

## Measuring the $\phi$ meson width in the medium from $p$ induced $\phi$ production in nuclei

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We study the  $A$  dependence of the  $\phi$  meson production cross section in proton nucleus reactions at energies just above threshold, which are accessible in an experimental facility like COSY. This  $A$  dependence has two sources: the distortion of the incident proton and the absorption of the  $\phi$  in its way out of the nucleus. This second process reduces the cross section in about a factor two in heavy nuclei. Thus we show that the  $A$  dependence of the cross section contains valuable information on the  $\phi$  width in the nuclear medium.

The study of the properties of vector mesons in a nuclear medium is one of the subjects in hadron physics which receives continuous attention (see for instance Ref. [1]). Although originally the  $\rho$  meson properties were mostly investigated, nowadays the  $\phi$  properties have got a lot of interest, because the medium renormalization in this case is more drastic than that of the  $\rho$ . Indeed, predictions of an increase of the  $\phi$  width by a factor five or six [2, 3] to ten [4], at normal nuclear matter density, have been made using different chiral approaches. Different reactions have been studied or suggested to test experimentally this large width [5, 6, 4, 7, 8, 9].

The aim of the present work is to propose a new method to determine the  $\phi$  width in the nuclear medium [10]. The traditional method in the works quoted above (except [9]) is to look for a broadening of the  $\phi$  width reconstructed from the invariant mass of its decay products. Here, instead, we use a different philosophy and we investigate the  $A$  dependence of  $\phi$  production in  $pA$  collisions, in a similar way as it was done in [9] with the  $\phi$  photoproduction in nuclei, which is the subject of experimental investigation at Spring8/Osaka [11]. The advantage of performing the reaction slightly above threshold is that one can rule out the contribution from coherent  $\phi$  production which might obscure the interpretation of the experimental results in [11]. The present reaction, with its particular kinematics, is amenable of experimental performance at facilities like COSY.

In order to implement the relevant nuclear effects in the  $\phi$  production cross section we will use a model based on many body techniques, successfully applied in the past in many works [12, 13] to study the interaction of different particles with nuclei. The model assumes a local Fermi sea at each point in the nucleus and provides a very simple and accurate way to account for the Fermi motion of the initial nucleon and the Pauli blocking of the final ones. On the other hand, we have to take into account the distortion of the incoming nucleon and the final  $\phi$  meson in their way through the nucleus, which are

evaluated in the present work using an eikonal approximation (see [ 10] for more details).

We also assume that the  $T$  matrix for our process is angular independent. This is supported by the experiment [ 14] where the angular dependence of  $pp \rightarrow pp\phi$  is almost flat.

For the evaluation of  $\mathcal{I}m\Pi$ , imaginary part of the  $\phi$  selfenergy in nuclear matter, we use the results of the model of Ref. [ 3] and its extension to finite  $\phi$ -meson momentum done in [ 9]. This model is based on the modification of the  $\bar{K}K$  decay channel in the medium by means of a careful treatment of the in medium antikaon selfenergies [ 2]. It uses a selfconsistent coupled channel unitary calculation, based on effective chiral Lagrangians, and taking into account Pauli blocking, pion selfenergies and mean-field potentials of the baryons (for the S-wave part) and hyperon-hole excitations (for the P-wave part). It corresponds to a  $\phi$  medium width at rest at  $\rho = \rho_0$  of the order of  $24 \text{ MeV}$ .

We also take into account  $\phi$  production from two-step processes. Let us imagine we have a  $pN$  collision of the initial proton going to any other channel than  $\phi$  production. In such cases the fast incoming proton will usually survive although with a reduced energy, by means of which it still can contribute to  $\phi$  production. We estimate the contribution from this mechanism, based on the  $p$  energy loss in the first collision  $\Delta E \simeq 400 \text{ MeV}$  or more [ 10].

We also study two-step process with  $\Delta$  intermediate states:  $NN \rightarrow N\Delta$  reaction followed by  $\Delta N \rightarrow NN\phi$ . This two body process would benefit with respect to the one considered above from the fact that the  $\Delta$  couples more strongly to pions and vectors than the nucleon. For instance, one can consider a mechanism from the model of [ 15, 16] which, with respect to the same one with a nucleon instead of a  $\Delta$ , would benefit from the factor  $f_{\pi N\Delta}/f_{\pi NN} = 2.13$  in the amplitude, hence a factor 4.5 in the cross section. Not surprisingly our results show that the two-step mechanism with  $\Delta$  excitation is more relevant than the two-step mechanism involving only nucleons. We shall also distinguish between  $\Delta$  excitation on the target and  $\Delta$  excitation on the projectile. The mechanism of  $\Delta$  excitation in the projectile appears to be more important than that of  $\Delta$  excitation in the target in the present reaction.

