SIS18 Injection

Beam Collimation in the Transfer Channel,
further Optimization of Injection Parameters,
and Modification of Set-Values

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FAIR Uranium Beam Review
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Outline

- Beam Collimation in the Transfer Channel
  - Motivation
  - Experimental Results
- Optimization of Injection
  - Motivation
  - New Machine Model
  - Settings Management System LSA
  - Integration of Beam Instrumentation
- Summary and Outlook

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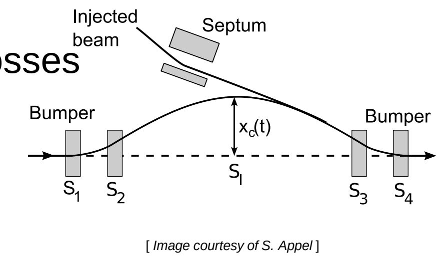
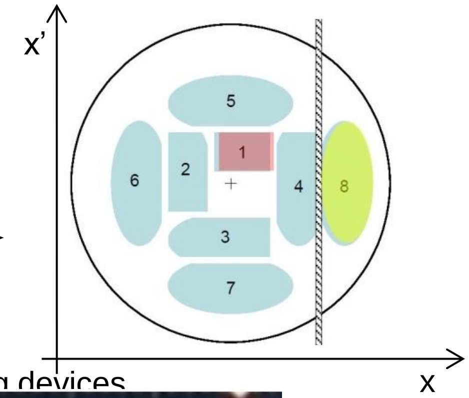
Collimation: Motivation

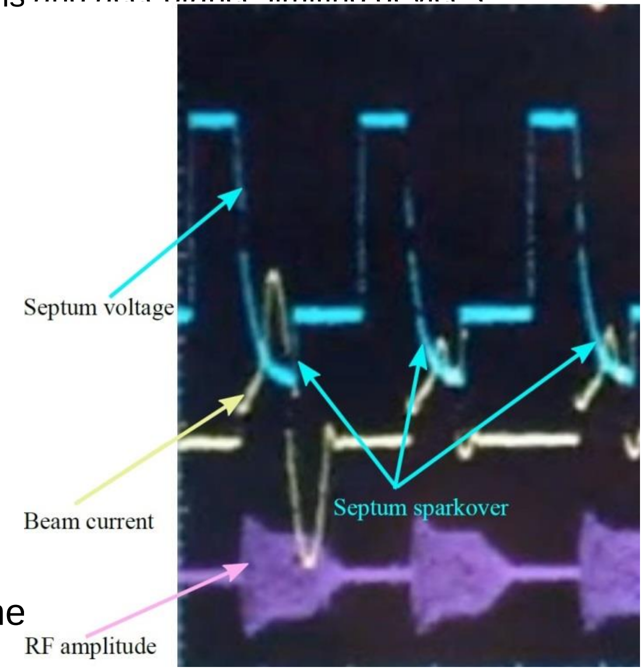
- Multi-turn injection principle
  - Paint an ellipse with ellipses
  - Trade-off between accumulated intensity and losses
    - High packing density → higher losses
    - Lower packing density → lower intensity
  - Loss locations
    - Ideal machine: all losses at septum wires
    - Real machine: losses in other place due to orbit distortions and acceptance limiting devices
  - Present operation at GSI (high charge states)
    - Optimization for intensity
    - Losses on both sides of septum wires



[*Image courtesy of S. Appel*]



- Problems with low charge state operation
  - Beam loss provokes sparkover in septum
  - Erosion of septum electrodes
  - Strong pressure increase in septum tank
    - Break-down of dynamic vacuum
    - High losses during cycle



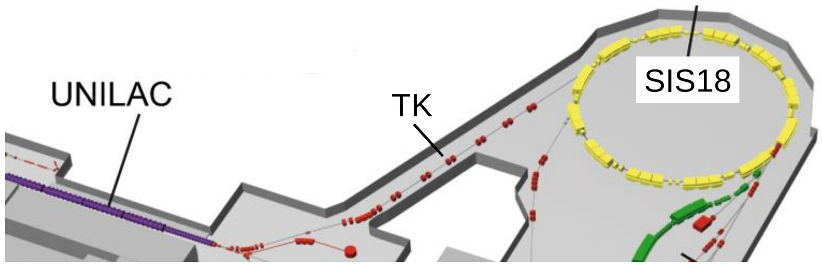
- Solution: collimation in transfer channel (TK)
  - Collimate beam before the ring in the transfer channe
  - Shift losses from ring to transfer channel
  - Potential to increase brilliance by cutting out hot core

