Di-pion Production in np-Interactions at Intermediate Energies

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Outlook

1. Introduction

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

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

ΔΔ-production.

Double pion production in NN collisions is one way to obtain information about the **NN**, ***π*N** and ***ππ*** states, including:

dibaryons,

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

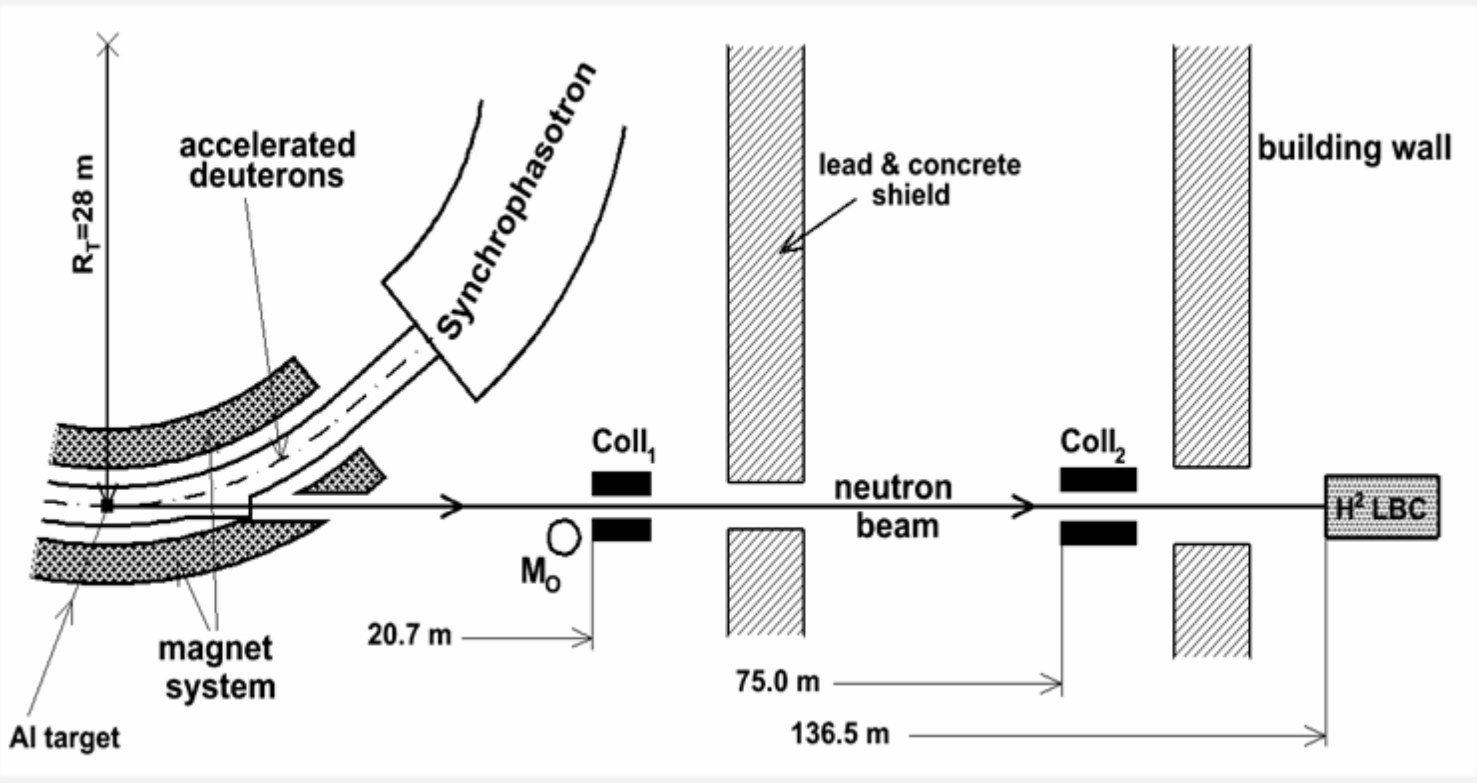
missing resonances etc.

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

- **Valencia** model[10]
- **Xu Cao** model[11]
- **(OPER+OBE)** model[3-6,7]

2. **Experiment:** study of inelastic np interactions

at accelerator facility of LHEP JINR

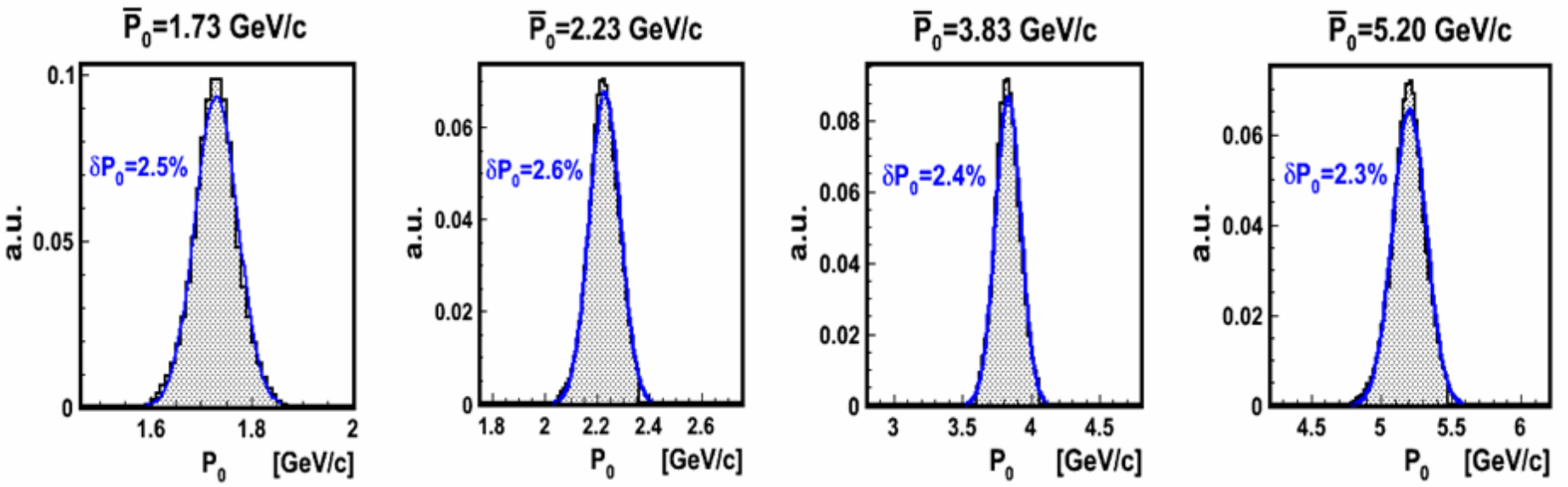


The unique of fullness and precision data are obtained.

It permits to carry out the detailed study of inelastic np interactions in a wide region of energies

- **Quasimonochromatic neutron channel: δP≈2.5% ,**

P_0=1.25; 1.43; 1.73; 2.23; 3.10; 3.83; 4.10 and 5.20 GeV/c,
4π geometry.



The following reactions with 2 π-mesons
in the final states were studied at these momenta

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

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

The study of π-meson production in NN-interactions are carried out in LHEP JINR.

The following reactions are investigated in Dubna:

- **$np \rightarrow np$ (pn)**
- **$np \rightarrow pp\pi^-$**
- **$np \rightarrow pp\pi^- \pi^0$**
- **$np \rightarrow np\ \pi^+ \pi^-$**
- **$np \rightarrow d\ \pi^+ \pi^-$ (ABC and DEF effects were observed)**
- **$np \rightarrow pp\ \pi^+ \pi^- \pi^-$**
- **$np \rightarrow pp\ \pi^+ \pi^- \pi^- \pi^0$ (η^0 and ω^0 were observed)**
- **$np \rightarrow np\ \pi^+ \pi^+ \pi^- \pi^-$**

using H^2 target and pure neutron beam ($\delta P_n \approx 2.5\%$). The detailed investigations are carried out at P_0=1.25, 1.43, 1.73, 2.23, 3.83 and 5.20 GeV/c.

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

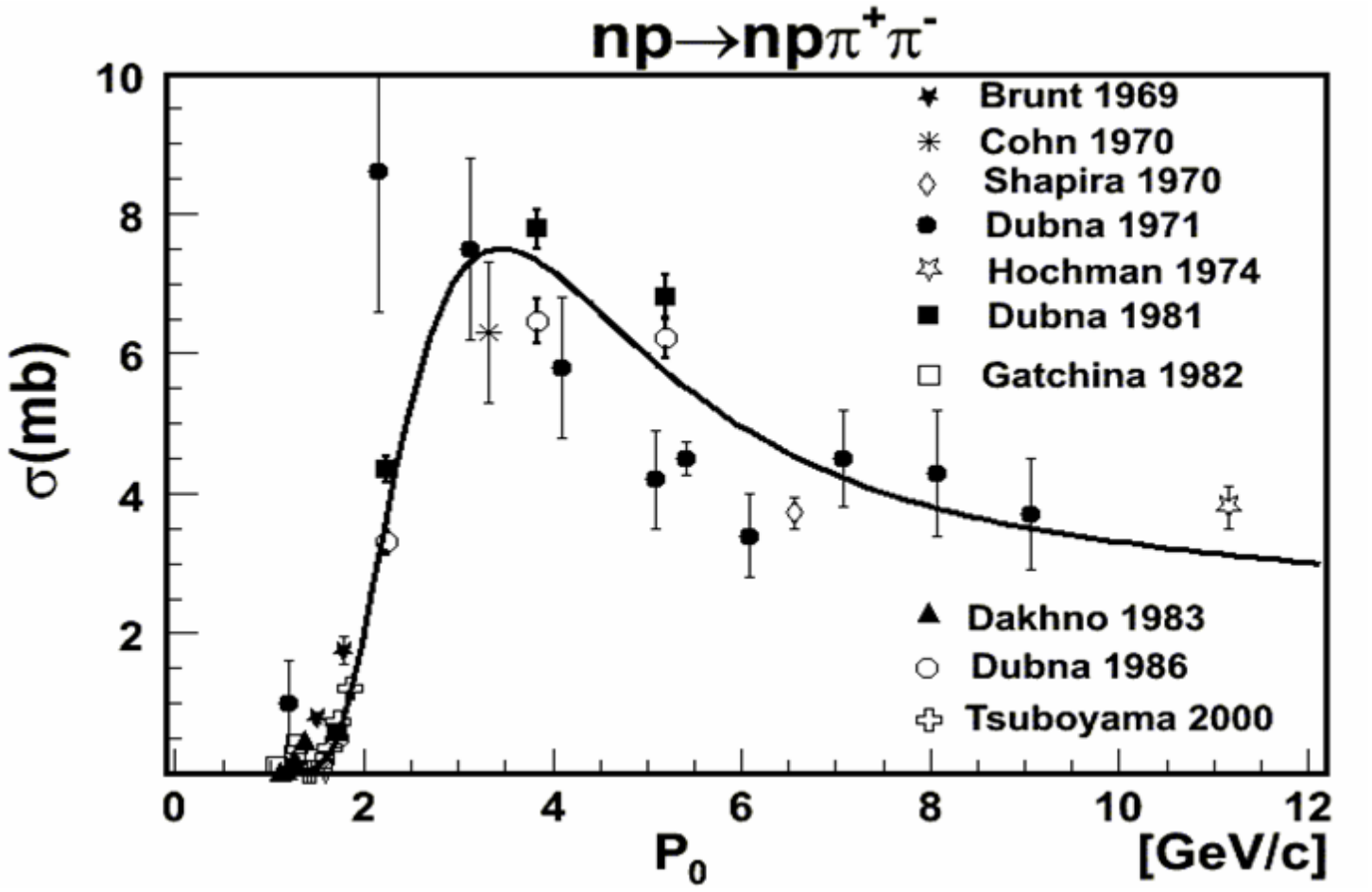
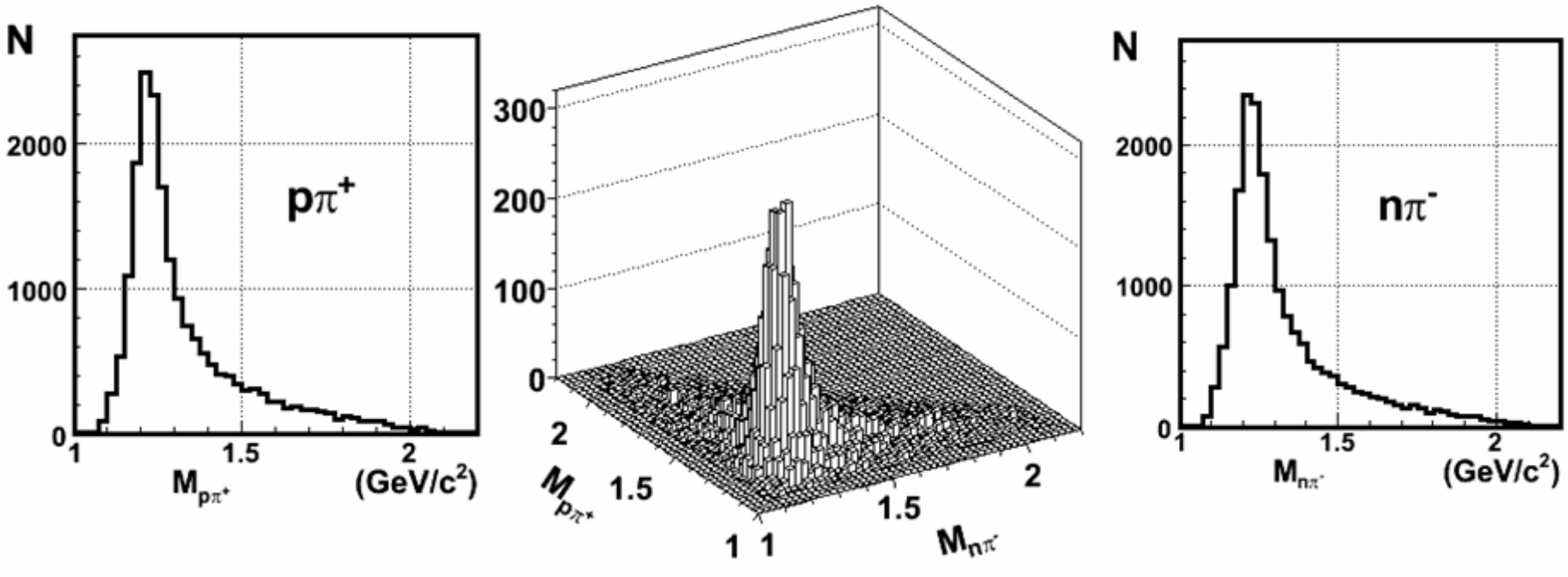


