The FAIR/GSI Accelerator Facility

Peter Spiller

on behalf on the GSI and FAIR project teams

DESY, Hamburg

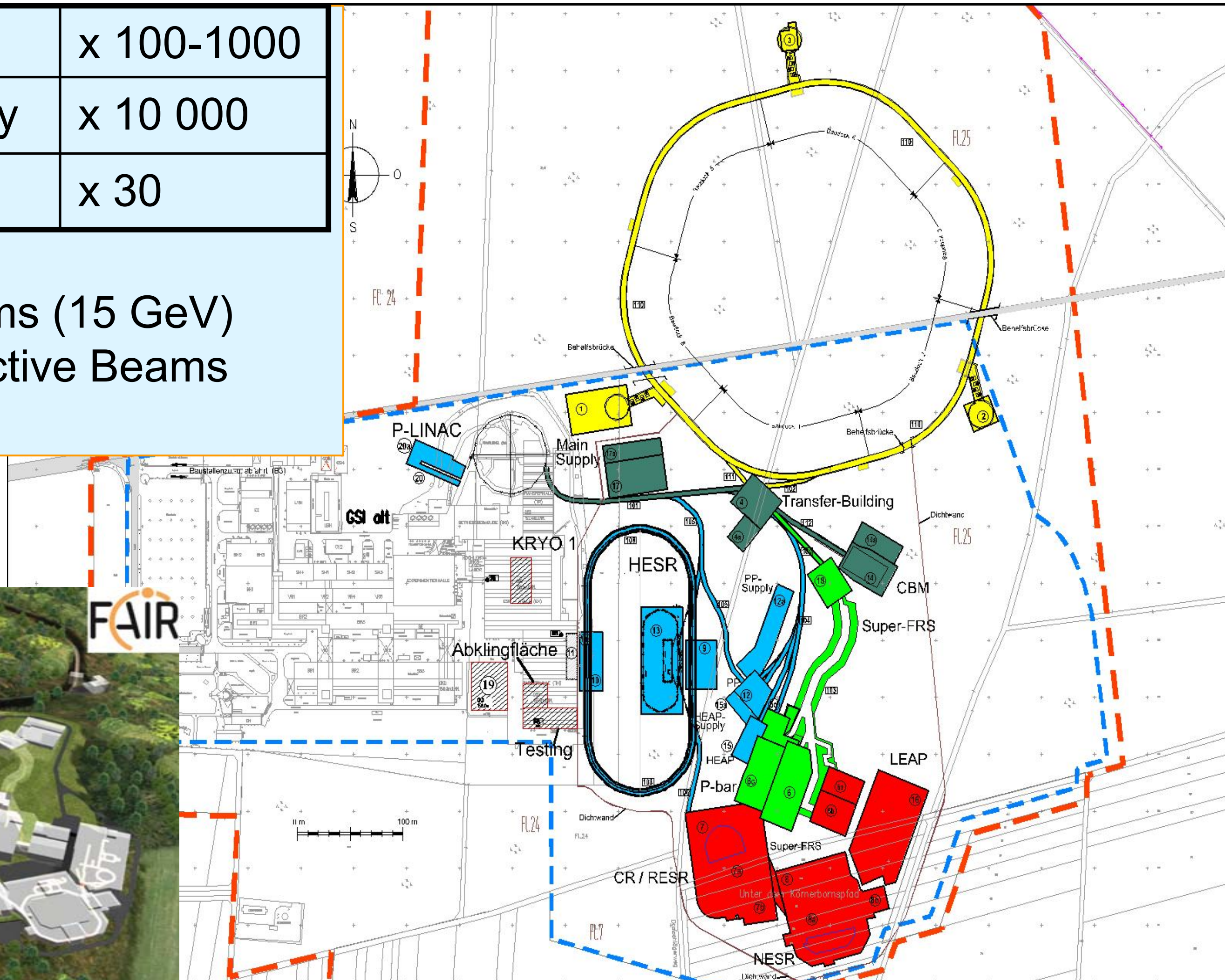
12. 9 2007

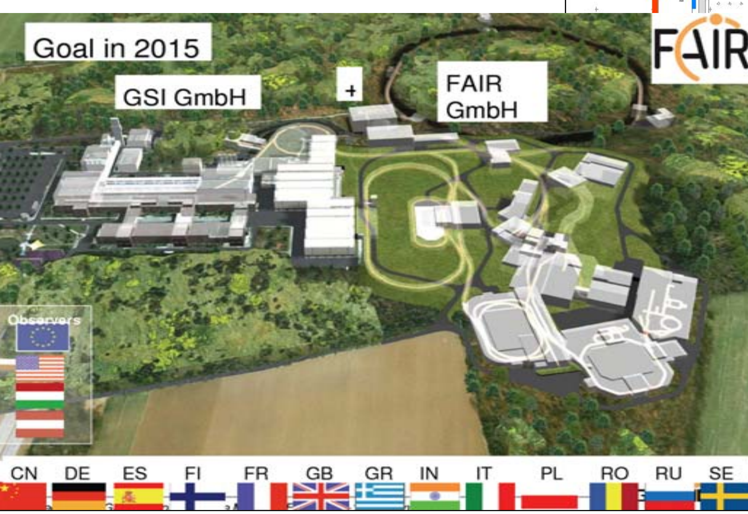
GSI

GSI/FAIR Accelerator Facility

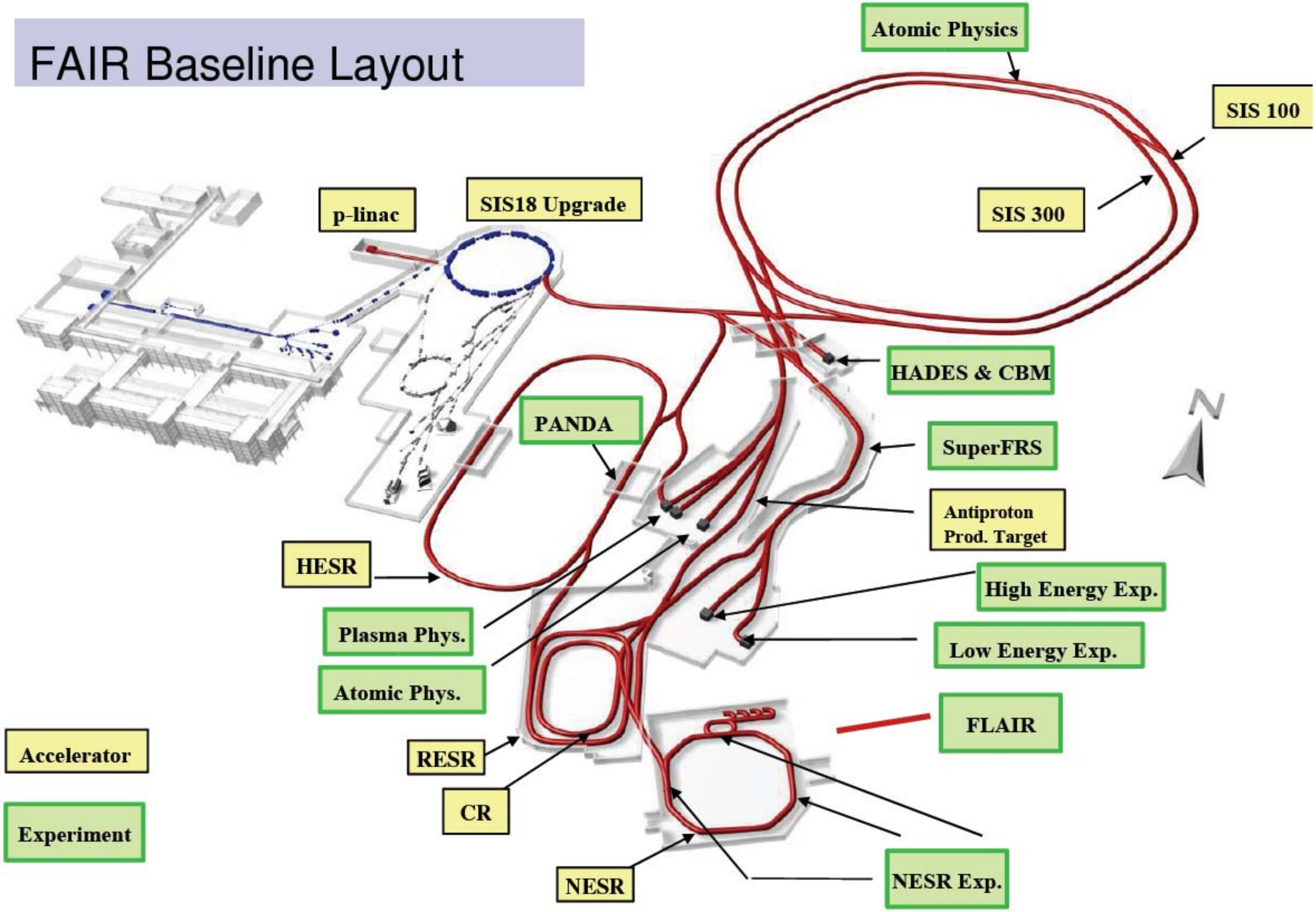
Primary Beam Intensity	x 100-1000
Secondary Beam Intensity	x 10 000
Heavy Ion Beam Energy	x 30

- New: Cooled pbar Beams (15 GeV)
- Intense Cooled Radioactive Beams
- Parallel Operation





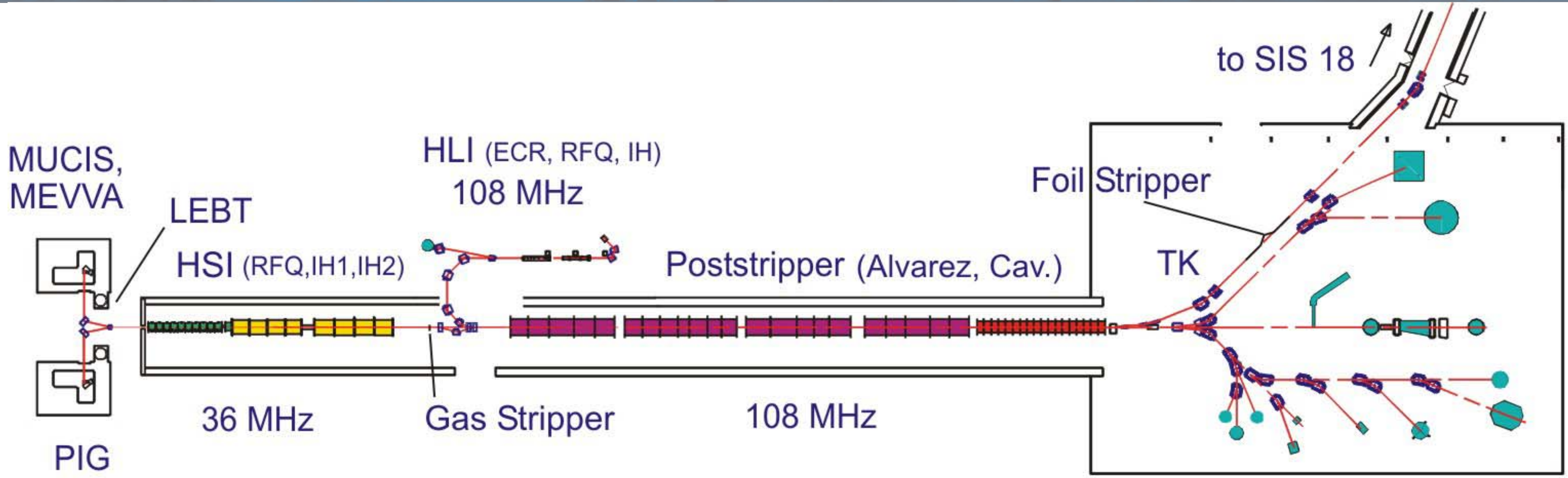
GAI/FAIR Accelerator Facility



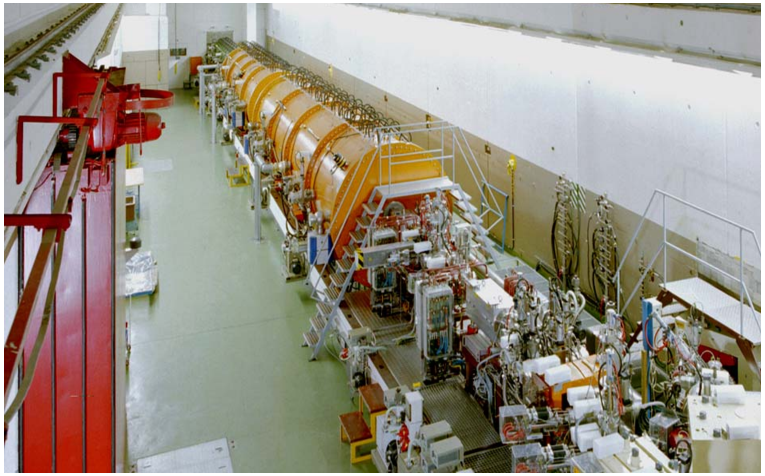
Universal Linear Accelerator UNILAC,

Ion Sources and the New Proton Linac

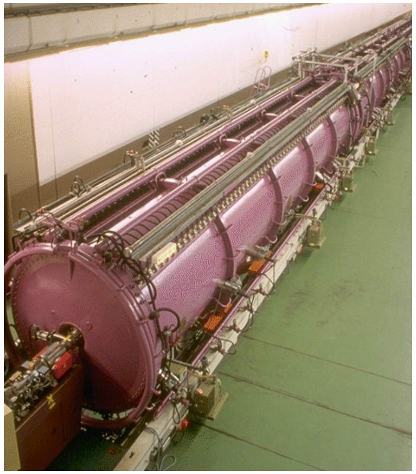
UNIversal Linear ACcelerator



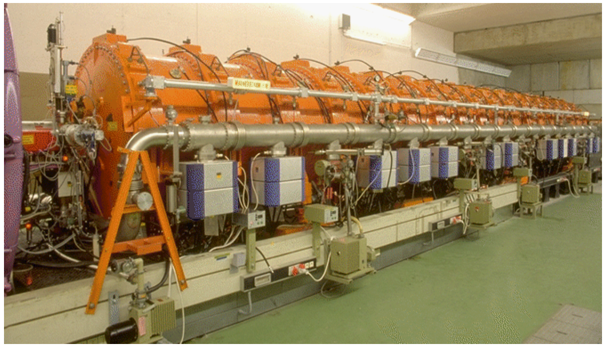
High Current Injector HSI



ALVAREZ

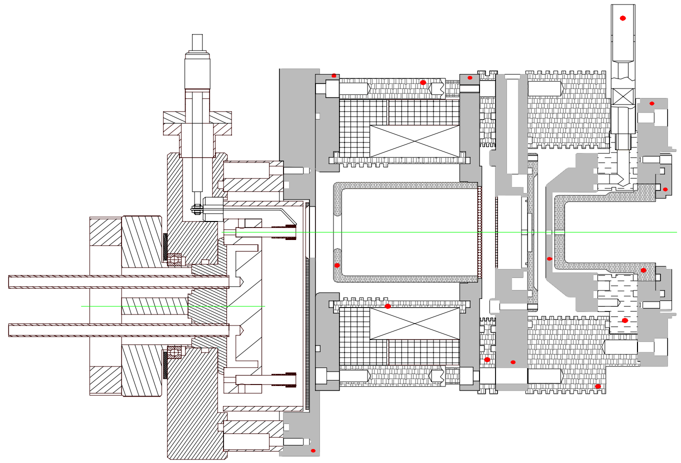


Single Gap Resonators



MEVVA and VARIS Ion Sources

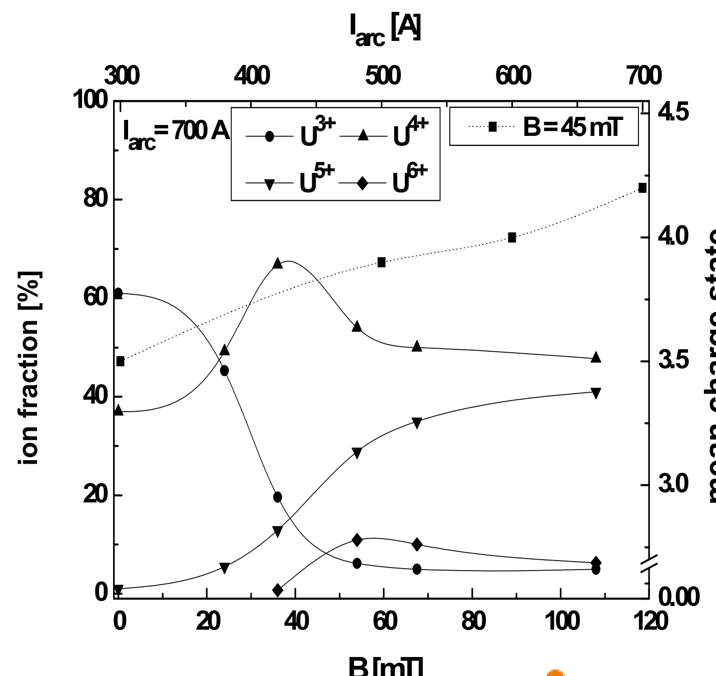
MEVVA
metal vapor vacuum arc



VARIS
vacuum arc ion source

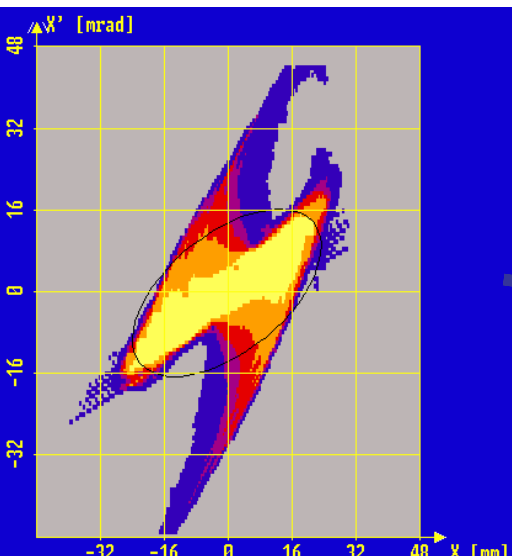
22 emA (67%) U^{4+} reached at HSI-RFQ input

Optimization of plasma parameters and geometry



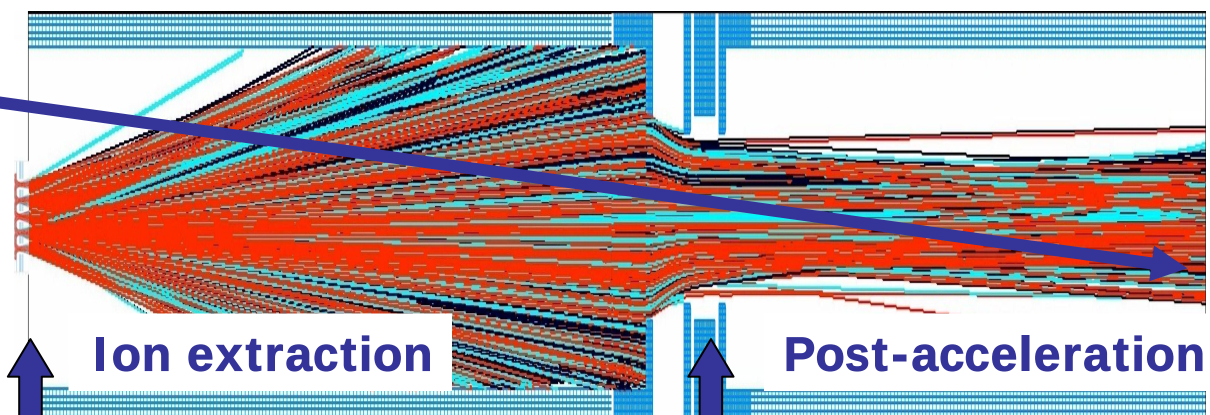
High Current Test Injector HOSTI

- Assembly of a High Current Test Injector for the exploration of the matching of maximum ion currents to the post- acceleration gap.
- Optimizing the post acceleration gap and LEBT system concerning beam quality (Brillance).
- Minimization of transmission losses.

