# INCLUSIVE HADRON PRODUCTION IN THE Υ-REGION

H. ALBRECHT, R. CHILDERS[1], C.W. DARDEN[1], G. DREWS, H. HASEMANN, E. McCLIMENT[2], W. SCHMIDT-PARZEFALL, H. SCHRÖDER, H.D. SCHULZ, F. SELONKE, E. STEINMANN and R. WURTH

*Deutsches Elektronen-Synchroton DESY, Hamburg, Germany*

W. HOFMANN, A. MARKEES and D. WEGENER

*Institut für Physik, Universität Dortmund, Germany*

K.R. SCHUBERT, J. STIEWE, R. WALDI and S. WESELER

*Institut für Hochenergiephysik, Universität Heidelberg, Germany*

P. BÖCKMANN and L. JÖNSSON

*Institute of Physics, University of Lund, Sweden*

and

M. DANILOV, Yu. SEMENOV, I. TICHOMIROV and Yu. ZAITSEV

*Institute of Theoretical and Experimental Physics, Moscow, USSR*

Received 30 March 1981

Inclusive production of $\pi^\pm$, $K^\pm$ and $\bar{p}$ has been measured in $e^+e^-$ annihilation for center of mass energies between 9.4 and 10.1 GeV. The hadron yields on the resonances Υ and Υ′ are compared to the off-resonance (continuum) yields with the aim of uncovering differences between three-gluon hadronization and quark–antiquark fragmentation. A noticeable difference is seen in the yield of protons and antiprotons which is (8.1 ± 2.1)% of all charged hadrons for Υ decay and (18.9 ± 6.9)% for Υ′ decay compared to (1.5 ± 1.1)% for non-resonant production.

Single particle inclusive cross sections of charged hadrons produced by $e^+e^-$ annihilations have been measured in a number of experiments [1] over a wide range of the center of mass energy $\sqrt{s}$. One remarkable observation is the almost perfect scaling in $s$ of the cross section $(s/\beta)\,\mathrm{d}\sigma/\mathrm{d}x$ for $x = 2E/\sqrt{s} \gtrsim 0.2$, where $\beta$ is the velocity of the hadron and $E$ its energy. In the quark–parton model approximate scaling is a consequence of the assumed quark–gluon structure.

It is believed that $e^+e^-$ annihilation proceeds via an initial quark–antiquark pair fragmenting into the observed hadrons in the continuum. In contrast, intermediate quarkonium states such as $J/\psi$ or Υ decay predominantly into three gluons which again fragment into hadrons. Hence one might expect to find differences in the particle spectra from quarkonium decay and from non-resonant production. For this reason we have measured inclusive spectra for the production of charged pions, kaons and antiprotons on the resonances Υ(9.46) and Υ′(10.02) and in the near-by continuum,

The data were taken with the double-arm spectrometer DASP at the DESY storage ring DORIS. From the integrated luminosity collected between October 1979 and April 1980 we used 373 $\mathrm{nb}^{-1}$ on the Υ, 471 $\mathrm{nb}^{-1}$ on the Υ′ and 515 $\mathrm{nb}^{-1}$ in the neighbouring continuum regions.

The DASP detector consists of a non-magnetic inner part accepting a solid angle of about 50% of $4\pi$, and a magnetic outer detector covering about 5% of $4\pi$. The

[1] On leave from University of South Caroline, USA.
[2] On leave from University of Iowa, USA.

outer detector, used for this analysis, consists of two identical spectrometer arms equipped with proportional chambers, Čerenkov counters, spark chambers, time-of-flight counters, sandwich shower counters and range counters behind an iron shield. A detailed description of the apparatus can be found in ref. [2].

An inclusive trigger was employed requiring a charged particle in one of the spectrometer arms. A considerable reduction in background, mainly from beam–gas interactions, was achieved by demanding at least one charged track also in the other arm or in the inner detector where in addition a minimum energy deposition of 500 MeV was required. This cut affects the inclusive trigger only slightly. Its efficiency was found to be 98% both for two- and three-jet Monte Carlo events [3] [‡1] run through a simulated detector.

