SIS18 Status and Future

GSI Accelerator Seminar

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March, 2022

SIS18 Development Categories

Separation of requirements for running operation + early science at Super-FRS and FAIR booster operation and earyl science for plasmaphysics at APPA

Topcs of the running operation and early science at Super-FRS (examples)

- Increase of intensity in average and per cycle
- Increase of efficiency of slow extraction
- Improve the micro spill structure
- Reducation of interaction between supercycles at parallel operation
- Reduction of beam loss and control of beam stability, especially at high current operation near the space charge limit.

Topics of the SIS100 booster operation (examples)

- Control of dynamic vacuum and restriction of charge related loss at heavy ions with intermediate charge states
- Minimization of effective beam loss at multiturn injection (<1 %)
- Increase of ramp rate (1.3 T/s > 10 T/s)
- Increase of repetition rate – Realization a batch operation
- Conservation of longitudinal phase space.
- Reduction of beam loss and control of beam stability, especially at high current operation near the space charge limit
- Adaptation of SIS18 Rf cycle to SIS100 Rf cycle

SIS18 Development Categories

Funding

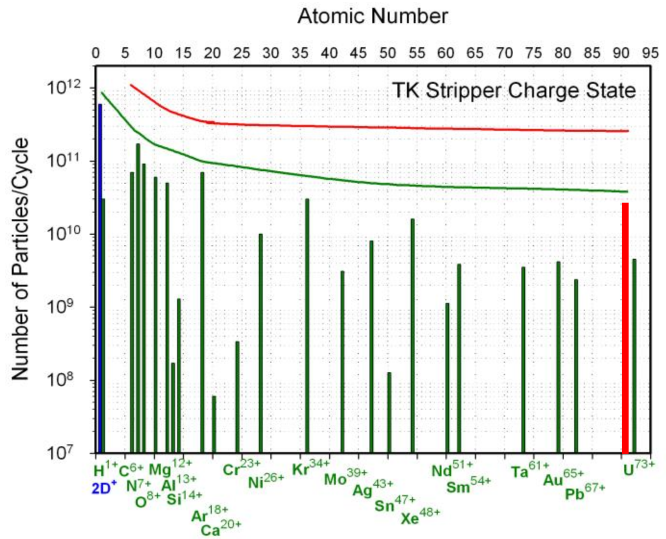
1. SIS18 upgrade towards the FAIR booster operation (link existing facility) (1).
2. Developments and improvements for the running experimental program (2).
3. Advanced accelerator R&D towards a SIS18 upgrade 2 program (3).

1. is (beside others) financed from FAIR projects funds and is focused onto the intermediate charge state heavy ion operation
2. is financed from annual institutional funds and is focused onto the requirements and needs of the presently performed experiments
3. is financed from ARD (accelerator research and development) funds, EUCARD/ARIES (accelerator reserach and innovation for european science and society)

+ Maintanance and Services

Reference Primary Beam Parameters

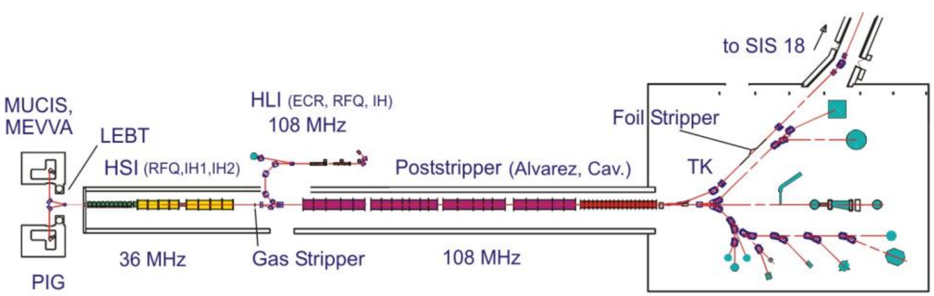
SIS18	Protons	Uranium
Number of ions per cycle	5 x 10^{12} (x50)	1.5 x 10^{11} (x100)
Inc. s.c. tune spread	-0.5	-0.5
Initial beam energy	70 MeV	11 MeV/u
Ramp rate	10 T/s	10 T/s
Final beam energy	4.5 GeV	200 MeV/u
Repetition frequency	2.7 Hz (x3)	2.7 Hz (x3)



SIS18 peak intensities and space charge limits for high and intermediate charge states

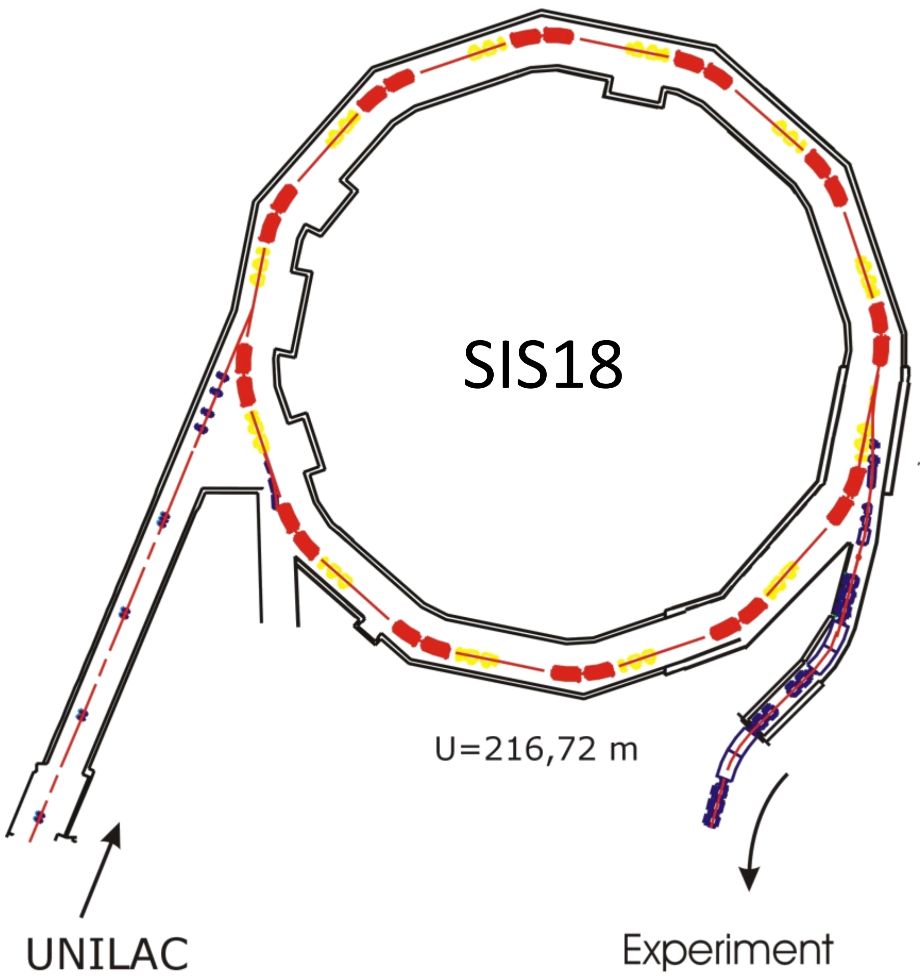
- FAIR peak intensity goals can only be reached by lowering the projectile charge states
- Incoherent space charge tune shift limits the maximum intensity in SIS18: $-dQ \propto Z^2/A$
- Poststripper charge states will be used

  (e.g.: Ar^{18+} > Ar^{10+}.........U^{73+} > U^{28+})
- Without stripping loss (charge spectrum) significantly enhanced particle current ($N_{uranium}$ x7) !

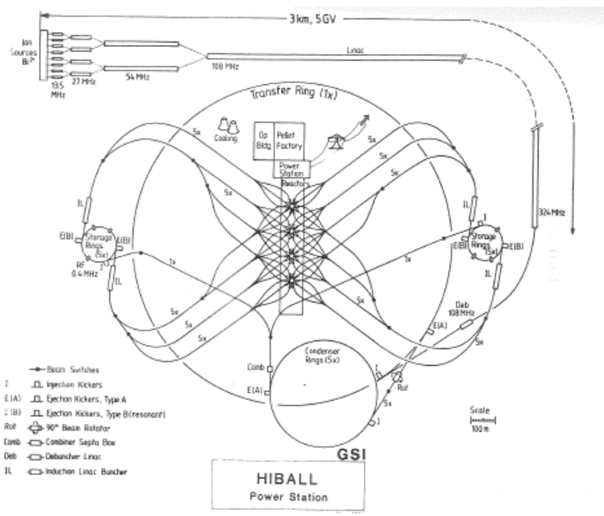


Transition from High to Low Charge State

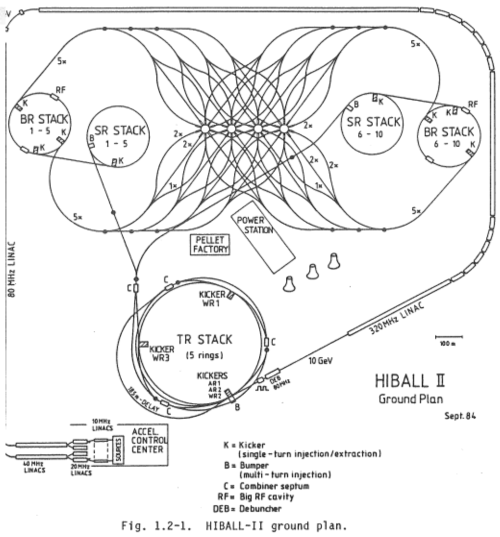
	Today	FAIR Booster
Reference Ion	U^{73+} →	U^{28+} !
Maximum Energy	1 GeV/u	0.2 GeV/u
Maximum Intensity	$4x10^{9}$	$1.5x10^{11}$
Repetition Rate	0.3 - 1 Hz	2.7 Hz



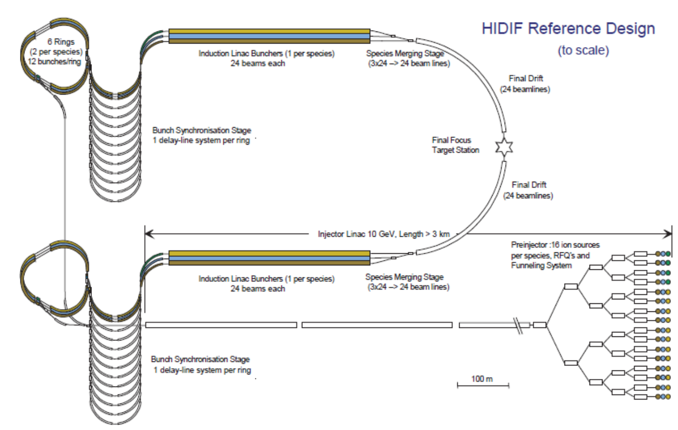
Today	FAIR	HIBALL
U^{73+}	U^{28+}	U^{1+}
10^9	$\sim 10^{12}$	10^{15}



