MESON AND HYPERON PRODUCTION RESULTS FROM THE DISTO SPECTROMETER AT SATURNE*

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The production of η, η', ω, ϕ, mesons, as well as Λ and Σ hyperons has been measured in proton-proton reactions with an incident beam momentum of 3.67 GeV/c with DISTO spectrometer at SATURNE. The first observation of the ϕ meson near the production threshold and the ϕ/ω cross sections ratio has been compared to predictions based on the OZI rule and on one-boson-exchange models. Measured inclusive cross section for K^- mesons production is about a factor of 20 lower than for inlcusive K^+ production at the same CM energy above threshold. This fact is in strong contrast to cross sections observed in sub-threshold heavy ion collisions. The production of η and η' mesons has also been measured, in an effort to gain information on the η'-nucleon coupling. The normal spin transfer coefficient (D_{NN}) has been determined for exclusive hyperon production with a polarized beam. A large negative coefficient has been observed, which is qualitatively consistent with expectations for a mechanism dominated by kaon-exchange and rescattering.

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1. Introduction

The large acceptance of the DISTO spectrometer allowed many different final states to be collected simultaneously, providing a data base for a very broad physics program:

Pseudoscalar η, η' and vector ω and ϕ mesons production have been studied. As a result, various questions ranging from: OZI rule violation in hadronic reactions, antikaons production cross section important for sub-threshold K^+,K^- creation in heavy-ion collisions to the exotic properties of the η' meson can be addressed, as will be presented in the upcoming sections.

One of the major questions being addressed is the hyperon production mechanism. Polarization observables in hyperon production are important to distinguish between different meson-exchange models reproducing near-threshold cross section measurements [1]. In pursuit of this problem we have made the first measurement which combines polarized beam with *exclusive* hyperon production kinematics.

2. Apparatus

A polarized proton beam from the SATURNE proton synchrotron with incident momentum $p_{\mathrm{beam}} = 3.67$ GeV/c was directed onto a liquid hydrogen target of 2 cm length, and multiple charge particle final states were measured with the DISTO spectrometer [2]. The charged particles were tracked through a magnetic spectrometer and detected by an array of scintillator hodoscopes and water Čerenkov detectors. The magnetic spectrometer consisted of a dipole magnet ($\sim 1.0\ T \times m$), 2 sets of scintillating fiber hodoscopes inside the field and 2 sets of multi wire proportional chambers (MWPC) outside the field. The large acceptance of the spectrometer ($\approx \pm 15^\circ$ vertical, $\pm 48^\circ$ horizontal) allowed for coincident detection of four charged particles, which was essential for the kinematically complete reconstruction of many final states ($pp\pi^+\pi^-$, $pp\pi^+\pi^-\pi^0$, $pp\pi^+\pi^-\eta$, ppK^+K^-, $pK\Lambda$, $pK\Sigma$). Particle identification was achieved using the light output from the water Cherenkov detectors and energy loss measurement in the hodoscope.

3. ϕ and ω meson production

It is by now widely accepted that the nucleon's structure is substantially more complex than the simplest picture of three valence quarks. Experimental information on the nucleon's structure functions with polarized beams [3] and the $\Sigma_{\pi N}$ term in pion nucleon elastic scattering [4, 5] suggest a significant contribution of strange sea quarks to the nucleon's wave function. In addition, $\bar{p}p$ annihilation studies [6] have observed that ϕ and ω meson cross section ratio is enhanced by up to two orders of magnitude relative to predictions based on a naive application of the Okubo–Zweig–Iizuka (OZI) rule [7]. Acording to the OZI rule, processes with disconnected quark lines in the initial or final state are suppressed. As a consequence of the near ideal SU(3) mixing, the ϕ meson production should be strongly suppressed as compared to the ω meson in reactions of hadrons with negligible strange quark content. The observed apparent violation of OZI rule in $\bar{p}p$ is most dramatic for channels with : (a) dominance of spin triplet $^3S_1$-wave annihilations at rest (b) small invariant mass of a final state particles (γ or π_0) and small invariant momentum transfer [6]. These findings have been interpreted in terms of polarized intrinsic $\bar{s}s$ contribution to the proton's wave function. In particular rearrangement diagrams of spin-triplet initial $\bar{p}p$ would yield preferentially spin triplet $\bar{s}s$ state such as the ϕ [8]. Alternatively, kaon exchange models have been proposed to explain the ϕ production [9]. Further insight on the origin of the enhanced ϕ/ω ratio in $\bar{p}p$ annihilation could be provided by studying near-threshold proton-proton reactions, where the kinematics are similar to $\bar{p}p$ but predictions based upon intrinsic strangeness in the nucleon and kaon exchange models might be expected to differ. One should note that due to the momentum and parity conservation spin triplet state is the only allowed spin configuration for the ϕ production in pp reactions at the threshold [10].