Fig.1 Cross-section of the reaction $np \to np\pi^+\pi^-$ vs momentum of incident beam. Solid line – Bystricky's approximation.

Reaction $np \rightarrow np\pi^+\pi^-$ is characterized by:

- plentiful production of the Δ_{1232} resonance ,



- strong anisotropy of the secondary hadrons
- domination of the small momentum transfers (*t*)

The following diagrams are taken to describe the reaction $np \to np\pi^+\pi^-$:

diagrams with $\pi N \to \pi N$ vertex **diagrams with $\pi N \to \pi\pi N$ vertex**

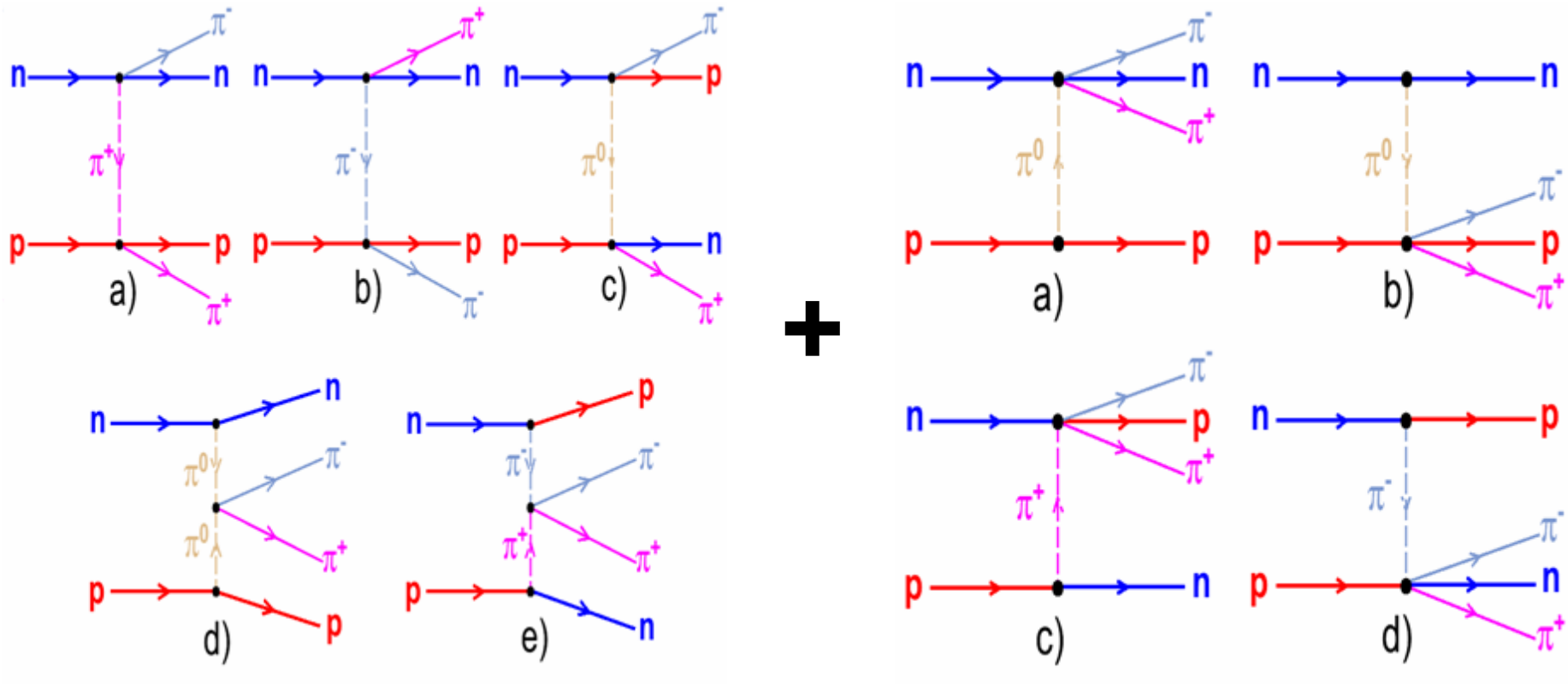


Fig.2 Diagrams for the reaction $np \to np\pi^+\pi^-$

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

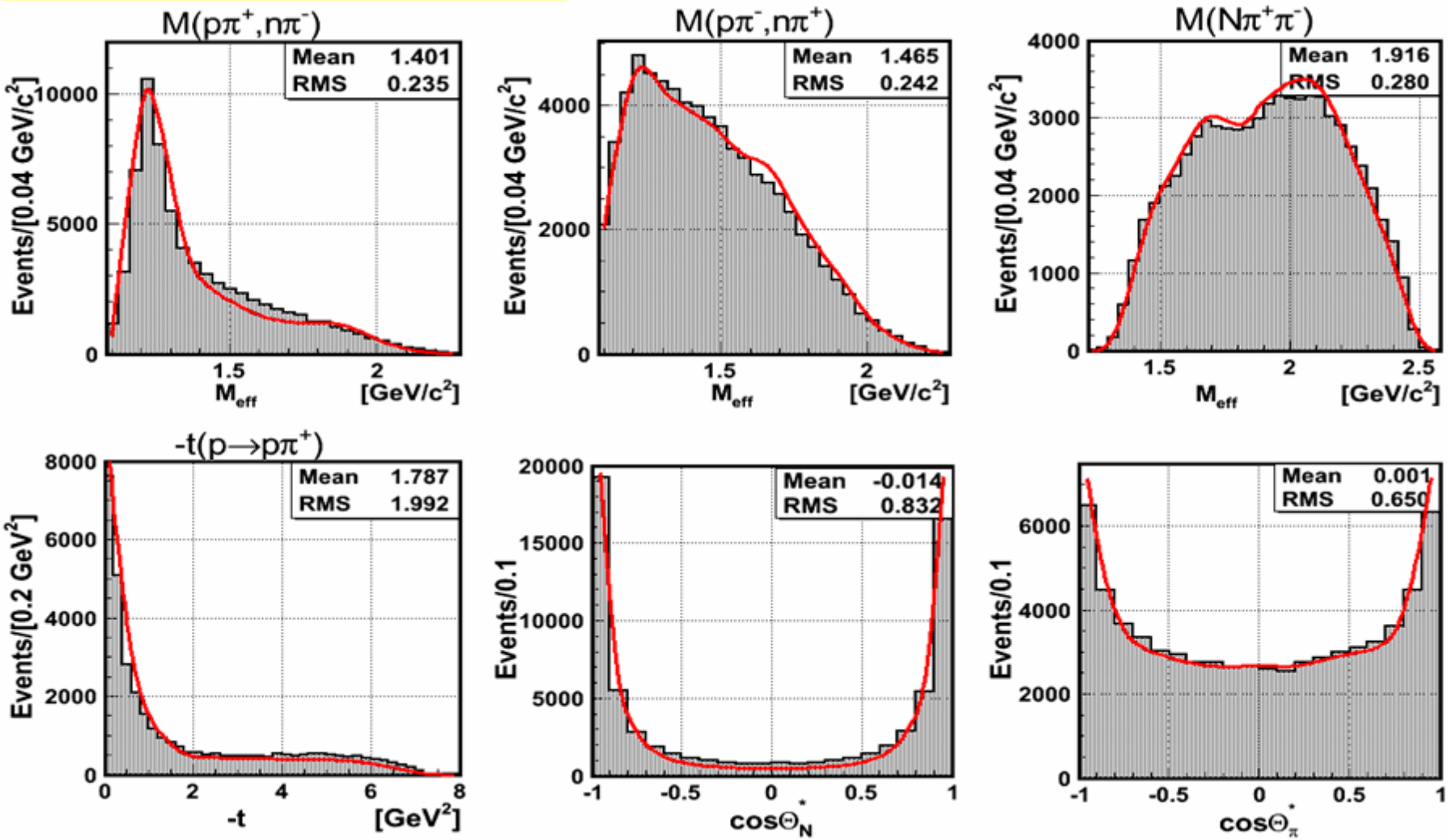
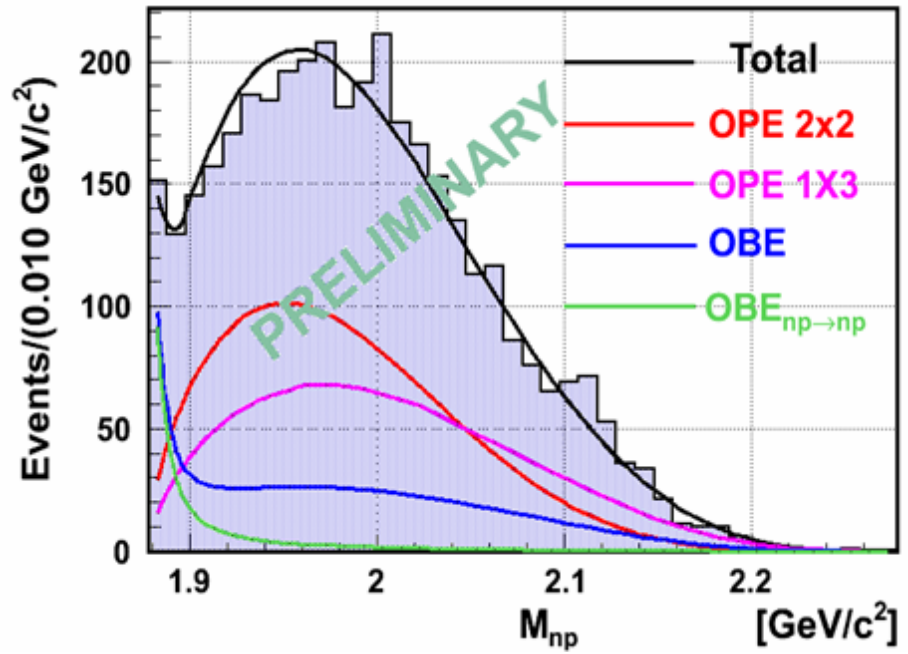


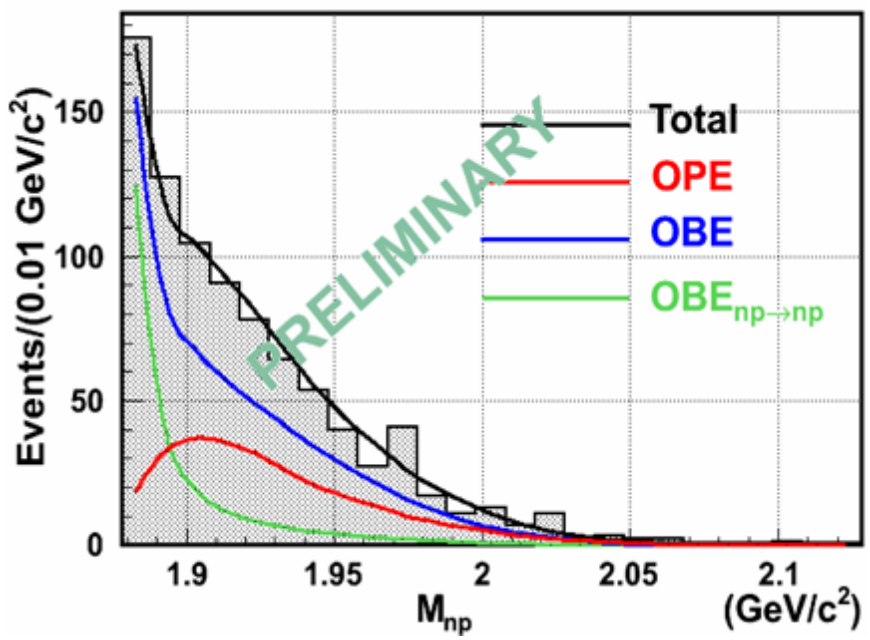
Fig.3. The distributions for the reaction $np \to np\pi^+\pi^-$ at P_0=5.20 GeV/c. Red line – calculations using OPER-model.

