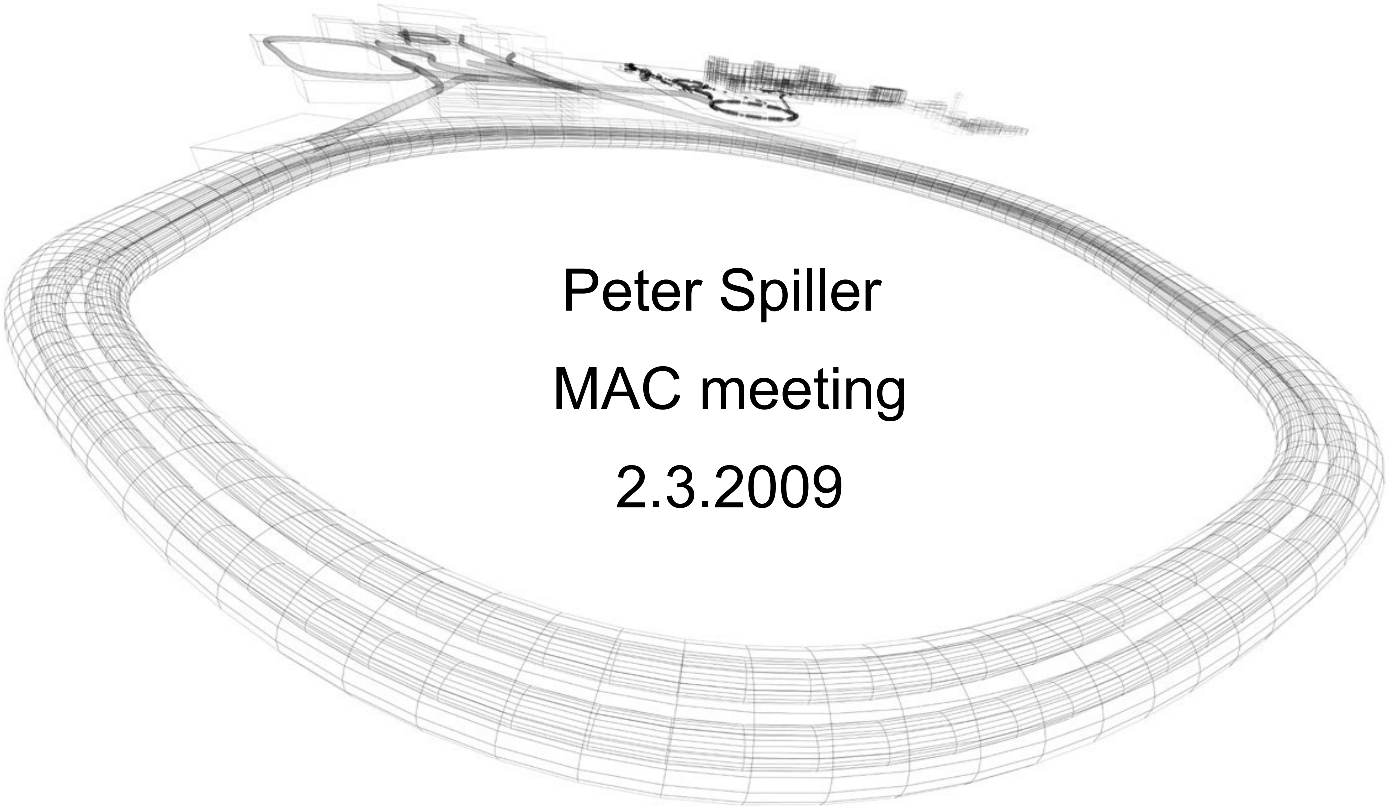
SIS100 System Design



Peter Spiller

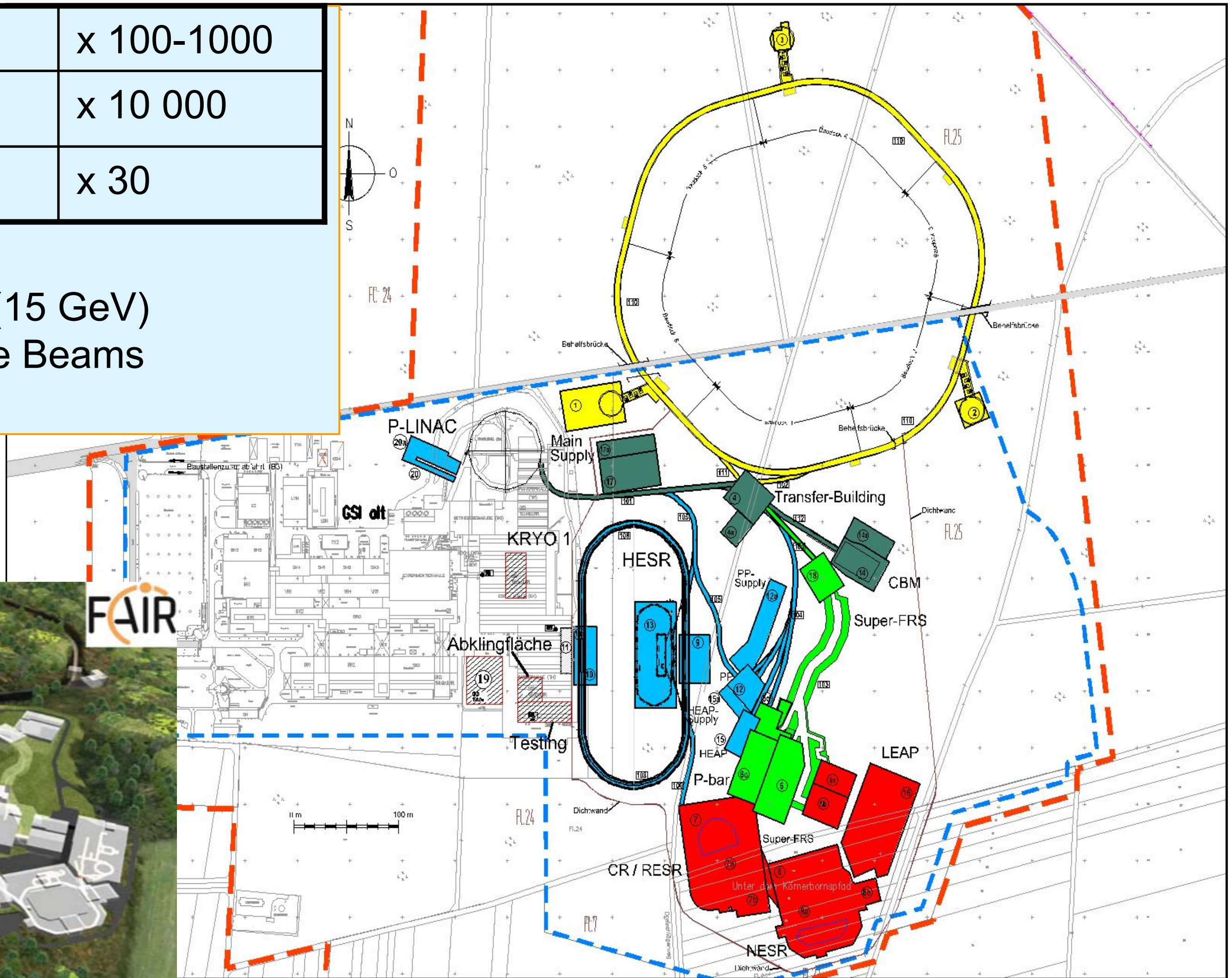
MAC meeting

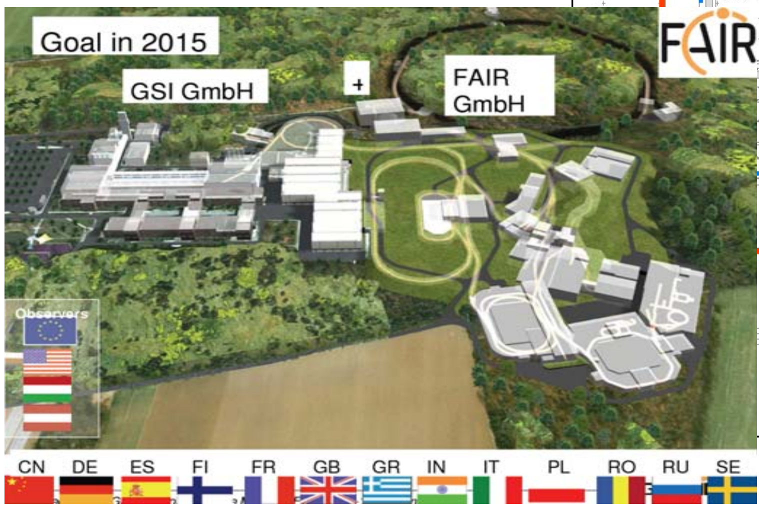
2.3.2009

GSI/FAIR Accelerator Facility

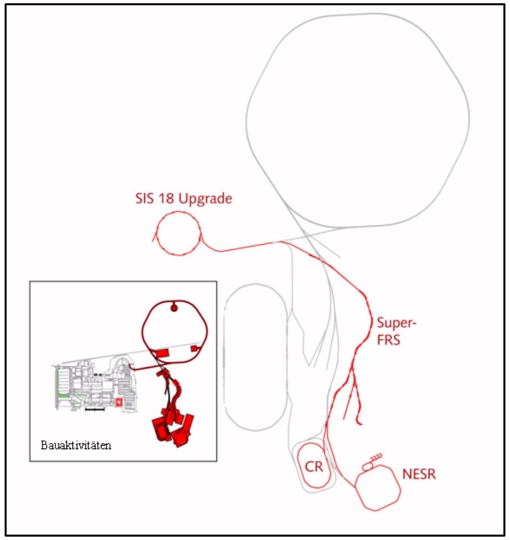
Primary Beam Intensity	x 100-1000
Secondary Beam Intensity	x 10 000
Heavy Ion Beam Energy	x 30

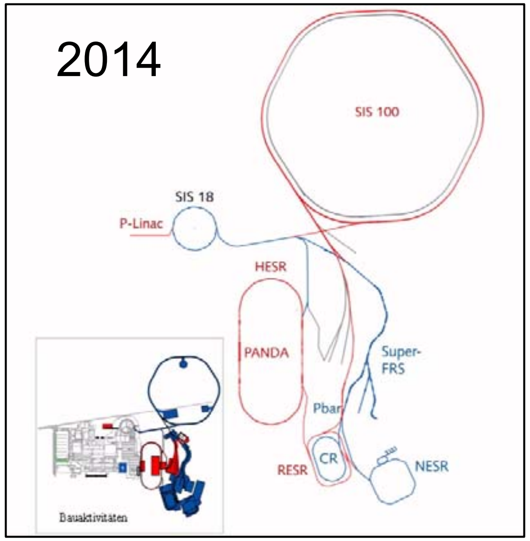
- New: Cooled pbar Beams (15 GeV)
- Intense Cooled Radioactive Beams
- Parallel Operation

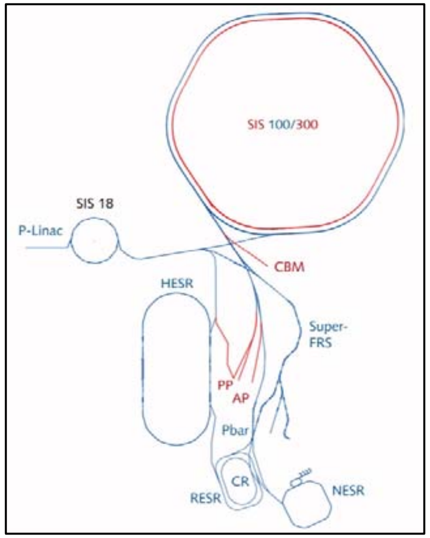




FAIR Uranium Intensity (staged realization)







