PROCEEDINGS OF SCIENCE

Production of charmed baryons and mesons in antiproton-proton annihilation

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An estimation for the production rate of charmed mesons (D, D_s) and baryons (Λ_c, Σ_c, Ξ_c, Ξ_c') in antiproton-proton ($\bar{p}p$) annihilation close to their respective kinematical thresholds is presented. The elementary charm production process is described by either baryon/meson exchange or by quark/gluon dynamics. Effects of the interactions in the initial and final states are taken into account rigorously. The calculations are performed in close analogy to studies on $\bar{p}p \to \bar{\Lambda}\Lambda$, $\bar{\Sigma}\Sigma$, $\bar{\Xi}\Xi$ and $\bar{p}p \to \bar{K}K$ performed by the Jülich group in the past, by connecting the processes via $SU(4)$ symmetry.

The predicted production cross sections of charmed baryons are typically in the order of 1 μb, while those for charmed mesons are in the order of $10-100$ nb.

VIII International Workshop On Charm Physics
5-9 September, 2016
Bologna, Italy

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PoS(CHARM2016)058

1. Introduction

Charmed hadrons constitute an important and promising probe for improving our understanding of the strong force in the nonperturbative regime of QCD. The FAIR facility, presently built at the GSI site in Darmstadt, has an extensive program aiming at a high-accuracy spectroscopy of charmed hadrons and at an investigation of their interactions with ordinary matter. In the P̄ANDA experiment [1] charmed hadrons will be produced in antiproton-proton ($\bar{p}p$) collisions. Presently little is known about the interaction strength of charmed hadrons with other particles. Specifically, this concerns their production via the aforementioned reaction. Evidently, a significant production rate is a prerequisite for investigating issues like in-medium properties of charmed hadrons, e.g. $c\bar{c}$-quarkonium dissociation or changes of the properties of D mesons due to chiral symmetry restoration effects on the light quarks composing these mesons.

In this contribution predictions for the charm-production reactions $\bar{p}p \to \bar{Y}_c Y_c$ ($\bar{Y}_c Y_c = \bar{\Lambda}_c^- \Lambda_c^+$, $\bar{\Lambda}_c^- \Sigma_c^+$, $\bar{\Sigma}_c \Sigma_c$, $\bar{\Xi}_c \Xi_c$) and $\bar{p}p \to \bar{D}D$, $\bar{D}_s D_s$ are presented for energies close to their respective thresholds [2, 3, 4, 5]. The work builds on the Jülich meson-baryon models for the reactions $\bar{p}p \to \bar{\Lambda}\Lambda$ [6] and $\bar{p}p \to \bar{K}K$ [7]. The extension of those models from the strangeness to the charm sector follows a strategy similar to our recent work on the DN and $\bar{D}N$ interactions [8, 9] namely by assuming as a working hypothesis $SU(4)$ symmetry constraints.

For completeness, it should be mentioned that there is already a fair amount of model calculations on the production of charmed baryons and mesons in the literature [10, 11, 12, 13, 14, 15, 16, 17, 18]. In some of these studies a quark-gluon description based on a factorization hypothesis of hard and soft processes [10, 14, 16] is employed, while in others a non-perturbative quark-gluon string model is used, based on secondary Regge pole exchanges including absorptive corrections [11, 13, 15].

2. The model

The calculations of the charm-production reactions $\bar{p}p \to \bar{Y}_c Y_c$ and $\bar{p}p \to \bar{D}D$, $\bar{D}_s D_s$ are done in complete analogy to past investigations of the strangeness-production reactions $\bar{p}p \to \bar{\Lambda}\Lambda$, $\bar{\Lambda}\Sigma$, $\bar{\Sigma}\Sigma$ [6] and $\bar{p}p \to \bar{K}K$ [7] by the Jülich group. In particular $\bar{p}p \to \bar{Y}_c Y_c$ is performed within a coupled-channel approach while for $\bar{p}p \to \bar{D}D$, $\bar{D}_s D_s$ a DWBA approach is employed. This allows us to take into account rigorously the effects of the initial $\bar{p}p$ interaction (ISI) and also of the final state interaction (FSI) which play an important role for energies near the production threshold [6, 19].

