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K_S^0 production in $\bar{p}p$ interactions at $\sqrt{s}=630$ and 1800 GeV

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Measurements of inclusive transverse-momentum spectra for K_S^0 mesons produced in proton-antiproton collisions at $\sqrt{s}$ of 630 and 1800 GeV are presented and compared with data taken at lower energies. The ratio, as a function of p_T, of the cross section for K_S^0 to that for charged hadrons is very similar to what is observed at lower energies. At 1800 GeV, we calculate the strangeness-suppression factor $\lambda = 0.40 \pm 0.05$.

We report measurements of the inclusive transverse-momentum spectra for K_S^0 produced in proton-antiproton collisions at the Fermilab Tevatron Collider. Results were obtained at center-of-mass energies of 630 and 1800 GeV over the rapidity range $|y| < 1$ using the Collider Detector at Fermilab (CDF). A comparison of our data with lower-energy data shows that the inclusive cross section at fixed momentum transverse to the beam axis (p_T) continues to increase rapidly with $\sqrt{s}$ from 23 to 1800 GeV, especially for $p_T \gtrsim 1$ GeV/c, while the ratio, as a function of p_T, of the cross section for K_S^0 to that for charged hadrons changes little with $\sqrt{s}$.

CDF (Ref. 1) is a large azimuthally symmetric general-purpose detector built to study $\bar{p}p$ collisions at the Tevatron Collider. The essential detector component for this analysis is the central tracking chamber (CTC), which was used to reconstruct K_S^0 decays into charged pions. The CTC (Ref. 2) is a cylindrical drift chamber located in a 1.515-T axial magnetic field, with 84 layers of sense wires lying between 0.3 and 1.4 m from the beam axis. For these data, the spatial resolution of each measurement was < 300 μm. Almost all our K_S^0 decay vertices occur well inside the inner CTC radius, and thus are not seen directly in the CTC.

The data samples used here are samples of minimum-bias events and are the same samples as used in Ref. 3. The trigger required at least one hit in each of two arrays of scintillation counters covering the pseudorapidity range $3.0 < |\eta| < 5.89$. As in Ref. 3, we use only events with at least four tracks in $|\eta| < 3$ in the vertex time-projection chamber (VTPC),[4] and an event vertex within 65 cm of the nominal interaction point (to insure full VTPC acceptance in $|\eta| < 3$). The number of events used, after selection cuts were applied, was 44000 at 1800 GeV and 3800 at 630 GeV.

Candidates for K_S^0 decay were obtained by first fitting pairs of oppositely charged tracks to a common vertex. Tracks were required to have $p_T > 250$ MeV/c and an impact parameter transverse to the beam axis greater than 2 mm. Pairs for which the χ^2 degree of freedom of the vertex fit was less than 5 were accepted for further analysis. A substantial background survives this selection. Therefore, in addition, we required that the reconstructed decay vertex be separated from the beam axis by more than 2 cm and that the distance of closest approach of the momentum vector of the K_S^0 candidate to the primary event vertex be less than 2 cm.

The invariant mass of pairs surviving these cuts is shown in Fig. 1, where both tracks are assumed to be pions. About 450 track pairs lie within 3σ of the K_S^0 mass; these are treated as K_S^0 candidates. There are about 100 background pairs under the peak. In the 630-GeV data, there are 27 K_S^0 candidates and about 11 background pairs under the peak. Pairs which lie from 5σ to 8σ above or below the K_S^0 mass are used to estimate and subtract from all physics distributions the contribution from this background.

In order to check for contamination from $\Lambda/\bar{\Lambda}$, we have calculated invariant masses for each K_S^0 candidate as if one daughter were a proton and one a pion. We find that $\Lambda/\bar{\Lambda}$ contamination is at most 1%.

The efficiency for finding K_S^0 is affected by inefficiencies in the track-reconstruction algorithm and the vertex-finding algorithm, as well as by subsequent selection criteria. The track-finding efficiency is a strong function of p_T for tracks with $p_T \lesssim 330$ MeV/c, which may go through several helix turns inside the CTC active volume. Also, confusion due to hits from unrelated tracks may cause K_S^0 daughter tracks to be misreconstructed such that the decay vertex fit is of unacceptable quality or some cut is not passed. We treat the K_S^0 efficiency as a function of the p_T of the kaon candidate and of the number of primary CTC tracks in the event in which the candidate was found. To estimate the efficiency, we generated ensembles of Monte Carlo K_S^0, using the full CDF detector simulation,[5] which models decay kinematics, multiple scattering and energy loss in the detector material, and the CTC acceptance and resolution. We then superimposed the simulated kaons on actual minimum-bias events, and the resulting CTC hit patterns were reconstructed. The selection cuts described above were chosen such that small uncertainties in our resolution will have a negligible effect on our efficiencies. The overall efficiency for our K_S^0 candidates, including the effects of decay length, pattern recognition, and fiducial cuts, ranges from 1% to 50% and averages 9%.

