Outline

• A4 Experimental Setup

• $\text{H}_2$ backward angle measurement
  
  *Recent results*

• $\text{D}_2$ backward angle measurement
  
  *Short overview of the existing data*

• Outlook: “A4-III” 0.62 GeV² forward angle measurement
Parity violating electron scattering

Asymmetry measurement

\[ A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \approx \frac{|M^{NC}|}{|M^{EM}|} \approx \frac{Q^2}{M_Z^2} \approx 10^{-6} \]

- Statistics: \( A_{PV} \approx 10^{-7} \)
- \( N \approx 10^{12} - 10^{14} \)

Demands:
  - Separation of elastic and inelastic events
  - Control of false asymmetries, polarization measurement, ...
A4 Experiment at MAMI

• Scatter polarized electrons off unpolarized protons
• Place a detector under a certain scattering angle
• Count single events

\[ A^{PV} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{N^+ - N^-}{N^+ + N^-} \]
A4 Experiment at MAMI

MAMI up to E=1.5 GeV

Compton Laser
Backscatter Polarimeter

PbF$_2$ Calorimeter

Transmisson Compton Polarimeter

Liquid hydrogen target

Luminosity monitors

Polarized GaAs electron source

I=20 mA, P=80%
MAMI accelerator

A4 experiment
Compton Backscatter Polarimeter

Measured asymmetry: \[ A_{\text{exp}} = P \cdot A_{PV} \]

\( \Rightarrow P \) has to be measured!

Principle of compton backscatter polarimeter
Compton Backscatter Polarimeter
Compton Backscatter Polarimeter
Compton Backscatter Polarimeter

Spectrum of back-scattered photons

Low beam energy:

\[ E_{\text{beam}} = 315 \text{ MeV} \]

\[ A_{\text{compton}} \sim P_{\text{beam}} \]
**PbF$_2$ Calorimeter**

- 1022 PbF$_2$ crystals in 7 rings and 146 frames
- Pure Cherenkov radiator, intrinsically fast
- Solid angle: \( \Omega = 0.6 \text{ sr} \), \( 0 \leq \Phi \leq 2\pi \)
  \[30^\circ \leq \Theta \leq 40^\circ \text{ or } 140^\circ \leq \Theta \leq 150^\circ\]
- Total rate \( \approx 100 \text{ MHz} \)
- Sum of 3x3 crystals
PbF$_2$ Cal. Readout electronics

• Analog and digital part
• 1022 individual channels
• Full analog sumup of incoming signals
• More than 6000 cables for data, trigger and veto information
Transmission Compton Polarimeter (TCP)

- Relative measurement of polarization
- Determination of electron spin angle
- Control of halfwave plate status

\[ A_{\text{Pola}} = \frac{T^R - T^L}{T^R + T^L} \]
## A4 backward angle measurements

<table>
<thead>
<tr>
<th></th>
<th>e+p</th>
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<th>e+(^4)He</th>
<th>e+d</th>
</tr>
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<tbody>
<tr>
<td>Sample</td>
<td>forward</td>
<td>backward</td>
<td>forward</td>
<td>backward</td>
</tr>
<tr>
<td></td>
<td>0.1 (GeV/c)^2</td>
<td></td>
<td>0.04 (GeV/c)^2</td>
<td>0.1 (GeV/c)^2</td>
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<tr>
<td>Happex</td>
<td>0.1 (GeV/c)^2</td>
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<td>0.1 (GeV/c)^2</td>
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<tr>
<td></td>
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<tr>
<td>A4</td>
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<tr>
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</table>

**E=854.3 MeV**

**E=315.3 MeV**
A4 Detector rearrangement

Detector

\( e^- \)

p-Target

\( 145^\circ \)

\( 35^\circ \)

Detector

Plane Steel Plate

Hydraulic Oil Plunger
A4 backward measurements

Additional background in the energy region of the elastic peak:

Photons from pion decay. Pions coming from

- Pion electroproduction
- Pion photoproduction
Additional scintillator system

PbF$_2$-Crystal

Electron Beam

Additional Counter

Scattering Chamber

Separation of charged and neutral particles
Additional scintillator system

Plastic Scintillator (EJ-204)  Photomultiplier Housing (XP2262B)

Scintillator Dimension : 20 mm x 50 mm x 400mm
Additional scintillator system

72 new plastic scintillators
Additional scintillator system
Readout and trigger electronics

**Analog unit**
- Data generation
  - SUM
  - Integrator & FADC
- Trigger-erzeugung
  - Local Max.
  - CFD
  - &
  - Trigger
  - PS
  - Vet-logic
  - Neighbour modules

