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AND ASSOCIATED PARTICLES PRODUCED
AT THE CERN ISR**

**CERN - Michigan State - Oxford - Rockefeller
Collaboration**

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A STUDY OF MASSIVE ELECTRON PAIRS AND ASSOCIATED PARTICLES PRODUCED AT THE CERN ISR

CERN¹⁾ - Michigan State²⁾ - Oxford³⁾ - Rockefeller⁴⁾ (CMOR) Collaboration

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Abstract

A sample of 105 e^+e^- events with an invariant mass greater than 11 GeV/c² produced in pp collisions at a center-of-mass energy of 62.3 GeV is discussed. Cross sections are presented as a function of mass, transverse momentum, and rapidity. The multiplicity, transverse momentum, and azimuthal dependence of associated particles are also studied.

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1. Introduction

A study of lepton pairs produced in hadronic interactions is sensitive to details of the fundamental constituent scattering in ways that are complementary to deeply inelastic lepton scattering processes. The first observation of massive lepton pairs in proton-nucleus collisions [1] was interpreted by Drell and Yan in terms of parton-antiparton annihilation [2]. In quantum chromodynamics (QCD), lepton pairs can also be produced through other diagrams involving gluon emission or absorption (Figure 1). Detailed measurements of massive lepton pairs can be used to constrain theoretical descriptions of hadronic structure [3].

The present publication describes a study of electron pairs (ISR experiment R-110) produced in proton-proton collisions at the CERN ISR at a center-of-mass (c.m.) energy, $\sqrt{s}$, of 62.3 GeV. The observation of electrons requires an open geometry which, unlike the study of muons in beam-dump experiments, allows the measurement of charged and neutral particles associated with the electron pair. Approximately one half of the data presented in this paper have been published previously [4].

2. Apparatus and Trigger

The apparatus, shown in Fig. 2, consisted of a superconducting solenoid [5] providing a magnetic field of 1.4 T and enclosing a system of four, double-layered cylindrical drift chambers [6]. The solenoid coil had an inner radius of 70 cm, an outer radius of 89 cm (the thickness corresponds to approximately 1 radiation length of material), and was 170 cm in length. The r.m.s. momentum resolution of the drift-chamber system was $\Delta p_T/p_T = 7\% p_T$ (p_T in GeV/c).

Four modules of lead-scintillator shower counters were also located inside the magnet. Each module was segmented azimuthally into 8 counters. Each counter was subdivided in depth into a front (C) and a back (D) compartment. The counters were 14 radiation lengths thick and consisted of 16 layers of scintillator interleaved with layers of

lead, 4 layers in the front compartment and 12 in the back. The energy deposited in each counter was recorded using photomultipliers at both ends of the front and back compartments. The position along the counter, z_c , of the particle responsible for the energy deposition in the counter was estimated using either the time difference between the pulses recorded in the phototubes at the two ends of the counter or the ratio of the pulse heights recorded in these phototubes. Each module was 1.5 m long, subtended 50° in azimuth and ± 1.1 units of pseudo-rapidity (η) centered at zero. The detection of electromagnetic showers was completed by two lead-glass (SF 5) modules located outside of the magnet in the angular region not covered by the shower counters. The proton beams of the ISR intersected with an angle of 14.7° resulting in a center of mass motion ($\beta=0.128$) toward one of the lead-glass arrays. A more complete description of the apparatus and calibration methods will be found in ref. 4. The r.m.s. energy resolutions, $\sigma(E)/E$, of the lead glass and shower counters were $(4.3/\sqrt{E} + 2)\%$ and $(16/\sqrt{E})\%$, respectively, with E in GeV.

The present analysis is restricted to e^+e^- pairs detected in the shower counters only. Shower counter "roads" were defined as the sum of all phototubes of the C and D counter for two adjacent counters. Roads were not formed across modules. The trigger required roads greater than 3.5 GeV in any pair of adjacent shower counters. It then required the presence of at least two such clusters separated by more than 60° in azimuth and with a sum (an approximation to invariant mass) greater than 8.5 GeV. These thresholds were raised to 4.0 GeV and 10 GeV, respectively, for about one third of the data presented here. The data correspond to an integrated luminosity of 249 pb^{-1} and were collected at an average instantaneous luminosity of $4 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$.

