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LARGE DEVIATIONS FROM THE POLARIZATION-ANALYZING POWER EQUALITY AND IMPLIED BREAKDOWN OF TIME REVERSAL INVARIANCE

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I am reporting here on the first test that compares the polarization (P) and the analyzing power (A) from measurements in a nuclear reaction and its inverse. We find an astonishingly large P-A difference. The clear implication is that time-reversal invariance (TRI) is broken in some component of the nuclear interaction, since the polarization-analyzing power equality follows directly from TRI.[1] Thus, in view of the fundamental position that the P-A theorem has held in spin-polarization physics, both in theory and experiment, I would be very surprised if the vast majority of you do not view our results with some skepticism. I am sure that you will not disappoint me.

The reactions chosen for the P-A comparisons were the two-nucleon transfers $^7Li(^3He,p)^9Be$ and $^9Be(^3He,p)^{11}B$, with 14-MeV incident ^3He ions, and their inverses studied at the same CM energies. The Q-values are large, implying considerable mass, energy, and momentum rearrangement. The experiments were initiated by the Laval group (R. J. Slobodrian, C. Rioux, R. Roy) through the measurements of the proton polarizations in the (^3He, $\vec{p}$) reactions, and results have already been published.[2] The analyzing powers in the inverse ($\vec{p}$, ^3He) reactions were measured at Berkeley (H. E. Conzett, P. von Rossen, F. Hinterberger, the latter two from the University of Bonn, plus the Laval Group).

Before showing our results, I will discuss briefly some of the previous P-A comparisons, all of which used elastic proton scattering.

The most accurate of these were made on $p+^3He$[3] and $p+^{13}C$[4]; it is necessary to scatter from a non-zero spin nucleus, otherwise parity conservation alone ensures that P=A. We have found[5] that neither of these comparisons was accurate enough to provide a significant test of TRI, because the equality between P and A depends on the equality of the two possible spin-flip probabilities. And, it is now know from measurements of the depolarization in p-nucleus elastic scattering that the spin-flip probabilities are very small,[6] which leads to P-A≈0 even if the probabilities are not equal as required by TRI. As shown in Ref. 4,

$$P-A = (\sigma^{-+} - \sigma^{+-})/\sigma \quad , \tag{1}$$

where σ^{-+} is the cross section for the scattering of a proton from an initial negative spin-state to a final positive spin-state, and $\sigma = (\sigma^{++} + \sigma^{+-} + \sigma^{-+} + \sigma^{--})/2$. The positive (+y) direction is along $\vec{k}_i \times \vec{k}_f$, and $\sigma^{-+} = \sigma^{+-}$ under TRI. Since the depolarization parameter is given by

$$D = 1-2S \tag{2}$$

with the (total) spin-flip probability

$$S = (\sigma^{+-} + \sigma^{-+})/2\sigma \quad , \tag{3}$$

measurements of D provide determinations of S. Now assume, for example, that $\sigma^{+-} = 2\sigma^{-+}$, which would be a clear and substantial breaking of TRI. Then, from Eqs. (1)-(3)

$$|P-A| = (1-D)/3 \quad . \tag{4}$$

From the measurement[7] of 1-D = 0.05±0.03 close to the energy and angle of the p-^{3}He experiment[3] and an estimate[5] of 1-D ≤ 0.06±0.02 at the energy and angle of the p-^{13}C experiment,[4] Eq. (4) gives |P-A| ≤ 0.017 and 0.02, respectively. These values are essentially as small as the experimental errors in these P-A comparisons, so the experiments do not provide tests of TRI.

It is immediately obvious from this discussion that tests of TRI using the P-A equality should be made through measurements in a reaction and its inverse where the spin-flip probability is expected or known to be large, and this is so for the reactions reported here.[2]

Since spin-exchange forces are well known components of the nucleon-nucleon interaction, we have also examined the, perhaps, most recent test of TRI in p-p scattering.[8] We have found[5] that here, also, no test of TRI was really made. The experiment used a 430-MeV beam of polarized protons, with the polarization vector lying in the scattering plane and oriented at 45° to the beam direction. After scattering once to the left and once to the right at $\theta_L = 30°$, the in-plane polarization orientations for the separate scatterings were compared. We find that the reported result follows directly from invariance with respect to rotation about the beam axis, so TRI was not tested. Again, it follows from the discussion above that tests of TRI in the basic nucleon-nucleon interaction should be made in p-p and/or n-p scattering through comparisons of P and A at energies and angles for which the quantity (1-D) is maximized.

