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RECENT RESULTS FROM SPEAR

Klaus Wacker
(Representing the Crystal Ball Collaboration*)
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Abstract

The first part of this talk is an experimental review of the properties of the Θ meson. Results or upper limits come from radiative J/ψ decays and $\gamma\gamma$ scattering for the final states $\eta\eta$, $\pi\pi$, $K\bar{K}$ and $\rho\rho$. In the second part, an upper limit is given for the production of low-mass particles in radiative J/ψ decays. Constraints for the existence of low-mass gluonic and Higgs mesons are derived.

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1. Introduction

The investigation of radiative J/ψ - decays has in recent years led to a number of interesting results in old-fashioned, non-charm physics. The highlights were the discovery of two new mesons, the Θ[1] and the ι[2]. Although these mesons have perfectly normal quantum numbers, they are unusual in two ways: Firstly, they are unexpected, i.e. they do not fit into existing multiplets in the naive quark model; secondly, they are produced in a channel in which no constituent quarks are transferred from the initial to the final state, whereas they do not seem to be produced copiously in "normal" hadronic reactions[3]. There have been many speculations that their main constituents are gluons[5].

Recent results from SPEAR come from two experiments, which are both running at other storage rings now: Crystal Ball and Mark II.(Crystal Ball is now running at DORIS, Mark II at PEP. A new experiment, Mark III, is now running at SPEAR, but there are no results at the time of this conference). In the ongoing analysis of SPEAR data, radiative J/ψ - decays play a major role in both groups. I will present here a necessarily biased selection of recent results. In the first part, I will give an overview of the present experimental knowledge of the Θ meson. In the second part, I will present an upper limit on the production of low-mass π pairs in radiative J/ψ - decays and discuss limits on low-mass gluonia or low-mass Higgs mesons.

2. Brief Characterization of the Experiments

The Crystal Ball[6] is a nonmagnetic detector specialized in the detection of electromagnetically showering particles. Its main part is a segmented array of NaI (Tl) shower counters arranged spherically around the interaction point. It covers 93% of 4π solid angle. The energy resolution is $\sigma_E/E = 2.6\%/E^{1/4}$. NaI (Tl) endcaps cover an additional 5% of 4π. Inside the main sphere there are two cylindrical spark chambers and one multiwire proportional chamber for the detection of charged particles and for measurement of their angles. The Crystal Ball has taken a data sample corresponding to 2.2×10^6 produced J/ψ's.

Mark II[7] is a magnetic detector which uses 16 cylindrical layers of drift chambers as its main device to track charged particles. The momentum resolution is $\sigma_p^2/p^2 = (1.5\%)^2 + (0.5\% p)^2$. Outside of this there is a layer of scintillation counters used to measure the time-of-flight (ToF) of charged particles. It can distinguish pions from kaons below 1.3 GeV/c at the one-standard-deviation level. Outside of the magnet coil there are lead-liquid-Argon shower counters with an energy resolution of $\sigma_E/E = 14\%/E^{1/2}$. The efficiency for low-energy photons is low, it reaches 50% of the maximum efficiency at about 200 MeV. Mark II has 1.3×10^6 J/ψ's. Only half of these data, however, were taken with operational shower counters.

It is clear that the strengths of the two detectors are complementary: The Crystal Ball is good at detecting photons and neutral hadrons decaying into photons, whereas Mark II is good at detecting charged hadrons.

3. What Do We Know about the Θ Meson?

3.1. $J/\psi \rightarrow \gamma\eta\eta$

The Θ meson was discovered by the Crystal Ball in radiative J/ψ - decays through its decay mode into $\eta\eta$[1]. Fig. 1 shows the $\eta\eta$ mass distribution. The curves show fits to the histogram which included a Breit-Wigner function to describe the Θ and a constant term for the background. The broken curve included also a Breit-Wigner function for the f'(1515) meson with mass and width as given by ref. 4. There was no statistically significant evidence for f' production, and the Θ parameters found by the two fits agreed within errors. The fitted Θ parameters (from the fit including f') were:

$$M_\Theta = (1670 \pm 50)\ \text{MeV}$$
$$\Gamma_\Theta = (\ 160 \pm 80)\ \text{MeV}.$$

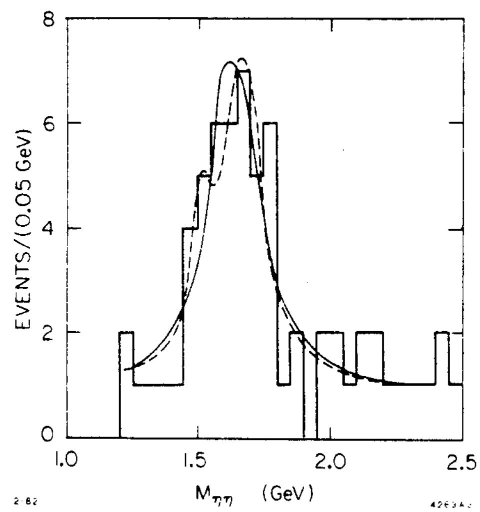

Fig. 1.

