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Close to threshold η' meson production in proton-proton collisions at COSY–11

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Abstract. We summarize results from measurements of excitation function for $pp \to pp\eta'$ reaction performed at COSY–11 detector. The determined cross sections enabled an extraction of the scattering length of the η'-proton interaction in the vacuum.

1 Introduction

Intensive quest for the η and η' bound states is currently ongoing at both theoretical e.g. [1–8] and experimental levels e.g. COSY [9–14], ELSA [15], GSI [16, 17], JINR [18], JPARC [19, 20], LPI [21], and MAMI [22, 23]. These studies were already supported by data provided by the COSY–11 collaboration [24–27] including determination of the total width of the η' meson [28, 29]. In addition, the first rough estimation of the η'-N interaction from the excitation function of the cross section for the $pp \to pp\eta'$ reaction was also performed [30]. Recent precise measurement in this field from the COSY–11 experiment [31] allows to summarize results on the η' meson production cross section in proton-proton collisions at COSY–11.

2 Motivation

It is impossible to prepare a beam or target out of short lived particles like the η or η' mesons. Therefore their interaction with other hadrons cannot be investigated in the standard way via scattering experiments. However, production of these mesons close to the kinematical threshold with low relative velocities with respect to nucleons gives a chance to study their interaction with nucleons. It may manifest itself as structures in a meson-nucleon invariant mass distributions and as enhancement in the excitation function with respect to predictions based on the assumption that the kinematically available phase space is homogeneously populated.

Measurements of the η– and η'–nucleon and nucleus systems may yield valuable new information about dynamical chiral and axial U(1) symmetry breaking in low energy QCD. The binding energies, meson-nucleon scattering lengths and in-medium masses of the η and η' are sensitive to the flavour-singlet component in the mesons and hence to the non-perturbative glue associated with axial U(1)

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dynamics [2, 3]. QCD inspired models including confinement, chiral and axial U(1) dynamics yield a range of predictions for the η and η' nucleon scattering lengths and binding in nuclei.

The quark condensate is modified in nucleus which changes the properties of hadrons in nuclear medium and these medium modifications can be understood at the quark level through coupling of the scalar isoscalar σ (and also ω and ρ) mean fields in the nucleus to the light quarks in the hadron.

3 The COSY–11 experiment

The collision of a proton from the COSY stochastically cooled beam [32] with a hydrogen cluster target proton of COSY–11 [33] may cause an η' meson creation. The ejected protons of the $pp \to pp\eta'$ reaction are then separated from the circulating beam by the magnetic field due to their lower momenta and were registered by the detection system consisting of drift chambers and scintillation counters. The reconstruction of the momentum vector for each registered particle is based on the measurement of track direction by means of the drift chambers and the knowledge of dipole magnetic field. Together with the independent determination of the particle velocity from the measured time of flight between scintillator detectors the particle identification is provided. Knowledge of the momenta of both protons before and after the reaction allows to calculate the mass of unobserved particles. Number of reconstructed η' mesons together with luminosity determination based on the cross section for elastically scattered pp events and registered number of $pp \to pp$ events allows for $pp \to pp\eta'$ cross section determination.

Measurements of the total cross section for $pp \to pp\eta'$ reaction together with theoretical excitation functions are summarized in Figure 1. COSY–11 data are gathered in Table 1.

4 Conclusions

The η' production cross sections in proton-proton collisions provided by COSY–11 collaboration for the last 16 years [24–27, 31] together with the recent precise determination of the η'-proton scattering length in free space [31] constitute a significant contribution to the study of the η' properties and the search of η' bound state [42].

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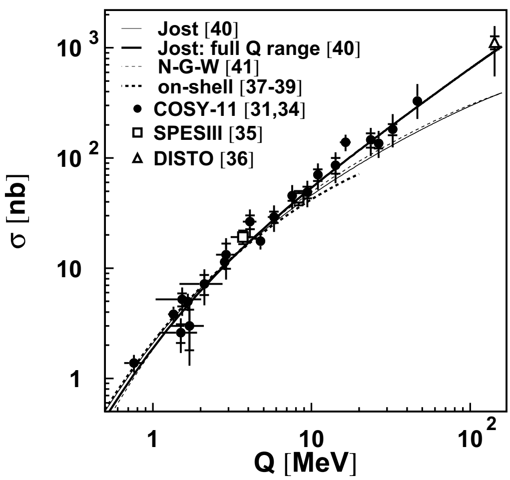

Figure 1. The total cross sections for the $pp \to pp\eta'$ reaction as a function of the excess energy Q. Experimental data with the statistical and systematic errors separated by dashes are marked as solid circles for the COSY–11 experiment [31, 34], as open squares for SPESIII measurements [35] and as open triangle for the DISTO experiment [36]. In addition the superimposed lines show results of fits parameterizing the pp-FSI enhancement factor as in Refs. [37–39] (thick dashed line), inverse of the squared Jost function [40] (thin solid line) and Niskanen-Goldberger-Watson model [41] (thin dashed line) with the η'-proton scattering length as a free parameter. The thick dashed line is shown only in the range of applicability of the formula used for the enhancement factor [37]. For comparison the thick solid line shows result of the fit obtained for the whole Q range with pp-FSI parametrization from Ref. [40].

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Table 1. Production cross-sections for the η' meson in proton-proton collisions measured at COSY–11 detector [31, 34]. Excess energy Q is given with the absolute systematic uncertainty and the cross sections values are given with the statistical and systematical uncertainty, respectively.

Q [MeV]			$\sigma_{pp\to pp\eta'}$ [nb]		
0.76	±	0.10	1.38	± 0.08	± 0.17
1.35	±	0.10	3.82	± 0.19	± 0.47
1.5	±	0.4	2.6	± 0.5	± 0.4
1.53	±	0.49	5.2	± 0.7	± 0.8
1.66	±	0.10	4.97	± 0.28	± 0.61
1.7	±	0.4	3.0	± 1.2	± 0.5
2.11	±	0.64	7.2	± 1.5	± 1.1
2.84	±	0.10	11.41	± 0.40	± 1.39
2.9	±	0.4	13.3	± 3.4	± 2.0
4.1	±	0.4	26.4	± 3.8	± 4.0
4.78	±	0.10	17.58	± 0.64	± 2.15
5.80	±	0.50	29.2	± 3.5	± 4.4
7.57	±	0.51	45.5	± 4.5	± 6.8
9.42	±	0.53	49.0	± 5.9	± 7.4
10.98	±	0.56	70.5	± 8.6	± 11
14.21	±	0.57	86	± 14	± 13
16.4	±	1.3	139	± 3	± 21
23.64	±	0.64	146	± 20	± 22
26.5	±	1.0	136	± 14	$^{+22}_{-26}$
32.5	±	1.0	182	± 21	$^{+36}_{-48}$
46.6	±	1.0	329	± 18	$^{+85}_{-122}$

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