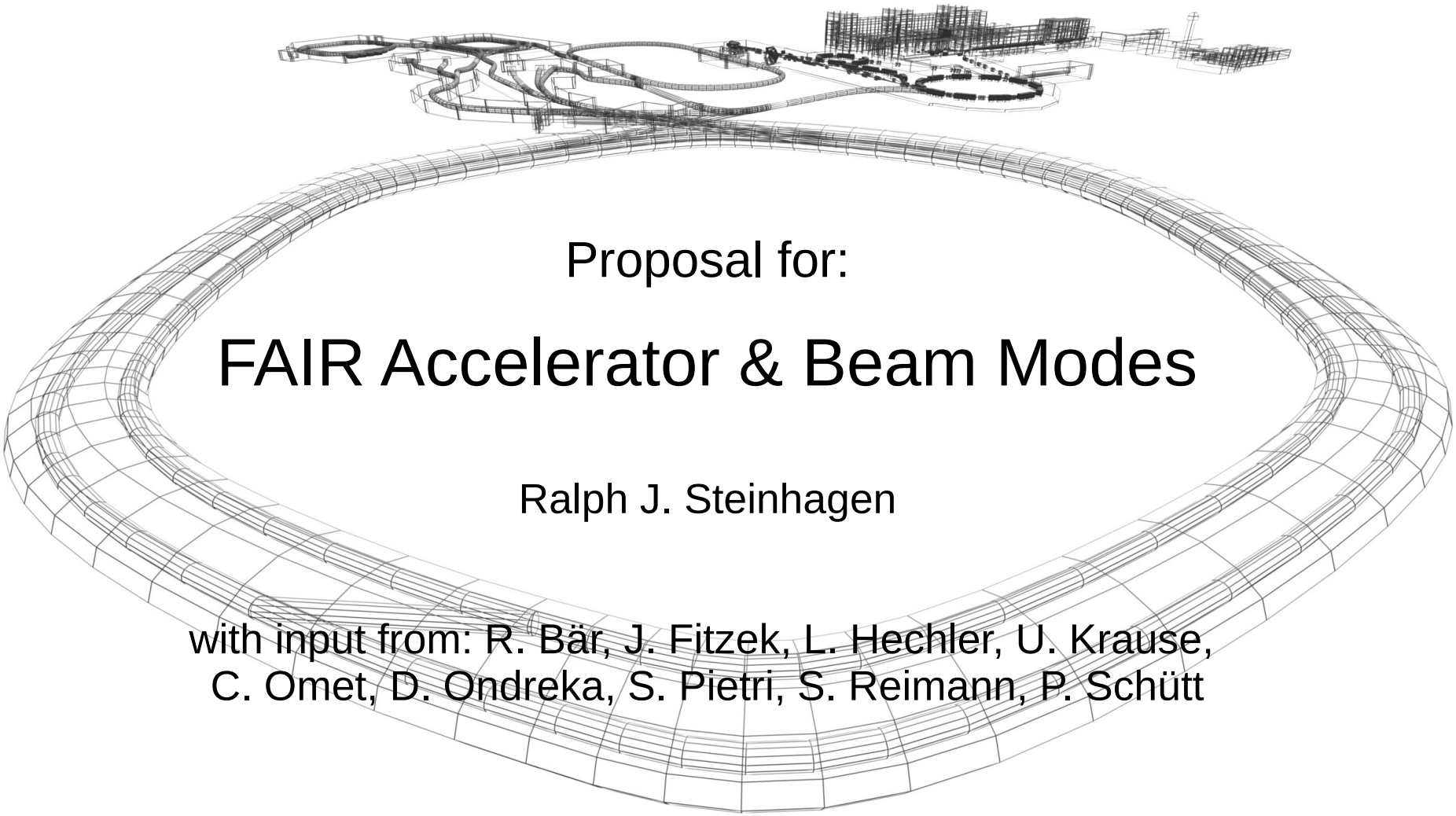


Proposal for:

FAIR Accelerator & Beam Modes

Ralph J. Steinhagen

with input from: R. Bär, J. Fitzek, L. Hechler, U. Krause,
C. Omet, D. Ondreka, S. Pietri, S. Reimann, P. Schütt

