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RECENT RESULTS FROM THE CRYSTAL BALL EXPERIMENT*

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Representing

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ABSTRACT

This report reviews several recent analyses from the Crystal Ball collaboration. The major topics discussed are the search for new states in radiative $\Upsilon(1S)$ decays, the search for lepton number-violating and inclusive η decay modes of the τ, and results from $\gamma\gamma$ physics.

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1. Introduction

From 1982, when the Crystal Ball detector[2] became operational at the DORIS II storage ring, to about 1984, the experiment's primary objective was Υ spectroscopy. The χ_b states were resolved and their masses, spins and hadronic widths were measured, the $\pi\pi$ hadronic transition and upper limits for the η hadronic transition between the $\Upsilon(2S)$ and $\Upsilon(1S)$ were measured, and searches for the η_b and η_b' states were made[3] These results can be classified as "bread and butter" physics because they are interesting and there was confidence the measurements were possible before they were begun.

From about 1984 to the present, more speculative analyses have been completed, many of which attempt to test the Standard Model. Going beyond the Standard Model involves looking for processes with small branching ratios and/or couplings. Such searches necessitate a large sample of clean events. For the Crystal Ball experiment, this translates to a large $\Upsilon(1S)$ data set because the $\Upsilon(1S)$ is very narrow, $(\Gamma(\Upsilon) \simeq \frac{2}{3}\Gamma(\psi))$, and its decays are OZI suppressed so that rare decays are easier to detect.

Several radiative decay modes of the $\Upsilon(1S)$ have been examined by the Crystal Ball group. The search for narrow resonances, in particular a Higgs boson, has been made in the inclusive photon spectrum. A non-minimal Higgs, or any particle decaying predominantly to the $\tau\overline{\tau}$ final state, has also been sought in radiative $\Upsilon(1S)$ decays. The search for radiative $\Upsilon(1S)$ decays to all-neutral final states has been performed. Finally, radiative decays to unseen particles have been investigated.

The Crystal Ball has also collected a large data set on the $\Upsilon(4S)$ and nearby continuum so that the total luminosity collected at DORIS II is about $250\,\mathrm{pb}^{-1}$. Many analyses become possible with such large data sets; in particular, about $500\,\mathrm{K}$ τ and $150\,\mathrm{K}$ B decays have been recorded. From the analyses using these data, this report concentrates on the search for lepton number-violating τ decays and for inclusive η decays of the τ. Results from B decays have been presented recently[4] and will not be included here. Finally, resonant π^0, η and η' production and $\pi^0\pi^0$ production near threshold, from two photon interactions are discussed.

2. The Inclusive $\Upsilon(1S)$ Photon Spectrum[5]

The goal of this analysis is to search for new states by observing the inclusive photon energy spectrum. A narrow resonance in the energy spectrum indicates the existence of a new state X produced by the process $\Upsilon(1S) \to \gamma X$. This analysis is based on an integrated luminosity of about 51 pb^{-1} corresponding to approximately 0.44×10^6 produced $\Upsilon(1S)$ events.

Figure 1 shows the final inclusive photon spectrum plotted in 2.0% bins. Note the detector resolution for the Crystal Ball is

$$\frac{\sigma_E}{E} = \frac{2.7 \pm 0.2\%}{\sqrt[4]{E}}.$$

This spectrum is fit with a polynomial background with the expected NaI line-shape fixed at 1% intervals along the spectrum. No narrow structures are ob-

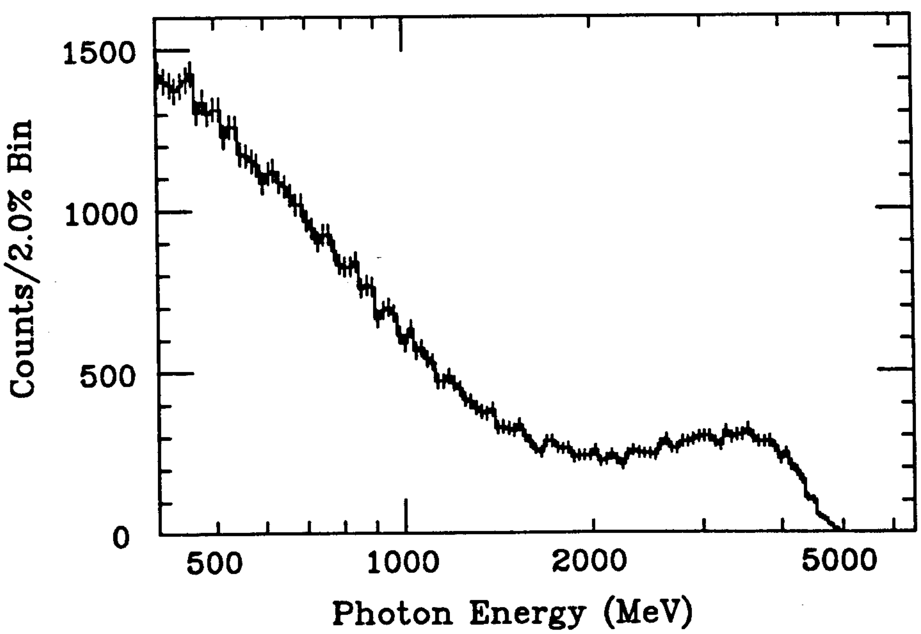

Fig. 1 The final $\Upsilon(1S)$ inclusive photon spectrum. No obvious narrow structures consistent with the decay $\Upsilon(1S) \to \gamma X$ are indicated.

served; the most significant structure lies at $E_\gamma = 4188$ MeV with a significance of less than 1.7.

Because no evidence for a new state is seen, an upper limit for the process $\Upsilon(1S) \to \gamma X$ is calculated. An essential element needed to extract upper limits for this process is the photon efficiency as a function of energy. Since the efficiency for this process depends on the properties of the state X, some assumptions about its decay modes must be made. In this analysis, X is assumed to decay to all possible fermion-antifermion pairs energetically accessible, where the coupling between X and the $f\bar{f}$ pairs is assumed to be proportional to the fermion mass. These assumptions are those expected for a minimal Higgs particle.

For photon energies above 4.00 GeV, the decay $\Upsilon(1S) \to \gamma X \to \gamma c\bar{c}$ is not energetically possible. In this case, the decay $X \to \tau\bar{\tau}$ is the dominant decay mode. Similarly, above photon energies of 4.06 GeV, the τ decay mode becomes inaccessible and the dominant decay mode of X is into strange quark pairs, $X \to s\bar{s}$. Finally, for photon energies above 4.68 GeV, the dominant decay modes of X are into light quark pairs and μ pairs. The photon efficiency as a function of photon energy for each of these decay modes is calculated from Monte Carlo simulations. The overall photon efficiency takes into account the $c\bar{c}$, $\tau\bar{\tau}$ and $s\bar{s}$ threshold effects and is the average of efficiencies of the energetically available decay modes, weighted by the mass squared and the color factor of the decay fermions. Figure 2 shows the final photon efficiency as a function of photon energy. The dashed vertical lines indicate the $c\bar{c}$, $\tau\bar{\tau}$ and $s\bar{s}$ thresholds. The thresholds are assumed to turn on quickly, so phase-space factors may smooth this result. The rapid drop in efficiency between 4 and 5 GeV is primarily due to Bhabha rejection cuts.