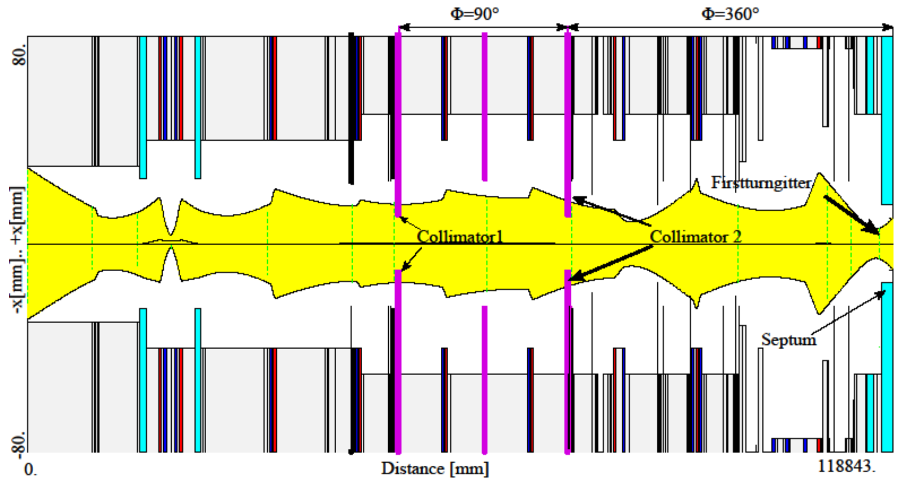
Collimation: Concept

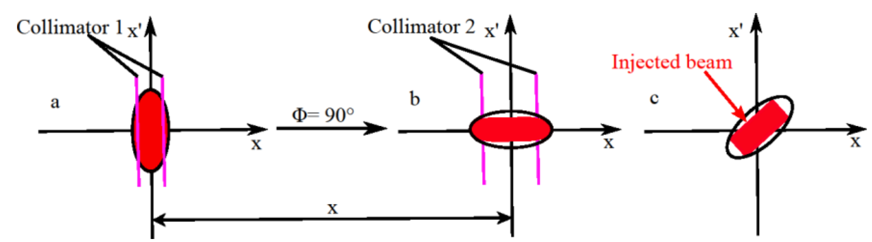
- Goals
  - Protection of injection septum
  - Improvement of dynamic vacuum in SIS18
  - Increase of brilliance through removal of halo

- Collimation in transfer channel (TK)
  - Horizontal collimation at two slits separated by 90 degree phase advance
  - Phase advance 360 degree to septum

