Beam Position Calibration for G_E^n

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November, 2008

Abstract

The goal per plane resolution of the BigBite tracking package in the dispersion direction is $\sigma_{pos} \sim 200\ \mu$m. It is, therefore, desirable to have a similar spatial resolution of the vertex of each event. This document details the process used to obtain the required vertex resolution.

1 Introduction

Information about beam position in the plane normal to beam direction may be extracted from the two beam position monitors (BPM's) located in the hall upstream of the target as well as from the driving currents of the raster. The location of these beam components is shown in Table 1, where the listed information comes from the Hall A Operations Manual of April 4, 2005. 'BPMA(B)' and 'Harp A(B)' refer to components IPM1H04A(B) and IHA1H04A(B), respectively. Units are meters in the z_{Hall} coordinate. Relevant coordinate systems are defined in Figs. 1 and 2. Information about the z_{Hall} component of the vertex must be extracted from spectrometers.

Raster	**BPMA**	**Harp A**	**BPMB**	**Harp B**	**Target**
-23.0	-7.517	-7.354	-2.378	-2.215	0.0

Table 1: Position of Relevant Beamline Components

A calibration of the BPM's results in a precise knowledge of the position of the raster spot. There is, however, a significant delay between the time of an event and the readouts of the BPM's. For this reason, the BPM's cannot be directly used for a precise determination of the vertex of each event. The readouts of the raster currents are much faster and are used for this purpose. The observed raster current distributions and the relation between raster current and BPM position is seen in Fig. 3. Additionally, the BPM's have a finite bandwidth and cannot reproduce the true position distribution created by the raster, which is driven with a triangular wave pattern. The sharp edges of this pattern contain high-frequency components which will be smoothed out by the finite bandwidth of the BPM. One result of this is the appearance of false "bedposts" in the observed position distribution of the BPM's. The method used to calibrate the BPM's as well as that used to extract a refined position from the raster current are detailed below.

2 BPM Calibration

BPM calibration requires taking a sequence of dedicated runs at various beam positions and performing a harp scan on each run. The GenBPM class accesses a text database 'db_urb.BPM(A/B).dat' to read in the following quantities:

- ADC information - the crate and address of the ADC reading BPM output.
- x,y,z offsets - these represent the position of the BPM with respect to an origin at the nominal beam position at the location of the target.
- Calibration coefficient - this is a conversion factor inherent to the BPM geometry which relates the size of the current readout to the spatial displacement of the beam from the BPM pickup wire. Its units are meters/(ADC channel).
- Pedestals - the pedestals on the four ADC channels corresponding to each BPM pickup wire.
- Rotation matrix - the BPM pickup wires are rotated at $\sim 45^\circ$ about the beamline with respect to the hall coordinate system. These are the four coefficients of the rotation matrix.

