Measurement of the beam normal single-spin asymmetry of $^{12}\text{C}$
Weak Mixing Angle

- Weinberg angle / weak mixing angle:
  - Important parameter in standard model
  - Relative coupling strength of weak and electromagnetic force
  \[ e = g \cdot \sin \theta_w \]

- Measurement by Parity Violation (PV):
  - Polarised electrons, scattered on protons
  - Cross section dominated by electromagnetic interaction
  - Small contribution from $Z^0$ exchange → Parity violation
  - Measurement of PV asymmetry → $Z^0$ contribution

\[ \begin{align*}
  & \text{Parity conserving} \\
  & \text{Large cross section} \\
  & \text{Parity violating} \\
  & \text{small cross section}
\end{align*} \]
Neutron Skin

- Heavy nuclei contain more neutrons than protons
- Spacial distribution of neutrons might be larger

- $Z^0$ Boson couples more strongly to Neutron
  \[ Q_w^n \approx -0.99 \]
  \[ Q_w^p \approx 0.07 \]

- Measurement by parity violation:
  - Electron scattering on nuclei
  - Parity violating contribution to cross section from $Z^0$ exchange
  - Measurement of PV asymmetry
    \[ \rightarrow \text{Neutron distribution} \]
• Difficulties of PV measurements:
  ● Large electromagnetic cross section, small asymmetry $\sim 10^{-6}$
  ● Long run times
  ● Necessary: Good understanding of background
  ● Especially: Helicity correlated background

• Beam normal (single spin) asymmetry:
  ● Helicity correlated background contribution
  ● Caused by transversal polarisation component

• Necessary to measure for all targets used in PV experiment
- Measurement of beam normal single spin asymmetry at PREX

\[ A_n \text{ [ppm]} \]

\[ Q \text{ [GeV]} \]

\[ E_{\text{Beam}} = 1 - 3 \text{ GeV} \]
Theoretical Predictions

- Origin of asymmetry
  - Interference of 1 and 2 photon exchange

- Calculations:
  - Gorchtein & Horowitz
    - Two photon exchange approximation
    - Including full range of intermediate excitation states
  - Cooper & Horowitz
    [Phys. Rev. C72, 034602 (2005)]
    - All orders of photon exchange
    - Coulomb distortion effects
    - Only elastic intermediate state

=> No consistent Theory but
  - Contribution to every PV experiment
  - Contribution to other measurements (e.g. proton radius)

\[ E_{\text{Beam}} = 850 \text{ MeV} \]
• Measurement of beam normal asymmetry on $^{12}$C
  • $E_{\text{Beam}} = 570$ MeV
  • Scattering angles = $15^\circ$ - $26^\circ$
  • $Q^2 = 0.02$ – $0.05$ GeV$^2$/c$^2$
    ($Q = 0.14$ – $0.22$ GeV/c)

• Requirements:
  • High quality transversely polarised electron beam of known polarisation
  • High rate capable detector system
• **MAinz MIcrotron**
  - 5-Stage electron accelerator
  - Continuous wave beam:
    \[
    E = 180 \text{ MeV} - 1.6 \text{ GeV} \\
    I_{\text{max}} = 100 \mu\text{A}
    \]
No polarimeter for direct vertical transversal polarisation measurement available

- Mott: horizontal transversal @ source
- Compton: longitudinal @ source
- Møller: longitudinal @ target

Polarimetry:
- Maximise and measure longitudinal polarisation at target
- Maximise transversal horizontal component at source
- Minimise longitudinal and horizontal component at source and target
Experimental Set-up

- Electron Beam:
  - $E = 570$ MeV
  - $I = 20 \mu A$

- Target:
  - $10 \text{ mm } ^{12}\text{C}$

- Magnetic Spectrometers:
  - Define angular acceptance (angles 15.11° - 25.9°)
  - Select elastic events

- Detectors:
  - Quartz-Cherenkov-Detectors
  - Reduced amplification → High rate capability
Low rate particle tracking mode:

Precise positioning of detectors & magnetic field setting
→ Only elastic line in detector acceptance
Minimising False Asymmetries

