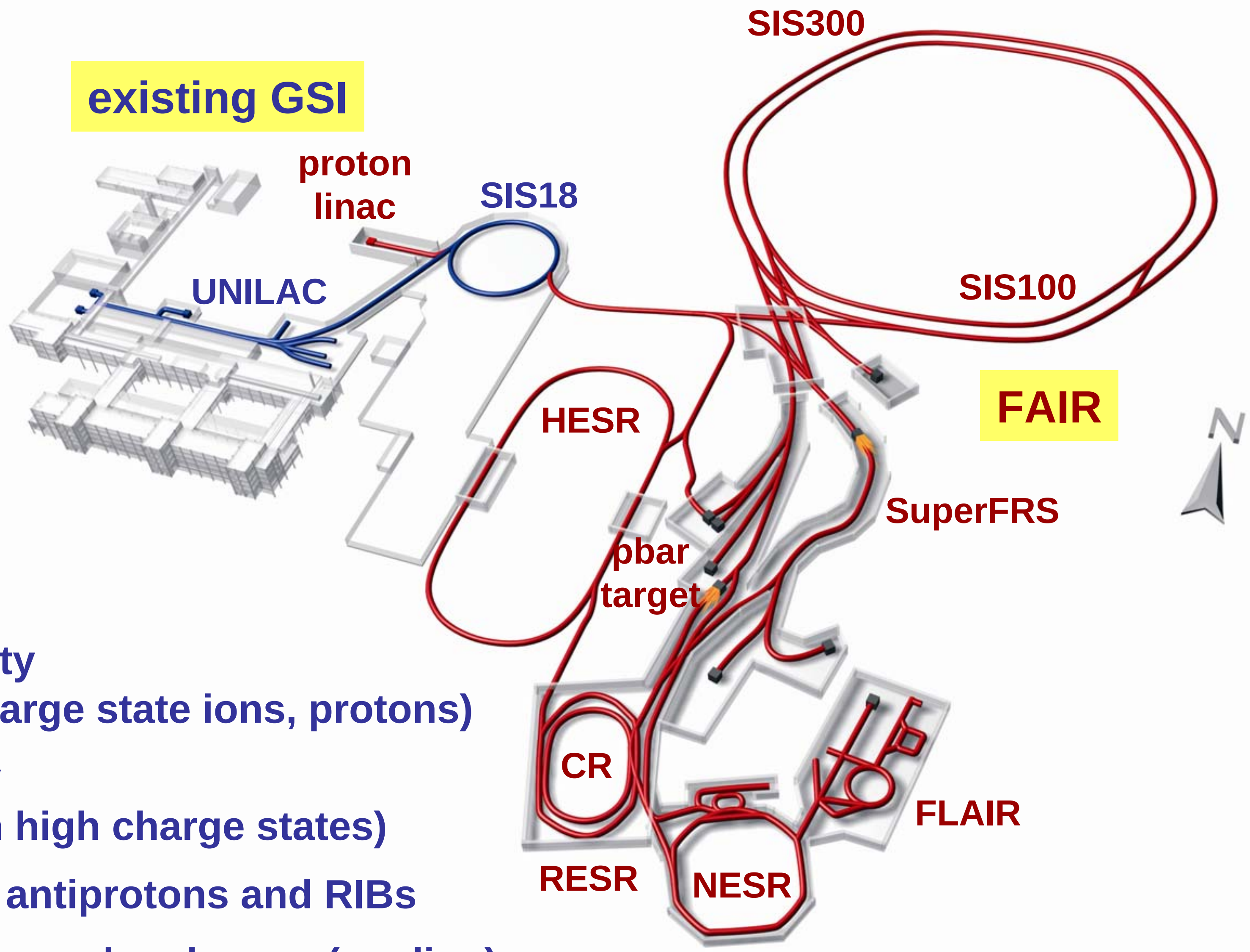
Advanced Design of the FAIR Storage Ring Complex

M. Steck

for the FAIR Technical Division and the Accelerator Division of GSI

The FAIR Accelerator Facility



goals:

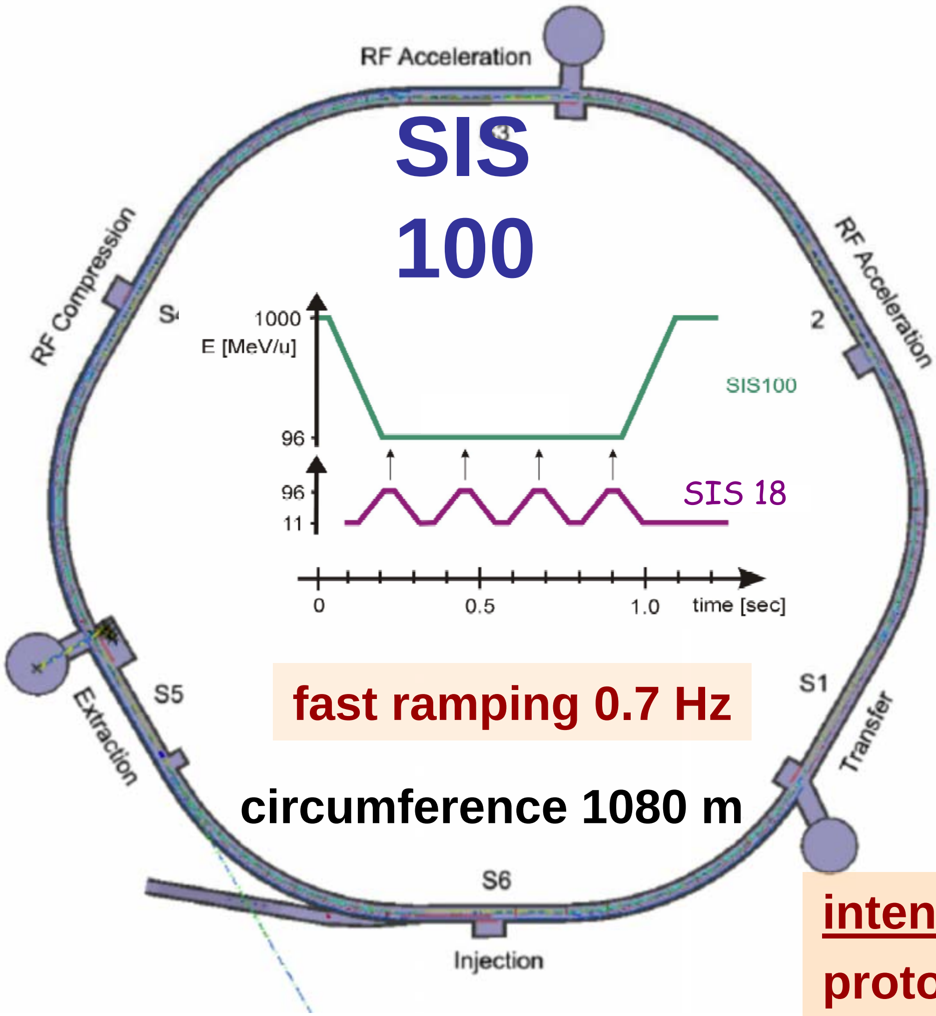
higher intensity
(heavy low charge state ions, protons)

higher energy
(heavy ions in high charge states)

production of antiprotons and RIBs

high quality secondary beams (cooling)

Fast Ramping Synchrotron SIS 100

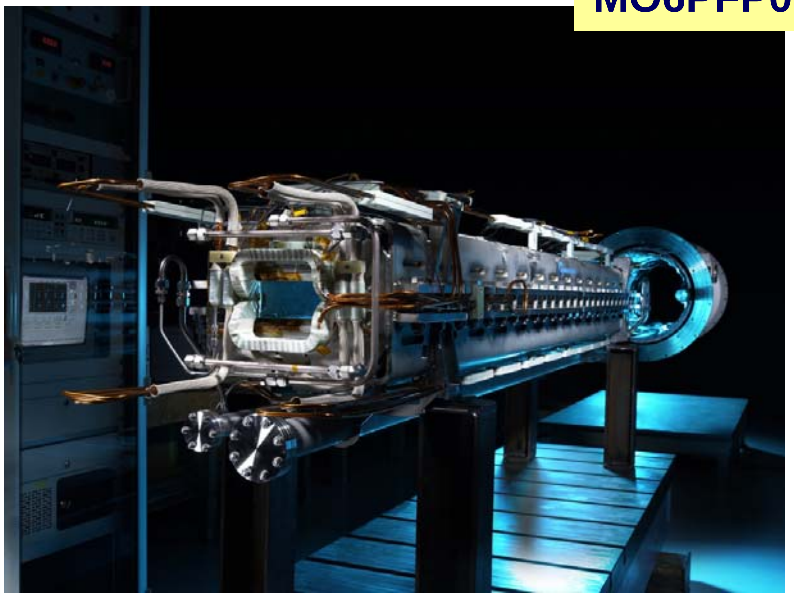


fast ramping 0.7 Hz

circumference 1080 m

First full size, fast ramping s.c. dipole prototype of Nuclotron type (JINR Dubna) successfully tested at GSI

MO6PFP065



<u>intensity goal (particles per cycle):</u>

protons (from p-linac/SIS18): 2×10^{13}

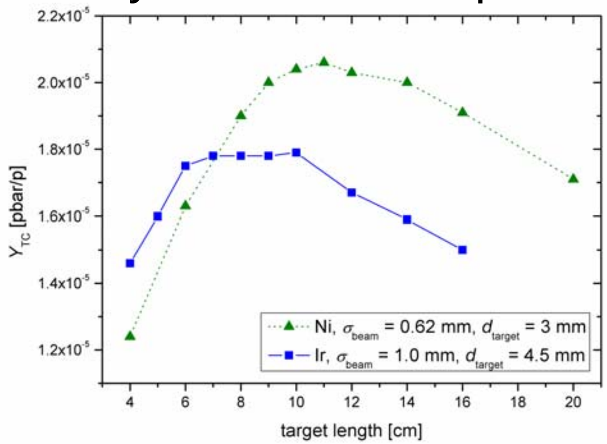
heavy ions U^{28+}(from UNILAC/SIS18): 5×10^{11}

