Beam Position and Elliptical Raster Analysis

A.Deur. Jefferson Lab & LPC/Université Blaise Pascal, (deurpam@jlab.org)

04\10\1999

Abstract

We present here the analysis of the Hall A Elliptical Raster. After a recall on analysis previously done on the Square Raster, we describe the Elliptical Raster new features, the method chosen to analyze it and the error estimation on the beam position.

Contents

1 Introduction **2**
- 1.1 Overview 2
- 1.2 magnetic optics 4
- 1.3 Vertex Reconstruction Using the Raster Coils Current 5

2 Analysis **6**
- 2.1 Centroid and Amplitude 6
- 2.2 Beam Position Event by Event 7
  - 2.2.1 BPMs_Raster Phase 7
  - 2.2.2 Beam Position offsets 8
  - 2.2.3 Phase Removal 8
  - 2.2.4 Cuts 9
  - 2.2.5 Optimization 10
- 2.3 Phase Stability. 14

3 Event by Event Analysis without phase subtraction. **16**

4 Error Estimate **17**

5 Conclusion **18**

1 Introduction

1.1 Overview

In order to avoid too high heat load in the target the electron beam is rastered at $\sim$ 20 kHz frequency. The Raster apparatus is composed by two coils for horizontal and vertical rastering. Each coil is powered by a function generator and an amplifier. The Raster is controlled by MCC. In September 1998 two knobs were installed in the counting house to allow Hall A shift operators to change the Elliptical Raster amplitude.

Two rastering patterns can be set with the Hall A Raster. The first one has a rectangular rastering pattern. The second one is a homogeneous Elliptical pattern. It was used during the experiments E94010, E95001 and part of the HAPPEX second run.

In the case of a rectangular pattern, both function generator deliver a sine signal of constant amplitude. The ratio between the two sine frequencies is a non rational number (here $\sqrt{2}$) to avoid a Lissajous pattern. The sine amplitude remains constant. As a sine wave spends more time in its extrema, The pattern is non homogeneous. *Fig. 1* shows the beam position distribution on the target in the horizontal and the vertical directions. A first Square Raster analysis was done for the experiment E91-026 [1]. Two more detailed analysis were done for the VCS (E93-050) experiment [2],[3].

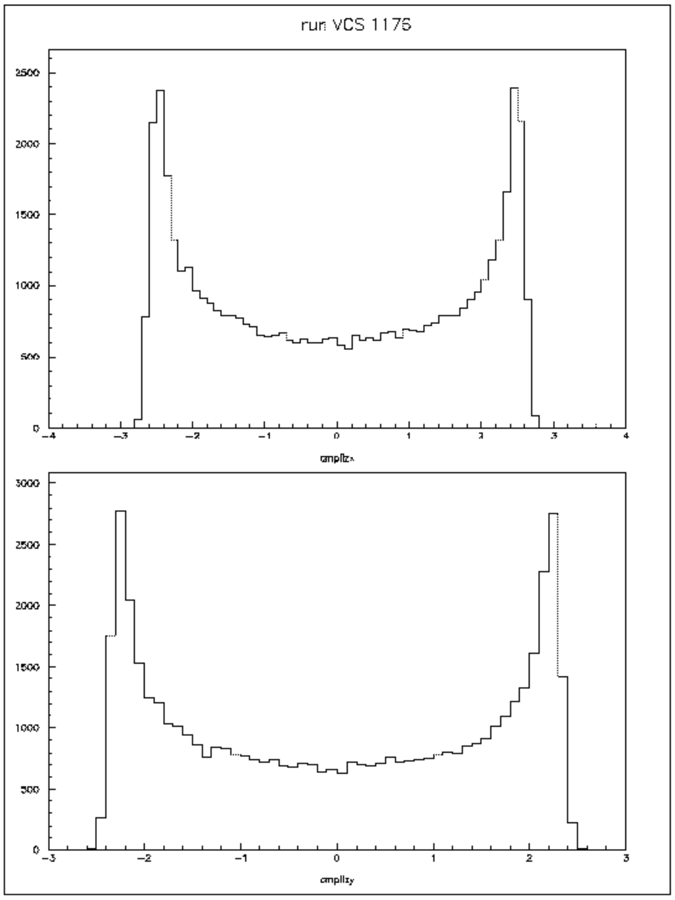

Fig. 1. Beam position distribution on the target for the Square Raster. Both axis are in mm.

In the case a elliptical pattern. The phase between the sine frequencies is $\frac{\pi}{2}$ and the amplitudes are modulated as a 49 Hz square root function of time. The square root function modulation allows a homogeneous distribution on the target (*Fig 2.*). This report presents the analysis done with this configuration.

