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PION PRODUCTION IN PROTON–PROTON COLLISIONS*

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Based on well established models for nucleon–nucleon and pion–nucleon scattering a model for pion production in proton–proton collisions is developed. The $\Delta(1232)$ is taken into account explicitly and is found to play an important role even at energies close to production threshold.

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We present a model calculation for the pion production reactions $pp \to pp\pi^0$, $pp \to pn\pi^+$ and $pp \to d\pi^+$. It is an extension of our earlier study for s-wave pion production [1] to higher partial waves. Now all NN partial waves up to $L = 2$ and all states with relative orbital angular momentum $l \leq 2$ between the NN system and the pion are considered in the final state. Furthermore the excitation of the $\Delta(1232)$ resonance is taken into account explicitly.

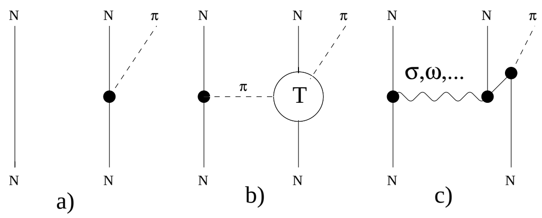

Fig. 1. Pion production mechanisms from NN states.

The pion production mechanisms included in the present work are shown in Figs. 1 and 2. First, in our basic model we have the usual direct production (Fig. 1a) and rescattering (Fig. 1b) contributions from NN states. In

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addition, contributions from pair diagrams (Fig. 1c) will be also considered. For the distortions in the initial and final NN states we employ the model CCF of Ref. [2]. This potential has been derived from the full Bonn model by means of the folded-diagram expansion. It is a coupled channel (NN, $N\Delta$, $\Delta\Delta$) model that treats the nucleon and the Δ degrees of freedom on equal footing. Thus, the $NN \leftrightarrow N\Delta$ T-matrices that enter in the evaluation of the pion production diagrams involving the Δ isobar (*cf.* Fig. 2) and the NN T-matrices that are used for the diagrams in Fig. 1 are consistent solutions of the same (coupled-channel) Lippmann-Schwinger-like equation.

A realistic meson-theoretical model of the πN interaction developed by the Jülich group [3] is utilized for the evaluation of the rescattering contributions.

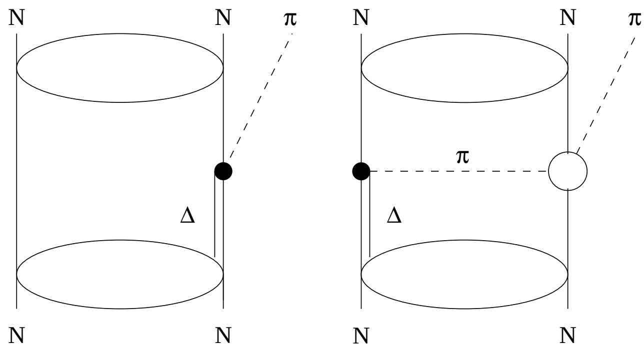

Fig. 2. Pion production mechanisms involving the Δ isobar. Diagrams where the Δ is excited after pion emission are also included.

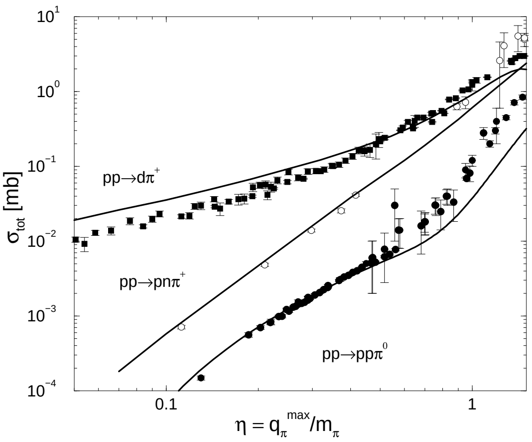

Fig. 3. Results for the different reaction channels as a function of η, the maximum center-of-mass momentum of the produced pion divided by the pion mass.

Results for the total cross section in the reaction channels $pp \to pp\pi^0$, $pp \to d\pi^+$ and $pp \to pn\pi^+$ are shown in Fig. 3. Evidently the predictions of the model are in good overall agreement with the data over a wide energy range. We want to emphasize that the results for the latter two channels do not involve any adjustable parameters and are therefore genuine predictions of our model. In case of $pp \to pp\pi^0$, however, the basic model (including direct production plus rescattering) yields only about 60% of the measured cross section. Here we have added contributions from the pair diagrams, Fig. 1c, and fixed their "strengths" so that we can reproduce the data (*cf.* Ref. [4]). The effect of those pair diagrams on the other reaction channels, $pp \to d\pi^+$ and $pp \to pn\pi^+$, is negligible so that the corresponding results remain practically unchanged [4].

As expected, the Δ excitation plays a crucial role for pion production at energies corresponding to η values around or larger than 1. Indeed, in this energy range it provides the bulk contribution to the total cross section [4,5]. However, we find significant effects of the Δ isobar on the pion production reaction over the whole considered energy range. Especially differential observables are strongly influenced by contributions involving the Delta - even at energies very close to threshold. This is demonstrated in Fig. 4 for the reaction $pp \to d\pi^+$ where we show A_2, a quantity which is determined from expanding the differential cross section in terms of Legendre polynomials:

$$4\pi(d\sigma/d\Omega) = A_0(\eta) + A_2(\eta)P_2(\cos\theta) + \dots .$$

Clearly, the data can be reproduced only after the contributions involving the Delta are taken into account.

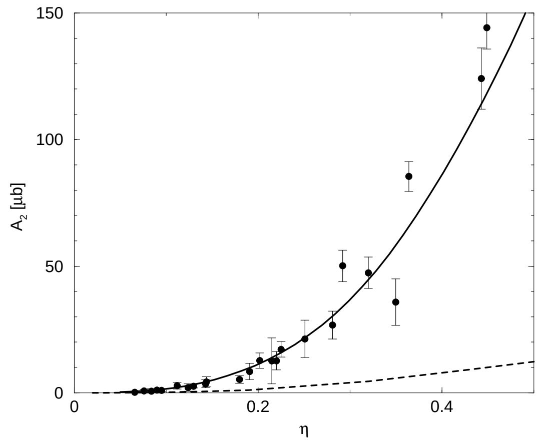

Fig. 4. A_2 for the reaction $pp \to d\pi^+$. The solid line is the full model. The dashed curve shows the result without including the Δ isobar.

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