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PRODUCTION OF MUON PAIRS IN THE CONTINUUM REGION BY 39.5 GeV/c

$\pi^{\pm}$, $K^{\pm}$, p AND $\bar{p}$ BEAMS INCIDENT ON A TUNGSTEN TARGET

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Abstract

Inclusive dimuon production by 39.5 GeV/c $\pi^\pm$, $K^\pm$, p and $\bar{p}$ is described for masses greater than 2.0 GeV/c². The π^- , π^+ and $(\pi^-\pi^+)$ continuum cross-sections exceed the naive Drell-Yan predictions by a factor ~ 2.4 . The pion valence structure function has been measured and is consistent with a corresponding measurement at 200 GeV/c.

We report further results of an experiment designed to measure muon pair production by 39.5 GeV/c $\pi^\pm$, $K^\pm$, p and $\bar{p}$ beam particles incident on a tungsten target using the Omega spectrometer¹⁾. The apparatus detected high mass muon pairs with good efficiency for x_F values above -0.5 (where $x_F = 2 p_L^*/\sqrt{s}$). The results of a study of the J/ψ in this experiment have already been published²⁾. Our earlier experiment at the same incident momentum yielded the first results on J/ψ ³⁾ and continuum⁴⁾ production with a fully identified beam. The experiment we report here represents a tenfold increase in statistics on those results.

The production of continuum dimuons from pion and kaon beams provides information on the meson structure functions that cannot be obtained from deep inelastic lepton scattering experiments. In the present experiment the cm energy squared, s , is relatively small, (76 GeV²) which has certain advantages. At any given value of $\tau (M_{\mu\mu}^2/s)$ the Drell-Yan cross-section $d\sigma/d\tau$ is proportional to $1/s$ times a function of τ only. This fact enables us to study larger values of τ . A second advantage lies in providing a test of scaling over a wide range of s whilst avoiding the low mass resonances and threshold phenomena.

The apparatus and trigger logic are described in Ref. 2. The event selection and beam normalization procedure for the continuum events is the same as that for J/ψ events²⁾. We present results for dimuon masses greater than 2.0 GeV/c² including 257 events with $M_{\mu\mu} > 4.0$ GeV/c². The like sign pair contribution ($\mu^-\mu^- + \mu^+\mu^+$) rises to a maximum of 10% in the lowest mass interval and is negligible above 3 GeV/c². We have subtracted this contribution, as a measure of random and decay background contributions to our $\mu^+\mu^-$ sample, as well as the tails of the J/ψ and ψ' .

The event acceptance has been computed for fully spin aligned dimuons with a $1 + \cos^2\theta_{cs}$ dependence on the polar Collins-Soper angle, θ_{cs} ⁵⁾, consistent with our measured angular distributions. The resulting π^- and π^+ continuum cross-sections are presented in Table I. The differential cross-sections $d\sigma/dM$ per tungsten nucleus for π^- , π^+ and $(\pi^-\pi^+)$ for $x_F > 0$ are shown on Fig. 1. These cross-sections fall very rapidly with increasing mass. For π^- an exponential fit gives

$d\sigma/dM = (6800 \pm 540) \exp(-(1.75 \pm 0.03)M) \text{ nb/GeV}^2/\text{W nucleus}$. These errors do not include the overall systematic normalisation error of Table I. In a previous experiment⁴⁾, we obtained $d\sigma/dm = (3000 \pm 850) \exp(-1.7 \pm 0.1)M \text{ nb/GeV}^2/\text{Cu nucleus}$. For comparison with the experimental data we have calculated the differential cross-sections using the Drell-Yan model assuming coloured quarks and a linear A dependence. This incorporates the structure functions for the pion valence and sea quarks of Ref.⁶⁾ which have been determined in a high statistics experiment at 200 GeV/c incident momentum, while for the nucleon the CDHS results⁷⁾ have been used. The measured values of the multiplicative factor, K, between experiment and the naive Drell-Yan prediction are for the π^- , π^+ , $(\pi^-\pi^+)$ data 2.45 ± 0.42 , 2.52 ± 0.49 and 2.22 ± 0.41 respectively (the $(\pi^-\pi^+)$ data has the advantage that hadronic processes and sea quark contributions cancel). These factors have been included to give the solid curves on Fig. 1. They are very similar to values observed in other experiments^{8,9)} and are evidence for the presence of higher order terms in the Drell-Yan process.

