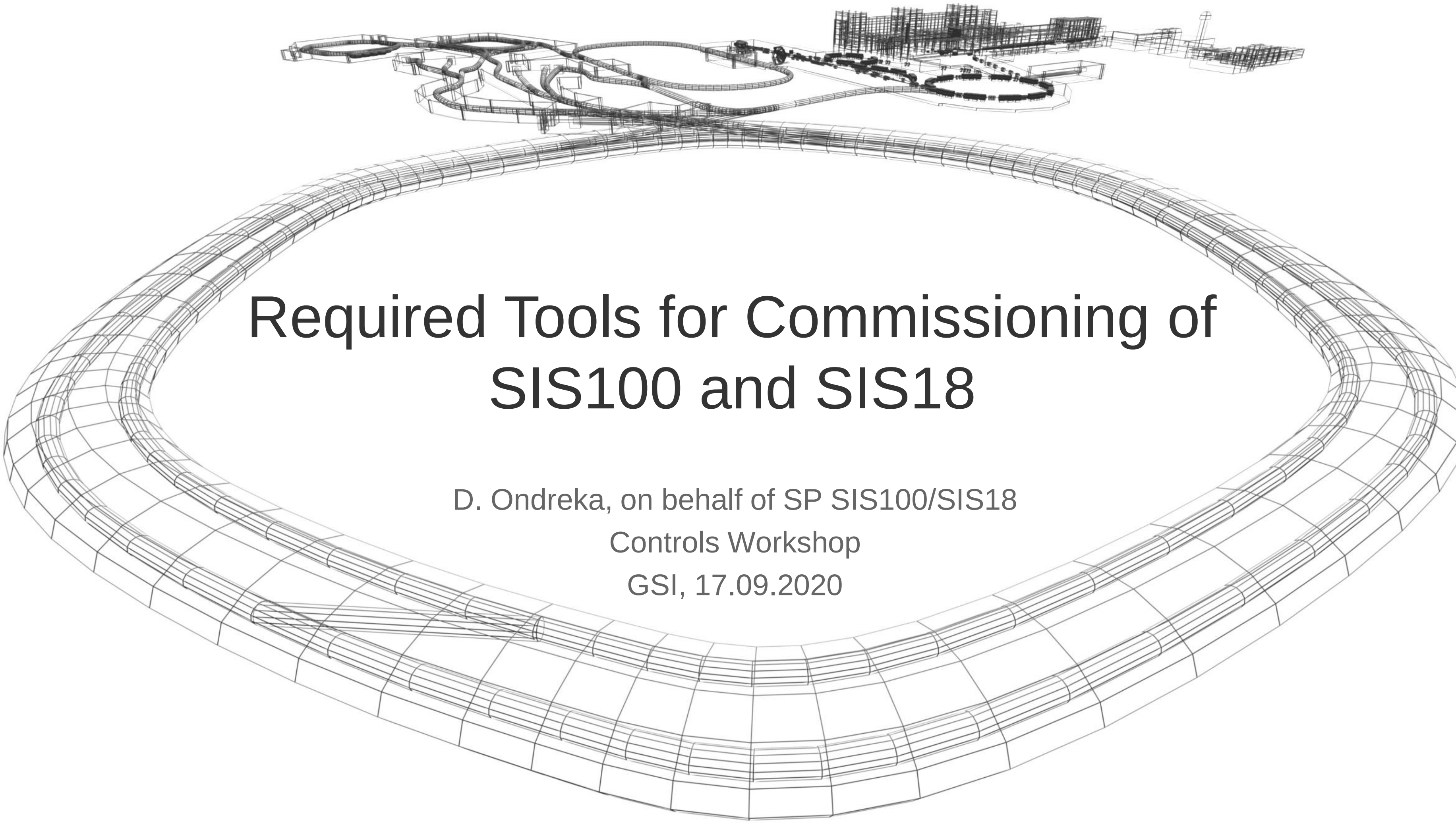


Required Tools for Commissioning of SIS100 and SIS18

D. Ondreka, on behalf of SP SIS100/SIS18

Controls Workshop

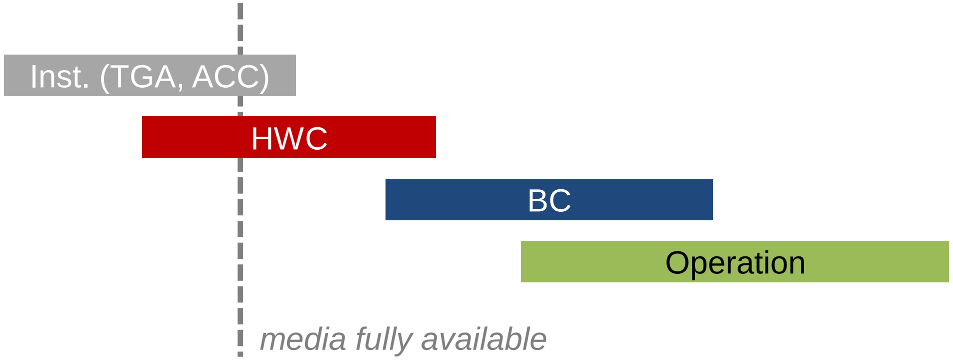
GSI, 17.09.2020

Outline

- Introduction
  - Overview of commissioning
  - Scope and prerequisites
- Machine control
  - Local cryogenics
  - Quench detection
- Beam based control
- Priorities

