Status of the FAIR Project

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Stored Beams in FAIR@GSI
GSI Helmholtzzentrum Darmstadt

COOL 13, Mürren, Switzerland
FAIR - Modularized Start Version (MSV)

not included in MSV:
(can be added later depending on funding)

**SIS300** high energy 300 Tm synchrotron
**RESR** accumulator ring for antiprotons
**NESR** storage ring for experiments and deceleration of ions an pbars
**FLAIR** low energy antiprotons

part of MSV:
**SIS100** heavy ion and proton synchrotron
**SuperFRS** and **pbar** target
**CR** pre-cooling of pbars (RIBs)
**HESR** isochronous mass measurements of RIBs
**HESR** accumulation of pbars and ions
**ESR** experiments with stored pbars and ions
**ESR** operation will be continued
**CRYRING@ESR** installation after the ESR
Proton Linac

The proton linac is designed to fill SIS18 with protons up to the space charge limit main goal: production of antiprotons

- ECR proton source & LEBT
- RFQ
- 2 re-bunchers
- 2 * 6 accelerating cavities
- 5 MW of beam loading (peak), 720 W (ave.)
- 11 MW of total rf-power (peak), 5 kW (ave.)
- 2 dipoles, 46 quadrupoles, 7 steerers

| Energy | 70 MeV |
| Current (oper.) | 35 mA |
| Design current | 70 mA |
| Beam pulse length | 36 µs |
| Repetition rate | 4 Hz |
| Rf-frequency | 325.224 MHz |
| Norm. horiz. emit. | 2.1 / 4.2 µm |
| Tot. mom. spread | ≤ ± 10^-3 |
| Linac length | ≈ 35 m |

collaboration with: University of Frankfurt  
CEA/Saclay, IN2P3, GANIL
SIS 100

fast ramping super-ferric dipole (4 T/s)

SIS 18 injects 4 times $5 \times 10^{12}$ protons per SIS100 cycle for 50 ns single bunch of 29 GeV protons

Series production of dipole magnets started first magnet expected soon magnet testing facility in preparation

negotiations about production and testing of super-ferric quadrupoles

circumference 1080 m
The RIB Separator SuperFRS

Design Parameters

\[ \varepsilon_x = \varepsilon_y = 40 \ \pi \text{mm mrad} \]

\[ \phi_x = \pm 40 \ \text{mrad}, \]

\[ \phi_y = \pm 20 \ \text{mrad} \]

\[ \frac{\Delta p}{p} = \pm 2.5 \% \]

\[ B \rho_{\text{max}} = 20 \ \text{Tm} \]

\[ R_{\text{ion}} = 1500 \]

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

Super-FRS

Pre-Separator

Main-Separator

Low-Energy Branch

High-Energy Branch

Ring Branch

Production Target

Focusing System

Driver Accelerator

Concrete

Working Platform

Iron

Detector Ladder 1

Target Wheel

Detector Ladder 2

Iron

Pillow seal

Beam axis

M. Steck, COOL 13, Mürren, Switzerland, 10-14 June 2013
Antiproton Target and Separator

**Target**
- Al block
- Ti window, inside:
  - Ni rod ($r = 0.15$ cm, $l = 10$ cm)
  - in graphite cylinder ($r = 1$ cm)
- air cooling

**Target Station**
- CERN-type Magnetic Horn
- target
- horn

**Antiproton Separator**
- proton dump

**CERN-type Magnetic Horn**
- 80 mrad
- target
- beam axis
- magnetic field area
The Collector Ring CR

circumference  221.5 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 $h=1$ \ ($U_{rf} = 200 \text{ kV}$)
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
Fast Bunch Rotation in CR

Fast bunch rotation of SIS100 bunch to provide optimum initial parameters for stochastic cooling. The total rf voltage of 200 kV at h=1 reduces the momentum spread from ±3.0 to ±0.7% after passage of the production target.

**SIS100 bunch after target**

- Bunch rotation ±3.0%
- 50 ns

**after bunch rotation and debunching in CR**

- Bunch rotation ±0.7%
- Adiabatic debunching ±0.6%

**SIS18 bunch compressor cavity**

CR bunch rotation cavity filled with magnetic alloy:
- Voltage: 40 kV
- Length: 1 m
- Frequency range: 1.13 – 1.32 MHz
- Rotation time: 1000 µs (pbars)
- 600 µs (RIBs)

