Strangeness physics with KAOS at MAMI

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for the Collaboration A1 at MAMI

Jan 2009
• challenges and prospects at the Mainz Microtron MAMI
  – installation and commissioning of the KAOS spectrometer

• strangeness electro-production at MAMI
  – first demonstration of kaon production at low $Q^2$ with KAOS in Sept 2008

• developments for hypernuclei experiments at MAMI
  – the extension of KAOS towards a two-arm spectrometer
New reaction channels opened up with MAMI-C

- coherent $\Phi(1020)$ production: $\Phi$ and K mesons in nuclei
- elementary kaon electroproduction at low $Q^2$
- electroproduction of hypernuclei
Adaption of the spectrometer facility to the strangeness channels

Maximum momentum limits survival probability to < 15% in vertical spectrometers A, B, C.
Installation of KAOS in 2007

Strangeness physics with KAOS at MAMI
Kaon production under forward angles

Planned measurements under small kaon angles in 2009 and 2010


Kinematics of the $^1H(e, e'K^+)\Lambda$ reaction

Five-fold differential cross section separates into virtual photon flux and virt. photoproduction cross section:

$$\frac{d^5\sigma}{d\Omega\,dE'\,d\Omega^*_K} = \Gamma \frac{d\sigma_v}{d\Omega^*_K}(W, Q^2, \epsilon, \theta_K, \phi)$$

Virtual photoproduction cross section is parameterised:

$$\frac{d\sigma_v}{d\Omega^*_K} = \frac{d\sigma_T}{d\Omega^*_K} + \epsilon_L \frac{d\sigma_L}{d\Omega^*_K} + \sqrt{2\epsilon_L(1+\epsilon)} \frac{d\sigma_{LT}}{d\Omega^*_K} \cos \phi + \epsilon \frac{d\sigma_{TT}}{d\Omega^*_K} \cos 2\phi$$

Kinematics as of 2008

<table>
<thead>
<tr>
<th>Virtual Photon</th>
<th>Beam</th>
<th>Electron Arm</th>
<th>Hadron Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q^2$</td>
<td>$W$</td>
<td>$E$</td>
<td>$E'$</td>
</tr>
<tr>
<td>GeV$^2$/c$^2$</td>
<td>GeV</td>
<td>GeV</td>
<td>GeV</td>
</tr>
<tr>
<td>0.05</td>
<td>1.670</td>
<td>1.508</td>
<td>0.455</td>
</tr>
</tbody>
</table>

$W_{th} = 1.61$ GeV for $K\Lambda$ production

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Probing the nuclear force in strange hadrons

the Y-N and Y-Y strong interactions
in the $J^P = 1/2^+$ baryon octet

Increasing strangeness

$V_{\Lambda N}^{\text{eff}} = V_0 + \Delta (\vec{s}_\Lambda \cdot \vec{s}_N) + S_N (\vec{l}_{\Lambda N} \cdot \vec{s}_N) + S_{\Lambda} (\vec{l}_{\Lambda N} \cdot \vec{s}_{\Lambda}) + T(s_{12})$

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Challenges and prospects

common features of electro-production at MAMI-C and JeffersonLab
• better resolution compared to (π⁺, K⁺) or (K⁻, π⁻)
• measurements at different kaon angles map out different parts of the Λ momentum distribution

unique with KAOS:
• double spectroscopy in a single spectrometer

simulated resolution: σₘ = 275 keV
Comparison to other production methods: access to new isotopes of hypernuclei

$\text{Comparison to other production methods: access to new isotopes of hypernuclei}$

$n \rightarrow \Lambda: (K^-, \pi^-); (K_{\text{stop}}^-, \pi^-); (\pi^+, K^+)$

$p \rightarrow \Lambda: (e, e'K^+); (K_{\text{stop}}^-, \pi^0)$

$pp \rightarrow n\Lambda: (\pi^-, K^+)$

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Comparison to other production methods: access to new hypernuclear states

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Jefferson Lab set-ups in Hall C & A

K⁺ (1.2 GeV/c)

Particles and Timing

SEGS
Short Orbit Spectrometer (Hadron arm)

Targets:
H, D, 3He, 4He cryo targets
Al dummy targets

Setup E91-016
³H, ³He

Setup E89-009
³He, ¹²B

Beam dump
Scattered electron
Spectrometer

Position & Timing
Detectors

Kaon
Spectrometer

Setup E01-011
²⁸Al

Electron beam
(1.8 GeV)

