A Proposed Correction to Anomalous Readings from Beam Position Monitors in CESR

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I. INTRODUCTION

Since 2006, localized anomalous results in the dispersion function (referred to as the dispersion anomaly) have been preventing the CESR team from knowing the dispersion accurately. Initially the anomaly was thought to be due to beam optics, however when corrections based on beam optics proved ineffective, the investigation was widened. It was determined that the problem must lie with one or more of survey problems (misplaced focusing quadrapole magnets), control problems (improper current supplied to those magnets) or data acquisition problems (broken readout electronics). More recently, Stu Peck, in an effort to lay the issue to rest once and for all took beam position data at a variety of beam currents and electronic attenuation settings, to discover any dependence of the effect on either beam strength or electronics. This paper describes the techniques used to analyze this data, and the discovery of a calibration procedure to correct the dispersion anomaly.

II. EXPERIMENTAL SETUP AND THEORY

Each Beam Position Monitor (BPM) consists of four buttons (often abbreviated butns) arranged in a square in the beam pipe. As a particle bunch passes a BPM, a charge is induced on each of the buttons. If the bunch passes closer to one of the buttons, more charge will be induced on that button. The voltage on each button is measured and then digitized, so our final result is in ADC counts (this is fine, because units cancel from our formula for position). The x component is shown here (in relative units), the y component is similar:

$$x = \frac{(b_2 + b_4) - (b_1 + b_3)}{\sum b_i}$$

Note that if some offset ΔS is added to each of the b_is, ΔS cancels from the numerator, but adds in the denominator:

$$x = \frac{(b_2 + b_4) - (b_1 + b_3)}{\sum (b_i + \Delta S)}$$

Thus our position formula not only assumes a linear response from the BPM buttons, it assumes zero offset.

The dispersion function is a measure of how the beam position varies with beam energy. It has units of length/%, and is determined primarily by the beam optics. The dispersion function is measured experimentally by taking the difference between position measurements (or orbits) of two beams at different energies. The theoretical dispersion function can be computed by considerations of the design specifications of the accelerator. The theoretical dispersion and the actual measured dispersion are compared in figure 1

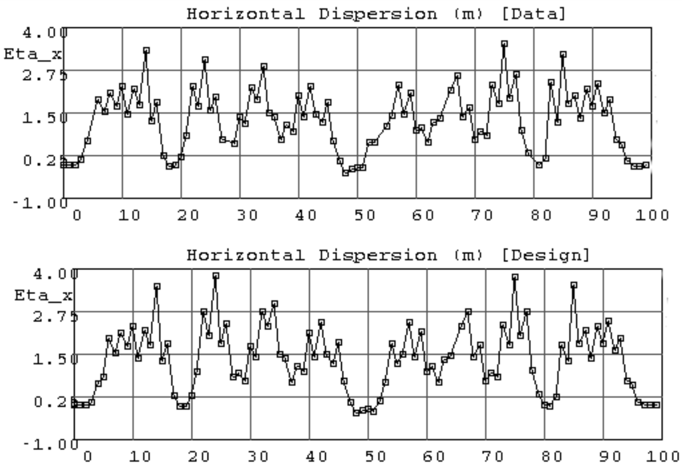

FIG. 1: A comparison of theoretical to measured dispersion. Note the anomalous region between BPMs 19 and 33. The difference is small, and can only be properly appriciated when viewed as a difference between design and measured (see fig. 5 This region has been dubbed the Horizontal Dispersion Anomaly.

As you can see, there is a significant departure from the expected behavior in the region between BPMs 19 and 33. This effect was dubbed the horizontal dispersion anomaly. For the CesrTA project to meet its beam size goals, its essential that we know the dispersion to within 5 cm, however the dispersion anomaly is on the order of 50 cm, so must be corrected.

III. INVESTIGATION AND CORRECTIONS

In order to explore the data, I wrote a suite of plotting and analysis utilities in python, customized to the particular format of the data being investigated. The first approach was to simply look at a signal-versus-beam-current plot, for the individual buttons. An example plot of a BPM in the anomalous region is shown in figure 2. Note that several different discrete attenuation settings are present on the same plot.

