Performance and Beam Loss in the SIS18 Synchroton

Peter Spiller

CARE-HHH Beams07, CERN, Geneva

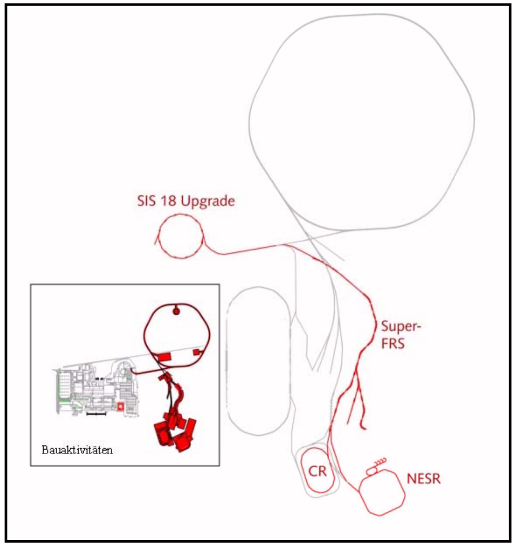
2.10.2007

Beam Loss Mechanism

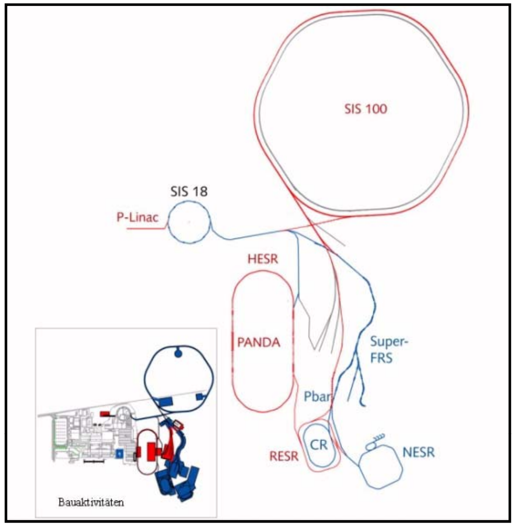
- Intensity goals
- Multi-turn injection
- Space charge
- Ionization and Recombination
- Acceleration
- Activation
- Slow Extraction

FAIR Project (staged planning)

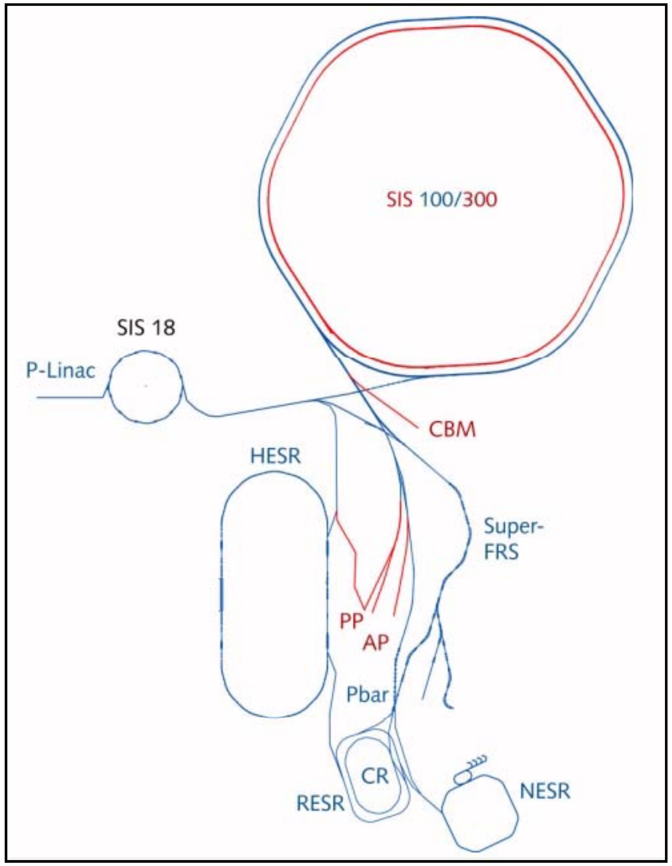
Stage 1



Stage 2



Stage 3



SIS18 – Intensity Requirements for FAIR

Fair Stage	Today	0 (Existing Facility after upgrade)	1 (Existing Facilty supplies Super FRS, CR, NESR)	2,3 (SIS100 Booster)
Reference Ion	U^{73+}	U^{73+}	U^{73+}	U^{28+} (p)
Maximum Energy	1 GeV/u	1 GeV/u	1 GeV/u	0.2 GeV/u
Maximum Intensity	$3x10^{9}$	$2x10^{10}$	$2x10^{10}$	$2x10^{11}$
Repetition Rate	0.3 Hz	1 Hz	1 Hz	2.7 – 4 Hz
Approx. Year		2008/2009	2011/2012	2012/2013

SIS18 upgrade program

Supported by EU Construction contract:

- **Task 1: RF System**
  New h=2 acceleration cavity and bunch compresion system for FAIR stage 0, 1
  (2009)
- **Task 2: UHV System**
  New, NEG coated dipol- and quadrupole chambers
  (2006-2008)
- **Task 3: Insertions**
  Set-up of a „desorption“ collimation system
  (2007-2008)
- **Task 4: Injection / Extraction Systems**
  New injection septum, HV power supply and large acceptance extraction channel
  (2007)
- **Task 5: Beam Diagnostics Systems**
  Fast residual gas profile monitor and high current transformer
  (2008)
- **Task 6: Injector**
  Set-up of a TK charge separator
  (2007)

SIS18 upgrade program

Not supported by EU Construction Proposal:

- **Pulse Power Connection**
  Dedicated 110 kV power connection and transformer for fast ramping
  (2006 and 2010)

- **Replacement of Main Dipole Power Supplies**
  Operation with 10 T/s up to 18 Tm
  (2010)

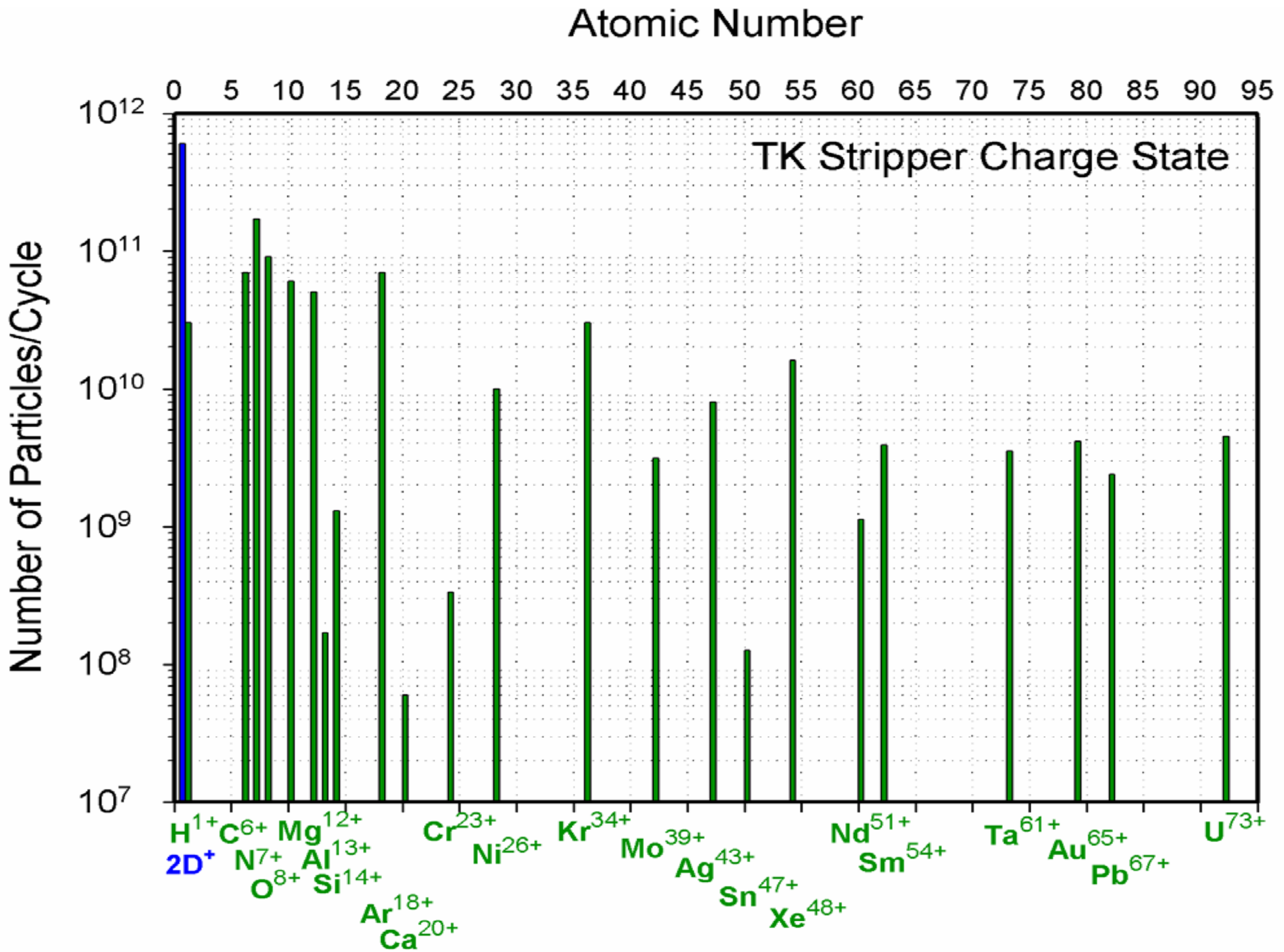
- **Longitudinal and Transverse Feed Back Systems**
  Damping of coherent oscillations, coupled bunch modes and phase stabilization

- **Beam Diagnostics upgrade**
  New digital front end electronics for BPMs (2007)
  New high current transformer (2006)

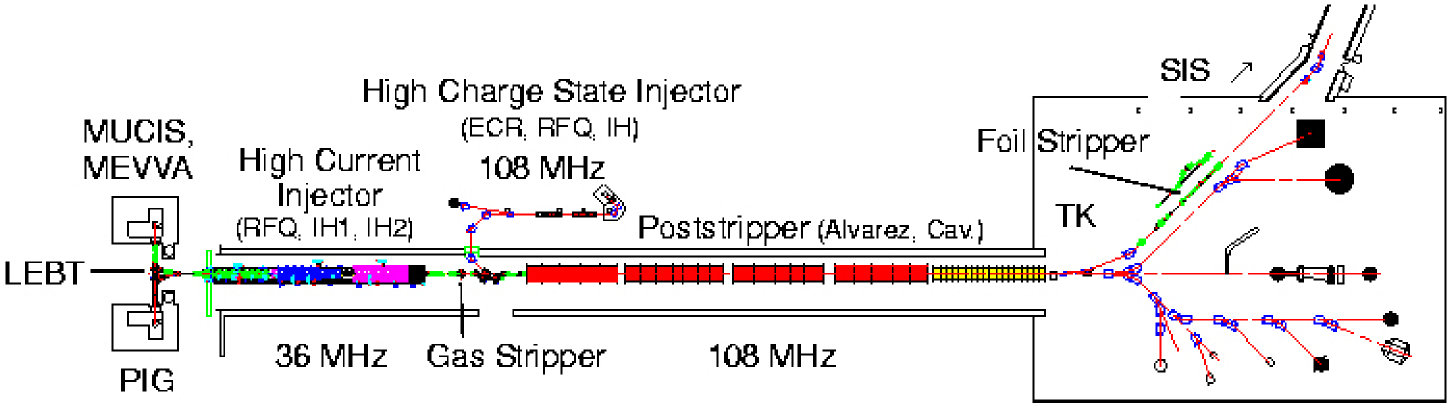
- **Machine Protection and Interlock Systems**
  Halo collimators, local shielding, transmission interlock etc.