$\eta\eta$ mass distribution in the reaction $J/\psi \rightarrow \gamma\eta\eta$ (Crystal Ball). The curves are explained in the text.

The rate of Θ production was measured to be:

$$BR(J/\psi \rightarrow \gamma\Theta) \times BR(\Theta \rightarrow \eta\eta) = (3.8 \pm 1.6) \times 10^{-4}.$$

We know from its production and decay mechanism that the Θ must have positive G and C parity and zero isospin. The spin and parity J^P are restricted to the series 0^+, 2^+, 4^+, ... The Crystal Ball analyzed the angular distribution and found that spin 2 was favoured over spin 0 with a likelihood ratio of 1:0.045. Higher spins were not considered. It has to be noted that the likelihood ratio does not take systematic errors into account.

Both the Crystal Ball and Mark II have looked for other decay modes of the Θ. No signal was found for the decay into $\pi\pi$. The Crystal Ball found an upper limit of $BR(J/\psi \to \gamma\Theta) \times BR(\Theta \to \pi\pi) < 6.0 \times 10^{-4}$ (90% C.L.) using the reaction $J/\psi \to \gamma\pi^0\pi^0$ (see Fig.8). Mark II[8] found this number to be $< 3.2 \times 10^{-4}$ (90% C.L.) using charged pions. Mark II did find signals consistent with Θ in the KK and $\rho\rho$ decay modes.

3.2. $J/\psi \to \gamma K^+K^-$

To investigate the reaction $J/\psi \to \gamma K^+K^-$ [8], events were selected with two oppositely charged particles which had a ToF consistent with that expected for kaons. A major background comes from the reaction $J/\psi \to K^+K^-\pi^0$, which was shown to be mostly due to $J/\psi \to K^{\pm *}K^{\mp}$. Most of these events could be removed by requiring that the kaons be acollinear by at least 30^0. The missing mass was required to be consistent with 0. From here on, two different methods were used. In method I, it was required that one photon shower was observed in the liquid-Argon shower counters. The missing vector was computed from the two charged tracks. Its component transverse to the direction of the observed shower, $p_{t\gamma}$, is expected to peak at zero for $K^+K^-\gamma$ events, whereas it has a broad, flat distribution for $K^+K^-\pi^0$ events in which one of the decay photons of the π^0 has escaped detection. $p_{t\gamma}$ was required to be less than 40 MeV. Finally, a kinematic fit with 4 constraints was done and events with $\chi^2 < 15$ were kept. The resulting K^+K^- mass spectrum is shown in Fig. 2. It shows a peak with position and width compatible with the Θ. The two curves represent fits analogous to those shown in Fig. 1. The background term turned out to be compatible with 0.

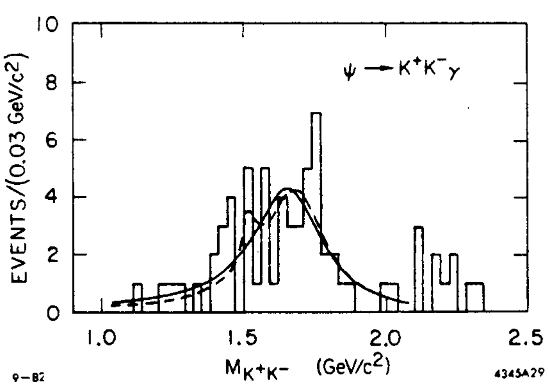

Fig. 2.

K^+K^- mass distribution in the reaction $J/\psi \to \gamma K^+K^-$ (Mark II, method I). The curves are explained in the text.

Method I yielded a very clean, but small data sample. It was investigated whether one could increase the data sample without increasing the background to unacceptable levels by loosening some of the cuts. In particular, if Mark II can do without detecting the photon, they gain not only by the increase in geometric acceptance by a factor of 1.5, but also because they can use the data taken without operational shower counter. With the other cuts essentially the same, this was called method II. There are several known and unknown sources of background which enter the event sample of method II. Radiative Bhabha events, which are harder to identify without the shower counter, constitute 10% of the event sample. These events tend to be peaked both at the highest and the lowest masses, only 1% is expected to be in the Θ mass region. Another background comes from $J/\psi \to K^*K$. The reaction $J/\psi \to K^{\pm *} K^{\mp} \to K^+K^-\pi^0$ is a background at high K^+K^- masses. The reaction $\psi \to K^{0*}K^0$, where the K^0 decays into neutrals and the K^{0*} decays into $K^{\pm}\pi^{\mp}$, enters the data sample, when the pion is misidentified as a kaon. This fake - K^+K^- mass peaks at around 1050 MeV. More background may come from multiparticle final states and other unknown sources.

