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MULTIMESON PRODUCTION IN *pp* INTERACTIONS AS A BACKGROUND FOR η AND η' DECAYS

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Abstract

Multimeson production in *pp* interactions comprises important background for η, ω and η' mesons production experiments and for the studies of their decays planned with WASA detector at COSY. The available information about the reactions is summarized and the need for efforts to describe the processes is stressed.

1 Multimeson production

Direct production of three or more pions in proton-proton interactions, has not received proper attention, neither experimentally nor theoretically, despite the fact that it comprises the main background for η, η' and ω production experiments. With a 4π facility such as WASA, aiming for measurements of decays of η and η' produced in pp interactions [1], the understanding of the $pp \to pp\pi\pi\pi$ reactions becomes very important as they constitute a severe background for studies of η and η' decays into three pions. Those decays provide key ingredients for determination of the ratios of light quark masses [2,3], since the partial decay widths are proportional to d and u quark mass difference squared. In addition precise studies of η' decays require knowledge of $pp \to pp\pi\pi\pi\pi$, $pp \to pp\pi\pi\pi\pi\pi$, $pp \to pp\pi\eta$ and $pp \to pp\pi\pi\eta$ reactions for beam energies around η' production threshold. For more than forty years there were only three experimental points available for the cross section of $pp \to pp\pi^+\pi^-\pi^0$ and $pp \to pn\pi^+\pi^+\pi^-$ reactions, all coming from bubble chamber experiments [4–6]. Only recently the data base has been extended by the measurements of $pp \to pp\pi^+\pi^-\pi^0$ and $pp \to pp\pi^0\pi^0\pi^0$ reactions cross sections near the threshold by the CELSIUS/WASA collaboration [7]. For the remaining reactions there is no data in that energy region.

The direct production should proceed by an excitation of one or two baryon resonances followed by the subsequent decays [8]. For example in the case of three pion production the low energy region a mechanism with simultaneous excitation of N^* and $\Delta(1232)P_{33}$ resonances is expected to dominate. The N^* involved has to decay into $N\pi\pi$ and therefore the lowest lying Roper ($N(1440)P_{11}$) and $N(1520)D_{13}$ resonances could be considered.

The influence of the resonances can be studied in the invariant mass distributions of the subsystems of the outgoing protons and pions. Such studies were done for the $pp \to pp\pi^+\pi^-\pi^0$ and $pp \to pn\pi^+\pi^+\pi^-$ reactions in bubble chamber experiments performed at higher energies (beam kinetic energies of 4.15 GeV and 9.11 GeV) with up to thousand events [9–11]. However, close to the threshold the analysis is not conclusive since the widths of the involved resonances are comparable with the available excess energy (Q). Therefore, in this case one expects that phase space distribution and the final state interaction among the outgoing nucleons provide a reasonable description of the observed cross sections. The near threshold cross sections for the single meson production via the nucleon-nucleon interaction can indeed be quite satisfactory described by such ansatz. For the productions of multiple mesons the assumption should hold even for higher excess energies since on average the energy available to the pairs of the outgoing particles will be lower. That is consistent with CELSIUS/WASA results on $pp \to pp\pi^+\pi^-\pi^0$ and $pp \to pp\pi^0\pi^0\pi^0$ reactions studied at $Q \approx 100$ MeV.

The production mechanism could be studied instead by measuring ratios of the cross sections for the different charge states. With the lack of information the simplest assumption is Fermi model [12], where amplitudes for all isospin states are put to be equal. The assumption leads to definite predictions for ratios between different charge states of the reactions. For example $\sigma(pp \to pp\pi^+\pi^-\pi^0) : \sigma(pp \to pp\pi^0\pi^0\pi^0) : \sigma(pp \to pn\pi^+\pi^+\pi^-) \equiv \sigma_1 : \sigma_2 : \sigma_3 = 8 : 1 : 10$. Resonances in the intermediate state will modify the ratios. The effect can be illustrated in the Isobar Model [8] where the ratio $\sigma_1 : \sigma_2 : \sigma_3$ is $7 : 1 : 25$ (assuming ΔN^* intermediate state) or $5 : 2 : 10$ (assuming $N_1^* N_2^*$). Experimentally: $\sigma_1 : \sigma_3$ at beam kinetic energy 2.0 GeV (1:2.53±0.46) [4] and at 2.85 GeV (1:1.59±0.27) [5]. The ratio $\sigma_1 : \sigma_2 = 5.2 \pm 0.8 : 1$ was measured at lower energy – 1.36 GeV in recent CELSIUS/WASA experiment [7]. One trivial modification to the predicted ratios close to threshold comes from difference between volumes of the phase spaces due to $m_{\pi^+} \neq m_{\pi^0}$ and it amounts to 18% at 1.36 GeV.

