Proton-proton collisions at production thresholds

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Recent results obtained by the COSY – 11 collaboration concerning the production of η and η' mesons in the $pp \to ppMeson$ reaction are presented. A comparison of the production amplitude for the π^0, η and η' mesons at the same phase space volume allows to conclude that the proton - η' interaction is in the order of, or smaller than, the proton-π^0 one.
A total cross section determined in a preliminary analysis of the data of elementary kaon and antikaon production via the $pp \to ppK^+K^-$ reaction measured at excess energy of $Q = 17$ MeV is reported.

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1. Introduction

In the last decade a copious set of data on the close-to-threshold production of mesons π^0, η, and η' in the collisions of protons has been collected at the high precision accelerators in Bloomington, Uppsala, Saclay and Jülich. The quality of the determined energy dependence of the total cross sections for the $pp \to pp\pi^0$ [1–3], $pp \to pp\eta$ [4–8], and $pp \to pp\eta'$ [9–11] reactions enables investigations of the microscopic description of the primary production mechanism [13–26] and the interaction of protons with the created

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meson [19, 27, 28]. Here a special emphasis is given to the still unknown interaction of protons with the η' meson, which can not be studied directly in the elastic η'-proton scattering, due to the short life time of this meson. This issue will be discussed in the next section where the qualitative phenomenological analysis will be presented which results in the rough estimation of an upper limit for the proton-η' scattering length. In the third section preliminary results concerning the studies of the open strangeness production via the $pp \to ppK^+K^-$ reaction close to the production threshold will be overviewed.

Since the subject of this report covers only a part of the COSY – 11 activity the interested reader is encouraged for further reading of an unexpected large difference, observed recently, in the close-to-threshold K^+ meson production depending whether it is associated with a Σ^0 or a Λ hyperon [29–31].

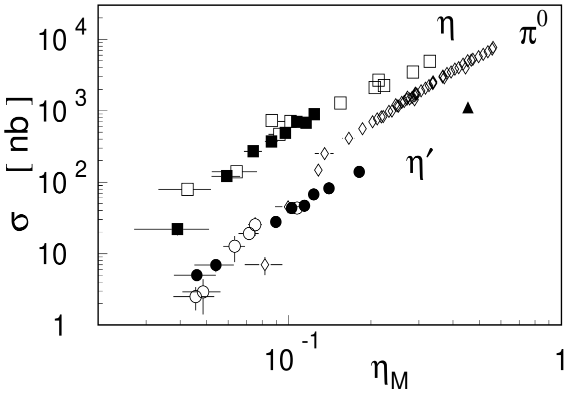
2. S-wave proton-η' interaction

Trying to compare the total cross section for the close-to-threshold production of different mesons one has to find an appropriate kinematical variable. Usually, the total cross section is presented as a function of the dimensionless parameter η_M [1, 2, 32] [1], which is defined as the maximum center-of-mass meson momentum in units of meson mass ($\eta_M = \frac{q_{max}}{M}$), or as a function of the excess energy Q [6, 8, 10]. In Figure 1a the total cross sections for the reactions $pp \to pp\pi^0$, $pp \to pp\eta$, and $pp \to pp\eta'$ are compared versus the parameter η_M and in Figure 1b versus the excess energy. One immediately notices the qualitative difference between both representations. For example, the η meson production cross section exceeds the π^0 cross section by a factor of 2 and more using η_M, whereas the π^0 meson cross section is always larger than the η one when the Q scale is employed. To find a proper variable for the comparison of the cross sections for mesons of significantly different masses we recall a definition of the total cross section, which is just the integral over phase space of the squared transition matrix element normalized to the incoming flux factor F:

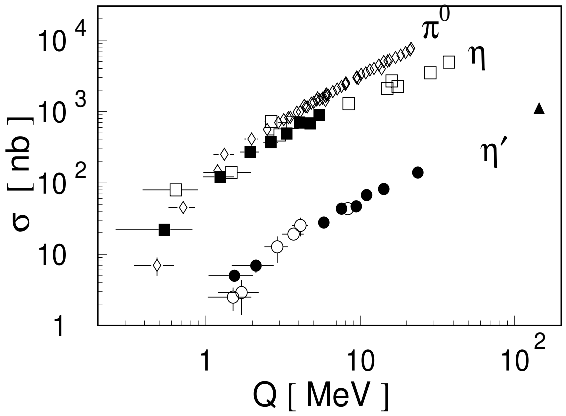
$$\sigma_{pp\to ppX} = \frac{1}{F} \int dV_{ps} \; |M_{pp\to ppX}|^2, \tag{1}$$

where X stands for the π^0, η or η' meson, V_{ps} denotes the phase space volume, and $F = 2 \ (2\pi)^5 \sqrt{s \ (s - 4 \ m_p^2)}$ [33], with s being the square of the total energy in the center-of-mass frame.

[1] In order to avoid ambiguities with the abbreviation for the eta-meson, we introduce an additional suffix M for this parameter, which usually is called η only.



a)



b)

Fig. 1. Total cross sections for the reactions $pp \to pp\pi^0$ (diamonds [1–3]), $pp \to pp\eta$ (squares [4, 6–8, 10]), and $pp \to pp\eta'$ (circles [9–11], triangle [12]) a) versus the maximum center-of-mass meson momentum normalized to the meson mass η_M, and b) as a function of the excess energy Q. The filled squares and circles indicate recent COSY – 11 results [4,9], and the filled triangle was reported on this conference [12].

This definition suggests that a natural variable for comparing the total cross sections for different mesons may be the volume of available phase space [28]. Note that in case of the same dynamics (transition matrix element) for the production of two different mesons we would obtain identical values for the total cross section as a function of V_{ps} independently from the produced meson masses, which would not be the case when the variables η_M or Q would have been employed.

Now, in order to study the proton-η' interaction we will employ two assumptions [28], which were lively discussed during this conference [34–37]:

1) in analogy with the *Watson-Migdal* approximation [38] for two body processes, we will assume that the complete transition amplitude for a production process $M_{pp\to ppX}$ factorizes approximately as:

$$|M_{pp\to ppX}|^2 \approx |M_0|^2 \cdot |M_{FSI}|^2 \cdot ISI,$$

where M_0 represents the total production amplitude, M_{FSI} describes the elastic interaction among particles in the exit channel, and ISI denotes the reduction factor due to the interaction of the colliding protons. This factorization, however, is valid only as long as the energy dependence of the total cross section is considered [35–37].

2) we will assume also that in the exit channel only the proton-proton interaction is significant ($|M_{FSI}|^2 = |M_{pp\to pp}|^2$).

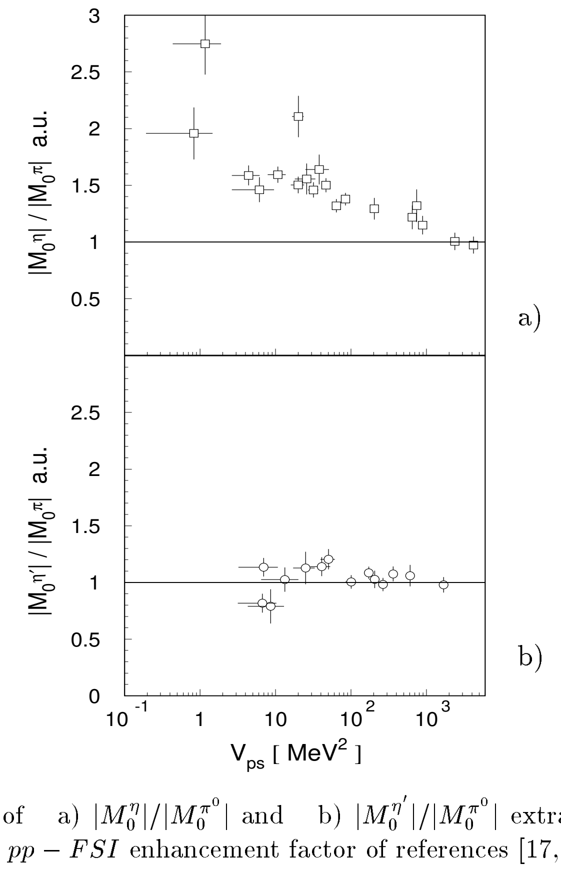


Fig. 2. The ratios of a) $|M_0^\eta|/|M_0^{\pi^0}|$ and b) $|M_0^{\eta'}|/|M_0^{\pi^0}|$ extracted from the data, assuming the $pp - FSI$ enhancement factor of references [17, 40].

