FAIR – Facility for Antiproton and Ion Research

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EPAC-04, July 2004, Luzern
GSI Darmstadt

Member of the Helmholtz Association
The Future International Facility at GSI: FAIR - Facility for Antiproton and Ion Research
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Beams now:

Z = 1 – 92  
(protons to uranium) up to 2 GeV/nucleon
Beam cooling

Beams in the future:

Intensity: 100 – 1000 fold  
Species: Z = -1 – 92  
(anti-protons to uranium)  
Energies: up to 35 - 45 GeV/u
Precision: beam cooling
Present GSI Accelerators

3 Ion sources
2 injectors

Heavy Ion Linac
UNILAC (<20 MeV/u)

Heavy Ion Synchrotron
SIS18 (2 GeV/u for A/q=2)

Fragment Separator
FRS

Experimental Storage Ring
ESR

GSI
### Schedule and Parallel Operation of Present GSI Accelerators

#### Beam-Time-Schedule 09.02.2004 - 11.03.2004

| Date | 0.2 | 10.2 | 11.2 | 12.2 | 13.2 | 14.2 | 15.2 | 16.2 | 17.2 | 18.2 | 19.2 | 20.2 | 21.2 | 22.2 | 23.2 | 24.2 | 25.2 | 26.2 | 27.2 | 28.2 | 29.2 | 1.3 | 2.3 | 3.3 | 4.3 | 5.3 | 6.3 | 7.3 | 8.3 | 9.3 | 10.3 | 11.3 |
|------|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| **ION-SOURCES** |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| ECR  |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| PIG  | 3He |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| MUCIS| 56 Mo | 40 Ar | 124 Xe | 56 Fe | 22 Ne | 209 Bi | 40 Ar |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| **UNILAC** |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 1. experiment | UU Mo 94 Mo Y7 40 Ar Y7 4.7 | UU ECR 22 Ne X1 7.0 MeV/u | machine | experiments | 11.4 MeV/u | 11.4 MeV/u | 1.4 MeV/u |
| 2. experiment | UU Mo X0 3He X6 40 Ar X0 40 Ar X1 5.2 MeV/u | UU ECR 22 Ne Z6 5.9 | machine | experiments | 3.6 MeV/u | 7.1 MeV/u | 5.9 |
| 3. experiment | UU Mo 40 Ar Z6 5.9 | UU Bi X0 209 Bi 7.0 MeV/u | machine | experiments | 22 Ne | 11.4 MeV/u | 11.4 MeV/u | 11.4 MeV/u |
| transfer-line | UU He 3He 11.4 | UU 124 Xe 11.4 | UU Bi 209 Bi | machine | experiments | 11.4 MeV/u | 11.4 MeV/u | 11.4 MeV/u | 11.4 MeV/u | 11.4 MeV/u | 11.4 MeV/u | 11.4 MeV/u | 11.4 MeV/u | 11.4 MeV/u | 11.4 MeV/u | 11.4 MeV/u |
| 1. experiment | US He HTM therapy-like US 124 Xe FRS | US 56 Fe HTB | machine | experiments | 1 GeV/u | 1 GeV/u | 1 GeV/u |
| 2. experiment | UU 124 Xe ESR 400 MeV/u cooler | UU 124 Xe HTA | UU 124 Xe HTA | 56 Fe HTA | 56 Fe HTA | 209 Bi HTA | 7.0 MeV/u | 11.4 MeV/u | 7.0 MeV/u | 11.4 MeV/u | 7.0 MeV/u | 11.4 MeV/u | 7.0 MeV/u | 11.4 MeV/u | 7.0 MeV/u | 11.4 MeV/u | 7.0 MeV/u | 11.4 MeV/u | 7.0 MeV/u | 11.4 MeV/u | 7.0 MeV/u | 11.4 MeV/u | 7.0 MeV/u | 11.4 MeV/u | 7.0 MeV/u | 11.4 MeV/u | 7.0 MeV/u | 11.4 MeV/u |
| 3. experiment | US He HTM therapy-like US 124 Xe FRS | US 56 Fe HTB | machine | experiments | 1 GeV/u | 1 GeV/u | 1 GeV/u |

