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Scaling violation favouring high multiplicity events at 540 GeV cms energy

UA5 Collaboration

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ABSTRACT

New data are presented on the charged multiplicity distribution for non single-diffractive events produced in $p\bar{p}$ interactions at a c.m. energy $\sqrt{s}$ = 540 GeV. The distribution in the full pseudorapidity range is compared with data from the ISR. Using the scaling variable $z = n/\langle n \rangle$ a change of shape is observed. The effect is manifested as an increase from 2% to 6% in the proportion of high multiplicity ($z>2$) events. For the central pseudorapidity range, $|\eta| \lesssim 1.5$, scaling is approximately valid up to $\sqrt{s}$ = 540 GeV.

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Introduction

The multiplicity distribution of hadrons produced in high energy particle collisions has long been known to deviate from a Poisson distribution, and has thus been regarded as a potentially useful source of information about the underlying production processes. Various models [1-8] of the low-p_t hadron production process in hadron-hadron collisions have led to predictions about the multiplicity distribution. The hypothesis of Feynman scaling led to the idea of KNO scaling [9], namely that at sufficiently high energies,

$$\langle n\rangle \sigma_n / \Sigma\sigma_n = \psi(z = n/\langle n\rangle)$$

where σ_n is the partial cross-section for producing a state of multiplicity n and $\psi(z)$ is an energy-independent function. In spite of the fact that Feynman scaling is not observed, as is shown, for example, by the continuing rise of the particle density in the central region up to CERN SPS Collider energy [10,11], KNO scaling has come to be regarded as a useful phenomenological framework for the comparison of distributions at different energies.

It has been known [12] for some years that KNO scaling is not strictly followed for inelastic hadronic interactions up to cms energy $\sqrt{s}$ = 63 GeV. This was thought not to be surprising because the inelastic cross-section is made up of two components: single diffraction dissociation where one of the colliding particles does not fragment; and the remaining non single-diffractive part which provides the bulk of produced particles.

New data [13] now exist for this non single-diffractive part in pp interactions which show that the shape of the charged multiplicity distribution, when expressed as a function of $z = n/\langle n\rangle$, may be approximately constant over the full ISR energy range, $\sqrt{s}$ = 30 to 62 GeV, suggesting that scaling might be a valid concept in this energy range for the non single-diffractive component. There thus exists a sound basis for comparison with still higher energy data from the SPS Collider, which affords a nearly tenfold increase in available energy. The purpose of this paper is to report on new $\sqrt{s}$ = 540 GeV data from the UA5 detector which confirm and make more precise earlier results [14] from this detector, showing a clear change in the shape of the scaled multiplicity distribution characterized by an enhanced probability for producing high multiplicity events.

Experimental details

The UA5 detector consists of two large streamer chambers, 6m x 1.25m x 0.5m, placed above and below the SPS beam pipe,10 cm apart, giving a geometrical acceptance of ~95% for the pseudorapidity range $|\eta| \lesssim 3$, falling to zero at $|\eta| \approx 5$ ($\eta = -\ell n \tan\theta/2$ where θ is the c.m.s. scattering angle). The reader is referred to earlier publications [10, 14-16] for details of the UA5 detector and analysis procedures. The detector was triggered by two large scintillation counter hodoscopes at each end, covering the pseudorapidity range $2<|\eta|<5.5$. The trigger rejected essentially all elastic and single-diffractive events, but accepted (95±2)% of non single-diffractive events as determined by Monte Carlo calculations. For these calculations simulated events were tracked through the detector, allowing for interactions and scattering, and processed in the same way as real measured events. The event generator in the Monte Carlo program was tuned by requiring the output to match all observed features of real events, namely pseudorapidity distributions as a function of charged multiplicity [17], the correlations between charged particles [18], and the observed yields of kaons [19] and photons [20] as a function of multiplicity.

