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The Search and Study of Low-Mass Scalar σ_0-meson at the Impulse of Neutron Beam P_n = 3.83 GeV/c

The investigation has been performed at the Veksler and Baldin Laboratory of High Energies, JINR.

Dear colleagues, it is the twentieth ISHEPP

and, at previous seminars our group presented works,

devoted to different physical problems.

It is a tradition to speak about our researches at Baldin's Autumn

and also in our tradition to do it in Russian

Introduction

This work is devoted to the study of scalar $0^+[0^{++}]$ σ_0 - mesons in the $\pi^+\pi^-$ - system from the reaction $np \to np\pi^+\pi^-$

Investigation of light scalar mesons is important both
for understanding of the mechanism of realization of chiral symmetry
for corresponding Lagrangians
and for an adequate description of an attractive part
of the nucleon-nucleon interaction potential.

It was noted by dr. Pennington that light scalar mesons constitute Higgs sector of strong interactions and that ensures finite masses of all kinds of light hadrons.
They are interesting because they are fundamental.

The low-mass σ_0-mesons can become a powerful tool to study of new state of matter. Predictions about varying of the σ_0-meson properties in intermediate conditions are obtained in some papers (Volkov).

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

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

The accuracy of the momenta of secondary charged particles from the reaction $np \to np\pi^+\pi^-$ are:

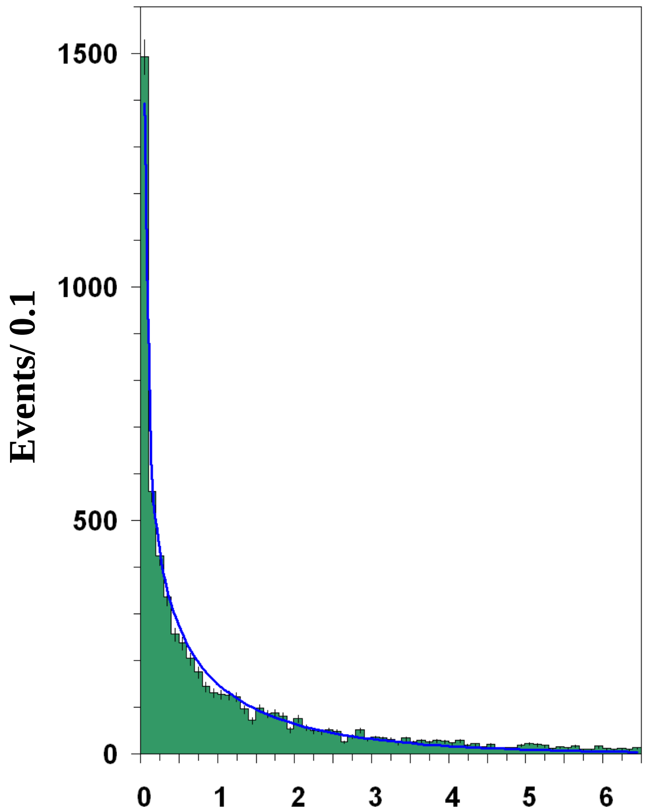
$\Delta P/P \approx 2\%$ for protons and $\Delta P/P \approx 3\%$ for π^+ and π^-.

The angular accuracy was $\leq 0.5°$.

The channels of the reactions were separated by the standard χ^2–method taking into account the corresponding coupling equations.

There is only one coupling equation for the parameters of the reaction $np \to np\pi^+\pi^-$ (energy conservation law) and the experimental χ^2–distribution must be the same as the theoretical χ^2–distribution with one degree of freedom.

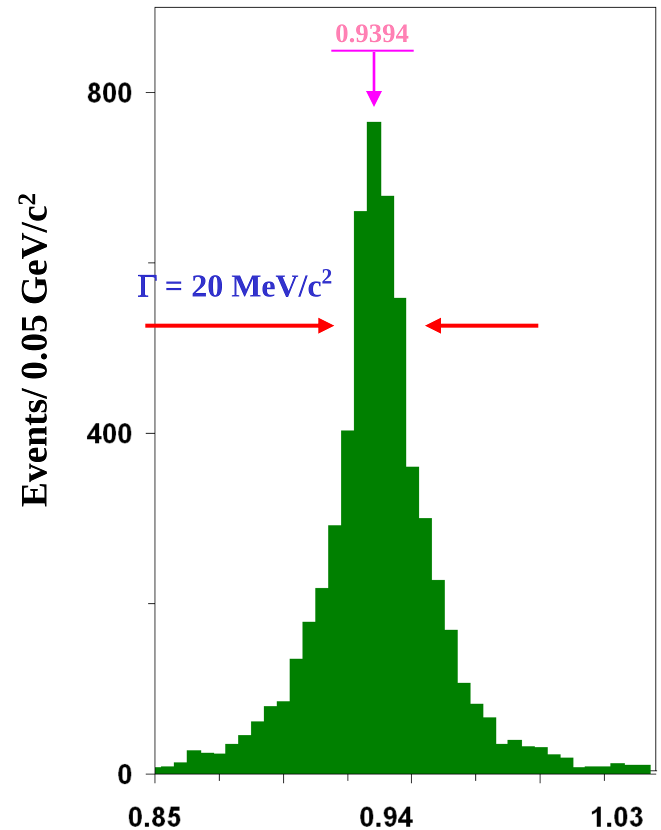
Reaction $np \to np\pi^+\pi^-$ at $P_n = 3.83$ GeV/c