Introduction: Overview commissioning

- Phases
  - Installation (not part of commissioning)
  - Hardware commissioning
  - Beam commissioning
  - Operation
- Phases will overlap
  - First HWC activities during installation phase, dep. on availability of media
  - Overlap between HWC and BC to be minimized, but reality may interfere
  - Overlap between BC and OP very likely due to staged commissioning approach
    - BC for individual operation modes due to cycle dependent tuning of local cryo system
    - Low intensities first, higher intensities later after commissioning of machine protection systems
    - Commissioned operation modes available for experiments
    - Requires real parallel operation of SIS18 and SIS100



Introduction: Scope

- Requirements for SIS100 commissioning regarding higher level functionality
  - Mostly software, some hardware
  - Control of local cryo
  - Control of machine
  - Beam commissioning tools

- HW commissioning (mostly) not covered
  - Commissioning of individual devices
    - Responsibility of technical groups
    - Have to define controls requirements for HW commissioning of their equipment
  - Remember: device commissioning interleaved with machine commissioning
    - No commissioning of SC magnet PCs without commissioning of cryo system
    - Synchronized ramps (i.e. data supply, timing) required for many systems
      - PCs of SC main magnet strings
      - RF system for commissioning synchronized operation

Introduction: Controls Prerequisites

- All devices integrated into CS
  - SCUs for active devices
  - BI devices
- Applications for general operation available
  - Scheduling of chains and patterns
  - Execution of patterns
  - Data supply
  - Basic device control
  - Handling of interlock system
- Expert applications available
  - Visualization of data from all BI devices
  - Visualization of data from generic digitizers

Many of these systems already in use for operation of GSI accelerators, but often need further development for FAIR

Introduction:
Beam Commissioning Phases

- Integration tests without beam
  - Operation of SIS100 as if beam was there
  - All systems required for day 1 BC must be ready
  - Test of all systems under operational conditions

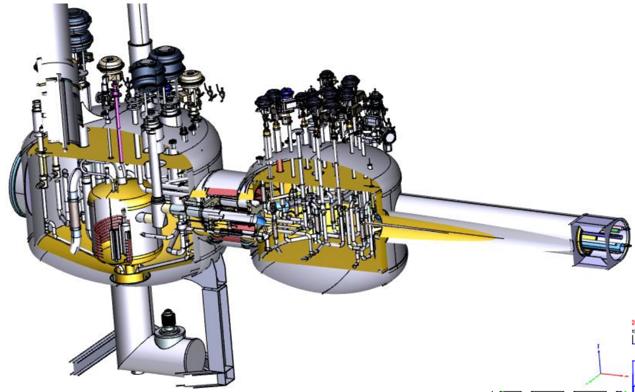
- BC of single low intensity mode
  - Commissioning of all essential functions (injection, acceleration, extraction)
  - Test of all BI devices with beam
  - Beam-based verification of magnet function (polarities, multipole content)
  - Some beam-based tools essential (e.g. trajectory/orbit control, B2B control)

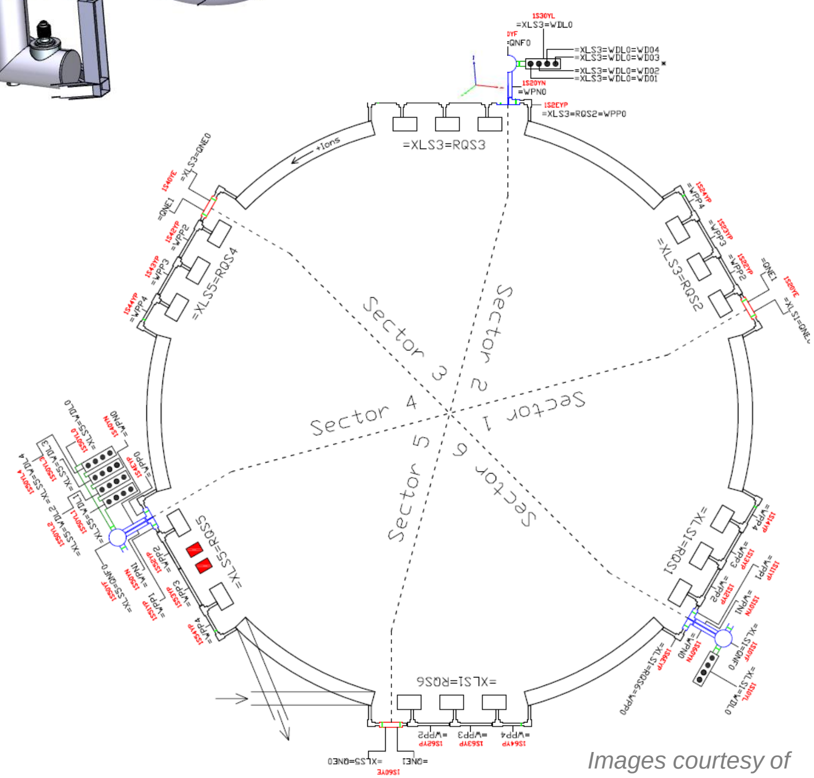
- BC of high intensity operation
  - Verification of machine protection systems
  - Mitigation of intensity dependent effects
  - Further beam-based tools required (control of tune/chroma, RF gymnastics)