The reaction $pp \to pp\phi$ was observed via K^+K^- decay of the ϕ meson, where kaons are identified using the Čerenkov detectors [11]. Since the 4-momenta of all particles in the final state have been measured, the events are kinematically over–determined. Therefore, 4-momentum conservation can be used for a drastic background suppression by requiring that the proton-proton missing mass ($M^{pp}_{\rm miss}$) be equal to the K^+K^- invariant mass ($M^{KK}_{\rm inv}$). The distribution of the difference of these two quantities is plotted in the left frame of figure 1 with clear signal from events consistent with K^+K^- production. The right frame of figure 1 presents K^+K^- invariant mass distribution. It can be seen that at this beam energy a large fraction of kaon pairs is produced via intermediate ϕ meson.

The reaction $pp \to pp\omega$ was identified via $\pi^+\pi^-\pi^0$ decay of ω meson with undetected neutral pion [11]. For this analysis the 4-particle missing mass $M^{pp\pi^+\pi^-}_{\rm miss}$ and 2 particle missing mass $M^{pp}_{\rm miss}$ must correspond to a missing π^0 and a missing ω, respectively.

The ϕ/ω ratio from our experiment (filled square) is shown on figure 2 together with existing higher energy proton-proton data [12]. All error bars shown are the sum of systematic and statistical errors. The dashed line corresponds to the OZI prediction multiplied by the ratio of available 3-body phase space for ϕ to ω production. Our result shows that the ϕ/ω ratio appears to rise slightly compared to the OZI rule expectations as one

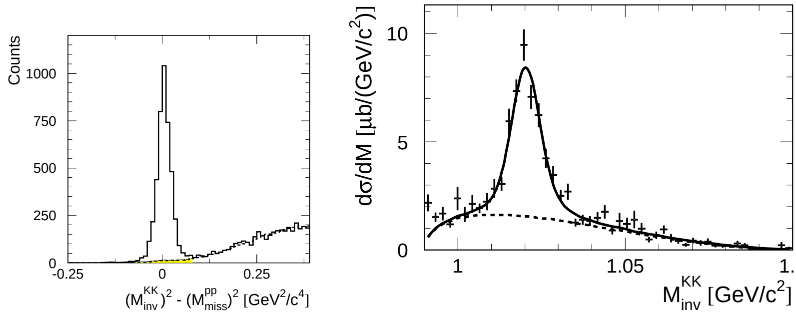

Fig. 1. (left) Spectrum of $(M_{\rm inv}^{KK})^2 - (M_{\rm miss}^{pp})^2$. The solid histogram is for events with kaon identification and the dashed histogram is the scaled background determined from events without kaon identification. (right)Acceptance corrected $M_{\rm inv}^{KK}$ distribution. The dashed curve is an estimate of the non-resonant contribution. The solid curve is the sum of the non-resonant and the ϕ meson contribution.