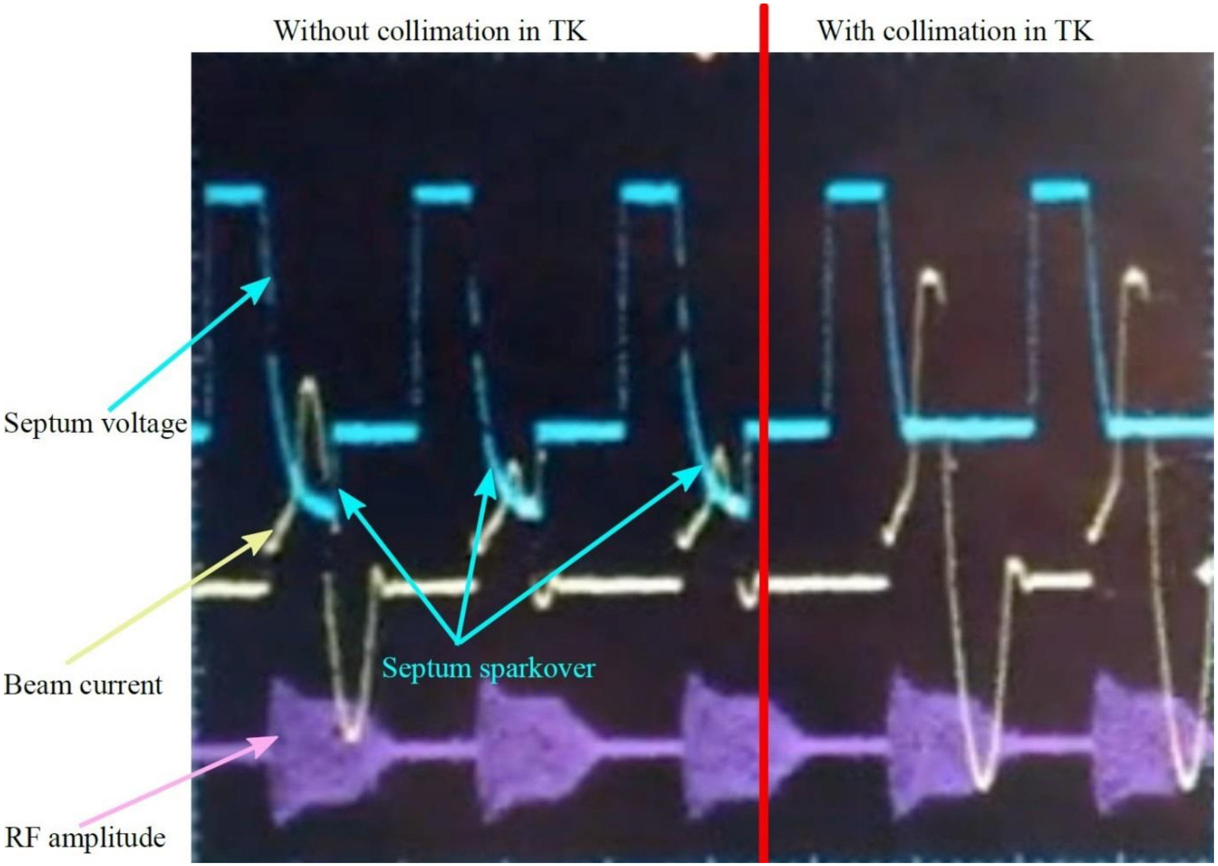
- Experimental Results
  - Septum protection works:
    No sparkover, stable operation over hours
  - Nearly loss-free injection can be realized
  - Small increase of extracted intensity







Collimation: Septum Protection

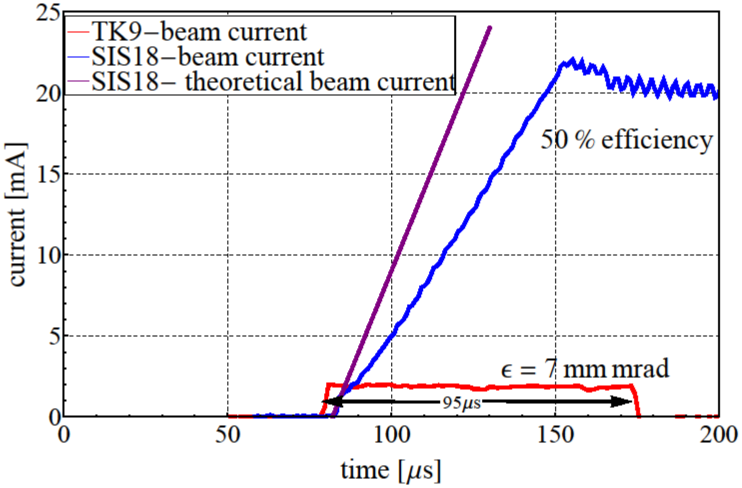


Without collimation:
- Sparkover and vacuum breakdown
- High losses during ramp

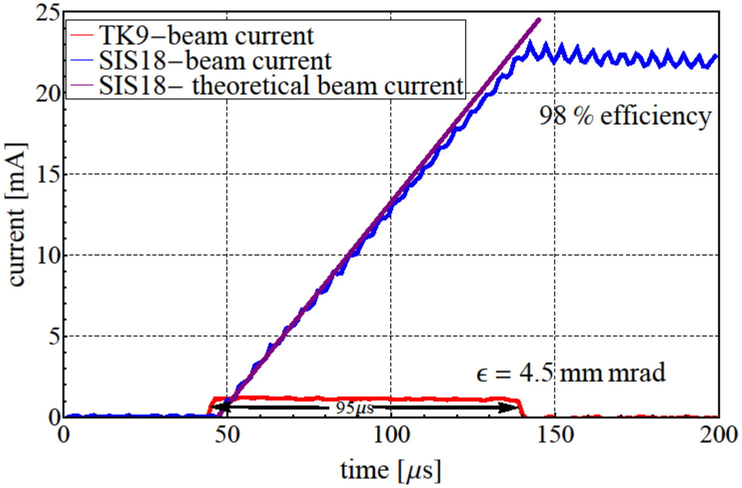
With collimation:
- Stable septum voltage (no sparkover)
- Stable beam current