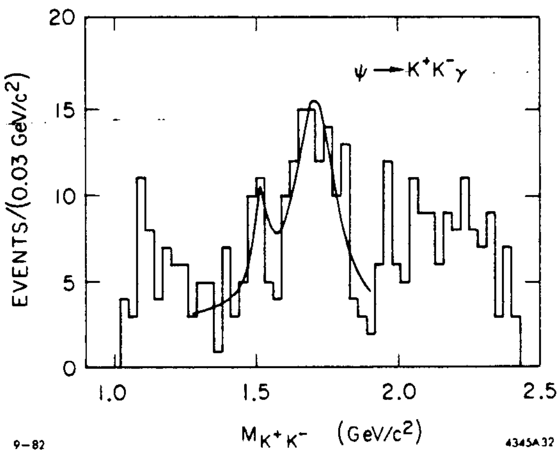

Fig. 3.

K^+K^- mass distribution in the reaction $J/\psi \to \gamma K^+K^-$ (Mark II, method II). The curve is from a fit analogous to the broken curves in Figs. 1 and 2.

Fig. 3 shows the resulting K^+K^- mass plot. As expected, there is more background than in Fig. 2, but also a bigger Θ signal. There is also some evidence for f' production. A fit analogous to the one represented by the broken curve in Fig. 1 yielded the following results:

$$M_\Theta = 1700 \pm 30 \text{ MeV} \qquad \Gamma_\Theta = 156 \pm 20 \text{ MeV}$$

$$BR(J/\psi \to \gamma\Theta) \times BR(\Theta \to K^+K^-) = (6.0 \pm 0.9 \pm 2.5) \times 10^{-4}.$$

The first error is statistical, the second systematic. The background in the Θ region was about 25% of the events.

Whereas the larger sample was used to determine resonance parameters, the cleaner sample of method I was used to do a spin determination with the same method as used by the Crystal Ball. The result is that spin 2 is favoured over spin 0 by 1:0.22. If systematic errors could be neglected, one could multiply this likelihood ratio with the one from the Crystal Ball to obtain an overall confidence level. However, systematic errors are not easily expressed in terms of likelihood ratios, and it has not been done here. Furthermore, there is at least one possible common error: Both data samples may contain f' events, which are known to have spin 2 and which would shift the likelihood ratio in favour of spin 2.

3.3. $J/\psi \to \gamma\, \rho^0\rho^0$

To investigate the reaction $J/\psi \to \gamma\rho^0\rho^0$ [9], Mark II has looked into the final state $\gamma\ \pi^+\pi^+\pi^-\pi^-$. The method used to select these events was similar to method I described in the previous paragraph: Events were selected with one observed photon and four charged tracks consistent with pions according to ToF. The missing mass recoiling against the charged particles was required to be consistent with zero. The remaining background after these cuts is the channel $\pi^0\pi^+\pi^+\pi^-\pi^-$, which has the highest branching ratio of all hadronic J/ψ - decays. It is reduced by a cut in $p_{t\gamma}$. The remaining background of about 40% of the sample is subtracted using events with higher $p_{t\gamma}$ as background sample and using the known shape of the $p_{t\gamma}$ distribution for normalization.

