EVIDENCE FOR A MASSIVE STATE IN THE RADIATIVE DECAYS OF THE UPSILON

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ABSTRACT: Evidence is presented for a state, which we call ζ, with a mass $M = (8322 \pm 8 \pm 24)$ MeV and a line width $\Gamma < 80$ MeV (90% confidence level) obtained using the Crystal Ball NaI(Tl) detector at DORIS II. The branching ratio to this state from the Υ(1S) is of order 0.5%.

It has been realized for some time that precision measurements of the radiative decay of the various quarkonium states provide a powerful tool with which to search for hypothetical particles, such as gluonic mesons(1), Higgs bosons(2), or supersymmetric particles(3). We report here such an investigation using Υ(1S) and Υ(2S) data that were obtained using the Crystal Ball NaI(Tl) detector(4) installed in the DORIS II storage ring at DESY. The data samples consist of about 100K produced Υ(1S) ($\int\mathcal{L}dt = 10.7\ pb^{-1}$) and of about 200K produced Υ(2S) (64.5 pb^{-1}). The ability of the Crystal Ball detector to resolve and measure monochromatic γ's in the DORIS II environment has been demonstrated(5). The results reported here were obtained using algorithms and subtraction techniques optimized for the region of E_γ from ∿ 700 to ∿ 2000 MeV. Other energy regions are still under investigation.

Below we describe two analyses of the reaction $\Upsilon \to \gamma X$ in which we search for monoenergetic photons signaling the production of a state X. The first analysis uses a sample of events at the Υ(1S) energy which has been selected for multihadron decays by efficiently removing beam gas, cosmic rays, e^+e^-X and QED events (including radiative $\gamma\tau\bar{\tau}$ events). The efficiency for selecting multihadron events is found to be $\varepsilon_h = (0.90 \pm 0.05)$. The resulting sample contains contributions from Υ(1S) and continuum decays approximately in the ratio of 2.5 to 1.

"Good" photons were selected by removing charged particles, photons with showers contaminated by energy depositions from nearby particles, and photons resulting from π^0decay. The π^0's were identified as either a pair of clearly separated photons or as a single cluster formed by the two merged photon showers. The general character of these cuts has been discussed in detail previously(4,6); however, for the region of E_γ studied here many of these previously used cuts needed considerable refinement. The resulting inclusive photon spectrum from the Υ(1S) (fig. 1) was fitted using a line shape measured at 1.5 GeV(4), variable amplitude and mean, a fixed $\sigma_E/E = 0.027/E^{1/4}$ (in GeV) (our expected resolution for photons in a multihadron environment) and a background polynomial of order 3. The fit yielded a 4.0 standard deviation signal of (89.5 ± 22.5) counts at $E_\gamma = (1074 \pm 9)$ MeV (statistical error only, an overall scale error of 2% on the energy is yet to be applied). By variation we find $\sigma_E/E = 0.028^{+0.013}_{-0.009}/E^{1/4}$, consistent with our expected resolution. No other line in fig. 1 can be fitted, consistent with our resolution, with a significance of more than 2.2 standard deviations.

Additional cuts designed to enhance multihadronic decays of the ζ were developed by the use of Monte Carlo simulations of the process $\Upsilon(1S) \to \gamma\zeta$, $\zeta \to$ 2 hadron jets: total multiplicity between 9 and 20 (only particles with energy deposition greater than 50 MeV are counted); charged multiplicity ≥ 2; neutral multiplicity ≤ 12; total energy deposited in the NaI(Tl) ≤ 8000 MeV; sphericity of the event ≥ 0.16. While charm quark jets were used as a model, jets due to lighter quarks or gluons lead to very similar results. Fitting as above (fig. 2) now yields a significance of 4.2 standard deviations for the signal with parameters

$$
\begin{aligned}
E_\gamma &= (1072 \pm 8 \pm 21)\ \text{MeV} \\
M &= (8319 \pm 10 \pm 24)\ \text{MeV} \\
\text{Counts} &= 87.1 \pm 20.5 \\
\chi^2 &= 24.8 \text{ for 41 degrees of freedom.}
\end{aligned} \qquad (1)
$$