Local Cryo:
Commissioning Steps

- Complex distributed system
  - Magnets and BPL
    - ~1500 Temperature sensors
    - 630 Heaters
  - Feed boxes, end boxes, current lead boxes
    - 315 sensors for temperature, pressure, vacuum, mass flow, level, position
    - 150 valves, 108 heaters, 3 pumps

- Cold commissioning
  - Operation without powering magnets
  - Checking of sensors and settings for static load
- Powering of magnets
- Development of operation modes
  - Goal: stable operation for beam commissioning
  - Fixed timing and fields to fix dynamic heat load
  - Learning curve for more complex modes



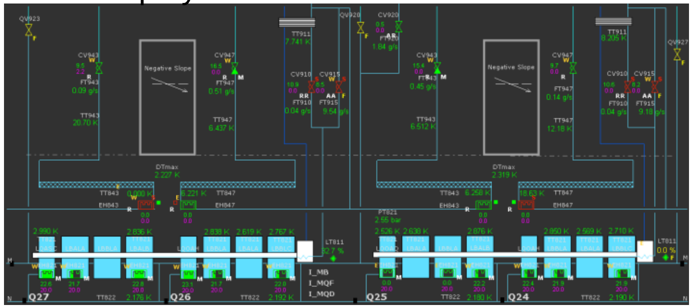


Images courtesy of T. Eisel (CRY)

Local Cryo:
Software for Commissioning

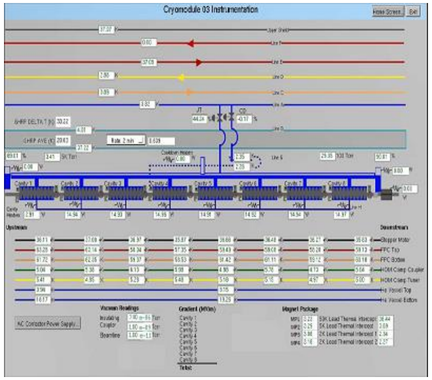
- Prerequisites
  - Control of cryo plant and distribution system
  - Integration of all local cryo sensors and actuators into control system
  - Manual read-out of sensor values
  - Manual setting of actuator values
- Requirements for cryo commissioning
  - Structured visualization of sensor and actuator states
  - Aggregation into functional sub-groups and visualization of their state
  - Definition of higher level parameters for controlling larger sets of actuators
  - Possibility for saving and restoring settings
- Requirements for operation
  - Automation of control
  - Mode dependent set values from LSA