The 90% confidence level upper limit curve for the decay $\Upsilon(1S) \to \gamma X$ is shown in Figure 3. This result can also be plotted as a function of recoil mass rather than the photon energy as shown in Figure 4.

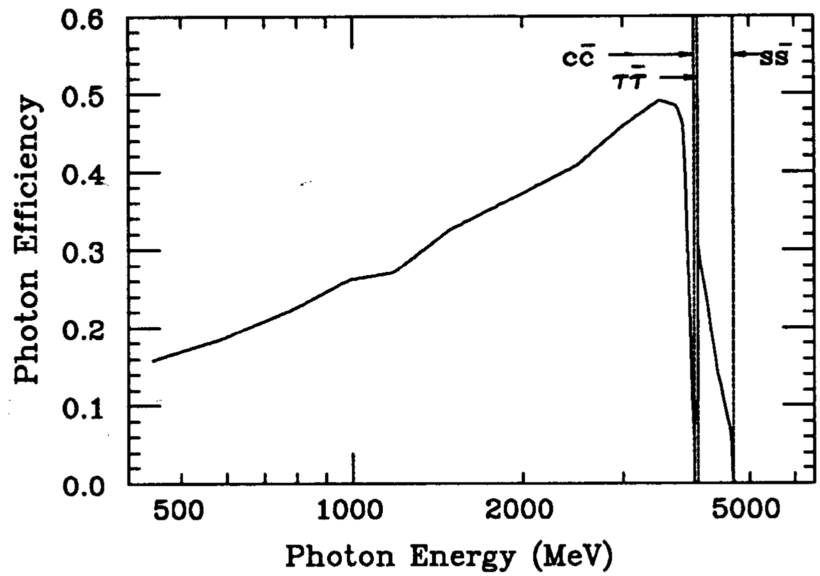

Fig. 2 The photon efficiency for the process $\Upsilon(1S) \to \gamma X$ as a function of photon energy. The state X is assumed to decay into fermion pairs with a coupling proportional to the mass of the fermion. The vertical dashed lines show the kinematic thresholds for the relevant fermions.

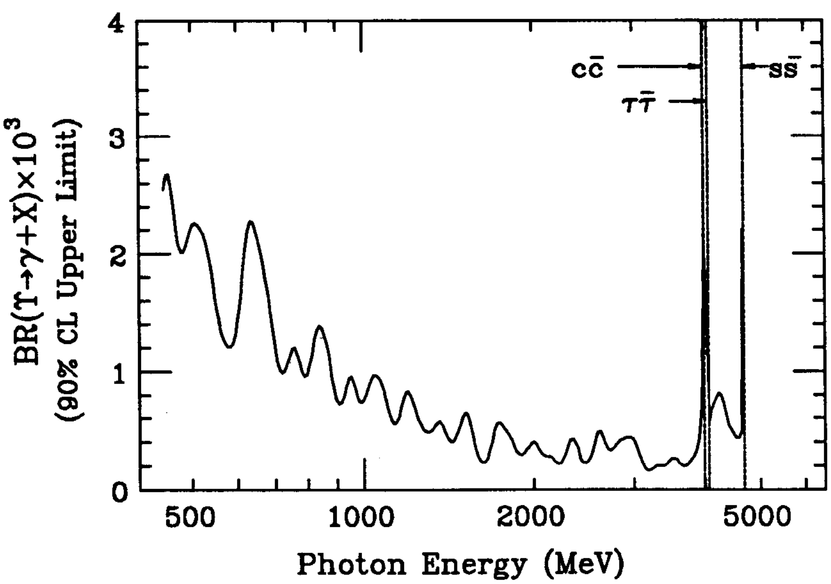

Fig. 3 The 90% confidence level upper limit for the process $\Upsilon(1S) \to \gamma X$ as a function of photon energy. The assumptions on the decay of X are found in the text. The vertical dashed lines show the kinematic thresholds for the relevant fermions.

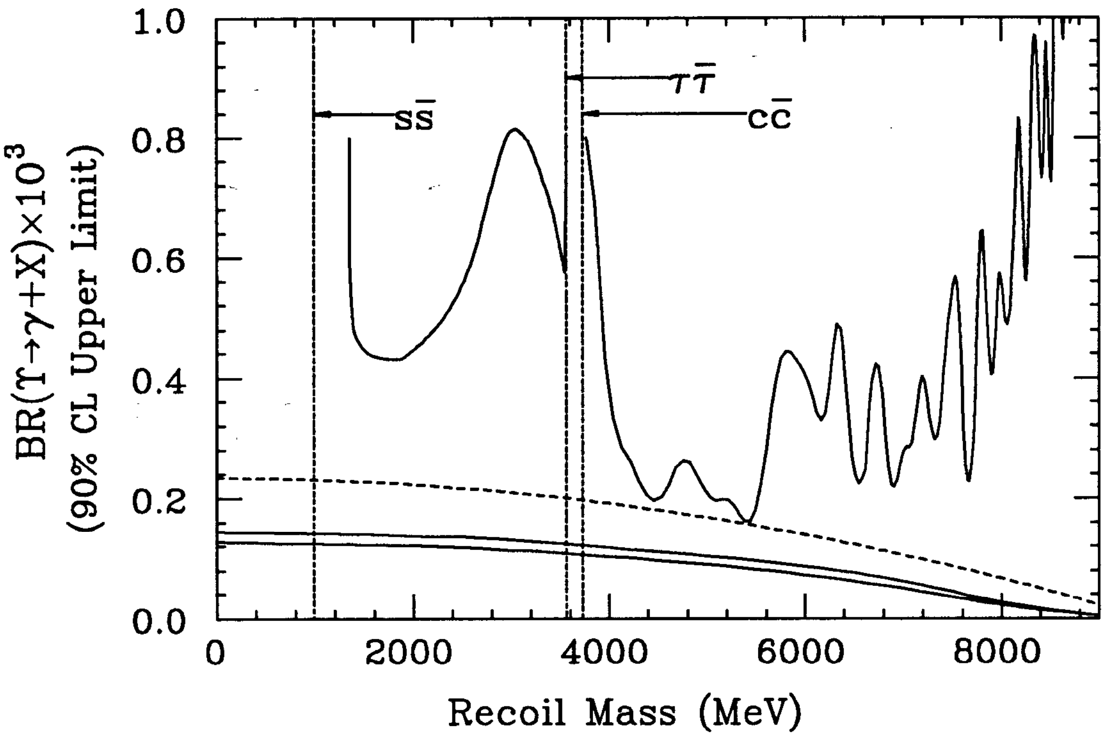

Fig. 4 The 90% confidence level upper limit for the process $\Upsilon(1S) \rightarrow \gamma X$ as a function of recoil mass. The vertical dashed lines show the kinematic thresholds for the relevant fermions. The horizontal dashed line corresponds to the lowest order calculation for the Wilczek mechanism. The two solid horizontal lines indicate the range of the theoretical estimate of the first order QCD radiative corrections to the Wilczek calculation.