Collimation: Injection Efficiency

Accumulation without collimation



Accumulation with collimation

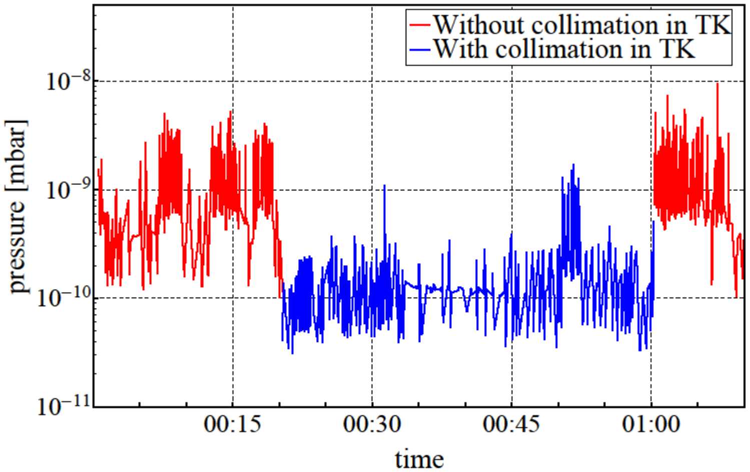


About 40% of the intensity of the injected beam are collimated

- Without collimation
  - Injection efficiency only ~ 50 %
  - High losses at injection septum
  - Late injection start
- With collimation
  - Injection efficiency ~ 95 %
  - Few losses at injection septum
  - Early injection start
  - Higher accumulated intensity (dynamic vacuum during injection?)

Collimation: Pressure and Transmission

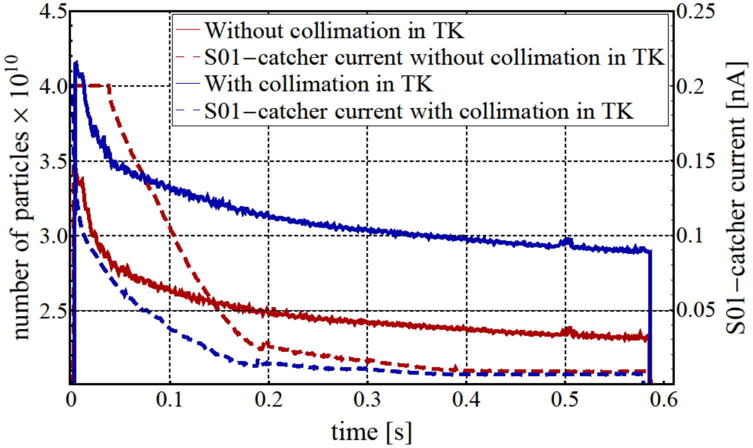
Long time pressure profile



Pressure inside injection septum vessel

- Reduced by an order of magnitude through collimation
- Corresponding reduction of beam loss current on ion catchers in the ring

Beam and catcher currents



Transmission over complete cycle

- Systematically higher injection efficiency
- Reduced beam loss currents behind septum
- Reduced relative beam loss
- Improved transmission (65% → 70% and higher intensity)

