Fast Helicity Reversal

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Injector Group

June 2, 2009

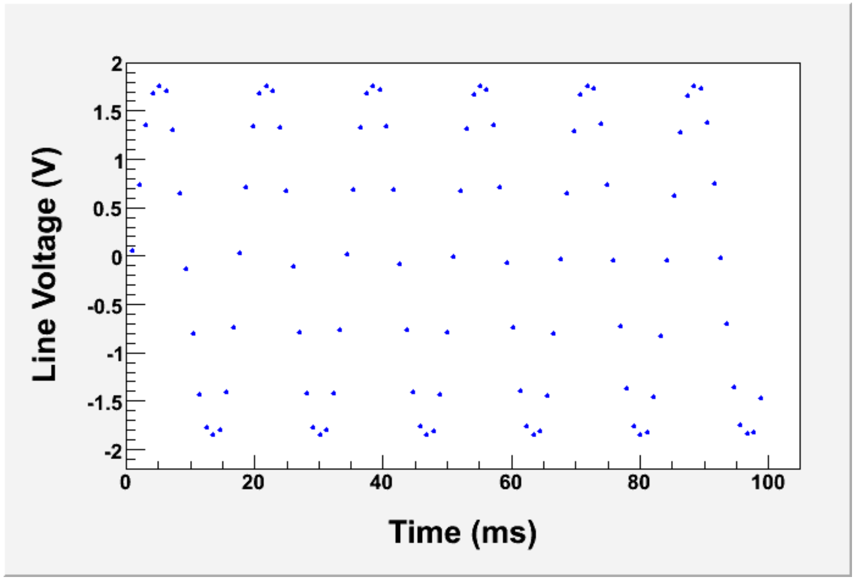
Outline

- 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

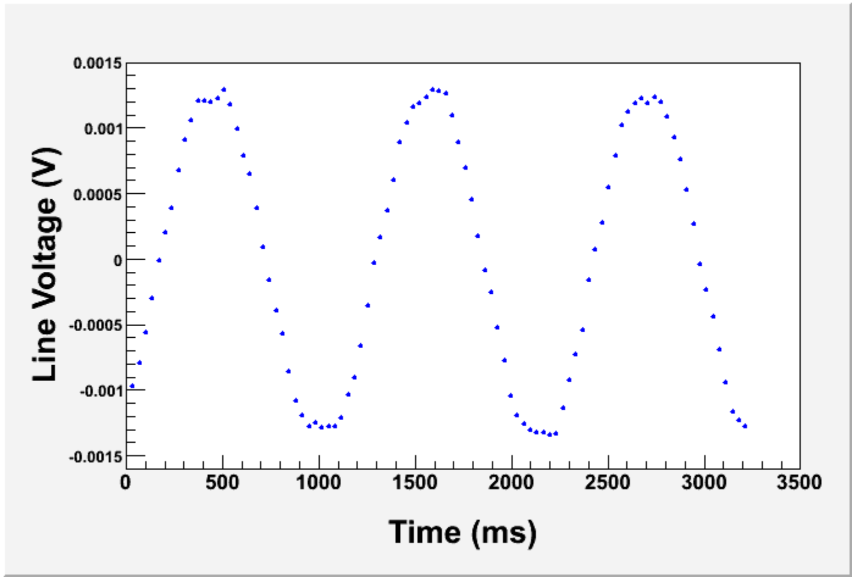
Now at 30 Hz Reversal, Why?

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

- For 30 Hz reversal, T_Stable (= 33.333 ms) contains exactly two cycles of 60 Hz line noise → by design, this reversal cancels line noise



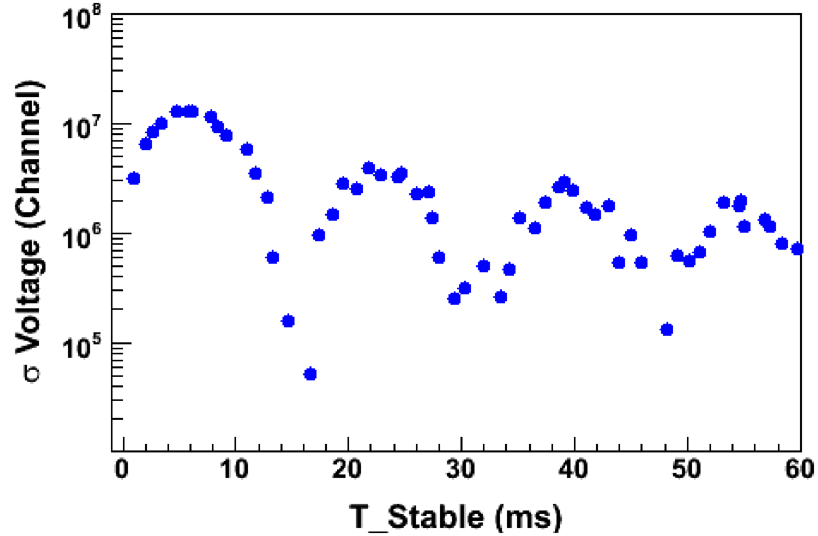
T_Stable = 0.980 ms

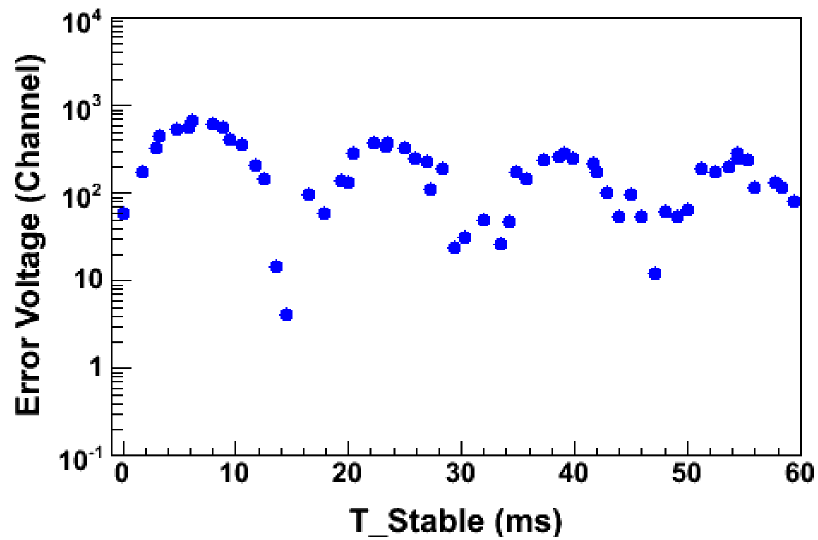


T_Stable = 33.333 ms

Widths and Errors, 60 Hz Noise

- 60 Hz line noise cancels at:
  I. Small T_Stable
  II. T_Stable = 16.667 ms
  III. T_Stable = 33.333 ms
  IV. …



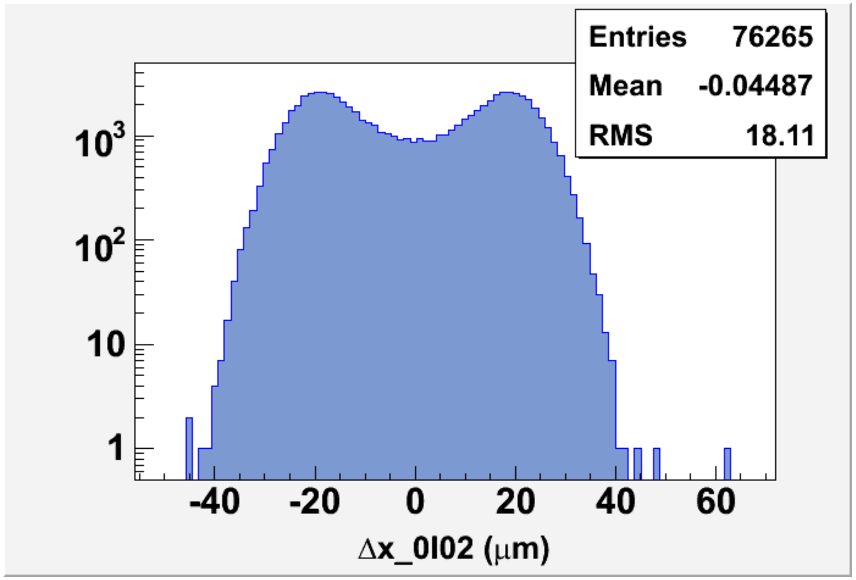


Note: Noise increases width of distributions → increases error on the mean, $\sigma/\sqrt{N}$, where *N* no. of data points. However, it does not change the mean.

Need Fast Reversal, Why?

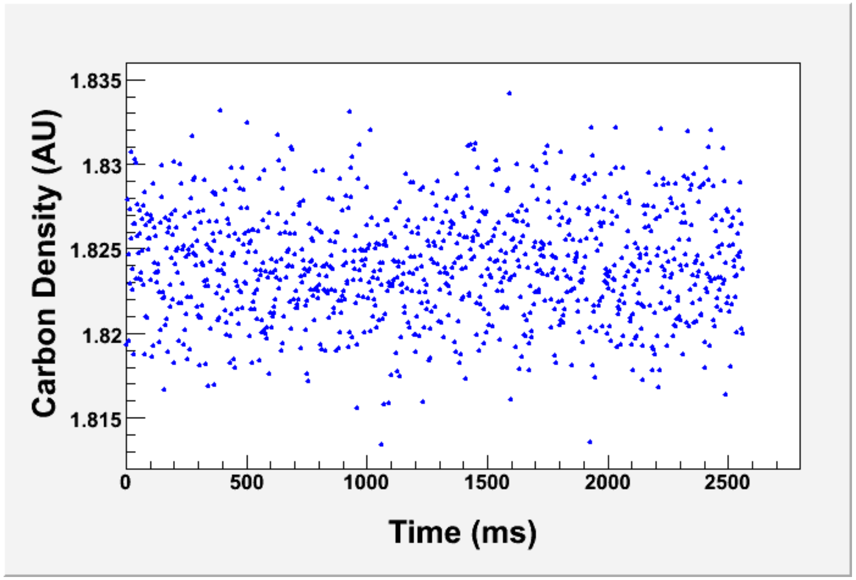
- Problem:
  - ➢ There are other sources of noise at low frequencies, *i.e.*, target density fluctuations, PSS Current Sensor, …

