arXiv:hep-ex/0104017 10 Apr 2001

10 April 2001

A study of the centrally produced $\pi^0\pi^0\pi^0$ channel in pp interactions at 450 GeV/c

The WA102 Collaboration

D. Barberis[4], F.G. Binon[6], F.E. Close[3,4], K.M. Danielsen[11], S.V. Donskov[5], B.C. Earl[3], D. Evans[3], B.R. French[4], T. Hino[12], S. Inaba[8], A. Jacholkowski[4], T. Jacobsen[11], G.V. Khaustov[5], J.B. Kinson[3], A. Kirk[3], A.A. Kondashov[5], A.A. Lednev[5], V. Lenti[4], I. Minashvili[7], J.P. Peigneux[1], V. Romanovsky[7], N. Russakovich[7], A. Semenov[7], P.M. Shagin[5], H. Shimizu[10], A.V. Singovsky[1,5], A. Sobol[5], M. Stassinaki[2], J.P. Stroot[6], K. Takamatsu[9], T. Tsuru[8], O. Villalobos Baillie[3], M.F. Votruba[3], Y. Yasu[8].

Abstract

The reaction $pp \to p_f(\pi^0\pi^0\pi^0)p_s$ has been studied at 450 GeV/c. The $\pi^0\pi^0\pi^0$ effective mass spectrum shows clear $\eta(547)$ and $\pi_2(1670)$ signals. Branching ratios for the $\eta(547)$ and $\pi_2(1670)$ are given as well as upper limits for the decays of the $\omega(782)$, $a_1(1260)$ and $a_2(1320)$ into $3\pi^0$.

Submitted to Physics Letters

1 LAPP-IN2P3, Annecy, France.
2 Athens University, Physics Department, Athens, Greece.
3 School of Physics and Astronomy, University of Birmingham, Birmingham, U.K.
4 CERN - European Organization for Nuclear Research, Geneva, Switzerland.
5 IHEP, Protvino, Russia.
6 IISN, Belgium.
7 JINR, Dubna, Russia.
8 High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan.
9 Faculty of Engineering, Miyazaki University, Miyazaki 889-2192, Japan.
10 RCNP, Osaka University, Ibaraki, Osaka 567-0047, Japan.
11 Oslo University, Oslo, Norway.
12 Faculty of Science, Tohoku University, Aoba-ku, Sendai 980-8577, Japan.

In a previous analysis of the centrally produced $\pi^+\pi^-\pi^0$ final state clear signals of the $\eta(547)$, $\omega(782)$, $a_1(1260)$, $a_2(1320)$ and $\pi_2(1670)$ were observed [1]. In particular, the $a_1(1260)$ and $a_2(1320)$ were observed to decay dominantly to $\rho\pi$. The $\pi_2(1670)$ was observed to decay to $\rho\pi$ and $f_2(1270)\pi$. In order to gain more information on the decays of these states it would be interesting to study the $\pi^0\pi^0\pi^0$ final state since only isospin zero isobars can contribute to this final state.

This paper presents new results from the WA102 experiment on the centrally produced $\pi^0\pi^0\pi^0$ final state in the reaction

$$pp \to p_f(\pi^0\pi^0\pi^0)p_s \tag{1}$$

at 450 GeV/c. The subscripts f and s indicate the fastest and slowest particles in the laboratory, respectively.

The data come from experiment WA102 which has been performed using the CERN Omega Spectrometer, the layout of which is described in ref. [2].

Reaction (1) has been isolated from the sample of events having two outgoing charged tracks plus six γs reconstructed in the GAMS-4000 calorimeter, by first imposing the following cuts on the components of the missing momentum: |missing P_x| $<$ 14.0 GeV/c, |missing P_y| $<$ 0.20 GeV/c and |missing P_z| $<$ 0.16 GeV/c, where the x axis is along the beam direction. A correlation between pulse-height and momentum obtained from a system of scintillation counters was used to ensure that the slow particle was a proton.

