Recalibration of the Brookhaven 200-MeV Polarimeter

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Introduction

Since the installation of the new polarized ion source (OPPIS), beam currents at the end of the Brookhaven LINAC have increased substantially so that instantaneous rates of 200 μA have become become typical. At this current, the scintillation detectors used to observe p+C scattering at 12° and 16° overloaded, and polarization measurements were unstable. To combat this problem, the horizontal plane detectors at 12° were moved to a much larger distance. Lead shielding and a collimator were included to restrict the observed charged particles to an origin at the target. The size of the carbon target was reduced. At the same time, the optics of this part of the beam line were improved to make a tighter beam spot in the hope that this would reduce the contribution from scattering off thick parts of the target ladder. On a strip target such as the carbon fiber used at the LINAC, this improvement tends to increase the rate. This raised the question of whether the calibration, made in 1982 at IUCF [1] and reported in 1989 [2], remained valid. Knowing the polarization at the end of the LINAC is crucial in evaluating whether there are significant losses in the polarization as the beam goes through the Booster and the early stages of AGS acceleration.

It was suggested in early 2001 that if a setup could be constructed that would observe p+d elastic scattering, then it would be possible to make use of the very precise analyzing powers measured as part of the polarimeter calibration at IUCF [3,4]. For a deuteron recoil angle of 42.6° in the lab and a laboratory energy of 200 MeV, the analyzing power is known to be $A = 0.507 \pm 0.002$. At the same time, the cross section is 2–3 orders of magnitude less than that for proton inclusive scattering. So p+d scattering cannot yield polarization values within a few minutes as do the 12° counters based on p+C scattering. One way to proceed is to use p+d scattering in a longer run to calibrate p+C scattering, which would then serve for routine measurements. Thus the design of the running involved interleaving p+C and p+d runs by swapping targets under conditions where the beam polarization was believed to be sufficiently stable to permit good time averages to be computed.

Scintillators were gathered at IUCF and mounted in a new setup. A series of CD_2 targets were installed on the target ladder. In runs in July and August, 2001, an initial electronics setup was shaken out. By August, it was possible to record one event for every pulse. A fraction of these were p+d elastic scattering events. The cross section for p+d elastic scattering is less than 1 mb/sr, about 1000 times less than the cross section for p+C scattering. The p+d events gave a reasonably clean signature in scintillator pulse height and relative timing of the deuteron and proton detector arms. To prevent signal deterioration, LINAC beam currents were kept below 50 μA instantaneous current. Under good conditions, the polarized beam intensity can be in the 200–300 μA range.

During the summer and early fall, various changes were made to the scintillators used to record p+d scattering, mostly to remove background in the form of a high instantaneous rate of protons. In the end, the deuteron detector telescope consisted of a degrader and three scintillators whose thicknesses were chosen so that deuterons from p+d scattering would stop in the second scintillator. The third then became a veto. The two proton arm detectors for each side were salvaged from the 16° p+C setup where they had run without absorbers. At $\theta_{\rm lab} = 64.1°$, the scattered proton angle, we ran with a 2.54-cm thick aluminum absorber. Protons from p+d scattering still travelled all the way through both detectors, but the energy deposited exceeded by a significant amount the energy from protons scattered near beam energy from carbon.

Later in the fall, the data acquisition was upgraded to allow more events to be recorded within a single LINAC pulse, consistent with the dead times for making the analog-to-digital conversion. By December, it was possible to repeat the calibration tests, and the p+d polarimeter was run for much of the RHIC polarized beam time through the end of January.

The p+d polarimeter system was run at various times during the spring of 2002 to check improvements made to OPPIS. Those tests will not be covered here.

August Calibration Run

Over the period of a few days, p+d events were collected and interspersed with periodic measurements of the beam polarization using p+C scattering at 12°. Data were also collected on the number of triggers in the p+d system as well as the rates in the 12° detectors with the CD_2 target material in place. Neither of these proved useful for routine polarimetry. The p+d coincidence rate contained too many random events, and PMT gain issues discussed below rendered the CD_2 rate in the forward scintillators useless.

Offline, the computer files containing p+d events were reanalyzed. Lower bounds were inserted on the acceptable pulse heights for each detector. Spectra were created to show the time-of-arrival difference between signals in the deuteron and protons arms, and these spectra were used to calculate the number of events for left or right scattering. A correction was made for random coincidences by subtracting the events recorded in a peak-width span at a time difference removed from the p+d peak.

The original calibration by Khiani [2] gave $A = 0.620 \pm 0.004$ for p+C inclusive scattering at $\theta_{\rm lab} = 12°$. This produced an average beam polarization of $p = 0.640 \pm 0.003$. Over the same time period, p+d runs gave a value after analysis of $p = 0.688 \pm 0.015$. In order to produce such a value, the p+C analyzing power would need to be reduced to $A = 0.576 \pm 0.013$, a 7% change. This goes in the direction neeeded to resolve a long-standing dissagreement with polarizations measured using p+C at $\theta_{\rm lab} = 16°$. For that angle, Khiari reports that $A = 0.511 \pm 0.004$, a value that produces a larger polarization than the 12° measurements by about 5% [5]. Unfortunately, the newer p+C analyzing powers now contradict a global analysis of p+C scattering reported by McNaughton [6]. His smoothed analyzing powers are $A = 0.616$ at $\theta_{\rm lab} = 12°$ and $A = 0.556$ at $\theta_{\rm lab} = 16°$, thus supporting the old analyzing power of Khiari at $\theta_{\rm lab} = 12°$ and suggesting that the value at $\theta_{\rm lab} = 16°$ is too low.

