SIS18upgrade Measures

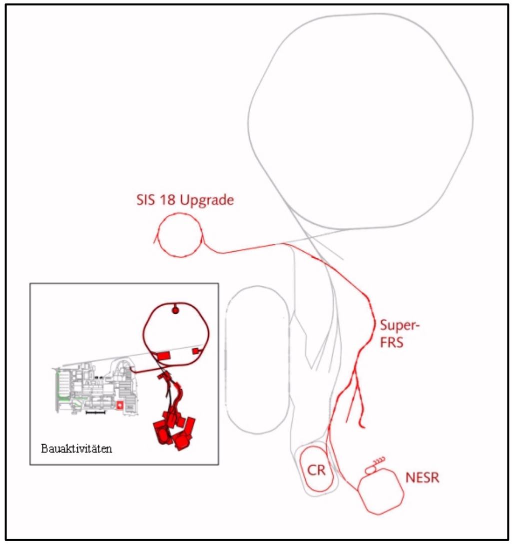
Peter Spiller

MAC meeting

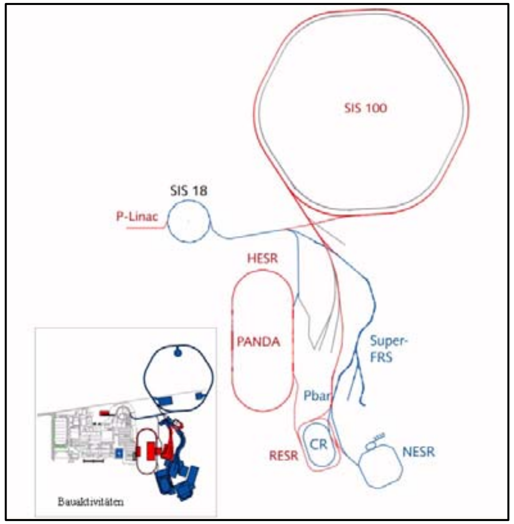
3.3.2009

Role of SIS18 in FAIR - Stages

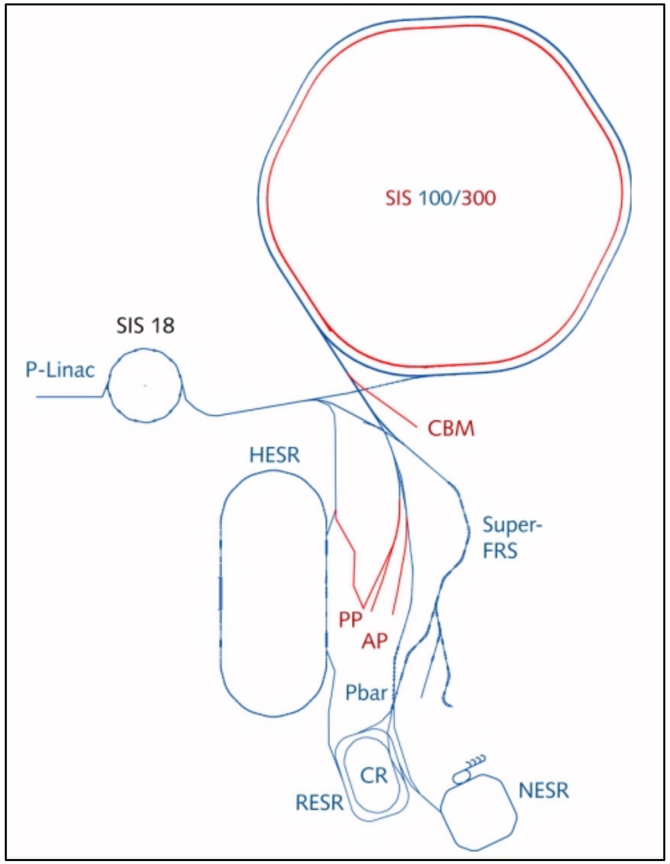
Stage 1



Stage 2



(Stage 3)



not part of startversion

Intensity Requirements for FAIR

Fair Stage	Today	Stage 0 (Existing Facility after upgrade)	Stage 1 (Existing Facilty supplies Super FRS, CR, NESR)	Stage 2 (SIS100 Booster)
Reference Ion	U^{73+}	U^{73+}	U^{73+}	U^{28+}
Maximum Energy	1 GeV/u	1 GeV/u	1 GeV/u	0.2 GeV/u
Maximum Intensity	$4x10^{9}$	$2x10^{10}$	$2x10^{10}$	$2x10^{11}$
Repetition Rate	0.3 - 1 Hz	1 Hz	1 Hz	2.7 Hz
Approx. Year		2009/2010	2011/2012	2012/2013

Intensity Requirements for FAIR

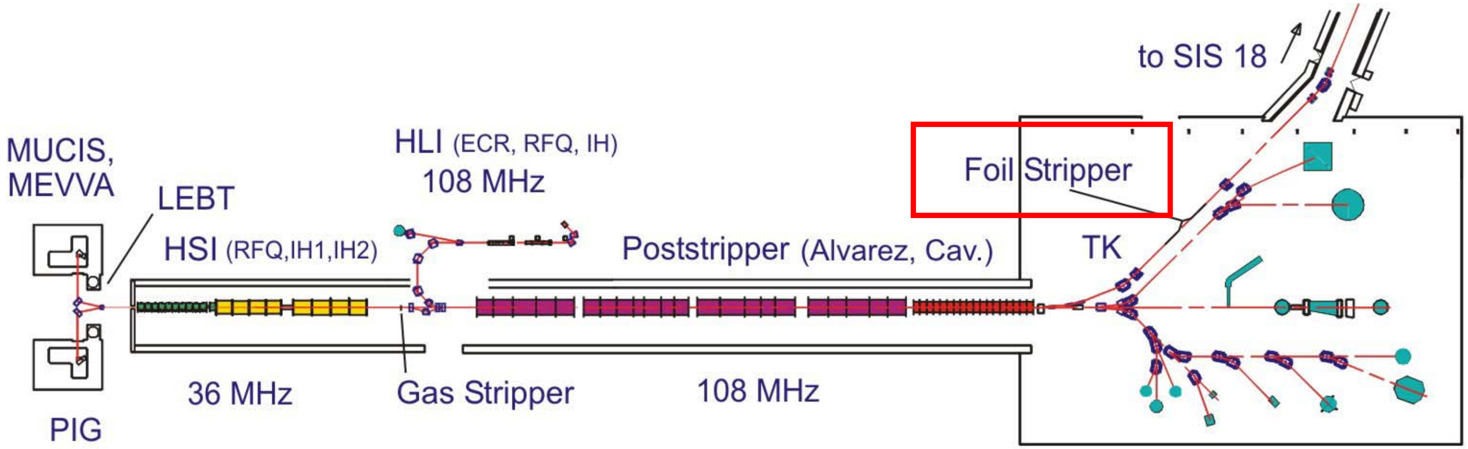
FAIR intensity goals can only be reached by lowering the charge states

Incoherent tune shift limits the maximum intensity in SIS18

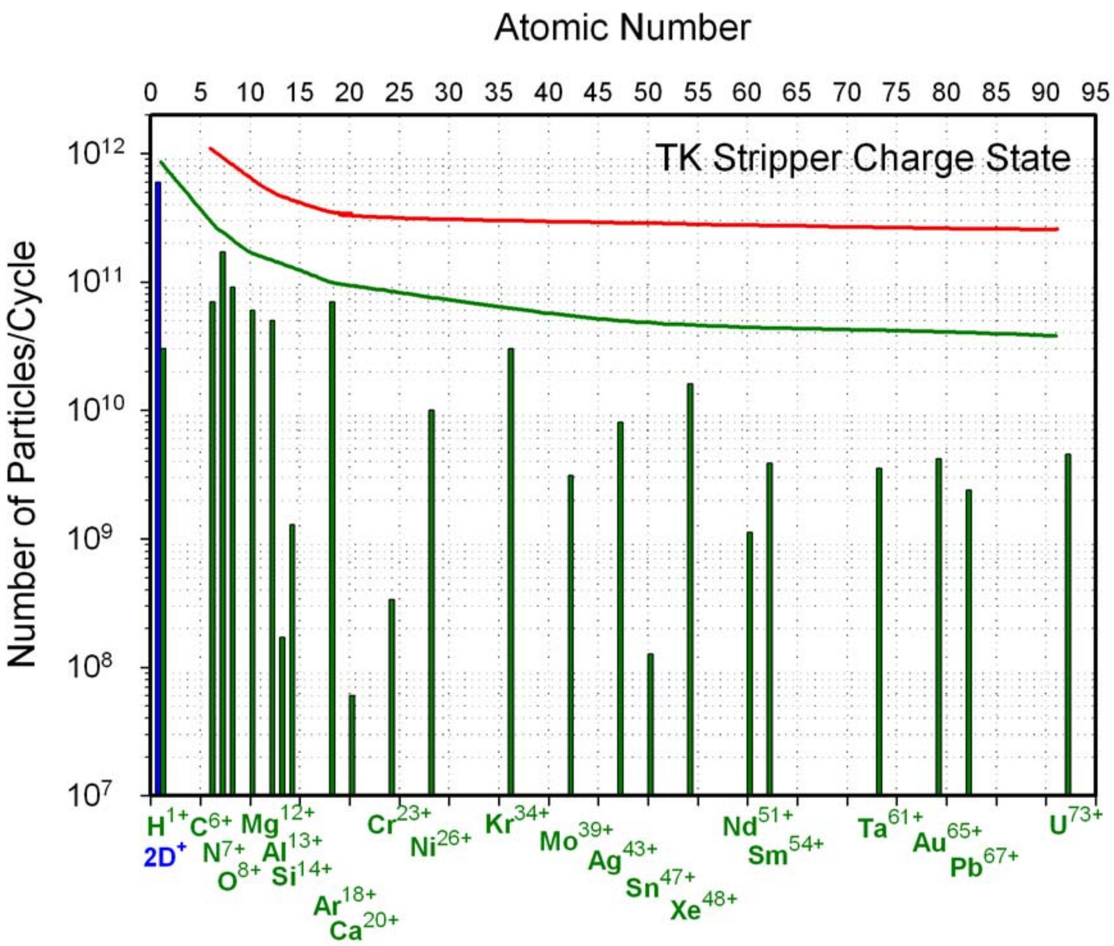
$-dQ \propto Z^2/A$ > Poststripper charge states will be used

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

No stripping loss (charge spectrum) in the transfer channel ($N_{uranium}$ x7)



