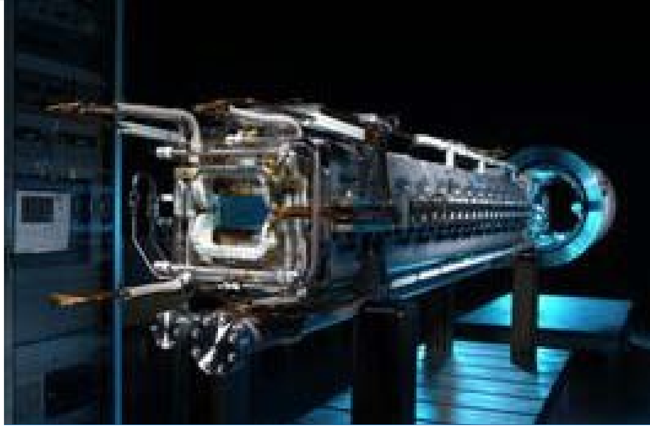


FAIR Accelerator Facility Control: Semi-Automation & Beam-Based Feedbacks

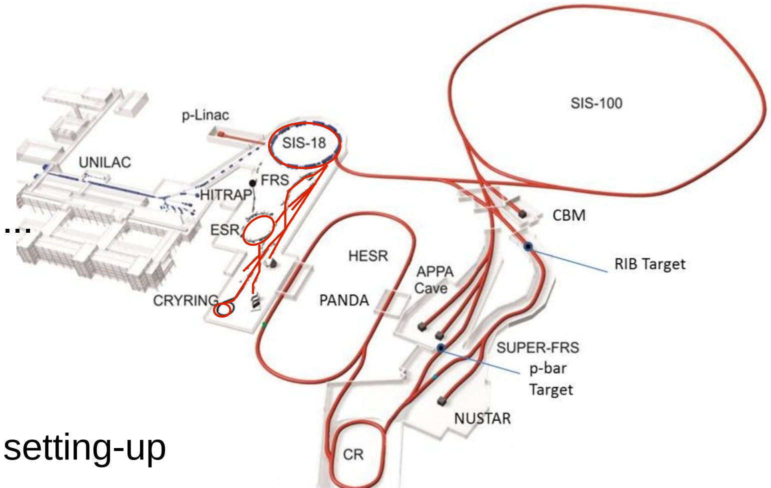
D. Ondreka,
Ralph J. Steinhagen

ARIES Accelerator Performance and Concept Workshop, 10th December 2018
Flemings Hotel, Frankfurt am Main, Germany

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

GSI HELMHOLTZ ASSOCIATION FAIR

Setting the Scene….



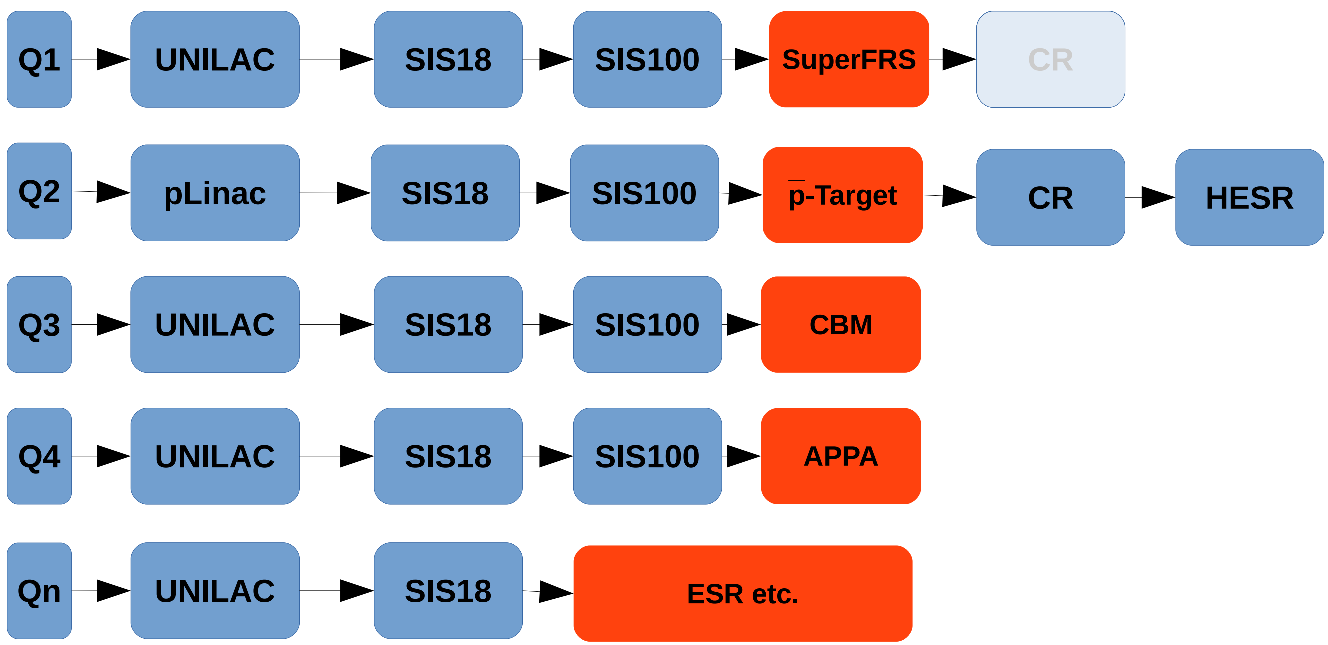
- FAIR ~4 x the size of existing GSI facility
  - non-linear operational complexity increase $O(n^2) \rightarrow O(n^5)$
  - efficiency scalling $\varepsilon_{FAIR} = \varepsilon_{UNILAC}\cdot\varepsilon_{SIS18}\cdot\varepsilon_{SIS100}\cdot\varepsilon_{Super\text{-}FRS}\cdot\varepsilon_{CR}\cdot\varepsilon_{HESR}\cdot \ldots$

- parallel operation of 5-7 distributed experiments
  - lasting typically only 4-5 days, few long-runners
  - large potential for cross-talk between users especially while setting-up
  - world-wide unique requirement: facility and key beam parameters reconfigured on a daily basis
    - energy, ion species, intensity, extraction type/length, …

- new challenges w.r.t. GSI:
  - operating beyond present beam parameter envelope, x10-100 higher intensities, x10 higher energies → machine protection & losses/activation become an important issue
  - high-intensity and higher-order feed-down effects require machine and beam parameter control well below the sub-percent level →beyond feed-forward-only (open-loop) modelling and machine reproducibility
  - need to operate FAIR with reduced skeleton crew consisting of only ~5-6 operators (nights & weekends)
    - minimise putting unnecessary stress on crews ↔ ergonomics, human-centric design, (semi-)automation (this talk)

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

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



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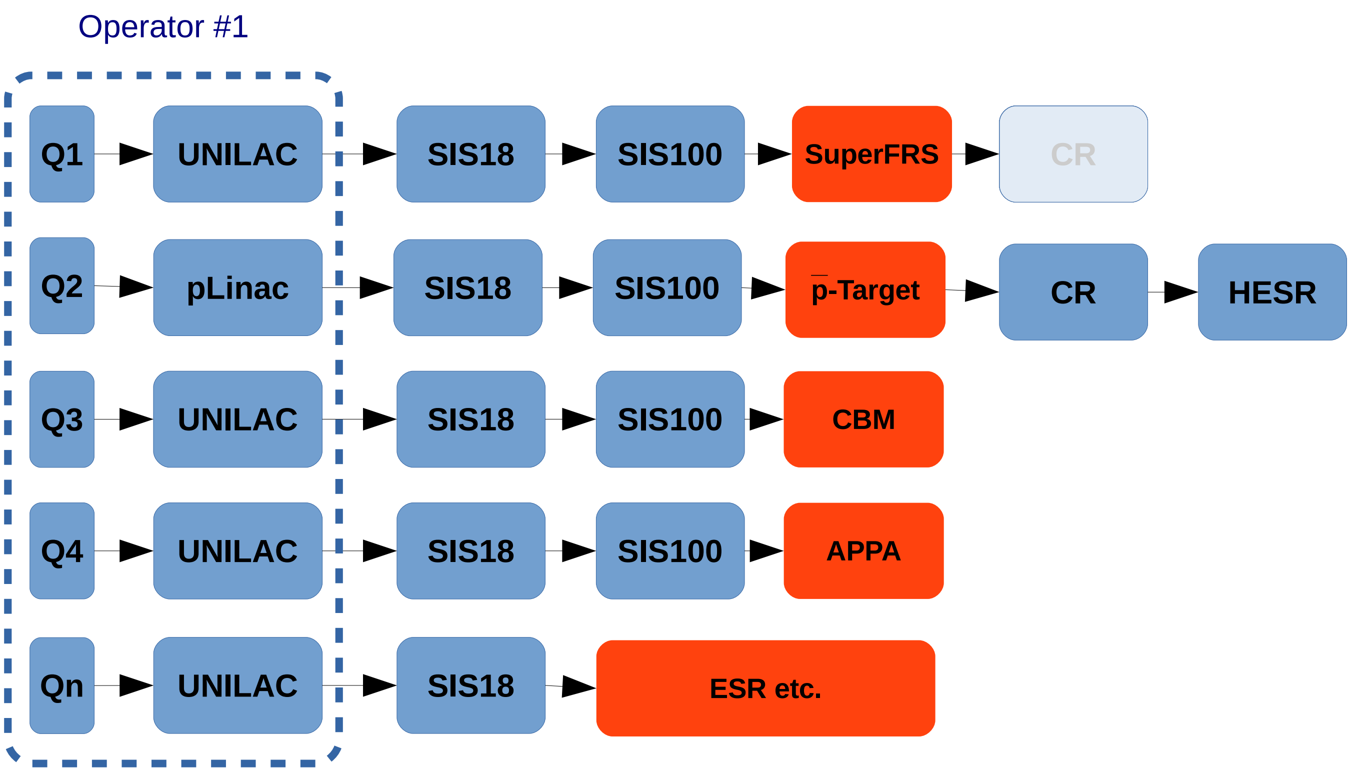

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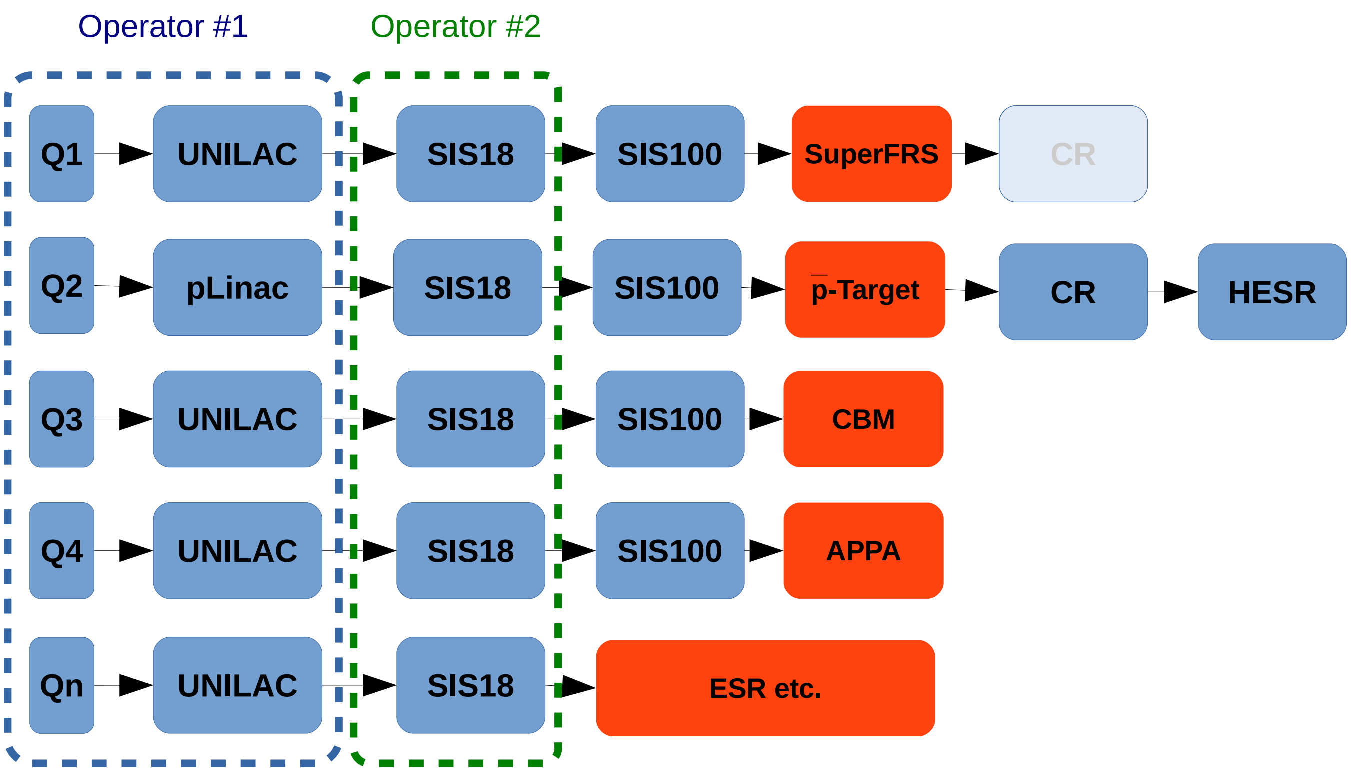

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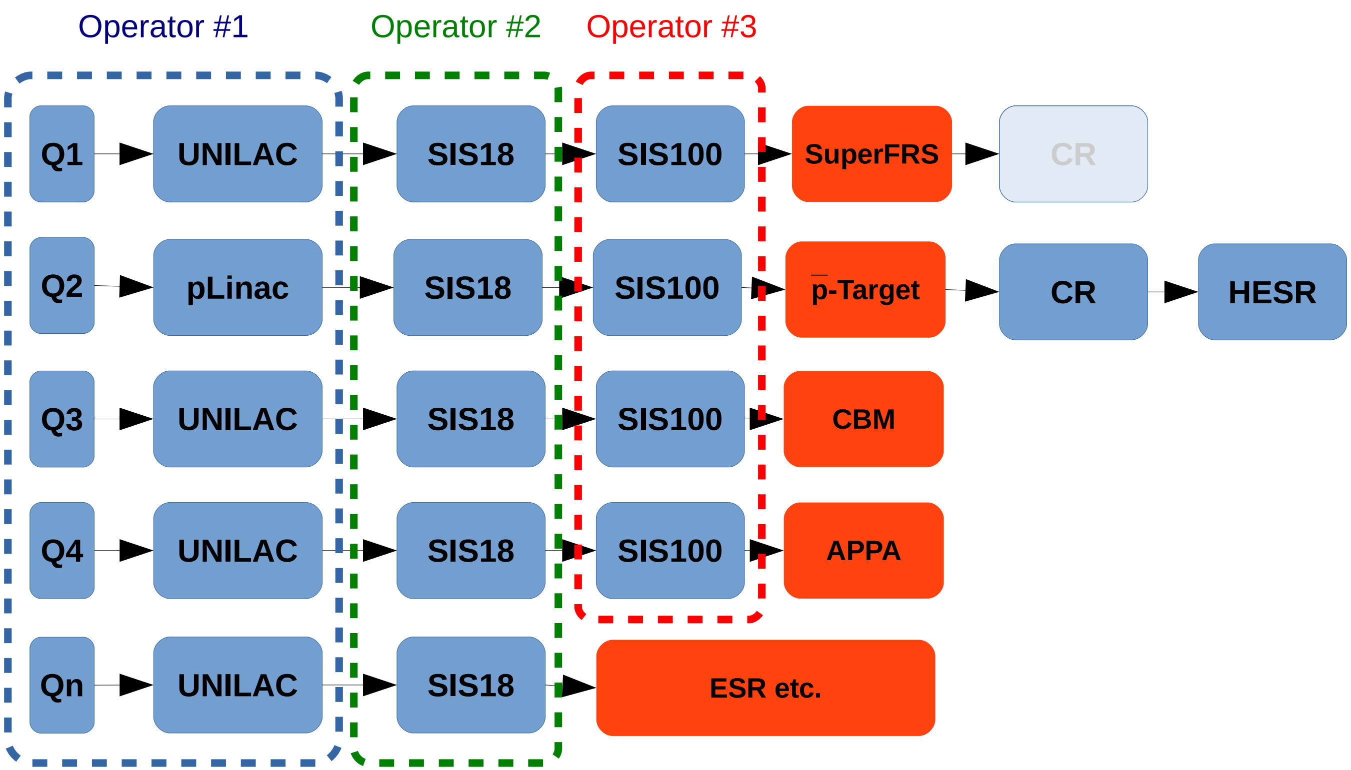

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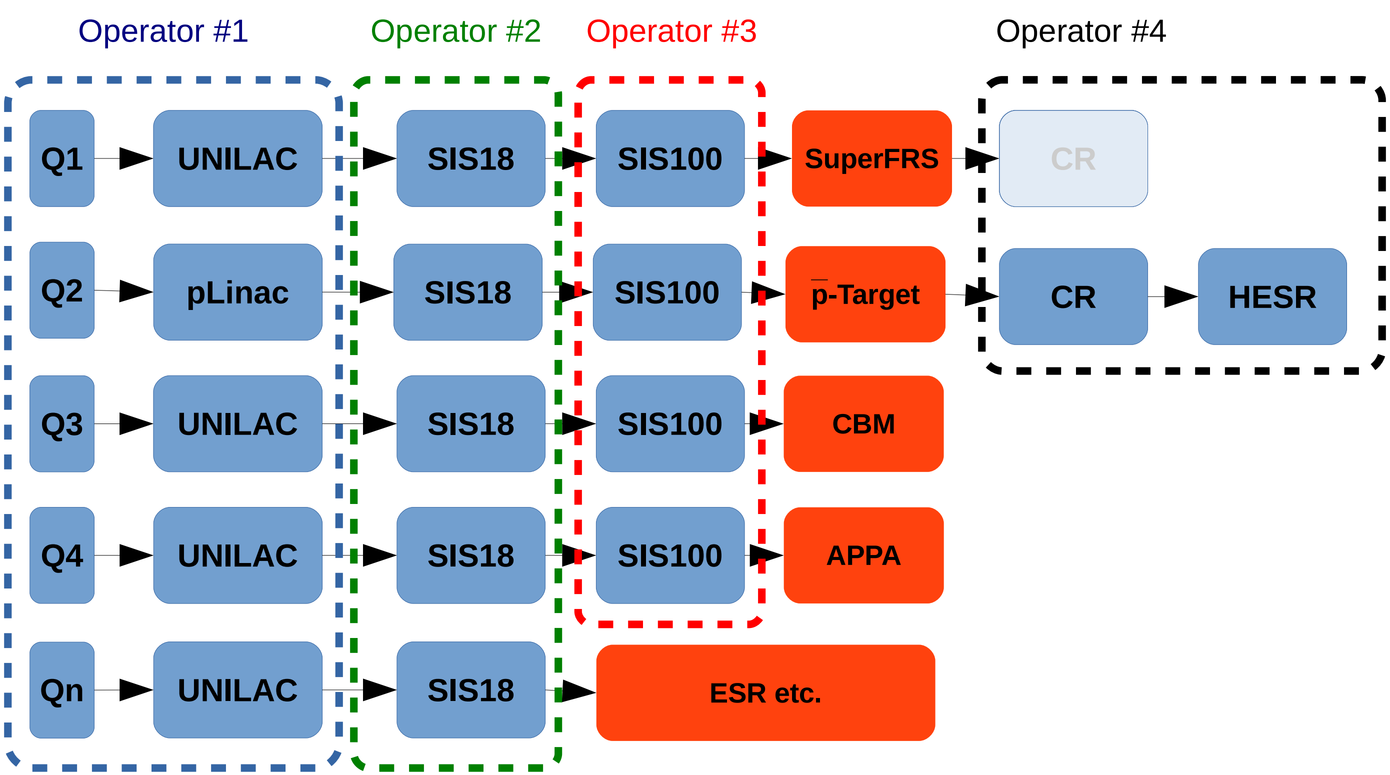

