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Observations of the Scalar Meson $f_0(980)$ in the Photoproduction Experiment E687 at Fermilab.

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Abstract. Observation of the scalar meson $f_0(980)$ is reported in the E687 photoproduction experiment at Fermilab. Evidence is given also for the quasi-exclusive associated $\phi(1020)f_0(980)$ photoproduction.

Pion-pion scattering, particularly in the I=0, s wave, has been seen as an important test of our understanding of the strong interaction [2,3]. The region around 1 GeV, featuring the $K - \bar{K}$ threshold, has always been considered critical. So far, most if not all calculations of the scattering amplitude ignore the surrounding of this s-wave, e.g., implicitly assuming that the scattering phenomena can be understood independently from the presence of other particles in the final state. One can always fear that such scattering amplitudes are not universal and are strongly perturbed by other real or virtual hadrons [4].

In this paper we show evidence for the photoproduction of the $f_0(980)$ scalar meson and that indeed the environment where the $f_0(980)$ is produced seems to play a relevant role. In particular, we report on the first observation of quasi-exclusive $\phi(1020)f_0(980)$ photoproduction.

The data have been collected in the photoproduction experiment E687 performed in the Wide Band Photon Beam Laboratory, exposing a beryllium target , a silicon microstrip telescope and a two-magnet spectrometer to the Wide Band Photon Beam from the Fermilab Tevatron. The experiment is oriented to detect charmed particles [5]. However the trigger, requesting the release of a large amount of hadronic energy in a hadron calorimeter, was also able to select light quark final states leading to the conversion of more than about 30 GeV of energy into charged hadrons. The photon Beam (average photon energy of 220 GeV) and the detector are described elsewhere [6,7].

A dedicated "Light Quark" event selection has been performed, yielding approximately 140 million low multiplicity triggers ($1 < n_{ch} < 7$). All tracks are required to come from the primary vertex and events with secondary interactions in the target are rejected. Based on that sample, two distinct analysis were performed to study the $f_0(980)$:

- Based upon a selection of semi-inclusive photoproduced $\pi^+\pi^-$ pairs with an invariant mass of about 1 GeV, the $f_0(980)$ yield has been studied versus the charged multiplicity, the amount of accompanying electromagnetic energy (e.g. mostly π^0) and various kinematic factors, such as $\sqrt{s}$, transverse momentum carried by the $\pi^+\pi^-$ and so forth.
- The $\pi^+\pi^-$ invariant mass spectrum has been studied in the quasi exclusive reaction $\gamma + N \to K^+K^-\pi^+\pi^- + N$[1].

The $\pi^+\pi^-$ invariant mass distribution in $1 MeV$ bins for the inclusive selection is shown in figure 1. A very weak (albeit undoubtedly statistically significant) signal around 0.970 GeV emerges from the huge continuous "background", above the tail of the $\rho(770)$ as shown in fig. 1a. As expected from Vector Dominance, no signal is observed in the quasi-exclusive di-pion channel. In addition, No simple cut based on either event charged multiplicity or kinematics (transverse momentum carried by the di-pion pair) has been found to improve the signal to noise ratio.

These distributions have not been corrected for acceptance. Given the inclusive character of the reaction and trigger based on hadronic energy, this acceptance correction is very model dependent. However, we know from extensive studies of the reaction $\gamma + N \to 2(\pi^+\pi^-) + N$ that the acceptance is relatively flat in that mass range. While the $f_0(980)$ bump observed in that sample is definitely not due to an acceptance bias, the exact shape of the smooth "background" under the signal can not be estimated reliably. Therefore, a quantitative determination of the interference pattern between the broad S-wave and the narrow manifestation of the $f_0(980)$ "resonance" is difficult. The distribution shown on figure 2 has been obtained by fitting the high statistical sample shown on fig. 1a. with a simple a smooth polynomial background and subtracting this "background" from the data sample. Despite this very qualitative treatment, this analysis provides nonetheless a certain amount of information: A pole mass of 968 ± 0.5 MeV and a width of 50 ± 2.4 MeV can be obtained based on a simple Breit-Wigner fit[2], consistent with previous observations of this state [8]. However, the $f_0(980)$ can not be fit by a single scalar relativistic Breit Wigner. Inspection of fig. 2 clearly indicates that a coupled Breit-Wigner of the "Flatté type" [9] is needed. Finally, as already observed by WA76 [10], this relatively narrow structure could interfere with broad s-wave resonances in the nearby mass region [2].

