**outline of the talk**

- **setting the stage with MAMI-C**
  - “old” and “new” spectrometers in Mainz
  - developments in detectors and electronics

  (also poster presentation: *A1 Collaboration: Detector developments for the kaon spectrometer at MAMI*)

  - hypernuclear formation in electroproduction

- **hypernuclear physics with **\(\bar{P}\)*****

  - production of multistrange systems
  - HPGe detectors under extreme conditions

  (also poster presentation: *A. Sanchez Lorente et al.: Production and spectroscopy of double hypernuclei at \(\bar{P}\)anda*)

- **summary of the activities**
Future hypernuclear spectroscopy in Mainz and Darmstadt

**Production spectroscopy**

- Projectile: $p,n \rightarrow \Lambda, \Xi, \ldots$
- $\gamma$ spectroscopy
- Excited state
- Ground state

**Decay spectroscopy**

- Weak: $\Lambda \rightarrow p\pi^-$, $\Lambda \rightarrow n\pi^0$
- Hadronic: $\Xi^0 n, \Xi^- p \rightarrow \Lambda\Lambda$, $\Sigma^+ n \rightarrow \Lambda p$, $\Sigma^- p \rightarrow \Lambda n$

**KaoS at MAMI-C**

**Panda at FAIR**

**HypHI at GSI**
it's a machine's world

[Queen, 1984]
Systematics of the \((e, e'K^+)\) reaction

- electron beams: excellent spatial and energy spread
  855 MeV electron beam at MAMI:
  - energy spread 13 keV (1 \(\sigma\) width)
  - horizontal emittance 13 \(\pi\) mm mrad (1 \(\sigma\) width)
  - vertical emittance 0.84 \(\pi\) mm mrad (1 \(\sigma\) width)
- 100 % duty factor with modern electron machines
- singles rates in focal plane detectors limit luminosity

- open strangeness at MAMI-C

[photon energy thresholds on the free nucleon]

- double coincidence spectroscopy
  - electron detection close to zero degree
    [definition of scattering plane]
  - kaon detection in forward direction
    [definition of reaction plane]

\[\downarrow\]
determines choice of spectrometer and detectors
The proposed operation of KaoS as a double spectrometer

issues for kaon detection:

- critical: Bremsstrahlung and pair production
- studies of positron background

issues for electron detection:

- critical: Bremsstrahlung and Møller electrons
- new focal plane detector with high rate capability

both pole face edges accessible for focusing

Probing hypernuclei at Panda and at MAMI-C
The KaoS spectrometer at GSI, Darmstadt, 1994 - 2002

[photos (c) by GSI]
The »three« spectrometer facility

Spectrometer A:
\[
\begin{align*}
\alpha & > 20^\circ \\
p & < 735 \text{ MeV/c} \\
\Delta\Omega & = 28 \text{ msr} \\
\Delta p/p & = 20\%
\end{align*}
\]

Spectrometer B:
\[
\begin{align*}
\alpha & > 8^\circ \\
p & < 870 \text{ MeV/c} \\
\Delta\Omega & = 5.6 \text{ msr} \\
\Delta p/p & = 15\%
\end{align*}
\]

Spectrometer C:
\[
\begin{align*}
\alpha & > 55^\circ \\
p & < 655 \text{ MeV/c} \\
\Delta\Omega & = 28 \text{ msr} \\
\Delta p/p & = 25\%
\end{align*}
\]
Arrival of KaoS at spectrometer hall on 11 June 2003

Probing hypernuclei at Panda and at MAMI-C
Graphical impression of the near future set-up
Installation of the spectrometer

- mechanical parts delivered in 2004/5
- mounting of parts started in 2006
- parking position for installation and tests
Magnetic chicane in the entrance beam-line

- large aperture and small angle acceptance
  → deflection of primary beam

- magnetic chicane needed for re-direction of beam

- two 30° sector magnets available
- beam transport and beam losses calculated
- position and choice of magnets optimized

Probing hypernuclei at Panda and at MAMI-C

14 October 2006
P Achenbach, U Mainz
A new beam-line for zero-degree acceptance

- modification of existing beam line
- adding 30 tons weight in 2.3 m length

(magnets originally used in the e⁻-e⁺ ring DCI Saclay)
The detector packages for KaoS
Development of a triple detector for the focal plane

- 20 triple boards per plane
- 120 cm x 30 cm active area
- $60^\circ$ detector configuration

[triple detector mounted on front-end board with 96 read-out channels (384 fibres)]
Probing hypernuclei at Panda and at MAMI-C

Position-sensitive photomultipliers

[R7259K 32-channel linear array w/o base] [H7260 32-channel with base]

