The FAIR Project Science Goals

FAIR = Facility for Antiproton and Ion Research

Studies of

short-lived rare isotope beams:	astrophysics, nucleosynthesis in supernovae and stellar processes
hadron matter with antiprotons:	confinement of quarks, generation of hadron masses

compressed hadronic matter in high energy nucleus-nucleus collisions

bulk matter in the high density plasma state:	inertial confinement fusion, astrophysics issues
Quantum Electrodynamics:	extremely strong electro-magnetic fields, ion-matter interactions

History and Status of the FAIR Project

2001 *CDR (conceptual design report)*

→ positive response of German Ministry of Science and Research

request: 1) international contribution 25 % of 670 Mio €

2) TDR (technical design report)

2004 *10 countries signed MoU (Finland, France, Great Britain, Greece, Italy, Poland, Russia, Spain, Sweden, Germany)*

Observers: China, Hungary, India

present: *international boards established*

AFI: administrative and financial issues

STI: scientific and technical issues

work on definition of project, financial contributions

Additions after CDR:

RESR: accumulator ring for antiprotons

AIC: antiproton - RIB collider

FLAIR: low energy antiproton physics

PAX: polarized antiprotons

....

Recent modifications: fit project into a cost frame of 1 Bio. €

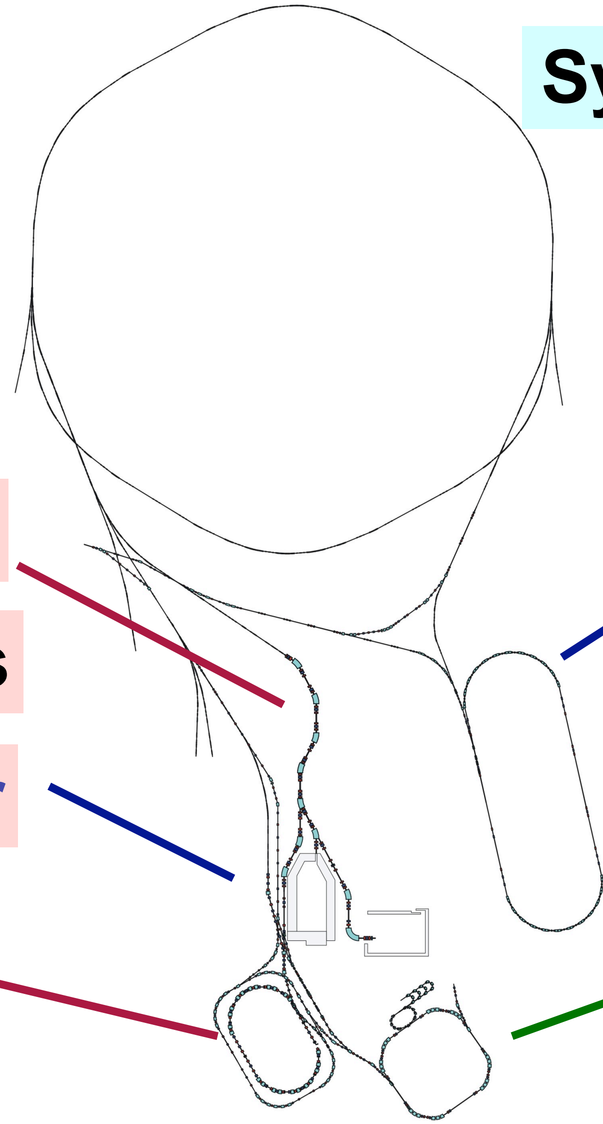
new cost estimates, additional subprojects and manpower included

TDR end of 2005, project definition to German government

The New FAIR Accelerators

Goals:
High beam intensity
High beam energy
High beam quality

Synchrotrons
SIS100
SIS300



HESR

SuperFRS

Separators

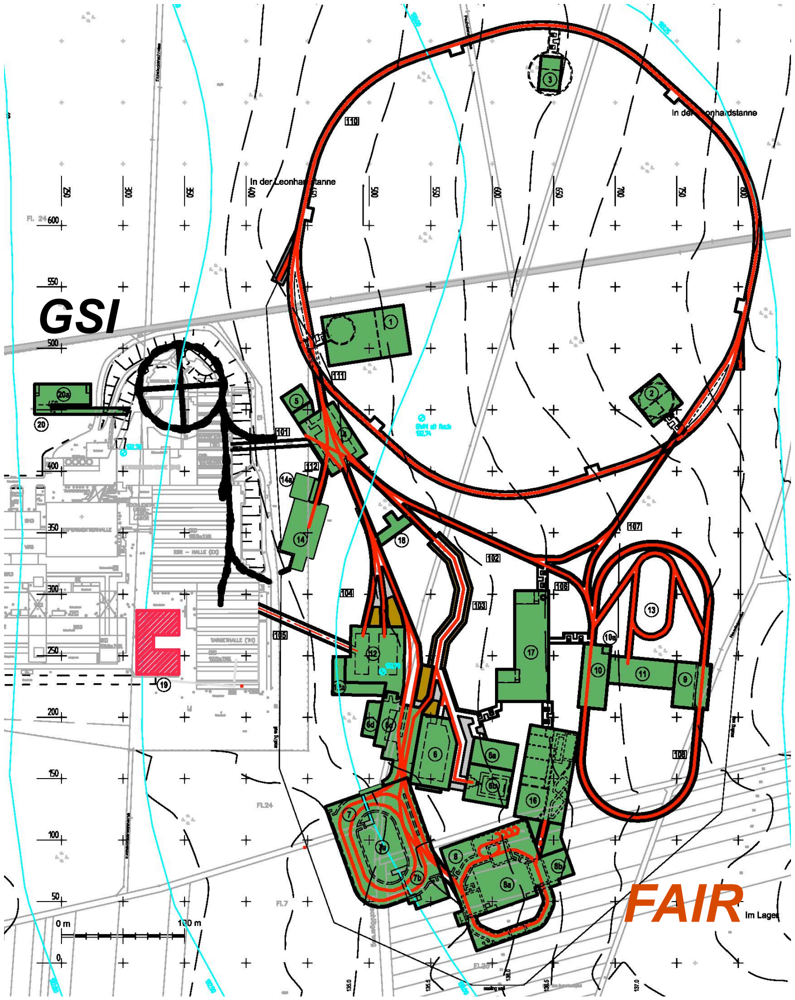
pbar separator

Storage Rings

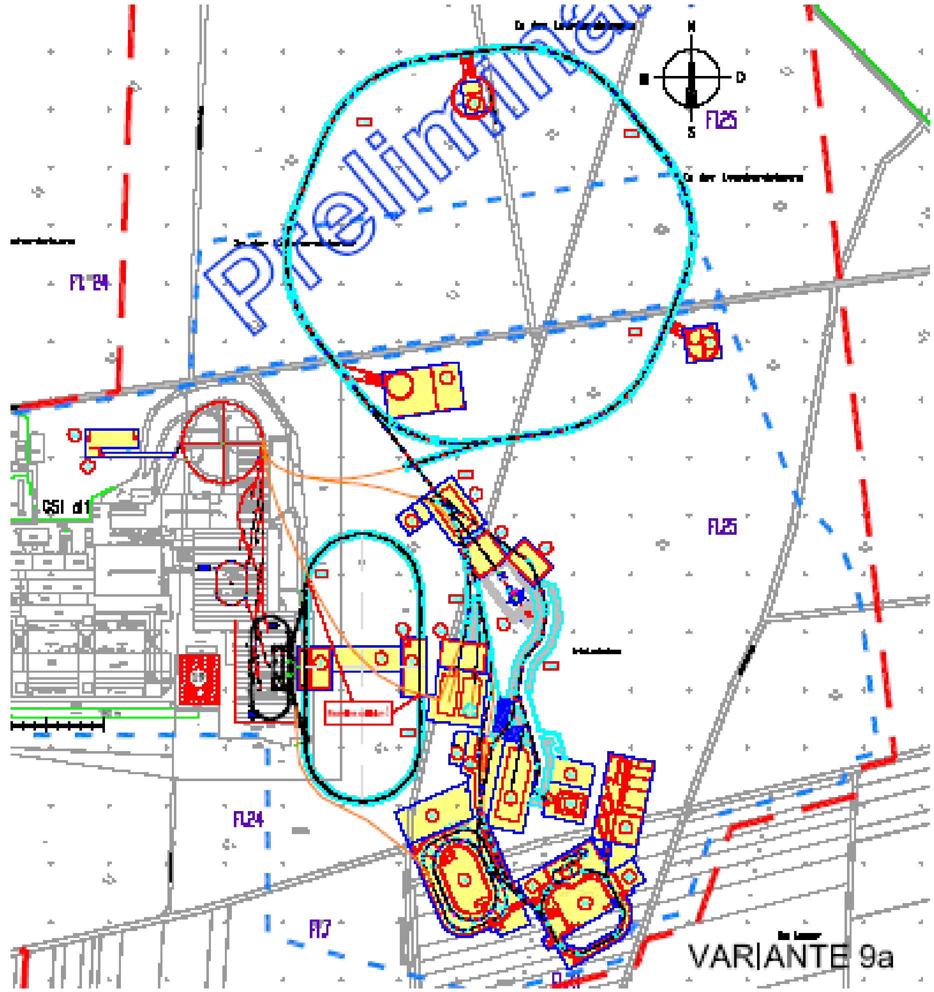
CR-complex
(CR, RESR)

