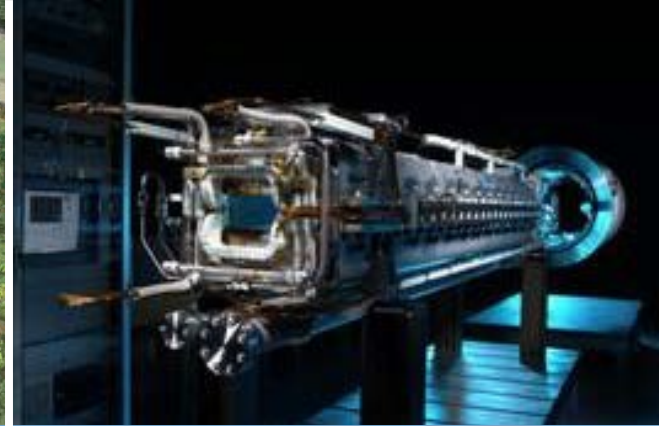




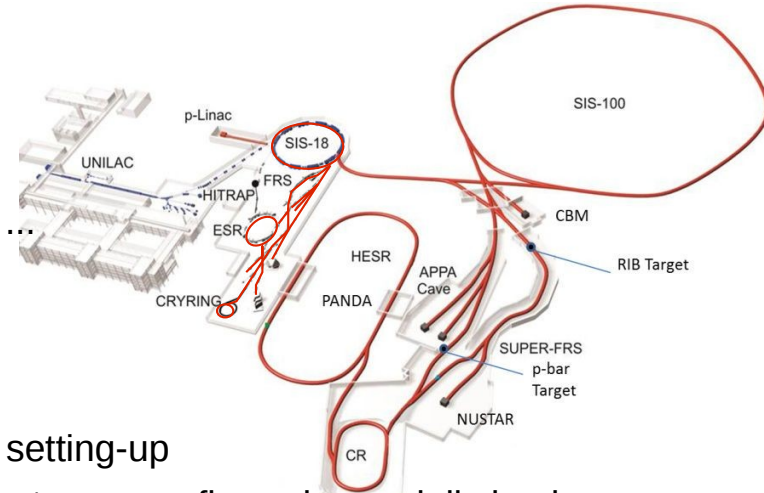
FAIR Accelerator Facility Control: Semi-Automation & Beam-Based Feedbacks

D. Ondreka,
Ralph J. Steinhagen

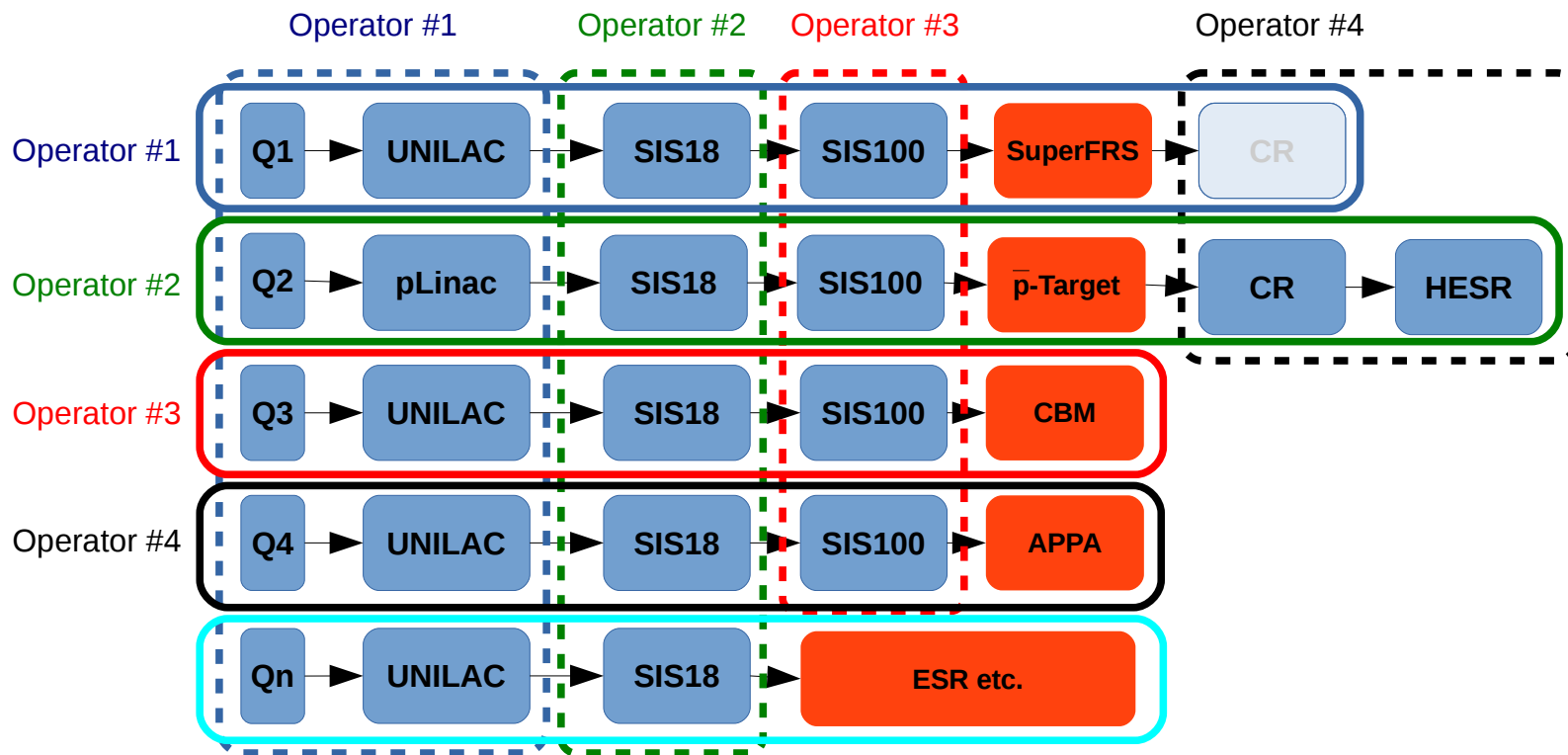
ARIES Accelerator Performance and Concept Workshop, 10th December 2018
Flemings Hotel, Frankfurt am Main, Germany



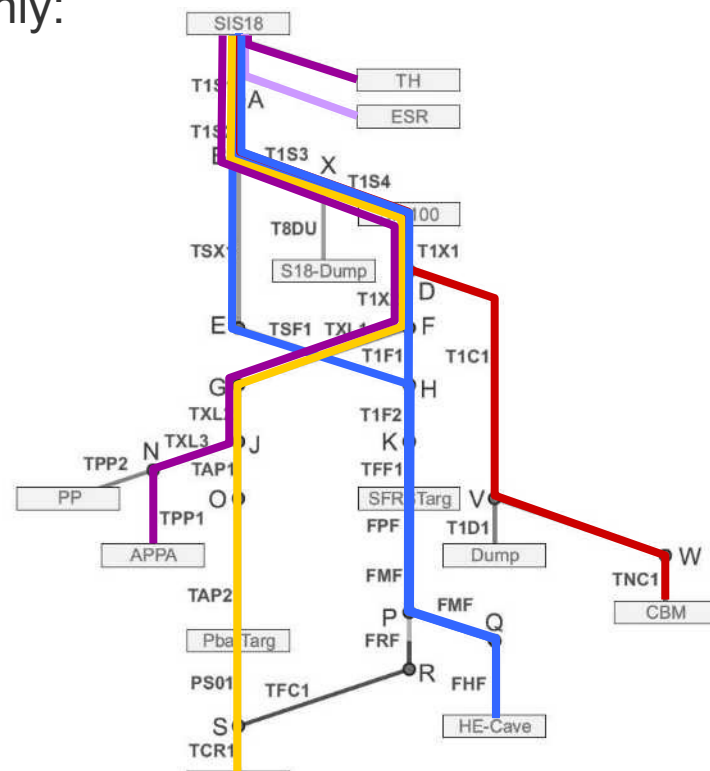
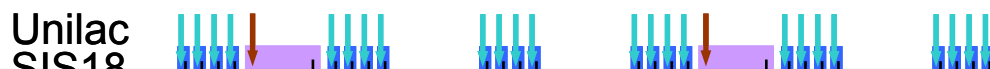
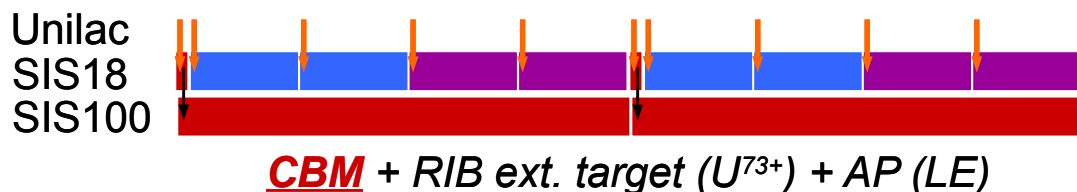
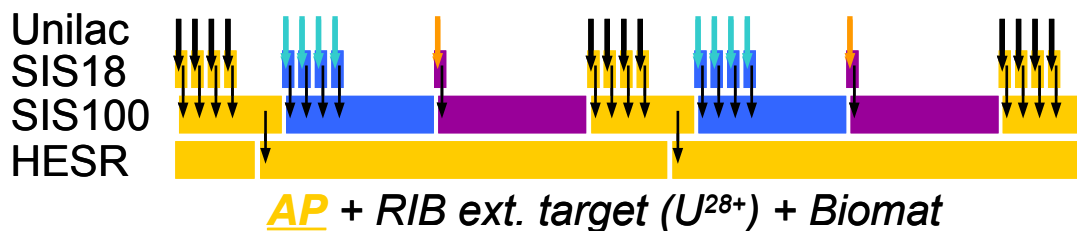
- FAIR ~4 x the size of existing GSI facility
 - non-linear operational complexity increase $O(n^2) \rightarrow O(n^5)$
 - efficiency scaling $\epsilon_{\text{FAIR}} = \epsilon_{\text{UNILAC}} \cdot \epsilon_{\text{SIS18}} \cdot \epsilon_{\text{SIS100}} \cdot \epsilon_{\text{Super-FRS}} \cdot \epsilon_{\text{CR}}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



- Some important OP boundary conditions:
 - Compared to GSI, FAIR facility size and complexity increases roughly by a factor 4
 - 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':



Periodic beam patterns, dominated by one **main** experiment
– change every two weeks, some run for 2-3 days only:



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, ...

