Design Study of HESR and CSR at FAIR

• The FAIR facility
• HESR design criteria
• Future upgrade prospects
• Summary
The FAIR Facility
The Staging Plan for Construction

Political request since early 2003:
“Build FAIR complex in three stages
in order to guarantee physics output at each stage”

Stage 1
2007 - 2011

Stage 2
2011 - 2013

Stage 3
2013 - 2015

From a talk by Dieter Krämer, GSI, June 19th, 2006
The Costbook Rev. 3.0

Investment Cost:

- Accelerators w/o sFRS* 592 M€
- Civil Construction 322 M€
- Experiments incl. sFRS 200 M€
  Sum 1114 M€
- Manpower 2400 FTE
  according to FCI 185 M€

Project Cost 1299 M€

“The Costbook reflects the present status of the estimate. The facility costs are evaluated on a component basis and then aggregated for the sub-systems and finally for the total facility.

This adds up to a total of 1114 M€ in investment cost.”

* sFRS equivalent 81 M€
## Costbook Version 2.67

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<th>HESR</th>
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The Antiproton path to HESR

- Protons with 30 GeV:
  - p-LINAC (70 MeV)
  - SIS 18 (6 GeV)
  - SIS 100 (29 GeV)

- P-bar Target

- Accumulation of p-bars:
  - Collector Ring
  - RESR

- HESR

Expected p-bar production rate: $1 \times 10^7 \text{ s}^{-1}$
The $\overline{p}$-beam is injected from RESR at 3.8 GeV/c

- **Advantage:**
  - Low energy beam lines and injection elements
  - Electron cooling at low energy

- **Disadvantage:**
  - HESR is a synchrotron
  - Reduced duty cycle
For commissioning **protons** can be injected from

- RESR at reversed field polarities
- SIS 18 at 12.7 Tm with same field polarity, but opposite direction
The HESR-Consortium

- Leadership in the consortium
- System design
- Magnet layout
- Stochastic cooling
- Integration of experiments

High Energy Electron Cooler

- Infrastructure
- Building
- System integration

- Ion Optics
- Injection Beam Lines
- Beam - Target Interaction
Basic Data of HESR

- Circumference 574 m
- Momentum (energy) range 1.5 to 15 GeV/c (0.8-14.1 GeV)
- Injection of (anti-)protons from RESR at 3.8 GeV/c
- Acceleration rate 0.1 (GeV/c)/s
- Electron cooling up to 8.9 GeV/c (4.5 MeV electron cooler)
- Stochastic cooling above 3.8 GeV/c
Additional Installations

2 compensation dipoles for the PANDA-chicane

Compensation solenoids for PANDA and the electron cooler
System Design

- Ring mainly cold (only short warm insertions)
- 2 Cryogenic subsections, cryogenic bypasses for warm sections

<table>
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<tr>
<th>Component</th>
<th>Quantity</th>
<th>Parameter</th>
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<tr>
<td>Dipoles</td>
<td>48</td>
<td>3.6 T</td>
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<tr>
<td>Quadrupoles</td>
<td>112</td>
<td>60 T/m</td>
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<td>Sextupoles</td>
<td>24</td>
<td>560 T/m²</td>
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<td>Correctors</td>
<td>112</td>
<td>1 mrad</td>
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Impression of the segmented 180 degree cryostat

September 24, 2006
HESR $\beta_{\text{target}} = 1\text{ m}$, $\gamma_{tr} = 6.5i$
# Modes of Operation with PANDA

<table>
<thead>
<tr>
<th>Experiment Mode</th>
<th>High Resolution Mode</th>
<th>High Luminosity Mode</th>
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<tbody>
<tr>
<td>Target</td>
<td>Pellet target with $4 \times 10^{15}$ cm$^{-2}$</td>
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<td>rms-emittance</td>
<td>1 mm mrad</td>
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<tr>
<td>Momentum range</td>
<td>1.5 – 8.9 GeV/c</td>
<td>1.5 – 15.0 GeV/c</td>
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<tr>
<td>Intensity</td>
<td>$1 \times 10^{10}$</td>
<td>$1 \times 10^{11}$</td>
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<tr>
<td>Luminosity</td>
<td>$2 \times 10^{31}$ cm$^{-2}$ s$^{-1}$</td>
<td>$2 \times 10^{32}$ cm$^{-2}$ s$^{-1}$</td>
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<tr>
<td>rms-momentum resolution</td>
<td>$1 \times 10^{-5} \ldots 4 \times 10^{-5}$</td>
<td>$1 \times 10^{-4}$</td>
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### Injection Parameters at 3.8 GeV/c for the ...

