FAIR Challenges

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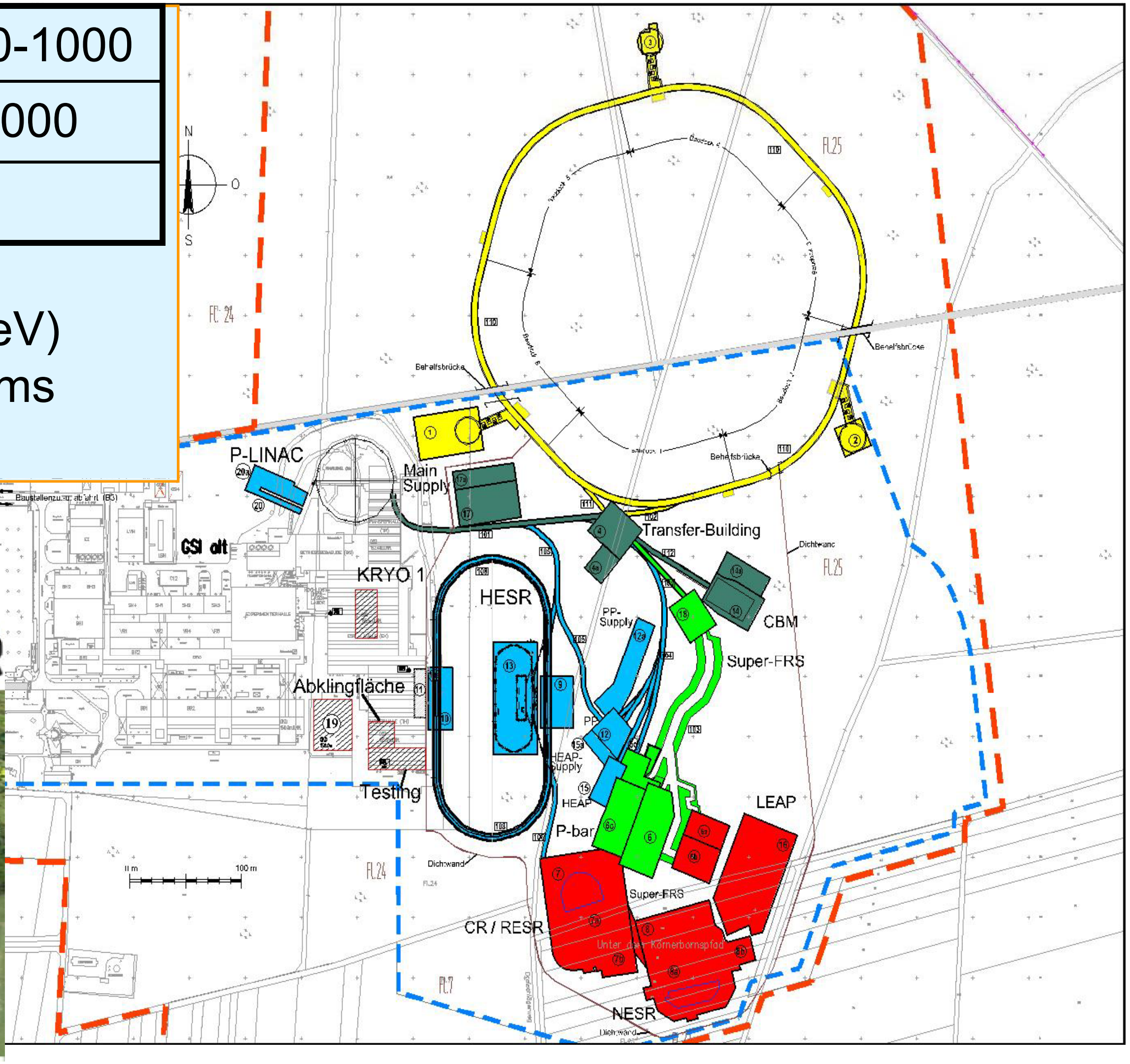
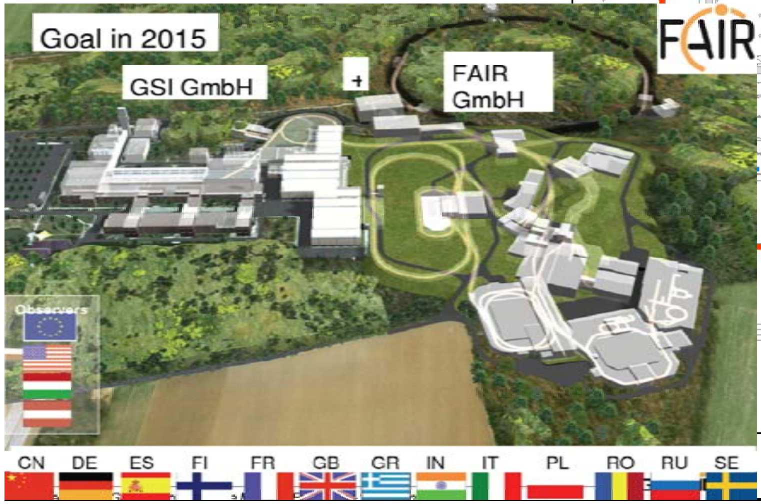
GSI/FAIR Accelerator Facility

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

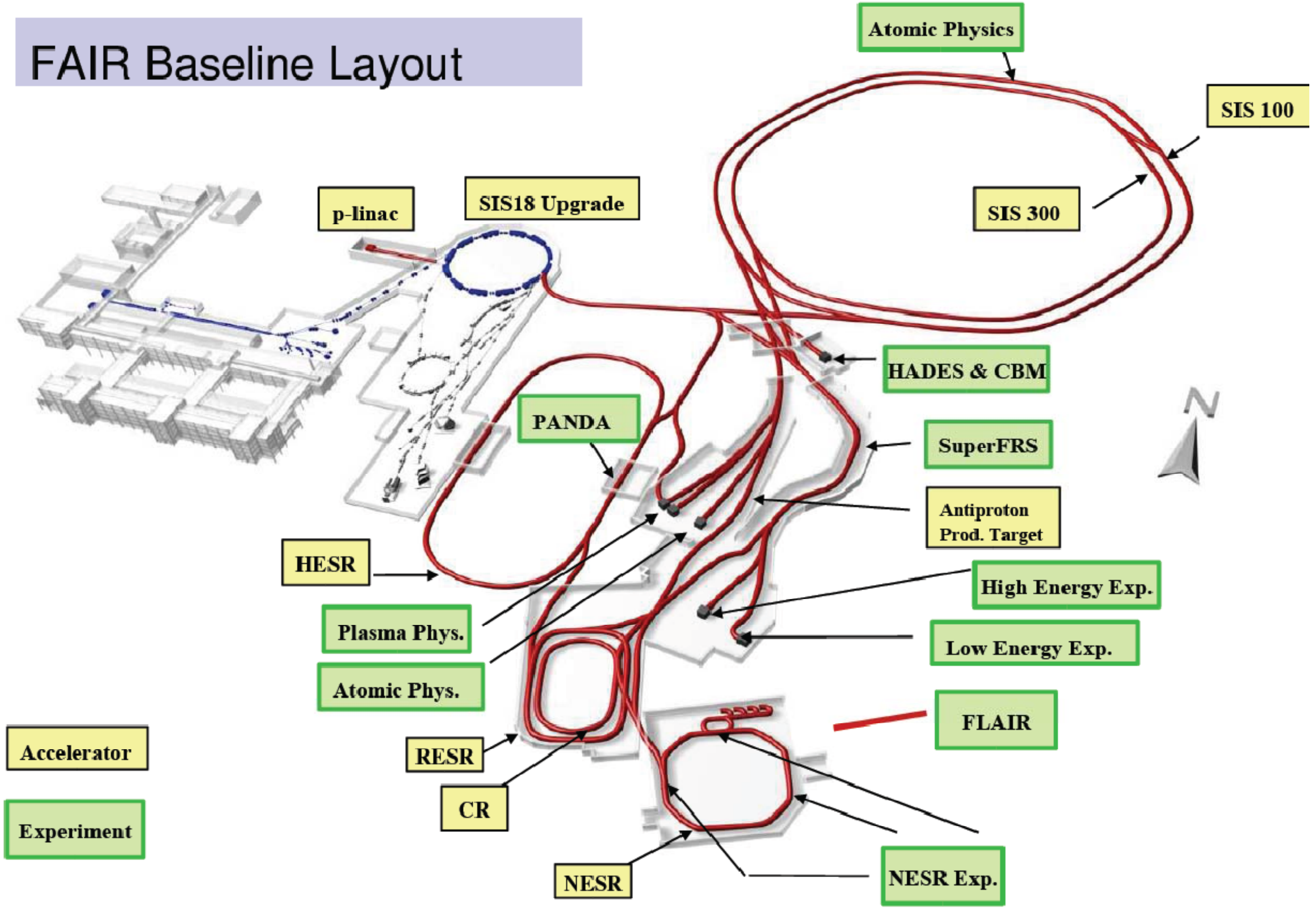
- New: Cooled pbar Beams (15 GeV)
- Intense Cooled Radioactive Beams
- Parallel Operation





GSI/FAIR Accelerator Facility

FAIR Baseline Layout



Atomic Physics

SIS 100

p-linac

SIS18 Upgrade

SIS 300

HADES & CBM

PANDA

SuperFRS

Antiproton
Prod. Target

HESR

High Energy Exp.

Plasma Phys.

Low Energy Exp.

Atomic Phys.

FLAIR

RESR

CR

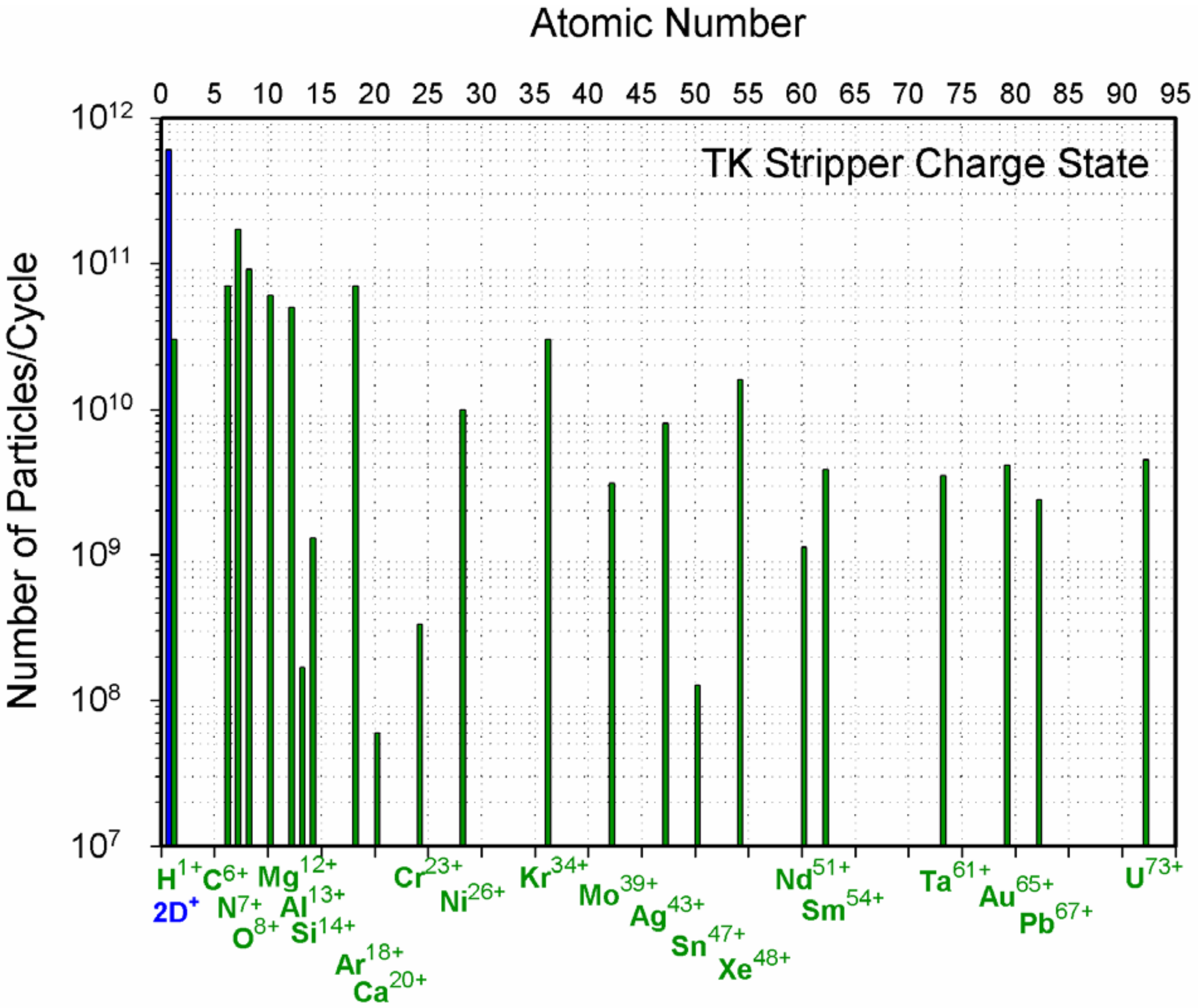
Accelerator

Experiment

NESR

NESR Exp.

