SIS Performance for Plasma Physics Experiments

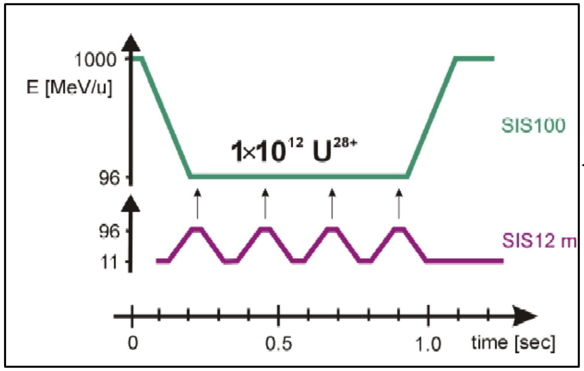
Peter Spiller

EMMI workshop

2.5.2011

Intensity Requirements for FAIR – Fit 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



Intermediate Charge States for FAIR

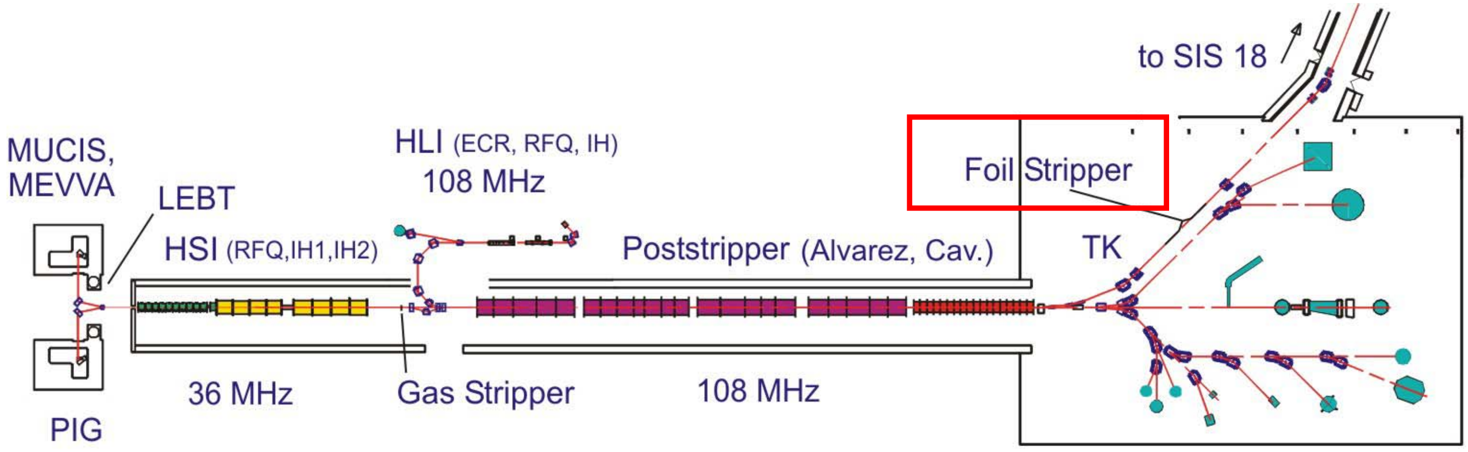
FAIR intensity goals can only be reached by lowering the charge states

Incoherent tune shift limits the maximum intensity in SIS18

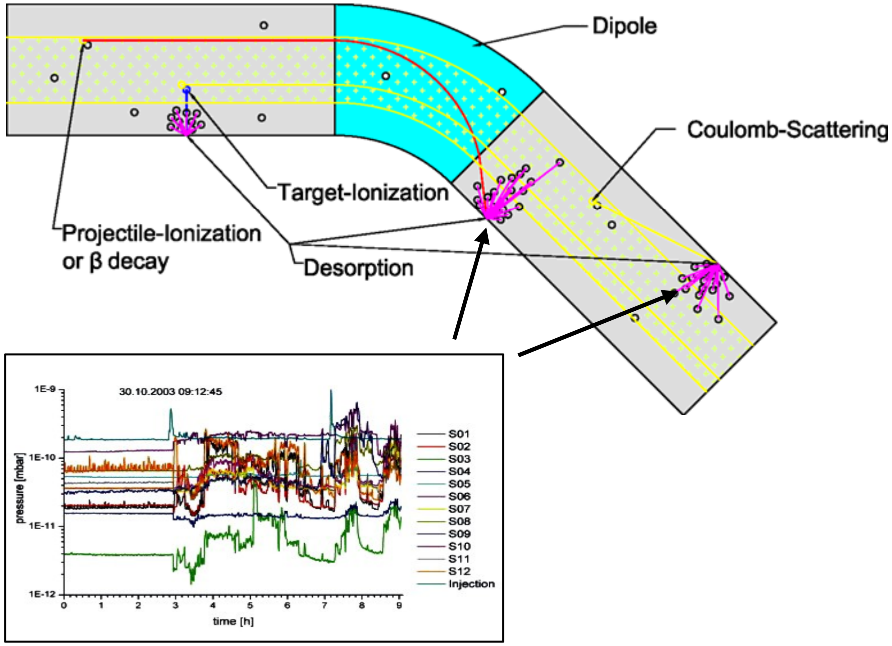
$-dQ \propto Z^2/A$ > Poststripper charge states will be used

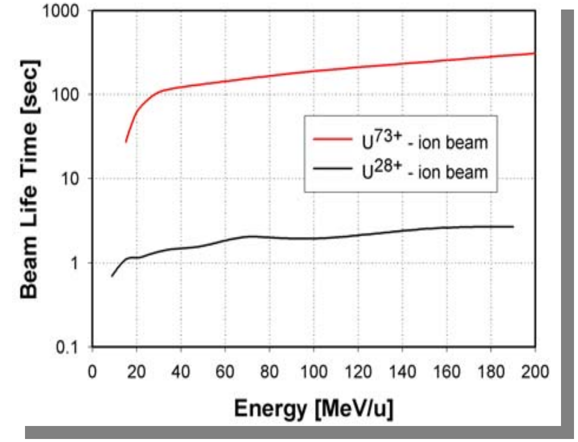
(e.g.: Ar^{18+} > Ar^{10+}..........U^{73+} > U^{28+})

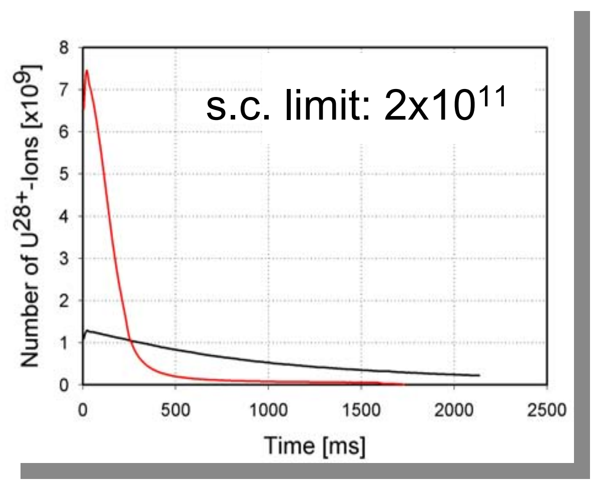
No stripping loss (charge spectrum) in the transfer channel ($N_{uranium}$ x7) !



