G^0 Beam Quality and Multiple Linear Regression Corrections

PAVI04

Kazutaka Nakahara

University of Illinois at Urbana Champaign

Caltech, Carnegie Mellon, Hampton, Illinois, IPN Orsay, ISN Grenoble, Jefferson Lab, Kentucky, Louisiana Tech, Manitoba, Maryland, Massachusetts, New Mexico State, Northern British Columbia, TRIUMF, Virginia Tech, William & Mary, Yerevan

Asymmetries and Beam-induced False Asymmetries

$$A = \frac{Y^{+}_{e+p} - Y^{-}_{e+p}}{Y^{+}_{e+p} + Y^{-}_{e+p}}$$

-D**A/A ~ 5% where A ~ 10^{-5} – 10^{-6}**

➔ systematic effects must be tightly controlled!!

- Helicity correlated changes in beam conditions induce false asymmetries depending on how sensitive the spectrometer is to such changes.

$$A_{false} = \frac{1}{2\langle Y \rangle} \sum_i \frac{dY}{dP_i}(dP_i)$$

Helicity correlated differences in beam parameter

$$dP_i = P_i^{+} - P_i^{-}$$

Detector sensitivity to changes in beam conditions. (i.e "slopes")

2 basic methods for reducing beam-induced false asymmetries:

1. Reduce the helicity correlation in the beam.
2. Use multiple linear regression to eliminate the false asymmetry.

Source of Helicity Correlation in Beam

Primary helicity devices are: Helicity (Polarization) Pockels' Cell, IA cell, PZT mirror.

There are several sources of helicity correlation:

1. Residual linear polarization of laser + cathode analyzing power.
2. QE gradient of cathode + helicity correlated laser motion.
3. Differential scraping of beam (primarily in the injector).
4. Beam loading effects + charge asymmetry.
5. Other?

Black Box

- measure the summed effect in the Hall!

Much of the helicity correlation comes from the source ➔ Measure the TOTAL helicity correlation of each beam parameter in the Hall, and null them out at the source.

3 main optical elements used to null out the helicity correlation:

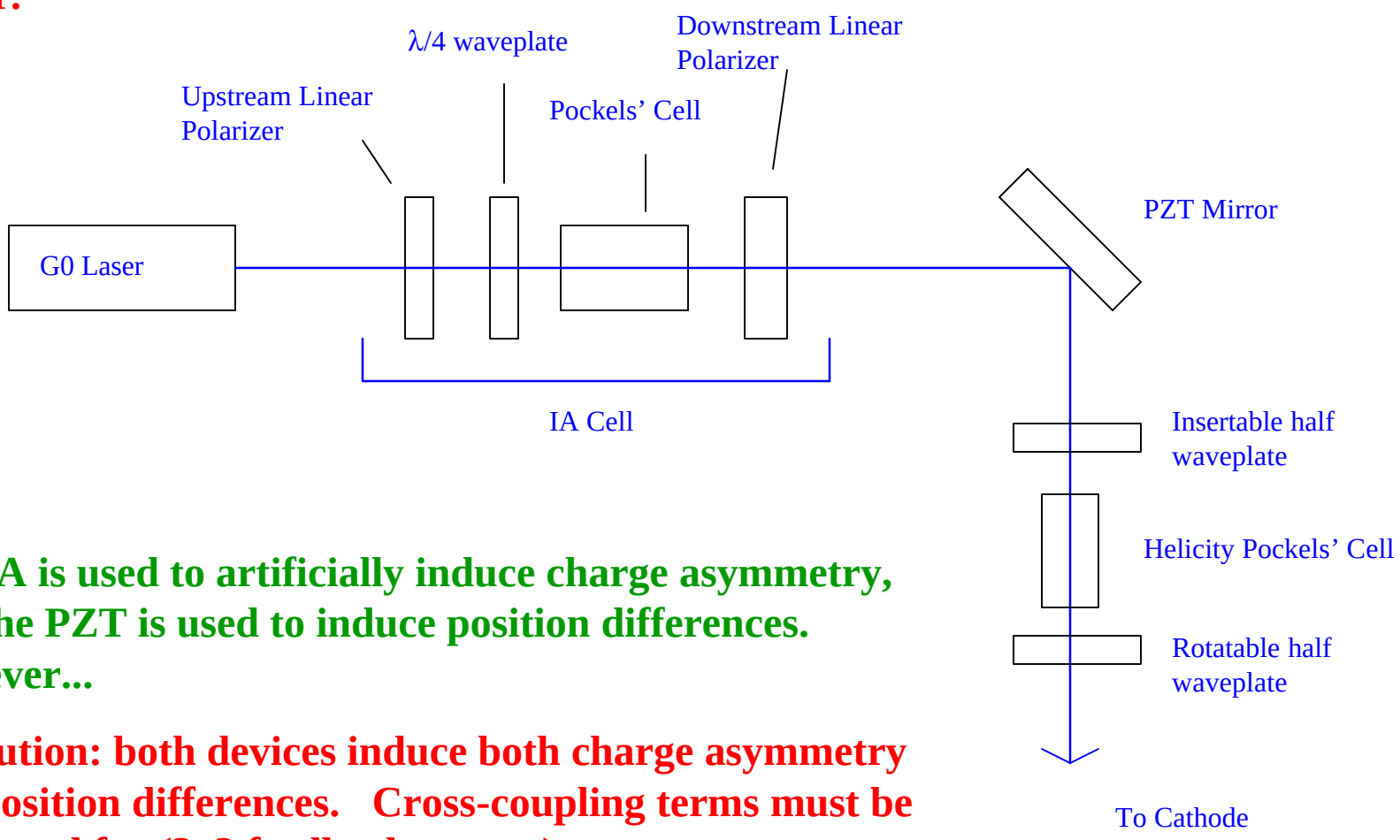
-Rotatable Half wave plate — Primarily used to null out charge asymmetry