TU6PFP063 **TU6PFP034**

Antiproton Target and Separator

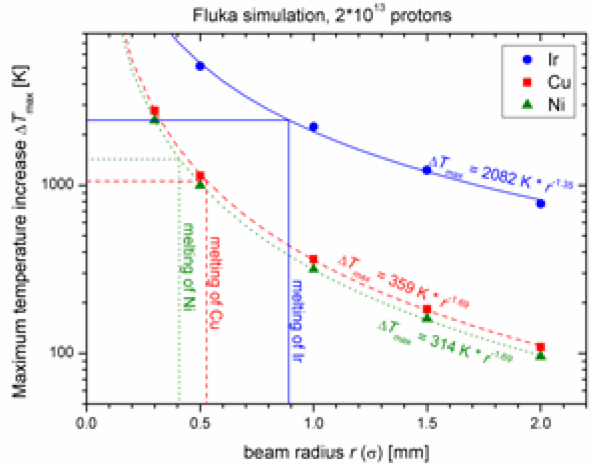
production rate of antiprotons

primary beam 29 GeV protons



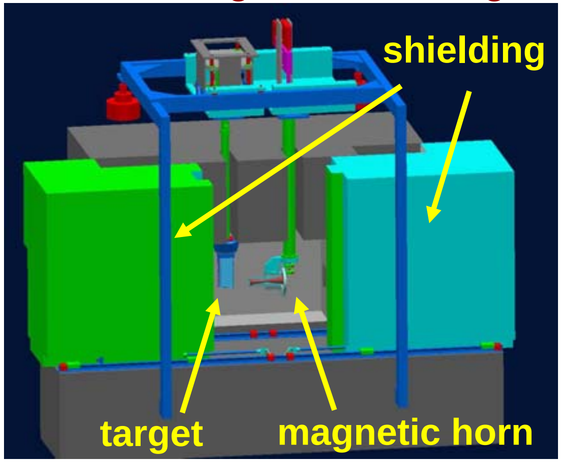
temperature of target

⇒ choice of nickel

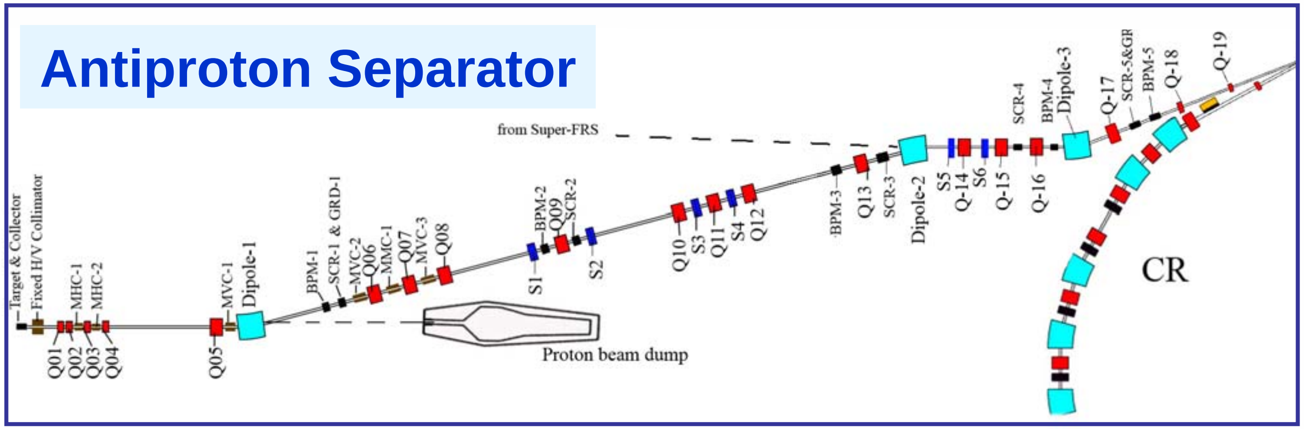


target station

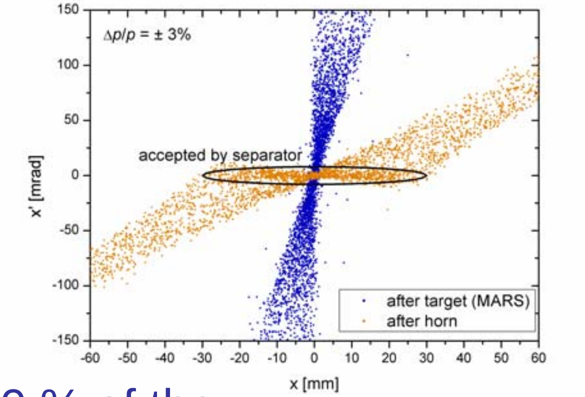
shielding and handling



Antiproton Separator



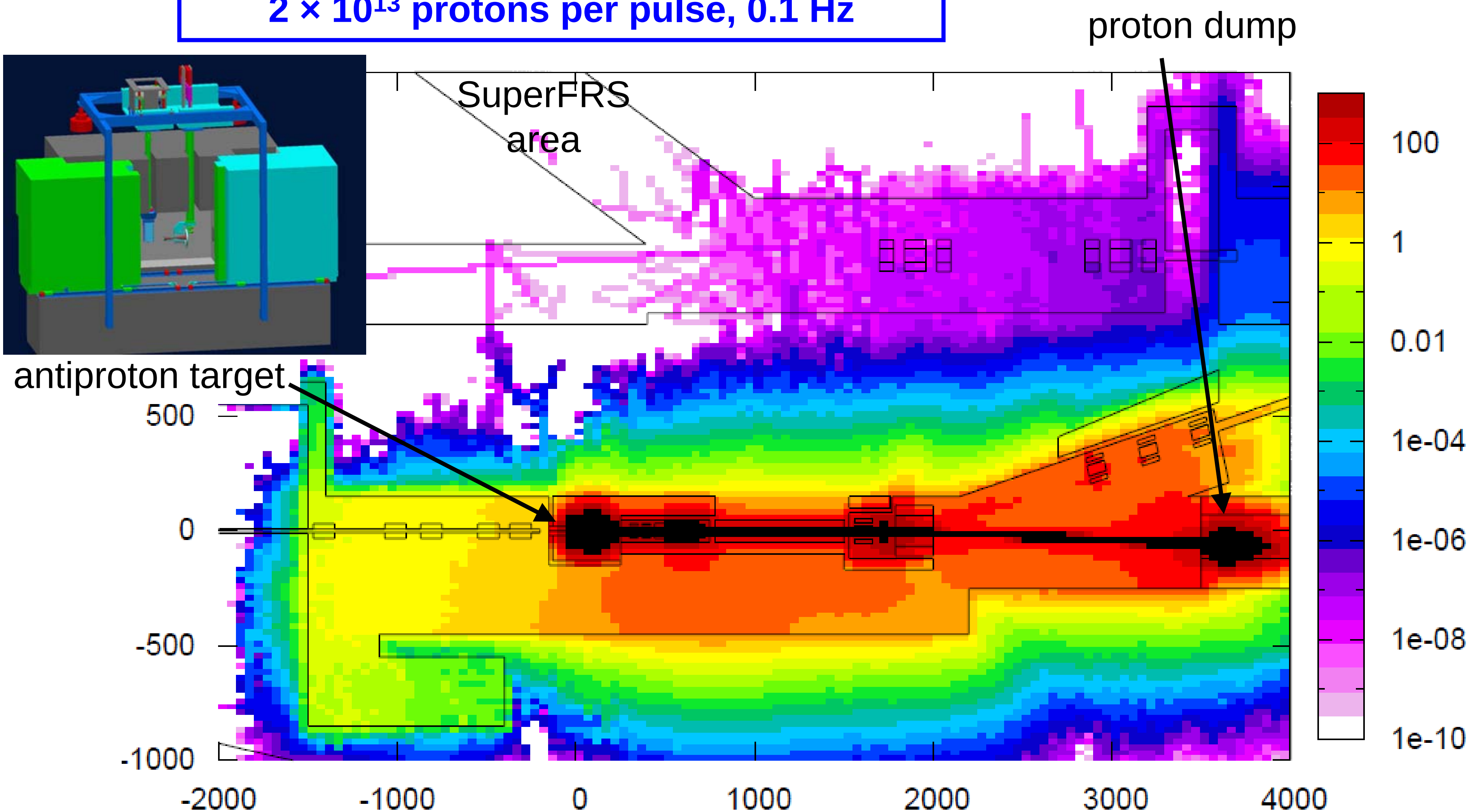
Particle tracking in separat



according to tracking calculations about 70 % of the produced antiprotons will be stored in the CR

