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$\bar{p}p \to \pi^0\pi^0$ from 600 to 1940 MeV/c

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Crystal Barrel data on $\bar{p}p \to \pi^0\pi^0$ are presented. Shapes of angular distributions are similar to data of Dulude et al, but show some systematic disagreements. Absolute normalisations disagree seriously. An amplitude analysis finds two alternative solutions. Both contain a $J^{PC} = 2^{++}$ resonance with $M = 2020 \pm 40$ MeV and $\Gamma = 235 \pm 70$ MeV, tentatively identified as the $\bar{q}q$ $^3F_2$ state. Both solutions also require $f_4(2050)$ and $f_4(2300)$.

We present high statistics data on $\bar{p}p \to \pi^0\pi^0$ taken at LEAR with the Crystal Barrel detector. Numbers of events are typically 60-230K per momentum. The reconstruction demands exactly four photon showers and a 6C kinematic fit to $\pi^0\pi^0$ with confidence level $> 10\%$. Events fitting other two-body channels $\pi^0\eta$, $\eta\eta$, $\pi^0\eta'$ and $\eta\eta'$ with higher confidence level than $\pi^0\pi^0$ are rejected. Angular distributions have been derived using confidence levels ranging from 20% to 1% and change by less than the errors. From Monte Carlo studies, the worst background is estimated to be 0.2% from $3\pi^0$ where two photons are lost, then 0.1% from $\omega\pi^0$, $\omega \to \pi^0\gamma$ when one photon escapes.

Fig. 1 shows differential cross sections corrected for detector acceptance. Errors are mostly smaller than the points. Dotted curves on 3 panels illustrate the acceptance. It varies only slowly with momentum and falls rapidly for a cm production angle θ with $|\cos\theta| > 0.85$; we discard data beyond $|\cos\theta| = 0.9$ and double the errors on the last bin. From 1200 to 1800 MeV/c, comparisons are made with nearby momenta of Dulude et al. [1], after renormalising their data to agree with ours. There is a similarity in the angular distributions but some small systematic disagreements.

Unfortunately, there is a strong disagreement with Dulude et al. concerning absolute normalisations. Fig. 2(a) compares our results with theirs after integration up to $|\cos\theta| = 0.85$. The integration is over only one hemisphere, i.e. each $\pi^0\pi^0$ event is counted only once. We have discussed the discrepancy with them, but no satisfactory explanation has been found. Our own procedures have been scrutinised carefully, and we can identify no significant problem with counting the beam, with target length and density, or with the Monte Carlo estimate of reconstruction efficiency. In other channels, we find excellent agreement between (i) 4γ events where both $\eta \to \gamma\gamma$ and (ii) 8γ events where one $\eta \to \pi^0\pi^0\pi^0$. This is a strong check on the Monte Carlo.

Fig. 2(b) shows the cross section for events fitting channels involving $(4+5+6+7+8)\gamma$, but uncorrected for detection efficiency. A straight line is fitted by eye to illustrate slight enhancements at 900 MeV/c and 1600 MeV/c, $M = 2050$ and 2290 MeV. There have been earlier observations of similar small T and U enhancements [2-5] in $\bar{p}p$ elastic and charge exchange scattering and in $\bar{p}p$ total cross sections.

Differential cross sections may be fitted with a Legendre series up to order 6 at 600 MeV/c, 8 from there to 1642 MeV/c, and 10 at 1800 and 1940 MeV/c. An amplitude analysis has been made, fitting all differential cross sections simultaneously at all momenta with 0^+, 2^+ and 4^+ resonances; alternatively a flexible analytic form has been used to fit a background amplitude in 0^+. Standard Blatt-Weisskopf centrifugal barriers ($R = 0.8$ fm) include the appropriate threshold behaviour.

We find an ambiguity between ${}^3F_2$ and a combination of ${}^3F_4$, ${}^3P_2$ and ${}^3P_0$. It derives from the fact that the ${}^3F_2$ cross section is a polynomial in $\cos\theta$ of order 4, the ${}^3F_4$ cross section is a different polynomial of order 4, while the ${}^3P_2$ cross section is of order 2 and the ${}^3P_0$ amplitude is flat. Interference helps resolve this ambiguity, but two solutions survive. The χ^2 of the two fits are 322 for solution 1 and 264 for solution 2; there are 323 differential cross sections and 9 normalisation parameters for the integrated cross section, fitted by 35 parameters for coupling constants, masses and widths. We have searched for Barrelet ambiguities by changing the sign of each resonant amplitude or the sign of each complete partial wave and restarting searches; no other stable solutions are found and we believe that further ambiguities are eliminated by fitting with analytic functions of $s = M^2$.