Beam related sources:
- beam current, energy, position, angle

=> beam stabilisation

- Remaining asymmetry:
  - beam current: ~ 1 ppm
  - other parameters: < 0.1 ppm

=> Correction in offline analysis

Non beam related sources:
- Ground noise,
- Gate length fluctuations,
- Electrical cross talk

- Hardware suppression
  - Synchronised with power grid
  - Random polarity sequence
  - Inversions of general sign

=> Offline corrections
Results

Inversion of general sign

Runs with equal spectrometer angles

Beam normal spin asymmetry, $A_L$ [ppm]

PMT A1-A5
B1-B3
Summed Signals A
B
Total $-23.8 \pm 1.0$ ppm

General Sign ($\lambda/2$ plate)

Run number

Inversion of general sign
Results

PREX ($E_{\text{Beam}} = 1 - 3 \text{ GeV}$)

Transverse Beam Asymmetry [ppm]

$Q^2$ [GeV$^2$/c$^2$]
**Implications**

- **Observations**
  - Data points don't agree with theory
  - Data shows different slope

- **Theory limitations**
  - Only 2 photon exchange
  - No Coulomb distortion effects included
  - Nuclear structure for heavy nuclei similar to hydrogen
  - Scattering angle: $\Theta \approx 0$

$\Rightarrow$ Theory present in many physical measurements needs to be improved
Parity violation experiments allow measurement of
  - Weinberg angle
  - Neutron Skin

Beam-normal asymmetry:
  - important background
  - Direct probe for two-photon exchange

Experiment:
  - Vertically polarised electron beam & Elaborate polarisation measurement
  - Spectrometers to select elastic events & Quartz Cherenkov detectors
  - Suppression & Correction for false asymmetries

Disagreement between theoretical prediction and measurement

Continuation of program:
  - Upcoming beam time in April:
    - Energy dependence of asymmetry
    - Different target material: Silicon
Theoretical Calculations

- Cooper and Horowitz
  [Phys Rev C 72, 034602 (2005)]
  - All orders of photon exchanges
  - Coulomb distortion effects
  - Only elastic intermediate state

- Gorchtein and Horowitz
  [Phys Rev C 77, 044606 (2008)]
  - Two photon exchange approximation
  - Including full range of intermediate excited states

Data from:
HAPPEX / PREX @ J-Lab

\( E_{\text{Beam}} = 1 - 3 \, \text{GeV} \)

\( E_{\text{Beam}} = 850 \, \text{MeV} \)

kinematic range of this experiment
• Intrinsic reduction of false asymmetries:
  • Spin flip synchronised with power grid frequency
    → ground noise
  • Polarity patterns: ↑↓↓↑ or ↓↑↑↓
    → low frequency noise, monotonous changes
  • Random sequence of Polarity patterns
    → monotonous changes
  • Inversion of … pola inverter every 5 minutes
    → electrical cross-talk in DAQ electronics
  • Inversion of absolute sign every day
    → Unknown sources of false asymmetries

• Random Variations of beam parameters cancel out
• Offline correction of remaining false asymmetries
Beam Stability

Current stabilisation disabled

Active beam stabilisation:
- Current (AC / DC)
- Position (AC / DC)
- Energy

Correlation of asymmetries in both spectrometers

Position stabilisation disabled
Polarity Correlated Beam Variations

- Beam Current Asymmetry [ppm]
- Horizontal Position Difference [µm]
- Vertical Position Difference [µm]
- Beam Energy Difference [eV]
- Horizontal Angle Difference [urad]
- Vertical Angle Difference [urad]
• Polarity-correlated variations cause false asymmetries:
  • Beam-current: directly influences measure Asymmetry
  • Beam-energy & beam-angle influence cross-section
  • Beam position on target influences Spectrometer-acceptance

• Correction factors:
  • Calculated: Current, Energy, Angle
  • Simulated: Beam Positions

<table>
<thead>
<tr>
<th></th>
<th>Correction Factor</th>
<th>Mean Value</th>
<th>Correction [ppm]</th>
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<tbody>
<tr>
<td>Beam Current</td>
<td>1 ppm / ppm</td>
<td>-0.94 ppm</td>
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<td>Beam Energy</td>
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<td>0.0023 keV</td>
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<tr>
<td>Hor. Angle</td>
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<tr>
<td>Vert. Angle</td>
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