- IA Cell
- PZT mirror

} Used as part of a charge and position feedback system

Beam Feedback (Hardware)

IA (intensity attenuator) cell and PZT (piezo-electric transducer) mirror to modulate the laser intensity and position at the cathode in a helicity-correlated manner.



The IA is used to artificially induce charge asymmetry, and the PZT is used to induce position differences. However...

➔ caution: both devices induce both charge asymmetry and position differences. Cross-coupling terms must be accounted for (3x3 feedback system).

Beam Feedback (Software)

3x3 feedback algorithm to include cross-terms

$$\begin{pmatrix} IA_{corrected} \\ PZTx_{corrected} \\ PZTy_{corrected} \end{pmatrix} = \begin{pmatrix} \frac{dIA}{dA_q} & \frac{dIA}{ddx} & \frac{dIA}{ddy} \\ \frac{dPZTx}{dA_q} & \frac{dPZTx}{ddx} & \frac{dPZTx}{ddy} \\ \frac{dPZTy}{dA_q} & \frac{dPZTy}{ddx} & \frac{dPZTy}{ddy} \end{pmatrix} \begin{pmatrix} A_{q\ meas} \\ dx_{\ meas} \\ dy_{\ meas} \end{pmatrix}$$

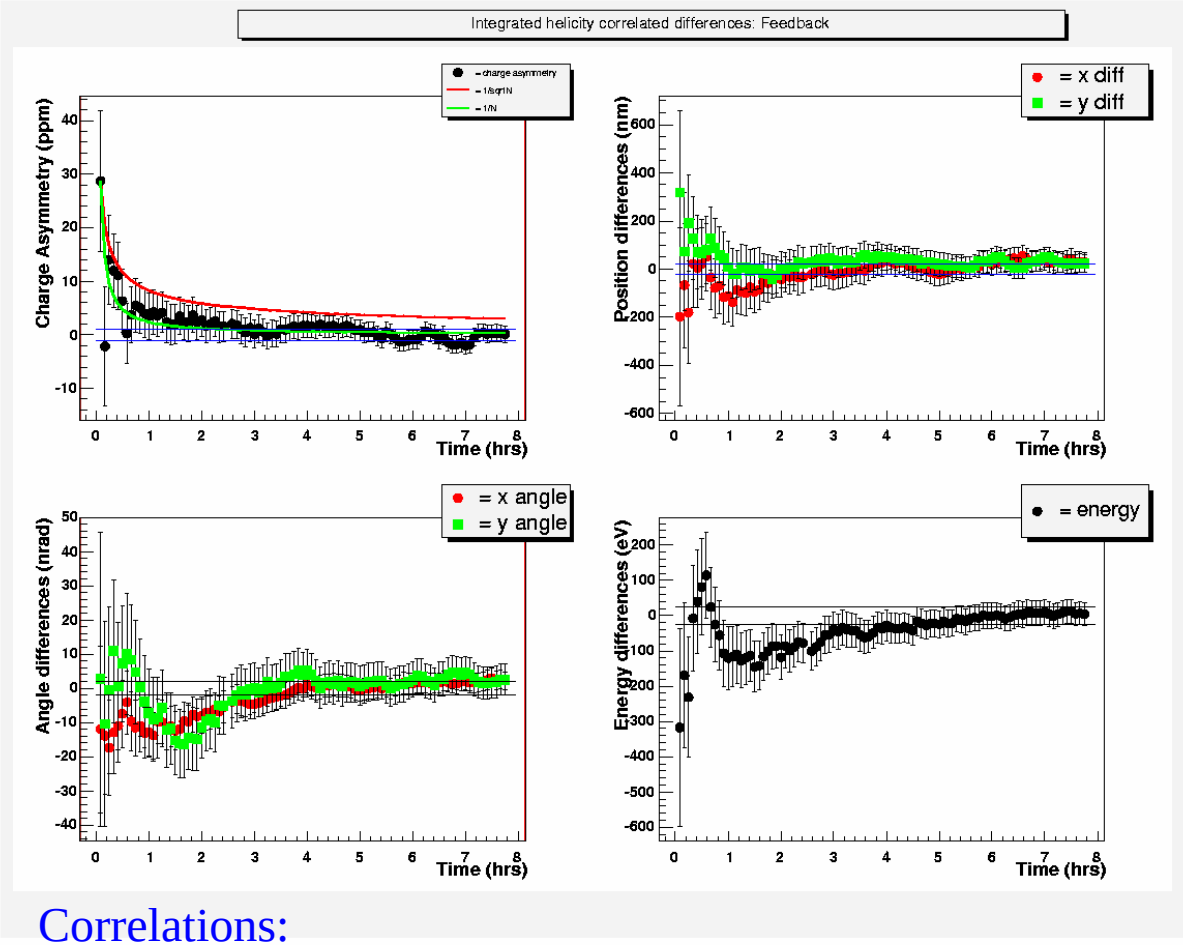
- Problems seen with stability of feedback parameters (especially when the diagonal elements become too small).

- Calibration of IA/PZT to see how much charge asymmetry/position differences they induce is required. Calibration was seen to be very sensitive to injector and accelerator tune. ➔ occasional calibration required.

- Thanks to the Jlab Accelerator group for their hard work!

Beam Feedback Results

Helicity correlated differences integrated over a few hours.



- Helicity correlated beam charge and position seen to converge to zero over the course of a few hours.

- We do not feedback on energy and angle differences, but they are seen to be small without feedback.

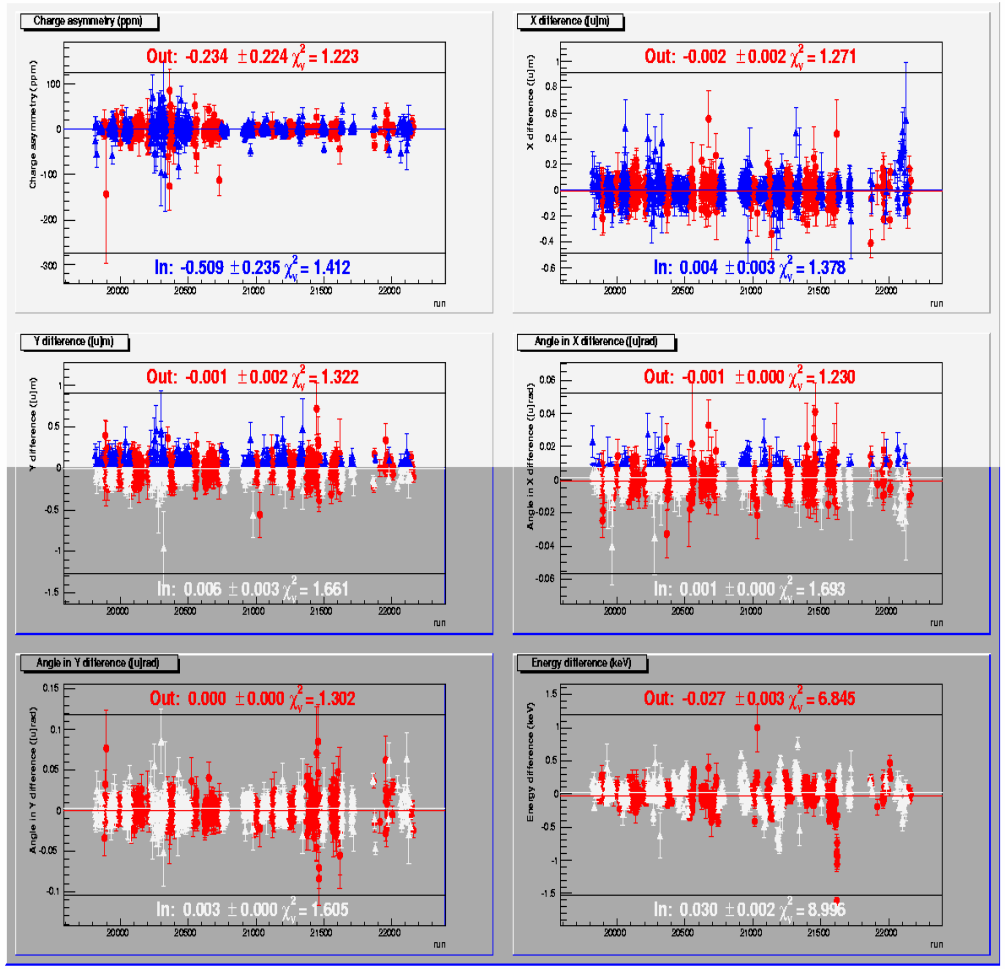
- All helicity correlated beam parameter differences are correlated amongst themselves.

