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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 associated $\phi(1020)f_0(980)$ photoproduction.

1 Introduction

Pion-pion scattering, particularly in the I=0, s wave, has been seen as an important test of our understanding of strong interaction[**?**, **?**]. The region around 1 GeV, featuring the K-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., implicitely assuming that the scattering phenomena can be understood independently from the presence of other particles in the final state. Although most relevant data have been obtained[**?**] with exclusive scattering, such as $pp \to \pi\pi pp$ where, if the pion pair is centrally produced and far away in rapidity from the baryons, one can always fear that such scattering amplitudes are not universal and are strongly perturbed by other real or virtual hadrons.[**?**].

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.

2 Experimental Setup and Event Selection

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 two magnet spectrometer" to the Wide Band Photon Beam from the Fermilab Tevatron. The experiment is oriented to detecting charmed particles; however the trigger, requesting the release of a large amount of hadronic energy in a hadron calorimeter, was able to select also light quark final states leading to the conversion of more than about 30 GeV energy into charged hadrons. Beam (average photon energy of 220 GeV) and setup are described elswhere [**?**, **?**].

A special Light Quark Skim (LQS) has been used, corresponding to approximately 140 million low multiplicity triggers ($n_{ch} = 2, 3, 4, 5, 6$). All tracks are requested to come from the primary vertex and events with secondary interactions in the target are rejected.

Two independent sub-selections have been used for this analysis:

sample A: selection aiming at an inclusive search of the $f_0(980)$;

sample B: selection to search for the $f_0(980)$ in final states containing two kaons and two pions ($K^+K^-\pi^+\pi^-$).

In selecting sample A a total of approximately 33 million events with a

$\pi^+\pi^-$ invariant mass between 0.8 and 1.2 GeV were selected. The Cherenkov cuts for the pion tracks were "pion - consistent", rejecting candidate tracks definitely identified as either electron, kaon or proton. Events with total charged momentum too low ($P_z < 25$ GeV/c), P_z being the momentum component along the beam axis) or too high ($P_z > 350$ GeV/c) were rejected, as being very likely electromagnetic background.

In selecting sample B (aiming at preserving events possibly containing high mass vector states decaying into $K^*(982)$, $\phi(1020)$ and $\rho(770)$), the cuts were: i- only two opposite sign pions, defined as "pion-consistent"; ii- only two charged kaons ("kaon consistent", but inconsistent with being either a definite proton or pion). These criteria yielded a total of 100,510 events.

3 Inclusive observation of the $f_0(980)$

The $\pi^+\pi^-$ invariant mass distribution in $1MeV$ bins, for the inclusive selection is shown in fig.s 1a,b,c. A whimpy signal around 0.970 GeV emerges from the huge continuous "background", after the tail of the $\rho(770)$ in fig. 1a.

The signal persists if no electromagnetic energy (e.g. $\pi^0, \eta, ...$ decays) is detected within the $\approx 100mr. \times 150mr.$ acceptance (albeit at the cost of a very significant loss in statistics -to make it visibile, the scale has been multiplied by a factor 10 in the figure). The observed effect cannot be enhanced by a stringent Pt cut, as shown in figure 1b. In fig. 1c,the spectrum is decomposed into the different multiplities, The effect is present in multiplicities $n_{ch} \geq 2$.

In the $n_{ch} = 2$ sample, the signal is strongly suppressed. In the 2π exclusive sample, due to both Vector Dominance and further suppression against broader states such as the $f_2(1270)$, no trace of a narrow $f_0(980)$ has been detected. Therefore, the combinatoric problems are unavoidable but still affordable.

