

# Measuring the $J/\psi$ -Nucleon dissociation cross section with PANDA

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With the PANDA detector at the HESR at FAIR it will be possible to study the production and absorption of charmed hadrons in nuclear targets. Of special interest in this context is the determination of the  $J/\psi$ -nucleon dissociation cross section. This can be determined with measurements of the  $J/\psi$  yield in  $\bar{p}A$  reactions using different target materials. The experiment is described and numerical simulations are presented.

## 1 Introduction

The inelastic  $J/\psi$ -nucleon cross section  $\sigma_{J/\psi N}$  is important in understanding the role of the formation of a Quark-Gluon-Plasma, QGP in the  $J/\psi$  suppression observed in high energy nuclear collisions. For an interpretation of these data the quantitative understanding of the nuclear effects - those which are not related to QGP formation - that also affect  $J/\psi$  production in nucleus-nucleus reactions is crucial. The inelastic scattering of the  $J/\psi$  state in cold nuclear matter is expected to be the dominant contribution of this kind. Its strength is described by the  $J/\psi$ -nucleon inelastic cross section,  $\sigma_{J/\psi N}$ .

$\sigma_{J/\psi N}$  can be determined with reactions, in which  $J/\psi$  are produced in nuclear medium. It is from the comparison of the expected number of produced  $J/\psi$  and the actually measured number of  $J/\psi$  escaping from the nuclear medium that the dissociation cross section is derived.

Current experimental values of  $\sigma_{J/\psi N}$  have mainly been obtained from inclusive hadro- and leptonproduction of  $J/\psi$  on nuclear targets [1]. In these experiments the determination of  $\sigma_{J/\psi N}$  is hampered by co-acting effects (co-movers, feed down, ...) which affect the number of escaping  $J/\psi$ s. Thus the various contributions have to be disentangled to extract the effect of the  $J/\psi$ -Nucleon dissociation on the observed suppression of the  $J/\psi$  yield.

In  $\bar{p}A$  reactions the momentum of the incident  $\bar{p}$  can be tuned such that  $J/\psi$ s are produced exclusively at a relatively well defined momentum. This will facilitate the analysis of the data significantly.

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## 2 The experiment

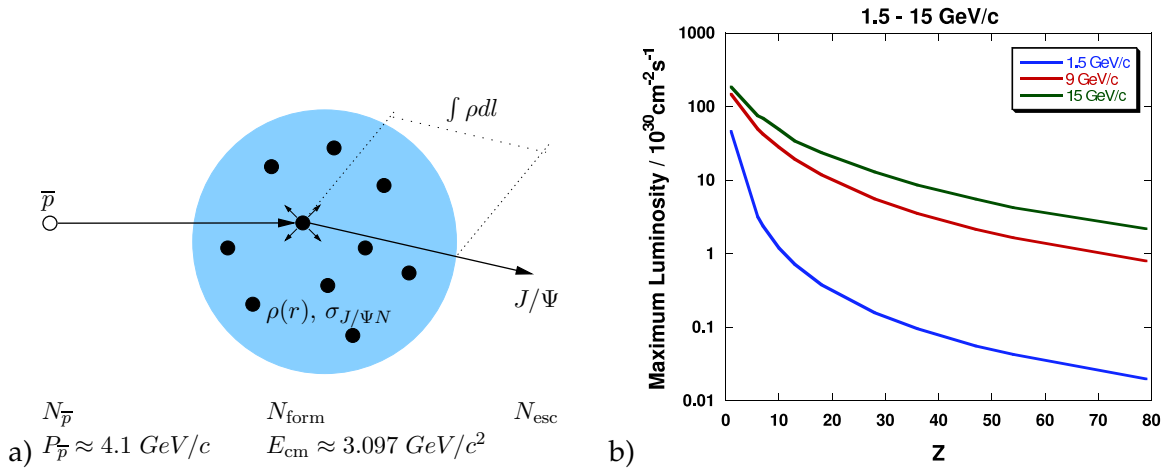
The idea for this experiment for measuring  $\sigma_{J/\psi N}$  can be traced back to a paper by Brodsky & Mueller [2]. The principle of the measurement is illustrated in figure 1a).  $J/\psi$ s are formed in  $\bar{p}A$  reactions, when an incident  $\bar{p}$  annihilates with a nucleon within a target nucleus. The momentum of the incident antiproton is tuned such that the center-of-mass energy  $E_{\text{cm}}$  of the antiproton-nucleon system is close to the resonance energy of the  $J/\psi$  of  $3.097 \text{ GeV}/c^2$  and  $J/\psi$  is formed exclusively. The formed  $J/\psi$  has an initial velocity and sets off to escape from the nucleus. There are two possible fates for the  $J/\psi$  - either it will decay due to its finite lifetime or it will be absorbed in an inelastic reaction with a nucleon.

