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SPIN EFFECTS IN EXCLUSIVE REACTIONS AT HIGH $P_\perp$*

Yousef Makdisi †
AGS Department, Brookhaven National Laboratory
Upton, New York 11973

BNL--38304

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ABSTRACT

Production and decay angular distributions from the process $\pi^- p \rightarrow \rho^- p$ at 90° in the center-of-mass are presented. A large spin flip amplitude is observed, the ramifications of which are noted in the context of the known theories.

It is becoming quite clear that spin is an important facet of the High Energy scattering domain. The interest in spin effects is growing as experiments probe further into hadron interactions at shorter distances with the expectation that this will lead to a better understanding of quark interaction dynamics.

Large polarizations have been observed in inclusive and exclusive reactions and the effects persisted at relatively large momentum transfer.[1] It should be noted that common wisdom had predicted these effects to be small and to vanish as energies got higher and reactions more violent.

In departure from discussing experiments using polarized beams or targets, we describe the spin effects observed in an exclusive two body reaction $\pi^- p \rightarrow \rho^- p$ which was part of a general program to measure cross sections and decay angular distributions of a large class of exclusive reactions at the kinematic limit, namely 90° in the center-of-mass system.

These experiments were carried out at the Brookhaven AGS where the beam energy is a good match between reaching a reasonably high $P_\perp$ and attaining good statistical accuracy in a manageable running period since exclusive cross sections fall sharply with beam energy. This compromise sets the experiment in a $P_\perp$ domain ranging from 2-2.5 GeV/c or an equivalent t of 8-14 $(GeV/c)^2$ where arguments are aplenty on whether perturbative QCD is applicable.

The experiment has been described elsewhere.[2] Briefly, we utilize a single arm spectrometer to measure the scattered baryon and side chambers to track the outgoing meson and its decay into $\pi^-\pi^\circ$ of which only the π^- is observed. Two related reactions are discussed here: the elastic $\pi^- p$ and the exclusive ρ meson production. While the elastics serve as a guide, the decay angular distributions of the ρ form the bulk of this paper.

Data were collected at two beam energies 10 and 13.4 GeV/c respectively. The missing mass spectra are shown in Fig. 1(a,b) where the elastic peak is shaded. The elastics sample contained 1150 events at 10 GeV/c and 230 events at 13.5 GeV/c resulting in average differential cross sections $d\sigma/dt$ of 1.69 ± 0.20 nb$(GeV/c)^2$

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†Reporting on behalf of the "Exclusive Collaboration" of AGS Exp. 755 (BNL/Minn/SE Mass).

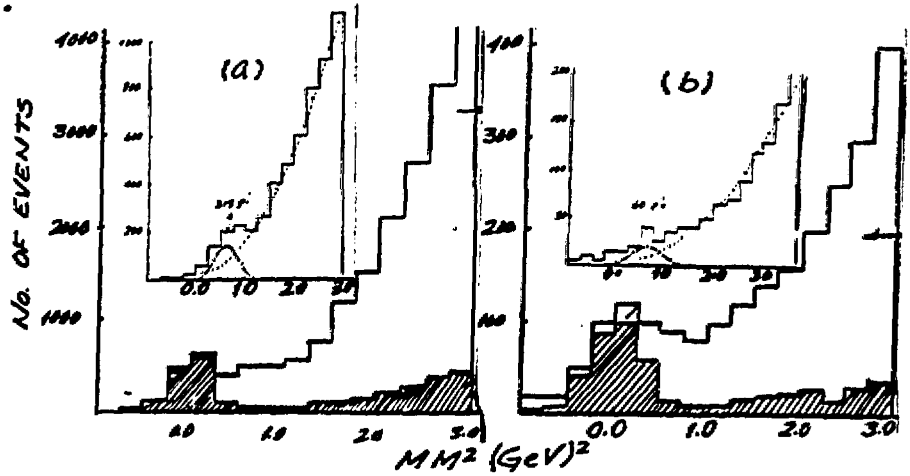

Fig. 1. Missing mass spectra for the 10 and 13.4 GeV/c data. The shaded regions represent the elastics cuts and the insets show the fit to the ρ mass and background.

and 0.23 ± 0.03 ηb/(GeV/c)^2 respectively. These points fall in line with the power low dependence of S^{-8} in $d\sigma/dt$ at fixed angles. The exponent being the number of constituent valence quarks participating in the reaction reduced by 2 from dimensional counting arguments. This dependence was first predicted by Brodsky and Farrar[3] and has been borne out by πp, pp and γp experiments. If this is an indication of hard scattering, we note that this sets in for beam momenta as low as 5 GeV/c. The corresponding ρ cross sections are 1.18 ± .27 and .15 ± .05 ηb/(GeV/c)^2 respectively. These two points follow a scaling power of 7.1 ± 1.8.

