Using COSY–11 apparatus for the precise studies of the natural width of the η' meson

Eryk Czerwiński and Paweł Moskal for the COSY–11 collaboration

Institute of Physics, Jagiellonian University, Poland & IKP Research Centre Jülich, Germany

Abstract. We present preliminary results and motivation of measurement of the total width of the η' meson ($\Gamma_{\eta'}$).

Keywords: eta-prime, total width, COSY–11
PACS: 13.75.Cs, 14.40.Aq

1. IMPORTANCE OF $\Gamma_{\eta'}$

The physics of the η' meson receives an increasing interest in view of the forthcoming measurements planned e.g. at the COSY, DAϕNE-2 and MAMI-C facilities where the η' will be produced in hadron-hadron, e^+-e^-, and γ-hadron reactions, respectively.

Experimentally the emphasis will be put on the studies of the η' meson decays which are of interest on its own account and certainly will provide inputs to the phenomenology of the Quantum Chromo-Dynamics [1] in the non-perturbative regime. Specifically, precise determinations of the partial widths for the η' decay channels will be helpful for the development of the Chiral Perturbation Theory. However, the experimental precision of the partial width for various decay channels – where only the branching ratio is known or will be measured – is governed by the precision of the knowledge of the total width. In the case of the η' meson the branching ratios are typically known with precision better than 1.5%, while the total width is established about 10 times less accurate [2]. Therefore, we expect that the precise determination of the natural width of the η' meson will have a strong impact on the physics results which will be derived from measurements carried out by collaborations: WASA-at-COSY [3], CBall-at-MAMI [4] and KLOE-2 [5, 6].

2. PREVIOUS EXPERIMENTS

In the last issue of the Review of Particle Physics only two direct measurements of the natural width of the η' meson are reported [2]. In the first experiment the width was established from the missing mass spectrum of the $\pi^- p \rightarrow nX$ reaction measured close to the threshold for the production of the η' meson [7]. The experimental mass resolution achieved was equal to 0.75 MeV/c^2 (FWHM) and the extracted value of $\Gamma_{\eta'}$ amounts to 0.28 ± 0.10 MeV/c^2. In the second experiment the value of $\Gamma_{\eta'}$ was derived from the threshold excitation function of the $pd \rightarrow {}^3He\,X$ reaction [8]. The study was performed at 20 different beam momenta, however, the error of the $\Gamma_{\eta'}$ was larger than in the previous measurement due to the large relative monitoring uncertainities. In this experiment $\Gamma_{\eta'} = 0.40 \pm 0.22$ MeV/c^2 was determined. The mean value of the width of the η' meson from the two direct measurements [7, 8] amounts to (0.30$\pm$0.09) MeV/c^2 [2] and differs from the value of (0.202$\pm$0.16) MeV/c^2 determined indirectly from the combinations of partial widths obtained from integrated cross sections and branching ratios [2]. The significantly more precise direct determination of the $\Gamma_{\eta'}$ should resolve this discrepancy.

3. NEW MEASUREMENT

Based on many years of experience gained with the COSY-11 apparatus [9, 10] we expect that combined with the excellent features of the stochastically cooled proton beam of COSY [11, 12] it will allow to significantly reduce the present uncertainty in the value of the natural width of the η' meson. The $\Gamma_{\eta'}$ will be derived directly from the missing mass distribution of the $pp \to ppX$ reaction measured near the kinematical threshold. The advantage of a study close to the threshold is that the uncertainities of the missing mass determination are much reduced since $\partial(mm)/\partial p$ tends to zero. Here by *mm* we denoted the missing mass and by *p* the momentum of the outgoing protons. The experiment was conducted for five discret values of beam momentum: 3211, 3213, 3214, 3218, and 3224 MeV/c, where the threshold value amounts to 3208.3 MeV/c. In order to improve the experimental resolution of the four-momentum determination of the registered particles and in order to decrease the spread of the momentum of the beam protons reacting with the target two major changes have been applied to the COSY-11 setup (Fig. 1). Namely, the spatial resolution of the measurement of the particle track coordinates in the drift chambers was improved by increasing the supply voltage up to the maximum allowed value and also the dimensions of the target in the direction perpendicular to the COSY beam was decreased from 9 to circa 1 mm. The changes were possible due to the development of the Münster type cluster-jet target [13, 14].

