INCLUSIVE CHARGED PARTICLE PRODUCTION NEAR THE KINEMATIC LIMIT IN e^+e^- ANNIHILATION AT 29 GeV

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Received 17 September 1985

Inclusive production of charged particles has been studied in e^+e^- annihilation at $\sqrt{s} = 29$ GeV using the high resolution spectrometer at PEP. Differential cross sections are presented in the range of scaled energy $0.1 < z < 1.0$. The data for $z > 0.5$ show the $(1-z)^2$ behavior predicted by the dimensional counting rules. Comparisons are made with predictions of the Lund string model and the Webber cluster model.

This paper presents results on charged particle cross sections as a function of the energy fraction z ($z = 2E/\sqrt{s}$) from e^+e^- annihilation at $\sqrt{s} = 29$ GeV. The data were collected in the first three years of operation of the high resolution spectrometer (HRS) at the PEP storage rings and correspond to an integrated luminosity of 185 pb^{-1}. The excellent momentum resolution of the HRS, together with the large data sample, allows for the first time an accurate measurement of these cross sections up to the kinematic limit.

The gross features of hadronic annihilation in e^+e^- collisions are well understood in the context of QCD, which describes the process as proceeding through an intermediate state of quarks and gluons. The transi-

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0370-2693/85/$ 03.30

tion from this partonic intermediate state to the observed particles is less well understood and must be parametrized by using data. There are some regions of the kinematics that are sensitive to the underlying mechanisms and so independent of the details of the hadronization. For example, dimensional counting rules [1] predict that, for values of Q^2 large compared to the final-state masses, cross sections are dependent only on the number of partons in the initial and final state.

For e^+e^- annihilation in particular, this means that the transition from quark to meson will result in an invariant energy distribution for the meson which falls as $(1-z)^2$, where z is the energy of the meson scaled by the energy of the quark from which it originates. One thus expects that for meson energies near the upper kinematic limit, where first-rank quark-to-meson transitions dominate, that the invariant, inclusive meson cross section should exhibit this $(1-z)^2$ behavior, where now z is the ratio of the meson energy to the beam energy [2]. For lower meson energies, the dependence on z should become steeper due to the effects of gluon radiation, vector meson production and decay, and higher-rank fragmentation.

Berger [3] has argued that at intermediate Q^2 the dimensional counting prediction should be modified to $(1-z)^2 + C/Q^2$ due to the presence of higher-twist effects. Here the constant C is related to the transverse momentum squared of the produced meson with respect to the initial quark direction and is expected to be of the order 0.5 GeV^2.

There are a number of models which attempt to describe the full evolution from the partonic intermediate state to the hadronic final state [‡1]. In one successful model, the Lund string model [5], the initial-state partons are assumed to create a string-like force field which breaks up by the polarization of the vacuum. In a second class of model such as that of Weber and Marchessini [6], the partonic state is allowed to evolve according to QCD to low Q^2 values. At this point, colorless hadronic clusters are formed, which subsequently decay into two final-state hadrons.

In order to measure the invariant cross sections and to compare to the predictions of these models, an hadronic data set was selected in the HRS detector [7] using both tracking and calorimeter information.

[‡1] See ref. [4] for a recent review.

The main features of the HRS relevant to the present analysis include tracking of charged particles in a 15-layer drift chamber which extends in radius from 0.2 to 1.1 m. A two-layer outer drift chamber provides additional position measurements at a radius of 1.96 m. The intrinsic resolution of the chambers of 200 μm, together with the 1.62 T magnetic field, yield a momentum resolution of $\sigma(p)/p = 0.002\, p$ (GeV). The tracking volume is surrounded by lead-scintillator shower detectors with a typical energy resolution of $\sigma(E)/E = 0.16/\sqrt{E}$.

Hadronic events were selected by requiring that the sum of the visible charged momentum and shower energy in the calorimeters be greater than 10 GeV and that the charged multiplicity be greater than 4. These cuts effectively removed events of Bhabha scattering and muon-pair production, and all but a small fraction of tau-pair events. To obtain the maximal possible resolution all tracks were required to be measured in at least one of the outer drift chamber layers. This restricts the solid angle to the central region of the detector. To remove fake tracks, the pattern of hits in the drift chambers was required to have no gap of greater than three layers and to have at least 10 digitizations. The extrapolation of the track to the barrel shower counter was required to be away from the edge of individual modules, to allow for an accurate measurement of the energy deposition. No track was allowed to have a signature in the shower counter system consistent with an electron, and as a further rejection of two-photon annihilation events and higher-order QED events, all events which had two tracks with a momentum greater than 10 GeV were removed. The remaining background from sources other than hadronic annihilation in the z range greater than 0.9 is estimated to be less than 0.1 track compared to a signal of 21 tracks.

The acceptance for tracks subjected to the above cuts was determined by a Monte Carlo technique. The generated tracks were subject to the selections listed above, but the exact momentum was used. The acceptance was found to rise linearly from 18% at $z = 0.1$ to 30% at $z = 0.6$ at which value it remains constant up to the kinematic limit. The purely geometrical acceptance is 39%. The lower efficiency at low z is mainly due to the fact that overlapping tracks in this region fail the gap criterion.