- **Development of High Current Operation**
  Compensation of resonances, impedance issues etc.
  (2007)

Status - Peak Intensities per Cycle



Charge Stripping



U^{4+} U^{28+} U^{73+}

Presently: High charge state operation (incl. transfer stripper)

FAIR Intensity goals can only be reached by means of low charge states:

Space Charge Limit $-dQ \propto Z^2/A$ > Poststripper charge states will be used

(e.g.: Ar^{18+} > Ar^{10+}.........U^{73+} > U^{28+})

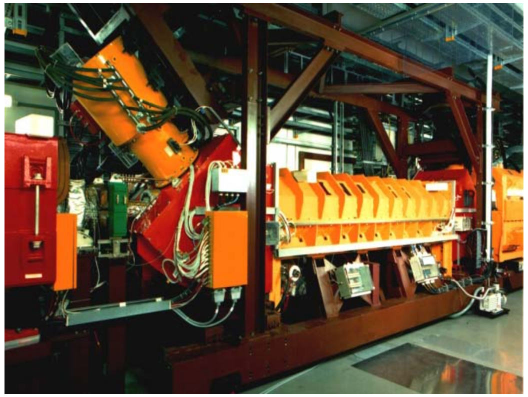
No beam loss due to charge spectrum (particle current x 7)

Injection and Stacking

Two ways to gain intensity

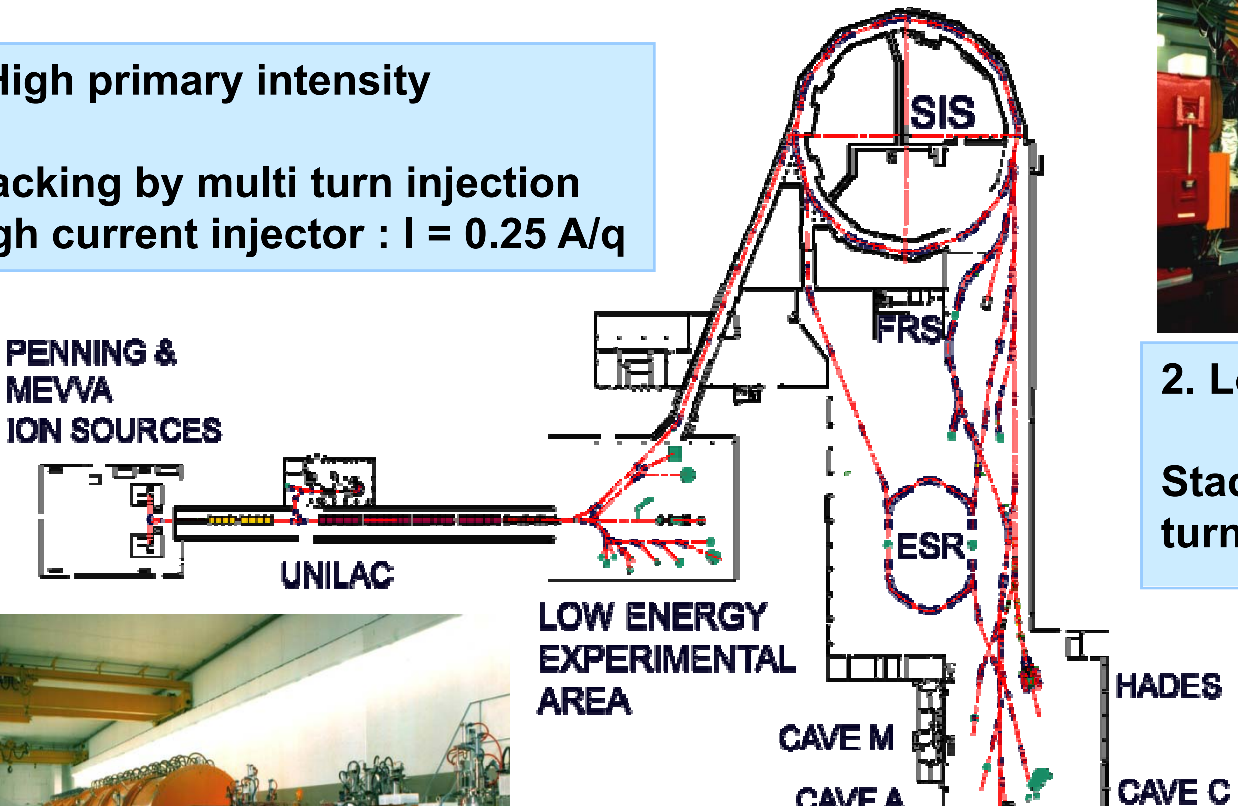
1. High primary intensity

Stacking by multi turn injection
High current injector : I = 0.25 A/q

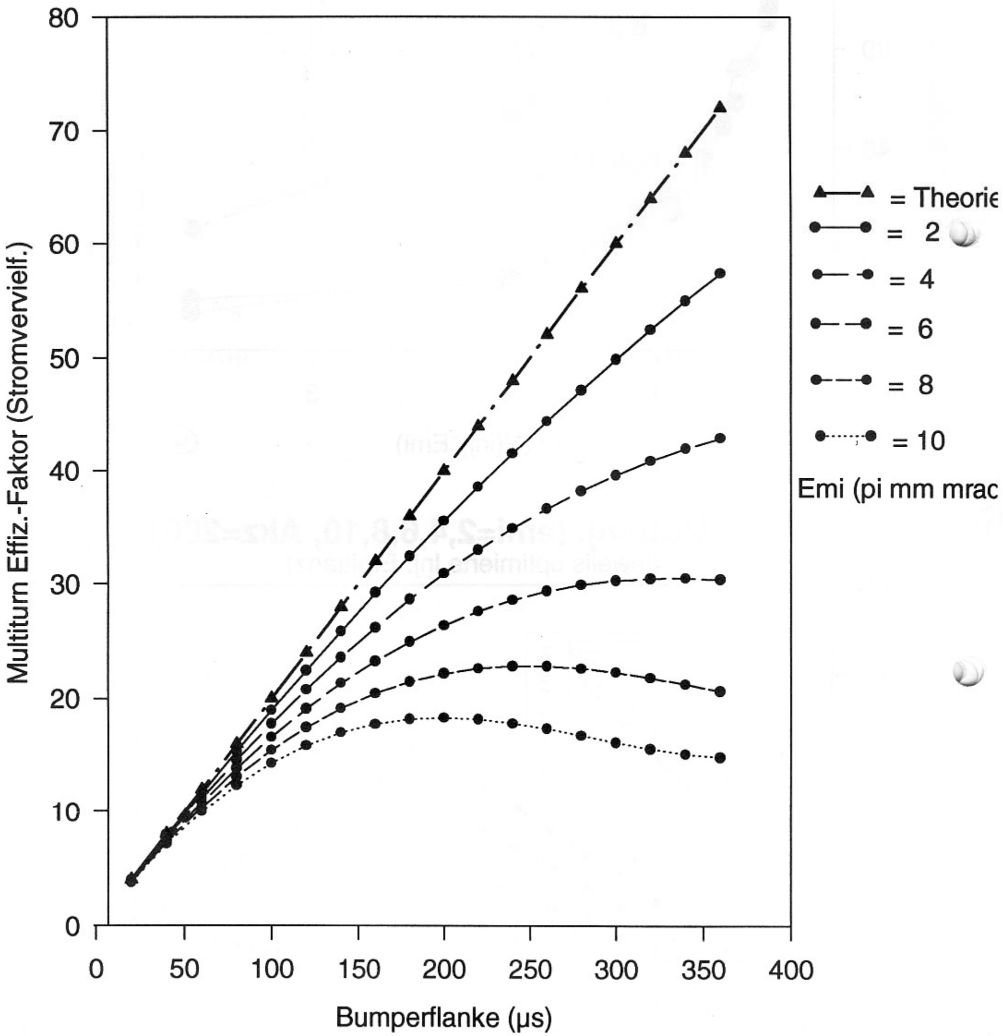


2. Low primary intensity

Stacking by multi-multi turn injection (e-cooling)



Loss during Multi-turn Injection



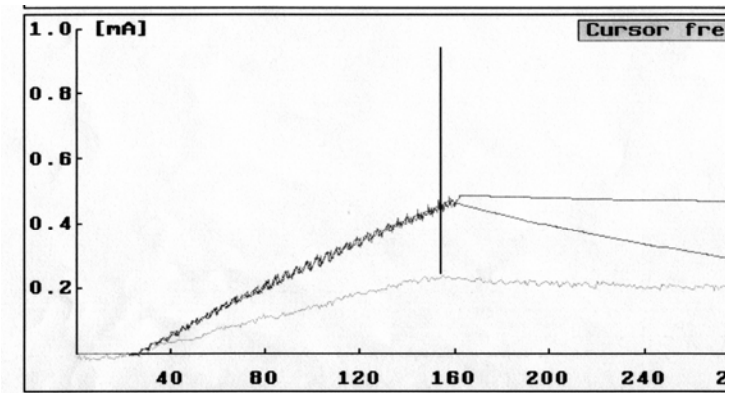
Beam loss is expected on the backside of the injection septum

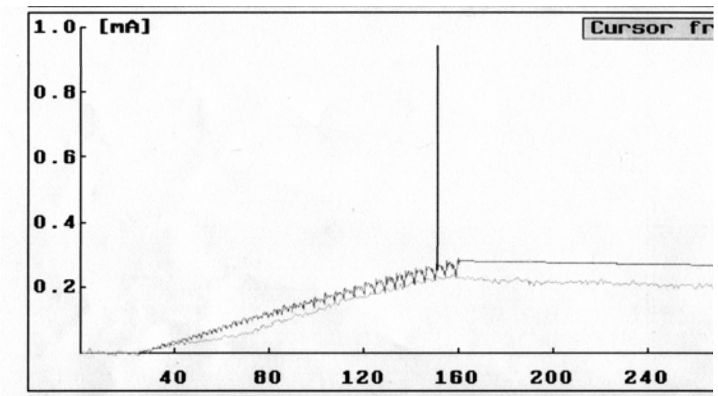
Beam loss depends on the emitance of the injected beam

Typical beam loss at present about 20-30 %

Loss during Multi-turn Injection

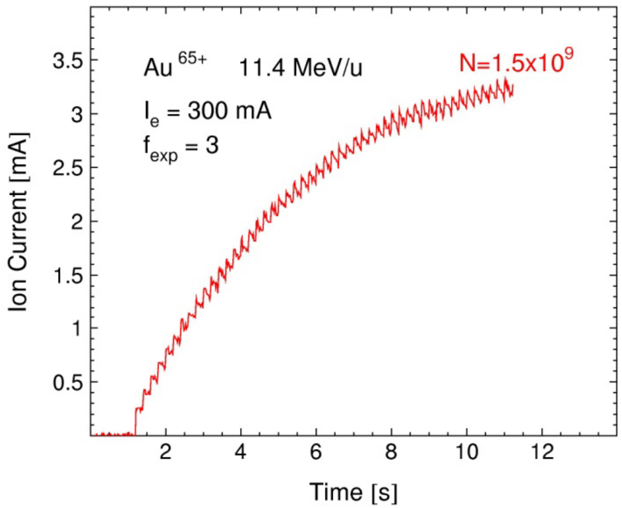
- Beam loss in SIS may be reduced and shift into the transfer channel by defining the injected emittance by the TK collimtor system.
- Almost the same intensity may be reached by injecting a lower emittance beam over a longer time



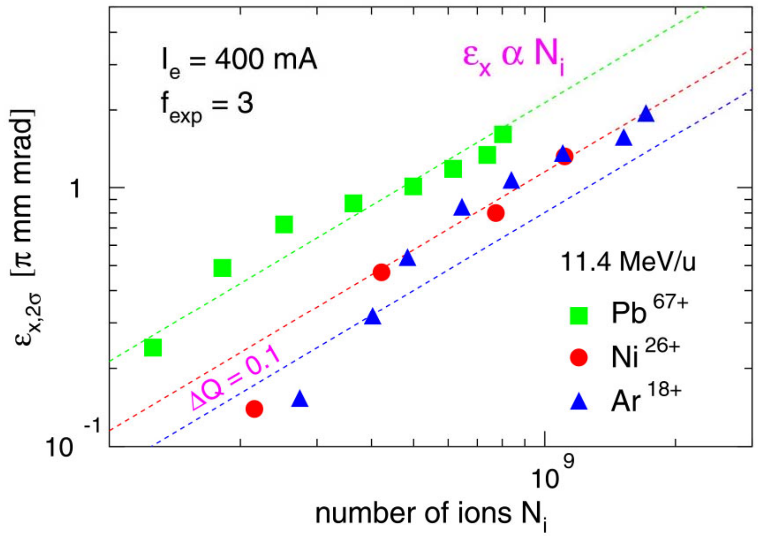


MMTI: MTI with e-Cooling

Intensity



Quality



Maximum incoherent tune spread dQ= -0.1 achieved. Transverse coherent oscillations and emittance blow-up limit the number of particle during multi-multi turn injection

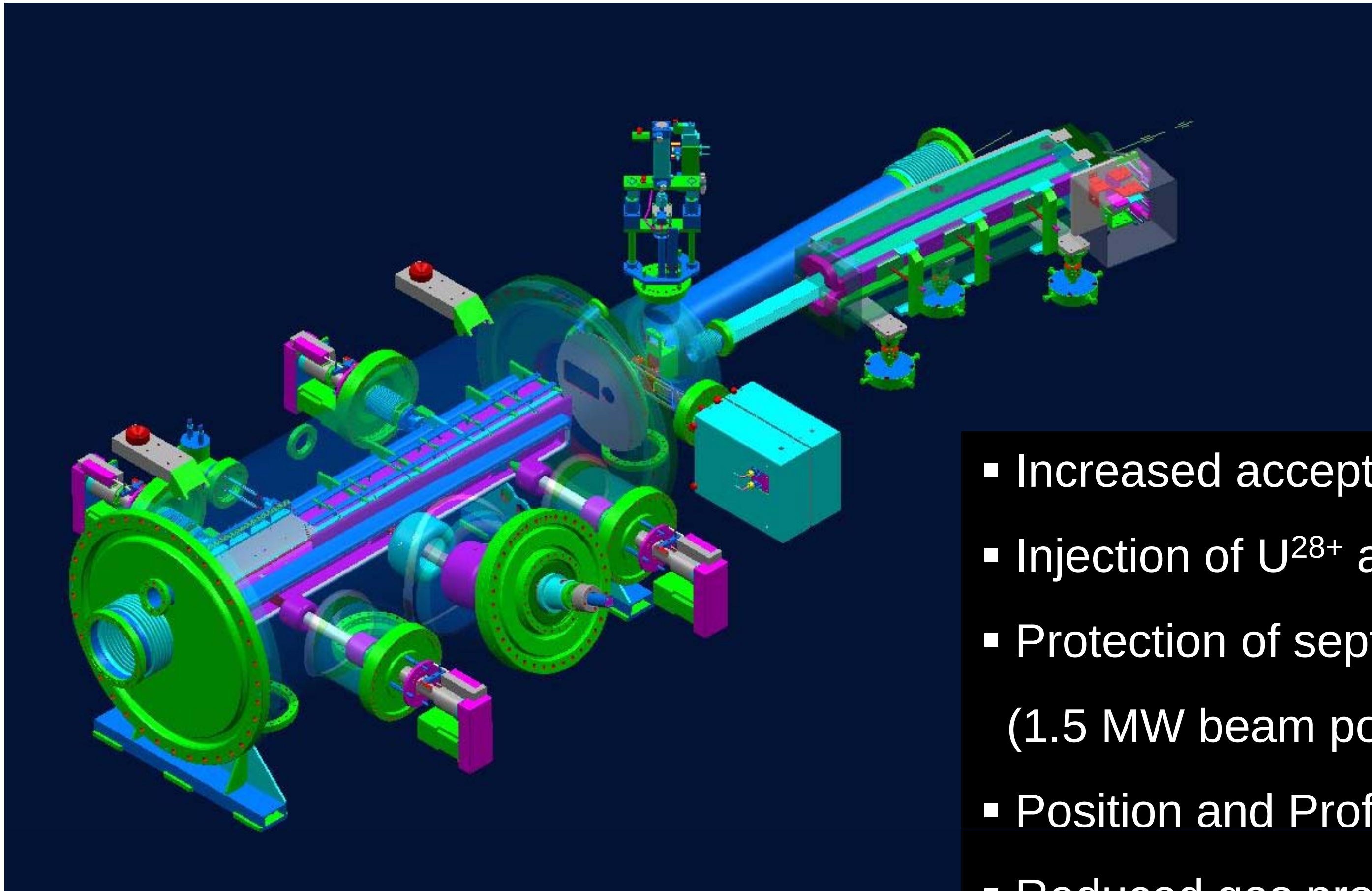
E - cooling of intermediate charge state heavy ions is expected to play no role in the FAIR synchrotron reference cycles (beside stage 1).

