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A STUDY OF ASSOCIATED PARTICLES AND SECOND-ORDER PROCESSES IN ELECTRON–PAIR PRODUCTION AT THE CERN INTERSECTING STORAGE RINGS

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ABSTRACT

The multiplicity of particles associated with electron pairs with mass greater than 11 GeV/c^2 is found to increase with the transverse momentum p_T of the electron pair. The associated particles are observed to recoil against the electron pair and compensate locally its transverse momentum. The data are compared with lower $\sqrt{s}$ dimuon data using the scaling form: $s^2p_T^2(d^3\sigma/dm^2dydp_T^2) = H(x_T, y, \tau)$.

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There is increasing evidence that the simple Drell–Yan annihilation process [1] (fig. 1a) is insufficient to describe the properties of lepton pairs produced in hadronic collisions. The cross-sections predicted using the Drell–Yan formalism and structure functions obtained from deep inelastic scattering are a factor of 2 to 3 lower than the data [2] (the so-called K factor). The lepton pairs are also produced with a mean transverse momentum $\langle p_T \rangle$ that is larger [3,4] than can be understood in terms of transverse motion of the initial-state partons ($\sim$ 1 GeV/c). Furthermore, $\langle p_T \rangle$ is observed to increase approximately linearly with $\sqrt{s}$, the centre-of-mass energy of the collision. These effects have been interpreted [5] 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.

The preceding letter [6] has described the analysis of data obtained in pp collisions at $\sqrt{s}$ = 62.3 GeV at the CERN Intersecting Storage Rings (ISR) leading to the observation of 63 electron pairs of mass greater than 11 GeV/c^2, with an estimated background of 5 events. The mean transverse momentum of the electron pairs was indeed found to be large, $\langle p_T \rangle = 2.50 \pm 0.25$ GeV/c, again implying the existence of higher order diagrams. This letter describes a study of the particles associated with these events.

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 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^0's was $-0.6 < y < +0.6$ over the lead-glass acceptance ($\Delta\phi = 114°$) and $-1.1 < y < +1.1$ over the shower-counter acceptance ($\Delta\phi = 200°$). 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, N_{ee}, is seen to increase as a function of the transverse momentum of the electron pairs (fig. 2), as already observed at the ISR in conjunction with muon pairs [7]. Also shown in fig. 2 is the mean multiplicity, N_c, associated with a single charged particle obtained with a minimum-bias trigger in the same detector and with the same cuts on the associated particles. Whereas the electron pairs were obtained at $\sqrt{s}$ = 62.3 GeV, minimum-bias data collected at $\sqrt{s}$ = 52.7 GeV were used to account approximately for the 11 GeV of available energy taken by the electron pair. The figure shows that N_{ee} and N_c are very similar except below transverse momenta of 1 GeV/c where N_{ee} is lower than N_c.

The resultant momentum, $\vec{p}_j$, of the associated particles was formed by adding their momenta vectorially. The difference in azimuth, $\delta\phi$, between $\vec{p}_j$ and the momentum of the electron pair was found. The distribution of $\delta\phi$ is shown in fig. 3a for electron pairs with transverse momentum less than 1 GeV/c and in fig. 3b for electron pairs with transverse momentum greater than 1 GeV/c. Whereas for $p_T < 1$ GeV/c there is no azimuthal correlation between the two vectors, for $p_T \geq$ 1 GeV/c the system of associated particles is produced predominantly at large $\delta\phi$, that is back-to-back with the electron pair.

The transverse momentum correlations between the electron pair and the associated particles were examined for events in which $\delta\phi > 135°$. A two-dimensional plot of p_T of the electron pair versus p_{JT}, the transverse momentum of the system of associated particles, is shown in fig. 4. A correlation between these two variables is observed. The mean electron pair p_T of this sample of events is 2.7 GeV/c (no acceptance correction has been applied), while the total transverse momentum of these events (electron pair + associated particles) has a mean of 1.7 GeV/c. These two features taken together indicate a local compensation of the transverse momentum of the electron pair in the central region.