So now let us turn to our measurements. The (^{3}He,$\vec{p}$) proton polarizations were measured with a pair of Si polarimeters, placed at equal left-right reaction angles. The Si polarimeter combines the high scattering efficiency of a thick analyzer with the good energy resolution obtained by adding the ΔE pulse from the analyzer detector to each of the E pulses from the left and right stopping detectors. Sample spectra from the $^{9}Be(^{3}He,\vec{p})^{11}B$ reaction are shown in Fig. 1. The ^{11}B ground-state peak is clearly resolved. Figure 2 shows sample spectra from left and right detector systems in determinations of the $^{11}B(\vec{p},^{3}He)^{9}Be$ analyzing powers. Again, the ^{9}Be ground-state peak is clearly separated.

In Fig. 3 are shown our P and A measurements in the $^{9}Be(^{3}He,\vec{p})^{11}B$ reaction. The open and closed circles represent two separate measurements of A. The solid triangles are the original P results with the intermediate energy bite (due to target thickness and beam energy-width) indicated by an arrow on the energy scale near the bottom of the figure. The open triangles are later checks of the original data. The solid squares are measurements made with a completely independent polarimeter at Berkeley and with the largest energy bite indicated. Finally, the inverted open triangles are measurements with the smallest energy bite. There is evidence for a decrease in P as the energy bite is increased, which is not unexpected. In any event, the smallest energy bite for the P measurement is nearest to the energy bite sampled in the A measurement (also indicated), and for this we find the largest P-A difference. In Fig. 4 is shown an excitation function of A at 37° lab, which is near the peak of A shown in Fig. 3. Over an energy span of some 800 keV, about 400 keV on either side of our original energy, we find a smooth variation of A. Thus, there are no sharp increases in A that could move its value closer to P with a small shift in the energy.

Figure 5 shows our P and A measurements in the $^{7}Li(^{3}He,\vec{p})^{9}Be$ reaction. The closed circles are the A values. The solid triangles are the original P results, and the open triangles are remeasurements. Again, the inverted triangles are thinner target results, and the energy bites are indicated as in Fig. 3. The large P-A differences shown here are, as I said, clearly astonishing.

In summary, then, we have found large differences between P in the $^{7}Li(^{3}He,p)^{9}Be$ and $^{9}Be(^{3}He,p)^{11}B$ reactions and A in their inverse processes. Since such an inequality between P (in a reaction) and A (in its inverse) directly implies a breakdown of TRI, it follows that this is clear evidence that the interaction of nuclear particles is not time-reversal invariant. Clearly, many more experiments are necessary to explore in detail the TRI breaking interactions.

