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Proton Polarization in Inclusive Processes at Fermilab Energies

R.O. Polvado, S.C. Ems, S.W. Gray, R.M. Lepore,
H.A. Neal, H.O. Ogren, D.R. Rust, and G.A. Walters

Department of Physics
Indiana University
Bloomington, Indiana 47405

Abstract

The results of an experiment conducted at Fermilab to measure the polarization of the final state proton in the reaction $p + p \rightarrow p\uparrow + X$ and $p + C \rightarrow p\uparrow + X$ are presented. Measurements were made at beam energies of 100, 200, 300, and 400 GeV for P_T from 0.5 to 1.5 GeV/c and X_f between -0.7 and -0.9.

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We report here the results of an experiment conducted in the Internal Target Area of Fermi National Accelerator Laboratory to measure the polarization in the inclusive processes $p + p \rightarrow p\uparrow + X$ and $p + C \rightarrow p\uparrow + X$ at incident energies of 100, 200, 300, and 400 GeV for values of P_T from 0.5 to 1.5 GeV/c and values of X_f between -0.7 and -0.9. A complete description of the internal target spectrometer and the Indiana polarimeter have been presented in an earlier article[(1)]. We measured the final state protons produced by the interaction of the main ring proton beam with a room temperature hydrogen jet or a rotating carbon filament target. The incident beam momenta were selected by pulsing the hydrogen jet at the appropriate time in the beam acceleration cycle and by selectively gating the fast electronics. For a single burst of the warm jet, an integrated luminosity of approximately 10^{34} $cm.^{-2}$ was attained for 2×10^{13} circulating protons. Luminosities from 4 to 5 times higher could be attained with the carbon target. The spectrometer defined the incoming particle trajectory and selected the momentum and production angle. The acceptance in the production angle was $\pm$ 2.88° vertically and $\pm$ 0.57° horizontally.

We determined the proton polarization by measuring the left-right asymmetry of the proton scattering distribution on a secondary target (a 5 cm. carbon block). This measurement was made in a polarimeter attached directly to the downstream end of the internal target spectrometer. The polarimeter (Fig. 1) consisted of a proportional chamber telescope before and after the carbon block. The entire polarimeter could be rotated 180° about the incoming beam direction. By averaging measurements made 180° apart, left-right instrumental asymmetries were reduced. The momentum acceptance was restricted by the polarimeter chambers to $\Delta p/p = \pm 5\%$. Using scintillators at the beginning of the spectrometer and in the polarimeter, a time of flight measurement allowed a clean separation of pions and protons over the entire momentum range.

The asymmetry (ε) is defined as $\varepsilon = (L - R) / (L + R)$ where L and R refer to the number of left and right protons scattering from the carbon block into the projected angle region (θ_X) between 6° and 22°. An online hardware preprocessor was used to eliminate events outside of the desired angular region. This device increased our effective data logging rate by a factor of 20 in the angular region between 6° and 22°. The polarization (P) of the incoming protons was calculated using $-\varepsilon = PA$ where A is the analyzing power of the carbon block which was determined in an earlier experiment[2]. The minus sign is included to conform to standard elastic
a scattering sign conventions for polarization in the limit of $X_f \to -1.0$[3].

One must be careful to use exactly the same event selection criteria for left and right scatters in order to prevent the introduction of a systematic error. To achieve this, we have studied both chamber alignment and selection criteria for events in the case of multiple tracks. The chambers were aligned so that the accepted angular region was the same for 0° and 180° orientations. The alignment was checked periodically by analyzing a sample of small angle scattering events. A good event in the case of multiple tracks upstream or downstream of the carbon was selected by following criteria: (a) only one track was present upstream of the carbon block and (b) no more than 2 tracks were present downstream of the carbon block. In the case of 2 tracks downstream of the block (3 - 8% of the events, depending on momentum), the track with the smaller angle was used to calculate the asymmetry. This selection procedure is consistent with the one used in the measurement of the analyzing power[2].

We have three consistency checks available for our measurements:

(1) About equal numbers of pion and protons were taken at p = 0.73 GeV/c

and p = 1.21 GeV/c for the hydrogen and carbon targets respectively. In both cases the pion results were consistent with zero asymmetry within a statistical uncertainty of ± 0.003.