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

The study of effective mass spectra of np – combinations at P_0=1.73 and 2.23 GeV/c shows the clear peack close the threshold ($\mathbf{M_{np} = m_n + m_p}$) that can not be described within the framework of OPER-model c using the diagrams from **Fig.2**.



P_0=2,23 ГэВ/с



P_0=1,73 ГэВ/с

Fig.4. Effective mass spectra of np-combinations from the reaction $np \to np\pi^+\pi^-$

It seems to be correct to use in addition the following diagrams of one baryon exchange (**OBE**) to describe the reaction $np \to np\pi^+\pi^-$ at low energies:

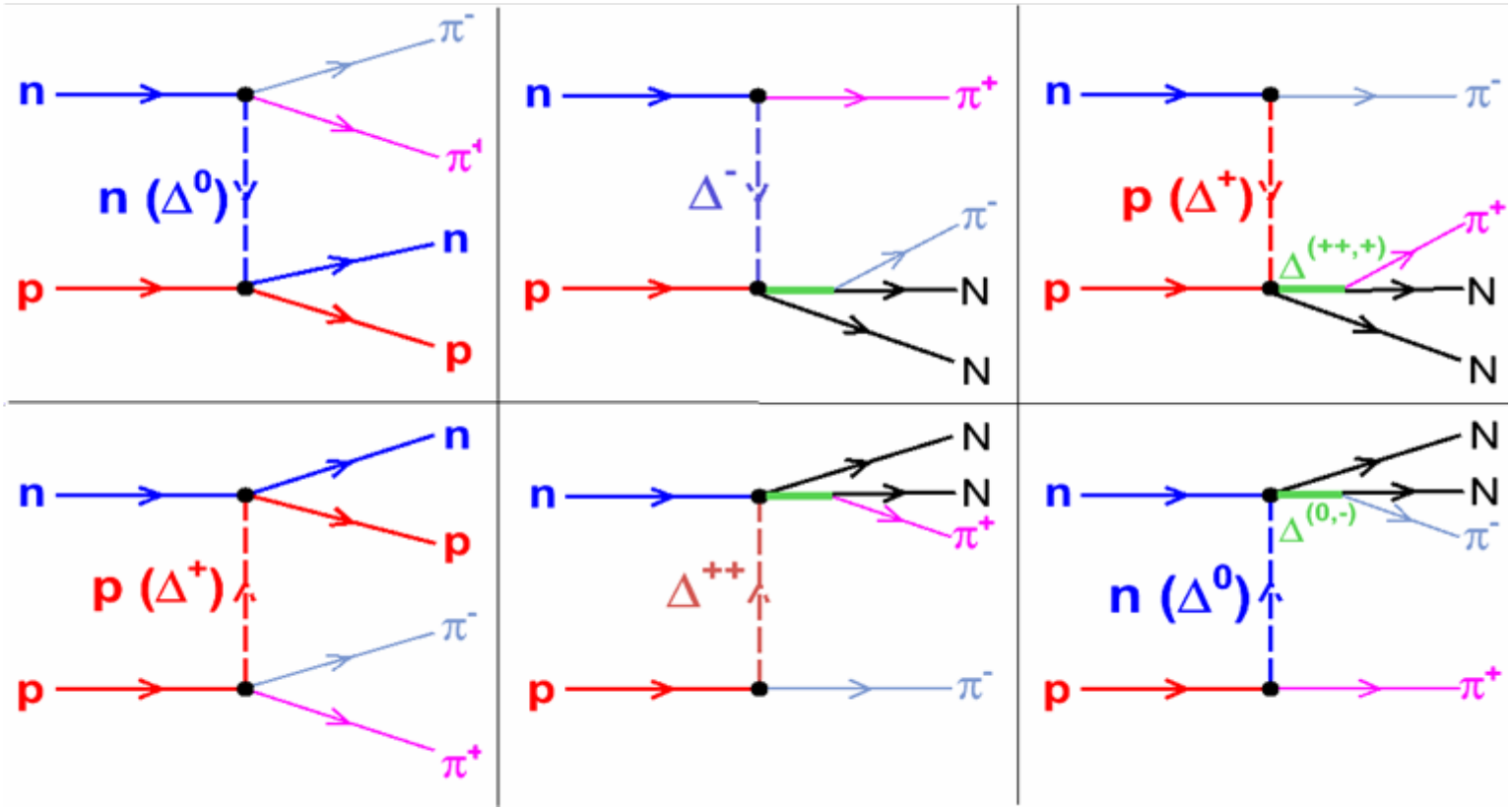


Fig.5 **OBE** diagrams for the reaction $np \to np\pi^+\pi^-$

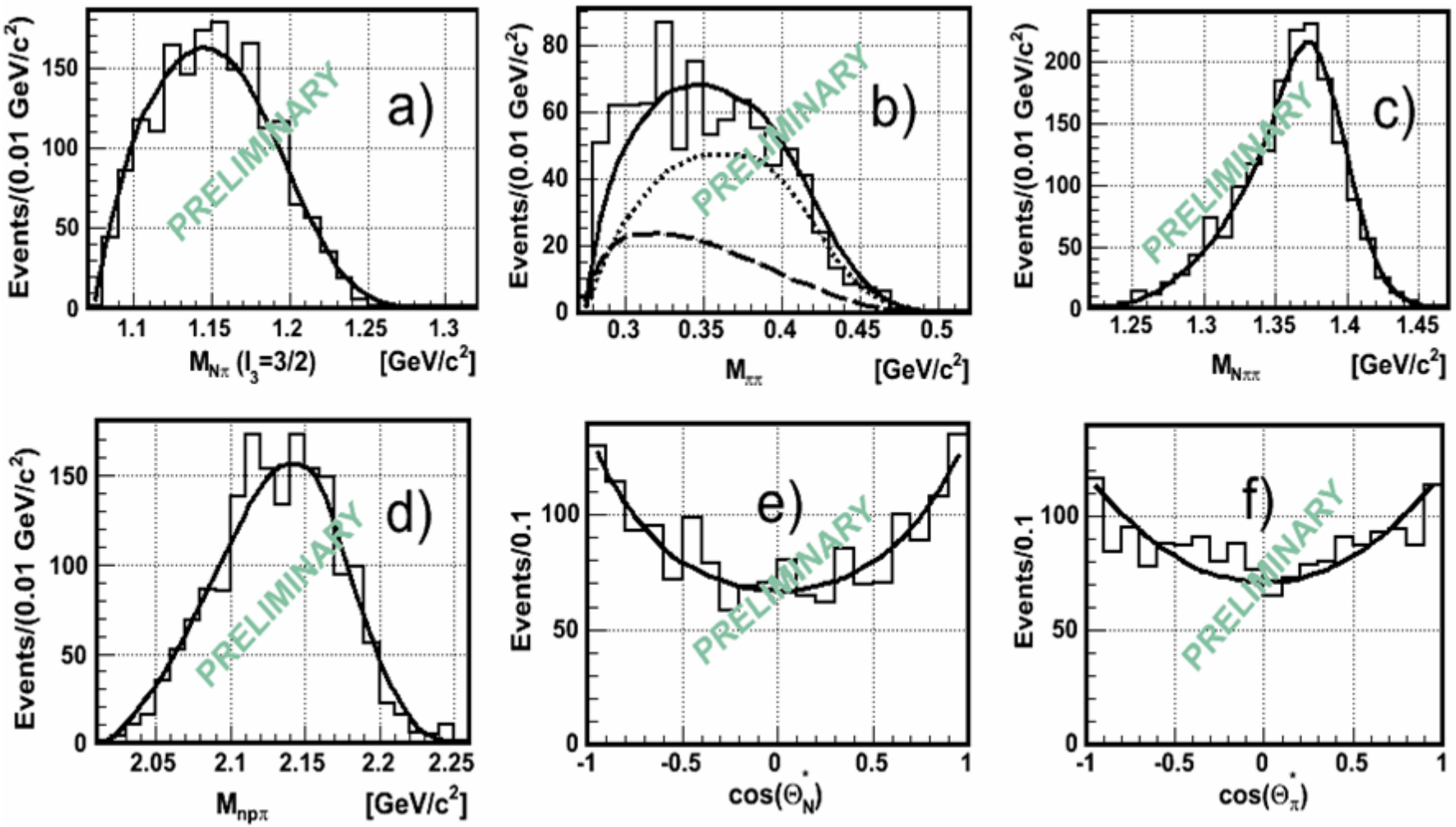
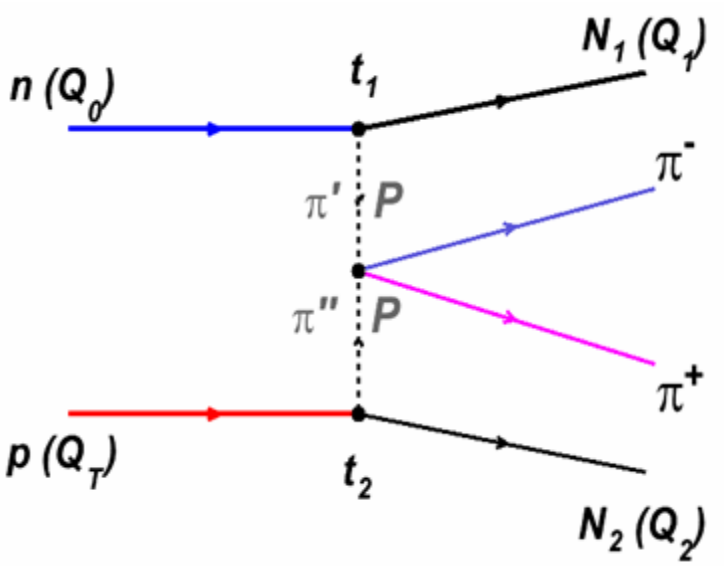


Fig.6. The distributions for the reaction $np \to np\pi^+\pi^-$ at P_0=1.73 GeV/c. Solid line – calculations using (OPER+OBE)-model.

The study of 2π mass spectrum close to the threshold results in necessity to take into account **"hanged diagrams" with Pomeron exchange.**

It leads to the better description of the reaction data.



