Systematic Error Investigation of the Spin Tune Analysis for an EDM Measurement at COSY

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Introduction

- Motivation for an EDM (Electric Dipole Moment) search:
  - CP violation

**Challenge:**
Disentangle EDM from systematic effects

**Systematic Tests of the Spin Tune Analysis**
Spin Tune Measurement

@ COSY: deuteron beam with a momentum of 0.970 GeV/c

\[ \nu_s = \frac{\text{spin rotations}}{\text{particle revolutions}} = \frac{|\Omega_s|}{\omega_{cycl}} \approx |\gamma G| \approx 0.1609 \]

Spin-Precession: \( f_s = \nu_s f_{rev} \sim 120 \text{ kHz} \quad (f_{rev} = 750 \text{ kHz}) \)

Counting Rates:
\[
\begin{align*}
N_{up}(t) &= a_{up}(t) \cdot [1 + P(t)A \cdot \sin(2\pi f_s t + \phi)] \\
N_{dn}(t) &= a_{dn}(t) \cdot [1 - P(t)A \cdot \sin(2\pi f_s t + \phi)]
\end{align*}
\]

- \( a \): Acceptance
- \( P \): Polarization
- \( A \): Analysing Power

Event rate: 5 kHz

500000 Events are detected for a 100 s cycle
Asymmetry Measurement

Counting Rates:
\[
N_{up}(t) = a(t) \cdot [1 + P(t)A \cdot \sin(2\pi f_s t + \phi)]
\]
\[
N_{dn}(t) = a(t) \cdot [1 - P(t)A \cdot \sin(2\pi f_s t + \phi)]
\]

**Up-Down** asymmetry (for constant \(a\) & \(PA\))
\[
\varepsilon_{hor} = \frac{N_{up} - N_{dn}}{N_{up} + N_{dn}} = PA \cdot \sin(2\pi f_s t + \phi)
\]

\[\epsilon_{hor} = 0\]

\[\epsilon_{hor} = PA\]
Measurement of the Spin Tune

Problem:
• On average one hit in detector every 25\textsuperscript{th} beam revolutions
  ⇒ No direct fit possible

Solution:
• Map all events into first spin oscillation period
• Calculate asymmetry for an one second interval and fit a sine

Assumption: Acceptance $a$ and Polarization $PA$ are constant in this time interval
Generate Random Time Values

1 Step: Assume a Linear Time dependency of Polarization and Acceptance

\[ N_{up, dn}(t) = \begin{cases} a_{up}(1 - \varepsilon_2 t)[1 + PA(1 - \varepsilon_1 t) \cdot \sin(2\pi f_s t + \varphi)] \\ a_{dn}(1 - \varepsilon_2 t)[1 - PA(1 - \varepsilon_1 t) \cdot \sin(2\pi f_s t + \varphi)] \end{cases} \]

2 Step: Generate Uniform distribution for \( x_1 \) & \( x_2 \) [0,1]

Calculating a Probability with the generated \( t \)

\[ p_{up}(t) = \frac{N_{up}(t)}{N_{up}(t) + N_{dn}(t)} \]

\( p_{up} \leq x_1 \) & \( x_2 > a_{up} \)

Event in up-Detector

\( p_{up} > x_1 \) & \( x_2 > a_{dn} \)

Event in dn-Detector

Generate Uniform time values [0,100] s

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Data Simulation of three different Cases

1. Constant $PA$ and $a$

\[ PA \]

\[ a_0 \]

2. Linear decreasing $PA$ and constant $a$

\[ PA \]

\[ a_0 \]

3. Linear decreasing $PA$ and $a$

\[ PA \]

\[ a_0 \]

Analysis assumes a constant Polarization $PA$ and Acceptance $a$
Parameters for fixed Spin Tune Simulations

\[ N_{\text{up, dn}}(t) = \begin{cases} 
\ a_{\text{up}}(1 - \varepsilon_2 t)[1 + PA (1 - \varepsilon_1 t) \cdot \sin(2\pi f_s t + \varphi)] \\
\ a_{\text{dn}}(1 - \varepsilon_2 t)[1 - PA (1 - \varepsilon_1 t) \cdot \sin(2\pi f_s t + \varphi)]
\end{cases} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>up</th>
<th>dn</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha ) [%]</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>( PA ) [%]</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>( f_s ) [kHz]</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>( \varphi ) [rad]</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

For each case 1000 data files with 500000 time values are generated for same Spin Tune.
Spin Tune determination for the Simulations

- Analysis determines a $\nu_s$ for each simulation
- Variance of the Spin Tune $\Delta \nu_s$ is determined

Systematic Error of the Spin Tune Analysis: $10^{-11}$

**Case 1:** Constant $PA$ and $a$

$\mu = (3.6 \pm 5.8) \cdot 10^{-12}$

**Case 2:** Linear decreasing $PA$ and constant $a$

$\mu = (-9.5 \pm 6.9) \cdot 10^{-12}$

**Case 3:** Linear decreasing $PA$ and $a$

$\mu = (-1.5 \pm 5.6) \cdot 10^{-12}$
Outlook & Summary

• The JEDI Collaboration developed a method to determine the Spin Tune with high precision

• The results show that the Spin Tune Analysis is robust: systematic error $10^{-11}$

The statistical error for a real deuteron measurement is of the order $10^{-10}$
Decreasing Polarization or Acceptance do not effect the Analysis Method