle

FAIR Commissioning & Control Strategy since 2015

- Hardware/Sub-Component into System Integration
into one coherent FAIR Commissioning, Operation and Controls Concept
  - devices/functions specified by the MCs & SPL
  - priorities on first commonalities, controls prerequisites, and then high-level (machine) specifics
    - SPL, MCs, experiment and management consensus and personnel resource driven & required
  - vertical and lateral integration into the control system & operation environment
→ verified during Hardware Commssioning (HWC), 'Dry-Runs' and Beam Commssioning (BC)
    - requires input and active participation by both equipment and accelerator experts
    - processes driven by 'commissioning procedures', functional requirements, consise interface description between different equipment groups, accelerator experts and SPLs/MCs

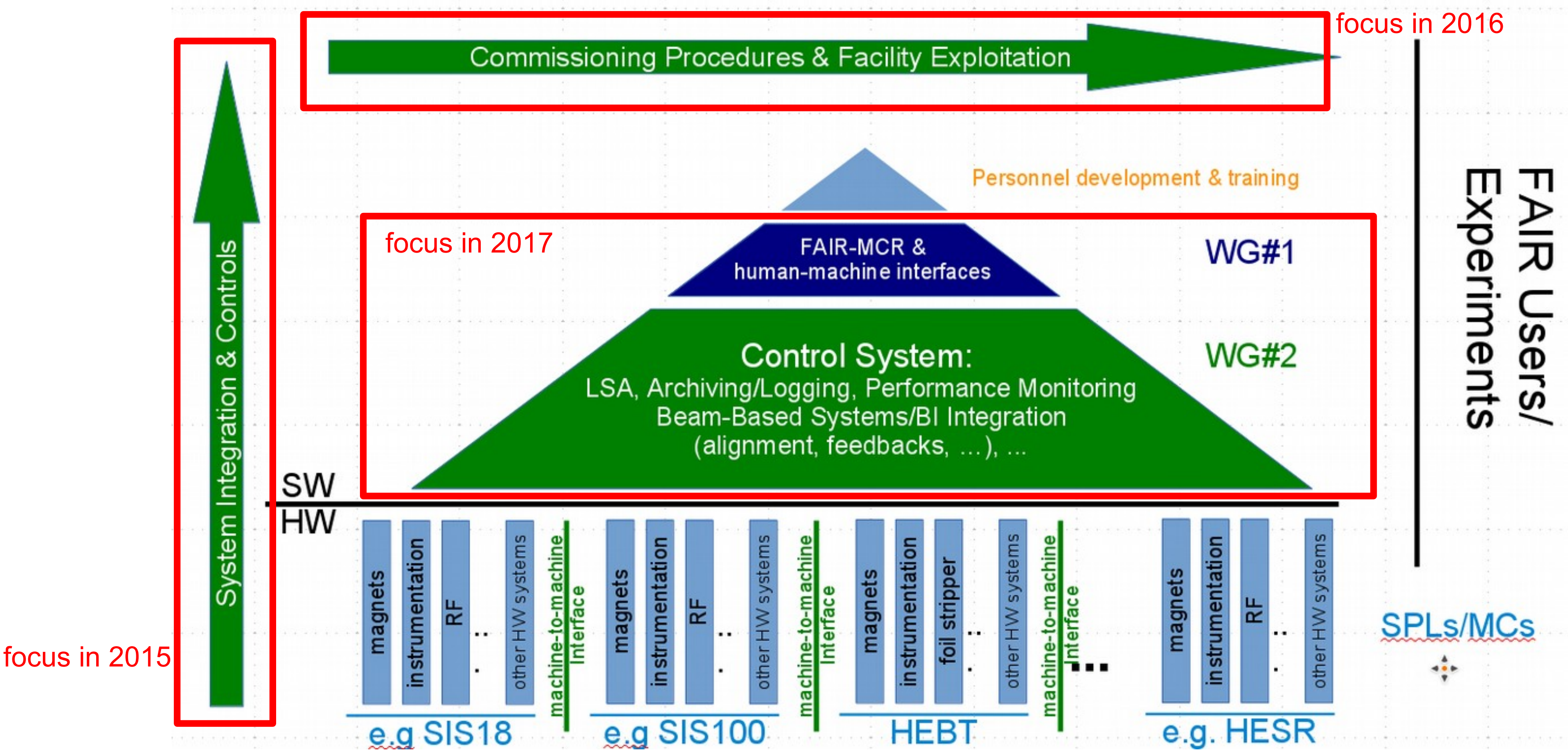
- FAIR (Parallel) Operation Concepts and Requirements
  - Feed-Forward ↔ model based control:
    - LSA settings supply, quasi-periodic/static operation, beam-production-chain concept, ...
  - (Semi-)Automation
    - Sequencer (Tesing, HWC & BC), Beam-Transmission Monitoring, Multi-Turn Injection-, Slow-Extraction Optimisations, …
  - Beam-Based Feedbacks (cycle-to-cycle)
    - trajectory, orbit, Q/Q', slow-extraction spill, optics, …

- FAIR Control Centre: Physical Control Room Ergonomics & Human-centred Design
  - 24h/7 FAIR Operation ist one of the most challenging tasks
  - Main-Control-Room should support and not 'get in the way' of operation

FAIR Commissioning & Control WG

more details: http://fair-wiki.gsi.de/FC2WG/

An accelerator is more than the sum of its parts:



- FAIR Commissioning & Control Working Group
  - platform to identify, coordinate, and work-out FAIR commissioning and operation
  - open to all who can participate and contribute to these subjects!

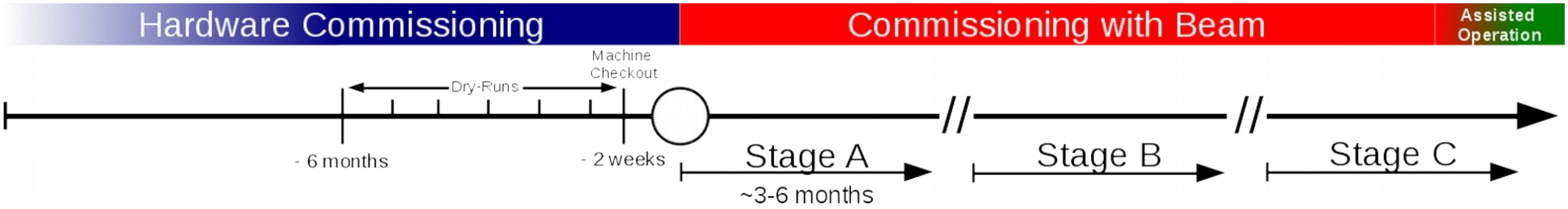
FAIR Commissioning Procedure I/II

- Develop a (initial/re-)commissioning and operation strategy:
  - memorandum of understanding between stake-holders (SPLs, MCs, AP, BI, CO, RF, ...)
    - define when, where and how the individual accelerator systems should fit in
  - identify and define missing procedures, equipment and tools, e.g.:
    - define, check the need or priority of applications vs. 'use cases'
    - define, check integration and interface between specific equipment and CO/OP environment
  - focus first on commonalities across then specifics within individual accelerators
    - MPLs/MCs define pace & resources of how fast to achieve the above
  - dissemination/knowledge transfer from groups that constructed and performed the initial HW commissioning to the long-term operation
    - training of operational crews (physics, operation, tools, ...)
  - scheduling tool for technical stops to follow-up possible issues found

*Procedure aims not only at the initial first but also subsequent re-commissioning e.g. after (long) shut-downs, mode of operation changes and/or regular operation

FAIR Commissioning Procedure II/II

https://fair-wiki.gsi.de/FC2WG/HardwareCommissioning/



- Distinguish two forms of 'commissioning':

  A) Hardware Commissioning (HWC → SAT A)
    - conformity checks of the physical with contractual design targets,
    - || commissioning of individual systems & tasks ↔ MPLs/equipment group responsibility

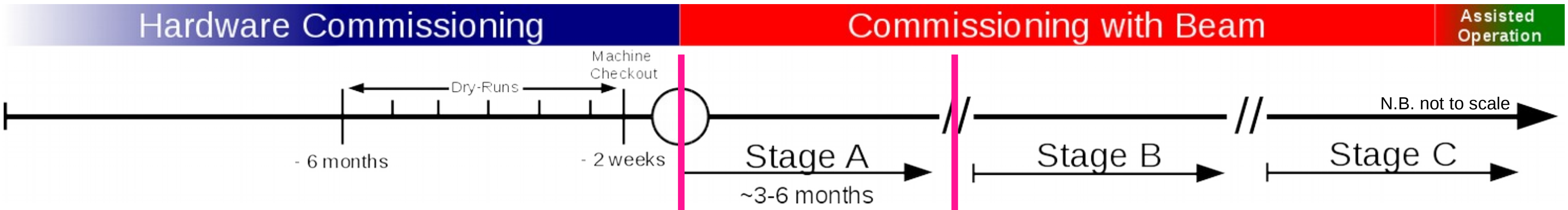
  B) Commissioning with Beam (BC → “SAT B” …)
    - Commissioning of beam-dependent equipment
    - Focus on tracking beam progress through the along the beam production chain (BPC)
      - threading, injection, capture, acceleration and extraction
    - + 'Dry-Runs': pre-checks at the end of HWC in view of beam operation:
      - Checks conformity of system's controls integration and readiness for Commissioning with Beam
      - check as much control/system functionality without beam as possible
      - Machine ist put into a state assuming that beam could be injected into the ring/segment
        - unavailable devices/systems are at first ignored, noted down, and followed-up at a defined later stage

Terminology:

- **Dry-runs**: a rehearsal of the accelerator performance/function, starting typically six month before the targeted real BC
  - needs to (partially) repeated after shut-down or longer technical stop with substantial modifications
  - initial frequency: 1-2 days every month
  - frequency increased depending on the outcome of the initial dry-run tests
- **Machine-Checkout**: intense accelerator performance tests (e.g. machine patrols, magnet/PC heat runs, etc.), typically two weeks before BC
  - needs to repeated after every shut-down or longer technical stop
  - repeated also on the long-term during routine operation of existing accelerators (already existing procedures/usus for existing machines)

Commissioning without & with Beam

https://fair-wiki.gsi.de/FC2WG/HardwareCommissioning/
https://fair-wiki.gsi.de/FC2WG/BeamCommissioning



- Split Beam Commissioning into three stages:
  - A) Pilot beams/"easily available" ions (e.g. Ar)
    - basic checks: threading, injection, capture, cool, convert, acceleration/decelerate, stripping & extraction
    - always done with 'safe' ie. low-intensity/brightness beam
      - Ions: simpler optics, beam dynamics → Protons: transition crossing
  - B) Intensity ramp-up & special systems
    - achieving and maintaining of nominal transmission and beam losses
    - commissioning of e.g. e-cooler, slow extraction, transverse fast feedbacks
    - commissioning and validation of machine protection & interlock systems
    - Possibly unsafe operations always preceded by checks with safe beam
  - C) Production operation with nominal intensities
    (N.B. first time counted as 'commissioning' or 'assisted operation' → later: 'regular operation')
    - push physics and beam parameter performance (emittance, momentum spread, ...)
    - identify and improve upon bottlenecks impacting FAIR's 'figure-of-merit
    - make fast setup and switch-over between different beam production chains routine

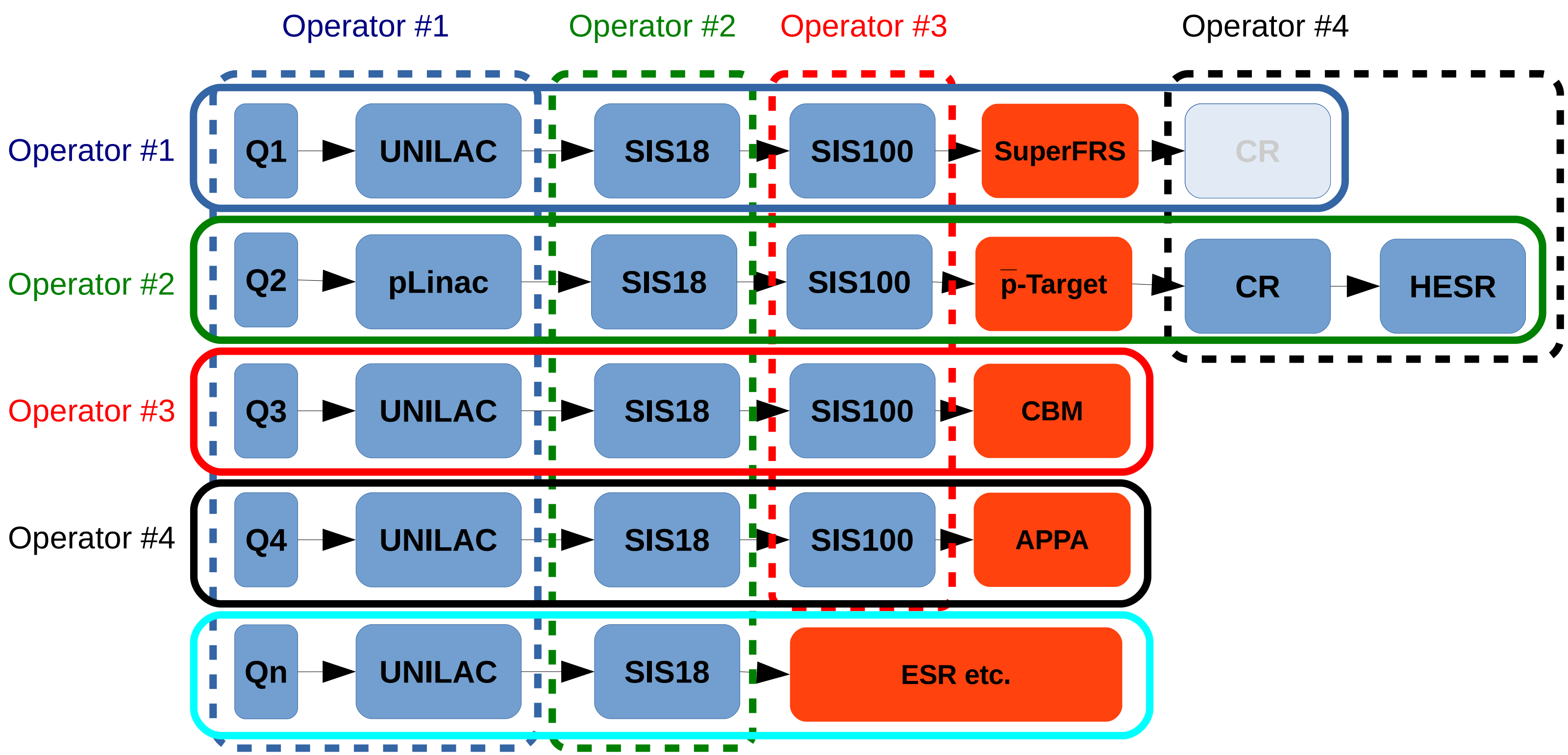
FAIR-'Day 0'

