Elastic np- Scattering at Intermediate Energies

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Outlook

1. Introduction
2. Selection of the *np→np* reaction
3. Experimental results
4. Pole model for elastic *np scattering*
5. Conclusion

1. Introduction

This work continue the study of np-interactions at the momenta of the neutrons 1÷5 GeV/c^2 and is devoted now to the study of elastic scattering.

The world data of elastic np-scattering were obtained many years ago and are very poor and incomplete. It is especially concerned so called charge exchange scattering.

The present study was carried out using the data obtained in an exposure of 1-*m* HBC of LHE (JINR) to a quasimonochromatic neutron beam with $\Delta P_n/P_n \approx 2.5\%$ and $\Delta\Omega_n \approx 10^{-7}$ sterad due to the acceleration of deuterons by synchrophasotron of LHE-JINR.

The accuracy of the momenta of secondary protons from the reaction is $\Delta P_p/P_p \approx 2.0\%$. The angular accuracy is $\leq 0.5^{\circ}$.

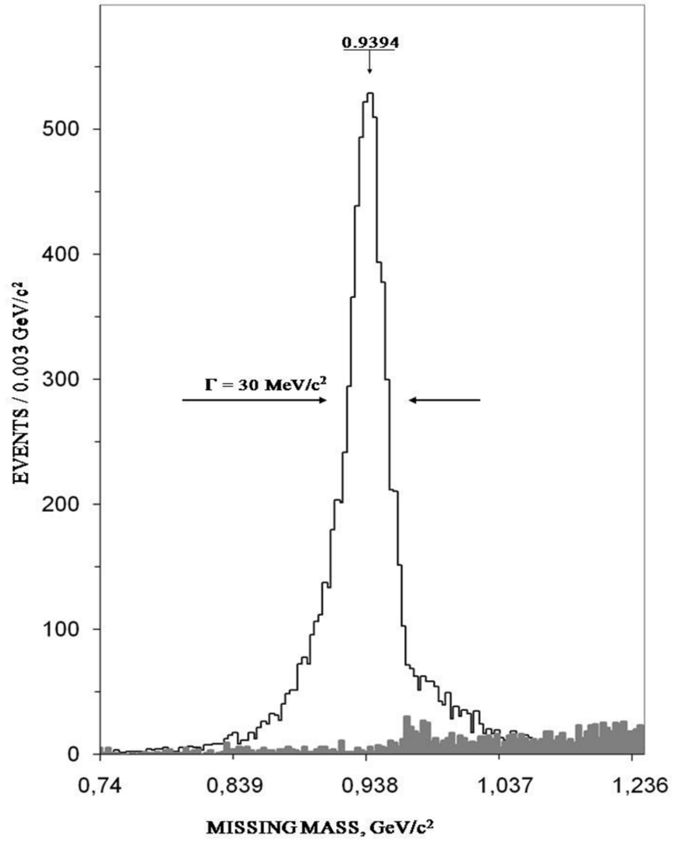
2. Selection of the elastic channel

The reaction **np→np** at the **P_n=1.43**, **2.23** and **5.20** GeV/c2 was separated by the standard χ^2–method.

The selected events were attributed as **elastic** np-interactions (**“El” set**) and other – **inelastic** one (**“Inel” set**).

The separation of elastic events using only missing mass procedure (like in most early studies) leads to an significant admixture of inelastic events (5÷15 %).

In Fig. it is shown the missing mass distribution at P_0=2.23 GeV/c. **Black bins** – events from (“Inel” set). The admixture of inelastic events leads to the error in determination of the elastic and inelastic cross-sections and to a distortion of the experimental distributions.

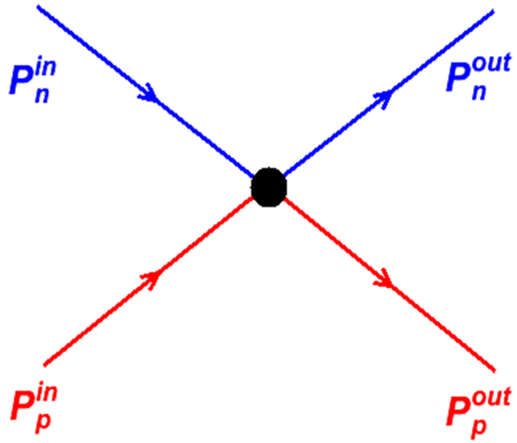


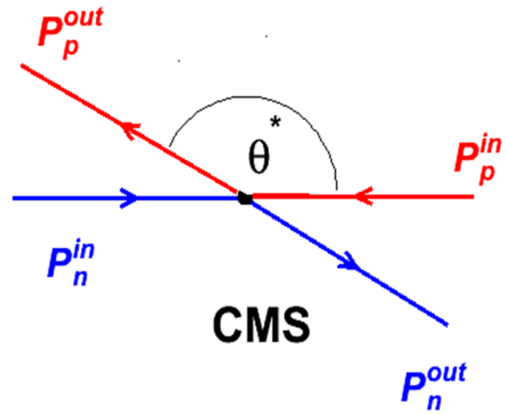
3. Experimental results

The characteristics of events from **"El" set**:

- 4π geometry
- a good determined parameters of primary and secondary particles
- a negligible admixture of inelastic events

Kinematics of the reaction **np→np** ⟶





2 groups of events:

↓

Forward scattering ($cos\Theta_p^* < 0$)
reaction without charge exchange ("0.ex"),
variable $t=(P_p^{in}-P_p^{out})^2$

Backward scattering ($cos\Theta_p^* > 0$)
reaction with charge exchange ("ch.ex"),
variable $u=(P_n^{in}-P_p^{out})^2$

The specifics of the bubble chamber results in the loss of the low energy protons.

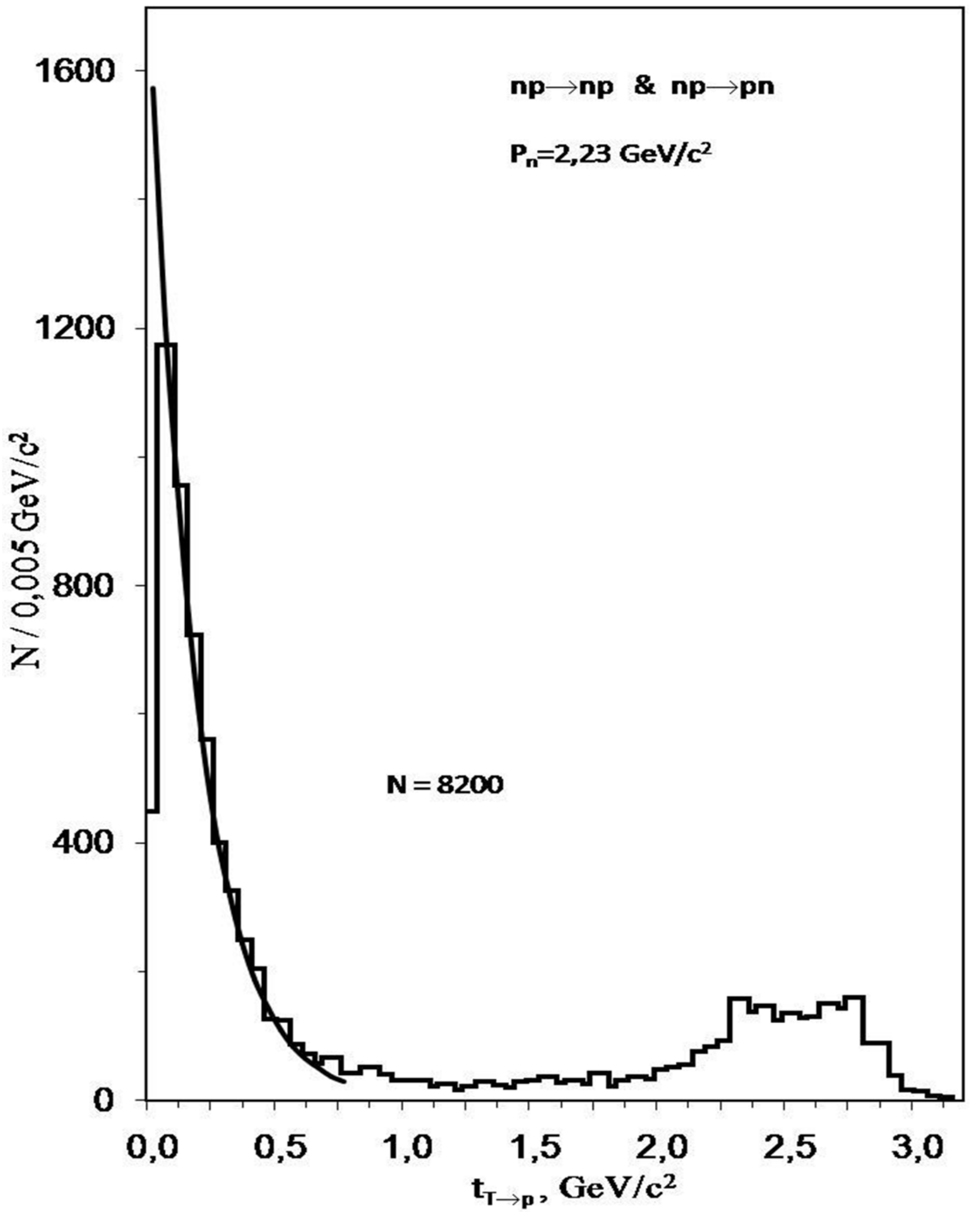
That leads to a deficit of the events with small 4-momentum transfers **t** (see Fig. for P_0=2.23 GeV/c) →

To determine the number of lost events the distribution on **t** was approximated by the function of the type $\mathbf{Ae^{-bt}}$ in the range 0.05 GeV^2<|**t**| < 0.75 GeV^2 .

