FAIR Commissioning & Control WG

3-Year Status, Strategy & Concepts

(more details at: https://fair-wiki.gsi.de/FC2WG)

Ralph J. Steinhagen, S. Reimann for the FC²WG

FAIR Figure of Merit

- Integrated luminosity/particle flux per experiment

$$\frac{\int \mathscr{L}(t)\ \mathrm{dt}}{\left[\int \mathscr{L}\ \mathrm{dt}\right]_{\mathrm{ref}}} \sim \int_{\mathrm{OP\ year}} \frac{dN_{\mathrm{ions}}/dt}{\epsilon_{\mathrm{x,y,s}}} \cdot \varepsilon_{\mathrm{FAIR}}\ \mathrm{dt}$$

Experiment constraints:

- dN_{ions}/dt constant (spill-structure)
- $dN_{ions}/dt|_{max}$ constraints
- ...
- beam brightness: N_{ions} & $\varepsilon_{x,y,s}$
  - x 10-100 higher intensities N_{ions}
  - x 10 beam energies

    → **new:**
  - machine protection
  - activation/loss minimisation (ALARA)

FAIR efficiency (simplified):

$$\varepsilon_{\mathrm{FAIR}} \approx \frac{\langle t_{\mathrm{physics}} \rangle}{\langle t_{\mathrm{physics}} \rangle + \langle t_{\mathrm{operation}} \rangle + \langle t_{\mathrm{down\text{-}time}} \rangle}$$

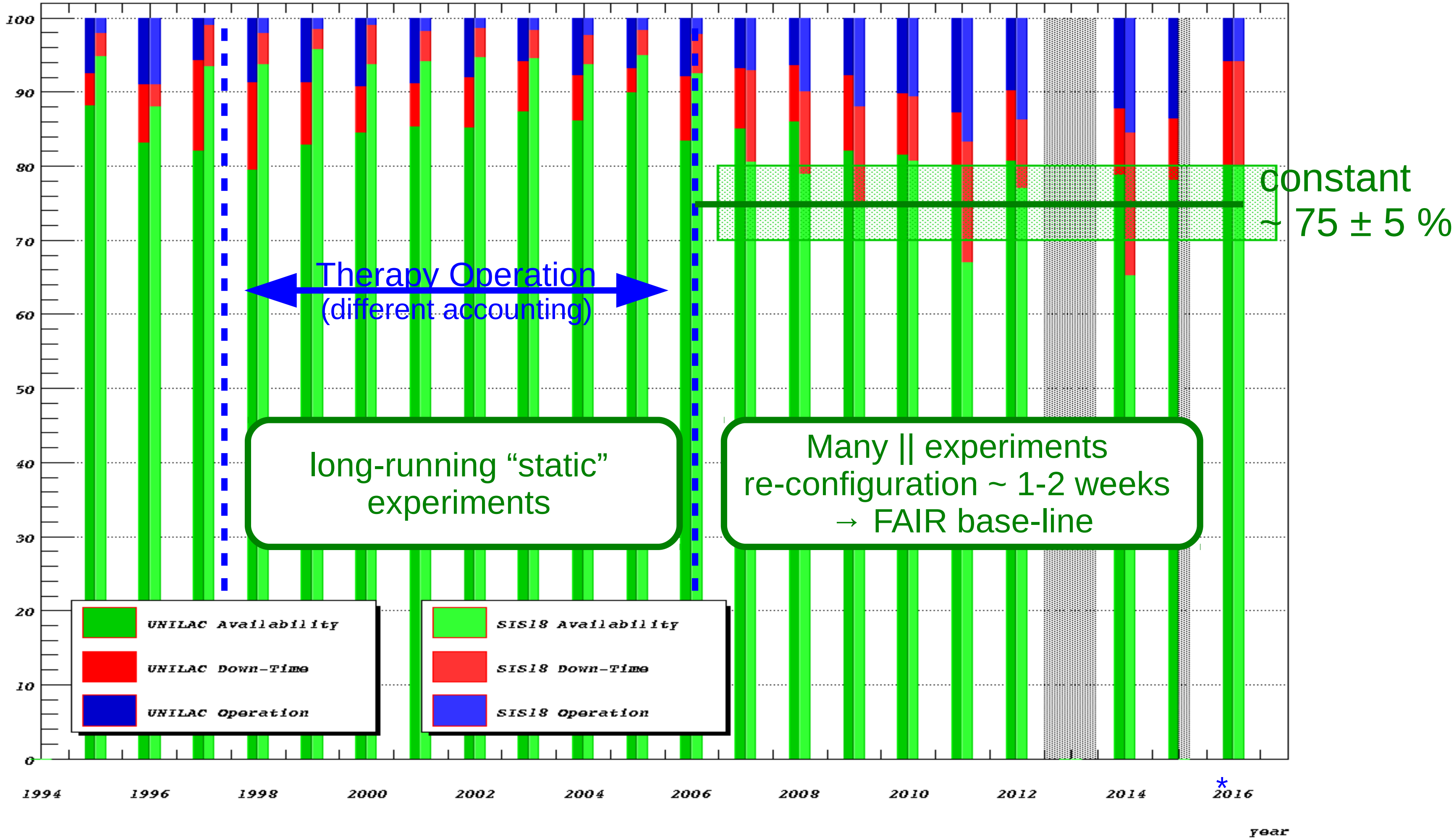
Primary FC²WG goals:

1. efficient operation
2. better & safe beam control

… across the whole accelerator facility

Accelerator Experience & Efficiency

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

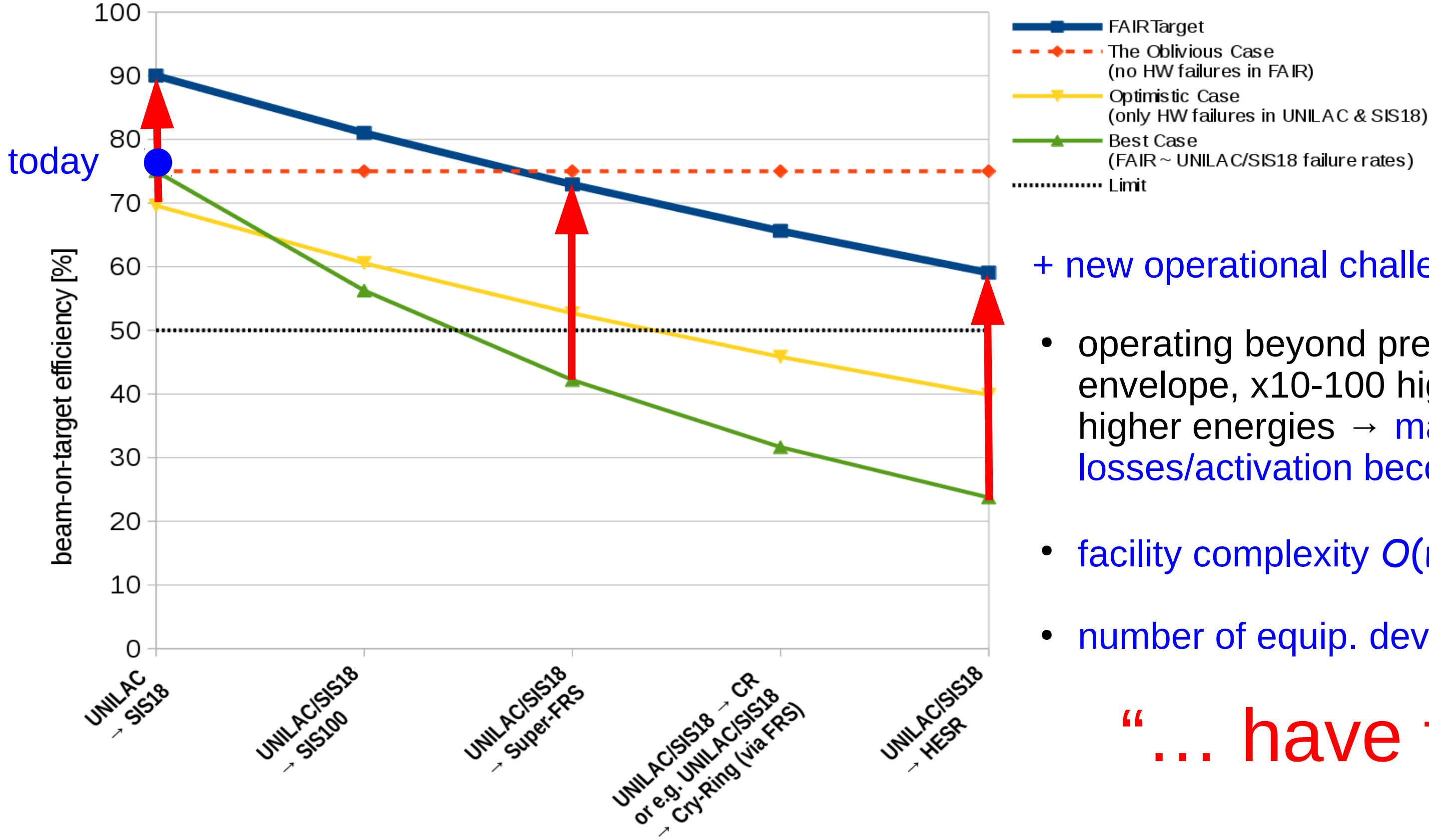


Based on: U. Scheeler, S. Reimann, P. Schütt et al., “Accelerator Operation Report”, GSI Annual Scientific Reports 1992 – 2015 + 2016 (D. Severin)
https://www.gsi.de/en/work/research/library_documentation/gsi_scientific_reports.htm
N.B. ion source exchanges are factored out from UNILAC & SIS18 data (~ 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

- 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 for FAIR:

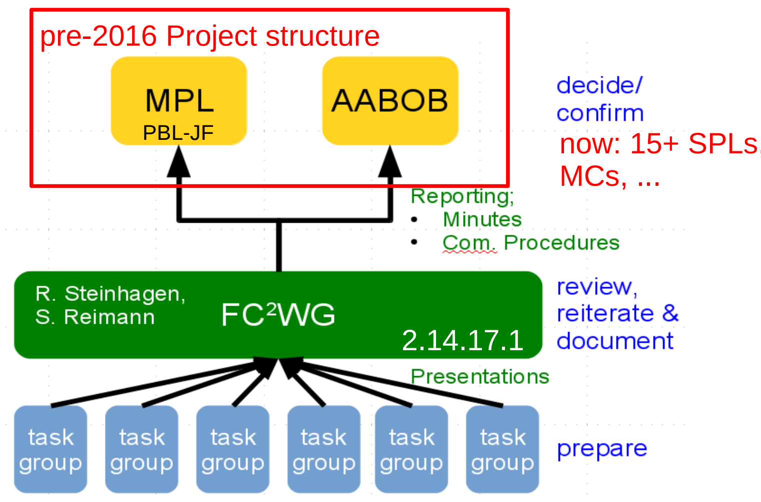
- operating beyond present beam parameter envelope, x10-100 higher intensities, x10 higher energies → machine protection & losses/activation become an issue
- facility complexity $O(n^2) \rightarrow O(n^5)$
- number of equip. devices >x10 w.r.t. GSI

"… have to improve!"

Scope: coordination, development and follow-up of a common and coherent concept, strategy, technical guide-lines, and specifications for the

1. Commissioning[1],
2. Control[2], and
3. Operation

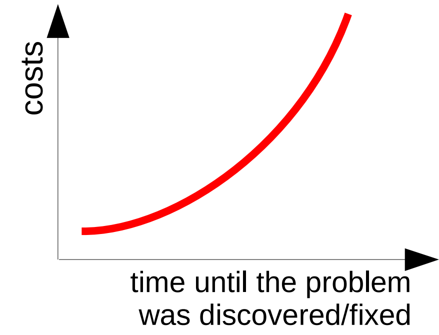
of the whole[3] FAIR Accelerator Complex



- Broken down into 2 Work Packages:
  - 2.14.17.1 FC²WG -- FAIR Commissioning & Control WG (link to: 2.14.10.1, 2.x.[3,4,6,7 & 12])
    - development of common concepts, functional guidelines, and drafting of related specifications (acc. tech-experts)
      - support and tools for device and machine commissioning
    - EDMS signatory process:: SPL, MCs, main equipment-GL, head FC²WG (as approval leader)
  - 2.14.17.2 FCC-WG – FAIR Control Centre WG (link to: 2.14.10.10)
    - technical control room infrastructure: consoles, furniture, IT infrastructure, etc. (mainly CO-IN, OP, Exp-reps.)
    - Machine-Civil-Construction Interface (↔ 'Campus Master Plan')

[1] commissioning covering the initial commissioning, subsequent re-commissioning & assisted operation phases (prior to 'regular operation')
[2] N.B. 'control' here dt. “Anlagenkontrolle”, including system integration and integration into day-to-day machine operation
[3] including all existing GSI and future FAIR accelerators as well as machine-experiment specific CO interfaces (e.g. target steering, spill control, data exchange)