Correlations:

- Position differences induce charge asymmetry through scraping.
- Charge asymmetry induces energy and position differences through loading.
- Position differences “appear” as energy differences at the dispersive point.

Parity Quality Beam

Total of 744 hours (103 Coulombs) of parity quality beam with a 4σ cut on parity quality.



Beam Parameter	Achieved (IN-OUT)	"Specs"
Charge asymmetry	-0.28 ± 0.28 ppm	1 ppm
x position differences	6 ± 4 nm	20 nm
y position differences	8 ± 4 nm	20 nm
x angle differences	2 ± 0.3 nrad	2 nrad
y angle differences	3 ± 0.5 nrad	2 nrad
Energy differences	58 ± 4 eV	75 eV

All parity quality specs have been achieved!!

Multiple Linear Regression

- Residual helicity correlations remain ➔ eliminate by correcting the yields through multiple linear regression. Assume a linear response of the yields to the 6 beam parameters.

The correction to the yield is: $$Y_{corrected} = Y_{measured} - \sum_i \frac{dY}{dP_i}(P_i - \langle P_i \rangle)$$

Find the slopes!!

Take into account the full correlation between beam parameters when determining the slopes.

$$\left(\frac{dY}{dP_i}\right) = M_{ij}^{-1} * \left(\langle dY * dP_j \rangle\right)$$

6x6 correlation matrix of the beam parameters

Basic assumption that the main sources of changes in detector yield come from the fluctuations in the 6 beam parameters. ➔ not necessarily true (there are other sources of yield fluctuations which must be accounted for).

