PROCEEDINGS OF SCIENCE

Measurement of the ϕ-meson nuclear transparency in proton-nucleus collisions

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The production of ϕ mesons at small angles in proton collisions with C, Cu, Ag, and Au targets has been measured via the $\phi \to K^+K^-$ decay at an incident energy of 2.83 GeV using the COSY-ANKE magnetic spectrometer. The measured target mass dependence for the production cross section can be related to the in-medium ϕ meson width. Comparison with different model calculations suggests a significant broadening of this width for normal nuclear density and evidence for a momentum dependence in the region of $p_\phi = 0.6 - 1.6$ GeV/c.

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1. Introduction

The study of the properties of light vector mesons (ρ, ω, ϕ) in nuclear medium, through their production with photon, proton and heavy–ion beams incident on nuclear targets, has been a very active research field for several years [1, 2]. Modification of their in-medium properties is expected to be connected with the partial restoration of chiral symmetry in hot/dense nuclear matter. The vacuum width of the $\phi(1020)$ meson is narrow compared to other nearby resonances. It is therefore a good probe to test for medium modifications because small effects should be experimentally observable. The main modification of the ϕ in nuclear matter is expected to be a broadening of its spectral function, whereas its mass should be hardly changed.

Dileptons from $\phi \to e^+e^-/\mu^+\mu^-$ decays experience no strong final-state interactions in a nucleus. Modification of the ϕ in the nucleus should be directly testable by examining $\ell^+\ell^-$ mass spectra. However, such a measurement is difficult due to the low branching ratios. The KEK-PS-E325 collaboration measured e^+e^- invariant mass distributions in the ϕ region in proton-induced reactions on carbon and copper at 12 GeV and deduced a mass shift of 3.4% and a width increase by a factor of 3.6 at normal nuclear density ρ_0 for ϕ momenta around 1 GeV/c [3]. This corresponds to an in-medium ϕ width of about 11 MeV in the nuclear rest frame for the average measured ϕ momentum.

An alternative way to determine the in-medium broadening of the ϕ meson has been adopted in [4, 5]. The variation of the ϕ production cross section (or nuclear transparency ratio) with atomic number A has been studied both experimentally and theoretically. This A-variation depends on the attenuation of the ϕ flux in the nuclear target which, in turn, is governed by the imaginary part of the in-medium ϕ self-energy or width. In the low-density approximation, this width is related to an effective ϕN total cross section $\sigma_{\phi N}$ [2]. The main advantage of this experimental method is that one can use the dominant decay mode $\phi \to K^+K^-$ (BR $\approx$ 50%).

A large in-medium ϕN total cross section of about 35 mb was inferred by the LEPS collaboration from measurements of K^+K^- pairs photoproduced on Li, C, Al and Cu targets at SPring-8 [4]. In the low-density approximation, this implies an in-medium ϕ width of about 97 MeV/c^2 in the nuclear rest frame for average ϕ momenta $\approx$ 1.8 GeV/c at density $\rho_0 = 0.16$ fm^{-3}. The value of $\sigma_{\phi N}$ is significantly larger than the cross section in free space, viz. $\approx$ 10 mb.

The CLAS collaboration studied ϕ photoproduction on ^{2}H, C, Ti, Fe, Pb targets by measuring the e^+e^- decay [5]. From an analysis of the transparency ratios normalised to carbon within the Glauber model, values of $\sigma_{\phi N}$ in the range of 16–70 mb were extracted for an average ϕ momentum of $\approx$ 2 GeV/c, which is not inconsistent with the LEPS result.

Both the LEPS and CLAS results are larger than that obtained at KEK. One possible reason for the discrepancy could be the different ϕ momenta. A study of momentum dependence of the in-medium width could therefore provide useful information about the properties of the ϕ meson in a nucleus.

2. Experiment and Results

We have measured the production of ϕ mesons at small angles in the collisions of 2.83 GeV protons with C, Cu, Ag, and Au targets via the $\phi \to K^+K^-$ decay, using the ANKE-COSY magnetic spectrometer. The 2.83 GeV proton beam energy corresponds to an excess energy of about 76 MeV above the free *NN* threshold where few production channels are open. Secondary ϕ production processes are also expected to be less important at small angles.