These two assumptions enable us to derive from the measured cross sections the phase space dependence of $|M_0^{\pi^0}|^2$, $|M_0^{\eta}|^2$, and $|M_0^{\eta'}|^2$ [28,39], since the $M_{pp\to pp}$ amplitude is known and the ISI factor can be calculated according to the formula from reference [37]. However, there is no unequivocal description for the $|M_{pp\to pp}|^2$ enhancement factor [28]. Therefore, to minimize ambiguities resulting from this uncertainties, we consider the ratios $|M_0^{\eta}|/|M_0^{\pi^0}|$ and $|M_0^{\eta'}|/|M_0^{\pi^0}|$ [28], which normalize the transition amplitude for η and η' to the one for π^0 production $|M_0^{\pi^0}|$. This should be independent of the model used for the determination of $|M_{pp\to pp}|^2$, and will allow an estimate of the relative strength of the π^0-proton and $\eta(\eta')$-proton interactions. Indeed, we examined that within the errors the ratio $|M_0^{\eta(\eta')}|/|M_0^{\pi^0}|$ does not depend on the model used for $|M_{pp\to pp}|^2$. As an example, in Figure 2 we show this ratio as obtained from the amplitude $|M_{pp\to pp}|^2$ taken from references [17, 40]. Figure 2a shows an increasing strength of $|M_0|$ for the η production at low V_{ps}, indicating a strong η-proton FSI, as was discussed previously for the cross section ratio by Calén et al. [6]. Note also that the ratio for the η' meson is constant over the phase space range considered (Figure 2b). This observation, and the fact that theoretical calculations predict the primary production amplitude to be constant within a few per cent [23, 25] independently from the mechanism assumed, allows us to conclude that the η'-proton scattering parameters are in the order of, or smaller than, the proton-π^0 ones.

3. Kaon and antikaon production

Two years ago at the MESON'98 we presented upper limits for the total cross section of the $pp \to ppK^+K^-$ reaction [41]. At present due to the gained statistics and the understanding of the background we are pleased to present an absolute value for the total cross section at an excess energy of $Q = 17$ MeV. The primordial motivation for studying this reaction was presented already ten years ago at this conference hall by W. Oelert [42]. It concerns the study of the K^+K^- interaction and the investigation of the structure of the $f_0(980)$ meson, which is still discussed to be either the usual $q\bar{q}$, the exotic state $qq\bar{q}\bar{q}$ or a strongly bound $K\bar{K}$ molecule.

In order to identify this reaction the four-momentum vectors for three positively charged particles are determined [44]. Figure 3 shows the preselected data where two of the positively charged particles are identified as protons. On the vertical axis the measured mass of the third registered particle is plotted as a function of the mass of an unobserved system. In the case of the $pp \to ppK^+K^-$ reaction both the invariant mass of the third particle and the missing mass – with respect to the identified (ppK^+) subsystem – should correspond to the mass of the kaon. Already at this level of analysis the group of events corresponding to the $pp \to ppK^+K^-$ reaction can be recognized.