Figure 4 indicates that only for Higgs mass around 5.5 GeV/c^2 does this analysis come close to the Wilczek estimate[6] for the branching ratio of a minimal Higgs particle. For a Higgs mass below about 4 GeV/c^2, the efficiency drop, due to Bhabha rejection in the hadron selection routines, causes a large increase in the corresponding upper limit. A different Bhabha rejection algorithm, tuned for this analysis, might improve the upper limit for Higgs' masses in the 1 to 4 GeV/c^2 range. The decay modes open to the Higgs for masses below 1 GeV/c^2 are sufficiently different from the decays into $c\bar{c}$ and $s\bar{s}$ that an entirely different analysis would be required to separate such decays from QED events. For a Higgs mass above 6 GeV/c^2, both a slow decrease in photon efficiency and an increase in the number of background photons causes a rise in the upper limit. In no mass range does this analysis rule out a minimal Higgs to the 90% confidence limit for the latest estimates of the $\Upsilon(1S)$ branching ratio which includes QCD radiative corrections.[7]

The above analysis can be applied to different assumptions on the decay modes of X. The major difference is that the photon efficiency may have different kinematic thresholds depending on the couplings and the possible decay products involved. If X decays predominantly through low multiplicity exclusive channels, for example, the $\tau\overline{\tau}$ final state predicted to dominate the Higgs decay in some non-minimal models, this analysis will have a lower sensitivity for their detection. The small band between the $\tau\overline{\tau}$ and $c\overline{c}$ thresholds in Figure 3 shows this directly. On the other hand, as long as X decays into muti-hadron final states, the detection efficiency remains high, and the upper limits found here will be approximately unchanged.

In summary, searching for the Higgs boson in radiative $\Upsilon(1S)$ decays appears the most direct method available for discovering a light Higgs. Unfortunately, no Higgs' masses have been experimentally ruled out by this method. To reach the current theoretical estimates for a Higgs' mass above 8 GeV would require a sample of about 10 million $\Upsilon(1S)$ decays gathered with a detector having a sensitivity five times that of the Crystal Ball. This would be an enormous undertaking spanning many years of data-taking.

3. The Semi-Exclusive Search for Radiative Decays $\Upsilon(1S) \rightarrow \gamma X \rightarrow \gamma\tau\overline{\tau}$

This search is also motivated by the possibility of observing a new state, including a Higgs boson, in radiative $\Upsilon(1S)$ decays.[8] In some non-minimal models,[9] the decay $H \rightarrow c\overline{c}$ is suppressed and the dominant decay is $H \rightarrow \tau\overline{\tau}$. The analysis presented above for the inclusive photon spectrum is also sensitive to this decay, but not quite to the level found here.

The data set used for this analysis corresponds to approximately 220 K produced $\Upsilon(1S)$ events. To efficiently tag these $\gamma\tau\overline{\tau}$ events, one τ is required to decay to $e\bar{\nu}_e\nu_\tau$ and the other to $\mu\bar{\nu}_\mu\nu_\tau$. Thus, the final state observed is an electron, a muon and a photon. Figure 5 shows the photon spectrum for events passing the $\Upsilon(1S) \rightarrow \gamma\tau\bar{\tau}$ selection criteria. The entries in this spectrum are consistent with τ pair production with initial state bremsstrahlung. Figure 6 shows the corresponding 90% confidence level upper limit for the branching ratio $BR(\Upsilon(1S) \rightarrow \gamma X \rightarrow \gamma\tau\bar{\tau})$. These limits are higher than the rates expected by the Wilczek mechanism, however, they can be used to constrain the vacuum expectation values for two-Higgs doublet models.

4. The Search for the Decay $\Upsilon(1S) \rightarrow \gamma$ + Unseen Particles[10]

This analysis, originally motivated by O. Nachtmann,[11] looks for the $\Upsilon(1S)$ decaying to a photon and any number of undetected particles. These unseen particles are not necessarily resonant; for example Nachtmann discusses the three-body decay $\Upsilon(1S) \rightarrow \gamma\lambda\bar{\lambda}$ where λ is a supersymmetric Goldstone fermion. This would be a very difficult experiment to perform by running on the $\Upsilon(1S)$ because the final state would be a single, non-resonant photon. To lower backgrounds, 57 pb^{-1} of $\Upsilon(2S)$ data, corresponding to approximately 185 K events, were used to tag $\Upsilon(1S)$ events by the hadronic transition $\Upsilon(2S) \rightarrow \pi^0\pi^0\Upsilon(1S)$. Because each of the two π^0s decay to two photons, and the $\Upsilon(1S)$ decays to a photon plus unseen, the final state has five photons. Events consistent with two π^0s and one remaining photon are selected and the mass recoiling opposite the $\pi^0\pi^0$ system is calculated. The energy of the unpaired photon is plotted against this recoil mass in Figure 7. The range indicated by the vertical dashed lines shows the $\Upsilon(1S)$ mass band. No events in this band with photon energy above 1200 MeV are found, which leads to the upper limit

$$BR(\Upsilon(1S) \rightarrow \gamma + \text{unseen}) < 2.3 \times 10^{-3}, \qquad M_{unseen} < 8.1\ \mathrm{GeV/c^2}.$$

This limit is only valid if the lifetime of the unseen particles is greater than 10^{-7} seconds.

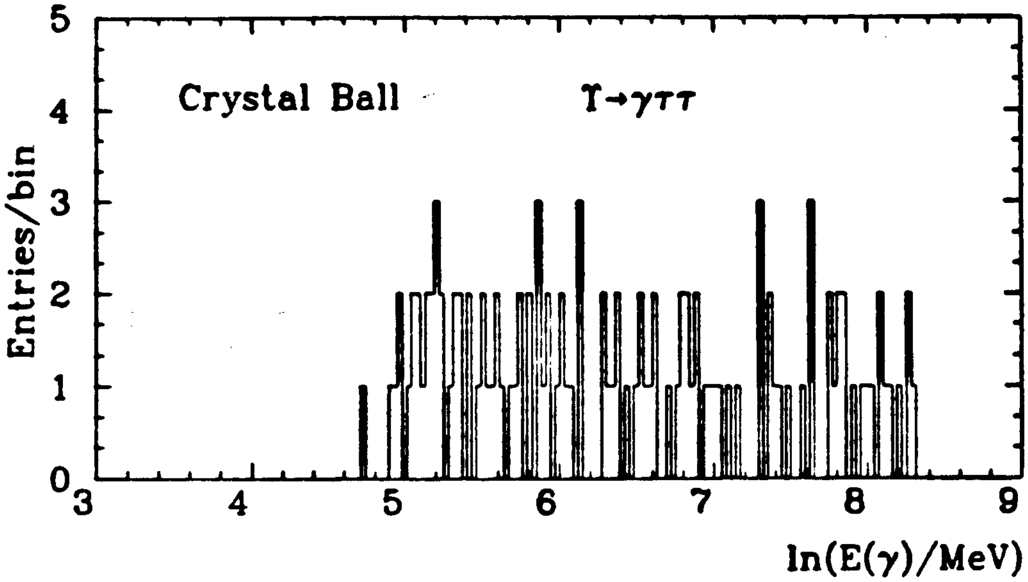

Fig. 5 The photon spectrum for events passing $\Upsilon(1S) \to \gamma\tau\bar{\tau}$ selection criteria. The events shown are consistent with QED.

