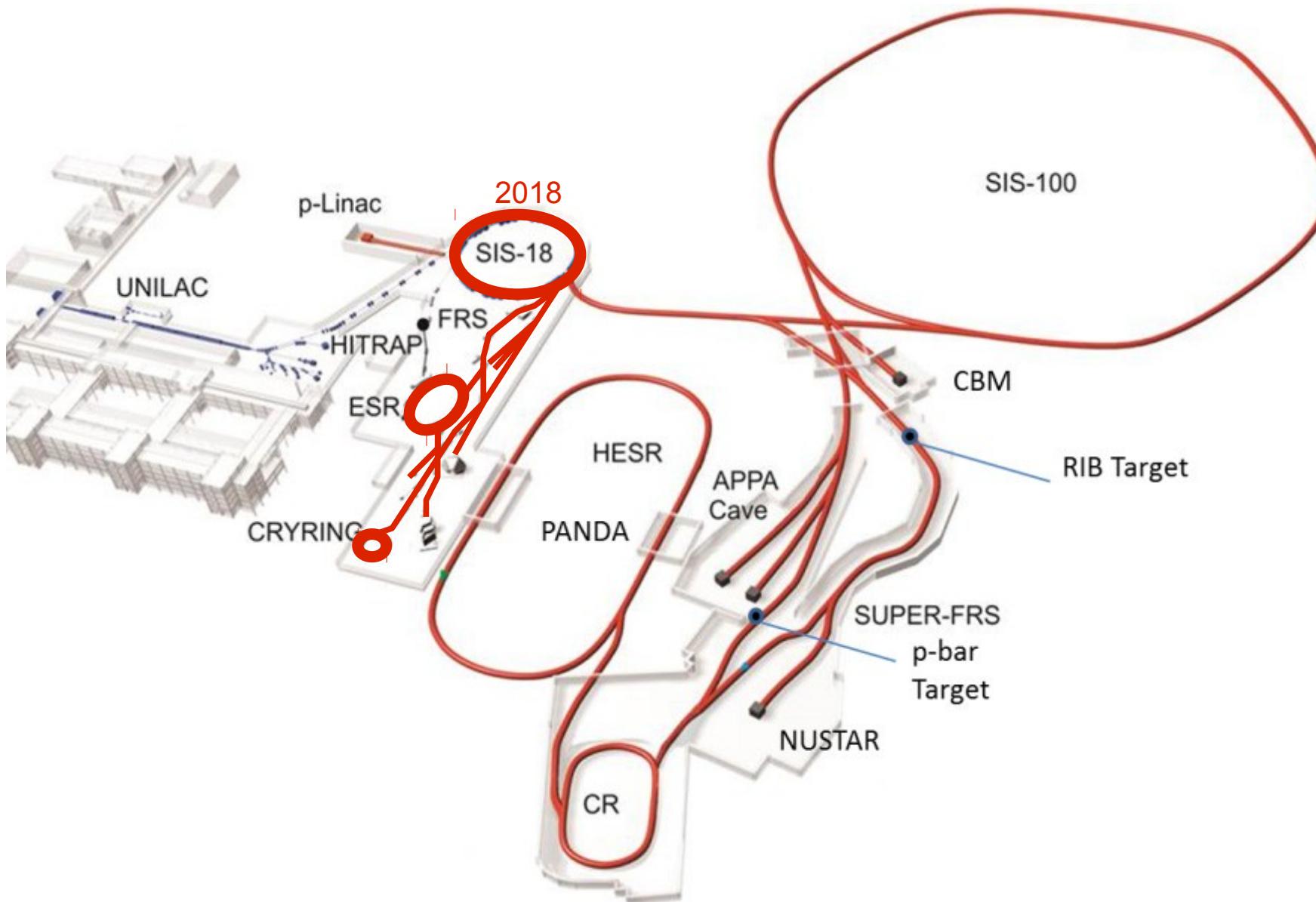


FAIR Machine Experiment Interface – Second Iteration & Proposals –

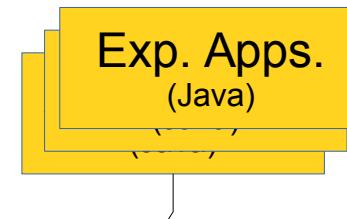
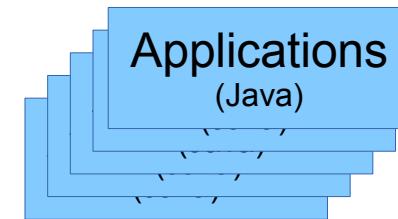
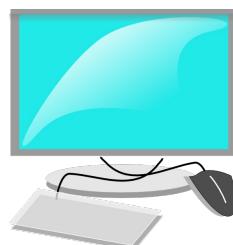
Ralph J. Steinhagen

With input from: FC²WG, R. Bär, F. Hagenbuck, D. Ondreka, D. Severin

- Introduction: New FAIR Acc. Control System Highlights
 - Machine-Experiment Interfaces:
 - a) Accelerator & Beam-Modes, Beam Mode transitions
 - b) Interface to Machine Protection (MP): Beam Aborts
 - c) Target Steering, Beam Performance Indicators & Macro-/Micro-Spill-Structure
 - some results from the proof-of-concept MDs
- ... with focus on controls & software interfaces



Tier 1: Application/Presentation



FAIR Facility Overview
('Page 1')

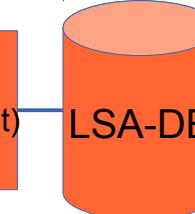
common generic API

Tier 2: Business Layer (Control Logic)

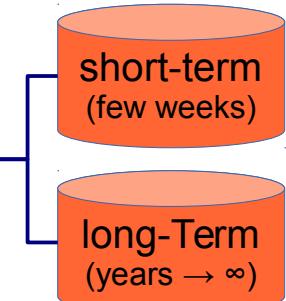


SCADA
(for prop. HW,
e.g. Cryo.)

LSA
(Settings Mgmt)
(Java)



Archiving
(Java, C++, tbc.)



JAPC (CMW = ZeroMQ-based)

Tier 3: Industrial Control & IT (aka. Front-Ends)



Timing
(FESA, HW, C++)

White Rabbit

Prop. HW
(non-FESA)

Front-End
(FESA, C++)

Front-End
(FESA, C++)

actual HW

actual HW

actual HW

- Non-monolithic, distributed accelerator control system
 - Standardised open interfaces across accelerator chain
- Full control on accelerator modelling & interdependencies
 - Consistency across devices and settings
 - Parameter hierarchy (trans. abstraction/separation of: accelerator physics ↔ controls)
- Tracking of accelerator performance & corresponding settings
- Distributed development & expertise (e.g. code shared with CERN)
 - Better more efficient code review & medium-/long-term maintenance
 - Continuous improvement & evolution to actual accelerators' & experiments' needs
- Better more flexible integration of beam-based diagnostics systems
 - possibility of arbitrary (user-driven) functions (+actual vs. reference comparisons)
→ opens the possibility of powerful semi-/fully automated cycle-to-cycle feedbacks
 - trajectory/target steering, orbit control, ...
 - Easy macro-spill-control,
 - ...

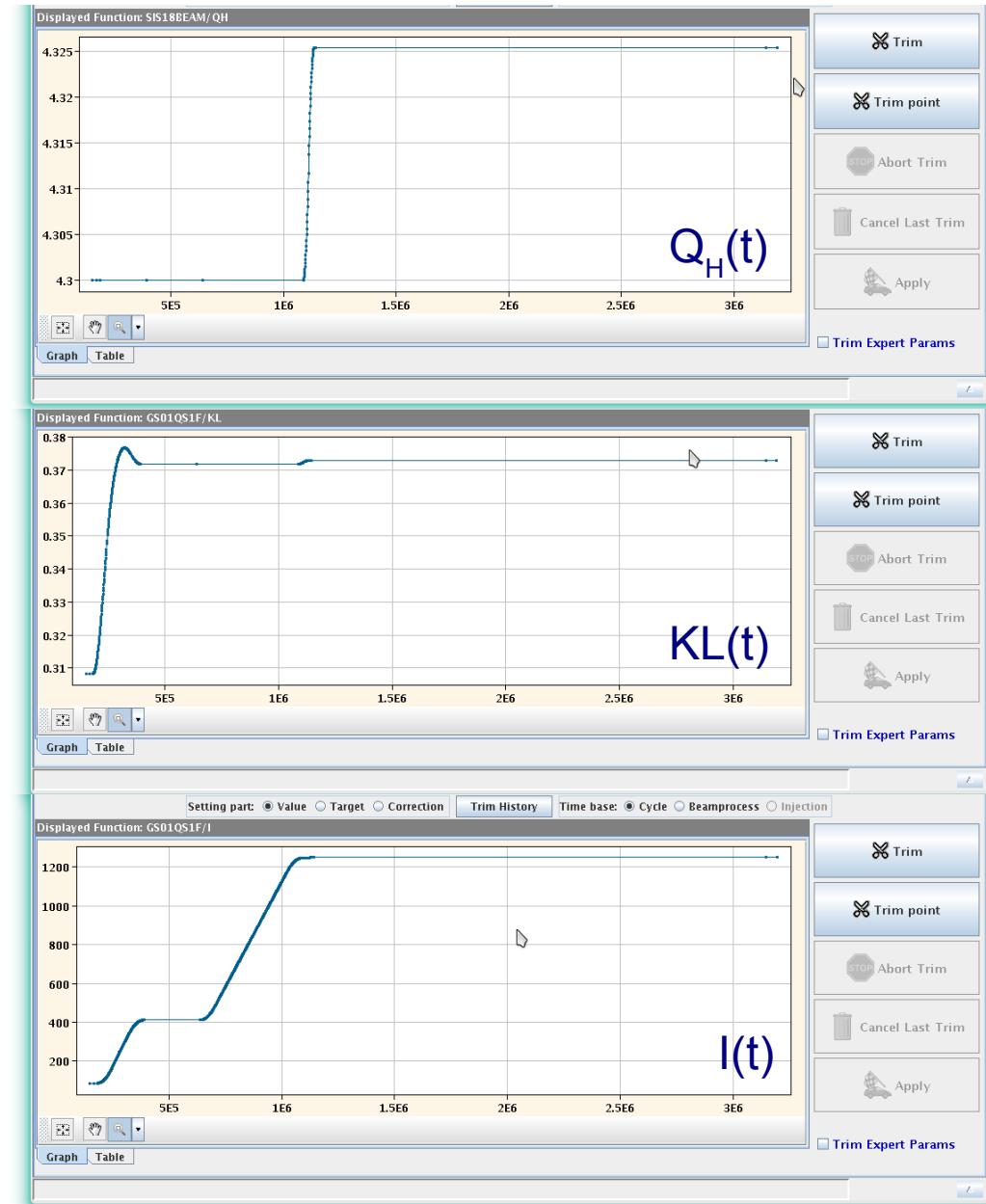
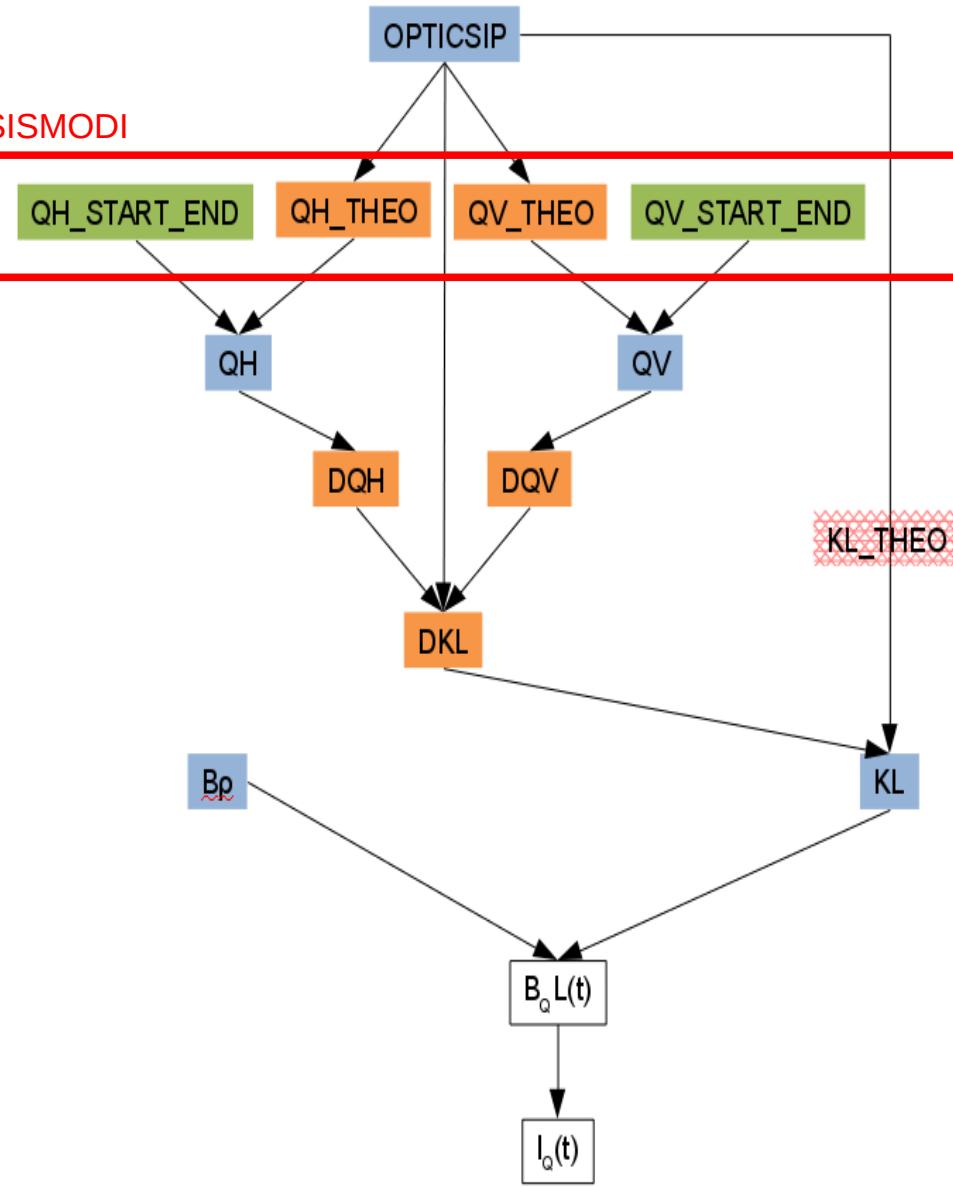
Good entry point:

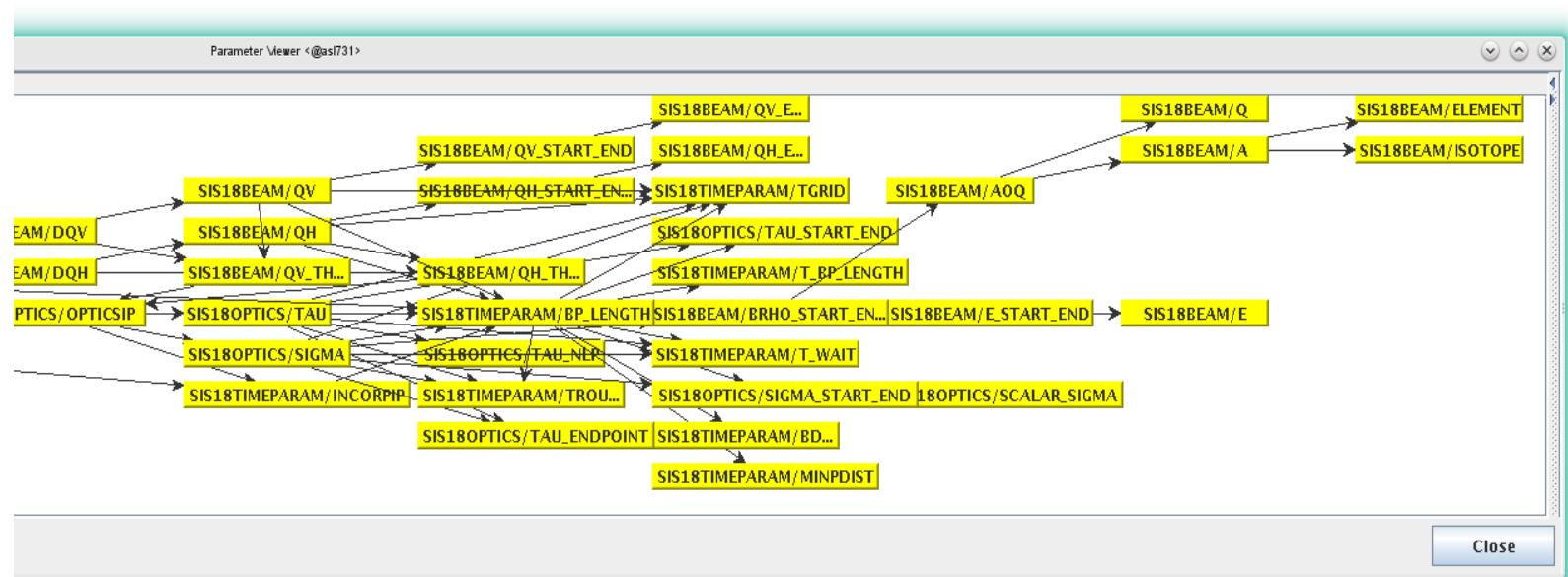
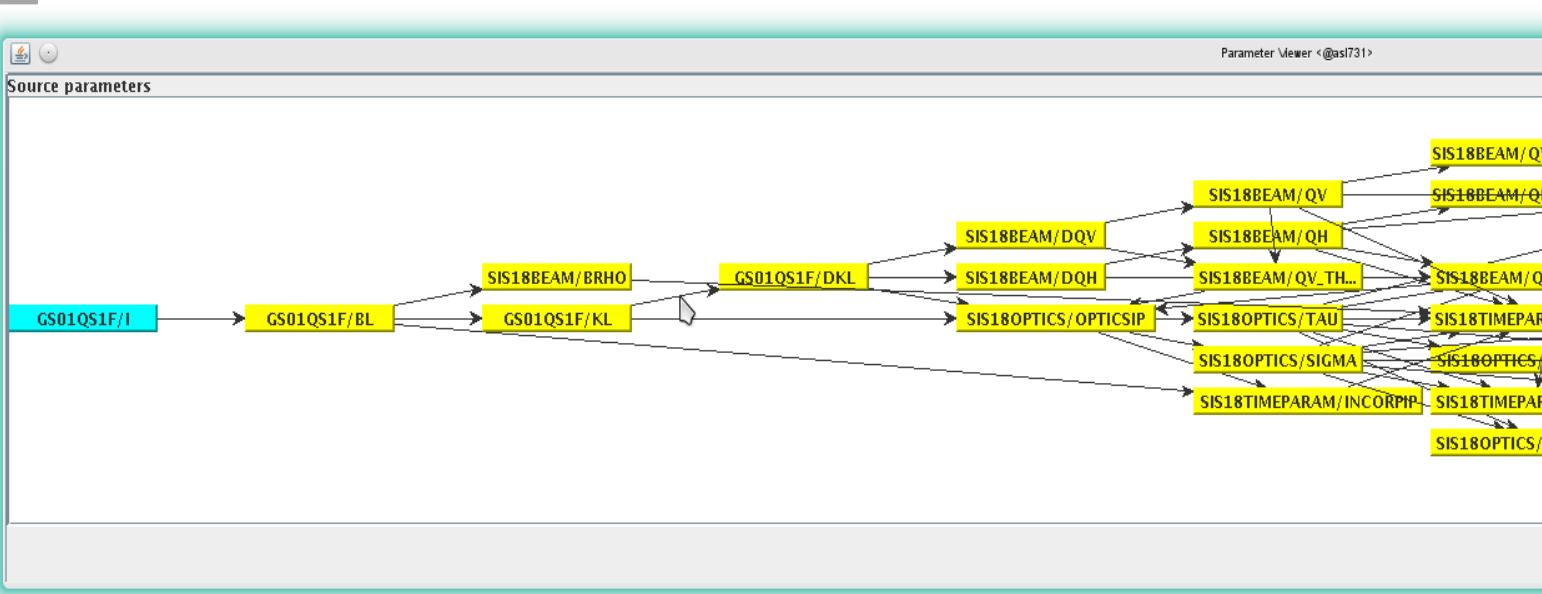
<https://www-acc.gsi.de/wiki/>

