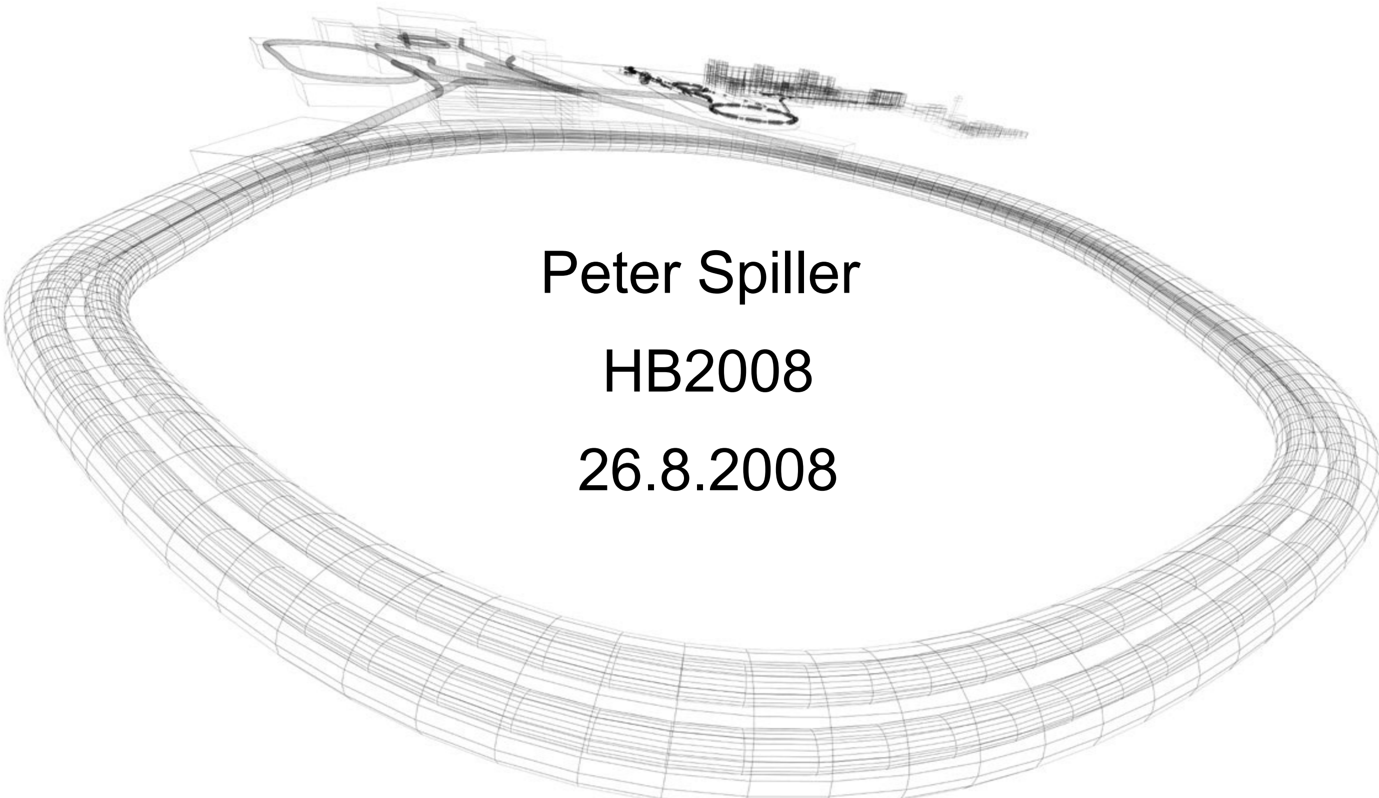
The Superconducting SIS100 Synchrotron for High Intensity Proton and Heavy Ion Beams



Peter Spiller

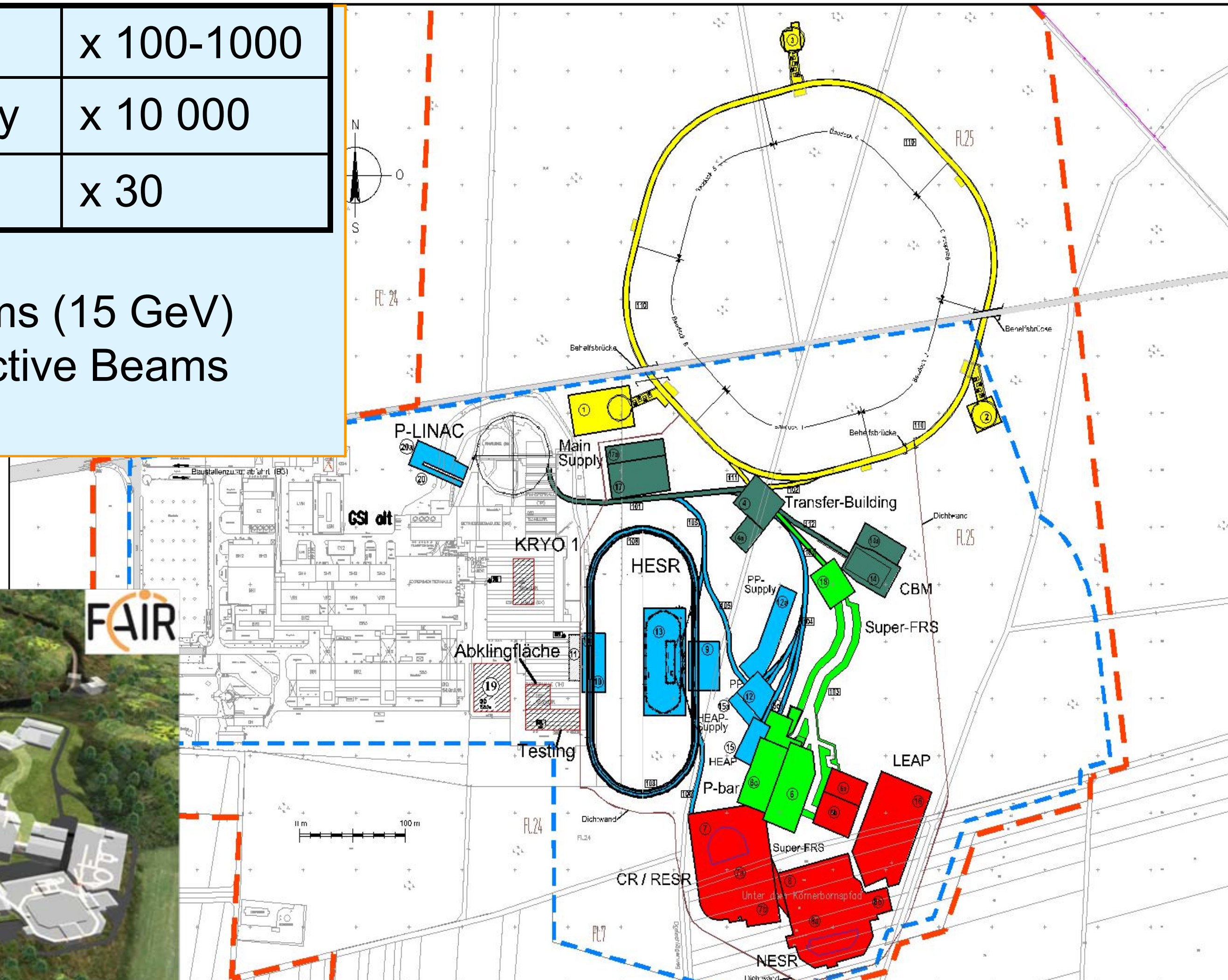
HB2008

26.8.2008

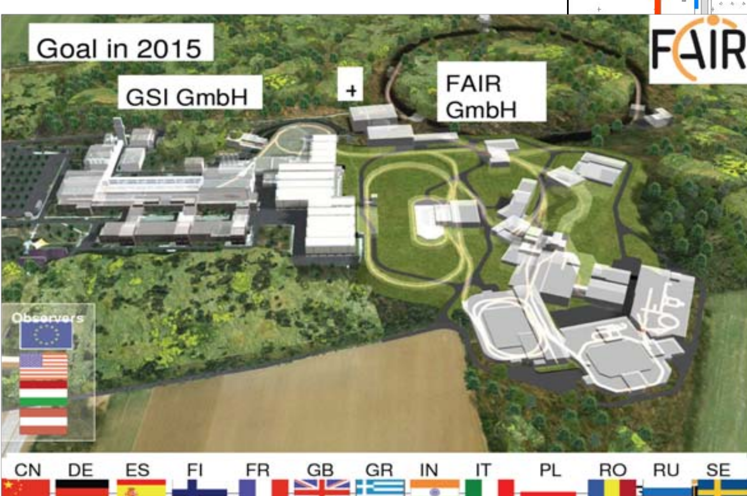
GSI/FAIR Accelerator Facility

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

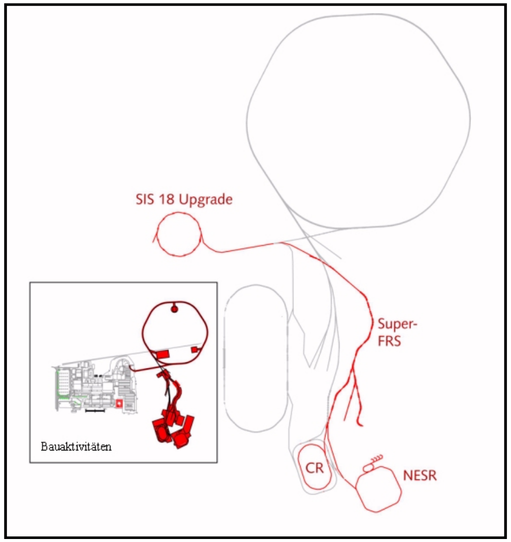
- New: Cooled pbar Beams (15 GeV)
- Intense Cooled Radioactive Beams
- Parallel Operation