Due to the high value of the dispersion at the position of the COSY-11 target, the

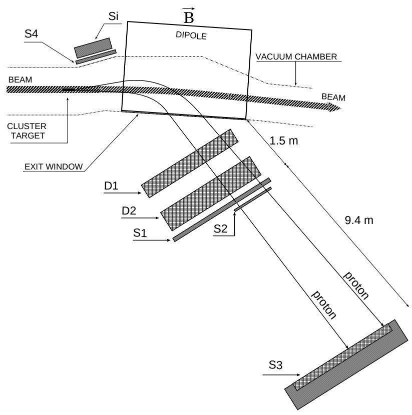

FIGURE 1. COSY–11 detection setup. D1 and D2 denote drift chambers used for reconstruction of trajectories of positively charged ejectiles. (S1-S2-S3) scintillator hodoscope is used for the time of flight determination. Elasticaly scattered protons are registered by silicon pad (Si) and scintillator (S4) detectors (recoil protons) and by drift chambers and S1 counter (forward protons).

decrease of the size of the reaction volume resulted in a significant reduction of the momentum spread seen by the target. The effect is visualized in Fig. 2a. As can be clearly implied from the figure, the information about target size is crucial for determination of beam momentum spread. It is also of great importance for the estimation of an error of momentum reconstruction of outgoing protons. Therefore, in order to control the systematical uncertainties each of the crucial parameters (like target dimesions or beam momentum spread) were monitored by at least two independent methods.

3.1. Target - a crucial element

The systematical error of the extraction of $\Gamma_{\eta'}$ will depend on the accuracy of the determination of the missing mass resolution. This depends predominantly on the knowledge of the momentum spread of the COSY beam (Fig. 2a) and on the accuracy of the four-momentum determination of the registered protons. In the case of the experimental technique used by the COSY-11 collaboration, both mentioned factors, depend on the dimensions of the target. Therefore it is crucial to monitor precisely the spatial size of the target perpendicular to the COSY beam. To this end we exploit two independent methods. One of the techniques relies on the measurement of the gas pressure in the last chamber of the cluster-jet dump (Fig. 2b-c), and the second method is based on the determination of the momentum distribution of elasticaly scattered protons (Fig. 2d-e). The gas pressure was measured as a function of the position of wires moving with the constant velocity through the cluster beam. These wires were rotated around the axis perpendicular to the beam of hydrogen clusters. In case that one or more wires crossed the target the clusters hitting a wire were stopped causing a decrease of the pressure in the last stage of the cluster dump. The wire device was located above the reaction point (Fig. 2c) allowing to monitor the target dimensions without disturbing the measurement of the $pp \to pp\eta'$ reaction. The knowledge of the wire thickness and geometry enables to calulate the target dimensions from the ditribution of the pressure as a function of the position of the device. Fig. 2b shows an example of the measured pressure as function of time using a constant angular velocity of the device. The extraction of the target dimensions is in progress. From a preliminary analysis we expect to achieve an accuracy of about 0.2 mm.

The second technique used for monitoring a target spatial size is based on the measurement of the momentum distribution of the elastically scattered protons. The momentum reconstruction of registered protons is performed by tracing back trajectories from drift chambers through the dipole magnetic field to the target, which is assumed to be an infinitely thin vertical line. In reality, however, the reactions take place in that region of finite dimensions where beam and target overlap. Consequently, assuming in the analysis an infinitesimal target implies a smearing of the momentum vectors and hence a decrease of the resolution of the missing mass signal. Therefore, we have developed a method to monitor this overlap by measuring the elastically scattered protons [10]. Trajectories of the protons scattered in the forward direction are measured by means of two drift chambers (D1 and D2) and a scintillator hodoscope (S1), whereas the recoil protons are registered in coincidence with the forward ones using a silicon pad detector

