2016-06-12: SIS18 MD Report

R. Steinhagen, H. Liebermann, B. Schlei

Main MD topic covered:

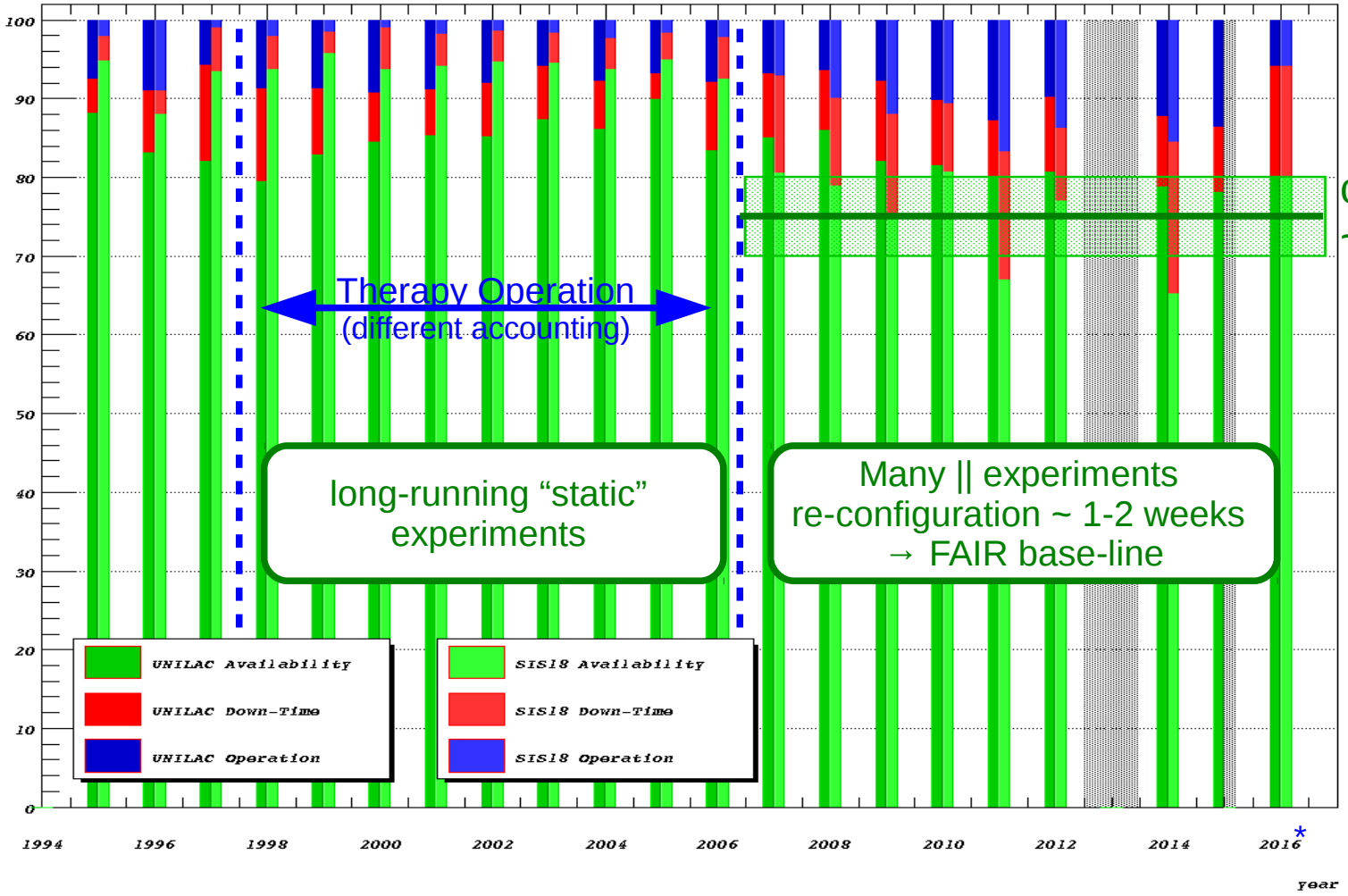
FAIR Accelerator Controls & Beam-Based Feedbacks Proof-of-Concepts

- Cycle-to-Cycle Orbit Feedback → details by B. Schlei
- K-modulation Studies – determining SIS18's magnetic centre
- Cycle-to-Cycle macro-spill-structure Feedback (slow-extraction)
  - or: "*The importance of bunnies for FAIR*"

special thanks to: D. Ondreka, P. Spiller, J. Stadlmann, S. Reimann, D. Severin,OP/BI crew on shift ...

Accelerator Experience & Efficiency

1995-2016: U. Scheeler, S. Reimann, P. Schütt et al.



constant
~ 75 ± 5 %

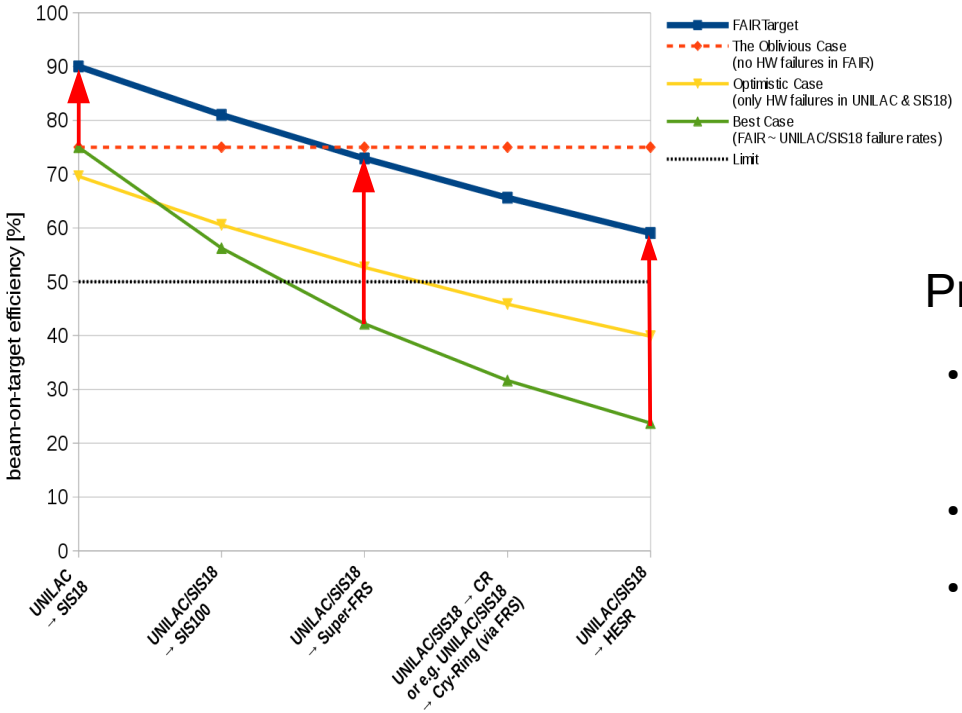
Based on: U. Scheeler, S. Reimann, P. Schütt et al., “Accelerator Operation Report”, GSI Annual Scientific Reports 1992 – 2015 + 2016 (D. Severin)
https://www.gsi.de/en/work/research/library_documentation/gsi_scientific_reports.htm
N.B. ion source exchanges are factored out from UNILAC & SIS18 data (~ 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

FAIR Challenges & Constraints
Accelerator Operation & Efficiency

- Beam-on-Target Figure of Merit ~75%
  → FAIR-BoT (efficiency ε_{FAIR}):

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



- New Accelerator Operation challenges:
  - ~ 4 x larger facility complexity
  - operation beyond present accelerator & beam parameter envelope:
    - x10 higher beam energies
    - x10-100 higher intensities

→ losses/activation & machine protection become important issues

Primary goals:

- maintain existing flexibility/parallelisms
  - N.B. > 3 exp. in || & 1-2 weeks/exp
- better & safe beam control
- efficient operation, target: 15% → <2 %

… across the whole accelerator facility

Beam-based Cycle-to-Cycle feedbacks

details at http://fair-wiki.gsi.de/FC2WG/

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:

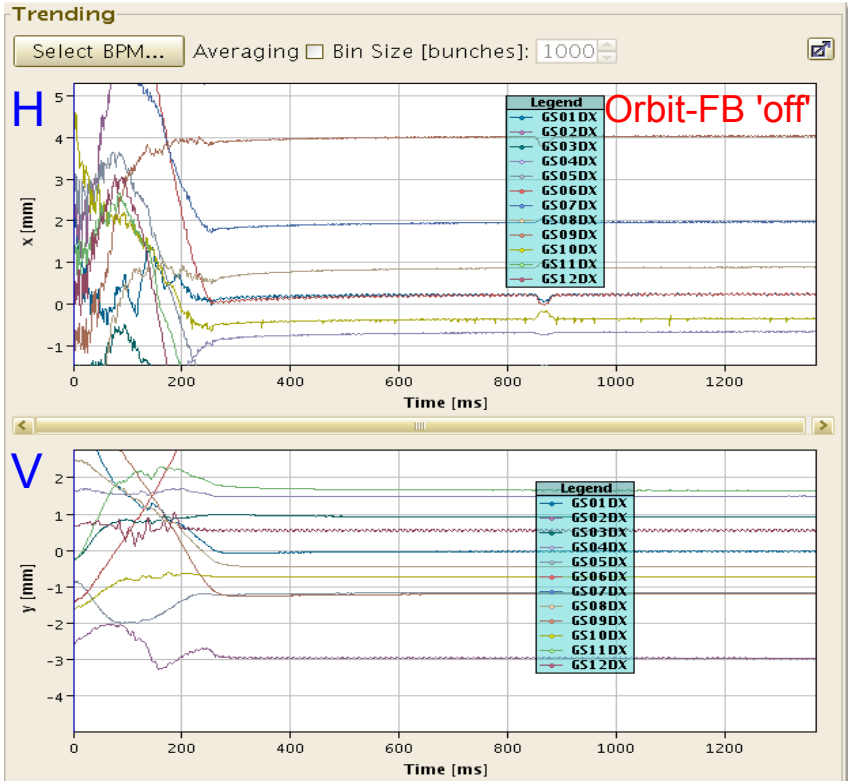
- SIS18: multi-turn-Injection (N.B. highly non-trivial, complex subject), Slow-Extraction (K.O. exciter, spill-structure, …)
- SIS100: Slow-Extraction (K.O. exciter, spill-structure, …), RF Bunch Merging and Compression
- ESR, HESR & CR: Stochastic cooling, Schottky diagnostics, …, tbd.

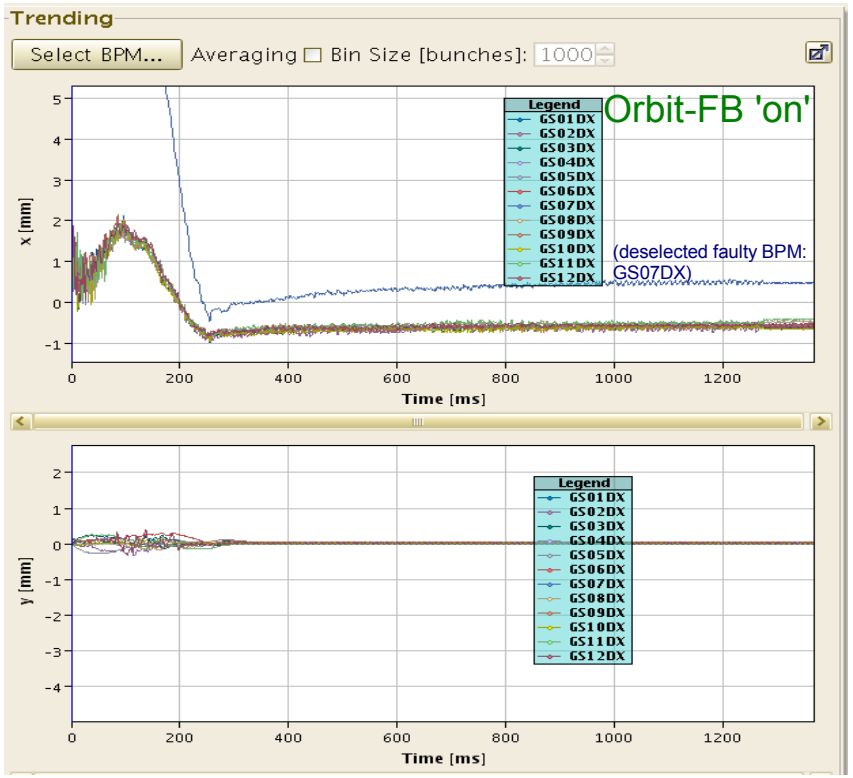
Generic:

- 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,
- …

2016-06-12: Orbit-FB Proof-of-Concept MD

B. Schlei, H. Liebermann, R. Steinhagen

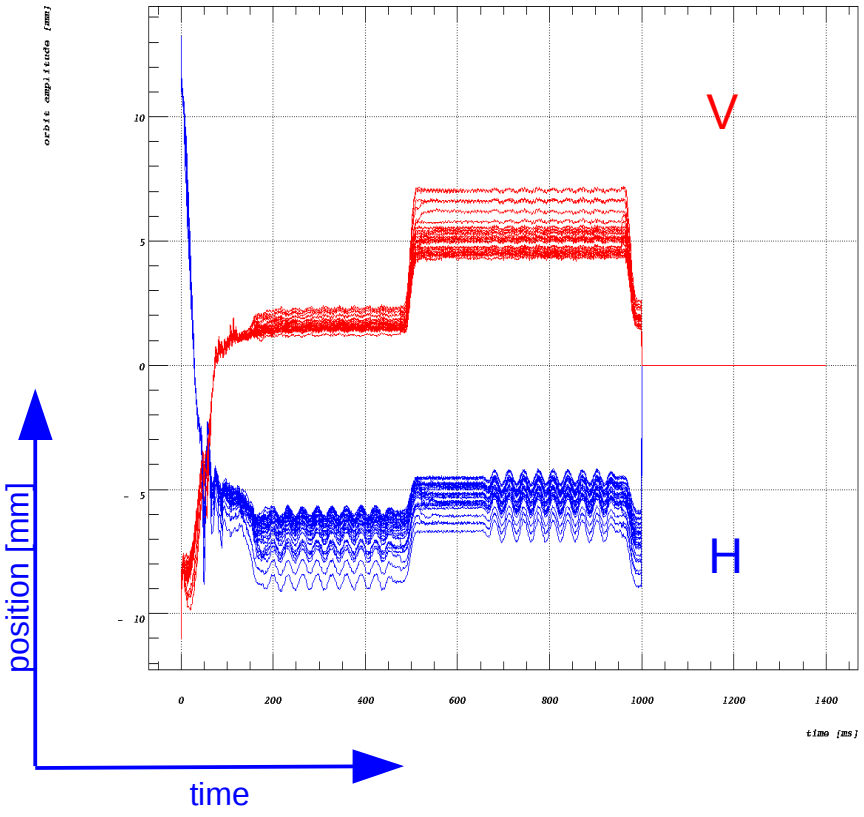


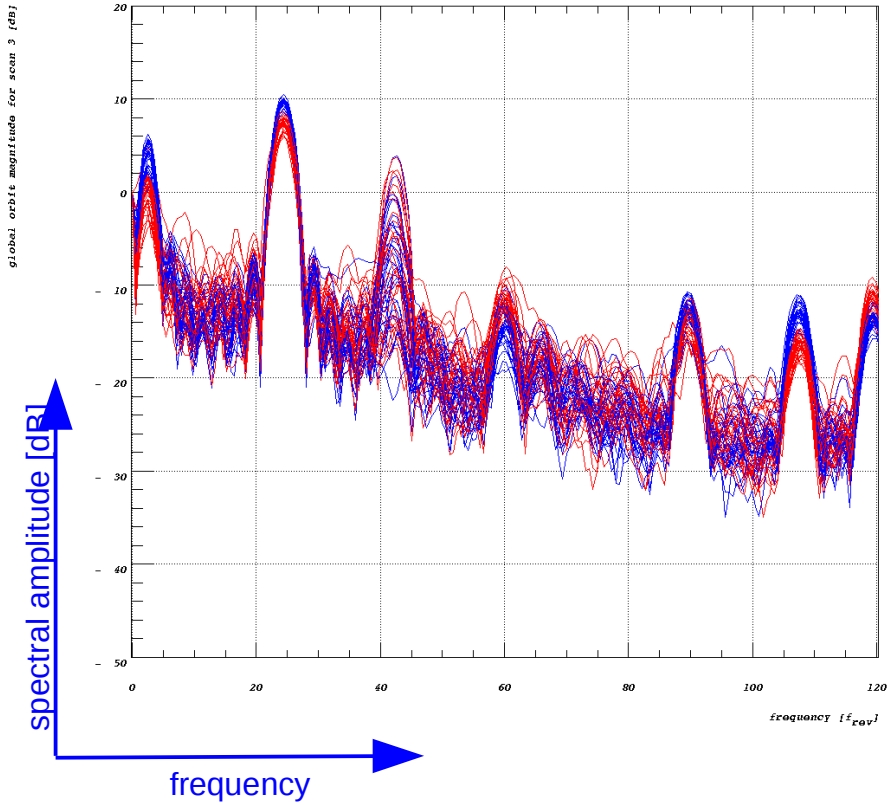


position [mm]