    → Cause larger widths of helicity correlated distributions, double-horned distributions, …

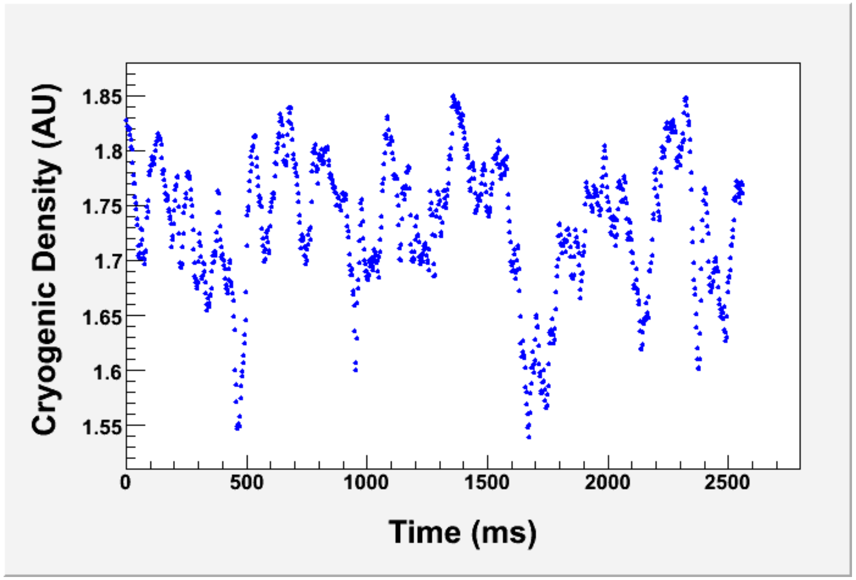


Target Density Fluctuations

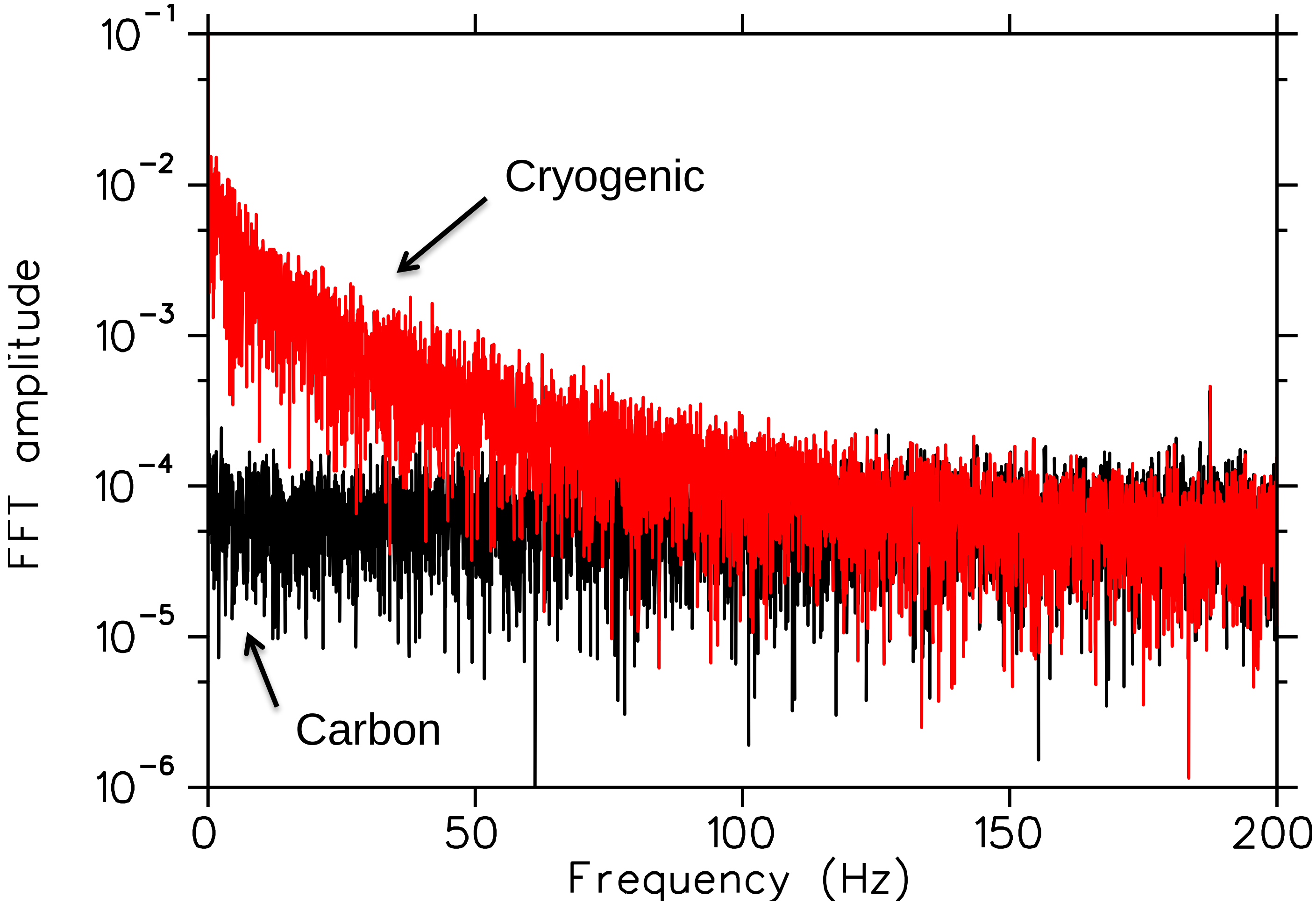
- ✓ Carbon target has only statistical fluctuations – no boiling



- ✓ Cryogenic target boils when heated by electron beam. For QWeak: 180 µA on 35 cm liquid hydrogen target (2.5 kW heat load)

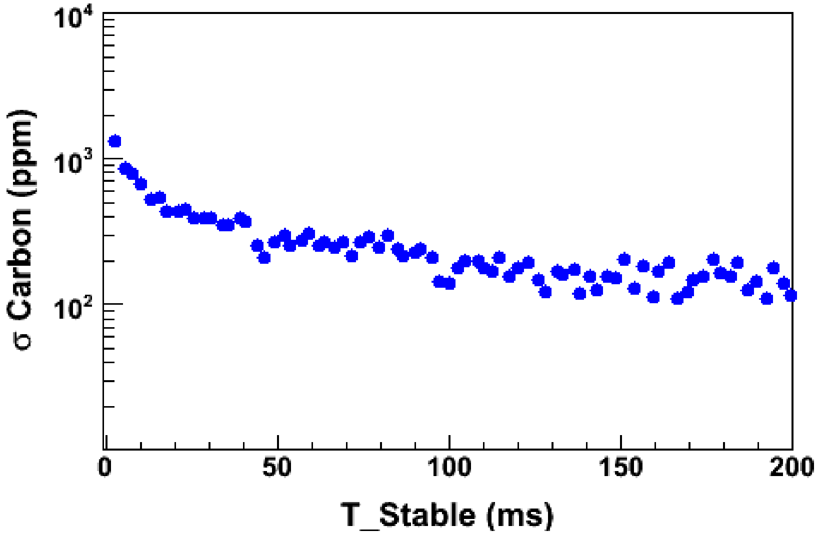


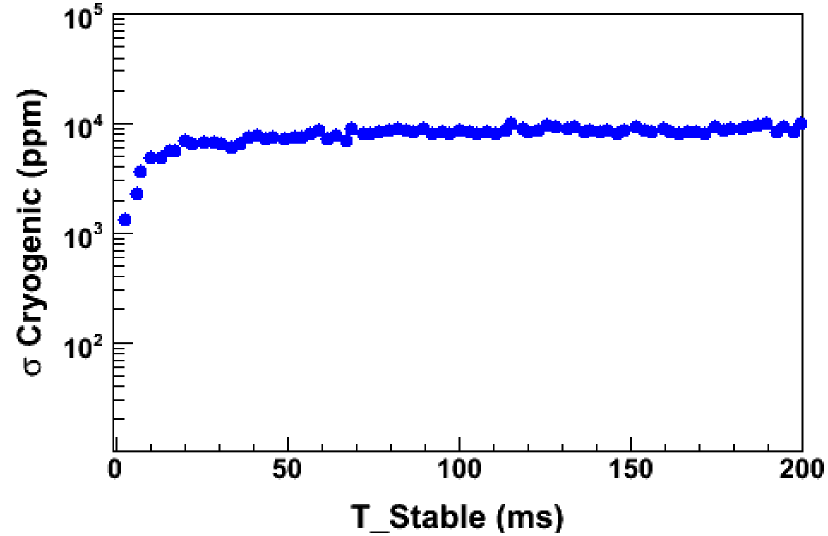
Fast Fourier Transform (FFT) of Target Density