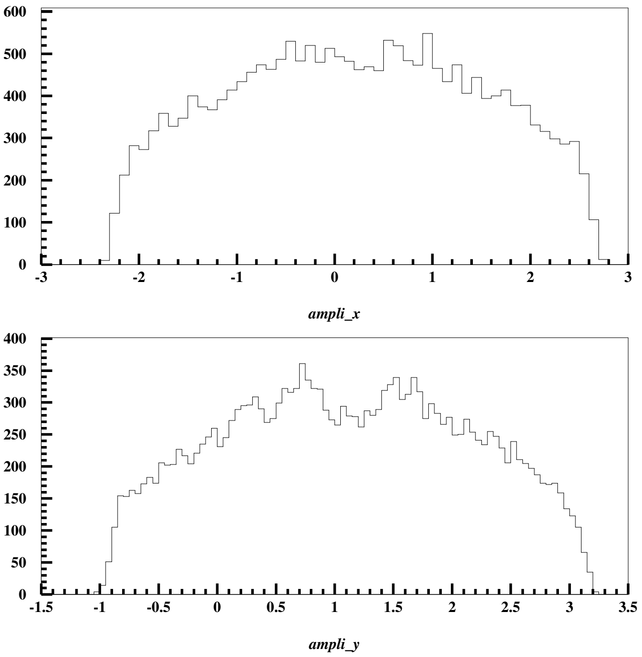

Fig. 2. Beam position distribution on the target for the Elliptical raster. Axis are in mm.

Two Pearson probes measure the coil currents. Each are read by two ADCs (LeCroy 1182 and VMIC 3123) and sent to the EPICS data stream. The acquisition is triggered by the HRSs main triggers (T1 and T3). The current derivative sign is also recorded.

1.2 magnetic optics

Four quadrupoles sit between the Raster coils and the target. The associated magnetic optics is described, at the first order, by a set of 2×2 matrices. However an appropriate frame choice reduces the final matrix to a scalar. Assuming the beam angle at the Raster place is proportional to the coils current, the horizontal rastering size is:

$\Delta x = kb_x\frac{I}{E}$

where:

- k is a constant containing the kinematic factors. It was optimized after the Raster commissioning in September 1997 (commissioning with a Raster DC current). The value is $k = 0.0228$
- b_x contains the magnetic optic information. It is magnet settings and beam energy dependent. The value can be computed using the code hafrbx.c

for the horizontal direction and hafrby.c for the vertical one (path: ~deurpam/hafrang).

- I is the coil current in Ampere.
- E is the beam energy in GeV.

The same formula stand for the vertical direction.

This formula and the EPICS records of the Raster current and quadrupole gradients provide one way to compute the beam position on the target. The table below gives the EPICS names of the four quadrupoles and typical values (during the e94-010 Raster commissioning)

quads	gradient (Gauss/cm)
MQA1H01	-18109
MQM1H02	12110
MQO1H03	11229.5
MQO1H03A	-720

That yields b_x=11.7 and b_y=20.6

These values came from the readout of the quadrupoles current. To get them one needs to request the raw data file from the Mass System Storage and uses the command *grep RB file_name.*

1.3 Vertex Reconstruction Using the Raster Coils Current

As mentioned above t he vertex reconstruction could be done by getting the information on the magnetic optics and the raster coils. However we need to correct for any beam drifts. The two principal beam motion, in addition to the raster action,van be a slow drift due to beam tuning change and a 60 Hz (plus the superior harmonics) noise. If the noise amplitude is small enough (use of the Fast Feedback) we can afford to not do the corrections. The raster currents do not have any information relative to these drifts. The corrections from the beam drift can only be done using the BPMs data (average position of the BPMs) if the beam drift is not too fast[1]. We need reliable BPMs informations in order to apply this correction.

Another information needed is the magnetic optics setting. The E94-010 commissioning shows that the magnet current readbacks are not alway reliable . The lack of information on the 60 Hz noise and the drift made us prefer a vertex reconstruction using mostly BPMs informations. However we still need the Raster current information. The difficulty of this analysis is the BPMs signal sampling does not allow a signal reconstruction. The 1 kHz sampling in comparison to the 20 kHz signal is too slow and, since the acquisition triggers when an event is accepted in the HRS, the delay between two consecutive sample is random.

[1] BPMs DAQ has a typical frequency of 1 kHz. 500 events provide are enough to compute a beam position estimation. Consequently the typical time of drift must be greater than 0.5 second to allow beam drift corrections.