The particles collected by the spectrometer arms were seperated into $e^\pm$, $\mu^\pm$, $\pi^\pm$, $K^\pm$, p and $\bar{p}$. Leptons were identified by exploiting the information of the shower counters, Čerenkov counters and iron absorbers. By means of time-of-flight measurements pions can be discriminated on a 95% confidence level from kaons up to momenta of 1.5 GeV/$c$, and protons (antiprotons) from pions and kaons up to 2.6 GeV/$c$. Most of the hadrons still coming from beam–gas interactions were eliminated by requiring that the reconstructed vertex lies within the interaction volume. This volume was determined from Bhabha scatters measured at the same time. The remaining beam–gas background was extrapolated into the interaction region and subtracted from the final hadron spectra, amounting to $< 11\%$ for pions, $< 5\%$ for kaons, and $< 2\%$ for antiprotons. Since the majority of the protons come from beam–gas interactions, only antiprotons were considered, assuming the proton yield to be the same as the yield for antiprotons.

The remaining hadrons, 1258 pions, 135 kaons and 39 antiprotons, were corrected for $\pi$ and K decays in flight, absorption by the detector material, misidentification of hadrons as leptons and failures in the track reconstruction. A detailed evaluation of these corrections is given in ref. [5]. The momentum dependent acceptance of the spectrometer arms and the efficiencies of the various counters were taken into account. The spectrometer arms cover polar angles between $\cos\theta = -0.5$ and $+0.5$. The extrapolation to the full angular range, which is needed for integrating the inclusive cross sections over $\theta$, was performed by a Monte Carlo calculation. From two-jet Monte Carlo events a momentum independent correction of + 6% was obtained, which we applied to the continuum spectra. For $\Upsilon$ and $\Upsilon'$ decays, simulated by three-jet events, the correction is zero.

Hadrons from $\tau$ decay were subtracted from the spectra by means of Monte Carlo calculations. Radiative corrections were applied [6] amounting to − 4% practically independent of momentum. Most of the low-energy muons from the two-photon process $e^+e^- \to e^+e^-\mu^+\mu^-$ cannot be identified by the range counters. However, we verified that they are rejected by the above selection criteria.

The integrated luminosity was determined from Bhabha scattering measured independently in the inner and outer detector as described previously [7].

Fig. 1 shows the invariant cross section $E\,\mathrm{d}^3\sigma/\mathrm{d}p^3$ as a function of the hadron energy $E$ for $\pi^\pm$ (i.e. the sum of $\pi^+$ and $\pi^-$), $K^\pm$ and twice the $\bar{p}$ production in the three regions of interest. The on-resonance cross sections refer to direct decays of $\Upsilon$ and $\Upsilon'$ only. Contributions from the non-resonant background and from vacuum polarization have been subtracted using $\sigma_{\mathrm{dir}} = \sigma_{\mathrm{on}} - \sigma_{\mathrm{off}}\,(\sigma^{\mathrm{on}}_{\mu\mu}/\sigma^{\mathrm{off}}_{\mu\mu})$. According to QCD, the direct decays obtained in this way are essentially decays into three gluons.

The invariant cross sections can be approximated by an exponential, $E\,\mathrm{d}^3\sigma/\mathrm{d}p^3 \propto \exp(-bE)$. From a least-squares fit we get $b = 4.4 \pm 0.3\ \mathrm{GeV}^{-1}$ for non-resonant pion production. This value agrees with the slope parameters for pion production in the continuum measured at other energies [2] [‡2], as shown in fig. 2. The slope appears to fall slightly, weaker than $1/\sqrt{s}$, with the center of mass energy.

The pion spectrum from direct $\Upsilon$ decay has a slope which is practically equal to the continuum value, if fitted over the entire measured energy range. However, its lower part ($E < 1$ GeV) falls off faster, with $b = 4.9 \pm 0.2\ \mathrm{GeV}^{-1}$.

The average number of charged pions, kaons and antiprotons can be calculated by a numerical integration of the measured spectra. Using for $R = \sigma_h/\sigma_{\mu\mu}$ the

‡1 In particular, we used the jet model versions of Sjöstrand et al. [4].

‡2 The slope parameter $b$ at 12 GeV was calculated from data in ref. [12].