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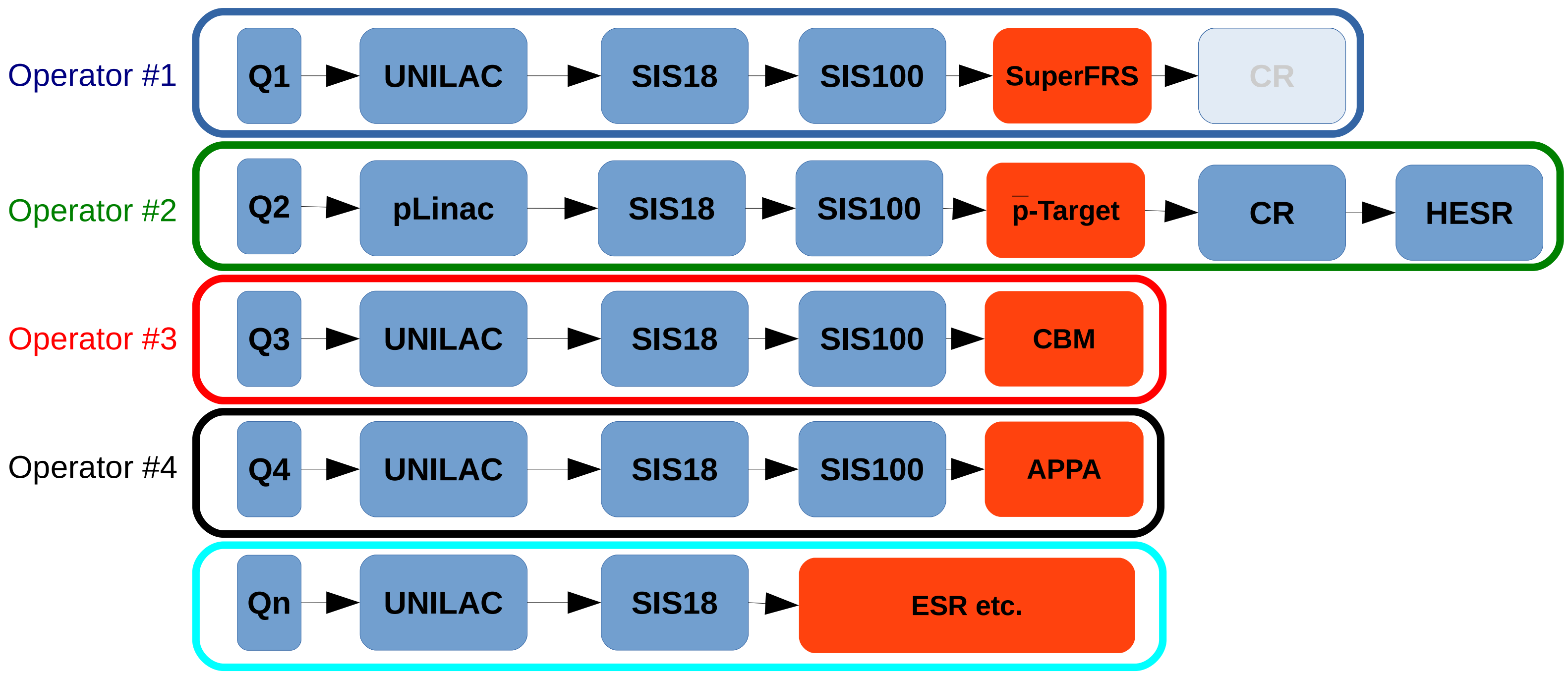

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Beam-Production-Chains

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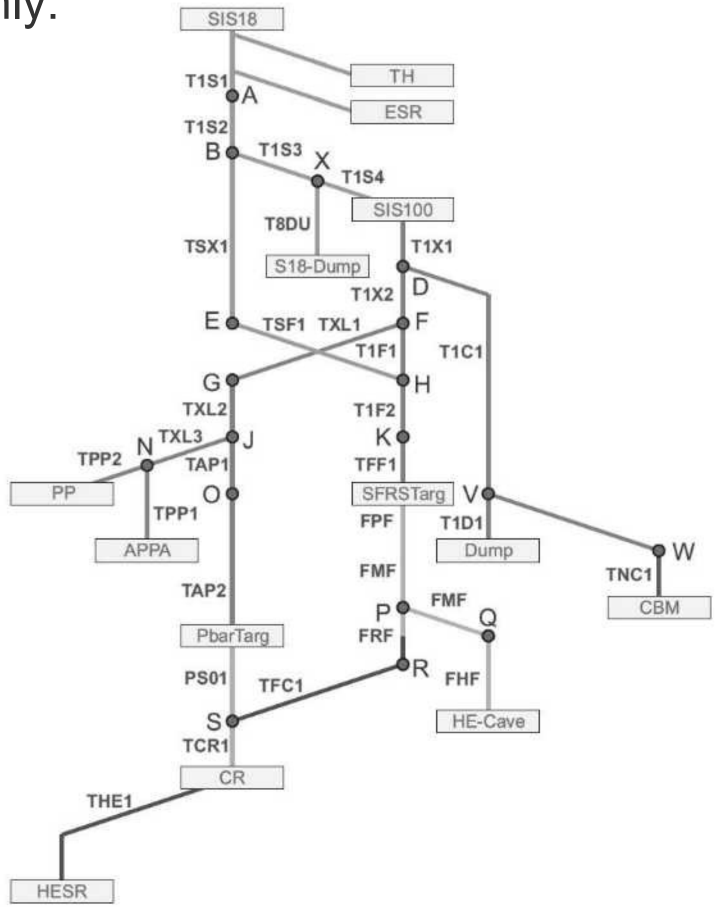

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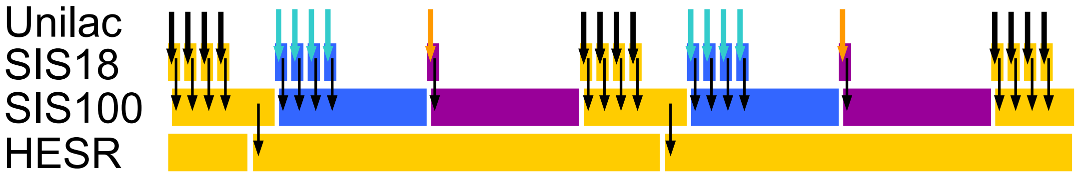
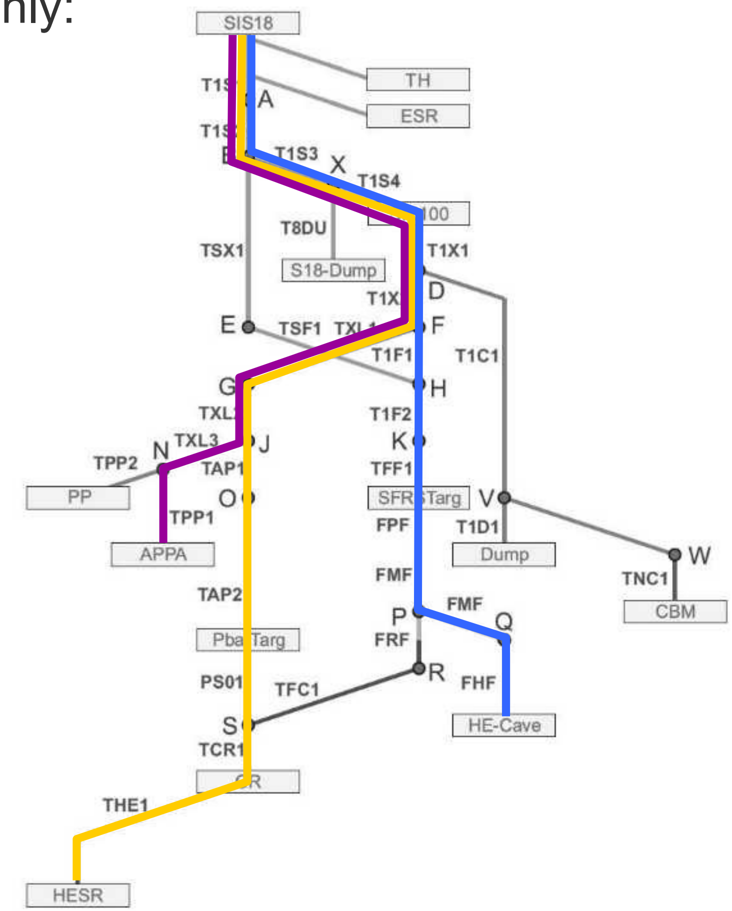


AP + RIB ext. target (U^{28+}) + Biomat



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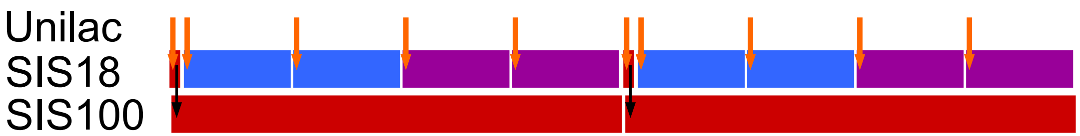
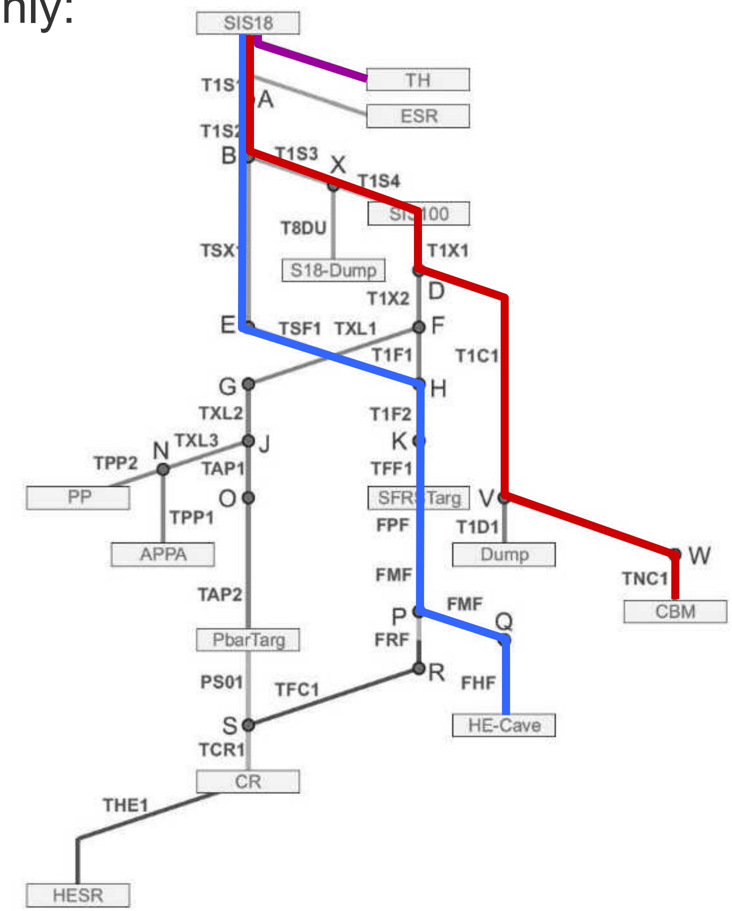


CBM + *RIB ext. target (U^{73+}) + AP (LE)*



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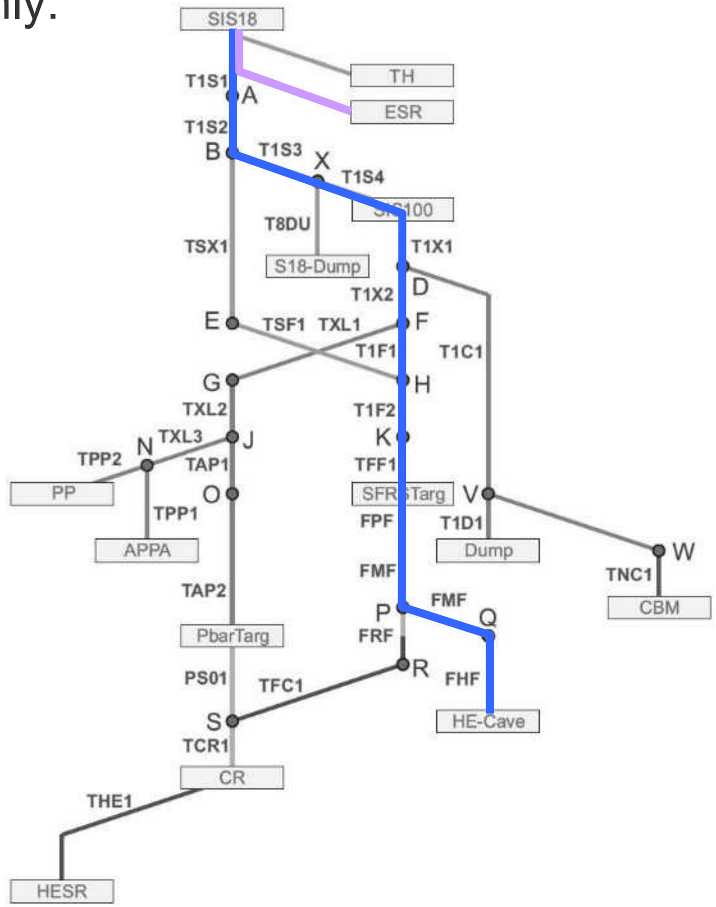

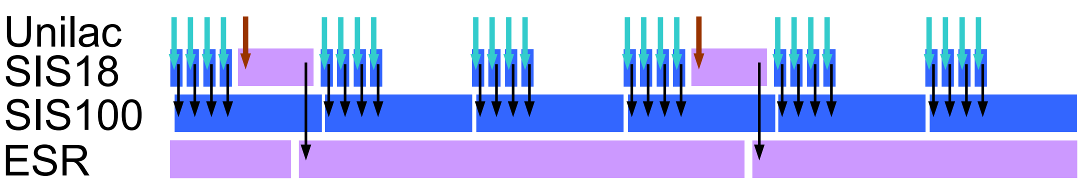

RIB ext. target (U^{28+}) + ESR

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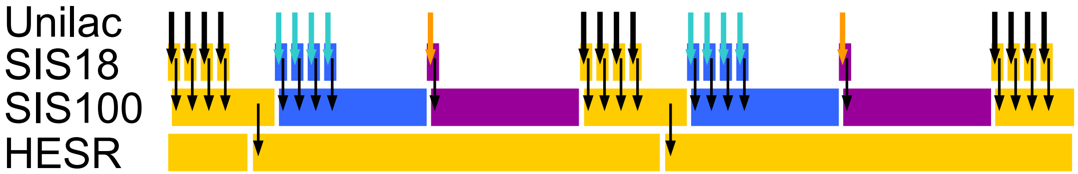

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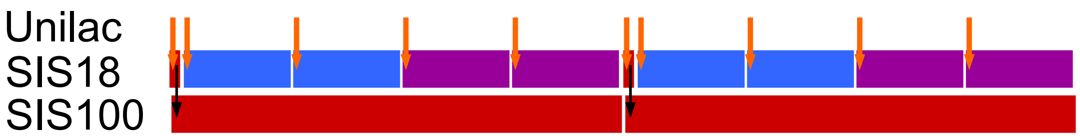

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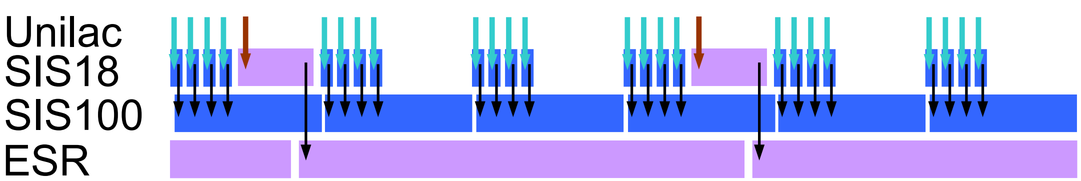

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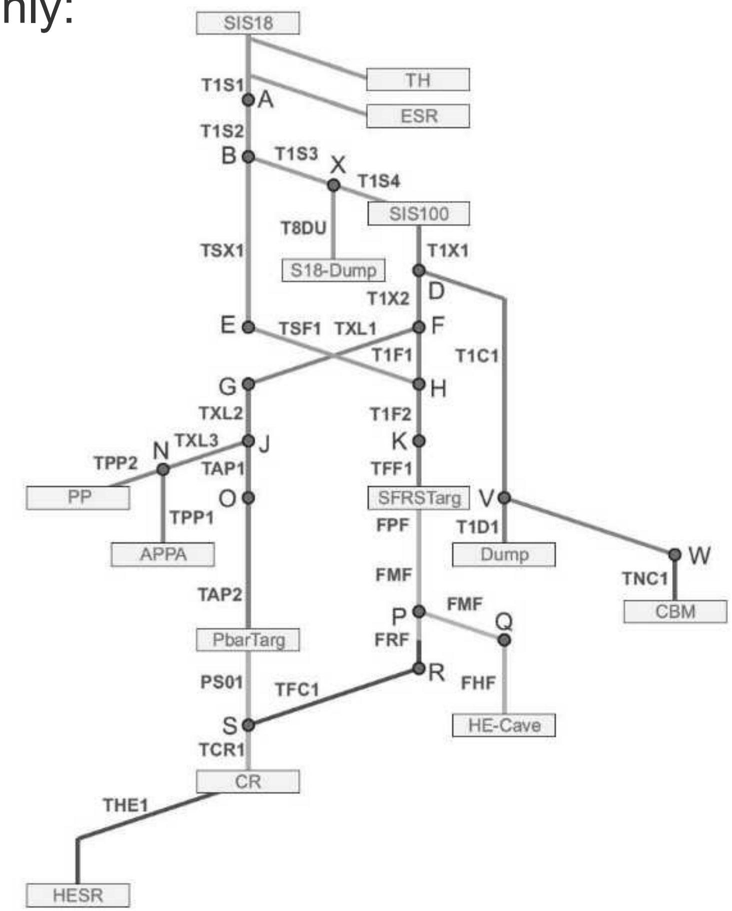

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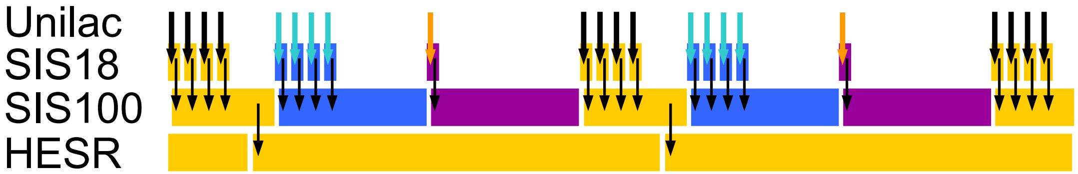

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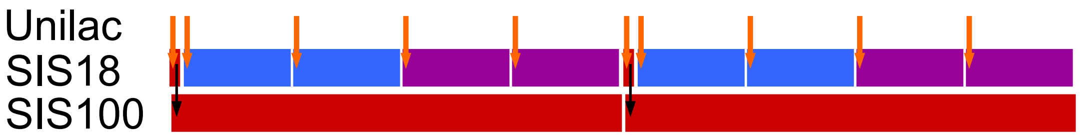

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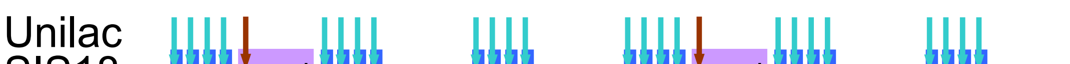