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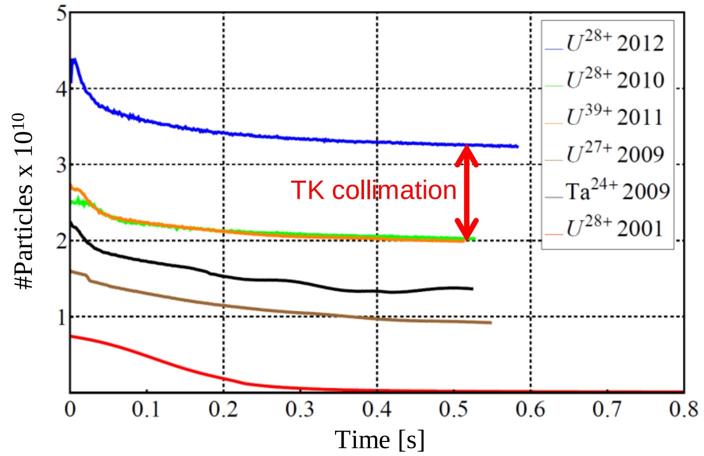
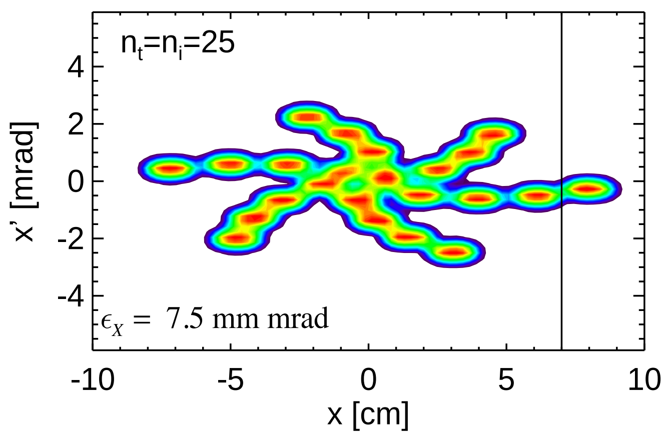
Optimization of Injection: Motivation

- Pushing the low charge state performance
  - Dominated by dynamic vacuum
  - Losses during injection must be avoided
  - TK collimation was a big step forward
  - Where's the limit, esp. regarding multi-turn injection?
- Limitations of today's operation wrt. MTI
  - Large number of low level input parameters (angles, times, amplitudes)
  - No dependence on beam parameters (intensity, emittances)
  - No relations between amplitude and timing parameters
  - Poor practical control over parameters of injected beam
  - No beam instrumentation to monitor phase space
- How to improve operation wrt. MTI
  - Better quantitative understanding required
  - Matching of theoretical model against experiment
  - Implementation of a better machine model for operation
  - Better practical control over parameters of injected beam
  - Beam instrumentation to monitor phase space

Progress of SIS18 low charge state performance



Simulation of optimized multi-turn injection

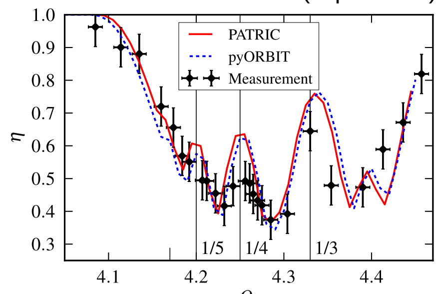


[Image courtesy of S. Appel]

Optimization of Injection: New Machine Model

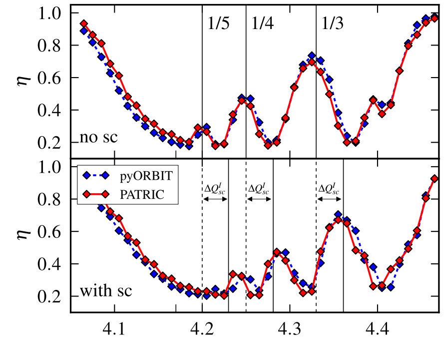
- Theoretical model of multi-turn injection
  - Developed by beam dynamics group (see talk by S. Appel)
  - Reproduces experimental results quite well
  - Suggests room for improvement
  - Difficult to use in present operation because input parameters are not available in present machine model

Beam loss versus tune (experiment)



