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$\bar{p}p \to \bar{\Lambda}\Lambda$ reaction in the one-gluon-exchange and the $^3P_0$ models

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As an alternative to conventional meson-exchange models, we study exclusive $\bar{p}p \to \bar{Y}Y$ production in the nonrelativistic one-gluon-exchange and the $^3P_0$ model. Adjusting the overall coupling strengths at $P_{lab}=2.0$ GeV/c, the main uncertainity originates from the oscillator constant. Though both models yield qualitative agreement with experiment, a more detailed comparison favors the one-gluon-exchange model.

With the recent advent of the low-energy antiproton ring (LEAR), a systematic study of the production mechanism for strange baryon-antibaryon pairs in $\bar{p}p$ annihilation becomes feasible. In fact, particularly for exclusive $\bar{p}p \to \bar{\Lambda}\Lambda$ production the rather scarce data[1] have been improved substantially around and slightly above the threshold.[2] Besides the threshold behavior of the total $\bar{p}p \to \bar{\Lambda}\Lambda$ cross section, angular distributions and asymmetries have been measured at four different energies. Information on other $\bar{Y}Y$ channels, particularly on the $\bar{\Lambda}\Sigma^0+\bar{\Sigma}^0\Lambda$ and the $\bar{\Sigma}^+\Sigma^+$ final state, will be available in the near future.

Exclusive $\bar{Y}Y$ production is highly interesting from the theoretical point of view. Besides the novelty of the reaction, such a process involves a large momentum mismatch of typically >600 MeV/c, even at threshold. Consequently, this reaction is ideally suited for probing exotic degrees of freedom at very short distances <0.4 fm. By testing the "quark core" of the baryon-antibaryon interaction we expect information on dynamical aspects, not only in the framework of the "old-fashioned" meson-exchange model, but rather on the level of quark and gluon degrees of freedom.[3,4]

In this spirit we present, the following estimates for the $\bar{p}p \to \bar{Y}Y$ cross sections, particularly for $\bar{\Lambda}\Lambda$ production in terms of the one-gluon-exchange [OGE, Fig. 1(a)][5] and the vacuum pair creation (VPC) $^3P_0$ model [Fig. 1(b)].[6]

Though both models parametrize quark-gluon dynamics in a similar framework, the philosophy behind them is rather different: While the OGE model relies on the perturbative gluon exchange in lowest order, the $^3P_0$ model parametrizes $\bar{q}q$ annihilation in the strong coupling limit. This characterizes the range where the two models should be applicable. For hard processes, like $\bar{c}c$ and $\bar{b}b$ creation, where $\alpha_s(q^2)$ is small, perturbation theory should be justified,[7] whereas "soft" $\bar{u}u$ and $\bar{d}d$ production should be more adequately described in the $^3P_0$ model.[8] For $\bar{s}s$ production around $q^2=(1 \text{ GeV})^2$, where neither a perturbative evaluation to first order in α_s nor in $1/\alpha_s$ seems to be justified.[9] Possibly, both parametrizations overlap.

The main obstacle for a formulation of $\bar{p}p \to \bar{Y}Y$ on the level of quarks are "conventional" initial and final state interactions due to the coupling of the $\bar{B}B$ system to the elastic and to inelastic channels. The introduction of purely phenomenological optical potentials—as done conventionally—raises immediately a serious double-counting problem. To avoid that, we proceed here rather pragmatically. Working in the plane wave Born approximation (PWBA) we sum up distortion effects in an effective, energy-independent coupling constant, which we normalize to the total cross section at 600 MeV/c above the $\bar{\Lambda}\Lambda$ threshold. The smooth energy dependence of the distortion effect in the $\bar{p}p$ channel, and presumably also in the $\bar{Y}Y$ channel supports such a simple prescription.

Final state interactions in the $\bar{Y}Y$ channel are not known experimentally. However, simple theoretical estimates indicate that at a scattering energy $p_{lab}=2$ GeV/c for the incoming $\bar{p}$ the $\bar{Y}Y$ interaction should be significantly weaker than the $\bar{p}p$ interaction. Hence, except for $\bar{Y}Y$ production very close to the corresponding $\bar{Y}Y$ threshold we expect distortion effects to be dominated by the very strong $\bar{p}p$ initial state interaction.[10-12]

With these preliminaries the differential cross section is given (in an obvious notation) by

$$\frac{d\sigma}{d\Omega}=\frac{P_f}{P_i}\frac{m_N m_\Lambda}{4\pi^2}|V(q)|^2 . \tag{1}$$

Following standard arguments (details are given in a forthcoming paper) the corresponding transition operator is given in the OGE model by[12,13]

$$\hat{T}=\frac{\alpha_s}{(2m_q)^2}\frac{(\lambda_q-\lambda_{\bar{q}}^*)^2}{24}\frac{(\sigma_q+\sigma_{\bar{q}})^2}{4}\delta(\mathbf{r}) , \tag{2}$$