2 Analysis

2.1 Centroid and Amplitude

The extraction of the average beam position (centroid) and the rastering amplitude was done in [2]. It shows that the BPMs data and HARP scans are consistent. However the BPMs data needed some calibration prior to be compared to the HARP informations. In this analysis we choose to use the BPMs data directly calibrated with the HARP.

Fig. 3 shows the beam position measured by HARP and the BPMs. The runs were taken with Raster off and HARP and BPMs measuring in the same time. The BPMs offsets and the HARP geometrical centers are from the 28 Sep 1998 survey. We see a linear relation between BPMs and HARP data. The two number P1 and P2 are the linear fit coefficients:

$HARP = P2 \times BPM + P1$

The Raster commissioning done at the beginning of E94-010 shows that the amplitude given by the HARP is 1.1 greater than the BPMs data (both x and y) . This is in agreement with [2].

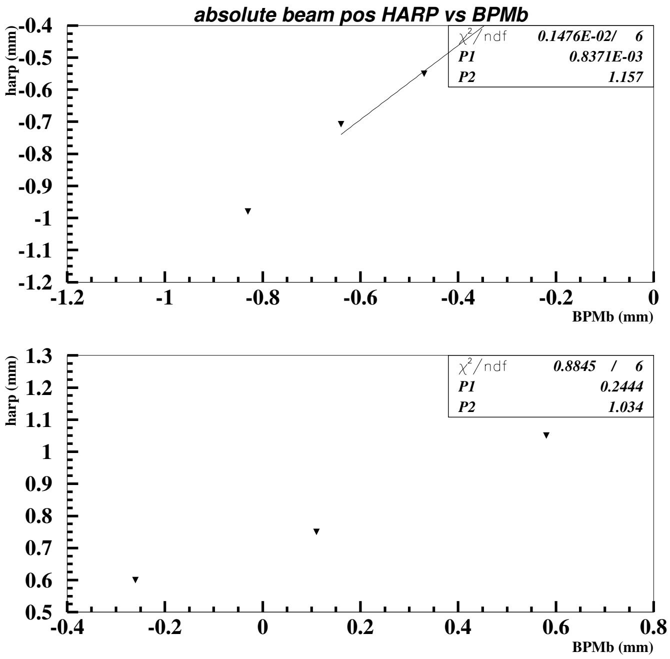

Fig. 3. HARP data vs BPMs data (axis are in mm)

2.2 Beam Position Event by Event

2.2.1 BPMs_Raster Phase

BPMs are not giving directly the beam position event by event. Due to hardware delay, the readout gives a delayed beam position. This time delay makes a significant shift on the beam position. It is written as a phase in the sine signal describing the beam position on target. To come back at the actual beam position we have to remove this phase from the sine signal. The phase between the BPMs data and the target actual position is equal to the time delay time 2 π time the raster frequency. Assuming there is no time delay between the Raster coil acquisition and the target true position, the target-BPMs delay is equal to the Raster-BPMs delay. this assumption was verified with data taken in coincidence. In this case one is able to reconstruct the beam position on target with both HRSs [3]. The phase is seen on a BPMs data vs Raster coil current data plot. The straight line expected without delay becomes an ellipse. [3] checked that the beam position reconstructed with both HRSs plotted vs Raster current gives a straight line. The Raster-BPMs phase is obtained by fitting the ellipse on a BPMs vs Raster coils plot (cf *Fig 4.*). The plot is given for the elliptical raster (the events fill the ellipse). For the Square Raster the events are distributed only on the ellipse edge.

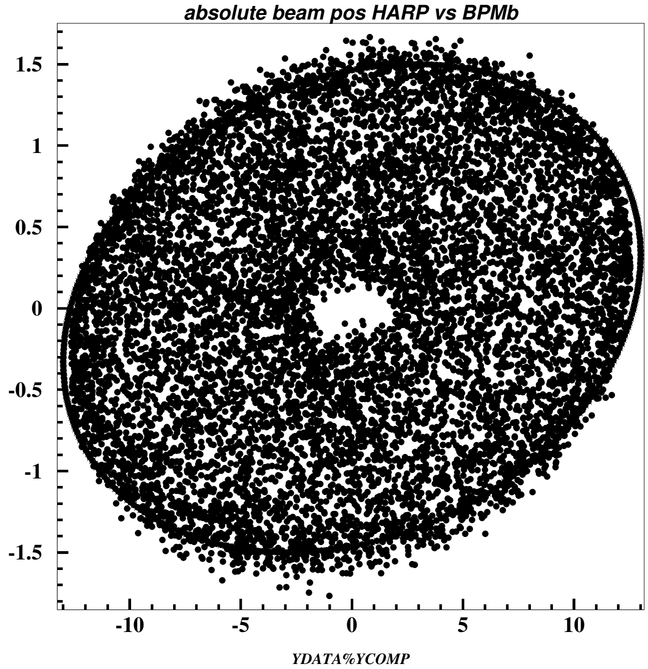

Fig. 4. BPMs data (in mm) vs raster coil data (in arbitrary unit). The fit of

the contour with an ellipse provides the raster-BPMs phase.