Our π^- continuum cross-sections, integrated over all x_F , are compared with published results¹⁰⁾ at 200 and 280 GeV/c incident momenta on a plot of $M^3 d\sigma/dM$ vs $\sqrt{\tau}$ in Fig. 2. A linear A dependence has been used to deduce the scaling cross-section per nucleon for each experiment but this is not critical as the A values of the targets used (tungsten and platinum) are similar. Published data from references⁹⁾ and ¹¹⁾ are not included as these results correspond to more limited x_F ranges. For our lowest masses the estimation of the cross-section involves an extrapolation of the observed x_F distribution into the negative x_F range. The estimated errors in this procedure have been included in Fig. 2. A precise test of scaling is further complicated by the presence of the Υ at $\sqrt{\tau} = 0.5$ (0.425) at incident momenta of 200 (280) GeV/c respectively. It might be argued that low mass data may include a hadronic (non Drell-Yan) contribution. Because the K factors observed for π^- , π^+ and $\pi^-\pi^+$ are similar any such effect must be small. The scaling violations observed in deep inelastic scattering experiments would be consistent with an increase in cross-section (at fixed $\sqrt{\tau}$) at lower $M_{\mu\mu}^2$. At fixed $\sqrt{\tau}$ our lower energy data correspond to a lower $M_{\mu\mu}^2$. Our data do lie around 20% above the higher energy

cross-sections throughout but the systematic errors are comparable with this difference.

Figure 3 shows the cross-sections for muon pair production for different incoming particles relative to π^- beam as a function of dimuon mass plus our corresponding J/ψ results in the mass interval 2.7-3.5 GeV/c^2 . The π^+/π^- ratio shown in Fig. 3a) is close to unity for J/ψ production, while for the continuum it decreases with increasing dimuon mass towards the asymptotically expected value of $1/4^*$, the ratio of the squares of the annihilating valence quark charges. This trend has been observed before^{4,10,11)}. For the other particles the ratios Fig. 3b)-e) fall with mass without a discontinuity at the J/ψ . This is consistent with expectations from the simple quark model at this energy. The small ratios for the K^+ and proton beams are consequences of the absence of valence $\bar{u}$ or $\bar{d}$ in these particles. The solid curves on Fig. 3 are not fits but they have been computed using the Drell-Yan model and the structure functions of reference^{6,7)}. Evidently they are in good agreement with our 40 GeV/c data. On Fig. 3d) the solid curve shows the calculated ratio for K^-/π^- where the $\bar{u}$ distribution for the K^- is taken to be the same as for the π^- while the dotted curve uses the results of reference¹²⁾ for the K^- structure function. The latter agrees better with the data providing further evidence that the $\bar{u}$ distribution in a K^- falls more steeply with x than in a π^- . The variation we observe for the K^-/π^- ratio as a function of x_F is also consistent with this result.

Figures 4a) and b) show the x_F distributions for continuum $\mu^+\mu^-$ pairs in the mass ranges 2.3 - 2.7 and 4.0 - 5.0 GeV/c^2 for π^- and π^+ beams. The x_F distributions are broader at the higher masses. At higher masses the predicted x_F distributions peak further from zero. This arises from the difference in valence quark distributions between pions

* This value is expected for isoscalar target with the additional assumption that u and d quarks have the same nucleon structure functions. In this experiment the tungsten target provides $\sim 15\%$ more d quarks because of the unequal number of protons and neutrons.

and nucleons because production at large $M_{\mu\mu}^2/s$ requires the annihilation valence quarks at large Bjorken x . The superimposed curves (normalised to the data for $x_F > 0$) are calculated using the structure functions listed above and again reproduce the shape of the x_F distributions reasonably well. The shape of the x_F distribution varies smoothly as a function of mass, including the J/ψ region.

The p_T^2 distributions for the π^- and π^+ induced dimuons are well fitted by an exponential form for $p_T^2 < 2.0 \text{ (GeV/c)}^2$. At higher p_T^2 the data fall more slowly than the exponential as observed in¹⁰⁾. In Table II we present the $\langle p_T^2 \rangle$ values for different mass slices for π^- and π^+ , and for different x_F intervals for the π^- data only. Values of $\langle p_T^2 \rangle$ for the minority beam particles are similar but less well measured. Corrections have been applied to $\langle p_T^2 \rangle$ to allow for the smearing effect of multiple scattering. There are no clear differences between the J/ψ and the neighbouring continuum nor between different beam particles in this experiment.

