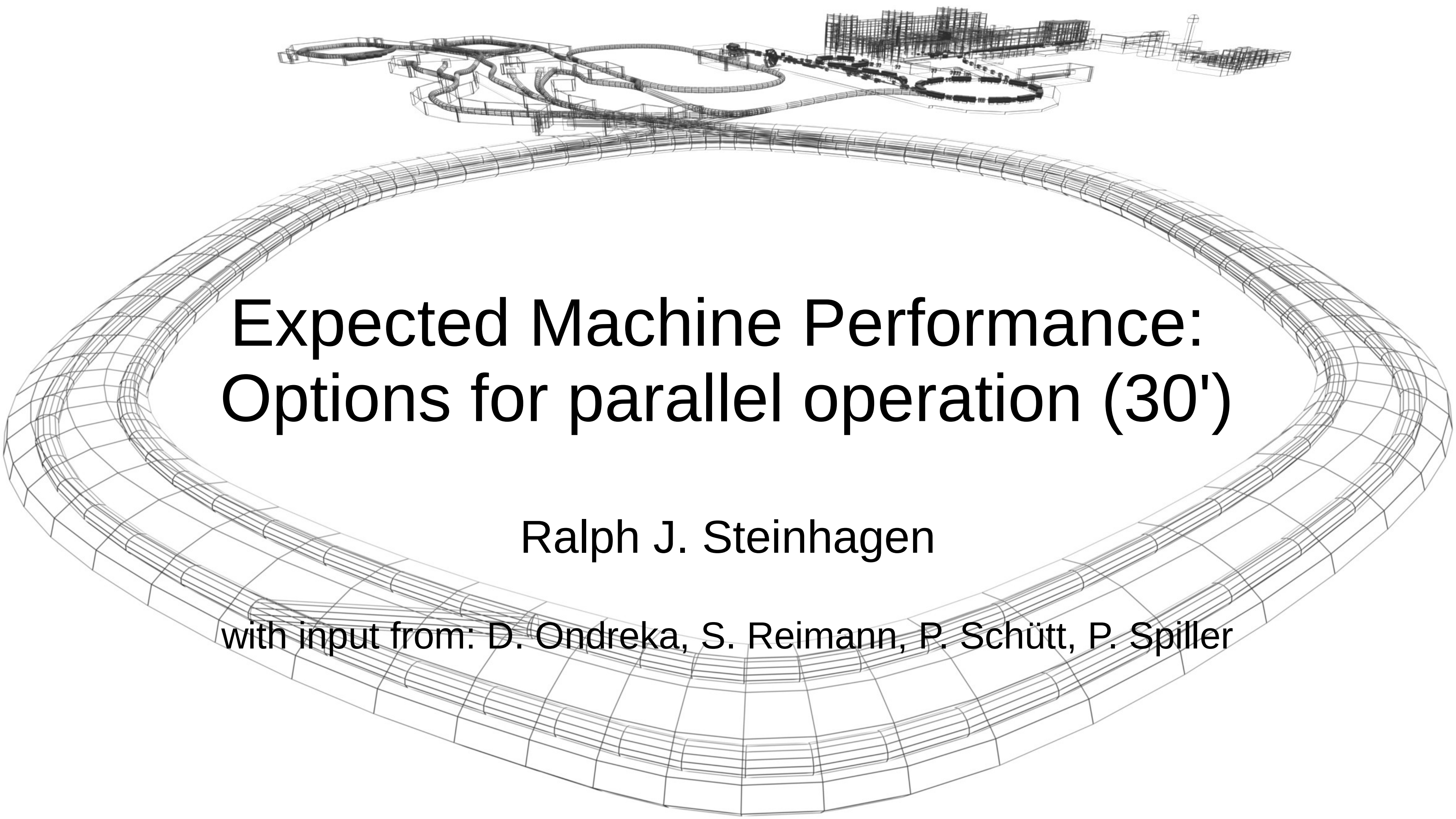
GSI Helmholtzzentrum für Schwerionenforschung GmbH

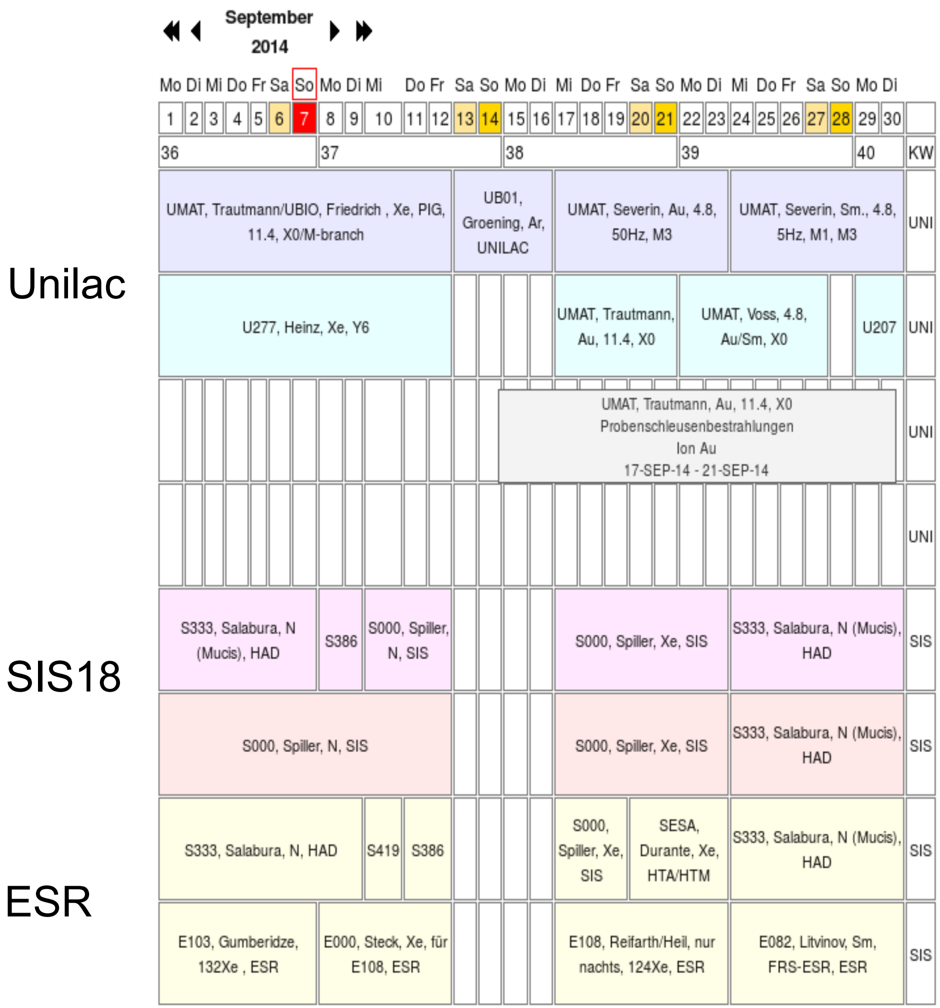


# Expected Machine Performance: Options for parallel operation (30')

Ralph J. Steinhagen

with input from: D. Ondreka, S. Reimann, P. Schütt, P. Spiller

# Typical GSI Operation & Beam Time Schedule




- GSI facility
  - 2 + 1 accelerators
  - 20 experimental areas
- Parallel operation
  - UNILAC, SIS18, ESR independent
  - 3 different ion species
  - 5 parallel experiments
- Experiments demand high flexibility
  - Variation of beam parameters (daily)
    - energy, intensity
    - extraction type
    - number of bunches
  - Change of beam sharing (daily)
  - Switching of ion species (weekly)
  - Adjustment of schedule (monthly)