HIBALL I



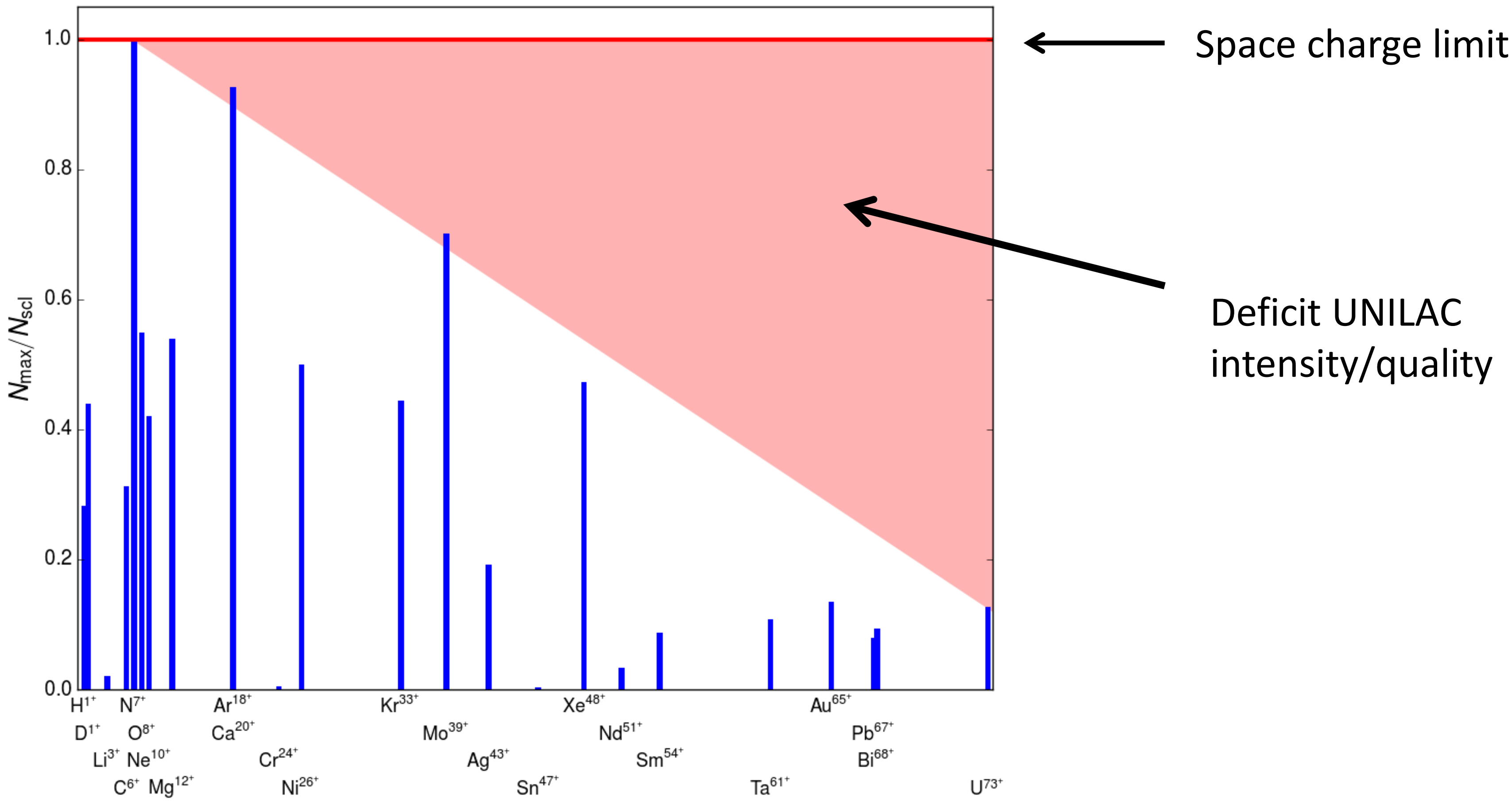
HIBALL II



HIDIF

Heavy Ion Fusion Goal: Energy Production 8 GW - 4.8 MJ Bi^{1+} / Bi^{2+}-ions

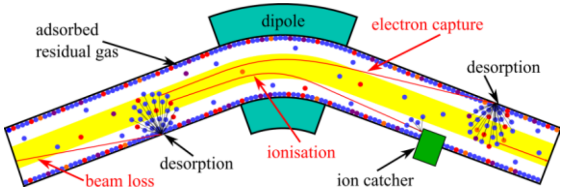
SIS18 Peak Intensity versus Space Charge Limit



With the completion of the SIS18upgrade program, the deficit from medium to high mass particles will not be closed without major improvements at the UNILAC:

Ionization and Dynamic Vacuum

The Dominating Intensity Limitation for Heavy Ion Beams in Synchrotrons is Ionisation in the Dynamic Vacuum.
This dominating loss mechanism appears much below the space charge limit.



Ionisation loss drives pressure bumps which itself accelerates the ionisation process.

> Dynamic vacuum instability

GSI has developed a world wide leading understanding of ionization beam loss and dynamic vacuum in heavy ion synchrotrons, including unique tools for self consistent simulations in time and space and technologies for curing these phaenomena.

Understanding: Simulation: STRAHSIM code

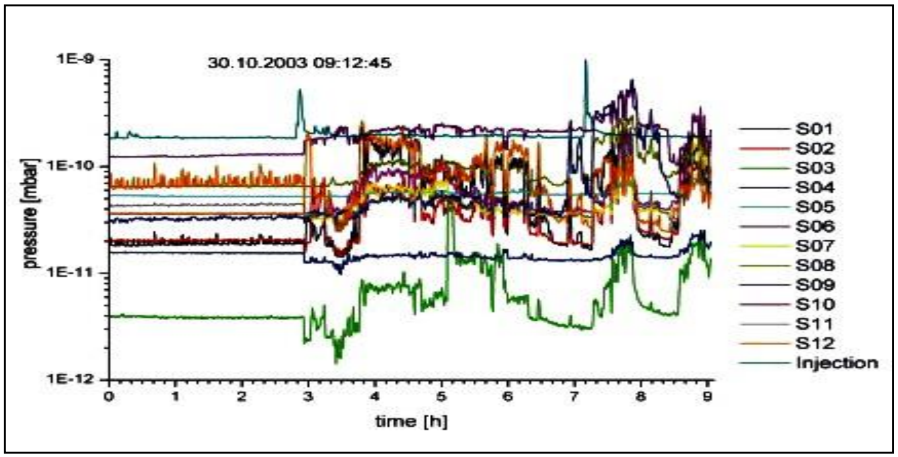
Dynamic vacuum and charge exchange driven beam loss in time and space

- Machine optics and collimation system
- Atomic cross sections for charge exchange
- Properties of pumping system (conventional, crogenic, NEG etc.)
- Gas desorption processes
- Realistic machine cycles

Counter Measures: New Concepts and Technologies (examples):

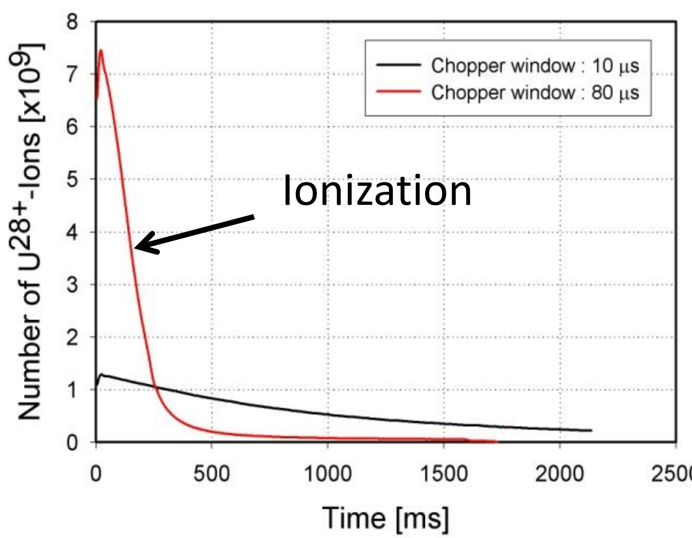
- Machine optics – Charge separator lattice (peaked distribution of ionizaton loss)
- NEG coating (distributed pumping)
- Low desorption surfaces and materials
- Ion catcher systems - room temperature and cryogenic
- Cryogenic, actively cooled magnet chambers (distributed pumping)
- Cryo-adsorption pumps

Ionization and Dynamic Vacuum



Static/Stationary (without beam) Dynamic (with beam)

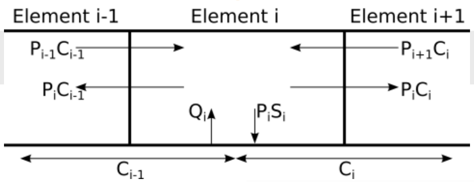
U^{28+}- operation in 2001



Main beam loss mechanism in SIS18 and SIS100 (far below the space charge limit)

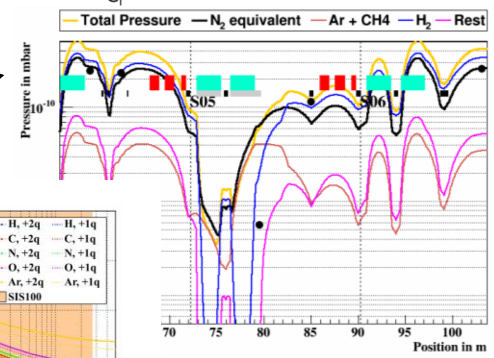
- Life time of U^{28+} is significantly lower than of U^{73+}
- Life time of U^{28+} depends strongly on the residual gas pressure
- Ion induced gas desorption ($\eta \approx$ 10 000) generates local pressure bumps
- Beam loss increases with intensity (dynamic vacuum)

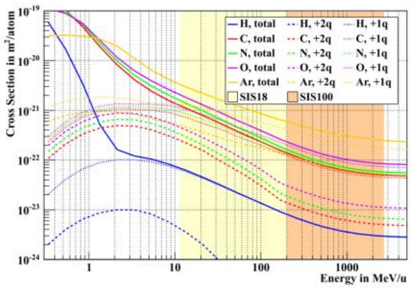
STRAHLSIM-Simulation of Dynamic Vacuum and Ionization Beam Loss

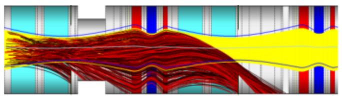


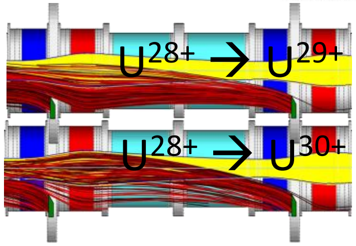
StrahlSim – a world wide unique code - has been developed in the past decade for FAIR at GSI:

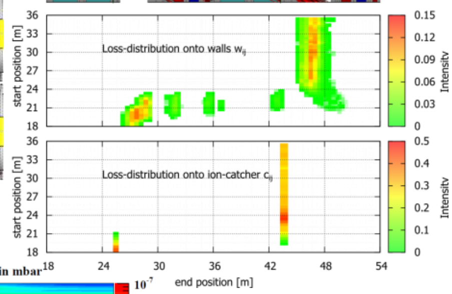
- Simulation of a self-consistent pressure profile along the ring (in space and time) for each residual gas component individually
- Number of charge exchanged ions is calculated for each time step individually, according to energy dependent cross sections for different ionization channels, including multiple ionization
- Loss distribution for each ionization channel is calculated via linear ion optics, ionized ions are distributed according to this tracking
- Simulation of ion induced desorption: Outgasing at the impact cells is increased, depending on the surface and the presence of ion catcher
- Number of lost ions and number of pumped gas particels is counted (saturation calculations)
- Pressure profile is re-calculated for the next time step → pressure profile evolution
- Realistic machine cycles is considered with shrinking of emittance and energy dependence of cross sections

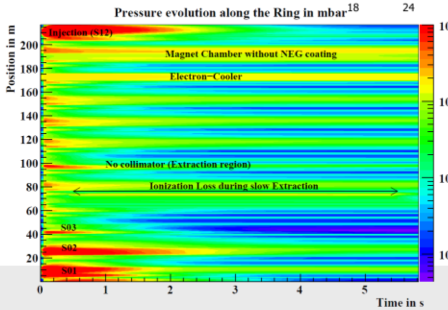












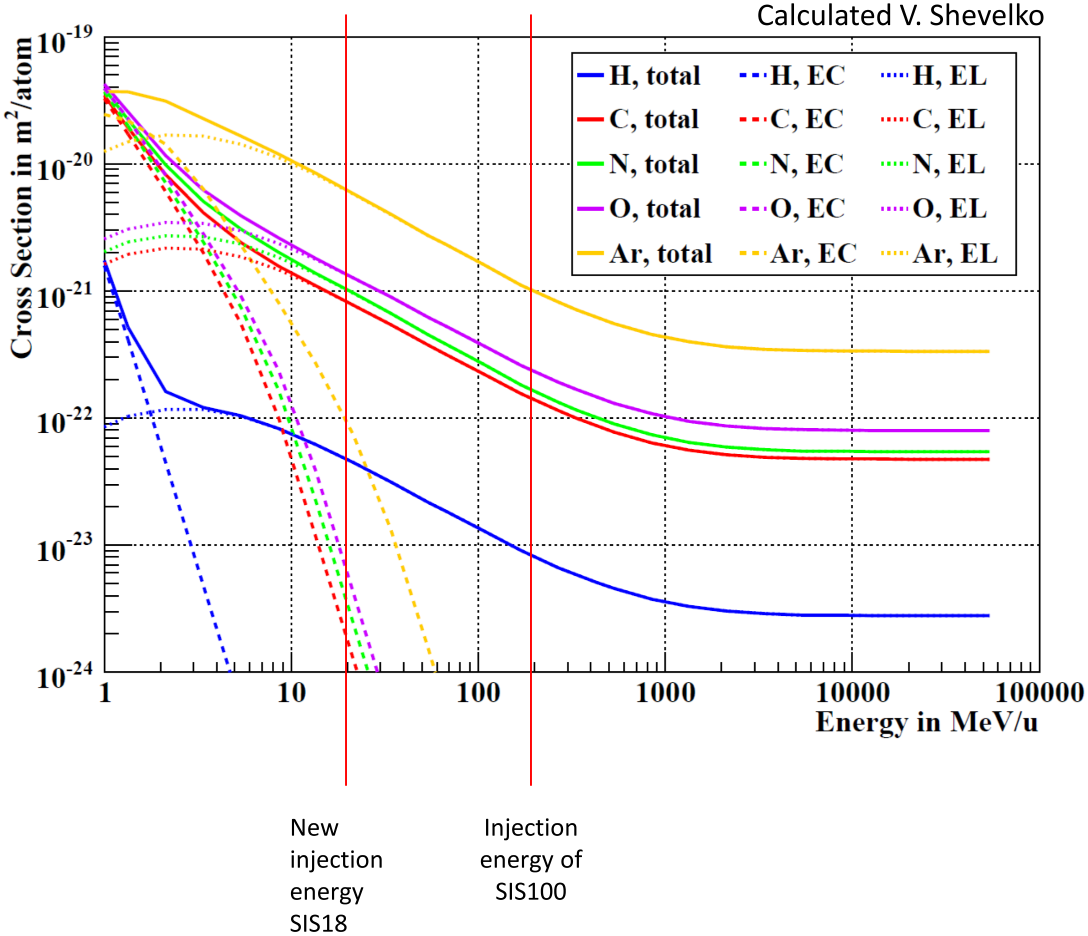
Ionization and Capture Cross Sections

Intense and unique collaboration with the GSI atomic physics department on cross sections for

- projectile ionization and multiple ionization
- electron capture
- target specific cross sections
- energy dependency
- target ionization

All data are summarized in a data base for the STRAHLSIM dynamic vacuum code.

