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(Presented by Herbert M. Steiner)

June 24, 1964

Using the Berkeley polarized-proton target, we have measured the polarization parameter $P(\theta)$ for proton-proton (p-p) scattering. The measurements were obtained at beam kinetic energies of 0.330, 0.680, and 0.740 GeV at the 184-in. synchrocyclotron and 1.70, 2.85, 3.50, 4.00, 5.05, and 6.15 GeV at the Bevatron. The angular regions measured were from 20° to 100° center of mass; the square of the four-momentum transfer ranged from 0.1 to 0.8 $(\mathrm{GeV}/c)^2$.

By means of copper absorber, the external cyclotron beam was degraded from the maximum energy of 0.74 GeV to the minimum of 0.33; the Bevatron external proton beam was spilled at various times during the acceleration cycle. The manner in which these beams were formed makes it unlikely that they contained any significant degree of polarization, and the symmetry of the arrangement was such that no component of beam polarization normal to the scattering plane would be expected.

I. EXPERIMENTAL METHOD

For these experiments, the target consisted of a 1-inch cube of $La_2Mg_3(NO_3)_{12} \cdot 24\ H_2O$, with approximately 1 percent of the La replaced by Nd^{142}. The hydrogen content was about 3% by weight and the hydrogen thickness was 0.15 g/cm^2. The free protons in the crystal were polarized by the dynamic-nuclear-orientation[1] technique, which for this experiment involved immersion of the target in a 1.2°K liquid helium bath inside a constant magnetic field of 18.75 kilogauss (kG). The appropriate "forbidden" transitions were excited by microwave radiation at about 71 kMc. A small variation of the microwave frequency made it possible to reverse the direction of the proton spins.

The polarization was continuously monitored by measuring the strength of the proton magnetic resonance at the frequency ν = 80 Mc. At approximately 12-hour intervals the spin system was allowed to come into thermal equilibrium with the liquid helium bath. Measurement of temperature and signal strength under these conditions gave the scale factor necessary for assigning the absolute polarization values.

The magnitude of target polarizations for these experiments ranged from 20% to 60%; the direction was reversed about every 45 minutes to minimize systematic error due to variations in beam geometry and detection efficiency.

Elastic p-p scattering events were separated kinematically from other events by counting protons in coincidence. Ten scintillation counters in an upper array were placed to catch the conjugate protons (Fig. 1). Acceptable events were required to satisfy the criteria: (a) coincidence in D_d, D_o, D_t, U_o; (b) one and only one of the counters $\alpha_0 - \alpha_9$; and (c) one and only one of the counters $\beta_0 - \beta_9$. Each event detected caused a count to be stored in one of

100 channels of a pulse-height analyzer, the address being determined by the particular combination of α and β counters.

The background counting rate was continuously monitored by the coincidences between upper array counters and lower array counters for which elastic p-p events were kinematically impossible. In addition, data were taken with a dummy target that consisted of elements similar to those of the crystal but with no free protons. In this way the background caused by quasi-elastic scattering from the nonhydrogenous materials could be evaluated. Figure 2 shows the magnitude of the elastic-to-background counting ratio for one case (6 GeV).

The lower limit on momentum transfer for which polarization could be measured was determined by the range of the recoil protons that could reach the lower counter array. The upper limit was set both by the decrease in the differential cross section and space restrictions imposed by the magnet yoke.

The polarization parameter is related to the p-p differential cross section by

$$\left(\frac{d\sigma}{d\Omega}\right)_{pol} = \left(\frac{d\sigma}{d\Omega}\right)_{unpol} [1 + P(\theta)P_T], \tag{1}$$

where P_T is the target polarization. The data were analyzed by means of a least-squares fit to (1) after a proper background subtraction was made.

II. RESULTS

In Fig. 3, the measured values of $P(\theta)$ are shown as a function both of center-of-mass scattering angle θ and square of four-momentum transfer for each of the incident-proton energies. Our data at 0.330 GeV are compared with those of Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis[2] at 0.315 GeV, obtained by the usual double-scattering techniques.

In addition to the random errors ascribed to counting statistics and to measurement of the strength of the proton magnetic resonance during the run, there were the following systematic effects. A systematic error common to all angles and energies is due to error in measuring the strength of the proton-magnetic-resonance signal at thermal equilibrium and in measuring the temperature at equilibrium.