The experimental (histogram)
and the theoretical (curve)
χ^2–distributions for the reaction
One can see a good agreement between them

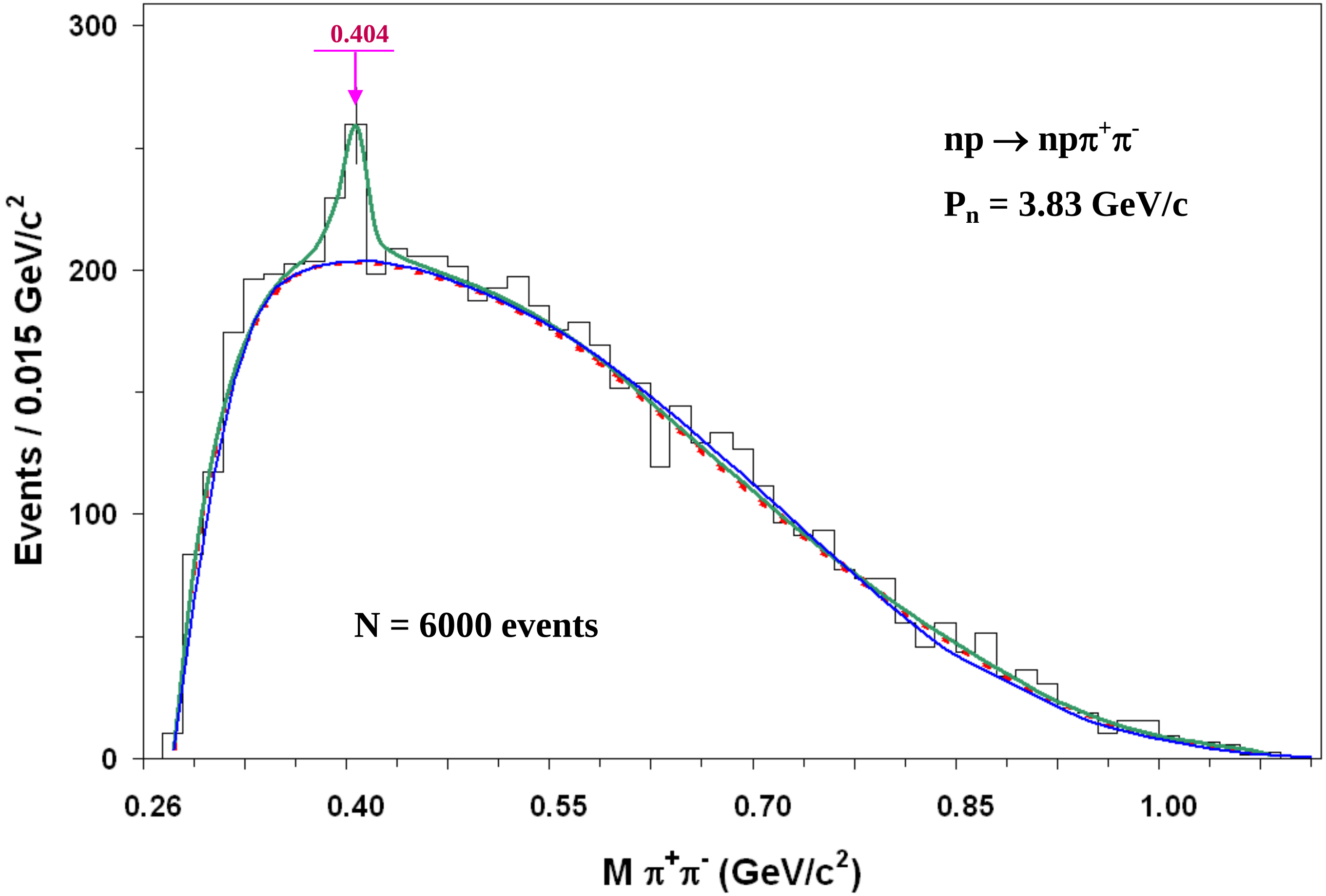
As a result,
6000 events
were selected
under the 4π geometry

an admixture
of other reactions
practically is absent



The missing mass (GeV/c^2) distribution
has the maximum at the value
equal to the neutron mass
with accuracy of 0.1 MeV/c^2,
the width at the half-height $20 MeV/c^2$
and is symmetric about the neutron mass.

The effective mass distribution of $\pi^+\pi^-$-combinations from the reaction $np \rightarrow np\pi^+\pi^-$ at P_n = 3.83 GeV/c



BACKGROUNDS:

Red line - up to 9th power Legendre polynomials. It describes this experimental distribution with $\overline{\chi^2} = 0.85 \pm 0.19$ and $\sqrt{D} = 1.41 \pm 0.13$ (without region of resonance)

Green line - the superposition of Legendre polynomials background and resonance curve taken in the Breit-Wigner form.

