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SPIN-SPIN CORRELATIONS IN PROTON-PROTON COLLISIONS AT HIGH ENERGY AND THRESHOLD ENHANCEMENTS*

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ABSTRACT

The striking effects in the spin structure observed in elastic proton collisions and the Nuclear Transparency phenomenon recently discovered at BNL are described in terms of heavy quark threshold enhancements. The deviations from scaling laws and the broadening of the angular distributions at resonance are also consistent with the introduction of new degrees of freedom in the pp system. This implies new s-channel physics. Predictions are given for the spin effects in pp collisions near 18.5 GeV/c at large p_T^2 where new measurements are planned.

INTRODUCTION

The spin-spin correlation parameter A_{NN} measured in large angle proton-proton collisions at high energy,[1] exhibit structure as a function of large $\sqrt{s}$ and p_T^2. This defies a simple explanation based on the scale invariant nature of the underlying fundamental constituent interactions. As a consequence, a prosperous theoretical industry has developed in an attempt to explain this striking behavior. I have chosen to classify the various models into three categories, according to their predictions for the large-angle behavior of A_{NN} above 12 GeV/c (where the spin effects have not been measured yet),

I) Models where A_{NN} grows to large values[2]

II) Oscillatory models[3]

III) Models where A_{NN} relaxes to the PQCD prediction[4] of $A_{NN} = \frac{1}{3}$.

In the first type I have included models with strong quark correlations, massive quark models, diquark models or models which incorporate other large distance effects.[2] The oscillation of the pp elastic scattering data about the s^{-10} power law has been inspirational for type II models, where an oscillatory behavior of A_{NN} is also expected.[3] As an example, in the model of Pire and Ralston,

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Invited talk presented at the Third Conference on the Intersections Between Particle and Nuclear Physics, Rockport, Maine, May 14–19, 1988 one would expect coherent effects in the pp system to arise from the imaginary part of the double log Sudakov corrections. In the third category, I include models such as the present one, based on perturbative QCD (PQCD) which incorporate the onset of new effects due to the opening of a heavy quark threshold at 12 GeV/c. Available data suggest a strong correlation of the spin behavior with other anomalous pp data at 12 GeV/c. The new effect, characteristic of threshold phenomena, would die away at higher energies, the system relaxing to its PQCD behavior.[4,5]

If we closely examine the pp elastic data at 90°, factoring out the PQCD dependence $F^4(t)/sp^2$ (which behaves as s^{-10} at very large s), we find a strict correlation with the A_{NN} data as shown in Fig. 1: a very rapid increase in the total cross section in the 8–12 GeV/c region which tails off at higher energies. This behavior is reminiscent of a threshold effect due to the introduction of new degrees of freedom. The pp elastic angular distribution exhibits the same trend: a rapid anomalous broadening which is maximum at 12 GeV/c [Fig. 2(c)]. This effect also dies away at higher energies. If we take seriously the correlation of anomalous A_{NN} with pp elastic data, this is not encouraging news for the type I models. Finally, the "color transparency" effect,[6] recently discovered at BNL by measuring the energy dependence of absorptive corrections to quasi-elastic pp scattering in various nuclear targets, exhibits an anomalous behavior at 12 GeV/c with respect to the QCD predictions. The QCD transparency disappears and normal attentuation is observed. The above considerations led Stanley Brodsky and myself to propose a simple model based on the opening of new degrees of freedom in the s-channel, which accounts for the observed structure in the pp system.[4]

The PQCD component of the model is the Constituent Interchange Model (CIM),[7] which is the dominant mechanism at large momentum transfer.[8] We do not include diffractive contributions and our model is only valid at large angles where hard scattering is important. To describe the observed structure we need to introduce two broad ($J = L = S = 1$) resonant amplitudes centered at $\sqrt{s} = 2.55$ GeV and 5.08 GeV and a sharp $^3F_3$ resonance at $\sqrt{s} = 2.17$ GeV, with widths of 1.6, 1.0 and 0.04 GeV respectively. These amplitudes intefere with the CIM amplitude to reproduce the experimental data. The required $\sqrt{s}$ values correspond to the $pp \to K^+\Lambda p$, $pp \to D^0\Lambda_c p$, and $pp \to \Delta p$ thresholds respectively. Other details of the model are described in Ref. 4.