First "Splash Events" in 2025

commissioning details & 'what-if-scenarios' planned in 2.14.17.1

First Ingredient: Quasi-Periodic Operation I/II
Operation/Control Paradigm

- Some important OP boundary conditions:
  A) Compared to GSI, FAIR facility size and complexity increases roughly by a factor 4
  B) Expect some improvement but 'Operator' & 'System Expert' will likely remain a scarce resource
  (N.B. ~5-6 operators (nights & weekend) ↔ pool of ~35 operators)
- One strategy option: 'One Operator per Accelerator Domain' vs. 'One Operator per Experiment':

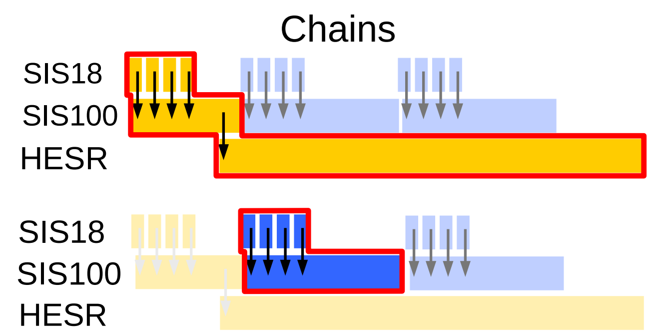


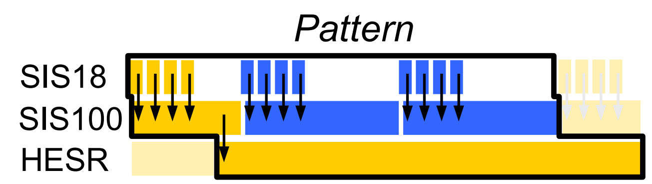
Timing System und Data Indexing

- *Beam-Production-Chain:*
  - organisational structure to manage parallel operation and beam transfer through FAIR accelerator facility
  - defines sequence and parameters of beam line from the ion-source up to an experimental cave (e.g. APPA, CBM, SuperFRS, ...)
  - definition of target beam parameters (set values): isotope, energy, charge, peak intensity, slow/fast extraction, …
- *Beam Pattern*:
  - grouping of beam production-chains that are executed periodically
  - can be changed of pattern within few minutes (target, requires automation for beam-based retuning)

→ decouple beam request from magnetic cycle
  - now: dynamic user beam request → magnetic cycle → beam injection
    - random magnetic cycle ↔ non-reproducible hysteresis
  - FAIR: pre-programmed magnetic cycle + dynamic user beam request → beam injection
    - optimises magnetic pattern ↔ reproducible hysteresis
    - N.B. beam extraction still programmed ad lib by experiments

- Both all Data-Acquisition (DAQs) and Archiving/Post-Mortem System follow and implement this concept



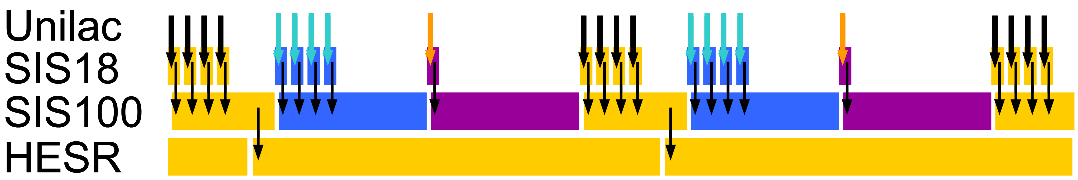


valid FAIR selector examples:
- *"FAIR.SELECTOR.ALL"*
  → listen to everything
- *"FAIR.SELECTOR.C=1"*
  → selects a given BPC
- *"FAIR.SELECTOR.S=12"*
  → selects a sequence within a BPC
  (similar to CERN's "Cycle" concept in a given accelerator)
- "FAIR.SELECTOR.P=34"
  → selects a specific process in a BPC
  (ie. 'injection', 'RF capture', 'ramp', 'extraction', ...)

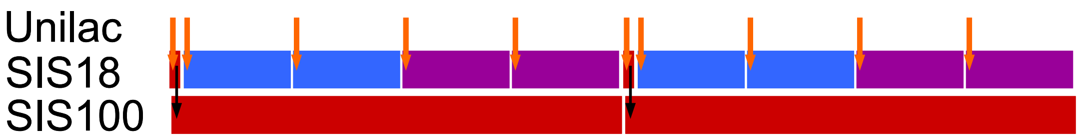
courtesy D. Ondreka

First Ingredient: Quasi-Periodic Operation II/II
Beam-Production-Chains

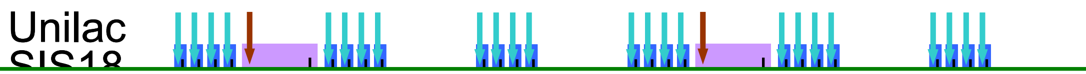
Periodic beam patterns, dominated by one ***main*** experiment – change every two weeks, some run for 2-3 days only:

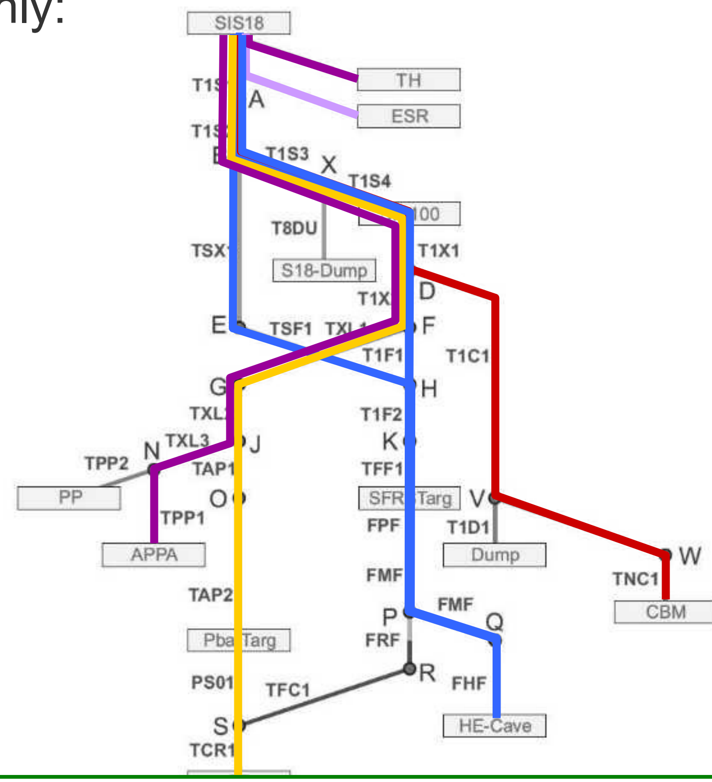


AP + RIB ext. target (U^{28+}) + Biomat



CBM + RIB ext. target (U^{73+}) + AP (LE)





FAIR Operational Challenge:

- presently: 2 shifts for setup of 2 accelerators→ FAIR target: 1-2 shift(s) for setting up 5 accelerators + tighter loss control
- Main strategy/recipe to optimise 'beam-on-target':
  - quasi-periodic cycle operation: limit major pattern changes by construction ↔ beam schedule planning (tools)
  - minimise overhead of context switches → smart tools, procedures & semi-automation, e.g. beam-based feedbacks, sequencer, …

Second Ingredient: (Semi-)Automation and Beam-Based Feedbacks at FAIR

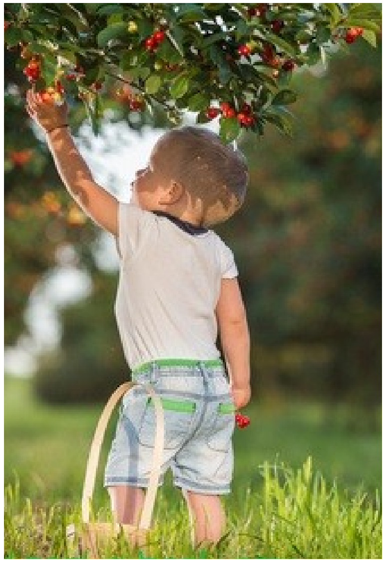
- … for efficient operation and commissioning → optimise routine task so that operation crew talents are utilised/focused on more important tasks that cannot be automated

Focus priorities on systems that have a big impact on setup, tracking and optimisation:

- ‘biggest bang-for-the buck’ or ‘low-hanging-fruits’*:
  - ie. systems that are best understood, require least effort/know-how to integrate/implement
- operationally critical or hard to achieve by-hand:
  - e.g. slow-extraction spill control, slow trajectory/focus drifts of beam-on-target
- mitigating drifts that are driven by feed-down effects due to higher-order parameter tuning: e.g. orbit, tune
- ...

Examples:

- beam-transmission-monitoring and other actual-vs-reference monitoring systems → identify, localise and fix failures/near-misses as early as possible
- semi-automated multi-turn/optics/slow-extraction monitoring/correction/… setup tools → improve facility turn-around and setup times
- classic beam-based feedbacks on trajectory, orbit, tune, chromaticity, etc. → monitor and maintain tight parameter tolerances
- Sequencer taks – automation of tasks not yet covered by other routine tools → big time saver for large-scale equipment acceptance/integration tests, recommissioning, or dry-runs
  - N.B. thousands of FAIR devices & machine proction systems that need to be periodically retested/validated



Beam-based Cycle-to-Cycle feedbacks

Generic Beam Control (focus on use-case)

1. Transmission Monitoring System
2. Orbit Control
3. Trajectory Control (threading, inj./extr., targets)
4. Q/Q'(') Diagnostics & Control
5. TL&Ring Optics Measurement + Control
   (LOCO, AC-dipole techniques etc.,)
6. RF Capture and (later) RF gymnastics
7. Longitudinal Emittance Measurement
8. Transverse emittance measurement
9. Transverse and longitudinal feedbacks

Bread-and-Butter systems for operation (items 1–4)

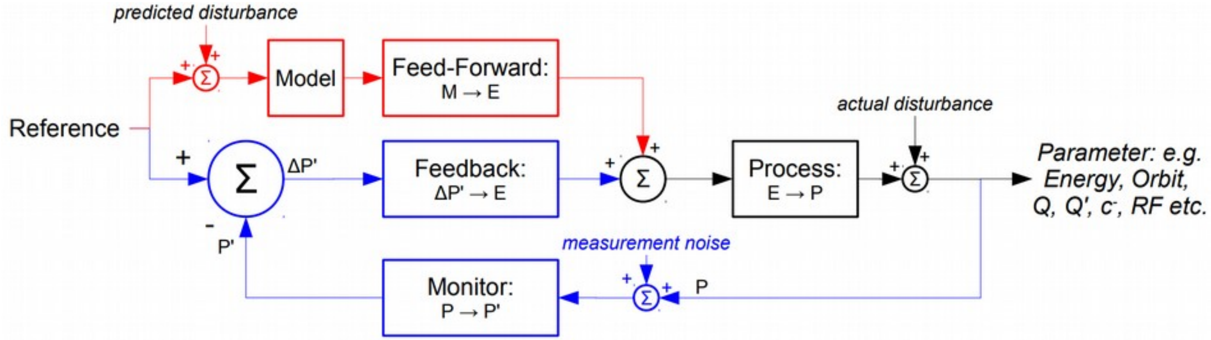
Machine-specific Beam-Based Systems:

- SIS18: multi-turn-Injection (N.B. highly non-trivial, complex subject), Slow-Extraction (K.O. exciter, spill-structure, …)
- SIS100: Slow-Extraction (K.O. exciter, spill-structure, …), RF Bunch Merging and Compression
- ESR, HESR & CR: Stochastic cooling, Schottky diagnostics, …, tbd.