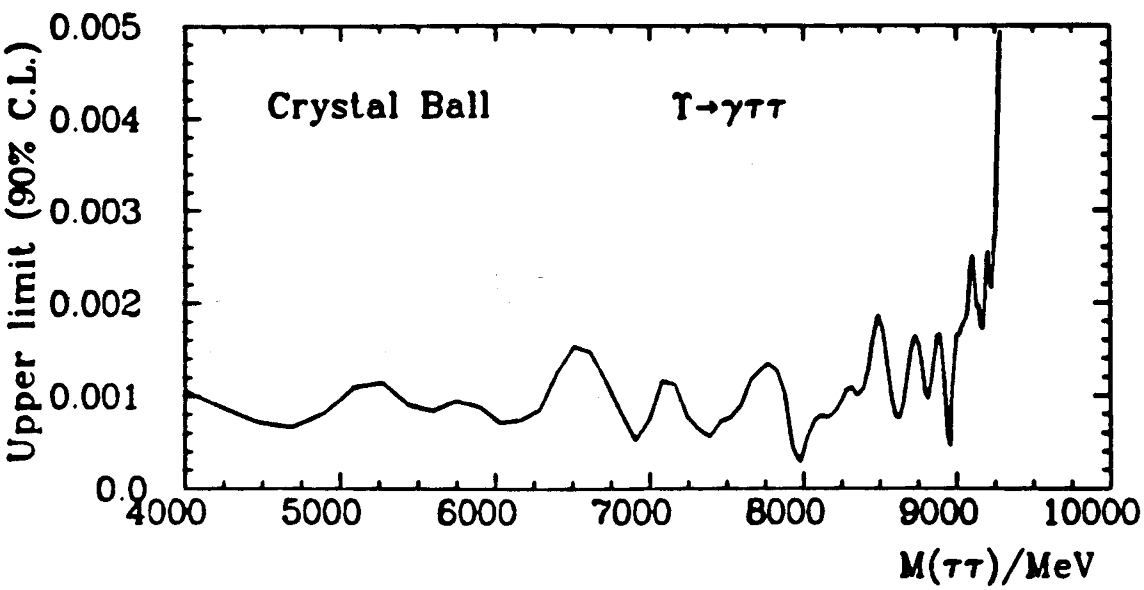

Fig. 6 The 90% confidence level upper limit for the process $\Upsilon(1S) \to \gamma\tau\bar{\tau}$ as a function of the $\tau\bar{\tau}$ invariant mass.

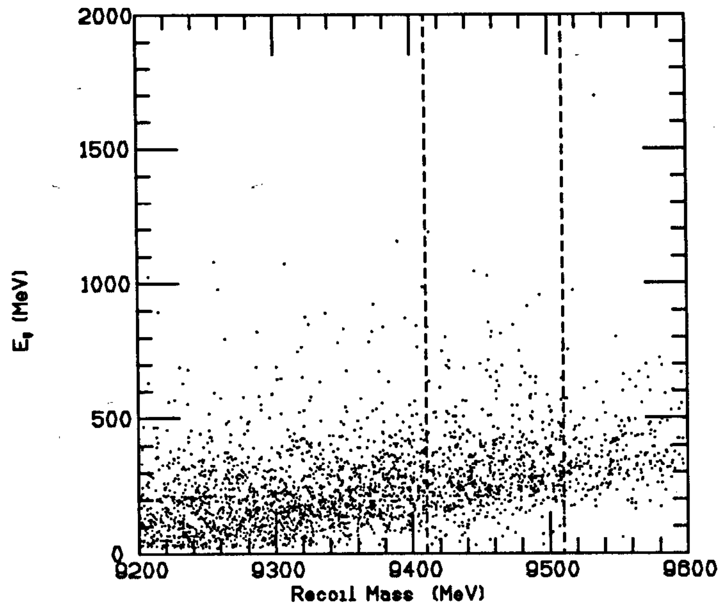

Fig. 7 E_γ vs recoil mass scatter plot. The vertical dashed lines indicate the $\Upsilon(1S)$ mass window. No events in this band above 1200 MeV are detected.

5. The Search for Exclusive $\Upsilon(1S)$ Decays to All-Neutral Final States[12]

The measurement of radiative decay modes of heavy bound $q\bar{q}$ systems may provide insight into the formation mechanism and the gluonic content of the light mesons produced as well as into some features of the bound $q\bar{q}$ system. Such decays have been measured on the J/ψ with branching ratios on the order of 10^{-3} and have yielded interesting results on the low mass meson sector.[13] These decays should also be present at the $\Upsilon(1S)$, but theoretical predictions of branching ratios range over several orders of magnitude.

This analysis is based on 306 K $\Upsilon(1S)$ events. The all-neutral decay modes considered are

$$\Upsilon \to \gamma\eta \qquad \eta \to 3\pi^0, 2\gamma$$

$$\Upsilon \to \gamma\eta' \qquad \eta' \to 2\pi^0\eta \qquad \eta \to 3\pi^0, 2\gamma$$

$$\Upsilon \to \gamma f_2 \qquad f_2 \to 2\pi^0.$$

Because there can be up to 11 photons in the final state, many of which overlap, the individual photon energies and directions cannot be reconstructed. A method called the "Global Shower Technique"[14] is used to calculate the invariant mass of a cluster of photons. First the direction of the center of the energy cluster is found using $\vec{c} = \frac{1}{E}\sum_i \vec{c_i} E_i$ where $\vec{c_i}$ is the direction vector from the interaction point to the crystal center, E is the total deposited energy in the cluster, and the sum runs over all crystals in the cluster with energy E_i. The width of the cluster is then calculated using $S = \frac{1}{E}\sum_i (\vec{c} - \vec{c_i})^2 E_i$. Finally, the invariant mass of the cluster is given by $M = \sqrt{S - S_\gamma}\, E$ where S_γ is the width of a single photon as determined from Monte Carlo studies.

Events consistent with a single photon recoiling against a neutral energy cluster are selected. The top histogram in Figure 8 shows the invariant mass of the energy clusters in these events. The other histograms show the mean and width expected from Monte Carlo simulations of each of the three decay modes listed above. Fitting the top plot with these Monte Carlo distributions leads to the upper limits shown in Table 1.

The $\Upsilon(1S) \rightarrow \gamma\eta$ and $\Upsilon(1S) \rightarrow \gamma\eta'$ results are the only experimental limits reported for these quantities, however, the theoretical estimates are anywhere from 1 to 3 orders of magnitude below these results. The $\Upsilon \rightarrow \gamma f_2$ limit presented here is close to one theoretical prediction, but the CLEO collaboration has already reported more restrictive upper limits which rule out this model.[15]

6. The Search for $\tau \rightarrow e\gamma$ and $\tau \rightarrow e\pi^0$ Decay Modes[16]

This search is motivated by the prediction of inter-family transitions in composite model theories[17] and by the historical precedent of searching for such transitions. The data sample used in this analysis consists of 61 pb^{-1} corresponding to 124 K τ leptons for the $\tau \rightarrow e\gamma$ search and 37 pb^{-1} or 76 K τ leptons for the $\tau \rightarrow e\pi^0$ search. A semi-inclusive approach is used to obtain a high detection efficiency for the τ decays investigated here. Monte Carlo studies indicate a high spatial correlation between the electron and the gamma or π^0 for these decay modes. An electron and a gamma or π^0 are required to be in one hemisphere, defined by the gamma or π^0 direction, with no additional particles

