K.-Th. Brinkmann, JLU Gießen & HFHF, for the PANDA collaboration

FAIR Physics With PANDA
Facility for Antiproton and Ion Research

Source: https://fair-center.de/ (Nov 26, 2021) © ion42/FAIR
Facility for Antiproton and Ion Research

Source: https://fair-center.de/ (Nov 26, 2021) © D. Fehrenz/GSI/FAIR
Facility for Antiproton and Ion Research

hadrons: structure and dynamics

nuclear and quark matter

nuclear astrophysics and exotic nuclei

atomic physics, plasma physics, applications
High-Energy Storage Ring for Antiprotons HESR

$10^{11}$ stored antiprotons

**momentum** range 1.5 to 15 GeV/c

internal **targets:**
- cluster jet and pellet ($\bar{p}p$)
- foils ($\bar{p}A$)

**luminosity at peak** intensity:

$L = 2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

(Phase One: $L = 1 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$)

$\delta p/p < 2 \cdot 10^{-4}$ (stochastic cooling)

interaction rate $2 \cdot 10^7 \text{ s}^{-1}$

**luminosity for highest resolution:**

$L = 2 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

$\delta p/p < 4 \cdot 10^{-5}$ (electron cooling)
Proton-Antiproton Annihilations at Darmstadt
Proton-Antiproton Annihilations at Darmstadt

DAY ONE
**PANDA is a modular multi-purpose device:**

- Excellent forward acceptance and resolution
- (Moderate) backward acceptance
- Wide dynamic range: particle momenta from 0.1 to 8 GeV/c
- Momentum measurements in magnetic fields ($\Delta p/p \approx 1\%$)
- Particle ID in wide momentum range ($e^\pm$, $\mu^\pm$, $\pi^\pm$, $K^\pm$, $p$, ...)
- Electromagnetic calorimeter: $\gamma$, $\pi^0$, $\eta$ ... ($e^\pm$)
- High-resolution vertex detection: $D^\pm$, $D^0$ / $K_s$, $\Lambda$, $\Sigma$, $\Omega$ ...
- High interaction rate beyond $2 \cdot 10^7$ s$^{-1}$
- Intelligent trigger design for parallel data acquisition at high rates and small branching fractions
Physics Objectives

Confinement of q in hadrons
Generation of mass
Structure of hadrons from q
Exotic bound states of q
Matter-antimatter (a)symmetries

Charming and exotic hadrons

Nucleon structure
Strange hadrons

Hadrons in nuclei
Timelike electromagnetic formfactors via lepton pair production  
(arXiv:1606:01118)

Transition distribution amplitudes (TDAs) through meson production  
(arXiv:1409:0865) talk by Stefan Diehl on Tuesday

Generalized distribution amplitudes (GDAs) by timelike Compton scattering  
and hard exclusive processes

Generalized parton distributions (GPDs) via antiproton scattering

Transverse parton distribution functions in Drell-Yan
Nucleon Structure

GDAs:

\[ p\bar{p} \rightarrow \gamma M \]

GPDs:


P. Kroll, A. Schäfer, EPJ A 26, 89-98 (2005)
Nucleon Structure

Timelike electromagnetic formfactors

\[ \bar{p}p \rightarrow e^-e^+ \text{ @ 1.5 GeV}/c: \sim 220/\text{day} \]
\[ \bar{p}p \rightarrow e^-e^+ \text{ @ 3.3 GeV}/c: \sim 10/\text{day} \]
\[ \bar{p}p \rightarrow \mu^-\mu^+ \text{ @ 1.5 GeV}/c: \sim 170/\text{day} \]

Access to unphysical region of formfactors

\[ \bar{p}p \rightarrow e^-e^+ \pi^0 \]
Hadron Spectroscopy

**PANDA:**
- Tuned to charmonium.
- High-resolution spectroscopy through resonance energy scans in formation.
- Line shapes, widths and masses.
- Branching ratios.
Hadron Spectroscopy: Lineshape of X(3872)

Strikingly narrow:

\[ \Gamma < 1.2 \text{ MeV} \]

*recent LHCb observation: width=1.4 MeV assuming BW

\[ \text{D}^0 \text{D}^{*0} \]

C. Hanhart et al.,
PRD 76 (2007) 034007

Energy scan with \( e^+ e^- \): energy resolution 1-2 MeV (primarily \( J^{PC}=1^{-} \))

Energy scan with \( p\bar{p} \): energy resolution 240 keV (E760/835@Fermilab)

\( \approx 50 \) keV (PANDA@FAIR)

---

Resonance cross section

Fit to measured data:
- Information on line-shape
- Extraction of mass and width

Measured yield at different beam energies

Beam resolution

虚像状态

结合状态
Hadron Spectroscopy: Lineshape of X(3872)