The Monte Carlo program was used to correct the data for trigger losses of non single-diffractive events, geometrical acceptance, and residual contamination of primary tracks by secondaries, e.g. by charged particles from strange particle decays and by $e^{\pm}$ from photons converting in the beam pipe. In the first UA5 run of October-November 1981 the beam pipe used was made of 0.4 mm corrugated steel and the contamination of $e^{\pm}$ from conversions of photons in it represented some 9% of the charged tracks pointing towards the vertex. In our earlier publication [14] we reported on data taken in this first run relating to 4442 events. In the second UA5 run in September 1982 a 2 mm thick beryllium beam pipe was substituted for the steel one in order to reduce the number of observed $e^{\pm}$ tracks and the probability of primary tracks being obscured by electromagnetic showers. The Collider mean luminosity for the 1982 run was $\sim 10^{26}$ cm^{-2} s^{-1}, over an order of magnitude higher than for the 1981 run, and resulted in a much lower proportion of background events. The different and more favourable conditions of this second run therefore permit a valuable check on the data from the first run.

Charged Multiplicity Distribution

From the second run 6362 events were measured and analysed, and the charged multiplicity distribution was obtained, fully corrected using the matrix technique described in ref. [14]. This distribution is shown in Fig.1(a), together with updated results from our 1981 run based on 5547 events. The errors(*) shown are statistical. The main sources of systematic errors are the uncertainties in the precise assignment of charged primaries to the production vertex, and uncertainties in the trigger efficiencies for the lowest multiplicity events, which depend on details of the Monte Carlo event generator and the geometrical acceptance of the trigger and the streamer chambers. We estimate that the combined systematic error is about twice as big as the statistical error on a point, and hence we conclude that the small discrepancies between the two distributions are fully consistent with these errors. This has been checked by comparing the moments of the distributions, which are likewise consistent. So, in order to reduce to some extent the systematic errors, and to improve the statistics, the two sets of data shown in Fig.1(a) were merged. Except where indicated the remainder of this paper refers to this total sample of 11,909 events, for which the multiplicity distribution is shown in Fig.1(b), and the resulting moments are listed in Table 1.

Energy Dependence of the Multiplicity Distribution

The non single-diffractive multiplicity distributions available from nine different experiments [13,21] in the energy range $\sqrt{s}$ = 11.3 to 62.2 GeV are compared to our data in Fig 1(b) where the quantity $\langle n\rangle\sigma_n/\Sigma\sigma_n$ is

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(*) In the case of 2-prongs, and to a decreasing extent 4-prongs and 6-prongs, there are uncertainties in the triggering efficiency, particularly because of a possible double-diffractive contribution which is difficult to estimate. These uncertainties have therefore been included with the statistical errors in Fig 1(a) and (b) to emphasize the special difficulties associated with these events.

plotted against $z = n/\langle n\rangle$ (*). Up to $\sqrt{s}$ = 62 GeV the data show scaling but the superimposed UA5 distribution is significantly different, with an increased probability for events with high multiplicities ($z \gtrsim 1.5$) and a change in shape at lower multiplicities. We recall that the distributions are normalized and have $\langle z\rangle=1$. To demonstrate the magnitude of this effect we show in Fig 2 the percentage of events having $z>1.5$, 2.0 and 2.5 plotted as a function of energy. An increase in each percentage is seen at the Collider, the effect becoming more marked the higher the z cut.

The significance of this change in shape can also be studied using the moments of the distribution. We choose to employ the $C_q = \langle n^q\rangle/\langle n\rangle^q$, in order to give weight to high multiplicities, instead of using, e.g., the γ-moments which are more sensitive to deviations about the mean. Exact KNO scaling implies that all C_q moments are energy-independent since $C_q \approx \int z^q\psi(z)dz$. In Fig 3 we plot for the same experiments the second to the fifth moment versus the energy, and we see that although in the range $\sqrt{s}$ = 30 to 62 GeV all moments might be said to have achieved constant values, as was concluded in ref [13], the UA5 values are significantly higher. Thus for example the highest moment C_5 has increased from 4.6 ± 0.2 for $30<\sqrt{s}<62$ to 8.8 ± 1.0 at 540 GeV. From the C_q values with detailed errors summarized in Table 1 one can see that the effect is highly significant.

