PROCEEDINGS OF SCIENCE

Di-pion production in np-interaction at intermediate energies

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The reactions $np \to np\pi^+\pi^-$, $np \to pp\pi^-\pi^0$ and $np \to d\pi^+\pi^-$ were studied at the various momenta of incident neutrons. It was shown that the characteristics of the reactions at the momenta above 3 GeV/c could be described by the model of reggeized π exchange (OPER) . At the momenta below 3 GeV/c, it was necessary to use additionally the mechanismof one baryon exchange (OBE).

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1. Introduction

Specific interest in NN collisions at intermediate energies is the study of excitation of baryons and their subsequent decays :

• $\Delta_{1232} \to N\pi$, $N^*_{1440} \to \Delta\pi$, $N^*_{1440} \to N\sigma$, $N^*_{1440} \to N\rho$,

• $\Delta\Delta$-production.

Double pion production in NN collisions is one way to obtain information about the NN, πN and $\pi\pi$ states, including:

• dibaryons,

• dipions (narrow σ-meson, state with I=2),

• missing resonances, etc.

Important task is the test of the models of pions production in NN-interaction:

• Valencia model [9],

• Xu Cao model [10],

• (OPER+OBE) model [3, 4, 5, 6, 7].

2. Experiment: study of inelastic np interactions at accelerator facility of LHEP JINR

The neutron beam was formed due to the stripping of deuterons accelerated by the synchrophasotron LHE JINR on internal Al target. The position of the target and the hole was chosen in such a way to select the neutrons emitted at 0° relative to direction of the deuteron beam. The neutron beam was formed by two steel collimator (**Coll**$_1$ and **Coll**$_2$) of the thickness 150 cm and 220 cm respectively and then made one's way to 1-meter hydrogen bubble chamber (**H**^{2} **LBC**).

Such scheme of the neutron beam forming (see Fig. 1) permitted to get the following characteristics of the beam: $\sigma P/P < 3\%$ and practically zero angular divergence. The admixture of the charged and neutral particles different from neutrons is practically absent. The admixture of the charged and neutral particles different from neutrons is practically absent.

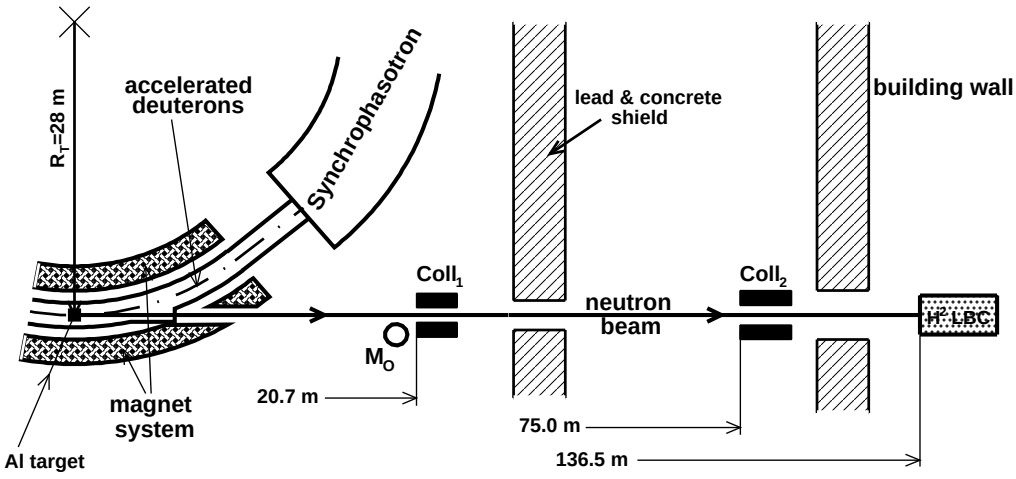

Figure 1: Neutron channel LHE JINR [1].

The spectra of the incident neutrons at 4 nominal momenta (from P_0=1.73 to P_0=5.20 GeV/c) are shown in Fig. 2. The unique of fullness and precision data are obtained. It permits to carry out

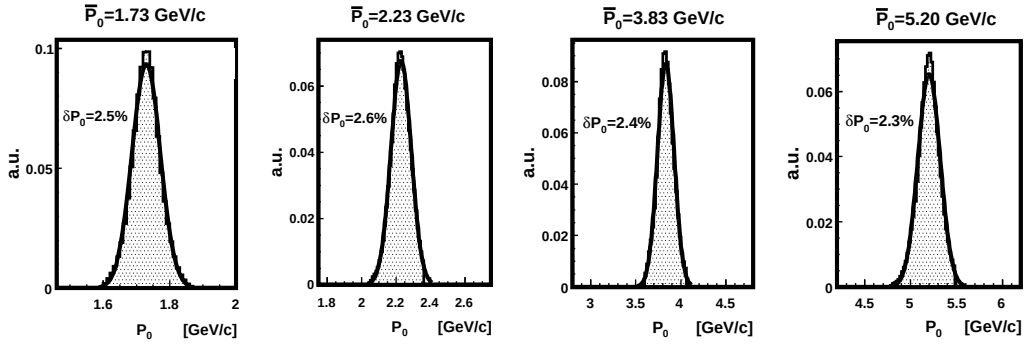

Figure 2: The spectra of the incident neutrons.

the detailed study of inelastic np interactions in a wide region of energies under condition of 4π geometry.

The results of the investigations of the following reactions with 2 π-mesons in the final states are presented:

$$np \to np\pi^+\pi^-$$
$$np \to pp\pi^-\pi^0$$
$$np \to d\pi^+\pi^-$$

The separation of the reaction were carried out by the standard χ^2-procedure.

