The FAIR Accelerator Facility

existing GSI

goals:

higher intensity (low charge states)
higher energy (high charge states)
production of antiprotons
high quality secondary beams (cooling)
The FAIR 13 Tm Storage Rings

from pbar target to FLAIR ions pbar
from SuperFRS RIBs to HESR pbar

Accumulator Ring
RESR

to HESR

Collector Ring
CR

Electron Ring
ER

New Experimental Storage Ring
NESR
Antiproton Target and Separator

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

Temperature of target

Target station shielding and handling

The Collector Ring CR

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

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
antiprotons
\(Q_x = 4.26, Q_y = 4.84\)
\(\gamma_t = 3.7\)
\(\eta = -0.016\)

RIBs
\(Q_x = 3.21, Q_y = 3.71\)
\(\gamma_t = 2.8\)
\(\eta = +0.185\)

isochronous
\(Q_x = 2.33, Q_y = 4.64\)
\(\gamma_t = 1.67-1.84\)
\(\eta = 0\)
Fast Bunch Rotation in CR

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 ($2.5 \rightarrow 0.5 \%$) after passage of production target.

**SIS100 bunch after target**

- $\pm 2.5 \%$
- 50 ns
- Bunch rotation
- $\pm 0.75 \%$
- Adiabatic debunching

**After bunch rotation and debunching in CR**

- $\pm 0.5 \%$

**Bunch rotation cavity (SIS18 bunch compressor)**

- Voltage 40 kV
- Length 1 m
- Frequency range 1.18 – 1.38 MHz
- Rotation time $\sim 100 \mu s$
Stochastic Cooling Developments

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

for details: THPP051

voltage and phase flatness

CR Closed orbit correction

- Number of vertical correctors: 18
- Number of horizontal correctors: 24 + 4
- Dipole correctors field variation: ± 0.02 T
- Number of monitors (h/v): 18
- Max. deflection angle: ± 2.3 mrad
- Max. mag. field of correctors: 0.1 T
- Eff. Length: 0.3 m
- Good field region: 380 x 160 mm²
- Field quality: ± 5x10⁻³
CR Closed orbit correction

MAD and WINAGILE simulations

Alignment rms errors used in tracking studies

<table>
<thead>
<tr>
<th>Element</th>
<th>Δx [mm]</th>
<th>Δy [mm]</th>
<th>Δz [mm]</th>
<th>Roll [mrad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipole</td>
<td>0.2</td>
<td>0.2</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Sextupole</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Closed orbit excursions before correction

<table>
<thead>
<tr>
<th></th>
<th>PBAR</th>
<th>RIB</th>
<th>ISO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>hor</td>
<td>ver</td>
<td>hor</td>
</tr>
<tr>
<td>ΔX_max [mm]</td>
<td>17.22</td>
<td>20.93</td>
<td>42.17</td>
</tr>
<tr>
<td>ΔX_average [mm]</td>
<td>9.76</td>
<td>11.57</td>
<td>14.71</td>
</tr>
</tbody>
</table>

Closed orbit excursions after correction

<table>
<thead>
<tr>
<th></th>
<th>PBAR</th>
<th>RIB</th>
<th>ISO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>hor</td>
<td>ver</td>
<td>hor</td>
</tr>
<tr>
<td>ΔX_max [mm]</td>
<td>3.07</td>
<td>2.52</td>
<td>1.40</td>
</tr>
<tr>
<td>ΔX_average [mm]</td>
<td>1.10</td>
<td>1.20</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Before correction
The most probable COD ≈ 20 mm

After correction
The most probable COD ≈ 1 mm

Orbit corrections are important for optimum stochastic cooling
The Antiproton Accumulator Ring

accumulation of antiprotons by a combination of rf stochastic cooling

- maximal accumulation rate: $3.5 \times 10^{10}$/h
- maximal stack intensity: $\sim 1 \times 10^{11}$

additional mode:
fast deceleration of RIBs to a minimum energy of 100 MeV/u
for injection into NESR (collider mode)

- circumference: 240 m
- magnetic bending power: 13 Tm
- tunes $Q_x/Q_y$: 3.12/4.11
- momentum acceptance: $\pm 1.0 \%$
- transverse acceptance: $25 \times 10^{-6}$ m
- transition energy: 3.3-6.4
Dynamic Aperture Calculations

$Q_x = 3.11$, $Q_y = 4.12$

$\Delta \frac{p}{p} = 0$

$\Delta \frac{p}{p} = -1 \%$

$\Delta \frac{p}{p} = +1 \%$

Frequency Map Analysis  calculated with PTC code (MAD)  for details:  THPC011  THPC057

Antiproton Accumulation in RESR

- Injection of $1 \times 10^8$ antiprotons every 10 s
- Pre-cooling in CR provides $\delta p/p = 1 \times 10^{-3}$, $\varepsilon_{x,y} = 5 \text{ mm mrad}$
- Maximum stack intensity: $1 \times 10^{11}$ antiprotons
- Pre-cooling after injection considered as option

Electrodes of Faltin type

Core cooling 2-4 GHz
Longitudinal, horizontal, vertical

Tail cooling 1-2 GHz
Longitudinal
The New Experimental Storage Ring

- 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
Accelerator Issues at NESR

- Electron cooling of ions and antiprotons
- Deceleration of ions to 4 MeV/u (in 1.6 s) 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
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: $2 \times 10^{-5}$
- 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

BETACOOL simulations Parkhomchuk model
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)

Accumulation of RIBs in NESR

Fresh injection at t=2.0 s

Stacking at 2 kV barrier voltage

Revolution time 0.9 μs

132Sn^{50+}
E_k = 740 MeV/u

Longitudinal stacking with Barrier Buckets (simulation by T. Katayama)
Proof of Principle in the ESR

all three schemes worked well:
cooling times close to expectations
efficient accumulation
high quality timing and kicker pulses required
Intensity limits: rf voltage and instabilities

for details: THPP048
Civil Construction of CR/RESR

Building

Ring Tunnel

from pbar target
from Super FRS

to HESR

to NESR

RESR

CR
NESR Civil Construction Planning

Lower (ring) level

rf, diagnostics, vacuum, controls

Upper level

power converters, common systems
FAIR Storage Ring Concept

FAIR Technical Division - Storage Ring:

C. Dimopoulou, A. Dolinskii, O. Gorda, V. Gostishchev,

many contributions from technical experts of GSI Accelerator and FAIR Division

advice by B. Franzke, T. Katayama,
D. Möhl, L. Thorndahl (CERN)

contributions by P. Shatunov, D. Shvartz and others from BINP