The extrapolation to the value |**t**|=0 permits to correct the number of elastic events from **“El” set**.

The determination of the loss for the events from **“Inel” set** was done by the same manner.

This procedure permits to correct both the number of elastic events and the total number of 1-prong events to calculate the corresponding cross-sections



The cross-section of the elastic scattering was calculated by the formula

$$\sigma_{el} = (N_{el}/N^{1}_{tot})\ \sigma^{1}_{top}$$

where N_{el} – the number of elastic events,

N^{1}_{tot} – the total number of 1-prong events,

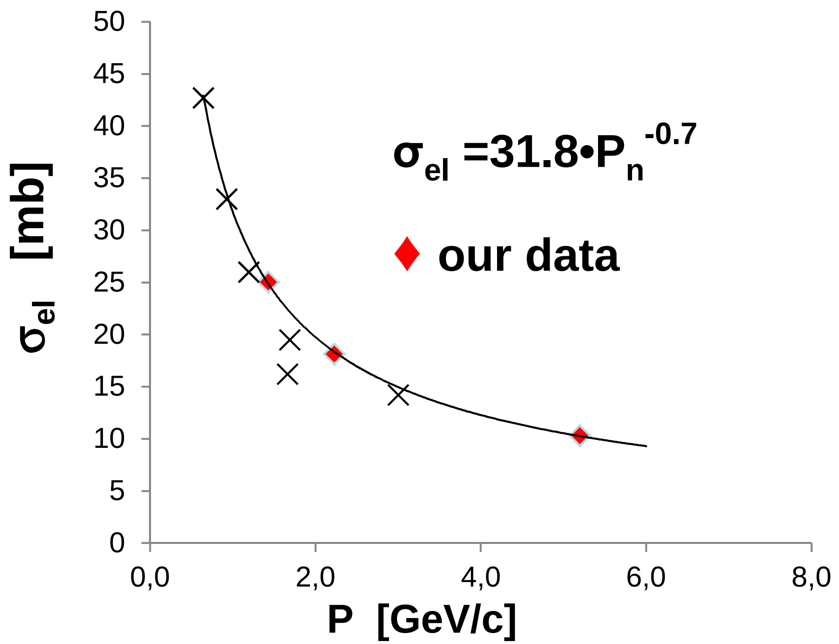
σ^{1}_{top} – the topological cross-section of 1-prong stars.

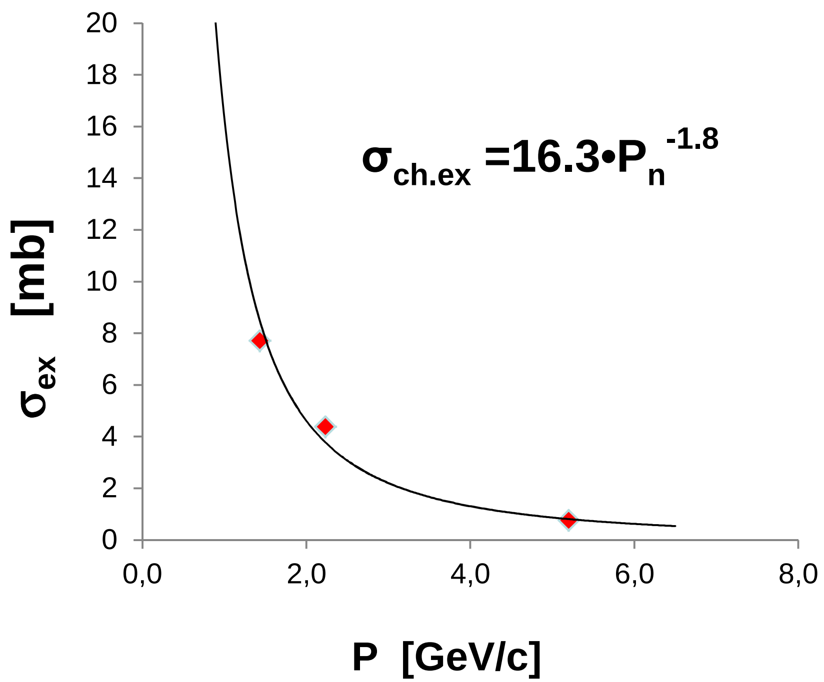
The charge exchange cross-sections was calculated by the formula

$$\sigma_{ch.ex} = (N_{el}(\cos\Theta_p^* > 0)/\ N_{el})\ \sigma_{el}$$ (no loss of low energy protons **!**).