Radiation in Antiproton Target Area

Equivalent Dose rate [Sv/h],
2 × 10^{13} protons per pulse, 0.1 Hz



The RIB Separator SuperFRS

Design Parameters

$\varepsilon_x = \varepsilon_y = 40\ \pi$ mm mrad

$\varphi_x = \pm 40$ mrad,

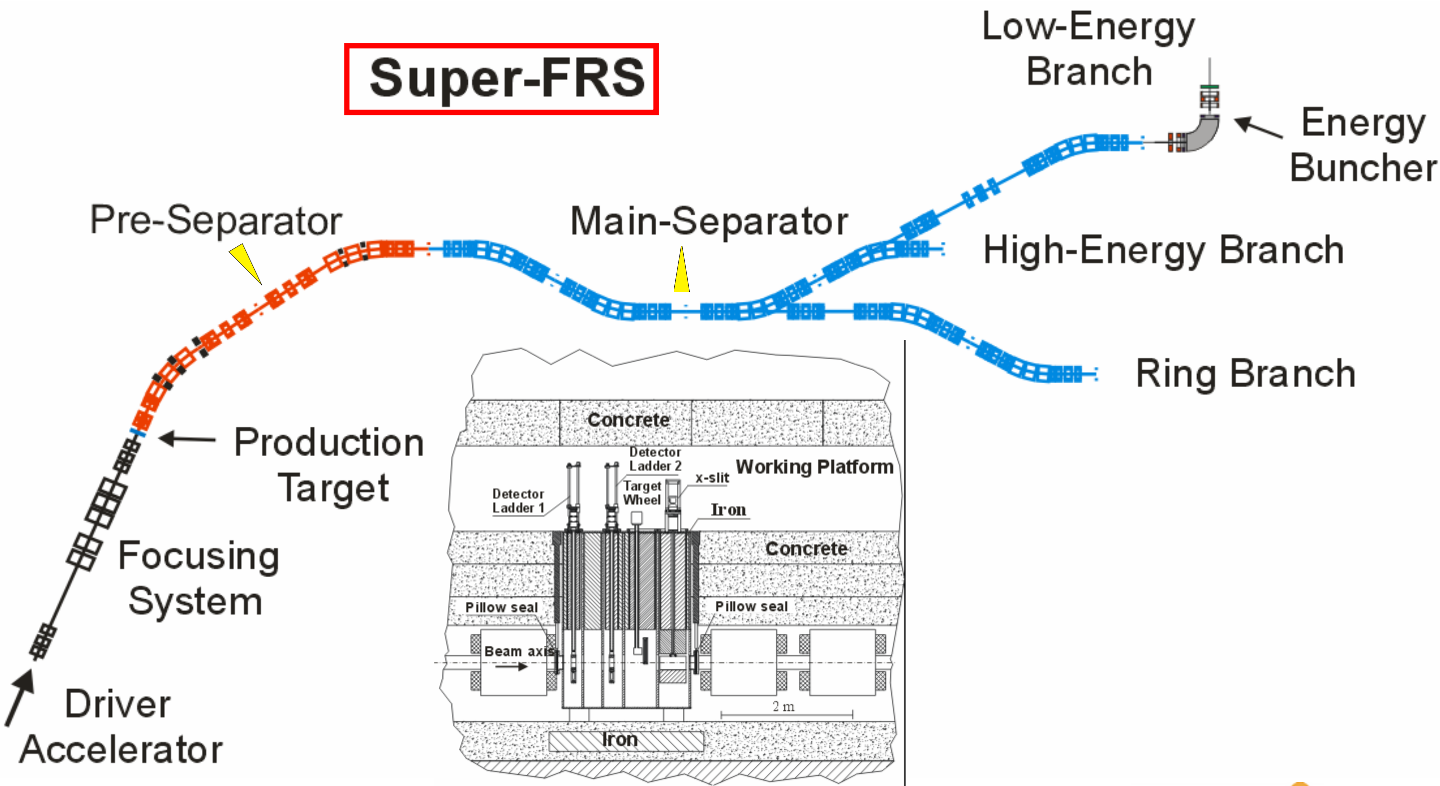
$\varphi_y = \pm 20$ mrad

$\frac{\Delta p}{p} = \pm 2.5\ \%$

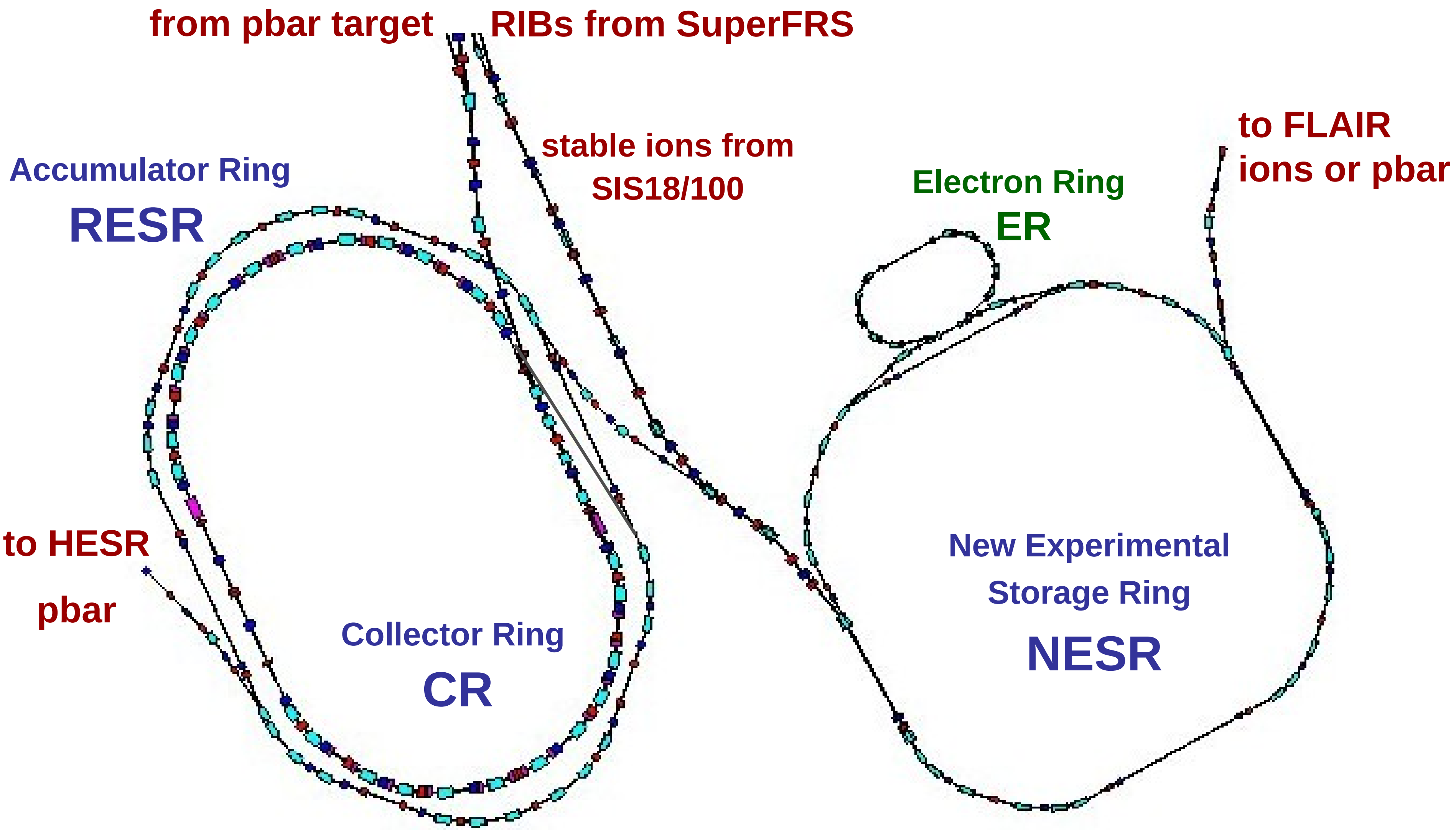
$B\rho_{max} = 20$ Tm

$R_{ion} = 1500$

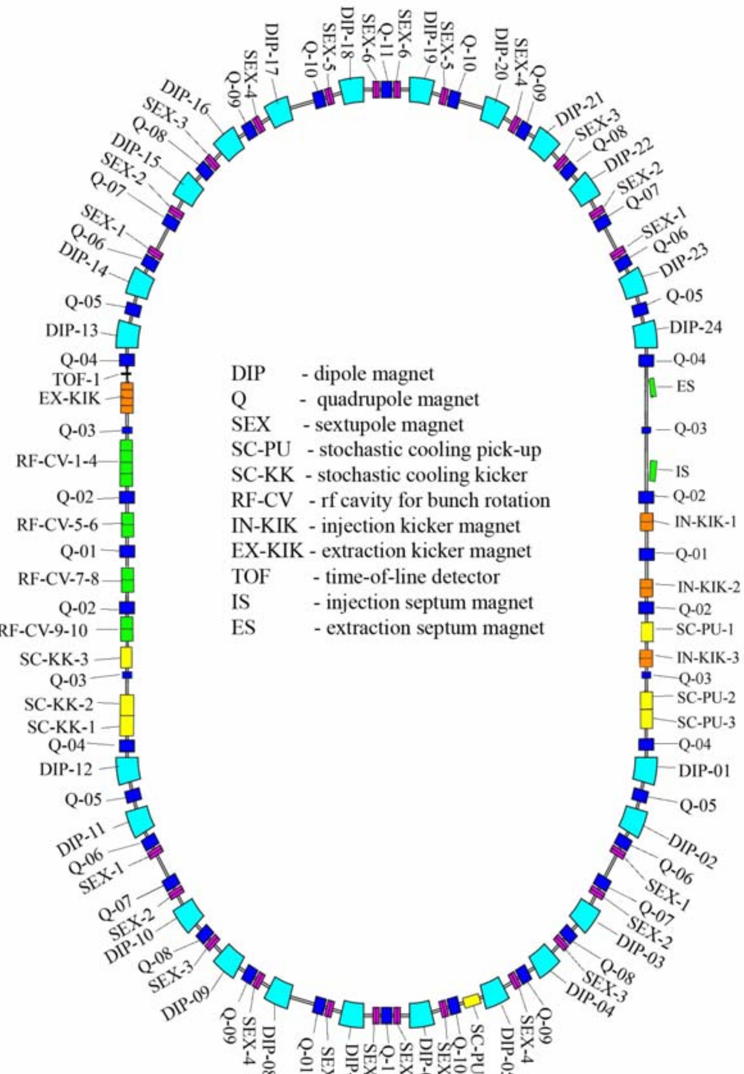
- **Multi-Stage**
- **Multi-Branch**
- **Superconducting**
- **Large Acceptance**



The FAIR 13 Tm Storage Rings



The Collector Ring CR



circumference 216 m
magnetic bending power 13 Tm
large acceptance $\varepsilon_{x,y}$ = 240 (200) mm mrad
$\Delta p/p = \pm$ 3.0 (1.5) %

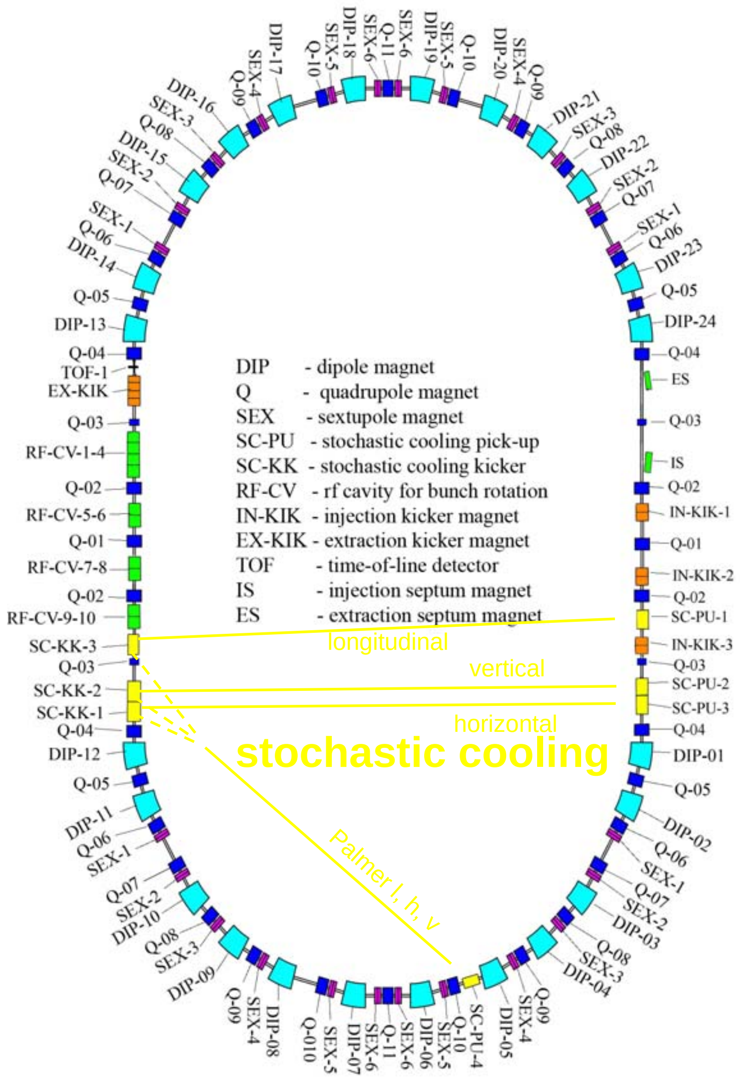
fast stochastic cooling (1-2 GHz)
of antiprotons (10 s) and
rare isotope beams (1.5 s)

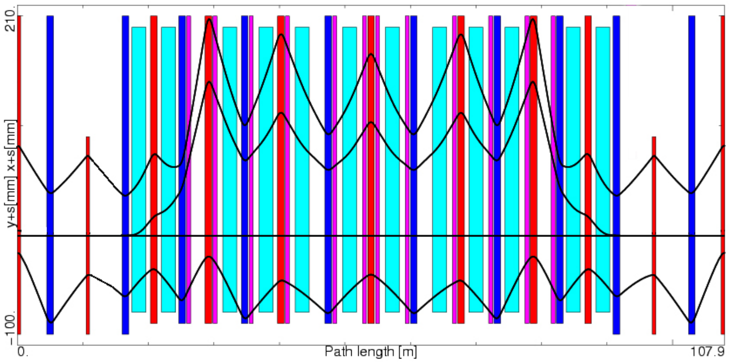
fast bunch rotation at h=1
with rf voltage 200 kV
adiabatic debunching
optimized ring lattice (slip factor)
for proper mixing
large acceptance magnet system

additional feature:
isochronous mass measurements
of rare isotope beams

option: upgrade of rf system to 400 kV
and stochastic cooling to 1-4 GHz

Ion Optical Modes of the CR





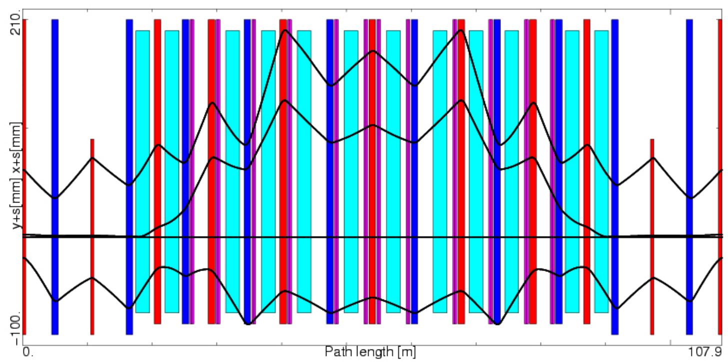
antiprotons

$Q_x = 4.26$, $Q_y = 4.84$

$\gamma_t = 3.7$

$\eta = - 0.016$

$\Delta p/p = \pm 3\ \%$



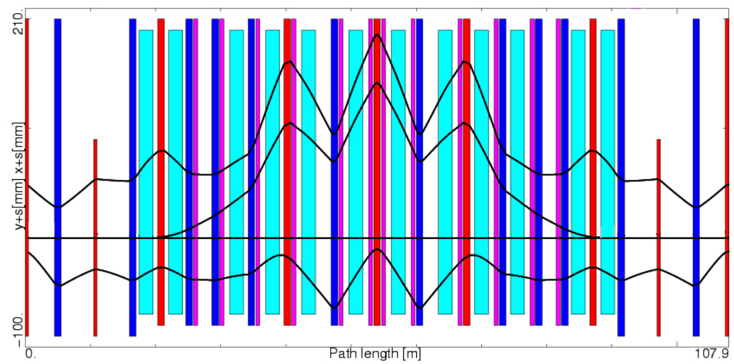
RIBs

$Q_x = 3.21$, $Q_y = 3.71$

$\gamma_t = 2.8$

$\eta = + 0.185$

$\Delta p/p = \pm 1.5\ \%$



isochronous

$Q_x = 2.33$, $Q_y = 4.64$

$\gamma_t = 1.67\text{-}1.84$

$\eta = 0$

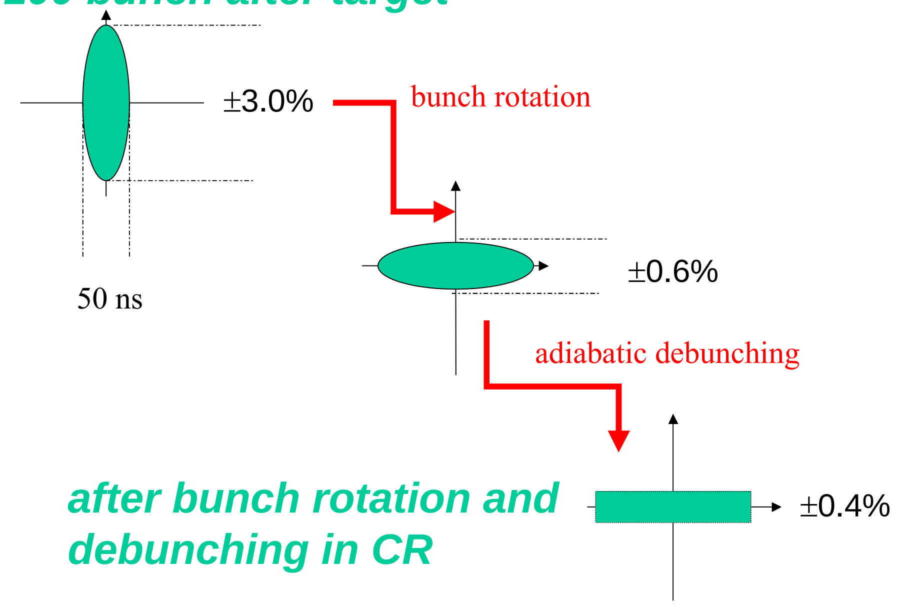
$\Delta p/p = \pm 0.5\ \%$

Fast Bunch Rotation in CR

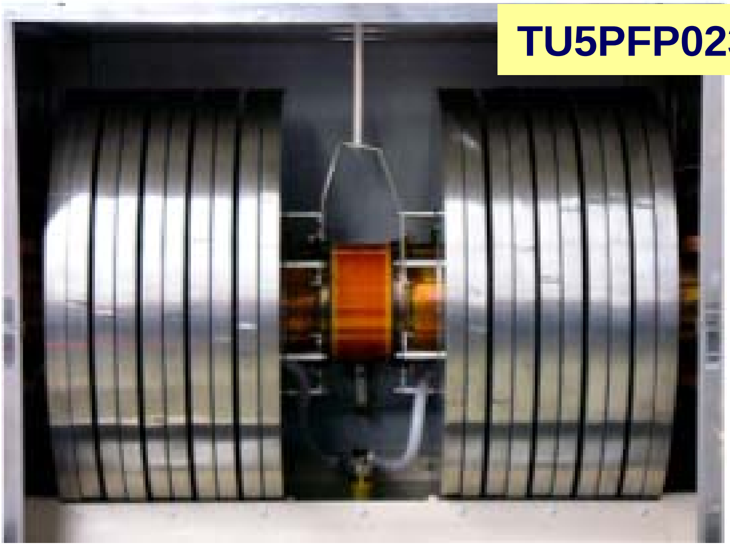
with magnetc alloy based rf system

Fast bunch rotation of SIS100 bunch
to provide optimum initial parameters
for stochastic cooling
total rf voltage 200 kV at h=1 reduces
the momentum spread (± 3.0 → ± 0.4 %)
after passage of production target

