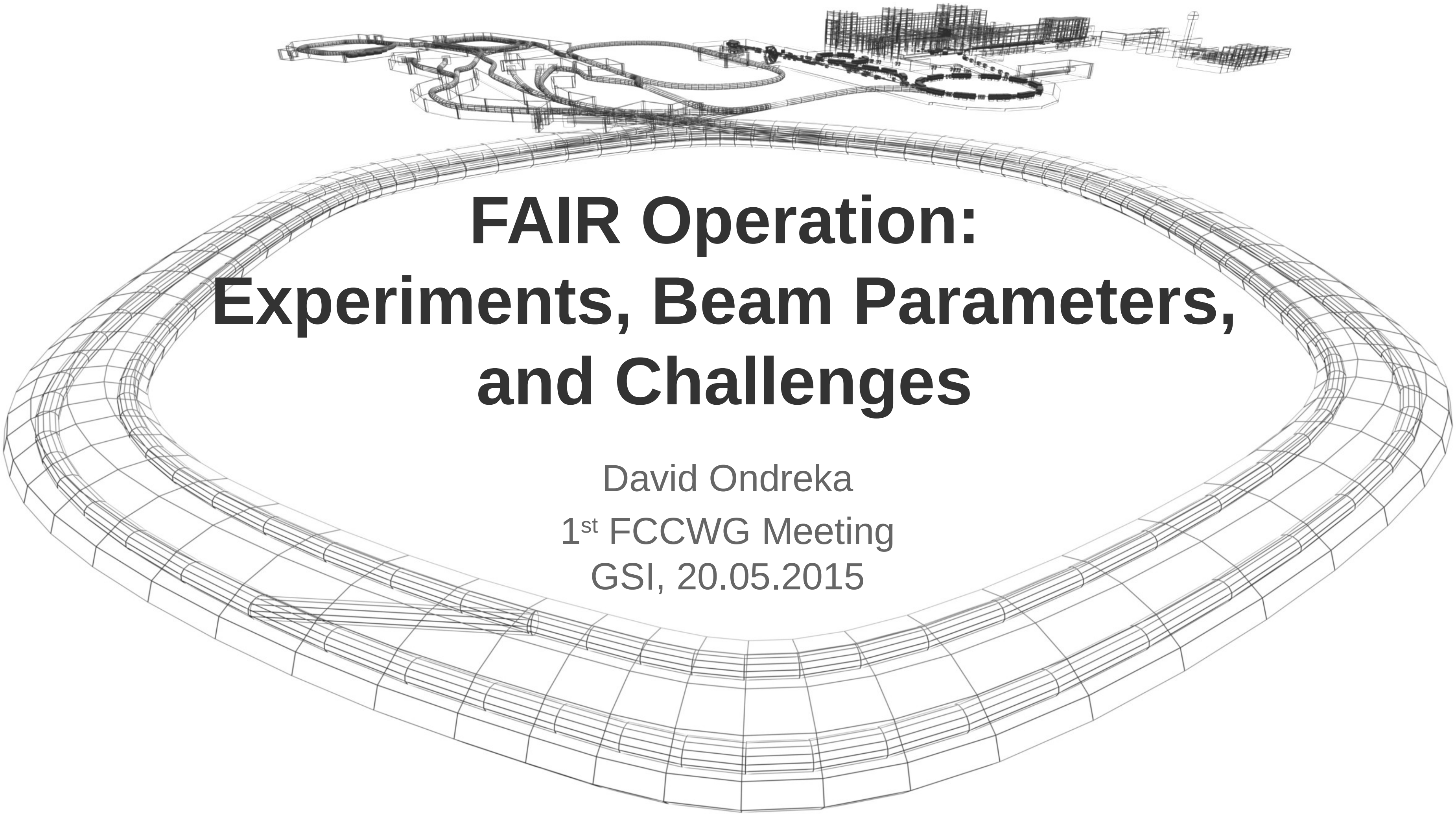

FAIR Operation: Experiments, Beam Parameters, and Challenges

David Ondreka

1st FCCWG Meeting
GSI, 20.05.2015

Overview

- FAIR Baseline Experiments
- Beam Parameters
- FAIR Operation
- Operational Challenges
- Summary