# Super Cycles at GSI: SIS18

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

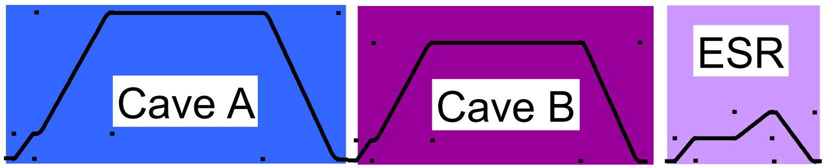
Time honored, but two major flaws:

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

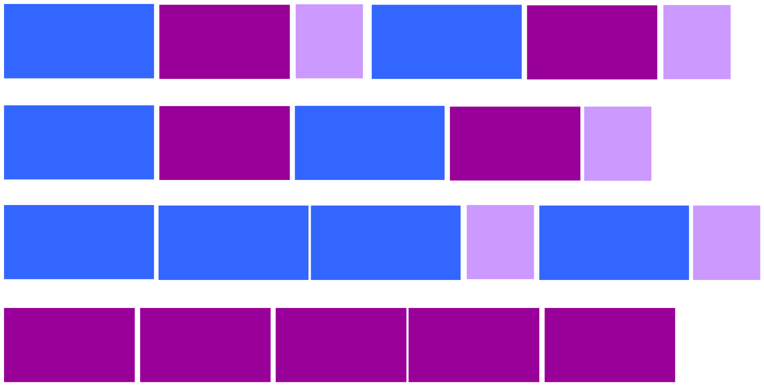
B) Next cycle not known
   - time for preparing transfer lines lost
   - sometimes leads to beam degradation
   - unnecessary idle time for long chains

Needs to be changed for FAIR...

Super cycle template



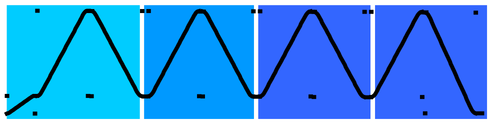

Possible execution sequences



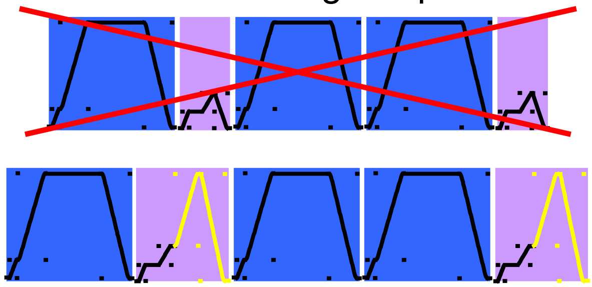
# Dynamic Magnet Effects

- 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

Hysteresis compensation

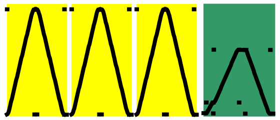


Conditioning ramps



- 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

Conditioning cycles



# FAIR Recap: 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

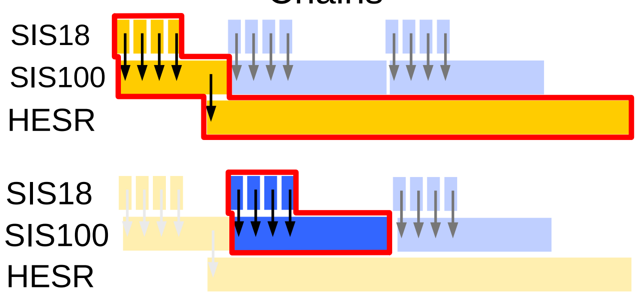
# Beam Production Chains & Patterns

- *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, …

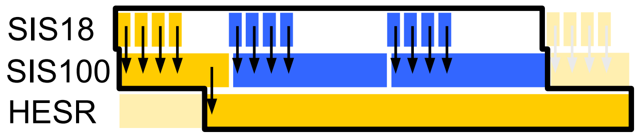
- *Beam Pattern*:
  - grouping of beam production-chains that are executed periodically
  - can be changed of pattern within few minutes (target, requires automation for beam-based retuning)

