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 (25μm) W or Fe wire and the scattered particle/shower is detected via scintillation or Cerenkov light several meters downstream of the wire. This light is converted to an electrical pulse via photomultiplier tubes (PMT). The PMT readout and wire motion are controlled and synchronized by VME electronics. This report describes results on increasing the dynamic range by using multiple wires of varying diameters. Profile measurements with this large dynamic range can be of use for machines with very large beam currents (e.g. energy recovering linacs) where any fractional beam loss represents a significant amount of beam power[1, 2].

INTRODUCTION

Experiments with the CLAS detector [3] in end-station B (Hall-B) at Jefferson Lab (JLAB) place strict requirements on the beam halo due to the small diameter target window (4mm). The target window frame represents a large amount of material when compared to that of the target. Halo outside of 4mm that interacts in the target frame could easily cause an event rate comparable to that of interactions in the target proper.

The beam profile is measured by correlating a wire scanner position with count rates in PMTs located downstream of the wire scanner. Due to the low operating beam current in Hall-B, typically 1 to 10nA, the PMT's can be operated in "count mode". The electron scatters from the wire via several mechanisms with bremsstrahlung, and Møller scattering dominating. The scattered electron or subsequent shower causes the PMT to respond either by Cerenkov light in the quartz window or by direct impact on the cathode of the PMT. This technique typically measures the beam profile with $Peak/Noise > 10^5$ response.

The dynamic range of 10^5 satisfies the experimenter's requirements, and often the beam profile is Gaussian over the complete dynamic range. In order to observe and measure beam halo with more sensitivity a new wire scanner with wires of multiple diameters was installed. Additionally background suppression using Møller coincidences is explored.

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DESIGN

The wire scanner assembly consists of a linear actuator with 5 inches of travel. The actuator is driven by a stepper motor, which drives the wire support structure into the beam axis. The wire configuration and support frame are shown in Figure 1. 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 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.

The PMTs [4] which detect the resulting scattered electron or shower are located 5m 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). 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 fed to the scaler. These coincidence rates are potentially cleaner than the individual rates, however the individual rates from the quartz only PMT's are already quite clean. 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[5] and PMT scalers[6] are VME modules contained within the same VME crate. EPICS controls[7] 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.

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 read 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

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was delivering beam ($1-40\mu$A) to the other two experimental halls (Halls A & C).

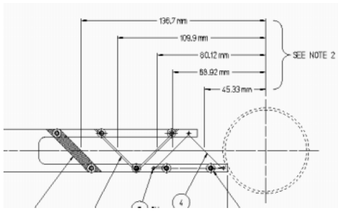

Figure 1: Mechanical schematic of the wire/plate support structure. The thin wire is 25μm in diameter. The thick wire is 1mm in diameter. The plate is 1mm by 10mm. The wire frame is moved into the beam along a 45° axis with respect to the horizontal axis.

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. [8]. The beam size is small compared 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. 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 2 shows the X and Y beam profile obtained using a motor speed 0.125mm/sec. A clear halo 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 3 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 4 shows the X and Y beam profile obtained using a motor speed 0.250mm/sec. This scan also shows a clear halo component, slightly larger than that found in Figure 2. These parameters determined by the fit for this scan and others not shown here are tabulated in Table 1.

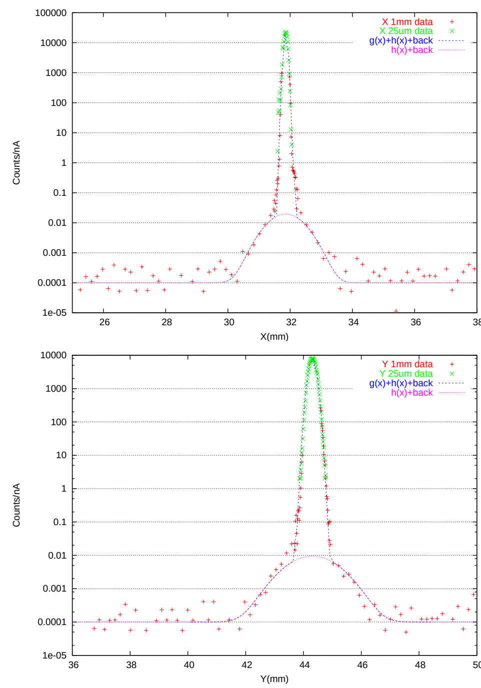

Figure 2: Beam Profile combining the 25μm and 1mm Fe wire data. The top(bottom) plot shows the X(Y) data and results of the fit to the data. The red points represent the 1mm wire data, the green points the 25μm wire data, the blue curve is the overall fit to the data and the red curve is the halo portion 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 small amount of beam halo has been observed in the Hall-B end-station. The source of the halo is unknown. Although the fact that the level of halo changed by several orders magnitude over several days, suggests that the source is an artifact of something changing in the accelerator.