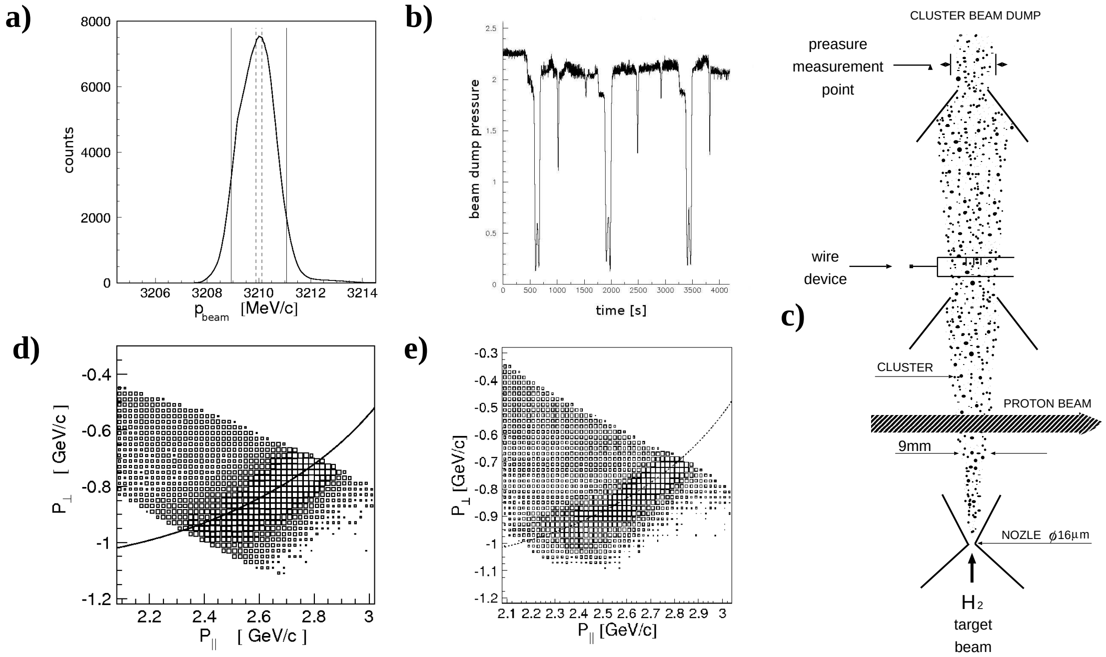

FIGURE 2. a) Beam momentum distribution obtained from the Schotky frequency spectrum measured during one of the previous COSY-11 runs. The range "seen" by 9 mm and 1 mm target is marked by the solid and dashed lines respectively. b) Distribution of the pressure measured during the wire device rotation. c) Schematic view of the of the target and beam crossing. d) and e): Distribution of the elastically scattered protons. Number of entries per bin is shown in logarithmic scale. Superimposed lines depict expected kinematical ellipses. d) One of the previous COSY-11 experiments (target width: 9 mm, p_{beam} =2010 MeV/c [15]) e) On-line data from the reported here experiment (target width: circa 1 mm, p_{beam} =3211 MeV/c)

arrangement (Si) and a scintillation detector (S4). The two–body kinematics gives an unambiguous relation between the scattering angles of the recoiled and forward flying protons. Therefore, the events of elastically scattered protons can be identified from the correlation line formed between the position in the silicon pad detector Si, and the scintillator hodoscope S1, the latter measured by the two drift chamber stacks. For those protons which are elastically scattered in forward direction and are deflected in the magnetic field of the dipole the momentum vector at the target point can be determined. According to two–body kinematics, the momentum components parallel and perpendicular to the beam axis form an ellipse. An example is shown in Fig. 2d-e. The width of the distributions can be used as a measure of the size of the interaction region. For the appraisal of the effect in Fig. 2d-e we present results obtained with targets of 9 and 1 millimeters.

3.2. Systematic error

Measurement of the missing mass distributions at five different beam energies will allow for monitoring the systematic uncertainities in the determination of the experimental mass resolution. This is mainly because the smearing of the missing mass due to the natural width of the η' remains unaltered when the beam momentum changes, whereas the smearing caused by the experimental uncertainities will narrow with the decreasing beam momentum and at threshold it will reach a constant value directly proportional to the spread of the beam momentum. The effect is shown in Fig. 3a. This figure illustrates also that the change of the target thickness by 8 mm results in a change of the mass resolution by about 0.3 MeV. Since we expect to control the target thickness with the accuracy better then 0.2 mm, the systematical error due to the determination of the target size should be smaller than 0.01 MeV.

Moreover, we can also control the influence on the mass resolution caused by a different experimental sources. For example from the angular distribution of the missing mass spectrum we will be able to estimate contributions to the mass resolution due to the spread of the beam momentum and due to the proton momentum reconstruction. This is because the resolution of the missing mass due to the spread of the beam momentum is almost independent of the polar emission angle of the η' meson, whereas the smearing of the missing mass due to the uncertainty of the proton momentum reconstruction does depend on the emission angle of the η' meson.

3.3. Preliminary results

An online analysis has revealed a signal originating from the production of the η' meson at each of the investigated beam momenta (Fig. 3b-f). As expected the width of the signal form the η' meson increases with increasing beam momentum. The width of the η' signal determined closest to threshold equals to approximatly 0.4 MeV (FWHM). Taking into account that the width of the η' is around 0.2 MeV we may estimate the achieved experimental resolution to be about 0.3 MeV just at the same order as the searched signal. Presented spectra were obtained with preliminary calibration of the detection system and they will be corrected for the possible broadening due to the changes of the beam optics which could caused the variations of the beam momentum value at the order of 10^{-5}. In order to enable such corrections we have monitored various parameters which could influence the beam conditions like current intensity in the COSY dipoles, the temperature of the cooling water of the magnets, air temperature, humidity and barometric pressure inside COSY tunnel. Independently, it will be possible to correct the variation of the beam momentum based on the distribution of the elasticaly scattered protons measured simultaneously with the $pp \rightarrow pp\eta'$ reaction. Thus there is still a room for the improvement of the experimental resolution. At present the off-line analysis of the data is in progress.