Intensities - Status and Goals



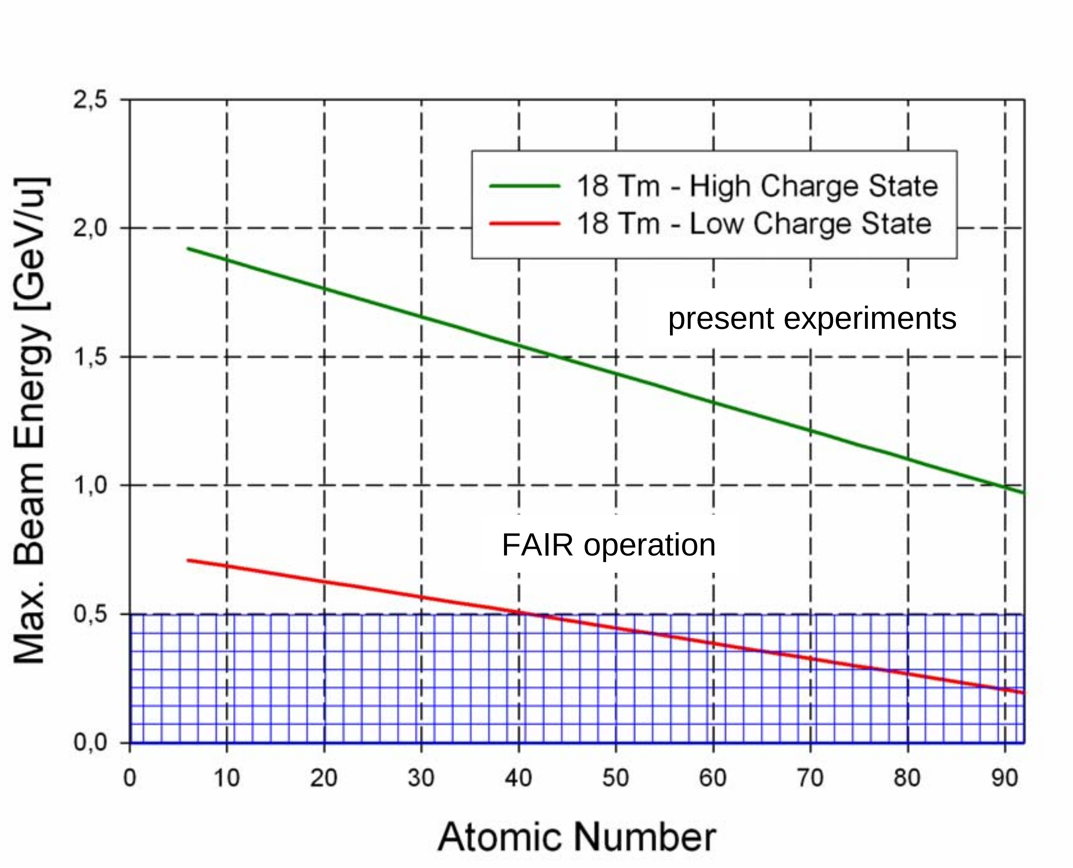
Space charge limit for intermediate chage state ions (without TK stripper)

Space charge limit for high charge state ions

(with TK stripper)

At present: High charge state operation (generated by transfer channel stripper)

Beam Energy



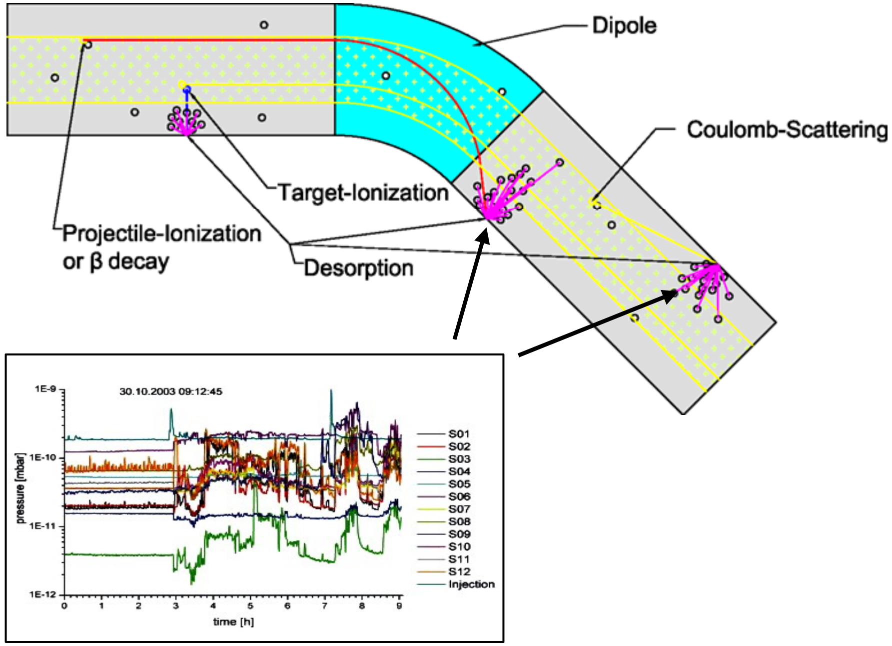
Range for RIB production

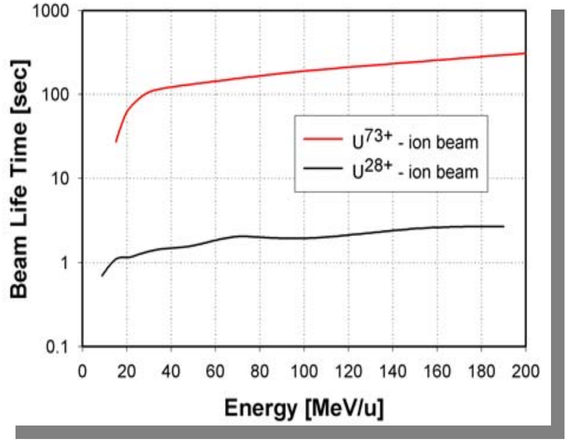
Equilibrium Charge States

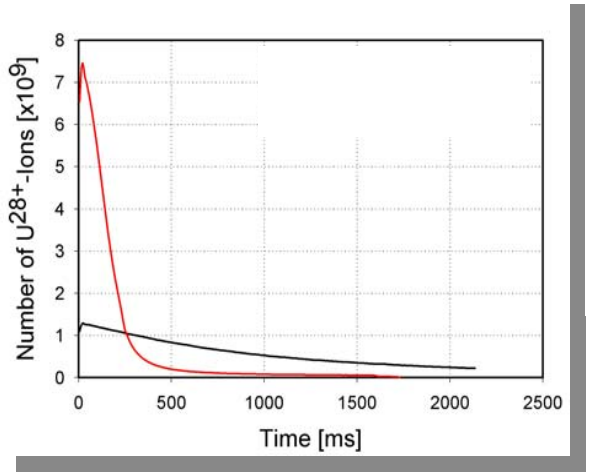
Ion	charge states with/ without TK stripper	equilibrium charge state SIS18 inject.	equilibrium charge state SIS18 extract.	equilibrium charge state SIS100 extrac.
$^{20}_{10}Ne$	7+	10+ (0,0114)	10+ (1,22)	10+ (9,50)
	10+	10+ (0,0114)	10+ (1,99)	10+ (13,95)
$^{40}_{18}Ar$	10+	17+ (0,0114)	18+ (0,75)	18+ (6,63)
	18+	17+ (0,0114)	18+ (1,76)	18+ (12,60)
$^{58}_{28}Ni$	14+	25+ (0,0114)	28+ (0,69)	28+ (6,27)
	26+	25+ (0,0114)	28+ (1,72)	28+ (12,37)
$^{84}_{36}Kr$	16+	31+ (0,0114)	36+ (0,49)	36+ (4,87)
	34+	31+ (0,0114)	36+ (1,65)	36+ (11,99)
$^{132}_{54}Xe$	21+	42+ (0,0114)	54+ (0,36)	54+ (3,95)
	48+	42+ (0,0114)	54+ (1,31)	54+ (10,06)
$^{181}_{73}Ta$	24+	51+ (0,0114)	72+ (0,26)	73+ (3,15)
	61+	51+ (0,0114)	73+ (1,17)	73+ (9,21)
$^{197}_{79}Au$	24+	54+ (0,0114)	78+ (0,22)	79+ (2,83)
	64+	54+ (0,0114)	79+ (1,11)	79+ (8,85)
$^{238}_{92}U$	28+	59+ (0,0114)	90+ (0,20)	92+ (2,71)
	73+	59+ (0,0114)	92+ (1,02)	92+ (8,30)

energy in brackets

Ionization Beam Loss and Dynamic Vacuum



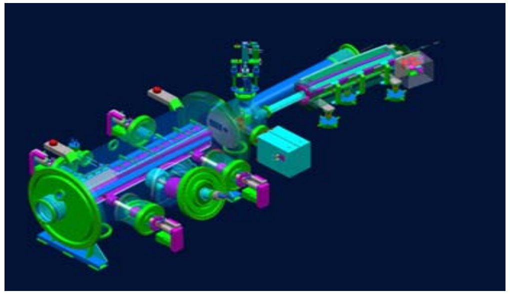




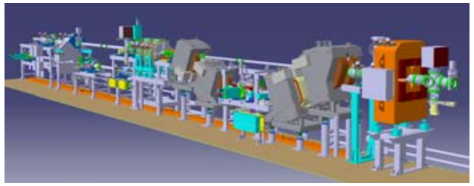
Main Issue of the Booster Operation:

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

SIS18upgrade Program

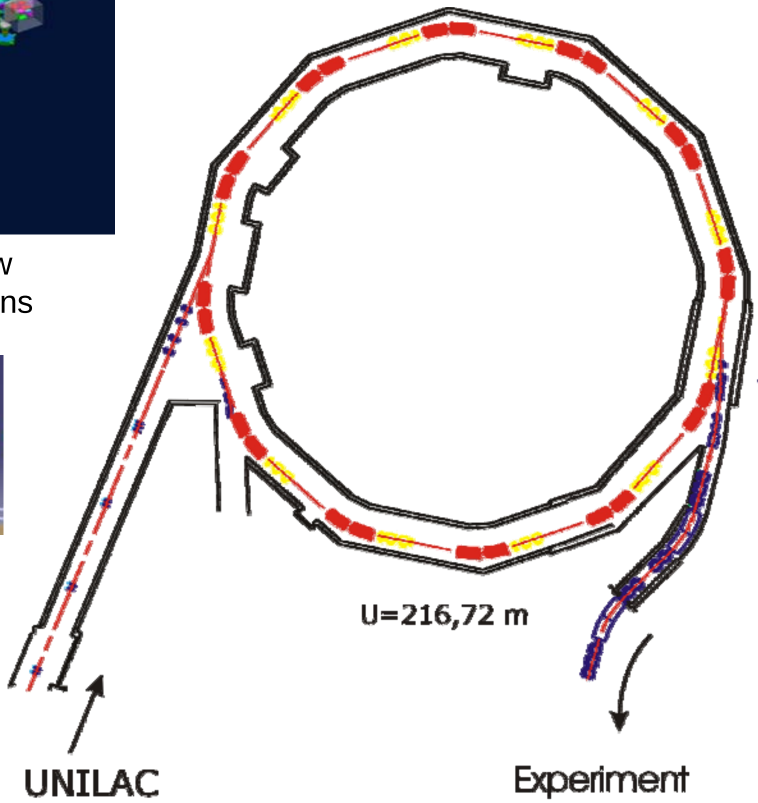


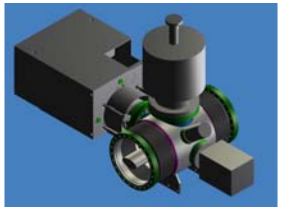
Injection system for low charged state heavy ions



