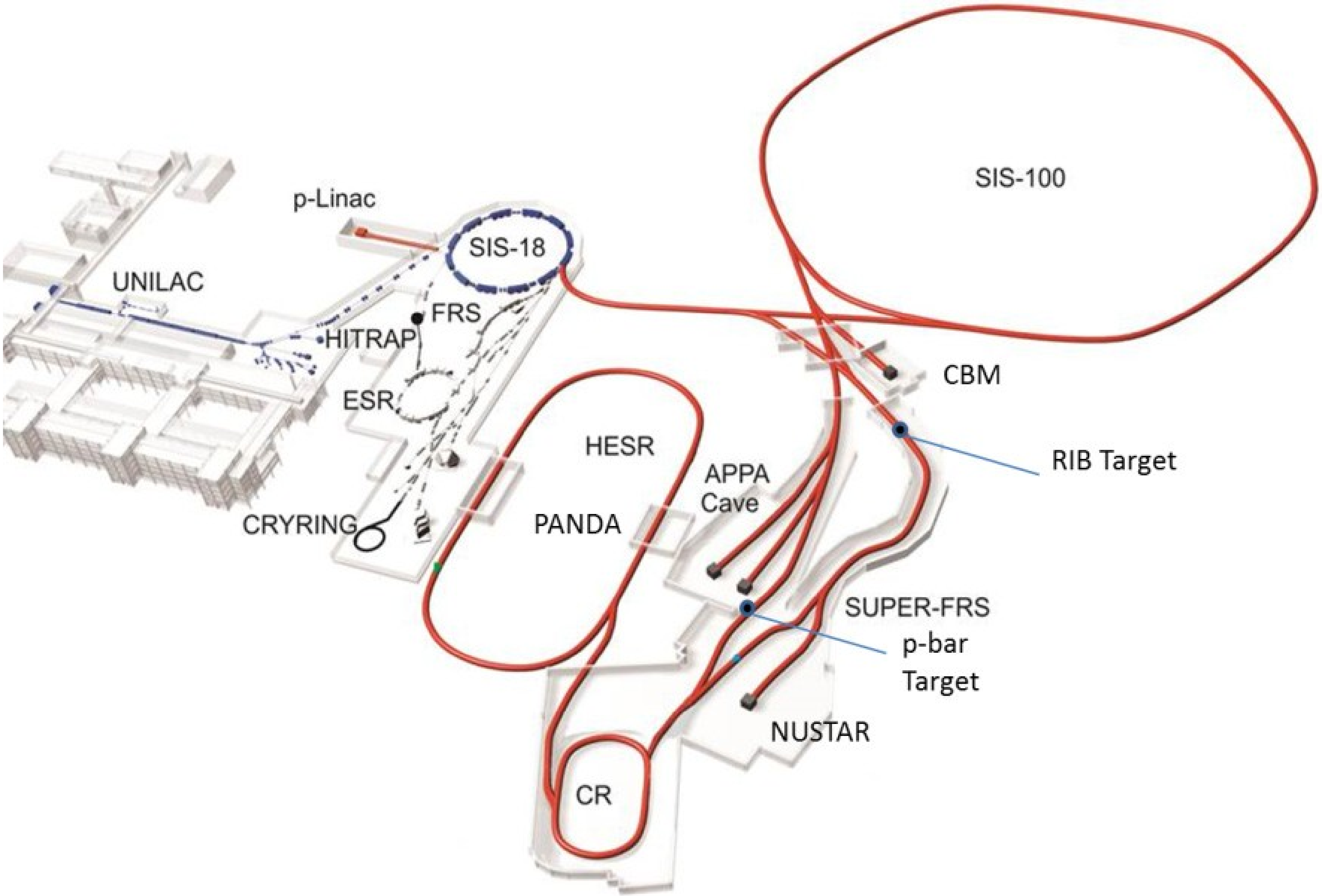
GSI Helmholtzzentrum für Schwerionenforschung GmbH

FAIR (Re-)Commissioning (in 2018)

Strategy & Concepts

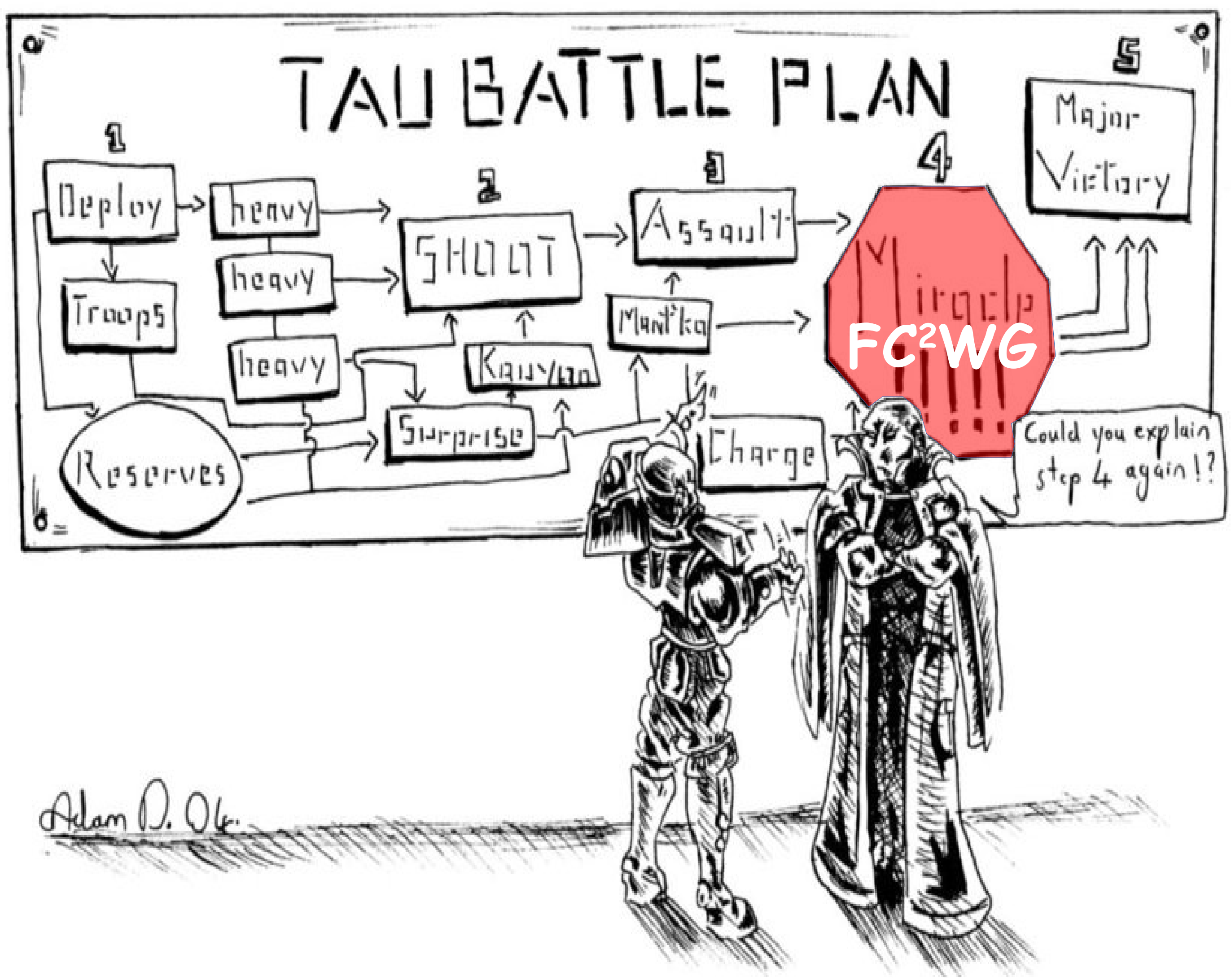
Ralph J. Steinhagen

… a FAIR amount of work ahead



Commissioning – Plan of Action

Beware joke!



