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CHARGED PARTICLE MULTIPLICITY DISTRIBUTIONS IN PROTON ANTIPROTON COLLISIONS AT 540 GeV CENTRE OF MASS ENERGY

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Abstract

Results on charged particle production in $p\bar{p}$ collisions at $\sqrt{s}$ = 540 GeV are presented. The data were obtained at the CERN $p\bar{p}$ collider using the UA1 detector, operated without magnetic field. The central particle density is 3.3±0.2 per unit of pseudo-rapidity for non-diffractive events. KNO scaling of the multiplicity distributions with results from ISR energies is observed.

The CERN SPS proton-antiproton collider has raised the centre of mass energy available at an accelerator to an order of magnitude higher than that attainable at the ISR. Comparisons of $p\bar{p}$ and pp scattering at $\sqrt{s}$ = 53 GeV have shown very similar charged particle rapidity and multiplicity distributions (1), so it is interesting to compare $p\bar{p}$ results at the collider with pp data from the ISR to see in a precise way how these distributions scale with energy. Cosmic ray results (2) had already indicated a continued rise of the average multiplicity per unit of pseudo-rapidity, $\eta = -\ln \tan\theta/2$, with increasing energy and this was confirmed by early collider data (3,4). However, the width of the central pseudo-rapidity distribution had grown less at $\sqrt{s}$ = 540 GeV compared to the ISR than would have been expected on kinematic grounds if the average transverse momentum of the particles remained constant (4). Later results (5) show that $\langle p_t \rangle$ for charged particles increases by ~20% over the energy range, which must partly explain the effect. Although the rise of the central pseudo-rapidity density $\frac{dn}{d\eta}$ (3,4) violates Feynman scaling (6), approximate KNO scaling (7) of the multiplicity distributions was observed (3,4).

We report results from data taken in December 1981 in the UA1 experiment (8) at the $p\bar{p}$ collider. For the events used in this analysis the detector was operated without magnetic field, which has the advantage that acceptance corrections are rather simple. Tracks are described by their pseudo-rapidity η and azimuthal angle ϕ around the beam. The present results are based on 8000 events and cover the pseudo-rapidity range $|\eta|<3.5$ for which the acceptance is fairly uniform at about 80%. The higher statistics allow a more quantitative check of KNO scaling than was possible using the preliminary data (3) and provide a more precise measurement of the central pseudo-rapidity density.

Two independent pairs of hodoscopes triggered the events. They were used in tightly timed coincidence to select preferentially beam-beam events. The first pair were ±6.2m from the crossing point and covered the angular range ~12 to ~56 mrad while the second pair were at ±2.9m with angular coverage from ~68 to ~400 mrad. The OR of the two triggers accepted close to 100% of all inelastic events with single diffraction excluded. Part of the data was taken with each of the two hodoscope pairs triggering separately. However the data obtained in the region $|\eta|<3.5$ for these reduced triggers show no noticeable differences and all data have been included in the present analysis.

Charged particle trajectories were measured by the central detector which is a cylinder of 5.8m length and 2.3m diameter containing 6 modules of drift chambers. Coordinates in the plane perpendicular to the wires were obtained from the drift time and the third coordinate by current division. The track finding efficiency of the reconstruction program for the present data is 96±1%, determined by visual scanning of 1000 events, and is independent of multiplicity. Beam-beam interactions were selected by timing cuts on the trigger hodoscopes and a cut on the longitudinal position of the reconstructed vertex. Tracks considered as associated to the vertex were selected by their closeness of approach to it in the drift plane. A Monte Carlo program incorporating the full details of the wire planes and multiple scattering was used to show that this removed less than 3% of true primary tracks. Beam gas events were further reduced to a level of less than 2% by a cut on the ratio of unassociated to associated tracks, with scanning used to check the procedure. After scanning it was estimated that less than 1% of good beam-beam interactions were eliminated by this procedure.