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

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
- mitigating drifts that are driven by feed-down effects due to higher-order parameter tuning: e.g. orbit, tune
- ...

Examples:

- beam-transmission-monitoring and other actual-vs-reference monitoring systems
→ identify, localise and fix failures/near-misses as early as possible
- semi-automated multi-turn/optics/slow-extraction monitoring/correction/... setup tools
→ improve facility turn-around and setup times
- classic beam-based feedbacks on trajectory, orbit, tune, chromaticity, etc.
→ monitor and maintain tight parameter tolerances
- Sequencer tasks – 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 protection systems that need to be periodically retested/validated



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

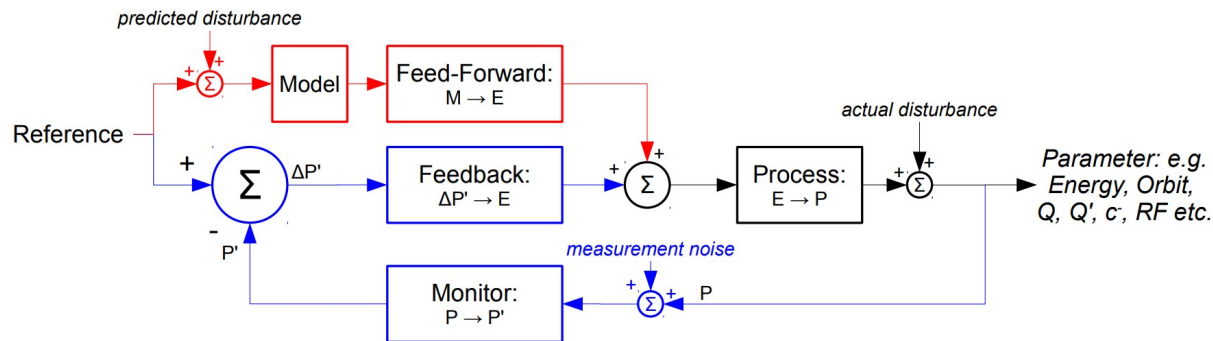
Bread-and-Butter
systems for operation

Machine-specific Beam-Based Systems:

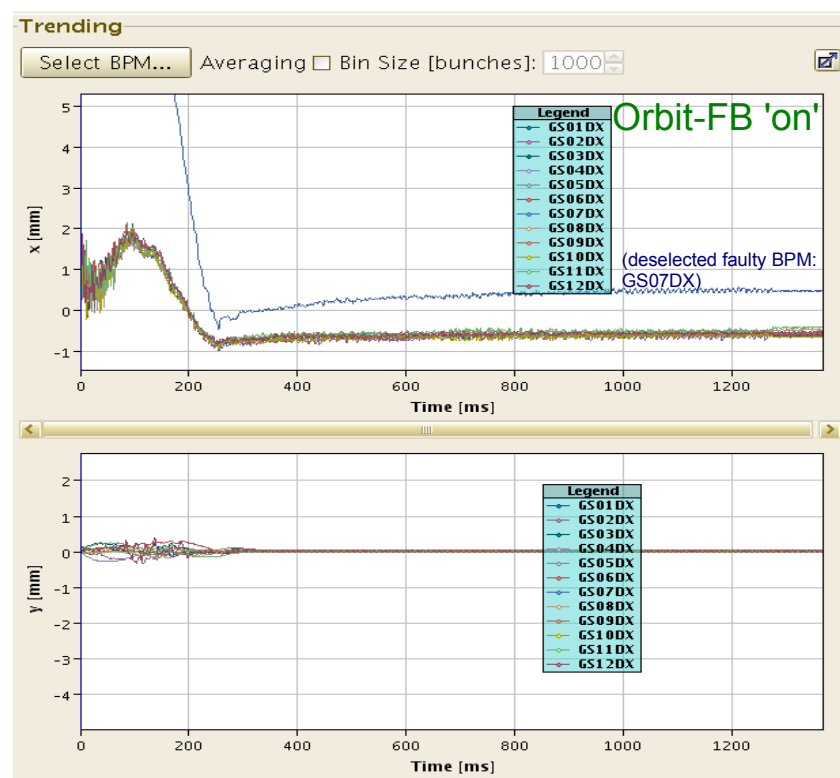
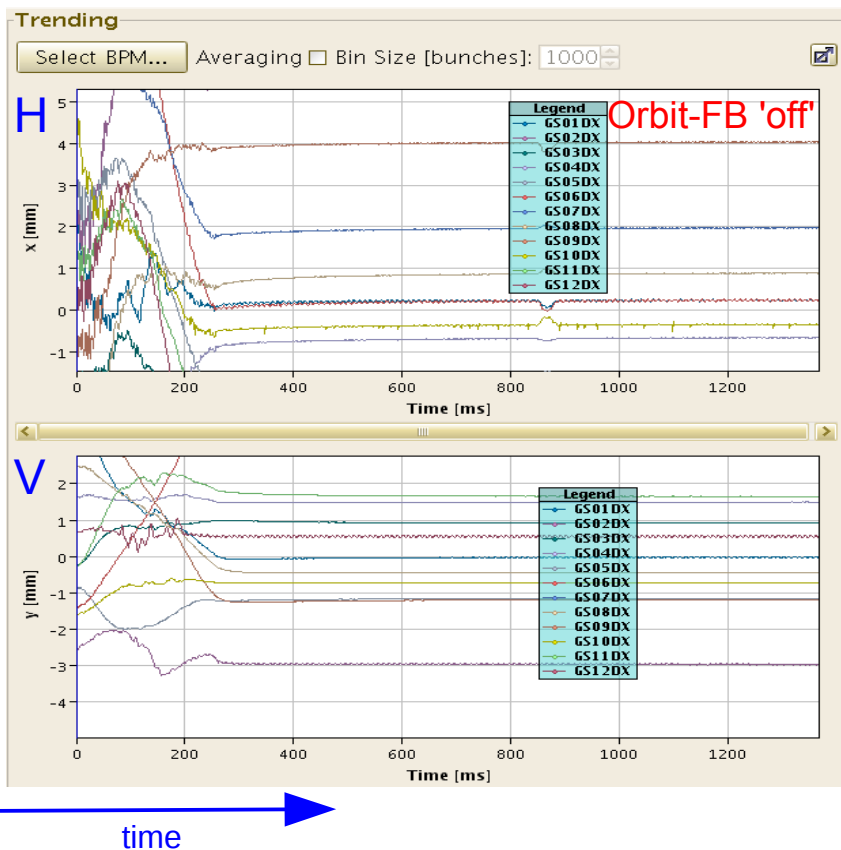
- SIS18: multi-turn-Injection (N.B. highly non-trivial, complex subject), Slow-Extraction (K.O. exciter, spill-structure, ...)
- SIS100: Slow-Extraction (K.O. exciter, spill-structure, ...), RF Bunch Merging and Compression
- ESR, HESR & CR: Stochastic cooling, Schottky diagnostics, ..., tbd.

Generic:

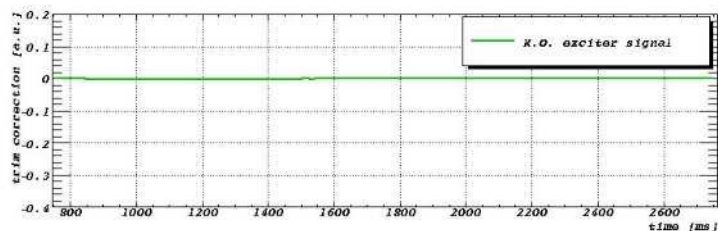
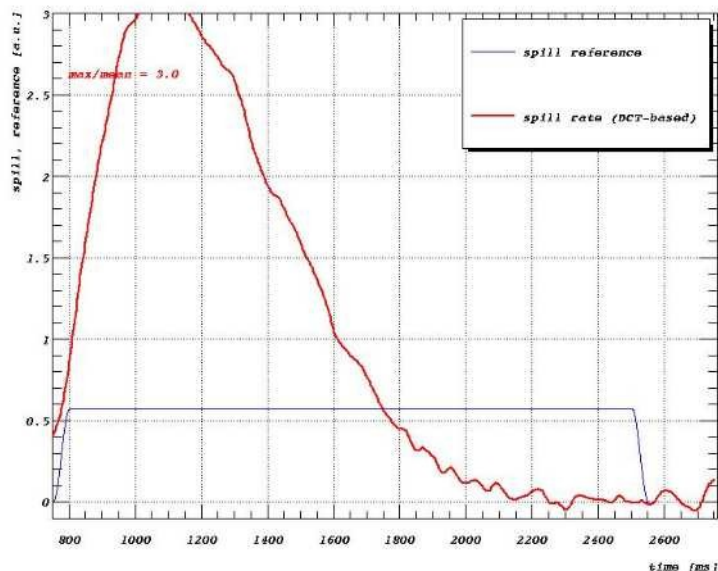
- [Remote DAQ of Analog Signals](#)
(strong impact on HKR migration/operation!)
- Facility-wide fixed-displays, facility & Machine Status ("Page One")
- context-based monitoring of controls and accelerator Infrastructure,