(2) The proton up-down asymmetry for all points and beam energies was found to be zero within statistical errors. This must be true for a parity conserving reaction since the up-down direction is perpendicular to the primary scattering plane.

(3) The data from the two positions of rotation of the polarimeter were analyzed separately and found to agree within statistical errors. After averaging, the residual instrumental asymmetry is much less than the indicated statistical error.

The polarization of proton-proton inclusive scattering for P_T = 0.5 GeV/c for beam energies of 100, 200, 300, and 400 GeV is shown in Fig. 2. For X_f = -0.7 and -0.8 the polarization is virtually independent of beam energy but for X_f = -0.9 there appears to be a decrease of polarization with increasing beam energy. Since the point P_T = 0.5 and X_f = -0.9 is in the triple Regge region, we used the formalism of Field and Fox[4] to calculate the s dependence which is expected. By assuming that only the PRR amplitude contributes to the polarization in $p + p \rightarrow p\uparrow + X$, the observed polarization should be

$$P = K' \frac{d^3\sigma/dp^3 \text{ (PRR)}}{d^3\sigma/dp^3 \text{ (all terms)}} .$$

For a constant X_f and P_T then, the triple Regge prediction is $P = K/s^{\frac{1}{2}}$. Fitting this equation to the data we find that K = 93.3 ± 20 GeV. The curve is plotted in Fig. 2(c).

In Fig. 3, the polarization for P_T = 1.0 GeV/c is shown. In general, the polarization shows very little dependence on X_f or beam energy. The average polarization for all values of X_f and E_{beam} for P_T = 1.0 GeV/c is $\bar{P}$ = +0.011 ± 0.005. It should be noted that a more significant polarization has been seen for the inclusive Λ process at this value of P_T[5].

The polarization for the proton in the reaction $p + C \rightarrow p\uparrow + X$ is shown in Fig. 4. In contrast to the $p + p \rightarrow p\uparrow + X$ data (Fig. 3c), the polarization using the carbon target (Fig. 4c) is significantly different from zero. In order to explain this difference we have postulated that the inclusively produced proton, which is relatively slow in the laboratory, has a secondary scatter within the carbon nucleus. We have attempted to estimate the polarization due to this rescattering by a simple model that assumes all inclusively produced protons scatter only once in the carbon nucleus. We use the measured proton-carbon differential cross section and analyzing power[6] to describe the secondary scatter and the proton-proton inclusive differential cross section to describe the primary interaction[7]. With the above model, we find that the net polarization due to rescattering is approximately -.08 at P_T = 1.0 GeV/c and X_f = -0.9 which is consistent with our observed result. For the P_T = 1.5 GeV/c carbon data (Fig. 4(a), 4 (b)) the rescattering model would predict a smaller observed polarization. This is also consistent with the data.

We wish to express our appreciation to the staff at the Fermilab Internal Target Area, led by Dr. T. Nash and Dr. P. McIntyre, for their assistance during set up and data taking. The cooperation of Argonne National Laboratory in the loan of a helium liquifier contributed significantly to this experiment. We would also like to acknowledge the cooperation of the E552 collaboration (University of Rochester, Rutgers University and Imperial College) during our shared use of the Internal Target Area. We are also indebted to several staff members of Indiana University and graduate students for their assistance on this project. These people include: J. Sauer, M. Corcoran, P. Smith, B. Martin, M. Daskovsky, F. Frederickson, and Professor K. Hinotani of Osaka Medical School. Finally, we would like to thank Ellen Traub and Lynne Foster for the figure drafting and typing of this manuscript. This work was supported by the U.S. Department of Energy.

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[7] The particles accepted by the spectrometer were originally scattered to larger or smaller angles but were rescattered into the spectrometer by a low energy interaction in the carbon nucleus. Using the polarization convention described before, this secondary scattering produces a net positive polarization for initial interactions at greater than the spectrometer central angle and a net negative polarization for initial interactions at less than the spectrometer central angle. Due to the decrease of the inclusive differential cross section with angle and the cut off at the elastic limit a net negative polarization would be seen in the polarimeter.

FIGURE CAPTIONS

FIG. 1 Elevation view of polarimeter. T1 and T2 are trigger counters. PC 1-8 are multiwire proportional chambers. HX and HY are hodoscope counters. R1-3 form a range telescope. Protons rescatter in carbon block C.