Calculated V. Shevelko



Intermediate Charge State Heavy Ions

Existing and planned Heavy Ion Accelerators operated with Low Charge States worldwide

AGS Booster	BNL	$5x10^9$	Au^{31+}
LEIR	CERN	$1x10^9$	Pb^{54+}
NICA Booster	JINR	$4x10^9$	Au^{32+}
SIS18	**GSI/FAIR**	$1.5x10^{11}$	U^{28+}
SIS100	**FAIR**	$5x10^{11}$	U^{28+}
B Ring	**HIAF**	$1x10^{11}$	U^{34+}

SIS18 served as a pilot facility for the development of

- new accelerator concepts
- new technologies and
- the understanding

... to overcome vacuum instabilities and ionization beam loss at high intensity heavy ion operation.

Ionization Beam Loss and Dynamic Vacuum determines the system design and the accelerator technologies of SIS18 and SIS100 and limit the maximum intensity much earlier than space charge and current effects.

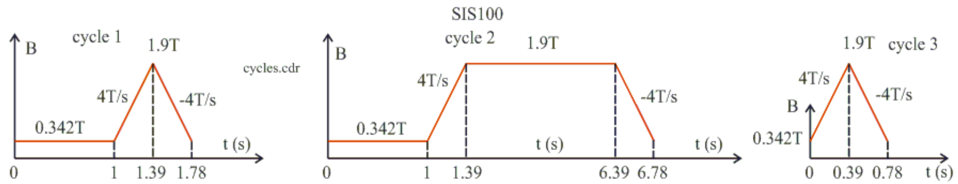
Strength of Charge Exchange Processes in the Reference Machine Cycle

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

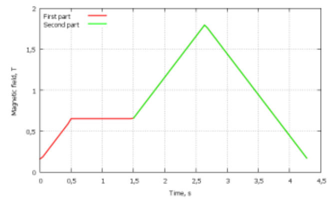
Accelerator	Institut	Ion species	Total integ. cross section	Number of ions	N x σ_{int}	Rep. rate [Hz]	N x σ x frep
AGS Booster	BNL	Au^{31+}	4.5×10^{-21}	5×10^{9}	2.2×10^{-11}	5	1.1×10^{-10}
LEIR	CERN	Pb^{54+}	5.5×10^{-20}	1×10^{9}	5.5×10^{-11}	0.25	1.4×10^{-11}
NICA Booster	JINR	Au^{32+}	4.9×10^{-21}	4×10^{9}	1.9×10^{-11}	0.25	4.7×10^{-12}
SIS18	GSI	U^{28+}	8.7×10^{-22}	1.5×10^{11}	1.3×10^{-10}	3	3.9×10^{-10}
SIS100	FAIR	U^{28+}	1.8×10^{-21}	6×10^{11}	1.1×10^{-9}	0.5	5.5×10^{-10}
Bring	HIAF	U^{34+}	2.5×10^{-21}	5×10^{11}	1.25×10^{-9}	0.09	1.1×10^{-10}

Machine Cycles and Integral Cross Section

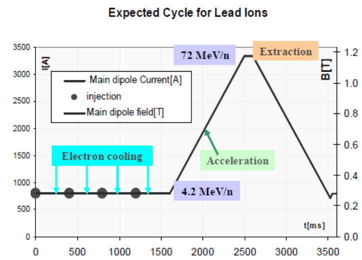
SIS100 cycles



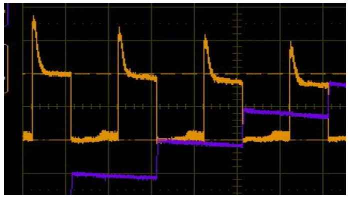
NICA booster cycle



LEIR cycle



AGS booster cycle



σ_{int} depends on the specific machine cycle

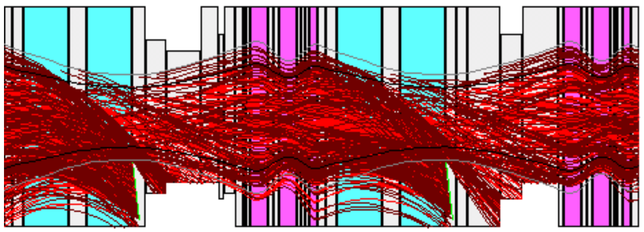
$\sim \int \sigma(E(t))\, dt$

GSI has provided STRAHLIM simulations for:

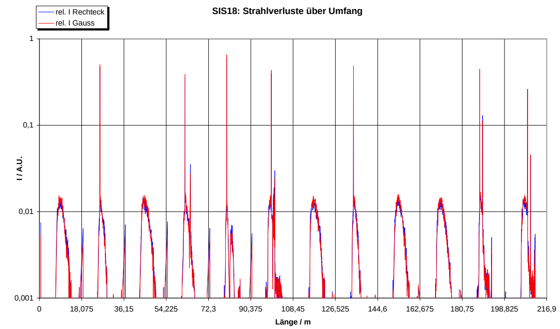
- AGS booster,
- NICA booster
- HIAF Bring

Ionization Loss Distribution

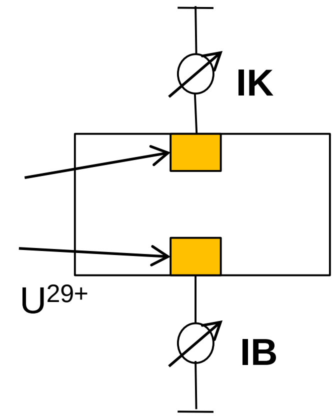
SIS18 Ion Catcher System



Ionization beam loss in section 11,12



Beam loss distribution U^{29+}



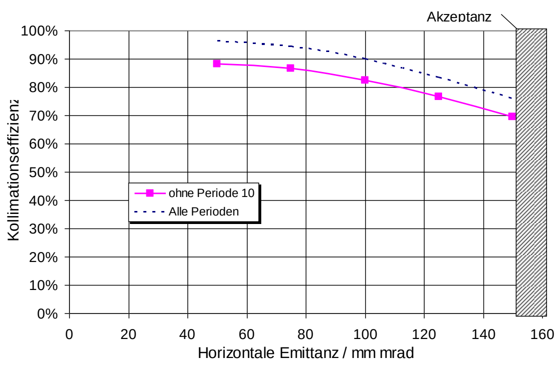
- Developed for heaviest ions

  (highest ionization cross sections)
- Triplet/ doublet structure is suitable but:

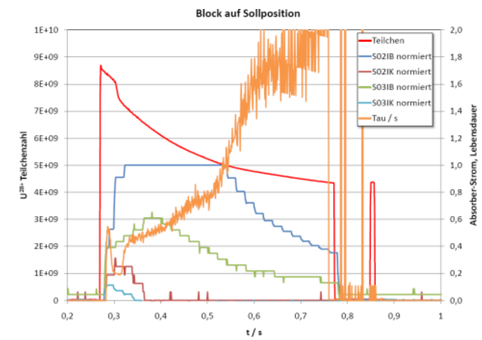
  bending power of dipoles to high

  > Limited collimation efficiency

  depending on emittance (70 %)



Scraper efficiency U^{29+}



Ion catcher current depends on energy dependence of cross sections

Dynamic Pressure Stabilization
- Recipe for SIS18 upgrade-

- Short cycle times, short sequences and short injection plateau

  Fast ramping (SIS18: 10 T/s, SIS100: 4 T/s)

  (power connection, power converters, Rf system,

  fast ramped (superconducting) magnets)
- XHV and huge pumping power

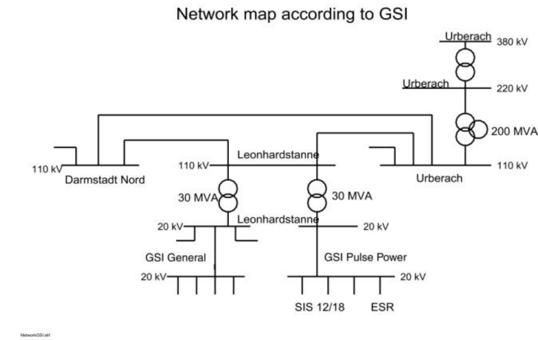
  (NEG-coating, cryo pumping - local and distributed)
- Localizing beam loss and controle/suppression of desorption gases

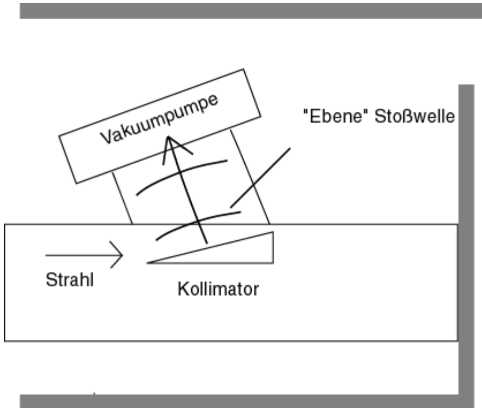
  (Ion catcher system with low desorption yield surfaces,

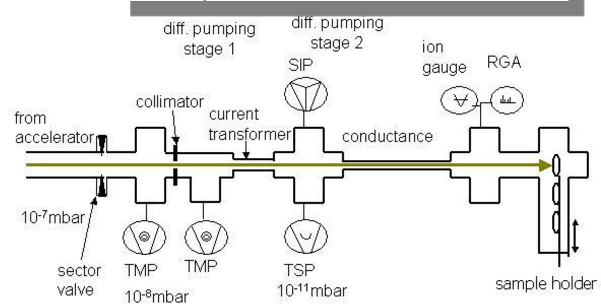
  Synchrotron optics and lattice design)
- Minimum „effective“ initial beam loss

  (TK halo collimation, low desorption yield surfaces, precise closed orbit

  closed orbit feed-back, no tracking errors, precise radial position (feed-back)







Halo Collimation in Transfer Channel

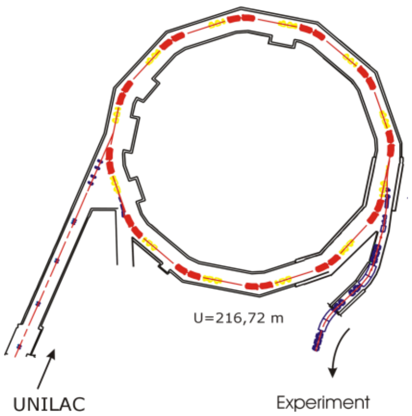
Collimation of transverse phase space and imaging optics upstream injection

1. Image plane

(Injection channel)

Imaging optical system

Object plane (three stage collimation)



2. Image plane

(Backside injection septum)

FAIR Booster Operation

Dynamic Vacuum (prevention of inital, systematic pressure bumps):

- Multiturn injection loss can not be significantly lowered, but losses have to be controlled by low desorption yield collimators. The effective loss in terms of desorption, shall be < 1%.
- Closed Orbit: Precise Closed orbit correction without local distortion.
- Tracking Errors: Radial position feed-back

HV Stability: Beam halo at high intensity induces high voltage break down in the injection septum. Beam power at 15 emA: 1,5 MW. Sharp edge distribution needed for a stable injection septum operation.