The acceptance as a function of pseudo-rapidity was found by exploiting the azimuthal symmetry about the beam. Using the real data, the correction factor for each bin of pseudo-rapidity required to produce a uniform ϕ-distribution was calculated from tracks observed in the ϕ-regions of 100% acceptance. The typical acceptance is 80% and an allowance of ±5% has been made to cover systematic errors in the corrections applied. Corrections have been made for primary tracks excluded by the cuts already discussed. The inclusion of secondary tracks has been studied by Monte

Carlo simulation using the relative rates found in the UA5 experiment for γ-ray (9) and neutral strange particle production (10). The corrections to the associated tracks from γ-conversions vary from 3% for $0<|\eta|<0.25$ to 15% for $3.25<|\eta|<3.5$, while corrections for strange particle decays are fairly uniform in pseudo-rapidity at about 4%. These reductions are partly offset by the corrections for losses due to nuclear interactions which vary from 1% to 9% over the range. The low-momentum cut-off caused by particles stopping in chamber walls etc. removes <1% of tracks and no correction has been applied.

The distribution of the average pseudo-rapidity density $\frac{dn}{d\eta}$ is given in figure 1. The errors shown are mainly systematic and arise from the estimated uncertainties in the corrections described above. The value at $\eta=0$ of 3.3 ± 0.2 is compatible with 3.6 ± 0.3 in our earlier paper (3), which had no correction for strange particle decays, and also with 3.0 ± 0.1 found by UA5 (4). It represents a 70% increase from the highest ISR energy $\sqrt{s}=63$ GeV (11). A further measurement obtained in the forward region of our apparatus is also shown on figure 1. Details of this part of the detector and the associated analysis are given in reference 12. The value of $\frac{dn}{d\eta} = 0.7\pm0.3$ for $\langle\eta\rangle = 5.5$ appears to be approximately independent of the multiplicity of the event. The shape of the $\frac{dn}{d\eta}$ distribution is in reasonable agreement with that found by UA5, confirming the narrowing compared to a simple extrapolation from the ISR data (i.e. a growth of about 2 units of pseudo-rapidity compared with 4.6 available). The dependence of the $\frac{dn}{d\eta}$ distribution on event multiplicity (figure 2) shows similar features to those observed at the ISR by Thomé et al (11). For low multiplicities a peaking towards large $|\eta|$ is seen and would be expected from momentum conservation.

Figure 3 shows the central pseudo-rapidity density $\left(\frac{dn}{d\eta}\right)_{\eta=0}$ compared to other results and illustrates the rise from ISR energies. This is consistent with a linear dependence on $\ell n(s)$. The inclusion of single diffraction scattering processes, for which the cross section has been measured by UA4 (13), would lower our point by 20±2% as these events would contribute negligibly near $\eta=0$. However, the quoted result is strictly comparable with that given for UA5 (4).

The pseudo-rapidity region $|\eta|<3.5$ includes on average about 80% of the tracks in an event. The acceptance of the central detector falls rapidly for $|\eta|>3.5$ so very little is gained by extending the region further. Nevertheless, the multiplicity distribution for the region covered should have approximately the same shape as that for a full inelastic event (i.e. excluding single diffraction scattering which does not trigger the apparatus). The effect of the incomplete ϕ acceptance has been studied for $|\eta|<3.5$ and for $0<|\eta|<1.5$ and $1.5<|\eta|<3.0$ separately, assuming no correlations between particles in ϕ, by a fitting procedure which starts from an original distribution with complete ϕ coverage and takes into account the acceptance in fitting the data. It is found in all cases that the fitted original distribution has the same shape as the observed one, except at very low multiplicities, and no serious distortion is introduced by the limited acceptance. It is unlikely that any correlations (15) would worsen this agreement, given such high acceptance, so we are confident that we can extract the properties of the multiplicity distributions to compare with other data. The inclusion of secondaries similarly should not significantly alter the shapes of the distributions as the production of γ-rays and strange particles are known to be proportional on average to the numbers of primary charged particles (9,10).

For ease of comparison we plot all distributions in terms of the KNO variables (7) and quote the corrected average multiplicities for each case. The following quantities have been computed:-

$$\frac{\langle n\rangle}{D} = \frac{\langle n\rangle}{[\langle n^2\rangle-\langle n\rangle^2]^{\frac{1}{2}}}$$

$$\gamma_2 = \frac{\langle(n-\langle n\rangle)^2\rangle}{\langle n\rangle^2}$$

$$\gamma_3 = \frac{\langle(n-\langle n\rangle)^3\rangle}{\langle n\rangle^3}$$

$$\gamma_4 = \frac{\langle (n-\langle n\rangle)^4\rangle - 3\langle (n-\langle n\rangle)^2\rangle^2}{\langle n\rangle^4}$$

These moments serve as a measure of the shapes of the distributions and are convenient for comparing the variations of shape as a function of energy. They are independent of $\sqrt{s}$ if KNO scaling is satisfied.