FAIR Baseline Experiments

- APPA
  - SPARC: atomic physics in strong fields
  - WDM+Hedgehob: dense plasma physics
  - BIOMAT: biomedical and materials research
- CBM
  - HADES : hadrons in dense nuclear matter
  - CBM: compressed baryonic matter
- NUSTAR
  - R3B: kinematically complete reaction studies with relativistic radioactive ion beams
  - ILIMA: In ring lifetime and mass spectroscopy
  - HISPEC/DESPEC: In beam and stopped beam γ spectroscopy of exotic nuclei
  - MATS: Mass and lifetime spectroscopy in traps
  - LASPEC: laser spectroscopy of exotic nuclei
  - EXL: In-ring reaction studies with exotic nuclei

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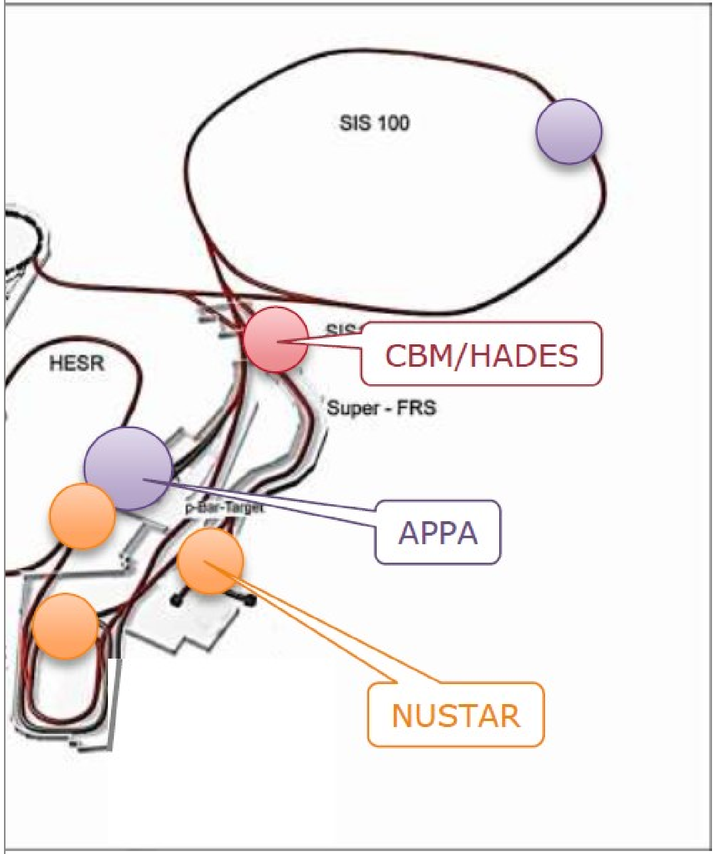

FAIR Beam Parameters: NUSTAR

- Reference ion U^{28+}
  - Highest design intensity
  - Beam energy high enough to cause damage (SIS100, Super-FRS target)
  - Tight loss and emittance budgets (dynamic vacuum, beam size)

Fixed Target	SIS18	SIS100
Ion	U^{28+}	
E_{ext}	200 MeV/u	1.5 GeV/u
N/pulse	$1.5 \cdot 10^{11}$	$5 \cdot 10^{11}$
Rep. rate	2.7 Hz	< 0.3 Hz
E_{beam}	1 kJ	**30 kJ**
Blow-up (trans.)	**1.4**	**1.2**
Blow-up (long.)	**2.0**	3.0
Loss budget	**≤ 20%**	**≤ 10%**