3. Event Selection

Since no charged-particle requirement was included in the trigger, the first step in the data reduction was to require a charged-particle track observed in the drift chambers to point to each of the two clusters. A track had to pass six requirements in order to be considered a valid electron candidate. First, in order that the measurement of the momentum of the track be reasonable, at least six drift chamber hits were required. The track must have originated from within 5 cm of the z axis (defined as the bisector of the beam directions, see Fig. 2b) and its point of closest approach to the z axis must have been within 50 cm of the nominal center of the interaction region. Tracks with momenta less than 1.5 GeV were not considered. A further track quality cut was placed on the confidence level of the least-squares fit to the track (χ^2 per degree of freedom required to be less than 5). Finally, tracks striking the support structure of the chamber were removed.

If a track struck the shower counters at least half a counter width from the edge of the module, an attempt was made to construct a cluster around it. The seed counter for the cluster was taken to be the counter struck by the track, or its nearest neighbour. The seed counter was required to contain at least 1 GeV of energy. The cluster was expanded outward from the seed to include counters which contained (i) more than 50 MeV, (ii) less energy than the previous counter added to the cluster, (iii) an energy deposition whose estimated position along the counter, z_c , matched the position of the track at the counter within ± 20 cm. The expansion terminated in a given direction if a counter failing to meet these requirements was found. If the cluster expanded in this manner was more than three counters wide it was discarded as an electron candidate, together with the corresponding track. This criterion was adopted after a study of the transverse shower shape of electrons observed in a 4 GeV test beam. The cluster was also required to have an energy-weighted ϕ (azimuthal angle) within 0.06 radians of the ϕ of the track. An energy-weighted z position was also formed for the cluster. In this case, only counters with at least 1 GeV

were used. The z position of the cluster and the z position of the track (evaluated at the expected maximum for shower deposition) were required to agree to within 15 cm.

The invariant mass, m , of the pairs was calculated using the energies as measured in the shower counters and had an r.m.s. resolution of 4% at $m = 15 \text{ GeV}/c^2$. In the analysis the cluster and mass thresholds were raised to 4.5 GeV and $11 \text{ GeV}/c^2$ respectively. The effect of these track and cluster cuts are tabulated in Table 1 for four distinct data sets collected over a period of four years. In Table 1, the data corresponding to the first two columns have been published previously [4], while that of column 3 represents data collected while one-half of the lead glass detector was in a retracted position [7]. This re-configuration is not important for the data presented in this paper.

Candidate electron pairs (two tracks with matched clusters) could be of opposite charge or of same charge, where the charge was determined by the track curvature. Drell-Yan events were of opposite charge while the background could be either same charge or opposite charge. By making the assumption that the charge of a track for background events did not depend on the charge of the other member of the pair, we estimated the expected background in the opposite sign events. This assumption is clearly true for background due to Dalitz decays and conversions. For the charged hadronic background this assumption depends on the absence of charge correlations, which is shown to be valid by the data of Albrow et al. [8]. The following definitions were made:-

- (++) = number of events with two positive tracks
- (- -) = number of events with two negative tracks
- (+ -) = number of events with a negative and a positive track
- S = Drell-Yan signal
- B = total number of background events
- B_{+-} = number of background events with the opposite sign

With no charge correlations, the distribution of background events into the various charge states is governed by the binomial distribution with p being the probability of getting a positive background track:

$$\begin{aligned} (++) &= Bp^2 && \text{(all } (++) \text{ and } (- -) \text{ events are background)} \\ (- -) &= B(1 - p)^2 \\ B_{+-} &= 2Bp(1 - p) \end{aligned}$$

B_{+-} is estimated to be $= 2\sqrt{++}(- -)$ and thus the Drell-Yan signal is

$$S = (+-) - 2\sqrt{++}(- -) \quad (1)$$

After requiring track and cluster matching the remaining background was expected to be due to:-

- (a) the spatial overlap of a charged hadron with a π^0 ;
- (b) electrons and positrons from Dalitz decays of π^0 's and photon conversions in the beam pipe (0.02 radiation lengths) and the first layer of the drift chamber (0.025 radiation lengths);
- (c) charged hadrons which deposited most of their energy in the shower counters after interacting in them.