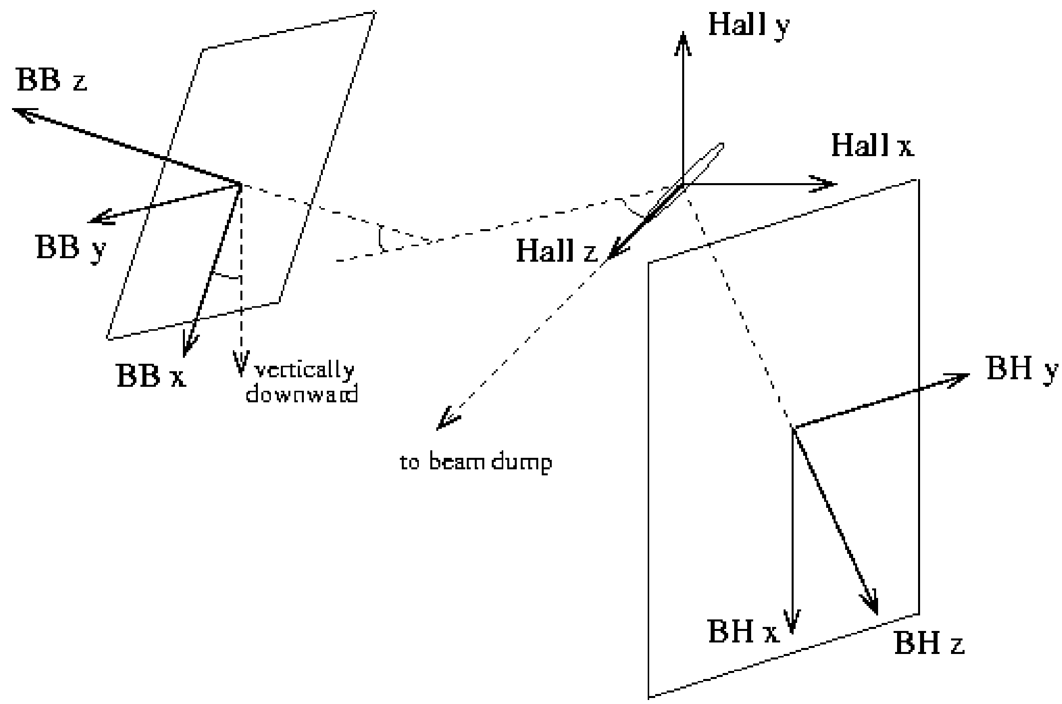


Figure 1: Hall and Detector Coordinate Systems

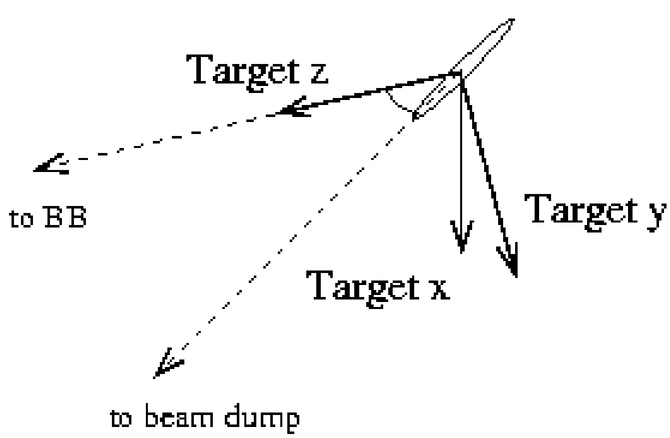


Figure 2: Target Coordinate System

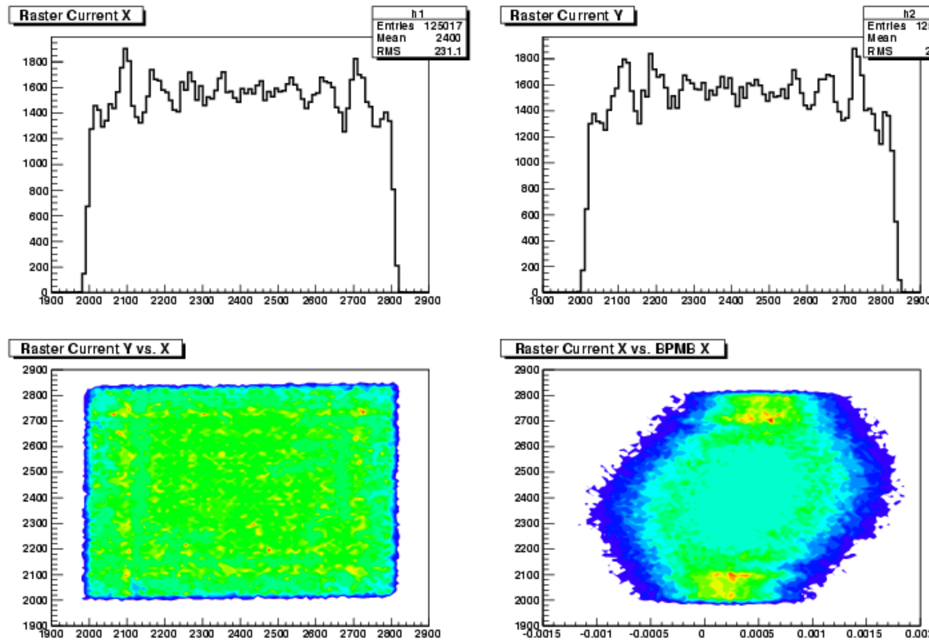


Figure 3: Raster Currents and Raster Current vs. BPM - Run 3356 - Optics Foils, Kin. 3

The values of these parameters during the E02-013 data collection period are listed in the Appendix. The pedestals may be measured by the ADC readout with beam off. The z offset may be obtained from survey data. This leaves the x and y offsets as the only free parameters to be fit to the harp scan data.