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

Ion Sources and LEBT R&D

MEVVA source

Optimization for maximum intensity at the desired charge state (VARIS)

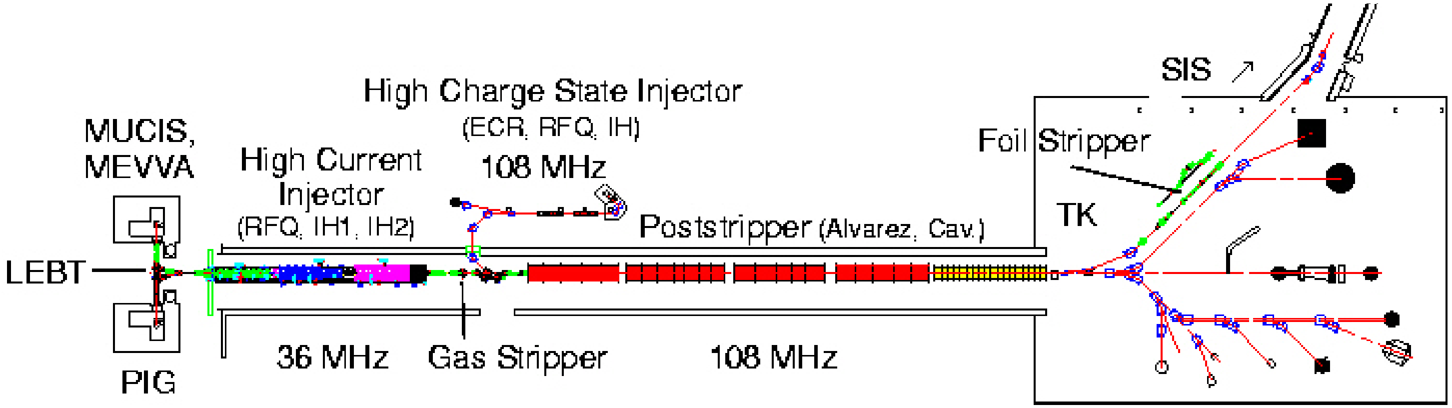
22 emA U^{4+} reached at UNILAC injection

High Current Test Injector

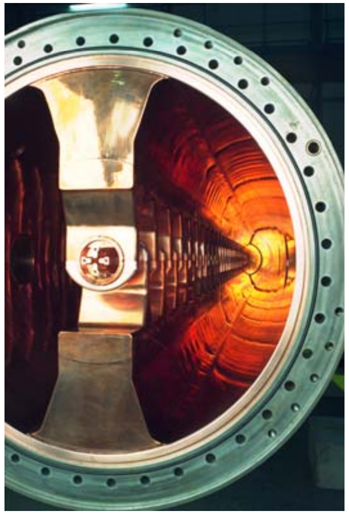
Optimization for maximum transmition and beam brilliance

(74 % loss from extraction system to UNILAC)

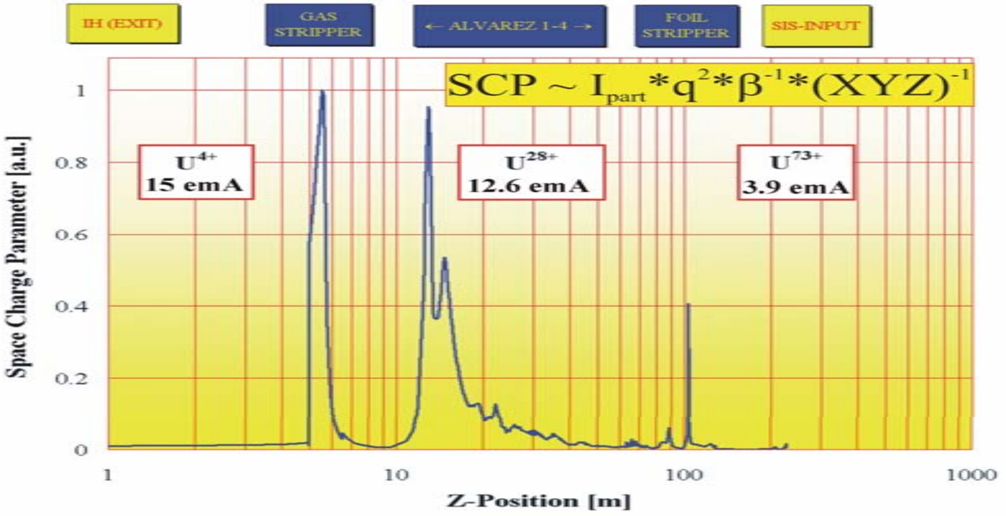
UNILAC upgrade

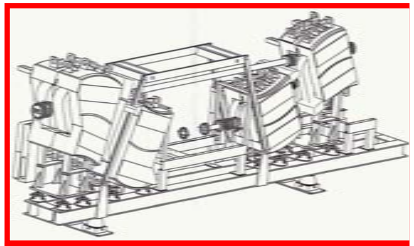


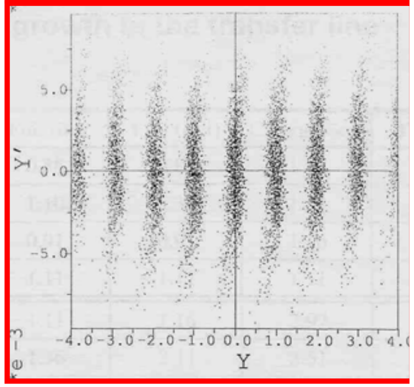
1.5 MW U^{4+} beam power for injection into SIS18



New RFQ with larger acceptance



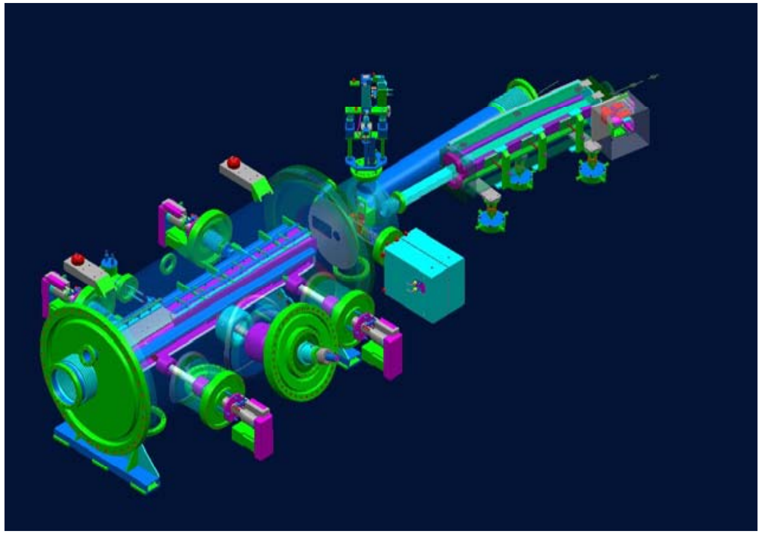


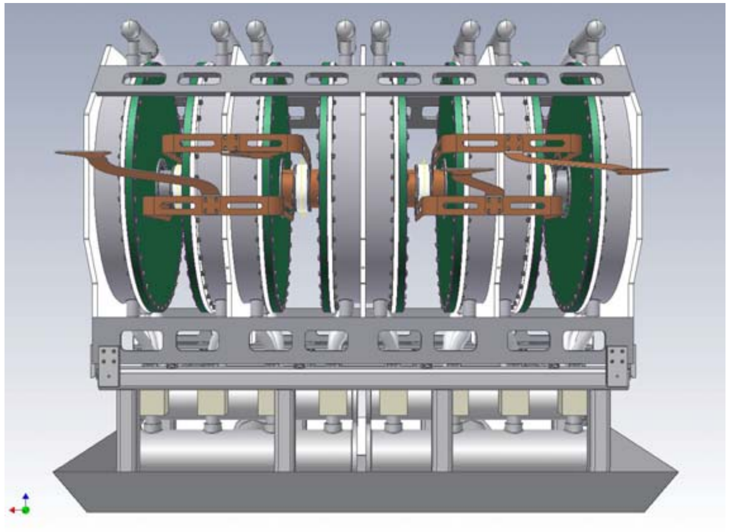


Space charge dominated transport after beam stripping

Phase advance –

SIS18 upgrade program



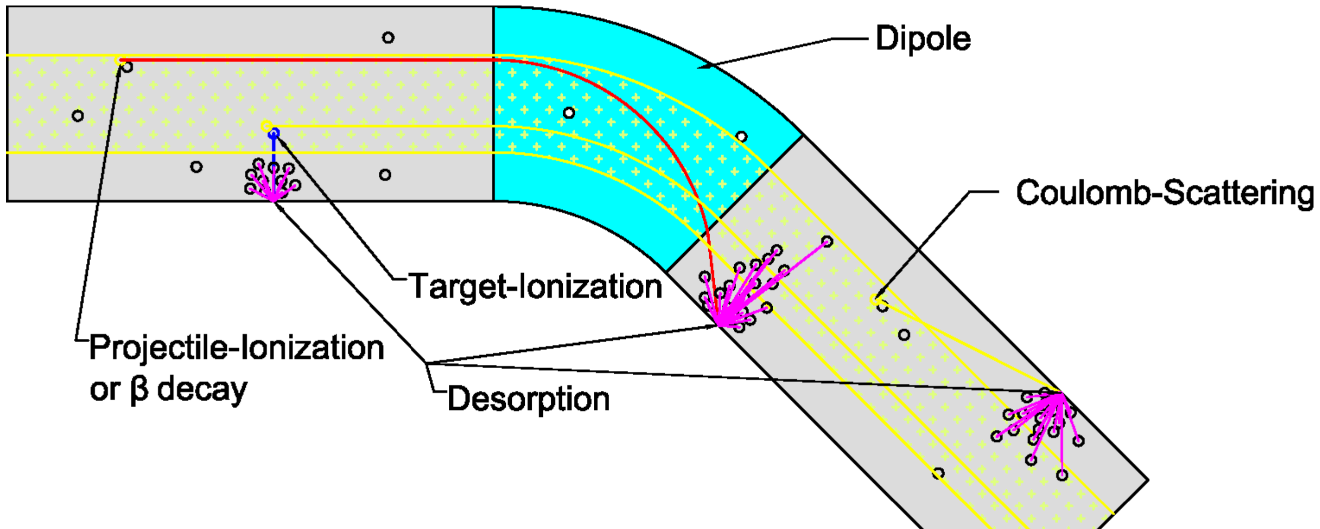


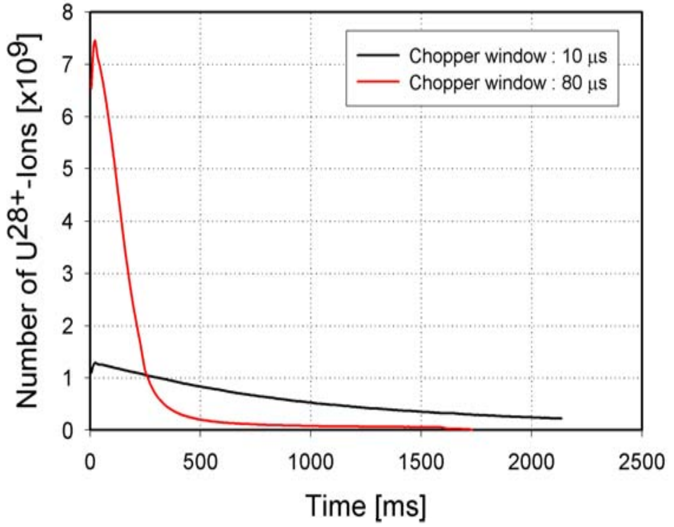
New heavy ion injection system with e-septum voltages up to 280 kV

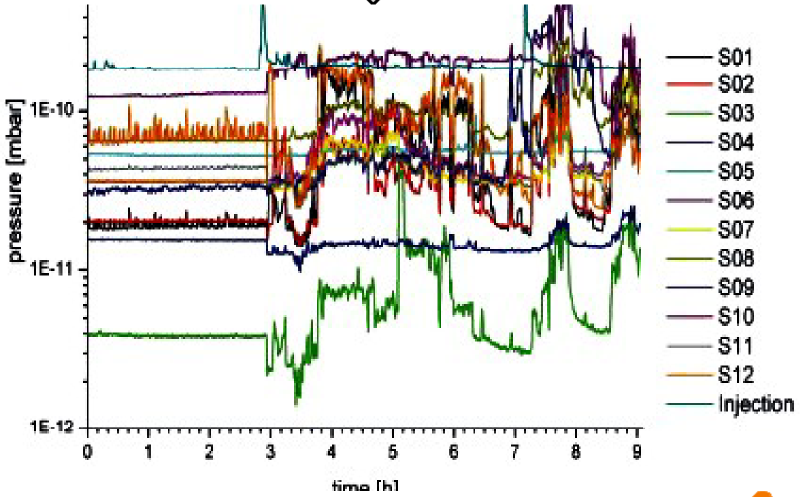
New broad band, high duty cycle MA acceleration cavity for the generation of a two harmonic bucket

0.5 MHz - 40 kV/gap

Beam Loss by Charge Change U^{28+} → U^{29+}





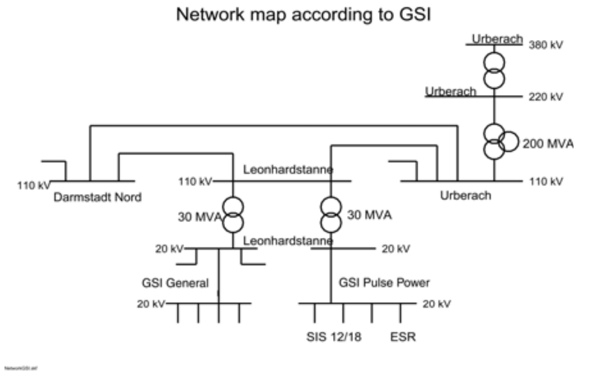


SIS18 upgrade - Vacuum Stabilization

- Short Cycle Times and Short Sequences

  SIS12/18: 10 T/s - SIS100: 4 T/s

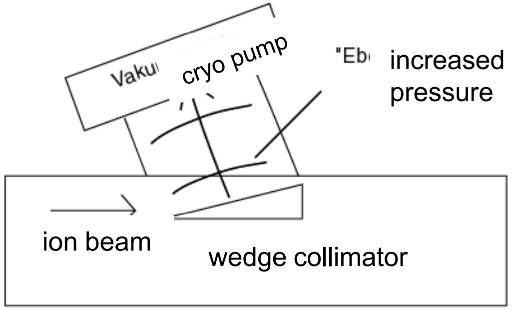
  (new power connection, power converters and Rf system)



- Enhance Pumping Power (UHV upgrade)

  (NEG-coating, cryo panels - local and distributed)

  (new magnet chambers, improved bake out system)

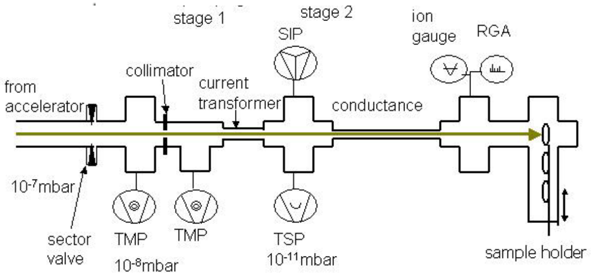


- Localizing beam loss and controle of desorption gases

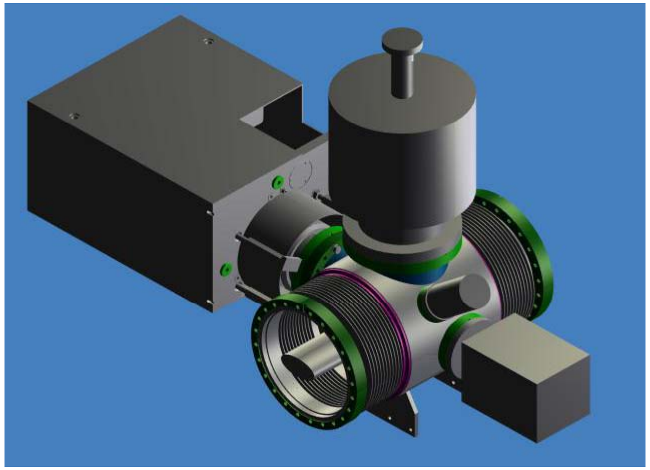
  (Collimator in S12, new collimation system)