Need to be more explicit w.r.t. 'item 4' for commissioning and operation of FAIR.

FAIR Commissioning & Control
– Summary, see also HIC4FAIR'2015

- FAIR facility shall continue to provide a high degree of flexibility
- Additional new challenges for FAIR:
  - higher energies, high-intensity operation, increased complexity, machine protection, minimising machine activation, …
    → control of particle losses becomes more important
  - beam becomes more sensitive to beam parameter changes, dynamic vacuum effects & magnet hysteresis
    → may change tune/orbit working point & impact slow extraction/losses, ...

- Main paradigm changes:
  - Need better control of hysteresis: decouple magnetic cycle from dynamic beam (extraction) request
  - Need beam intensity ramp-up concept
    - no injection of high-intensity beam into an 'empty' machine
    - settings need to be (re-)validated with increasing beam intensity and whenever magnetic pattern changes
  - Flexibility comes with some overhead costs → trade-off between 'flexibility' & 'beam-on-target' required
    - new complexity: larger accelerator chain → example next slide
    - caveat: mode of operation changes costs → trade-off between flexibility, machine availability, and beam-on-target
  - Need to limit of what can be setup in parallel
    - re-tuning of machine parameter & potential cross-talk with other beams for high-intensity beams
    - e.g. intercepting transfer-line diagnostics

- Main optimisation strategy/recipe, aim at:
  - quasi-periodic cycle operation
    - minimise major pattern changes by construction ↔ beam schedule planning (tools)
  - minimise overhead costs of changing beam patterns and context switches
    - optimise operation ↔ smart tools & procedures, e.g. beam-based feedbacks, sequencer, …
    - improved planning of commissioning & beam schedule

today's focus

FAIR Challenges & Constraints
… SIS18 Operation Experience & Efficiency I/II

Statistik Betrieb | Beginn 01.01.2014 22:00 | Ende 31.12.2014 22:00

Status		Ereignis	Gesamt	Minuten	Prozent
SAT		Strahl auf Target (inkl. Nachoptimieren)	12000.35 h	720021	50.18
NO		Nachoptimieren	92.63 h	5558	0.39
STDBY		Standby	6782.43 h	406946	28.36
UNTERBR			5039.55 h	302373	21.07
	EINST		2206.85 h	132411	9.23
	QW		520.52 h	31231	2.18
	AUSF		2312.18 h	138731	9.67
GESAMT			**23914.97 h**	**1434898**	**100.00**

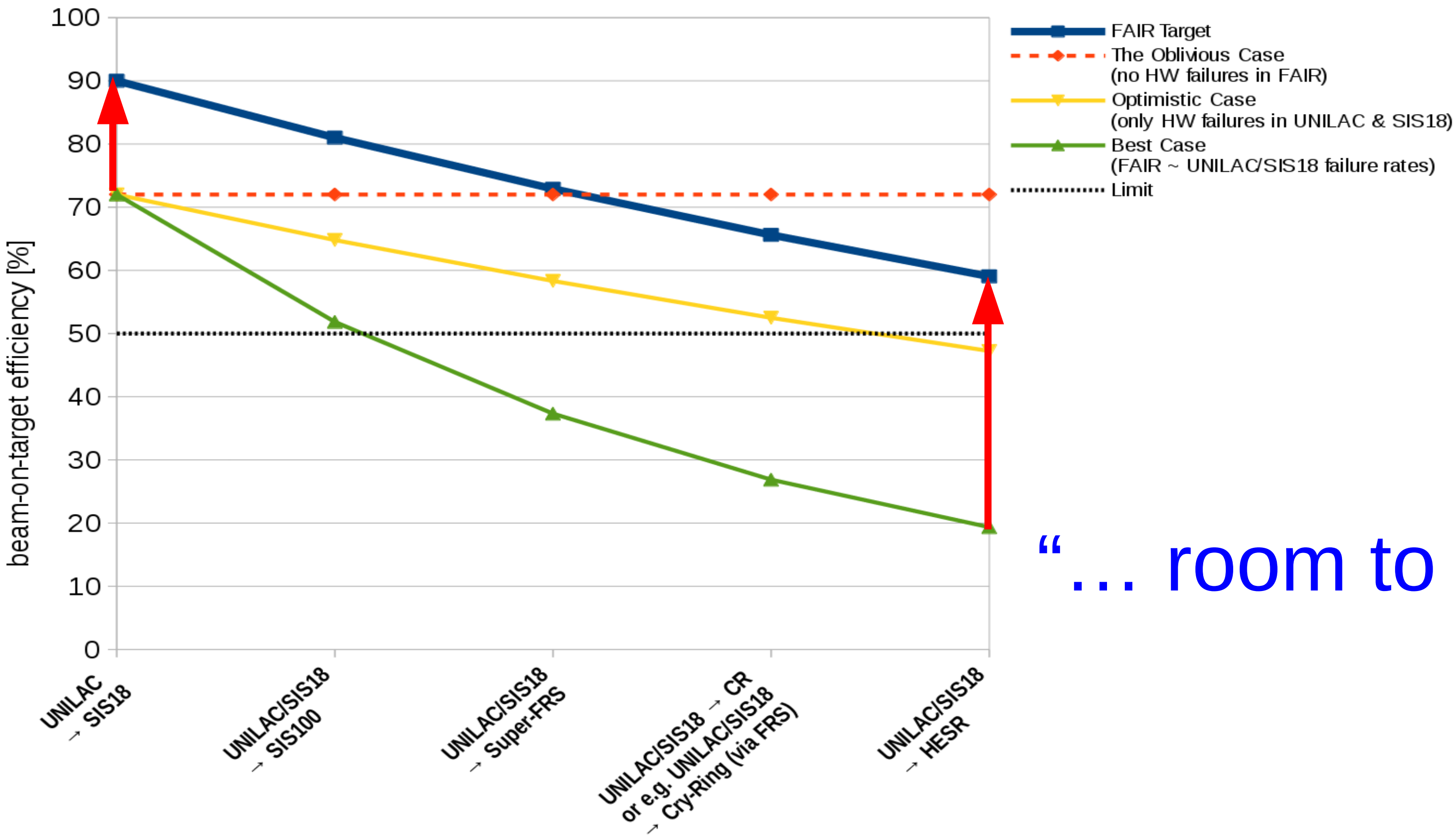
- possibly pessimistic/simplistic[1,2] estimate, control room experience:
  - presently: '~ 1 shift UNILAC setup + 1 shift SIS18+TL setup' ↔ 1-2 weeks of experiments
- 2014: Beam-on-Target (BoT) figure of merit (FoM) of ~70%
  - sufficient for present mode of operation (~20% HW failures, ~13% setup)
  - however: high losses/activation & FoM does not scale for FAIR

[1]possibly strong assumption that new machines can be operated with the same routine, ease and efficiency as the present GSI infrastructure, …
[2]complex beam chains (e.g. HESR) with long beam setup times are typically run longer/more static than shorter (SIS18 experiments)

- FAIR-BoT (efficiency ε_{FAIR}):

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

  - further convoluted with HW failures, availability of infrastructure



"… room to improve!"