High Current Injection

1.5 MW Heavy Ion Beam Injection

1. Precise charge separation in transfer channel (new charge separator)
2. Installation of a beam profile monitor directly in front of injection channel
3. Installation of protection slits directly in front of injection channel
4. Increased electrode distance and higher septum voltage (?)
5. Shift of beam loss into the transfer channel by means of the TK6/8 collimators
6. Installation of an advanced cathode with enhanced high voltage break stability (IHCE, Tomsk)
7. Confirmation of the present injection scheme (loss free)
8. Systematic filling of vertical acceptance by linear coupling (study)

Injection System upgrade



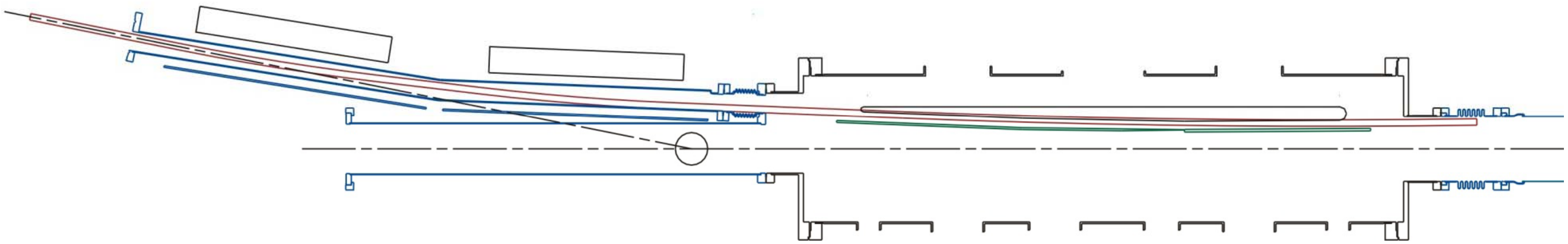
- Increased acceptance
- Injection of U^{28+} at reference energy
- Protection of septum electrodes (1.5 MW beam power)
- Position and Profile verification
- Reduced gas production

Final design of the revised injection system

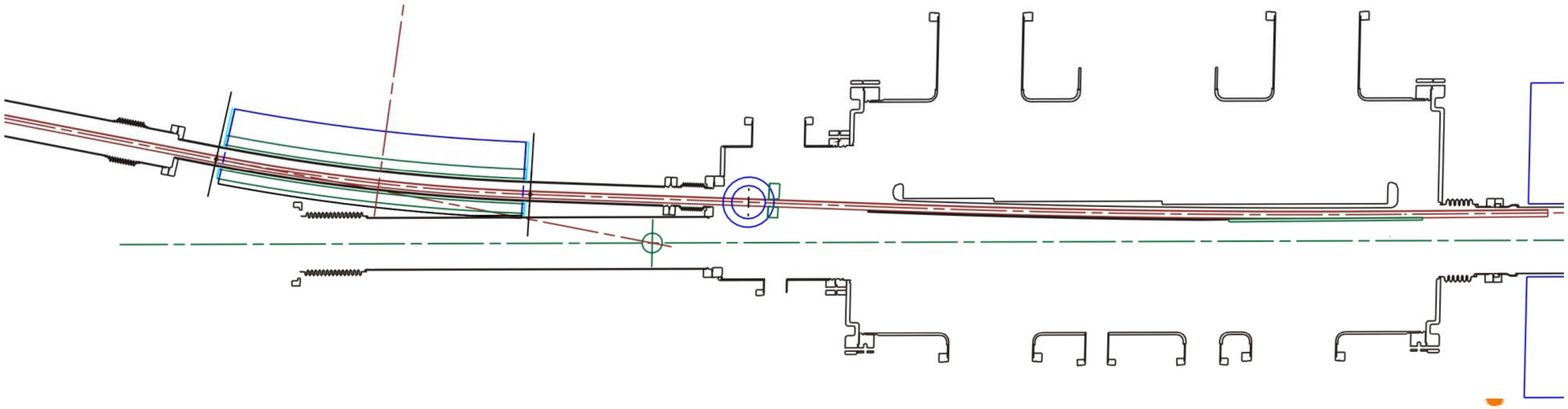
Installation scheduled for 2007

SIS18 Injection System upgrade

Existing Injection System

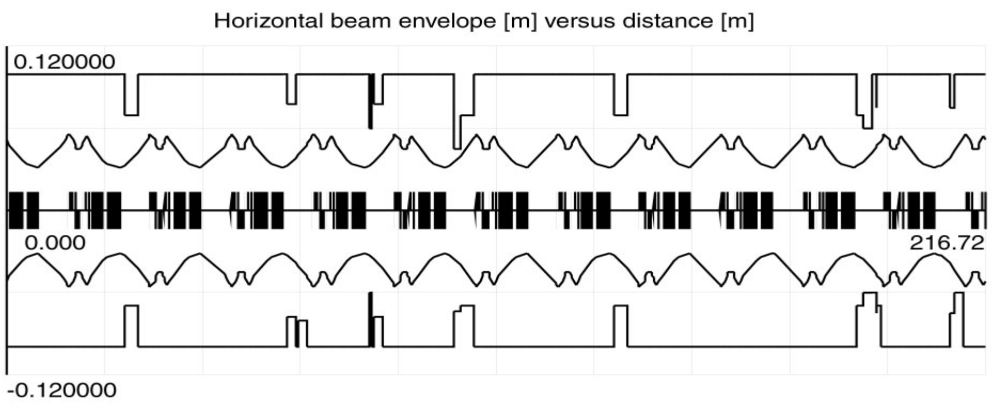


New Injection System



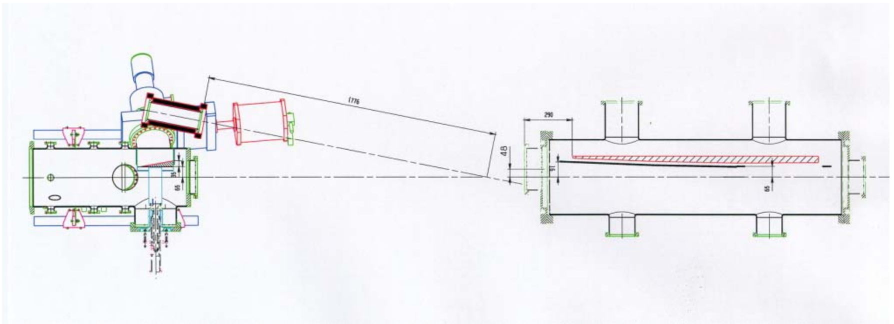
Protection of Septa

Magnet Chambers do not define the acceptance but the septa



Rf failure > Radial motion > Deposition in Septum Wires

Protection of Injection Septum (backside)