Debuncher rf system ordered as German In-kind
CR Stochastic Cooling

cooling of rare isotopes (\(\beta = 0.83\)) and antiprotons (\(\beta = 0.97\))

bandwidth 1-2 GHz

presentation by C. Dimopoulou

movable electrodes in pick-up tank electrodes can be cooled

heat-shield for prototype tank

kicker tanks in CR
CR Stochastic Cooling Prototypes

Electrode prototype (slot line type)

vacuum tank for moving electrodes

programmable linear actuator

milled module body with combiner board

optical delay line

poster by C. Peschke
Notch Filter Development

Optical delay line

Test set-up of notch filter at ESR

- Laser Receivers
- Switchable Fine Delay
- Laser Modulator

notch depth better than 45 dB

frequency deviation $\leq 5 \times 10^{-5}$

poster by W. Maier
Palmer Cooling for RIBs

Design of the Palmer pick-up for pre-cooling of RIBs

Rare isotopes have high charge, hence offer strong signal.
Faltin electrodes have flat frequency response but are large and insensitive.
Faltin pick-ups are suitable for pre-cooling of RIBs.
Plunging is not necessary.

Palmer cooling signal combination for vertical and simultaneous horizontal and longitudinal cooling.

Poster by D. Barker and L. Thorndahl
The High Energy Storage Ring HESR

**HESR Parameters**

- circumference 574 m
- momentum (energy) range 1.5 to 15 GeV/c (0.8-14.1 GeV)
- injection of antiprotons from CR accumulation with barrier bucket and stochastic cooling (later accumulation in RESR)
- 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
- option: high energy electron cooling

**Storage of antiprotons**

**presentation by D. Prasuhn**
Accumulation in the HESR

idea: accumulate pre-cooled antiprotons from CR by combination of barrier buckets and stochastic cooling

presentation by T. Katayama
Electron Cooling in the HESR

The COSY (HESR) 2 MeV Electron Cooler

Technical Design – Layout BINP
Basic Parameters and Requirements

- Energy Range: 0.025 ... 2 MeV
- High Voltage Stability: < 10^{-4}
- Electron Current: 0.1 ... 3 A
- Electron Beam Diameter: 10 ... 30 mm
- Cooling section length: 2.694 m
- Toroid Radius: 1.00 m
- Variable magnetic field (cooling section solenoid): 0.5 ... 2 kG
- Vacuum at Cooler: 10^{-9} ... 10^{-10} mbar
- Available Overall Length: 6.390 m
- Maximum Height: 5.7 m
- COSY beam Axis above Ground: 1.8 m

presentation by V. Kamerdzhiev

Antiproton Cooling: at injection energy and below: 0.8 – 3 GeV

Ion and RIB Cooling: In the energy range 0.2 – 3.5 GeV/u injection at 0.74 GeV/u

applications:
• compensation of target heating and intrabeam scattering
• accumulation of ions

presently assembled for commissioning at COSY

M. Steck, COOL 13, Mürren, Switzerland, 10-14 June 2013
Operation of the HESR with Ions

SPARC experiments with stored and e-cooled ion beams
Energy range: 200 MeV/u – 3 GeV/u
Reference ions: $^{238}$U$^{92+}$ and $^{132}$Sn$^{50+}$

ECOOL 2 MeV
$L_c$=2.7 m

HESR
C=575 m
max. $B\rho$=50 Tm
$\gamma_{tr}$=6.2,
$Q_x$=$Q_y$=7.62

Stochastic Cooling system
800 MeV/u - 8 GeV/u

Internal gas-jet target
possible position:
$\beta_x$=16 m, $D_x$=0.5 m, $\beta_y$=9 m

SPARC Experimental Set-up

3 GeV antiprotons
740 MeV/u ions

Injection from CR

PANDA

SPARC laser lab

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The Existing ESR

Fast injection (stable ions / RIBs)
Stochastic cooling (> 400 MeV/u)
Electron cooling (3 - 430 MeV/u)
Laser cooling (C³⁺ 120 MeV/u)
Internal gas jet target
Acceleration/deceleration (down to 3 MeV/u)
Fast extraction (reinjection to SIS / HITRAP)
Slow (resonant) extraction
Ultraslow extraction (charge change)
Beam accumulation
Multi charge state operation
Schottky mass spectrometry
Isochronous mode (TOF detector)

The ESR will be a valuable test bed to develop techniques for FAIR
Laser Cooling of C\(^{3+}\) at the ESR

\[ E_{\text{kin}} = 122 \text{ MeV/u} \]
\[ \beta = 0.47, \gamma = 1.13 \]
\[ C^{3+} \xrightarrow{2s \rightarrow 2p, \lambda = 155 \text{ nm}} \]

Optical diagnostics

Presentation by D. Winters
Single Ion Detection at the ESR

allows analysis of cooling dynamics for single ions

decay and cooling
Proof-of-Principle Experiment in the ESR

using a single bunch of Ar\textsuperscript{18+} at 400 MeV/u from SIS

mainly to demonstrate the method and benchmark codes, limited by ESR hardware (no dedicated barrier bucket rf system)

presentation by T. Katayama
**PoP-Experiment ESR**

Stacking by combination of rf and stochastic cooling with good efficiency and reliability

