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LIMITS ON THE PRODUCTION OF LARGE TRANSVERSE MOMENTUM DIRECT PHOTONS DEDUCED FROM THE MEASUREMENT OF LOW-MASS ELECTRON PAIRS

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ABSTRACT

The hadronic production of electron pairs with masses between 200 and 500 MeV and large transverse momentum has been measured at the CERN Intersecting Storage Rings (ISR). The expected relation between low-mass electron pairs and real photons is used to determine the direct hadronic production of photons. Contrary to indications from some previous experiments, the observed spectrum is consistent with expectations from the decay of known mesons, and leads to a value for the ratio of direct photons to π^0 of

$$\frac{\gamma}{\pi^0} = (0.55 \pm 0.92)\%$$

for $2 < p_T < 3$ GeV and $\langle\sqrt{s}\rangle = 55$ GeV.

Copious production of real photons at high transverse momentum by direct hadronic processes has been suggested by theoretical models [1-5] and some experimental results [6-8]. For example, direct photon production at the level of (20 ± 6)% of π^0 production has been reported for $2.8 < p_T < 3.8$ GeV and $\sqrt{s} = 45$ GeV and 53 GeV at the CERN Intersecting Storage Rings (ISR). The accuracy of such measurements of photon production is limited by large subtractions of photons from π^0 and other meson decays, antineutron and K_L^0 backgrounds of poorly known magnitude, and sensitivity to any non-linearity of the energy response of the detector.

If real photons are produced hadronically, there should be a corresponding production of virtual photons which appear as electron pairs. For low electron-pair masses, measured by the scale of m_ρ, the relationship between real and virtual photons [Eq. (1) below] should be accurate, allowing an estimate of photon production to be made while avoiding the above limitations. The measurements are made relative to the production of electron pairs from ρ^0 and ω^0 decays. Detector acceptance, backgrounds, and energy response are similar for $\gamma_{virtual} \to e^+e^-$ and $\rho^0 + \omega^0 \to e^+e^-$ samples. Direct virtual photons are distinguishable from virtual photons from meson decays (i.e. Dalitz pairs) by the mass spectrum of the electron pairs. In an appropriate mass region, subtractions of Dalitz contributions are small relative to the expected yield of direct virtual photons.

We have studied the inclusive reaction $p + p \to e^+e^- + X$ using lithium/xenon transition radiation detectors [9] and liquid argon calorimeters [10]. The apparatus detected electron pairs produced with high transverse momentum and low rapidity, and covered the full range of electron pair masses with good resolution and electron pair identification. Production of the neutral vector mesons ρ^0/ω^0, ϕ, J/ψ, and Υ has been measured using this apparatus, and is reported elsewhere [11-14]. This letter reports measurements of the production of electron pairs with invariant masses between 200 and 500 MeV. Below 200 MeV the electron pair spectrum is dominated by Dalitz pairs from meson decays, especially from π^0 decays at masses below the π^0 mass. The $\rho^0 + \omega^0 \to e^+e^-$ signal, observed simultaneously with the same trigger and electron pair identification, provides the normalization for the data.

The trigger selected events with two showers in the same detector module, separated in azimuth by at least 8.5°, each of energy greater than approximately 1 GeV and correlated in azimuth with a charged track. For these events, analogue signals from the whole detector were recorded for off-line reconstruction of tracks and showers and identification of electron pairs. The spatial resolution of the detector allowed showers to be separated down to a minimum separation of about 3°. We have combined data at $\sqrt{s}$ = 52 and 63 GeV, with $\langle \sqrt{s} \rangle$ = 55 GeV.

Backgrounds from charged hadrons were suppressed at the trigger level by demanding longitudinal and radial shower development characteristic of electrons. Residual charged hadrons were eliminated by a requirement on the transition radiation signals. Decay photons could cause background by converting to electron pairs, or by spatially overlapping with a charged track in the detector. These backgrounds were eliminated by strict requirements on pulse height in the scintillator hodoscopes, on the geometrical χ^2 of the track and track-shower fits, and by searching the detector for another photon which, when combined with an electron candidate, gave the π^0 mass. These requirements were made in such a way as to allow the stringency of all cuts to be simultaneously varied, in order to allow study of the background contributions to various mass regions. The off-line requirements chosen for final electron pair identification gave an efficiency of 22% for two true electrons.

The invariant mass distribution of the observed direct electron pairs is shown in Fig. 1a for pairs with $2.0 < p_T < 3.0$ GeV. The spectrum peaks at the mass of the ρ^0 and ω^0, and the width of the peak is consistent with Monte Carlo estimates (dashed curve on figure) of the ρ^0 mass width combined with the effects of the experimental resolution. The number of electron pairs in this peak is consistent with the $\rho^0 + \omega^0 \rightarrow e^+e^-$ cross-section measured by this experiment using events where the two electrons enter different detector modules [14] and with two other measurements [15-16] of ρ production at the ISR, assuming equal ρ^0 and ω^0 production. These measurements indicate that ρ^0 production is approximately equal to π^0 production in this p_T region.