Fig. 1 shows the two photon mass spectrum (5606 events) for 6γ-events when the mass of the other two 2γ-pairs lies within a band around the π^0 mass (100–170 MeV). A clear π^0 signal is observed with a small background. Events belonging to reaction (1) have been selected using a kinematical fit (7C fit, four-momentum conservation being used and the masses of three π^0s being fixed). The major background to the $\pi^0\pi^0\pi^0$ final state comes from the decay of the η' and $f_1(1285)$ to $\eta\pi^0\pi^0$. A kinematical fit has been used to remove these events. The final sample consists of 3590 events and has less than 2 % contamination from the $\eta\pi^0\pi^0$ final state. The combinatorial background is also reduced by the fact that only the combination with the lowest χ^2 is retained.

Fig. 2 shows the acceptance corrected $\pi^0\pi^0\pi^0$ effective mass spectrum renormalised to the total number of observed events. In addition to a clear $\eta(547)$ signal there is a broad enhancement which is probably due to the $\pi_2(1670)$.

The $\pi^0\pi^0\pi^0$ mass spectrum shown in fig. 2 has been fitted with a Gaussian (σ = 16MeV) to describe the $\eta(547)$, a Breit-Wigner convoluted with a Gaussian (σ = 32 MeV) to describe the $\pi_2(1670)$ and a background of the form $a(m - m_{th})^b \exp(-cm - dm^2 - em^3)$, where m is the $\pi^0\pi^0\pi^0$ mass, m_{th} is the threshold mass and a,b,c,d,e are fit parameters. The fit is found to describe the data well and yields masses for the $\eta(547)$ and $\pi_2(1670)$ of:

$$m(\eta(547)) = 545 \pm 0.6 \pm 0.5 \text{ MeV},$$

$$m(\pi_2(1670)) = 1685 \pm 10 \pm 30 \text{ MeV}$$

and

$$\Gamma(\pi_2(1670)) = 265 \pm 30 \pm 40 \text{ MeV}.$$

A Dalitz plot analysis of the $\pi^0\pi^0\pi^0$ final state has been performed using Zemach tensors and a standard isobar model [3]. The analysis has assumed σ, $f_0(980)$, $f_2(1270)$ and $f_0(1370)$ intermediate states and that only relative angular momenta up to 2 contribute. The σ stands for the $\pi\pi$ S-wave amplitude squared, and the parameterisation of Zou and Bugg [4] has been used in this analysis.

The geometrical acceptance of the apparatus has also been evaluated over the Dalitz plot of the $\pi^0\pi^0\pi^0$ system in 40 MeV intervals between 0.8 and 2.0 GeV. In order to perform a spin parity analysis the log likelihood function, $\mathcal{L}_j = \sum_i \log P_j(i)$, is defined by combining the probabilities of all events in 40 MeV $\pi^0\pi^0\pi^0$ mass bins from 0.80 to 2.0 GeV. In order to include more than one wave in the fit the incoherent sum of various event fractions a_j is calculated:

$$\mathcal{L} = \sum_i \log \left(\sum_j a_j P_j(i) + (1 - \sum_j a_j) \right) \tag{2}$$

where the term $(1 - \sum_j a_j)$ represents the phase space background which is a free parameter in each bin. The negative log likelihood function $(-\mathcal{L})$ is then minimised using MINUIT [5]. Different combinations of waves and isobars have been tried and insignificant contributions have been removed from the fit. The fit generates the phase space background as that part of the data not associated with a given wave on a bin by bin basis and one requirement is that this background is a smoothly varying function that shows no residual resonance structure.

Above 0.8 GeV only the addition of the $J^{PC} = 2^{-+}$ $f_2(1270)\pi^0$ S-wave produces a significant change in the likelihood. We can not exclude up to 3 % contribution of the $J^{PC} = 2^{-+}$ $f_2(1270)\pi^0$ D-wave in the $\pi_2(1670)$ region. Nor can we exclude that up to 10 % of the $\pi_2(1670)$ comes from a $\sigma\pi$ final state. The addition of any 1^{++} wave changes the log likelihood by less than 1 unit and hence is classed as insignificant. However, in order to estimate an upper limit on the amount of $a_1(1260)$ decaying to $\pi^0\pi^0\pi^0$ we include both the $1^{++}\sigma\pi$ P-wave and the $1^{++}f_0(1370)\pi$ P-wave in the final fit. The results of the final fit are shown in fig. 3. The $J^{PC} = 2^{-+}$ $f_2(1270)\pi^0$ S-wave well describes the peak in the $\pi_2(1670)$ region. The 1^{++} wave is small and flat.