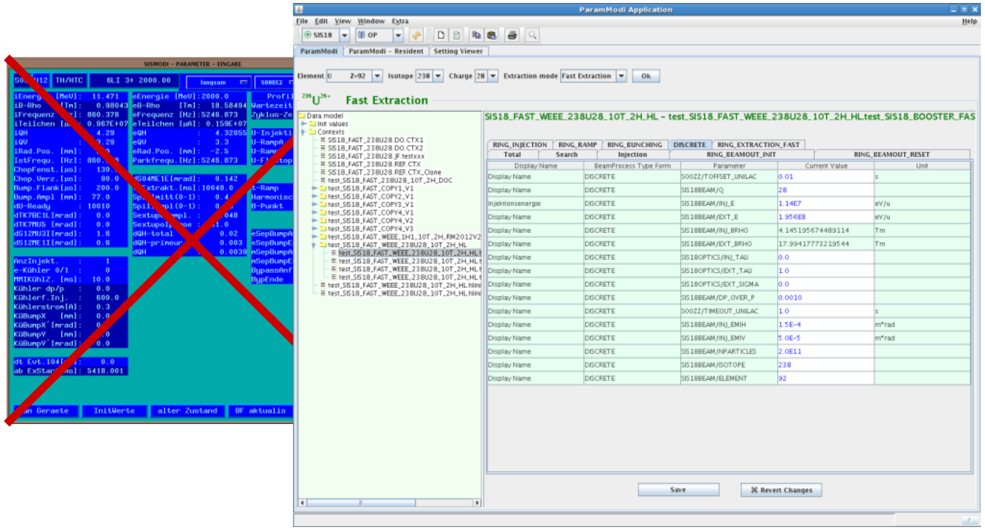
[Image courtesy of S. Appel]

Beam loss versus tune (simulated optimal values)



[Image courtesy of S. Appel]

- Requirements on the new machine model
  - Based on theoretical model including space charge
  - Tailored to the high current working point
  - Control by high level physics parameters corresponding to the input parameters of the theoretical model
  - Inclusion of effects depending on parameters of the injected beam (intensity, emittance)



Optimization of Injection: Intensity Effects

- Intensity dependent effects during multi-turn injection can be quite significant (see talk by S. Appel)

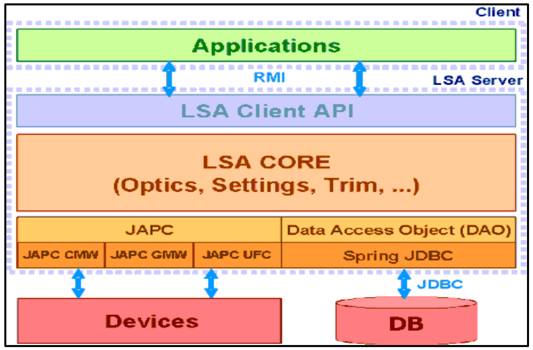
- Compensation by the machine model
  - Model must depend on particle number
  - Intensity dependent effects must be modeled
    - Analytical or numerical models when possible
    - Empirical dependencies when necessary
  - Experimental verification crucial
  - Limits of validity need to be determined

- Beyond the model
  - Model will never be ideal
  - Residual effects may still be significant
  - Do NOT resort to "turning knobs"
  - Rely on measurements instead
  - Requires good integration of beam instrumentation

Effect	Counter measure	Model type
Tune shift due to transverse SC	Intensity dependent tune correction	Parameterized analytical model
Increase of momentum spread due to longitudinal SC	Intensity dependent correction of RF amplitude for capture	Parameterized analytical model
Energy loss in SIS18 due to resistive impedance	Intensity dependent energy correction	Empirical curve *(alt.: direct measurement)*
Energy shift in UNILAC	Intensity dependent energy correction	Empirical curve *(alt.: direct measurement)*
Increase of transverse emittance in UNILAC	Intensity dependent emittance as input parameter	Empirical curve *(alt.: direct measurement)*

Optimization of Injection: Settings Management

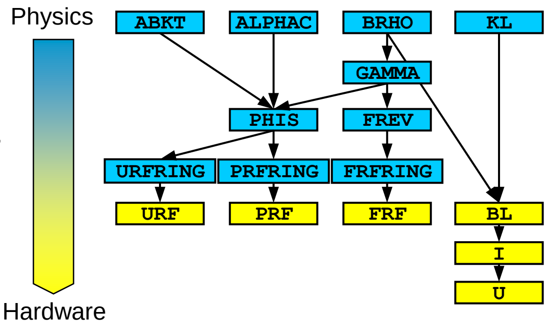
- Settings management in the FAIR CS
  - Based on LSA: Settings management system of CERN
  - Collaboration with CERN to adapt to FAIR needs
  - Modern 3-tier Java architecture (Client, Server, DB)
  - Prototype operational for SIS18 since 2010