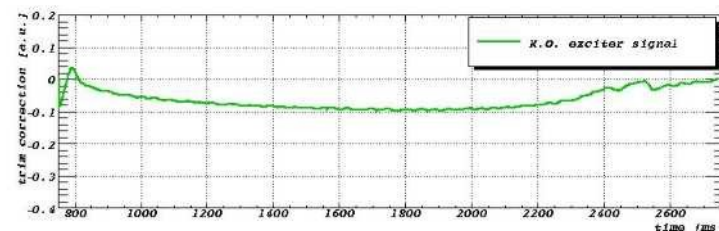
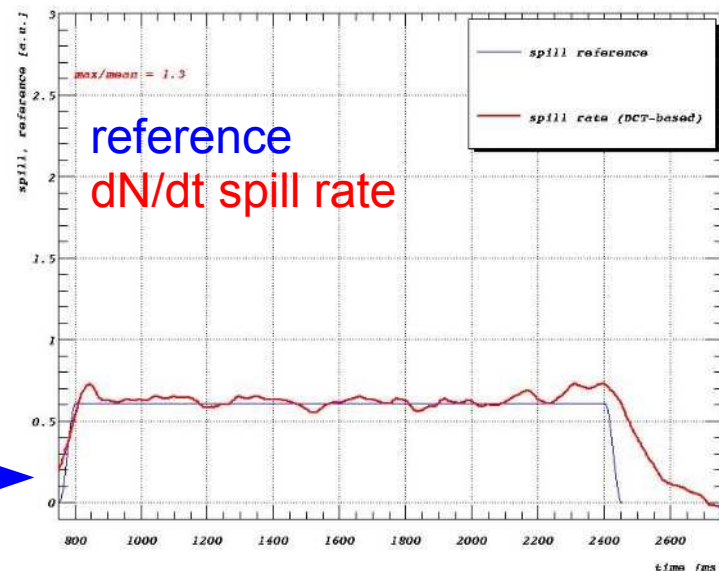
- Real-World challenges of FB & (semi-) automation:
(hint: usually control theory or beam physic isn't the problem)
 - not necessarily speed (ie. kHz $\rightarrow$ GHz range) – second-scale feedbacks or tools are often already quite sufficient for >90% of the problems
 - Computers are better than humans 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, ...
 - overall strength depends on the reliability of the weakest link in the chain



- 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 $\Delta p/p$ mismatch $\rightarrow$ radial-loop/Energy-FB



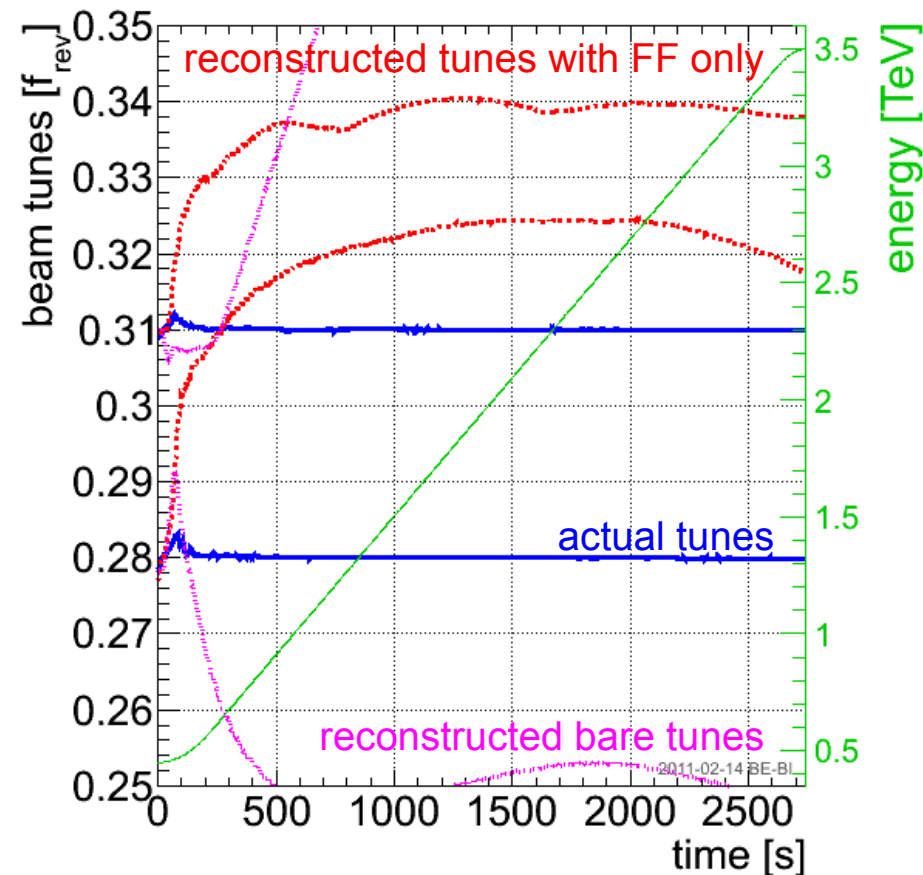
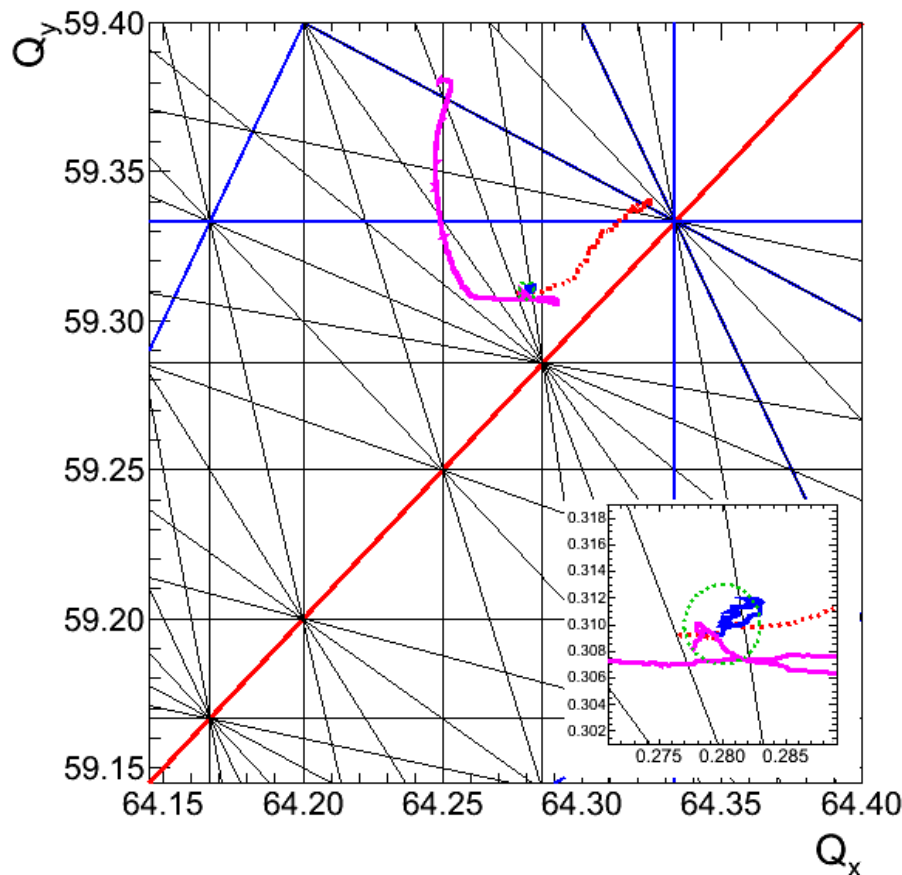
Fill-to-Fill
FB on dN/dt
(DCCT-based)