In order to determine cuts that would eliminate these sources of background while preserving a good electron-detection efficiency, the response of the shower counters to electrons and charged pions was studied in test beams at the CERN Proton Synchrotron. The cuts enumerated below and in Table 2 were then applied to the data:-

- (i) In order to ensure that the two tracks have a common vertex, cuts were made on their distance of closest approach; this distance should be less than 1.3 cm in the better-measured x-y plane, and less than 2.5 cm in the z (along the beams) direction.
- (ii) The ratio, $C/(C+D)$, of the energy deposited in the front compartments of the counters contributing to the cluster, to the total energy of the cluster was required to be typically in the range $0.10 < C/(C+D) < 0.42$. The actual values of the cut used had a weak

energy dependence. Fig. 3 shows the distribution in this variable for the 2944 electron candidates satisfying the cuts described in Table 1.

(iii) More than 93% of the energy of the cluster was required to be concentrated in two adjacent shower counters. The quantity R_C is defined as the ratio of energy in the two counters nearest the track divided by the total energy of the cluster. Fig. 4 shows a histogram of values of R_C for the 2944 electron candidates.

(iv) The measurements of the energy of the candidate electron as given by the shower counters and of its momentum as given by the drift chambers were required to agree within their uncertainties. The variable α was used to match the energy of a cluster with the momentum of a track pointing to it.

$$\alpha = (E_{\text{cluster}}/p_{\text{track}} - 1)/E_{T_{\text{cluster}}} \quad (2)$$

For a perfectly measured electron, α will be zero. However, because of resolution, α will in general not be zero. The resolution is dominated by the measurement of the momentum which is inversely proportional to the transverse momentum. This dependence is provided by the factor of $1/E_{T_{\text{cluster}}}$ in the expression for α .

The spatial overlap of a charged track and a photon from π^0 decay will usually have a positive α . Single charged hadrons will rarely deposit all of their energy in the shower counter (a depth of approximately 0.6 interaction lengths) and thus will have negative values for α . The distribution of α is shown in Fig. 5.

(v) One source of background was from Dalitz decays of the π^0 which would give real electrons or positrons. These events were removed by a cut on the invariant mass found by combining the candidate electron track with any other track in the event. The quantity m_{eT} for the candidate track is the smallest mass that can be formed with any of the tracks. Thus Dalitz decays can be removed by requiring that m_{eT} be greater than two standard deviations of the resolution above the mass of the π^0 . Fig. 6 shows the distribution of m_{eT} for the candidate tracks.

(vi) Since hadrons which cause background events are expected to be parts of jets, it is likely that other hadrons will emerge near them. Hence further suppression of background events was obtained by requiring that the sum of the momenta of all charged and neutral particles within a cone of 25° half angle centered on the electron candidate be less than $1.3 \text{ GeV}/c$. While it is expected that this cut (referred to as the p_J cut) will have little effect on electron pairs from the basic Drell-Yan process, it could produce some inefficiency for events with a recoil jet. The efficiency of this cut is difficult to estimate without a detailed knowledge of the whole event structure.

(vii) In order to ensure that the electron energy was well-measured, it was required that it pass through at least 13 radiation lengths of the shower counter (depth cut). This is an important cut only for those particles passing near the edge of the shower counters.

Note that Table 2 is sub-divided into the same four data sets as Table 1. In addition, the numbers of events at each stage in the analysis are separately shown for each charge combination and a signal calculated using equation (1).

The efficiency of each cut was determined from the numbers of events when all cuts were made, compared with the numbers when that particular cut was omitted. Results for the cuts made in Table 2 are shown in Table 3. The efficiency of the p_J cut and the α cut were determined and are presented with the statistical errors shown. The other cuts were seen to have an efficiency consistent with unity. In these cases, the lower limit of a 90% confidence level is given in the table. The minimum thickness cut was part of the definition of geometrical acceptance and hence is not evaluated in Table 3.