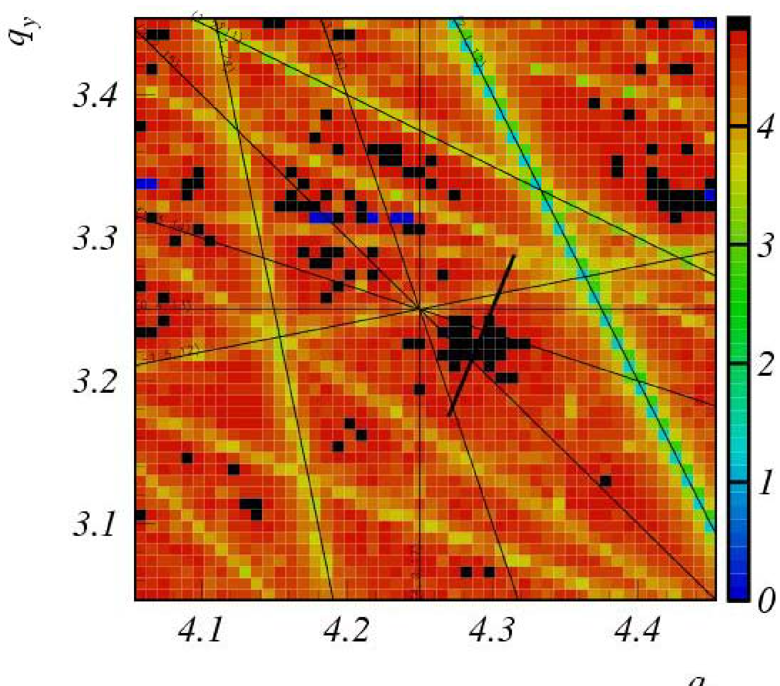
S12 Collimator

Protection of Extraction Septum

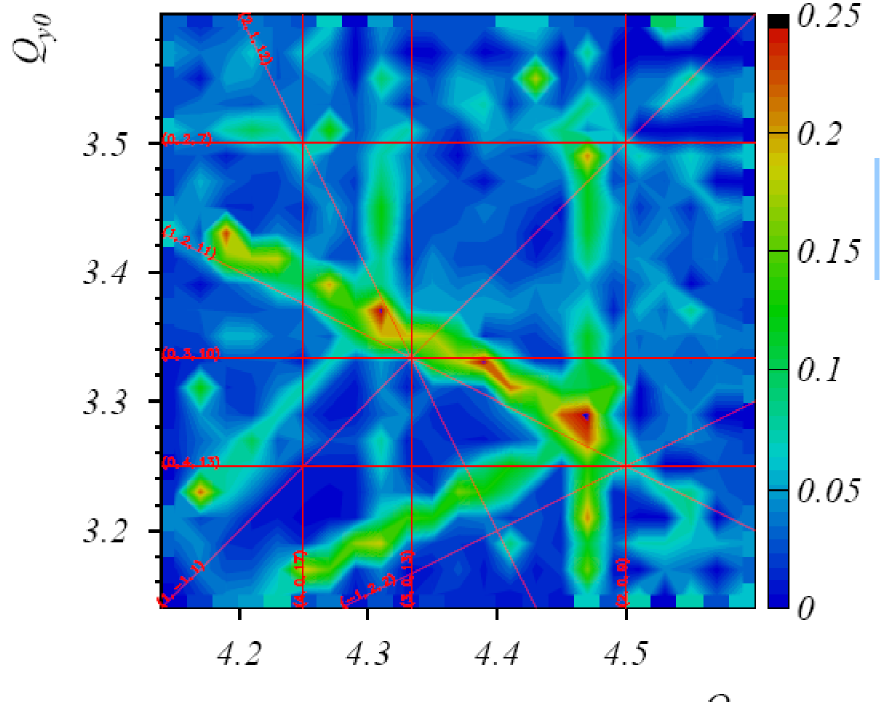
S03 Collimator and Bump

Space Charge and Resonances

Resonance, Resonance Correction, Dynamic Aperture, Trapping und Beam Loss



Calculated tune diagram based on measured magnetic fields



Measured tune diagram based on beam loss during tune scan

G. Franchetti, A. Parfenova, C. Omet, P. Schütt, B. Franczak

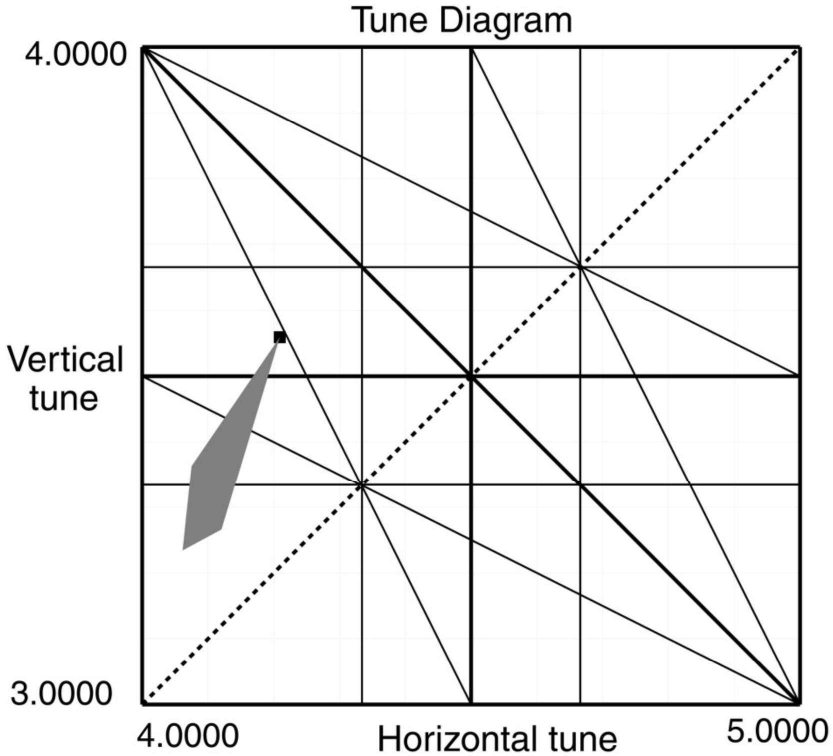
High Current Working Points

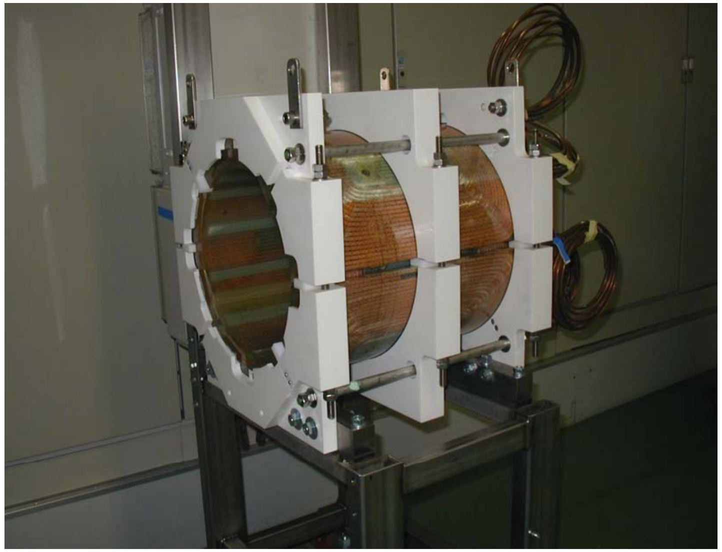
Resonance correction for the final high current working point

Compensation of different Resonances (Qv = 3.5, Qv = 3.33 und Qh – Qv = 1) for the minimization of beam loss at the final

High Current Working Point

(Qh = 4.2, Qv = 3.6).

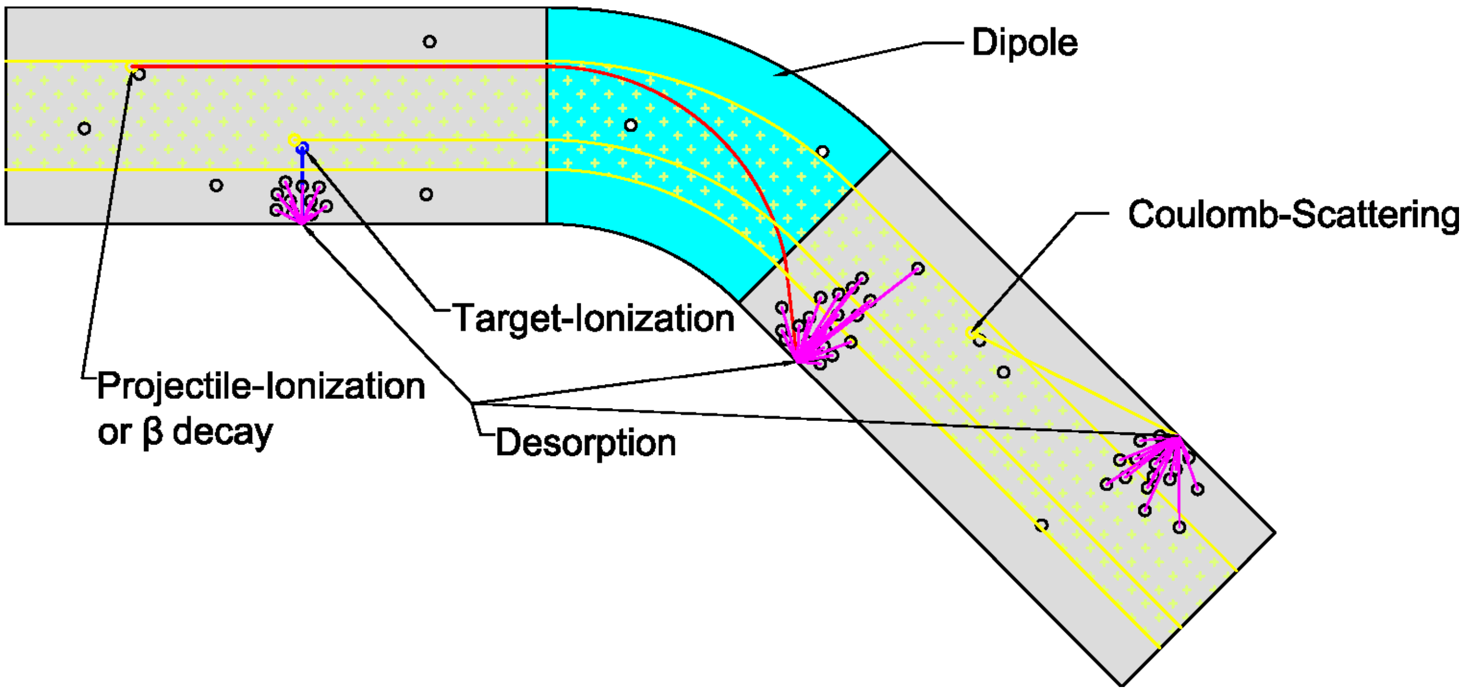




Present measurement campaign on the nonlinear properties of SIS prepares the use of the correction elements for resonance correction

Beam Loss by Charge Change

$U^{28+} \rightarrow U^{29+}$ $U^{73+} \rightarrow U^{72+}$

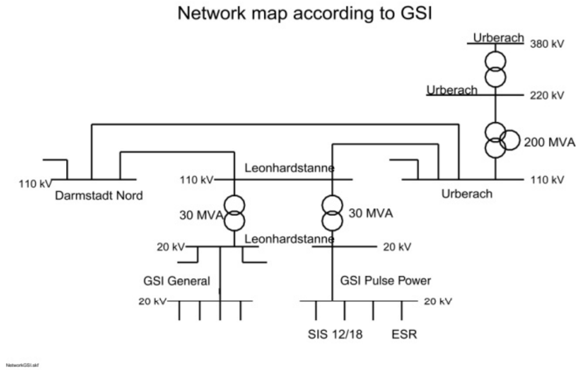


SIS18 upgrade - Vacuum Stabilization

- Short Cycle Times and Short Sequences

  SIS12/18: 10 T/s - SIS100: 4 T/s

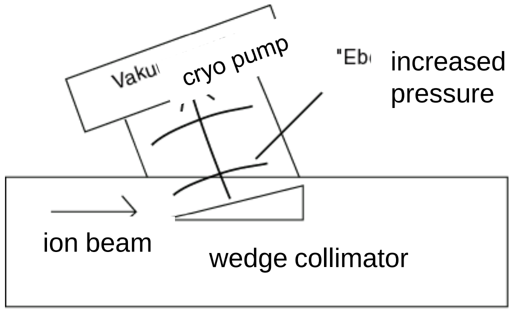
  (new power connection, power converters and Rf system)



- Enhance Pumping Power (UHV upgrade)

  (NEG-coating, cryo panels - local and distributed)

  (new magnet chambers, improved bake out system)

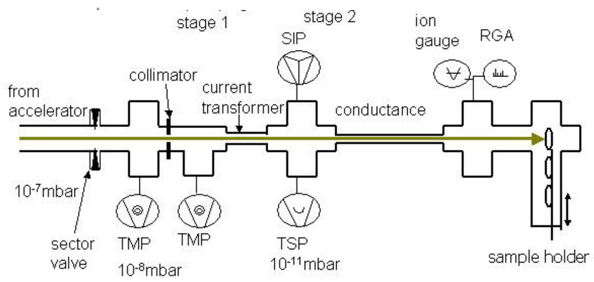


- Localizing beam loss and controle of desorption gases

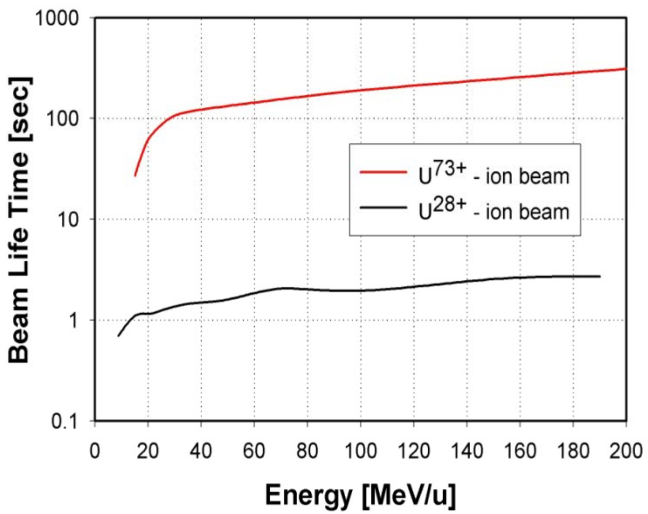
  (Collimator in S12, new collimation system)

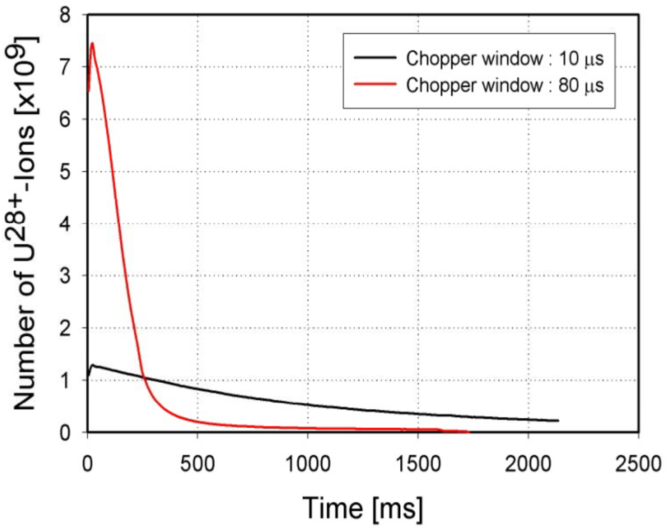
- Materials with low desorption yields

  Teststand, ERDA measurements



Life Time and Beam Loss

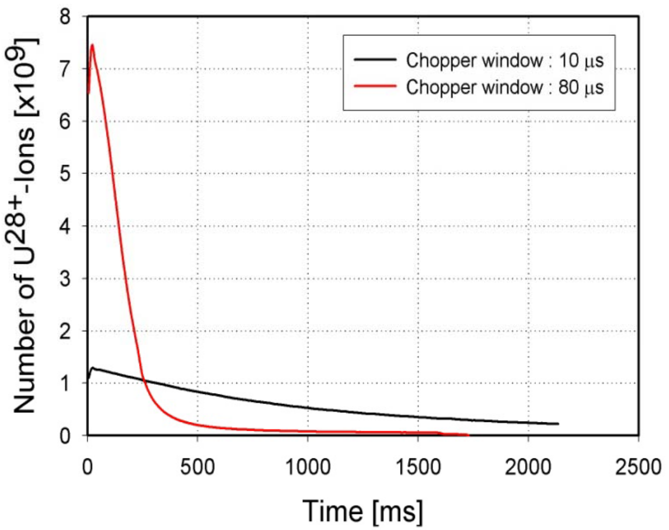




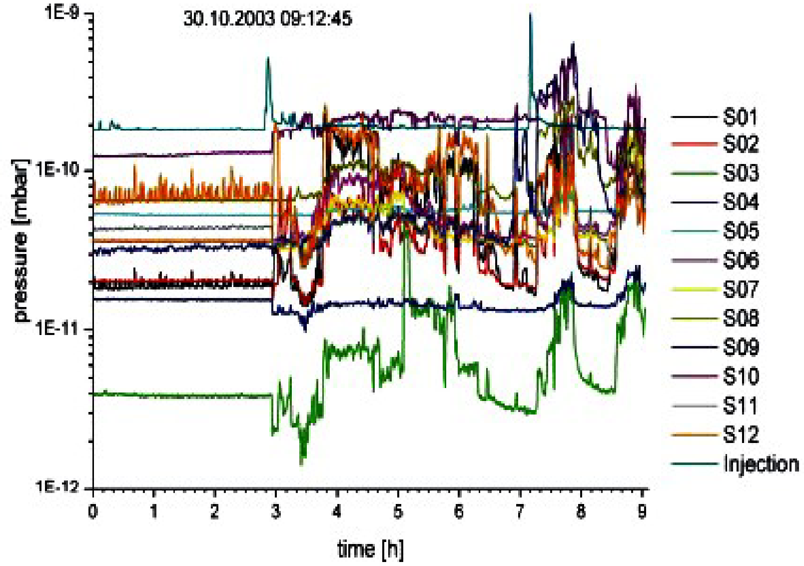
- **Life time of U^{28+} is significantly lower than of U^{73+}**
- **Life time of U^{28+} depends strongly on the residual gas pressure and composition**
- **Ion induced gas desorption ($\eta \approx$ 10 000) increases the local pressure**
- **Beam loss increases with intensity (dynamics vacuum, vacuum instability)**

