Polarimetry for monitoring long coherent spin precession and polarization based feedback

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on behalf of the JEDI Collaboration
Motivation

Planar magnetic and/or electric ring:
• invariant spin axis vertical
• spin in horizontal plane: precession around vertical axis
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special case:
frozen spin $\rightarrow f_{\text{precession}} = f_{\text{revolution}}$

- first goal:
establish, maintain and monitor long coherent spin precession

EDM measurement
Cooler Synchrotron COSY

COSY provides cooled & polarized protons and deuterons with $p = 0.3 - 3.7$ GeV/c
Experimental setup

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2. bunch and (pre-)cool
3. turn spin by means of a RF solenoid into horizontal plane
4. extract beam slowly (within 100-1000 s) onto a carbon target, measure asymmetry and precisely determine spin precession

spin tune:

$$|\nu_s| = |\gamma G| = \frac{\text{spin precessions}}{\text{particle turn}} = \frac{f_{\text{prec}}}{f_{\text{rev}}} \approx \frac{120 \text{ kHz}}{750 \text{ kHz}} \approx 0.16$$
Polarimetry

- reaction: elastic d+C scattering
- up/down asymmetry $\propto P_x$ projection on x-axis
- left/right asymmetry $\propto P_y$ projection on y-axis

Asymmetry measurement

Detector signal

\[ N_{up,down} = 1 \pm PA \sin(2\pi \cdot f_{prec} t) \]
\[ = 1 \pm PA \sin(2\pi \cdot v_s \cdot n_{turns}) \]

P: polarisation, A: analysing power

Asymmetry

\[ \varepsilon = \frac{N_{up} - N_{down}}{N_{up} + N_{down}} = PA \sin(2\pi \cdot v_s \cdot n_{turns}) \]

Challenges

- precession frequency \( f_{prec} \approx 120 \text{ kHz} \)
- \( v_s \approx -0.16 \) \( \rightarrow \) 6 turns / precession
- event rate \( \approx 5000 \text{ s}^{-1} \) \( \rightarrow \) 1 hit / 25 precessions
  \( \rightarrow \) no direct fit of the rates
Asymmetry measurement

single reference clock

COSY rf → beam revolutions: counting turn number \( n \)

detector events → assign turn number \( n \) → phase advance \( \varphi_s = 2\pi \nu_s n \)

for intervals of \( \Delta n = 10^6 \) turns: \( \varphi_s \rightarrow \varphi_s \mod 2\pi \)

scan \( \nu_s \) in some interval around \( \nu_s = \gamma G \)

true \( \nu_s \) a priori not known

\[
\sigma_{\nu_s} \lesssim 10^{-6}
\]

maximum asymmetry \( \nu_{s,\text{max}} \)

see: “Measuring the polarization of a rapidly precessing deuteron beam”

Phys.Rev. STAB 17, 052803 (2014)
Asymmetry measurement

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Application: spin coherence time (SCT)

Ensemble of $\approx 10^9$ deuterons: coherent precession needed!

- unbunched beam: $\frac{\Delta \gamma}{\gamma} \approx 10^{-5} \implies$ decoherence in $< 1$ s
- bunching: eliminate effects on $\frac{\Delta p}{p}$ in 1st order $\rightarrow \tau \approx 20$ s
- correcting higher order effects using sextupoles and (pre-) cooling $\rightarrow \tau \approx 1000$ s

November 4-6, 2015
Beam Dynamics meets Diagnostics, Florence
Application: spin coherence time (SCT)

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![Graph showing asymmetry versus time](image)
Application: SCT vs chromaticity

chromaticity: $\Delta Q_{x,y}/\Delta p$

$(Q_{x,y} :$ betatron tunes, $p :$ momentum)

• also controlled by sextupoles (MXS, MXG: different sextupole families in COSY)

• compare:

  points of fixed* chromaticity
  
  points of longest SCT

  chromaticity settings and and longest SCT are correlated!

*Note: chromaticy $\approx$ zero is special for choice of particle type and beam momentum
Application: precise determination of $\nu_s$

Monitoring phase of asymmetry ($\nu_s$ fixed):

$$\nu_s = \nu_{s,true}$$

$$\nu_s = \nu_{s,true} + \delta \nu_s$$

Application: precise determination of $\nu_s$

- spin tune $\nu_s$ can be determined to $\sigma_{\nu_s} \approx 10^{-8}$ in $\Delta t \approx 2s$
- average $\bar{\nu}_s$ in 1 cycle ($\approx 100s$) determined to $\sigma_{\nu_s} \approx 10^{-10}$
- tool for: study long term stability of the ring
dedicated online feedback systems
probing ring imperfections