→ 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

Chains



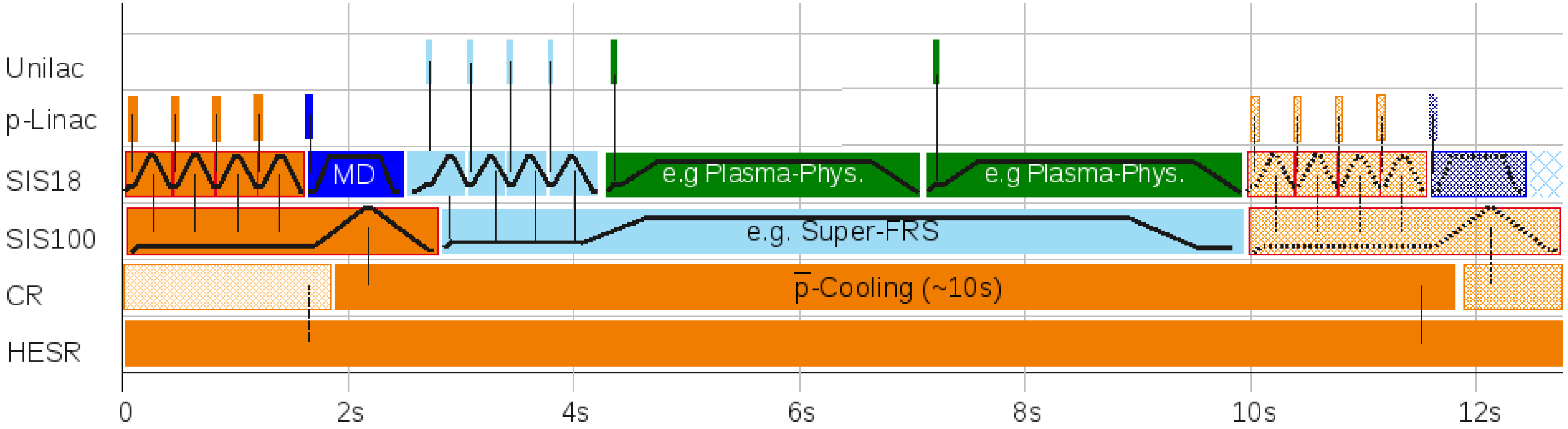

*Pattern*




courtesy D. Ondreka

# Beam Production Chains & Patterns
## Example I/II

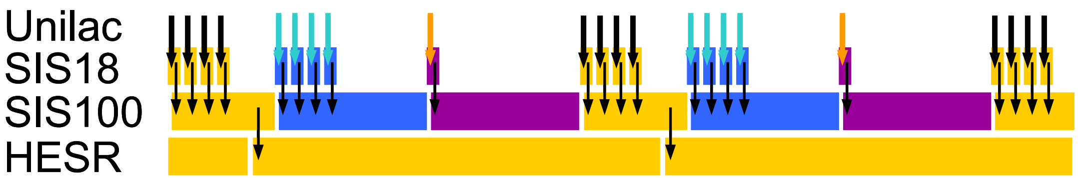
- Periodic beam patterns, dominated by one **main** primary experiment
  - example: $\bar{p}$-production in HESR
- Secondary experiments fill gaps to optimise facility/accelerator duty cycle
- additional cycles to setup future beam requests or test new accelerator concepts or parameter (working points)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



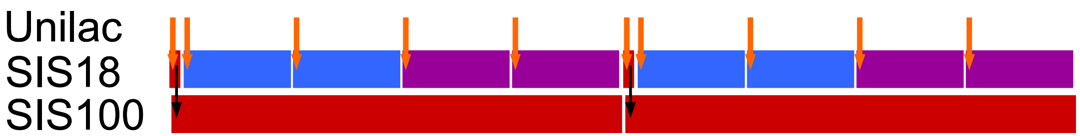
# Beam Production Chains & Patterns

## Example II/II

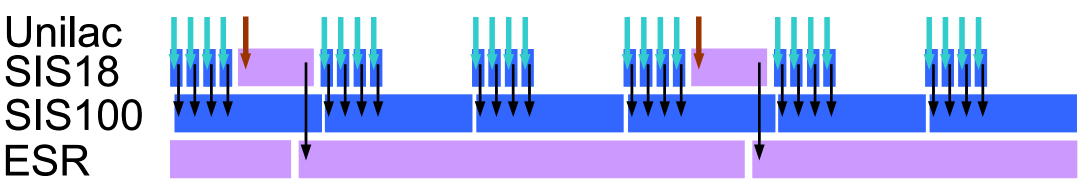
Periodic beam patterns, dominated by one ***main*** experiment:



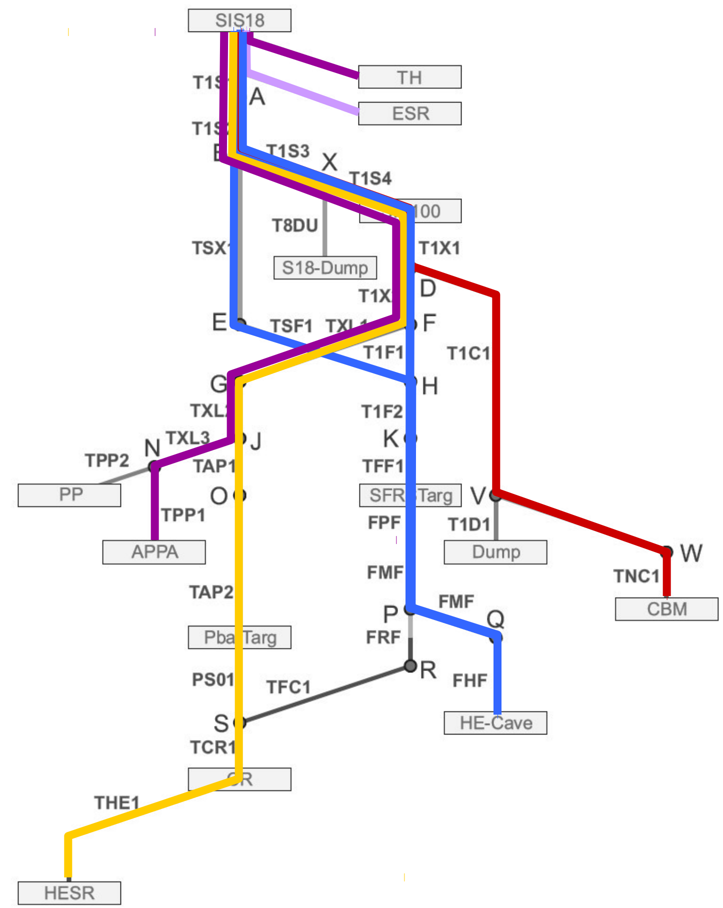

***AP*** *+ RIB ext. target ($U^{28+}$) + Biomat*




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




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




courtesy D. Ondreka

# FAIR Parallel Operation Options
## Some Boundary Conditions

- FAIR will be very flexible w.r.t. parallel operation scenarios.
  - mostly defined by UNILAC, SIS18, SIS100 & HEBT
- Some limitations to flexibility:
  - UNILAC: one high-intensity source + 2 low(er) intensity sources
    - limits choice of ions running in parallel
    - reliability in case of failures, repairs, or upgrade scenarios
    - p-linac would provide an valuable complement
      - high-intensity ion in || to high-intensity protons operation
      - healthy redundancy for UNILAC
    - ...
  - SIS18/SIS100:
    - limitations w.r.t. peak power consumption
    - exclusivity of laser cooling experiments
    - cycle-to-cycle movement of 2-stage collimation system → 1.5 collimation system (single foil, one-sided collimator + multiple-turns)?
    - …
  - HEBT:
    - invasive diagnostics (screen, grids, MWPC), devices that cannot be (re-)moved cycle-by-cycle, ...
      - impact on parallel machine setup
    - ...
  - Super-FRS, CR & HESR
    - slow w.r.t. rigidity changes (Super-FRS: ~ 15 min. H. Weick, yesterday)
    - polarity changes ($\bar{p}$ ↔ ion operation)

# Additional New Constraints: High-Intensity Operation I/II

- FAIR High-Intensity Targets: → more details: V. Kornilov's & C. Omet's talk
  - Accelerator operation does not become easier with higher intensities!
    - 10-100 x higher intensities & ~6 x higher energies than present GSI facility
    - beam becomes more sensitive to:
      - beam parameter changes: tune, orbit, chromaticity, optics errors, machine non-linearities, …
      - dynamic vacuum effects (higher losses)
      - magnet hysteresis → may change tune/orbit working point & impact slow extraction/losses
  - Machine Protection = 'Investment Protection'
    - minimise risk of beam induced equipment damage
    - minimise accelerator activation ↔ ALARA

- Control of particle losses becomes important
  - more precise monitoring and control of machine parameter

- Limits setup of new experiment in parallel to/and high-intensity experiments
  - use of intercepting devices in common transfer lines & rings
    - e.g. beam screens, Faraday cups, ...
  - change of beam parameters (intensities, rigidity, slow/fast extraction)
  - change of beam pattern/cycle structure → aim at keeping a reproducible machine

