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NEAR-THRESHOLD MESON PRODUCTION IN pp COLLISIONS*

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A program of near threshold investigations of meson production channels in $\vec{p}+p$ collisions has been carried out by the DISTO collaboration. Preliminary results are given. The ability of the experimental apparatus to eventually determine total and differential cross-sections is demonstrated. A number a spin observables will also be evaluated. The potentialities of these measurements for the understanding of two leading problems in meson physics: OZI rule violation in ϕ production and status of the η' meson, are discussed.

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1. Introduction

DISTO is a large acceptance spectrometer installed at Saturne. The synchrotron provides up to $\sqrt{s}=3$GeV in $\vec{p}$+p collisions, this puts a spectrum of light mesons within the reach of the experiment. Data taking was performed at 3 different incident kinetic energies. A first analysis of $T_{\text{beam}}=2.85$ GeV data has identified the production of $X=(\pi^+\pi^-),\eta,\omega,\eta',(K^+K^-)$ and ϕ in ppX final states. A more detailed analysis of these channels is under way, aiming at deriving total and differential cross-sections from the large acceptance and independent monitoring of the luminosity provided by the detection system. A number of spin observables will also be determined, either from the polarized nature of the incident protons delivered by Saturne or from the angular distribution of the decays of vector mesons. Channels with associated hyperon production such as $pK^+\vec{Y}$ form the other facet of the experiment and will not be further discussed here.

Preliminary results are given in Sec. 3, including ϕ/ω and η'/η total cross-section ratios (this "cross-normalization" is used here to supplement

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yet unprocessed luminosity data). The obtained ϕ/ω ratio, to be refined later, bears already some significance concerning the problem of the OZI rule violation in ϕ production which is outlined in Sec. 2.

2. OZI rule violation

The Okubo–Zweig–Iizuka (OZI) [1] rule states that diagrams with disconnected quark lines are suppressed. So that the creation of a new flavor confined in one particle as is the case in $A + B \to \phi X$ where hadrons A, B and the single or multi-particle final state X consist of only light quarks, can only proceed because the ϕ is not an ideal mixture of SU(3) states. This led to a prediction by Lipkin [2] of the cross-section for ϕ production compared to that for ω production:

$$R = \frac{\sigma(A + B \to \phi X)}{\sigma(A + B \to \omega X)} = \tan^2 \delta \cdot f \simeq 4.2 10^{-3} \cdot f \,,$$

where δ is the deviation of the ϕ/ω mixing angle from the ideal one and f is a kinematical phase space factor.

Results for ϕ/ω production in $\bar{p}p$ annihilation obtained at LEAR strongly contradict this prediction, whereas pp and πp production had previously been found to depart only slightly from it. The overall situation is reviewed in [3]. It displays the following features:

- It is channel dependent: $\bar{p}p \to \phi X$ exhibits enhancements of a factor 30–50 when $X = \phi, \gamma$ and none when, *e.g.*, $X = \eta$.
- It is a near-threshold effect.
- It is dependent upon the quantum numbers of the initial state. The quantum number that matters is controversial though: the spin-triplet configuration is found to be dominant most of the time, like in the sequence $\bar{p}p \to \phi\pi(^3S_1 \gg {}^1P_1), \phi\pi\pi(^3S_1 \gg {}^1S_0, {}^3P_J \gg {}^1P_1)$ [5], but the highly violating $\bar{p}p \to \phi\gamma(^1S_0 \gg {}^3P_J)$ [6] does not follow the rule.

A widely discussed explanation of this violation requires a significant contribution of strange quarks to the nucleon's wave function. Indeed studies of the proton's spin structure via deep inelastic scattering indicate around 10-20% $s\bar{s}$ contribution to the proton (albeit at a different value of q^2) [4]. The proponents of this explanation [3] suggest two diagrams where the intrinsic strange quarks are transfered to the final meson through OZI-allowed shake-out and rearrangement diagrams, *cf.* Fig. 1.