Using the acceptance corrected number of events from fits to the $\pi^0\pi^0\pi^0$ and $\pi^+\pi^-\pi^0$ [1] mass spectra the branching ratio for the $\eta(547)$ to $\pi^0\pi^0\pi^0$ and $\pi^+\pi^-\pi^0$ has been calculated to be:

$$\frac{\eta(547) \to \pi^0\pi^0\pi^0}{\eta(547) \to \pi^+\pi^-\pi^0} = 1.35 \pm 0.06 \pm 0.09$$

which is in agreement with the PDG value [6] of 1.40 $\pm$ 0.03. The branching ratio for the $\pi_2(1670)$ to $\pi^0\pi^0\pi^0$ and $\pi^+\pi^-\pi^0$ has been calculated in a similar manner to be:

$$\frac{\pi_2(1670) \to \pi^0\pi^0\pi^0}{\pi_2(1670) \to \pi^+\pi^-\pi^0} = 0.29 \pm 0.03 \pm 0.05$$

There is no evidence for a $\pi^0\pi^0\pi^0$ decay mode of the $\omega(782)$, $a_1(1260)$ or $a_2(1320)$ therefore an upper limit has been calculated. The masses and widths determined from the fit to the $\pi^+\pi^-\pi^0$ channel have been convoluted with the experimental resolution for the $\pi^0\pi^0\pi^0$ final state. The number of events, N, within 90 % of the predicted resonance profile has been

determined and the upper limit has been calculated using $2\sqrt{N}$. For the $\omega(782)$

$$\frac{\omega(782) \to \pi^0\pi^0\pi^0}{\omega(782) \to \pi^+\pi^-\pi^0} < 9 \times 10^{-4} \ \ (90\% \ \ CL)$$

to be compared with the PDG upper limit of 3×10^{-4} [6] which came from one experiment.

For the $a_1(1260)$

$$\frac{a_1(1260) \to \pi^0\pi^0\pi^0}{a_1(1260) \to \pi^+\pi^-\pi^0} < 8 \times 10^{-3} \ \ (90\% \ \ CL)$$

if on the other hand we used the total number of events in the 1^{++} wave we would get:

$$\frac{a_1(1260) \to \pi^0\pi^0\pi^0}{a_1(1260) \to \pi^+\pi^-\pi^0} < 9 \times 10^{-3} \ \ (90\% \ \ CL)$$

This imposes tight constraints on the decay of the $a_1(1260)$ to isobars which have isospin 1. In particular, it is in disagreement with the claimed observation of $\sigma\pi$, $f_0(1370)\pi$ and $f_2(1270)\pi$ decay modes of the $a_1(1260)$ in ref. [7]. This claim was based on a Dalitz plot analysis of the $a_1(1260)$ observed in τ decays. Combining all the I = 0 decays claimed in ref. [7] we have calculated the number of events we would expect to observe in the $\pi^0\pi^0\pi^0$ mass spectrum based on the number of $a_1(1260)$ observed in the $\pi^+\pi^-\pi^0$ final state of experiment WA102 [1]. Superimposed on the $\pi^0\pi^0\pi^0$ mass spectrum in fig. 4 is the $a_1(1260)$ signal we would expect to observe based on this number of events. As can be seen, irrespective of any results from the spin analysis, the number of events in the $\pi^0\pi^0\pi^0$ spectrum is much smaller than the predicted signal. The fact that the η branching ratio we have measured is in agreement with the PDG value indicates that our normalisation between the $\pi^0\pi^0\pi^0$ and $\pi^+\pi^-\pi^0$ channels is correct. Therefore this discrepancy in the possible I=0 decay modes of the $a_1(1260)$ could either be due to an overestimate of the number of $a_1(1260)$ events in the $\pi^+\pi^-\pi^0$ final state of the WA102 experiment or due to an error in the spin analysis performed by CLEO in ref. [7].

Finally, for the $a_2(1320)$ we obtain

$$\frac{a_2(1320) \to \pi^0\pi^0\pi^0}{a_2(1320) \to \pi^+\pi^-\pi^0} < 9 \times 10^{-3} \ \ (90\% \ \ CL)$$

In summary, a study of the centrally produced $\pi^0\pi^0\pi^0$ system shows prominent signals of the $\eta(547)$ and $\pi_2(1670)$. Branching ratios for the $\eta(547)$ and $\pi_2(1670)$ are given. Upper limits are calculated for the $\omega(782)$, $a_1(1260)$ and $a_2(1320)$ which can be used to constrain the possible decays of these states to isobars with isospin zero.

