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INCLUSIVE SPECTRA OF ELECTROPRODUCED K^+ -MESONS

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Abstract

We report measurements of kaon electroproduction from a hydrogen target carried out at DESY. The invariant cross section for the reaction $e p \rightarrow e K^+ + \text{anything}$ is given as a function of the variables q^2 , W , x , $p_{\perp}^2$ and ϕ in the following region:

$$-0.5 < q^2 < -0.1 \text{ GeV}^2$$

$$2.0 < W < 2.8 \text{ GeV}$$

$$0.3 < x < 1.0$$

$$p_{\perp}^2 < 0.25 \text{ GeV}^2$$

$$0^\circ < \phi < 360^\circ$$

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Introduction

One way to gain more insight into the hadronic structure of elementary particles is to study the final state hadrons in electron-scattering experiments at high energies. Here we present inclusive K^+ -distributions of the reaction

$$e^- + p \rightarrow e^- + K^+ + \text{anything} \quad (1)$$

obtained by detecting the K^+ -meson in coincidence with the scattered electron in an electron-proton scattering experiment at DESY⁺.

In first order quantum-electrodynamics electroproduction can be regarded as photoproduction with virtual photons. The incident electron emits a virtual photon which interacts with the target proton. The unknown part is the reaction

$$\gamma_v + p \rightarrow K^+ + \text{anything} \quad (2)$$

where γ_v indicates the virtual photon.

To study the dynamical behaviour of this process and for comparison with photoproduction and pure hadronic reactions we show the dependence of the cross section on the kinematical variables q^2 , W , x , $p_{\perp}^2$ and ϕ which are defined in the following way:

$$q^2 = (e - e')^2 \quad \text{is the four-momentum squared of the virtual photon.}$$

Here e and e' are the four-momenta of the incoming and outgoing electrons respectively.

$$W = \sqrt{(q + P)^2} \quad \text{is the centre of mass energy of the virtual photon and the target proton, where } q \text{ and } P \text{ indicate the four-momenta of the virtual photon and the target proton.}$$

⁺ Some preliminary results on part of the reported data were presented at Bonn Conference [1] where too high a normalization was used.

$x = p_{||}^{**}/p_{\max}^{**}$ is the Feynman longitudinal variable, where $p_{||}^{**}$ is the longitudinal momentum of the outgoing kaon with respect to the direction of the photon and $p_{\max}^{**}$ is the maximum momentum of the outgoing kaon at the observed value of W , which is obtained in the reaction $\gamma_V + p \rightarrow K^+ + \Lambda(1116)$. Both momenta refer to the c.m.s. of the photon and the target proton.

$p_{\perp}^2$ is the square of the transverse momentum of the outgoing kaon with respect to the direction of the photon.

ϕ is the azimuthal angle of the outgoing kaon, which is the angle between the polarization plane, subtended by $\vec{e}$ and $\vec{e}'$, and the production plane, subtended by $\vec{q}$ and the momentum $\vec{p}$ of the kaon.

As a consequence of the one-photon exchange mechanism the cross section of reaction (1) factorizes in $2\pi\Gamma$, describing the flux of virtual photons, and the cross section $d\sigma/d^3p$ for reaction (2) [2],

$$\frac{d\sigma}{dq^2 dW d^3p} = 2\pi\Gamma \frac{d\sigma}{d^3p} \quad (3)$$

where Γ is given by

$$\Gamma = \frac{\alpha}{2(2\pi)^2} \frac{W}{E_0^2 M^2 |q^2|} \frac{W^2 - M^2}{1 - \epsilon}.$$

Here E_0 is the energy of the primary electron in the laboratory frame, M the mass of proton and ϵ the degree of the transverse polarization of the photon

$$\epsilon = \frac{4 E_0 E' + q^2}{2 E_0^2 + 2 E'^2 - q^2}$$

where E' is the energy of the scattered electron.

In this paper the differential cross section for virtual photoproduction is given in the Lorentz invariant form normalized with the total cross section

$$\frac{E}{\sigma_{\text{tot}}} \cdot \frac{d\sigma}{d^3p}$$

(E is the energy of the detected kaon. The values of σ_{tot} were taken from ref. [3]).