4. Cross Section Extraction

The acceptance was calculated using a Monte Carlo program which included apparatus acceptance, resolution effects, and trigger requirements. Events were generated according to the quark-antiquark annihilation model of Drell and Yan [2] using the structure

function distributions of Duke and Owens [9] and with a p_T distribution used by the CFS group [10]:

$$dN/dp_T \propto p_T [1 + (p_T/p_0)^2]^{-6} \quad (3)$$

where $p_0 = 2.33 \langle p_T \rangle$.

The decay angular distribution was taken to be $1 + \cos^2\theta^*$. Here θ^* is the decay angle measured in the Collins-Soper frame [11], where the axis is taken to be the average of the two proton beam directions in the electron pair center of mass. The total acceptance varied from 10% at $m = 11 \text{ GeV}/c^2$ to 21% at $m = 20 \text{ GeV}/c^2$.

Table 2 shows a total number of opposite-charge events of 105 after all cuts have been applied. The estimate of background using the same-charge sample is 6 events leaving a net signal of 99. This number was used for all subsequent analysis. The cross section $d^2\sigma/dm dy|_{y=0}$ for $11 < m < 25 \text{ GeV}/c^2$ is shown in Fig. 7. The data are in good agreement with other $pp \rightarrow e^+e^-$ results [12, 13] obtained at the same $\sqrt{s}$. Another experiment [14] measured the dimuon continuum at the ISR in the same mass range and with similar statistics but at a larger mean rapidity. The values of $d^2\sigma/dm dy|_{y=0}$ obtained at Fermilab at $\sqrt{s} = 27.4 \text{ GeV}$ by the CFS Collaboration [10] are also plotted in Fig. 7. It can be seen that at the lower $\sqrt{s}$ of the Fermilab experiment the cross-sections are lower than the data presented here by about a factor of 20 at $m = 12 \text{ GeV}/c^2$ and a factor of 100 at $m = 20 \text{ GeV}/c^2$. It is of interest to note that the higher cross-sections at the ISR are compensated by the high interaction rate in the p-nucleus Fermilab experiment such that the mass spectra of both experiments run out of events at about $20 \text{ GeV}/c^2$.

The authors of reference 3 have made a complete evaluation of the QCD description of lepton pair production in hadronic collisions. The analysis includes both leading order and higher order terms, including the terms of order α_s which give rise to the so-called K-factor. Fig. 8 compares the data of this experiment with the theoretical predictions of ref. 3. Comparing the integrated cross section above $11 \text{ GeV}/c^2$ with the lowest order

prediction, we find a K-factor of 1.75 ± 0.60 . We have also evaluated the K-factor as a function of mass and show this in Fig. 9 together with a line representing the integral K-factor.

In the Drell-Yan model [2] the quantity $m^3 d^2\sigma/dm dy|_{y=0}$ or alternatively $s d^2\sigma/d\sqrt{\tau} dy|_{y=0}$ is expected to be a function of τ ($=m^2/s$) only, rather than a function of m and s separately. Scaling violations would invalidate this prediction but they have been shown [15] to be less than 10 % in the τ and $\sqrt{s}$ range of these experiments. The validity of this scaling prediction is demonstrated in Fig. 10, where the scaled cross-sections from this experiment and from CFS are seen to agree in spite of the large differences observed in $d^2\sigma/dm dy|_{y=0}$.

In order to determine the mean transverse momentum, $\langle p_T \rangle$, of the electron pairs the value of $\langle p_T \rangle$ used in the Monte Carlo was varied until the output p_T distribution best represented the data. In this way $\langle p_T \rangle$ was found to be 2.30 ± 0.15 GeV/c. The transverse momentum distribution, corrected for acceptance, is shown in Fig. 11. Also shown in Fig. 11 is the theoretical curve of reference 3.

In contrast to the naive parton model, QCD predicts that the mean transverse momentum will increase as a function of $\sqrt{s}$ for fixed values of τ . Fig. 12 shows the value of $\langle p_T \rangle$ obtained in this experiment compared with data obtained at lower $\sqrt{s}$ [10, 14, 16]. A linear increase with $\sqrt{s}$ is clearly seen.

