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SEARCH FOR MASSIVE PHOTON PAIR PRODUCTION
AT THE CERN INTERSECTING STORAGE RINGS

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ABSTRACT

A search for massive photon pair production at $\sqrt{s} = 63$ GeV has been carried out on the data sample previously employed for the electron pair production study. Positive evidence is reported for $m_{\gamma\gamma} > 6$ GeV, with a production cross-section similar to Drell-Yan electron pairs. The ratio $\gamma\gamma/\pi^0\pi^0$ was measured to be $\sim 10^{-3}$ for a p_T of each γ or π^0 above 3 GeV/c.

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^{†††)} Work supported by the US National Science Foundation.

1. INTRODUCTION

Direct two-photon production in hadronic interactions has been discussed in the theoretical literature by many authors [1-4].

We present here the first experimental evidence for the process $pp \rightarrow \gamma\gamma + X$ at $\sqrt{s} = 63$ GeV, when each photon emerges near 90° in the centre of mass with a transverse momentum of at least 2 GeV/c.

The lowest-order QCD diagrams are shown in Fig. 1. The sub-processes (a) $q\bar{q} \rightarrow \gamma\gamma$ and (b) $gg \rightarrow \gamma\gamma$ dominate the cross-section, and at our energies their relative contributions at 90° have been estimated to be $(gg \rightarrow \gamma\gamma)/(q\bar{q} \rightarrow \gamma\gamma) \sim 0.15$ to 0.30 [2]. At the level of the parton model, process (a) involves the same structure functions as does the Drell-Yan process $pp \rightarrow e^+e^- + X$ (Fig. 1f). At the QCD level, the two-photon production gives additional information, being sensitive to the quark propagator which relates the process to the single direct photon production. The $q\bar{q} \rightarrow \gamma\gamma$ process is also sensitive to the charge of the quark to the fourth power. We have calculated (to first-order QCD) the cross-sections for $pp \rightarrow \gamma\gamma + X$ and $pp \rightarrow \ell\ell + X$ [5], and these are displayed in Fig. 2a for the 90° configuration and in Fig. 2b for a 20° back-to-back production. As one can see in Fig. 2a we expect the two photons to be produced with cross-sections similar to those of the dileptons at 90° . A comparison of the two processes for the configurations of Fig. 2b could provide a significant test of the quark propagator.

In this paper we will compare the $\gamma\gamma$ cross-section with the $\ell\ell$ production at 90° . The advantage of normalizing the $\gamma\gamma$ data to the Drell-Yan events is that part of the higher-order QCD corrections are the same in both processes [4].

The production environment of the photon and electron pairs is expected to be similar. Photons produced according to the diagrams of Figs. 1a and 1b are emitted with equal and opposite transverse momentum and unaccompanied by hadrons. In our analysis, we have selected $\gamma\gamma$ events which were *not accompanied by hadrons*. This requirement will not bias the $\gamma\gamma/\ell\ell$ ratio, but will suppress background due to various mechanisms of bremsstrahlung photon production, described in Figs. 1c, 1d, and 1e.

2. THE DATA SAMPLE AND THE METHOD OF ANALYSIS

In the following we describe the method of analysis adopted in order to establish experimentally the existence of direct photon pairs in the presence of the much more abundant high- p_T production of opposite-side π^0 pairs.

The sample of data is basically the same as that previously used for the study of large-mass electron pair production [6], of π^0 inclusive cross-section at high p_T [7], and of $\pi^0\pi^0$ correlations [8]. It corresponds to an integrated luminosity of about 8×10^{37} cm $^{-2}$. The four detector modules (Fig. 3) were arranged in two opposite pairs (conventionally labelled "Up" and "Down") around the ISR interaction region. The effective plane for the determination of the coordinates of electromagnetic showers in the lead/liquid-argon calorimeters was at a distance of 85 cm from the interaction centre. Each calorimeter covered a solid angle of about 0.9 sr in the laboratory and was segmented laterally and longitudinally to provide measurement of the electron-photon energy and to enhance the hadron rejection.

The events were recorded whenever a localized energy deposition, above a suitable trigger level, was detected in at least one Up and one Down calorimeter.

A series of proportional chambers, plastic scintillator hodoscopes, and lithium foil transition radiators, followed by xenon proportional chambers, were fully operational and used in the analysis, but were not required in the trigger.