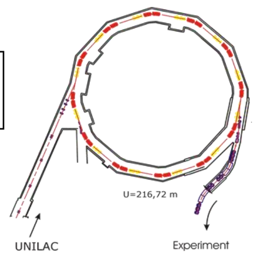
Mechanisms Effecting the Life Time of U^{28+} Ions

Losses in the injection channel and during the multiturn injection process

1. Image plane (Injection channel)

Imaging optical system

Object plane (three stage collimation)



2. Image plane (Backside injection septum)

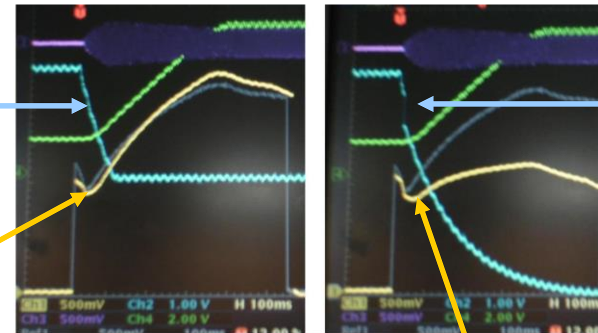
Halo Collimation in Transfer Channel

Shifting the beam loss from the inside of SIS18 into the transfer channel

High Voltage Break Down in electrostatic septa

Voltage of electrostatic injection septum

Beam current over acceleration

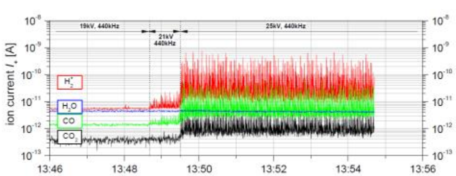


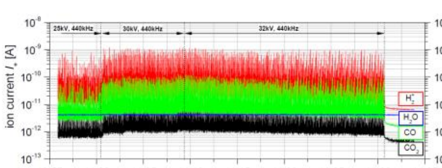
High voltage break down

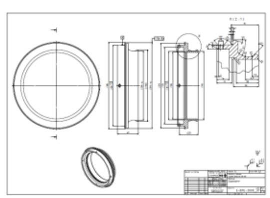
Beam current under the influence of pressure bump

Strong pumping is needed in the electrostatic septa, e.g. by means of NEG panels

Electron Multipacting in Rf Gaps







- In the couse of developing SIS100 Rf bunch compression cavities, for the first time a flashlight has been observed during the Rf pulse.
- The flashlight is been accompanied by a signficant pressure bump in the cavities.
- The same effect has been observed in the SIS100 FOS acceleration cavity above 15 kV gap voltage.
- Specially design Rf gap to suppress electron multipacting

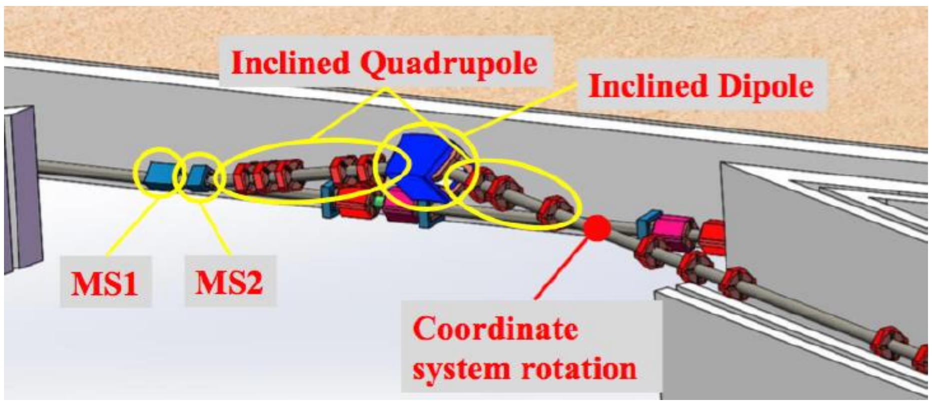
Two-Plane MTI Injection

A new SIS18 two plane injection system may:

a) Reduced beam loss during injection

b) Relax the required beam intensity from UNILAC (longer injection time)

<> Higher MTI gain with same UNILAC intensity

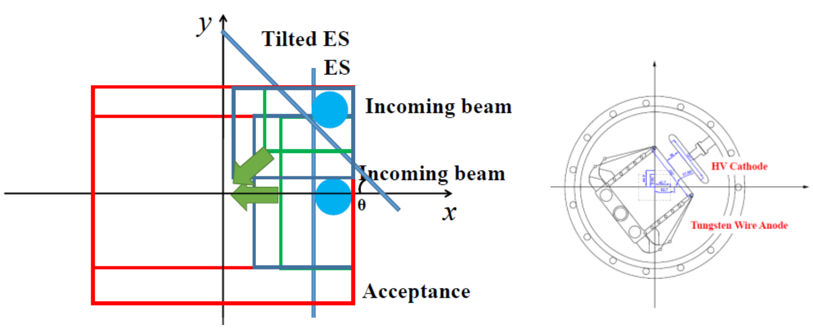


Sketch of Bring (HIAF) injection system

Single Plane: $N_{inj} \approx \frac{A}{1.5\varepsilon_i}$

Two-Plane: $N_{inj} \approx \frac{A_x}{\varepsilon_{ix}} \times \frac{A_y}{\varepsilon_{iy}} \times f$

$f \approx 0.1 \sim 0.125$

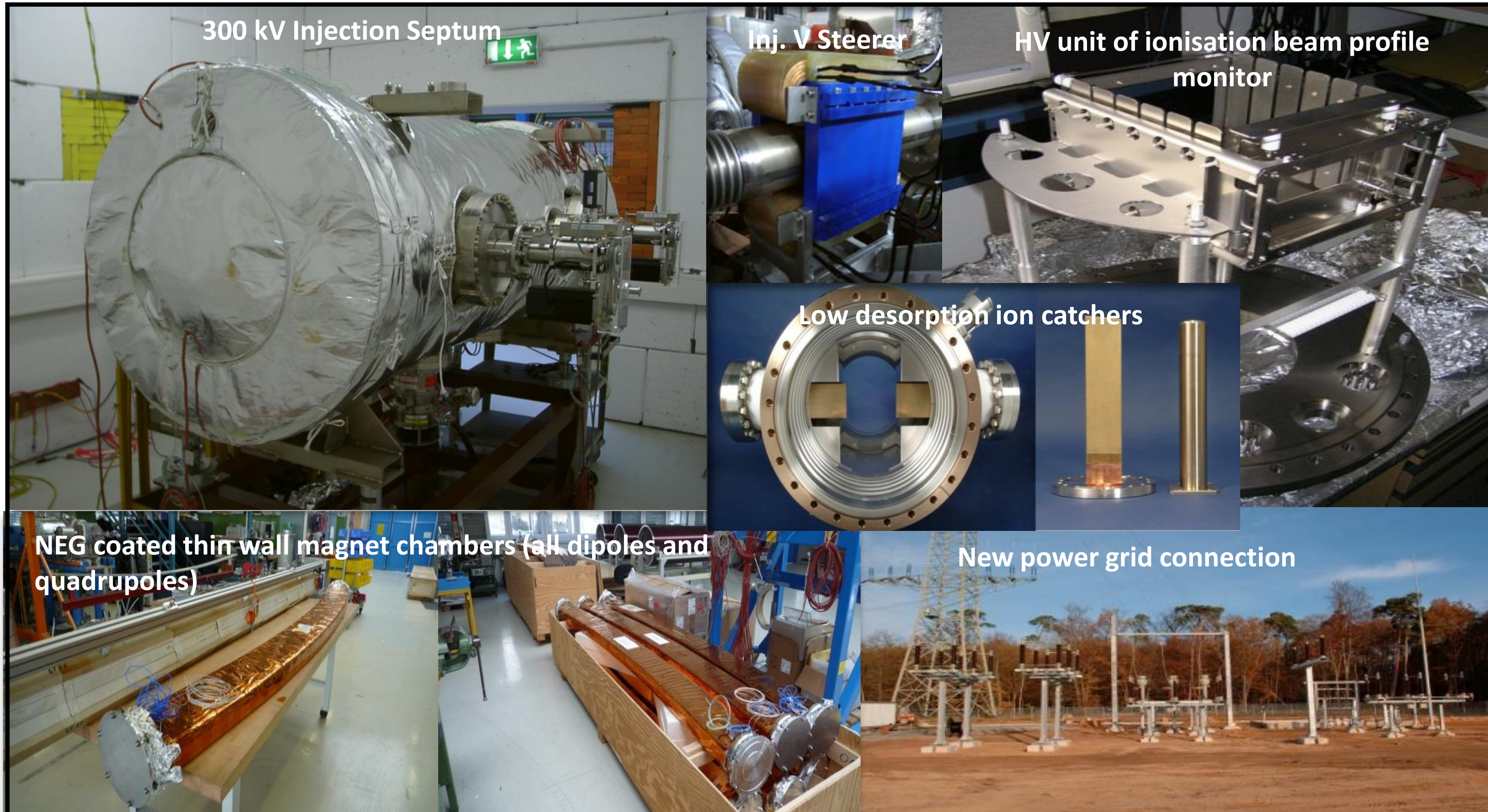


Two plan injection with tilte electrostatic septum

Beam parameters and acceptances for injection into Bring very similar to SIS18

SIS18 Upgrade Program 2005 – 2013
Implementation of New Key Technologies

The upgrade program is dedicated to intermediate charge state heavy ion operation for FAIR



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SIS18 Upgrade Program 2013 – 2021
Implementation of New Key Technologies

The upgrade program is dedicated to intermediate charge state heavy ion operation for FAIR

Three new MA acceleration cavities installed (50 kV, h=2) and power converters

Replacement of main dipole power converter (for 10 T/s, 50 MW)

In the past, the EU has supported the upgrade program as an investment in a major European Research Infrastructure.

SIS18/SIS100 IPM magnet system manufactured and delivered

Bipolar dipole magnet and power converter for the connection of transfer line to SIS100

The originally defined SIS18upgrade program is completed.

Preparation of the Existing Accelerator Tunnels and Buildings for FAIR

SIS18 Civil Construction GAF and WTK

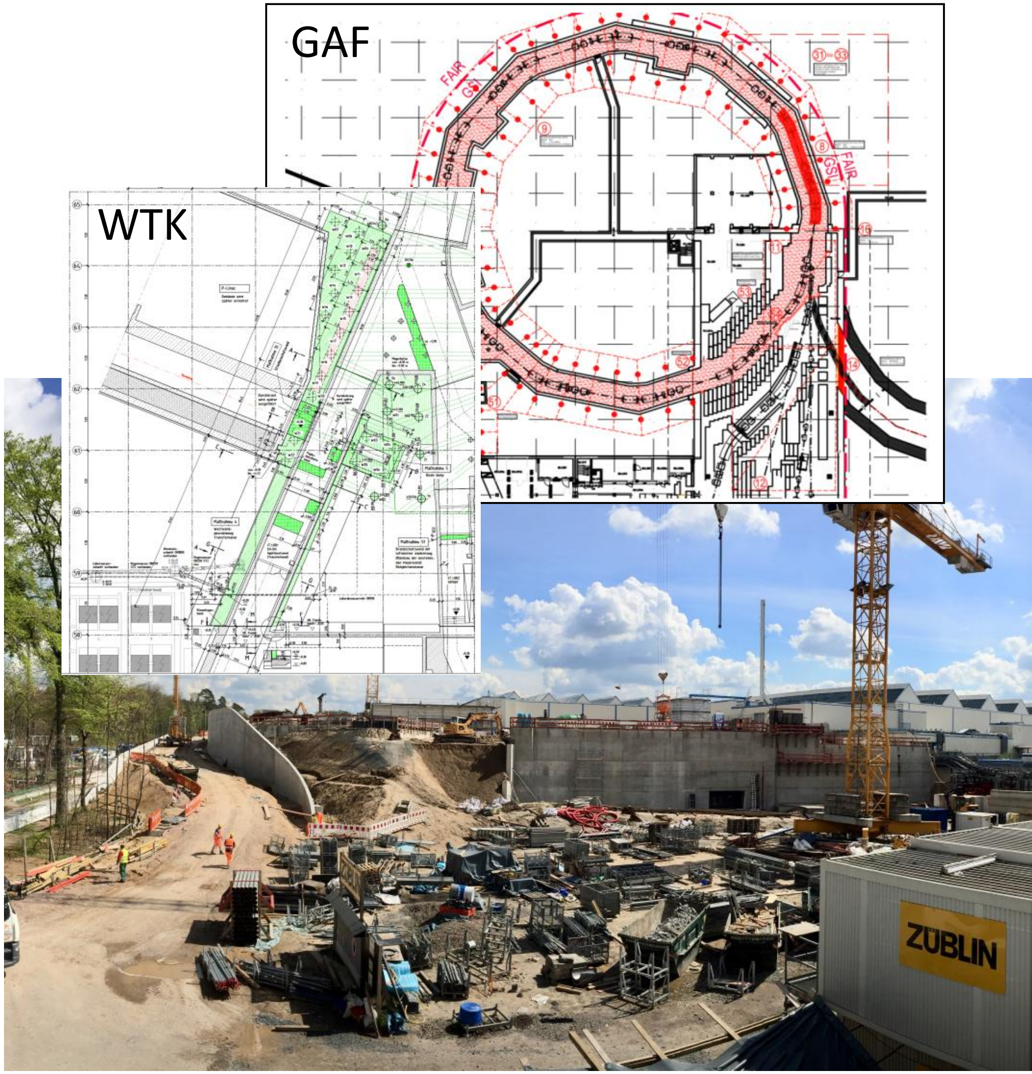
GAF (Gebäude Anbindung FAIR):

- **Shielding enhancement** on top of the existing SIS18 tunnel and at other locations for fast cycled operation with 5×10^{12} Protons per Second. (1% Proton beam loss at final energy)

- **Radioactive air management** system
- **Fire prevention system** (nitrogen venting)
- **Interface** to the FAIR tunnel 101
- An inner and outer **reinforment wall**
- **Power link** of main operation building to new transformer station North

WTK (Westwand Transfer Kanal)

- **Beam dump** for the proton linac on the western side of the transfer channel (TK)
- Shielding enhancement of the TK eastern wall and interface for an early construction of the p-linac building



GAF and WTK Project

Original situation

Interface for new Proton linac completed.