Storage Ring	SIS18	SIS100
Ion	U^{28+}	
E_{ext}	200 MeV/u	1.5 GeV/u
N/pulse	$1.5 \cdot 10^{11}$	$5 \cdot 10^{11}$
Rep. rate	2.7 Hz	0.5 Hz
E_{beam}	1 kJ	**30 kJ**
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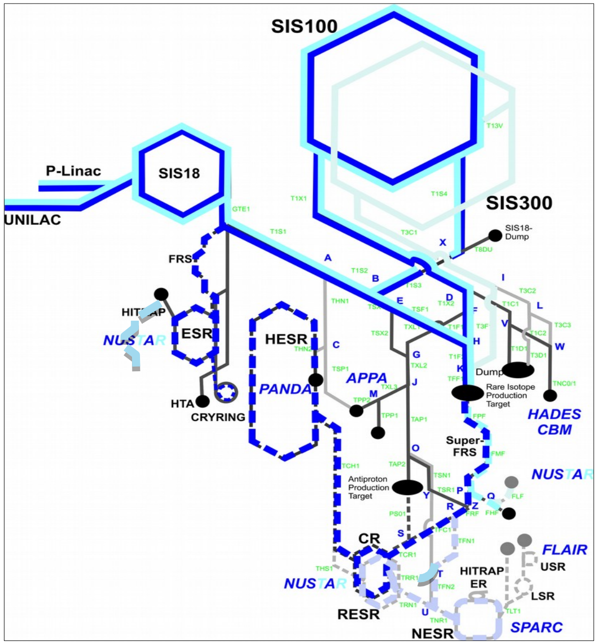
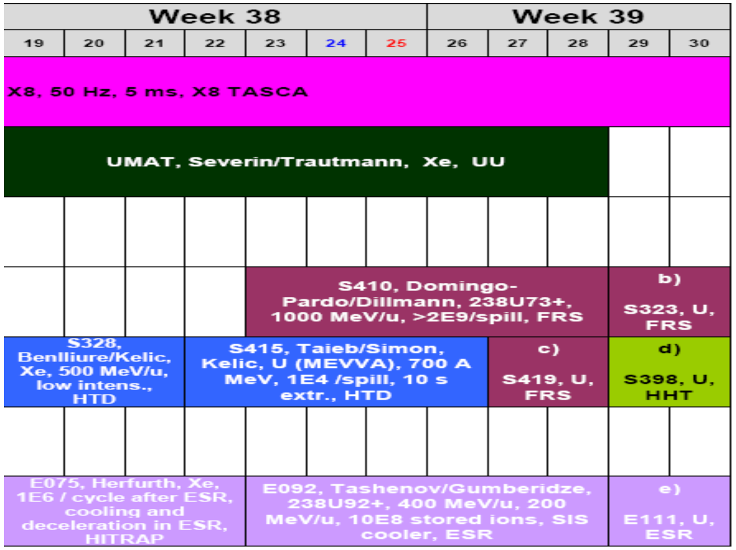


- Other ion species
  - Limited by space charge in SIS18
  - Low charge state ions similar to U^{28+}
    - Similar emittance and loss budgets
    - Less demanding with decreasing Z
  - High charge state less demanding (e.g. U^{73+})
    - Lower intensities due to space charge
    - More adiabatic damping at high energies
    - Dynamic vacuum not an issue

FAIR Operation

- Main requirements
  - Maximization of duty cycle
  - Flexibility similar to GSI
  - Beam patterns
    - Periodic (e.g. NUSTAR fixed target or ring)
    - Non-periodic (e.g. PP, APPA in (H)ESR)
- Complexity increase over GSI
  - More cycling machines per experiment
  - Stronger constraints from beamlines
- Frequent changes of experiments
  - Beam set-up must be routine (even with long accelerator chains)
  - Set-up should ideally not influence others