2.2.2 Beam Position offsets

The offsets on the beam position (i.e. the beam centroid positions) are computed according to section 2.1. It was updated each 5000 events (each 3 to 6 seconds) to make the analysis code independent of any slow drift of the beam centroid during the experiment runs.

2.2.3 Phase Removal

The Elliptical Raster analysis to extract the beam position event by event is more complicated than with the Square Raster[2]one. The formula used in the Square Raster analysis to remove the phase are not valid anymore. Taking the notations of [3]:

- φ : Raster-BPMs phase
- $B_{i_{true}}$: Position from the BPMs after Phase removal.
- B_{i_m} : Position from the BPMs before Phase removal.
- R_i : Position computed from the Raster current.
- S_i: Sign of the Raster current derivative.

We have:

$B_{i_{true}} = B_a M(t) cos(\varpi t)$

$B_{i_m} = B_a M(t) cos(\varpi t + \varphi)$

$R_i = R_a M(t) cos(\varpi t)$

so[3]

$B_{i_{true}} = B_{i_m} + B_a M(t)[cos(\varpi t) - cos(\varpi t + \varphi)]$

as

we have finally:

$B_{i_{true}} = B_{i_m} + B_a(\frac{R_i}{R_a} - M(t) cos(-S_i acos(\frac{R_i}{R_a M(t)} + \varphi))$

The crucial point is that the phase removal operation depends of the modulation value $M(t) \propto \sqrt{t}$.

[2]We choose to do an analysis looking at x and y independently. It allows to used the important informations resulting from the E93-050 work [3] on the target since this experiment was able to reconstruct the event positions using both spectrometers. This provides a powerful check. We could have done a Circular Raster analysis looking at the radius and the angle of the Raster spot as suggested by M. Kuss. However this way has its own difficulties. Due to the magnetic optics the spot is an ellipse, not a circle. The formula to get the radius need a phase removal since there is also a phase between the X_BPMs data and the Y_BPMs data. The 60 Hertz noise, mainly in the X (horizontal) direction, is adding a difficulty to get the radius. We have also to fit the sine envelope while the sampling is not very good.

[3]S_i is not anymore the true derivative of a sine wave as in [3] but the derivative of the modulated sine wave. However as the modulation period is long in comparison to the sine period and as $\sqrt{t}$ is a strictly and slowly increasing function of t, S_i remains a very good approximation of the sine derivative.

2.2.4 Cuts

Since the phase removal depends on the modulation instantaneous amplitude the square root is approximated as a step function (*Fig. 5*). The number of steps is a variable of the analysis code.

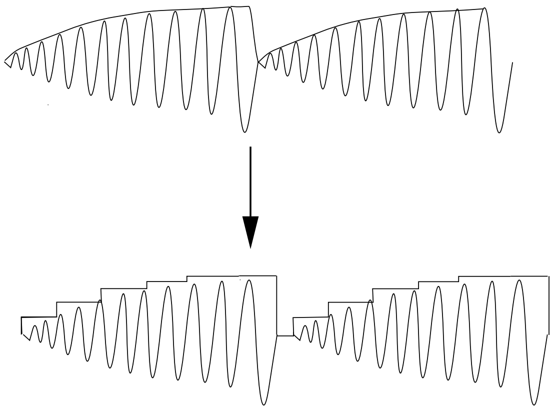

Fig. 5. Approximation of the raster envelope (the actual sine wave frequency is much more higher than in the picture).

As the modulation amplitude is approximated to a constant on each step we can come back to a traditional "Square Raster Phase Removal". The cuts on each step are done by normalizing the BPMs data by the coil current data. We project the result in a frame rotated by about 45 degree and translated by the Raster coil current offset and the BPMs data offset. This allow to do a simple ellipsoidal cut in the canonical frame of the ellipse. It also avoids the apparent BPMs-Raster phase shift (cf section 2-3).

The next step is to fit the ellipse and to cut on its amplitude. Each cut on the ellipse amplitude is corresponding to one step on the step function of *Fig. 5*. *Fig. 6* shows the fit of the ellipse and the different cuts before the phase removal.