Charge separator for higher intensity and high quality beams

Power grid connection





Scrapers and NEG coating for pressure stabilization

h=2 acceleration cavity for faster ramping

The SIS18upgrade program: Booster operation with intermediate charge state heavy ions

SIS18 upgrade Goal: Pressure Stabilization

- Short cycle times and short sequences

  SIS18: 10 T/s - four batch sequence for SIS100 injection

  (new power connection, power converters and Rf system)

- Enhance pumping power (UHV upgrade)

  (NEG-coating - local and distributed)

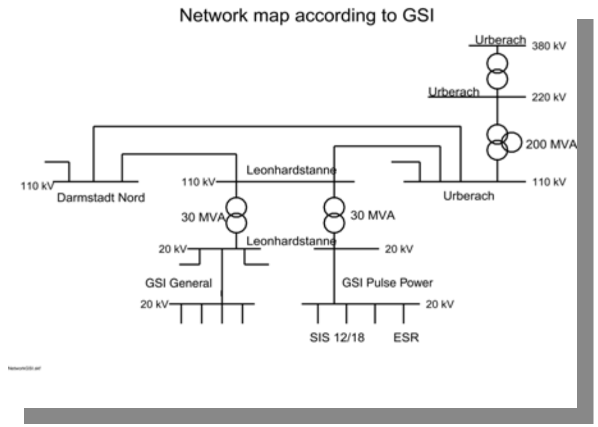
  (new magnet chambers, improved bake out system)

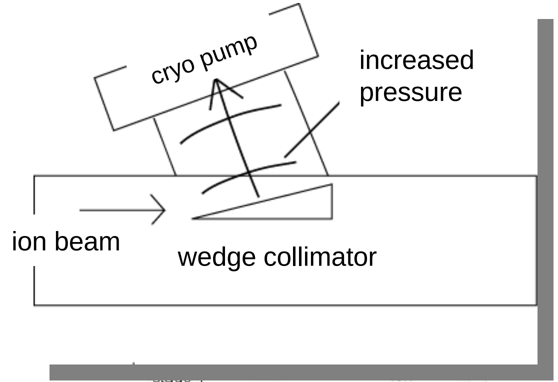
- Localizing beam loss and controle/suppression of desorption gases

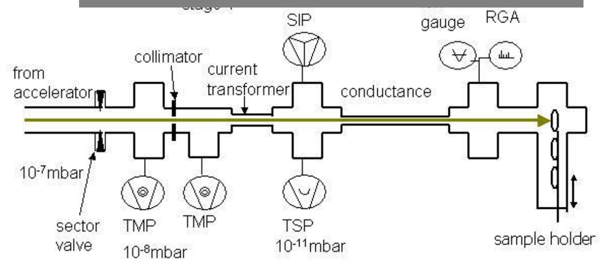
  (Catcher system)

- Materials with low desorption yields

  η-Teststand, ERDA measurements,







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
  (2012)
- **Task 2: UHV System**
  New, NEG coated dipol- and quadrupole chambers
  (2009)
- **Task 3: Insertions**
  Set-up of a „low-desorption“ scraper system
  (2009)
- **Task 4: Injection / Extraction Systems**
  New, large acceptance injection system plus HV power suppy
  (2008)
- **Task 5: Beam Diagnostics Systems**
  Fast residual gas profile monitor and high current transformer
  (2009)
- **Task 6: Injector**
  Set-up of a TK charge separator
  (2008)

SIS18 upgrade program

Not supported by EU construction program:

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

- **Replacement of Main Dipole Power Supplies**
  Operation with 10 T/s up to 18 Tm
  (2012)

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

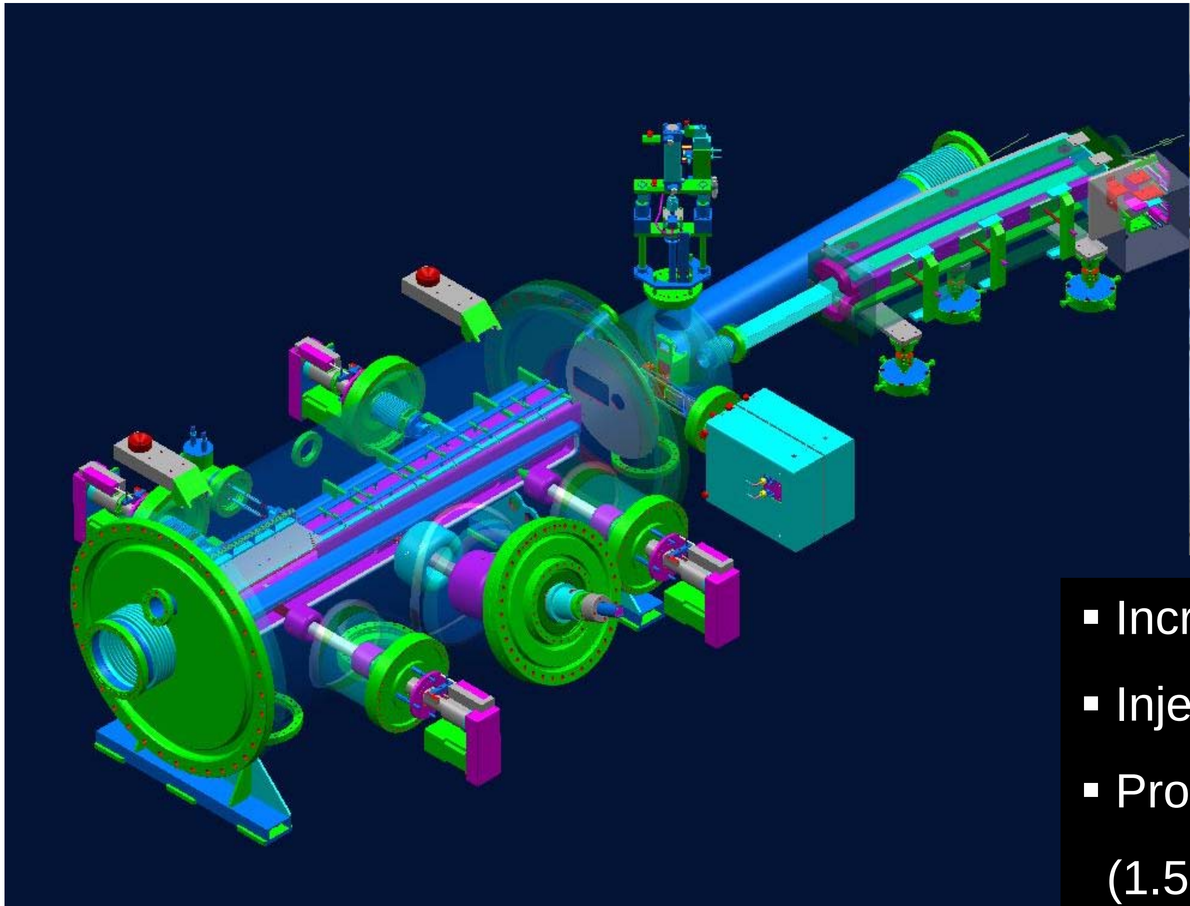
- **Beam Diagnostics upgrade**
  New digital front end electronics for BPMs (2009)
  New high current transformer (2006)

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

- **Development of High Current Operation**
  Compensation of resonances, impedance issues etc.
  (2009....)

.... and several others

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 new injection system

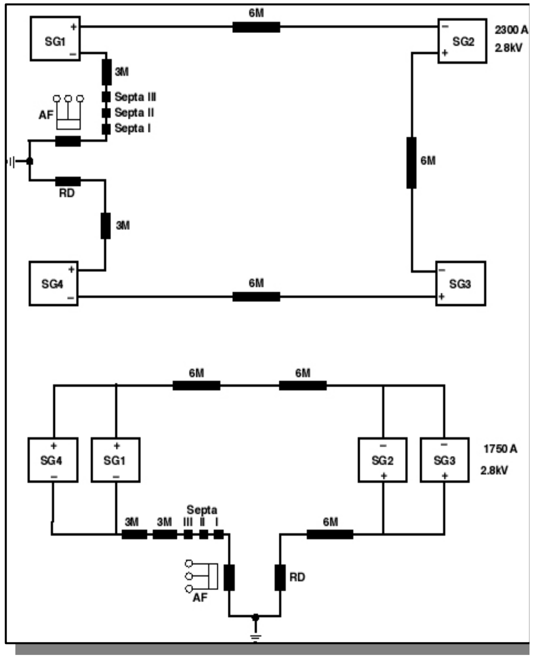
Project completed

Fast Ramping

High average beam intensity requires fast short cycle times with fast ramping.