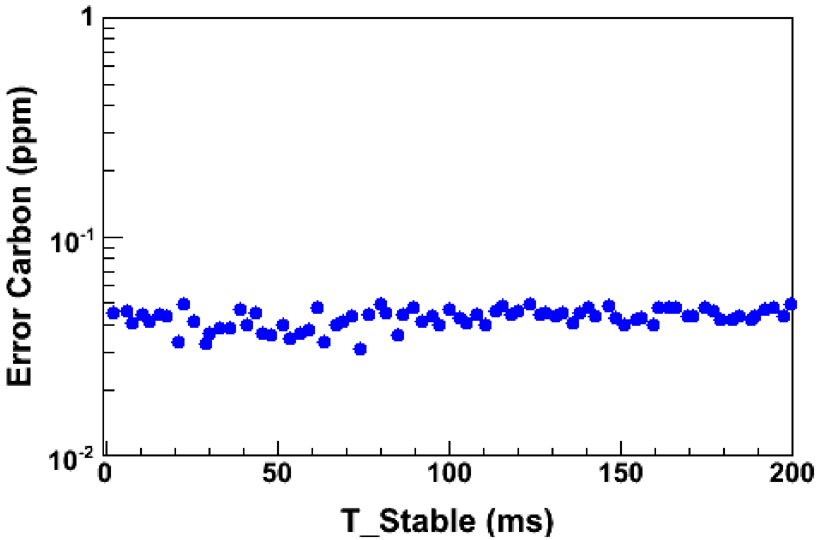


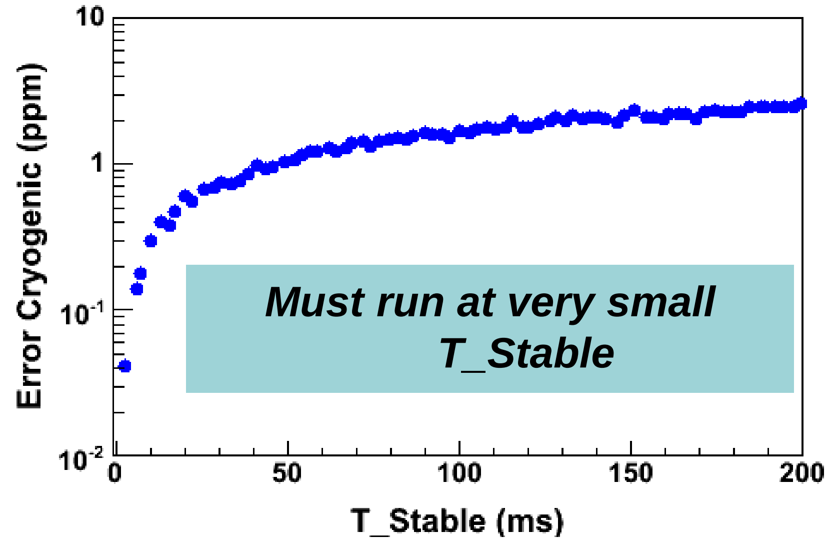
Widths and Errors

For Errors, assume 1 month long experiment





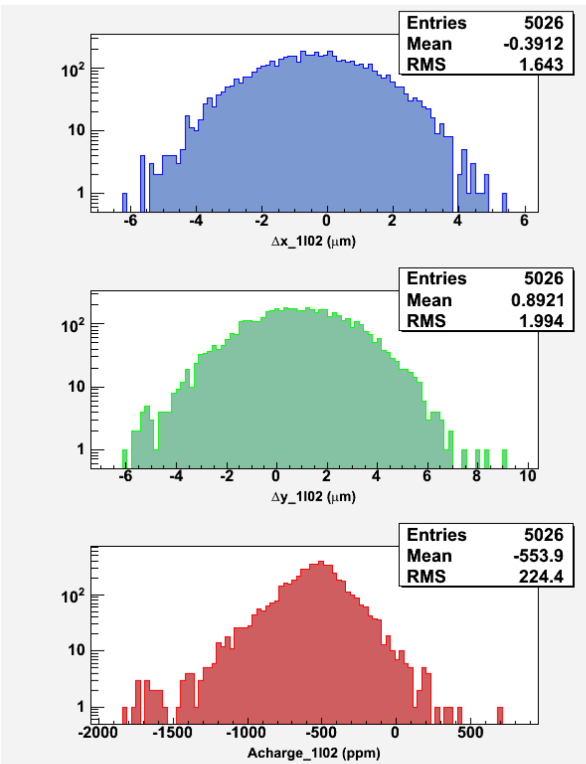


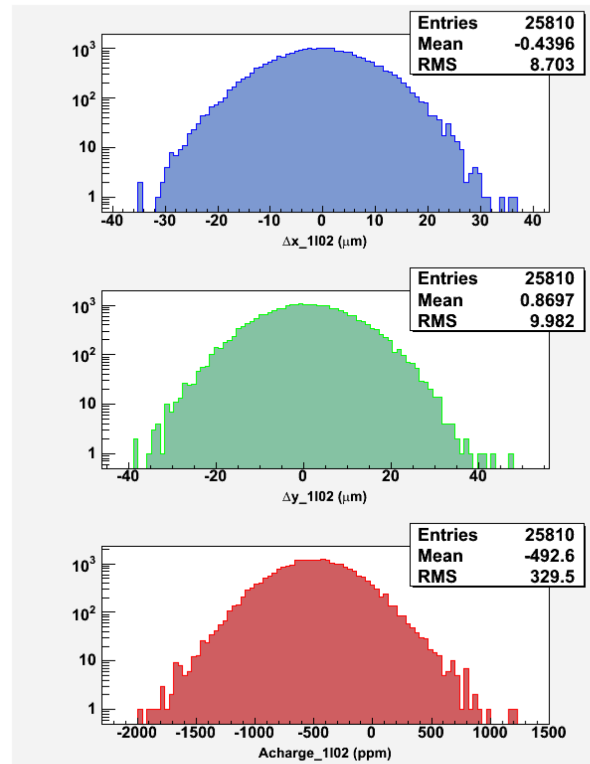


Widths at 1 kHz and 30 Hz

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

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



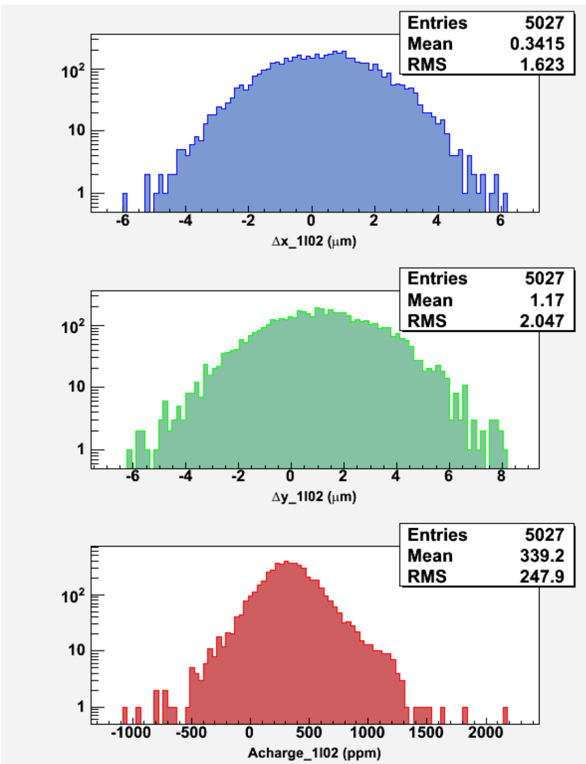


30 Hz, T_Stable = 33.333 ms, T_Settle = 500 µs, OUT

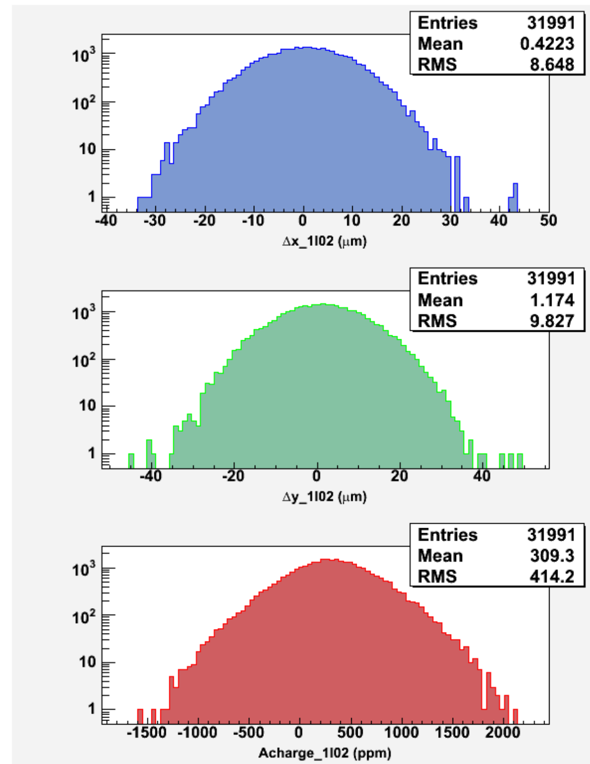
1 kHz, T_Stable = 0.980 ms, T_Settle = 60 µs, OUT