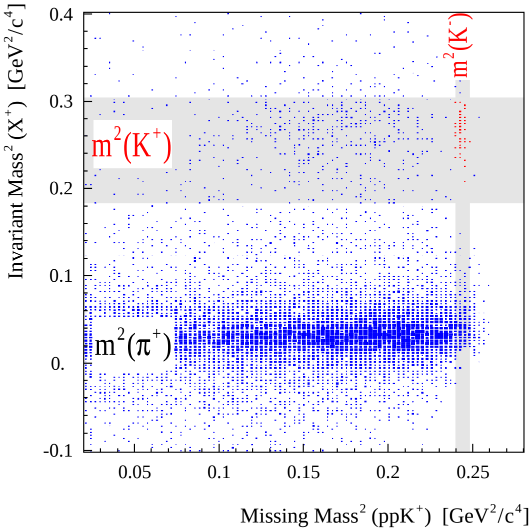


Fig. 3. Results of the preliminary analysis [43]: Invariant mass of one out of three positively charged particles which was not identified as a proton versus the missing mass of an assumed (ppK^+)-subsystem. The shaded areas, centered around the mass of the kaon, indicate three standard deviations of the experimental resolution.

The projection of events contained in the horizontal shaded area onto the missing mass axis reveals a clear signal originating from the K^+K^- meson pair production, as presented in Figure 4. The much broader structure seen on the left side of the peak is due to the K^+ meson production associated with the hyperon resonances $\Lambda(1405)$ or $\Sigma(1385)$ (eg. $pp \to pK^+\Lambda(1405) \to pK^+\Sigma\pi \to pK^+\Lambda\gamma\pi \to pK^+p\pi\gamma\pi$). In this case the missing mass of the ppK^+ system corresponds to the invariant mass of the ($\pi\pi\gamma$) subsystem. Demanding an additional signal in a silicon pad detector [45] at the position expected for the K^- meson the background is reduced by more than one order of magnitude [43]. This additional requirement diminishes the signal from the $pp \to ppK^+K^-$ by about 50 % only [43], which is understood by the decay of the K^- meson on its way to the dedicated silicon detector.

The preliminary analysis of the data taken at the excess energy of $Q = 17$ MeV results in a cross section value of 2.1 ± 0.8 nb [43,44,46,47]. When compared to the value $200 \pm 11 \pm 80$ nb determined at $Q = 111$ MeV [48], one observes that the cross section for the production of the K^- meson in the elementary proton-proton collisions increases much stronger than the corresponding one for the K^+ [30,49] meson.

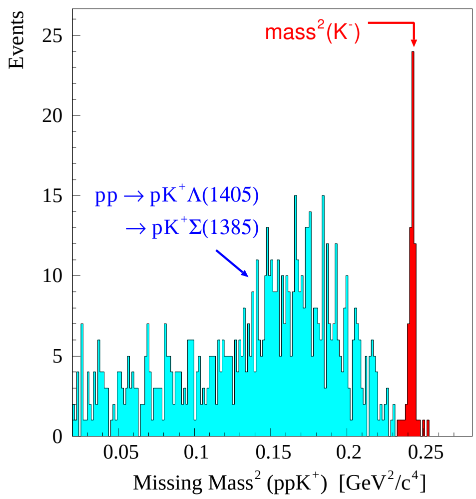


Fig. 4. Result of a preliminary analysis [43]: Missing mass with respect to an identified (ppK^+)-subsystem as measured at excess energy of $Q = 17$ MeV.

REFERENCES

[1] A. Bondar et al., Phys. Lett. **B 356** (1995) 8.

[2] H. O. Meyer et al., Nucl. Phys. **A 539** (1992) 633.

[3] H. O. Meyer et al., Phys. Rev. Lett. **65** (1990) 2846.

[4] J. Smyrski et al., Phys. Lett. **B 474** (2000) 182.

[5] H. Calén et al., Phys. Rev. Lett. **79** (1997) 2642.

[6] H. Calén et al., Phys. Lett. **B 366** (1996) 39.

[7] E. Chiavassa et al., Phys. Lett. **B 322** (1994) 270.

[8] A. M. Bergdolt et al., Phys. Rev. **D 48** (1993) R2969.

[9] P. Moskal et al., Phys. Lett. **B 474** (2000) 416.

[10] F. Hibou et al., Phys. Lett. **B 438** (1998) 41.

[11] P. Moskal et al., Phys. Rev. Lett. **80** (1998) 3202.

[12] P. Salabura et al., Proceedings of this conference.