MODEL PREDICTIONS

The predictions of the model and comparison with experiment are shown in Figs. 2 and 3. As shown in Figs. 2(a) and 2(b), the deviations from the simple scaling predicted by the PQCD amplitudes are readily accounted for by the

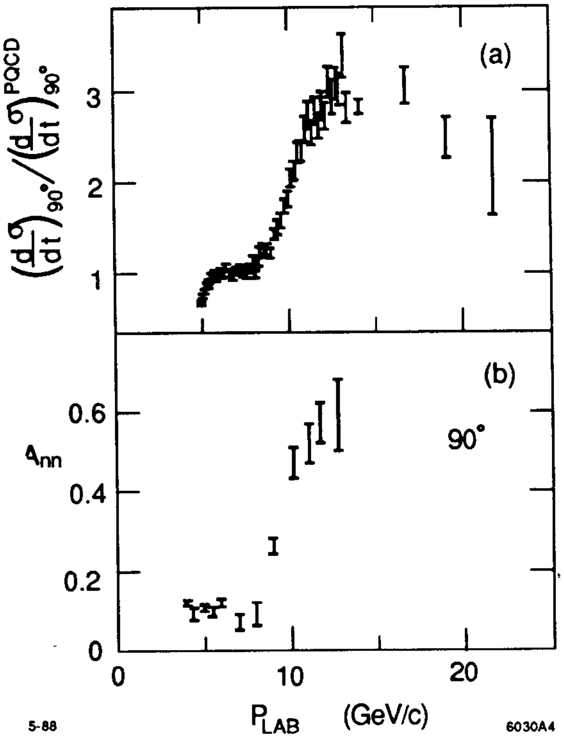

Fig. 1. Onset of threshold effects in $d\sigma/dt$ and A_{NN} at 90° near 12 GeV/c.

resonance structures. In Fig. 2(a) the solid curve is the prediction of the model and the dotted line is the background PQCD prediction. In Fig. 2(b) we show the ratio of $d\sigma/dt$ at 90° to the PQCD prediction. The angular distribution (normalized to the data at $\theta_{\rm cm} = \pi/2$) is predicted to broaden relative to the steeper perturbative QCD form, when the resonance dominates. As shown in Fig. 2(c) this is consistent with experiment, comparing data at $p_{lab} = 7.1$ and 12.1 GeV/c. The solid and dotted lines are predictions for $p_{lab} = 12.1$ and 7.1 GeV/c, respectively. The narrow peak which appears near 1.3 GeV/c in Fig. 3(a) corresponds to the onset of the $pp \to p\Delta(1232)$ channel. The model is also consistent with the recent high energy data point for A_{NN} at $p_{lab} = 18.5$ GeV/c and $p_T^2 = 4.7$ GeV^2 [see Fig. 3(b)]. The data show a dramatic decrease of A_{NN} to zero or negative values. This is explained in our model by the destructive interference effects about the resonance region. The same effect accounts for the depression of A_{NN} for $p_{lab} \approx 6$ GeV/c shown in Fig. 3(a). The comparison of the angular dependence of A_{NN} with data at $p_{lab} = 11.75$ GeV/c is shown in Fig. 2(c). References for the data are given in Ref. 4.

The most striking test of the model is its prediction for the spin correlation A_{NN} shown in Fig. 3(a). The rise of A_{NN} to $\simeq 60\%$ at $p_{lab} = 11.75$ GeV/c is correctly reproduced by the high energy $J = 1$ resonance interfering with a

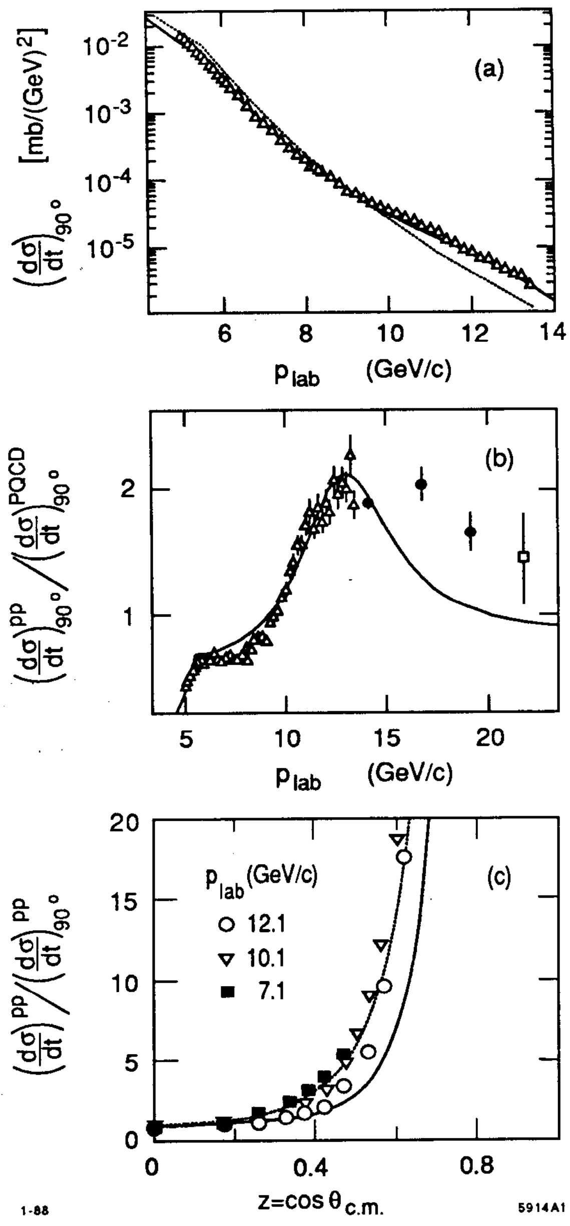

Fig. 2. *pp* elastic cross sections.