3. Reaction $np \to np\pi^+\pi^-$

In Fig. 3 the cross-section of the reaction $np \to np\pi^+\pi^-$ is presented vs momentum of incident beam.

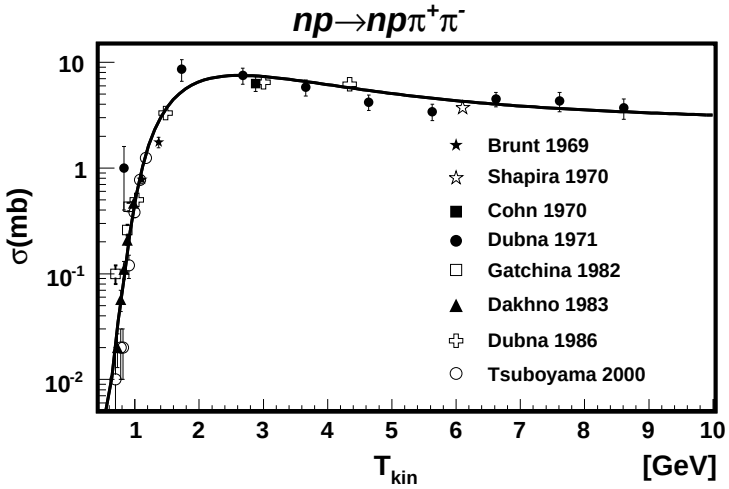

Figure 3: The cross-section of the reaction $np \to np\pi^+\pi^-$. Our data - **Dubna 1986** [2]. Solid line is the result of the approximation by Lagerre polynomials.

Reaction $np \to np\pi^+\pi^-$ is characterized by:
• plentiful production of the Δ_{1232} resonance (Fig. 4),

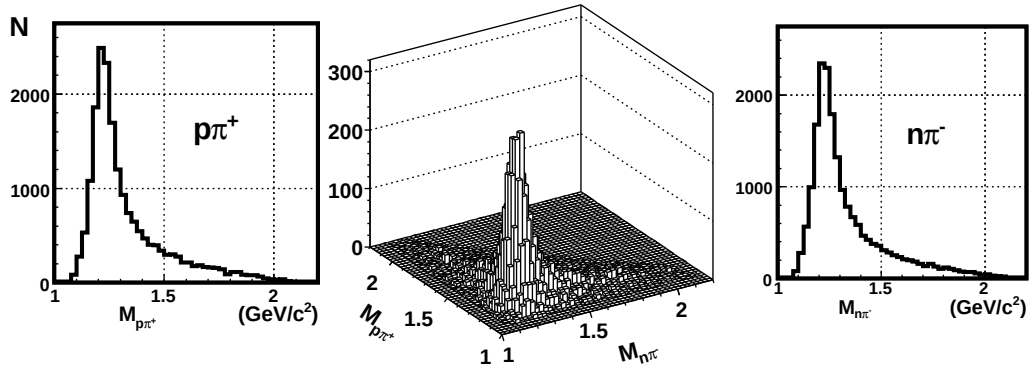

Figure 4: The distributions of $M_{p\pi^+}$ and $M_{n\pi^-}$ from the reaction $np \to np\pi^+\pi^-$ at P_0=5.20 GeV/c.

• strong anisotropy of the secondary hadrons,
• domination of the small momentum transfers (t).

The diagrams in Fig.5 are taken to describe the reaction $np \to np\pi^+\pi^-$. Diagrams on the left upper panel (a-c)describe the production of the $N\pi$-resonances. The parameters of the resonances were taken from PWA. The amplitudes $T_{\pi N\to\pi N}$ were used as vertex functions.

Diagrams on the right panel (d-g)describe the production of the $N\pi\pi$-resonances. The parameters of these resonances were taken from PDG . There are taken to accountall resonances denoted as(****) and (***). The amplitudes $T_{\pi N\to\pi\pi N}$ were used as vertex functions.

Diagrams on the left lower panel (i-j) describe $\pi\pi \to \pi\pi$-scattering ("hanged diagrams") and will be discussed below.

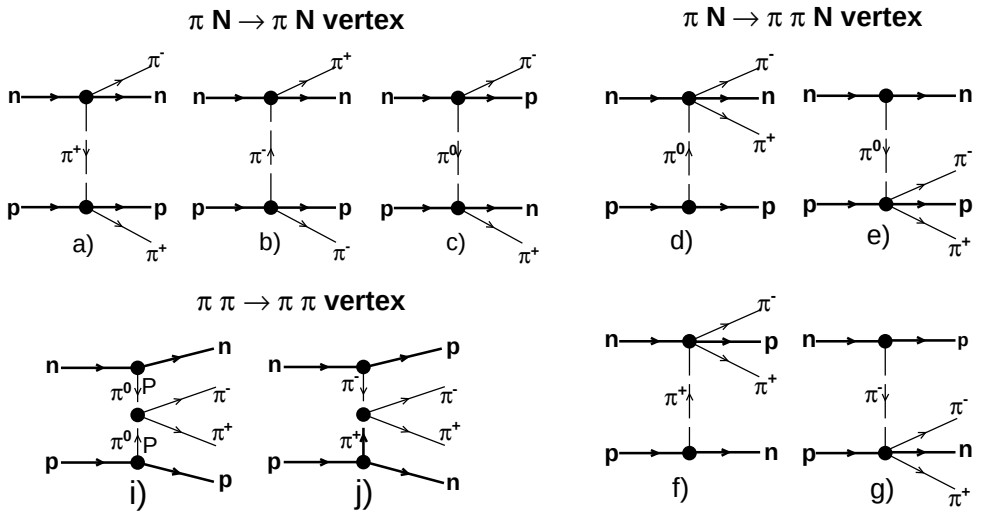

Figure 5: OPER diagrams for the reaction $np \to np\pi^+\pi^-$

3.1 Reaction $np \to np\pi^+\pi^-$ at $P_0 > 3$ GeV/c

One can see a good description of the experimental distributions by theoretical curve in Fig. 6.