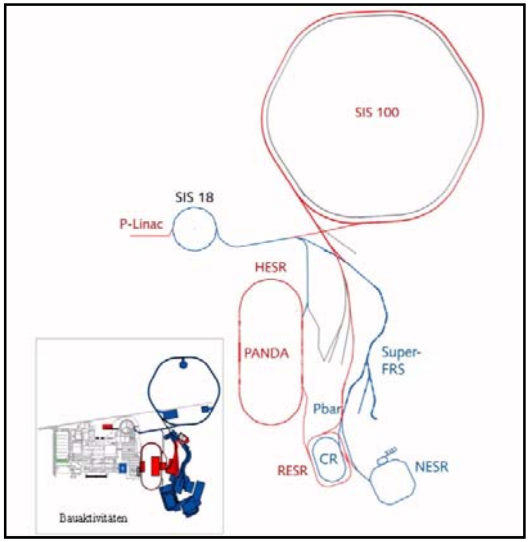
Two-Company Model



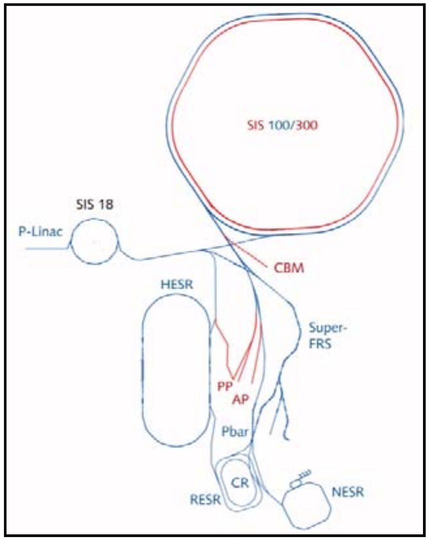
FAIR Uranium Intensity (staged realization)



Stage 1



Stage 2



Stage 3

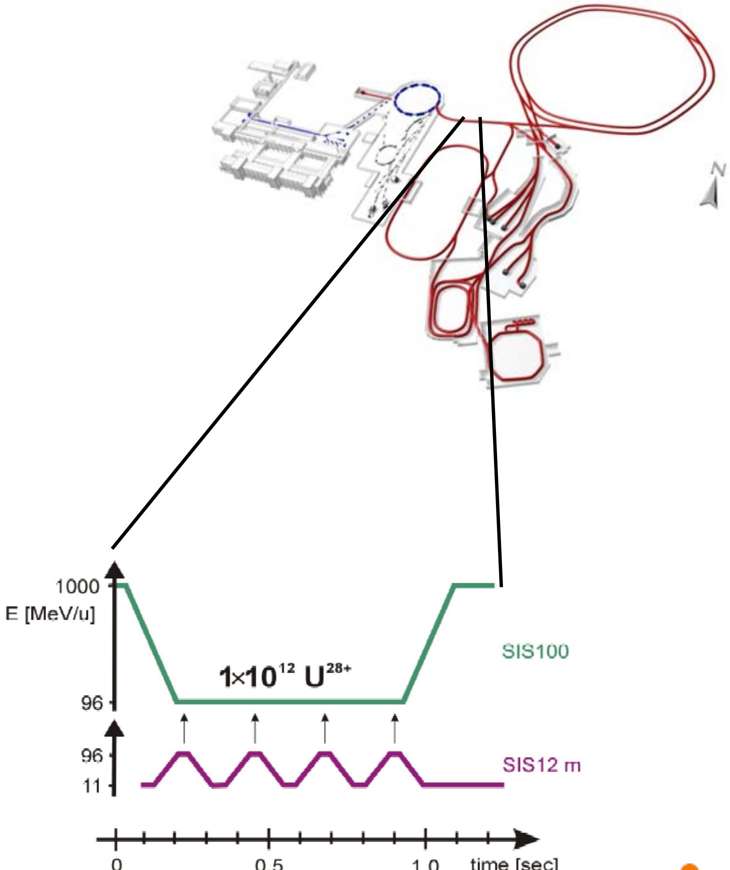
Uranium Beam Intensities		
SIS18	SIS100 (Start Version)	SIS100/300
2×10^{10} /cycle	5×10^{11} /cycle	5×10^{11} /cycle
Slow Extraction at 1 GeV/u and 1.4 s Spill		
1.1×10^{10} /s	1.5×10^{11} /s	3.5×10^{11} /s
Fast Extraction at 1 GeV/u		
5.4×10^{10} /s	3.5×10^{11} /s	not foreseen

Beam Parameters SIS18/SIS100

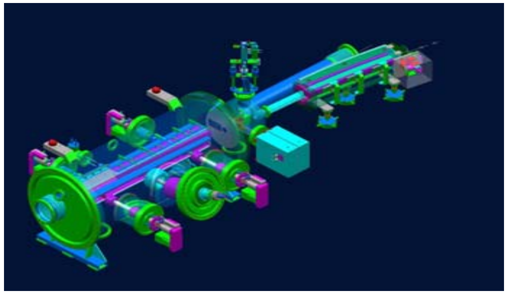
SIS18	Protons	Uranium
Number of ions per cycle	5 x 10^{12}	1.5 x 10^{11}
Initial beam energy	70 MeV	11 MeV/u
Ramp rate	10 T/s	10 T/s
Final beam energy	4.5 GeV	200 MeV/u
Repetition frequency	2.7 Hz	2.7 Hz

SIS100	Protons	Uranium
Number of injections	4	4
Number of ions per cycle	2.5 x 10^{13} ppp	5 x 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	0.7 Hz	0.7 Hz

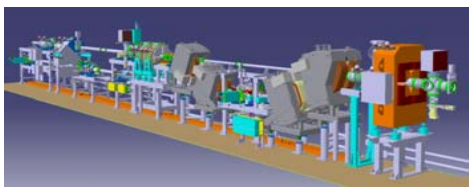
All other ion species will be accelerated as well !



SIS18upgrade Program

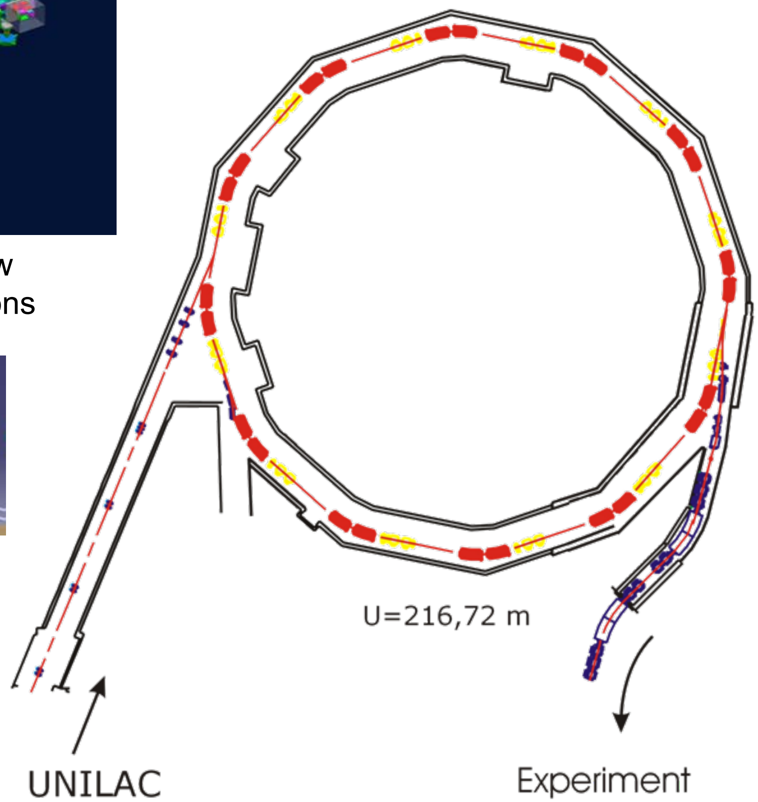


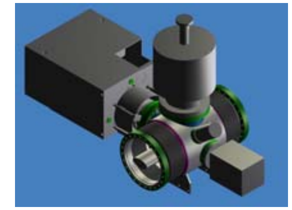
Injection system for low charged state heavy ions



Charge separator for higher intensity and high quality beams

Power grid connection





Scrapers and NEG coating for pressure stabilization

h=2 acceleration cavity for faster ramping

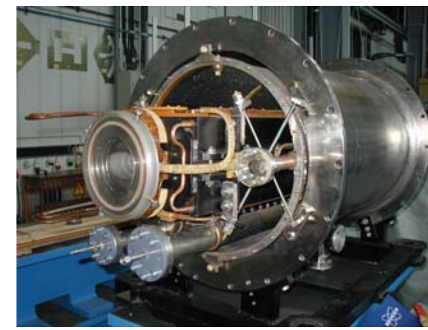
The SIS18upgrade program: To reach the space charge limit for the heaviest ions.

