INCLUSIVE HADRON PRODUCTION BY e^+e^- ANNIHILATION FOR s BETWEEN 13 AND 25 GeV^2

DASP Collaboration

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Charged hadron production via $e^+e^- \to h^\pm X$ where $h^\pm = \pi^\pm, K^\pm, \bar{p}$ has been measured for s values between 13 and 25 GeV^2. Inclusive cross sections and the evidence for scaling are presented.

One of the basic properties of electron hadron scattering is the almost perfect scale invariance exhibited by the structure functions in the deep inelastic region. Inclusive hadron production in e^+e^- annihilation is expected to possess similar properties. First measurements on this subject were carried out by the SLAC-LBL collaboration who observed approximate scaling of the sum over all charged hadrons produced [1], but scale invariance was not tested separately for each particle species. In this paper we present inclusive spectra for $\pi^\pm$, $K^\pm$ and $\bar{p}$ production and test scaling for values of the cms energy squared, s, between 13 and 25 GeV^2.

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The experiment was done at the DESY storage ring DORIS using the double-arm spectrometer DASP, Details of the apparatus and the analysis procedure can be found in ref. [2], where results on hadron spectra from J/ψ and ψ' decays were presented. The spectrometer allows the separation of e, μ, π, K and p by means of iron absorbers, shower, time-of-flight and Cerenkov counters. The time-of-flight measurement separates pions from kaons up to 1.6 GeV/c, protons (antiprotons) from pions and kaons up to 3 GeV/c. The Cerenkov and shower counters serve to identify electrons (see ref. [3]). The Cerenkov thresholds for pions and kaons are 2.8 and 10 GeV/c, respectively, well above the momenta considered here. The Cerenkov counter information is particularly important in rejecting electrons at low momenta ($p \lesssim 0.5$ GeV/c) where the shower counter pulse height spectra from electrons and hadrons start to overlap.

Below some minimum momentum particles are swept out of the acceptance by the spectrometer magnets. In order to have good acceptance at low momenta the magnets were run at one third and one fifth of the maximum current, leading to a minimum accepted momentum of 0.25 GeV/c and 0.15 GeV/c, respectively. With these settings the rms momentum resolution was approximately $\Delta p/p \simeq \pm 2\% \cdot p$ (GeV/c) and $\pm 3\% \cdot p$ respectively. The minimum momentum to trigger the detector was 0.14 GeV/c for a pion, 0.28 GeV/c for a kaon, and 0.45 GeV/c for a proton (antiproton).

A genuine inclusive trigger was employed to take these data: besides a charged particle in one of the spectrometer arms no other requirement was imposed on the final state.

The luminosity was determined from Bhabha scattering at a mean angle of 8° measured concurrently with the inclusive data.

Data were taken at cms energies between 3.6 and 5 GeV. They were grouped into five intervals: 3.60–3.67 (583 nb^{-1}); 3.99–4.10 (1155 nb^{-1}); 4.36–4.44 (652 nb^{-1}); 4.10–4.36 plus 4.44–4.8 GeV (1152 nb^{-1}) and 5 GeV (1183 nb^{-1}). The numbers in brackets give the integrated luminosity for which data were collected at each energy region. The second and third intervals are centered at the structures seen in the total cross section at 4.05 and 4.4 GeV [1,4,5].

A total of 8500 $\pi^{\pm}$, 650 $K^{\pm}$, and 100 $\bar{p}$ were used for this analysis. Since the majority of the protons was due to beam gas interactions only antiprotons were considered. The proton yield was assumed to be the same as for antiprotons. Cross sections were determined following the procedure described in ref. [2]. A restricted angular acceptance was used which covered typically polar angles between $\cos\theta = -0.55$ and 0.55. Corrections were applied for nuclear absorption, for π and K decays in flight and for tracks failing the geometrical reconstruction. Inefficiencies due to cuts in the shower energy the time-of-flight and the requirement that the Cerenkov counter had not fired were taken into account. The beam gas background, importamt in the case of pions, was extrapolated into the interaction region and was subtracted for each momentum interval. Radiative corrections were applied. They amounted to −15% at 3.6 GeV, −5% at 4.05 GeV and −8% at higher energies.