Stage 1 (FAIR startversion) **Stage 2** **Stage 3**

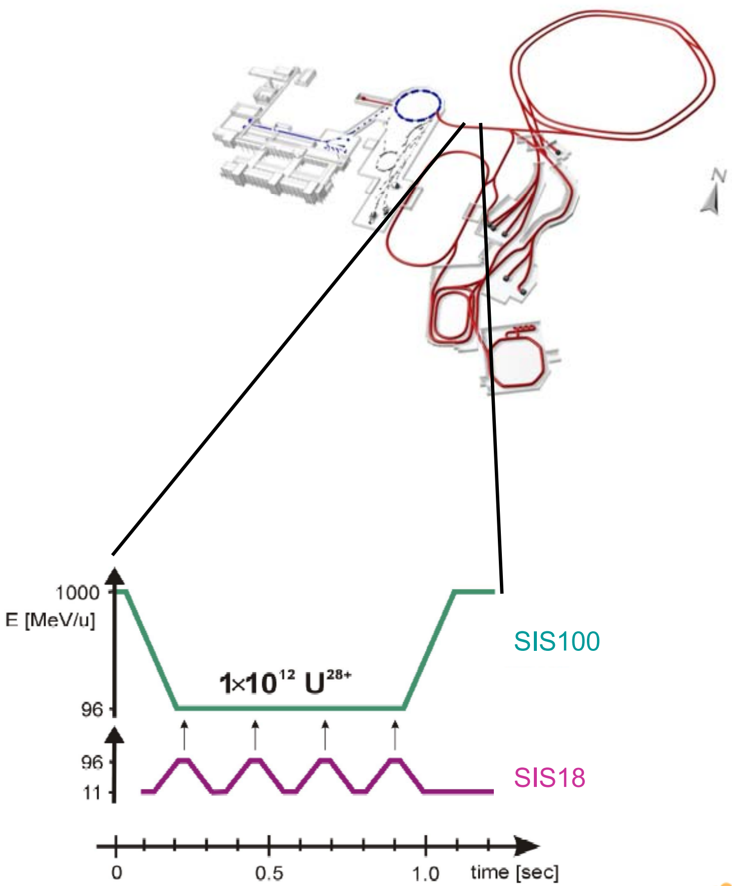
Uranium Beam Intensities in RIB Energy Range		
SIS18	SIS100	SIS100/300
2×10^{10} /cycle (U^{73+})	5×10^{11} /cycle (U^{28+})	5×10^{11} /cycle (U^{28+})
Slow Extraction at 1 GeV/u and 1.4 s Spill		
1.1×10^{10} /s	1.5×10^{11} /s	3.5×10^{11} /s
Fast Extraction at 1 GeV/u		
5.4×10^{10} /s	3.5×10^{11} /s	not foreseen

Beam Parameters SIS18/SIS100

SIS18	Protons	Uranium
Number of ions per cycle	5×10^{12}	1.5×10^{11}
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	2.7 Hz

... and all other ion species

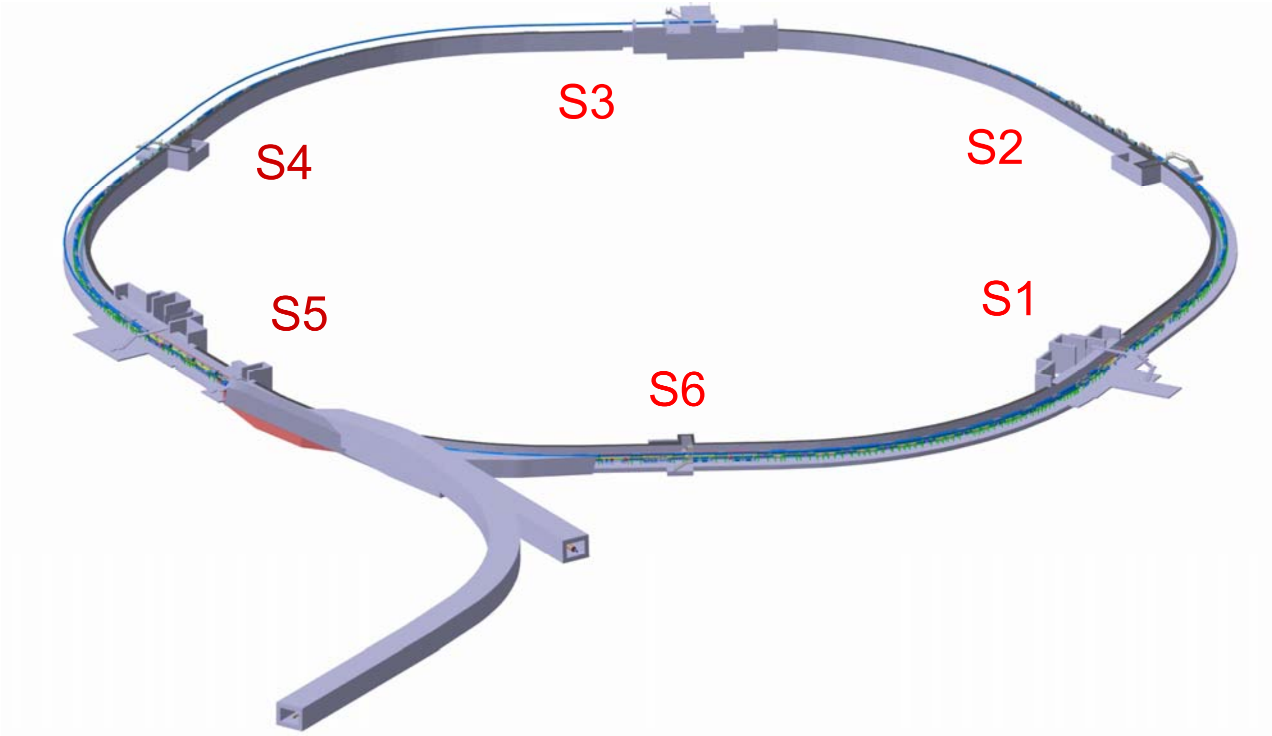
SIS100	Protons	Uranium
Number of injections	4	4
Number of ions per cycle	2.5×10^{13} ppp	5×10^{11}
Maximum Energy	29 GeV	2.7 GeV/u
Ramp rate	4 T/s	4 T/s
Beam pulse length after compression	50 ns	90 - 30 ns
Extraction mode	Fast and slow	Fast and slow
Repetition frequency	0.5 Hz	0.7 Hz



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 Acceleration (Ferrite loaded)
S3: Rf Acceleration (Ferrite loaded)
S4: Rf Compression (MA 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

Two Stage Synchrotron SIS100/300

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

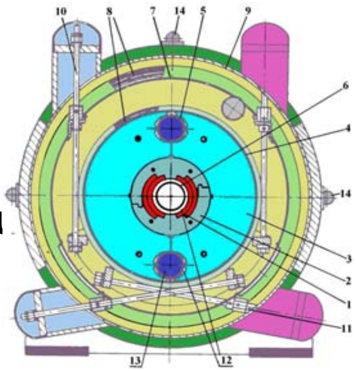
SIS100 with fast-ramped superconducting magnets and a strong bunch compression system.

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.

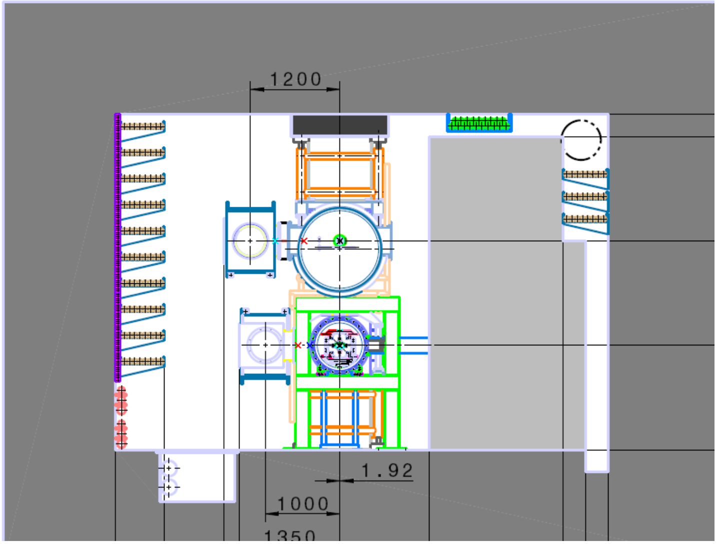


Highly charges ions e.g. U^{92+}-ions up to 34 GeV/u
Intermediate charge state ions U^{28+}- ions at 1.5 to 2.7 GeV/u with 100% du

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

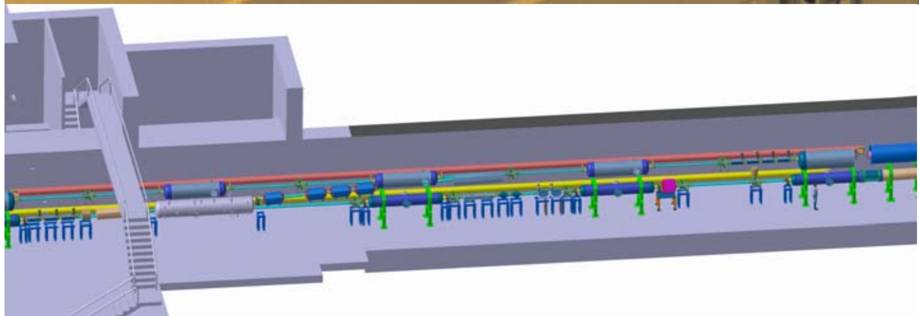
System and Ion Optical Design

Realisation of two-stage SIS100/SIS300 concept in one tunnel is challenging:

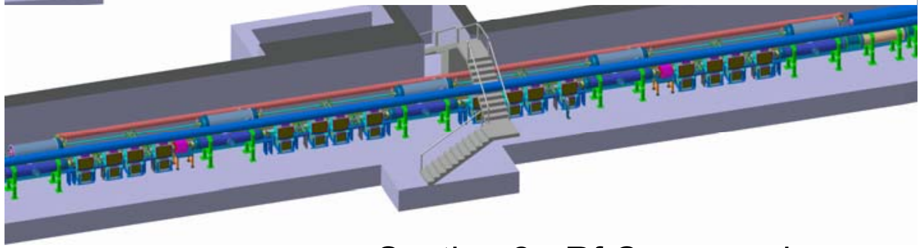


- Geometrical matching of both synchrotrons with different lattice structures (Doublet and FODO) and different magnet technologies (superferric and cosθ)
- Ratio between straight section length and arc length with fixed circumference defined by the warm straight section requirements of SIS100
- Fast, slow and emergency extraction in one short straight and precisely at the same position, with the same angle and fixed distance between the SIS100 and SIS300 extraction channel
- Vertical extraction of SIS100 bypassing SIS300 (on top of SIS100)
- Transfer between SIS100 and SIS300, 1.4 m difference, many geometrical constraints