Acknowledgements

This work is supported, in part, by grants from the British Particle Physics and Astronomy Research Council, the British Royal Society, the Ministry of Education, Science, Sports and Culture of Japan (grants no. 1004100 and 07044098), the French Programme International de Cooperation Scientifique (grant no. 576) and the Russian Foundation for Basic Research (grants 96-15-96633 and 98-02-22032).

References

[1] D. Barberis *et al.,* Phys. Lett. **B422** (1998) 399.

[2] D. Barberis *et al.,* Phys. Lett. **B397** (1997) 339.

[3] M. Abramovich *et al.,* Nucl. Phys. **B23** (1970) 466.

[4] B. S. Zou and D. V. Bugg, Phys. Rev. **D48** (1993) R3948.

[5] F. James and M. Roos, MINUIT Computer Physics Communications **10** (1975) 343; CERN-D506 (1989).

[6] D.E. Groom *et. al.,* Particle Data Group, European Physical Journal **C15** (2000) 1.

[7] D.M. Asner *et al.,* Phys. Rev. **D61** (2000) 012002.

Figures

Figure 1: The M($\gamma\gamma$) when the other two $\gamma\gamma$ pairs lie in the π^0 mass region.

Figure 2: The $\pi^0\pi^0\pi^0$ effective mass spectrum, with fit described in the text.

Figure 3: Results of the spin parity analysis.

Figure 4: The $\pi^0\pi^0\pi^0$ effective mass spectrum, with superimposed the number of events expected from the $a_1(1260)$, see text.

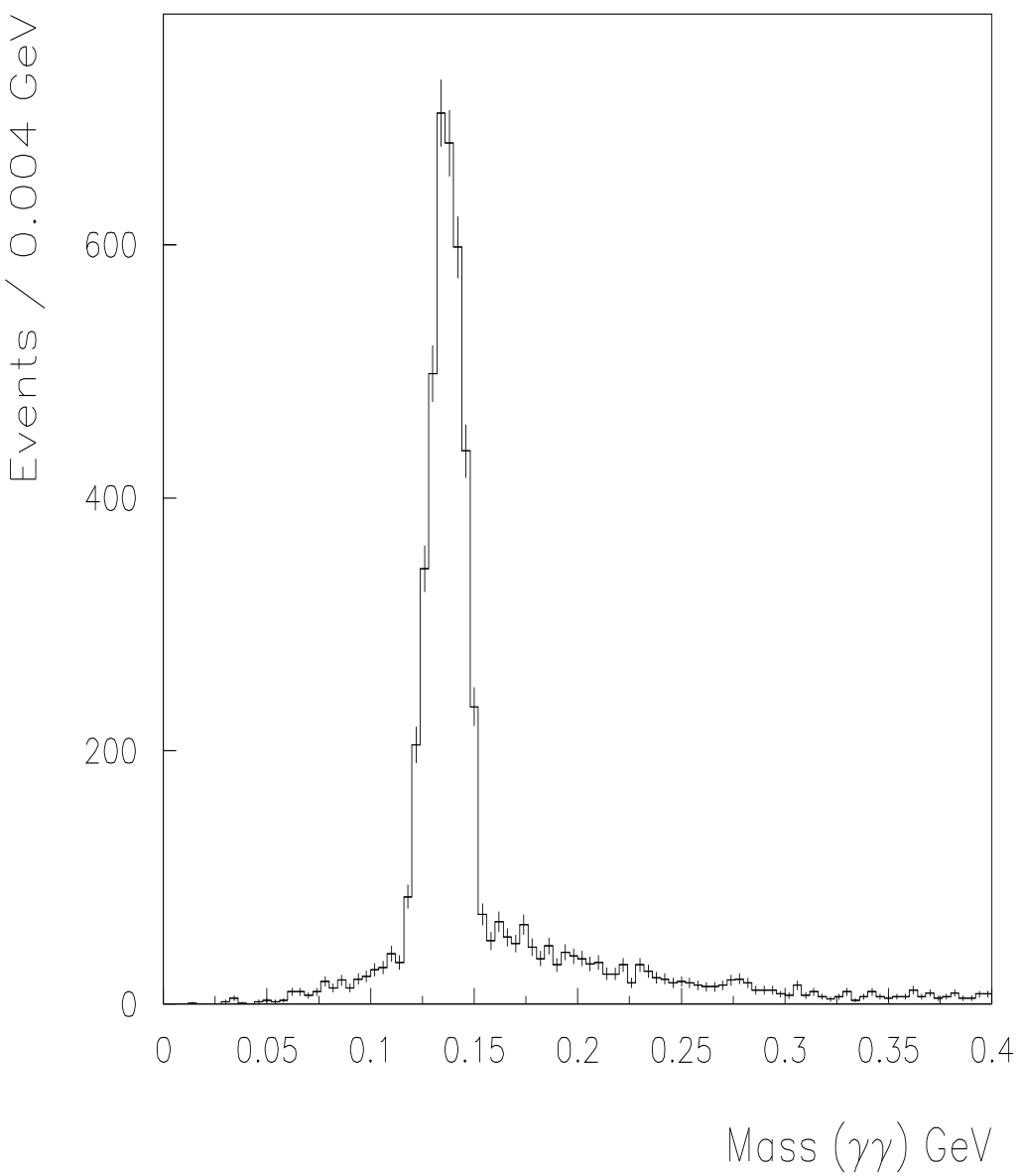
Events / 0.004 GeV
600
400
200
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Mass ($\gamma\gamma$) GeV