LHC: display of two arc cells in CRYO-SCADA



LHC Project Report 1169, 2008

LCLS-II: cryo module control

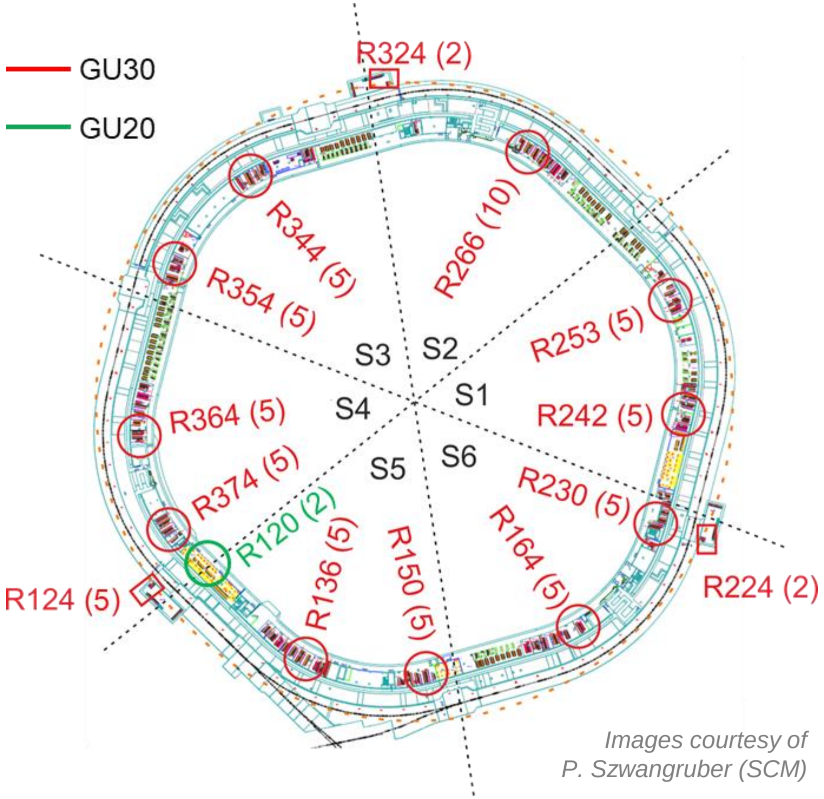


ICALEPCS‘19, WEPHA002

Machine Control: Quench detection

- Needed for safe operation of SC magnets
  - Detection of quench by voltage measurements
  - 10 kHz sampling for post-mortem
  - Logging at 10 Hz foreseen
- Distributed around SIS100
  - About 1200 voltage detectors
  - QuD cabinets in 15 rooms in supply tunnel
  - Priority sequence from trigger matrix
- Post-mortem system essential
- High-level software required
  - Quickly find root cause of quenches
  - Inspection of priority sequence
  - Analysis of current and quench data

QuD: Analog detection and digital read-out boards



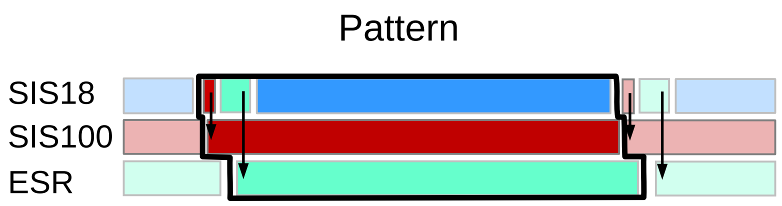
Images courtesy of P. Szwangruber (SCM)

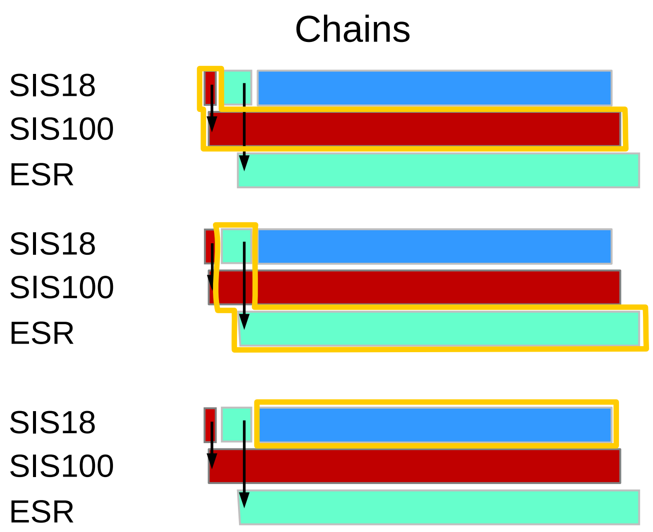
Machine Control:
Patterns and Chains for Parallel Operation

- Concepts for modeling beam patterns
  - Pattern
    Block of cycle executions across the facility to deliver a certain beam pattern
  - Chain
    Sequence of cycles spanning machines to deliver beam to a single experiment

- Use of patterns during commissioning
  - Independent patterns for disjoint parts
    - SIS100 dry runs independent of GSI operation
  - Combined periodic patterns
    - SIS100 beam commissioning in parallel to operation of SIS18 for experiments
  - User interface for fast adaptation of patterns or creation of new patterns required

- Requirements for parallel operation
  - Nested chains SIS100 BC parallel to SIS18