NESR

The FAIR Project Topology

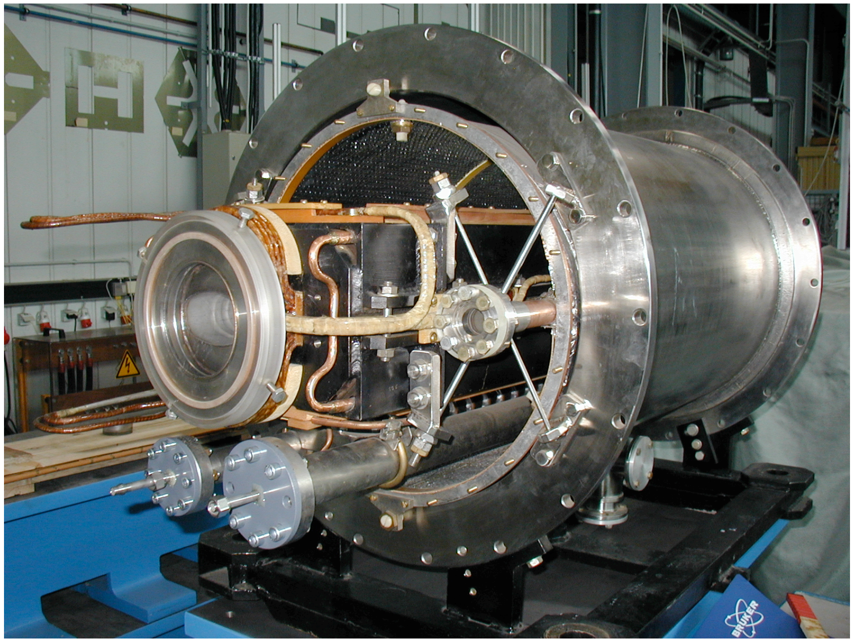


TR draft version, March 05



latest version, September 05

SIS100 Superconducting Magnet R&D

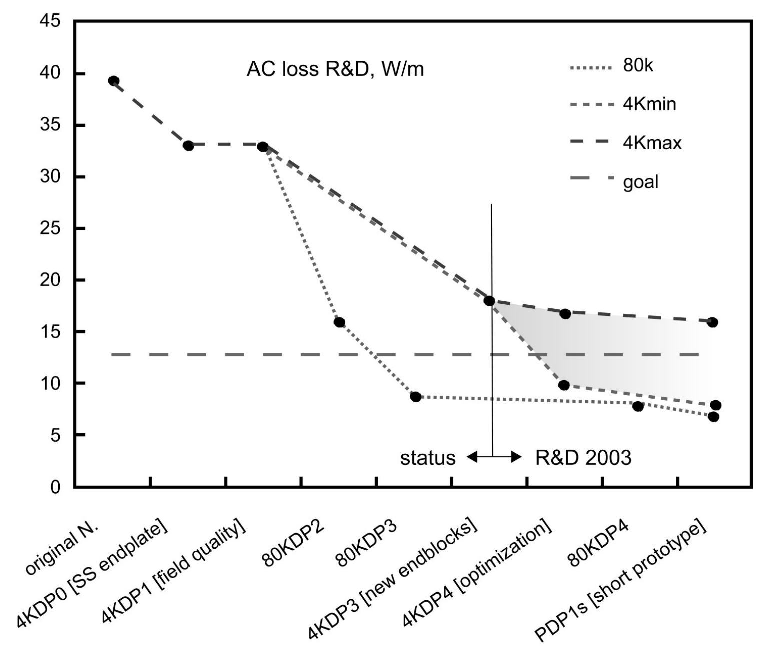


Nuclotron Dipole

- **B_{max} = 2 T – dB/dt = 4T/s**
- **Window frame magnet with s.c. coil**
- **Main task :**
  Reduction of AC losses during ramping improved iron yoke design (40 > 13 W/m)

in collaboration with JINR Dubna

significant R&D progress achieved on dynamic losses and field quality



RF Systems for SIS100

- **Dual Harmonic Acceleration Systems SIS100**
  20 ferrite loaded cavities - $V_{a,tot}$ =400 kV
  frequency range : 1.15 – 2.67 MHz, h=10
  (8 ferrite loaded cavities - $V_{a,tot}$ =150 kV
  frequency range : 2.3 – 5.35 MHz, h=20)

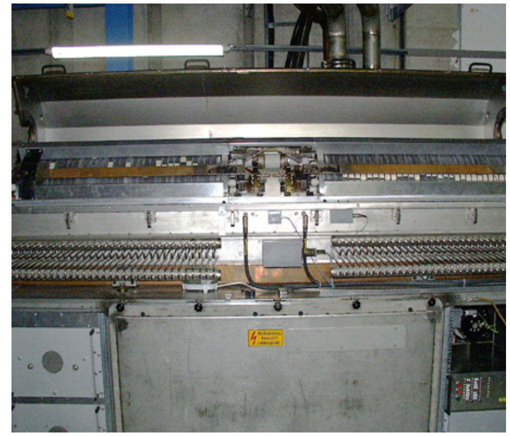
  alternative solution: MA loaded cavities

- **Compression Systems SIS100**
  25 MA loaded cavities - $V_{c,tot}$ = 1 MV
  frequency range : 465 kHz (±70) (h= 2)

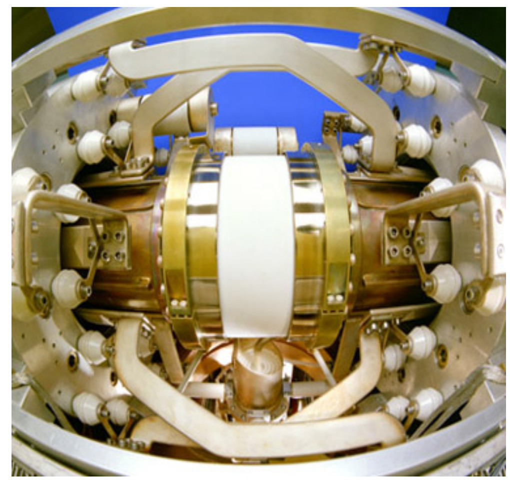
- **Barrier Bucket Systems SIS100 (precompression and stacking)**
  broad band MA loaded cavities - V_b = 2 x 15 kV

total length of RF-Systems ~ 90 (115) m
(~ 10 % of ring circumference)

- **Dual Harmonic Acceleration Systems SIS300**
  6 ferrite-loaded cavities - V_{tot} = 80 kV (h=10)
  frequency Range: 2.67 – 2.76 MHz