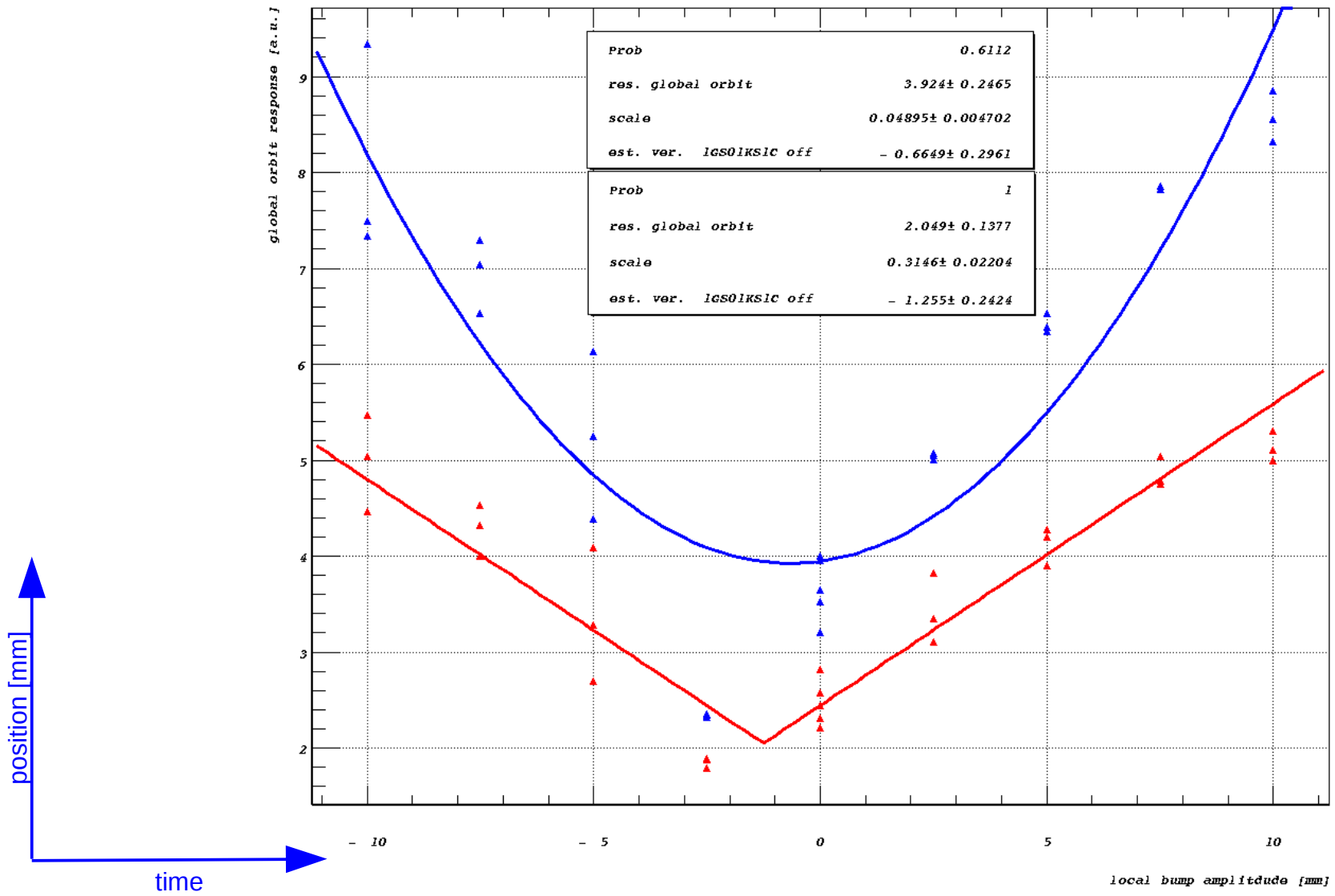
time

- 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 Δp/p mismatch → radial-loop/Energy-FB

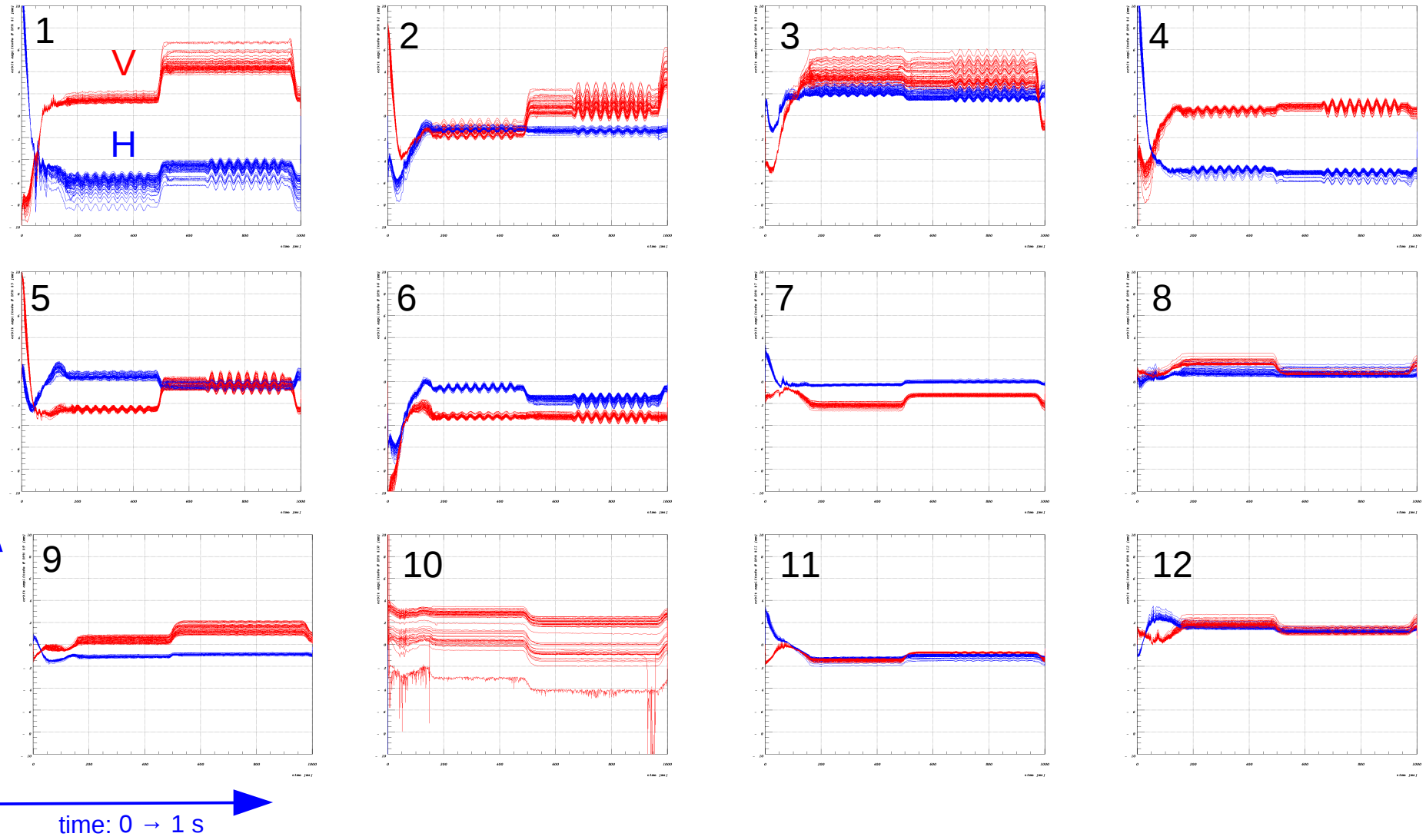




- ~ 700 nearly fully autonomous measurements (night-shift activity)
- some workarounds needed, but overall success and results look promising
  - need to follow-up: BI reliability, performance issues