Detector Sensitivities to Beam

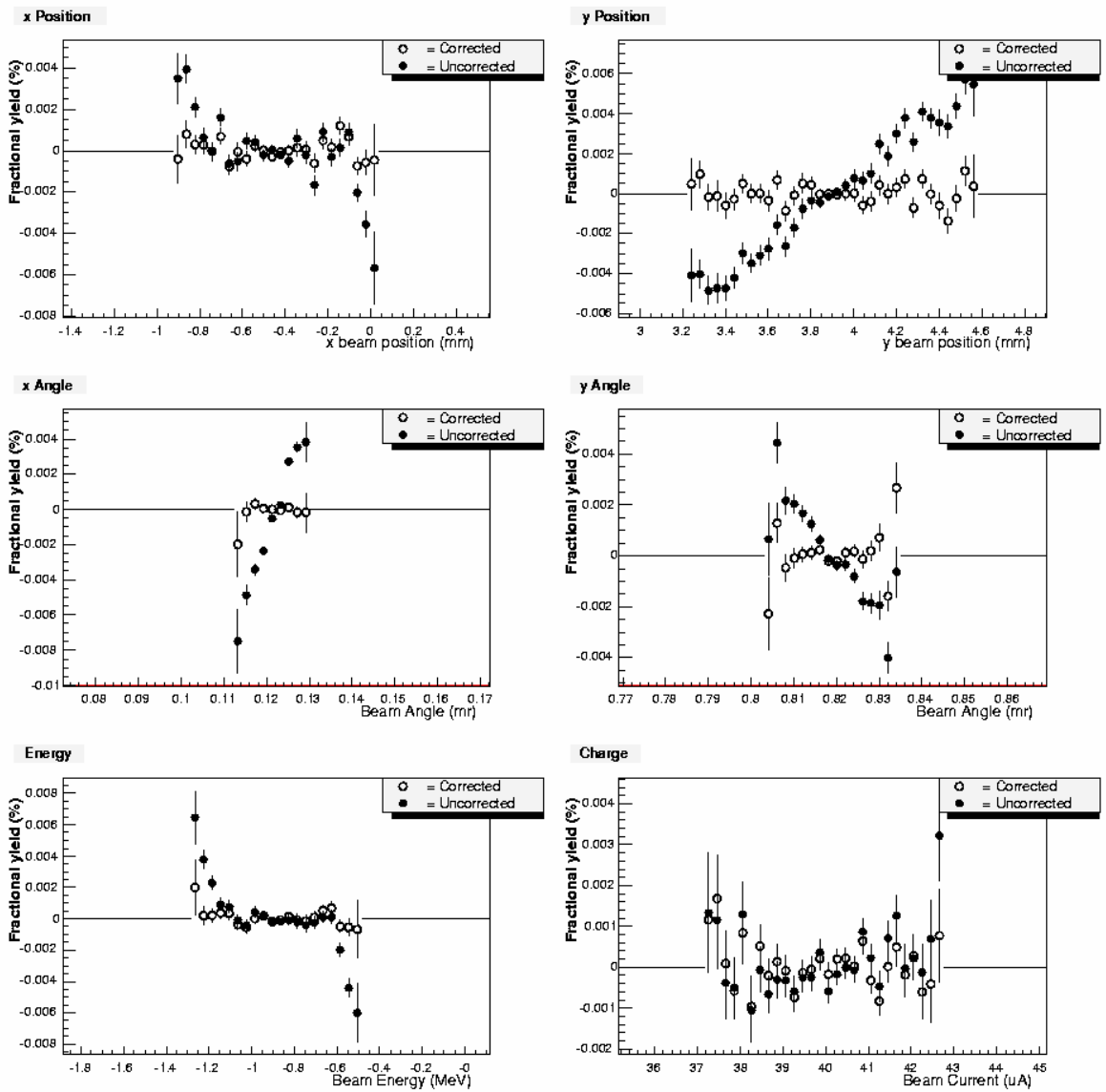
2 basic methods of determining the slopes.

1. "Natural Beam Motion" – may not have enough dynamic range to determine the slopes (dY/dP_i).

2. "Coil Modulation" – artificially dither the beam by "large" amounts to get enough dynamic range.

Yield vs. Beam parameter

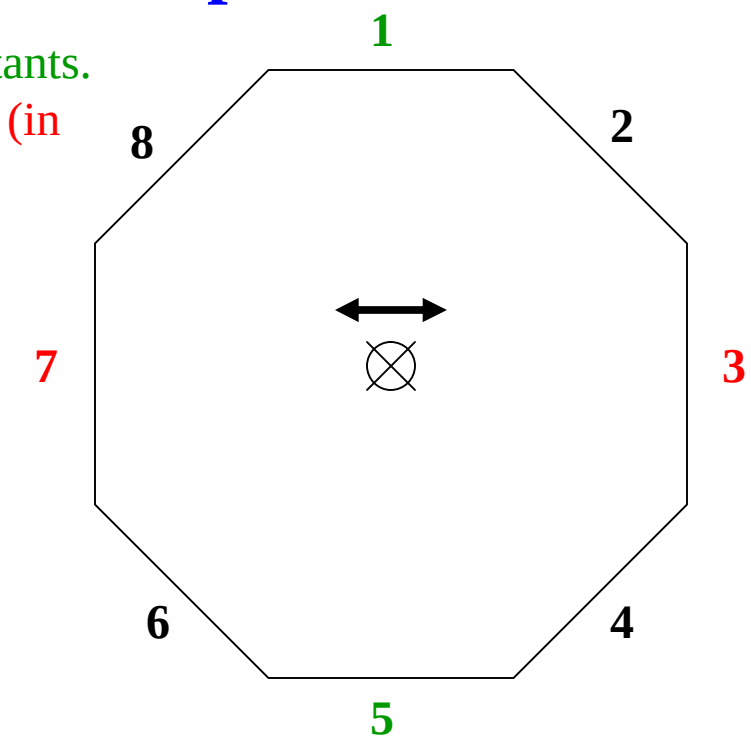
Natural beam motion and coil modulation show consistent slopes.