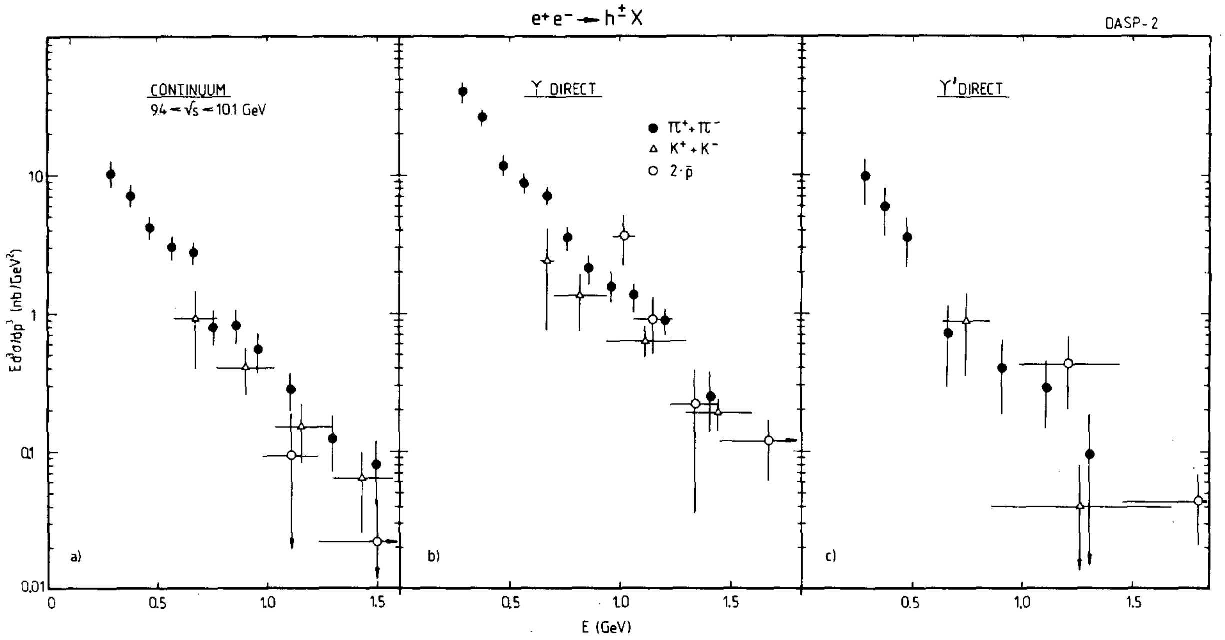


Fig. 1. Invariant cross sections $E\, d^3\sigma/dp^3$ as a function of particle energy $E$ for the sum of $\pi^+$ and $\pi^-$, $K^+$ and $K^-$ and twice the $\bar{p}$ production in the continuum (a), and for direct decays of $\Upsilon$ (b) and $\Upsilon'$ (c).

value measured in this experiment [8], $R = 3.6 \pm 0.2$, and the exponential fits described above in order to extrapolate to zero energy, we find a total charged hadron multiplicity of $6.9 \pm 0.6$ in the continuum and

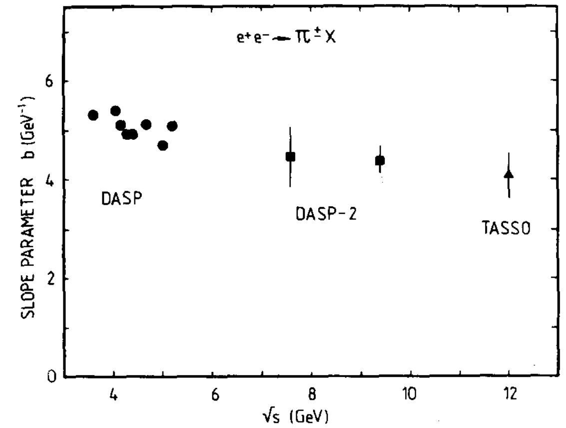


Fig. 2. Slope parameter $b$ versus $\sqrt{s}$ for non-resonant $\pi^\pm$ production obtained from exponential fits to the invariant cross sections, $E\, d^3\sigma/dp^3 \propto \exp(-bE)$. Data points are from DASP [2], TASSO [7], and this experiment, where the point at 7.6 GeV was obtained from unpublished data.

$7.9 \pm 0.6$ for direct $\Upsilon$ decay, in agreement with other experiments [9,10]. The average fraction of the center of mass energy carried by the charged hadrons was calculated in the same way as the average multiplicity. We obtain $\langle E_{ch}\rangle_{off}/\sqrt{s} = (51.8 \pm 8.0)\%$ in the continuum and $\langle E_{ch}\rangle_{on}/\sqrt{s} = (48.0 \pm 3.6)\%$ for direct $\Upsilon$ decays, in agreement with results from PLUTO [11].