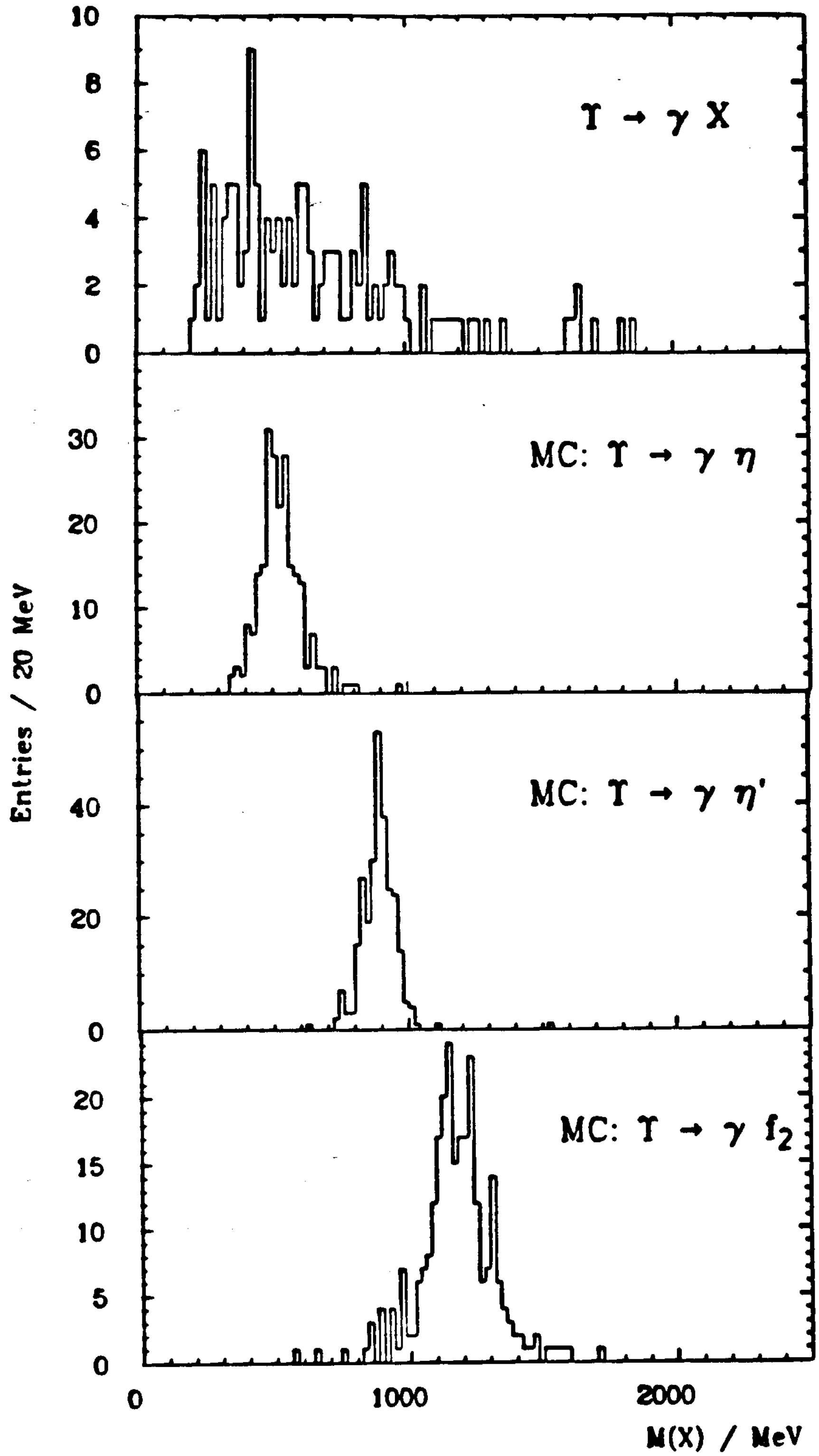

Fig. 8 The top plot shows the observed invariant mass for the state X consistent with the process $\Upsilon(1S) \to \gamma X$. The other 3 plots indicate the mean and width expected for the corresponding decay mode calculated from Monte Carlo simulations.

Theoretical Predictions			
	$\Upsilon \to \gamma + \eta$	$\Upsilon \to \gamma + \eta'$	$\Upsilon \to \gamma + f_2$
Intemann *Phys. Rev.* D27 (1983) 275	6.3×10^{-7} 1.3×10^{-7}	2.5×10^{-6} 5.3×10^{-7}	
Deshpande, Eilam *Phys. Rev.* D25 (1982) 270	1.5×10^{-4}	$\approx 10^{-3}$	
Körner *et al.* *Nucl. Phys.* B229 (1983) 115	3.4×10^{-5}	1.6×10^{-4}	1.4×10^{-4}
Experimental Results			
CLEO preliminary CLNS 86/714			$< 4.8 \times 10^{-5}$
Crystal Ball preliminary 90% C.L.	$< 3 \times 10^{-4}$	$< 1 \times 10^{-3}$	$< 4 \times 10^{-4}$

Table 1 Theoretical predictions and experimental results for exclusive radiative decays of the $\Upsilon(1S)$.

in this hemisphere. The decay products of the other τ lepton in the opposite hemisphere are required to have low multiplicity; 1 to 3 charged tracks and an arbitrary number of neutrals. This second τ lepton is not analysed further, thus the term "semi-inclusive."

Events consistent with radiative Bhabha events are rejected. Figures 9 and 10 show the $e\gamma$ and $e\pi^0$ invariant mass spectra; no significant signal with the expected width is seen at the τ mass. Thus, the 90% confidence level upper limits are calculated to be

$$BR(\tau \to e\gamma) < 3.4 \times 10^{-4}$$
$$BR(\tau \to e\pi^0) < 4.4 \times 10^{-4}.$$

The above numbers represent the best existing limits for these reactions.

The limit on $\tau \to e\gamma$ can be translated into a lower limit on the composite-

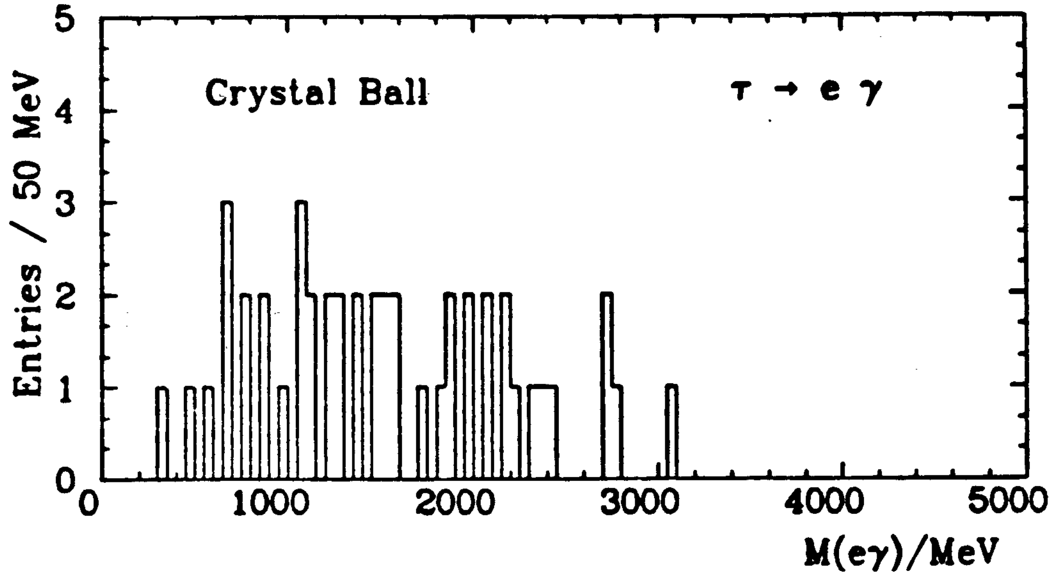

Fig. 9 The invariant $e\gamma$ mass. No enhancement at the τ mass is observed.