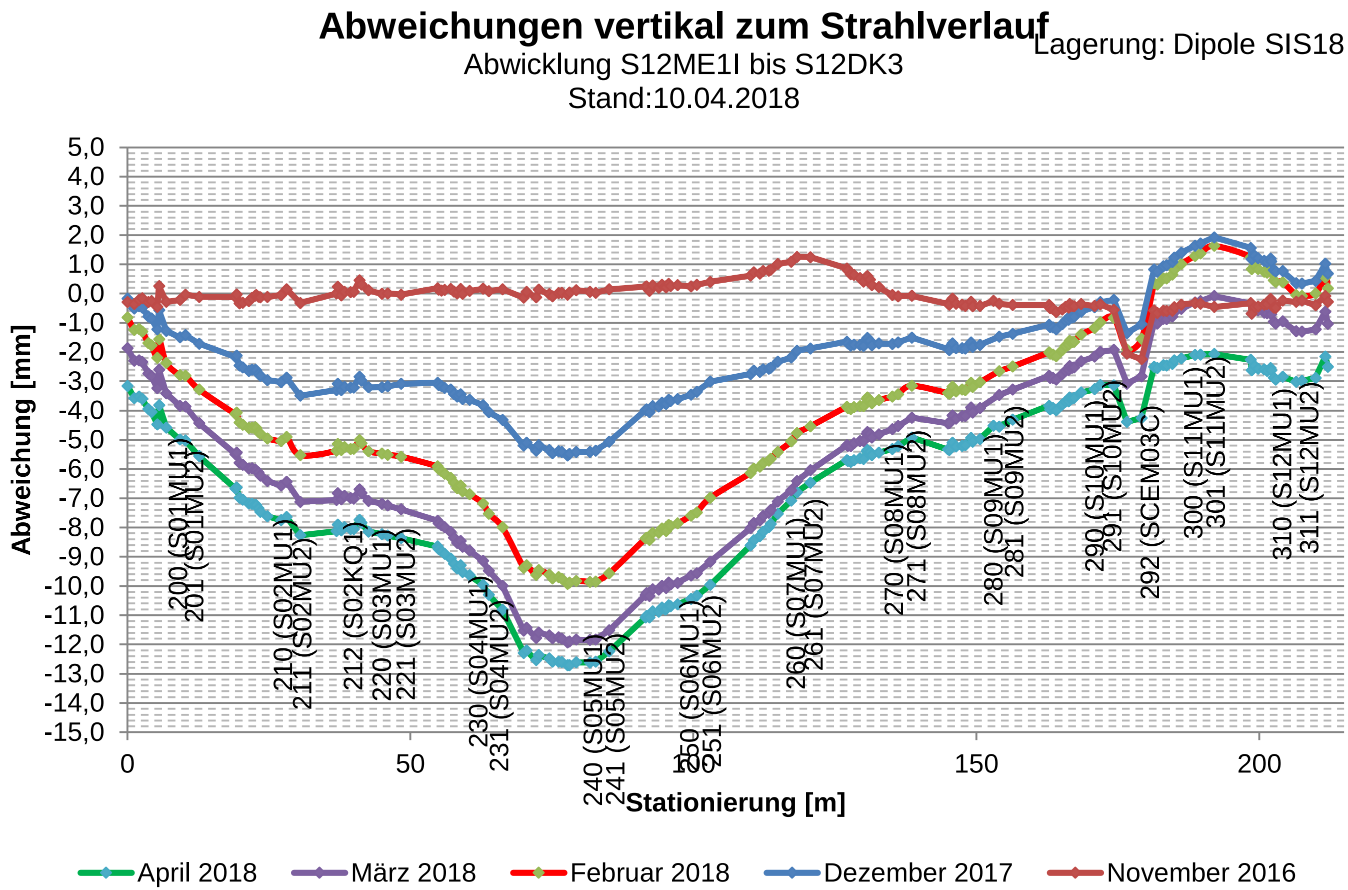
Reinforcement of SIS18 roof and new technical operation building TG1 completed.

Interface for FAIR tunnel 101

Remaining activities:

1. Shielding enhancement in kicker-room (2022) and
2. Shielding enhancement on top of SIS18 extraction

Measured Vertical Misalignment



There will be quite a lot of movement over the next years, as ground water is increasing, loads are changing and constrcution nearby (HESR) is executed.

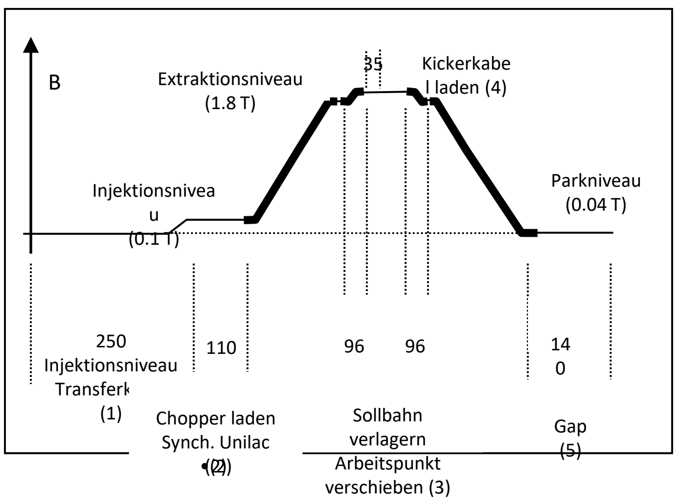
FAIR Transformer Station North

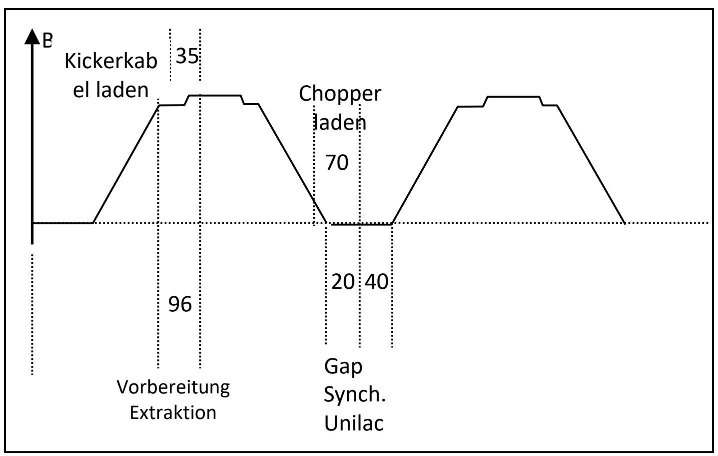
- Transformer Station North (FAIR Puls Power) enables the operation of SIS18 with 50 MW and SIS100 with 25 MW pulse power.
- No further compensation measures (capacitive storage, fly wheel etc.) required.

High Repetition Booster Cycle

- Established power grid connection enables ramping with 10 T/s.
- Transition from single cycle operation to „batch operation“.
- Built on the available MMTI cycle (UNILAC request).

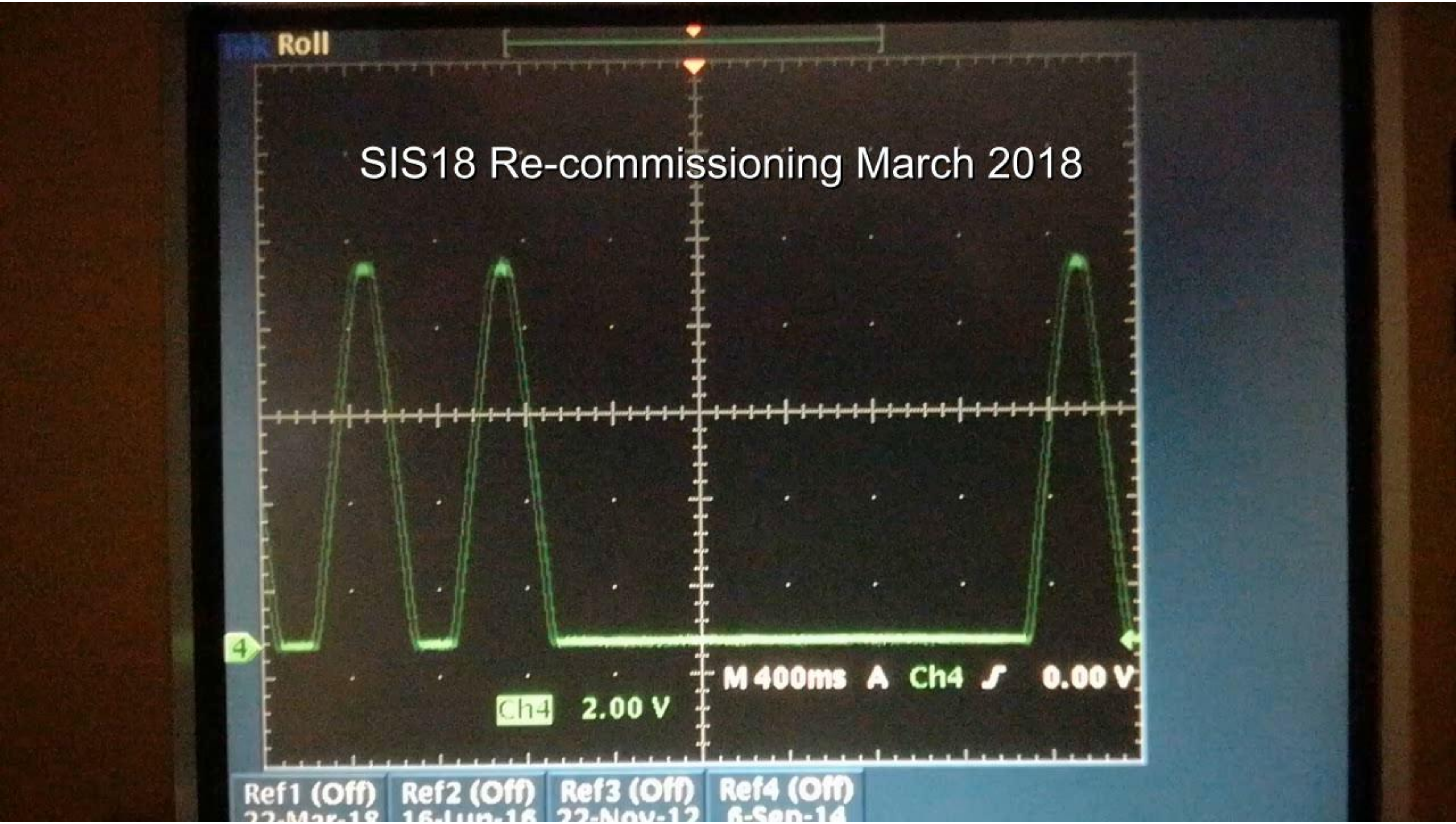
- Open action item:
  Present cable connection between transformer station (TK) and main power converters does not allow maximum ramping an high duty cycle.





First beam test, including high repetition MEVVA source operation: Machine run 2022

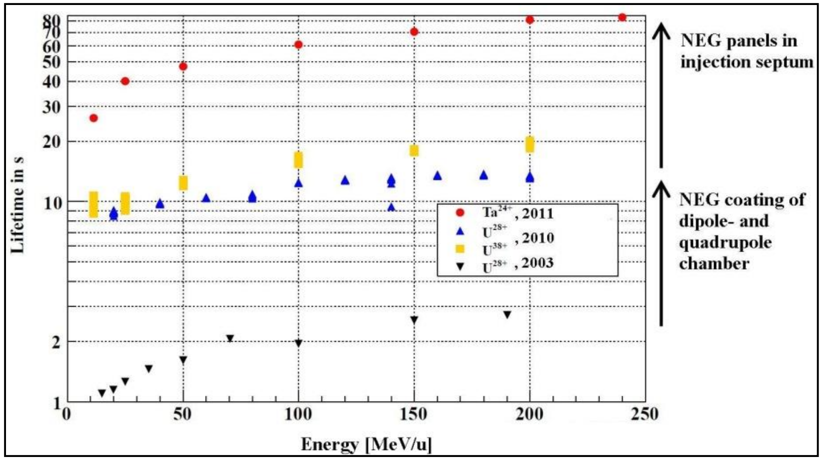
Fast Repetition Operation with Maximum Ramp Rate



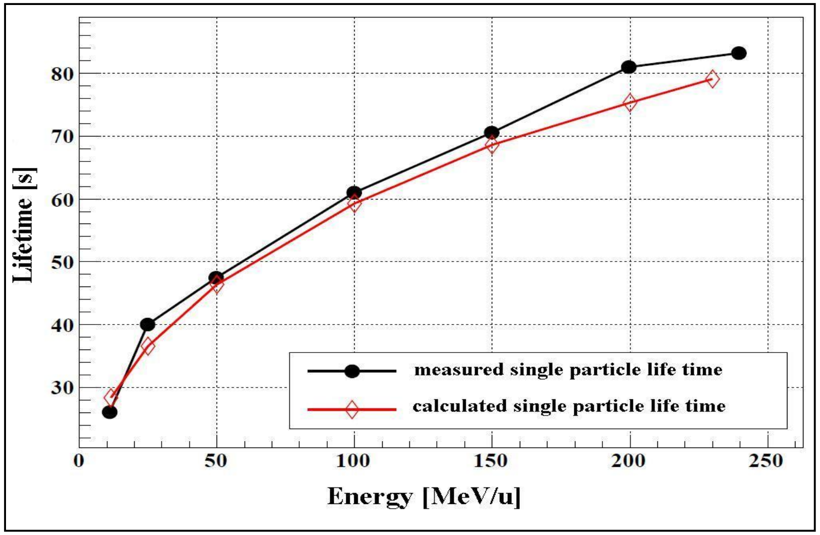
(Static) Single Particle Lifetime

As a result of the various upgrade stages, the beam lifetime could be continuously increased. These Figures show the measured lifetimes of intermediate charge state, heavy ions for different stages of the UHV system upgrade.