Instructions for taking a harp scan are outlined in the document located at:

http://hallaweb.jlab.org/equipment/beam/harp_halla/harp.html.

Analyzing the data will yield the x and y positions of the beam at the position of the harp. Calibrating the BPM's consists of adjusting the x and y offsets in the BPM database such that the BPM calculation of beam position coincides with that of the harp scan. For the particular case of E02-013, it was not possible to run a harp scan with the raster off. Therefore, a customized analysis script was used to determine the center of the rastered beam spot by fitting a normalized distribution to the harp scan data. See the Appendix for the harp runs and location of the analysis script.

The result is that the position of the raster spot with respect to the nominal beam position is known to the level of precision of the agreement between the two position measurement methods. This task was completed using harp scan data collected in April 2006 and its results are valid for the extent of the E02-013 data collection period.

3 Refined Position and Direction

The goal is to use knowledge of the raster current to extract both the position and direction of the beam at the z position of the vertex of each event, relying on the spectrometers to provide this z-component. This is made possible by knowledge of the relationship between raster current and beam displacement at the target. This may be determined by examining optics foil data by the method detailed below. It is also necessary to know the average position and direction of the beam over a time scale spanning many raster cycles. This time-averaged information may be provided by the BPM's. The beam position at the target is given by:

$$r_i = \langle r_i \rangle + m_i \cdot (I_i - \langle I_i \rangle), \tag{1}$$

where m represents the displacement of the beam per unit raster current, the subscript i represents the x,y coordinates, and $\langle r \rangle_i$ represents the time-averaged position of the beam. I_i is the raster current recorded at the time of the event, while $\langle I \rangle_i$ is the time-averaged raster current.

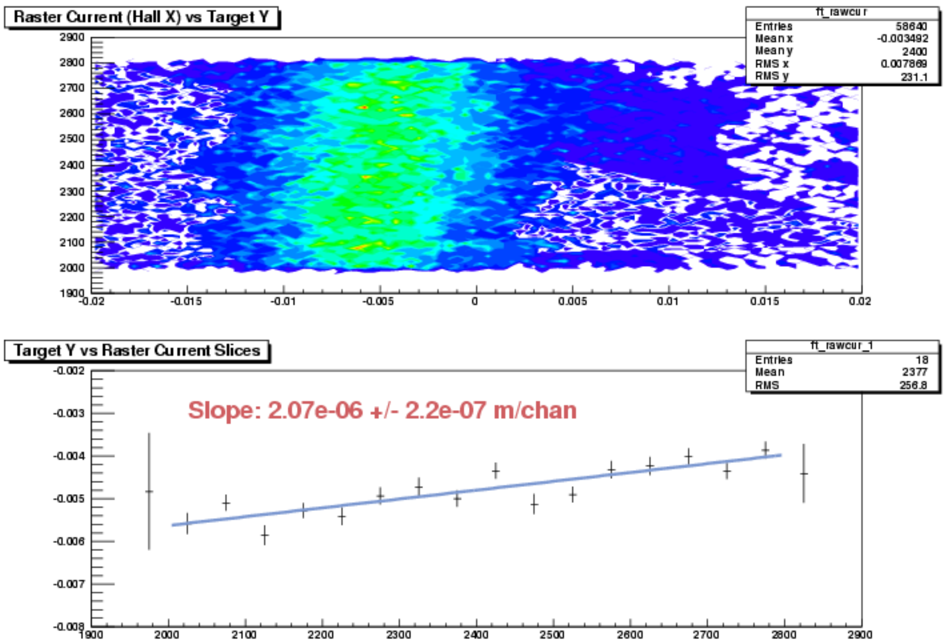


Figure 4: Correlation of Horizontal Raster Current and $\mathrm{y_{target}}$

3.1 Determination of $\langle r \rangle_i$

A running average of the projection of the beam position at the target, as determined by the BPM's is stored in the Process method of the GenBeam class. This average stores by default 1000 values. The raster frequency (25 kHz) is much higher than the trigger frequency ($\sim$1 kHz), so that 1000 events is more than sufficient to create a true average position.

