USSR STATE COMMITTEE FOR UTILIZATION OF ATOMIC ENERGY

INSTITUTE FOR HIGH ENERGY PHYSICS

受入
88-7-391
高工研図書室

И Ф В Э 88-76
ОЭФ

V.D.Apokin, Yu.I.Arestov, N.I.Belikov, N.S.Borisov*),
A.A.Derevshchikov, O.A.Grachev, Yu.M.Kazarinov*),
B.A.Khachaturov*), V.Yu.Khodyrev, M.Yu.Liburg*),
V.N.Matafonov, Yu.A.Matulenko, A.P.Meshchanin,
A.I.Mysnik, A.B.Neganov*), S.B.Nurushev, A.F.Prudkogliad,
V.L.Rykov, L.F.Soloviev, V.L.Solovianov,
A.N.Vasiliev, Yu.A.Usov*)

DETERMINATION OF THE CROSS SECTION OF THE PROCESS $\pi^+\pi^- \to \pi^0\pi^0$ IN THE DIPION MASS RANGE $0.55<M<2.0$ GeV FROM THE REACTION $\pi^- p \to \pi^0\pi^0 n$ AT 39.1 GeV/c

Submitted to "Yad. Phys."

*) Joint Institute for Nuclear Research, Dubna

Serpukhov 1988

УДК 539.12.132.

М - 24

Abstract

Apokin V.D. et al. Determination of the Cross Section of the Process $\pi^+\pi^+ \to \pi^0\pi^0$ in the Dipion Mass Range $0.55 < M < 2.0$ GeV from the Reaction $\pi^- p \to \pi^0\pi^0 n$ at 39.1 GeV/c: IHEP Preprint 88-76. - Serpukhov, 1988. - p. 10, figs. 6, refs.: 22.

The total cross section for the process $\pi^+\pi^- \to \pi^0\pi^0$ in the dipion mass range M=0.55÷2.0 GeV has been determined from the peripheral transition $\pi^- \to \pi^0\pi^0$ on the carbon and propane-diol targets at the initial π^--momentum 39.1 GeV/c.

Аннотация

Апокин В.Д. и др. Сечение процесса $\pi^+\pi^- \to \pi^0\pi^0$ в области энергий в с.ц.м. $0{,}55 < M < 2$ ГэВ из реакции $\pi^- p \to \pi^0\pi^0 n$ при 39,1 ГэВ/с: Препринт ИФВЭ 88-76. - Серпухов, 1988.- 10 с., 6 рис., библиогр.: 22.

Полное сечение процесса $\pi^+\pi^- \to \pi^0\pi^0$ в области дипионных масс $0{,}55 < M < 2{,}0$ ГэВ определено из периферических переходов $\pi^- \to \pi^0\pi^0$ на углеродной и пропан-диоловой мишенях при начальном импульсе π^--мезонов 39.1 ГэВ/с.

© Институт физики высоких энергий, 1988

INTRODUCTION

The $\pi\pi$-scattering is an interaction of spinless particles which is the simplest case in the field theory. A pion can be considered as a simple $q\bar{q}$ state in additive quark approaches. In these two points lies the physical interest to the experimental study of the $\pi\pi$ vertex in the non-physical region.

Our recent knowledge of $\sigma(\pi\pi)$ is based on experiments at low initial energies[1-7]*). An impressive analysis has been made in ref.[8] for the transitions $\pi\pi \to \pi\pi$, $\pi\pi \to K\bar{K}$, $\pi\pi \to \eta\eta'$ and $P\bar{P} \to \pi\pi$. Peripherality of interaction was quite a significant assumption that led to the Chew-Low formula. As is known, at our initial energies the production amplitudes of quasi-two-body reactions are well factorized, and the $\pi\pi$ vertex can be, in principle, isolated.

Two main difficulties arise in experimental study. Firstly, how to extract the so-called pion exchange. Secondly, how to extrapolate the virtual $\pi\pi$-vertex to the physical point $t=m_\pi^2$ within the limited experimental statistics. The general consideration as well as experimental attemps (see, for example,[9]) show that the result of extrapolation can be strongly affected by the way of extrapolation. These problems are discussed in the text.