Figure 5 shows $\langle p_T^2 \rangle$ versus mass for π^- induced dimuons from this and other experiments at different energies^{10,13,14)}. The dependence of $\langle p_T^2 \rangle$ on mass seems to be rather similar at all energies. However the dependence of $\langle p_T^2 \rangle$ for the J/ψ appears to be stronger than for the continuum²⁾. For all mass intervals including the J/ψ ²⁾ region we observe a smooth decrease of $\langle p_T^2 \rangle$ with increasing x_F . This fall is very striking at high masses where it must at least partly reflect the approach to the kinematic boundary.

The $\cos\theta_{GJ}$ decay angular distributions of the combined sample of π^- and π^+ induced dimuons have been studied for $|\cos\theta_{GJ}| < 0.8$ making the assumption that the azimuthal distribution ϕ_{GJ} is isotropic. (θ_{GJ} , ϕ_{GJ} are the Gottfried-Jackson decay angles). The distributions have been fitted with the form $1 + \alpha \cos^2\theta_{GJ}$ and yield values of $\alpha = 0.44 \pm 0.17$ (0.44 ± 0.48) for the mass regions $2.3\text{--}2.7 \text{ GeV}/c^2$ ($4.0\text{--}5.0 \text{ GeV}/c^2$) for $x_F > -0.25$. We have also studied α for the $2.3\text{--}2.7 \text{ GeV}/c^2$ mass region as a function of x_F . We observe α values of 0.56 ± 0.49 , 0.92 ± 0.30 , 0.12 ± 0.29 , and 0.12 ± 0.40 for the x_F regions $-0.25 \rightarrow 0$, $0 \rightarrow 0.25$, $0.25 \rightarrow 0.5$, > 0.5 respectively. There is some evidence for a decrease in α with increasing x_F as first observed at $225 \text{ GeV}/c$ incident momentum¹⁵⁾.

In order to determine the pion structure function we have fitted

the data for π^+ and π^- simultaneously in the mass interval 2.0-2.7 GeV/c² for x_F between -0.1 and 0.8 with the pion valence distribution parameterized as $Ax^\alpha(1-x)^\beta$. The pion sea is fixed as $B(1-x)^\gamma$ where $\gamma=5$ and B is such that 6% of the pion momentum is carried by each sea quark flavour while for the nucleon valence and sea the CDHS parameters⁷⁾ have been used. The fitted results give $\alpha=0.44\pm.12$ and $\beta=0.98\pm.15$ and a K factor of 2.6 ± 0.5 to be compared with $\alpha=0.40\pm0.06$ and $\beta=0.90\pm0.06$ in reference⁶⁾. We have examined the effect of varying the parameters determining the pion sea and the nucleon valence and sea within reasonable limits and obtain a systematic error of 0.1 in α and β . There is no evidence within experimental error of any scaling violation from the shape of the pion structure function between 40 GeV/c and 200 GeV/c; the parameter β would have been expected to have been smaller by ~ 0.2 at 40 GeV/c according to some QCD estimates¹⁶⁾.

In conclusion we observe at 40 GeV/c only a small change in the scaled continuum cross-sections $M^3 d\sigma/dM$ from the values measured at 200 GeV/c and 280 GeV/c. The measured π^+ and π^- continuum cross-sections are a factor 2.4 larger than the simple Drell-Yan prediction. The behaviour of cross-sections for all beam particle types is consistent with the predicted variation when using the meson and nucleon structure functions determined at 200 GeV/c. The $\langle p_T^2 \rangle$ shows a dependence on dimuon mass similar to that observed at higher energies and decreases with x_F for both continuum and J/ψ events.

