Facility for **Anti-Proton and Ion Research**

**FAIR = International Accelerator Facility 'next' to GSI**

Austria | China | Finland | Germany Hessen | India
--- | --- | --- | --- | ---
Polen | Romania | Russia | Slovenia | Spain
UK | Sweden

F. Maas
GSI and Mainz University

SPIN08
- Highlights at GSI/FAIR
- Resources available at GSI/FAIR
- Opportunities for collaboration
The evolution of the universe

from the big bang to the galaxies
Quark gluon plasma and the phases of nuclear matter

- What are the properties of the quark-gluon plasma?
- What are the phases of nuclear matter at different temperatures and densities?
RHIC, LHC: Quark Gluon Plasma at high temperatures $T$ and low net baryon densities $\rho$

FAIR: comprehensive research program at high densities and medium temperatures
Including rare probes
The CBM detector
Hadron physics

• How did constituents of matter (nucleons) emerge microseconds after the big bang from the initial quark-gluon-plasma?

• Why do isolated quarks not exist? Why are they confined in hadrons?

• Why are protons and neutrons so much heavier than their constituents? What determines the spin of the nucleon?
The Nobel Prize in Physics 2004
"for the discovery of asymptotic freedom in the theory of the strong interaction"

Gross  Politzer  Wilczek

The problems of strong Quantum Chromodynamics (QCD)

- gluonic excitations: glueballs and hybrids
- precision spectroscopy of the charmonium system - confinement
- open and hidden charm in nuclei: medium modifications
- hypernuclear spectroscopy
- EM nucleon structure

The non-perturbative regime of QCD: antiproton beams

\[ R \text{ [m]} \]

\[
\begin{align*}
0.4 & \quad 0.35 & \quad 0.3 & \quad 0.25 & \quad 0.2 & \quad 0.15 & \quad 0.1 \\
10^{-18} & 10^{-17} & 10^{-16} & & & & \\
\end{align*}
\]
Atomic and fundamental physics

- atomic matter in the strongest available electromagnetic fields;
- test of fundamental theories and symmetries
Atomic and plasma physics

- What are the properties of plasmas in stars and planets?
• What are the nuclear reactions leading to nucleo-synthesis in the universe? How are heavy elements made? What is hereby the role of instable nuclei?
• What are the properties of very instable nuclei? Where are the limits of existence of atomic nuclei?
The chart of atomic nuclei

- stable nuclei
- nuclides with known masses
- measured with FRS-ESR
- observed nuclei

synthesis of elements in supernova explosions
synthesis of elements in supernova explosions

eutron number
proton number

To be measured at existing GSI facility

stable nuclei
nuclides with known masses
to be measured with the FRS-ESR
observed nuclei

synthesis of elements in supernova explosions
Reaching the r-process path: to be measured at FAIR

- stable nuclei
- nuclides with known masses
- to be measured with FAIR facility
- observed nuclei

Synthesis of elements in supernova explosions
FAIR Research Highlights

Hadron Structure, QCD & Medium
Cooled antiprotons < 15 GeV, 500 users

Warm Dense Plasmas
bunchcompression Petawatt- Laser; 250 users

Materials Science,
Space- and Radiation Biology
(Ion- & antiproton- beams; 350 users

QCD-Phase Diagram: CBM
HI beams 2 to 45 AGeV; 400 users

Nuclear Astrophys. NUSTAR
RI beam- fragmentation; 600 users

Fundamental Symmetries
Ultra-High EM Fields
SPARC; FLAIR
Antiprotons, Hi-Z ions; 250 users

Accelerator Physics:
Eight Rings & two Linacs

GSI

FAIR

SIS 100/300

CBM

Rare-Isotope Production Target

Antiproton Production Target

UNILAC

P-Linac

SIS 18

ESR

HESR

PP& AP

Panda

Super FRS

RESR

CR

NESR

FLAIR
FAIR Research Highlights

Gain Factors

- Beam intensities up 100 – 10000- fold
- Beam energies up 20- fold
- Production of antimatter beams
- Factor 10000 in beam brilliance via cooling
- Efficient 4- fold parallel operation of programs
## FAIR Research Highlights