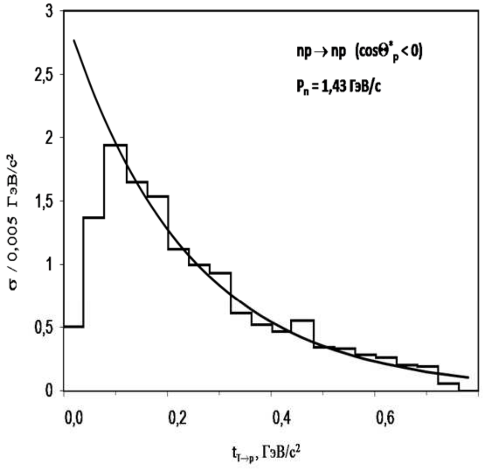
The “pure” elastic cross-sections was calculated by the formula

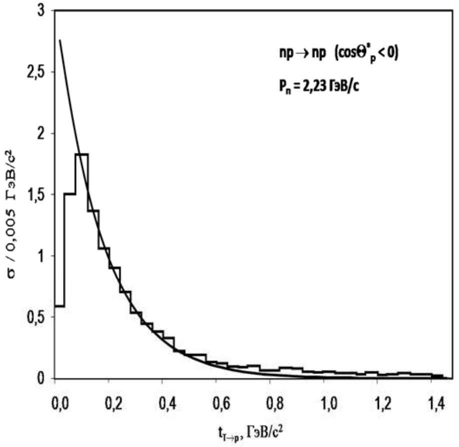
$$\sigma_{0.ex} = \sigma_{el} - \sigma_{ch.ex}\ .$$

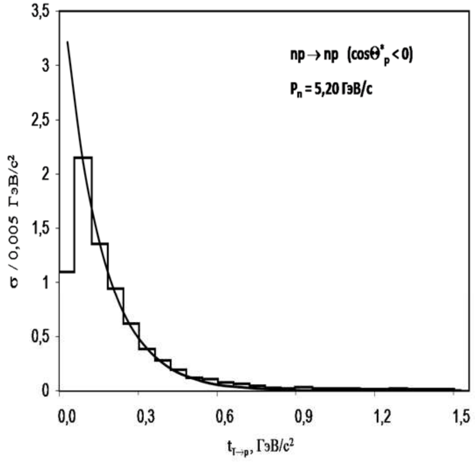


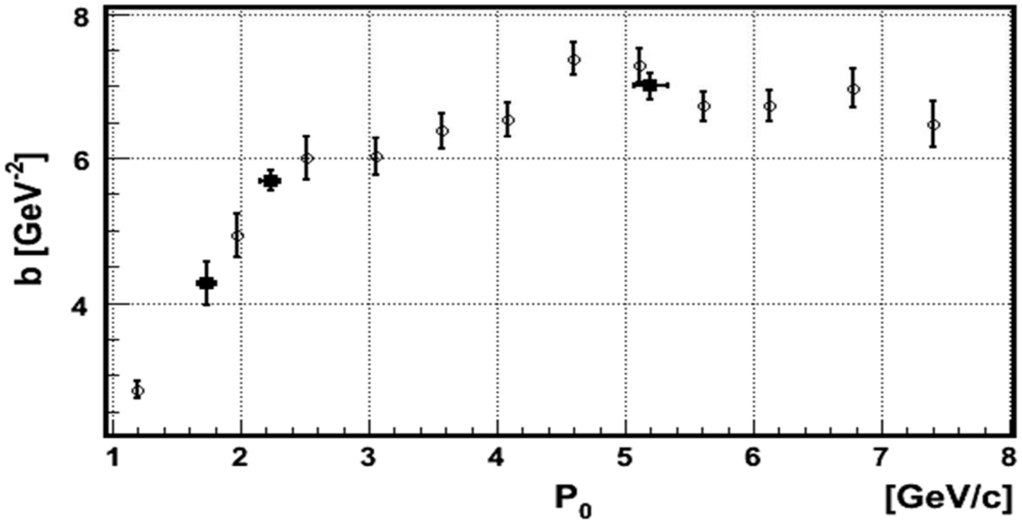


There were determined the slope parameter **b** for “pure” elastic (“0.ex”) distributions of dσ/dt:









█ – our data

O – data from [NN and ND interactions - a compilation. **UCRL**-20000 NN, august 1970.]