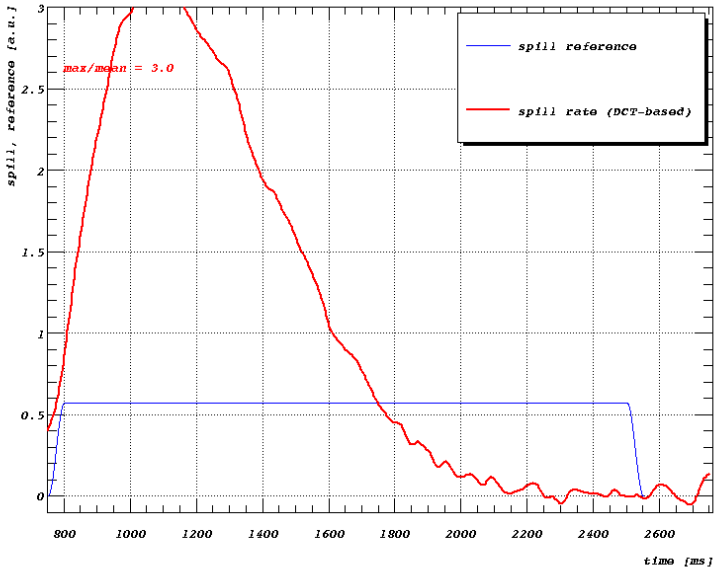

global orbit response [a.u.]
Prob 0.6112
res. global orbit 3.924± 0.2465
scale 0.04895± 0.004702
est. ver. lGS01KS1C off − 0.6649± 0.2961
Prob 1
res. global orbit 2.049± 0.1377
scale 0.3146± 0.02204
est. ver. lGS01KS1C off − 1.255± 0.2424
9
8
7
6
5
4
3
2
− 10
− 5
0
5
10
local bump amplitdude [mm]
position [mm]
time

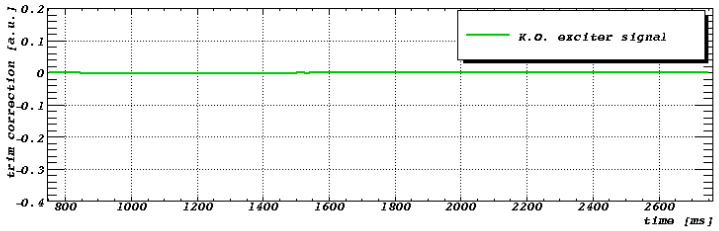
SIS18 'Orbit' & 'BPM' Reproducibility
over ~ 8 hour period



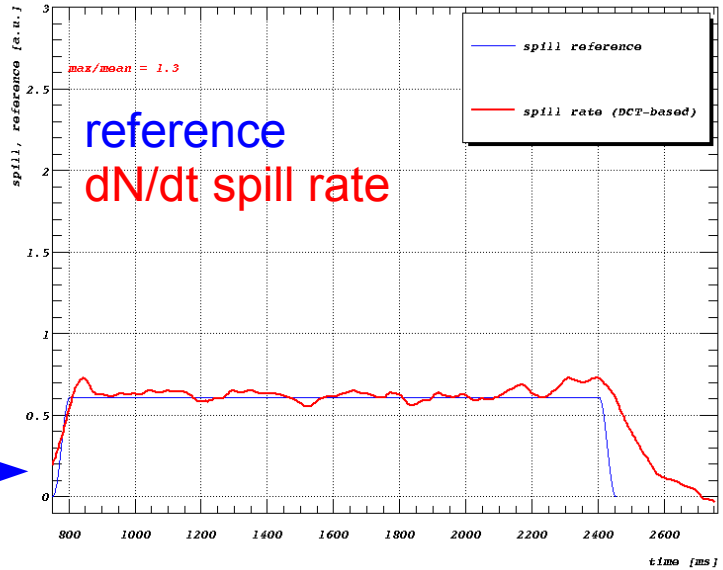
2016-07-03: Macro-Spill-FB Proof-of-Concept MD

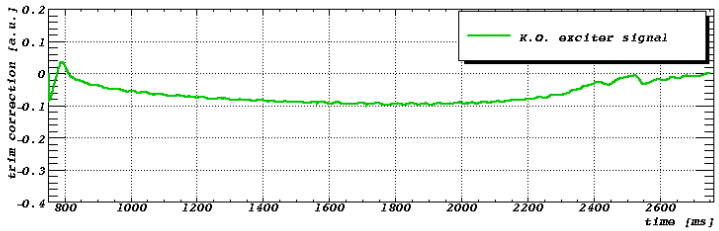
R. Steinhagen, H. Liebermann





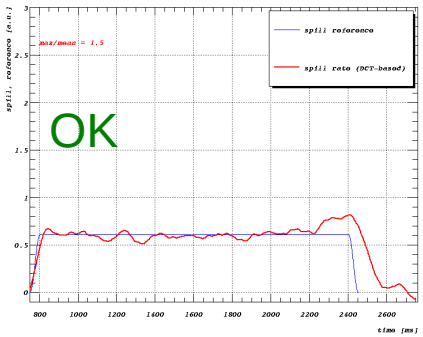
Fill-to-Fill
FB on dN/dt
(DCCT-based)

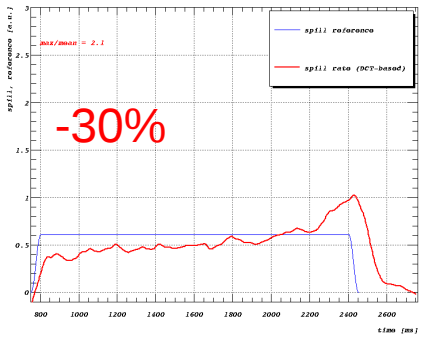


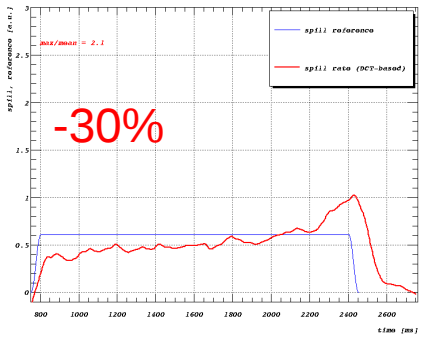


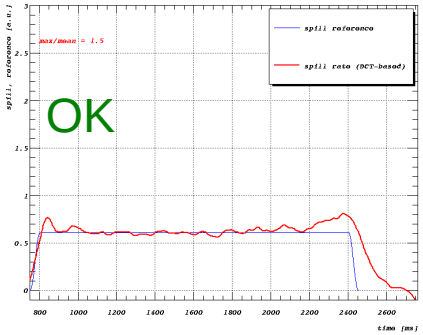
- some workarounds needed, but overall success and results look promising
  - need to follow-up: K.O. exciter power-limitation handling (easily for >10 Tm operation)
    - Alternative: FB using fast extraction quadrupole or main-quads
  - Desirable: direct FB signal from experimental detectors
  - routine operation for 2018 feasible (provided priority/manpower will be allocated for OP/CO integration)

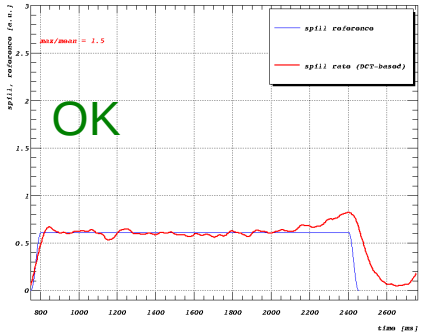
2016-07-03: Macro-Spill-FB Proof-of-Concept MD
SIS18 Spill Reproducibility