The number of  $J/\psi$  formed in the nucleus  $N_{\text{form}}$  and the number of  $J/\psi$  escaping the Nucleus  $N_{\text{esc}}$  are related through

$$(1) \quad N_{\text{esc}} = N_{\text{form}} \left( 1 - \sigma_{J/\psi N} \left\langle \int \rho \cdot dl \right\rangle \right)$$

$\langle \int \rho \cdot dl \rangle$  is the average integrated nucleon density along the path of the  $J/\psi$  through the nucleus, where the average is to be taken over all formations.

Equation (1) represents a recipe for the measurement of  $\sigma_{J/\psi N}$ . It contains a few quantities which either need to be determined experimentally ( $N_{\text{esc}}$ ) or by simulation/calculation ( $N_{\text{form}}, \langle \int \rho \cdot dl \rangle$ ). The success of the measurement thus depends on the exact determination of the absolute values of these quantities.



**Figure 1:** a) Illustration of the  $\bar{p}A$  reaction which is used to measure the  $J/\psi$ -Nucleon dissociation cross section  $\sigma_{J/\psi N}$ . b) Luminosity of the HESR with a nuclear target as function of the atomic number of the target material [3].

### 3 Measurement with PANDA

$J/\psi$ s are experimentally best identified by their decay into lepton pairs  $e^+e^-/\mu^+\mu^-$ . The corresponding branching ratio is 5.9 % for either of these two decay channels [4]. The simple topology in this reaction allows to efficiently identify  $J/\psi$ s decaying into lepton pairs with a detector like PANDA and also can be exploited to reduce the background to an acceptable level. The cross section for formation of  $J/\psi$  in  $\bar{p}A$  is by a factor of a few times  $10^9$  smaller than the total inelastic cross section of typically 1 b. Thus a background suppression of at least  $10^{-10}$  has to be and can be achieved with PANDA (see [3] for further details). The reconstruction efficiency for the decay channel  $J/\psi \rightarrow e^+e^-$  was estimated to be around 70% and somewhat less for  $J/\psi \rightarrow \mu^+\mu^-$ .

The number of formed  $J/\psi$ ,  $N_{\text{form}}$  is given by

$$(2) \quad N_{\text{form}} = \int L dt \cdot \langle \sigma_{\text{form}} \rangle$$

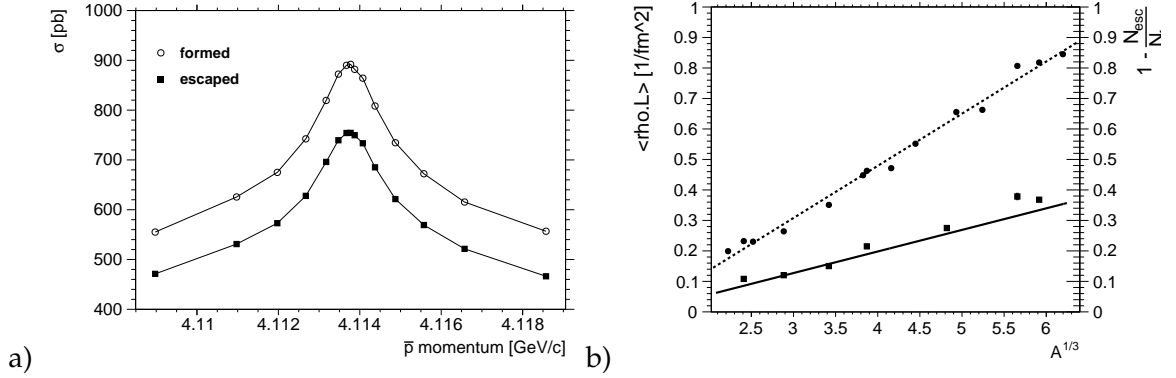
$\int L dt$  is the luminosity integrated over the measurement time.  $\langle \sigma_{\text{form}} \rangle$  is the average formation cross section.

The measurement of the luminosity will have to be carried out instantaneously with a dedicated luminosity monitor. The achievable luminosity at the High Energy Storage Ring, HESR at the future FAIR with a nuclear target is shown in figure 1b) [3]. Due to the enhanced absorption and scattering in heavier targets, the luminosity decreases with increasing atomic number of the target material. At the  $J/\psi$  resonance momentum the achievable luminosity will range from  $\approx 5 \frac{pb^{-1}}{d}$  at  $Z \leq 10$  to  $\approx 10^{-2} \frac{pb^{-1}}{d}$  at  $Z \geq 40$ .