E.g. the measured lifetimes of intermediate charge state, heavy ions after NEG coating of the dipole- and quadrupole chambers and after inserting NEG panels in the injection septum.



After the installation of NEG panels in the injection septum, a perfect agreement has been achieved between the measured and expected beam lifetime and its energy dependence.

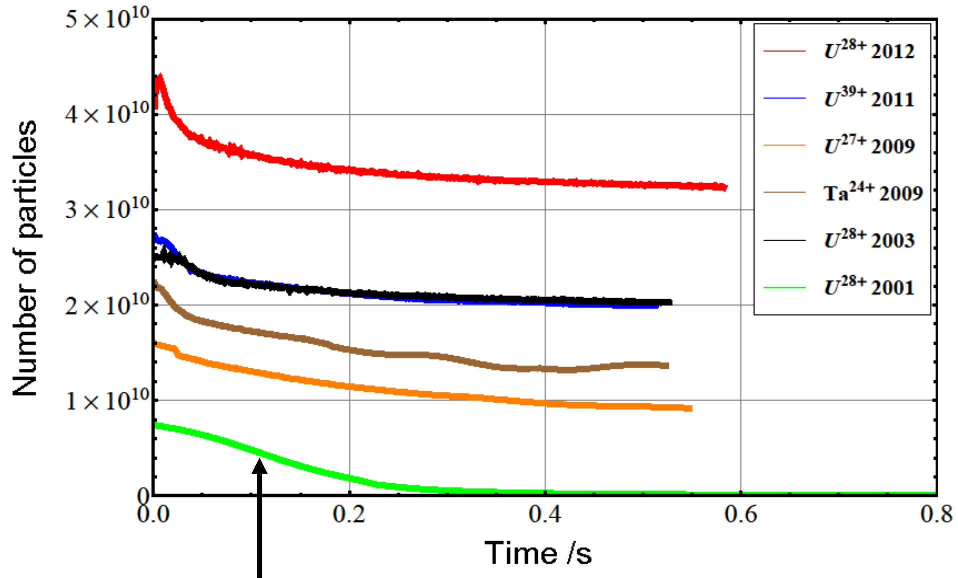


SIS18 Status U^{28+} -Beam Intensity

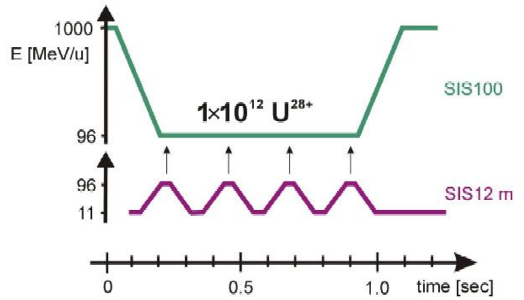
World record intensity for intermediate charge state heavy ions in heavy ion booster.

The feasibility of high intensities with intermediate charge state heavy ions has been demonstrated.

World record



2001 FAIR conceptual design report (FAIR proposal)



Stacking in SIS100 (4x)

At SIS100 commissioning:

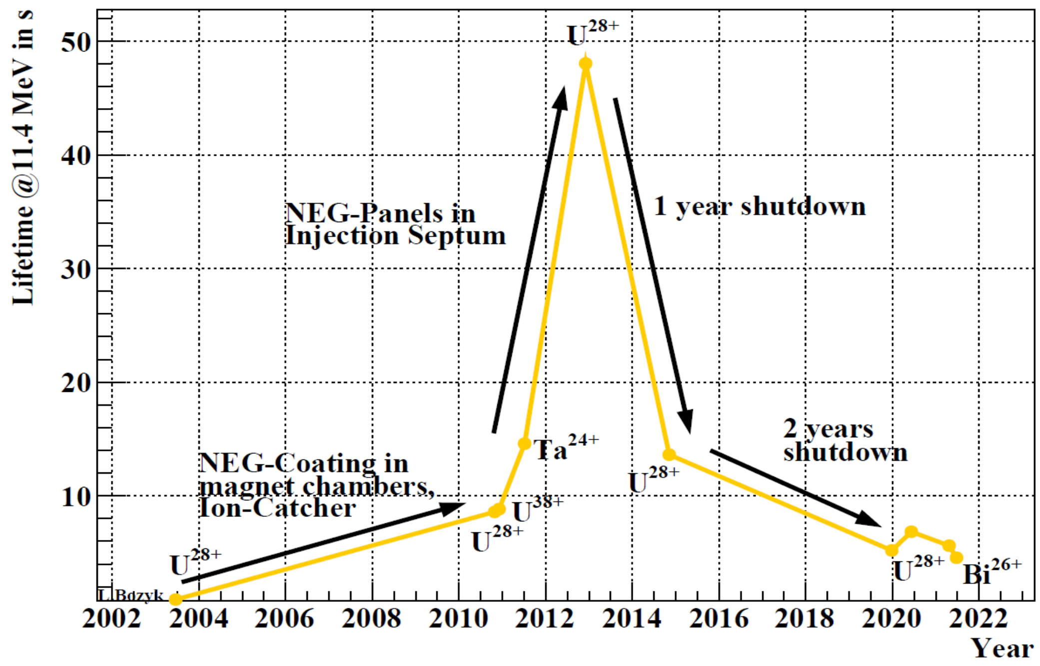
An intensity of U^{28+}-beams of 1-2 x10^{11} per cycle is safe

At APPA/PP commissioning:

2 x10^{10} Uranium ions per cycle is safe.

Further upgrade measures are investigated for reaching the intensity goal for the most heavy ions (e.g. Uranium with 1.5x10^{11} per cycle at a (high) repetition rate of 2.7 Hz.)

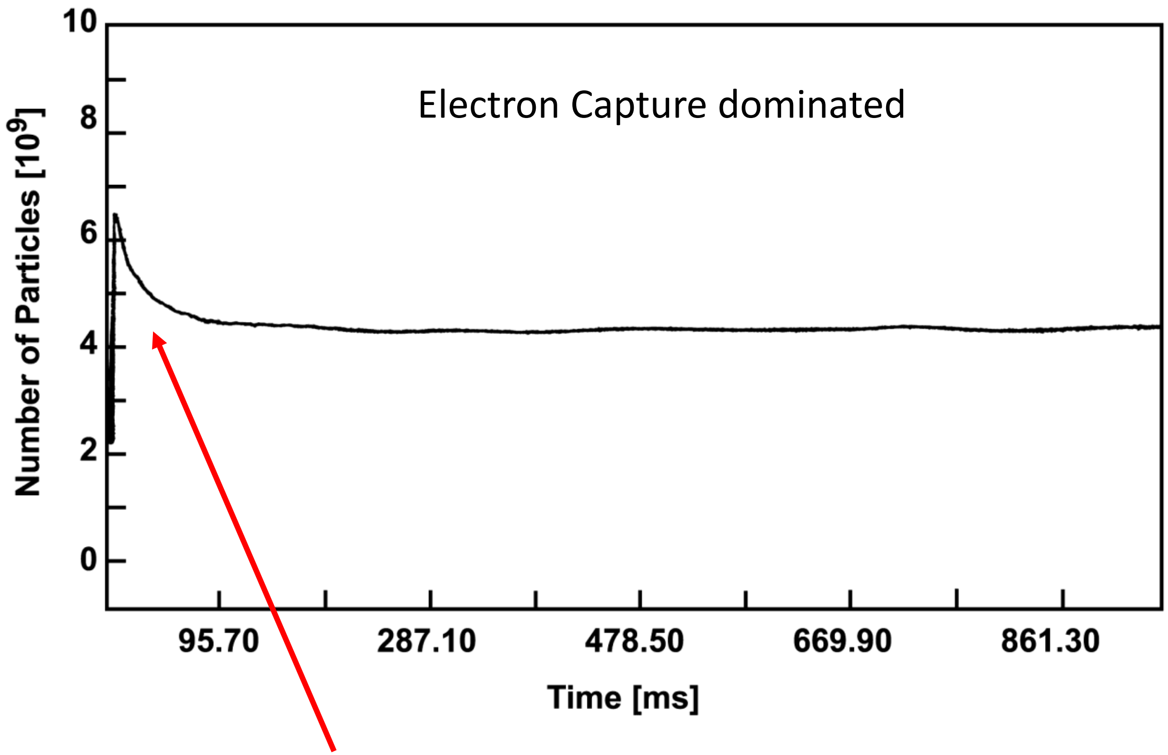
Single-Particle Lifetime of Low Charge State Heavy Ions



- Reduced NEG pumping power ? No relevant bake-out cycles since 2018.
- Strategy for replacement of all (very old) IZ pumps.
- Enhanced pumping required in extraction system.
- Long range solution required !

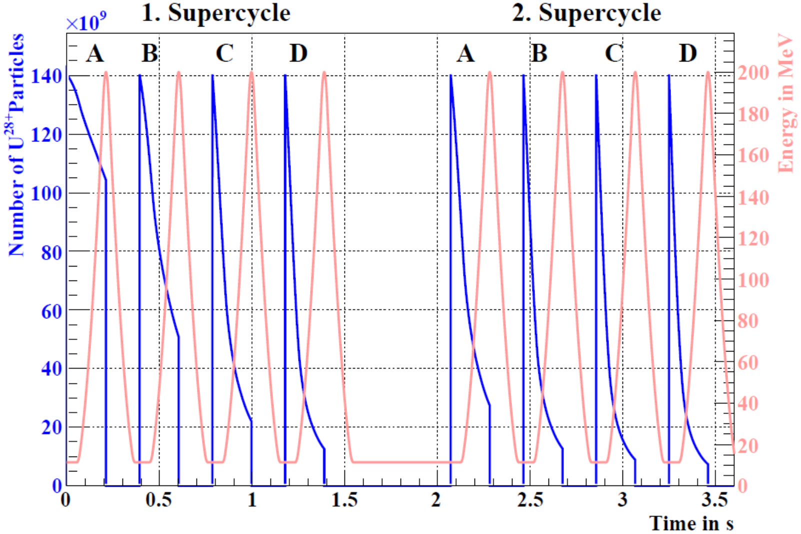
„Best“ U^{73+} Beam

December 2003 !



Electron capture dominated loss ?

FAIR Booster Operation and Ionization Beam Loss



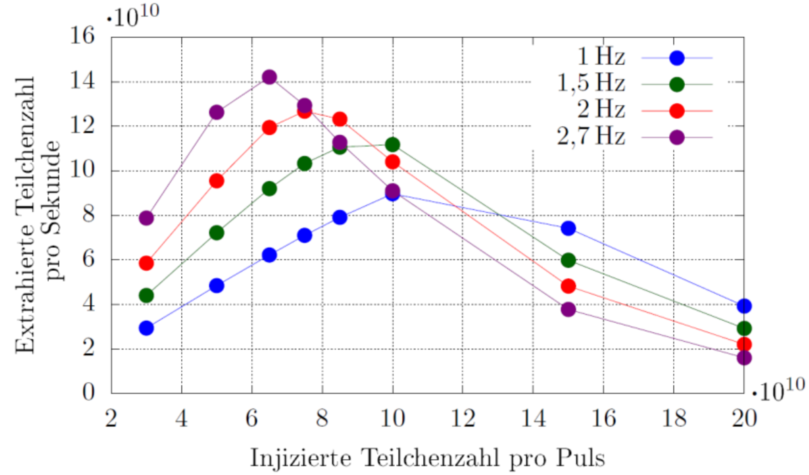


Abbildung 3: Extrahierte Teilchenzahlen pro Sekunde aufgetragen über die injizierte Teilchenzahl pro Zyklus mit 1 % Injektionsverlust.

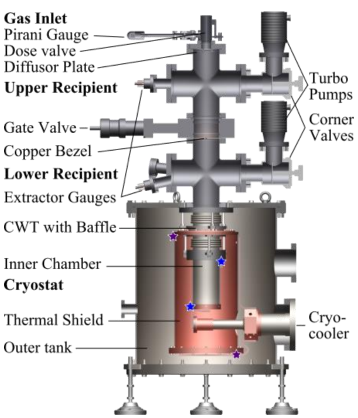
Predicted by projectile ionization and transmission in the 3 Hz SIS18 booster operation.

New simulations possible by means of improved models for cold-warm transitions.