FAIR Operation & Rules

Accelerator and Beam Modes

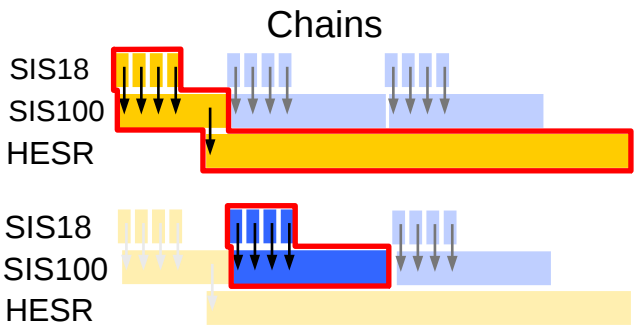
- Purpose:
  - A) Communication of intended accelerator operation to experiments, FAIR and wider community
    - what to expect and when
  - B) Conditioning of control sub-system responses
    - e.g. logging, interlocks, management of critical settings (RBAC), machine sequencer, access system, …

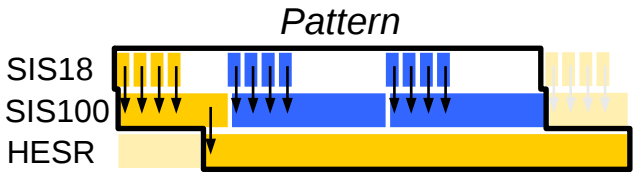
→ associated rules of what is allowed, when, where etc. some examples:

- Limit parameter changes during data taking – aka. 'Stable Beams'/'Production Runs'
- no beam data being logged during 'shut-down' period
- no high-intensity beam injected into an 'empty' machine
- block certain operation during un-safe mode of operation, e.g.
  - moving in beam screens during production runs or while high-intensity beam is being extracted
  - settings change that could affect efficiency/safety of machine operation (e.g. slow-extraction)
  - uncontrolled remote tests on an operational devices during beam operation

Glossary I/II
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)