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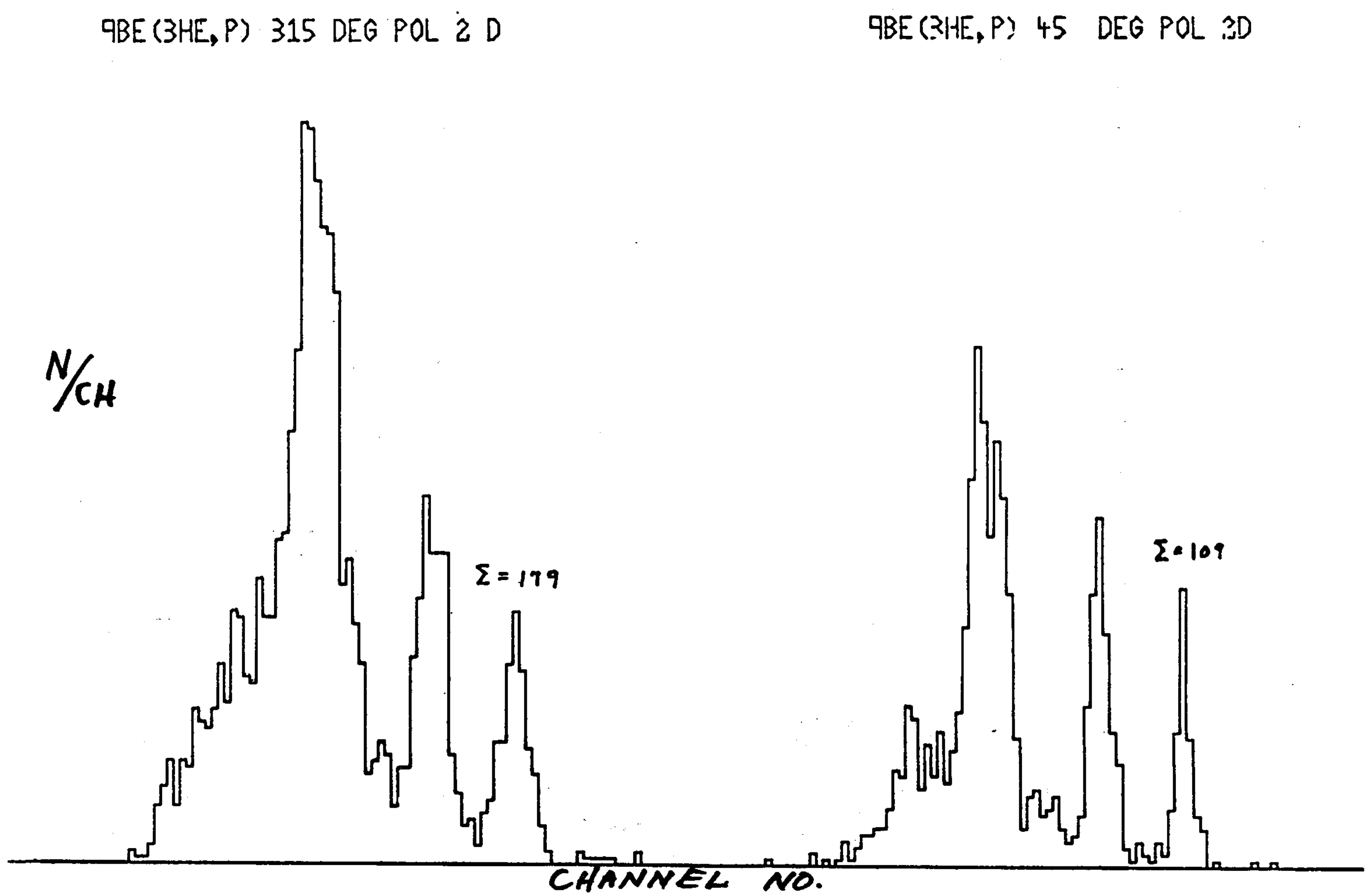

