Recent Results from MAMI

Hans-Jürgen Arends
Mainz University
- 855 MeV cw electron beam
- 100 \(\mu\)A current (30 \(\mu\)A at 80% Polarization)
- Excellent beam quality
- New stage (HDSM) \(\Rightarrow\) 1500 MeV

Dec. 2008: 1557 MeV
Sept. 2009: 1604 MeV
A1: The »three« spectrometer facility

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

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

Spectrometer C:
\[ \alpha > 55^\circ \]
\[ p < 655 \text{ MeV/}c \]
\[ \Delta \Omega = 28 \text{ msr} \]
\[ \Delta p/p = 25\% \]
High-precision $p(e,e')p$ measurement at MAMI
Motivation

(see J. Friedrich and Th. Walcher, EPJ A 17 (2003) 607)
Motivation

Discrepancies for the proton charge radius

- 0.809(11) fm: Stanford (Hand et al., 1963)
- 0.862(12) fm: low $Q^2$ at Mainz (Simon et al., 1979)
- 0.847(09) fm: dispersion relation (Mergell et al., 1996)
- 0.890(14) fm: Hydrogen Lamb shift (Udem et al., 1997)

(see J. Friedrich and Th. Walcher, EPJ A 17 (2003) 607)
High-precision $p(e,e')p$ measurement at MAMI

$Q^2$: 0.004 to 1 (GeV/c)$^2$

$\langle r_E^2 \rangle^{1/2} = 0.879$ fm

+/- 0.005 (stat) +/− 0.004 (syst)

+/- 0.002 (model) +/- 0.004 (group)

PRELIMINARY

Global fit of form factor models to cross sections

J. Bernauer et al., to be published

~ 1000 settings (overlapping)

~ $10^9$ events

PRELIMINARY
Polarisation observables in $\gamma p \rightarrow \eta p$

Sensitivity to $D_{13}$:

Asymmetry with transverse polarised target: $T \sim \text{Im}(E_{0+}^* (E_{2-} + M_{2-}))$
Target asymmetry in $\gamma p \rightarrow \eta p$

$$T \sim \text{Im} \left( E_{0+}^* (E_{2-} + M_{2-}) \right)$$

Breit-Wigner resonances in $J^P = 1/2^-$ and $3/2^+$ partial waves (standard $\eta$–MAID)

energy dependent phase shift between $J^P = 1/2^-$ and $3/2^+$ partial wave amplitudes

Tiator et al., PRC C60 (1999)

Phoenix (Bonn): A. Bock et al., PRL 81 (1998)
Recoil proton polarisation: $p(\, e, \, e' \, \vec{p}) \, \eta$

First experiment with MAMI C and the 3-spectrometer setup

\[
P_y \sim \text{Im} \, (E_{0+}^* (E_{2-} + M_{2-})) \sim T
\]

\[
\Theta = 120^\circ
\]

Merkel et al., PRL 99:132301 (2007)

Energy dependent phase shift between $J^P = 1/2^-$ and $3/2^+$ partial wave amplitudes

Breit-Wigner resonances in $J^P = 1/2^-$ and $3/2^+$ partial waves
Recoil proton polarisation: \( p( e, e' \vec{p} ) \eta \)

First experiment with MAMI C and the 3-spectrometer setup

\[
P_y \sim \text{Im} \left( E_{0+}^* (E_{2-} + M_{2-}) \right) \sim \Theta
\]

\[\Theta = 120^\circ\]

energy dependent phase shift between \( J^P = 1/2^- \) and \( 3/2^+ \) partial wave amplitudes

Breit-Wigner resonances in \( J^P = 1/2^- \) and \( 3/2^+ \) partial waves

More kinematic settings: \( W=1525 \text{ MeV}, \Theta=90^\circ, W=1500 \text{ MeV}, \Theta=120^\circ \)

Merkel et al., PRL 99:132301 (2007)
Recoil proton polarisation: $p\left( e, e' p \right)$ $\eta$

