LARGE DYNAMIC RANGE BEAM PROFILE MEASUREMENTS *

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Abstract

Large dynamic range ($Peak/Noise > 10^5$) beam profile measurements are routinely performed in the Hall-B beamline at Jefferson Lab. These measurements are made with a 1 to 10nA electron beam current with energies between 1 to 6 GeV. The electron beam scatters off of a thin W or Fe wire and the scattered particle/shower is detected via scintillation or Cerenkov light several meters downstream of the wire. This report describes results on increasing the dynamic range by using multiple wires of varying diameters. Profile measurements with this large dynamic range are of use for accelerators with large amount of stored energy (e.g. energy recovering linacs [ERL]) where small beam loss represents a significant amount of beam power. Results on measuring the transverse profile with large dynamic range during the CEBAF energy recovery experiment is also presented.

INTRODUCTION

Transverse beam profile measurements are typically performed to extract the transverse width of the beam. Such measurements place a modest demand on the signal to noise of the technique. Typically a signal to noise ratio of 100 is more than sufficient for such measurements. This paper describes the large (greater than 10^5) dynamic range beam profile technique used at JLAB. The technique has been used for two experiments, beam acceptance for the CLAS detector in end-station B and for measuring the width of the energy recovered beam during the JLAB energy recovery [ER] experiment. Transverse beam profiles with five to six orders of magnitude dynamic range represent a challenge for the diagnostics. The technique described in this paper is similar/identical to several other efforts summarized in the recent HALO2003 conference[1].

CLAS Experiment

Experiments with the CLAS detector [2] in end-station B at Jefferson Lab (JLAB) place strict requirements on the beam halo due to the small diameter target window (2 to 4mm). The target frame represents a large amount of material when compared to that of the target. Beam particles outside of target window interacting in the target frame can result in an event rate comparable to that of interactions in the target proper. The transverse beam profile measured with sufficient dynamic range provides a mechanism for determining the acceptability of the delivered beam and minimizing or eliminating completely the background from non-target interactions.

Energy Recovery Experiment

Presently there is interest in constructing energy recovery linacs [3, 4] for different applications. A feature of ERLs is the amount of stored energy in the beam. Small loss of beam will result in energy deposition in the beam pipe and possible loss of vacuum. Continuous operation of an ERL requires that the beam loss from injection to energy recovered beam dump be typically less than 1ppm. The JLAB Energy Recovery [ER] experiment is a test of the energy recovery concept using a large number of RF cavities[5]. The electron beam is injected with 55MeV(20MeV) of energy, accelerated to 1GeV and the phase shifted $180°$ and energy recovered through the RF section back down to the injected energy. One of the issues of interest is the beam shape of the energy recovered beam. The dynamic range that the transverse beam profile after energy recovery retains a Gaussian shape provides information on how much of the beam is retained [ie not lost] in the Gaussian core.

TRANSVERSE PROFILES FOR THE CLAS EXPERIMENT

The beam profile is measured by correlating a wire scanner position with count rates in photomultiplier tubes [PMT] located downstream of the wire scanner. The wire scanner assembly consists of a linear actuator which moves the horizontal and vertical wires through the beam. The actuator is driven by a stepper motor, which drives the wire support structure into the beam axis. The wire support is driven at a $45°$ with respect to the horizontal axis, which enables both the X and Y profiles to be measured with one axis of motion.

The PMTs [6] which detect the resulting scattered electron or shower are located downstream of the wire scanner. The distance between the wire scanner and PMTs is optimized for symmetric Møller scattering at beam energy of 5 GeV. Four 2” diameter PMTs are installed outside of a 3” diameter beam pipe, located in the following configuration: top, bottom, beam left, and beam right. The top-bottom PMT pair uses Cerenkov light in the quartz window to detect the scattered/showering particle(s). The left-bottom PMT pair has 0.5” scintillator in addition to the quartz window for detection of the scattered/showering particle(s). Due to the low operating beam current in Hall-B, typically 1 to 10nA, the PMTs can be operated in “count

* This work is supported by the Southeastern Universities Research Association (SURA) which operates the Thomas Jefferson National Accelerator Facility (JLAB) for the United States Department of Energy under contract DE-AC05-84ER40150.

mode". The PMT signals are discriminated and counted via a VME scaler. In addition to counting the individual PMT rates, the top-bottom and left-right coincidence rates are also fed to the scaler. These coincidence rates have a much lower background than the individual rates. In addition to the PMT rates, signals proportional to the beam current are also scaled and are used to normalize the PMT rates to the beam current.