We performed calculations for the following nuclei:  ${}^{12}_6C$ ,  ${}^{16}_8O$ ,  ${}^{24}_{12}Mg$ ,  ${}^{27}_{13}Al$ ,  ${}^{28}_{14}Si$ ,  ${}^{31}_{15}P$ ,  ${}^{32}_{16}S$ ,  ${}^{40}_{20}Ca$ ,  ${}^{56}_{26}Fe$ ,  ${}^{64}_{29}Cu$ ,  ${}^{89}_{39}Y$ ,  ${}^{110}_{48}Cd$ ,  ${}^{152}_{62}Sm$ ,  ${}^{208}_{82}Pb$ ,  ${}^{238}_{92}U$ .

In our analyses we are concerned about the  $A$  dependence, no so much on the absolute values of the cross sections, since the  $\phi$  absorption effect is reflected in this  $A$  dependence. To see this most clearly, we calculate the following observable - the normalized ratio:  $R(^AX)/R(^{12}C)$ , where  $R(^AX) = \sigma_A/(A\sigma_{free})$ . Fig. 1 shows corresponding curves for the one-step and one- plus two-step mechanisms and for different energies. We see that this normalized  $R$  changes very little when including the two-step mechanisms for both the  $T_p$  considered. Note that for the energy closer to the threshold ( $T_p = 2.7 \text{ GeV}$ ) the changes due to the two-step contributions are smaller.

Thus we conclude that the  $A$  dependence obtained in the present work is reliable and the calculations clearly show that proton induced  $\phi$  production in nuclei at energies just above threshold can indeed be used to get information on the  $\phi$  width in the medium.

In order to see which experimental precision is needed to get a definite information on the  $\phi$  width in the medium, we have performed the same calculations assuming  $\phi$  widths in the medium to be one half or twice the width used so far [ 3, 9]. In Fig. 2

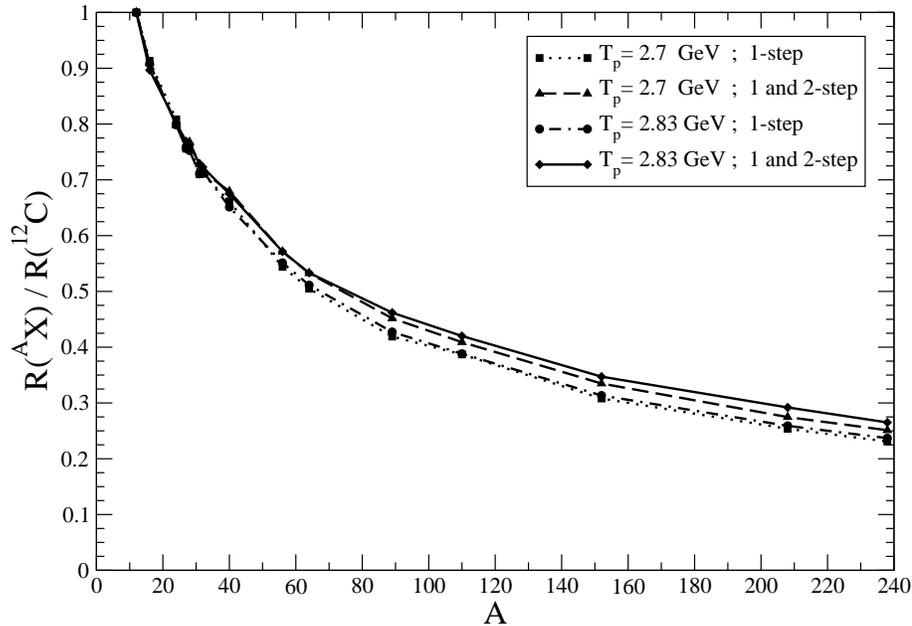


Figure 1. Ratio of the nuclear cross section normalized to  $^{12}\text{C}$  for two different incident proton kinetic energies,  $T_p$ , including or not the two-step mechanisms. The two-step process with nucleon intermediate states was evaluated with  $\Delta E = 400 \text{ MeV}$ . From [10].

we show the results of these calculations for  $T_p = 2.83 \text{ GeV}$  (without the inclusion of the two-step processes). Comparing Figs. 1 and 2 we clearly see that the uncertainties due to the two-step mechanism are far smaller than the differences in the results obtained by using these different  $\phi$  widths. The three curves shown there should serve to get a fair answer about the  $\phi$  width in the medium by comparing with experimental results. The uncertainties one might have from the approximate knowledge of the two-step processes still would allow us to be sensitive to the value of the  $\phi$  width in the medium to the level of 25% of the  $\phi$  width we have used.