Ionization Beam Loss and Dynamic Vacuum



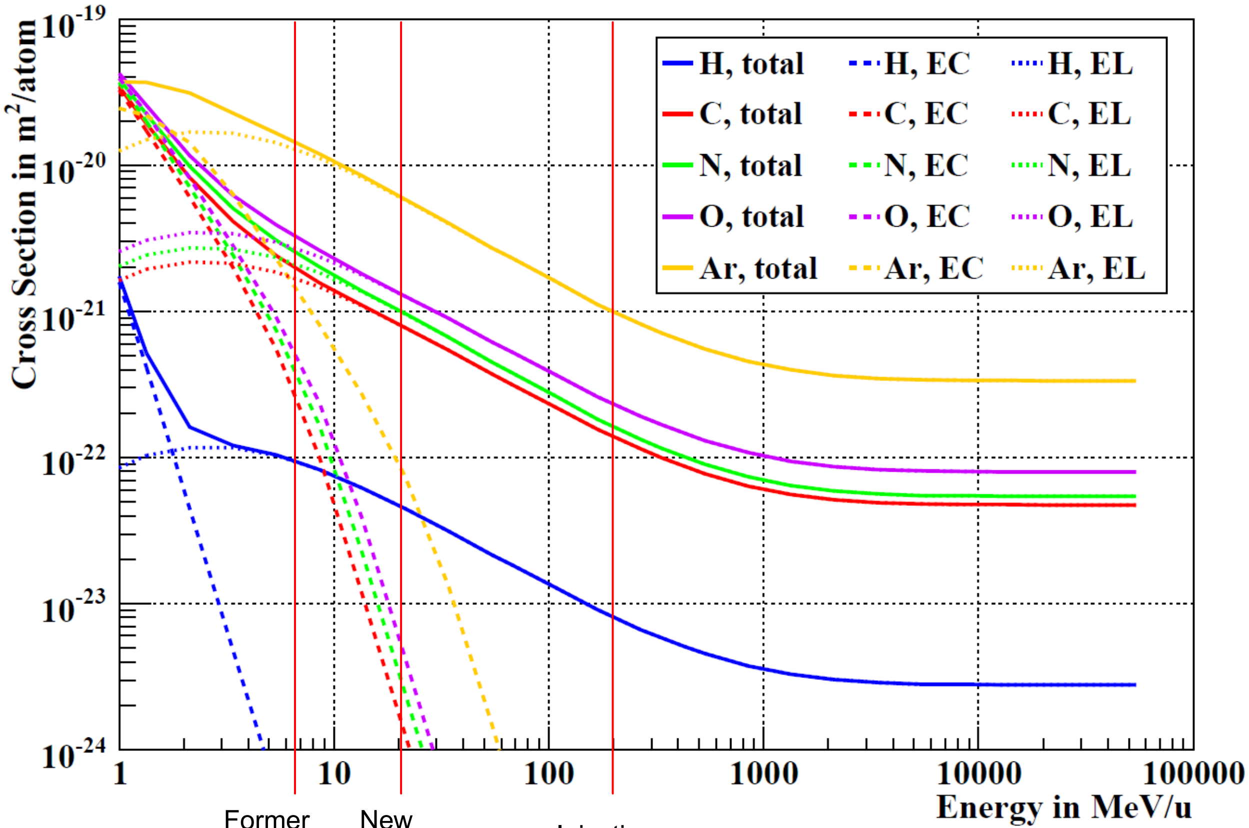




Main Issue of the Booster Operation:

- 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)

Ionization and Capture Cross Sections



Former injection energy SIS18

New injection energy SIS18

Injection energy of SIS100

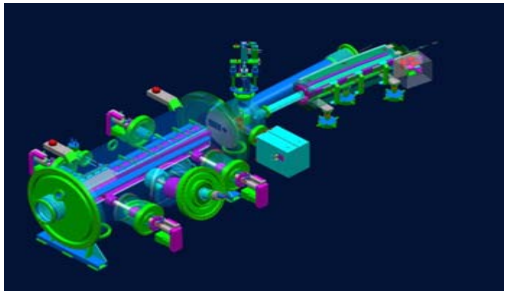
Calculated V. Shevelko

Strength of Charge Exchange and Dynamic Vaccum

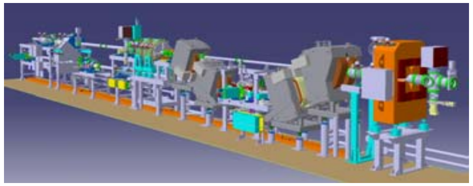
Charge exchange loss and dynamic vacuum scale with : [N x σ_{int}] x f_{rep}

Accelerator	Institut	Ion species	Total integ. cross section	Number of ions	N x σ_{int}	Rep. rate [Hz]	N x σ x frep
AGS Booster	BNL	Au31+	4.5E-21	5x109	2.2E-11	5	1.1E-10
LEIR	CERN	Pb54+	5.5E-20	1x109	5.5E-11	0.25	1.4E-11
NICA Booster	JINR	Au32+	4.9E-21	4x109	1.9E-11	0.25	4.7E-12
SIS18	GSI	U28+	8.7E-22	1.5x1011	1.3E-10	3	3.9E-10
SIS100	FAIR	U28+	1.8E-21	6x1011	1.1E-9	0.5	5.5x-10

SIS18upgrade Program

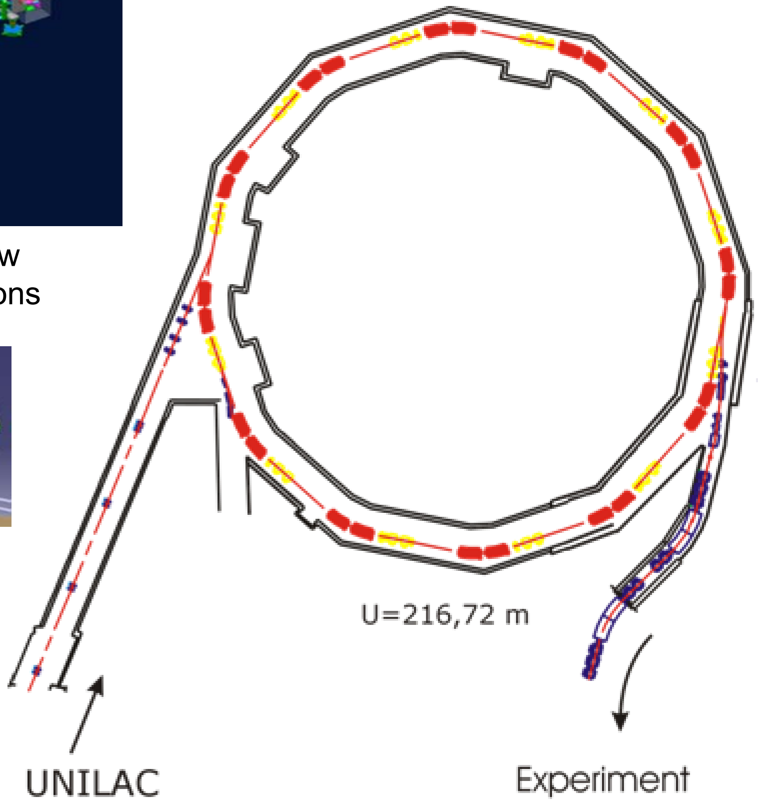


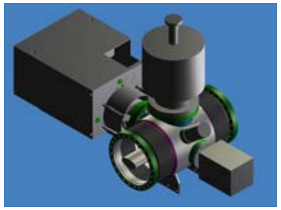
Injection system for low charged state heavy ions