SIS100 bunch after target



TU5PFP023



SIS18 bunch compressor cavity
prototype for

CR bunch rotation cavity
filled with magnetic alloy

voltage 40 kV
length 1 m
frequency range 1.17 – 1.37 MHz
rotation time 100 μs (pbars)
600 μs (RIBs)

TU5PFP024

CR Stochastic Cooling Electrodes

Fast Stochastic Pre-cooling

system band width 1-2 GHz

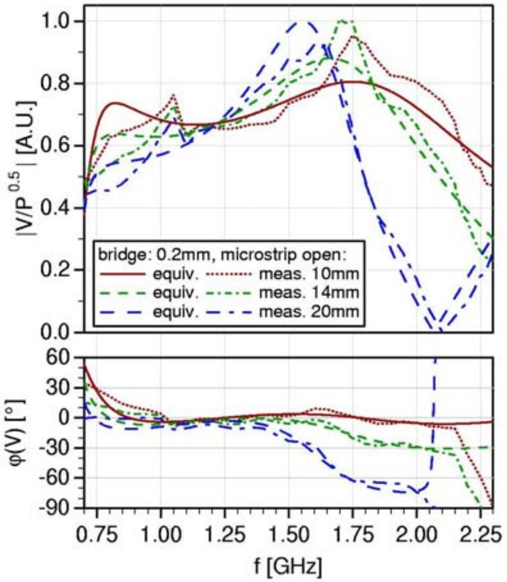
matched to velocities β = 0.83 - 0.97

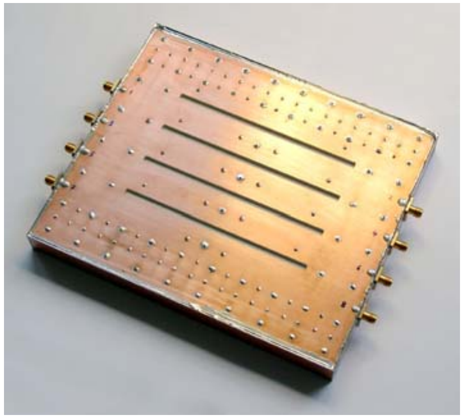
rf power ~ 1-2 kW per system

Optimization of flatness of electrodes

voltage

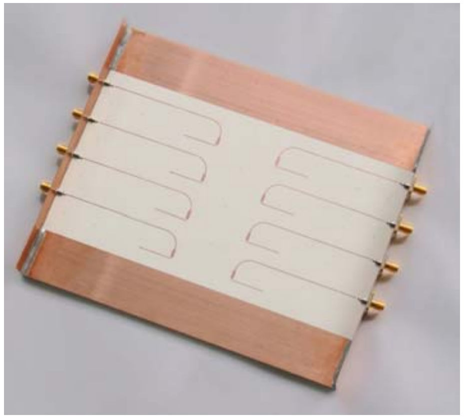
phase





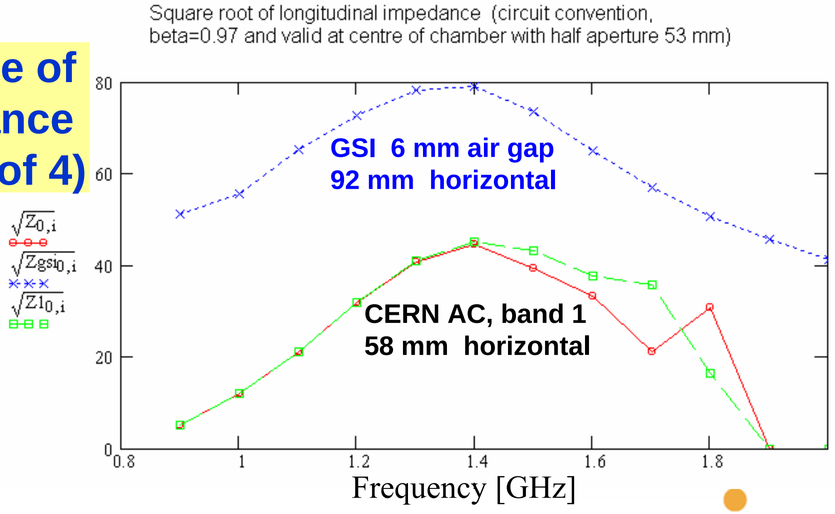
electrode prototype (slotline type)

front side



back side

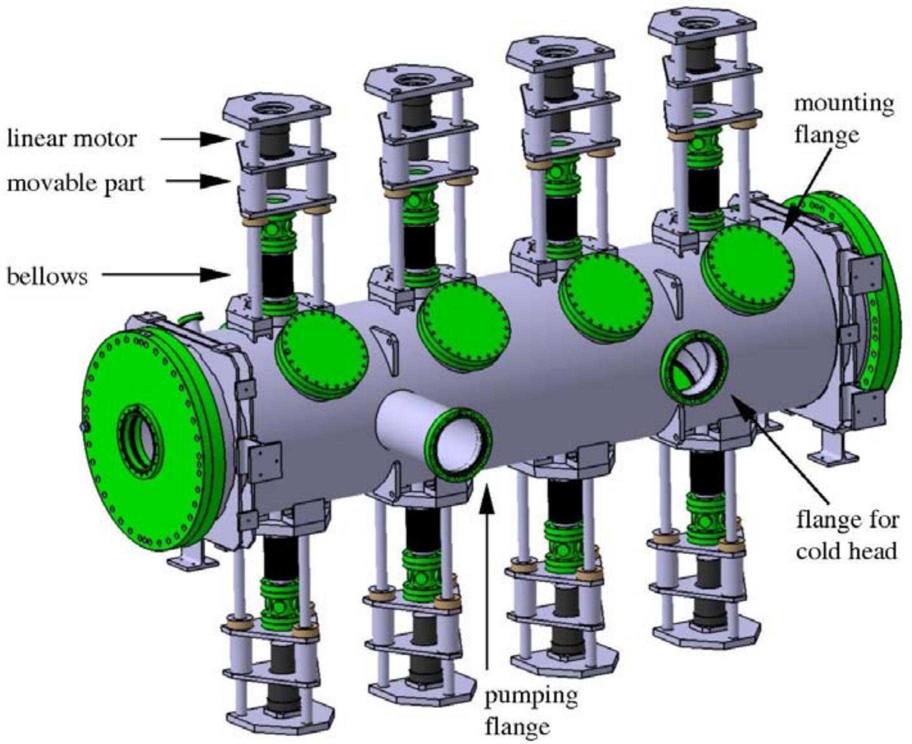
increase of impedance (factor of 4)

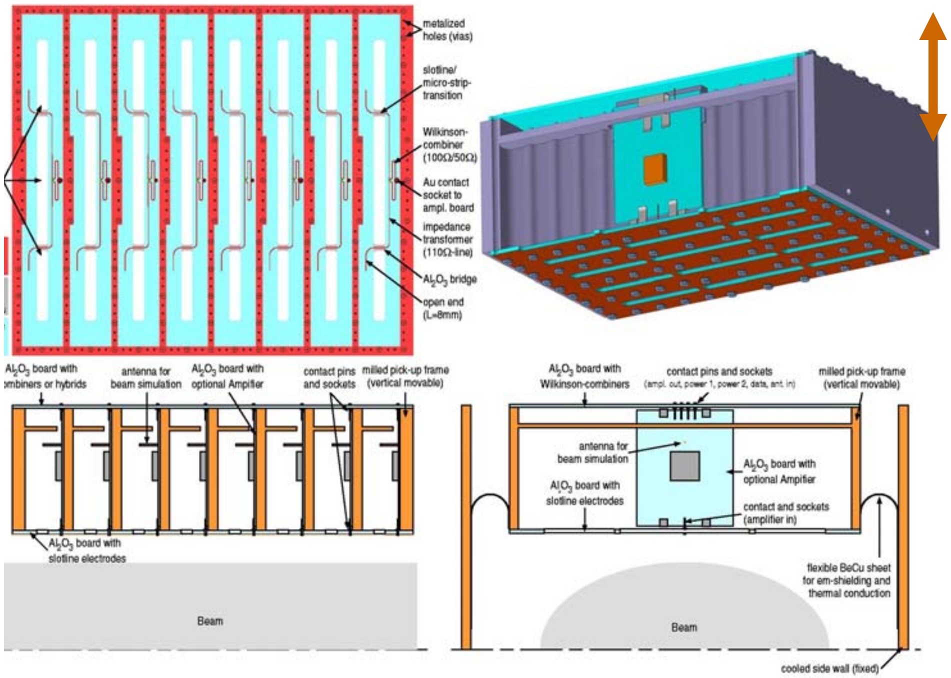


CR Stochastic Cooling

vacuum tank
with actuators for electrode movement including cold heads (20 K) and cooled pre-amplifiers (option)

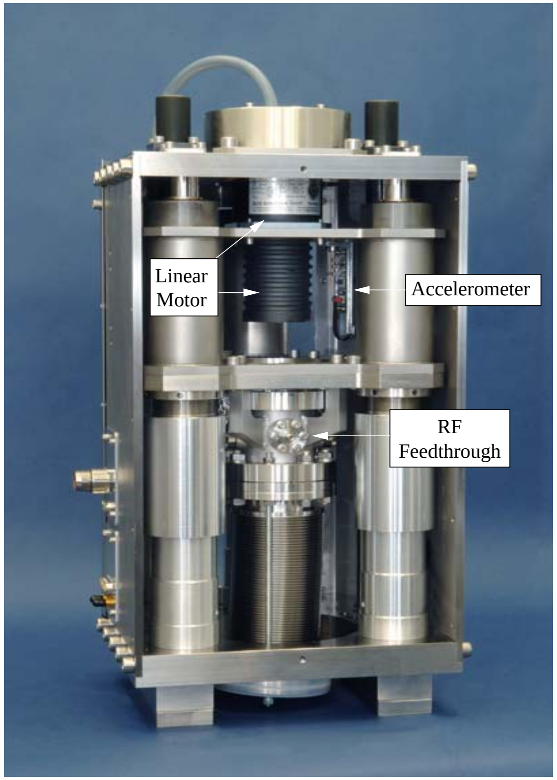
Installed in the vacuum tank: electrodes (and pre-amplifiers) can be cooled to 20 K



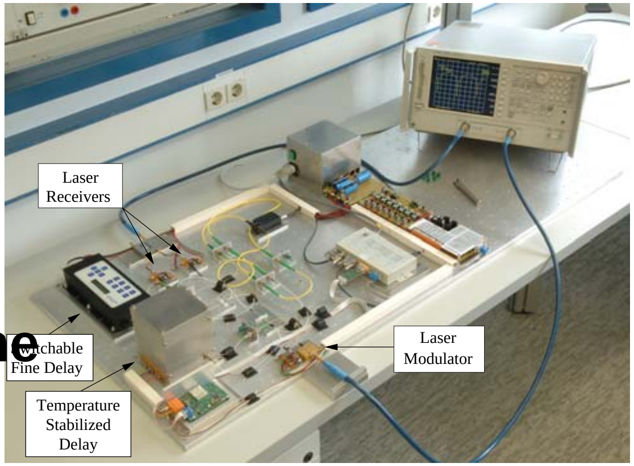


CR Stochastic Cooling Prototypes

vacuum tank for moving cold electrodes



programmable
linear actuator

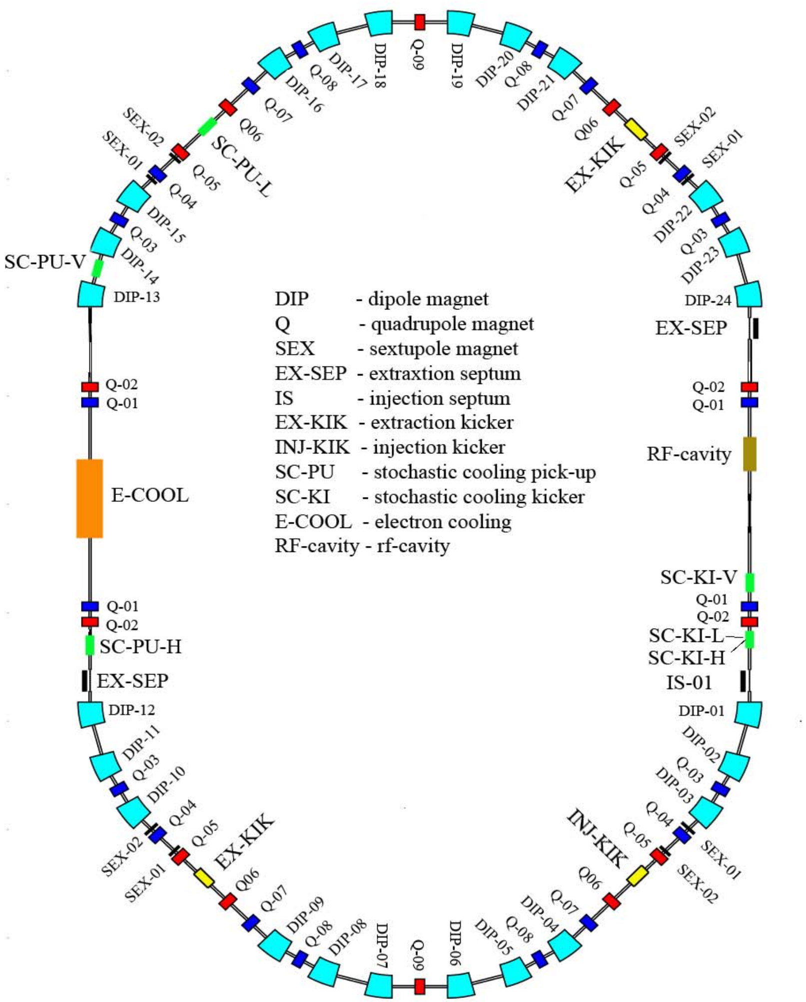


optical delay line

prototype development supported by EUFP6 design study

RESR

The Antiproton Accumulator Ring



circumference	240 m
magnetic bending power	13 Tm
tunes Q_x/Q_y	3.12/4.11
momentum acceptance	±1.0 %
transverse accept. h/v	25×10^{-6} m
transition energy	3.3-6.4