Specifically, some more meat in:

- Glossary: <https://www-acc.gsi.de/wiki/FAIR/FAIRGlossar>
- Timing: <https://www-acc.gsi.de/wiki/Timing/>
- FESA: <https://www-acc.gsi.de/wiki/FESA>
 - <https://www-acc.gsi.de/wiki/FESA/WhatIsFESA>
- LSA: <https://www-acc.gsi.de/wiki/Applications/Lsa MainPage>
 - <https://www-acc.gsi.de/wiki/Applications/LsaPresentationsAndPublications>
 - <https://www-acc.gsi.de/wiki/Applications/LsaFrequentlyAskedQuestions>
 - <https://edms.cern.ch/ui/#!master/navigator/document?D:1935804008:1935804008:subDocs>
- Applications: <https://www-acc.gsi.de/wiki/Applications/>

SISMODI

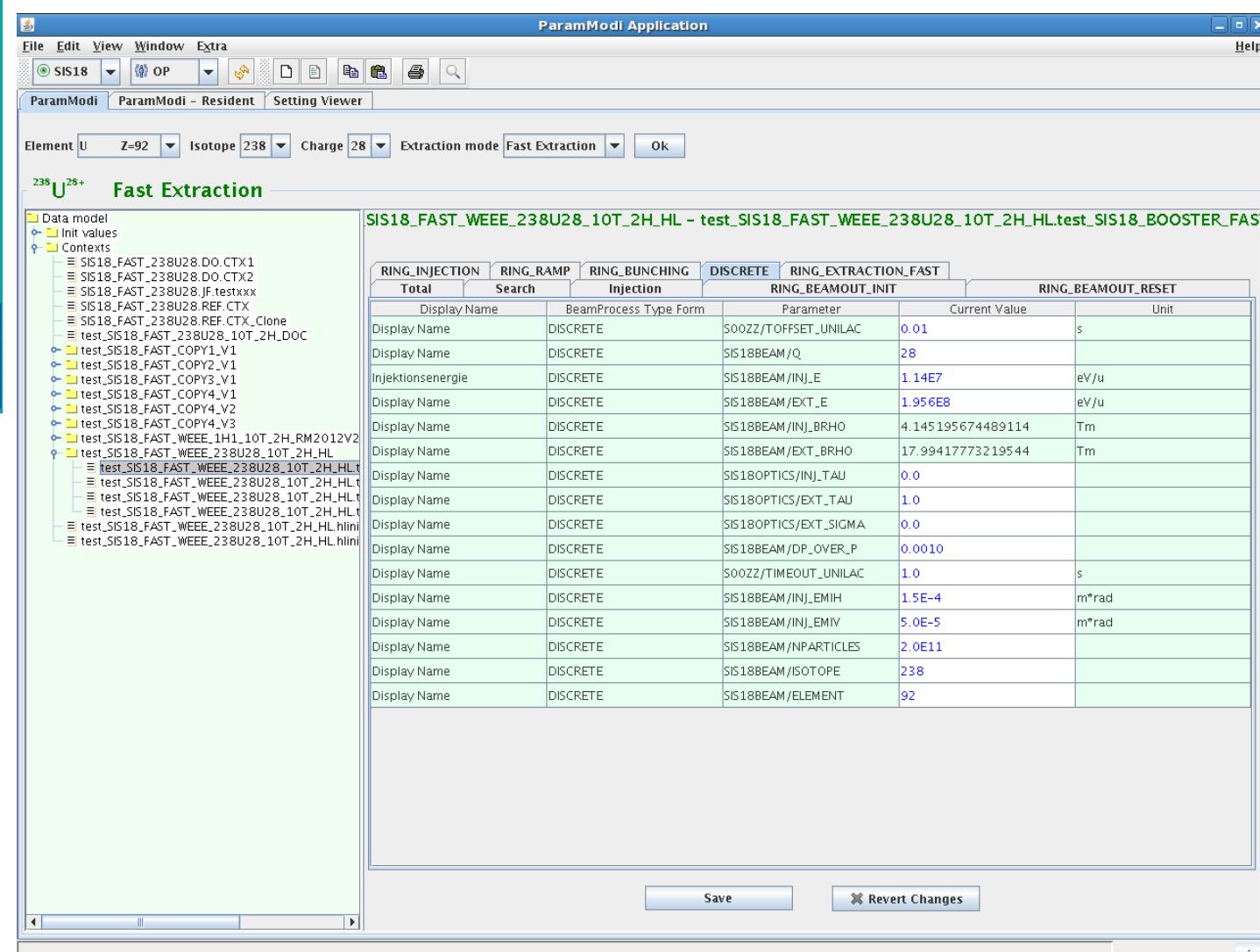
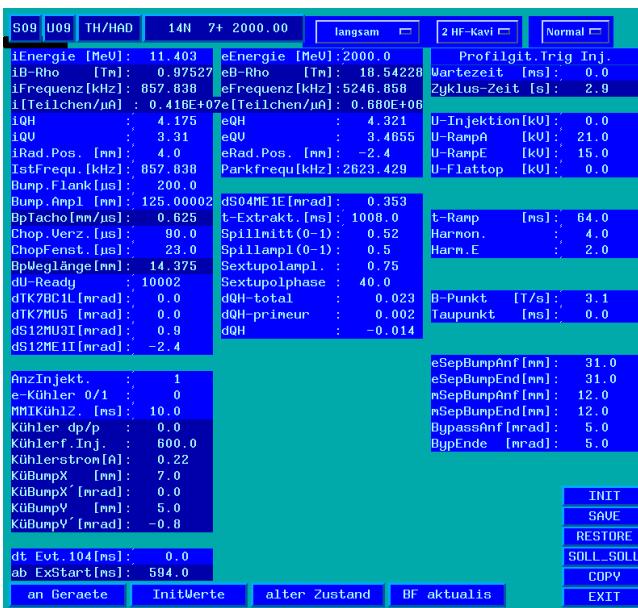






Disclaimer: KISS Restart in 2018

SISMODI → ParamModi (function-equivalent)





- Purpose:

- Communication of intended accelerator operation to experiments, FAIR and wider community
 - what to expect and when, beam time performance tracking & analysis
- Conditioning of control sub-system responses
 - e.g. logging, interlocks, management of critical settings (MCS & RBAC), machine sequencer, access system, ...
 - associated rules of what is allowed, when, where etc. e.g.:
 - Limit parameter changes during data taking – aka. 'Stable Beams'/Production Runs'
 - No high-intensity beam injected into an 'empty' machine
 - Block certain operation during unsafe mode of operation

- Main modes:

- 1) Accelerator (Machine) Modes

- covering rule sets outside of beam operation
- defined per accelerator/transfer-line segment

- 2) Beam Modes

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

- proposal: extend this concepts also to experiment targets

- required for safe primary-beam intensity ramp-up & OP-Exp. Hand-shake (see later)
- more fine-grained options for facility availability, performance tracking & analysis

Quality Management	Document Type:	Document Number:	Date: 02.10.2015
FAIR @ GSI	Technical Concept	Template Number:	Page 1 of 15

Document Title:	Accelerator and Beam Modes
Description:	Technical Concept for definition and integration of Accelerator Modes and Beam Modes in the accelerator control system
Division/Organization:	CSCO, PBSP
Field of application:	Project FAIR@GSI, existing GSI accelerator facility
Version	V 0.2

Abstract
 This technical concept proposes two fundamental modes: the 'accelerator mode' covering rule sets and operational sequence outside of beam operation and that are defined per accelerator or beam-line section (e.g. shutdown, setup, physics run, etc.); and the 'beam mode' covering rule sets during beam operation and that are defined pre accelerator or beam-line section and Beam-Production-Chain (e.g. no beam, pilot beam, stable beam, etc.).

The purpose of these modes is to communicate the intended accelerator operation, and to condition the various control sub-system responses (e.g. archiving, interlock and fast-beam-abort system, management of critical settings, etc.). The accelerator control system will distribute this information to the accelerator devices, experiments and wider FAIR community.

Prepared by:	Checked by:	Approved by MPLs + Mks:
R. Steinhagen R. Bär	S. Jülicher (CO) I. Lehmann C. Omet (SIS-100 MP) D. Ondreka (System Planning) A. Reiter (BI) P. Schütt (Operation) D. Severin	F. Hagenbuch (HEBT) M. Winkler (Super-FRS) O. Döllnitsky (CR) R. Brodhage (µ-Lines) P. Spiller (SIS-100) K. Knie (μ-bar Separator) H. Reich-Sprenger (Common Systems) H. Kolmrus (Cryogenics) R. Bär (Control) R. Steinhagen (FAIR Comm. & Control) S. Reinmann (Operation)

copy on:
<https://fair-wiki.gsi.de/FC2WG/>

Follows annual life-cycle of accelerator facility

- **Operation without Beam:**

- SHUTDOWN
 - could imply possibility of open/controlled access or no powering
- COOLDOWN (SIS100, SFRS)
 - typ. 2-3 weeks, limited/no access
 - need to distinguish between a 'warm' and cold' shut-down?
- BAKE-OUT (SIS18, HEBT, ...) – similar to cool-down
- WARM-UP (SIS100, SFRS)
- RECOVERY (SIS100, SFRS)
 - after quench, partial vacuum loss, typ. few hours - day
 - includes e.g. periodic magnet CYCLING to stabilise hysteresis
- MACHINE-CHECKOUT
 - operations tests without beam in view of beam operation
 - (e.g. power converter calibration, magnet patrol, etc.)
 - done once after a long shutdown, typ. few weeks before beam operation
- ACCESS (during beam operation periods)
 - controlled access for specific tasks only (signature by MCs & OP)

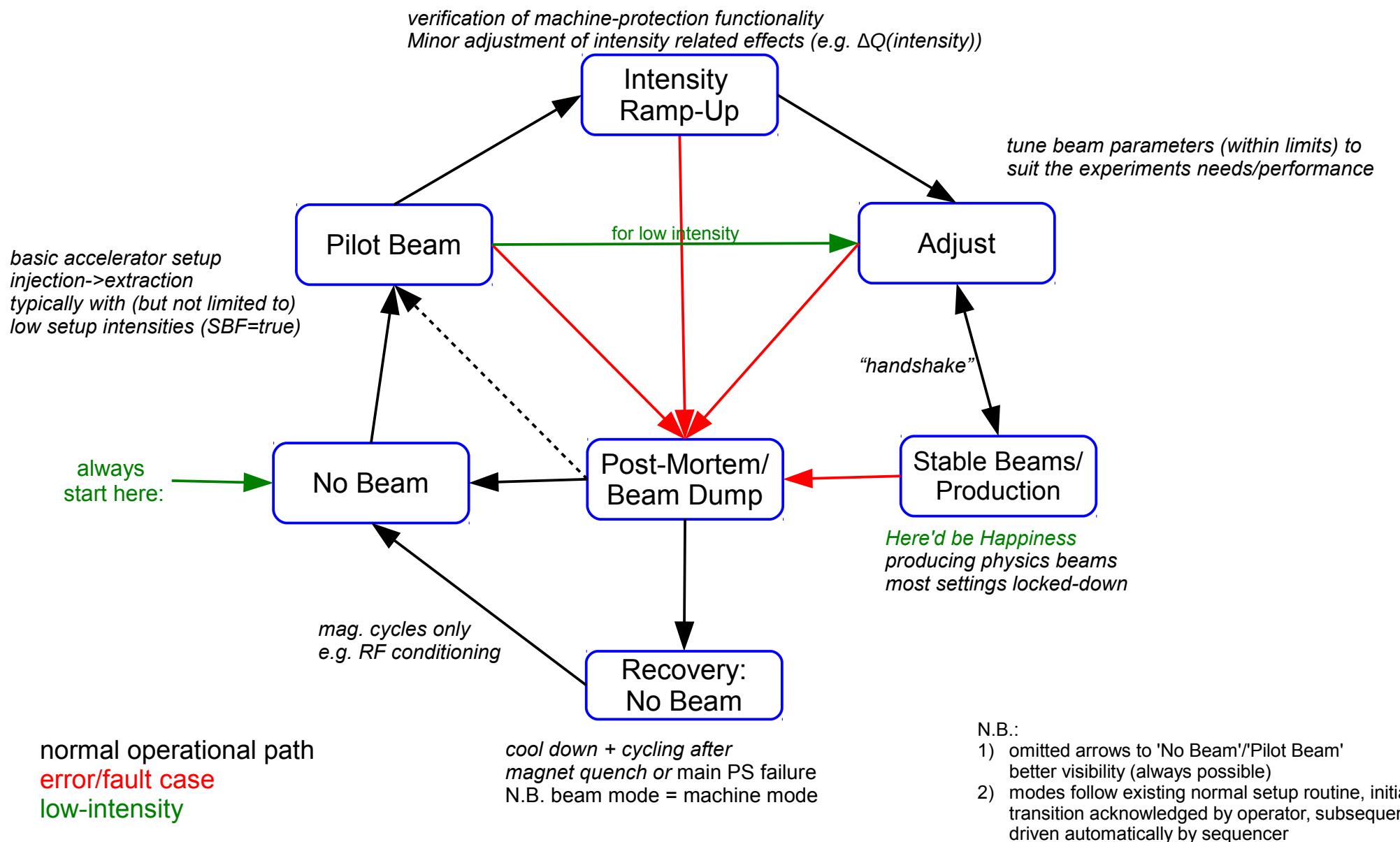
- **Operation with Beam:**

- BEAM SETUP
 - focus on initial/re-commissioning, machine setup after long shut-down + OP training
- PHYSICS
- MACHINE DEVELOPMENT
 - focus on accelerator/beam physics aspects
- MACHINE TEST (during beam operation periods)
 - controls, RF, new front-end, ... tests w/o beam + OP training
 - Ad-hoc during beam operation but not 'Physics' nor 'MD'



operation without beam
(part of shut-down coordination)

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



- **Beam Presence Flag (BPF)** – indicates that cycle/settings have been validated with Pilot- or Physics-Beam in the recent past (< days, tbd.)
 - main usage: prevent high-intensity injections into an 'empty' machine with new untested magnetic settings or modified machine conditions
 - defined per accelerator or transfer-line segment (where necessary)
- **Setup Beam Flag (SBF)** – indicates beam used to setup the beam production chain (typically low-intensity)
 - defined per accelerator or transfer-line segment (where necessary)
 - SBF provides flexibility of masking interlocks during setup (e.g. MWPC/screen protection)
 - Used to enforce interlocks with high-intensity (primary) beam
- **Injection/Extraction Permit** – indicates if subsequent accelerator chain is ready (safe) to receive beam (→ fast beam aborts, discussed later)

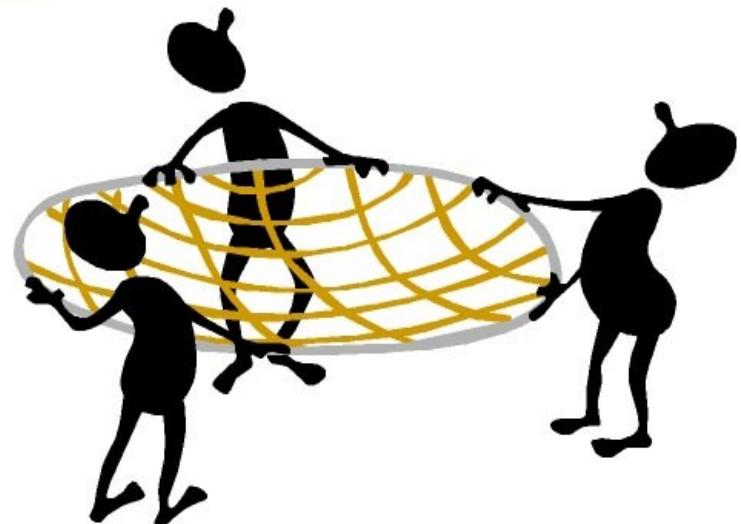
- New FAIR Timing System will be deployed in 2018
- CO will replace existing HW-AFE with more powerful SW solution
 - Any experiment that urgently still needs the old legacy solution?
 - N.B. old-HW would be mapped via SW stack to new unit but would safe time/development for legacy HW-hybrid



- Software beam-request-unit features:
 - Functional equivalent to existing unit (besides specific HW interfaces)
 - + Feedback on accelerator interlock status,
 - Accelerator & Beam Modes of preceding accelerator chain
 - beam-presence- and setup-beam-flags
 - Available beam configurations,
 - Provides also experiment's interface to set requested Accelerator & Beam Modes



\neq



1. Programmed, Slow Beam Abort:

- Experiments sets e.g. 'Beam Mode xxx' → 'No Beam' – cycle-to-cycle basis
- Beam request interface to be agreed upon (HW, SW, which beam parameter info, ...)