Other results are presented in Table

Pn [GeV/c]	1.43	2.23	5.20
σ_{el} [mb]	25.05±0.3	18.14±0.4	10.31±0.5
$\sigma_{ch.ex}$ [mb]	7.72±0,3	4.39±0.3	0.77±0.5
$\sigma_{0.ex}$ [mb]	17.33±0.3	13.75±0.4	9.54±0.5
$d\sigma_{0.ex}/dt\|_{t=0}$ (mb/GeV^2)	72.6	73.3	59.3
$d\sigma_{ch.ex}/du\|_{t=0}$ (mb/GeV^2)	42.6	21.1	5.0

4. Pole model for elastic np scattering

np→**np** reaction is described by the following diagrams:

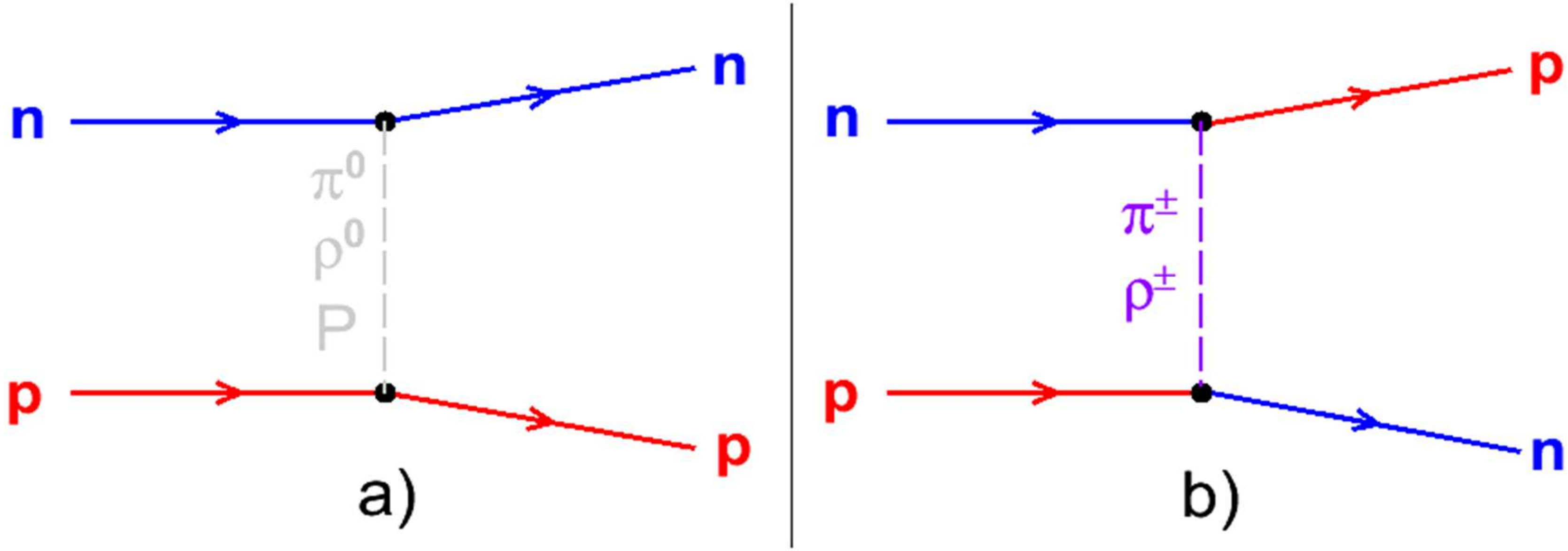


Diagram a) corresponds to “pure” elastic scattering with exchange by neutral particles:

$\boldsymbol{\pi^0}$-meson, $\boldsymbol{\rho^0}$-meson and pomeron (**P**).

Diagram b) corresponds to charge exchange scattering with exchange by charged particles:

$\boldsymbol{\pi^\pm}$-meson and $\boldsymbol{\rho^\pm}$-meson.

The exchange by other mesons ($\boldsymbol{\omega^0}$, $\mathbf{A_2}$, etc.) does not concidered.

The differential cross-section for the reaction **np→np** is written as:

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s q^2} |T|^2$$

where **s** – square of total energy in CMS,

q – momentum of the incident particles in CMS,

$|T|^2$ – square of the matrix element of the reaction.

For charge exchange np scattering the matrix element is written

$$|T_{ch.ex}|^2 = |T_\pi + T_\rho|^2$$

where $T_\pi = F \frac{t A_\pi}{t - m_\pi^2} F$ corresponds to $\pi^\pm$-meson exchange

and $T_\rho = F \frac{A_\rho e^{i\varphi}}{t - m_\rho^2} F$ corresponds to $\rho^\pm$-meson exchange.

A_π and A_ρ – parameters depending only on variable **s**,

φ – shift between π and ρ amplitudes of scattering.