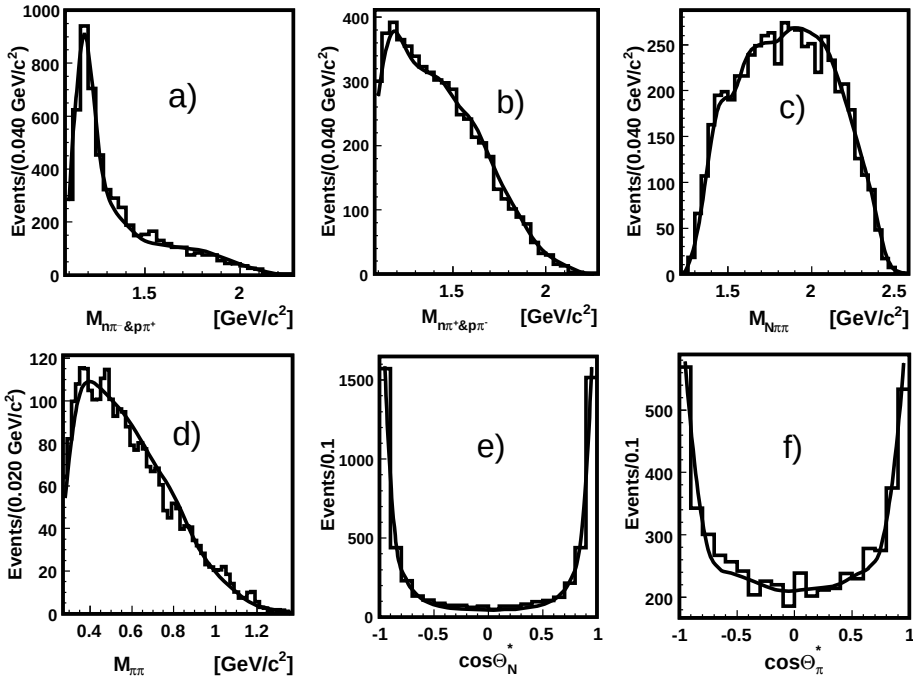

Figure 6: The distributions for the reaction $np \to np\pi^+\pi^-$ at P_0=5.20 GeV/c. Solid line - calculations using OPER-model

3.2 Reaction $np \to np\pi^+\pi^-$ at $P_0 < 3$ GeV/c

However it was insufficient the diagrams in Fig.5 to get a full description of the reaction $np \to np\pi^+\pi^-$ at lower energies. The study of effective mass spectra of np combinations at P_0=1.73

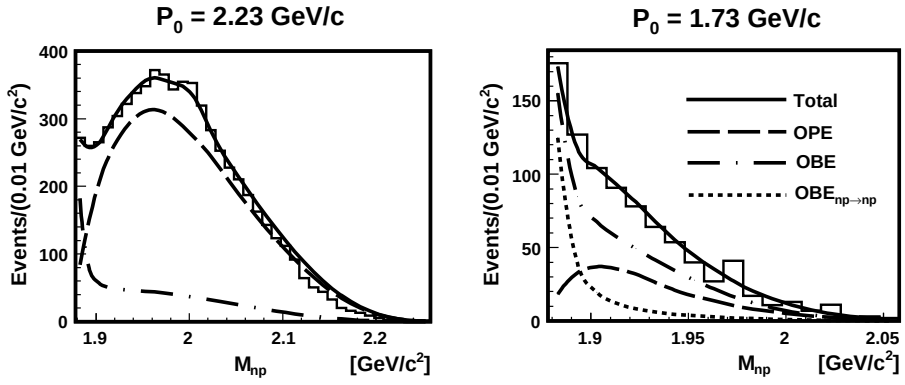

Figure 7: The effective mass spectra of of np combinations from the reaction $np \to np\pi^+\pi^-$ at P_0=2.23 and 1.73 GeV/c.

and 2.23 GeV/c (Fig.7) shows the clear peak close the threshold ($M_{np} = m_n + m_p$) that can not be described within the framework of OPER-model using only the diagrams from Fig.5.

Therefore the model of Regge poles with baryon exchange and nonlinear trajectories, suggested in [6, 7] was used to describe these features. The following diagrams of one baryon exchange (OBE) including N and Δ_{1232} (N^*_{1440}-exchange is negligible) were taken into account within the framework of this model (see Fig.8):

