conservation in atomic transitions will rule out all "natural" quark-lepton symmetric $SU(2)_L \otimes U(1)$ gauge models. The $SU(2)_L \otimes SU(2)_R \otimes U(1)$ model with four quarks and four leptons appears to accommodate this and other neutral-current experiments and may provide interesting insight into *CP* and *P* nonconservation in weak interactions.[17] A six-quark extension of this model is possible, if we want to accommodate the *y* anomaly.

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[17]We note that unlike the $SU(2)_L \otimes U(1)$ model with four quarks where the Yukawa interaction of the Higgs fields generates *CP* nonconservation [see S. Weinberg, Phys. Rev. Lett. 37, 657 (1976), and P. Sikivie, Phys. Lett. 65B, 141 (1976)], in the $SU(2)_L \otimes SU(2)_R \otimes U(1)$ models, all interactions (weak, electromagnetic as well as *CP* nonconservation ones) are generated by gauge principle.

Atomic-Number Dependence of Large-Transverse-Momentum Hadron Production by Protons*

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We have measured at Fermilab the production of hadrons at ~90° in the c.m. system as a function of incident proton energy, atomic number A of the production target, and the transverse momentum $p_\perp$ of the produced hadron. The A dependence of the production cross section of the hadrons can be described by a function $A^{\alpha(p_\perp)}$, where the power α rises with $p_\perp$. At $p_\perp$ ~5 GeV/c, α is ~1.1 for $\pi^\pm$ and K^+, and ~1.3 for p, $\bar{p}$, and K^-. The energy dependence of the power is also measured.

In an earlier paper[1] we reported on the atomic-number (A) dependence of hadron production at large transverse momentum ($p_\perp$). Similar data have also been reported by other groups.[2,3] These results were surprising because the A dependence of the hadron yield, when fitted to a form $A^{\alpha(p_\perp)}$,

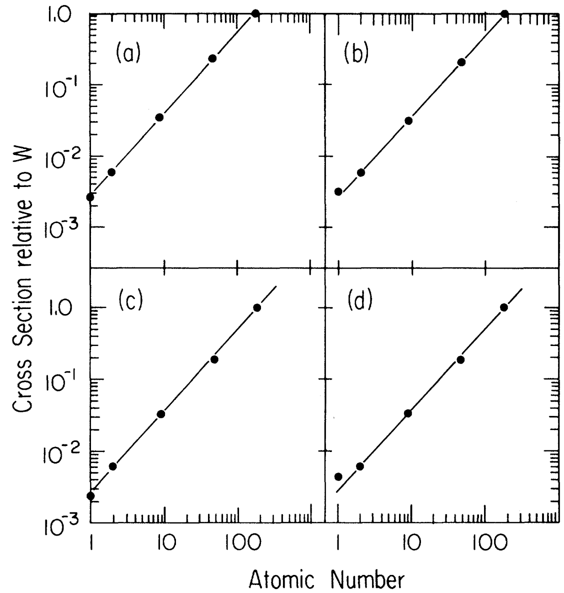

FIG. 1. The invariant cross section for π production relative to tungsten for various atomic numbers at 400 GeV; (a) π^- at $p_\perp = 3.85$ GeV/c, (b) π^+ at $p_\perp = 3.85$ GeV/c, (c) π^- at $p_\perp = 5.38$ GeV/c, (d) π^+ at $p_\perp = 5.38$ GeV/c. The errors are smaller than or equal to the size of the points.

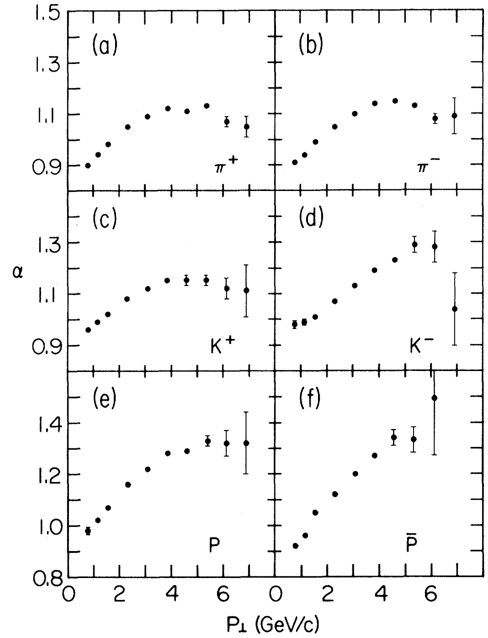

FIG. 2. The power α of the A dependence of the invariant cross section vs $p_\perp$ for the production of hadrons by 400-GeV protons; (a) π^+, (b) π^-, (c) K^+, (d) K^-, (e) p, and (f) $\bar{p}$. Unless indicated otherwise, the errors are smaller than or equal to the size of the points.

showed values of α in excess of unity at large $p_\perp$. This effect has been the subject of considerable discussion in the recent literature.[4-12]

In order to place the effect on a firmer experimental basis, the measurements of Ref. 1, obtained with targets of 0.2 nuclear interaction length, were repeated with *thin* targets (0.03 interaction length) of Be, Ti, and W. We have measured the hadron yields at ~90° in the proton-nucleon c.m. system for incident protons of 200, 300, and 400 GeV energy. At 400 GeV we have also made measurements with a liquid-deuterium target (~0.06 interaction length).