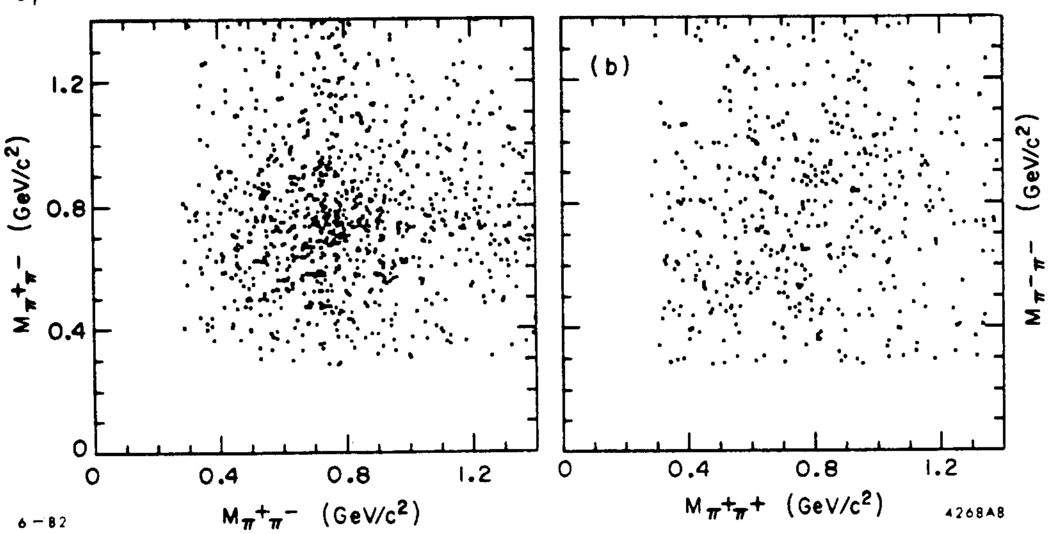

Fig.4. Scatterplot of a) $\pi^+\pi^-$ vs. $\pi^+\pi^-$ mass and b) $\pi^+\pi^+$ vs. $\pi^-\pi^-$ mass in the reaction $J/\psi \rightarrow \gamma\ \pi^+\pi^+\pi^-\pi^-$ (Mark II).

Fig. 4a shows a scatterplot of $\pi^+\pi^-$ versus $\pi^+\pi^-$ mass (2 combinations per event). For comparison, Fig. 4b shows a scatterplot of the like-sign mass combinations. There is a clear enhancement in the unlike-sign combinations at the mass of $\rho(770)$. The fraction of $\gamma\rho^0\rho^0$ events, as opposed to uncorrelated $\gamma\ \pi^+\pi^+\pi^-\pi^-$, was determined by a maximum-likelihood fit. The $\rho^0\rho^0$ distribution used in the fit was a product of two Breit-Wigner functions, symmetrized to take the presence of identical Bosons in the final state into account. A similar fit was done to the π^0 background events and the results were subtracted binwise. The resulting $\rho^0\rho^0$ mass distribution is shown as solid line in Fig. 5. In another fit the channel $\gamma\rho^0\pi^+\pi^-$ was also allowed to contribute. The results are shown as dots in Fig. 5. This resulted in a lower $\rho^0\rho^0$ contribution at some points, but did not change the overall shape. Instead of uncorrelated $\gamma\rho^0\pi^+\pi^-$, it was also tried to fit $\gamma A_1^{\pm}\pi^{\mp} \rightarrow \gamma\rho^0\pi^+\pi^-$, without significant change in the result.

There is a clear enhancement at around 1600 MeV and no significant signal elsewhere. When the $\rho^0\rho^0$ mass spectrum was fitted with a Breit-Wigner function, a mass of 1650 ± 50 MeV with a width of 200 ± 100 MeV was obtained. These parameters are compatible with the Θ, however, the Mark II authors did not claim that this signal was the Θ. The reasons for this reserve were firstly that the enhancement was right above the ρρ threshhold and secondly that a spin determination was not possible. For these reasons a nonresonant threshold effect could not be excluded. A branching ratio was given for the reaction $J/\psi \to \gamma\rho^0\rho^0$ with $m_{\rho^0\rho^0} < 2$ GeV, independent of any resonance interpretation. It was measured to be $(1.25 \pm 0.35 \pm 0.40) \times 10^{-3}$.

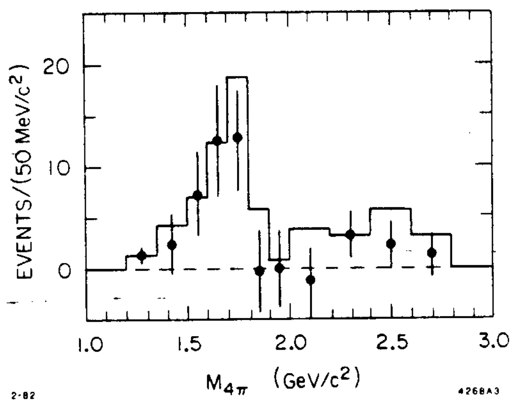

Fig. 5.
$\rho^0\rho^0$ mass distribution in the reaction $J/\psi \to \gamma\rho^0\rho^0$ (Mark II). The solid line and the dots represent two different fits (see text).

3.4. $\gamma\gamma \to \eta\eta$

The radiative J/ψ - decays mentioned so far are the only reactions in which the Θ has been seen. This reaction is, according to perturbative QCD in lowest order, mediated by 2 gluons. Since QCD also predicts that gluons can form bound states, it has been conjectured that the Θ is such a gluonic meson. In order to check this hypothesis, it is useful to look for other channels to which the Θ may couple. The two-photon channel lends itself as it has the same quantum numbers as two gluons, but different couplings. A pure gluonium state, which has no electrically charged constituents, has a very small coupling to $\gamma\gamma$. It is expected that gluonic mesons mix with ordinary mesons of the same quantum numbers (f and f' in case of the Θ). Measurement of the partial width $\Gamma(\Theta \to \gamma\gamma)$ helps determine the mixing parameters.