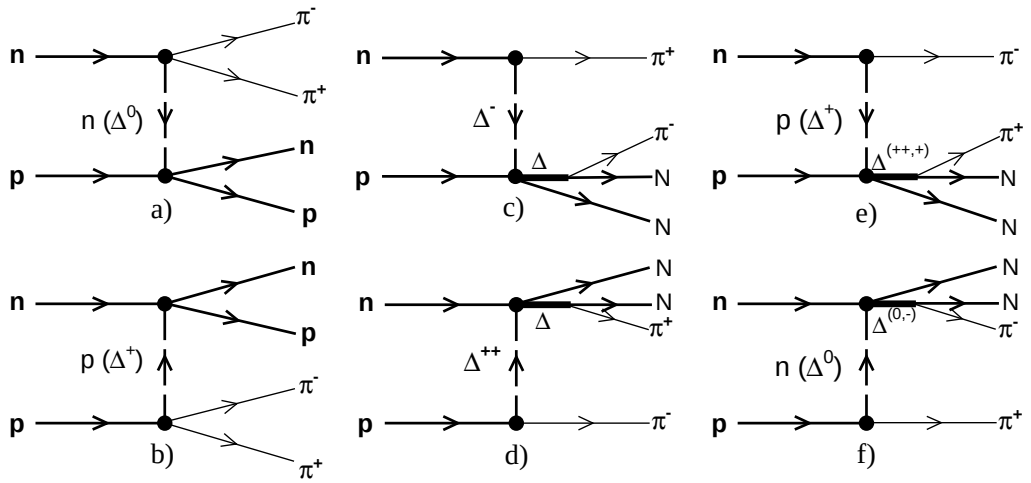

Figure 8: OBE diagrams for the reaction $np \to np\pi^+\pi^-$

In results, such joint (OPER+OBE)-model permits to get a good description of the characteristics of the reaction $np \to np\pi^+\pi^-$ at the considered energies. Fig.9 show the mass and angular distributions of the reaction $np \to np\pi^+\pi^-$ at P_0=1.73 GeV/c. The contribution of the baryon-exchange mechanism increase with decreasing of the incident neutron energy: from $\sim$ 17% at P_0=2.23 GeV/c to $\sim$ 37% at P_0=1.73 GeV/c.

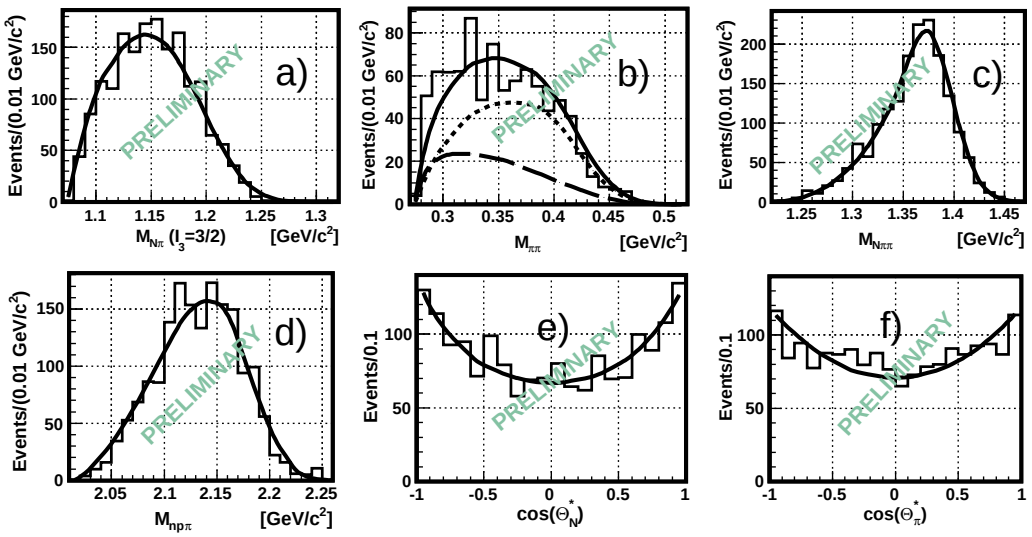

Figure 9: The distributions for the reaction $np \to np\pi^+\pi^-$ at P_0=1.73 GeV/c. Solid line - result of the calculations using (OPER+OBE)-model.

The study of 2π mass spectrum close to the threshold results in necessity to take into account "hanged" diagram with Pomeron exchange [5]. It leads to the better description of the reaction data (Fig.10).

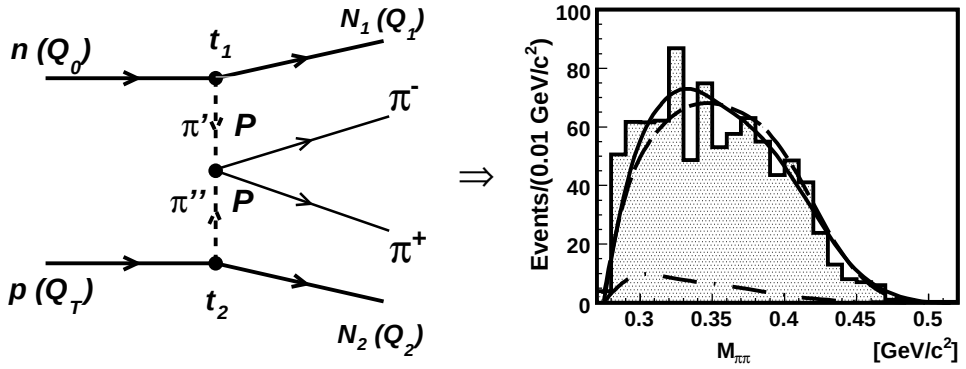

Figure 10: "Hanged" diagram with Pomeron exchange for the reaction $np \to np\pi^+\pi^-$ (left panel). The effective mass spectra of $\pi^+\pi^-$-combinations at P_0=1.73 GeV/c (right panel): dashed line - old (OPER+OBE) model, dash-dotted line - contribution of "hanged" diagram, solid line - new (OPER+OBE) model ("hanged" diagram is added).

The calculations of the characteristics of the reaction $np \to np\pi^+\pi^-$ were also carried out using Valencia model [9]. The results showed a good description of the angular spectra, partially satisfactory description of the masses spectra and absolutely unsatisfactory description of the dibaryon masses (Fig.11).

