ϕ-meson production in pN collisions close to threshold

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Abstract. At the ANKE facility of COSY Jülich, the reactions $pp \to pp\phi$ and $pn \to d\phi$ have been investigated. Data for the total cross section in the pp entrance channel have been obtained at excess energies of 19 MeV, 35 MeV and 76 MeV. In case of the pn entrance channel the energy dependence of the cross section up to 80 MeV has been extracted by exploiting the intrinsic momentum of the target neutron using a deuterium target. The new ϕ data combined with the existing data on ω-meson production provides the ϕ/ω production ratio in both, the pp- and pn-channels. The ratios of both channels are found to be similar and about eight times larger than the ratio based on Okubo-Zweig-Iizuka (OZI) rule.

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The OZI rule states that processes with disconnected quark lines between the initial or final state are suppressed. Accordingly, the production of ϕ-mesons from initially non-strange states is expected to be substantially suppressed relative to ω-meson production. The cross-section ratio for ϕ- and ω-meson production under similar kinematical conditions should thus be of the order of $R_{\text{OZI}}=\sigma_\phi/\sigma_\omega=4.2\times10^{-3}$ [1]. One may expect that a certain amount of $s\bar{s}$ quarks in the nucleon would manifest itself in a reaction cross section that significantly exceeds R_{OZI}. These questions have led to a large experimental activity involving different hadronic reactions. Many of experimental results agree with the predictions of the OZI rule. However, in specific channels like $\bar{p}p$ annihilation [2], enhancements of ϕ/ω-ratio by up to two orders of magnitude have been observed and discussed as being either a hint that ϕ-meson production occurs from $s\bar{s}$ in the nucleons [3] or that final-state interactions are significant [4]. A systematic analysis of the ϕ/ω cross-section ratio in pp collisions and πN interactions has been performed [6] and almost all of the existing data shows that a ϕ/ω-ratio is smaller than $3\times R_{\text{OZI}}$. Only the ratio derived from ϕ-meson production measured at DISTO [7] in pp collisions at an excess energy of 83 MeV gives a value being 7 times larger than R_{OZI}. However a significant uncertainty remains regarding the relative contribution of partial waves to ϕ- and ω-meson production. Thus data of the reaction $pp \to pp\phi$ at lower excess energies combined with existing data for ω-meson production [8, 9] can provide more precise knowledge on the ϕ/ω-ratio. Up to now ϕ-production data for nucleon-nucleon collisions are available only for the pp-channel. It is therefore of interest to obtain com-

[1] The ANKE Collaboration: http://www.fz-juelich.de/ikp/anke.

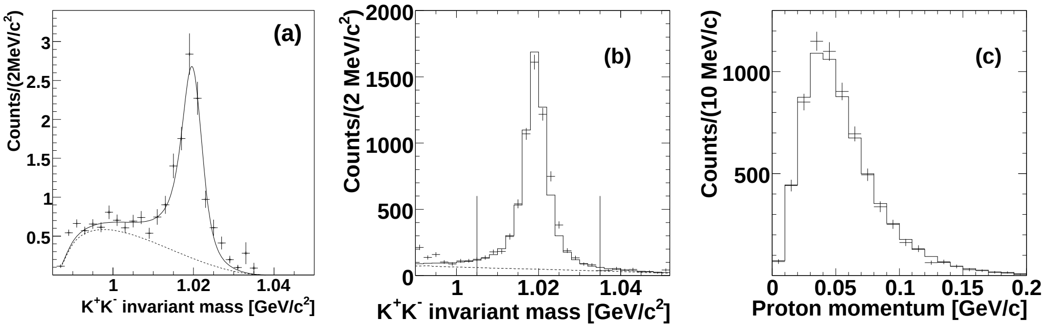

FIGURE 1. a) Efficiency corrected K^+K^- invariant mass distribution for the reaction $pp \to ppK^+K^-$ at 19 MeV excess energy. The dashed curve indicates the non-resonant contribution based on a four-body phase space. The error bars indicate the statistical uncertainty. b) K^+K^- invariant mass distribution for the reaction $pd \to dK^+K^-p$. c) Momentum spectrum of the final proton in comparison with a Monte-Carlo simulation based on the spectator model.

plementary data for the reactions $pn \to pn\phi$ and $pn \to d\phi$. Such data will contribute the understanding of the ϕ-production process as well as the origin of the enhancement of ϕ/ω-ratio. In particular the reaction $pn \to d\phi$ is a filter for the isosinglet initial state. New data for $pn \to d\phi$ combined with recent results from ANKE on ω-meson production in $pn \to d\omega$ [10] enable one to study the isospin and spin dependence of the ratio.