The Crystal Ball has looked for Θ production in $\gamma\gamma$ scattering in the $\eta\eta$ decay mode. The data were taken at center-of-mass energies between 4 and 7 GeV and represent an integrated luminosity of 21 pb^{-1}. We are looking for the reaction $e^+e^- \to e^+e^-\eta\eta \to e^+e^-\gamma\gamma\gamma\gamma$, where the outgoing electrons are scattered under very small or 0 angle and are not observed. According to QED, the final state hadrons are produced by the collision of two virtual, but very nearly on-shell photons. Candidate events were selected[10] by requiring that there were 4 clean photon showers and nothing else in the detector. The two-photon origin of these events was established by observing that a) the energy seen is less than the center-of-mass energy and b) the transverse momentum distribution of the 4-photon system peaks at 0.

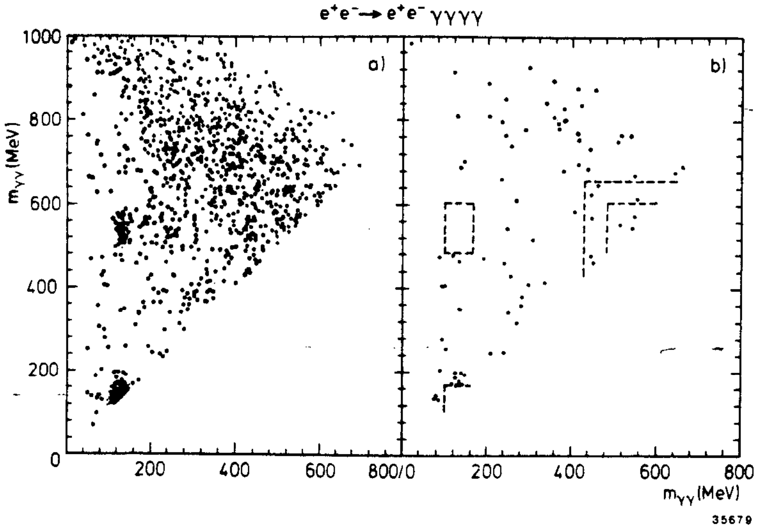

Fig. 6.

a) Scatterplot of high vs. low $\gamma\gamma$ mass for 4-photon events with $1040 < m(4\gamma) < 1480$ MeV, 3 combinations per event (Crystal Ball).
b) same as a), but $\pi^0\pi^0$ and $\pi^0\eta$ events removed. The broken lines indicate the $\pi^0\pi^0$, $\pi^0\eta$, and $\eta\eta$ regions and the $\eta\eta$ control region.

We first turn our attention to a 4-photon mass (W) region where we know[10] that there are signals from $f \to \pi^0\pi^0$ and $A_2 \to \pi^0\eta$. Fig. 6a shows a scatterplot of high vs. low $\gamma\gamma$ mass with 3 combinations per event, which clearly shows $\pi^0\pi^0$ and $\pi^0\eta$ signals. There is also a continuum background which is mostly due to wrong combinations of events in the peaks. When these events were removed (Fig. 6b), very few events remained which did not show any clustering in the $\eta\eta$ region. Events in the $\eta\eta$ region indicated in the figure were considered possible signal events, whereas the larger, surrounding $\eta\eta$ control region was used to estimate background. Fig. 7 shows the distribution of events in the signal and the control region and the normalized difference as function of W. There is no signal. To obtain an upper limit for the Θ, events in the W range 1400-1800 MeV were used. The 2-photon flux was calculated according to ref. 11. It was assumed that the

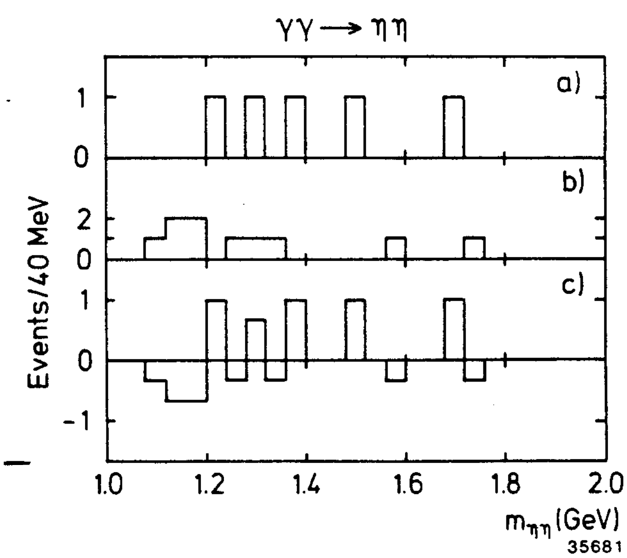

Fig. 7.

a) Distribution of events in the $\eta\eta$ region as function of W (Crystal Ball)
b) The same for events in the $\eta\eta$ control region
c) Normalized difference of distributions a) and b).