Generic:

- Remote DAQ of Analog Signals
  (strong impact on HKR migration/operation!)
- Facility-wide fixed-displays, facility & Machine Status (“Page One”)
- context-based monitoring of controls and accelerator Infrastructure,

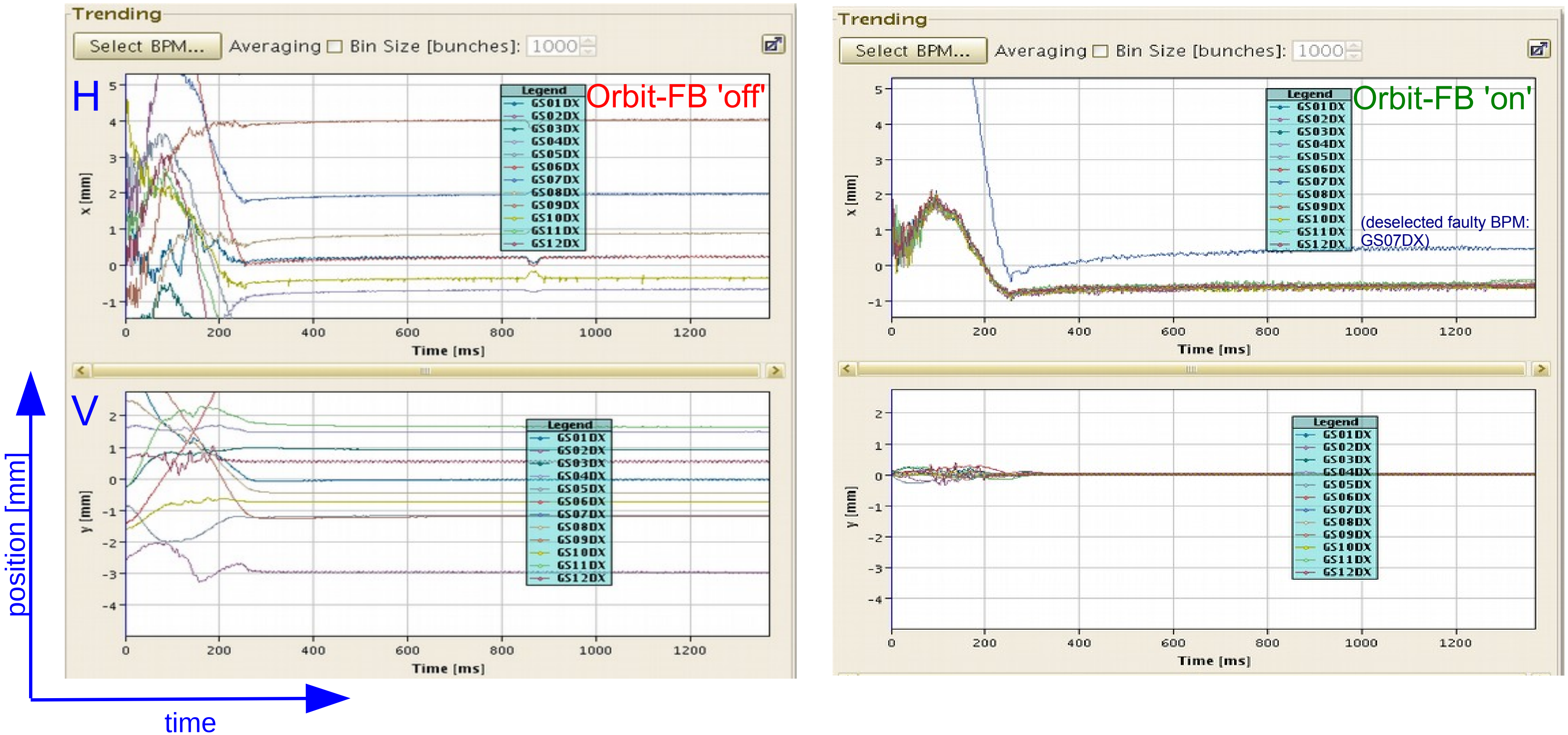
Some notes on implementation



- Real-World challenges of FB & (semi-) automation:
  (hint: usually control theory or beam physic isn't the problem)
  - not necessarily speed (ie. kHz → GHz range) – second-scale feedbacks or tools are often already quite sufficient for >90% of the problems
  - Computers are better than humans for repetitive/quantitative tasks, however: FBs are essentially only as good as
    - beam- or machine-parameter measurements they are based-upon
    - integration into the controls & operation environment and exception handling
      - interfaces, interfaces, interfaces….
      - long-term maintenance, upgrades, adaptations, ...
    - developer skills that needs to cover multiple domains: acc. HW, BI, RF, Controls, machine modelling, beam physics, …
    - overall strength depends on the reliability of the weakest link in the chain

Cycle-to-Cycle Orbit-FB Proof-of-Concept

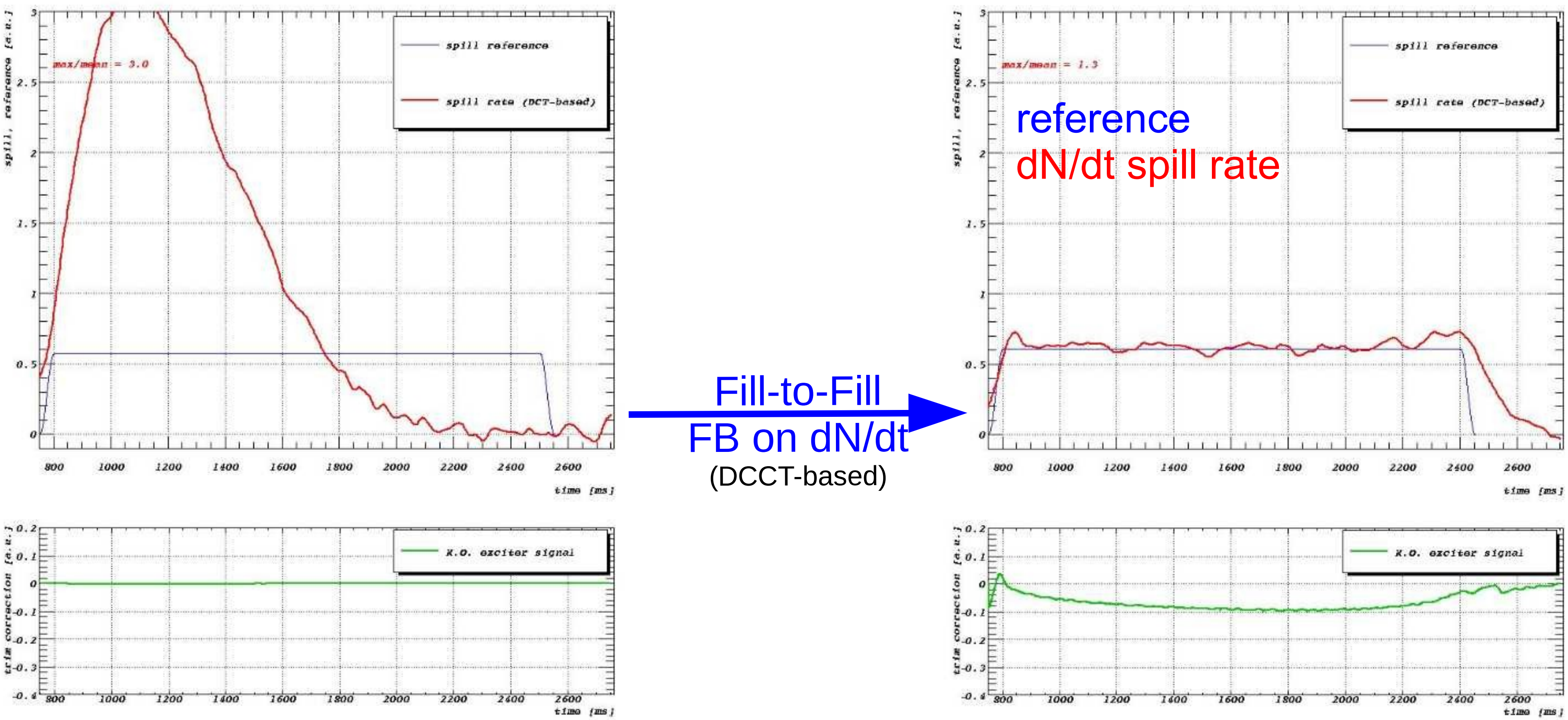
B. Schlei, H. Liebermann, R. Steinhagen



- some workarounds needed, but overall success and results look promising
  - need to follow-up: reliability, performance issues related to CO & BI + detailed integration before being put into regular operation
  - N.B. remaining horizontal oscillation due to uncorrected Δp/p mismatch → radial-loop/Energy-FB

Cycle-to-Cycle Macro-Spill-FB Proof-of-Concept

R. Steinhagen, H. Liebermann



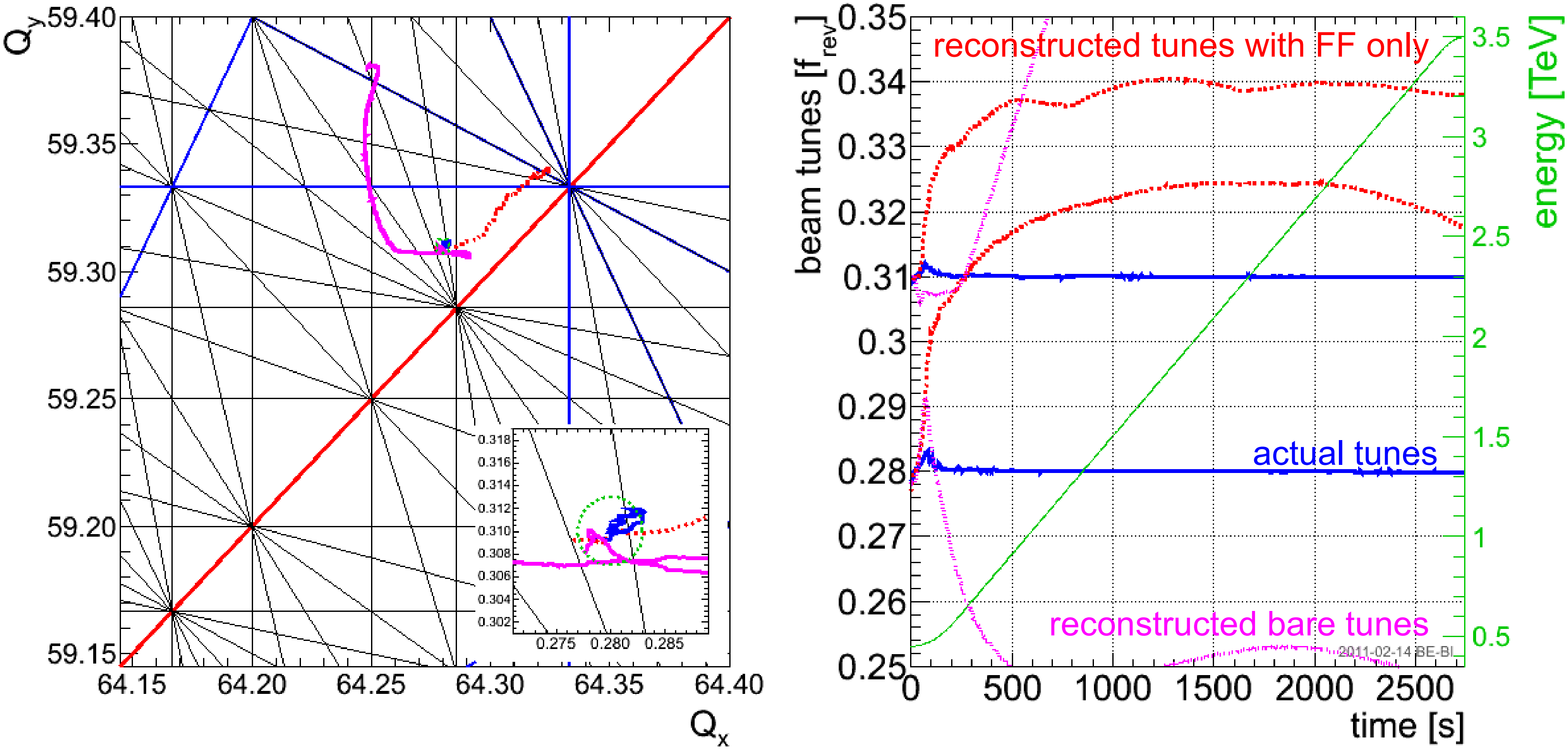
- some workarounds needed, but overall success and results look promising
  - need to follow-up: K.O. exciter power-limitation handling (easily for >10 Tm operation)
    - Alternative: FB using fast extraction quadrupole or main-quads
  - Desirable: direct FB signal from experimental detectors

animated GIF - link

Higher-Order Beam Parameter Stability

Example: LHC Tune Feedback Operation

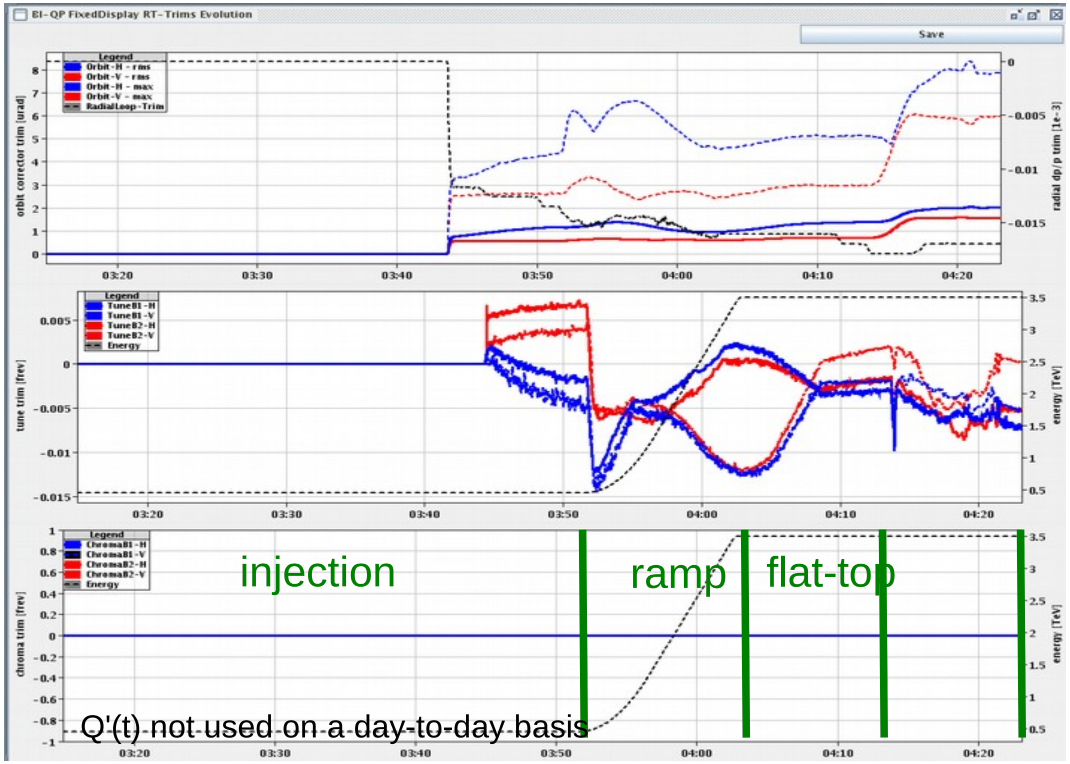
- Tune-FB driving and accelerating early commissioning in 2009-2011
  - tunes kept stable to better than 10^{-3} for most part of the ramp and squeeze
- even though perturbations were unrelated to quads, feedback helped mitigating these feed-down effects while allowing OP crews to work on other more pressing issues … (N.B. BBQ instrumentation was key-ingredient to success)