### Gain Factors
- Beam intensities up 100 – 10000- fold
- Beam energies up 20- fold
- Production of antimatter beams
- Factor 10000 in beam brilliance via cooling
- Efficient 4- fold parallel operation of programs

### Construction Period, Cost, Users
- Construction in phases until 2016
- Total cost 1.2 B€
- Scientific users: 2500 - 3000 per year
**FAIR Research Highlights**

**Gain Factors**
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**Construction Period, Cost, Users**
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**Financing**
- 65 % Federal Government of Germany
- 10 % State of Hessen
- 25 % Partner Countries
  → FAIR GmbH: 15 International Shareholders
FAIR Start Event: 7 November 2007

A splendid perspective and eminent challenge!
Compact & efficient accelerator design:
Rapidly cycling sc magnets: $\text{d}B/\text{d}t \sim 4\text{T/s}$

Fast ramping:
Frequency variable ferrite or MA loaded resonators

Beam quality:
Electron & Stochastic Cooling

XHV $\sim 10^{-12}$ mbar
Accelerator Developments

Compact & efficient accelerator design:
Rapidly cycling sc magnets: $dB/dt \sim 4T/s$

- Prototyp SIS100 bending magnet  BNG, BINP April 08, JINR – late 08
- Prototyp SIS300 bending magnet  INFN Jan./Feb. 2009, IHEP Protvino – late 09
- Prototyp bending magnet Super-FRS  FAIR China – April 2008

Fast ramping:
Frequency variable ferrite or MA loaded resonators

XHV $\sim 10^{-12}$ mbar
Key Experiments at FAIR:
- CBM: Compressed Baryon Matter QGP
- R3B: Multistrange Objects & Hypermatter
- NUSTAR: Neutron-Star Matter; SuperNova Elements
- PANDA: Charmonium, Glueballs in Vac+Nucl Matter
- FLAIR: Cold Compressed Baryon Matter, FundSym
- SPARC: Supercritical QED- Fields
- WDM: ExtreMe Matter Densities
FAIR QCD-Physics Program with Antiprotons

strange and charmed (anti-) baryons in nuclear field

inverted deeply virtual Compton scattering

J/ψ spectroscopy confinement, in-medium effects

hidden and open charm in nuclei

glueballs (ggg) hybrids (ccg)

EM-Nucleon Structure

PANDA

CP-violation (D/Λ - sector)

HESR Consortium
Jülich / Uppsala / Stockholm / GSI

HESR

inverted deeply virtual Compton scattering

spin structure of the proton: polarized antiprotons in PAX
PAX-collider:

asymmetric collider: polarised antiprotons on polarised protons to study spin structure and dynamics (3GeV + 15 GeV, mostly DY)

proposal exists and is highly rated from QCD-PAC at FAIR

Aproval depends on demonstration of method to polarize antiprotons

see talk of Hans stroeher
Layout of the Antiproton Detector

- High Rates
  - Total $\sigma \sim 55$ mb
  - peak $> 10^7$ int/s
- Vertexing
  - $(\sigma_p, K_S, \Lambda, \ldots)$
- Charged particle ID
  - $(e^\pm, \mu^\pm, \pi^\pm, p, \ldots)$
- Magnetic tracking
- Elm. Calorimetry
  - $(\gamma, \pi^0, \eta)$
- Forward capabilities
  - (leading particles)
- Sophisticated Trigger(s)

in ring experiment
wide angle compton scattering
Handbag factorization in excl. reactions

wide angles: large $s, -t, -u$  
deploy virtual: large $Q^2$
only one active parton (others are spectators, collinear fact.)

GPD
$\gamma^{(*)}p \rightarrow \gamma p$
$\gamma^{(*)}p \rightarrow Mp$

2h-DA
$\gamma^{(*)}\gamma \rightarrow p\bar{p}, \pi\pi, ...$
$p\bar{p} \rightarrow \gamma^{(*)}\gamma, \gamma\pi, ...$

meson DA
$\gamma\pi(\eta, \eta')$ transition FF
Handbag factorization in excl. reactions

wide angles: large $s, -t, -u$

deeply virtual: large $Q^2$

only one active parton (others are spectators, collinear fact.)