Figure 4 shows the observed multiplicity distributions for $|\eta|<1.5$ and $|\eta|<3.5$. It is noticeable that the central region $|\eta|<1.5$ has a flatter shape than the fuller region. This is reflected in the moments, which are given in Table 1. For comparison the values obtained by Thomé et al (11) at $\sqrt{s}=63$ GeV are given and are quite similar to our own. The errors on the γ-moments are statistical only. The systematic errors estimated from the acceptance studies are of the same order as the statistical errors. No allowance has been made for the exclusion of single diffraction events which, if included, would increase the moments by one or two standard deviations. However, these are also not included in the moments quoted for Thomé et al (11).

It is of most interest to compare the moments for the larger region with results from lower energies. As already explained, we observe only 80% of the full multiplicity on average. Slightly lower moments may be expected for the full distribution since the moments are found to decrease as the range of rapidity sampled is increased. However, the quantity $\frac{<n>}{D}$ for $|\eta|<3.5$ is in good agreement with that found by UA5 (4) for all η. Figure 5 shows plots of γ_2, γ_3 and γ_4 as a function of energy for each region. Little change has taken place from ISR energies showing that KNO scaling is occuring over this very large energy range.

Another way of illustrating this is to compare our data with curves that fit lower energy data. The Slattery parametrization (16) gives a good fit to FNAL data and the de Groot formula (17), derived theoretically from an uncorrelated cluster model, is a good representation of the ISR results. Both are compared with our distribution for $|\eta|<3.5$ in figure 4. The de Groot curve is a better description for large multiplicities where the results are least sensitive to acceptance effects.

In conclusion, we have presented measurements of $\frac{dn}{d\eta}$ and multiplicity distributions for $|\eta|<3.5$ based on 8000 events obtained in the UA1 detector without magnetic field.

The central pseudo-rapidity density $\left(\frac{dn}{d\eta}\right)_{\eta=0}$ for for non-diffractive events is 3.3 ± 0.2 compared with 3.6 ± 0.3 found from earlier UA1 data (3), which had no correction for strange particle decays, and 3.0 ± 0.1 found by UA5 (4). It represents a 70% rise from the highest ISR energy ($\sqrt{s}$=63 GeV) (11).

The shape of the pseudo-rapidity distribution is in reasonable agreement with that found by UA5, confirming the narrowing of about 2 units with respect to what would be expected from a simple extrapolation from ISR energies. The dependence of this distribution on event multiplicity is similar to that found at the ISR(11).

The multiplicity distribution for $|\eta|<3.5$, taken to be representative of the shape of the full distribution, exhibits KNO scaling with lower energy data as manifested by the γ-moments and simple shape comparisons. The distribution for $|\eta|<1.5$, which also scales, has however a different shape from the full distribution, as also observed at the ISR(11).

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	$\langle n\rangle$	$\frac{\langle n\rangle}{D}$	γ_2	γ_3	γ_4
UA1 $\lvert\eta\rvert<1.5$	9.8 ±0.7	1.51 ±0.05	0.441 ±0.017	0.308 ±0.021	0.216 ±0.050
ISR $\sqrt{s}$=63 GeV $\lvert\eta\rvert<1.5$	6.3 ±0.1	-	0.46 ±0.01	0.28 ±.02	0.29 ±.05
UA1 $\lvert\eta\rvert<3.5$	21.1 ±1.5	1.84 ±0.07	0.296 ±0.011	0.122 ±0.007	0.027 ±0.008
ISR $\sqrt{s}$=63 GeV All η	12.70 ±0.12	1.83 ±.03	0.297 ±0.010	0.125 ±0.007	0.051 ±0.006
UA5 All η	26.8 ±2.1	1.8 ±0.2	-	-	-

Table 1 Moments of the multiplicity distributions as defined in the text. The moments for $|\eta|<1.5$ in both UA1 and ISR results are for events with at least one track in this $|\eta|$ range.

Figure Captions

1. Pseudo-rapidity density distributions for all charged multiplicities corrected for acceptance and backgrounds but excluding single diffraction events.

2. Pseudo-rapidity density distributions for various intervals of observed charged multiplicity corrected for acceptance and backgrounds.