Θ has spin 2 and is in a helicity state ± 2*. The resulting upper limit was

$$\Gamma(\Theta \to \gamma\gamma) \times BR(\Theta \to \eta\eta) < 0.3 \text{ keV (95\% C.L.)}.$$

Systematic errors were included. If, instead of helicity ± 2, an isotropic angular distribution was assumed, the upper limit increased by a factor of 1.9 due to decreased acceptance. If the spin were zero, the upper limit would increase by another factor of $2L + 1 = 5$.

The TASSO collaboration[12,13] at PETRA found two more upper limits on $\Theta \to \gamma\gamma$. They are

$$\Gamma(\Theta \to \gamma\gamma) \times BR(\Theta \to K\bar{K}) < 0.3 \text{ keV (95\% C.L.)}$$
$$\Gamma(\Theta \to \gamma\gamma) \times BR(\Theta \to \rho^0\rho^0) < 1.2 \text{ keV (95\% C.L.)}.$$

These numbers cannot be compared directly, since the branching ratios are not known. One can form ratios with the corresponding partial widths in ψ decays such that the branching ratios cancel. The results are summarized in Table 1. The $\rho^0\rho^0$ signal of section 3.3 was assumed to be due to Θ. The best upper limit for $\Gamma(\Theta \to \gamma\gamma)/\Gamma(J/\psi \to \gamma\Theta)$ comes from the $K\bar{K}$ channel.

tensor meson T	decay channel X	$\Gamma(J/\psi \to \gamma T) \times BR(T \to X)$ (eV)	ref.	$\Gamma(T \to \gamma\gamma) \times BR(T \to X)$ (eV)	ref.	$\frac{\Gamma(T \to \gamma\gamma)}{\Gamma(J/\psi \to \gamma T)}$
Θ	$\eta\eta$	24 ± 10	1	< 300		< 13
	$K\bar{K}$	$76 \pm 11 \pm 32$	8	< 300	13	< 4
	$\rho^0\rho^0$	$79 \pm 22 \pm 25$	9	< 1200	12	< 15
f	all	95 ± 25	4	2900 ± 500	4	31 ± 10
f'	$K\bar{K}$	$11 \pm 4 \pm 6$	8	$110 \pm 20 \pm 40$	13	10 ± 10

Table 1

Comparison of the production of tensor mesons by $\gamma\gamma$ scattering and by radiative ψ-decays. Where two errors are given, the first is statistical and the second systematic.

This ratio does not mean much by itself, but it can be compared to other tensor mesons. Measurements exist for f and f', although they have large errors in case of the f'. We find that $\Gamma(f \to \gamma\gamma)/\Gamma(\psi \to \gamma f)$ is considerably bigger than the corresponding Θ upper limit. If we interpret $\Gamma(T \to \gamma\gamma)/\Gamma(J/\psi \to \gamma T)$ as a qualitative measure of the charge as opposed to gluon content of a meson, we find the

*The reason for this assumption is that it is true for the f[10].

numbers consistent with the naive picture that the f consists mostly of u and d quarks, the f' mostly of s quarks and the Θ mostly of gluons. However, one should not overinterpret this ratio - it is just the only way to compare the experimental results in the absence of absolute branching ratio measurements.

3.5. Θ Summary

Since its discovery in the reaction $J/\psi \to \gamma\eta\eta$, considerable progress has been made in the experimental knowledge about the Θ. Another decay channel, $K\bar{K}$, has been identified. If the signal seen in $\rho^0\rho^0$ also comes from the Θ, then the known branching ratio for $J/\psi \to \gamma\Theta$ is $(5.3 \pm 1.7) \times 10^{-3}$, which is as large as the largest known branching ratio in radiative J/ψ - decays, that of the ι. Meaningful upper limits have been obtained for $\Gamma(\Theta \to \gamma\gamma)$. Of course, much more information is needed. Most notably, a high-statistics spin determination with good confidence level is lacking.