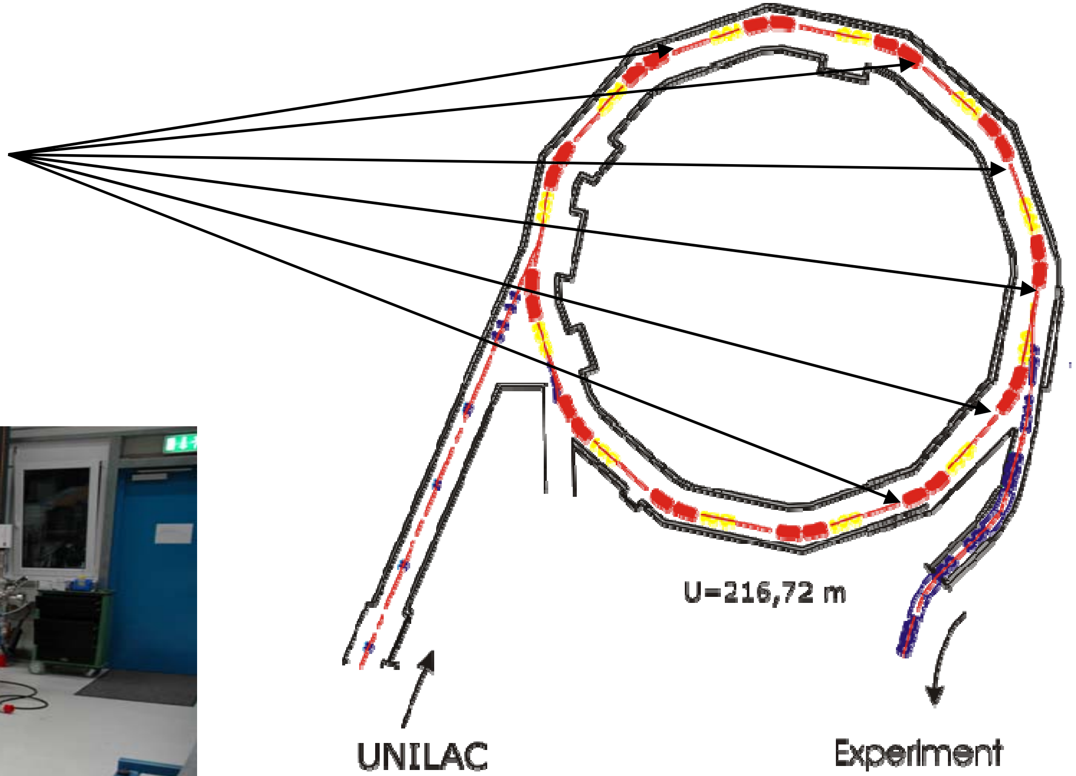
- Materials with low desorption yields

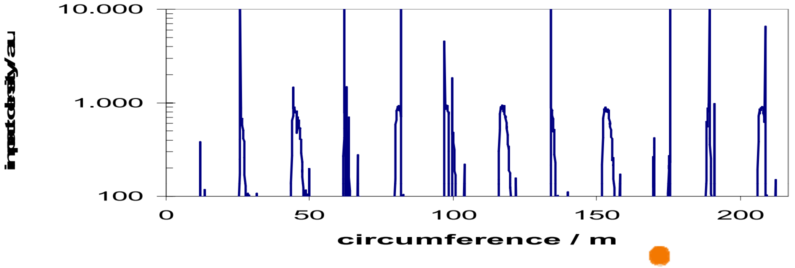
  Teststand, ERDA measurements



SIS18 upgrade - Vacuum Stabilization



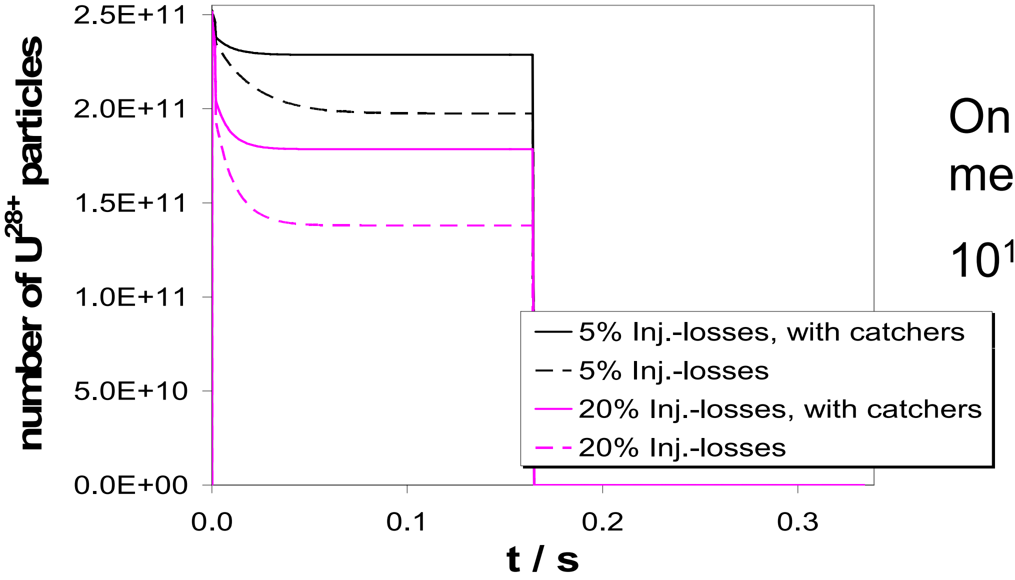




Collimators and NEG coating suppression of desorption and strong pumping

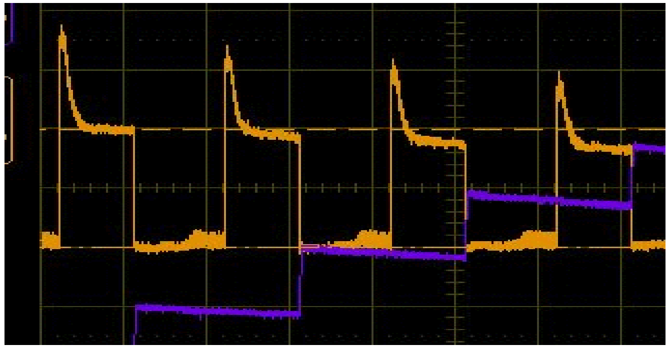
SIS18 – High Intensity U^{28+} Operation

Final U^{28+}- booster operation



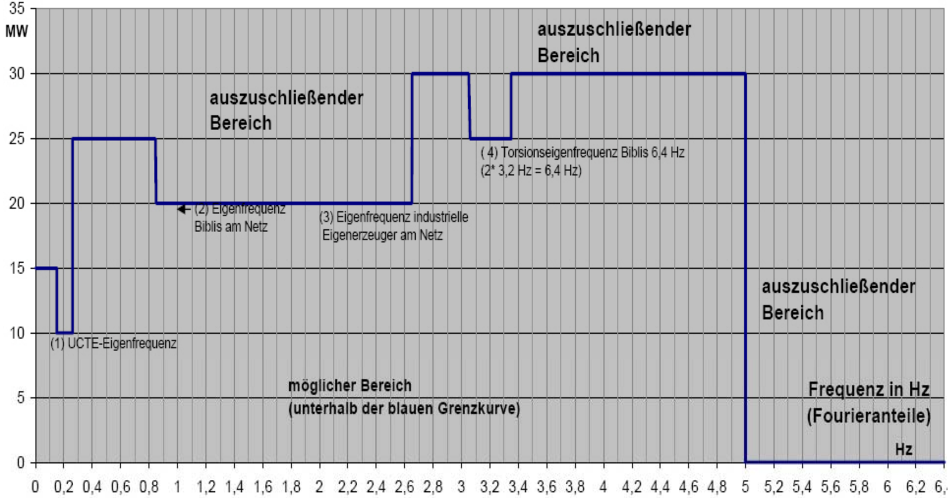
Only the combination of the upgrade measures leads to the desired result !

10^{11} U-ions per cycle



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

Synchrotron Pulse Power Supply

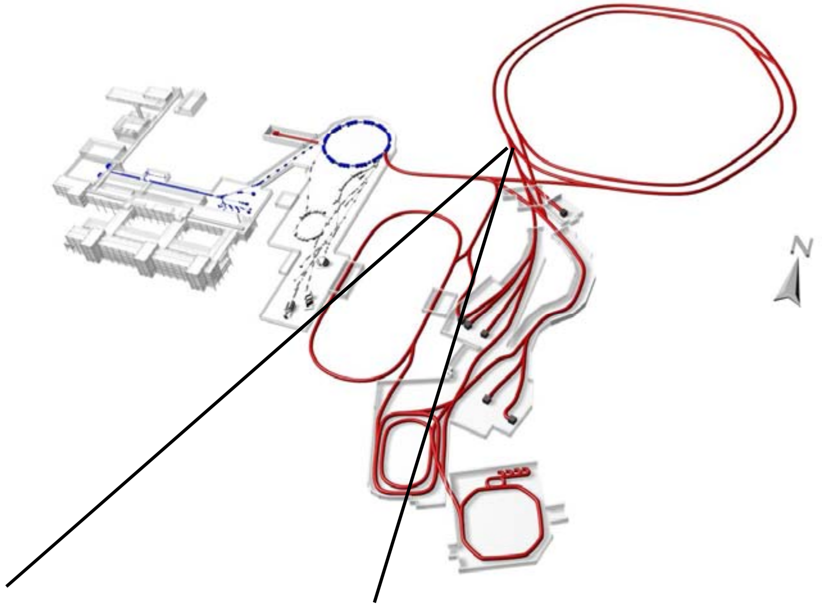


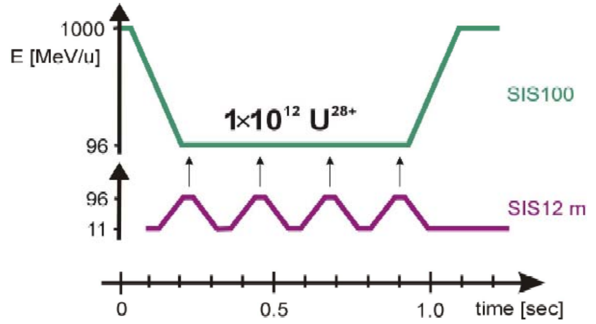
	Pulse Power	Field Rate
SIS18	5 MW	1.3 T/s
SIS12	+26 MW -17 MW	10 T/s
SIS18	+ 42 MW	10 T/s
SIS100	± 18 MW	4 T/s
SIS300	± 23 MW	1 T/s

- Fast ramping causes high pulse power
- New 110 kV power grid connection
- No local compensation facility

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

Peter Spiller, CARE HHH, CERN, 2.10.07

Two Stage Synchrotron SIS100/300

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

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

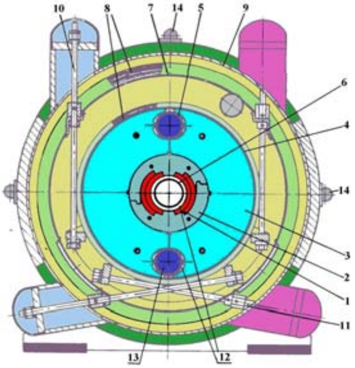
Intermediate charge state ions e.g. U^{28+}-ions up to 2.7 GeV/u
Protons up to 30 GeV

$B\rho$= 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.

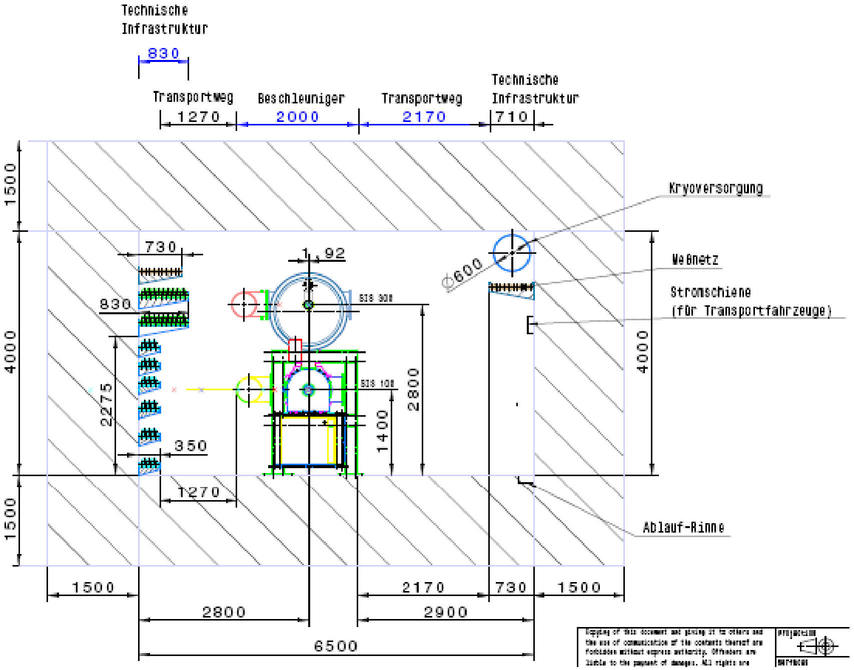
Highly charges ions e.g. U^{92+}-ions up to 34 GeV/u
Intermediate charge state ions U^{28+}- ions at 1.5 to 2.7 GeV/u with 100% du



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

System and Ion Optical Design

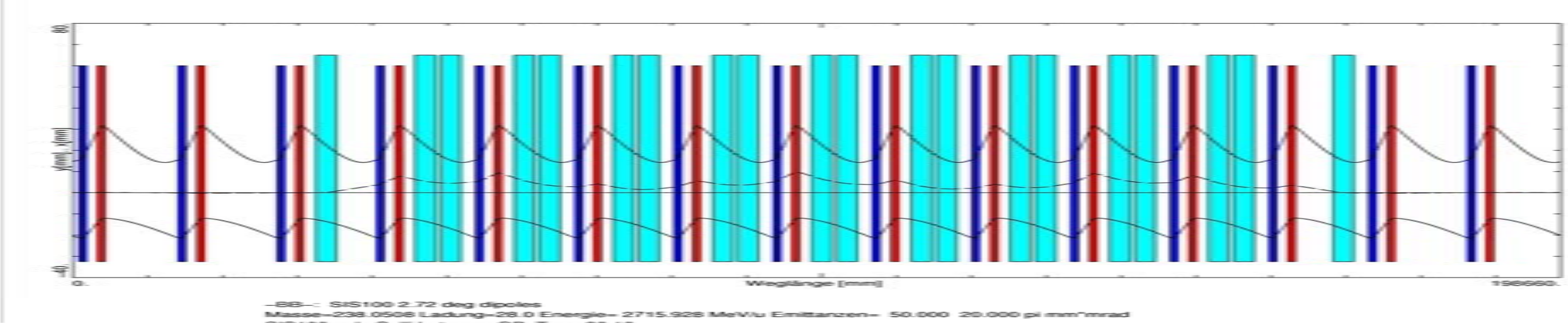
Realisation of two stage SIS100 and SIS300 concept in one tunnel is challenging:



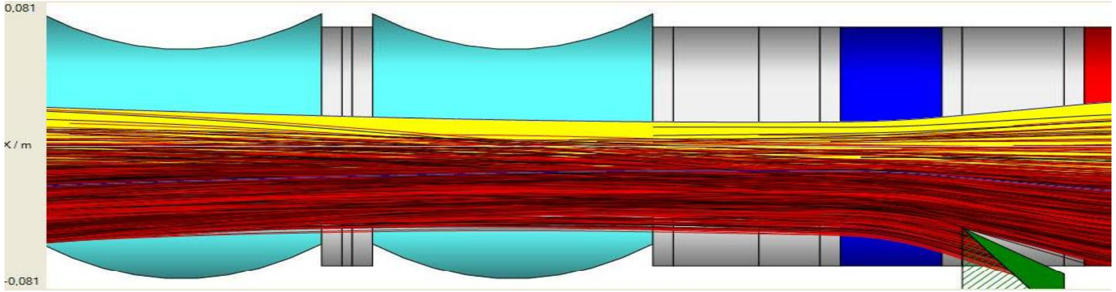
- Geometrical matching of both synchrotrons with different lattice structures (Doublet and FODO) and different magnet technologies (superferric and cosθ)
- Ratio between straight section length and arc length with fixed circumference defined by the warm straight section requirements of SIS100
- Fast,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

Low Charge State Heavy Ion Lattice

- 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

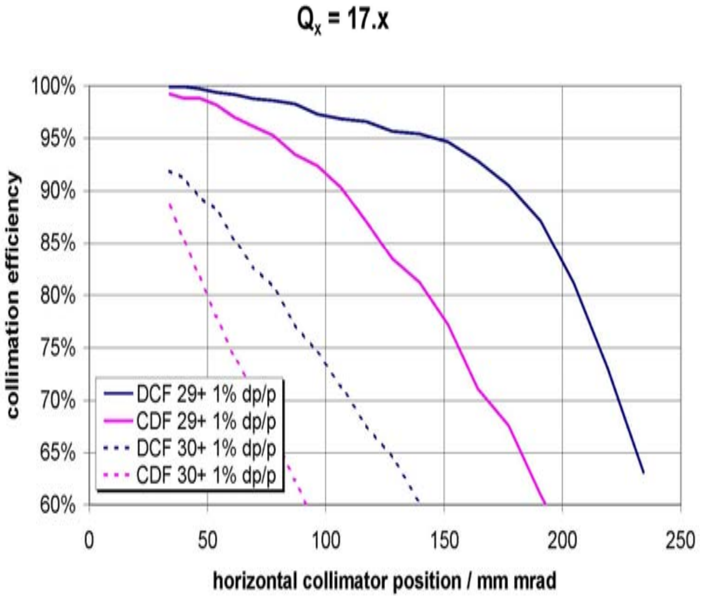
- Studies for different SIS100 working points
- Comparison between scraper positions
- Code development continued and applied to beta beams study, AGS booster/SIS18 comparison (confirmed the $(dE/dx)^2$ scaling)

Cross section estimations for

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

b) Lighter ions: Intensity expectations SIS100

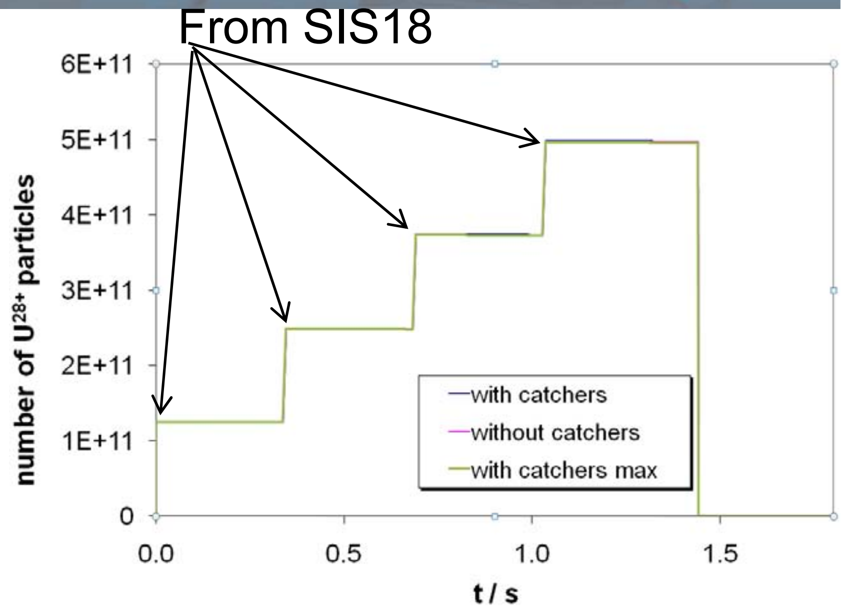
c) Other Energies: Scraper requirements for SIS300



Dynamic Vacuum R&D

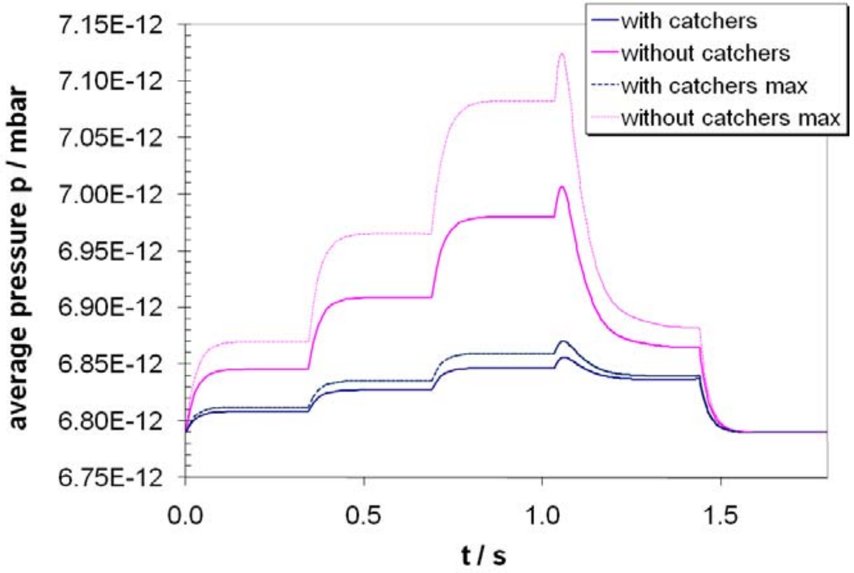
Residual Gas Pressure Dynamics

- STRAHLSIM: Unique code for the simulation of the residual gas pressure dynamicy
- Desorption Yield Measurements
- ERDA Measurements
- Relativistic Atomics Physics Models


From SIS18

SIS100 ionization beam losses

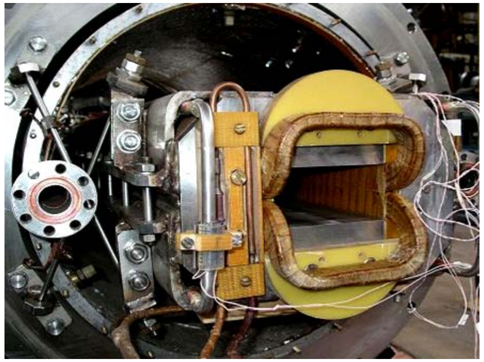
- Cyrogenic surfaces:
- η is small due to $(dE/dx)^2$
- Low loss expected (<1%)
- Load to cryogenic system is reduced by catcher system @ 70K.
- Lighter ions have lower s_{pi}, residual gas will remain stable.



SIS100 Fast Ramped S.C. Magnets

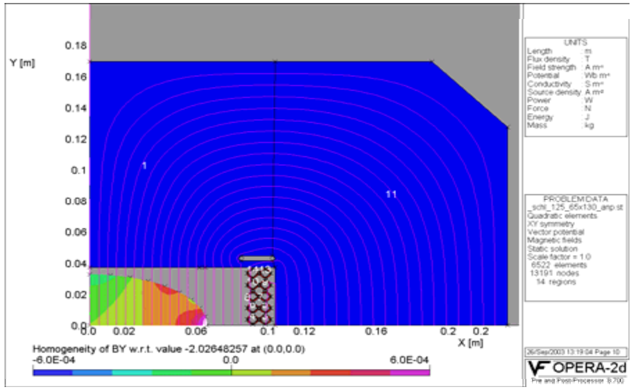
R&D Goals

- **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)



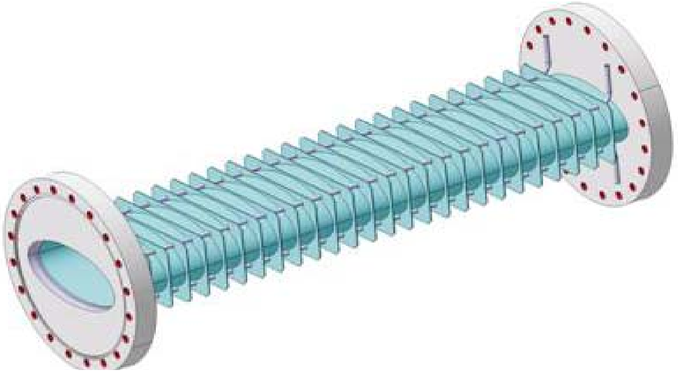
Activities

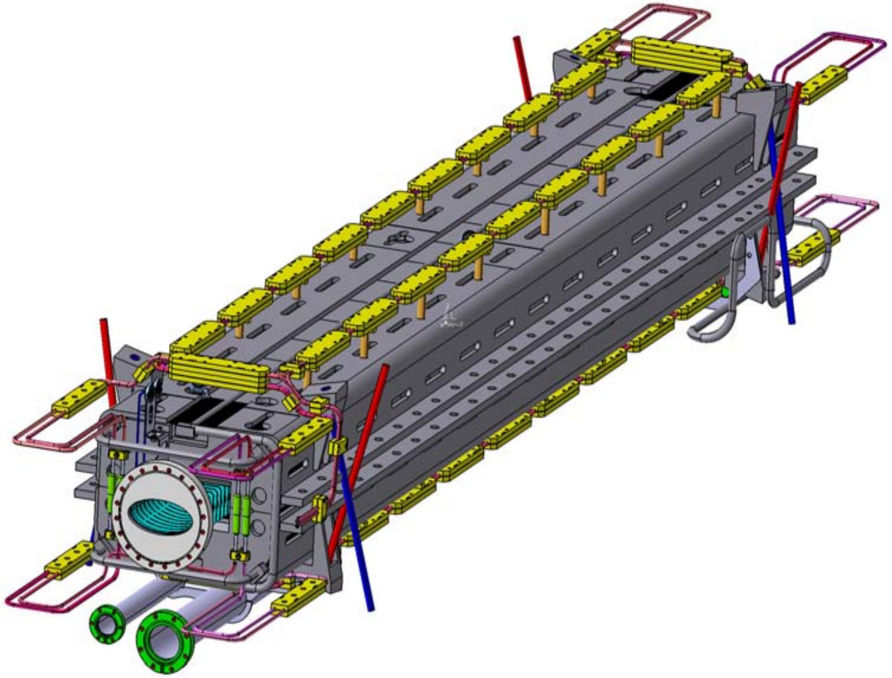
- AC Loss Reduction (exp. tests, FEM)
- 2D/3D Magnetic Field Calculations (OPERA, ANSYS, etc.)
- Mechanical Analysis and Coil Restraint (design, ANSYS) (>Fatigue of the conductor and precise positioning)



Experimental studies with modified Nuklotron magnets in JINR

SIS100 S.C. Magnets: Full Size Model Dipole

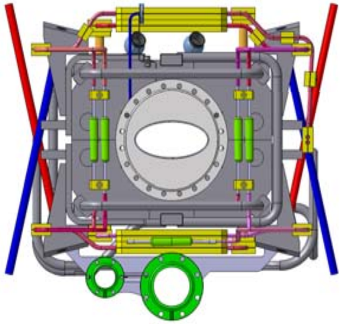




Full Lenth Models “Prototypes”

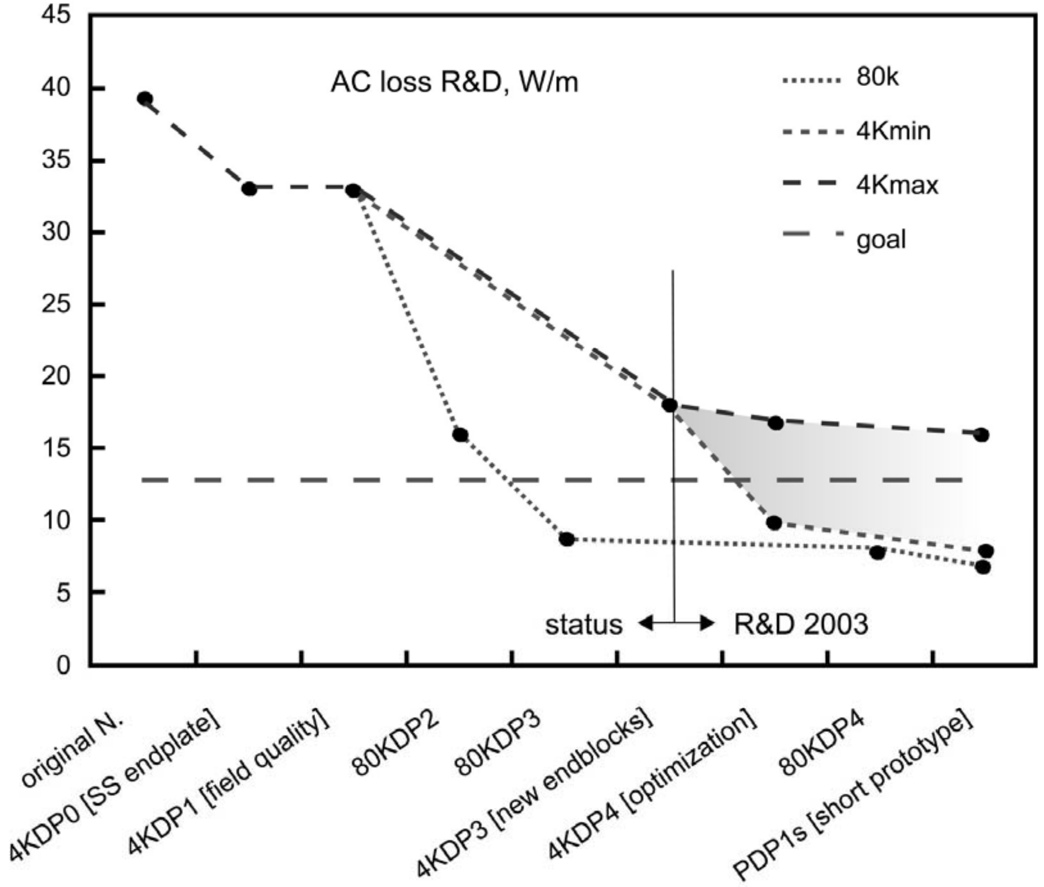
- Straight dipoles (JINR Dubna, BNG Wuerzburg)
- Curved dipole (BINP Novosibirsk)

