Fast Helicity Reversal

Riad Suleiman
Injector Group

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Outline

- Why Changing Helicity Reversal Rate?
  - Reduce Noise Contributions to Measurement Error

- PQB at 30 Hz Helicity Reversal

- PQB at 1 kHz Helicity Reversal
  - Charge Asymmetry
  - Position Differences
  - Charge Asymmetry Separation

- How to Reduce 60 Hz Line Noise with Fast Helicity Reversal?

- Summary
Now at 30 Hz Reversal, Why?

- Power line 60 Hz frequency is major source of noise in parity experiments

- For 30 Hz reversal, $T_{\text{Stable}} (= 33.333 \text{ ms})$ contains exactly two cycles of 60 Hz line noise $\rightarrow$ by design, this reversal cancels line noise

$T_{\text{Stable}} = 0.980 \text{ ms}$

$T_{\text{Stable}} = 33.333 \text{ ms}$
60 Hz line noise cancels at:

I. Small $T_{\text{Stable}}$

II. $T_{\text{Stable}} = 16.667 \text{ ms}$

III. $T_{\text{Stable}} = 33.333 \text{ ms}$

IV. ...

**Note:** Noise increases width of distributions $\rightarrow$ increases error on the mean, $\sigma / \sqrt{N}$, where $N$ no. of data points. However, it does not change the mean.
Need Fast Reversal, Why?

- Problem:
  - There are other sources of noise at low frequencies, *i.e.*, target density fluctuations, PSS Current Sensor, ...

  → Cause larger widths of helicity correlated distributions, double-horned distributions, ...
Target Density Fluctuations

- Carbon target has only statistical fluctuations – no boiling

- Cryogenic target boils when heated by electron beam. For QWeak: 180 µA on 35 cm liquid hydrogen target (2.5 kW heat load)
Fast Fourier Transform (FFT) of Target Density

![Graph showing FFT amplitude against frequency for Cryogenic and Carbon materials. The Cryogenic data is plotted in red, and the Carbon data is plotted in black. The x-axis represents frequency in Hz, ranging from 0 to 200 Hz. The y-axis represents FFT amplitude, with a logarithmic scale ranging from $10^{-6}$ to $10^{-1}$. The Cryogenic data shows a higher amplitude at lower frequencies, indicating a different distribution compared to Carbon.]
Widths and Errors

For Errors, assume 1 month long experiment

Must run at very small $T_{\text{Stable}}$
Widths at 1 kHz and 30 Hz

Note: For statistical (white) noise, the increase in width going from 30 Hz to 1 kHz is:

$$\sqrt{\frac{33.333}{0.980}} = 5.8$$

30 Hz, T_Stable = 33.333 ms, T_Settle = 500 µs, OUT

1 kHz, T_Stable = 0.980 ms, T_Settle = 60 µs, OUT
Note:

- No significant noise reduction for position differences
- Factor of 3 noise reduction for charge asymmetry width

30 Hz, $T_{Stable} = 33.333$ ms, $T_{Settle} = 500$ µs, IN

1 kHz, $T_{Stable} = 0.980$ ms, $T_{Settle} = 60$ µs, IN
PQB
30 Hz Reversal, 500 µs
Aq = -952.43 + 1252.02 \sin(2\theta + 65.86) + -841.07 \sin(4\theta + 66.39)

\Delta x = -0.39 + 0.52 \sin(2\theta + 64.99) + -0.40 \sin(4\theta + 89.46)

\Delta y = 0.88 + 0.30 \sin(2\theta + 52.80) + -0.22 \sin(4\theta + 125.73)
Run 690, PITA = -120, IHWP OUT, ILP OUT, QWK_1I02

\[ A_q = -938.92 + 1160.79 \sin(2\theta + 38.98) + 2740.88 \sin(4\theta + 12.66) \]

\[ \Delta x = -0.30 + 0.50 \sin(2\theta + 33.64) + -1.50 \sin(4\theta + 177.87) \]

\[ \Delta y = 0.90 + 0.30 \sin(2\theta + 21.32) + 0.98 \sin(4\theta + 3.05) \]
Run 691, PITA = 0, IHWP IN, ILP OUT, QWK_1I02

\[ A_q = 799.62 + 1220.48 \sin(2\theta + 63.16) + 595.06 \sin(4\theta + 97.69) \]

\[ \Delta x = 0.48 + 0.45 \sin(2\theta + 57.87) + 0.41 \sin(4\theta + 114.58) \]

\[ \Delta y = 1.36 + 0.26 \sin(2\theta + 46.04) + 0.25 \sin(4\theta + 152.48) \]
Run 692, PITA = -120, IHWP IN, ILP OUT, QWK_1I02

\[ A_q = 776.38 + -1145.43 \sin (\theta + 36.03) + -3131.25 \sin (\theta + 13.94) \]