If the above effects are indeed due to higher order diagrams, then it is expected that the Drell-Yan form discussed in the previous letter be modified. The form of the cross-section in a region where second-order effects dominate becomes:

$$d^3\sigma/dm^2dp_T^2dy = (1/s^2p_T^2)\,H(x_T,y,\tau) \ ,$$

where m, p_T, and y are, respectively, the mass, transverse momentum, and rapidity of the electron pair, $\tau = m^2/s$ and $x_T = 2\,p_T/\sqrt{s}$. At a given τ and y the quantity $s^2p_T^2\,(d^3\sigma/dm^2dp_T^2dy)$ is then expected to be a function of x_T only, irrespective of $\sqrt{s}$. A plot of this quantity is shown in fig. 5 for the events in the range $11 < m < 15$ GeV/c^2 (mean $\sqrt{\tau}$ of 0.19). The data of the CFS Collaboration [3] in the mass interval 5 to 6 GeV/c^2 and at $\sqrt{s} = 27.4$ GeV are also shown in the figure. The shape of the two distributions is similar, but the data of this publication are lower than the CFS data. As discussed in ref. [6], the requirement of little energy in the vicinity of the electron candidates could result in an underestimate of the cross-sections measured in this experiment.

In conclusion:

a) The multiplicity of particles associated with electron pairs is found to increase with p_T.

b) This multiplicity is similar to that associated with single charged particles except for $p_T <$ 1 GeV/c where it is lower.

c) Above 1 GeV/c the associated particle system is observed to be produced predominantly opposite in azimuth to the electron pair.

d) A correlation between the transverse momentum of the electron pair and that of the associated particle system is observed.

These effects are consistent with second-order diagrams involving the production of a recoil jet becoming important at transverse momenta greater than 1 GeV/c.

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REFERENCES

[1] S. Drell and T.M. Yan, Phys. Rev. Lett. **25** (1970) 316.

[2] J. Badier et al., Phys. Lett. **89B** (1979) 145.
J. Badier et al., preprint CERN EP/84-16.
B. Betev et al., preprint CERN EP/83-153.

[3] A.S. Ito et al., Phys. Rev. **D23** (1981) 604.

[4] A.L.S. Angelis et al., Phys. Lett. **87B** (1979) 398.
D. Antreasyan et al., Phys. Rev. Lett. **45** (1980) 863.

[5] H. Fritzsch et al., Phys. Lett. **73B** (1978) 80.
G. Altarelli et al., Phys. Lett. **76B** (1978) 351.
G. Altarelli et al., Phys. Lett. **76B** (1978) 356.
F. Halzen et al., Phys. Rev. Lett. **40** (1978) 1117.
K. Kinoshita et al., Properties of large p_T jets in massive lepton-pair production, KYUSHU-78-HE-12.
K. Kajantie, Nucl. Phys. **B139** (1978) 72.
See also the Review Talk by E. Berger, Hadronic production of massive lepton pairs at the 1982 Fermilab Workshop on Drell-Yan Processes, ANL-HEP-CP-82-72.

[6] A.L.S. Angelis et al., preceding letter.

[7] D. Antreasyan et al., Nucl. Phys. **199B** (1982) 365.

Figure captions

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

Fig. 2 Associated multiplicity as a function of p_T for electron pairs (solid circles) and for single charged hadrons (open circles).

Fig. 3 The distribution in $\delta\phi$ (defined in the text)
a) for electron pairs with $p_T < 1$ GeV/c.
b) for electron pairs with $p_T \geq 1$ GeV/c.

Fig. 4 The transverse momentum of the electron pair versus the net transverse momentum of the system of associated particles for events with $\delta\phi > 135°$.

Fig. 5 The quantity $s^2 p_T^2 (d^3\sigma/dm^2 dp_T^2 dy)|_{y=0}$ as a function of x_T $(= 2\,p_T/\sqrt{s})$.