Spin tune: feedback system

Wien filter: signal build up (M. Rosenthal)
Spin tune: feedback system

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Phase variation per cycle

Variation cycle-by-cycle
Spin tune: feedback system

Challenges:

• maintain phase relation between precession & rf ExB dipole
• maintain resonance condition for rf solenoid & ExB rf dipole
• maintain frozen spin condition in a future dedicated ring

Idea:

• control and stabilize spin tune via COSY rf cavity:
  \[
  \frac{\Delta \nu_s}{\nu_s} = \frac{\Delta \gamma}{\gamma} = \beta^2 \frac{\Delta p}{p} = \frac{\beta^2}{\eta} \frac{\Delta f}{f}
  \]

• control relative phases by accelerating/decelerating spin precession
Spin tune: feedback system

**COSY rf control**

- 24 bit
- LSB = 0.12 Hz
- + data valid
- + flat top

**Converter board**

- 10 bit = bits 0 ... 8 + sign
- 24 bit = bits 5 ... 29

**COSY rf generator**

- 32 bit
- 10 bit = ± 2 Hz
- LSB = 3.7 mHz

**NetlO**

- Δ\(f\) (10 bit)
- + data valid

**TDC**

**Computer**

- stand-alone DAQ

**deuterons @ 0.97 GeV/c**

\[
f = 750 \text{ kHz}
\]

\[
\beta = 0.46, \eta = -0.6
\]

\[
\Delta f = 2 \text{ Hz} \Rightarrow \frac{\Delta f}{f} = 2.7 \cdot 10^{-6} \Rightarrow \frac{\Delta \gamma}{\gamma} = 1 \cdot 10^{-6}
\]

\[
\Delta f = 3.7 \text{ mHz} \Rightarrow \frac{\Delta f}{f} = 5 \cdot 10^{-9} \Rightarrow \frac{\Delta \gamma}{\gamma} = 2 \cdot 10^{-9}
\]

**R&D with beam:**

- end of November 2015
Spin tune: probing ring imperfections

- EDM causes tilt of spin closed orbit
- Tilt can also be caused by ring imperfections (e.g. field imperfections)

Effect on spin tune

M. Rosenthal
Spin tune: probing ring imperfections

• spin tune is perturbed by small kicks $\sim a$ by ring imperfections
  \[ \nu_0 = \gamma G + O(a^2) \]

• idea: probe imperfections by adding artificial imperfections spin kicks $\chi_1, \chi_2$ by means of e-cooler solenoids

• measure spin tune change
  \[ \Delta \nu_S = \nu_S(\chi_1, \chi_2) - \nu_0 \]

• expectation
  \[ \Delta \nu_S \propto (y_\pm - a_\pm)^2 \]
  \[ y_\pm = \frac{1}{2} (\chi_1 \pm \chi_2) \]
  \[ a_\pm: \text{in-plane ring imperfections} \]
Spin tune: probing ring imperfections

$$\Delta v_s = 3.01072(66) \cdot 10^{-6}$$
Spin tune: probing ring imperfections

spin tune map:

- parabolic behavior confirmed
- saddle point provides information on spin kicks by in-plane ring imperfections

$\Delta \nu_s(y_- = const)$

$y_- = 9.25 \text{ mrad}$

$y_- = 3.7 \text{ mrad}$
Outlook: Polarimeter development

Status:

- EDDA is in operation since about 20 years
- acceptance limits polarimeter efficiency

\[
\sigma \cdot A^2
\]

data: PLB 549, 307 (2002)

crucial for feedback system
Outlook: Polarimeter development

- "database" measurements: pC, dC analyzing powers at various beam momenta using the WASA-at-COSY forward detector
- Development of a dedicated polarimeter for high precision EDM measurements

Modular design

LYSO
+ PMT
+ divider
Summary

• Polarimetry + time stamping (single long range TDC)
  → resolving fast spin precession
  → extract polarization
  → determine spin tune with high precision

• Applications
  → tune accelerator for long spin coherence times (≥ 1000s)
  → stabilize spin tune and maintain phase lock to external rf signals (solenoid, ExB dipole), “feedback system”
  → study spin tune response of accelerator parameters (field imperfections, orbit changes, ...)

• Upcoming activities
  → provide analyzing powers for pC and dC scattering
  → development of a dedicated polarimeter for EDM measurements
Jülich Electric Dipole Moment Investigations:

• ≈ 100 members:
  Aachen, Daejeon, Dubna, Ferrara, Grenoble, Indiana, Ithaca, Jülich, Krakau, Michigan, Minsk, Novosibirsk, St. Petersburg, Stockholm, Tbilisi, ...

• see
  http://collaborations.fz-juelich.de/ikp/jedi