Current Status of the FAIR Project

D. Krämer for the FAIR Design Team, PAC, Albuquerque, June 2007
FAIR: Motives and Objectives

• Provide the European research area with a world-leading scientific infrastructure for nuclear and hadron research

• Build on the experience of GSI, the German competence center for hadron and nuclear physics

• Realize FAIR in an international cooperation
High Intensity Precision Beams of Heavy Ions and Antiprotons

Fundamental Research into the microscopic structure of matter

&

Creation of matter nuclear astrophysics and the evolution of the universe

Matter in extreme states and material studies & applications

Structure and fundamental properties of anti-matter
The Pillars of the FAIR Complex

From existing GSI UNILAC & SIS18 & new proton linac

100 Tm Synchotron
SIS100

Antiproton production

Collector & Cooler Ring

Rare isotope Production & separator

300 Tm Stretcher Ring
SIS300

Compressed Barionic Matter experiment

High Energy Storage Ring

HESR & PANDA

Accumulator Ring
Deceleration

New Experimental Storage Ring

NESR

+ Experiments:
E-I collider
Nuclear Physics
Atomic Physics
Plasma Physics
Applied Physics
Technical Realization of FAIR

Accelerator Components & Key Characteristics

<table>
<thead>
<tr>
<th>Ring/Device</th>
<th>Beam</th>
<th>Energy</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIS100 (100Tm)</td>
<td>protons</td>
<td>30 GeV</td>
<td>4x10^{13}</td>
</tr>
<tr>
<td></td>
<td>$^{238}$U</td>
<td>1 GeV/u</td>
<td>5x10^{11}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(intensity factor 100 over present)</td>
</tr>
<tr>
<td>SIS300 (300Tm)</td>
<td>$^{40}$Ar</td>
<td>45 GeV/u</td>
<td>2x10^{9}</td>
</tr>
<tr>
<td></td>
<td>$^{238}$U</td>
<td>34 GeV/u</td>
<td>2x10^{10}</td>
</tr>
<tr>
<td>CR/RESR/NESR</td>
<td>ion and antiproton storage and experiment rings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HESR</td>
<td>antiprotons</td>
<td>14 GeV</td>
<td>~10^{11}</td>
</tr>
<tr>
<td>Super-FRS</td>
<td>rare-isotope beams</td>
<td>1 GeV/u</td>
<td>&lt;10^{9}</td>
</tr>
</tbody>
</table>

Existing facility: provides ion-beam source and injector for FAIR

New future facility: provides ion and anti-matter beams of highest-intensity and up to high energies
The International Committee Structure
(for XFEL & FAIR)

ISC
International Steering Committee
Delegates from partner states

STI Working Group
- Baseline Technical Report
  - accelerator TR's
  - experiment proposals
  - civil construction plans
  (~ 3500 pages)
- PAC & TAC Review Reports
- Cost Book
- Cost Review Reports
  - accelerator & civil construction (CORE-A)
  - experiments (CORE-E)

AFI Working Group
- Convention
- Articles of Association
- By-Laws
- Final Act Document
- Legal Framework Report (LFI)
- Full Cost Structure Report (FCI)

All documents are ready

Observe:

Austria China Finland France Germany Greece India Italy Poland Spain Sweden Russia Great Britain Romania
The FAIR Baseline Technical Report

FAIR Baseline Technical Report

Volume 1: Executive Summary
Volume 2: Technical Report Accelerators and Scientific Infrastructure
Volume 3: Techn. Experiment Proposals on QCD physics
Volume 4: Techn. Experiment Proposals on Nuclear Structure and Astrophysics
Volume 5: Techn. Experiment Proposals on Atomic Physics, Plasma Physics and Applied Physics
Volume 6: Techn. Report Civil Constructions

http://www.gsi.de/fair/reports/btr.html

Handed to ISC in April 2006 accepted as „The Project“
## ISC FAIR – Roadmap: Establishment of FAIR GmbH as Project Owner