Cryo-Pumping in SIS18

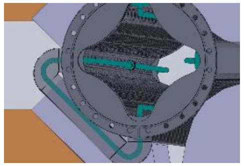
Application of Cryopumping in Room-Temperatur Synchrotrons

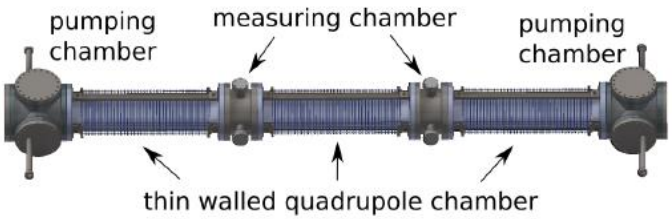
Cryo-Teststand



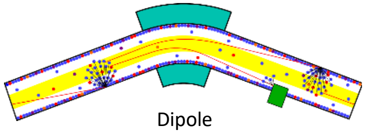
Investigation of properties of cryopumping
(Phd thesis F. Chill)

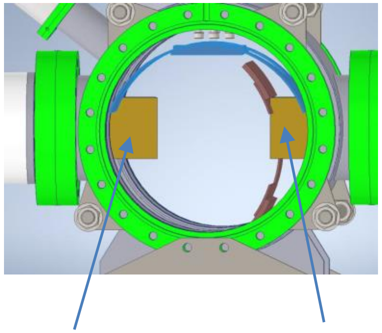
(Phd thesis S. Aumüller)





Cryogenic inserts in thin Wall Quadrupole Chamber

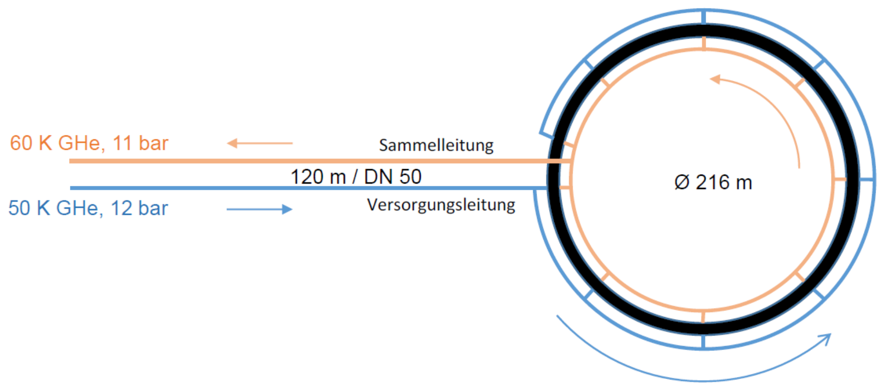




Cryogenic Inserts in Ion Catcher System

Cryopumping in SIS18

Feasibility study for a cryopump integration into SIS18 magnet chambers, by ILK, Dresden completed.
Study includes estimation of total heat load and possible LHe supply by STF.



Cryogenic supply of SIS18 ring LHe ring line from STF

High Intensity, High Energy Protons

Major Intensity Increase by Methane Operation from Source

- Fast extraction

  Peak intensity test
  $1{,}5 \times 10^{11}$ Protons injected
  6×10^{10} Protons accelerated

- Slow extraction
  4.5 GeV with g_T–shifted optics successfully demonstrated.
  Intensity at slow extraction (flat top): 6×10^{10} p/spill for 4 h.

Due to missing calibration of counters, no precise extraction efficiency measured.

Slow extraction performed by means of both, fast quadrupole (4.5 GeV) and KO extraction (150 MeV).

High Current Operation

Properties of MTI at High Beam Currents

- The linac longitudinal emittance, growth with increasing beam current
  (measured at the beginning of the transfer channel and after injection into SIS)
  SIS18: the coasting beam momentum spread depends on the current

- The linac center energy, changes with increasing emittance (beam loading in buncher cavities ?)
  SIS18: the Rf frequency must be tunes according to the current

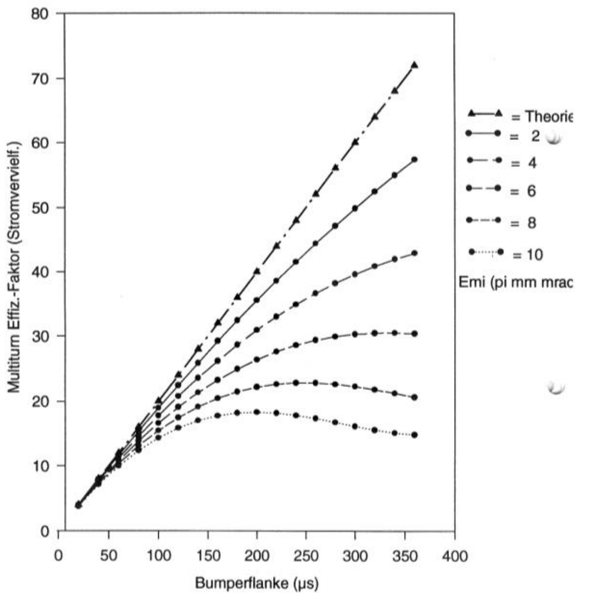
- The horizontal tune for highest injection efficiency changes with increasing current
  SIS18: the tune (PC) has to be changed for different beam current (set-values)

- The center beam energy is slowed down after injection into SIS18 by resistive wall imp.
  SIS18: fast capture (2ms and acceleration start)

- The optimal working point for MTI may not be the best high current working point (losses after injection)

- Debunching may be improved by a more effective debuncher cavity at the end of UNILAC ?

- At operation with TK stripper (injection of highly charged ions), the center energy changes according to the degradation of the stripper thickness.



High Intensity Operation

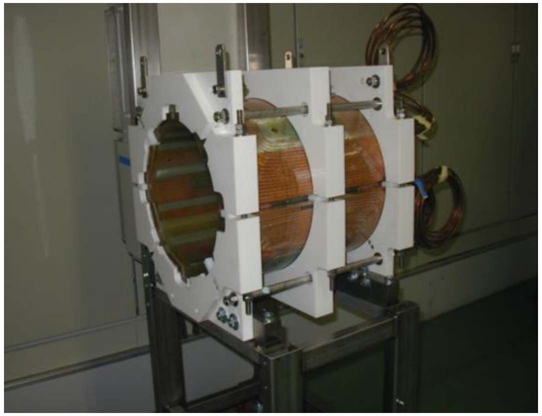
High Current Working Points
There is no systematic approach yet to compensate resonances and to fix a “final” high current working point.

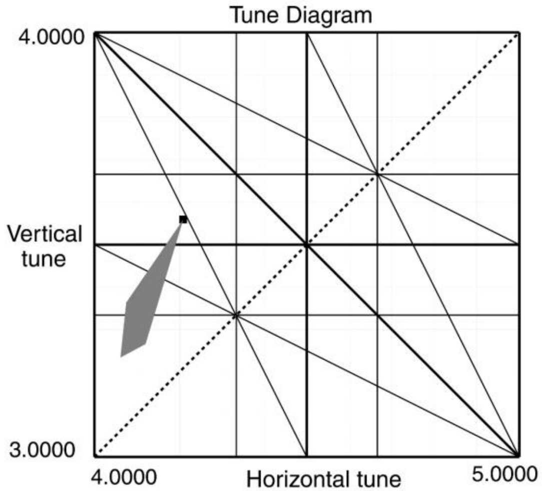
Resonance correction for the final high current working point

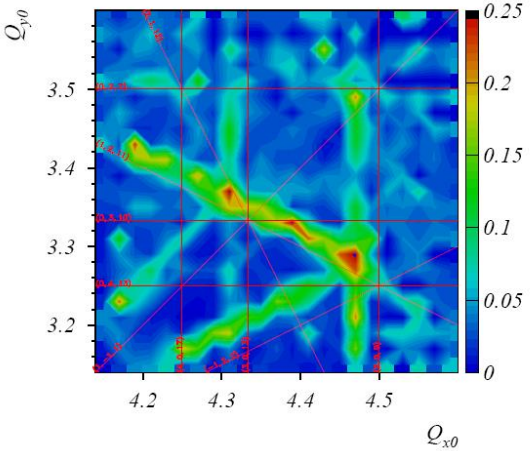
Compensation of different Resonances (Qv = 3.5, Qv = 3.33 und Qh – Qv = 1) for the minimization of beam loss at the final

High Current Working Point

(Qh = 4.2, Qv = 3.6).





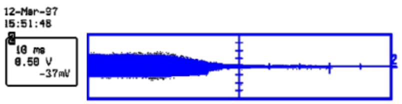


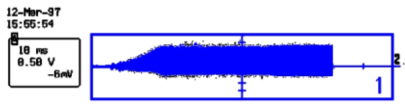
Measured tune diagram based on tune scans indicates dense population with resonances

High Intensity Operation

Impedances and Beam Stability

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

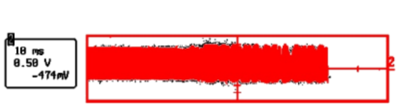




Bunch Amplitude before Debunching (h=4)

Low Current Ne 10^9 ions

Bunch Amplitude after Rebunching (h=1)



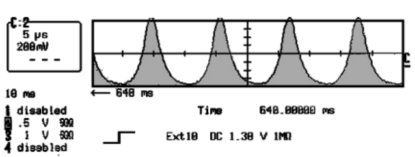
Bunch Amplitude before Debunching (h=4)

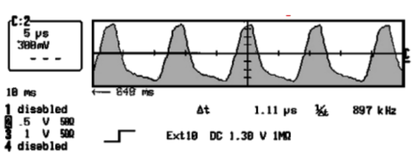
Bunch Amplitude after Rebunching (h=1)

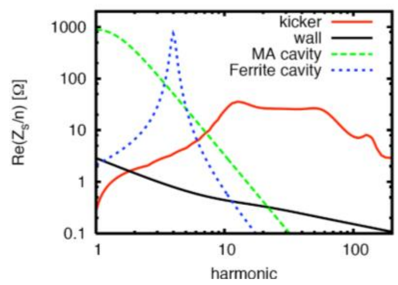
High Current Ne 10^{10} ions

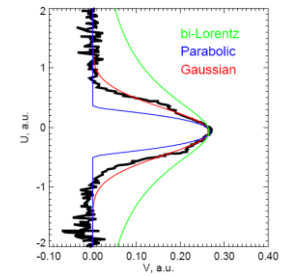
Final Bunch Profil at Low Current (1)

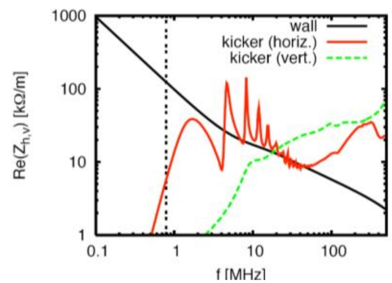
Final Bunch Profil at High Current (2)

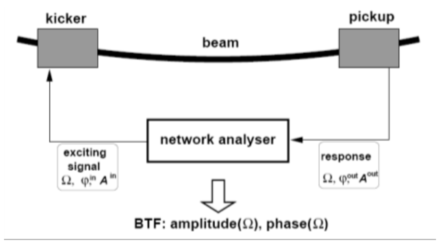












Goal: Determination of impedance spectrum -

Measurement of

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

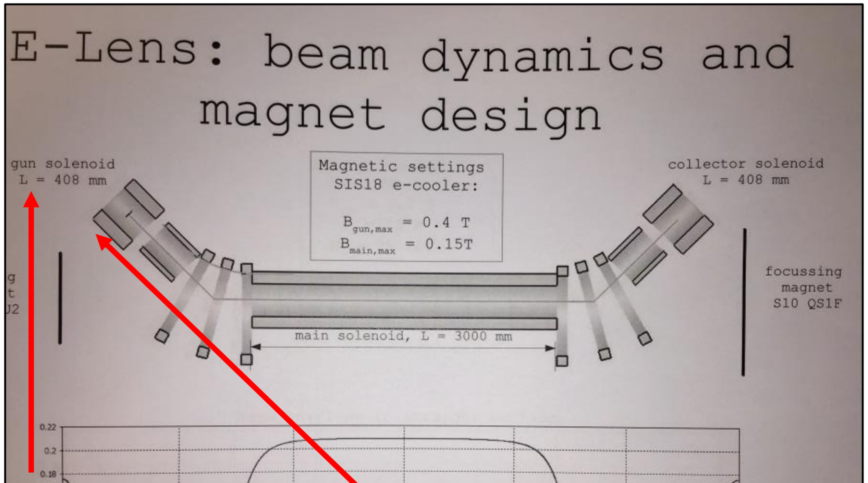
Options for damping: TFS, octupoles, e-lens.
No demonstration of functionality in practical operation.

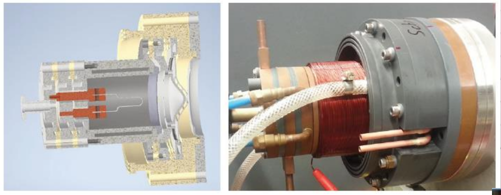
Future Perspectives/R&D:
Electron Lens for Space Charge Compensation

Goal:
Compensation of space charge defocusing and intensity limit in synchrotrons. Development and set-up of a prototype e-lens for SIS18.

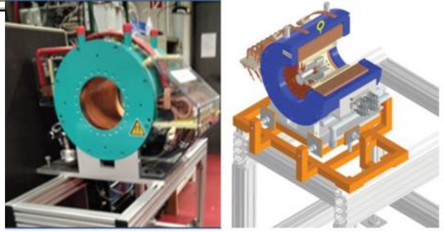
- ARIES (EU) funded development of E-gun and Rf modulator.
- Modulated electron beam matching longitudinal ion beam profile.
- R&D partners: IAP Frankfur (e-gun), TU Riga (Rf modulator) and CERN (Test stand).
- Simulations on electron and ion beam propagation.
- Modifications of electron gun for transversly homogenuous beam.
- Continuation of magnet design.
- Develop an overall 3 D modell
- Road map under discussion.

