3π and 4π meson production in np interactions at intermediate energies

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Abstract. The study of 3π and 4π meson production in np interactions was carried out at the momenta of incident neutrons $P_0=3.83, 4.42$ and 5.20 GeV/c. The characteristics of the reactions were satisfactorily described by OPER model. For the better description of the reaction $np \rightarrow pp\pi^+\pi^-\pi^0$ it was necessary to take into account the production of $\eta^0$ and $\omega^0$ mesons.

1 Introduction

The study of multipion production in NN collisions is one way to obtain information about the NN, $\pi N$ and $\pi\pi$ states, including:

dibaryons (including $I=2$ in $pp\pi^+$),
dipions (narrow $\sigma^0$ meson, $\pi\pi$ state with $I=2$),
pentaquarks ($I=5/2, S=+1$),
missing resonances, etc.

Also the important task is the test of various models of pion production in NN interaction, such as, for example, Valencia model [1], Xu Cao model [2] and OPER model [3, 4].

2 Experiment

The neutron-proton interactions were studied using neutron beam and liquid hydrogen bubble (target) at the JINR Synchrophasotron [5]. The unique in fullness and precision data were obtained. It allowed to carry out the detailed study of inelastic np interactions in in a wide range of energies using the quasimonochromatic neutrons with $P_0<2.5\%$ under condition of $4\pi$ geometry.

The following reactions with 3 and 4 π mesons in the final states were studied:

\begin{align*}
np &\rightarrow pp\pi^+\pi^-\pi^-, \\
np &\rightarrow pp\pi^+\pi^-\pi^0, \\
np &\rightarrow np\pi^+\pi^-\pi^- 
\end{align*}

at the momenta of $P_0=3.83, 4.42$ and 5.20 GeV/c (see figure 1).

The accuracy of the momentum and scattering angle reconstruction for the secondary charged particles was $\sigma_p/p \sim 2\%$ and $\sigma_\theta \sim 10$ mrad, respectively. The separation of the reaction channels

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were carried out by the standard $\chi^2$ procedure using corresponding constraint equations [6]. Finally, the numbers of events that were selected for the further study:

- $np \rightarrow pp\pi^+\pi^−\pi^−$: 390 events, $P_0=3.83$ GeV/c
- $np \rightarrow pp\pi^+\pi^−\pi^0$: 66 events, $P_0=4.42$ GeV/c
- $np \rightarrow np\pi^+\pi^−\pi^−$: 83 events, $P_0=5.20$ GeV/c

The cross sections of the considered reactions were presented in [7].

### 3 Data analysis

This reaction is characterized by:
- plentiful production of the $\Delta$ resonance, both from direct production and from $\Delta^*$ and $N^*$ decays through the mode $\Delta\pi$,
- large peripherality of the secondary nucleons.

The model of reggeized $\pi$ meson exchange suggested in ITEP [3] was taken to describe the experimental distributions of the considered reactions. The advantages of this model are:
- small number of free parameters (3 in our case),
- wide range of the described energies (2–200 GeV),
- calculated values are automatically normalized to the reaction cross section.

The following diagrams were taken into account to calculate the characteristics of the reactions $np \rightarrow NN3\pi$ and $np \rightarrow NN4\pi$:

![Diagrams of OPER model for the reactions of 3$\pi$ and 4$\pi$ meson production in np interactions.](image-url)
3.1 Reaction $np \to p\pi^+\pi^−\pi^−$

The results of the calculations using OPER model for the reaction $np \to p\pi^+\pi^−\pi^−$ are shown in figure 3 for the data at $P_0 = 5.20\text{ GeV/c}$ and in figure 4 for the data at $P_0 = 4.42\text{ GeV/c}$ and $P_0 = 3.83\text{ GeV/c}$. One can see a good agreement between the experimental data and theoretical calculations.

![Figure 3](image-url)

**Figure 3.** The distributions for the reaction $np \to p\pi^+\pi^−\pi^−$ at $P_0=5.20\text{ GeV/c}$. Solid line - calculations using OPER model.

3.2 Reaction $np \to p\pi^+\pi^−\pi^−π^0$

The results of the calculations using OPER model for the reaction $np \to p\pi^+\pi^−\pi^−π^0$ are shown in figure 5 for the data at $P_0 = 5.20\text{ GeV/c}$.

One can see a good agreement between the experimental data and theoretical calculations except the region of $\eta^0$ and $ω^0$ mesons at the masses of $π^+π^−π^0$ combinations. As far as it concerned the description of $\eta^0$ and $ω^0$ mesons it is necessary to take into account the diagrams of the type that are shown in figure 6.

The diagrams 6a and 6b describe $\eta^0$-meson production through the production of $N^*_1(1535)$ resonance in $πN$ interaction with the consequent decay $N^*_1(1535) \to N\eta^0$. The "hanged" diagrams 6c and 6d describe $η^0$ meson production due to $a-π$ or $σ-η$ interaction.

The results at $P_0=4.42\text{ GeV/c}$ and $P_0=3.83\text{ GeV/c}$ are not presented due to a small statistics. But OPER model also described satisfactorily the experimental distribution and the signal of $η^0$ and $ω^0$ mesons production was also observed at these energies.

3.3 Reaction $np \to nπ^+π^+π^−π^−$

The results of the calculations using OPER model for the reaction $np \to nπ^+π^+π^−π^−$ are shown in figure 7 for the data at $P_0 = 5.20\text{ GeV/c}$ and in figure 8 for the data at $P_0 = 4.42\text{ GeV/c}$ and $P_0 = 3.83\text{ GeV/c}$.

One can see a good agreement between the experimental data and theoretical calculations.
**Figure 4.** The distributions for the reaction $np \rightarrow p\pi^+\pi^-\pi^-$ at $P_0=4.42$ GeV/c and $P_0=3.83$ GeV/c. Solid line - calculations using OPER model.

**Figure 5.** The distributions for the reaction $np \rightarrow p\pi^+\pi^-\pi^0$ at $P_0=5.20$ GeV/c. Solid line - calculations using OPER model.

### 4 Conclusion

Multi $\pi$ mesons production in np interaction is provided by the excitation and $N\pi$ and $N\pi\pi$ decays of $\Delta^*$ and $N^*$ resonances (taken from PWA and GIM).

The large peripherality of the secondary hadrons leads to the idea to use some exchange models ($\pi$, P etc. exchange).

It was shown that there are no noticeable signal of $\rho$ meson production in the considered reactions.
OPER model allows to obtain a good description of the characteristics of 3 and 4 pions production in np interactions. To get a better description of the reaction \( np \rightarrow pp\pi^+\pi^-\pi^0 \) it is necessary take into account \( \eta^0 \) and \( \omega^0 \) production.

References

[2] Xu Cao, Bing-Song Zou and Hu-Shan Xu, PR C 81, 065201 (2010)  
Figure 8. The distributions for the reaction $np \rightarrow n p\pi^+\pi^+\pi^-\pi^-$ at $P_0=4.42$ GeV/c and $P_0=3.83$ GeV/c. Solid line - calculations using OPER model.