2. Faster Beam Abort (within-cycle) via timing network (ms-scale)

- requires: FMECA Analysis (soon) & post-mortem (when it occurs) from exp.

3. Fast Beam Abort (FBAS, within cycle) via digital optical link (us-scale)

- requires: FMECA Analysis (soon) & post-mortem (when it occurs) from exp.
 - Proof of limited false-positive rate
- Meant for protection against dangerous direct impact of primary beams
- SIS100 FBAS limit on false-positive MP triggers « 1 trigger/day (for nom. Operation))

4. Non-MP-related Spill-Aborts: medical-type-operation/int. dose control

- not part of FAIR base-line ↔ activation issues/where to dump remainder of beam

Dump	Official Name				Losses*
“SIS18 dump”	HHD	setup-only	< 10^9	@18 Tm	40% (per 10h)
<i>SIS18 → SIS100 extr.-setup dump</i>	T8DUSD1	setup-only	< 10^9	@18 Tm 0.5 Hz max! (no 3 Hz OP with HI!)	5% 90%
			$1.5 \cdot 10^{11}$ ions/s	200 MeV/u	5%
			$5 \cdot 10^{12}$ protons/s	4 GeV	5%
<i>SIS18 → SIS100 (only @ stripper & collimators)</i>	<i>Tunnel 101</i>		$5 \cdot 10^{12}$ ions/s	4.7 GeV/u	2%
<i>SIS100 internal emergency dump</i>	Tunnel 110 (Pt. 9), 1S54SD1		$3 \cdot 10^{11}$ U ²³⁸ /s	2.7 GeV/u	10%
			$2 \cdot 10^{13}$ protons/s	29 GeV	3%
<i>SIS100 extr.-setup dump</i>	Tunnel 112 T1D1SD1		< 10^9 ions	0.5 Hz max!	40%
			$5 \cdot 10^{11}$ ions/s	34 GeV/u	3%
			$2 \cdot 10^{13}$ protons/s	29 GeV	3%

- Losses* = integrated total losses over 365 days
 - N.B. typically run < 200 days, not all with high intensity & high energy → gain some factor,
 - However: limit does not include activation limits (maintainability) and is shared with operational (unavoidable) losses (injection losses, capture losses, fast/slow extraction inefficiency, halo colimation, ...)

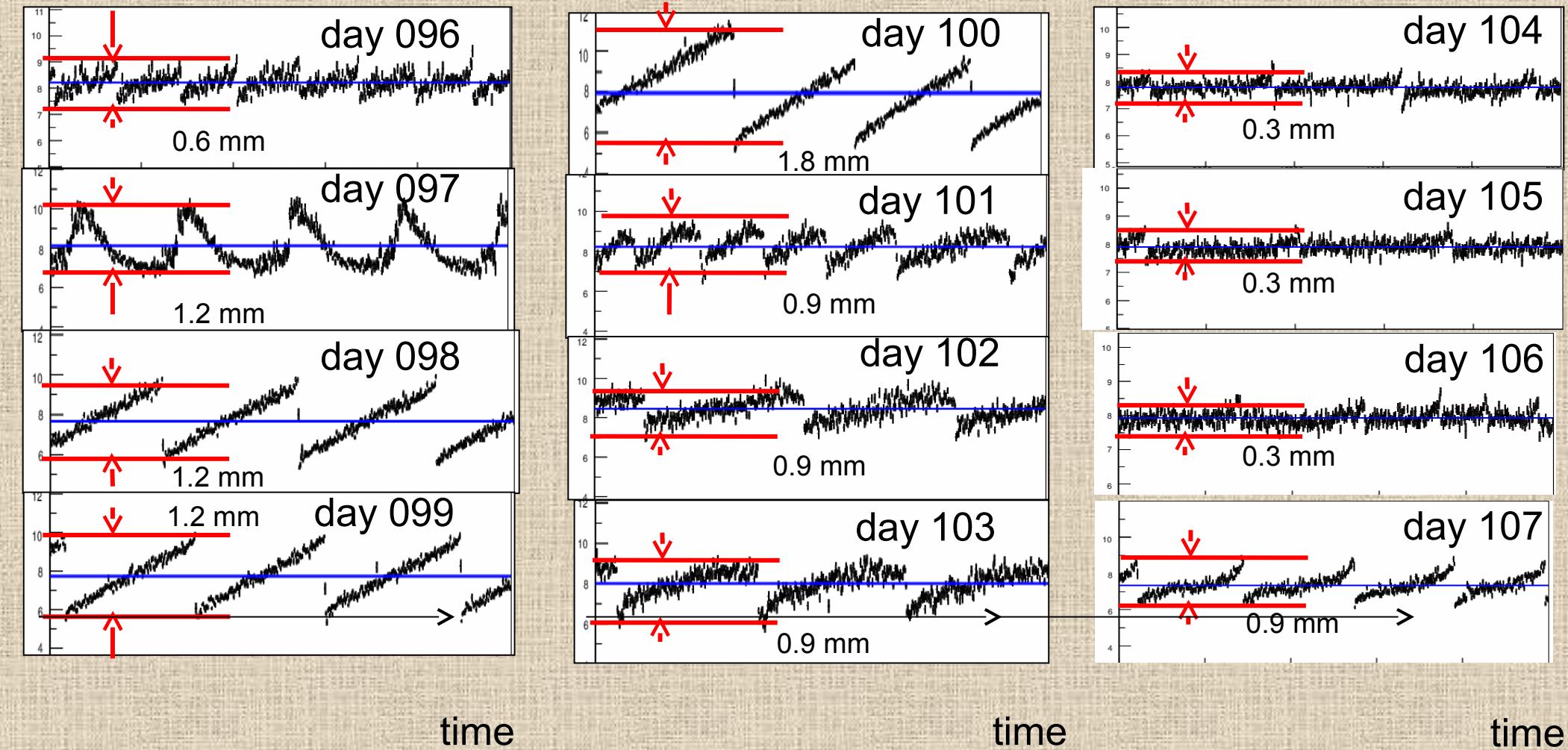
Dump	Official Name				Losses*
<i>SIS100 internal emergency dump</i>	Tunnel 110 (Pt. 9), 1S54SD1		$3 \cdot 10^{11} \text{ U}^{238}/\text{s}$	2.7 GeV/u	10%
			$2 \cdot 10^{13} \text{ protons/s}$	29 GeV	3%

- Losses* are shared between 'regular (un-)controlled losses' & 'exceptional losses'
- Experiment Diversity@FAIR: shouldn't favour single exp. beyond above others (within reasonable limits)
- ALARA:
 - Minimise false-positive triggers by design (result of FMECA)
 - keep MP stress & op. losses well below legal limits → aim at only a couple of FBAS/day
 - limit loss based on average calculated per hour (or at least not more than a day)
 - keeps beam-time schedule predictable over a couple of weeks/months, less "dirty" tricks
- Additional dead-time (beyond PM ack. & cool-down) based on actual cycle losses

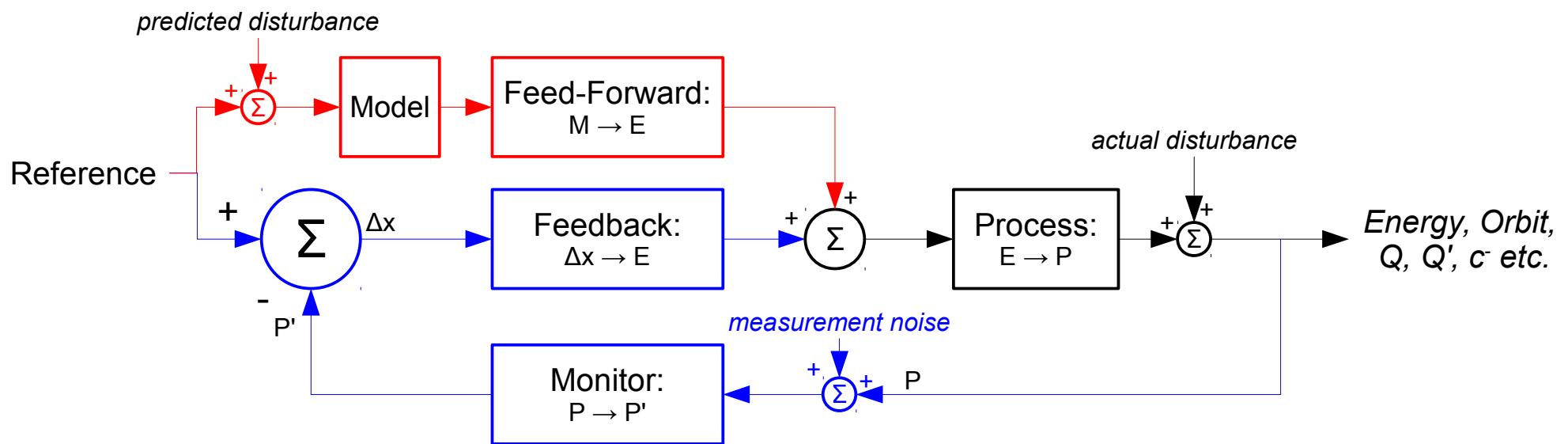
'Limit := $\int n_{\text{lossed}}(t) [\text{particles}] \cdot E^a(t) [\text{GeV}] dt / \# \text{experiment}$ '

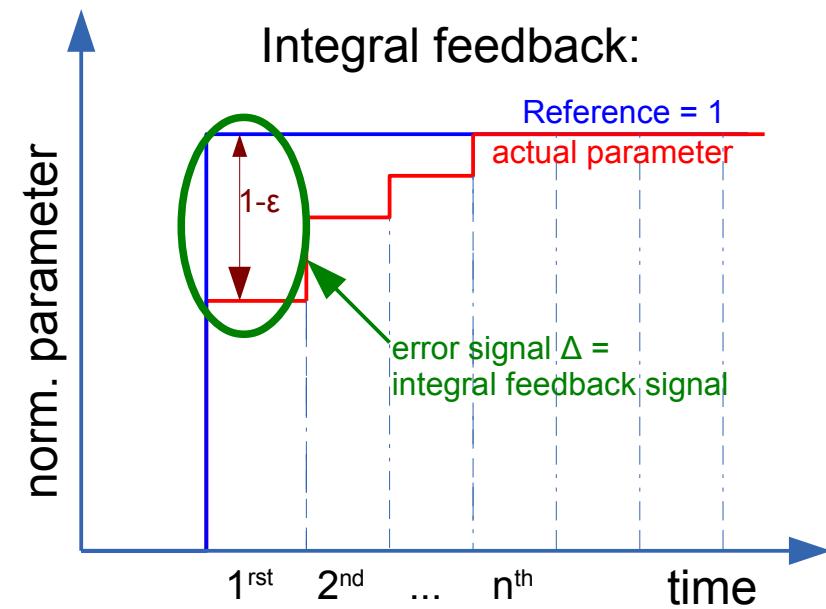
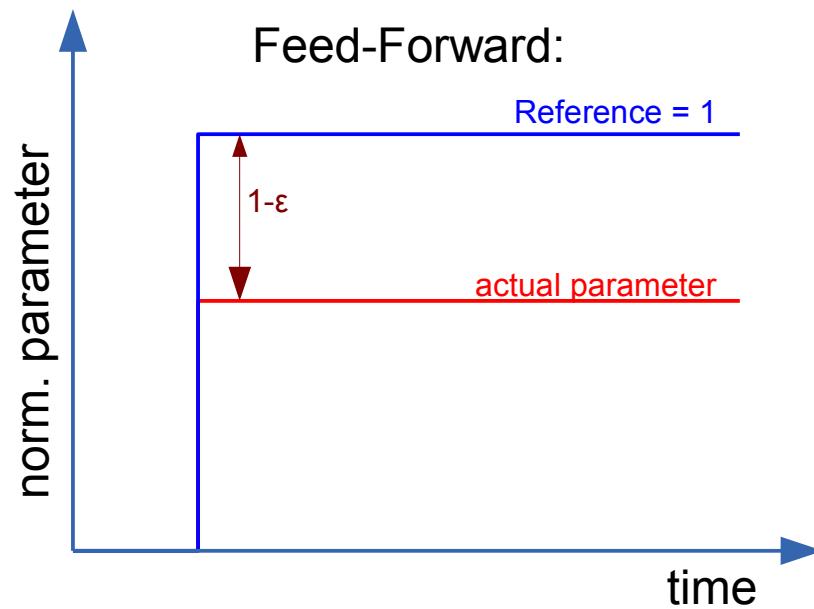
 - less penalty for confirmed lower energy or lower intensity losses (→ Transmission Monitoring System, FC2WG #6)
 - exponent 'a' to be checked (e.g. LHC (protons) $a \approx 1.7$, ions @ FAIR energies?)
- Re-assess limits after first year of operation with real high-intensity beams

Beam position stability – day-wise



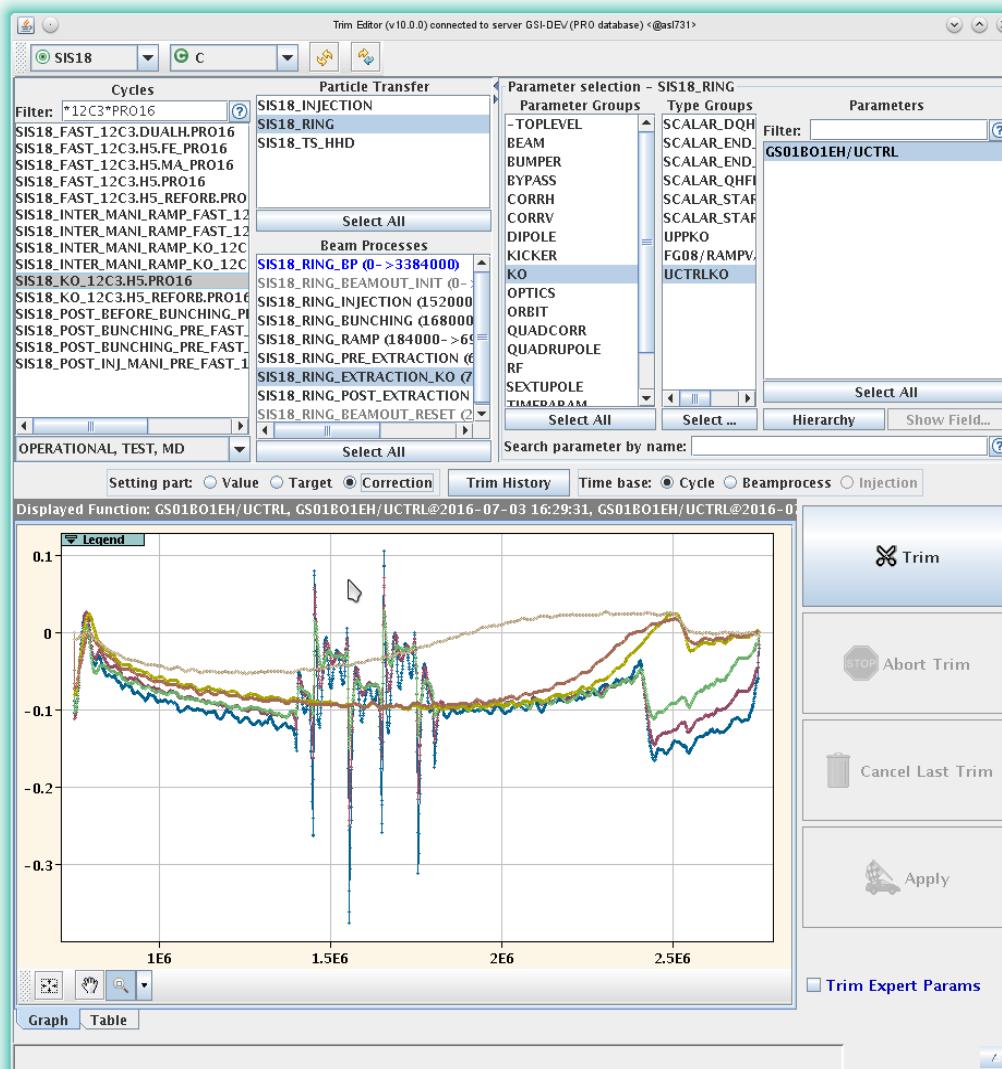
- **Feed-Forward: (FF)**
 - Steer parameter using precise process model and disturbance prediction
- **Feedback: (FB)**
 - Steering using rough process model and measurement of parameter
 - Two types: within-cycle (repetition $\Delta t << 10$ hours) or cycle-to-cycle ($\Delta t > 10$ hours)





Uncertainties and scale error of beam response function affects convergence speed (= feedback bandwidth) rather than achievable stability

Generic LSA trim interface:



... open to all accelerator parameter that fulfil basic control theory criteria:

- **Stability**: “parameter should be ~ reproducible from fill-to-fill ...”
 - good OP experience provided hysteresis is respected
- **Controllability**: “need affine (but not necessarily linear dependence between observable effect and control actuator, ...”
- **Observability**: “... need to be able to measure it reliability (noise, ...), ...”
→ *N.B. interface to experiment's detectors*

Generic Beam Control (focus on use-case)

1. **Transmission Monitoring System**
(R. Steinhagen, FC²WG Meeting #6)
2. **Orbit Control** (work in progress)
3. **Trajectory Control** (threading, inj./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 OP
ideally for SIS18 restart

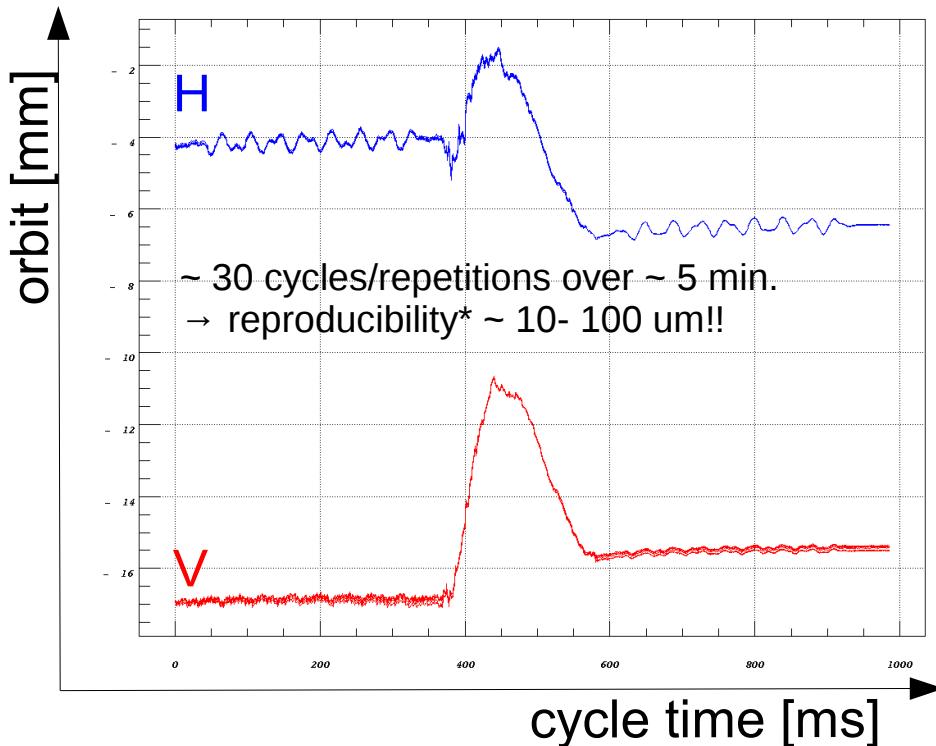
Machine-specific Beam-Based Systems:

- 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,
- ... “*the sky is the limit*”

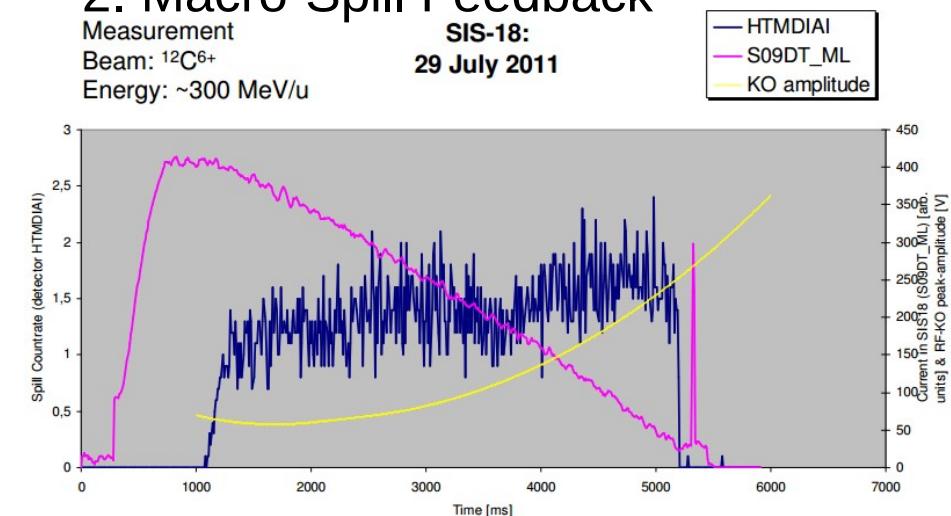
1. Orbit/Trajectory (e.g.Target-) Steering



2. Macro-Spill Feedback

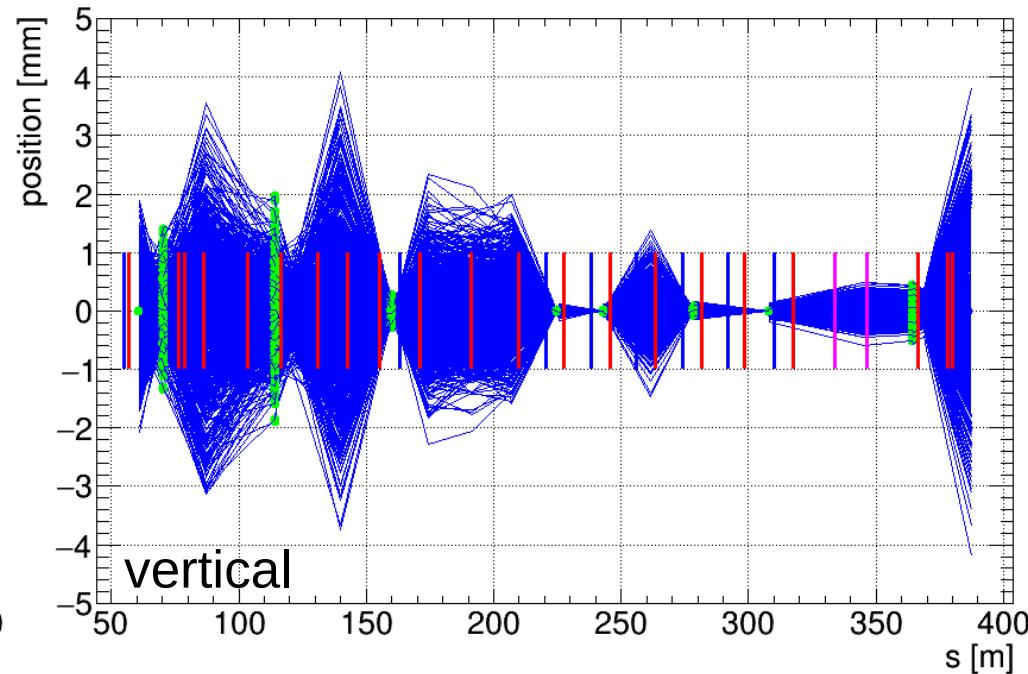
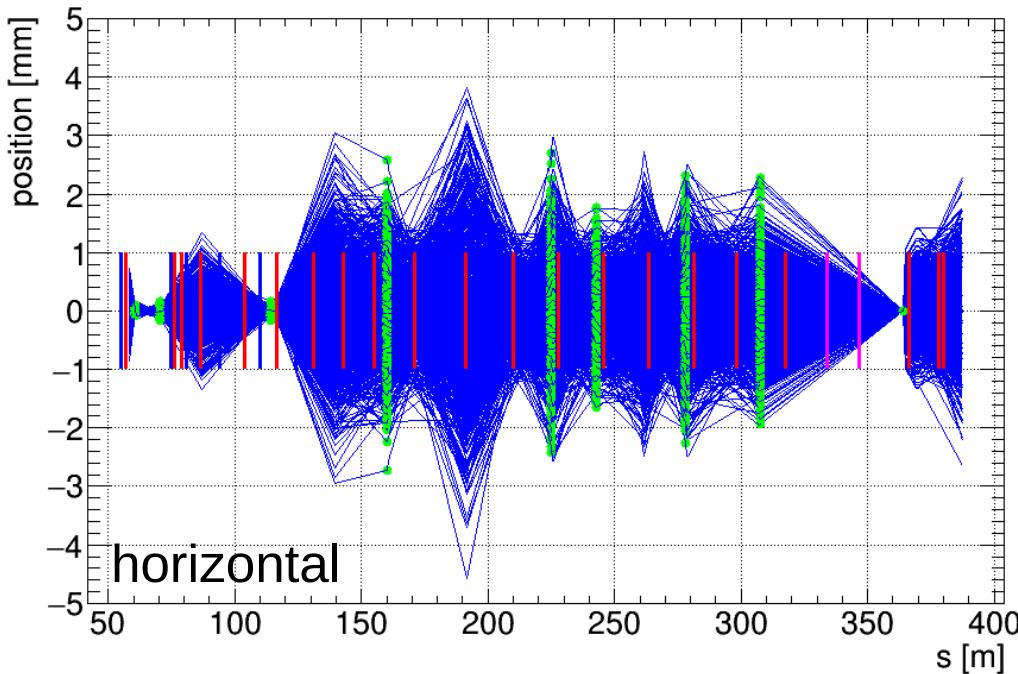
Measurement
Beam: $^{12}\text{C}^{6+}$
Energy: ~300 MeV/u

SIS-18:
29 July 2011

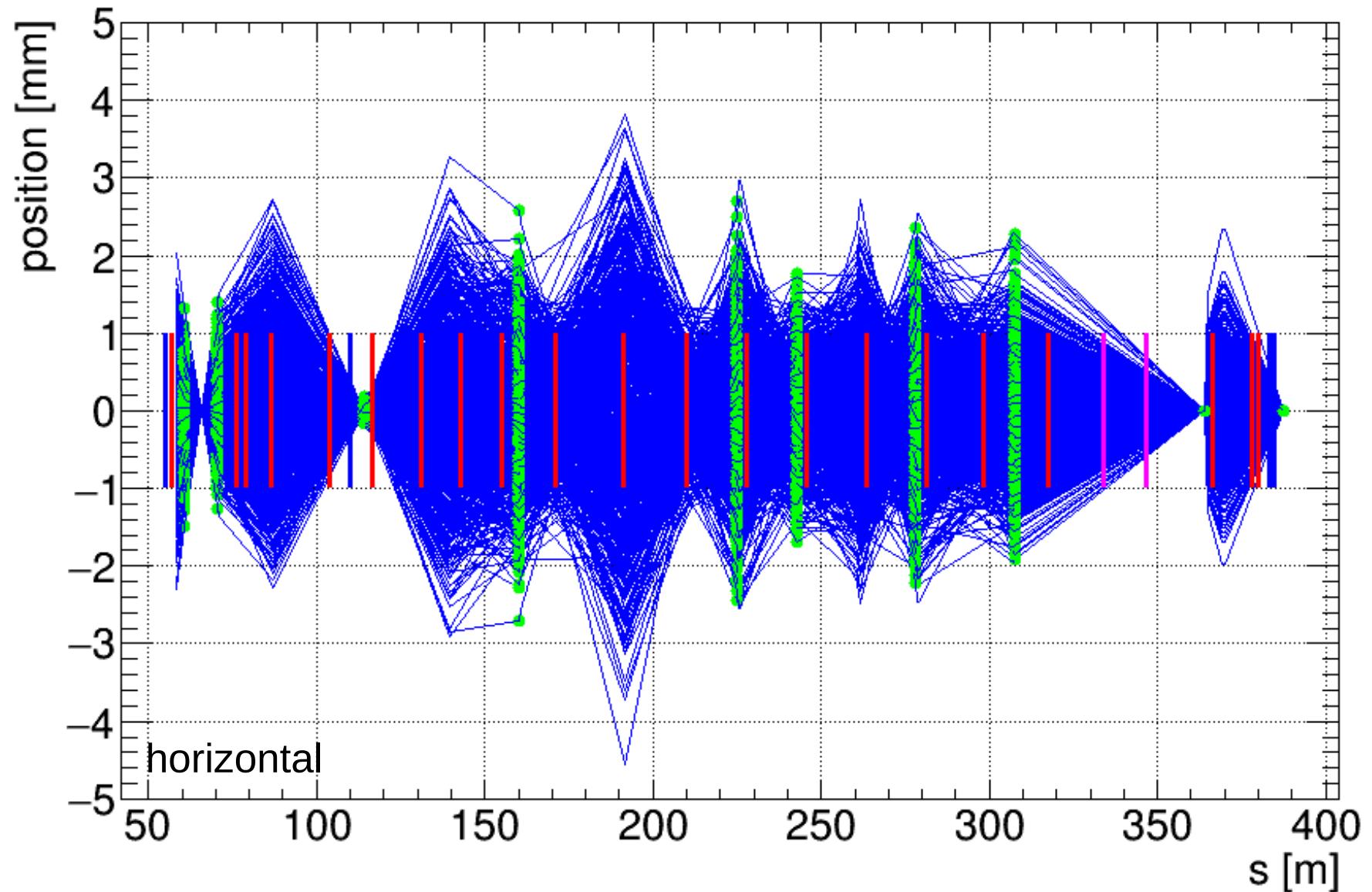


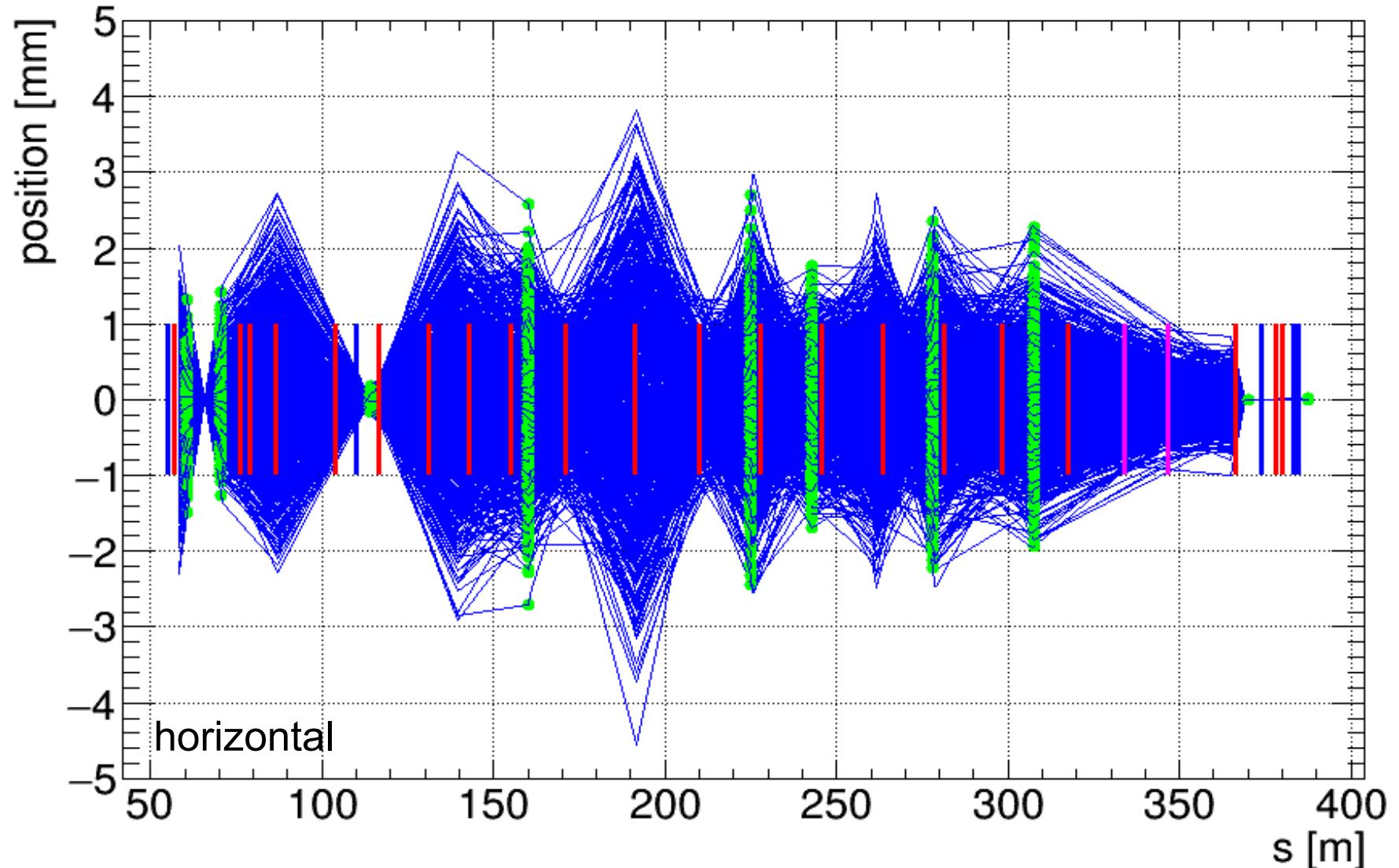
courtesy C. Bert, A. Constantinescu, D. Ondreka, M. Kirk et. al.