The data must be corrected to account for the fact that the target crystal is nonuniformly polarized. This nonuniformity is due to the presence of temperature gradients within the crystal, radiation damage in the region of high beam intensity, and limited penetration of the microwave radiation to the interior of the crystal. In order to estimate the size of this correction, the variations in beam density and detection efficiency of the rf system across the crystal were folded in with an assumed distribution of target polarization. These results were compared with data taken with a 1/4-inch-diameter beam spot irradiating various portions of the crystal. For the runs at 1.70 to 6.15 GeV, a 15% positive correction was made to $P(\theta)$ and a 10% systematic error is due to this effect.

For the runs at 0.330 to 0.740 GeV, the thermal contact of the crystals to the helium bath was improved and the rf-detection-system sensitivity made more uniform, so that the correction was estimated to be less than 4% and was not applied to the data. The insert for each plot in Fig. 3 gives the total systematic error for that energy.

III. DISCUSSION

Calculations based on Regge poles have given expressions for proton-proton polarization in the limit of high energy and small momentum transfer.[3,4] Consideration of only the Pomeranchuk pole and the nearest neighboring pole that communicates with the $(p\bar{p})$ system gives $P \propto s^{(\alpha_n - \alpha_p)}$ [large s and small fixed $(-t)$]. Here t is the square of the four-momentum transfer given by $t = -2q^2(1 - \cos\theta)$, q being the c.m. momentum; s is the invariant mass squared, $s = 4M^2 + 4q^2$; α_p and α_n are the positions of the Pomeranchon and its nearest neighbor at low momentum transfer. Polarization is shown for $(-t) = 0.28\ (\mathrm{GeV}/c)^2$ in Fig. 4. The point at $s = 20.3\ (\mathrm{GeV})^2$ is from reference 11. As shown in Fig. 4, there is not a good fit to any power-law behavior; however, it is not clear that these measurements can be considered asymptotic in energy.

Figure 5 shows the variation of maximum polarization over a range of 1.5 decades in incident beam energy. The values shown below 0.30 GeV are representative of several measurements made in this region.

FOOTNOTES AND REFERENCES

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†Abstract for Part I submitted as UCRL-11440 Abstract.

‡Abstract for Part II submitted as UCRL-11439 Abstract.

§Now at Centre d'Etude, Nucleaire, Saclay.

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FIGURE CAPTIONS

Fig. 1. Diagram of experimental arrangement.

Fig. 2. Example of elastic-to-background counting ratio at 6 GeV.

Fig. 3. Polarization as a function of center-of-mass angle θ and four momentum transfer squared (-t) for various beam energies T_p. RSE means relative systematic error. (a) Δ, Data from Ref. 2; O, data from this experiment.

Fig. 4. Log P vs log s; The errors include systematic error. (a) $P \propto s^{-0.82}$ (b) $P \propto s^{-1.27}$

Fig. 5. Maximum polarization as a function of beam energy T_p. Values from this experiment include systematic error. O, data from this experiment; ∇, data from Ref. 5; $\Diamond$, data from Ref. 6; Δ, data from Ref. 2; $\square$, data from Ref. 7; $\Diamond$, data from Ref. 8; $\square$, data from Ref. 9; Δ, data from Ref. 10; ∇, data from Ref. 11.