The trigger efficiency (Fig. 4a) is essentially the same for electrons and photons.

In the absence of a magnetic field, we consider that with our apparatus the only possible difference between the acceptances of $\gamma\gamma$ and $\ell\ell$ pairs could arise from different production kinematics. From Fig. 4b we conclude that there is a difference of at most 15% between the acceptance of Drell-Yan pairs with a decay angular distribution proportional to $1 + \cos^2 \theta$, and the acceptance of a resonance source decaying isotropically into two photons.

The reconstruction of the electromagnetic showers has been carried out in the same way as for the data on electron pairs [6] and on direct photon production [9] already published. Similarly, the performance of the calorimeters and of the associated software has been simulated with the well-tested EGS [10] Monte Carlo. With the trigger threshold used here, the useful range for the p_T of a detected π^0 or photon starts at about 2 GeV/c and extends up to 9 GeV/c. The relatively small distance between the calorimeters and the interaction region implies a correspondingly high probability that the photons from a high- p_T π^0 will merge into a single shower. At lower p_T the dominant source of single photon candidates is the limited geometrical acceptance of the two direct photons. To limit these effects in the data used in the present analysis, we imposed the same selection criteria as were previously used for the direct photon studies [9]. In particular, this applied to the fiducial volume; to the radius and longitudinal development of the showers; to the absence of additional showers in the calorimeter where the photon or π^0 is detected; and finally, to the absence of any sizeable energy (100 MeV) left unassigned after reconstructing all showers of the event.

In order to search for a signal in the most sensitive and reliable way, the basic quantity we studied is the ratio R of the number of events with a single detected shower to the number of events with a π^0 detected in the same p_T range, in a given calorimeter. We will use the subscript s or π to distinguish the case where the particle detected in one calorimeter is in coincidence either with a single shower (R_s) or with a π^0 (R_π) detected in one of the *opposite* calorimeters in the same p_T range.

The comparison of R_s with R_π permits us to search for $\gamma\gamma$ events without being sensitive to the precise values of detection efficiencies. The argument is qualitatively as follows: for the case (which is experimentally the dominant one) where $\pi^0\pi^0$ pairs are produced, each single shower detected would actually be the consequence of a π^0 misidentification: given the symmetry and the fact that the probability of misidentification of a π^0 in one calorimeter is not correlated with the probability of misidentification in the calorimeter where the second element of the pair is detected, it clearly follows that $R_s = R_\pi$. Since a single photon has no chance of being mistakenly detected as a π^0 , the genuine $\gamma\pi^0$ events (i.e. a direct photon, whose p_T is balanced by a recoiling jet with a π^0 as a leading particle), cannot give rise to detected $\pi^0\pi^0$ events. A sample of events consisting of a mixture of $\pi^0\pi^0$ and $\gamma\pi^0$ events would hence give $R_s < R_\pi$. On the contrary, adding true $\gamma\gamma$ events to a $\pi^0\pi^0$ sample would result in $R_s > R_\pi$. In conclusion, experimental values of $R_s/R_\pi > 1$ represent evidence for $\gamma\gamma$ events.

More quantitatively, let us denote by

$N_{\pi\pi}$ the number of $\pi^0\pi^0$ events,

$N_{\gamma\pi}$ the number of events with a single γ and a recoil π^0 ,

$N_{\gamma\gamma}$ the number of $\gamma\gamma$ events,

where the γ 's and/or π^0 's are pointing to opposite pairs of calorimeters, each having a p_T above a given threshold.

Let us also define

$P_{\pi\pi \rightarrow \pi\pi}$ as the probability that a pair of π^0 's will be detected as such;

$P_{\pi\pi \rightarrow s\pi}$ as the probability that a pair of π^0 's will be detected as a single shower and a π^0 ;

$P_{\pi\pi \rightarrow ss}$ as the probability that a pair of π^0 's will be detected as a pair of single showers;

$P_{\gamma\pi \rightarrow s\pi}$ as the probability that a $\gamma\pi^0$ event will be detected as a single shower and a π^0 ;

$P_{\gamma\pi \rightarrow ss}$ as the probability that a $\gamma\pi^0$ event will be detected as a pair of single showers;

$P_{\gamma\gamma \rightarrow ss}$ as the probability that a $\gamma\gamma$ event will be detected as a pair of single showers.