The systematic uncertainty in the overall normalization is estimated to be ±10%. The errors shown below for the cross section data do not include this uncertainty; they are purely statistical.

The differential cross section for inclusive hadron production,

$$e^+e^- \to h^{\pm} X \qquad (1)$$

has the general form [6]

$$\frac{d^2\sigma}{dx\, d\Omega} = \frac{\alpha^2}{s} \beta x \{ m\bar{W}_1 + \tfrac{1}{4}\beta^2 x\, \nu \bar{W}_2 \sin^2\theta \} \qquad (2)$$

where α is the fine structure constant, $\alpha = 1/137$, m is the mass of h which in the overall cm system has four momentum $p = (\boldsymbol{p}, E)$, velocity $\beta = |\boldsymbol{p}|/E$, fractional energy $x = 2E/\sqrt{s}$ and production angle θ measured with respect to the incoming beam. Denoting by q the four momentum of the virtual photon, $q = p_{e^+} + p_{e^-}$, the energy of the photon in the h rest system is given by

$$\nu = \frac{q \cdot p}{m} = \frac{E}{m}\sqrt{s}.$$

The structure functions $\bar{W}_1$ and $\bar{W}_2$ depend on the variables s and ν. The second term in eq. (2) vanishes if the contributions from transverse and longitudinal photons (as seen in the rest frame of h) are equal and is negative if the transverse part dominates.

We have fitted the angular distributions to the form $1 + a\cos^2\theta$ determining a as a function of particle momentum and of s. The data for $p < 1.5$ GeV/c are compatible with $a = 0$ but also with $a = 1$. We have assumed $a = 0$ in extrapolating the angular distribution to $\cos\theta = \pm 1$ in order to integrate the differential cross section over $\cos\theta$. For a value of $a = 1$ the cross sections would have to be increased by 24% ‡.

Neglecting the second term in eq. (2) leads to

$$\frac{d\sigma}{dx} = \frac{4\pi\alpha^2}{s} \beta x\, m\bar{W}_1(s, \nu). \qquad (3)$$

If $\bar{W}_1(s, \nu)$ is scale invariant the structure function de-

‡ The SLAC-LBL collaboration has determined a summing over all hadrons [1]. Their data indicate for $\sqrt{s} < 4.8$ GeV $a \approx 0.2$ for $0.5 < p < 1$ GeV/c and $a \approx 0.5$ for $1 < p < 1.5$ GeV/c. These a values would increase our cross sections by 5% for $x \lesssim 0.5$ and by 13% above.