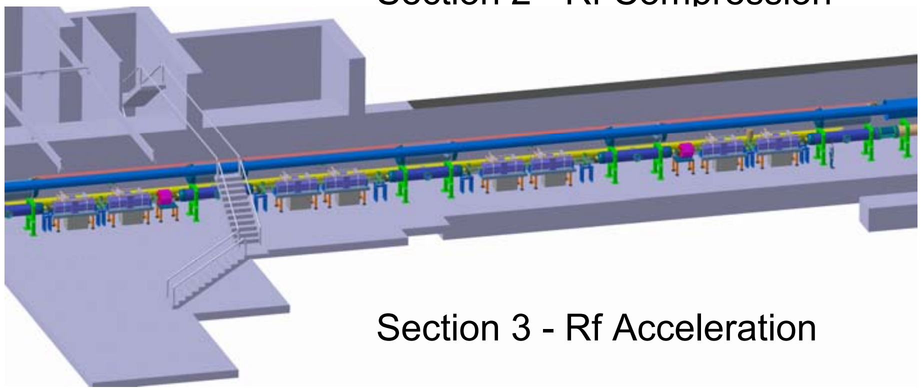
Straight Sections and Arc



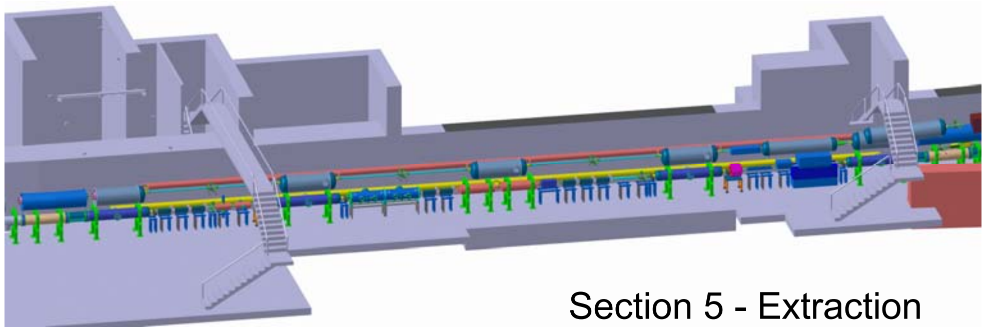
Section 1 - Transfer



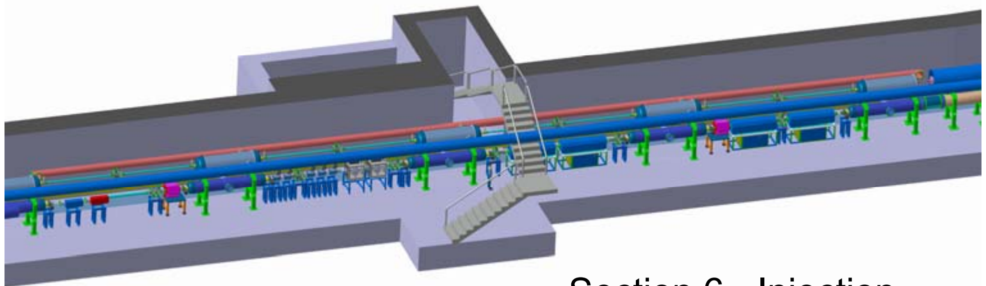
Section 2 - Rf Compression



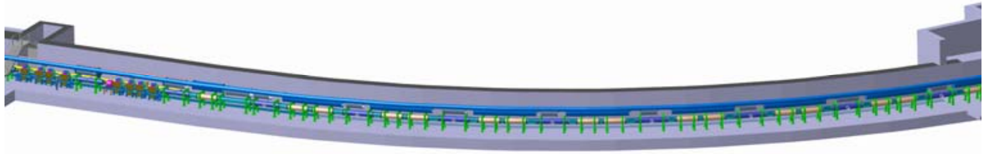
Section 3 - Rf Acceleration



Section 5 - Extraction

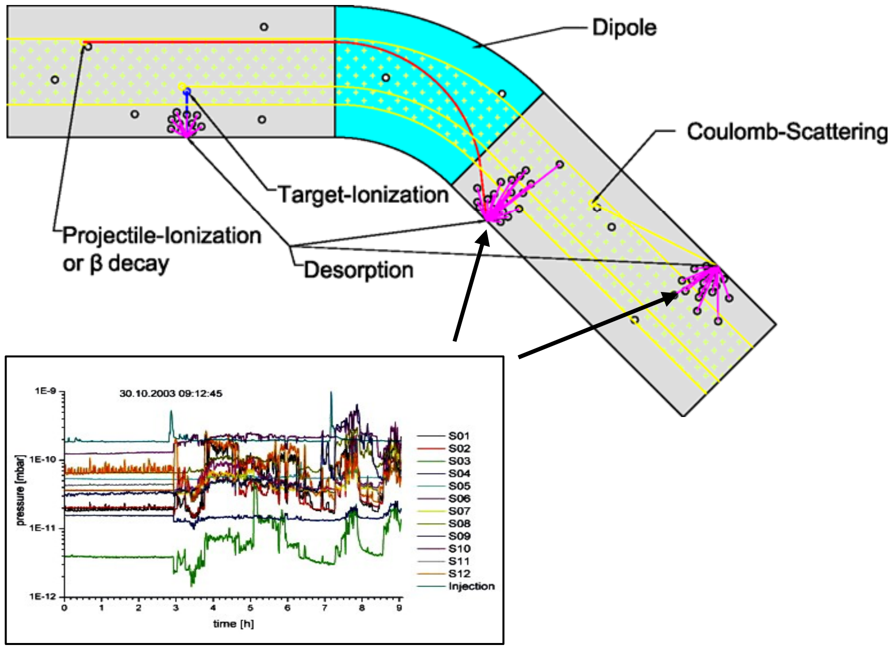


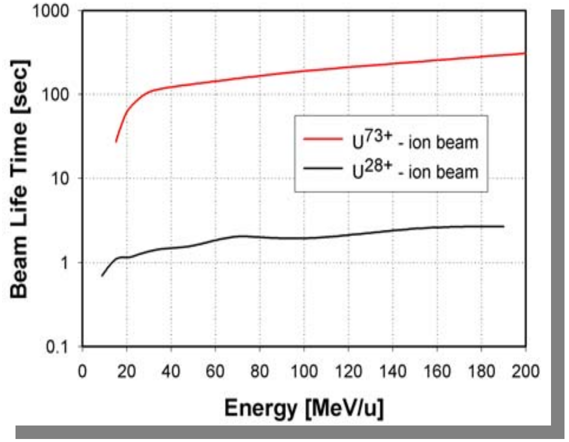
Section 6 - Injection

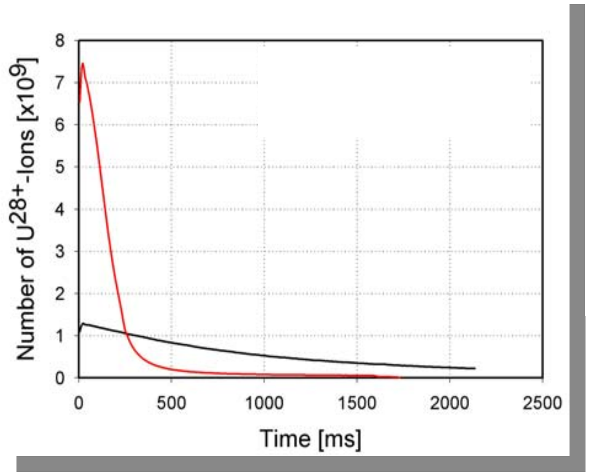


Arc

Ionization Beam Loss and Dynamic Vacuum







Main Issue for the SIS100 System Design:

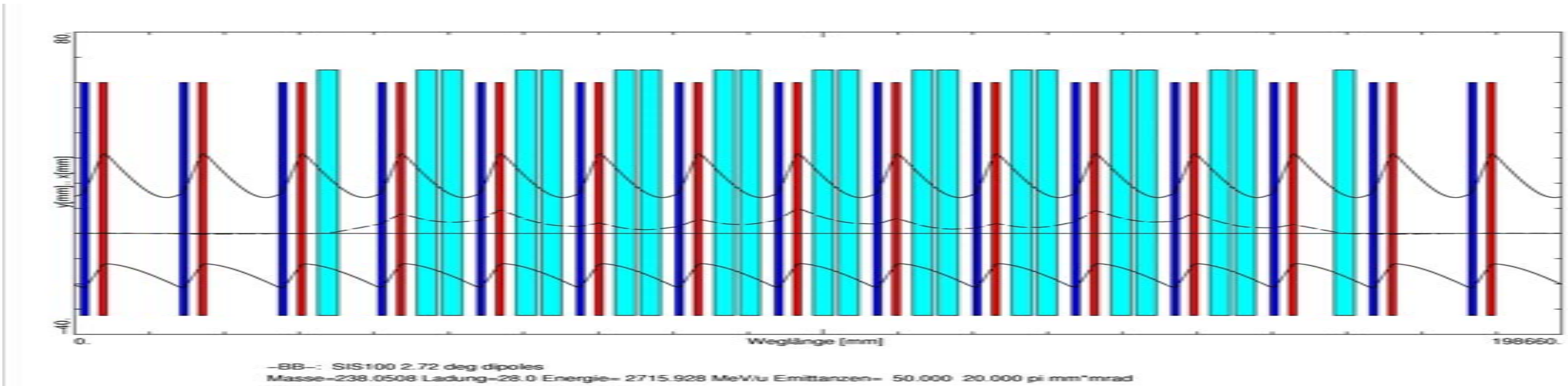
- Life time of U^{28+} is significantly lower than of U^{73+}
- Life time of U^{28+} depends strongly on the residual gas pressure
- Ion induced gas desorption ($\eta \approx$ 10 000) increases the local pressure
- Beam loss increases with intensity (dynamic vacuum)

Intermediate Charge State Heavy Ion Operation

- Optimized lattice for peaked distribution of ionization beam loss
- Catcher system for ionization loss control with low desorption yield material
- Strong distributed pumping system
  (sufficient area and sufficiently cold (actively cooled) vacuum chambers)
- Long term pumping after built up of stacks of monolayers (cryogenic surfaces)
- Infinitely refreshable (e.g. in a shut downs)
- Low systematic beam loss to prevent initial pressure bumps
- Low initial static pressure with a small amount of heavy components
  (warm sections determine the average, initial pressure)
- Fast ramping and short cycle times (for a fast decrease of cross sections)

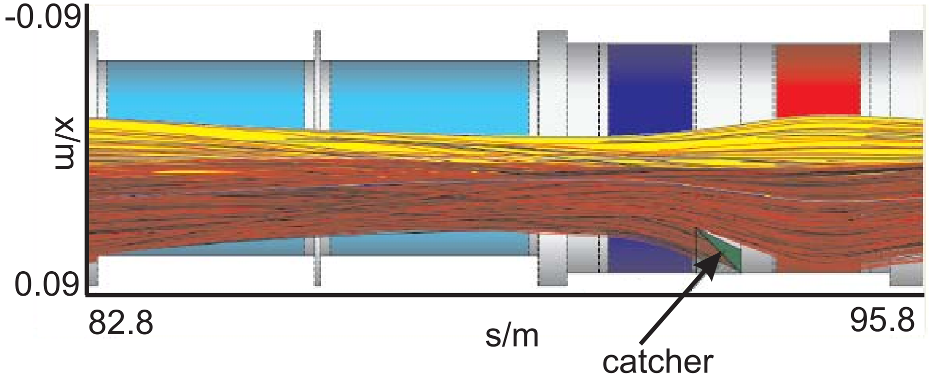
Lattice Characteristics

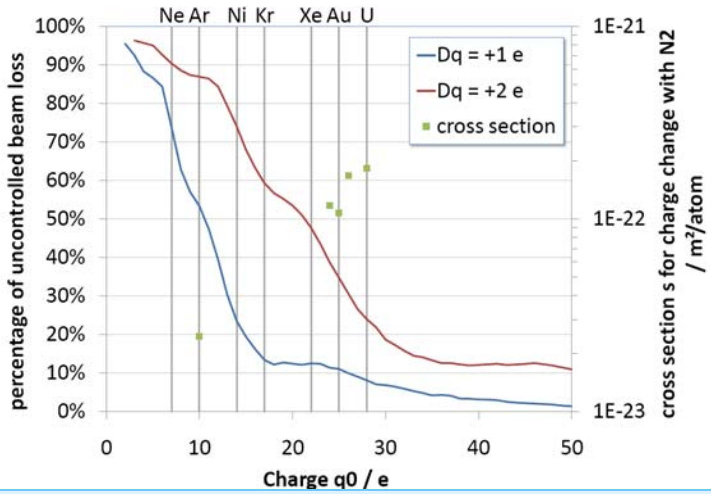
- Maximum transverse acceptance (minimum 3x emittance at injection)
  at limited magnet apertures (problems: pulse power, AC loss etc.)
- Vanishing dispersion in the straight sections for high dp/p during compression
- Low dispersion in the arcs for high dp/p during compression
- Sufficient dispersion 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 catcher system for ionization beam loss



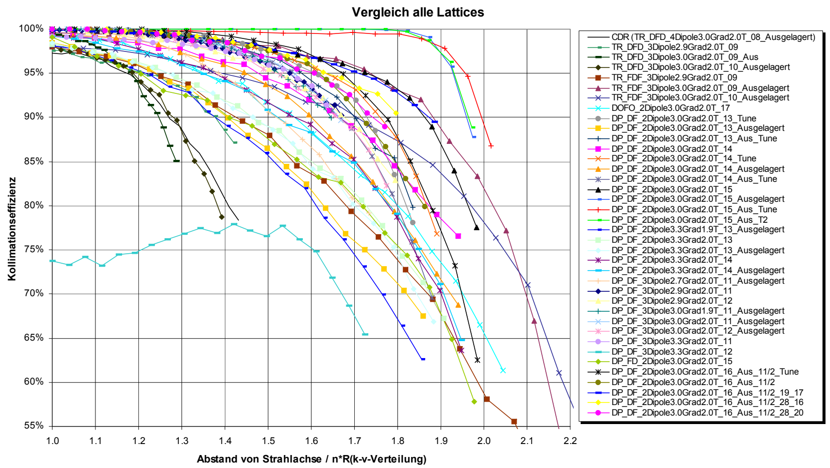
Charge Separator Lattice for Ionization Loss

