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Beam Charge Measurement for E97-110

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Abstract

This report describes the charge determination for Jefferson Lab Hall A experiment E97-110. A brief summary of the beam current monitors (BCMs) and their calibration is given. The remainder of this report details how the BCM offsets were obtained for the second run period.

1 Introduction

For experiment E97-110, asymmetries and cross sections were measured for polarized electron scattering from polarized ^{3}He. One of the essential quantities needed for these measurements is the beam current to determine the number of incident electrons on the target. Since the beam current's uncertainty goes directly into the cross section uncertainty, determining the current accurately reduces the uncertainty on the cross section measurement. The first section of this report will give a brief overview of the Hall A beam current monitors (BCMs) and their calibration. The second section will address the BCM offsets and issues related to their variation during the experimental run period

2 Beam Charge Measurement

The beam current is measured by two beam current monitors (BCMs), which are located 25 cm upstream from the target. The BCMs are stainless steel cylindrical high-Q ($\sim$ 3000) waveguides that are tuned to the beam's frequency (1497 MHz) [1]. The voltage levels at their outputs are proportional to the beam current. The RF output signals from the cavities are then split into two parts: sampled and integrated data. In between the two BCM cavities is an Unser Monitor (Parametric Current Transformer) which provides an absolute measurement of the current and can be used to calibrate the cavities. However since the Unser's output signal drifts over a time period of several minutes, it is not used for continuous current monitoring. For this experiment, the Faraday cup was used in the calibration [2], and the Unser was used as a crosscheck of the calibration.

The sampled data are processed by a high-precision digital AC voltmeter. The digital output of the voltmeter represents the RMS of the input signal once every second. The output is then recorded every 1–2 s by the data logging process. The integrated data are sent to an RMS-to-DC converter and then to a voltage-to-frequency converter. The output frequency is then sent to the VME scalers and injected into the data stream. The scalers accumulate during the run and each BCM scaler provides a number proportional to the time-integrated voltage level, which represents the total beam charge. The RMS-to-DC output is linear for currents between 5 to 200 μA. A set of amplifers were introduced with gain factors of 1, 3 and 10 to extend the linearity below 5 μA.

The beam current and hence charge, $Q_a = I_a t$, is obtained from the BCM scaler reading as follows:

$$I_a = \frac{\frac{N_a}{t} - f_a}{k_a}, \quad (1)$$

where a = 1, 3, 10 is the gain factor, t is the time for each run (in seconds) and N_a is the BCM scaler reading for each gain factor. The calibration constants k_a and BCM offsets f_a are determined from calibration runs. For E97-110, the calibration was performed during the experiment in August 2003 [3]. The values of the calibration constants are give in Table 1, and compared to earlier calibrations [2], these results vary by $< 1\%$. The offsets are discussed in Section 3.

Amplification	Upstream Cavity	Downstream Cavity
1	1338.4	1335.5
3	4100.7	4140.9
10	12467.5	13015.1

Table 1: The E97-110 BCM calibration constants [3].

3 BCM Offsets

3.1 Helicity Ungated Offsets

The BCM offsets are determined from the calibration runs during the periods without beam delivery to the experimental hall. The time dependence of the offsets were checked by using runs with periods without beam or cosmic runs and were expected to be reasonably stable during the experiment. Figure 1 shows the offset rate in Hertz for the upstream and downstream BCMs for the three amplification factors. The offset values for each run were determined by averaging the scaler readings for each BCM over the entire run.

Unfortunately the offsets were not stable during the experiment. Around 300 hours, the offset rate for the upstream BCM signal dropped for all three gain factors and also for the downstream BCM with x1 amplification. The upstream x1 gain signal recovered and was slightly higer than it was before the drop. The other three BCM signals remained small or close to zero for the remainder of the experimental run period. The cause of the drop remains unknown. The downstream BCM with gain factor x10 was also seen to fluctuate between 140 and 280 Hz, especially after the experiment had run 500 hours.

For experiment E97-110, the data were taken with beam currents between 0.5 and 10 μA. For currents above 5μA, the x3 gain signals were used, and below 5μA, the x10 gain signals were used. The x1 gain signals were not used in the data analysis. At 1μA, the uncertainty in the BCM offsets becomes significant and can result in an uncertainty of $\sim 1\%$ in the charge. Since the charge goes directly into the cross section measurement, minimizing the uncertainty due to the BCM offsets is important. Instead of using a constant offset for the 6 BCM signals for the entire run period, further analysis was conducted to determine offsets for periods when the offsets changed.

For the four BCM signals where the offset rate dropped, the run period was typically broken into three time periods: before the drop, during the drop and after the drop. Since the offsets are reasonably stable before and after the drop, the offsets for each run during the two periods were averaged together. For the upstream x1 gain signal, a linear interpolation was used after the drop period. The drop period occurred between runs 2632 and 2697, which affects 49 production runs. Upon further investigation, runs 2685 and 2686 indicate that the drop occurred over a few runs. The offsets during this period were obtained by using a linear interpolation between the runs right before, during and right after the drop.