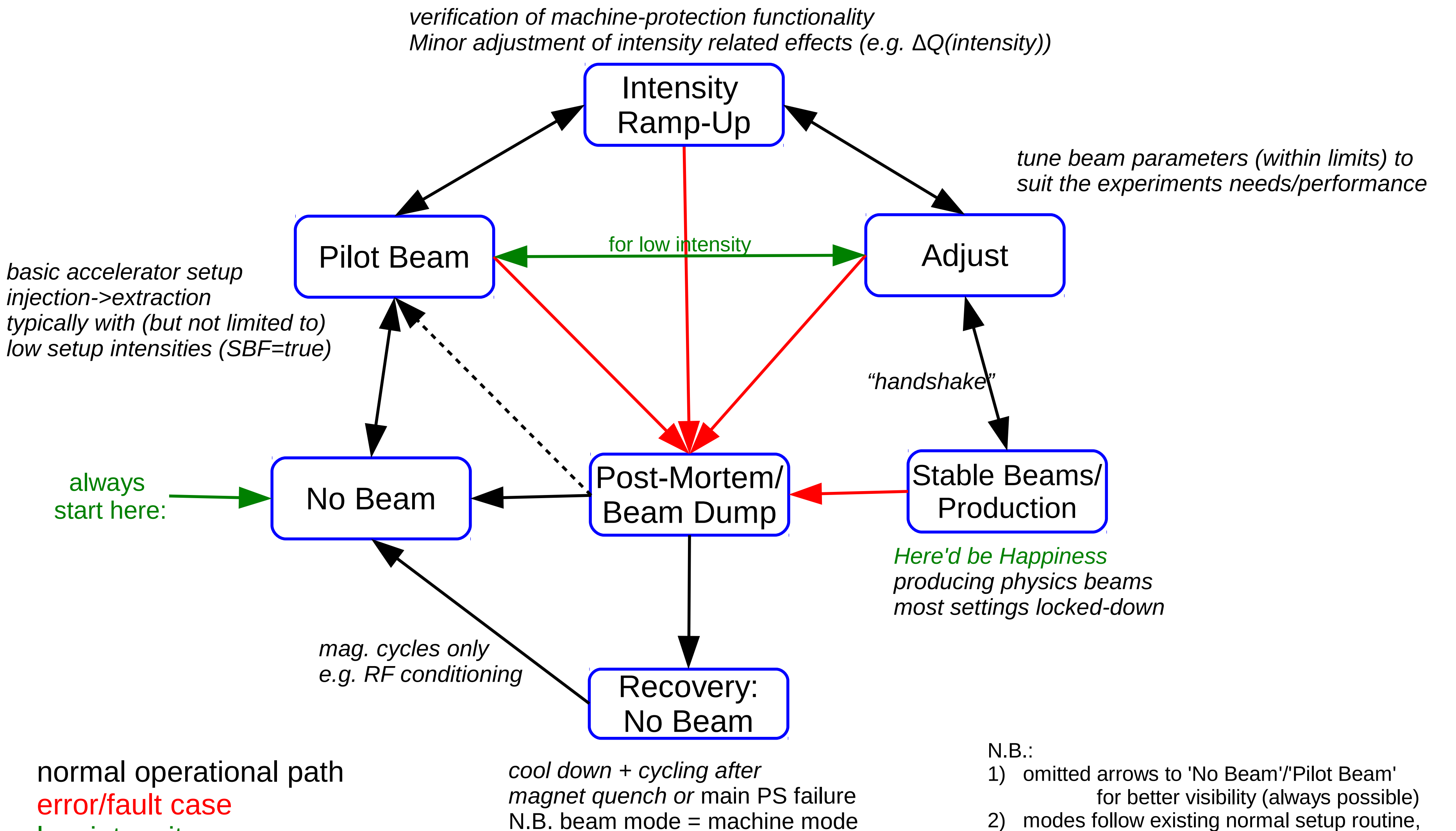
# Additional New Constraints: High-Intensity Operation II/II