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

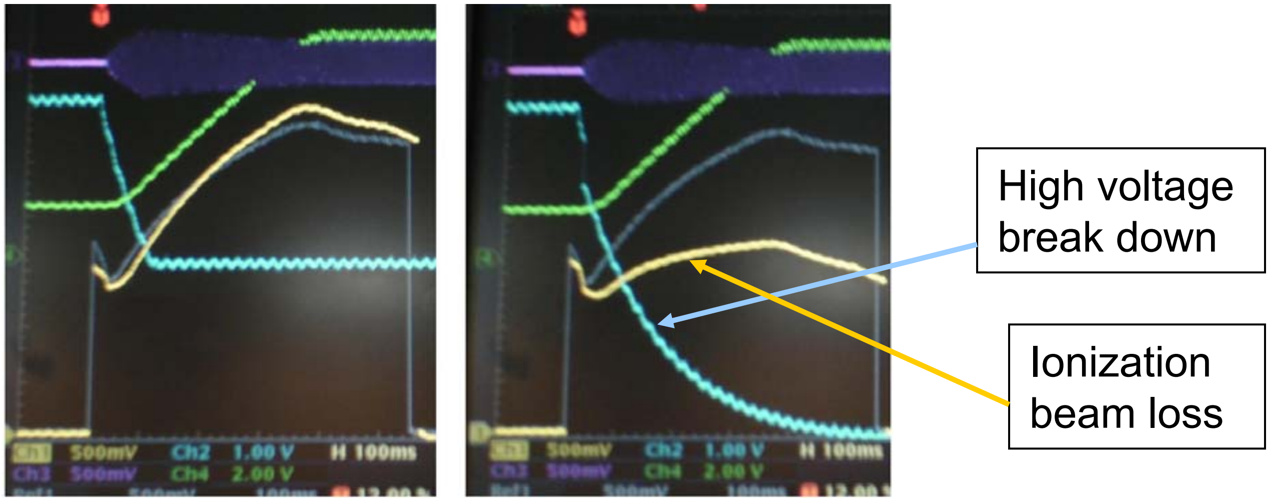
Upgrade dedicated to pressure stabilization

Supported by EU Construction contract:

- **RF System (fast acceleration – short cycle time)**
  New h=2 acceleration cavity and bunch compresion system for FAIR stage 0, 1
  (2012)
- **Replacement of Main Dipole Power Supplies (fast acceleration – short cycle time)**
  Operation with 10 T/s up to 18 Tm
  (2012)
- **UHV System (high distributed pumping power) - completed**
  New, NEG coated dipol- and quadrupole chambers
  (2009)
- **Insertions (low desorption materials, local pumping power) - completed**
  Set-up of a „low-desorption“ scraper system
  (2009)
- **Injection / Extraction Systems (higher injection energy) - completed**
  New, large acceptance injection system plus HV power suppy
- **Power Grid Connection - completed**
  Dedicated 110 kV power connection and transformer for fast ramping

Minimization of Initital Pressure Bumps

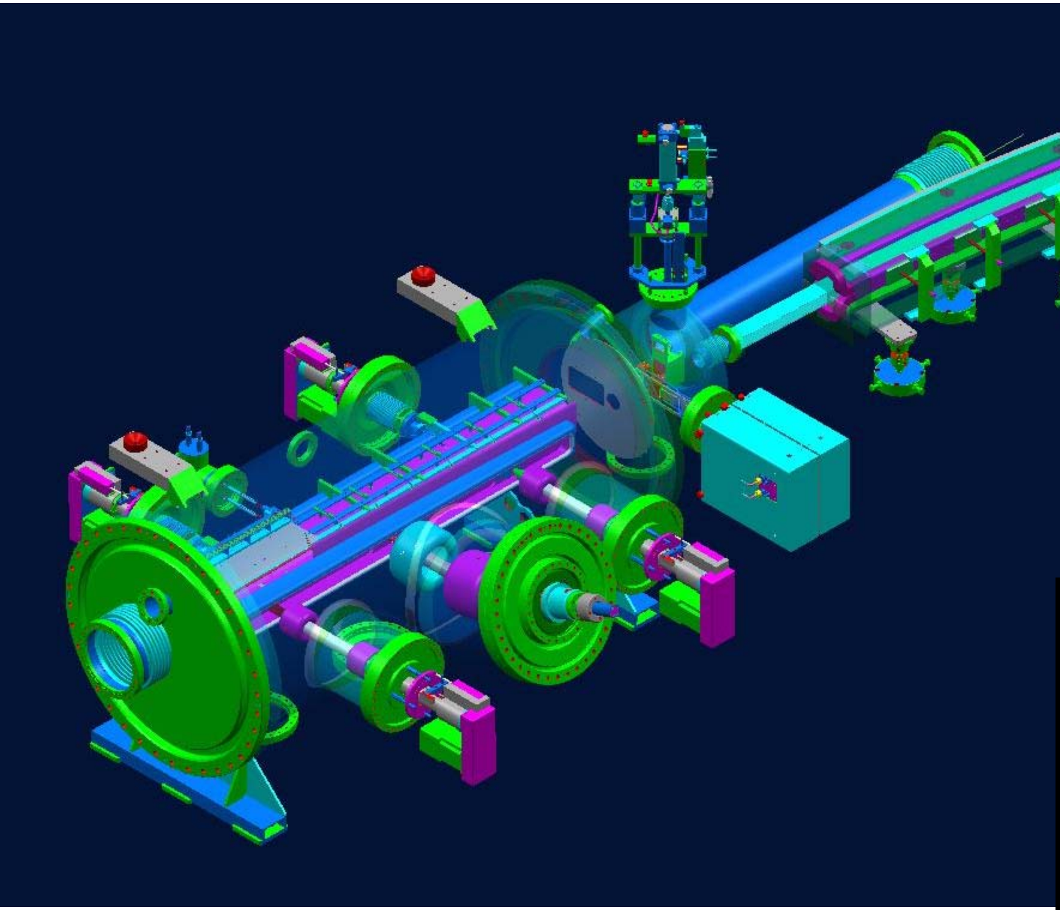
Injection of a MW heavy ion beam.



Gas desorption in the injection channel of the injection septum results in HV voltage break downs which again generates pressure bump and ionizes a large fraction of the beam after injection.

Stronger pumping is needed in the injection septum.
NEG panels are prepared for the next shut down.