Fundamental FC²-Principles: Reworking, re-optimisation is inefficient and costly

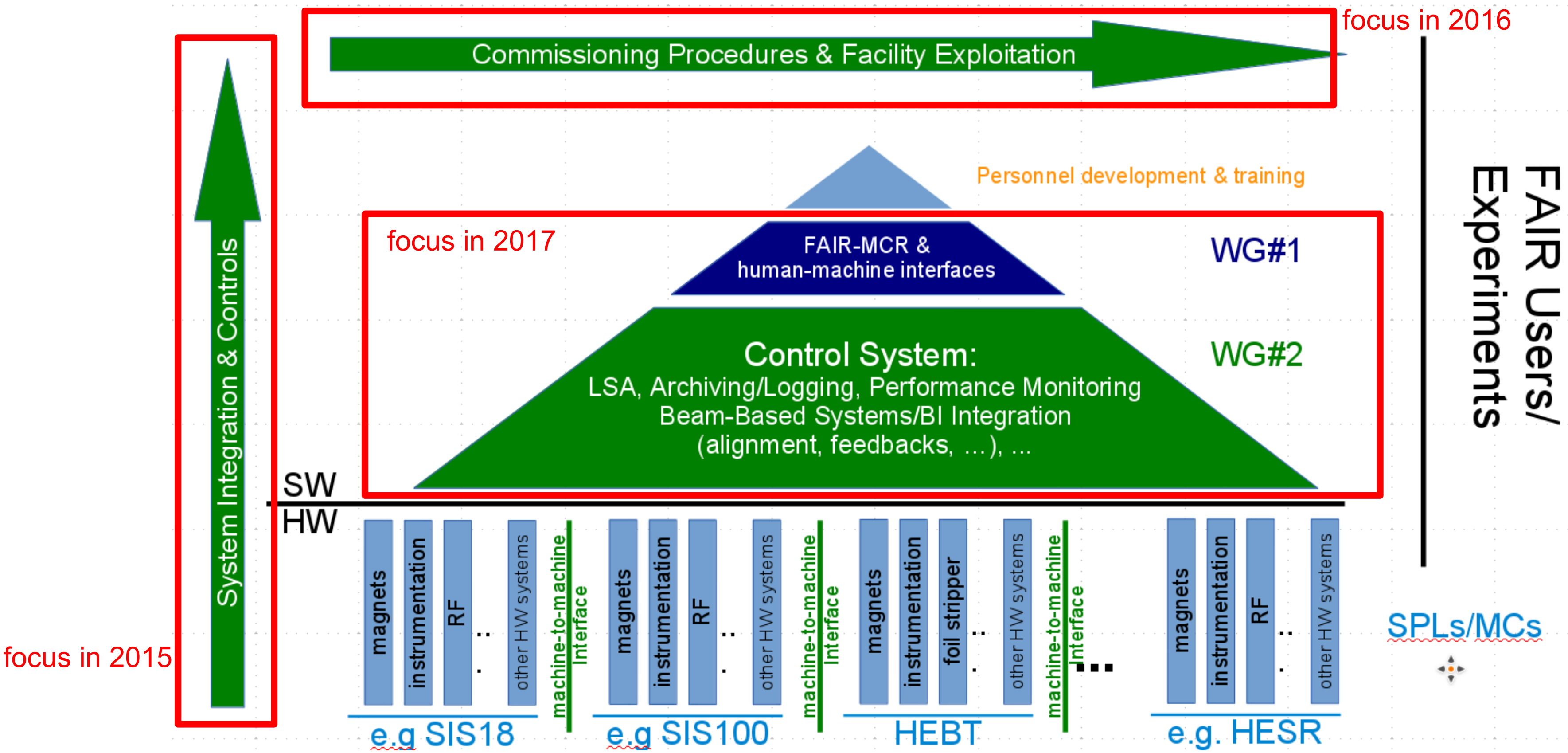


Proposal to follow a long-term strategy and 'lean principles':

- Continuous improvement
  - Right processes to produce right results & for getting it right the first time
    - *commissioning procedures as evolving operation standard*
    - system integration: determine of what, how and when is needed
      - N.B. lack of resources ↔ prioritisation!! (N.B. steering of resources by SPLs & MCs)
  - Prevention of inefficiencies, inconsistencies & wastes by design
    - 'poka-yoke' or 'error proofing' principle – culture of stopping and fixing
      1. early, when and where they occur (at the source)
      2. with low-intensity beam rather than with high-intensity beam
      3. addressing first basic parameters before complex higher-order effects
    - Examples:
      - now: semi-automated testing tools for individual devices now → later: time savings for large-scale FAIR SATs
      - first fix injection, trajectory, orbit, Q/Q' before addressing space-charge or slow-extraction problems
      - important losses for low-intensity beam have larger impact for high-intensity beam (↔ activation)
        - pilot-beam concept: always verify machine safety with low-intensities before moving on to high-intensity beams

- Respect for people – “develop people, then [/and] build products [/accelerators]”
  - optimise operation ↔ smart tools & procedures, e.g. beam-based feedbacks, sequencer, …
    - automate routine task so that operator talents are utilised and focused on more important tasks
  - training, investment in and development of people – minimise overburden/strain of personnel
  - FAIR is a large facility and needs wider support: communicate concepts and strategy to broader base → 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!

FC^2WG 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

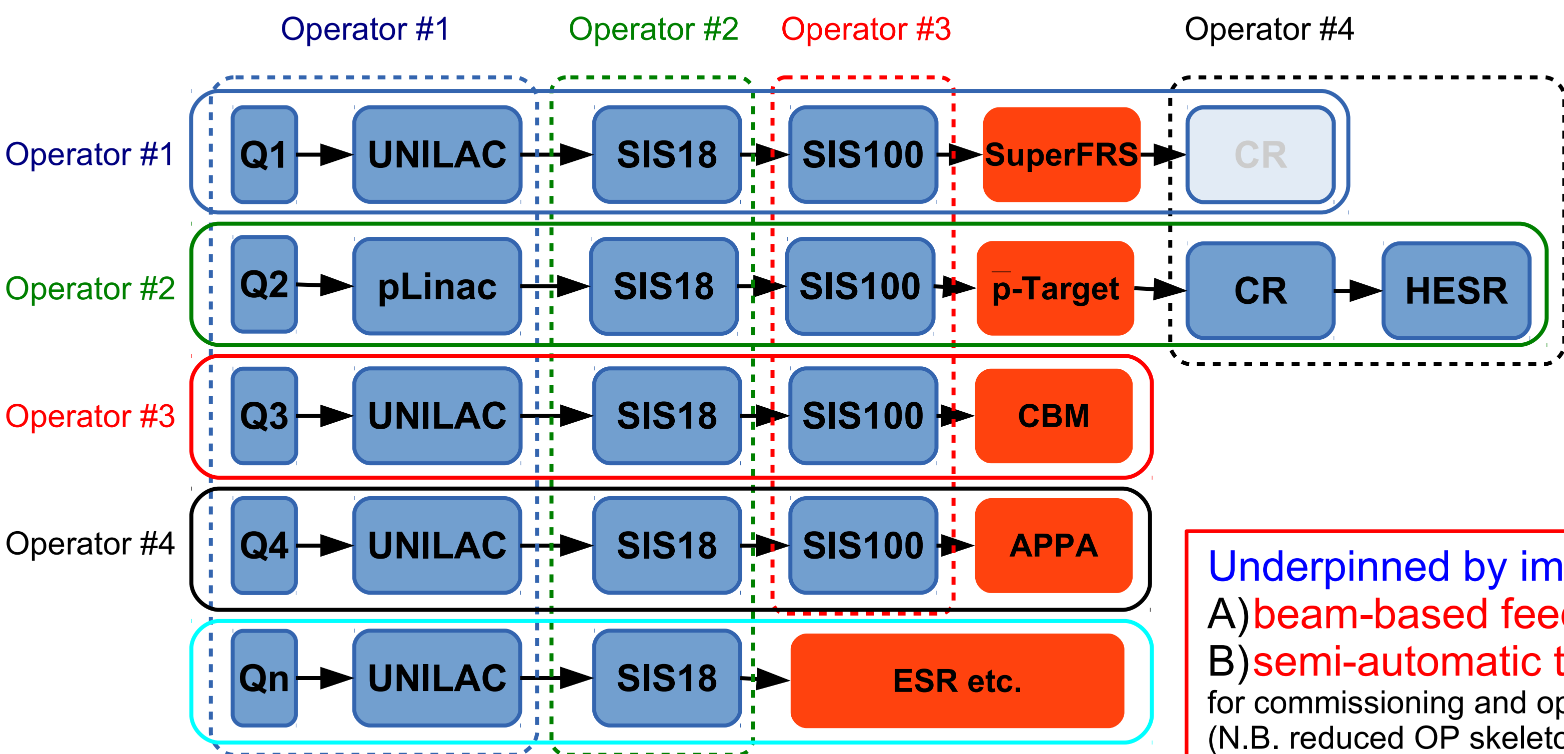
- Facility & Interface Analysis
  - Procedures: Hardware Commissioning (HWC), HWC-'Machine Check Out', Beam Commissioning (BC), BC-Stage A (pilot beams), BC-Stage B (intensity ramp-up), BC-Stage C (nominal/production operation) Beam parameters, FAIR performance model, optimisation, Accelerator & Beam 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