The apparatus used has been described in detail in Ref. 1. It consists of a single-arm magnetic spectrometer which accepts hadrons produced at a fixed angle of 77 mrad with respect to the incident proton beam in the Proton East Area at the Fermi National Accelerator Laboratory. This fixed angle corresponds, in the p-nucleon c.m. system, to a production angle of 77°, 88°, and 97° for 200-, 300-, and 400-GeV incident protons, respectively. Two Cherenkov counters identify the detected particles as pions, kaons, and protons.

To minimize systematic errors, data were taken at a fixed $p_\perp$ setting of the spectrometer with each of the three nuclear targets successively placed in the beam. Hence the relative cross sections depend only on the observed yield of hadrons relative to the incident-beam intensity measured by a secondary-emission monitor. The precision of the relative cross sections was determined by the stability of the monitors which was better than 3%. For $p_\perp \geq 5$ GeV/c the errors were usually dominated by statistics. No absolute measurements were required.

Figure 1 shows the cross section relative to W for $\pi^\pm$ production, as a function of A, at $p_\perp = 3.85$ and 5.38 GeV/c for 400-GeV incident protons. One can see that all the cross sections except hydrogen are well represented by a power-law dependence. The result for hydrogen does not lie on the power-law curve. This is a reflection of the fact that the π^+/π^- yield ratio for nuclei is ~1.15 and is weakly dependent on $p_\perp$ while it rises above 2.0 when measured on hydrogen at high $p_\perp$.[11]

We have made a least-squares fit to the invariant cross section using the power law

$$E d\sigma_i(p_\perp, A)/d^3p = I_i(p_\perp) A^{\alpha_i(p_\perp)},$$

where the index i refers to the outgoing hadron i. Included in the fits are measurements on D_2, Be,

TABLE I. Values of the exponent $\alpha_i(p_\perp)$ for production of hadrons by 400-GeV protons.

p (GeV/c)	α_{π^+}	α_{π^-}	α_{K^+}	α_{K^-}	α_p	$\alpha_{\bar{p}}$
0.77	0.90 ± 0.01	0.91 ± 0.01	0.96 ± 0.01	0.98 ± 0.02	0.98 ± 0.02	0.92 ± 0.02
1.16	0.94 ± 0.01	0.94 ± 0.01	0.99 ± 0.01	0.99 ± 0.01	1.02 ± 0.01	0.96 ± 0.01
1.54	0.98 ± 0.01	0.99 ± 0.01	1.02 ± 0.01	1.01 ± 0.01	1.07 ± 0.01	1.05 ± 0.01
2.31	1.05 ± 0.01	1.05 ± 0.01	1.08 ± 0.01	1.07 ± 0.01	1.16 ± 0.01	1.12 ± 0.01
3.08	1.09 ± 0.01	1.10 ± 0.01	1.12 ± 0.01	1.13 ± 0.01	1.22 ± 0.01	1.20 ± 0.01
3.85	1.12 ± 0.01	1.14 ± 0.01	1.15 ± 0.01	1.19 ± 0.01	1.28 ± 0.01	1.27 ± 0.01
4.62	1.11 ± 0.01	1.15 ± 0.01	1.15 ± 0.01	1.23 ± 0.01	1.29 ± 0.01	1.34 ± 0.03
5.38	1.13 ± 0.01	1.13 ± 0.01	1.15 ± 0.02	1.29 ± 0.03	1.33 ± 0.02	1.33 ± 0.05
6.15	1.07 ± 0.02	1.08 ± 0.02	1.12 ± 0.04	1.28 ± 0.06	1.32 ± 0.05	1.49 ± 0.22
6.91	1.05 ± 0.04	1.09 ± 0.07	1.11 ± 0.10	1.04 ± 0.14	1.32 ± 0.12	

Ti, and W. Inclusion of the deuterium point in the fit does not change the exponent, but it does decrease the error. In every case, we find a satisfactory fit to a power law. We have also made a fit with the function

$$E d\sigma(p_\perp, A)/d^3p = a(p_\perp)A^{2/3} + b(p_\perp)A + c(p_\perp)A^{4/3}.$$

This form is suggested if the A dependence is due to multiple collisions within the nucleus. Reasonable fits are also obtained with positive values for a, b, and c. The precision of the data is insufficient to distinguish between the two functional forms.