New lattice design for intermediate charge state heavy ion operation with ionization beam loss





Fraction of ions missing the catchers increases for lighter ion and multiple ionization

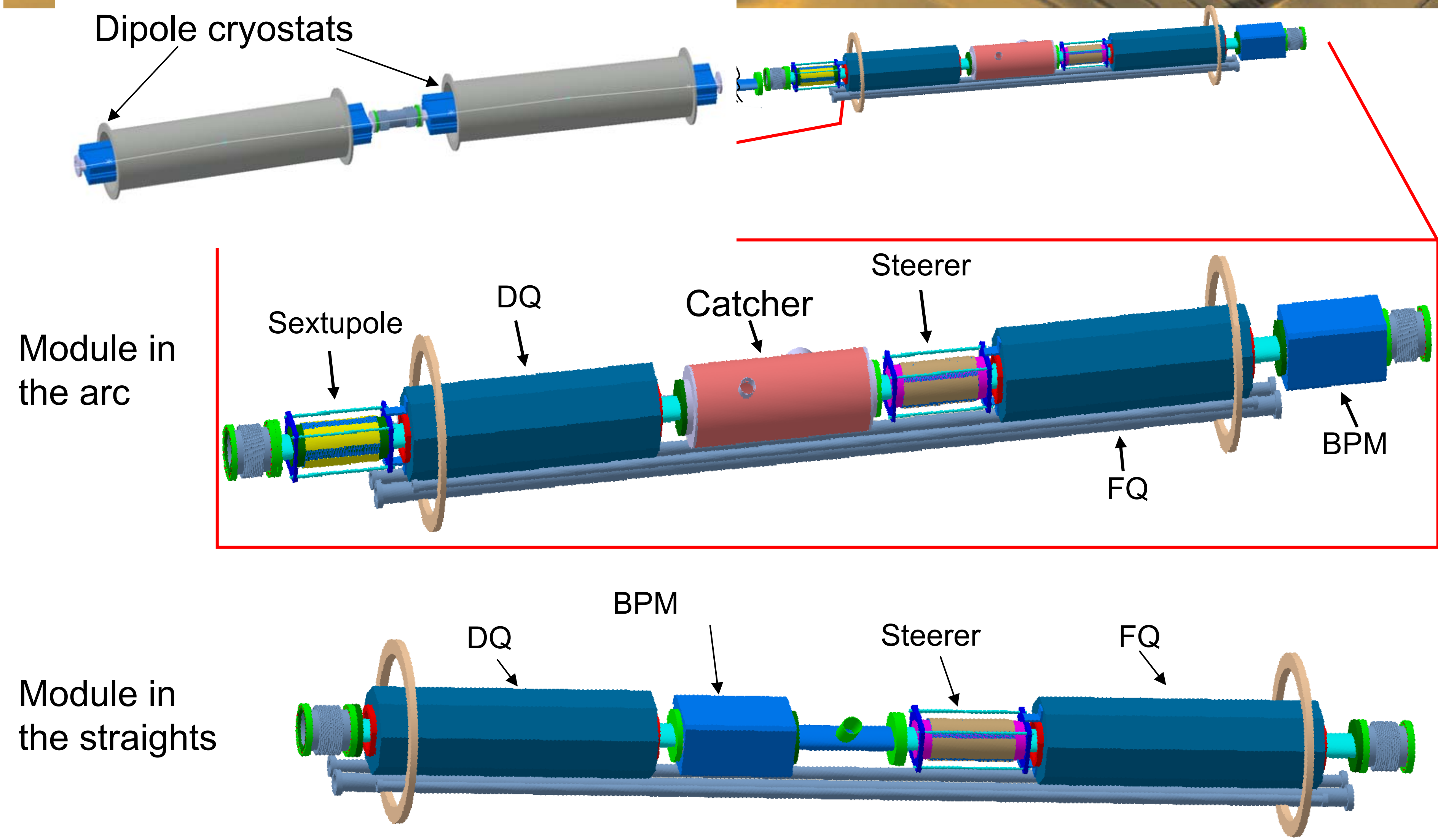


Catching efficiency has been compared for different lattice types as a function of the distance of the catcher from the beam edge (for $U^{28+} > U^{29+}$)

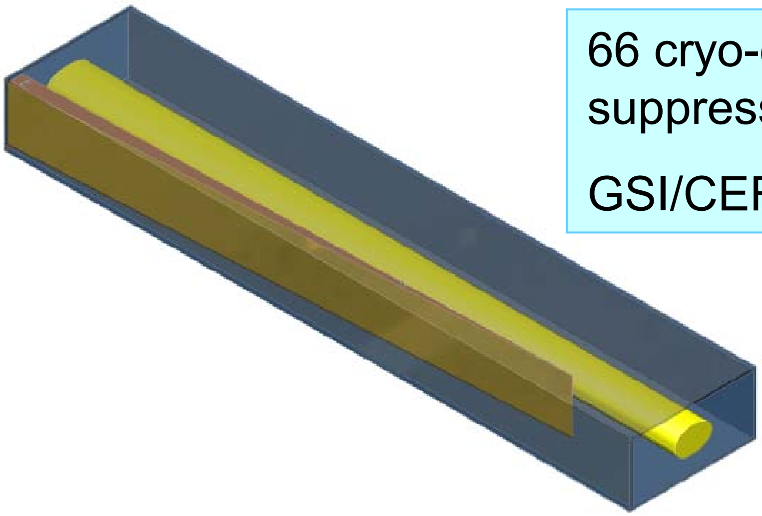
talk by L. Bozyk and H. Kollmus

HELMHOLTZ GEMEINSCHAFT GSI FAIR

Principle Cell Layout



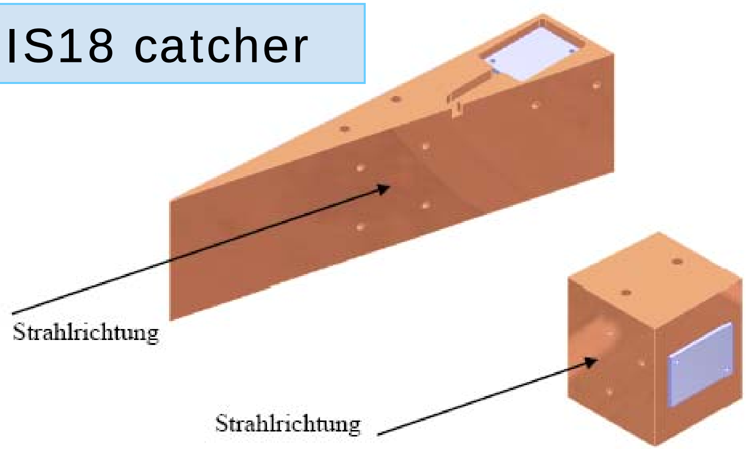
EU FP7- ColMat Cryo-Catcher



66 cryo-catchers foreseen in the SIS100 arcs for the suppression and control of desorption gases

GSI/CERN collaboration - GSI: Work package leader

SIS18 catcher

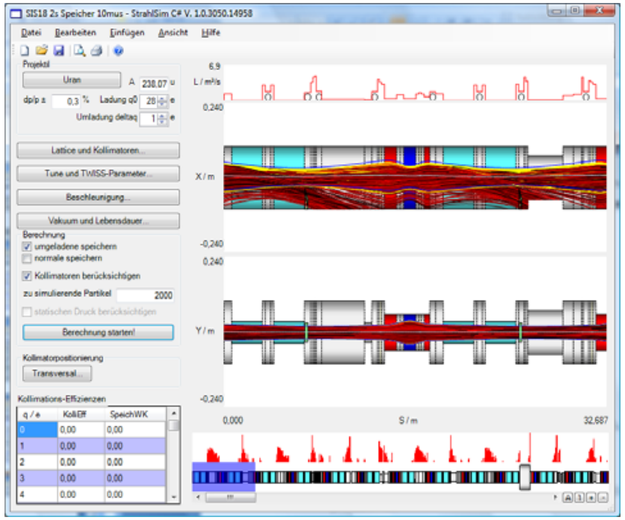


- Different geometries
- Different temperatur levels
- Test with beam at GSI facility
- Effective desorption yield
- Pumping properties for different residual gas components

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)

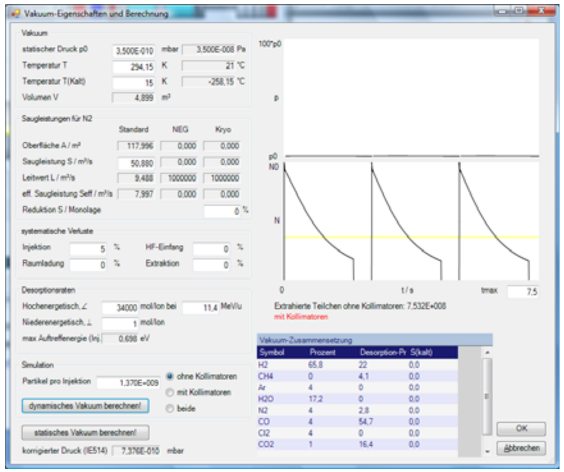


Static Vacuum

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 ionisation $s_{pi}(E, Dq)$ from Shevelko, Olson, work in conjunction with AP
- Coulomb scattering
- Target ionisation
- Intra beam scattering



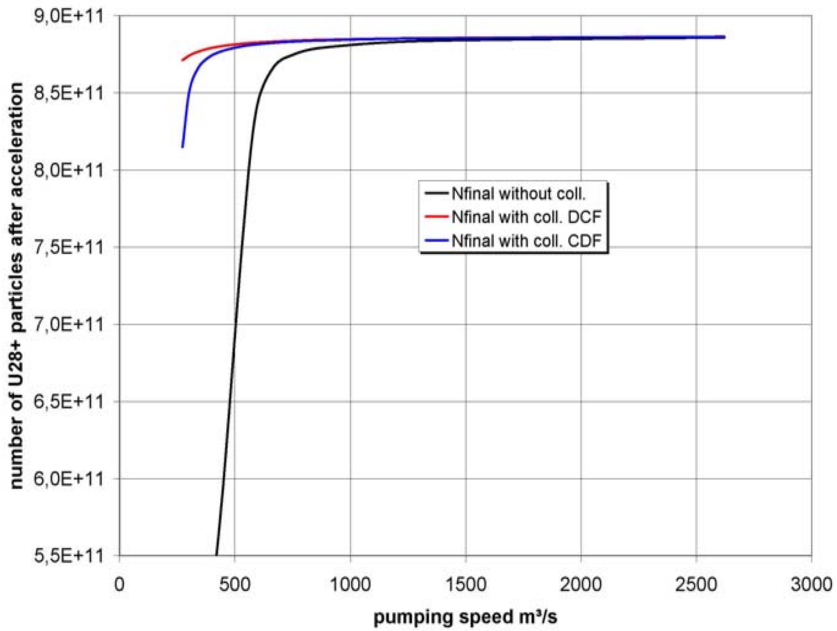
Ion stimulated desorption

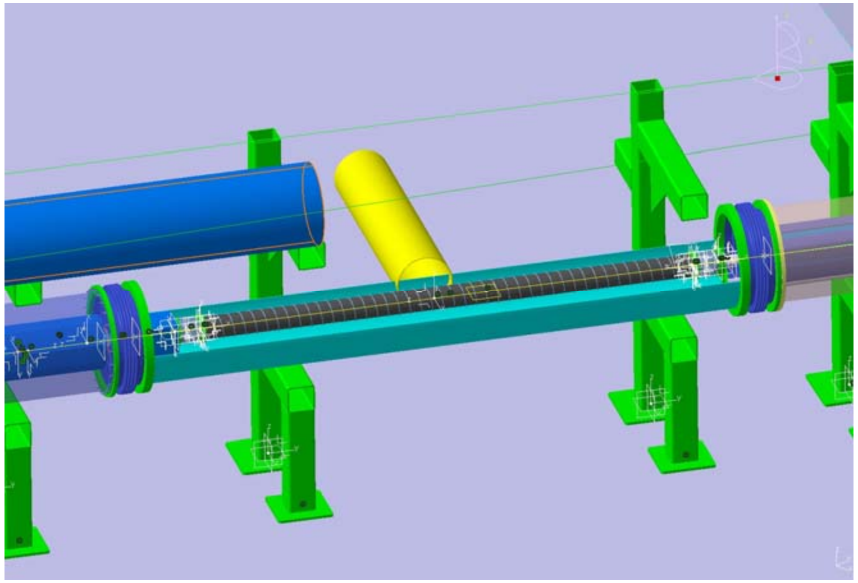
(Desorption rate η scaled with $(dE/dx)^2$, beam scrubbing included) couples beam losses to pressure rises