FAIR Operation/Control Paradigm

FC2WG Meetings #1, 4, 8, 18, ...

- 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
- One strategy item: 'One Operator per Accelerator Domain' vs. 'One Operator per Experiment':



Underpinned by importance of:
A) beam-based feedbacks
B) semi-automatic tools
for commissioning and operation of FAIR
(N.B. reduced OP skeleton crew (nights) of ~5-6 operators)

Accelerator & Beam Modes

https://edms.cern.ch/document/1823352/

- Purpose:
  - Communication of intended accelerator operation to experiments,
    FAIR
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  2) Bea
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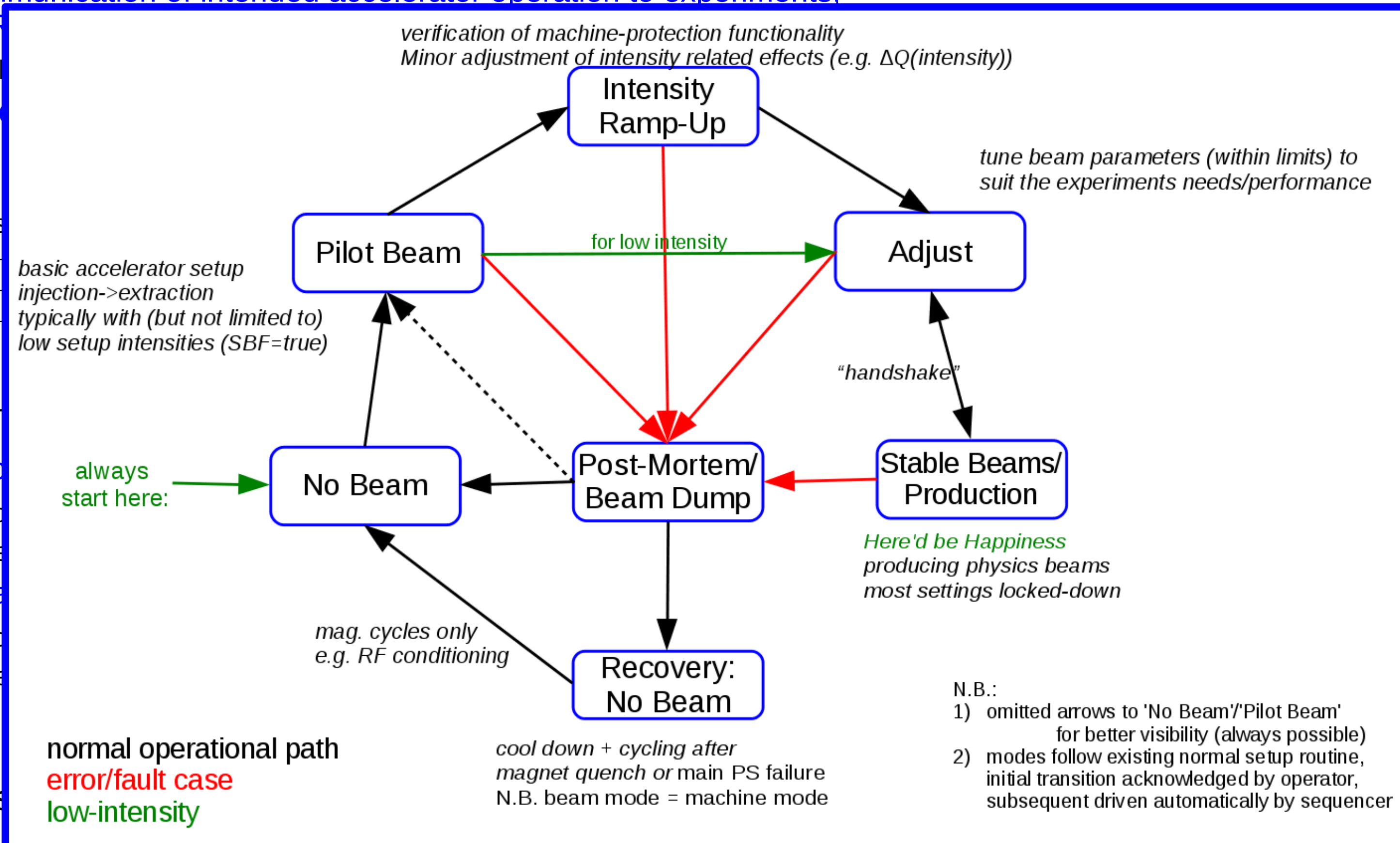
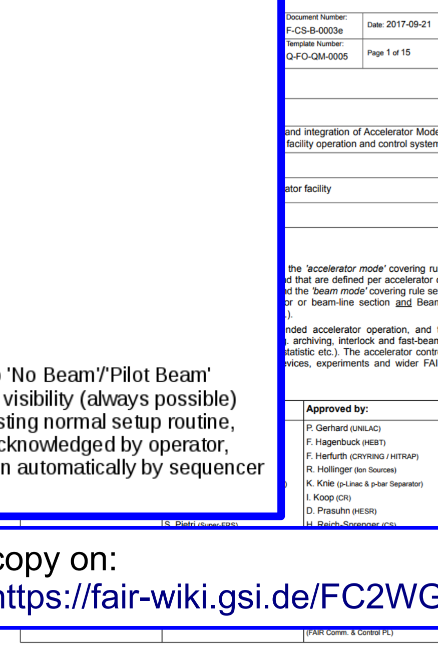
  - required for safe primary-beam intensity ramp-up & 'OP-Exp. Hand-Shake' etc.
  - more fine-grained options for facility availability, performance tracking & analysis