accumulation of antiprotons by a combination of rf and stochastic cooling

max. accumulation rate 3.5 (7)×10^{10}/h

max. stack intensity ~ 1 × 10^{11}

additional mode:

fast deceleration of RIBs (antiprotons) to a minimum energy of 100 MeV/u

for injection into NESR (ER)

for collider mode experiments

RESR Dynamic Aperture Calculations

TH6PFP078

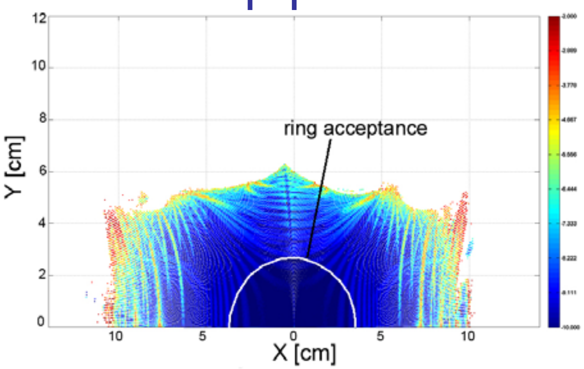
FR5REP118

$Q_x = 3.11, Q_y = 4.12$

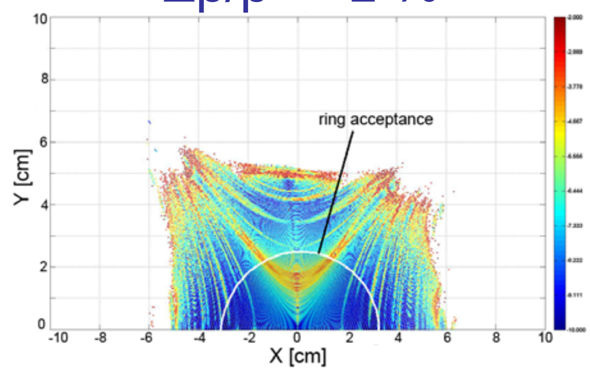
field errors

Harmonic order	2	3	4	5	6	7	8	9	10
Dipole	0	0.12	0	-0.016	0.0	0.017	0	-0.001	0
Quadrupole	0	4.0	2.8	3.0	14.0	1.8	2.5	1.0	2.0
Sextupole	0	0	0	0	0	0	0	6.0	0

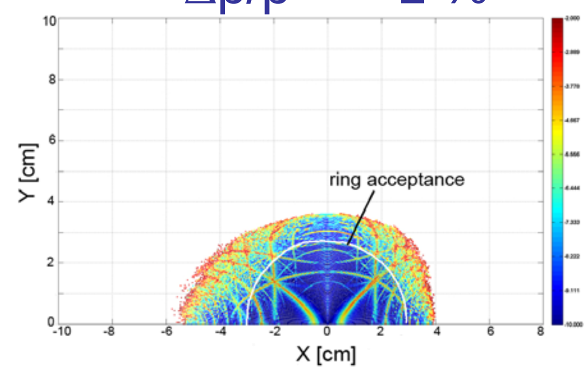
$\Delta p/p = 0$

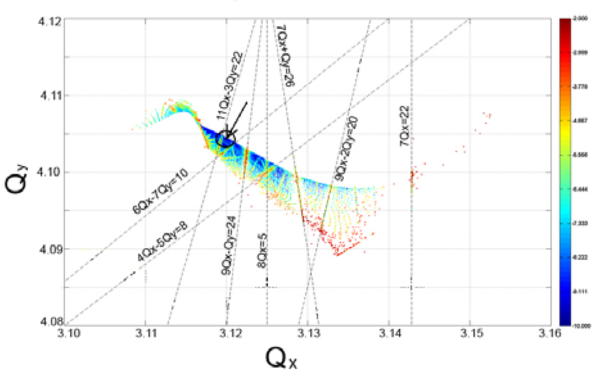


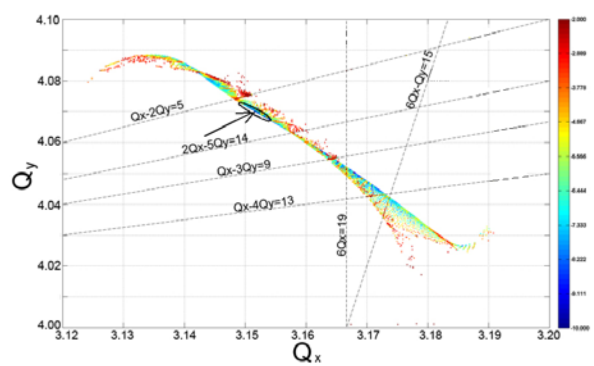
$\Delta p/p = -1$ %

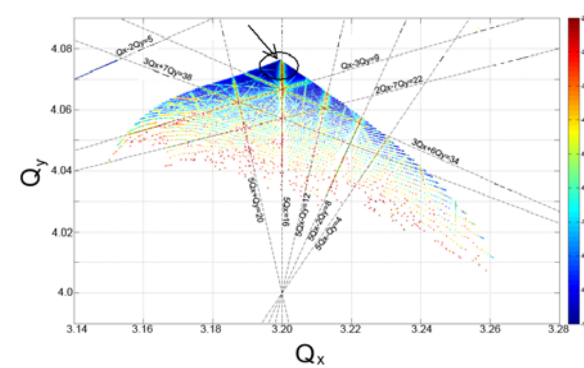


$\Delta p/p = +1$ %





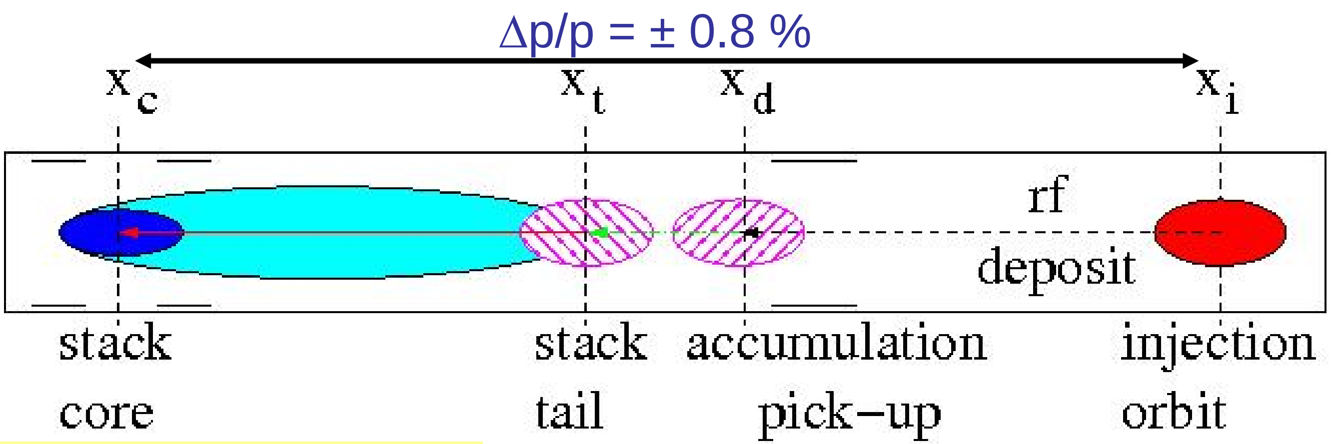




Frequency Map Analysis

calculated with PTC code (MAD)

Antiproton Accumulation in RESR



in collaboration with
D. Möhl, L Thorndahl (CERN)
T. Katayama

core cooling 2-4 GHz

longitudinal
horizontal
vertical

tail cooling 1-2 GHz

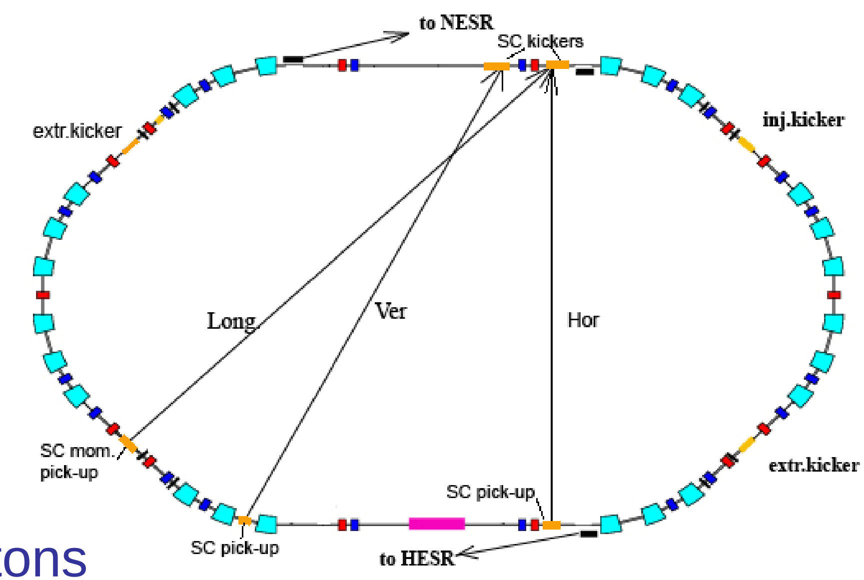
longitudinal

injection of 1×10^{8} antiprotons every 10 s

pre-cooling in CR provides
$\delta p/p = 1\times10^{-3}$, $\varepsilon_{x,y} = 5$ mm mrad

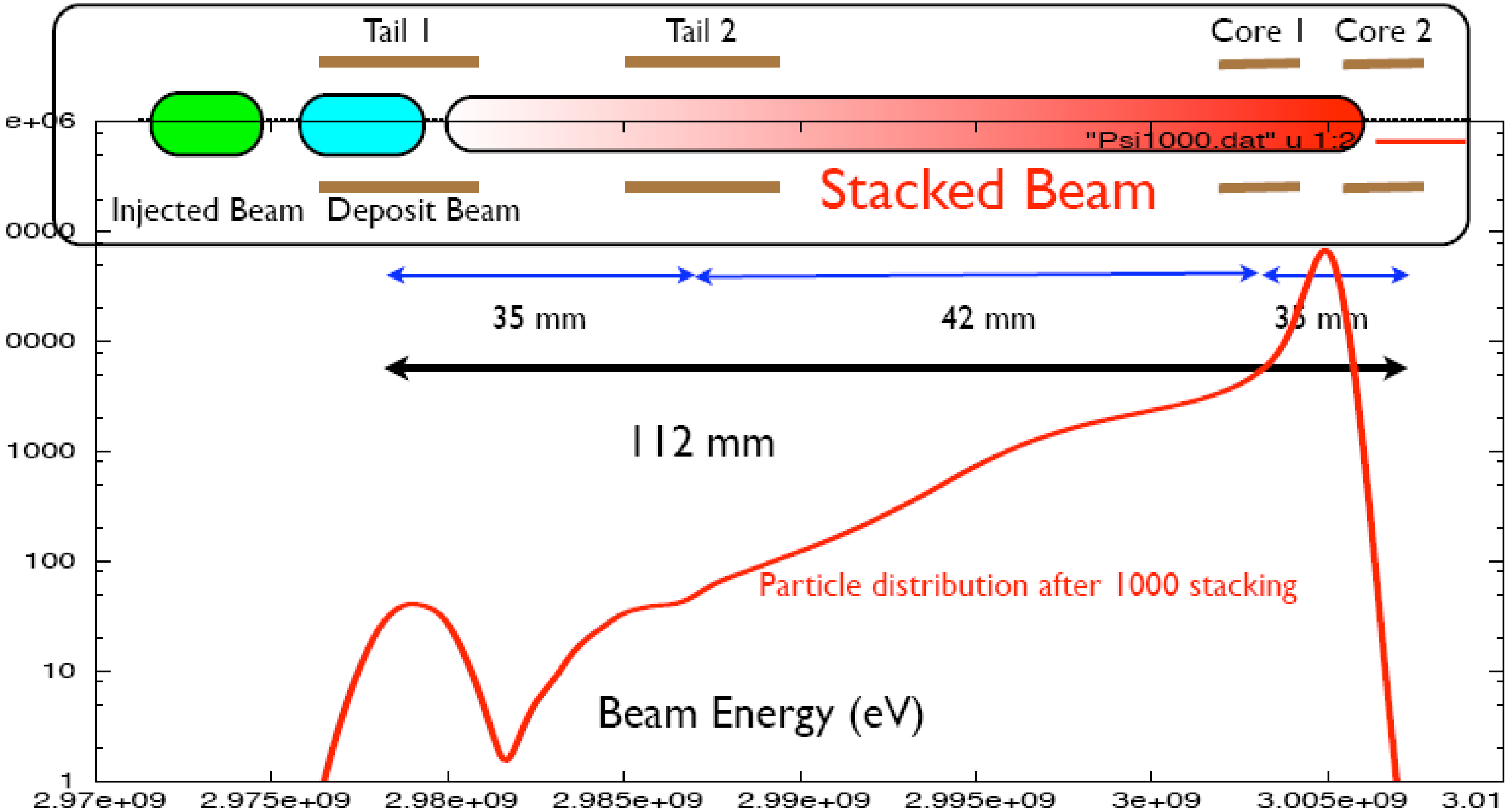
maximum stack intensity: 1×10^{11} antiprotons