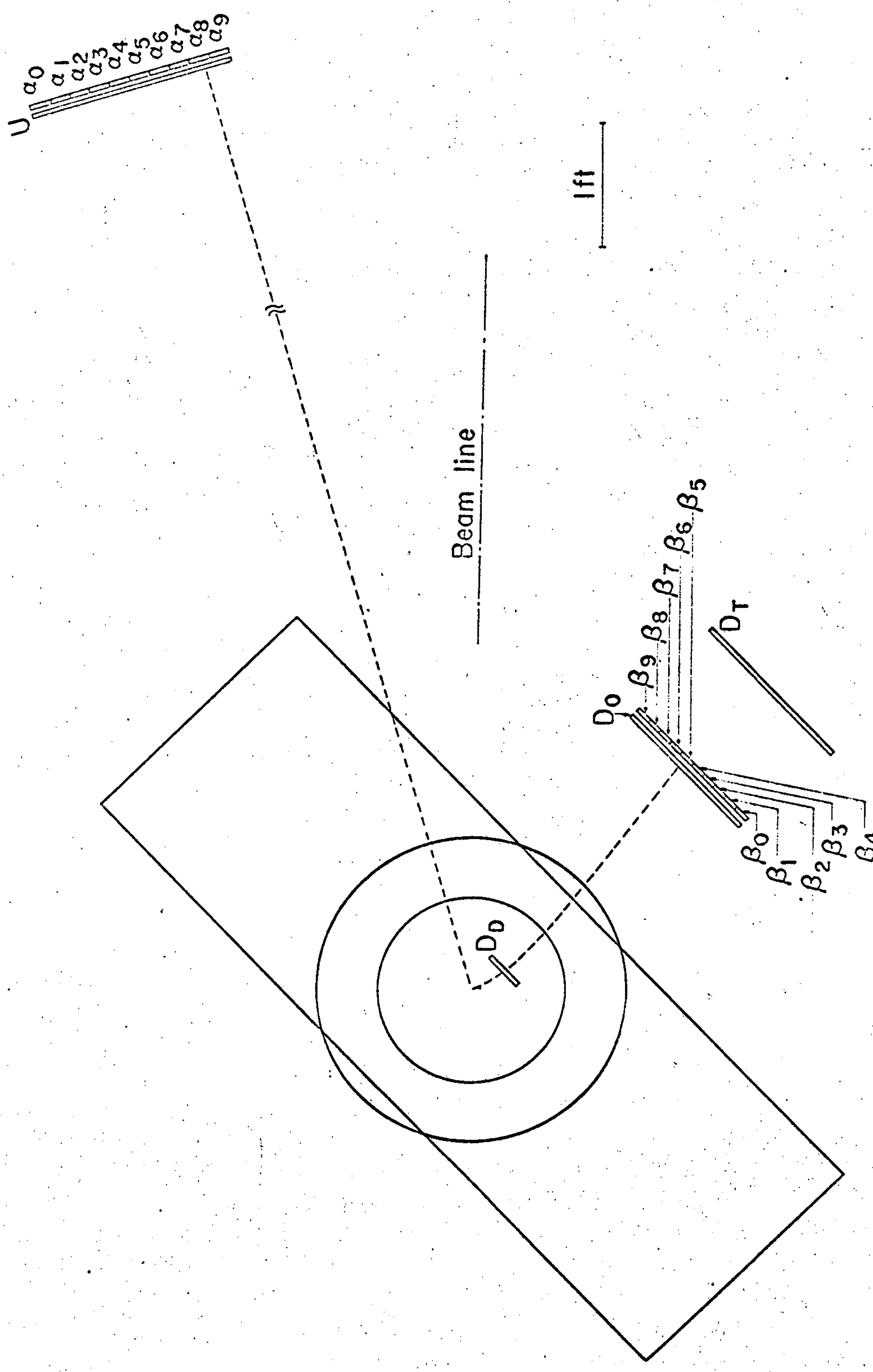
U
α0 α1 α2 α3 α4 α5 α6 α7 α8 α9
1ft
Beam line
D0 β9 β8 β7 β6 β5
DT
DD
β0 β1 β2 β3 β4