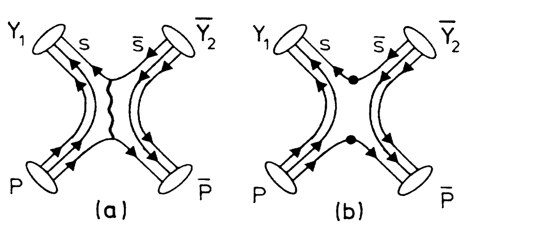

FIG. 1. Schematical representation of $\bar{p}p \to \bar{Y}Y$ in the (a) one-gluon exchange and (b) the vacuum pair creation model.

where $\underline{\lambda}$ denotes SU_3 Gell-Mann matrices for the color sector. Correspondingly, the $^3P_0$ operator reads[14]

$$\hat{T} = g_{^3P_0}\Theta^\dagger\Theta \ , \tag{3}$$

with

$$\Theta = (\chi_{\bar{q}q}^{S=1},\nabla)^{J=0}\delta(\mathbf{r}) \ .$$

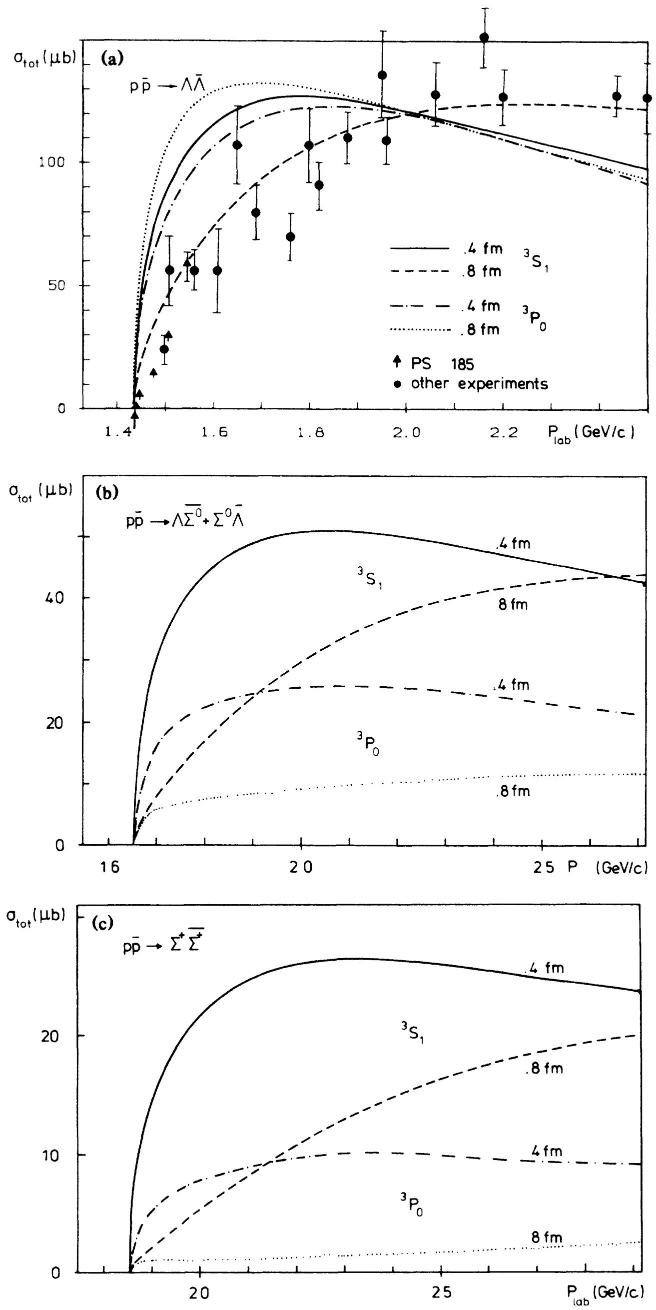

FIG. 2. Energy dependence of the total $\bar{p}p \rightarrow \bar{Y}Y$ cross section into (a) the $\bar{\Lambda}\Lambda$, (b) the $\bar{\Lambda}\Sigma^0 + \bar{\Sigma}^0\Lambda$, and (c) the $\bar{\Sigma}^+\Sigma^+$ antihyperon-hyperon channels. Compared are the OGE model [Fig. 1(a); full and dashed line] and the VPC model [Fig. 1(b); dashed-dotted and dotted line] for two oscillator radii $R = 0.4$ fm and 0.8 fm. The data for the $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ channel (for the other channels the existing experimental data are very poor) are taken from Refs. 1 and 2.

Note that g_{OGE} and $g_{^3P_0}$, which are originally given as

$$g_{OBE} = \alpha_s/(2m_q)^2 \ , \qquad g_{^3P_0} = \gamma^2/(2m_{eff}) \ , \tag{4}$$

are treated in the following as effective coupling constants.