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1) By quasi-exclusive, we mean that no other particles were observed in the spectrometer

2) Errors are statistical only

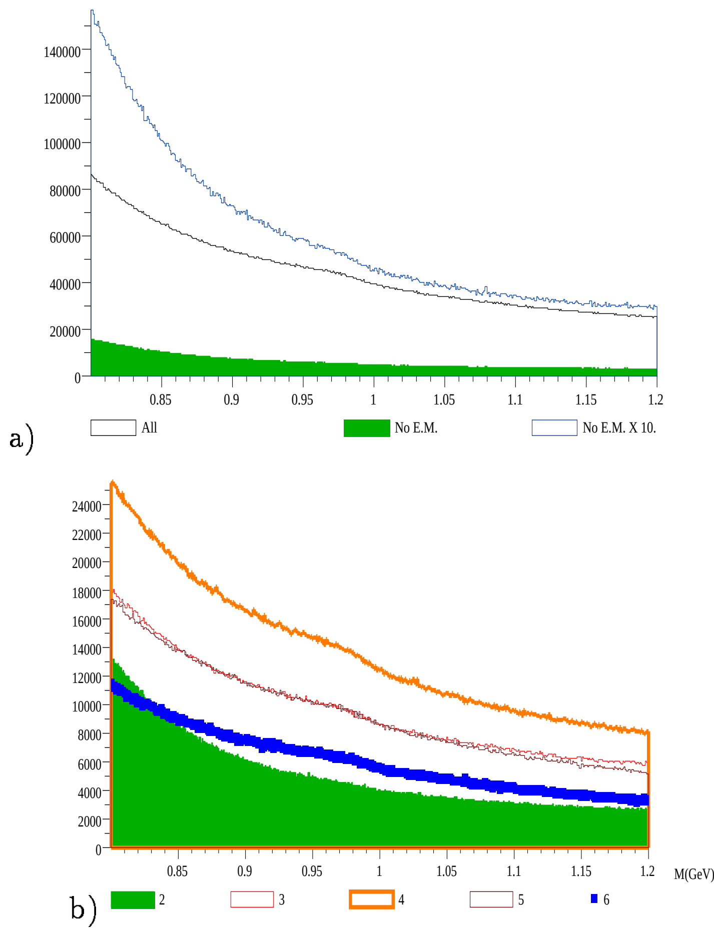

FIGURE 1. a)- $M_{2\pi}$ spectrum in 1 MeV bins, in the range 0.8-1.2 GeV/c, for the total inclusive sample ($3.4\,10^7$ entries). Also shown is the same spectrum in events without electromagnetic energy release in the calorimeters (solid histogram, labelled No E.M., $4.0\,10^6$ entries). The same is redrawn -intermediate histogram- in a finer 10x scale for a better reading; b)- same spectrum for different charged multiplicities $n_{ch} = 2, 3, 4, 5, 6$