5. Systematic Errors

The main sources of systematic error in the evaluation of the cross section are measurement of the luminosity of the ISR, energy calibration of the detector, modelling of the detector and physics processes, and the acceptance calculation.

The luminosity of the ISR was measured by the Van der Meer method [17] with an uncertainty of about 10%. The overall energy scale uncertainty, due to calibration beam momentum uncertainty and calibration time dependence was estimated to be less than 5%.

Uncertainties due to the relative balancing of energy deposition in the two compartments of the calorimeter were estimated to contribute about 10% to the cross section.

Systematic errors associated with the simulation of the detector were estimated by comparing the results of Monte Carlo programs run under different configurations involving several different levels of detail in the detector geometry and different requirements for acceptance of electron pair candidates. Particularly important in this context were the plane-by-plane efficiencies of the drift chambers and the geometric boundaries of the shower counters. These effects were estimated to contribute a combined uncertainty to the cross section normalization of $\pm 22\%$. Lack of knowledge of the underlying event structure and any possible associated jet is expected to contribute an uncertainty of $\pm 17\%$ due to the requirement of isolation for each electron.

Systematic errors in the acceptance calculations arise primarily because of uncertainties in the input, theoretical distributions. Principal uncertainties include the input structure functions, the transverse momentum distribution, and the decay angle distribution.

The structure functions assumed in the standard Monte Carlo were those of Duke and Owens, set I [9]. To test for sensitivity to this choice, the Monte Carlo was run with other assumptions, such as Duke and Owens, set II, and also the CDHS structure function [18] as parametrized by the NA10 group [19]. The relative stability of the result to these variations permits a systematic error of $\pm 3\%$ to be assigned to structure function uncertainties.

The average transverse momentum for the electron pairs measured from the acceptance-corrected data was found to be 2.3 ± 0.15 GeV/c. When the Monte Carlo was run with an average transverse momentum of 2.0 GeV/c or 2.6 GeV/c, the change in the resulting cross section was $\pm 3\%$.

Similarly, the standard Monte Carlo program assumed a decay angle distribution of $1 + \cos^2\theta^*$ and input distributions of $1 + 2\cos^2\theta^*$ or isotropic were found to change the final cross section by $\pm 15\%$. The data ruled out variations beyond this range.

Because the Drell-Yan cross section falls off rapidly as a function of mass, the results are sensitive to the knowledge of the energy resolution of the detector. If the assumed resolution was changed by 25% from its nominal value of $(16/\sqrt{E})\%$ the cross section was observed to change by 2%.

Adding in quadrature all of the systematic errors discussed above, the total systematic error in the cross section was 35%, with an additional overall energy scale uncertainty of 5%.

6. Associated Event Structure

There is increasing evidence [20] that the simple Drell-Yan annihilation process [2] (Fig. 1a) is insufficient to describe the properties of lepton pairs produced in hadronic collisions. The cross-section predicted using the Drell-Yan formalism and structure functions obtained from deep inelastic scattering are lower than the data. The lepton pairs are also produced with a mean transverse momentum $\langle p_T \rangle$ that is larger than can be understood in terms of transverse motion of the initial-state partons (~ 1 GeV/c). Furthermore, as we have seen in Fig. 12, $\langle p_T \rangle$ is observed to increase approximately linearly with $\sqrt{s}$, the center-of-mass energy of the collision. These effects have been interpreted [3] in terms of higher order processes such as gluon Compton scattering (Fig. 1b) and quark-antiquark annihilation into a virtual photon and a gluon (Fig. 1c). Both these processes imply the existence of a jet recoiling against the lepton pair.

We searched for evidence of an associated jet by studying particles produced in the same event as the electron pair. Clusters of neutral energy observed in the lead glass and shower counters were assumed to be π^0 's, and charged particles observed in the drift chambers were assumed to be charged pions. Only particles of transverse momentum

greater than 0.2 GeV/c were considered. Charged particles were required to project back to the electron-pair vertex. The acceptance in rapidity, y , for charged particles was $-1.2 < y < +1.2$ over the full azimuth, ϕ . The acceptance for π 's was $-0.6 < y < +0.6$ over the lead-glass acceptance ($\delta\phi = 114^\circ$) and $-1.1 < y < +1.1$ over the shower-counter acceptance ($\delta\phi = 200^\circ$). The multiplicity of an event was defined as the number of charged and neutral particles satisfying the above requirements, excluding the two electrons. These multiplicities were not corrected for apparatus effects.