Since the downstream x3 gain signal was reasonably stable, the offsets for all the runs were averaged together. A more careful analysis was done for the downstream x10 BCM. The offsets for this BCM were broken up into four time periods. For the 6° data, a linear interpolation was used. The remaining three time periods are associated with the 9° data. Here the offsets for each run were averaged together for each period. There were two runs for the downstream x10 BCM that had offset rates around 280 Hz. The runs in this period were taken with the beam current at 10μA. These offsets can be safely ignored, since the BCMs with x3 gain factors are used instead. The offsets from the analysis described above are given in Table 2. The table also provides the uncertainty on the offsets, the range of runs for each offset, and the time period in hours where each offset is valid. For the periods when a linear interpolation was used, the range of offsets is given.

BCM	Offset (Hz)	Uncertainty	Range (Run #)	Time (hours)
u1	163.6	0.8	2284 - 2632	29.8 - 290.07
u1	191.6	0.1	2697 - 2703	313.6 - 321.4
u1	168.6 - 178.0	2.0	2778 - 4217	372.9 - 1226.95
d1	56.0	0.9	2284 - 2632	29.8 - 290.07
d1	19.1 - 57.8	16.0	2643 - 2685	290.0 - 307.6
d1	3.4	0.6	2686 - 4217	307.6 - 1226.95
u3	129.1	1.0	2284 - 2632	29.8 - 290.07
u3	63.7 - 132.1	28.3	2643 - 2685	290.0 - 307.6
u3	37.7	1.1	2686 - 4217	307.6 - 1226.95
d3	88.2	0.9	2284 - 4217	29.8 - 1226.95
u10	97.6	2.4	2284 - 2632	29.8 - 290.07
u10	52.6 - 93.4	17.9	2643 - 2685	290.0 - 307.6
u10	1.25 - 26.9	5.2	2686 - 2697	307.69 - 313.7
u10	1.3	0.4	2698 - 4217	313.6 - 1226.95
d10	152.0 - 171.3	2.0	2284 - 3265	29.8 - 716.4
d10	225.4	1.1	3485 - 3486	835.2 - 837.8
d10	150.6	5.6	3486 - 3854	854.0 - 1036.5
d10	210.3	19.5	4073 - 4217	1144.5 - 1226.95

Table 2: The BCM offsets and their uncertainties as described in the text.

When the offset was determined by averaging several runs together, the uncertainty was determined by calculating the uncertainty of the mean. For the drop period, the maximum uncertainty was determined by using the difference between the offset before the drop and the calculated offset from the linear interpolation throughout the drop time period. This method is represented in Eq. (2).

$$\sigma_{\text{offset}} = \sqrt{\sum_{i=t_{\text{min}}}^{t_{\text{max}}} \frac{\left[f_{\text{b}} - (p_0 + p_1 * i)\right]^2}{N(N-1)}} \tag{2}$$

Here f_{b} is the BCM offset before the drop, t_{min} and t_{max} are the time limits corresponding to the drop period, and p_0 and p_1 are the constant and slope coefficients from the linear