[0.8 x 7 mm² anode, 1 mm ch pitch]
Active high-voltage generation in the base

- base voltage 140 V dc → no expensive connectors or stiff cables
- control module serves up to 508 bases

[provided by HV Sys, Russia]

**Specifications:**
- max anode current: < 2 mA
- voltage stability: 0.05 %

Cockcroft-Walton voltage multiplication

Probing hypernuclei at Panda and at MAMI-C
Signal discrimination and processing

- 4 channels per DTD chip
- double threshold principle
- LVDS output signals

[discriminator card based on GSI-Chip3]
Kinematical definition of a hypernuclear electroproduction at MAMI-C
Recoil momentum in strangeness production

- typical momentum transfers: $\approx 300 - 600$ MeV/c
- minimum momentum transfer for $\theta_K = 0^\circ$
- energy and momentum transfer independent:

$$Q^2 = -q_\mu q^{\mu} = \omega^2 - \vec{q}^2$$

[estrangeness electroproduction $(e, e' K^+)$]

[momentum transfer $\to 0$ for “magic momentum”]

[estrangeness exchange $(K^-, \pi^-)$]

[momentum transfer $\to 0$ for “magic momentum”]

[minimum momentum transfer for $\theta_\pi = 0^\circ$]

[momentum distributions cannot be measured]
Extracting hypernuclear structure information

- Cross sections calculated with harmonic oscillator potential and DWIA
- Typical $K^+$ angular distributions peaked at $0^\circ$, falling rapidly:

$$\text{[M. Sotona and S. Furullani, Prog. Theor. Phys. Suppl. 117, 151 (1994)]}$$

Angular distribution of kaons associated with a hypernuclear state sensitive to $\Lambda$ wave function
Hypernuclear formation in impulse approximation

impulse approximation:

\[ \vec{p}_{A-1} = -\vec{k} \]

3-momentum conservation at the vertices:

\[ \vec{p}_Y = \vec{p}_{A-1} + \vec{p}_\Lambda \]

\[ \Rightarrow q(k) \equiv |\vec{p}_\Lambda - \vec{p}_{A-1}| = |\vec{p}_Y + 2\vec{k}| \]

with \( \vec{k} \) the momentum of the virtual proton, and \( \vec{p}_Y \) the recoil momentum of the hypernucleus

proton momentum distribution:

approximate Fermi Gas distribution

\[ F = 2\pi \int_0^\infty n(k)k^2 dk, \]

where the distribution function, \( n(k) \), is Gaussian:

\[ n(k) = \frac{1}{(2^{-4}k_F^2\sqrt{\pi})^3} e^{-\frac{\sqrt{2}k^2}{k_F^2}} \]

Fermi momentum \( k_F(^{12}\text{C}) = 210 \text{ MeV/c} \)

Transition form factor for $N \rightarrow \Lambda$

$$F_{N\Lambda} = \int \int e^{-\frac{q(k)}{p_{\sigma}} n(k)} k^2 dk \ d\cos \theta$$

$$= \frac{1}{2p_{\sigma}} \left\{ \frac{k_F^2}{e^{\frac{1}{2}\frac{p_Y}{\sigma_{\sigma}}}} - \frac{p_Y}{\sigma_{\sigma}} \left( -\sqrt{2}k_F^2 + p_Y \sigma_{\sigma} \right) \text{erfc}\left[ -\frac{p_Y}{\sqrt{2}k_F} + \frac{k_F}{\sqrt{2}\sigma_{\sigma}} \right] 
+ e^{\frac{2p_Y}{\sigma_{\sigma}}} \left( \sqrt{2}k_F^2 + p_Y \sigma_{\sigma} \right) \text{erfc}\left[ \frac{p_Y}{\sqrt{2}k_F} + \frac{k_F}{\sqrt{2}\sigma_{\sigma}} \right] \right\}$$

$^{11}\text{B} + \Lambda \rightarrow ^{12}_{\Lambda}\text{B} ; \quad \sigma_{\sigma} = 100 \text{MeV/c} \quad k_F = 150 \text{MeV/c, 200 MeV/c, 250 MeV/c}$
Kinematical optimisation using a Figure Of Merit for formation rate

$$FOM = S_\Lambda \times \Gamma \quad \text{with} \quad \Gamma = \frac{\alpha}{2\pi^2} \frac{E'}{E} \frac{k\gamma}{E^2} \frac{1}{1-\epsilon}$$

$$[ Q^2 = 0.01 \text{GeV}^2/c^2, W = 11.995 \text{GeV}, E = 1.50 \text{GeV}, E' = 0.650 \text{GeV}, \theta_e = 5.8^\circ, p_K = 0.446 \text{GeV}/c, p_Y = 0.423 \text{GeV}/c, \text{and } \theta_K = 5.5^\circ ]$$