As you can see, the signal sits on a considerable pedestal, or linear offset, as can be seen by a simple extrapolation to zero. Also interesting to note is the nonlinearity of the signal at low signal levels, or high attenuation settings. This nonlinearity is present to a much greater degree in other BPMs, especially in the region of BPMs 50 and 80. Because of this nonlinearity, as a next step we elected to investigate quadratic fitting of the individual button data. We generated a table of quadratic fit parameters, and plotted them versus BPM number to see if there was any noticeable pattern in the anomoulous region. No such pattern was detected. Upon further consultation with Dave Rubin, investigation would result by simply applying a linear fit to only the points in the linear region. The result of one such fit can be seen in fig. 3. Note especially the large signal offset, and the small nonlinearity at low signal strength.

The next step was to compute the fit parameters for all the BPMs and buttons, and look for trends there. No noticeable trends were observed in the slope, however the intercept (or

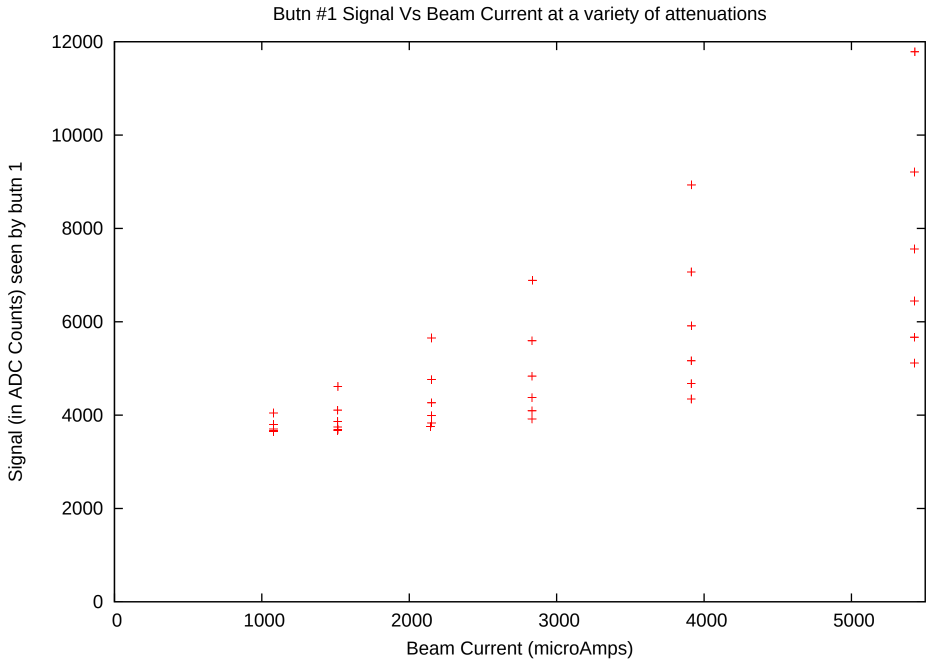

FIG. 2: A plot of the signal Vs. beam current seen by BPM 28, button 1. Note especially the fact that a linear extrapolation would not go through the origin. Also note the nonlinearities at low signal/high attenuation. This BPM is in the anomalous region. BPMs in normal regions behave largely similar, except for offsets smaller by at least a factor of two.

constant offset term) displayed really remarkable BPM dependence. As you can see in fig. 4 there is a sudden increase in linear offset between BPMs 19 and 33, the region corresponding to the anomaly. Additionally, all these BPMs are on a single processor. This plot serves as strong evidence that the dispersion anomaly is due to data acquisition hardware errors.

John Sikora examined the processor in question, and determined that it was indeed behaving strangely, however as a replacement is not immediately forthcoming, it became important to implement a fix. As a result, we wrote some code which averages the offset over the lowest two attenuation settings and all four buttons (although the infrastructure to correct buttons individually exists in the code) and then corrects each BPM individually, subtracting off the offset. Because of the averaging, the code does not handle outliers well, however initial results are very promising.