In the framework of one-photon exchange the cross section can be parametrized as [4]

$$\frac{E}{\sigma_{\text{tot}}} \cdot \frac{d\sigma}{d^3p} = \Gamma = f_u + \epsilon f_L + \epsilon f_p \cos 2\phi + \sqrt{2\epsilon(\epsilon+1)} f_{\perp} \cos \phi. \quad (4)$$

The subscripted functions depend on q^2 , W , x and $p_{\perp}^2$ only and they describe the contributions from the unpolarized transverse virtual photons, the longitudinal photons, the transverse linear polarization of the photons and the interference between the transverse and longitudinal components.

2. Data Analysis and Corrections

The experimental details of the spectrometers which detected the scattered electron and the outgoing kaon can be found in ref. [5]. The separation of kaons, pions and protons by means of time of flight measurement system and a Čerenkov counter has been described in ref. [6]. To cover the W -interval from 2.0 to 2.8 GeV and q^2 from -0.5 to -0.1 GeV² data were taken at two different

energies of the incident electron, $E_0 = 4.0$ GeV and 4.9 GeV. Corrections were made for the efficiency loss in the trigger counters, the electron Čerenkov counter and shower counters, for the strong interaction of the kaons, the target walls and the loss in the automatic data analysis procedure.

The decay of the kaons was incorporated in the acceptance calculations. The kaons were defined by appropriate cuts in the time of flight spectra, which leads to momentum dependent corrections. Also we had to correct for the background of pions and protons within the kaon cuts at each point where the cross section was calculated. The background corrections vary between 1 % and 20 %.

The uncertainties in all these corrections including that in the intensity of the primary beam add up to an overall systematic error of less than 8 % which is not included in the errors given in this report. Neither have the radiative corrections been taken into account, which are of the order of a few per cent.

3. Results

The accepted range of the azimuthal angle ϕ depends on the variables q^2 and W . Therefore the data were analysed in four distinct (q^2, W) -regions with the following limits in ϕ :

Region A	$-60^\circ < \phi < 60^\circ$
Region B	$-90^\circ < \phi < 90^\circ$
Region C	$0^\circ < \phi < 360^\circ$
Region E	$90^\circ < \phi < 270^\circ$

We calculated the invariant cross section $E/\sigma_{\text{tot}} \cdot d\sigma/d^3p$ averaged over the accepted ϕ -range. The values are given in tables 2 - 5.

In region C the ϕ -dependence of the cross section was studied according to (4) at two different (q^2, W) -points. The result is given in table 1. Compared with

$f_u + \epsilon f_L$ the polarization term f_p and the interference term f_I are small (10 % to 20 % of $f_u + \epsilon f_L$). Thus the important term is the ϕ -independent part of the cross section. Assuming a similar behaviour in the other (q^2, W) -regions the polarization term and interference term multiplied by the appropriate factors, that is the ϕ -average of $\epsilon \cos 2\phi$ and $\sqrt{2\epsilon(\epsilon + 1)}$ respectively, can be ignored, enabling one to combine the data from all regions.

Fig. 1 shows the x -dependence at $W = 2.65$ GeV and $q^2 = -0.23$ GeV² for different transverse momenta. By comparison with the data of pion production [7], which range from 0.5 to 0.3 GeV⁻² in the x -interval from 0.5 to 0.8 , we see that the kaon-cross section is an order of magnitude smaller than the pion cross section. The same ratio between the K^+ - and π^+ -production was observed in photoproduction [8] and in pp-scattering [9]. The kaon-electroproduction experiment of Alder et al. [10] yields, in forward direction at $q^2 = -1.15$ GeV² and $W = 2.65$ GeV, slightly higher values, about 0.07 GeV⁻², than ours at $q^2 = -0.23$ GeV².

Keeping x fixed the cross section falls with $p_\perp^2$. In fig. 2 the dependence of the cross section on $p_\perp^2$ is plotted at $W = 2.65$ GeV and $q^2 = -0.23$ GeV². The line is an exponential form $e^{-ap_\perp^2}$ with a slope of $a = 5$ GeV⁻² which fits the data well. Only the $0.6 < x < 0.7$ -region shows a different behaviour. This can be explained by the dominance of the $K^+A(1520)$ -channel which in this x -region can only contribute to $p_\perp^2 > 0.1$ GeV². An exponential distribution with a slope of 5 GeV⁻² corresponds to a mean $p_\perp$ of 0.4 GeV. Similar mean transverse momenta have been found in photoproduction of kaons [8] and in pure hadronic reactions like $\pi^+ + p \rightarrow K^+ + \text{anything}$ [11] and $p + p \rightarrow K^+ + \text{anything}$ [9].