3.2 Determination of m

The beam displacement per unit raster current may be directly obtained in the horizontal direction by plotting the average horizontal position of the track produced in the spectrometer as a function of horizontal raster current. This relationship is shown in Fig. 4. The upper plot shows the distribution of events over this two-dimensional space. It should be noted that a constant ADC offset of $\sim 2400 channels$ has been added to the raster current signal. A slight correlation may be noted corresponding to increased beam displacement for increased raster currents. The value of this slope is extracted by binning the data into bins of width 200 channels in raster current. A gaussian fit is applied in order to obtain the average value of the spectrometer variable "B.tr.fT.y" for each bin. The results are shown in the lower plot. The slope of the linear fit to this data represents the ratio of beam displacement in the horizontal spectrometer component per unit raster current (units are ADC channels). Converting this to the horizontal direction in the hall requires a multiplicative factor of $\frac{1}{\cos\theta}$, where θ is the angle between the spectrometer and the downstream beamline. This yields

$$m_x \equiv \left(\frac{I}{\mathrm{B.tr.fT.y}} \frac{1}{\cos\theta}\right), \tag{2}$$

The ratio of the width of the BPM distribution to that of the raster current distribution gives an estimate of the conversion between beam displacement and raster current, which may be compared to the value calculated by this method.

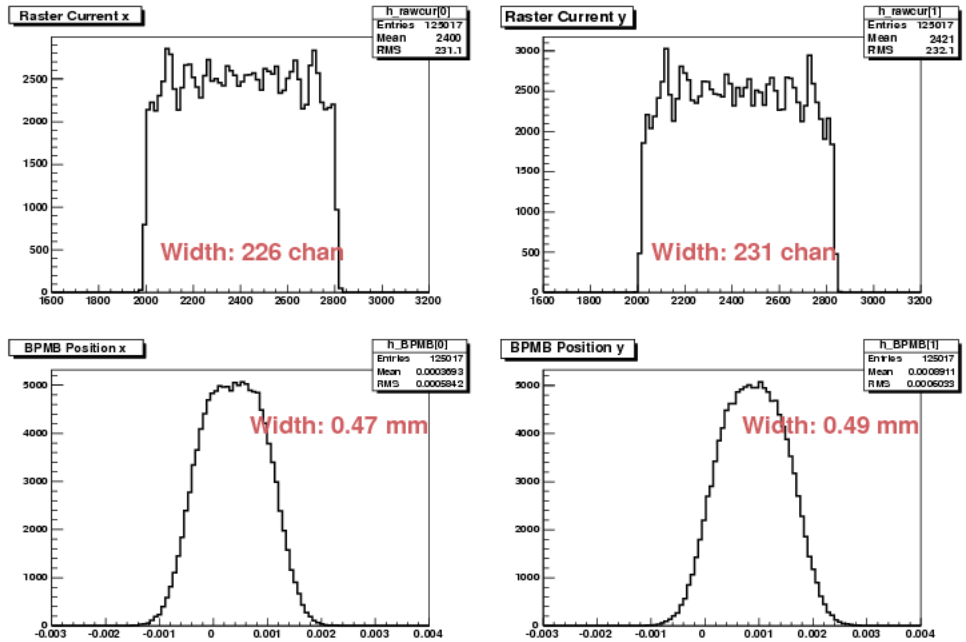


Figure 5: Raster Current and BPM Distributions

The parameter for the vertical position, m_y is more difficult to measure directly since it is in the spectrometer's bend-plane. The parameter $m_y(z)$ may be obtained by scaling the apparent size of the raster pattern observed by the BPM's in the Y-direction $(\sigma_y(BPM))$ by the ratio of $m_x(z)$ to the apparent size of the raster pattern observed by the BPM's in the X-direction$(\sigma_x(BPM))$. That is,

$$m_{\mathrm{y}} \approx m_{\mathrm{x}} \cdot \frac{\left(\frac{\sigma_y(\mathrm{BPM})}{\sigma_y(\mathrm{Raster})}\right)}{\left(\frac{\sigma_x(\mathrm{BPM})}{\sigma_x(\mathrm{Raster})}\right)}. \tag{3}$$

The scaling term is merely approximate due to the fact that the width of the BPM distribution is not a true representation of the width of the raster spot. The scale factor may be calculated at either BPM; BPMB is used due to its proximity to the target.