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

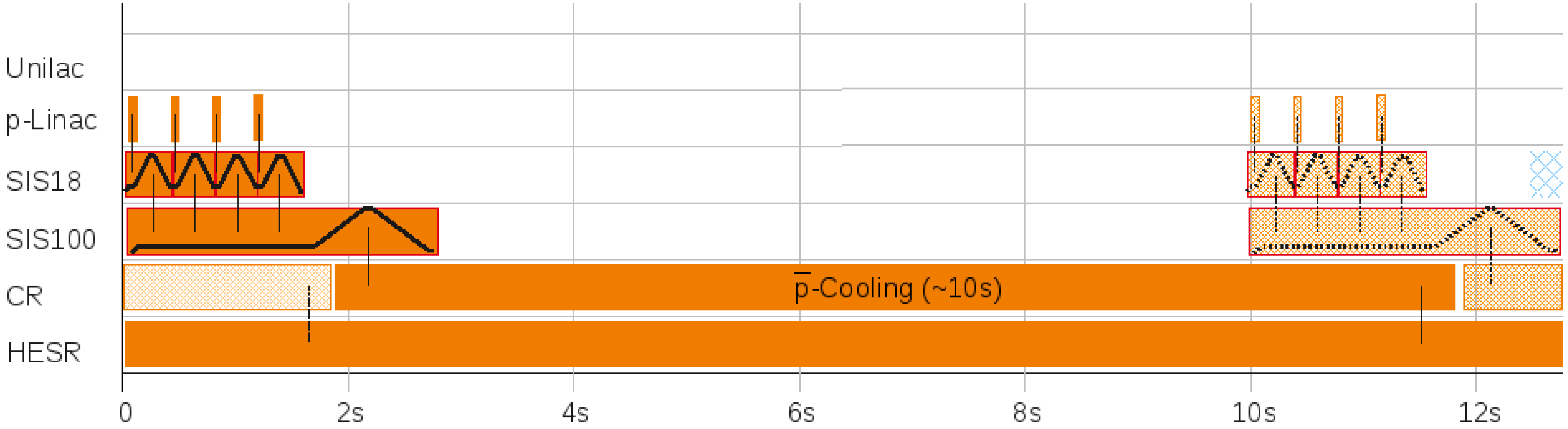



normal operational path
error/fault case
low-intensity

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

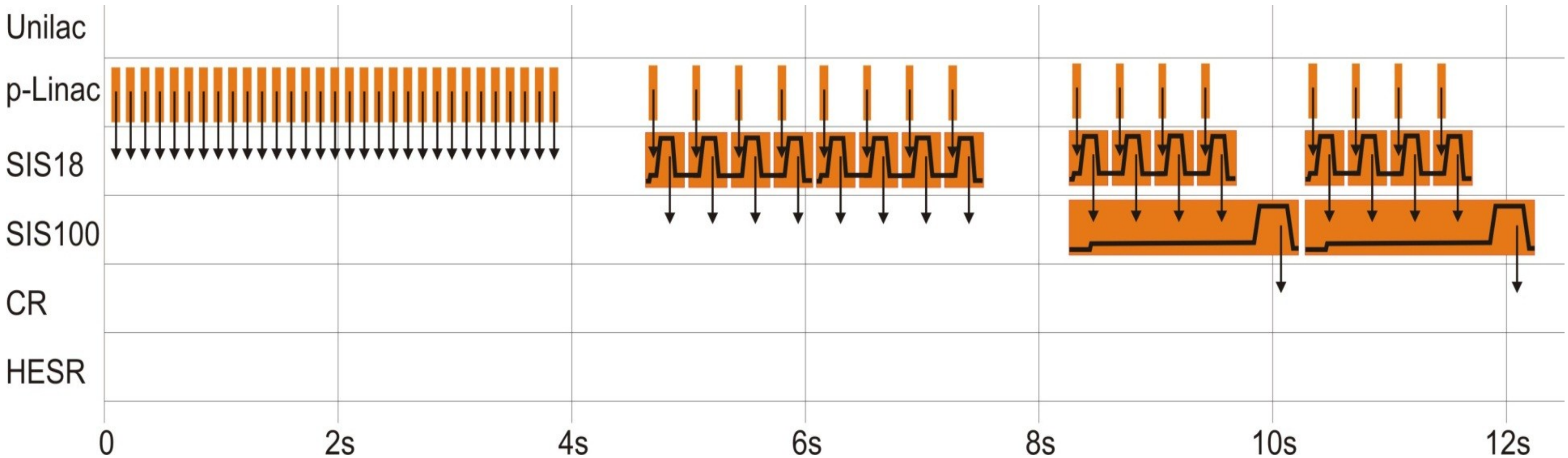
# Setup of Primary Experiment
## example: $\bar{p}$-Production

- Start with primary experiment → move through chain, one accelerator at a time
- First step – Beam Mode: Pilot Beam
  - Getting pilot/low-intensity beam through the accelerator chain
    - basic accelerator setup: injection->extraction, typically with (but not limited to) low setup intensities (SBF=true)
    - N.B. typically an iterative tuning process to get the actual beam parameters to their theory values
- Option I: initialize complete beam production chain, fixed beam pattern, starting with similar or previous  magnetic cycle reference
  - e.g. from previous experiment run, other ion species with same rigidity, etc.



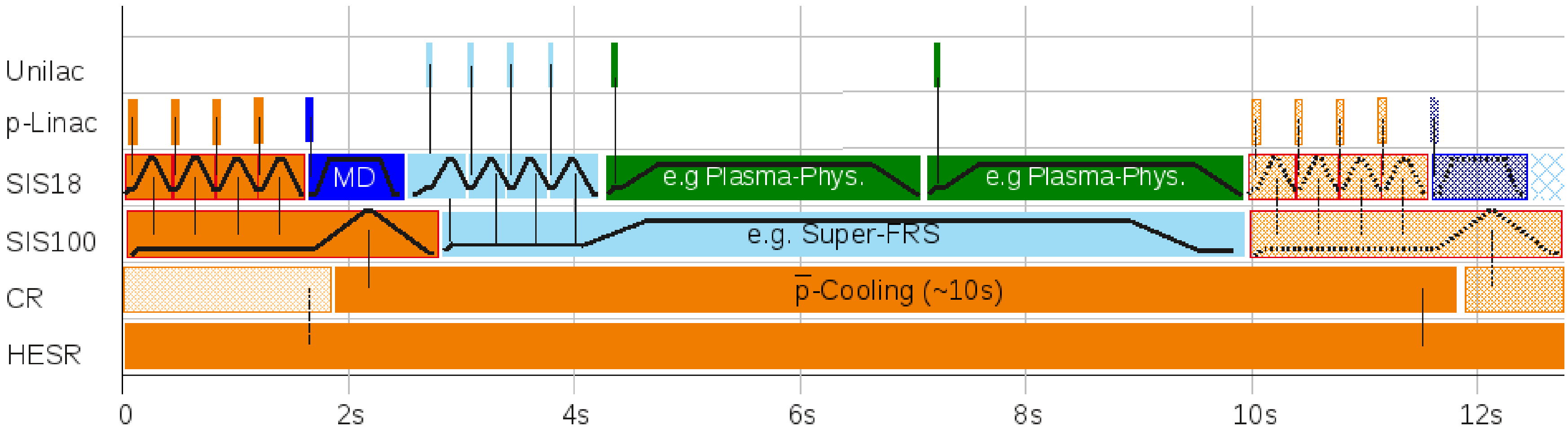
# Setup of Primary Experiment
## example: $\bar{p}$-Production

- First step – Beam Mode: Pilot Beam
  - Getting pilot/low-intensity beam through the accelerator chain
    - basic accelerator setup: injection->extraction, typically with (but not limited to) low setup intensities (SBF=true)
    - N.B. typically an iterative tuning process to get the actual beam parameters to their theory values
- Option II: higher repetition rate for injector tuning, e.g. multi-turn injection in case of new rigidity, ion species, injection settings, etc.
  - dedicated setup for primary: optimises/minimises time spend using interceptive devices or interference with secondary experiments
  - beam dumps available behind SIS18 and SIS100, p-Linac runnin at maximum repetition rate



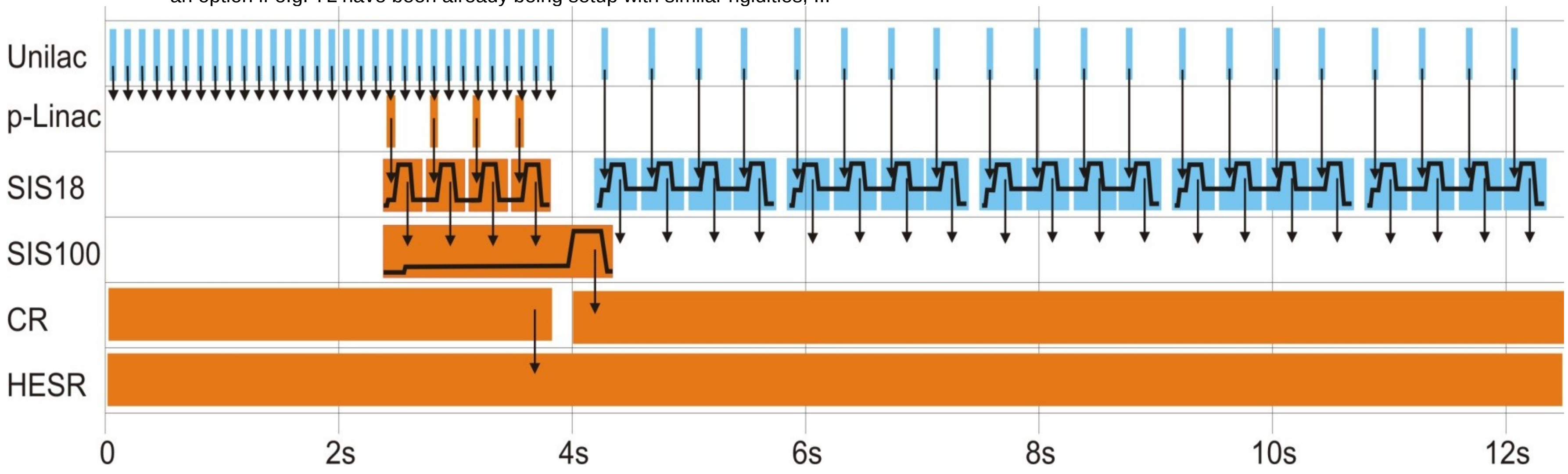
# Setup of Secondary Experiments
## example: $\bar{p}$-Production + CBM & Super-FRS