The number of observed events will then be:

$$O_{ss} = N_{\pi\pi}(P_{\pi\pi \rightarrow ss}) + N_{\gamma\pi}(P_{\gamma\pi \rightarrow ss}) + N_{\gamma\gamma}(P_{\gamma\gamma \rightarrow ss})$$

$$O_{s\pi} = N_{\pi\pi}(P_{\pi\pi \rightarrow s\pi}) + N_{\gamma\pi}(P_{\gamma\pi \rightarrow s\pi})$$

(1)

$$O_{\pi\pi} = N_{\pi\pi}(P_{\pi\pi \rightarrow \pi\pi}).$$

It should be noted that real $\gamma\gamma$ events contribute only to O_{ss} , and that in the above formulae for O_{ss} and $O_{s\pi}$ we actually include *all* neutral meson contributions ($\pi, \eta, \dots$). By definition

$$R_s = 2O_{ss}/O_{s\pi}; R_\pi = O_{s\pi}/2O_{\pi\pi}; \quad R_s/R_\pi = 4O_{ss} \cdot O_{\pi\pi}/(O_{s\pi})^2. \quad (2)$$

The above detection probabilities clearly depend on the geometry of the detectors, on their response to photons, and on the correlations between the two particles of the pair.

Figure 5a shows, as a function of p_T , the Monte Carlo calculated probability that a π^0 with both decay photons incident on a calorimeter is misidentified and accepted as a single shower (open circles) or that it is instead reconstructed as an accepted π^0 (solid dots). Figure 5b shows the probability that a single photon is accepted as a single shower. The oscillation in the points reflects the statistical accuracy of the Monte Carlo. Clearly, above 6 GeV the probability that the decay photons of a π^0 merge into a single shower becomes important. In order to calculate the detection probabilities for pairs, needed to predict R_s and R_π , a full Monte Carlo simulation of the apparatus has been carried out including the measured $\pi^0\pi^0$ correlations [8] and the contribution, according to the measured cross-sections [11], of other neutral mesons such as η , ω , and η' , which produce high- p_T photons in their decays. As far as $\gamma\pi^0$ events are concerned, from an independent study of the correlations [12] between a π^0 or a high- p_T single direct photon and the charged particles in the recoil jet, we have checked that they are correlated in the same way as $\pi^0\pi^0$ pairs: in place of the $(N_{\gamma\pi}/N_{\pi\pi})$ ratio we have therefore used as input for the Monte Carlo the measured ratio γ/π^0 [9] of the respective single-particle inclusive cross-sections.

Figures 6, 7, and 8 give the results of the calculation for R_s and R_π for various trigger threshold values of the π^0 or shower of lowest p_T and as a function of the p_T of the other partner of the pair. The contributions of the different sources to R_s and R_π are shown separately. It should be remarked that for pairs of mesons the Monte Carlo, including the correlation effects, does indeed give $R_s = R_\pi$. At relatively low p_T , the most important contribution comes from $\pi^0\pi^0$ and π^0 -neutral meson pairs. At higher p_T the dominant source is given by $\gamma\pi^0$ events and this differentiates slightly between R_s and R_π , the R_s remaining always smaller than R_π .

Figure 9 summarizes the expected dependence of the ratio R_s/R_π in the absence of a real $\gamma\gamma$ signal. Figure 10a shows the values measured experimentally for R_s (solid dots) and R_π (open circles), plotted with their statistical error bars. The Monte Carlo calculated values are also shown for comparison (R_π :; R_s : ---). The experimental values for R_s are always higher than for R_π , contrary to expectation and the Monte Carlo prediction in the absence of a real $\gamma\gamma$ signal. Instead, the values of R_π agree well with the corresponding Monte Carlo calculations.

The measured value of R_s/R_π and the same ratio calculated in the absence of a real $\gamma\gamma$ source are displayed in Fig. 10b for the three different p_T thresholds.