Fig. 1

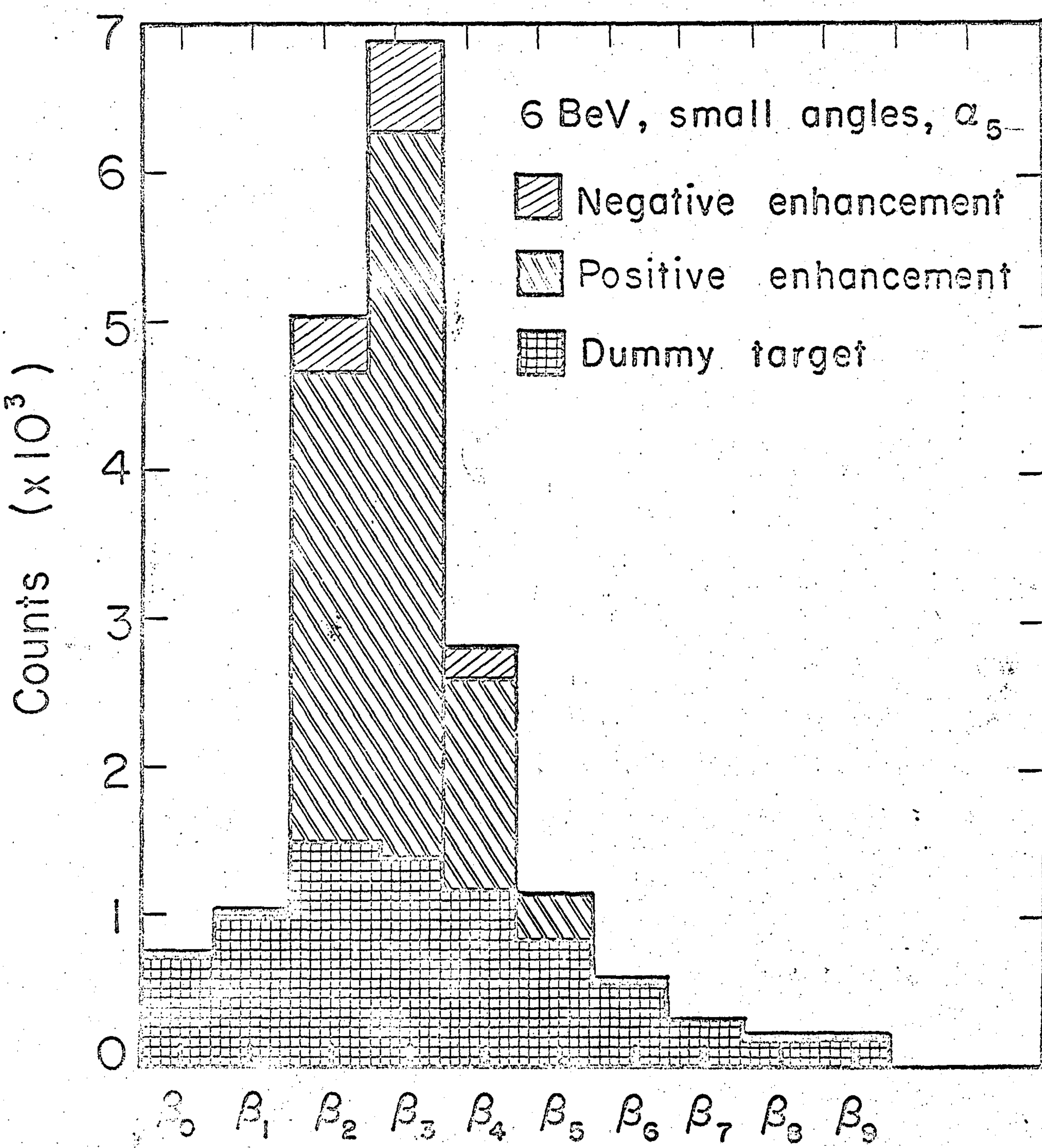

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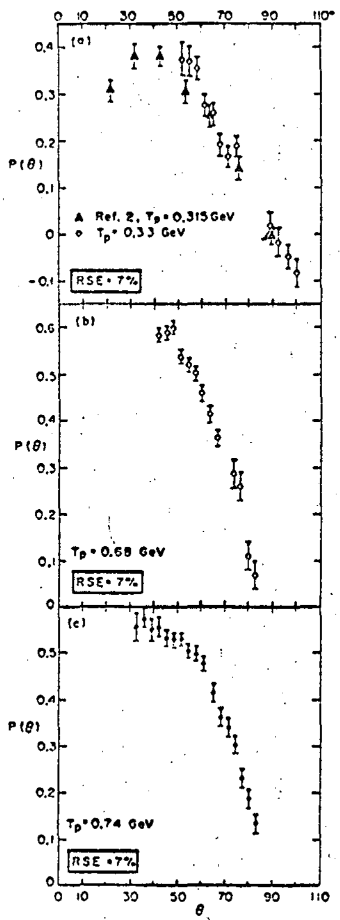
Fig. 2



