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HIGH p_T $K^\pm/\pi^\pm$ PRODUCTION IN p-p COLLISIONS AT THE ISR;
STRANGENESS SUPPRESSION AND GLUON EFFECTS

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ABSTRACT

The ratios of high p_T charged kaon to pion production cross sections at $\sqrt{s} = 45$ and 62 GeV are presented. The values of the $K^\pm/\pi^\pm$ ratios are essentially independent of both $\sqrt{s}$ and $x_T = 2 p_T/\sqrt{s}$ and are compatible with a strangeness suppression factor $\lambda = 0.55$. By contrast, the K^-/π^- values fall with x_T suggesting a gluonic origin of K^- . QCD calculations agree with the measurements.

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1. INTRODUCTION

The relative yields of high transverse momentum kaons and pions produced in proton-proton collisions provide sensitive tests for models describing hard scattering of proton constituents. From the experimental point of view the production ratios of like-charged particles (e.g. K^+/π^+ and K^-/π^-) at the same momenta involve small systematic uncertainties. In this letter we report results for charged kaons and pions obtained with the Split Field Magnet detector at the ISR at $\sqrt{s} = 45$ GeV and a c.m. polar angle $\theta \approx 50^\circ$. We compare them with similar results reported previously by our group for $\sqrt{s} = 62$ GeV and $\theta \approx 50^\circ$ [1], and also with the Chicago-Princeton results for $\sqrt{s} = 27$ and 23 GeV at $\theta \approx 90^\circ$ [2]. A brief description of the apparatus and analysis is provided in a preceding letter [3] in which measurements of inclusive pion production cross sections at $\sqrt{s} = 45$ GeV are presented.

In the framework of QCD the inclusive production ratios K^+/π^+ and K^-/π^- at high transverse momentum p_T are expected to be different. Presumably a high p_T π^+ meson ($u\bar{d}$ quark content) is produced dominantly from a scattered up-quark which has extracted a $d\bar{d}$ pair from the vacuum, while a K^+ meson ($u\bar{s}$) comes from an up-quark plus an $s\bar{s}$ pair. Thus the ratio K^+/π^+ reflects strangeness suppression in the fragmentation process.

Likewise, a high p_T π^- meson ($d\bar{u}$) is produced dominantly from a scattered down-quark. However, K^- mesons ($s\bar{u}$) contain no valence quarks in common with the beam proton and must therefore be produced from other processes such as (a) $\bar{u}$ or s scattering, (b) "rank re-ordering" [4] in which a valence quark has scattered but is not contained in the fastest fragment, i.e. the observed meson, or (c) gluon scattering. Such processes contribute relatively little to high p_T K^+ , π^+ , π^- production [5]. Thus one expects the K^-/π^- ratio to be smaller than the K^+/π^+ ratio.

2. RESULTS

A threshold Cerenkov counter was used to separate pions from kaons and protons above $p_T \approx 3$ GeV/c. The production ratios $p^\pm/K^\pm$ have been measured separately at $\sqrt{s} = 23$ and 27 GeV [2] and at 62 GeV [6]. Here they were used to calculate the $K^\pm/\pi^\pm$ ratios from the measured ratios $\pi^\pm/(\text{hadrons})^\pm$ at $\sqrt{s} = 45$ and 62 GeV. The p/K^+ ratio at $\sqrt{s} = 45$ GeV was derived by interpolating the data at $\sqrt{s} = 23, 27$ and 62 GeV at fixed p_T . To obtain the $\bar{p}/K^-$ ratios at $\sqrt{s} = 45$ and 62 GeV in the relevant p_T range, the available data [2,6] were interpolated and extrapolated assuming the same slopes of the p_T and $\sqrt{s}$ dependences that were observed in the p/K^+ data. The results have been corrected for Cerenkov counter inefficiencies (negligible for $p_T \geq 3.5$ GeV/c) and for decays in flight ($\leq 10\%$). Corrections for nuclear absorption, calculated to be about 14%, were applied as well. The estimated total uncertainty of the $K^\pm/\pi^\pm$ ratios at 45 and 62 GeV is dominated by the $p^\pm$ subtraction (see table 1). Uncertainties from decays in flight, Cerenkov inefficiency, and nuclear absorption are each less than $\pm 1.0\%$.