Because each π^0 carries a different fraction of the momentum of its jet, we expect the real $\gamma\gamma$ events to manifest a better balance of their transverse momentum than the background originating in $\pi^0\pi^0$ pairs. The quantity $z = p_{T1} \times \cos \theta/p_{T\pi}$ describes the transverse momentum balance of a pair. In Fig. 11 we display the R_s/R_π ratio for balanced pairs ($z \approx 1$) and for unbalanced pairs ($z \neq 1$) for p_T trigger > 2 GeV/c. The background will contribute to the unbalanced pairs, and their R_s/R_π ratio (open circles) is indeed lower than the same ratio for balanced pairs (open triangles); it is in good agreement with our Monte Carlo prediction (solid line).

The difference between the measured value of R_s/R_π and the value calculated for it on the assumption that no real $\gamma\gamma$ source exists is directly related, according to the definitions given in (1) and (2), to the number $(O_{ss})_{\gamma\gamma}$ of real $\gamma\gamma$ events contained in the observed sample

$$(O_{ss})_{\gamma\gamma} = \frac{(O_{ss})^2}{4O_{\pi\pi}} \left\{ \left(\frac{R_s}{R_\pi} \right)_{\text{measured}} - \left(\frac{R_s}{R_\pi} \right)_{\text{MC for no } \gamma\gamma} \right\} \quad (3)$$

3. RESULTS

Table 1 summarizes the results obtained. In order to ensure the greatest freedom from systematic errors, the above analysis was performed using only the calorimeter information. As a consequence, the observed net $\gamma\gamma$ signal $(O_{ss})_{\gamma\gamma}$ still includes, in addition to any detected true $\gamma\gamma$ event, *electron pair* events which up to this stage of the analysis are accepted with essentially the same efficiency, and which display the same correlation. The electron pairs can, however, be easily distinguished and removed by using the additional information on charged tracks provided by the scintillation hodoscopes, the cylindrical multiwire proportional chambers (MWPCs), and the linear MWPC coupled to the lithium foil transition radiators which precede the liquid-argon calorimeter. From the previous study of electron pair production [6] we know that in $(87 \pm 5)\%$ of cases an electron produces a recognized track in these detectors. In order to make sure that we subtract the electron pairs, we have accepted as such all events in which both detected single showers are accompanied by a charged track within a 10° cone around the shower, without imposing any other requirement. We have subsequently checked that the events selected in this way are indeed electron pairs, because in fact 80% of them satisfy the full set of criteria imposed during the original analysis for electron pairs. In addition, their mass spectra, shown in Fig. 12, are quite compatible with the expected ones, given the p_T cut on each shower, and they clearly show the Y resonance. This confirms the validity and the sensitivity of the method of analysis. The number of events (see Table 1) obtained by direct subtraction, after correction for track-finding inefficiency but without attempting to remove possible background in the electron pair sample, is hence a safe, lower limit of the true number of $\gamma\gamma$ events [13]. For example, for $p_T > 3$ GeV/c we observe 119 $\gamma\gamma$ candidates. The uncorrelated background is estimated to be 63 ± 10 events, assuming a ratio $R_s/R_\pi = 0.89$ which was predicted by our Monte Carlo. By subtraction we obtain a combined signal of $(56 \pm 15)\gamma\gamma + e^+e^-$ events.

Repeating the whole procedure for showers and π^0 which do have associated tracks in a 10° cone around them, we obtain an e^+e^- signal of 19 ± 4.5 events. This is an overestimate of the real dilepton signal because it will contain $\gamma\gamma$ events which happen to overlap with tracks in the 10° cone. After correction for track inefficiency, we estimate our dilepton signal in this sample to be 25 ± 6 events. By subtraction, the net $\gamma\gamma$ signal is 31 ± 16 events. In summary, for $p_T > 2$ GeV/c no statistically significant net $\gamma\gamma$ signal is obtained because of the size of the background; for both $p_T > 3$ GeV/c and $p_T > 4$ GeV/c we are left with a number of $\gamma\gamma$ events that is more than three times the uncertainty in the number of events expected in absence of a true $\gamma\gamma$ signal.

Since in the liquid-argon calorimeters the detection efficiency of a high-energy photon or electron is essentially the same, we can directly determine the ratio of $\gamma\gamma$ to electron pair events, within the geometrical acceptance of the apparatus and the imposed p_T cuts. In order to derive the ratio of the $\gamma\gamma$ cross-sections to the Drell-Yan electron pair continuum production (which is interesting for the theoretical comparison, as mentioned in the Introduction), we have subtracted the contribution from the Y resonances and assumed that the production distribution for $\gamma\gamma$ and the e^+e^- continuum are the same.