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_

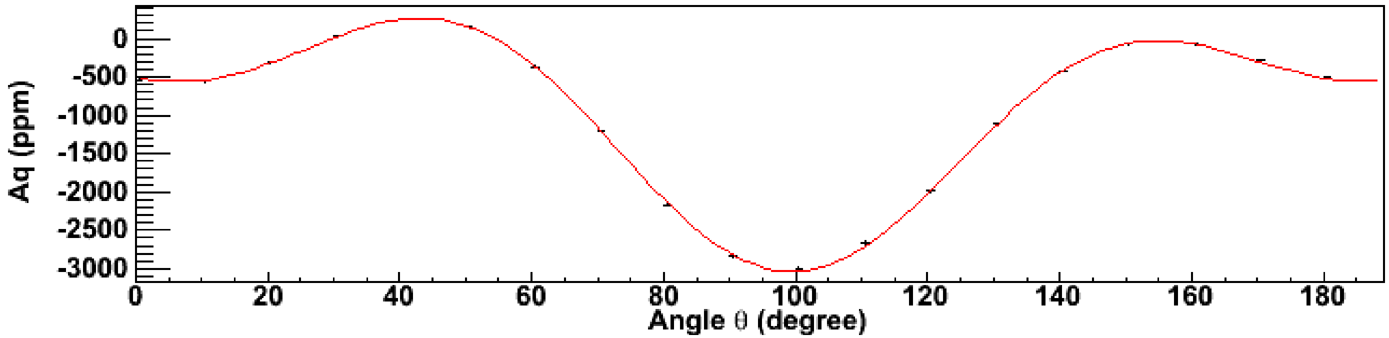


_1 kHz, T_Stable = 0.980 ms, T_Settle = 60 µs, IN_

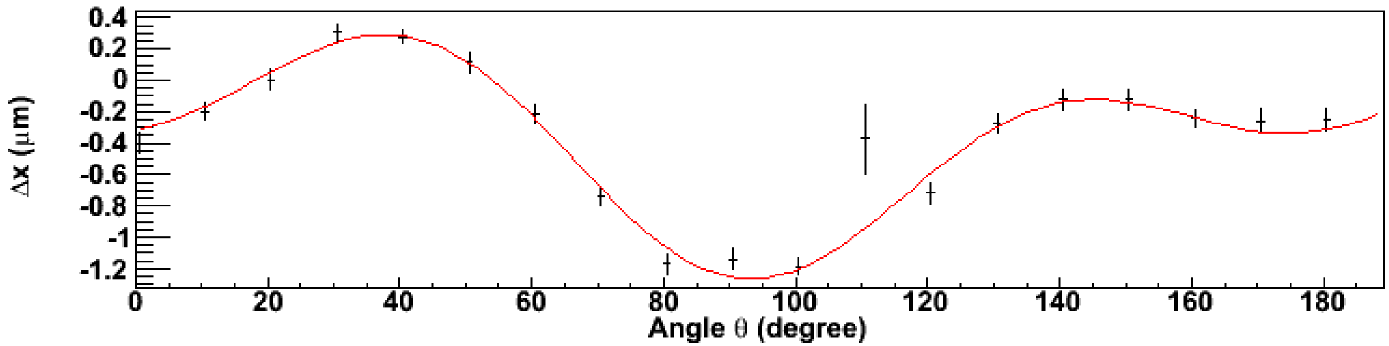
PQB

30 Hz Reversal, 500 µs

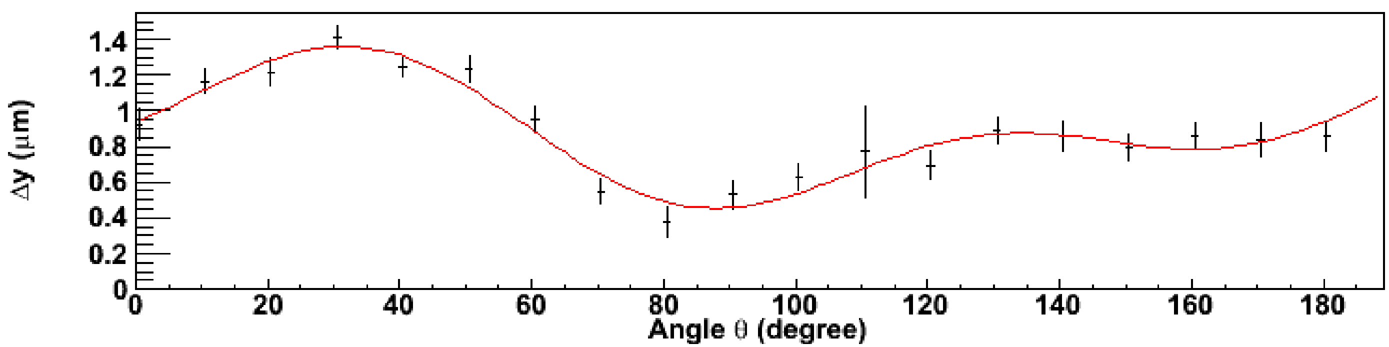
Run 689, PITA = 0, IHWP OUT, ILP OUT, QWK_1I02



$$Aq = -952.43 + 1252.02 \sin(2\theta + 65.86) + -841.07 \sin(4\theta + 66.39)$$

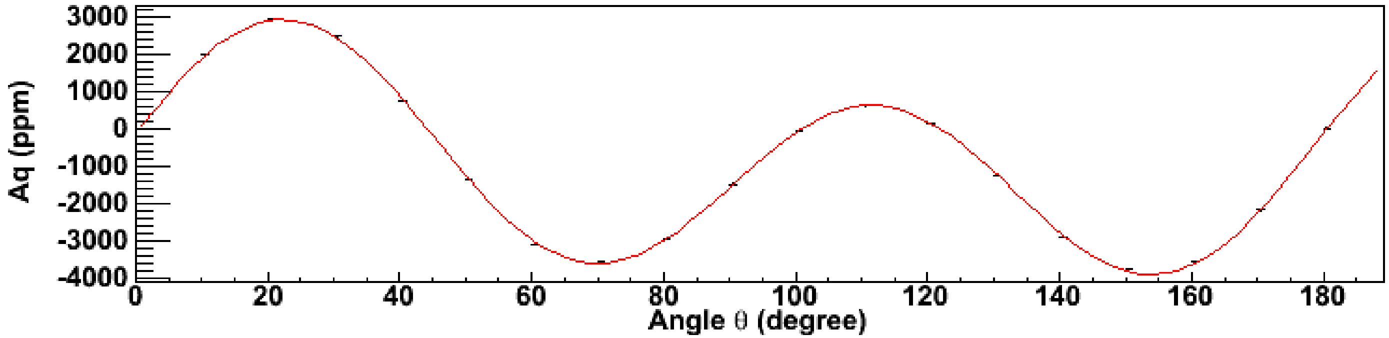


$$\Delta x = -0.39 + 0.52 \sin(2\theta + 64.99) + -0.40 \sin(4\theta + 89.46)$$

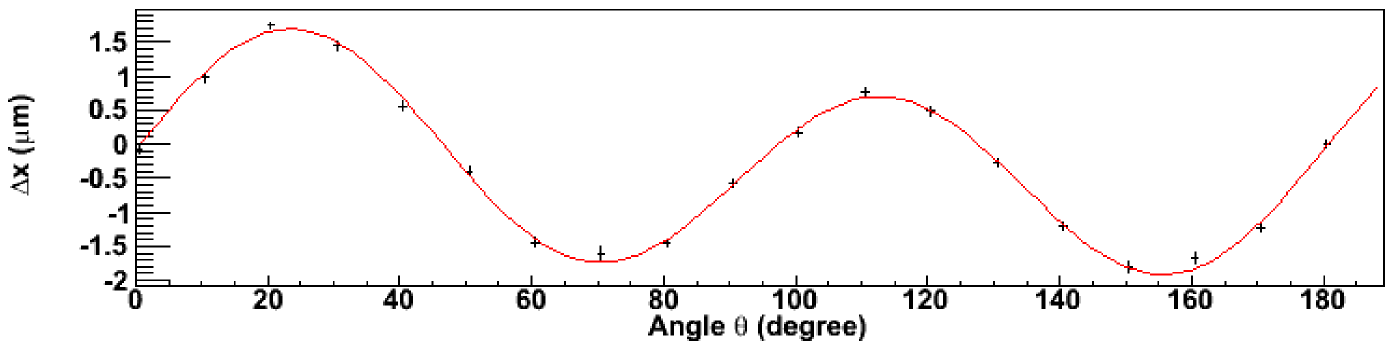


$$\Delta y = 0.88 + 0.30 \sin(2\theta + 52.80) + -0.22 \sin(4\theta + 125.73)$$

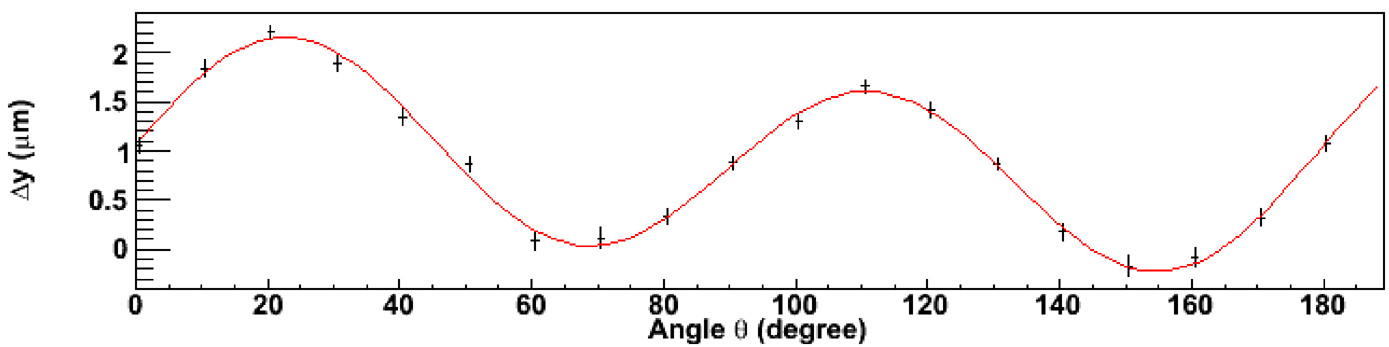
Run 690, PITA = -120, IHWP OUT, ILP OUT, QWK_1I02



Aq = -938.92 + 1160.79 sin (2θ+ 38.98) + 2740.88 sin (4θ+ 12.66)

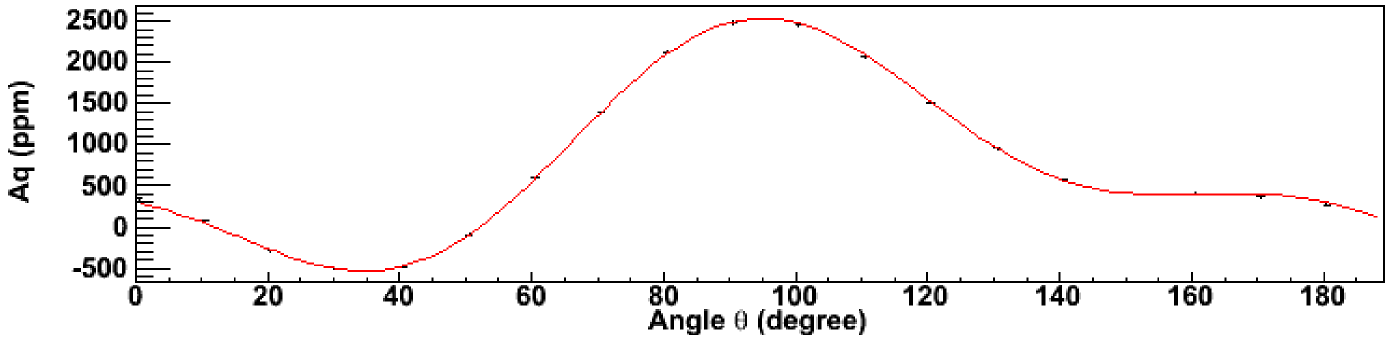


Δx = -0.30 + 0.50 sin (2θ+ 33.64) + -1.50 sin (4θ+ 177.87)

