Physics with Open Charm Mesons at $\overline{\text{PANDA}}$

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Abstract. We present a study of the physics performance of the $\overline{\text{PANDA}}$ detector based on Monte-Carlo simulations. The possibility to measure D , D^* and $D_{sJ}^*(2317)$ mesons has been investigated. A reliable detection of open charm decay products of charmonium decays and sufficient level of background suppression have been demonstrated.

Keywords: PANDA; HESR; charmed mesons; threshold production.

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INTRODUCTION

The study of the charmonium spectrum above the $D\overline{D}$ breakup threshold at $3.73 \text{ GeV}/c^2$ is an important part of the physics program of the forthcoming $\overline{\text{PANDA}}$ experiment at FAIR/Darmstadt [1]. The scope of experiments include a confirmation of the higher vector states at 4040, 4160 and $4415 \text{ MeV}/c$ together with systematic investigation of the D_{sJ} and D_s^* mesons. In addition, there are also several hypotheses which can be tested using the unprecedented beam quality delivered by the HESR facility. For example the confirmation of an interpretation of the $X(3872)$ state, recently discovered by the BELLE collaboration, as a $D^0\overline{D}^{*0}$ molecule requires a precision measurement of all 1D and 3D states. Another kind of experiment is threshold production of the recently discovered D_{sJ}^* mesons, which will precisely measure their masses and decay widths, with the goal to strongly constrain models of their structure.

HIGHER CHARMONIA

Physics background

Above the $D\overline{D}$ breakup threshold at $3.73 \text{ GeV}/c^2$ the charmonium spectrum is poorly known (see Fig. 1, left) since e^+e^- experiments have only measured $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ in large energy steps. Here, rather washed-out structures were observed. The latest, much more accurate measurements by BES [2] do not confirm the sharp states reported by [3]. It is an open question whether the higher vector states at 4040, 4160, and $4415 \text{ MeV}/c^2$ are realistic.

Several theories exist explaining the relative narrowness of the $\psi(4040)$ state. It can be a $D^*\overline{D}^*$ molecule [4]. According to an other idea [5] the $\psi(4040)$ and $\psi(4160)$ are strong mixtures of ground state hybrid charmonium at $\sim 4.1 \text{ GeV}/c^2$ and $\psi(3S)$ of conventional charmonium. Both theories predict different decay patterns for both states.

It is of critical importance to investigate this mass region in small energy steps.

FIGURE 2. Distribution of the transverse and longitudinal distances of the vertex location to the primary vertex position of D mesons are shown on the left and right figures, respectively. The expected locations are shown by the dashed lines. See text for more explanations.

FIGURE 3. The reconstructed $\psi(3770)$ and $\psi(4040)$ invariant masses are shown on the left and right figures, respectively. The expected peaks positions are marked by the dashed lines.

From the analysis of a large sample of background events a signal to background ratio of ~ 3 for the $\psi(3770)$ state have been determined. For the $\psi(4040)$ only lower limit of 1.27×10^{-2} has been determined.

THRESHOLD PRODUCTION OF $D_{sJ}^*(2317)$

The recent observation by the **BABAR** collaboration of a narrow $D_{sJ}^*(2317)^+$ mesonic state [6] greatly stimulates the interest to the open charm spectroscopy. This observation was confirmed by **CLEO** [7], which also noticed a second $D_{sJ}(2463)^+$ resonance. Finally, both states were confirmed by **Belle** [8].

The $D_{sJ}^*(2317)^+$ state was identified as a scalar $c\bar{s}$ system, but it has a significantly smaller mass and width than expected (e.g. [9]). Many theories have appeared after that discovery explaining the unexpected properties of $D_{sJ}^*(2317)^+$ (see [10] or [11]). For example, the *chiral doubling* model introduces the *chiral partners* to four already known charm-strange mesonic states, i.e. $D_s(1969)$, $D_s^*(2112)$, $D_{s1}(2536)$ and $D_{s2}(2573)$. The

schematic of the chiral doubling theory is shown on Fig. 1, right. The "left plaquette" of the cube represents standard charm-strange mesons, whereas the "right plaquette" stands for chiral doublers. Similar patterns can be applied also for the non-strange charmed mesons.