3.1 Fits to the inclusive mass distribution.

In order to prove that a signal in present in our data we have to tackle the problem of describing the background, i.e. the shape of the $\pi\pi$ mass spectrum under the claimed signal. The two pion mass differential cross section can be parametrised as:

$$d\sigma/dm_{2\pi} \propto N_{NR}e^{-\alpha} + |A|^2 \tag{1}$$

a)
b)
c)

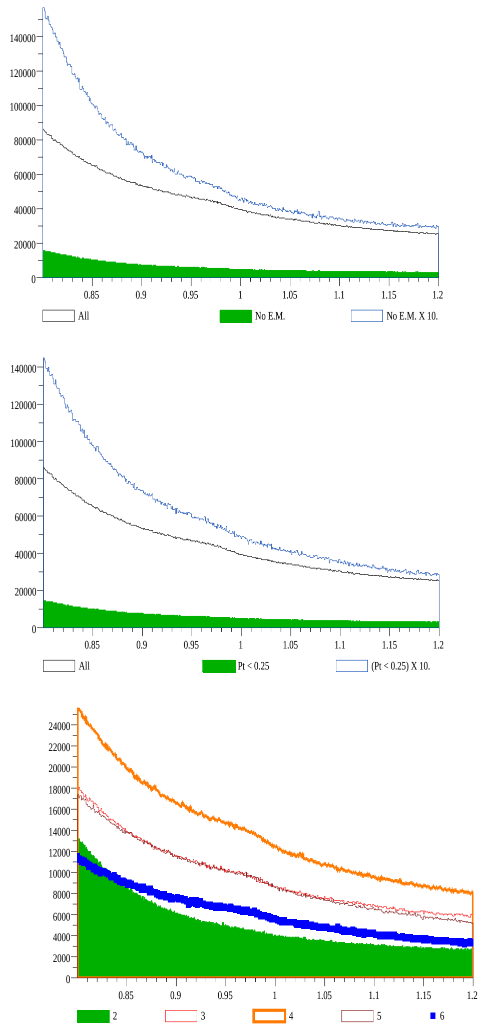


Figure 1: a)- $M_{2\pi}$ spectrum in 1 MeV bin, in the range 0.8-1.2 GeV/c, for the total inclusive sample ($3.4\,10^7$ entries). Also shown is the same spectrum in events without electromagnetic energy release in the calorimeters (solid histogram, labelled No E.M., $4.0\,10^6$ entries). The same is redrawn -intermediate histogram- in a finer 10x scale for a better reading; b)- same spectrum as in a) -upper histogram- compared to the spectrum obtained by rejecting all events with a total transverse momentum larger than 0.25 GeV/c (solid histogram). The same is redrawn -intermediate histogram- in a finer 10x scale for a better reading; c)- same spectrum for different charged multiplicities $n_{ch} = 2, 3, 4, 5, 6$

The first term parametrises the "non-resonant" continuum as well as the tail of the dominant $\rho(770)$ meson. The second term describes the resonant s-wave of interest. That is:

$$A_{f_0} = e^{i\delta_{f_0}} \frac{m_{f_0}\Gamma_{f_0}(m)}{(m_{f_0}^2 - m_{2\pi}^2) - i m_{f_0}\Gamma_{f_0}(m)} \tag{2}$$

while α is a 5th order polynomial parametrization (the C_i's are free parameters) :

$$\alpha = \sum_{i=1}^{5} C_i * (m_{2\pi} - 1.0)^i \tag{3}$$

In the following, when necessary, the amplitude A will be written as a sum of Breit Wigner functions as:

$$A = \sum_k e^{i\delta_k} A_{BW,k} \tag{4}$$

Despite the large number of free parameters describing the non-resonant component, the χ^2 corresponding to a one Breit Wigner fit shown in fig. 2a to the mass spectrum in the interval $0.85 - 1.15\ GeV/c^2$ is not very good (523.8 for 391 degrees of freedom -hereafter dof). In fig. 2b the residuals (data-fit) show non satisfactory fluctuations. However, a significant signal is clearly visible once this non-resonant background is subtracted out, as as shown by fig. 2c.

The fitted parameters of a single assumed resonance are :