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
- Aim for reduced gas production

Final design of the new injection system

Project completed

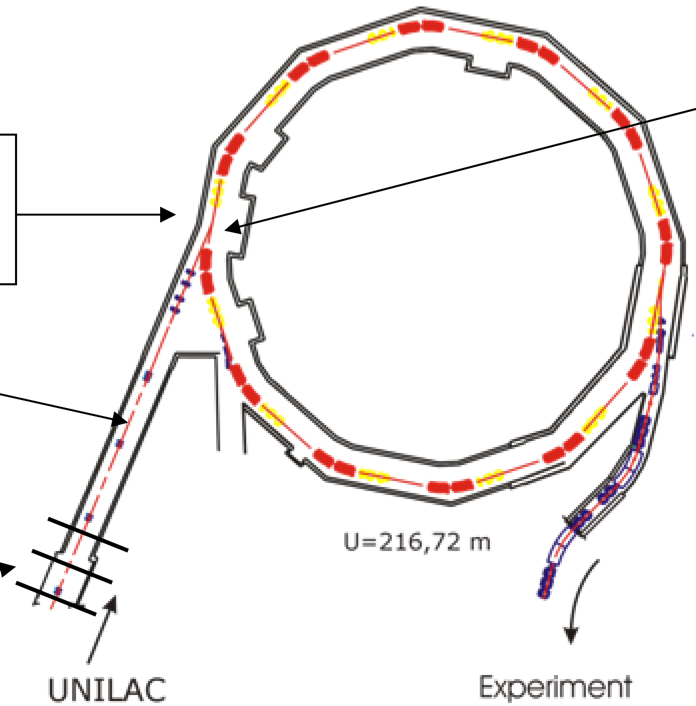
Injection of a Sharp Edge Beam

1. Image plane

(Injection channel)

Imaging optical system

Object plane (Three Collimators)



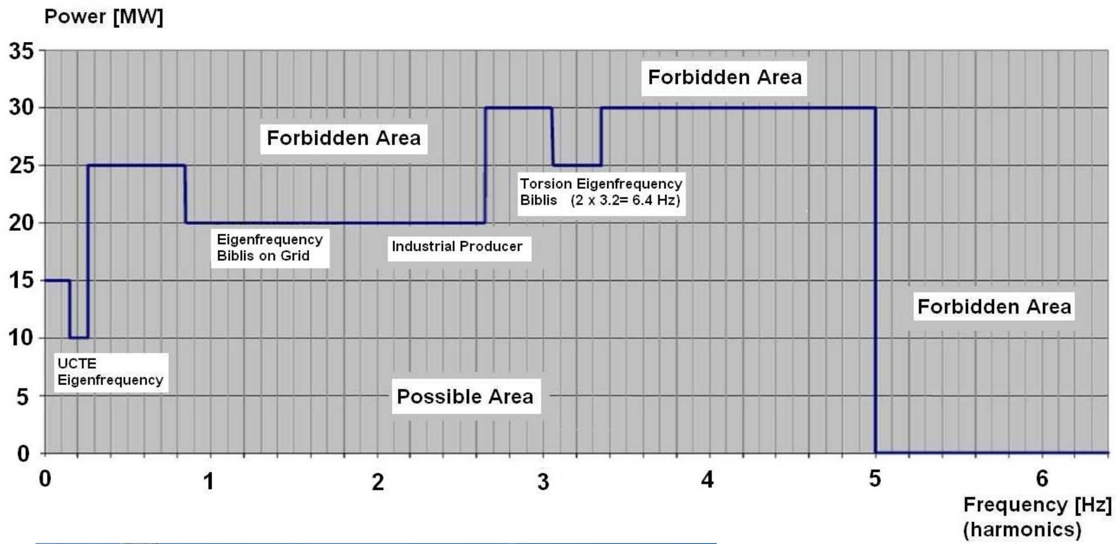
2. Image plane

(Backside injection septum)

Package

Imaging system from the collimator up to the injection channel and the backside of the septum

New 110 kV Power Connection



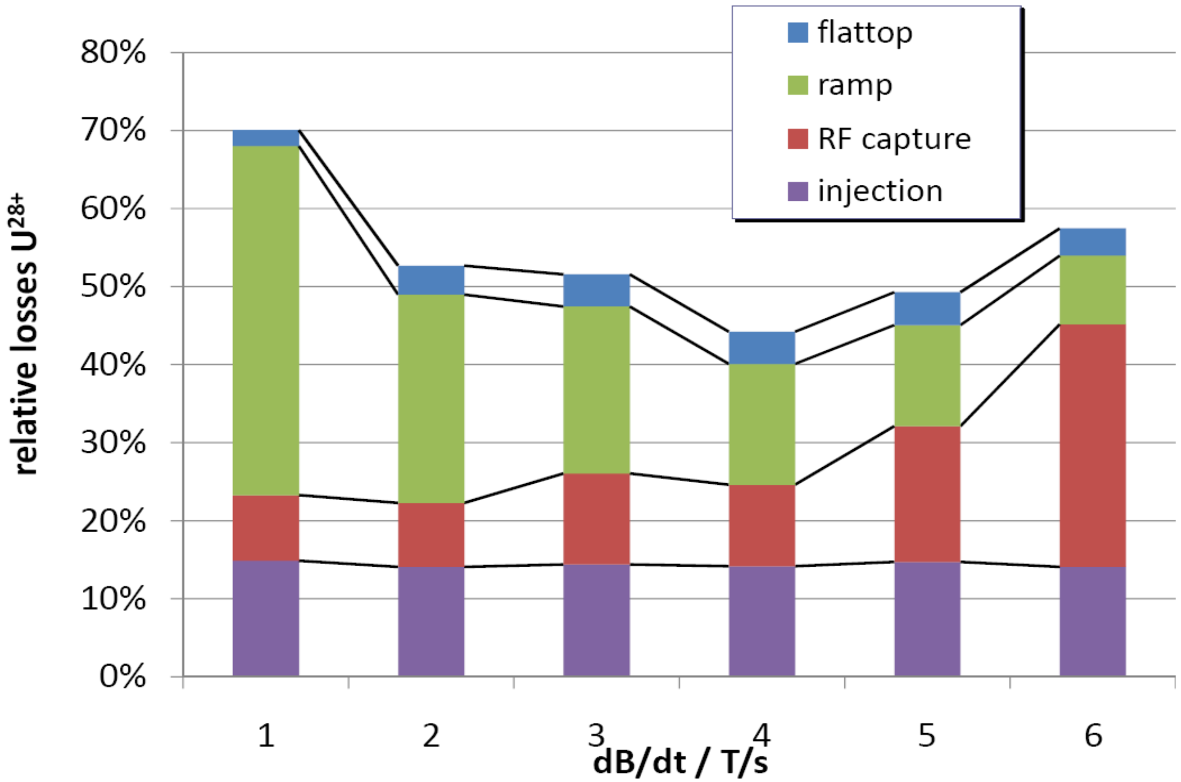
	Pulse Power	Field Rate
SIS18	5 MW	1.3 T/s
SIS12	+26 MW -17 MW	10 T/s
SIS18	+ 42 MW	10 T/s
SIS100	± 26 MW	4 T/s
SIS300	± 23 MW	1 T/s

