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Pseudorapidity distributions of charged particles produced in $\bar{p}p$ interactions at $\sqrt{s}=630$ and 1800 GeV

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We present measurements of the pseudorapidity (η) distribution of charged particles ($dN_{ch}/d\eta$) produced within $|\eta| \leq 3.5$ in proton-antiproton collisions at $\sqrt{s}$ of 630 and 1800 GeV. We measure $dN_{ch}/d\eta$ at $\eta=0$ to be $3.18\pm0.06(\text{stat})\pm0.10(\text{syst})$ at 630 GeV, and $3.95\pm0.03(\text{stat})\pm0.13(\text{syst})$ at 1800 GeV. Many systematic errors in the ratio of $dN_{ch}/d\eta$ at the two energies cancel, and we measure $1.26\pm0.01\pm0.04$ for the ratio of $dN_{ch}/d\eta$ at 1800 GeV to that at 630 GeV within $|\eta| \leq 3$. Comparing to lower-energy data, we observe an increase faster than $\ln(s)$ in $dN_{ch}/d\eta$ at $\eta=0$.

We present measurements of the pseudorapidity distribution of charged particles ($dN_{ch}/d\eta$, where the pseudorapidity $\eta=-\ln[\tan(\theta/2)]$, and θ is the polar angle in the laboratory frame) produced within $|\eta| \leq 3.5$ in proton-antiproton collisions observed at center-of-mass energies ($\sqrt{s}$) equal to 630 and 1800 GeV. Measurements are made with the Collider Detector at Fermilab (CDF). Since the same detector and analysis are used at both energies, many systematic errors in the ratio of η distributions at the two energies cancel almost completely.

Multiparticle production in high-energy hadron-hadron collisions has been described by statistical hydrodynamical models,[1] and also by models that combine parton-parton interactions with string fragmentation models.[2,3] In models of the former type, the energy dependence of $dN_{ch}/d\eta$ in the central region, given an equation of state and a velocity of sound, is determined by the initial energy density neglecting leading particles.[1,4,5] Models of the latter type describe this energy dependence in terms of multiple parton-parton scattering, or equivalently, the number of strings or chains contributing to particle production.[2,3] Existing data, extending from $\sqrt{s}=15$ up to 900 GeV (Refs. 6–8) exhibit a rise in the value of $dN_{ch}/d\eta$ at $\eta=0$ consistent with a $\ln(s)$ dependence on s.

CDF is an azimuthally symmetric, 4π detector at the Fermilab Tevatron collider. Details of CDF are described elsewhere.[9] The present analysis uses data from two detector subsystems: the vertex time-projection chamber (VTPC) (Ref. 10) to provide charged-particle tracking, and the beam-beam counters (BBC) (Ref. 11) to trigger the detector. Figure 1 shows a cross-sectional view of one quadrant of the inner detector including the BBC and VTPC.

The BBC consists of two sets of scintillation counters placed along the beam axis 5.82 m on either side of the interaction region. The counters cover the η range $3.2 \lesssim |\eta| \lesssim 5.9$.

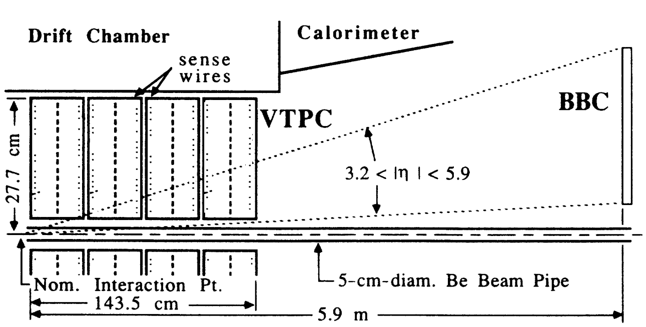

FIG. 1. Cross-sectional view of one quadrant of the VTPC and BBC. Note the difference in horizontal and vertical scales.