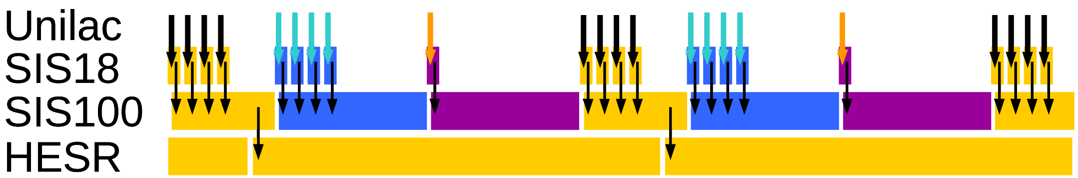
	GSI	FAIR
Accelerators	3	4
Exp. areas	20	6
Parallel Exp.	5	2
Accelerators / Exp.	**1-3**	**3-5**



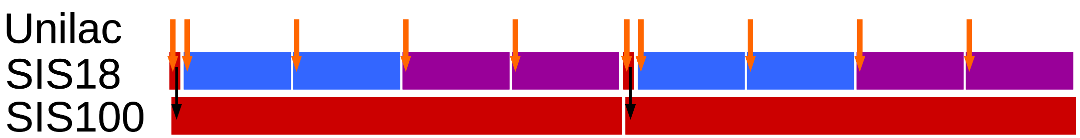
- Beam time schedule
  - Similar to GSI operation (same users)
  - Maybe more long-runners (statistics)
  - Short setup beam times as today
- Flexibility demanded by experiments
  - Variation of beam parameters (daily)
  - Change of beam sharing (daily)
  - Switching of ion species (weekly)
  - Adjustment of schedule (monthly)

FAIR Parallel Operation Options

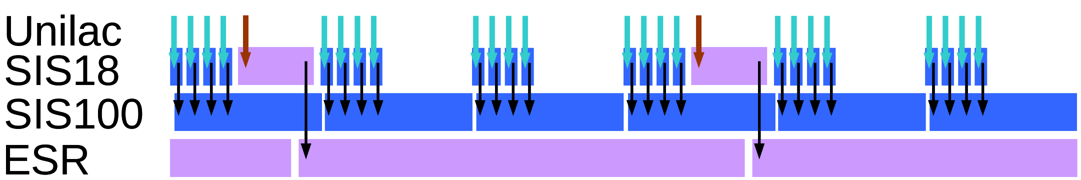
Periodic beam patterns, dominated by one ***main*** experiment:



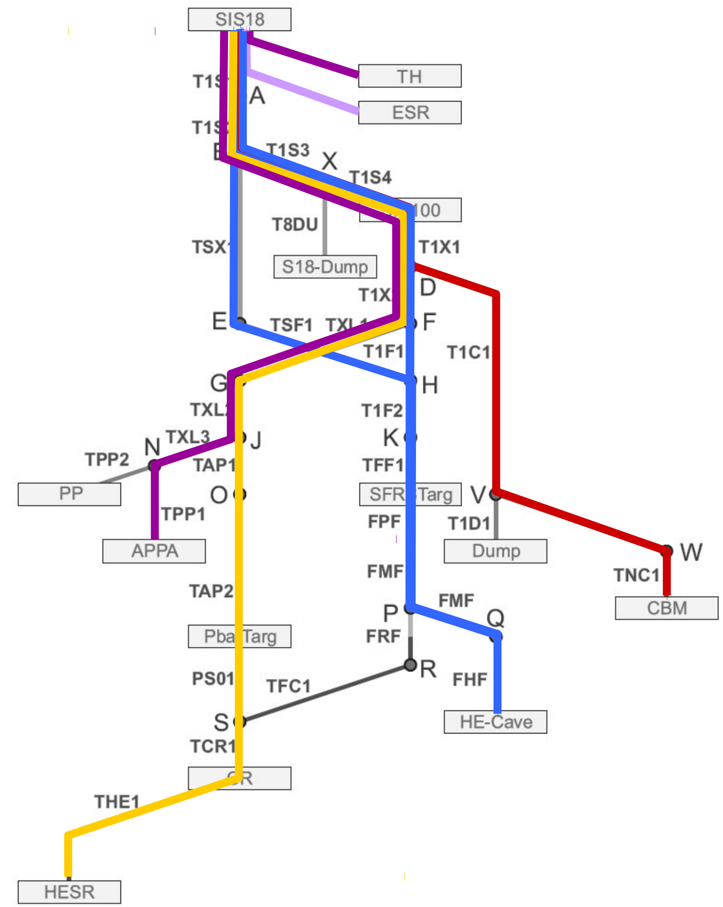
AP + RIB ext. target (U^{28+}) + Biomat



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



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



FAIR Operation: Challenges

- Present GSI operation
  - Experiment set-up
    - 1 shift Unilac set-up per ion species
    - 1/2 shift per SIS18 experiment
    - Interruption of other experiments
    - Optimization by turning knobs
    - Little direct integration of beam instrumentation
  - Mutual influence
    - TK interferences (timing, species switching)
    - Magnetic hysteresis in SIS18
    - On-demand sharing (block mode or alternating)
    - Experience: Tight schedules create troubles
  - Operational robustness
    - Set-up and optimization procedures depend on operator, little standardization
    - Few performance indicators
    - No performance history
  - Error prevention and analysis
    - Unilac pulse time shortening (HW)
    - SIS18: no particular measures taken (Operators will ‘play’ with every beam!)
    - Error detection requires reproducibility (no history of data for later analysis)

- Does it scale to FAIR?
  - Experiment set-up
    - Unilac + SIS18 as before
    - 1 additional shift per SIS100 experiment?
    - Set-up of new exp. parallel to long-runners?
    - Poor efficiency and safety of knob turning in high intensity operation
  - Mutual influence
    - Magnetic hysteresis in SIS100
    - Change of SIS18 super-cycle while SIS100 runs?
    - What if experiments can’t take beam?
  - Operational robustness
    - Do we want to depend on expert operators?
    - How do we measure performance? (Transmission isn’t everything...)
    - How do we know we’re as good as we can? (Compare with past performance!)
  - Error prevention and analysis
    - Blind knob turning may lead to unnecessary activation, quenches or machine damage
    - Some failures may be too frequent to ignore but difficult to reproduce, then what?

Machine Protection

SIS100 is not LHC, but:

- High intensity beams can destroy sensitive equipment
  - SIS100: el.stat. septum wires
  - HEBT: intercepting BI devices (grids, screens)
  - Super-FRS: target for single compressed bunch
  - Hardware interlock system required
  - No ‚playing around‘ with high intensity beams

- S.c. magnets can be quenched by beam
  - Equipment protected by quench protection
  - Recovery time reduces machine availability
  - No ‚playing around‘ with high intensity beams

- Excessive losses create activation
  - Poses problems for hands-on maintenance
  - Easily detected by transmission monitoring
  - No ‚sloppy handling‘ of high intensity beams

- Hardware solutions for damage protection
  - SIS100: Fast beam abort system
  - SIS18, Super-FRS: Extraction inhibit
  - Detection of intercepting BI devices

- Software support by control system
  - Transmission control switching off beam
  - Radiation monitoring
  - Protection of critical settings
  - Tools for reliable and robust set-up procedures

Obvious consequence:

Control system must know when beam intensity becomes dangerous!

 Interlock system must receive reliable data on beam intensity (e.g. FCTs)

Machine Performance

- Beam quality
  - Optimal beam quality maximizes useful events
  - Tight budgets on emittance/brilliance
    - Dilution causes losses and larger beam size
  - Need tools to monitor
    - Transverse emittance
      (e.g. injection mismatch, non-linearities)
    - Longitudinal emittance
      (e.g. stripper foil degradation, injection mismatch)
- Efficiency
  - Reduction of set-up time increases beam on target
  - Need standardized set-up routines
  - Need beam based tools guiding operators through set-up procedures (instead of knob turning)
- Availability
  - Error prevention increases beam on target
  - Help operators avoid errors leading to down-time
    (e.g. transmission interlocks, quenches)
  - Need support by control system to protect operators and enforce robust operation
    (e.g. beam presence flag, intensity ramp-up procedures)