*modulo BPM stability/bias

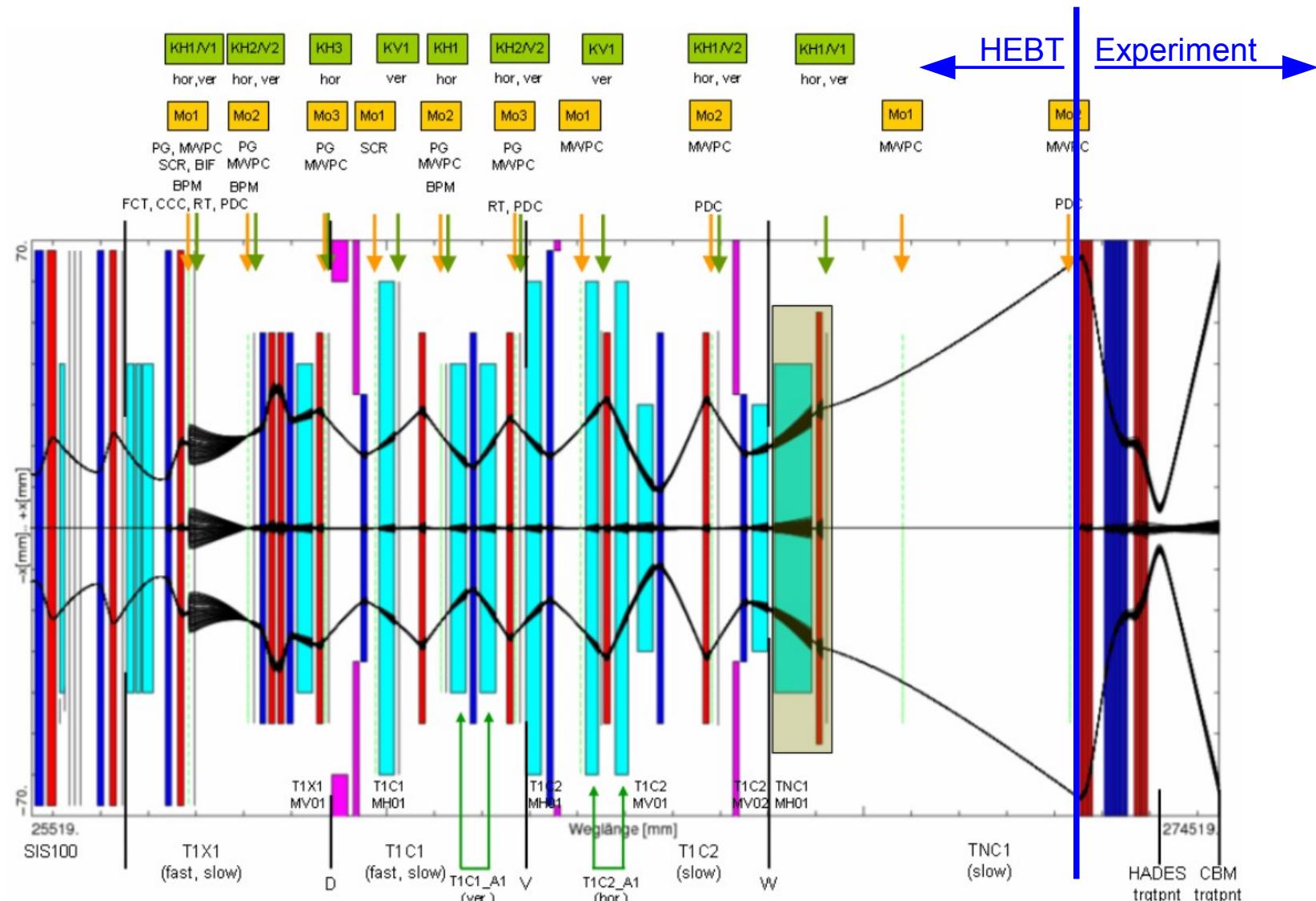


- Trajectory in transfer line OK ($< \sim 3$ mm)
- Larger deviations at \bar{p} -Target: ± 2 mm
 - Needs some interface definition (BPM near target)

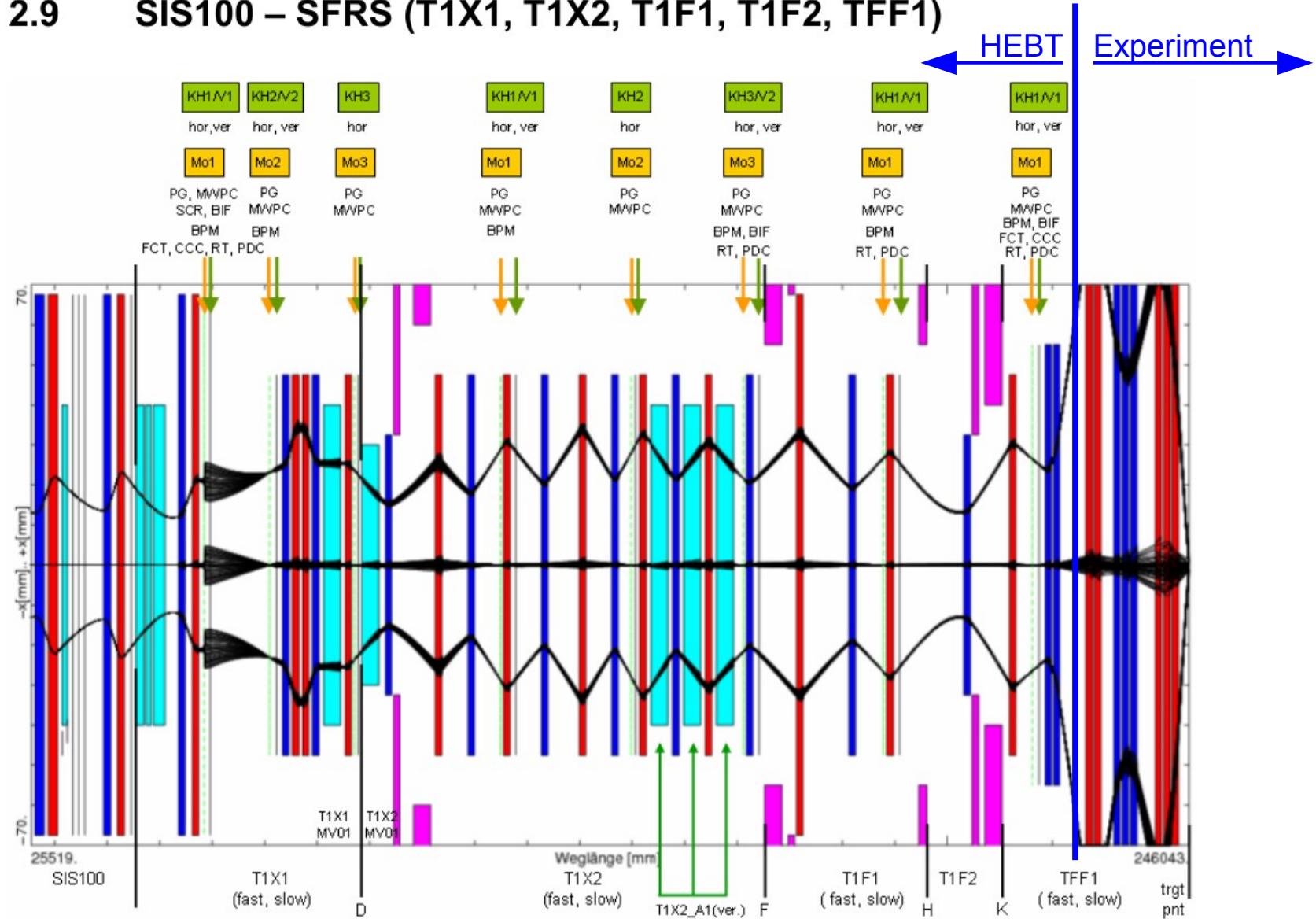




2.13 SIS100 – CBM (T1X1, T1C1, T1C2, TNC1)



2.9 SIS100 – SFRS (T1X1, T1X2, T1F1, T1F2, TFF1)



- **Target Steering – FESA integration of Exp. Specific Detectors**

(if not already based on BI standard, N.B. FESA being a front-end server architecture wrapped around whichever experiment control system)

- $x(t)$, $y(t)$, $\Delta p/p(t)$ + r.m.s. & status bits → **cycle-to-cycle feedbacks (ms-level binning)**
- target temperature, BLMs & radiation (interlock) levels (if not part of accelerator infrastructure), ...
- for setup (& online, if available): $\langle \sigma_x \rangle$, $\langle \sigma_y \rangle$ or if available: $\sigma_x(t)$, $\sigma_y(t)$, 2D distribution
 - at target and directly after last final-focus magnet

- **Beam Performance Indicators & (Micro-) Spill-Structure**

- General Parameters:

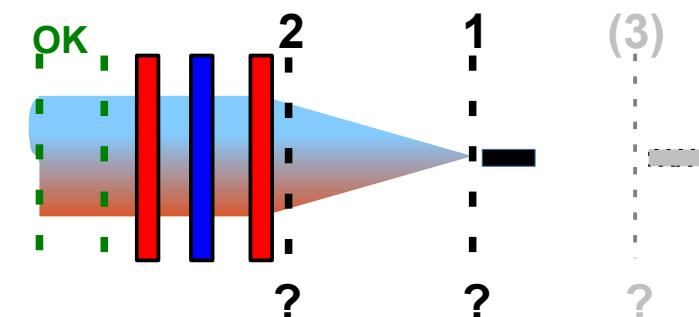
- (avg.) bunch length [ns], bunch profile [ns scale] + r.m.s. & status bits
- total numbers of particles extracted on target (transmission efficiency)
- particles recorded by experiments (accelerator/experiment efficiency), in relation to expected rates (model assumptions: cross-sections, detector efficiencies) → **the real performance indicator 'integrated "useful" luminosity'**
- beam-induced background information (signal-to-background from an experiment point-of-view → input/discussion required)
 - primary beam, secondary beams (up-stream/down-stream generated)

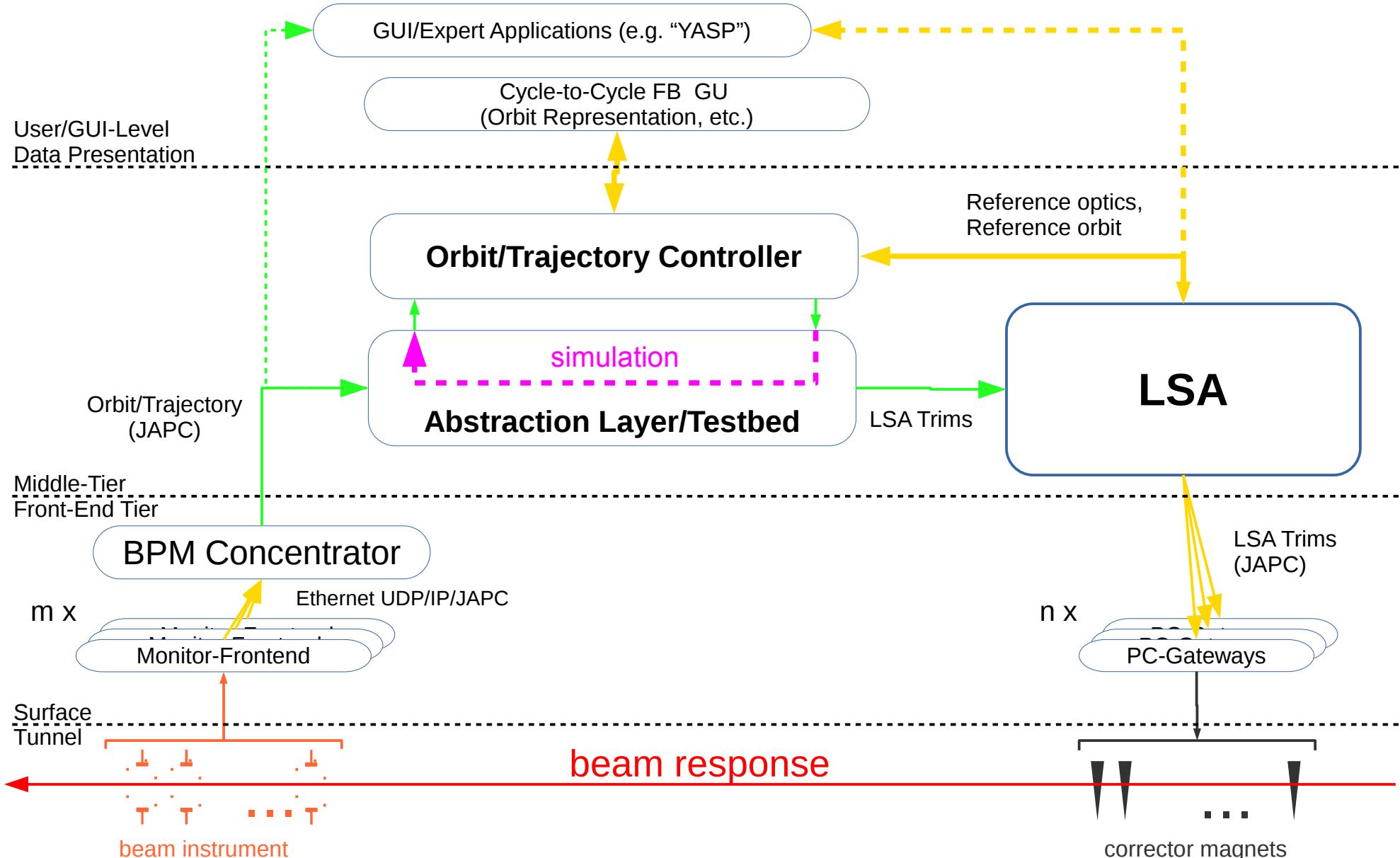
- Slow spill structure → **cycle-to-cycle feedbacks (binning: 1 ms or 100 us, tbd.)**

- Binned particle rate dN/dt – total & 'by bunch' (→ bunched beam extraction)
- pile-up histogram, spectrum (2D array: 1 FFT per 10% of the spill duration), integrated r.m.s. (from 0 → detector bandwidth), detector bandwidth

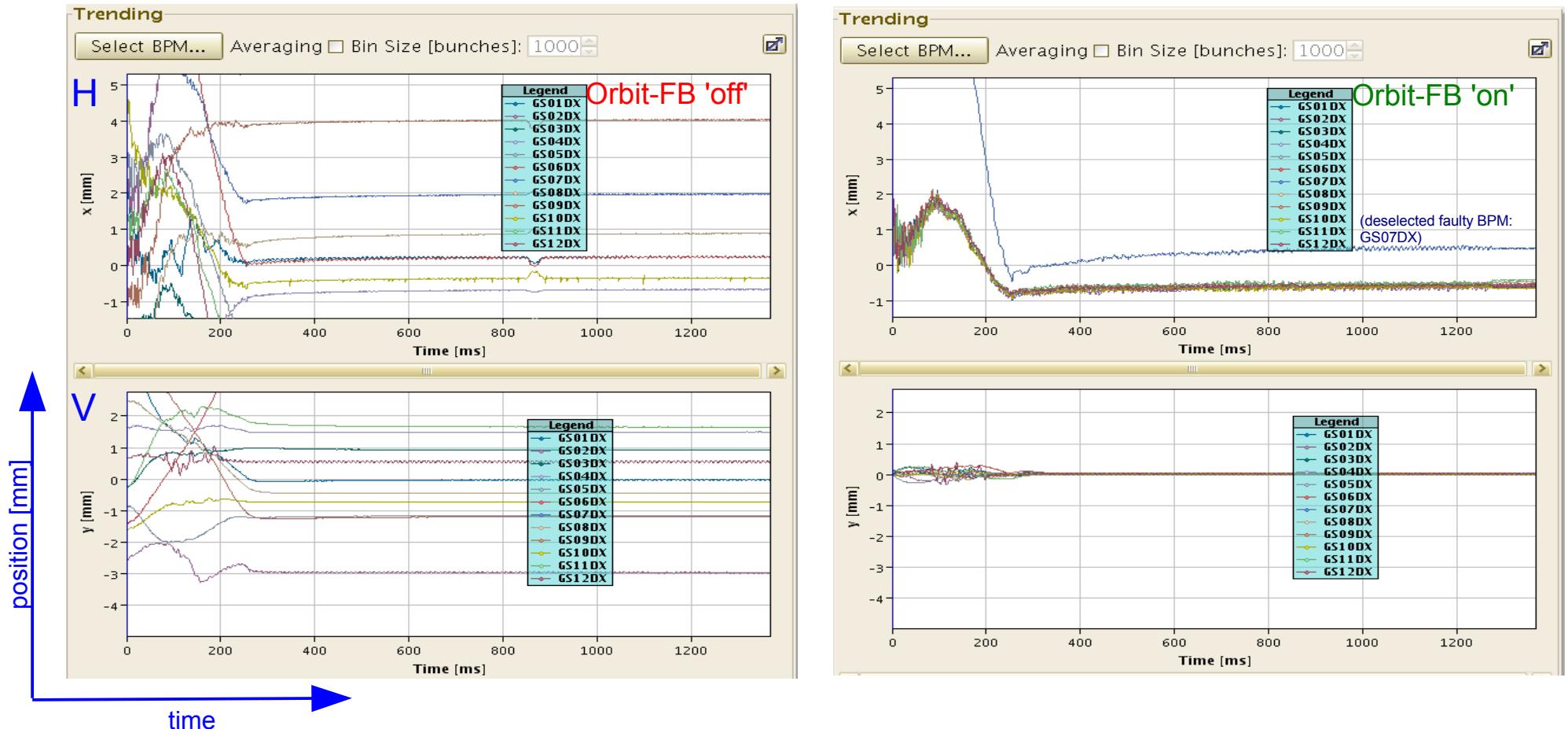
- Fast spill structure → **fast in-cycle feedbacks (future option, priority tbd. → disclaimer)**

- proposal: digital optical Gigabit-link (cables pulled to SIS18/SIS100 K.O. exciter, SW protocol to be defined)