Strikingly narrow:

$\Gamma < 1.2$ MeV

Recent LHCb observation: width=1.4 MeV assuming BW

C. Hanhart et al., PRD 76 (2007) 034007

Nov 29, 2021
**PANDA:**
- Rich set of polarization observables
- Double- and triple-strange baryons (e.g. excitation spectrum of \( \Xi \) and \( \Omega \) states)

<table>
<thead>
<tr>
<th>( p_{\text{beam}} ) (GeV/c)</th>
<th>Reaction</th>
<th>( \sigma ) (( \mu b ))</th>
<th>( \varepsilon ) (%)</th>
<th>Rate @ ( 10^{33} \text{ cm}^{-2} \text{s}^{-1} )</th>
<th>S/B</th>
<th>Events /day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.64</td>
<td>( \bar{p} p \rightarrow \Lambda \Lambda )</td>
<td>64.0</td>
<td>16.0</td>
<td>44 s(^{-1})</td>
<td>114</td>
<td>3.8 ( \times ) 10(^6)</td>
</tr>
<tr>
<td>1.77</td>
<td>( \bar{p} p \rightarrow \Sigma^0 \Lambda )</td>
<td>10.9</td>
<td>5.3</td>
<td>2.4 s(^{-1})</td>
<td>&gt;11**</td>
<td>207 000</td>
</tr>
<tr>
<td>6.0</td>
<td>( \bar{p} p \rightarrow \bar{\Sigma}^0 \bar{\Lambda} )</td>
<td>20</td>
<td>6.1</td>
<td>5.0 s(^{-1})</td>
<td>21</td>
<td>432 000</td>
</tr>
<tr>
<td>4.6</td>
<td>( \bar{p} p \rightarrow \bar{\Xi}^+ \Xi^- )</td>
<td>~1</td>
<td>8.2</td>
<td>0.3 s(^{-1})</td>
<td>274</td>
<td>26000</td>
</tr>
<tr>
<td>7.0</td>
<td>( \bar{p} p \rightarrow \bar{\Xi}^0 \Xi^- )</td>
<td>~0.3</td>
<td>7.9</td>
<td>0.1 s(^{-1})</td>
<td>65</td>
<td>8600</td>
</tr>
</tbody>
</table>

**Phase-1**

Nov 29, 2021

KTB, Light Cone 2021
Hypernuclei

- Production: $\bar{p}N \rightarrow \Xi^- \Xi$
- Recattering in primary target nucleus
- Deceleration in secondary target
- Capture of $\Xi$ atomic cascade of $\Xi^-$
- $\Xi p \rightarrow \Lambda \Lambda$ conversion fragmentation $\rightarrow$ excited $\Lambda \Lambda$-nucleus
- $\gamma$-decay of $\Lambda \Lambda$ hypernuclei
- Weak pionic decay
PANDA ...

- is a unique facility featuring a broad physics program employing antiprotons.
- is therefore complementary to running and future experiments.
- enlists modern detector technologies.

The experimental program at PANDA ...

- covers aspects of nuclear, hadron and particle physics across the transition from elementary nucleons to elementary quarks.
- puts precision spectroscopy alongside high discovery potential.
Members of the PANDA collaboration

UP Marche Ancona
U Basel
IHEP Beijing
U Bochum
Abant Izzet Baysal
U Gießen
Giresun U
U Glasgow
KVI Groningen
Gauhati U, Guwahati
USTC Hefei
URZ Heidelberg
Doğuş U, Istanbul
Okan U, Istanbul
FZ Jülich
IMP Lanzhou
INFN Legnaro
Lund U
H1 Mainz
U Mainz
RINP Minsk
ITEP Moscow
MPIE Moscow
U Münster
BINP Novosibirsk
Novosibirsk State U
IPN Orsay
U Wisconsin, Oshkosh
U & INFN Pavia
PNPi St. Petersburg
Wet Boh. U, Pilzen
Charles U, Prague
Czech TU, Prague
IHEP Protvino
IRfu Saclay
KTH Stockholm
Stockholm U
SUT, Nakhon Ratchasima
SVNIT Surat-Gujarat
S Gujarat U, Surat-Gujarat
FSU Tallahassee
U & INFN Torino
Politecnico di Torino
U Uppsala
SMI Vienna
NCBJ Warsaw
U York
Thank you, stay healthy and safe!
PANDA ...

- is a unique facility featuring a broad physics program employing antiprotons.
- is therefore complementary to running and future experiments.
- enlists modern detector technologies.

The experimental program at PANDA ...

- covers aspects of nuclear, hadron and particle physics across the transition from elementary nucleons to elementary quarks.
- puts precision spectroscopy alongside high discovery potential.