3. The central pseudo-rapidity density for this and other experiments as a function of centre of mass energy $\sqrt{s}$.

4. Observed multiplicity distributions, plotted in KNO variables a) $|\eta|<1.5$ and b) $|\eta|<3.5$. The dashed curve is the Slattery parameterisation (16) of Fermilab data and the solid curve the model of de Groot (17) which gives a good fit to ISR results.

5. The moments γ_2, γ_3 and γ_4 defined in the text for these and other data as a function of $\sqrt{s}$; a) $|\eta|<1.5$ with at least one track in this region, b) all η for other data (see reference 11), $|\eta|<3.5$ for this experiment. The moments are independent of energy if the multiplicity distributions obey KNO scaling.

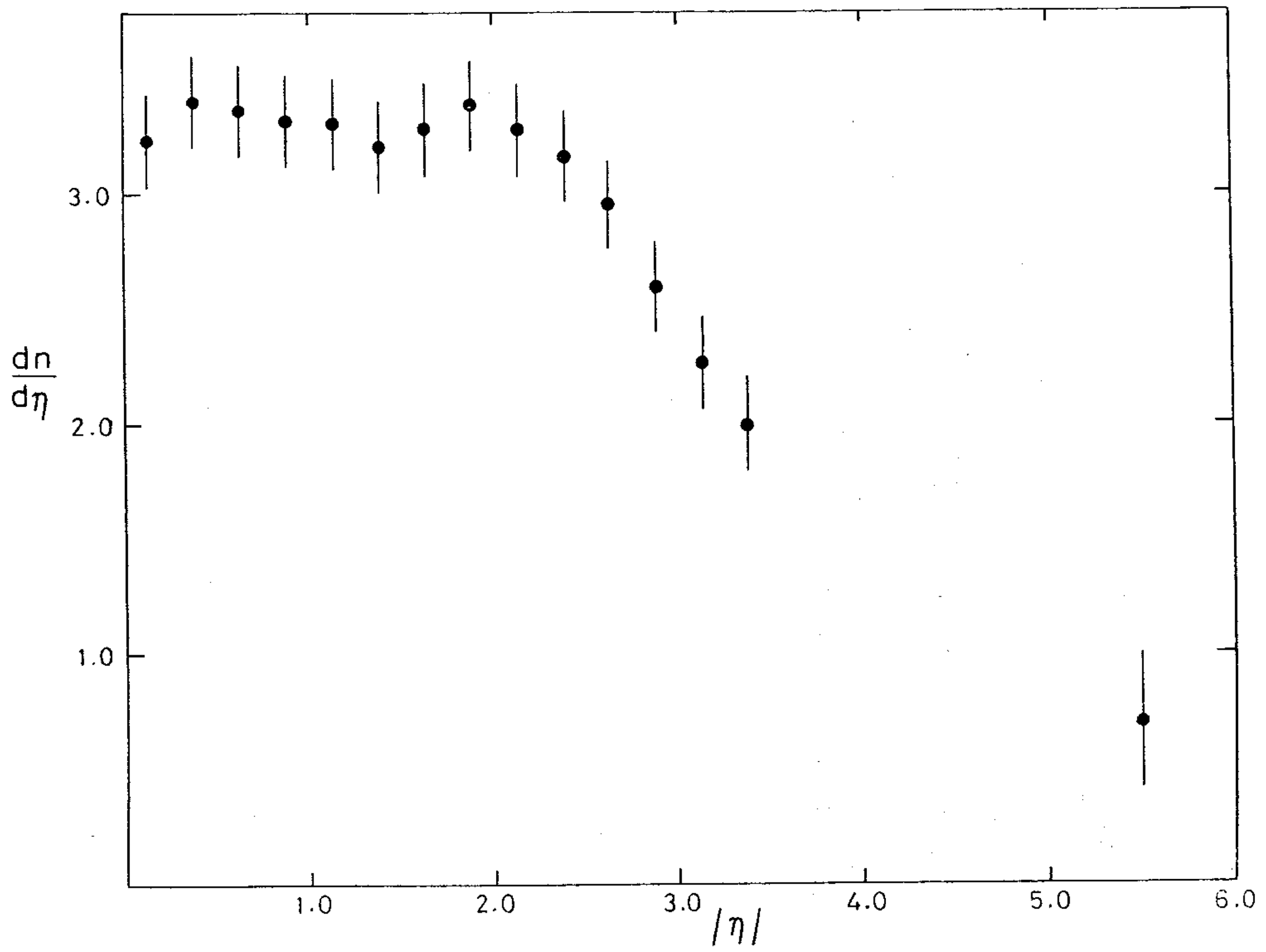

Figure 1

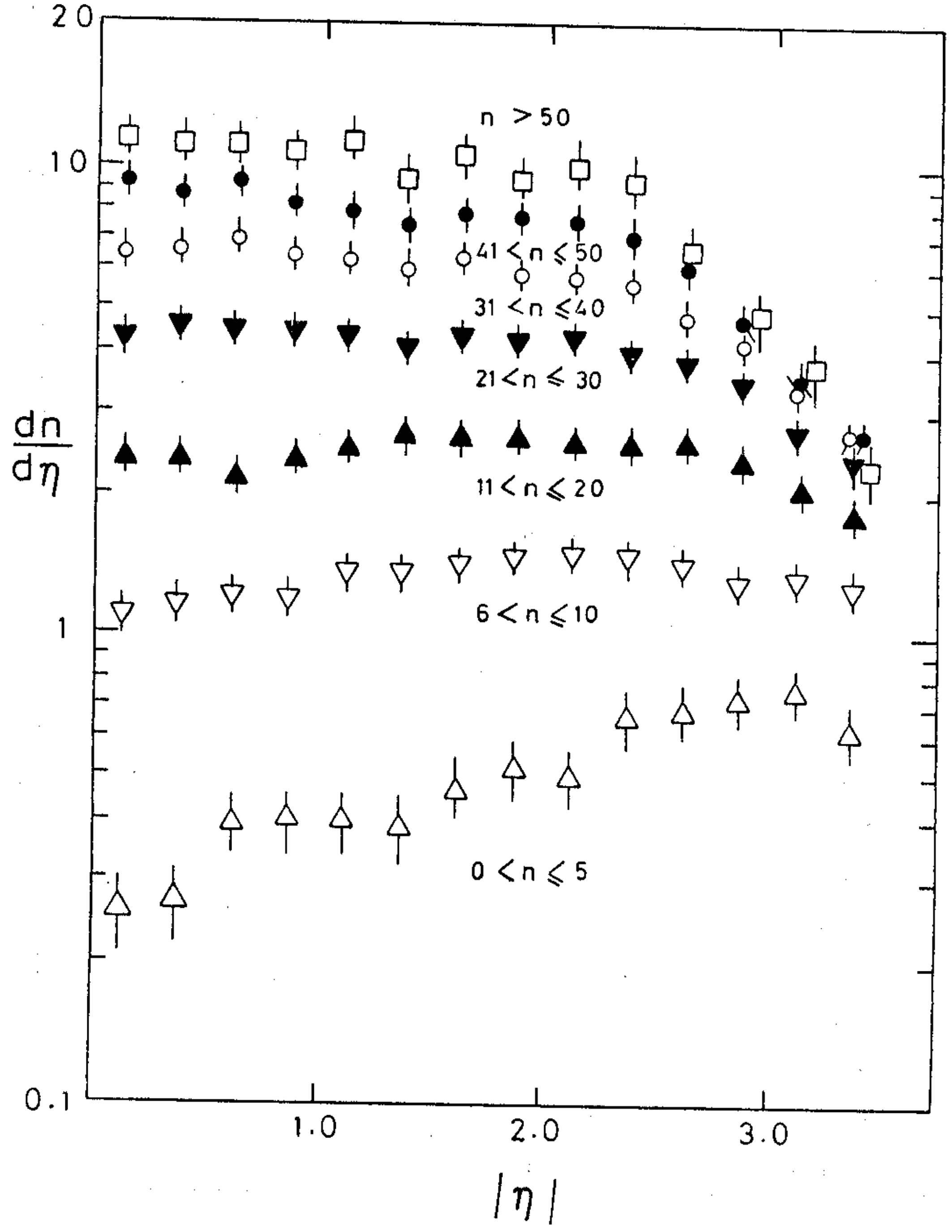
20
10
1
0.1
1.0
2.0
3.0
$\frac{dn}{d\eta}$
$|\eta|$
n > 50
41 < n ≤ 50
31 < n ≤ 40
21 < n ≤ 30
11 < n ≤ 20
6 < n ≤ 10
0 < n ≤ 5