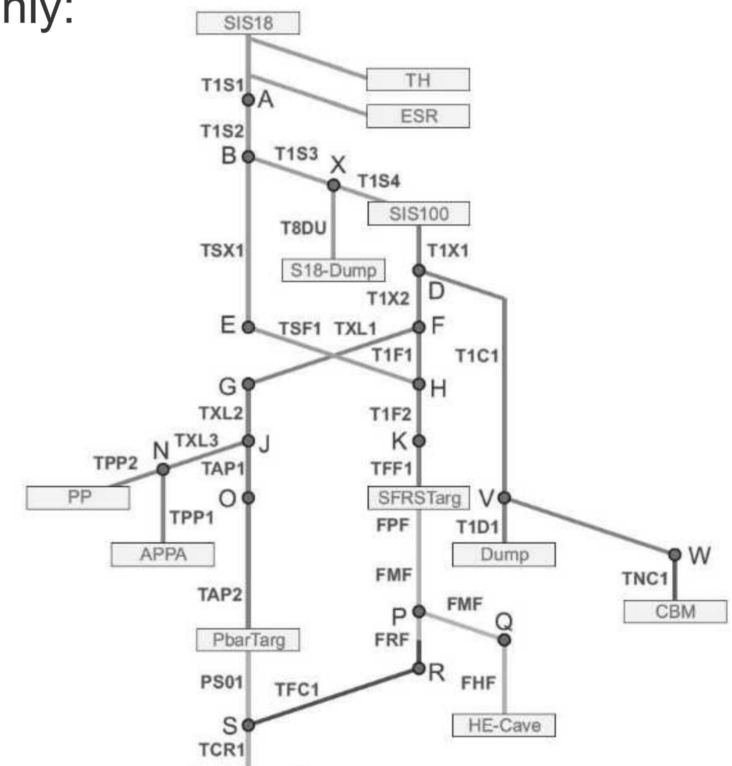

FAIR Operational Challenge:

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

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

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

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

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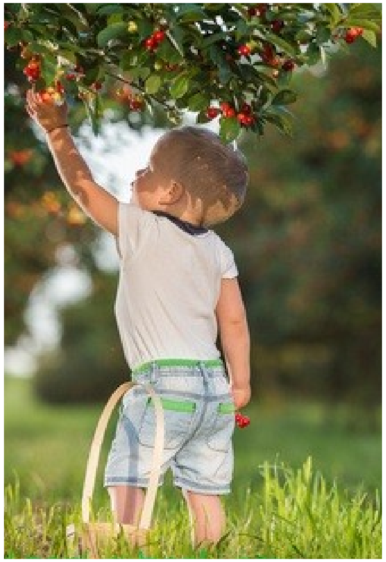

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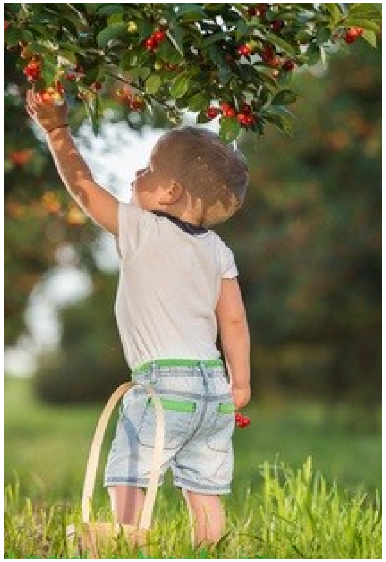

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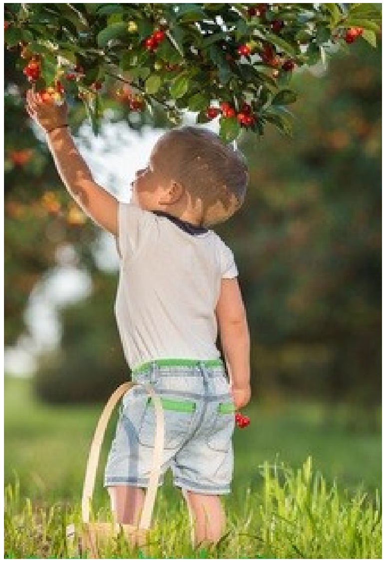

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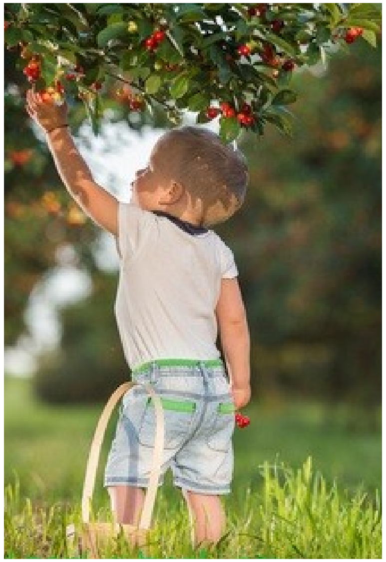

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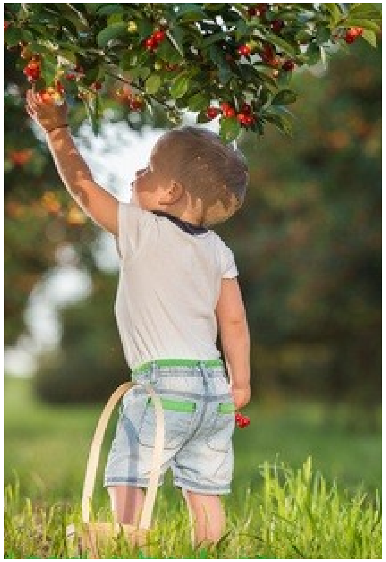
- Sequencer taks – automation of tasks not yet covered by other routine tools → big time saver for large-scale equipment acceptance/integration tests, recommissioning, or dry-runs
  - N.B. thousands of FAIR devices & machine proction systems that need to be periodically retested/validated



Beam-based Cycle-to-Cycle feedbacks

Generic Beam Control (focus on use-case)

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

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

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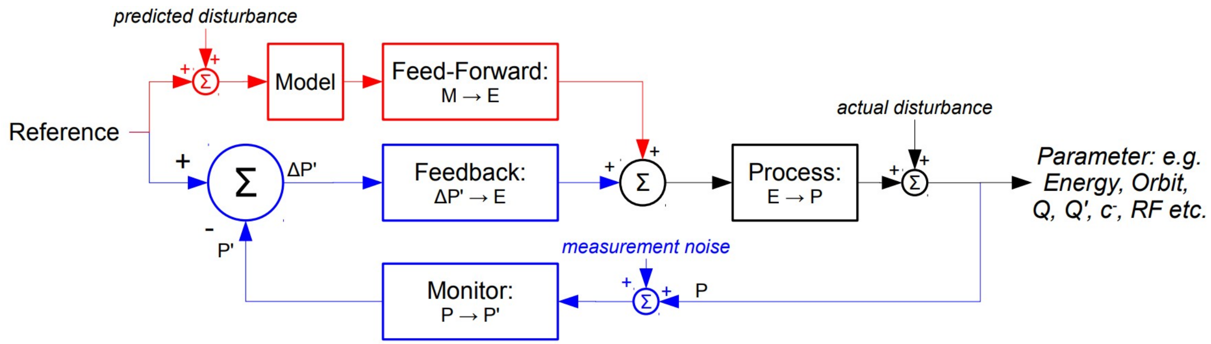
Machine-specific Beam-Based Systems:

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

Generic:

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

Some notes on implementation



- Real-World challenges of FB & (semi-) automation:
  (hint: usually control theory or beam physic isn't the problem)

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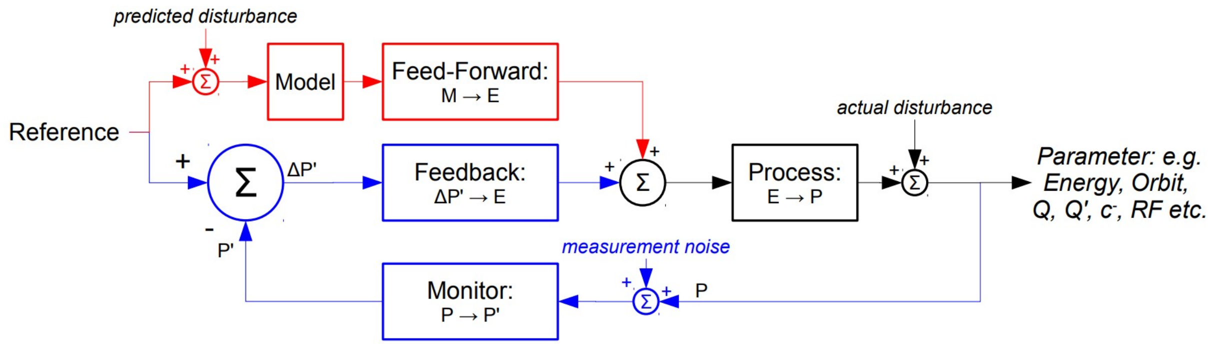

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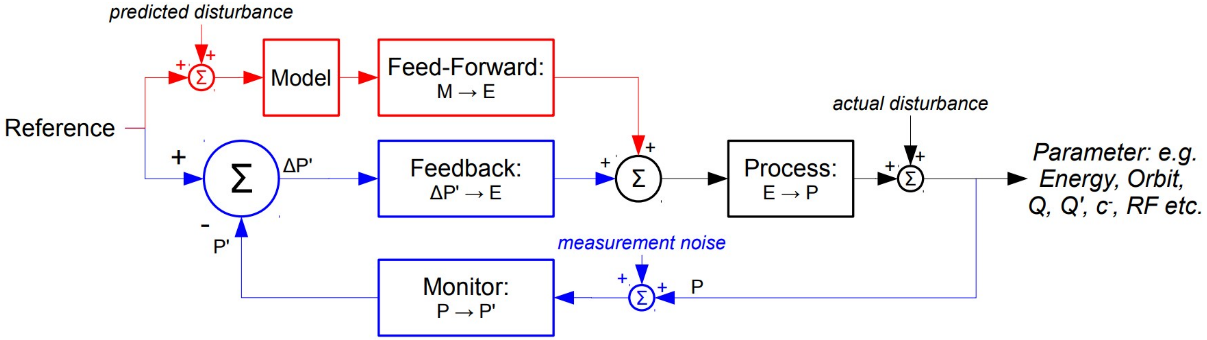

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  - Computers are better than humans for repetitive/quantitative tasks, however: FBs are essentially only as good as
    - beam- or machine-parameter measurements they are based-upon
    - integration into the controls & operation environment and exception handling
      - interfaces, interfaces, interfaces….
      - long-term maintenance, upgrades, adaptations, ...
    - developer skills that needs to cover multiple domains: acc. HW, BI, RF, Controls, machine modelling, beam physics, …

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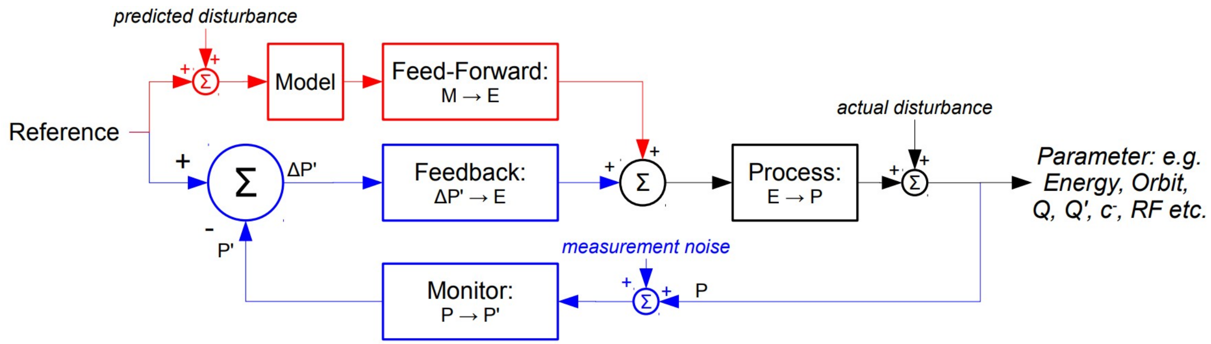

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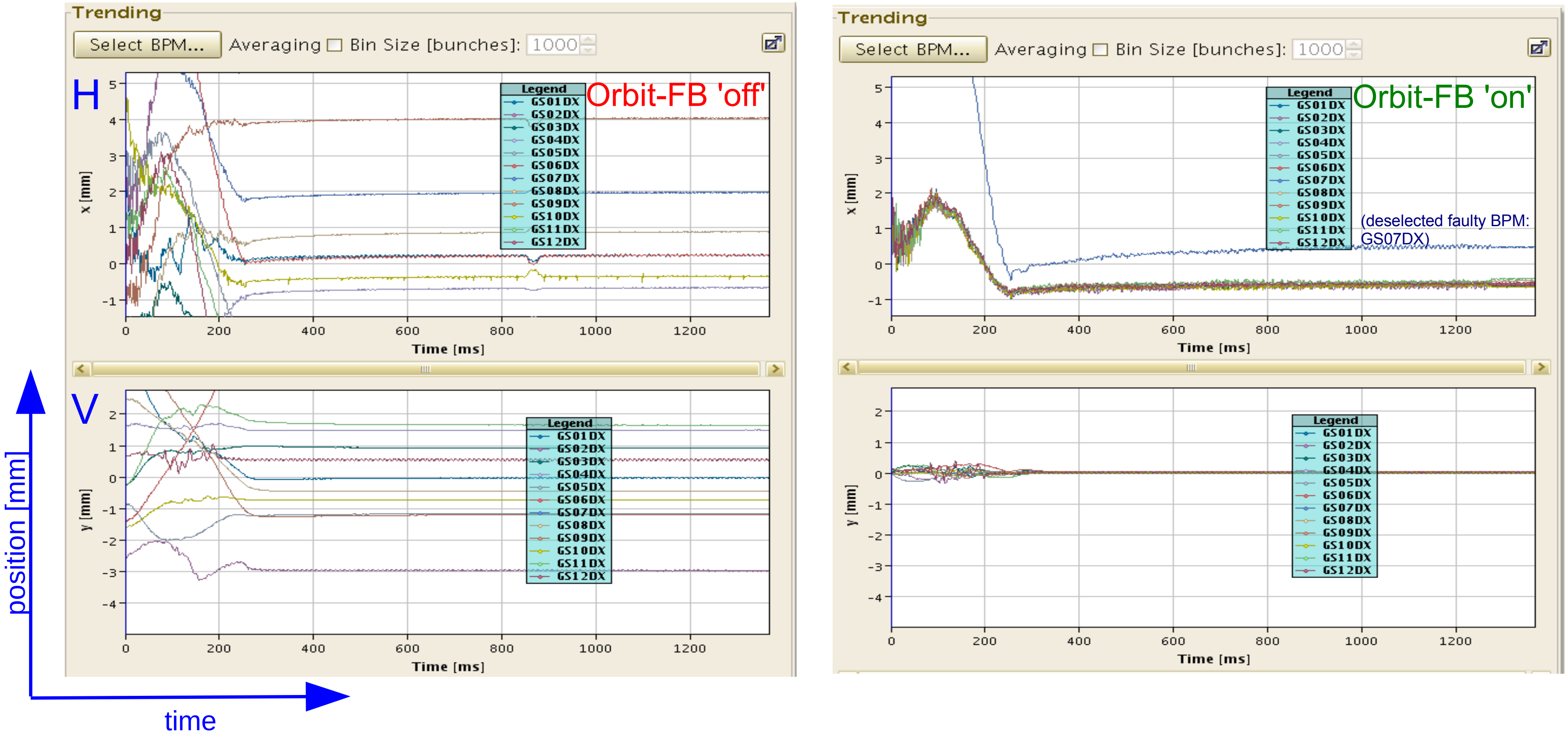
    - overall strength depends on the reliability of the weakest link in the chain

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

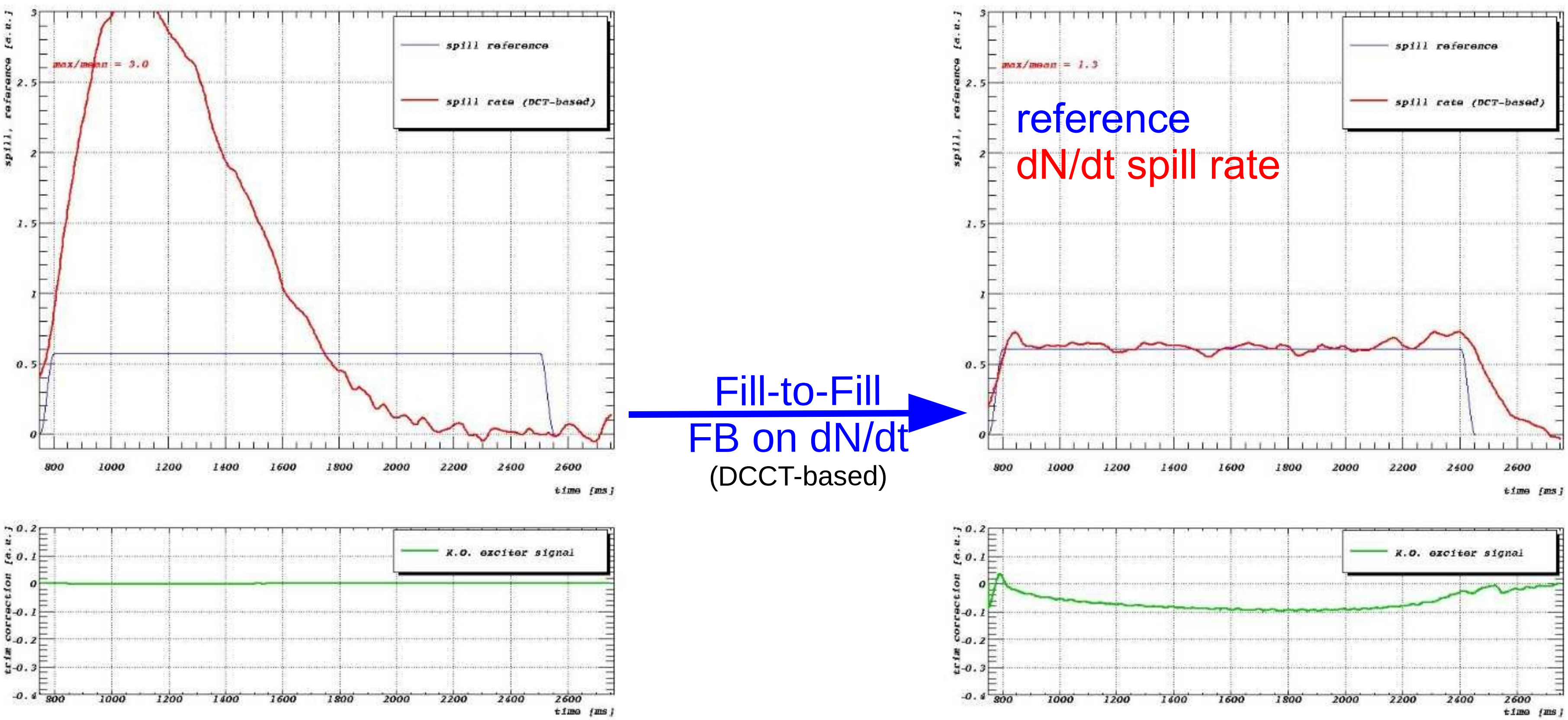
B. Schlei, H. Liebermann, R. Steinhagen



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

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

R. Steinhagen, H. Liebermann



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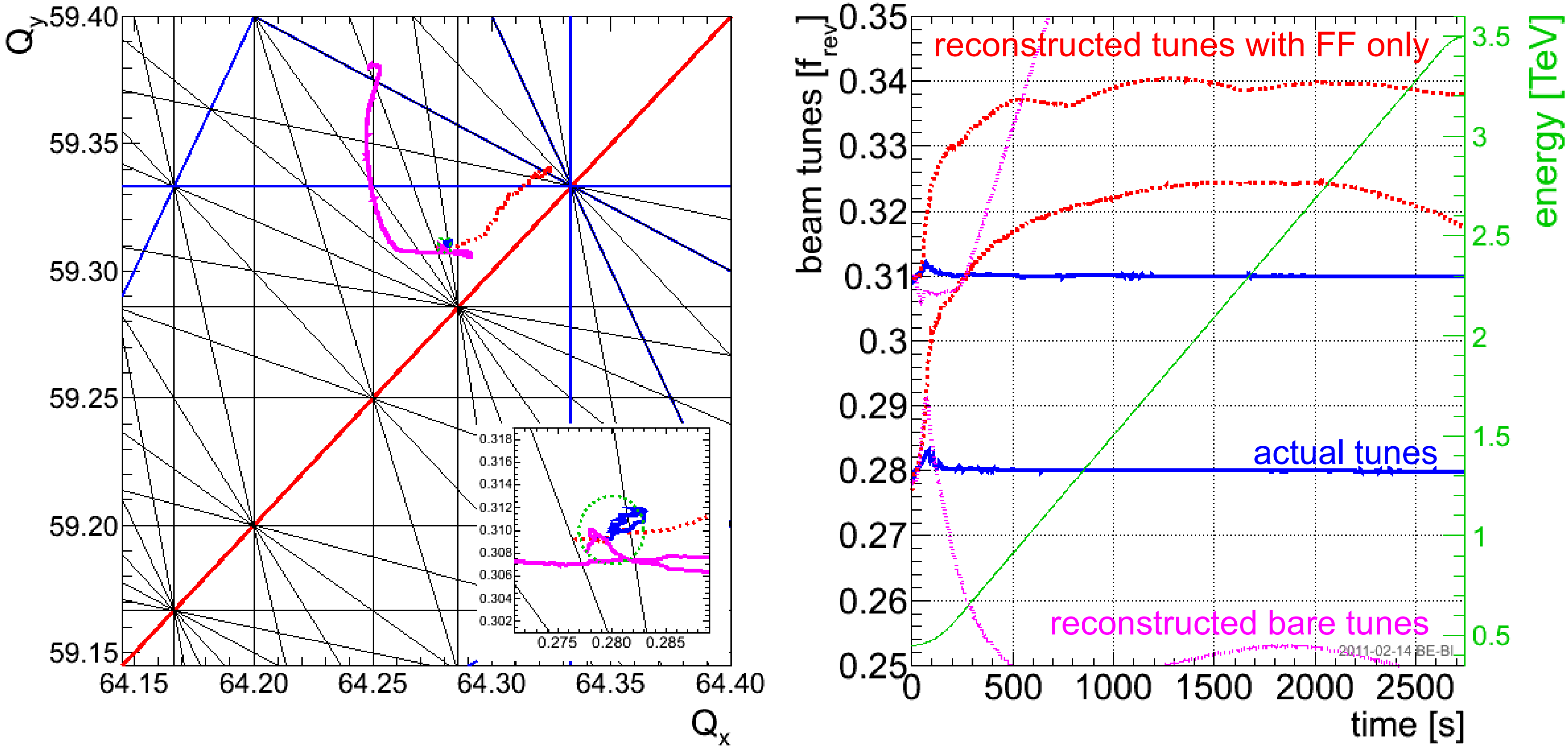
  - need to follow-up: K.O. exciter power-limitation handling (easily for >10 Tm operation)
    - Alternative: FB using fast extraction quadrupole or main-quads
  - Desirable: direct FB signal from experimental detectors