We have performed indirect measurements of the total cross section $\sigma_{\pi\pi}(M^2)$ for the reaction $\pi^+\pi^- \to \pi^0\pi^0$ with the centre-of-mass energy in the range $0.55 \leqslant M \leqslant 2.0$ GeV. For $M > 1$ GeV the normalized data are published for the first time. Our results are obtained as a by-product in the frame of the polarization experiment PROZA.

---

*) The list of refs. includes only experimental papers concerning the cross section for $\pi^+\pi^+ \to \pi^0\pi^0$.

1. DATA SELECTION AND DETECTOR EFFICIENCY

We study the quasi-elastic reaction

$$\pi^- C_{12} \to \pi^0\pi^0 + C_{12}^* \qquad (1)$$

on the carbon target at the initial momentum 39.1 GeV/c. The kinematic region is determined in terms of the momentum transfer squared $t'=t_{max}-t > 0$ and the dipion mass M:

$$0 \leqslant t' \leqslant 1.5 \text{ GeV}^2/c^2, \qquad (2)$$

$$0.55 \leqslant M \leqslant 2.0 \text{ GeV}.$$

In ref.[10] this reaction was investigated for the values of M in the f(1270) mass region in detail. The kinematic variables are shown on the peripheral Born diagram in Fig. 1.

The total statistics which covers kinematic region (2) and is used in the present analysis is $4.5 \cdot 10^4$ events. Besides we have two-pion events ($2.2 \cdot 10^5$ events) also off the polarized propane-diol target with a hydrogen component. Using the data on the carbon and "empty" targets we are able to extract the reaction

$$\pi^- p \to \pi^0\pi^0 + n \qquad (3)$$

in kinematic bounds (2). In the f(1270) mass region this reaction was studied in ref.[11].

The $\pi\pi$-cross section $\sigma_{\pi\pi}$ obtained in reaction (1) at each value of M is larger than that in reaction (3) by a factor $Z_{eff}(M^2,t)$. This factor, which is called an effective nuclear charge, is defined as a relation between differential cross section of reactions (1) and (3)[10]. Using standard subtraction procedure we have determined the differential cross section $d^2\sigma/dM^2dt$ for reaction (3) which is used to deduce the values of $\sigma_{\pi\pi}(M^2)$.

The description of the experimental set-up can be found in refs.[12,13]. On the first stage of the experiment the γ-detector-260 having 260 lead glass blocks was used. Later it was substituted by a bigger detector-800 with 800 lead glass blocks. Geometrical acceptance of the two detectors ($\theta_x \cdot \theta_y$ mrad^2) is characterized by the following angles: $78 \cdot 46$ mrad^2 - for the detector-260, and $77 \cdot 60$ mrad^2 - for the detector-800. The detectors were installed at the distances of 5.4 and 7.9 m from the target, respectively. The available statistics for reactions (1) and (3) are the mixture of two samples of events obtained with two different γ-detectors.

For the analysis four-γ-events were selected with the total energy $E_{4\gamma}=39\pm5$ GeV. The forward (in the general c.m. system) production of two pions with extreme total energy is required for quasi-elasticity of reactions (1) and (3). This energy cut is discussed in ref./10/. Also this energy cut supports the idea of the peripheral production of the two-pion-system due to a large distance between dipion and recoil particle in the rapidity scale.

Each two γ's forming π^0 were examined by $\cos\theta^*_{\gamma\gamma}$ distribution ($\theta^*_{\gamma\gamma}$ is the decay angle in the pion rest frame). The cut $|\cos\theta^*_{\gamma\gamma}|< 0.8$ was accepted to limit ourselves by the uniform $\cos\theta^*_{\gamma\gamma}$-distribution.

Other cuts including t-depending conditions are listed in refs./10,11/.

For extrapolation procedure we used the events with small momentum transfers $-t < 0.1$ GeV^2/c^2. This sample consists of $3\cdot10^4$ events for the carbon target and $1.45\cdot10^5$ events for the propane-diol target.