- Second step – Beam Mode: Intensity-Ramp-Up
  - verification of machine-protection functionality, (minor) adjustment of intensity related effects (e.g. ΔQ(intensity))
- Add magnetic cycles of other (potential) secondary experiments ↔ account for hysteresis effects early on
  - Example: U28+ (or similar beams)for CBM and SuperFRS
  - N.B. initially cycles can/will run 'empty' (ie. w/o beam)
- Need to repeat 'Intensity-Ramp-Up' whenever secondary experiment or beam pattern changes
  - e.g. change from U28+ → Ni, N, Xe, ...



# Setup of Secondary Experiment
## example: CBM

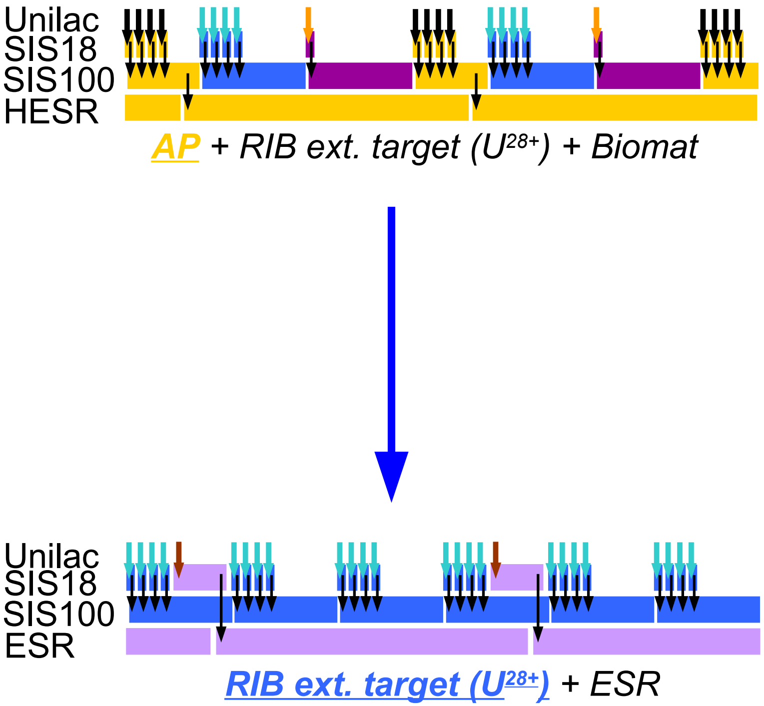
- Exploit advantage of two Linacs:
  - better availability w.r.t. machine failures, maintenance, upgrade scenarios, etc.
  - commissioning of UNILAC does not interfere with p-Linac → could do $U^{28+}$ beam tuning between the proton pulses
    - but: limited/no parallel commissioning of different ion species in UNILAC
- However
  - proton beam may be disturbed due to hysteresis effects → should aim at keeping fixed pattern in SIS18/100
  - sensitive device protection from high intensity proton beam → limited: Pilot Beam & Setup-Beam Intensities
  - But remains an option if:
    A) new protons & ions experiments are setup in parallel
    B) ions are setup in parallel without using intercepting devices in TL/rings and without large changes in rigidity, tune, Q' etc.
      - an option if e.g. TL have been already being setup with similar rigidities, ...



# Change of Beam Pattern

… an operational necessity

- Techniques minimise hysteresis exists but cannot guarantee that changes are transparent for high-intensities
  - ie. intensity dependence of working point (injection/extraction orbit, tune, injection, …)
- Change of working point potentially dangerous or induce heavy losses
→ necessity of beam intensity ramp-up
(pilot beam → re-validate → ...)
  - possible consequences:
    - small hysteresis effect
→ can be fast (little/no retuning)
    - large hysteresis effect
→ may need substantial re-tuning



# Malfunctions & Responses

- Common malfunctions
  - Category I: intermittent failures ↔ recovery within few seconds to minutes possible
    - e.g. RF transients (sparking), increase of beam loss (e.g. through bad settings)
  - Category II: minor HW device failures ↔ blocks only selected beams or est. few minutes to few hours recovery time
    - e.g. correctors failures, septa sparking, …
  - Category III: major failure ↔ blocks all beams or est. 1 up to few days recovery time
    - main dipole, quadrupole or sextupole failues (quench, MPS fault, …)

- Possible responses (underlying constraint: keep magnetic hysteresis as long as reasonably possible):

for Category I:

- dump beam & inhibit inj./extr., but continue magnetic cycle → assess malfunction scope, then
- either (1st time): reset HW, re-inject and verify with last beam intensity (~1 cycle) → OK? → 'Stable Beams'
- or (2nd time): reset HW, re-inject and verify with pilot beam (~1 cycle) → intensity-ramp-up (~2-3 cycles, if necessary) → OK? → 'Stable Beams'
- or: re-classify as 'Category II'

for Category II:

- dump beam or inhibit inj./extr., but continue magnetic cycle → assess malfunction scope, then
- either: reset HW, re-inject with disabled device (if possible) → verify with pilot beam (~1 cycle) → intensity-ramp-up (~2-3 cycles, if necessary) → OK? → 'Stable Beams'
- or (longer recovery/tuning): switch to SIS18/100 setup beam dump → as above
- or: re-classify as 'Category III'

for Category III:

- Dump beam & inhibit inj./extr., stop magnetic cycle in corresponding machine, initiate (quench) recovery procedures
- Initially: continue with pattern in preceding machines (↔ availability of || exp.) → assess scope of malfunction
- Change facility to new beam production chain pattern

# SIS18 Operation Experience & Efficiency

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 |

| 1st-order prediction*: | SETUP | Beam-on-Target | long-term BoT Goal |
|---|---|---|---|
| SIS18 | 13% | 70% | 90% |
| SIS18+SIS100 | 24% | 49% | ~80% |
| SIS18+SIS100 +Super-FRS/CR | 34% | 34% | ~70% |
| SIS18 → HESR | 42.4 | 24% | ~65% |

*Assumes same[1] operational efficiency for: SIS100, Super-FRS/CR & HESR operation, excl. 'STDBY'