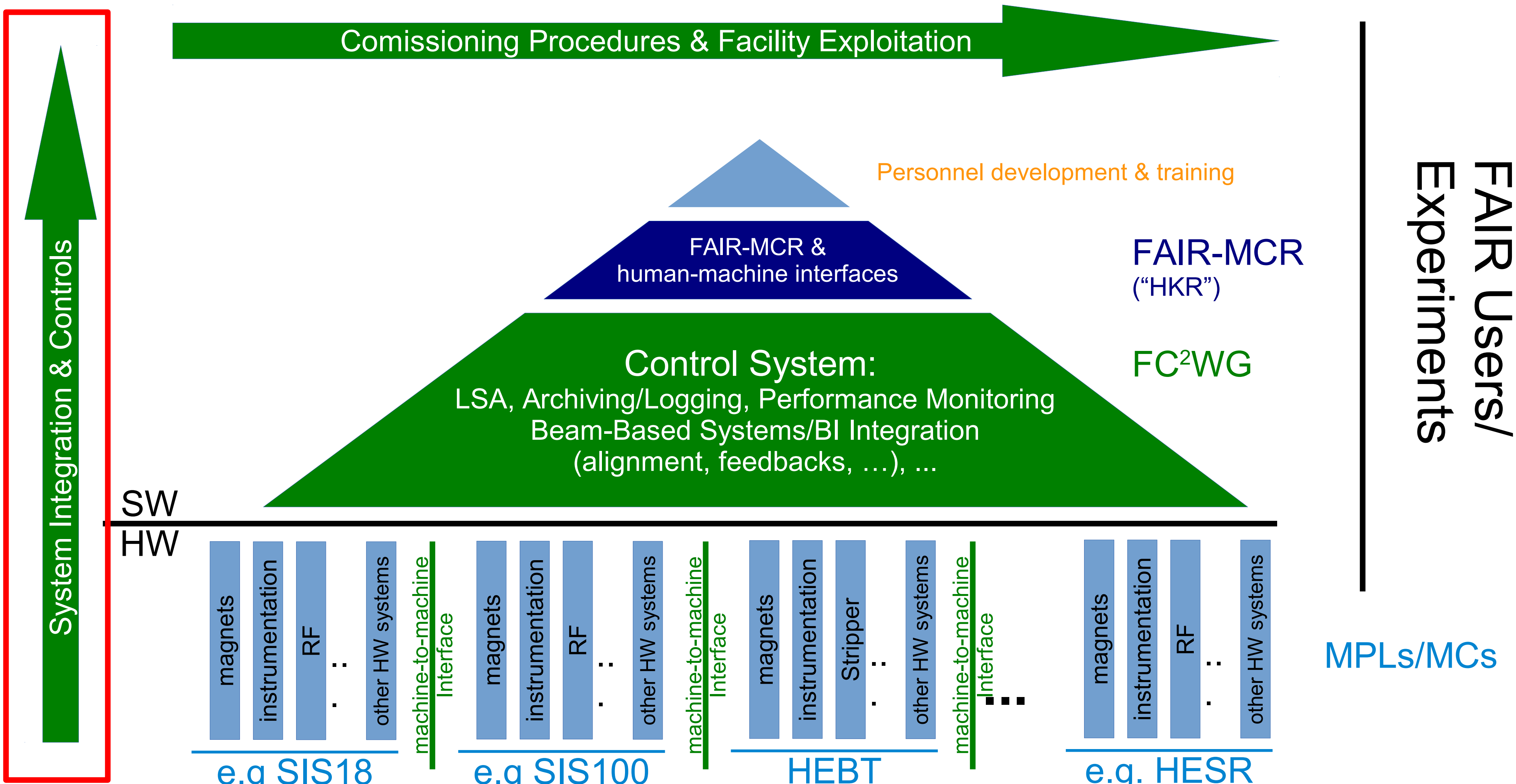
Global Requirements & Constraints

- Much larger facility, cannot reliably extrapolate from present 'UNILAC→SIS18→ESR' operation to requirements for FAIR
  (9+ resp. 13 accelerators, higher/unsafe intensities, more users)
- Will be in a constant flux of frequent adaptations to new cycles/beam parameters, etc. present estimate:
  - avg. experiment run: ~ 1-2 weeks + many new storage rings and transfer lines with high(er) complexity → machine setup time-scale
  - high-intensity operation requires more and better fine-tuning
    - dynamic vacuum, activation & machine protection (mainly septa, instrumentation, etc.)
  - limited operator resources: 4-5 (beam operation) + 1 (infrastructure, cryo)

→ need to be smart and develop an efficient commissioning procedure, training and tools to facilitate fast turn-around and maintain (or improve) present operational efficiency

Fundamental Axiom

An accelerator is more than the sum of its parts:



Control Core Topics

- Archiving – Follow-up:
  - summary and documentation (+ GSI/CERN discussion) on FC2WG wiki
  - second specification iteration by Q3-2015
  - CSCO: first technical implementation concept (S. Jülicher et al.) → Q3-2015 (??)
- Accelerator & Beam Modes – Follow-up:
  - summary and documentation on FC2WG wiki
  - specification iteration (confirmation) by Q3-2015
- Role-Based-Access (RBAC) & Management of Critical Settings (MCS) → to be addressed this year
  - Organise review + use-case-analysis
    - 1st iteration: small round and using SIS18/SIS100 as an example (KISS + efficient)
    - 2nd iteration: wider community → Q3-2016
    - 3rd iteration: early specification → Q4-2016 (realistic?)
- CO/SW Test-Bed Strategy
  - during construction phase: needed to facilitate dry-runs and GUI/FB developments before all HW systems are available/ready
  - during operation phase: (offline) OP Training during shut-downs & during H.I. operation (no/limited live training possibility)
  - During high-intensity operation: testing of new CO concepts ↔ optimisation of beam availability/minimise cross-talk with ongoing operation (CERN experience ...)
- Integration of BI/CO equipment into Beam-Based Semi-Automated Control Loops
  - via LSA, aka. 'slow cycle-to-cycle feedbacks'
  - need CO-SW developer-'accelerator expert' pairing, priority list & milestone planning → next slide

Beam-Based System Integration – Pairing I/II Generic Priorities (ie. all machines)

… key to efficient and fast transitions between pattern and parallel operation!

Beam-Instrumentation (focus on HW)

- Overview and strategy (M. Schwickert, FCWG #4)
  - MP relevance, OP robustness, reliability, nice-to-have
- Group I: Intensity monitoring across + BLMs across transfer lines & rings (M. Sapinski, S. Damjanovic, FCWG #9)
- Group II: Orbit/Trajectory & Q/Q'
- Group III: Beam Loss & Vacuum
- Group IV: longitudinal diagnostics (bunch shape/length, splitting/merging, abort gap monitoring, tomography, ...)
- Group V: emittance diagnostics and preservation (after optics)

Machine Protection (focus on HW)

- High-intensity Operation (C. Omet, FC2WG #7)
- Fast Beam Abort System (M. Mandakovic, FC2WG #7)

Beam Control (focus on use-case)

1. Transmission Monitoring System (R. Steinhagen, FC²WG Meeting #6)
2. Orbit Control (work in progress)
3. Trajectory Control (threading, inj./extraction, ??)
4. Q/Q'(') Diagnostics & Control (??)
5. RF Capture and (later) RF gymnastics (??)
6. TL&Ring Optics Measurement + Control (LOCO, AC-dipole techniques etc.,)
7. Longitudinal Emittance Measurement (?)
8. Transverse emittance measurement (?)
9. Transverse and longitudinal feedbacks (RF: ???)

Bread-and-Butter systems for OP ~ ideally for SIS18 restart

Beam-Based System Integration – Pairing II/II
Machine Specific & Generic Systems

- Machine Specific Integration of 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
  - (Super-)FRS: tbd.
  - ESR, HESR & CR:
    - Stochastic cooling, Schottky diagnostics, …, tbd.