The resulting scaling cross section $(s/\beta)\, d\sigma/dz$ is

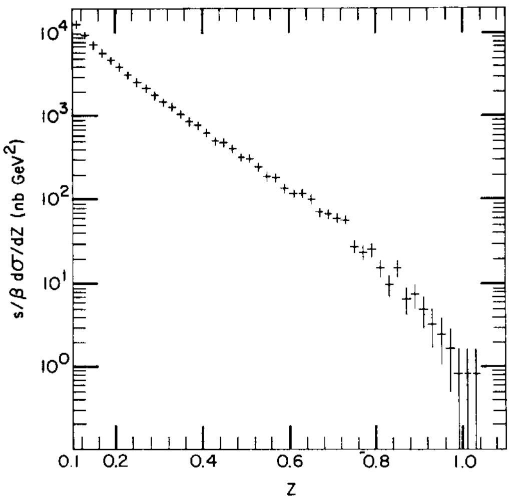

Fig. 1. Inclusive differential cross section of charged particles as a function of z.

shown in fig. 1. We use $\sqrt{s} = 28.3$ GeV as the acceptance corrected value of the mean center of mass energy after initial-state radiation. The measurements extend to $z = 1$ with reasonable statistical accuracy; in fact there are only two tracks which exceed the kinematic limit and these are within the range expected from the resolution of the detector. The events with tracks at large z were individually scanned, and the jet

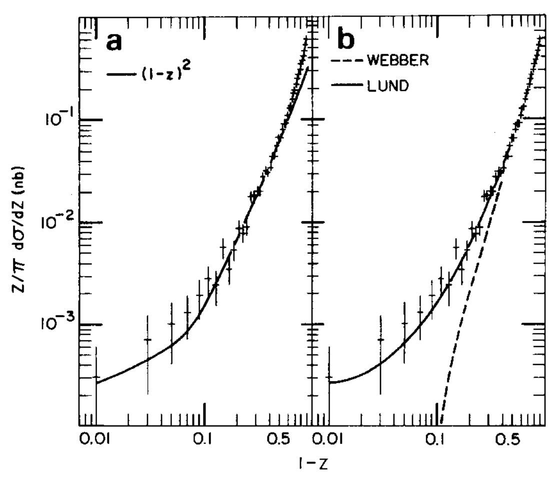

Fig. 2. (a) Invariant differential cross section of charged particles as a function of $1 - z$ together with the prediction from dimensional counting. (b) Invariant differential cross section of charged particles as a function of $1 - z$, together with the predictions from the Lund Monte Carlo (full line) and the Webber Monte Carlo (dashed line).

opposite to the high momentum track was found to be consistent in all respects with normal fragmentation.

Fig. 2 shows the invariant cross section $F(z) = (z/\pi)\, d\sigma/dz$ as a function of $(1 - z)$, together with the predictions from dimensional counting (fig. 2a); the Lund Monte Carlo (full line in fig. 2b), and the Webber Monte Carlo (dashed line in fig. 2b). The predictions have been corrected for initial-state radiation and have been smeared with a gaussian resolution function with width consistent with the resolution of the detector. The flattening for $z > 0.9$ results from the resolution smearing.

In the prediction from dimensional counting, only first-rank meson production is considered, both pseudoscalar and vector. The vector meson production is generated according to our measurements [8]. The curve has been normalized to the data between $0.5 < z < 0.6$, and the prediction is seen to agree well with the data at larger z. The data exhibit the expected steepening at lower values of z where they lie above the curve since the contributions from higher-rank fragmentation are not included in the calculation. If the data are fitted to the form $(1 - z)^n$ for $z > 0.5$, then a value of $n = 2.08 \pm 0.21$ is obtained.

The predictions of the Lund Monte Carlo program also agree very well with the data over the full range in z covered by this experiment. By contrast, the Webber calculation falls below the data at values of z above 0.7, although in the lower z range, the agreement is excellent. Clearly the cluster algorithm is inadequate at the extremes of the phase space. A similar result is found from the Gottschalk cluster Monte Carlo program [‡2].

The statistical accuracy of the experiment precludes a sensitive investigation of possible higher twist effects. The data give an upper limit of 2.0 GeV^2 at 90% CL for the parameter C.

In conclusion we have measured inclusive charged-particle production up to the kinematic limit and have compared it with the predictions of several models. The z dependence near the kinematic limit is predicted well by dimensional counting and the Lund MC; the cluster models, however, predict too small a rate at the very highest z values.

[‡2] See fig. 48 of ref. [4].

This work was supported by the US Department of Energy. We thank the technical staff of PEP for providing the luminosity on which this data is based.

References

[1] See, e.g. D. Sivers, Annu. Rev. Nucl. Part. Sci. 32 (1982) 149.
[2] G.R. Farrar and D.R. Jackson, Phys. Rev. Lett. 35 (1975) 1416.
[3] E.L. Berger, Z. Phys. C4 (1980) 289.
[4] M. Derrick and T. Gottschalk, Report of the Snowmass Hadronization Group, in: Proc. 1984 Summer Study on the Design and utilization of the Superconducting Super Collider (Snowmass, CO, June–July 1984) p. 49.
[5] B. Andersson et al., Phys. Rep. 97 (1983) 32.
[6] B.R. Webber, Nucl. Phys. B238 (1984) 492; G. Marchessini and B.R. Webber, Nucl. Phys. B238 (1984) 1.
[7] D. Bender et al., Phys. Rev. D30 (1984) 515.
[8] M. Derrick et al., Phys. Lett. 158B (1985) 519.