- possibly pessimistic/simplistic[1,2] estimate, control room experience:
  - presently: '~ 1 shift UNILAC setup + 1 shift SIS18+TL setup' ↔ 1-2 weeks of experiments
  - potential target after 2-3 years of FAIR operation:
    - simple experiments (e.g. attached to SIS18/SIS100): 1-2 shift setup ↔ 1-2 weeks beam-on-target
    - more complex experiments (e.g. at HESR): ~week setup ↔ months of operation (HESR),
- Need to factor in efficiency evolution: early beam commissioning → reaching final beam parameter
  - short-term: ~6 month beam commissioning (day-shifts, 50%), limited parallel experiments (ie. nights & weekends)
  - medium-term: few day shifts of beam commissioning/week (~15 - 20%), rest beam operation
  - long-term: mainly beam operation, 1-2 days per 2-3 weeks for BC & MDs

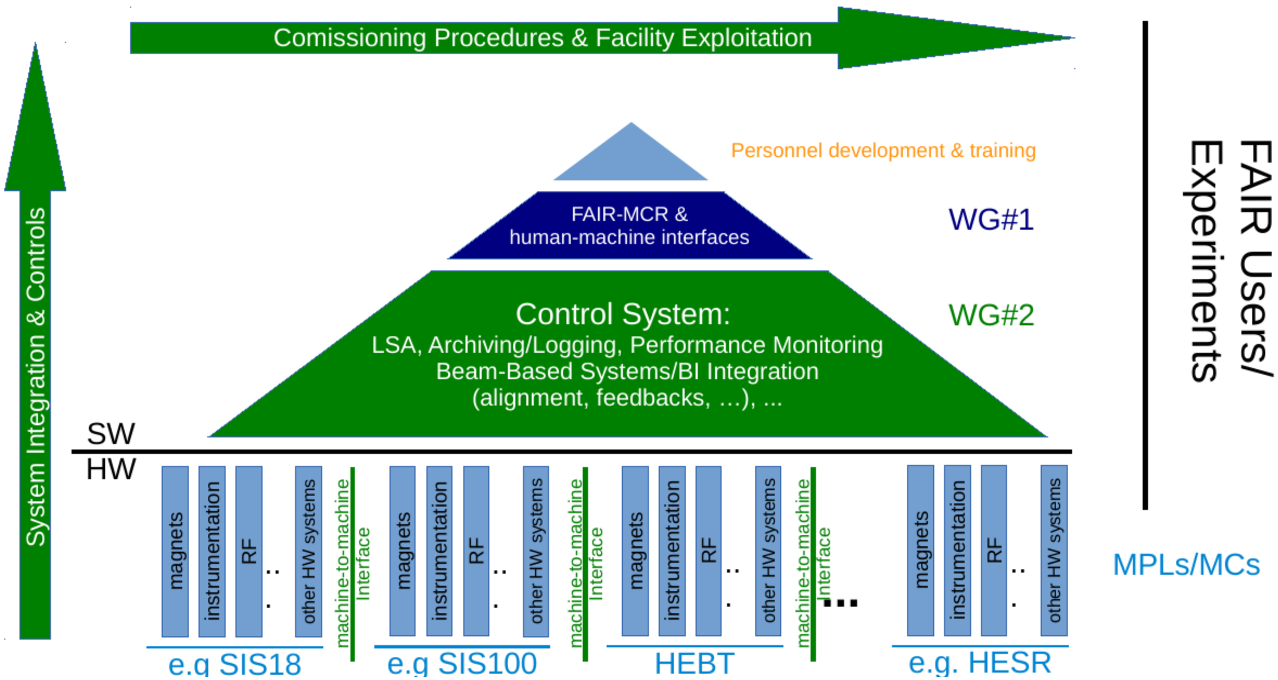
[1] possibly strong assumption that new machines can be operated with the same routine, ease and efficiency as the present GSI infrastructure, …
[2] complex beam chains (e.g. HESR) with long beam setup times are typically run longer/more static than shorter (SIS18 experiments)

# FAIR Parallel Operation & Efficiency Cost of Context Switches

- FAIR will be very flexible w.r.t. parallel operation scenarios.
- Caveat: unavoidable overhead costs for context switches
  → trade-off between 'flexibility' and machine availability ('beam-on-target'):
  I. initial setup of accelerator chain (virgin cycle):
     - *initially ~1 shift/GSI machine/transfer-line involved + few months of initial commissioning of SIS100, CR, …*
     - *long-term target: 1-2 shifts for SIS100, 'n' x (??) shifts for Super-FRS, CR, HESR*
  II. tuning for high-intensity operation: *new territory here thus no firm estimate (yet)*
     - *long-term target: 1-2 shifts depending on novelty of parameters for initial setup*
  III. Revalidation/re-tuning after 'beam pattern'/'mode of operation' changes
     - *long-term target: 10-20 minutes depending on*
       - *less critical for fast-extraction ↔ less dependence on orbit & Q/Q'*
       - more critical for slow-extraction (SIS18/SIS100) & multi-turn injection (SIS18) ↔ dependence on orbit & Q/Q'
- 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:
    - optimise operation/automation ↔ smart tools & procedures, e.g. beam-based feedbacks, sequencer, …
      - N.B. also liberates operators from tedious task to focus on error (pre-)diagnosis and facility optimisations
    - optimise beam planning schedule to factor-in these costs for mode of operation changes

# FAIR Commissioning & Control
# http://fair-wiki.gsi.de/FC2WG/

An accelerator is more than the sum of its parts:




- FAIR Commissioning & Control Working Group
  - platform to discuss, coordinate and work-out FAIR commissioning and operation
  - open to all who can participate and contribute to this subject!
    → feel free to register your interest

# Summary

- New challenges for FAIR:
  - high-intensity operation, increased complexity, machine protection, minimising machine activation, …
  - beam becomes more sensitive to beam parameter changes, dynamic vacuum effects & magnet hysteresis
- FAIR facility can provide a high degree of flexibility
- 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
    - 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 beam schedule

# FAIR, can we do it?

Yes ,we can!