- Generic:
  - Remote Acquisition of Analog Signals → needs to be finalised by Q1-2017 (UNILAC ~ OK, SIS18, ESR!?!)
    - strong impact on HKR migration/operation!
  - Fixed-displays, Facility & Machine Status ("Page One")
  - Context-based monitoring of Controls and Accelerator Infrastructure
    - electrical power network, power converter infrastructure, cryogenics & vacuum, other facilities: water, personnel safety radiation monitors, ...
    - controls and timing network (latencies, instantaneous/avg. bandwidth load), FE CPU/temperature loads
  - Tools for
    - check-out test analysis (SAT, passed, in-progress, fault)
    - availability analysis → e-logbook & error/fault/down-time tracking (→ probably LOAO)

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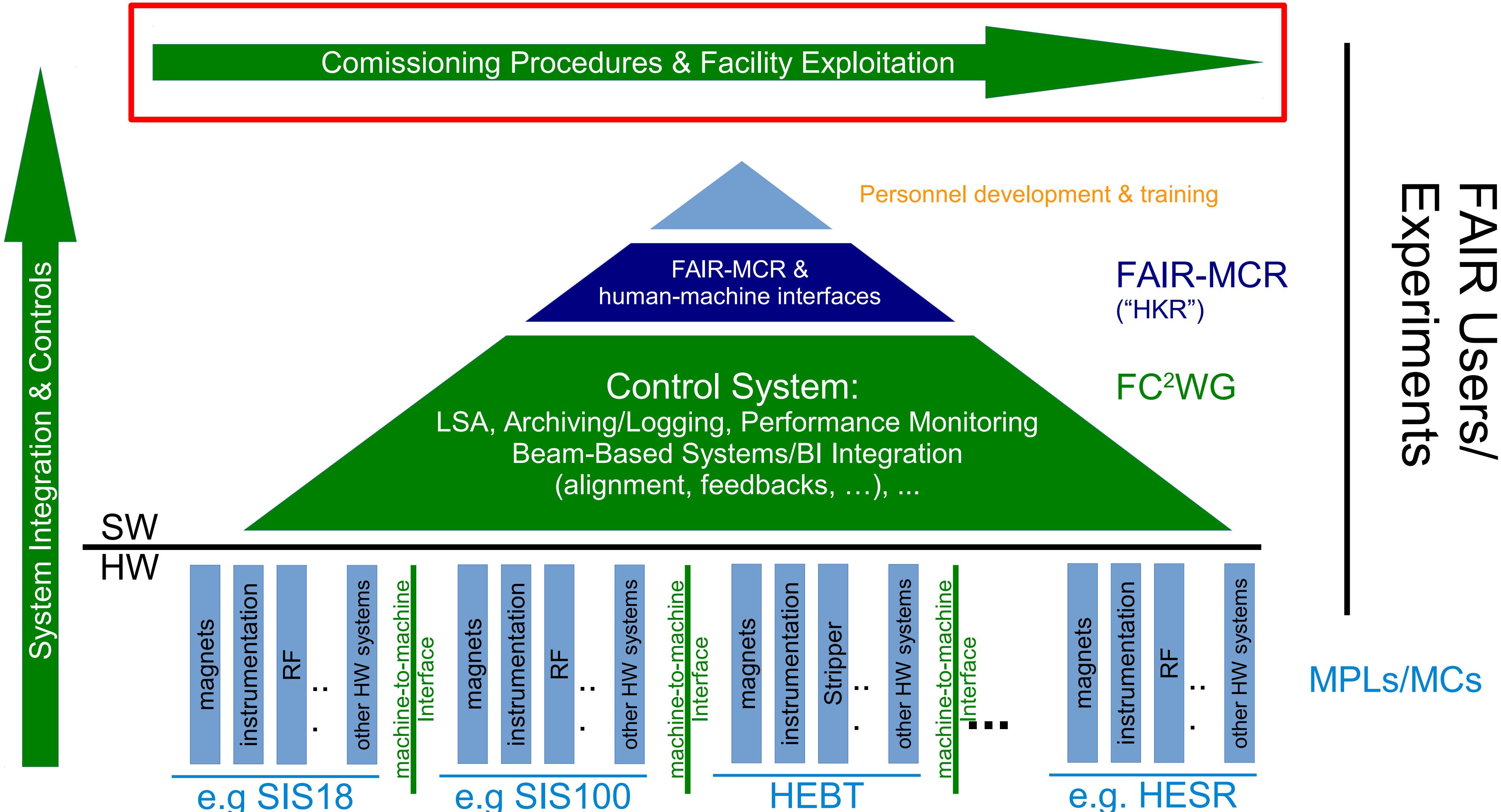


Re-working, re-optimisation is inefficient and costly

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

- Continuous improvement
  - Right processes to produce right results and for getting it right the first time
    - *commissioning procedures as evolving operation standard*
    - system integration: definition of what, how and when (prioritisation) is needed
  - Prevention of inefficiencies, inconsistencies & waste 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, low-quality or alternate* beam rather than with high-intensity beam
      3. addressing first basic parameters before complex higher-order effects
    - Example #1: first fix injection, trajectory, orbit, Q/Q' before addressing space-charge or slow-extraction problems
    - Example #2: important losses for low-intensity beam have larger impact for high-intensity beam (↔ activation)

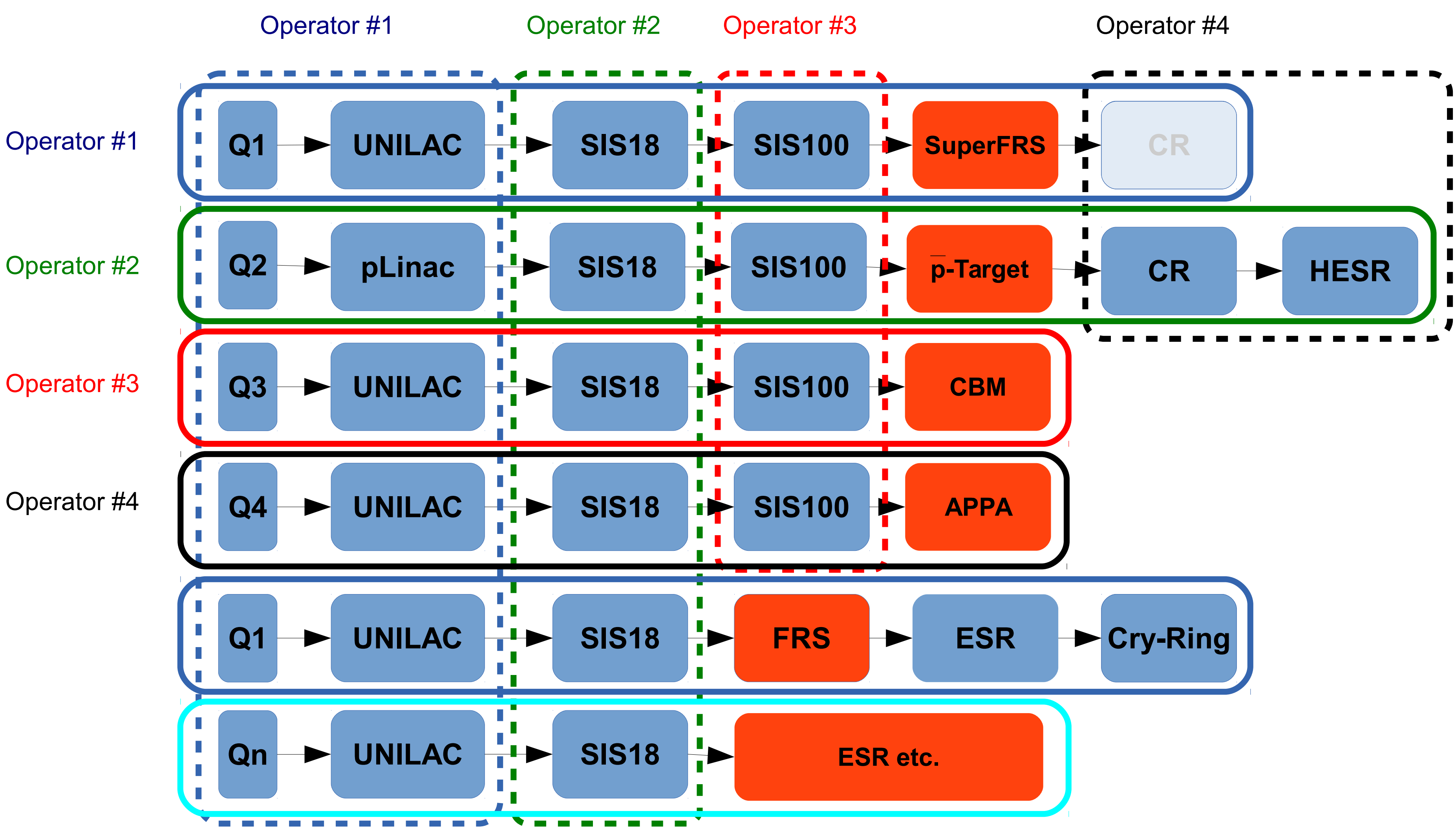
- Respect for people – "develop people, then build products"→ FC²WG #1, S. Reimann
  - optimise operation ↔ smart tools & procedures, e.g. beam-based feedbacks, sequencer, …
    - automate routine task so that operator talents are utilised and focused on more important tasks
  - training, investment in and development of people – minimise overburden/strain of personnel