The mean multiplicity, $\langle n \rangle$, increases as a function of the transverse momentum of the electron pairs (Fig. 13), as already observed at the ISR in conjunction with muon pairs [21]. This may be interpreted as evidence that low values of transverse momentum are less likely to be associated with a recoil jet. The mean multiplicity exhibits no strong dependence as a function of mass. This distribution is shown in Fig. 14.

We next examine Φ , the difference in azimuth between the momenta of associated particles and the momentum of the electron pair. The distribution of Φ is shown in Fig. 15, both for electron pairs with transverse momentum less than 2 GeV/c and for electron pairs with transverse momentum greater than 2 GeV/c. Whereas for $p_T < 2$ GeV/c there is no azimuthal correlation between the electron pair and the associated particles, for $p_T > 2$ GeV/c associated particles are produced predominantly at large Φ , that is back-to-back with the electron pair. The data presented in Figs. 13 and 15 imply that low transverse momentum electron pairs are produced by the basic Drell-Yan process with the associated particles arising only from spectator jets. As the transverse momentum of the electron pair increases, more associated particles are seen concentrated in the central region and furthermore they tend to recoil against the electron pair. This is consistent with the increasing importance of second order diagrams involving a recoil jet in the production of lepton pairs of increasing transverse momentum.

We searched for transverse momentum correlations between the electron pair and the associated particles. A two-dimensional plot of p_T of the electron pair versus p_{Tj} , the

transverse momentum of the system of associated particles, is shown in Fig. 16. Some correlation between these two variables is observed as might be expected if a recoil jet were present. This can be seen in Fig. 17, where the mean transverse momentum of the system of associated particles, $\langle p_{Tj} \rangle$, is plotted as a function of p_T . A completely contained jet with perfect resolution might be expected to have $\langle p_{Tj} \rangle$ equal to p_T , while imperfect jet containment would result in a lower slope. Fig. 17 clearly departs from the idealized situation, especially at low p_T where the presence of spectator particles would dilute the effect of the jet. In an attempt to combine the azimuthal correlation and momentum-balancing information, we constructed $\langle -\cos\Phi_j p_{Tj} \rangle$, in which the effect of spectator particles should sum to zero. Fig. 18 shows this variable, the projection of the "jet" transverse momentum in the direction opposite to that of the electron pair, as a function of p_T and, indeed, more convincing evidence of a recoil jet is exhibited.

7. Summary and Conclusions

About 100 electron pairs of mass greater than $11 \text{ GeV}/c^2$ produced in pp collisions at $\sqrt{s} = 62.3 \text{ GeV}$ were observed. Differential cross sections and transverse momentum distributions agree with QCD calculations that include higher order terms (of order α_s). When compared with data from lower centre of mass energy experiments, the results of this measurement support the scaling hypothesis predicted by the Drell Yan model. A mean transverse momentum of $2.30 \pm 0.15 \text{ GeV}/c$ is measured for these pairs thus confirming the increase of the mean transverse momentum with $\sqrt{s}$ expected from QCD.

The open geometry and the presence of the magnetic field permitted the simultaneous observation of charged and neutral particles associated with the electron pair. It appears that, for higher values of the transverse momentum of the electron pairs, there are more associated particles and they tend to recoil against the electron pair. This is consistent with the expectations of higher order diagrams involving a recoil jet.

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Table Captions

Table 1 Effect of Cuts on Electron Pair Candidate Events.

Table 2 List of Final Cuts on Electron Pair Candidates.

Table 3 Efficiency of Cuts.

Figure Captions

Fig. 1 Some processes contributing to lepton-pair production in hadronic collisions.

Fig. 2 (a) The apparatus viewed along the beam axis.
(b) Plan view of the apparatus.

Fig. 3 Distribution of $C/(C+D)$ (defined in the text) for all electron candidates.