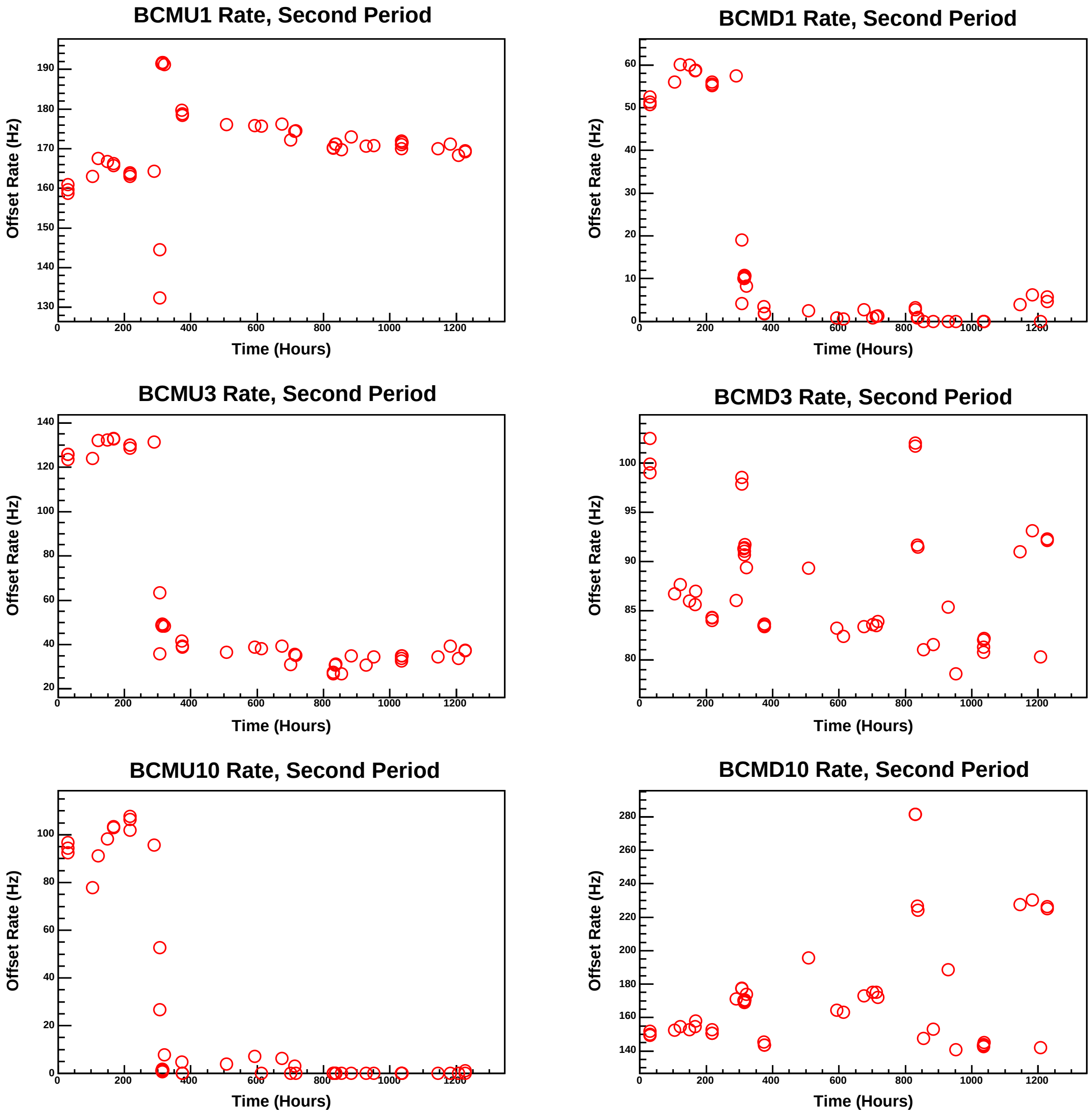

Figure 1: The BCM offset rates for the upstream (left) and downstream (right) BCMs for gain factors of 1 (top), 3 (middle), and 10 (bottom). The horizontal axis represents days since the start of the second run period.

interpolation. These coefficients are given in Table 3. The summation in Eq. (2) was performed for each hour between t_{min} and t_{max} for a total number of N samples (hours).

BCM	p_0 (Hz)	p_1 (Hz/hr)	Time (hours)
u1	182.1	–0.011	372.9 - 1226.95
d1	694.9	–2.197	290.0 - 307.6
u3	1259.0	–3.886	290.0 - 307.6
u10	810.2	–2.463	290.0 - 307.6
u10	1342.0	–4.274	307.69 - 313.7
d10	151.5	0.034	29.8 - 716.4

Table 3: The linear interpolation coefficients and the time period in hours where they are valid.

3.2 Helicity Gated Offsets

The discussion in Section 3.1 was restricted to the scalers ungated by the helicity signal. The BCM offsets gated and ungated by helicity should be similar. These offsets were checked to avoid unintentionally creating a charge asymmetry between electrons with '+' and '–' helicity signals. A representative sample of runs were chosen to study the helicity gated offsets throughout the experimental run period. The results of this study are summarized in Table 4.

BCM	Range (Run #)	Δoffset '+' (Hz)	Δoffset '–' (Hz)
u1	2284 – 4217	–1.1	0.8
d1	2284 – 2786	–1.1	1.3
d1	2787 – 4217	–0.2	0.6
u3	2284 – 4217	–1.0	1.1
d3	2284 – 4217	–1.0	1.1
u10	2284 – 2786	–0.8	1.0
u10	2787 – 4217	0.1	0.3
d10	2284 – 4217	–1.0	1.1

Table 4: The difference between helicity gated and ungated BCM offsets.

The table shows the difference between the helicity gated and ungated offsets for the two helicity pulses. Typically the offsets for the '+' BCM signals were 1 Hz less than the ungated offsets, and the '–' BCM signals were 1 Hz greater than the ungated offsets. Since the differences are small compared to the BCM signals at 1μA, an uncertainty of 0.5 Hz was assigned to the differences in Table 4. For the data analysis, the helicity gated offset differences were taken into account. For the helicity gated signals, the total offset uncertainty is given by adding the ungated offset uncertainty in quadrature with the gated offset uncertainty.

References

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[2] M. Jones, Report on BCM calibration for Nov 13 2002 run, Technical Report, (2002).

[3] T. Holmstrom, (private communication).