copy on:
https://fair-wiki.gsi.de/FC2WG/

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
- Milestones:
  - Conceptual prototype for 2016/17 (in-kind)
  - Aim at testing this for > 2018

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)

transmission

un-controlled losses

controlled losses

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, ...

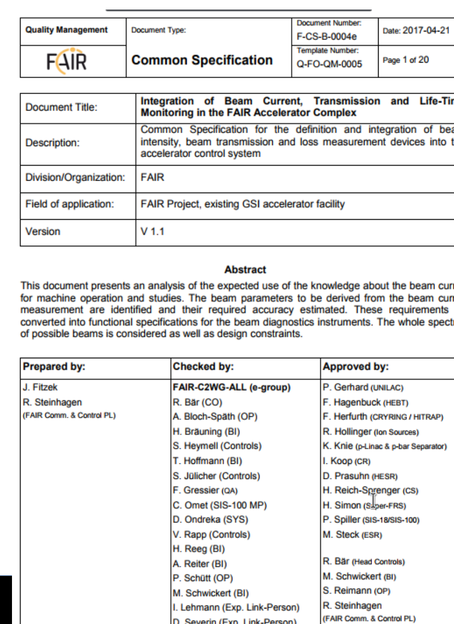
less-avoidable losses
(may need to accept a given amount)

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

beam instabilities, aperture
constraints, slow beam drifts
across e-septa
→
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.

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

Digitization of Analog Signals at FAIR
https://edms.cern.cn/document/1823376/

Quality Management	Document Type:	Document Number: F-CS-C-0002e	Date: 2017-09-21
FAIR	Common Specification	Template Number: Q-FO-QM-0005	Page 1 of 29

Document Title:	**On the Digitization of (generic) Analog Signals in the FAIR Accelerator Complex**
Description:	Detailed specification for the integration of time-domain digitizers with analog bandwidths and sampling frequencies ranging from DC to up to hundreds of MHz into the accelerator control system
Division/Organization:	FAIR
Field of application:	FAIR Project, existing GSI accelerator facility
Version	V 1.1

Abstract

This document describes the generic integration of time-domain digitizers with analog bandwidths and sampling frequencies ranging from a few MHz to hundreds of MHz. These digitizers shall provide generic monitoring and diagnostics of accelerator-related devices that otherwise do not require further dedicated IO control features, specific post-processing (e.g. fast feedback loops), or where these features are already handled through another existing infrastructure.

This specification aims at providing a generic abstraction of the vendor-specific digitizer software interfaces, a limited range of generic data post-processing on the acquired data, and integration of these devices into the FAIR control systems by providing FESA standardised software interfaces.