Absolute normalization depends strongly on the detection efficiency for two-pion events. This problem looks as a serious one in the f(1270) mass region due to spin 2 of the resonance. The acceptance of the detectors is limited by $|\cos\theta^*| \leqslant 0.6$ where θ^* is the decay angle for the process $f(1270)\to\pi^0\pi^0$ in the f(1270)-rest frame. We treat this problem in refs./10,11/. To solve this problem, one should, first, estimate the value of the S-D wave interference in $\pi^0\pi^0$ production. Second, one should estimate the f(1270) production cross section in the unobservable region $|\cos\theta^*| > 0.6$. Using the new data on the polarization asymmetry in reaction (3)/14/, we can evaluate the S-D interference. It turns out to be at the background level. This allows one to reasonably determine the contribution of the Breit-Wigner peak in the observed region $|\cos\theta^*| < 0.6$. Extrapolation to the region $|\cos\theta^*| > 0.6$ has been performed using the spin density matrix for the decay $f(1270)\to\pi^0\pi^0$ from ref./15/. Uncertainties of this approach lead to a systematic error of $\leqslant 25\%$ in estimating the cross section $\sigma_{\pi\pi}(M^2)$.

For the present investigation we have recalculated the efficiency function in the selected interval $-t \leqslant 0.1$ GeV^2/c^2 with small step $\Delta t=0.02$ GeV^2/c^2. We used the modified spin density matrix elements from ref./15/ as was done in refs./10,11/. In the mass region of $M < 1.04$ GeV and $1.54 < M < 2.0$ GeV the detection efficiency was determined as a function of M and t assuming the uniform distribution in $\cos\theta^*$ (and ϕ^*).

2. SOME REMARKS ABOUT "PION" EXCHANGE

How strong are the arguments which imply the pion-exchange dominance in the process in Fig. 1? The most serious evidence for the pion exchange is the energy dependence of the experimental cross section of reaction (3). It is described by the expression $\sigma \sim S^{-n}$, where $n=2.7\pm 0.2$ in the f(1270) mass region[11] and $n=2.3\pm 0.2$ in the low mass region ($M < 1$ GeV)[16].

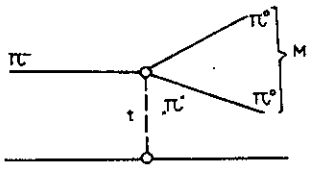

Fig. 1. The graph for the peripheral production in reactions (1) and (3).

The absence of the $\rho^0(770)$ state in the upper vertex (see Fig. 1) leads to a weak influence or almost absence of A_1 and A_2 exchanges. Nevertheless, the experimental data on polarization asymmetry in reaction (3)[14] argue for additional terms in the production amplitude (Fig. 1). The asymmetry is on the level $\simeq -0.1$ in the dipion mass region $M \leqslant 1$ GeV, and this value is larger by a factor of ~ 3 in the f(1270) mass region. In terms of exchanges this can be interpreted as a result of interference of the pion exchange and additional exchange.

After all we conclude that the pion exchange in process (3) (Fig. 1) is dominant at small $-t$ although the experimental data do not exclude the small fraction of additional exchanges.

3. BASIC FORMULA

We use the relation

$$\sigma_{\pi\pi}(M^2,\ m_\pi^2,\ t) = \left[\frac{4\pi}{g}\right]^2 \frac{\lambda^2(S,m_\pi^2,m_N^2)}{m_\pi^2\lambda(M^2,m_\pi^2,t)} \frac{(t-m_\pi^2)^2}{F(t)} \frac{d^2\sigma}{dM^2dt}. \quad (4)$$

Here m_π, m_N and M denote the pion, nucleon and dipion masses, respectively. F(t) is a form-factor of the Benecke-Durr type $\exp[a(t-m_\pi^2)]$ [17] which is normalized to 1 at the point $t=m_\pi^2$. The exponential slope a depends on the mass M (see, for example, ref.[18]). Within the experimental er-

rors the value $a \approx 5.0$ GeV$^{-2}/c^{-2}$ is relevant to our data in the f(1270) region as well as to the data in ref./18/. In practice possible deviations of the slope a do not affect the final result due to small values of -t used in the extrapolation. The πNN coupling constant is defined by $g^2/4\pi = 29.0$, and $\lambda(x,y,z)$ is the known kinematic function. In expression (4) we have omitted the efficiency function. The limit of expression (4) at $t \to m_\pi^2$ is denoted by $\sigma_{\pi\pi}(M^2)$, which is used throughout the paper.