$$m_{f_0(980)} = 968 \pm 0.5\ ;\ \ \Gamma_{f_0(980)} = 50. \pm 2.35$$

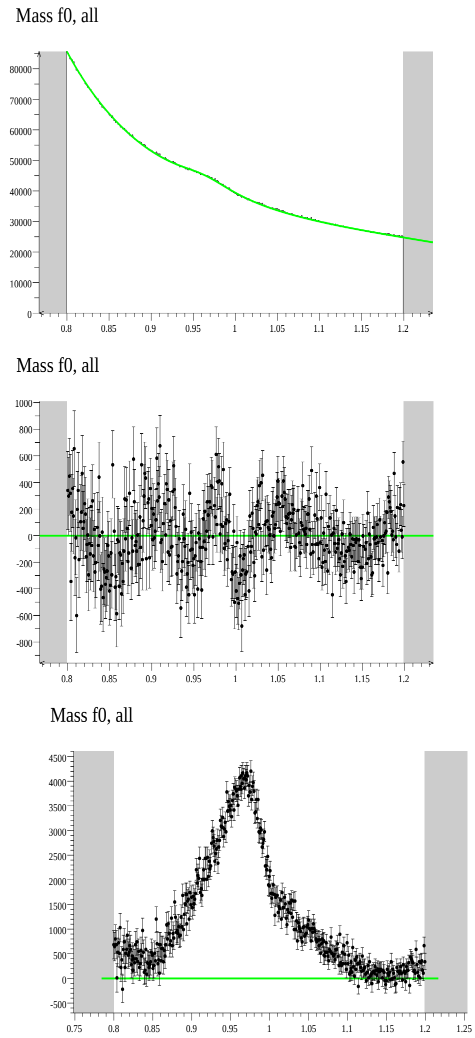
.

Increasing the mass range to $0.8 \leftrightarrow 1.2\ GeV/c^2$ the fit gives:

$$m_{f_0(980)} = 962.5 \pm 0.5\ ;\ \ \Gamma_{f_0(980)} = 87.7 \pm 2.35\, MeV$$

.

The errors are statistical only. The mass is not stable and seems to be correlated to the way the background is described. The "non-resonant" component is expected to be non-trivial, given the sample. For instance, the Jacobian peak for the $\phi(1020) \to \pi^+\pi^-\pi^0$, with missing π^0 is in this range, as well as the low-mass tail of the $f_2(1270)$. In addition, the $\rho(770) \leftrightarrow \phi(1020)$ interference effect plays an important role.



a)

b)

c)

Figure 2: a)- Fit of the $M_{2\pi}$ spectrum with only one Breit-Wigner; b)- the residuals (Data - fit); c)- the residuals (Data - fit) from the $M_{2\pi}$ spectrum, when the amplitude for the signal has been fixed to zero.

The overall yield for the signal is hard to determine, given the uncertainty of the background shape. We find roughly a few hundred thousands events in the peak: only less than 1 % of the events in the sample would contain a possible $f_0(980)$ signal.

In spite of the difficulties of dealing with semi-inclusive mass distributions, and the absence of a well definite reference frame to perform proper partial wave analyses, our result provides nonetheless a certain amount of information:
- The $f_0(980)$ can not be fitted by a single scalar relativistic Breit Wigner;
- inspection of fig. 2c clearly indicates that a coupled Breit-Wigner of the "Flatteé type" [**?**] is needed.
-as already observed by WA76[**?**], this relatively narrow structure could interfere with broad s-wave resonances in the nearby mass region [**?**].

4 Evidence for associated $\phi(1020)f_0(980)$ photoproduction

Since the $f_0(980)$ signal in exclusive two pion channel is highly suppressed and having observed the $f_0(980)$ state in the highly inelastically produced final states we investigated the possibility that the $f_0(980)$ might be present in collisions containing kaons, in particular associated to the production of the well known narrow $\phi(1020)$ di-kaon resonance.

This has been recently suggested by F.E. Close el al. [**?**] in view of the possible role played by the $f_0(975)$ and the $a_0(980)$ in the dynamics of quarks confinement.

The event sample was obtained by requiring:
a)- $n_{ch} = 4$;
b)- only two positive and two negative tracks.
c)- no electromagnetic energy released in the event (no additional neutral pions).
d)- two particles are pion consistent (no "definite" electron or kaon or proton);
e)- two particles are kaon consistent (no "definite" electron or pion or proton);
f)- the two kaons of opposite charge have an invariant mass within 5 MeV of the $\phi(1020)$ mass, that is $|m_{2K} - 1.020| < 0.005\, GeV/c^2$;

The $M_{2\pi}$ mass distribution, in 20 MeV bins is shown in fig. **??**a. The same distribution is repeated also in fig.s **??**b and c in 4 MeV/c^2 limited