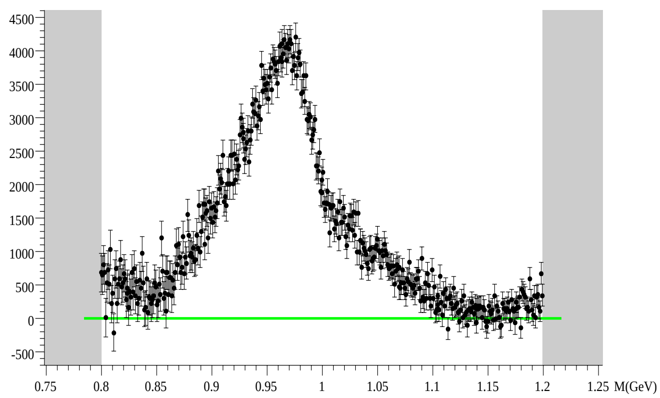

FIGURE 2. The residuals (Data - fit) from the $M_{2\pi}$ spectrum. Note that the amplitude for the $f_0(980)$ signal has been fixed to zero in this fit performed a broad mass range. This obviously gives an unacceptable χ^2, but provides a clear graph of the signal. The text describes briefly the fit assumptions.

The search for a dynamical or topological criteria to select an event sample with a more prominent $f_0(980)$ signal has been performed based on the $K^+K^-\pi^+\pi^-$ semi-exclusive sample. The $\phi(1020)f_0(980)$ sample in particular seems to be very promising: despite the lower statistics[3], the probability to produce the $f_0(980)$ state with respect to the broader "background" state(s) is definitely higher than in the inclusive di-pion sample, as shown in figure 3. Fixing the mass and width to the values obtained in the inclusive sample, the statistical evidence for the signal is greater than $5\,\sigma$, with acceptable χ^2, and with a signal to noise ratio of approximately 1/1. In contrast, the $K^+K^-\pi^+\pi^-$ sample, shown on fig. 4, has no such $f_0(980)$ relative enhancement. It might be worth noting that a similar $f_0(980)$ signal has been found in J/ψ decay [11,12]. Moreover, it has been shown that the branching ratio $J/\psi \rightarrow \omega f_0(980)$ is at least three times smaller than $J/\psi \rightarrow \phi(1020)f_0(980)$. In our data, the $\phi(1020)f_0(980)$ mass spectrum does not show a narrow resonance state. We conclude from this that a detailed analysis of the shape of the $f_0(980)$ and it's coupling to other scalar waves can not always be done in isolation, one must also look at other hadrons co-produced, particularly the $\phi(1020)$ meson.

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[3] In addition to the usual strangeness suppression factor, the $\phi(1020)$ inclusive yield is only a few % of the total K^+K^- yield, as the dominant channel comes from $K^*(892)K\pi$ photoproduction