Fig. 4 Distribution of R_C (defined in the text) for all electron candidates.

Fig. 5 Distribution of α (defined in the text) for all electron candidates.

Fig. 6 Distribution of m_{eT} (defined in the text) for all electron candidates.

- Fig. 7 The cross-section $d^2\sigma/dm dy|_{y=0}$ obtained in this experiment and others (R110 Previous [4], R108 [12], R806 [13], R209 [14]) at $\sqrt{s} = 62.3$ GeV and by the CFS Collaboration [10] at $\sqrt{s} = 27.4$ GeV. (The data of reference 14 have been converted from their original form of $d\sigma/dm$.)
- Fig. 8 The cross-section $d^2\sigma/dm dy|_{y=0}$ obtained in this experiment compared with the theoretical predictions of ref. 3, using the structure functions of Duke and Owens (ref. 9). The results of using sets I and II are indistinguishable.
- Fig. 9 The dependence of the K-factor (defined in the text) as a function of invariant mass.
- Fig. 10 The scaling quantity $s d^2\sigma/d\sqrt{t} dy|_{y=0}$ obtained in this experiment at $\sqrt{s} = 62.3$ GeV and at $\sqrt{s} = 27.4$ GeV by the CFS Collaboration [10].
- Fig. 11 The acceptance corrected distribution of the transverse momentum of electron pairs with masses greater than $11 \text{ GeV}/c^2$. Also shown are the theoretical predictions of ref. 3.
- Fig 12 The mean transverse momentum of lepton pairs produced in pp collision plotted as a function of $\sqrt{s}$. Also shown are the results from CFS [10], R209 [14] and the Omega collaboration[16].
- Fig. 13 Mean associated multiplicity as a function of the transverse momentum of the electron pairs.
- Fig. 14 Mean associated multiplicity as a function of the invariant mass of the electron pairs.

- Fig. 15 The mean multiplicity as a function of Φ (defined in the text)
(a) for electron pairs with $p_T < 2$ GeV/c.
(b) for electron pairs with $p_T \geq 2$ GeV/c.
- Fig. 16 The net transverse momentum of the system of associated particles versus
the transverse momentum of the electron pairs.
- Fig. 17 The mean value of the transverse momentum of the system of associated
particles as a function of the transverse momentum of the electron pairs.
- Fig. 18 The mean value of the jet transverse momentum projected in a direction
opposite to the electron pair plotted as a function of the transverse
momentum of the electron pairs.

Cut Description	Old "1980" Data	Old "1981-82" and 82 Data	New Half Back Data	New Normal Geo. Data
Events passing preliminary filter	6841	5822	6886	4596
Number of events with at least 2 good tracks with matched 4GeV clusters	1965	650	857	631
Number of events with two good tracks pointing at nonadjacent sextants and $m > 11$ GeV	715	263	442	301
$X \equiv$ number of events with $E_{cluster} > 4.5$ GeV	615	229	369	259
Luminosity (picobarns) ⁻¹	102	40	66	41
$X / \text{Luminosity (events/pb}^{-1})$	6.0 ± 0.2	5.7 ± 0.4	6.0 ± 0.3	6.3 ± 0.4

Effect of Cuts on Electron Pair Candidate Events.