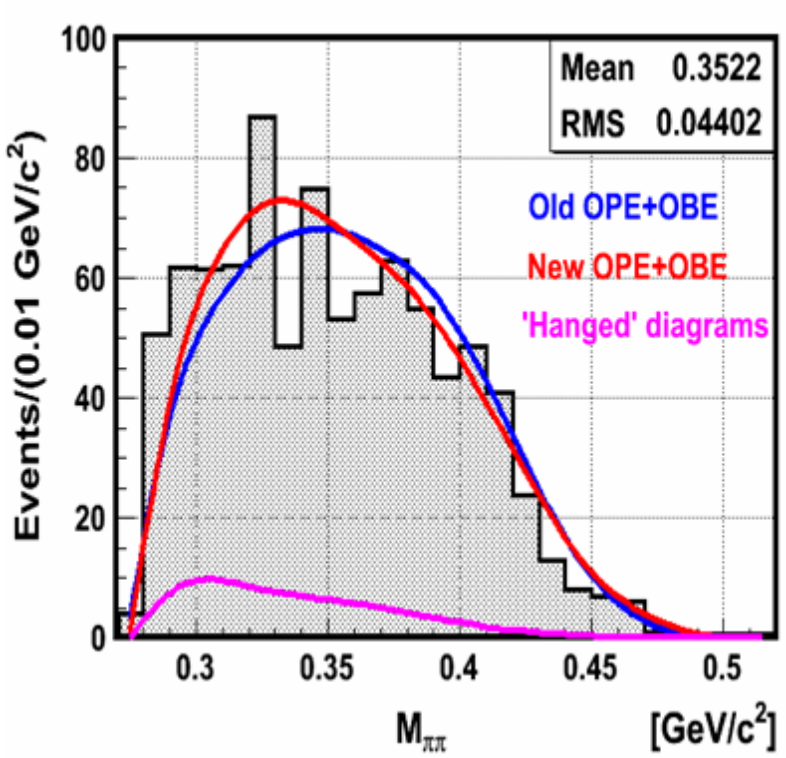


Fig.7 "hanged" diagram and 2π mass spectrum at P_0 =1,73 ГэВ/с

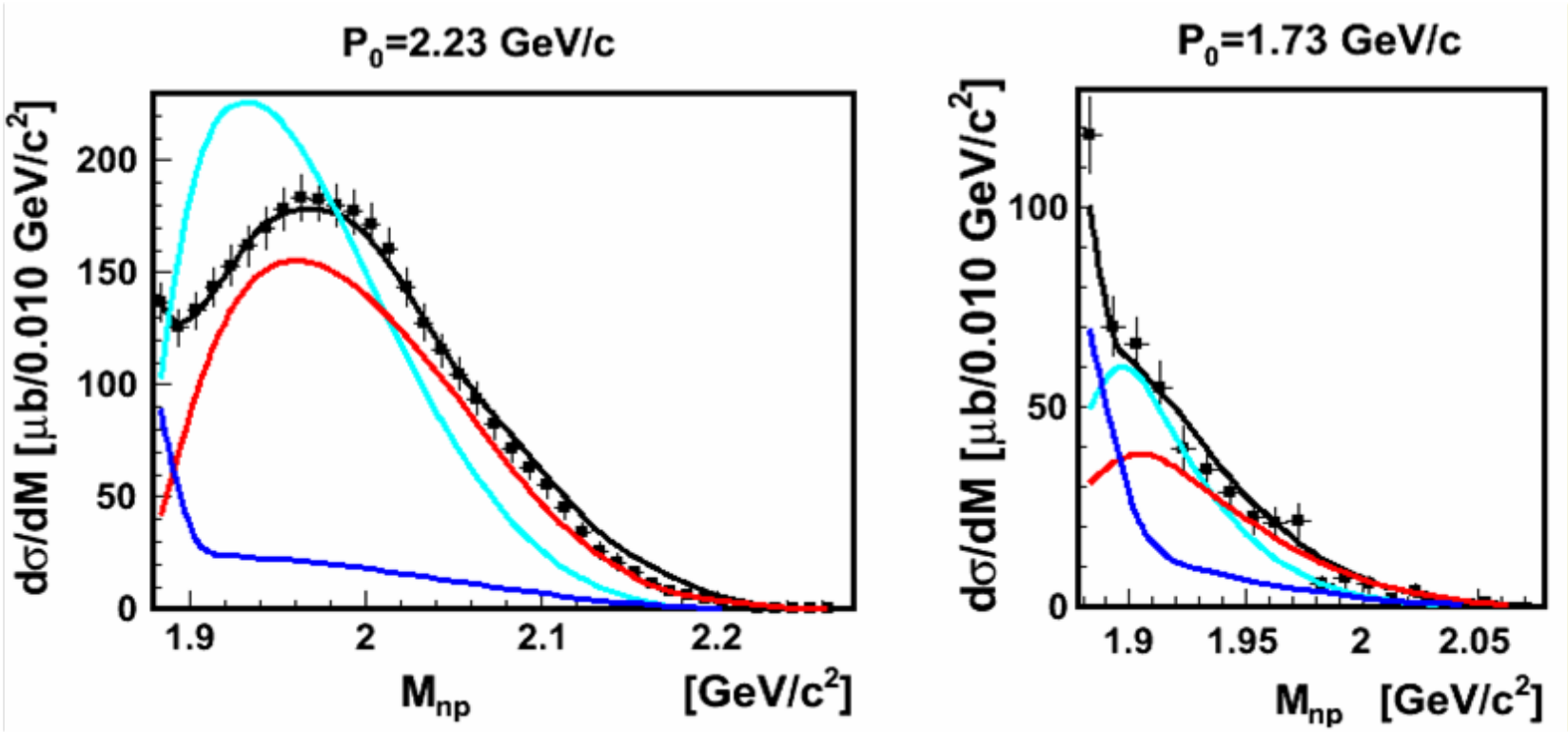


Fig.8 Description of the effective mass spectra of np-combinations from the reaction $np \to np\pi^+\pi^-$ at P_0=2.23 GeV/c and 1.73 ГэВ/c . Black curve – contribution of (OPER+OBE)-model , red curve – contribution of OPER-model , blue curve – contribution of OBE-model , sky blue curve – contribution of Valencia model

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

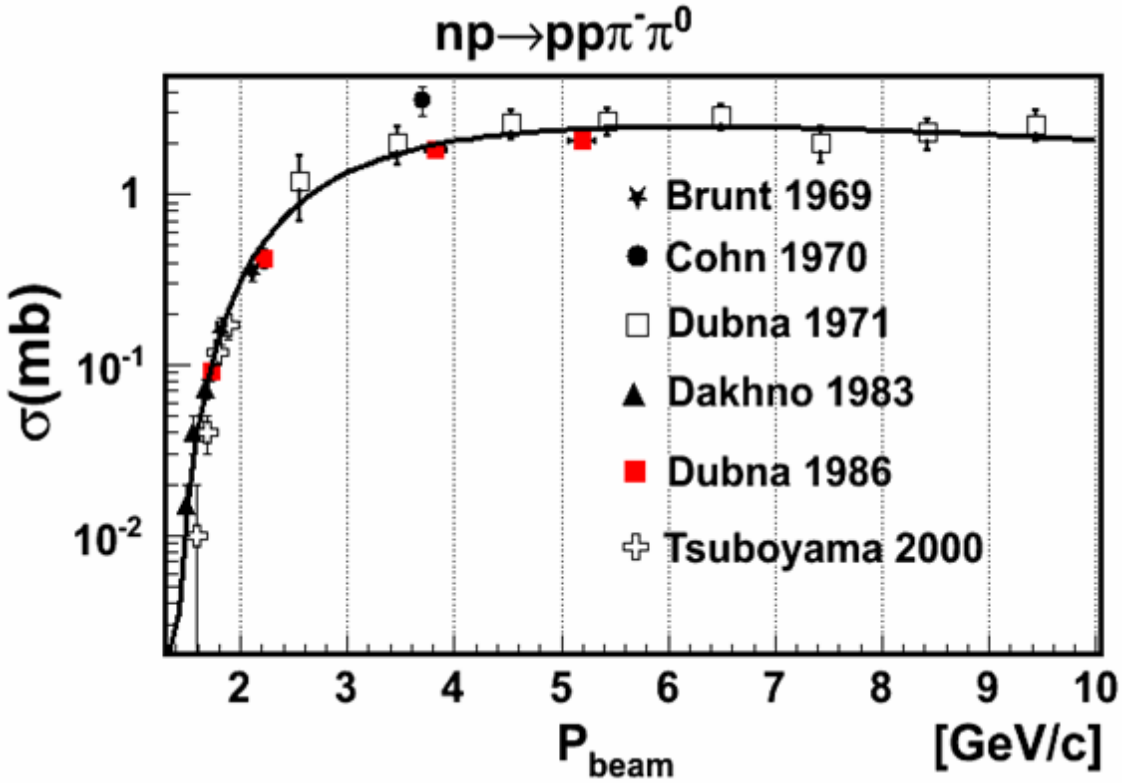


Fig.9 The cross sections of the reaction $np \to pp\pi^- \pi^0$ (■ Dubna 1986).

(**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 $np \to np\pi^+ \pi^-$ (presented at previous HADES CM)

4a. Reaction $np \to pp\pi^- \pi^0$ at $P_0 > 3$ GeV/c

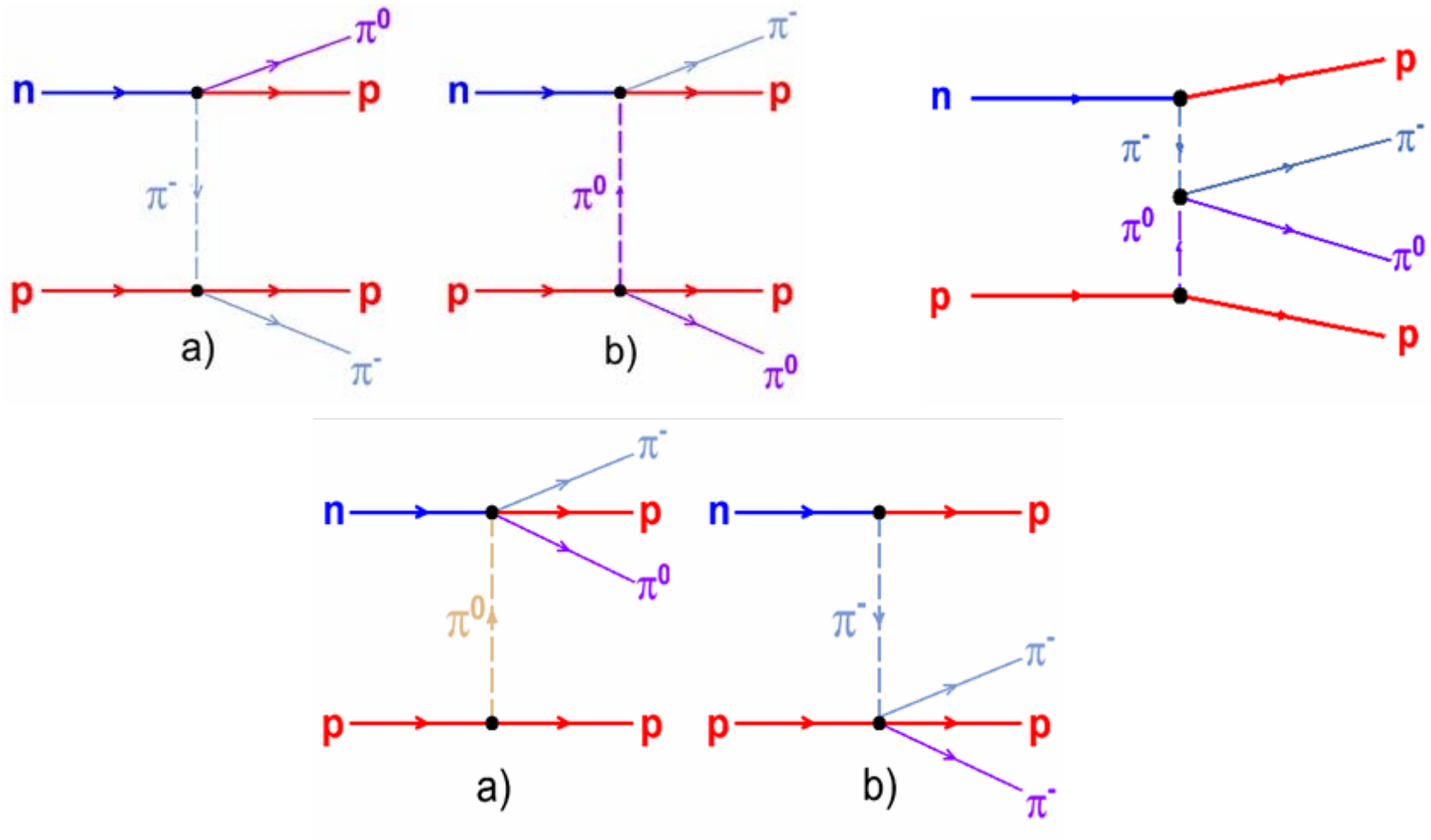
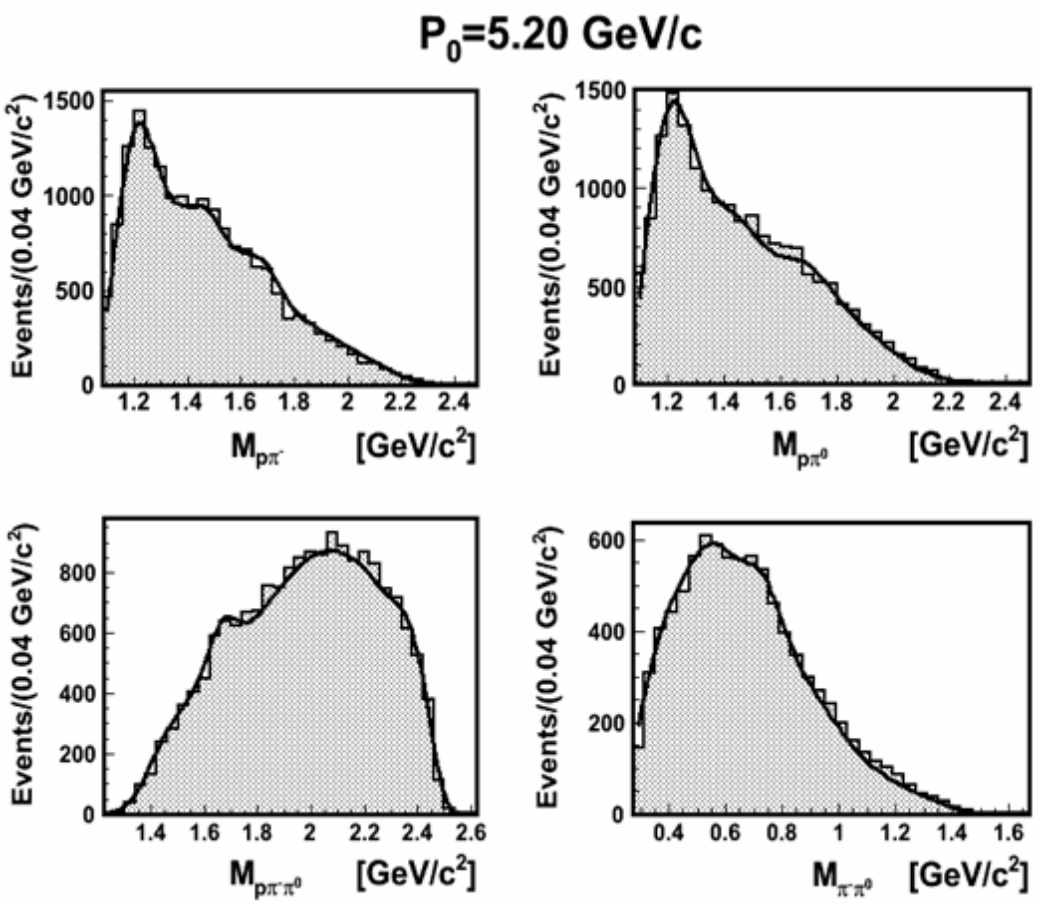