**Notes:**
- **UU** = tune UNILAC and transfer-line
- **US** = tune SIS and high energy beam-lines
Present GSI Accelerators

3 Injectors: 2 HSI + 1 ECR

HSI:
- 10 mA Ar\(^{1+}\)
- 20 mA Ar\(^{10+}\)
- 15 mA U\(^{4+}\)
- 2.5 mA U\(^{28+}\)
- 0.5 mA U\(^{73+}\)

Heavy Ion Synchrotron
SIS18 (2 GeV/u for A/q=2)

Heavy Ion Linac
UNILAC (<20 MeV/u)

Fragment Separator
FRS

Experimental Storage Ring
ESR

Upgrade towards the Future Facility:
Frequency (electrical power grid!)
0.3 Hz → 3 Hz

Space charge reduction (vacuum!)
U\(^{73+}\) → U\(^{28+}\)
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- HSI: 10 mA Ar$^{1+}$
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Upgrade towards the Future Facility:
- Frequency (electrical power grid!): 0.3 Hz → 3 Hz
- Space charge reduction (vacuum!): U$^{73+}$ → U$^{28+}$
Production of exotic nuclear beams by fragmentation

advantage:
shortlived isotopes
\(T_{1/2} < \text{ms}\) accessible

About 1000 nuclear residues identified

A/Z-resolution \(\sim 10^{-3}\)
Elektronenstrahlgekühlte Ionenstrahlen

G.I. Budker, At. En. 22 (1967) 346
G.I. Budker, A.N. Skrinsky et al., IEEE NS-22 (1975) 2093
Speicherringe: Gekühlte Ionenstrahlen
Speicherringe: Gekühlte Ionenstrahlen

![Graph showing ion intensity before and after cooling.](image)

- **Ionenintensität**
- **rel. Ionengeschwindigkeit** \( \frac{v}{v_0} \)

1. **Elektronenkollektor**
2. **Elektronenkanone**
3. **Hochspannungsplattform**
4. **Magnetisches Feld**
5. **Elektronenstrahl**
6. **Ionenstrahl**

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**GSI**

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Schottky Frequenz Spectrum

Intensity / arb. units

33800 33900 34000 34100 34200 34300 34400 345000

Frequency / Hz

$143^m_{\text{Sm}}^{62+}$

$143^g_{\text{Sm}}^{62+}$

754 keV

(1 particle)

(1 particle)

$m/\Delta m \approx 700000$
FAIR: Facility Characteristics

SIS 100/300

UNILAC

SIS

FRS

ESR

NESR

HESR

Super FRS

CR

RESR
Primary Beams
- $10^{12}$/s; 1.5-2 GeV/u; $^{238}\text{U}^{28+}$
- Factor 100-1000 over present in intensity
- $2(4)\times10^{13}$/s 30 GeV protons
- $10^{10}$/s $^{238}\text{U}^{73+}$ up to 35 GeV/u (up to 90 GeV protons)

Secondary Beams
- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3 - 30 GeV

Storage and Cooler Rings
- Radioactive beams
- e – A collider
- $10^{11}$ stored and cooled 0.8 - 14.5 GeV antiprotons

Key Technical Features
- Cooled beams
- Rapidly cycling superconducting magnets
New SIS 100/300 Synchrotron

Two synchrotrons in one tunnel (1080 m circumference)

R&D program in rapidly cycling superconducting magnets

Booster and compressor

SIS100

Stretcher and high energy ring

SIS 300

Nuclotron dipole magnet:
B=2T, dB/dt=4T/s

RHIC type dipole magnet:
B=4T→6T, dB/dt=1T/s
R&D in Superconducting Magnet Technology