The rearrangement diagram is particularly attractive since it offers, together with the polarization of the intrinsic strangeness, a basis for explaining the dependency upon the initial spin state. This is so far only schematic

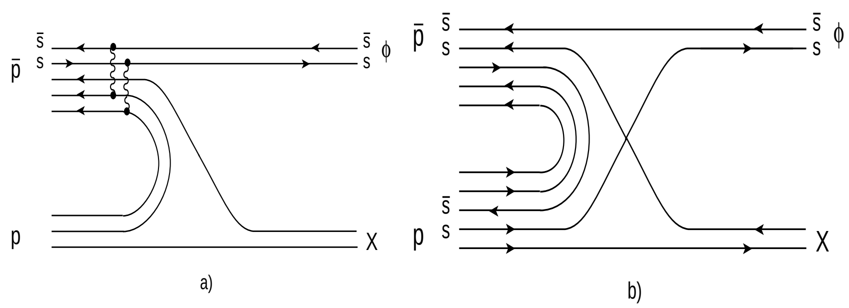

Fig. 1. OZI allowed shake-out (a) and rearrangement (b) diagrams in the presence of intrinsic strangeness in the nucleon (quoted from [3]).

though. In an idealized view where the polarization of the intrinsic strange quarks is transmitted unaltered to the final state, which would favor the initial triplet state, it would have to be positive, contrary to what results from polarized lepton deep inelastic scattering are hinting at [7].

The intrinsic strangeness picture can easily be ported to the $pp \to pp\phi$ case. On the other hand the phenomenology of the near threshold region has been worked out by Rekalo [7]. It is found that a final S-wave can only be produced from an initial triplet independent of the mechanism at play. So that we have a picture where the ϕ production should be enhanced in our energy domain which possesses the features found to elicit strong violation in $\bar{p}p$ while the excitation of P-waves away from threshold would bring about a dilution of this favorable configuration, leading to the moderate enhancement observed at high energy [8].

Another important conclusion of Rekalo's formalism concerns spin observables. At threshold there is a single transition amplitude, which determines the expectation values for all spin observables independent of the dynamics of the reaction, in particular the ϕ is produced polarized with a spin density matrix equal to $\rho_{00} = 0, \rho_{11} = \rho_{1-1} = \frac{1}{2}$ relative to the beam axis, with consequently a $\sin^2(\Theta)$ distribution for the decay kaons, where Θ is relative to the beam axis and evaluated in the ϕ frame. This provides a means of investigating the progressive departure from pure S-wave production away from threshold.

Besides the intrinsic strangeness scenario other, more conventional, explanations have been proposed for the abundant ϕ production from $\bar{p}p$ annihilation. Detailed calculations, which, in order to be comprehensive, have to resort to a variety of mechanisms, either two-step or VMD, are available for most channels [9]. In this frame an anomalously high ϕ yield in DISTO would require yet another specific treatment.

3. Experimental method and preliminary results

DISTO [10] is a dipole spectrometer consisting of four layers of positional detectors, scintillating fibers and MWPC's and two layers of hodoscopes, plastic scintillators and water Čerenkov's. All these detectors span an angular range of $\pm 48°$ and $\pm 15.5°$ in the horizontal and vertical dimensions respectively. The liquid H_2 target is positioned at the center of the dipole.

A trigger requiring four charged particles enables the detection of η, ω, η' and ϕ from their main charged decay modes: $\pi^+\pi^-\pi^0, \pi^+\pi^-\eta$ and K^+K^-. Tracking in the dipole field yields a kinematically complete measurement even for those reactions where a neutral goes undetected. In the case of

$$pp\ (\rightarrow pp\phi\ ) \rightarrow ppK^+K^-$$

the system is over-determined, which aids in discriminating the kaon pairs against the four orders of magnitude higher background of pions by requiring 4-momentum conservation. The resulting K^+K^- invariant mass distribution, with a ϕ peak, is shown in Fig. 2. The $pp\pi^+\pi^-\pi^0$ final state is selected by requiring the 4 particle missing mass to be consistent with a missing π^0, and then the η and ω mesons appear in the pp missing mass spectrum.

