Heavy $E^-$ hyperatoms at PANDA

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In collaboration with E. Friedman
Helmholtz-Institut Mainz

THEIA Workshop, Speyer, 27.11.2019

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### Past

- KEK E224
- BNL E885
- Talk: A. Mathis

### Present

- J-PARC E07
- J-PARC E05
- STAR ALICE

### Future

- J-PARC E70
- J-PARC E03
- PANDA

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K. Nakazawa et al., PTEP (2015) 033D02

Topics

• The PANDA experiment at FAIR

• Strangeness nuclear physics at PANDA

• $\Xi^-\,^{208}\text{Pb}$ hyperatom experiment at PANDA
Facility for Antiproton and Ion Research
FAIR - under construction

SIS 100 Ring – Sep./Oct. 2019

Concrete: 8 x Frankfurt stadium
Steel: 9 x Eiffel Tower

https://www.gsi.de/forschungbeschleuniger/fair/bau_von_fair/bilder_und_videos.htm
PANDA at FAIR

PANDA situated in High Energy Storage Ring
• Modularized start version
  – $10^{10} \bar{p}$ stored
  – Luminosity up to $2 \times 10^{31}$ cm$^{-2}$ s$^{-1}$
  – $p_{\bar{p}} = 1.5 – 15$ GeV/c
  – $\Delta p/p = 5 \times 10^{-5}$
Physics pillars of \( \bar{\text{PANDA}} \)

**Spectroscopy**
- Hidden/open-charm states
- Gluon-rich QCD states
- Light-meson systems

**Nucleon structure**
- Generalized parton distributions
- Drell Yan process
- Time-like form factors

**Bound states and dynamics of QCD**
- Strange baryon spectroscopy
- Hyperon production & pol.
- Hyperon transition form factors
- Strangeness in \( \bar{p}p \)

**Hadrons in nuclei**
- Hyperon-nucleus dynamics
- Hypernuclei and **Hyperatoms**

**Nuclear physics**
PANDA as hyperon factory

Production rates:
@ 2 MHz $\bar{p}p$

- $\Lambda\bar{\Lambda}$: $\sim 1000$ /s
- $\Xi^-\Xi^+$: $\sim 100$ /s

Strangeness nuclear physics

See talk by J. Pochodzalla


Pochodzalla et al., Nuclear Physics A 954 (2016) 323–34
# PANDA schedule

<table>
<thead>
<tr>
<th>Phase</th>
<th>2017</th>
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<td>Day-1 Setup</td>
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- **Phase-0**
  - $\bar{p} \rightarrow$ HESR

- **Day-One**
  - $0.5 \text{ fb}^{-1}$
  - $\Lambda$ in $^{20}\text{Ne}$

- **Full Setup**
  - $1 \text{ fb}^{-1}$
  - Hyperatoms
  - Hypernuclei

*Talk by J. Messchendorp*
PANDA detector

Hypernuclear/atom setup not shown

- Almost 4π
- Avg. 20 MHz
- Software trigger

- High res. tracking + PID
- Vertex reconstr. for e.g. D, K^0_S, hyperons
- PWO calorimeter
Production of hyperatoms/nuclei

• **Primary target**
  – Production of Ξ⁻
    \[ \bar{p}N \rightarrow \Xi^- \Xi^+/0 \]
• **Secondary target**
  – Stopping of Ξ⁻
  – **Atomic** cascade of Ξ⁻
  – **Nuclear** conversion
    \[ \Xi^- + \text{p} \rightarrow \Lambda\Lambda + 28 \text{ MeV} \]
• **PANGEA**
  – X-Ray spectroscopy of heavy Ξ⁻ **hyperatoms** (0.1 - 1 MeV)
  – \( \gamma \) spectroscopy of light \( \Lambda\Lambda \) **hypernuclei** (0.1 - 10 MeV)
Hypernuclear/atom setup

- Dedicated target system
- PANGEA
Target system

Primary target

Secondary target

Hyperatom $^{208}\text{Pb}$

Hypernuclei $^{11}\text{B+Tracker}$

$\bar{p}$

$20 \text{ mm}$
Primary target - Prototype

- 2D positioning system
  - Several targets
  - Steerable for constant luminosity

- Small
- UHV compatible, magnetic field and radiation hard

Carbon filament (r ~3µm)
Secondary target optimization

- Optimization of absorber shape
  - Maximize $\Xi^-$ stopping
  - Minimize X-ray absorption

Based on events generated in GiBUU
PANda GErmanium Array

- Collaboration with NuSTAR (DEGAS)
- 20 triple HPGe detectors
- Full energy efficiency ~5 % @ $^{60}\text{Co}$
- Electro-mechanical cooling (~LN2 temp.)
- BGO veto
- Fully integrated design
PANGEA: Cooling

- Improved thermal insulation
- X-Cooler II/III too weak

Courtesy of I. Kojouharov
PANGEA - Prototype

Courtesy of I. Kojouharov
PANGEA: First spectrum

Flying assembly with prototype of preamplifier

FWHM: 2.8 keV ($^{60}$Co)

Too high temperatures prevented fully biasing!