Beam Loss and Dynamic Vacuum

Beam Loss



Dynamic Pressure



- Beam loss induced desorption degenerates the residual gas pressure and composition
- Degenerated residual gas pressure reduces the beam life time

> Instable during high intensity operation, heavy ion operation

Pre-conditions for Intense Heavy Ion Beams

- Minimized systematic and initial beam loss
  > precise machine settings, controle
  and feed back

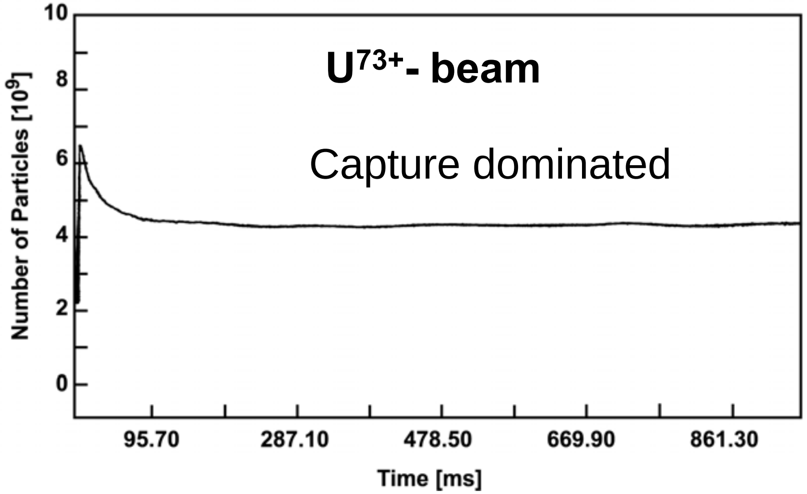
- Precise transverse and longitudinal
  matching

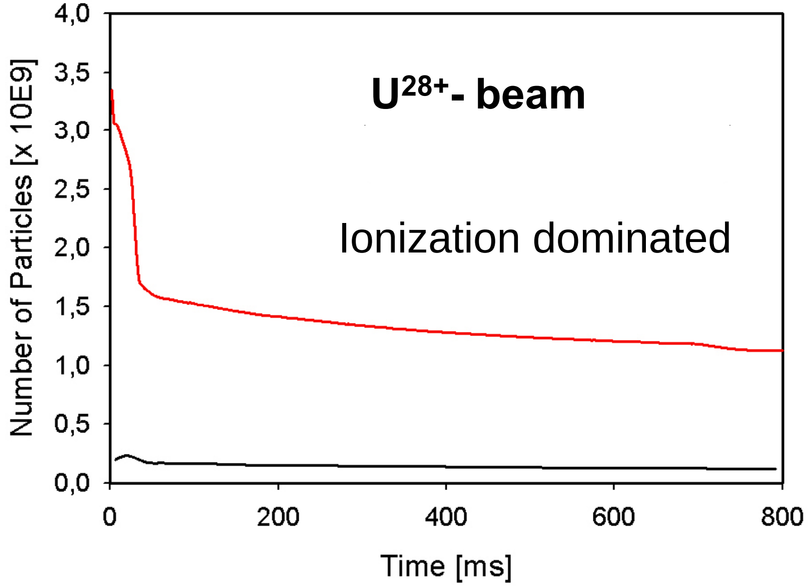
- Collimation of not matching beam tails in TK

- Controle of systematic loss (unavoidable)

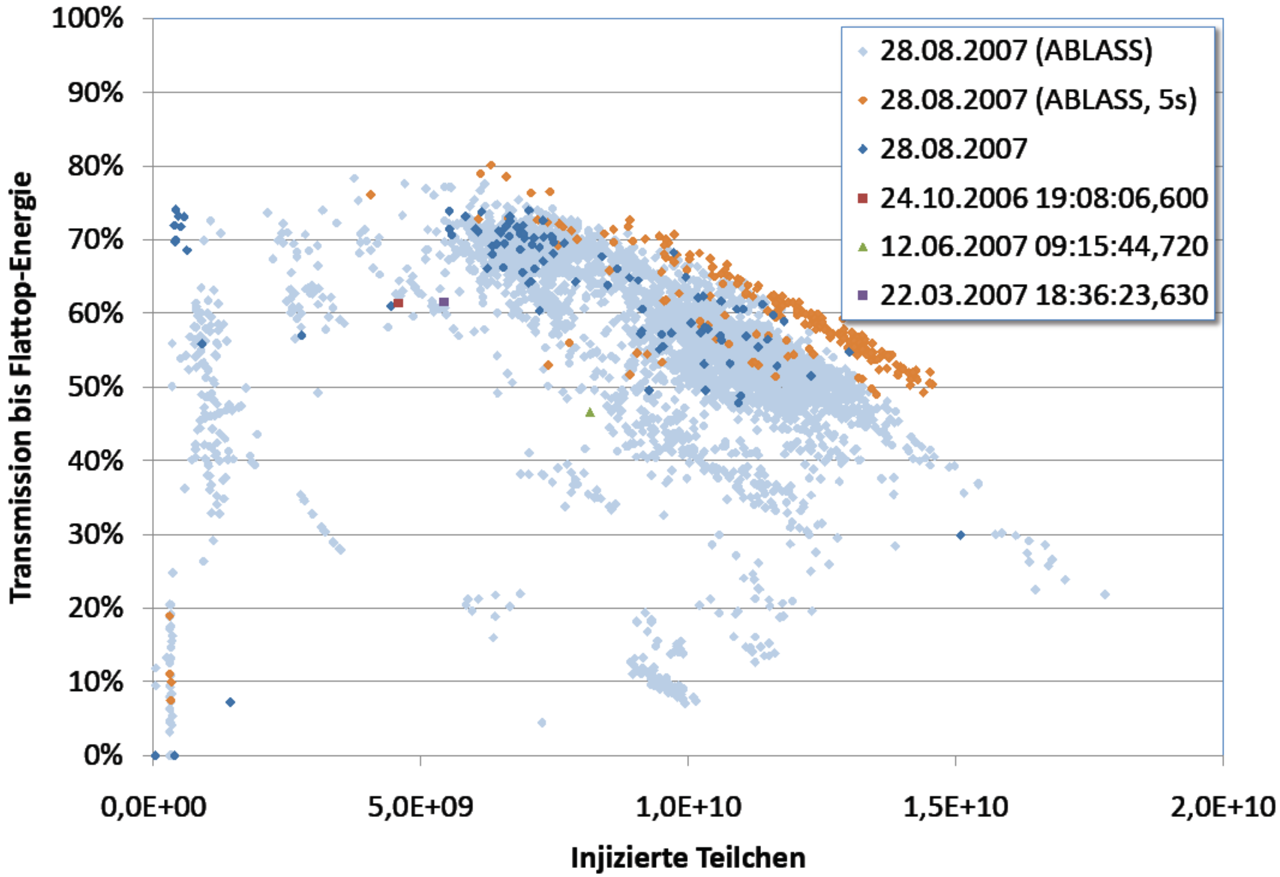
  e.g. multi-turn injection in dedicated

  collimation systems



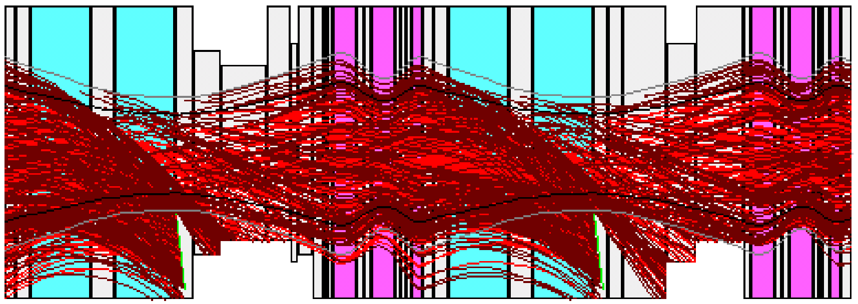


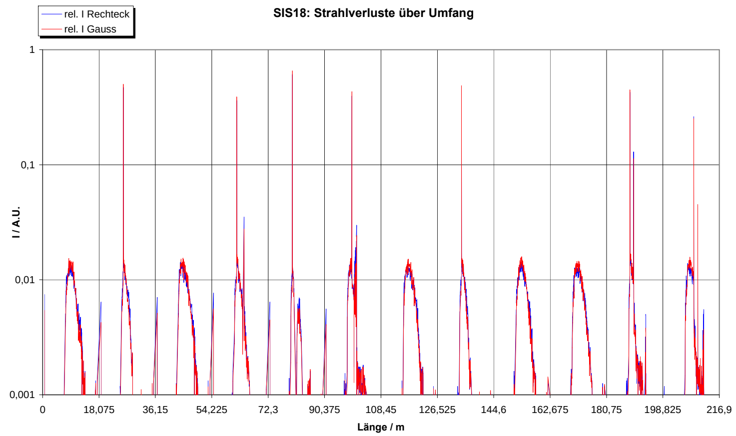
Transmission of U^{28+}



Minimization of ionization beam loss during low charge state heavy ion operation requires an optimized machine setting without initial systematic beam loss

Charge Scraper System



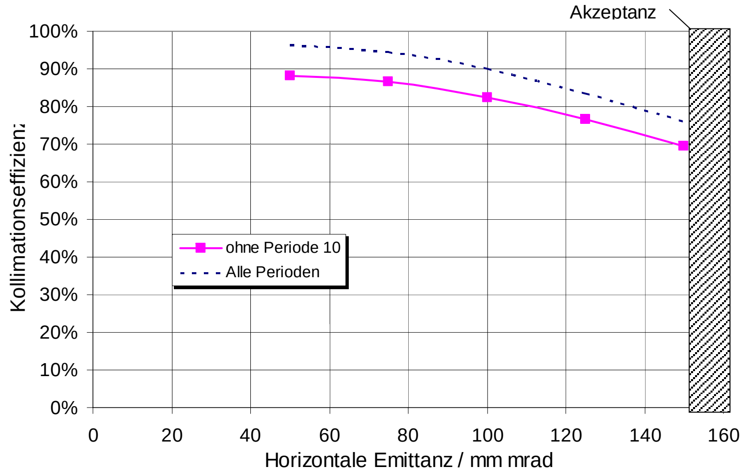


Ionization beam loss in section 11,12

Beam loss distribution $U^{28+} > U^{29+}$

- **Developed for heaviest ions (highest ionization cross sections)**
- **Loss positions for lighter ions are different**
- **Triplet/ doublet structure is suitable but: bending power of dipoles to high > Limited collimation efficiency**

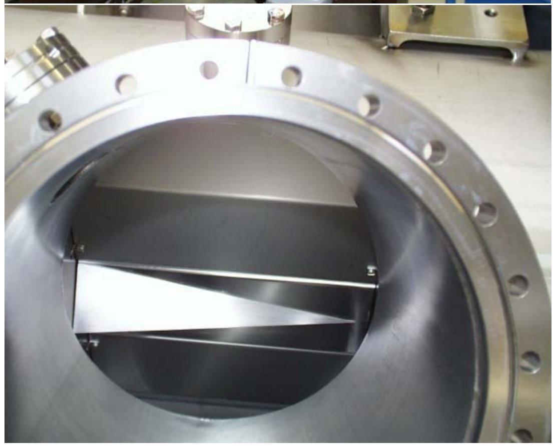
talk: C. Omet

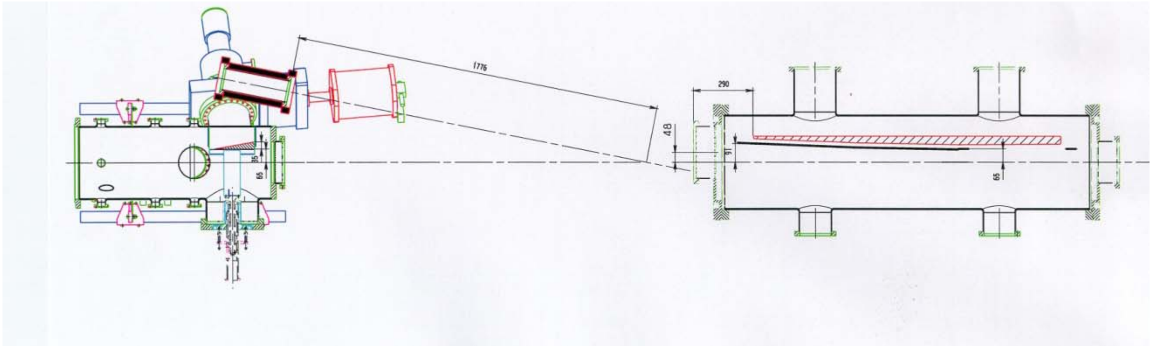


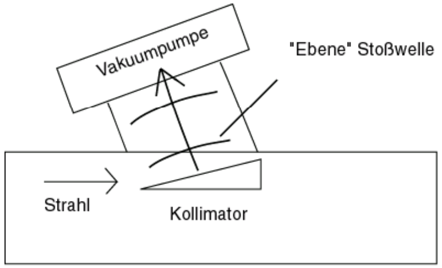
Collimation efficiency $U^{28+} > U^{29+}$