GPD

$\gamma^{(*)}p \rightarrow \gamma p$

$\gamma^{(*)}p \rightarrow Mp$

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meson DA

$\gamma\pi(\eta, \eta')$ transition FF

under study now

Peter Kroll
What can be done at FAIR?

- measure cross section for $p\bar{p} \rightarrow \gamma\gamma$ at high energies
- extract form factors $|R_V^p|, R_{\text{eff}}^p$
- factorization - form factors independent of $t$?
- helicity correlation of proton and antiproton ($A_{LL}$) allows to determine $|R_A^p|$ and $|R_P^p|$ separately
- together with form factors $G_M^{p(n)}$ and $F_2^{p(n)}$
  (ISR measurements e.g. Babar,..)
  one may attempt an analysis of the $p\bar{p}$ DAs
spin structure using Drell-Yan process
Unpolarised Drell-Yan Asymmetries —

40K ev with $E_p = 15$ GeV on fixed target, $1.5 < M < 2.5$ GeV/c$^2$

$s \sim 30$ GeV$^2$

azimuthal asymmetry

$\cos(2\phi)$ contribution

$\cdot$ small asymmetries

$\cdot$ their dependence on $p_T$

$0.2 < x_{1,2} < 0.8$

error bars allow investigation of:

$2 < p_T < 3$ GeV/c

$1 < p_T < 2$ GeV/c

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- small asymmetries
- their dependence on $p_T$

1$< p_T < 2$ GeV/c

2$< p_T < 3$ GeV/c

timelike electromagnetic form factors
Results with the expected statistics calculated for $Ge=Gm$
### Background:

<table>
<thead>
<tr>
<th>Process</th>
<th>3.7 GeV/c</th>
<th>5.9 GeV/c</th>
<th>7.9 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+\pi^-$</td>
<td>$10^8$</td>
<td>$10^8$</td>
<td>$10^8$</td>
</tr>
<tr>
<td>$\pi^0\pi^0$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma\gamma + \gamma e^+e^-$</td>
<td>$10^6$</td>
<td>$10^6$</td>
<td>$10^6$</td>
</tr>
<tr>
<td>$\gamma\gamma \gamma\gamma$</td>
<td>$10^6$</td>
<td>$10^6$</td>
<td>$10^6$</td>
</tr>
<tr>
<td>$\gamma e^+e^- + \gamma e^+e^-$</td>
<td>$10^6$</td>
<td>$10^6$</td>
<td>$10^6$</td>
</tr>
</tbody>
</table>

### Background under control

<table>
<thead>
<tr>
<th>Process</th>
<th>Ge=0</th>
<th>Ge=Gm</th>
<th>Ge=3·Gm</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu^+\mu^-$</td>
<td>$10^6$</td>
<td>$10^6$</td>
<td>$10^6$</td>
</tr>
</tbody>
</table>
feasibility study
for a transversely polarised target
(future)
Key QCD Experiment at FAIR

Measure single-spin asymmetry $A_N$ in Drell-Yan reactions

Leading-twist Bjorken-scaling $A_N$ from $S, P$-wave initial-state gluonic interactions

Predict: $A_N(DY) = -A_N(DIS)$ Opposite in sign!

$Q^2 = x_1x_2s$

$Q^2 = 4 \, \text{GeV}^2, s = 80 \, \text{GeV}^2$

$x_1x_2 = .05, x_F = x_1 - x_2$

$\overrightarrow{s} \cdot \overrightarrow{q} \times \overrightarrow{p}$ correlation

$pp \rightarrow \ell^+ \ell^- X$
Single-spin polarization effects and the determination of timelike proton form factors

\[ P_y = \frac{\sin 2\theta \text{Im} G_E^* G_M}{D \sqrt{\tau}} = \frac{(\tau - 1) \sin 2\theta \text{Im} F_2^* F_1}{D \sqrt{\tau}} \]

\[ D = |G_M|^2 (1 + \cos^2 \theta) + \frac{1}{\tau} |G_E|^2 \sin^2 \theta \]

\[ \tau = \frac{q^2}{4m_B^2} \]