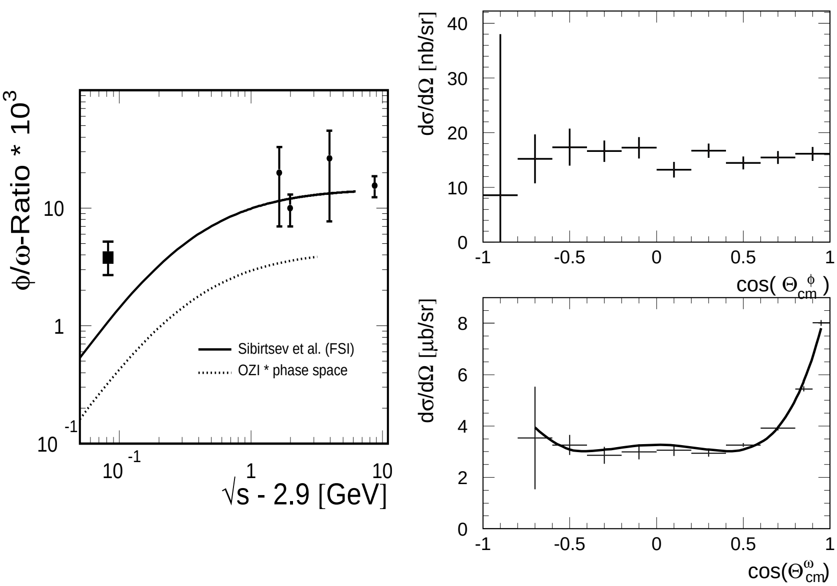

Fig. 2. (left) Ratio of the exclusive total cross sections for the $pp\phi$ and $pp\omega$ reactions as a function of the available energy above the ϕ production threshold. Shown is the value measured in this work (square) together with data at higher energies (dots) and model calculations described in the text. (right) Angular distribution of the ϕ and ω mesons (top and bottom, respectively). The error bars indicate only the statistical errors and for the ω meson the curve shows a fit with the sum of even Legendre polynomials.

approaches the threshold. The solid line results from a model calculation by Sibirtsev *et al.* [13] using a one pion exchange model and including the proton-proton final state interactions. Although the higher energy data agree well with the predictions of Sibirtsev et al., near threshold the measured ratio is enhanced by about a factor 3. In other models of [14] and [15] ϕ production dominantly arise from the known coupling to the $\pi\rho$ channel.

The angular distributions of the ϕ and ω mesons are shown in Fig. 2. Since the entrance channel is symmetric, the observed symmetry about $\cos(\Theta_{\rm cm}) = 0$ is expected. From the upper distribution we conclude that the ϕ meson is predominantly in a S-wave state relative to the pp system. The ω meson's angular distribution has been fit with an expansion using the first three even Legendre polynomials. The deviations from isotropy indicate that higher partial waves are involved in the ω production.

The production cross for ϕ and ω production can be determined using normalization to simultaneously measured η yield. The cross section for the reaction $pp \to pp\eta$ at our beam energy has been derived from a fit to accurately measured data [16, 17] with exception of the measurement at $p_{\rm beam} = 2.8\,{\rm GeV}/c$ by E. Pickup *et al.* with a large systematic error due to background subtruction. From the fit we estimate the total cross section for the reaction $pp \to pp\eta$ at $p_{\rm beam} = 3.67$ GeV$/c$ to be $135 \pm 35\mu$b. Based on this normalization, the ω and ϕ production cross sections are $50 \pm 3 \pm 19\mu$b and $0.19 \pm 0.014 \pm 0.08\mu$b, respectively, including both the statistical and systematic errors for the ω and ϕ meson results. The ω production cross section is in good agreement with existing data [17,18] (near $\sqrt{s}-\sqrt{s_{\rm th}} \sim 0.41$ GeV), which provides a very important indication that the acceptance correction procedure and absolute normalization method do not introduce a systematic bias significantly larger than the quoted systematic errors.