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

4 T/s must become standard operation now !

Project completed

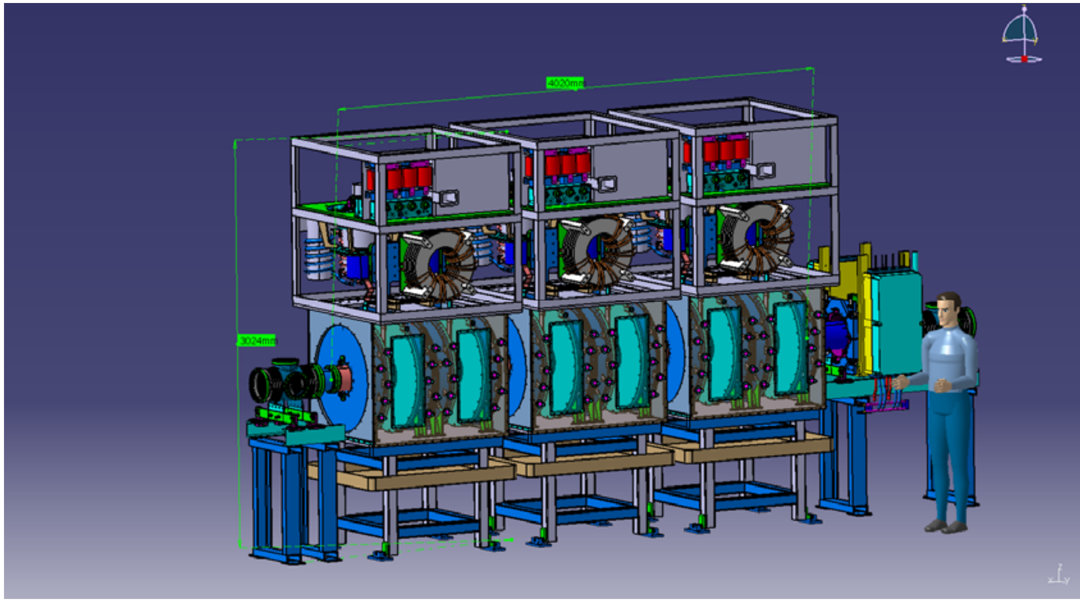
U^{28+} - Beam Loss at High Ramp Rates



- 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 minimum loss
  (30 % safety)
- Flat bunch profile (high Bf) for lower inc. tune shift
  two harmonic acceleration
  h=4 (existing cavity) and h=2 (new cavity)
- Compatibility with SIS100 Rf cycle

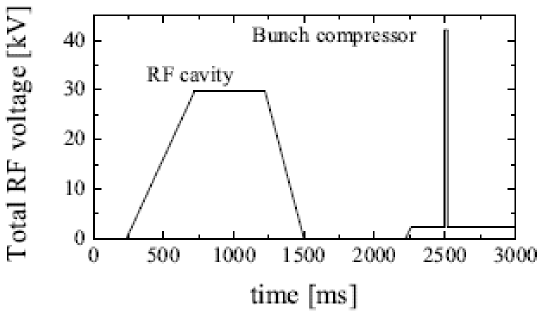
Installation end of 2012

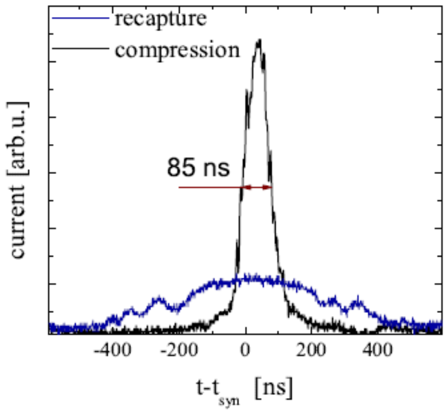
P. Hülsmann,
H. Klingbeil

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

Bunch Compression

Bunch compressor in SIS18





Bunch length after compression at 300 MeV/u

Fixed frequency operation possible.

Experimemt must specify the final energy in advance.

O. Chornyi, P. Spiller

Bunch Merging

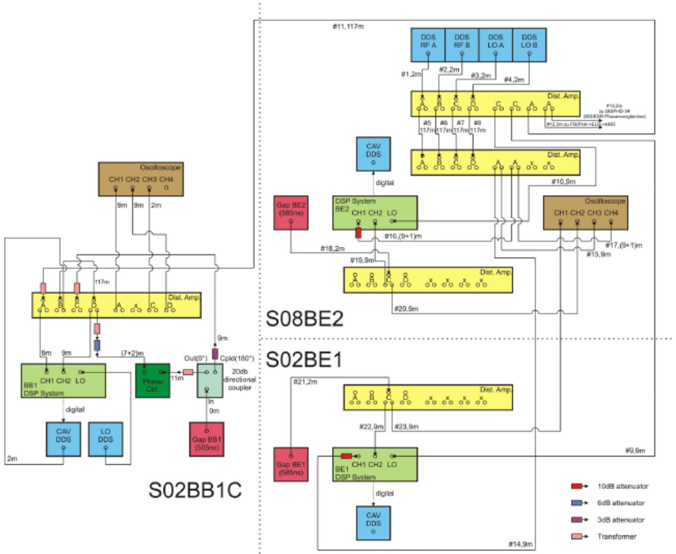
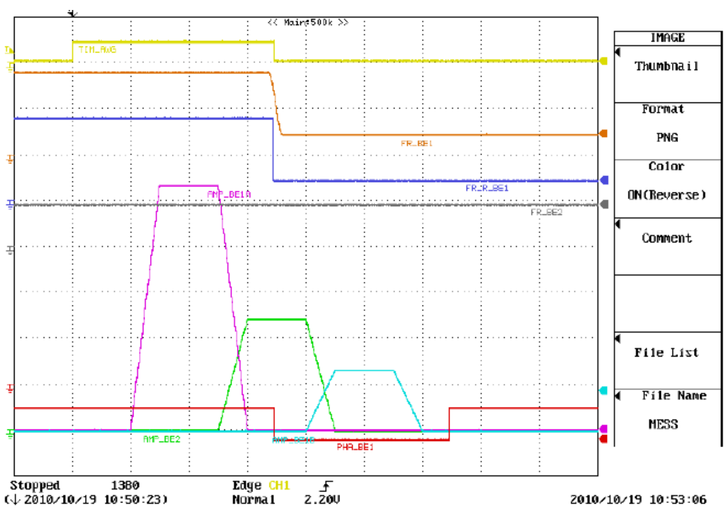
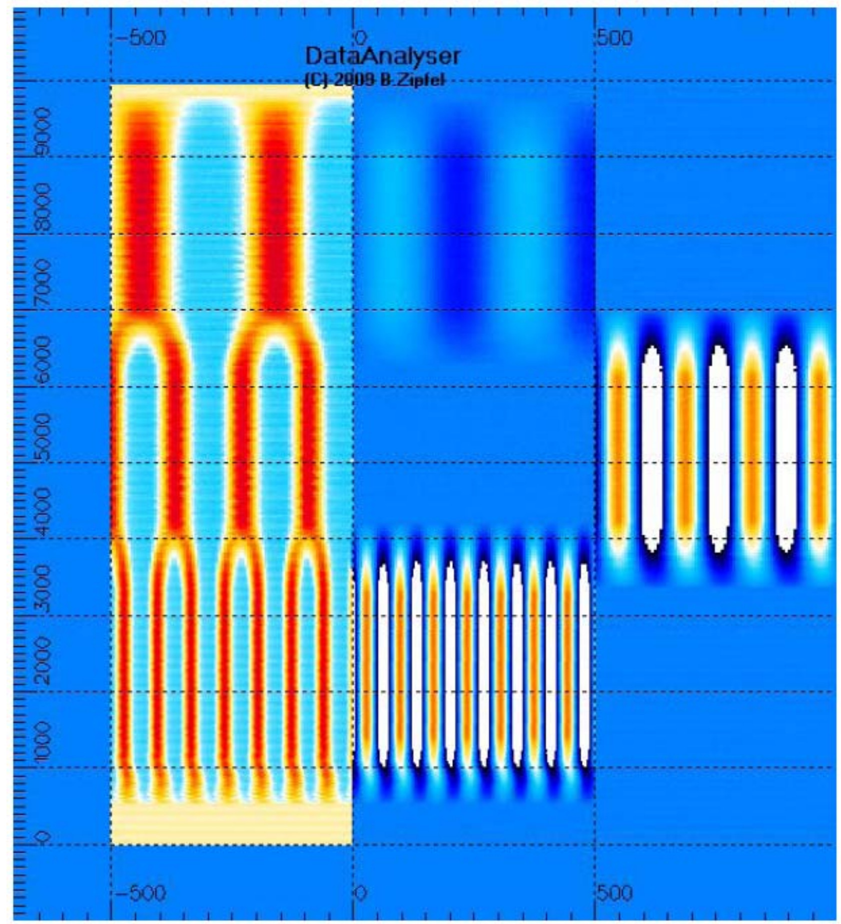