In the language of valence quark diagrams, both elastic scattering and exclusive ρ production can proceed via one or all of the diagrams shown in Fig. 2. Other reactions can proceed via a subset of these. Thus, the importance of measuring exclusive reactions.

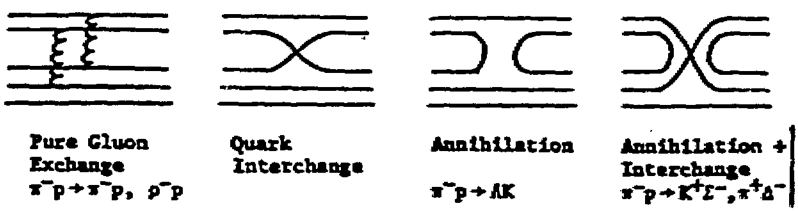

Fig. 2. Quark diagrams for meson-baryon scattering.

Spin dependence, under certain assumptions, could readily separate the first diagram from the rest. In the world of quarks, with nearly massless fermions, one can equate chirality and helicity. Quark gluon coupling being purely vector will result in strict helicity conservation. Any helicity flip amplitudes are expected to be small and of the order of constituent quark masses divided by their respective energies. In hadron scattering, under perturbative assumptions, individual quarks interact perturbatively conserving helicity. Thus, helicity is preserved for the whole reaction.

The helicity amplitudes are proportional to the angular distribution matrix elements of the decaying rho meson. Assuming parity conservation, these distributions for a spin 1 particle are given by

$$(4\pi/3)\ W(\theta,\phi) = r_{0,0}\cos^2\theta + r_{1,1}\sin^2\theta - r_{1,-1}\sin^2\theta\cos 2\phi - 2\,(\mathrm{Re}\ r_{1,0})\sin 2\theta\cos\phi \qquad (1)$$

when θ and ϕ are the polar and azimuthal angles in the center-of-mass system of the rho meson.

A few results can be pointed out readily:

a) Helicity Conservation reduces the off diagonal elements to zero. The expression becomes

$$4\pi/3\ W(\theta,\phi) = r_{1,1} + (r_{0,0} - r_{1,1})\cos^2\theta \qquad (2)$$

with no ϕ dependence. Figure 3 (a,b) show the ϕ angular distributions of the selected ρ events. There is a striking similarity between the two sets of data. The ϕ dependence is not flat but consistent with $\sin^2\phi$ lending evidence to some helicity nonconservation in the reaction.

b) If pure gluon exchange is assumed then only $r_{0,0}$ will be nonzero.

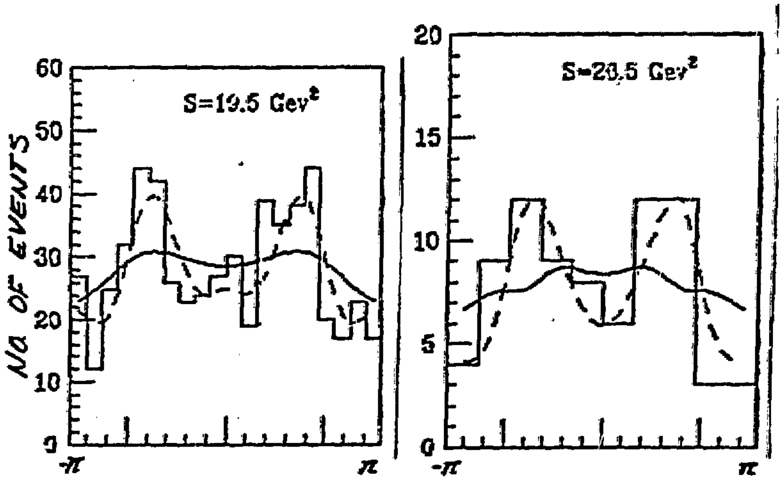

Fig. 3. ϕ (CM Helicity Frame). Fits to the ϕ decay angular distribution for ρ mass $.25 < p < 1.0\ \mathrm{GeV}^2$. The solid line represents the acceptance.