<table>
<thead>
<tr>
<th>Meetings</th>
<th>ISC</th>
<th>AFI</th>
<th>ISC</th>
<th>AFI</th>
<th>joint meeting ISC/SH</th>
<th>Convention Final Act</th>
<th>AoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>07/06</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Negotiations (ongoing, 'till end of 2006)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Convention, Final Act, AoA; Joint Core Team</td>
<td>Bylaws, draft FAIR GmbH structure and kick-off staff</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mandate for IKAB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>First meeting: start senior staffing</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>01/07</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Signature of Convention and Final Act</td>
<td></td>
</tr>
<tr>
<td>02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03</td>
<td></td>
<td></td>
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<tr>
<td>04</td>
<td></td>
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<tr>
<td>05</td>
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<td></td>
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<tr>
<td>06</td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

### Contracting Parties
- Negotiations (ongoing, 'till end of 2006)

### Shareholders
- Convention, Final Act, AoA; Joint Core Team
- Bylaws, draft FAIR GmbH structure and kick-off staff

### ISC
- Mandate for IKAB

### AFI
- Elaboration of the Bylaws (ongoing)
  - Completion of draft Bylaws

### STI
- Monitoring of technical planning and project costs (ongoing process up to the formation of FAIR GmbH)

### Bylaw Subgroup
- Technical project decisions (follow up design changes) / FAIR preparation tasks (ongoing process up to the formation of FAIR GmbH)

### Joint Core-Team
- Technical evaluation of potential in-kind contributions (ongoing process up to the formation of FAIR GmbH)

### IKAB
- Technical evaluation of potential in-kind contributions (ongoing process up to the formation of FAIR GmbH)

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**.. Roadmap is behind schedule by 9 month ..**
Recent decision by German Minister Ms. Schavan:

**Start of the International FAIR Project**

**on November 7, 2007**

together with all partners that have expressed their commitment on FAIR.
Assumed project start in late 2006, first experiments in 2012, staged commissioning of machines up to 2015. Schedule needs revision - Civil construction is the critical path.
Project Costs

Scrutinized by CORE, TAC, STI …

Germany committed part of funding

25% of funds have to come from non-German partners

Baseline Costbook
March 2006

As of today: commitment by India (3%) and Rumania (1%) AND positive bilateral negotiations
FAIR Work Packages

94 WPs defined, following WBS, FBTR and Cost Book schematics

13 subprojects

15 technical systems

FAIR WPs

No final decision up to now – awaiting expressions of interest of intern. partners

Finally contracts between partner and FAIR GmbH

Invitation to all partner state accelerator labs to participate in workshop on detailing realization of commitments (Oct. 1, 2007)
R&D on Key-Components during Preparatory Phase
by GSI & Partner Institutes since 2001

SIS300 sc magnets

NESR Electron Cooling

SIS100 rapidly cycling sc magnets

Variable frequency
MA&ferrite loaded cavities

INFN
Istituto Nazionale di Fisica Nucleare

BROOKHAVEN NATIONAL LABORATORY

IHEP
Protvino

CEA

BINP Novosibirsk
Posters and Talks on FAIR

G. Moritz, FRYKI01, talk

J. W. Stetson, talk

W. Bayer TUPAN012

U. Blell MOPAN012
C. Omet TUPAN013
A. Parfenova TUPAN016
G. Clemente TUPAN017
M. Steck TUPAN016
R. Tölle TUPAN024
P. Spiller TUPAN014
J. Stadlmann TUPAN015
V. Kornilov TUPAN018
C. Benedetti TUPAN024
R. Tölle TUPAN024
G. Moritz, FRYKI01, talk

J. W. Stetson, talk

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P. Spiller TUPAN014
J. Stadlmann TUPAN015
V. Kornilov TUPAN018
C. Benedetti TUPAN024
SIS100/300 Design Parameters