The mass acceptance is shown in Fig. 1b for electron pairs with $2 < p_T < 3$ GeV. It falls at high masses, but in the low-mass region of interest for this study it is some 50% higher than at the ρ, ω mass. The mass distribution in Fig. 1a shows a significant signal in this low-mass region. Studies (described in detail in ref. 14) showed that the level of background suppression in the final sample of electron pairs were similar in the low-mass region ($200 < m_{ee} < 500$ MeV) and the ρ^0, ω^0 mass region ($575 < m_{ee} < 950$ MeV). Background contributed at most 10% of the $\rho^0 + \omega^0$ peak and at most 20% of the low-mass pairs.

Dalitz pairs from $\eta^0 \to \gamma e^+e^-$, $\omega^0 \to \pi^0 e^+e^-$, and $\eta'(958) \to \gamma e^+e^-$ decays contribute significantly to the observed yield of low-mass electron pairs. Assuming that at large p_T, i) η^0 production is 55% of π^0 production [17], ii) η' production is equal to η^0 production, iii) ω^0 production is equal to ρ^0 production, and iv) all particle production follows an E_T^{-8} ($E_T^2 = m^2 + p_T^2$) distribution [18], the over-all Dalitz contribution to the low-mass spectrum is shown by the dotted line in Fig. 1a. The $\eta^0 \to \gamma e^+e^-$ contribution is the most significant; however, $\omega^0 \to \pi^0 e^+e^-$ decays are also important at all masses. At masses near 500 MeV, η^0, η', and ω^0 Dalitz contributions become approximately equal.

Additional corrections were therefore made to the observed electron pair yields to account for: i) $\eta' \to \gamma e^+e^-$ contributions in the $\rho^0 + \omega^0$ region, ii) electron pairs from the low-mass tail of the ρ^0 which were observed with $m_{ee} < 500$ MeV due to finite mass resolution of the detectors, and iii) continuum contributions to the ρ^0, ω^0 region based on the continuum signal in the low-mass region. The points with error bars in Fig. 1 show the yield of low-mass electron pairs in terms of $\rho^0 + \omega^0 \to e^+e^-$ after these corrections. The error bars reflect both statistical and systematic uncertainties.

The production of electron pairs from virtual photons expected for a given level of photon production is [19]

$$(q^2 + m^2)^{\frac{1}{2}} \frac{d\sigma(\gamma \rightarrow ee)}{d^3q\ dm^2} = \frac{\alpha}{2\pi m^2} \left(\frac{\gamma}{\pi^0}\right) \left[E \frac{d\sigma(\pi^0)}{d^3p}\right], \qquad (1)$$

where we have assumed m_T scaling and evaluated the invariant π^0 cross-section for given q and m^2 by the relations $p_L = q_L$ and $p_T^2 = q_T^2 + m^2$. The ratio of direct photon production to π^0 production (γ/π^0) has a p_T dependence which is between p_T^0 and p_T^2 in most models. This p_T dependence is not very significant for a small p_T interval such as $2.0 < p_T < 3.0$ GeV. The dashed line in Fig. 1a shows the spectrum, including detector acceptance, excepted for $\gamma/\pi^0 = 10\%$. This curve is seen to lie consistently much higher than the observed spectrum. For the entire mass region $200 < m_{ee} < 500$ MeV, the expected $\gamma \rightarrow e^+e^-/\rho^0 + \omega^0 \rightarrow e^+e^-$ ratio is 2.41 if $\gamma/\pi^0 = 10\%$; whereas the observed ratio is 0.13 ± 0.22, where the error includes systematic uncertainties. It should be noticed that the spectrum expected for $\gamma/\pi^0 = 10\%$ is already higher than the observed spectrum even before Dalitz subtractions.

Interpreting the observed $\gamma \rightarrow e^+e^-/\rho^0 + \omega^0 \rightarrow e^+e^-$ ratio in terms of direct photon production gives $\gamma/\pi^0 < (0.55 \pm 0.92)\%$ for $2.0 < p_T < 3.0$ GeV. Similar analysis for all $p_T > 2.0$ GeV results in slightly smaller γ/π^0 limits. If direct photon production falls more slowly with increasing p_T than does the π^0 production, the estimate of γ/π^0 would be reduced. In conclusion, the extrapolated γ/π^0 ratio, based on the observed virtual photon rate after subtraction of Dalitz contributions, is $O(\alpha)$ contrary to the predictions of models suggesting copious production of single photons.