S12 Wedge Scraper for Septum Protection

Wedge shaped scraper + secondary chamber + cryo- or NEG pumping



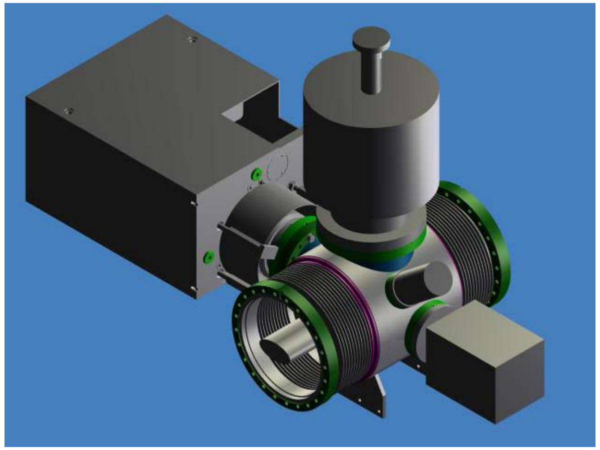




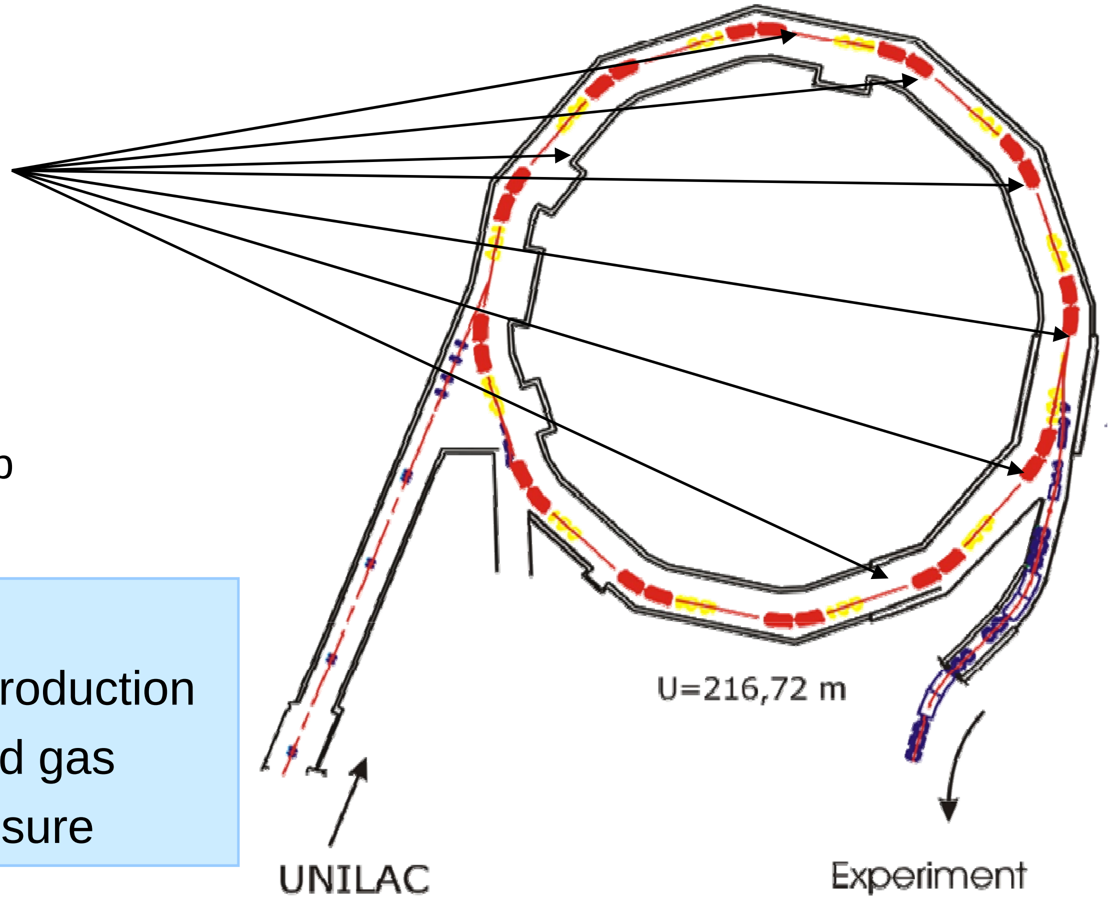
The collimation system has to confine the desorption gases or supress production of them ($\eta_{eff} = 0$)

Additional collimator is planned to controle and concentrate the multi-turn injection loss

SIS18 Charge Scraper System



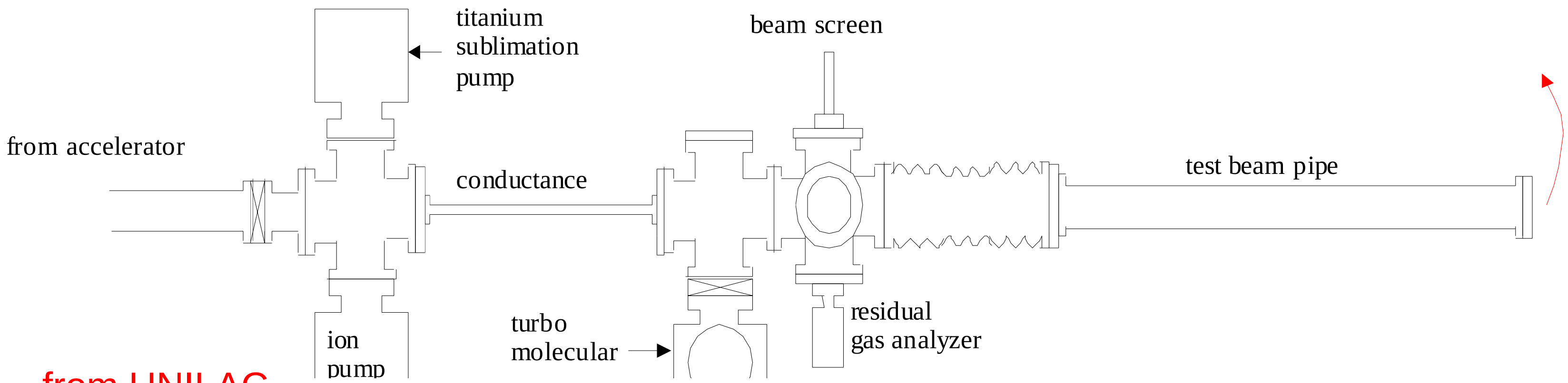
Installation behind each dipole group



Goals:

- Minimization of desorption gas production
- Capture and removal of desorbed gas
- Stabilization of the dynamic pressure

Desorption Teststand and ERDA measurements



from UNILAC

- **Desorption yield measurements with different materials and coatings**

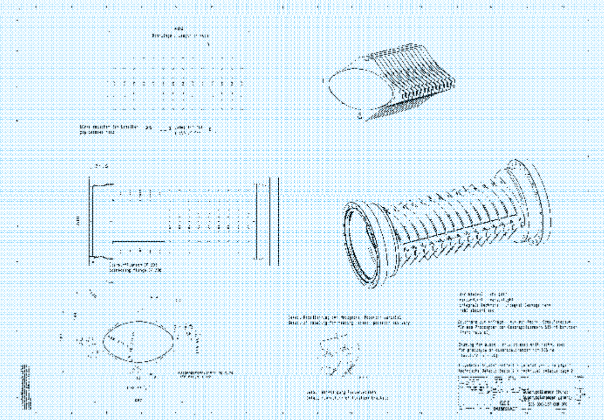
  NEG- and Cryo surfaces
- **Measurements at low (HLI), intermediate (UNILAC) und high beam energies (SIS)**
- **ERDA studies on the diffusion process in the bulk of matter**

Signficant progress on the reduction of desorption yield reachedProposal for low desorption yield materials and coating

UHV system upgrade

- Generation of extremly low static pressures of $p_0 < 5x10^{-12}$ mbar and increased average pumping speed by up to a factor of 100
- Stabilization of dynamic pressure to $p(t)_{max} < 10^{-9}$ mbar
- Removement of contamination with heavy residual gas components

- **Replacement of all dipole- and quadrupole chambers by new, NEG coated chambers**
- **Improved bake-out system for operation up to 300K**



UHV system upgrade

Project Status

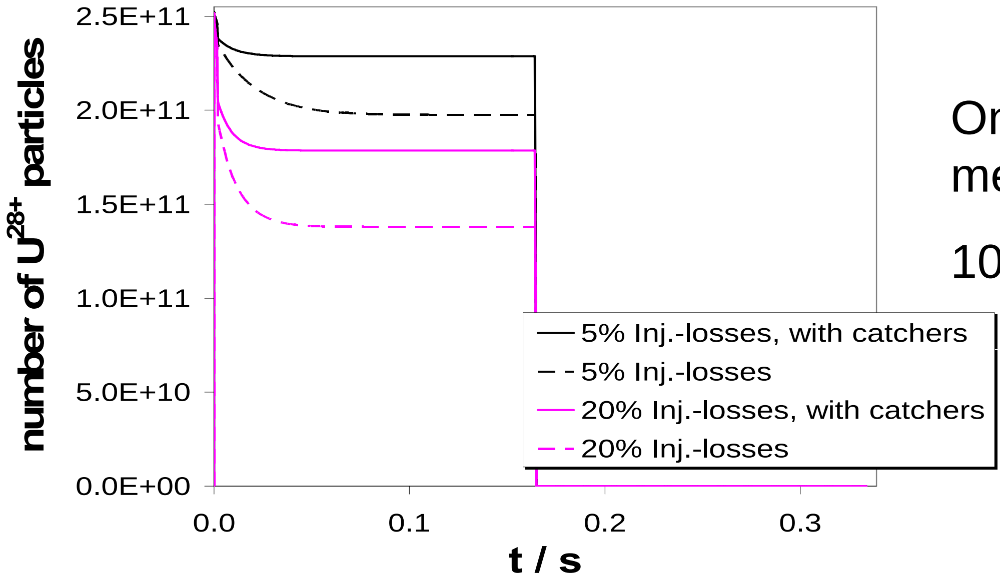
- NEG coating facility successfully commissioned at GSI

  NEG coating know-how acquired

- Manufacturing of new dipole chambers completed
- Upgrade of bake-out system for a temperature of 300°C completed
- First SIS sector with new, coated dipole and quadrupole chambers equipped
- Replacement of further dipole chambers (northern arc - 10 pieces) in the 2007 shut down
- Manufacturing of quadrupole chambers in BINP in preparation (difficult)

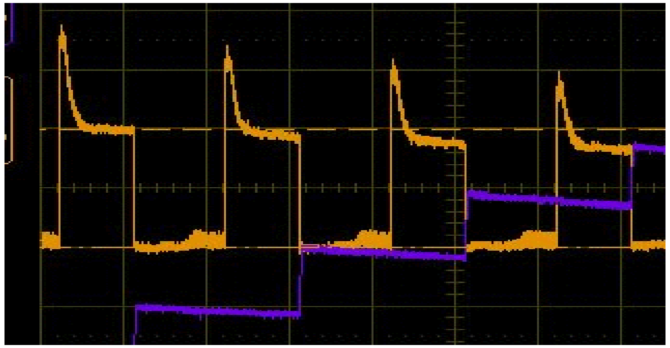
SIS18 – High Intensity U^{28+} Operation

Final U^{28+}- booster operation



Only the combination of the upgrade measures leads to the desired result !

10^{11} U-ions per cycle



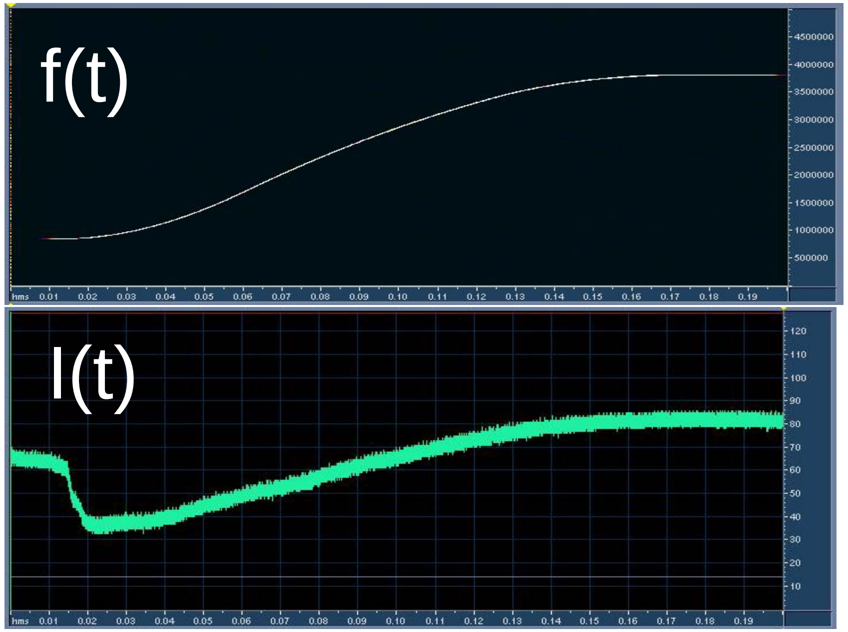
AGS Booster operation with electron capture dominated beam loss on a level of 10^9 Au-ions / cycle

Fast Ramped Operation

Acceleration test in 2001

with special power connection

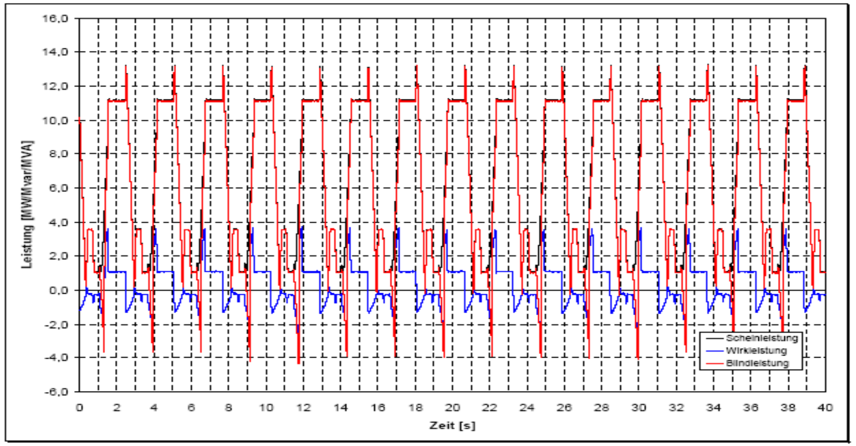
Au^{65+}-beam: E= 250 MeV/u, dB/dt= 5.5 T/s



- Transition triplett > Doublet focussing
- Loss at beginning of magnet ramp
- Shift of radial position – Tracking errors ?

