Study of $f_0(995)$ resonance in the $\pi^0\pi^0$ decay channel

GAMS Collaboration (Joint CERN-IHEP experiment)


1 Institute for High Energy Physics, Protvino 142284, Russia
2 Institut Interuniversitaire des Sciences Nucléaires, B-1050 Brussels, Belgium
3 Los Alamos National Laboratory, Los Alamos, NM 87544, USA
4 Laboratoire d’Annecy de Physique des Particules, F-74019 Annecy-le-Vieux, France
5 Université de Montréal, Laboratoire de Physique Nucléaire, H3C, 337 Montréal, Canada

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Abstract. A high-statistics study of the $\pi^0\pi^0$-system produced in the $\pi^-p\rightarrow\pi^0\pi^0n$ reaction at 38 GeV/c has been carried out at the IHEP accelerator using the GAMS-2000 multiphoton spectrometer. A partial-wave analysis which includes $S$, $D_0$, $D_-$, and $D_+$ waves has been performed in the $|t|$-range up to $1$ (GeV/c)$^2$. The $S^*/f_0(980)$ resonance is seen as a dip in the $S$-wave amplitude at small $|t|$. A distinct peak with a mass of $997 \pm 5$ MeV and a width of $48 \pm 10$ MeV is observed in the $S$-wave at $|t| > 0.3$ (GeV/c)$^2$. The production cross sections are measured.

Introduction

In this work the GAMS Collaboration continues the analysis of the $\pi^0\pi^0$ system produced in the charge-exchange reaction

$$\pi^-p\rightarrow\pi^0\pi^0n$$

$$\rightarrow 4\gamma$$

(1)

at 38 GeV/c $\pi^-$ beam momentum. The previous studies of this reaction [1, 2] had been pursued at low momentum transfers ($|t| < 0.2$ (GeV/c)$^2$) where the one-pion exchange (OPE) contribution is enhanced. A strong upper limit on the production cross section of the $f_2(1810)$ resonance, claimed by Cason et al. [3] in the $D_0$-wave, had been set and the $f_2(1270)$ production cross section had been measured in the $D_0$, $D_+$, and $D_-$ waves. In the present work a partial-wave analysis (PWA) of the $\pi^0\pi^0$ system has been carried out in the 4-momentum transfer range extending up to $1$ (GeV/c)$^2$. The goal is to study the $t$-behaviour of the $S$-wave in the $\pi^0\pi^0$ mass region around 1 GeV. The presence of the $S^*/f_0(980)$, the lightest scalar meson ($J^{PC}T^2 = 0^+ 0^+$) which has been a puzzle since the 1970's [5], in particular, makes this region very interesting.

The measurements have been performed at the IHEP 70 GeV proton accelerator. The multiphoton hodoscope spectrometer GAMS-2000 [6] was used to detect four photons in the final state of the reaction (1). A total of $2 \cdot 10^6\pi^0\pi^0$-events were collected during two one-month runs (1982 and 1984). The distance $L$ between the target and GAMS, that was 12 m during the first run, has been reduced to 4.3 m in the second run, improving the efficiency at high masses at the cost of a somewhat lower mass resolution. Also, the accumulated statistics in the second run was four times larger than those in the first one. The experimental setup, the measurement conditions, the calibration of the spectrometer, and the event reconstruction procedure have been described in details elsewhere [6, 7].

1 Event selection

A number of criteria are used in order to reject physical and instrumental backgrounds during event selection. Tighter selection criteria are applied in the $|t| < 0.2$ (GeV/c)$^2$ range, claimed by Cason et al. [3] in the $D_0$-wave had been set and the $f_2(1270)$ production cross section had been measured in the $D_0$, $D_+$, and $D_-$ waves. In the present work a partial-wave analysis (PWA) of the $\pi^0\pi^0$ system has been carried out in the 4-momentum transfer range extending up to $1$ (GeV/c)$^2$. The goal is to study the $t$-behaviour of the $S$-wave in the $\pi^0\pi^0$ mass region around 1 GeV. The presence of the $S^*/f_0(980)$, the lightest scalar meson ($J^{PC}T^2 = 0^+ 0^+$) which has been a puzzle since the 1970's [5], in particular, makes this region very interesting.

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The efficiency is parametrized as a function of the $\theta_{GJ}$ and $\phi_{TY}$ (Treiman–Yang) angles in the Gottfried-Jackson frame, of the $\pi^0\pi^0$ invariant mass, and of $|t|$ in the form of a four-dimensional Fourier series as described in [9]. At small momentum transfer it reaches a maximum when $\cos \theta_{GJ} = 0$ (≈ 50% at a mass of 1 GeV). It drops to zero when $\cos \theta_{GJ}$ approaches 1. The region of zero efficiency disappears with increasing $|t|$, and the efficiency dependence on $\cos \theta_{GJ}$ becomes smoother providing more favorable conditions for PWA.

The PWA includes $S$, $D_0$, $D_-$, and $D_+$ waves (the contribution of higher waves is negligible in the mass range under study [10]). It is carried out in several $|t|$-intervals, up to 1 (GeV/c)$^2$. The efficiency in each interval is integrated over $t$ according to the experimental $t$-dependence. The $\pi^0\pi^0$-events are grouped into 20 MeV mass bins. The events for which the efficiency drops below 2% are discarded. Angular distributions in each mass bin are fitted independently with the maximum likelihood method using two different procedures. In the first one, the two-dimensional [$\cos \theta_{GJ}, \phi_{TY}$] histograms are fitted; in the second one, the event-by-event procedure is used. Both procedures give similar results, within the statistical errors. Below the results obtained with the event-by-event procedure are given.

3 PWA results

Two non-trivial solutions are found in each $t$-interval. The first one is characterized by unphysically large $D$-waves near the threshold of reaction (1). For the second (physical) solution the $S$ and $D_0$ waves (the latter being a tail of the $f_2(1270)$) give the major contributions to the cross section in the 1 GeV mass region at low $|t|$. The intensities of the $D_-$ and $D_+$ waves are about 10% of that of the $D_0$-wave. The relative contribution of the latter decreases with increasing $|t|$, while the $D_-$-wave intensity becomes comparable with that of the $S$-wave in this mass region.

The $S$-wave in both low-$|t|$ and high-$|t|$ regions is shown in Fig. 2 for the physical and unphysical solutions. At low momentum transfer, $|t| < 0.2$ (GeV/c)$^2$, both solutions are in a good agreement with the previous results [1]. The physical solution exhibits a dip below 1 GeV (Fig. 2a), the result of the $S^*/f_0(980)$ destructive interference with the continuum. A rapid variation of the phase shift between the $S$ and $D_0$ waves confirms the presence of the $S^*/f_0(980)$ resonance (Fig. 2b). A broad structure is observed at 1.2 GeV with a width of about 300 MeV; it can be naturally associated with the $\epsilon f_0(1300)$ meson [5]. Its mass agrees with that of the $S$-wave resonance seen both