Figure 2

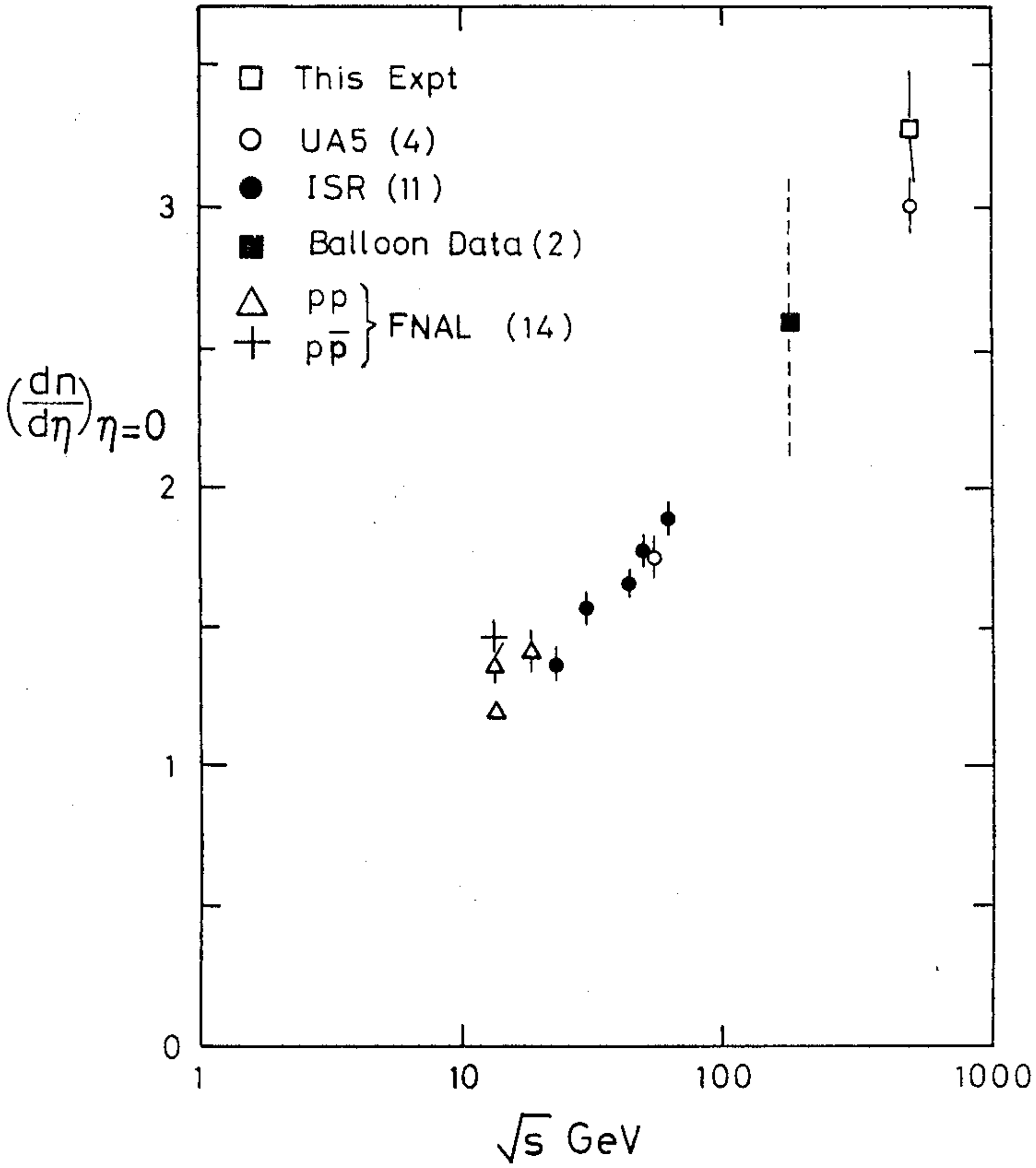
□ This Expt
○ UA5 (4)
● ISR (11)
■ Balloon Data (2)
△ pp
+ p$\bar{p}$
FNAL (14)
$\left(\frac{dn}{d\eta}\right)_{\eta=0}$
0
1
2
3
1
10
100
1000
$\sqrt{s}$ GeV