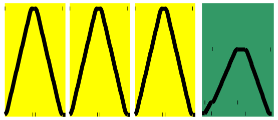
How to monitor emittance

- Longitudinal emittance
  - Coasting beam momentum spread
    (e.g. SIS18 at injection)
  - Longitudinal beam profiles
    (e.g. detecting degradation over time)
  - Phase space tomography
- Transverse emittance
  - Beam profiles
    (e.g. detecting degradation over time)
  - Combination with optics measurements to determine absolute values

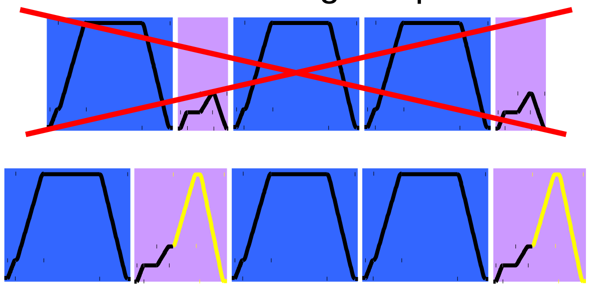
Dynamic Magnet Effects

- Mostly iron dominated magnets
  - Hysteresis (memory) effects
  - Eddy current effects
  - Reproducible for known history
- Possible cures by software
  - Choice of cycle sequence
    - Conditioning cycles for clean history
    - Periodic patterns to fix history
    - Conditioning ramps to avoid hysteresis
    - Reserve time for eddy current decay
  - Modification of settings during setup
    - Parameters for compensation of hysteresis
    - Field corrections based on measurements
  - Cycle-to-cycle feedback systems (software)
    e.g. for radial position, orbit and tune
- Hardware measures
  - Real-time feedback systems
    e.g. for radial position, orbit and tune

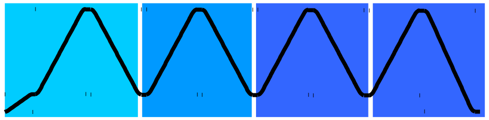
Conditioning cycles



Conditioning ramps



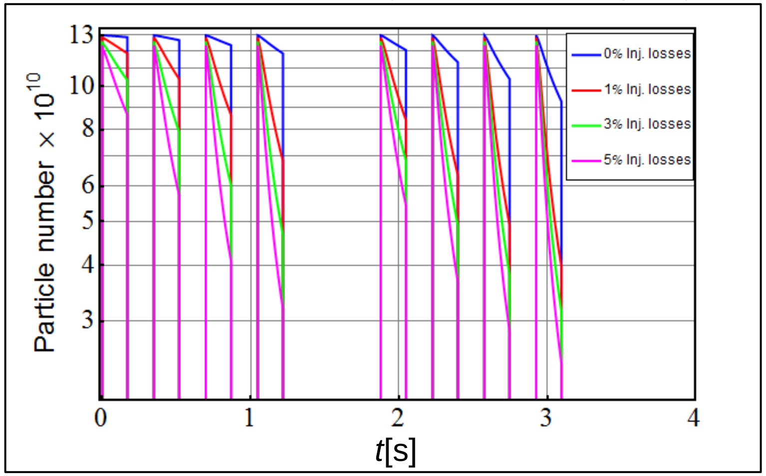
Hysteresis compensation



Dynamic Vacuum

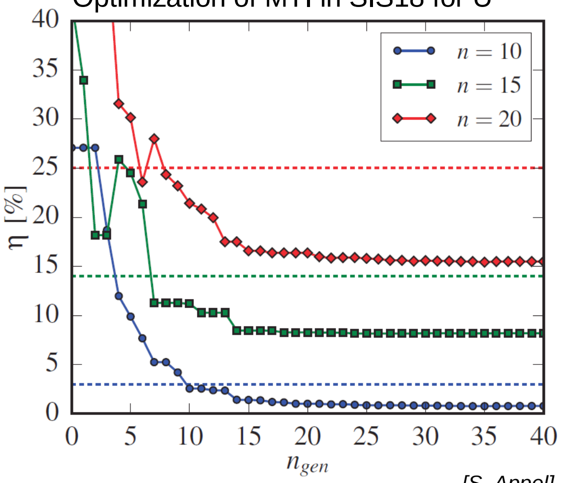
- Minimization of losses in SIS18
  - Improved MTI model, beam-based set-up based on FCT, IPM, Grids
  - Optimization and monitoring of longitudinal emittance to avoid capture losses
  - Precise control of orbit and tune during the ramp to avoid losses during ramp
  - Intensity modulation over 4 booster cycles in SIS18 to optimize bunch intensity
  - Online analysis of collimator currents and vacuum measurements for optimization
- Dynamic vacuum in SIS100
  - Similar constraints on beam control
  - Good integration of cryo catcher currents, BLM data and vacuum data readings
  - Long-term storage of data for offline analysis
  - Expect surprises!