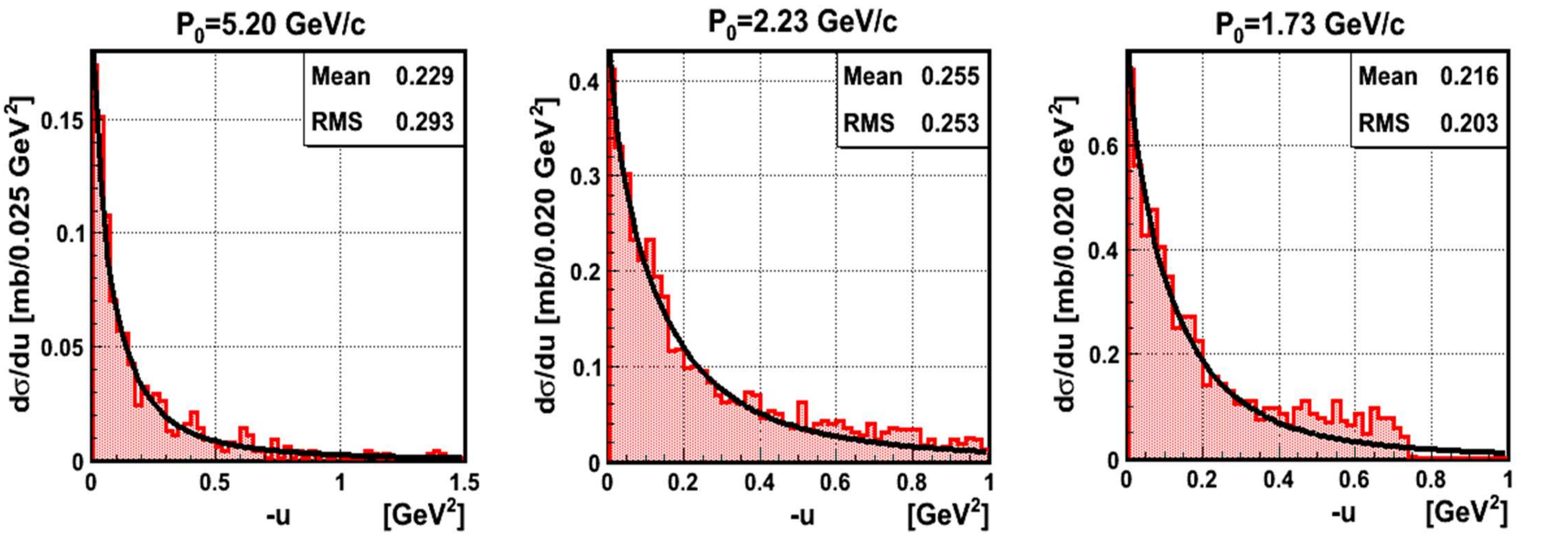
Nucleon formfactor **F** at each vertex was taken in the form

$$F(t) = \frac{\Lambda}{\Lambda - t}$$

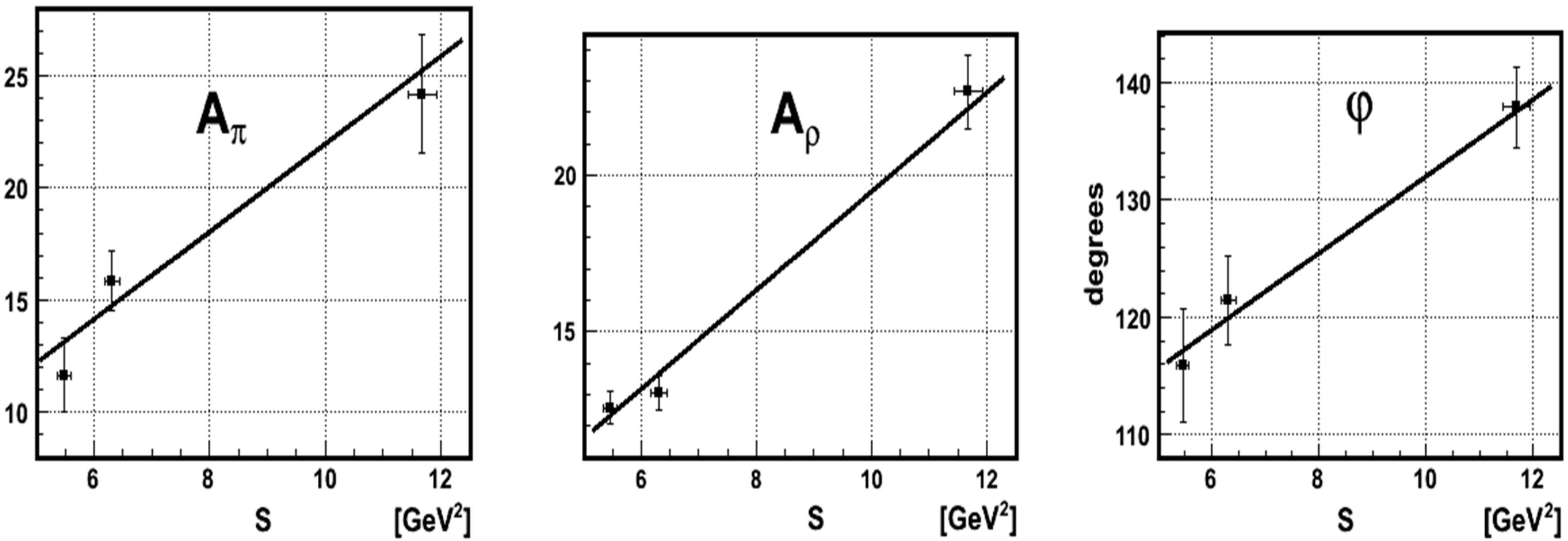
and depends only on variable t.