animated GIF - link

Higher-Order Beam Parameter Stability

Example: LHC Tune Feedback Operation

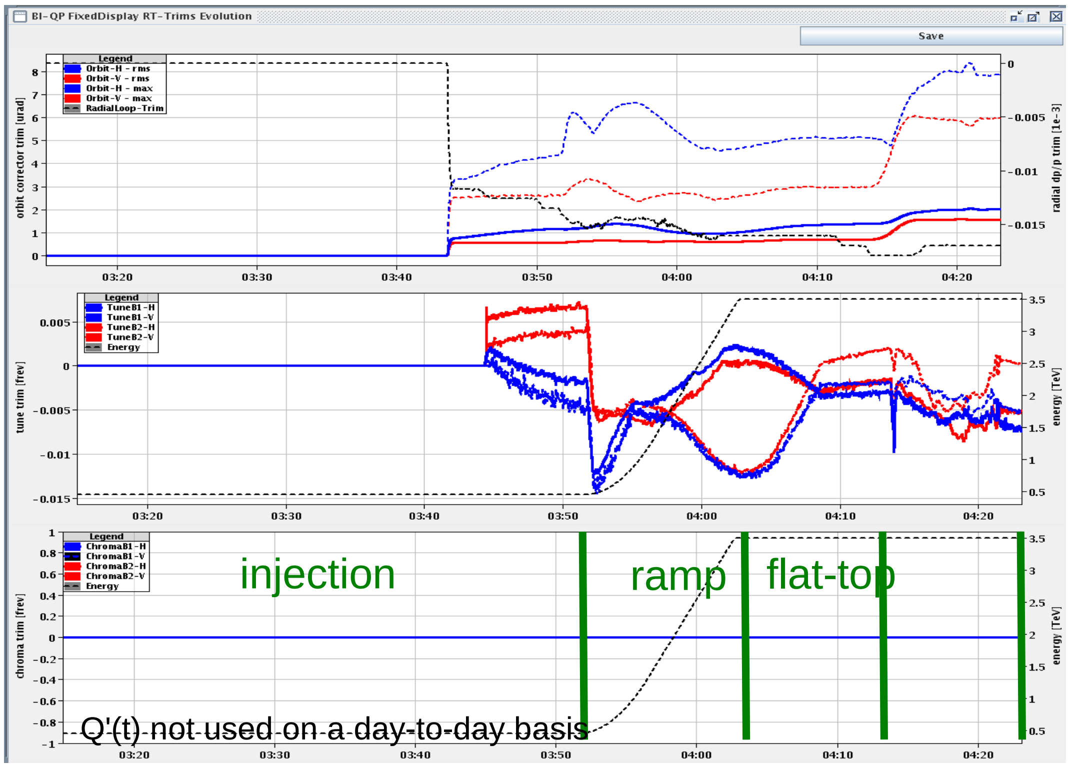
- Tune-FB driving and accelerating early commissioning in 2009-2011
  - tunes kept stable to better than 10^{-3} for most part of the ramp and squeeze
- even though perturbations were unrelated to quads, feedback helped mitigating these feed-down effects while allowing OP crews to work on other more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



Higher-Order Beam Parameter Stability

Example: Feedback Integration and Operation at LHC

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



Orbit-FB & Radial-Loop Trims (µrad)

Tune-FB trims

Q'(t)-FB trims

Energy (TeV)

β*-squeeze

FAIR Archiving System
https://edms.cern.ch/document/1176039/

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

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

Archiving

Post-Mortem

FAIR Archiving System

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

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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

Prepared by:	Checked by:	Approved by:
V. Rapp L. Hechler R. Steinhagen	**FAIR-C2WG-ALL** A. Reiter (BI) M. Schwickert (BI) J. Fitzek (CO) S. Reimann (OP) P. Schütt (OP) C. Omet (SIS-100 MP) D. Ondreka (System Planning) I. Lehmann (Machine-Exp.) D. Severin (Machine-Exp.) **MPLs & MCs***	R. Bär (Controls) R. Steinhagen (FAIR Comm. & Control)

Archiving

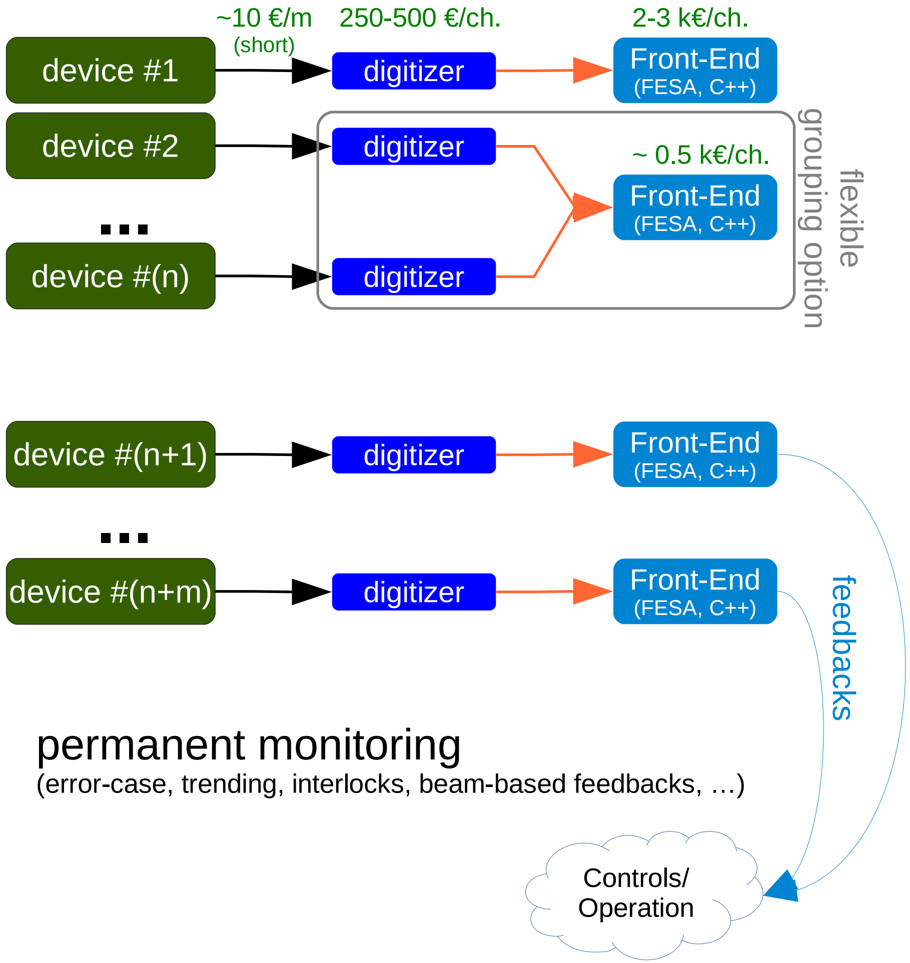
Post-Mortem

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

Digitization of Analog Signals at FAIR

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

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



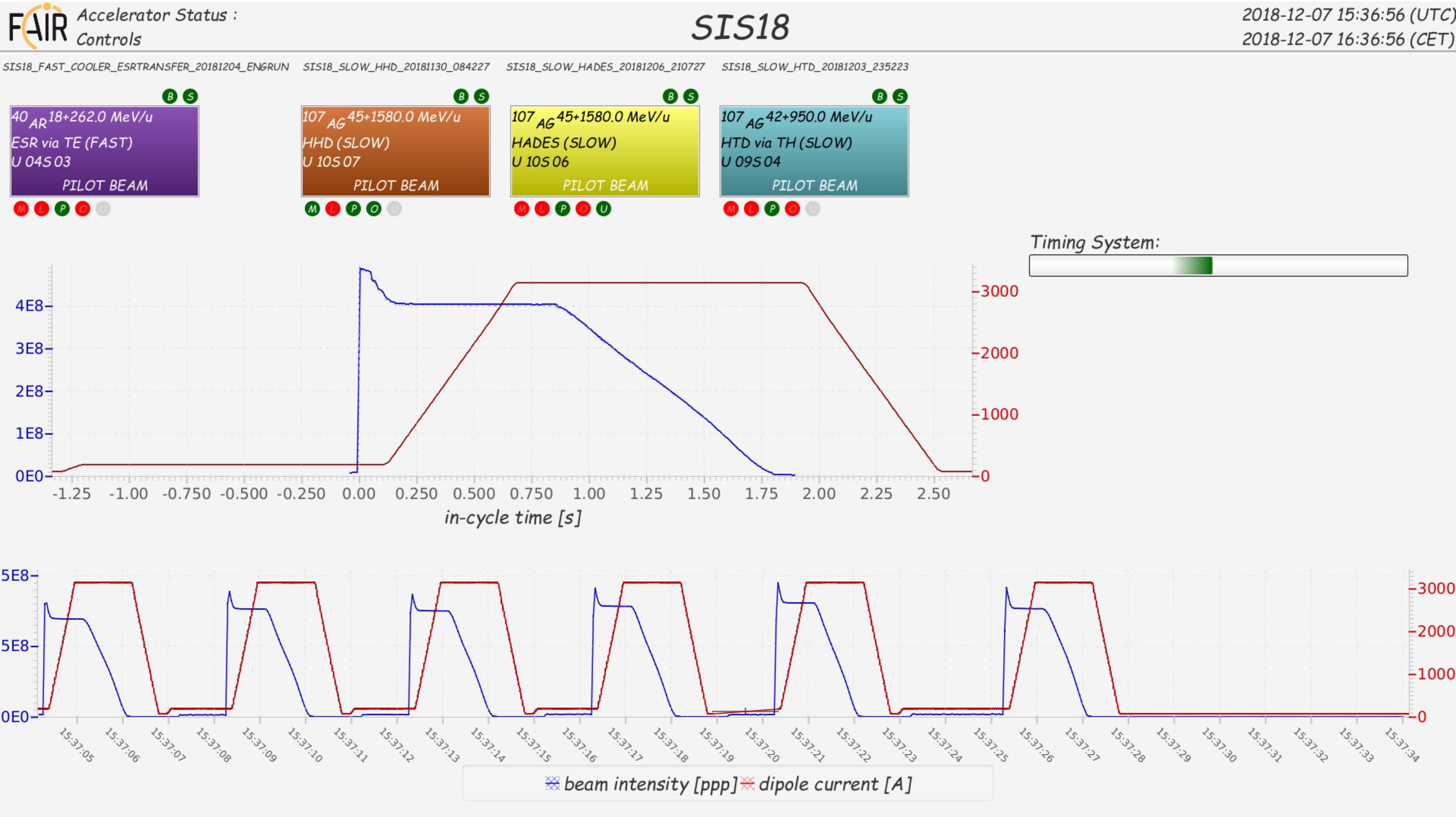
permanent monitoring
(error-case, trending, interlocks, beam-based feedbacks, …)

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

link: more details

Digitization of Analog Signals at FAIR

Example: SIS18 Machine Status



Beam Transmission Monitoring (BTM)

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

Ion-Source

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

transmission

Experiment

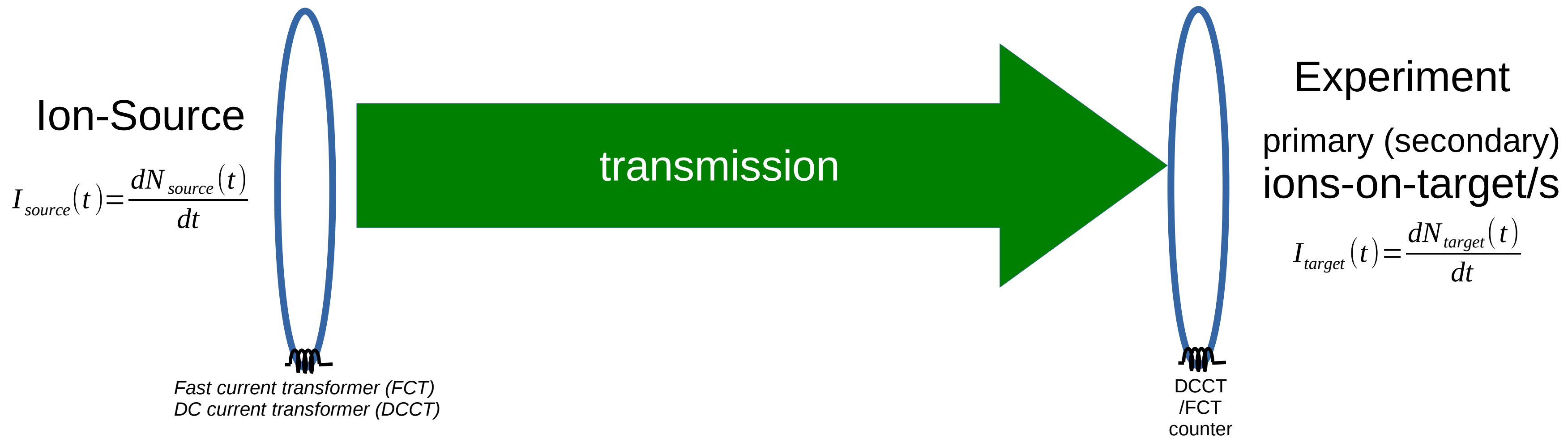
primary (secondary)

ions-on-target/s

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

Beam Transmission Monitoring (BTM)

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



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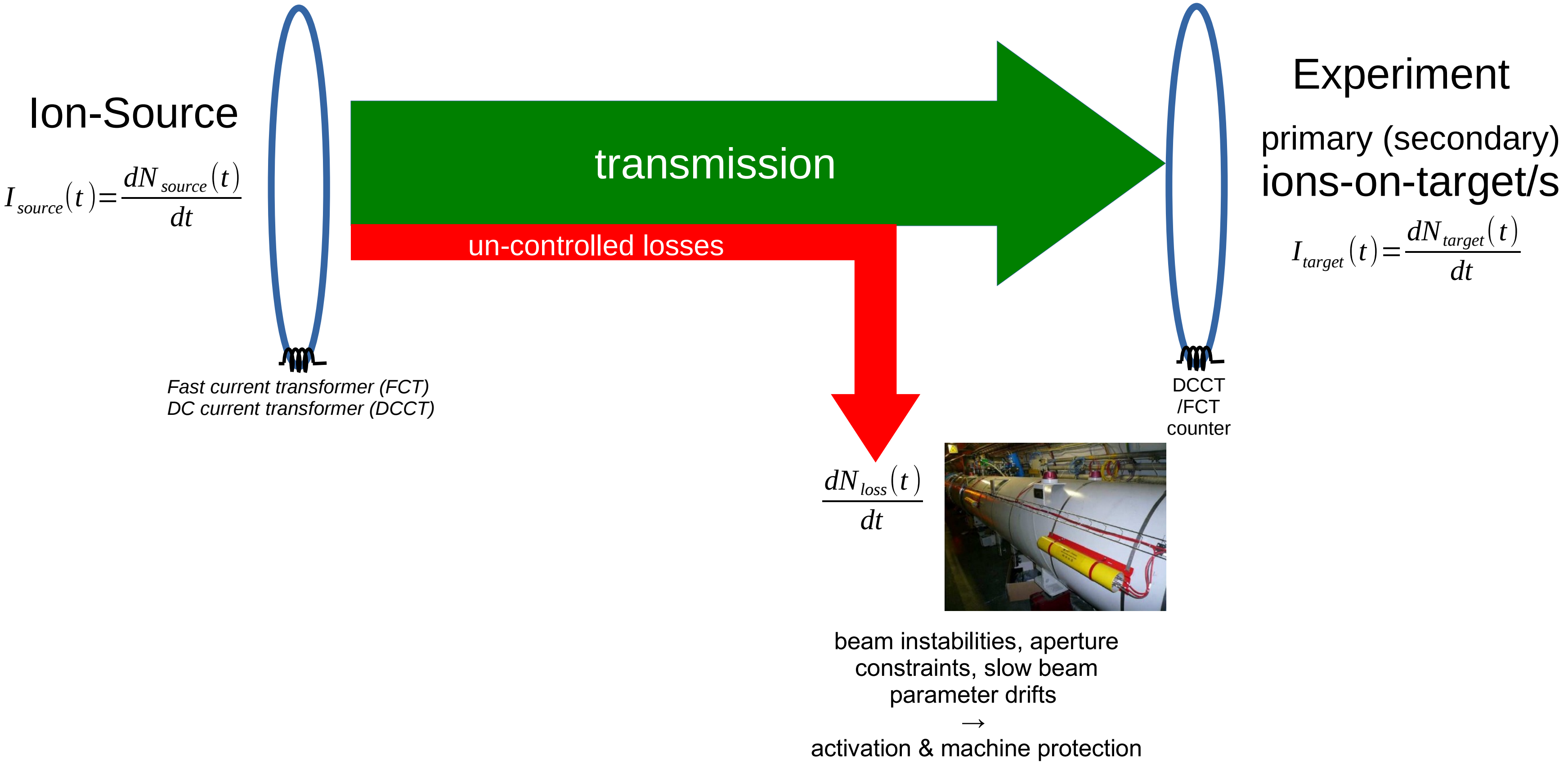