The decay angular distributions were fit with a sum of spherical harmonics $Y^L_M(\theta,\phi)$ with the series cut off at $L = 2$. Table I has the corresponding density martrix elements for the two beam energies.

TABLE I

		Helicity Conserving		Non Conserving	
		$r_{0,0}$	$r_{1,1}$	$r_{1,-1}$	$Re(r_{1,0})$
10 GeV	(ρ mass)	.07 ± .21	.46 ± .11	.29 ± .07	.05 ± .04
	(>ρ mass)	.31 ± .21	.35 ± .11	-.05 ± .07	-.02 ± .04
13.4 GeV	(ρ mass)	1.00 ± .34	.00 ± .17	.26 ± .18	.03 ± .15
	(>ρ mass)	.25 ___	.37 ___	.02 ___	.02 ___

The 13.4 GeV/c results are still preliminary. Additional analysis is underway to determine the sensitivity of the results to the shape of the background.

The experiment lacked sensitivity to the $r_{0,0}$ and $r_{1,1}$, namely cos θ terms, but was very sensitive to the ϕ terms. The fact that $r_{1,-1}$ is large is a good indication that helicity is not conserved and the spin flip term is substantial. This term is consistent with zero for masses above that of the rho. While the 10 GeV data is statistically significant, the 13.4 GeV/c data consolidate these findings.

Where does this leave us with respect to the various theoretical interpretations? The lack of helicity conservation negates the pure gluon exchange picture in favor of a mixture of the above diagrams since quark exchange or annihilation would allow helicity nonconservation. Cross sections will serve to assess the relative contributions of these diagrams to the scattering process.

G. Farrar[4] combined these data along with, A_n measurement at 28 GeV and A_{nn} data at 11.75 GeV/c in pp elastic scattering[1] to estimate that the higher twist amplitudes in this exclusive process to be ~ 30% compared to leading terms. Helicity nonconservation arises from the interference between the leading and nonleading twist amplitudes.

Nardulli, Preparata and Soffer[5] use a meson exchange model to obtain the observed angular distributions namely the θ and ϕ dependence. But our data differ from their predictions of the ratios of certain exclusive cross sections.

One last comparison of our results with ρ meson data taken at 6 GeV/c and up to $t \sim 1\ (GeV)^2$ from Gordon et al.[6] are presented in Fig. 4. It is remarkable that the density matrix elements are similar over such a wide gap in t. This probably indicates that soft scattering is still present there even at $t \sim 9\ (GeV)^2$. These results can only point to the fact that more experimental data are needed as input and that theoretical understanding is still lacking.

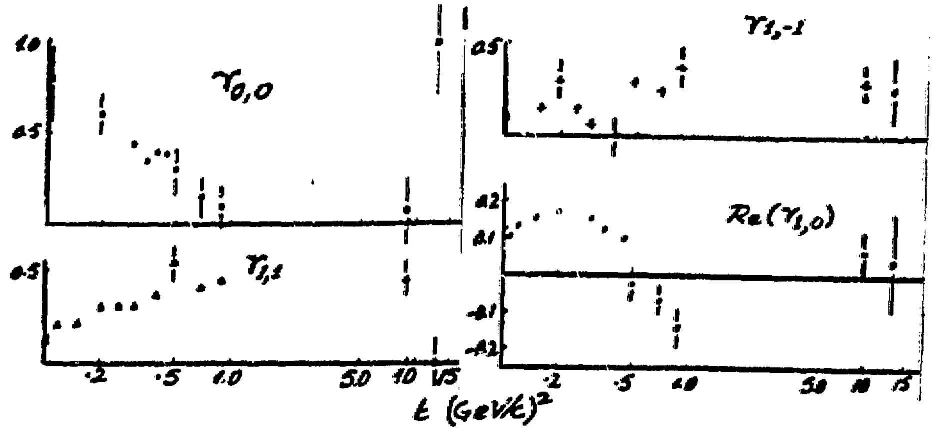

Fig. 4. The density matrix elements vs. t.

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