Due to lack of microscopic model calculations, of the same kind as those for single meson or for double pion production the semiclassical Isobar Model is at present the only option to describe more complicated reactions below $\sqrt{s} \approx 5$ GeV. The modern version of the isobar model is used as input to relativistic ions calculations using transport equations [13, 14]. Reliability of the calculations can be tested in simpler cases by comparison with existing calculations for the double pion production [15]. The implementation of the resonances in the Isobar Model, their production cross sections and decay branching ratios can be evaluated by studying exclusive meson production reactions. Multimeson production in proton-proton interactions provides very sensitive test of the parameters. The existing calculations within the framework have focused so far on production of dileptons in proton-proton interactions with the aim to understand the background for high density nuclear matter probes [16]. The byproduct of such studies were calculations of the background for η and η' decays involving dileptons (see for example ref. [17]). There is a need to extend the calculations to obtain predictions also for multimeson processes.

2 Background for η, η' decays

A feature of $\eta(\eta')$ detection from $pp \to pp\eta(\eta')$ in the WASA detector is the precise tagging by missing mass technique with a resolution of a few MeV/c^2. The resolution of the invariant mass of the decay system is typically considerably worse. Therefore a figure of merit to describe background from direct production process, leading to the identical final state as for an $\eta(\eta')$ decay, is given by $\rho_B \equiv d\sigma_B/d\mu|_{\mu=m_{\eta(\eta')}}$ – the differential cross section for the background at the $\eta(\eta')$ peak in the pp missing mass μ. Figure 1 shows inclusive ρ_B values for η' derived from the COSY-11 measurements [18–20]. When estimating the background for a given decay channel, quantity $\rho_B \Delta\mu$ (where $\Delta\mu$ is the resolution in the missing mass) should be compared to $\sigma_{\eta(\eta')} BR_i$ (production cross section times branching ratio for the decay mode). The ρ_B value depends on the total cross section and on the reaction mechanism. For $\eta(\eta')$ production close to threshold the background distributions at the edge of the phase space are relevant. For both signal and the multimeson production this region of the phase space is strongly influenced by pp final state. When approaching the threshold the ρ_B decreases quickly and in addition missing mass resolution improves (since it is constrained more by the beam momentum resolution) increasing signal to background ratio. The price is however a lower production cross section $\sigma_{\eta(\eta')}$.

Detailed studies of $\eta \to \pi\pi\pi$ decays in $pp \to pp\eta$ reaction at beam energy 1.36 GeV by CELSIUS/WASA collaboration shows that background from direct three pion production is 10–20% for the $\pi^0\pi^+\pi^-$ and 5% for the $\pi^0\pi^0\pi^0$ channel in the final data sample [7, 22]. This allows for precise study of the η decays providing large number of events is collected. For η' decays the situation is quite different: the three pion decays have branching ratios at percent or permil level [23]. In comparison to the η meson the η' production

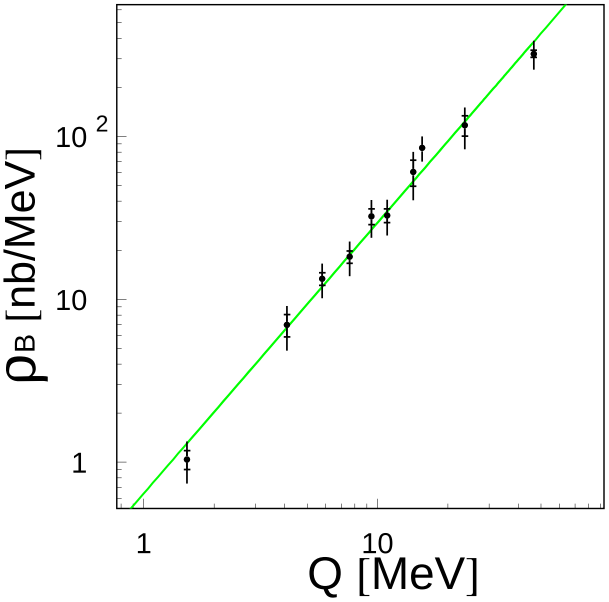

Figure 1: Inclusive differential cross section ρ_B for multipion production derived from the COSY-11 data [18–20]. The line is the parametrization $\rho_B = \alpha(Q/(1\text{ MeV}))^\beta$ fitted to the data: $\alpha = 0.64 \pm 0.14$ [nb/MeV] and $\beta = 1.66 \pm 0.08$ [21].

cross section at similar excess energies is about 30 times lower [18–20, 24–26]. Finally the total cross section for multipion reactions increases strongly when going from η to η' production threshold region, e.g. for $pp \to pp\pi\pi\pi$ reaction 50–100 times. In conclusion embarking on the η' decay program in pp interactions requires much better understanding of multimeson production reactions.

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