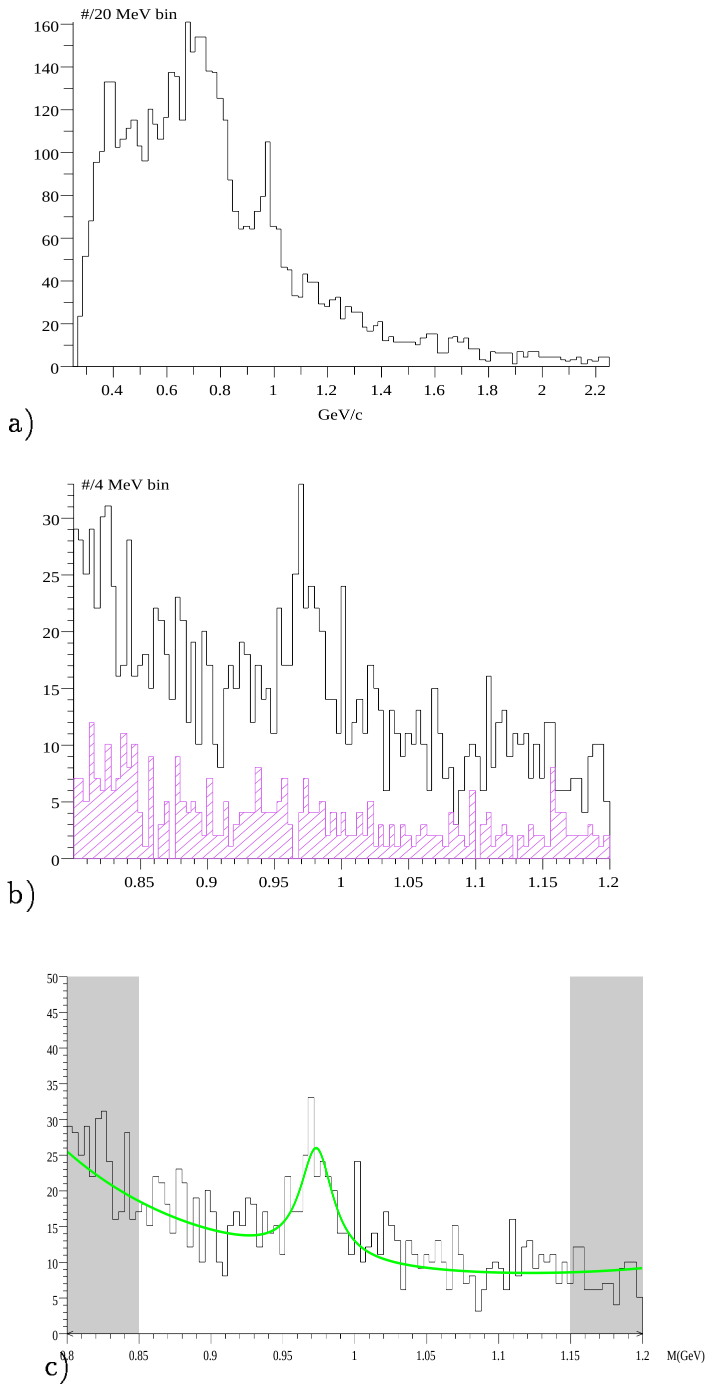

FIGURE 3. a)- The full 2π mass spectrum, in 20 MeV/c^2 bins, associated to a $\phi(1020)$ particle; b)- same as in a) in 4 MeV/c^2 bins, limited to the mass range $0.8 - 1.2$ GeV/c^2 (black histogram) also shown the spectrum for the "background" sample (dashed histogram). This background has been obtained by selecting events at low K^+K^- invariant mass, excluding the $\phi(1020)$. c)- same spectrum as in b) fitted by a Breit-Wigner plus a background term (4 free parameters).

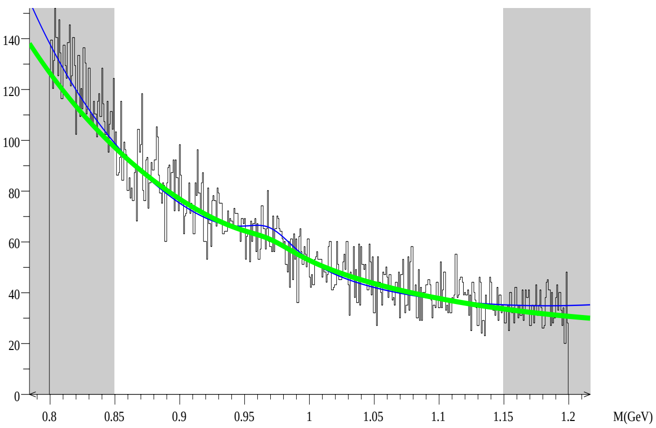

FIGURE 4. The $\pi^+\pi^-$ invariant mass spectrum (1 MeV bin) from the "exclusive" $K^+K^-\pi^+\pi^-$ sample, rejecting $\phi(1020)f_0(980)$ events, has been fitted by a Breit-Wigner plus a second order polynomial background term. The thick grey line corresponds to leaving the Breit-Wigner amplitude vary freely, yielding only a 1.5 σ effect, while the thin dark line has been obtained by fixing this amplitude equal (in absolute) to the one observed in the $\phi(1020)f_0(980)$ sample, noting that the event yield in this sample is $\approx$ 30 times bigger than the $\phi(1020)f_0(980)$ sample.

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