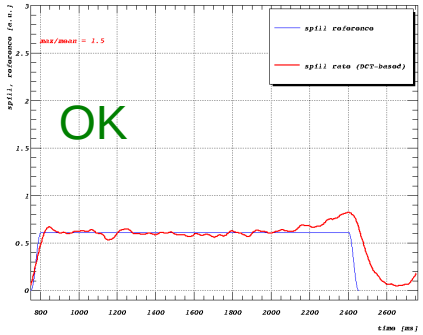




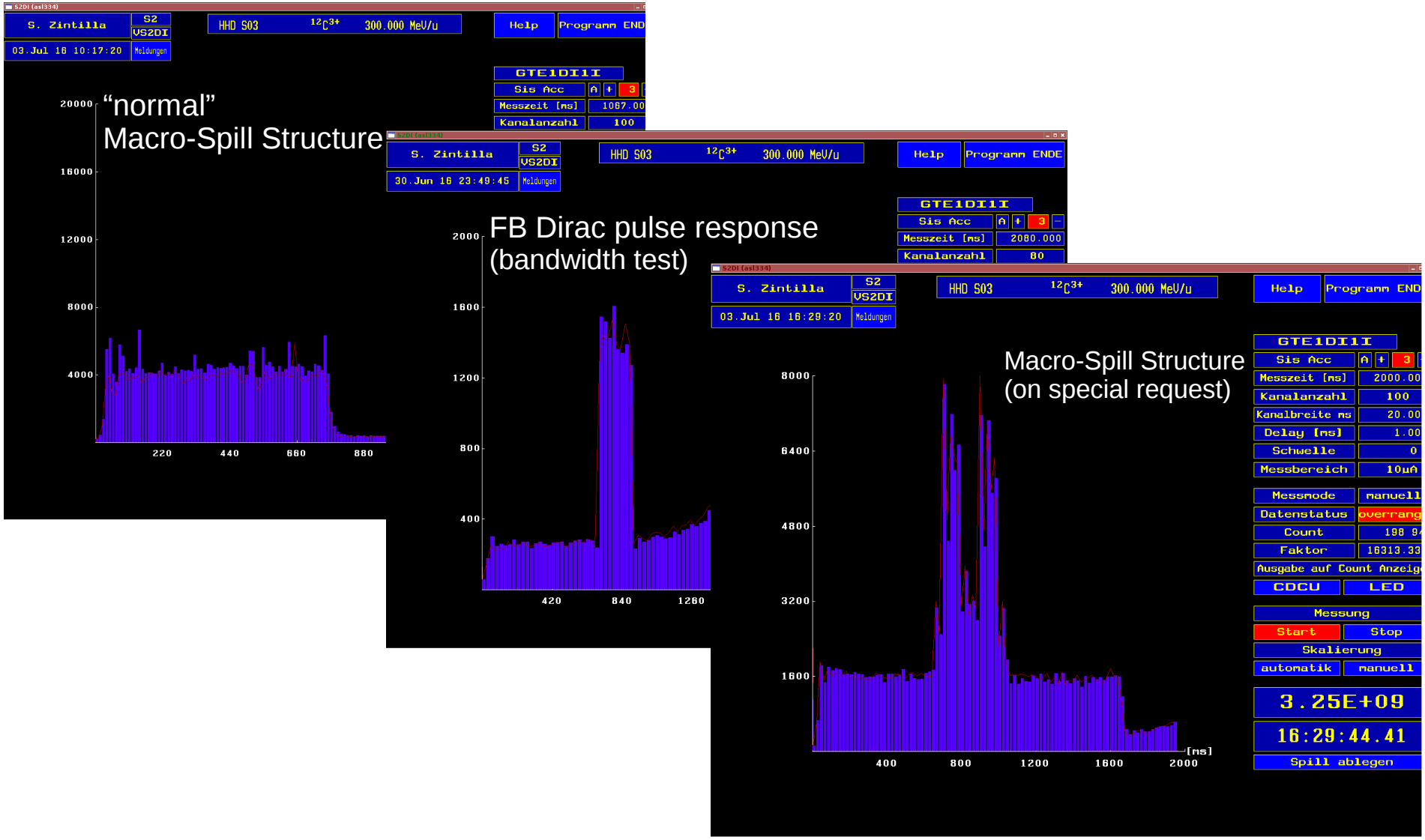






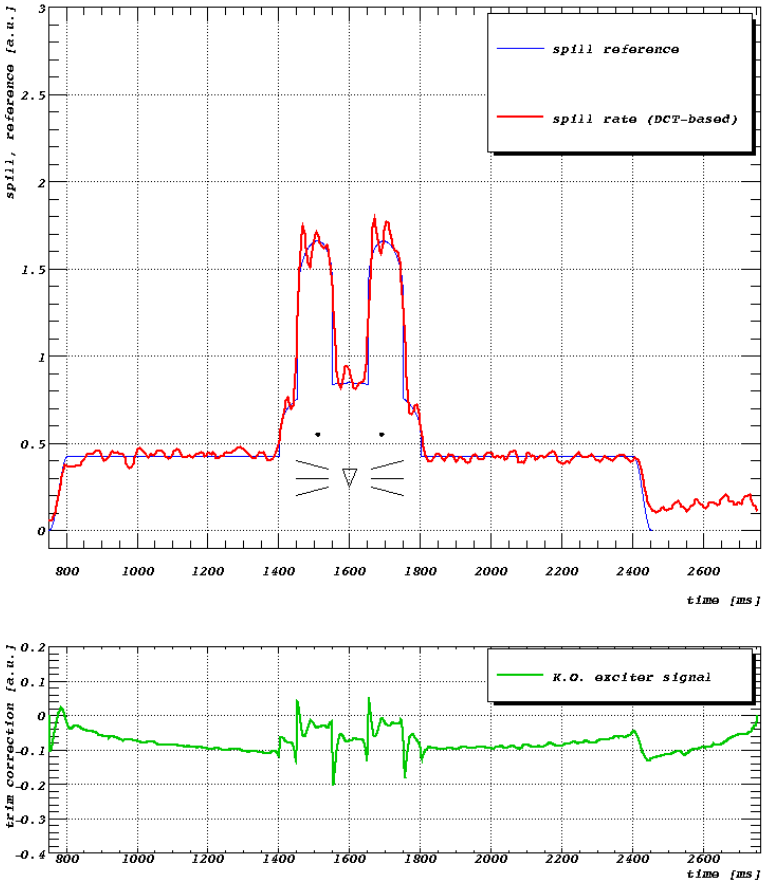


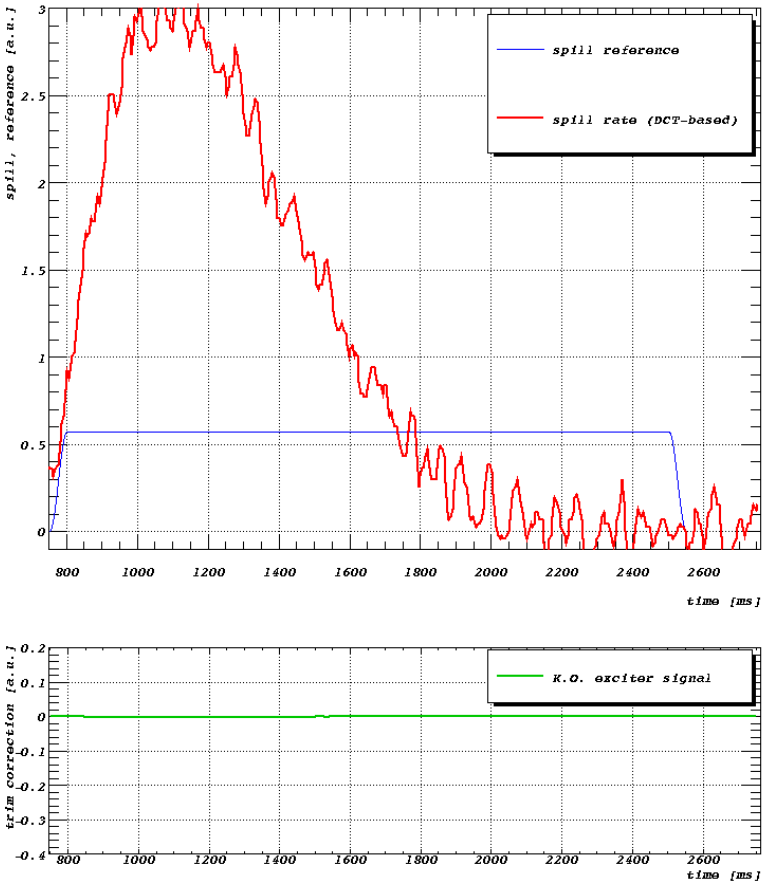
… as seen in extraction channel (counters)