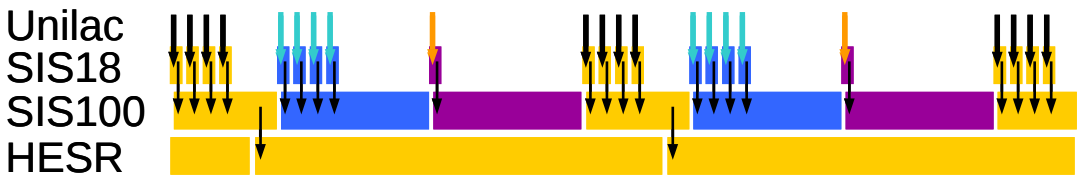




courtesy D. Ondreka

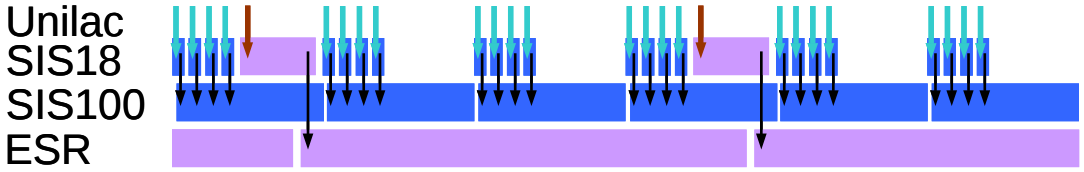
Example: Chain & Pattern

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

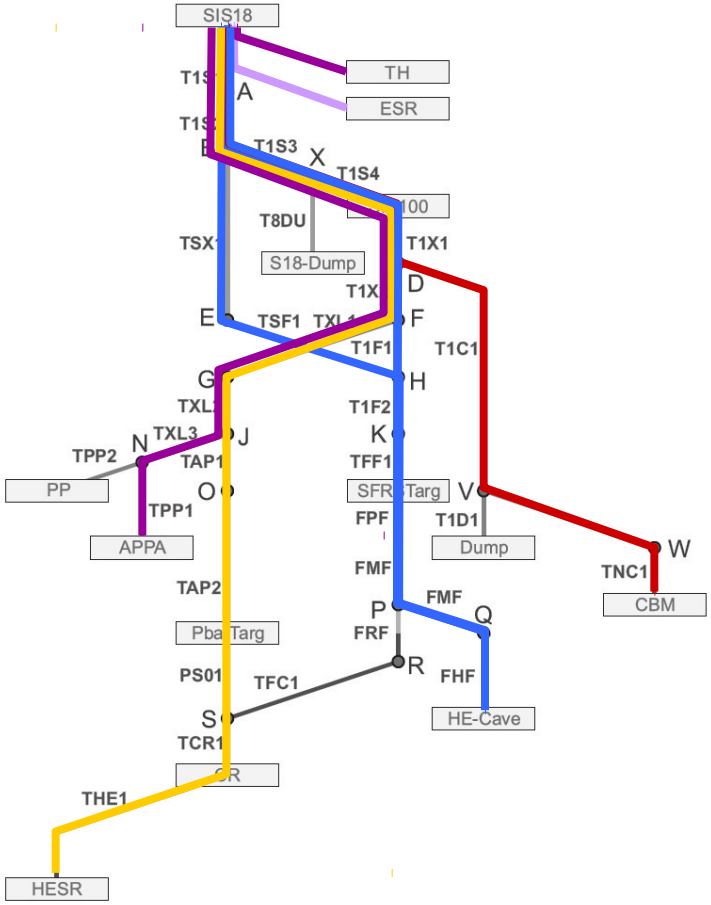


AP *+ RIB ext. target (U^{28+}) + Biomat*

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



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



courtesy D. Ondreka

Glossary II/II
'Mode' & 'Actual States'

Mode:

- deliberate user-driven state used to precondition the control system behaviour and responses independent of the actual accelerator or beam state → 'reference' or 'desired target' of operation (long-term)
  - formal agreement between accelerator operations and experimental users w.r.t. what to expect
- Tracked by operator (initially) and semi-automated sequencer to follow normal operational sequence
  - Example 1: 'Shut-Down' →'Cool-Down' → 'Machine Check-Out'
  - Example 2: … → 'no beam' → 'pilot beam' → 'intensity ramp-up' → 'adjust' → 'stable beams/production for physics' → ...
  - need to limit number of mutually exclusive and concise modes ↔ overhead of settings generation and their checks
- no real-time requirements

Actual State:

- measured current state of the accelerator/beam (short-term)
  - perviates accelerator & beam mode definition & equally used as a ad-hoc/post condition
  - Examples: Beam-Presence-Flag (BPF), Setup-Beam-Flag (SBF), Injection & Extraction Permit (MP interlock states)
- real-time requirements

- Examples:
  - 'No Beam' beam mode declares intend (as an agreement) that there will be no beam in the machine
  - 'Beam Presence Flag' is measured actual state whether there is (/was) beam in the machine or not
    - N.B. obviously a 'NO BEAM' beam mode & 'BPF=true' should lead to an interlock

- Shouldn't mix 'modes' with 'actual states' to prevent circular dependencies, priority/causality inversions

Accelerator & Beam Modes

- Main modes:

1) Accelerator (Machine) Modes
   - covering rule sets outside of beam operation
   - defined per accelerator/transfer-line segment

2) Beam Modes
   - covering rule sets during beam operation
   - defined per accelerator/transfer-line segment and beam-production-chain

3) 'is operational' mode (boolean flag)
   - defines whether device/machine control is handled by OP from MCR (formalised handover from development/'machine check-out' to OP)
   - e.g. non-MCR access to 'operational device ' is locked down as soon as e.g. 'MACHINE-CHECKOUT' mode is reached (↔ access via RBAC still possible)