After an initial correction, we recomputed the observed dispersion function, and compared the two. The result can be seen in fig. 5

As you can see, the dispersion anomaly between BPMs 19 and 33 is apparently corrected, in fact to within the 5 cm goal, meeting CesrTA specifications. Due to outliers in the region of BPM 80, the dispersion function is actually made worse by the correction in this region. This is likely due to nonlinearities in the BPM response in those regions causing the linear fit and thus the offset correction to be erroneous. This could be corrected by a better understanding of the linearity of the BPMs in this region, and perhaps by an investigation

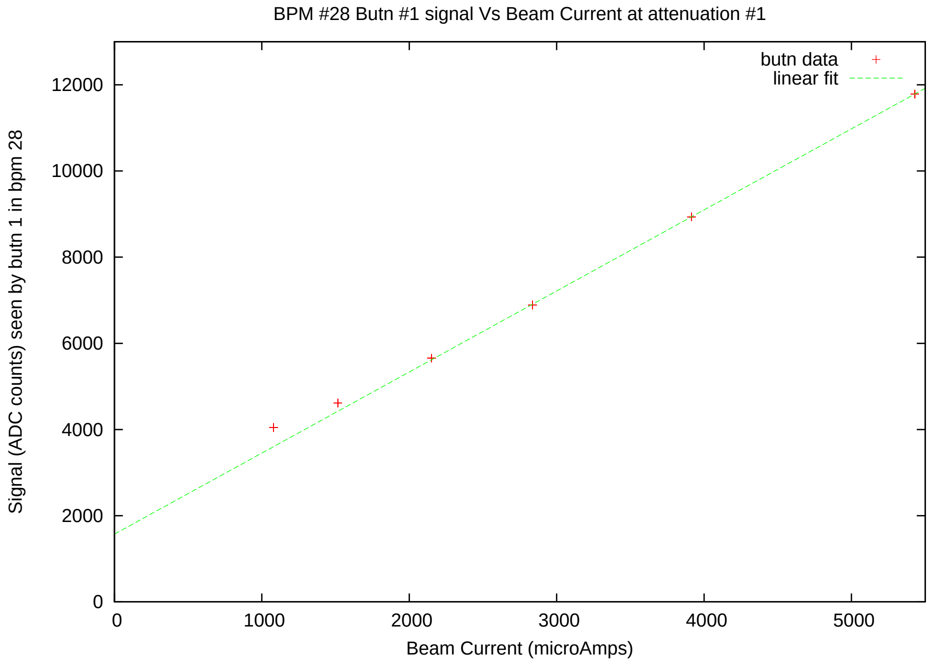

FIG. 3: A plot of the signal versus beam current recorded by BPM 28, button 1, lowest attenuation, with a linear fit to the two highest-signal points. Note the large (close to 2000 ADC counts) y-intercept, and the nonlinearity at low signal.

of whether they are truly working in the high-signal linear region.

IV. CONCLUSIONS AND FURTHER WORK

We discovered a very promising solution to the dispersion anomaly at CESR, and implemented a rough calibration fix. further work should focus on ensuring the fix is outliers-resistant, and investigating the linearity of the BPMs in the region of BPM 80. Going forward, the programs developed will likely be used in the calibration of the long-awaited new digital BPM system.

V. ACKNOWLEDGMENTS

I'm grateful to my mentor Dr. James Crittenden for all his support and advice, and also to Dr. David Rubin, who introduced me to the problem and pointed me in the direction of the solution. Also thanks to Professor Rich Galik, for organizing the REU and LEPP for hosting it. This work was supported by the National Science Foundation REU grant PHY-0552386 and research co-opertaive agreement PHY-0202078.