Both the stepper motor controller[7] and PMT scalers[8] are VME modules contained within the same VME crate. EPICS controls[9] are used for both devices and state code is used to synchronize the motor motion and scaler readout. During a wire scan the motor position and scaler values are written to a file for further analysis. The minimum time between scaler reads is $\sim \frac{1}{60}$sec and is determined by the maximum update rate on the motor position. The motor speed and time between scaler reads are configurable at the beginning of each scan.

There are two wire scanners at the end of the transport line, upstream of the experimental target. One wire scanner [CLAS wire scanner] uses 50μm W wires and routinely measures the beam profile over five orders of magnitude. A second wire scanner [Integrating CLAS wire scanner] uses wires and integrating plates and is used for increased sensitivity.

The CLAS Wire Scanner

The CLAS wire scanner is located 12m upstream of the PMT bundle and scans 50μm X and Y wires through the beam. The scan speed is configurable and typically speeds of 1mm/sec are used, but slower speeds result in better sensitivity. This wire scanner measures the beam profile with a $Peak/Noise > 10^5$ response. Figure 1 shows a beam profile obtained with a wire speed of 0.25mm/sec and the bottom PMT. Figure 2 shows the same profile but using the coincidence signal between the top and bottom PMTs. The coincidence data is background free, and requires an unacceptably long integration time in order to determine the background level. The end result is that the coincidence signal has an indeterminate signal to noise level.

The achieved dynamic range of 10^5 satisfies the experimenter's requirements, and often the beam profile is Gaussian over the complete dynamic range. To observe and measure beam width with more sensitivity the integrating CLAS wire scanner is used.

THE INTEGRATING CLAS WIRE SCANNER

The wire configuration and support frame for the integrating wire scanner are shown in Figure 3. The wire configuration consists of 25μm diameter X and Y wires, 1mm diameter X and Y wires and a 1mm x 10mm X plate. All wires are made out of Fe for consistency and the plate is stainless steel for convenience. This wire scanner is 5m upstream of the PMT bundle.

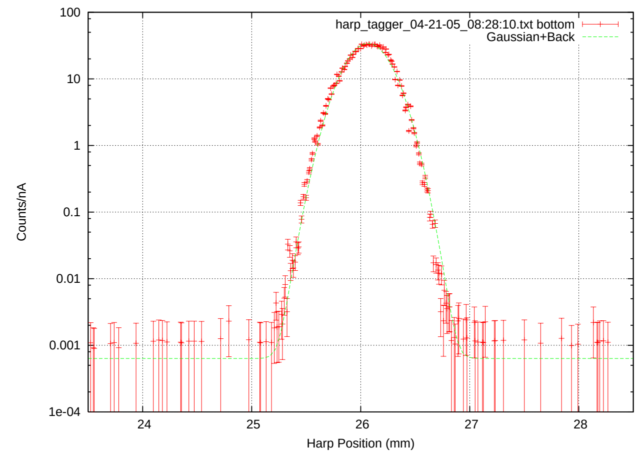


Figure 1: Beam profile [X] using a 25μm wire and PMT readout. The green curve is the result of a fit to the data using a Gaussian plus constant background as the functional form. The data for scan is taken simultaneously with that in Figure 2.