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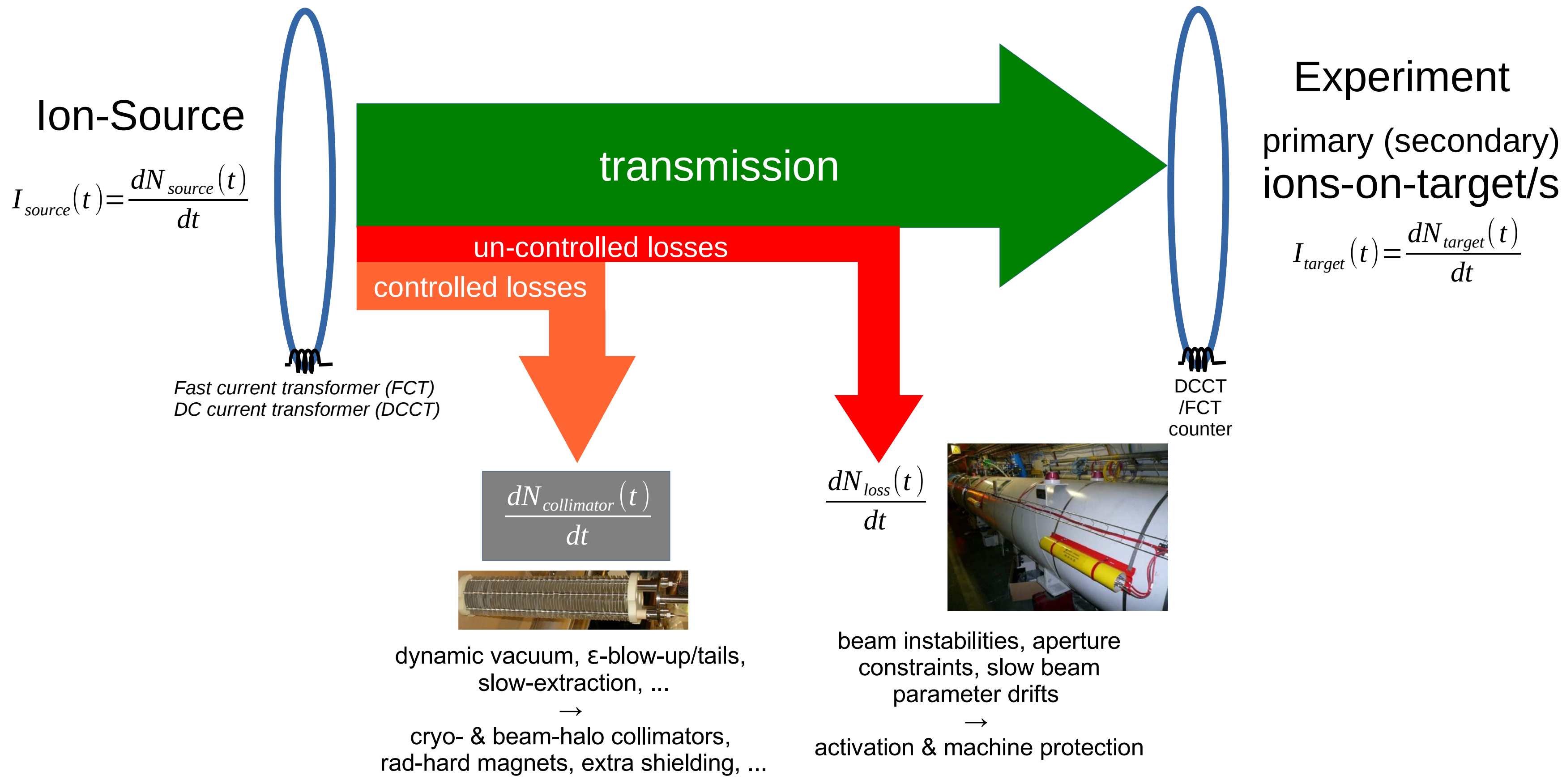

Beam Transmission Monitoring (BTM)

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

Experiment

primary (secondary)
ions-on-target/s

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

DCCT
/FCT
counter

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

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

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

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

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

Beam Transmission Monitoring (BTM)

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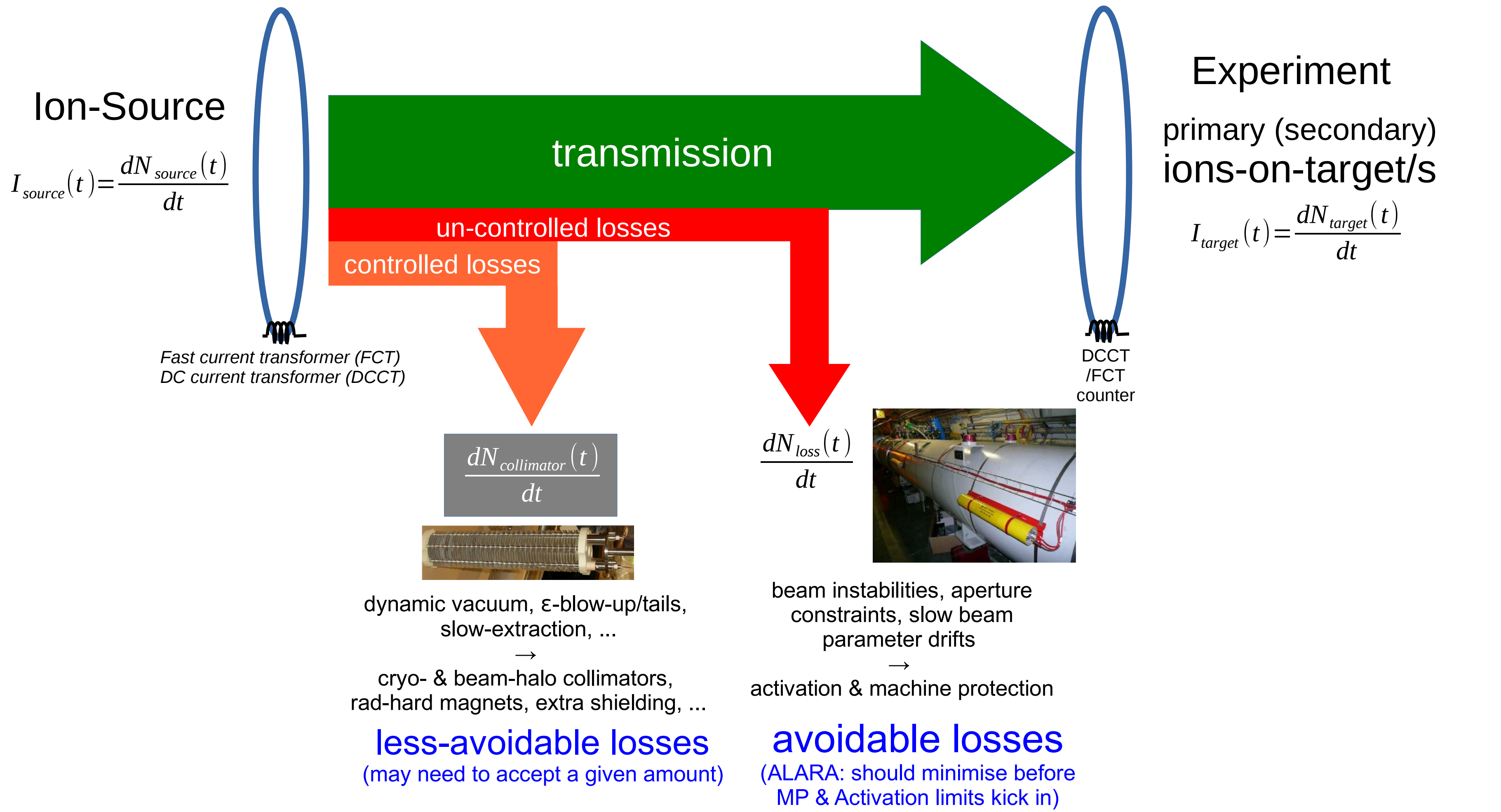

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/FCT
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$$\frac{dN_{collimator}(t)}{dt}$$

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

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

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

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

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

online dosimetry (abs. reference)

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

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

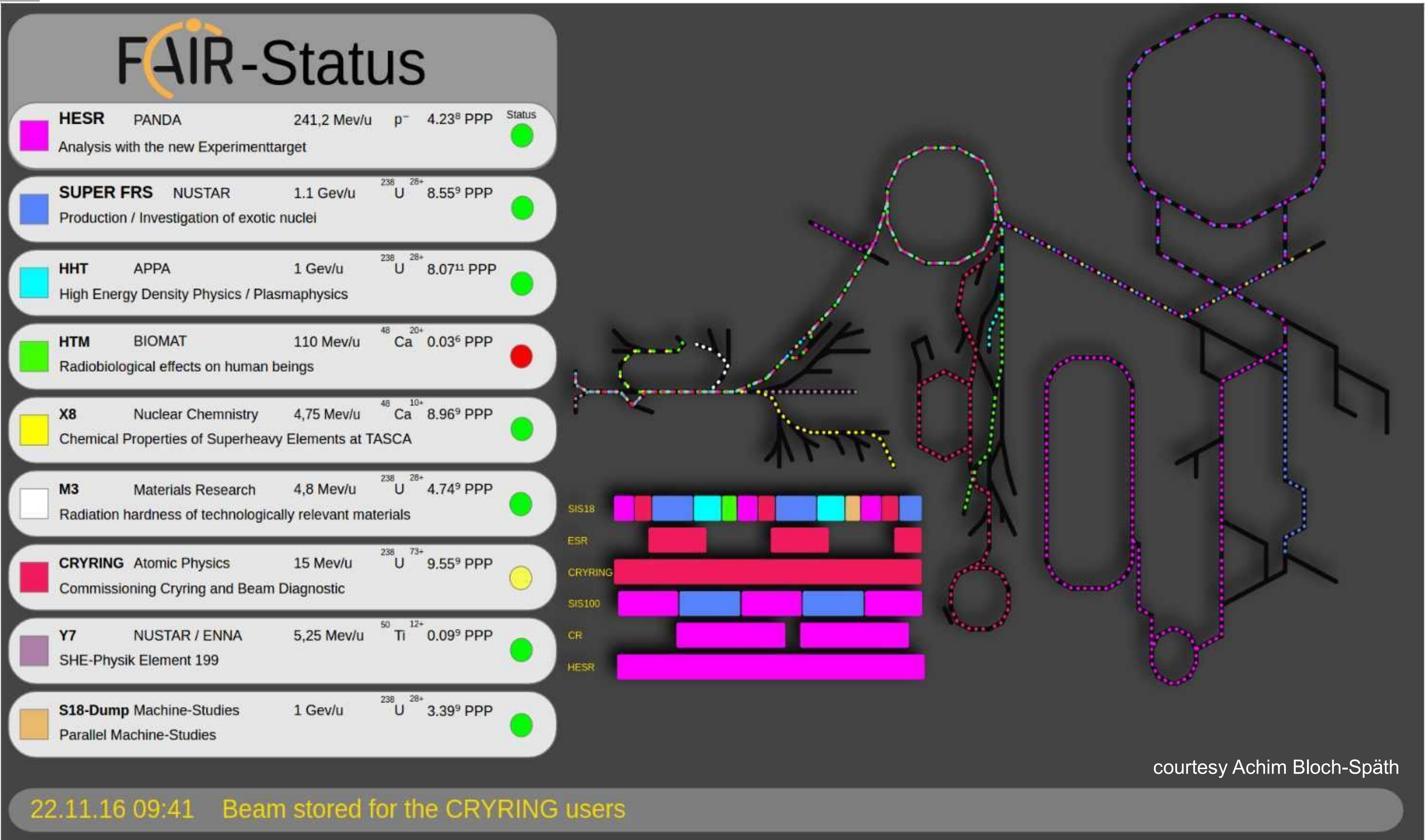
Abstract

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

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

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

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



FCC Fixed-Display & Workstation Layout
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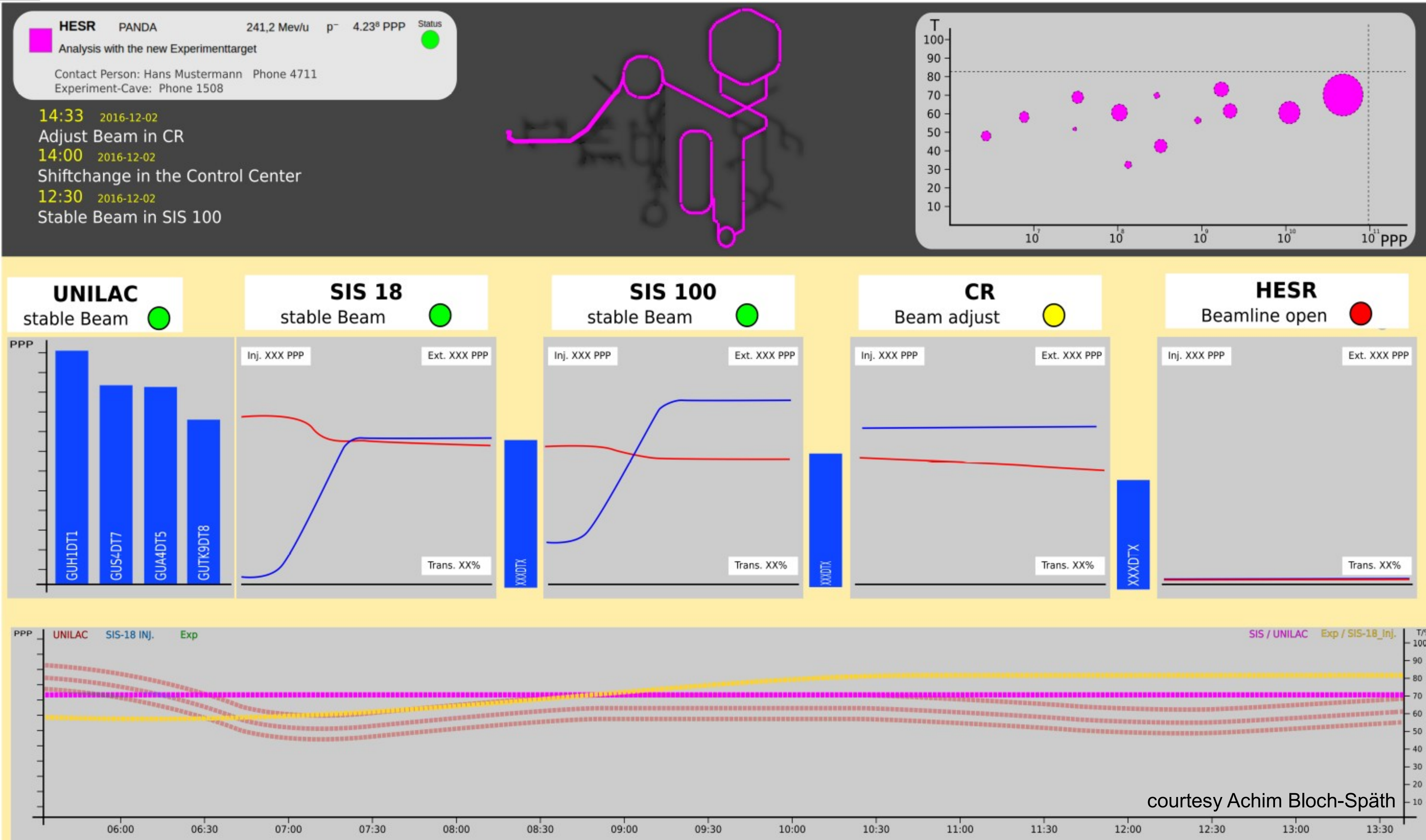
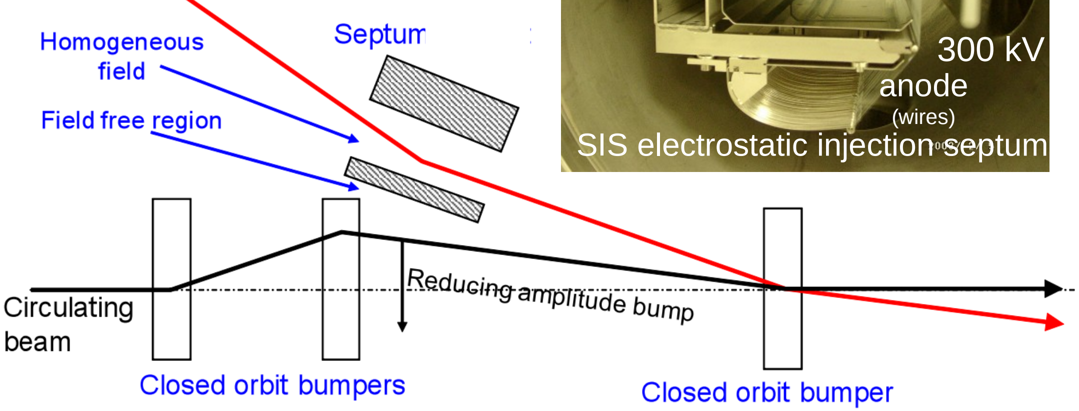
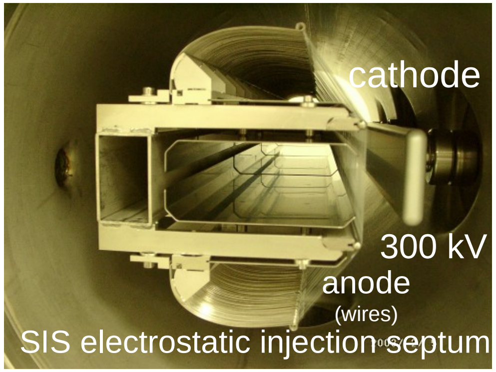


From a linac

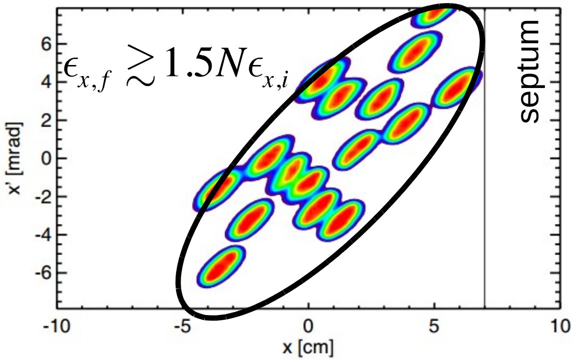
e.g. SIS-18, CERN PSB

courtesy Mike Barnes





Simulation: without space charge



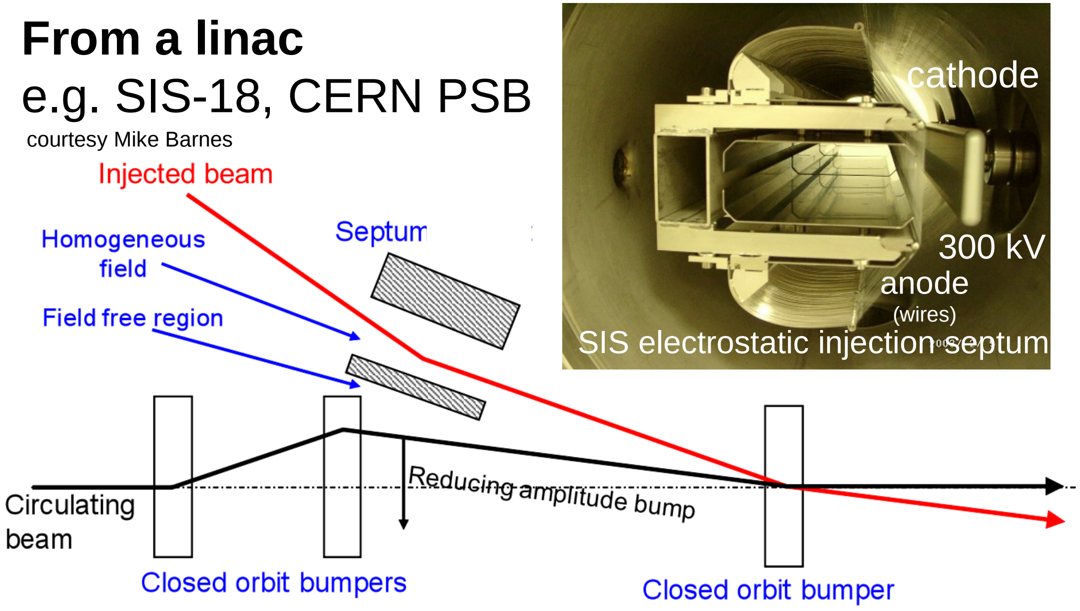
SIS18 Multi-Turn Injection (H-Phase-Space Painting)

Y. El-Hayek, S. Paret

From a linac

e.g. SIS-18, CERN PSB

courtesy Mike Barnes



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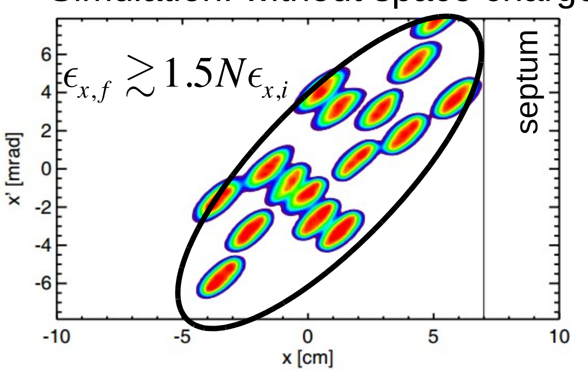