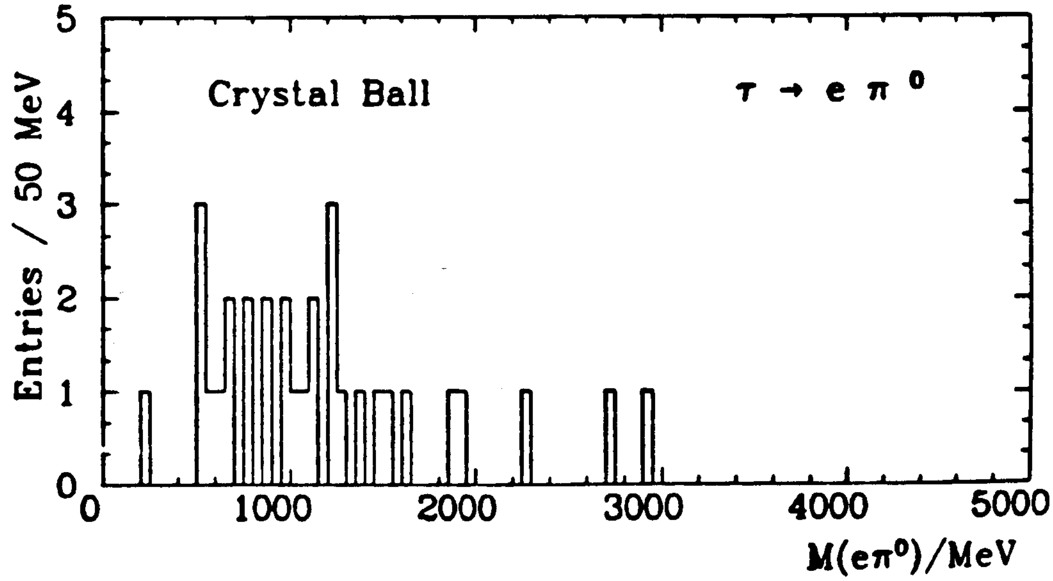

Fig. 10 The invariant $e\pi^0$ mass. No enhancement at the τ mass is observed.

ness mass scale: $\Lambda/\sqrt{\alpha} > 65$ TeV.[17] This limit is somewhat model dependent, in particular, the unknown coupling constant α can vary between 1 and the τ Yukawa coupling, ≈ 0.01. No explicit limit calculations have been done for $\tau \rightarrow e\pi^0$, a reaction which is also of potential interest for composite models.

7. Search for $\tau \rightarrow \eta X$ Decays[18]

This analysis is motivated by the apparent discrepancy between the published inclusive and exclusive measurements of the τ branching fractions into 1 charged prong plus neutrals. Table 2 shows the inclusive and sum of exclusive branching fractions of the τ for 1 and 3 charged prongs compiled from the most recent results.[19] These preliminary results soften the apparent discrepancy in the one charged prong mode but still allow undiscovered τ decay modes.

Recent τ Decay Summary	1 Charged Prong	3 Charged Prongs
Sum of Exclusive Decays (%)	83.2 ± 2.4	11.9 ± 0.7
Inclusive Measurement (%)	86.8 ± 0.3	13.1 ± 0.3
Difference	3.6 ± 2.4	1.2 ± 0.8
Difference (Published)	8.8 ± 2.0	0.4 ± 0.8

Table 2 A comparison between the inclusive and the sum of exclusive τ decay modes for 1 and 3 prong decays. These values summarize recent preliminary results. The difference calculated from published numbers is also given for comparison.

The data set used for this analysis consists of 82 pb^{-1} corresponding to about 90 K $\tau^+\tau^-$ pairs; about half the available data. To select events, one τ is tagged with the electron from the $\tau \rightarrow e\overline{\nu_e}\nu_\tau$ decay. The other τ is required to decay to one charged particle plus ≥ 3 photons. The cut at three or more photons was chosen because the decay $\tau^- \rightarrow \nu_\tau\pi^-\eta$, with only two photons in the final state, is forbidden as a first class current. Other likely decays, for example $\tau^- \rightarrow \nu_\tau\pi^-\eta\pi^0$, have four or more photons. The cut was set at three in case one photon was undetected.

The points in Figure 11 show the "electron" spectrum. "Electron" is in quotes to indicate that at the lower energies shown, π and ρ particles contribute to this plot from the $\tau \rightarrow \pi\nu$ and $\tau \rightarrow \rho\nu$ decay modes. This is perfectly acceptable because they also tag τ decays. The central question is, how does one have confidence that these decays are really $\tau^+\tau^-$ events and not low-multiplicity hadronic decays which mimic τ pairs. To estimate the background contribution to the spectrum of points in Figure 11, a Monte Carlo simulation of $\tau^+\tau^-$ events was subjected to the same selection cuts. The histogram in Figure 11 shows the absolute Monte Carlo calculation for the $\tau^+\tau^-$ contribution. The background level is given by the excess the data points have over the histogram. The data and Monte Carlo agree in shape and magnitude, indicating the data sample is very nearly pure $\tau^+\tau^-$ production, assuming the Monte Carlo efficiency is correct.

Finally, photons not consistent with π^0 decays are paired and their invariant mass calculated. Figure 12 shows the π^0 subtracted $\gamma\gamma$ invariant mass spectrum. A clear η signal appears, indicating the existence of $\tau \rightarrow \eta X$ decays.

Several checks have been made to rule out the possibility that the η signal is from hadronic decays:

- The "electron" spectrum agrees with the Monte Carlo in shape and amplitude, as discussed above.
- The η signal appears as expected if the "electron" spectrum is cut at 1500 MeV to enhance real electrons, if harder pattern cuts are used to select electrons, or if exactly four photons are required from the τ decay.
- Three-gluon and $q\bar{q}$ Monte Carlo events and separated beam data show no η signal.
- No Monte Carlo events simulating $\gamma\gamma \rightarrow \eta, \eta'$ pass the selection cuts.
- The η signal is not from B decays; the data sample of 82 pb^{-1} consists of $\Upsilon(1S)$ and $\Upsilon(2S)$ events only.

