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$\Lambda\bar{\Lambda}$ production in $p\bar{p}$ collisions

P. G. Ortega[1)] D. R. Entem F. Fernández

Grupo de Física Nuclear and IUFFyM, Universidad de Salamanca, E-37008 Salamanca, Spain

Abstract We describe the production of $\Lambda\bar{\Lambda}$ in $p\bar{p}$ collisions using a constituent quark model which has been successfully applied to the $N\bar{N}$ system.

Key words non-relativistic quark model, hyperon-antihyperon production

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1 Introduction

During the last decade the experiments done by the PS-185 Collaboration at LEAR have greatly enhanced our knowledge on the hyperon production process in proton-antiproton collisions. The study of this reaction has attracted considerable attention because not only it has been measured total and differential cross sections, but the whole set of spin structure, which is essential to distinguish among all theoretical models proposed. This interest has been renewed because of the construction of the antiproton facility FAIR and its low energy facility FLAIR, which will provide new and precise data for reactions involving antiproton beams, which motivates the theoretical studies of such reactions.

Historically, there are essentially two pictures to describe this strangeness formation: The conventional meson-exchange model where the production mechanism is mediated by the exchange of strange mesons; and the traditional quark models where the hyperon-antihyperon pair is produced from the proton-antiproton state via the annihilation of a $u\bar{u}$ pair and the subsequent creation of an $s\bar{s}$ pair.

A crucial point is that the previous transition mechanisms have different characteristic features. As many authors have pointed out, the study of spin observables, specially depolarization and spin transfer observables (D_{nn} and K_{nn}), can be the key to distinguish between different models, although neither meson exchange nor quark based models are able to give a consistent description of all the observables.

2 The model

The calculation was done in the framework of the constituent quark model of Ref. [1], which incorporates the basic features of QCD. The advantage of this model compared to traditional meson exchange and gluon annihilation is that it includes both mechanisms in the same framework. The kaons are generated as Goldstone bosons of the spontaneous chiral symmetry breaking, and gluons as perturbative contributions from QCD.

Once the microscopic model is fixed we use Resonant Group Method [2] to derive the interaction. For the problem in study we only need direct potentials, no particle exchange between clusters. That simplifies the reaction, and we end with four possible diagrams.

The scattering problem is solved using the coupled channel Lippmann-Schwinger equation. To calculate all the observables we use the density-matrix formalism, following Ref. [3]. This formalism was originally developed in helicity basis, allowing a more natural description of spin observables. The information of the scattering of two spin-$\frac{1}{2}$ particles is resumed in an on-shell complex spin-matrix M. This M matrix can be related with the Lippmann-Schwinger transition matrix T previously calculated.

3 The interactions

Besides the meson exchange diagrams, in the $q\bar{q}$

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1) E-mail: pgortega@usal.es

system there are annihilation contributions. The real part of this potential can be derived in our model by annihilation diagrams of the one-gluon and one-pion exchange. But to have a realistic model it is important to include the annihilation into mesons. To take into account this effect we chose a gaussian optical potential which simplifies the calculation. We need them to complete the description of $\mathrm{p}\bar{\mathrm{p}} \to \mathrm{p}\bar{\mathrm{p}}$ and $\Lambda\bar{\Lambda} \to \Lambda\bar{\Lambda}$.

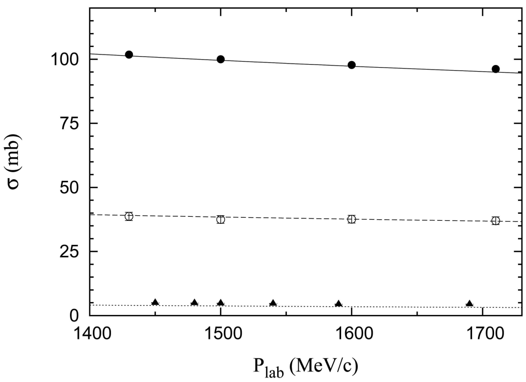

Fig. 1. Total (solid line), elastic (dashed line) and charge exchange (dotted line) cross section for $\mathrm{p}\bar{\mathrm{p}} \to \mathrm{p}\bar{\mathrm{p}}$ reaction. Experimental data from Ref. [4] (circles and squares) and Ref. [5] (triangles).

We only show the results for the total, elastic and charge exchange cross section for $\mathrm{p}\bar{\mathrm{p}} \to \mathrm{p}\bar{\mathrm{p}}$ in Fig. 1, because the $\Lambda\bar{\Lambda}$ interaction has no experimental data available. A reasonable description of the empirical data is obtained not only for the total cross section, but the differential cross section, due basically to π exchange.

To study the reaction we consider three different transition mechanisms for the non-diagonal interaction:

1) Our constituent quark model, that describes the process with the exchange of a Kaon and the annihilation through a gluon.

2) The same mechanism generalized to include the strange scalar κ.

3) To compare these two models with traditional ones based on the exchange of a Kaon on a baryonic level we study one of these models available in literature. This model will not be exactly the same as in the literature due to the optical potential and RGM description, but it will give us an idea of the limitations of meson exchange models.

We will use the same description for initial and final channels interactions for all transition mechanisms.

4 Results

To compare the three transition mechanisms proposed we first must adjust all of them to the total cross section. The chiral coupling constant of our CQM don't need to be the same for the strange sector, because of the generalization from $SU(2)_{\mathrm{F}}$ to $SU(3)_{\mathrm{F}}$. Nevertheless, the original coupling constant is able to reproduce the experimental data in a relative good way. However, if we want to fit the total cross section we need to decrease slightly the value of the chiral constant for the strange sector. We can justify this decrease in a breaking of $SU(3)_{\mathrm{F}}$ symmetry. The results are presented in Fig 2.