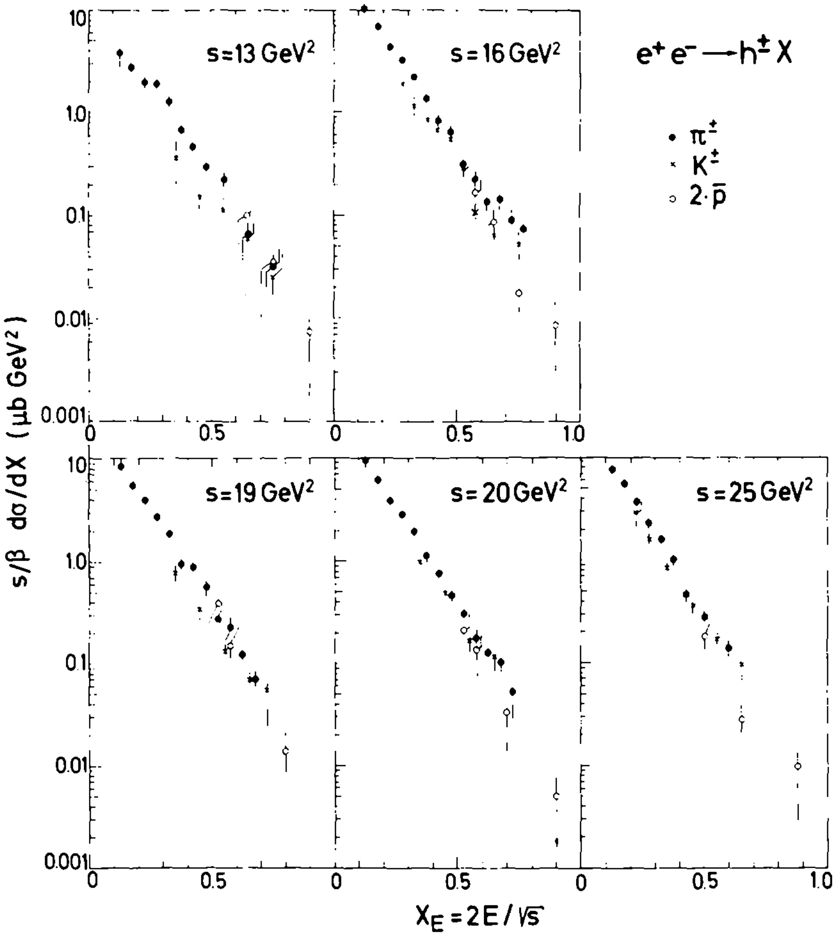
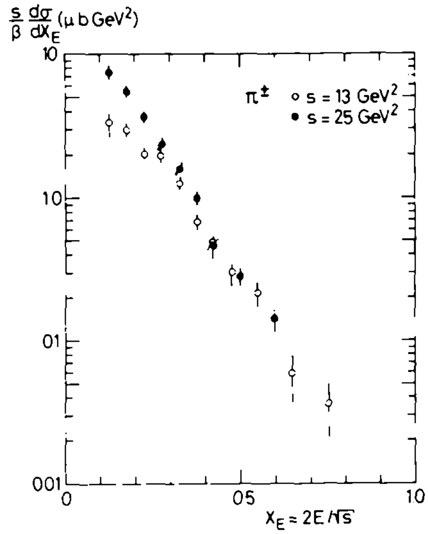


Fig. 1. The cross section $(s/\beta)\, d\sigma/dx$, $x \equiv x_E = 2E/\sqrt{s}$, versus x for the sum of π^+ and π^-, K^+ and twice the $\bar{p}$ yield for s values between 13 and 25 GeV^2.



pends only on the ratio ν/s or $x = 2m\nu/s$ so that $s\, d\sigma/\beta\, dx \sim x\bar{W}_1$ is a function of x alone.

Fig. 1 shows the x dependence of $s\, d\sigma/\beta\, dx$ for $\pi^\pm$ (i.e. sum of π^+ and π^-), $K^\pm$ and twice the $\bar{p}$ production as measured in the five energy intervals. The π, K and $\bar{p}$ cross sections for $x \gtrsim 0.2$ decrease nearly exponentially. Moreover, with increasing energy $\sqrt{s}$, and increasing x the cross sections for the three particle species become more and more alike. The $\bar{p}$ data, within large errors, do not show any significant change with s, i.e. they appear to scale.

In order to test the pion data for scaling we compare in fig. 2 the π cross sections at the "non-resonant"

Fig. 2. Comparison of the cross section $(s/\beta)\, d\sigma/dx$ versus x for $\pi^\pm$ at $s = 13$ and 25 GeV^2.

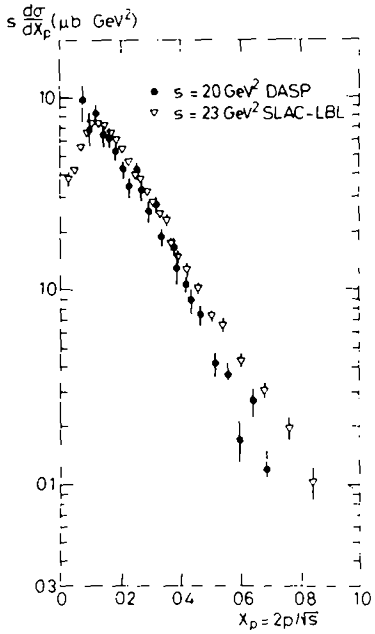


Fig. 3. The cross section $s\,d\sigma/dx_p$, $x_p = 2p/\sqrt{s}$, summed over all charged hadrons, versus x_p as measured in this experiment at $\sqrt{s} = 4.5$ GeV and by SLAC-LBL at $\sqrt{s} = 4.8$ GeV (ref. [1]).

energies $s = 13$ and 25 GeV^2. Below $x \approx 0.25$ the cross section rises by a factor of 1.5 to 2 between $s = 13$ and 25 GeV^2. At higher x values the two cross section sets agree within errors.