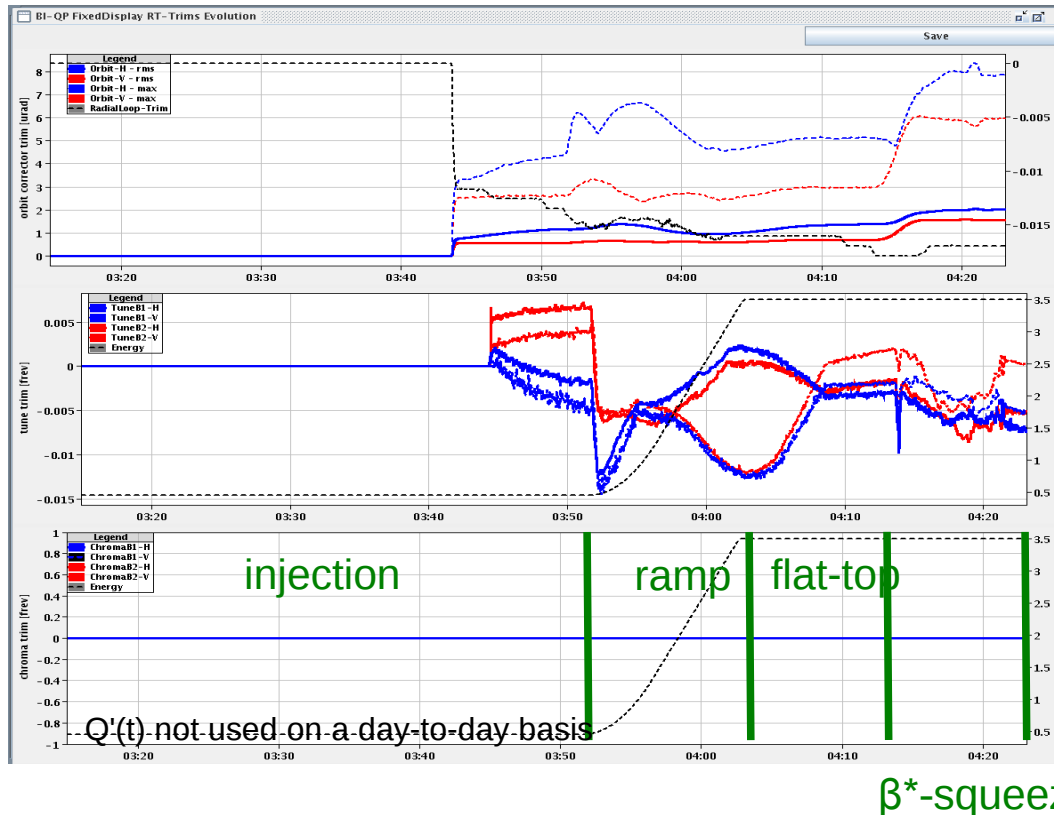
- some workarounds needed, but overall success and results look promising
 - need to follow-up: K.O. exciter power-limitation handling (easily for >10 Tm operation)
 - Alternative: FB using fast extraction quadrupole or main-quads
 - Desirable: direct FB signal from experimental detectors

[animated GIF - link](#)

- 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)



- 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)



- ... 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



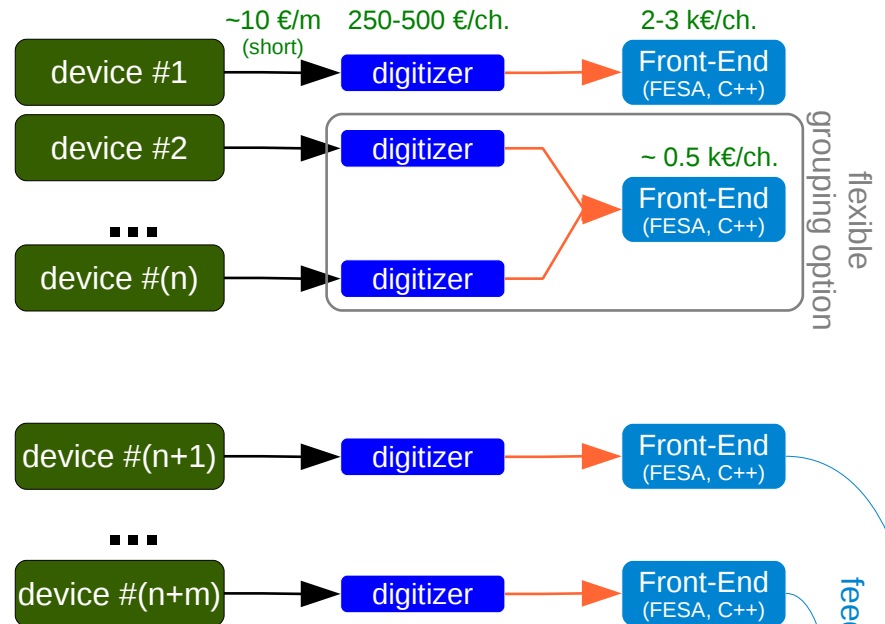
Quality Management	Document Type:	Document Number:	Date: 2016-07-18
	Detailed Specification	F-DS-C-11e Template Number: Q-FO-QM-0005	Page 1 of 24

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)

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

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



flexible grouping option

feedbacks

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

SIS18_FAST_COOLER_ESRTRANSFER_20181204_ENGRUN SIS18_SLOW_HHD_20181130_084227 SIS18_SLOW_HADES_20181206_210727 SIS18_SLOW_HTD_20181203_235223

40 AR 18+262.0 MeV/u
ESR via TE (FAST)
U 04S03
PILOT BEAM

M L P O U

107 AG 45+1580.0 MeV/u
HHD (SLOW)
U 10S07
PILOT BEAM

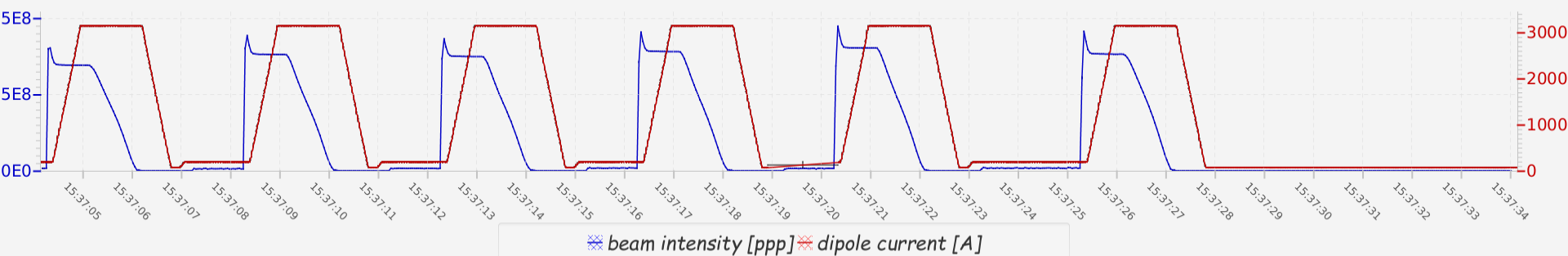
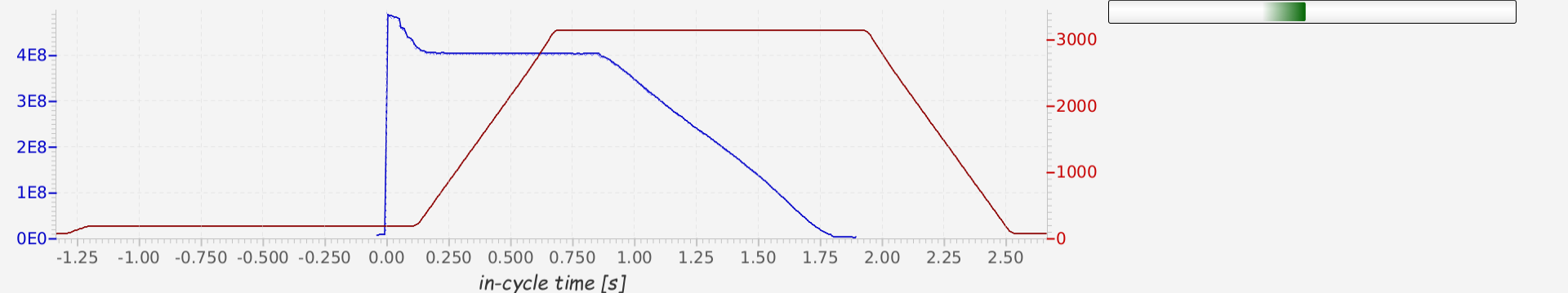
M L P O U

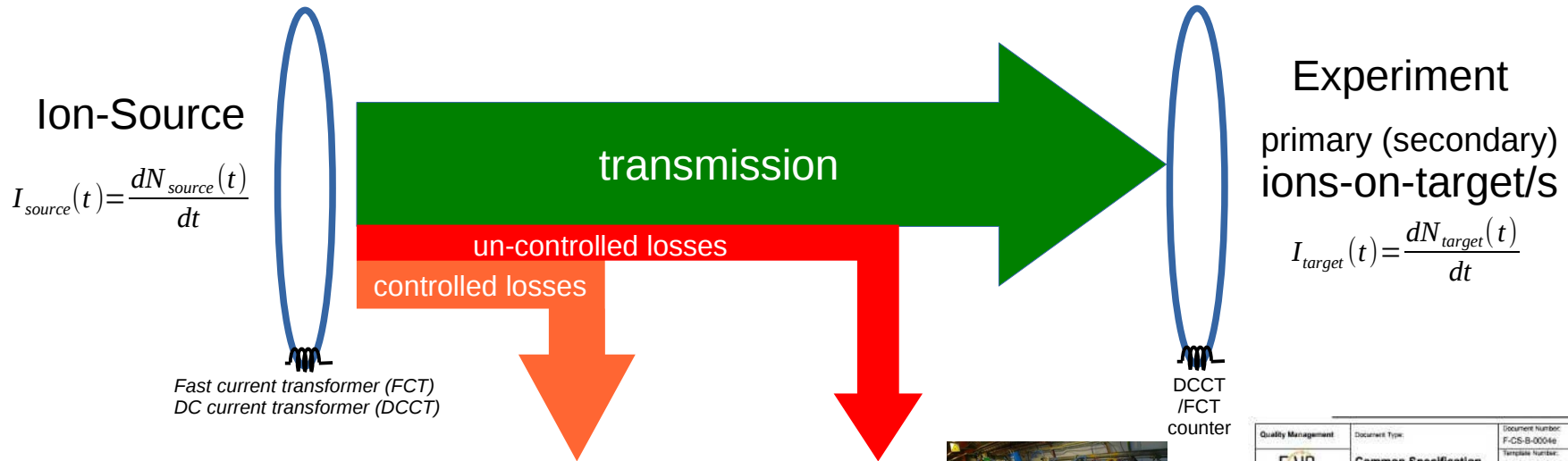
107 AG 45+1580.0 MeV/u
HADES (SLOW)
U 10S06
PILOT BEAM