$\Theta = 120^\circ$

K. Grießinger et al., to be published

target asymmetry measurement with real photons in progress in A2 (MAMI) and ELSA
Crystal Ball / TAPS

at MAMI since 2003
\( \pi^0 \) photoproduction near threshold

Test of LETs

A. Schmidt et al., PRL 87 (2001) 23501
V. Bernard et al., EPJ A 11 (2001) 209
Asymmetry for $E_\gamma = 157.4 \pm 11.5$ MeV

PRELIMINARY

CB-TAPS Preliminary
DMT 2001
ChPT
Schmidt - TAPS

(Dave Hornidge)
$E_\gamma = 177.8 \pm 0.7 \text{ MeV}$

$\theta_{\text{CM}} = 0 - 180 \text{ deg}$

(Dave Hornidge)
Target windows account for ~ 30% at 90 deg and 180 MeV!
π⁰ production near threshold

Preliminary

(D. Hornidge, publ. in prep)

measurement of T and F in preparation at MAMI and HIγS (H. Weller)
\( \eta \) photoproduction \( \gamma p \rightarrow \eta p \)

(see I. Strakovsky, 6B)

Our data show a dip near \( W = 1670 \) MeV in the total cross section and its association with a significant dip in the forward differential cross section. This feature was missed or questionable in the analysis of previous data.

(E.F. McNicoll et al., in preparation)
\( \gamma p \rightarrow \pi^0 \eta p \)

blue line: the best fit with

\( D_{33}(1700) \),  
\( P_{33}(1600) \),  
\( P_{31}(1750) \),  
\( F_{35}(1905) \),  
and Born terms

Partial contributions:

Red line: \( D_{33}(1700) \)  
Green line: \( P_{33}(1600) \)  
Black line: \( P_{31}(1750) \)  
Dashed red line: \( F_{35}(1905) \)  
Dashed blue line: Born terms

V. Kashevarov et al.: EPJ A (2009) 141  
A. Fix et al., EPJ A 36 (2008) 61
\[\gamma p \rightarrow \pi^0 \eta p\]  

*Beam helicity asymmetry*

(preliminary) to be published

Data from July 2007 and April 2009 runs

- Fourier fit (3 terms)
- \(D_{33}(1700)\) only
- Isobar model 6 resonances (A.Fix et al.)

More spin observables will be measured (T and F, pol. beam and pol. target)
Dalitz Plot Parameter $\alpha$ for $\eta \to 3\pi^0$

Basic strong interaction process $\pi^0 \pi^0 \rightarrow \pi^0 \pi^0$

$|A(\eta \rightarrow 3\pi^0)|^2 \sim [1 + 2\alpha z]$

$z = 6 \sum_{i=1}^{3} \left( \frac{E_i - m_\eta/3}{m_\eta - 3m_\pi^0} \right)^2 = \frac{\rho^2}{\rho_{\text{max}}^2}$

M. Unverzagt et al., EPJ A (2009)

$\alpha = -0.032 +/- 0.003$
Kaon Photoproduction

Decay sub-cluster energy

$K^+ \rightarrow \mu^+ \nu_\mu$

$K^+ \rightarrow \pi^0 \pi^+$

Incident and decay sub-cluster time difference

Mean life, $\tau \approx 12$ ns

Incident subcluster from $K^+ \sim 3$ns

Decay sub-cluster from $K^+ \rightarrow \mu^+ \nu_\mu$ decay $\sim 20$ns

$K^+$ missing mass

$\Lambda$ mass

$\Sigma^0$ mass

T. Jude (Edinburgh)
Kaon Photoproduction $\gamma p \rightarrow \Lambda K^+$ (Preliminary)

Kaon MAID with $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$ and $D_{13}(1900)$
Frozen spin target fully functioning – **Polarization > 90%**

- ~1000 hours relaxation time & low He consumption – long measurement time!
- Running with **transverse** polarized target!
Polarized Frozen Spin Target