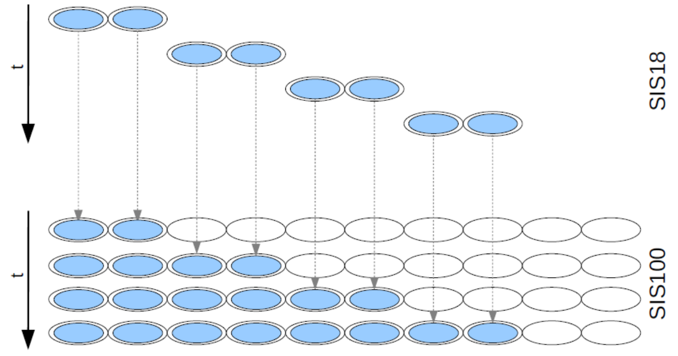




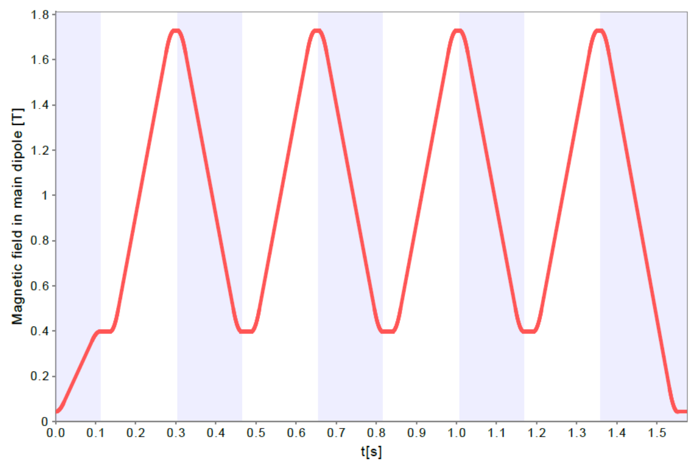
Machine Control:
SIS18 Booster Mode

- Cycle time needs to be minimized
  - Ramps up and down at 10 T/s (max)
  - No ramping down to idle level after extraction
  - Minimization of length of injection plateau
    - No waiting for UNILAC allowed
    - No gaps between cycles
  - Minimization of length of extraction plateau
    - No extra times for orbit bump at MS, creation during rounding times instead
    - Max. 10 ms flattop to sync with SIS100
- Expected cycle times
  - Design value 2.7 Hz or 370 ms
  - Precise value depends on AEG dipole
  - Final value expected in range 360 to 380 ms

Stacking scheme for RIB



SIS18 booster ramps



Machine Control:
SIS18 Booster Mode Requirements

- UNILAC timing system / PZ
  - Reservation of TK for whole super-cycle
  - Deterministic and known time interval between beam request and beam delivery
  - UNILAC controlled by new WR timing system
- FAIR timing system
  - Synchronization with 50 Hz
  - Completely deterministic timing
- FG frontends
  - Elimination of preparation time (except first BP)
  - Can be done by sending FG_PREP in previous BP
- LSA
  - Integration of UNILAC coupling to avoid waiting
  - Multiple sequences for SIS18 in chain to SIS100
- SIS18 model
  - Cycle time must be multiple of 20 ms

- Timeline
  - Need tested system for beam commissioning (2025)
  - Want booster mode ready for machine experiments starting from 2023
  - Intermediate steps using existing UNILAC PZ starting from 2021

Machine Control:
Bunch-To-Bucket (B2B) Transfer System

- B2B transfer
  - Transfer of bunched beam from one machine to another
  - Essential for operation of SIS100
  - Not a standard transfer scheme in GSI
  - Requires precise synchronization of the RF systems of SIS18 and SIS100

- B2B transfer system for FAIR
  - Concept has been developed based on BuTiS (RRF) and timing system (ACO)
  - Avoids comparison of analog signals
  - Needed on day one of BC

- Control software for B2B transfer
  - Monitoring and adjustment of beam params
  - Example of beam based application

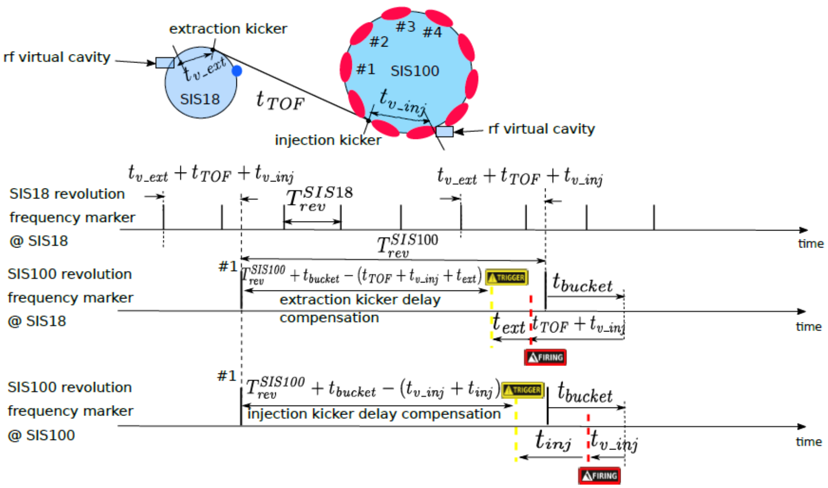


Image from J. Bai, PhD Thesis, 2017

Beam Based Control: Motivation

- Efficiency of beam commissioning strongly depends on available tools
  - SIS100 more complex than SIS18 and tighter constraints by beam dynamics
  - Manual tuning based on observing BI data displays very time consuming