**Data storage**
- Memory
- FIFO
- Polarisation

**Digital unit**
- FPGA
- CFD
- Local Max.

**Electron tagger**
- prog. Delay
- CFD
- Scintillator

**Pile up logic**
- PbF$_2$
- $S_1$
- $S_2$
- $S_3$

**Data generation**
- $S_1$
- $S_2$

**Polarisation**
- MAMI

**Trigger-erzeugung**
- Trigger
- Local Max.
- CFD

**Neighbour modules**
- CFD

**Readout and trigger electronics**
Coincidence spectrum

**PbF₂ coincidence spectrum**

- Separation of scattered electrons from photons
- Elastic peak clearly visible
- *But:* Still some background in the coincidence spectrum (gamma conversion)
Background subtraction

Method: **Shift** and scale from MC study:

- **Shift:** Photons convert into $e^+e^-$ pairs. Charged particles lose energy in the material ($\approx 35$ MeV)

- **Scale:** Only a fraction $\varepsilon \approx 0.11$ of the photons convert in the material between target and detector
Shift and scale: Data and MC simulation

Coincidence spectrum from experiment

Background estimated from measured noncoincidence spectrum

$\pi^0$ decay photons (photo-production) from MC0

$\pi^0$ decay photons (electro-production) from MC

$\pi^0$ decay photons (aluminium) from measurement
Extraction of PV asymmetry

- Apply upper and lower cut
- Number of counts for the two helicities $N^+, N^-$

Calculate asymmetry:

$$A = \frac{N^+ - N^-}{N^+ + N^-}$$
Analysis

• Elastic events for one run:

\[ N^+ = \sum_{c=1}^{1022} N_c^+ , N^- = \sum_{c=1}^{1022} N_c^- \]

• Experimental Asymmetry:

\[ A_{ex} = \frac{N^+ - N^-}{\rho^+ - \rho^-} \]

\[ \frac{N^+}{\rho^+} + \frac{N^-}{\rho^-} \]

with \( \rho \) target density

\[ A_{ex} = P \cdot A_{phys} + \sum_{i=1}^{6} a_i X_i \]

P: Beam polarisation

X₁: Current asymmetry

X₂: Horiz. position diff.

X₃: Verti. position diff.

X₄: Horiz. angle diff.

X₅: Verti. angle diff.

X₆: Energy diff.

• Determination of \( a_i \) via multiple linear regression
Beam parameter

Asymmetries and differences in current, position, angle, energy

Example: Beam current asymmetry

Beam current Asymmetry

Mean: -0.30 ppm

σ: 3.37 ppm

N: 15118
Beam parameter and false asymmetries

<table>
<thead>
<tr>
<th>Beam parameter $\bar{X}_i$</th>
<th>False Asymmetry $a_i\bar{X}_i$ (Estimation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(helicity correlated)</td>
<td></td>
</tr>
<tr>
<td>Current Asymmetry $A_i$</td>
<td>-0.30 ppm</td>
</tr>
<tr>
<td>Horizontal position diff. $\Delta X$</td>
<td>-87.0 nm</td>
</tr>
<tr>
<td>Vertical position diff. $\Delta Y$</td>
<td>-23.8 nm</td>
</tr>
<tr>
<td>Horizontal angle diff. $\Delta X'$</td>
<td>-8.5 nrad</td>
</tr>
<tr>
<td>Vertical angle diff. $\Delta Y'$</td>
<td>-2.5 nrad</td>
</tr>
<tr>
<td>Energy diff. $\Delta E$</td>
<td>-0.41 eV</td>
</tr>
<tr>
<td></td>
<td>-0.25 ppm</td>
</tr>
<tr>
<td></td>
<td>+0.61 ppm</td>
</tr>
<tr>
<td></td>
<td>-0.86 ppm</td>
</tr>
<tr>
<td></td>
<td>-0.09 ppm</td>
</tr>
<tr>
<td></td>
<td>+0.10 ppm</td>
</tr>
<tr>
<td></td>
<td>+0.16 ppm</td>
</tr>
</tbody>
</table>
Polarization measurement

Average polarization: P=70.3 %
Statistical uncertainty: 0.8 %
Systematic uncertainty: 4 %
Asymmetry analysis results

Asymmetries Coinc GVZ out

- **GVZ IN:** Mean is negative
- **GVZ OUT:** Mean is positive

<table>
<thead>
<tr>
<th>Asymmetries Coinc GVZ out</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
<td>7277</td>
</tr>
<tr>
<td>Mean</td>
<td>18.27</td>
</tr>
<tr>
<td>RMS</td>
<td>118</td>
</tr>
</tbody>
</table>

**GVZ out**
- $\chi^2 / \text{ndf} = 97.70 / 79 = 1.24$
- Fit Mean = $(17.70 \pm 1.36) \text{ ppm}$

**GVZ in**
- $\chi^2 / \text{ndf} = 118.50 / 94 = 1.26$
- Fit Mean = $(-16.51 \pm 1.51) \text{ ppm}$
A4 backward results ($H_2$)