*N.B. alternate: e.g. commissioning the anti-proton beam lines and rings with protons"

FAIR Operation/Control Paradigm

S. Reimann FC2WG #1, 2015-05-21

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



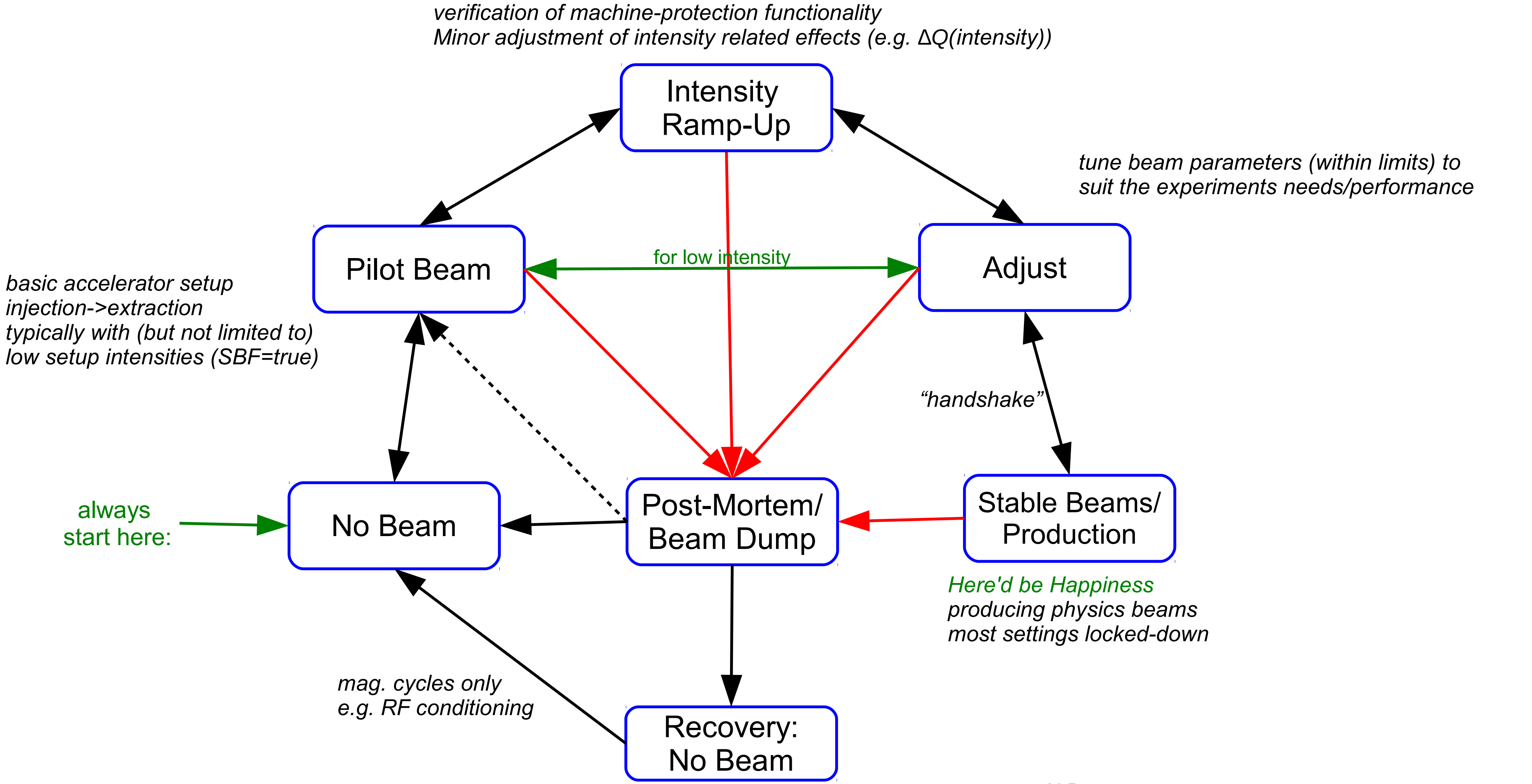
High-Intensity Operation

Additional measures for safe and reliable high-intensity operation:

- Pilot-Beam Concept:
  - new injection into an empty/untested machine must always be preceded by a pilot (ie. low-intensity) beam to validate injection, orbit, Q/Q', ... extraction
  - rationale: prevent “discovering” failed HW, bad settings with (potentially un-safe) high-intensities
- Intensity-Ramp-Up Concept:
  - Highest-intensities (> ~10^{10} ppb) only after successful intensity ramp-up
  - Need to verify beam parameters after every major cycle (hysteresis) or setting changes (Q/Q' working point, optics)
  - rationale: staged verification of intensity-related parameters, shift of working points, settings and systems (ie. better to discover/analyse/mitigate losses at low than high intensities)
- Additional concept: 'Beam-Presence-Flag' & 'Setup-Beam-Flag'
  - improves machine availability for low-intensity (safe masking of interlocks) while guaranteeing safety for high-intensity operation
  - For details see: http://fair-wiki.gsi.de/FC2WG/

FAIR Beam Modes – State Diagram

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



normal operational path
error/fault case
low-intensity

cool down + cycling after
magnet quench or main PS failure
N.B. beam mode = machine mode

N.B.:
1) omitted arrows to 'No Beam'/'Pilot Beam' for better visibility (always possible)
2) modes follow existing normal setup routine, initial transition acknowledged by operator, subsequent driven automatically by sequencer

FAIR Commissioning Procedure I/II

- Develop a (initial/re-)commissioning and operation strategy:
  - MoU between various stake-holders (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

- Distinguish two forms of 'commissioning':

  A) Hardware Commissioning (HWC)

    - Formal functional checks and acceptance tests of the physical objects
    - HW System integration into the controls/OP environment
    - Done during initial commissioning and as part of the 'machine check-out' after every (longer) technical stops (e.g. annual shut-down)

  B) Commissioning with Beam (BC)

    - thread, inject, capture, cool, accelerate, decellerate, convert, strip, and extract through the accelerator chain
    - commissioning of beam-dependent equipment

Hardware Commissioning

- Covers two aspects:
  1. Initial hardware acceptance tests
     - Checks conformity with contractual design targets
     - Done once, or after major upgrade or modifications
       - mainly done by system responsible/experts
       - coordinated by machine project leaders

  covered by present project structure

  2. 'Machine Checkout' – presently not covered (yet)
     - Checks conformity of system's controls integration <u>and</u> readiness for beam commissioning/operation
       - Checked during 'dry-runs' – periodic (partial) facility tests coordinated by CO/OP
     - Needs to repeated after every shut-down or longer technical stop
       - Presently done on a system-by-system basis
       - Would benefit from a more global approach