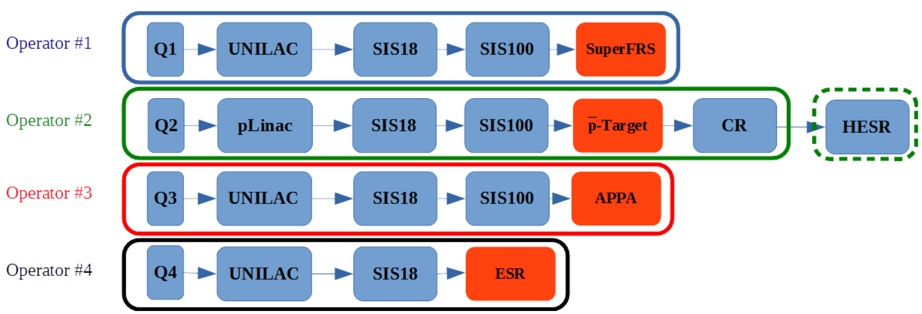
Manual orbit tuning in SIS18 and SIS100

	SIS18	SIS100
#Cells	12	84
#BPMs	2 x 12	2 x 83
#Steerers	2 x 12	2 x 83
#COC Knobs	48	**332**

How long will it take to get the first turn in SIS100 without beam based threading?

- Requirements from parallel operation
  - Limited number of operators
  - Efficient operation requires support for
    - Reduction of set-up time per accelerator
    - Reproducibility of beam parameters
    - Monitoring and maintaining of beam quality

Parallel operation concepts: 1 OP per chain



Beam based control: Concept

- Beam based control
  - Combine beam signals, accelerator physics, and control theory to control beam efficiently
  - Employ computers for repetitive tasks and quantitative reproducibility
  - Automation possible but not mandatory
- Cycle-to-cycle feedback
  - Measure in a number of cycles, calculate and send correction for the next cycle
  - Works very well for reproducible part of beam parameters
  - Seamless integration of signal sources and beam influencing devices is essential
  - Fast trims crucial if many feedbacks are running
- Beam based systems for SIS100
  - Many are useful for SIS18 (or others) as well
  - Testing with existing machines essential to have proven system for SIS100 BC

Architecture of SIS18 cycle-to-cycle orbit feedback

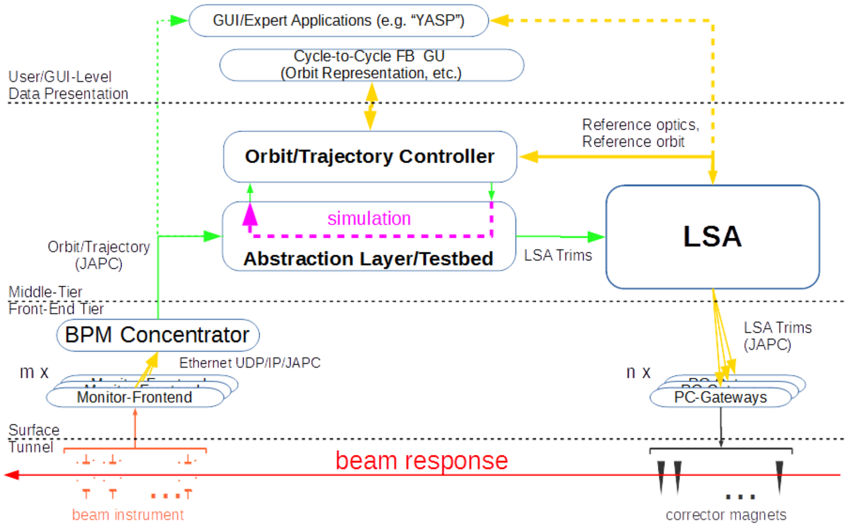


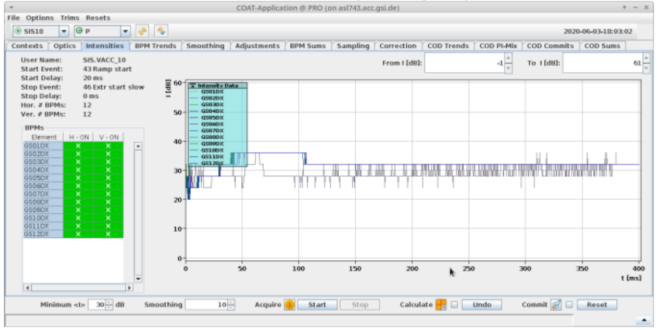
Image courtesy of R. Steinhagen

Beam Based Control:
Closed Orbit Feedback (Cycle-to-Cycle)

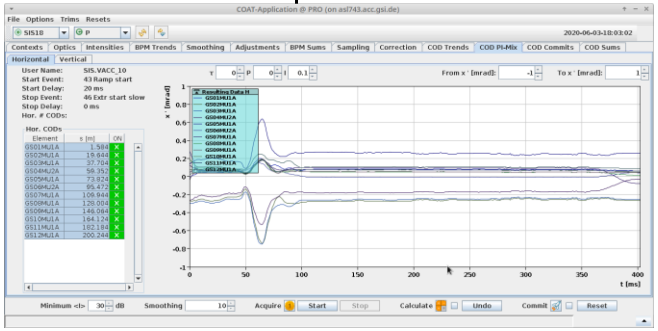
COAT: Closed Orbit And Trajectories *(B. Schlei)*