Fast ramping test in 2006

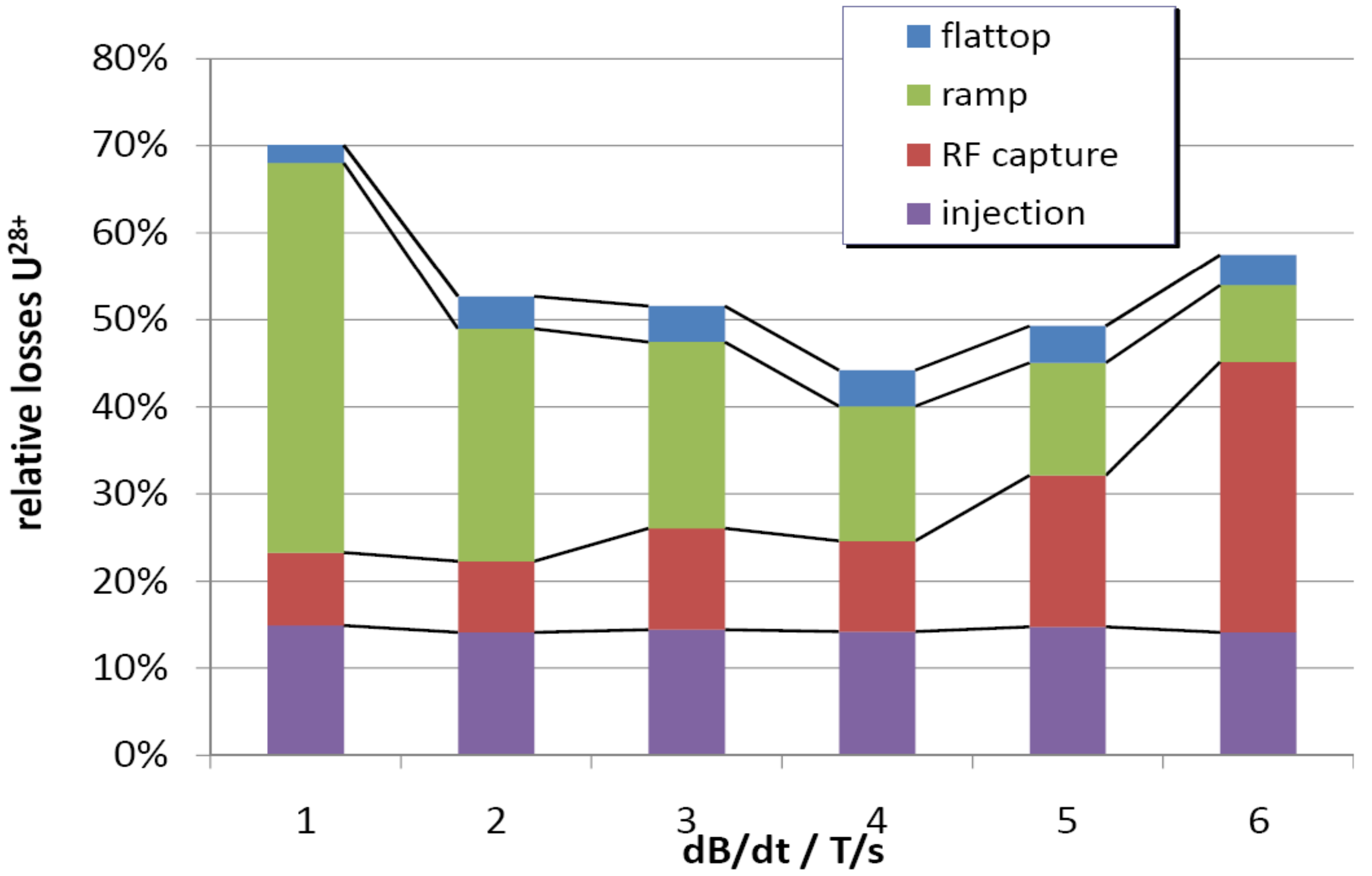
with new power connection and 10 T/s



Verlauf Wirk- und Blindleistung Transformator (23.10.06 18:00 Uhr)

- No undesirable interaction measured by HSE in the 20 kV/110kV nor by RWE in the 220/380 kV grid.
- Strong voltage variation in the GSI internal 20 kV grid

U^{28+} Beam Loss at High Ramp Rates



C. Omet

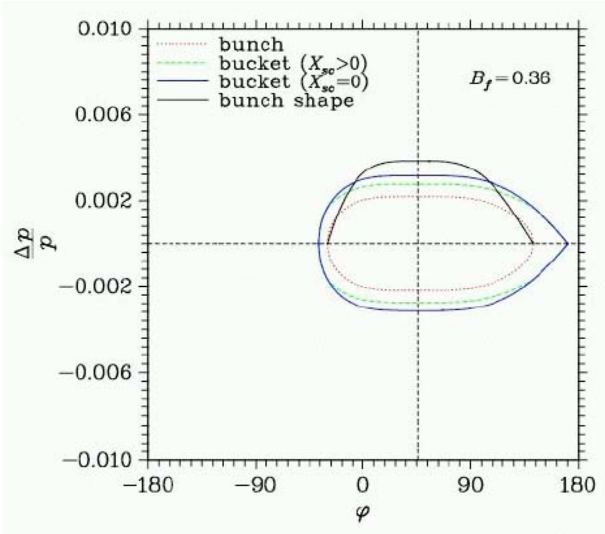
Fractional loss of different mechanisms during fast ramping

New h=2 Acceleration System

- **Sufficient Rf voltage for fast ramping with low charge state heavy ions**

  U^{73+} acceleration with 4 T/s ($2x10^{10}$ ions)

  U^{28+} acceleration with 10 T/s ($2.5x10^{11}$ ions)



- **Sufficient bucket area for low loss acceleration**

- **Flat bunch profile (high Bf) for lower inc. tune shift**

  Two harmonic acceleration

  h=4 (existing cavity) and h=2 (new Kavität)

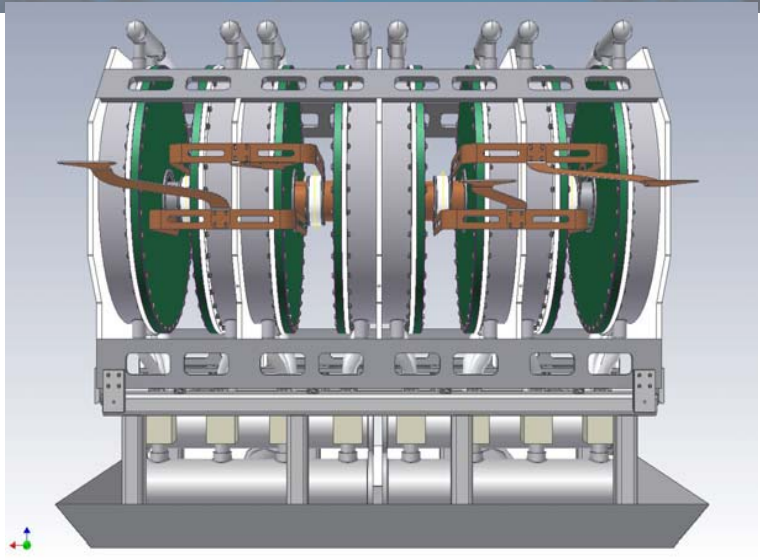
- **Compatibility with SIS100 Rf cycle**

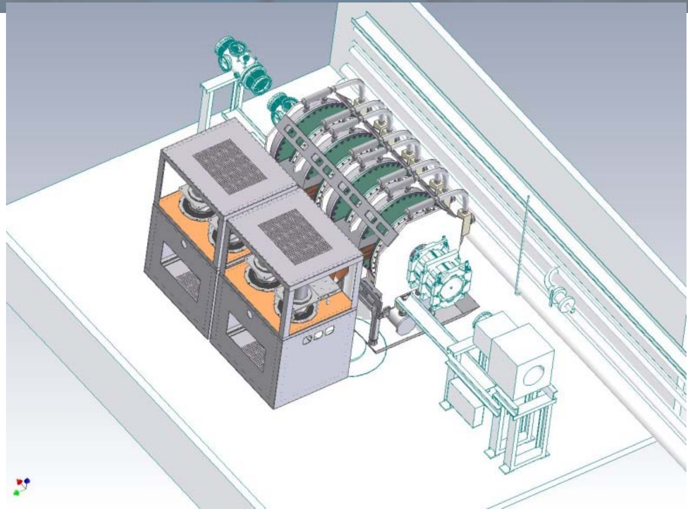
  (Transition from two-harmonics to one harmonics during ramping)

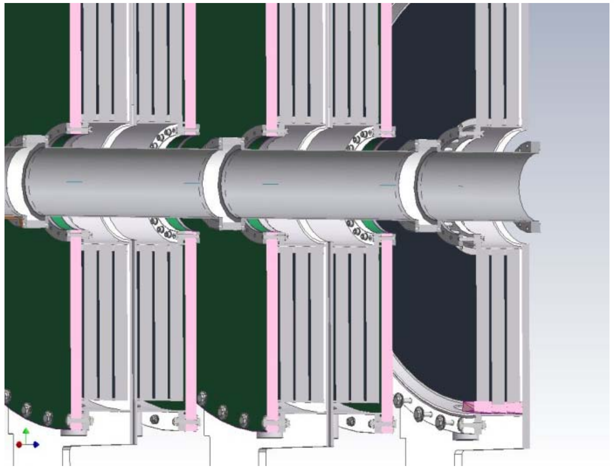
- **No long. feed back system required in SIS18 (OBF)**

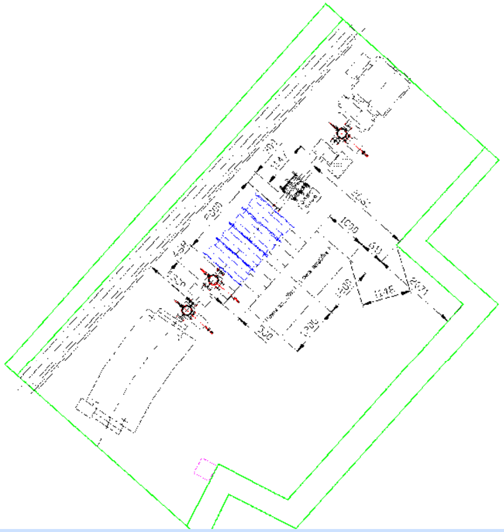
- **50 kV – high power requirements – additional space provided in tunnel**

New h=2 Acceleration System









S01

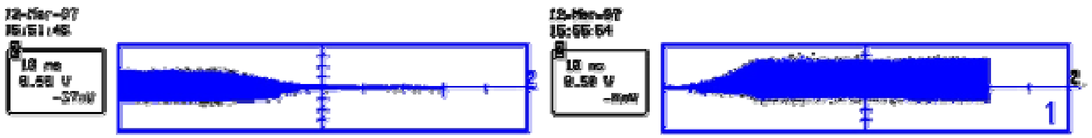
P. Hülsmann,

H. Klingbeil
et.al.

Design studies for the new, high duty cycle MA loaded, h=2 acceleration cavities

Coasting Beam Instability

Cavity Impedance: 3 kOhm – Resistive Wall Impedance: 1.5 kOhm

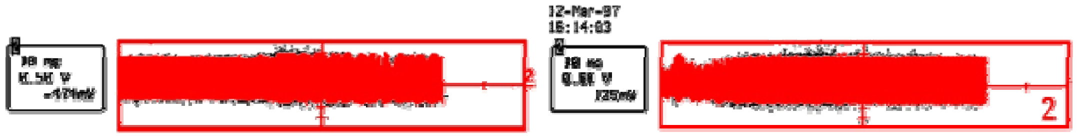


10^9 Ne-ions

Bunch Amplitude before Debunching (h=4)

Niedriger Strom

Bunch Amplitude after Rebunching (h=1)



10^{10} Ne-ions

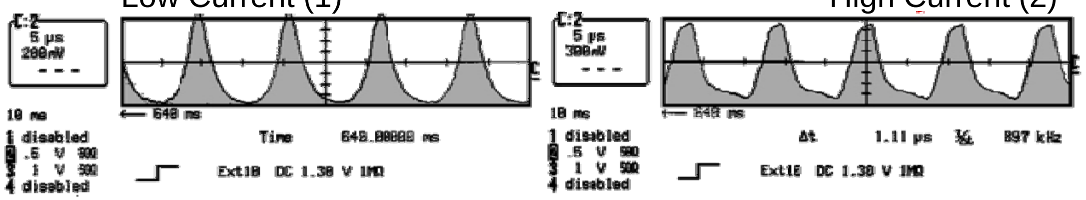
Bunch Amplitude before Debunching (h=4)