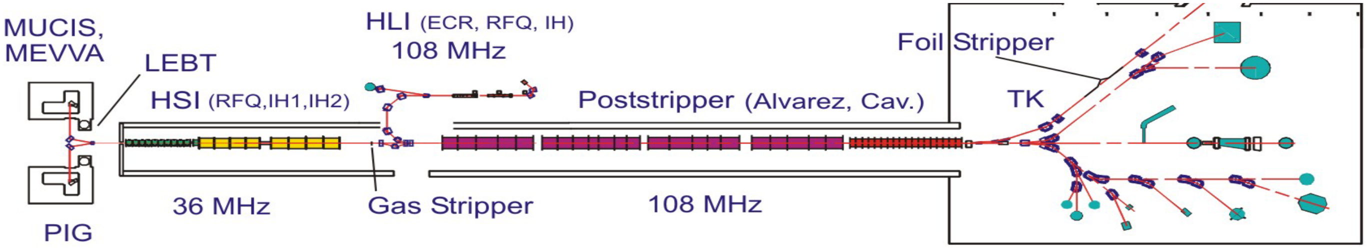


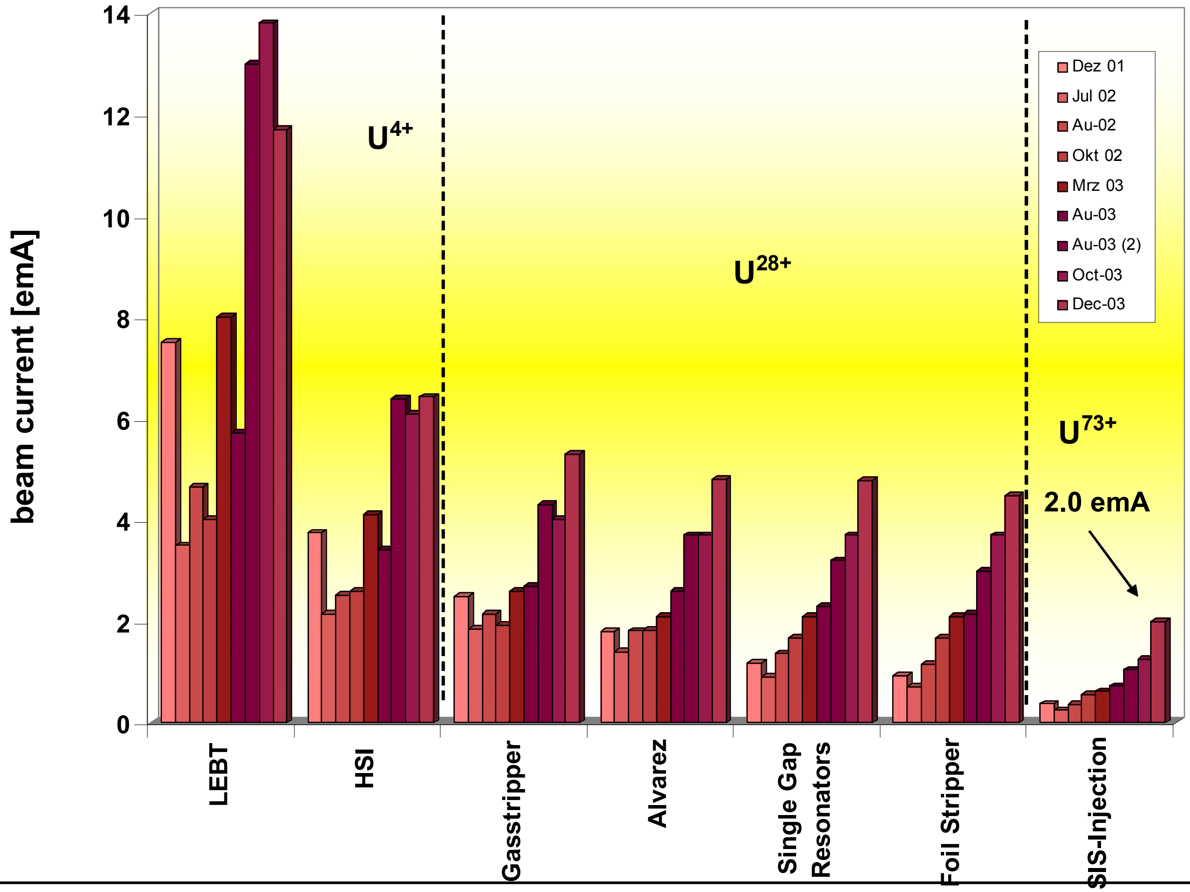
Emittance at 2.2 keV/u

From 94 emA U^{4+} only 37 emA are accelerated to 2.2keV/u
Only 22 emA arrive at HSI-RFQ entrance : Losses > 74 %

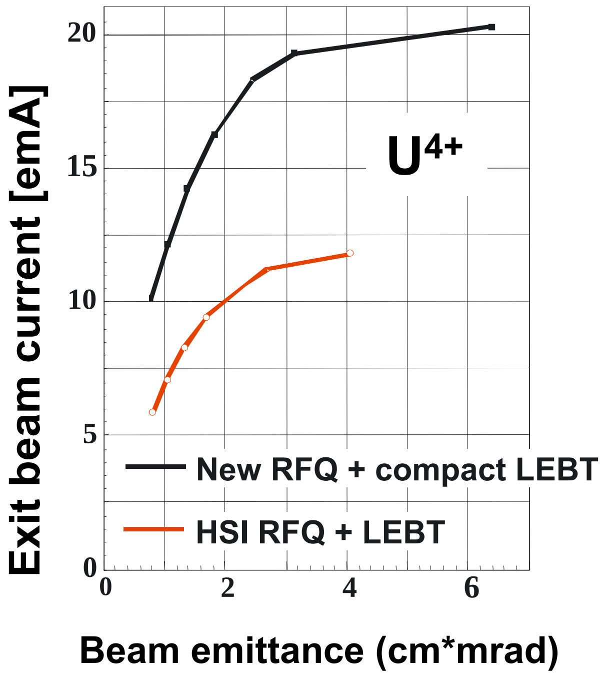


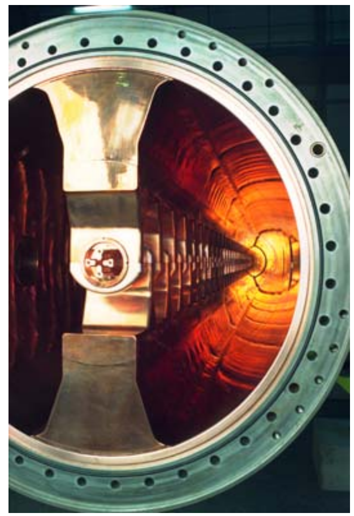
Status – Uranium Beams



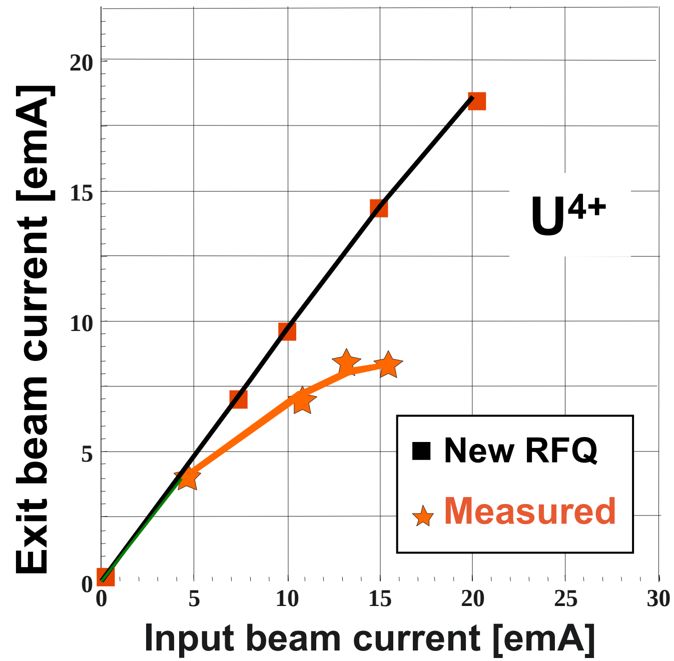


New Front-end System for U^{4+}





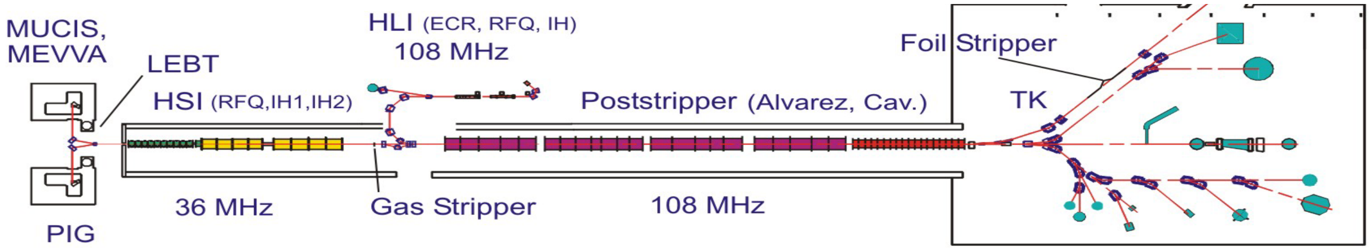
RFQ intensity gain factor: 1.8

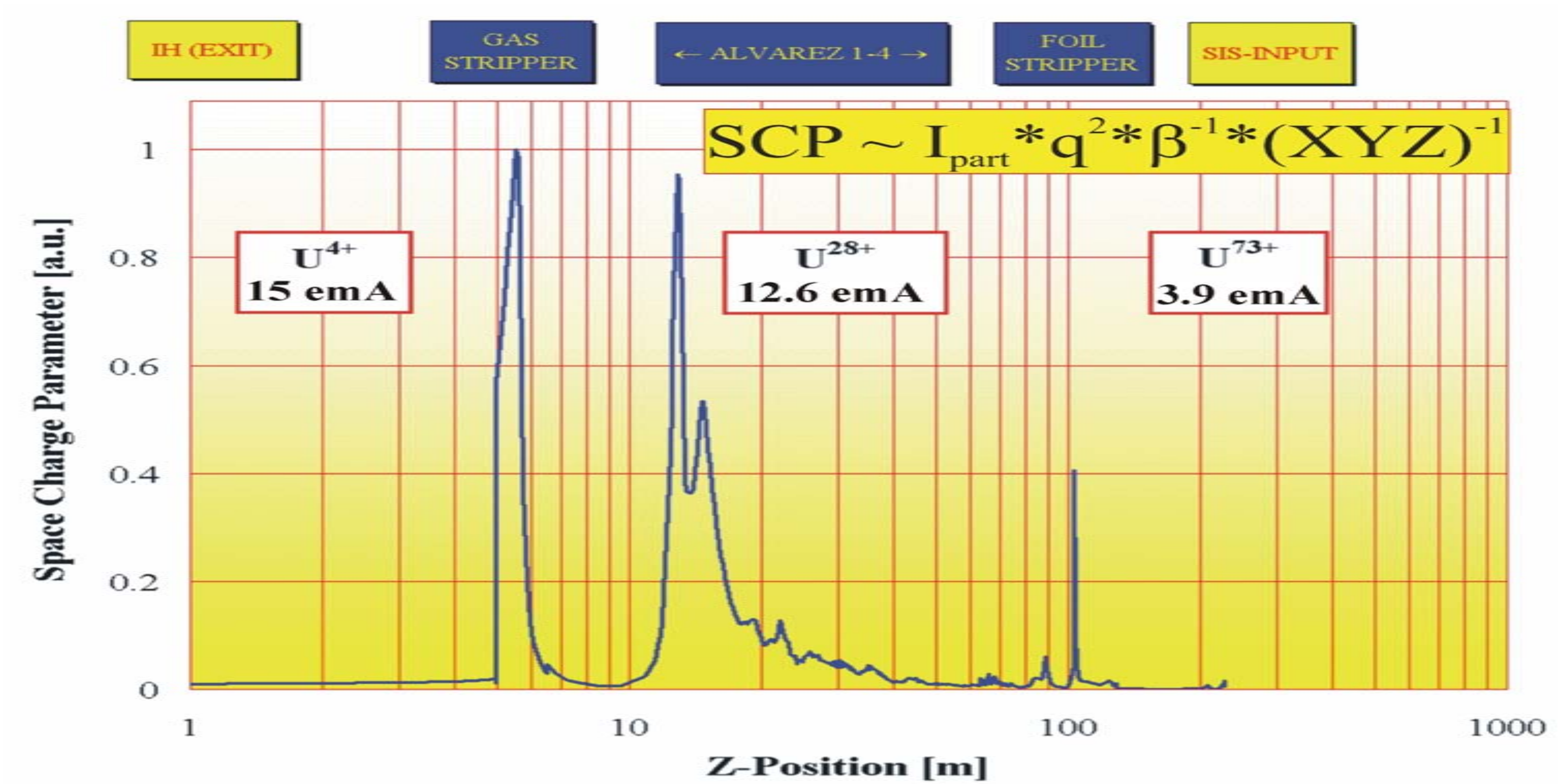


RFQ-Upgrade: Exchange of RFQ-rods, modified IRM,

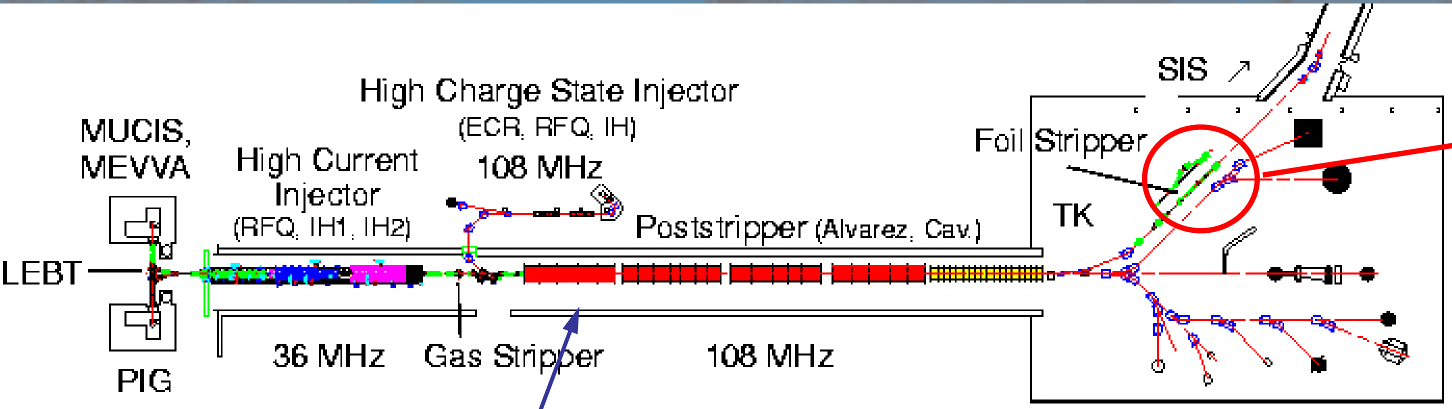
> longer and larger acceptance

Space Charge along UNILAC

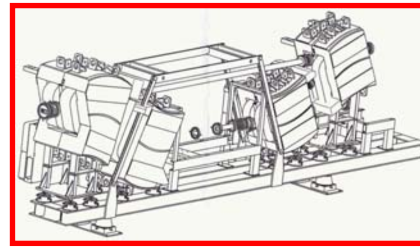




Conservation of Emittance for SIS-Injection

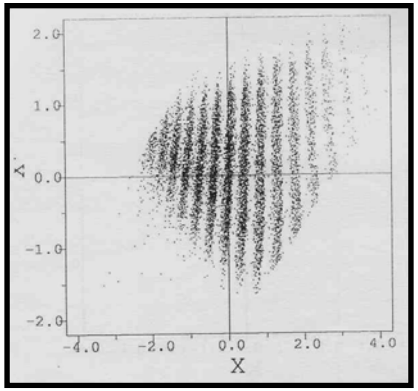


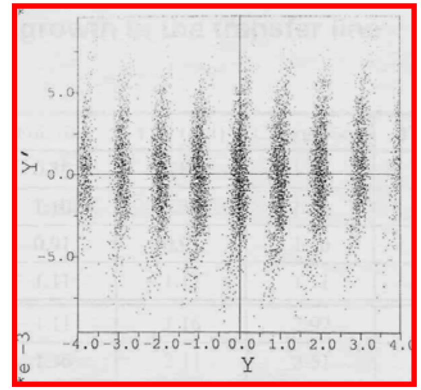
TK charge state separator

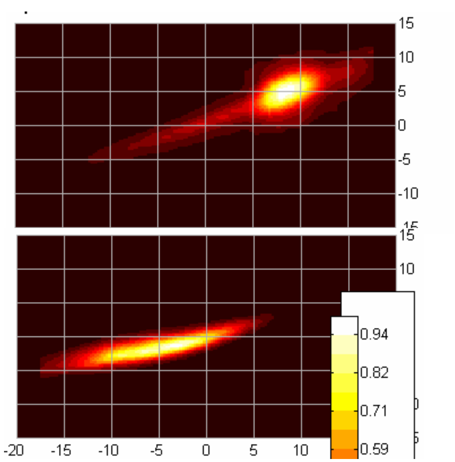


New power supplies → higher focusing strength (phase advance) in Alvarez-Quadrupoles

Beam line separation







$\Delta\Phi_o$ = 39°

$\Delta\Phi_o$ = 51°

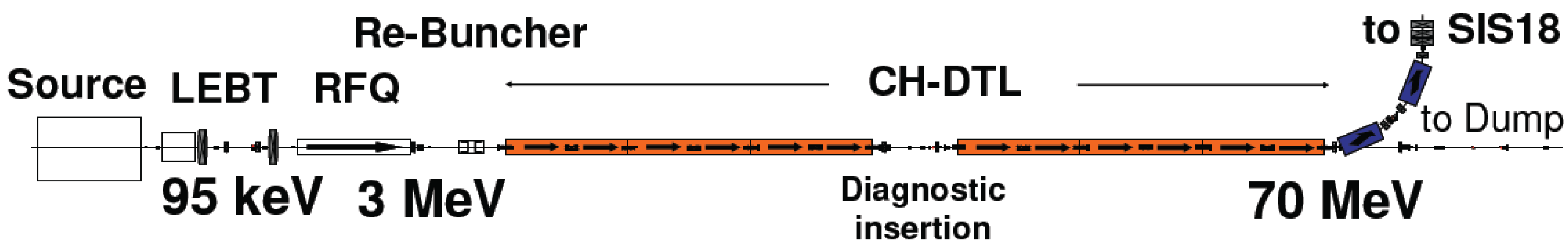
Improvement of beam brilliance: 30 %

- Improvement of beam brilliance: 40-50 %
- Charge state separation at high intensities
- Lower transmission losses in TK and the SIS

UNILAC Upgrade (2005-2009)

- High Current Test Bench for Ion Development (Post acceleration)
- Dedicated U^{4+}-High Current-Frontend (Compact LEBT + RFQ upgrade)
- Further investigation of the high current matching to Alvarez-DTL
- Increased zero current phase advance in the Alvarez-DTL
- High current beam diagnostics along whole UNILAC
- Compact charge separator for the separation of U^{73+} under sc-conditions