M L P O U

107 AG 42+950.0 MeV/u
HTD via TH (SLOW)
U 09S04
PILOT BEAM

M L P O U





Quality Management	Document Type	Document Number	Date
FAIR	Common Specification	F-CS-9-0004e	2017-04-21
		Template Number	Page 1 of 20
		Q-FD-QM-0005	

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:
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	P. Schott (OP)	S. Reinhardt (OP)
	M. Schwickert (BI)	R. Steinhagen
	I. Lehmann (Exp. Link-Person)	FAIR Comm. & Control PL
	D. Severin (Exp. Link-Person)	

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)

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

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

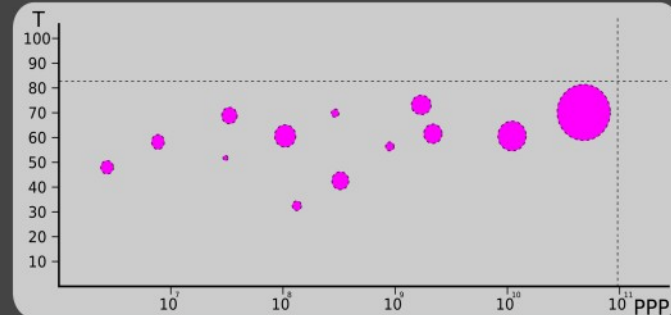
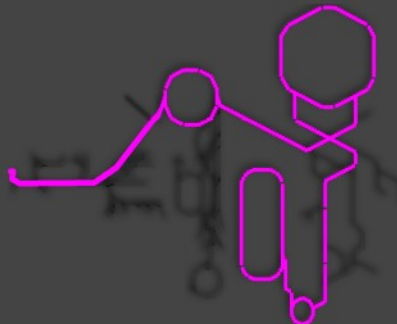
§§ Radiation Permit – limits on total dose per year (facility & external)

HESR PANDA 241,2 MeV/u p^- 4.23⁸ PPP Status ●

Analysis with the new Experimenttarget

Contact Person: Hans Mustermann Phone 4711
Experiment-Cave: Phone 1508

14:33 2016-12-02
Adjust Beam in CR
14:00 2016-12-02
Shiftchange in the Control Center
12:30 2016-12-02
Stable Beam in SIS 100



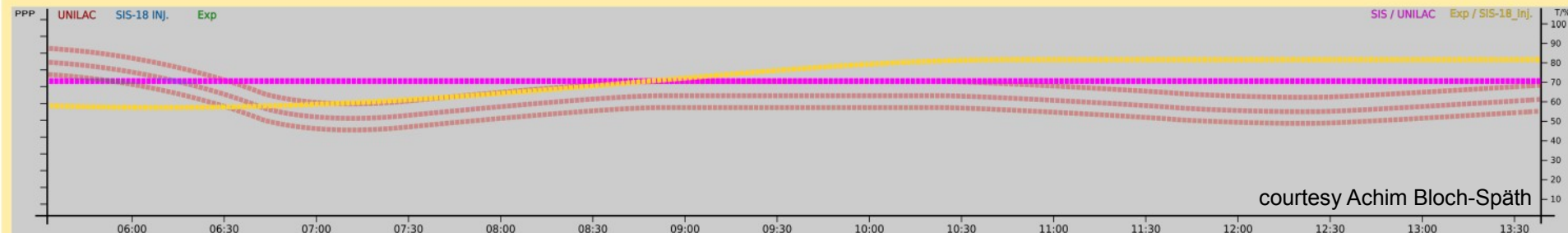
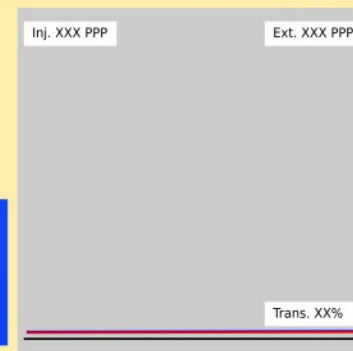
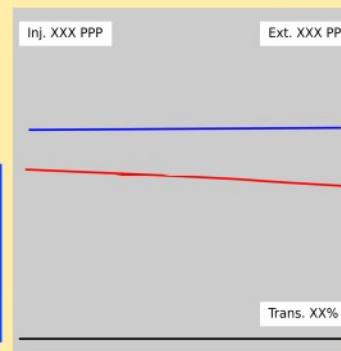
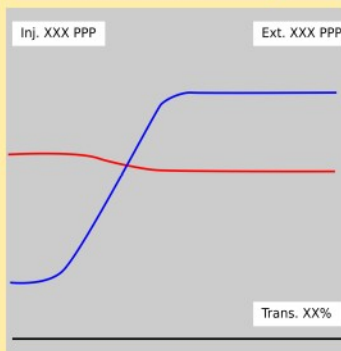
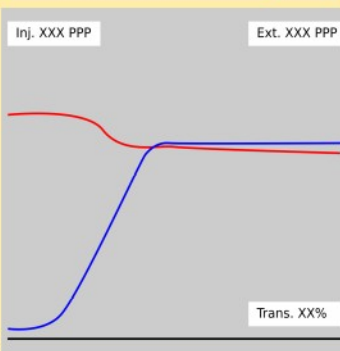
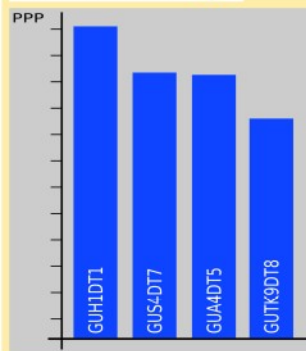
UNILAC
stable Beam ●

SIS 18
stable Beam ●

SIS 100
stable Beam ●

CR
Beam adjust ●

HESR
Beamline open ●

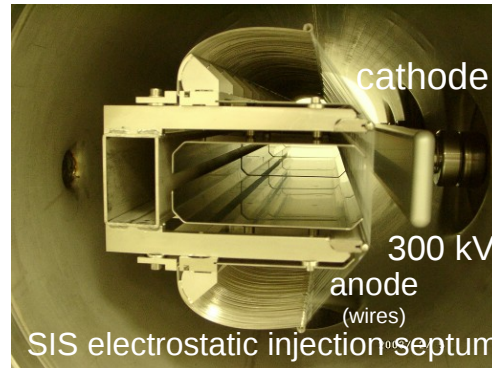
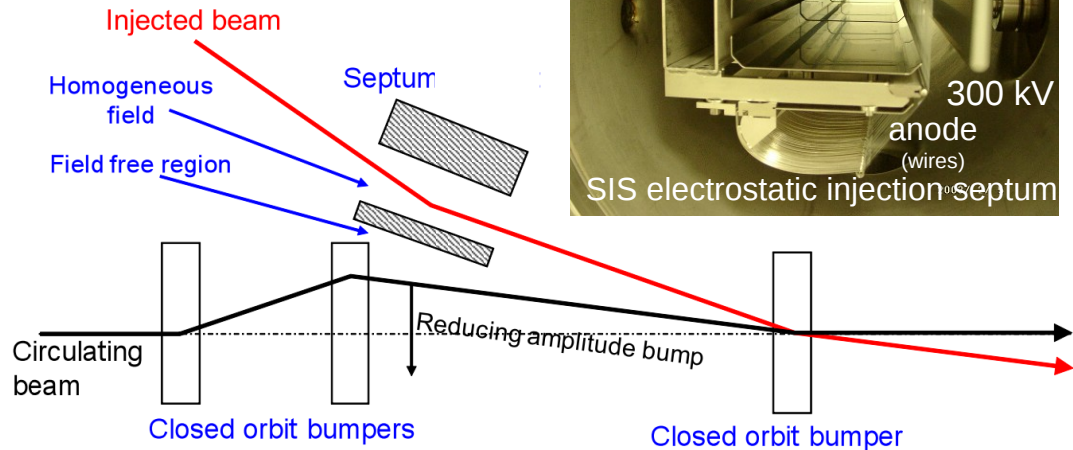