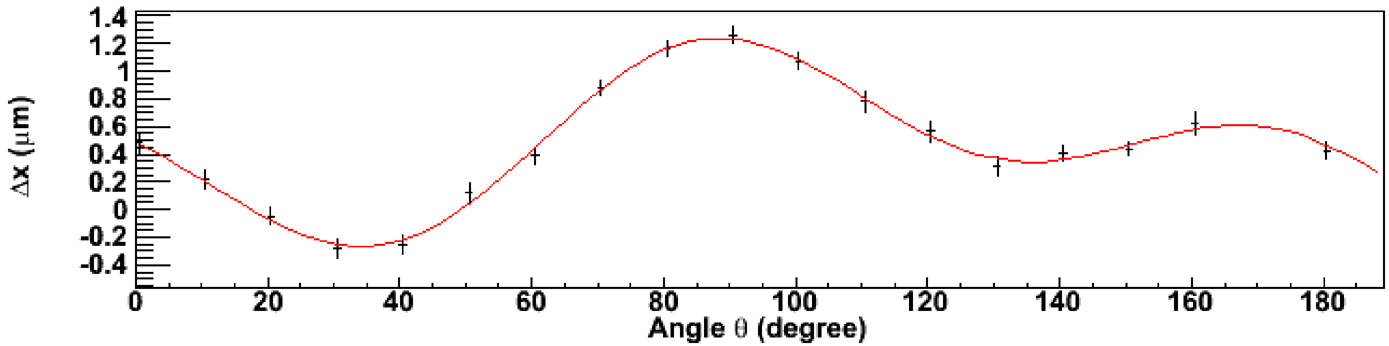


Δy = 0.90 + 0.30 sin (2θ+ 21.32) + 0.98 sin (4θ+ 3.05)

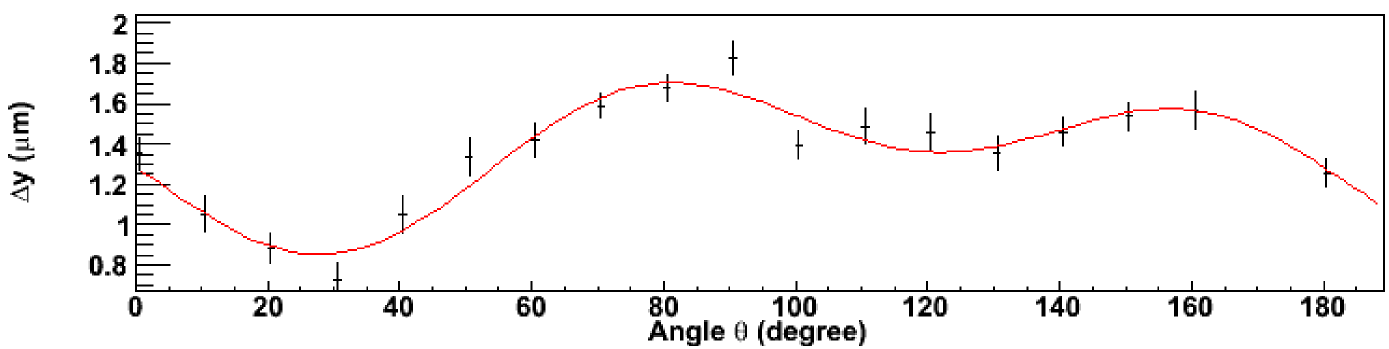
Run 691, PITA = 0, IHWP IN, ILP OUT, QWK_1I02



$Aq = 799.62 + -1220.48 \sin(2\theta + 63.16) + 595.06 \sin(4\theta + 97.69)$

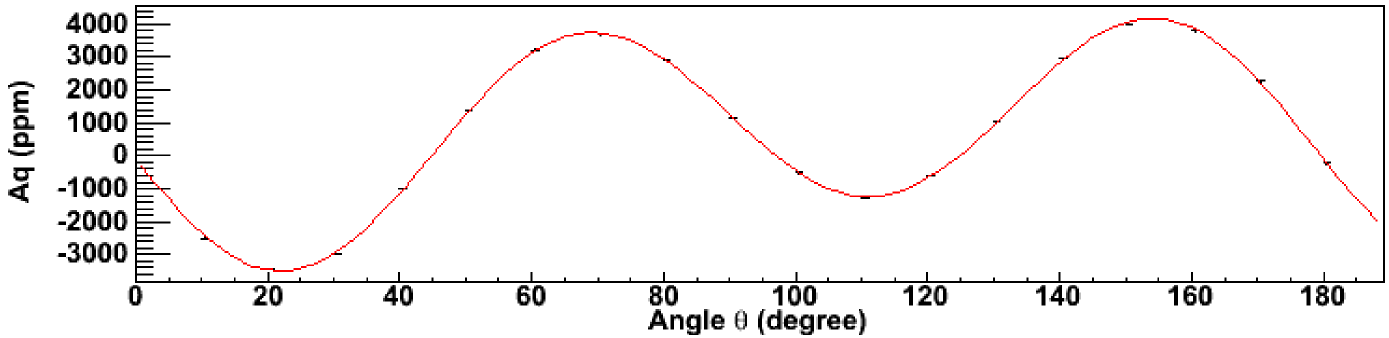


$\Delta x = 0.48 + -0.45 \sin(2\theta + 57.87) + 0.41 \sin(4\theta + 114.58)$

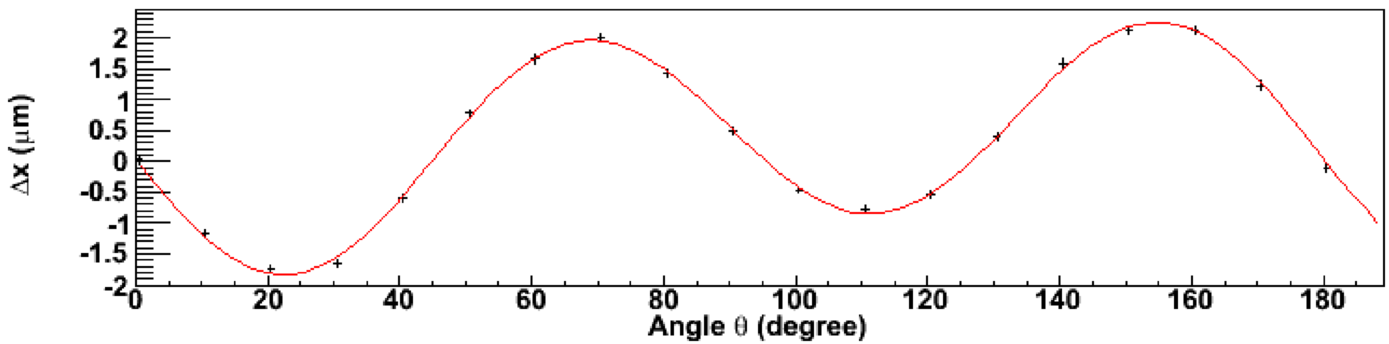


$\Delta y = 1.36 + -0.26 \sin(2\theta + 46.04) + 0.25 \sin(4\theta + 152.48)$

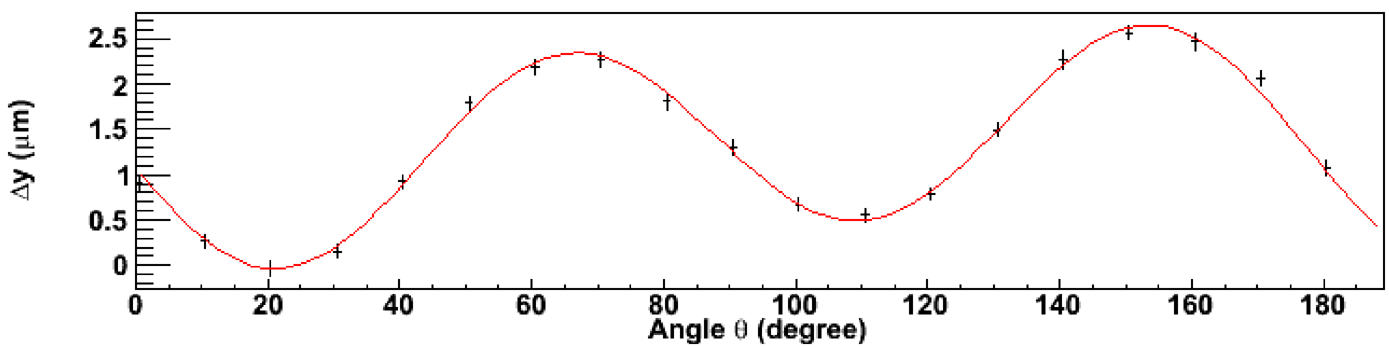
Run 692, PITA = -120, IHWP IN, ILP OUT, QWK_1I02