Proton Linac

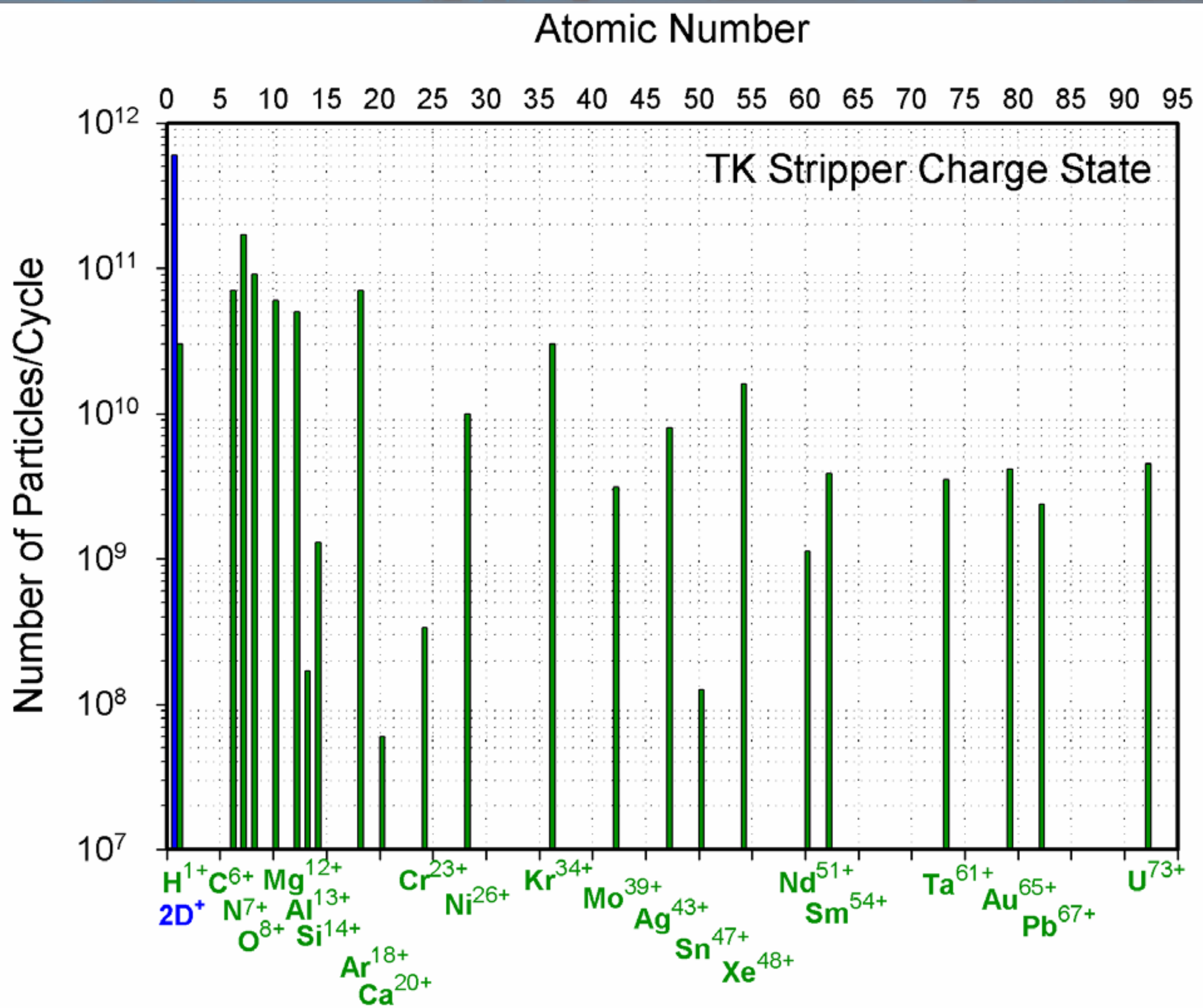


- Proton source & LEBT
- RFQ
- 2 re-bunchers
- 2*6 rf-coupled Crossed bar H-cavities
- 5.1 MW of beam loading (peak), 710 W (average)
- 11 MW of total rf-power (peak), 1600 W (average)
- 2 dipoles, 45 quadrupoles, 7 steerers
- 10 turbo pumps, 34 ion pumps, 9 sector valves
- 41 beam diagnostic devices

Beam energy	70 MeV
Beam current (op.)	35 mA
Beam current (des.)	70 mA
Beam pulse length	36 µs
Repetition rate	4 Hz
Rf-frequency	325.224 MHz
Tot. hor emit (norm.)	4.2 µm
Tot. mom. spread	$\leq \pm 10^{-3}$
Linac length	≈ 35 m

SchwerIonenSynchrotron SIS18

Status - Peak Intensities per Cycle



Presently: High charge state operation (transfer stripper)

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
  (2007)
- Task 6: Injector
  Set-up of a TK charge separator
  (2007)

SIS18 upgrade program

Further SIS18 upgrade measures:

- 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)

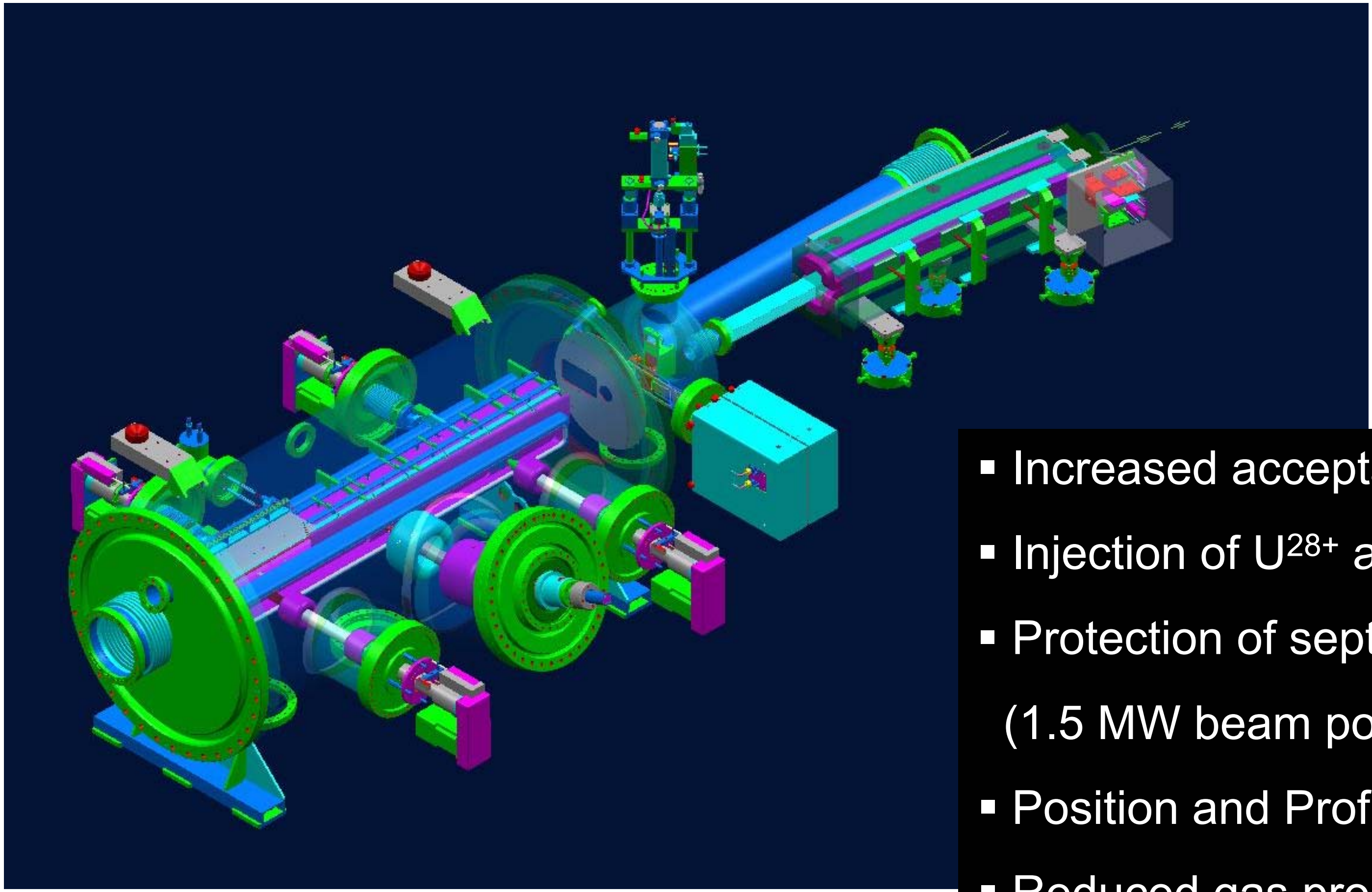
- Longitudinal and Transverse Feed Back Systems
  Damping of coherent oscillations, coupled bunch modes and phase stabilization

- 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)

SIS18 - Injection System upgrade

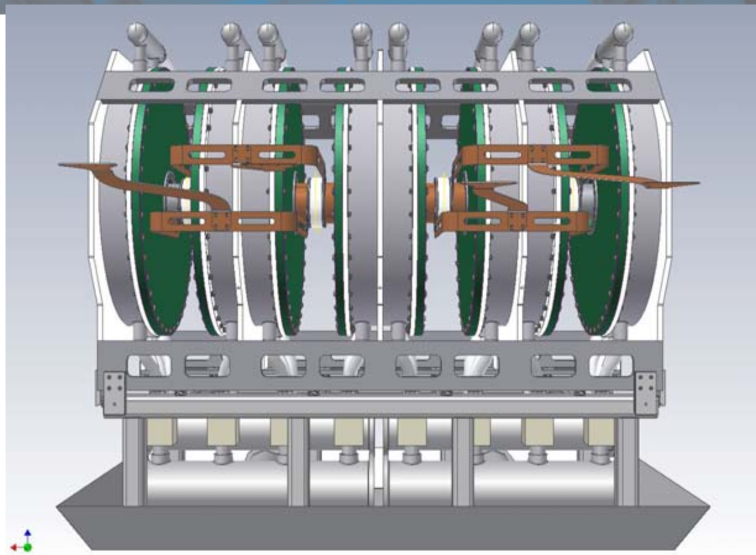


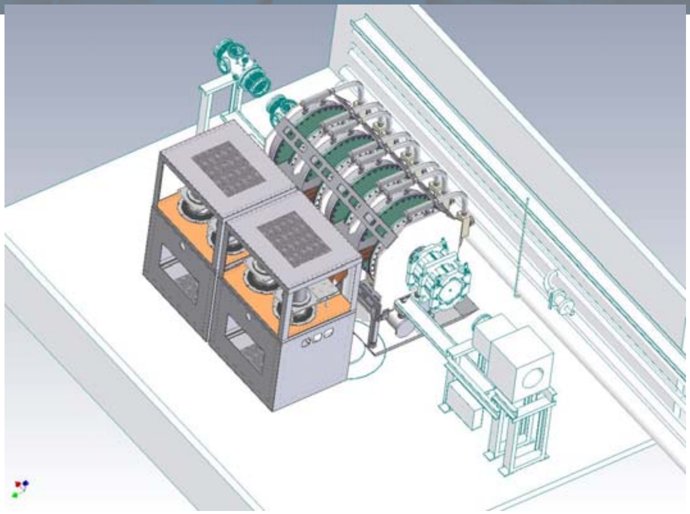
- Increased acceptance
- Injection of U^{28+} at reference energy
- Protection of septum electrodes (1.5 MW beam power)
- Position and Profile verification
- Reduced gas production

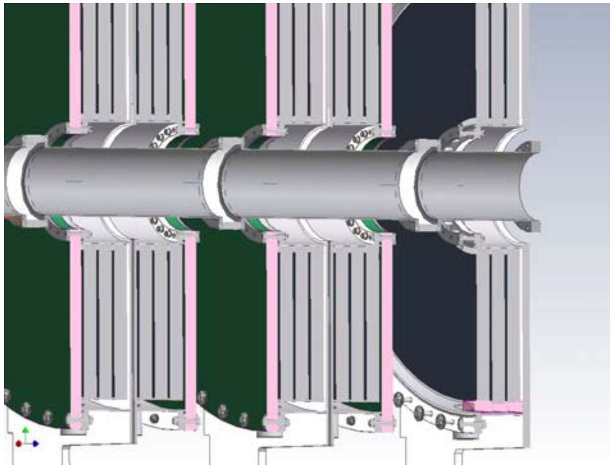
Final design of the revised injection system

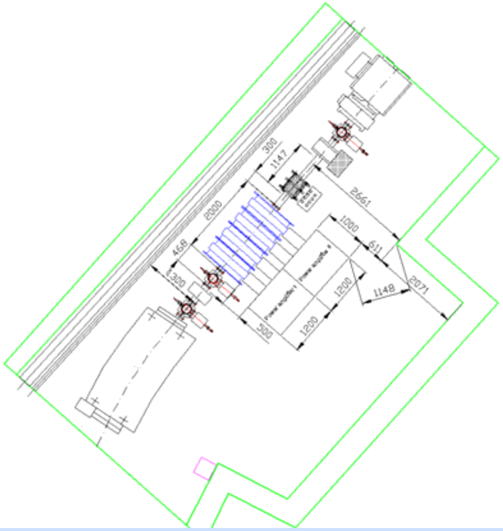
Installation scheduled for 2007

New h=2 Acceleration System









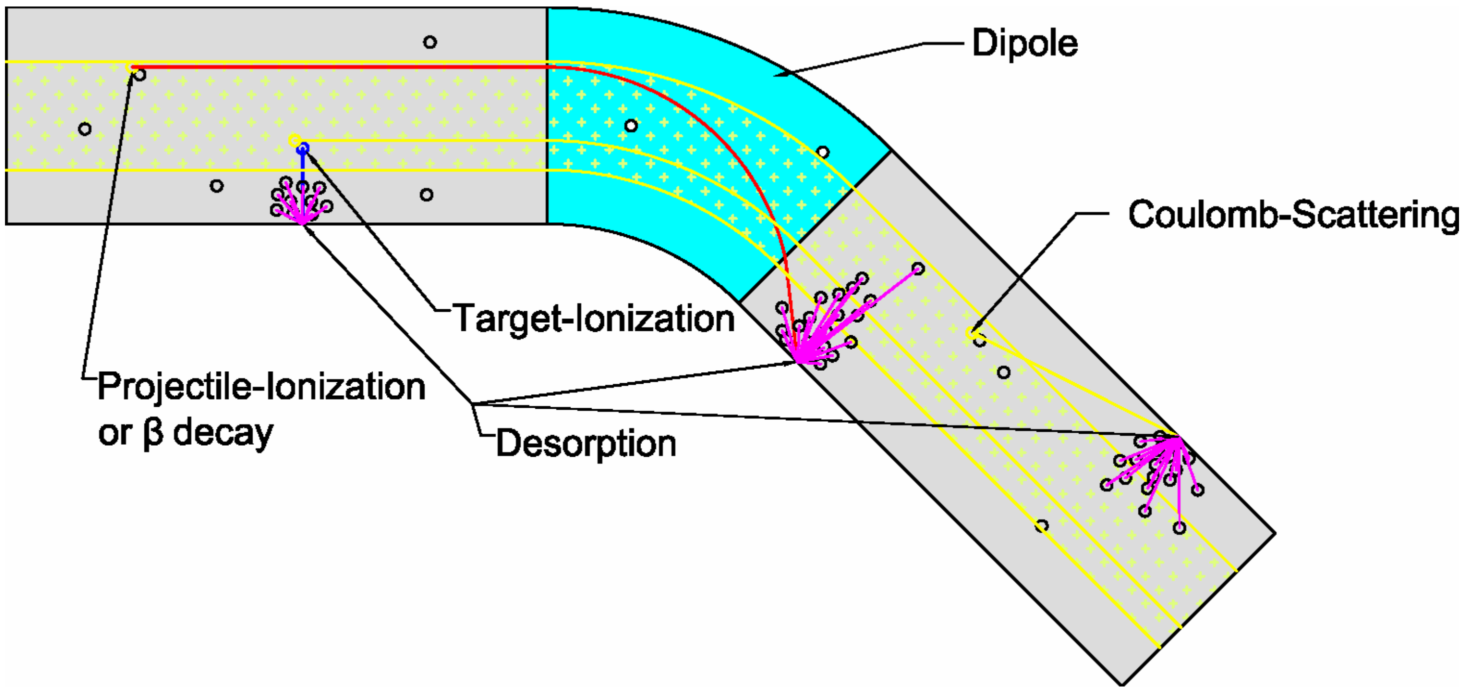
S01

P. Hülsmann,

H. Klingbeil et.al.

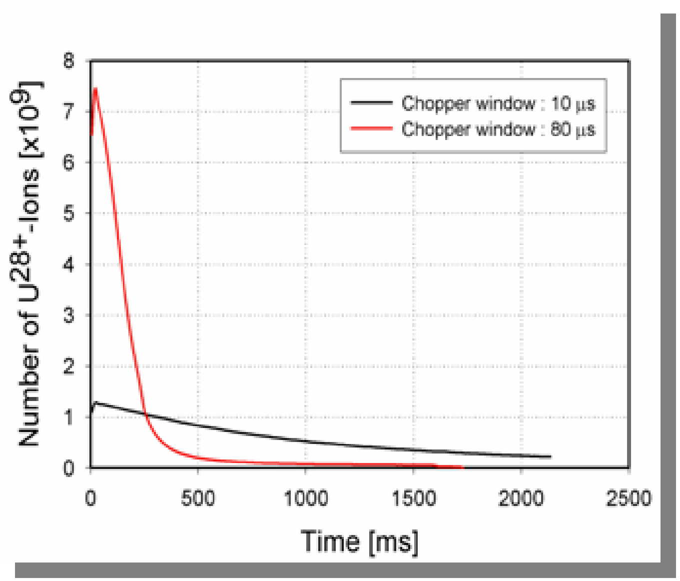
Design studies for the new, high duty cycle MA loaded, h=2 acceleration cavities

Beam Loss by Charge Change $U^{28+} \rightarrow U^{29+}$

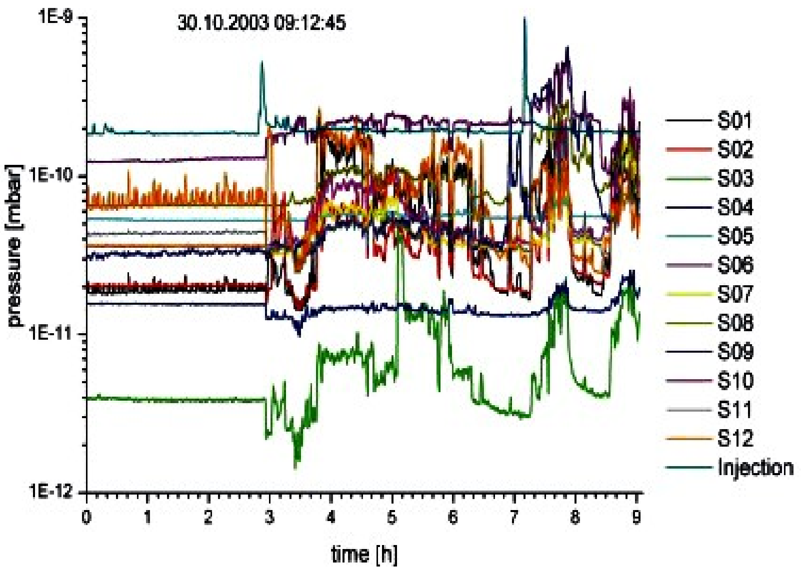


Beam Loss and Dynamic Vacuum

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

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)

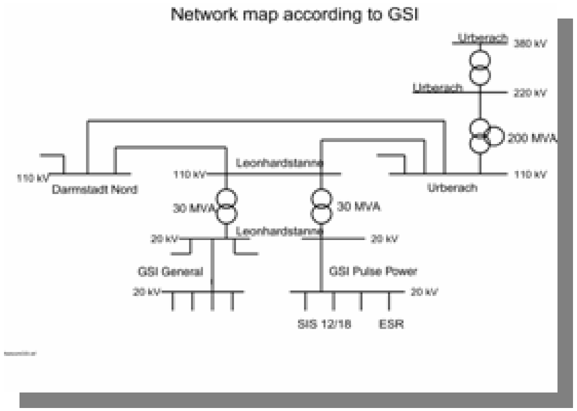
  (new magnet chambers, improved bake out system)

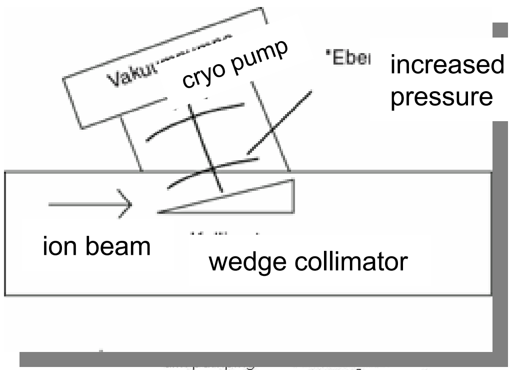
- Localizing beam loss and controle of desorption gases