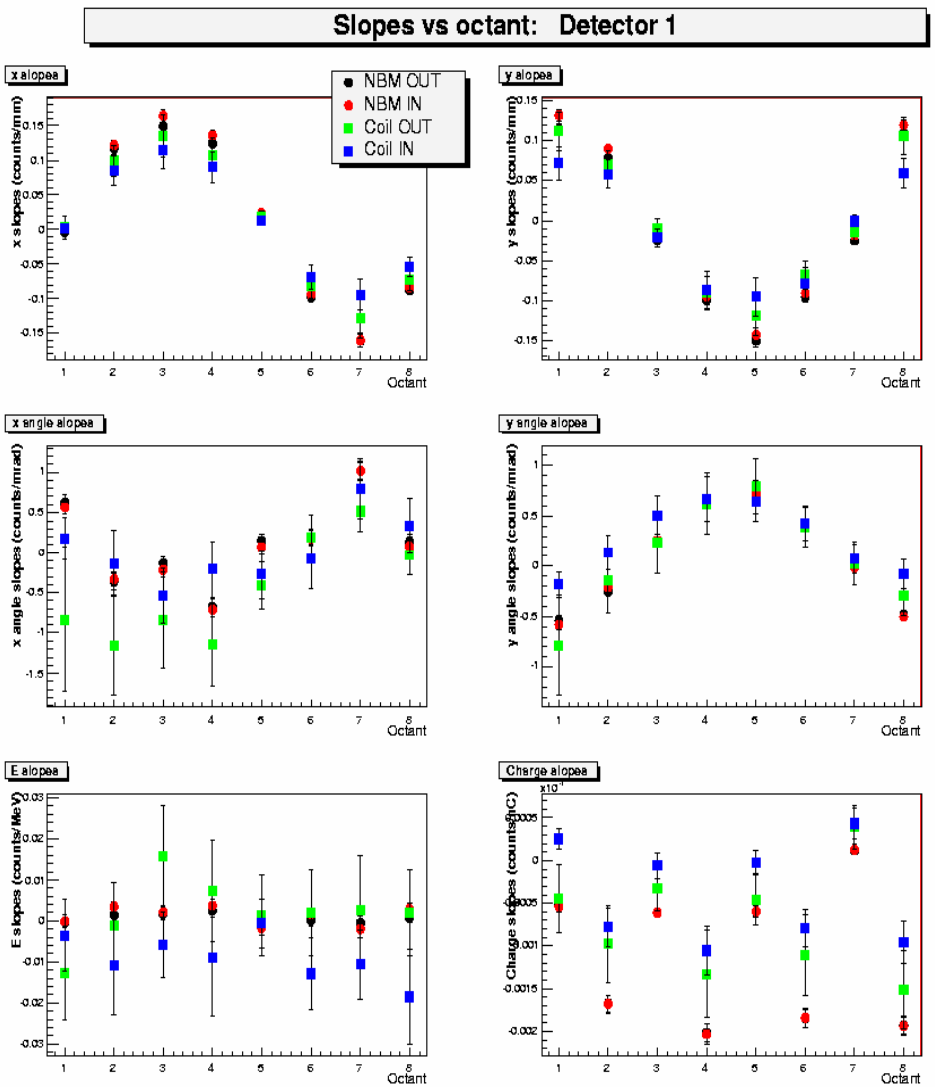


Characteristics/Checks of Slopes

Spectrometer is made up of 8 azimuthally symmetric octants.

➔ Diametrically opposing octants should have opposite (in sign) slopes for position and angle.