- DNP to achieve ~ 90 % proton, 80 % deuteron
- Horiz. Dilution cryostat (Dubna), T~ 30 mK
- Two holding coils: solenoid → longitudinal, saddle coil → transverse
First measurement of transverse spin observable $F$ in $\gamma p \rightarrow \pi^0 p$

$$\frac{d\sigma}{d\Omega} = \left( \frac{d\sigma}{d\Omega} \right)_{\text{unpol}} \left[ 1 - P_{\gamma}^{\text{lin}} \Sigma(\theta) \cos(2\phi) ight]$$

$$+ P_\times \left[ - P_{\gamma}^{\text{lin}} H(\theta) \sin(2\phi) + P_{\gamma}^{\text{circ}} F(\theta) \right]$$

$$+ P_y \left[ - T(\theta) + P_{\gamma}^{\text{lin}} P(\theta) \cos(2\phi) \right]$$

$$+ P_z \left[ - P_{\gamma}^{\text{lin}} G(\theta) \sin(2\phi) + P_{\gamma}^{\text{circ}} E(\theta) \right]$$

- $F$ asymmetry: circ. polarized photons, transverse pol. Target
- Need to separate out contribution from $^{12}\text{C}$ and $^{16}\text{O}$ and $^{3/4}\text{He}$
- Requiring proton removes coherent contributions
- Other kinematic cuts and remaining underground fitted & subtracted
- Data shown from 39 hours minus, 39 hours plus pol. test data, Crystal Ball only

- VERY PRELIMINARY!
First measurement of transverse spin observable $F$ in $\gamma p \rightarrow \pi^0 p$

Background Subtraction on $MM(\gamma, \pi^0) - m_p$

$E_\gamma = 400 - 500$ MeV

different $\Theta_\pi$ bins
First measurement of transverse spin observable $F$ in $\gamma p \rightarrow \pi^0 p$

PRELIMINARY

Data at 1.5 GeV has been taken
The CB proton polarimeter

4cm Thick Graphite Cylinder
Outer radius 97mm
40cm downstream of target

Graphite tube
Inner radius 60mm
Outer radius 95mm
Length 20cm

\[
\frac{N^+ (\phi'_p) - N^- (\phi'_p)}{N^+ (\phi'_p) + N^- (\phi'_p)} = C_x P\gamma_{\text{circ}} A \sin \phi'_p
\]

Data
G4 total
G4 no nuclear int

\[\chi^2 / \text{ndf} = 1.812 / 9\]
\[p^0 \ 0.0626 \pm 0.0069\]

Dan Watts
$C_x \quad - \quad$ transferred poln. from circ. pol $\gamma : \quad p(\gamma, \pi^0)p$
Pion production on the deuteron
(as a neutron target)

Data:
- full circles: $\gamma d \to \pi^+ nn$
- empty circ.: $\gamma p \to \pi^+ n$

Curves: models by
- Arenhövel & Fix (solid)
- Levchuk (dashed)
- Schwamb (dash-dotted)
- Darwish (dotted)
Pion production on the deuteron
(as a neutron target)

Data:
full circles: $\gamma d \rightarrow \pi^- pp$
(MAMI)
open circles: Benz et al. (1973)

Curves: models by
Arenhövel & Fix (solid)
Levchuk (dashed)
Schwamb (dash-dotted)
Darwish (dotted)
Helicity dependent $\gamma d \rightarrow \pi NN$ diff. cross sections

Polarized $^3$He gas target for real photons

(with Institute of Physics, Mainz)

- Solenoid inside CB
- Polarimetry inside Helmholtz coils on upstream side
- Automatic transport between both positions
Setup
Helicity difference of total photoabsorption on $^3$He
(preliminary)
Summary

A1 Collaboration:

• High-precision p(e,e')p, prelim. charge radius compatible with value from Lamb shift

• p(e,e' p)\eta recoil polarization agrees with previous T data

A2 Collaboration:

• new \pi^0 photoproduction near threshold, prelim. \Sigma smaller than previous results

• new high-precision \eta photoproduction data

• helicity asymmetry of \gamma p \rightarrow \pi^0 \eta p

• K^+ photoproduction with Crystal Ball feasible via weak K^+ decay
Summary

- Mainz polarized frozen-spin target with transverse polarization in operation, first preliminary data on F observable for $\pi^0$ production

- Polarized D and $^3$He as neutron targets, preliminary helicity-dependent cross sections

- pol. beam, pol. target, recoil polarimeter available, heading towards a „complete experiment“