Our results for the K^+/π^+ and K^-/π^- ratios are displayed in fig. 1 and given in table 1. The most prominent trend is the very significant difference between the ratios. In particular the following details emerge:

(a) K^+/π^+

The K^+/π^+ production ratios at both $\sqrt{s} = 62$ and 45 GeV are compatible with a constant value of 0.456 ± 0.003 (statistical) ± 0.018 (systematic) as shown in fig. 1.

In fig. 2, our results are further compared with the Chicago-Princeton measurements performed at $\sqrt{s} = 27$ and 23 GeV for $\theta \approx 90^\circ$ [2]. The latter results are much below this average for values of p_T below 3 GeV/c ($x_T \leq 0.2$) and are relatively constant above $p_T = 3$ GeV/c at values similar to ours. This suggests that above $p_T = 3$ GeV/c, the ratio K^+/π^+ is essentially independent of both x_T and $\sqrt{s}$.

Qualitatively, this result agrees well with the idea that the dominant contribution to both π^+ and K^+ production arises from up-quark scattering and that in the fragmentation to a K^+ the up-quark extracts a $s\bar{s}$ pair from the vacuum (with a probability $P(s\bar{s}) = \lambda P(d\bar{d})$) rather than a $d\bar{d}$ pair. Thus one expects

$$\frac{K^+}{\pi^+} \approx \frac{P(s\bar{s})}{P(d\bar{d})} = \lambda.$$

We have compared our data with predictions from a QCD Monte-Carlo program, whose details are described in the preceeding letter [3] and in refs [7,8]. The ratio K^+/π^+ is predicted (fig. 2) to be independent of $\sqrt{s}$ over the range from 27 to 62 GeV at a value of about 0.41 and to rise very slowly with x_T in our kinematical range.

The value of the predicted ratio (i.e. 0.41) is smaller than the strangeness suppression factor $\lambda = 0.5$ used in the fragmentation model [4] because of vector meson (e.g. K^*) production and decay. Scaling the predicted to the measured value, one obtains $\lambda = 0.55 \pm 0.05$ for our kinematic region, in which the observed meson carries 70-80% [9] of the parton's momentum. The quoted uncertainty reflects the K^+/π^+ measurement precision as well as the estimated uncertainty in relative vector meson production. This result can be compared with $\lambda = 0.3 \pm 0.1$ extracted with the same fragmentation model from measurements of e^+e^- and lepton-nucleon collisions where the observed mesons carry generally less than 50% of the parton momentum [10]. A more direct determination of λ is expected from a measurement of K^* production at large transverse momentum [11].

(b) K^-/π^-

Table 1 and fig. 1 indicate that the K^-/π^- ratio is substantially smaller than the K^+/π^+ ratio at both $\sqrt{s} = 62$ and 45 GeV. This is expected since K^- mesons do not share any valence quarks with protons. Furthermore K^-/π^- falls from ≈ 0.35 at $x_T \approx .1$ to ≈ 0.1 at $x_T \approx .3$ at both energies, indicating a "softer" source of K^- mesons than that of π^- mesons.

This agrees qualitatively with the idea that the gluon structure function (and likely the gluon fragmentation function) is softer than those of quarks.

There is also an indication of a 'scale breaking' effect in our data: the K^-/π^- ratio at constant x_T decreases with $\sqrt{s}$, i.e. it depends on $Q^2 \propto p_T^2$. Evaluated at $x_T \approx 0.18$, in the region of highest precision, one finds a difference between the two data sets of about 0.04 ± 0.006 , whereas the relative systematic uncertainty is ≤ 0.01 .