FAIR Accelerator Modes

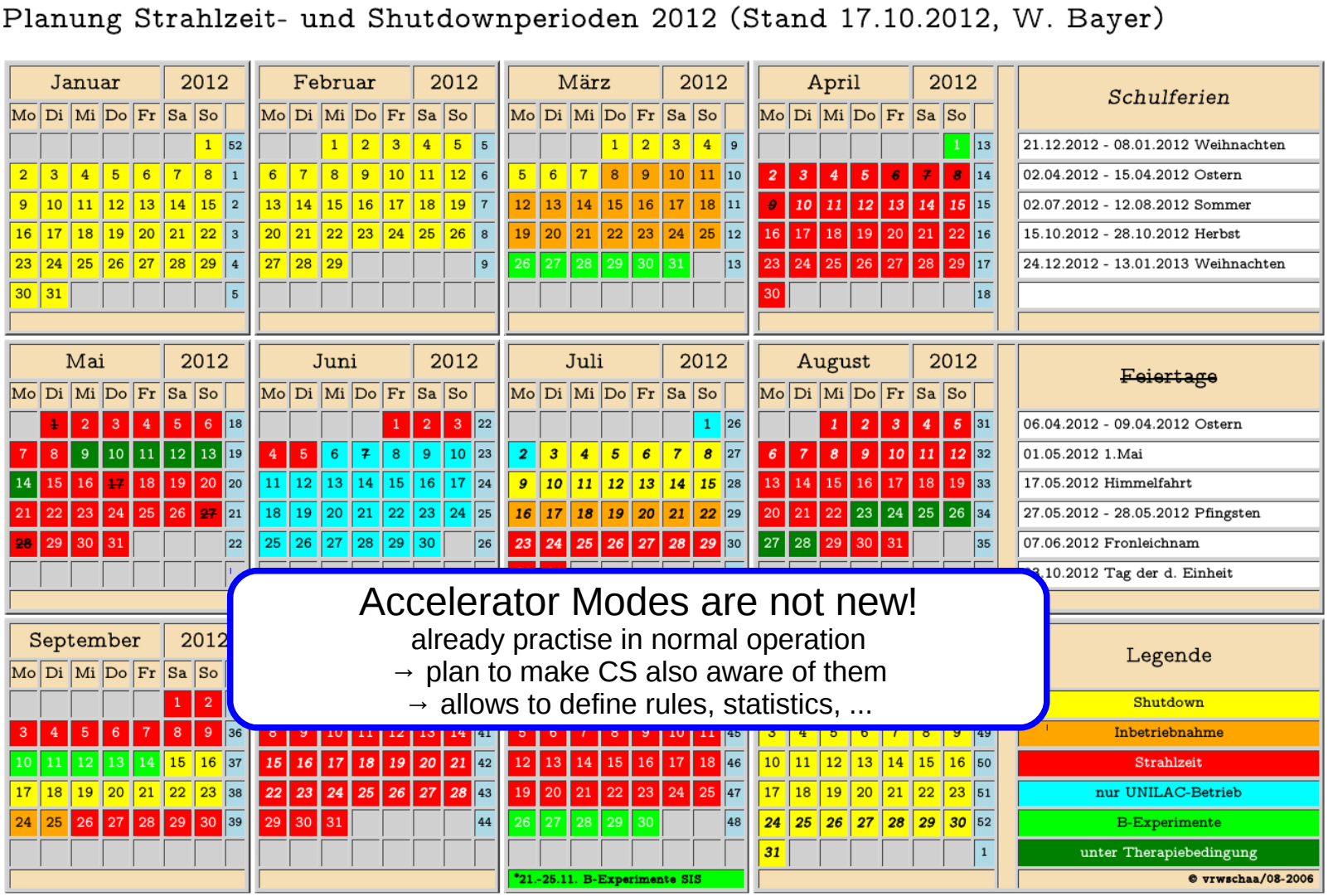
Follows annual life-cycle of accelerator facility