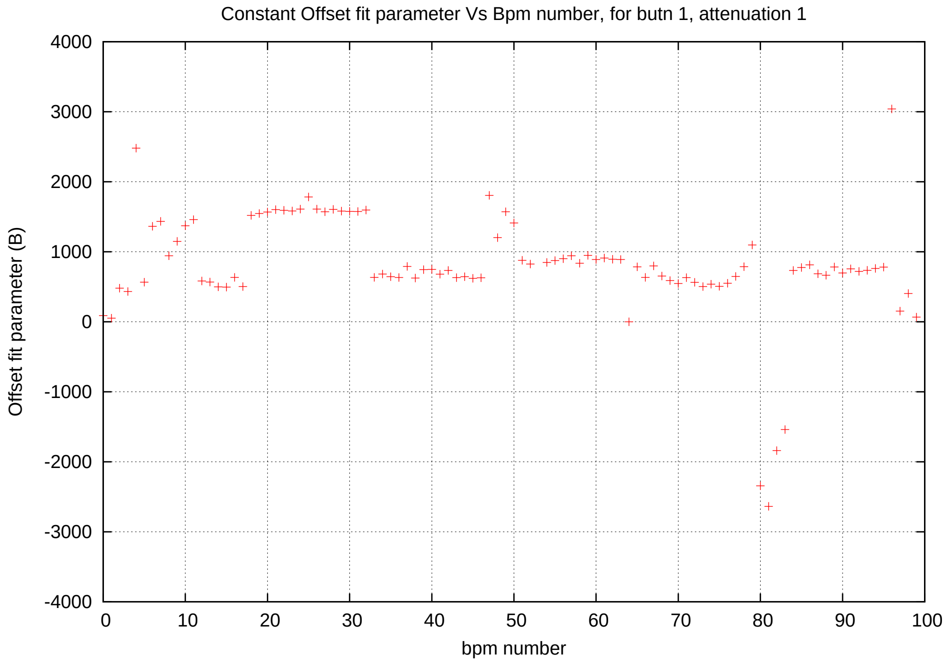

FIG. 4: A plot of the constant offset fit parameter versus BPM number. There is a sudden discrete jump in offset between BPMs 19 and 33. Interestingly, there is a single processor unit that handles BPMs 19-33. Given the calculations shown above demonstrating the detrimental effect of this signal offset, this serves as a strong suggestion as to what is causing the dispersion anomaly.

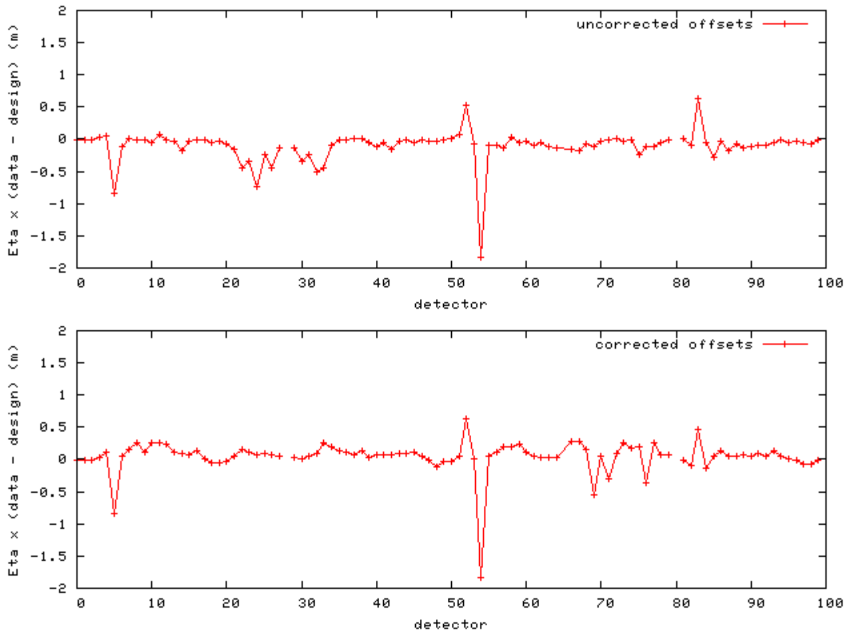

FIG. 5: The the difference between the design and measured dispersion functions before and after correction. Note the dispersion anomaly between BPMs 19 and 33 is apparently corrected, in fact to within the 5 cm goal. Due to outliers in the region of BPM 80, the dispersion function is actually made worse by the correction in this region. This is likely due to nonlinearities in the BPM response in those regions causing the linear fit and thus the offset correction to be erroneous.