Figure 1

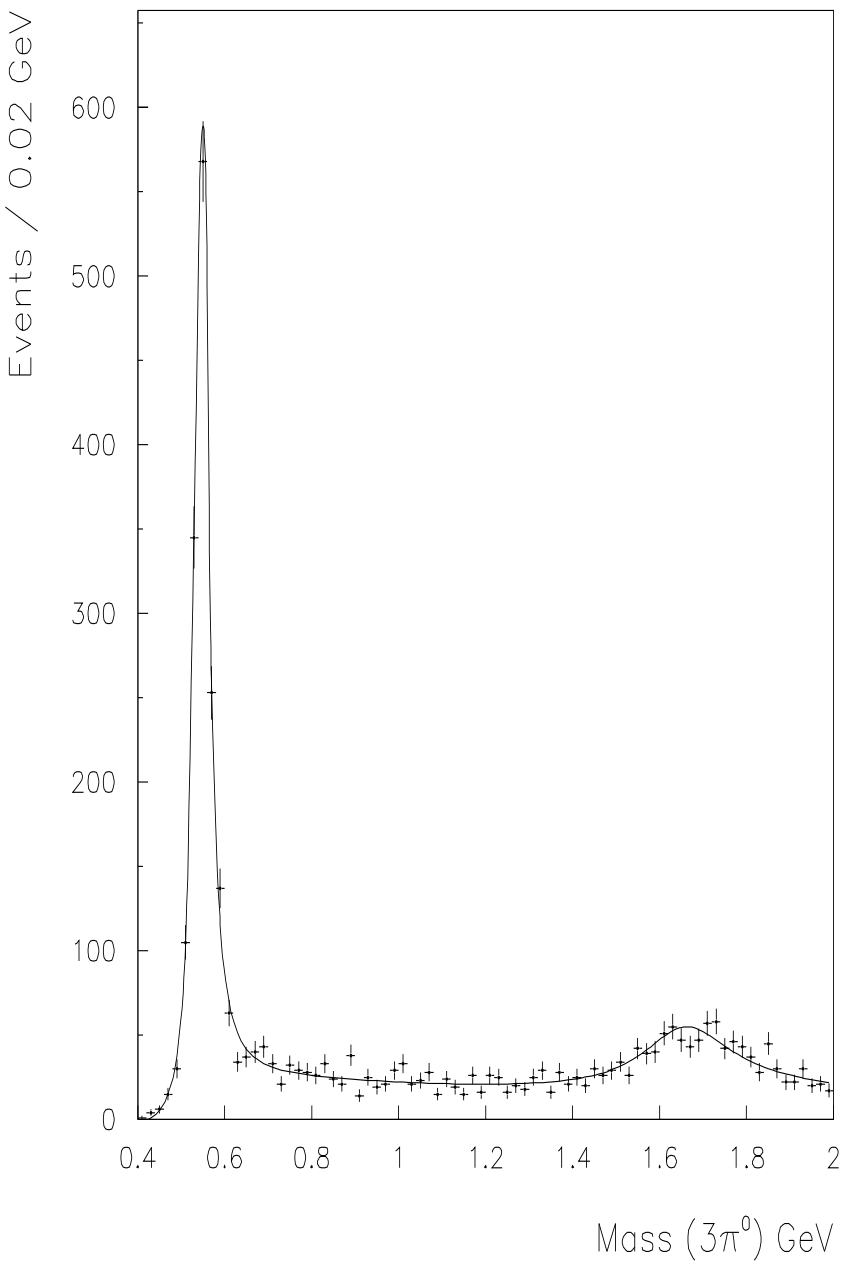
Events / 0.02 GeV
600
500
400
300
200
100
0
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Mass ($3\pi^0$) GeV