Fig.10 The main diagrams of the reaction $np \to pp\pi^- \pi^0$

Fig.11 Mass and **angular** spectra of the reaction

$np \rightarrow pp\pi^- \pi^0$ at P_0=5.20 GeV/c



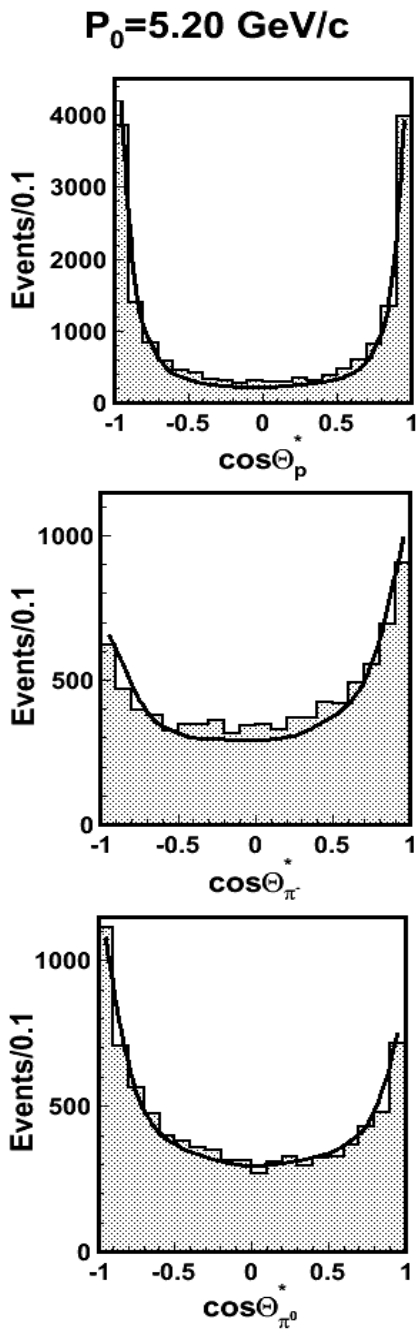
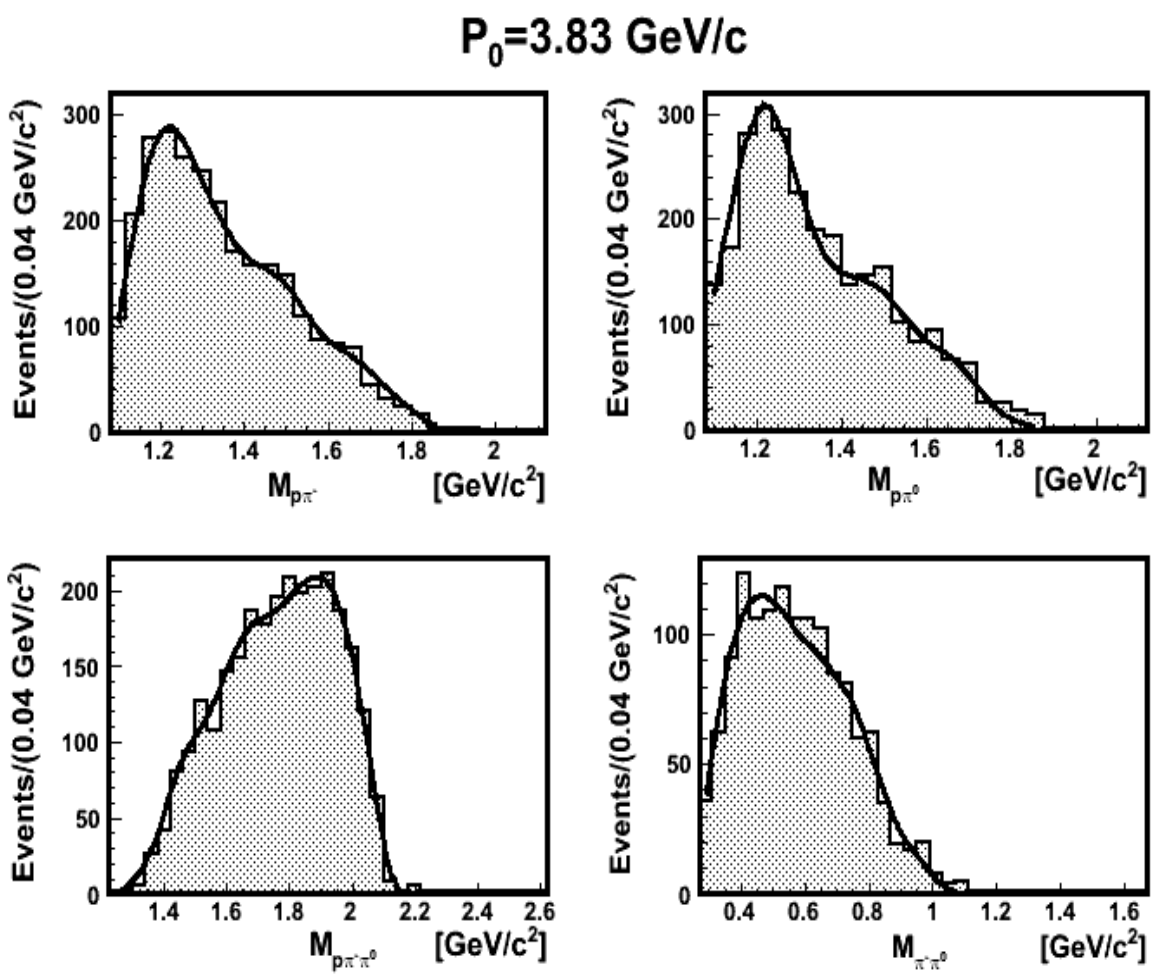
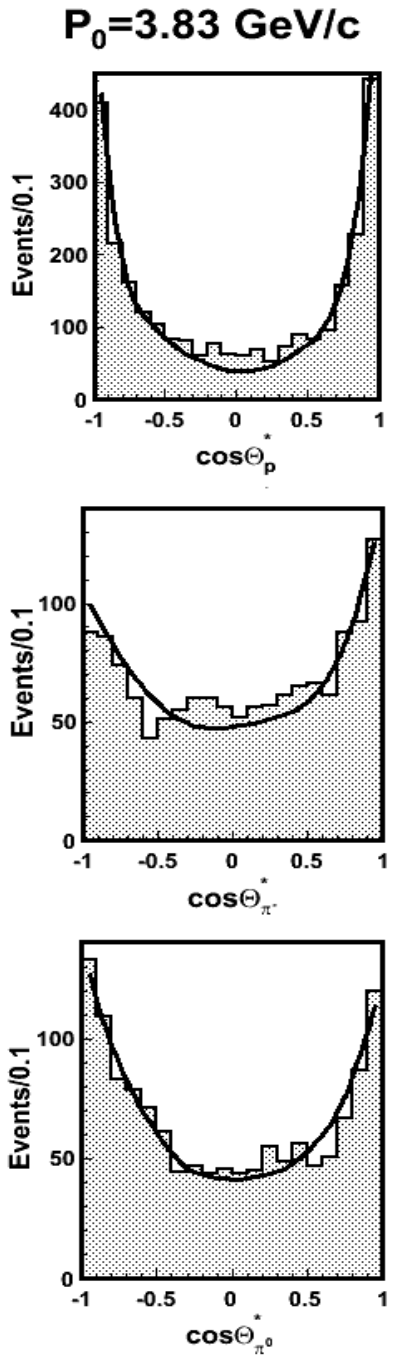


Fig12. Mass and **angular** spectra of the reaction

$np \rightarrow pp\pi^- \pi^0$ at P_0=3.83 GeV/c





4b. Reaction $np \to pp\pi^- \pi^0$ at $P_0 < 3$ GeV/c

Fig.13 Diagrams corresponding to the reaction $np \to pp\pi^- \pi^0$ in the framework the model of **one baryon−exchange (OBE)** (in addition to the diagrams of OPER-model):

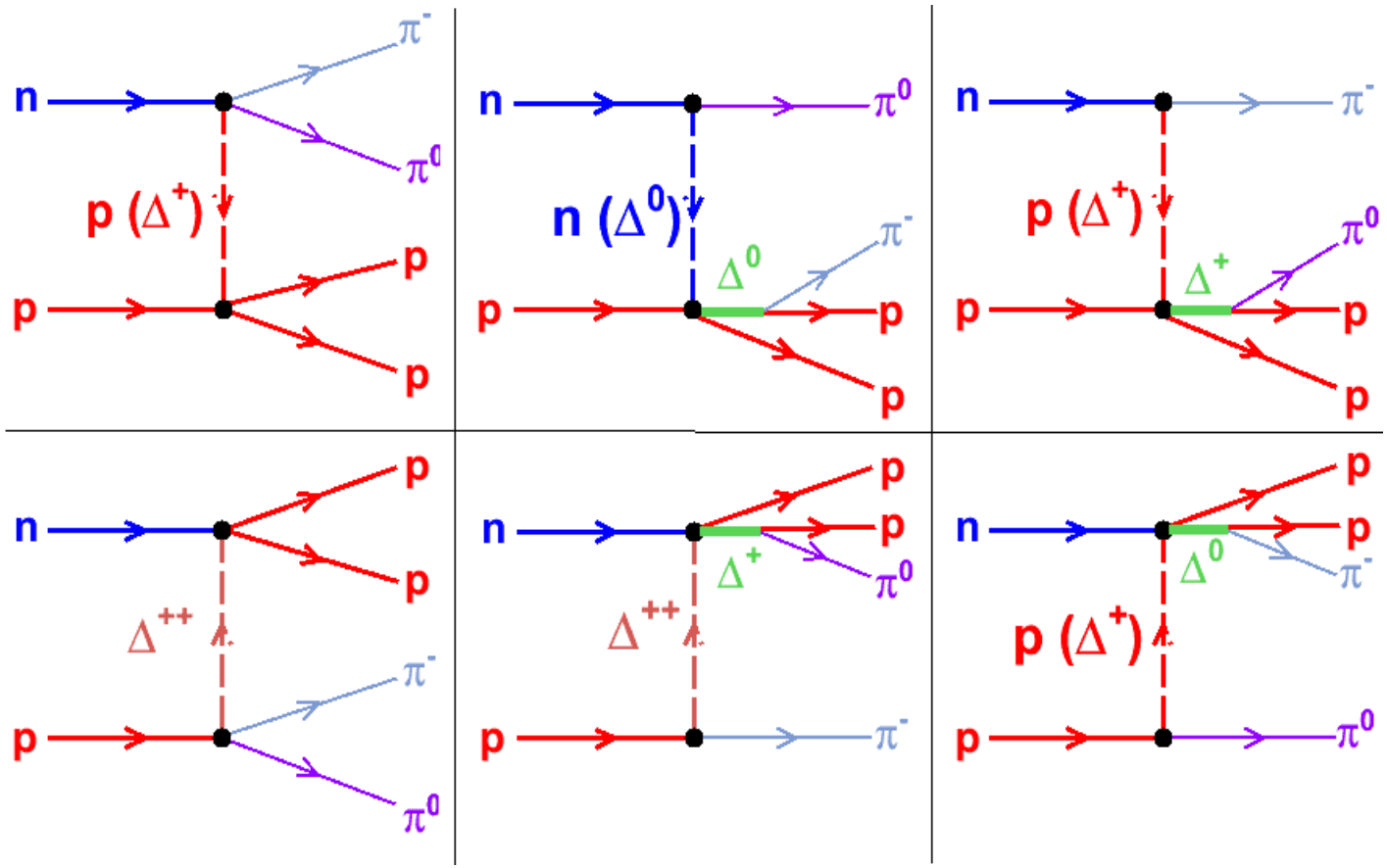


Fig.14 **Mass** and **angular** spectra of the reaction $np \to pp\pi^- \pi^0$ at P_0=2.23 GeV/c