FIG. 2 Polarization results at P_T = 0.5 GeV/C from H_2. (a) X = -0.7, (b) X_f = -0.8, and (c) X_f = -0.9. The curve shown in 2(c) is a fit to a Triple Regge model.

FIG. 3 Polarization results at P_T = 1.0 GeV/C from H_2. (a) X_f = -0.7, (b) X_f = -0.8, and (c) X = -0.9.

FIG. 4 Polarization results from carbon. (a) P_T = 1.5 GeV/C, X = -0.8, (b) P_T = 1.5 GeV/C, X = -0.9, and (c) P_T = 1.0 GeV/C, X = -0.9.

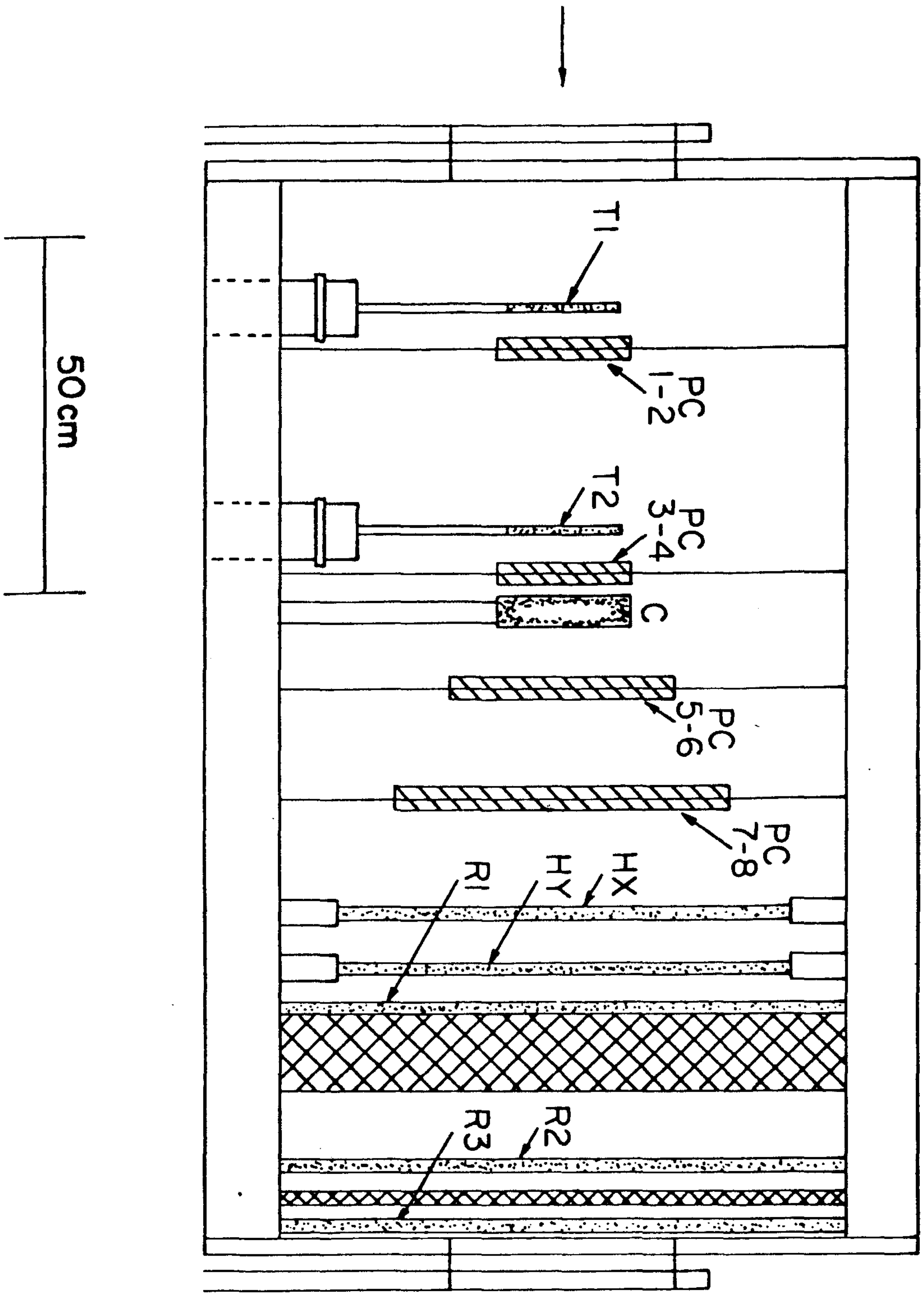

Figure 1

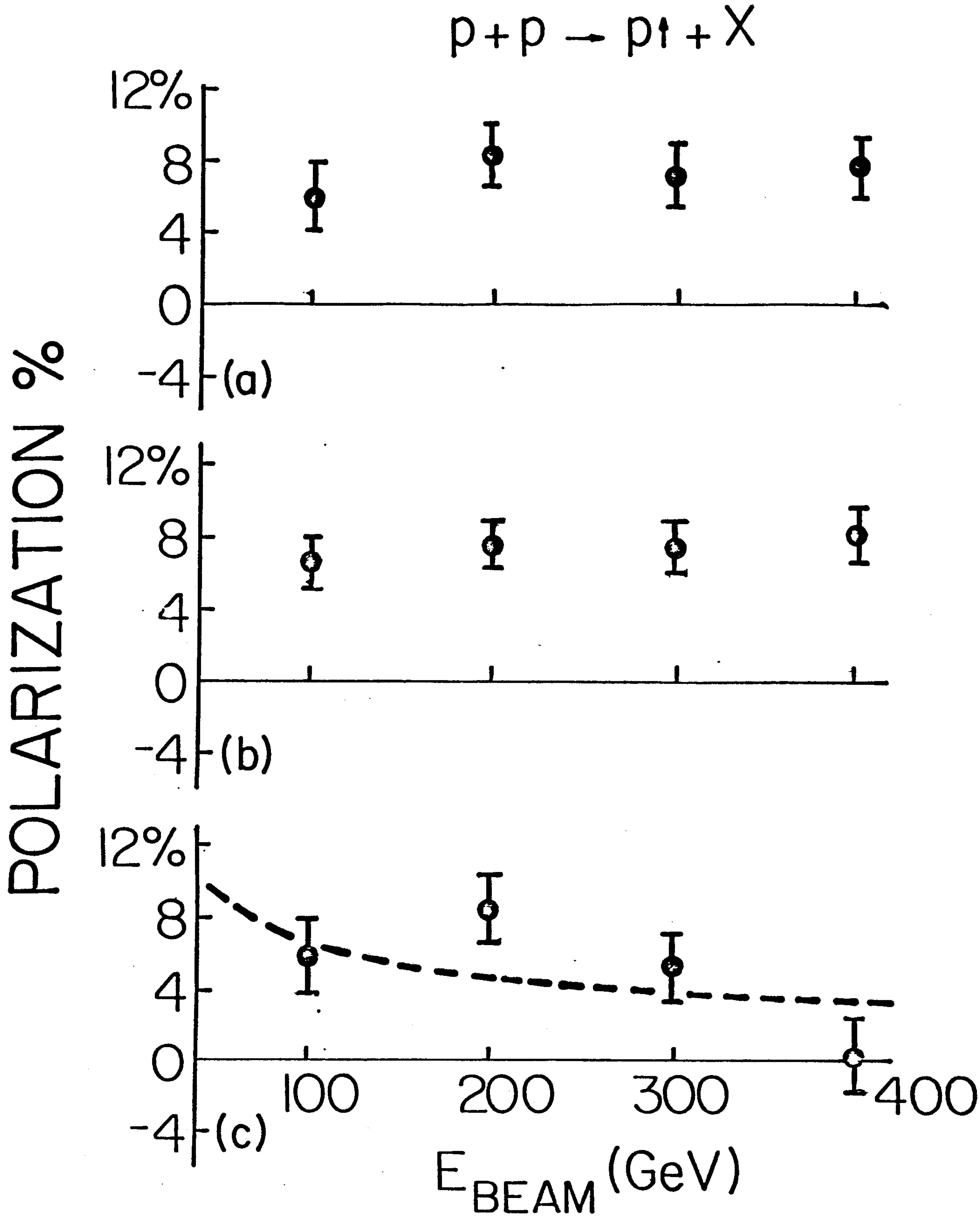
p + p → p↑ + X
POLARIZATION %
12%
8
4
0
-4
(a)
12%
8
4
0
-4
(b)
12%
8
4
0
-4
(c)
100
200
300
400
E_{BEAM} (GeV)