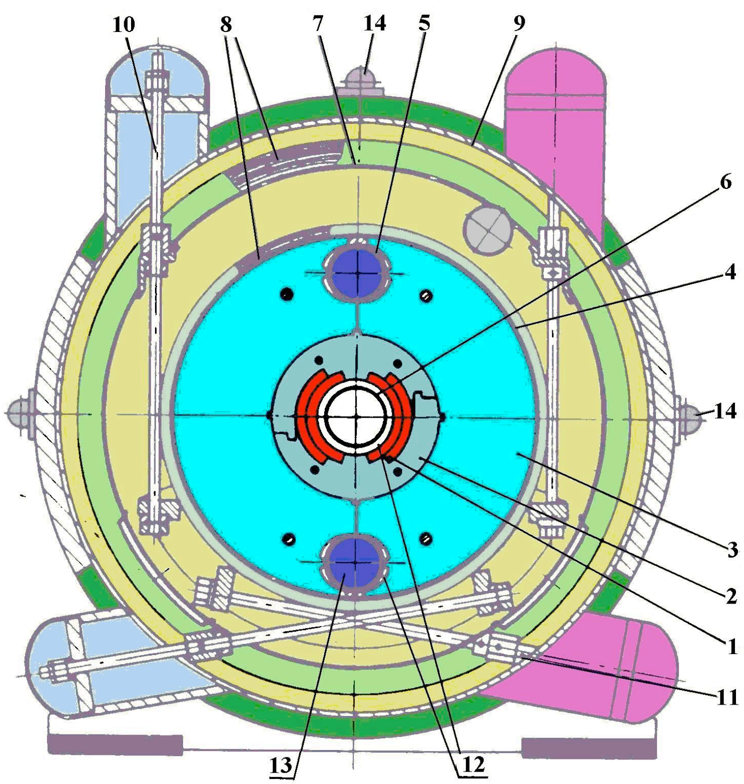
SIS18



GSI

SIS300 Magnet R&D

in collaboration with IHEP, Moscow



Cross section of the UNK dipole (4.5 K)

with **two** layer coil

Operation parameters : 5.11 T at 0.11 T/s

Design Study for a model dipole based on the UNK magnet design

Goals:

- Increase field 5.1 → 6.0 T
- Increase ramp rate 0.11 → 1. T/s
- Increase bore 80 → 100 mm
- Reduction of AC losses
  - filament diameter
  - wire twist pitch
  - wire coating
  - cable (interstrand) losses