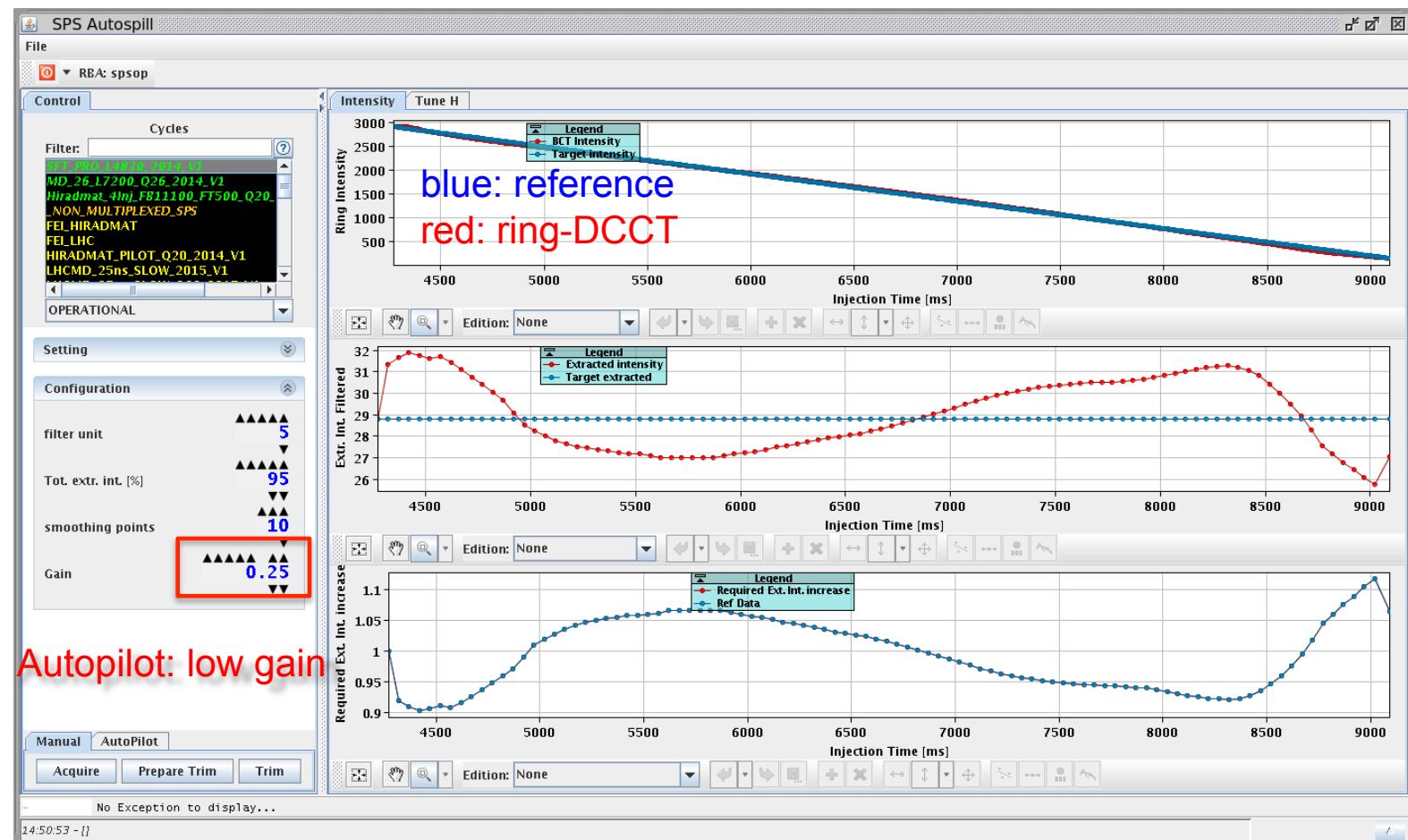
- some workarounds needed, but overall success and results look promising
 - need to follow-up: reliability, performance issues related to CO & BI + detailed integration before being put into regular operation (→ routine operation for 2018 looks feasible)
 - N.B. remaining horizontal oscillation due to uncorrected $\Delta p/p$ mismatch → radial-loop/Energy-FB

from SISMODI:

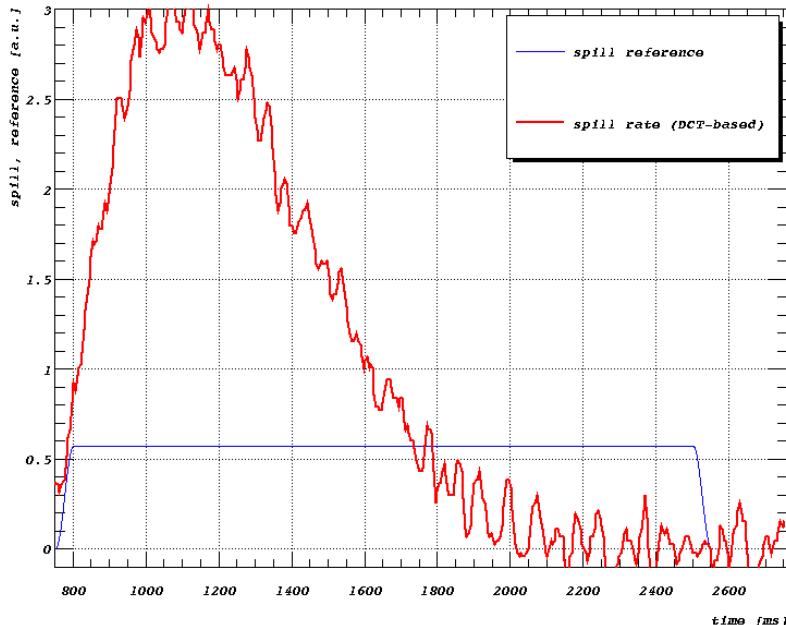
```
eEnergie [MeV]: 150.0
eB-Rho [Tm]: 5.97614
eFrequenz[kHz]:2011.561
eTeilchen [μA]: 0.122E+06
eQH : 4.29998
eQU : 3.26
eRad.Pos. [mm]: -2.0
Parkfrequ[kHz]:1062.66

dS04ME1E[mrad]: 1.337
t-Extrakt. [ms]: 1000.0
Spillmitt(0-1): 0.32
Spillampl(0-1): 0.6
Sextupolampl.: 0.15
Sextupolphase : 105.0
dQH-total : 0.035
dQH-primeur : 0.022
dQH : -0.01
```

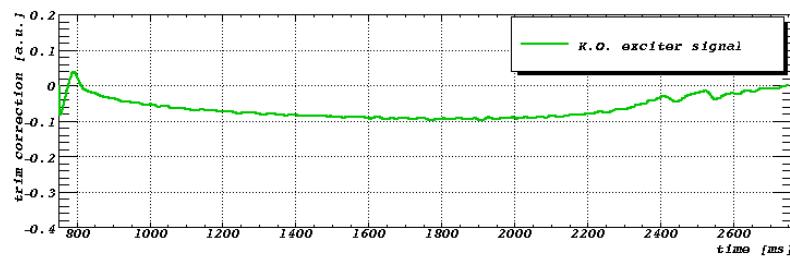
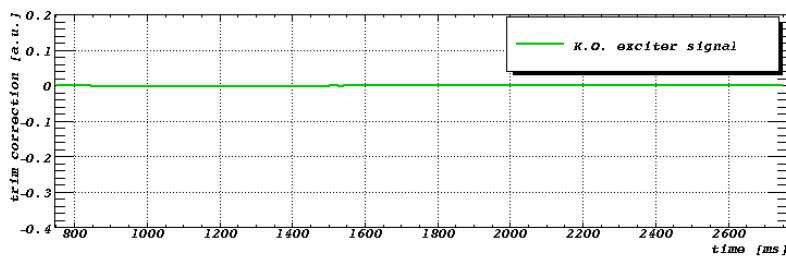
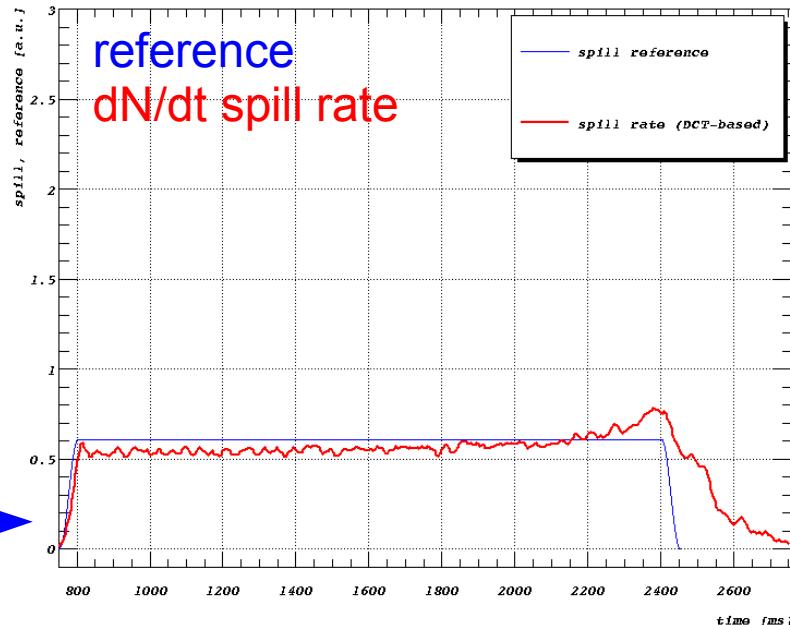
to LSA-based cycle-to-cycle feedback:



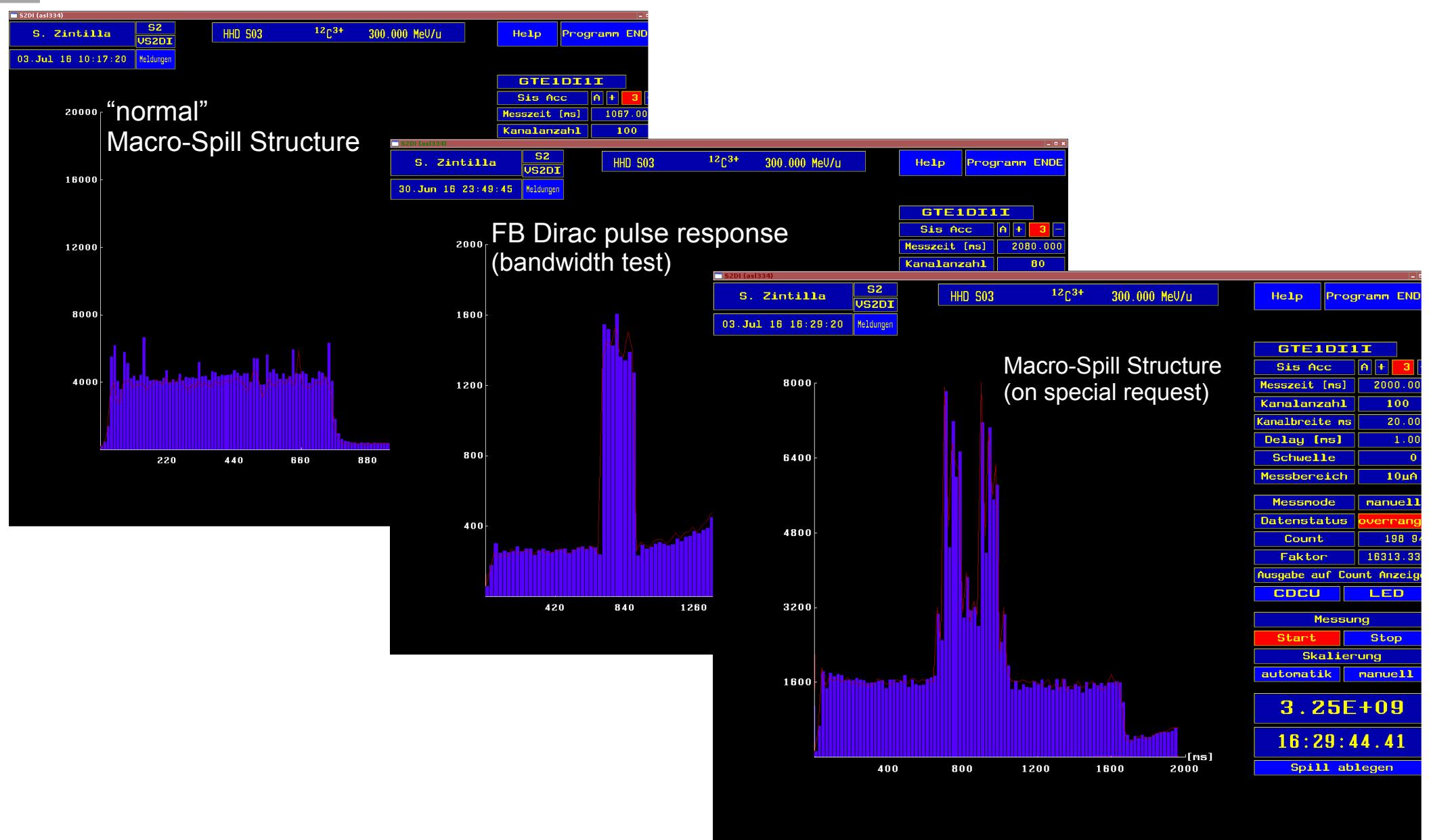
courtesy V. Kain, J. Wenninger, CERN



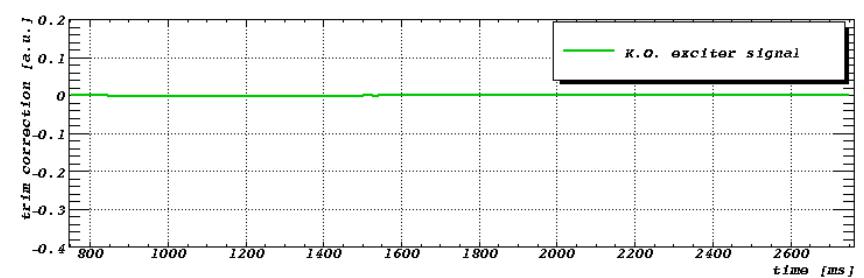
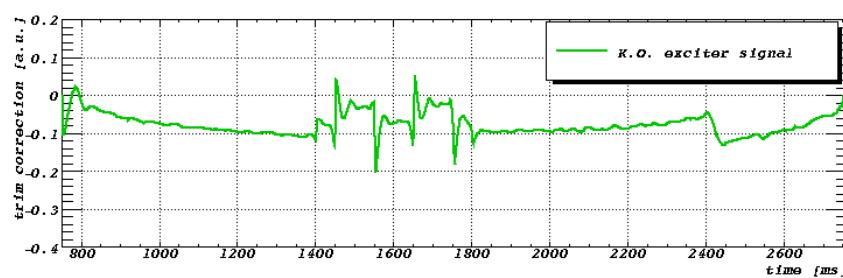
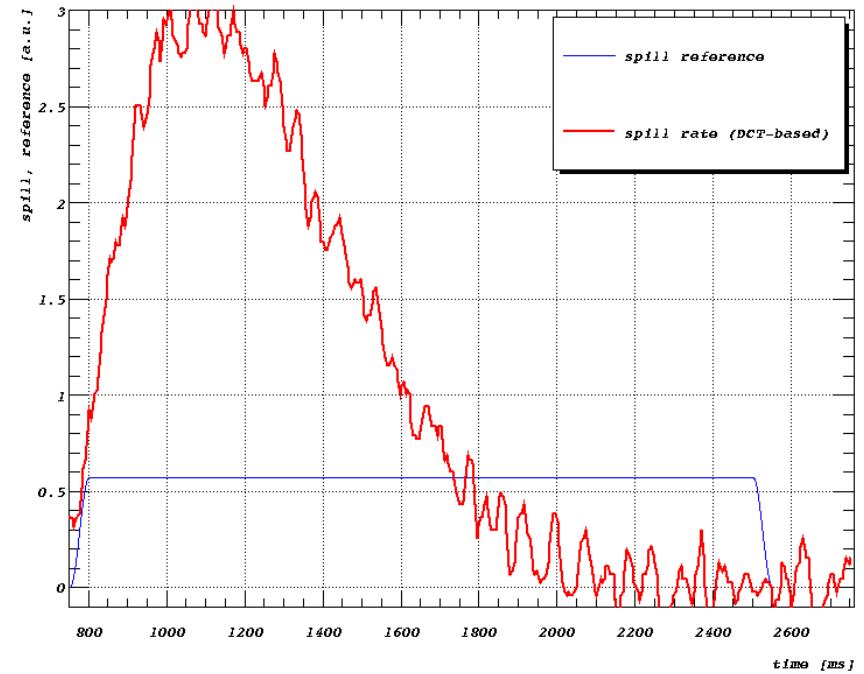
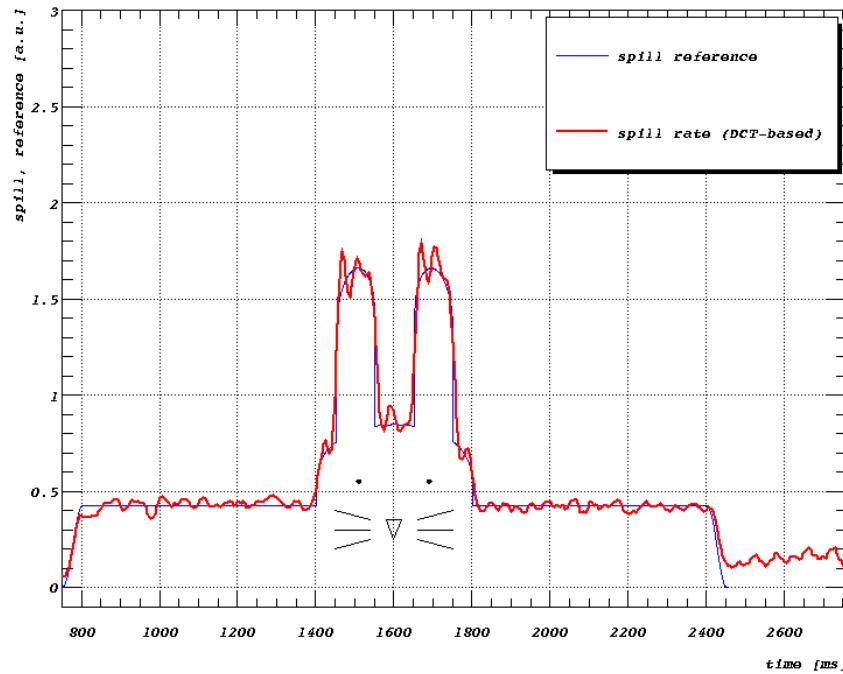
**Fill-to-Fill
FB on dN/dt
(DCCT-based)**



- 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
 - routine operation for 2018 feasible (provided priority/manpower will be allocated for OP/CO integration)