As a first step, we have studied the nuclear transparency ratio normalised to carbon, $R = (12/A)(\sigma^A/\sigma^C)$, averaged over the ϕ momentum range 0.6–1.6 GeV/c [6, 7]. Here σ^A and σ^C are inclusive cross sections for ϕ production in pA ($A =$ Cu, Ag, Au) and pC collisions in the angular cone $\theta_\phi < 8^\circ$. The comparison of the ratio with model calculations [8, 9, 10] yields an in-medium ϕ width of $33-50$ MeV/c^2 in the nuclear rest frame for an average ϕ momentum of 1.1 GeV/c for normal nuclear density ρ_0=0.16 fm^{-3}.

Large numbers of reconstructed ϕ mesons for each target (7000–10000) were accumulated over the course of the experiment. This allows the data to be divided into six bins of approximately equal statistics in order to achieve a more detailed investigation. In Fig. 1 the preliminary results on the momentum dependence of the measured transparency ratios is shown for all the combinations, Cu/C, Ag/C and Au/C. A decrease of the ratios with p_ϕ could be a signal of contributions of secondary ϕ production processes, especially for the lower momenta.

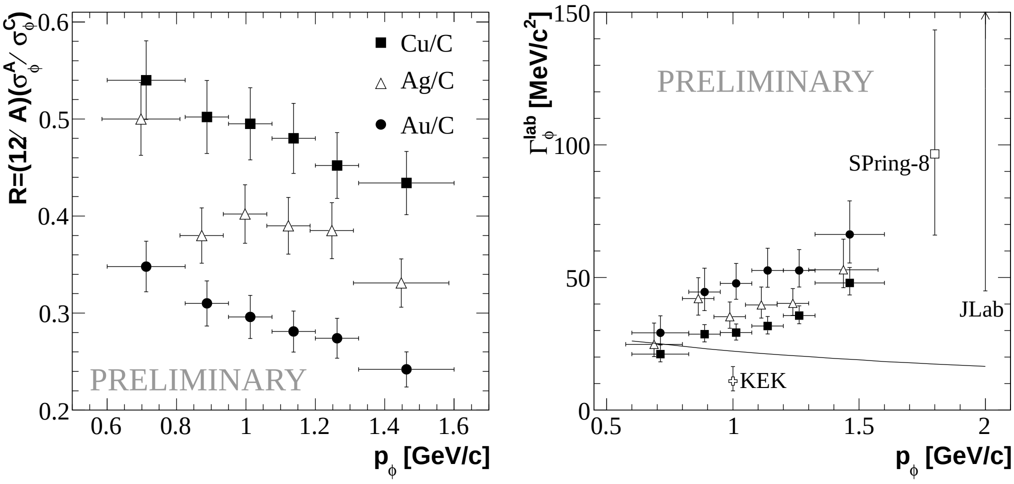

Figure 1: Left: Momentum dependence of the transparency ratios for the four nuclei studied. Right: Momentum dependence of the ϕ in-medium width for normal nuclear density extracted using different models: Model 1 (full squares), Model 2 (full circles) and Model 3 (open triangles). Experimental results from KEK-PS-E325 [3], Spring-8 [4] and JLab [5] are also plotted. The theoretical prediction of [11, 12] is shown by the solid line.

Any extraction of in-medium ϕ widths is model dependent; we consider three approaches.

Model 1: The eikonal approximation of the Valencia group [8] uses the predicted ϕ self-energy in nuclear medium [11, 12] both for the one-step ($pN \to pN\phi$) and for the two-step ϕ production processes, with nucleon and Δ intermediate states.

Model 2: Paryev [9] developed the spectral function approach for ϕ production in both the primary proton-nucleon and secondary pion-nucleon channels.

Model 3: The Rossendorf BUU transport calculation [10] includes a variety of secondary ϕ production processes. In contrast to Models 1 and 2, where ϕ absorption is governed by its width, Γ_ϕ, Model 3 describes it in terms of an effective in-medium ϕN cross section $\sigma_{\phi N}$ that can be related to the ϕ width Γ_ϕ within the low-density approximation (LDA).

In Fig. 1 the in-medium ϕ width in the nuclear rest frame at normal nuclear density obtained in these models is presented. Similar behaviour is seen for all three approaches and the differences come mainly from the divergent descriptions of the secondary production processes. The ϕ width extracted is in agreement with the Spring-8 [4] and JLab [5] results that have been measured for slightly higher momentum and exceeds the Valencia prediction [11, 12].

