Perspectives with PANDA

• The new accelerator complex of GSI
• The antiproton’s activity
• The PANDA scientific program

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LNF
Primary Beams
- $10^{12}$/s; 1.5 GeV/u; $^{238}\text{U}^{28+}$
- Factor 100-1000 present in intensity
- $2(4) \times 10^{13}$/s 30 GeV protons
- $10^{10}$/s $^{238}\text{U}^{73+}$ up to 25 (-35) GeV/u

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 (0) - 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
HESR - High Energy Storage Ring

- Production rate $2 \times 10^7$/sec
- $P_{\text{beam}} = 1 - 15$ GeV/c
- $N_{\text{stored}} = 5 \times 10^{10} \overline{p}$
- Internal Target

High luminosity mode
- Lumin. = $2 \times 10^{32}$ cm$^{-2}$ s$^{-1}$
- $\delta p/p \sim 10^{-4}$ (stochastic cooling)

High resolution mode
- $\delta p/p \sim 10^{-5}$ (electron cooling)
- Lumin. = $10^{31}$ cm$^{-2}$ s$^{-1}$
Summary of Research Areas at the GSI Future Facility

Structure and Dynamics of Nuclei - Radioactive Beams
- Nucleonic matter
- Nuclear astrophysics
- Fundamental symmetries

Hadron Structure and Quark-Gluon Dynamics - Antiprotons
- Non-pertubative QCD
- Quark-gluon degrees of freedom
- Confinement and chiral symmetry
- Hypernuclear physics

Nuclear Matter and the Quark-Gluon Plasma - Relativistic HI - Beams
- Nuclear phase diagram
- Compressed nuclear/strange matter
- Deconfinement and chiral symmetry

Physics of Dense Plasmas and Bulk Matter - Bunch Compression
- Properties of high density plasmas
- Phase transitions and equation of state
- Laser - ion interaction with and in plasmas

Ultra High EM-Fields and Applications - Ions & Petawatt Laser
- QED and critical fields
- Ion - laser interaction
- Ion - matter interaction
Antiproton Physics Program

Charmonium (c\bar{c}) spectroscopy: precision measurements of mass, width, decay branches of all charmonium states, especially for extracting information on the quark confinement.

Search for gluonic excitations (charmed hybrids, glueballs) in the charmonium mass range (3 – 5 GeV/c²).

Search for modifications of meson properties in the nuclear medium, and their possible relationship to the partial restoration of chiral symmetry for light quarks.

Precision γ-ray spectroscopy of single and double hypernuclei for extracting information on their structure and on the hyperon-nucleon and hyperon-hyperon interaction.

Inverted DVCS to extract parton distributions. Proton form-factors at large Q² up to 25 GeV²/c⁴. D-meson decay spectroscopy BR and decay dalitz plots CP-Violation in the D/Λ sector.
Charmonium Physics

\[ e^+e^- \rightarrow \Psi' \rightarrow \gamma \chi_{1,2} \rightarrow \gamma \gamma J/\psi \rightarrow \gamma \gamma e^+e^- \]

- **e^+e^-** interactions:
  - Only 1− states are formed
  - Other states only by secondary decays (moderate mass resolution)

- **p p** reactions:
  - All states directly formed (very good mass resolution)

\[ \text{Br}(p p \rightarrow \eta_c) = 1.2 \times 10^{-3} \]

\[ \text{Br}(e^+e^- \rightarrow \psi) \cdot \text{Br}(\psi \rightarrow \gamma \eta_c) = 2.5 \times 10^{-5} \]
Charmonium Physics

Charmonium spectrum, glueballs, spin-exotics cc-glue hybrids with experimental results