The VTPC is a set of eight time-projection chambers that measure the trajectory of charged particles as they exit the beam pipe. The chambers provide nearly uniform acceptance over 2π in azimuth and about ±3 units in η. Each chamber (called a module) surrounds the beam pipe and consists of two planes of sense wires attached to opposite ends of back-to-back drift regions. The sense-wire planes are segmented azimuthally into octants and aligned perpendicular to the beam axis. Each octant has 24 parallel sense wires arranged in increasing distance from the beam axis.

Ionization deposited in the chamber drifts along the beam direction toward the nearest sense wire. By measuring the arrival time of the ionization, we determine the distance at which the particle crosses a wire layer within a given octant. We assign an azimuthal position corresponding to the center of the octant to tracks that traverse only a single module. An 11.5° rotation between adjacent modules allows three-dimensional reconstruction of tracks that traverse more than one module.

For the data presented here, we achieve a measurement precision better than 0.07 units of η for $\eta>3$, and better than 0.005 near $\eta=0$. The chamber resolves track pairs that pass through the same octant if separated by at least 0.06 units of η; tracks in different azimuthal segments are unambiguously resolved.

Low-density construction materials and a beryllium beam pipe minimize the amount of material particles traverse before entering the active volume. At $\eta=0$, the amount of material corresponds to 0.5% of a radiation length, increasing to 7.5% at $\eta=3.6$. Contamination from photon conversions and hadronic interactions is less than a few percent of the multiplicity within $|\eta|<3$ (see Fig. 2).

The detector trigger requires at least one hit in each set of BBC counters in coincidence with the beam crossing. The present analysis uses about 30000 triggers at 1800 GeV and 9400 triggers at 630 GeV collected during the 1987 run. Additional details of the minimum-bias runs and the BBC trigger acceptance can be found in Ref. 12.

Several off-line software cuts eliminate beam-gas background and select $\bar{p}p$ collisions from the data sample. The selection procedure retains events that pass either of the following two tests: (1) a minimum of four tracks in the VTPC with at least one in each of the forward and backward hemispheres; (2) an interaction point derived from VTPC information (requiring at least two tracks) within 16 cm of that determined from BBC time of flight (at least three hits in each set of BBC counters). We do not correct for events missed by the trigger or selection procedure.

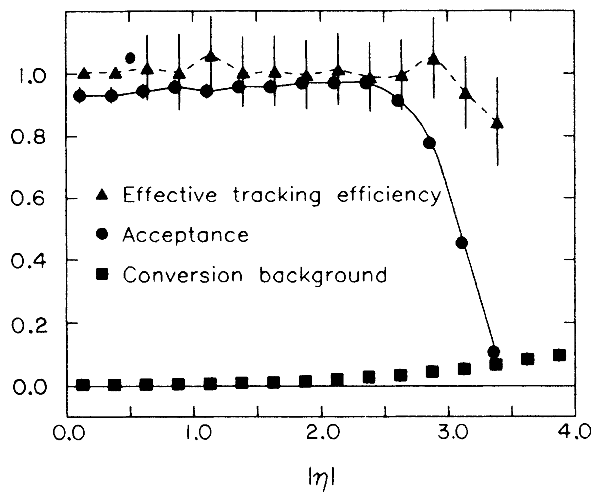

FIG. 2. Effective tracking efficiency, acceptance, and fraction of observed tracks attributed to background from photon conversions vs $|\eta|$. Curves are drawn to guide the eye.

Data from runs with one or more missing $\bar{p}$ bunches allow estimation of the fraction of beam-gas interactions that pass the event-selection criteria. We set upper limits of $<0.2\%$ beam-gas background at 1800 GeV, and $<2.0\%$ at 630 GeV. The background introduces negligible bias. From the same data, we also estimate that $(13\pm6)\%$ of events with vertices found in the VTPC are missed by the selection procedure.

Additional event selection in the final analysis includes only those events with interaction vertices within ± 12 cm of the middle of individual VTPC modules. This cut avoids nonuniformities in the acceptance caused by gaps between modules. The final event sample contains about 21 000 events at 1800 GeV, and 2800 events at 630 GeV.