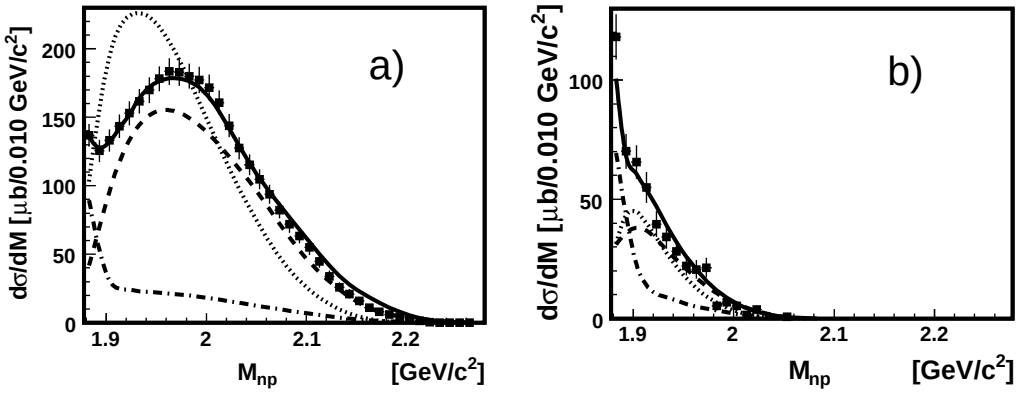

Figure 11: The effective masses spectra of np-combinations from the reaction $np \to np\pi^+\pi^-$ at P_0=2.23 GeV/c (left panel) and 1.73 GeV/c (right panel). Dashed line is the result of the calculation using OPER-model. Dash-dot line is the result of the calculation using OBE-model. Solid line - the sum of OPER and OBE models. Dotted line - the result of the calculation using Valencia model [9].

May be it is due to the fact that Valencia model do not take into account a mechanism of the baryon exchange.

4. Reaction $np \to pp\pi^-\pi^0$

In Fig. 12 the cross-section of the reaction $np \to np\pi^+\pi^-$ is presented vs momentum of incident beam.

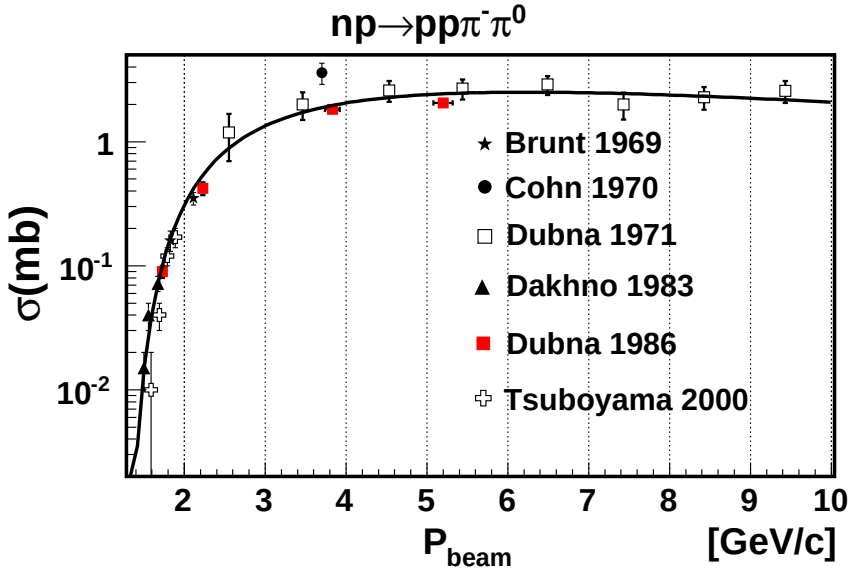

Figure 12: The cross sections of the reaction $np \to pp\pi^-\pi^0$ (our data are denoted as **Dubna 1986** [2]).Solid line is the result of the approximation by Lagerre polynomials.

(OPER+OBE)-model was taken to describe the characteristics of the reaction $np \to pp\pi^-\pi^0$. The parameters of the model were obtained during the investigation of the reaction $np \to np\pi^+\pi^-$.

4.1 Reaction $np \to pp\pi^-\pi^0$ at $P_0 > 3$ GeV/c

The following diagrams of OPER-model were taken to describe the reaction $np \to pp\pi^-\pi^0$ at $P_0 > 3$ GeV/c (Fig.13):

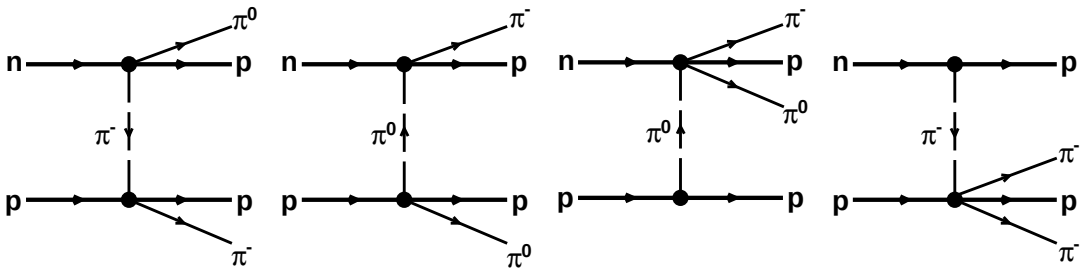

Figure 13: Main OPER diagrams for the reaction $np \to pp\pi^-\pi^0$.

The study shown that the contribution of the "hanged" diagrams are negligible comparing to the reaction $np \to np\pi^+\pi^-$ at these energies.

In Fig.14 one can see a good description of the experimental data by theoretic curves.