$Aq = 776.38 + -1145.43 \sin(2\theta + 36.03) + -3131.25 \sin(4\theta + 13.94)$



$\Delta x = 0.38 + -0.51 \sin(2\theta + 29.90) + -1.71 \sin(4\theta + 2.77)$

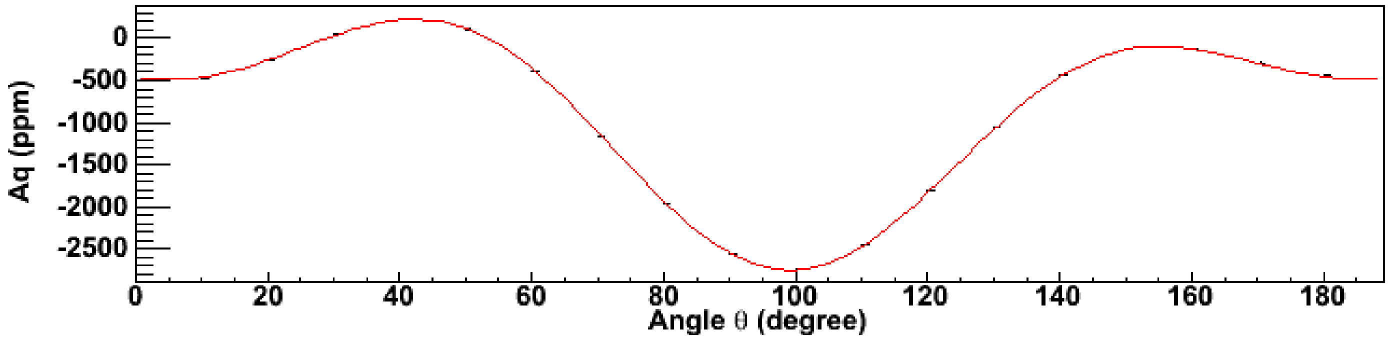


$\Delta y = 1.36 + -0.30 \sin(2\theta + 19.77) + -1.13 \sin(4\theta + 9.48)$

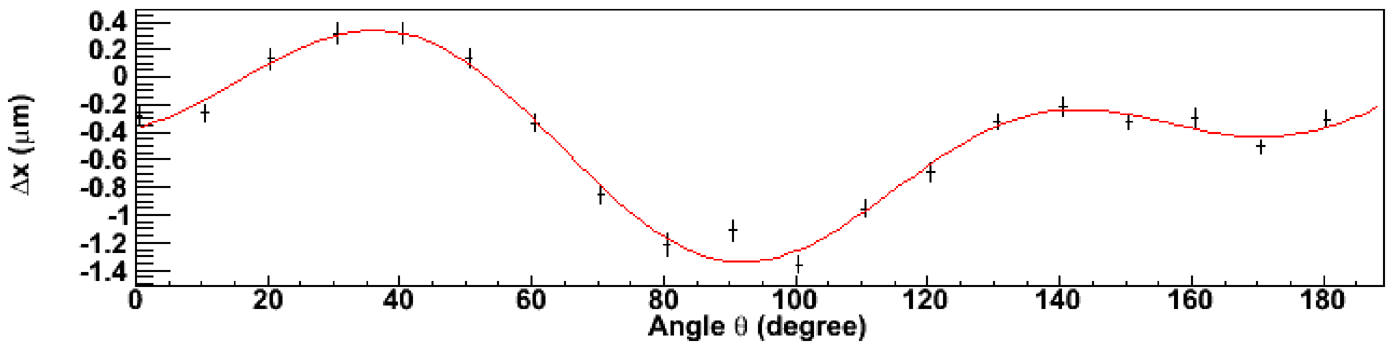
PQB

1 kHz Reversal, 60 µs

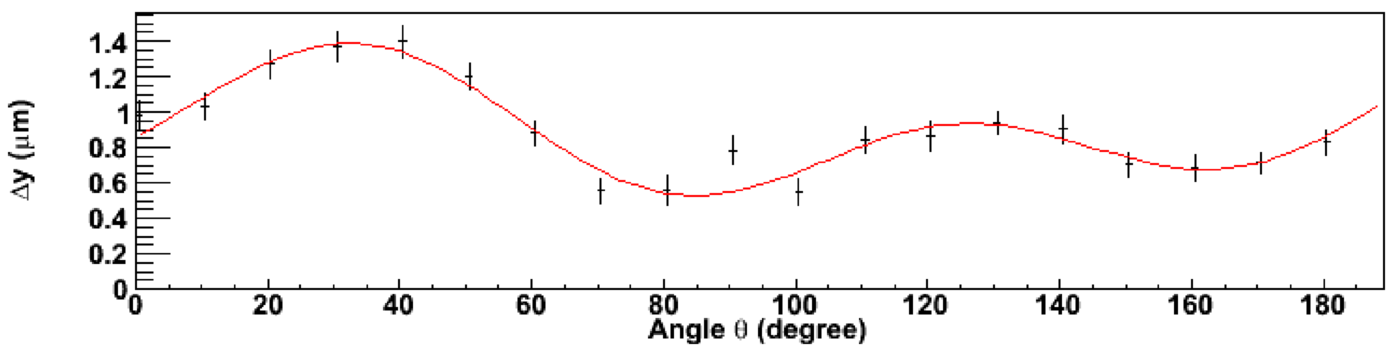
Run 719, PITA = 0, IHWP OUT, ILP OUT, QWK_1I02



$Aq = -882.51 + 1146.30 \sin(2\theta + 65.43) + -726.68 \sin(4\theta + 68.60)$

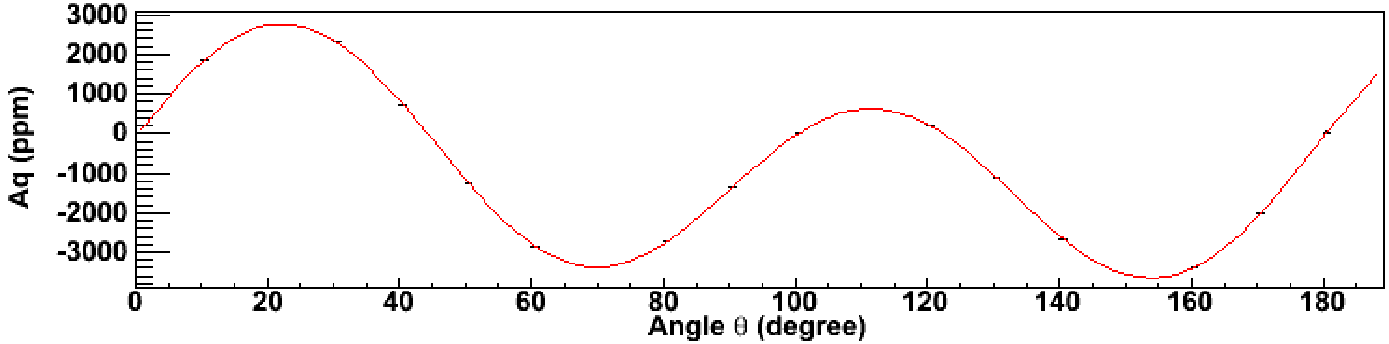


$\Delta x = -0.44 + 0.55 \sin(2\theta + 61.11) + -0.42 \sin(4\theta + 98.24)$

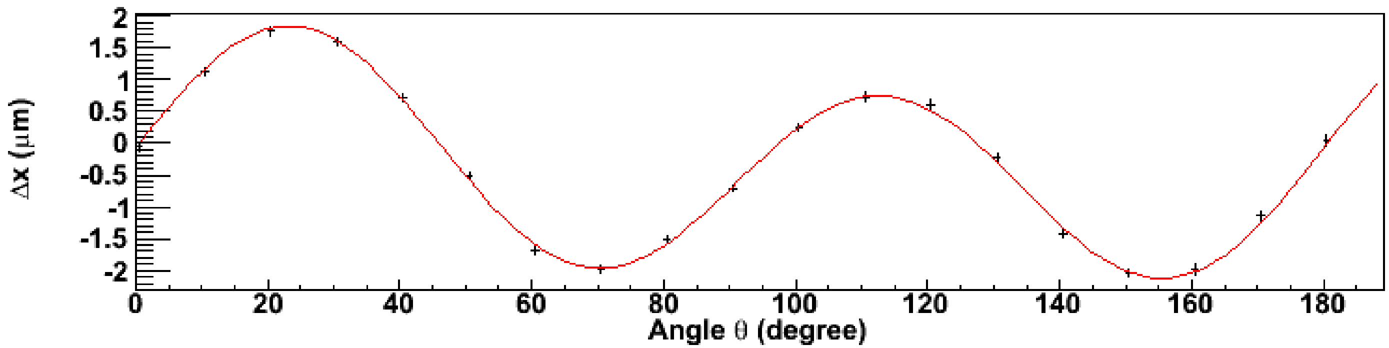


$\Delta y = 0.89 + 0.24 \sin(2\theta + 40.39) + -0.27 \sin(4\theta + 134.21)$

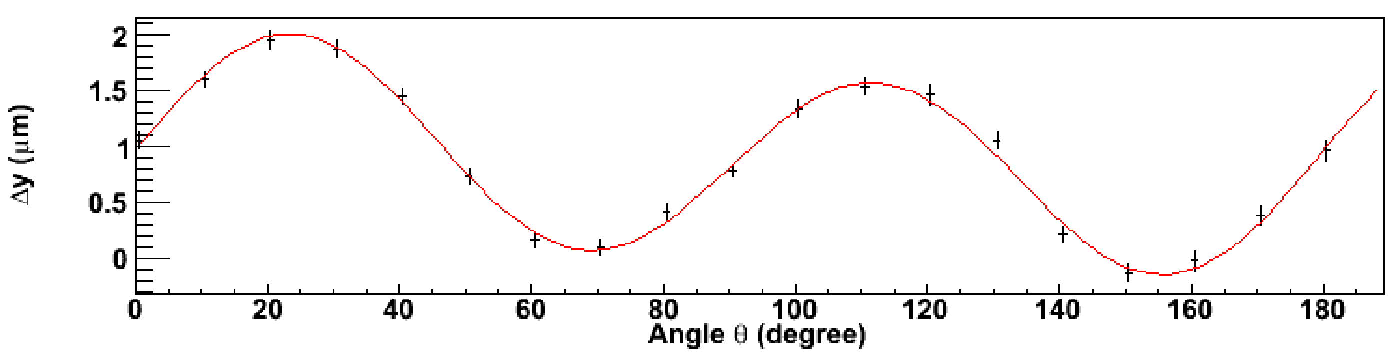
Run 720, PITA = -120, IHWP OUT, ILP OUT, QWK_1I02



Aq = -878.34 + 1073.63 sin (2θ+ 38.71) + 2578.10 sin (4θ+ 12.83)

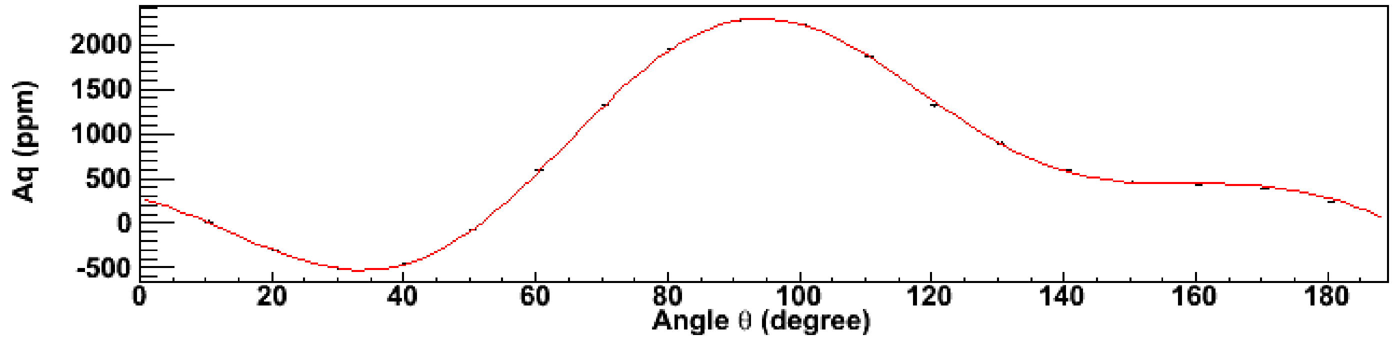


Δx = -0.36 + 0.55 sin (2θ+ 36.13) + -1.66 sin (4θ+ 178.68)

