Modeling polarization asymmetry

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I comment on the relation of the calculation of Fujita and Matsuyama to the polarization-asymmetry model of DeGrand and Miettinen.

The polarization of baryons produced inclusively in low-transverse-momentum processes is a striking yet poorly understood phenomena. Baryon polarization increases roughly linearly with increasing baryon transverse momentum and with increasing fraction x_F of the incident hadron's longitudinal momentum carried off by the baryon.[1] The magnitude of the polarization of all baryons produced in the fragmentation of a proton beam is roughly equal, although the sign of the polarization varies dramatically from baryon to baryon, while the asymmetry of Λ's produced in the fragmentation of a K^- is much larger.[2]

The model for baryon polarization in low-transverse-momentum processes which was proposed by DeGrand and Miettinen[3] had several key ingredients. We began by assuming that there is some ordering of flavor quantum numbers in the infinite-momentum-frame wave function of the beam and target particles, so that the quarks which carry the valence quantum numbers of the hadrons also carry most of their momenta while the quarks and antiquarks which have no quantum numbers in common with the hadrons (the so-called "sea partons") carry very little of the hadron's momentum. This is a standard parton-model assumption. Next, we assumed that during the formation process the outgoing baryon was formed from the coalescence of three quarks which carry its valence quantum numbers, and that the three quarks each carried out about one-third of the baryon's momentum. We took SU(6) wave functions for these quarks as well as for the valence-quark wave functions of the fragmenting hadron. With these assumptions we were able to formulate a simple rule which continues to account for all the observed regularities in hyperon polarization: Quarks which gained longitudinal momentum during the baryon formation process have a greater probability of recombining with their spins down while quarks which lose longitudinal momentum during the reaction tend to have a greater probability of recombining with their spins up. All the observed regularities in $p \rightarrow B + X$ arise solely from this rule plus Clebsch-Gordan coefficients.

This rule is our contribution to the phenomenology of polarization in low-transverse-momentum reactions.

Finding a dynamical explanation of this rule has proven to be very difficult. The problem is that the process is a long-distance effect of QCD, where QCD is strongly interacting. The only reliable nonperturbative calculational scheme for QCD which exists at present, lattice gauge theory, has been so far restricted to static observables. Thus one is reduced to phenomenological model building.

Until the work of Fujita and Matsuyama,[4] I was aware of two approaches to the problem. The older one is our semiclassical explanation:[3] One expects a spin-momentum relation for fermions similar to the one required by our rule whenever their direction of motion is not parallel to any forces (in this case the ones causing them to bind into the outgoing baryon) acting on them. We also constructed a crude model for the x_F and p_T dependence of Λ polarization; it qualitatively resembles the data but fails in detail.[5] The dynamic model contains no convincing explanation for the near equality of the magnitudes of the different hyperon polarizations produced from proton beams, but can give a qualitative explanation for the relative magnitudes of Λ polarization from proton and kaon fragmentation. What I believe to be a similar explanation, couched in the language of the Lund string model, has been given by Sköld.[6]

More recently, Dharmaratna, Goldstein, and Ringland[7] have proposed interference effects between various orders of perturbative QCD scattering diagrams as the origin of the polarization asymmetry. However, they have not yet extended their calculations sufficiently for a comparison with data. To me, this sort of model building is probably the most fruitful since it holds out the possibility of a fully quantum-mechanical explanation of the process; however, it will probably also only provide a hint of what is going on since the ultimate explanation must be nonperturbative.

My objection to the model of Matsuyama and Fujita is that it is not obvious to me that the quarks whose spins are responsible for a polarization asymmetry are ever in energy eigenstates of some potential until after the whole production process is complete. If they are never in an energy eigenstate, the pattern of splittings of energy levels in a potential is not directly relevant to the existence of a polarization asymmetry. Of course, one can always expand a wave function as a superposition of eigenstates in any basis one chooses, but the expansion coefficients will be time dependent. As an example, consider the reaction $p \rightarrow \Sigma^+$ and consider the two valence u quarks which will pass from the proton's wave function into the Σ's, carrying some of its polarization. Before the reaction begins, these two quarks are part of the proton wave function. They carry some large fraction of the proton's longitudinal momentum and have a transverse momentum characteristic of the bound state. At the end of the reaction they are part of the Σ, with much less longitudinal momentum (about two-thirds of the momentum of the Σ) as well as some moderate transverse momentum. At intermediate times the forces acting on the quarks are not easy to quantify, but they can probably not be described by a linear potential from some well-specified origin.

It may be that a potential model can describe the late stages of inclusive production. In that case, the results of Matsuyama and Fujita show that polarization does not arise during that part of the reaction.

In summary, I am willing to believe that one cannot account for the polarization data in terms of the energy levels of a Dirac particle in a linear potential. It is not obvious to me that that model is an appropriate one for describing the polarization process. I believe that the spin-momentum correlation rule which Miettinen and I invoked to explain the polarization data which was known at the time we made it continues to be correct. The origin of the rule, however, continues to be obscure.

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[1]For a recent compilation of data, see T. DeGrand, J. Markkanen, and H. I. Miettinen, Phys. Rev. D **32**, 2445 (1985).
[2]Cf. S. Gourlay *et al.*, Phys. Rev. Lett. **56**, 2244 (1986).
[3]T. DeGrand and H. I. Miettinen, Phys. Rev. D **23**, 1227 (1981); **24**, 2419 (1981); **31**, 661(E) (1985).
[4]T. Fujita and T. Matsuyama, preceding paper, Phys. Rev. D **38**, 401 (1988).
[5]B. Lundberg, thesis, University of Wisconsin, 1984.
[6]L. Sköld, Phys. Scr. **31**, 464 (1985).
[7]W. Dharmaratna, G. Goldstein, and G. Ringland, Report No. TUFTS-TH-G86-2, 1987 (unpublished).