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References

1. Omega Spectrometer, O. Gildemeister, International Conference on Instrumentation for high energy physics (Frascati 1973).
2. M.J. Corden et al., (submitted to Phys. Lett.).
3. M.J. Corden et al., Phys. Lett. 68B (1977), 96.
4. M.J. Corden et al., Phys. Lett. 76B (1978), 226.
5. J.C. Collins and D.C. Soper, Phys. Rev. D16 (1977), 2219.
6. J. Badier et al., CERN/EP/79-67.
7. J.G.H. de Groot et al., Phys. Lett. 82B (1979), 456.
8. J. Badier et al., Phys. Lett. 89B (1979), 145.
9. R. Barate et al., Phys. Rev. Lett. 43 (1979), 1541.
10. J. Badier et al., CERN/EP/79-68.
11. K. Anderson et al., Phys. Rev. Lett. 42 (1979), 948.
12. J. Badier et al., Phys. Lett. 93B (1980), 354.
13. K. Anderson et al., Phys. Rev. Lett. 42 (1979), 944.
14. J. Alspector et al., Phys. Lett. 81B (1979), 397.
15. K.J. Anderson et al., Phys. Rev. Lett. 43 (1979) 1219.
16. W. Kienzle (private communication).
17. E. Berger, ANL-HEP-PR-78-12.

TABLE IContinuum cross-sections nb/W nucleus/GeV/c²

Mass Range GeV/c ²	2.0-2.3	2.3-2.7	3.5-4.0	4.0-4.5	4.5-5.0	5.0-6.0	6.0-7.0
$\pi^-(x_F > 0)$	156±5 (39)	86±3 (18)	9.8±0.5 (2.3)	4.3±0.3 (0.8)	1.9±0.2 (0.5)	0.31±0.09 (0.11)	0.10±0.05 (0.05)
$\pi^+(x_F > 0)$	76±4 (19)	44±2 (10)	5.1±0.4 (1.6)	2.0±0.3 (0.5)	0.5±0.2 (0.2)	0.10±0.06 (0.06)	<0.04±0.04 (0.04)
$\pi^-(\text{all } x_F)$	264±8 (84)	130±4 (38)	15.0±0.8 (3.8)	6.4±0.5 (1.4)	2.8±0.4 (0.7)	0.38±0.11 (0.14)	0.14±0.07 (0.07)

Errors are statistical only. Bracketed errors are estimated statistical and systematic errors.

Figure captions

- 1) Differential cross-sections $d\sigma/dM$ (nb/GeV/c²/W nucleus) for $x_F > 0$ versus mass. Overall systematic and normalisation errors have been included in the quoted errors.
 (a) π^- (b) π^+ (c) $(\pi^- - \pi^+)$
 The solid curves are calculated from the Drell-Yan model using the structure functions of reference¹²⁾ and assuming a linear A dependence. The multiplicative factors K that have been used in each case are shown on the figure.
- 2) $M^3 d\sigma/dM$ for all x_F as a function of $\sqrt{\tau} = M/\sqrt{s}$ for π^- induced dimuons. The data at 200 and 280 GeV/c incident momenta is from reference¹⁰⁾. Overall systematic and normalisation errors have been included in the quoted errors from our experiment at 40 GeV/c.
- 3) (a) Ratio for π^+ induced to π^- induced dimuon cross-sections versus dimuon mass for $x_F > 0$. (b) Id. for $\bar{p}$. (c) Id. for p . (d) Id. for K^- . (e) Id. for K^+ .
 The dashed symbols refer to the mass bin which contains mainly J/ ψ events. The solid curves have been calculated using the Drell-Yan model and the structure functions of reference⁶⁾. The dotted curve in (d) uses the kaon structure function of reference¹²⁾.
- 4) $d^2\sigma/dM dx_F$ versus x_F for :
 (a) π^- and π^+ induced events for $2.3 < M < 2.7$ GeV/c² and
 (b) π^- and π^+ induced events for $4.0 < M < 5.0$ GeV/c .
 The solid (dashed) curves represent the $\pi^-(\pi^+)$ calculations from the Drell-Yan model and the structure functions of reference⁶⁾ normalised to the data for $x_F > 0$.
- 5) $\langle p_T^2 \rangle$ versus mass (M) for π^- induced dimuons from this experiment and references^{10,13,14}. The prescription of reference¹⁷⁾ has been used to convert $\langle p_T \rangle$ of reference¹⁴⁾ to $\langle p_T^2 \rangle$.

Fig.1

Fig.2

Fig.3

Fig.4

Fig. 5