3.3 Beam Direction

The beam direction is stored as the difference of the position at BPMB with the position at BPMA and has units of meters. A running average of this direction is stored and the event beam direction is calculated as this average direction plus the directional shift created by the raster current. That is,

$$dir_i = \langle dir_i \rangle + (m_i \cdot (I_i - \langle I_i \rangle)) * \frac{\mathrm{z_B} - \mathrm{z_A}}{\mathrm{z_{targ}} - \mathrm{z_{raster}}}. \tag{4}$$

3.4 Obtained Coefficients

The 4 coefficients which are necessary input are: The average currents which drive the x and y rasters and the resulting beam displacement per raster current in the x and y directions. Results for Run 4582 are shown in Table 2.

It is useful to compare the two methods for estimating the effect of the raster on the beam position. The ratio of the sigma width of the horizontal BPMA and BPMB distributions to the sigma width of the raster current distributions are $2.04 \cdot 10^{-6}$(m/chan and $2.10 \cdot 10^{-6}$(m/chan respectively, while the ratio obtained from the optics foils study is $3.36 \cdot 10^{-6}$. The ratios of the latter number to the former are

Coord	$\langle \mathbf{I_x} \rangle$	m
x	2400	$(-3.36 \cdot 10^{-6})$ (m/chan)
y	2400	$(-3.29 \cdot 10^{-6})$ (m/chan)

Table 2: Run by run coefficients - Run 4582.

both 1.6. The relationship between the raster current distribution and BPM distributions are displayed in Fig. 5, where the printed sigma widths are those of a normal distribution ($\sigma = \frac{FWHM}{\sqrt{12}}$ for the raster currents and a Gaussian distribution for the BPM's.

4 Results

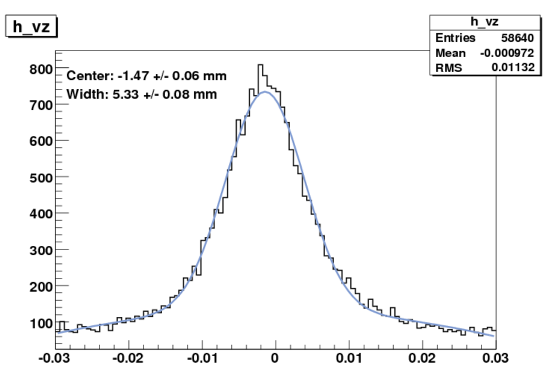
This section considers the quality of the calibration and its resulting precision.

4.1 Horizontal

The improvement of resolution in the horizontal direction should narrow the apparent width of the carbon foils, allowing one to calculate the resulting precision in beam position. The width of the z-coordinate reconstruction of the central foil both before and after calibration is shown in Fig. 6. The before plot displays the apparent z-direction width of the central foil for the case when no position corrections are applied. The maximum reduction in this width is $\sim 1\%$ as may be seen by considering the contributions to the observed width:

$$\sigma^2_{\text{total}} = \sigma^2_{\text{beam}} + \sigma^2_{\text{other}}, \tag{5}$$

where σ_{total} denotes the observed width of the foil, σ_{beam} represents the contribution of the rastering to this width, and σ_{other} contains all other contributions. In this case $\sigma_{\text{total}} = 5.33$ mm, while the sigma width of the 3 mm uniform raster pattern is $\frac{3 \text{ mm}}{\sqrt{12}} = .87$ mm. The result is that $\sigma_{\text{other}} = 5.26$ mm. Because the resolution cannot be improved beyond σ_{other}, the maximum improvement in apparent width is approximately 70 microns. The size of this effect makes a direct measurement of the precision by this method difficult: The observed reduction in width is consistent with both infinite resolution in beam position as well as with no improvement in the beam position resolution. Another effect the calibration should have, though, is the reduction of the correlation between horizontal raster current and the z position of the reconstructed vertex. This correlation is shown in Fig. 7 both before and after the calibration. The dependence of the reconstructed z-direction position on raster current is reduced by a factor of 5 by the applied correction.