Blue line - calculated by means of OPER model

The results of approximation

$M_{Res} \pm \Delta M_{Res}$, MeV/c^2	$\Gamma_{Res} \pm \Delta\Gamma_{Res}$, MeV/c^2	S.D.	σ μb
404 ± 3	14 ± 3.8	4.2	86 ± 32

The first column contains
the experimental values of the resonance masses and their errors.
The second column contains
the experimental values of the total width of the resonances.
The third column contains
the statistical significances of the resonances, determined by formula: $S.D. = N_{Res.}/\sqrt{N_{back.}}$.
The fourth column contains
the resonance cross-sections.
For the cross sections errors, we have taken into account the cross section error for the reaction $np \rightarrow np\pi^+\pi^-$ **at** $P_n = 3.83 GeV/c$ **(** $\sigma_{np\rightarrow np\pi^+\pi^-} = (6.46 \pm 0.32)mb$ **)**

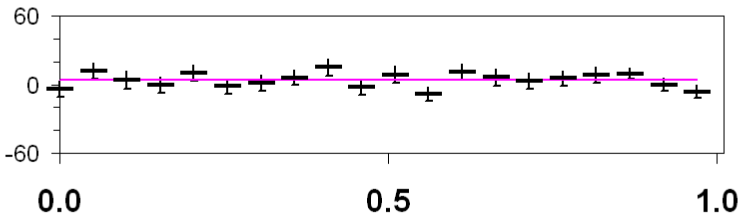
The mass resolution function grows with increasing mass as: $\Gamma_{res}(M) = 4.2\left[\left(M - \sum_{i=1}^{2} m_i\right)/0.1\right] + 2.8$,

where: M – the mass of the resonance, m_i – the rest mass of the particles composing this resonance, M and m_i are in GeV/c^2; coefficients 4.2 and 2.8 are in MeV/c^2.
The mass resolution for the resonance is 7.8 MeV/c^2.

The true width of the resonance, obtained by formula: $\Gamma_{Res}^{true} = \sqrt{\left(\Gamma_{Res}^{exp}\right)^2 - \left(\Gamma_{res}\right)^2}$, **is 10.4 MeV/c^2.**

We have tried to estimate the quantum numbers for the observed resonance in $\pi^+\pi^-$-system

The distributions of emission angles
of π^+ - meson
in the helicity coordinate system
(subtracted background)
are described by a sum of
even-power Legendre polynomial
with maximum power being equal to 2J,
where spin of the resonance $\geq$ J



The distribution is isotropic

G - parity

$G=(-1)^n$, where n is a number of rotations in charging space.
For the $\pi^+\pi^-$-system n=2 and G=+1

P - parity

The spin of the resonance J=0 => the orbital moment l=0
and $P=(-1)(-1)(-1)^l=+1$

C – parity

At performance of conditions of the CP – invariance, with positive parity, C=+1

Isotopic spin I

$G=C(-1)^I$, where I – isotopic spin of the system. This way, for our system, I=0 or I=2.
But there are no corresponding signal in the $\pi^-\pi^-$ -system from the reaction $np \rightarrow pp\pi^+\pi^-\pi^-$, which also have been studied by us. The peak with $M_{\pi^-\pi^-}$=0.397GeV/C^2 has J $\geq$6 and doesn't match a resonance observable now.
Isotopic spin of the resonance is I=0

The most probable spin
for the resonance is J=0

Thus, the peculiarity observed in our experiment, with a high probability, has quantum numbers

$I^G(J^{PC}) = 0^+(0^{++})$

and may be identified as σ_0 –meson

Conclusion

- **We have observed the resonance in the system** $\pi^+\pi^-$ **mesons from the reaction** $np \rightarrow np\pi^+\pi^-$ **at** $P_n = (3.83 \pm 0.08)\ GeV/c$ **with** $M_{\pi^+\pi^-} = 404 \pm 3 MeV/c^2$, $\Gamma = 14 \pm 3.8\ MeV/c^2$, **statistical significance S.D.= 4.2 and quantum numbers of** σ_0 **– meson** $0^+(0^{++})$
- **This effect corresponds to resonance with** $M_{\pi^+\pi^-} = 408\ MeV/c^2$ **from the reaction** $np \rightarrow np\pi^+\pi^-$ **at** $P_n = (5.20 \pm 0.12) GeV/c$**, presented at ISHEPP-XIX**
- **The main problem of this research is lack of statistics but these results is the good instruction for other experiments, such as HADES and NICA/MPD, considering necessity to study also other decay modes of** σ_0 **– meson.**
- **The study of** σ_0 **– mesons of hot and dense matter will give much information about the properties of this matter.**

We thanks dr. V.L. Lyuboshitz, dr. A.I. Malakhov, dr. M.V. Tokarev, dr. Yu.V. Zanevsky for the help in work and useful discussions.

THANKS for Your attention