Collaboration Network

SIS 100: window-frame magnet

BNL (US) 1/2001
Twente University (NL)
Jena University (D)
IHEP (RU) 6/2002

Large Aperture Magnets (Storage Rings, SFRS, R3B)

NSCL/MSU (US) 1/2002
CEA (F)

Magnet Design Software

CERN (CH)
TU Darmstadt (D)

Consulting

CERN (CH) 8/2002
FZ Karlsruhe (D)
DESY (D)
M.N. Wilson (GB)
B. Hassenzahl (US)

SIS200/300 \( \cos \theta \) magnet

JINR (RU) 2/2000
LBNL (US)
Bochvar Institute (RU)
BINP (RU) 6/2002

Cryogenics

TU Dresden (D)
ACT Inc. (US)
FAIR: Research Areas

- Nuclear Structure Physics and Nuclear Astrophysics with Radioactive Ion-Beams
- Hadron Physics with Antiprotons
- Physics of Nuclear Matter with Relativistic Nuclear Collisions
- Plasma Physics with Highly Bunched Laser- and Ion-Beams
- Atomic Physics and Applied Science
- Accelerator Physics
Proton-rich nuclei
• Proton radioactivity
• Proton - neutron pairing
• Isospin symmetry
• Tests of standard model and symmetries
• Nucleosynthesis

Superheavy elements
• Shell stabilization
• Long-lived nuclei

Neutron-rich nuclei
• Neutron drip line
• Shell quenching
• Skins and halos
• Loosely bound systems
• Soft collective modes
• Nucleosynthesis

Structure and Dynamics of Nuclei – Radioactive Beams at FAIR
Nuclear Physics in the Universe

Proton number $Z$

Accreting white dwarf

Nova Cygni 1992

Elements in our solar system

Sun

Neutron number $N$

rp-process

$^{126}$

$^{82}$

r-process

Neutron star

Supernova 1987A

GSI
Production of exotic nuclear beams by fragmentation

advantage:
shortlived isotopes ($T_{1/2} < ms$) accessible

1$^{32}$Sn

Land Collaboration
P. Adrich et al., 2004

About 1000 nuclear residues identified

A/Z-resolution $\sim 10^{-3}$
Physics program at the High Energy Storage Ring (HESR)

- $J/\psi$ spectroscopy
- Confinement
- Glueballs ($ggg$)
- Hybrids ($c\bar{c}g$)
- Hidden and open charm in nuclei
- Strange and charmed baryons in nuclear fields
- Inverted deeply virtual Compton scattering
- CP-violation ($D/\Lambda$ - sector)
- Fundamental symmetries: antiprotons in traps (FLAIR)
- New proposals: ASSIA, PAX (pol. target; pol. $p$ – beams)
QCD- Phase Diagram

study of compressed baryonic / strange matter in nucleus-nucleus collisions up to laboratory energies of 35 AGeV

important probe: dilepton pairs
NN Collisions at 2-40 AGeV

- Optimum production of baryons with strange quarks
- Maximum compression in heavy-ion collisions
- Threshold for antiprotons
- Threshold for charm quarks

Ion energy [AGeV]
High Power Density in Matter – Physics of Dense Plasma

- Magnetic Fusion
- Inertial Cofinment Fusion
- PHELIX
- Laser Heating
- Ideal plasmas
- Strongly coupled plasmas
- Ion Beam Heating
- SIS 18
- Solid state density
- Sun Core
- Sun Surface
- Jupiter

Temperature [eV]

Density [cm^{-3}]

1 mbar
1 kbar
1 Mbar
1 Gbar
1 Tbar

10^0
10^1
10^2
10^3
10^4
10^5

1 eV
10 eV
100 eV

10^{12} 10^{15} 10^{18} 10^{21} 10^{24} 10^{27} 10^{30}
1. Extreme Static Electromagnetic Fields