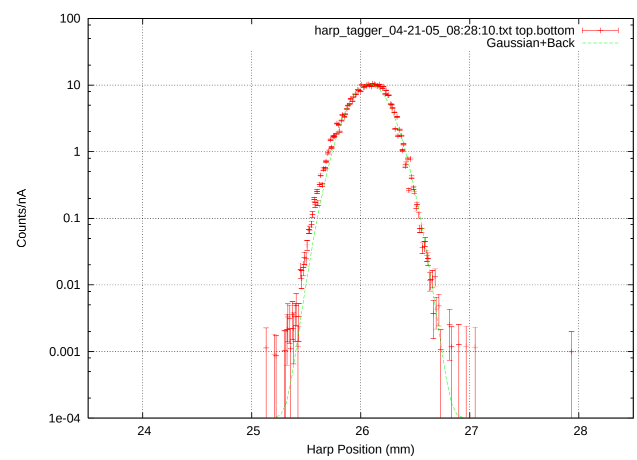


Figure 2: Beam profile [X] using a 25μm wire and the coincidence signal between the top and bottom PMTs. The data for scan is taken simultaneously with that in Figure 1.

Scans were taken in Hall-B with a 1 GeV electron beam with 6 nA of beam current. Scans were taken periodically over several days, while trying to optimize the motor speed and scaler acquisition rate. A slow motor speed results in a high number of data points that allow better matching between the 25μm and 1mm wire or plate data. However, a slow scan speed (0.125mm/sec) often resulted in an incomplete wire scan due to a beam trip. During these scans CEBAF was delivering beam ($1 - 40\mu$A) to the other two experimental halls (Halls A & C).

Integrating Wire Analysis

Once a scan file has been written to disk, offline analysis must be performed to combine the 25μm wire data with the 1mm wire or plate data. The technique used is similar to that found in Ref. [10]. The beam size is small com-

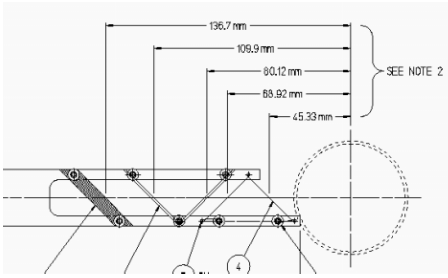


Figure 3: Mechanical schematic of the wire/plate support structure. The thin wire is 25μm in diameter. The thick wire is 1mm in diameter. The plate is 1mm by 10mm. The wire frame is moved into the beam along a 45° axis with respect to the horizontal axis.

pared to the 1mm wire diameter and the X plate. Therefore this data must be differentiated before combining with the 25μm wire data. In order to determine the scale factor and position alignment a χ^2 minimization is performed to match the 25μm data with the differentiated data. The two data sets need to overlap by at least two orders of magnitude [after scaling] in order for the procedure to converge. Noise is suppressed on the 25μm wire data sample, by only using data with more than 10 counts.

Naively one expects a scale factor of 1600 for the 1mm wire, based on the square of the ratio of the wire diameters. The scaler factor for the match between the 1mm wire data and the 25μm wire data had a range between 1400 and 1900 for the scans that were taken. On each individual scan there are four matches that need be performed, two sides of two profiles. The minimum scale factor of the four (1400) is used to match the 1mm data with the 25μm data.

The scale factor for the X plate data will depend on the extent of the beam in the X dimension. Again a χ^2 minimization is performed and scale factor is found to be ~ 1750.

Once the data has been combined it is fitted to the following functional form

$$F = b + G(A_{core}, \sigma_{core}, mean) + G(A_{halo}, \sigma_{halo}, mean) \quad (1)$$

where the G represents a Gaussian function and b is a constant background term. Both the core Gaussian and the halo Gaussian have the same mean.

RESULTS

Figure 4 shows the X and Y beam profile obtained using a motor speed 0.125mm/sec. A small second Gaussian component is observed with the 1mm wire data, which is too small to be observed with the 25μm wire. The parameters determined by the fit are listed in Table 1. Figure 5 shows the X profile for the same scan using the $1 \times 10\text{mm}^2$ plate data. The parameters determined by the fit to the plate data agree with those obtained with the 1mm, see Table 1 suggesting that the scale factor is properly determined.

Figure 6 shows the X and Y beam profile obtained using a motor speed 0.250mm/sec. These parameters determined by the fit for this scan and others not shown here are tabulated in Table 1.