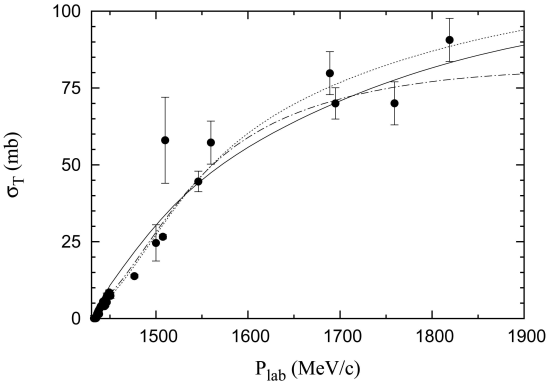

Fig. 2. $\mathrm{p}\bar{\mathrm{p}} \to \Lambda\bar{\Lambda}$ total cross section. Solid line represents the exchange of a Kaon on a baryonic level, dash-dotted line our CQM and with a dashed line CQM+κ. Experimental data from Refs. [6–12].

Once we have fitted the total cross section the differential cross section is described in good agreement for all the three transition models. It is expected that individual partial waves contribute rather differently for the three transition mechanisms under examination. That's hard to see in total or differential cross section, but we can in polarization and spin observables.

The polarization observables do not show evident differences among mechanisms (see Fig. 3).

A bigger contrast is found in spin correlations. There is plenty of data available, we show some graphics confirming this statements. All models predict strong triplet interactions, so spin correlations between final states are similar and we cannot use them to chose a model. The observable needed can be found in the measure of spin correlation between initial and final states.

Traditionally, the observables chosen to discriminate models were D_{nn} and K_{nn}, the so called depolarization and spin transfer.

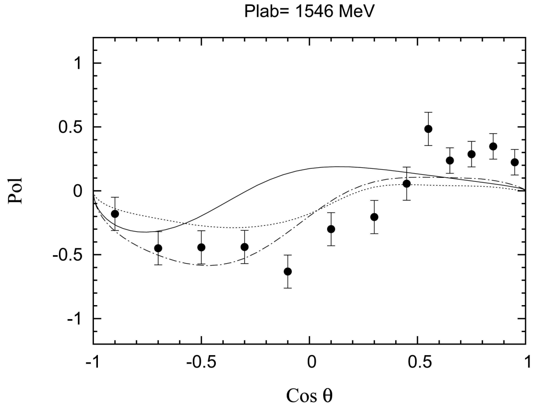

Fig. 3. Polarization for $p_{\rm lab}=1546.2$ MeV, using the same convention as in Fig. 2. Experimental data from Ref. [10].

We present the graphics of these observables for $p_{\rm lab}=1637$ MeV, one of the two energies they have been measured for, in Fig. 4 and Fig. 5. Obviously, initial and final state interactions modified the amount of spin transferred. However, most of the differences between models persist.

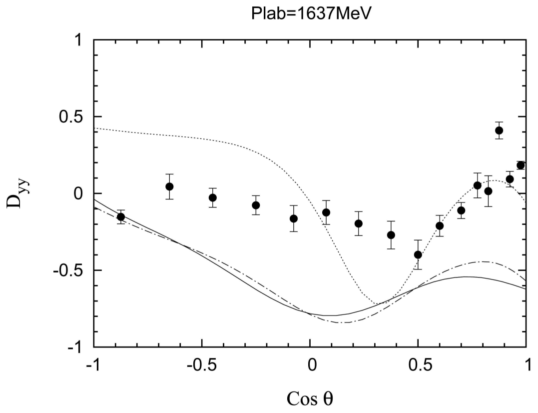

Fig. 4. Depolarization for $p_{\rm lab}=1637$ MeV. The same convention as in Fig. 2. Experimental data from Ref. [3].

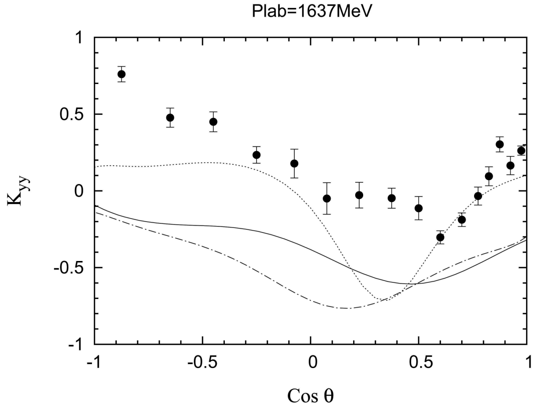

Fig. 5. Spin transfer for $p_{\rm lab}=1637$ MeV. The same convention as in Fig. 2. Experimental data from Ref. [3].

As we can see, CQM and the Kaon on a baryonic level models present a much bigger spin flip than CQM$+\kappa$, because of the scalar part.

4.1 Summary

In this paper we studied a coupled channel calculation of the reaction $\rm p\bar{p}\to\Lambda\bar{\Lambda}$, finding that is well-described in terms of quark degrees of freedom. For that, we used a constituent quark model widely used in baryon and meson spectroscopy and NN interaction.

To correctly describe the total cross section the chiral constant for the strange sector had to be slightly decreased, due to a breaking of $SU(3)_{\rm F}$ symmetry.

We considered three different transition mechanisms for the non-diagonal interaction, concluding that, if we have to choose one of them, the inclusion of the exchange of a scalar strange particle κ improves the description of the empirical data. But still more precise data is needed, and that's a challenge for future experiments.

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