The algorithms to merge the data sets have been developed and will continue to be improved so that the merged profiles can be obtained shortly after the scan has been completed. This will result in a quicker feedback to the operators and perhaps in isolating the source of this halo.

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	scan3	scan3-X plate	scan4
Date	Dec. 5 17:09	Dec. 9 14:45	Dec. 9 14:51	Dec. 9 14:51	Dec. 10 18:22
$\sigma_{core}[\mathrm{X}](mm)$	0.045	0.053	0.052	0.052	0.106
$\sigma_{halo}[\mathrm{X}](mm)$	0.380	0.470	0.494	0.476	0.656
$\sigma_{core}[\mathrm{Y}](mm)$	0.104	0.111	0.110		0.085
$\sigma_{halo}[\mathrm{Y}](mm)$	0.949	0.855	0.771		0.617
$\frac{A_{halo}}{A_{core}}[\mathrm{X}]$	$4.2 * 10^{-5}$	$1.1 * 10^{-5}$	$8.0 * 10^{-6}$	$7.3 * 10^{-6}$	$3 * 10^{-4}$
$\frac{A_{halo}}{A_{core}}[\mathrm{Y}]$	$1.3 * 10^{-5}$	$4.8 * 10^{-6}$	$5.8 * 10^{-6}$		$< 7 * 10^{-5}$
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

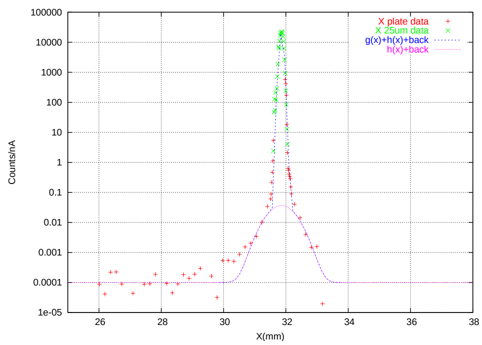

Figure 3: X Beam Profile combining the 25μm and 1×10mm^2 steel plate data. The red points represent the 1mm wire data, the green points the 25μm wire data, the blue curve is the overall fit to the data and the red curve is the halo portion of the fit. The ordinate is plotted with a log-scale and the count rate is normalized to the beam current.

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[2] C. Tennant, *et al.*, “Beam Characterization in the CEBAF-ER Experiment”, these proceedings.

[3] B. Mecking, *et al.*, “The CEBAF Large Acceptance Spectrometer (CLAS)”, to be published in NIM-A 2003.

[4] XP2622 photomultiplier tubes from Photonics Corporation (formerly Phillips), www.photonics.com.

[5] VME VS4 stepper motor control from Oregon Micro Systems, www.omsmotion.com.

[6] VME scaler, VSC16, from Joerger Electronics, www.joergerinc.com.

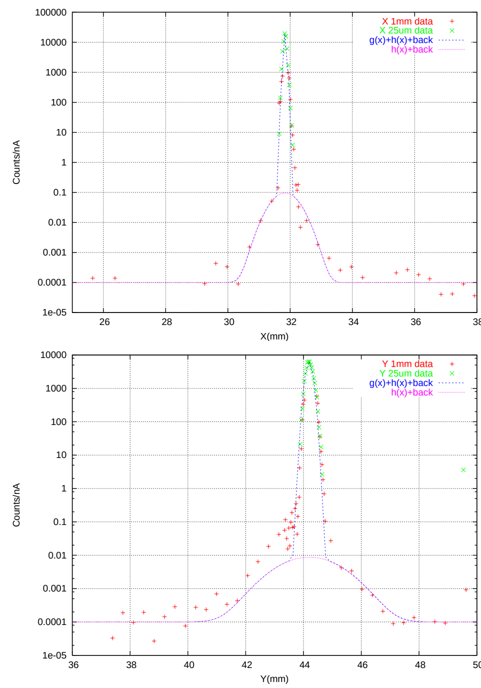

Figure 4: Beam Profile combining the 25μm and 1mm Fe wire data. The top(bottom) plot shows the X(Y) data and results of the fit to the data. The red points represent the 1mm wire data, the green points the 25μm wire data, the blue curve is the overall fit to the data and the red curve is the halo portion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

[7] Experimental Physics and Industrial Control System (EPICS), http://www.aps.anl.gov/epics.

[8] J.H. Kamperschroer, *et al.*, “Analysis of Data from the LEDA Wire Scanner/Halo Scraper”, Proceedings of the 2001 Particle Accelerator Conference, Chicago.