- POF ARD Subtopic 2





Electron gun design and prototype at IAP



Gun solenoid

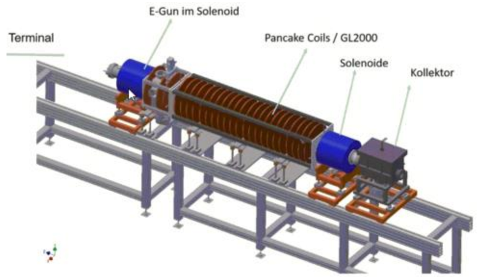


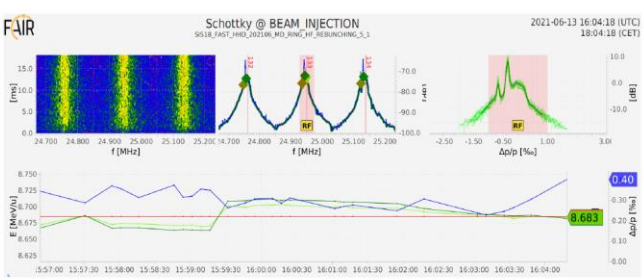
Table 1: SCC Electron Lens Requirements

Peak electron current	10 A
Extraction voltage	30 kV
Magnetic field	0.6 T
Interaction length	3.36 m
Horizontal beam radius	35 mm
Vertical beam radius	20 mm
Min. modulation frequency	0.4 MHz
Max. modulation frequency	1 MHz
Modulation bandwidth	10 MHz

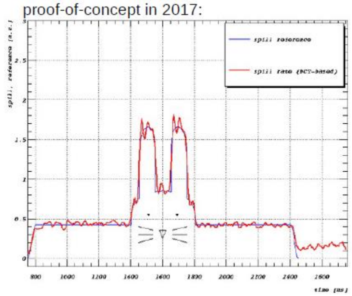
Digitized Observables

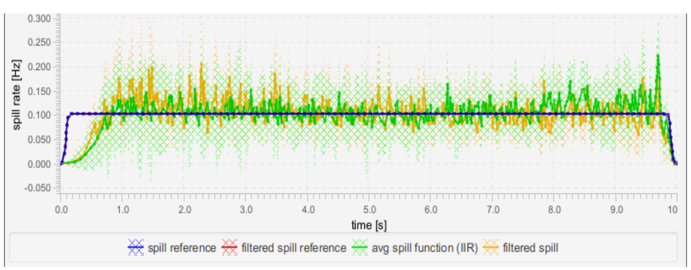
- The low loss budget in the FAIR booster operation (e.g. 1 % in Proton operation) requires a signficantly improved beam control and machine operation.
- Additional observabled required for operation. Important observables presently missing or expert-only.
- Pre-condition for operation from FAIR main control room.

- Digitization of former analogue signals enables the development of beam based feed-back systems.
- Examples: automated Rf tuning, automated orbit correction, automated spill control.
- First applications have been developed and are under testing.
- Observation of frequency spectrum in the pulse power grid may enable advanced fold detection.
- The potential of KI (AI) technics (e.g. for injection optimization) will be evaluated in the frame of ARD and EU programs.
- Digitizer framework – Frame contract in procurement.



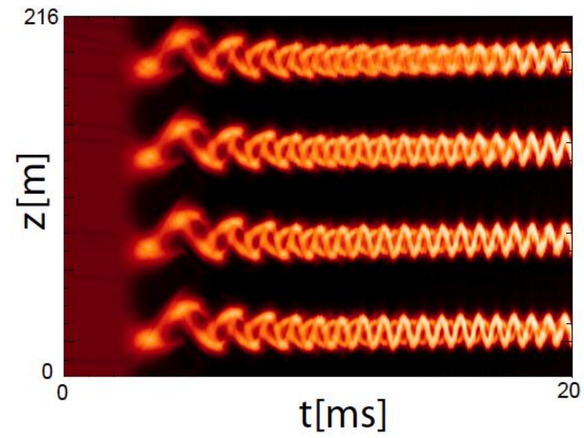
proof-of-concept in 2017:





Longitudinal Phase Space

- Rf mismatch to revolution frequency at injection generates longitudinal emittance blow-up.
- Mismatch generates coherent oscillations which are not damped during high current operation (in a single) harmonics bucket).
- Rf capture has to be adiabatic. Issue: Eigenfrequency control of cavities.
- Minimize longitudinal emittance blow-up needed to limit the required RF voltages in SIS18 and SIS100 ($\propto dp/p^2$).
- Degradation of stripper foil generates increased energy distribution and center energy shift.
- Automatic RF fine tuning by control of radial position based on Schottky measurement.
- Observation of the last years: Longitudinal emittance at heavy ion operation is to large for the SIS18 Rf bucket (especially at fast ramping).
- Dual harmonic operation is required for the FAIR booster mode and at operation nearby the space charge limit.



Observation:
Persistent dipolar or quadrupolar bunch oscillations above a threshold intensity.

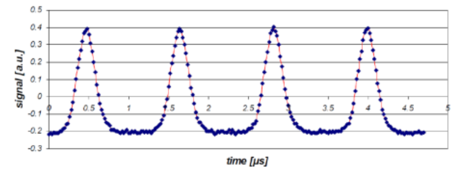


Figure 4: Bunch Profile Single-Harmonic Operation (B. Zipfel)

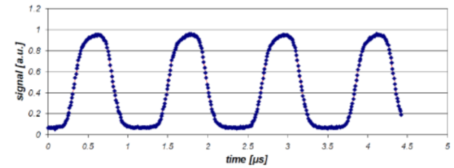


Figure 5: Bunch Profile Dual-Harmonic Operation (B. Zipfel)

Flattend bunches at dual harmonic operation.

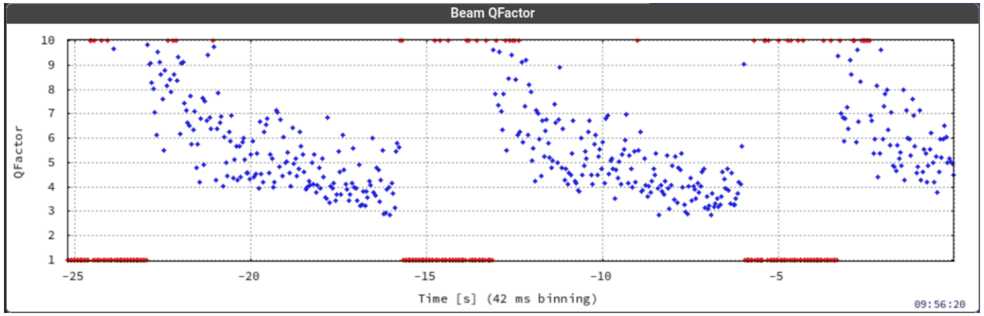
Slow Extraction: Micro Spill Structure

Tune wobble experience with HADES Proton beam time:

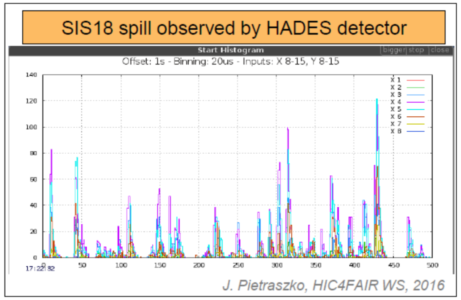
- HADES provides good quality factor measurement for main control room. However, the detector is saturating already at rather low intensities.
- Tune wobble seem to improve the micros spill structrure.
- The difference in quality between main and fast quadrupole is minor.
- Single turn injection (small horizontal beam size) seems to enable better Q-factor.
- Defficit in diagnostics for machine setting.
- Further systematic studies needed.

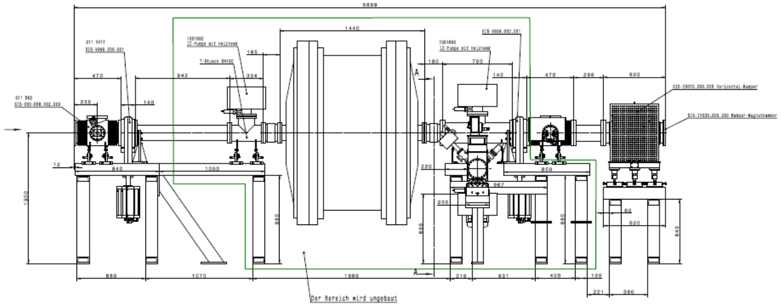
- The tune wobble concept may not be applicable to SIS100

Q-Faktor mit reduziertem Chopperfenster (Single-Turn-Injektion)

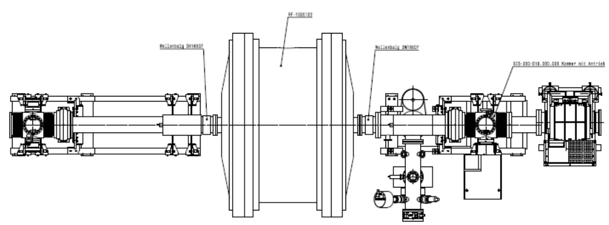


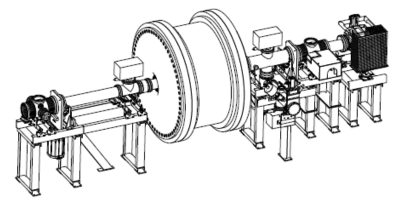
Slow Extraction: Micro Spill Structure





High frequency cavity for micro spill smoothing (proof of principle)



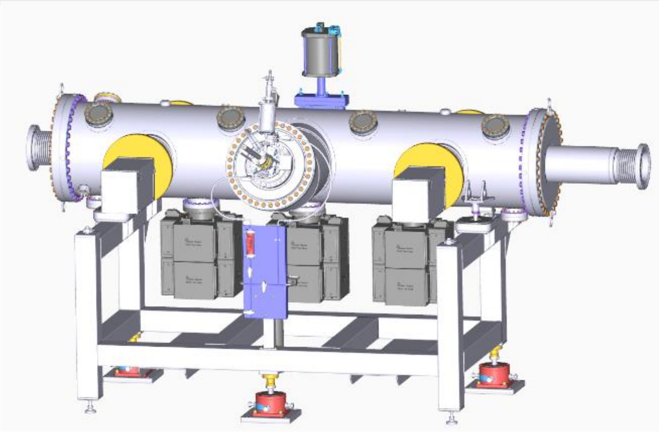


Spill smoothing by bunching

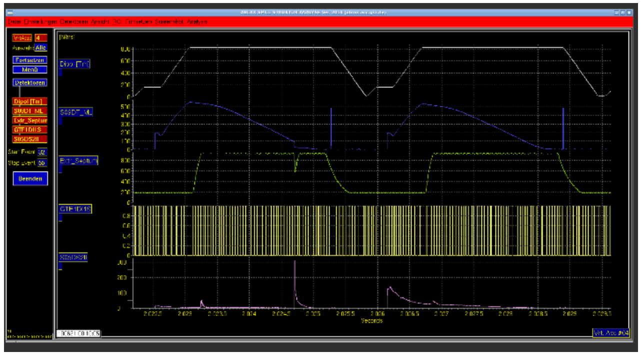
- Tune ripple by synchrotron motion and chromaticity
- VHF spill cavity under development

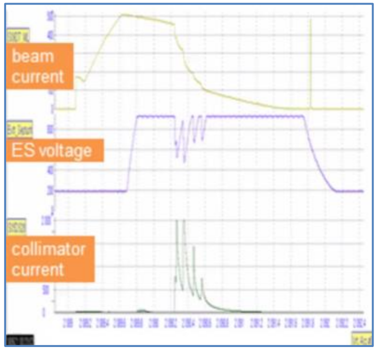
- Demonstration of spill smoothing at AGS, BNL in different operation modes.
- Installation of the test cavity in shut down 2022.
- High shunt impedance limits the use of the test cavity and probably also the beam intensity.

Slow Extraction: Electrostatic Septum



Design of prolongated SIS18 extraction septum





High voltage break down during slow extraction

Strength, Efficiency and Stability

- The origin for the„missing“ deflection angle has been found. X-ray diagnostics has indicated too low septum voltage.
- Design of a new extraction septum is completed. Procurement decision postponed.
- R&D: Is a stable operation of a HV wire septum possible at the desired high intensities of heavy ions in SIS18 and SIS100 ?
- Does a prolongated, new septum provide better HV stability ?
- Indications, that more discharges observed in heavy ions operation. Will be further investigated.
- Implementation of data logging.
- Distinguish: Intrinsic high voltage stability and beam induced high voltage stability.
- Do we gain by a different cathode surface (treating).
- Thermal load at high intensity heavy ion operation (high dE/dx)

Destroyed SIS18 E-septum wires

+ Several other topics and issues
+ Maintanance, replacements and services

Thank you all for the first class collaboration on an outstanding high level of experties.

D. Ondreka, J. Stadlmann, L. Bozyk, N. Pyka, Y. El Hayek, P. Forck, B. Galander, R. Steinhagen, H. Liebermann, A. Krimm, R. Balss, U. Blell, I. Petzenhauser, M. Petryk, S. Heberer, K. Thoma, S. Aumüller, R. Singh, M. Schwickert, N. Pyka, H. Welker, V. Plyusnin, O. Boine Frankenheim, S. Sorge, A. Oeftiger, V. Kornilov, M. Kirk, S. Appel, H. Klingbeil, D. Lens and many others.