… what's also possible with the Spill-FB

animated GIF - link



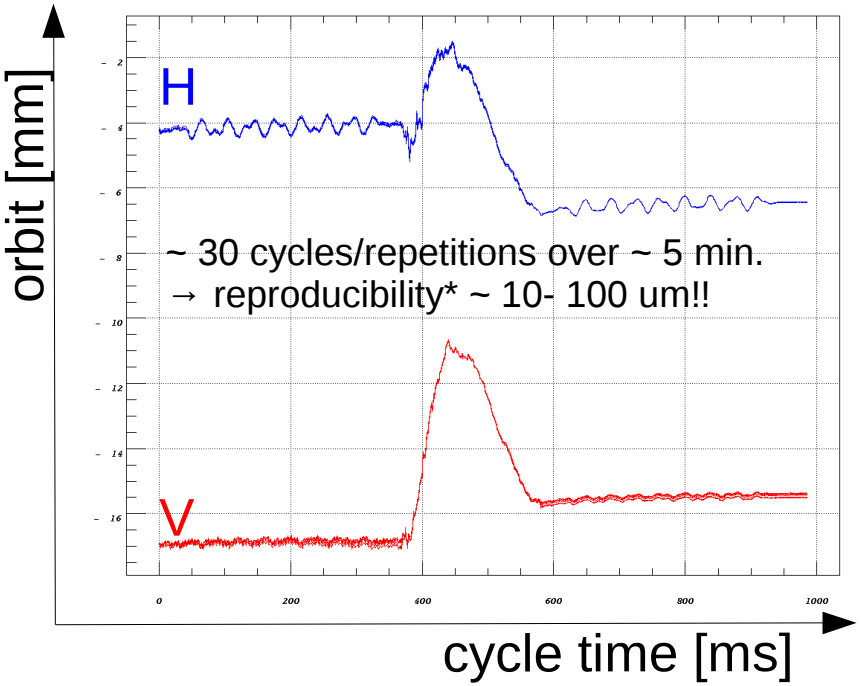


FAIR, can we do it?

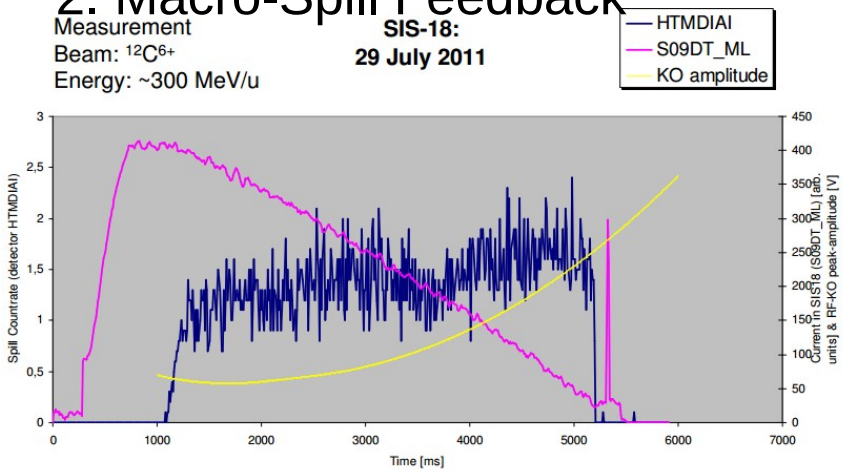
Yes, we can!

2016 SIS18 MD's Proof-of-Concepts

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



2. Macro-Spill Feedback

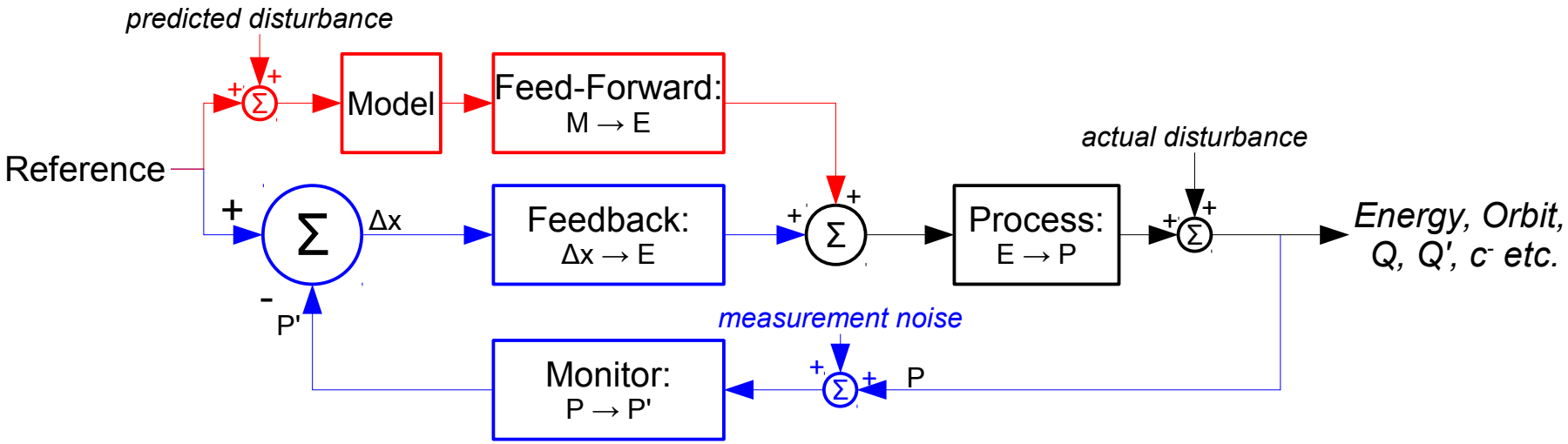


courtesy C. Bert, A. Constantinescu, D. Ondreka, M. Kirk et. al.

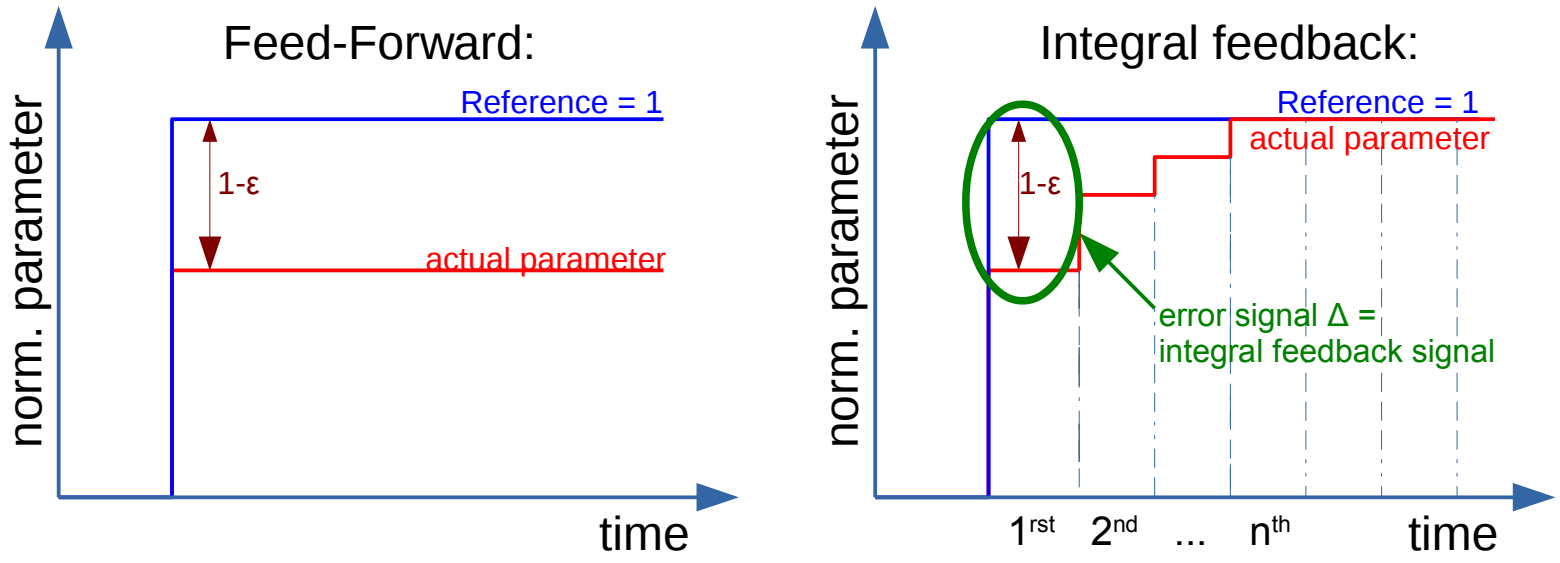
*modulo BPM stability/bias

Control Theory Paradigms I/II

- 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 Δt<<10 hours) or cycle-to-cycle (Δt>10 hours)