The RIB Separator SuperFRS

Design Parameters

$å_x = å_y = 40$ ð mm mrad

$ö_x = \pm 40$ mrad,

$ö_y = \pm 20$ mrad

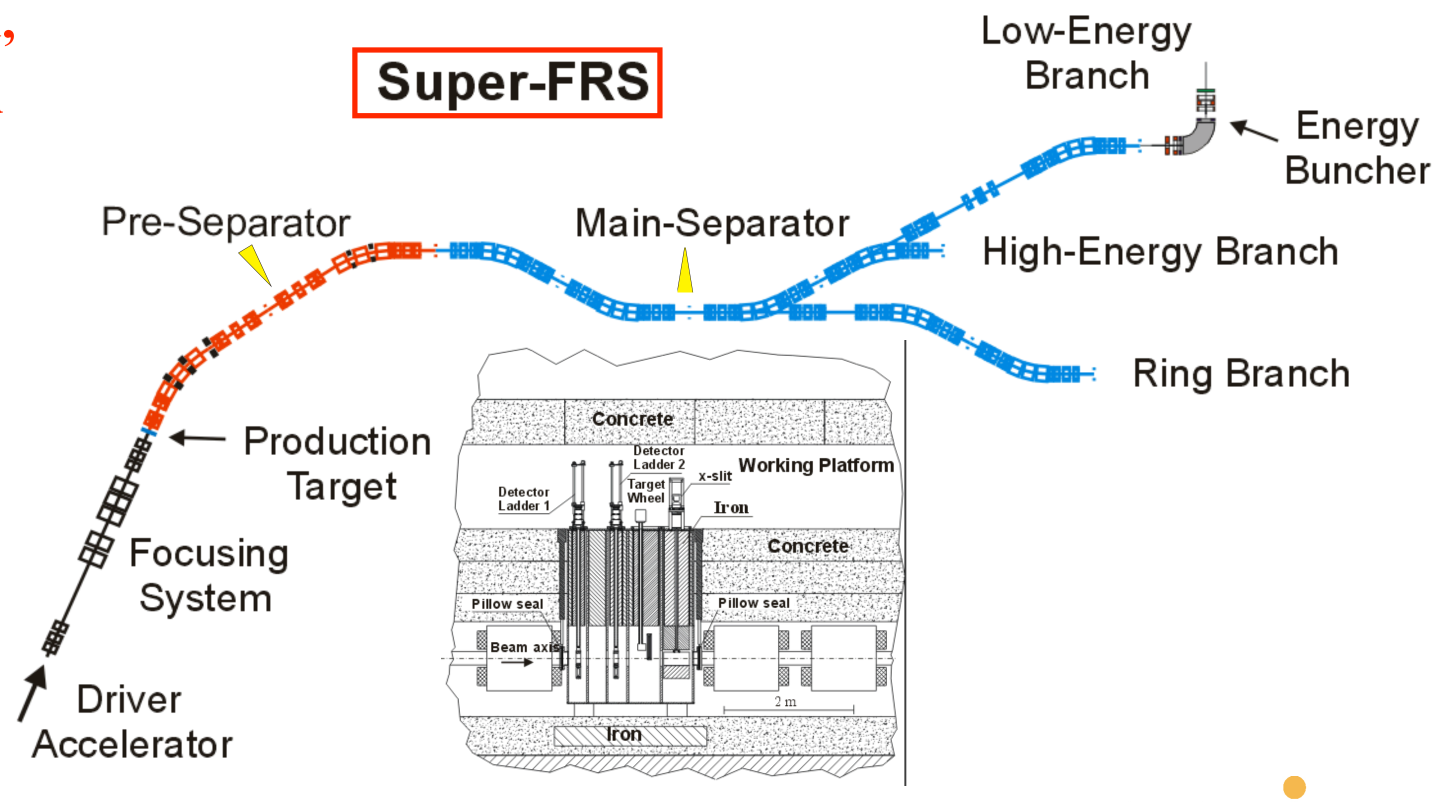
$\frac{Äp}{p} = \pm 2.5\,\%$

$Bñ_{max} = 20$ Tm

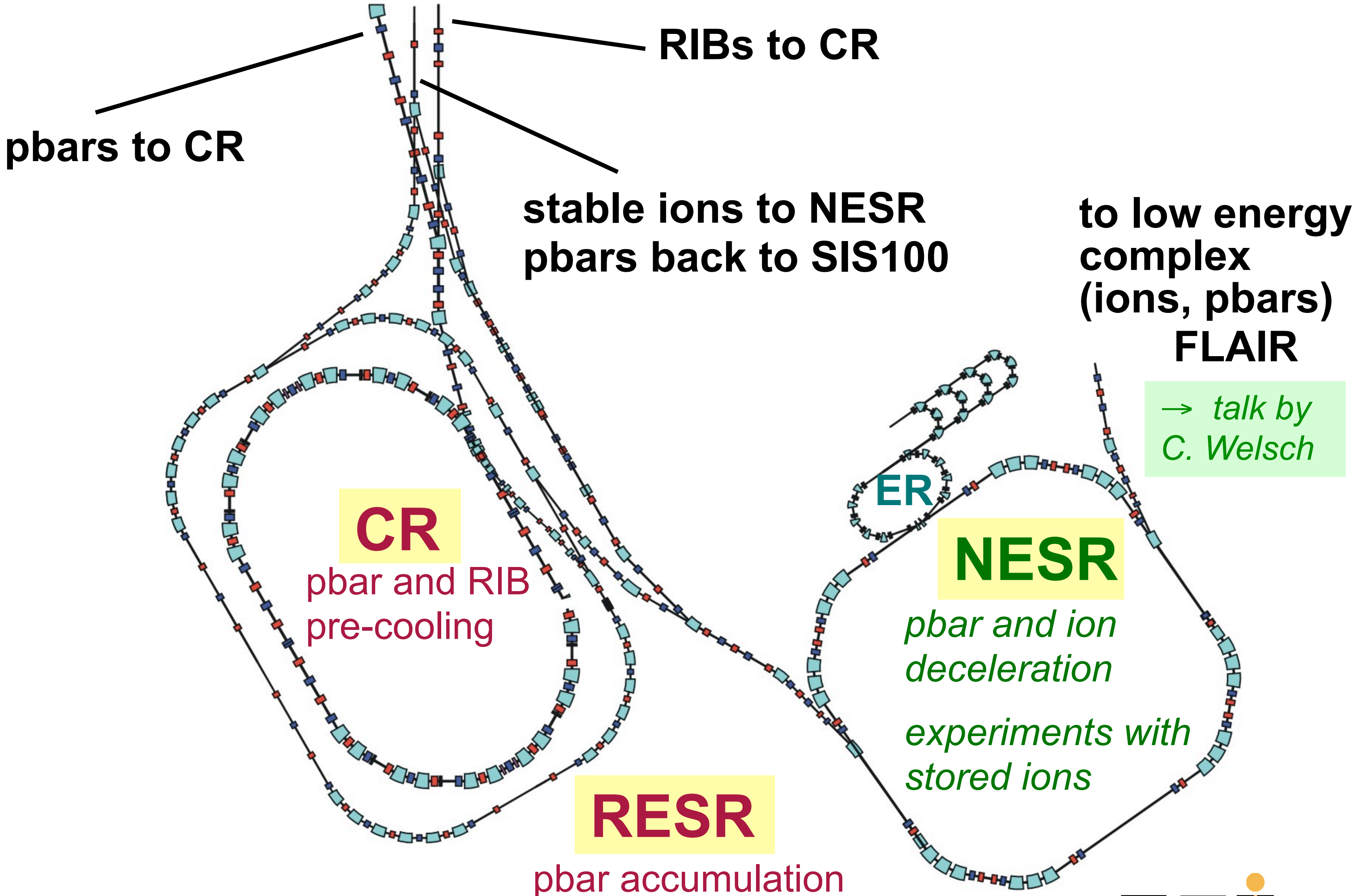
$R_{ion} = 1500$

- Multi Stage
- Multi-Branch
- Superconducting
- Large Acceptance

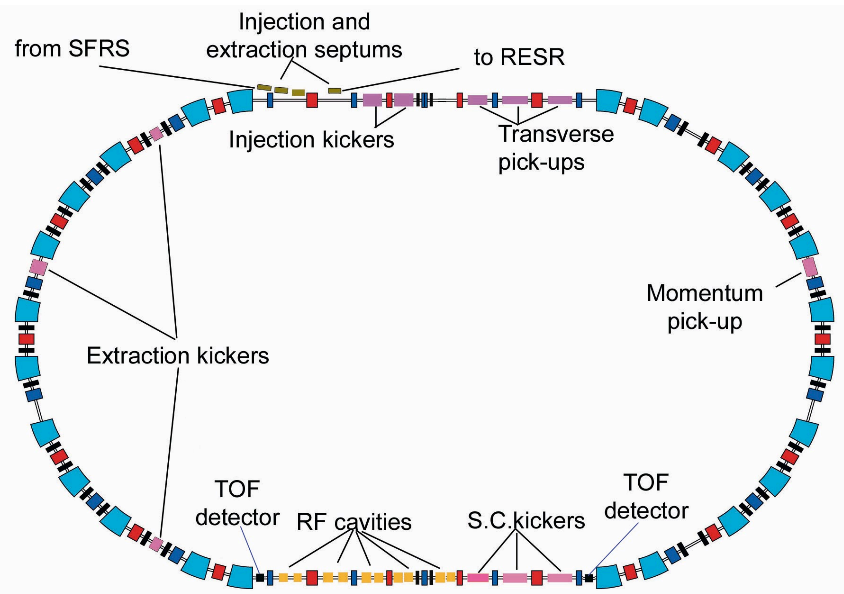
Super-FRS



The FAIR 13 Tm Storage Rings



The Collector Ring CR



- **fast stochastic cooling of antiprotons and rare isotope beams**
  fast bunch rotation with rf voltage 200(400)kV
  adiabatic debunching
  stochastic pre-cooling system 1-2(1-4)GHz
  optimized ring lattice for proper mixing
  large acceptance superconducting dipoles

circumference 212 m
magnetic bending power 13 Tm

isochronous mass measurements of rare isotope beams

operation at transition energy

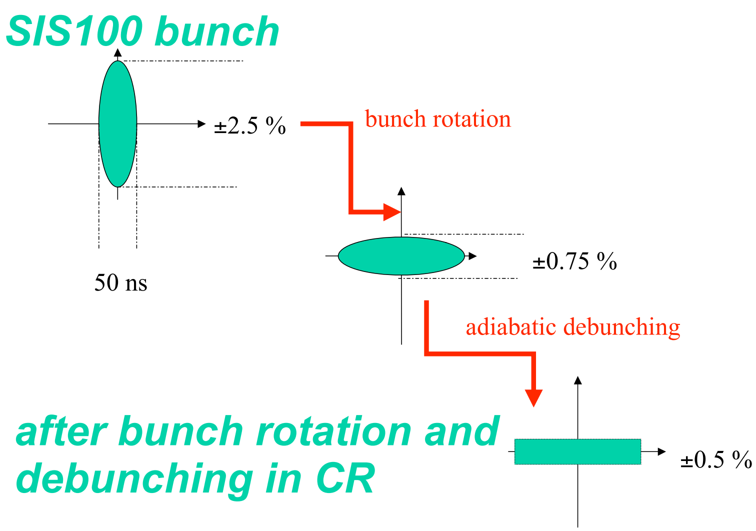
	RIB	pbar	isochronous (RIB)
energy	740 MeV/u	3.0 GeV	≤ 790 MeV/u
tunes Q_x/Q_y	3.17/3.18	4.42/4.24	2.55/3.17
mom. accept.	± 1.5 %	± 3.0 %	± 0.7 %
transv. accept.	200×10^{-6} m	240×10^{-6} m	$70/50\times10^{-6}$ m
transition energy	2.9	3.54	≥ 1.84

→ talk by F. Nolden

Techniques for Fast Cooling in CR

Fast bunch rotation of SIS100 bunch

rf voltage 200 (400) kV at h=1
after passage of production target
to reduce momentum spread (2.5→ 0.5 %)



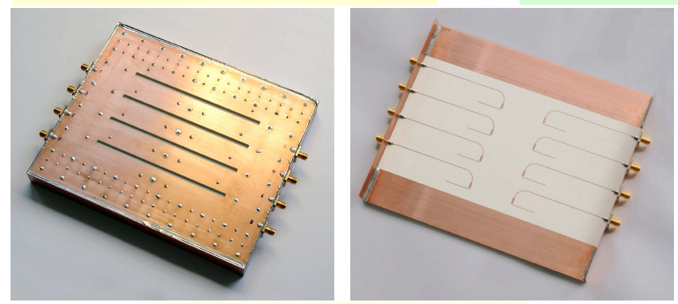
providing optimum initial parameters
for stochastic cooling

Fast stochastic pre-cooling

system band width 1-2 (1-4) GHz
matched to velocities β = 0.83 - 0.97
rf power ~ 1-2 kW per system

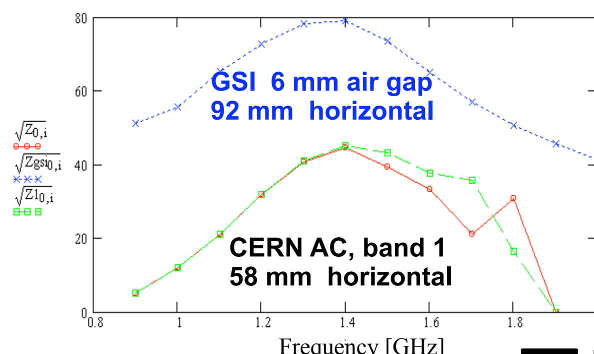
→ poster by C. Peschke

electrode prototype



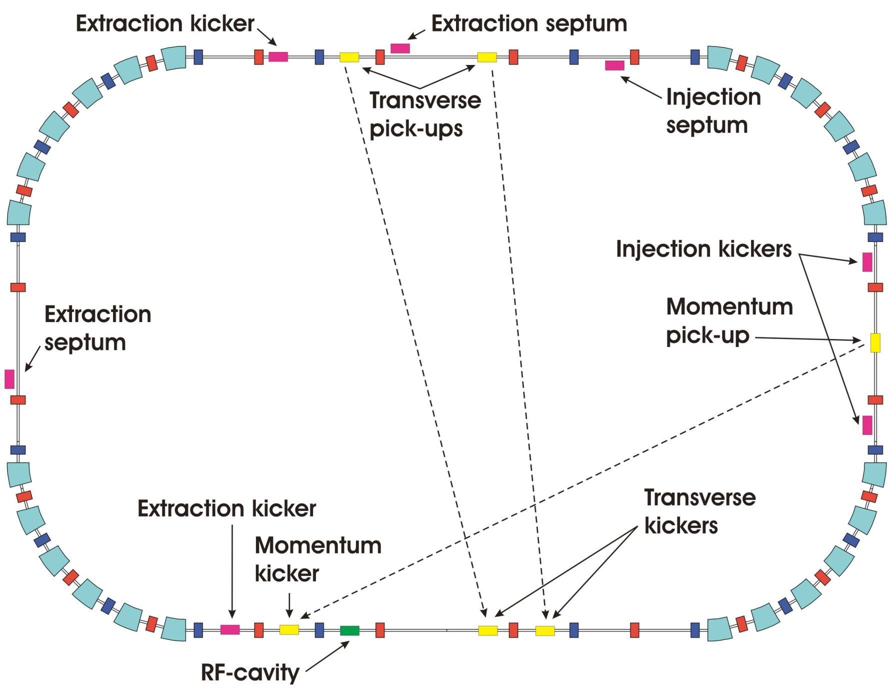
front and back side

Increase of impedance (factor of 4)



analysis by L. Thorndahl

RESR
The Accumulator and Decelerator Ring



circumference	245.5 m
magnetic bending power	13 Tm
tunes Q_x/Q_y	3.8/3.3
momentum acceptance	±1.0 %
transverse accept. h/v	$80/35 \times 10^{-6}$ m
transition energy	3.62