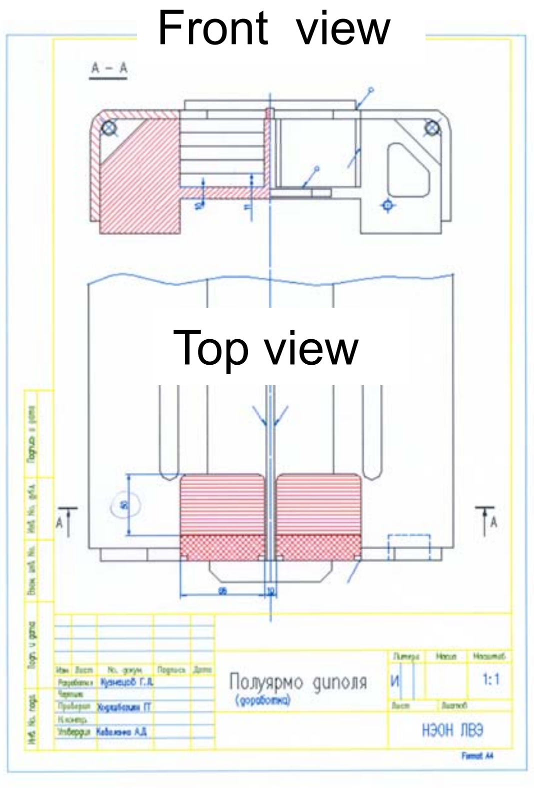
Design review for both dipoles passed



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

Operation Cycles and Magnet Cooling Limits

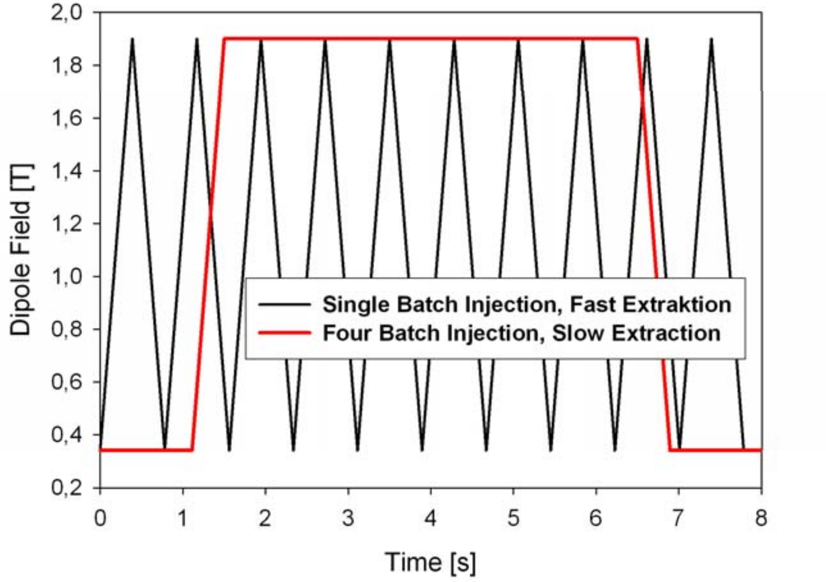
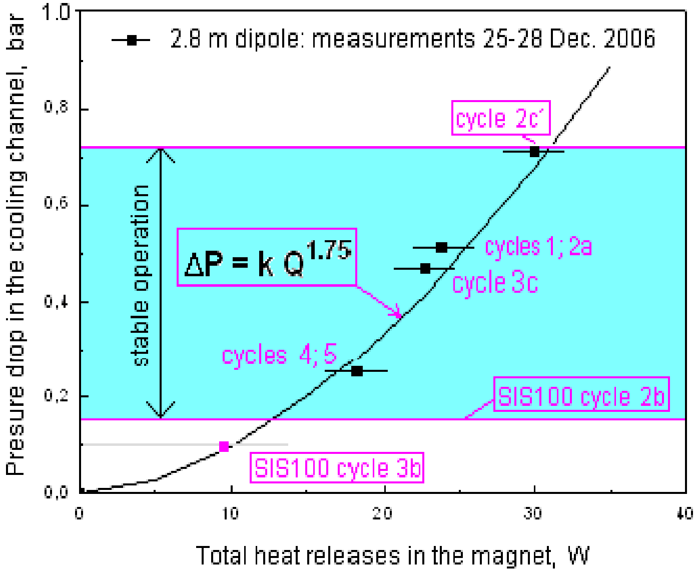
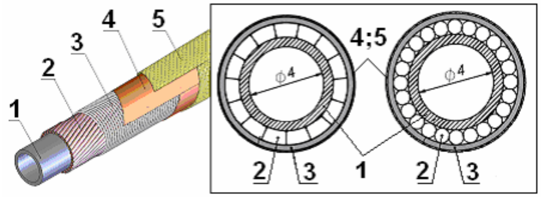


TABLE II OPERATION CYCLES AND EXPECTED LOSSES

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





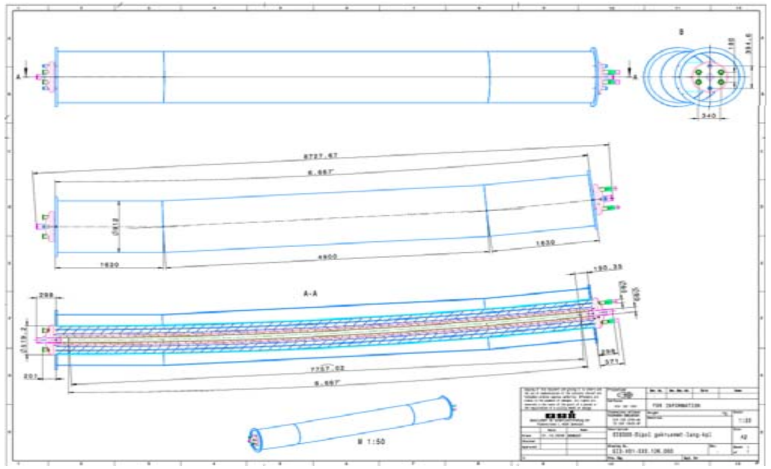
Alternative coil design and high current cable

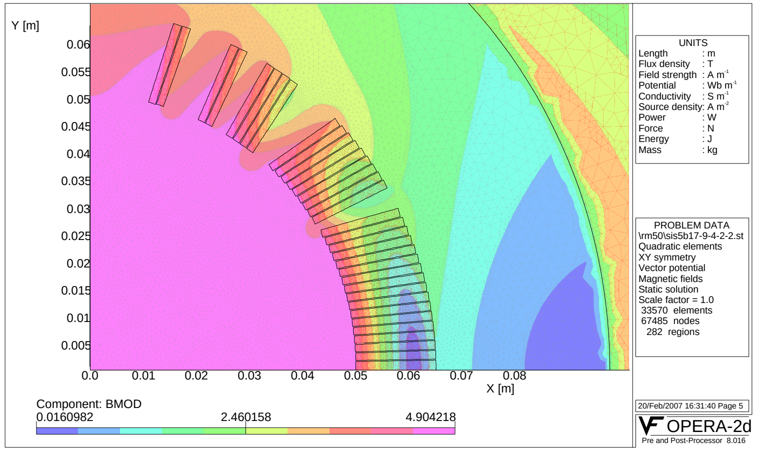
SIS300 Fast Ramped, Curved S.C. Dipole

SIS300: 4.5 T single layer coil
Ramp rate: 1 T/s
Bending angle: 6.66 deg
Bending radius: 66.67 m

LHC : 8.33 T two layer coil
Ramp Rate: 0.007 T/s
Bending angle: 0.29 deg
Bending radius: 2803 m

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

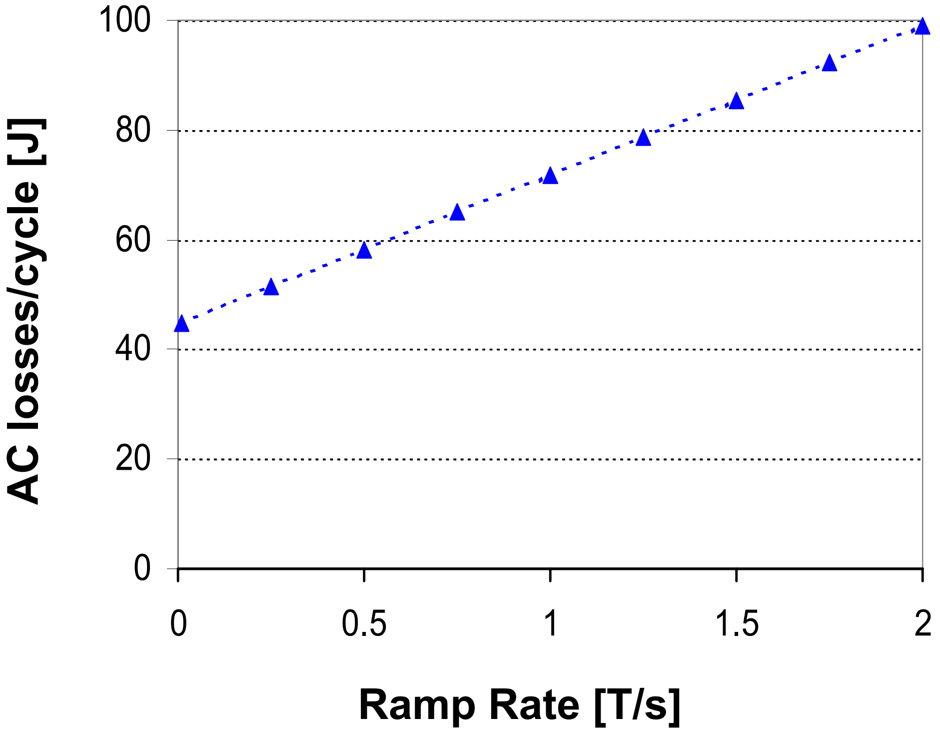




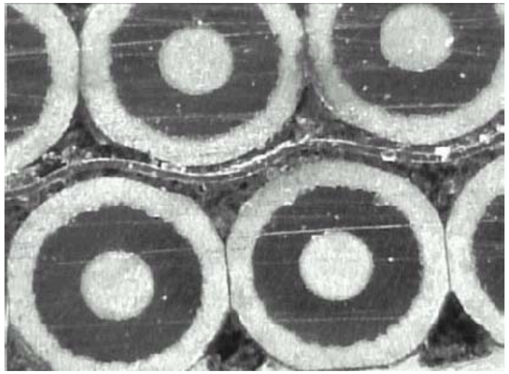
5-blocks configuration selected for SIS300 dipole (INFN)

SIS 300 Fast Ramped S.C. Magnet

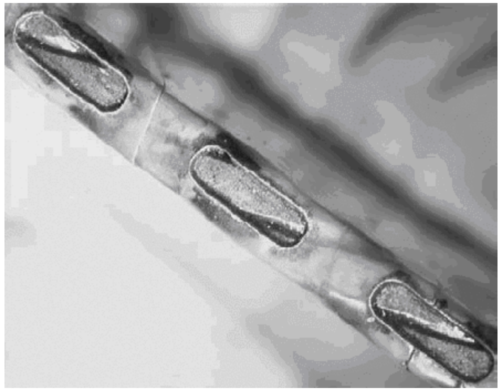
Results of the model magnet : 4.38 T @ 2 T/s