Figure 1

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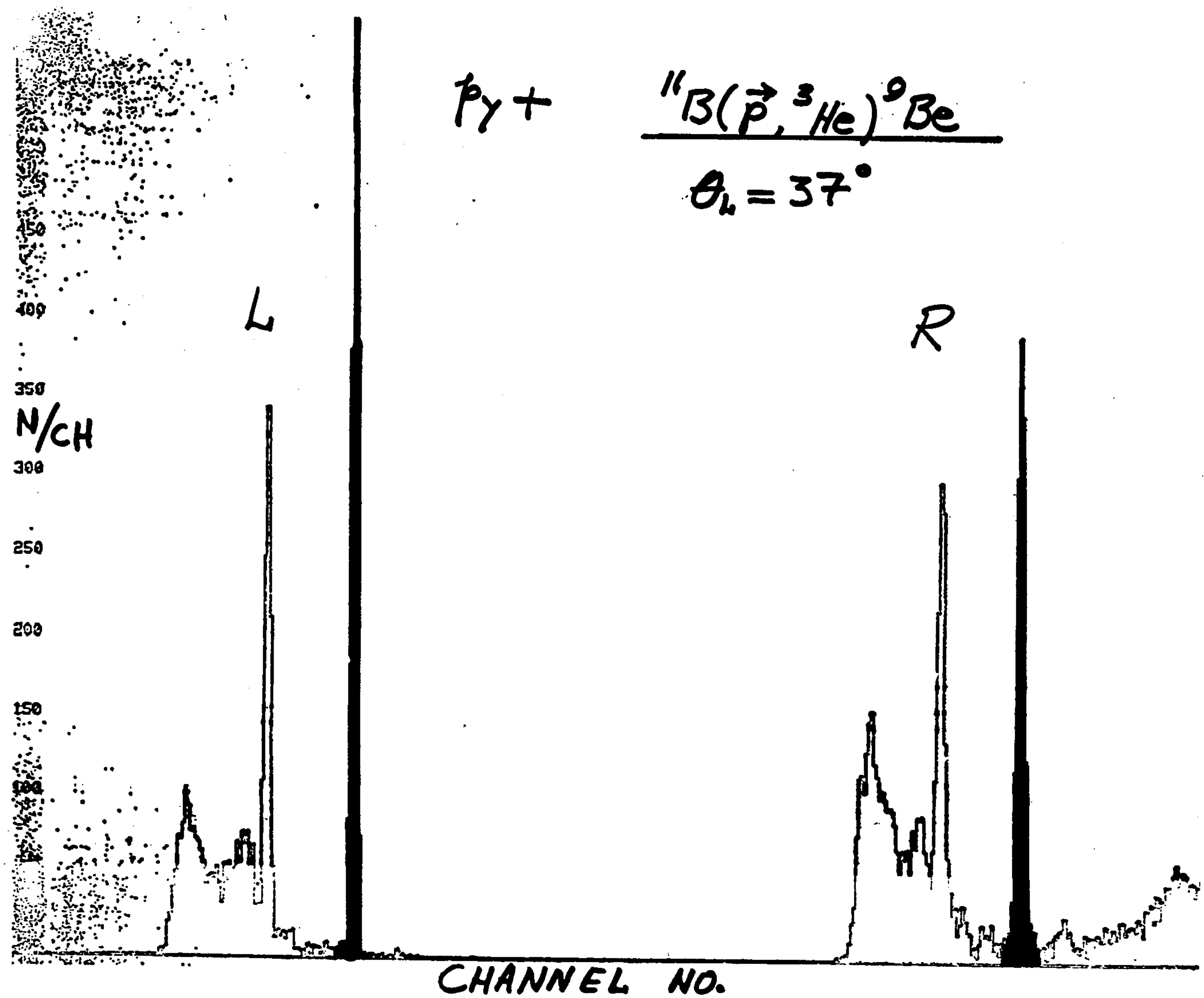