# Appendix

# System Analysis & Topics to be covered

- Facility & Interface Analysis
  - Procedures: HWC, HWC-'Machine Check Out', BC-I, BC-II, BC-III
  - Beam parameters, FAIR performance model and optimisation
- Beam Instrumentation & Diagnostics – System Integration
  - Intensity (DCCTs, FBCT), trajectory & orbit (BPMs), Q/Q', optics (LOCO & phase-advance), longitudinal & transverse emittance (WCM, screens, IPM, etc.), beam loss (BLMs), $\Delta p/p$, long. bunch shape, abort gap monitoring, long. Tomography, aperture model, ...
- Accelerator Hardware – System Integration
  - Power converter, magnets, RF, injection/extraction kicker, tune kicker/AC-dipole, beam dump, collimation/absorbers, cryogenics, vacuum, radiation monitoring, magnet model, k-modulation, ...
- Control System
  - Archiving, analog signal acquisition, test-beds, timing, bunch-to-bucket transfer, cyber security & role-based-access, middleware, RT & Feedbacks, daemons, semi-automated procedures, …
- Components
  - Post-mortem, safe-beam settings management, machine protection ↔ interlocks, beam quality checks
- Applications
  - Sequencer, GUIs, fixed-displays

# FCWG – Topics cont'd

- Commissioning in Stages:
  - HWC – Stage I: HWC & Machine Check-Out
    - power converter, RF, dry-runs, ...
  - HWC – Stage II: test-beds and what can we check w/o beam
  - BC – Stage I: rough machine checkout
    - 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

# Even more FAIR Parallel Operation Options

see text for explanation of the color codes.

| rows: main user / columns: parasitic user | SIS18 - SIS100 - SuperFRS | SIS18 - SIS100 - SuperFRS - CR | SIS18 - SuperFRS | SIS18 - SuperFRS - CR | SIS100 - CBM | Antiprotons: CR - HESR | SIS18 - SIS100 - APPA | SIS18 - SIS100 - APPA (Plasma physics) | SIS18 - APPA | SIS18 - ESR | SIS18 - HTA or HTM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SIS18 - SIS100 - SuperFRS | | | | | | | | #5 | #1 | #1 | #1 |
| SIS18 - SIS100 - SuperFRS - CR | | | | | #6 | | #6 | | #6 | #6 | #6 |
| SIS18 - SuperFRS | | | | | | | | | | | |
| SIS18 - SuperFRS - CR | | | | | #6 | | #6 | | #6 | #6 | #6 |
| SIS100 - CBM | | | | | | | | | | | |
| Antiprotons: CR - HESR | #2 | | #2 | | #3 | | #4 | #5 | #4 | #4 | #4 |
| SIS18 - SIS100 - APPA | | | | | | | | | | | |
| SIS18 - SIS100 - APPA (Plasma physics) | #5 | #5 | #5 | #5 | #5 | #5 | | | | #5 | #5 |
| SIS18 - APPA | | | | | | | | | | | |
| SIS18 - ESR | #1 | #6 | #1 | #6 | #6 | #4 | #6 | #5 | #6 | | #1 |
| SIS18 - HTA or HTM | | | | | | | | | | | |

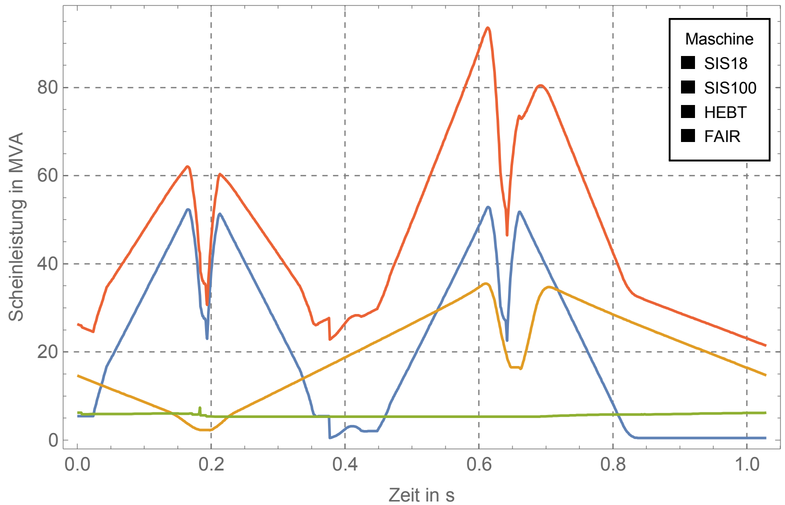
Sharing is not desired
Sharing is not possible
Sharing is possible
reference pattern

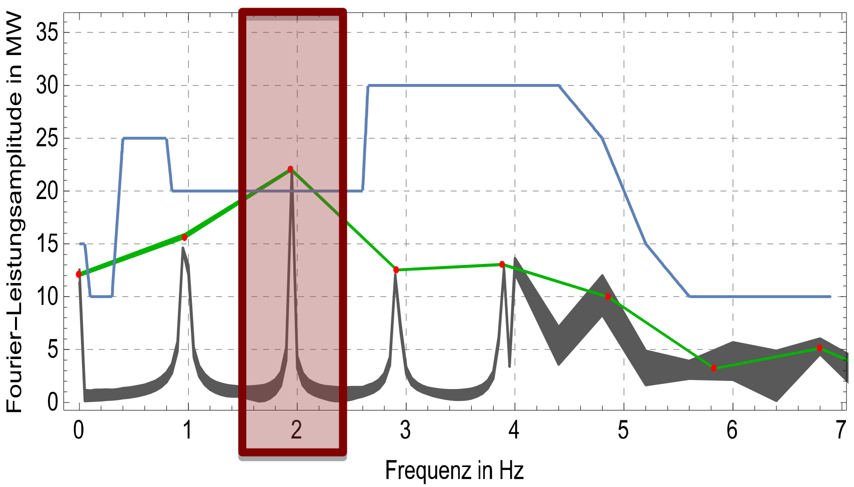
## In a nutshell:

- Most parallel operation/sharing options are possible
- Some may not make sense from
  - an OP efficiency point-of-view
    - requiring too frequent source changes
  - possibly physics point-of-view
  - HW limitations, notably:
    - Super-FRS (slow rigidity changes)
    - CR (slow rigidity changes)
    - CR polarity changes ($\bar{p} \leftrightarrow$ ion operation)

P. Schütt, O. Geithner, P. Forck, “FAIR Operation Modes – Reference Modes for the Modularized Start Version (MSV)”, 2015-02-13

- Most parallel operation possible within limits
- A notable (probably pathological) exception:
  - Triangle CBM (10,6 GeV)-APPA (18 Tm) Operation
    - max ramp rate hit peak and spectral power limits of available primary FAIR power distribution
- In any case one should anticipate and monitor the actual power usage and expected peak loads



# Planned (new) for FAIR: Integration of Beam-Based Systems

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

Generic Priorities:

1. Transmission Monitoring System
2. Orbit Control
3. Trajectory Control (threading, injection/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

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

improve beam-based control of accelerator working-point

Machine Specific Priorities (focus on SIS18 & SIS100)

- Multi-Turn-Injection (N.B. highly non-trivial, complex subject)
- Slow-Extraction (K.O. exciter, spill-structure, feedback, …)
- RF Bunch Merging and Compression

# References


- D. Ondreka, “FAIR Machine Cycles”, 6th MAC, 2011-10-11
- H. Liebermann, D. Ondreka, “SIS100 Cycles”, V.2.4.1, 2014-02-26
- P. Schütt. “FAIR Accelerator Operation”, 2013-09-12
- P. Schütt, O. Geithner, P. Forck, “FAIR Operation Modes – Reference Modes for the Modularized Start Version (MSV)”, 2015-02-13