- **Operation without Beam:**
  - SHUTDOWN
    - could imply possibility of open/controlled access or no powering
  - COOLDOWN (SIS100, SFRS)
    - typ. 2-3 weeks, limited/no access
    - need to distinguish between a 'warm' and cold' shutdown?
  - BAKE-OUT (SIS18, HEBT, …) – similar to cool-down
  - WARM-UP (SIS100, SFRS)
  - RECOVERY (SIS100, SFRS)
    - after quench, partial vacuum loss, typ. few hours - day
    - includes e.g. periodic magnet CYCLING to stabilise hysteresis
  - MACHINE-CHECKOUT
    - operations tests without beam in view of beam operation
    - (e.g. power converter calibration, magnet patrol, etc.)
    - done once after a long shutdown, typ. few weeks before beam operation
  - ACCESS (during beam operation periods)
    - controlled access for specific tasks only (signature by MCs & OP)
- **Operation with Beam:**
  - BEAM SETUP or MACHINE SETUP
    - focus on initial/re-commissioning, machine setup after long shut-down + OP training
  - PHYSICS
  - MACHINE DEVELOPMENT
    - focus on accelerator/beam physics aspects
- MACHINE TEST (during beam operation periods)
  - controls, RF, new front-end, ... tests w/o beam + OP training
  - Ad-hoc during beam operation but not 'Physics' nor 'MD'

operation without beam
(part of shut-down coordination)

describe main aim
of machine operation
+
info & Accounting
type modes

Example: GSI Beam Schedule aka. “Strahlzeitplan”



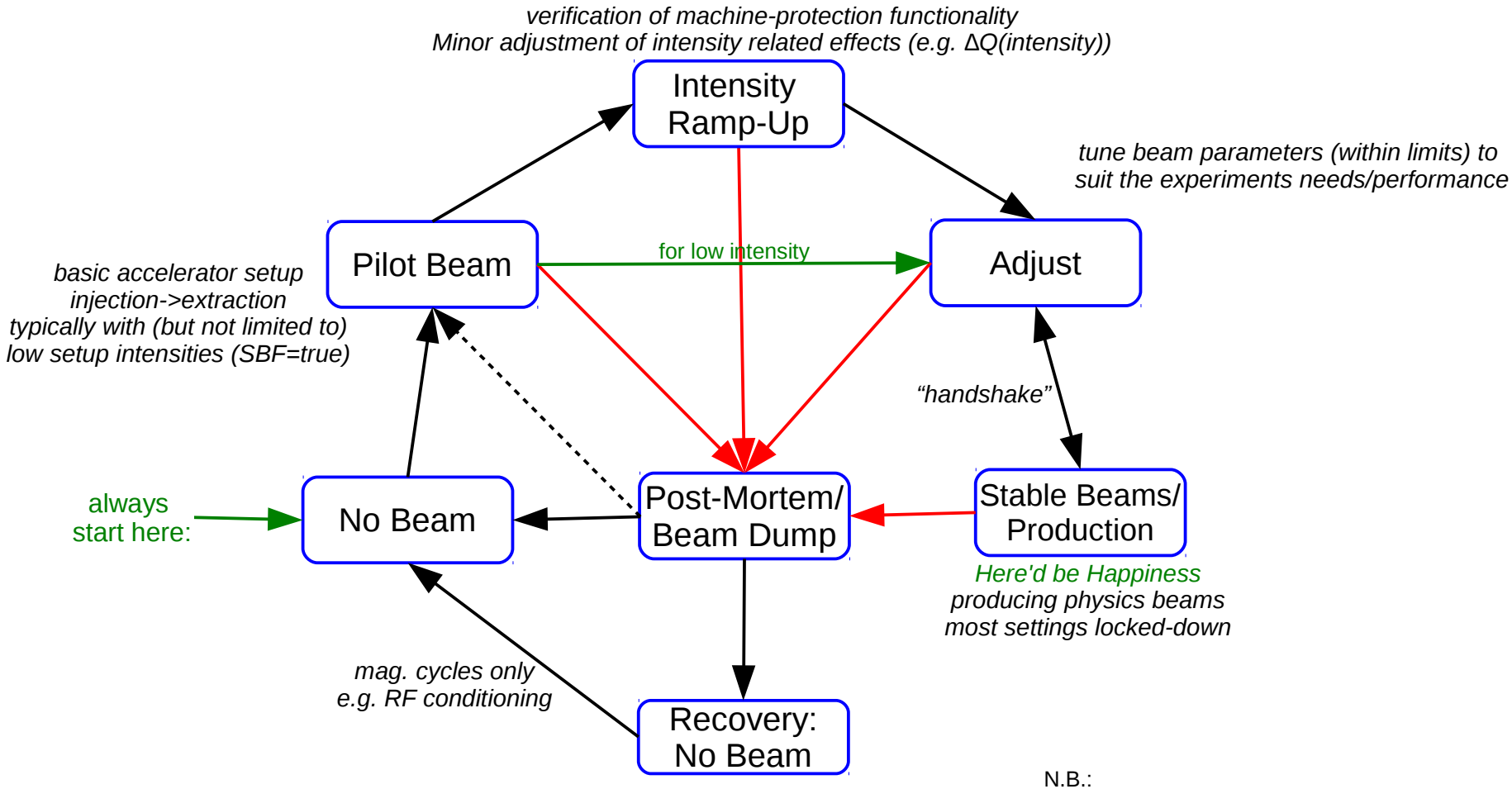
Accelerator Modes are not new!