Table 2 summarizes the relevant quantities for the calculation of this ratio. We estimate that the ratio $\gamma\gamma/e^+e^-$ continuum $= 1.7 \pm 1$ for $p_T > 3$ GeV/c, and $d^2\sigma/dm_{\gamma\gamma}^2 dm_{e^+e^-}^2 = (8 \pm 4) \times 10^{-35} \text{ cm}^2/\text{GeV}$ for $8 \leq m_{\gamma\gamma} \leq 11$ GeV [13].

It is also interesting to compare the $\gamma\gamma$ signal with the $\pi^0\pi^0$ production for the same kinematic p_T range. In particular, this makes it possible to evaluate the size of the possible spurious sources that could contribute to the $\gamma\gamma$ signal detected by us. The number of observed $\pi^0\pi^0$ events is 185 for $p_T > 3$ GeV/c and 22 for $p_T > 4$ GeV/c. The corresponding net $\gamma\gamma$ signals observed are 31 and 7. The Monte Carlo program gives a ratio of 1.2×10^{-2} for the relative acceptance of a $\pi^0\pi^0$ pair over that for a $\gamma\gamma$ pair for the same kinematics and p_T range. The difference between the $\pi^0\pi^0$ and $\gamma\gamma$ acceptance comes largely from the localized energy deposition required in the trigger. Because additional charged hadrons are found experimentally [11] to be more frequently associated with π^0 's rather than with direct

photons, we expect that their stringent requirement on the unassigned energy may further depress the relative π^0 acceptance. We have indeed found that without the unassigned energy requirement, the number of accepted π^0 pairs increases by a factor of 1.7. Taking this effect into account, we finally estimate

$$\gamma\gamma/\pi^0\pi^0 = (1.2 \pm 0.6) \times 10^{-3} \text{ for } p_T > 3 \text{ GeV}/c$$

and

$$\gamma\gamma/\pi^0\pi^0 = (2.6 \pm 1.8) \times 10^{-3} \text{ for } p_T > 4 \text{ GeV}/c.$$

4. BACKGROUNDS

Uncorrelated pairs of mesons (π^0 , η , ω , η') decaying into photons were estimated and subtracted (see Table 1).

We have considered the following additional sources of background to the signal:

- Dileptons could simulate diphotons if the track-finding algorithm was inefficient for both tracks. This inefficiency was estimated to be $(2 \pm 1)\%$ causing an enhancement of the $\gamma\gamma$ signal by 0.5 ± 0.3 events for $p_T > 3 \text{ GeV}/c$ and 0.3 ± 0.2 events for $p_T > 4 \text{ GeV}/c$.
- We have studied in detail the possible size of a $\gamma\gamma$ signal due to anomalously high production of $\eta\eta$ or $\eta'\eta'$ pairs, although there is no experimental [8] or theoretical indication of the presence of such pairs. We estimate that a complete correlation of η 's and η' 's (i.e. if every η or η' produced at 90° would always be accompanied by an η or η' in the opposite side) could be responsible for $\sim 20\%$ of the observed $\gamma\gamma$ signal.
- Hadrons interacting in the first layers of a calorimeter can simulate a single shower. The rejections by our calorimeters at the trigger level and the tight selection criteria used in our analysis will result in only 0.4% of charged pions being accepted as a single shower in our p_T range [9]. In order to simulate two-photon events, this will have to happen for both showers. After accounting for the different species of hadrons and using our estimate of $\gamma\gamma/\pi^0\pi^0 \sim 10^{-3}$ and our track reconstruction efficiency of 0.87 ± 0.05 , we concluded that the hadronic contamination to the $\gamma\gamma$ signal is negligible.