Benchmarked with many machine experiments (and at other accelerators)

Dynamic Vacuum

- The UHV system is conductance limited
- Cold surfaces (< 10 K) provide an high effective pumping power suitable to stabilize the pressure in the arc
- Active cooling of magnet chambers plus cooling of drift tube chambers
- In a stable situation the pressure peak in the warm straight sections defines the amount of ionization loss

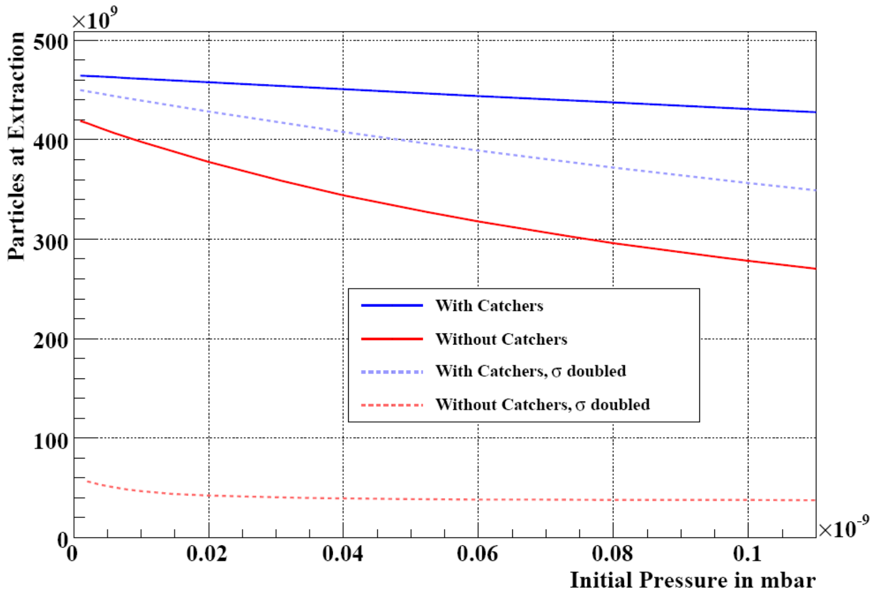




Cooling of missing dipole beam pipe

Ionisation Beam Loss and Dynamic Vacuum

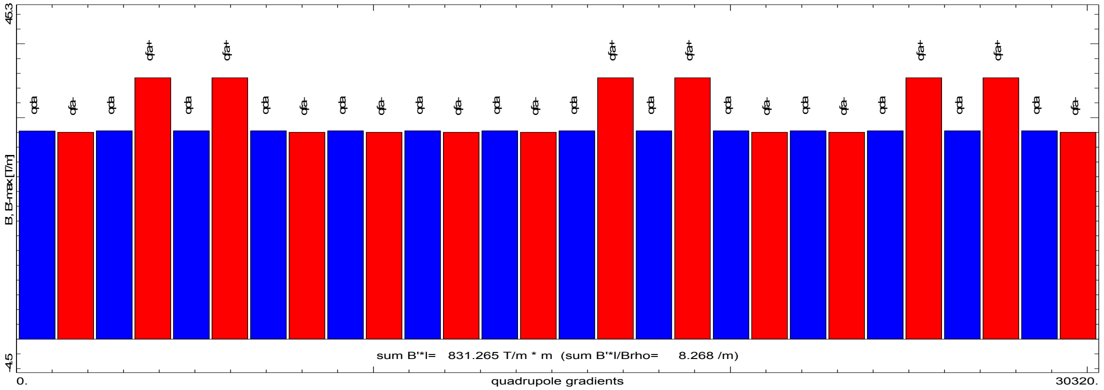
STRAHLSIM Examples:



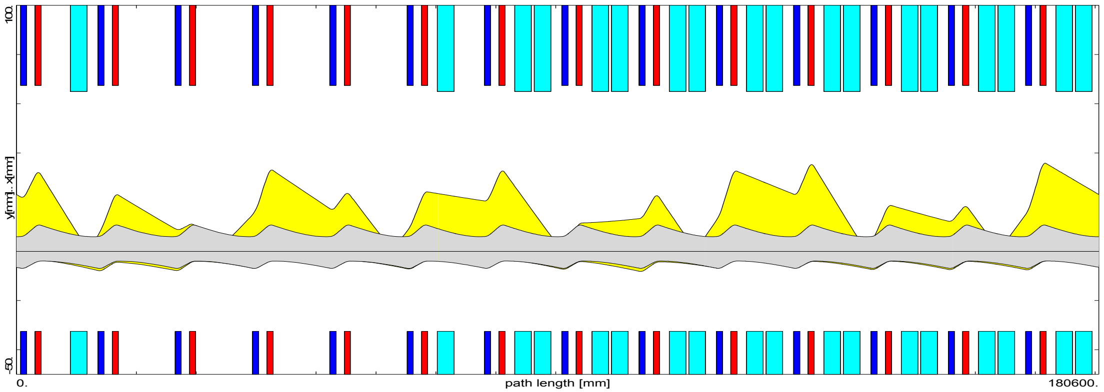
Extracted ions as a function of the the static, inital pressure

with and withou catcher and with twice the ionization cross section

Optical Setting for Proton Operation



Quadrupole setting with three circuits
(two F and one D quadrupole)



Envelops with standard setting (grey)
and shifted transition energy (yellow)

Beam:

γ_{min} = 3,36 (2.2 GeV)

γ_{max} = 32 (29 GeV)

Lattice:

Symmetric: γ_T=17

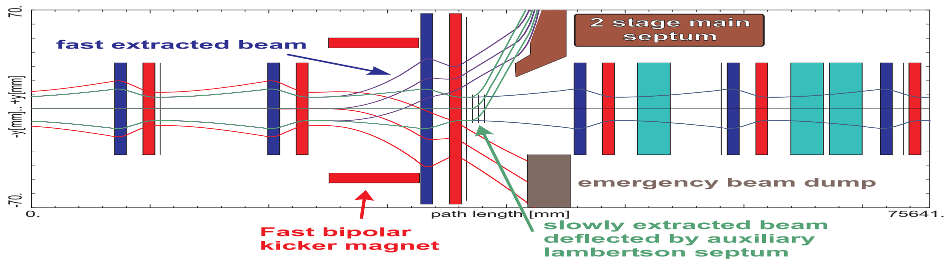
Proton: γ_T = 44

No crossing of transition energy γ_T and danger of beam loss

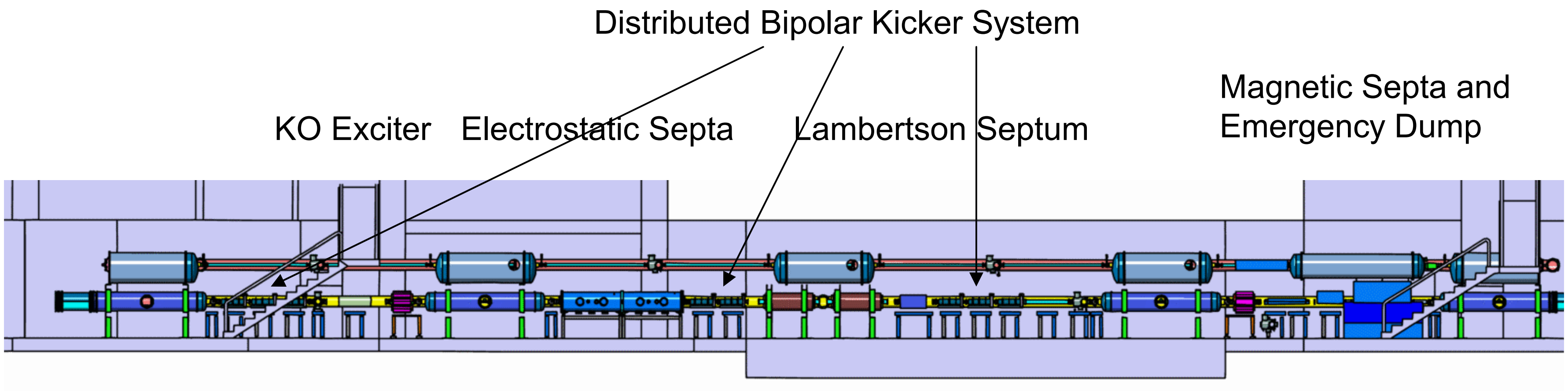
Extraction Systems

SIS100

- Fast extraction towards experiments
- Slow extraction towards experiments
- Fast extraction toward emergency dump
- Fast (vertical) extraction (transfer) towards SIS300



- Cooling test of high power extraction septum in preparation at GSI
- Wire heating of electrostatic septa due to beam load under investigation
- Design study for pulse power generator for bipolar, ramped kicker magnets started
- Prototype for a two stage pseudospark switch under development.

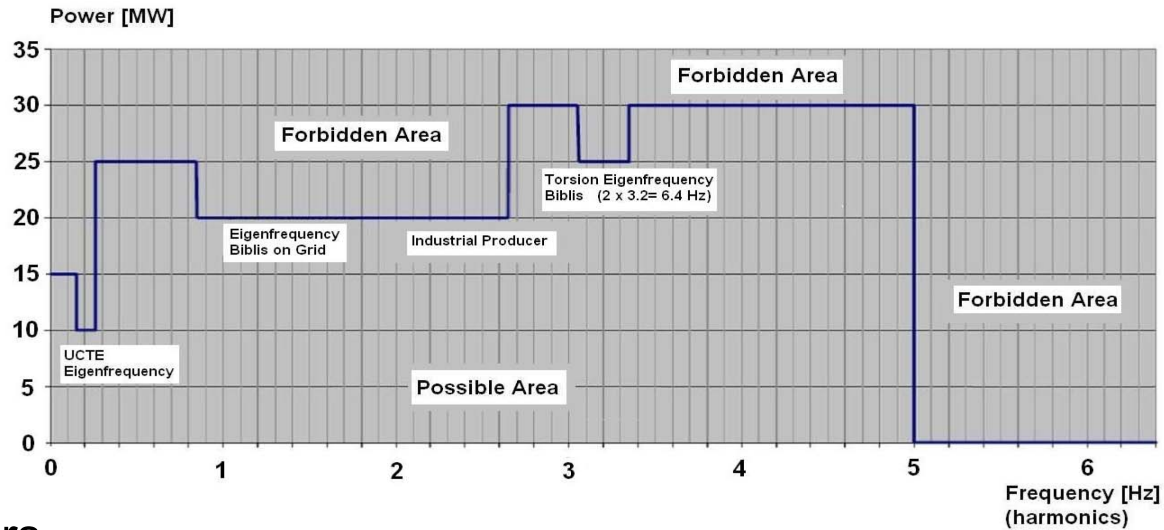


Pulse Power and Power Grid Connection

High average intensity and the intermediate charge state, heavy ion operation require fast ramping with high puls power

	Pulse Power	Field Rate
SIS18	+ 42 MW	10 T/s
SIS100sc	± 26 MW	4 T/s
SIS300	± 23 MW	1 T/s
SIS100nc	75 MW	4 T/s

New 110 kV Power Connection



talk by H. Ramakers

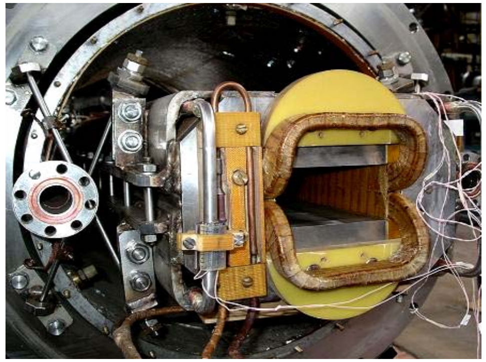
Fast Ramped Superferric Magnets

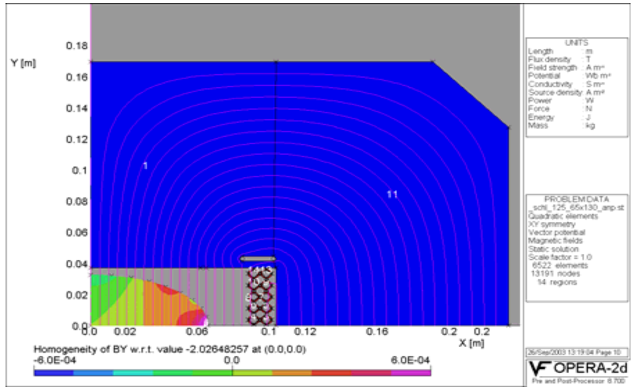
R&D Goals

- **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 at JINR

talk by P. Schnitzer

Full Length SIS100 Prototype Dipoles

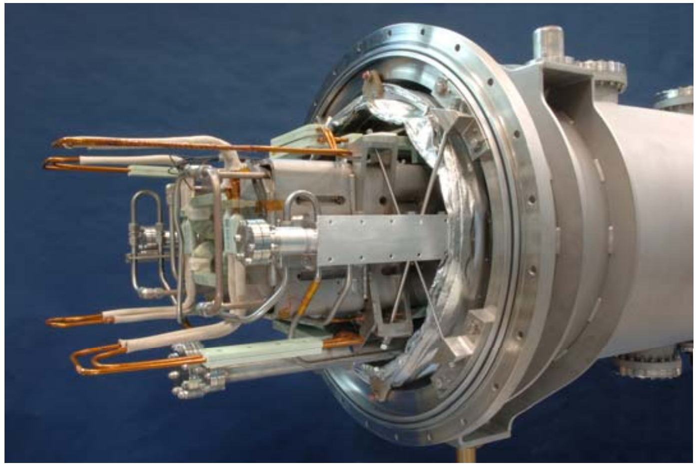


Figure 29 Vacuum chamber of SIS100 curved magnet.

