Hadronic interaction of η and η' mesons with nucleons*

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Due to their short life-time, flavour-neutral mesons cannot be utilized as free secondary beams or targets, and therefore a study of their interaction with nucleons is not possible via direct scattering experiments. This interaction is, however, accessible via its influence on the energy dependence – and on the phase space distributions of the cross sections for reactions in which these mesons are produced.

In case of the $pp \to pp\eta$ reaction the experimentally determined distributions of the differential cross sections close to the production threshold cannot be described by taking into account the S-wave proton-proton and proton-η interaction only. Here we show that the angular distributions determined at the COSY-11 facility reveal some evidence for P-wave admixture in the proton-proton subsystem already at an excess energy as low as Q = 15.5 MeV. We also present that one can estimate the relative strength of the η-nucleon and η'-nucleon interactions by comparison of the η and η' production yield.

1. COMPARISON OF THE p-η AND p-η' INTERACTIONS

Close to the kinematical threshold the total cross section for the meson production via the nucleon-nucleon interaction grows rapidly with increasing excess energy Q. It is well established [1] that for the $pp \to pp\eta$ [2] and $pp \to pp\eta'$ [3] reactions this total cross section changes by about two orders of magnitude within a Q range of about ten MeV. The shape of the excitation function is predominantly determined by the changes of the phase space volume and by the final state interaction among the produced particles. The precision of the experiments performed at the cooler synchrotrons allows to distinguish the subtle effects originating from

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the meson-nucleon interaction. A quantitative derivation of the $p-\eta$ and $p-\eta'$ hadronic potentials requires, however, a sophisticated theoretical treatment since the distortion caused by the nucleons is by orders of magnitude larger than that due to the meson–nucleon forces, and even small fractional inaccuracies in the description of nucleon–nucleon effects may obscure the inference on the meson–nucleon interaction. To minimize the ambiguities which may result from these discrepancies – at least for the qualitative estimation of the effects of the unknown meson–nucleon interaction – one can compare the spectra from the production of a meson under investigation to the spectra determined for the production of a meson whose interaction with nucleons is established. To visualize the influences of the $p-\eta$ and $p-\eta'$ interaction on the energy dependence of the total cross section we have compared the modulus of the primary transition amplitude $|M_0|$ of the $pp \to pp\eta$ and $pp \to pp\eta'$ reactions to the one extracted from the data on the $pp \to pp\pi^0$ reaction [4] [3].

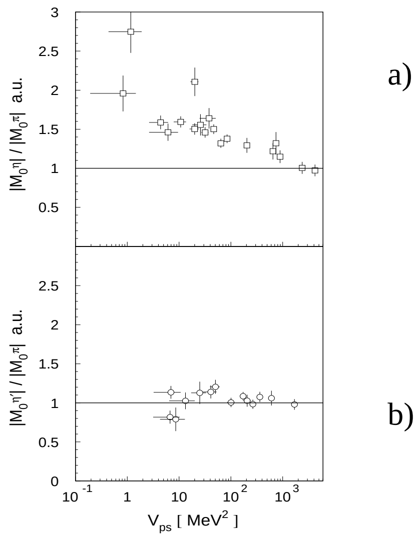

Figure 1. The ratios of a) $|M_0^{\eta}|/|M_0^{\pi^0}|$ and b) $|M_0^{\eta'}|/|M_0^{\pi^0}|$ extracted from the experimental data for $pp \to pp\eta$ [2] and $pp \to pp\eta'$ [3] reactions. $|M_0^{\pi^0}|$ was calculated by interpolating the data of reference [5]. The figure is adapted from reference [4].

Figures 1a and 1b show the dependence of $|M_0|$ on the phase–space volume for η and η' production normalized to $|M_0^{\pi^0}|$. The values of $|M_0|$ were extracted from the experimental data disregarding the proton–meson interaction. If the influence of the neglected interactions were the same in the case of the η (η') and π^0 production the points would be consistent with the solid line. This holds in case of the $pp \to pp\eta'$ reaction indicating the weakness of the proton–η' interaction independently of the prescription used for the proton–proton FSI [4]. In case of the η' meson its low–energy interaction with the nucleons was expected to be very weak since there exists no baryonic resonance which would decay into $N\eta'$ channel [8]. In contrary, the existence of the $N^*(1535)$ resonance, which decays significantly into nucleon and the η meson, indicates that the $N\eta$ interaction is much stronger than the $N\eta'$ one, and indeed as depicted in figure 1a the strong effects of the ηpp FSI at low V_{ps} are visible.

As a next step for a quantitative understanding of the $pp\eta$ dynamics a full three-body description of the system with the complex hadronic potentials is required as well as an exact determination of the magnitudes of the contributing partial waves. Some aspects of the latter issue are discussed in the next section.

[3]The S-wave π-proton interaction is negligibly weak in comparison to the proton-proton one. The real part of the $\pi-p$ scattering length ($|a_{p\pi}| = 0.13$ fm [6]) is more than a factor of 50 smaller than $|a_{pp}| = 7.83$ fm [7].

2. DIFFERENTIAL CROSS SECTIONS FOR THE REACTION $pp \to pp\eta$

On previous conferences we have already reported on the phase space density distribution determined for the $pp \to pp\eta$ reaction at an excess energy of Q = 15.5 MeV [9,10]. The obtained spectrum – shown here in figure 2 – revealed a strong deviation from the expectation based on the factorization of the transition amplitude into the constant primary production and the on-shell incoherent pairwise interaction among the produced particles (see solid and dashed lines).