- Laser fields: $10^{22} \text{ W/cm}^2$
- $\Delta E \approx 500 \text{ eV}$
- $Z \cdot \alpha \approx 1$

- $\Delta E \approx 10^{-6} \text{ eV}$
- $Z \cdot \alpha \approx 10^{-2}$

Atomic Physics
2. Extreme Dynamic Fields

\[ U^{92+} \]

\[ \gamma = 1, 2, 3, 4, 5 \]

\[ t \leq 0.1 \text{ as} \]

\[ I \approx 10^{21} \text{ W/cm}^2 \]

\[ \nu \approx \text{MHz} \]

\[ b \sim 10^6 \text{ fm} \]
2. Extreme Dynamic Fields

**PHYSICS IN ACTION**

**Ten thousand times faster than a laser, and just as strong**

From Jim McGuire in the Department of Physics, Tulane University, New Orleans, USA, and Bruce W Shore in the Fachbereich Physik, Universität Kaiserslautern, Germany

The kinetic energy of a fully stripped uranium ion accelerated to 1 GeV per nucleon is about $10^{10}$ times greater than the binding energy of the electrons in a helium atom. It is no surprise, then, that such an ion can cause a helium atom to explode. What is surprising, however, is that such a collision can be described as "gentle" because the ion, which is travelling at close to the speed of light, transfers essentially no momentum to the atom. Such collisions therefore allow the dynamics of electronic transitions in helium atoms – in particular the dynamics of the correlations between the electrons – to be probed in great detail (R. Mohrhammer et al., 1993 Phys. Rev. Lett. 79 9621). How can this happen?

The first important point is that the particles do not collide head-on – rather the

$$\gamma = 1 \quad 2 \quad 3 \quad 4 \quad 5$$

$$0 \quad 87 \quad 94 \quad 97 \quad 98$$

Percent of Light Velocity

$$t \leq 0.1 \text{ as}$$

$$I \approx 10^{21} \text{ W/cm}^2$$

$$\nu \approx \text{MHz}$$

$$b \sim 10^6 \text{ fm}$$
The Structure of Matter

- **Gravitational Force**
  - General Relativity

- **Electromagnetic Force**
  - QED
  - Electroweak Force
    - Weak Force
      - Standard Model

- **Strong Force**
  - QCD

Research with Beams of Hadrons and Ions

- Ion-Matter Interactions
  - Dense Plasmas
    - HI Beams $\rightarrow$ 12 TW/g
  - Ultra High EM Fields
    - Nuclei at the Extremes
      - RIBs $\rightarrow$ 1.5 - 2 GeV/u

Quark Gluon Structure of Hadrons

- Antiprotons 0-15(30) GeV
- Quark Matter
  - Relativ. HI $\rightarrow$ 35 GeV/u
Physics of the Universe

RESEARCH WITH ION BEAMS
• Novae, supernovae
• Synthesis of heavy elements
• r-process and rp-process
• Neutron stars – strangeness matter
• Synthesis of light elements
• Dark matter
• Chiral symmetry breaking
• Quark-gluon plasma

15 billion years
1 billion years
300,000 years
3 minutes
1 thousandth of a second

3 K
20 K
3,000 K
10^9 K
10^12 K

HI Beams → 12 TW/g
RIBs → 2 GeV/n
Antiprotons 0-15(30) GeV
Relativ. HI → 35 GeV/n
Key Developments and Milestones

1996-99   Discussion of Future Directions for the GSI Facilities
          (Workshops and White Papers from 9 Working Groups, Loi Antiprotons)

2000   Development of Facility Concept

2001   Conceptual Design Report (700 pages, ca. 500 authors worldwide)

2002   Evaluation by the German Wissenschaftsrat & Recommendation for Realization

2002-03   Formation of Proto-Collaborations (PANDA / CBM / NUSTAR / FLAIR )

2003   Decision by the Federal Government to Construct Facility
        (2 conditions: 25% of funding from international sources; technical staging)

2002-2003   Development of Staged Construction Concept and Science Programs

2003   2nd International Workshop

2004   Letters of Intent: 1800 participants, (PANDA: ~ 320 participants, 44 institutions, 11 countries; CBM ~ 250 participants, 38 institutions, 15 countries; NUSTAR: ~450 participants, 98 institutions, 27 countries; FLAIR: ~ 250 participants, 48 institutions, 14 countries; ...)