Figure 3

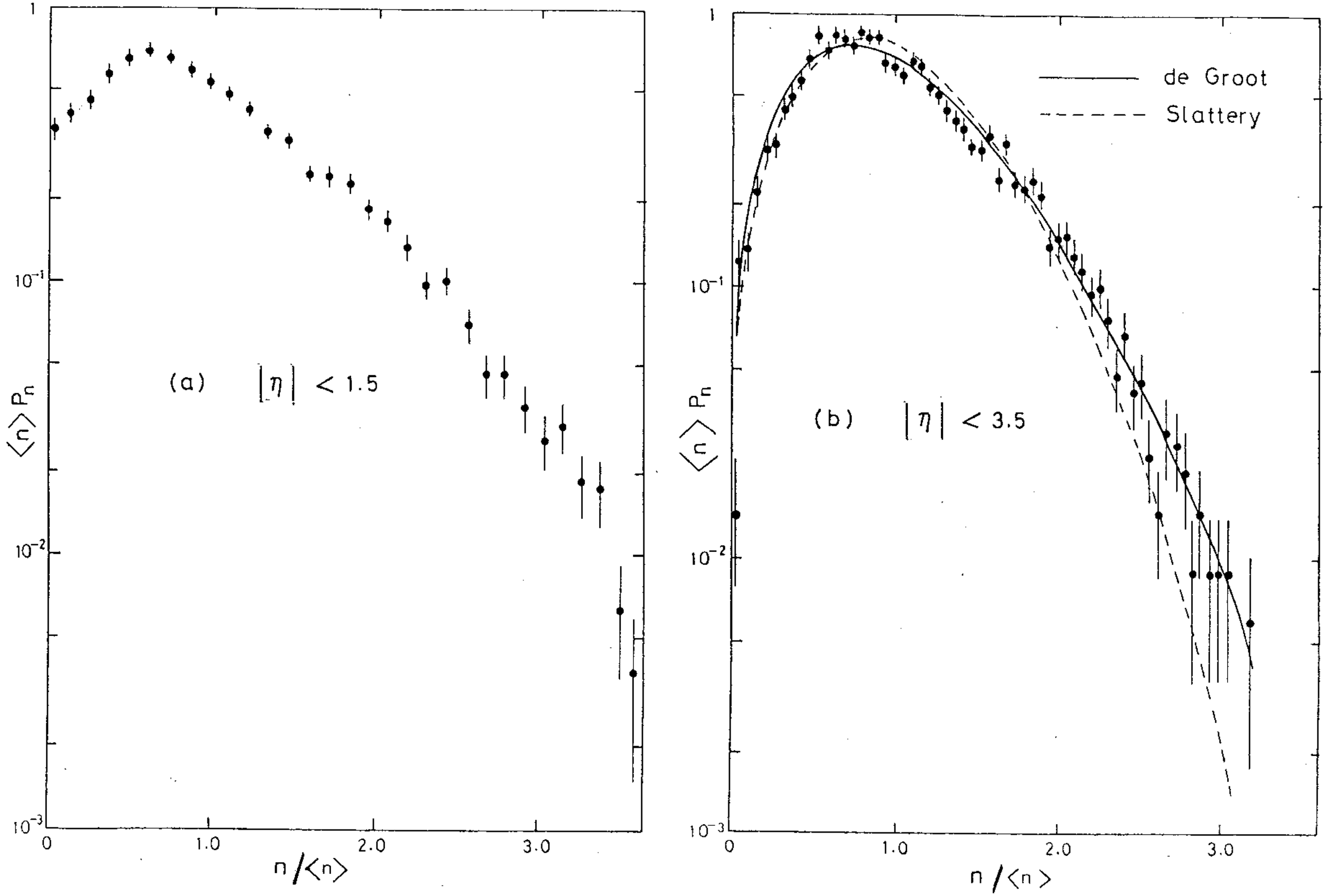
1
10^{-1}
10^{-2}
10^{-3}
$\langle n \rangle P_n$
0
1.0
2.0
3.0
$n / \langle n \rangle$
(a) $|\eta| < 1.5$
(b) $|\eta| < 3.5$
de Groot
Slattery