In each interval of the dipion mass M we measured the t-distributions in the region $-t \leqslant 0.1$ GeV$^2/c^2$ in five bins (with step $\Delta t = 0.02$ GeV$^2/c^2$) and weighted them as shown in (4). Extrapolation to the point $t = m_\pi^2$ was performed via straight line fit with five points. There was also four-point fits with one t-interval dropped out. Within the sizable errors we did not attempt to compare the straight lines with other extrapolation functions (see ref./9/). Finally we note that the substitution of $F(t) \equiv 1$ into (4) changes our results on $\sigma_{\pi\pi}(M^2)$ insignificantly.

4. EXPERIMENTAL RESULTS

At $-t \to 0$ the detection efficiency appears to be small for the dipion masses M close to threshold due to the holes in the centre of the γ-detectors. Besides at $M \approx 0.5$ GeV a narrow peak in the $\pi^0\pi^0$ mass distribution is observed which comes from the decay of short-living neutral kaons. This is why a lower limit 0.55 GeV for M is chosen in (2).

4.1. Two-pion distributions

Below we describe kinematic distributions for reaction (1). Within the experimental errors the distributions for reactions (1) and (3) turn out to be very similar. And they differ only in their normalization. The errors quoted are statistical only. The estimation of systematic errors (see section 2) gives the values $\approx 15\%$ and $\approx 25\%$ out of and in the f(1270) mass region, respectively.

In Fig.2 the t'-distributions are presented for three mass regions: on the left of f(1270), f(1270)-region and the right of f(1270). Two exponential slopes are evidently seen. In the f(1270) mass region they are equal to 9.0 GeV$^{-2}/c^{-2}$ and 3.2 GeV$^{-2}/c^{-2}$. At topright of Fig.2 the same distributions are shown at $-t < 0.1$ GeV$^2/c^2$. A dip in the region $-t \leqslant m_\pi^2$ which is typical for pion exchange is

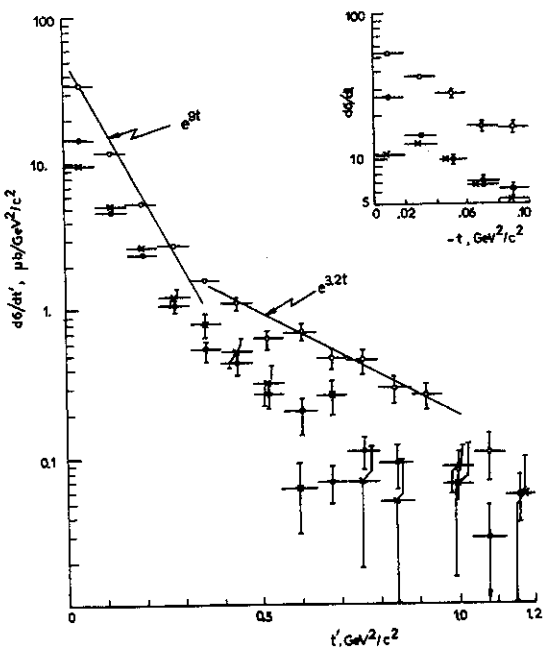

Fig. 2. t'-distribution of the $\pi^o\pi^o$ system in reaction (1) in different $\pi^o\pi^o$ mass intervals: e - $0.55 < M < 0.68$ GeV; o - $1.04 < M < 1.54$ GeV, x - $1.79 < M < 2.00$ GeV. The straight lines are drawn for comparison.