Figure 2

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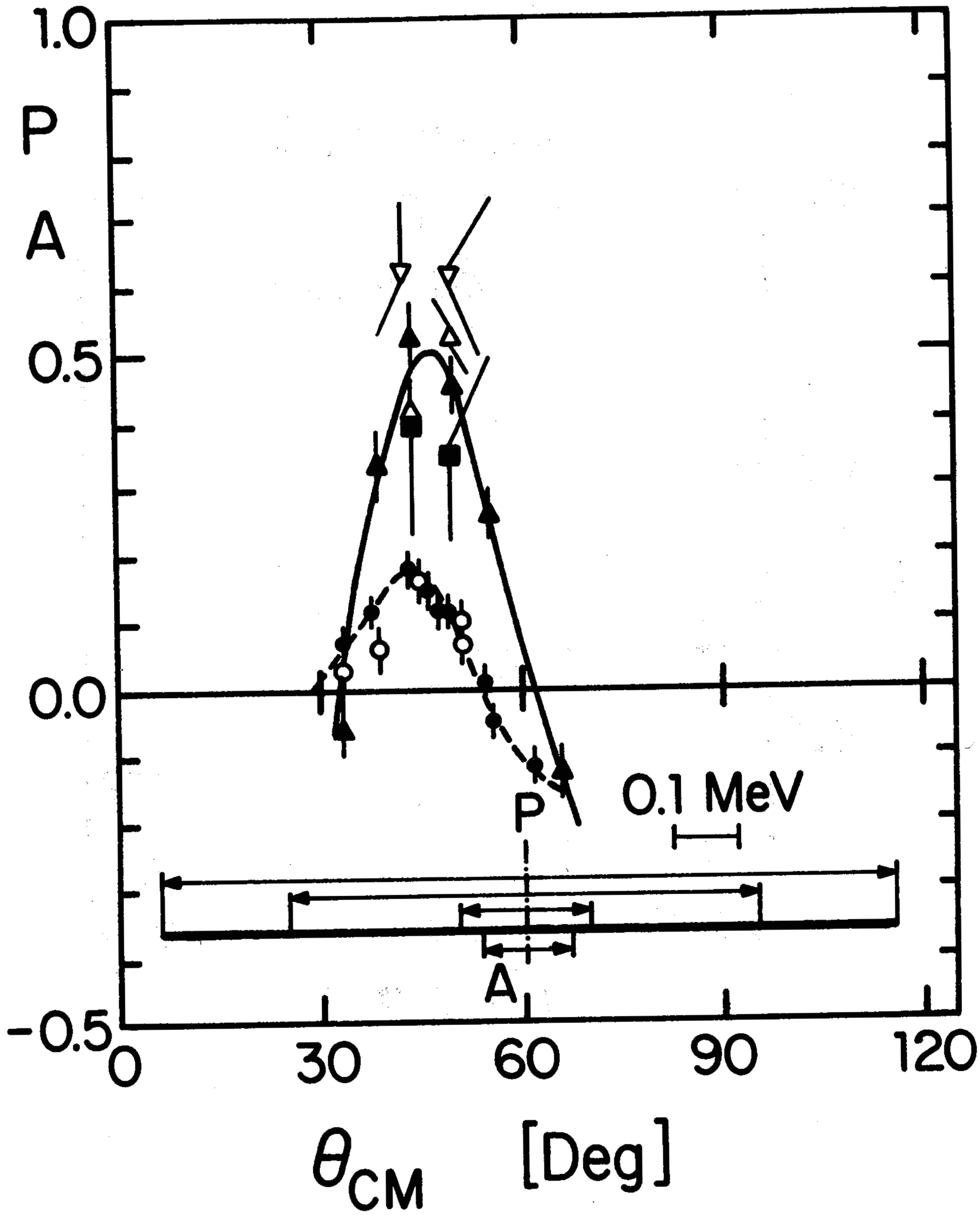