Figure 2

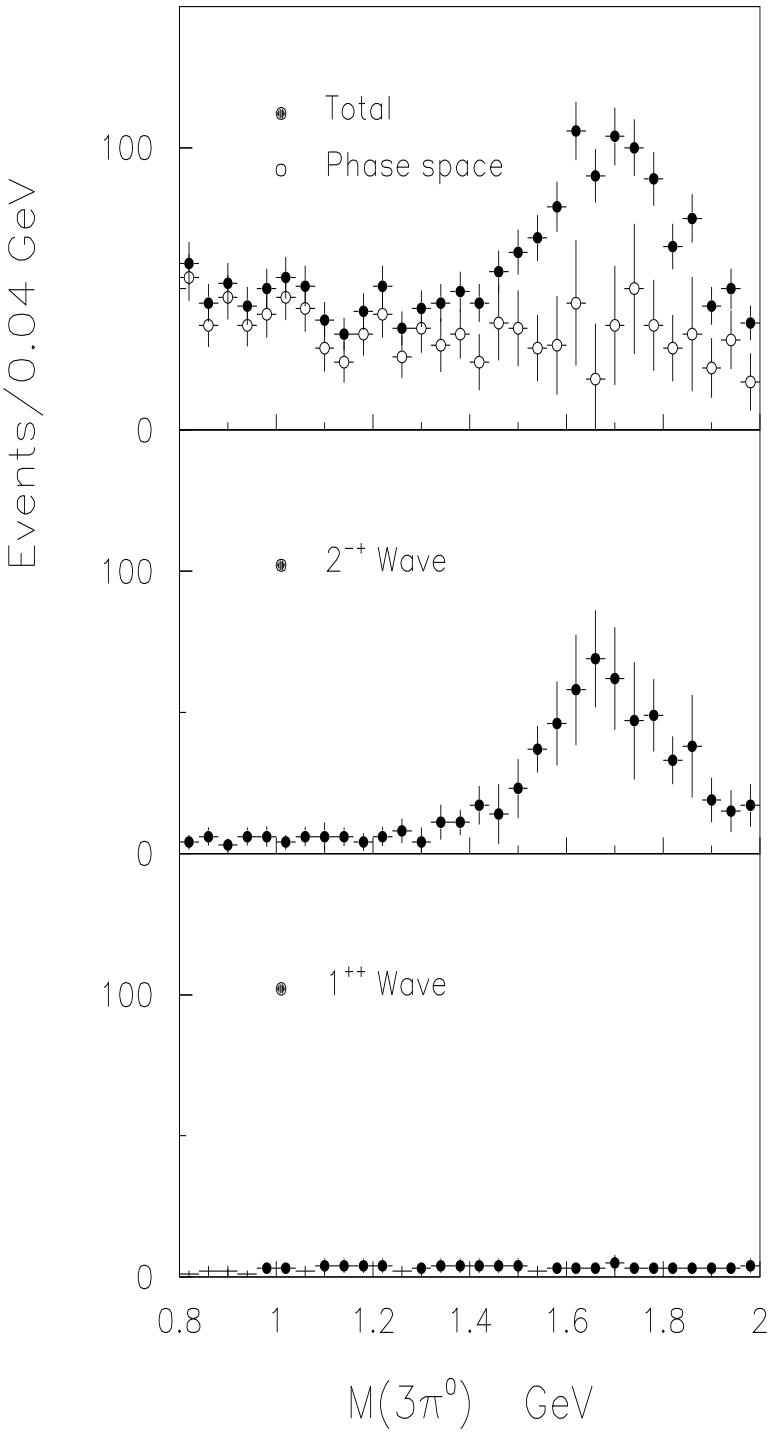
Total
Phase space
100
0
Events/0.04 GeV
2^{-+} Wave
100
0
1^{++} Wave
100
0
0.8
1
1.2
1.4
1.6
1.8
2
$M(3\pi^0)$ GeV