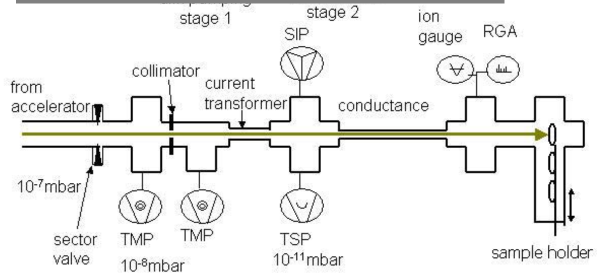
  (Collimator in S12, new collimation system)

- Materials with low desorption yields

  Teststand, ERDA measurements



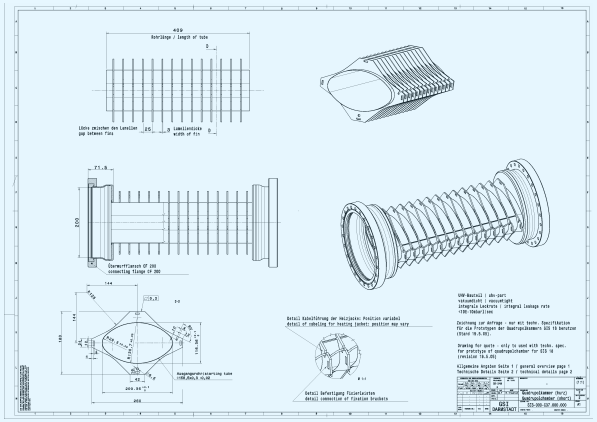




UHV system upgrade

- 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

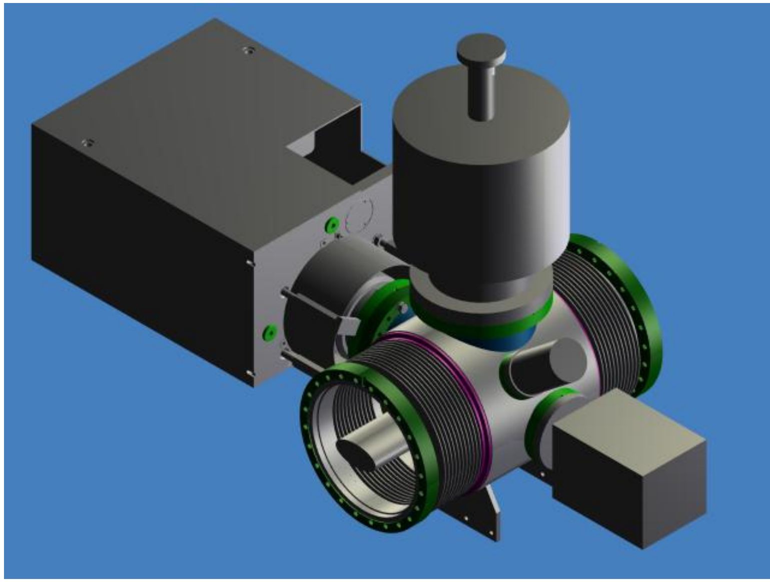
- **Replacement of all dipole- and quadrupole chambers by new, NEG coated chambers**
- **Improved bake-out system for operation up to 300K**



Charge Scraper System Technology

Goals:

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

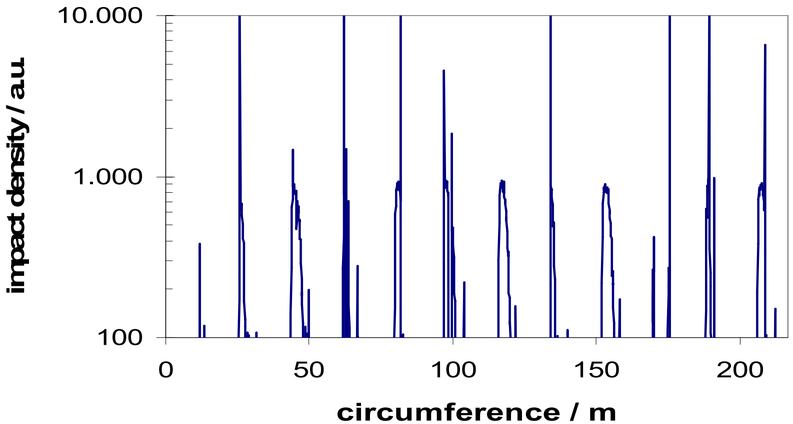


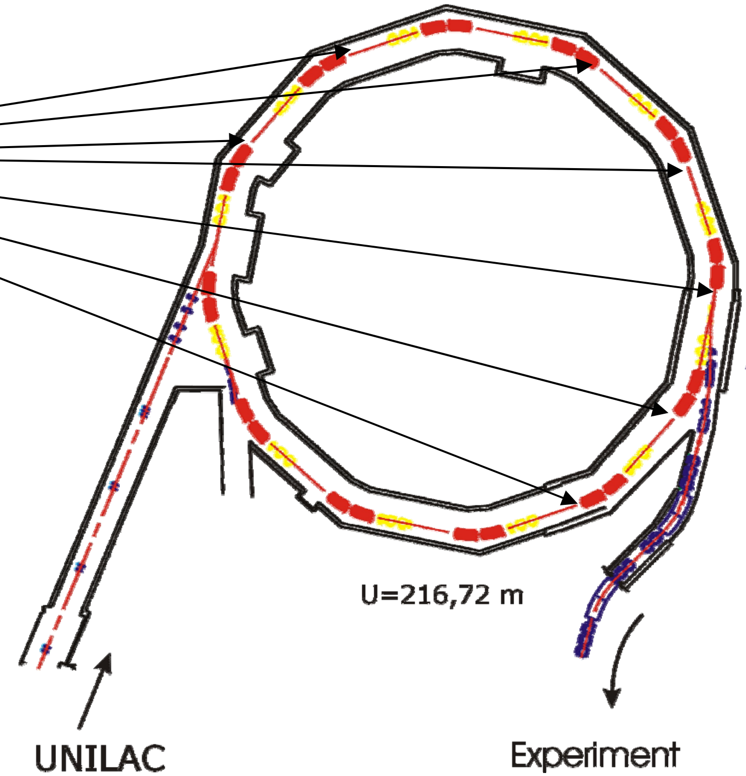
- Wedge or block shaped beam stopper made of low desorption yield material
- Secondary chamber for confinement of desorption gases
- NEG coated chamber walls
- **Integration of UHV diagnostics and current measurement**

Two prototypes order for installation in 2007 shut down

SIS18 Charge Scraper System

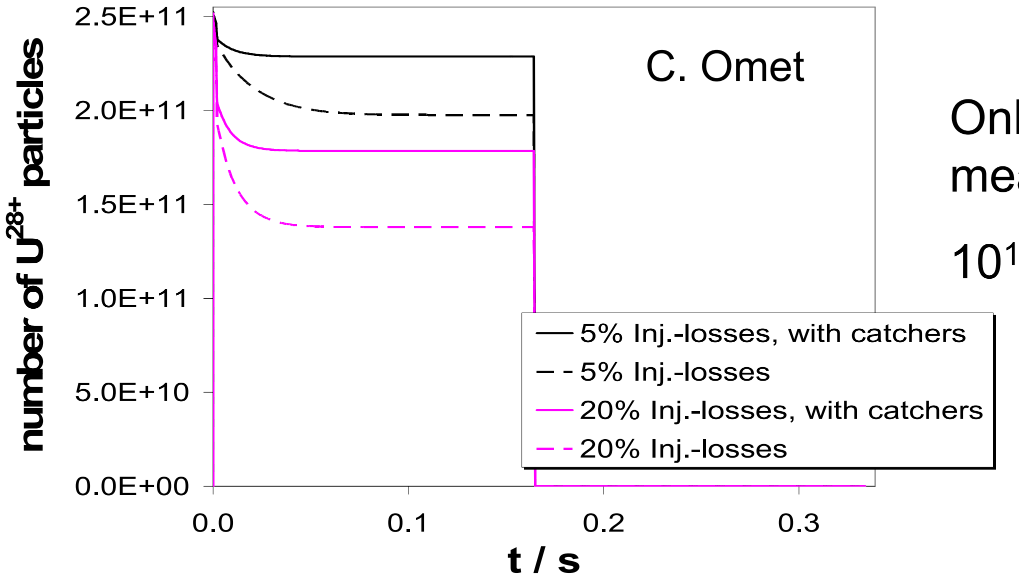
Installation behind each second dipole magnet





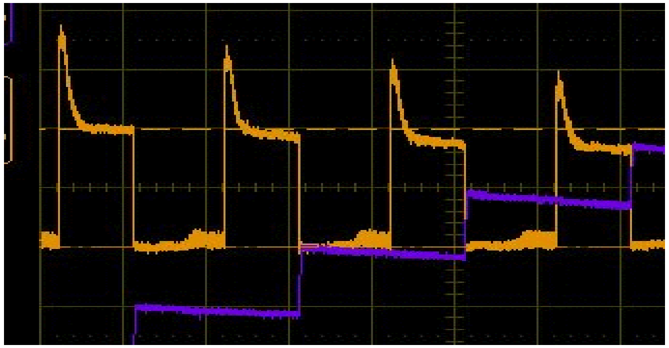
SIS18 – High Intensity U^{28+} Operation

Final U^{28+}- booster operation



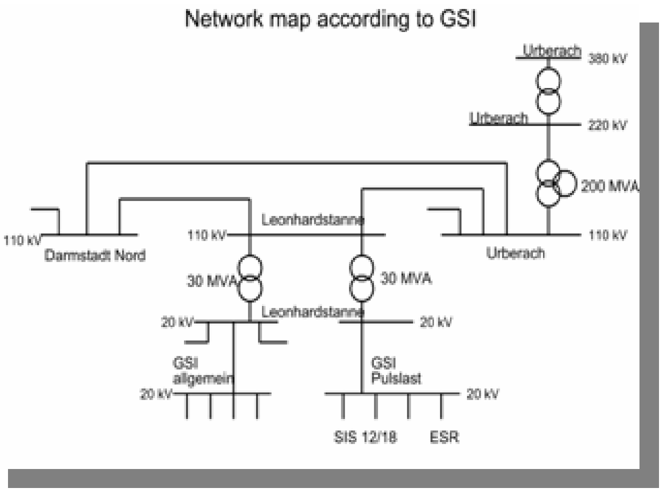
Only the combination of the upgrade measures leads to the desired result !

10^{11} U-ions per cycle



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

GSI Pulse Power Connection



Before 2006:

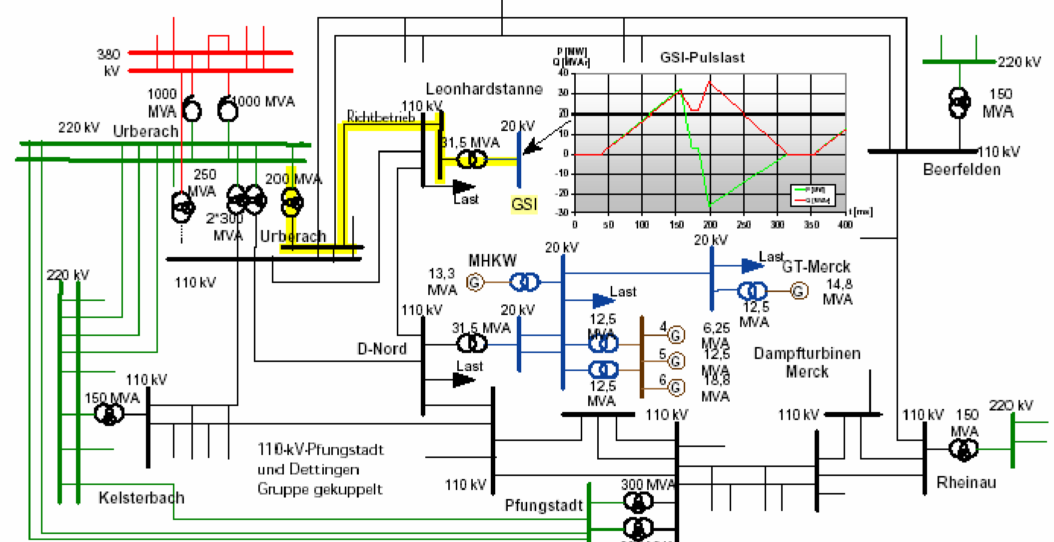
GSI in series connection with Darmstadt North

Stage 1 (from Sommer 2006):

Separate 110kV power line to Urberach – Extension and re-arrangement of Leonhardstanne

GSI Darmstadt - Ausschnitt des untersuchten Netzes (Prinzipbild)
(GSI Impulslast direkt am 220-kV-Netz)

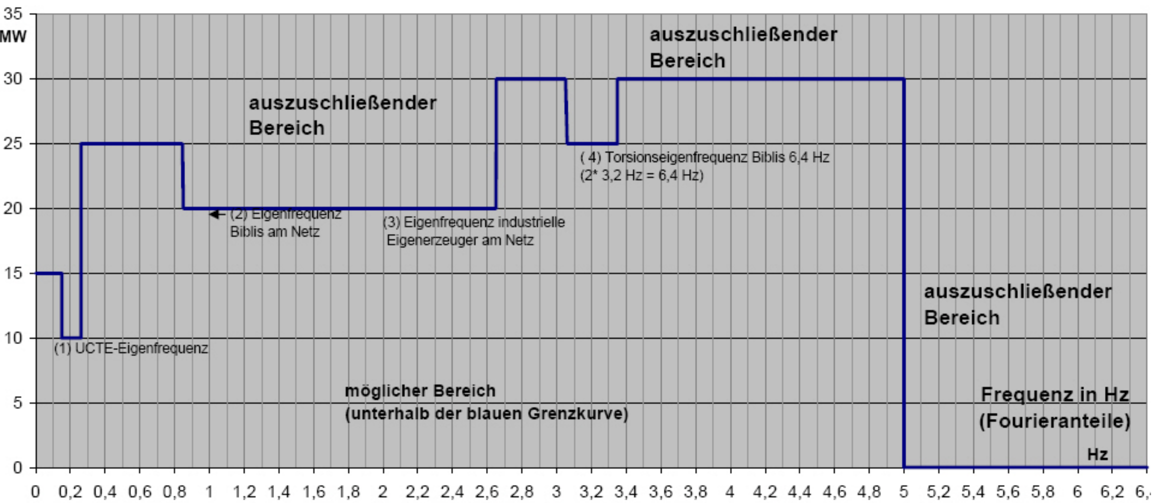
RWE



Stage 2 (from 2010 ?):

Additional 63 MW puls power transformer in Leonhardstanne

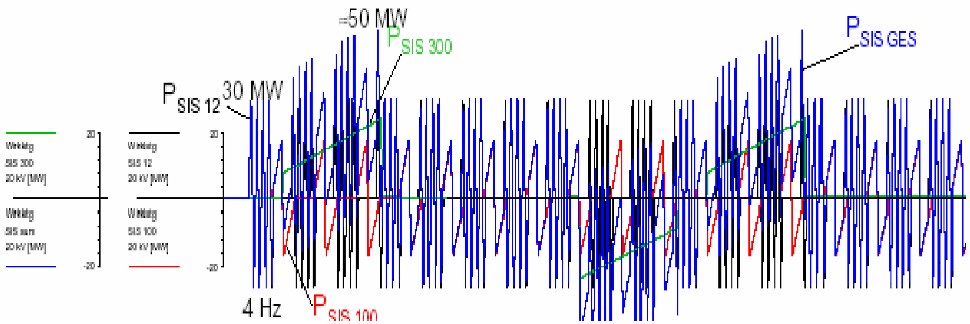
Power Oscillation



	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	± 18 MW	4 T/s
SIS300	± 23 MW	1 T/s

GSI Darmstadt 2. Ausbaustufe – Simulation: 30s mit Überlagerung SIS-12 Viererzyklus, SIS-100, SIS-300 (typischer Verlauf der GSI)

RWE



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

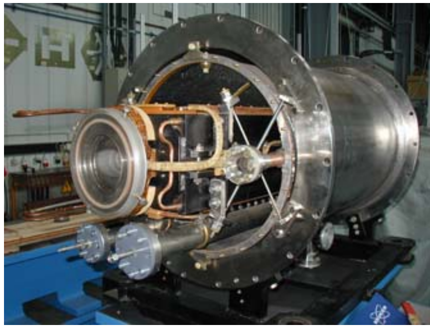
H. Ramakers, EET

FAIR Synchrotrons SIS100 and SIS300

Two Stage Synchrotron SIS100/300

- **1. High Intensity- and Compressor Stage**

SIS100 with fast-ramped superconducting magnets and a strong bunch compression system.

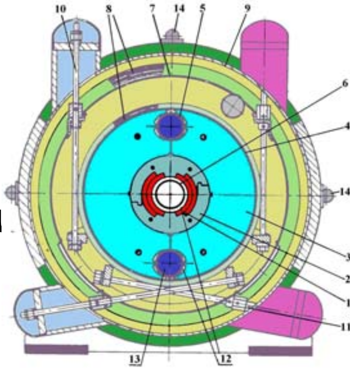


Intermediate charge state ions e.g. U^{28+}-ions up to 2.7 GeV/u
Protons up to 30 GeV

$B\rho$= 100 Tm - B_{max}= 1.9 T - dB/dt= 4 T/s (curved)

- **2. High Energy- and Stretcher Stage**

SIS300 with superconducting high-field magnets and stretcher function.