- **accumulation of antiprotons by stochastic cooling**
  max. accumulation rate 7×10^{10}/h
  (first stage 2.6×10^{10}/h)
- **fast deceleration of RIBs**
  from 740 to 100 MeV/u
  with maximum ramp rate 1T/s

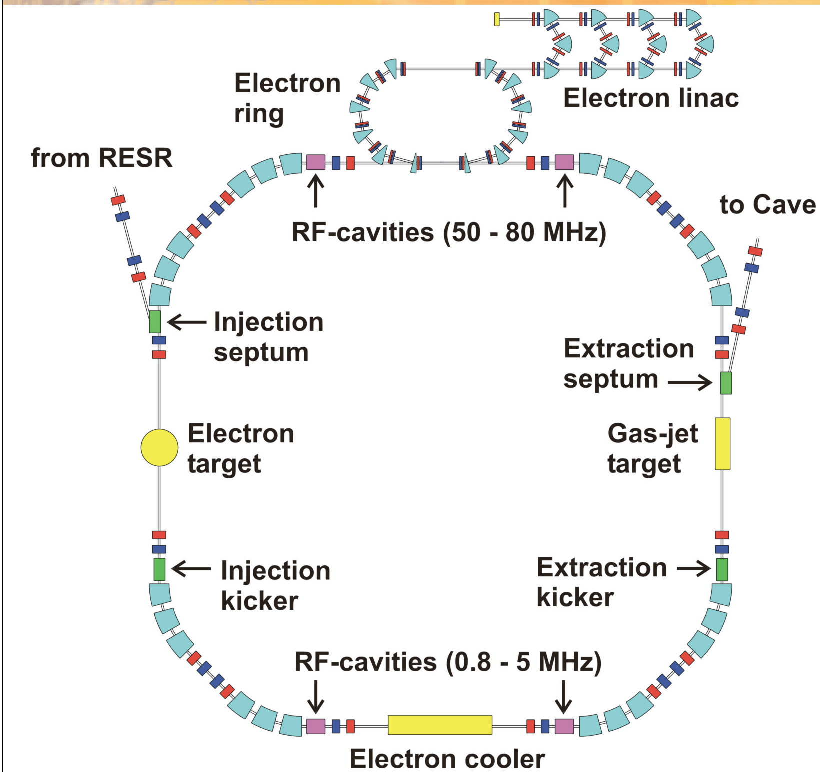
reuse of ESR components
use of NESR dipole magnets

accumulation scenario ?
classical CERN scheme ↔ barrier bucket accumulation
(large momentum acceptance) (short rf barriers, timing)

→ talk by T. Katayama

NESR

Versatile Storage Ring for Physics Experiments



circumference	222.11 m
magnetic bending power	13 Tm
tunes Q_x/Q_y	3.4 / 3.2
momentum acceptance	±1.75 %
transverse accep. h/v	$160/100\times10^{-6}$ m
length of straight section	18 m

Ions

storage and cooling of ion beams in the energy range 740 → 4 MeV/u

maximum deceleration rate 1 T/s

experiments with internal target

luminosity up to 10^{29} $cm^{-2}s^{-1}$

RIB accumulation by electron cooling

collider mode

1) **with electrons** *luminosity up to 10^{28} $cm^{-2}s^{-1}$*
2) **with antiprotons** *luminosity up to $10^{23}cm^{-2}s^{-1}$*