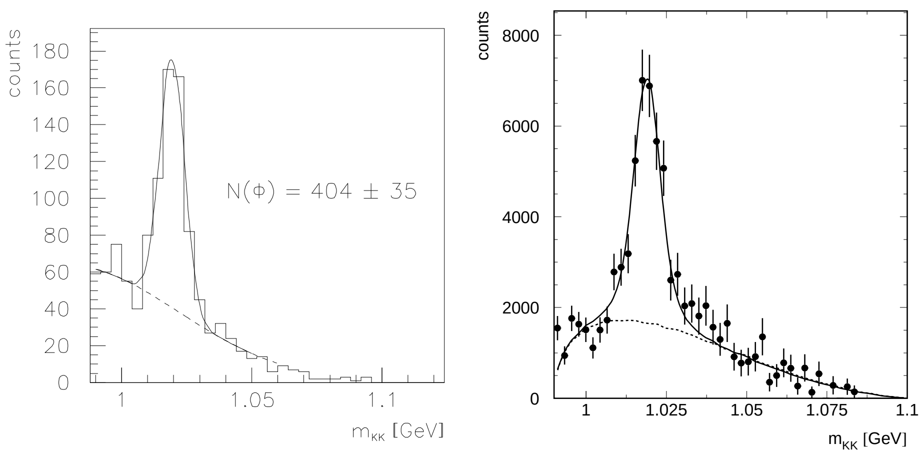

Fig. 2. K^+K^- invariant mass: raw (left) and acceptance corrected (right).

An independent trigger is used to simultaneously measure pp elastic scattering for the determination of the luminosity.

The raw mass distributions are corrected for acceptance loss and detection and reconstruction inefficiencies with help of a multi-dimensional differential efficiency array derived from a GEANT-like simulation of the experiment. This is rendered possible by the large horizontal acceptance of the detection system which ensures complete coverage of phase space once all physical symmetries are taken into account. Beam polarization effects are simply taken care of by summing over the different spin states. A proper treatment of the polarization effects due the vector meson spin would require an iterative process. For the present, a sole iteration has been performed, assuming no polarization, and has been found to be consistent with the data within the error bars.

Determinations of the total yield and kinematical distributions for both mesons are then extracted from the resulting physical distributions. The value obtained for the total cross-section ratio is:

$$\phi/\omega = 0.0030\,(\pm 0.0005 \text{ stat.})\,(^{+0.0010}_{-0.0008} \text{ syst.})\,.$$

It is compared in Fig. 3 to the OZI prediction, which is strongly lowered by the small phase space open to ϕ production near threshold (further lowering could arise from taking into account spin degrees of freedom which are neglected in the present calculation). An enhancement by about a factor 10 over this naive application of OZI is observed. However this comparison

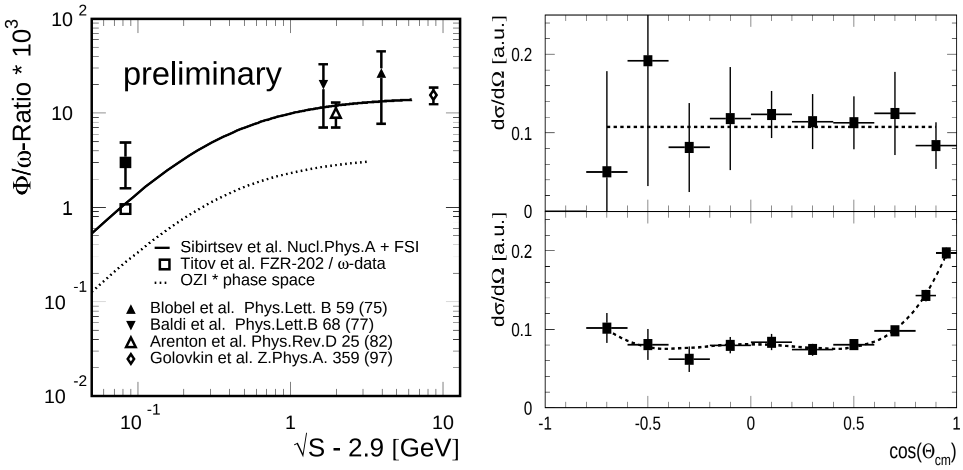

Fig. 3. Left: ϕ/ω cross-section ratio in *pp* collision as a function of the energy above threshold. DISTO's preliminary value at 83 MeV (solid square) is compared to higher energy results, OZI prediction neglecting spin degrees of freedom and model calculations. Right: Angular distributions of the ϕ (top) and ω (bottom) mesons, fitted by Legendre expansions.

is rendered uncertain by the difference in dynamics revealed by the angular distribution of the mesons: higher order partial waves contributing to $\simeq$ 40% of the ω production while the ϕ's are found to be isotropic. The comparison with a model calculation by Sibirtsev [11], drawing on the large

$g_{\phi\rho\pi}$ coupling constant to reproduce high energy results, is more informative. DISTO's value is underestimated by a factor 3, meaning that it still presents a challenge to conventional mechanisms, although the present discrepancy could perhaps be fixed by resorting to a two-step process involving $K\bar{K}$ pairs similar to those used successfully in the $\bar{p}p$ case [9].