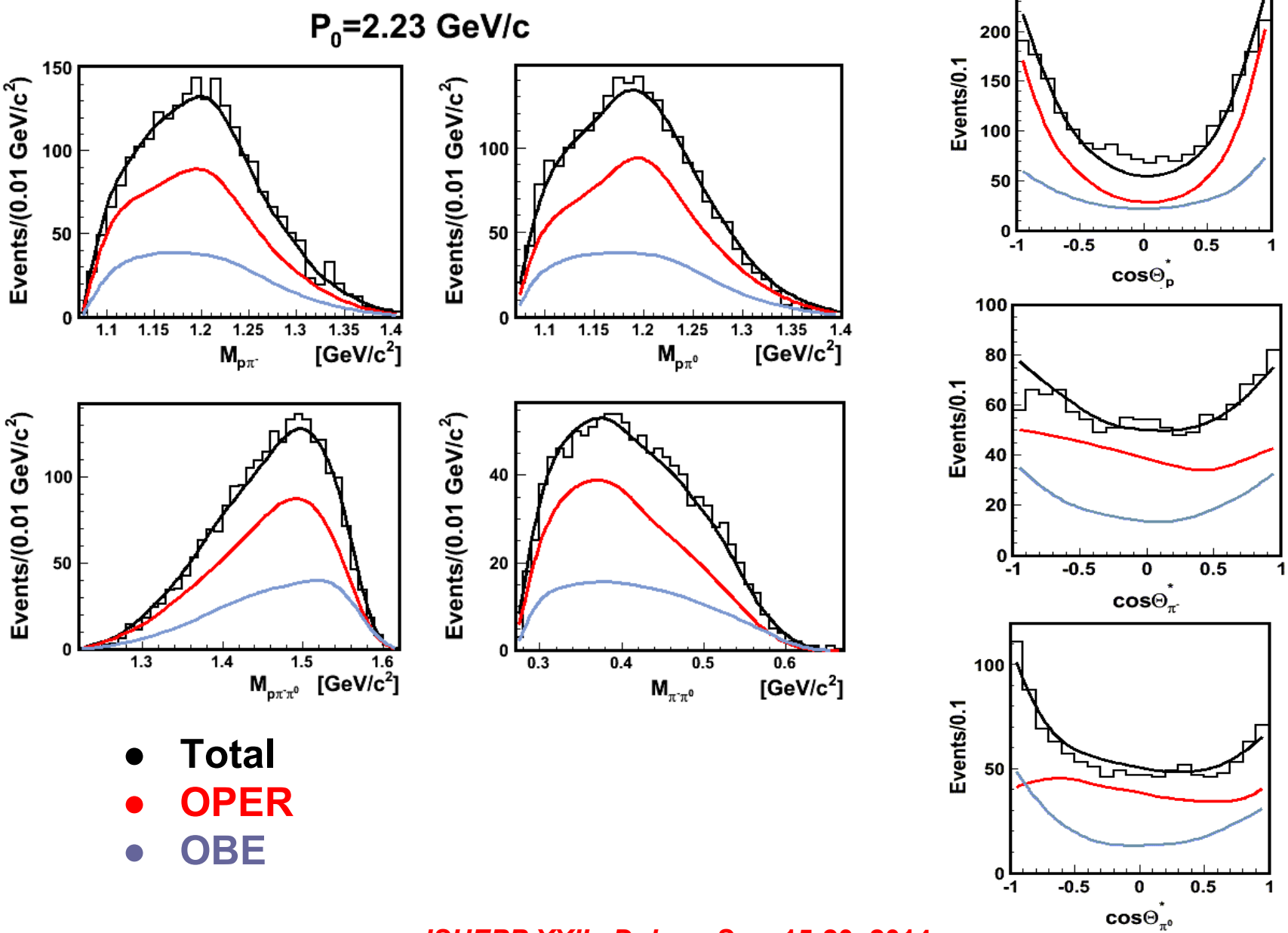
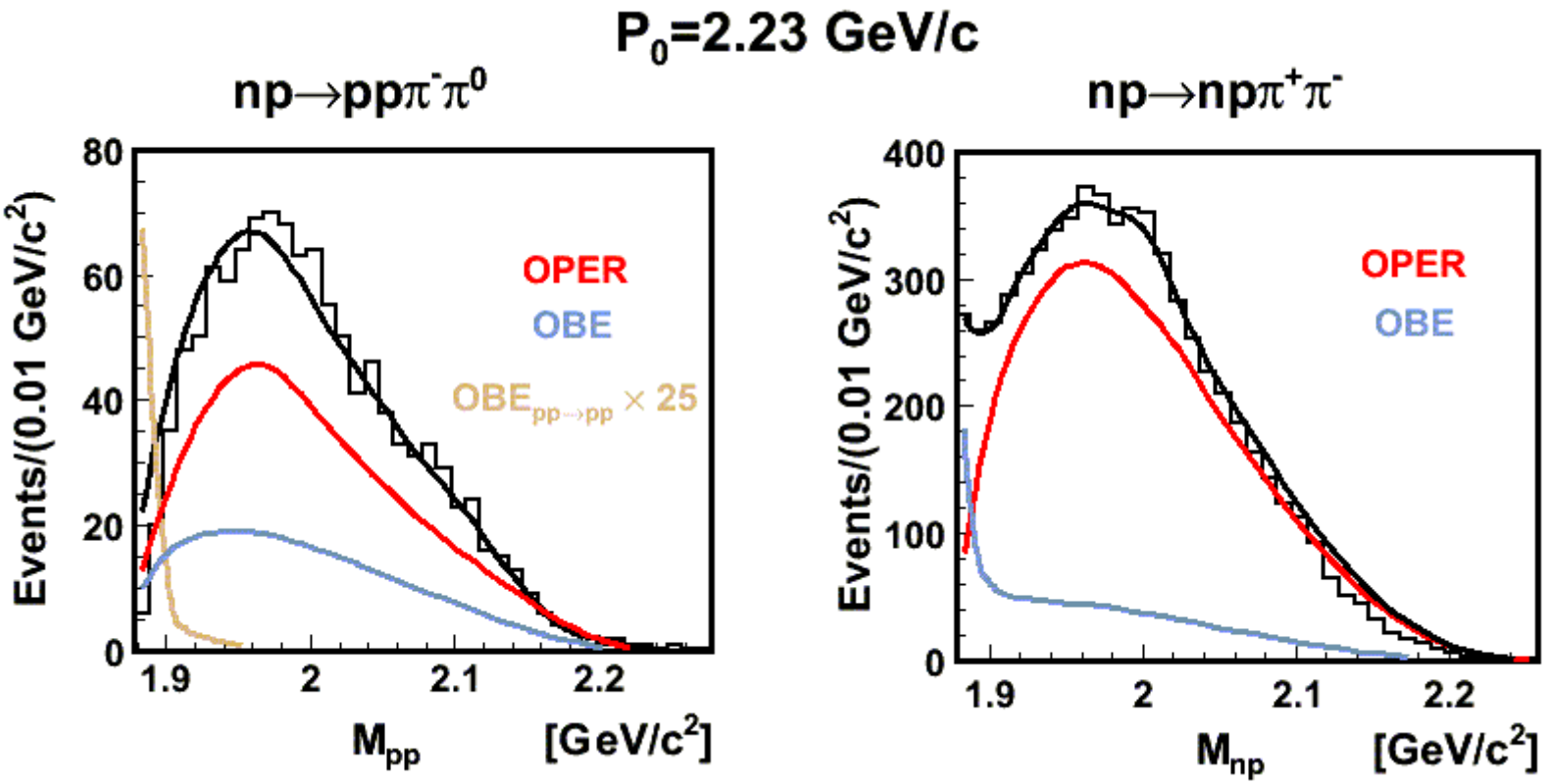


Fig.15 Dibaryon mass spectra from the reactions
$np \to pp\pi^- \pi^0$ and $np \to np\pi^+ \pi^-$ at P_0=2.23 GeV/c



Decrease the contribution of the NN→NN factor of OBE-model near the threshold of M_{NN} masses

Fig.16 **Mass** and **angular** spectra of the reaction $np \to pp\pi^- \pi^0$ at P_0=1.73 GeV/c

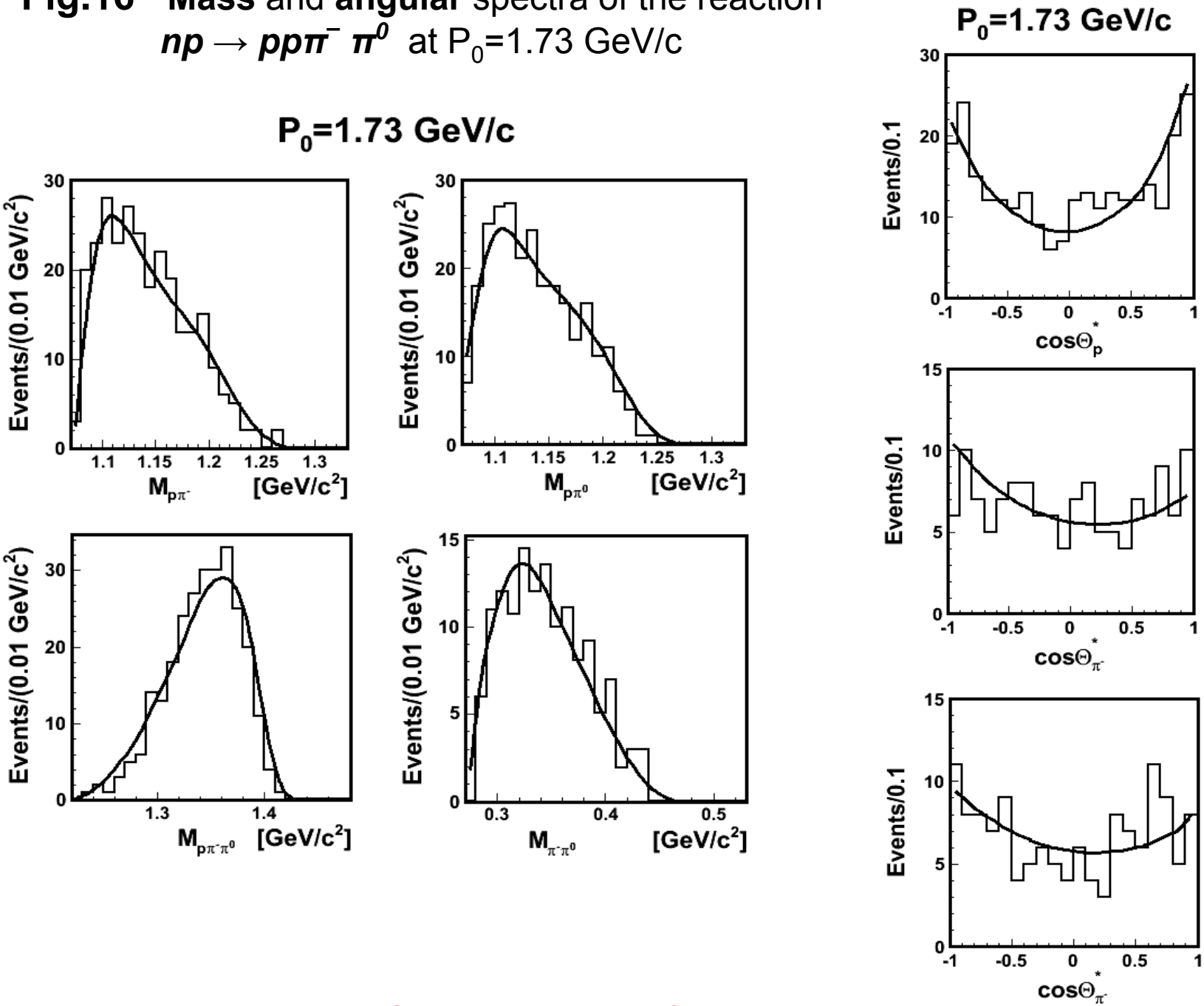
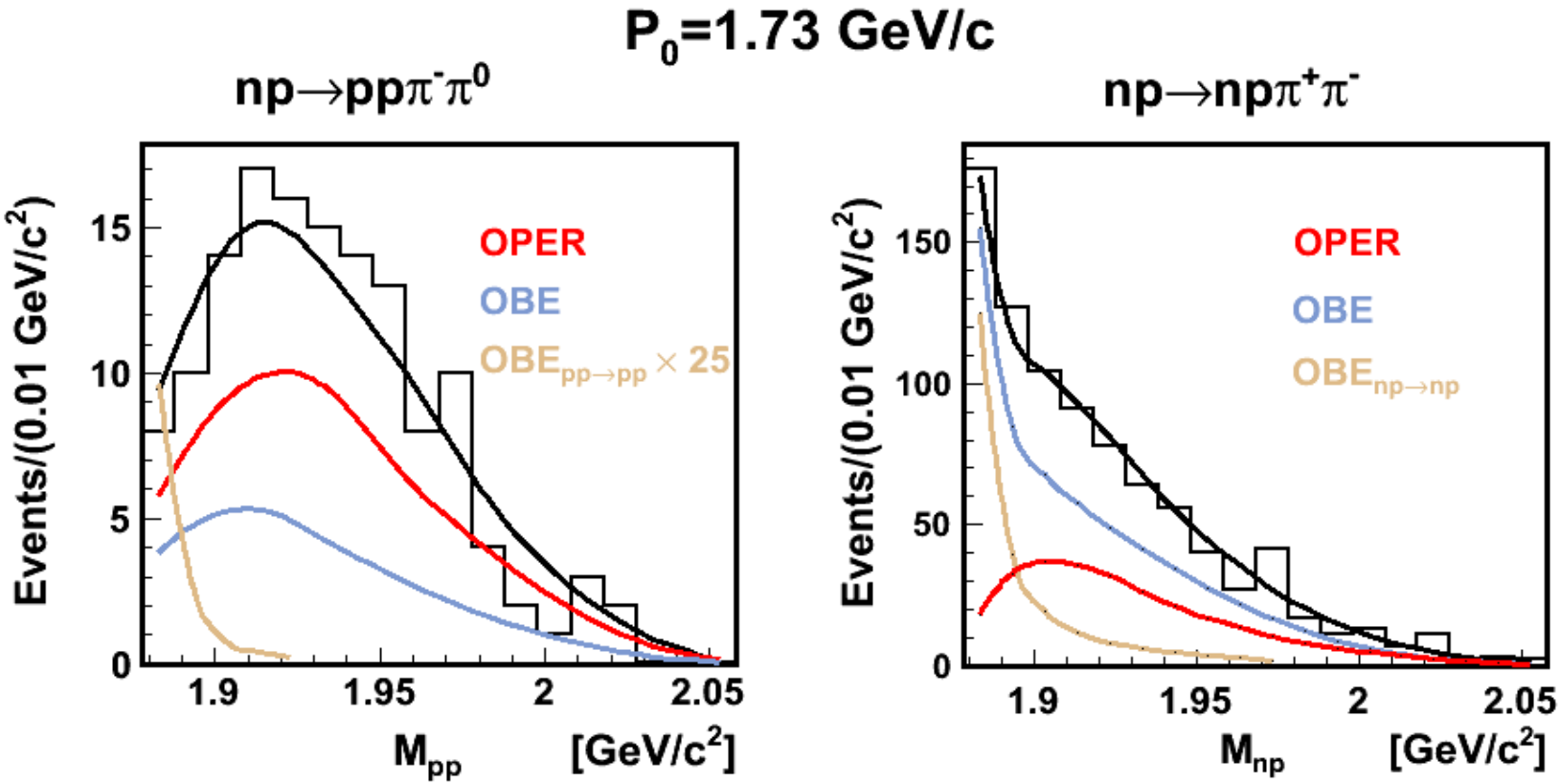