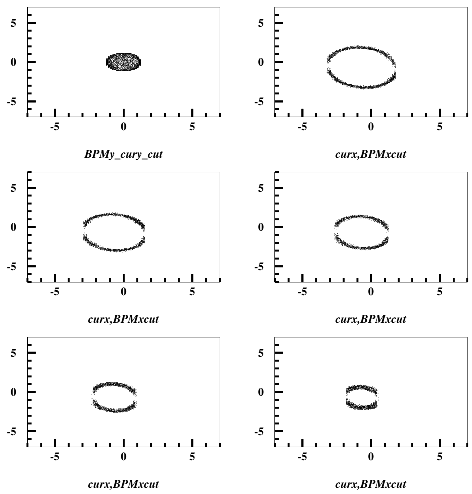

Fig. 6. Fit and cuts on the Raster vs BPMs ellipse

The phase can now be removed using the formula of [3]. A ideal result of the phase removal is a straight line bent at 45^o in the BPMs vs Raster plots.

2.2.5 Optimization

The cuts depend on several parameters:

- Amplitude of the BPMs signal
- Amplitude of the coil current
- Rotation angle of the frame (cf. 2.2.4)
- The ellipse center and
- The two ellipse radii

Because of noise the BPMs signal amplitude cannot be absolutely defined. We choose to define it as the width at half height of the BPMs events distribution. For a perfect homogeneous distribution (rectangular distribution) it gives the right amplitude but not anymore when too much noise is present. Consequently the frame rotation angle may vary around is nominal value of 45^o. We optimized the cuts by sweeping this parameter around 45^o. The code chooses the value leading to the Raster vs BPMs plot the closest to a straight line.

Fig. 7 and *Fig. 9* show the plots of BPMs vs coil current data for x and y after the phase removal but before optimization. *Fig.* 8 and *Fig.10* show the BPMs vs coil current data for x and y after the phase removal and optimization.

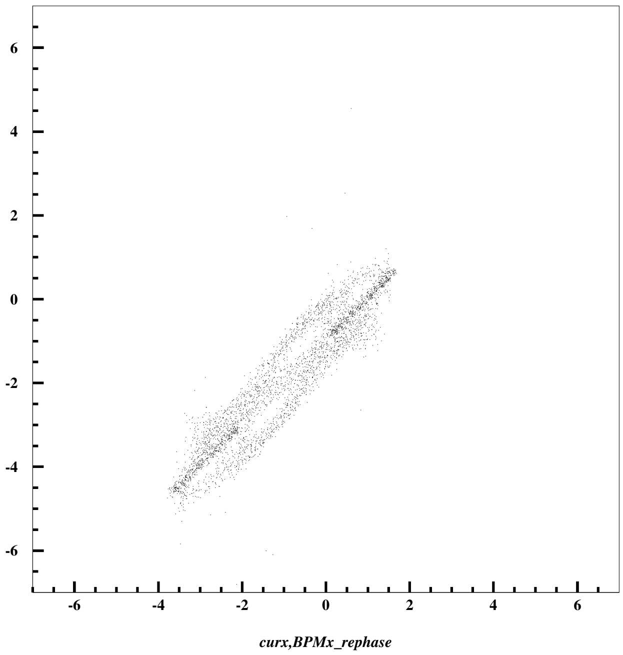

Fig. 7. x_BPMs vs x_Raster current after the phase removal and before optimization (scale in mm).

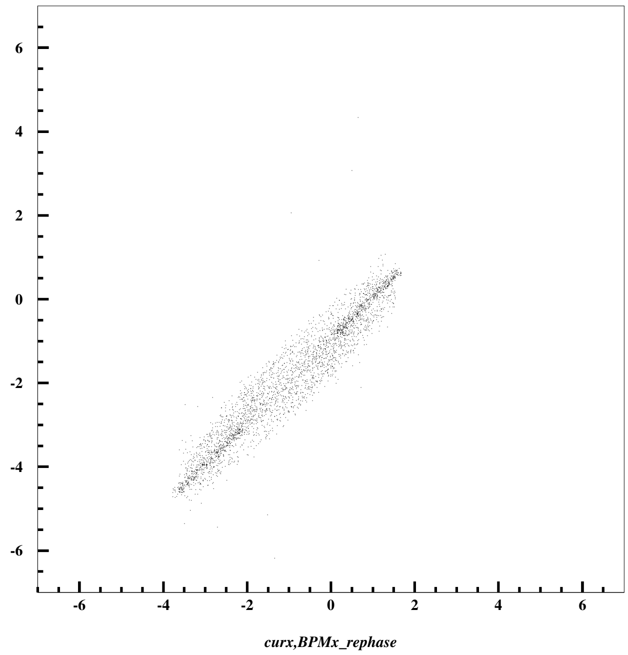

Fig. 8. x_BPMs vs x_Raster current after the phase removal and optimization (scale in mm).

