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STUDY OF PHOTONS PRODUCED SIMULTANEOUSLY WITH THE J/ψ PARTICLES AT THE CERN INTERSECTING STORAGE RINGS

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ABSTRACT

As a part of the study of the inclusive production of electron pairs in pp collisions at the CERN Intersecting Storage Rings (ISR), a search has been performed for additional photons accompanying J/ψ particles. The results suggest that (43 ± 21)% of the J/ψ's are produced via the photonic decay of one of the χ(3.5) states.

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It has been suggested [1-3] that the production of the J/ψ particle via the decay of an intermediate state $\chi(3.5)$, $\chi \rightarrow J/\psi$ + anything, represents a major fraction of the inclusive hadronic J/ψ cross-section. This could account for the observed small ratio of ψ' production relative to J/ψ production ($\sim$ 2.0%) [4]. We have tested this hypothesis by searching for J/ψ plus photon coincidences at the CERN ISR.

The J/ψ's were produced in pp collisions at an average $\langle\sqrt{s}\rangle$ = 55 GeV (74% of the total luminosity at $\sqrt{s}$ = 52 and 26% at $\sqrt{s}$ = 62 GeV) and detected by their decay into electron pairs. The apparatus consisted of four modules, each covering $90^\circ \pm 40^\circ$ in polar angle and 40° in azimuth. The energies of the electrons and photons were measured by liquid-argon calorimeters. Discrimination between electrons and hadrons was provided by measurement of the longitudinal and transverse distribution of the showers in the liquid-argon calorimeter and by two sets of lithium/xenon transition radiation detectors (TRDs). The apparatus and triggers are fully described elsewhere [5,6].

To obtain a clean sample of J/ψ events with a relatively small background, strict off-line requirements were imposed upon the signals from the detector planes; these were similar to those described in references 5 and 6. Figure 1 shows the invariant mass distribution of electron pairs satisfying these requirements.

For the purpose of this analysis, we have defined the J/ψ region to be between 2.67 and 3.52 GeV ($\sim \pm 2\sigma$ of the measured mass resolution). There are 748 electron pair events in this region, with a background of about 12% including electron pair continuum. Of these events, 205 included at least one detected photon (39 had two photons and 6 had three photons). We have excluded those cases where a photon converted before the second lithium/xenon TRD.

The following further requirements were imposed upon this sample of 205 J/ψ plus photon events:

a) If two or more photons were detected and any pair had a mass consistent with that of the π^0, both photons were rejected.

b) If more than 300 MeV of energy had not been assigned to any shower in the calorimeter containing the photon, the photon was rejected in order to remove events where the reconstruction program might have been confused.

c) As the reconstruction program was known to have a poor efficiency for reconstructing low-energy showers, the photons were required to have an energy greater than 400 MeV.

Requirements (a) and (b) removed respectively 9% and 4% of the sample, whereas the 400 MeV cut (c) removed a further 37% of the events, leaving a total of 140 photons in the sample. These photons were combined with the J/ψ's after constraining the effective mass of the electron pair to be 3.1 GeV, and the resulting mass distribution is shown in fig. 2a. The dotted line in this figure represents the estimated background, which was obtained by taking a sample of photons from untriggered modules in events which gave the same trigger as the J/ψ events and combining these photons at random with the complete sample of J/ψ's. This background distribution was then normalized to the number of events in the high-mass tail (> 3.72 GeV) of the distribution of fig. 2a.

We observe that the J/ψ plus photon invariant mass spectrum shows a peak above the background distribution, and the result of subtracting this background is shown in fig. 2b. There is an excess of 25 ± 9 events in the mass region $3.36 < m_{ee\gamma} < 3.72$ GeV. The error of 9 events is the statistical error only. We attribute this excess of events to the decay of the χ states, in particular to the $\chi/P_c(3.51)$ state which has the largest branching ratio into J/ψ's plus photon, although the apparatus does not have the resolution necessary to enable us to distinguish the several χ states. Furthermore, the contribution to J/ψ plus photon events from other decay processes, such as $\psi' \to J/\psi\pi^0\pi^0$, $\psi' \to J/\psi\eta$, etc., is expected to be small and would give a quite different invariant mass distribution.