- Signal source
  - BPM signals, digitized by BI group
  - Interface presently machine dependent, unification for FAIR
- Correction algorithm (service layer)
  - Data validation and filtering
  - Optics retrieval and SVD computation
  - Response matrix based correction
- Visualization (UI layer)
  - Context selection
  - Display of
    - signals (raw and filtered)
    - calculated corrections
    - response matrix properties
  - Setting of parameters for PI controllers
  - Deselection of faulty BPMs and steerers

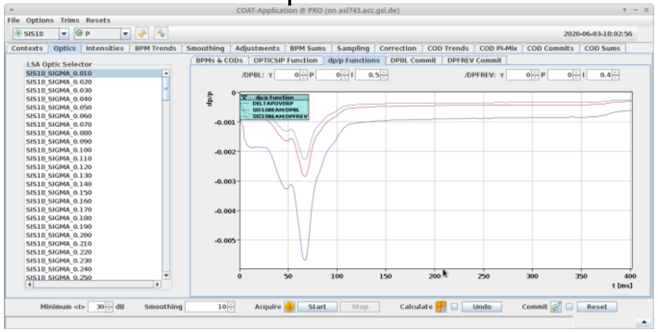
BPM intensity display



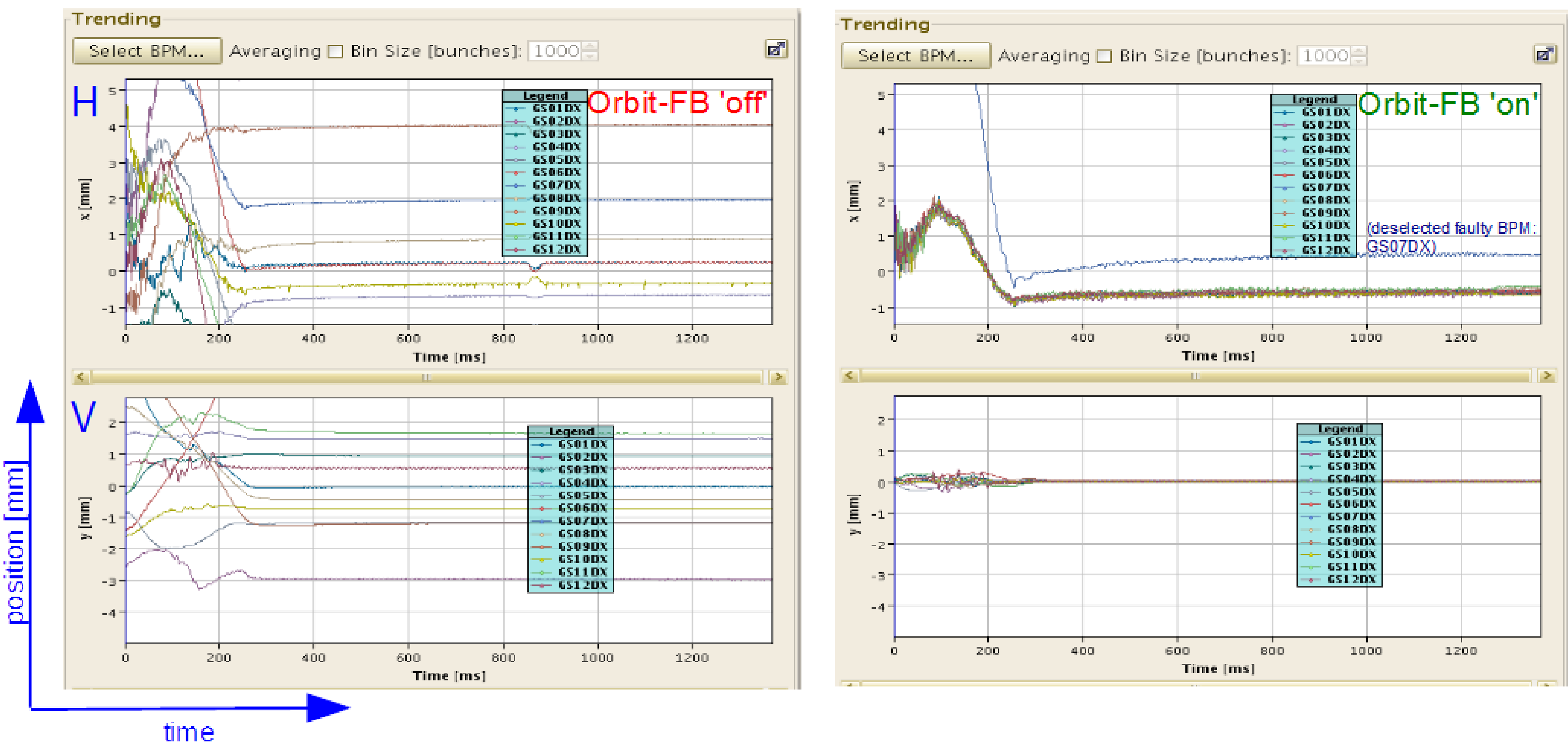
Control of dispersion corrections



Control of dispersion corrections



Beam Based Control:
Closed Orbit Feedback (Cycle-to-Cycle)