Two-Stage Synchrotron SIS100/300

SIS100 is part of an optimized two-stage concept

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

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

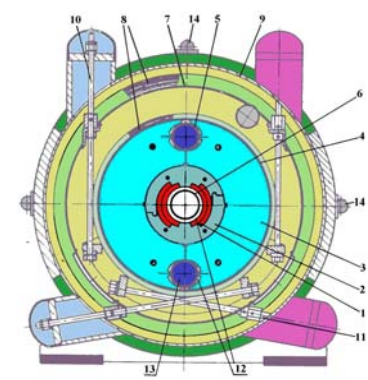


Intermediate charge state ions e.g. U^{28+}-ions up to 2.7 GeV/u
Protons up to 30 GeV

$B\rho$= 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.



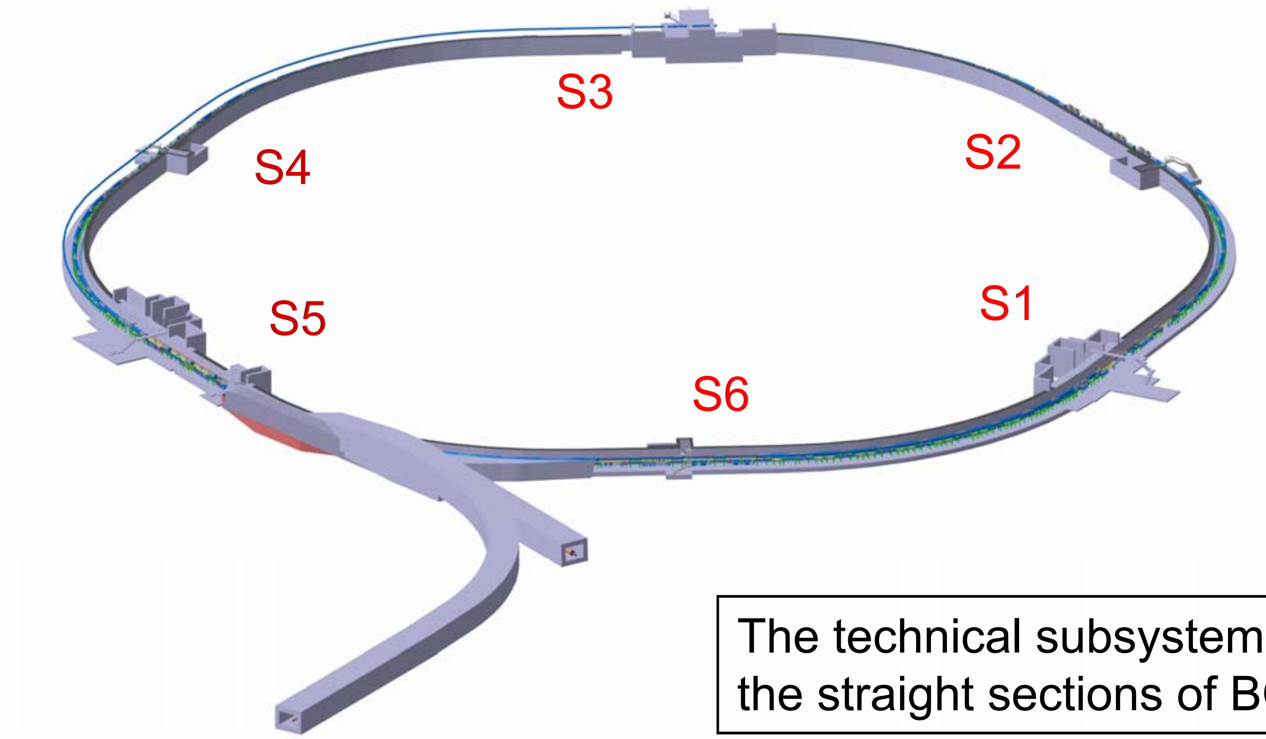
Highly charges ions e.g. U^{92+}-ions up to 34 GeV/u
Intermediate charge state ions U^{28+}- ions at 1.5 to 2.7 GeV/u with 100% duty cycle

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

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)

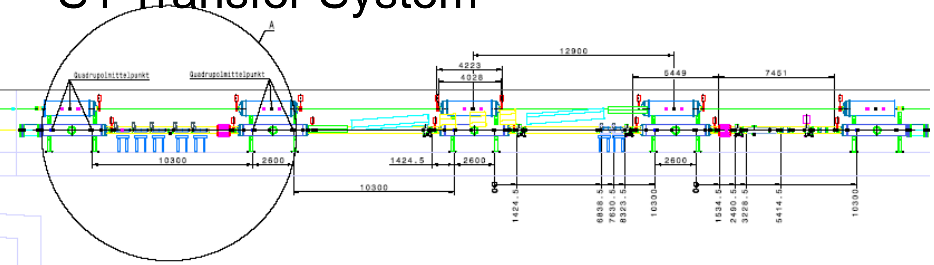
S5: Extraction Systems (slow and fast)

S6: Injection System plus RF Acceleration and Barrier Bucket

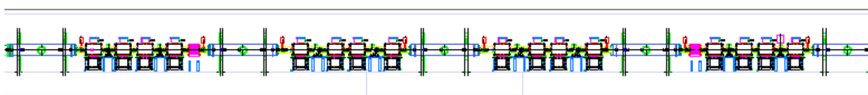
The technical subsystems define the length of the straight sections of BOTH synchrotrons

SIS100 Straight Sections

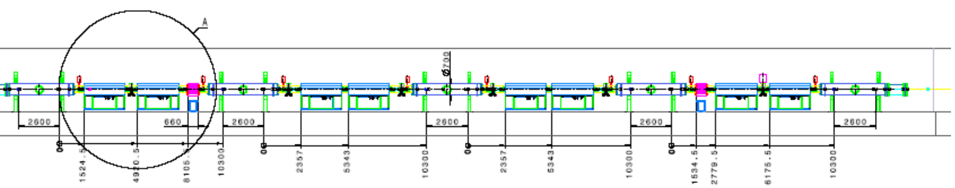
S1 Transfer System



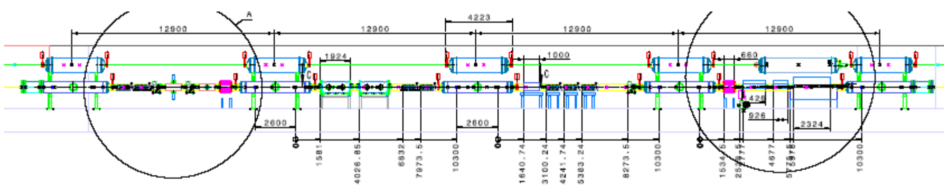
S4 Compression Systems



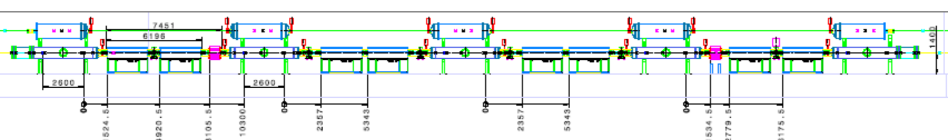
S2 Acceleration Systems



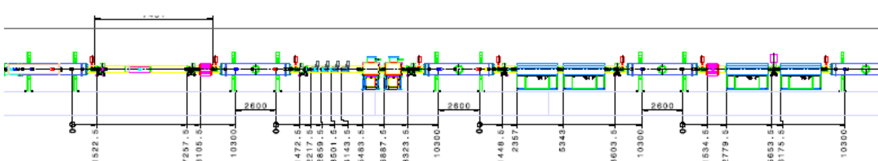
S5 Extraction Systems



S3 Acceleration Systems



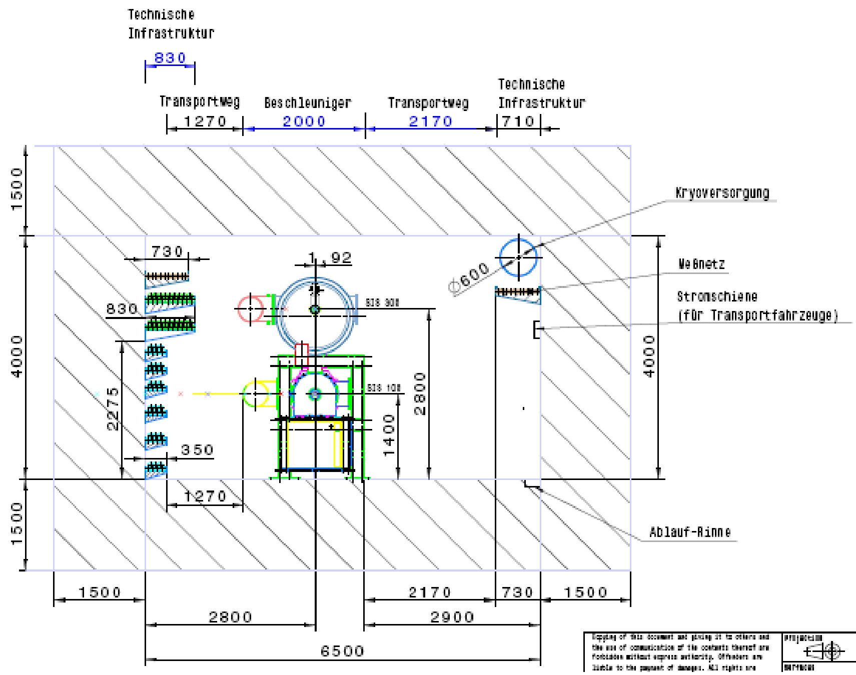
S6 Injection System



Distribution of all devices completed. The machine layout as described in the Technical Design Report is final: SIS100 will be built according to the present layout.