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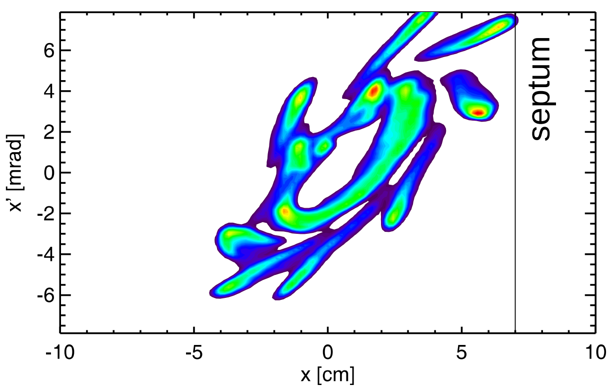

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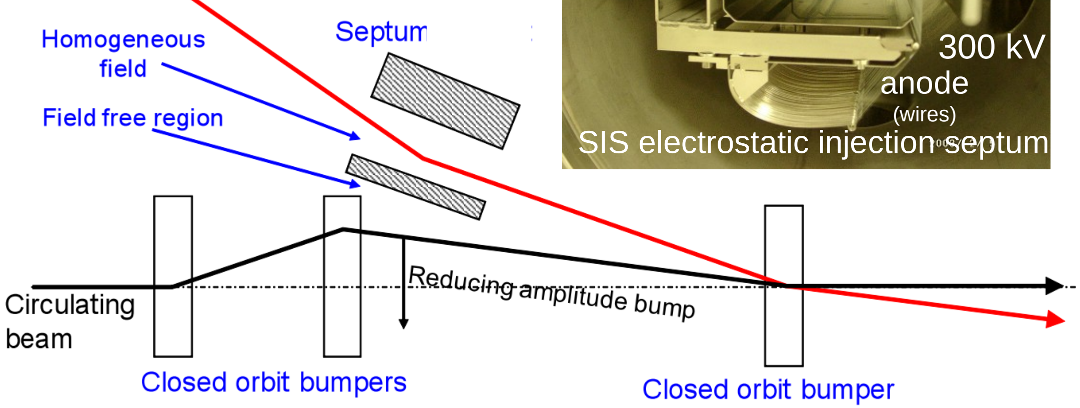
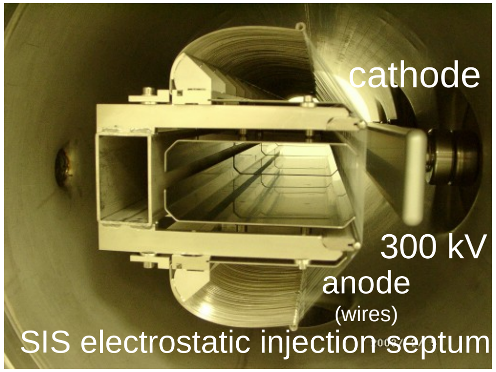
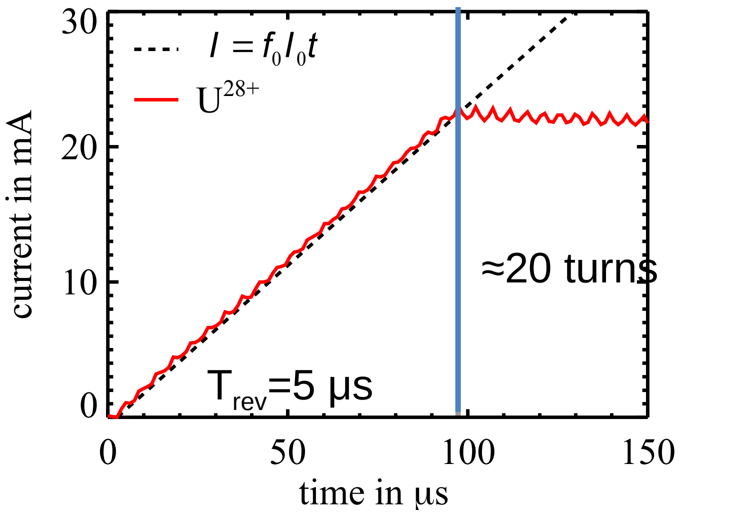
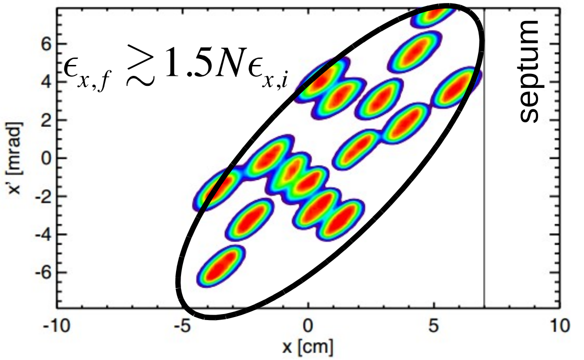




Measured MTI performance in SIS-18



Simulation: without space charge



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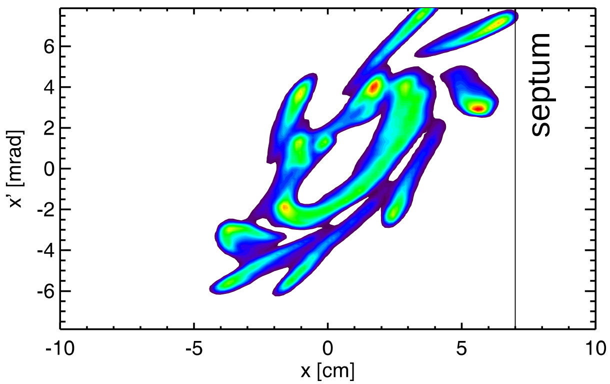

Y. El-Hayek, S. Paret

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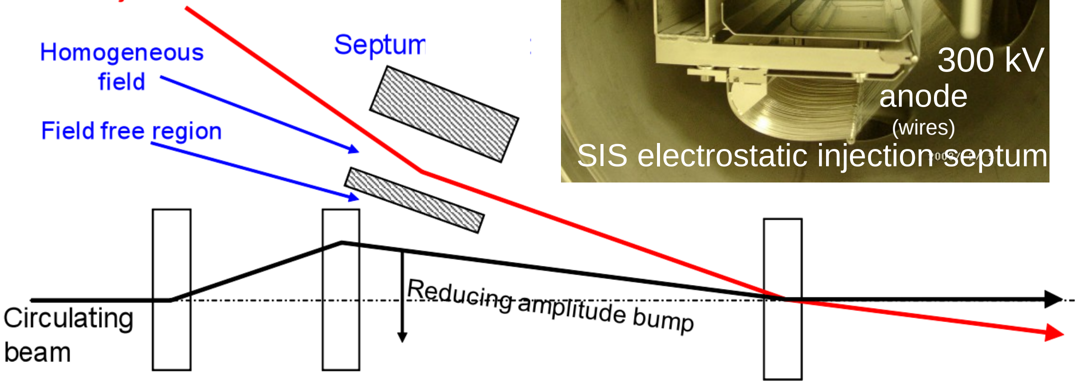

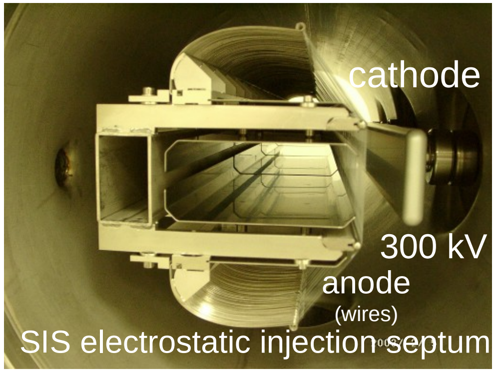

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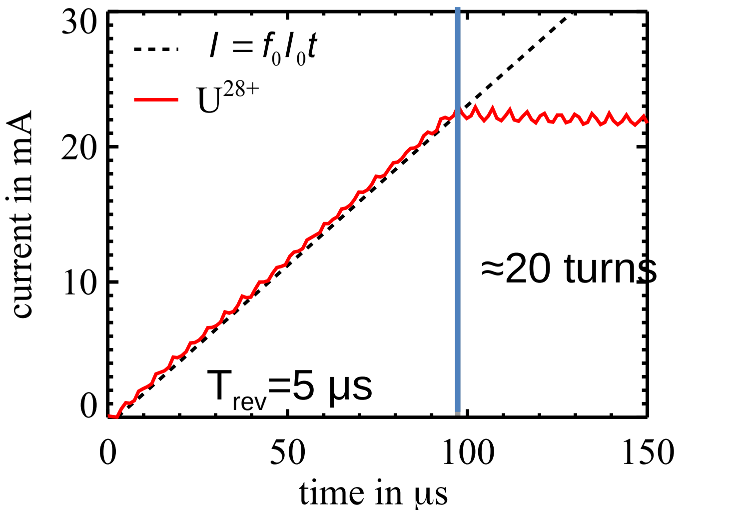

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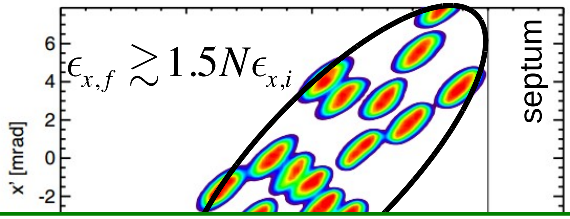

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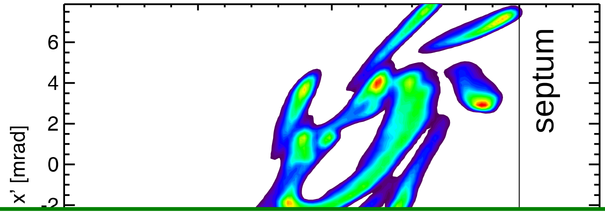
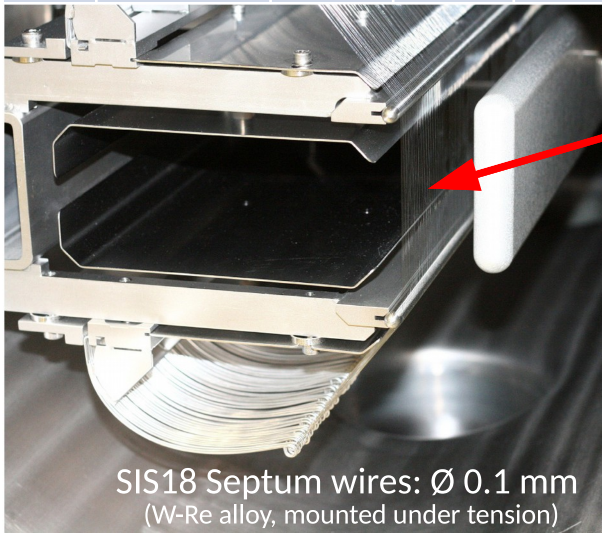


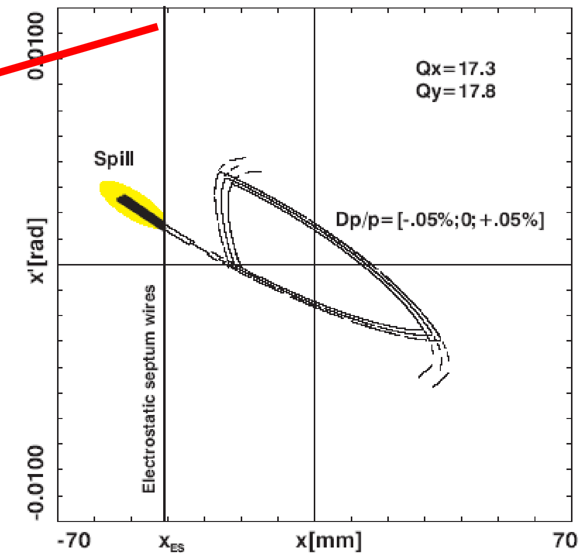
Injection losses → dynamic vacuum pressure rise
(highly complex: easy to simulate ↔ hard to measure/tune with beam)
looking forward to: injection steering (BPMs) & turn-by-turn profiles (IPMs)

Slow Extraction from SIS-100

Intense Heavy-Ion Beams for NuSTAR & CBM

Ion	Energy	N/s	spill	Power
U^{28+}	1.5 GeV/u	5E11	> 1 s	10 kW


SIS18 Septum wires: Ø 0.1 mm
(W-Re alloy, mounted under tension)



Tracking simulations:
5 % (approx. 500 W) loss in the septum wires
U^{92+} beam loss in warm magnet > 5 W/m

Non-trivial machine protection:
protection of septa wires
down-stream absorbers setup
activation minimisation

Slow Extraction from SIS-100

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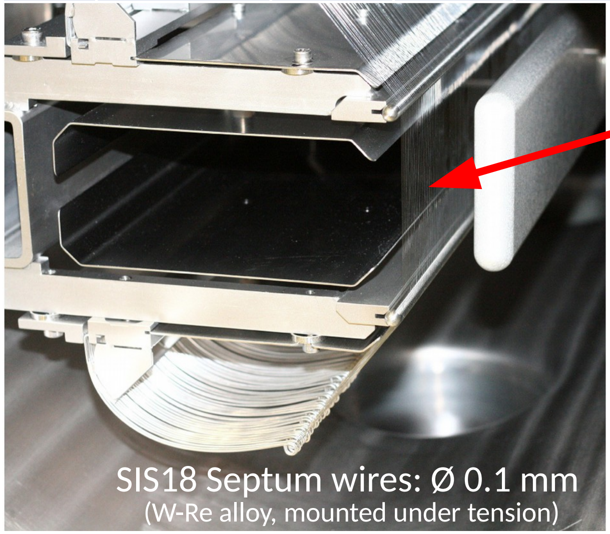

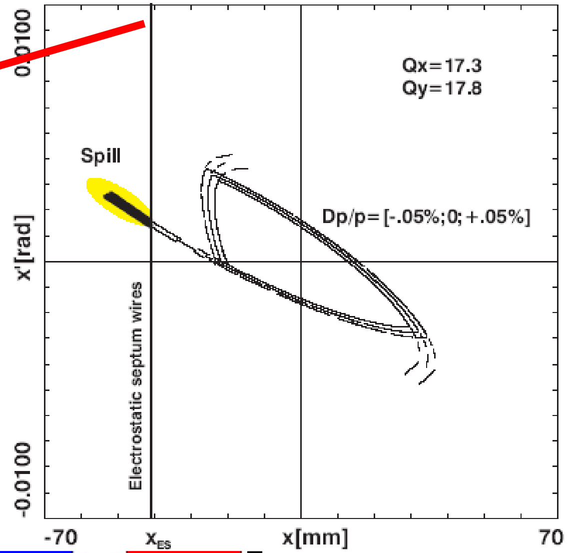

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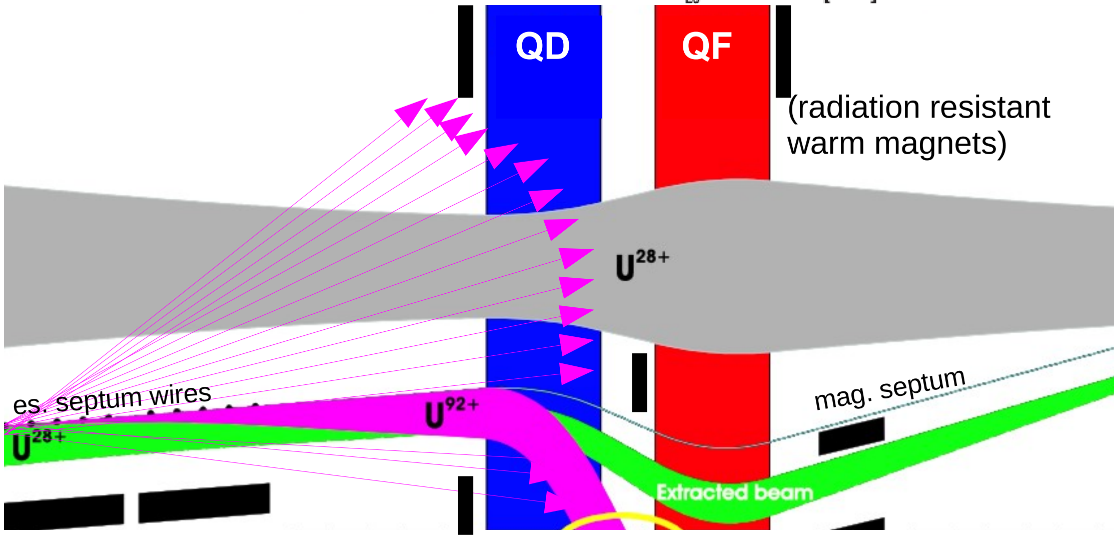

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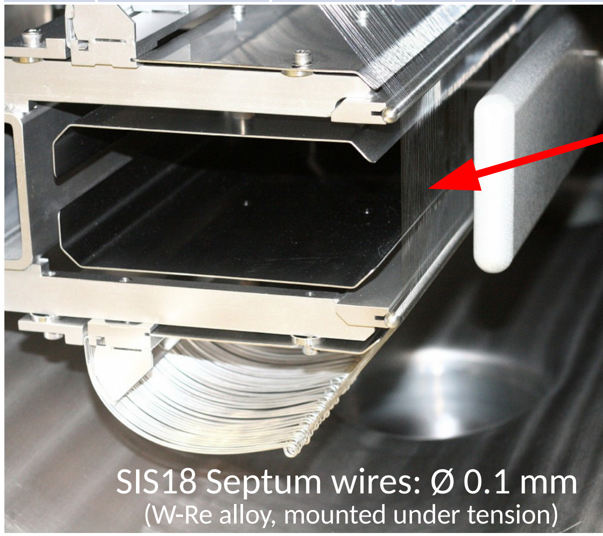
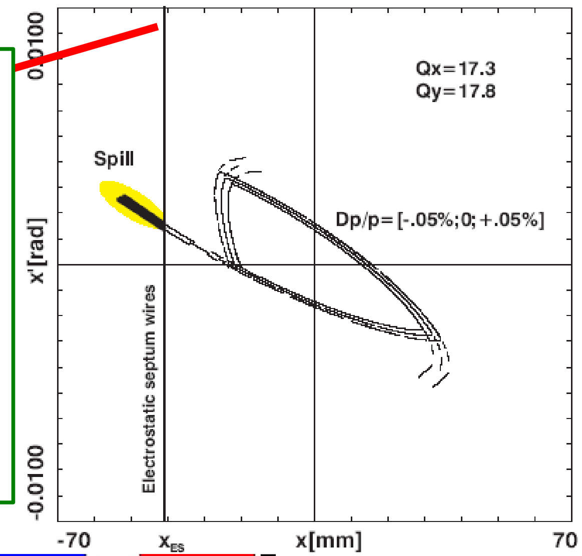
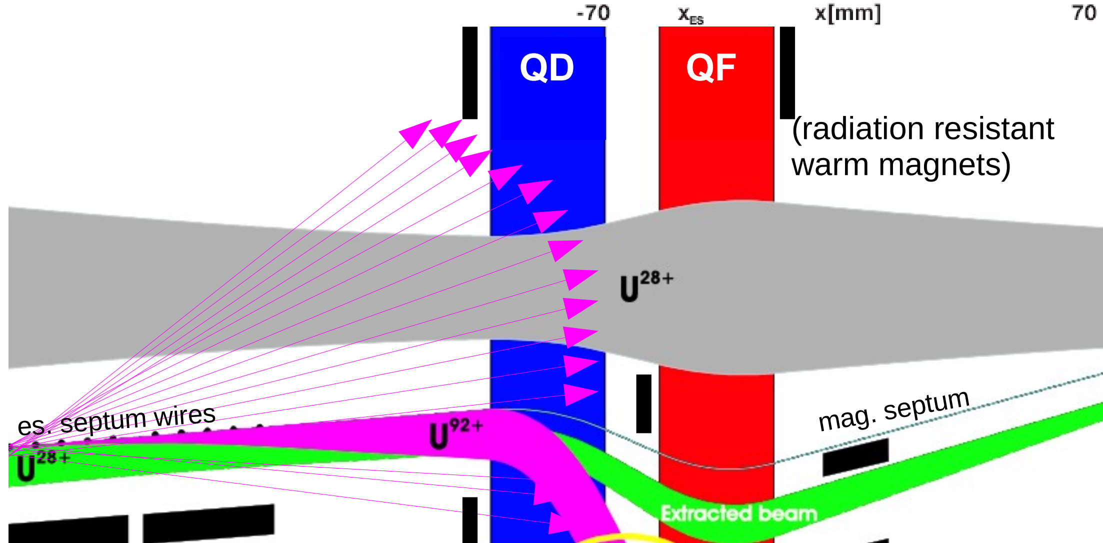