Measure relative phase of form factors

FAIR Workshop
October 15-16, 2007

Novel Anti-Proton QCD Physics

Stan Brodsky
SLAC
Ideas for Transversely Polarised Target

- technically extremely difficult (2T solenoid)
- keep good particle identification for all EM structure physics
- parasitic setup (thin target) not possible
- dedicated setup (remove silicon vertex detector)
- atomic beam source target (storage cell)
- install thin countersolenoid, run with 1 T solenoid

PANDA long. solenoid field

present target
feasibility study
for a future eN-collider
feasibility study
for a future eN-collider

- add polarised electron beam to HESR@FAIR
- 3 GeV electron onf 15 GeV/c protons
- $s = 180 \text{ GeV}^2$

- can a luminosity of $10^{33} \text{ cm}^{-1}\text{s}^{-1}$ be reached?
- dynamics of polarisation?
3 study groups
(since August 21, 2008)
machine study group (Jülich, Bonn, Mainz, Dortmund)

<table>
<thead>
<tr>
<th></th>
<th>HESR</th>
<th>e-Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [GeV]</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Circumference [m]</td>
<td>576</td>
<td>576</td>
</tr>
<tr>
<td>Bending radius [m]</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>normalized emittance [m rad]</td>
<td>$2 \cdot 10^6$</td>
<td></td>
</tr>
<tr>
<td>geometric emittance [m rad]</td>
<td>$1.3 \cdot 10^7$</td>
<td></td>
</tr>
<tr>
<td>Beta function at IP [m]</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Beam radius [mm]</td>
<td>0.112</td>
<td>0.112</td>
</tr>
<tr>
<td>Bunch length [m]</td>
<td>0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Number of particles</td>
<td>$3 \cdot 10^{12}$</td>
<td></td>
</tr>
<tr>
<td>Bunch current [mA]</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Bunches per ring</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>collision frequency [MHz]</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>Bunch separation [m]</td>
<td>5.76</td>
<td>5.76</td>
</tr>
<tr>
<td>total beam current [A]</td>
<td>0.25</td>
<td>2</td>
</tr>
<tr>
<td>synchr. rad. loss [kW]</td>
<td>478</td>
<td></td>
</tr>
<tr>
<td>Laselett tune shift</td>
<td></td>
<td>0.083</td>
</tr>
<tr>
<td>beam beam parameter</td>
<td>0.015</td>
<td>0.01</td>
</tr>
<tr>
<td>Beam Polarisation [%]</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Luminosity [$cm^{-2}s^{-1}$]</td>
<td>$2 \cdot 10^{32}$</td>
<td></td>
</tr>
</tbody>
</table>
Physics Study Group

Acceptances for three **key experiments** with the PANDA detector are being simulated to demonstrate sensitivities for double polarized measurements at

- 15 GeV $p + 3$ GeV $e$
- $7.5/GeV/u \, d + 3$ GeV $e$
Theory Study Group

HERMES member A. Schäfer (Kyoto Univ.) has proposed and pushed (me) to re-think the eN collider at GSI.

He is setting up a theory working group to spell out the physics case and define a road map. Something like a CERN yellow book or the DAFNE books will be needed.

Interaction with the Physics Study Group is mandatory.

deBoer, M.Diehl, P.Kroll, Metz, P.Mulders, D.Müller, Vogelsang, M.Stratmann, M.Vanderhaeghen and others are preparing a first workshop.
PANDA Working group on EM nucleon structure: 3 workshops at Orsay and Ferrara

CERN-GSI/FAIR-JLab Workshop on Meson Spectroscopy

Workshop
Physics and Methods in Meson Spectroscopy

October 22 - 24 2008
Physik Department E18
Technische Universität München
Science Campus Garching
New Seminar Room/MPE
Summary

FAIR: new center for Nuclear and Hadron Physics near Darmstadt, Germany

Working group on EM nucleon structure in PANDA

Future (midterm) idea (small scale):
transversely polarised target
with dedicated setup

Future (longterm) idea (large scale):
polarised eN collider at HESR using PANDA