already practise in normal operation

→ plan to make CS also aware of them

→ allows to define rules, statistics, ...

Proposal:
FAIR Beam Modes – State Diagram



normal operational path
error/fault case
low-intensity

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 Beam Modes

- Follows life-cycle of beam setup and production – also not new, de-facto how
  - NO BEAM
    - prevent/stop beam being injected by design (↔ mode)
  - PILOT BEAM – alternate: Beam Setup?
    - Establishing main machine parameters: injection steering, RF capture, ramp, orbit, Q/Q', optics checks, extraction
      - typically done with low setup-intensities
  - INTENSITY RAMP-UP – should we differentiate stages? e.g.: INT. RAMP-UP #1, INT. RAMP-UP #2, ... ?
    - beam parameter tuning and checks related to increasing intensities (e.g. slow extraction, space-charge, etc.)
    - check of interlocks & machine protection functionalities (limited user group only ↔ special RBAC role for e.g. interlock settings)
  - ADJUST
    - Perform actions/change minor beam parameters (“minor” needs to be defined)
    - tune beam parameters (within limits) to suit the experiments needs/performance
  - STABLE BEAMS – alternate: PRODUCTION (for physics)
    - main intend is to deliver stable beam to experiments
    - tbd: very limited machine tuning
  - BEAM-DUMP or POST-MORTEM
    - response to quench, MP action, or other action that needs to be analysed before one can continue with normal operation
  - RECOVERY
    - recovering from severe post-mortem, essentially includes 'CYCLING'
- For storage rings (essentially only ESR & HESR)
  - Do we need INJECTION/ACCUMULATION & RAMP modes?

Beam Modes are not new!
already practise in normal operation
→ plan to make CS also aware of them
→ allows to define rules, statistics, ...

Accelerator vs. Beam Mode Matrix

N.B. defined per accelerator/transfer line segment

Beam Mode	Accelerator Mode: Shut-down	Cool-down	Warm-Up	Recovery	Beam Operation: Machine-Checkout	Access	Machine Test	Beam Setup	Physics	Machine Development
No Beam	X	X	X	X	X	X	X	X	X	X
Pilot Beam								X	X	X
Intensity Ramp-Up								X	X	X
Adjust								X	X	X
Stable Beams									X	
Post-Mortem								X	X	X
Recovery								X	X	X

N.B. defined per accelerator/transfer line segment & beam production chain

concatenation of <accelerator mode>:<beam mode>
e.g. 'Shut-down:No Beam', 'Physics:Pilot Beam'

Beam (Past) Presence Flag (BPF)

- indicates that cycle/settings have been validated with Pilot- or Physics-Beam in the recent past*
  - main usage: prevent high-intensity injections into an 'empty' machine with new untested magnetic settings or modified machine conditions
  - defined per accelerator or transfer-line segment (where necessary)
  - flag being set if settings are basically OK (excluding high-intensity effects) w.r.t. basic accelerator function. Example:
    1. empty machine → beam mode set to 'PILOT BEAM'
    2. check/tune: injection, RF capture, orbit, tune, chromaticity, ramping, extraction, transmission, …
    3. Compare results with targets (either by design or from Archiving System)
    4. if result is with predefined limits→ 'BPF:=true' + time stamp
       - initial check done by operator, subsequent updates by sequencer
    5. sequencer: repeat steps 2-4 in parallel and update time stamp when applicable
  - To be discussed/defined:
    - when are 'settings' are the 'same', 'marginally' and 'sufficiently' different to force stepping back to 'pilot beams' ↔ affects: settings check, tolerance bands & MCS
    - Proposal to automatically expire when 'Accelerator Mode' changed
      - e.g. Physics→Access → Physics
    - when to 'expire' the BPF: after a few minutes, hours, days, weeks?
      - N.B. *'recent past' ↔ slightly different definition compared to LHC