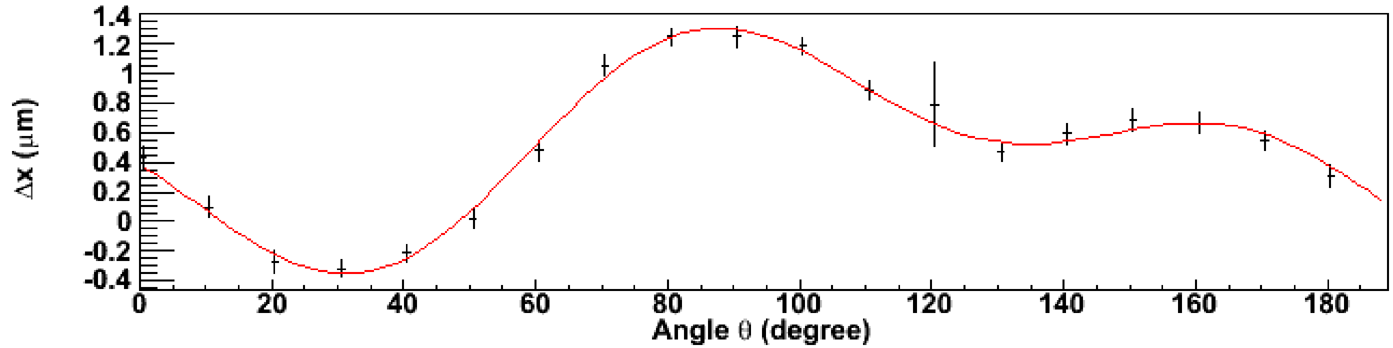


Δy = 0.88 + 0.24 sin (2θ+ 18.61) + 0.91 sin (4θ+ 0.57)

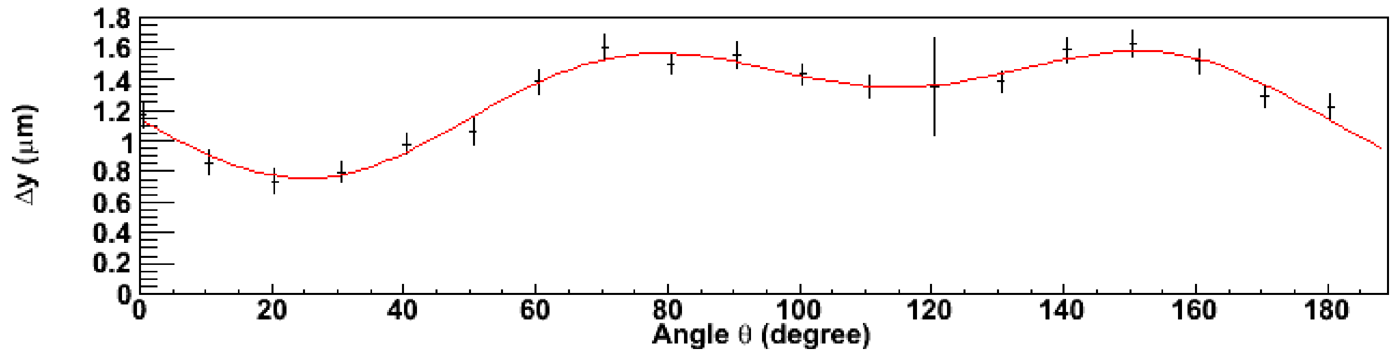
Run 717, PITA = 0, IHWP IN, ILP OUT, QWK_1I02



$Aq = 736.66 + -1116.76 \sin(2\theta + 62.29) + 535.61 \sin(4\theta + 103.86)$

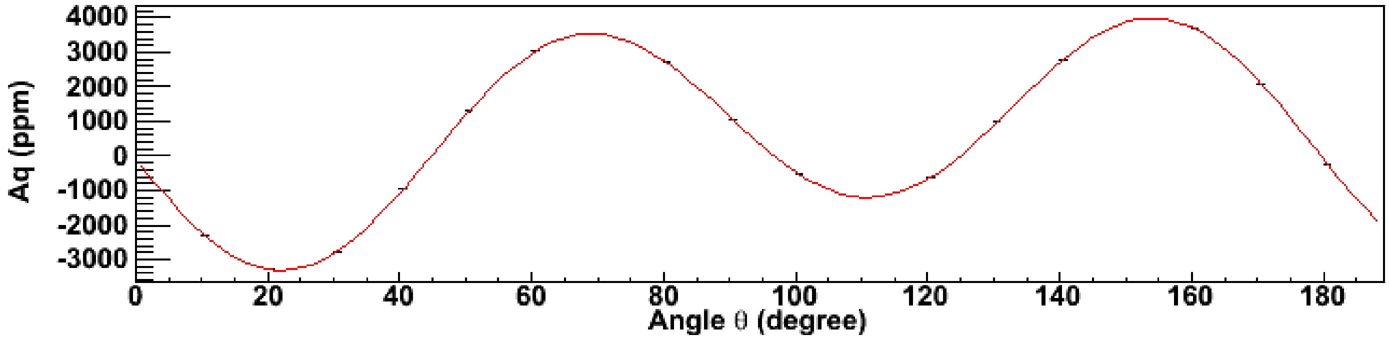


$\Delta x = 0.52 + -0.56 \sin(2\theta + 54.86) + 0.40 \sin(4\theta + 126.11)$

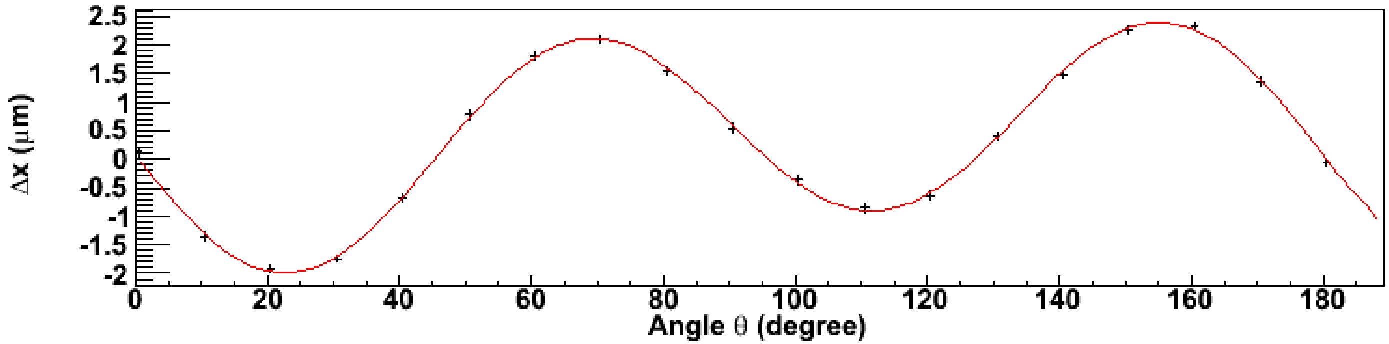


$\Delta y = 1.29 + -0.30 \sin(2\theta + 39.10) + 0.24 \sin(4\theta + 170.90)$

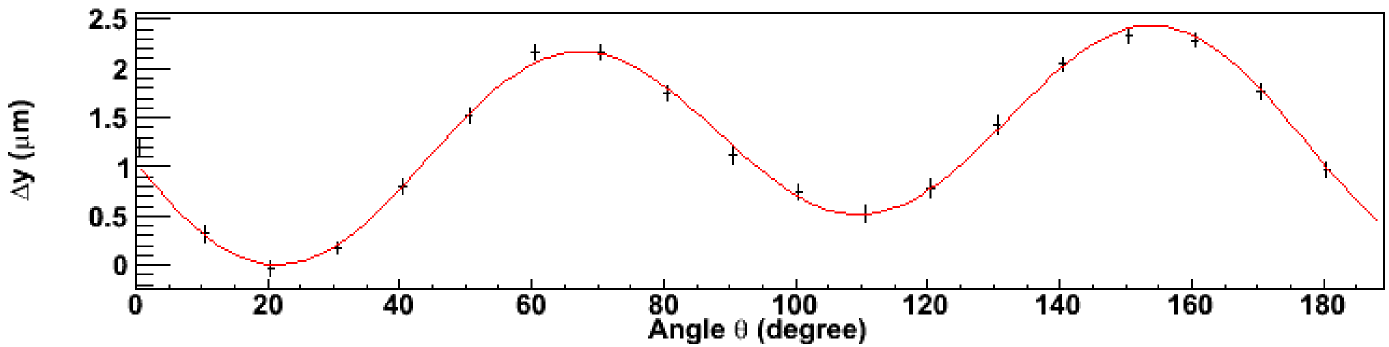
Run 718, PITA = -120, IHWP IN, ILP OUT, QWK_1I02



Aq = 734.01 + -1077.36 sin (2θ+ 35.12) + -2988.61 sin (4θ+ 14.19)