Fig.17 Dibaryon mass spectra from the reactions

$np \to pp\pi^- \pi^0$ and $np \to np\pi^+ \pi^-$ at P_0=1.73 GeV/c



Decrease the contribution of the NN→NN factor of OBE-model near the threshold of M_{NN} masses

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

The experimental results at P_0=1.73 and 2.23 GeV/c were published in
[*A.Abdivaliev et al*. **NP B168** (1980), pp.385-393]

It seems to be reasonable to take into account the following **OBE diagrams** to describe the data:

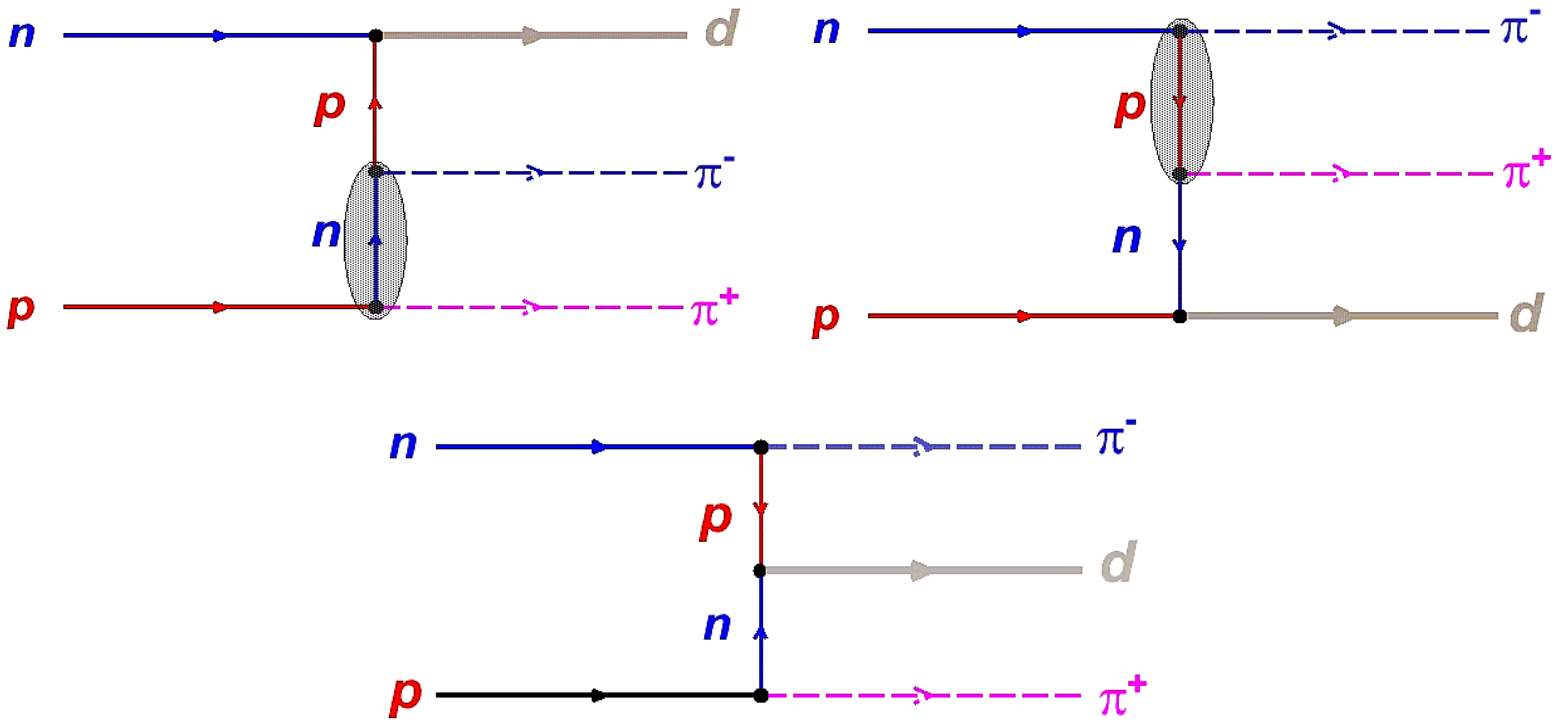


Fig.18

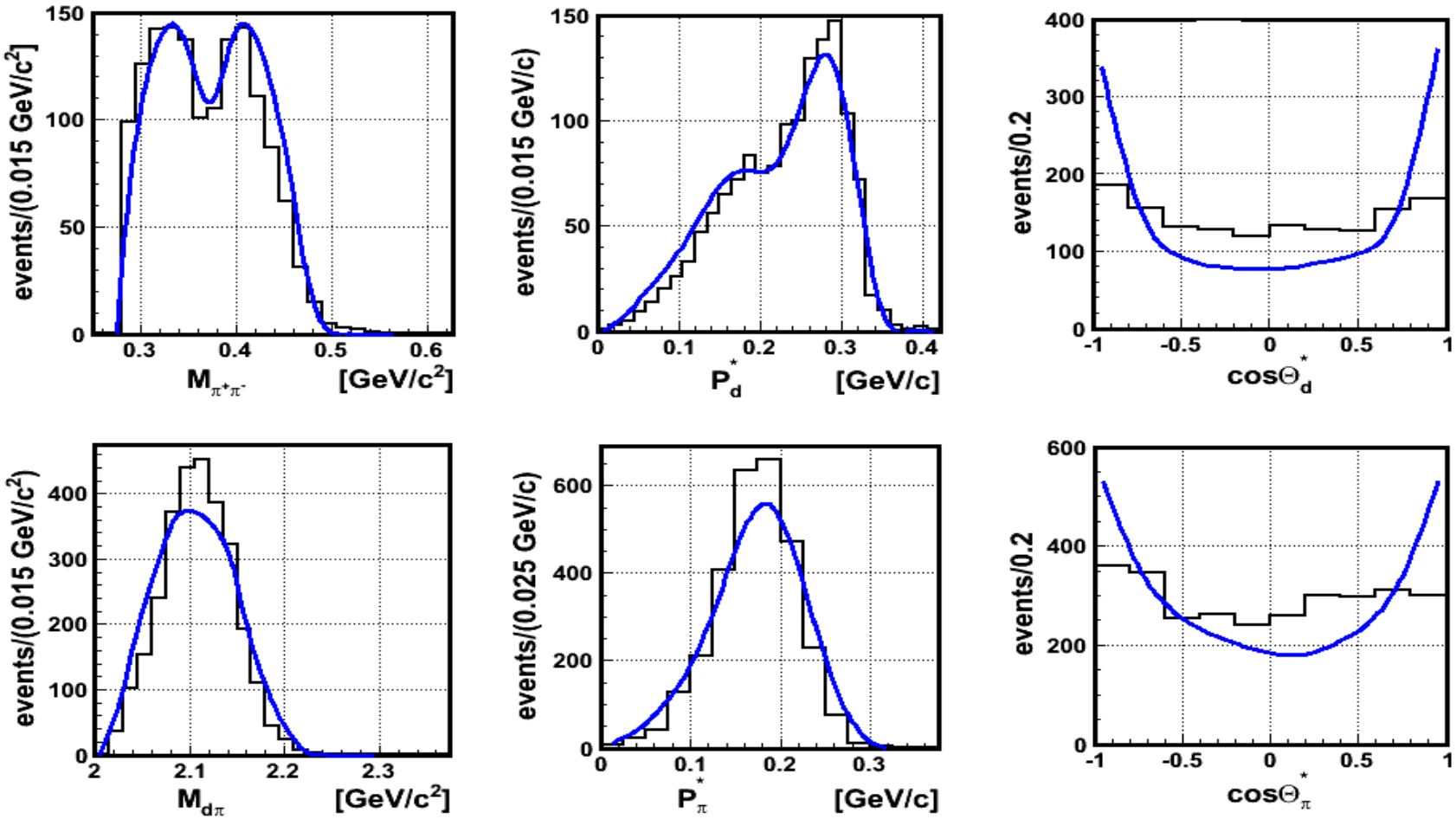


Fig.19. The distributions for the reaction $np \rightarrow d\,\pi^+\,\pi^-$ at P_0=1.73 GeV/c.

Solid line – calculations using OBE-model.

One can see ABC and DEF bumps in 2π mass spectrum.