Setup* Beam Flag (SBF) I/II

- Indicates beam used to setup beam production chain
  (typically low-intensity)
  - Interlocks targeted for high-intensity operation may impact setup and availability with low-intensities.
  - defined per accelerator or transfer-line segment (where necessary)
  - SBF provides flexibility of masking interlocks during setup periods
    - Flag derived automatically by beam current transformers (simple threshold)
    - 'SBF=TRUE': less critical interlocks can be masked
      → improves availability
    - 'SBF=FALSE': masked interlocks are automatically un-masked
      → limits risk of forgotten but for high-intensities critical masked interlocks
  - Examples:
    - temporary transmission of 20% OK during setup but shouldn't keep this disabled once moving to high-intensity operation with same beam type
    - Beam screens, wire-grids create extraction/injection interlock when inserted to protect themselves. Interlock can be however be masked if the 'SBF==true' + additional beam mode requirements: e.g. not in 'STABLE BEAMS' or 'INTENSITY RAMP-UP', etc.

Setup* Beam Flag (SBF) II/II

- *N.B. why 'Setup' and not 'Safe': SBF formerly also coined as 'safe beam flag', but 'setup' preferred to 'safe' since
  1. some of the setup operations need to be done with un-safe beam intensities,
  2. there is no unconditional 'safe intensity' for some very sensitive devices (e.g. SIS100 e.-s. septa, Si tracker)
  3. Old/known concept: should stick to common terminology already established in other facilities (CERN)
  - Examples:
    - e.g. setup of slow extraction (different emittances due to 'emittance↔intensity' correlation, etc.)
    - e.g. setup of BLM thresholds with nominal beam intensities

- SBF-maskable interlock candidates: mostly more complex & BI-derived interlocks:
  - beam transmission & beam loss monitoring (↔ beam availability during beam setup)
  - beam screens & multi-wire grids (protect when necessary)
  - orbit during injection, ramp & extraction (↔ uncertain reliability)
  - long-term: longitudinal (easier) & transverse emittance

- To be discussed:
  - BPF & SBF transmission via timing system alongside accelerator & beam mode information
    - no BCT information → 'SBF:=FALSE'
    - if $(t_{now}-t_{BPF})>\Delta t_{thresh.}$' → BPF:=FALSE'
  - Integration of SIS18/SIS100 current transformer, threshold definition, time-scales, reliability
    - Simple threshold, evaluated 100 (10?) ms before SIS18/SIS100 extraction; no information → 'SBF:=FALSE'

Additional States

- Injection/Extraction Permit
  - SIS100 equipped with fast-abort-system that de-facto defines this
  - need similar structure also for SIS18, Super-FRS, HEBT, … to suppress extraction/injection of unsafe high intensity beam
    - e.g. when beam screens are inserted in transfer-line

Summary/Next Steps

- Accelerator & Beam Modes:
  - 'modes' are deliberate user-driven states declaring the intended operation/sequences
    - Communication of intended accelerator operation to experiments, FAIR and wider community
    - Conditioning of control sub-system responses
  - Proposed modes:
    - Accelerator Modes (11): SHUTDOWN, COOLDOWN, WARM-UP, RECOVERY, MACHINE-CHECKOUT, ACCESS, MACHINE TEST, Operation with Beam (info): BEAM SETUP, PHYSICS & MACHINE DEVELOPMENT
      - covering rule sets outside of beam operation, defined per accelerator/transfer-line segment
    - Beam Modes (7): NO-BEAM → PILOT BEAM → INTENSITY RAMP-UP → ADJUST → STABLE BEAMS + POST−MORTEM & RECOVER
      - covering rule sets during beam operation, defined per accelerator/transfer-line segment and beam-production-chain
- 'Actual States' – measure current states
  - Beam-Presence-Flag, Setup-Beam-Flag, Injection/Extraction Permit
    - N.B. should refer to 'setup beam' rather than 'safe beam'
- Next steps:
  - re-Iterate concept through FAIR Commissioning & Control WG (FC^{2}WG)
  - Prepare and circulate dedicated specification via EDMS as reference document (target: Q3-2015)
    - N.B. present information spread out/included into documents with other larger/different focus