Vacuum induced losses during SIS18 booster super-cycle



[Y. El-Hayek]

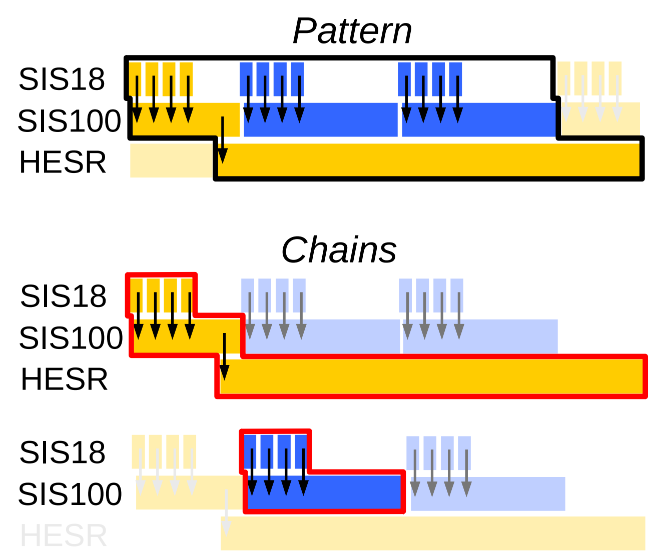
Optimization of MTI in SIS18 for U^{28+}



[S. Appel]

Parallel Operation

- Representation in the control system
  - Need strong CS support for handling beams for different experiments
  - Concepts of *Pattern* and *Chain*
  - Tools for creating and manipulating patterns



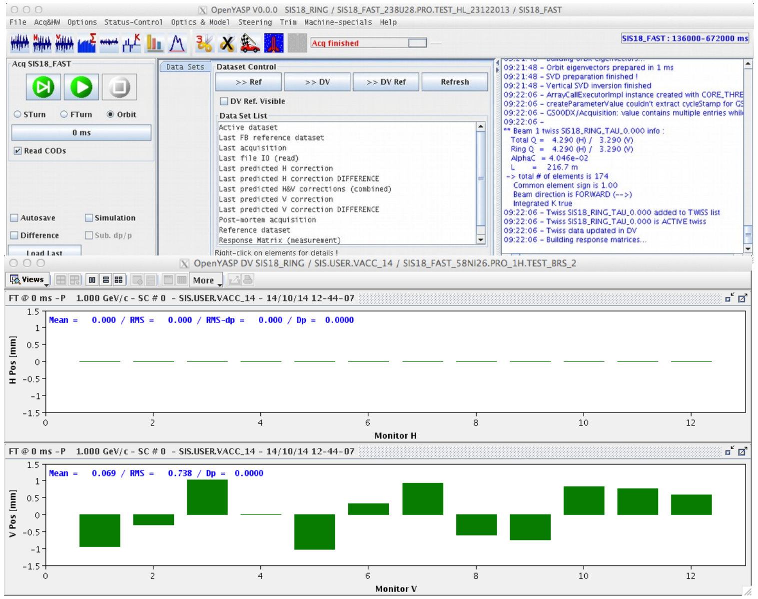
- Operation concept
  - Focus on beams (i.e. chains) rather than on accelerators
  - Allow simultaneous manipulations in same accelerator for different beams
  - Requires corresponding console concept

- Set-up of new beams parallel to long-runners
  - Base procedures on non-intercepting BI if possible
  - Build optimized tools for efficient use of intercepting BI
  - Establish standard settings for beam transfer lines (transfer okay if extraction adjusted properly)
  - Use conditioning ramps to preserve magnetic cycle to avoid disturbing long-runners
  - We know that this can be done from therapy!