Because of the observed sensitivity of the strangeness-production cross sections to the initial $\bar{p}p$ interaction [6] we examine its effect also in the charm sector. This is done by considering several variants of the $\bar{N}N$ potential. Details of those potentials can be found in Refs. [2, 3]. Here I just want to mention that they differ primarily in the elastic part where we consider variations from keeping only the longest ranged contribution (one-pion exchange) to taking also other ingredients from a G-parity transformed NN interaction [6]. All these models reproduce the total $\bar{p}p$ cross section in the relevant energy range and they describe also data on integrated elastic and charge-exchange cross sections and even $\bar{p}p$ differential cross sections, cf. Refs. [2, 3].

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The microscopic charm-production processes are described by either meson exchange (D, D^*) in case of $\bar{p}p \to \bar{Y}_c Y_c$, or baryon exchange ($\Lambda_c$, Σ_c, $\Sigma_c(2520)$) for $\bar{p}p \to \bar{D}D$. The transition potentials are derived from the corresponding transitions in the strangeness-production channels ($\bar{Y}Y$, $\bar{K}K$) under the assumption of $SU(4)$ symmetry. In order to assess uncertainties in the model we study, in addition, the effect of replacing the meson-exchange transition potential by a charm-production mechanism derived in a constituent quark model [2, 5, 19].

3. Results for $\bar{p}p \to \bar{\Lambda}_c^- \Lambda_c^+$, $\bar{\Lambda}_c^- \Sigma_c^+$, $\bar{\Sigma}_c \Sigma_c$, $\bar{\Xi}_c \Xi_c$

Total reaction cross sections for $\bar{p}p \to \bar{\Lambda}_c^- \Lambda_c^+$ and $\bar{p}p \to \bar{\Lambda}_c^- \Sigma_c^+$ are presented in Fig. 1. Our results are shown as bands in order to reflect the variation of the predictions when different ISI's are used. We display results for our meson-exchange potential (red bands) but also those based on an adaption [5] of the $^3S_1$ quark-gluon transition mechanism of Ref. [19] (blue/hatched bands). In the latter case we scaled the effective quark-gluon coupling strength, fixed in our study of $\bar{p}p \to \bar{\Lambda}\Lambda$ [6], with $(m_c/m_s)^2$ using the constituent quark masses $m_s = 550$ MeV and $m_c = 1600$ MeV [2].

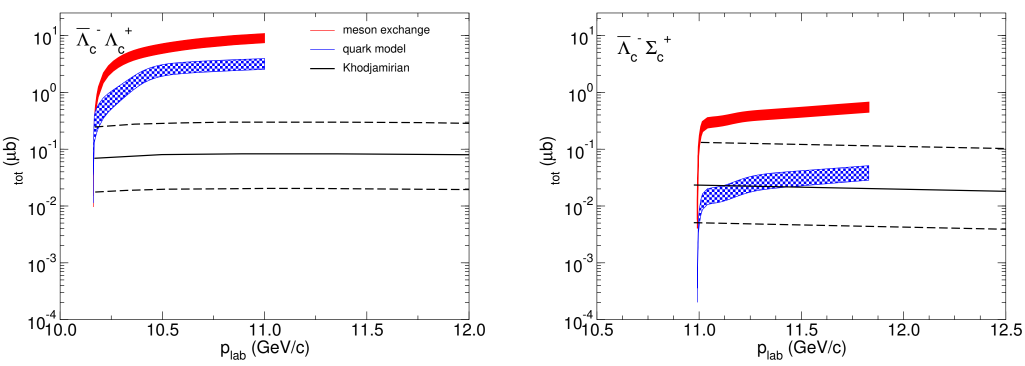

Figure 1: Total reaction cross sections for $\bar{p}p \to \bar{\Lambda}_c^- \Lambda_c^+$ (left) and $\bar{p}p \to \bar{\Lambda}_c^- \Sigma_c^+$ (right) as a function of the laboratory momentum p_{lab}. The solid (red) band are results for the meson-exchange transition potential while the hatched (blue) band correspond to quark-gluon dynamics. Our predictions are compared to those of Ref. [15] (black lines).