Figure 2

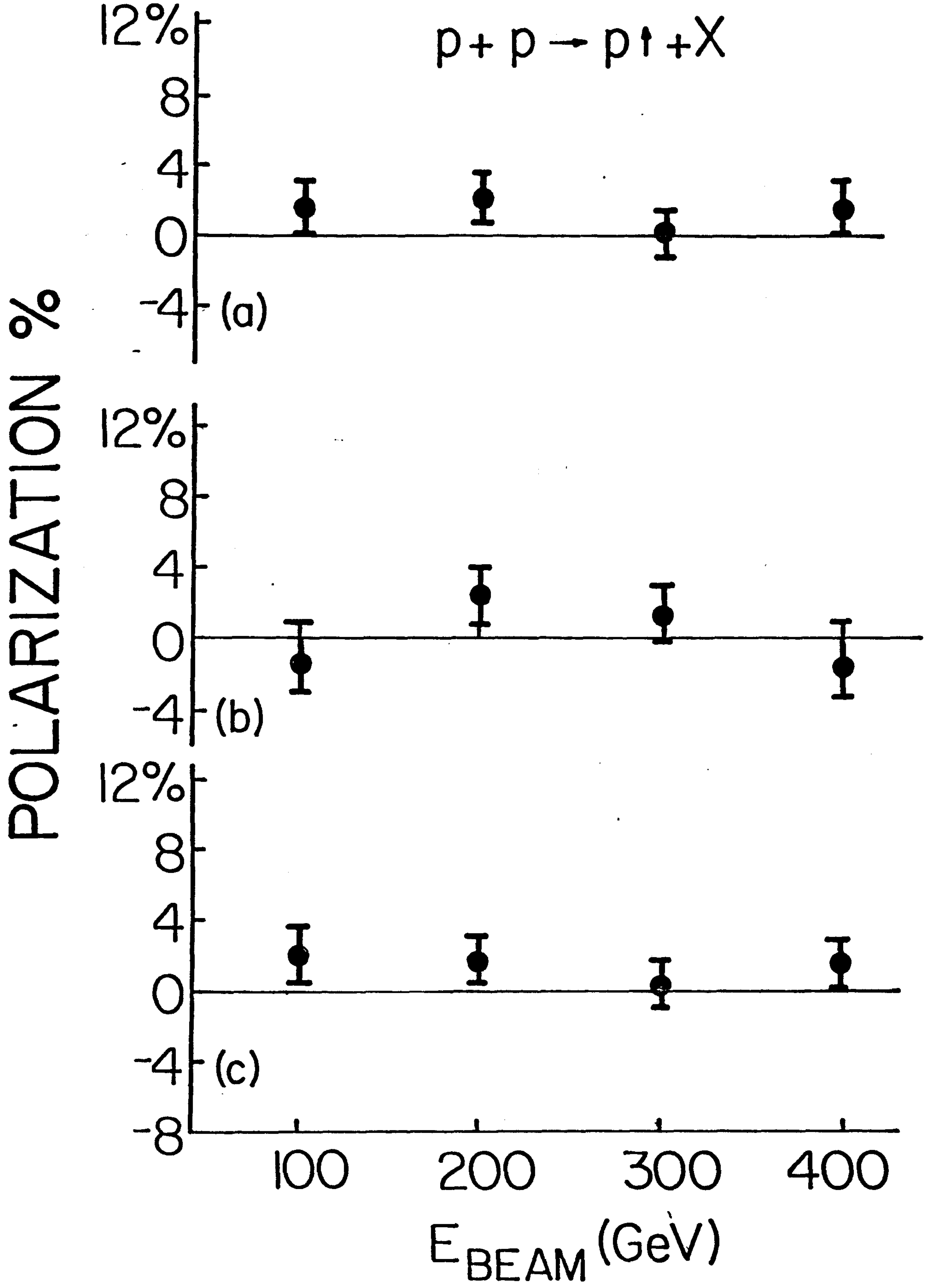
p + p → p↑ + X
POLARIZATION %
12%
8
4
0
-4
(a)
12%
8
4
0
-4
(b)
12%
8
4
0
-4
(c)
-8
100
200
300
400
E_{BEAM} (GeV)