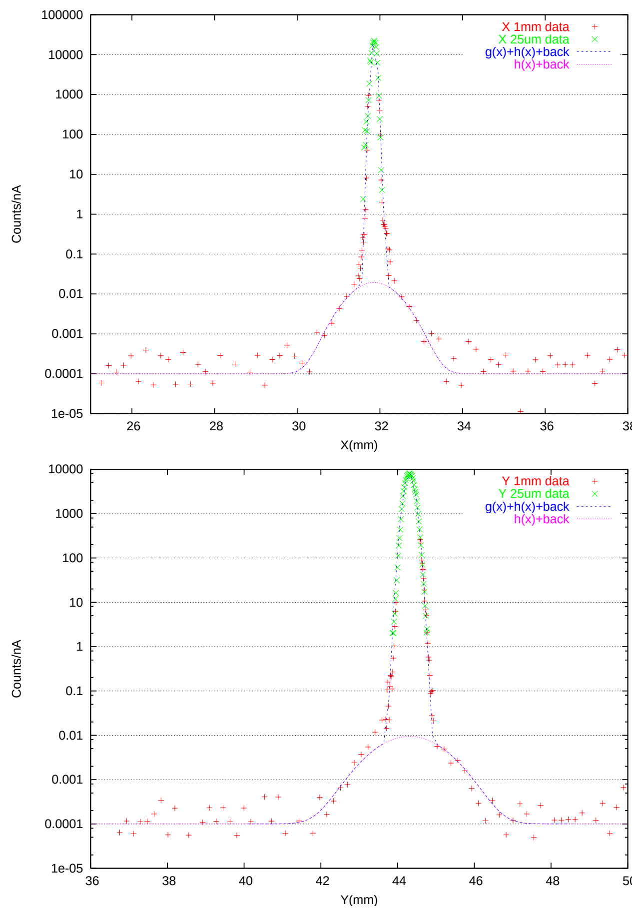


Figure 4: Beam Profile combining the 25μm and 1mm Fe wire data. The top(bottom) plot shows the X(Y) data and results of the fit to the data. The red points represent the 1mm wire data, the green points the 25μm wire data, the blue curve is the overall fit to the data and the red curve is the halo portion of the fit. The ordinate is plotted with a log-scale and the count rate is normalized to the beam current.

The figures show a signal Peak/Noise ratio of $\sim 10^8$ which is an improvement over the existing system. With this increased dynamic range a small second Gaussian component of the beam has been observed in the Hall-B end-station. The source of this second Gaussian is unknown. Scans taken within of few minutes of each other yield consistent results, while scans taken a few days show that the size of the second Gaussian component is changing.

Table 1: Profile parameters obtained by fitting the data to the sum of two Gaussian functions with a common mean for all the scans.

	scan1	scan2 (Fig. 6)	scan3 (Fig 4)	scan3-X plate (Fig 5)	scan4
Date	Dec. 5 17:09	Dec. 9 14:45	Dec. 9 14:51	Dec. 9 14:51	Dec. 10 18:22
σ_{core}[X](mm)	0.045	0.053	0.052	0.052	0.106
σ_{halo}[X](mm)	0.380	0.470	0.494	0.476	0.656
σ_{core}[Y](mm)	0.104	0.111	0.110		0.085
σ_{halo}[Y](mm)	0.949	0.855	0.771		0.617
$\frac{A_{halo}}{A_{core}}$[X]	$4.2 * 10^{-5}$	$1.1 * 10^{-5}$	$8.0 * 10^{-6}$	$7.3 * 10^{-6}$	$3 * 10^{-4}$
$\frac{A_{halo}}{A_{core}}$[Y]	$1.3 * 10^{-5}$	$4.8 * 10^{-6}$	$5.8 * 10^{-6}$		$< 7 * 10^{-5}$
Motor Speed	0.250mm/sec	0.250mm/sec	0.125mm/sec	0.125mm/sec	1.5mm/sec
Wires	25μm/1mm	25μm/1mm	25μm/1mm	25μm/1x10mm^2 plate	50μm