4. Inclusive K^- meson yield

Currently there is much interest to determine the total K^- production cross section in nucleon-nucleon reactions near threshold. This cross section is of particular importance for heavy ion physics. In heavy ion collisions it has been observed that the K^- and K^+ production cross sections are the same in sub-threshold reactions that are measured at the same center of mass energy relative to the respective thresholds [19] (see also contribution of P. Senger to this conference). The necessity to include processes in calculations of heavy ion collisions that enhance the K^- yield relies on the expectation that the K^- cross section is much lower in pp reactions. However, the K^- meson cross section data have either been before deduced from $\overline{K}_0$ results [20], or taken from different exclusive channels with one or two pions in the final state. Furthermore, there is a lack of $pp \to K^- X$ data for the regime $\sqrt{s} - \sqrt{s_0} < 0.5$ GeV where most of the K^- mesons are produced in heavy ion collisions [22]. Therefore, the DISTO [23] (Fig. 1) result provides an important comparison for the heavy ion data since it is the first K^- cross section measurement in the near threshold region. This result is equivalent to the inclusive cross section since no other channel including hadrons is kinematically allowed (N.B. $Q = \sqrt{s} - \sqrt{s_0} = 0.11$ GeV$/c^2 < M_{\pi^0}$). Recently, COSY-11 has also reported on K^- near threshold cross section measurement (see P. Moskal contribution to this conference).

The total inclusive K^- cross section, with the absolute normalization discussed above, of $(0.21 \pm 0.11 \pm 0.08)\mu$b has been determined. This cross section is about a factor 20 lower than $pp \to K^+ + X$ data at a similar available energy [24].

5. η' meson coupling to the nucleon

The η' meson has unusual properties related to important aspects of QCD. For instance, chiral symmetry gives rise to a group of nearly massless pseudoscalar particles (so called Goldstone bosons). However, the mass of the η' meson is much larger than the remaining eight pseudoscalar mesons $(\pi, \eta$ and $K)$. This was the cause of much concern until it was realized that quantization effects in QCD lead to the chiral $\mathrm{U}_A(1)$ anomaly which allows the SU(3) singlet state (η_1) to acquire mass by mixing with pseudoscalar gluon states. Due to the small pseudoscalar mixing angle ($\Theta_P \approx -10°$ to $-20°$) [25], a gluonic admixture would primarily increase the η' meson's mass. Nevertheless, it is still disputed how to appropriately describe the constituents of this meson.

The production of the η' meson in proton-proton reactions has been observed directly above the threshold [27, 28], however, an extraction of $g_{\eta' NN}$ is difficult due to the large Final State Interactions (FSI). On the other hand, the preliminary DISTO results presented here were measured at a beam momentum sufficiently above threshold so that the FSI no longer dominates the production mechanism.

The η' mesons were identified by observing the $\eta' \to \pi^+\pi^-\eta \to \pi^+\pi^- +$ *neutrals* decay channel [26]. After selecting events with four charged particles $(pp\pi^+\pi^-)$ it was required that the proton-proton missing mass (M^{pp}_{miss}) be equal to the η' mass and that the four particle missing mass $(M^{pp\pi^+\pi^-}_{\mathrm{miss}})$ be equal to the η mass. The obtained proton-proton missing mass distribution with clear η' signal is shown on Fig. 3. The dashed curve represents the background contribution and the solid curve shows sum of the background and the signal (dotted curve). After full acceptance corrections and absolute normalization via the η cross section, a total production cross section has