The efficiency for this selection was investigated in a few ways. First we used a γ-jet-jet Monte Carlo simulation for various fixed photon energies and jet-jet models ($u\bar{u}$, $c\bar{c}$, gg). Second we superimposed Monte Carlo generated photons onto real hadronic events at the c.m. energy of interest (Υ(1S) or Υ(2S)). The various methods show systematic differences (fig. 3), causing a large contribution to the systematic error of the efficiency. Therefore we estimate a photon efficiency near 1 GeV of (18 ± 10)% leading to a branching ratio

$$B[\Upsilon(1S)\to\gamma\zeta,\zeta\to\text{hadrons}] = (0.47 \pm 0.11 \pm 0.26)\%. \qquad (2)$$

A number of checks were made to ensure that the signal was not instrumental or induced by the analysis procedure. First all the cuts used to obtain the inclusive photon spectrum of fig. 1 were removed one at a time; this procedure indicated that none of the cuts used had anomalous effects. Second, by dividing the data appropriately, no preference for a particular period or geometrical region could be detected. Correlations between γ-energy and the triggers generated by the events containing the candidate γ's were found to be essentially constant moving from below to beyond the region of $E_\gamma = 1$ GeV. Off-resonance data, Monte Carlo 3g and $q\bar{q}$ events, and random beam cross events were subjected to the same analysis procedure and showed no significant fluctuations near 1 GeV. Finally, J/Ψ data taken at SPEAR and analyzed by the same program showed no narrow line at about 1 GeV.

The Υ(2S) data set, analyzed similarily to the Υ(1S) sample, does not show any narrow line (fig. 4). This is strong evidence that the signal from the 1S is not artificially induced. However, a signal for the ζ from the cascade $\Upsilon(2S)\to\pi\pi\Upsilon(1S)$, or $\gamma\gamma\Upsilon(1S)$, is expeced. A fit using a fixed width $\sigma_E/E = 0.033$ (taking account of the Doppler broadening) leads to an upper limit of 70 events (90% c.l.) at $E_\gamma = 1072$ MeV. This is consistent with an expectation of 53 ± 13 events based on the observed signal on the Υ(1S). No peak is observed either for the direct process $\Upsilon(2S) \to \gamma + \zeta$ (8.32 GeV), i.e. at $E_\gamma = 1556$ MeV. While the detection efficiency (fig. 3) has rather large systematic uncertainties as mentioned before, the ratio of efficiencies ε(1070 MeV)/ε'(1560 MeV) is uncertain to about 10% of this ratio. Thus we find an upper limit $\frac{B[\Upsilon(2S)\to\gamma+\zeta]}{B[\Upsilon(1S)\to\gamma+\zeta]} < 0.22$ (90% c.l.).

The second analysis was motivated by a possible Higgs interpretation of the signal described above for which the decay into $\tau^+\tau^-$(2) might be substantial. Disregarding the motivational bias, this data set can be viewed as a set of low multiplicity events orthogonal to the multihadronic sample. A new preselection was performed on all the recorded Υ(1S)-region triggers by requiring a total energy of at least 1200 MeV and at least two particles in the detector. As in the first analysis, an initial set of cuts was applied to arrive at an inclusive photon spectrum in the E_γ-region of 700 to 2000 MeV. Care was taken not to exclude $\gamma\tau\bar{\tau}$ events, using Monte Carlo calculation as a guide. QED-background was substantially reduced by exploiting the correlation of the γ with the beam direction (strong in the case of radiative QED and weak for a possible ζ related $\gamma\tau^+\tau^-$ final state). In addition e^+e^-X events, beam gas interactions, and cosmic ray events were excluded. The remaining series of cuts was derived from the Monte Carlo simulation of $\Upsilon(1S) \to \gamma\zeta \to \gamma\,\tau^+\tau^-$. In essence these cuts were boundary tunings (both in the one and two dimensional distributions) of such variables as thrust, multiplicity, event track-alignment, transverse momentum to the beam, etc., determined by the $\gamma\tau^+\tau^-$ like configuration. In particular, a total multiplicity requirement of less than 9 guarantees no overlap with the results of (1). A check with the Monte Carlo was made by evaluating the efficiency of the sum of all these cuts for Monte Carlo $\gamma\tau^+\tau^-$ events for 10 discrete values of E_γ between 600 and 2000 MeV. The efficiency distribution obtained is approximately constant (at 24%) from 700 to 1500 MeV, and then drops off to ∿ 18% at 2000 MeV. A fit to the final signal (fig. 5) with σ_E/E fixed at $2.7\%/E^{1/4}$, yields a 3.3 standard deviation signal with the following parameters:

$$\begin{aligned} E_\gamma &= (1062 \pm 12 \pm 21)\ \text{MeV} \\ M &= (8330 \pm 14 \pm 24)\ \text{MeV} \\ \text{Counts} &= 23^{+7.9}_{-7.2} \\ \chi^2 &= 29.9 \text{ for 41 degrees of freedom,} \end{aligned} \qquad (3)$$

in excellent agreement with the values recorded in (1). Fitting with a variable width yields a $\sigma_E/E = 0.034^{+0.027}_{-0.012}/E^{1/4}$, consistent with the expected resolution. These results are statistically independent of those shown in (1). The combined significance of both peaks is thus greater than 5 standard deviations. The observed peaks are consistent with the known Crystal Ball resolution function at $E_\gamma \sim 1$ GeV, which is an asymmetric Gaussian of FWHM (64 ± 5) MeV[4]. Unfolding this resolution from the combined observed FWHM (82 ± 23) MeV yields a 90% c.l. upper limit on the intrinsic ζ width of 80 MeV.

To obtain a value for $B[\Upsilon(1S) \to \gamma\zeta]$ which includes final states contributing to the second signal and not to the first we assume as a model that the ζ has two kinds of decay, represented by $c\bar{c}$ and $\tau\bar{\tau}$ MonteCarlo models. The data is found to be consistent with these models and indicates that inclusion of low multiplicity $\tau\bar{\tau}$ like final states will increase the branching ratio (2) by about 20%. Using the $c\bar{c}$ Monte Carlo alone to model both signals results in a poor fit to the data (2-3 standard deviation disagreement). However, this may be due to an inadequate $c\bar{c}$ Monte Carlo. It must be emphasized that we do not prove that the ζ decays into $c\bar{c}$ and $\tau\bar{\tau}$, we only show consistency with the model used as an aid in extracting the signal of (3).

We have also looked for a possible signal from $\Upsilon(1S) \to \gamma\zeta \to \gamma\tau^+\tau^-$ where $\tau^\pm \to e^\pm\nu\nu$, $\tau^\mp \to \mu^\mp\nu\nu$. An upper limit of 0.2% (90% c.l.) for $B[\Upsilon(1S) \to \gamma\zeta, \zeta \to \tau^+\tau^-]$ has been found, compatible with the signal from the second analysis even if that were entirely due to a $\tau\bar{\tau}$-decay of the ζ. Additionally, an upper limit of 3.2×10^{-4} (90% c.l.) for the branching ratio $B[\Upsilon(1S) \to \gamma\zeta, \zeta \to e^+e^-]$ has been determined.

In conclusion we have observed two statistically independent signals at the same mass; one of 4.2 and the other of 3.3 standard deviations. The fact that both peaks appear at the same position with a compatible width supports the hypothesis that we are seeing the same state in two different channels; then the combined significance of both peaks is greater than 5 standard deviations. Both our signals have widths consistent with the detector energy resolution. The weighted averages for the parameters of this new state, herein named ζ, are

$$E_\gamma = (1069 \pm 7 \pm 21)\ \text{MeV}$$
$$M = (8322 \pm 8 \pm 24)\ \text{MeV}$$
$$\Gamma < 80\ \text{MeV (90\% c.l.)}$$
$$B[\Upsilon(1S) \to \gamma\zeta] \sim 0.5\%.$$

The interpretation of this new state as the neutral Higgs boson expected in the standard model gives a disagreement of approximately two orders of magnitude between this observed branching ratio and that predicted. This branching ratio can be accomodated in some extensions of the standard model, e.g. two-Higgs doublet models. A less model-dependent quantity is the ratio $\frac{B[\Upsilon(2S) \to \gamma\zeta]}{B[\Upsilon(1S) \to \gamma\zeta]}$, in which the strength of the Higgs' coupling to b-quarks cancels out; in either model this ratio is predicted to be ~ 1.0[2], while our upper limit is 0.22, in apparent disagreement. Further, given the limited statistics of the experiment, it cannot be proven that the mode $\zeta \to \tau\bar{\tau}$ exists, although our analysis is consistent with it.