Parameter **Λ** was taken equal to $\mathbf{m_N^2}$.

In result it was obtained a good description of the differential cross-sections for charge exchange elastic **np→np** scattering at 3 energies:



The calculated parameters $\mathbf{A_\pi}$, $\mathbf{A_\rho}$ and $\boldsymbol{\varphi}$ are linearly dependent on **s** variable:



$$\mathbf{A_\pi} = 2.27 + 1.94s\ ,$$
$$\mathbf{A_\rho} = 3.25 + 1.64s\ ,$$
$$\boldsymbol{\varphi} = 99.4^0 + 3.3^0 s$$

For “pure” elastic np-scattering the matrix element was chosen in the following form:

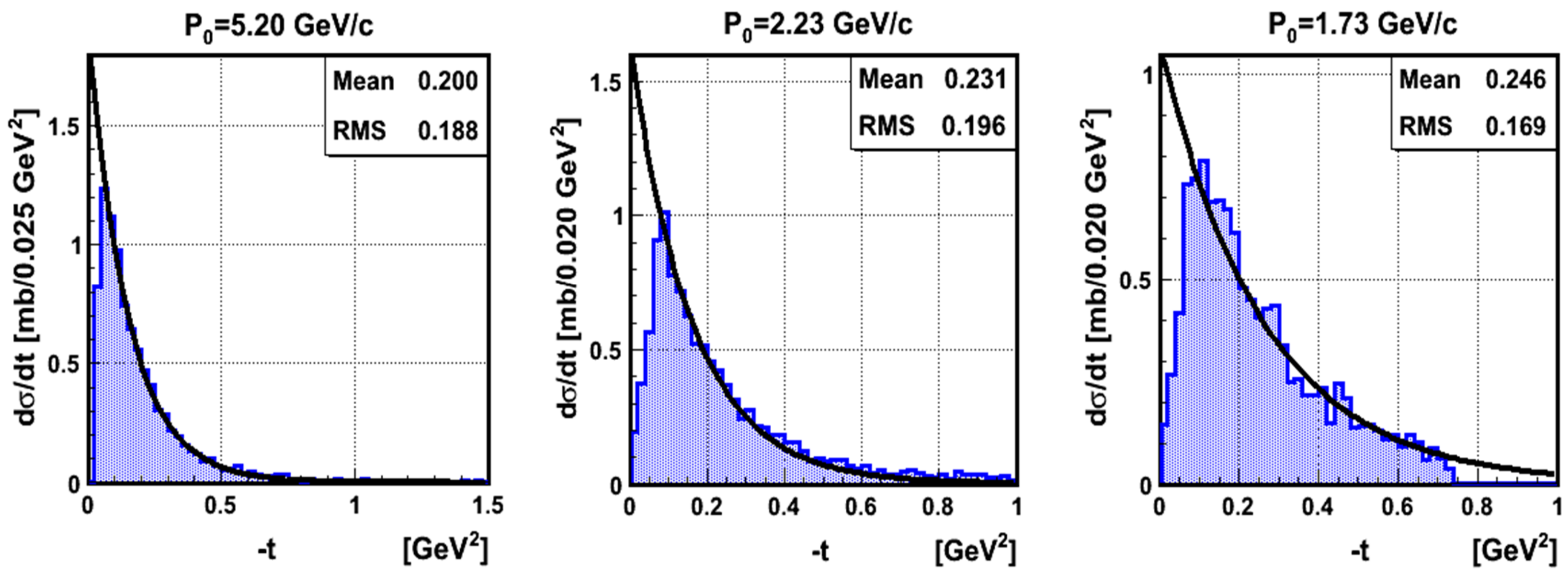
$$|T_{"0" ex}|^2 = \frac{1}{4}|T_\pi + T_\rho|^2 + |T_P|^2$$

where $T_P = A_P\, e^{bt}$ corresponds to pomeron exchange.