B-factories are abundant sources of data on charmonium

X(3872) first seen by Belle
Then confirmed by others

?(3943) enancement in J/Ψω mass spectrum


B-factories are abundant sources of data on charmonium
<table>
<thead>
<tr>
<th>Decay Channels</th>
<th>Mass</th>
<th>Decay Channels studied</th>
<th>Total BR seen (%)</th>
<th>Decay Channels With error &lt;30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_c$</td>
<td>2979.6±1.2</td>
<td>21</td>
<td>60.3</td>
<td>3</td>
</tr>
<tr>
<td>$\eta'_c$</td>
<td>3654.0±6.0</td>
<td>4</td>
<td>~0</td>
<td>0</td>
</tr>
<tr>
<td>$J/\psi$</td>
<td>3096.92±0.01</td>
<td>135</td>
<td>44.2</td>
<td>83</td>
</tr>
<tr>
<td>$\psi'$</td>
<td>3686.09±0.03</td>
<td>62</td>
<td>77.1</td>
<td>29</td>
</tr>
<tr>
<td>$\chi_{c0}$</td>
<td>3415.2±0.3</td>
<td>17</td>
<td>12.3</td>
<td>10</td>
</tr>
<tr>
<td>$\chi_{c1}$</td>
<td>3510.59±1.0</td>
<td>13</td>
<td>33.6</td>
<td>6</td>
</tr>
<tr>
<td>$\chi_{c2}$</td>
<td>3556.26±1.1</td>
<td>19</td>
<td>26.3</td>
<td>10</td>
</tr>
<tr>
<td>$h_c$</td>
<td>3770.0±2.4</td>
<td>2</td>
<td>~0</td>
<td>1</td>
</tr>
<tr>
<td>$\psi$ (3770)</td>
<td>3836±13</td>
<td>1</td>
<td>~0</td>
<td>0</td>
</tr>
<tr>
<td>$X(3872)$</td>
<td>3872.0±0.6</td>
<td>3</td>
<td>~0</td>
<td>0</td>
</tr>
<tr>
<td>$\psi$ (4040)</td>
<td>4040±10</td>
<td>6</td>
<td>~0</td>
<td>1</td>
</tr>
<tr>
<td>$\psi$ (4160)</td>
<td>4159±20</td>
<td>1</td>
<td>~0</td>
<td>0</td>
</tr>
<tr>
<td>$\psi$ (4415)</td>
<td>4415±6</td>
<td>2</td>
<td>~0</td>
<td>0</td>
</tr>
</tbody>
</table>
Exotic hadrons

The QCD spectrum is much richer than that of the naive quark model, and also the gluons can act as hadron components. The “exotic hadrons” fall in three general categories:

- **Multiquarks** $\left( q\bar{q}(q\bar{q}) \right)$
- **Hybrids** $(q\bar{q})g$
- **Glueballs** $gg$

In the $c\bar{c}$ meson spectrum, the density of states is lower and therefore the overlap...
Exotic hadrons

In the light meson region, about 10 states have been classified as “Exotics”. Almost all of them have been seen in pp...

<table>
<thead>
<tr>
<th>Main non-q̅q candidates</th>
</tr>
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<tbody>
<tr>
<td>f_0(980)</td>
</tr>
<tr>
<td>f_0(1500)</td>
</tr>
<tr>
<td>f_0(1370)</td>
</tr>
<tr>
<td>f_0(1710)</td>
</tr>
<tr>
<td>η(1410); η(1460)</td>
</tr>
<tr>
<td>f_1(1420)</td>
</tr>
<tr>
<td>π_1(1400)</td>
</tr>
<tr>
<td>π_1(1600)</td>
</tr>
<tr>
<td>π(1800)</td>
</tr>
<tr>
<td>π_2(1900)</td>
</tr>
<tr>
<td>π_1(2000)</td>
</tr>
<tr>
<td>a_2'(2100)</td>
</tr>
</tbody>
</table>
Charmed Hybrids

- Gluonic excitations of the quark-antiquark-potential may lead to bound states

- LQCD:
  \[ m_H \sim 4.2-4.5 \text{ GeV} ; J^{PC} 1^- \]

- Flux tube-Model predicts \( H \) \( D\bar{D}^{**} \) (+c.c.) decays
  
  - If \( m_H < 4290 \text{ MeV}/c^2 \)
  
  - \( \Gamma_H < 50 \text{ MeV}/c^2 \)

- Some exotics can decay neither to \( D\bar{D} \) nor to \( D\bar{D}^*\) +c.c.
  
  - e.g.: \( J^{PC}(H)=0^{+-} \)
    
    - Flux-tube allowed
      \[ \chi_{c0} \phi, \chi_{c2} \phi, \eta_c, \eta_1, h_1 \]
      \[ h_0, \eta \]
    
      - Flux-tube forbidden
        \[ J/\psi f_2, J/\psi (\pi\pi)_S \]
    
    - Small number of final states with small phase space
Mesons in nuclear matter

One of the fundamental question of QCD is the generation of MASS

The light meson masses are larger than the sum of the constituent quark masses!