At small x ($0.4 < x < 0.6$), the cross section is nearly constant from $W = 2.2$ to 2.8 GeV (fig. 3). Bebek et al. [12] also have seen no variation

in the cross section between $W = 2.2$ and 3.1 GeV at $q^2 = -1.2 \text{ GeV}^2$ and $0.2 < x < 0.6$. This implies that Feynman scaling roughly works for smaller x even at such low energies. But at high x ($0.8 < x < 1.0$) the cross section is rapidly decreasing with increasing x , see fig. 4. The larger values of $p_{\perp}^2$ for the high W -points can explain only a small amount of this decrease. Since only the production of $\Lambda(1116)$, $\Sigma(1193)$, $\Sigma(1385)$ and $\Lambda(1405)$ contributes to this x -region, the slope can easily be explained by decreasing production of these exclusive channels.

In figs. 5 and 6 the q^2 -dependence is shown at $W = 2.43$ and 2.65 GeV for different x -intervals. The lines in the figures correspond to the mean of all points of the same x -interval. The cross section is constant or weakly rising. Since the π^+ -production falls by a factor of two from $q^2 = -0.1$ to -0.6 GeV^2 at $W = 2.65 \text{ GeV}$ [7], this q^2 -behaviour supports the quark-parton model [13] which predicts a rising K^+ - over π^+ - ratio with increasing $|q^2|$.

4. Summary

The exponential decrease of kaon production with $p_{\perp}^2$ shows a similar slope as found in photoproduction and in pure hadronic reactions. At high x the cross section strongly decreases with rising energy W due to non-diffractive two-body channels. But at smaller x we see a nearly W -independent behaviour. The invariant cross section normalized with σ_{tot} shows a flat q^2 -behaviour.

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Figure Captions

Fig. 1 The x -distribution for $W = 2.65$ GeV at different transverse momenta.

Fig. 2 The $p_{\perp}^2$ -distribution for $W = 2.65$ GeV at different x -values. The solid lines correspond to an exponential with a slope of 5 GeV^{-2} .

Fig. 3 The W -dependence for small x . The full symbols belong to $E_0 = 4.0$ GeV, the open symbols to $E_0 = 4.9$ GeV.

- : $q^2 = -0.5 \text{ GeV}^2$, $0.0 < p_{\perp}^2 < 0.02 \text{ GeV}^2$, $0^\circ < \phi < 360^\circ$
- △ : $q^2 = -0.4 \text{ GeV}^2$, $0.0 < p_{\perp}^2 < 0.02 \text{ GeV}^2$, $-90^\circ < \phi < 90^\circ$
- : $q^2 = -0.3 \text{ GeV}^2$, $0.0 < p_{\perp}^2 < 0.04 \text{ GeV}^2$, $-60^\circ < \phi < 60^\circ$
- ▼ : $q^2 = -0.18 \text{ GeV}^2$, $0.0 < p_{\perp}^2 < 0.025 \text{ GeV}^2$, $-60^\circ < \phi < 60^\circ$
- ▽ : $q^2 = -0.18 \text{ GeV}^2$, $0.025 < p_{\perp}^2 < 0.1 \text{ GeV}^2$, $-60^\circ < \phi < 60^\circ$

Fig. 4 The W -dependence for high x . The full symbols belong to $E_0 = 4.0$ GeV, the open symbols to $E_0 = 4.9$ GeV.