courtesy Achim Bloch-Späth

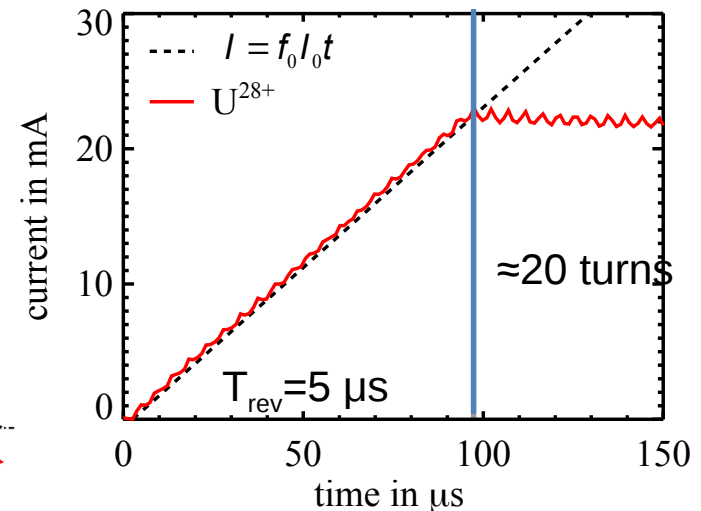
From a linac

e.g. SIS-18, CERN PSB

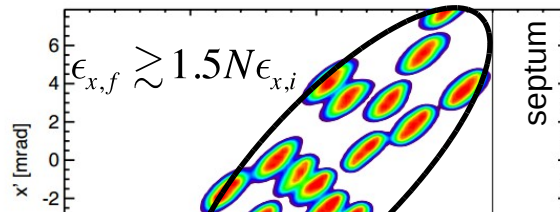
courtesy Mike Barnes



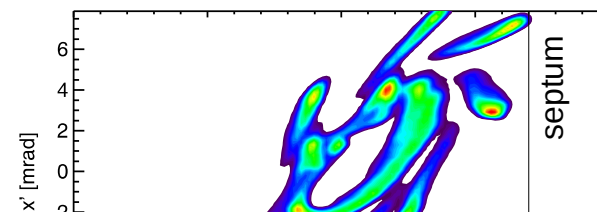
Measured MTI performance in SIS-18



Simulation: without space charge

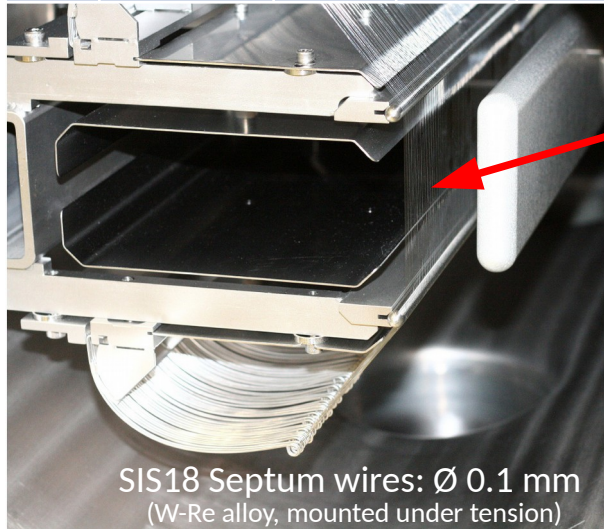


Simulation: with space charge

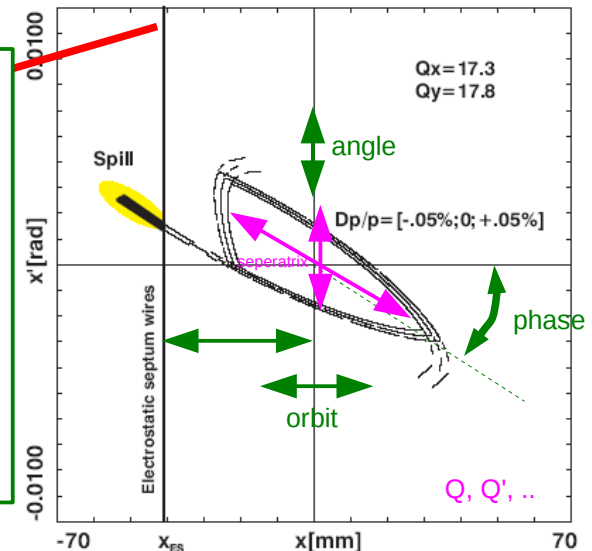


Injection losses → dynamic vacuum pressure rise
 (highly complex: easy to simulate ↔ hard to measure/tune with beam)
 looking forward to: injection steering (BPMs) & turn-by-turn profiles (IPMs)

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



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)

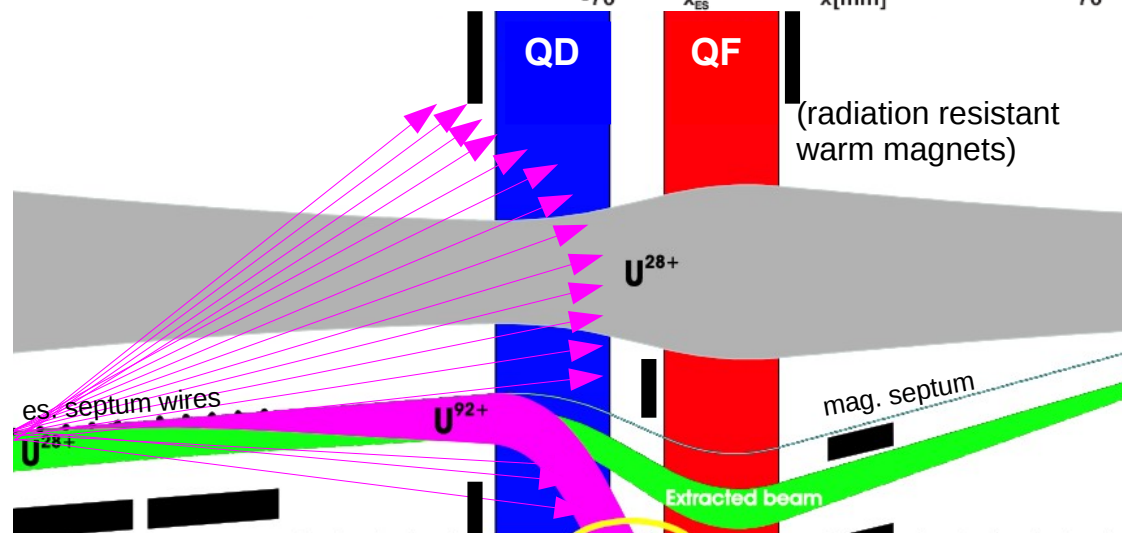


Tracking simulations:

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



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

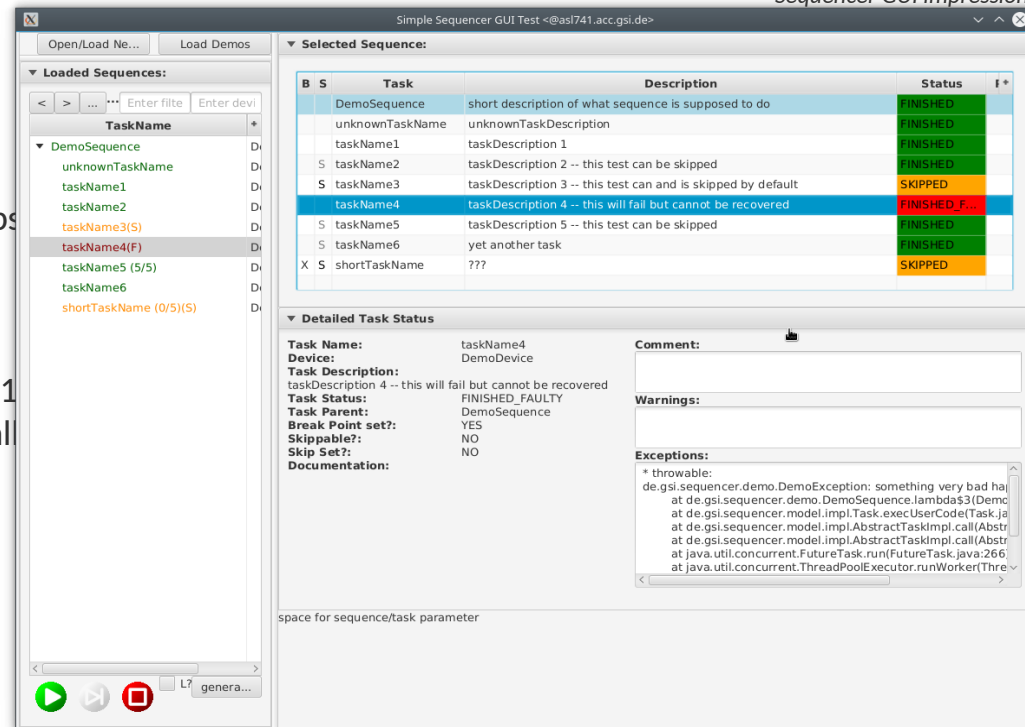
Sequencer GUI impression

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:

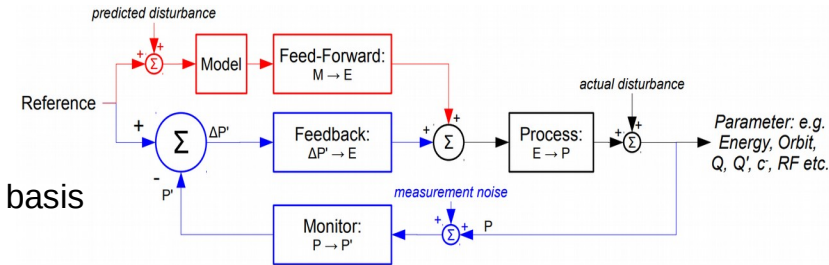
- was tested and used already since Dry-runs in 201
- establish process of writing Sequencer tasks parallel to development (in progress)