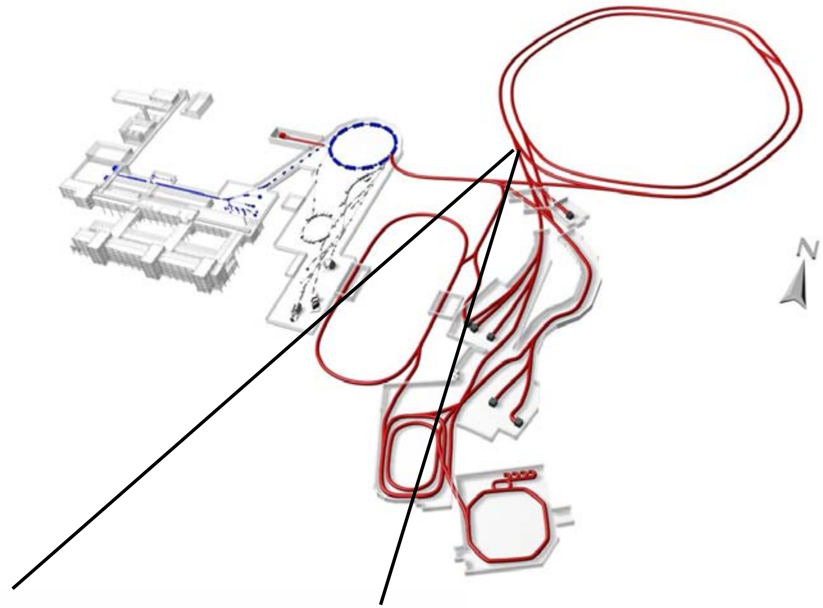
Highly charges ions e.g. U^{92+}-ions up to 34 GeV/u
Intermediate charge state ions U^{28+}- ions at 1.5 to 2.7 GeV/u with 100% d

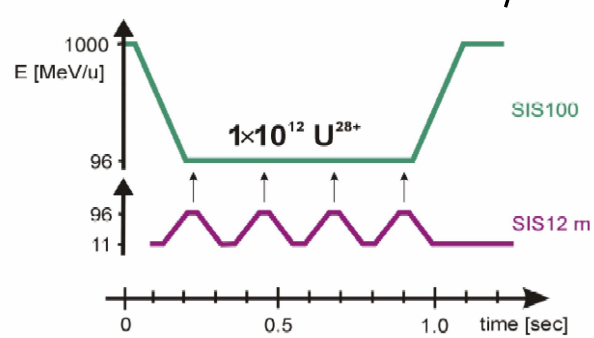
$B\rho$= 300 Tm - B_{max}= 4.5 T - dB/dt= 1 T/s (curved)

Beam Parameters

SIS100	
Heavy Ion Operation	U^{28+} : Fast Extract.: $5x10^{11}$ ppp Slow Extract. Possible
Proton Operation	p: Fast Extract.: 2.5 – $5x10^{13}$ ppp
SIS300	
Heavy Ion Stretcher Mode	U^{28+} : Slow Extract.: $3x10^{11}$ pps (d.c.)
Heavy Ion High Energy Mode	U^{92+} : Slow Extract.: $1x10^{10}$ pps

New Beam Parameter List

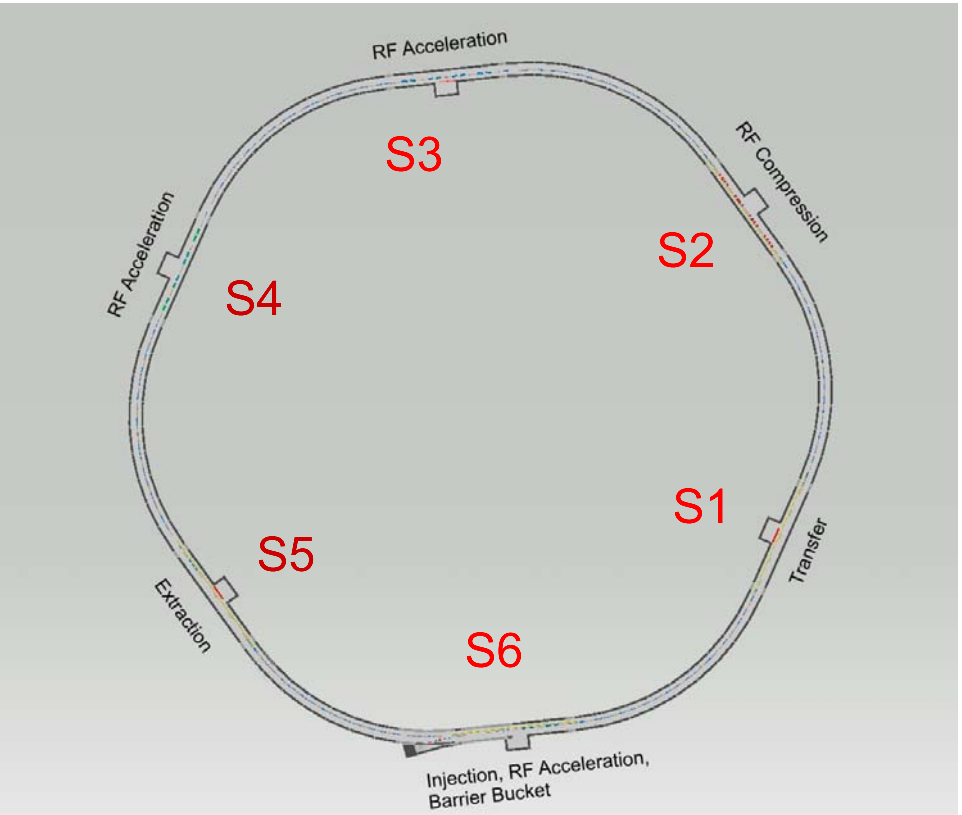




Technical Subsystems

Sixfold Symmetry

- Sufficiently long and number of straight sections
- Reasonable line density in resonance diagram
- Good geometrical matching to the overall topology



S1: Transfer to SIS300

S2: Rf Compression (MA loaded)

S3: Rf Acceleration (Ferrite loaded)

S4: Rf Acceleration (Ferrite loaded)

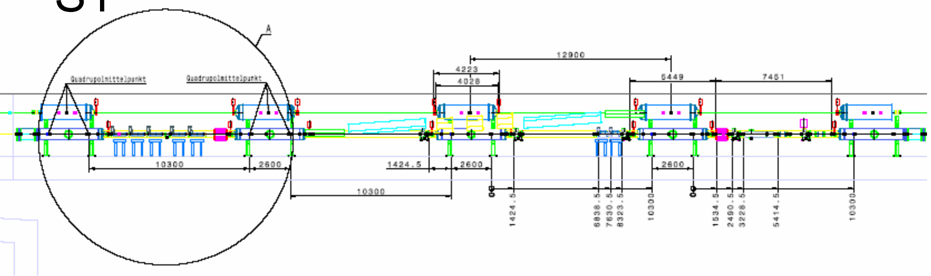
S5: Extraction Systems (slow and fast)

S6: Injection System plus RF Acceleration and Barrier Bucket

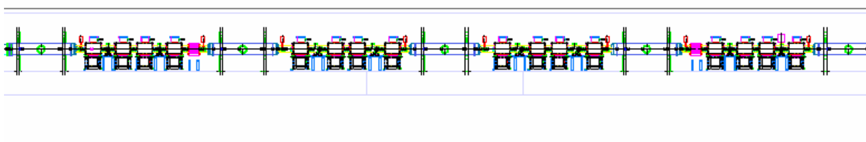
The SIS100 technical subsystems define the length of the straight sections of both synchrotrons

SIS100 Straight Sections

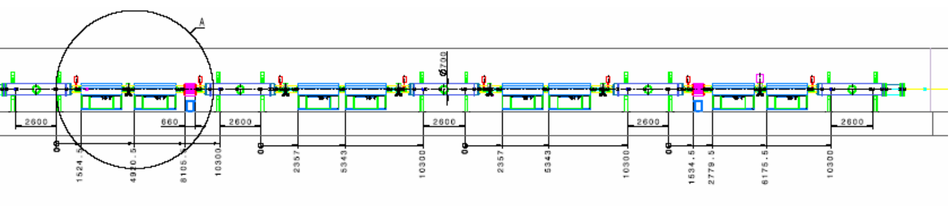
S1



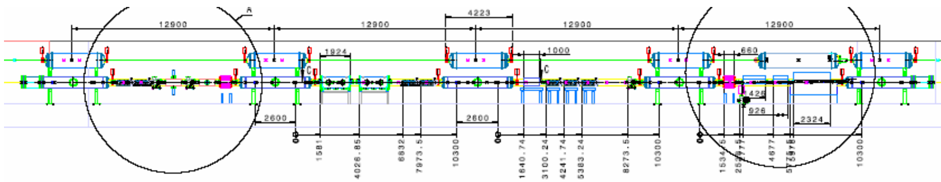
S4



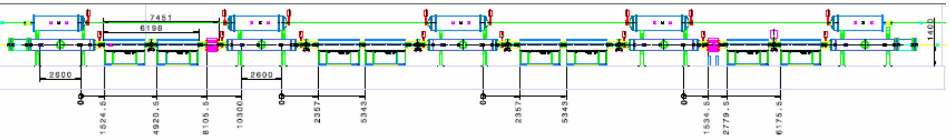
S2



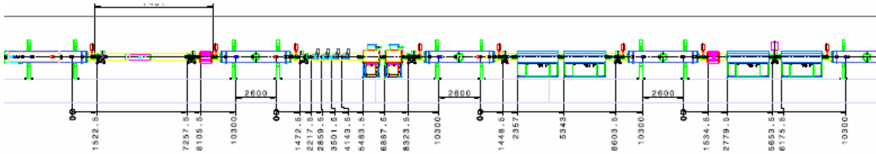
S5



S3



S6

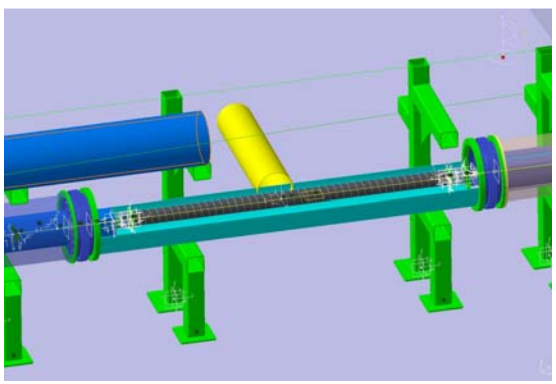


Distribution of all devices completed

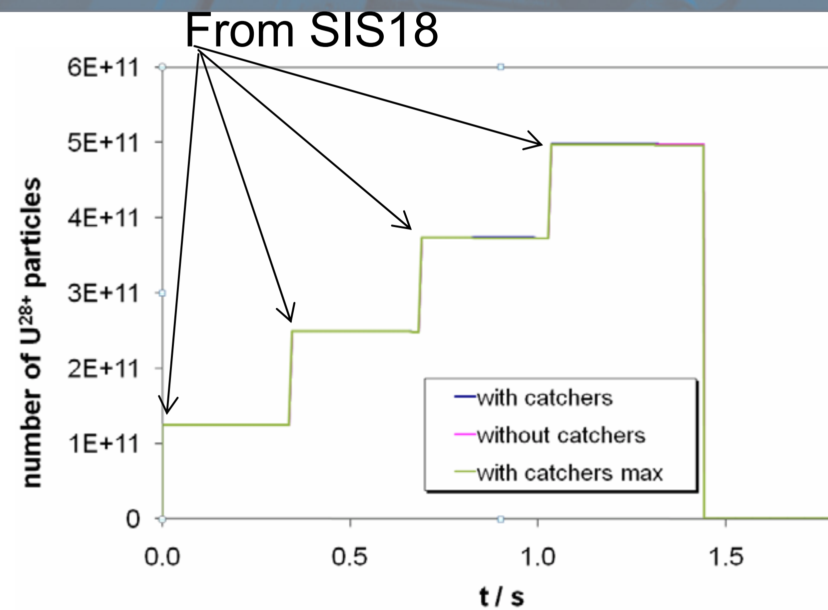
Dynamic Vacuum

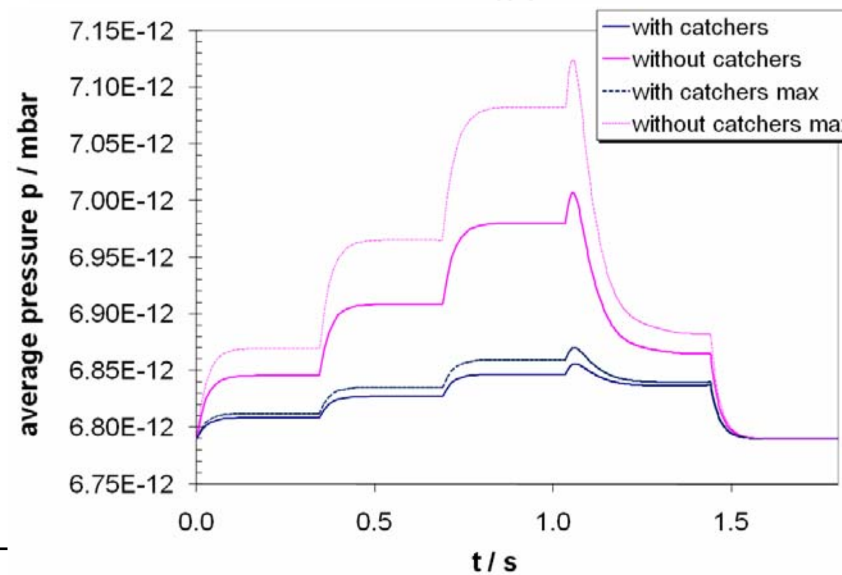
SIS100 ionization beam losses

- Cyrogenic surfaces:
- η is small due to $(dE/dx)^2$
- Low loss expected (<1%)
- Load to cryogenic system is reduced by catcher system @ 70K.
- Lighter ions have lower s_{pi}, residual gas will remain stable.



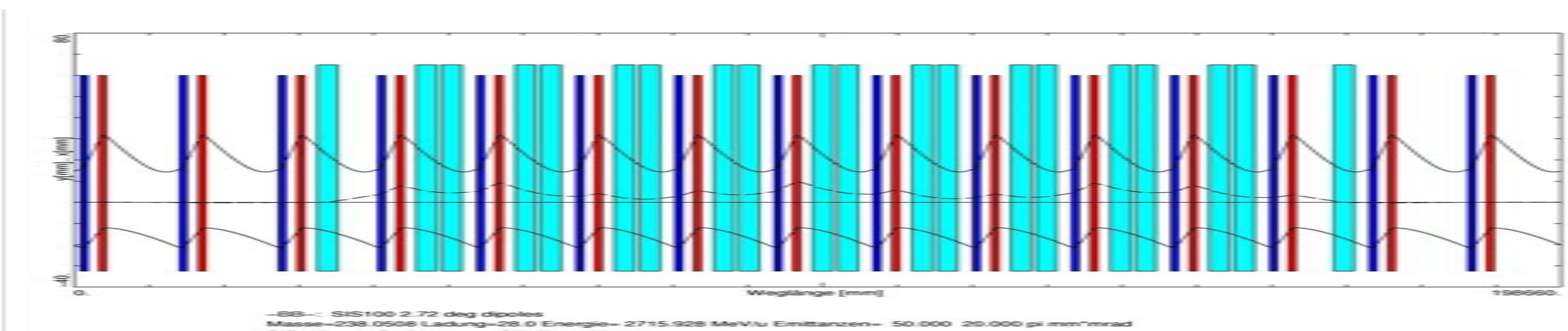
Cooled magnet and drift chambers



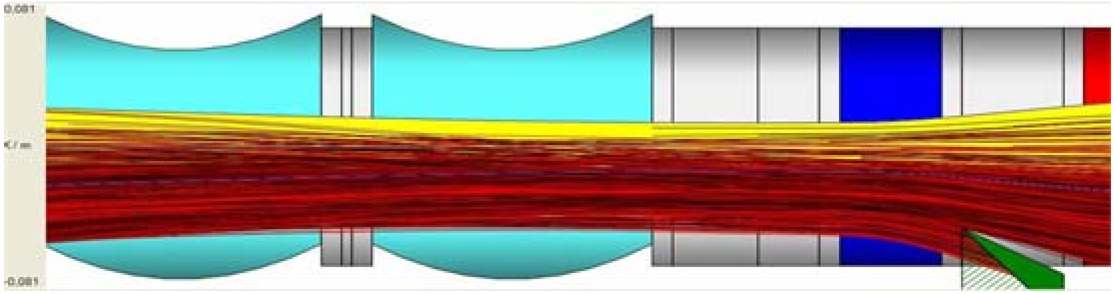


Lattice Design Criteria

- Maximum transverse acceptance (minimum 3x emittance at injection) at limited magnet apertures (problems: pulse power, AC loss etc.)
- Vanishing dispersion in the straight sections for high dp/p during compression
- Low dispersion in the arcs for high dp/p during compression
- Sufficient dispersion in the straight section for slow extraction with Hardt condition
- Shiftable transition energy (three quadrupole power busses) for p operation
- Sufficient space for all components and efficient use of space
- Enabling slow, fast and emergency extraction and transfer within one straight.
- Peaked distribution and highly efficient collimation system for ionization beam loss



Charge Scraper System



C. Omet

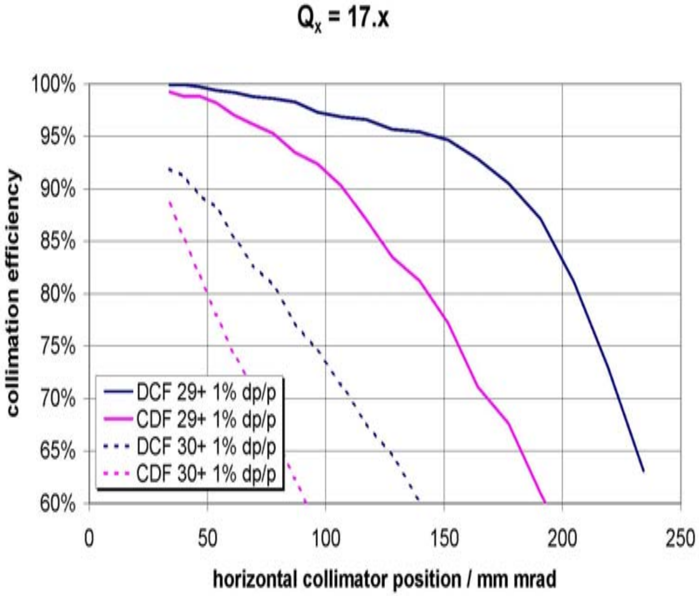
- Studies for different SIS100 working points
- Comparison between scraper positions
- Code development continued and applied to beta beams study, AGS booster/SIS18 comparison (confirmed the $(dE/dx)^2$ scaling)

Cross section estimations for

a) U^{73+}: SIS18 operation in FAIR stage 1

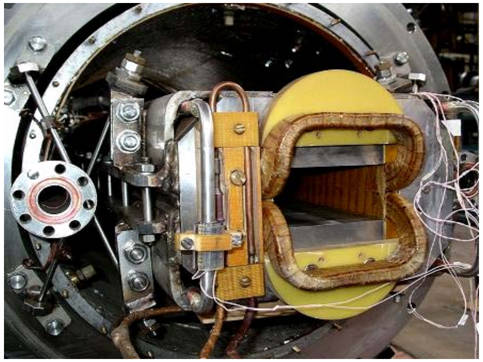
b) Lighter ions: Intensity expectations SIS100

c) Other Energies: Scraper requirements for SIS300

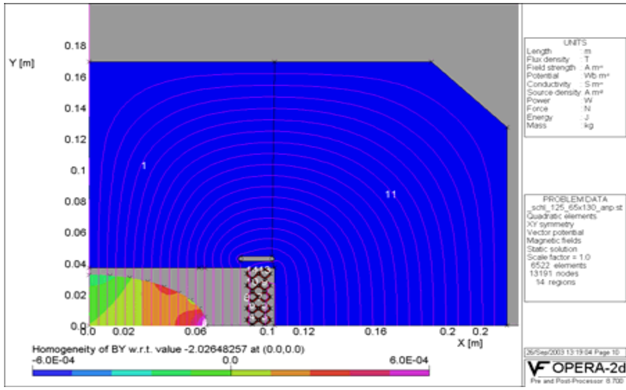


SIS100 Magnets: R&D

R&D Goals



- **Reduction of eddy / persistent current effects at 4K (3D field, AC loss)**
- **Improvement of DC/AC-field quality**
- **Guarantee of long term mechanical stability** ($\geq 2 \cdot 10^8$ cycles)

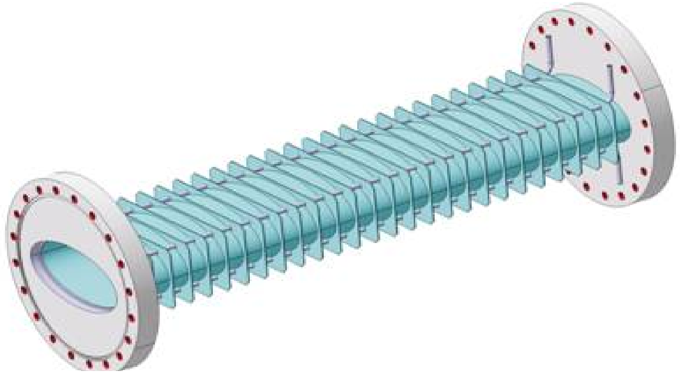


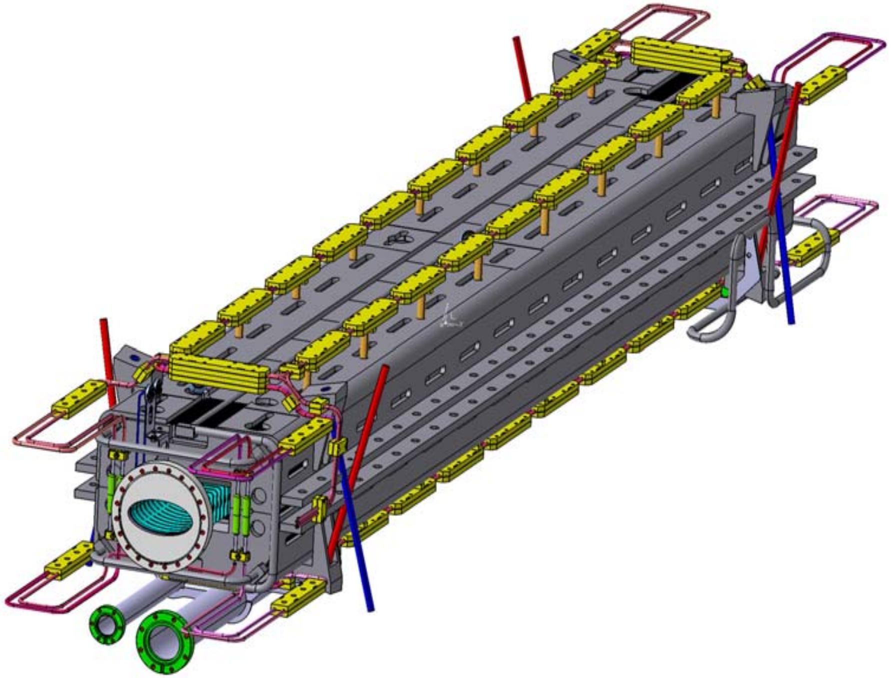
Activities

- AC Loss Reduction (exp. tests, FEM)
- 2D/3D Magnetic Field Calculations (OPERA, ANSYS, etc.)
- Mechanical Analysis and Coil Restraint (design, ANSYS) (>Fatigue of the conductor and precise positioning)