Commissioning with Beam

- Split Beam Commissioning into three stages:

I. Pilot beams/”easily available” ions (e.g. U28+, 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

II. 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

III. Production operation with nominal intensities
   (N.B. first time counted as 'commissioning' → later: 'regular operation')
   - push physics and beam parameter performance (emittance, momentum spread, ...)
   - identify and improve upon bottlenecks impacting FAIR's 'figure-of-merit
   - <u>make fast setup and switch-over between different beam production chains routine</u>

Scheduling
Dry-Runs & Commissioning with Beam (BC)

- Important aspects that need to be factored in:
  - efficiency evolution: early beam commissioning → reaching final beam parameter
  - dry-runs & BC (notably Stage I) are aimed at identifying issues early on
    - machine alignment, magnet/BI polarity issues, controls “features”, …
    - To note:
      - SIS18/ESR/.. have been offline/disassembled for one year
      - new controls system: concepts, FECs, data supply (LSA), user interfaces, …
      - operational challenges

  → require follow-up → should plan and pencil in some adequate time into the beam schedule (technical stops, preliminary physics/calibrations runs, etc.)

- Rough scheduling proposal:
  - Short-term (BC stage I): ~ 3-6 month beam commissioning (day-shifts, 50%), limited parallel experiments (ie. nights & weekends)
  - Medium-term (BC stage II): few day shifts of beam commissioning/week (~15 - 20%), rest beam operation
  - Long-term (BC stage III): mainly beam operation, 1-2 days per 2-3 weeks for BC & MDs

Commissioning Phases* Example I/II

Phase	Description
A.1	Injection and first turn: transfer lines, injection commissioning; threading, initial commissioning beam instr.
A.2	Circulating pilot: establish circulating beam, closed orbit, tunes, RF capture
A.3	injection initial commissioning: initial commissioning of beam instrumentation cont'd, beam dump
A.4	Ramp: transition crossing (protons), control of orbit, Q/Q', ...
A.5	Injection & Extraction optics: beta beating, dispersion, coupling, non-linear field quality, aperture
A.6	Extraction: fast extraction, slow extraction, ...
A.7	Final Focus/Target Steering: transfer lines, final focus, internal/external target steering, ...
A.8	Preliminary physics runs: “physics” with intermediate safe beam parameter (experiment detector setup etc.)
A.9	Special aspects: special machine functions, e.g. stochastic/e-cooling, transverse FB, special RF manipulation

*inspired by commissioning and SW analysis efforts for LHC:
http://lhccwg.web.cern.ch/lhccwg/overview_index.htm
http://lhccwg.web.cern.ch/lhccwg/Bibliography/background-material.htm
http://proj-lhc-software-analysis.web.cern.ch/proj-lhc-software-analysis/
http://lhc-commissioning.web.cern.ch/lhc-commissioning/machine-checkout.htm

Commissioning Phases* Example II/II

- Defined for each phase:
  - Short description of should be achieved
  - Entry and Exit conditions – clear definition of handover specs
    - definition of must-have systems,
    - op. procedures (e.g. machine patrol)
    - List of systems to be considered “operational” afterwards
  - Machine setup:
    - optics, beam type, MP equipment in place
  - Procedure:
    - detailed 'cookbook': check list of individual steps (settings, gains, …)
    - Optional items e.g. for night-time shift or delayed by another item
  - List of possible problems and first-order remedies
  - Open questions/action items
  - References (!!) & Acronyms

*for examples (LHC context) see e.g:https://edms.cern.ch/cedar/plsql/project.info?proj_id=1027639877

Example: Injection and First Turn

- Need – entry conditions
  - HW/SW conditions: full machine check-out, dry-runs performed, technical services available, ...
  - Machine state: ion optics, beam parameters to be used, ...
- Procedure:
  - Injection preparation: check transfer line settings, timing, kicker & power supply statuses, ...
  - Commission last meters of transfer line: check magnet & pick-up polarity, rough optics checks, commission beam instruments, ...
  - ...
- Potential Problems & Mitigation:
  - Cannot thread beam (beam lost somewhere) → Causes: … Diagnostics: ... Remedies: ...
- Open Questions:
  - UNILAC to SIS18 timing: first turn definition, ...
- Have – exit conditions:
  - Fully commissioned screens/IPMs, can exclude BI/kicker polarity errors, ...

Example: Injection and First Turn

- Short description of should be achieved
  - Commissioning of the last section of the transfer line and the injection
  - First commissioning of key beam instrumentation
  - Commissioning of the trajectory acquisition and correction
  - Threading the beam around the ring (first turn)
  - Closing the orbit to be ready for phase A.2 (establishing circulating beam)

Entry & Exit Conditions

Entry conditions

- Full checkout and dry-run performed
- Technical services available
  - Controls network
  - Electrical network
  - Cooling and ventilation
  - Access and safety systems
- Vacuum system
  - Insulating vacuum (SIS100, Super-FRS)
  - Beam vacuum (machine)
  - Beam vacuum (experiments)
- Deliverables for the power circuits
  - Cryogenics, water cooling, …
  - Cryostat instrumentation
  - Powering interlocks
  - QPS and energy extraction
  - Power converter currents checked
  - Main lattice circuits (dipoles, quadrupoles, sextupoles) powered
  - Experimental magnets & compensators OFF
  - …
- High level controls, ...
- Timing systems, …
- Machine protection subsystems, …
- Radiation monitoring systems, ...

Exit conditions (Objectives)

- Commissioning of TK/HEST/HEBT segment end, injection and thread around ring
- Trajectory acquisition and correction commissioning
- Beam Instrumentation
  - BPM: acquisition, auto-triggered asynchronous mode, first polarity checks
  - Beam Screens/Grids: acquisition, profiles
  - ICTs & DCCTs: acquisition, first calibration cross-check.
  - BLM: acquisition, first adjustment of thresholds
- Measurements
  - Partial polarity and calibration error checks in correctors and BPMs – Priority 1
  - Dedicated polarity and calibration error checks in correctors and BPMs – Priority 2
  - Systematic kick/response optics measurements – Priority 2
  - Injection septa and bumper transfer functions checked – Priority 2
  - Dedicated aperture checks – Priority 2
  - Energy mismatch between previous injector and ring corrected to 0.1% – Priority 2
  - Sextupoles polarities checked – Priority 2
- Machine Protection
  - FBAS operational with all beam and injection permits
  - MASP operational with all beam and injection permits
  - Safe Machine Parameters for beam injection permits (SBF, BPF)
  - (SW) Interlock system operational with all beam permits
- Controls & Applications
  - BI data acquisition, applications, displays and archiving
  - Sequencer, Accelerator & Beam mode state-machine ready
  - Post-Mortem: shot-by-shot beam quality for injection
- Injection System, ...
- Magnets, ...

Next Steps

- Iterate/agree on structure/terminology:
  - HWC (dry-runs)
    - SAT → MPL/MC domain
    - Dry-run – last 6 month before commissioning with beam (BC)
  - BC stages I, II, II
    - BC phases (A.1 injection, …)

- Plan & coordinate dry-runs in view of SIS18 re-commissioning in 2018
  - extend also to ESR & Cryring?
  - driven by SIS18 constraints & CSCO milestone plan and availability
  - tentative schedule:
    - start 6 month before scheduled commissioning with beam, frequency ramp-up
      - 1 day every month (T_{BC} - 6...3 months)
      - 1-2 days every two weeks (T_{BC} - 3 months – 2 weeks)
      - Last two weeks every morning (afternoon to follow-up bugs)

- Start developing beam commissioning procedure → aim at tentative plan in Q3/4-2016
  - Active participation & volunteers appreciated → small activity groups, documentation on wiki
    - Please feel free to propose further participants you consider pertinent or whom it may concern

Comments? Questions?