Thin wall (0.3 mm), corrugated, He-cooled UHV chamber

Straight Dipoles

- manufactured by BNG, Würzburg
- manufactured by JINR, Dubna

Curved Dipole

- manufactured by BINP, Novosibirks

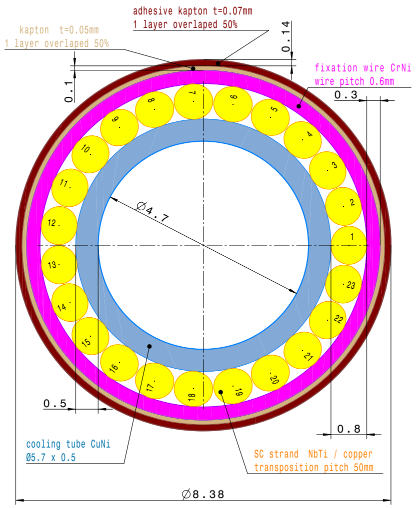
Quadrupole

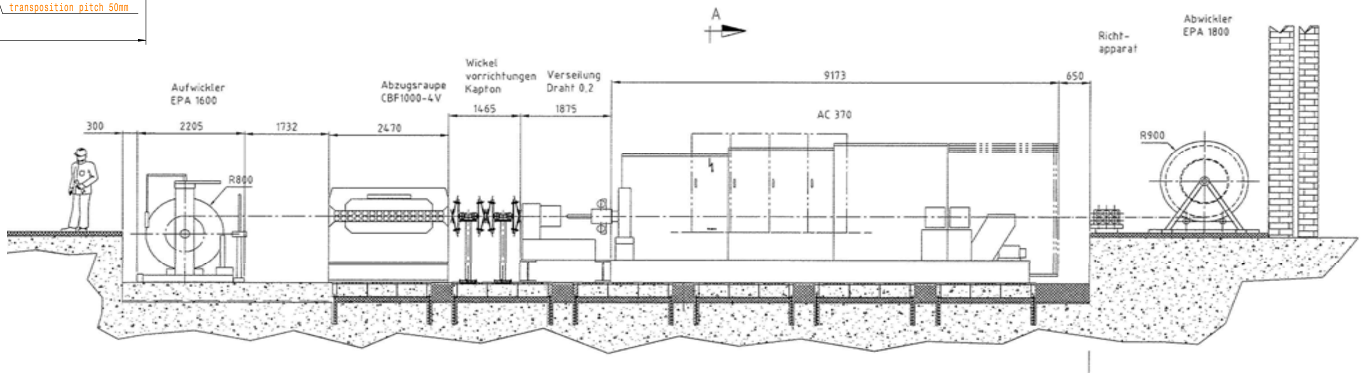
- manufactured by JINR, Dubna

Figure 17 SIS100 curved magnet assembled without vacuum chamber.

Nuklotron Cable Production at BNG

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





Operation Cycles and Magnet Cooling Limits

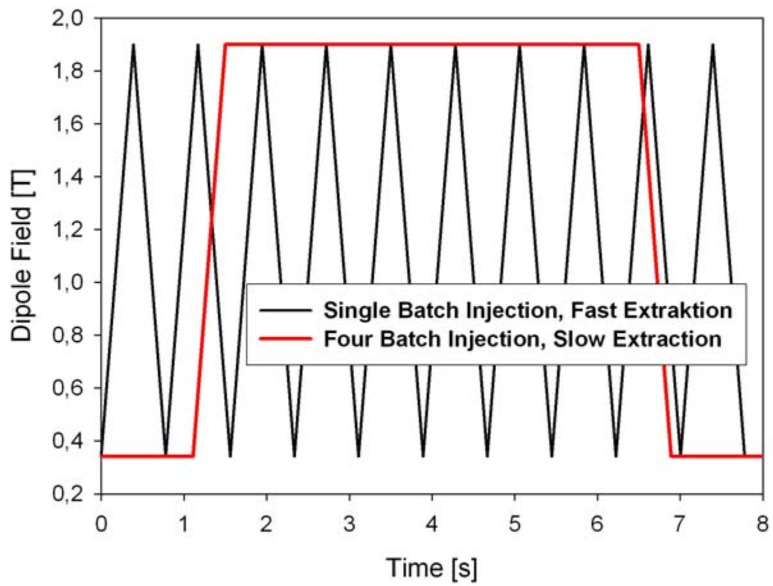
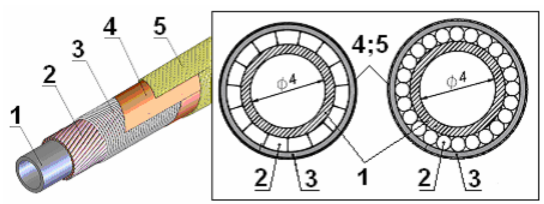


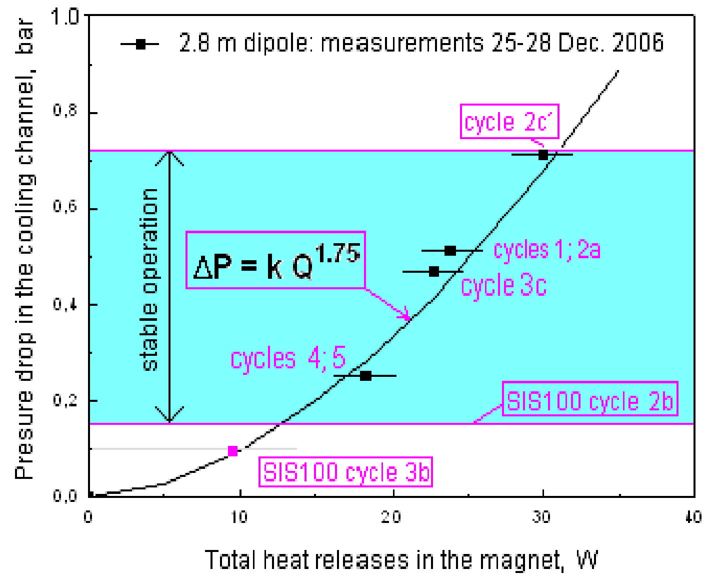
TABLE II OPERATION CYCLES AND EXPECTED LOSSES

cycle	B_{max} (T)	t_f (s)	cycle period (s)	Q_d (J/cycle)	P_d(W)	Q_q (J/cycle)	P_q(W)
1	1.2	0.1	1.4	35.2	25.2	13.1	9.4
2a	1.2	0.1	1.4	35.2	25.2	13.1	9.4
2b	0.5	0.1	1.0	8.8	8.8	3.3	3.3
2c	2.0	0.1	1.82	89	48.9	24.4	18.9
3a	1.2	1.3	2.6	35.2	13.5	13.1	5.0
3b	0.5	1.0	1.9	8.8	4.6	3.3	1.8
3c	2.0	1.7	3.4	89	26.2	34.4	10.1
4	2.0	0.1	5.0	89	17.8	34.4	6.9
5	2.0	0.1	5.0	89	17.8	34.4	6.9

- Singel layer coil with low hydraulic resistance
- High current cable
- Active heaters to stabilize the crogenic load

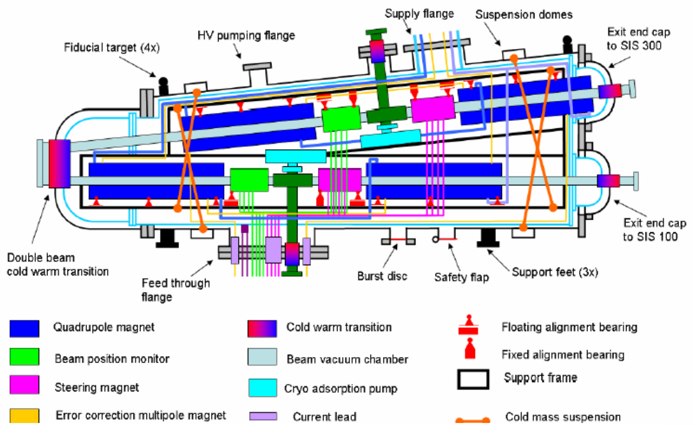


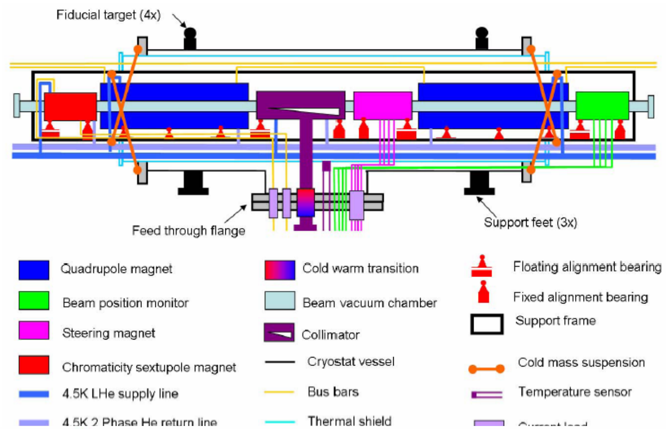
Alternative coil design and high current cable

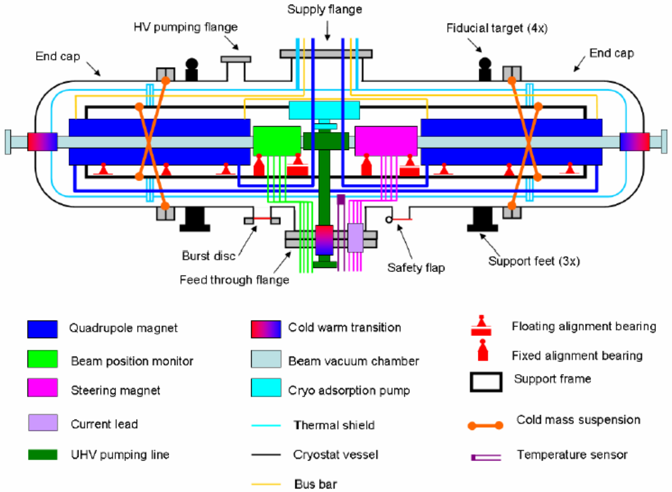


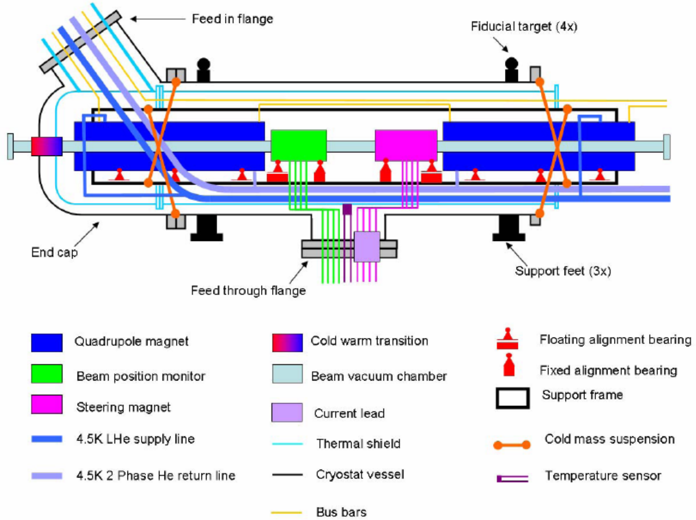
Cryomagnetic Quadrupole Units

Two standard cells but a large number of different quadrupole modules



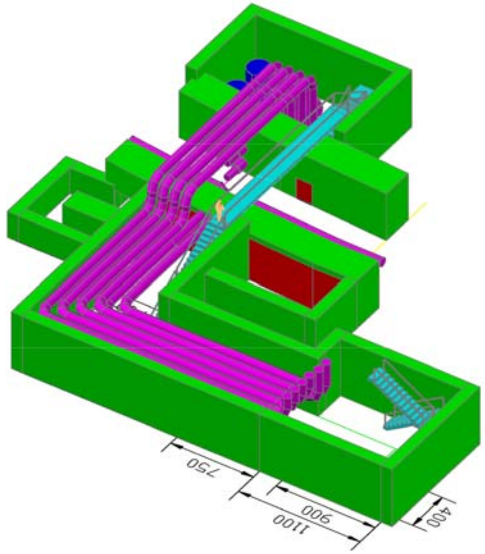






Local Cryogenics

- Feed Boxes
- Feed-in Cryostat
- Current Lead Boxes
- Cold Links
- Cryogenic Bypass Lines
- End Caps
- Measurement Technique
- Special Cryostats ?