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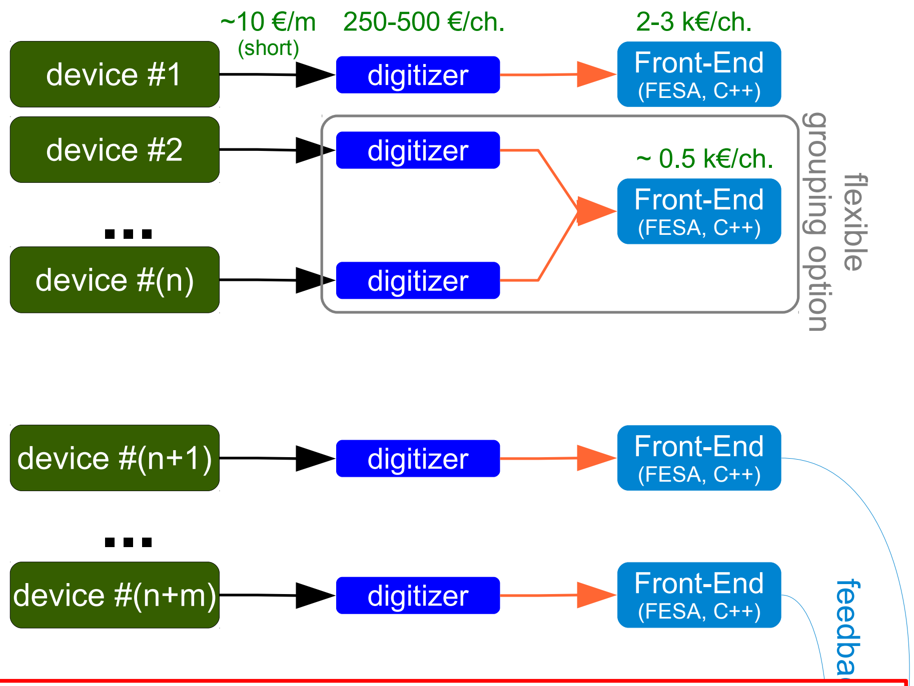
- limited test-coverage, trending

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



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

link: more details

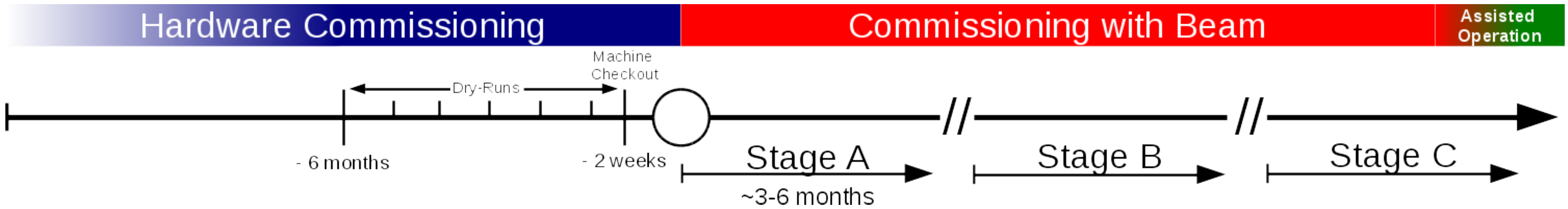
FAIR Commissioning Procedure I/II

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



A) Hardware Commissioning (HWC → SAT A)

- conformity checks of the physical with contractual design targets
- || commissioning of individual systems & tasks ↔ SPLs/equipment group responsibility

B) Commissioning with Beam (BC → "SAT B" …)

- sequential, focus on tracking beam progress along the beam production chain (BPC)
  - + 'Dry-Runs': pre-checks at the end of HWC in view of BC (w/o beam, system integration conformity & BC readiness):

- Split Beam Commissioning into three stages:

Stage-A) Pilot beams/"easily available" ions (e.g. Ar) → protons (N.B. transition crossing effects)

- basic checks: threading, injection, capture, cool, convert, acceleration/decelerate, stripping & extraction
- always done with 'safe' ie. low-intensity/brightness beam (↔ Setup-Beam-Flag concept)

Stage-B) Intensity ramp-up & special systems

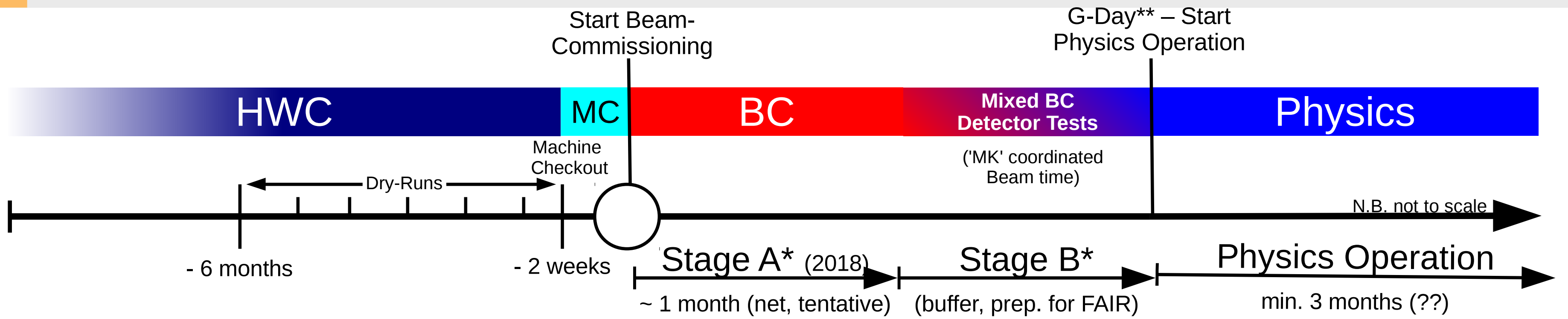
- achieving and maintaining of nominal transmission and beam losses
- commissioning and validation of machine protection & interlock systems (+ e-cooler, slow extraction, transverse fast feedbacks, ...)