The invariant cross sections of the three types of hadrons in the continuum and on the $\Upsilon$ resonances are close together (cf. fig. 1). However, antiproton production appears to be more abundant on resonance than off resonance. The ratio between the yields of $2\bar{p}$ and all charged hadrons is indeed as high as $(8.1 \pm 2.1)\%$ for direct $\Upsilon$ decay compared to $(1.5 \pm 1.1)\%$ in the continuum. This increase of $(6.6 \pm 2.4)\%$ has a statistical significance of 2.8 standard deviations. A similar effect of 2.5 standard deviations is found for direct $\Upsilon$ decays.

The fractions of the various charged particles are summarized in table 1. Using the mean charged multiplicity as determined above, the average number of antiprotons per event comes out to be $\langle\bar{p}\rangle = 0.32 \pm 0.08$ on the $\Upsilon$, and $\langle\bar{p}\rangle = 0.05 \pm 0.03$ in the continuum.

Table 1
Particle ratios in the momentum range $0.3 < p < 1.5$ GeV/$c$.

| | $2\bar{p}$ | $K^{\pm}$ | $\pi^{\pm}$ |
|---|---|---|---|
| continuum | 0.015 ± 0.011 | 0.183 ± 0.039 | 0.802 ± 0.059 |
| Υ | 0.081 ± 0.021 | 0.154 ± 0.027 | 0.765 ± 0.048 |
| Υ′ | 0.189 ± 0.069 | 0.119 ± 0.072 | 0.692 ± 0.129 |

It is interesting to note that a similar rise in the antiproton yield has been seen on the J/ψ [2] . In the continuum, a large production of (anti)baryons has recently been reported by PETRA groups around 30 GeV [12]. Since it is believed that gluon emission processes become appreciable at this energy and that, on the other hand, the J/ψ and Υ states decay primarily via three gluons, one may wonder whether more copious baryon production is connected with gluon fragmentation.

In fig. 3a the continuum scaling cross section $(s/\beta) \times \mathrm{d}\sigma/\mathrm{d}x$ for charged pions produced near the Υ resonance is compared with the cross sections measured by DASP at 5.2 GeV [2]and by PETRA experiments at 12 and 30 GeV [12]. Although approximate scaling is expected only for $x \gtrsim 0.2$, the cross sections of all experiments agree within a factor of two even down to $x = 0.05$ where our data start to overlap that of the other experiments. If we use $x_p = 2p/\sqrt{s}$ instead of $x = x_E = 2E/\sqrt{s}$, the cross sections $s\,\mathrm{d}\sigma/\mathrm{d}x_p$ for all charged hadrons scale very well with $s$ for $x_p \gtrsim 0.2$, as can be seen from fig. 3b. The enhanced DASP cross section which appears in the $x_E$ spectrum, shows up here as a shoulder around $x_p = 0.35$.

In summary we find a very similar behavior of the invariant and scaling cross sections for inclusive charged pion, kaon and antiproton production on and near the Υ resonance. The most prominent difference is a rise seen in the antiproton yield at the Υ and Υ′ resonances. This effect of about three standard deviations, which was also seen in the J/ψ region deserves a more