- Shortening of cycle time (intermediate charge states)
- Higher repetition rate (booster operation 2.7)
- Increased average intensity (x 2-9)

Present Operation:
$dB/dt = 1.3$ T/s – 1/3 Hz



A. SIS18 Modus

B_{max}= 1.8 T - dB/dt = 4 T/s
I_{max} = 3500 A - V_{max} = 5.5 kV
2 groups each 2 parallel power converters
2 groups each 12 Dipole
$P_{\mathbf{max}}$ = +19/-17 MW

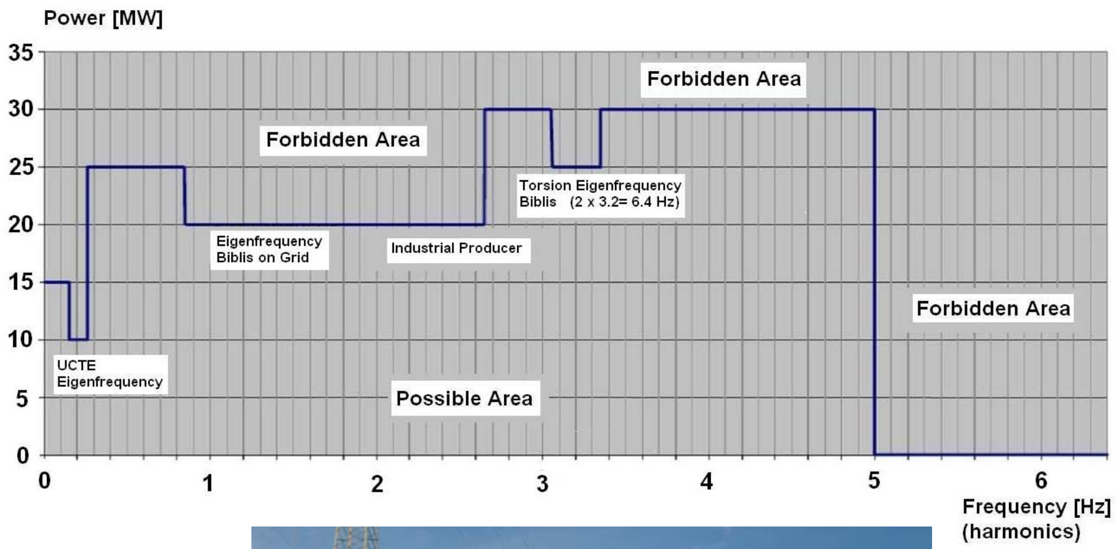
B. SIS12 Modus

B_{max} = 1.2 T - dB/dt = 10 T/s - I_{max} = 2300 A - V_{max} = 11.2 kV
4 in power converters in series supply 4 groups each 6 dipols
$P_{\mathbf{max}}$ = +26/-23 MW

(U^{73+} : E_{max} = 512 MeV/u)

Power converter upgrade for 10 T/s up to 18 Tm

New 110 kV Power Connection



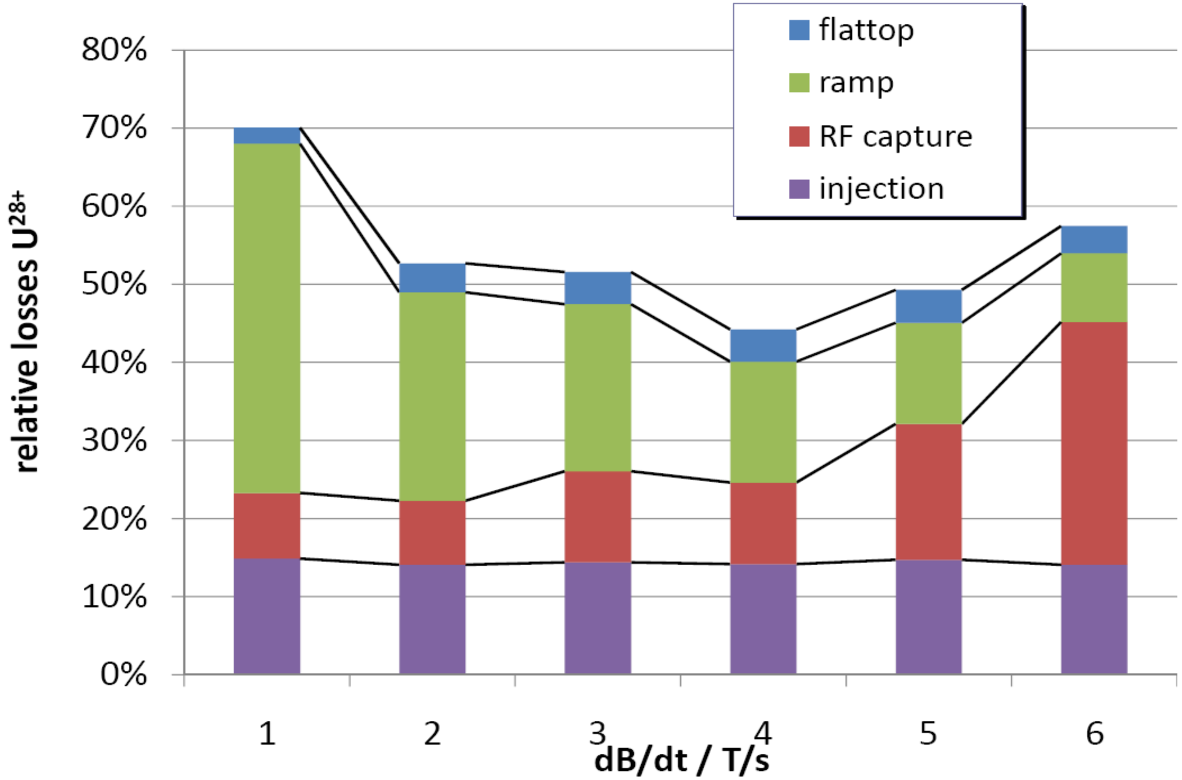
	Pulse Power	Field Rate
SIS18	5 MW	1.3 T/s
SIS12	+26 MW -17 MW	10 T/s
SIS18	+ 42 MW	10 T/s
SIS100	± 26 MW	4 T/s
SIS300	± 23 MW	1 T/s

- Study of electromechanical resonance (damping) of Biblis B generator shaft
- Measurements of torsion and power oscillation in the grid

Project completed

> H. Ramakers

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



- Ionization loss decreases with ramp rate
- RF capture loss increases with ramp rate

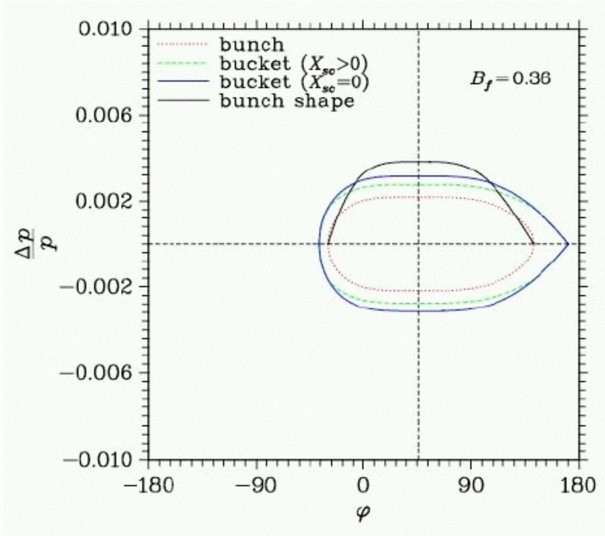
Fractional loss of different mechanisms during fast ramping

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 ($2x10^{11}$ ions)

- Sufficient bucket area for loss free acceleration
  (30 % safety)

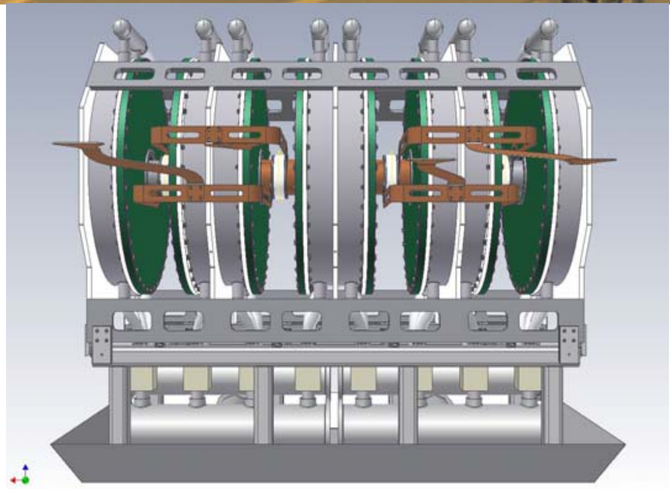
- Flat bunch profile (high Bf) for lower inc. tune shift
  two harmonic acceleration
  h=4 (existing cavity) and h=2 (new cavity)

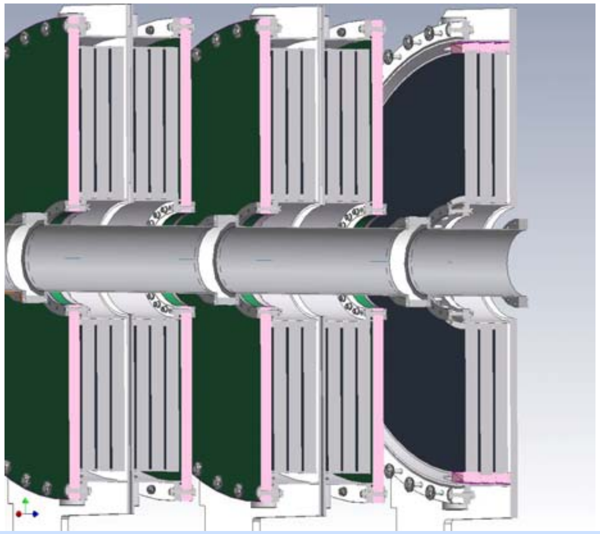


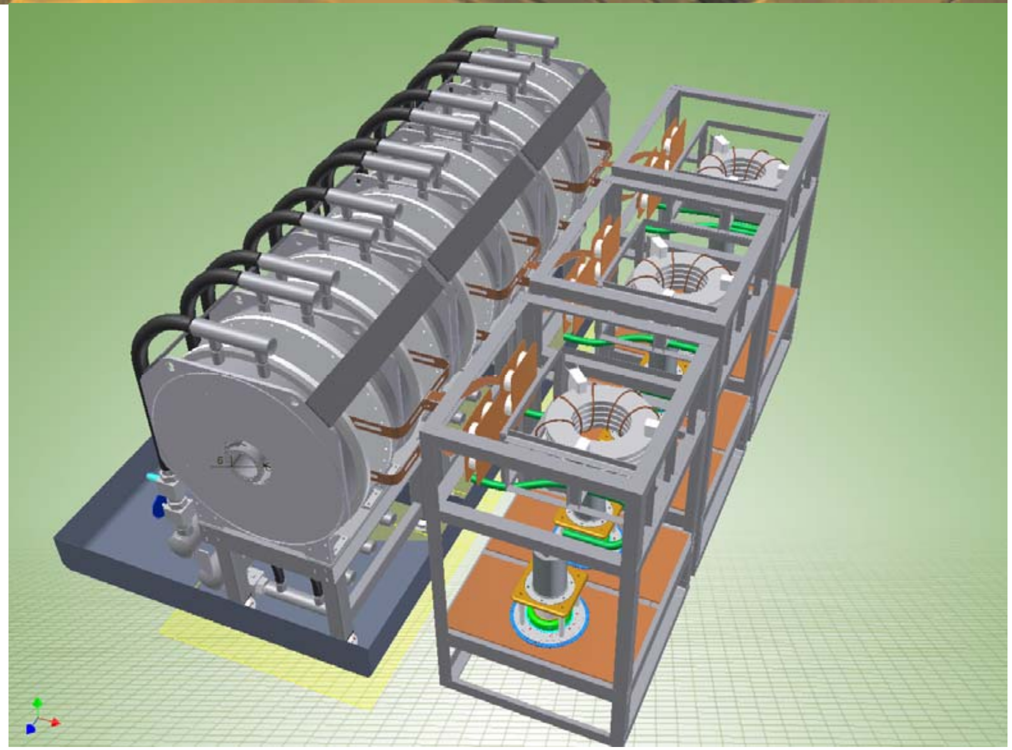
- Compatible with SIS100 RFcycle
  (Transition from two-harmonics to one harmonic during ramping at constant dB/dt)

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

New h=2 Acceleration System







Installation in 2012

P. Hülsmann,
H. Klingbeil

Design studies for the new, high duty cycle MA loaded, h=2 acceleration cavities (0.5 MHz - 50 kV)

Residual Gas Profile Monitor

***IPM:* High performance RGM for turn-by-turn readout *and* 0.1 mm resolution**
required for high current studies at SIS18/100/300, cooling studies at storage rings.