N.B. animated GIF





• Beam-Modes & Beam Mode transitions

- Beam parameter requests ↔ Beam Schedule (aka. "Strahlzeitplan"):
 - beam type, charge state, beam rigidity ([Tm]), intensity, spill-rate, ... (more?)
- Beam-Mode Transition for Experiments: 'No-Beam' → 'Pilot Beam', ...
 - Special Machine-Experiment Hand-Shake: Adjust ↔ 'Stable-Beams'

• Interface to Machine Protection (MP) → Beam Aborts:

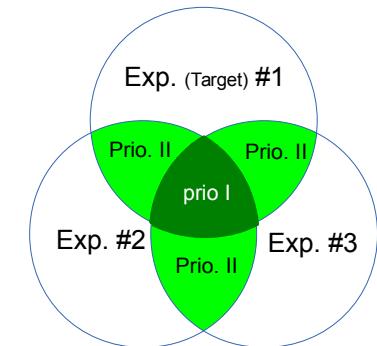
- Programmed, slow Beam Abort: Exp. 'Beam Mode xxx' → 'No Beam' – cycle-to-cycle basis
- Faster Beam Abort (within-cycle) via timing system (ms-scale) → [post-mortem & FMECA for Experiments](#)
- Fast Beam Abort (FBAS): digital optical link (us-scale) → [post-mortem & FMECA for Experiments](#)
 - protection against dangerous direct impact of primary beams & SIS100 FBAS limit on false-positive MP triggers ≪ 1 trigger/day (for nom. Operation))
- Non-MP-related spill-aborts: medical-type-operation/dose rate control
 - not part of FAIR base-line ↔ issue of activation/where to dump remainder of beam

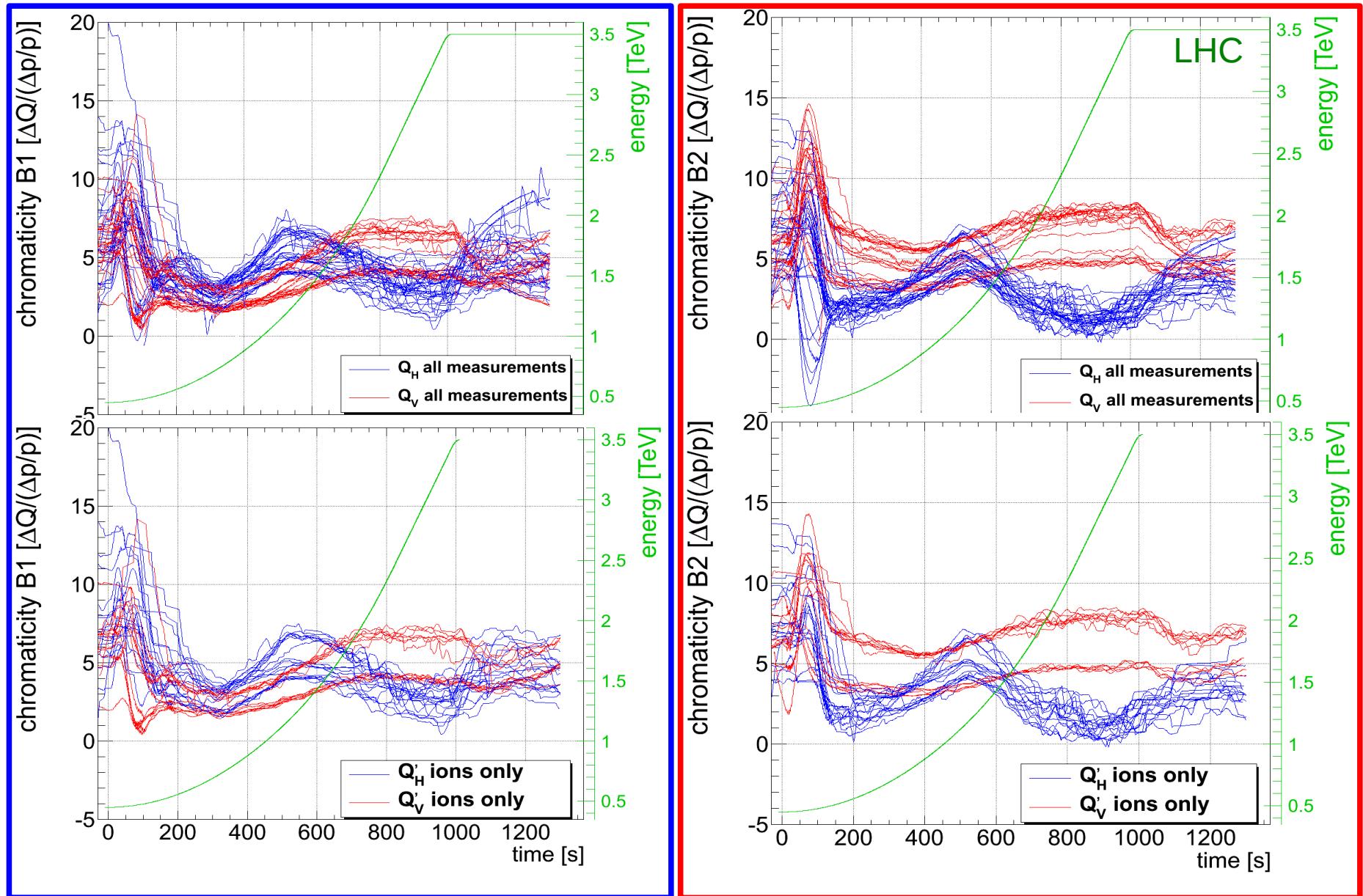
• Target Steering:

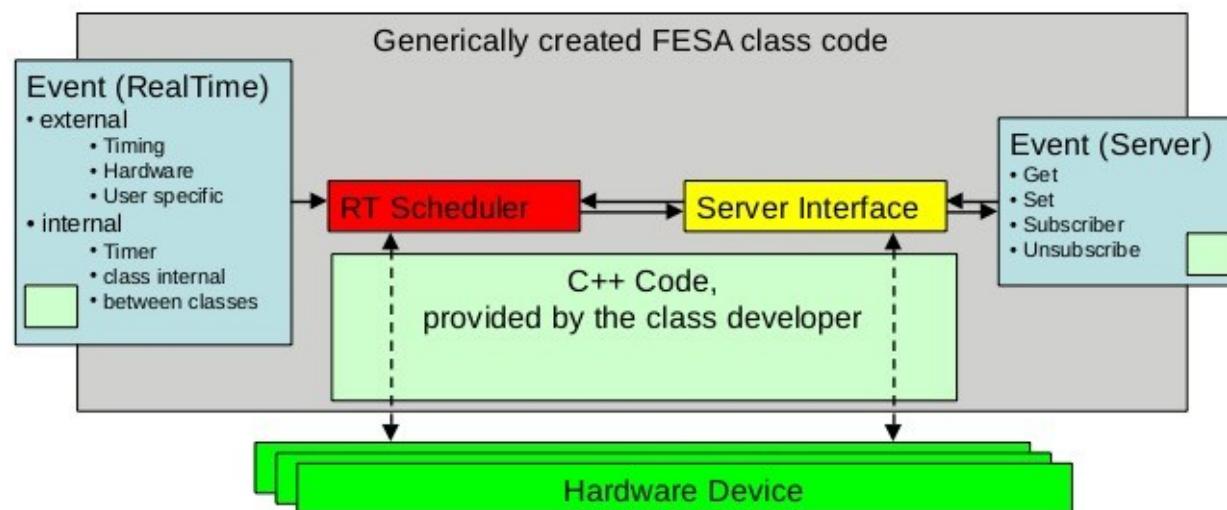
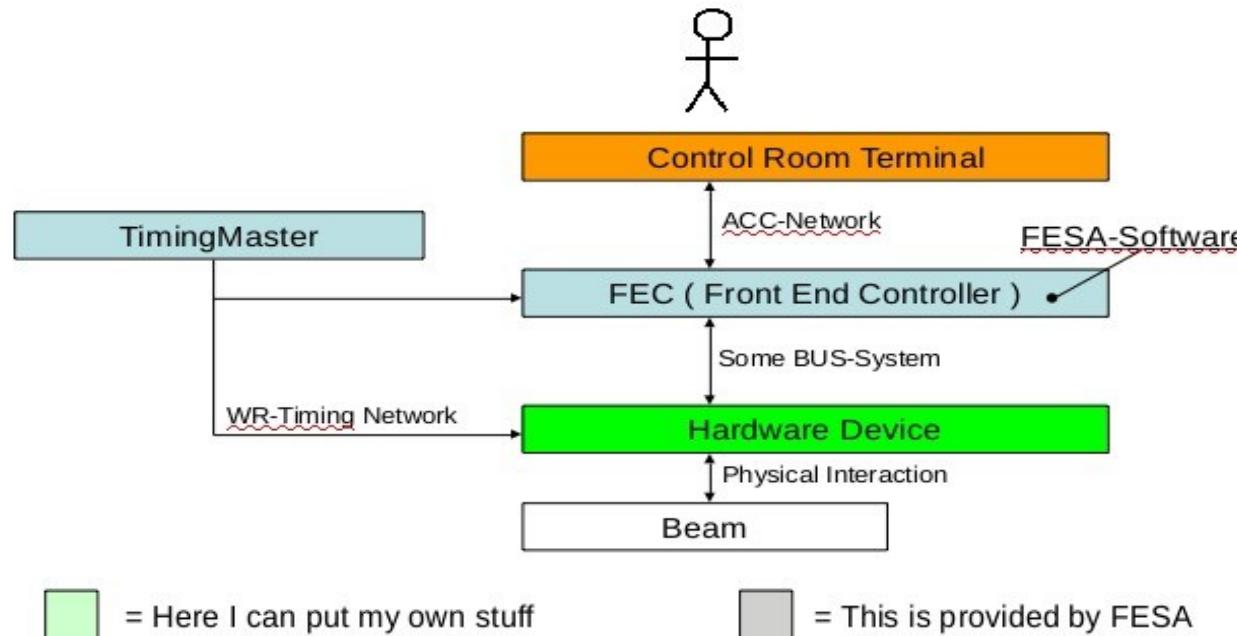
- $x(t)$, $y(t)$, $\Delta p/p(t)$ + r.m.s. & status bits → cycle-to-cycle feedbacks (ms-level binning)
- Target temperature, BLMs & radiation (interlock) levels (if not part of accelerator), ...
- for setup (& online, if available): $\langle \sigma_x \rangle$, $\langle \sigma_y \rangle$ or if available: $\sigma_x(t)$, $\sigma_y(t)$, 2D distribution

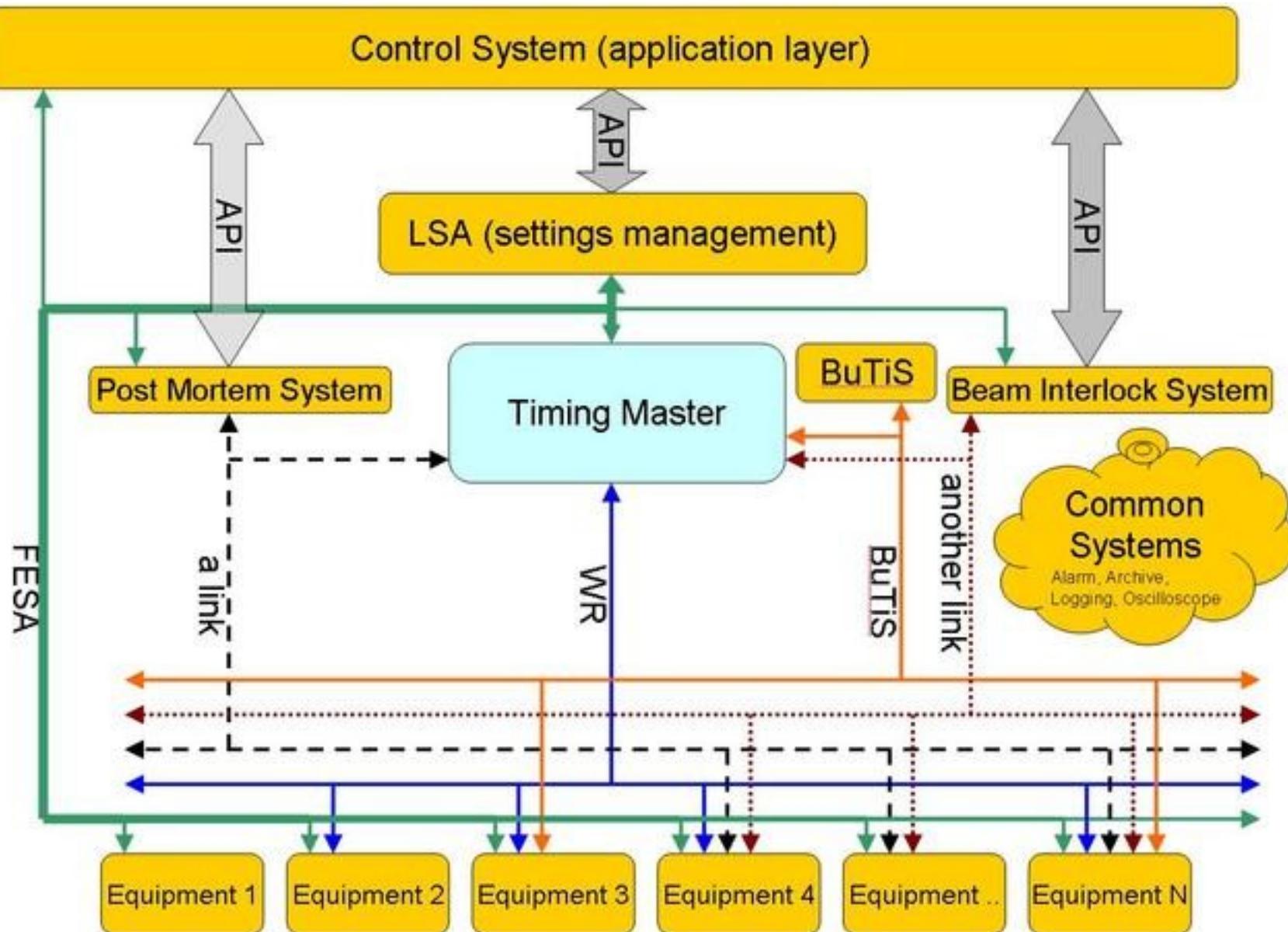
• Beam Performance Indicators & (Micro-) Spill-Structure

- General:
 - avg. bunch length [ns], bunch profile [ns scale] + r.m.s. & status bits
 - total numbers of particles extracted on target (transmission efficiency)
 - [particles recorded by experiments \(accelerator/experiment efficiency\)](#), in relation to expected rates (model assumptions: cross-sections, detector efficiencies)
 - beam-induced background information (signal-to-background from an experiment point-of-view → input/discussion required)
 - primary beam, secondary beams (up-stream/down-stream generated)
- Slow spill structure → cycle-to-cycle feedbacks (binning: 1 ms or 100 us, tbd.)
 - Binned particle rate dN/dt – total & 'by bunch' (→ bunched beam extraction)
 - pile-up histogram, spectrum (2D array: 1 FFT per 10% of the spill duration), integrated r.m.s. (from 0 → detector bandwidth), detector bandwidth
- Fast spill structure → fast in-cycle feedbacks
 - digital optical Gigabit-link (cables pulled to SIS18/SIS100 K.O. exciter, SW protocol to be defined)

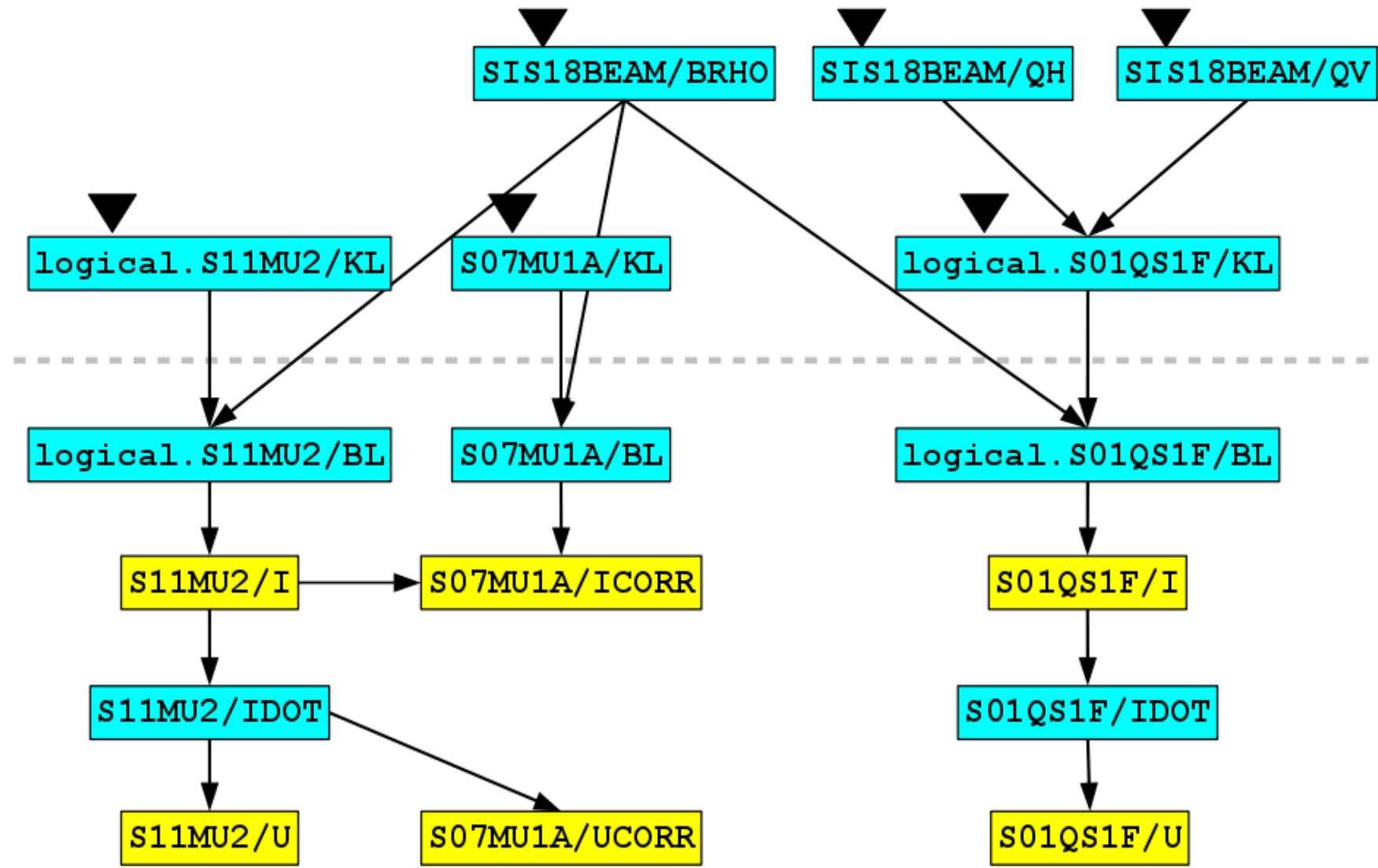








Physik



N.B. defined per
accelerator/transfer line segment

		Accelerator Mode									
		Beam Operation									
Beam Mode	No Beam	X	X	X	X	X	X	X	X	X	X
	Pilot Beam								X	X	X
	Intensity Ramp-Up								X	X	X
	Adjust								X	X	X
	Stable Beams									X	
	Post-Mortem								X	X	X
	Recovery								X	X	X