Optics, Q/Q'(",'") drive uncertainties on slow-extraction performance
→ remedy: control of the machine optics, Q/Q', linearisation prior to s.e., …
(highly complex, a lot of work ongoing)





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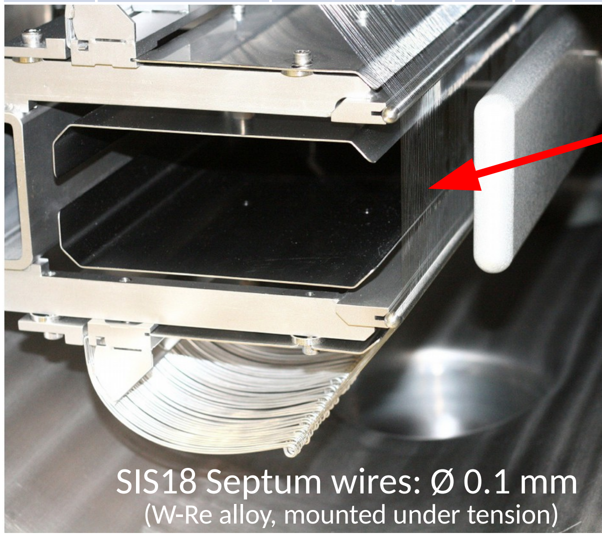

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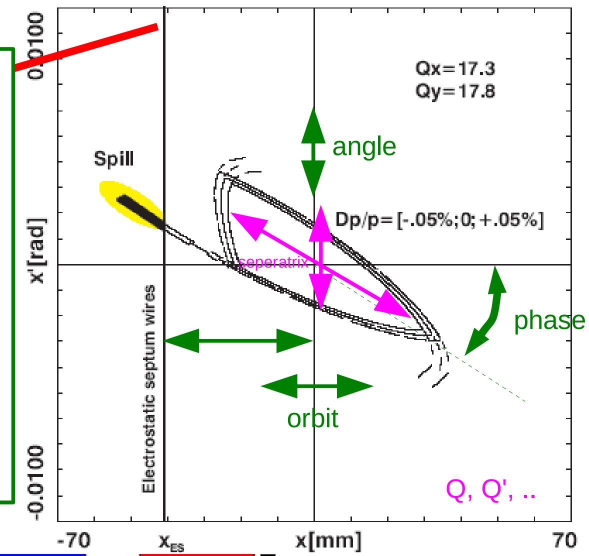

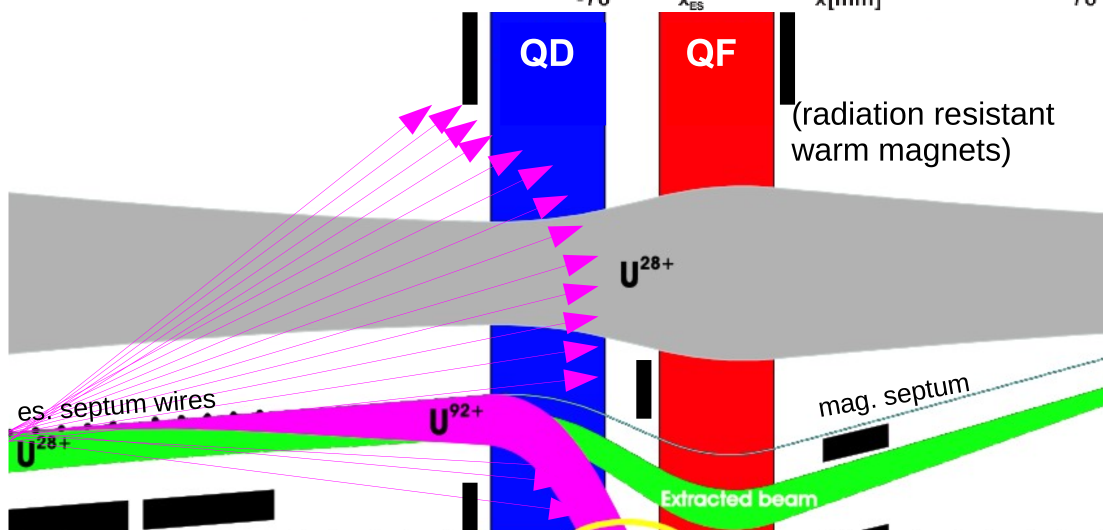

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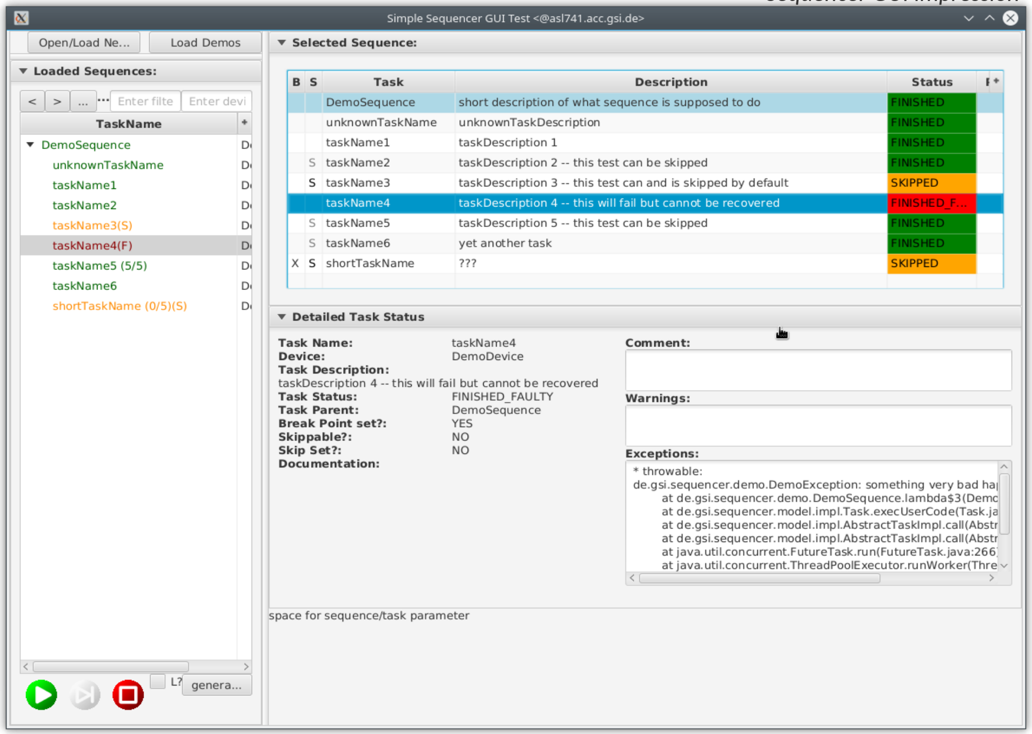
Sequencer Framework
Semi-automated Tests for HW and Beam Commissioning

HW and beam commissioning require efficient tools for testing

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

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

Sequencer GUI impression



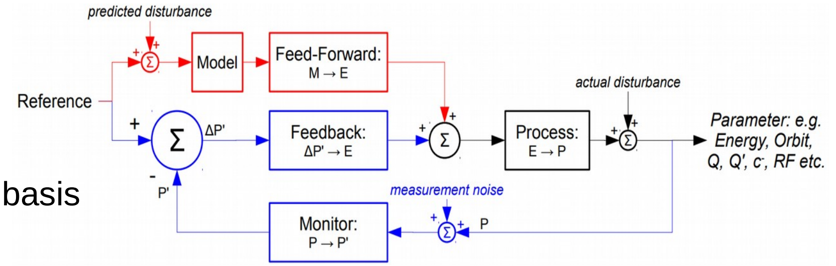
Sequencer architecture conceptually divided into:

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

Operational experience so far:

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

Summary

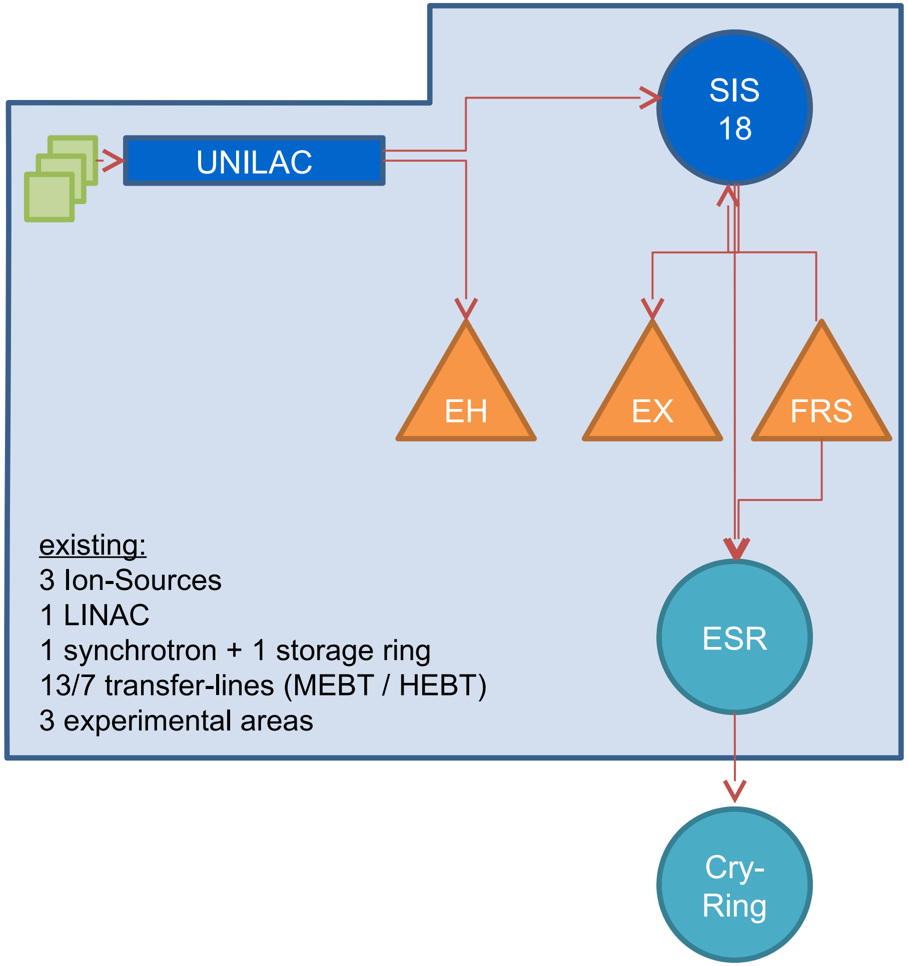


- FAIR ~4x the size of GSI,
  - non-linear operational complexity increase $O(n^2) \rightarrow O(n^5)$
  - 5-7 parallel experiments + typically lasting only 4-5 days
    → world-wide unique requirement: reconfigure facility on a daily basis
  - new challenges w.r.t. GSI:
    - x10-100 higher intensities,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

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

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

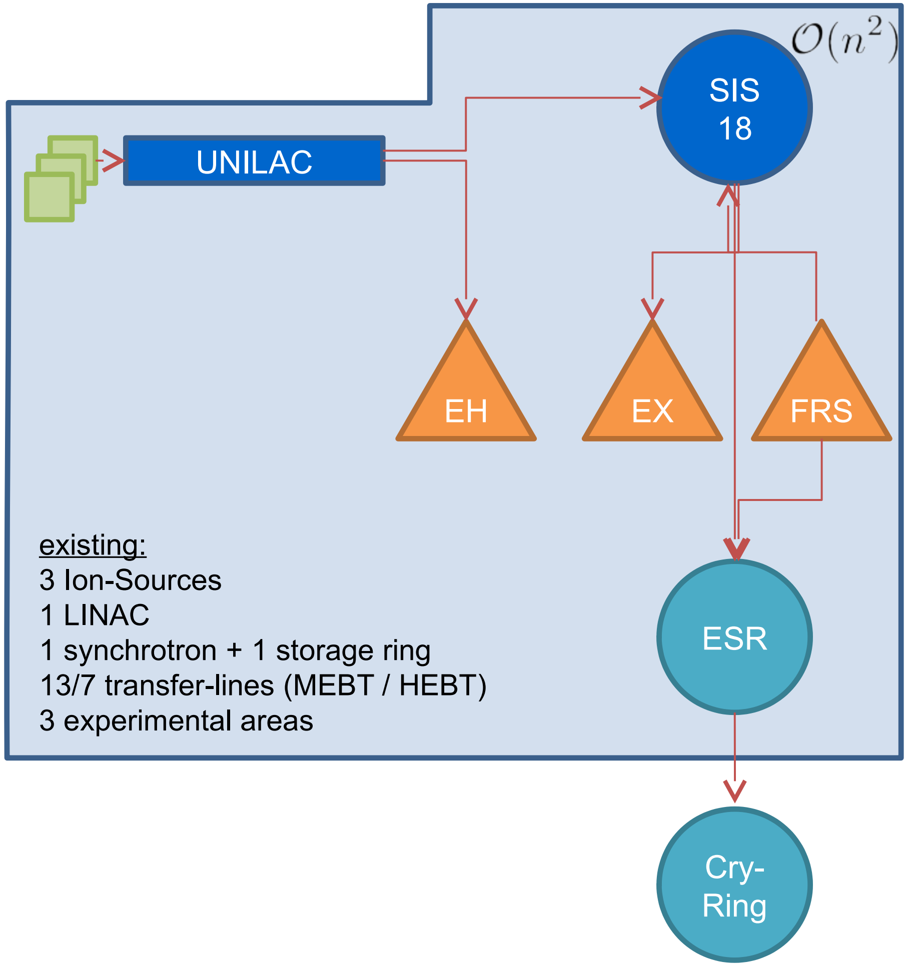
GSI to FAIR Transition
GSI 3 → FAIR 8½ (11+) accelerator(-like) machines



<u>existing:</u>
3 Ion-Sources
1 LINAC
1 synchrotron + 1 storage ring
13/7 transfer-lines (MEBT / HEBT)
3 experimental areas

GSI to FAIR Transition

GSI 3 → FAIR 8½ (11+) accelerator(-like) machines



<u>existing:</u>
3 Ion-Sources
1 LINAC
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13/7 transfer-lines (MEBT / HEBT)
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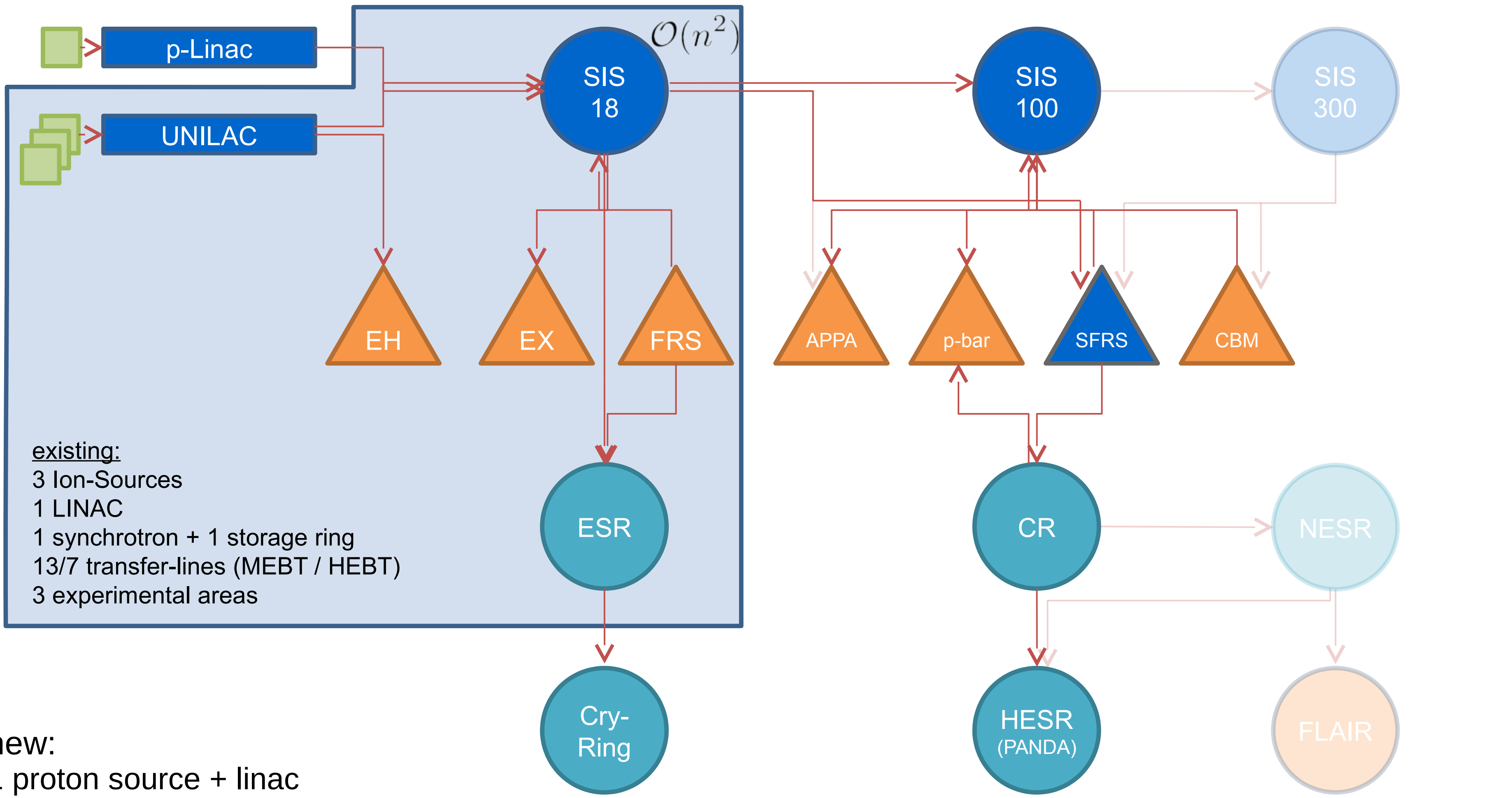
GSI to FAIR Transition

GSI 3 → FAIR 8½ (11+) accelerator(-like) machines



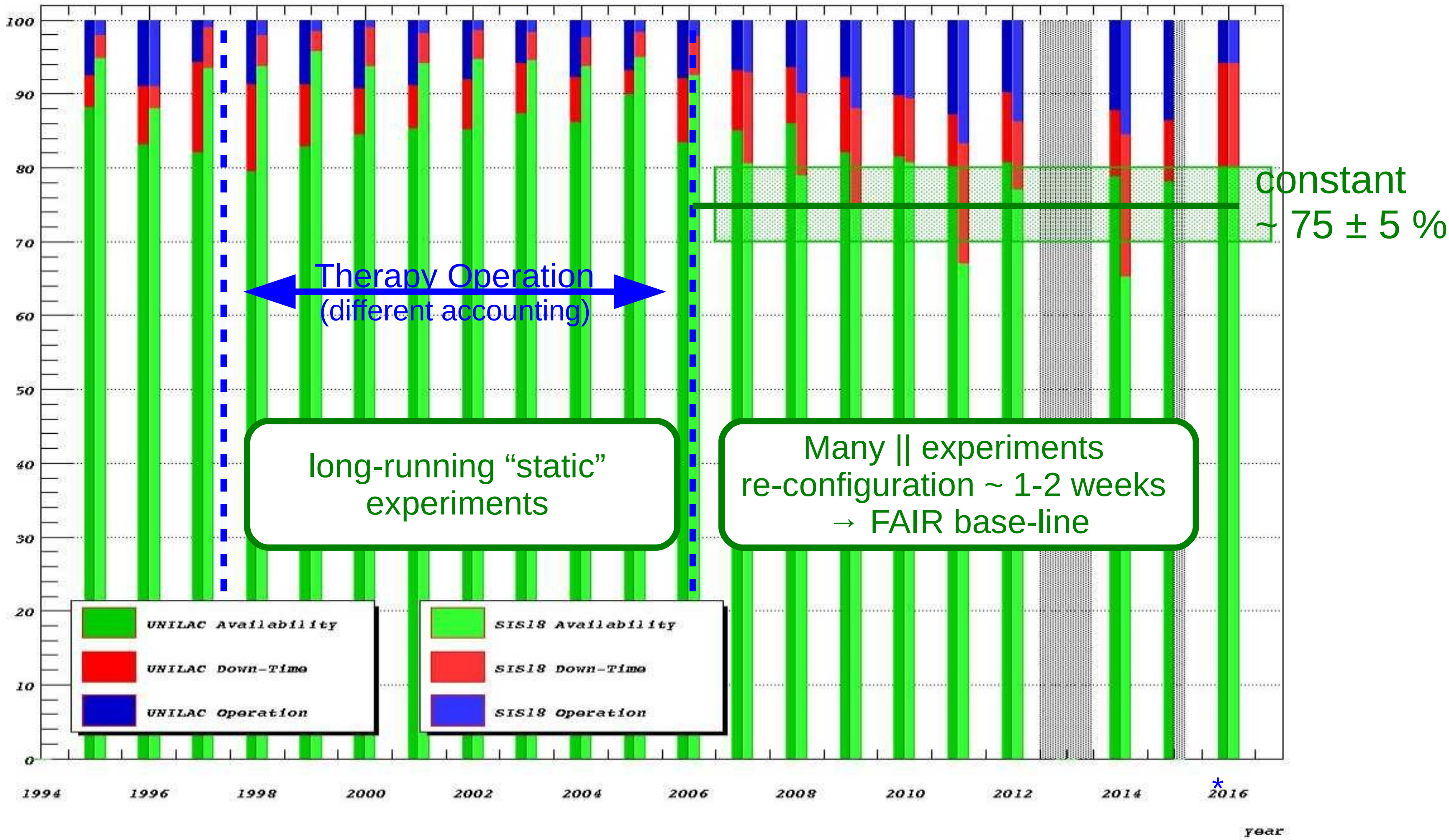
new:
1 proton source + linac
4 synchrotrons & storage rings
18 (26) transfer-lines
4 (5) experimental areas

MSV 0-3

MSV

$\mathcal{O}(n^5)$

Accelerator Experience & Efficiency
1995-2016: U. Scheeler, S. Reimann, P. Schütt et al.