In fig. 3 we compare our results with the Chicago-Princeton data at $\theta \approx 90^\circ$ for $p_T > 3$ GeV/c [2]. This comparison appears to confirm the scalebreaking trend, though some of the difference may come from the different scattering angles [12]. Also shown are our predictions for the production ratios K^-/π^- for $\theta = 50^\circ$ at $\sqrt{s} = 62$ and 45 GeV and for $\theta = 90^\circ$ at $\sqrt{s} = 27$ GeV as well as the predictions for the "no gluons" case. In the latter no subprocesses with gluons in the initial or final states are allowed such that graphs including the triple gluon vertex do not contribute.

We note:

- (a) The predictions are typically within 10-20% of the data.
- (b) Between $\sqrt{s} = 45$ and 62 GeV, the predicted difference due to scale breaking is about 0.03 at $x_T = 0.18$, in agreement with the experimental evidence.
- (c) The data do not agree with the prediction for the "no gluons" case, which is essentially independent of $\sqrt{s}$ and θ with little dependence on x_T . This indicates a substantial contribution from gluon scattering to K^- production. From our QCD calculations we find that, whereas scattered gluons contribute only ≈ 20 -25% of π^+ and K^+ mesons and $\approx 35\%$ of π^- mesons, they yield $\approx 60\%$ of K^- mesons for $p_T \gtrsim 4$ GeV/c.

3. CONCLUSIONS

We have measured the K^+/π^+ ratio and found that for $p_T > 3$ GeV/c it is essentially independent of both x_T and $\sqrt{s}$ with an average value of 0.46 ± 0.02 . This result agrees well with the idea that π^+ and K^+ mesons are produced dominantly from valence up-quarks of the proton, with $d\bar{d}$ and $s\bar{s}$, respectively, extracted from the sea. Comparison with our QCD calculation leads to the interpretation that there is a strangeness suppression factor $\lambda = 0.55 \pm 0.05$ in our kinematical range.

The K^-/π^- ratio is always smaller than the K^+/π^+ ratio and falls with increasing x_T . QCD predictions agree reasonably well with the measurements of the K^-/π^- ratio both in normalization and slope in x_T . Our QCD calculations indicate that $\approx 60\%$ of the K^- mesons at $p_T \approx 4$ GeV/c may originate from gluon scattering, whereas the π^- mesons arise dominantly from quark scattering. Hence the measured K^-/π^- ratio provides valuable information about the gluon structure function (though convoluted with scattering cross sections and fragmentation functions).

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TABLE 1

Production ratios π^+/h^+ , π^-/h^- , K^+/π^+ and K^-/π^- vs p_T and x_T at $\theta = 50^\circ$ for $\sqrt{s} = 45$ and 62 GeV. The errors given include statistical errors and all systematic uncertainties except for the one from $p^\pm$ subtraction. The uncertainties due to the latter correction are smaller than 5% for the ratio K^-/π^- at $p_T \leq 4$ GeV/c for both energies and for the K^+/π^+ ratio at $\sqrt{s} = 45$ GeV; for all other data they are smaller than 2%.