Higher-Order Beam Parameter Stability

Example: Feedback Integration and Operation at LHC

- Most accelerator facilities: stability of actual observable became secondary
- trims become de-facto standard to assess the FB and machine performance and to improve machine modelling (done off-line)



Orbit-FB & Radial-Loop Trims (µrad)

Tune-FB trims

Q'(t)-FB trims

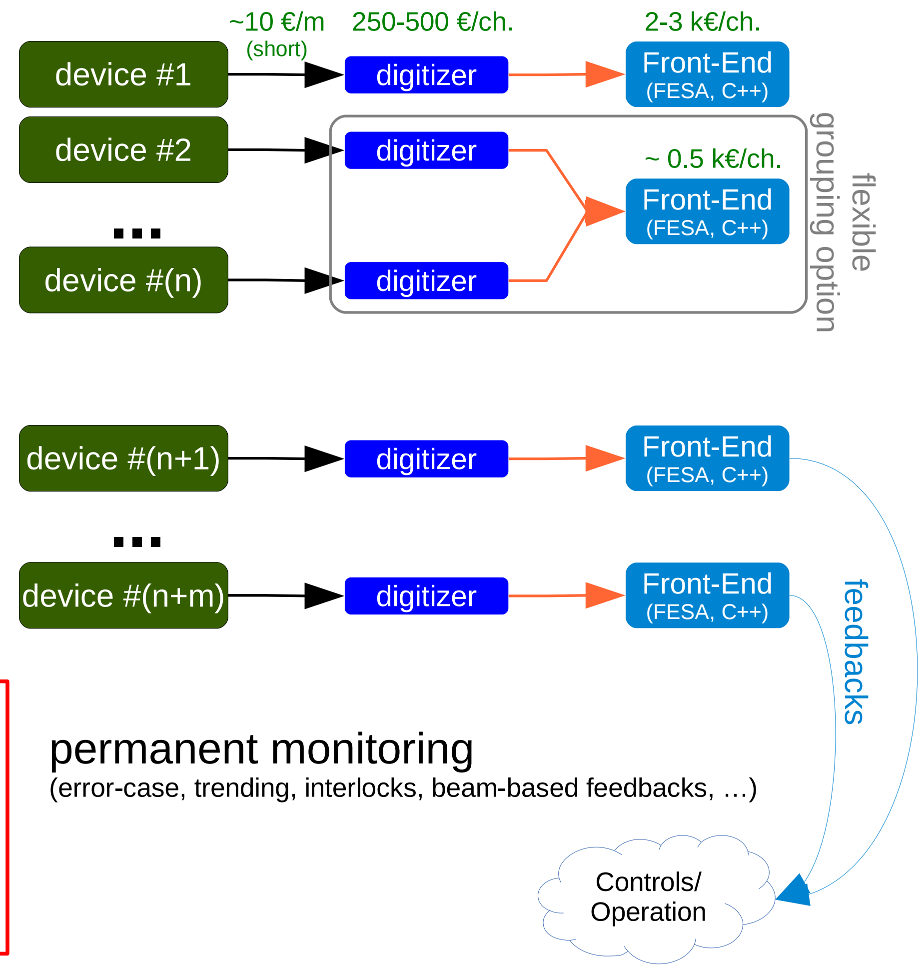
Energy (TeV)

β*-squeeze

Digitization of Analog Signals at FAIR

https://edms.cern.ch/document/1823376/

- targeted concept
  (underlying assumption: scopes/digitizers are cheap, RF switches are expensive)

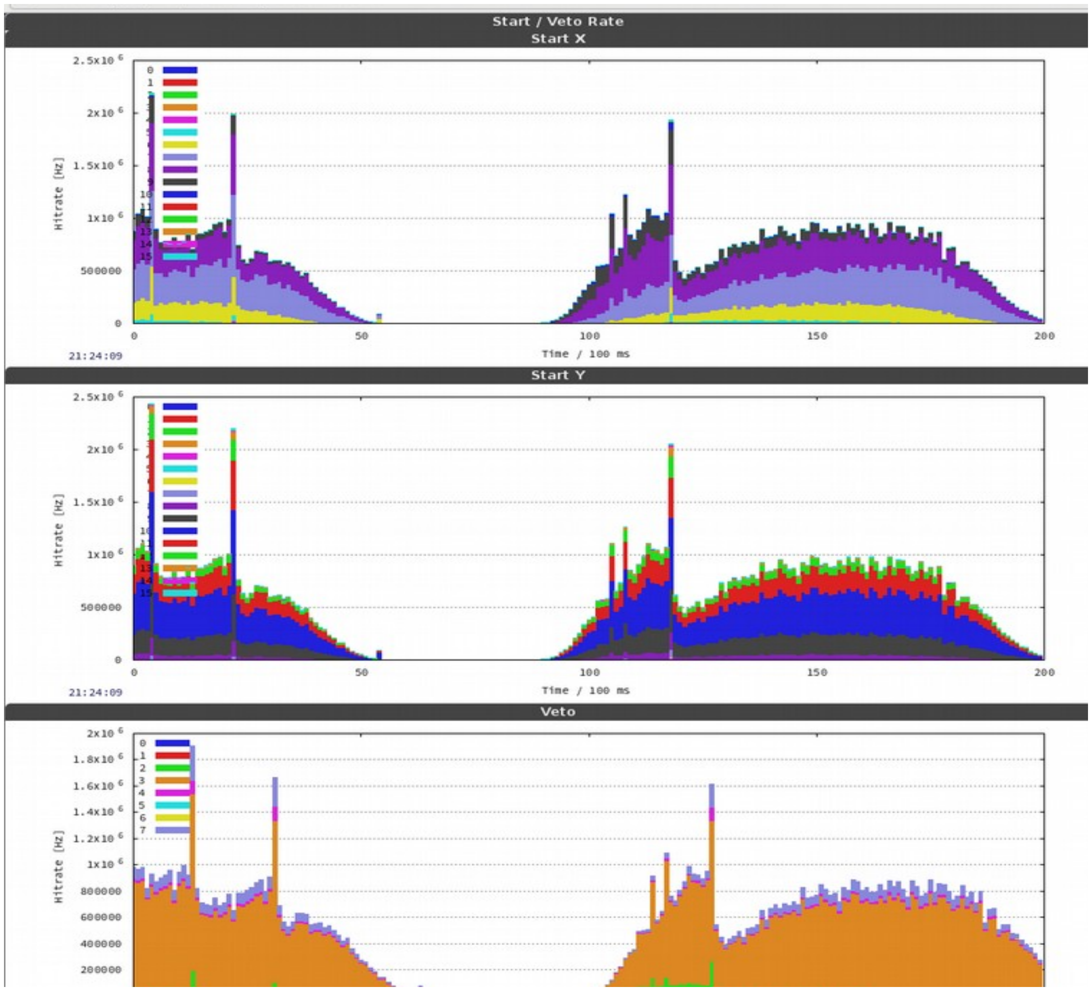


permanent monitoring
(error-case, trending, interlocks, beam-based feedbacks, …)

start deployment ≥2018 (SIS18), crucial for:
- migration to new FAIR Control Centre (FCC),
- optimisation of commissioning & operation
- automated tracking/isolation of faults (↔ post-mortem)
- less-biased performance indicator

link: more details

In a control room not so far far away...

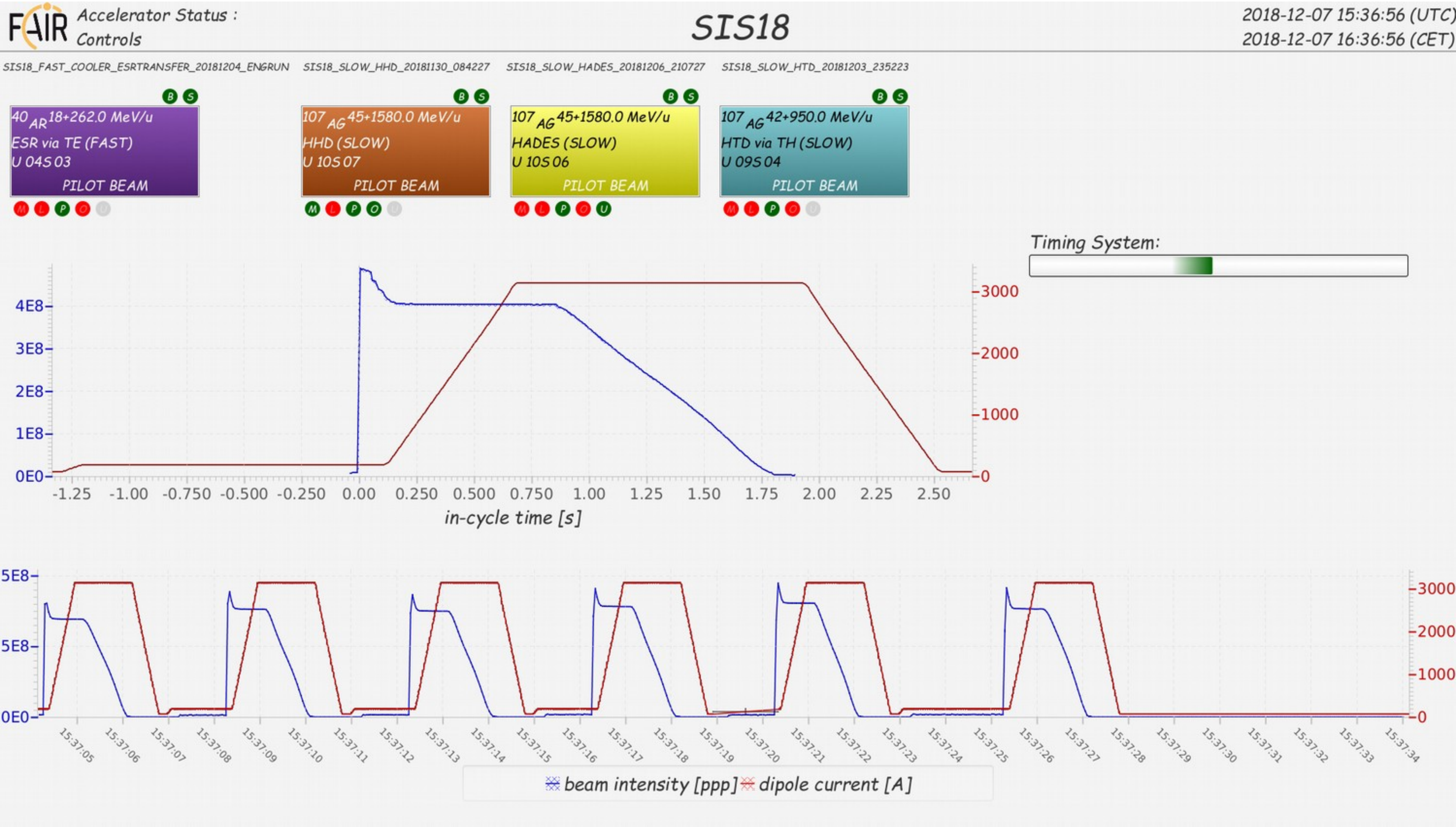


Digitizer et. al are key to monitor all critical devices that may act upon the beam!

- continuous actual-vs-reference monitoring: automatically isolate/ localise faults for rare events
- complimented by Archiving System → tracking of (especially) rare events.

Digitization of Analog Signals at FAIR

Example: SIS18 Machine Status



FAIR Archiving System

https://edms.cern.ch/document/1176039/

- *… collect and store all pertinent accelerator data centrally to facilitate the analysis and tracking of the accelerator performance as well as its proper function.*

- Combined Archiving and Post-Mortem storage concepts
- Aim at storing maximum reasonable amount of data
  - facilitates data mining (performance trends, rare failures, …)
  - key to understanding and improving accelerator performance
  - also: use feedback action to improve machine model (data mining)!