In order to check these results for reproducibility, we decided to repeat the calibration of the LINAC polarimeter again during the spin commissioning in December, 2001.

December Calibration Run

The slow ADCs and TDCs from the August calibration were replaced by FERA readout into a CAMAC buffer. This allowed several events to be recorded and stored during a single beam pulse without the overhead of CAMAC readout into a computer. The front ΔE scintillators and the back veto scintillators in the deuteron arms were made smaller to reduce random rates. Incidentally, a programmable discriminator used previously to select signals from the scintillators was replaced with a fixed discriminator located in the LINAC tunnel with levels set to what was found to work best during the previous run. With the new scintillators, it was necessary to check voltage and timing settings to obtain optimum performance.

The calibration again consisted of interleaving p+C runs with p+d runs with the idea that the ratio of the beam polarization measured with these two systems was a check of the p+C calibration. Additionally, scaler readout with the CD_2 target was made using both p+C rates and p+d coincident rates to see whether either of these could also serve as a measure of the beam polarization.

In order that this operation be practical during the AGS polarized beam development, periodic switching of the beam from the Booster to the straight-through line at the LINAC where the polarimeter is located was implemented. The rate for the p+d system still needed to be reduced, and one of the quadrupoles was defocussed, also in beam sharing mode, so that the calibration was made at a smaller current. This procedure may increase detector rates if the tails of the beam reach the target frame.

Despite improvements to the data acquisition, the overall p+d rate turned out again to be low. In part, this was due to the fact that with beam sharing, only 1 pulse every 5 seconds was available in the polarimeter line. Second, for reasons discussed in more detail below, rate problems with the p+d scintillator systems forced operation at the edge of the beam spot where currents were effectively less than about 20 μA, again cutting rate. Thus this calibration was spread out over four days of running.

During the calibration, beam polarizations recorded by p+C scattering varied between 0.67 and 0.71. These variations were treated as real, and could be associated with changes in the operation of the ion source between pulsed and DC mode in the ionizer. The changes from one mode to another served to keep the ionizer cleaner, and this helped to maintain a higher polarization. Beam polarization ratios between p+C and p+d scattering were calculated only for runs that came together during a single mode. Only the ratios were averaged over the whole calibration.

The electronics was set so that only the higher pulse height signals associated with p+d scattering were allowed to generate the logic signals going into the coincidence between the deuteron and proton arms. Later, even higher cuts were placed on the pulse height signals for analysis. Upper cuts were avoided since there was evidence for pileup of real events in the pulse height spectra. The time peak for p+d scattering remained narrow. Summing was made in the time spectrum, gated on correct scintillator pulse height. A small background of randoms, no more than a few percent, was subtracted from the time peak as needed.

The ratio of the beam polarization measured with p+d scattering to that measured with p+C scattering was found to be

$$p_{\rm d}/p_{\rm C} = 0.987 \pm 0.014,$$

a value consistent with one. Detailed polarimeter measurements for each stable ion source cycle are listed in Table I. Because systematic errors are likely to increase this statistical error, there is no recommendation from this calibration that the analyzing power used in the p+C analysis be changed. But the previous ratio of $p_{\rm d}/p_{\rm C} = 1.08 \pm 0.02$ from the August calibration was not reproduced. For both runs the polarization measured with p+C scattering was similar.

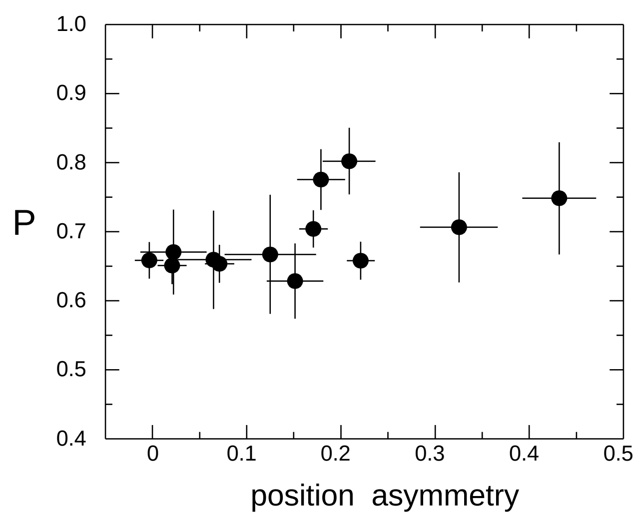
Table I. Partial Results from December Calibration