Hoher Strom

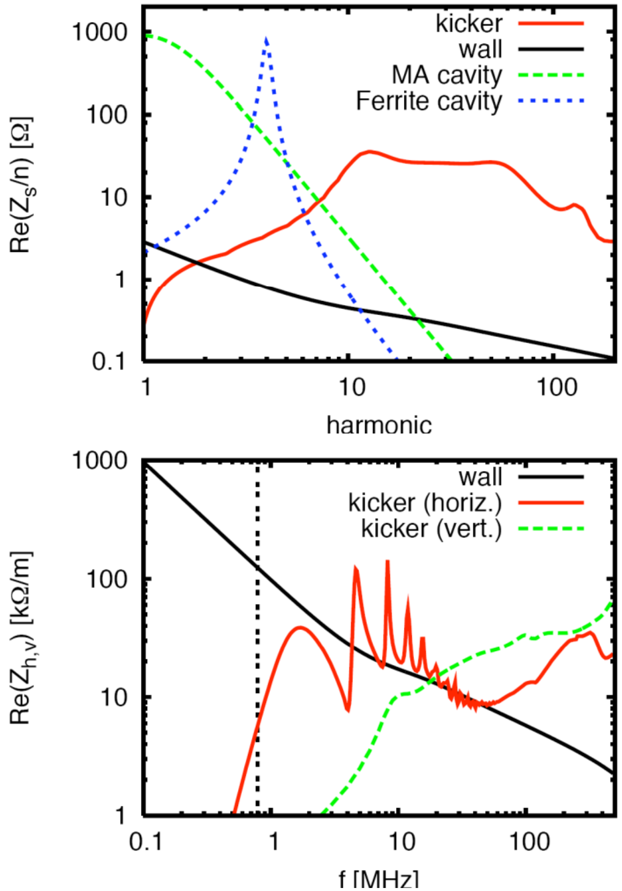
Bunch Amplitude after Rebunching (h=1)

Final Bunch Profil at Low Current (1)

Final Bunch Profil at High Current (2)

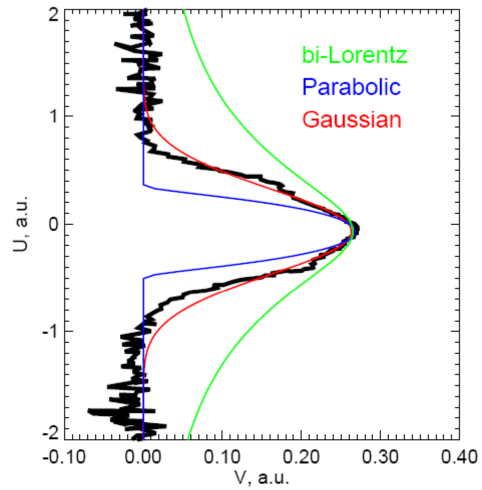


Impedance and Beam Stability



Measurement of

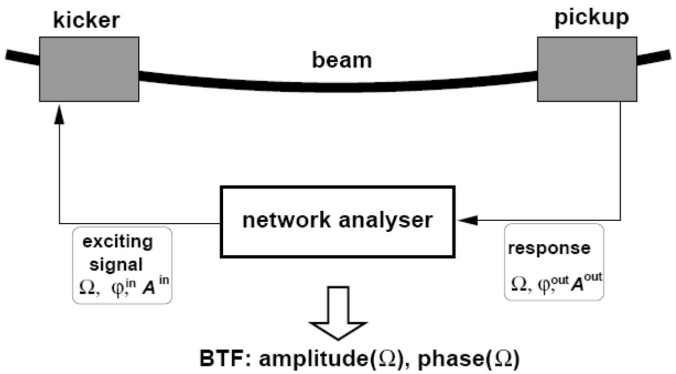
- Beam stability diagram
- Betatron tune Q,
- Chromaticity ξ
- Momentum spread dp/p



O. Boine-Frankenheim,

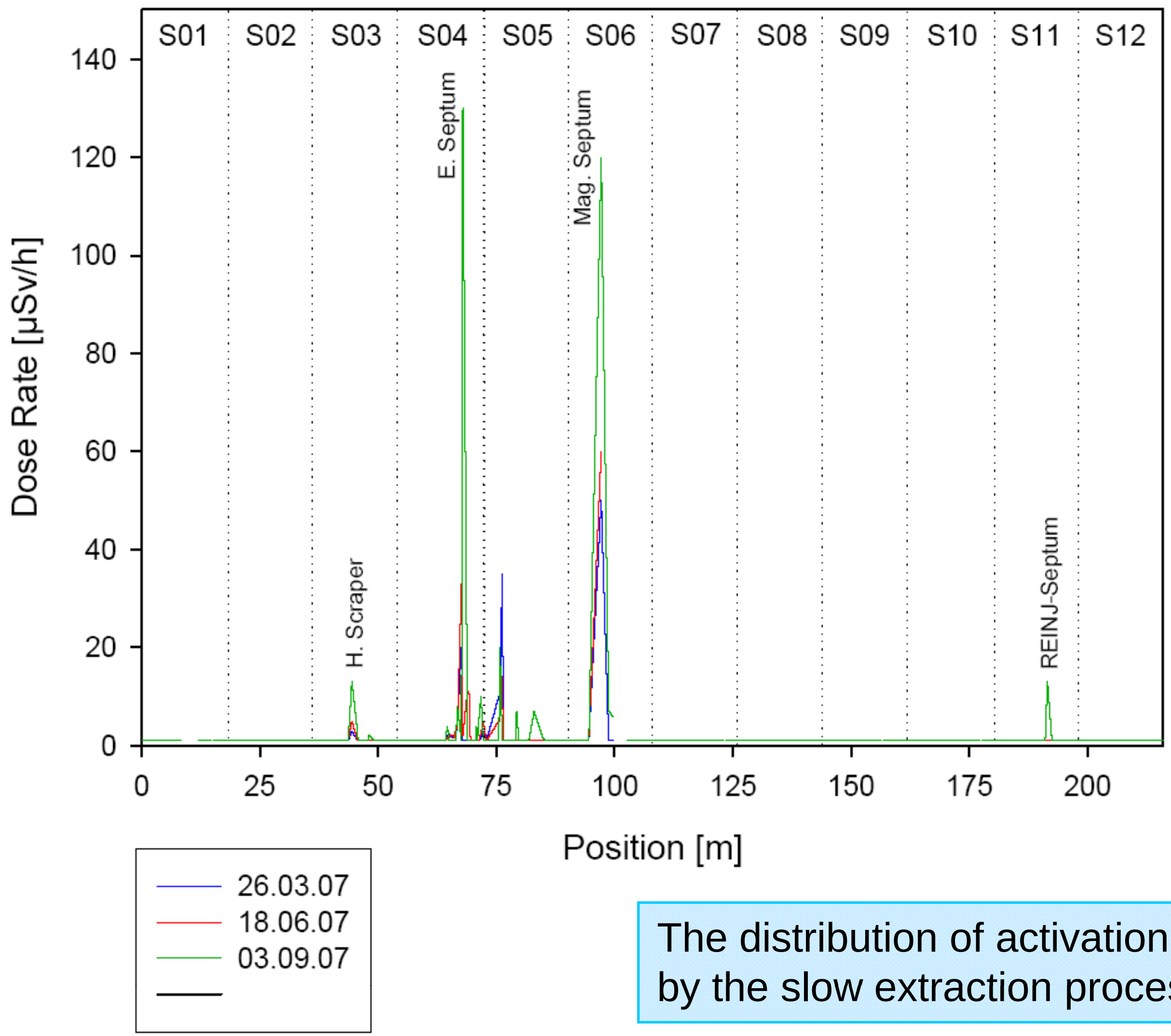
V. Kornilov,

I. Hofmann et.al.



Goal: Determination of impedance spectrum - Measurement of kicker- and resistive wall impedance and their influence on beam stability

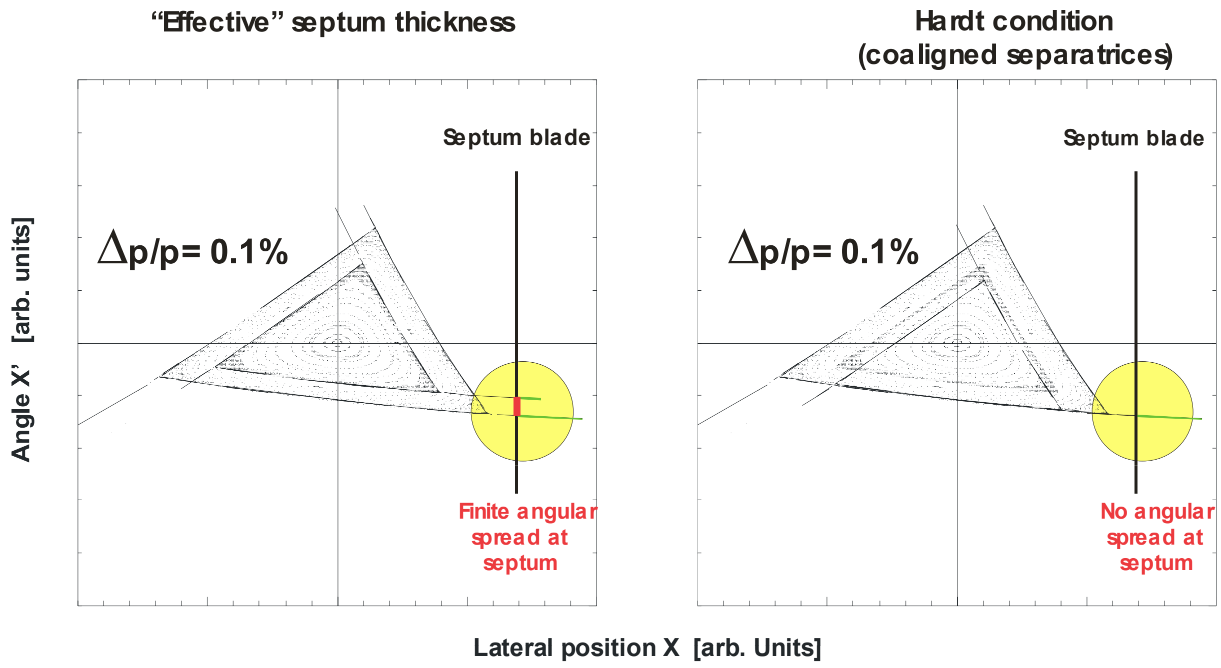
Activation



The distribution of activation is presently dominated by the slow extraction process

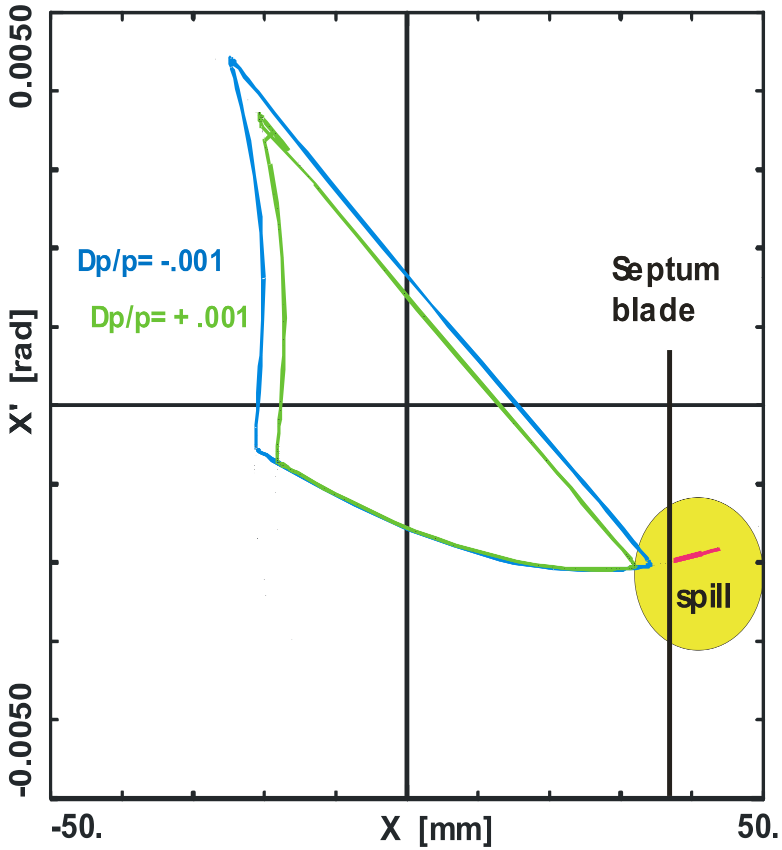
Beam Loss at Slow Extraction

Hardt condition: $D_n \cos(\alpha - \Delta\mu) + D_{n'} \sin(\alpha - \Delta\mu) = -4\pi (Q' / S)$



D_n	**Dispersion at ES**
$D_{n'}$	**Derivative of dispers.**
α	**Orientation separatrix at sextupole**
$\Delta\mu$	**Phase advance sextupole - ES**
Q'	**Chromaticity**
S	**Sextupole strength**

Beam Loss at Slow Extraction



Hardt condition realized

(via chromaticity control)

thus minimum beam loss

First experiment at SIS18

Extraction efficiency raise

from 83 to 93%