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

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

Mode:

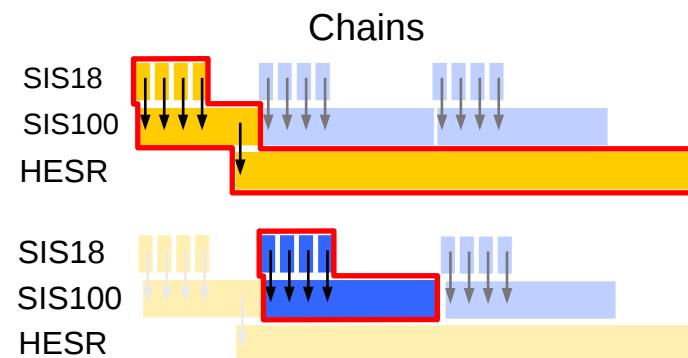
- deliberate user-driven state used to precondition the control system behaviour and responses independent of the actual accelerator or beam state → 'reference' or 'desired target' of operation (long-term)
 - formal agreement between accelerator operations and experimental users w.r.t. what to expect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

Actual State:

- measured current state of the accelerator/beam (short-term)
 - pervades accelerator & beam mode definition & equally used as a ad-hoc/post condition
 - Examples: Beam-Presence-Flag (BPF), Setup-Beam-Flag (SBF), Injection & Extraction Permit (MP interlock states)
- real-time requirements
- Examples:
 - 'No Beam' beam mode declares intend (as an agreement) that there will be no beam in the machine
 - 'Beam Presence Flag' is measured actual state whether there is (/was) beam in the machine or not
 - N.B. obviously a 'NO BEAM' beam mode & 'BPF=true' should lead to an interlock
- Shouldn't mix 'modes' with 'actual states' to prevent circular dependencies, priority/causality inversions

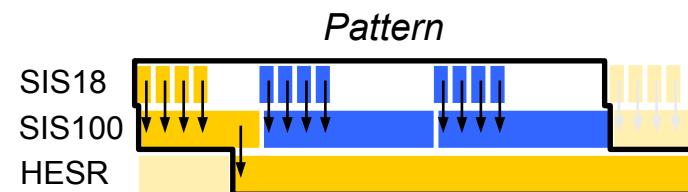
- **Beam-Production-Chain:**

- 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:**

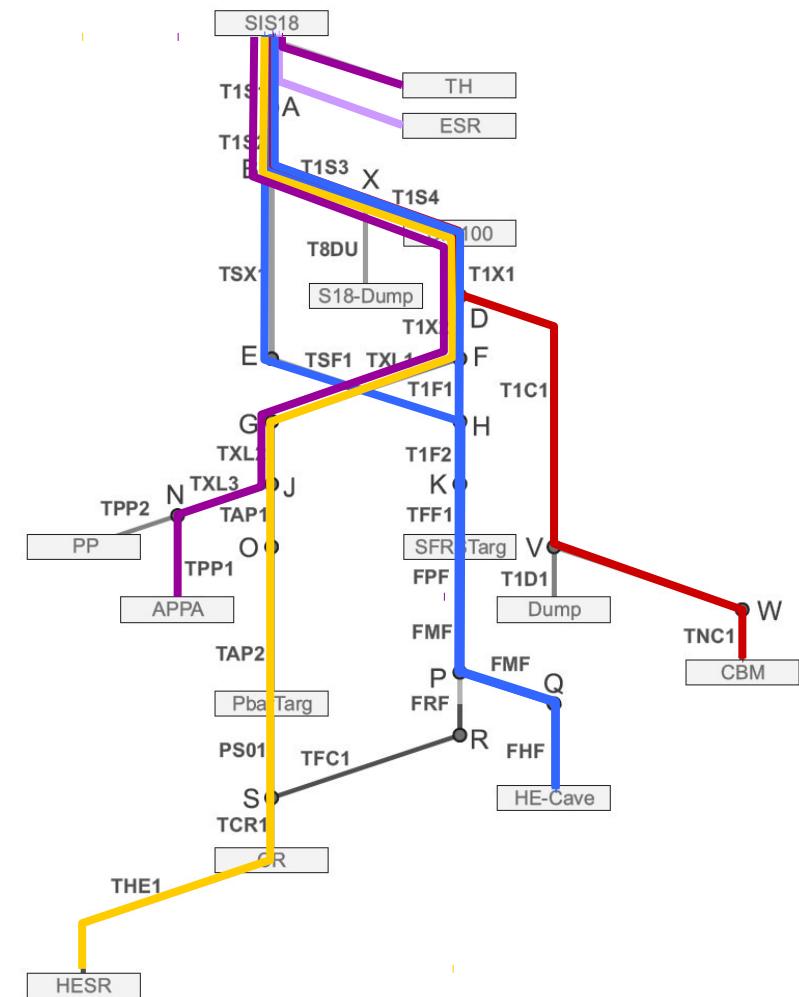
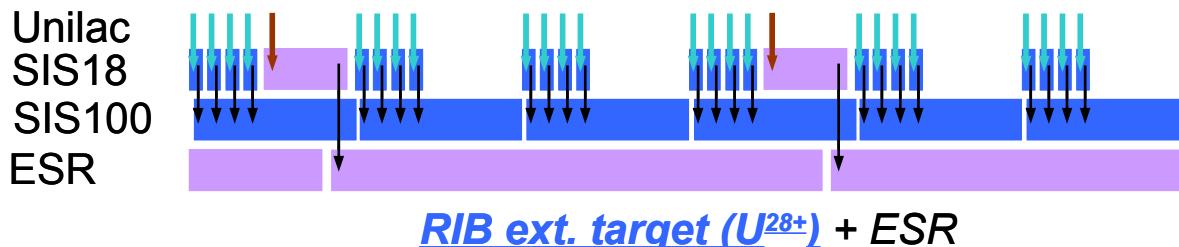
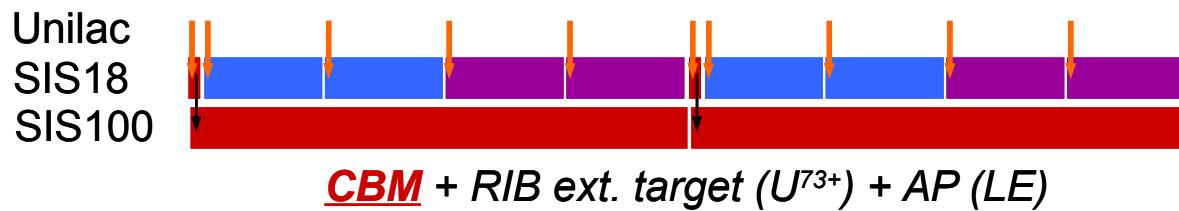
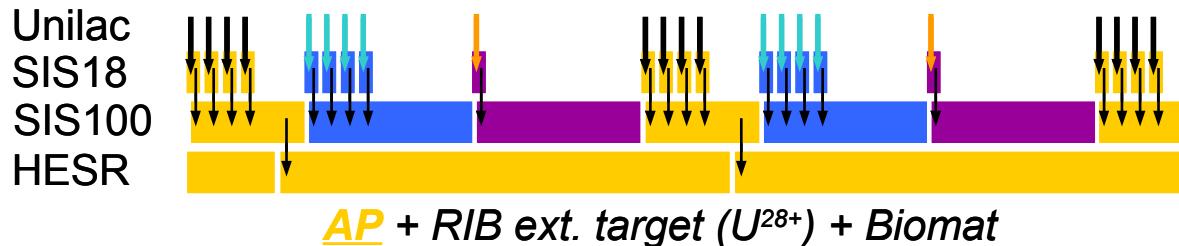
- grouping of beam production-chains that are executed periodically
- can be changed of pattern within few minutes (target, requires automation for beam-based retuning)



Glossary III/III

Example: Chain & Pattern

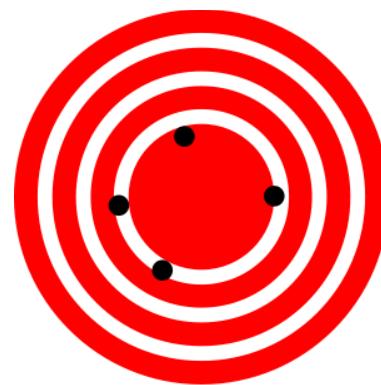
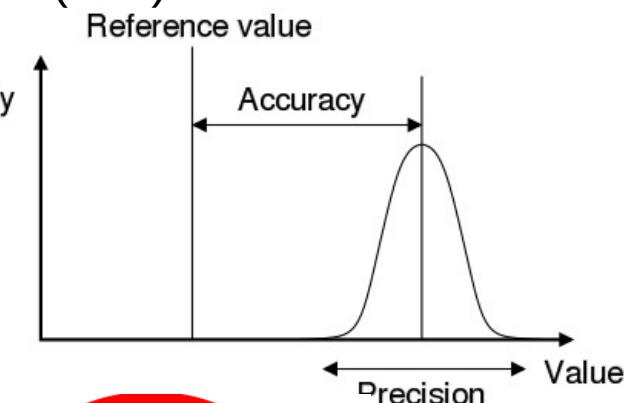
Periodic beam patterns, dominated by one main experiment:



courtesy D. Ondreka

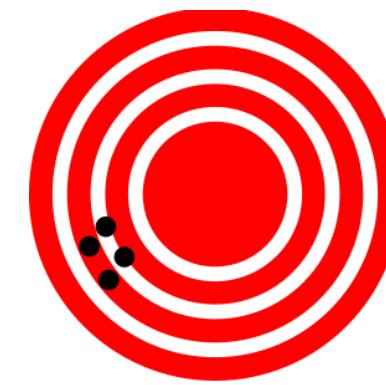
Good summary: http://en.wikipedia.org/wiki/Accuracy_and_precision

- **Accuracy:** “[..] closeness of measurements [...] to its actual (true) value”
- **Precision** (also: reproducibility or repeatability): “[..] degree to which repeated measurements under unchanged conditions show the same results.”
- Example: “Target analogy” and the two extreme cases



High **accuracy**, but low **precision**

obtained through beam-based alignment

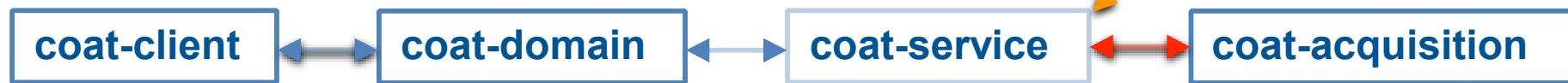


High **precision**, but low **accuracy**

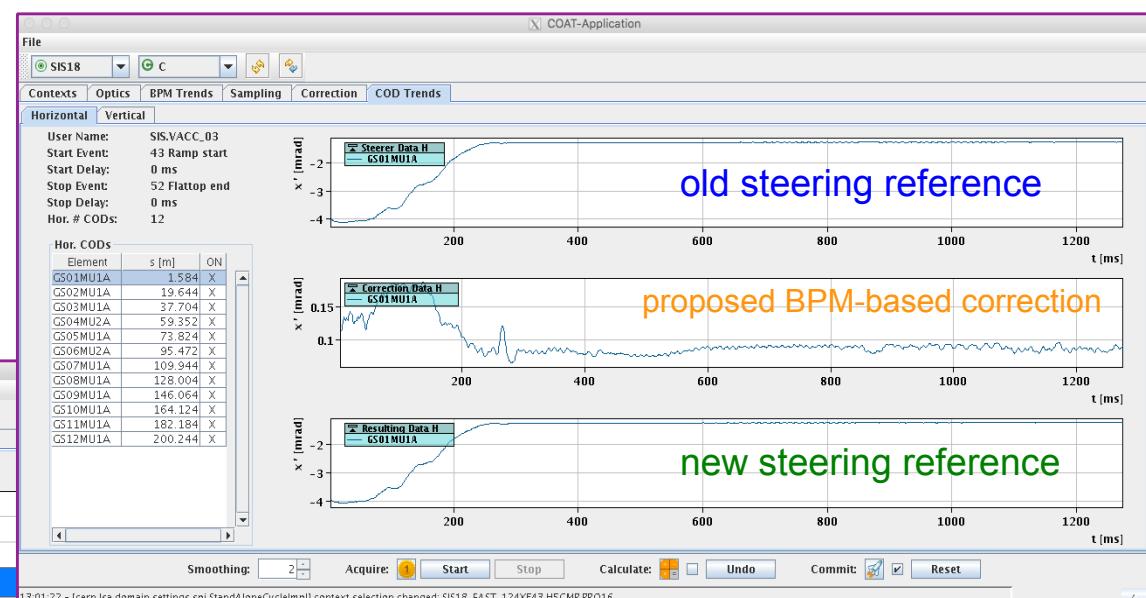
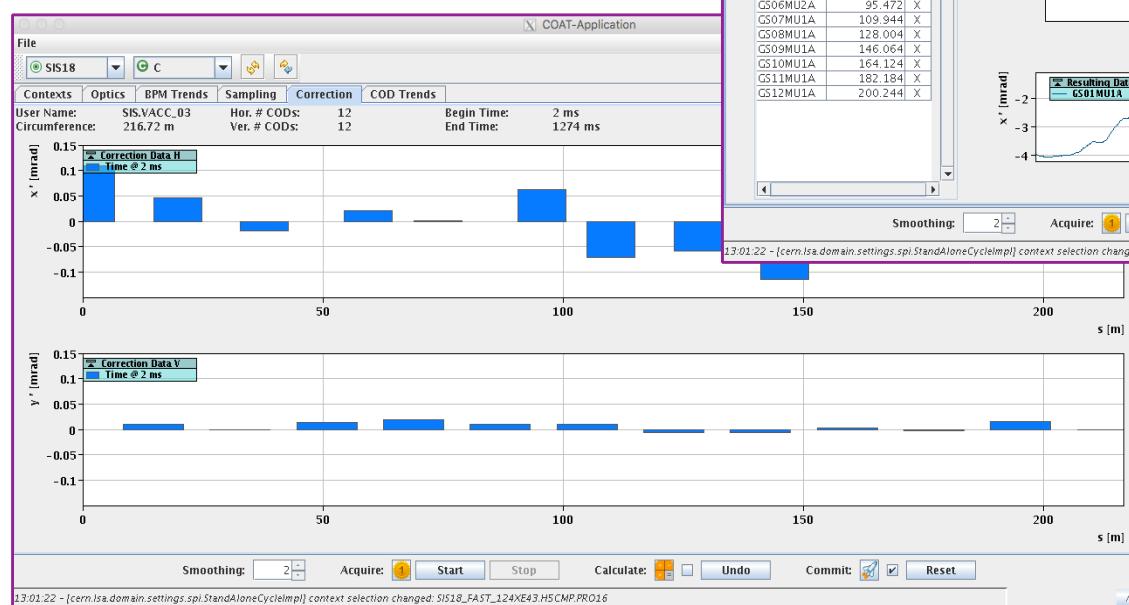
we need this from the BPMs

- **Resolution:** smallest change that produces a response in the measurement

COAT - controlling orbits and trajectories:



First working prototype



Dump	Official Name				Losses*
[...]					
<i>SIS100 internal emergency dump</i>	Tunnel 110 (Pt. 9), 1S54SD1		$3 \cdot 10^{11} \text{ U}^{238}/\text{s}$	2.7 GeV/u	10%
[...]			$2 \cdot 10^{13} \text{ protons/s}$	29 GeV	3%

- 1S54SD1 foreseen as protective dump to mitigate beam-related severe machine protection issues but should not be used regularly with nominal beam.
- Losses* are shared between 'regular (un-)controlled losses' & 'exceptional losses'
 - Regular losses: losses on electro-static septa for slow extraction (except for SIS100 ~ 10%)
 - (N.B. for comparison: SIS18 operation in 2014 → up to 50% nominal losses during slow-extraction)
 - Exceptional losses: real machine-protection events + false-positive MP events
 - Strong impact of false-positive beam dumps
- Two paths:
 - A) Assess & minimise 'false-positive' MP rate → 'Failure Mode, Effects and Criticality Analysis' (FMECA) for Experiments, similar to what has been done for SIS100 (C. Omet et al.)
 - Magnets/power converter are straight one-to-one copy of SIS100 results (numbers,
 - Do not include issues related to SIS100, HEBT (covered in separate FMECA)
 - B) Implement 'dead-time' after false-positive (& also nominal) emergency beam dumps
 - Intrinsic: acknowledgement (= analysis) of post-mortem event + cool down of dump block (if necessary)