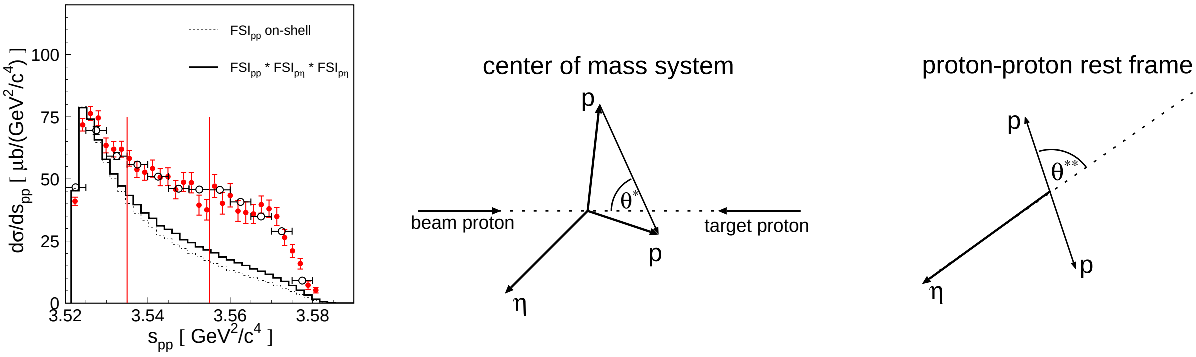

Figure 2. **(left side)** Distribution of the square of the proton-proton invariant mass (s_{pp}) for the $pp \to pp\eta$ reaction at an excess energy of Q = 15.5 MeV. The data obtained by the TOF collaboration [11](open circles) have been normalized in magnitude to the results of the COSY-11 collaboration [10](closed circles). The integrals of the phase space weighted by the square of the proton-proton on-shell scattering amplitude (dashed line)–FSI$_{pp}$, and by the product of FSI$_{pp}$ and the square of the proton-η scattering amplitude (solid line), have been normalized arbitrarily at small values of s_{pp}. The solid line was obtained assuming a scattering length of $a_{p\eta}$ = 0.7 fm + i 0.4 fm. **(middle and right side)** Definition of the angles used in the text.

The experimental data obtained independently by TOF [11] and COSY-11 [10] using different detection systems agree perfectly with each other and make possible systematical errors rather improbable. The data show also a fully isotropic distribution over the polar emission angle of the η meson in the center-of-mass frame [11,9], and are consistent with an isotropic angular distribution of the relative momentum of the protons seen in the center-of-mass system [11] (angle θ^* on the middle side of figure 2).

According to preliminary investigations based on the meson exchange model [12], the observed distribution of the proton-proton invariant mass cannot be explained assuming that the production of the outgoing particles takes place exclusively with the relative angular momentum equal to zero. The discrepancy between the solid line of figure 2 and the data is also too large to be explained by the underestimation of the s-wave proton-η interaction. Inspired by that difficulty we checked the partial wave distribution in the proton-proton system deriving from the data the angular distribution of the proton momentum in the rest frame of proton-proton system (angle θ^{**} on the right side of figure 2). A possible non-zero angular momentum between outgoing protons should manifest itself in an unisotropic population of the angle between the relative proton-proton momentum and the recoil particle (η) seen from the di-proton rest system [13]. The distributions determined for three intervals of s_{pp} are shown in figure 3. As a first step we restricted the analysis assuming that only S– and P– waves contribute, and we fit the data by the linear combination of the Legendre polynomials up to the second degree, which in case of two identical particles reads: $\frac{d\sigma}{d\Omega} = a\ (\ 1 + b\ P_2(cos\theta^{**})\ )$. In this representation the parameter b is a measure of the relative amplitude of the P– and S–wave contributions.

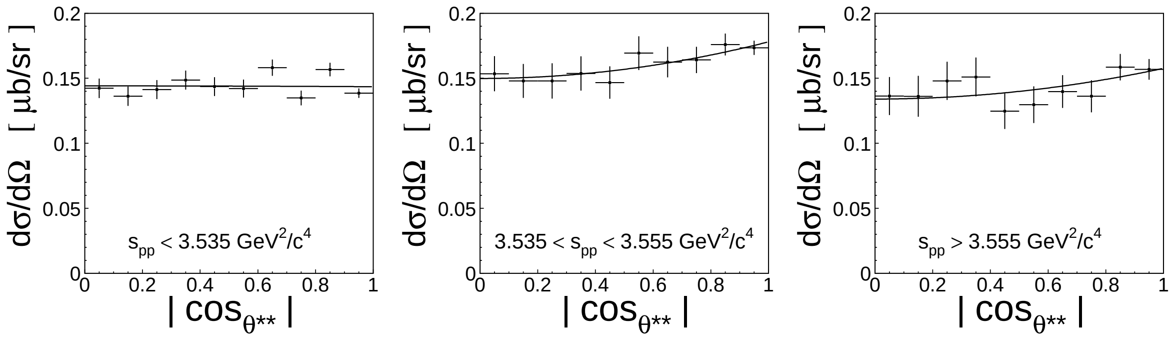

Figure 3. Distribution of the polar angle of the relative proton-proton momentum with respect to the momentum of the η meson as seen in the di-proton rest frame. Figures correspond to the three different s_{pp} intervals marked by the vertical lines in figure 2.

As a result we obtained that b is consistent with zero for $s_{pp} < 3.535$ GeV^2/c^4 and amounts to ≈ 0.12 for the middle and upper ranges of s_{pp}. This value supports the hypothesis that an admixture of P-waves in the proton-proton subsystem is not negligible already at an excess energy of Q = 15.5 MeV.

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