pre-cooling after injection considered as option



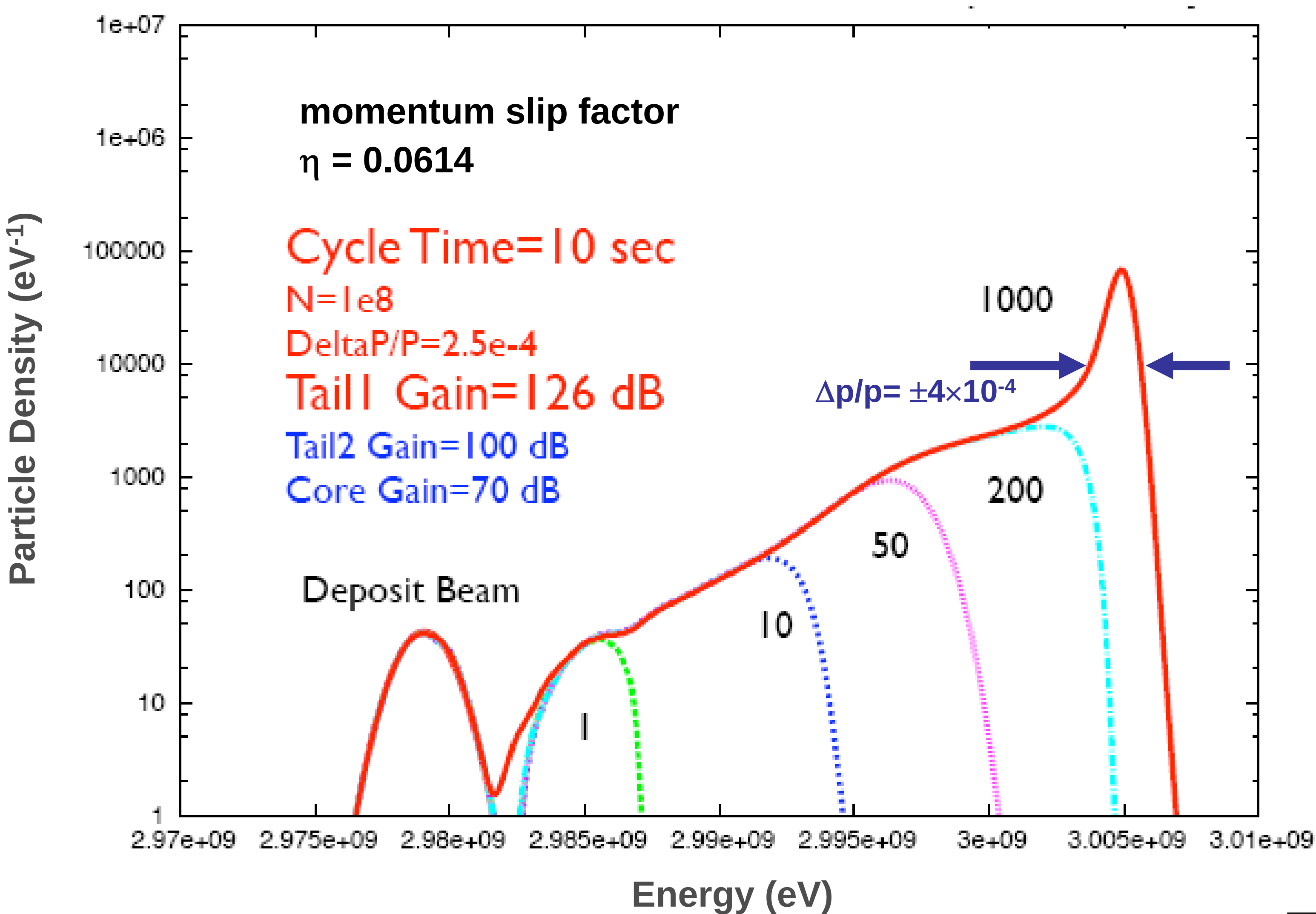
Accumulation System for RESR

Longitudinal stochastic cooling system: tail and core cooling



electrodes: loop couplers or Faltin-type

Distribution of Accumulated Antiprotons

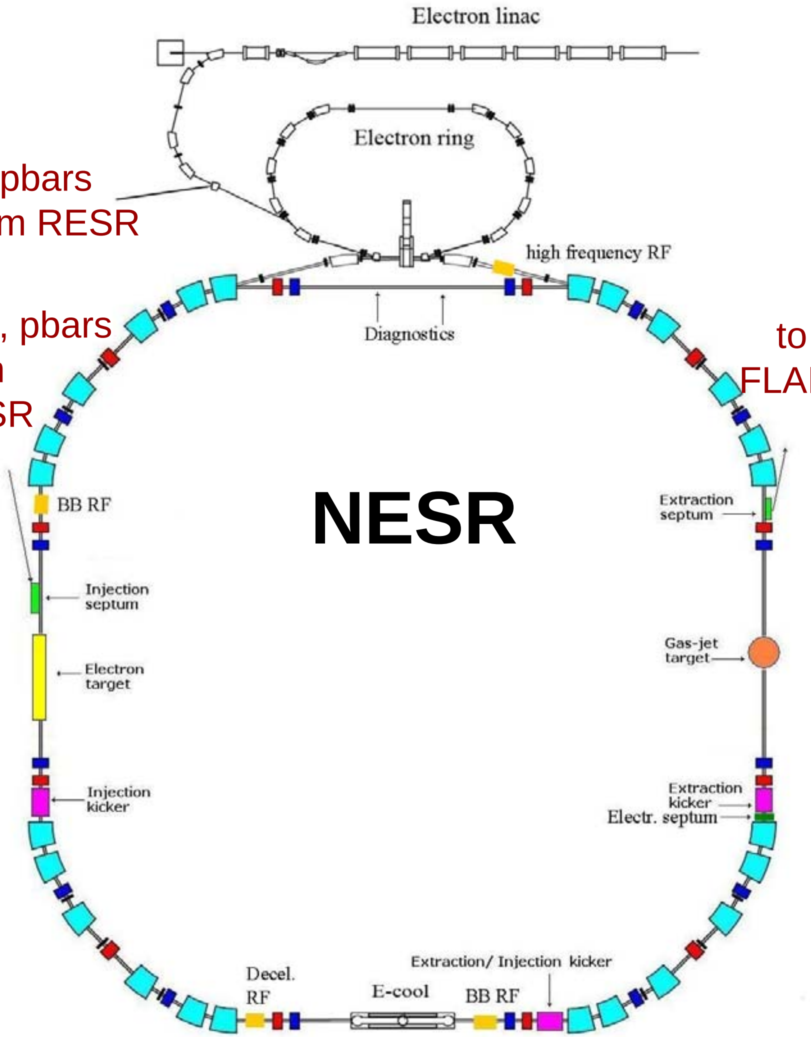


The New Experimental Storage Ring

pbars from RESR

ions, pbars from RESR

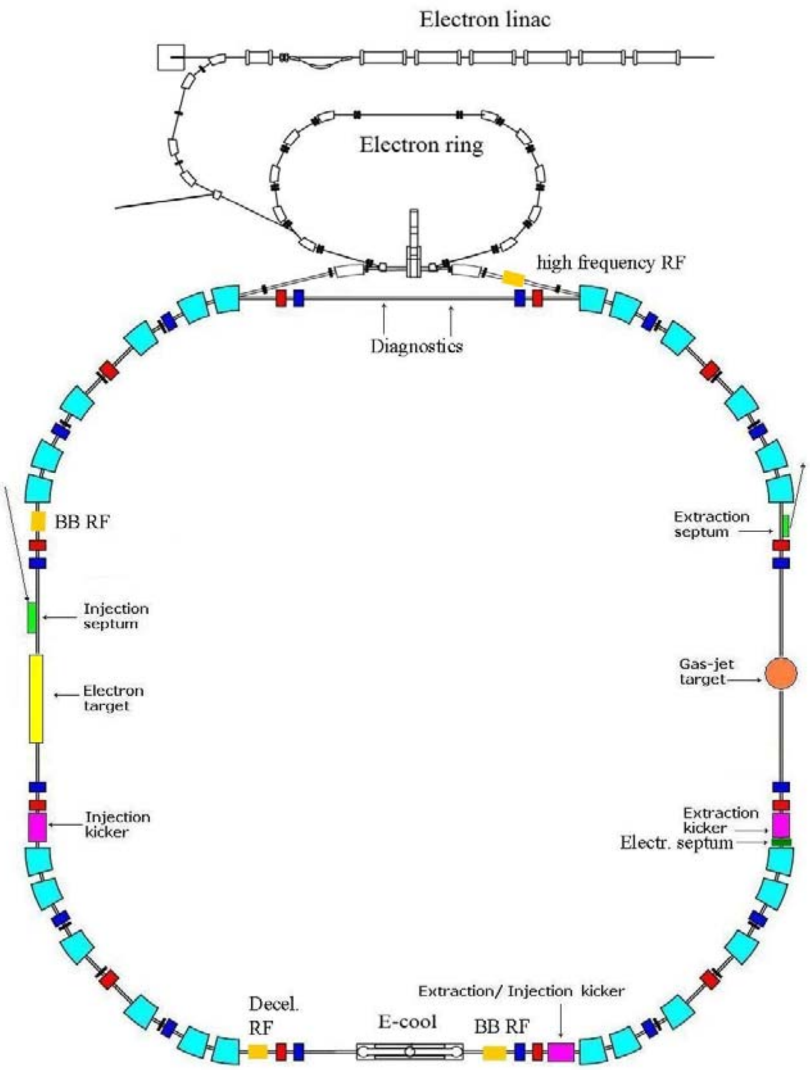
to FLAIR



- Electron cooling of ions and antiprotons
- Fast deceleration of ions to 4 MeV/u

  and antiprotons to 30 MeV
- Fast extraction (1 turn)
- Slow (resonance) extraction
- Ultraslow (charge changing) extraction
- Longitudinal accumulation of RIBs
- Electron-Ion collisions (bypass mode)
- Antiproton-ion collisions
- Internal target
- Electron target
- High precision mass measurements