For Gaussian wave functions[15]

$$\psi(\mathbf{r}_1,\mathbf{r}_2,\mathbf{r}_3,\mathbf{r}) = (\sqrt{3}\pi R^2)^{-3/2}\exp\left[-\sum_i(\mathbf{r}_i-\mathbf{r})^2/(2R^2)\right] \times\delta\left(\tfrac{1}{3}(\mathbf{r}_1+\mathbf{r}_2+\mathbf{r}_3)-\mathbf{r}\right) \ , \tag{5}$$

together with the completely antisymmetric color term

$$\chi_c = e_{ijk}\langle q_i,q_j,q_k\rangle \ , \tag{6}$$

the transition matrix element yields

$$V(^3S_1;\mathbf{q}) = \tfrac{4}{9}\,g_{OGE}M_{SF}\exp(-q^2R^2/3) \ , \tag{7}$$

and

$$V(^3P_0;\mathbf{q}) = \sum_{m,m'} g_{^3P_0}K(m,m')[\mathbf{e}_m\mathbf{e}_{m'}^* - \tfrac{2}{3}R^2(\mathbf{e}_m\mathbf{q})(\mathbf{e}_{m'}^*\mathbf{q})] \times \exp(-q^2R^2/3) \ , \tag{8}$$

respectively [above M_{SF} and $K(m,m')$ denote appropriate spin-flavor factors]. The polarization vectors $\mathbf{e}_m$ and $\mathbf{e}_m$ reflect the annihilation of the $\bar{q}q$ $(q = u,d)$ and the creation of the $\bar{s}s$ pair in the spin-triplet $(1,-m)$ and $(1,-m')$ states, respectively.

With g_{OGE} and $g_{^3P_0}$ fixed from the data, the oscillator parameter R remains the only free parameter in the two models. [As an effective radius, R should not be confused with the conventional baryon radius, in our static model for the $\bar{q}q \rightarrow \bar{s}s$ transition operator, R summarizes, in addition, nonstatic corrections in (p/m), or, equivalently, nonlocalities of the order of the $\bar{s}s$ Compton-wave length.]

Characteristic results are presented in the following figures. In Fig. 2 the total cross section for $\bar{p}p$ annihilation into $\bar{\Lambda}\Lambda$ and—to illustrate the differences—into other $\bar{Y}Y$ channels are compared. The differential cross section for $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ at a lab momentum of 1508 MeV/c is shown in Fig. 3. The basic trends of the results are easily understood: They dominantly reflect the interplay of the large momentum transfer, the size of the interacting objects, and phase-space constraints. Comparison with recent experimental data from LEAR for the channel[6] indicates that a consistent fit of the energy dependence of both the total and the differential cross section with a given R is difficult in the $^3P_0$ model. The data seem to favor the OGE model: a qualitative consistency is obtained with the effective oscillator constant $R = 0.8$ fm. Comparing other $\bar{Y}Y$ channels with $\bar{\Lambda}\Lambda$ production our results predict a stronger sensitivity on R due to an increase in the momentum transfer and from the different SU_6 wave functions.

Summarizing, we have presented simplistic calculations for the $\bar{p}p \rightarrow \bar{Y}Y$ reaction in the "QCD-inspired" OGE and $^3P_0$ model. As a preliminary conclusion, existing data seem to favor an effective one-gluon exchange mechanism.

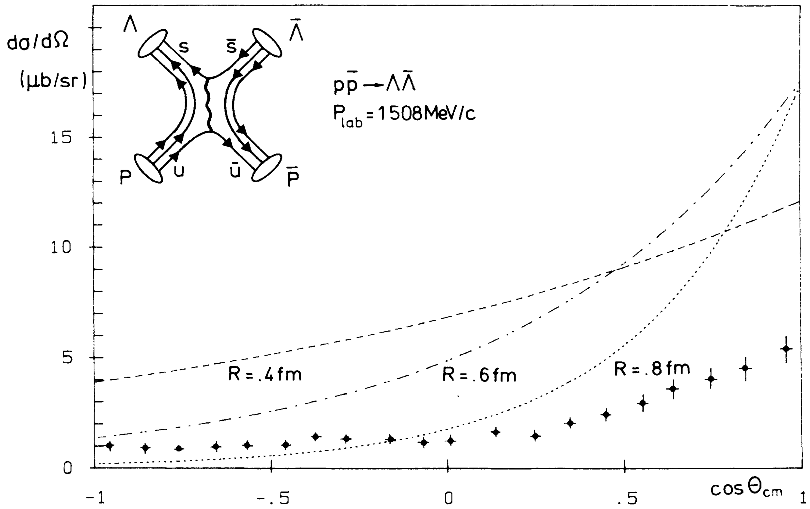

FIG. 3. Differential $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ cross section at a lab momentum of 1508 MeV/c for the OGE and the VPC model. The predictions for three different oscillator constants are compared with recent data from LEAR (Ref. 2).

For a more quantitative insight, however, a systematic comparison with different observables for the $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ reaction (cross section, analyzing power, and spin correlations) and an extension of the experimental information on other $\bar{Y}Y$ channels are obviously necessary.

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