Probing hypernuclei at Panda and at MAMI-C
Production of multistrange systems at Panda
Double $\Lambda$ hypernucleus production

- $\bar{p}$ $\rightarrow$ $3$ GeV/c
- $\Xi^-$ in secondary target nucleus
- $\Xi^-$ atoms: x-rays
- conversion:
  \[ \Xi^- (dss) p(uud) \rightarrow \Lambda(uds) \Lambda(uds) \]
  $\Delta Q = 28$ MeV
  conversion probability $\sim 5$-10%

Expected count rates

\[ \sigma_{pp}(\Xi\Xi) = 2 \mu b \quad @ \quad 3 \text{ GeV/c} \]

by using, e.g., a \(^{12}\text{C}\) wire target:

\[ @ \mathcal{L} = 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \text{ HESR will produce } \Xi^-\Xi^- \text{ pairs } @ \sim 7 \times 10^2 \text{ Hz} \]

- joint \( \Xi^-\Xi^- \) escape probability: \( \sim 5 \times 10^{-4} \)
  (trigger on \( \Xi^- + p_\Xi = 100 - 500 \text{ MeV/c} \))
- \( \Xi^- \) reconstruction efficiency: \( \sim 50\% \)
- \( \Xi^- \) stopping and capture probability: \( \sim 20\% \)

\[ \sim 3 \times 10^3 \text{ captured } \Xi^- \text{ /d} \]

- \( \Xi^-p \rightarrow \Lambda\Lambda \) conversion probability: \( 5\% \)

\[ \sim 150 \Lambda\Lambda\text{-hypernuclei } \text{ /d} \]

- \( \gamma \)-ray emission/event: \( 50\% \)
- \( \gamma \)-ray Ge photopeak efficiency: \( 10\% \)

\[ \sim 7 \text{ “golden events” } \text{ /d} \]

- \( K^+K^+ \) trigger

\[ \sim 700 \text{ events } \text{ /d} \]
HESR: High Energy Storage Ring

8 MeV Electron Cooler

RF Cavities

Inj. Kicker

Beam Momentum: 1.5 - 15 GeV/c
High Intensity Mode:
Luminosity: \(2 \times 10^{32}\) cm\(^{-2}\)s\(^{-1}\) (2 \times 10^7Hz)
\(\delta p/p\) (st. cooling): \(~10^{-4}\)

High Resolution Mode:
Luminosity: \(2 \times 10^{31}\) cm\(^{-2}\)s\(^{-1}\)
\(\delta p/p\) (e- cooling): \(~10^{-5}\)

Target and Detectors

Probing hypernuclei at Panda and at MAMI-C

14 October 2006
P Achenbach, U Mainz
Probing hypernuclei at Panda and at MAMI-C

The Panda detector

- hermetic \((4\pi)\)
- high rate
- PID \((\gamma, \text{e}, \mu, \pi, K, p)\)
- trigger \((\text{e, } \mu, K, D, \Lambda)\)
- compact
- modular

Hypernuclei detection

1. solid state micro-tracker (thickness \(~3\) cm)
2. high rate capable Ge array
Probing hypernuclei at Panda and at MAMI-C

Problems

- large volume detectors
- high ambient magnetic field
- limited access
- long operation time
- spatial constraints
Ge detectors under extreme conditions

Solution of $\ell N_2$ free autonomous cooling:
-electromechanical cooling (ORTEC X-cooler II)
- based on Klemenko cycle (mixed gas refrigerants)
Probing hypernuclei at Panda and at MAMI-C

Experiments at GSI in 2004-5

- ALADiN dipole magnet
- Co source of 370 kBq
- VEGA clover and Euroball cluster

supported by a 6th European Framework HadronPhysics I3 Joint Research Activity
Performance of HPGe detectors in high magnetic fields

VEGA and Euroball cluster HPGe detectors were tested in the field provided by the ALADiN magnet at GSI.

- No problems in the electronics due to the magnetic field were observed.
- A small degradation of the energy resolution by $1 \sim 2$ keV was found.
Summary on open strangeness production at Panda and at MAMI-C

- experiments with KaoS at MAMI-C
  - (separation of longitudinal and transverse cross sections in $^1H(e, e'K^+)\Lambda$)
  - $\Lambda$ hypernuclei: by measuring the kaon angular distribution mapping the bound $\Lambda$ wave function
    $\Rightarrow$ installation of the KaoS spectrometer in progress

- multistrange systems at Panda: $\bar{p}p \to \Xi^-\Xi^+$, $\bar{p}n \to \Xi^-\Xi^0$
  - $\Lambda\Lambda$ hypernuclei production
  - ( $\Omega$ atom production )
    $\Rightarrow$ incorporation of HPGe detectors into Panda in progress