Experimental studies with modified Nuklotron magnets in JINR

SIS100 Magnets: Full Size Model Dipole

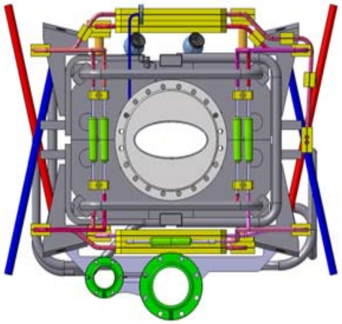




Full Lenth Models "Prototypes"

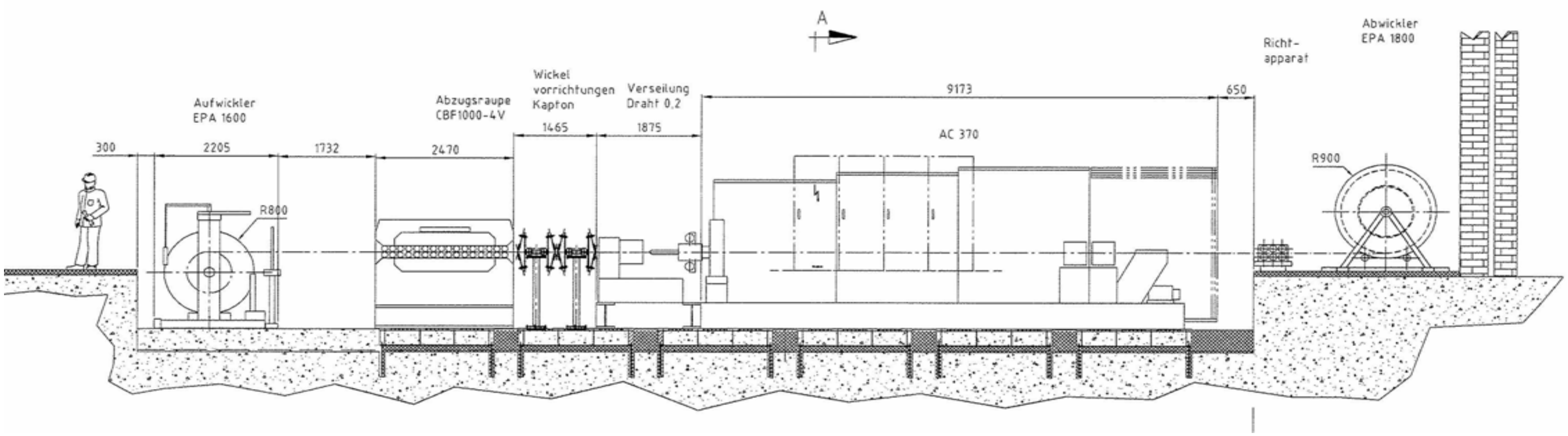
- Straight dipoles (JINR Dubna, BNG Wuerzburg)
- Curved dipole (BINP Novosibirsk)

Design review for both dipoles passed



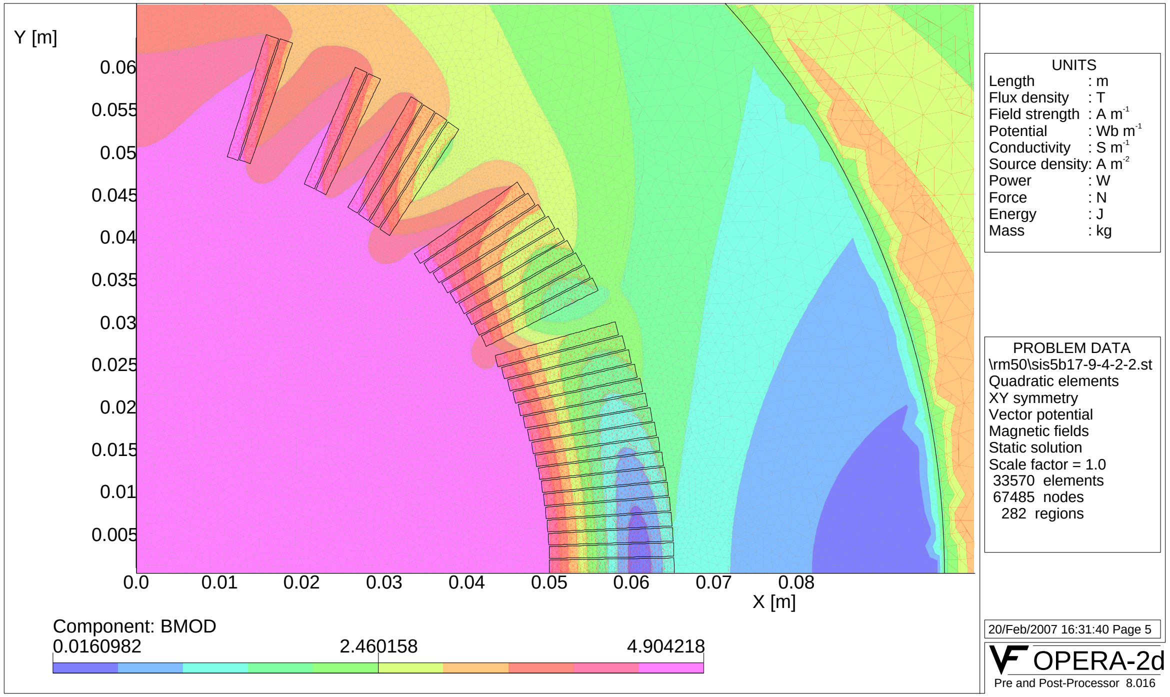
SIS100 Magnets: Cable Production

Second Nuklotron type cable production capability set-up at BNG in Würzburg



5-blocks selected configuration for SIS 300 dipole (INFN)

Block number	5
Turn number:	17-9-4-2-2
Current	8924 A
Bpeak	4.90 T
Bpeak / Bo	1.09
Temperature margin	0.99 K
Coil inner radius	50 mm
Yoke inner radius	98 mm



The proposed 5-blocks configuration with larger aperture has:

- Excellent and stable field quality
- Acceptable temperature margin (lower limit)
- Low harmonic perturbation during the ramp
- Reasonable losses

Radiofrequency: Overview

	FBTR	f [MHz]	#	Technical Concept
Acceleration System	h=10 400 kV	1.1–2.7	20	Ferrit ring core, "narrow" band cavities
Compression System	h=2 640 kV	0.395- 0.485	16	Magnetic alloy ring core, broad band (low duty cycle) cavities
Barrier Bucket System	15kV	2	2	Magnetic alloy ring core, broad band (low duty cycle) cavities

Ferrit loaded accel. cavity

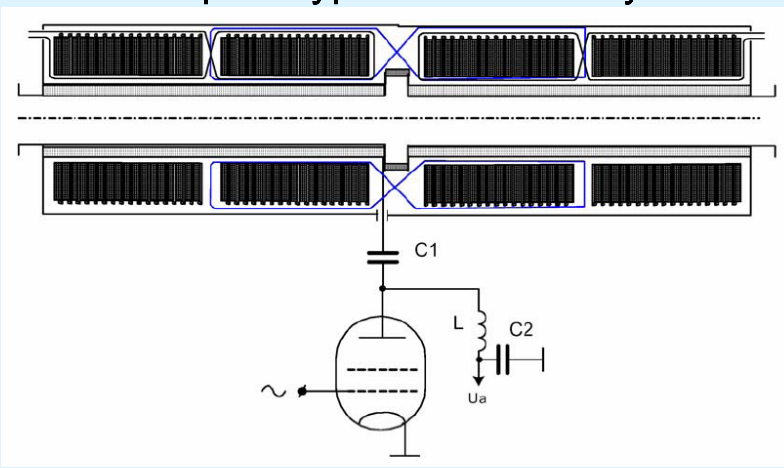
MA test cores at GSI

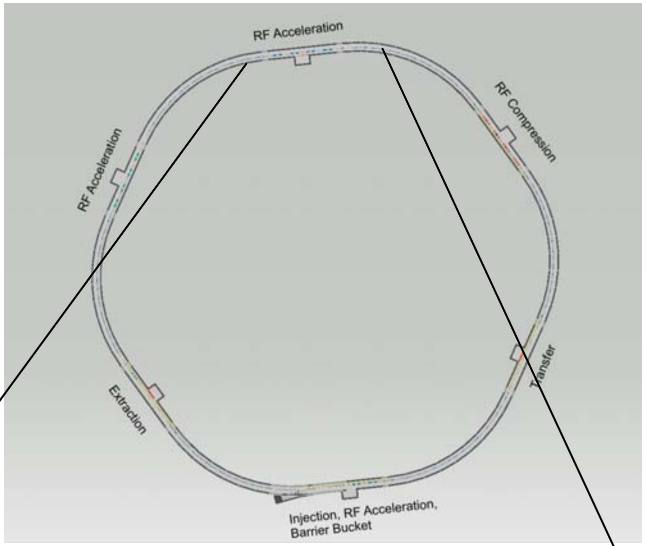
SIS18 bunch compressor

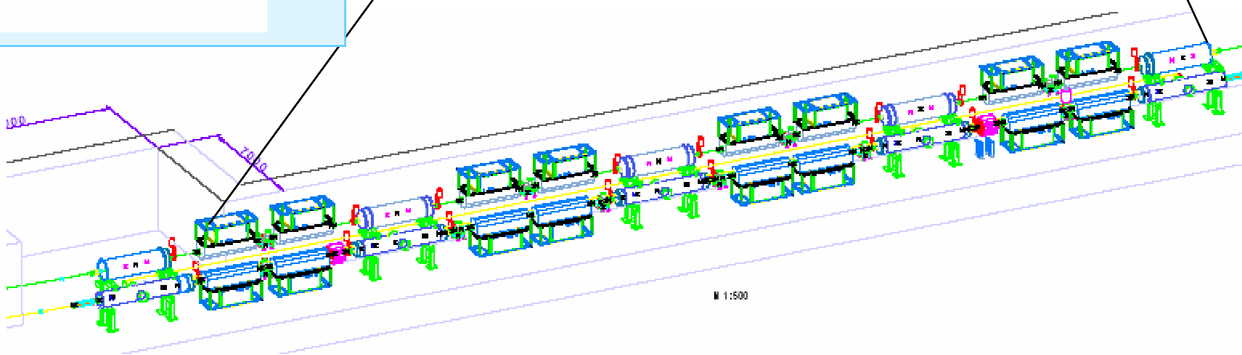
Radiofrequency: Acceleration Sections

Acceleration Cavities:

- Design study completed (BINP)
- Start call for prototype tender in July 2007



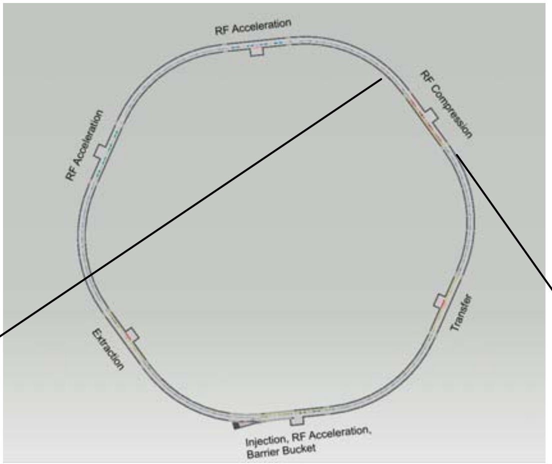




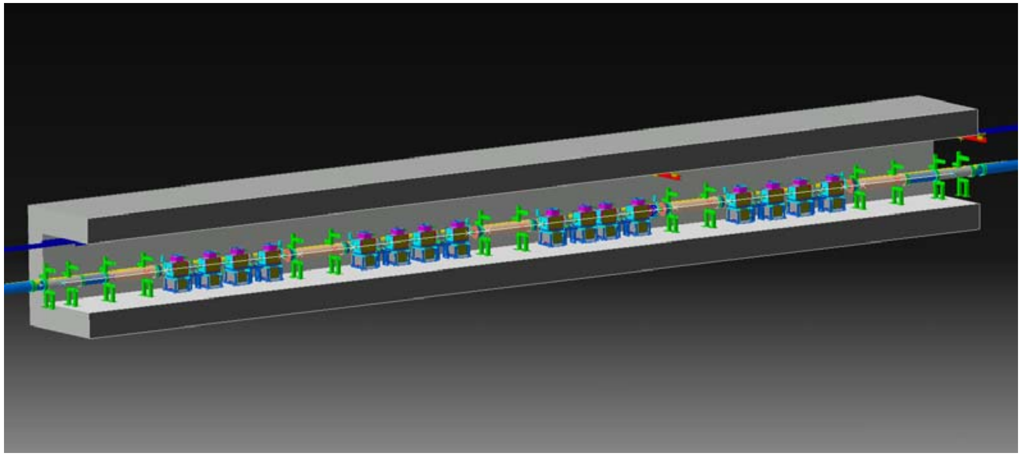
Radiofrequency: Compression Section

Compression Cavities:

- SIS18 compression system (ready for installation) and CR debuncher system, with very similar techn. parameters completed
- No dedicated developments for SIS100 compression system. Purchasing without additional in-house R&D.

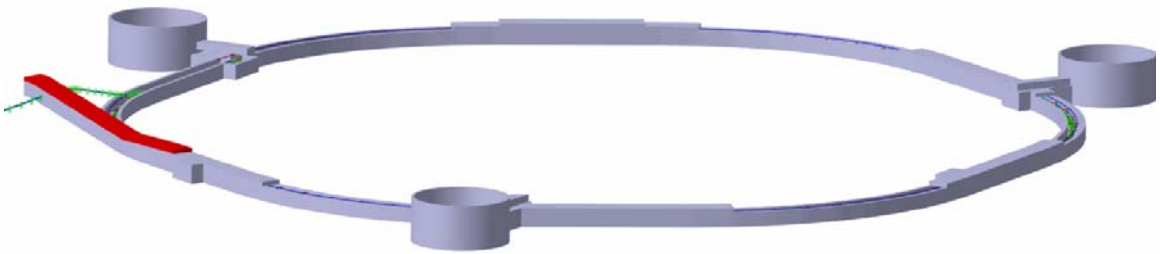


SIS18 Bunch Compressor



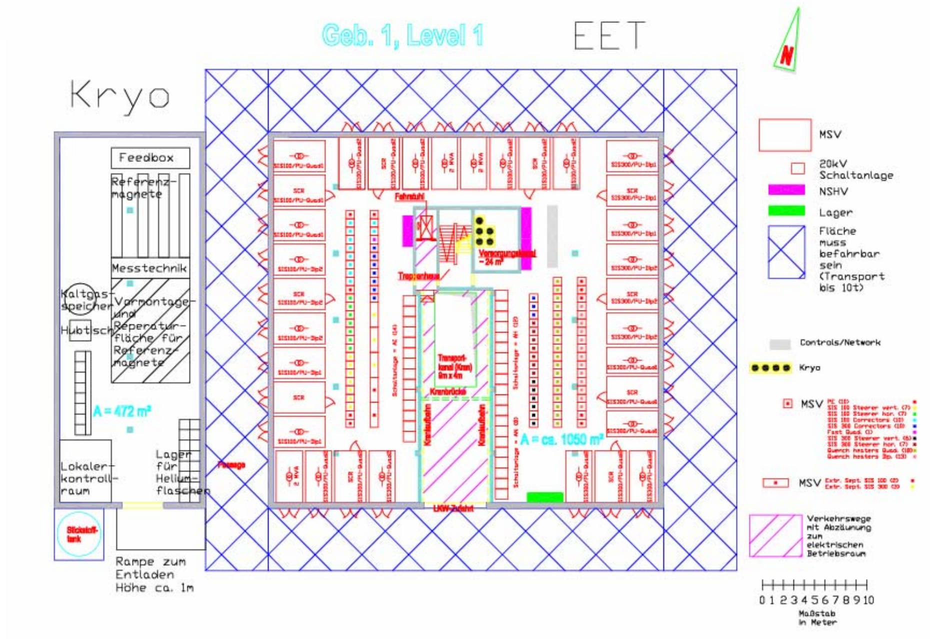
16 MA compression cavities in section S2

Synchrotron Main Supply Buildings



Document „Specifications for Synchrotron Buildings“ includes main accelerator aspects

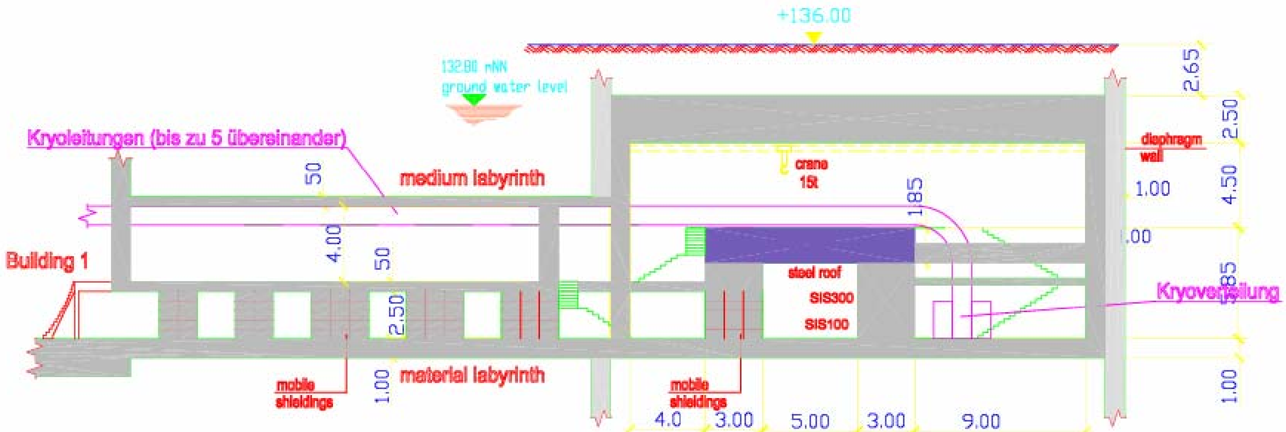
- **Table of floor space requirements**
- **Tables for cranes and double floor**
- **Distribution of supply units for all buildings and floors**
- **Cable planning started**
- **General specifications**