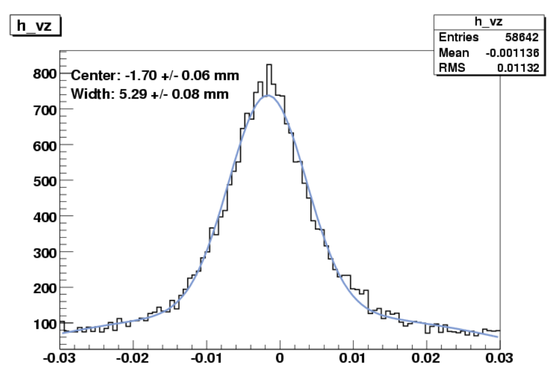


Figure 6: Width of the z-coordinate of central foil before and after raster correction

4.2 Vertical

It is possible to investigate the accuracy of the obtained coefficients in the vertical direction by examining the relationship between p_{diff} and vertical raster current using elastic events with the H_2 target, where

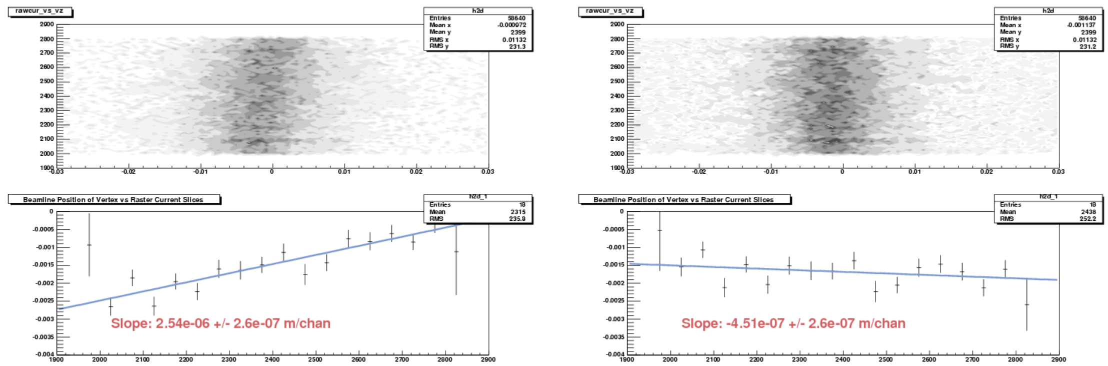


Figure 7: Correlation of horizontal raster current and z-coordinate of central foil before and after raster correction

$p_{\rm diff}$ represents the difference in the observed momentum and the momentum calculated from the position of the detected proton. This situation is shown in Fig. 8. Consider an event whose calculated vertex position is lower than the actual vertex of the event. The bend angle of the reconstructed track in the dispersive direction will be artificially small, resulting in an observed momentum larger than the momentum calculated using the proton position ($p_A > p_B$). That is, events whose vertices are taken to be artificially low will have positive values of $p_{\rm diff}$, while those with artificially high vertices will have negative values of $p_{\rm diff}$. Vertical raster current is a useful parameter to observe this relationship. The variation of $p_{\rm diff}$ with raster current was examined with data from Run 4427 (4th kinematic setting) both before and after the refined position calibration is shown in Fig. 9. The dependence of p_{diff} is reduced by a factor of 100 by the applied corrections. The momentum resolution is perhaps slightly improved after the calibration. These resolutions calculated before and after the calibration are shown in Fig. 10

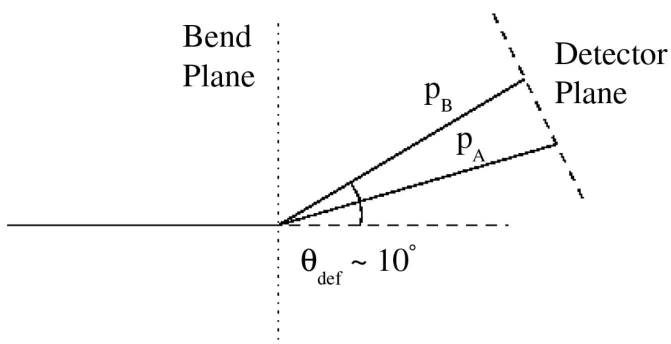


Figure 8: Geometry of vertex reconstruction - the red line represents a track with an artificially high vertex and, therefore, larger reconstructed bend angle.