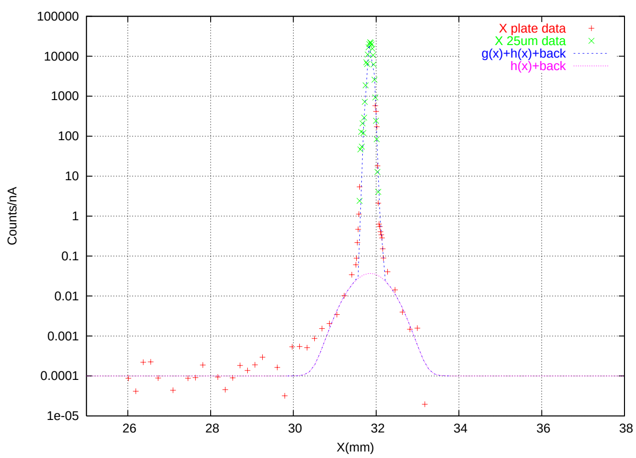


Figure 5: X Beam Profile combining the 25μm and 1×10mm^2 steel plate data. The red points represent the 1mm wire data, the green points the 25μm wire data, the blue curve is the overall fit to the data and the red curve is the halo portion of the fit. The ordinate is plotted with a log-scale and the count rate is normalized to the beam current.

ENERGY RECOVERY TRANSVERSED PROFILES

Large dynamic range beam profile measurements of the energy recovered beam are made with a wire scanner located upstream of the energy recovered beam dump. The wire scanner mechanism is a standard JLAB wire scanner which holds two 25μm W wires.

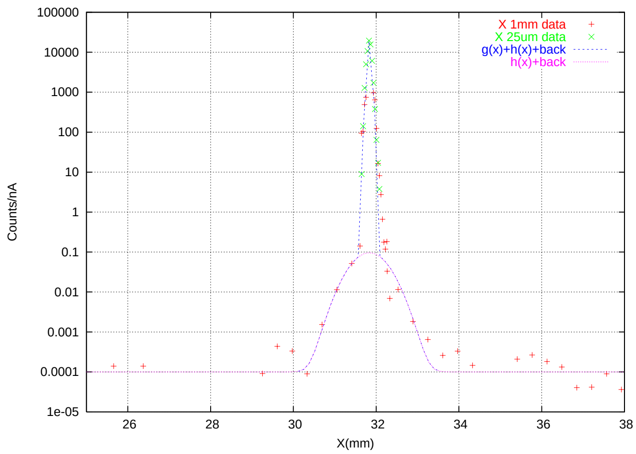
The wire scanner is only 2m upstream of the dump, limiting the choice of locations for the PMTs. Additionally the proximity of the dump causes some concern about high levels of background originating from the beam dump. Three PMTs are located on the beam pipe [beam left, top and right]. The distance between the PMTs and the wire scanner is chosen to maximize acceptance of Møller scattered electrons, just in case the background from the beam dump is an issue. In order to make use of the Møller electrons, the PMTs are operated in “count mode” and the left-right PMTs are used in a coincidence circuit. Background from the beam dump turned out to not be an issue, and the coincidence signal is abandoned.

Figure 7 shows the profile for the 55MeV ER configuration and the profile for the 20MeV ER configuration in shown in Figure 8. The 55MeV profile shows a clean beam distribution over almost five decades of amplitude, with a small distortion on the left of the X profile. The wide horizontal beam profile in the 20MeV ER configuration is what limited the CW beam current delivery during this part of the experiment. In an attempt to measure the profile with beam currents greater than 1μA, one the PMTs is operated in “current mode” during the 20MeV portion of the experiment. The current mode data and count mode data are merged using similar technique as that used for the CLAS integrating plate data.

SUMMARY

Transverse beam profiles with dynamic range of five orders of magnitude are performed regularly in the end-station B transport line. Using integrating plates and wires the dynamic range can in extended another two to three orders of magnitude. Such sensitive profiles show a small second Gaussian component. The diameter of the 1mm integrating wire is comparable to the width of the second Gaussian term and is not fully integrating this source. This might account for the some of the data to prefer a lower scale factor [1400] then the geometric factor [1600]. On the other hand the 1mm$\times$10mm plate is more then sufficient. Changing the X/Y 1mm diameter wires to X/Y 1mm$\times$5mm plates is planned.