quantity	value	ref.
Θ mass, width (MeV)	1670 ± 50 $\quad 160 \pm 80$	1
	1700 ± 30 $\quad 156 \pm 20$	8
	$[1650 \pm 50$ $\quad 200 \pm 100]$	9
$BR(J/\psi \to \gamma\Theta)BR(\Theta \to \eta\eta)$	$(3.8 \pm 1.6)\ 10^{-4}$	1
$BR(J/\psi \to \gamma\Theta)BR(\Theta \to K\bar{K})$	$(12.0 \pm 1.8 \pm 5.0)\ 10^{-4}$	8
$BR(J/\psi \to \gamma\Theta)BR(\Theta \to \pi\pi)$	$< 6 \times 10^{-4}$ (90% C.L.)	1
	$< 3.2 \times 10^{-4}$ (90% C.L.)	8
$BR(J/\psi \to \gamma\rho\rho$, $m_{\rho\rho} < 2$ GeV)	$[(3.75 \pm 1.05 \pm 1.20)\ 10^{-3}]$	9
$\Gamma(\Theta \to \gamma\gamma)BR(\Theta \to \eta\eta)$	< .3 keV (95% C.L.)	
$\Gamma(\Theta \to \gamma\gamma)BR(\Theta \to K\bar{K})$	< .3 keV (95% C.L.)	13
$\Gamma(\Theta \to \gamma\gamma)BR(\Theta \to \rho\rho)$	< 3.6 keV (95% C.L.)	12
spin 2 vs. spin 0 Confidence Level	95%	1
	78%	8

Table 2

Experimental results about the Θ meson. Where two errors are given, the first is statistical, the second systematic. Branching ratios were corrected for unseen charge states assuming isospin 0. The numbers from ref. 9 are not necessarily related to Θ.

The most interesting question, whether Θ is a gluonic meson, is not easy to answer. There is no quantum number "gluoniumness" - the gluon content of a meson has to be inferred using all available information and allowing for mixing with quarkonia. With our present knowledge the result is model-dependent at best.

Table 2 shows a compilation of experimental results about the Θ.

4. An Upper Limit for Low-Mass Particles Produced in Radiative J/ψ - Decays

The motivation for a search for low-mass particles produced in radiative J/ψ - decays comes from a number of predictions for the existence of a low-mass gluonic meson. The result will also be used to place a constraint on a possible low-mass Higgs meson.

4.1. The Experimental Upper Limit

The Crystal Ball has investigated the reaction $J/\psi \to \gamma\pi^0\pi^0$. To do this, events were selected which have 3, 4, or 5 clusters of neutral energy and no charged tracks. A π^0 can appear as 1 or 2 clusters, depending mainly on its energy. The energy distribution in every cluster was fitted with either one or the sum of two electromagnetic shower patterns in order to determine whether it is due to a single photon or to two merged photons from a π^0. The events where then kinematically fitted to the hypothesis $\gamma\pi^0\pi^0$, where the π^0 mass was put in as a constraint when the π^0 was seen as two separate photons. Events were kept when the χ^2 probability was better than 10%.

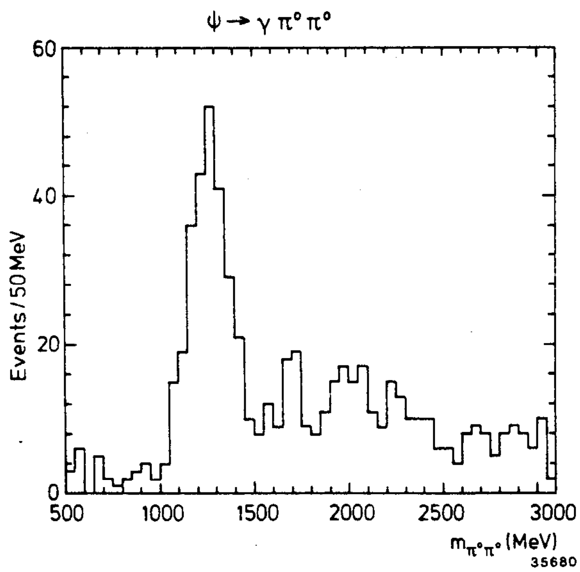

Fig. 8.

$\pi^0\pi^0$ mass distribution for the reaction $J/\psi \to \gamma\pi^0\pi^0$ (Crystal Ball).

Fig. 8 shows the $\pi^0\pi^0$ mass distribution. The most prominent feature is a peak due to the f(1270) meson, the analysis of which has been published[18]. We further note that there are very few events below 1 GeV. Fig. 9 shows the detection efficiency as function of $\pi^0\pi^0$ mass. The efficiency does not vary rapidly over the mass range 500-3100 MeV. (It does drop sharply below 500 MeV due to the overlap of photons from two different pions). We observe 28 events in the mass range 500-1000 MeV with an average efficiency of 32%. This corresponds to a branching ratio of about 4×10^{-5}. To obtain upper limits for any narrow object with a width not bigger than 100 MeV, we use sideband subtraction to estimate background. The result is

$$BR(J/\psi \to \gamma X \to \gamma\pi^0\pi^0) < 1.3 \times 10^{-5} \text{ (95\% C.L.)}$$

for any X with $500 < m_X < 1000$ MeV and $\Gamma_X < 100$ MeV.