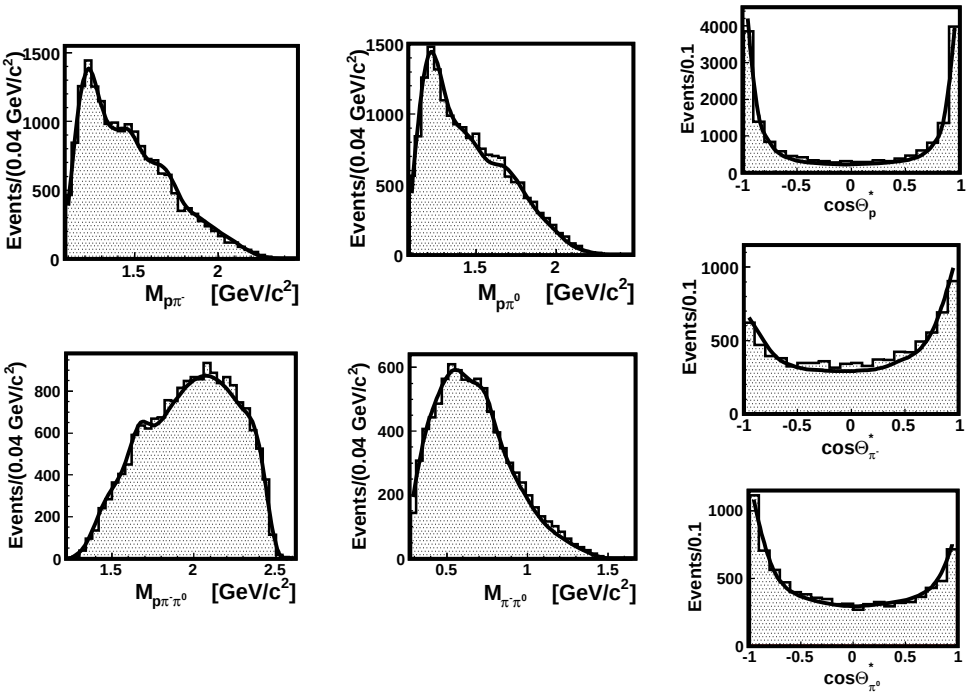

Figure 14: Mass and angular spectra from the reaction $np \to pp\pi^-\pi^0$ at P_0=5.20 GeV/c. Solid line - result of calculations using OPER-model.

4.2 Reaction $np \to pp\pi^-\pi^0$ at $P_0 < 3$ GeV/c

The following diagrams of OBE-model were taken to describe the reaction $np \to pp\pi^-\pi^0$ at $P_0 < 3$ GeV/c (Fig.15) in addition to the diagrams of OPER-model:

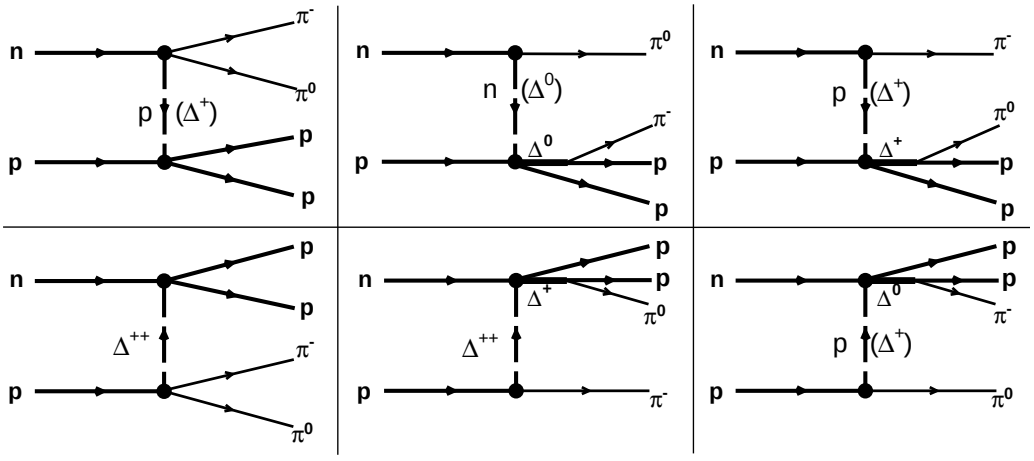

Figure 15: Diagrams corresponding to the reaction $np \to pp\pi^-\pi^0$ in the framework of the model of one baryon exchange (OBE) in addition to the diagrams of OPER-model.

One can see a good description of the experimental distributions by theoretical curves calculated using OPER and OBE models (Fig.16).