FCWG – Topics cont'd

- Commissioning in Stages:
  - HWC – Stage I: HWC & Machine Check-Out (S. Reimann/P. Schütt?)
    - power converter, RF, dry-runs, ...
  - HWC – Stage II: test-beds and what can we check w/o beam (J. Fitzek)
  - BC – Stage I: rough machine checkout (tbd.)
    - from injection through extraction, done with “pilot”/“probe”/safe beam intensities only:
      - “easily available” ions (U28+, Ar, etc.) – get particles through the chain (UNILAC → SIS18 → SIS100)
      - protons: check transition crossing/avoidance scheme, etc.
  - BC – Stage II: higher intensities
    - e-cooler, space-charge effects, intensity ramp up
    - slow extraction, other machine specific features
    - Secondary particle recapture ($\bar{p}$ & SFRS targets) into CR → HESR
  - BC – Stage III: increasing intensity/high-intensity proton operation
    - Tighten screws on interlocks, collimation and OP procedures
    - fine-tuning of working point
    - Shift to regular day-to-day operation

Super Cycles at GSI: SIS18

- Cycles are stand-alone
- Template determines *possible* execution sequences
- Beam requests determine *actual* execution sequence

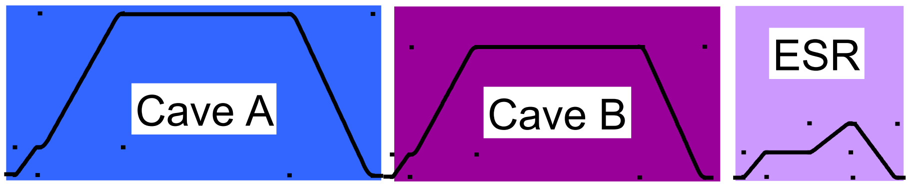
Time honored, but two major flaws:

A) Unpredictable magnetic history
   - frequently leads to beam degradation
   - empty cycles needed, wasting duty cycle

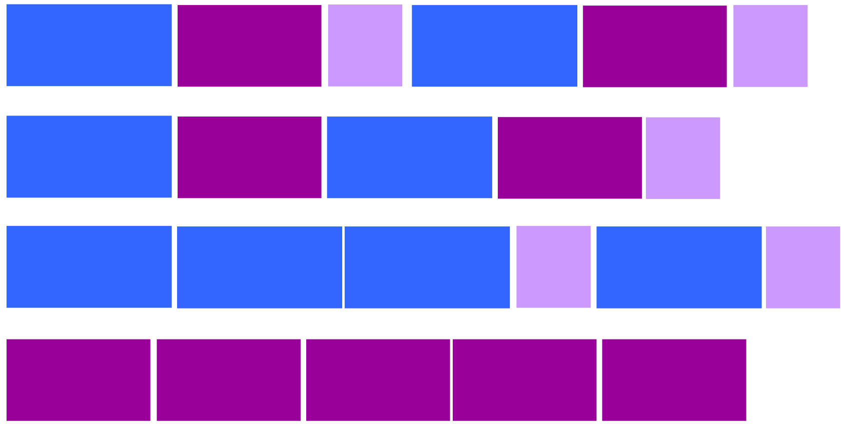
B) Next cycle not known
   - time for preparing transfer lines lost
   - sometimes leads to beam degradation
   - unnecessary idle time for long chains

Needs to be changed for FAIR...

Super cycle template



Possible execution sequences

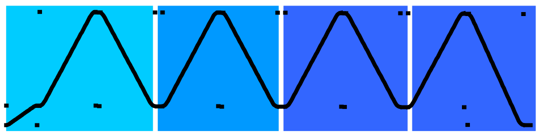


Dynamic Magnet Effects

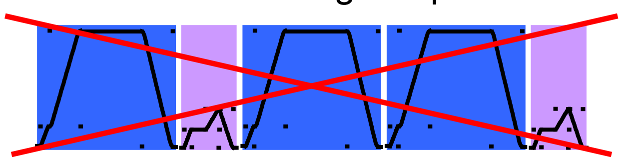
- Mostly iron dominated magnets
  - hysteresis (memory) effects
  - eddy current effects
  - reproducible for known history
  - impact on cycles:
    - critical for multi-turn injection & slow extraction
    - less critical for bucket-to-bunch transfer & fast-extraction

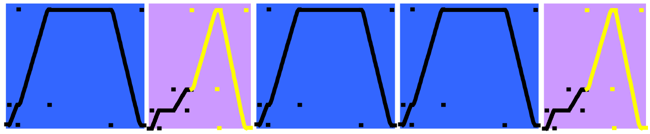
- Possible procedural cures
  - choice of cycle sequence
    - A) periodic patterns to fix history
    - B) conditioning ramps to avoid hysteresis (e.g. ESR low rigidity experiments)
    - C) conditioning cycles for clean history (ie. for PP)
  - modification of settings during setup
    - parameters for compensation of hysteresis
    - add. dead-time for eddy-current decay
    - field corrections based on beam-based feedbacks and measurements