Figure 4

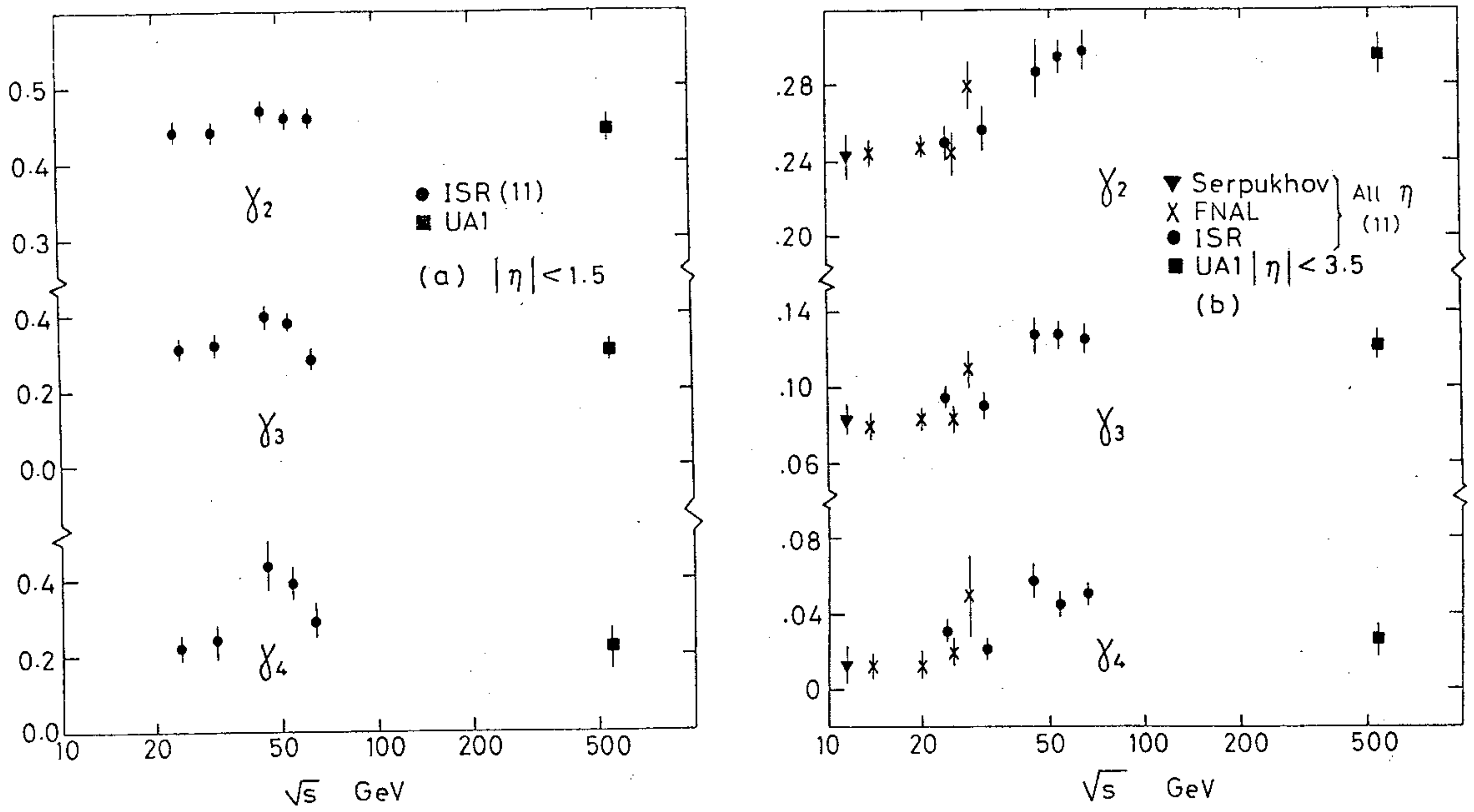
0.5
0.4
0.3
0.4
0.2
0.0
0.4
0.2
0.0
γ_2
γ_3
γ_4
● ISR (11)
■ UA1
(a) $|\eta| < 1.5$
10
20
50
100
200
500
$\sqrt{s}$ GeV
.28
.24
.20
.14
.10
.06
.08
.04
0
γ_2
γ_3
γ_4
▼ Serpukhov
X FNAL
● ISR
All η
(11)
■ UA1 $|\eta| < 3.5$
(b)
10
20
50
100
200
500
$\sqrt{s}$ GeV

Figure 5