Figure 3

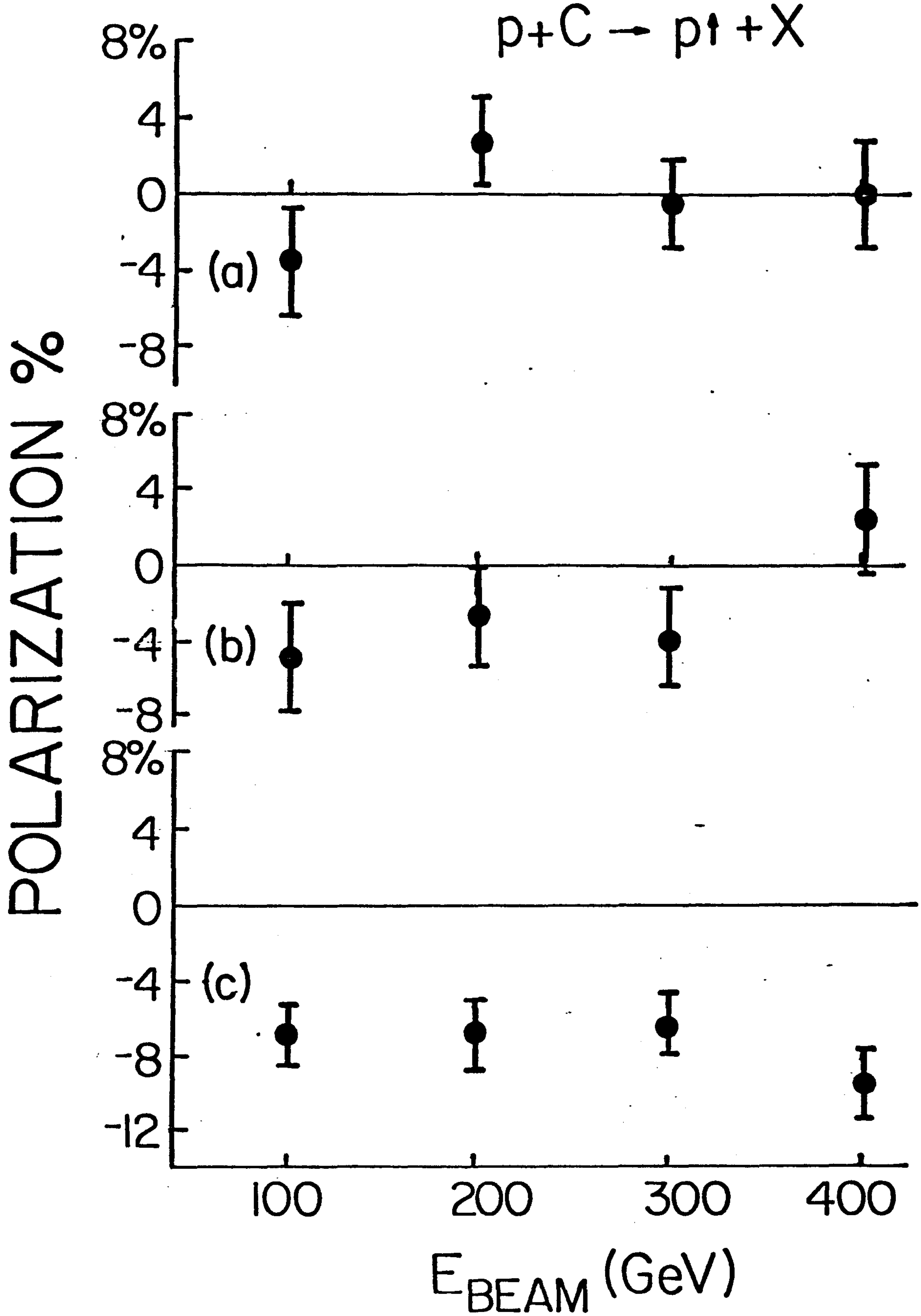

Figure 4