To be included in the η distribution, a track must traverse a minimum of 11 of the available 24 wire layers and pass an impact-parameter cut. The impact parameter, defined as the longitudinal distance from the event vertex to the track intercept with the beam axis, divided by the expected resolution, must be less than ten.

To obtain the final η distribution, the observed distribution must be corrected for geometric and kinematic acceptance, tracking efficiency, and charged-particle background from decays and secondary interactions in the beam pipe and VTPC. The solid circles in Fig. 2 show the acceptance as a function of $|\eta|$ averaged over azimuth.

The VTPC operates in a 1.5-T magnetic field coaxial with the beam axis, and the resulting curvature of tracks causes a loss of tracking efficiency for particles with transverse momentum (p_t) less than about 50 MeV/c. These tracks spiral entirely within the outer radius of the VTPC. Extrapolating the inclusive p_t spectrum[12] to $p_t=0$, we find the fraction of such tracks to be $(3\pm2)\%$ (for both 630 and 1800 GeV). We adjust the acceptance to include the effects of tracks below this low-p_t cutoff.

The tracking efficiency is measured from a visual scan of about 400 events from the 1800-GeV sample. Mistakes made by the reconstruction program are corrected during scanning, and the corrected tracks subjected to the above track selection. The ratio of the number of accepted tracks before and after the scan yields the effective efficiency plotted as solid triangles in Fig. 2. Note that this quantity exceeds unity in regions where the reconstruction finds more tracks than the scan. The corrections are less than 5% over most of the η acceptance, while contributions to the systematic uncertainty are about 1.2% near $\eta=0$, rising to about 11% for $\eta>1.0$.

We estimate and subtract charged-particle background from photon conversions, decays of neutral (and charged) particles, and secondary hadronic interactions in the beam pipe and VTPC. The solid squares plotted in Fig. 2 show, as a function of $|\eta|$, the fraction of tracks that contribute to the observed η distribution resulting from photon conversions. The points are calculated from a Monte Carlo simulation assuming the average photon η distribution is approximately equal to that of charged particles.[13] Although the background level is extremely small in the central region, it rises to nearly 10% at $|\eta|=3.5$. The plot is valid for both 630- and 1800-GeV data.

The decay of neutral kaons to charged pions is the dominant source of background from particle decays. Assuming a K/π ratio equal to 0.11 ± 0.01 at 1800 GeV,[14] and 0.10 ± 0.01 at 630 GeV (extrapolating from Ref. 15), Monte Carlo studies indicate background levels between 2 and $3\%\pm1\%$ over our η range. Assuming 80% of charged particles are pions, and a charged-to-neutral pion ratio equal to two, we estimate Dalitz decays of neutral pions to contribute an additional 1% at all η values. All other decays (excluding contributions from charged-mode decays of η mesons[16]) contribute negligibly to the observed $dN_{ch}/d\eta$ distribution. Monte Carlo calculations indicate that background from secondary hadronic interactions is insignificant.

Corrected η distributions for both 630 and 1800 GeV are plotted in Fig. 3(a). Statistical uncertainties lie entirely within the plotted symbols, while systematic uncertainties (one standard deviation for 1800 GeV) are indicated along the lower edge of the plot. Uncertainties in the tracking efficiency dominate the systematic uncertainty, and are common to both distributions. For comparison, a measurement from the CERN SPS collider performed by UA5 at $\sqrt{s}=546$ GeV (Ref. 8) is also plotted in Fig. 3(a).

From a study of the energy dependence of our corrections, we find that systematic effects in the ratio of $dN_{ch}/d\eta$ at the two energies cancel at the level of $\pm3\%$. The ratio is plotted as a function of $|\eta|$ in Fig. 3(b). The scatter in the points is well within the systematic uncertainty, and the ratio is consistent with being flat. We obtain the value $1.26\pm0.01\pm0.04$ for the average ratio within $|\eta|\leq3$.