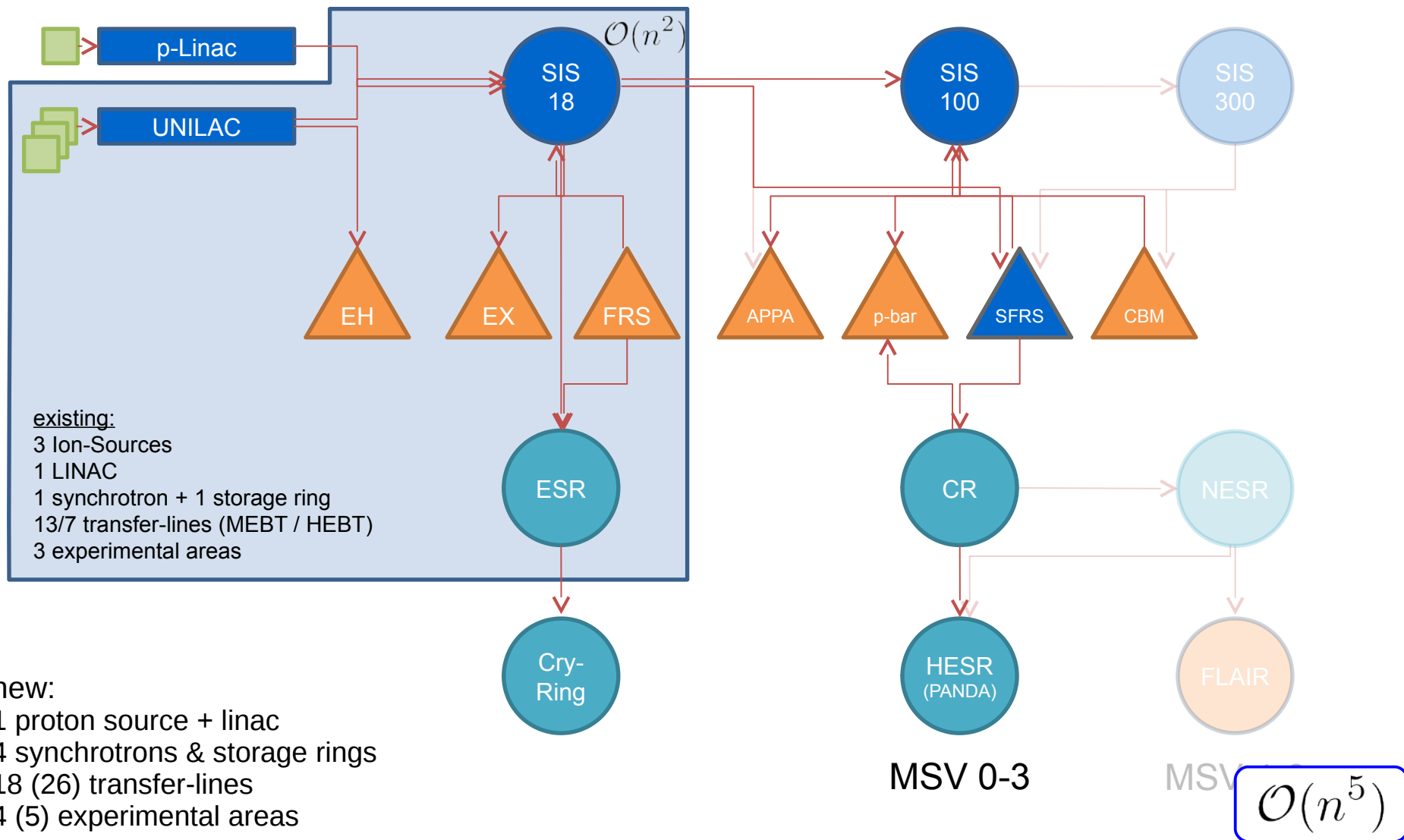


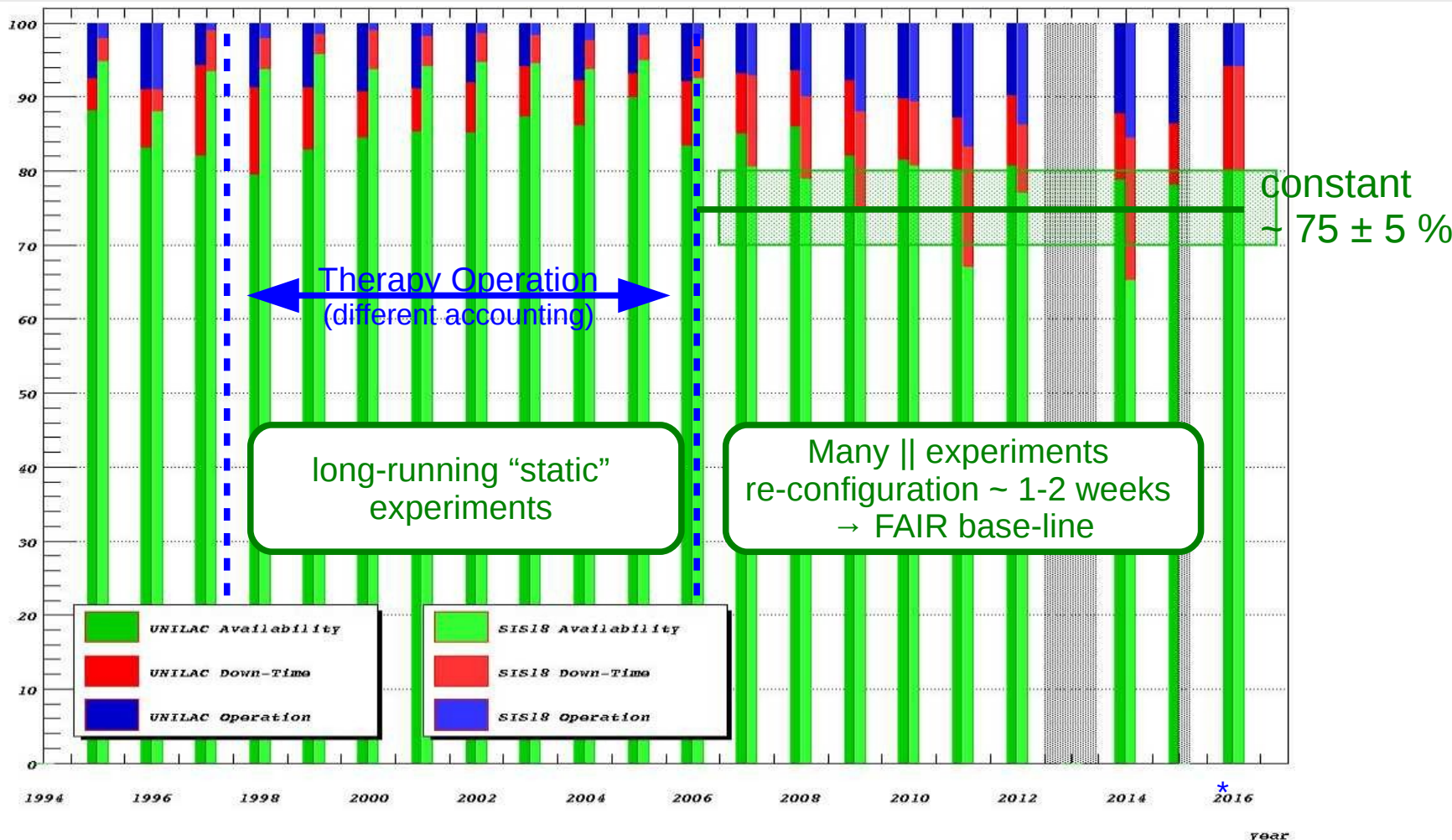
The screenshot shows the 'Simple Sequencer GUI Test' window. It features a 'Loaded Sequences' panel on the left with a tree view of tasks. The main panel displays a 'Selected Sequence' table with columns for Task, Description, and Status. Below the table is a 'Detailed Task Status' section for the selected task 'taskName4', showing its description, status, and various parameters. At the bottom, there is a 'Comments' section and a 'Warnings' section. The status of the tasks in the table is as follows:

B	S	Task	Description	Status
		DemoSequence	short description of what sequence is supposed to do	FINISHED
		unknownTaskName	unknownTaskDescription	FINISHED
		taskName1	taskDescription 1	FINISHED
S		taskName2	taskDescription 2 -- this test can be skipped	FINISHED
S		taskName3	taskDescription 3 -- this test can and is skipped by default	SKIPPED
		taskName4	taskDescription 4 -- this will fail but cannot be recovered	FINISHED_FAILED
S		taskName5	taskDescription 5 -- this test can be skipped	FINISHED
S		taskName6	yet another task	FINISHED
X	S	shortTaskName	???	SKIPPED

- 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, ...)**







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

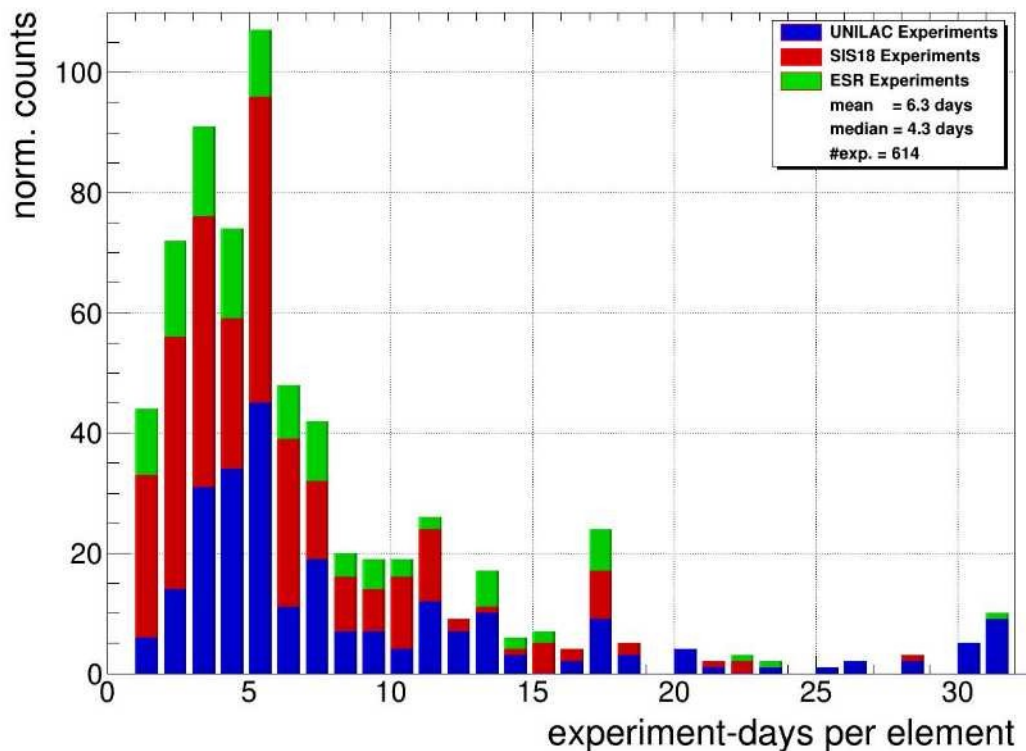
N.B. ion source exchanges are factored out from UNILAC & SIS18 data ($\sim$ constant overhead)