Stage-C) Production operation with nominal intensities

- 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

Recommissioning & Operation in 2018 I/II

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

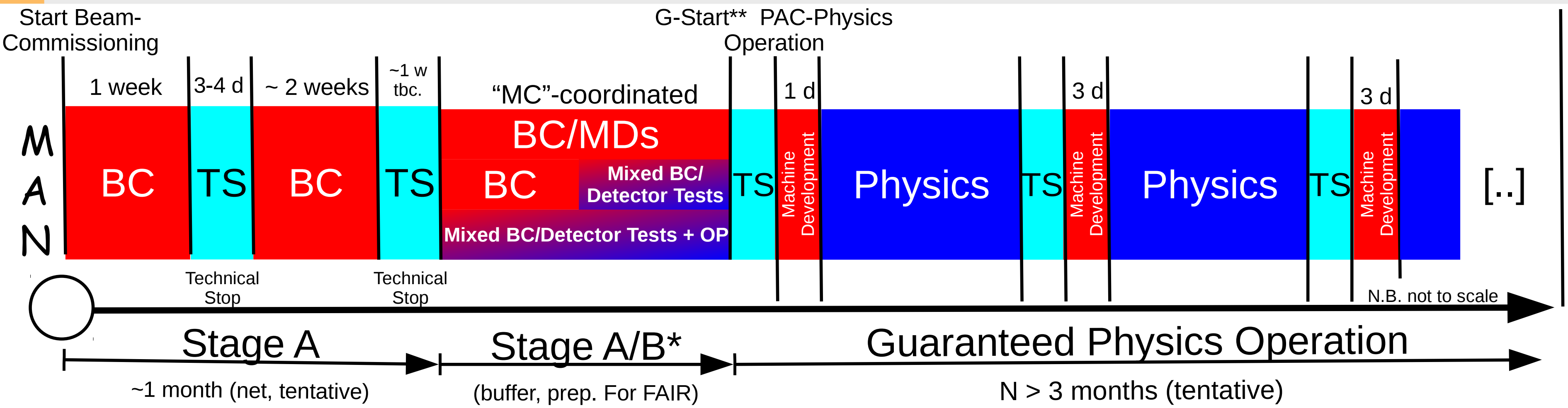


- Hardware Commissioning → coordinated by Sub-Project-Leaders & Machine Coordinators
  - link-existing facilities (GAF), upgrades, machine re-alignment, “SATs”, HW systems (equip. groups),
- Dry-Runs – for all machines post (possibly also UNILAC), each two days, fixed dates (↔ experts availability), starting:
  - Dry-Run #1 – 25.10.2017: CO-core: LSA, Timing System, Archiving System, SCUs, CO core application, …
  - Dry-Run #2 – 14.11.2017: as before + tbd.
  - Dry-Run #3 – 12.12.2017: as before + tbd.
  - Dry-Run #4 – 09.01.2018: as before + BI + related applications
  - Dry-Run #5 – 06.02.2018: as before + Experiments (proposal) + Machine-Experiment Interfaces
  - Dry-Run #6 – 20.02.2018: as before + AEG + “last-minute” checks
  - Dry-Run #7 – 06.03.2018: buffer
- Machine-Checkout – intensive “last minute checks” (N.B closed tunnel/machine):
  - UNILAC: -1 month → BC- 'day 0'
    - patrols, heat runs: RF & power supply conditioning, ...
  - SIS, ESR, CRY: -3 weeks → BC- 'day 0'
    - patrols, heat runs: RF & power supply/AEG conditioning, safety systems: personnel safety, access system, legal ZKS & RP checks (§66 Abs. 2 StrlSchV), “very last-minute” checks/bug fixes: vacuum, power, BI, CO, ...

* in 2018: light-version w.r.t. commissioning of new machines
** “guaranteed” start physics operation (Plan A), no hick-ups, sacrificial buffer being activities related to 'Stage B'

Recommissioning & Operation in 2018 II/II

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



- Stage-A: Initial Beam Commissioning (BC): 2 dedicated 3 week@24h/7 BC blocks, main aim:
  - drive beam expeditiously through the Beam Production Chain: sources → synchrotrons & beam transfers → exp. targets & storage rings
  - check basic 'accelerator mechanics': threading, injection, capture, cool, convert, acceleration/decelerate, stripping & extraction
  - identify beam-related limitations: polarities, RF, beam instrumentation, machine alignment, effective physical machine aperture, ...
- Immediately followed by dedicated, scheduled Technical Stop (TS)
  - needed for follow-up of HW (tunnel) and SW issues (CO, …)
- Stage-A/B*: Mixed-BC, Machine-Development, Detector Tests (aka. "splash events" for experiments) & Operator Training
  - N.B. "old machine" but completely new CO, substantial modifications
- Physics operation: as promised/targeted nett 3 months (to be confirmed), grouped into 2-3 blocks interleaved with
  - TS: routine maintenance → increases overall availability, follow-up of OP/CO/equipment issues + major ion species/source changes
  - MDs: follow-up of beam physics issues, CO improvements (e.g. beam-based FBs), improve facility to reach nominal FAIR parameters
    - N.B. also better for guaranteeing smooth restart/picking-up of physics operation after technical stops (experts availability)