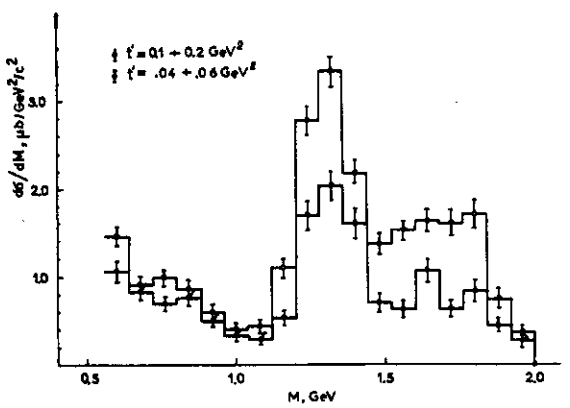

Fig. 3. Mass distribution of the two-pion system in reaction (1) for two t-intervals: $-t = 0.1 \div 0.2$ GeV$^2/c^2$, $-t = 0.04 \div 0.06$ GeV$^2/c^2$.

not seen due to rough binning. More fine binning would be beyond the experimental accuracy.

The mass distributions are shown in Fig.3. We have chosen two t-intervals. The interval $-t=0.1\div0.2$ GeV$^2/c^2$ gives a sizable contribution to the cross section, and the interval $-t=.04\text{-}.06$ GeV$^2/c^2$ is used for extrapolation procedure. The mass distributions exhibit a large peak with maximum at $M \simeq 1.3$ GeV, and they are smooth in the regions $M=0.55\text{-}1.0$ GeV and $M > 1.5$ GeV. The local minimum at $M=1.0\div1.1$ GeV which is seen in Fig. 3 was observed in all relevant experiments (see, for example, refs.[1-7]).

The $\cos\theta^*$-distributions at $-t=0.05\div0.1$ GeV$^2/c^2$ are shown in Fig.4 (θ^* is the decay angle of $\pi^o\pi^o$ system in the helicity rest frame). They are not corrected for detection efficiency. As is seen, the detector-260 acceptance is rather good in the mass region $M \leqslant 1.04$ GeV ($|\cos\theta^*| < 1$). For the f(1270)-meson and $M \geqslant 1.5$ GeV the acceptance decreases down to $|\cos\theta^*| = 0.65$ and 0.4, respectively.

Our results plotted in Figs.2-4 give a general insight into peripheral two-pion production in reactions (1) and (3) at 39 GeV/c.

4.2. Extrapolation and $\sigma_{\pi\pi}(M^2)$

Fig.5 demonstrates the t-dependence of the off-mass-shell $\pi\pi$ cross section $\sigma_{\pi\pi}(M^2, m_\pi^2, t)$ defined in section 4. The experimental errors are large, so we did not try to vary the fitting function. The straight-line fits to the physical point $t=m_\pi^2$ were performed with five points t_i. Some fits with various χ^2 are shown in Fig.5 (solid lines). The quality of the fitting procedure depends on statistics, and it is typical for such experiments.

We treat the results of such extrapolation as on-shell cross section $\sigma_{\pi\pi}(M^2)$ of the process $\pi^+\pi^- \to \pi^o\pi^o$. It is shown in Fig.6 and is compared with other experiments at $M < 1$ GeV. The wide peak at $M \simeq 1.25\text{-}1.35$ GeV is due to the f(1270) D-wave resonance. With M increasing from 0.55 to 1.05 GeV the cross section $\sigma_{\pi\pi}(M^2)$ decreases rapidly. In this region our data are consistent with the results of previous experiments at lower initial energies. These results within the errors are shown as a shaded area in Fig. 6. The large errors in our data at small M are explained by a small detection efficiency at small -t due to the holes in the centre of the γ-detectors. In the region $M < 1$ GeV the problem is why $\sigma_{\pi\pi}(M^2)$ is strongly exchanced.

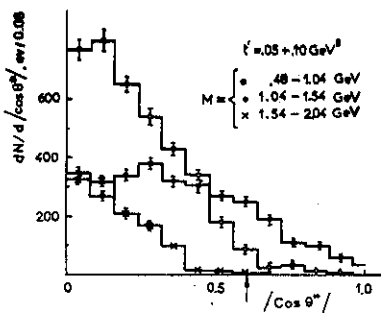

Fig. 4. cos θ^*-distributions in reaction (1) for $-t=0.05\div0.10$ GeV$^2/c^2$ in three mass intervals: M = =0.55÷1.04 GeV, M=1.04÷1.54 GeV, M=1.54÷2.00 GeV (not weighted by efficiency). The distributions are shown for the detector-260 only.