Table 1

Cut Description		Old "1980" Data	Old "1981-82" Data	New Half Back Data	New Normal Geo. Data
Events with two good tracks pointing to non-adjacent sextants with $E_{electron} > 4.5\text{GeV}$ and $m > 11\text{GeV}$	all	615	229	369	259
	(+-)	331	117	186	136
	(++)	218	80	124	90
	(--)	66	32	59	33
	Signal	91 ± 43	15 ± 27	15 ± 34	27 ± 28
$\Delta xy < 1.3\text{cm}$	all	518	180	272	198
	(+-)	289	92	139	107
	(++)	181	62	88	64
	(--)	48	26	45	27
	Signal	102 ± 39	12 ± 24	13 ± 29	24 ± 24
$\Delta z < 2.5\text{cm}$	all	514	180	270	197
	(+-)	285	92	137	107
	(++)	181	62	88	63
	(--)	48	26	45	27
	Signal	102 ± 39	12 ± 24	11 ± 29	25 ± 24
$-0.10 < \alpha < 0.38$	all	381	115	178	123
	(+-)	219	63	94	68
	(++)	136	34	52	43
	(--)	26	18	32	12
	Signal	100 ± 32	14 ± 18	12 ± 23	23 ± 19
$0.10 < \frac{C}{C+D} < 0.42$	all	215	70	92	71
	(+-)	134	43	54	45
	(++)	67	20	26	18
	(--)	14	7	12	8
	Signal	73 ± 23	19 ± 14	19 ± 16	21 ± 14
$R_c > 0.93$	all	157	53	63	48
	(+-)	110	34	40	34
	(++)	40	14	15	8
	(--)	7	5	8	6
	Signal	77 ± 19	17 ± 12	18 ± 13	20 ± 10
$m_{eT} > 0.145\text{GeV}$	all	134	46	56	39
	(+-)	98	30	36	30
	(++)	31	12	15	7
	(--)	5	4	5	2
	Signal	73 ± 17	16 ± 11	19 ± 12	23 ± 9
$p_J < 1.3\text{GeV}$ with half angle cone size of 25 deg	all	59	19	26	16
	(+-)	54	16	22	16
	(++)	5	2	3	0
	(--)	0	1	1	0
	Signal	54 ± 7	13 ± 6	19 ± 7	16 ± 4
Minimum thickness of material traversed in shower counters by track	all	57	16	26	16
	(+-)	53	14	22	16
	(++)	4	2	3	0
	(--)	0	0	1	0
	Signal	53 ± 7	14 ± 4	19 ± 7	16 ± 4

Table 2

List of Final Cuts on Electron Pair Candidates.

Cut	Cut Efficiency
Δxy and Δz	>0.90 with a 90% confidence level
m_{eT}	>0.91 with a 90% confidence level
R_e	>0.87 with a 90% confidence level
$\frac{c}{c+d}$	>0.79 with a 90% confidence level
Depth	>0.96 with a 90% confidence level
α	0.93 ± 0.06
p_J	0.77 ± 0.08

Efficiency of Cuts.

Table 3

Fig. 1

Some processes contributing to lepton-pair production in hadronic collisions.

Back Lead Glass

Strip Chamber

Front Lead Glass

B Counters

Drift Chambers

A Counters

Magnet Yoke

**Superconducting
Coil**

Fig. 4 Distribution of R_c (defined in the text) for all electron candidates.

Fig. 5. Distribution of $\alpha(1.5 < \theta < 2.5)$ for all electron candidates.

Fig. 6

Distribution of m_{eT} (defined in the text) for all electron candidates.

Fig. 7

The cross-section $d^2\sigma/dm dyl_{y=0}$ obtained in this experiment and others (R110 Previous [4], R108 [12], R806 [13], R209 [14]) at $\sqrt{s} = 62.3 \text{ GeV}$

Fig. 8

The cross-section $\frac{d^2\sigma}{dm dyl_{y=0}}$ obtained in this experiment compared with the theoretical predictions of ref. 3, using the structure functions of Duke

Fig. 9

The dependence of the K-factor (defined in the text) as a function of

Fig. 10

The scaling quantity $s \frac{d^2\sigma}{d\sqrt{\tau} dyl_{y=0}}$ obtained in this experiment at $\sqrt{s} =$

Fig. 11

The acceptance corrected distribution of the transverse momentum of electron pairs with masses greater than $11 \text{ GeV}/c^2$. Also shown are the

Fig 12

The mean transverse momentum of lepton pairs produced in pp collisions plotted as a function of $\sqrt{s}$. Also shown are the results from CFS [10]

Fig. 13

Mean associated multiplicity as a function of the transverse momentum of

Fig. 14

Mean associated multiplicity as a function of the invariant mass of the

Fig. 15

The mean multiplicity as a function of Φ (defined in the text)

(a) for electron pairs with $p_T < 2 \text{ GeV}/c$.

Fig. 16

The net transverse momentum of the system of associated particles versus

Fig. 17

The mean value of the transverse momentum of the system of associated

Fig. 18

The mean value of the jet transverse momentum projected in a direction