System Layout and Ion Optical Design

Design of two-stage SIS100 and SIS300 concept in one tunnel was challenging:

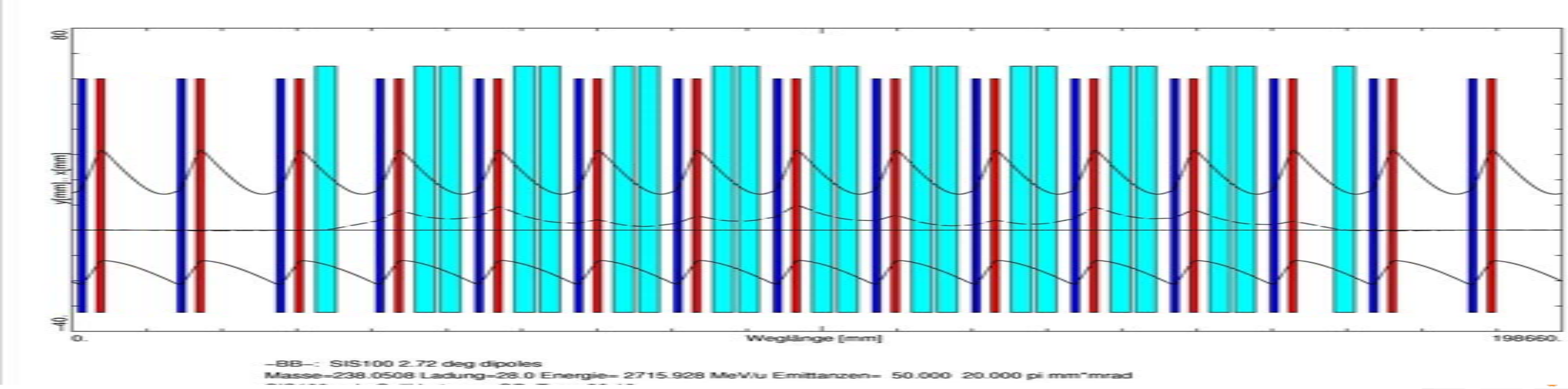


- Geometrical matching of both synchrotrons with different lattice structures (Doublet and FODO) and different magnet technologies (superferric and cosθ)
- Ratio between straight section length and arc length with fixed circumference defined by the warm straight section requirements of SIS100
- Fast, 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

SIS100 Lattice Characteristics

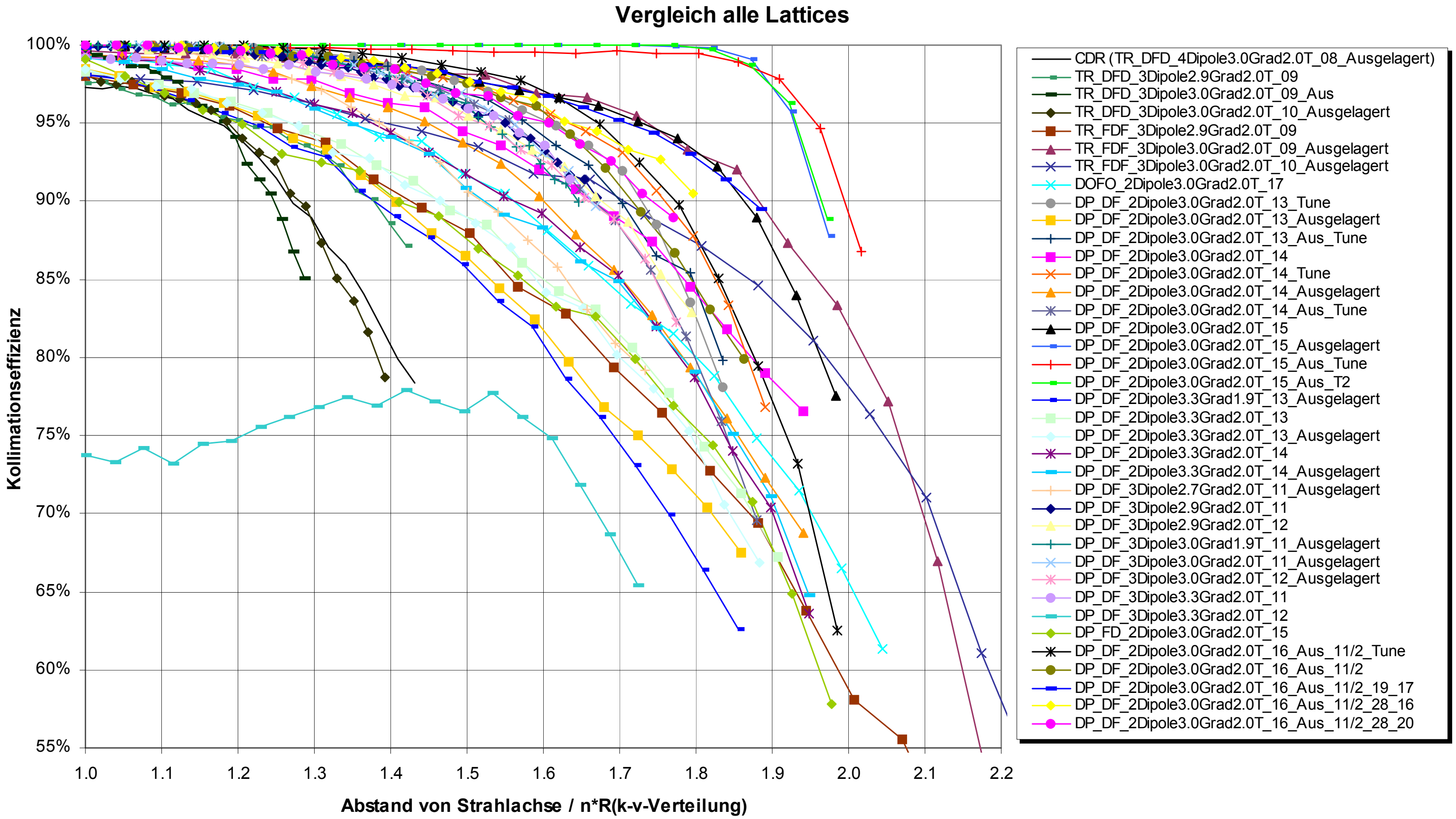
Flexible, multi-purpose lattice: Doublet (no FODO) lattice

- Maximum transverse acceptance (minimum 3x emittance at injection) for large beam sizes at limited magnet apertures (problems: pulse power, magnet 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



Lattice for Low Charge State Heavy Ions

Comparison of collimation efficiency for ionization beam loss for different types of lattices



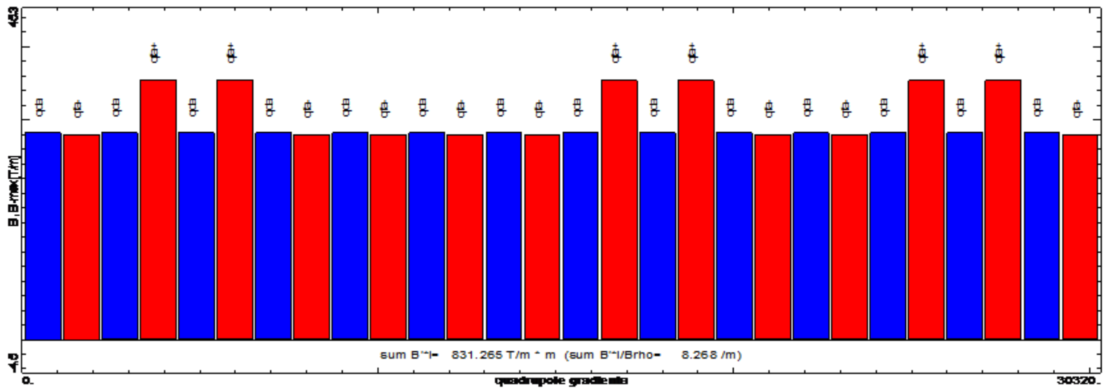
SIS100 Doublet Lattice = Charge Separator Lattice

Operation Modes

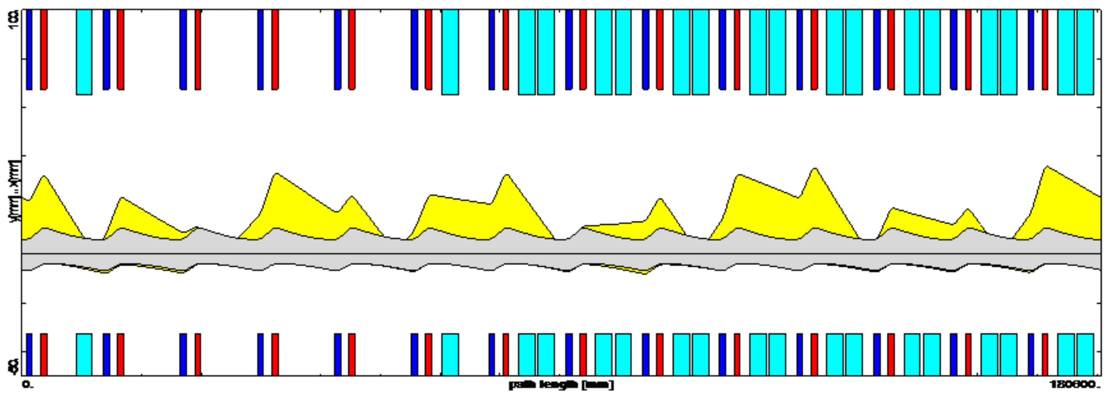
Three Reference Working Points for Three Reference Modes