electron target

Antiprotons

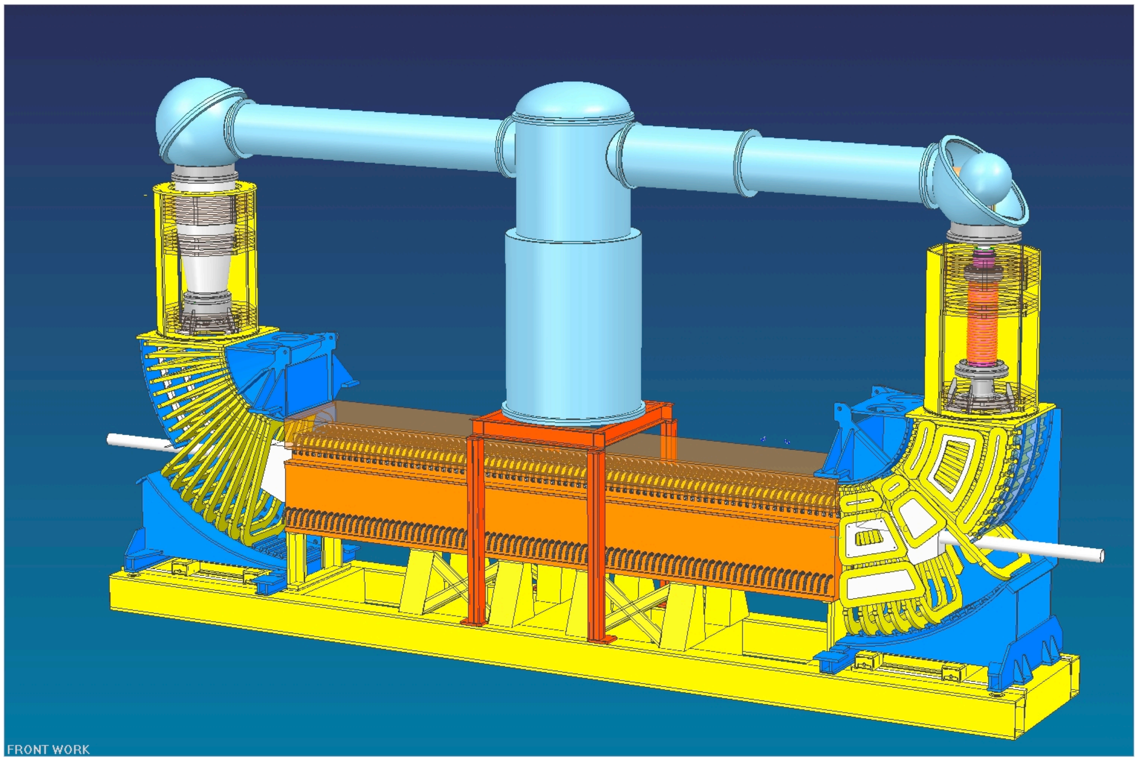
deceleration 3000 → 800 → 30 MeV

electron cooling at 800 MeV

GSI

NESR Electron Cooler

design by BINP, Novosibirsk



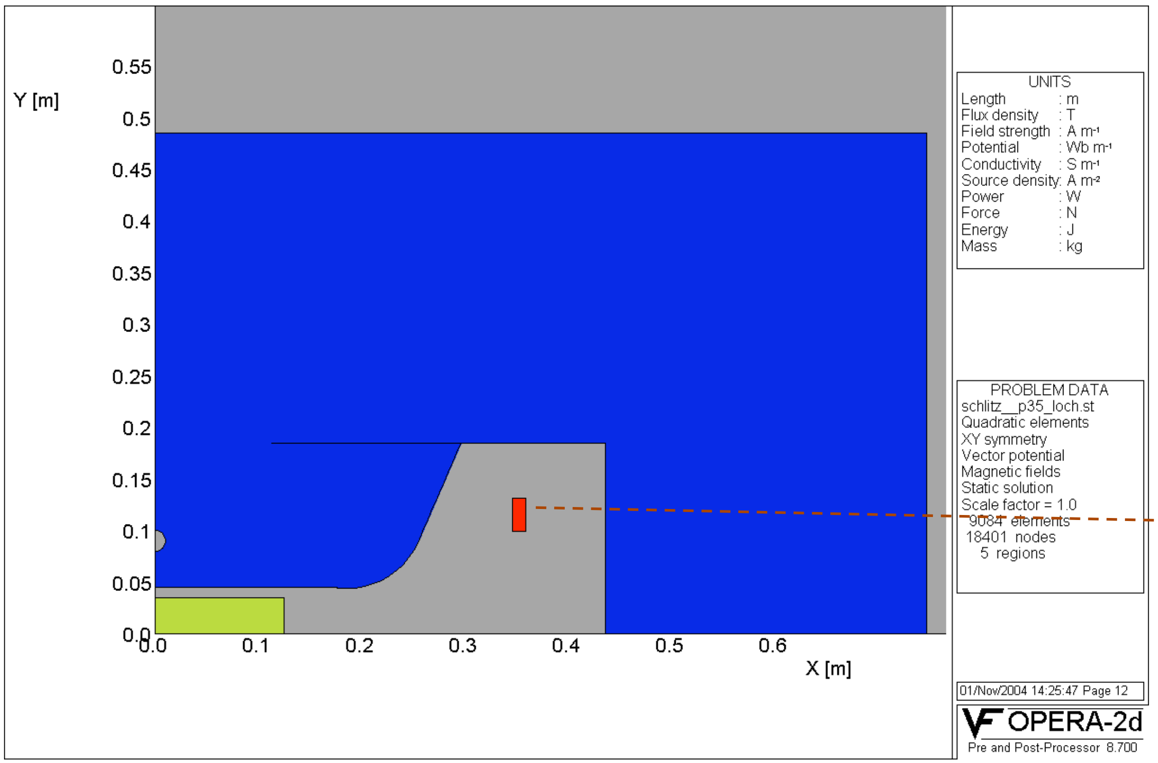
Cooler Parameters

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

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

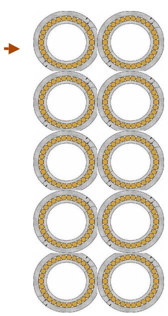
Super-ferric Dipole Magnets for NESR/RESR

preliminary 2D-design of NESR dipole



C. Mühle

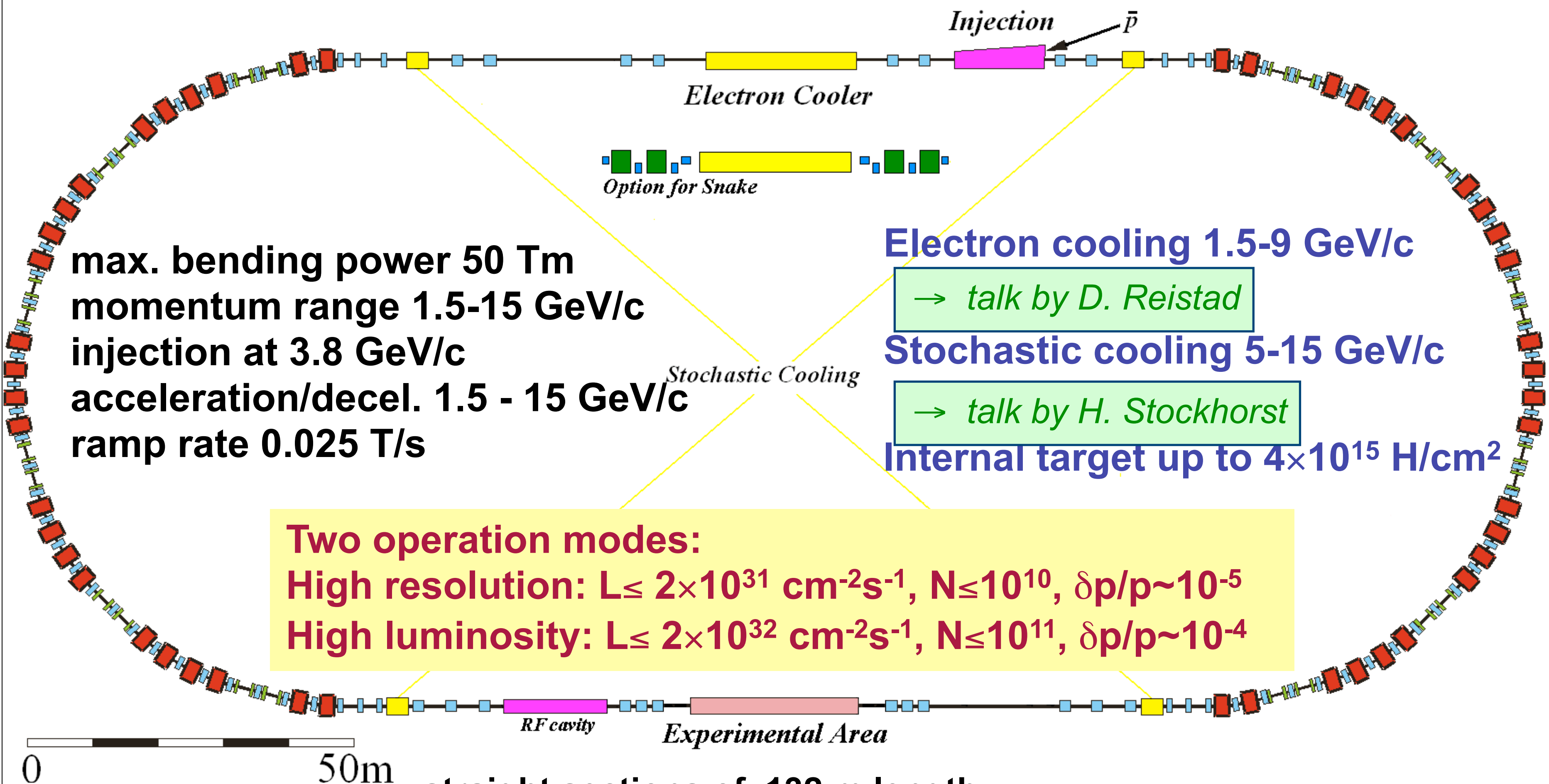
- fast ramping 1T/s
- large dynamic range (0.06 - 1.6 T)
- large useful aperture (250 × 90 mm²)



Coil:
6000 A
10 turns
150 A/mm²

The High Energy Storage Ring HESR

designed by a consortium between FZ Jülich, TSL Uppsala, GSI



max. bending power 50 Tm
momentum range 1.5-15 GeV/c
injection at 3.8 GeV/c
acceleration/decel. 1.5 - 15 GeV/c
ramp rate 0.025 T/s