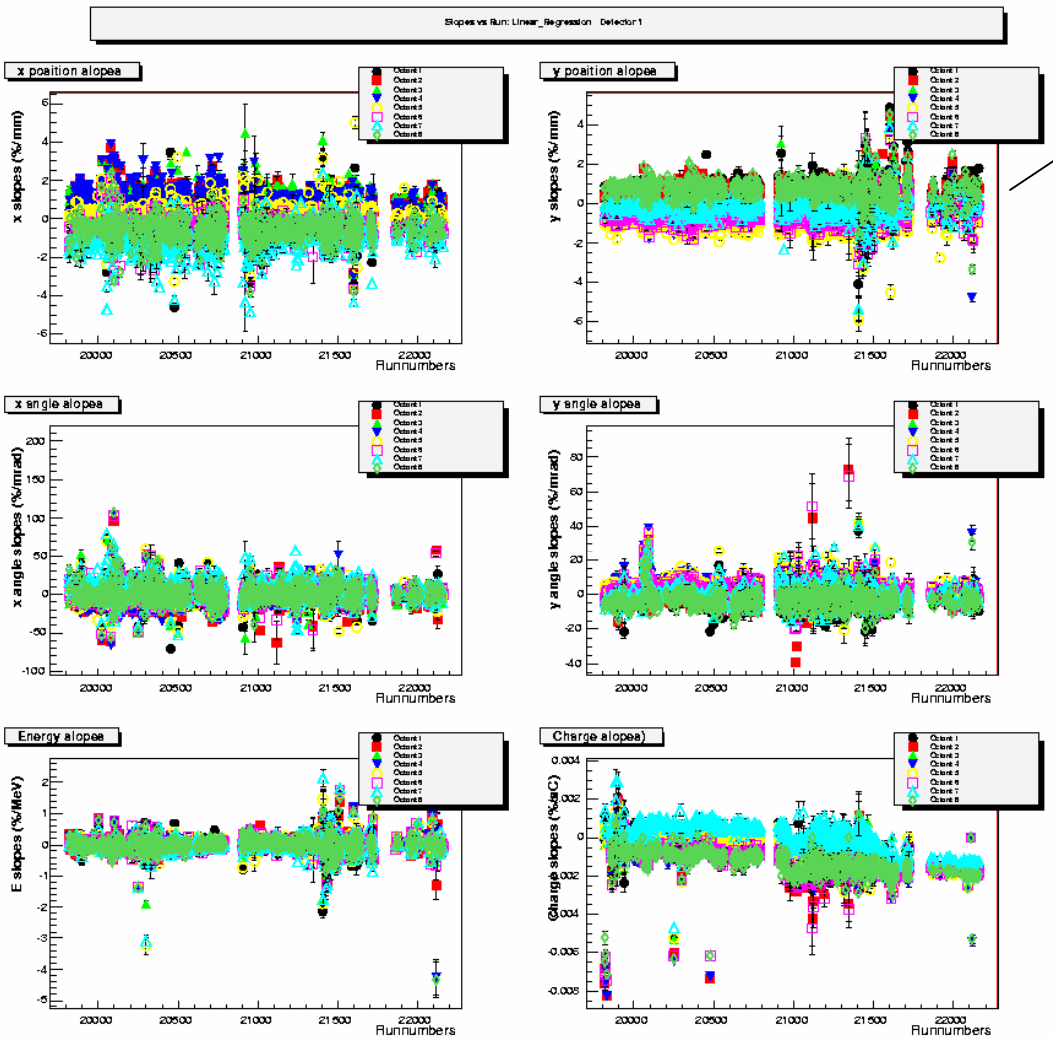




1. Slopes should show an octant dependence.
2. False asymmetries are suppressed for position/angle motion when summed over all octants.
3. Octant dependence in charge slopes due to different deadtime corrections between NA (odd octant) and FR (even octant) electronics.

Characteristics/Checks of Slopes continued...

Slopes should be stable over time. ➔ Octant dependence seen consistently over time.



Individual colors represent different octants.

Lessons learned:

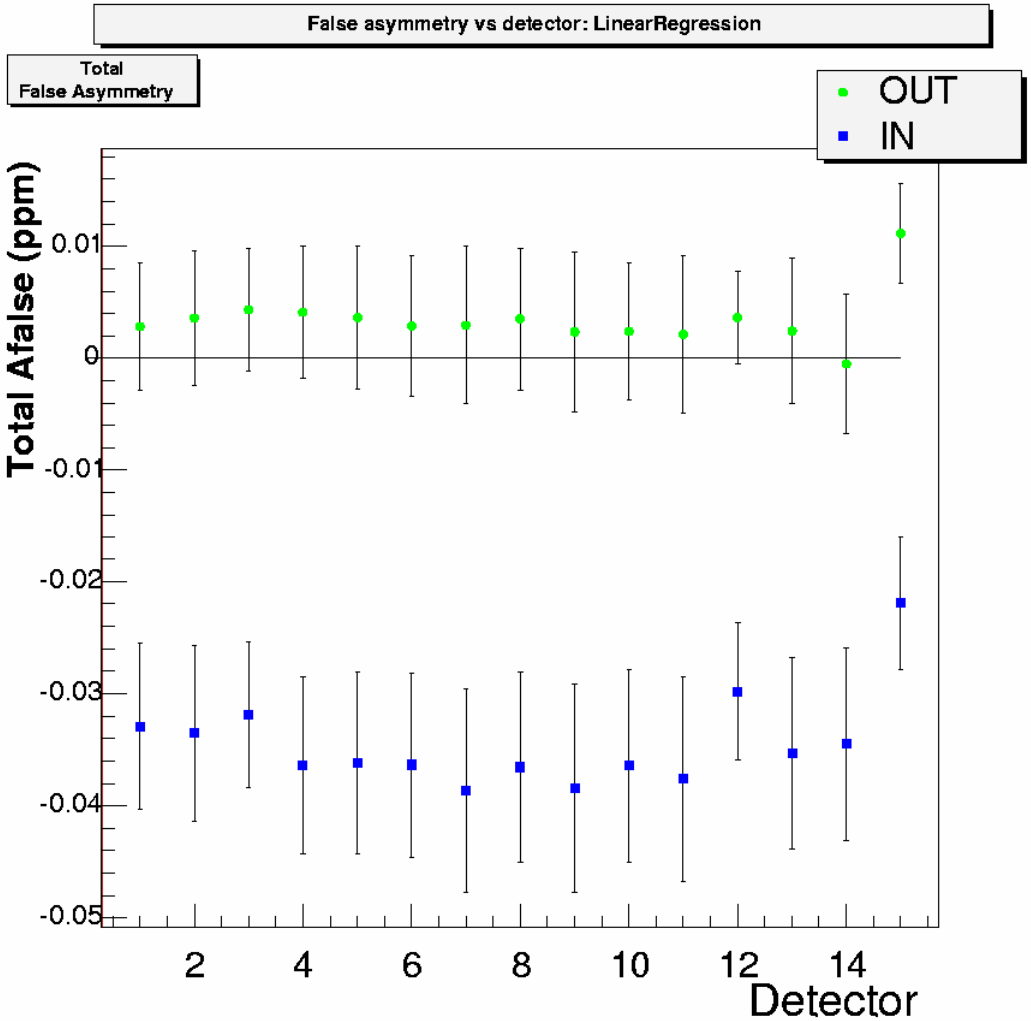
-Stability is highly dependent on the stability of beam/electronics/detectors.

➔ Any instability that causes yields to change in a manner uncorrelated to the 6 beam parameters would cause large excursions in calculation of slopes.

- Further analysis pending ➔ expected to remove sources of fluctuations in slopes over time.

False Asymmetries

The helicity correlation in the beam parameters are seen to have a relatively small contribution to the overall uncertainty.



- Total false asymmetries of order 10^{-8}.

-Error dominated by uncertainties in beam parameter differences.

-False asymmetries NOT statistically distributed over detectors due to correlations between detectors. Analysis pending to eliminate further correlations.

-Largest contribution to false asymmetry from charge asymmetry.

Parameter	False asymmetry
Charge	10^{-8}
Position	10^{-9}
Angle	10^{-8} to 10^{-9}
Energy	10^{-9}

Summary / Lessons Learned

Beam Feedback:

- Fully coupled 3x3 feedback was necessary to reduce the helicity correlation.

- Calibration of IA/PZT (feedback devices) was seen to be very sensitive to accelerator/injector tune.

- All parity quality specifications were met during the G0 Forward angle measurement.

Multiple Linear Regression:

- Octant/azimuthal dependence seen for position and angle slopes.

- Slope measurements seen to be very sensitive to many aspects of the apparatus (beam, electronics, detectors, etc).

- False asymmetries were seen to be of order 10^{-8}. Azimuthal symmetry suppresses false asymmetries due to position motion.

Reducing Helicity-correlation in Beam

6 beam parameters monitored for

helicity correlation:

Beam Parameter	"Specs" (over 700 hours)	Noise
Charge	< 1 ppm	< 2000 ppm
Position (x,y)	< 20 nm	< 20 μm
Angle (x,y)	< 2 nrad	< 2 μrad
Energy	< 75 eV	< 30 keV

All "specs" have been met!!

→ - Manipulation at the source to control helicity correlation.

- Improve transmission and laser stability to reduce noise.