Tunes (h/v)		WP2 17.30 / 17.42	WP1 18.84 / 18.73	WP3 20.84 / 20.73
Mode of SIS100 operation		Ions, slow extraction	Ions, fast extraction	Protons, high energy
Amplitude function beta maximum	(h/v) m	19.8 / 19.6	19.6 / 19.6	20.4 / 19.9
Dispersion function alpha-p maximum alpha-p minimum	m m	1.44 -1.11	1.73 -0.12	1.30 -0.33
Phase advance per lattice cell	deg	74 / 75	81 / 80	89 / 89
Transition energy		14.29	15.58	17.48
Natural chromaticity ξ_{nat} /Q	(h/v)	-1.16 / -1.16	-1.19 / -1.2	-1.25 / -1.26
Transverse acceptance	(h/v) mm·mrad	201 / 54	206 / 54	203 / 53

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)

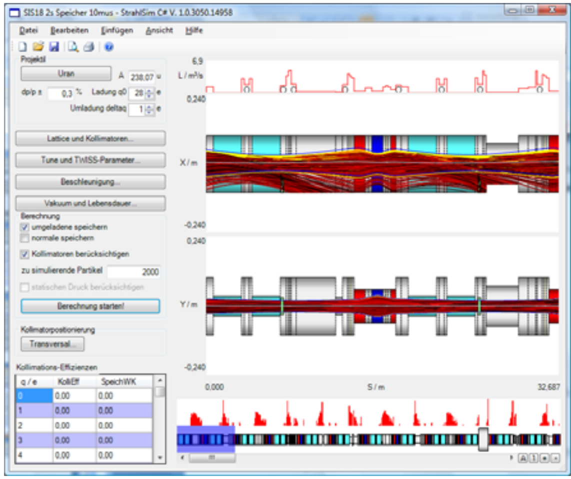
Lattice:

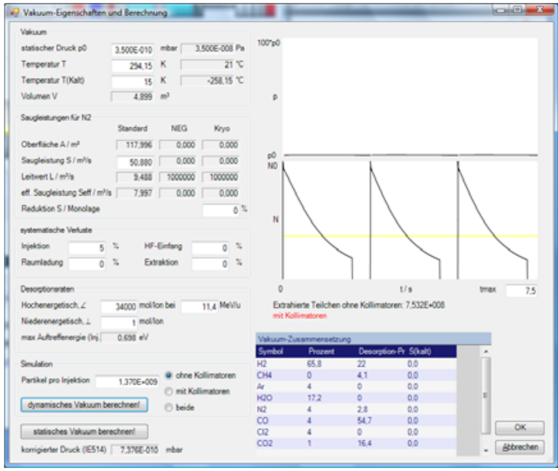
Symmetric: γ_T=17

Proton: γ_T = 44

No crossing of transition energy γ_T and danger of beam loss

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 incl. systematic losses (injection, RF capture)
- $S_{eff,cold}(p, T)$: Cold surfaces pumping speed, incl. saturation
- $S_{eff,NEG}(p, t)$: NEG surfaces pumping speed, incl. saturation
- Projectile ionisation/capture $s_{pi}(E, Dq)$ from Shevelko, Olson, work in conjunction with AP
- Coulomb scattering
- Target (residulat gas) ionisation

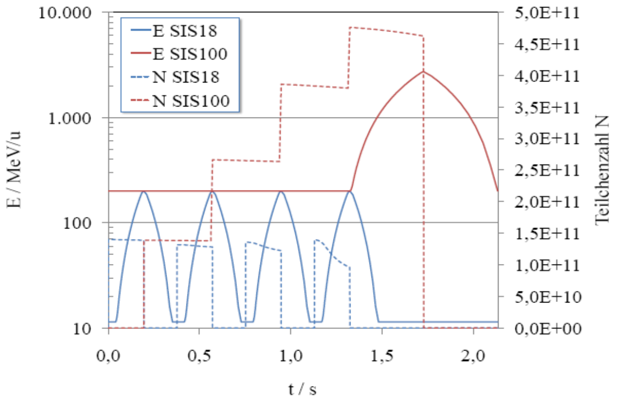
Ion stimulated desorption

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

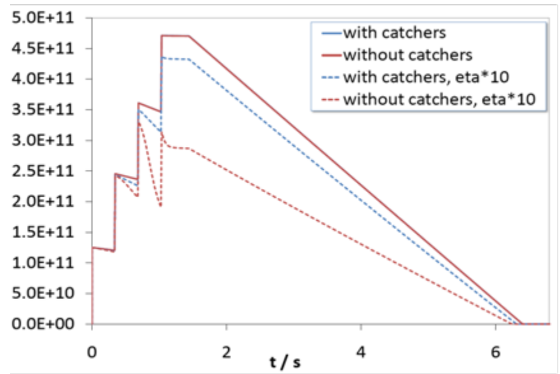
Benchmarking with many machine experiments (at GSI and at other accelerators)

Ionization Beam Loss and Dynamics of Pressure

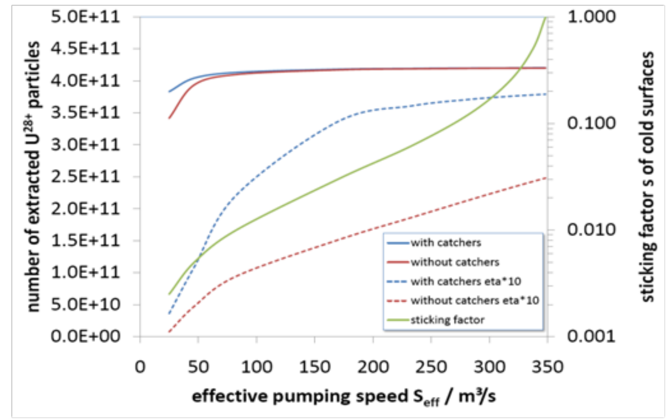
Short Term Studies (Cycles)



Ionization loss during stacking and acceleration in SIS18 and SIS100

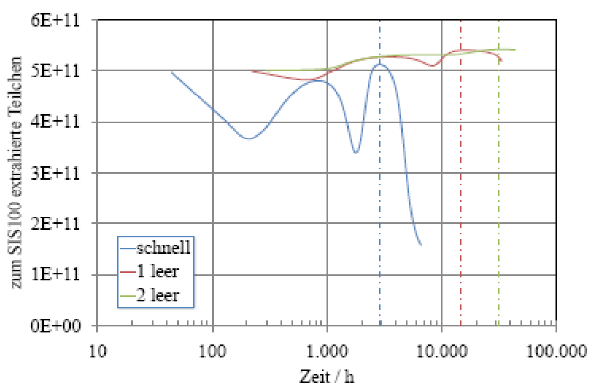


Safety studies for beam survival in SIS100

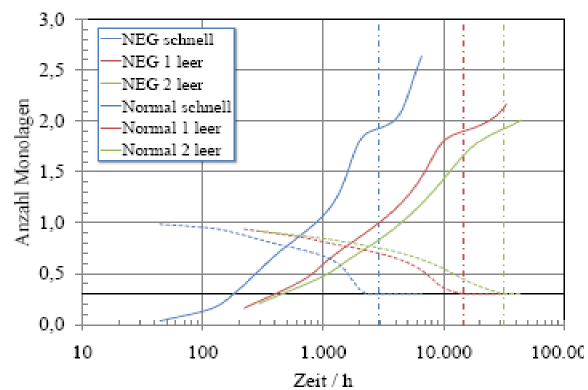


Extracted ions versus pumping speed of cryogenic surfaces

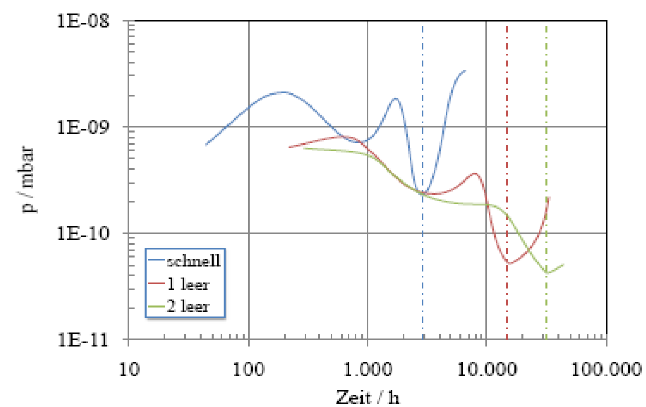
Long Term Studies



Extracted ions over months



Number of monolayers over months

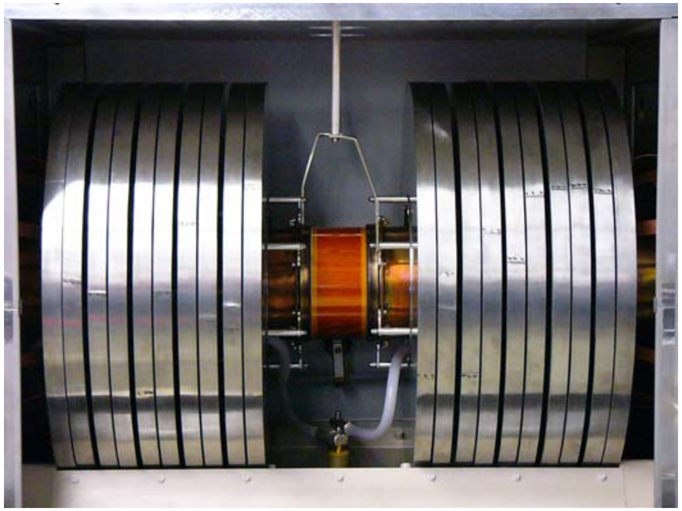


Pressure over months

SIS100 Radiofrequency: 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	15kV	2	2	Magnetic alloy ring core, broad band (low duty cycle) cavities