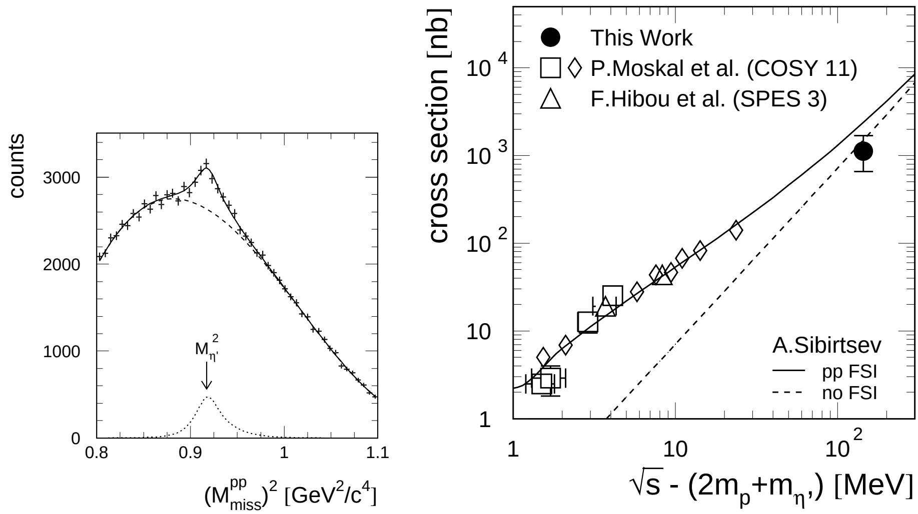

Fig. 3. (left) Raw spectra of $(M^{pp}_{\rm miss})^2$ for events with four charged particles ($pp\pi^+\pi^-$) in the final state and 4-particle missing mas ($M^{4p}_{\rm miss}$) consistent with a missing η meson. (right) Total cross section for the $pp \to pp\eta'$ production as a function of the available energy above the production threshold. This measurement is the circle data point and the other points are taken from the literature. The curves are calculations described in the text.

been determined to be $(1.12 \pm 0.15 \pm 0.4)\mu$b and is plotted as the filled point in figure 3 together with other existing data and one-boson exchange model calculations including (solid line) and excluding (dashed line) proton-proton final state interactions [30].

6. Spin transfer in exclusive hyperon production

Study of polarization observables in the production of hyperons is a very promising tool in the identification of the most effective degress of freedom in hadronic interactions. Transition from quark and gluons to mesonic degrees of freedom could be elucidated for example by examining the evolution of spin observables in Λ production in proto-proton reactions where a large body of experimental data for inclusive reactions appears to span the transition regime ($5 < \sqrt{s} < 60$ GeV).

We concentrate here on spin transfer coefficient (D_{NN}) from the polarized beam to the produced hyperon becouse they are sizable and and subject to simple interpretation withinh either meson exchange or constituent quark reaction models [34]. The subscripts N label quantization axis normal to the production plane formed by the beam proton and the produced hyperon momentum vectors. Hyperon production candidates were selected from events with four reconstructed tracks, consistent with identification as p and K^+ from a primary vertex within the target volume and p and π^- from a decay vertex displaced by ≥ 1 cm [31]. Exclusive Λ production events were identified as those with both the invariant mass of the $p\pi^-$ pair ($M_{p\pi^-}$) and the missing mass reconstructed from the pK^+ pair equal, within resolution, to the Λ mass.