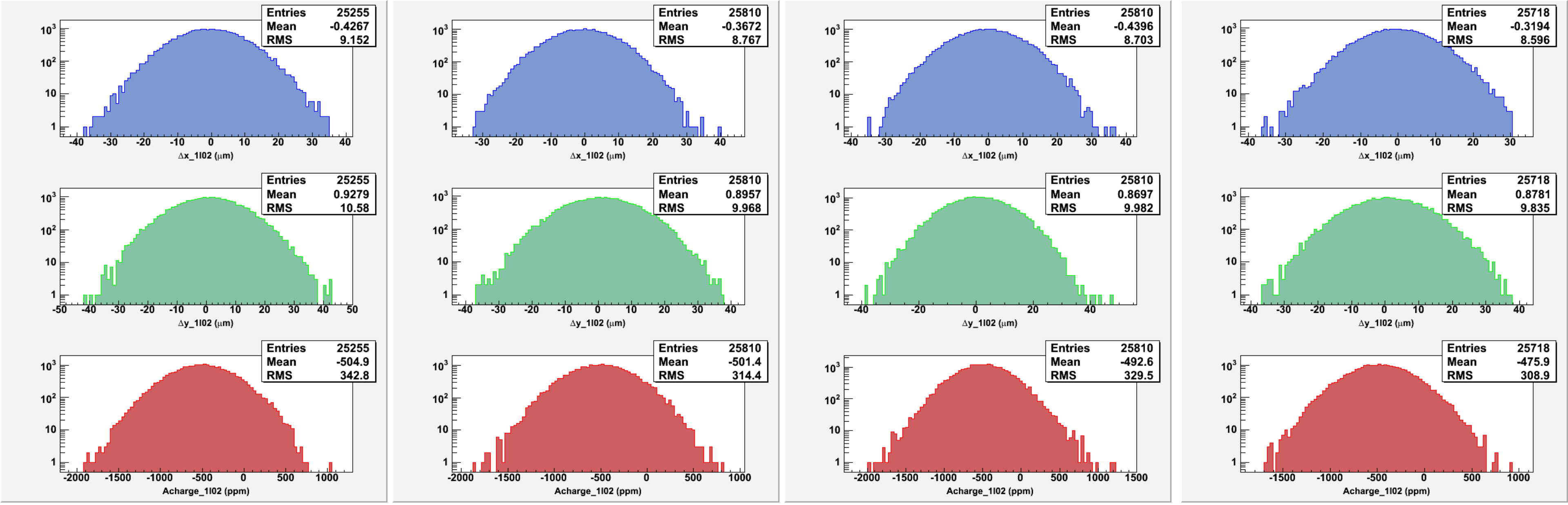
Δx = 0.39 + -0.56 sin (2θ+ 30.46) + -1.84 sin (4θ+ 1.20)



Δy = 1.28 + -0.29 sin (2θ+ 21.21) + -1.02 sin (4θ+ 7.62)

PQB

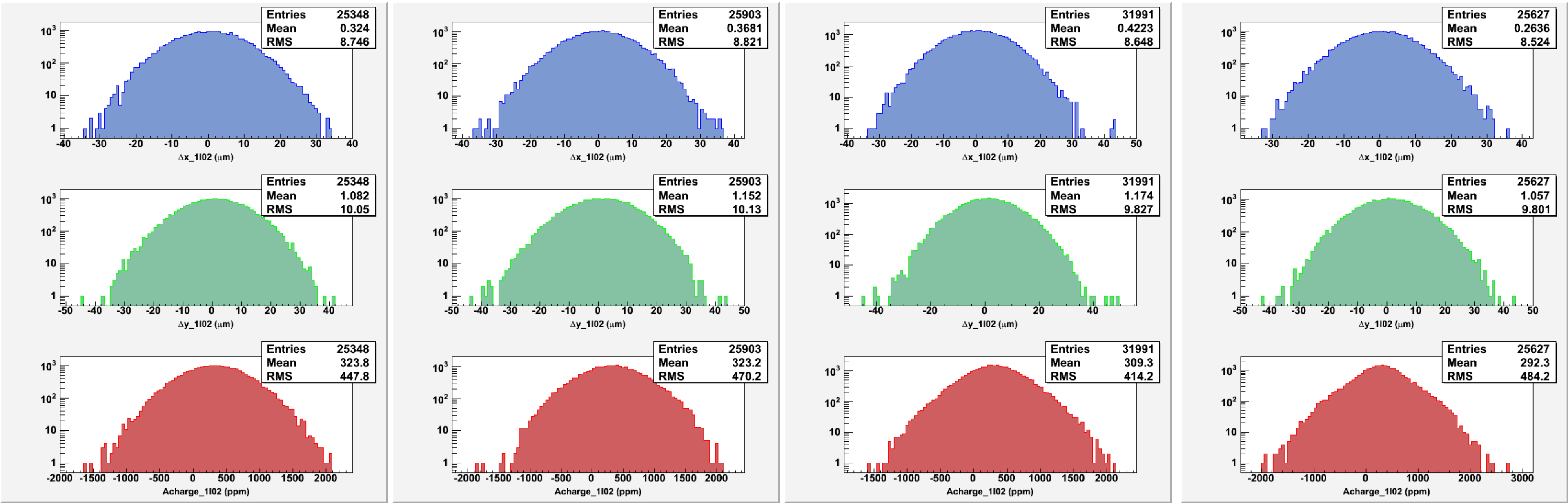
1 kHz Reversal, Different choices of T_Settle



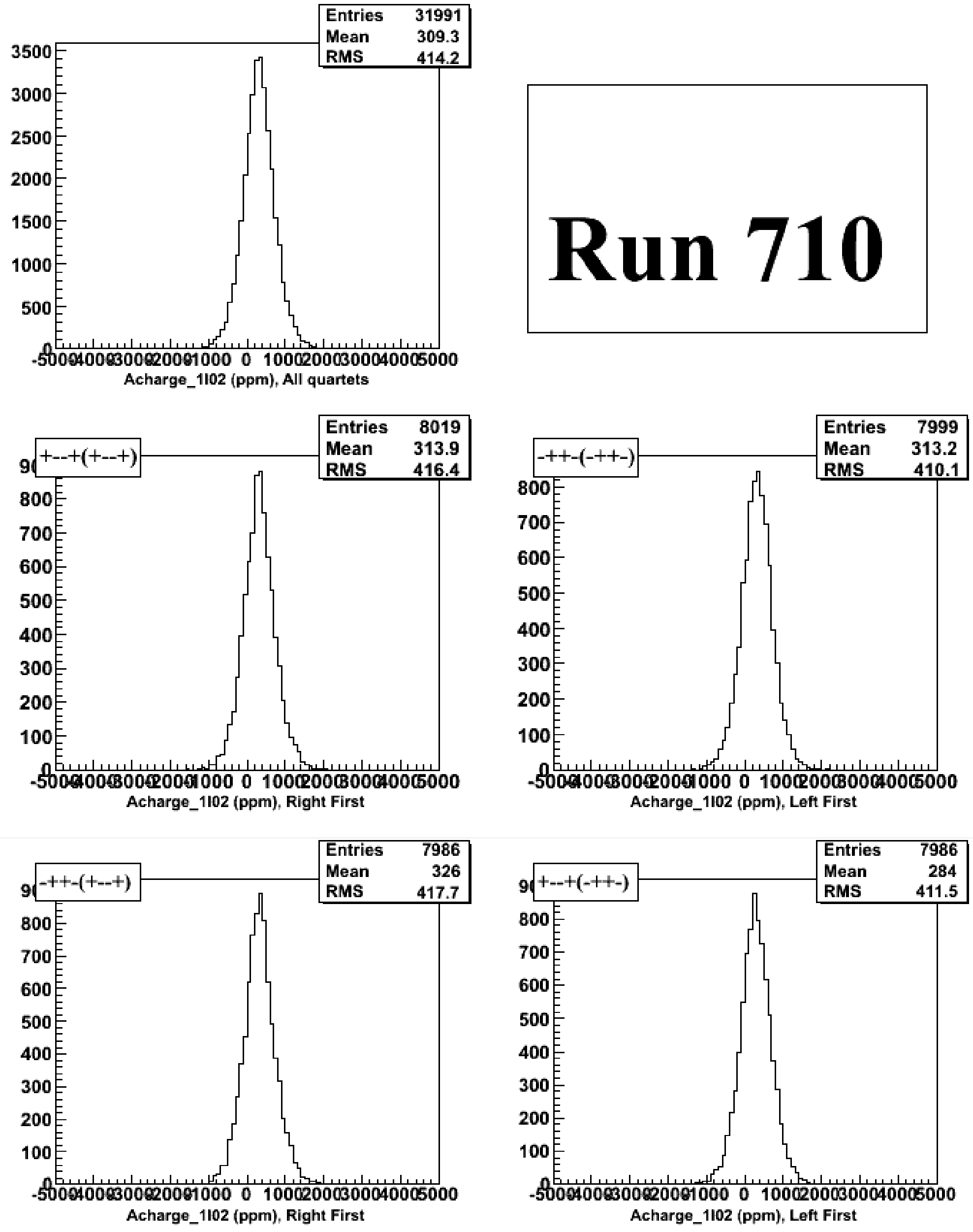
1 kHz, 500 μs, OUT

100 μs | **60 μs** | **10 μs**

1 kHz, 500 μs, IN



Charge Separation at 1 kHz



How to Reduce 60 Hz Line Noise?

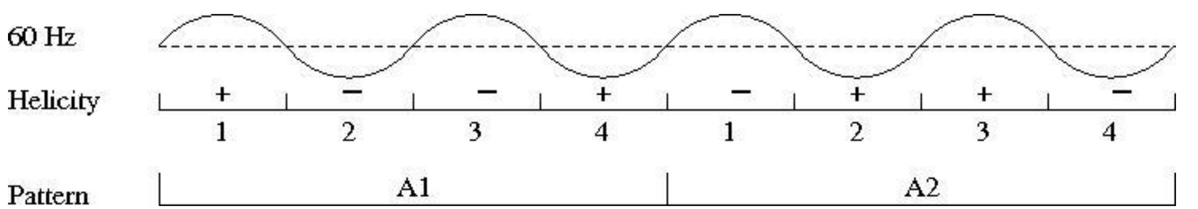
1. Choose small T_Stable (1 ms) → fast helicity reversal (1 kHz)

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:

Experiment	Frequency	Clock	Pattern
HAPPEx III & PVDIS	29.6 Hz	Free	Quartet
PREx	240 Hz	Line-Locked	Octet
QWeak	1 kHz	Free	Quartet

- New Helicity Board to be installed on July 6, 2009

Backup Slides

	Chan 1	Chan 2	Chan 3	Chan 4	Chan 5	Chan 6	Chan 7	Chan 8
ADC1	QPD pm	QPD pp	QPD mm	QPD mp		Multi Sync	Battery 1	Battery 2
ADC2	1I02				1I04			
ADC3	1I06				0I02			
ADC4	0I02A				0I05			
ADC5	0I07				0L01			
ADC6	0L02				0L03			
ADC7	0L04				0L05			
ADC8	0L06				0L07			
ADC9	0L08				0L09			
ADC10	0L10				0R03			
ADC11	0R04				0R05			
ADC12	0R06				BCM 0L02	Battery 3	Battery 4	Phase Monitor

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)