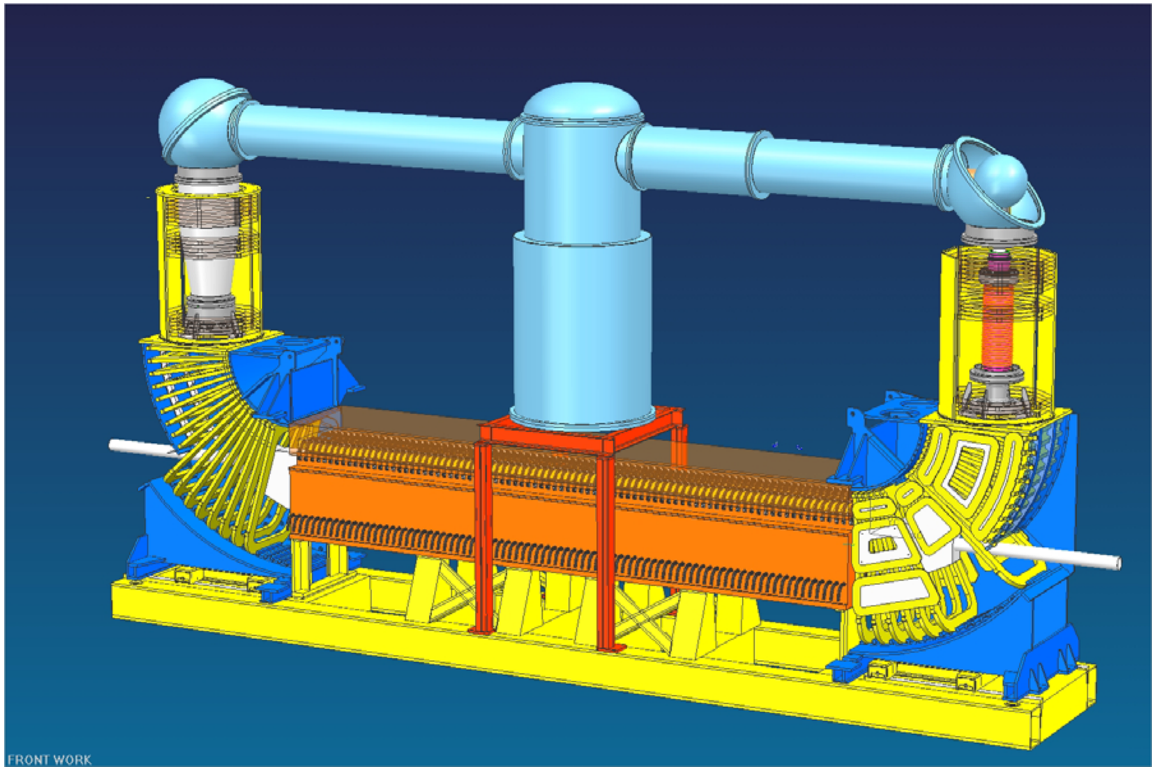
Parameters of the NESR



Circumference [m]	222.8
Straight section length [m]	18
Horizontal acceptance [mm mrad]	150
Vertical acceptance [mm mrad]	40
Momentum acceptance [%]	± 1.5
Max. momentum deviation [%]	± 2.5
Horizontal tune	4.2
Vertical tune	1.87
Transition energy	4.59
Maximum dispersion [m]	6.8
Horizontal chromaticity	5.9

NESR Electron Cooler

design by BINP, Novosibirsk



Electron Cooler Parameters

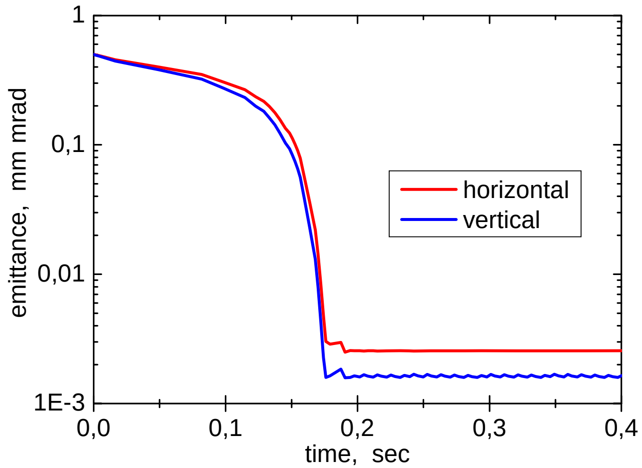
energy	2 - 450 keV
max. current	2 A
beam radius	2.5-14 mm
magnetic field	
gun	up to 0.4 T
cool. sect.	up to 0.2 T
straightness	2×10^{-5}
vacuum	$\leq 10^{-11}$ mbar

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

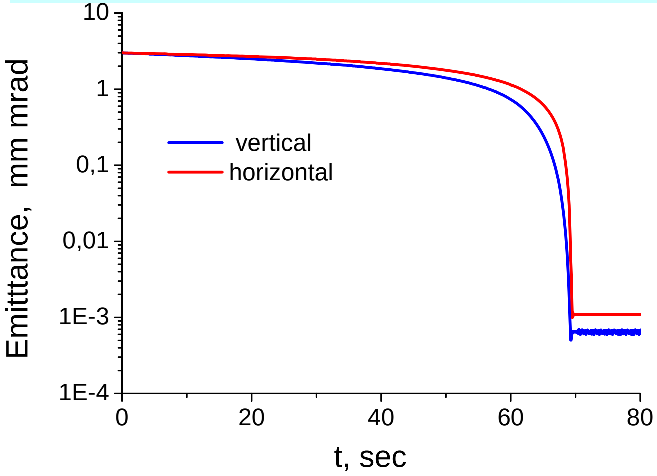
Electron Cooling in the NESR

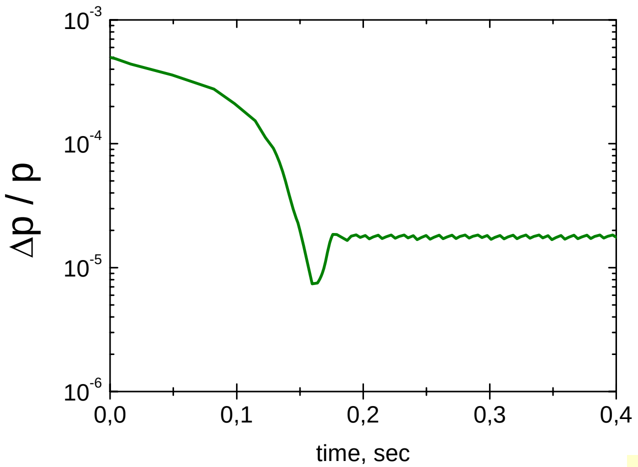
$^{132}Sn^{50+}$, $N_i = 10^8$, E = 740 MeV/u,
I_e= 1 A, r_e= 0.5 cm, B = 0.2 T

Antiprotons, E_i = 800 MeV
I_e= 2 A, r_e= 1 cm, B = 0.2 T

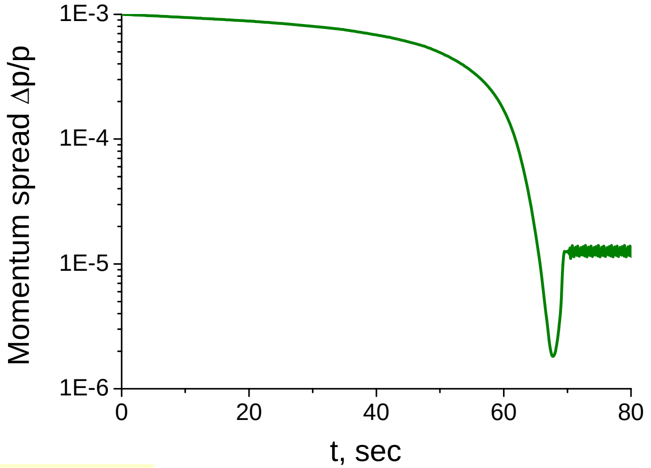


emittance





momentum spread

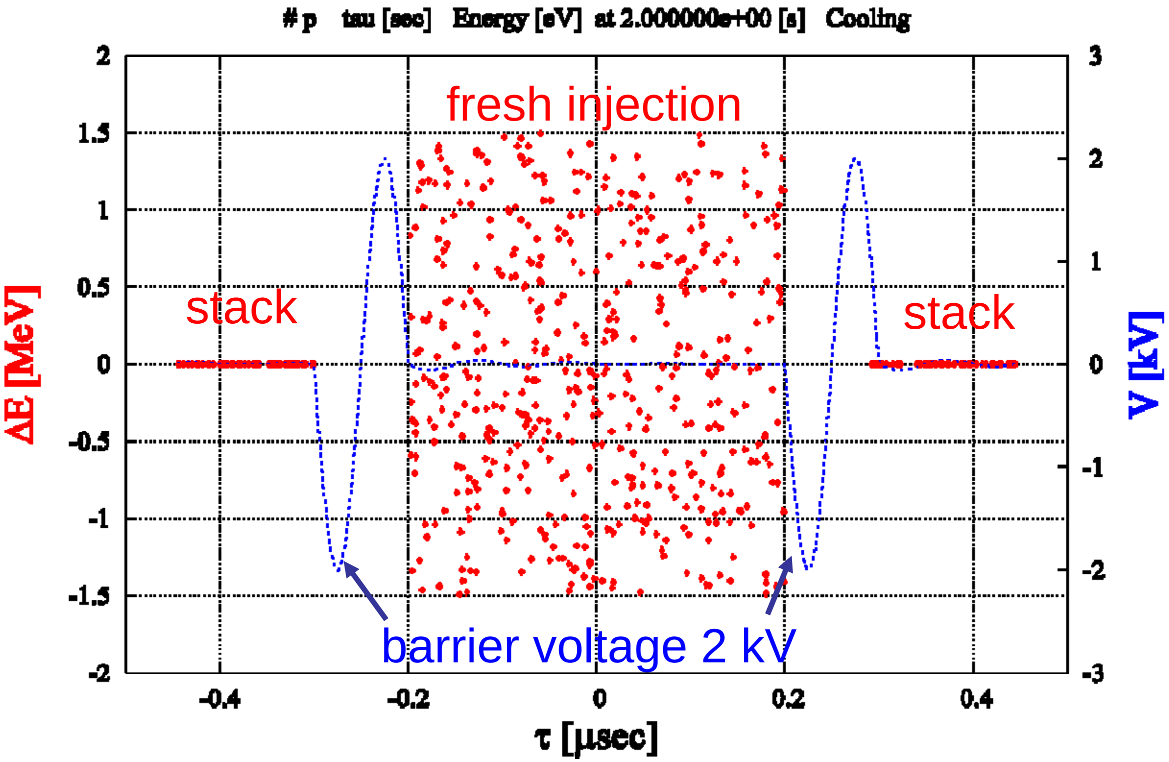


BETACOOL simulations

Accumulation of RIBs in NESR

basic idea: confine stored beam to a fraction of the circumference, inject into gap apply strong electron cooling to merge the two beam components

⇒ fast increase of intensity (for low intensity RIBs)