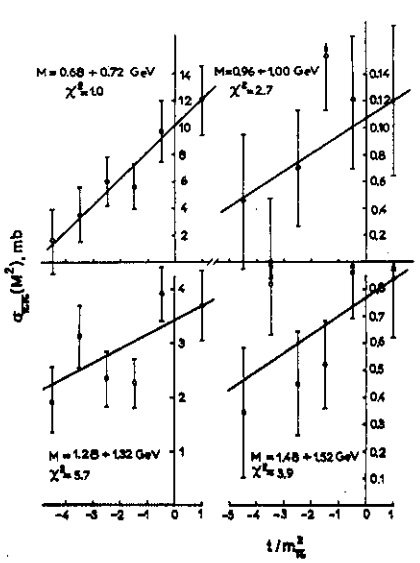

Fig. 5. t-dependence of the off-shell "pion-pion" cross section $\sigma_{\pi\pi}(M^2, m_\pi^2, t)$ for various values of M.

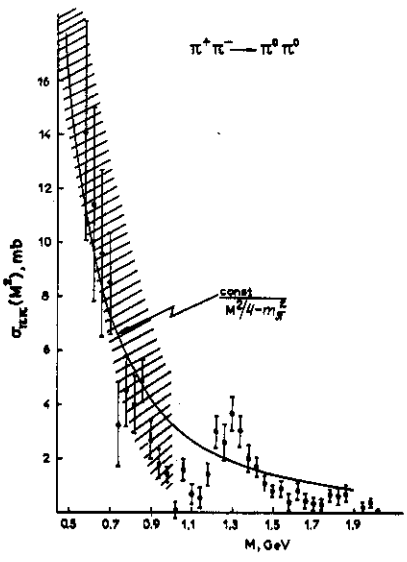

Fig. 6. The pion-pion cross section $\sigma_{\pi\pi}(M^2)$ for the reaction $\pi^+\pi^- \to \pi^0\pi^0$. Our data are compared with previous results (refs. /1, 5/) which are shown as a shaded area. The solid curve represents the Regge energy dependence for the ρ-pole contribution (in arbitrary units).

Is this a trivial near-threshold enhancement or a resonance influence? Ref.[2] suggests the existence of a very broad S-wave $\pi\pi$-resonance centred at M=600±100 MeV. But this statement seems to be alone.

As to the $\sigma_{\pi\pi}(M^2)$ fall-off at $M \simeq 1.0$-1.1 GeV, in principle, the two dynamical hypothesis can be proposed. First, near this point the densities of both S- and D-waves themselves go down to minimum. Second, the massive S- and D-wave interfere destructively in this mass region. Estimations of the S-wave density have been made in ref.[2] at 10 GeV/c, in ref.[8] at 22 GeV/c, in ref.[19] at 25 GeV/c. They all exhibit minimum near M=1 GeV. Hence they seem to support the first hypothesis.

On the other hand, the magnitude of the cosine of the relative S-D phase measured in refs.[19,20] can be sizable in this mass region. This indicates a certain contribution which comes from the S-D interference. The last statement holds within the large experimental errors.

Numerous discussions on the wave structure of the $\pi\pi \to \pi\pi$ cross section are summarized in ref.[21] including the estimations in the chiral limit.

The cross section $\sigma_{\pi\pi}(M^2)$ in the mass region $1.5 < M < 2.0$ GeV is small as shown in Fig.6, and it exhibits no clear structure.

The invariant $\pi^0\pi^0$ masses measured in this work are rather far from $\pi\pi$-threshold. So the comparison of the cross section $\sigma_{\pi\pi}(M^2)$ with the Regge-type behaviour seems reasonable. The solid line in Fig.6 shows the energy dependence $\sim 1/M^2$ which follows from the leading ρ-pole contribution. A similar behaviour has been investigated in ref.[22] for transitions $\pi\pi \to \pi\eta$, $\eta\eta'$ and $\phi\pi^0$.