Quality Management	Document Type:	Document Number: F-DS-C-11e	Date: 2016-07-18
FAIR	Detailed Specification	Template Number: Q-FO-QM-0005	Page 1 of 24

Document Title:	**Detailed Specification of the FAIR Accelerator Control System Component "Archiving System"**
Description:	This document is the Detailed Specification of the accelerator control system component 'Archiving System'. Its task is to collect and store all pertinent accelerator data centrally to facilitate the analysis and tracking of the accelerator performance as well as its proper function.
Division/Organization:	CSCO
Field of application:	FAIR Project, existing GSI accelerator facility
Version	V 4.5

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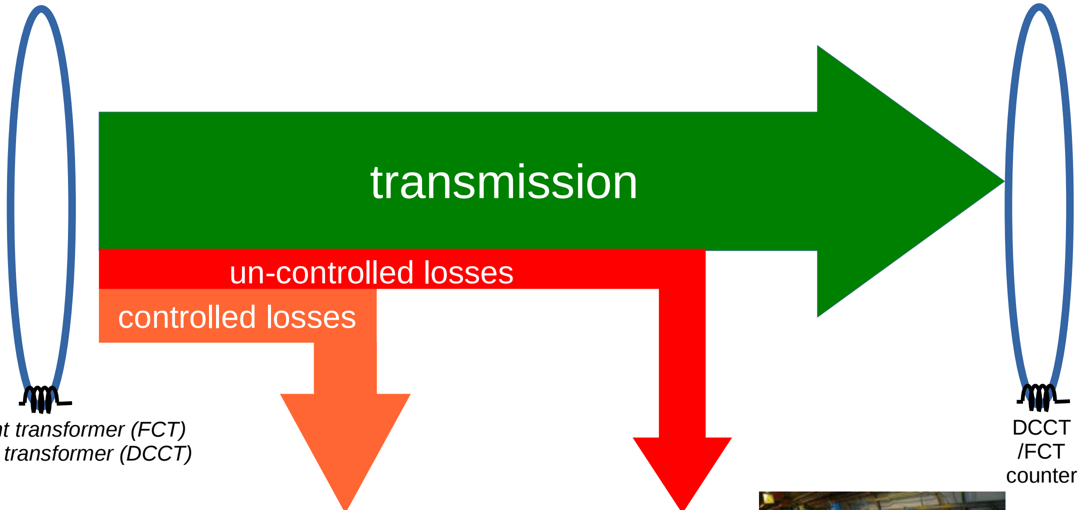
Archiving

Post-Mortem

N.B. importance: quantitative accelerator performance and bug/fault-tracking indicators

Beam Transmission Monitoring (BTM)

https://edms.cern.ch/document/1823362/



Ion-Source

$$I_{source}(t) = \frac{dN_{source}(t)}{dt}$$

Fast current transformer (FCT)
DC current transformer (DCCT)

DCCT /FCT counter

Experiment

primary (secondary)
ions-on-target/s

$$I_{target}(t) = \frac{dN_{target}(t)}{dt}$$

$$\frac{dN_{collimator}(t)}{dt}$$

dynamic vacuum, ε-blow-up/tails, slow-extraction, ...
→
cryo- & beam-halo collimators, rad-hard magnets, extra shielding, ...

less-avoidable losses
(may need to accept a given amount)

$$\frac{dN_{loss}(t)}{dt}$$

beam instabilities, aperture constraints, slow beam parameter drifts
→
activation & machine protection

avoidable losses
(ALARA: should minimise before MP & Activation limits kick in)

online dosimetry (abs. reference)

Quality Management	Document Type:	Document Number: F-CS-B-0004e	Date: 2017-04-21
FAIR	Common Specification	Template Number: Q-FO-QM-0005	Page 1 of 20

Document Title:	**Integration of Beam Current, Transmission and Life-Time Monitoring in the FAIR Accelerator Complex**
Description:	Common Specification for the definition and integration of beam intensity, beam transmission and loss measurement devices into the accelerator control system
Division/Organization:	FAIR
Field of application:	FAIR Project, existing GSI accelerator facility
Version	V 1.1

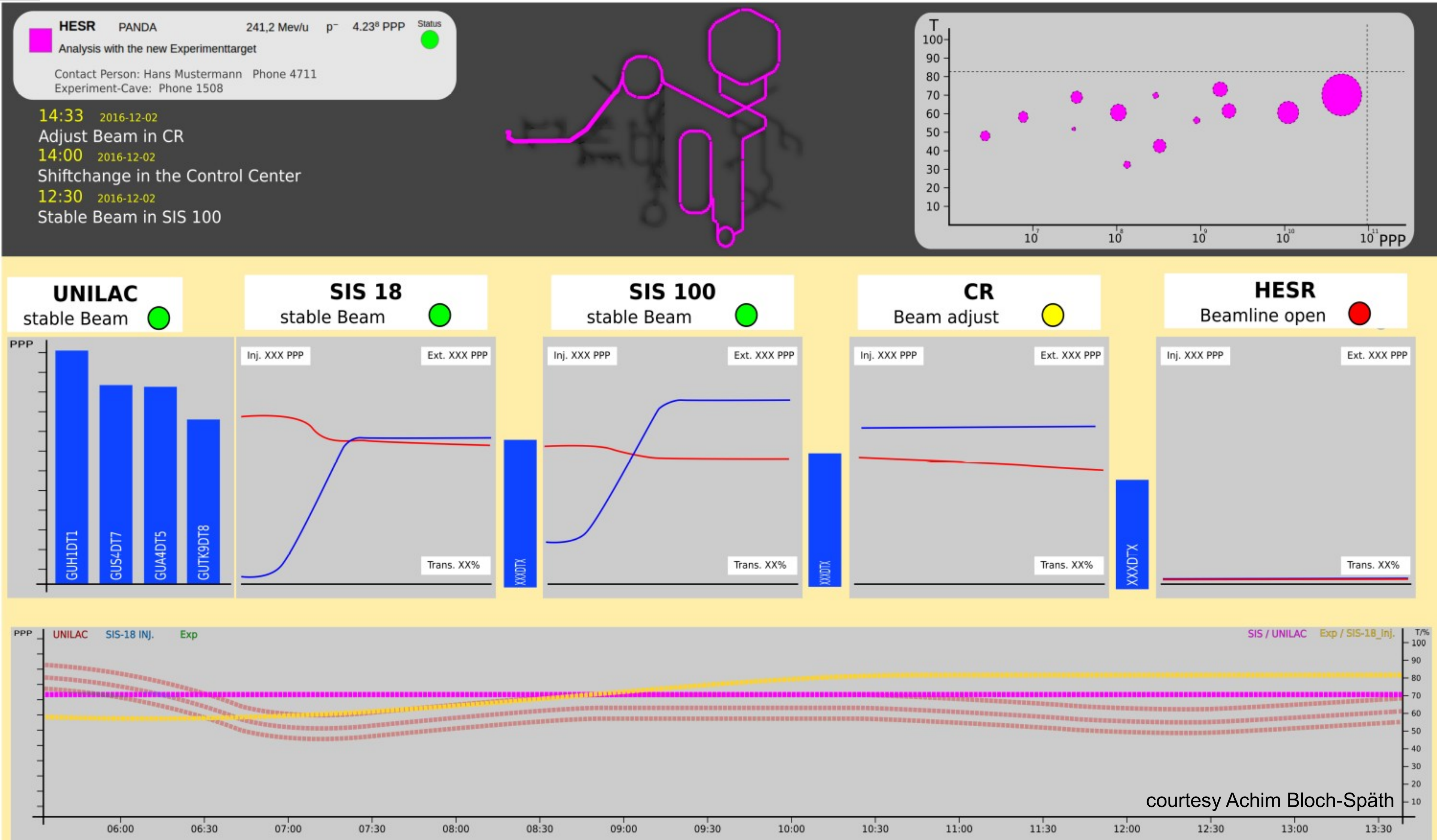
Abstract

This document presents an analysis of the expected use of the knowledge about the beam current for machine operation and studies. The beam parameters to be derived from the beam current measurement are identified and their required accuracy estimated. These requirements are converted into functional specifications for the beam diagnostics instruments. The whole spectrum of possible beams is considered as well as design constraints.

Prepared by:	Checked by:	Approved by:
J. Fitzek R. Steinhagen (FAIR Comm. & Control PL)	**FAIR-C2WG-ALL (e-group)** R. Bär (CO) A. Bloch-Späth (OP) H. Bräuning (BI) S. Heymell (Controls) T. Hoffmann (BI) S. Jülicher (Controls) F. Gressler (GA) C. Omet (SIS-100 MP) D. Ondreka (SYS) V. Rapp (Controls) H. Reeg (BI) A. Reiter (BI) P. Schütt (OP) M. Schwickert (BI) I. Lehmann (Exp. Link-Person) D. Severin (Exp. Link-Person)	P. Gerhard (UNILAC) F. Hagenbuck (HEBT) F. Herfurth (CRYRING / HITRAP) R. Hollinger (Ion Sources) K. Knie (p-Linac & p-bar Separator) I. Koop (CR) D. Prasuhn (HESR) H. Reich-Sprenger (CS) H. Simon (Super-FRS) P. Spiller (SIS-18/SIS-100) M. Steck (ESR) R. Bär (Head Controls) M. Schwickert (BI) S. Reimann (OP) R. Steinhagen (FAIR Comm. & Control PL)

§§ Radiation Permit – limits on total dose per year (facility & external)

FCC Fixed-Display & Workstation Layout
Information Density Hierarchy (↔ BTM Concept)



courtesy Achim Bloch-Späth

Sequencer Framework

Semi-automated Tests for HW and Beam Commissioning

HW and beam commissioning require efficient tools for testing

- perform initial and acceptance tests, early detection of non-conformities and faults
- perform QA and regular re-validation tests
- considering size and complexity of FAIR, and limited resources: efficient and reliable execution and documentation of tests

→ Development of a **Sequencer framework**, as a core part of the FAIR control system to aid semi-automated testing

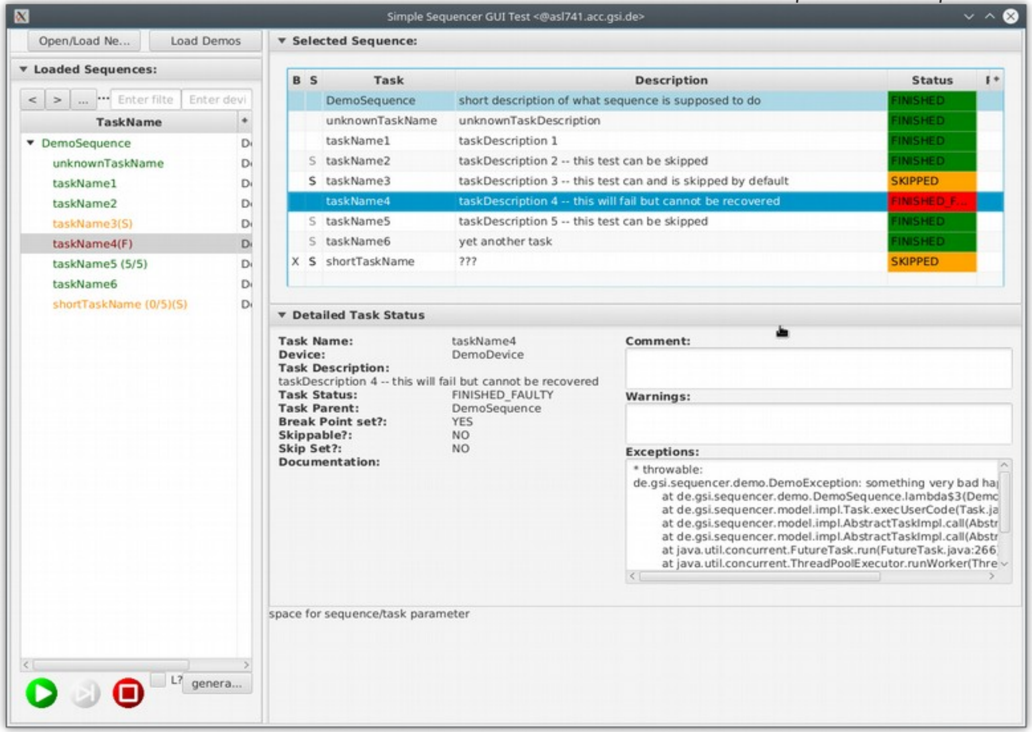
Sequencer architecture conceptually divided into:

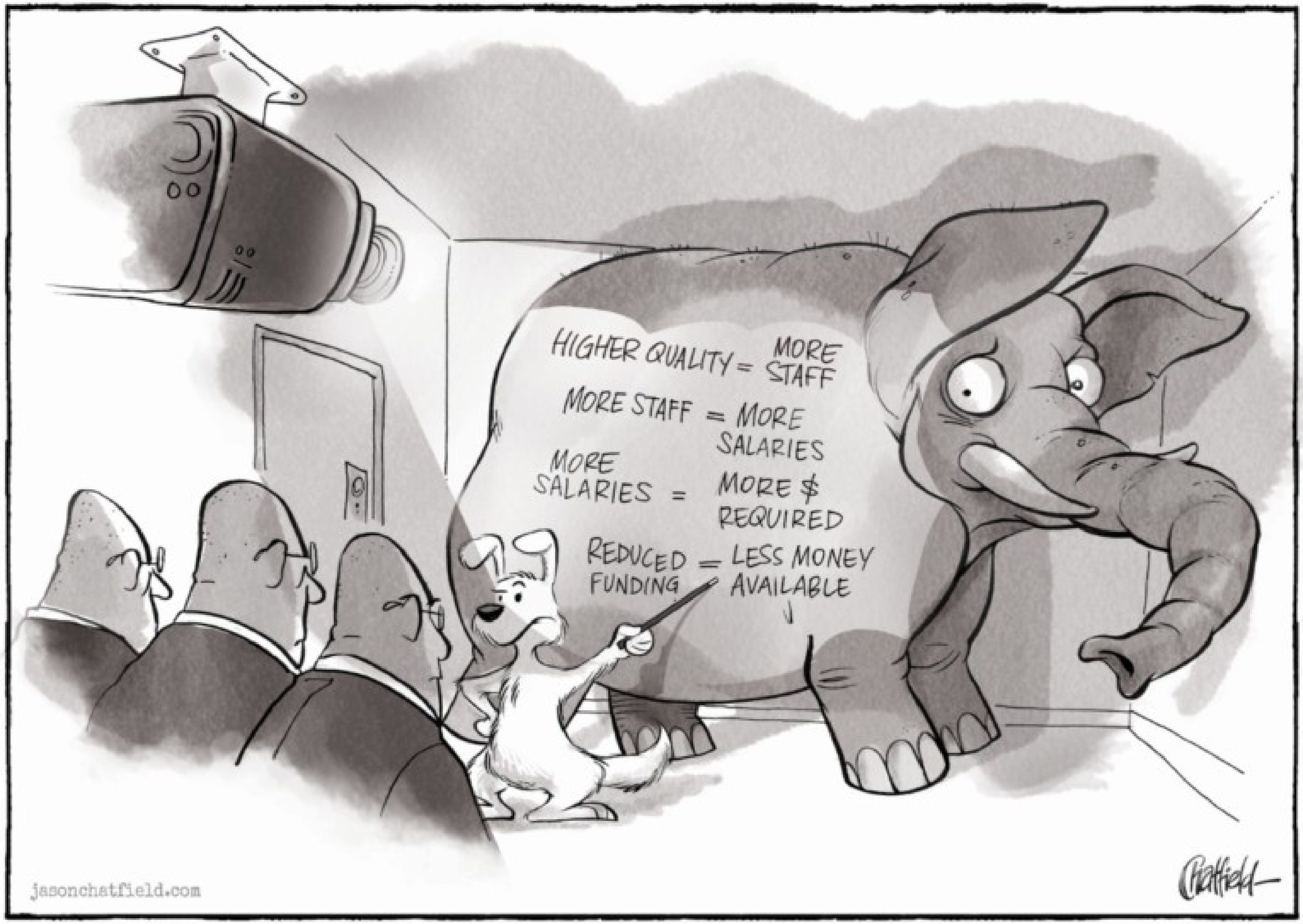
- middle-tier *sequencer service* (run sequences, generate automated reports)
- the *sequences* with a subset of *tasks* (testing steps)
- graphical user interface (GUI) program