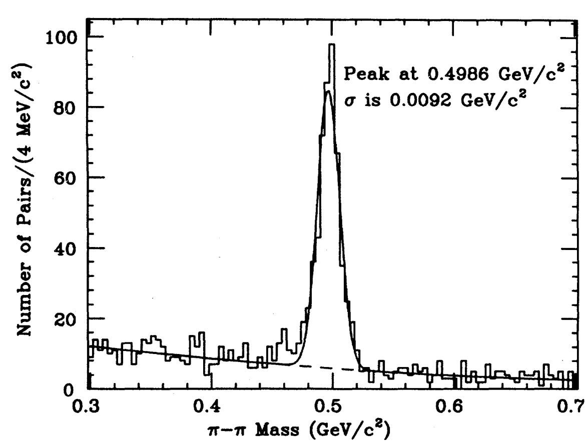

FIG. 1. Invariant mass with a π-π mass assignment for oppositely signed track pairs passing all geometrical cuts. 1800-GeV data are shown. The curve and the peak and σ values are results of a fit to a Gaussian plus a linear background.

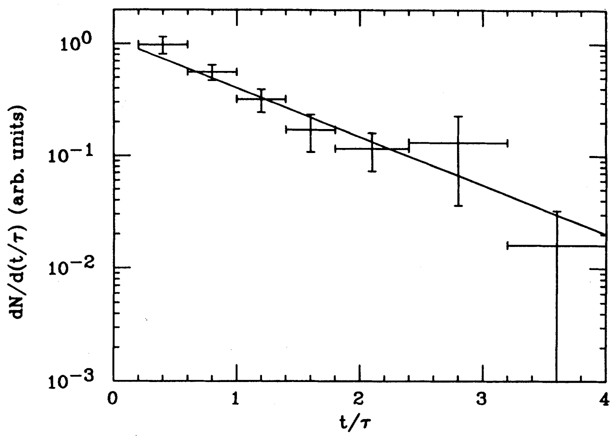

FIG 2. Corrected K_S^0 lifetime distribution for the 1800-GeV data. τ is the K_S^0 proper lifetime. The line shown has a slope of -1.

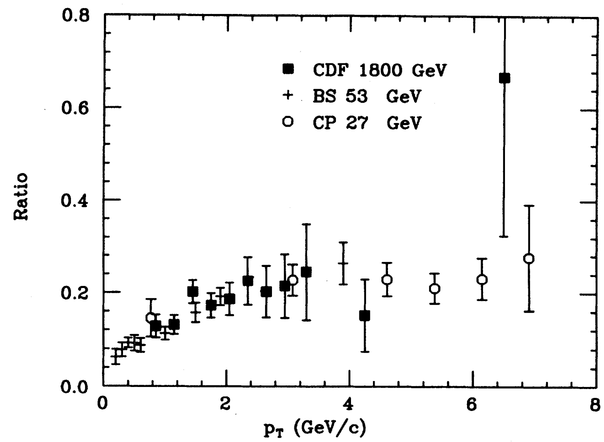

FIG. 4. Ratio cross section for K_S^0 to that for charged hadrons: CDF ($|y|<1.0$), British-Scandinavian (BS) ($y=0$) (Ref. 17), and CP ($y=0$) (Ref. 16) Collaborations.

To verify the efficiency calculations, we have made a background-subtracted corrected lifetime distribution (Fig. 2). The fitted slope of this distribution is -1.3 ± 0.2, consistent with the expected value of -1.

As in Ref. 3, the normalization of our inclusive cross sections is based on estimated effective cross sections for events which pass our trigger and selection criteria. Those cross-section values are 43 ± 6 mb at 1800 GeV and 34 ± 3 mb at 630 GeV. Uncertainties in our estimates of these cross sections are the principal source of error in the overall normalization of the presented results.

Our results are shown with lower-energy data in Fig. 3. The cross sections shown have been corrected for the unseen decays $K_S^0 \rightarrow \pi^0\pi^0$. The shape of the inclusive cross section at 630 GeV agrees reasonably well with the fit to UA5 data taken at $\sqrt{s}=546$ GeV.[6]

Figure 4 shows the ratio of our K_S^0 cross section to our charged-hadron cross section as a function of p_T. Also plotted is charged-kaon data from experiments at lower $\sqrt{s}$, averaged over positive and negative kaons. All data are in reasonable agreement.

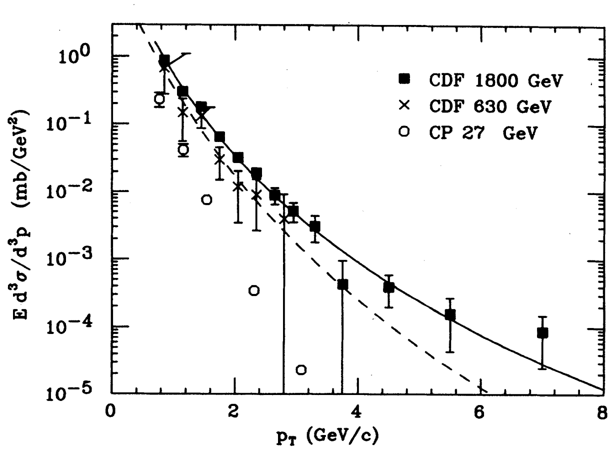

FIG. 3. Inclusive cross sections for rapidity $|y|<1.0$: CDF 1800 GeV, CDF 630 GeV, and Chicago-Princeton (CP) ($y=0$) (Ref. 16). The dashed line is a fit to UA5 data taken at $\sqrt{3}=546$ GeV, Ref. 6, and the solid line is a fit to CDF 1800-GeV data with p_0 fixed at 1.3 GeV/c.