**First Stage:** Acceleration + Compression

**Second Stage:** Acceleration + Stretching

<table>
<thead>
<tr>
<th>Reference Ions</th>
<th>SI S100</th>
<th>SI S300</th>
</tr>
</thead>
<tbody>
<tr>
<td>U^{28+} p</td>
<td></td>
<td>U^{28+} U^{92+}</td>
</tr>
<tr>
<td>Magnet. rigidity</td>
<td>100 Tm</td>
<td>300 Tm</td>
</tr>
<tr>
<td>Circumference</td>
<td>1083 m</td>
<td>1083 m</td>
</tr>
<tr>
<td>Number of Particles</td>
<td>5 \cdot 10^{11}</td>
<td>3 \cdot 10^{11} /s</td>
</tr>
<tr>
<td></td>
<td>5 \cdot 10^{13}</td>
<td>1 \cdot 10^{10} /s</td>
</tr>
<tr>
<td>Energy</td>
<td>2.7 GeV/u</td>
<td>2.7 GeV/u</td>
</tr>
<tr>
<td></td>
<td>29 GeV</td>
<td>34 GeV/u</td>
</tr>
<tr>
<td>Beam time structure</td>
<td>25 – 90ns</td>
<td>d.c. slow ext.</td>
</tr>
<tr>
<td></td>
<td>50 ns</td>
<td></td>
</tr>
<tr>
<td>Dipole flux density</td>
<td>2 T</td>
<td>4.5 T</td>
</tr>
<tr>
<td>Ramp Rate</td>
<td>4 T/s</td>
<td>1 T/s</td>
</tr>
</tbody>
</table>
## SIS100 Working Points and Lattice Parameters

<table>
<thead>
<tr>
<th></th>
<th>WP2</th>
<th>WP1</th>
<th>WP3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tunes (h/v)</strong></td>
<td>17.30 / 17.42</td>
<td>18.84 / 18.73</td>
<td>20.84 / 20.73</td>
</tr>
<tr>
<td><strong>Mode of SIS100 operation</strong></td>
<td>Ions, slow extraction</td>
<td>Ions, fast extraction</td>
<td>Protons, high energy</td>
</tr>
<tr>
<td><strong>Amplitude function beta maximum</strong></td>
<td>(h/v) m</td>
<td>19.8 / 19.6</td>
<td>19.6 / 19.6</td>
</tr>
<tr>
<td><strong>Dispersion function alpha-p maximum alpha-p minimum</strong></td>
<td>m m</td>
<td>1.44 / -1.11</td>
<td>1.73 / -0.12</td>
</tr>
<tr>
<td><strong>Phase advance per lattice cell</strong></td>
<td>deg</td>
<td>74 / 75</td>
<td>81 / 80</td>
</tr>
<tr>
<td><strong>Transition energy</strong></td>
<td>14.29</td>
<td>15.58</td>
<td>17.48</td>
</tr>
<tr>
<td><strong>Natural chromaticity $\xi_{nat}/Q$</strong></td>
<td>(h/v)</td>
<td>-1.16 / -1.16</td>
<td>-1.19 / -1.2</td>
</tr>
<tr>
<td><strong>Transverse acceptance</strong></td>
<td>(h/v) mm·mrad</td>
<td>201 / 54</td>
<td>206 / 54</td>
</tr>
</tbody>
</table>
Progress in SIS Magnet R&D

MoU on prototype R&D
SIS300 bending magnet

Straight mark I full scale dipole magnet
under fabrication at BNG / Würzburg
Curved mark I full scale dipole magnet
under fabrication at BINP / Novosibirsk
R&D continued at JINP / Dubna incl.
Quadrupole prototype

GSI001, first 4 T prototype by BNL
6 T prototype under construction at Dubna
Curved 4.5 T dipole magnet
under fabrication at INFN
SIS 100 Dipole under Construction

Other on-going sc magnet activities:
Super-FRS: quadrupole (Toshiba)
radiation resistant magnets (BINP)
superferric dipole (IMP)
**Layout of Super-FRS**

- **Superferric Multiplet**
- **Dipole Unit** 3 x 9.75°
- **MF1**
- **MF2**
- **Main-Separator**
- **Low-Energy Branch**
- **High-Energy Branch**
- **Spectrometer / Energy Buncher**
- **Ring Branch**
- **Pre-Separator**
- **Beam Dumps**
- **Exit Slit Pre-Separator**
- **Degrader 1**
- **Degrader 2**