Operational experience so far:

- was tested and used already since Dry-runs in 2017
- establish process of writing Sequencer tasks parallel to development (in progress)

Sequencer GUI impression




HIGHER QUALITY = MORE STAFF
MORE STAFF = MORE SALARIES
MORE SALARIES = MORE $ REQUIRED
REDUCED FUNDING = LESS MONEY AVAILABLE
jasonchatfield.com
Chatfield

Controls & FC²WG Topics – more than "Control System" & Data Supply

primary aim: provide tools, extensions to, and integration of the existing basic technical system to ensure a swift, efficient commissioning and control of the accelerator facility

- Facility & Interface Analysis
  - Procedures: Hardware Commissioning (HWC), HWC-'Machine Check Out', Beam Commissioning (BC), BC-Stage A (pilot beams), BC-Stage B (intensity ramp-up), BC-Stage C (nominal/production operation) Beam parameters, FAIR performance model, optimisation, Accelerator & Beam Modes
- Beam Instrumentation & Diagnostics – System Integration (into operation and controls environment)
  - Intensity (DCCTs) & beam loss (BLMs) → Beam Transmission Monitoring System (BTM), trajectory & orbit (BPMs), Q/Q', optics (LOCO & phase-advance), longitudinal & transverse emittance (FCTs, WCM, screens, IPM, etc.), Δp/p, long. bunch shape (FCTs, Tomography), abort gap monitoring, ...
- Accelerator Hardware – System Integration (into operation and controls environment)
  - Power converter, magnets, magnet model, RF, injection/extraction kicker, tune kicker/AC-dipole, beam dump, collimation/absorbers, cryogenics, vacuum, radiation monitoring, k-modulation, technical infrastructure (power, cooling/ventilation), machine-experiment interfaces
- Control System
  - Archiving system, acquisition/digitization of analog signal , test-beds, timing, bunch-to-bucket transfer, cyber security, role-based-access, middleware, real-time & cycle-to-cycle feedbacks, daemons
- Components
  - post-mortem, management of critical settings (safe-beam settings), machine protection, interlocks, beam quality checks, daemons, 'facility status display', aperture model, ...
- Applications
  - Sequencer (semi-automated test/commissioning procedures), fixed-displays, ...
  - Beam-Based Applications & GUIs

topic started
topic active
topic not started

Control System Architecture Stack

Not exhaustive...

Presentation Tier

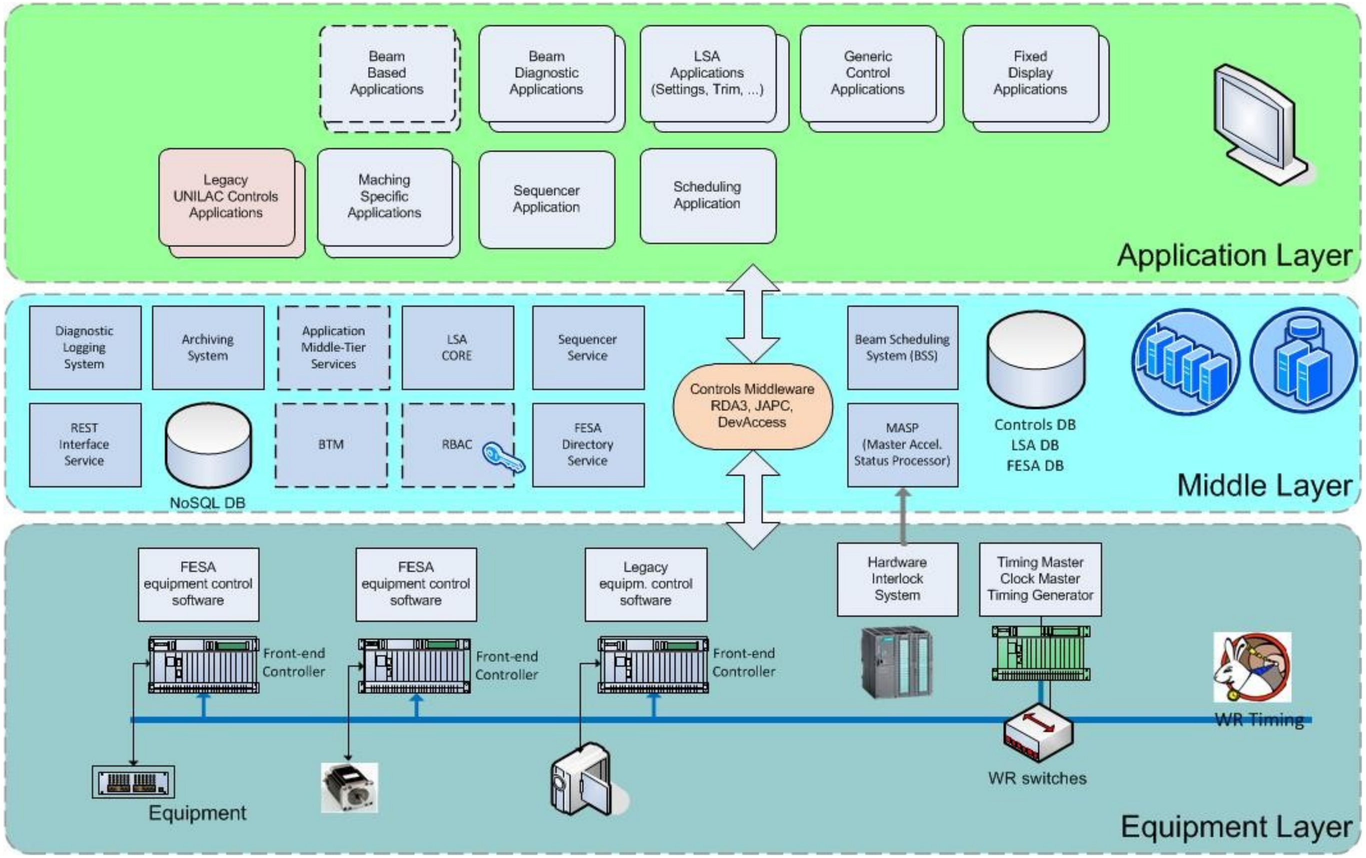
JavaFx
JAVA Swing

Middle Tier
powerful servers

Java

Resource Tier
FESA

C++
VHDL



python
Qt ???

Linux
ØMQ

- Standard 3 tier model; distributed OO system
- Modular design with well defined interfaces

Topics vs. Resources & Staging

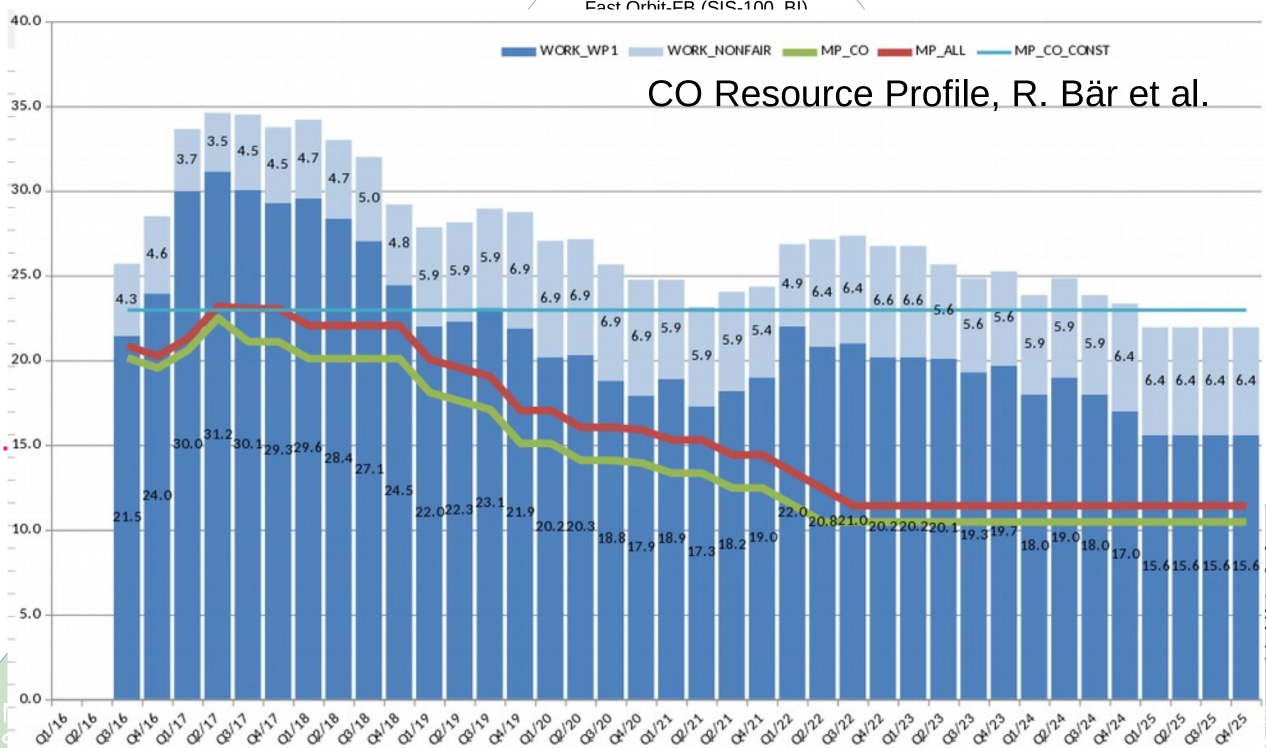
R. Bär & R. Steinhagen

topic started
topic active
topic not started

...
BC-Stage B,
BC-Stage C,
Machine Availability Anlysis, adv. beam parameters optimisation, FAIR performance model, optimisation, Fast Orbit-FB (SIS-100, BI)

FC²: 105 person-years (missing)

2025



ACO: 203 person-years

),
,
6):
plication,
Schottky,
al Settings
(MCS ... s, Web Facility Overview ("Page-1"), Web Developments, Fixed Displays, MASP GUI, Beam Requestor GUI, Archiving GUI, Fast Beam Abort, Post Mortem Analysis, Monitoring GUI, IonSource GUI, BTM GUI

Control System Effort & Cost Comparison

GSI/FAIR ↔ CERN (COCOMO II -based)

GSI/FAIR

Total: 3.2 MSLOCs

language:	SLOCS
java:	1236810 (38.38%)
cpp:	990110 (30.73%)
ansic:	492459 (15.28%)
f90:	160651 (4.99%)
python:	159864 (4.96%)
sh:	74152 (2.30%)
fortran:	49298 (1.53%)
asm:	30226 (0.94%)
php:	17493 (0.54%)
pascal:	7662 (0.24%)
ada:	1177 (0.04%)
yacc:	1113 (0.03%)
perl:	917 (0.03%)
tcl:	285 (0.01%)
awk:	105 (0.00%)

legacy systems → f90

CERN

Min: 12.0 MSLOCs

language:	SLOCS
java:	8618862 (71.80%)
cpp:	2592078 (21.59%)
ansic:	558217 (4.65%)
python:	129853 (1.08%)
sh:	53927 (0.45%)
ada:	14382 (0.12%)
perl:	13609 (0.11%)
php:	12506 (0.10%)
cs:	3556 (0.03%)
ml:	2052 (0.02%)
tcl:	1780 (0.01%)
jsp:	1302 (0.01%)
csh:	968 (0.01%)
yacc:	959 (0.01%)
awk:	328 (0.00%)
exp:	281 (0.00%)
fortran:	72 (0.00%)
sed:	11 (0.00%)
ruby:	7 (0.00%)

N.B. here:

SLOCS	total physical Source Lines of Code
FTE	person-year (Full-Time-Equivalent) according to COCOMO (II)

costs intern:
1 FTE = average salary = 50 kEUR/year (overhead = 2.40)
costs extern:
1 FTE = average salary = 160 kEUR/year (overhead > 2.40)

generated using David A. Wheeler's 'SLOCCount'.