- Stand-alone (fat client) version prepared for use in operation starting from 2021
- New features will allow even to suppress the common horizontal motion on ramp
- Follow-up during usage by operations crew to improve reliability and robustness

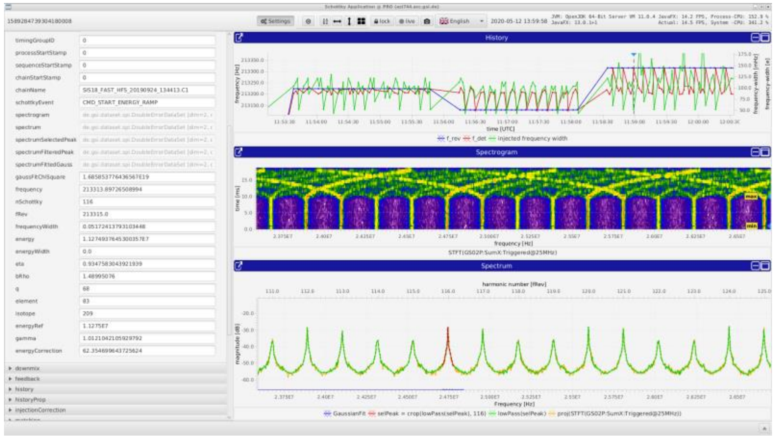
Beam Based Control:
Longitudinal monitoring and matching

Schottky Application *(A. Krimm)*

- Signal source
  - Stripline Schottky signal
  - Time domain digitization on generic digitizer
- Signal analysis (service layer)
  - Spectrum calculation by FFT
  - Increased S/N ratio by using many lines
  - Peak detection algorithms
  - Fit of frequency and width
- Visualization (UI layer)
  - Spectrogram (vs. time and time slice)
  - Display of beam parameters
  - History of freq./energy for monitoring
  - Correction by trim if necessary
- Prototype version prepared for use in operation starting from 2021

Coasting beam in SIS18 after injection

Bunched beam in SIS18 just before ramping



Beam Based Control: Future Architecture

- Middle tier service layer
  - Data retrieval from devices (BI devices, digitizers, SCUs, services)
  - Data aggregation and processing
  - Publication of processed data for other services or UIs

- Middle tier service framework
  - Separation of functional code from generic service tasks (aggregation, communication)
  - Minimization of user code
  - Keeps system maintainable
  - Communication supports CMW protocol
  - C++ based due to availability of libraries
    - Signal processing
    - Data handling
    - Mathematics

- Micro-services concept
  - Small, well-defined functionality
  - Keep services small and maintainable
  - Depending on required processing power even one service instance per BPC
  - Load balancing on server cluster
  - Major domo pattern for starting and distributing services

- Data visualization and interaction
  - Visualization framework (ChartFX)
  - Libraries for efficient data handling

R. Steinhagen / A. Krimm

Beam Based Control: Priorities

- Prio 1 systems
  - Trajectory control/steering (transfer lines and ring for threading)
  - Closed orbit control (ring)
  - Injection matching (longitudinal)
  - Bunch-to-bucket control
- Prio 2 systems
  - Transmission monitoring
  - Transfer line optics control
  - Control of spill shape/structure (slow extr.)
  - Control of RF gymnastics
- Prio 3 systems
  - Control of tune and chromaticity
  - Optics measurement and correction (ring)
  - Optics control and matching (transfer lines)
  - Set-up and control of slow extraction
  - Set-up and verification of collimator settings
  - Validation of machine protection systems
  - Final focus control at beam target
  - Beam quality monitoring (emittances, etc.)

Priorities as defined by SPL SIS100

Summary:
SIS100 Priority 1 Items

Software

- Control of local cryo
  - Aggregated visualization
  - Monitoring including warnings
  - High-level abstraction for simplified control
- Quench detection
  - High-level visualization
  - Quench analysis
- Timing and patterns (Framework, model and GUIs)
  - SIS18 booster mode
  - Nested patterns
- Beam based tools
  - Trajectory and orbit control
  - Control of B2B transfer
  - Injection matching

Hardware/Infrastructure

- Core systems
  - Timing system for nested patterns
  - B2B transfer system
  - Post-mortem system
- Generic services
  - Digitization
    - BI signals (BEA)
    - Generic digitizers (ACO)
  - High BW data visualization (SYS)
  - Middle-tier service framework (SYS)
- Computing infrastructure
  - Server cluster for middle-tier services
    - Generic services
    - Development env. (CI/CD)

Note: Focus on essential aspects with long lead times, which are missing or not finished yet

Thanks for your attention!

I'd like to thank all colleagues who contributed material for this talk, consciously or unconsciously.
There are certainly many more than I mentioned, and I'd like to acknowledge their work.