2004   Formation of the International Steering Committee (ISC-FAIR) and working groups (AFI-FAIR & STI-FAIR); first financial plan from the German government (federal and state)
**COSTS**

Building and infrastructure: 225 Mio. €

Accelerator: 265 Mio. €

Experimental stations / detectors: 185 Mio. €

Total: 675 Mio. €

**SCHEDULE**

![Timeline chart showing the schedule for development, design of components, construction, and commissioning.](chart)

**Users interest**

- Accelerator physics
- Radiation biology
- Materials research
- Plasma research
- Atomic physics
- Nuclear matter research
- Antiproton physics
- Nuclear structure physics

- New facility
- GSI today
**General Planning**

- **SIS18 Upgrade**
  - 70 MW Connection
  - Proton-Linac

**Civil Construction 1**

- SIS100
- Transfer Line SIS18-SIS100
- High Energy Beam Lines

**Civil Construction 2**

- RIB Prod.-Target, Super-FRS
- RIB High+Low Energy Branch
- Antiproton Prod.-Target
- CR-Complex

**Civil Construction 3**

- HESR & 4 MV e⁻ – Cooling
  - In NESR

**Civil Construction 4**

- SIS300*
  - 8 MV e⁻ – Cooling
  - e-A Collider

**Civil Construction**

- Production and Installation

**Experiment Potential**

- *SIS300 installation together with SIS100

**Civil Construction 5**

- SIS100/300 Tunnel, SIS Injection+Extraction+Transfer
- Transfer Buildings/Line Super-FRS,
  - Auxiliary Bldgs., Transfer Tunnel to SIS18,
  - Building APT, Super-FRS, CR-Complex
  - RIB High+Low Energy Branch,

- CBM-Cave, Pbar-Cave, Reinjection SIS100

**Accuracy: 6-8 months**

- 2.7x10¹¹ /s²³⁸U²⁸⁺ (200 MeV/u)
  - 5x10¹² protons per puls

- 1x10¹¹/s²³⁸U²⁸⁺ (0.4-2.7GeV/u)
  - 2.5x10¹³ p (1-30 GeV)
  - 3-30 GeV pbar→fixed target
  - 10.7 GeV/u²³⁸U→HADES

- 1x10¹²/s²³⁸U²⁸⁺
  - 100% duty cycle
  - pbar cooled
  - p (1-90 GeV)
  - 35 GeV/u²³⁸U²⁹²⁺
  - NESR physics
  - plasma physics
Radiation Safety Approval Procedure

In February 2002, one year before the “green light” was obtained from the German government, GSI applied for the Construction of an International Facility for the Research with Ion and Proton Beams at the Hessian Ministry for Environment.

In December 2003, GSI received official letter with the first approval:

....the planned facility will fulfill the requirements in accordance with the German radiation protection laws for the construction of the whole installation and the operation as outlined in the Conceptual Design Report.
International (Committee) Structure for the Facility for Antiproton and Ion Research (FAIR)

International Steering Committee
(ISC-FAIR) H. Schunck

Working Group on Administrative and Financial Issues
(AFI-FAIR) H-F. Wagner

Working Group on Scientific and Technical Issues
(STI-FAIR) S. Gales

PAC / QCD
R. Chiavassa

PAC / NSTR
R. Casten

PAC / APPA
D. Schwalm

TAC / ACC
Y. Cho
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Loi Submission (1800 authors):
Jan. 15 & April 15, 2004
PAC Meeting:
June 14-16, 2004

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FAIR: Facility for Antiproton and Ion Research