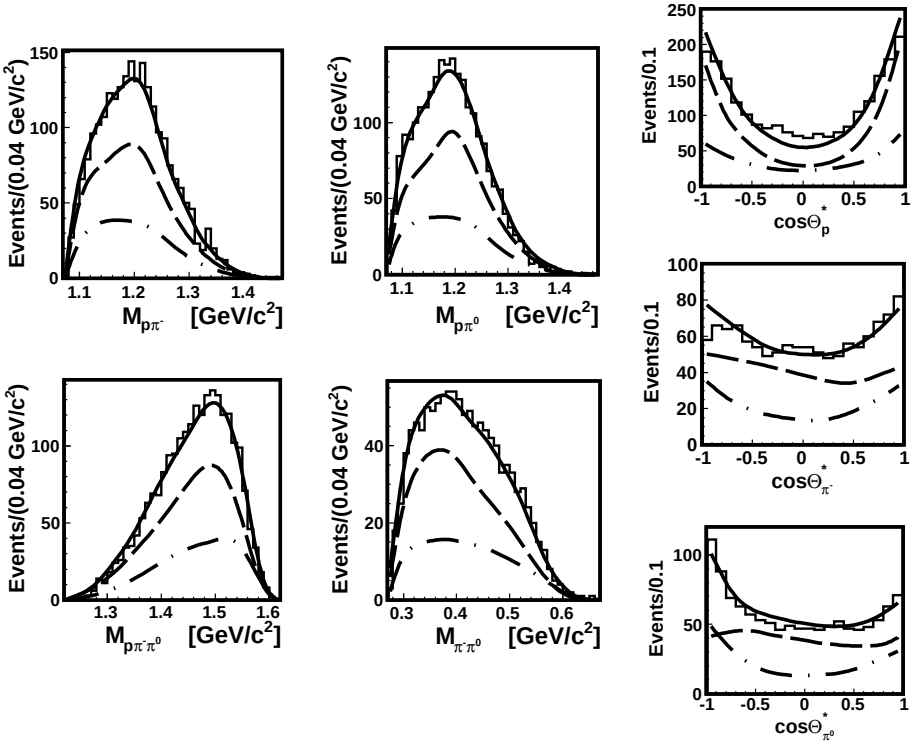

Figure 16: Mass and angular spectra from the reaction $np \to pp\pi^-\pi^0$ at P_0=2.23 GeV/c. Dashed lines - result of calculations using OPER-model, dash-dot lines - result of OBE-model, solid lines - the sum of these models (OPER+OBE).

Fig.17 show dibaryon mass spectra from the reactions $np \to np\pi^+\pi^-$ and $np \to pp\pi^-\pi^0$ at P_0=2.23 GeV/c. One can see a relative decrease of the contributions of $NN \to NN$ vertex functions in the corresponding OBE diagrams.

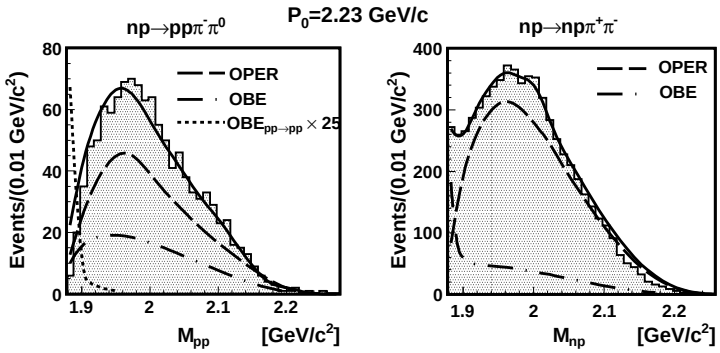

Figure 17: Dibaryon mass spectra from the reactions $np \to np\pi^+\pi^-$ and $np \to pp\pi^-\pi^0$ at P_0=2.23 GeV/c. Dashed lines - result of calculations using OPER-model, dash-dot lines - result of OBE-model, solid lines - the sum of these models (OPER+OBE).

5. Reaction $np \to d\pi^+\pi^-$

In Fig. 18 the cross-sections of the reaction $np \to d\pi^+\pi^-$ are presented vs momentum of incident beam.

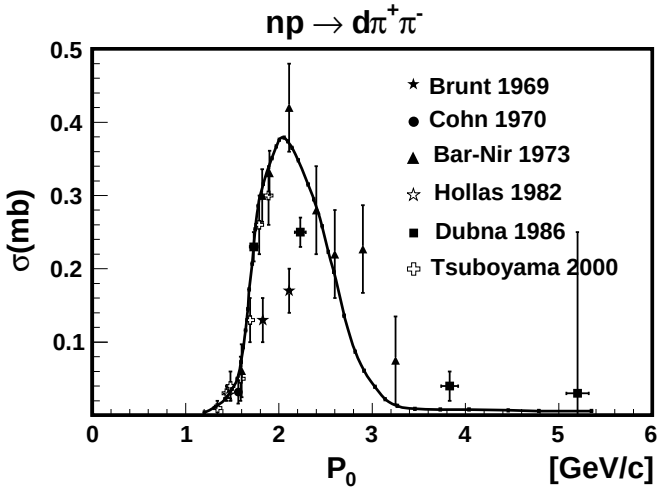

Figure 18: The cross sections of the reaction $np \to d\pi^+\pi^-$ (our data are denoted as **Dubna 1986** [2]).Solid line is the result of the approximation by Lagerre polynomials.

The experimental results at P_0=1.73 and 2.23 GeV/c were published in [2, 8].

As far as concerned the reaction $np \to d\pi^+\pi^-$ at P_0=3.83 and 5.20 GeV/c the only cross-sections were calculated. An insufficient statistics could not to study its characteristics detailed at theswe energies.

The reaction $np \to d\pi^+\pi^-$ is characterized by a fusion of neutron and proton into the deutron. This fact differs this reaction from two one ($np \to np\pi^+\pi^-$ and $np \to pp\pi^-\pi^0$) concidered above that have only verteciеs with elastic and non-elastic N-N scattering (Fig.8 and Fig.15). Thus it seems to be reasonable to take into account OBE diagrams shown in Fig.19 to describe the experimental data of this reaction:

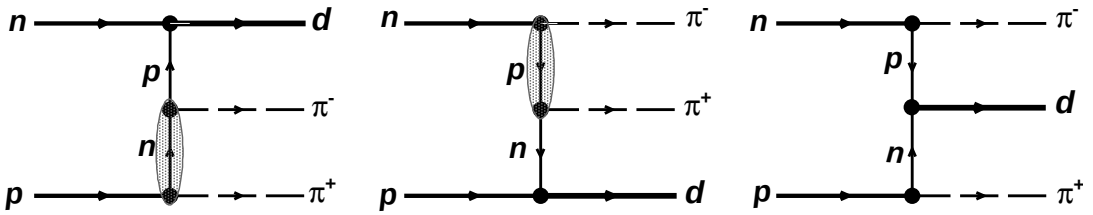

Figure 19: Diagrams corresponding to the reaction $np \to d\pi^+\pi^-$ in the framework of the one baryon exchange (OBE) model.