Drift Chamber
Hodoscope
Target
Splitter Magnet
Target

D
DC
TOF

HKS
High-resolution Kaon Spectrometer

Hodoscope

Beam line
Photon line

Setup Hall C
Roadmap to hypernuclei at MAMI

Feb/March 2009:
- installation of electron arm vacuum chamber and first fibre detector plane
- installation of read-out and trigger electronics

12--14 June 2009:
- electron arm beam-test and completion of Kaos as double spectrometer

16 June -- 3 July 2009:
- data taking campaign with Kaos at 30° for kaon production at low $Q^2$

Aug/Sept 2009:
- installation of second fibre detector plane

Autumn 2009:
- installation of first dipole of magnetic chicane

2009/10:
- preparation of zero degree operation with Kaos,
- modification of A1 scattering chamber, modification of A1 beam-line

2010:
- data taking campaign with Kaos at 0° for kaon production
Hadron arm as completed in Feb 2008
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1st order focusing optics of KAOS
Two-arm spectrometer operation of KAOS
Strangeness physics with K\textsc{aos} at MAMI

**Status of beam-line for zero-degree acceptance**

- limited space in the existing beam-line
- flexible positioning of 2x30 tons magnets in 3 m height

(magnets originally used in the e\textsuperscript{−}-e\textsuperscript{+} ring DCI Saclay)
The detector packages for KAOS

2 MWPC

2 TOF walls

hadron arm

electron arm

2 planes of fibres with MaPMT read-out

extra planes of fibres possibly with SiPM read-out

target

dipole

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Particle identification by TOF

- Hadron arm:
  - FWHM = 1 ns

- Huge background of random coincidences that needs to be suppressed

- Momentum acceptance from 300 – 700 MeV/c

Particle identification by TOF

- FWHM = 1 ns

- K

- Particle identification by TOF

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kaon momentum limited by electron kinematics for $Q^2=0.042 \ (\text{GeV/c})^2$ and $W=1692 \ \text{MeV}$
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\[ n = 1.07 \]

\[ p \sim 450 \text{ MeV/c} \]
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$E=1508 \text{ MeV}; \quad Q^2 = 0.05 (\text{GeV/c})^2; \quad W=1670 \text{ MeV}, \quad pK=466 \text{ MeV/c}$

$m = \sqrt{\frac{1}{\beta^2} - 1}$

TOF cut

Cut on energy loss

Cut on kaons

Missing Mass reconstruction

Phase-space in $p(e,e'\Lambda)K$
$\Lambda$- and $\Sigma$-hyperons in a single kinematic setting

[Kaos: preliminary analysis]

$E = 1508$ MeV; $Q^2 = 0.036$ (GeV/c)$^2$; $W = 1750$ MeV

$p_K = 642$ MeV/c  $p_K = 466$ MeV/c
Angular acceptance and optics

Theta at target

Phi at target

Theta in dispersive plane

Phi in non-dispersive plane

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1. established full hadron instrumentation operation under different beam and acceptance conditions

2. established coincidence spectroscopy with one of the vertical spectrometers as electron arm

3. determined spectrometer optics, i.e. the transfer matrix
Status of electron arm instrumentation

1. fibre detector developed and in mass production
2. front-end electronics developed and in mass production
3. trigger and read-out electronics available
4. new vacuum chamber is available
New front-end electronics for the fibre detector

Front-End Electronics for the KAOS Spectrometer at MAMI


In-beam tests at MAMI and GSI

Gaussian fit
maximum: 34770 counts
maximum at: 0.015 ns

Gaussian fit
maximum: 3999 counts
maximum at: 0.075 mm

[P. Achenbach, et al., In-beam tests of scintillating fibre detectors at MAMI and at GSI, Nucl. Instr. and Meth. 593 (2008)]
Flexible trigger concept

- strong correlation between momenta/positions

\[ e + ^{12}C \rightarrow e + K + ^{12}B \]

- goal: suppression of background on trigger level

- requirements
  - correlation of $> 60 \otimes 4000$ channels
  - tracking information (clustering)
  - flexibility (different beams, magnet settings…)
  - programmable, fast trigger decision
Conclusion

1a) The strangeness physics programme at MAMI is progressing with KAOS operational since Oct 2008

1b) a first physics campaign dedicated to low $Q^2$ kaon electro-production is scheduled for June 2009

2a) the extension of the KAOS spectrometer towards a two-arm operation under zero degree is progressing

2b) first physics campaigns dedicated to hypernuclear physics are expected to come in 2010