➢ **e^- or ions detection:**
- E-field $E \approx \pm 50$ V/mm, $\Delta E/E < 1\%$
- B-field for guidance $B \approx 30$ mT, $\Delta B/B < 1\%$
- MCP (100x40 mm^2)

➢ **High resolution mode:**
- 100 μm spatial resolution
- ≈ 10 ms time resolution

⇒ CCD readout

➢ **Turn-by-turn mode:**
- 1 mm spatial resolution
- ≈100 ns time resolution

⇒100 photo-detectors

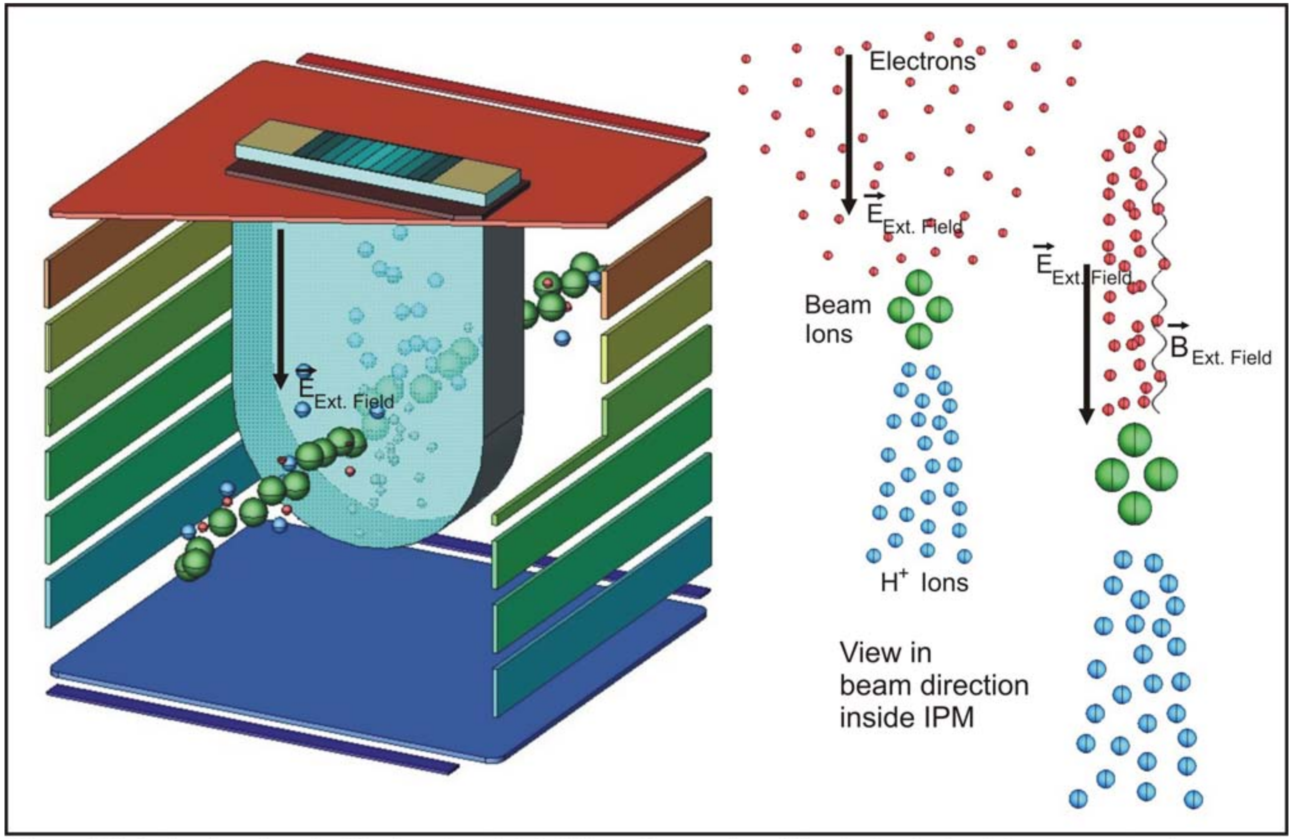


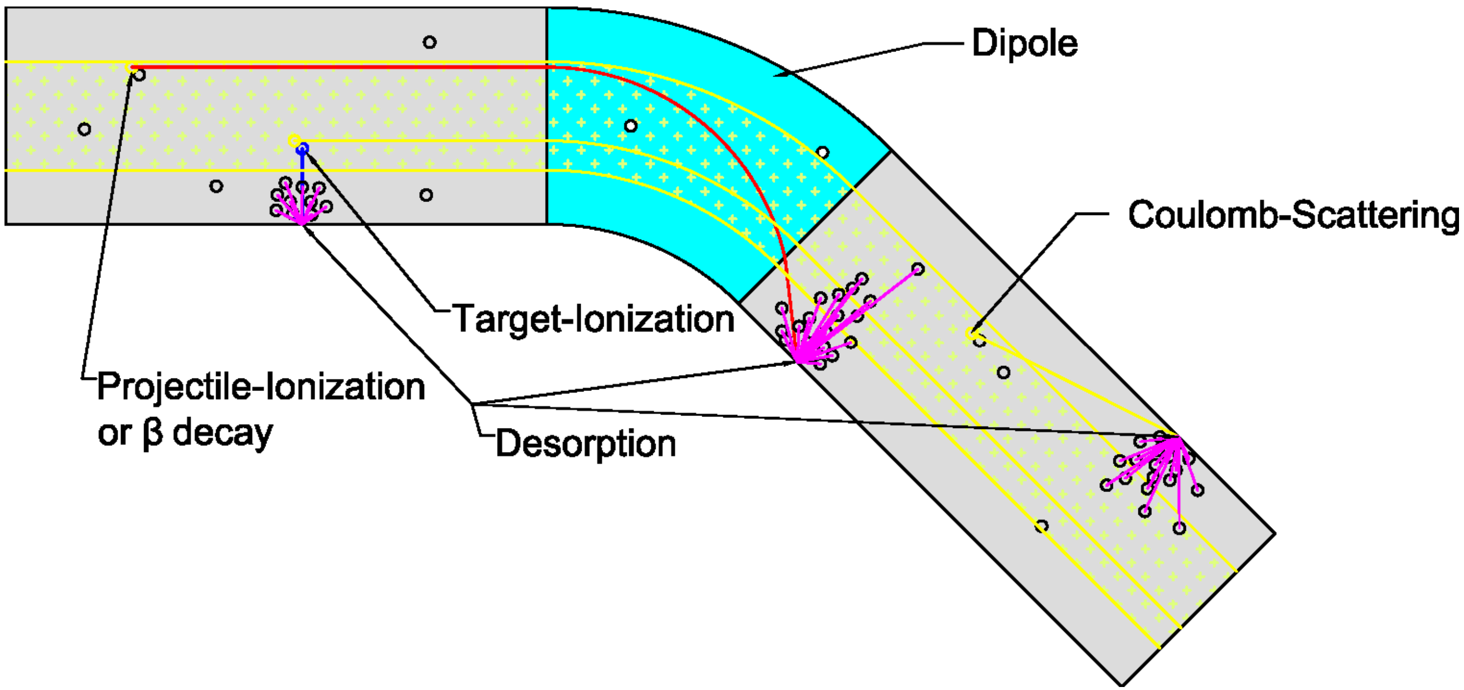
Figure XX: Ionization Area inside the electric Field box. Expansion of the ionized cloud due to space charge effects, with and without magnetic field due to space charge effects.

Upgrade Beam Diagnostics System

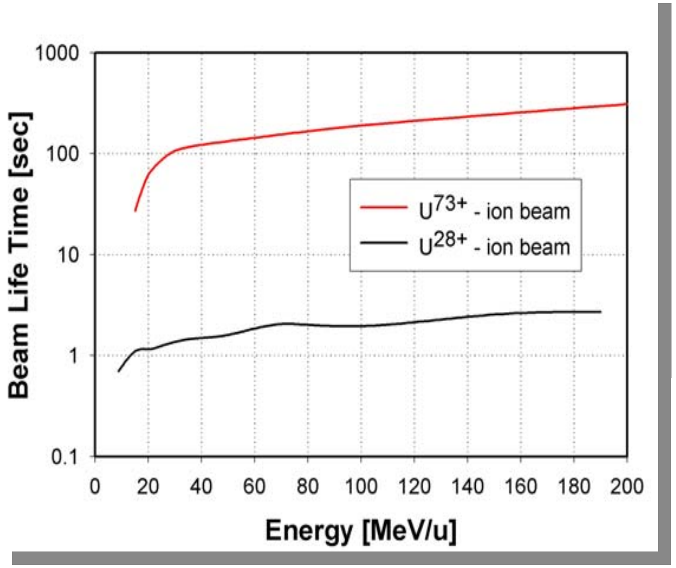
- Profile and beam position verification in front of injection septum
- Digital, programmable front-end electronics for BPMs (ordered)
- New, stable pre-amplifiers for BPMs
- Independend diagnostics for feed back systems (TFS and LFS)
- High current transformer (5 A) installed
- Fast transformer in SIS18
- Fast transformer in extraction channel
- Q - value measurement and evtl. radial feed back during ramping
- New, residual gas profile monitor for high time and spatial resolution