As can be seen, in case of $\bar{p}p \to \bar{\Lambda}_c^- \Lambda_c^+$ we obtain cross sections that are of the same order of magnitude for both charm-production scenarios, though the ones based on the quark model tend to be roughly a factor three smaller. cf. left side of Fig. 1. The situation is different for $\bar{p}p \to \bar{\Lambda}_c^- \Sigma_c^+$ where the predictions for the quark model are clearly smaller, actually by more than one order of magnitude. For the ease of comparison we include in Fig. 1 also results from Khodjamirian et al. [15] (solid curve; the dashed curves indicate the uncertainty). In that study, following Kaidalov and Volkovitsky [11], a non-perturbative quark-gluon string model is used, however, with baryon-meson coupling constants derived from QCD lightcome sum rules. Interestingly, for $\bar{p}p \to \bar{\Lambda}_c^- \Sigma_c^+$ those results obtained in a rather different framework are more or less in line with our quark-model predictions. However, in case of $\bar{p}p \to \bar{\Lambda}_c^- \Lambda_c^+$ much lower cross sections are predicted.

The difference between the results for the two considered production mechanisms is even more pronounced for $\bar{p}p \to \bar{\Sigma}_c \Sigma_c$ where pertinent results for the different charge channels can be found in Fig. 2. While meson-exchange leads to cross sections in the order of 0.5-1 μb those based on quark-gluon dynamics are down by roughly three orders of magnitude. The situation is similar for the production of Ξ_c and Ξ_c', see Ref. [5], where the cross sections for $\bar{p}p \to \bar{\Xi}_c\Xi_c$ are comparable to those for $\bar{p}p \to \bar{\Sigma}_c\Sigma_c$ in the meson-exchange picture, but again down by three orders of magnitude in the quark model.

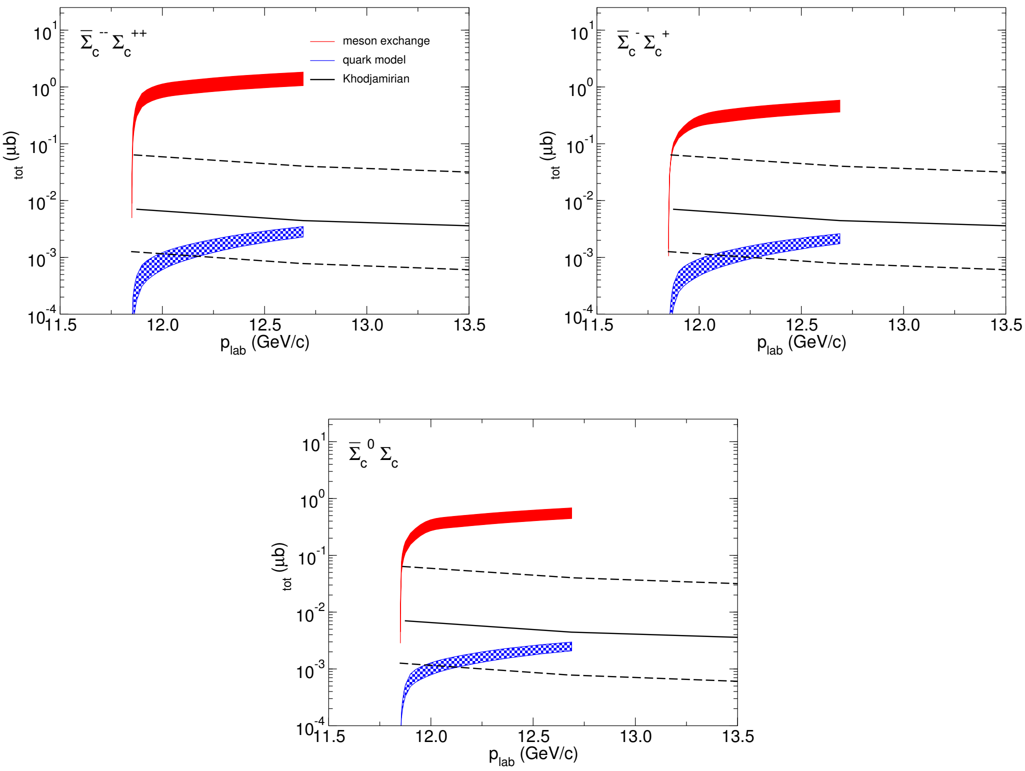

Figure 2: Total reaction cross sections for $\bar{p}p \to \bar{\Sigma}_c\Sigma_c$ as a function of the laboratory momentum p_{lab}. Same description of curves as in Fig. 1.