The vertex fuction $T_{np\to d}$ was calculated using CD-Bonn potential.

In Fig.20 one can see clear peaks in the masses of $\pi^+\pi^-$-combinations close to $\sim$350 and $\sim$400 MeV/c^2 (so called ABC and DEF anomaly). These effects and momenta and masses distributions are good reproduced within framework of OBE model. But the theoretical curve for

angular distributions of deuteron and pions are too sharp. It is necessary further development of OBE model to improve the description of experimental data.

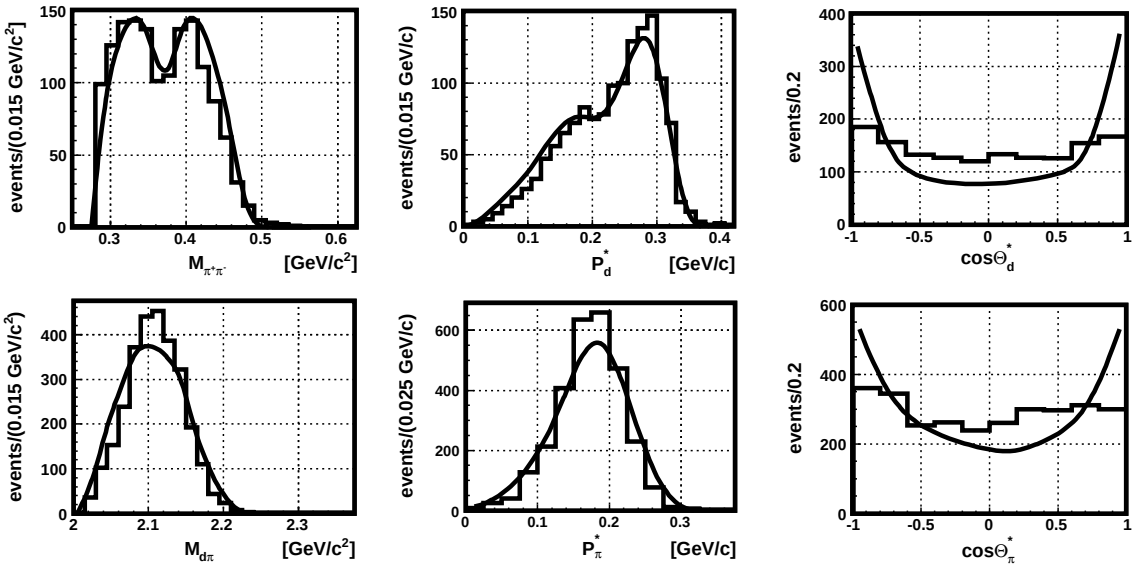

Figure 20: The distributions for the reaction $np \to d\pi^+\pi^-$ at P_0=1.73 GeV/c. Solid line - calculations using OBE-model. One can see ABC and DEF bumps in 2π mass spectrum.

As far as concerned dipion masses from the reaction $np \to d\pi^+\pi^-$ at P_0=2.23 GeV/c (Fig.21)it is difficult to say that ABC and DEF bumps are confidently observed. Obviously it is due to an insufficient statistics.

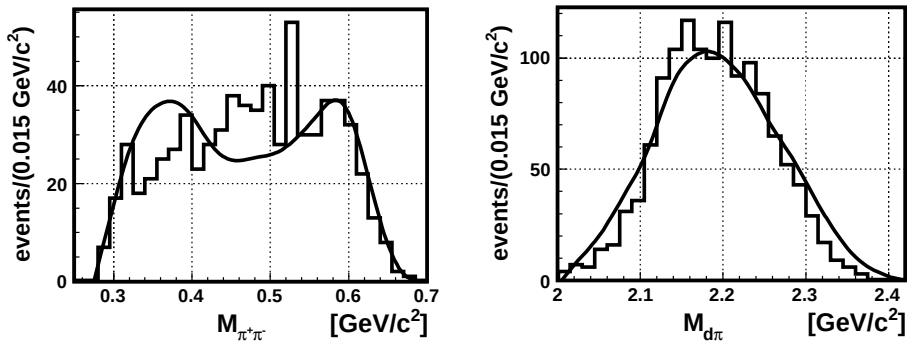

Figure 21: The distributions for the reaction $np \to d\pi^+\pi^-$ at P_0=2.23 GeV/c. Solid line - calculations using OBE-model.

6. Other reactions

- $np \to nn\pi^+\pi^0$ (no data) is isotopically conjugated to the reaction $np \to pp\pi^-\pi^0$.
- $np \to np\pi^0\pi^0$ (no data).

Characteristics of these reactions can be calculated using (OPER+OBE)-model.

• $np \to d\pi^0\pi^0$ (no data).

M.b. characteristics of this reaction can be calculated using modified OBE-model.

Moreover (OPER+OBE)-model can calculate the characteristics of the multi-pion production in the reactions of πN interactions at a wide region of incident energies..

7. Conclusion

The careful study of 2π-meson production was carried out in np-interaction at the momenta of the incident neutrons from 1.73 to 5.20 GeV/c in the reactions $np \to np\pi^+\pi^-$, $np \to pp\pi^-\pi^0$ and $np \to d\pi^+\pi^-$. It was shown that combined (OPER+OBE) model can successfully describe dipion production in np-interaction at the energies 1-5 GeV under condition of 4π geometry.

It was shown the importance of the "hanged" diagrams for better description of the dipion masses. at low energies.

The further development of the OBE-model is necessary for the better description of the reaction $np \to d\pi^+\pi^-$.

(OPER+OBE)-model can be used as an effective tool to simulate various reactions of hadronic interactions.

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