5. CONCLUSIONS

We have presented the first evidence for the process $pp \rightarrow \gamma\gamma + X$ at $\sqrt{s} = 63 \text{ GeV}$. The analysis was carried out on a data sample which contains dielectron and diphoton candidates. In order to achieve a strong rejection of the backgrounds, we have used the same selection criteria as that used in our direct photon studies. The method of long-range high- p_T correlation between the two single photon or electron candidates proved to have sufficient sensitivity to unravel the Y signal in our sample, just by requiring loose tracks in association with our photon candidates. We report a cross-section

$$d^2\sigma/dm_{\gamma\gamma}dy|_{y=0} = (8 \pm 4) \times 10^{-32} \text{ cm}^2/\text{GeV}$$

for $8 \leq m_{\gamma\gamma} \leq 11 \text{ GeV}$ and a ratio $\gamma\gamma/e^+e^- = 1.7 \pm 1$ for $p_T(\gamma,e) > 3 \text{ GeV}/c$, which is in good agreement with the theoretical expectation.

Our $\gamma\gamma$ events could also be interpreted as heavy $C = +$ states (0^{++} , 0^{+-} , 2^{++}) of the Y family decaying electromagnetically. Using a branching ratio of 2×10^{-4} for $\eta_b \rightarrow \gamma\gamma$ and the cross-section [14]

$$d\sigma/dy(pp \rightarrow \eta_b + X)|_{y=0} \approx 3 \times 10^{-33} \text{ cm}^2,$$

we estimate

$$\frac{\sigma(pp \rightarrow \eta_b + X) \times b(\eta_b \rightarrow \gamma\gamma)}{\sigma(pp \rightarrow Y + X) \times b(Y \rightarrow e^+e^-)} = 1/20.$$

This ratio together with the number of Y events (see Table 2) predicts that at most one event of our $\gamma\gamma$ sample could be explained by an η_b decay.

A comparison of the process $pp \rightarrow \gamma\gamma + X$ with the two-jet production in $\gamma\gamma$ collisions [15] and with the possibility of massive glueball states [16] materializing as a pair of photons could provide additional understanding of QCD.

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$$\frac{d\sigma}{dt}(q\bar{q} \rightarrow \gamma\gamma) = \frac{2\pi}{3} a^2 \frac{1}{s^2} \left(\frac{\hat{t}}{\hat{u}} + \frac{\hat{u}}{\hat{t}} \right)$$
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 $\eta/\pi^0 = 0.55 \pm 0.07$, $\omega/\pi^0 = 0.87 \pm 0.17$, $\eta'/\pi^0 = 0.90 \pm 0.25$.
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Table 1

Statistics of the observed events

Momentum		$p_T > 2 \text{ GeV}/c$	$p_T > 3 \text{ GeV}/c$	$p_T > 4 \text{ GeV}/c$
Observed events	$\left\{ \begin{array}{l} s\bar{s} \\ s\pi \\ \pi\pi \end{array} \right.$	1773	119	27
		2643	229	21
		1097	185	22
$R = R_s/R_\pi$ observed		1.11 ± 0.05	1.68 ± 0.21	5.39 ± 2.06
$R = R_s/R_\pi$ Monte Carlo		0.99 ± 0.05	0.89 ± 0.05	0.76 ± 0.05
Calculated background	$s\bar{s}$	1576 ± 78	63.0 ± 10	4 ± 2
Signal $\gamma\gamma + e^+e^-$		197 ± 89	56 ± 15	23 ± 5.5
Observed events with an associated track in a 10° cone around each shower or π	$\left\{ \begin{array}{l} s\bar{s} \\ s\pi \\ \pi\pi \end{array} \right.$	110	20	12
		117	7	1
		68	13	2
Calculated background to e^+e^- events		50 ± 11	0.2 ± 0.7	0.1 ± 0.2
e^+e^- signal		60 ± 15	19 ± 4.5	12 ± 3.5
e^+e^- corrected for track inefficiency		79 ± 20	25 ± 6	16 ± 4.5
$\gamma\gamma$ (by subtraction)		118 ± 91	31 ± 16	7 ± 7

Table 2

Estimate of the $\gamma\gamma$ cross-sections

p_T requirement for each shower	$p_T > 3 \text{ GeV}$
e^+e^- events	25 ± 6
e^+e^- events: $8 \leq m_{e^+e^-} \leq 11 \text{ GeV}$	15 ± 5
$(Y' + Y'' + Y''')/e^+e^-$ continuum: $8 \leq m_{e^+e^-} \leq 11 \text{ GeV}$ as measured with same data [6]	0.9 ± 0.3
$Y' + Y'' + Y'''$ events	7 ± 4
$\gamma\gamma/e^+e^-$ continuum = $31 \pm 16/18 \pm 6$	1.7 ± 1
$\gamma\gamma$ averaged for $8 \leq m_{\gamma\gamma} \leq 11 \text{ GeV}$: $d^2\sigma/dm dY _{Y=0} =$	$(8 \pm 4) \times 10^{-35} \text{ cm}^2/\text{GeV}$