Cycle	p(p + C)	p(p + d)	$p_{\rm d}/p_{\rm C}$
1	0.673 ± 0.004	0.663 ± 0.023	0.986 ± 0.035
2	0.703 ± 0.006	0.693 ± 0.044	0.986 ± 0.063
3	0.673 ± 0.005	0.688 ± 0.024	1.023 ± 0.036
4	0.722 ± 0.007	0.776 ± 0.044	1.074 ± 0.062
5	0.722 ± 0.007	0.802 ± 0.048	1.112 ± 0.067
6	0.710 ± 0.005	0.656 ± 0.020	0.924 ± 0.029
average			0.987 ± 0.017

Systematic Errors

The main difficulty with both the p+C and p+d systems was the sensitivity of the photomultiplier tubes to rate.

Figure 1: Correlation between p+d polarizations measured during the August run and the geometrical asymmetry, (L–R)/(L+R), for the rates recorded by the left and right scattering systems.



In the p+d case, too high a rate would cause the gain to drop, and the signals of interest would fall below the discriminator cutoff. Under different running conditions, gains were observed to change by a factor of a few. In all cases, measurements were made at rates that caused the PMT gain to saturate, a phenomenon that could easily be observed by tracking the time dependence of the falling pulse height at the beginning of the LINAC pulse. During the August run, stable but still saturated conditions were found with currents of 50 μA. In December with the beam current still 50 μA, the CD_2 target was placed at the edge of the beam in such a place that the effective current was in the range of 10 - 20 μA. Only at this level was it possible to keep the p+d signals above threshold with enough efficiency that the rates for left and right scattering were comparable. Some short runs were made in which the efficiency of the right-hand system was lower by perhaps a factor of two than the left-hand system. In these cases, there is some indication (weak statistics) that the polarization is systematically larger. Figure 1 shows that the scatter plot of p+d polarization tends to rise with positive geometrical asymmetry (unpolarized rates to beam left exceed those to beam right). This effect has this sign because the p+d analyzing power is negative (we use a positive A for the deuteron) while proton inclusive analyzing powers are positive.

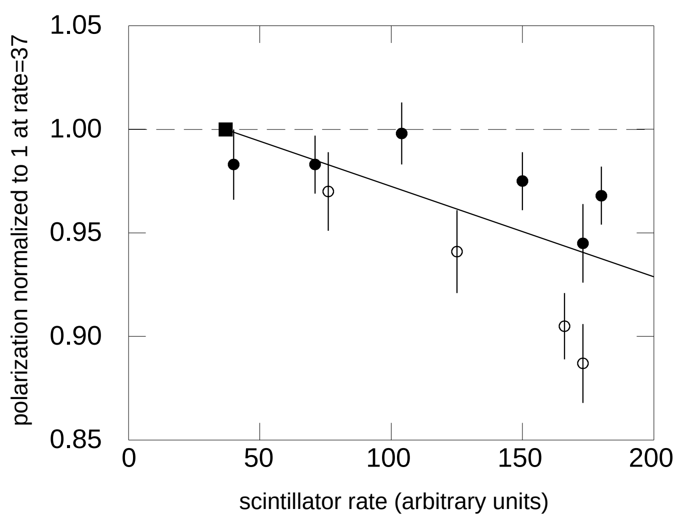


Figure 2: Ratio of the p+C polarization, as a function of the p+C rate, to the polarization measured at the lowest rate. The beam currents were adjusted by defocussing LINAC quad 14 (solid) or closing slits (open).

For the p+C system, there is also a reduction in photomultiplier gain with increasing rate. Here the effects are not as severe. Since the positive analyzing power is associated with the primary proton rate into these scintillators, the effect of reduced gain shows up as a smaller polarization value. A number of tests were made during the course of the December run comparing p+C measurements at beam currents between 50 and 200 μA. Figure 2 shows two such scans in which the beam current was controlled by defocussing LINAC quad 14 (solid points) or closing slits near OPPIS (open points). The horizontal axis is scintillator rate in arbitrary units. For both scans, polarizations are divided by the polarization at the lowest rate (37) to show the percentage reduction. A linear fit is included as a guide to the eye. (The rate values correspond roughly to linac beam current in μA.) Additional checks gave qualitatively similar results. It is important to keep these changes in mind when interpreting the results of p+C polarization measurements.

The experience with rate limitations suggests that there are systematic effects whose contribution to the calibration error exceeds the statistical error quoted above. An estimate of 0.02 or even 0.03 would appear to be appropriate.

It would be desirable to have polarization measurements that are less sensitive to beam currents for currents typically used at the LINAC. For this, it will be necessary to further alter both the p+C and p+d systems to be more rate tolerant.

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[2] F.Z. Khiari *et al.*, Phys. Rev. D **39**, 45 (1989).
[3] S.P. Wells *et al.*, Nucl. Instrum. Methods **A325**, 205 (1993).
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[5] A. Zelenski, private communication.
[6] M.W. McNaughton *et al.*, Nucl. Instrum. Methods **A241**, 435 (1985).