Figure 2 shows the value of the exponent $\alpha_i(p_\perp)$ as a function of $p_\perp$ for the various hadrons, produced by 400-GeV protons. All of the exponents rise above unity at large $p_\perp$, and tend to show a saturation for $p_\perp > 4$ GeV/c. The exponents for pion production may even show a decrease at the highest values of $p_\perp$. These values of $\alpha_i(p_\perp)$ are given in Table I.

Data were taken with 200-, 300-, and 400-GeV incident protons for $p_\perp$ values of 0.77, 3.08, and 4.62 GeV/c, respectively. The energy dependence of the exponent α for these three values of $p_\perp$ is shown in Fig. 3. While in some cases there is an energy dependence for low $p_\perp$, there is no significant energy dependence at high $p_\perp$. The values of $\alpha_i(p_\perp)$ at 300 GeV are in good agreement with our previous measurements, which were carried out with targets of 0.20 nuclear interaction length.

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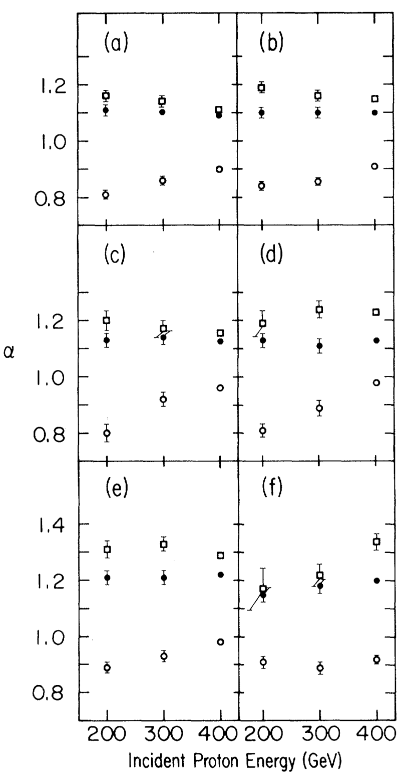

FIG. 3. The energy dependence of the power α of the A dependence of the invariant cross section for the production of hadrons by protons. The points with open circles are for $p_\perp = 0.77$ GeV/c, with closed circles for $p_\perp = 3.08$ GeV/c, and open squares for $p_\perp = 4.62$ GeV/c; (a) π^+, (b) π^-, (c) K^+, (d) K^-, (e) p, and (f) $\bar{p}$. Unless indicated otherwise, the errors are smaller than or equal to the size of the points.

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Chiral Substructure of the Nucleon*

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The representation mixing induced by the spontaneous breaking of chiral symmetry is a spatially varying phenomenon. A model for this effect predicts the form of the spin-dependent structure functions of deep inelastic lepton scattering and leads to the relation $1-\alpha_{A_1}(0)=2[1-\alpha_\rho(0)]$.

The Nambu-Goldstone realization of chiral symmetry leads naturally[1] to representation mixing of quarks and their bound states. In this Letter we describe this representation mixing in the context of the parton model[2] and point out how this phenomenon is probed in polarized electroproduction experiments. We suggest that the mixing exhibits spatial variation[3] and that the nucleon consequently possesses an interesting chiral substructure. Our description of this structure is summarized in predictions of the spin-dependent structure functions $G(x)$ and a relation between the A_1 and ρ Regge trajectories, $1-\alpha_{A_1}(0)=2[1-\alpha_\rho(0)]$.

Chiral symmetry is spontaneously broken[4] when some chirally noninvariant triggering field acquires a vacuum expectation value v. This phenomenon leads in quark models to the spontaneous generation of a quark mass m. In bound-state models[5] one anticipates that v, and hence m, will be spatially dependent quantities, approaching some asymptotic values in regions far from the localized bound state. This means that the chiral representation mixing which results from the spontaneously generated quark mass will also vary across the region of the bound state. The domain in which the mixing is a significant phenomenon is simply that region in which v is appreciably large.

In the quark model, the composite field $\bar{\psi}\psi$ is the triggering field for spontaneous chiral symmetry breaking, and the vacuum expectation value v is a measure of the density of quark-antiquark pairs. Phenomenologically,[6] this density is large only for small values of the longitudinal momentum fraction x. We expect, therefore, that the effects of chiral representation mixing should be significant only in the small-x region.

A concrete model for this mixing can be constructed if we consider a single valence quark embedded in a sea of gluons and quark-antiquark pairs. In the absence of interactions the valence quark's spin would be a constant of motion and, in the context of some broken SU(6) symmetry scheme, the distribution of quark spins would be completely determined. Interactions with the sea will, however, transfer the valence quark's spin to particles in the sea. We assume that these interactions are of short range in rapidity and discuss them, for simplicity, as if they were local in x. Our results are thus most reliable for small x, which, as we have noted, is the only region where we expect significant mixing to occur.

Let $\sin^2\theta$ denote the probability that the valence quark's spin is altered[7] by its interactions with the sea. If the density of the sea relative to valence quarks is $N(x)$, and if $\mathcal{H}(x)$ denotes the probability of a spin-flip interaction between valence