AC-Losses @ 4T, 1T/s, 0.125Hz : 9 Watt/m

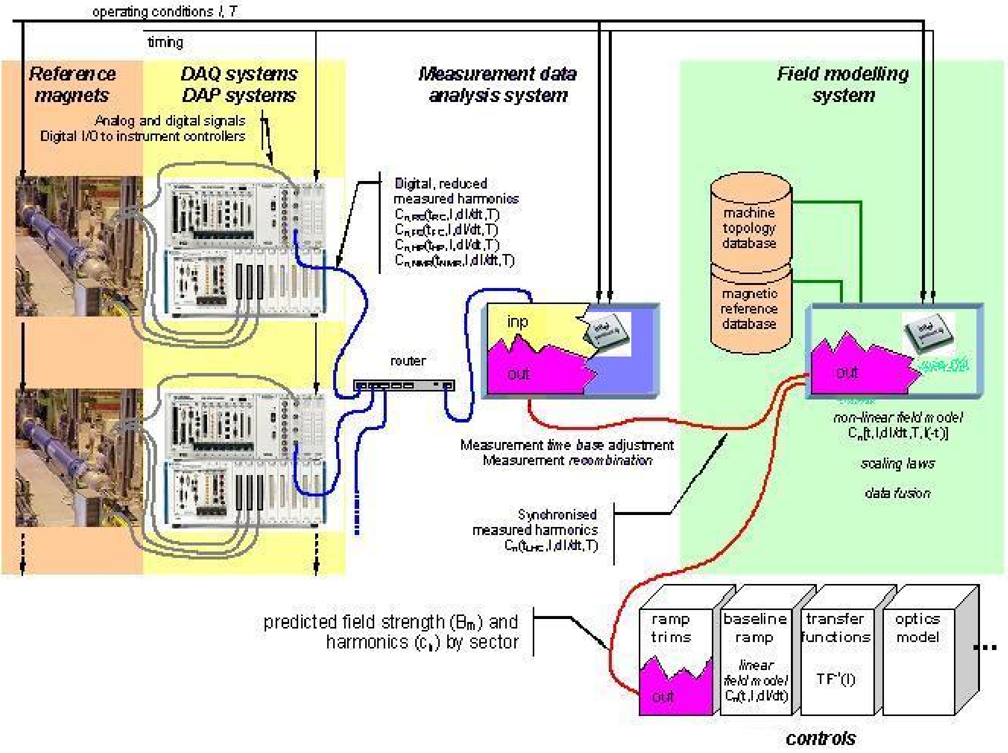


Cored rutherford cable

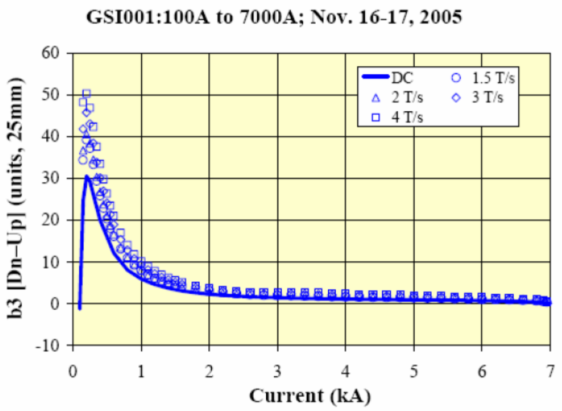


Laser cutted cooling slots

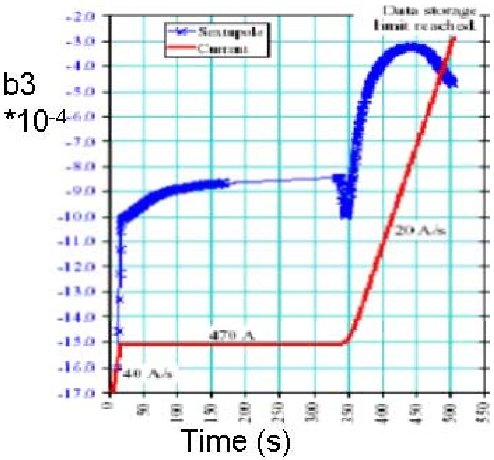
Transient Field Errors in SIS300



Fast feed back system



Sextupole componet during fast ramping



Snap back effect

Radiofrequency Systems: 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

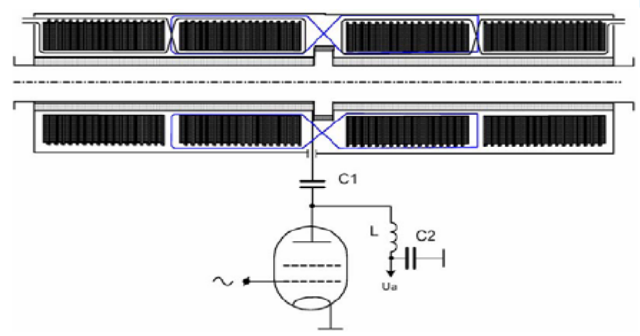

MA test cores at GSI

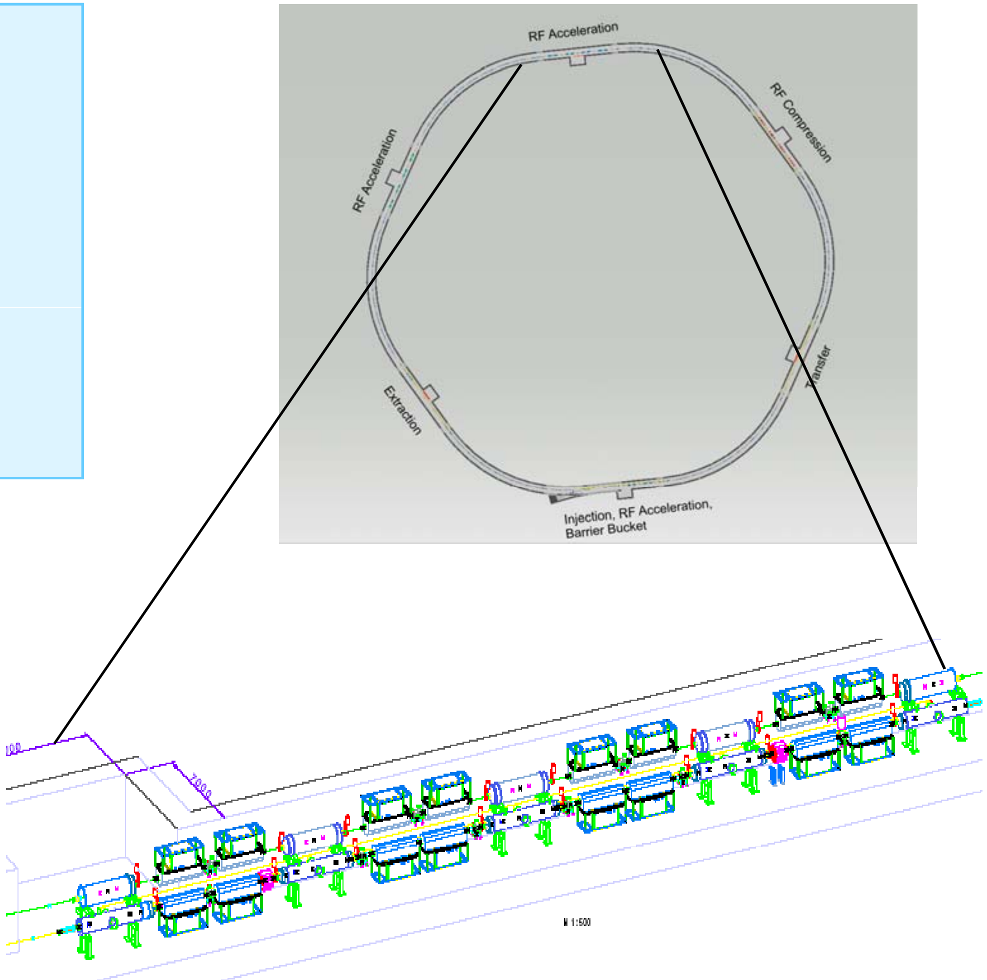

SIS18 bunch compressor

Radiofrequency: Acceleration Sections

Acceleration Cavities:

- Design study completed (BINP)





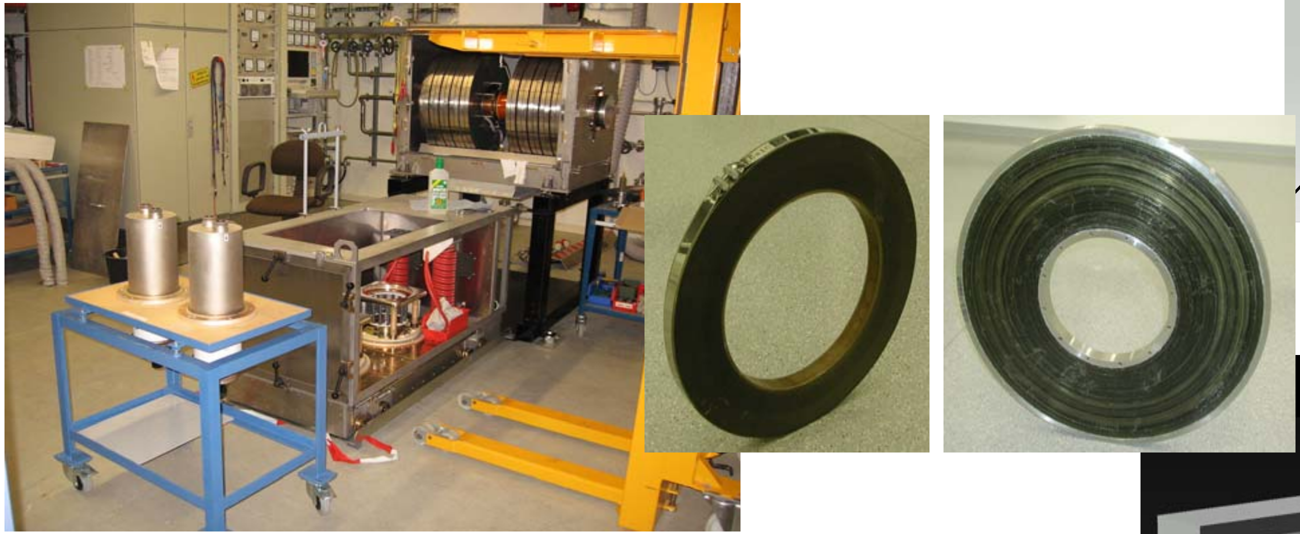
Minimization of shunt impedance:

Fast semi-conductor gap switch R&D

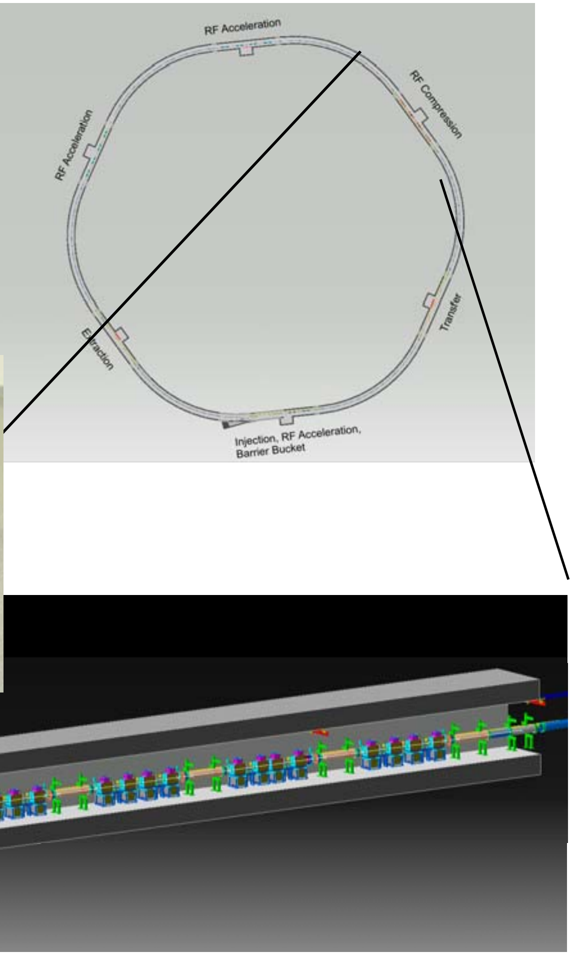
Bunch Compression Systems

Short Pulse, High Power MA Cavities:

SIS18 compression system (ready for installation), CR debuncher system and SIS100 compression system



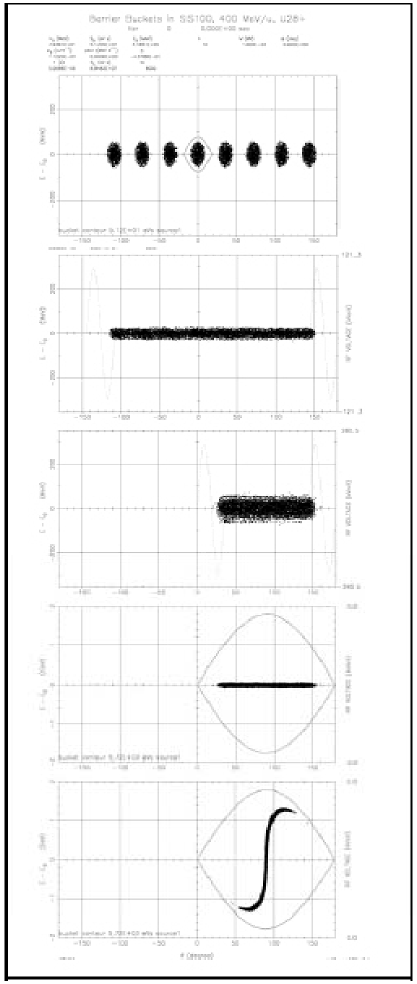
SIS18 short pulsed (500 µs), high power bunch compressor developement and world MA core material survey

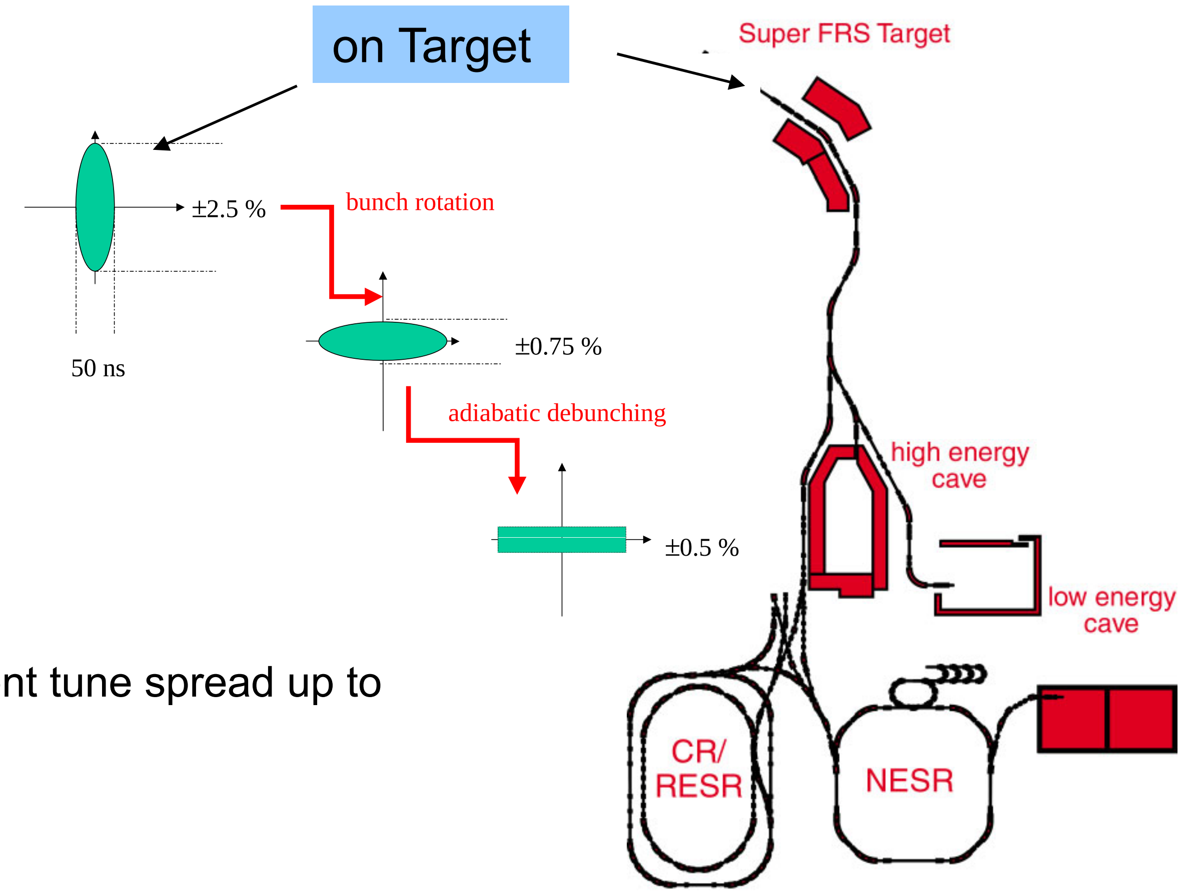


16 MA compression cavities in section S2

Bunch Compression in SIS100

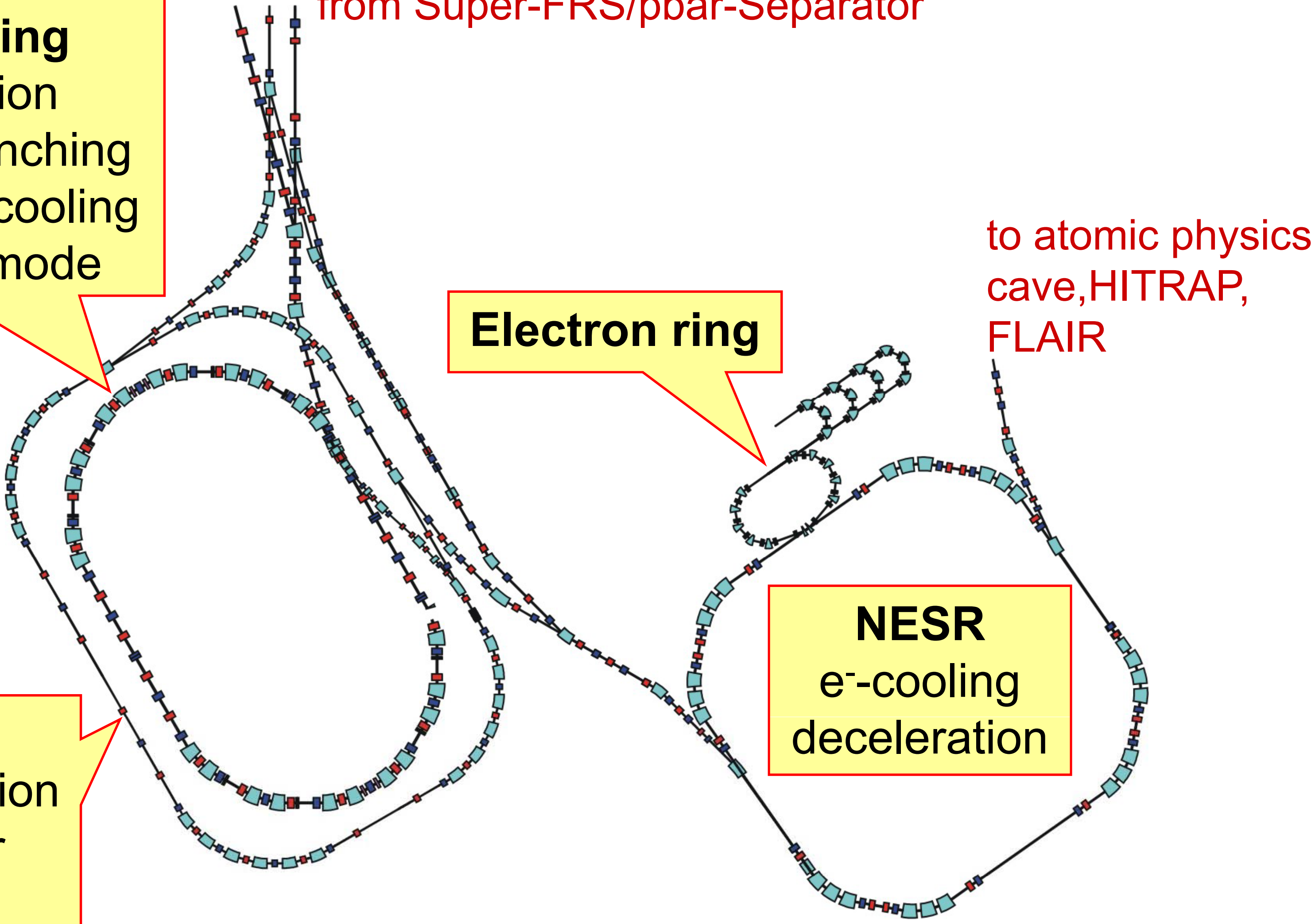
Short pulses for optimum target matching and fast cooling in CR