Considering the relatively poor mass resolution available, it must be said that the excess of events in the χ mass region could also be attributed to a dynamical effect which causes the photon spectrum to be different for the J/ψ events and the background sample. However, χ decay seems the most natural interpretation of fig. 2b.

The observed number of 25 events was corrected for the 10% probability of a photon converting in the apparatus before the second lithium/xenon TRD and the 15% inefficiency of the reconstruction program for soft photon showers (of energies between 400 and 800 GeV), leading to a corrected number of 31 ± 11 events. The observed number of electron pair events in the 2.67 to 3.52 GeV region was corrected for the expected background, leading to 658 J/ψ events in this region. Comparison of these two figures with the results of a Monte Carlo calculation*) for the χ acceptance, including the 400 MeV cut, indicates that the fraction of J/ψ's produced via the decay of an intermediate χ state is:

$$\frac{B_{\chi\to J/\psi\gamma}(d\sigma_{\chi}/dy)\big|_{y=0}}{(d\sigma_{J/\psi}/dy)\big|_{y=0}} = 0.43 \pm 0.21 \ ,$$

where the error of 50% also includes a 35% systematic uncertainty due to photon reconstruction efficiency and background subtraction.

Our task of processing a large amount of data was greatly lightened by the assistance of the following people: Mr. R. Hogue and Ms. B. Smith of BNL, and Mme S. Bapst-Deville of CERN, to whom we owe much gratitude.

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*) For the Monte Carlo calculation we have assumed a p_T distribution of the form $e^{-1.3p_T}$, a flat rapidity distribution, and isotropic decays.

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Figure captions

Fig. 1 : Invariant mass distribution of electron pairs.

Fig. 2 : Invariant mass distributions of:

a) J/ψ plus photon;

b) after subtraction of the background indicated in (a). The dotted line shows the Monte Carlo prediction for the $\chi(3.51)$ state.