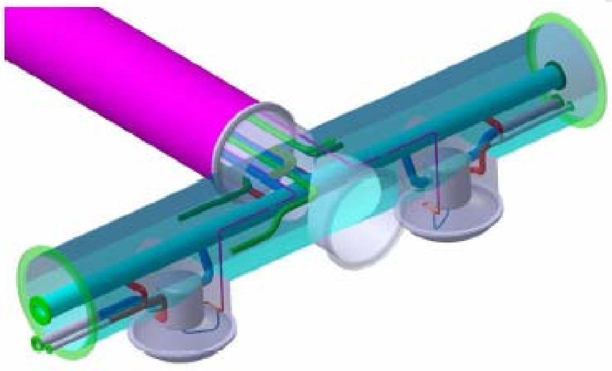


Supply concept:

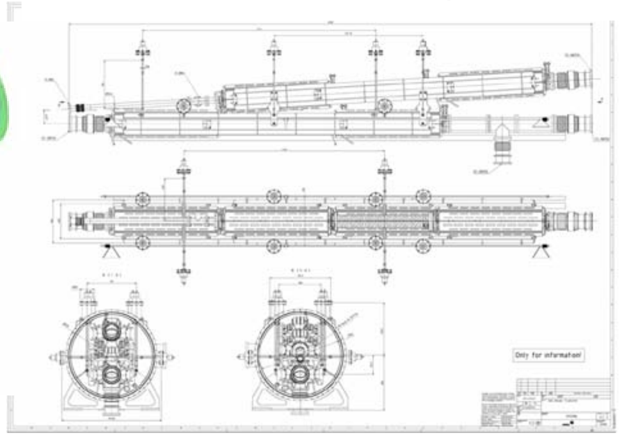
Cold links between on- and underground building

Feed-box underground

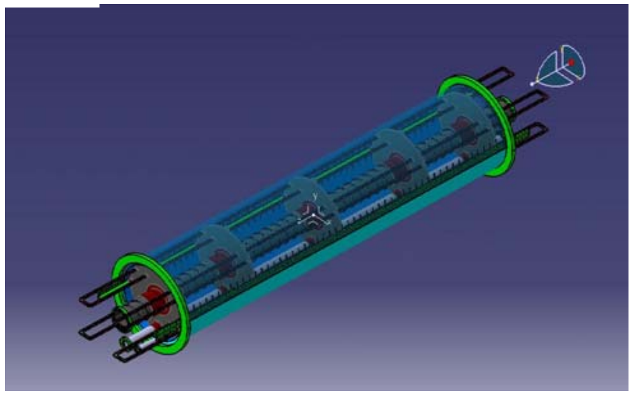
Current lead-box on ground



Study feed-in cryostat



Study on injection/ extraction quadrupole modules

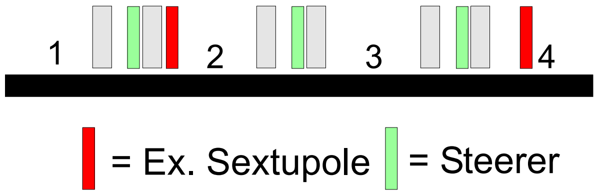


Study on missing cooling cryostat in missing dipole gap

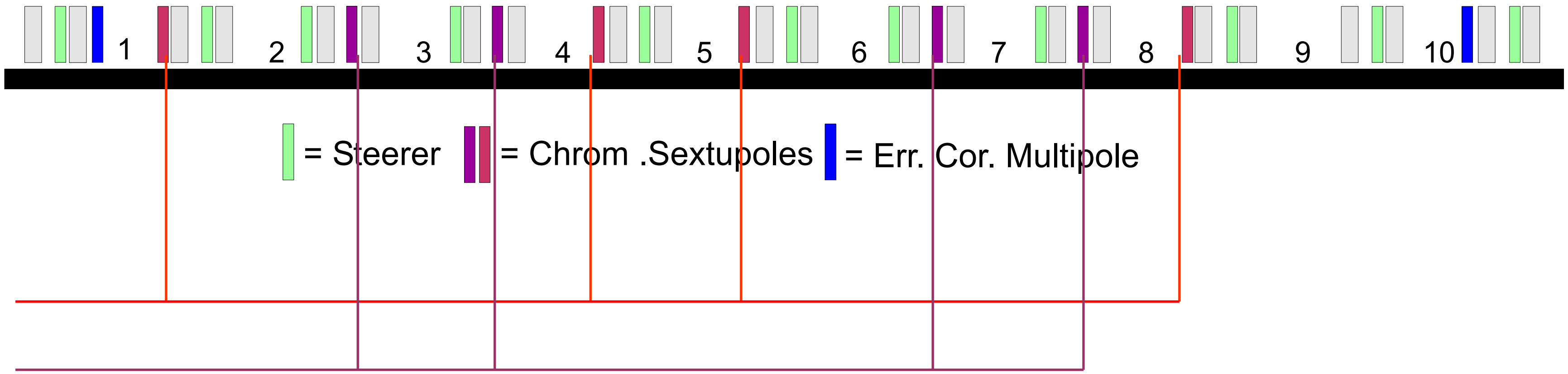
Correction System

Individual supply:
Steerers (green)
Correction Multipoles (blue)
Resonance Sextupoles (bright red)

SIS 100 Straight



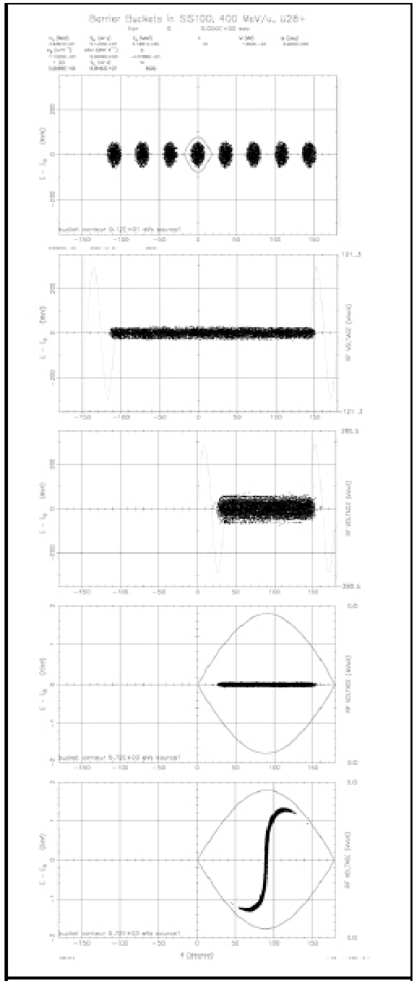
SIS 100 Arc

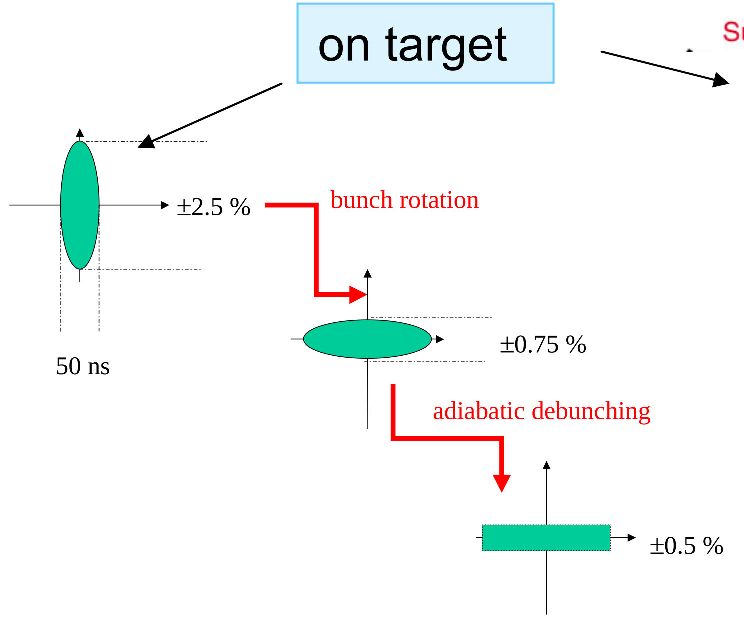


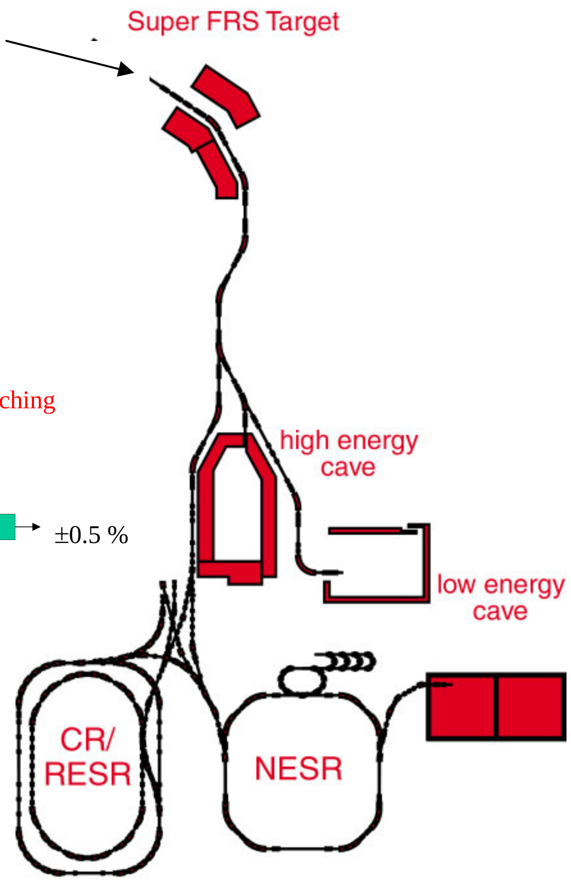
Chromaticity Sextupoles (red / pink):
2 x 4 sextupoles per arc in series connection
2 arcs in series connection

Rf Cycle for Heavy Ions

Short compressed pulses for optimum target matching and fast cooling in CR







talk by O. Boine-Frankenheim

Incoherent tune spread up to dQ $\approx$-1

Rf Cycle for Protons

	Bunch pattern	Harmonic numbers	Duration (approx.)
Injection from SIS-18	4 bunches / 6 empty	10	1.1 s
Merging	2 bunches / 3 empty	$10 \rightarrow 5$	0.1 s
Batch compression	2 bunches / 8 empty	$5 \rightarrow 6 \rightarrow 7 \rightarrow 8 \rightarrow 9 \rightarrow 10$	0.3 s
Merging	1 bunch / 4 empty	$10 \rightarrow 5$	0.1 s
Acceleration	1 bunch / 4 empty	5	0.4 s