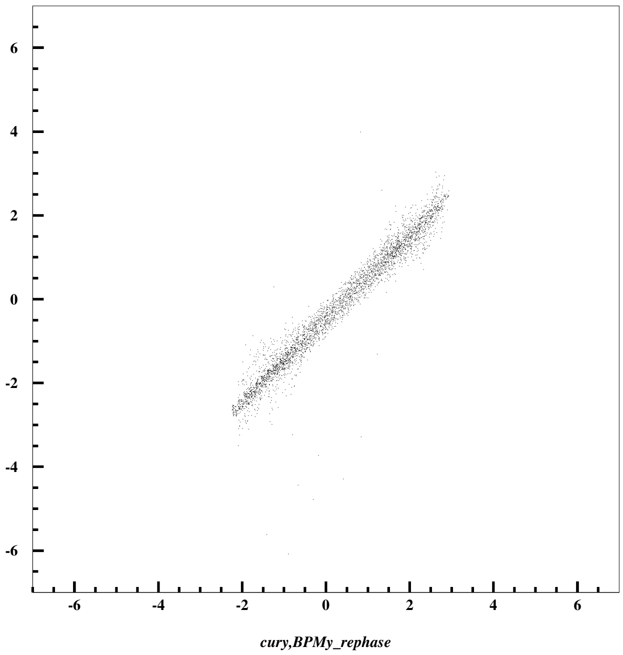

Fig. 9. y_BPMs vs y_Raster current after the phase removal and before optimization (scale in mm).

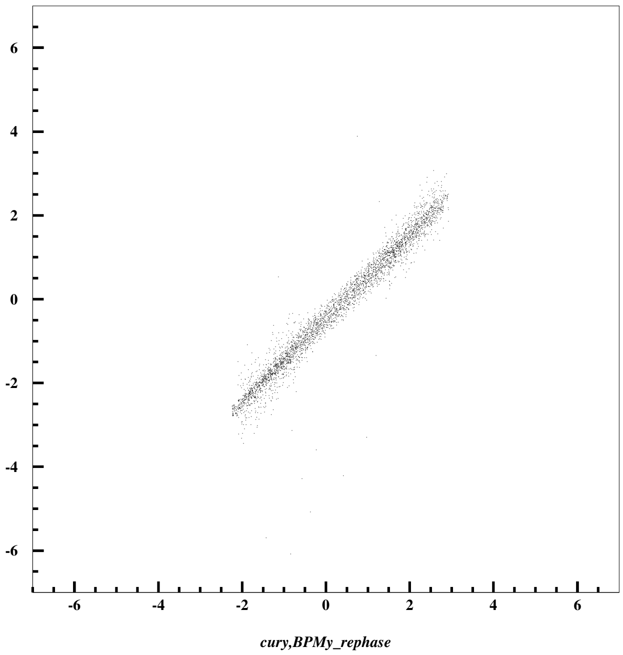

Fig. 10. y_BPMs vs y_Raster current after the phase removal and optimization (scale in mm).

2.3 Phase Stability.

The Raster-BPMs phase is due to hardware so it is an *a priori* fixed value unless some hardware modifications happen in the BPMS acquisition. [1] and [3] observe that the phase was fixed during the whole E91-026 and E93-050 experiments[4]. The phase value was the same for the two experiments. *Fig. 11.* presents some plots of x_BPMs vs x_Raster for runs covering the whole E94-010 experiment[5].

[4]These experiments used the Square Raster.
[5]This experiment used the Elliptical Raster.