Electron cooling 1.5-9 GeV/c

→ talk by D. Reistad

Stochastic cooling 5-15 GeV/c

→ talk by H. Stockhorst

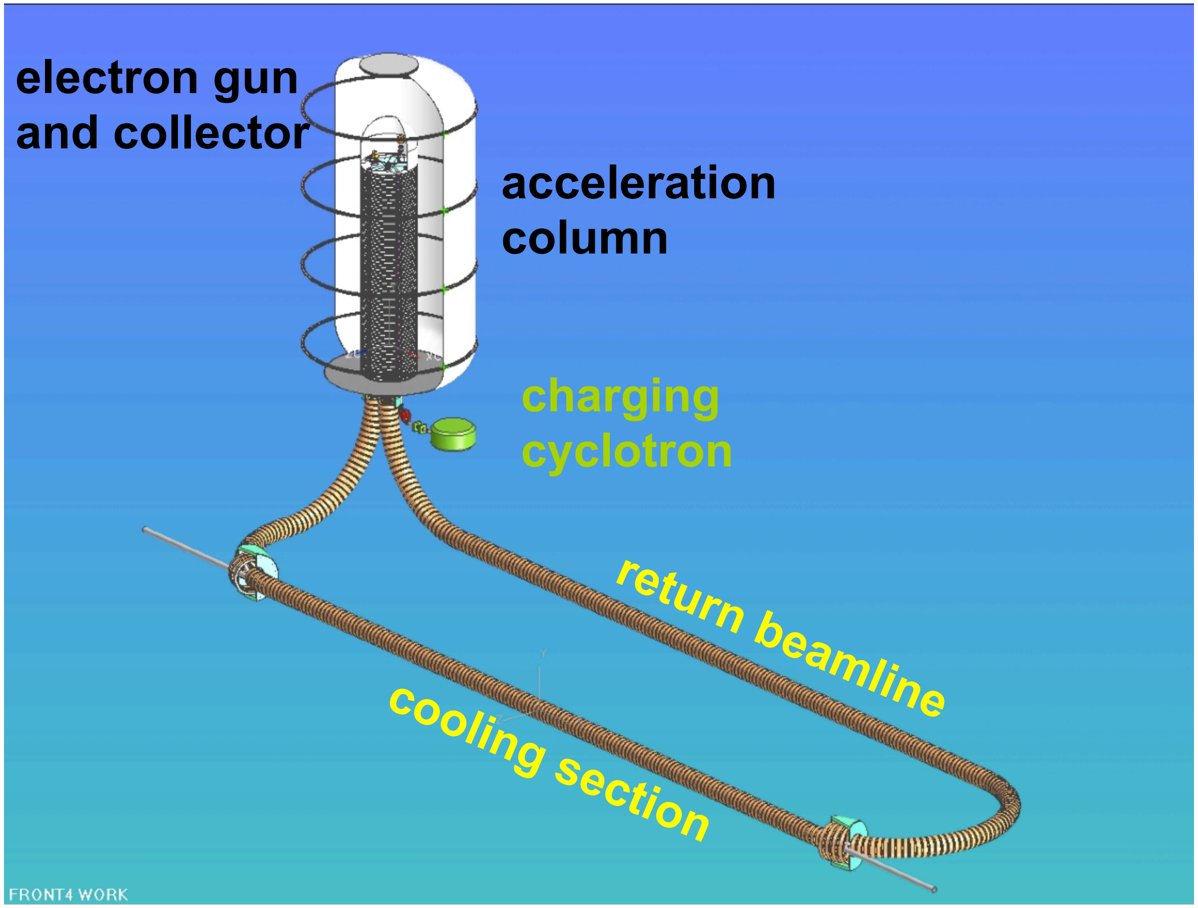
Internal target up to 4×10^{15} H/cm^2

Two operation modes:
High resolution: $L \leq 2\times10^{31}$ cm^{-2}s^{-1}, $N \leq 10^{10}$, $\delta p/p \sim 10^{-5}$
High luminosity: $L \leq 2\times10^{32}$ cm^{-2}s^{-1}, $N \leq 10^{11}$, $\delta p/p \sim 10^{-4}$

straight sections of 132 m length
ring circumference 574 m.

The HESR Electron Cooling System 1

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

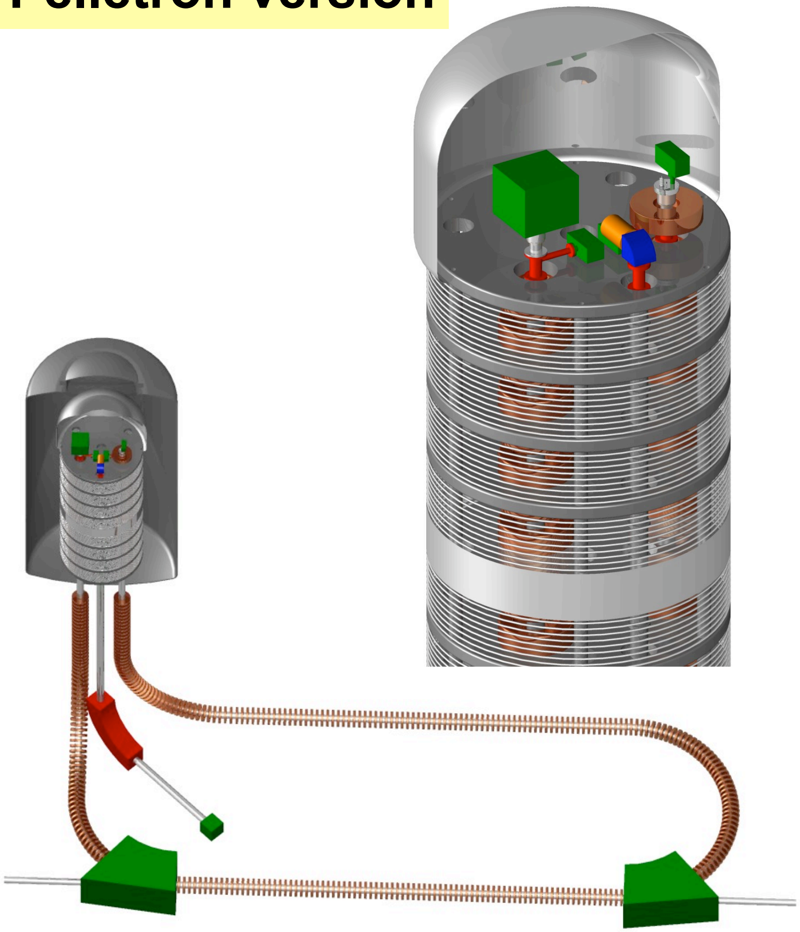
design study by BINP, Novosibirsk, 2003

→ *talk by V. Reva*

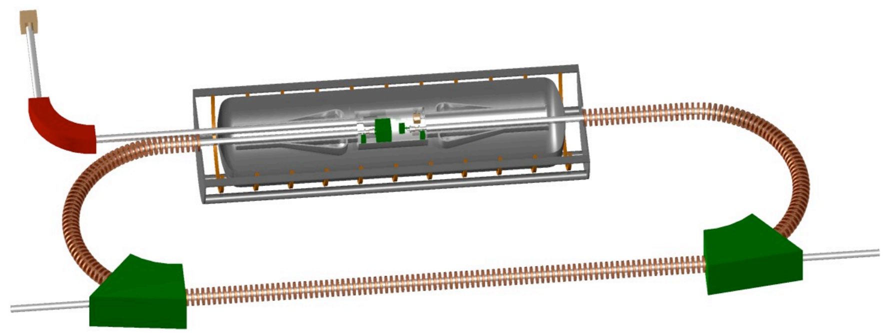
now: design continued by TSL

The HESR Electron Cooling System 2

The Pelletron version



The Dynamitron version

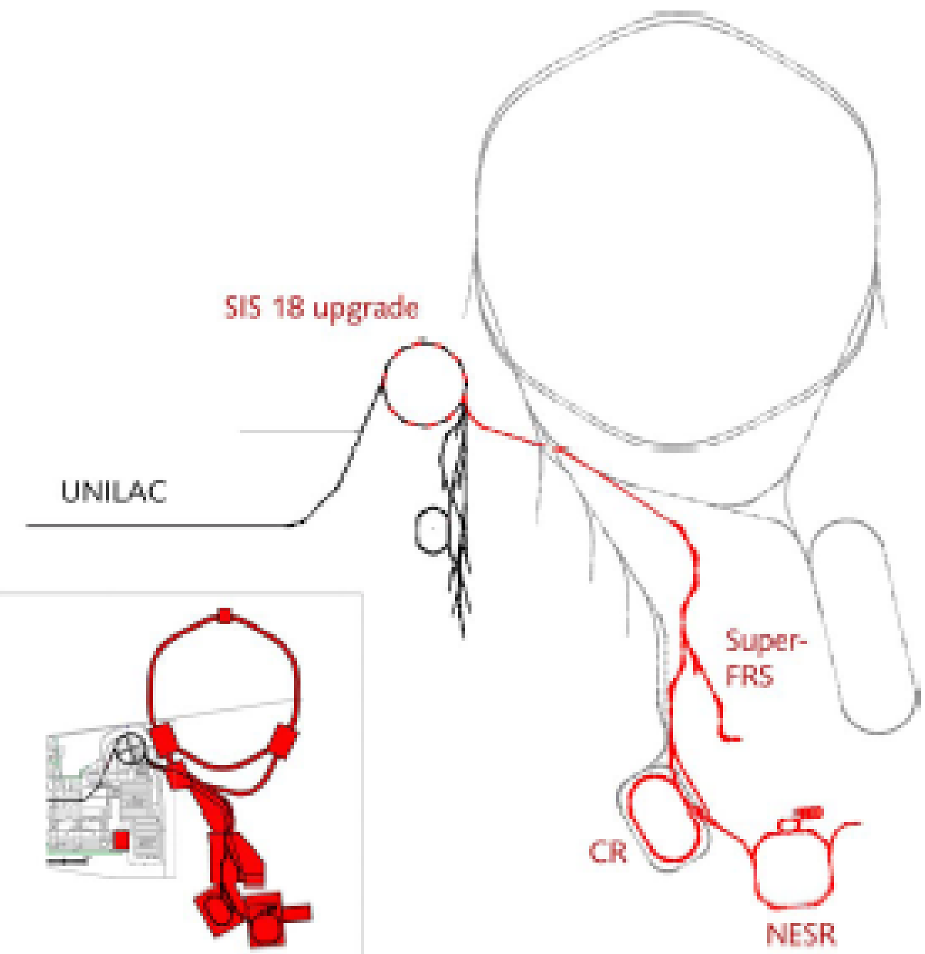


comparison of systems

→ *talk by D. Reistad*

Staging of the FAIR Project - Stage 1

Stage 1



Civil Construction

- Ringtunnel for double ring synchrotron incl. technical buildings
- Buildings housing the SFRS, the CR and NESR plus nuclear structure and atomic physics experiments
- Office building