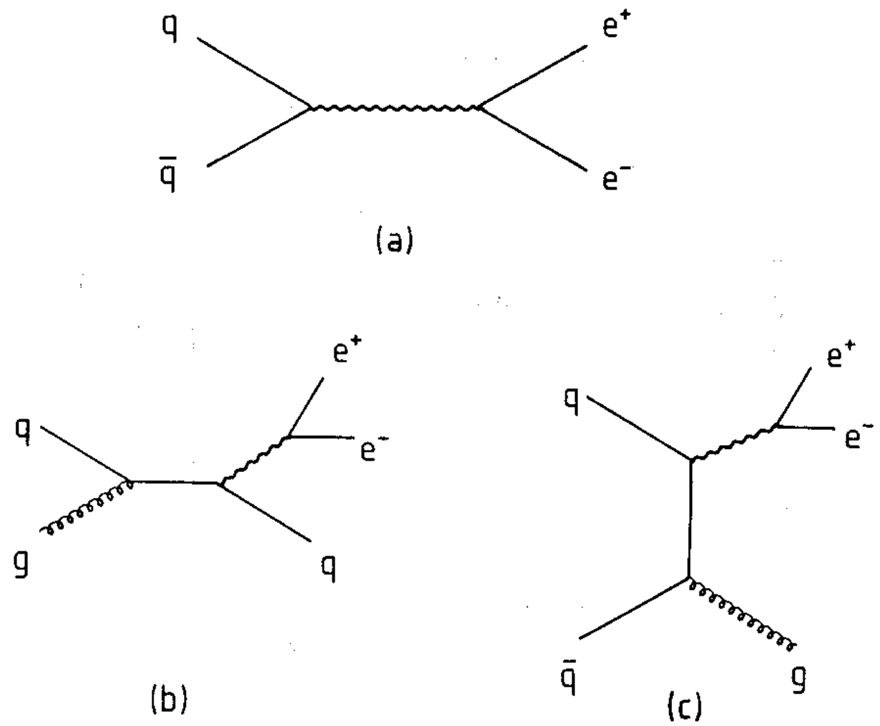

q
e+
q̄
e−
(a)
q
e+
e−
g
q
(b)
q
e+
e−
q̄
g
(c)