Predictions for the $D_{sJ}^*(2317)^+$ width range from 10 to $\sim 200 \text{ keV}$ and can give a good hint on its internal structure. The existing e^+e^- -colliders can't provide the width measurement with sufficient precision. The upper limit on the visible width, settled by the **BABAR**, is $\Gamma_{exp} < 4.6 \text{ MeV}$. That problem can be solved by the **PANDA** experiment by measuring the excitation function of $\bar{p}p \rightarrow D_{sJ}^*(2317)^+ D_{sJ}^*(2317)^-$ close to the threshold.

The cross section behavior in the vicinity of the threshold depends on the beam momentum spread as it shown on Fig. 4. The invariant mass distribution for the

FIGURE 4. Energy dependence of $\bar{p}p \rightarrow D_{sJ}^*(2317)^+ D_{sJ}^*(2317)^-$ cross section for 10^{-5} (left) and 10^{-3} (right) relative momentum spread of the antiproton beam. The figures are taken from [12].

$D_{sJ}^*(2317)^+ D_{sJ}^*(2317)^-$ pairs is shown on Fig. 5 for 50 000 signal events without background. The invariant mass resolution σ and the reconstruction efficiency ε are found to be:

$$\sigma_{D_{sJ}^+ D_{sJ}^{*-}} = 24 \text{ MeV}/c^2 \quad \text{and} \quad \varepsilon_{D_{sJ}^+ D_{sJ}^{*-}} \simeq 4.0\%$$

CONCLUSIONS

The simulations of the three benchmark reactions $\bar{p}p \rightarrow \psi(3770)$, $\bar{p}p \rightarrow \psi(4040)$ and $\bar{p}p \rightarrow D_{sJ}^*(2317)^+ D_{sJ}^*(2317)^-$ show the capability of the **PANDA** detector to select the signals of these reactions from background. The reconstruction efficiencies for the different types of D and D_s mesons are shown in Table 1. A reasonable good signal to background ratio has been obtained despite the very small initial ratio of the signal/background of $\sim 10^{-8}$.

The detector structure is not yet fixed, so one can expect the further improvements in the invariant mass resolution and background rejection power. Nevertheless the results

FIGURE 5. Reconstructed $D_{sJ}^*(2317)^+ D_{sJ}^*(2317)^-$ invariant mass. The expected peak position is shown by the dashed line.

TABLE 1. Reconstruction efficiency of D and D_s mesons.

Decay	Branching, %	Efficiency, %
$D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$	9.2	27
$D^0 \rightarrow K^\mp \pi^\pm$	3.8	31
$D^0 \rightarrow K^\mp \pi^\pm \pi^\mp \pi^\pm$	7.5	20
$D_s^\pm \rightarrow K^\mp K^\pm \pi^\pm$	4.4	30*

* Identification of only one kaon was required.

already look promising now and show that the $\overline{\text{PANDA}}$ detector meets the physics requirement.

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REFERENCES

1. M. Kotulla and others, “Technical Progress Report,” *Panda Collaboration*, Facility for Antiproton and Ion Research, Darmstadt, 2005.
2. J.Z. Bai and others, *Phys. Rev. D*, **57**, 3854 (1998).
3. L. Antoniazzi and others, *Phys. Rev. D*, **50**, 4258 (1994).
4. L. Okun, *MV’77*, 1977.
5. F.E. Close and P.R. Page, *Phys. Lett. B*, **366**, 323–328 (1996).
6. BABAR Coll., B. Aubert et al., hep-ex/0304021.
7. CLEO Coll., D. Besson et al., hep-ex/0305017, hep-ex/0305100.

8. BELLE Coll., P. Krokovny et al., hep-ex/0308019.
9. M.A. Nowak, M. Rho and I. Zaled, *Phys. Rev. D*, **48**, 4370 (1993).
10. M.A. Nowak, hep-ph/0311154, 2003.
11. Eef van Beveren and G. Rupp, hep-ph/0306155, 2004.
12. A. Gillitzer, "How to measure sub-MeV width", XII. PANDA Collaboration Meeting, 2005.