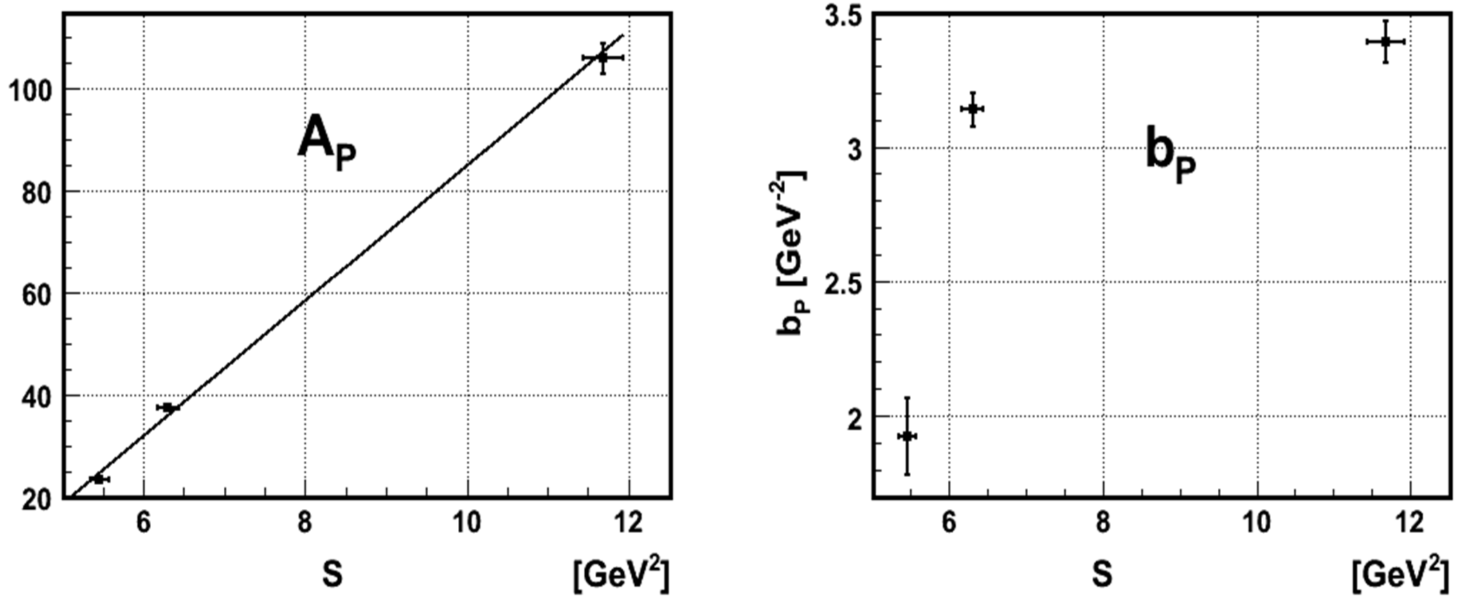
The interference between (π,ρ) and P-exchange is negligible.

The factor ¼ in the expression for $\mathbf{T}_{"0"ex}$ is due to isotopic relations.

The description of the differential cross-sections for “pure” elastic **np→np** scattering is presented in the figure below:



The dependence of the parameters $\mathbf{A_P}$ and $\mathbf{b_P}$ on variable **s** are shown in figure below:



One can see a linearly dependence on variable **s** for the parameter $\mathbf{A_P}$:

$$\mathbf{A_P} = -48.25+13.33\mathbf{s}$$

As far as concerned the parameter $\mathbf{b_P}$, its dependence on variable **s** is more complicate and may be it needs to construct some special function or to tabulate it.

The presented simple pole model provides a satisfactory description of the characteristics for elastic np→np scattering at the momenta of incident neutrons P_0 = 1.73÷5.20 GeV/c (S = 5÷12 GeV^2).

It was shown that it is necessary take into account the diagrams with pomeron exchange even at relatively small energies.

The model can be used to simulate reaction of elastic np→np scattering at various energies in the considered region (for example, for NICA/MPD project).

5. Conclusion

- **The present work was carried out to study the elastic np- scattering at intermediate energies. The used experimental methods permitted to select elastic events carefully and to do the analysis of them.**

- **The obtained results essentially supplement the data about the reaction of elastic np→np scattering especially for charge exchange channel.**

- **The simple pole model provides a satisfactory description of elastic np→np scattering and can be used to simulate the reaction at the intermediate energies (for example, for NICA/MPD project).**

Thanks for Your attention