The η' signal results from:

$$pp \to pp\eta' \to pp\pi^+\pi^-\eta\,,$$

where η decays via, undetected, neutral modes to match the trigger requirements. Its identification is analog that of the η and ω, *cf.* Fig. 4. The total cross-section value derived from the measured η'/η ratio and the known η production rate [12],*viz.*

$$\sigma(pp \to pp\eta') = (1.1 \pm 0.2 \text{ stat. } {}^{+1.4}_{-0.6} \text{ syst.})\,\mu b\,,$$

is plotted in Fig. 5 together with threshold measurements by COSY 11 [13] and SPES3 [14]. DISTO's energy domain turns out to be an ideal com-

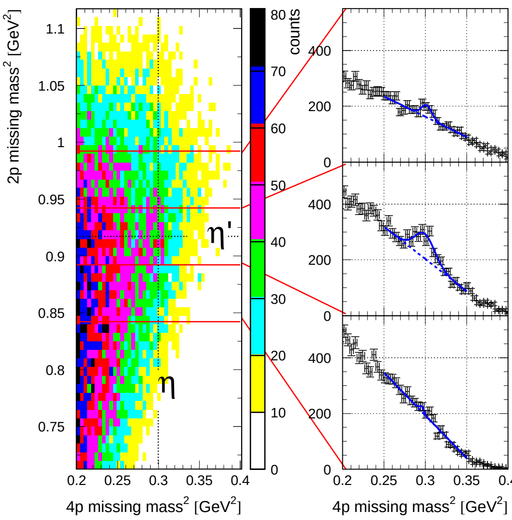

Fig. 4. Left: Correlation of the 4-particle ($pp\pi^+\pi^-$) missing mass and 2-particle (pp) missing mass for events with four charged particles ($pp\pi^+\pi^-$) in the final state. Right: Projection of the left figure with respect to the three different gates on the 2-particle missing mass. The η signal in the 4-particle missing mass is only visible when selecting on the $\eta\prime$ in the 2-particle missing mass distribution.

plement to these. It is probing the reaction at vanishingly low FSI and is hence expected to help in clearing up the uncertainties affecting the determination of the $g_{\eta' pp}$ coupling constant from the energy dependency of the cross-section in [13]. This hinges on the relative magnitude of the heavy meson exchange and FSI contributions to the production amplitude on the one hand and on the other hand on the role of the $D_{13}(2080)$ resonance.

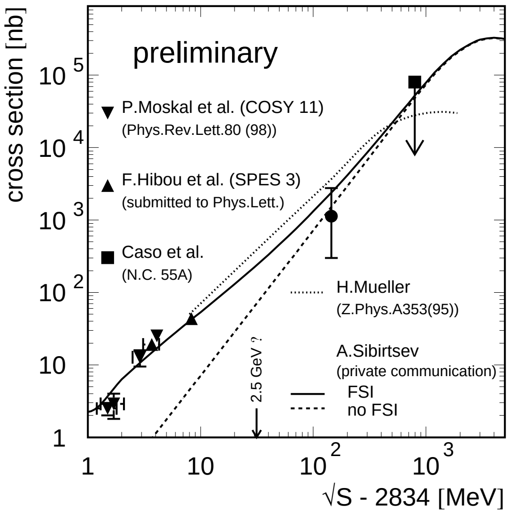

Fig. 5. $pp \rightarrow pp\eta'$ cross-section as a function of the energy above threshold. DISTO's result (solid circle) is plotted together with threshold measurements and two model calculations underlining the importance of final state interactions (FSI). DISTO's other data taking energy, filling the gap between threshold and the present 144 MeV point, is indicated by the arrow.

4. Conclusion

The ability of DISTO data to provide useful information on near threshold meson production has been demonstrated. Five times more $T_{\text{beam}} =$ 2.85 GeV statistics than processed so far is at hand on tape, as well as data at 2.5 and 2.015 GeV.

A large enhancement of ϕ production over the OZI prediction as expected from the close analogy between the near threshold $pp \rightarrow pp\phi$ and $\bar{p}p \rightarrow \phi\pi$ in the context of the intrinsic strangeness model is not found. Still the measured value represents a challenge for conventional explanations. Apart from yielding smaller error bars the processing of the full statistics will allow further constraining of the models through the determination of polarization observables and kinematical dependencies.

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