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 $\frac{1}{2}$ UNILAC (w/o A3 & A4)
- only 1 element in SIS18



bottom line (1st order):

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

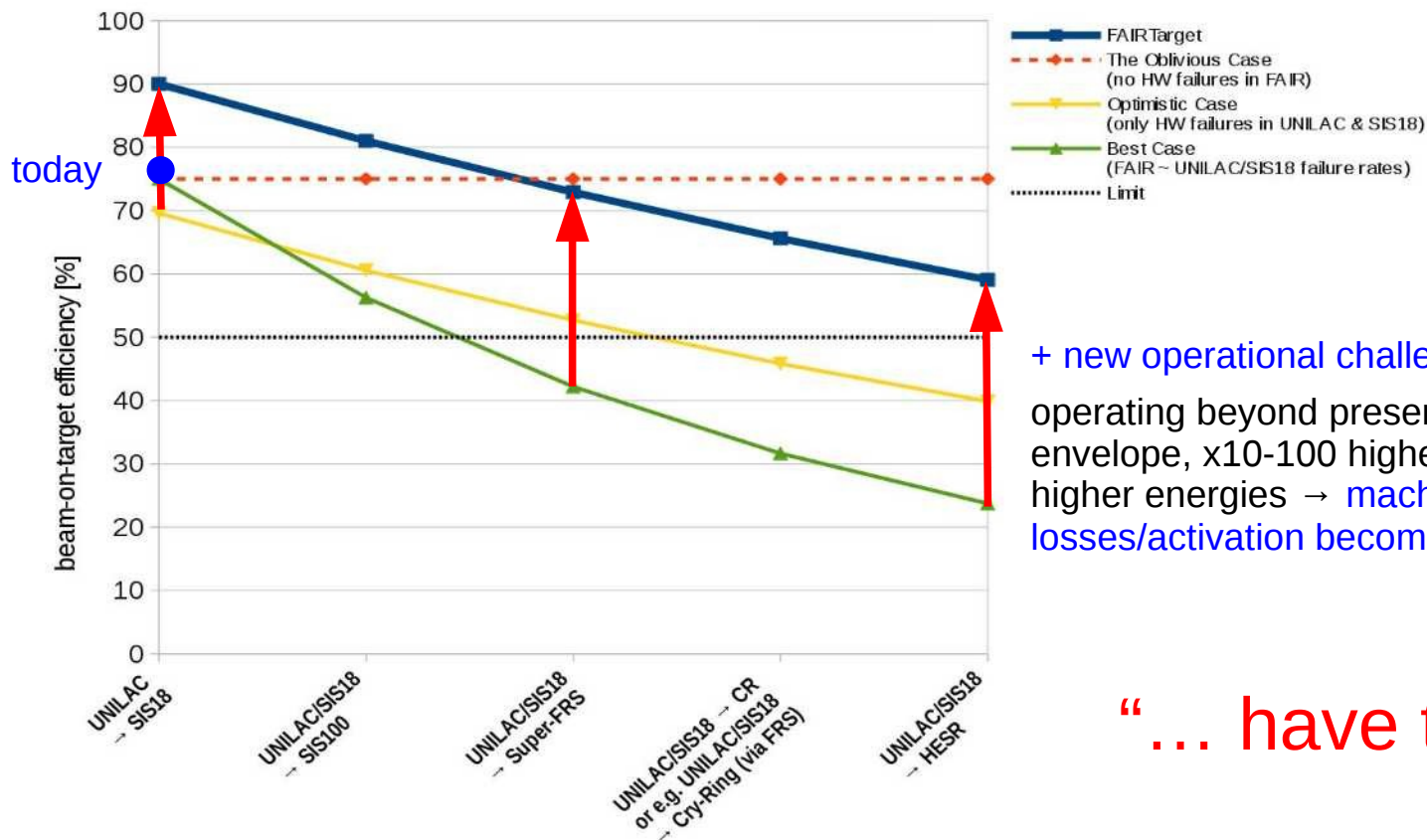
B) FAIR will accommodate about 5-6 parallel experiments

→ 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}):

$$\epsilon_{\text{FAIR}} := \prod_i^{n_{\text{machines}}} \epsilon_i = \epsilon_{\text{UNILAC}} \cdot \epsilon_{\text{SIS18}} \cdot \epsilon_{\text{SIS100}} \cdot \epsilon_{\text{SuperFRS}} \cdot \epsilon_{\text{CR}} \cdot \epsilon_{\text{HESR}} \dots$$



+ 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!”

Presentation Tier

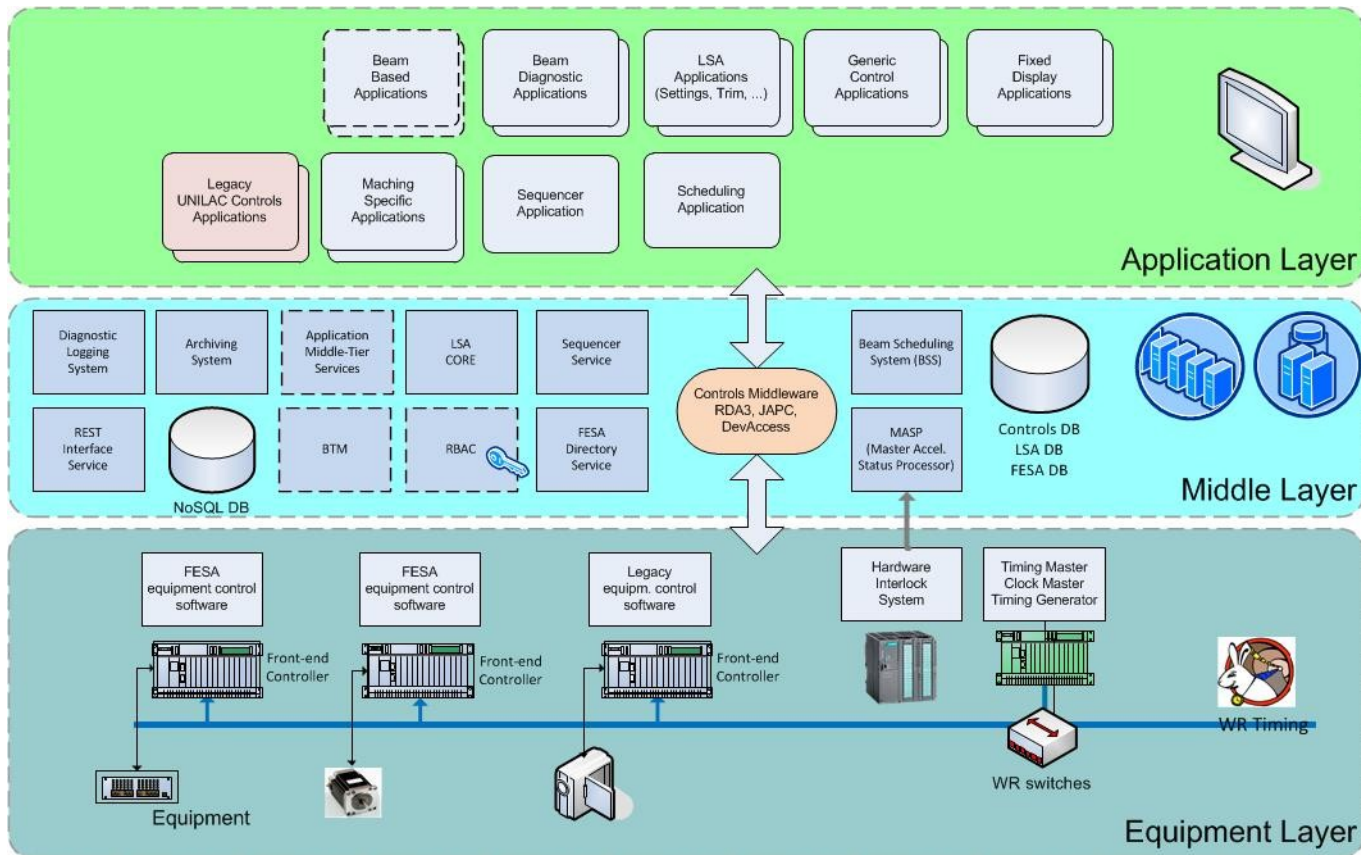


Middle Tier powerful servers



Resource Tier FESA

C++



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

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.), $\Delta p/p$, 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