The energy recovered transverse beam profile measured in a similar method the routine end-station B shows a well behaved Gaussian shape over five orders of magnitude. In order to achieve the desired six orders of magnitudes, integrating plates are needed. Beam heating of the integrating plates is an issue as the beam currents of the ER experiment range from 1μA to 100μA. Experiments with chemical vapor deposited Silicon Carbide (CVD SiC) suggest that this material can withstand intercepting such beam currents[11] and would make a good choice for an integrating plate.



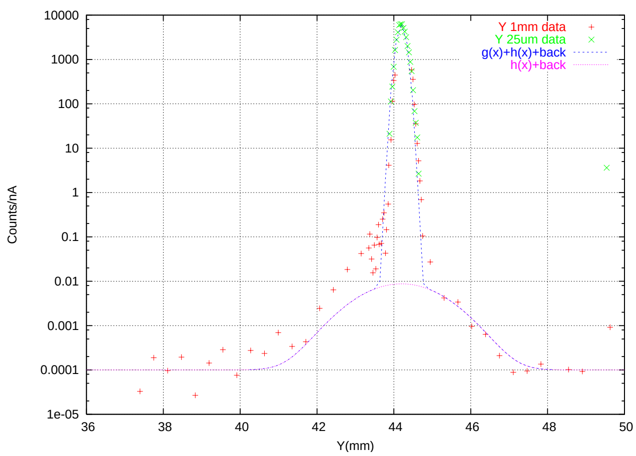


Figure 6: Beam Profile combining the 25μm and 1mm Fe wire data. The top(bottom) plot shows the X(Y) data and results of the fit to the data. The red points represent the 1mm wire data, the green points the 25μm wire data, the blue curve is the overall fit to the data and the red curve is the halo portion of the fit. The ordinate is plotted on a log-scale and the count rate is normalized to the beam current.

ACKNOWLEDGMENTS

The author thanks the Hall-B colleagues and CLAS collaborators for beamtime to perform these measurements. Thanks also to M. Zarecky, P. Hemler and D. Kashy for engineering and design support. The CEBAF operations staff efforts to delivery stable beam during these measurements is also greatly appreciated.

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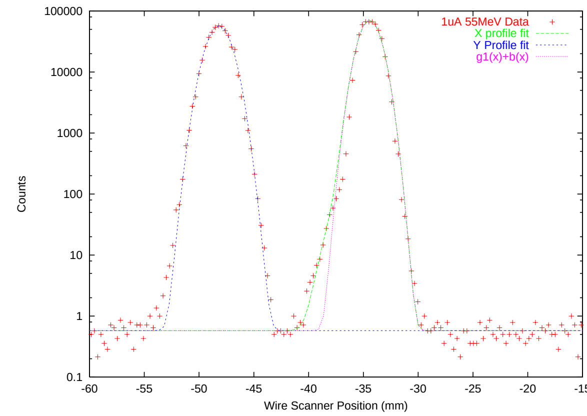

Figure 7: Beam profile after energy recovery for the 55MeV injection configuration.

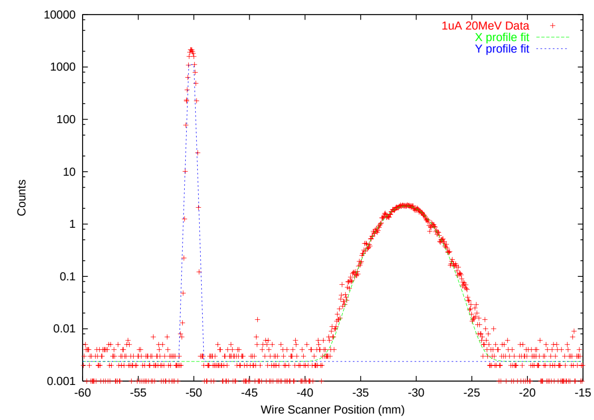

Figure 8: Beam profile after energy recovery for the 20MeV injection configuration.

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