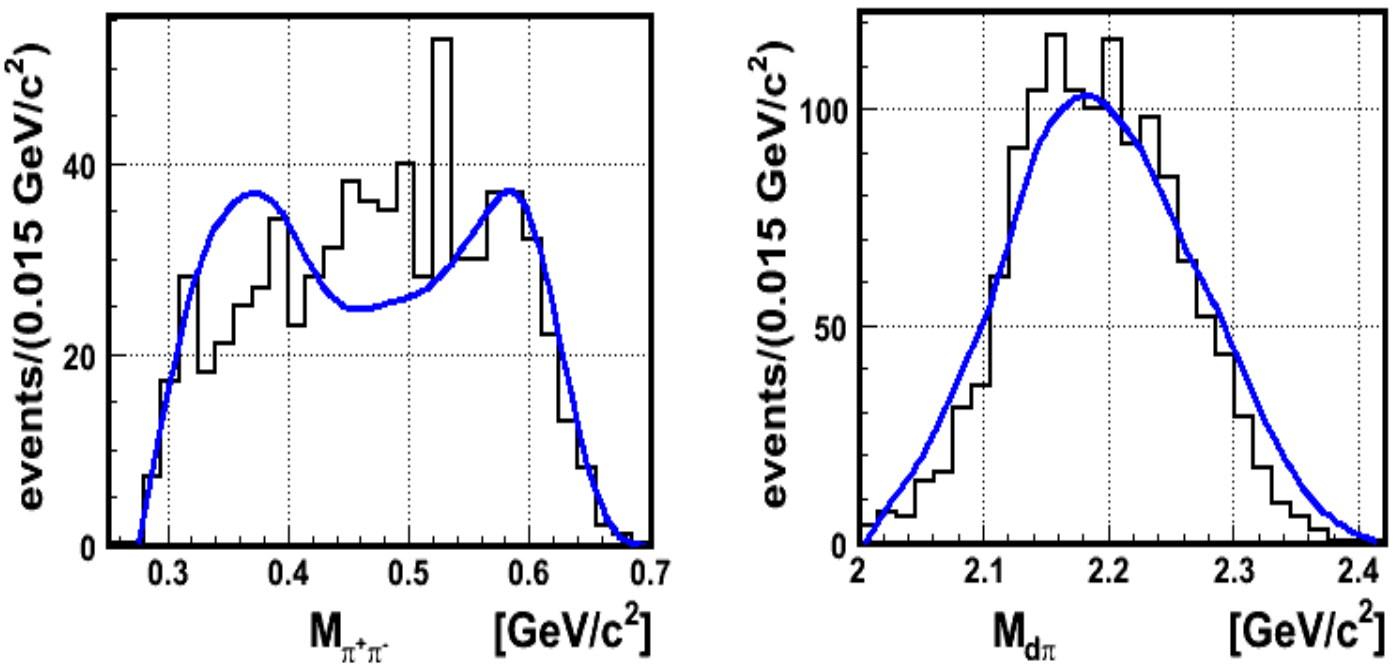


Fig.20. The distributions for the reaction *np* → *d* π^+ π^- at P_0=2.23 GeV/c. Solid line – calculations using OBE-model.

5. Other reactions

- **$np \to nn\,\pi^+\pi^0$ (no data)** – isotopically conjugated to the reaction $np \to np\pi^+\pi^-$
- **$np \to np\,\pi^0\pi^0$ (no data)**

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

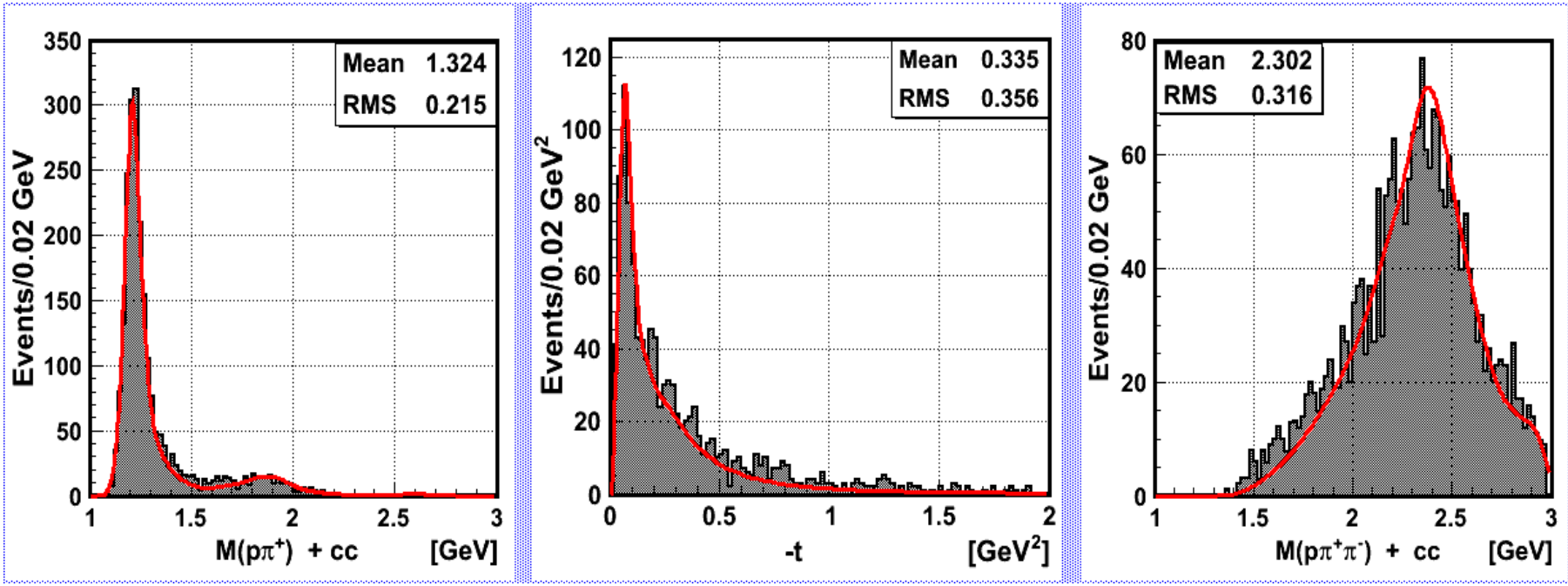
- **$np \to d\,\pi^0\pi^0$ (no data)**

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

Example:

Reaction pbar p → pbar p $\pi^+ \pi^-$ at P_0 = 7.23 GeV/c

Using OPER model we try to describe the experimental distributions from the reaction **pbar p → pbar p $\pi^+ \pi^-$** at P_0 = 7.23 GeV/c



It is observed a good agreement between experimental data and theory.

6. Conclusion

- **2π-mesons production in np-interaction is provided by the excitation and decay of Δ^* and N^* - resonances (especially in $\Delta\Delta$ subreaction). reaction $np \to d\,\pi^+\,\pi^-$.**

- **The large peripherality of the secondary hadrons leads to the idea to use some exchange models (π, P etc. exchange).**

- **It was shown that decrease of the incident energy ($P_0 < 3$ GeV/c) lead to the necessity to take into account the baryon exchange (N and Δ).**

- **(OPER+OBE) – model permits to get a good description of the characteristics of $np \to np\pi^+\,\pi^-$ and $np \to pp\,\pi^-\,\pi^0$ reactions. To get a satisfactory description of the reaction $np \to d\,\pi^+\,\pi^-$ it is neseccary the further development of OBE model.**

P.S. **(OPER+OBE) – model can be used as an effective tool to simulate various reactions of hadron interactions.**

References:

- **Experiment and data processing**

1. A.P.Gasparian et al. Prib.Tekh.Eksp., 77, N2 (1977), pp. 37-42.
2. C.Besliu et al. YaF 43 (1986), pp. 888-892.

- **OPER-model**

3. *L.Ponomarev*. **Part. and Nucl.**, v.7(1), pp. 186-248, 1976, JINR, Dubna (in russian).
4. *A.P.Jerusalimov et al*. Study of the Reaction **np** → **np**π^+ π^- at Intermediate Energies. http://arxiv.org/pdf/1102.1574.pdf
5. *A.P.Jerusalimov et al*. Analysis of the Reaction **np** → **np**π^+ π^- from the point of view of The OPER-model. http://arxiv.org/pdf/1203.3330.pdf
6. *A.P.Jerusalimov*. Contribution of the 'hanged' diagrams into the reaction **np** → **np**π^+ π^- at Intermediate Energies. http://arxiv.org/pdf/1208.3982v1.pdf

- **OBE-model**

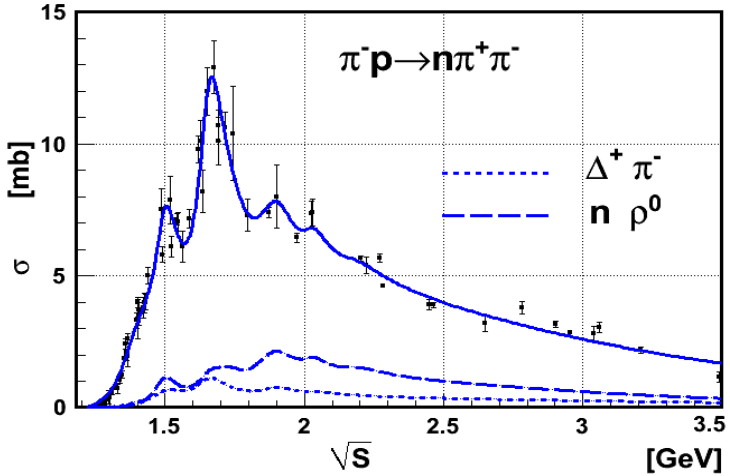
7. *A.B. Kaydalov and A.F. Nilov*. **YaF**, v.41(3),pp. 768-776, 1985 ; **YaF**, v.52(6), pp. 1683-1696, 1990.
8. NN and ND interactions - a compilation. **UCRL**-20000 NN, august 1970.
9. *V.Barashenkov and B.Kostenko*. JINR Comm. 4-84-761, 1984, JINR, Dubna. (in russian).

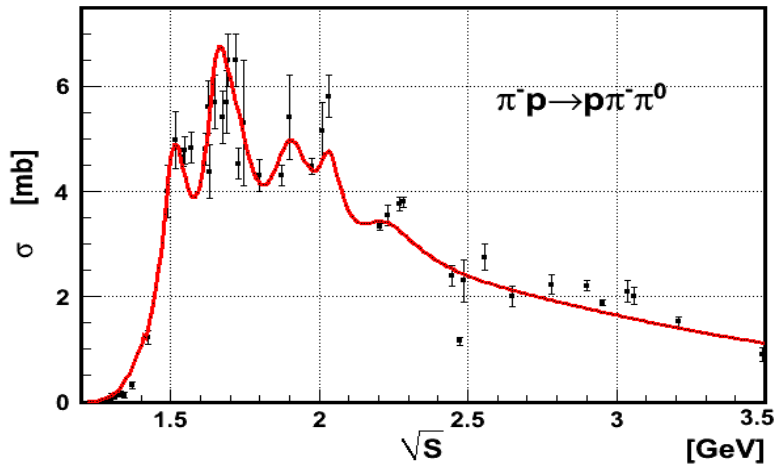
- **Other models**

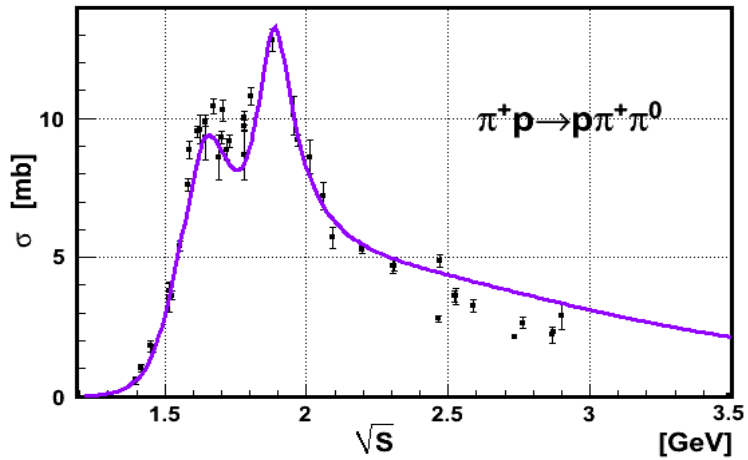
10. L. Alvarez-Ruso, E. Oset, E. Hernandez. NP A633, 519 (1998).
11. Xu Cao, Bing-Song Zou and Hu-Shan Xu. PR C81, 065201 (2010).

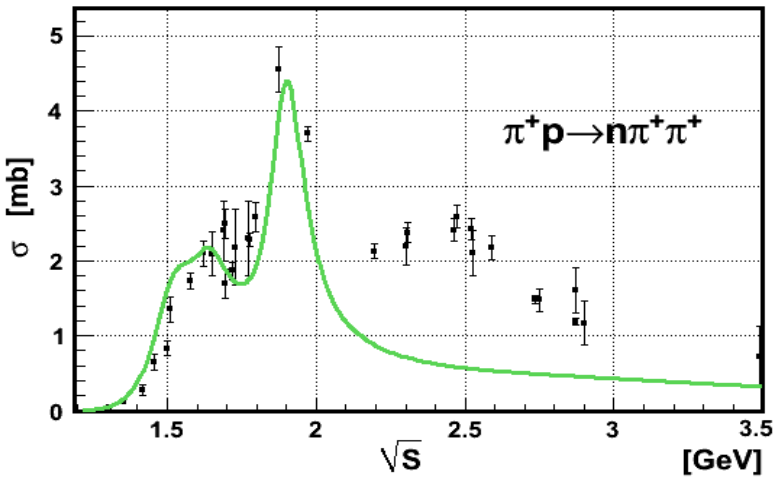
Thank You
for
attention !

The following cross-sections were calculated using **GIM** :









One can see a satisfactory description of cross-sections, except $\pi^+ p \to n \pi^+ \pi^+$

May be it is necessary to put into **GIM** **S**-wave of $\pi^+\pi^+$ scattering with **I**=2.