4.3 Direction

The direction profile normalized to units of milliradians, by scaling the direction variable by the distance between the BPM's may be seen in Fig. 11, both before and after calibration. The Gaussian shape of the profile is a consequence of the finite bandwidth of the BPM, resulting in the observed smooth distribution. The calibrated data is forced to the expected normal distribution. Additionally, the uncalibrated data show no correlation between beam diretion and raster current, while the calibrated beam directions are similarly forced to be proportional to this current.

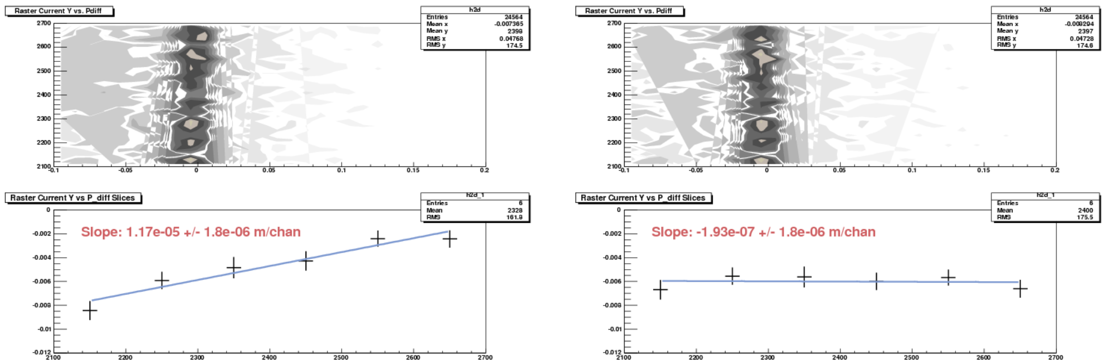


Figure 9: Correlation of vertical raster current and p_{diff} before and after calibration.

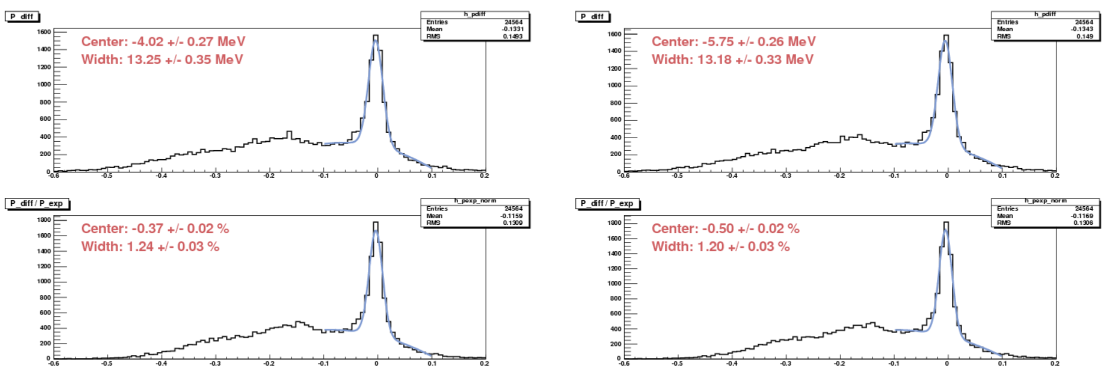


Figure 10: p_{diff} (above) and $\frac{p_{\mathrm{diff}}}{p_{\mathrm{exp}}}$ (below) before and after calibration

