Charm Production in \(\bar{p}A\)-Collisions at the Charmonium Threshold

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Abstract. We discuss the production of charmonium states in antiproton-nucleus collisions at the \(\psi'\) threshold. It is explained that measurements in \(\bar{p}A\) collisions will allow to get new information about the strengths of the inelastic \(J/\psi N\) and \(\psi' N\) interaction, on the production of \(\Lambda_c\) and \(D\) in charmonium-nucleon interactions and for the first time about the nondiagonal transitions \(\psi' N \rightarrow J/\psi N\). The inelastic \(J/\psi\)-nucleon cross section is extracted from the comparison of hadron-nucleus collisions with hadron-nucleon collisions. Predictions for the ratio of \(J/\psi\) to \(\psi'\) yields in antiproton-nucleus scatterings close to the threshold of \(\psi'\) production for different nuclear targets are presented.

INTRODUCTION

This work is based on ref. [1]. In this paper we make predictions for antiproton-nucleus collisions at the \(\psi'\) threshold. This measurement will be possible at the future antiproton-nucleus experiment at the GSI [2]. We demonstrate that in these collisions the cross section for the nondiagonal transition \(\psi' + N \rightarrow J/\psi + N\) can be measured. We account for the dependence of the cross sections on energy, and the dependence of the elastic cross section on the momentum transfer.

The charmonium production in \(\bar{p}A\) collisions at the \(\psi'\) threshold is well suited to measure the genuine charmonium-nucleon cross sections. At higher energies formation time effects makes the measurement of these cross sections more difficult [3]. These cross sections and the cross section for the analysis of charmonium production data at SPS-energies [4, 5]. At collider energies, i.e. at RHIC and LHC, the formation time effects will become dominant and charmonium states will be produced only far outside of the nuclei [6]. However, measurements of the genuine charmonium-nucleon cross sections as well as the cross section for the nondiagonal transition \(\psi' + N \rightarrow J/\psi + N\) are also important at collider energies for the evaluation of the interaction of charmonium states with the produced secondary particles.

MODEL DESCRIPTION AND RESULTS

In the semiclassical Glauber-approximation the cross section to produce a \(\psi'\) in an antiproton-nucleus collision is
\[ \sigma (\bar{p} + A \rightarrow \psi') = 2\pi \int db \cdot b dz_1 \frac{np}{A} \rho(b, z_1) \sigma (\bar{p} + p \rightarrow \psi') \exp \left( -\int_{-\infty}^{z_1} dz \sigma_{\bar{p}Ninel} \rho(b, z) \right) \times \exp \left( -\int_{z_1}^{\infty} dz \sigma_{\bar{p}Ninel} \rho(b, z) \right) \]  

(1)

In this formula, \( b \) is the impact parameter of the antiproton-nucleus collision, \( n_p \) is the number of protons in the nuclear target, \( z_1 \) is the coordinate of the production point of the \( \psi' \) in beam direction, and \( \rho \) is the nuclear density. \( \sigma (\bar{p} + p \rightarrow \psi') \) is the cross section to produce a \( \psi' \) in an antiproton-proton collision. \( \sigma_{\bar{p}Ninel} \) is the inelastic antiproton-nucleus collision. \( \sigma_{\psi'Ninel} \) is the inelastic \( \psi' \)-nucleon cross section.

All the factors in eq. (1) have a rather direct interpretation. The first exponential gives the probability to find an antiproton at the coordinates \((b, z_1)\), which accounts for its absorption, and \( \frac{np}{A} \rho(b, z_1) \sigma (\bar{p} + p \rightarrow \psi') \) is the probability to create a \( \psi' \) at these coordinates. The factor \( \frac{np}{A} \) accounts for the fact that close to the threshold the antiproton can produce a \( \psi' \) only in a collision with a proton but not with a neutron. The second gives the probability that the produced \( \psi' \) has no inelastic collision in the nucleus, i.e. that it survives on the way out of the nucleus.

Similarly, in the semiclassical Glauber-approximation the cross section to subsequently produce a \( J/\psi \) in an antiproton-nucleus collision is

\[ \sigma (\bar{p} + A \rightarrow J/\psi + X) = 
2\pi \int db \cdot b dz_1 dz_2 \theta(z_2 - z_1) \frac{np}{A} \rho(b, z_1) \sigma (\bar{p} + p \rightarrow \psi') \exp \left( -\int_{-\infty}^{z_1} dz \sigma_{\bar{p}Ninel} \rho(b, z) \right) \times \exp \left( -\int_{z_1}^{\infty} dz \sigma_{\bar{p}Ninel} \rho(b, z) \right) \sigma (\psi' + N \rightarrow \psi + X) \rho(b, z_2) \exp \left( -\int_{z_2}^{\infty} dz \sigma_{\psi'Ninel} \rho(b, z) \right) \]  

(2)

In fig. 1 we used five sets of parameters. "normal" means that the inelastic antiproton-nucleon cross section is \( \sigma_{\bar{p}Ninel} = 50 \) mb, the inelastic cross section of the \( \psi' \) is \( \sigma_{\psi'Ninel} = 7.5 \) mb, the inelastic cross section of the \( J/\psi \) is \( \sigma_{\psi'Ninel} = 0 \) mb, and the cross section for the nondiagonal transition \( \psi' + N \rightarrow J/\psi + N \) is \( \sigma (\psi' + N \rightarrow \psi + N) = 0.2 \) mb. The other sets differ by only one of these parameters each:

- In "\( \psi \)-absorption" \( \sigma_{\psi'Ninel} = 3.1 \) mb.
- In "large \( \psi' \) absorption" \( \sigma_{\psi'Ninel} = 15 \) mb.
- In "small nondiagonal" \( \sigma_{J/\psi N \rightarrow \psi'} = 0.1 \) mb.
- In "large nondiagonal" \( \sigma_{J/\psi N \rightarrow \psi'} = 0.4 \) mb.