Incoherent tune spread up to dQ ≈-1

Storage Ring Complex



from Super-FRS/pbar-Separator

Collector Ring
bunch rotation
adiabatic debunching
fast stochastic cooling
isochronous mode

Electron ring

to atomic physics cave,HITRAP, FLAIR

NESR
e^--cooling
deceleration

RESR
pbar accumulation
fast RIB/pbar
deceleration

Antiprotons and RIBs in the CR

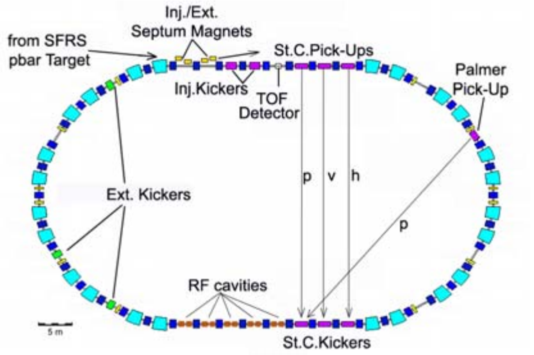
Two different energies and velocities:
b = 0.83 at 740 MeV/u for RIBs
b = 0.97 at 3 GeV/u for antiprotons

Synchronize particles and signals between pick-up and kicker

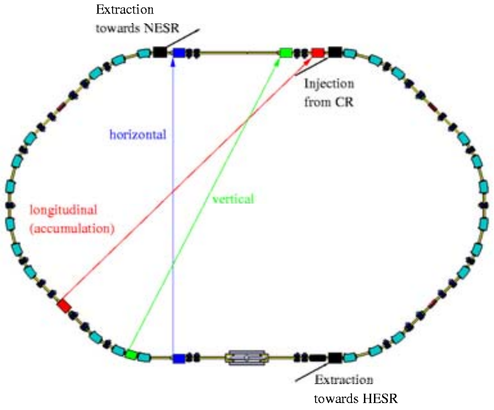
- **Two completely different optical settings with different acceptance**
- **dp/p = ± 1.75 %, emittances 200 mm mrad for RIBs**
- **dp/p = ± 3.00 %, emittances 240 mm mrad for antiprotons**

- **reversed polarity for magnet power supplies**
- **cryogenic pick-ups for antiprotons**

CR

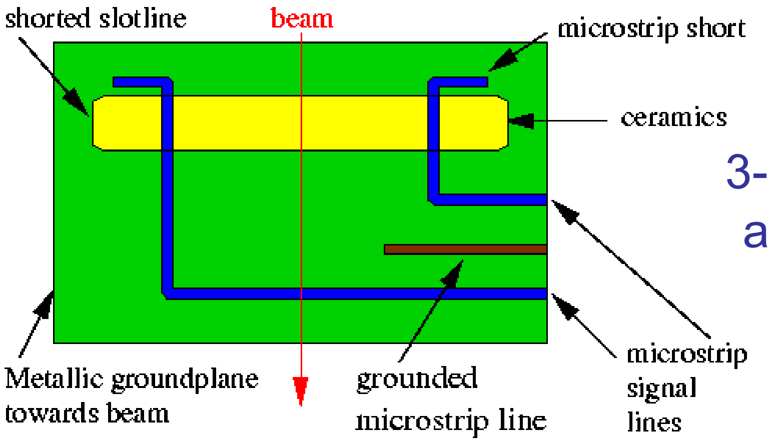


RESR



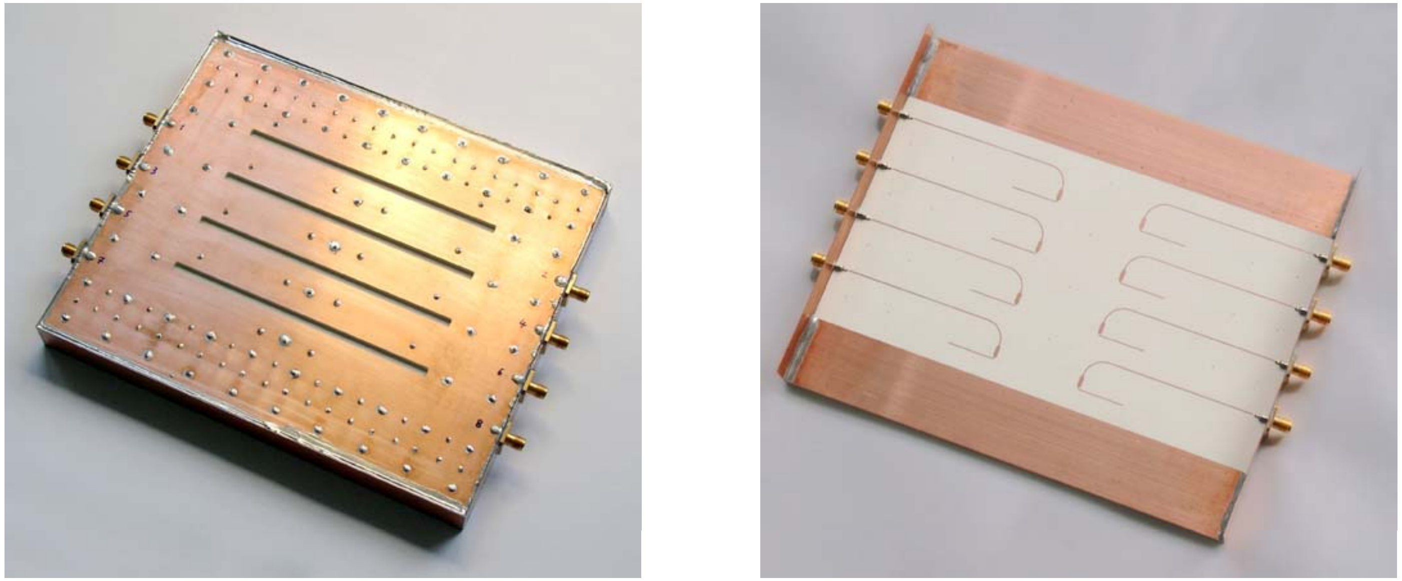
Electrodes for Stochastic Cooling

structure for use at two velocities β=0.83, β=0.97



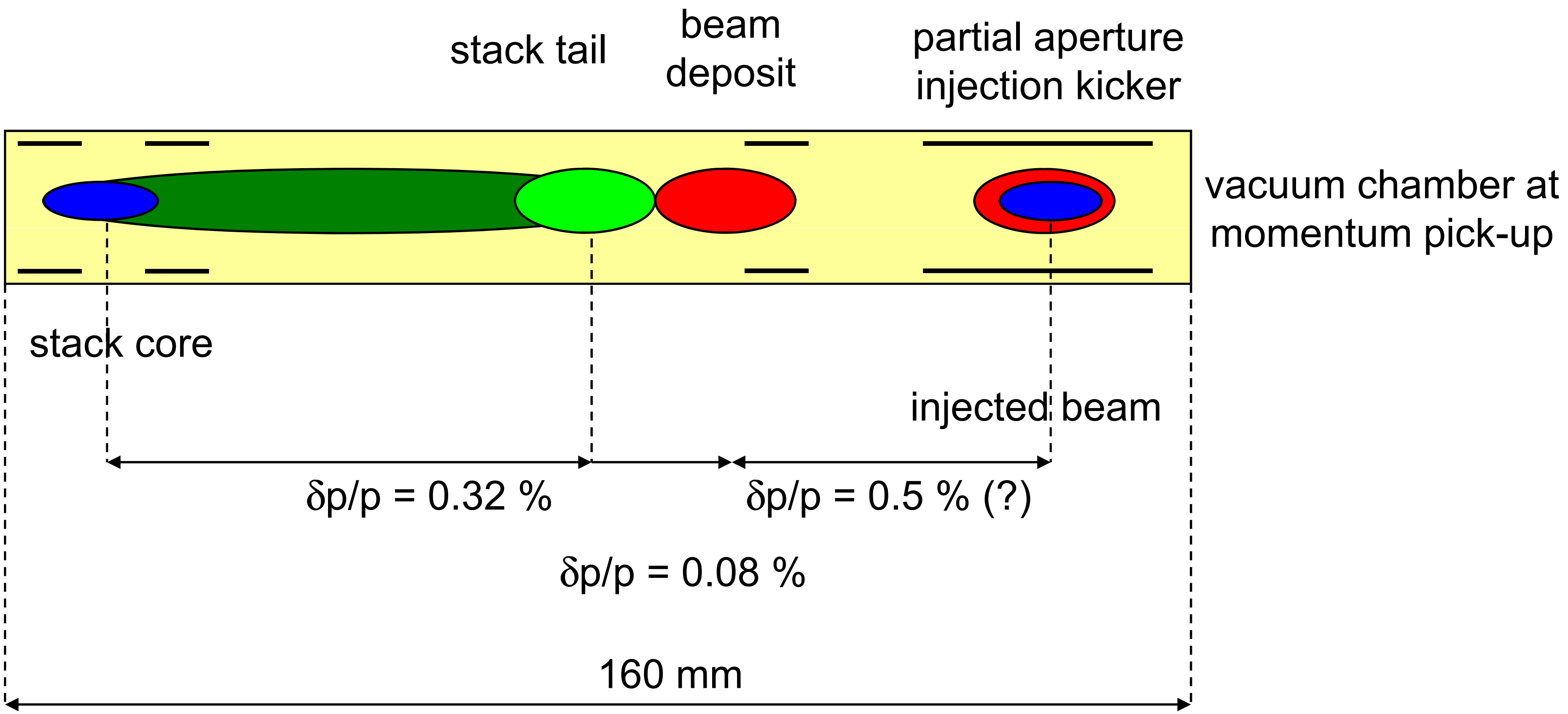
3-D field calculations at TEMF Darmstadt

prototype electrode



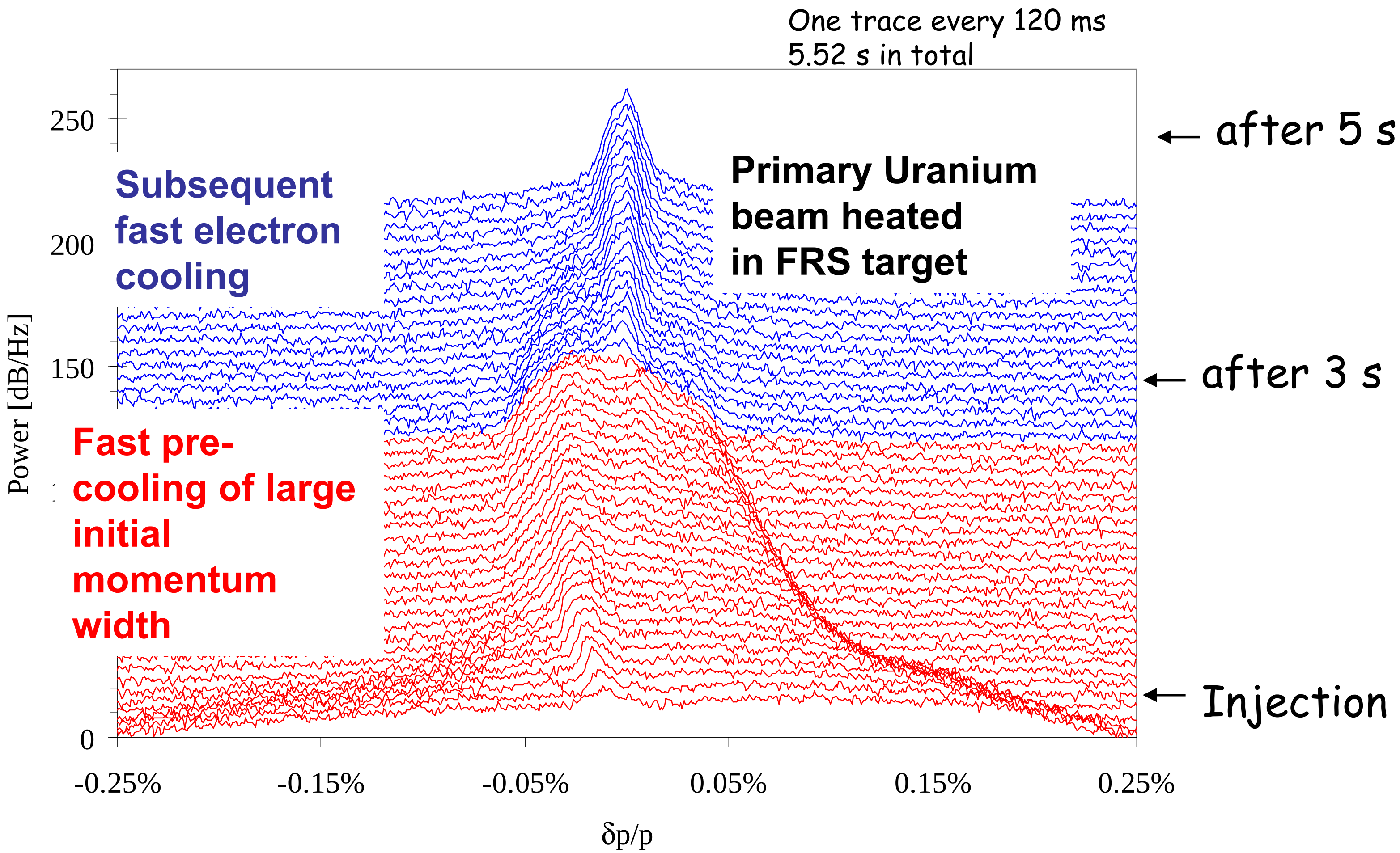
beam side **back side**

Antiproton Accumulation in RESR



- Exponential gain profile stack tail to stack core
- Exponential decrement given by intensity ratio
- Can be realized by suitable pick-up
- Yields distance tail-core