Hysteresis compensation

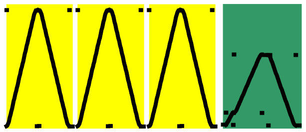


Conditioning ramps





Conditioning cycles

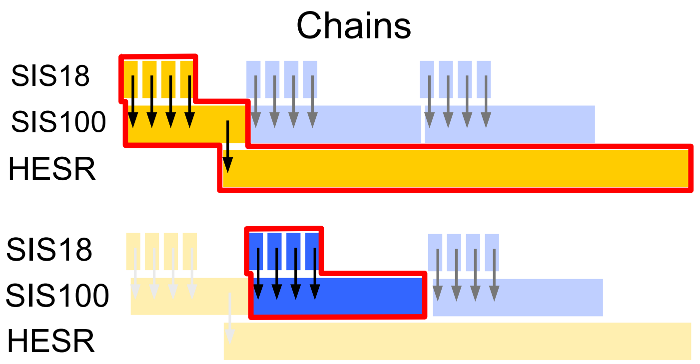


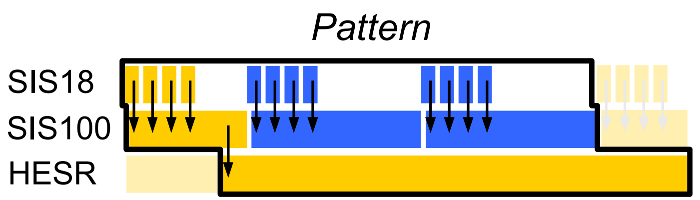
Beam Production Chains & Patterns

- *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

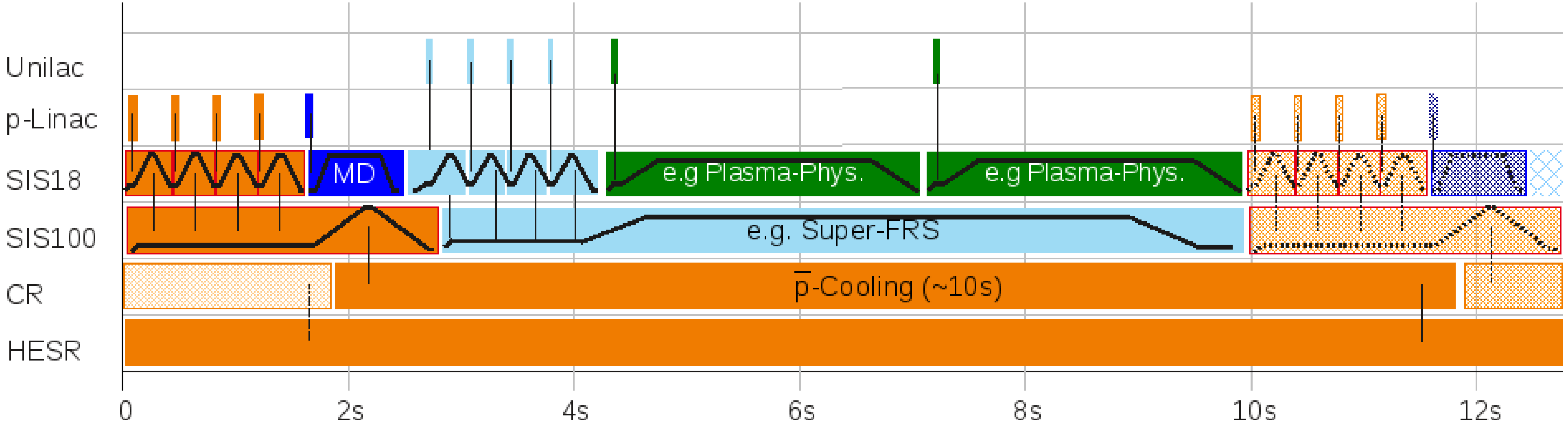




courtesy D. Ondreka

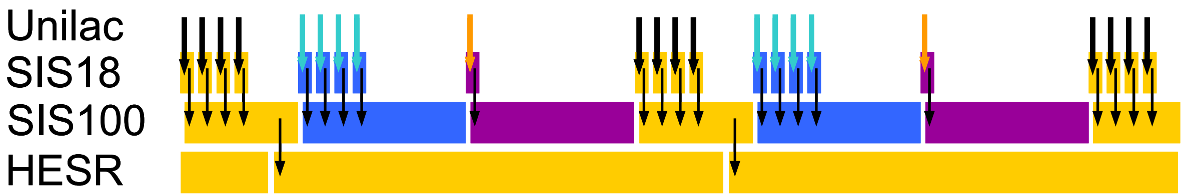
Beam Production Chains & Patterns
Example I/II

- Periodic beam patterns, dominated by one **main** primary experiment
  - example: $\bar{p}$-production in HESR
- Secondary experiments fill gaps to optimise facility/accelerator duty cycle
- additional cycles to setup future beam requests or test new accelerator concepts or parameter (working points)
- Important: maintain pattern as long as reasonably possible ↔ hysteresis

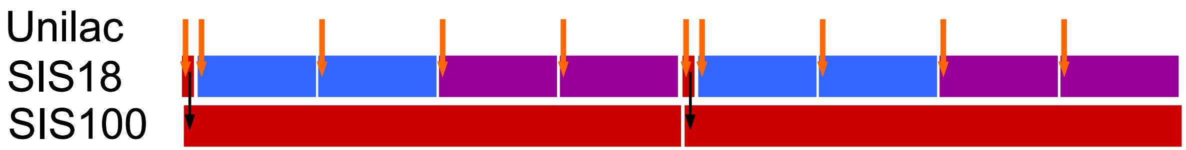


Beam Production Chains & Patterns
Example II/II

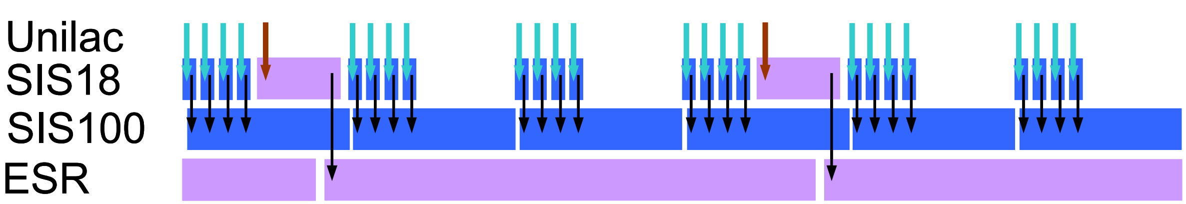
Periodic beam patterns, dominated by one ***main*** experiment:



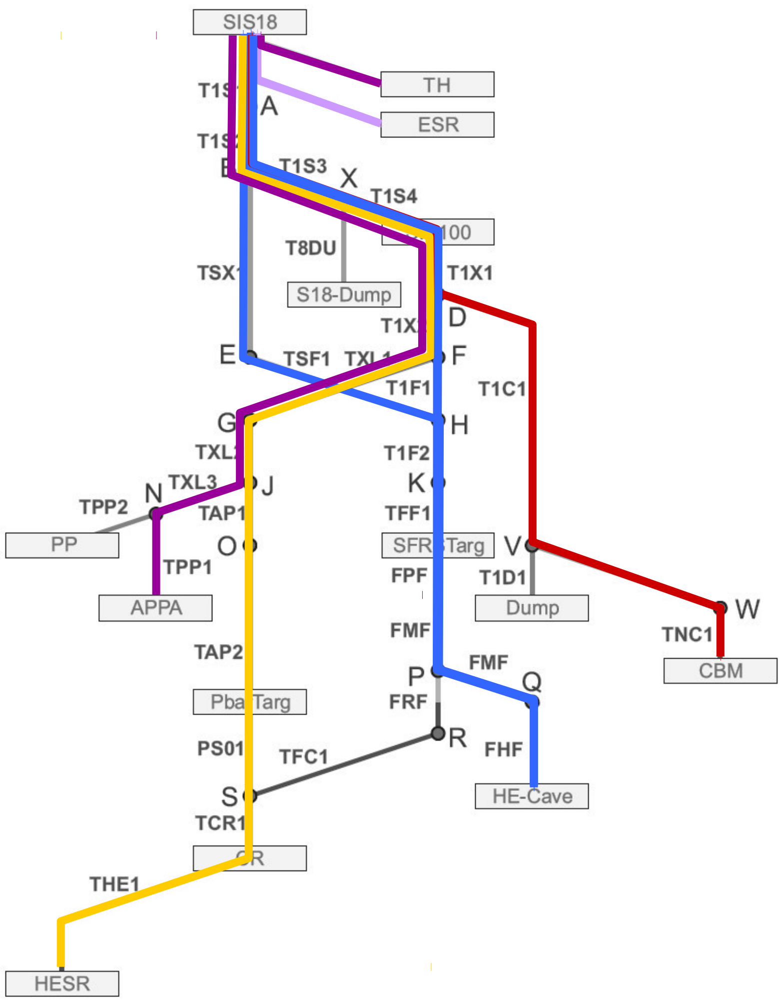
AP + RIB ext. target (U^{28+}) + Biomat



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



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



courtesy D. Ondreka

Non-Tunnel HW Topics to be discussed/decided

- FCT or DCCTs
  - Generation of 'Beam-Presence-Flag' & 'Safe-Beam-Flag' → masking of interlocks/fast-abort-signals
  - time-scale: few ten to hundred milliseconds before extraction
  - option: transmission monitoring? (dI/dt “Interlock”)
- BLMs + cryo-collimator → integration into fast beam abort
  - time-scale: milliseconds → few turn (?, tbd.)
  - Rationale:
    - A) protection of sensitive equipment
      - e.g. electro-static septum, slow-extraction/spill abort (transients)
    - B) redundant MP element
      - “second line of defense” in case other MP measures fail
    - C) High-Intensity Operation: control of transmission, activation (ALARA)
      - BLMs much more sensitive than FCT/DCCTs at high-intensities
    - D) Quench prevention – tbd. ???
  - Idea: could also protect against transients during slow-extraction
- Other BI derived interlocks?
- SIS18/SIS100 BPMs → add. RF-Hybrid & RF-LP-Filter
  - improve robustness (bunch length/shape, intensity variations, less dependency on VGAs, ...)
  - better performance for injection steering & optics measurements (AC-dipole technique)
    - Trade-off: BPMs sensitivity (~1 (now) → 0.1 mm (target)) vs. larger K.O./TFS exciter kicks (δ ≈ 8-16 µrad @ injection)