It is worth noting that the ratio of the total cross section to μ-pair cross section, $R = \sigma^{tot}/\sigma_{\mu\mu} \sim s\sigma^{tot}$ rises from 2.5 at $s = 13$ GeV^2 to 4 or 5 above $s = 16$ GeV^2 (refs. [4,5]). Fig. 2 indicates that the increase in R comes mainly from low x particles.

The SLAC-LBL collaboration has already measured inclusive particle production in this energy range [1]. Since they did not separate particles they used instead of $x = x_E = 2E/\sqrt{s}$ the variable $x_p = 2P/\sqrt{s}$ to analyze inclusive hadron production.

In fig. 3 the data obtained as a function of x_p by SLAC-LBL at $s = 23$ GeV^2 are compared to ours at 20 GeV^2. Our data are also summed over all charged hadrons. For $x_p \lesssim 0.5$ the data sets agree well. For $x_p > 0.5$ the two measurements start to diverge; the cross sections of this experiment are smaller than those of SLAC-LBL. The same trend is observed when the data at $s = 25$ GeV^2 are used for comparison with SLAC-LBL. The fact that we used $a = 0$ to integrate over the angular distribution can only account for a part of the discrepancy (see above). Systematic errors in the high x_p region are estimated by SLAC-LBL to be be $\lesssim 20\%$ [1].

In fig. 4 $(s/\beta)\,d\sigma/dx$ is plotted for $\pi^\pm$ and K$^\pm$ as a function of s for fixed x. A large increase in the π cross section at $s = 16$ GeV^2 is most prominent for $x < 0.4$. The π cross sections at $s = 13$ and 25 GeV^2 for $x \gtrsim 0.4$ are equal within errors. The K cross sec-

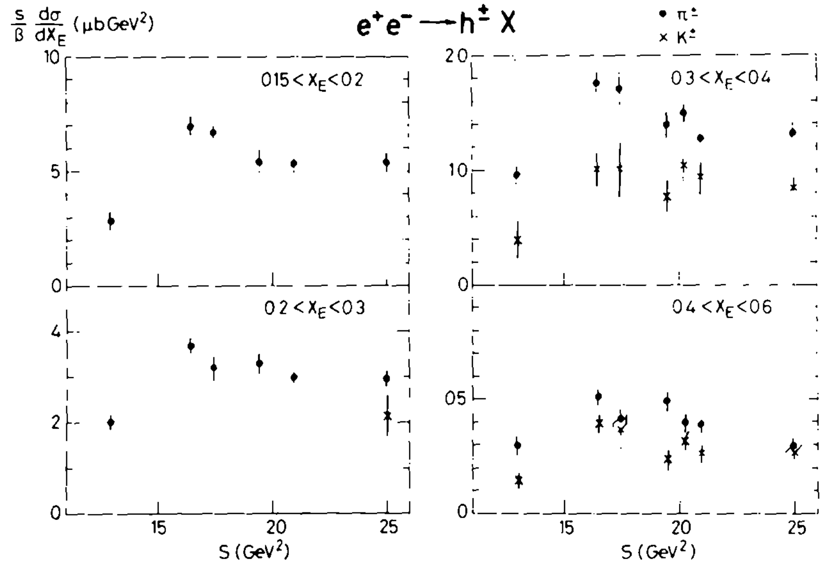


Fig. 4. The cross section $(s/\beta)\,d\sigma/dx$ versus s for fixed x intervals for $\pi^\pm$ and K$^\pm$ production.

tions increase by a factor of two or three from $s = 13$ to $s = 16\ \mathrm{GeV}^2$. In the highest x interval, 0.4 to 0.6, the K cross section becomes the same as the π cross section as s increases.

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