[13] C. Wilkin, Proceedings of the 8th International Conference on the Structure of Baryons (Baryons 98), World Scientific (1999) 505, e-Print Archive: nucl-th/9810047.

[14] V. Bernard, N. Kaiser, Ulf-G. Meißner, Eur. Phys. J. **A 4** (1999) 259.

[15] E. Hernández, E. Oset, Phys. Rev. **C 60** (1999) 025204.

[16] C. Hanhart et al., Phys. Lett. **B 444** (1998) 25.

[17] R. Shyam, U. Mosel, Phys. Lett. **B 426** (1998) 1.

[18] C.J. Horowitz, H.O. Meyer, D.K. Griegel, Phys. Rev. **C49** (1994) 1337.

[19] M.T. Pẽna, H. Garcilazo, D.O. Riska, e-Print Archive: nucl-th/0006011

[20] M. Batinić, A. Švarc, T.-S. H. Lee, Phys. Scripta **56** (1997) 321.

[21] T. Vetter et al., Phys. Lett. **B 263** (1991) 153.

[22] F. Kleefeld, M. Dillig, Proceedings of the 8th International Conference on the Structure of Baryons (Baryons 98), e-Print Archive: nucl-th/9811003.

[23] K. Nakayama et al., Phys. Rev. **C 61** (2000) 024001.

[24] S.D. Bass, 8th International Workshop on Deep Inelastic Scattering and QCD (DIS 2000), e-Print Archive: hep-ph/0006348

[25] E. Gedalin, A. Moalem, L. Razdolskaja, Nucl. Phys. **A 650** (1999) 471.

[26] A. Sibirtsev, W. Cassing, Eur. Phys. J. **A 2** (1998) 333.

[27] V. Baru et al., Eur. Phys. J. **A 6** (1999) 445.

[28] P. Moskal et al., Phys. Lett. **B 482** (2000) 356.

[29] S. Sewerin et al., Phys. Rev. Lett. **83** (1999) 682.

[30] J. Balewski et al., Phys. Lett. **B 420** (1998) 211.

[31] S. Sewerin et al., Nucl. Phys. **A 663&664** (2000) 473c.

[32] H. Machner, J. Haidenbauer, J. Phys. **G 25** (1999) R231.

[33] E. Byckling, K. Kajantie, *Particle Kinematics*, John Wiley & Sons Ltd. (1973).

[34] F. Kleefeld, Proceedings of this conference, e-Print Archive: nucl-th/0005037.

[35] J.A. Niskanen, Phys. Lett. **B 456** (1999) 107.

[36] V. Baru et al., e-Print Archive: nucl-th/0006075.

[37] C. Hanhart, K. Nakayama, Phys. Lett. **B 454** (1999) 176.

[38] K.M. Watson, Phys. Rev. **88** (1952) 1163.

[39] P. Moskal et al., Int. Conf. STORI'99, AIP Conf. Proc. 512 (2000) 65.

[40] M.L. Goldberger, K.M. Watson, Collision Theory, Wiley, New York, 1964.

[41] P. Moskal et al., Acta Phys. Pol. **B 29** (1998) 3091.

[42] W. Oelert, Proc. of the Workshop on Meson Production, Interaction and Decay, Cracow, World Scientific, Singapore, 1991, p.199.

[43] C. Quentmeier, T. Lister, M.Wolke et al., Poster presented at the Spring Conference of the German Physical Society, Dresden 2000.

[44] M. Wolke et al., Int. Conf. STORI'99, AIP Conf. Proc. 512 (2000) 143.

[45] S. Brauksiepe et al., Nucl. Instr. & Meth. **A 376** (1996) 397.

[46] T. Lister, C. Quentmeier, M.Wolke et al., Ann. Rep. 1999, IKP FZ-Jülich, Jül-3744, Feb. 2000, p. 41.

[47] A. Khoukaz et al., Nucl. Phys. **A 663&664** (2000) 565c.

[48] F. Balestra et al., Phys. Lett. **B 468** (1999) 7.

[49] R. Bilger et al., Phys. Lett. **B 420** (1998) 217.