Courtesy of I. Kojouharov
X-ray spectroscopy of $\Xi^-$-hyperatoms
Observables

Energy shift $\Delta E_{n_0}^{\text{nuc}}$ and width $\Gamma_{n_0}^{\text{abs}}$

Nuclear absorption

$$Y_{\gamma_2} = \frac{N_{\gamma_2} \land \gamma_1}{N_{\gamma_1} \land \gamma_0} \frac{\Gamma_{n_0+1}^{\text{abs}}}{\Gamma_{n_0+1}^{\text{abs}} + \Gamma_{n_0+1}^{\text{em}}}$$

$$\gamma_0 \land \gamma_1 \land \gamma_2$$
Simplified assumption:

\[ U(r) \propto \left(1 + \frac{\mu}{M}\right) b_0 \left(\rho_n(r) + \rho_p(r)\right) \]

\[ \rho_{n,p}(r) = \frac{\rho_{n,p}^0}{1 + \exp\left(\frac{r - c_{n,p}}{a_{n,p}}\right)} \]

\[ b_0 = 0.25 + i0.04 \]

\[ a_n = a_p \]

\[ c_{n,p} \text{ fixed by } R_{p,rms} \text{ and n skin} \]

\[ \rho_{n,p}^0 \text{ from N and Z} \]

Schematic calculations to explore experimental sensitivity.
Calculations performed with code provided by E. Friedman
Possible targets

\[ \text{FWHM}_{\text{Ge}}(558 \text{ keV}) \sim 1.4 \text{ keV} \]

\[ Y_{\gamma_2} = \frac{Y_{n_0}}{Y_{n_0+1}} = \frac{\Gamma_{\text{rad}}^{n_0+1}}{\Gamma_{\text{rad}}^{n_0+1} + \Gamma_{\text{abs}}^{n_0+1}} \]

Calculations performed with code provided by E. Friedman
Systematic uncertainties

- Neutron skin $\Delta_{np}$ in $^{208}$Pb well-established
- Present uncertainty of $\Delta_{np}$ -> Systematic uncertainty in observables
- $\delta(\Delta E^{nuc}_{(10,9)\rightarrow(9,8)})_{sys} \sim \pm 100$ eV
• Signals after cuts and efficiencies \(1237\)
  – 180 days at 2 MHz \(\bar{p}\)C

\[ \delta(\Delta E^{nuc}_{(10,9)\rightarrow(9,8)})_{stat} = \pm 140 \text{ eV} \]
Estimation of $V_{E}$

\[
\delta(\text{Re}(V_{E}))_{\text{stat}} \approx \delta(\text{Im}(V_{E}))_{\text{stat}} \approx 1 \text{ MeV}
\]

\[
b_0 = 0.25 + i0.04
\]
Complementary experiments

See talk before lunch
K. Tanida

PANDA
180 days, 2 \times 10^6 \text{s}^{-1}

J-Parc E03
Phase-1

J-Parc E07
30 days

J-Parc E07: \Xi^- - C hyperatoms not included
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<tr>
<th><strong>PANDA Hyperatoms</strong></th>
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<td>Design of modified beam pipe</td>
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<td>Commissioning ($p@HESR$)</td>
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<td>Construction of 6 detectors with XC2/LN2 cooling</td>
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<td>Setup and commissioning (DEGAS)</td>
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<td>Construction of holding structure</td>
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<td>Commissioning with 1 detector ($p@HESR$)</td>
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<td>Commissioning with 1 detector($\bar{p}@HESR$)</td>
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Take-home message

• PANDA@FAIR is a versatile experiment with a broad physics program

• Strangeness nuclear physics is an important pillar of PANDA

• Heavy hyperatoms unique for PANDA, complementary to J-PARC E03/07
Backup Slides
Stopping of secondary $\Xi^-$
FEP-efficiency PANGEA

![Graph showing FEP-efficiency against energy.](image)
HPGe irradiation test

• Irradiation test at COSY with single crystal prototype
• 5.5 days COSY
  → 96 days ČPANDA
Results

• DAQ and therm. issues decrease performance

• PSA allows partial resolution recovery

• Annealing recovers initial crystal performance → Detector withstands irradiation

• New systematic test: TRIGA reactor (2019/20)