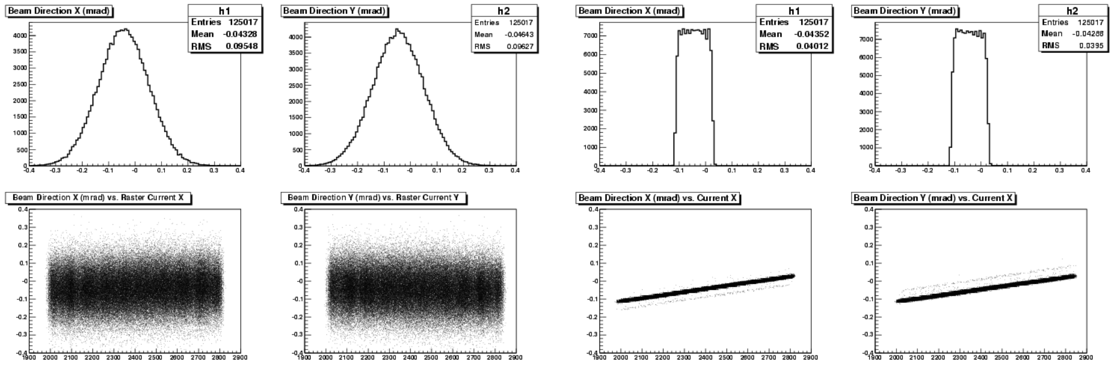


Figure 11: Beam direction profile before and after calibration

5 Conclusion

The GenBeam class, employs the GenBPM and GenRaster classes to obtain a running average of the beam position at the target, as well as a precise position of the beam position for each event. There are 4 coefficients which are required to perform this calculation and whose values should be monitored for variation between runs.

6 Appendix

This appendix provides the details of the BPM calibration which was performed in April 2006.

The harp scans used for the BPM calibration are located in a folder at http://hallaweb.jlab.org/experiment/E02-013/beamcalib/harpscans/ while the script which was used to analyze the data and extract the center of the rastered beam is located at http://hallaweb.jlab.org/experiment/E02-013/beamcalib/harpscan_plotter.C.

6.1 Harp Scans

The harps s.cans used in the BPM calibration are listed below. MCC controlled the harps. A review of the Hall A DAQ runs taken during the scan period is given in HALog entry 169207

IHA1H03A.04012006_16:31	IHA1H03B.04012006_16:35
IHA1H03A.04012006_16:39	IHA1H03B.04012006_16:40
IHA1H03A.04012006_16:42	IHA1H03B.04012006_16:43
IHA1H03A.04012006_16:44	IHA1H03B.04012006_16:45
IHA1H03A.04012006_16:47	IHA1H03B.04012006_16:49
IHA1H03A.04012006_16:48	IHA1H03B.04012006_16:51
IHA1H03A.04012006_16:51	IHA1H03B.04012006_16:55
IHA1H03A.04012006_16:53	IHA1H03B.04012006_16:59
IHA1H03A.04012006_16:54	
IHA1H03A.04012006_16:58	

6.2 BPM Database

The contents of the BPM databases (db_urb.BPMA.dat and db_urb.BPMB.dat) are shown below. The x and y position offsets were determined by the results of the harp scan, while the z-position are those listed in the Hall A Ops Manual. The elements of the rotation matrix correspond to a 45 degree rotation of the BPM pickup wires with respect to the hall coordinates. This rotation was not measured empirically. The calibration coefficient which sets the length scale of the BPM was also not calibrated empirically.

BPM A

keyword	crate	header	offset
detmap	28	0xfadc1182	1

keyword	Offset X	Offset Y	Offset Z
posoff	0.00110	0.00086	-7.517

keyword	BPM length scale
calibration	0.01887

keyword	1	2	3	4
pedestals	691	719	693	729

keyword	(0,0)	(0,1)	(1,0)	(1,1)
rotation	0.707	-0.707	0.707	0.707

BPM B

keyword	crate	header	offset
detmap	28	0xfadc1182	5

keyword	Offset X	Offset Y	Offset Z
posoff	-0.00030	0.00240	-2.378

keyword	BPM length scale
calibration	0.01887

keyword	0	1	2	3
pedestals	668	650	670	661

keyword	(0,0)	(0,1)	(1,0)	(1,1)
rotation	0.707	-0.707	0.707	0.707