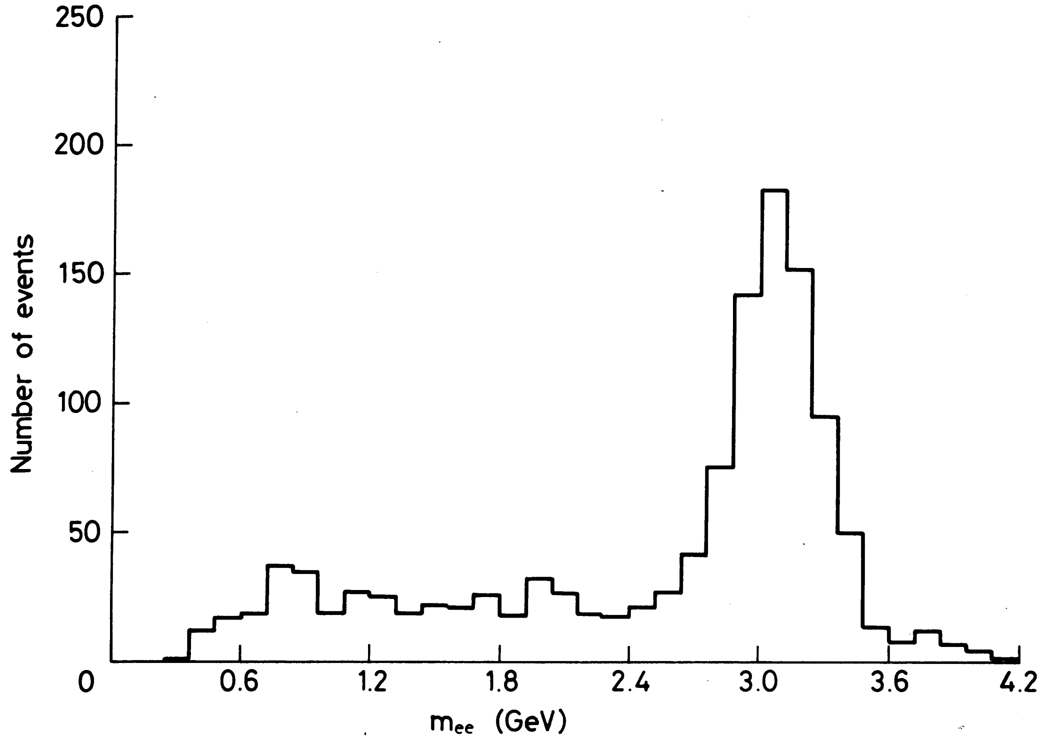

Fig. 1

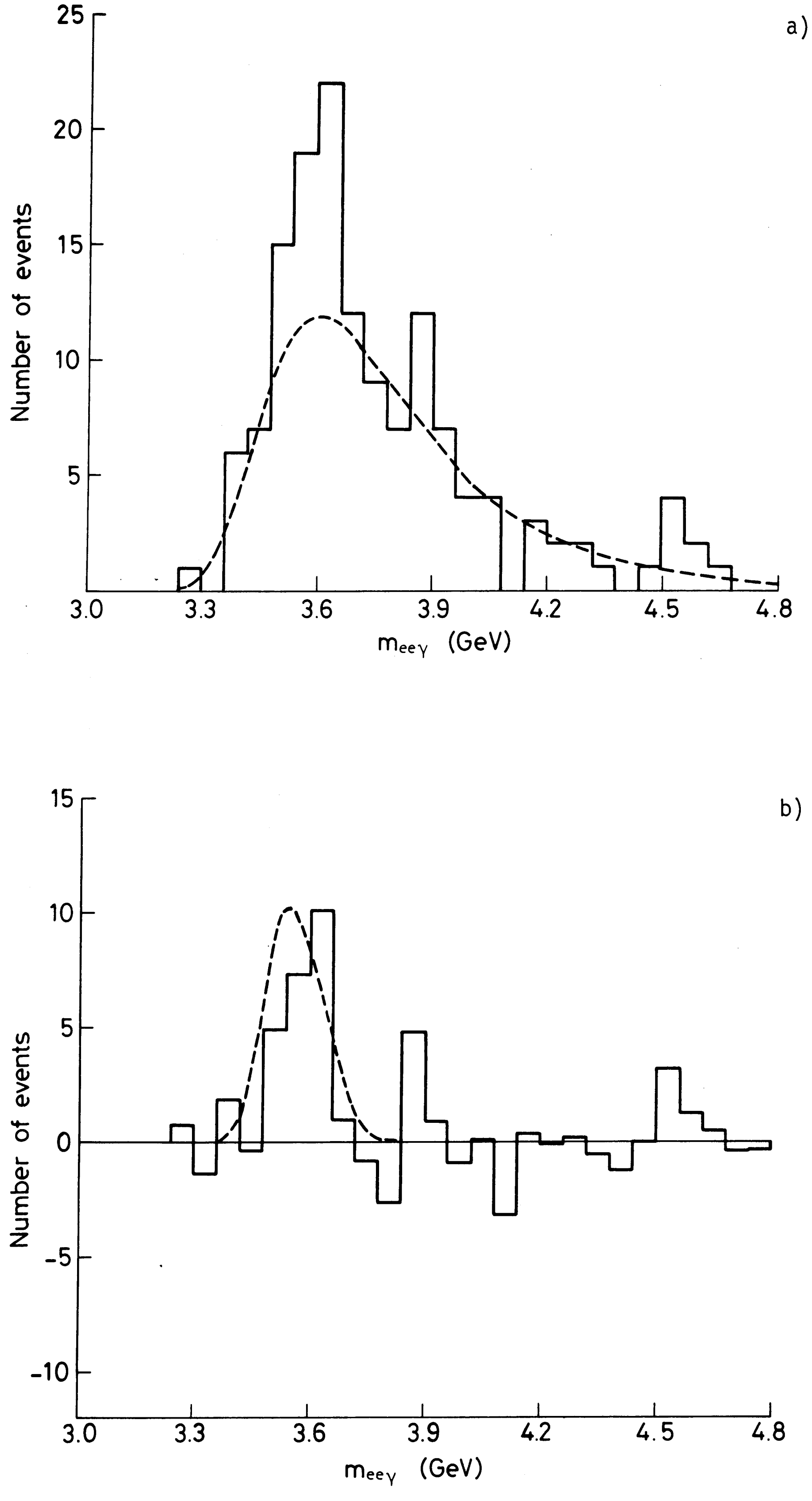
a)
25
20
15
10
5
Number of events
3.0
3.3
3.6
3.9
4.2
4.5
4.8
meeγ (GeV)
b)
15
10
5
0
-5
-10
Number of events
3.0
3.3
3.6
3.9
4.2
4.5
4.8
meeγ (GeV)

Fig. 2