Figure 3

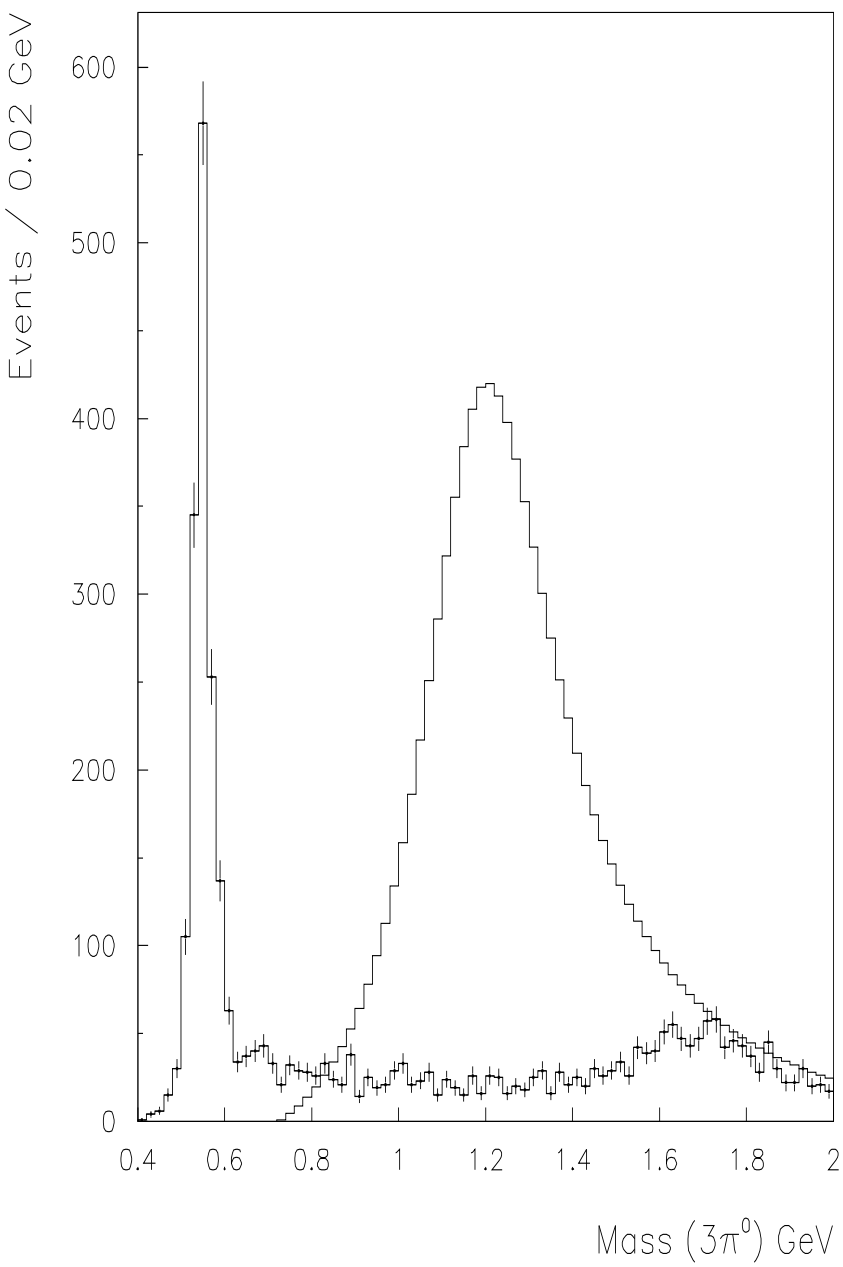
Events / 0.02 GeV
600
500
400
300
200
100
0
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Mass ($3\pi^0$) GeV

Figure 4