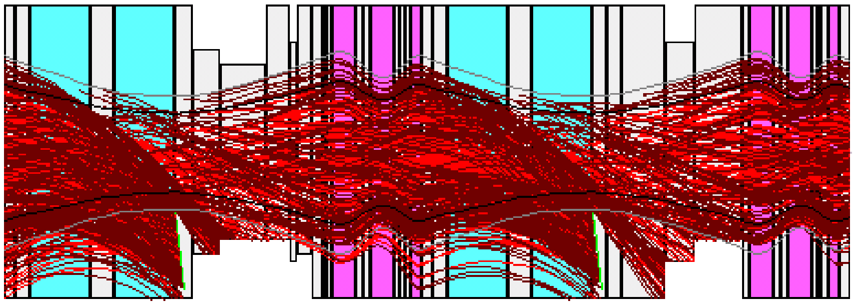
Figure 1: New Standard SIS18 LLRF System Topology [5]



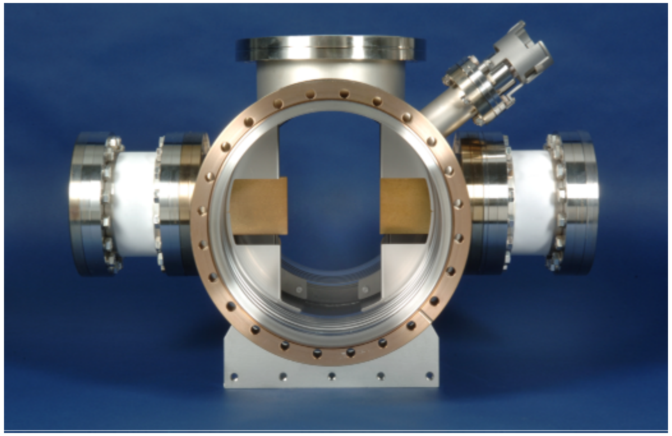


H. Klingbeil et al

Charge Catcher System



Trajectories of ionization beam loss



Goals:

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

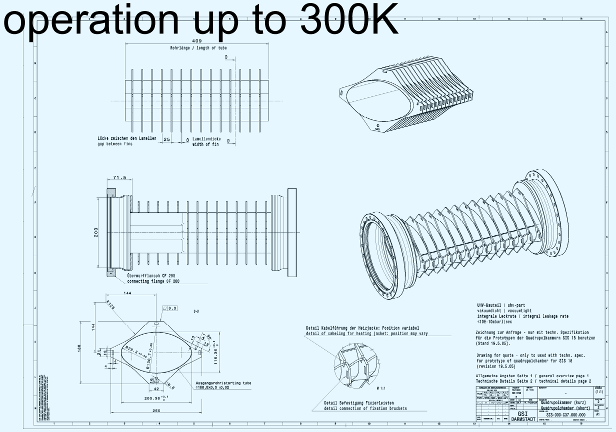
Installation of series (10 catchers) completed.

UHV system upgrade

Goals:

- 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
- Replacement of dipole and quadrupole chambers completed

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

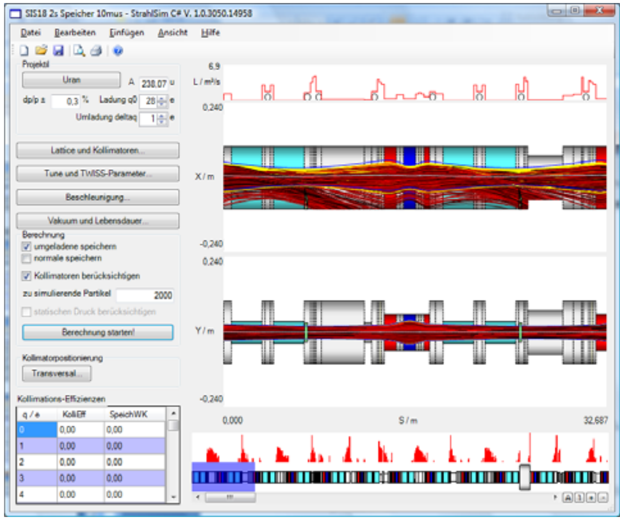
p_0, S_{eff}, Vacuum-conductances, NEG coating, cryogenic surfaces, Static residual gas components

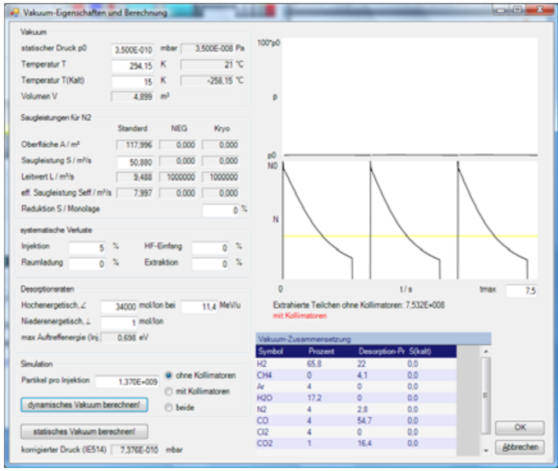
Dynamic (Source of beam losses)