**Projectile:**
- Elements p - U
- Energy up to 1.5 GeV/u
- Intensity $10^{12} - 10^{13}$ /s (depending on element)

**Acceptance:**
- $\varepsilon_x = \varepsilon_y = 40 \pi$ mm mrad
- $\Phi_x = \pm 40$ mrad
- $\Phi_y = \pm 20$ mrad
- $\Delta P/P = \pm 2.5\%$

**Features:**
- 2 Separator-stages
- Multi-branch system
- Large acceptance utilizing sc magnets
- Handling concept for high-radiation area
CR-RESR Complex

From Super-FRS, antiproton separator
 Tasks of the CR

1. Cooling of secondary beams of radioactive ions (RI)

- Initial RI beam
  \[ \varepsilon_{\perp} = 200 \text{ mm mrad} \]
  \[ \Delta p/p = 3\% \]

- From Super-FRS
  \[ 1.5 \text{ sec} \]

- CR

- To the NESR
  \[ \varepsilon_{\perp} \leq 0.5 \text{ mm mrad} \]
  \[ \Delta p/p \leq 0.05\% \]

- Final RI beam

2. Cooling of antiproton beams (Pbar)

- Initial antiproton beam
  \[ \varepsilon_{\perp} = 240 \text{ mm mrad} \]
  \[ \Delta p/p = 6\% \]

- From antiproton separator
  \[ 10 \text{ sec} \]

- CR

- To the RESR
  \[ \varepsilon_{\perp} \leq 5 \text{ mm mrad} \]
  \[ \Delta p/p \leq 0.1\% \]

- Final Pbar parameters

3. Mass spectrometer of radioactive ions RI (TOF)

- RI beam
  \[ \varepsilon_{\perp} = 100 \text{ mm mrad} \]
  \[ \Delta p/p = 1\% \]

- From Super-FRS
  \[ \text{few turns} \]

- CR

- \[ \frac{\Delta m}{m} = \gamma_{ir}^2 \frac{\Delta f}{f} \]
CR Beam Envelopes

P-bar mode: $\varepsilon_{x,y}=240 \text{ mm mrad}$, $\Delta p/p=+3.0 \%$

Large Acceptance Machine:

Hor. aperture $A = 400 \text{ mm}$
Ver. aperture $A = 180 \text{ mm}$

RIB mode: $\varepsilon_{x,y}=200 \text{ mm mrad}$; $\Delta p/p=+1.5$

Isochronous mode:

$\varepsilon_{x,y}=100 \text{ mm mrad}$; $\Delta p/p=+0.5 \%$
CR Dipole Prototype Development in China

IMP Lanzhou
IPP Hefei
IEE Beijing

The assembly of die
First lamination finished
Coil fabrication
Magnet design

CAS
RESR: Stochastic Cooling & Accumulation Scheme

Deceleration of pre-cooled RIB to 100 MeV/u

&

Accumulation and cooling of $10^{11}$ antiprotons

- Two transverse cooling systems (horizontal, vertical)
- Three longitudinal systems (hand-over system, stack-tail system, stack-core system)

Accumulation orbit $\frac{dp}{p}=+0.8\%$

Accumulation rate $1.5 \times 10^7$ s$^{-1}$
Accumulation time 3.5 h
Number of particles $10^{11}$

Injection orbit $\frac{dp}{p}=-0.8\%$
The New Experimental Storage Ring

Experiments with radioactive and stable ions at gas-jet or pellet target
Preparation of the low energy antiproton beams
Electron scattering on radioactive nuclei (collider mode)
Ion-electron interaction studies

- **Injection energy:**
  - Radioactive Ion Beams (RIB) 100 – 740 MeV/u
  - Antiproton beams (Pbar) 3 GeV
- **Lowest extraction energy:**
  - RIB 4 MeV/u
  - Pbar 30 MeV
- **Emittance:**
  - RIB 0.1 – 1 mm mrad
  - Pbar 1 mm mrad
- **Momentum spread:** < 10^{-4}
NESR Lattice functions