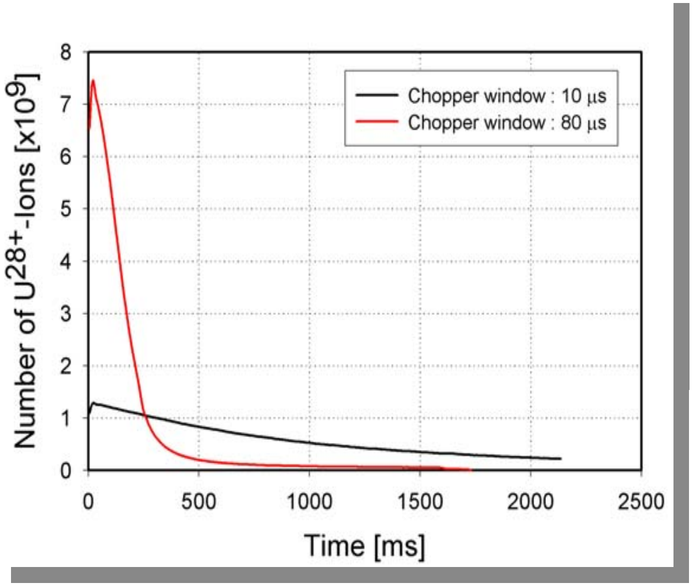
Beam Loss due to Charge Change

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



Life Time and Beam Loss



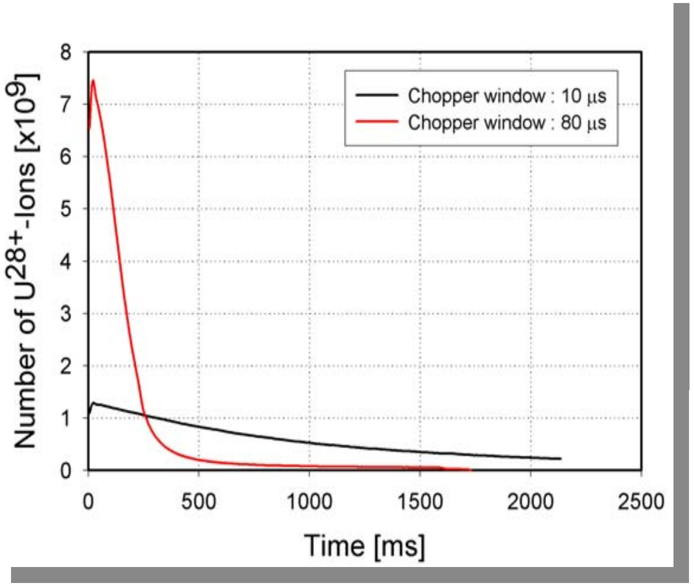


- Life time of U^{28+} is significantly lower than of U^{73+}
- Life time of U^{28+} depends strongly on the residual gas pressure and composition

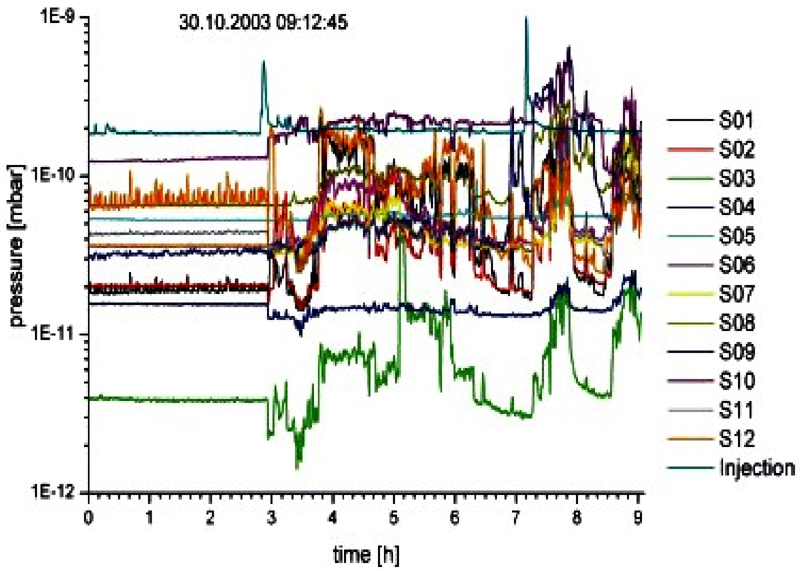
- Ion induced gas desorption ($\eta \approx$ 10 000) increases the local pressure
- Beam loss increases with intensity (dynamics vacuum, vacuum instability)

Beam Loss and Dynamic Vacuum

Beam Loss by Charge Changes



Dynamic Pressure



- Beam loss induced desorption degenerates the residual gas pressure and composition (in the dynamic case CO dominated)
- Degenerated residual gas leads to a further reduction of beam life time and anhanced beam loss
- Instability at high intensity heavy ion operation

Dynamic Vacuum – STRAHLSIM Code

Linear beam optics

Loss pattern due to charge change

Collimation efficiency

Reads and writes many formats (AML, MIRKO, MAD-X, WinAGILE)

Static Vacuum

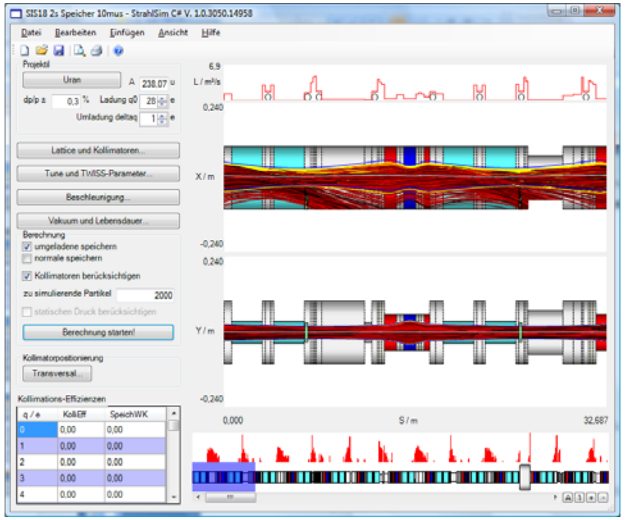
p_0, S_{eff}, Vacuum-conductances, NEG coating, cryogenic surfaces, Static residual gas components

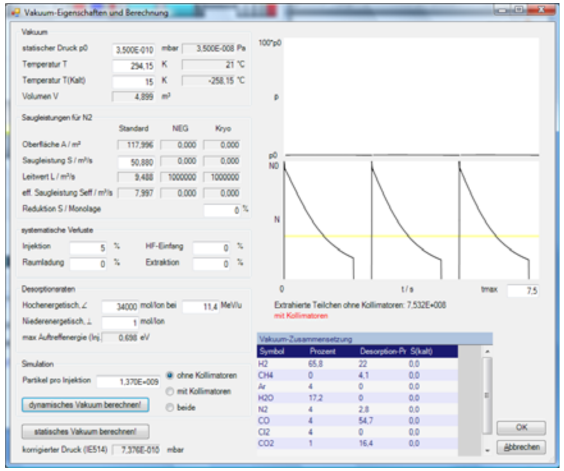
Dynamic (Source of beam losses)

- Synchrotron cycle
- $S_{eff,cold}(p, T)$: analytic model, incl. saturation
- $S_{eff,NEG}(p, t)$: Saturation
- Systematic losses (injection, RF capture)
- Projectile ionisationand capture $s_{pi}(E, Dq,Z)$ from Shevelko, Olson work in conjunction with AP
- Coulomb scattering
- Target ionisation
- Intra beam scattering

Ion stimulated desorption

- Desorption rate η scaled with $(dE/dx)^2$
- Beam scrubbing included

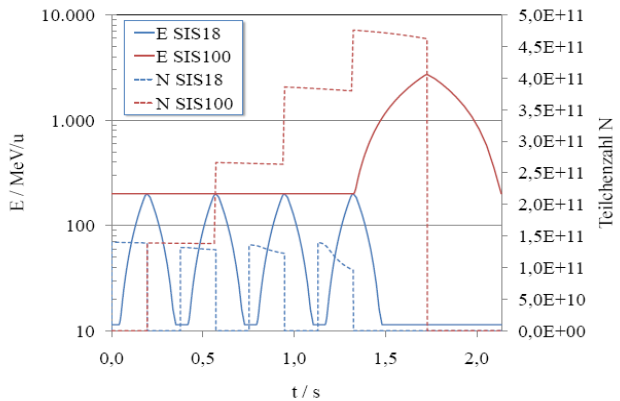




Benchmarked with many machine experiments (and at other accelerators)

Multi-Cycle and Long Term Studies

Multi-cycle Studies

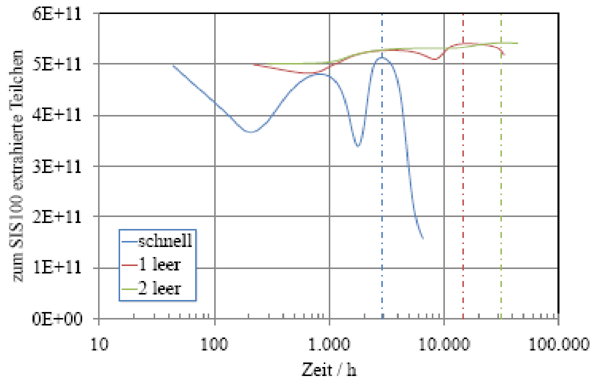


Ionization loss during stacking and acceleration in SIS18 and SIS100

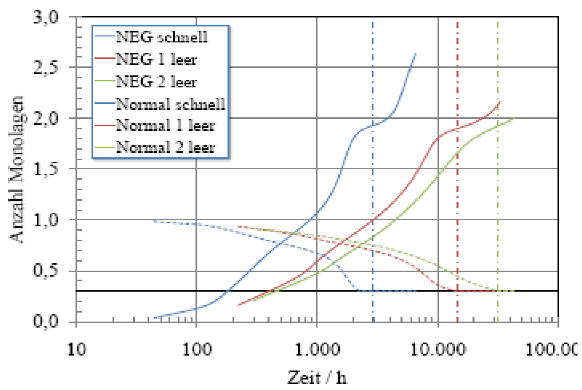
- The pressure at the end of the first cycle is the pressure at the beginning of the second cycle > Relaxation of the peak pressure over many cycles
- Modulation of the intensity in the booster cycles may lead to highes average numbers
- Pumping power of NEG depends on number of monolayers

  (decreas of half an order per monolayer)