Fig. 1

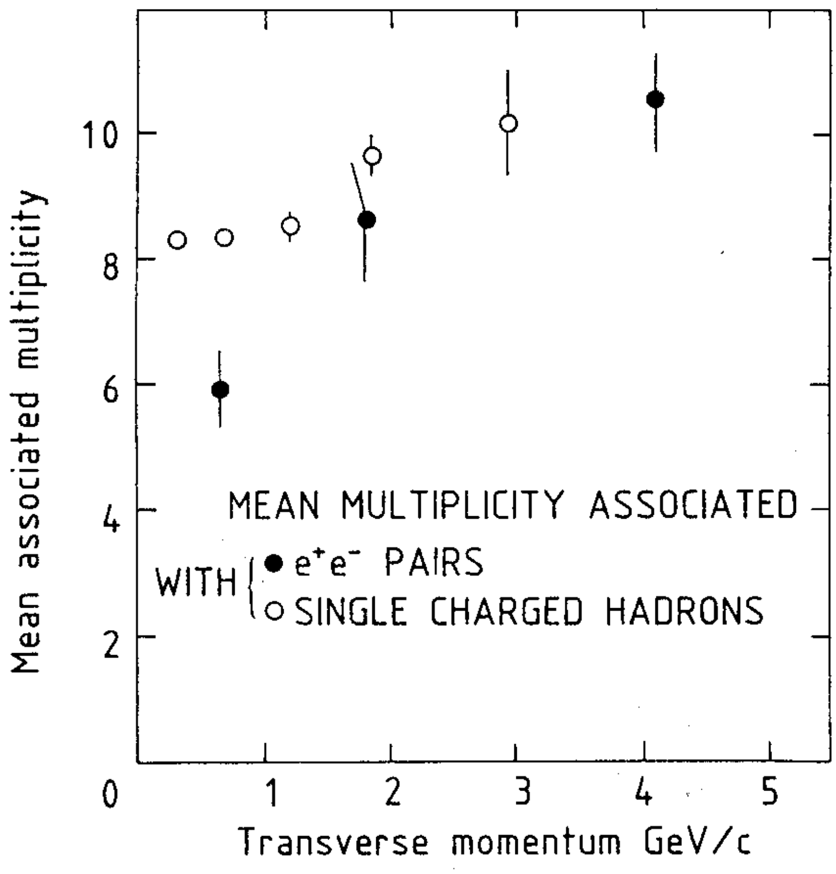
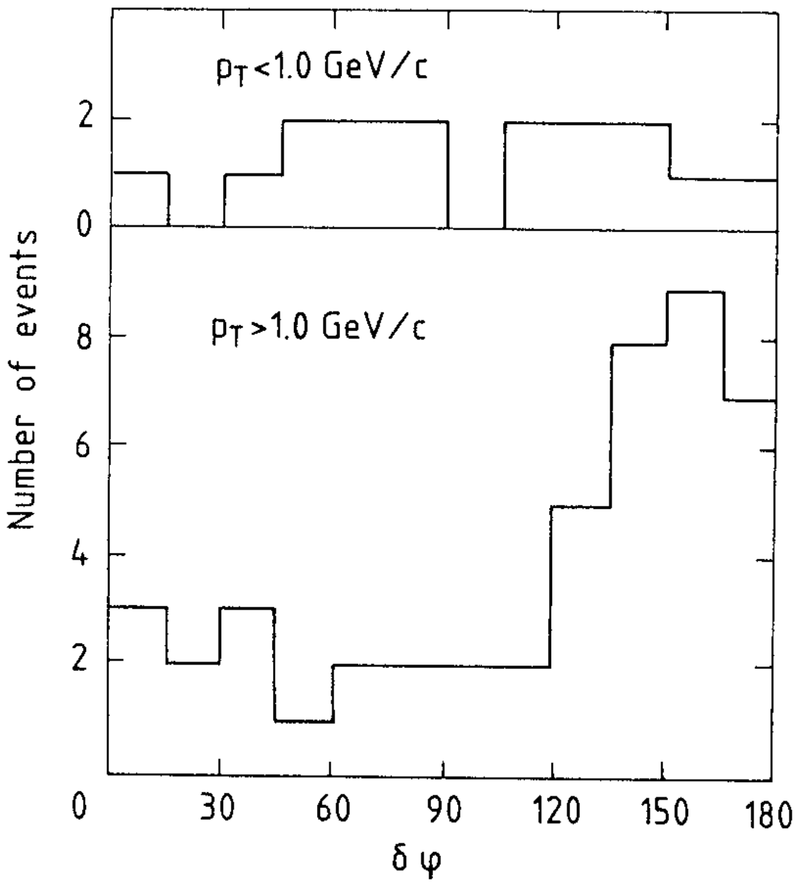
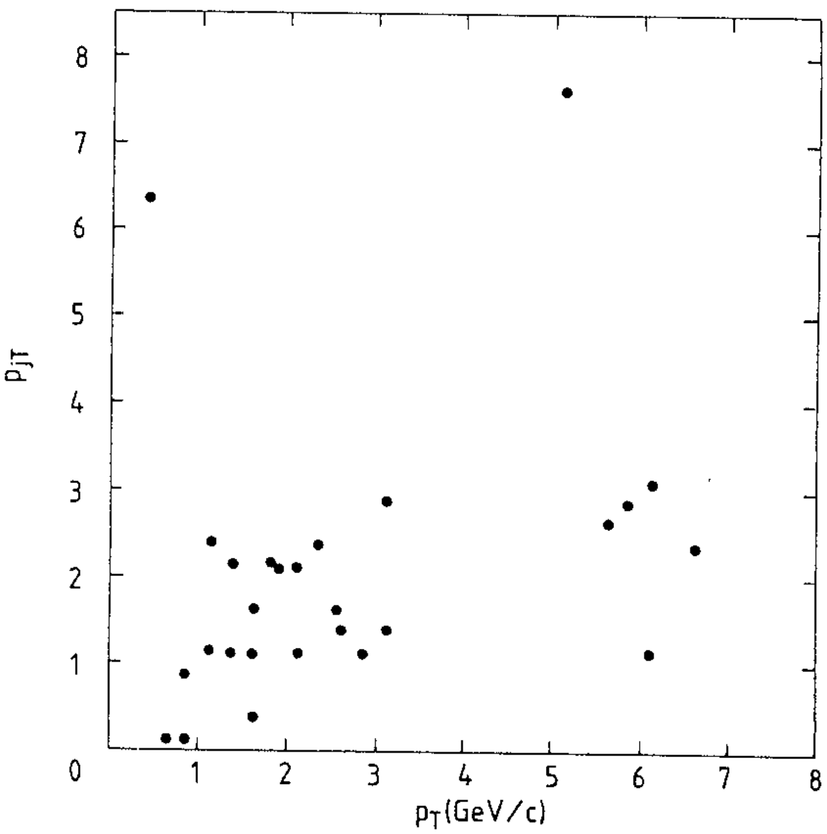

Mean associated multiplicity
Transverse momentum GeV/c
0
1
2
3
4
5
2
4
6
8
10
MEAN MULTIPLICITY ASSOCIATED
WITH
● e+e− PAIRS
○ SINGLE CHARGED HADRONS