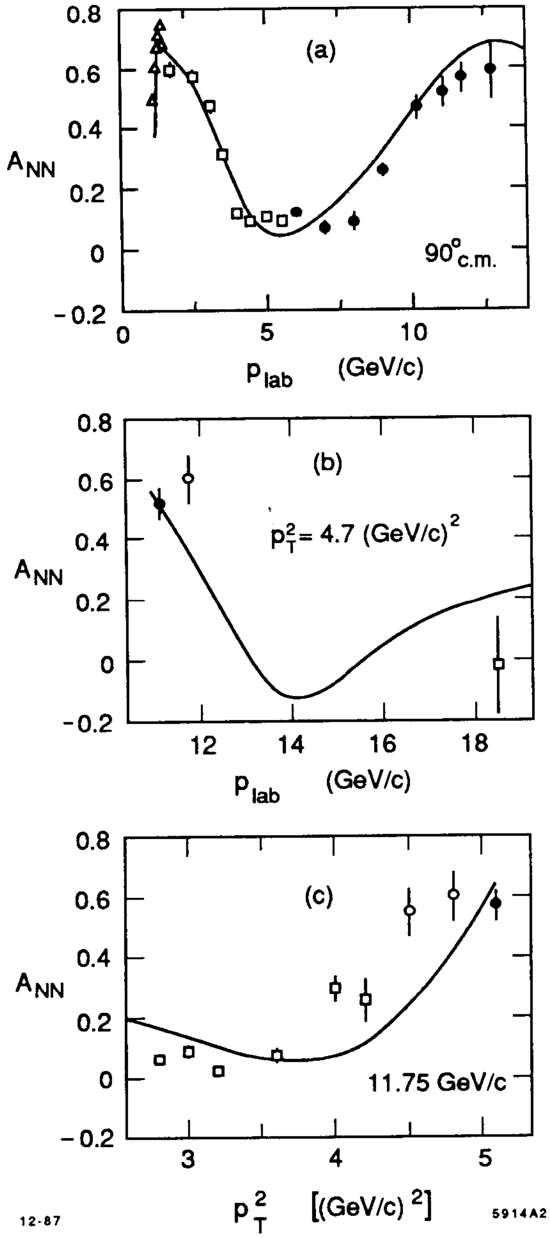

Fig. 3. A_{NN}.

PQCD background. In addition using unitarity we predict total charm production cross section of 1 μb near threshold, just below the preliminary limits set by BNL E766.[9] The model prediction for strangeness production near threshold is about 1mb, consistent with experiment (see Ref. 4).

CONCLUSIONS

I have given a brief account of various possible explanations of the anomalous spin-spin correlation data and how different models can be classified according to their prediction of A_{NN} at large angles above 12 GeV/c. Measurements of A_{NN} in this energy region are crucial. Our model predictions above 12 GeV/c at 90° are shown in Fig. 4. We also predict an increase in A_{NN} from 10% at $P_T^2 = 7$ (GeV/c)^2 to 40% at $P_T^2 = 8.2$ (GeV/c)^2 at $P_{lab} = 18.5$ GeV/c.

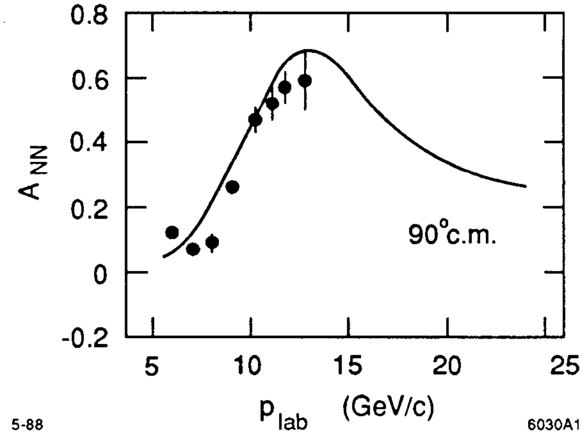

Fig. 4. Model prediction of A_{NN} above 12 GeV/c.

The anomalous pp elastic data is consistent with the onset at 12 GeV/c of a threshold effect due to the opening of new degrees of freedom. The data are well reproduced by the interference of two broad and highly inelastic resonance structures at $\sqrt{s} = 2.55$ GeV and 5.08 GeV. These energies correspond to the threshold value for open strangeness ($pp \rightarrow \Lambda K^+ p$) and open charm ($pp \rightarrow \Lambda_c D^\circ p$) respectively. The model may be interpreted in terms of actual "hidden-flavor" resonances near the respective thresholds. On the other hand, the successful description of a wide range of data may simply reflect an adequate parametrization of the threshold effects in the NN system arising from opening of new (heavy flavor) inelastic channels.

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