4. Results for the reactions $\bar{p}p \to \bar{D}D$ and $\bar{p}p \to \bar{D}_sD_s$

Our predictions for the reaction $\bar{p}p \to \bar{D}D$ are presented in Fig. 3 (top). Let us first focus on the effects of the inital- and final state interaction. The transition from $\bar{p}p$ to $\bar{D}D$ is generated by the exchange of charmed baryons, in particular the Λ_c and Σ_c [3]. Under the assumption of $SU(4)$ symmetry the pertinent coupling constants are given by

$$f_{\Lambda_c ND} = -\frac{1}{\sqrt{3}}(1+2\alpha) f_{NN\pi} \approx -1.04\, f_{NN\pi},$$
$$f_{\Sigma_c ND} = (1-2\alpha) f_{NN\pi} \approx 0.2\, f_{NN\pi},$$

where we assumed for the F/(F+D) ratio $\alpha \approx 0.4$. Thus, one expects that Λ_c exchange dominates the transition while Σ_c exchange should be suppressed. Specifically, this implies that $V^{\bar{p}p\to D^0\bar{D}^0} \gg$

$V^{\bar{p}p\to D^+D^-}$. Indeed, within the Born approximation the cross sections predicted for $D^0\bar{D}^0$ are more than two orders of magnitude larger than those for D^+D^-, cf. the dotted lines Fig. 3. However, once the ISI is included the situation changes drastically and now both channels are produced at a comparable rate (red bands). In fact, now the cross section for D^+D^- is even somewhat larger than the one for $D^0\bar{D}^0$. Note that again the bands represent the variation due to differences in the employed $\bar{N}N$ (ISI) interactions. The shown results include also effects from the FSI, which however, modify the predictions only on a modest level.

For the quark model the situation is very different. Here the transition potential in the isospin $I=0$ channel is zero, see Ref. [3] for details, and thus $V^{\bar{p}p\to D^0\bar{D}^0} = V^{\bar{p}p\to D^+D^-}$ as indicated by the dashed lines in Fig. 3. When the effects of ISI and FSI are included we arrive at cross sections that are slightly smaller than those for baryon-exchange but still compatible with them within the uncertainty due to the ISI, see the hatched (blue) bands.

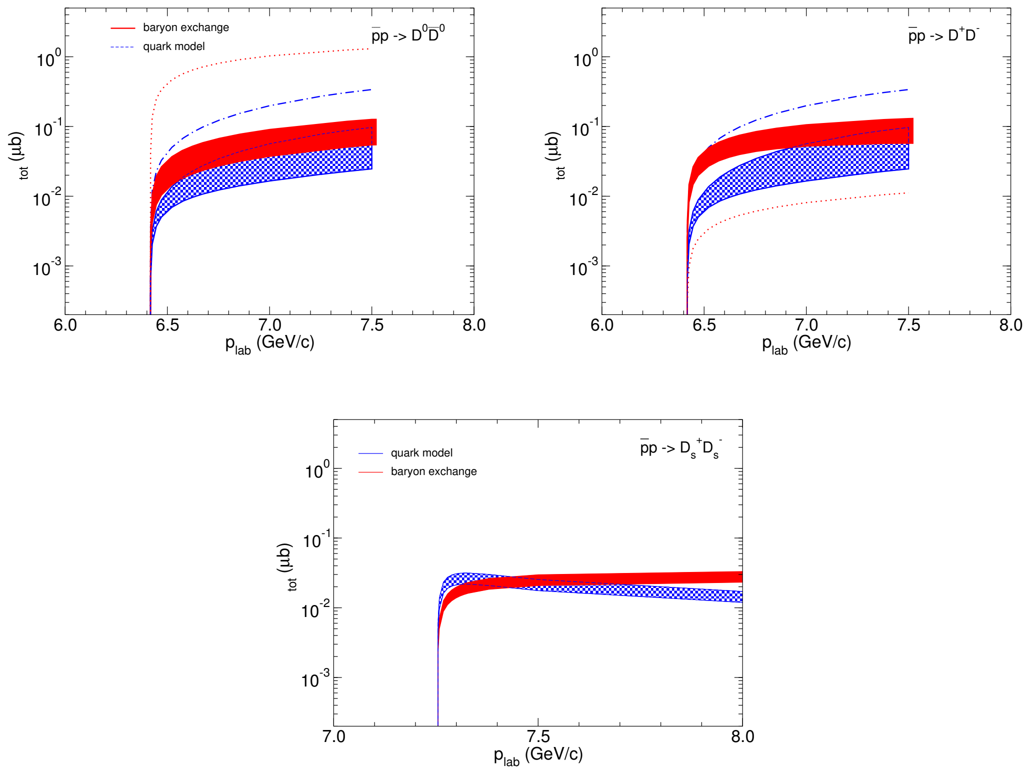

Figure 3: Total reaction cross sections for $\bar{p}p\to\bar{D}D$ (top) and $\bar{p}p\to\bar{D}_sD_s$ (bottom) as a function of p_{lab}. The bands represent the results of the full calculation while the lines indicate those obtained in Born approximation.