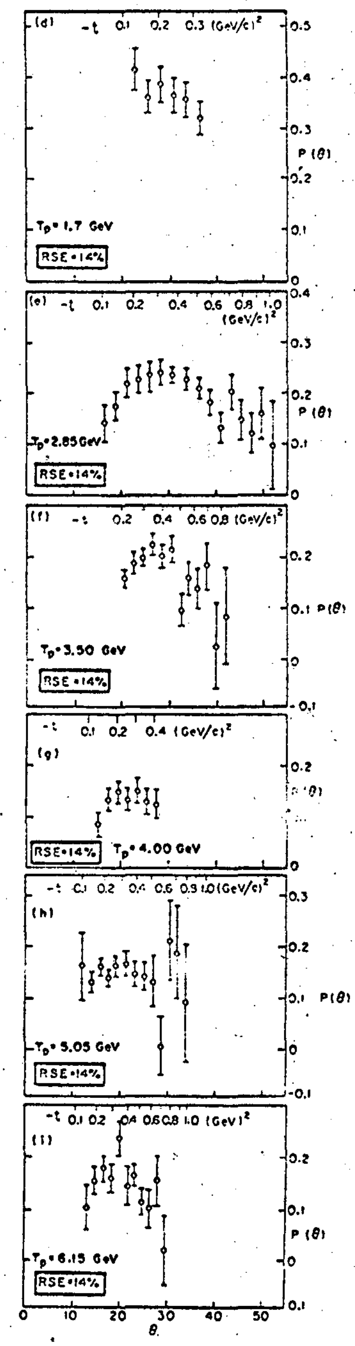


Fig. 3. Polarization as a function of center-of-mass angle θ and four momentum transfer squared (-t) for various beam energies T_P. RSE means relative systematic error. (a) △, Data from Ref. 2; O, data from this experiment.

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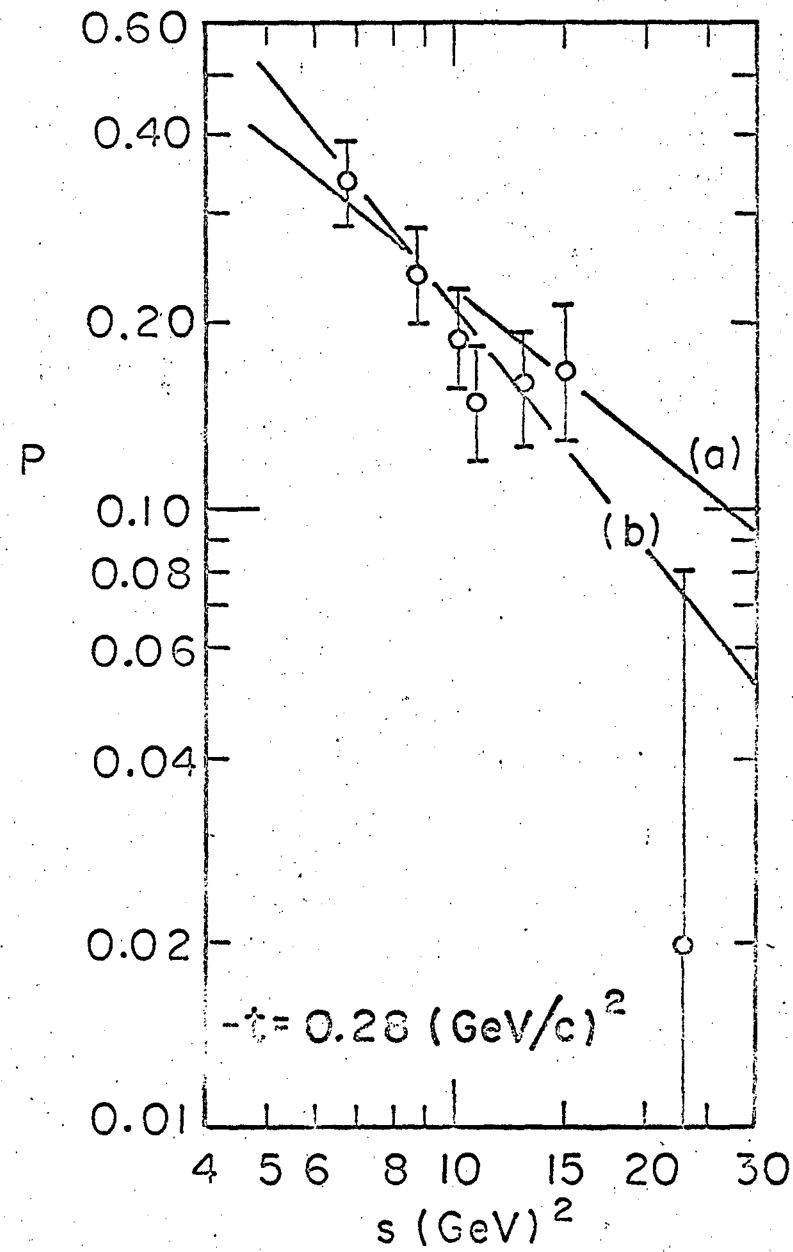