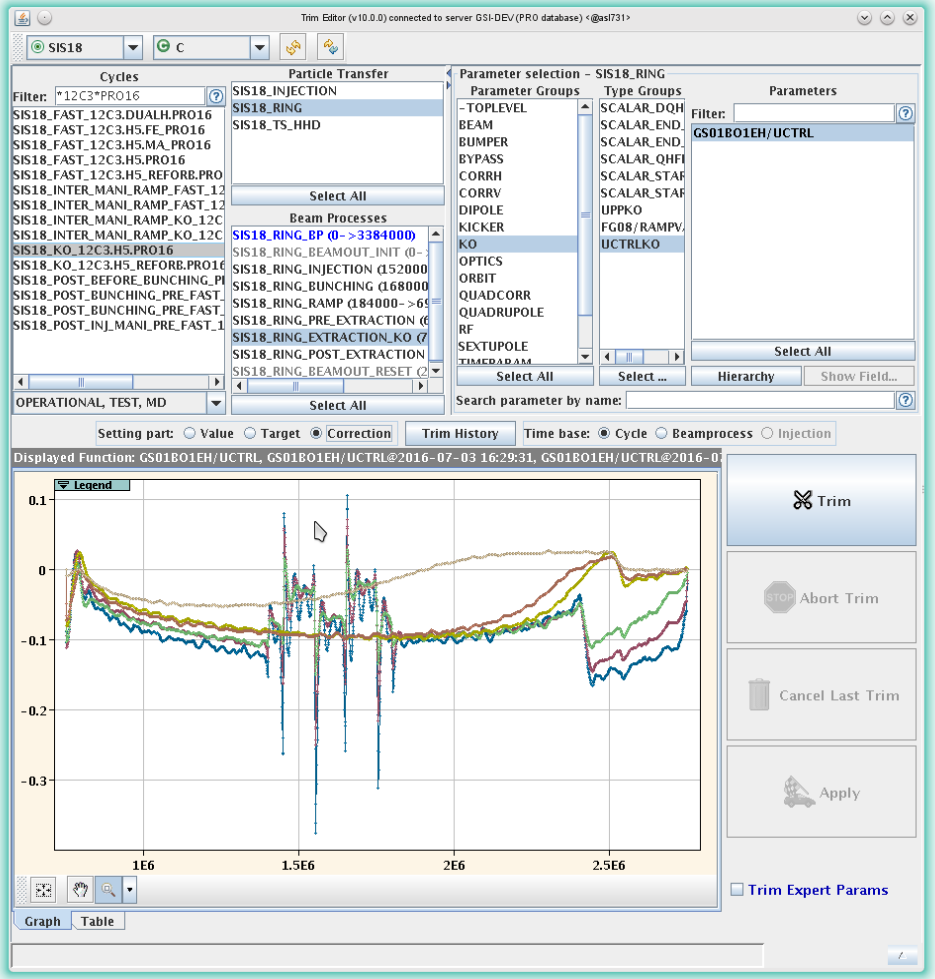
Control Theory Paradigms II/II



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

LSA-based Cycle-to-Cycle Feedbacks

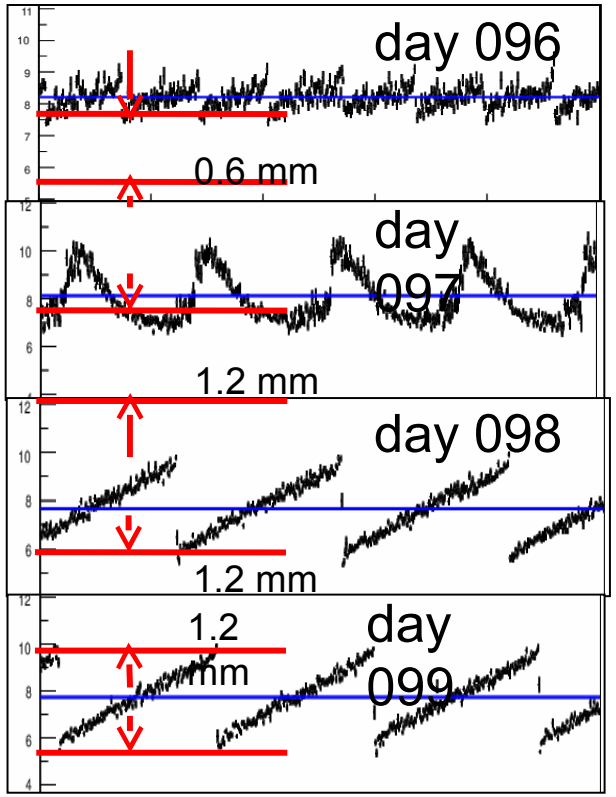
Generic LSA trim interface:

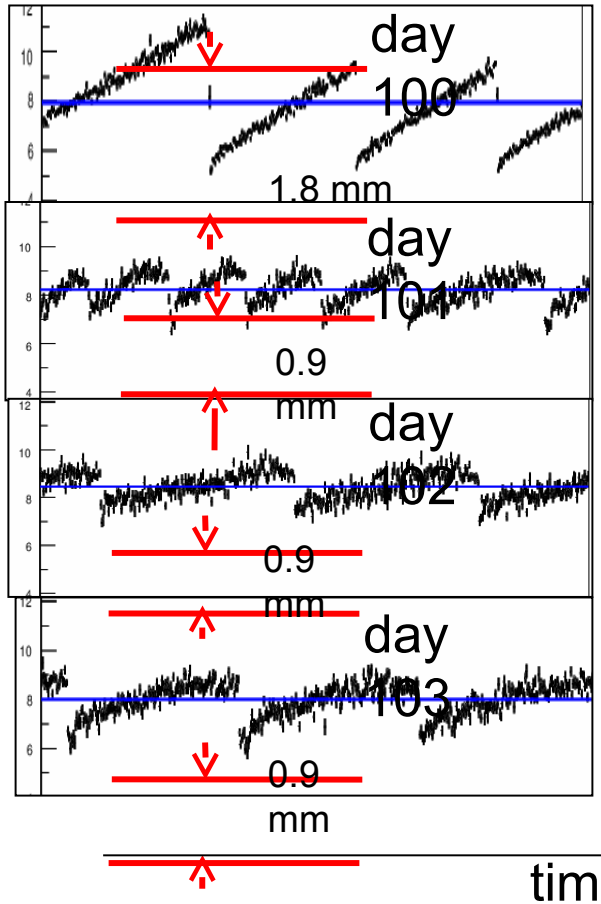


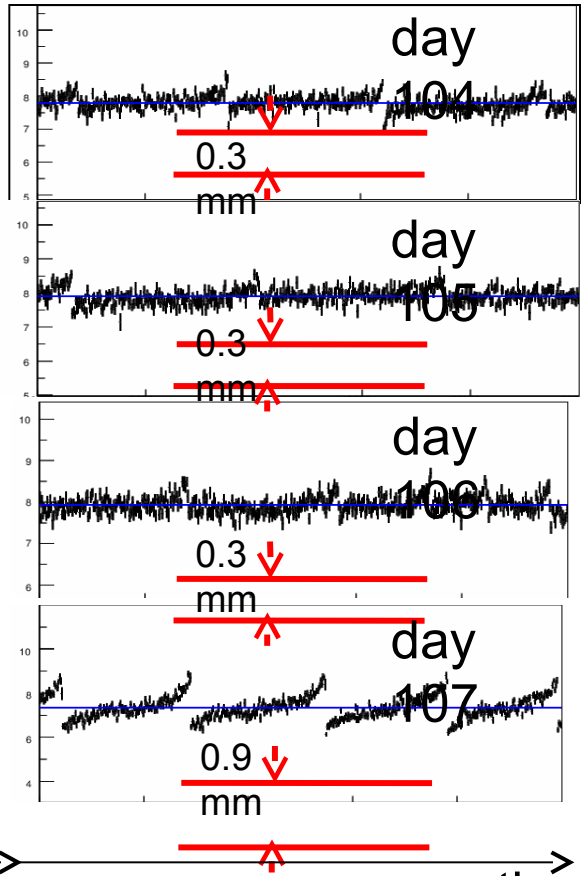
… open to all accelerator parameter that fulfil basic control theory criteria:

- 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

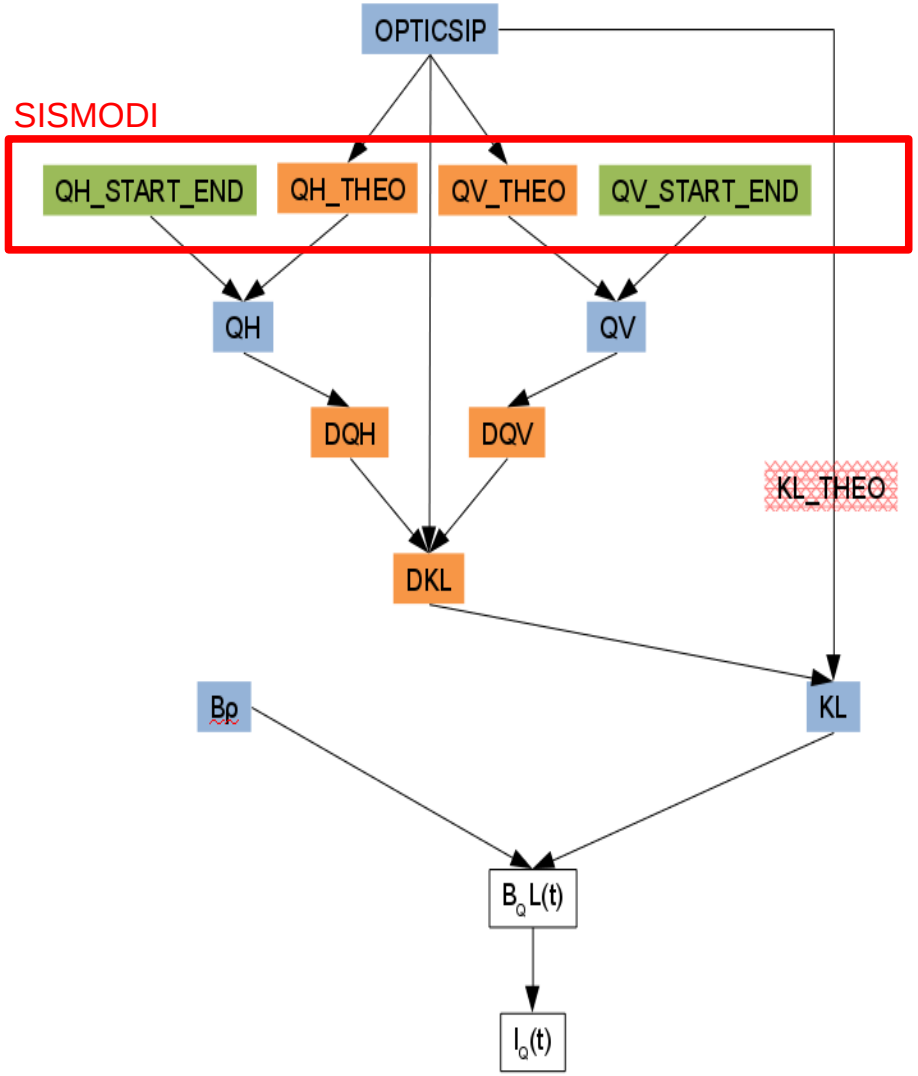
Beam position stability – day-wise

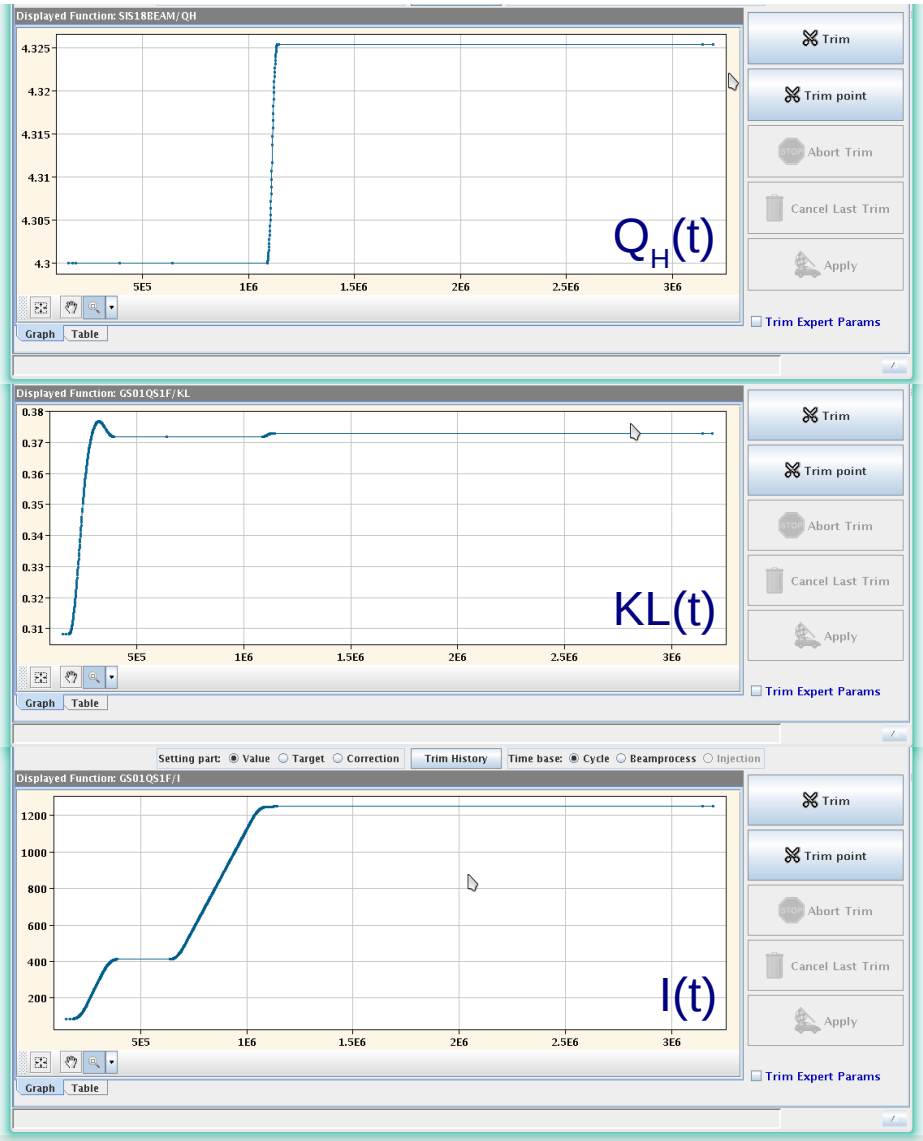






LSA Parameter Hierarchy





FAIR Figure of Merit

- Integrated Luminosity per experiment

$$\frac{\int \mathscr{L}(t)\ \mathrm{d}t}{\left[\int \mathscr{L}\ \mathrm{d}t\right]_{\mathrm{ref}}} \sim \int_{\mathrm{OP\ year}} \frac{dN_{\mathrm{ions}}/dt}{\epsilon_{\mathrm{x,y,s}}} \cdot \varepsilon_{\mathrm{FAIR}}\ \mathrm{d}t$$

Experiment constraints:

- dN_{ions}/dt constant (spill-structure)
- $dN_{ions}/dt|_{max}$ constraints
- ...
- beam brightness: N_{ions} & $\varepsilon_{x,y,s}$
  - x 10-100 higher intensities N_{ions}
  - x 10 beam energies
    → **new:**
  - machine protection
  - activation/loss minimisation (ALARA)

FAIR efficiency (simplified):

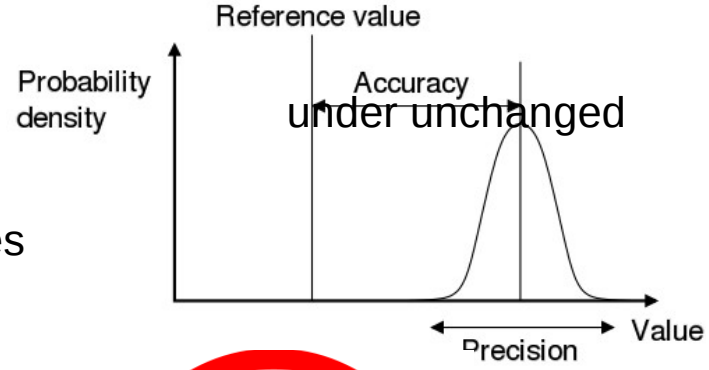
$$\varepsilon_{\mathrm{FAIR}} \approx \frac{\langle t_{\mathrm{physics}} \rangle}{\langle t_{\mathrm{physics}} \rangle + \langle t_{\mathrm{operation}} \rangle + \langle t_{\mathrm{down\text{-}time}} \rangle}$$

Primary FC²WG goals:
1. efficient operation
2. better & safe beam control
   … across the whole accelerator facilitiy

Terminology: Accuracy & Precision (also ISO 5725)

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