The experiments have been performed at the ANKE facility [11] using a proton beam from the COSY accelerator. ANKE is a magnetic spectrometer and has detector systems for positively and negatively charged ejectiles. An internal cluster jet target has been operated with hydrogen and deuterium. ϕ-meson production on the proton target has been measured at three fixed excess energies of ε=19, 35 and 76 MeV [12], whereas the production on deuterium has been studied at a fixed proton beam energy of 2.65 GeV [13]. One proton or deuteron has been detected in coincidence with the K^+K^- pair. Particles have been identified by their time-of-flight information and reconstructed momenta. The final selection of both reactions $pp \to pK^+K^-p$ and $pd \to dK^+K^-p$ has been achieved by a missing mass cut on the non-detected proton.

The total cross section of ϕ-meson production has been determined using the K^+K^- invariant mass distribution corrected for the fraction of non-resonant K^+K^- production. Figure 1 (a) shows the K^+K^- invariant mass distribution for the proton target. The dashed curve shows the non-resonant contribution based on four-body phase-space, while the solid line shows the total contribution including the ϕ resonance with an experimental resolution of 2.36 MeV/c^2 (FWHM). In Figure 1 (b), the K^+K^- invariant mass distribution is shown for the deuterium target. Here, the non-resonant K^+K^- contribution is significantly smaller compared to the proton target and is less than 8% in the ϕ mass region 1.020 ± 0.015 GeV/c^2. This contribution could be easily subtracted. The momentum distribution of the unobserved proton for events in the ϕ peak is shown in Fig. 1 (c). As expected for a spectator proton, this spectrum peaks at very low values and there are few events with momenta above about 150 MeV/c. To confirm the spectator hypothesis, a Monte Carlo simulation has been performed where the intrinsic momentum in the target deuteron has been derived from the Bonn potential and the simulation fits

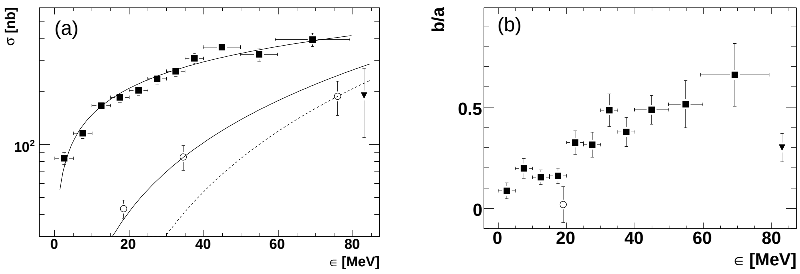

FIGURE 2. a) Total cross section for $pp \to pp\phi$ (open circles) and $pn \to d\phi$ (fi lled squres) as a function of excess energy ε. DISTO data [7] is also shown by triangle. For lines see text. b) The contribution of $\cos^2\Theta$ term normalized to the one of $sin^2\Theta$ term on the decay distribution of K^+. For more detail see text.

very well the shape of the data for momenta up to at least 150 MeV/c. Based on this, the energy dependence of the total cross section for $pn \to d\phi$ has been extracted using the internal motion of the target neutron.

The results for the total cross sections for $pp \to pp\phi$ and $pn \to d\phi$ near the production threshold are shown as a function of excess energy in Fig.2 (a). For the pp-channel, the dashed line shows a phase space calculation normalized to pass through the highest energy ANKE point, while the solid line, which includes pp final state interaction effects, is a fit to all the ANKE data. For the pn-channel, data points almost follow a phase–space behavior (upper solid) and the values are much higher than those of $pp \to pp\phi$, but this is due in part to there being a three– rather than a two–body final state. However, very near threshold, isoscalar s–wave ϕpn production can be estimated from our $d\phi$ data using final–state–interaction theory, a technique that has been tested for η production [14]. This approach yields $\sigma(pn \to pn\phi)/\sigma(pp \to pp\phi) \approx 2.3 \pm 0.5$, which is only about a third as big as the ratio for η production [14].