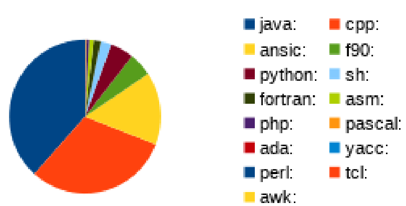
Development Effort Estimate

	GSI/FAIR	CERN
Development Effort Estimate	871 FTEs	3320 FTEs
Total Estimated Cost to Develop	104 MEUR	395 MEUR

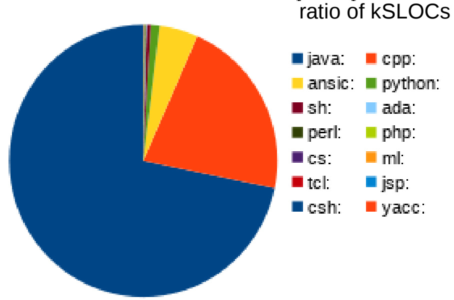
N.B. FTEs are very rough estimates with large error bars for a project of this size… !!

→ in-lack of better tools at least qualitative scaling, relations and order of magnitude seems reasonable

GSI code base (SVN) ratio of kSLOCs



CERN code base (SVN) ratio of kSLOCs



FAIR Control Centre (FCC)

https://edms.cern.ch/document/1821654/

Requirements & Conceptual Design – primary goals:

- provide sufficient room for the operation of the existing and enlarged GSI/FAIR facility
  - includes control of technical infrastructure, cryogenics, and storage-ring experiments or those tightly interwined with acclerator operation
- ergonomics: Main Control Room should not “get in the way of it’s primary function”
  - establish functional relationships between MCR & ancillary rooms
  - validate/check w.r.t. FAIR Commissioning & Control concept
  - validate/check whether input for building planner is feasible and consistent with DIN/ISO norms
- Keep within set budget

Quality Management	Document Type	Document Number: F-CS-B-0002e	Date: 2017-06-21
FAIR	Common Specification	Template Number: Q-FO-QM-0005	Page 1 of 25

Document Title:	**Common Specification for the FAIR Control Centre in view of Commissioning, Operation, and operational Exploitation of the FAIR Accelerator Facility**
Description:	Functional requirements, ergonomics, and design of the FAIR Control Centre (FCC) covering: FCC Main Control Room (MCR), MCR-related meeting and conference rooms, visitor's gallery, and ancillary infrastructure.
Division/Organization:	FAIR/GSI
Field of application:	FAIR Project, existing GSI accelerator facility
Version	V 1.1

Abstract

This document describes the user-level functional requirements, ergonomics considerations, and derived design of the FAIR Control Centre (FCC) from an accelerator commissioning, operation, and operational exploitation point of view, including experiments that are tightly intertwined with accelerator operation. This specification builds upon best practises and operational experiences with similar, existing accelerator infrastructures at GSI, CERN and other large international laboratories, and summarises the present user-community understanding, discussions and ergonomics in view of the future operation of FAIR. This document extends, combines, and supersedes previous FAIR specifications F-DS-C-21e and F-DS-C-22e.

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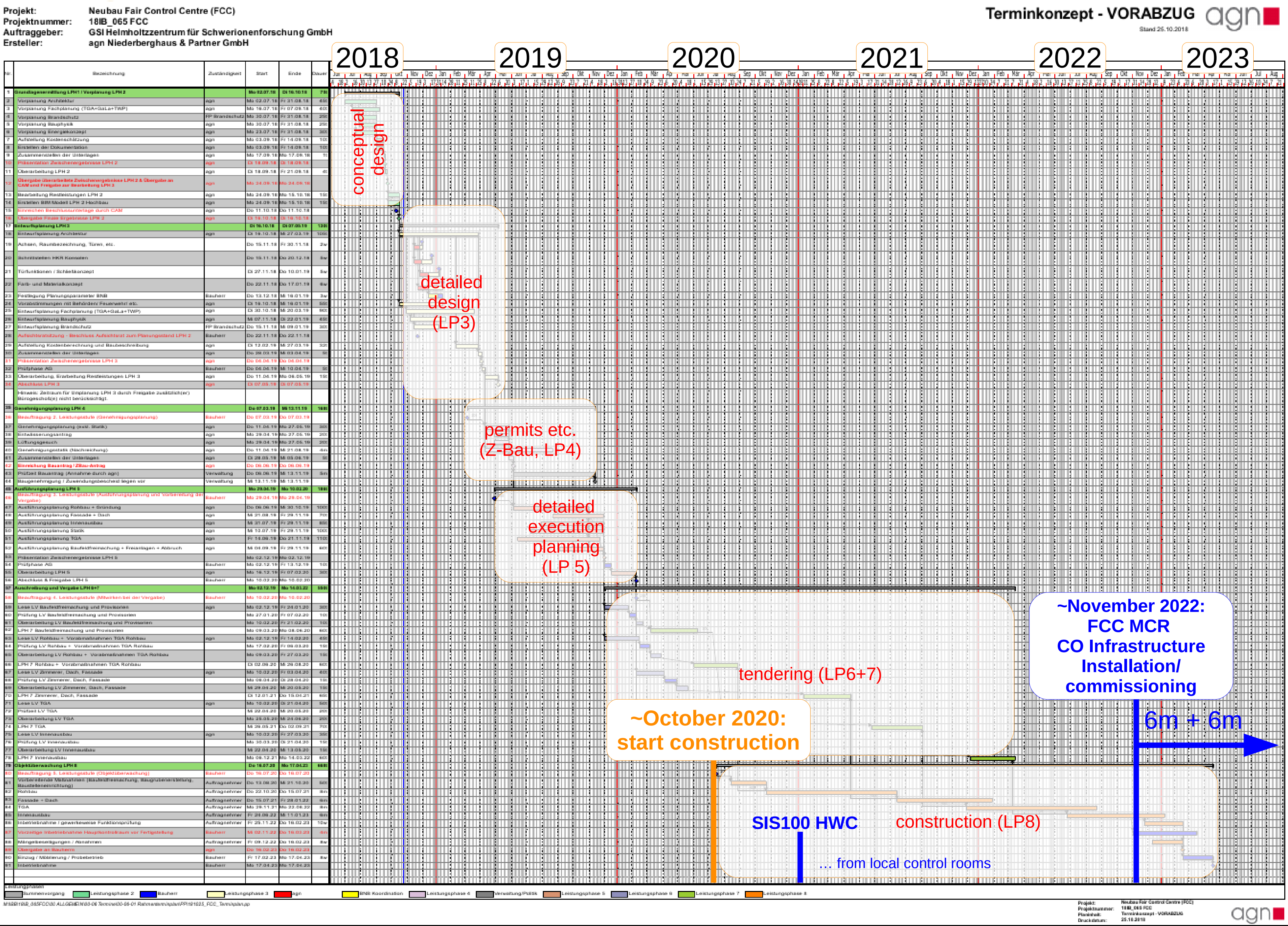
FCC estimated “ready” for HWC starting 2022 (+ backup option)

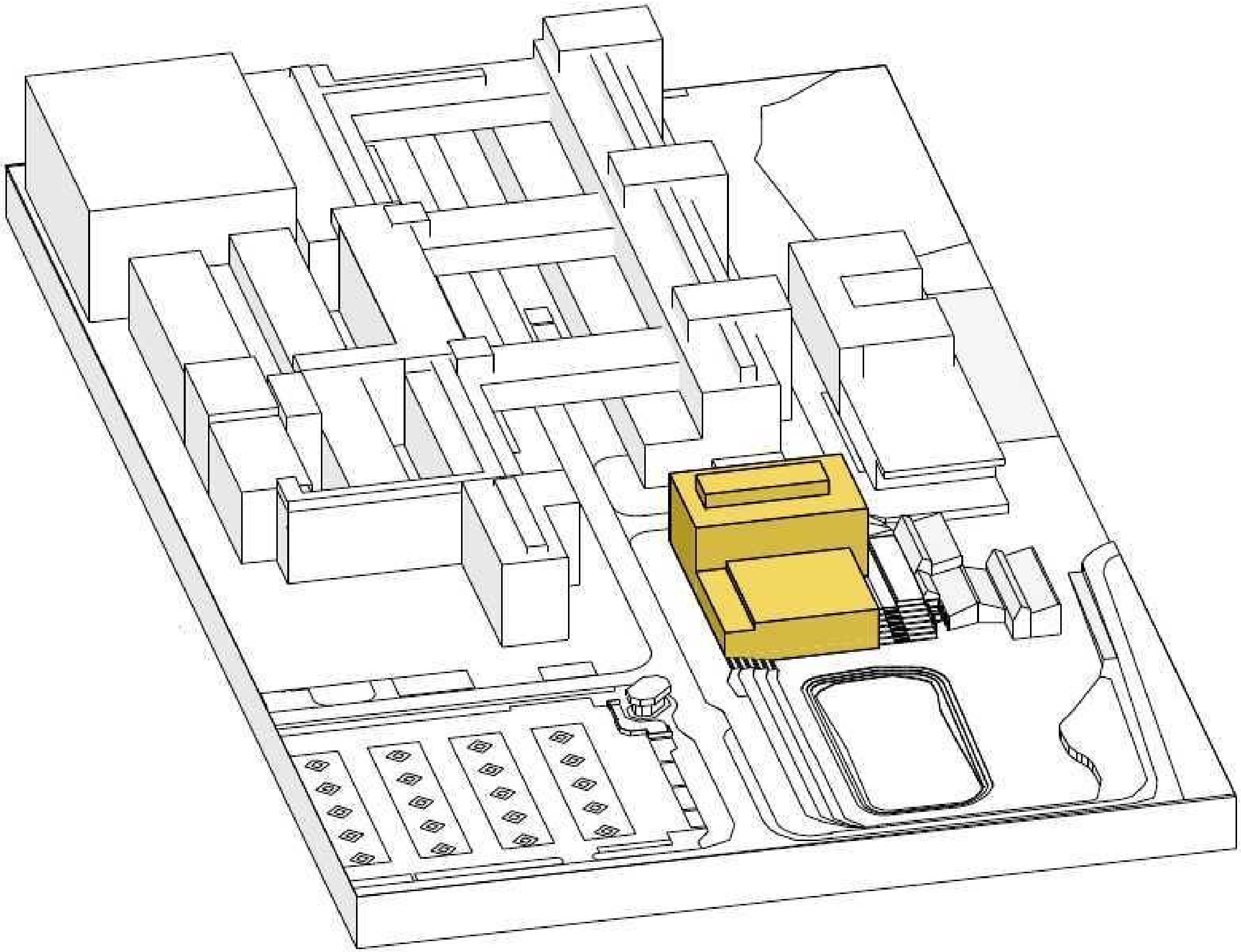
Open issues:

- OP-readiness (notably UNILAC) to move to new FCC building


Projekt: Neubau Fair Control Centre (FCC)
Projektnummer: 18IB_065 FCC
Auftraggeber: GSI Helmholtzzentrum für Schwerionenforschung GmbH
Ersteller: agn Niederberghaus & Partner GmbH
Terminkonzept - VORABZUG
Stand 25.10.2018
agn
2018
2019
2020
2021
2022
2023
conceptual design
detailed design (LP3)
permits etc. (Z-Bau, LP4)
detailed execution planning (LP 5)
tendering (LP6+7)
~October 2020: start construction
~November 2022: FCC MCR CO Infrastructure Installation/ commissioning
6m + 6m
SIS100 HWC
construction (LP8)
… from local control rooms

FAIR Control Centre (FCC)

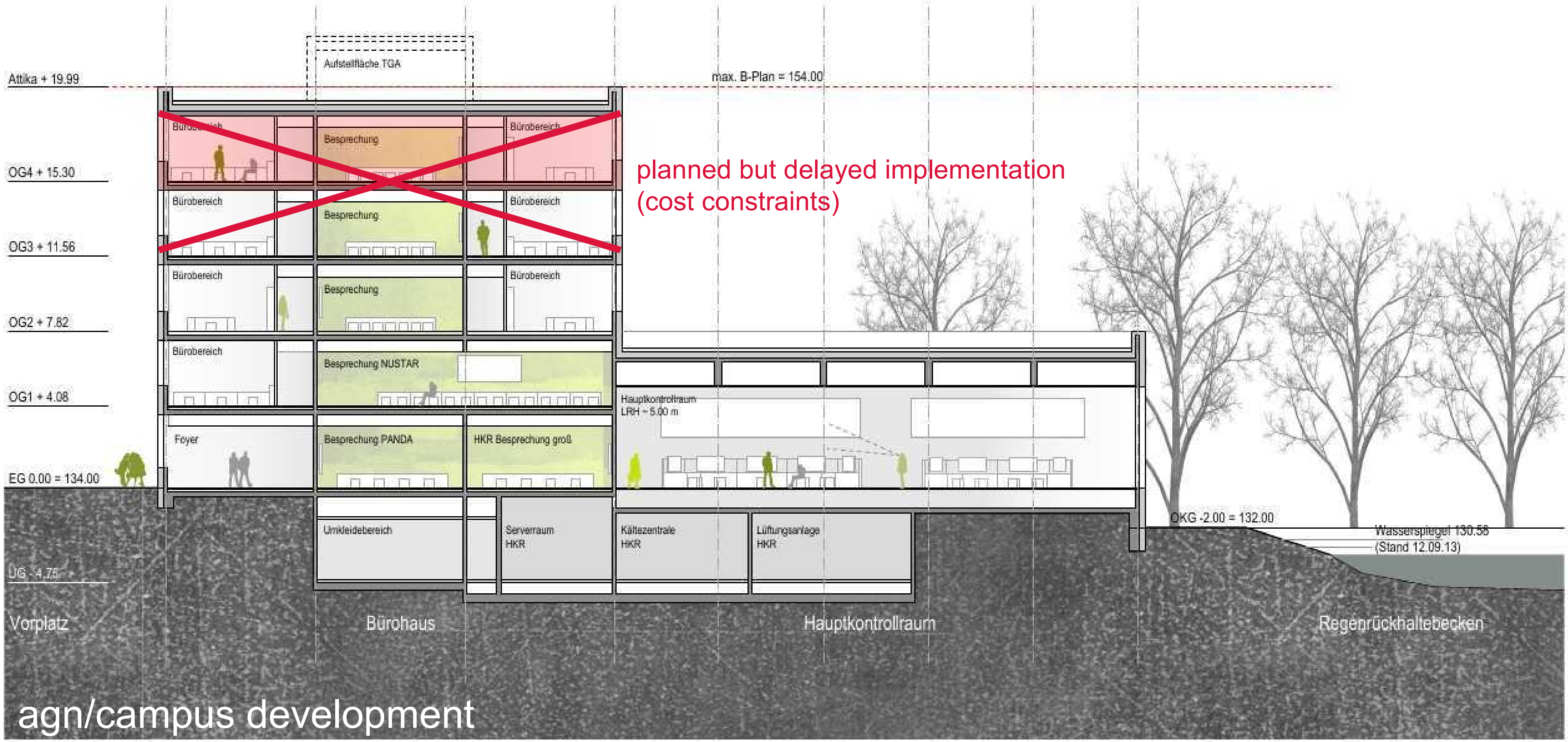
LPh2/3 concept



FAIR Control Centre (FCC)