4.2. Is there a Scalar Gluonium?

One of the bound states of gluons predicted by QCD is expected to have the quantum numbers of the vacuum, $J^{PC} = 0^{++}$. The possible mixing of this state with the vacuum leads in some models to predictions of very low masses. Note that for masses below about 1 GeV, $\pi\pi$ is the only open two-body decay channel and 1/3 of $\pi\pi$ has to be $\pi^0\pi^0$ due to isospin invariance. As the upper limit is far below typical branching ratios for radiative J/Ψ - decays into gluonia, any narrow gluonium state with a mass between 500 and 1000 MeV can be ruled out. This contradicts the prediction[14] of $m(0^{++}) \sim 700$ MeV which was obtained using QCD sum rules. However, later sum rule calculations[15,16] resulted in higher 0^{++} masses of between 1 and 1.6 GeV which cannot be ruled out by this result. More recently, lattice calculations[17] resulted in scalar gluon masses between 700 and 900 MeV. This can be ruled out unless this object is very wide.

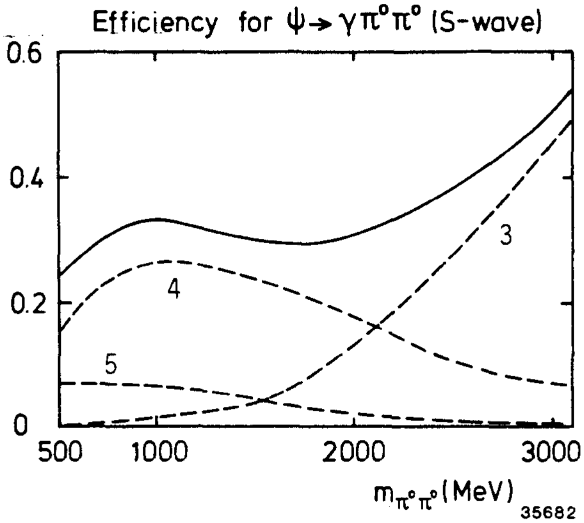

Fig. 9.

Detection efficiency for $J/\psi \to \gamma\pi^0\pi^0$ as function of $\pi^0\pi^0$ mass. The broken curves show the efficiencies for events with 3, 4, and 5 clusters, the solid curve is the sum. The $\pi\pi$ system is assumed to be in an S-wave.

4.3. Is there a Light Higgs Meson?

Gauge theories of electroweak interactions predict the existence of at least one Higgs meson[19] . Little is known about its mass. Theoretical considerations suggest a mass on the order of 10 GeV or more, however, this is not a stringent limit. The best experimental lower limit comes from the Crystal Ball[20]: $m_H >$ 50 MeV.

Higgs mesons lighter than J/ψ are produced in radiative J/ψ - decays with the following branching ratio[21]:

$$BR(J/\psi \to \gamma H) = BR(J/\psi \to \mu^+\mu^-) \frac{G_F m_\psi^2}{4\sqrt{2}\,\pi\alpha} \left(1 - \frac{m_H^2}{m_\psi^2}\right)$$

$$\sim 6 \cdot 10^{-5} \left(1 - \frac{m_H^2}{m_\psi^2}\right).$$

Higgs particles are expected to decay into pairs of the heaviest particles allowed by kinematics. A Higgs particle in the mass range of 500 to 1000 MeV would decay mostly into π pairs, a third of which would be neutral pions. Combining the upper limit on $\pi^0\pi^0$ production with the predicted branching ratio for $J/\psi \to \gamma H$, we obtain an upper limit on the branching ratio for $H \to \pi\pi$:

$$BR(H \to \pi\pi) < 72\% \ (95\% \text{ C.L.}) \text{ for } 500 < m_H < 1000 \text{ MeV}.$$

Theoretical estimates[19] predict that the $\pi\pi$ - decay mode strongly dominates $\mu\mu$, the only other sizable decay mode in this mass range. $\pi\pi$ branching ratios are expected to be close to 100%, although there is some uncertainty and branching ratios less than 72% are conceivable at the higher end of the mass range. With this exception, Higgs mesons in the mass range 500 to 1000 MeV are ruled out.

To summarize this section, a stringent upper limit was obtained for low-mass (500-1000 MeV) particles produced in radiative J/ψ - decays. A narrow gluonic meson is ruled out and the existence of a Higgs meson is very unlikely in this mass range.

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