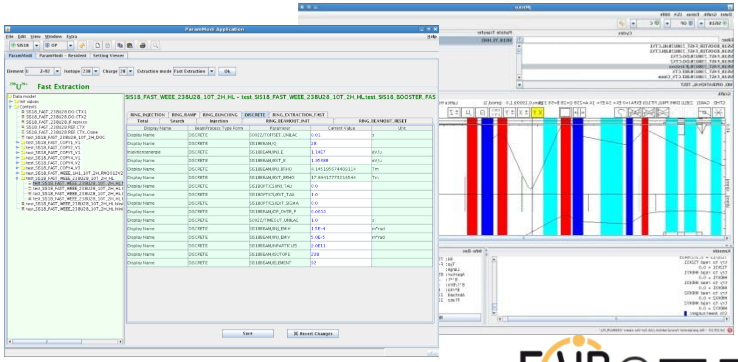
LSA Software Stack

- Machine modeling using LSA
  - Device and optics data stored in DB
  - Explicit hierarchy of parameters and their relations
  - Rules for calculating child from parents
  - Changes propagated from physics to hardware
  - Physics parameters used to control machine

SIS18 parameter hierarchy



- Benefits of using LSA
  - Improved maintainability through modern architecture
  - Easy adaptation of model to new requirements
  - Easy use of BI data in calculation of set values



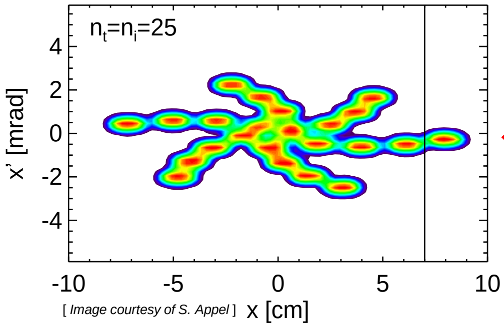
New Java Applications for FAIR

HELMHOLTZ GEMEINSCHAFT

FAIR@GSI

Optimization of Injection: Integration of BI

- BI for multi-turn injetion: Status quo
  - Only gross properties of beam used
    - Beam current
    - Injection efficiency
    - Transmission
  - No direct coupling to settings
  - Application of theoretical model difficult
    - No measurement of parameters of injected beam
    - No measurement of painted phase space



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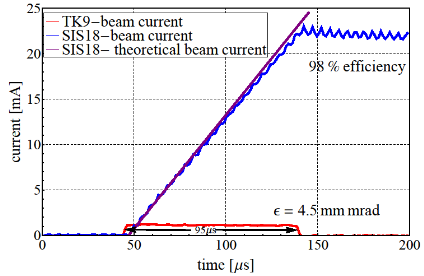
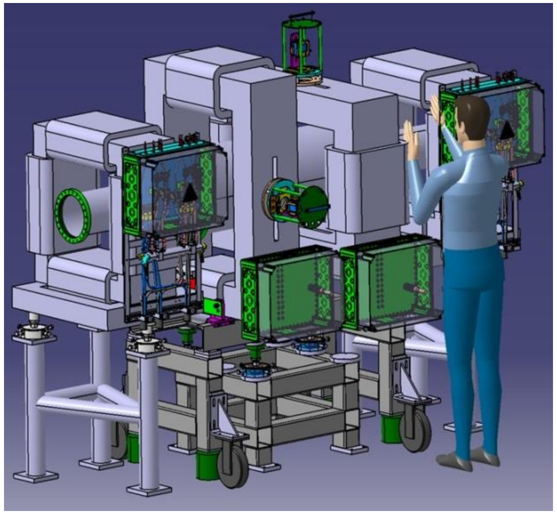