- 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

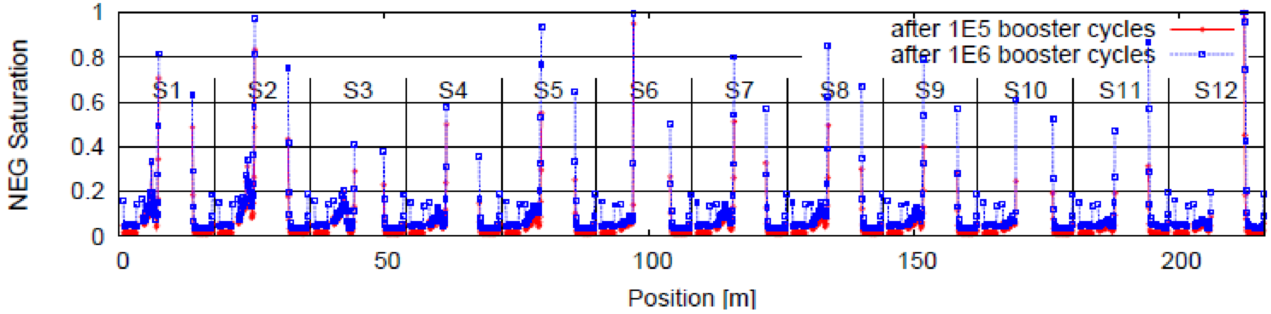




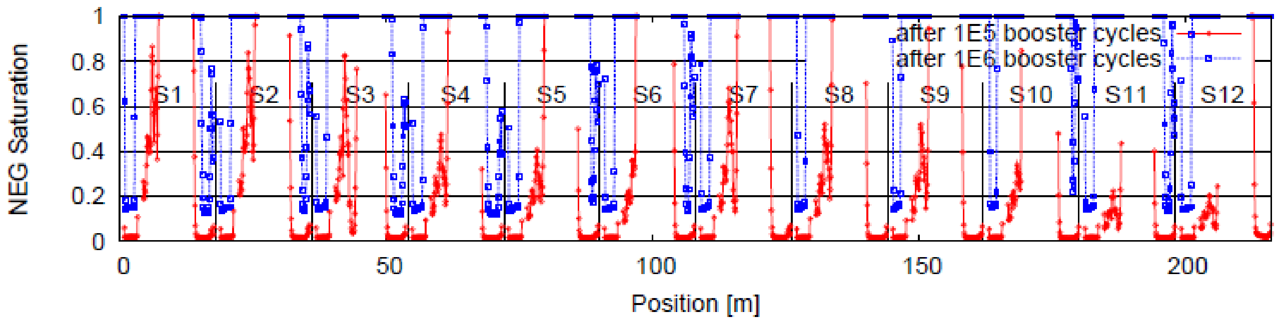
Benchmarked with many machine experiments (and at other accelerators)

2nd Generation of STRAHLSIM Code

- Spatial and Time Resolved Simulation of Dynamic Vacuum and Charge Exchange Beam Loss
- Better modelling of localized effects (no conductivity averaging over the circumference)
- Self determined static vacuum depending on the UHV system and machine layout.
- Long term stability (transmission) and NEG saturation depends on the beam scrubbing.



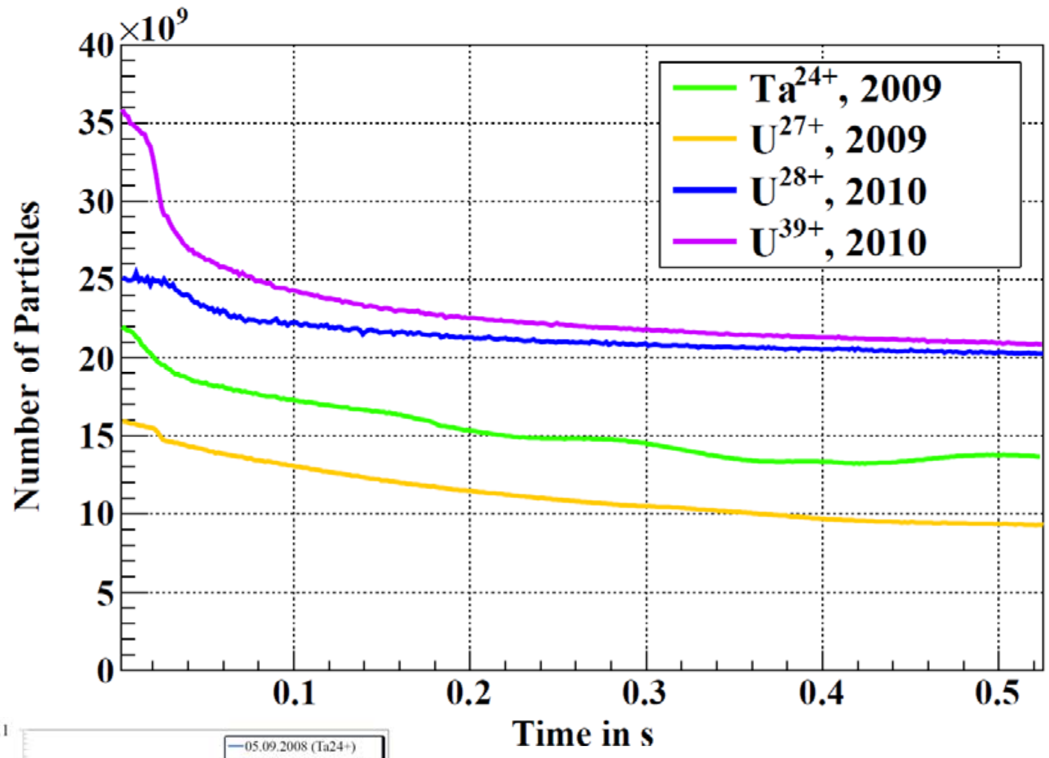
NEG saturation with scrubbing

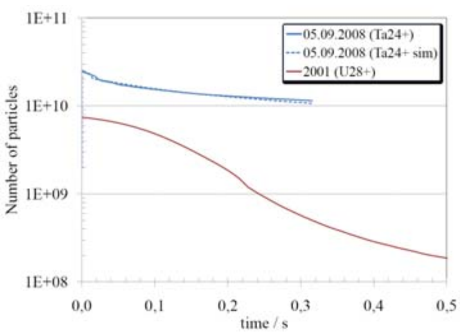


NEG saturation without scrubbing

See poster Patrick Puppel

SIS18 Intensity Records with Intermediate Charge States



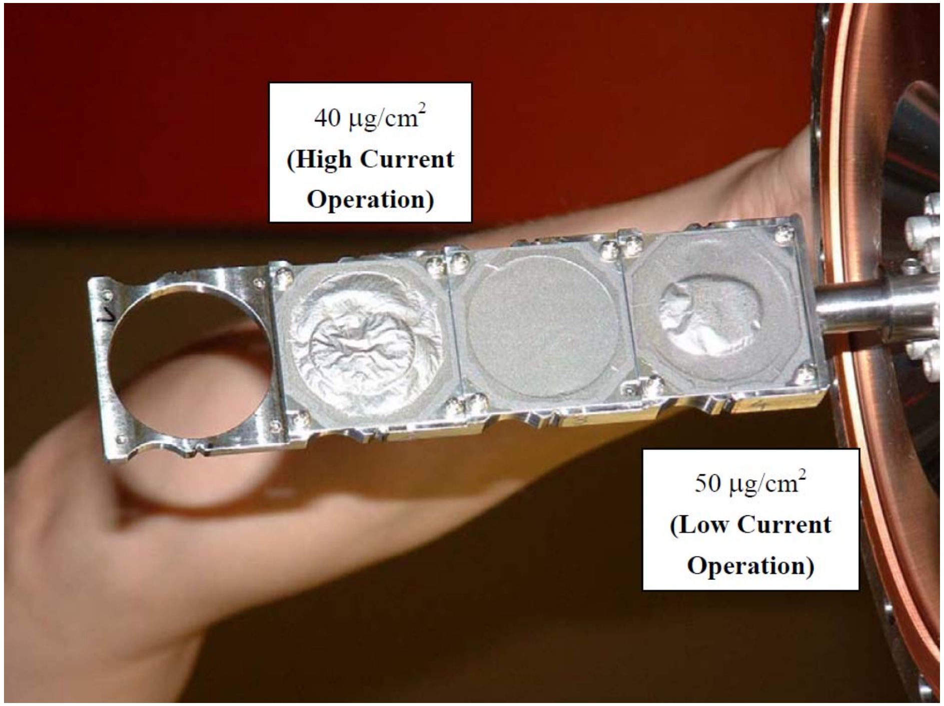


Intensity enhancement has been achieved by:

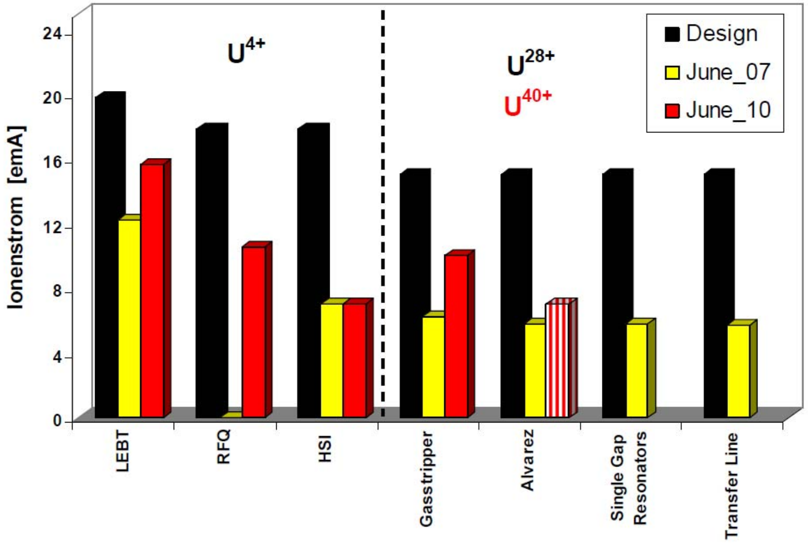
- Increased injection energy (11.4 instead of 7.1 MeV/u and therefore lower cross sections
- Brakes of 1-8 s between the cycle to accomodate for the low insufficient effective pumping power
- Carefull machine setting with minimized systematic loss
- Low desorption ion catcher system with local (strong, high conductivity) NEG pumping.
- NEG coating of all magnet chambers.

$2x10^{10}$ U^{40+} ions at 350 MeV/u

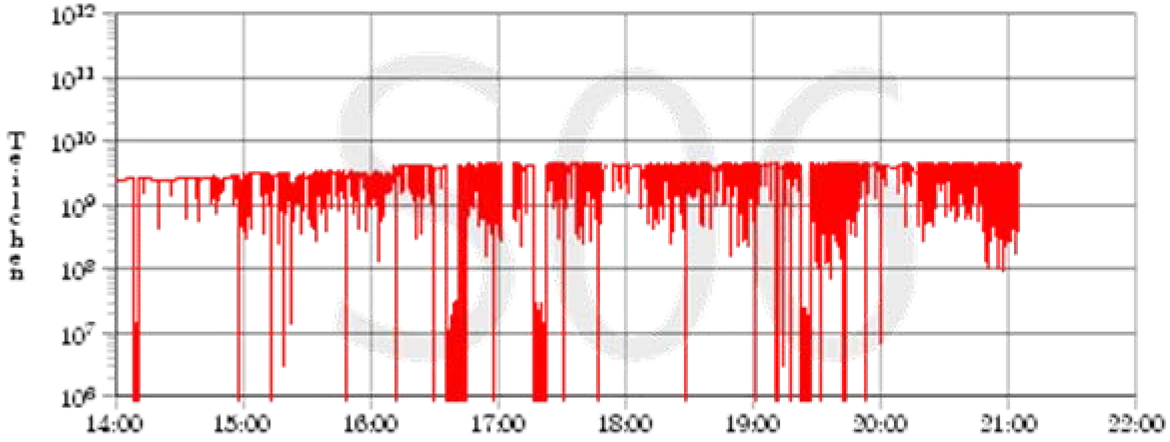
Foil Stripper (U^{40+}) instead of Gas Stripper (U^{28+})



Carbon foils after operation



U^{73+} - Operation

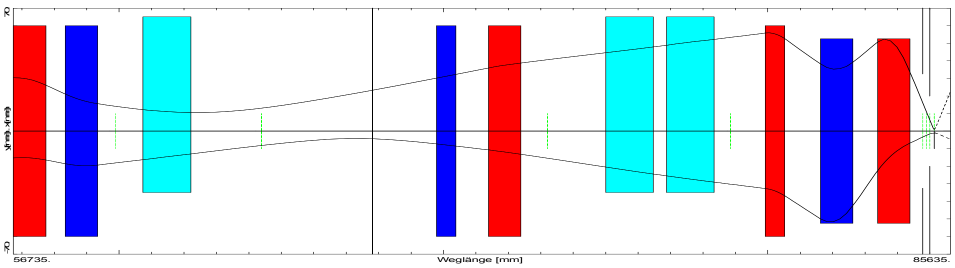


U^{73+} run on October 28th with long term stable 4.5 x 10^9 ions

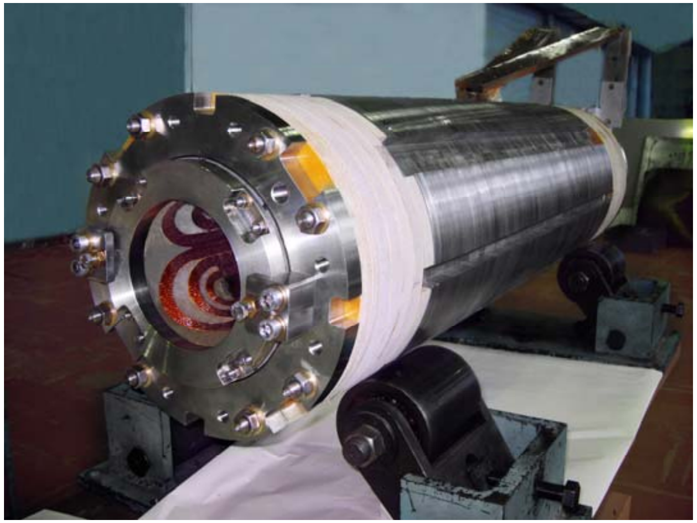
U^{73+} basically unchanged

Transverse Focusing at HHT

- The existing final focusing system has been designed for 6 Tm beams only.
- The highest intensities can be reached with low charge state beams and maximum rigidity (18 Tm).



HHT final focusing with two SIS300 quadrupoles



SIS300 quadrupole prototype at IHEP

The quadrupole shall be installed in a common cryostat with He bath cooling.

Also SIS100 quadrupole may be consideres (cheaper).

Using SIS100/300 quadrupoles benefits from the existens of the toolings need for the magnet production, which would be cost driving.

The last two quadrupoles should be replaces by a s.c. focusing system

Summary

- Six major upgrade measures (big investments) have been defined and are partly completed to prepare SIS18 for the booster operation with high intensity, intermediate charge state heavy ions
- Major progress has been achieved in the understanding and simulations of the dynamic vacuum, gas desorption and beam loss by charge changes and it long term behaviour under influence of saturating NEG surfaces and beam scrubbing effects.
- 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, especially related to initial systematic beam loss 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.
- For FAIR a factor of 10 in intensity per cycle and a factor of 30 in intensity per second is missing.