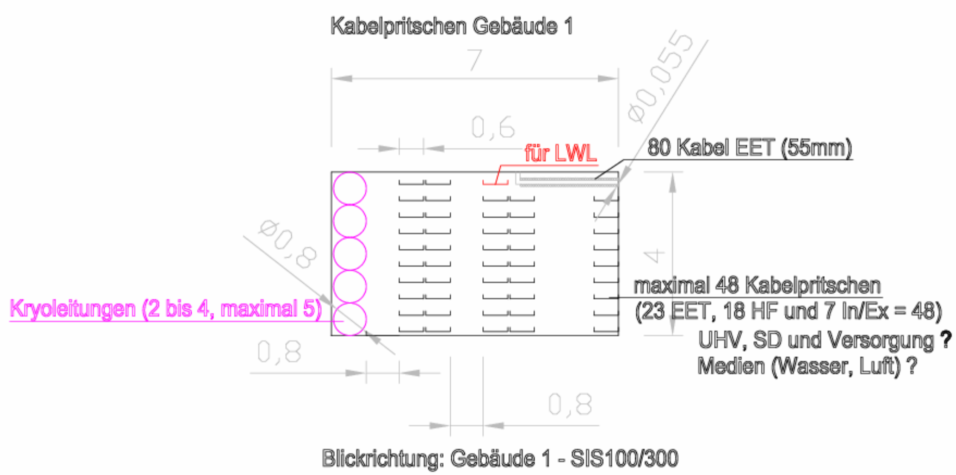


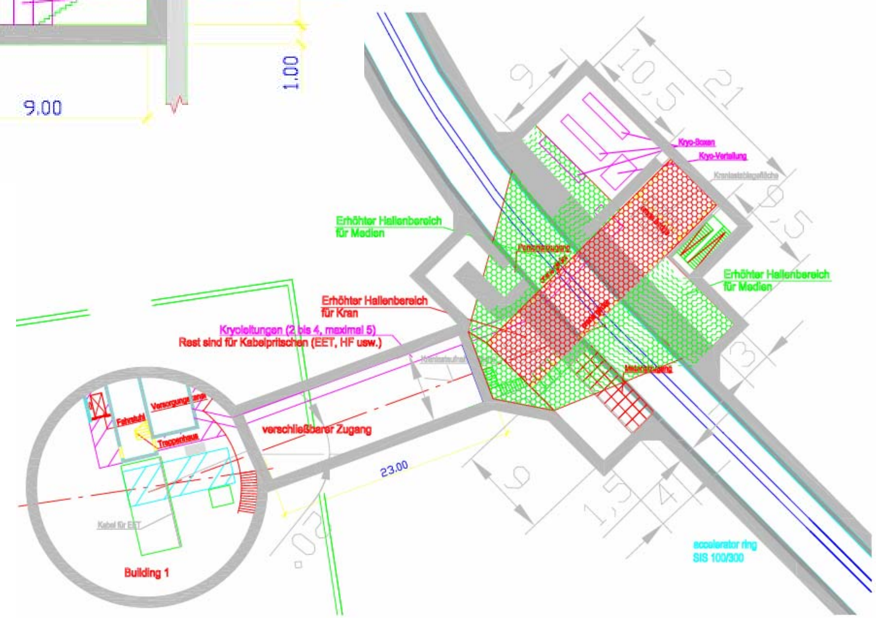
plus Load List

Civil Construction: Supply Tunnel

Building optimization for cryogenic and media supply required





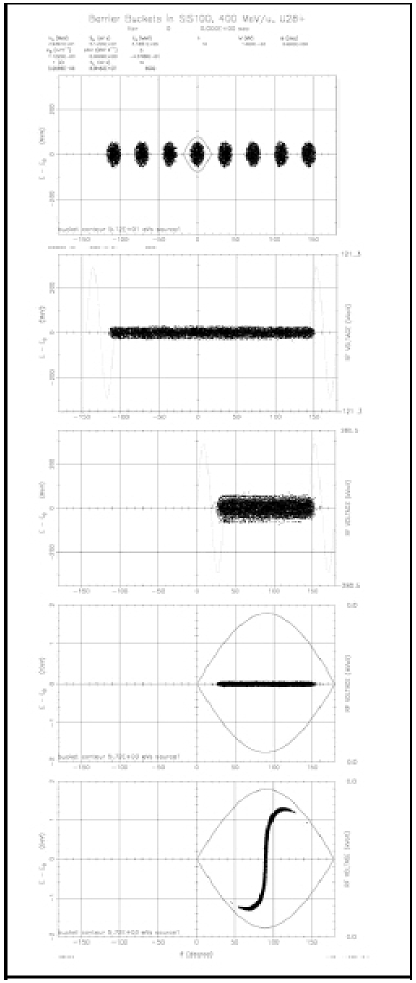


FAIR Storage Rings

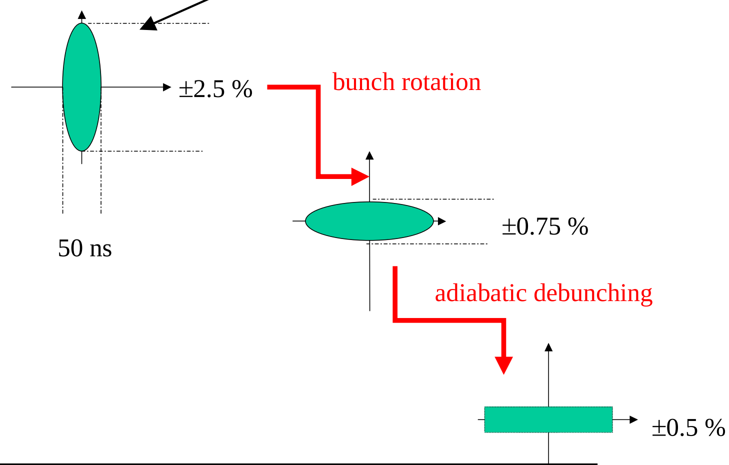
CR, RESR, NESR and HESR

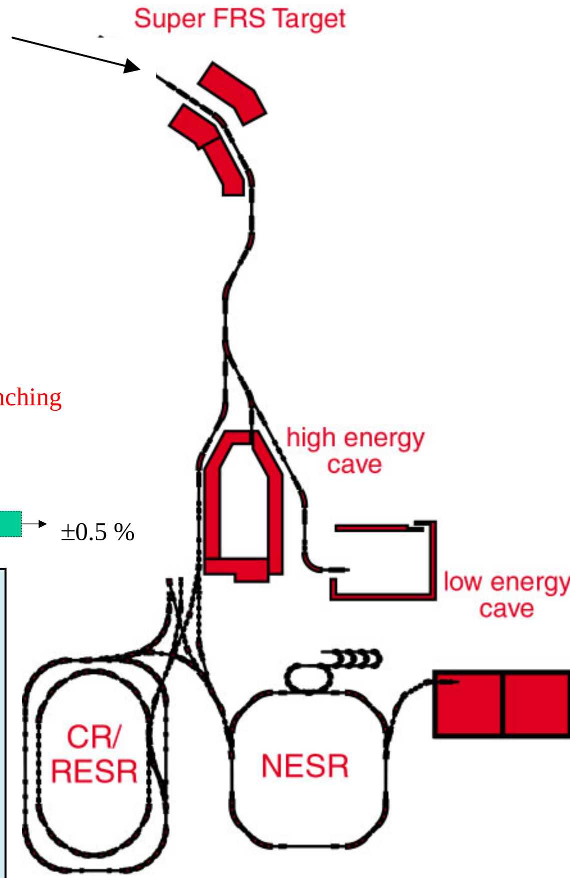
Bunch Compression in SIS100

Short pulses for optimum target matching and fast cooling in CR



on Target





New : Detailed beam dynamics studies, including different options for pre-bunching, taking into account realistic cavity properties (shunt impedance), space charge and others.

Operation and Function of the Storage Rings

RIB Physics | **Pbar Physics** | **Atomic Physics**

SIS 100

- 1×10^{12} ions, 50 ns bunch
- 2.5×10^{13} protons, 50 ns bunch
- 1×10^{10} ions

Super-FRS

max. 5×10^{9} RIBs per cycle at 740 MeV/u

Pbar-target

1×10^{8} pbars per cycle at 3 GeV

CR/RESR-Complex

Bunch rot., ad. debunching, stoch. precooling

Fast deceleration to 200 - 400 MeV/u

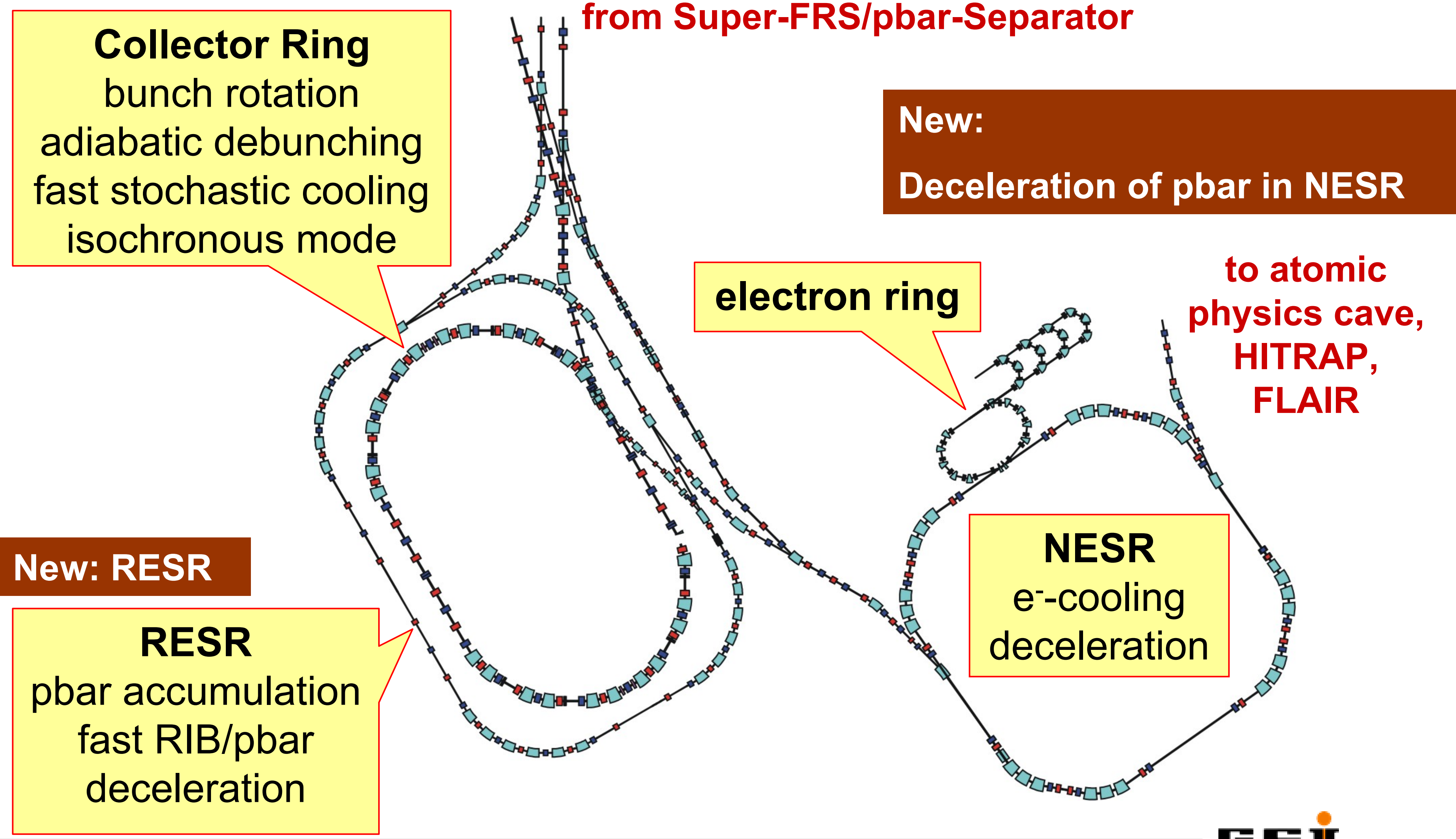
Accumulation of up to 5×10^{11} pbars

Pbar reinjection

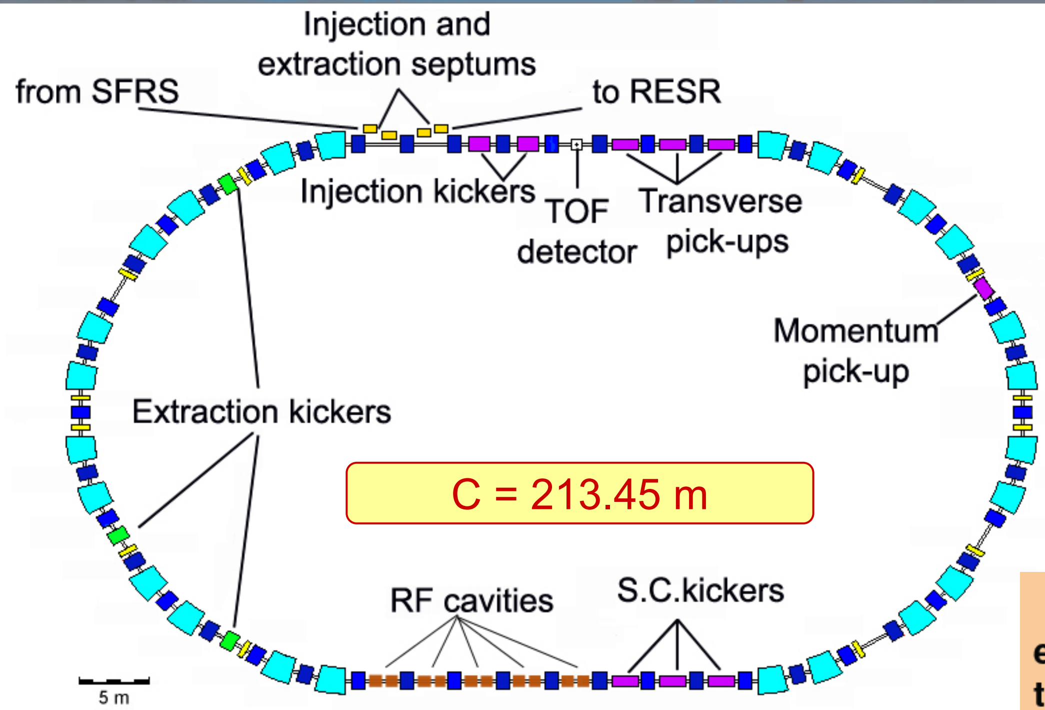
NESR

Electron cooling, deceleration to E < 100 MeV/u, in-ring-experiments (gas-jet-target, e-A collisions, electron target), fast and slow extraction

Storage Ring Complex



Collector Ring CR



Main task:
fast cooling
bunch rotation
adiabatic debunching
stochastic precooling
isochronous mode

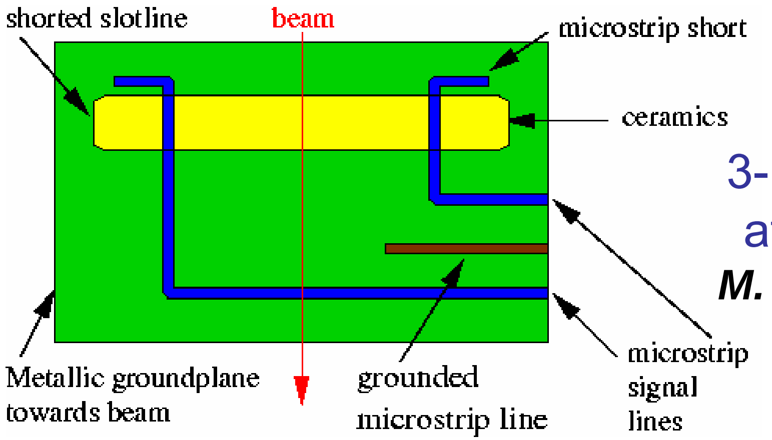
	RIB	pbar
energy	740 MeV/u	3.0 GeV
tunes Q_x/Q_y	3.17/3.18	4.42/4.24
mom. accept.	± 1.5 %	± 3.0 %
transv. accept.	200×10^{-6} m	240×10^{-6} m
transition energy	2.9	3.54

Detailed lattice design, split ring > symmetric structure

Detailed pick-up and kicker design studies for both β of RIBs and pbar

Electrodes for Stochastic Cooling

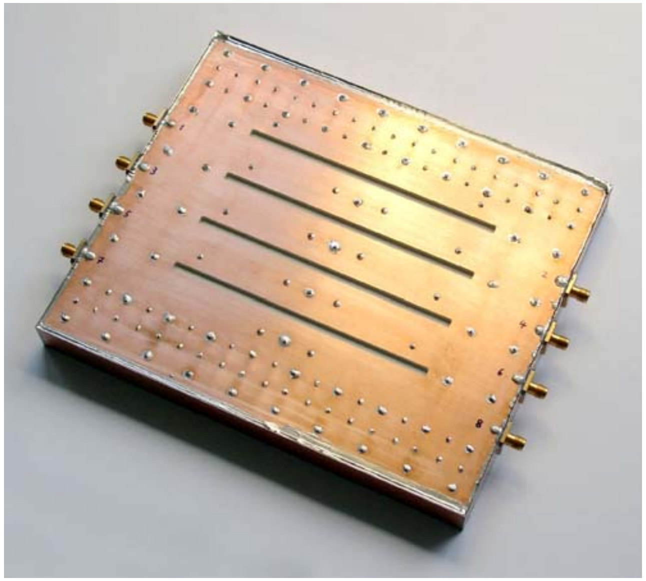
structure for use at two velocities $\beta=0.83$, $\beta=0.97$



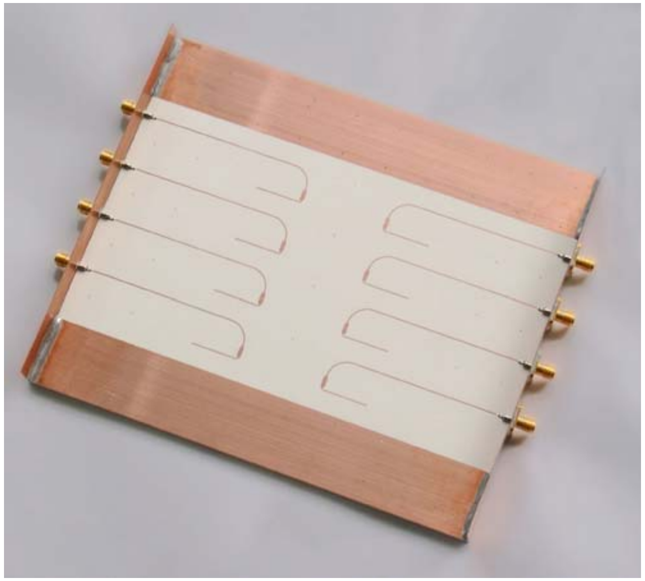
3-D field calculations at TEMF Darmstadt