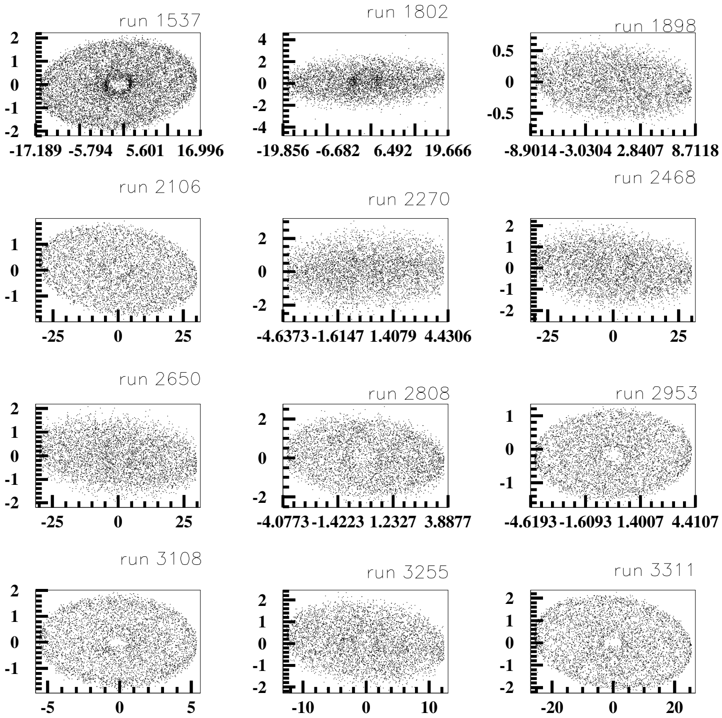

Fig. 11. Horizontal BPM data (mm) vs horizontal Raster current data (arbitrary unit) for runs covering the entire E94-010 experiment (scale in mm).

The bending of the ellipse should reflect the phase. However the figure seems to indicate that the phase changed constantly during the experiment. These changes however do not reflect any phase modification during E94-010. A new feature of the Elliptical Raster is the knobs controlling the Raster amplitude. If the knobs are not used (and if the BPMs are properly calibrated and rephased) the Raster-BPMs plot should be a 45^o straight line. A change of the Raster current amplitude will rotate this line. The ellipse rotations in *Fig. 11.* are due to the use of these knobs rather than an actual phase change. In the Elliptical Raster analysis code the Raster currents are normalized to the BPMs so we are always coming back to a 45^o line making the code to be independent of this "knob effect".

The phase stability during the whole experiment is checked *a posteriori* if reasonable results emerge of the phase removal code.

We first relied on [3] for the proper π-choice of the phase (there is a π uncertainty on the phase that can be fixed using vertices reconstruction allowed by coincidence experiments). The phase values in [3] are $\varphi_x = -1.4$ and $\varphi_y = -1.7$. However it was not possible to remove the y phase with this value.

It's seems the y phase changed during the experiment E93-027 [4] preceding E94-010. The phase value used for this analysis are: $\varphi_x = -1.4$ and $\varphi_y = +1.35$.

3 Event by Event Analysis without phase subtraction.

Another way to compute the beam position on the target is to use the raster coil currents to figure the rastering pattern and the BPMs data to figure the centroid and the size of the pattern. The calibration of the raster current with the BPMs avoids the phase and the magnetic optics problems. The average position of the beam computed over 500 events gives the centroid. This analysis is simpler than the phase subtraction method but requires the beam drift to not be too fast in comparison to the DAQ frequency (max 2kHz). The approximation on the centroid makes this method to be less precise but its simplicity makes it less CPU consuming. *Fig 12* is a comparison between the two methods. The improvement seen between figure 12 and Figures 8 and 10 demonstrates the consistency of the two methods.

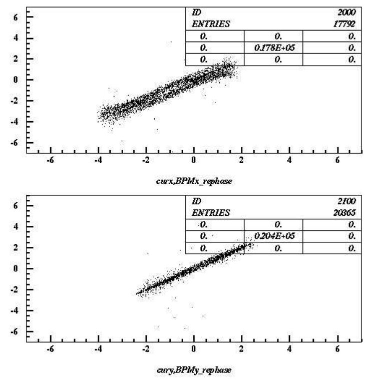

Fig. 12. comparison between the two event by event analysis methods. In vertical, the event position is given using this method while the horizontal is using the phase subtraction method. Scales are mm.

4 Error Estimate

We estimate the maximum error due to an imperfect phase removal. The *fig 13.* shows the worst result seen after the phase removal. An elliptic fit led to a phase of 0.3 rad. When the sine wave is varying the most rapidly (at ϖt=0) we get a systematic shift on the position of $\triangle x_{max} = Asin(0 + 0.3) = 0.30A$. Assuming we are on the top of the $\sqrt{t}$ envelope and we set a 4 mm diameter to the spot size we have $\triangle x_{max} = 0.59$ mm.