$\sqrt{s} = 45$ GeV					
p_T	x_T	π^+/h^+	K^+/π^+	π^-/h^-	K^-/π^-
3.10	0.140	0.571 ± 0.015	0.455 ± 0.028	0.694 ± 0.033	0.361 ± 0.055
3.30	0.149	0.576 ± 0.004	0.454 ± 0.007	0.721 ± 0.016	0.322 ± 0.025
3.50	0.158	0.581 ± 0.005	0.454 ± 0.009	0.741 ± 0.004	0.296 ± 0.006
3.70	0.167	0.578 ± 0.006	0.468 ± 0.011	0.748 ± 0.005	0.289 ± 0.008
3.90	0.176	0.585 ± 0.007	0.464 ± 0.013	0.764 ± 0.007	0.269 ± 0.010
4.10	0.185	0.597 ± 0.008	0.450 ± 0.015	0.768 ± 0.008	0.265 ± 0.012
4.30	0.194	0.596 ± 0.011	0.460 ± 0.021	0.772 ± 0.010	0.262 ± 0.015
4.50	0.203	0.608 ± 0.013	0.446 ± 0.024	0.806 ± 0.012	0.215 ± 0.016
4.70	0.212	0.625 ± 0.016	0.424 ± 0.029	0.767 ± 0.017	0.272 ± 0.026
4.90	0.221	0.582 ± 0.019	0.518 ± 0.040	0.806 ± 0.018	0.217 ± 0.025
5.40	0.243	0.635 ± 0.018	0.434 ± 0.034	0.818 ± 0.018	0.202 ± 0.024
6.41	0.289	0.628 ± 0.042	0.487 ± 0.091	0.874 ± 0.040	0.131 ± 0.048
$\sqrt{s} = 62$ GeV					
3.12	0.099	0.592 ± 0.008	0.445 ± 0.015	0.710 ± 0.017	0.357 ± 0.028
3.37	0.107	0.597 ± 0.003	0.444 ± 0.006	0.713 ± 0.009	0.355 ± 0.013
3.62	0.115	0.594 ± 0.004	0.459 ± 0.008	0.722 ± 0.004	0.342 ± 0.008
3.87	0.123	0.589 ± 0.005	0.480 ± 0.010	0.738 ± 0.006	0.316 ± 0.009
4.10	0.131	0.608 ± 0.005	0.453 ± 0.009	0.728 ± 0.004	0.330 ± 0.007
4.30	0.137	0.622 ± 0.005	0.436 ± 0.009	0.751 ± 0.005	0.295 ± 0.008
4.50	0.143	0.608 ± 0.006	0.472 ± 0.012	0.751 ± 0.005	0.296 ± 0.010
4.78	0.152	0.608 ± 0.006	0.484 ± 0.012	0.771 ± 0.005	0.267 ± 0.008
5.18	0.165	0.623 ± 0.008	0.468 ± 0.016	0.778 ± 0.007	0.258 ± 0.010
5.59	0.178	0.636 ± 0.011	0.454 ± 0.022	0.801 ± 0.009	0.225 ± 0.013
6.07	0.193	0.649 ± 0.011	0.440 ± 0.021	0.801 ± 0.010	0.226 ± 0.014
6.67	0.212	0.624 ± 0.017	0.503 ± 0.036	0.852 ± 0.010	0.159 ± 0.013
7.44	0.237	0.683 ± 0.020	0.398 ± 0.037	0.863 ± 0.019	0.146 ± 0.023
8.44	0.269	0.623 ± 0.040	0.532 ± 0.091	0.906 ± 0.032	0.096 ± 0.036

FIGURE CAPTIONS

- Fig. 1 K^+/π^+ production ratios in proton-proton collisions at $\sqrt{s} = 62$ and 45 GeV for $\theta \approx 50^\circ$, plotted as function of x_T . The solid line is a fit to the K^+/π^+ ratio.
- Fig. 2 K^+/π^+ production ratios vs x_T at $\sqrt{s} = 62$ and 45 GeV for $\theta \approx 50^\circ$ and at $\sqrt{s} = 27$ and 23 GeV for $\theta \approx 90^\circ$ [2]. The dashed line comes from a QCD calculation with $\lambda = 0.5$.
- Fig. 3 K^-/π^- production ratios vs x_T at $\sqrt{s} = 62$ and 45 GeV for $\theta \approx 50^\circ$ and at $\sqrt{s} = 27$ and 23 GeV for $\theta \approx 90^\circ$ [2]. Also displayed are the results of QCD calculations.

Fig. 1

Fig. 2

Fig. 3