Cross sections from spins 0 to 6 are shown in Fig. 3. The first and second columns show the two solutions. The second (right-hand) solution is close to that reported by Hasan and Bugg [6], from an analysis of $\bar{p}p \to \pi^-\pi^+$ data, including polarisation. Their Fig. 3 is close to our fit to ${}^3F_4$ and ${}^3H_4$. Our spin 6 contribution is small and only ${}^3H_6$ is needed. It affects differential cross sections by amounts barely visible by eye; but it does affect χ^2 by almost a factor 2. It has no significant effect on fitted masses and widths of resonances.

To fit the data, it is essential to include two 4^+ resonances, $f_4(2050)$ and $f_4(2300)$. The former is fixed at the mass and width of the PDG [7]. Its peak is moved up in mass to 2090 MeV by the $L = 3$ centrifugal barrier in $\bar{p}p$. Parameters fitted to $f_4(2300)$ are $M = 2285 \pm 10$ MeV, $\Gamma = 195 \pm 30$ MeV in solution 1 or $M = 2312 \pm 10$ MeV, $\Gamma = 210 \pm 20$ MeV in solution 2. Errors indicate three standard deviation departures from the optimum, after re-optimising all parameters fitted to the data. Parameters of $f_4(2300)$ are similar to earlier values [7].

For spin 2, both solutions require a 2^+ resonance close to 2020 MeV: $M = 2005 \pm 20$ MeV, $\Gamma = 225 \pm 20$ MeV in solution 1 or $M = 2030 \pm 30$ MeV, $\Gamma = 250 \pm 45$ MeV in solution 2. These values are close to those reported by Zou at this conference [8] from his analysis of $\eta\pi^0\pi^0$ data. In their analysis of $\bar{p}p \to \pi^-\pi^+$, Hasan and Bugg found a 2^+ resonance at 1996 MeV with a width of 134 MeV. The proximity of $f_2(2020)$ to $f_4(2050)$ suggests it is the expected ${}^3F_2$ $\bar{q}q$ state. The large branching ratio for $f_2(2020)$ to $\bar{p}p$ ${}^3F_2$ compared to ${}^3P_2$ likewise suggests identification as $\bar{q}q$ ${}^3F_2$. The 2^+ resonance observed at 1920 MeV in $\omega\omega$ by GAMS [9] and VES [10] is then a candidate for the $n = 3$ ${}^3P_2$ $\bar{q}q$ state, and the $f_2(1565)$ may be interpreted as $\bar{q}q$ $n = 2$ ${}^3P_2$.

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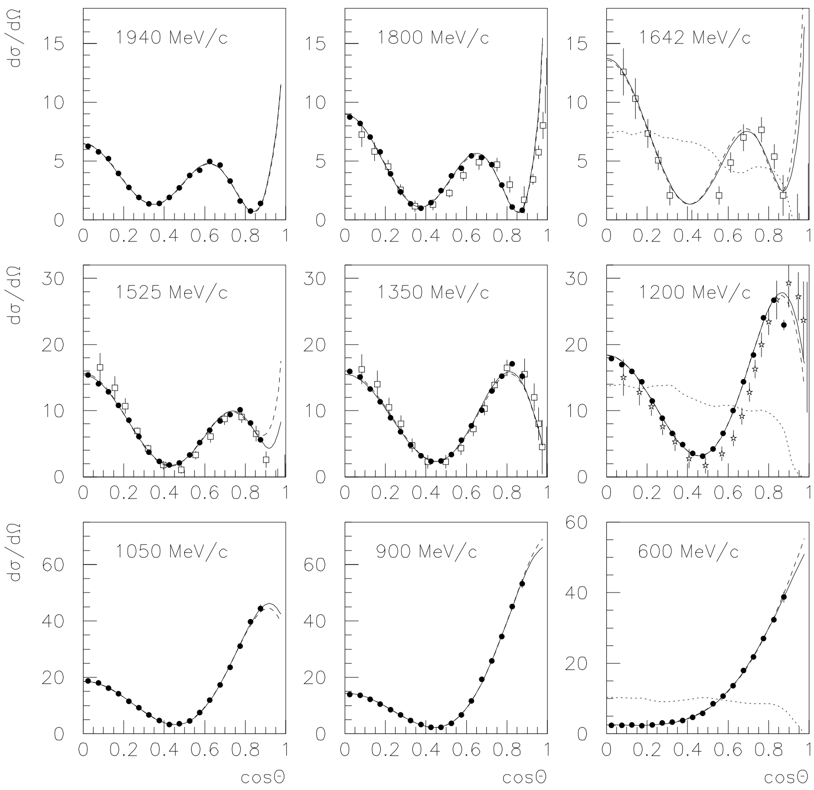