LPh2/3 concept

FAIR Control Centre (FCC)



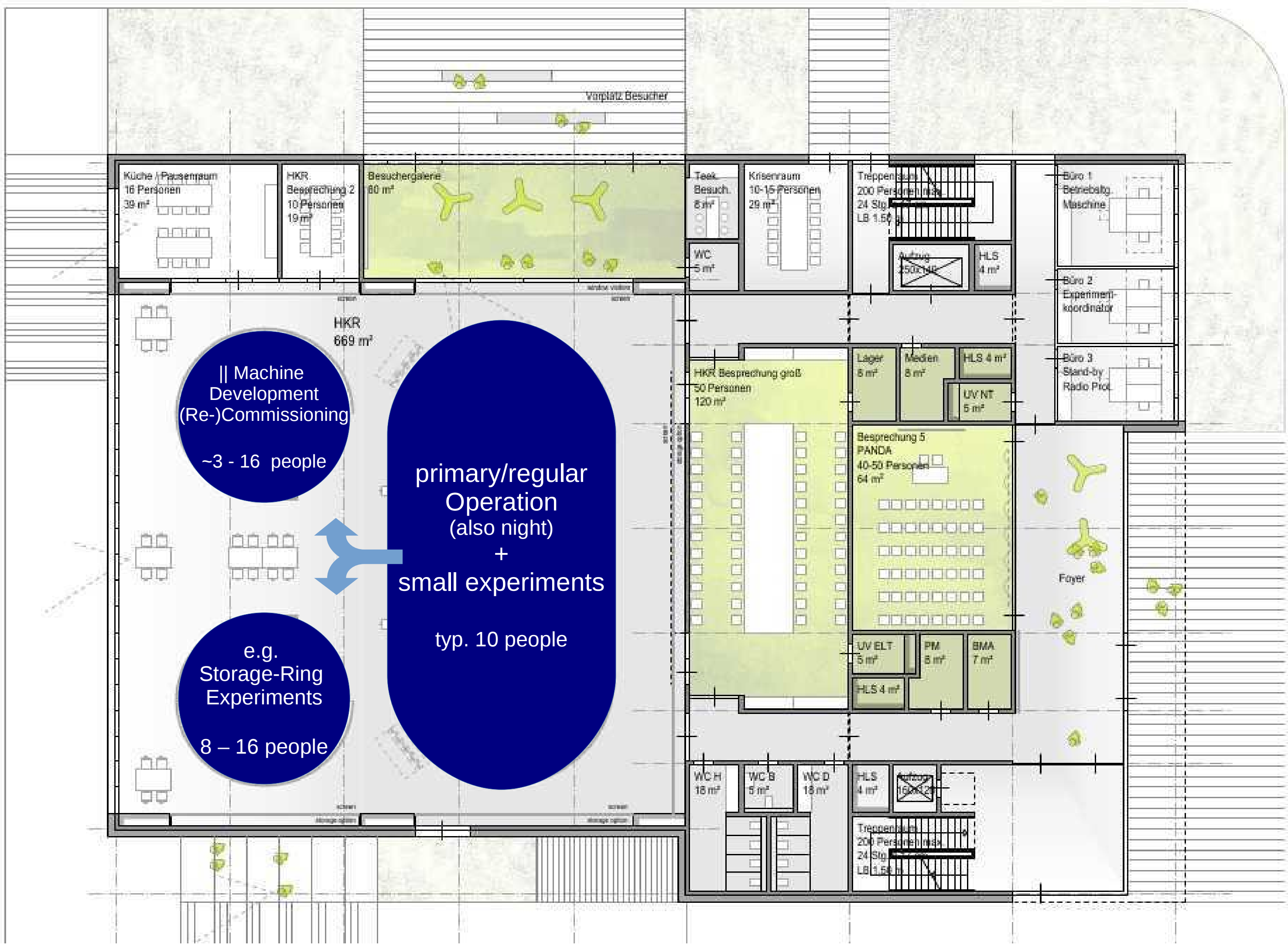
FAIR Control Centre (FCC)

Architectural View/Context I/II

FAIR Control Centre (FCC)
Architectural View/Context II/II

FCC Main Control Room Floor

… work in progress

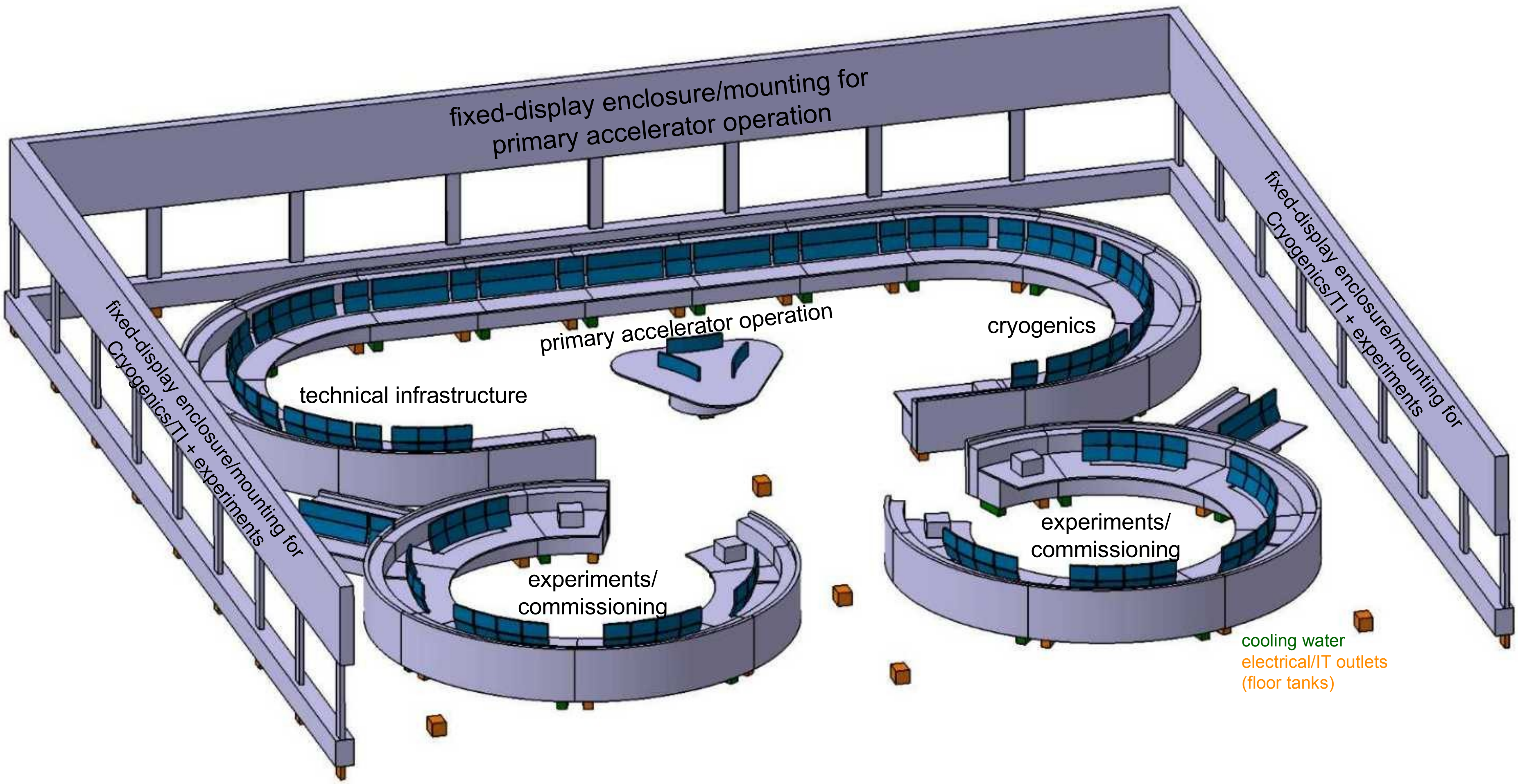


FCC Primary-User Concept
Main Control Room – Interior View (100° view angle)

FCC Primary-User Concept
Main Control Room – Visitor View #1

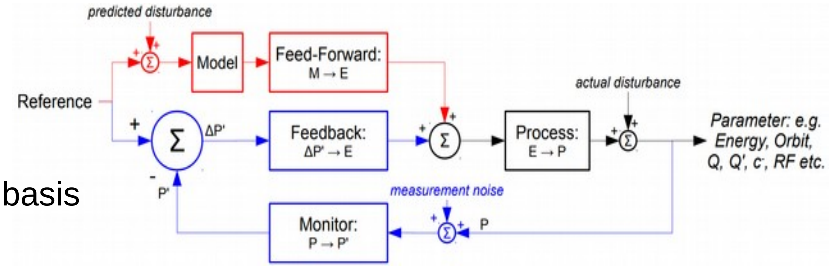
FAIR Control Centre (FCC)

Mechanical Console and Fixed-Display Pre-Design



David See et al.

Summary



- FAIR ~4x the size of GSI,
  - non-linear operational complexity increase $O(n^2) \rightarrow O(n^5)$
  - 5-7 parallel experiments + typically lasting only 4-5 days
    → world-wide unique requirement: reconfigure facility on a daily basis
  - new challenges w.r.t. GSI:
    - x10-100 higher intensities, x10 higher energies
      → machine protection & losses/activation become an important issue
    - high-intensity and higher-order feed-down effects require machine and beam parameter control on the sub-percent level
      →beyond static feed-forward (open-loop) machine modelling and machine reproducibility
    - have to be able to operate FAIR with reduced OP skeleton crew of ~5-6 operators → minimise unnecessary stress on crews

- Beam-Based feedbacks and (semi-)automated setup tools are key ingredient for efficient operation and commissioning → optimise and automise routine task so that OP talents are utilised/focused on more important tasks that cannot be automated
  - actual-vs-reference monitoring system → identify, localise and fix failures/near-misses as early as possible
  - classic beam-based feedbacks → monitor and maintain tight parameter tolerances
  - semi-automated setup tools → improve facility turn-around and setup times
  - Sequencer to automate tasks not yet covered by other tools → saves on tedious revalidation and conformity checks

- Real-World challenges of feedbacks & (semi-) automation
  - not necessarily speed – FB & tools operating on second-scales already quite sufficient for >90% of the problems
  - Computers are better than humans for repetitive/quantitative tasks but overall strength depends on the reliability of the weakest link in the chain (instrumentation, integration into controls/OPs, developer, ...)

FAIR, can we do it?

Yes, we can!

Thank You!

Accelerator Controls Commonalties/Differences GSI/FAIR ↔ CERN

	GSI/FAIR	CERN
vertical/horizontal controls integration:	• ACO (alone) bears full responsibility for controls core infrastructure, vertical and horizontal integration • notable exception: BI & partially: Ring-RF	• Equip. groups responsible for vertical HW & SW integration • CO responsible for controls core infrastructure and some lateral systems (timing, LSA, Oasis, Alarms, ...) • OP et al. heavily involved in horizontal integration & control room apps development
settings supply (LSA-based)	• Beam-Production-Chain, Pattern and flexible Beam-Process- & Timing concepts → different lab-specific implementations	• Super-Cycle, Hypercycle & semi-static Timing concepts → different lab-specific implementations
control room visualisations/tools:	• only few (legacy-type) Java/Swing dependencies • JavaFX as primary workhorse for applications • strong Java/C++ community • very small Python community (↔serious maintenance issues) • evaluating: C++/Qt & WebAssembly	• massively invested into Java & Swing (500+ apps) • custom web-based technologies/tools • JavaFX projects now frozen → discontinued • strong Java & Python community • evaluating: Python/Qt & WebAssembly
controls code base	3.2 Million SLOCs • ~10% to be replaced legacy	• 12 Million SLOCs
application devs outside controls:	• only a few CO-type devs outside ACO: 3 BI, 2 SYS, 3 OP (beginner) ACO: 2 (+1) JavaFX + 2 Java-Swing-only devs • 1 web-based app developer (OP)	• est. total: > 100 FTEs (BE-BI, BE-CO, BE-ICS, BE-OP, BE-RF, BE-ABP, ...) • producing the bulk of useful (often rapid-prototyped) tools • second-job of many operators and EICs • nearly all groups have their own SW section with their application developer
experiment client composition:	• vast majority running less than a week • require (presently) typically 1-2 days to setup	• long-running experiments (weeks … months, ie. @ LHC) • less overhead w.r.t. machine setup vs. beam-on-target
accelerator operation:	• GSI: pool of about 20 operator (2-3 Ops/shift) • FAIR: 5-6 acc. Ops/shift + 1-2 Cryo-/TI-Ops/shift • very-low degree of automation: predominantly manual tuning based on analog hardware	pool of about 90+ operators/EICs (+ Cryo/TI Ops) • high degree of automation, beam-based tools, modular system design, …