- **rf** $h=1$ stacking on unstable fixed point
- **stacking with fixed barriers** unsuccessful due to limited rf amplitude
- **Ar$^{18+}$ 400 MeV/u**

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**Graphs:**

1. **Left Graph:**
   - $I_{ESR}$ (mA) vs. $t$ (s)
   - Lines for different configurations:
     - G
     - G+3dB
     - G+6dB
     - G-3dB
   - $t=0$, G; $t=300$ s, G+3dB; $t=400$ s, G-3dB

2. **Right Graph:**
   - $I_{ESR}$ (mA) vs. $t$ (s)
   - Lines for different parameters:
     - $V_{RF} = 115$ V; $I_{SAT} = 0.2$ mA
     - $V_{RF} = 210$ V; $I_{SAT} = 0.34$ mA
     - $V_{RF} = 300$ V; $I_{SAT} = 0.53$ mA

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M. Steck, COOL 13, Mürren, Switzerland, 10-14 June 2013
Test of Notch Filter Cooling at the ESR

Optical delay line installed in the ESR for tests of TOF and notch filter cooling using existing electrodes designed for Palmer cooling

Palmer cooling

Time-of-Flight cooling

Notch filter cooling

Ar$^{18+}$ 400 MeV/u

poster by W. Maier
goal:

1) antiprotons of 300 keV – 30 MeV
2) highly charged ions and RIBS energies 40 keV/u – 4 MeV/u

offered as a Swedish in-kind contribution to FAIR of value 2 M€
CRYRING@ESR

presentation by F. Herfurth

CRYRING installation in existing Cave B formerly occupied by FOPI set-up

disassembly of FOPI experiment after decision of GSI management

CRYRING transport to GSI is completed, preparations for reassembly have started
CRYRING Moving to GSI

arriving at GSI

disassembly of FOPI detector

magnet straight section at GSI

CRYRING dipoles at GSI

departing from Stockholm

plan: reconstruction of cave in 3rd quarter

start of CRYRING reassembly still in 2013
Future Use of CRYRING@ESR

Stand alone operation with beam injected from ion source + RFQ
test bed for accelerator developments for FAIR
e.g. diagnostics, new control system, training of operators

Experiments with decelerated ions and RIBS from the ESR
in-ring experiments
slow (fixed target) and fast extraction (traps)

options in future:
• transfer secondary beams (antiprotons, RIBs from SuperFRS)
  from CR/RESR to ESR and CRYRING
• move CRYRING behind RESR
  sharing antiprotons with HESR
Start of FAIR GmbH

Signing of the Convention by 9 countries in Castle Biebrich, Wiesbaden

4 October 2010
FAIR GmbH Shareholders

**Germany** (October 2010)
GSI Helmholtzzentrum für Schwerionforschung GmbH, Darmstadt

**Russia** (October 2010)
State Atomic Energy Corporation ROSATOM, Moscow (17.4%)

**India** (October 2010)
Bose Institute, Kolkata (3.5%)

**Sweden and Finland** (October 2010)
Swedish Research Council, Stockholm (1.5%)

**Romania** (October 2010)
Romanian National Authority for Scientific research, Bucarest (1.2%)

**Slovenia** (October 2012)
Ministry of Education, Science, Culture and Sport, Ljubljana

**Poland** (March 2013)
Jagiellonian University, Krakow (2.33 %)

- Ratification process in **France** continued after election of new parliament

**Associate Partner** UK (May 2013)
Science and Technologies Facilities Council, London
FAIR after 2020
Preparation of Building Site

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handing of building permit by city council

B. Sharkov, H. Stöcker (FAIR) (GSI) preparing the ground

drilling of holes for pillars

new construction road
buildings and civil construction are responsibility of the FAIR GmbH

so far no update of the schedule for construction of buildings
original plan to finish buildings in 2017 is compromised
most of 2013 will be needed to complete detailed planning
Procurement of Accelerator Components

contracts so far:
SIS100 dipole modules (BNG, Germany)
HESR dipoles and quadrupoles (SigmaPhi, France)
Beam line magnets and vacuum chambers (Russian consortium)
CR debuncher cavities (RI, Germany)

in preparation:
SIS100 rf systems
SIS100 quadrupole modules (JINR Dubna, Russia)
CR dipole and sextupole magnets incl. vacuum chambers (BINP, Russia)
CR stochastic cooling power amplifiers
SuperFRS dipole magnets
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D. Möhl, L. Thorndahl (CERN)

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