Figure 1. $d\sigma/d\Omega$ from this experiment (black circles) compared with the fit; dotted curves illustrate the acceptance. Open squares show a comparison with earlier data of Dulude et al. at 1184, 1361, 1534, 1630 and 1799 MeV/c after renormalising to our integrated cross sections.

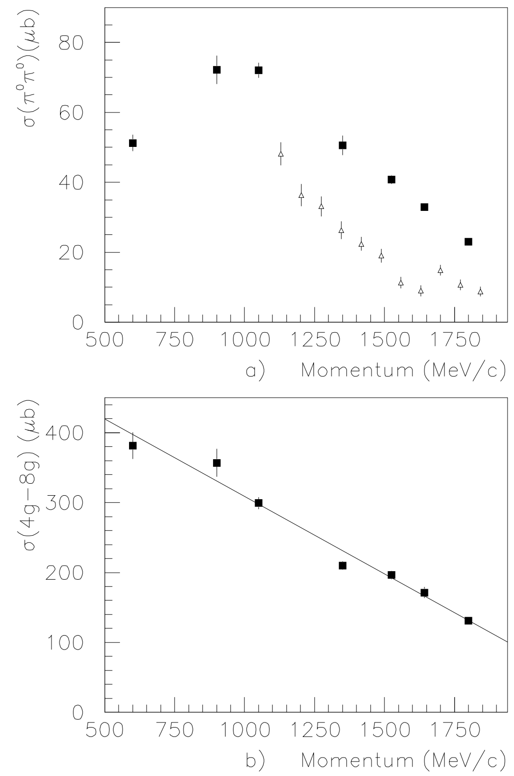

Figure 2. (a) $\sigma(\pi^0\pi^0)$ integrated from $\cos\theta = 0$ to 0.85; black squares are Crystal Barrel results, open triangles those of Dulude et al. (b) cross section for all events fitting 4 to 8 γ, without correction for detection efficiency.

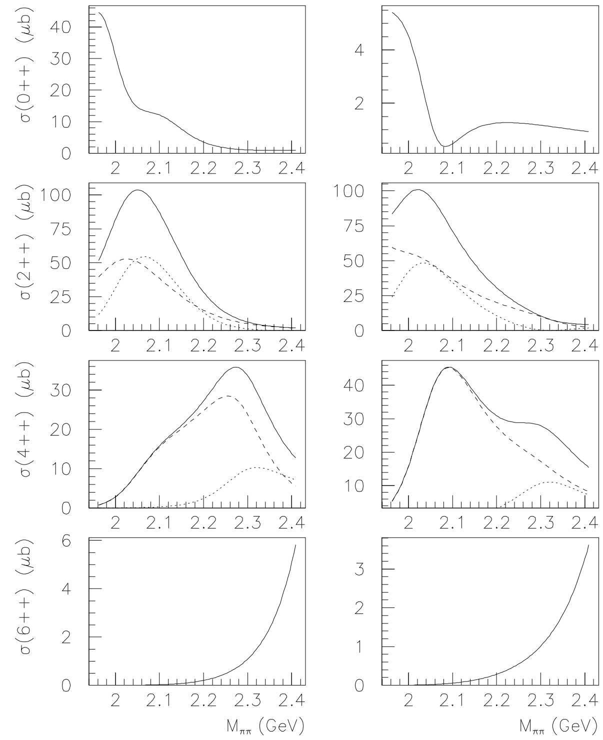

Figure 3. Intensities fitted to 0^+, 2^+, 4^+ and 6^+ v. $\pi\pi$ mass. The left-hand column shows solution 1 and the right-hand column solution 2. Dashed curves show $^3P_2$ and $^3F_4$ cross sections and dotted curves $^3F_2$ and $^3H_4$ intensities; their sum is shown by the full curves.