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Figure captions

Fig. 1a : The experimental mass spectrum for the electron pairs is given by the histogram for $p_T > 2.0$ GeV. Events with $p_T > 3.0$ GeV are shaded. The dashed-dotted curve shows the predicted spectrum for the ρ, ω with the assumptions described in the text. The dotted line shows the prediction for the low-mass Dalitz pairs, in addition to the tail of the ρ, ω^0. The dashed line at the top left side shows the prediction for the low-mass pairs corresponding to $\gamma/\pi^0 = 10\%$. The points with errors represent the experimental low-mass spectrum with the expected Dalitz pairs subtracted.

Fig. 1b : Relative acceptance of the apparatus as a function of the e^+e^- invariant mass for electron pairs with $2 < p_T < 3$ GeV.

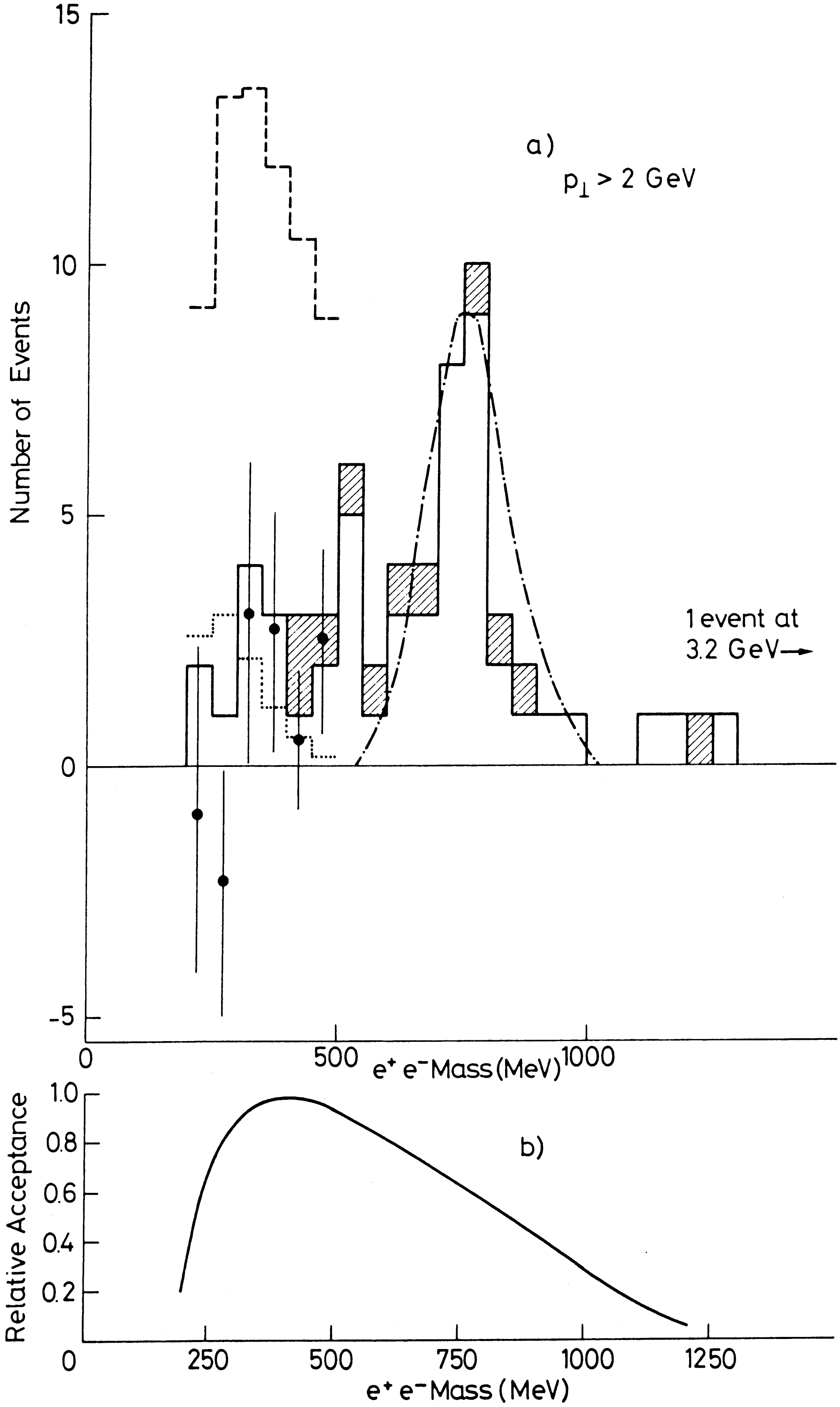
a)
p⊥ > 2 GeV
1 event at
3.2 GeV
Number of Events
e⁺ e⁻ Mass (MeV)
b)
Relative Acceptance
e⁺ e⁻ Mass (MeV)

Fig. 1