\[ \Delta x = 0.38 + -0.51 \sin (\theta + 29.90) + -1.71 \sin (\theta + 2.77) \]

\[ \Delta y = 1.36 + -0.30 \sin (\theta + 19.77) + -1.13 \sin (\theta + 9.48) \]
PQB
1 kHz Reversal, 60 µs
Run 719, PITA = 0, IHWP OUT, ILP OUT, QWK_1102

\[ A_q = -882.51 + 1146.30 \sin(2\theta + 65.43) - 726.68 \sin(4\theta + 68.60) \]

\[ \Delta x = -0.44 + 0.55 \sin(2\theta + 61.11) - 0.42 \sin(4\theta + 98.24) \]

\[ \Delta y = 0.89 + 0.24 \sin(2\theta + 40.39) - 0.27 \sin(4\theta + 134.21) \]
Run 720, PITA = -120, IHWP OUT, ILP OUT, QWK_1I02

\[ A_q = -878.34 + 1073.63 \sin(2\theta + 38.71) + 2578.10 \sin(4\theta + 12.83) \]

\[ \Delta x = -0.36 + 0.55 \sin(2\theta + 36.13) + -1.66 \sin(4\theta + 178.68) \]

\[ \Delta y = 0.88 + 0.24 \sin(2\theta + 18.61) + 0.91 \sin(4\theta + 0.57) \]
Run 717, PITA = 0, IHWP IN, ILP OUT, QWK_1I02

\[ A_q = 736.66 + -1116.76 \sin(2\theta + 62.29) + 535.61 \sin(4\theta + 103.86) \]

\[ \Delta x = 0.52 + -0.56 \sin(2\theta + 54.86) + 0.40 \sin(4\theta + 126.11) \]

\[ \Delta y = 1.29 + -0.30 \sin(2\theta + 39.10) + 0.24 \sin(4\theta + 170.90) \]
Run 718, PITA = -120, IHWP IN, ILP OUT, QWK_1I02

\[ \Delta q = 734.01 + -1077.36 \sin (2\theta + 35.12) + -2988.61 \sin (4\theta + 14.19) \]

\[ \Delta x = 0.39 + -0.56 \sin (2\theta + 30.46) + -1.84 \sin (4\theta + 1.20) \]

\[ \Delta y = 1.28 + -0.29 \sin (2\theta + 21.21) + -1.02 \sin (4\theta + 7.62) \]
PQB
1 kHz Reversal, Different choices of T_Settle
1 kHz, 500 µs, OUT

1 kHz, 500 µs, IN

100 µs

60 µs

10 µs
Charge Separation at 1 kHz

Run 710
How to Reduce 60 Hz Line Noise?

1. Choose small T_Stable (1 ms) → fast helicity reversal (1 kHz)

2. Cancel 60 Hz noise by design:
   - Choose T_Stable = 33.333 ms (exactly two 60 Hz cycles). This is 30 Hz (Actually 29.6 Hz) helicity reversal
   - Choose T_Stable = 16.666 ms (exactly one 60 Hz cycle). This is 60 Hz helicity reversal
   - Choose T_Stable + T_Settle = 8.333 ms (half 60 Hz cycles), select **Quartet Pattern**, line-phase locked. Then, \( A = +1-2-3+4 \) (or \(-1+2+3-4\)). This is 120 Hz helicity reversal.
   - Choose T_Stable + T_Settle = 4.167 ms, select **Octet Pattern**, line-phase locked. Then, \( A = +1-2-3+4-5+6+7-8 \). This is 240 Hz helicity reversal

Will patterns compromise cancellation of other low frequency noises?
Summary

- Fast Helicity Reversal is needed:
  - Reduces noise from target density fluctuations by huge factor
  - Reduces noise on beam current by factor of 3
  - No significant reduction in beam position noise

- Beam Properties at 1 kHz is very similar to 30 Hz and PQB is good

- T_Settle of 50 µs is very reasonable

Future Parity Experiment:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Frequency</th>
<th>Clock</th>
<th>Pattern</th>
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<tbody>
<tr>
<td>HAPPEx III &amp; PVDIS</td>
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<td>Quartet</td>
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<tr>
<td>PREx</td>
<td>240 Hz</td>
<td>Line-Locked</td>
<td>Octet</td>
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<tr>
<td>QWeak</td>
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- New Helicity Board to be installed on July 6, 2009
Backup Slides
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<th>Channel</th>
<th>Chan 1</th>
<th>Chan 2</th>
<th>Chan 3</th>
<th>Chan 4</th>
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Notes:
1. For each BPM, the wires are: +X+, +X-, +Y+, +Y-.
2. There are only two injector BPMs we are not reading: 0R01 and 0R02.
y-position Differences
(No Outliers)