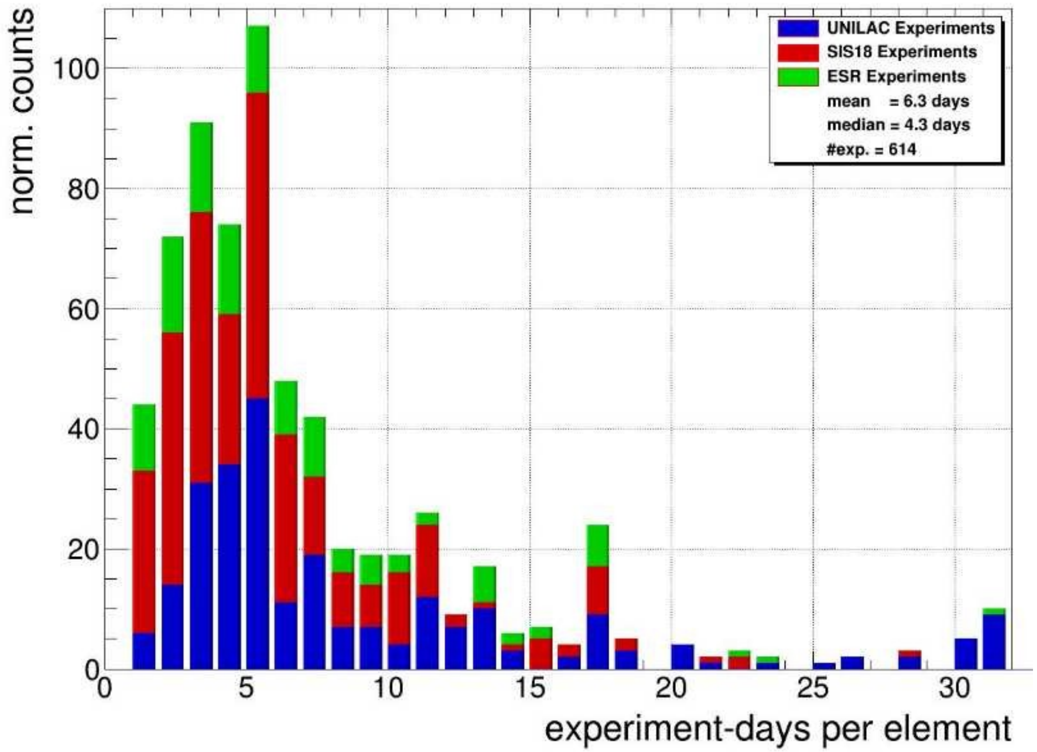


Based on: U. Scheeler, S. Reimann, P. Schütt et al., "Accelerator Operation Report", GSI Annual Scientific Reports 1992 – 2015 + 2016 (D. Severin)
https://www.gsi.de/en/work/research/library_documentation/gsi_scientific_reports.htm
N.B. ion source exchanges are factored out from UNILAC & SIS18 data (~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

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

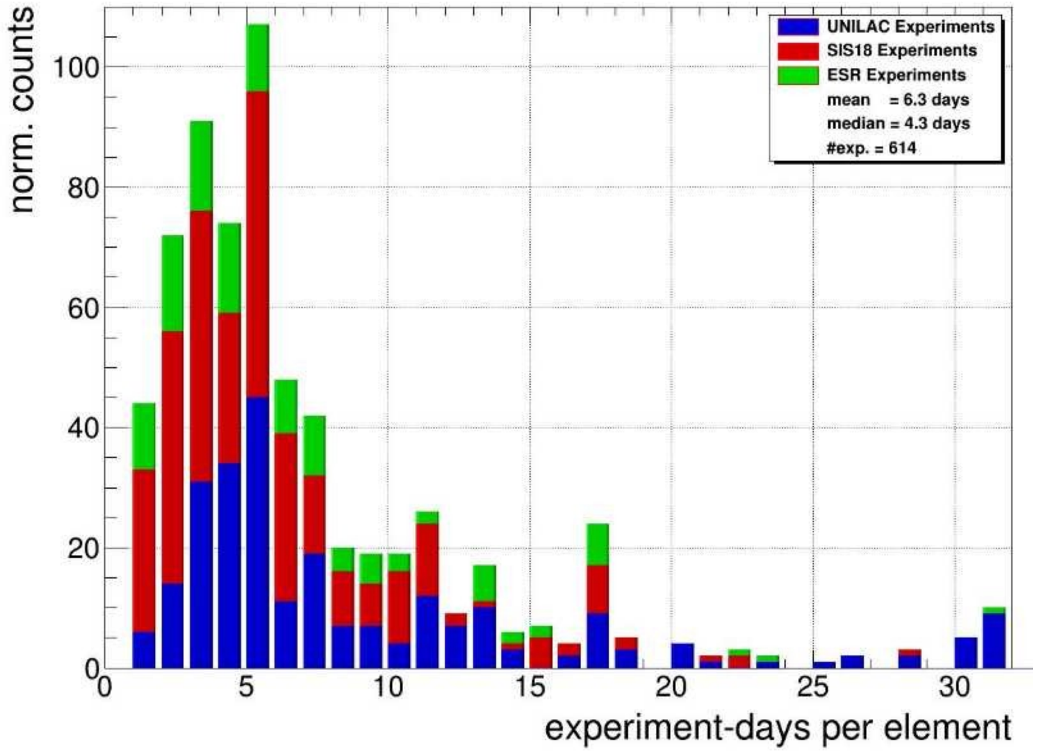
Accelerator Experience & Efficiency

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



Accelerator Experience & Efficiency

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



bottom line (1st order):

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

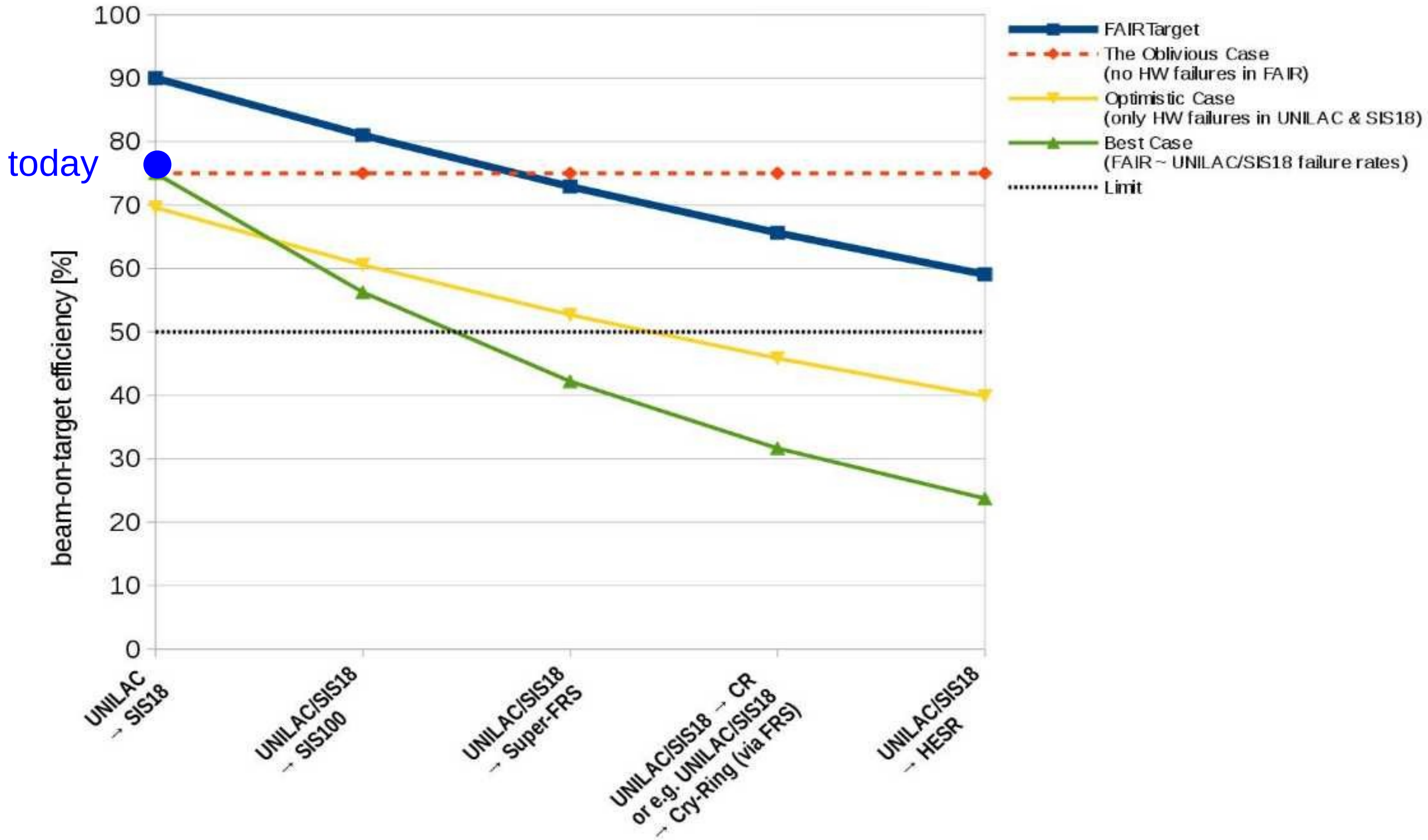
B) FAIR will accommodate about 5-6 parallel experiments

→ expect:

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

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

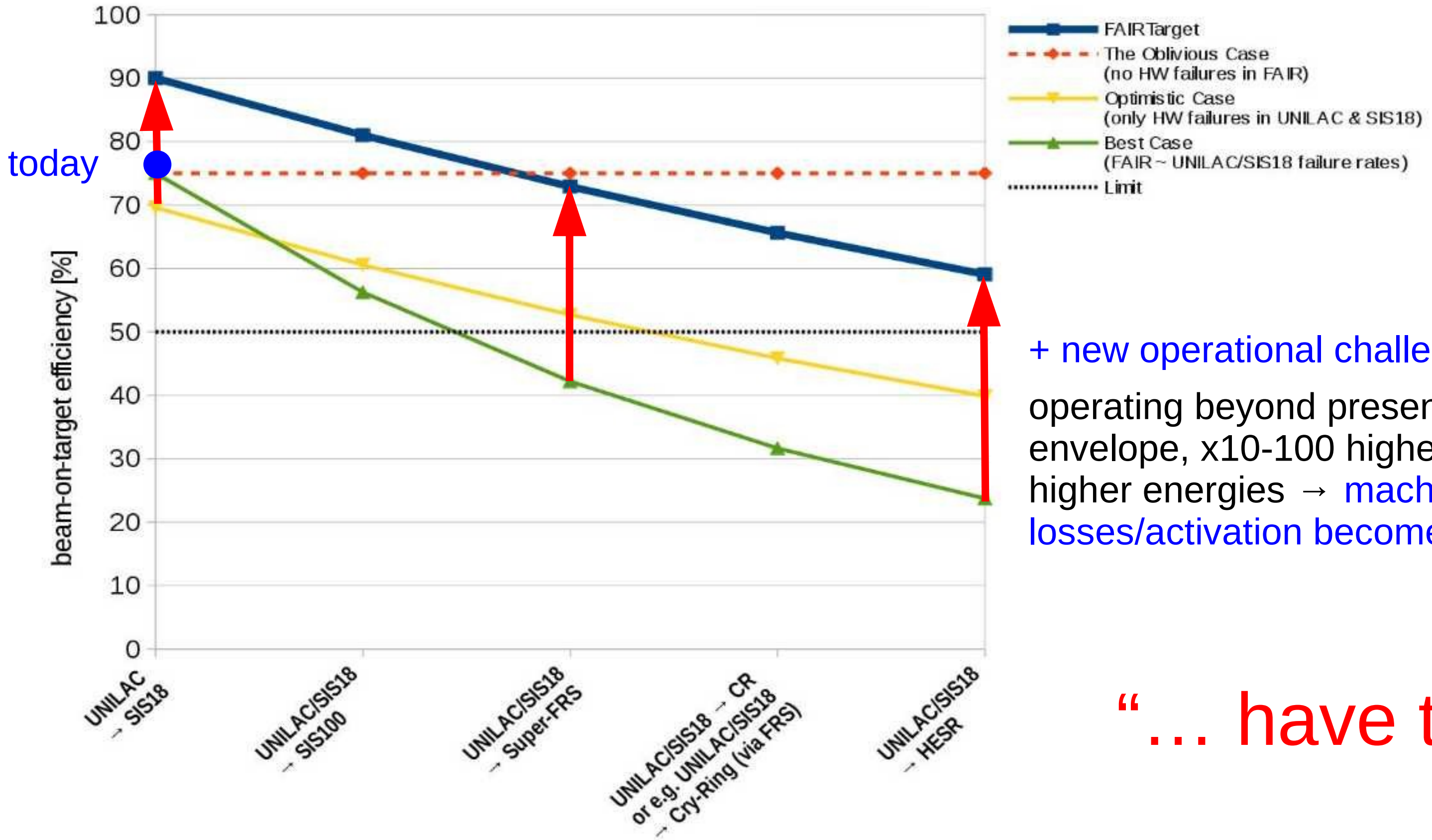
$$\varepsilon_{FAIR} := \prod_{i}^{n_{machines}} \varepsilon_i = \varepsilon_{UNILAC} \cdot \varepsilon_{SIS18} \cdot \varepsilon_{SIS100} \cdot \varepsilon_{SuperFRS} \cdot \varepsilon_{CR} \cdot \varepsilon_{HESR} \cdot \ldots$$



FAIR Challenges & Constraints
… SIS18 Operation Experience & Efficiency

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

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



+ new operational challenges:

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

"… have to improve!"

Control System Architecture Stack

Not exhaustive...

Presentation Tier

JavaFx

JAVA Swing

Middle Tier

powerful servers

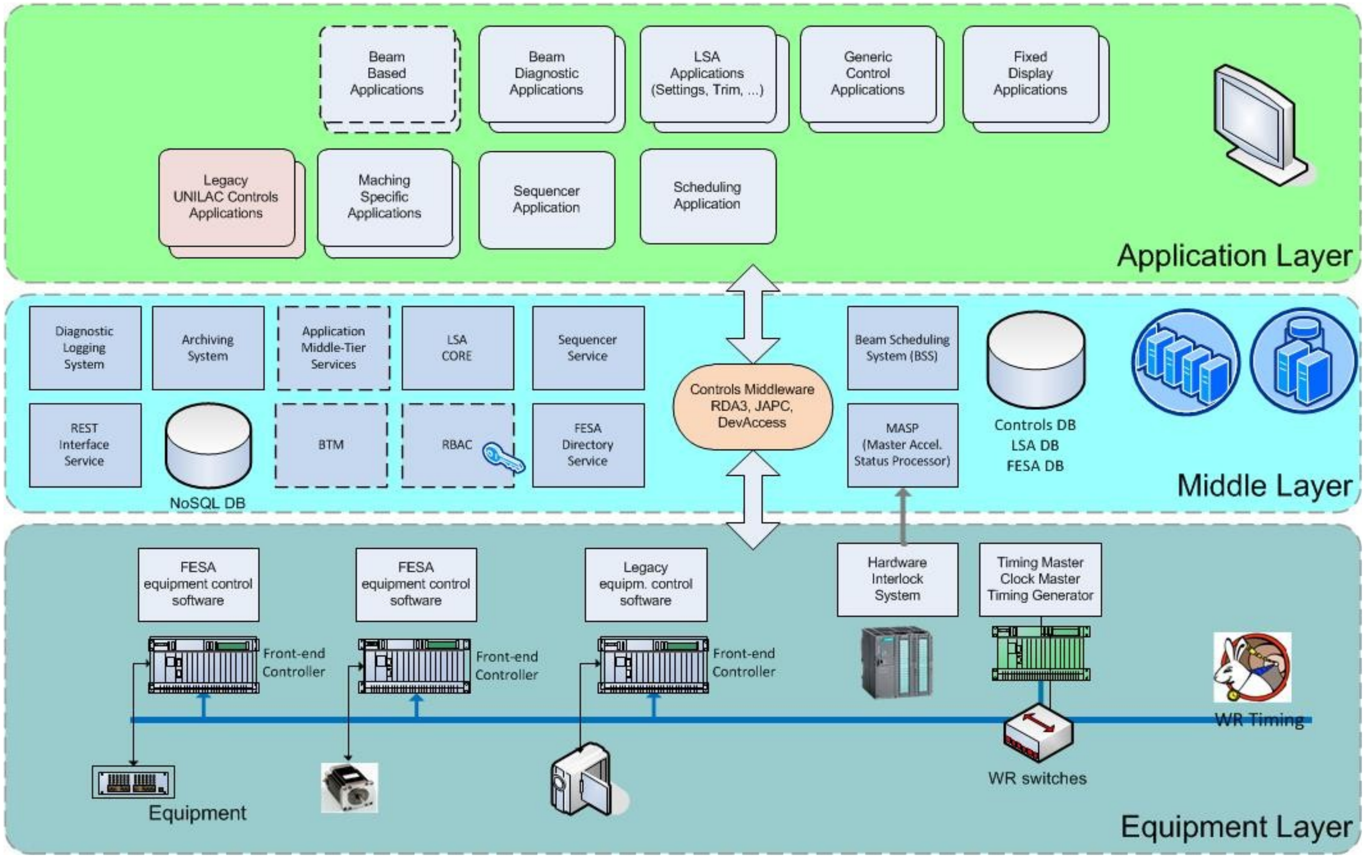
Java

Resource Tier

FESA

C++

VHDL



python

Qt ???

Linux

ØMQ

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

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

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

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

topic started
topic active
topic not started