Figure captions

- Fig. 1: $\gamma\gamma$ production diagrams:
a) $q\bar{q} \rightarrow \gamma\gamma$
b) $gg \rightarrow \gamma\gamma$
c), d), e) various bremsstrahlung photon diagrams simulating $\gamma\gamma$ production
f) Drell-Yan: $q\bar{q} \rightarrow e^+e^-$
- Fig. 2: Comparison of the production cross-sections of diphotons and dileptons in pp interactions at $\sqrt{s} = 62 \text{ GeV}$ [5]:
a) as a function of p_T when both γ 's and electrons emerge at 90° ;
b) as a function of the centre-of-mass angle of one γ or electron, when the second one is emitted at 20° with $p_T = 3 \text{ GeV}/c$.
- Fig. 3: Geometrical arrangement of the apparatus for the dilepton and diphoton studies.
- Fig. 4: a) Trigger efficiency for single showers
b) Mass acceptance for the geometrical configuration of Fig. 3 for $\gamma\gamma$ and $\ell\ell$. We have assumed a production that is uniform in rapidity with a p_T dependence $dN/dp_T^2 \sim e^{-bp_T}$, $b = 1.4 \text{ GeV}^{-1}$. The e^+e^- decay distribution follows $dn/d\cos\theta = 1 + \cos^2\theta$, when θ is measured in the s-channel helicity frame. We have determined [6] from this dilepton sample: $B = 1.40 \pm 0.15 \text{ GeV}^{-1}$ and $dn/d\cos\theta = 1 + (1.15 \pm 0.34) \times \cos^2\theta$. For the acceptance of the $\gamma\gamma$ pairs, we have assumed a resonance with an isotropic decay distribution.
- Fig. 5: Monte Carlo calculated probability (including detection and reconstruction efficiency) for:
a) a π^0 , with both decay photons incident on a calorimeter, to be accepted as a single shower (open circles) or a π^0 (solid dots);
b) a single photon to be identified as a single shower.
- Fig. 6: The γ/π^0 ratio calculated by the Monte Carlo program for a π^0 or shower trigger threshold of $p_T > 2 \text{ GeV}/c$ as a function of the p_T of the other member of the pair. R_s and R_+ (see text) are similar in the absence of direct photon source. Note that R_s is below R_+ in the presence of direct photons.
- Fig. 7: As Fig. 6 for $p_T > 3 \text{ GeV}/c$.
- Fig. 8: As Fig. 6 for $p_T > 4 \text{ GeV}/c$.
- Fig. 9: Monte Carlo calculated dependence of the ratio R_s/R_+ on p_T , for three different thresholds.
- Fig. 10: a) The observed γ/π^0 ratio when a single shower (R_+ , solid dots) or a π^0 (R_s , open circles) triggered in the opposite side. The Monte Carlo calculated values are superimposed for comparison: R_+ ; R_s
b) The observed and the Monte Carlo calculated R_s/R_+ ratio for three different p_T thresholds.
- Fig. 11: The observed R_s/R_+ ratio for p_T "balanced" pairs (open triangles) and for p_T "unbalanced" pairs (open circles) for the threshold $p_T > 2 \text{ GeV}/c$. The solid line represents the Monte Carlo background prediction for R_s/R_+ .
- Fig. 12: Invariant mass spectrum for e^+e^- pairs. The e^+e^- pair is defined as a $\gamma\gamma$ pair when each shower is accompanied by a charged track within a 10° cone. The spectrum was not corrected for geometrical acceptance or trigger efficiency. For the shower reconstruction efficiency, we have required at most 200 MeV of unassigned energy per calorimeter (or 100 MeV for the events in the hatched histogram).

Fig. 1

Fig. 2

Fig. 3

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Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10a

Fig. 10b

Fig. 11

Fig. 12