The $\pi^0\pi^0$ mass spectrum below $\leqslant 2$ GeV can be probably saturated by various resonances: S(975), ε(1300), f(1270), h(2030). According to the dual conception, the Regge dependence $1/M^2$ can be considered as an averaged behaviour of the $\pi\pi$ cross section over the resonance region (Fig.6).

CONCLUSION

Finally, our results have been obtained at the highest initial momentum so far used to extract cross section $\sigma_{\pi\pi}(M^2)$ of the process $\pi^+\pi^- \to \pi^0\pi^0$. This makes a factorizability hypothesis for the production amplitudes more reliable than that at the initial momenta of some GeV/c's. Our

values of $\sigma_{\pi\pi}(M^2)$ at $M \leqslant 1$ GeV are close to other data within the errors. The new results have been obtained for the dipion mass range $1 \leqslant M \leqslant 2$ GeV. The non-resonance cross-section of the reaction $\pi^+\pi^- \to \pi^0\pi^0$ in this mass interval is on the level 0.5-1 mb with an increase up to $\simeq 4$ mb in the f(1270) mass region.

It is a pleasure for authors to thank Dr. A.Bel'kov for fruitful discussions.

References

1. Deinet W. et al., Phys. Lett. 30B, 359 (1969).
2. Shibata E.I., Frisch D.H. and Wahlig M.A., Phys. Rev. Lett. 25, 1227 (1970).
3. Skuja A. et al., Phys. Rev. Lett. 31, 653 (1973).
4. Brown K.J. et al., Phys. Rev. Lett. 21, 1257 (1968).
5. Bensinger J.R. et al., Phys. Lett. 36B, 134 (1971).
6. Cason N.M. et al., Phys. Rev. D28, 1586 (1983).
7. Clark R.K. et al., Phys. Rev. D32, 1061 (1985).
8. Longacre R.S. et al., BNL report 39953, July, 1987 (Subm. to 2-nd Int. Conf. on Hadron Spectroscopy, KEK, Tsukuba, Japan, April 1987).
9. Prucop J.P. et al., Phys. Rev. D10, 2055 (1974).
10. Апокин В.Д. и др., ЯФ 46, 1108 (1987).
11. Апокин В.Д. и др., препринт ИФВЭ 86-239, Серпухов (1986).
12. Апокин В.Д. и др., препринт ИФВЭ 81-15, Серпухов (1981).
13. Аввакумов И.А. и др., препринт ИФВЭ 82-49, Серпухов (1982).
14. Apokin V.D. et al., IHEP-preprint 87-44, Serpukhov (1987).
15. Alexander G. et al., Nucl. Phys. B131, 365 (1977).
16. Болотов В.Н. и др., ЯФ 24, 106 (1976).
17. Benecke J., Dürr H., Nuovo Cimento. 56A, 296 (1968).
18. Бинон Ф. и др., ЯФ 38, 1199 (1983).
19. Apel W.D. et al., Sov. Nucl. Phys. 41, 347 (1985).
20. Apel W.D. et al., Nucl. Phys. B160, 42 (1979).
21. Бельков А.А., Бунятов С.А. и др. Пион-пионное взаимодействие. М.: Энергоатомиздат, 1985, 128 с.
22. Кайдалов А.Б., Нилов А.Ф., Пономарев Л.А., ЯФ 44, 205 (1986).

Received March 25, 1988.

В.Д.Апокин и др.
Сечение процесса $\pi^+\pi^- \to \pi^0\pi^0$ в области энергий в с.ц.м. $0{,}55 < M \leq 2$ ГэВ из реакции $\pi^-p \to \pi^0\pi^0 n$ при 39,1 ГэВ/с.

Редактор А.А.Антипова. Технический редактор Л.П.Тимкина.
Корректор Е.Н.Горина.

Подписано к печати 20.04.88. Т-10683. Формат 60x90/16.
Офсетная печать. Печ.л. 0,62. Уч.-изд.л. 0,82. Тираж 250.
Заказ 396 . Индекс 3622. Цена 10 коп.

Институт физики высоких энергий,142284,Серпухов Московской обл.

10 коп. Индекс 362

ПРЕПРИНТ 88-76, ИФВЭ, 1988