- : $q^2 = -0.5 \text{ GeV}^2$, $0.0 < p_{\perp}^2 < 0.05 \text{ GeV}^2$, $0^\circ < \phi < 360^\circ$
- ▲ : $q^2 = -0.4 \text{ GeV}^2$, $0.0 < p_{\perp}^2 < 0.04 \text{ GeV}^2$, $90^\circ < \phi < 270^\circ$
- △ : $q^2 = -0.4 \text{ GeV}^2$, $0.01 < p_{\perp}^2 < 0.07 \text{ GeV}^2$, $-90^\circ < \phi < 90^\circ$
- : $q^2 = -0.3 \text{ GeV}^2$, $0.0 < p_{\perp}^2 < 0.04 \text{ GeV}^2$, $0^\circ < \phi < 360^\circ$
- : $q^2 = -0.3 \text{ GeV}^2$, $0.03 < p_{\perp}^2 < 0.11 \text{ GeV}^2$, $-60^\circ < \phi < 60^\circ$
- ▼ : $q^2 = -0.18 \text{ GeV}^2$, $0.0 < p_{\perp}^2 < 0.07 \text{ GeV}^2$, $-60^\circ < \phi < 60^\circ$
- ▽ : $q^2 = -0.18 \text{ GeV}^2$, $0.1 < p_{\perp}^2 < 0.25 \text{ GeV}^2$, $-60^\circ < \phi < 60^\circ$

Fig. 5 The q^2 -dependence for $W = 2.43$ GeV. The lines correspond to the mean value of the points with the same x -value.

- : $0.4 < x < 0.6$, $p_{\perp}^2 < 0.04 \text{ GeV}^2$
- △ : $0.6 < x < 0.8$, $p_{\perp}^2 < 0.05 \text{ GeV}^2$
- : $0.8 < x < 1.0$, $p_{\perp}^2 < 0.1 \text{ GeV}^2$

Fig. 6 The q^2 -dependence for $W = 2.65$ GeV. The lines correspond to the mean value of the points with the same x -value.

- ▽ : $0.3 < x < 0.4$, $0.005 < p_{\perp}^2 < 0.035 \text{ GeV}^2$
- : $0.4 < x < 0.6$, $0.015 < p_{\perp}^2 < 0.075 \text{ GeV}^2$
- △ : $0.6 < x < 0.8$, $0.03 < p_{\perp}^2 < 0.1 \text{ GeV}^2$
- : $0.8 < x < 1.0$, $0.05 < p_{\perp}^2 < 0.2 \text{ GeV}^2$

Table Captions

Table 1 The values of $f_u + \epsilon f_L$, f_p and f_L at small $p_{\perp}^2$
($p_{\perp}^2 < 0.01 \text{ GeV}^2$).

Table 2 The q^2 -dependence.

Table 3 The W -dependence.

Table 4 The x -dependence.

Table 5 The $p_{\perp}^2$ -dependence.

Table 6 The ϕ -dependence.

Abbreviations and definitions used in tables 2 to 6

μ mean of the kinematical interval.

Δ total width of the interval.

$\langle \rangle$ mean of the interval weighted by the acceptance.

Reg ϕ -region.

$$\alpha \equiv \epsilon \frac{1}{\Delta\phi} \int_{\Delta\phi} \cos(2\phi) d\phi$$

$$\beta \equiv \sqrt{2\epsilon(\epsilon + 1)} \frac{1}{\Delta\phi} \int_{\Delta\phi} \cos\phi d\phi$$

$\sigma_t \equiv \sigma_{\text{tot}}$ total cross section for virtual photons.

δf error on f .

m_x invariant mass of the unobserved particles.

$t \equiv (q - p)^2$ square of the four-momentum transfer from the
photon to the kaon.

Table 1

$q^2 =$ $W =$ $q^2 =$ $W =$	-0.28 2.15 -0.50 2.255	GeV^2 GeV GeV^2 GeV	$0.6 < x < 0.8$ $0.8 < x < 1.0$ $0.4 < x < 0.6$ $0.6 < x < 0.8$ $0.8 < x < 1.0$	0.0518 ± 0.0097 0.0826 ± 0.0073 0.1058 ± 0.0122 0.0665 ± 0.0123 0.0508 ± 0.0043	$f_u + \epsilon f_L$ GeV^{-2}	0.0294 ± 0.0168 0.0173 ± 0.0134 0.0266 ± 0.0225 -0.0144 ± 0.0110 0.0134 ± 0.0078	f_p GeV^{-2}	-0.0054 ± 0.0093 0.0012 ± 0.0067 -0.0083 ± 0.0114 0.0123 ± 0.0055 0.0039 ± 0.0039	f_L GeV^{-2}
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Table 2

25020

Fig. 3

Fig. 2

Fig. 5

Fig. 6

Fig. 4