Invariant cross sections were fitted with the functional form[7]

$$E\frac{d^3\sigma}{d^3p}=\frac{Ap_0^n}{(p_T+p_0)^n}\,. \tag{1}$$

We find that p_0 and n are highly correlated. The data are not sufficient to simultaneously fit all three parameters; therefore, we fix p_0 at 1.3 GeV/c, as in Ref. 3. The fit parameters A and n and their statistical uncertainties are given in Table I. The fit to the 1800-GeV data is shown in Fig. 3.

The mean value of transverse momentum $\langle p_T \rangle$ and the K_S^0 central rapidity density $\rho_K(0) \equiv dN/dy\,|_{y=0}$ can be obtained by evaluating integrals involving the K_S^0 momentum distribution. To integrate over all p_T we must extrapolate the cross section below 0.7 GeV/c. For the values shown in Table II, we adopt the extrapolation used by the UA5 Collaboration,[8] where the power-law form (1) is used for $p_T > 0.4$ GeV/c, and the form $E\,d^3\sigma/d^3p = C\exp(-bm_T)$ is used below 0.4 GeV/c, and continuity of function and slope is demanded at the transition. With this extrapolation, about 30% of all K_S^0 lie above 0.7 GeV/c.

By varying the position of the transition point between the two forms, and by varying the functional form below the transition point,[9] we estimate that for the 1800-GeV

TABLE I. Results of fits of the power-law form (1). Uncertainties given are statistical only.

$\sqrt{s}$ (GeV)	A [mb/(GeV^2/c^3)]	n	$\chi^2/N_{\rm DF}$
630	37 ± 33	8.2 ± 1.1	2.2/6
1800	45 ± 9	7.7 ± 0.2	8.1/11

TABLE II. Variation with $\sqrt{s}$ of mean p_T, central rapidity density, and strangeness-suppression factor. UA5 results are from Ref. 8. Uncertainties given for CDF values are statistical only.

Expt.	$\sqrt{s}$ (GeV)	$\langle p_T \rangle$ (GeV/c)	K/π	$\rho_K(0)$	λ
UA5	200	0.53 ± 0.07	0.089 ± 0.011	0.14 ± 0.02	0.26 ± 0.03
UA5	546	0.57 ± 0.03	0.095 ± 0.009	0.15 ± 0.02	0.30 ± 0.03
CDF	630	0.5 ± 0.1	0.12 ± 0.06	0.2 ± 0.1	0.4 ± 0.2
UA5	900	0.62 ± 0.08	0.100 ± 0.008	0.18 ± 0.02	0.29 ± 0.02
CDF	1800	0.60 ± 0.03	0.13 ± 0.02	0.26 ± 0.03	0.40 ± 0.05

data, the probable uncertainty due to the extrapolation procedure is 0.05 GeV/c on $\langle p_T \rangle$, and 0.03 on $\rho(0)$.

The strangeness-suppression factor λ represents the probability of producing a strange quark from the vacuum relative to that of producing an up or down quark. In statistical quark models,[10,11] λ can be calculated from the ratio $\rho_K(0)/\rho_\pi(0)$, where $\rho_\pi(0)$ is the average of the positive- and negative-pion rapidity densities at $y=0$. To obtain $\rho_\pi(0)$ we subtract the measured kaon contribution and an assumed $p\bar{p}$ contribution from our measured values of charged-hadron $dN/d\eta$ at $\eta=0$.[12] The $p\bar{p}$ contribution is estimated assuming a K/p ratio of 1.48, calculated from exponential fits to UA2 data.[13] In transforming from η to y, we assume that the p_T spectra of $\pi^\pm$ follow the inclusive charged-hadron spectrum of Ref. 3, and that the p_T spectrum of protons is identical to that of K_S^0 and charged hadrons are similar, and that the p_T spectrum of protons is identical to that of K_S^0. Our results are shown in Table II. At 1800 GeV, the model of Ref. 10 gives us a λ value that is 0.02 higher than the value obtained using the model of Ref. 11, compared to statistical uncertainties of 0.05. The numbers in Table II are calculated in the model of Ref. 10. Both our 1800- and 630-GeV results are consistent with the value 0.29 ± 0.02 calculated by Malhotra and Orava[14] from a very wide range of experimental data. Our results are not very sensitive to the assumed K/p ratio; varying K/p between 1 and 2 changes our K/π estimate by 0.003 and our λ value by 0.01.

We have divided our data sample roughly into thirds according to the primary charged-track multiplicity, where the multiplicity is measured by the CDF VTPC in the range $|\eta| < 3$. Using the same procedure outlined above, we have estimated the K/π ratio and λ for each multiplicity range.[15] We do not see any statistically significant change with multiplicity of K/π or λ.

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