Spontaneous chiral symmetry breaking seems to play a decisive role in the mass generation of light mesons.

How can we check this?
Hadrons in nuclear matter

Since density increase in nuclear matter is possible a partial restoration of chiral symmetry

- Light quarks are sensitive to quark condensate

Evidence for mass changes of pions and kaons has been observed

- Deeply bound pionic atoms
- Kaon-production environments

\[ f^*_{\pi} = 0.78f_{\pi} \]
**Mesons in nuclear matter**

With $\bar{p}$ beam up to 15GeV/c these studies will be extended

Sub-threshold enhancement for D and $\bar{D}$ meson production

**expected signal:**

- strong enhancement of the D-meson cross section, relative $D^+ D^-$ yields, in the near/sub-threshold region.

**Mass modifications of mesons**

<table>
<thead>
<tr>
<th>Meson</th>
<th>Vacuum Mass</th>
<th>Nuclear Medium Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^-$</td>
<td>25 MeV</td>
<td>$\rho = \rho_0$</td>
</tr>
<tr>
<td>$\pi^+$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K^+$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K^-$</td>
<td>100 MeV</td>
<td></td>
</tr>
<tr>
<td>$D^+$</td>
<td>50 MeV</td>
<td></td>
</tr>
<tr>
<td>$D^-$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure:**

- $p\bar{p} \rightarrow D^+ D^-$
- Masses of mesons in vacuum and nuclear matter.
- Graph showing in-medium and free masses for $D^-$, $D^+$, $K^+$, $K^-$.
Mesons in nuclear matter

The lowering of the $D\bar{D}$ thresh.
- allow $\Psi', \chi_{c2}$ charmonium states to decay into this channel
- states above $D\bar{D}$ thresh. would have larger width

thus resulting in a substantial increase of width of these states

Idea
- Study relative changes of yield and width of the charmonium state $\Psi(3770)$.
  BR into $J^P\ell^+\ell^-$ ($10^{-5}$ in free space)

Other physics topics

- Reversed Deeply Virtual Compton Scattering and Drell-Yan processes
- CP-violation (D/Λ – sector)
  - D⁰⁻D⁰ mixing
    SM prediction < 10⁻⁸
  - compare angular decay asymmetries for ΛΛ
    SM prediction ~ 2·10⁻⁵
- Rare D-decays:
  D⁺→μ⁺ν (BR 10⁻⁴)

Cross section σ ≈ 2.5 pb @ s ≈ 10 GeV²
L = 2·10³² cm⁻² s⁻¹ → 10³ events per month
Other physics topics

- Electromagnetic Form Factors of the Proton in the Time-Like Region from threshold up to $20 \, \text{GeV}^2/c^4$

- Precise measurement of cross-sections for neutrino factory design
QCD systems to be studied at PANDA
Detector requests:

- nearly $4\pi$ solid angle (partial wave analysis)
- high rate capability ($2 \cdot 10^7$ annihilations/s)
- good PID ($\gamma$, e, $\mu$, $\pi$, K, p)
- momentum resolution ($\sim 1\%$)
- vertex info for D, $K^0_S$, $\Lambda$ ($c_\tau = 317$ $\mu$m for $D^\pm$)
- efficient trigger (e, $\mu$, K, D, $\Lambda$)
- modular design (Hypernuclei experiments)
PANDA Detector (top view)

- **DIRC:** Detecting Internally Reflected Cherenkov light
  - straw tube tracker
  - mini drift chambers
  - muon counter
  - electromagnetic calorimeter
  - micro vertex detector

- **Solenoidal magnet**
- **Iron yoke**

**Length:** ~2 m upstream, ~10 m downstream
Summary

• A new Hadron-Facility is underway in Europe: FAIR @ GSI
• A wide experimental physics program going from meson spectroscopy to hypernuclear physics etc. will be accessible with the new GSI antiproton beam
• New and interesting results will come in many fields thanks to the unprecedented characteristics of the beam and to the potentiality of the PANDA general purpose detector