Our calculations were done in symmetric nuclear matter, i.e. in order to calculate  $R = \sigma_A / (A\sigma_{free})$  we took a total free elementary  $\phi$  production cross section  $\sigma_{free} = (\sigma_{pn,\phi} + \sigma_{pp,\phi})/2$ . Experimentally we have poor knowledge about these elementary cross sections [14]. Nevertheless, our results can still be used to compare with experiment for asymmetric nuclei if one takes for  $\sigma_{free}$  the isospin weighted combination  $(N\sigma_{pn,\phi} + Z\sigma_{pp,\phi})/A$ . Hence, in order to extract the optimum information on the  $\phi$  width it would be useful to have data on  $\phi$  production on neutron targets, for what experiments on the deuteron would also be most welcome.

**Acknowledgments** One of us, L.R., acknowledges support from the Ministerio de Educación, Cultura y Deporte. This work is partly supported by DGICYT contract number BFM2003-00856, and the E.U. EURIDICE network contract no. HPRN-CT-2002-00311.

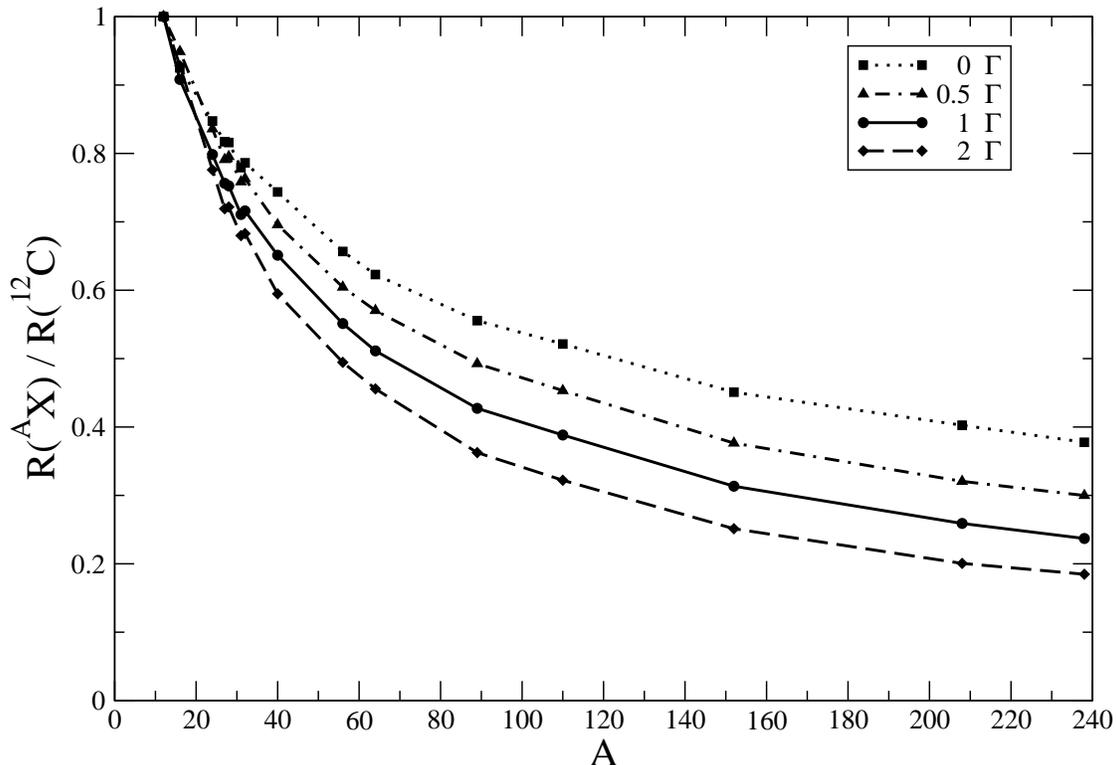


Figure 2. Ratio of the nuclear cross section normalized to  $^{12}\text{C}$  for  $T_p = 2.83$  GeV and multiplying the  $\phi$  width in the medium,  $\Gamma$ , by different factors. From [ 10].

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