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Figure 3

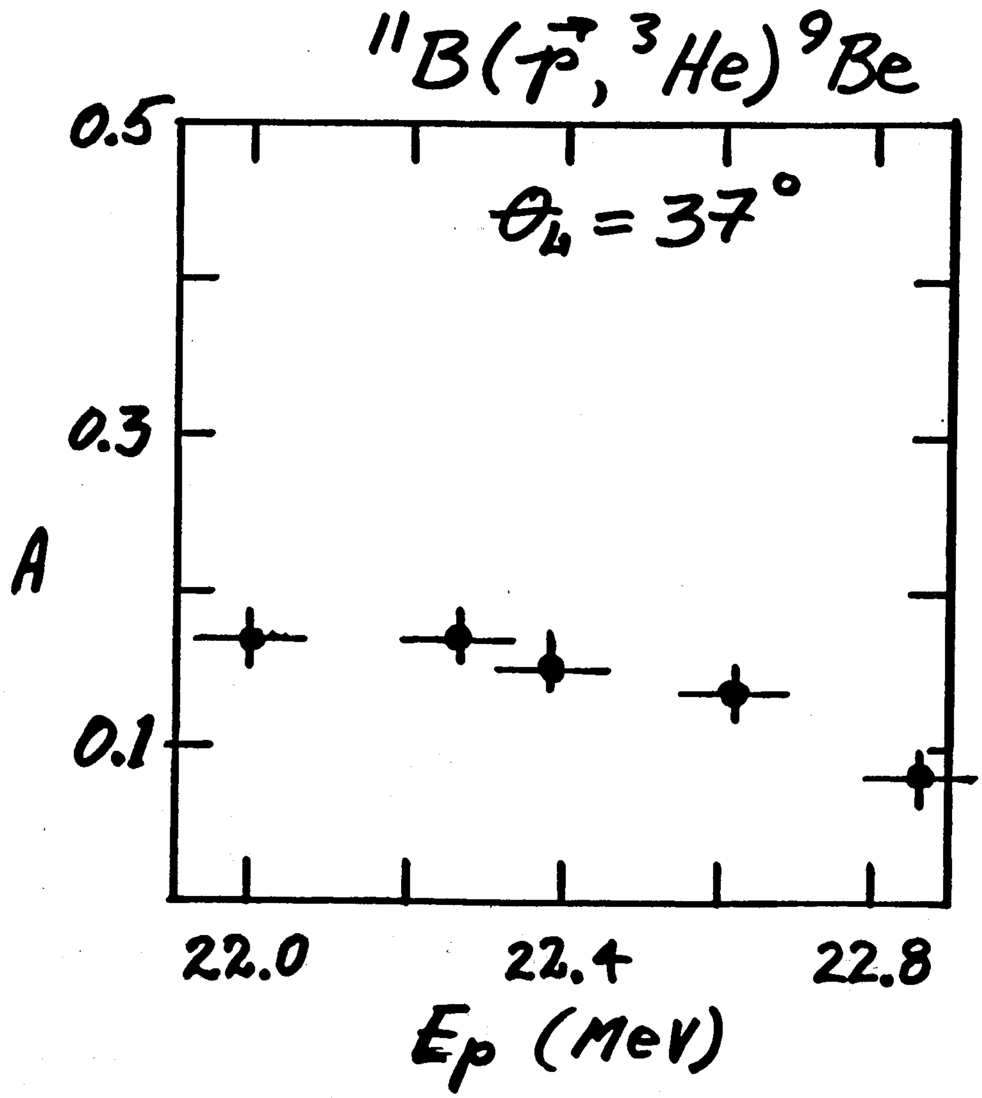

Figure 4 XBL 809-11816

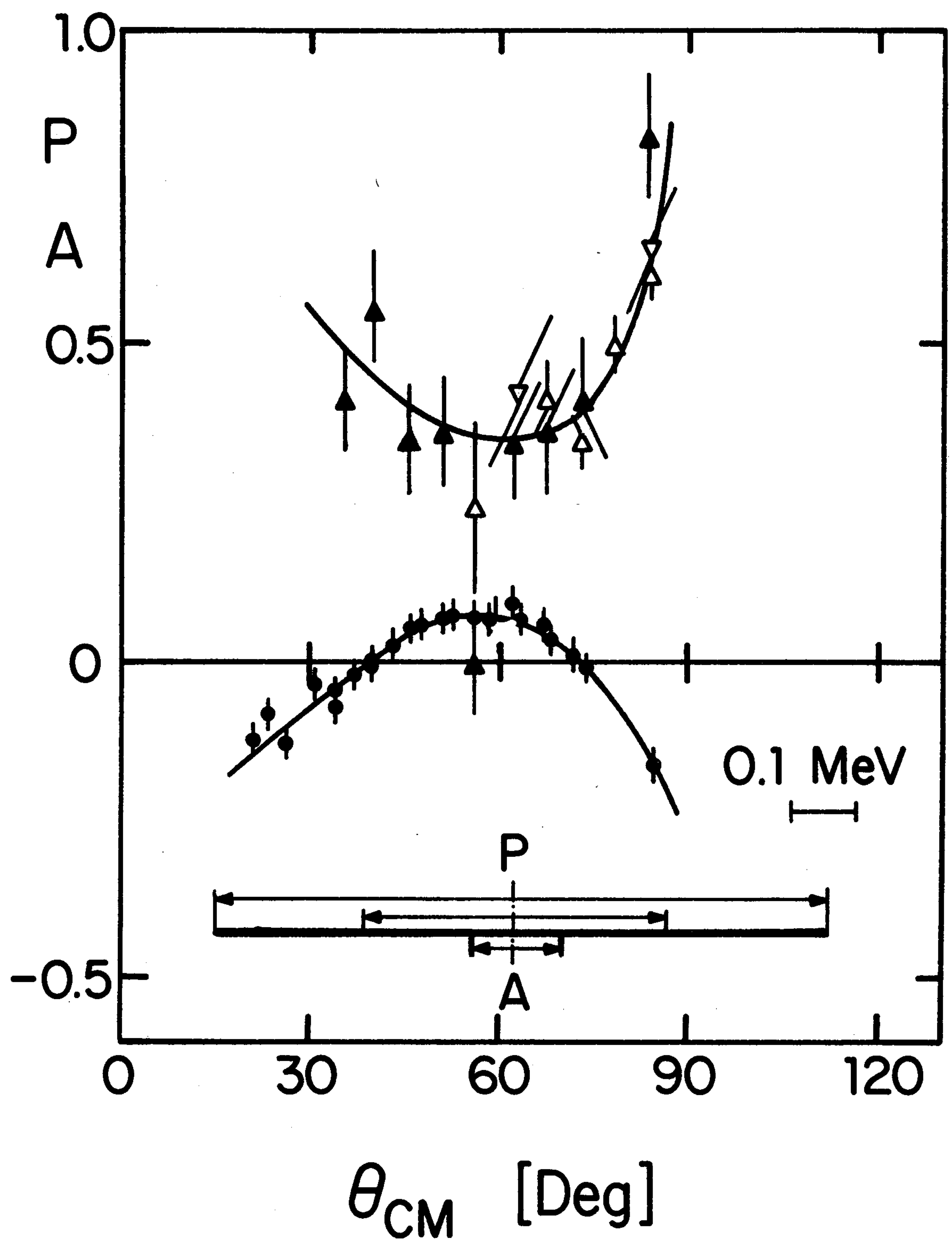

Figure 5

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