Results for $\bar{p}p\to\bar{D}_sD_s$ are presented at the bottom of Fig. 3. The cross sections for this reaction are roughly an order of magnitude smaller than those predicted for $\bar{p}p\to\bar{D}D$. Again the results obtained from baryon-exchange and from quark-gluon dynamics are comparable.

5. Summary

I have presented results for the production of charmed baryons in $\bar{p}p$ collisions from a model calculation performed within the meson-exchange picture, in close analogy to the Jülich analysis of the reactions $\bar{p}p \to \bar{\Lambda}\Lambda$, $\bar{\Lambda}\Sigma$, and $\bar{\Sigma}\Sigma$, utilizing $SU(4)$ symmetry. In addition a charm production mechanism based on quark-gluon dynamics has been considered. For both scenarios the predicted cross sections for $\bar{p}p \to \bar{\Lambda}_c^- \Lambda_c^+$ are in the order of 1–7 μb. On the other hand, for other charmed baryons (Σ_c, Ξ_c) drastic differences in the predicted production rate are observed. While calculations in the meson-exchange picture suggests that the cross sections could be still in the order of 0.1-1 μb those for the quark models turn out to be three orders of magnitude smaller.

Furthermore I have presented predictions for $\bar{p}p \to \bar{D}D$ and $\bar{p}p \to \bar{D}_s D_s$ obtained in the same spirit, i.e. by connecting these reactions with $\bar{p}p \to \bar{K}K$ via $SU(4)$ symmetry. Here the cross sections found are in the order of 10–100 *nb* for both considered charm-production mechanisms.

References

[1] W. Erni et al. (Panda Collaboration), arXiv:0903.3905 [hep-ex].

[2] J. Haidenbauer and G. Krein, Phys. Lett. B **687**, 314 (2010).

[3] J. Haidenbauer and G. Krein, Phys. Rev. D **89**, 114003 (2014).

[4] J. Haidenbauer and G. Krein, Phys. Rev. D **91**, 114022 (2015).

[5] J. Haidenbauer and G. Krein, Phys. Rev. D **95**, 014017 (2017).

[6] J. Haidenbauer et al., Phys. Rev. C **45**, 931 (1992); Phys. Rev. C **46** (1992) 2158; Nucl. Phys. A **562**, 317 (1993); Phys. Rev. C **47**, 2982 (1993).

[7] V. Mull and K. Holinde, Phys. Rev. C **51**, 2360 (1995).

[8] J. Haidenbauer, G. Krein, U.-G. Meißner and A. Sibirtsev, Eur. Phys. J. A **33**, 107 (2007); Eur. Phys. J. A **37**, 55 (2008).

[9] J. Haidenbauer, G. Krein, U.-G. Meißner and L. Tolos, Eur. Phys. J. A **47**, 18 (2011).

[10] P. Kroll, B. Quadder and W. Schweiger, Nucl. Phys. B **316**, 373 (1989).

[11] A. B. Kaidalov and P. E. Volkovitsky, Z. Phys. C **63**, 517 (1994).

[12] B. Kerbikov and D. Kharzeev, Phys. Rev. D **51**, 6103 (1995).

[13] A. I. Titov and B. Kämpfer, Phys. Rev. C **78**, 025201 (2008).

[14] A. T. Goritschnig, P. Kroll and W. Schweiger, Eur. Phys. J. A **42**, 43 (2009).

[15] A. Khodjamirian, C. Klein, T. Mannel and Y. M. Wang, Eur. Phys. J. A **48**, 31 (2012).

[16] A. T. Goritschnig, B. Pire, and W. Schweiger, Phys. Rev. D **87**, 014017 (2013); Phys. Rev. D **88**, 079903(E) (2013).

[17] R. Shyam and H. Lenske, Phys. Rev. D **90**, 014017 (2014).

[18] R. Shyam and H. Lenske, Phys. Rev. D **93**, 034016 (2015).

[19] M. Kohno and W. Weise, Phys. Lett. B **179**, 15 (1986).

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