M. Balk (TU Darmstadt)

prototype electrode

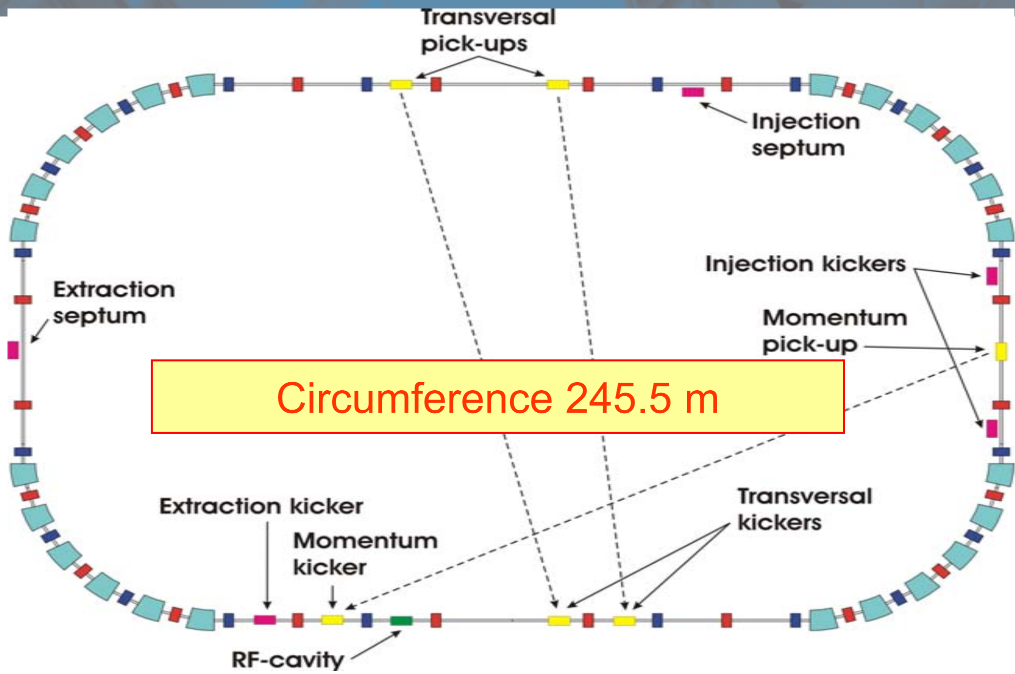


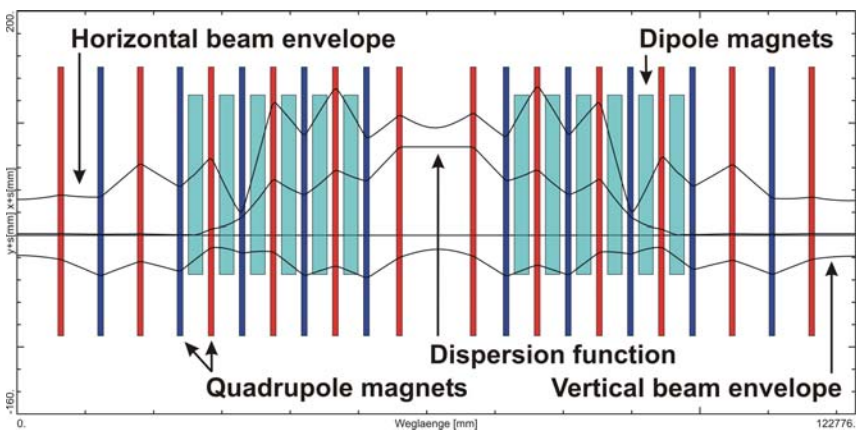
beam side



back side

RESR





Main tasks:
Pbar accumulation (10^{11})
Fast deceleration of RIBs

Destailed lattice layout optimized for stochastic cooling with rf stacking

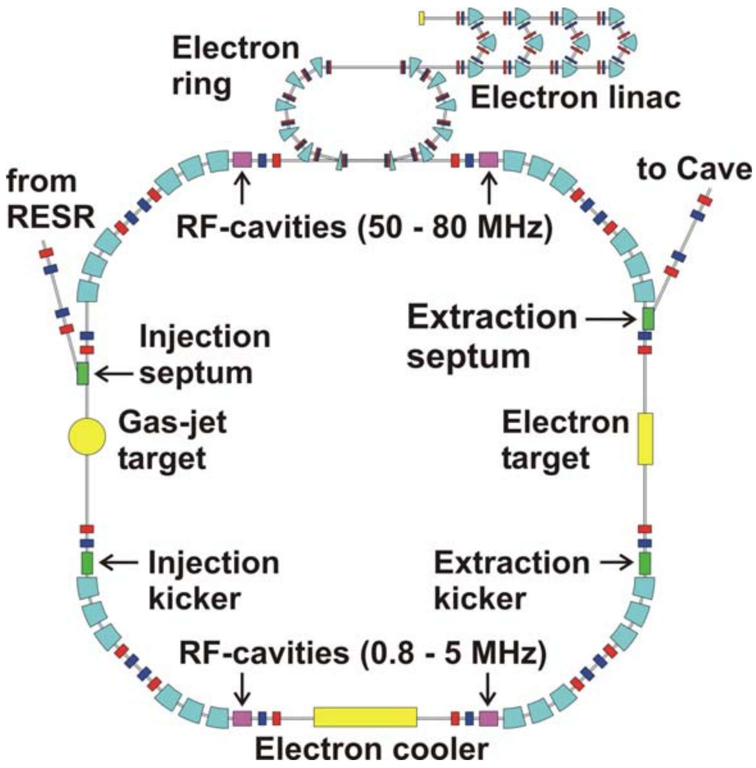
Quadrupoles from ESR

Preliminary studies on stochastic pbar accumulation

Stacking concept not fixed

(barrier bucket under investig.)

NESR



NESR:

Circumference	222.11 m
Max. bending power	13 Tm
Ramp rate	1 T/s
Energy range:	
Ions	4 – 840 MeV/u
Pbar	30 MeV – 3 GeV

Electron ring:

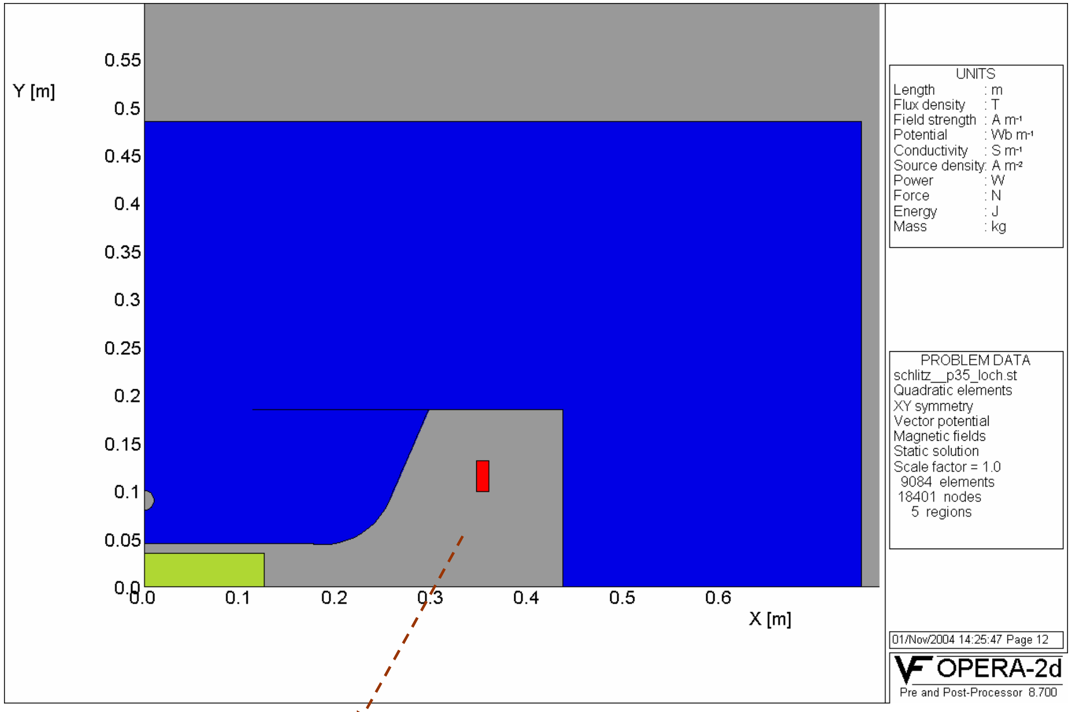
Circumference	45.22 m
Electron energy	200-500 MeV

Detailed lattice layout for storage ring and collider mode

Three rf systems: a) deceleration b) e-interaction, c) burrier bucket accumulation

Super-ferric NESR Dipole Magnet

2D-design

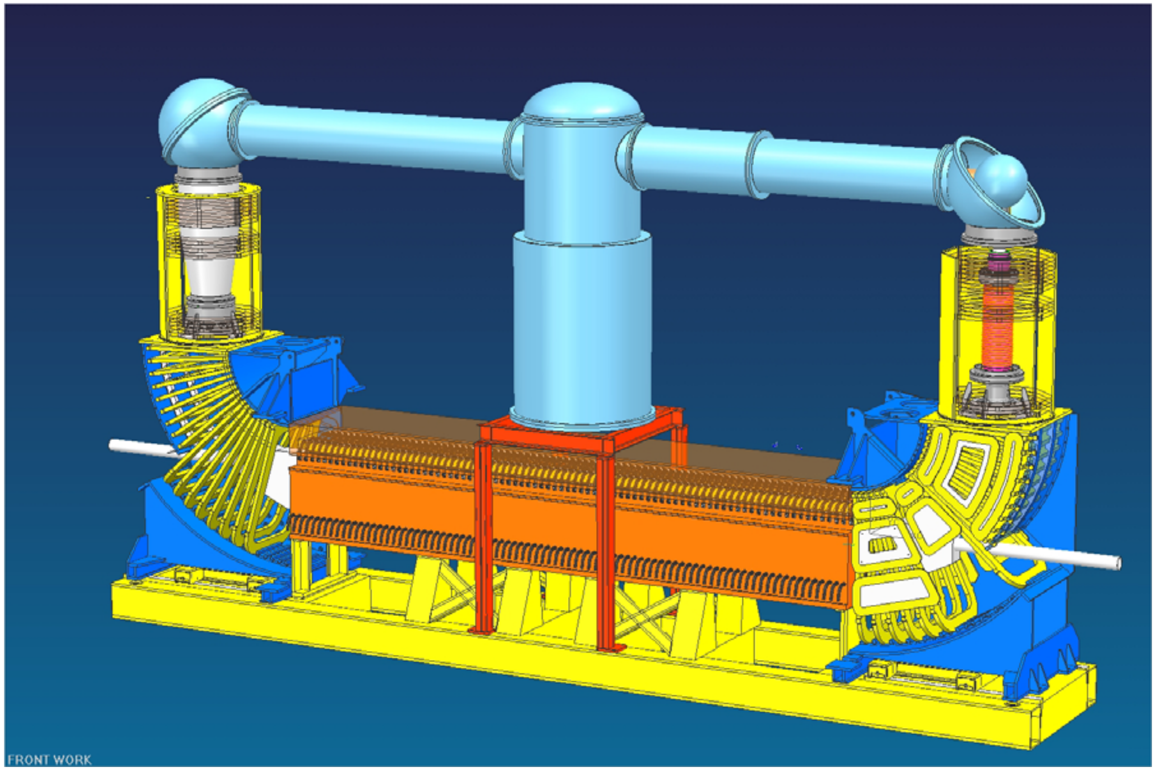


- fast ramping 1T/s
- large dynamic range (0.06-1.6T)
- large useful aperture (250×90mm^2)

Coil:
6000 A
10 turns
150 A/mm^2

NESR Electron Cooler

designed by BINP, Novosibirsk



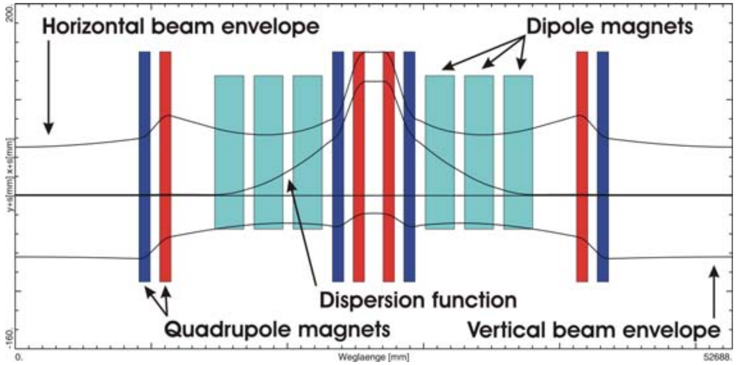
Cooler Parameters	
energy	2 - 450 keV
max. current	2 A
beam radius	2.5-14 mm
magnetic field	
gun	up to 0.4 T
cool. sect.	up to 0.2 T
straightness	2×10^{-5}
vacuum	$\leq 10^{-11}$ mbar

- high voltage up to 500 kV
- fast ramping, up to 250 kV/s
- magnetic field quality

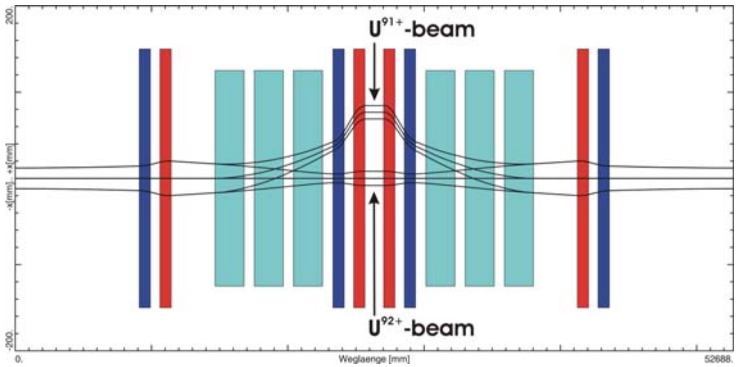
CSRe 300kV E-Cooler

built by BINP

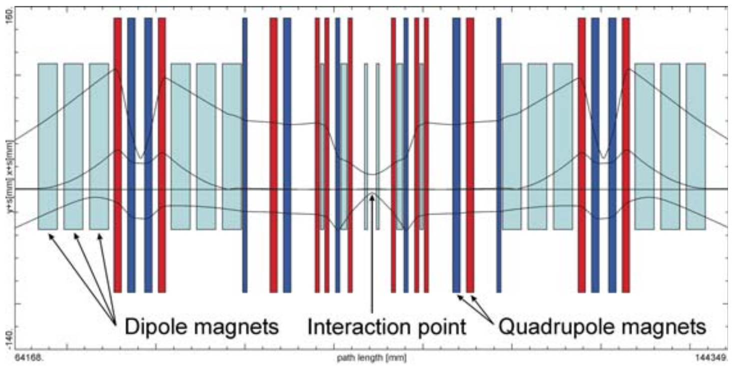
NESR Optical Functions



Envelope and Dispersion Function



Separation of U Charge States



Electron Nucleus Interaction

(minimum β functions for e-interaction)

HESR Reference Design

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

HESR consortium consists of FZJ, GSI and TSL

Beam Parameter:

0.8 - 14.5 GeV $\overline{p}$

N_{max} = 10^{10} (HRM), 10^{11} (HLM)

$L = 2 \times 10^{32}\ cm^{-2}s^{-1}$

$N_{target} = 10^{15}$-$10^{16}\ cm^{-2}$

Beam Quality:

0.001 – 0.1 mm mrad

dp/p= 10^{-5} (HRM), 10^{-4} (HLM)

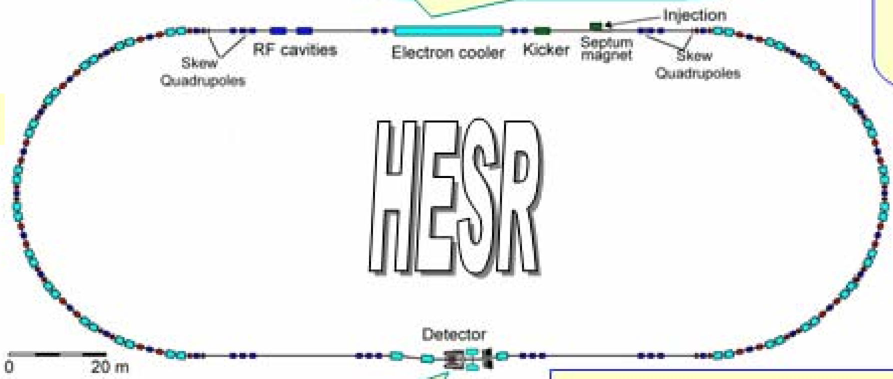
Beam Accumulation:

$2*10^{7}$/s ($7*10^{10}$/h)

Conceptional design report

Electrons: 1 A, 8 MV
Interaction length: 30 m
Long. B field: 1-5 kG
$-\Delta\dot{T}_{\overline{p}} \propto \rho_e T_{\overline{p}}^{-3/2} \ln(B)$

Circumference: 443.4 m
Beam Rigidity: 50 Tm
Dipole field: 4T
$\Delta\dot{T}_{\overline{p}} \propto \rho_{\overline{p}} T_{\overline{p}}^{-3/2}$



Pellet-Target

- H_2 (ρ=0.08 g/cm³)
- 70000 pellets/s

$\overline{p}$

d=1 mm

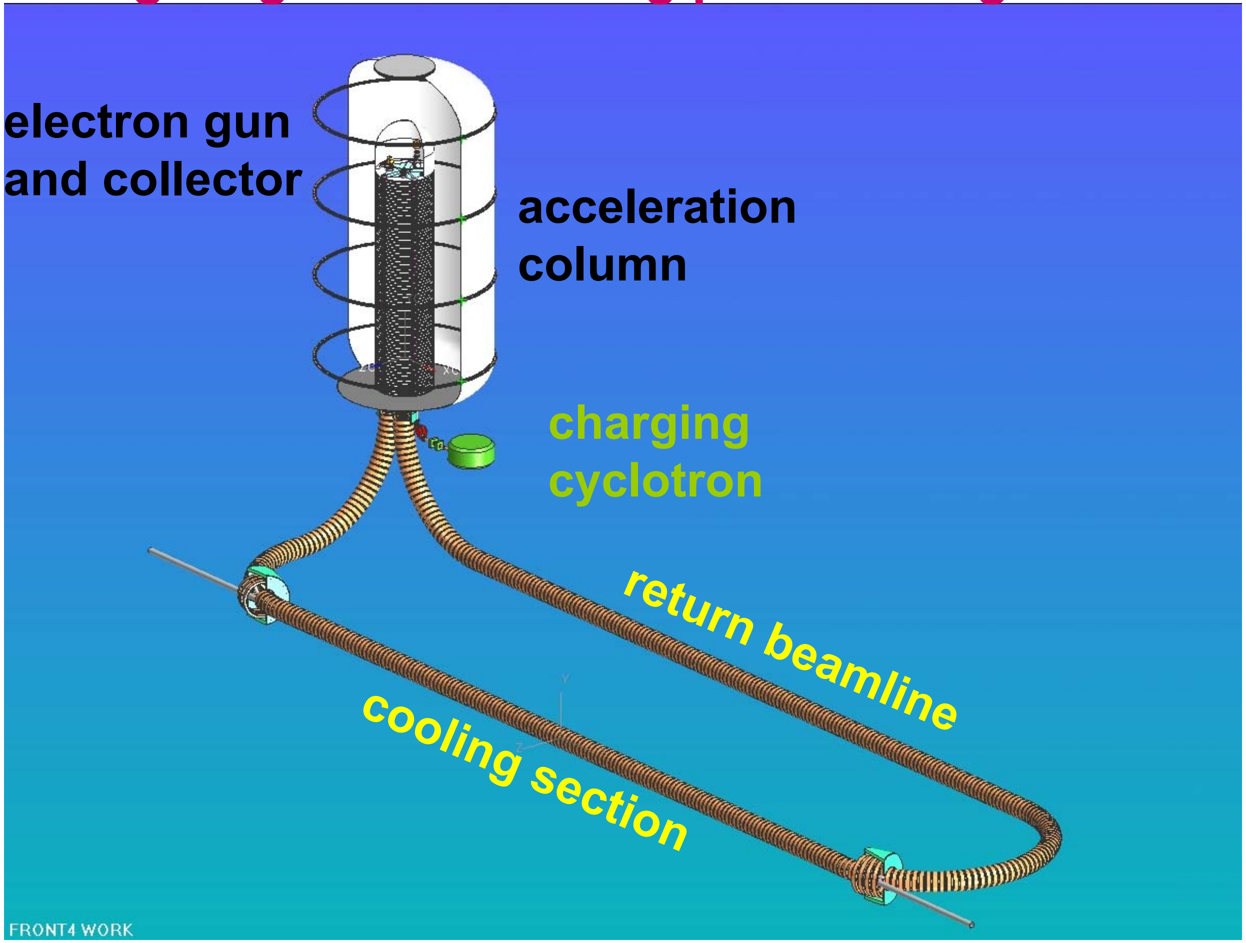
$\Delta\dot{T}_{\overline{p}} \propto \rho_{H_2} d$

Accelerator R&D work:

- magnetized e-cooler (8 MV)
- stochastic cooling system
- broadband feedback system
- RF cavities, sc magnets
- impedance budget

The HESR Electron Cooling System

Strong magnetized cooling provides highest cooling rates



energy 0.4 - 8 MeV
current up to 2 A

magnetic field 0.2 - 0.5 T
(superconduct. solenoids)
in cooling section 30 m

electrostatic accelerator
charged by H^--beam

bending by electrostatic
fields for highest
recuperation efficiency

design study by BINP, Novosibirsk ↔ **alternatives studied by TSL, Uppsala**

Official Project Start in November 2007