Fig. 2



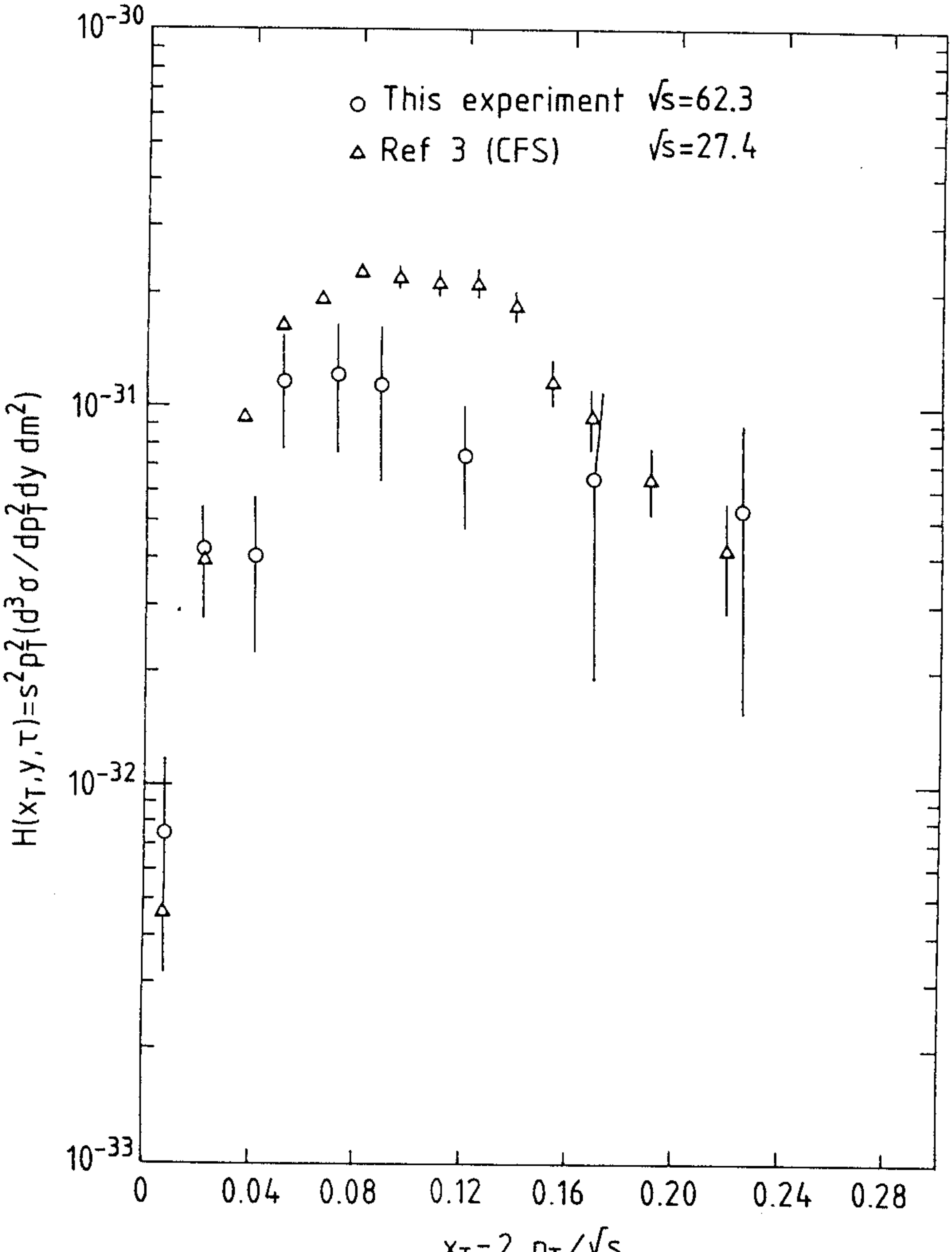
p_T<1.0 GeV/c
p_T>1.0 GeV/c
Number of events
0
2
4
6
8
0
2
0
30
60
90
120
150
180
δ φ

Fig. 3



p_{jT}
0
1
2
3
4
5
6
7
8
1
2
3
4
5
6
7
8
p_T(GeV/c)

Fig. 4



○ This experiment √s=62.3
△ Ref 3 (CFS) √s=27.4
10^-30
10^-31
10^-32
10^-33
H(x_T, y, τ)=s^2 p_T^2 (d^3σ/dp_T^2 dy dm^2)
0
0.04
0.08
0.12
0.16
0.20
0.24
0.28
x_T = 2 p_T/√s

Fig. 5