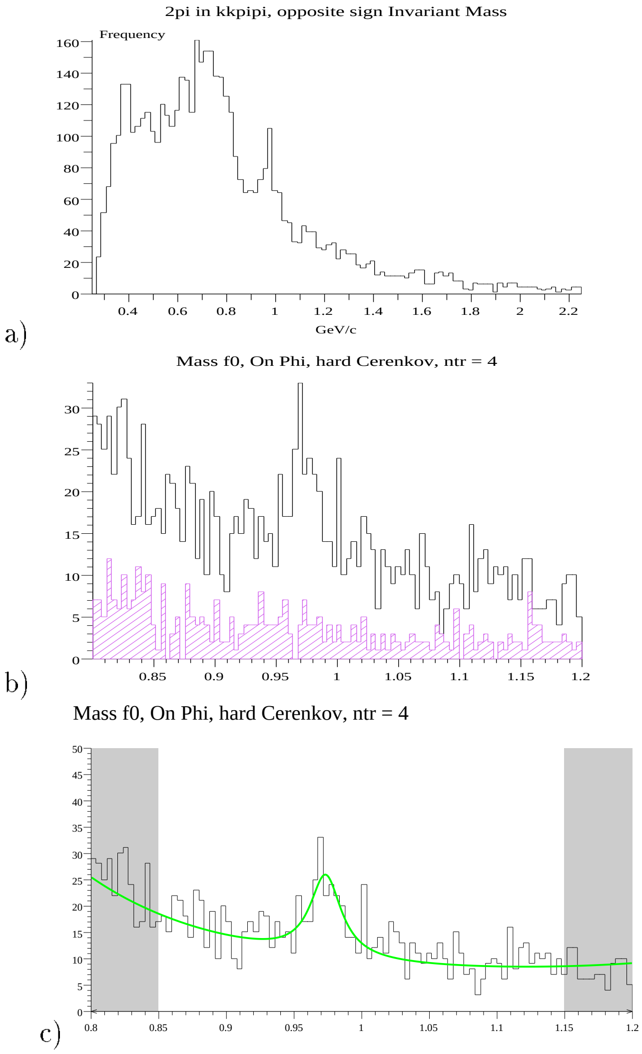


Figure 3: a)- The full 2π mass spectrum, in 20 $MeV/c^{@}$ bins, associated to a $\phi(1020)$ particle; b)- sam e as in a) in 4 MeV/c^2 bins, limited to the mass range $0.8-1.2\ GeV/c^2$ (black histogram) also shown the spectrum for the "background" sample (dashed purple histogram); c)- same spectrum as in b) fitted by a Breit-Wigner plus a background term (3 free parameters).

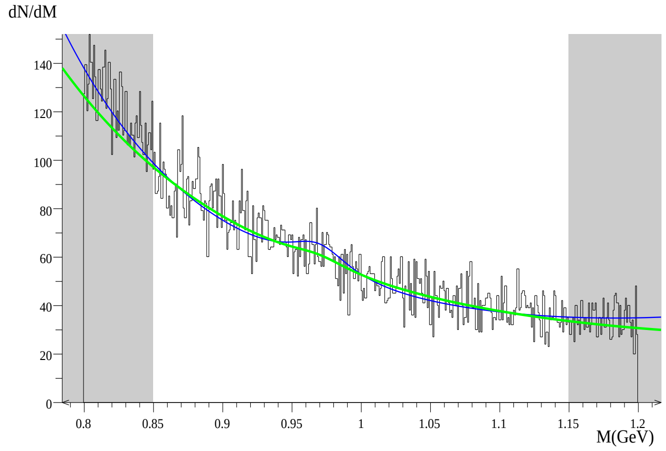


Figure 4: The $\pi^+\pi^-$ invariant mass spectrum from the "exclusive" $K^+K^-\pi^+\pi^-$ sample, rejecting $\phi(1020)f_0(980)$ events, has been fitted by a Breit-Wigner plus a second order polynomial background term. The thick green line corresponds to leaving the Breit-Wigner amplitude vary freely, yielding only a 1.5 σ effect, while the thin blue line has been obtained by fixing this amplitude equal to the one observed in the $\phi(1020)f_0(980)$ sample.

to the mass range $0.8 - 1.2$ GeV/c^2. Fig. **??**b shows also, as a dashed histogram, the "non ϕ" background obtained by requiring $|m_{2K} - 1.045| < 0.005$ GeV/c^2.