About 1100 h of data
$N_{\text{coinc}} = 2.1 \times 10^{12}$

$A_{\text{coinc}} = (-17.23 \pm 0.84_{\text{stat}} \pm 0.89_{\text{syst}})$ ppm

$\chi^2 / \text{NDF} = 16.70 / 14 = 1.19$
$Q^2 = 0.23 \ (\text{GeV}/c)^2$ backward $(H_2)$

Parity violating asymmetry from experiment:

$A_{\text{pv}} = (-17.23 \pm 1.21) \ \text{ppm}$

Standard model calculation with no strangeness assumption:

$A_0 = (-15.87 \pm 1.22) \ \text{ppm}$

=> Linear combination of strange form factors:

$G_{M^s} + 0.26 \ G_{E^s} = -0.12 \pm 0.11 \pm 0.11$
A4, $Q^2=0.23 \text{ (GeV/c)}^2$

Disentangling of Strange Form Factors
A4, $Q^2=0.23 \ (GeV/c)^2$

Hydrogen, combined results ($H_2$)

$G_M^s = -0.14 \pm 0.16$

($\pm 0.11_{\text{exp}} \pm 0.11_{\text{FF}}$)

$G_E^s = 0.050 \pm 0.042$

($\pm 0.038_{\text{exp}} \pm 0.019_{\text{FF}}$)
A4, $Q^2=0.23 \text{ (GeV/c)}^2$

Deuterium

Aim: Disentangling of $G_M^s$ and $G_A^p$ by experiment
# Beam parameter \( (D_2) \)

940 hours of asymmetry data on tape:

<table>
<thead>
<tr>
<th>Label</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current asymmetry</td>
<td>0.07 ppm</td>
</tr>
<tr>
<td>X2</td>
<td>Position diff. X</td>
<td>-349.8 nm</td>
</tr>
<tr>
<td>X3</td>
<td>Position diff. Y</td>
<td>-95.9 nm</td>
</tr>
<tr>
<td>X4</td>
<td>Angle diff. X</td>
<td>-38.4 nrad</td>
</tr>
<tr>
<td>X5</td>
<td>Angle diff. Y</td>
<td>-8.5 nrad</td>
</tr>
<tr>
<td>X6</td>
<td>Energe difference</td>
<td>0.19 eV</td>
</tr>
</tbody>
</table>
Background subtraction ($D_2$)

Spectrum of charged particles
Spectrum of neutral particles
Corrected spectrum

Energy / ADC

Chan 24 Run 52000 bgcorr

Entries: 248
Mean: 29.15
RMS: 7.099

Shift

and scale
Outlook: “A4-III”

2006: MAMI-C Energy upgrade from $E=855$ MeV to $E=1508$ MeV

PbF$_2$ Calorimeter: Scattering angle $\theta=35^\circ$

$\Rightarrow$ Elastic scattering: Momentum transfer of $Q^2=0.62$ GeV$^2$
Outlook: “A4-III”

G0 forward angle result:

\[ G_E + \eta G_M \]
Outlook: “A4-III”

G0 forward angle result:
Outlook: “A4-III”

Basic parameter:

• Beam energy: $E = 1508$ MeV
• Scattering angle: $\theta = 35^\circ$
• Momentum transfer: $Q^2 = 0.62$ GeV$^2$

Requirements:

• Turn calorimeter to forward angle configuration
• Adjust chicane of Compton Polarimeter to higher beam energy
• Adjustment and new installation of beam stabilization systems

Goal:

• Standard model asymmetry without strangeness $A_0 = -25.5$ ppm
• Collect 700 hours of asymmetry data
• => Measure $A_{PV}$ with statistical uncertainty $\Delta A_{PV} < 1$ ppm
Outlook: “A4-III”

First production beamtime in March 2009:

Commissioning of the new energy stabilization system
Outlook: “A4-III”

Energy spectra: Measurement and MC Studies

- Elastically scattered electrons
- Inelastically scattered electrons
- Decay Photons
Summary

• Backward angle measurements at $Q^2=0.22$ GeV$^2$ performed on hydrogen and deuterium

• Hydrogen data: analyzed and combined with A4 forward data

• Strange Form Factors: small, compatible with zero at $Q^2=0.22$ GeV$^2$

• Deuterium data: Analysis is ongoing

• Outlook: A4-III, again at forward angles, $Q^2=0.62$ GeV$^2$
Full MC simulation results

Super Spectrum ring 3 (coinc.)

- Coincidence spectrum from experiment
- Elastically scattered electrons
- Inelastically scattered electrons
- \( \pi^0 \) decay photons (photo-production)
- \( \pi^0 \) decay photons (electro-production)
- Electrons scattered in aluminium