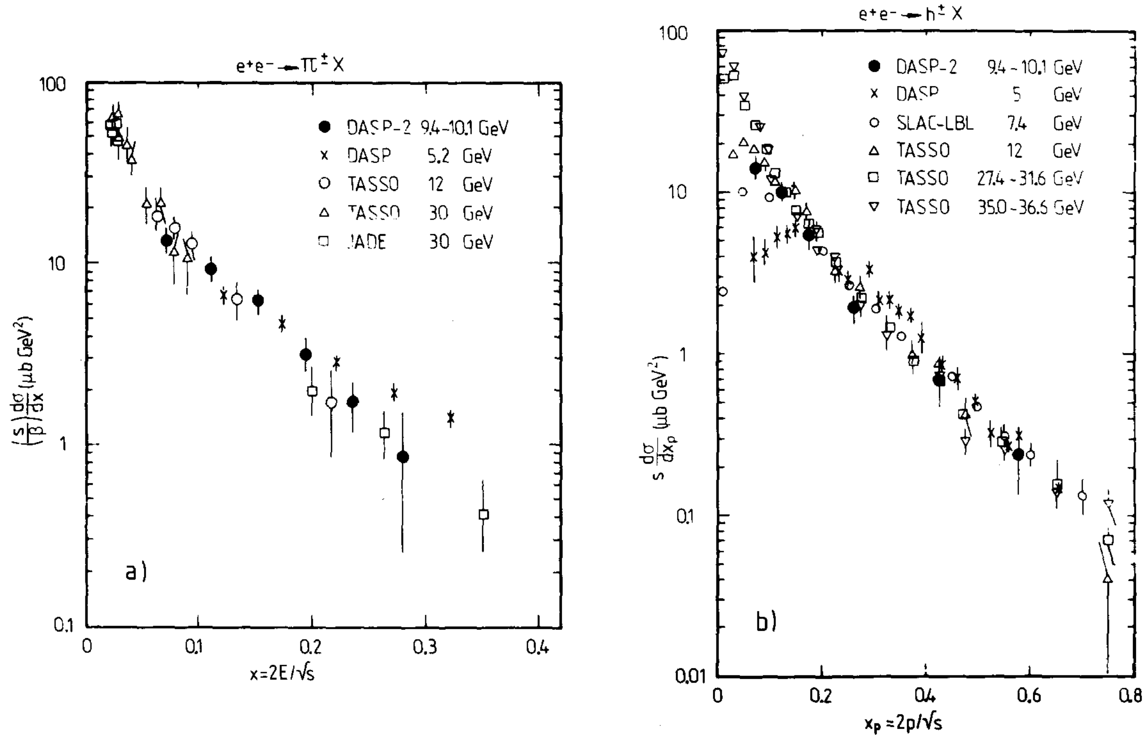


Fig. 3. (a) The scaling cross section $(s/\beta)\,\mathrm{d}\sigma/\mathrm{d}x$ versus $x = 2E/\sqrt{s}$ for charged pion production in the continuum near the Υ including the spectra measured at other energies by DASP [2], TASSO and JADE [12]. (b) The quantity $s\,\mathrm{d}\sigma/\mathrm{d}x_p$ versus $x_p = 2p/\sqrt{s}$ for charged hadrons as measured in this experiment, by DASP [2], by SLAC–LBL [13] and by TASSO [12].

thorough investigation both theoretically and experimentally.

We thank Dr. K. Wille and the DORIS group for their excellent work in operating the storage ring, We are endebted to Professors E. Lohrmann, H. Schopper and G.A. Voss for their support. The invaluable cooperation of A. Krolzig and all members of the group F51 is gratefully acknowledged. We wish to thank B. Hildebrandt for his help in data processing. The non-DESY members of the collaboration want to thank the DESY directorate for their kind hospitality. This work was supported in part by the Bundesministerium für Forschung und Technologie.

*References*

[1] For recent reviews see, for example, G. Wolf, DESY 80/13 (Febr. 1980);
B.H. Wiik, invited talk at the 20th Intern. Conf. on High energy physics (Madison, WI, 1980).
[2] DASP Collab., R. Brandelik et al., Nucl. Phys. B148 (1979) 189.
[3] R.D. Field and R.P. Feynman, Nucl. Phys. B136 (1978) 1.
[4] T. Sjöstrand et al., Univ. of Lund, LU-TP-79-8 (1979); LU-TP-80-3 (1980).
[5] E. Steinmann, thesis, Univ. of Hamburg (1981).
[6] F.A. Berends and R. Kleiss, DESY 80/66 (1980); DESY 80/73 (1980).
[7] DASP-2 Collab., H. Albrecht et al., Phys. Lett. 93B (1980) 500.
[8] K.R. Schubert, talk given at the 1980 Rencontre de Moriond (Les Arcs, 1980).
[9] PLUTO Collab., Ch. Berger et al., DESY 80/117 (Dec. 1980), submitted to Z. Phys. C.
[10] LENA Collab., B. Niczyporuk et al., DESY 81/008 (Jan. 1981, submitted to Z. Phys. C.
[11] C. Gerke, thesis, Univ. of Hamburg (1979).
[12] D. Pandoulas, rapporteur talk at the 20th Intern. Conf. on High energy physics (Madison, WI, 1980); Imperial College preprint IC/HENP/80/5 (1980).
[13] G.G. Hanson, talk given at the 18th Intern. Conf. on High energy physics (Tbilisi, USSR, 1976); SLAC-PUB-1814 (1976);
G.J. Feldmann and M.L. Perl, Phys. Rep. 33 (1977) 285.