Close to threshold, the nucleon transition of ${}^3P_1 \to {}^1S_0$ and ${}^1P_1 \to {}^3S_1$, coupled to a s-wave ϕ-meson relatively to final nucleon pair, must be dominant in the reactions $pp \to pp\phi$ and $pn \to d\phi$, respectively. Here the alignment of the ϕ–meson spin direction must be along the beam axis and thus the polar angular distribution of the decay kaons in the ϕ–meson rest frame must then display a $\sin^2\Theta$ shape relative to the beam direction. Any additional $\cos^2\Theta$ contribution is induced by higher partial waves. The experimental distribution was parameterized in the most general form: $\mathrm{d}\sigma/\mathrm{d}\Omega = 3(a\sin^2\Theta + 2b\cos^2\Theta)/8\pi$ and the ratio b/a representing the minimum fraction of higher partial waves is shown in Fig.2 (b). The dominace of $\sin^2\Theta$ term is very clear at the lower energies for both reactions and all the data for reaction $pn \to d\phi$ are well represented by $b/a \approx (0.012 \pm 0.001)\,(\varepsilon/\mathrm{MeV})$ indicating that the higher partial wave is significant for the larger ε, whereas $sin^2\Theta$ term still give major contributions even at 83 MeV for $pp \to pp\phi$ reaction [7].

The new results of ϕ-meson production at low excess energies from ANKE, in combination with the ω-meson production [8, 9, 10], provide ϕ/ω-ratios for pp- and pn-channel. Figure 3 (a) shows all existing total cross section data extending to the higher energy and the corresponding ϕ/ω cross section ratios, normalized to R_{OZI}, are shown in Fig.3 (b). For the reaction $pp \to ppV$ ($V = \omega, \phi$), within the presented

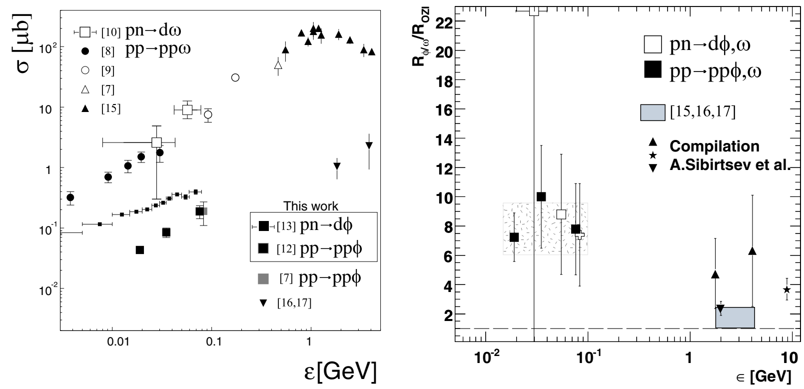

FIGURE 3. a) Preliminary total ϕ cross-sections from ANKE together with existing data for ϕ- and ω-meson production in nucleon-nucleon collisions. The error bars for $pn\to d\phi$ indicate the systematic uncertainties. b) ϕ/ω cross-section ratios normalized to R_{OZI}. The hatched area presents a weighed average taking into account only the low energy data below 100 MeV excess energy. The thick dashed horizontal line indicates the ϕ/ω-ratio based on OZI predictions.

uncertainties the ratios below DISTO energy point are equal, and we have therefore calculated a weighted mean by first fitting and interpolating the ω results. This gives $R_{\phi/\omega} = (3.3\pm0.6)\times10^{-2} \sim 8\times R_{\mathrm{OZI}}$. The production ratio obtained from high energy ppV data is $\sim(1-2.4)\times R_{\mathrm{OZI}}$ [15, 16, 17]. Together with our findings, this means that there must be a significant energy dependence of the OZI enhancement factor, which requires more theoretical work to understand its origin. For the reaction $pn\to dV$, there is a measurement of ω production in proton–neutron collisions at 57^{+21}_{-15} MeV [10] and, comparing this with our data, we find that at this energy $\sigma(pn\to d\phi)/\sigma(pn\to d\omega) = (4.0\pm1.9)\times10^{-2} \approx 9\times R_{\mathrm{OZI}}$, althought the ratio has large statistical and systematic uncertainty, the large excess from R_{OZI} for the I=1 in initial state seems also present for the isosinglet case. An improvement of ω-data at lower energies is clearly essential to make a quantitative conclusion for the origin of the ratio in the isosinglet state.

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