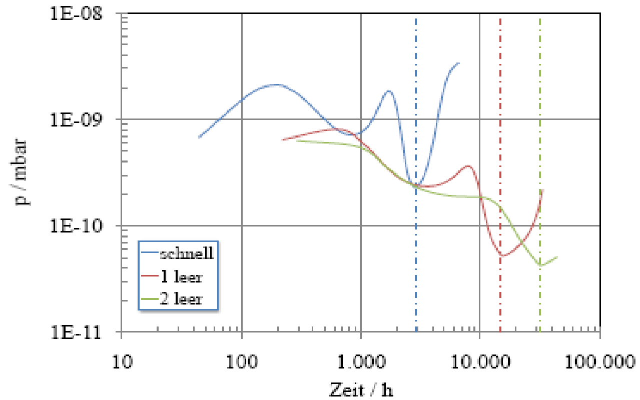
Long Term Studies



Accumulated ions over months

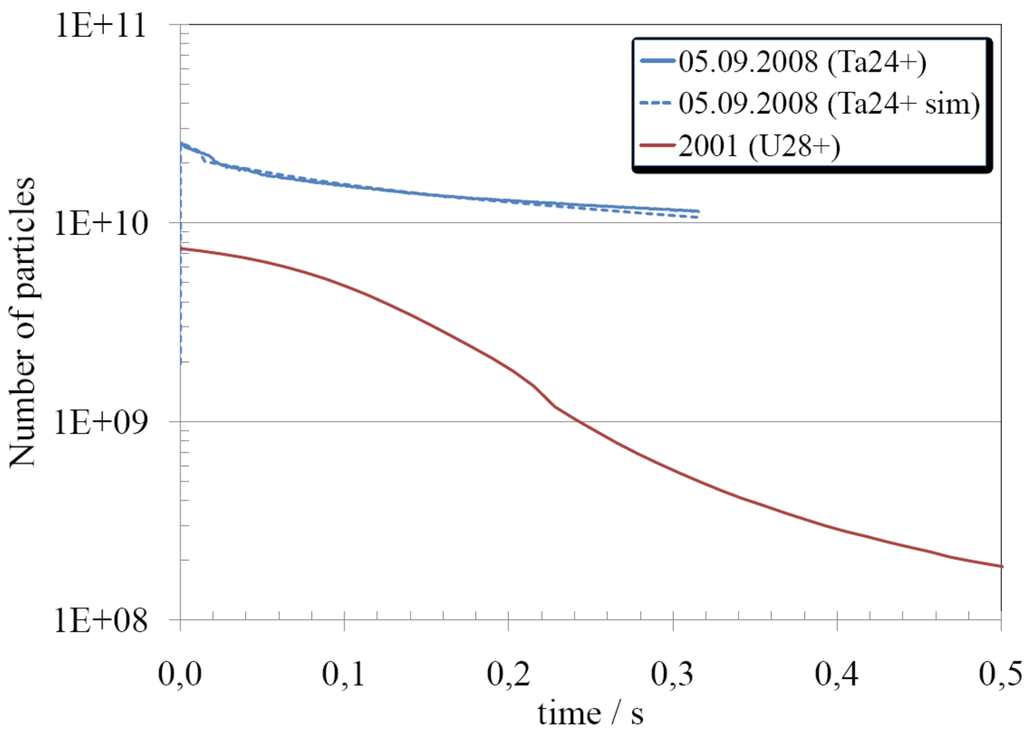


Number of monolayers over months



Pressure over months

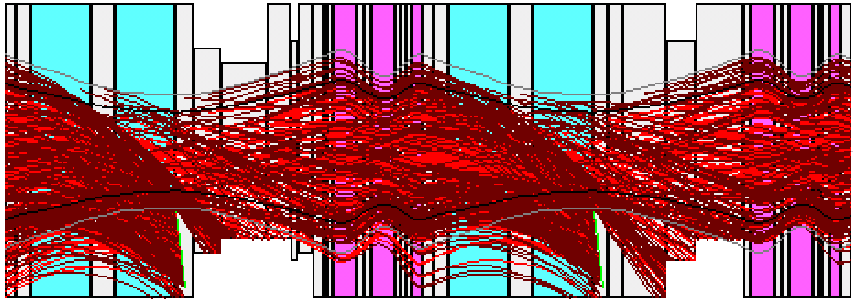
Progress with Intermediate Charge State Heavy Ions



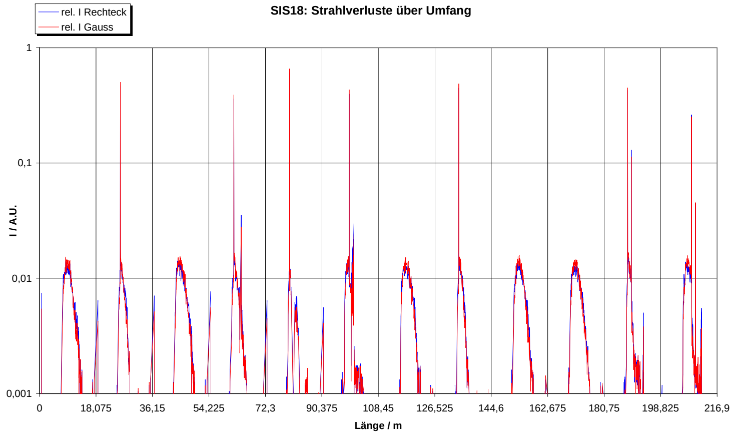
Intensity enhancement has been achieved by:

- Increased injection energy (11.4 instead of 7.1 MeV/u and therefore lower cross sections
- Breaks of 8 s between the cycle to accomodate for the low insufficient effective pumping power
- Carefull machine setting with minimized systematic loss
- Slight contributio by the two prototype collimators and a number of NEG coated dipole chambers

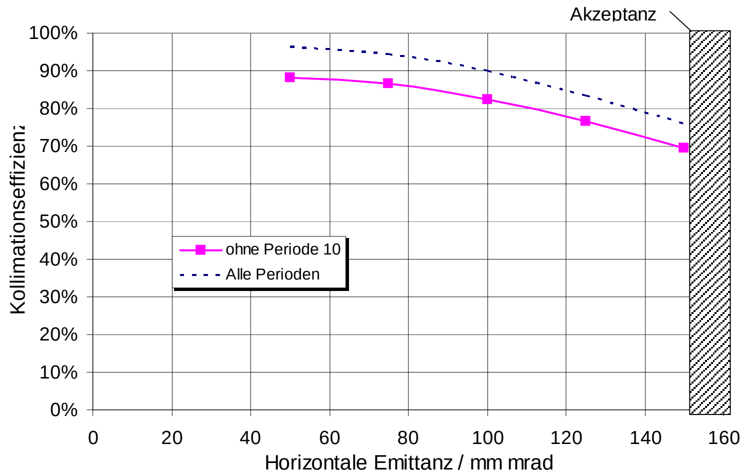
Charge Catcher System



Ionization beam loss in section 11,12



Beam loss distribution U^{29+}



Catching efficiency U^{29+}

- Developed for heaviest ions
  (highest ionization cross sections)

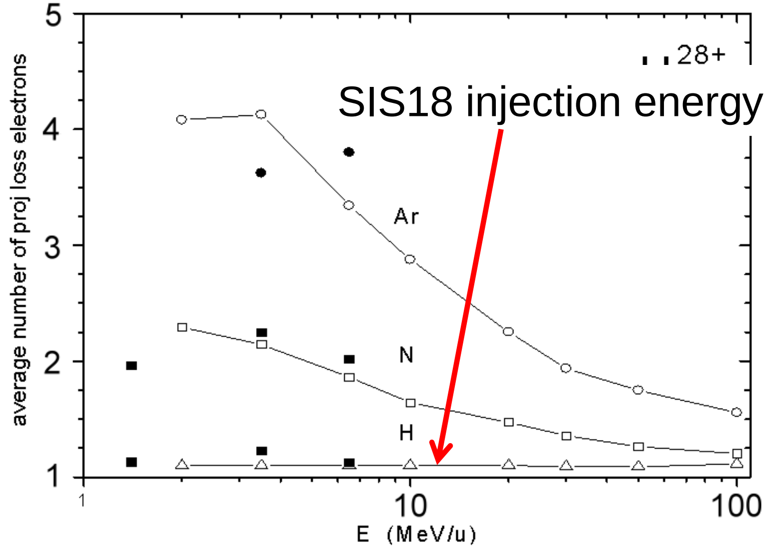
- Triplet/ doublet structure is suitable but:
  bending power of dipoles to high

  > Limited catching efficiency
    depending on emittance (70 %)

Cross Sections and Multiple Ionisation

- Improved, relativistic atomics physics models and cross sections (Shevelkov/Stöhlker)
- Life time measurements in SIS18 and ESR for benchmarking of cross sections
- Lighter ions have lower cross sections
- Cross section for residual gas components are different: Ar is about 100 higher than H

R. Olsen et.al., HIF04

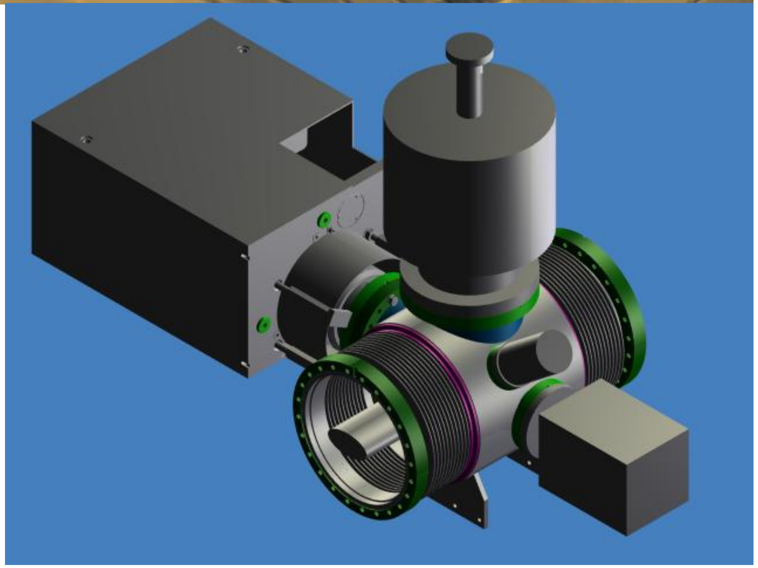


Multiple ionization reduces the catcher efficiency

Charge Catcher System - Technology

Goals:

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



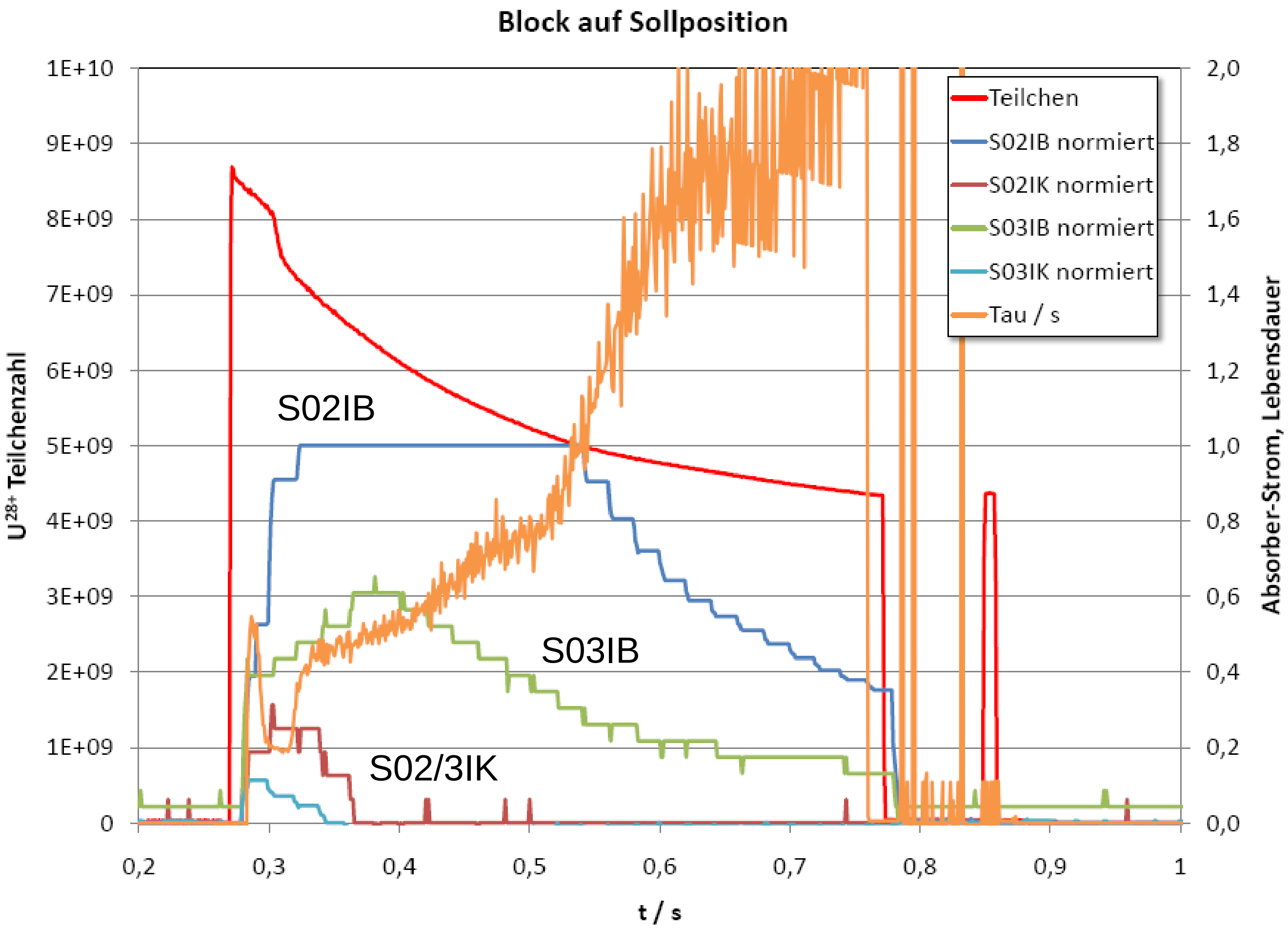
- Wedge and block shaped beam stopper made of low desorption yield material tested
- Secondary chamber for confinement of desorption gases
- NEG coated chamber walls
- Integration of UHV diagnostics and current measurement

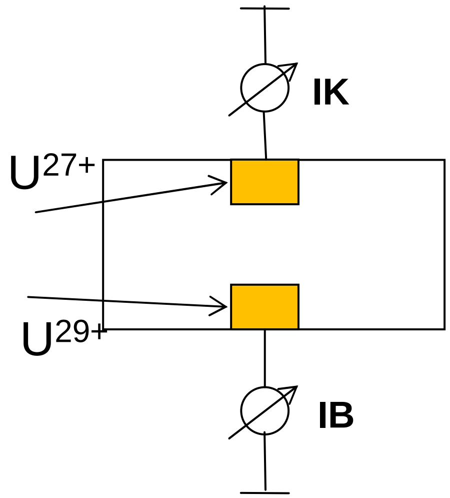
Two prototypes succesfully tested in 2007 shut down

Significantly reduced desorption yield

Installation of series (10 catchers) will be completed at the end of 2009

Measurement of Ionisation and Capture Loss



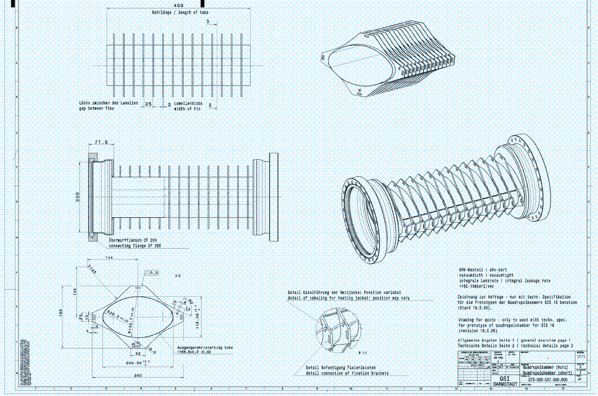


UHV system upgrade

Goals:

- Generation of extremly low static pressures of $p_0 < 5\times10^{-12}$ 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

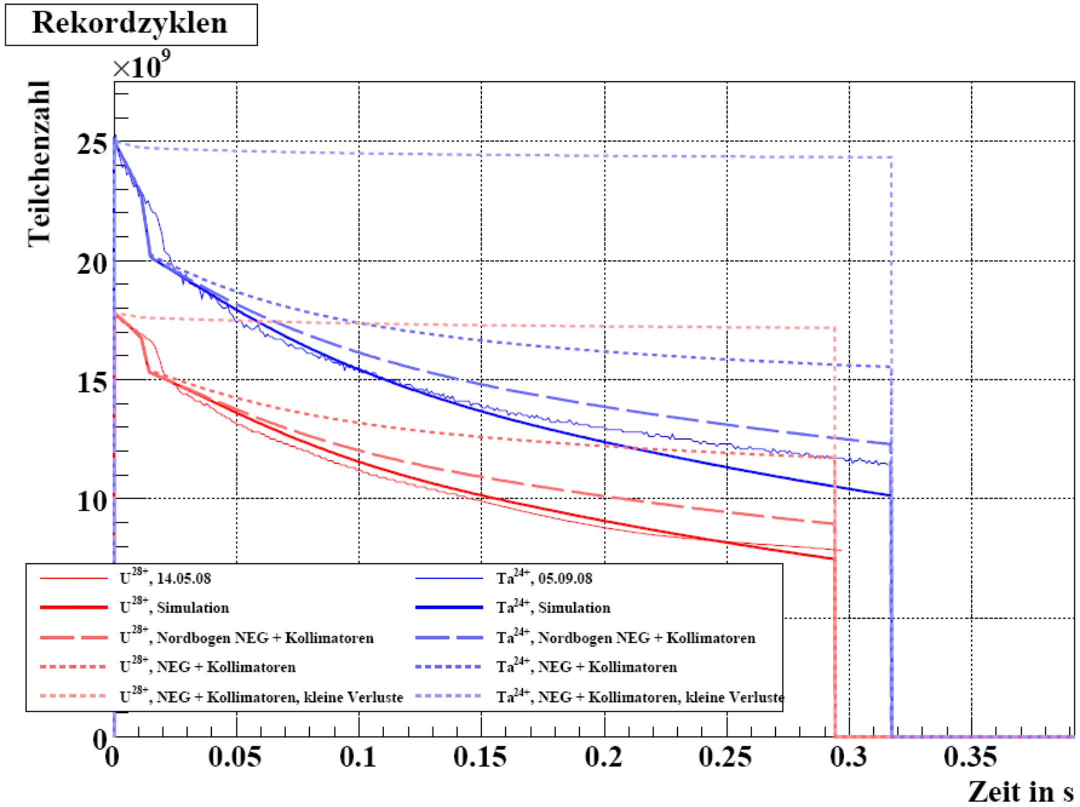
Project Status

- 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
- Replacement of dipole chambers almost completed
- Manufacturing of quadrupole chambers at BINP – First chambers arrived at GSI
- Exchange completed at the end of 2009

Prediction for 2010

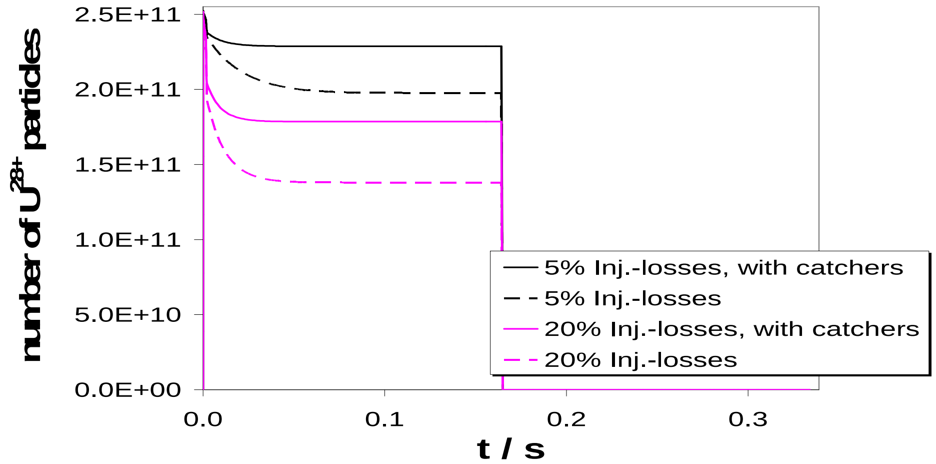


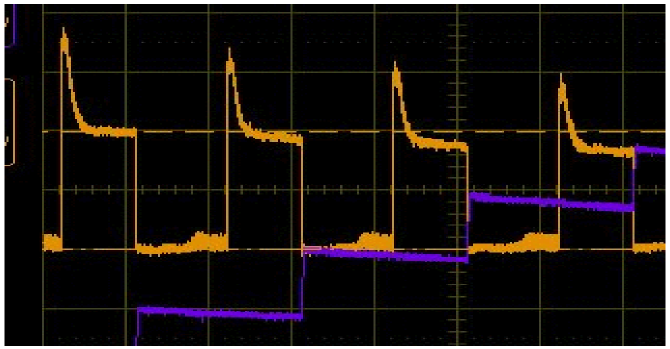
Important is the minimization of the initial systematic loss and pressure bump

Situation at machine experiments in 2008 and in 2010 after completion of the catcher- and UHV system

U^{28+}- Booster Operation

Simulated U^{28+}- booster operation





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

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

10^{11} U-ions / cycle

Important:

Initial, systematic beam loss must be controled to prevent pressure bumps

(effective loss in the order < 5 %)

Summary

- Six major upgrade measures (big investments) have been defined to prepare SIS18 for the booster operation with high intensity, intermediate charge state heavy ions
- Two measures have been completed. Three measures will be completed in 2009 and one in 2012.
- Major progress has been achieved in the understanding and simulations of the dynamic vacuum, gas desorption and beam loss by charge changes.
- An important simulation and measurement campaign is running adressing the high current and high space charge operation
- It is known, that a number of "minor" issues have to be adressed in parallel to the six major measures. The dynamic vacuum simulations indicate that a succesful completion of these minor measures is a preconditions for the booster operation.
- Major progress has already been achieved in the unique acceleration of high intensity, intermediate charge state heavy ions.