Increasing Efficiency

- Set-up time reduces beam-on-target
  - Minimize set-up time by introducing reliable, robust set-up procedures
  - CS applications, using beam based approaches whenever possible (minimize ‘knob turning’)
  - Strong integration of BI into CS
- Example from GSI operation
  - Orbit correction expected to be very important for high intensity performance
  - Present orbit correction strategy
    - 2x2x2x12 = 96 SISMODI parameters for correction at injection and extraction, adjusted manually
    - No correction during ramp possible
    - No correction of radial position possible
  - Naïve scaling to SIS100 (12 → 84)
    - 2x2x2x84 = 672 parameters for orbit correction?
    - How long would it take to adjust these?
    - Correction during ramp required
  - Need something else
    - MIRKO Expert: example for integration of BI data and set value generation

- Beam based set-up
  - ‘knob turning’ sometimes unavoidable, but should be replaced by beam based approach if possible
  - BI data in combination with model allows for quantitative prediction of corrections
  - Tailored applications establish standard for set-up leading to reliable and reproducible performance
  - Critical settings can be protected by intercepting unreasonable values (e.g. decimal place error)



Preparing for the Unknown

- FAIR accelerators are partly aliens
  - We have strong expectations about their behavior
  - Will (hopefully) largely turn out true
  - Be prepared to reveal the hidden ‘features’:
     Log data as much as you can
- Examples from GSI operation
  - Mysterious reduction of SIS18 current:
    - No transmission change in UNILAC
    - By accident UNILAC profile grids had been printed
    - Vertical beam position changed
    - Traced to change of beam request timing
  - Sudden pressure rise in SIS18 extraction sector
    - All vacuum valves closed
      (logged, but not order nor source of vac. interlock)
    - FRS suspected guilty, but no hard evidence
  - Unexpected activation of H=2 cavity in SIS18
    - Comparison of beam loss patterns might help chasing down the source, but no data available
  - Dynamic vacuum questions
    - Topic often comes up in analysis of MD studies
    - Of course, nobody thought about recording…

Why we should log data as much as we can:

- We don’t know in advance which data might be interesting/useful later
- Performance evaluation
  - Why was beam XY better/worse than before?
  - Search for long-term drifts and their causes
- Collect data routinely
  - No risk of forgetting to record data
  - Accumulation of data not only during MDs
  - Large data sets for all kinds of analysis
  - Somebody’s noise is somebody else’s signal
- New machines/operation modes
  - Backup data in case of unexpected problems
- MD studies often reveal unexpected effects
  - Relevant data might not have been recorded
  - Repetition of study would waste beam time
- Analysis of rare events
  - Typically not easily reproducible
  - Might have a history of ‘near misses’
  - Might not be detectable by post-mortem

Summary

- FAIR Baseline Experiments: 11@22
- Beam Parameters
  - High intensities with damage potential for sensitive equipment
  - Tight budgets on losses and emittance blow-up
- Operational Challenges
  - Parallel operation increases complexity and complicates set-up procedures
  - Well adapted tools required
    - Concept of pattern and chains, applications for handling them
    - Machine protection by hardware and software interlock systems
    - Set-up beam concept and intensity ramp-up procedures
    - Protection of operator from accidentally applying dangerous settings
    - Reliable and reproducible set-up procedures implemented in software
    - Beam based set-up preferred over ‘knob turning’
    - Data archiving for long-term analysis and analysis of unexpected events
  - Corresponding console concept
    - Focus on beam through accelerator chain instead of accelerator
    - Allow simultaneous manipulation of different beams in same accelerator