$^{132}Sn^{50+}$

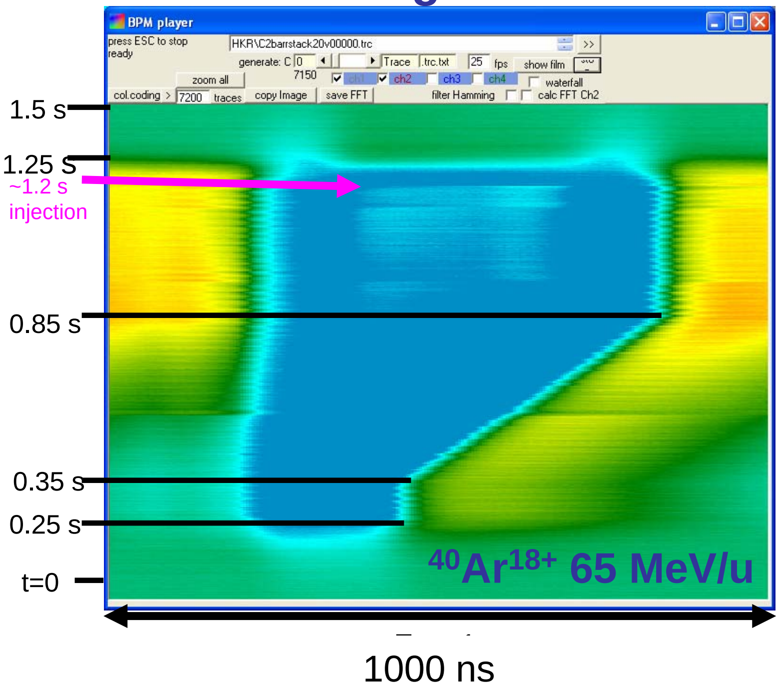
E_k = 740 MeV/u

simulation of longitudinal stacking with barrier buckets

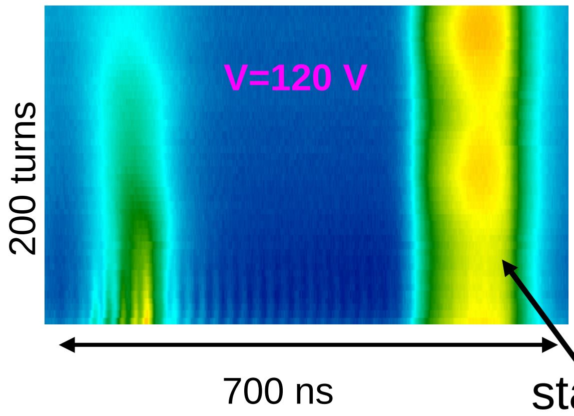
revolution time 0.9 μs

Proof of Principle in the ESR

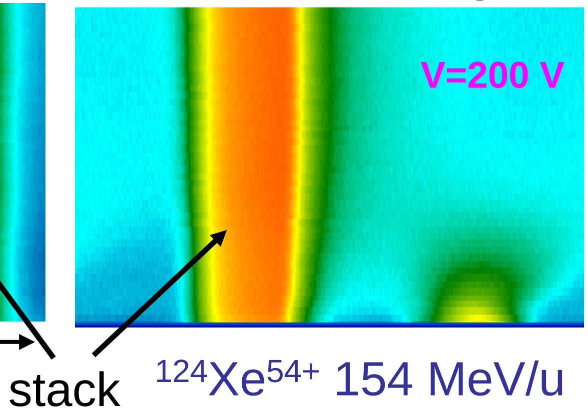
moving barrier

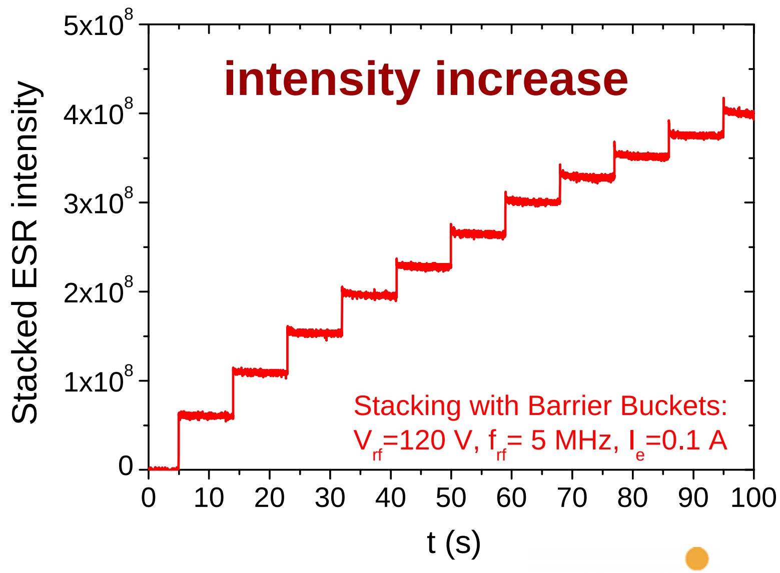


fixed barrier



h=1 unstable fixed point

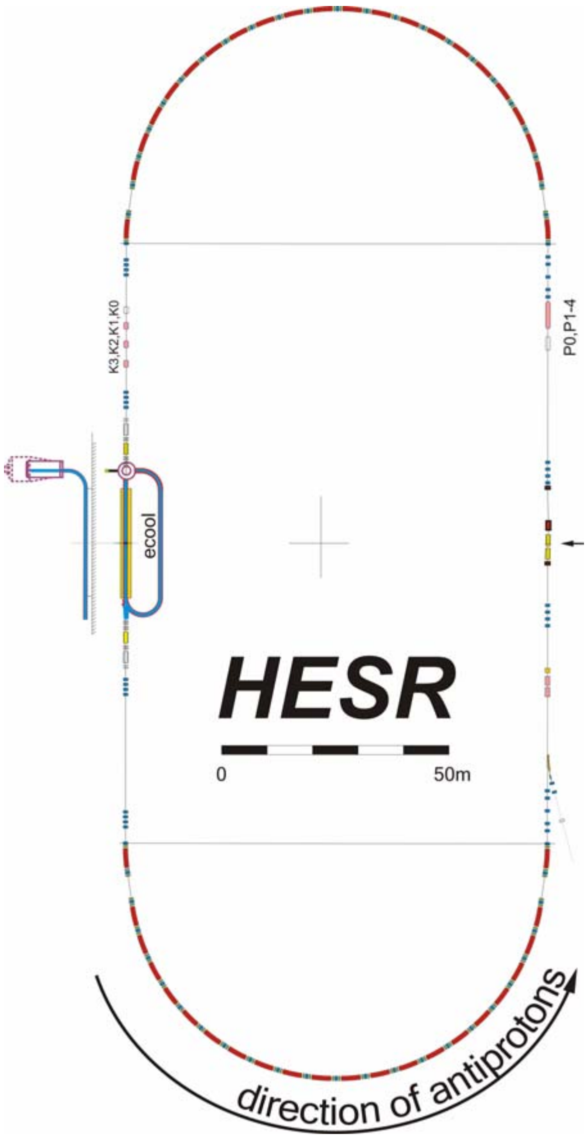




all three schemes successfully tested:

- cooling times close to expectations
- efficient accumulation
- high quality timing and kicker pulses required
- intensity limits: rf voltage and instabilities

The High Energy Storage Ring HESR



HESR Consortium: FZJ, GSI, TSL

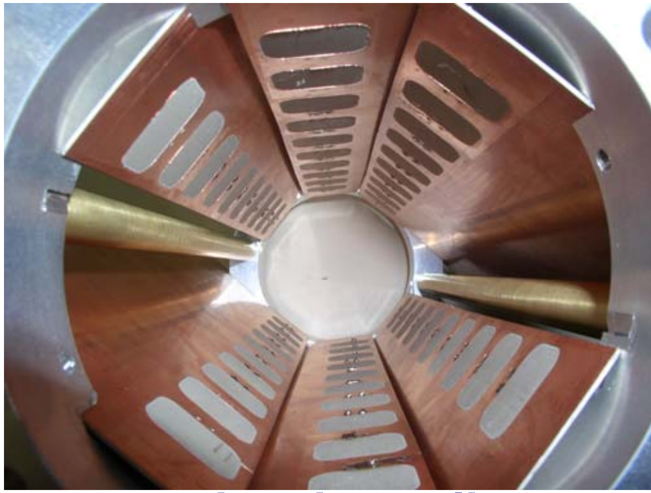
- circumference 574 m
- momentum (energy) range
- 1.5 to 15 GeV/c (0.8-14.1 GeV)
- injection of (anti-)protons from RESR at 3.8 GeV/c
- Maximum dipole field: 1.7 T
- dipole field at injection: 0.4 T
- dipole field ramp: 0.025 T/s
- acceleration rate 0.2 (GeV/c)/s

- internal experiment PANDA: dipole field ramp: 0.015 T/s internal hydrogen target

Cooling in the HESR

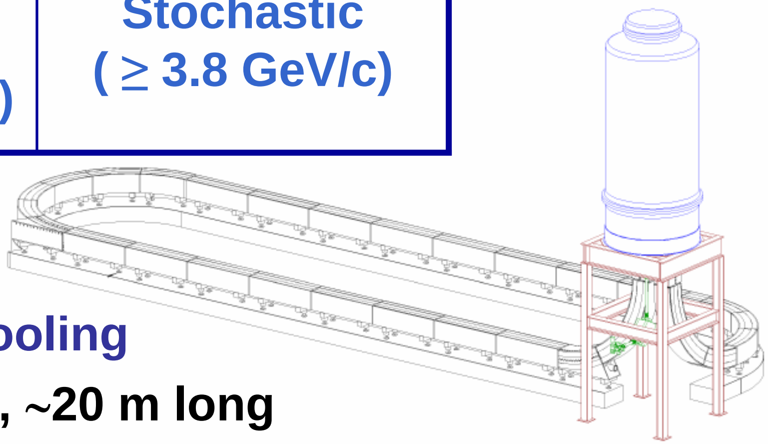
TU6PFP078 TU5PFP022

Effective target thickness (pellets):	4×10^{15} cm^{-2}	
Beam radius at target (rms):	0.3 mm	
Mode	High Resolution	High Luminosity
Momentum range	1.5 - 8.9 GeV/c	1.5 – 15 GeV/c
Antiproton number	10^{10}	10^{11}
Peak luminosity	2×10^{31} cm^{-2}s^{-1}	2×10^{32} cm^{-2}s^{-1}
Momentum spread	$\Delta p/p \leq 4 \cdot 10^{-5}$	$\Delta p/p = 1 \cdot 10^{-4}$
Beam cooling	Electron ($\leq$ 8.9 GeV/c)	Stochastic ($\geq$ 3.8 GeV/c)



stochastic cooling

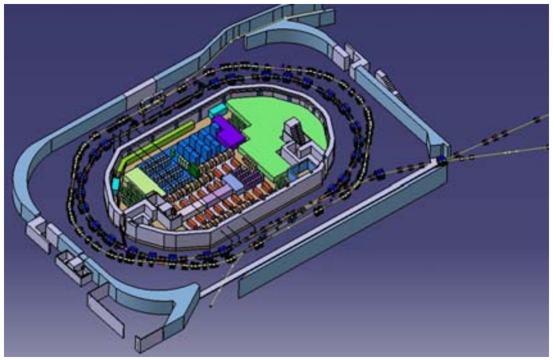
printed loop coupler, 2-4 GHz



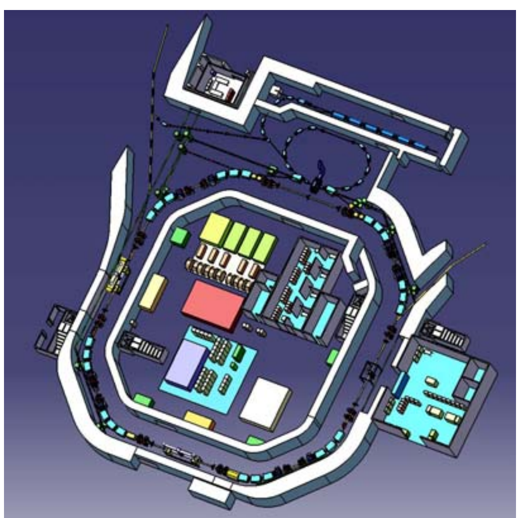
electron cooling

5 MeV, 1 A, ~20 m long

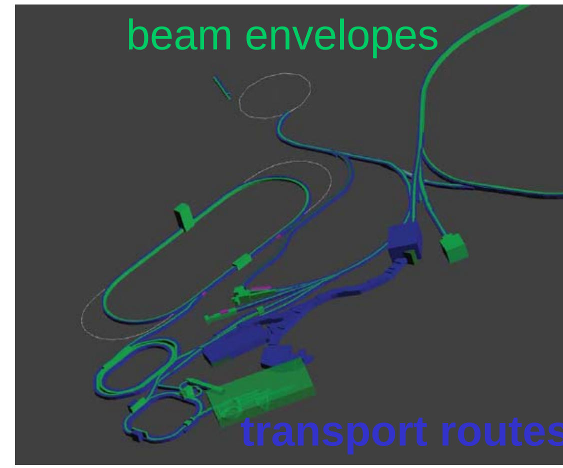
FAIR Construction Planning



technical details of
accelerator buildings



general site design

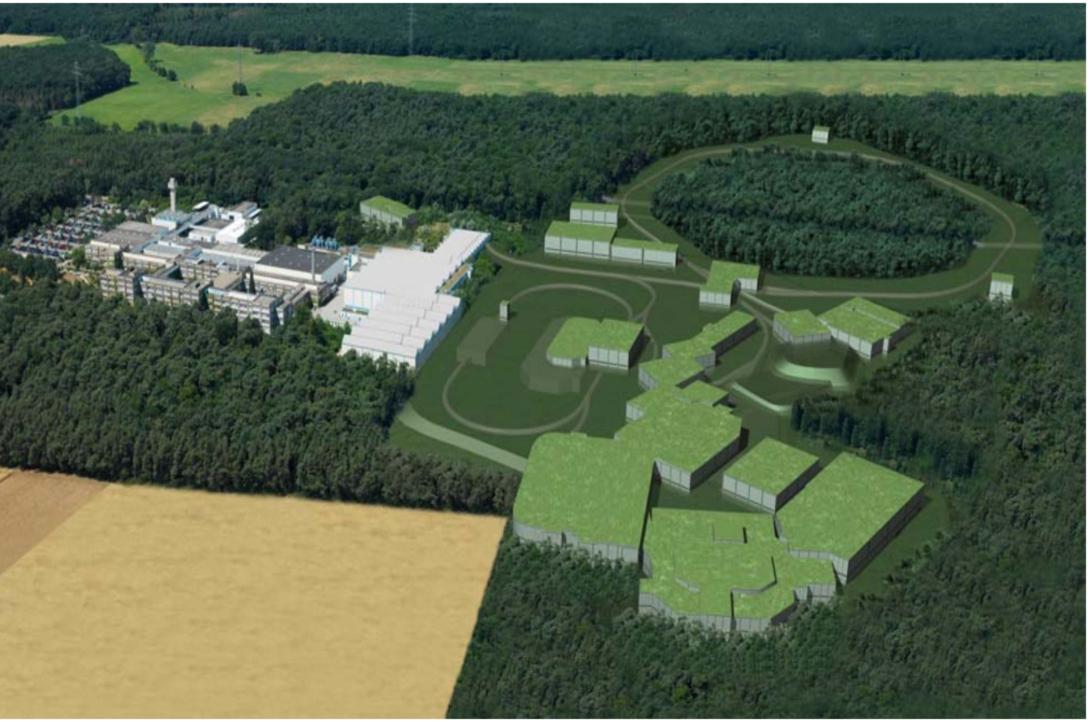


3D landscaping
('form follows beam')

Road Map towards FAIR

Austria China Finnland France Germany Greece India Italy Poland Slovakia Slovenia Spain Sweden Romania Russia UK

Observers



start version: ad valorem 940 M€
(German contribution 75 %)

Latest news: ***FAIR Newsletter***
http://www-win.gsi.de/FAIR-Newsletter/

Nov. 2007
FAIR Start Event

Oct. 2008
Finalization of legal documents the Convention with its five Annexes and the Final Act

May 2009
Cross-Checking Conference
German, English, French, Spanish, Russian, Chinese, Italian

Summer 2009
Signature of the Final Act for FAIR
Formation of FAIR GmbH