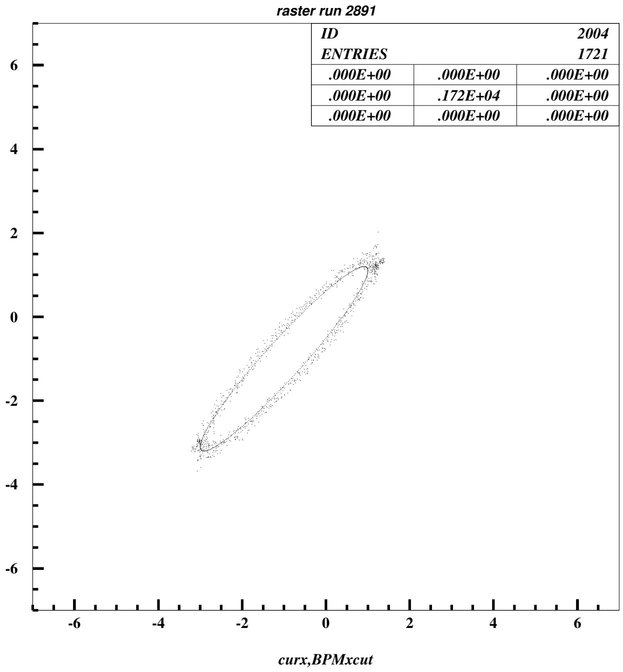

Fig. 13. Fit (continue line) of the x_Raster vs x_BPMs data (scale in mm).

The fit *Fig 14.* yields a phase of 0.07 rad for y leading to a maximum error of $\triangle y_{max} = 0.14$ mm.

The smaller 60 Hz noise in vertical direction explains the smaller error in y compared to the one in x.

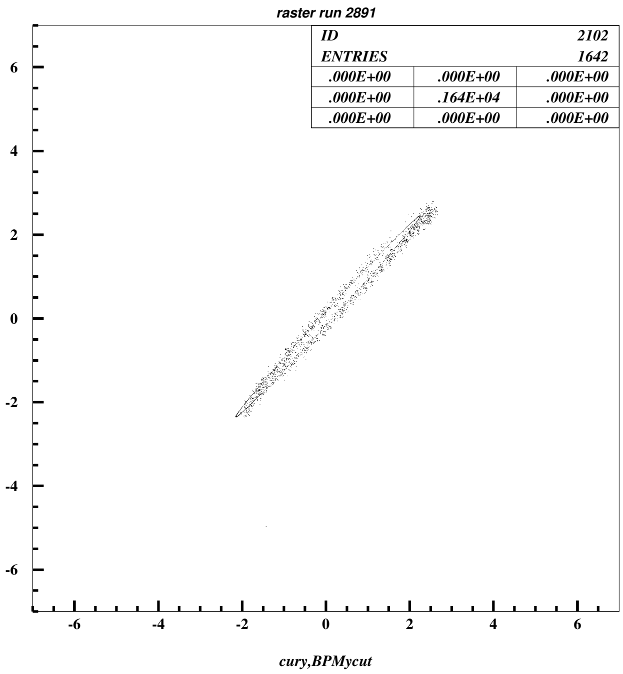

Fig. 14. Fit (continue line) of the y_Raster vs y_BPMs data (scale in mm).

5 Conclusion

The error estimation led to:

- $\triangle x_{max} = 0.6$ mm
- $\triangle y_{max} = 0.1$ mm

Note that $\triangle x_{max} = 0.6$ mm is a maximal value of the error in the case of the worst phase phit. With the average quality of the phase fit, the error will be of the order of 0.2 mm.

The precision on the position is not as good as the one achieve in [3]. The steps approximation of *fig. 5* and the phase removal that has to be done for each step yield additional errors. Another source of errors is when the beam envelope is going down from its maximum value to zero. The phase extraction could bring erroneous results since in this domain the sign of the derivative S_i may be wrong (the envelope is dropping too quickly). As this Elliptical Raster analysis has to be less precise and easy than the Square Raster one, one should either use the Square Raster for experiment requiring precise beam position event by event, try to find a more efficient analysis method or change the BPMs acquisition system (by adding a quick clock or increasing the BPMs acquisition rate for example).

The kumacs used to determine the Raster-BPMs phase can be found following the path ~deurpam/hafrang/xbpm.kumac and ~deurpam/hafrang/ybpm.kumac.

The code uses to remove the phase can be found at ~deurpam/hafrang/nt_rast2.f (use the makefile nlink to compile it on Sun machine).

References

[1] A. Deur. Raster analysis manual (non published) (deurpam@jlab.org)

[2] L. Todor. Jefferson Laboratory Hall A E93-050 Experiment. Hall A Beam position calibration (non published) (luminita@jlab.org)

[3] G . Laveissiere. Beam position studies (non published) (geraud@jlab.org)

[4] M. Jones private communication (jones@jlab.org)