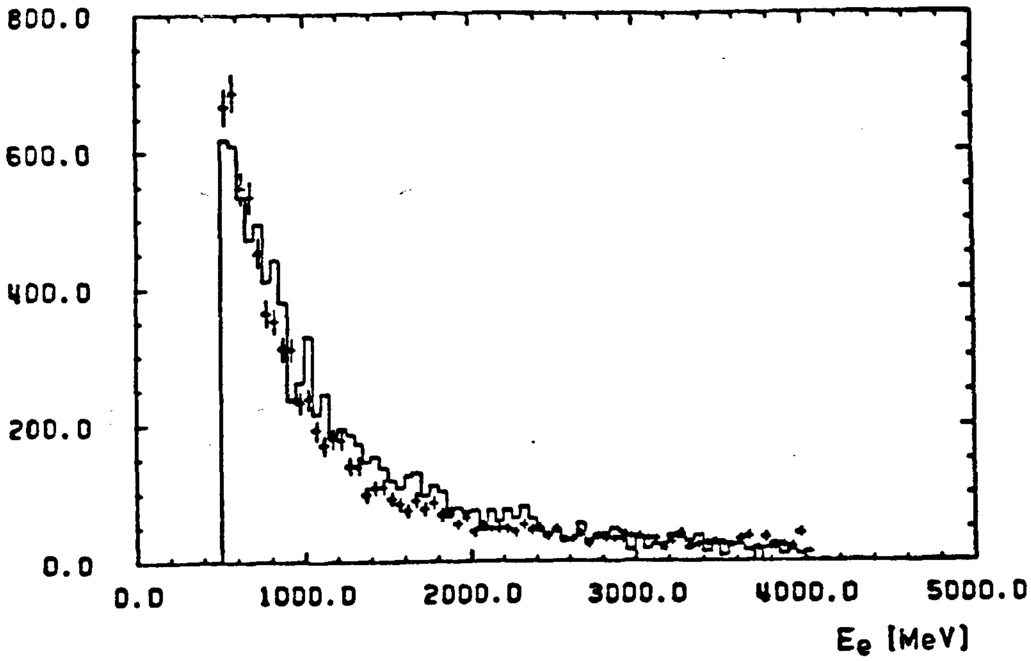

Fig. 11 The "electron" energy spectrum. At lower energies, π and ρ particles enter this plot. The points correspond to the data while the histogram is derived from a Monte Carlo simulation. The points and data are not normalized to each other.

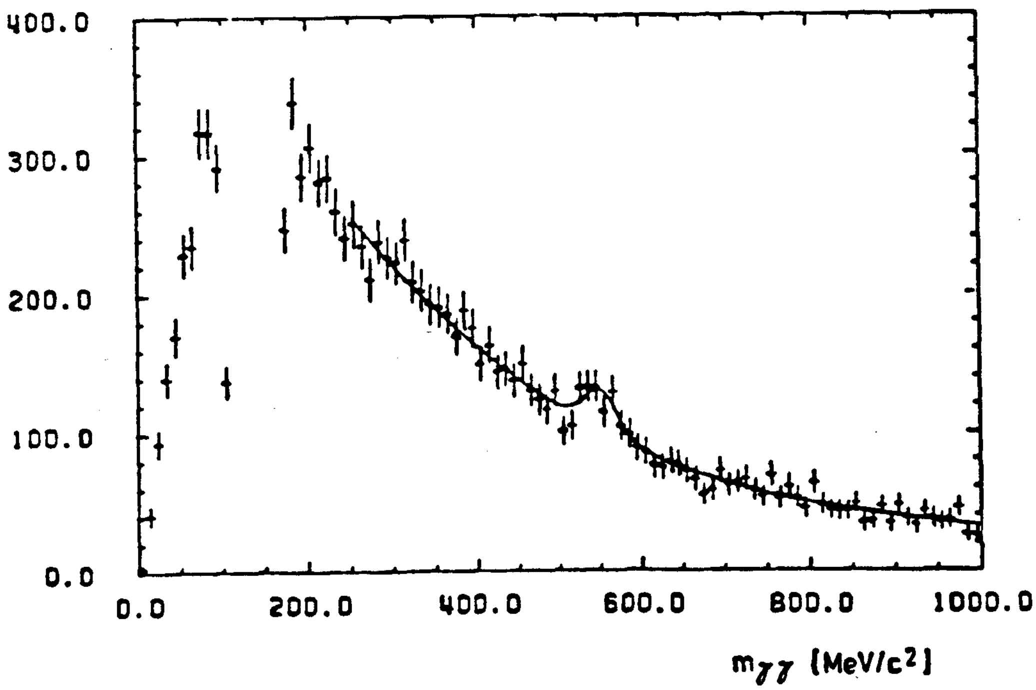

Fig. 12 The invariant $\gamma\gamma$ mass spectrum. Pairs consistent with π^0s are subtracted.

Although there is evidence for the decay $\tau \to \eta X$, this analysis is preliminary and awaits further background studies and efficiency calculations.

8. Results on Photon-Photon Collisions

This is a brief review of recent Crystal Ball two photon results. Figure 13 shows the $\gamma\gamma$ invariant mass plot for the process $\gamma\gamma \to X \to \gamma\gamma$, for 50 pb^{-1} of data.[20] The π^0, η and η' are all clearly seen in this one plot. A transverse-momentum cut of $|\sum \vec{P_T}| < 0.1\, M_{\gamma\gamma}$ was used here. A more detailed analysis of each of these three states and an analysis specific to the process $\gamma\gamma \to \eta' \to \eta\pi^0\pi^0$[21] gives the following results

$$\begin{aligned}
\Gamma(\pi^0 \to \gamma\gamma) &= 7.8 \pm 0.4 \pm 0.9\,\text{eV} \\
\Gamma(\eta \to \gamma\gamma) &= .51 \pm .02 \pm .06\,\text{KeV} \\
\Gamma(\eta' \to \gamma\gamma) &= 5.0 \pm 0.6 \pm 0.8\,\text{KeV} \quad (\eta' \to \gamma\gamma) \\
&= 4.1 \pm 0.3 \pm 0.8\,\text{KeV} \quad (\eta' \to \eta\pi^0\pi^0).
\end{aligned}$$

The analysis of $\gamma\gamma \to \eta' \to \eta\pi^0\pi^0$ can also be used to derive the upper limit for $\Gamma(X \to \gamma\gamma)$ from the process $\gamma\gamma \to X \to \eta\pi^0\pi^0$ for an isoscalar X, assuming $\Gamma_X = 50$ MeV. The 90% confidence level upper limit is shown in Figure 14. No radially excited 0^{-+} state is seen, in particular, the $\eta(1275)$ is not observed.

Finally, the reaction $\gamma\gamma \to \pi^0\pi^0$ is studied below the f_2 to measure the non-resonant two photon production of $\pi^0\pi^0$ and to search for scalar resonances.[22] Figure 15 shows the invariant mass of the $\pi^0\pi^0$ system for $90\,\text{pb}^{-1}$ of data. The cross section is plotted in arbitrary units because some efficiency factors have not yet been determined. No narrow states below the f_2 are seen, but a sizable $\pi^0\pi^0$ production is evident.