Betatron functions $\beta_x$, $\beta_y$

Dispersion functions [m] versus distance [m]

Maximum Dispersion 7.5 m

$Q_h = 3.37$

$Q_v = 3.18$

$\varepsilon_x = 160 \text{ mm mrad}$,

$\varepsilon_y = 35 \text{ mm mrad}$,

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

Hor. Aperture up to $A = 300 \text{ mm}$
The NESR Electron Cooler

design by BINP, Novosibirsk

Cooler Parameters
- energy: 2 - 450 keV
- max. current: 2 A
- cathode radius: 1 cm
- beam radius: 0.5-1.4 cm
- hollow cathode option
- magnetic field
  - gun: up to 0.4 T
  - cool. sect.: up to 0.2 T
  - straightness: \(\leq 5 \times 10^{-5}\)
  - adiabatic expansion option
- cool. section length: 5 m
- max. power in collector: 15 kW
- vacuum: \(\leq 10^{-11}\) mbar

Issues:
- high voltage up to 500 kV
- fast ramping, up to 250 kV/s
- magnetic field quality
High Energy Storage Ring
for antiprotons

- Momentum: 1.5 – 15 GeV/c
- Straights: Cooler and target section
- Ring circumference: 573 m.
HESR Ion Optics and Lattice Parameters

**Arches:** 4-fold symmetry, with dispersion suppression and imaginary gamma transition.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length</td>
<td>573.11 m</td>
</tr>
<tr>
<td>Tune $Q_x, Q_y$</td>
<td>9.16, 9.18</td>
</tr>
<tr>
<td>Phase advance per arc</td>
<td>$3 \cdot 2 \pi$</td>
</tr>
<tr>
<td>$\beta_{x,y}^{\text{Target}}$</td>
<td></td>
</tr>
<tr>
<td>$\beta_{x,y}^{\text{ElectronCooler}}$</td>
<td></td>
</tr>
<tr>
<td>$\beta_{x,y}^{\text{max Straights}}$</td>
<td></td>
</tr>
<tr>
<td>$\beta_{x,y}^{\text{max Arcs}}$</td>
<td></td>
</tr>
<tr>
<td>$D_{x}^{\text{max Arcs}}$</td>
<td>12 m</td>
</tr>
<tr>
<td>Nat. Chromaticity $Q'_{x,y}$</td>
<td>-28 to -16</td>
</tr>
<tr>
<td>$\gamma_{tr}$</td>
<td>6.0i, flexible</td>
</tr>
<tr>
<td>Dipole field, max.</td>
<td>3.6 T, curved</td>
</tr>
<tr>
<td>Quadrupole gradient</td>
<td>23, 43 T/m</td>
</tr>
<tr>
<td>Sextupole strength</td>
<td>460 T/m²</td>
</tr>
</tbody>
</table>
- $\pm 17$ m free space between quadrupoles around the target
- 10 m free space behind the target
- Compensation dipoles between quadrupoles
- Orbit deviation: 50 mrad, 400 mm (max)
- Project „GO“ this year!
- Designs have been frozen.
- R&D on key components is well advanced,
- sc magnet-prototypes are under construction.
- Technical designs of conventional components has started.
- Civil Construction planning has started – execution work expected to start in early 2009.
- Detailed negotiations on partners’ contributions ongoing.
Acknowledgements

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R. Maier et. al.
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Collaborating laboratories:
BNL, CERN, DESY, FZ Karlsruhe, KVI Groningen, MSU.
FAIR member states:
China: IMP, IEE, IPP
France: INP Orsay
Great Britain: CLRC Daresbury
Italy: INFN Genoa
Poland: Uni Cracow
Russia: BINP, IHEP, ITEP, IHCE, Uni Moscow and JINR
Spain: CIEMAT
Sweden: TSL Uppsala, MSL Stockholm

and many individuals that helped: 2400 worldwide

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