SIS18 ferrit loaded accel. cavity

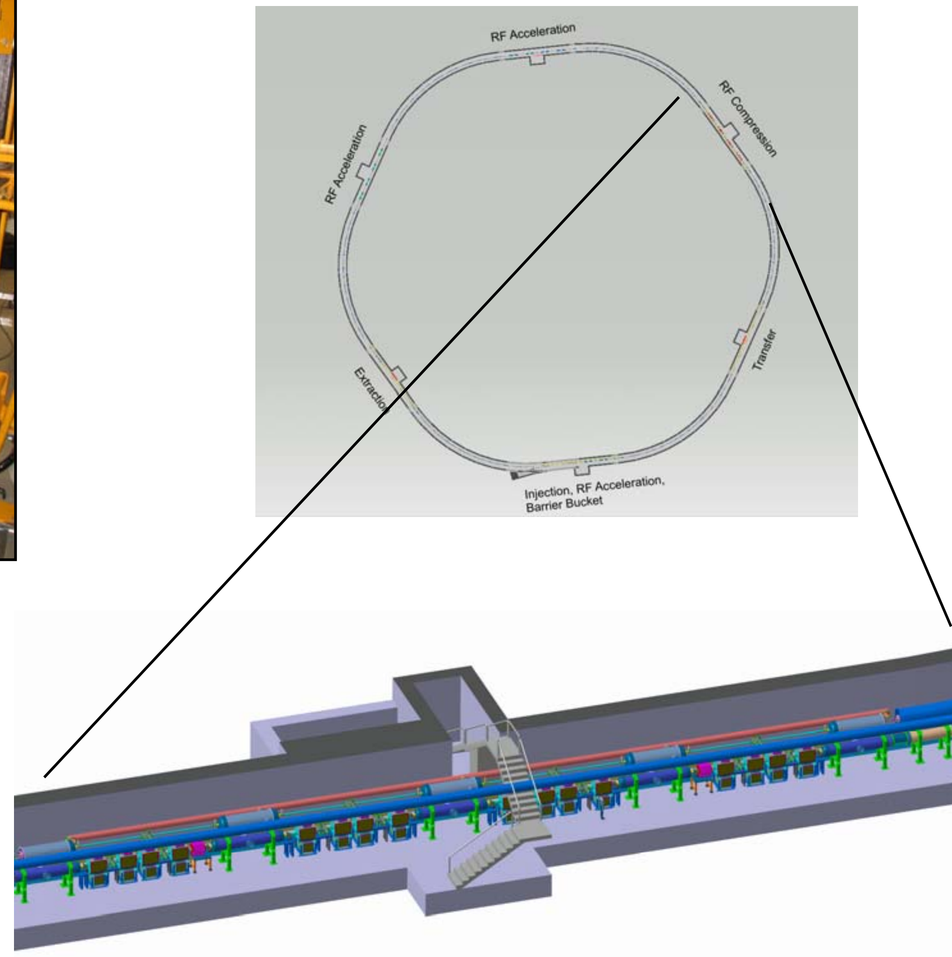


SIS18 MA loaded bunch compression cavity

Bunch Compression Systems

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

World wide MA core
material survey

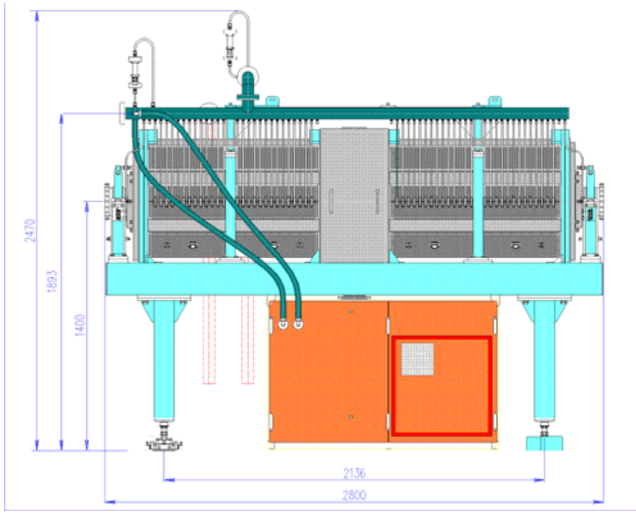


16 MA compression cavities in section S2

Rf: Acceleration Sections

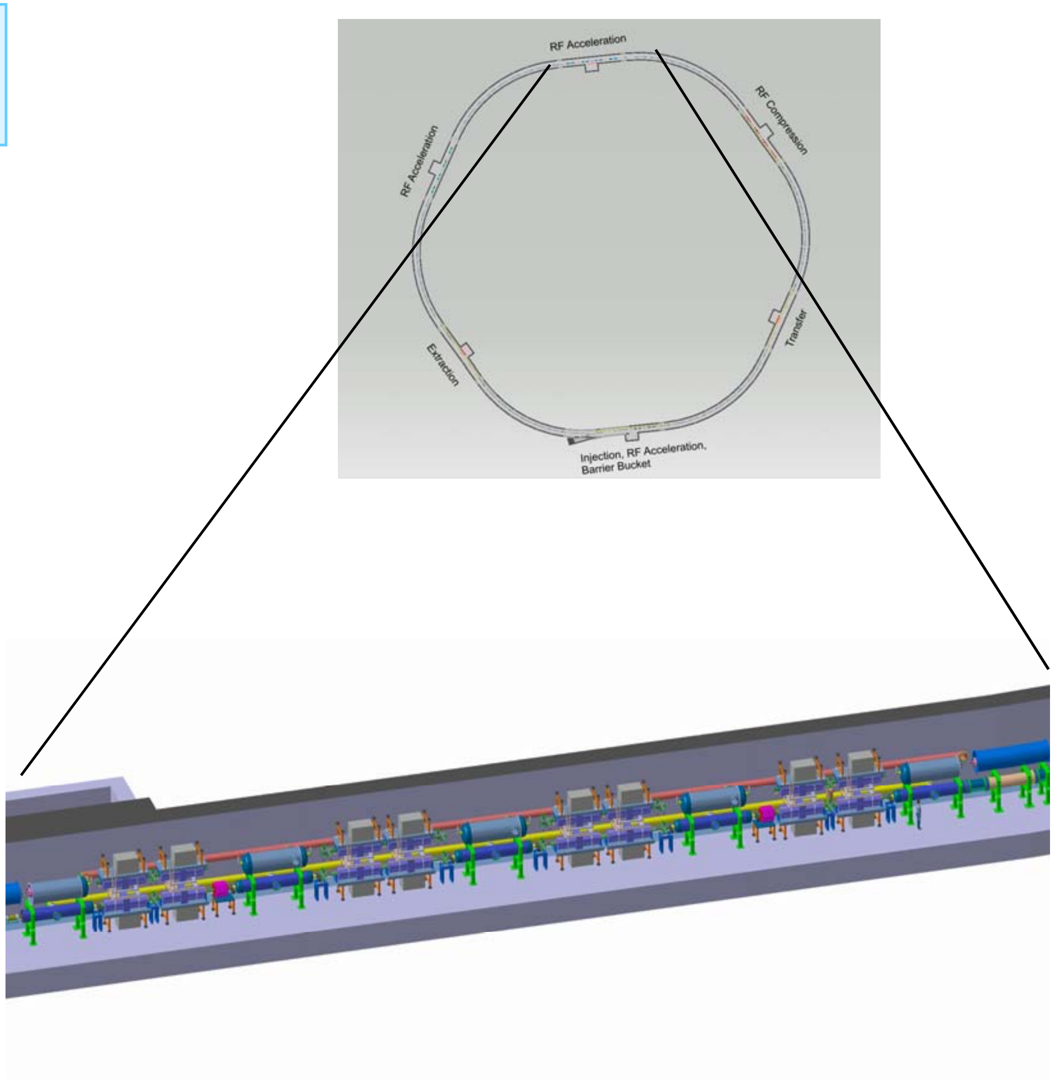
Acceleration Cavities:

- Design study completed (BINP)



Minimization of shunt impedance:

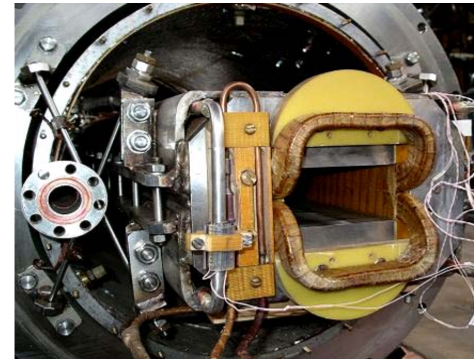
Fast semi-conductor gap switch R&D



SIS100 Fast Ramped S.C. Magnets

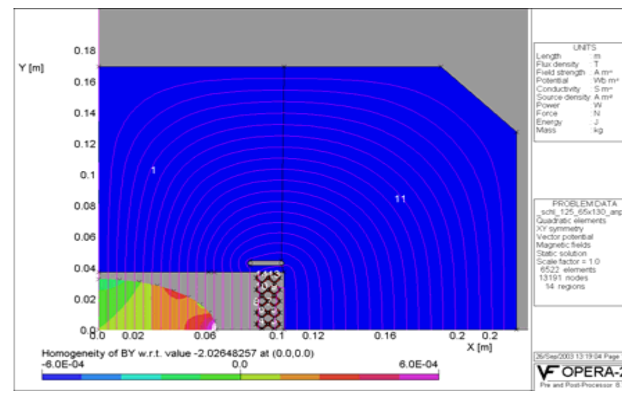
R&D Goals

- **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

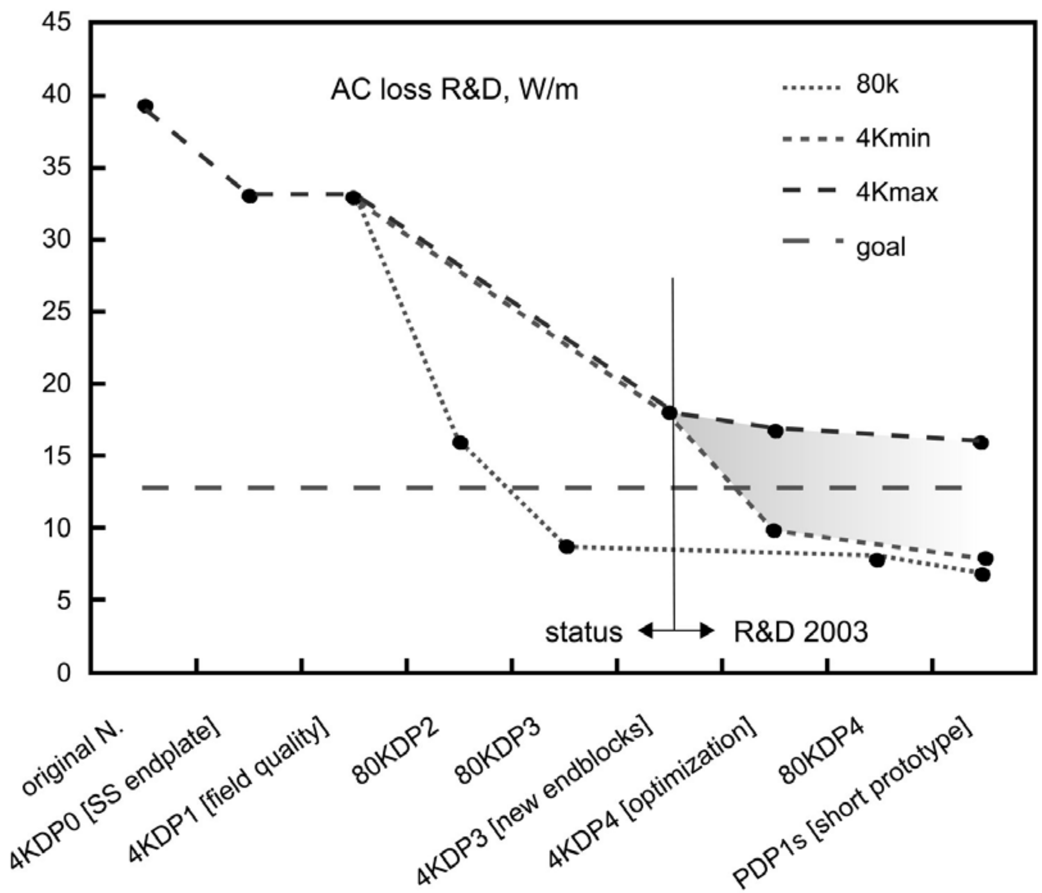
- AC Loss Reduction (exp. tests, FEM)
- 2D/3D Magnetic Field Calculations (OPERA, ANSYS, etc.)
- Mechanical Analysis and Coil Restraint (design, ANSYS) (>Fatigue of the conductor and precise positioning)

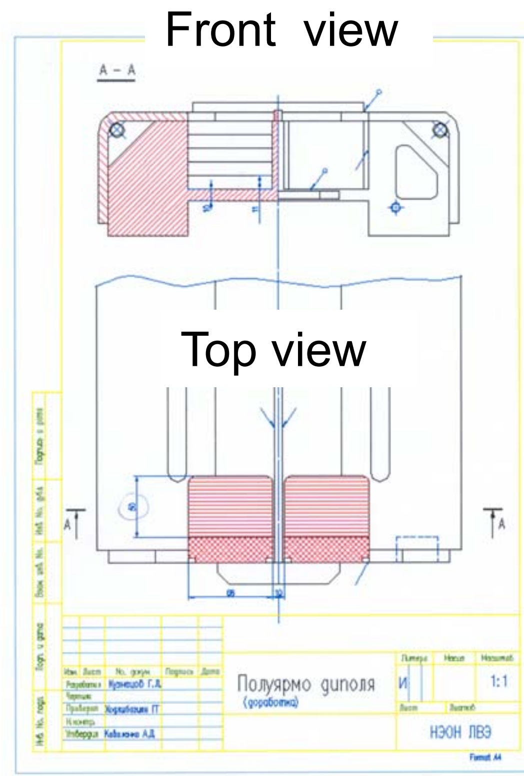


Experimental studies with modified Nuklotron magnets in JINR

SIS 100 Fast Ramped S.C. Magnets

R&D goal: AC loss reduction to 13 W/m @ 2T, 4 T/s, 1 Hz

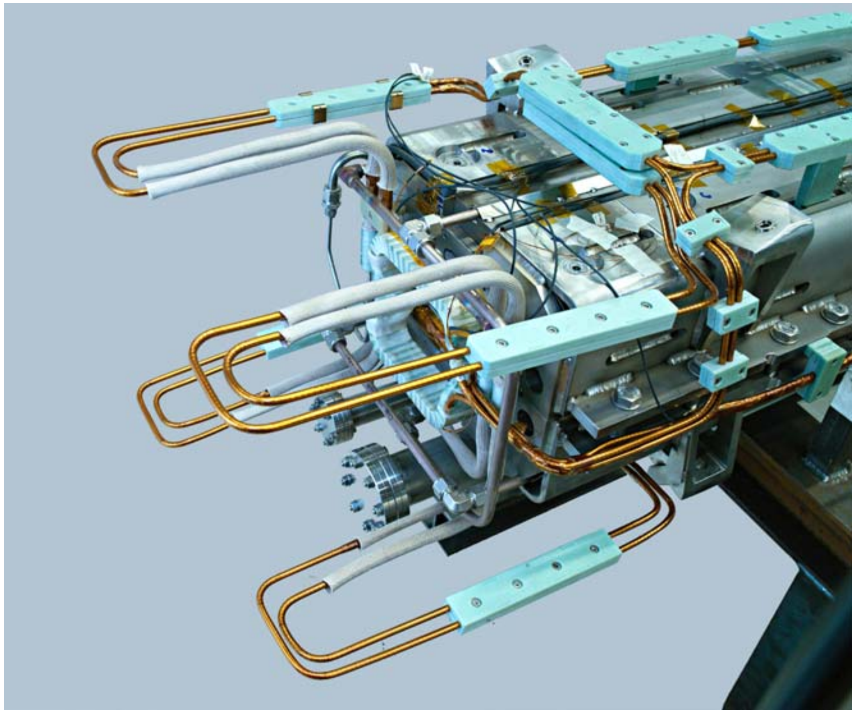




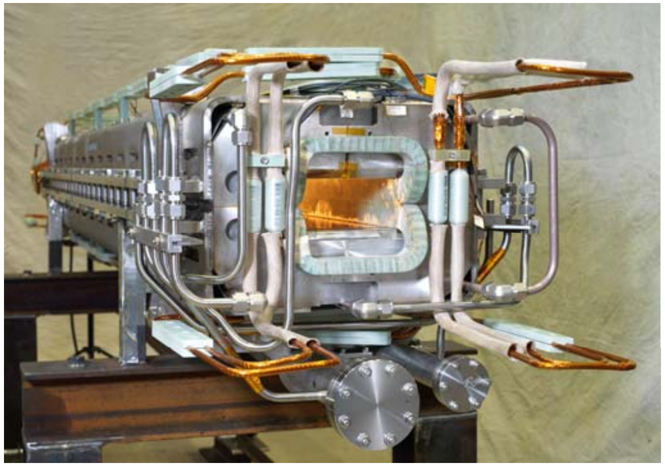
New endblock design

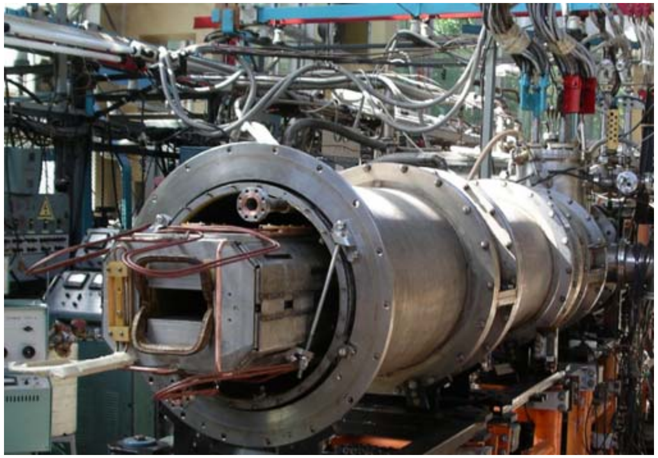
Full Length SIS100 Prototype Dipole

Manufactured by BNG (Würzburg)