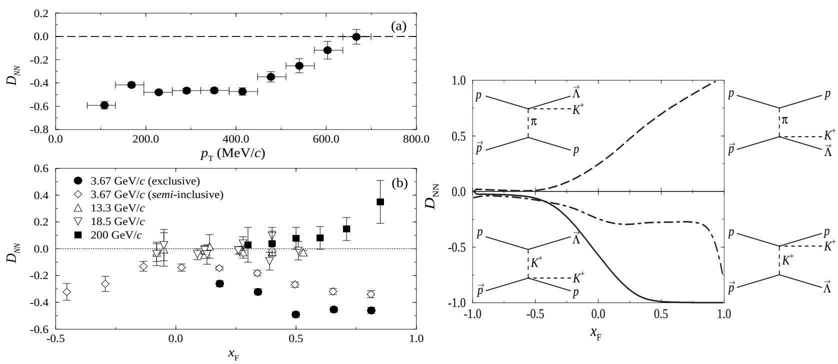

Fig. 4. left:(a) Measured D_{NN} values vs. transverse momentum transfer for the *exclusive* $pK^+\Lambda$ reaction. (b) D_{NN} as a function of x_F for the present *exclusive* Λ production and for *inclusive* Λ production at various higher incident momenta from Refs. [32, 33]. Also shown for comparison are the *semi*-inclusive results from the present data. right:Theoretical calculation [1] of D_{NN} for various *exclusive* Λ production mechanisms: kaon-exchange (solid curve),pion-exchange (dashed), or both combined with a $\Lambda - p$ final state interaction (dot-dashed). The Feynman diagrams indicate the dominant exchange contributions for positive vs. negative x_F. The calculations are integrated over *all* phase space in other kinematic variables.

Figure 4 shows the D_{NN} results for the exclusive Λ production as a function of both (a) the transverse momentum transfer p_T (from $\vec{p}$ to $\vec{\Lambda}$) and (b) the Λ's longitudinal momentum, expressed as a fraction (x_F) of its maximum kinematically allowed value. The negative sign signifies that the component of the Λ polarization that is correlated with the beam spin is oriented *opposite* to the beam spin. The error bars in Fig. 4 include statistical, but not systematic, uncertainties from the background subtraction and the $\Lambda - \Sigma^0$ peak fitting. We estimate the associated systematic errors to be $\leq \pm 0.02$ and ± 0.04, respectively, and do not affect the striking qualitative behavior observed for D_{NN} or the conclusions drawn below.

As it has been mentioned above, D_{NN} parameter is especially sensitive to the hyperon production mechanism. For example, in a meson-exchange framework, D_{NN} distinguishes clearly between π- and K-exchange contributions. This is illustrated in Fig. 4 by theoretical calculations employing the model of Ref. [1]. At large positive x_F, D_{NN} is maximally different for the two dominant contributions indicated in the figure. To conserve angular momentum and parity, kaon emission at this vertex (bottom right diagram, Fig. 4) causes a spin-flip, yielding $D_{NN} = -1$ whereas the pion emission process (upper right) requires $D_{NN} = +1$. The predicted D_{NN} tends toward zero for both mechanisms at the more negative x_F, since the hyperon is then connected preferentially to the *un*polarized (target) proton.

The large negative values observed for D_{NN} at $x_F > 0$ in Fig. 4(b) can thus be interpreted in a meson-exchange framework to suggest kaon-exchange dominance. The full theoretical calculation (dot-dashed curve in Fig. 4, not yet folded with the experimental acceptance) is qualitatively similar to the measurements.

7. Summary

In conclusion, the production of η, η', ω and ϕ mesons as well as Λ and Σ^0 hyperons has been studied by measuring their charged decay products in pp reactions at $p_{\mathrm{beam}} = 3.67$ GeV/c:

The ϕ/ω cross section ratio has been measured and is observed to exceed a naive application of the OZI rule by an order of magnitude. Although calculations using the known $\phi - \pi\rho$ coupling are able to explain the enhancement observed at higher energies, these predictions still underestimate the near threshold behavior by a factor 3. However, more refined calculations may well provide an explanation for this increase without explicitly requiring a significant contribution of $s\bar{s}$ to the nucleon's wave function.

Furthermore, we have determined the inclusive K^- production cross section in a energy regime that is very important for the interpretation of heavy ion induced reactions in which the effects of partial restoration of chiral symmetry are being studied.

The total η' meson production cross section has also been measured. This result will be useful to help determine the strength of the η'-nucleon coupling. Moreover, this coupling may provide further insights to the potentially strong gluonic component of the η' meson.

We have reported the first polarization transfer measurements for an exclusive hyperon production reaction, $pK^+\Lambda$. The large negative values observed for D_{NN} at positive x_F represent a robust qualitative behavior suggestive of a production mechanism dominated by kaon-exchange, and quite different from high-energy observations for inclusive hyperon production.

Finally, these results also provide a very important starting point for the understanding of hadronic properties in a dense nuclear environment as will be measured by the HADES detector which is under construction at GSI.

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