In order to quantify the level of significance of the $\pi\pi$ signal, the $M_{2\pi}$ spectrum asssocited to the "$\phi(1020)$" has been fitted to a scalar Breit Wigner function of the type (2) plus a background term of the type (3), limiting the polynomial expansion for α to a linear and a quadratic term.

We find an about 3σ signal (of 167 ± 47 events over background ; a χ^2 of 73.45 for 68 dof with:

$$m_{f_0(980)} = 973 \pm 2.5 \;\; \Gamma_{f_0(980)} = 28. \pm 10. \, MeV$$

and an unnormalized amplitude of 0.674 ± 0.20. This fit is shown in fig. **??**c.

Te significance of the signal could be enhanced with a P_t cut. Likewise, relaxing the veto on neutrals, e.g., allowing for E.M. energy in the event, simply raises the flat background component of the spectrum.

The signal seems to be enhanced by the presence of hidden strangeness. We selected the exclusive "Off ϕ" $K^+K^-\pi^-\pi^+$ events (No Pt cut, but vetoing events with E.M. and rejecting event with $|m_{KK} - 1.020| < 0.007$) and perform the usual straight Breit-Wigner fit, using the fixed pole mass and width for the fit presented on fig. **??**c. The 2π mass spectrum is shown in fig. **??**. It is clear that the $f_0(980)$ yield is not improved, while the background is considerably increased: the $\phi(1020)$ over K^+K^- cross section is about 1/30.

The exclusive $\phi(1020)f_0(980)$ enhancement does not seem to come from a narrow higher mass resonance. The $2\pi 2K$ mass spectrum doesn't show any relevant structure.

5 Conclusions

We have observed the $f_0(980)$ scalar meson in a high statistics photoproduction experiment at the right mass location. Due to the complicated shape of the background and the presence of several known states in the nearby mass region, a more sophisticated analysis is needed to extract the exact position of the mass pole and the correct value of the Breit Wigner width.

Given the results reported in Section 4, we claim we have observed a somewhat unexpected dynamical correlation between the photoproduction of the two narrow states $\phi(1020)$ and $f_0(980)$.

A similar $f_0(980)$ signal has been found in J/ψ decay [**?**, **?**]. Moreover, it has been shown that the branching ratio $J/\psi \to \omega f_0(980)$ is at least three times smaller than $J/\psi \to \phi(1020)f_0(980)$.

So far, there has been in the literature no strong evidence for exclusive $f_0(980)$ production, neither at e^+e^- machines nor in photoproduction. This state, seen as a narrow peak, seems to be correlated with associate production of hidden strangeness, or strong $s\bar{s}$ annihilation, as in the charm decay $D_s^+ \to 2\pi^+\pi^-$.

References

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[1] See, for example, M. Harada *et al.*, Phys. Rev. **D54**, 1991 (1996), and references therein;

[2] N.A. Törnqvist, Zeit. Phys. **C68**, 647 (1995);

[3] F.E. Close *et al.*, Phys. Lett. **B319**, 291 (1993);

[4] P.L. Frabetti *et al.*, N.I.M. in Phys. Res. **A329**, 62 (1993);

[5] P.L. Frabetti *et al.*, N.I.M. in Phys. Res. **A320**, 519 (1992);

[6] D. Morgan and M.R. Pennington, Zeit. Phys. **C48**, 623 (1990);

[7] T.A. Armstrong *et al.*, Zeit. Phys. **C51**, 351 (1991).;

[8] A. Falvard *et al.*, Phys. Rev. **D38**, 2706 (1988);

[9] MARK-III Collaboration (W.S. Lockman for the collaboration). SLAC-PUB-5139, Nov 1989. 9pp. Presented at 3rd Int. Conf. on Hadron Spectroscopy, Ajaccio, France, Sep 23-27, 1989. Published in Ajaccio Hadron 1989: 109-118 (QCD161:I407:1989).