One can see that the result depends much more strongly on the nondiagonal cross section than on the absorption cross sections of the \( J/\psi \) and the \( \psi' \). Therefore, this process is well suited to measure the nondiagonal cross section.
The cross section for the production of $\psi'$ that doesn’t undergo an inelastic rescattering is $\sigma (\bar{p} + A \rightarrow \psi' + \text{nuclear fragments})$ is given by eq. (1). The cross section for the production of $\psi'$, whether they have subsequent inelastic scatterings or not is given by

$$\sigma (\bar{p} + A \rightarrow \psi')_{\text{w/oinel}} = 2\pi \int db \cdot b dz_1 \frac{n_p}{A} \rho (b, z_1) \sigma (\bar{p} + p \rightarrow \psi') \exp \left( - \int_{-\infty}^{z_1} dz \sigma_{\text{inel}} \rho (b, z) \right). \quad (3)$$

Assuming that the $\Lambda_c$ channel is the only possible final state in inelastic collisions (i.e. the $D\bar{D}$ channel as well as the nondiagonal transition is neglected as a correction here), the fraction of the initially produced $\psi'$ that ends up in the $\Lambda_c$ channel is

$$\frac{N_{\Lambda_c}}{N_{\psi'\text{initial}}} = 1 - \frac{\sigma (\bar{p} + A \rightarrow \psi' + \text{nuclear fragments})}{\sigma (\bar{p} + A \rightarrow \psi' + \text{nuclear fragments})_{\text{w/oinel}}} \quad (4)$$

Here we neglected the final state interactions of $\Lambda_c$ as they may only effect the momentum distribution of $\Lambda_c$ since the $\Lambda_c$ energy is below the threshold for the process $p + \Lambda_c \rightarrow N + N + D$. For this reaction the $\Lambda_c$ would need an energy of 4.2 GeV in the rest frame of the proton, while it has in average less than 3 GeV. The change of the momentum distribution of $\Lambda_c$ would provide unique information about the $\Lambda_cN$ interaction and could be a promising method for forming charmed hypernuclei. Obviously eq. (4) is valid also for $\bar{D}$ production. The fraction for the $\psi'$ and the $J/\psi$ threshold is depicted in fig. 2.

One can see that the result depends strongly on the inelastic cross section of the $J/\psi$ and the $\psi'$. Therefore, this process is well suited to measure the inelastic cross section.
FIGURE 2. The ratio of the number of $\Lambda_c$ divided by the number of produced $J/\psi$ and $\psi'$ respectively states at the threshold of $J/\psi$ and $\psi'$ production respectively. Shown are the nuclear targets O, S, Cu, W, and Pb. The lines are just to guide the eye.

CONCLUSIONS

It was shown that the future $\bar{p}A$-experiments at the GSI are well suited to measure genuine $J/\psi$ nucleon and $\psi'$ nucleon cross sections, i.e. the inelastic and the nondiagonal ($\psi'N \rightarrow J/\psi N$) cross sections.

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REFERENCES

1. L. Gerland, L. Frankfurt and M. Strikman, Phys. Lett. B 619, 95 (2005) [arXiv:nucl-th/0501074].
2. H. Koch [PANDA Collaboration], Nucl. Instrum. Meth. B 214 (2004) 50.
3. L. Gerland, L. Frankfurt, M. Strikman, H. Stöcker and W. Greiner, Phys. Rev. Lett. 81, 762 (1998) [arXiv:nucl-th/9803034].
   L. Gerland, L. Frankfurt, M. Strikman, H. Stöcker and W. Greiner, Nucl. Phys. A 663, 1019 (2000) [arXiv:nucl-th/9908052].
   L. Gerland, L. Frankfurt, M. Strikman and H. Stöcker, Phys. Rev. C 69, 014904 (2004) [arXiv:nucl-th/0307064].
4. C. Spieles, R. Vogt, L. Gerland, S. A. Bass, M. Bleicher, H. Stöcker and W. Greiner, Phys. Rev. C 60, 054901 (1999) [arXiv:hep-ph/9902337].
5. E. L. Bratkovskaya, A. P. Kostyuk, W. Cassing and H. Stöcker, Phys. Rev. C 69 (2004) 054903 [arXiv:nucl-th/0402032].
6. L. Gerland, L. Frankfurt, M. Strikman, H. Stöcker and W. Greiner, J. Phys. G 27 (2001) 695 [arXiv:nucl-th/0009008].