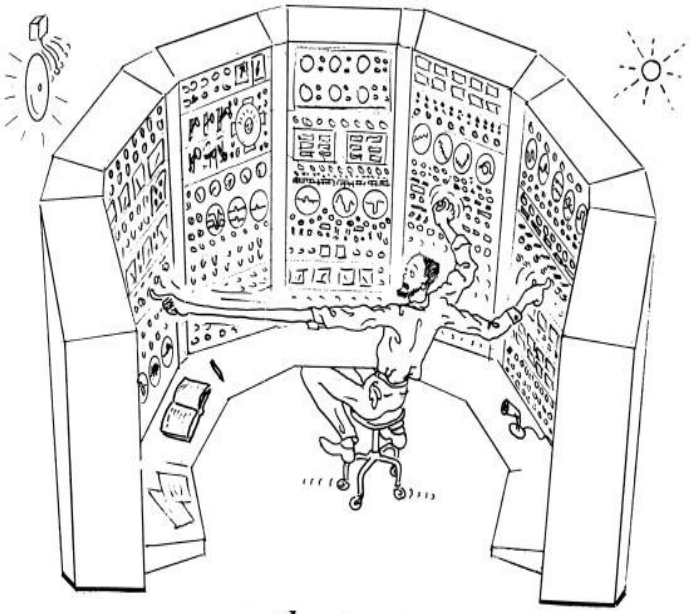
Historic Cross-References

- P. Schütt, “Betrieb der GSI/FAIR Beschleunigeranlagen”, V 7.0, EMDS, #1057366, 2010-10-15 (dated/incomplete)
  - link: https://edms.cern.ch/file/1057366/1/Betriebskonzept-V7.pdf
- J.Fitzek et al., “Detailed Specification of the FAIR Accelerator Control System Component 'User Applications'“, F-DS-C-04e, V3.0, 2012-08-16
  - link: https://edms.cern.ch/file/1176028/1/F-DS-C-04e_User-Applications-v3.0.pdf
- R. Alemany, M. Lamont, S. Page: “LHC Modes”, LHC-OP-ES-0005 rev 1.0, EDMS, #865811
  - link: https://edms.cern.ch/file/865811/1.1/LHC-OP-ES-0005-10-10.pdf
  - update: https://edms.cern.ch/file/1070479/1.6/LHC-OP-ES-0022-V1_6.docx

Appendix

Two Perspectives on FAIR
'Accelerator' and 'Beam Modes'

. . . the experimental physicist



. . . the operator

… two modes:

'Beam-on or Beam-off'

needs good compromise

… more than two modes

Accelerator & Beam Modes – Cont'd

- Mode changes need to be logged and used as meta-data for archiving & system machine performance analysis, e.g.
  - Accelerator performance: intensity/particles-on-target during 'Stable Beams'
  - Accelerator availability: how was allocated beam time spread across 'Beam Setup', 'Intensity Ramp-Up', 'Adjust' & 'Stable Beams' for given experiment
    - establishes reference for future, identifies bottlenecks/inefficiencies to be targeted
  - Beam parameter stability during 'Stable Beams' (e.g. orbit, Q/Q', transmission)
- Accelerator modes are independent for every machine/transfer line segment
  - Respect modes in accelerator chain
    - e.g. cannot have down-stream machine in 'production beams' while up-stream machine is e.g. in 'ACCESS', 'PILOT BEAMS', etc.
- Beam modes are different for beam production chains
  - e.g. SIS100 could be in 'PRODUCTION' for U^{28+} but in 'SETUP' for Au^{79+}
    - Need to check for accelerator modes that are global (e.g. access, recover, cool-down