9. Summary and Conclusions

Experimentally, $\Upsilon(1S) \to \gamma + H$ searches are just beginning to reach the sensitivity needed to test theoretical predictions. Excluding Higgs masses below about 5 GeV/c^2 seems within reach of the next round of planned experiments

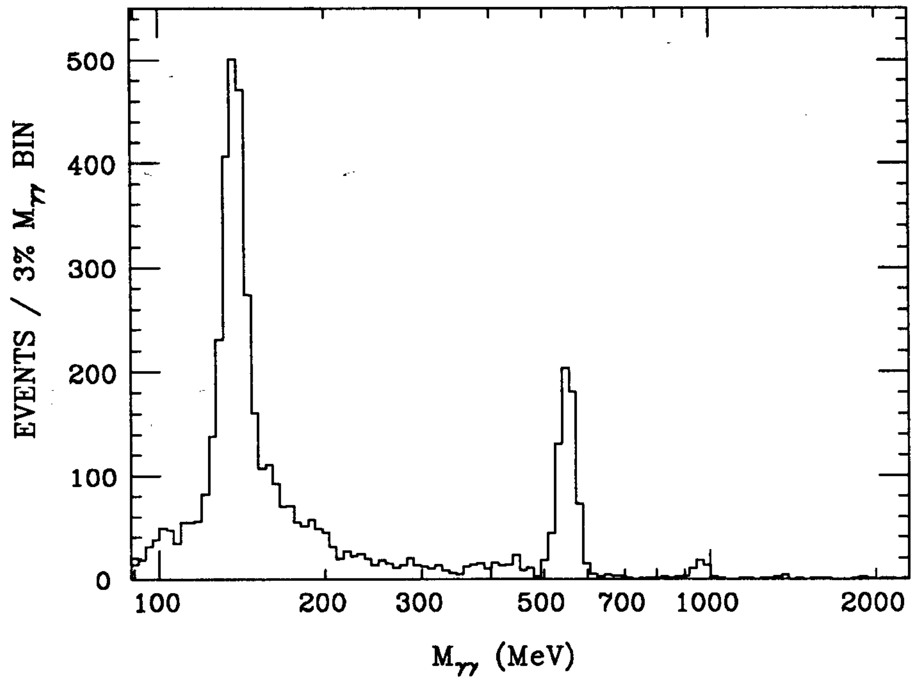

Fig. 13 The invariant $\gamma\gamma$ mass spectrum.

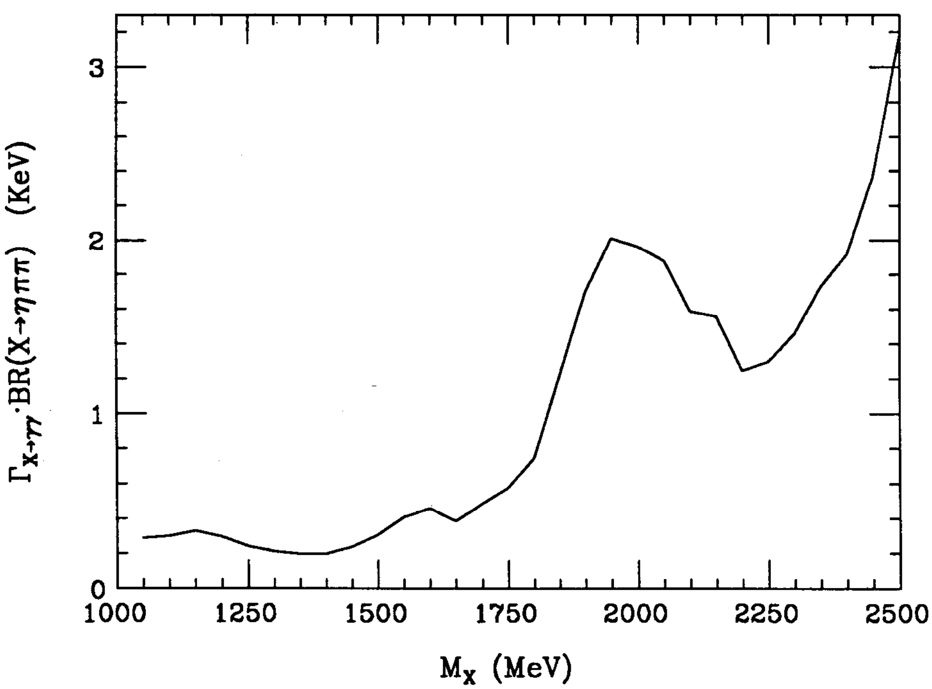

Fig. 14 The 90% confidence level upper limit for the $\gamma\gamma$ production of an isoscalar state X, assuming $\Gamma_X = 50$ MeV. No radially excited 0^{-+} state is observed.

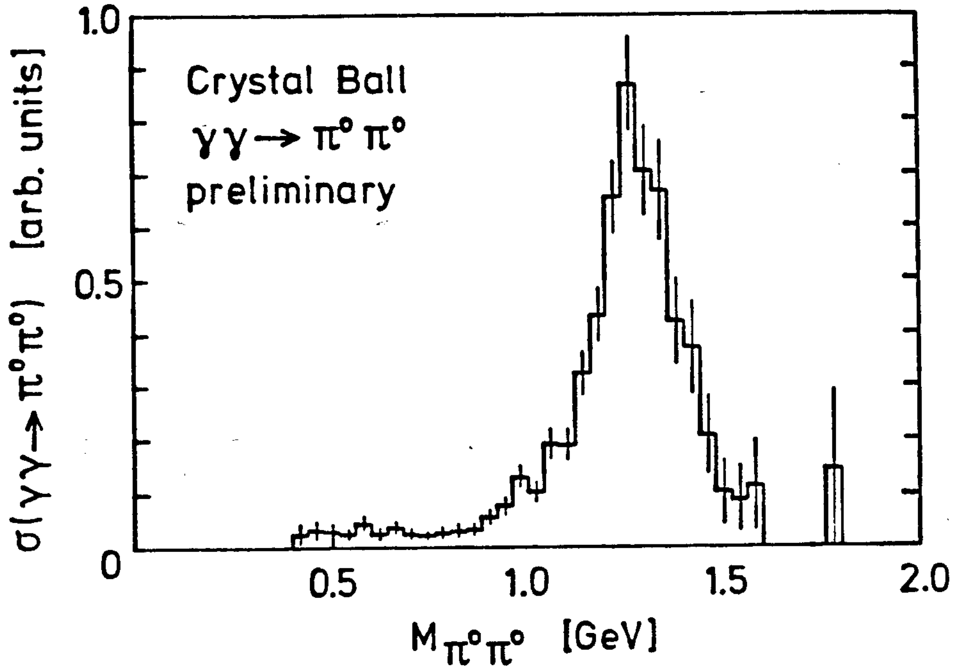

Fig. 15 The invariant $\pi^0\pi^0$ mass spectrum. No new states are observed below the f_2.

but excluding masses above about 8 GeV will probably require new production and detection techniques for radiative $\Upsilon(1S)$ decays. This assumes the theoretical prediction does not drop further; because the first order QCD radiative corrections to the Wilczek calculation reduce the rate by about a factor of two, higher-order corrections may further suppress this prediction. No exclusive decay modes of the $\Upsilon(1S)$, excluding the leptonic decays, have been observed to date. Thus the Υ is relatively barren compared to the J/ψ.

No hint of compositeness has been observed in τ decays. The upper limits quoted for the $\tau \to e\gamma$ and $\tau \to e\pi^0$ decays are the best in existence. Evidence has been presented for an inclusive η decay mode of the τ, but further background studies and efficiency calculations are needed.

The two photon width of the π^0, η and η' have been measured. No new states are seen in the $\eta\pi^0\pi^0$ final state, or in the $\pi^0\pi^0$ final state below the f_2 in two photon interactions.

These results show no deviation from those expected in the Standard Model.

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