ACKNOWLEDGMENTS

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 programme (Hadron Physics, N4:EtaMesonNet, RII3-CT-2004-506078), the support of the Polish Ministry of Science and Higher Education under

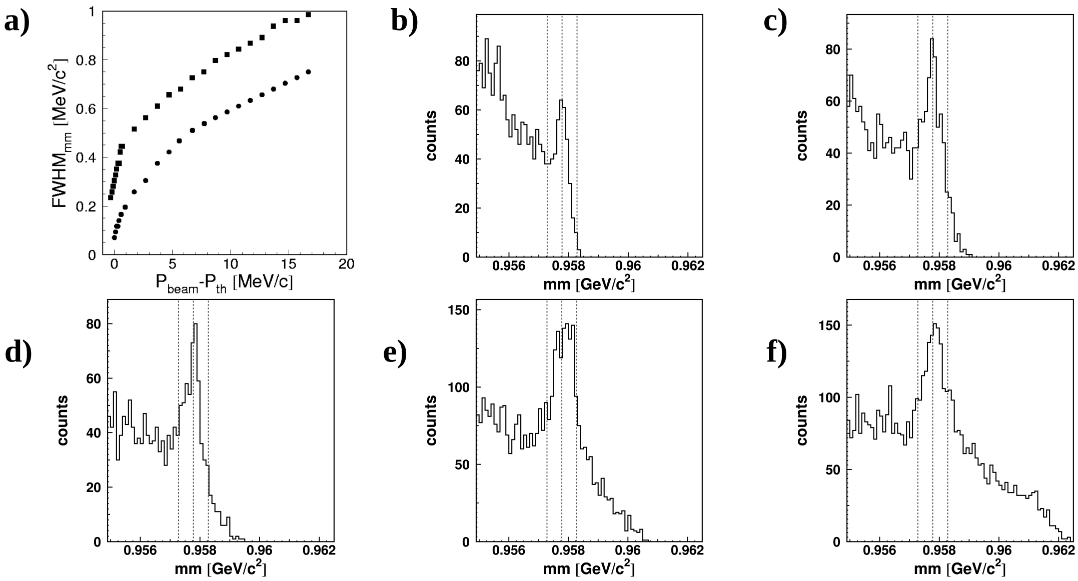

FIGURE 3. a) Simulated FWHM of missing mass signal as a function of beam momentum above the threshold for the η' meson creation in proton-proton collision. Squares: target width 9 mm. Circles: target width 1 mm [16]. P_{beam} and P_{th} denote the nominal beam momentum and the threshold momentum value for the η' meson production in the $pp \to pp\eta'$ reaction. Plots from b) to e): Missing mass spectra for the $pp \to ppX$ reaction measured at COSY–11 detection setup at the beam momenta: a) 3211, b) 3213, c) 3214, d) 3218, e) 3224 MeV/c. Dashed lines indicate a ± 0.5 MeV/c^2 band around the mass of the η' meson.

the grants No. PB1060/P03/2004/26, 3240/H03/2006/31 and 1202/DFG/2007/03, and the support of the German Research Foundation (DFG).

REFERENCES

1. B. Borasoy and R. Nißler, these proceedings.
2. W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006).
3. H.-H. Adam *et al.*, e-Print Archive: nucl-ex/0411038.
4. A. Thomas, these proceedings.
5. F. Ambrosino *et al.*, e-Print Archive: hep-ex/0603056.
6. C. Bloise, these proceedings.
7. D. M. Binnie *et al.*, Phys. Lett. B **83**, 141 (1979).
8. R. Wurzinger *et al.*, Phys. Lett. B **374**, 283 (1996).
9. S. Brauksiepe *et al.*, Nucl. Instrum. Meth. A **376**, 397 (1996).
10. P. Moskal *et al.*, Nucl. Instr. & Meth. A **466**, 448 (2001).
11. D. Prasuhn *et al.*, Nucl. Instr. & Meth. A **441** 167 (2000).
12. H. Stockhorst *et al.*, these proceedings.
13. H. Dombrowski *et al.*, Nucl. Instrum. Meth. A **386**, 228 (1997).
14. A. Täschner *et al.*, these proceedings.
15. R. Czyżykiewicz, PhD thesis, Jagiellonian University (2007).
16. E. Czerwiński, Thesis, Jagiellonian University (2006).