Synchrotron frequency for Rf manipulations at high gamma to low > Rf manipulations for single bunch generation takes to long

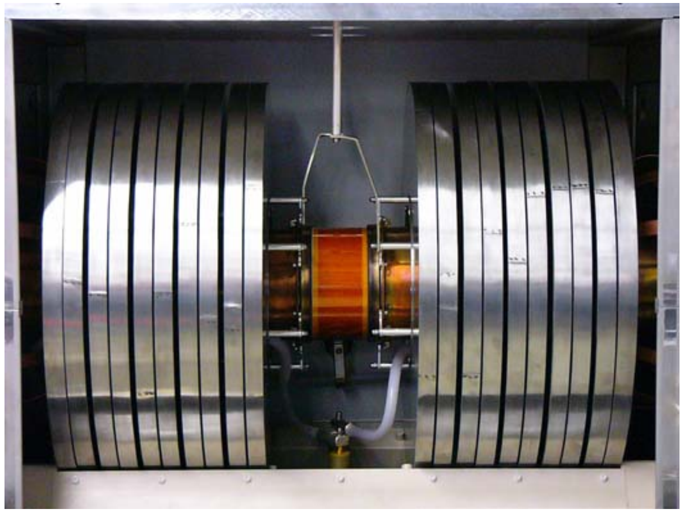
Standard scheme for single bunch generation and compression not applicable

RF Systems Overview

	FBTR	f [MHz]	#	Technical Concept
Acceleration System	h=10 400 kV	1.1–2.7	20 (SIS100) 8 (SIS300)	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	15 kV	2	2	Magnetic alloy ring core, broad band (low duty cycle) cavities

talk by H. Klingbeil

SIS18 ferrit loaded accel. cavity

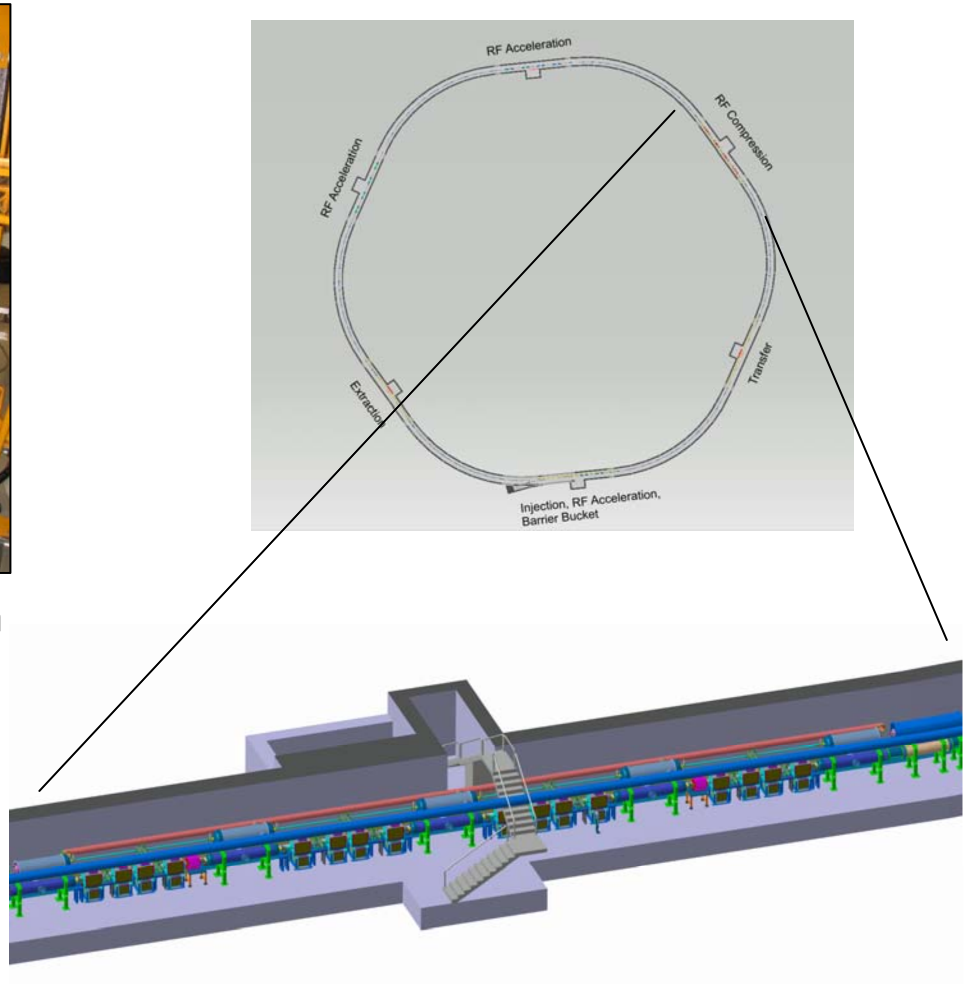


SIS18 MA loaded bunch compression cavity

RF Bunch Compression Section

Short pulse (500 μs), high power bunch compressor developed at GSI

World wide MA core material survey

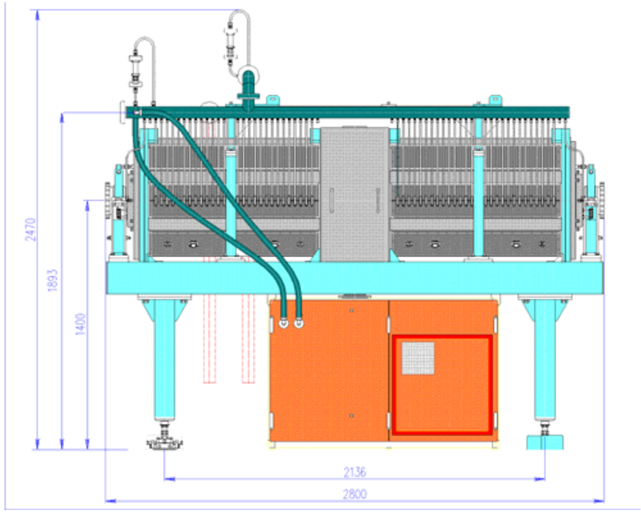


16 MA compression cavities in section S2

RF Acceleration Sections

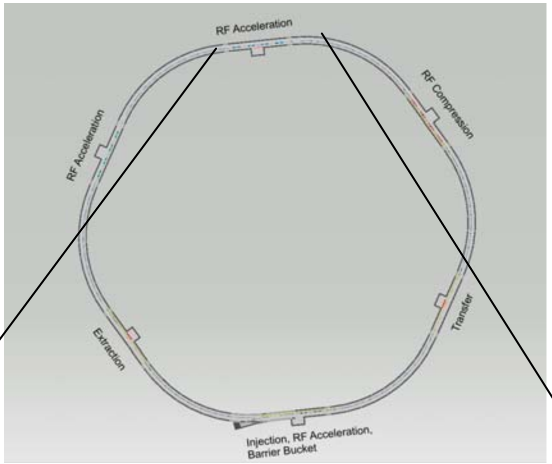
Acceleration Cavities:

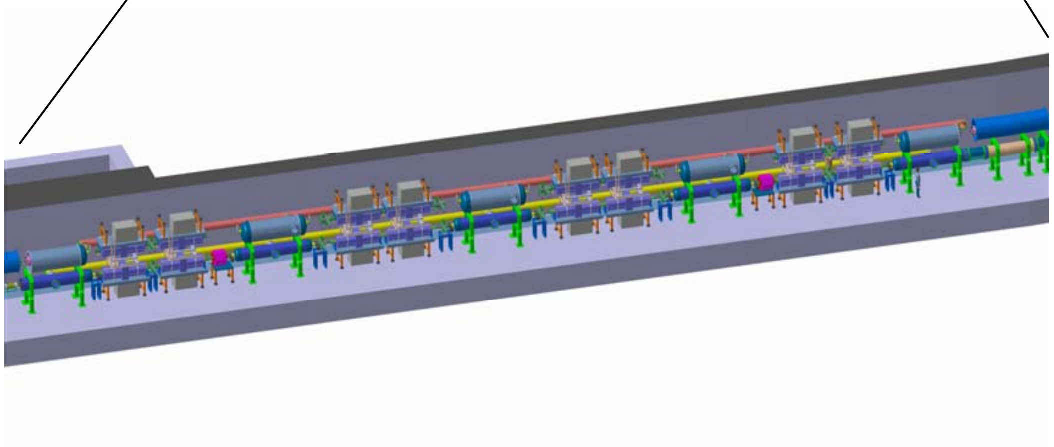
- Design study completed (BINP)



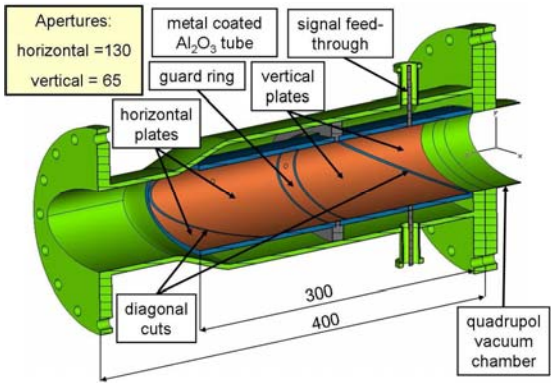
Minimization of shunt impedance:

Fast semi-conductor gap switch R&D

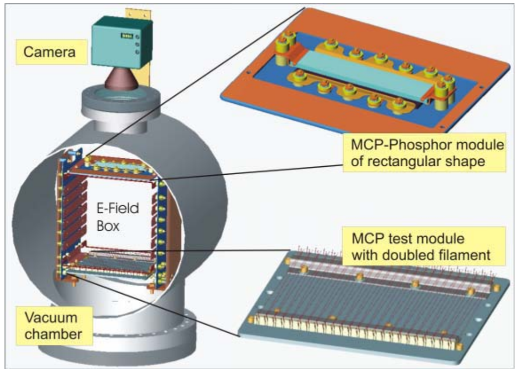




Beam Instrumentation



BPM FEM studies on cross talk and resonances



Ionization Beam Profile Monitor similar to the present SIS18/ESR development

Device Measurement Application

DCCT dc-current stored current, lifetime

GMR-DCCT dc-current for high currents

CCC dc-current for low currents

ACCT Pulsed current injection efficiency

BPM center-of-mass closed orbit & feedback turn-by-turn lattice functions

Exciter+BPM center-of-mass tune, BFT, PLL

Quad. BPM quad. moment BTF, matching

Schottky longitudinal: $\Delta p/p$, cooling transverse: tune, chromaticity

WCM or FCT bunch structure matching, bunch gymnastics

IPM beam profile cooling, matching

BLM beam loss matching, halo, scraper, losses

Grid/Screen beam profile first turn

Wide dynamic range of beam parameters to be measured

talk by M. Schickert

Expression of Interests for SIS100 Components

Component	Expression of interest	
SIS100 2.8		
Dipoles 2.8.2.1	9 JINR (~50 %) 12 VNIINM (wires) / 13 GSI	
Quadrupoles 2.8.2.2	9 JINR (~50%)	
Sextupoles 2.8.2.3	9 JINR (~50%)	
other 2.8.2.4/5/6	9 JINR (~50%)	
Power Supplies 2.8.3	13 GSI (Interfaces)	4 Finland
RF Systems 2.8.4	13 GSI, partly	
Injection/Ejection 2.8.5	9 JINR (~50 %)	
Beam Diagnostics 2.8.6	9 JINR (~50 %); with 8 ITEP (partly) / 13 GSI (partly)	
Vacuum 2.8.7	9 JINR (~50 %) /18 ICSI (pumps) 7 CUT / 13 GSI V,G,Boc,NEGch	
Collimators 2.8.11	9 JINR (~50 %)	
Cryogenics 2.8.12	15 Wroclaw Univ Technol.	

Two EOI meetings on SIS100 inkind contributions in 2008

Summary

- The SIS100 system design has been optimized for the acceleration of intermediate charge state heavy ions, with sufficient flexibility for proton acceleration.
- Major progress has been achieved in the understand and simulation of dynamic vacuum, gas desorption and connected beam loss by charge changing processes.
- The R&D status of the technical subsystems allows starting the final engineering design for all components. There are models, prototypes or running systems which prove the technical feasibility of each SIS100 component.