Accelerator

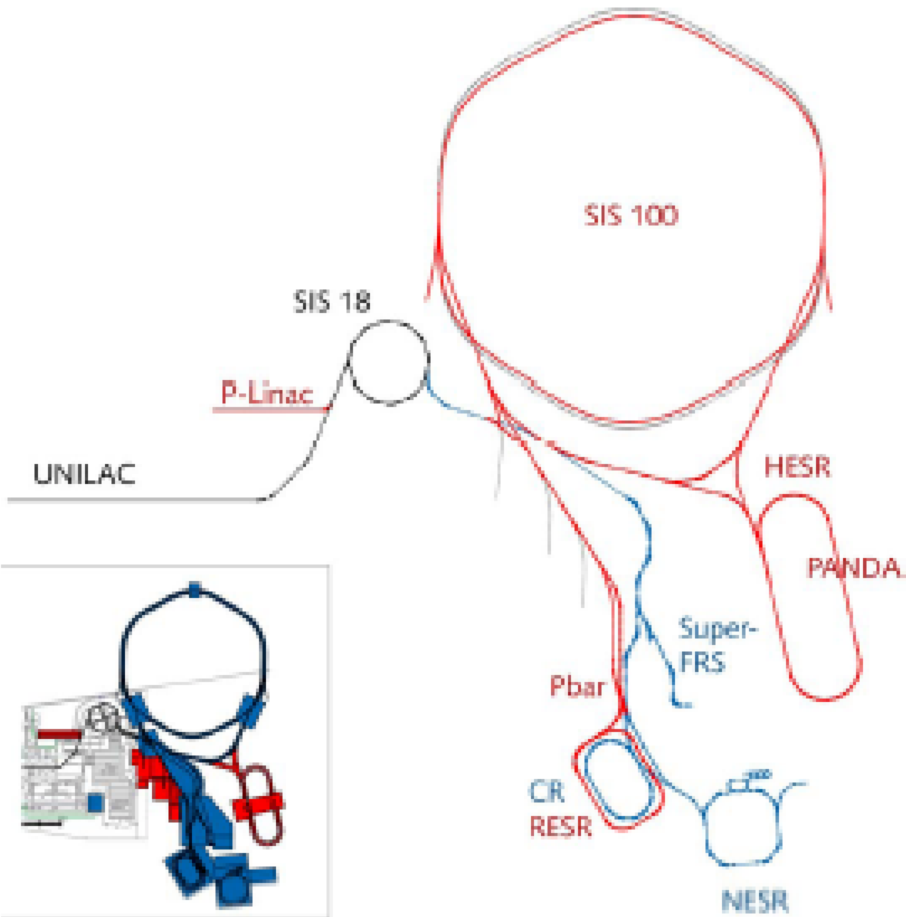
- 2 x 10^{11}/puls U^{28+} at 200 AMeV
- 4 x 10^{10}/puls U^{73+} at 1000 AMeV
- 4 Hz up to 12 Tm; 1 Hz up to 18 Tm
- Bunch compression to 70 ns

Research

- Nuclear structure and nuclear astrophysics (gain factor in intensities for radioactive secondary beams: ~100)
- Plasma physics at 'old' facility (gain factor in power density: ~200)
- Atomic physics studies with highly charged/radioactive ion beams)

Staging of the FAIR Project - Stage 2

Stage 2



Civil Construction (completed)

- p linac building
- HESR building
- Buildings housing nuclear collision, plasma physics and atomic physics experiments

Accelerator

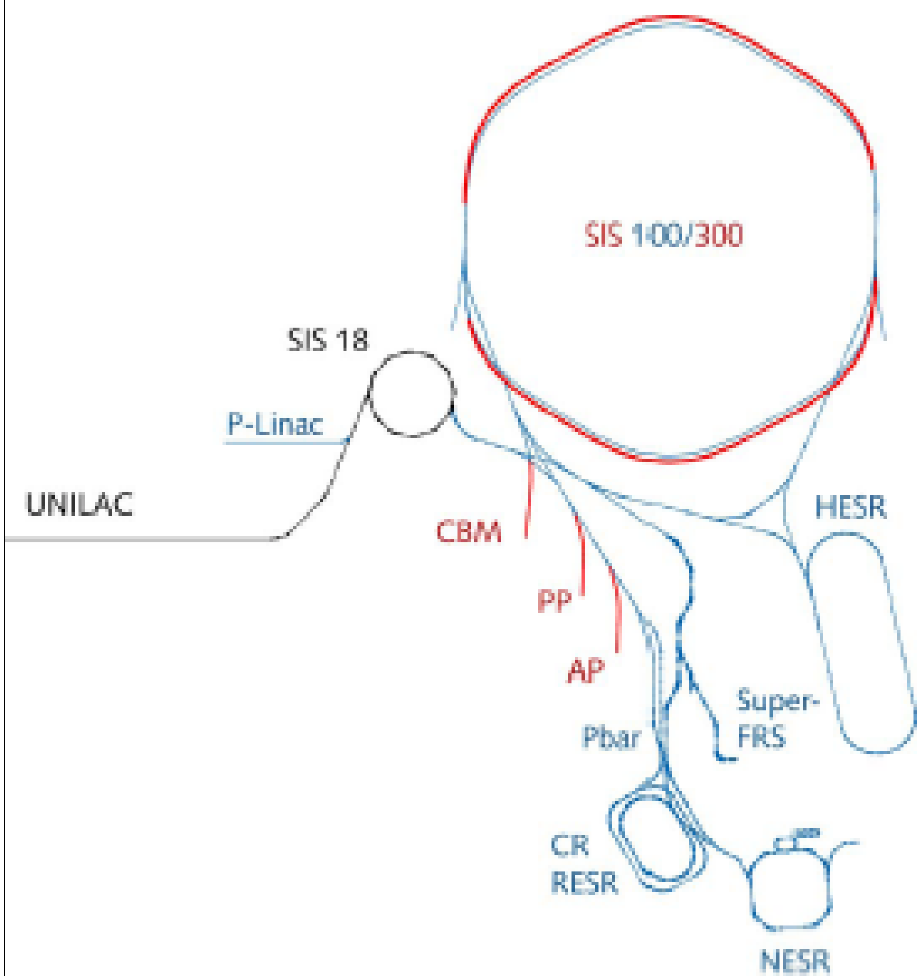
- 1 x 10^{12}/puls U^{28+} at 2,7 AGeV
- 1 x 10^{11}/puls U^{73+} at 8,3 AGeV (Ne^{10+} bis 14 AGeV)
- Bunch compression to 50 ns
- 2,5 x 10^{13}/puls protons up to 29 GeV
- up to 10^{11} antiprotons accumulated, stored and cooled in the HESR up to 15 GeV
- low (down to zero) energy antiprotons at NESR and HITRAP

Research

- Nuclear structure and nuclear astrophysics (full gain factor in intensities for radioactive secondary beams: ~1000-10000)
- QCD studies with protons and antiprotons
- precision studies with antiprotonn beams addressing fundamental symmetries and interactions

Staging of the FAIR Project - Stage 3

Stage 3



Accelerator

- 2 x 10^9/puls U^{92+} up to 34 AGeV
- Stretcher option with long extraction times from seconds up to minutes
- High energy e-cooling for HESR

Research

- Full energy and luminosity for nuclear collisions program at CBM
- Precision QCD Studies at PANDA up to 15 GeV
- Plasma research (full gain factor in power density: ~2500)
- Atomic reaction studies with fast beams

- *Full parallel operation of up to four experiments*