In order to understand further the model calculations, the double differential cross sections for ϕ production have been evaluated within the ANKE acceptance window for different momentum bins. For the estimation of the integrated luminosity the flux of π^+ mesons with momentum $\approx$ 500 MeV/c produced at small angles was measured. Double differential cross sections for forward π^+ production at 2.83 GeV have been determined, combining the available experimental data [13, 14] (for details see [15]).

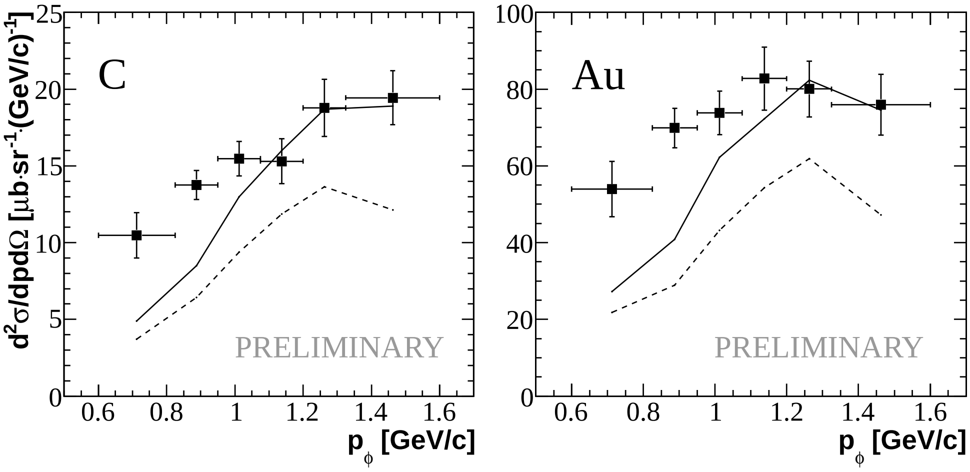

Figure 2: Comparison of the measured double differential cross section for ϕ production at small angles (full squares) for carbon (left) and gold (right) nuclei with the predictions of Models 2 (solid lines) and 3 (dashed lines).

The double differential cross sections for ϕ production were estimated in the Paryev and BUU calculations and in Fig. 2 the measured cross sections for carbon and gold nuclei are compared with the predictions in these models. The extracted central values of the in-medium ϕ width or $\sigma_{\phi N}$ cross section have been used to estimate the ϕ production cross section within these models. The BUU calculation describes rather well the high momenta, where direct ϕ production dominates. Both models strongly underestimate ϕ production at low momenta. This suggests that some process, whose contribution to the ϕ production cross sections increases for low ϕ momenta and with the size of the nucleus, is not included in the models.

However, the transparency ratio normalised to carbon is less sensitive to nuclear effects or secondary production processes than the production cross section. Taken together, analysis of our data shows evidence for a momentum dependence of the in-medium ϕ meson width. Our findings are not inconsistent with the results from SPring-8 and JLab at slightly higher ϕ momenta.

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References

[1] R. S. Hayano and T. Hatsuda, Rev. Mod. Phys. **82**, 2949 (2010).

[2] S. Leupold, V. Metag, and U. Mosel, Int. J. Mod. Phys. E **19**, 147 (2010).

[3] R. Muto *et al.*, Phys. Rev. Lett. **98**, 042501 (2007).

[4] T. Ishikawa *et al.*, Phys. Lett. B **608**, 215 (2005).

[5] M. H. Wood *et al.*, Phys. Rev. Lett. **105**, 112301 (2010).

[6] A. Polyanskiy *et al.*, Phys. Lett. B **695**, 74 (2011).

[7] M. Hartmann *et al.*, AIP Conf. Proc. **1322**, 349 (2010).

[8] V. K. Magas, L. Roca and E. Oset, Phys. Rev. C **71**, 065202 (2005).

[9] E. Ya. Paryev, J. Phys. G **36**, 015103 (2009).

[10] H. Schade, University of Dresden, PhD thesis (2010).

[11] D. Cabrera and M. J. Vicente Vacas, Phys. Rev. C **67**, 045203 (2003).

[12] D. Cabrera, L. Roca, E. Oset, H. Toki, and M. J. Vicente Vacas, Nucl. Phys. A **733**, 130 (2004).

[13] V. V. Abaev *et al.*, J. Phys. G **14**, 903 (1988).

[14] J. Papp *et al.*, Phys. Rev. Lett. **34**, 601 (1975); J. Papp, Report LBL-**3633** (1975).

[15] A. Polyanskiy *et al.*, Hadron 2011 proceedings (to be published in eConf C).