- Second straight dipole and quadrupole under manufacturing at JINR
- Curved dipole under manufacturing at BINP

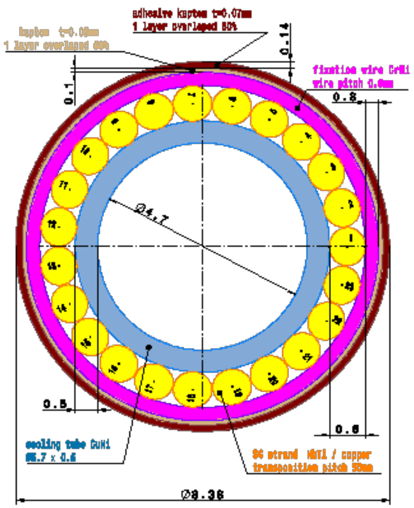


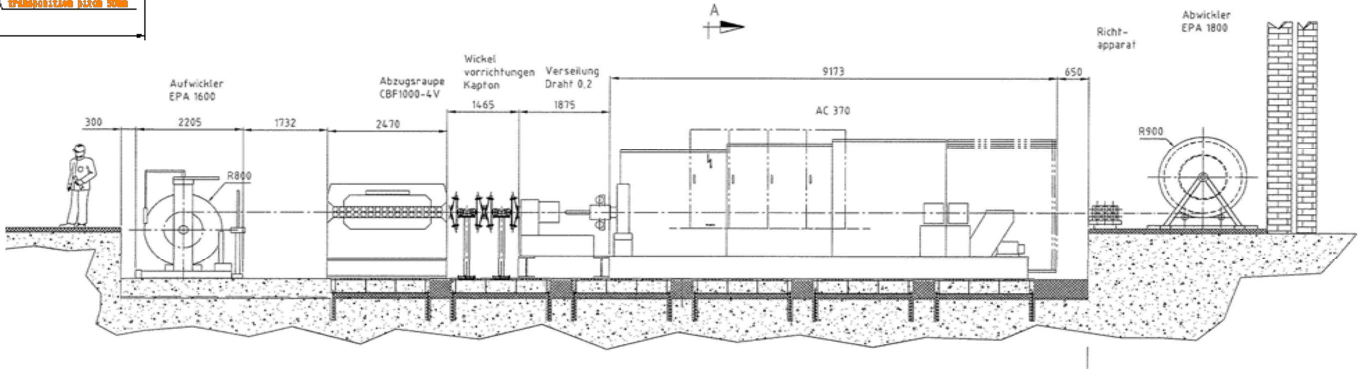


Prototype SIS100 dipole in JINR

Nuklotron Cable Production at BNG

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

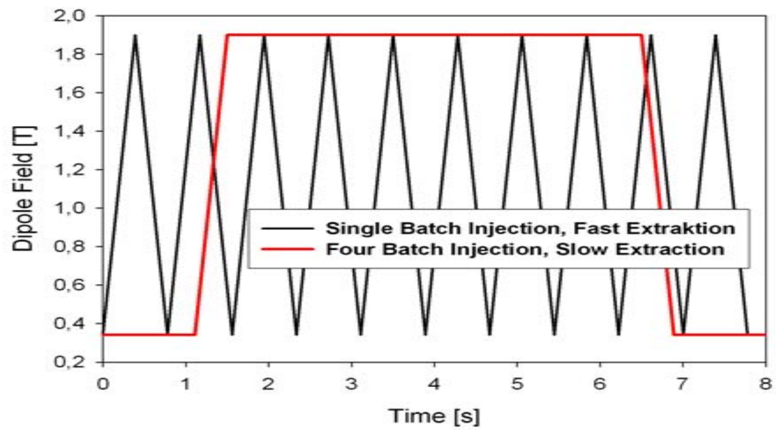




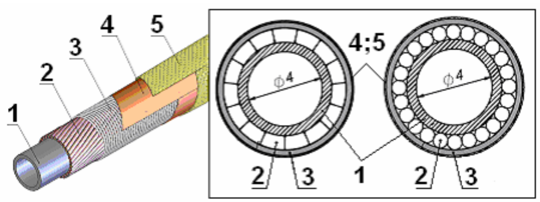
Operation Cycles and Magnet Cooling Limits

Triangular Cycles must be possible

Risk of beam loss on long injection plateau



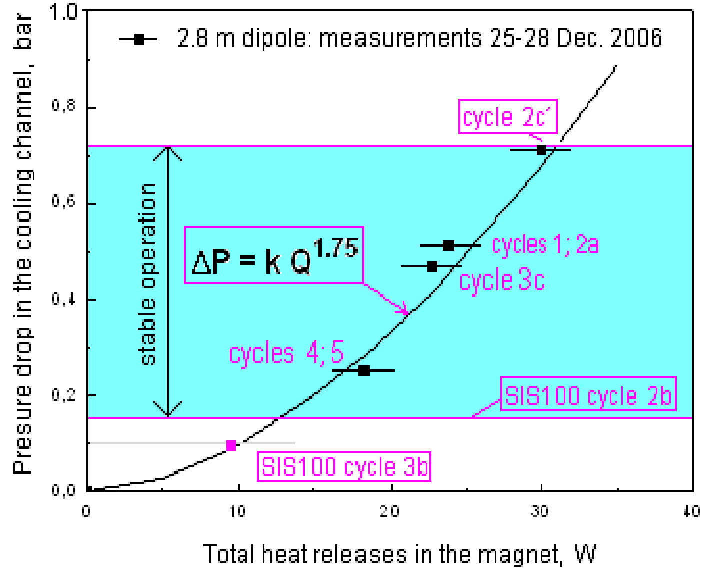
- Singel layer coil with low hydraulic resistance
- High current cable
- Active heaters to stabilize the crogenic load



Alternative coil design and high current cable

TABLE II OPERATION CYCLES AND EXPECTED LOSSES

cycle	B_{max} (T)	t_r (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



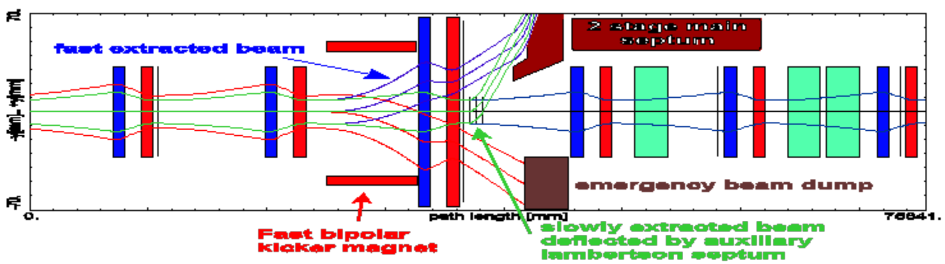
Extraction System

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

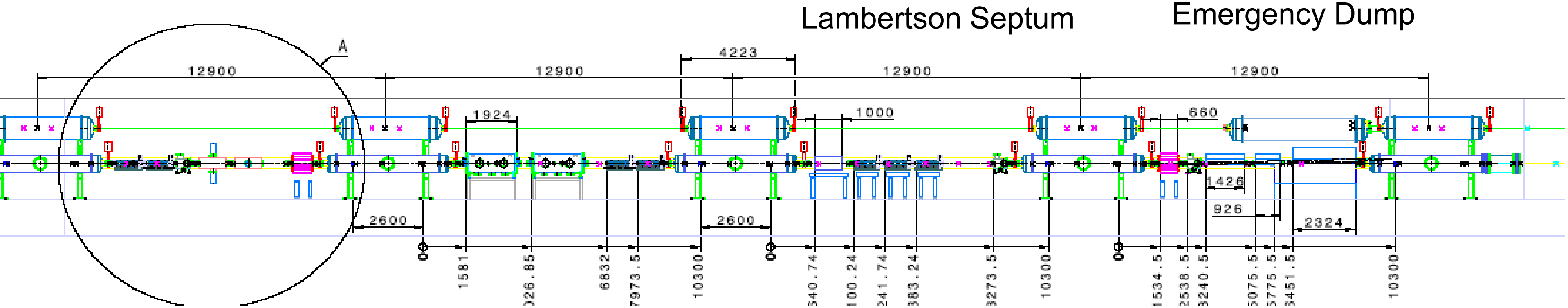
Fast Extraction:
- Distributed, bipolar and ramped kicker system

Slow Extraction:
- Combination of horizontal excitation and vertical extraction

- Chromaticity control: Hardt condition partially realized (separatrices co-aligned) thus minimized beam loss



Halo Scraper
Electrostatic Septa
Bipolar Kicker System
Lambertson Septum
Magnetic Septa and Emergency Dump



Expression of Interest for SIS100 Components

Component	WBS	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.	

Events in 2008 (beside committee meetings)

- November 2007

"Political" FAIR kick-off event

March 2008

Technical Design Report (380 pages)

- April 2008

International EOI Meeting

July 2008

FAIR CC kick-off meeting – signing of architect and planner contract

- September 2008

First meeting and formation of international pre-collaboration board aiming for the finalization of the technical design

Road Map

2008 Conceptual design, technical design studies and R&D completed

Machine layout fixed !

Realisation in the frame of an international SIS100 working group

2009-2012 Finalization of the engineering design

2011-2013 Manufacturing of components

2013-2014 Installation and commissioning