<table>
<thead>
<tr>
<th>High Resolution Mode</th>
<th>High Luminosity Mode</th>
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<tbody>
<tr>
<td>$(1 \times 10^{10} \text{ p})$</td>
<td>$(1 \times 10^{11} \text{ p})$</td>
</tr>
<tr>
<td>$\varepsilon_{\text{rms}, \text{geom.}} = 0.1 \text{ mm mrad}$</td>
<td>$\varepsilon_{\text{rms}, \text{geom.}} = 0.6 \text{ mm mrad}$</td>
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<tr>
<td>$\Delta p/p_{\text{rms}} = 1.5 \times 10^{-4}$</td>
<td>$\Delta p/p_{\text{rms}} = 3.8 \times 10^{-4}$</td>
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</table>
High Resolution Mode
between 1.5 and 8.9 GeV/c

• Injection at 3.8 GeV/c
  - $N = 10^{10}$ particles
  - $\varepsilon_{\text{rms}} = 0.1$ mm mrad
  - $\Delta p/p_{\text{rms}} = 1.5 \times 10^{-4}$

• Acceleration/Deceleration to required momentum (up to 60 s)

• Experiment with electron cooling
Electron Cooling : HR-Mode @ p = 8.9 GeV/c

- Electron cooling and target ON
- Equilibrium dominated by IBS

Final rms-momentum spread with target and IBS : \(3.0 \times 10^{-5}\)
Stochastic Cooling: HL-Mode @ \( p = 3.8 \text{ GeV/c} \)

Transverse and longitudinal stochastic cooling

Including IBS+Target

Final rms-momentum spread:
\[ \approx 1.5 \times 10^{-4} \]
• The present layout is based on 48 straight dipole magnets in the arcs

• Still under investigation: Costs for curved dipole magnets
  – Increase of momentum acceptance
  – Reduction to 32 longer magnets
  – Reduction of ring circumference
  – Extension in east-west direction reduced by 17 m
Comparison of the HESR lattice with straight or curved dipole magnets

- Straight dipoles:
  - 48 dipoles with 1.8 m length
  - Sagitta of 38 mm
  - High order field components for the off-center beam

- Curved dipoles:
  - 32 dipoles with 2.7 m length
  - No sagitta
  - Beam is centered in the dipole
Advantage of the curved dipole lattice:

More space between PANDA-hall and Plasma Physics Cave
Steps in View of Future Experiments

1. for production of polarized antiprotons:
   - APR and CSR

2. For PAX in its optimum stage:
   - “asymmetric” collider

3. Upgrade of the electron cooler to 8 MeV
The “symmetric collider” scheme worked out by Yuri Shatunov

HESR with \( p\bar{p} \) option (sketch)
Problems connected to the symmetric collider lattice
Preparations in view of the symmetric collider:

- We continue the design of the HESR as planned now
- It is checked if the position of HESR can be moved by 30 m to the South
- This gives space for the future extension in North – South direction
Summary

or:
My Personnel View of the HESR tasks

- **PANDA is part of the CORE program**: The layout of HESR to meet the PANDA experimental requirements is finalized

- **PAX is a 2nd generation experiment**: Buildings and infrastructure for PAX and the additional rings are foreseen. An upgrade to the asymmetric collider is taken into account in the planning. Electron cooling can be upgraded to maximum HESR energy

- **The symmetric collider is a project of the far future**: The topology of FAIR will foresee space “not to exclude” a later rearrangement of the HESR
Technical Challenges for HESR

• Design of curved dipole magnets ($\rho = 13 \text{ m}$)
• High bandwidth stochastic cooling system (4 to 8 GHz)
• High energy electron cooler (4.5 MeV $\rightarrow$ 8 MeV)
• Beam dynamic issues for high phase space density beams