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Fig. 4

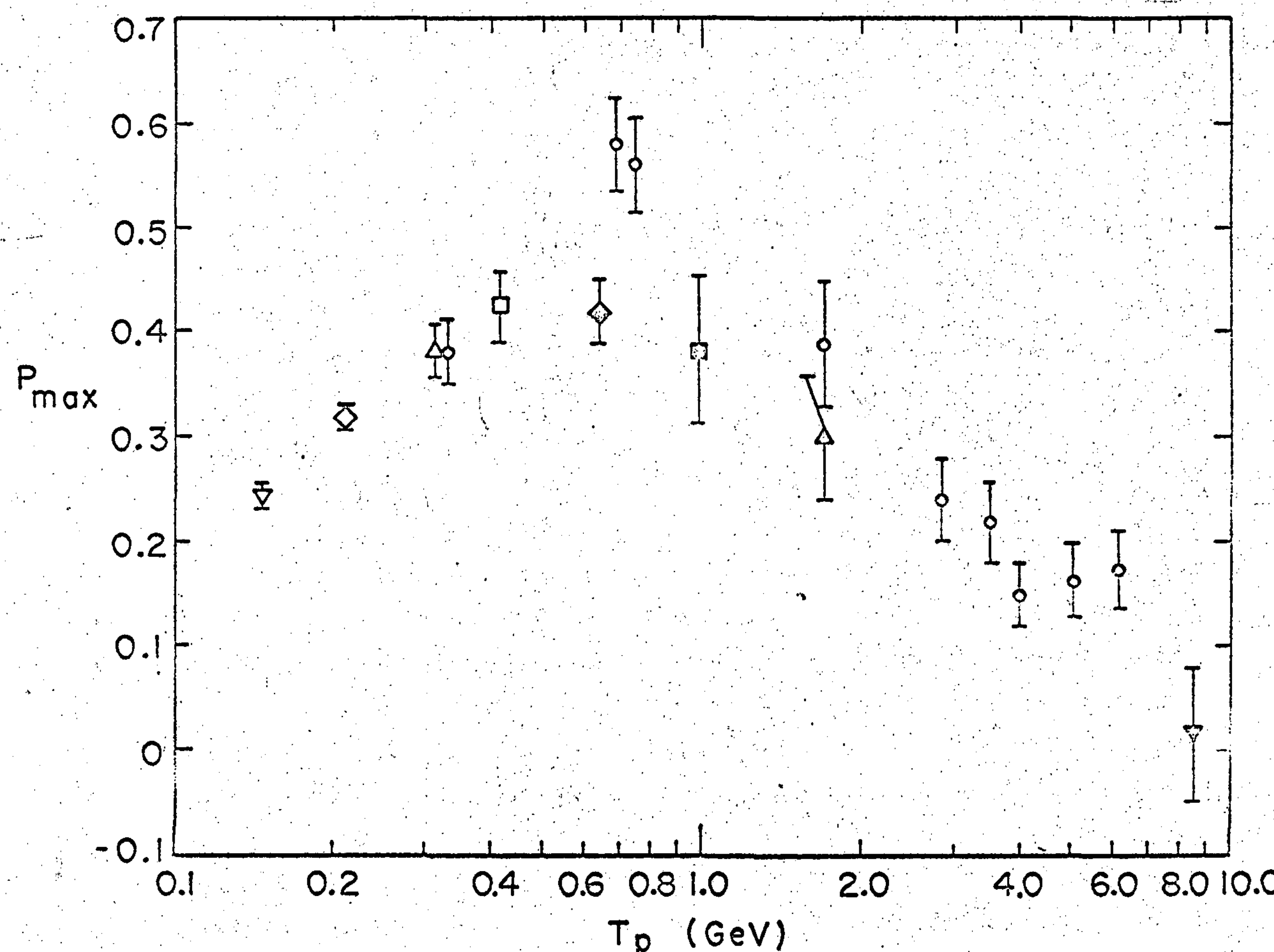

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Fig. 5