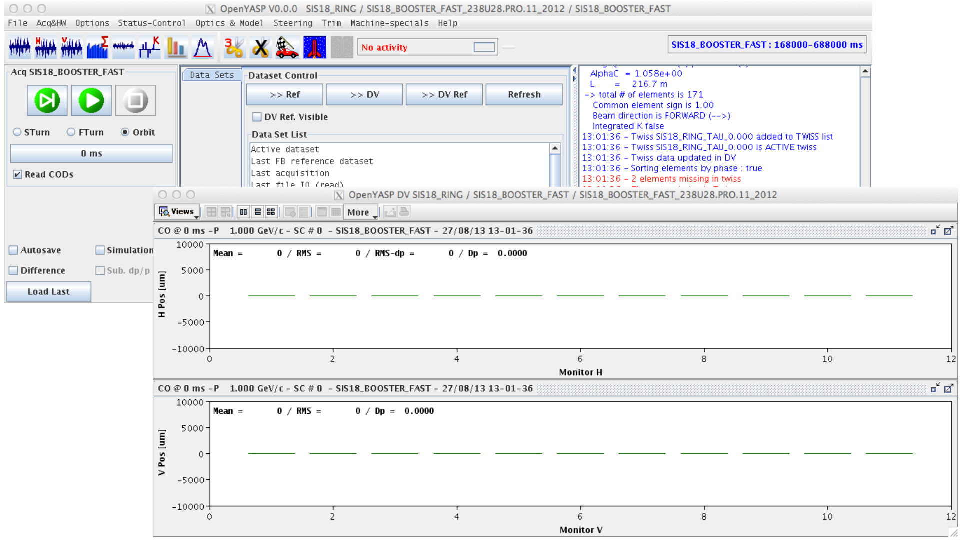
- BI for multi-turn injection: Future
  - Use BI to gain detailed information about the beam
    - Parameters of injected beam (position, angle, Twiss parameters)
    - Closed orbit
    - Fast IPM for monitoring the phase space painting
  - Use BI data to calculate corrections to the injection parameters
    - Dedicated applications for setting up injection
    - Reduction of number of “knobs”
    - Faster set-up times due to better information
    - Correct for intensity dependent effects where model fails
  - Integration into dedicated applications for operation

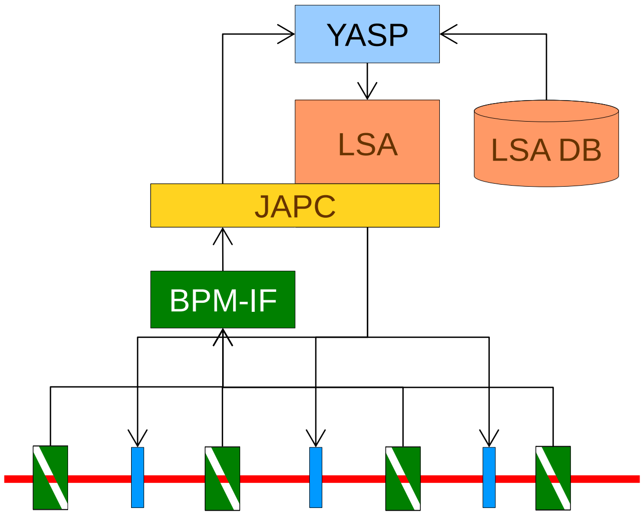


Digital mock-up of the fast IPM for SIS18

Optimization of Injection: Improved Orbit Control

- Precise orbit control essential for quantitative control of multi-turn injection
- Status quo
  - Vertical orbit acceptable
  - Poor control over horizontal orbit
  - 6 out of 12 horizontal correctors unipolar
  - Limited control parameters in setting generation
- Developments
  - New BPM readout system (available)
    - Modern front-end system
    - Accessible via standard API (JAPC)
  - Power converter upgrade
    - 6 new bipolar power converters to be installed soon
    - 12 bipolar correctors in both planes
    - Controllable over new setting generation system (LSA)
  - New application for orbit control
    - YASP: orbit control application from CERN
    - Requires corrector control via LSA
    - Requires BPM readout via JAPC
    - Presently being adapted for SIS18
  - Tests planned for beamtime 2014





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- Collimation in the transfer channel
  - Stable operation through protection of septum
  - Better dynamic vacuum due to fewer losses in ring
  - Increased intensity and transmission
  - Limits not known due to lack of quantitative model

- Optimization of injection
  - Theoretical model developed by beam physics (S. Appel)
  - New machine model to be implemented using LSA
  - Inclusion of intensity dependent effects
  - Integration of beam instrumentation for better control

- Tests foreseen in the upcoming beamtime
  - Test of new machine model (without intensity effects)
  - Verification of theoretical model
  - Study of intensity dependent effects

Special thanks for providing me with material to:

- Y. El-Hayek (experiments on collimation)
- S. Appel (theoretical model)