The formation probability in a single  $\bar{p}p$  is well described by the Breit-Wigner formula and is a function of the available center-of-mass energy  $E_{\text{cm}}$  (corrections for initial-state radiation can be applied [5]). The formation cross section at resonance in a  $\bar{p}p$  reaction and final decay into a  $e^+e^-$  pair is 275.7 nb (relevant parameters have been determined by [6]). The effective formation cross section  $\langle \sigma_{\text{form}} \rangle$  in  $\bar{p}A$  reactions however is considerably smaller than this peak value. Due to the Fermi motion of the nucleons in the nucleus, the available  $E_{\text{cm}}$  is determined not only by the energy of the beam particle but also depends on the Fermi momentum of the involved nucleon. Thus  $\langle \sigma_{\text{form}} \rangle$  is the formation probability averaged over all particular formations.

The value of  $\langle \sigma_{\text{form}} \rangle$  was determined by Monte Carlo simulations using a Glauber type model. The nucleus is described by a radial nucleon density profile  $\rho(r)$  which is taken from [7,8]. The distribution of the Fermi-motion is modeled using a local Thomas-Fermi approximation in which the Fermi momentum  $P_F$  depends on the local nucleon density  $\rho(r)$  as  $P_F = \hbar c(3\pi^2\rho(r))^{1/3}$ . It is assumed, as has been pointed out by Farrar et al. [9] that the formation time of  $J/\psi$  is short enough such that color transparency effects can be neglected.

In this model the formation points are not homogeneously distributed in the nucleus. The number of antiprotons decreases with increasing depth  $s$  due to the absorption in the nuclear matter. With the total  $\bar{p}p$  cross section of  $\approx 7 \text{ fm}^2$  at 4 GeV/c [10] and a typical nuclear density of  $0.1 \text{ fm}^{-3}$  the penetration depth is typically in the order of a few fm only. For the Monte Carlo simulation thus first a location within the nucleus is selected according to the survival probability of the antiprotons ( $\propto e^{-\sigma_{tot} \int_{-\infty}^s \rho(x,b) dx}$ ). Then the momentum of the nucleon is selected according to the local distribution of the Fermi-momentum. Together with the momentum of the beam particle, which is distributed according to a Gaussian function with a relative width of typically  $10^{-4}$  (this corresponds to the High Intensity mode of the HESR), and under consideration of the nuclear binding energy, the  $E_{cm}$  is computed. This is finally inserted into the Breit-Wigner formula to compute the formation probability. In order to compute the dissociation probability the nucleon density along the path of the  $J/\psi$  is integrated up to the point where the  $J/\psi$  decays. Figure 2 shows results of these simulations.



**Figure 2:** a)  $\langle \sigma_{form} \rangle$  and  $\langle \sigma_{esc} \rangle$  as function of the  $\bar{p}$  momentum in a  $^{40}\text{Ca}$  target b)  $(1 - N_{esc}/N_{form})$  (square symbols) and  $\langle \int \rho \cdot dl \rangle$  as function of nuclear mass of the target material.

In the left panel the expected cross section for formation  $\langle \sigma_{form} \rangle$  and the cross section for escaping and decaying into an electron-positron pair  $\langle \sigma_{esc} \rangle$  is plotted as function of the beam momentum. The peak value of  $\langle \sigma_{esc} \rangle$  is in the order of 700 pb in this case. With a total reconstruction efficiency of 50% and an average luminosity of  $10^{31} \text{ cm}^{-2}\text{s}^{-1}$  the number of  $J/\psi$  per day would be around 300.

According to equation (1)  $\sigma_{J/\psi N}$  is obtained by the quotient of  $(1 - N_{esc}/N_{form})$  and  $\langle \int \rho \cdot dl \rangle$ . For consistency checks, measurements of  $N_{esc}$  should be carried out for several beam momenta which allow to reconstruct the broadened resonance and should also be repeated with different target materials.

The square symbols plotted in the right panel of figure 2 represent the quantity  $(1 - N_{esc}/N_{form})$  and the circular symbols show the quantity  $\langle \int \rho \cdot dl \rangle$  for different target materi-

als. The dotted line is the best linear fit to the  $\langle \int \rho \cdot dl \rangle$  points, whereas the bold line is the dotted line scaled to match the  $(1 - N_{\text{esc}}/N_{\text{form}})$  data points best. The scaling factor is the measurement of  $\sigma_{J/\psi N}$  and in these simulations its value is found to be very close to the value which was used as input.

## 4 Conclusions

Measurements of the  $J/\psi$  yield in  $\bar{p}A$  reactions close to resonance in different target materials allow to determine the  $J/\psi$ -nucleon dissociation cross section. The experiment depends on an accurate measurement of the number of  $J/\psi$  escaping the nucleus and an accurate prediction of the number of  $J/\psi$  formed in the nuclear medium. The presented simulations suggest, that in light target materials with this reaction up to a few hundred  $J/\psi$  will be formed and detected with the PANDA detector per day. Measurements on different target materials will allow to check results for consistency.

## Acknowledgments

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