Finally, for $dN_{ch}/d\eta$ at $\eta=0$, we measure 3.18 $\pm0.06(\text{stat})\pm0.10(\text{syst})$ at 630 GeV, and 3.95 $\pm0.03(\text{stat})\pm0.13(\text{syst})$ at 1800 GeV. Figure 4 summarizes the energy dependence of $dN_{ch}/d\eta$ at $\eta=0$ for our data and for non-single-diffractive data[8,13] at lower energies. Statistical and systematic uncertainties

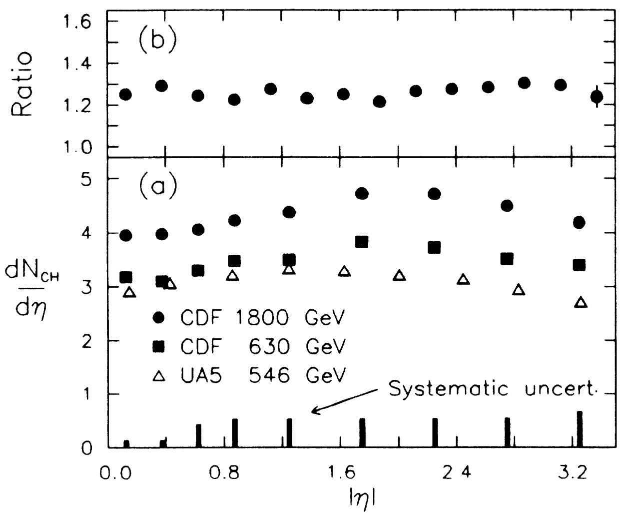

FIG. 3. (a) $dN_{ch}/d\eta$ measured by CDF at 1800 and 630 GeV, and by UA5 at 546 GeV. (b) The ratio of $dN_{ch}/d\eta$ at 1800 GeV to that at 630 GeV.

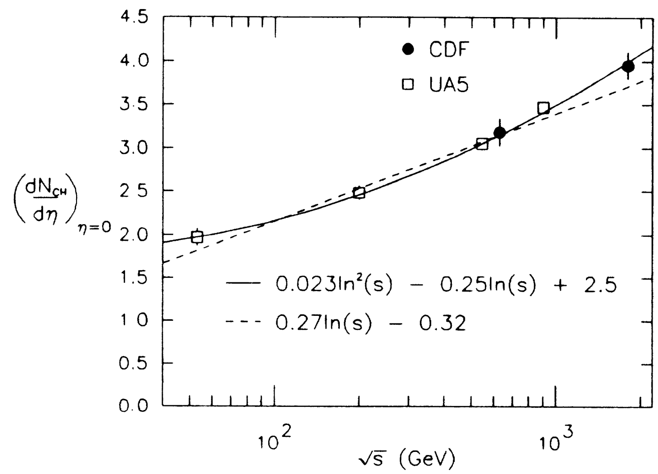

FIG. 4. $dN_{ch}/d\eta$ at $\eta=0$ as a function of $\sqrt{s}$ measured by UA5 (Refs. 8 and 13) and CDF. The curves are the result of fits.

are added linearly for the CDF points. The curves show fits to a linear dependence on $\ln(s)$ (dashed line) and a quadratic dependence on $\ln(s)$ (solid curve). The result of the $\ln(s)$ fit is

$$(0.27\pm0.02)\ln(s)-(0.32\pm0.22)\,,$$

with $\chi^2=8.95$ for four degrees of freedom; the quadratic fit yields

$$(0.023\pm0.008)\ln^2(s)-(0.25\pm0.19)\ln(s)+(2.5\pm1.0)\,,$$

with $\chi^2=0.72$ for three degrees of freedom. The fits clearly favor an energy dependence stronger than $\ln(s)$, confirming the trend observed by UA5.

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[16]CDF has not yet measured inclusive η-meson production. Since no other measurements of the η/π ratio at $\sqrt{s}$ energies comparable to those at CDF are available, we omit this correction. However, UA5 notes an excess of photons over that expected from π^0 decay alone, and quotes an upper limit of $\eta/\pi^0=0.30$ assuming the excess to come from η decays (Ref. 13). Under this assumption, we estimate that, at most, 5% of the observed $dN_{ch}/d\eta$ distribution at CDF originates from the decay of η mesons to charged particles.