Combined Stochastic and Electron Cooling

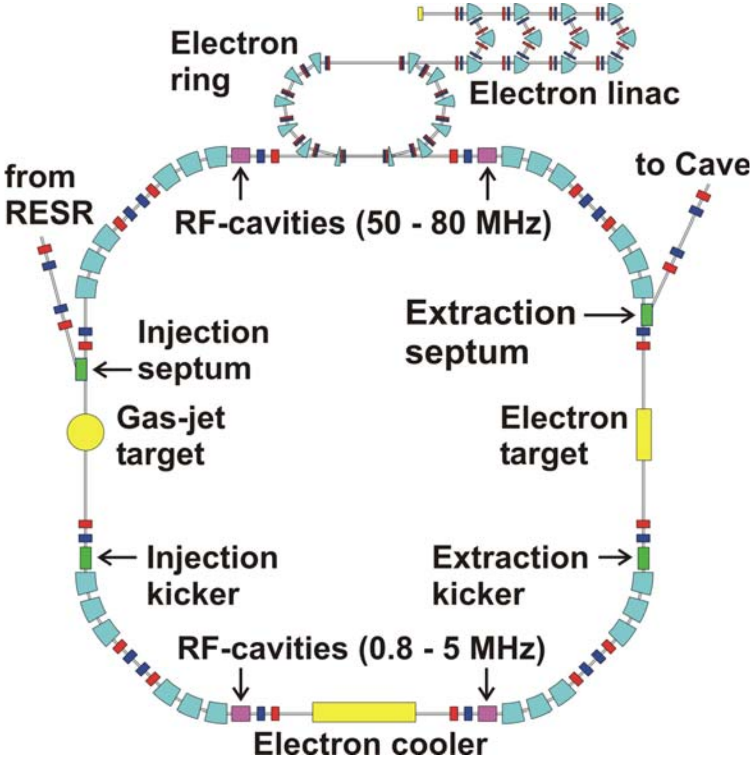


Subsequent fast electron cooling

Primary Uranium beam heated in FRS target

Fast pre-cooling of large initial momentum width

RIB Experiment Ring 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:

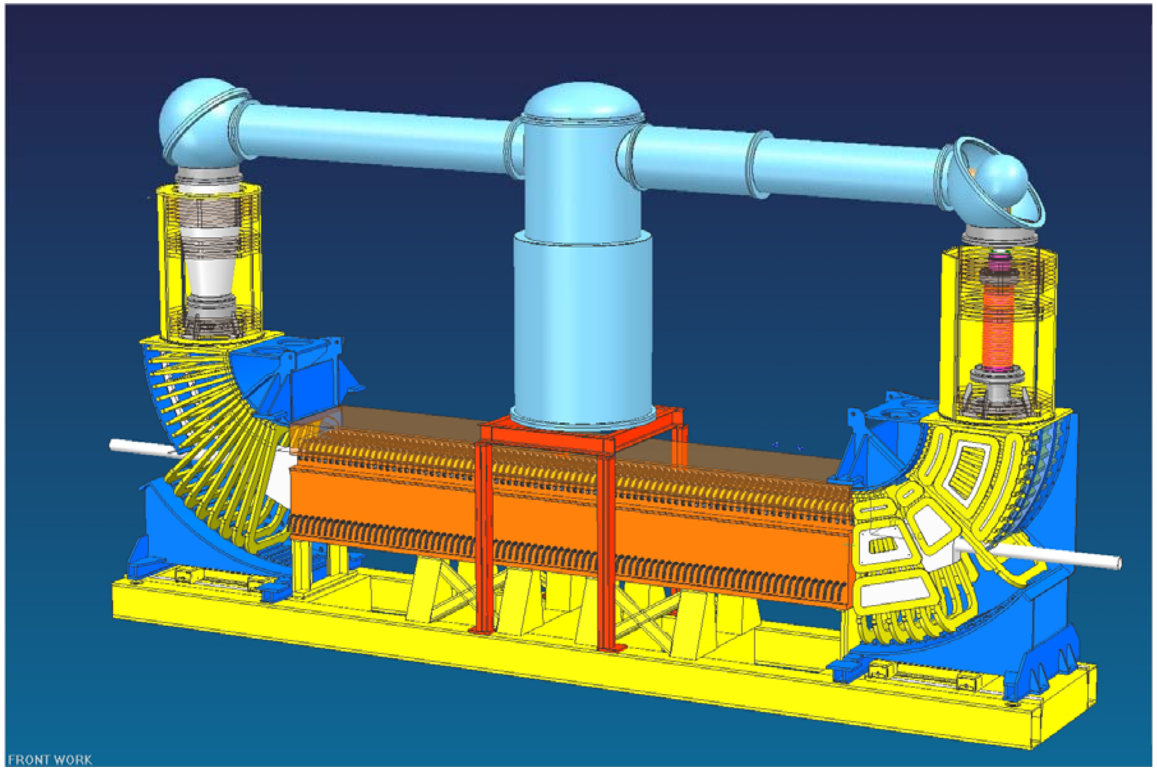
Circumference	45.22 m
Electron energy	200-500 MeV

Detailed lattice layout for storage ring and collider mode

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

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

Antiproton Storage Ring HESR

HESR consortium consists of FZJ, GSI and TSL

Conceptional design report

Beam Parameter:

0.8 - 14.5 GeV $\overline{p}$

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

$L = 2x10^{32}\ cm^{-2}s^{-1}$

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

Beam Quality:

0.001 – 0.1 mm mrad

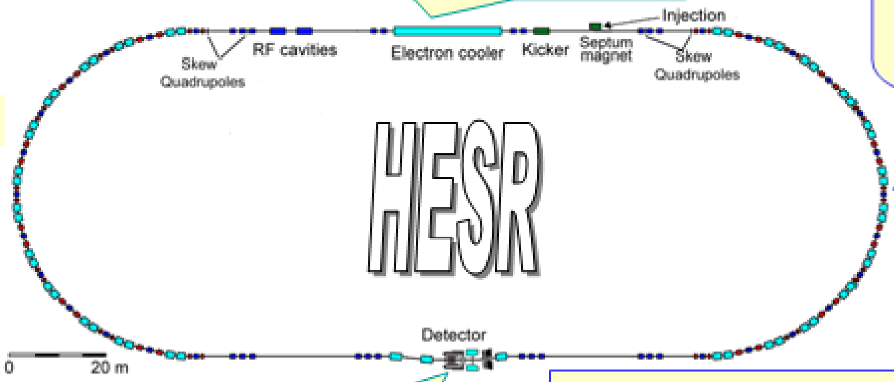
dp/p= 10^{-5} (HRM), 10^{-4} (HLM)

Beam Accumulation:

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

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

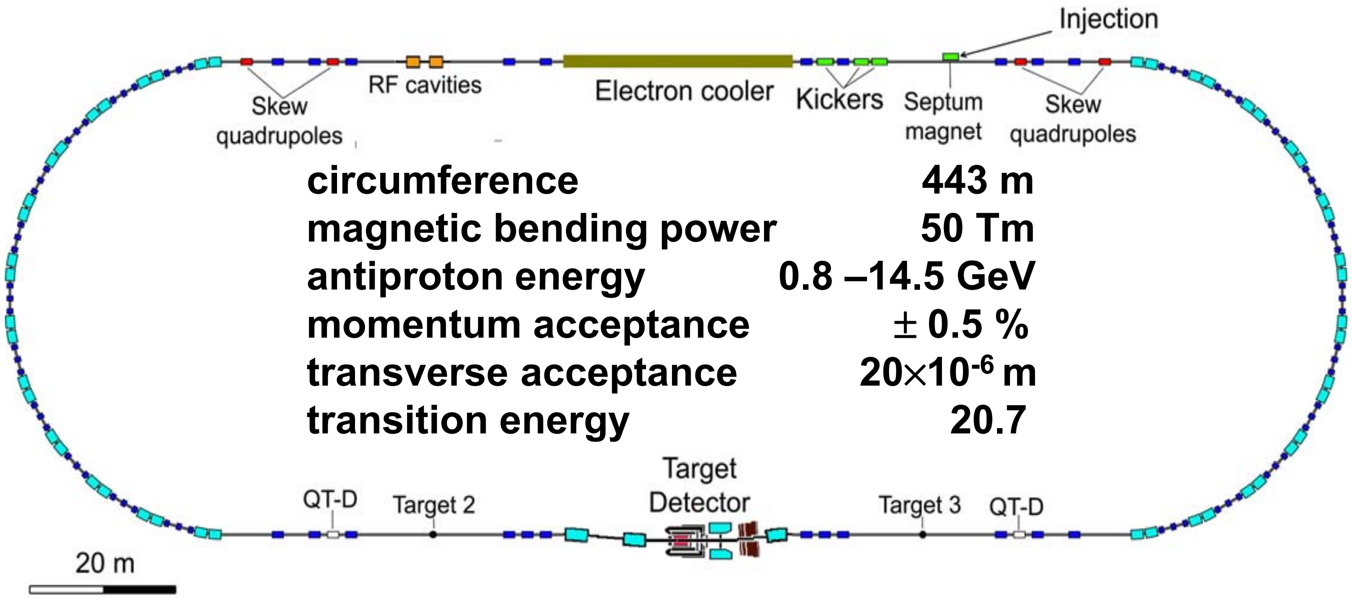
d=1 mm

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

Accelerator R&D work:

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

Antiproton Storage Ring HESR

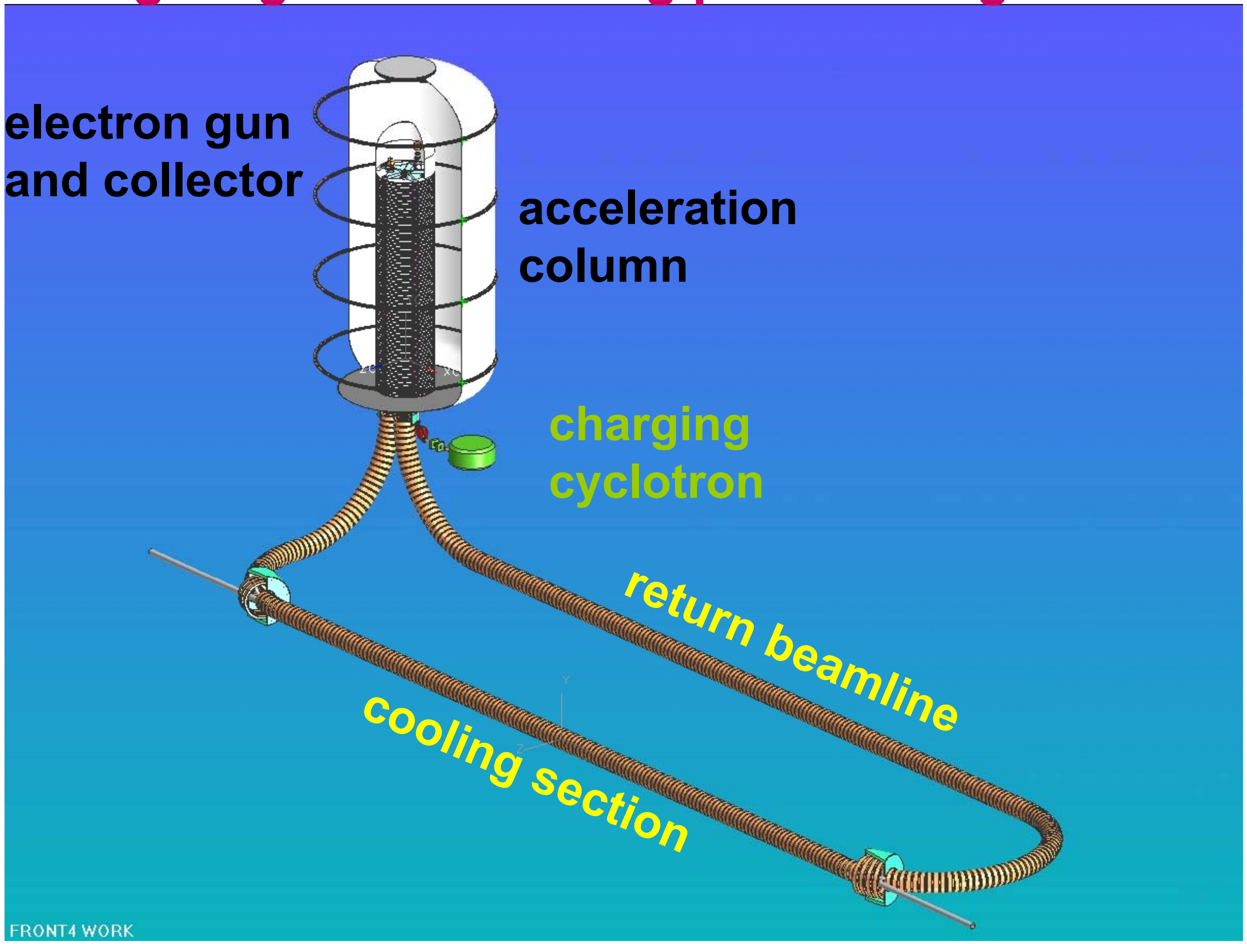


circumference	443 m
magnetic bending power	50 Tm
antiproton energy	0.8 –14.5 GeV
momentum acceptance	± 0.5 %
transverse acceptance	20×10^{-6} m
transition energy	20.7

- **ramped (synchrotron like) operation**
- **electron cooled antiprotons in the energy range 0.8-14.5 GeV (novel design for powerful cooling)**
- **excellent energy resolution 100 keV with electron cooled antiproton**
- **internal hydrogen target (pellet, cluster) with density up to 5×10^{15} cm^{-2}**
- **maximum luminosity 2×10^{32} cm^{-2}s^{-1} (consuming all produced antiprotons)**

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**

Summary Challenges

Magnets : high ramp rate of curved, s.c. magnets, long term mechanical reliability, together with sufficiantly good field quality

RF Systems : high voltages, low impedance, low frequency, as short as possible, moderate pulse power

UHV : huge pumping speed, low desorption rates, ultra high static vacuum highly efficient collimation system

Beam dynamics : low loss budget at highest heavy ion beam intensities and with impedances of huge extraction and rf systems

(quenching, activation, desorption, life time of organic materials etc.)

Stochastic cooling : fast cooling of antiprotons and rare isotopes in a ring with different optical settings but same pick-ups structures

HE electron cooling : Electrostatic e-beam accelerator for appropriate e-beam quality

And others..........