* For more detail see C. Peck et al. (CB Collaboration) DESY 84-064/SLAC-PUB 3380 (1984); contributed paper to this conference no. 918.

Fig. 1

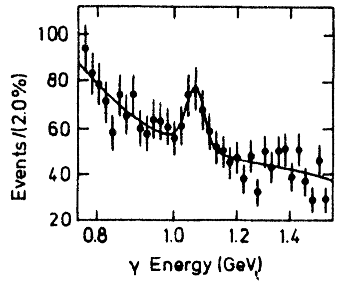


Fig. 2

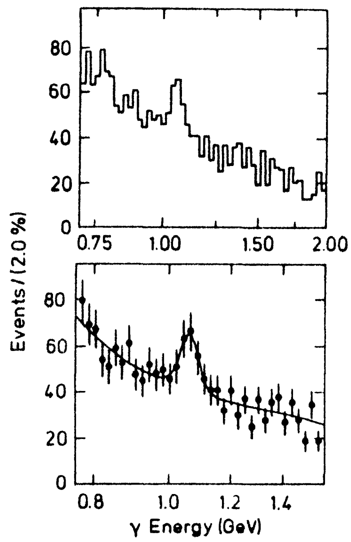


Fig. 3

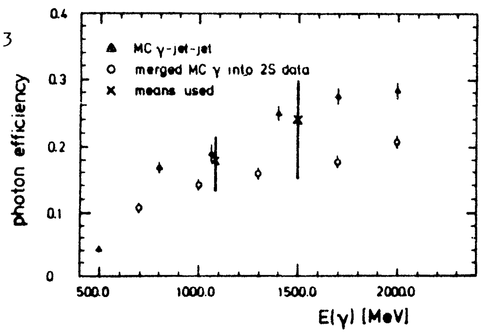


Fig. 4

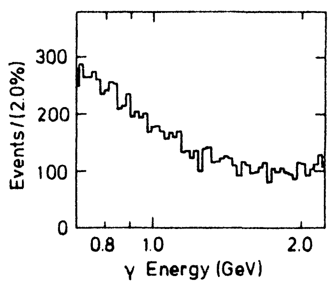
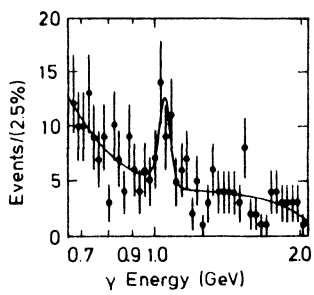


Fig. 5



References

(1) See e.g. J.D. Bjorken, Proc. Summer Inst. on Particle Physics, 1980, SLAC-224.

(2) F. Wilzek, PRL 39, 1304 (1977); J. Ellis et al., Pl 83B, 339 (1979); S. Weinberg, PRL 36, 294 (1976); H.E. Haber, G.L. Kane, PL 135B, 196(1984).

(3) See e.g. H.E. Haber, G.L. Kane, PRep to appear.

(4) J. Gaiser et al., SLAC-PUB-3232; J. Gaiser, PH.D. Thesis, SLAC-255.

(5) J. Irion et al., SLAC-PUB-3325.

(6) C.D. Edwards, Ph.D.Thesis, CALT-68-1165.

(7) Lund-MC version 5.2; cf. B. Andersson et al., PRep 97, 33 (1983).

Figure Captions

Fig. 1: $\Upsilon(1S) \to \gamma$ + high multiplicity
Fig. 2: $\Upsilon(1S) \to \gamma$ + high mult., with "physics" cuts
Fig. 3: γ efficiency for $\Upsilon(2S)$ (almost identical for $\Upsilon(1S)$)
Fig. 4: $\Upsilon(2S) \to \gamma$ + high multiplicity
Fig. 5: $\Upsilon(1S) \to \gamma$ + low multiplicity