Experimental evidence [23] that scaling holds in the central region in the variable $z = n/\langle n\rangle$ has been advanced by the UA1 collaboration. In Fig 4(a) we compare their data with ours. Both sets of data relate to $|\eta|<1.5$, and have included only events with at least one track in $|\eta|<1.5$. There is reasonably good agreement except at high and low multiplicities. The moments of these UA1 and UA5 central region distributions are summarized in Table 2, where the differences in the γ-moments can be attributed to the different proportions of high and low

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(*) In ref. [14,22] we entertained the possibility that the non-single diffractive data, including UA5's at $\sqrt{s}$ = 540 GeV, might scale in variable $z' = (n-\alpha)/(\langle n\rangle-\alpha)$ with $\alpha \sim 2$, but this is now excluded by the new ISR data [13] which scale in z.

multiplicity events in each case. Our data in the range $|\eta|<1.3$ with the same requirement of at least one track in this pseudorapidity range are then compared in Fig 4(b) with pp inelastic data(*) at $\sqrt{s} = 53$ GeV for the same pseudo-rapidity range [24], from which we confirm the UA1 result that scaling appears to hold approximately in the central region. However, since the triggers in the two experiments of Fig.4(b), and the further requirement of at least one track in the pseudorapidity range, accept different fractions of the inelastic cross-section, the significance of this observation is not entirely certain.

In conclusion, we have studied the multiplicity distribution for the full pseudorapidity range for non-single diffractive particle production. We observe a definite change of shape of the scaled distribution in comparison with data up to the highest ISR energy. This change may be regarded as a shift at Collider energy towards higher multiplicity events, having $z>2.0$ or $n_{ch}>60$, of magnitude ~4%. We emphasize that the effect is real, the probability of high multiplicity events being simulated by a superposition of two events in the same bunch-bunch crossing being negligibly small ($<10^{-5}$). Our data are for $p\bar{p}$ collisions, and most of the lower energy data for pp collisions, but annihilation is expected to be too small (~0.1% of the events by extrapolation of the annihilation or ($p\bar{p}$-pp) difference cross-section [24]) to be responsible for the effect. We thus observe a clear violation of KNO scaling in the non single-diffractive component. In the central region, $|\eta|\lesssim 1.5$, scaling is approximately valid up to 540 GeV.

(*) The $\bar{p}p$ and pp data given in ref. [24] are in agreement and we show the latter only which has the smaller errors.

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Table 1

Moments of the charged multiplicity distribution at $\sqrt{s}$ = 540 GeV obtained from merged 1981 and 1982 data from UA5 are given in column (a). The errors given are statistical and then systematic. The C-moments are defined by $C_q = \langle n^q \rangle / \langle n \rangle^q$. Over the ISR energy range $30.4 < \sqrt{s} < 62.2$ GeV [13] these C_q moments are seen in Fig 3 to be reasonably constant, and the corresponding averages are quoted in column (b).

	(a) SPS Collider UA5	(b) ISR
$\langle n \rangle$	29.1 ± 0.3 ± 0.9	-
$D_2 = \langle (n - \langle n \rangle)^2 \rangle$	16.3 ± 0.3 ± 0.3	-
$\langle n \rangle / D_2$	1.79 ± 0.02 ± 0.06	2.22 ± 0.02
C_2	1.31 ± 0.01 ± 0.03	1.20 ± 0.01
C_3	2.12 ± 0.03 ± 0.11	1.67 ± 0.03
C_4	4.05 ± 0.10 ± 0.30	2.63 ± 0.09
C_5	8.8 ± 0.4 ± 0.9	4.6 ± 0.2

Table 2

Moments of the charged particle multiplicity distributions for $|\eta| < 1.5$ at $\sqrt{s} = 540$ GeV. Events with at least one track in this η range have been used. The UA5 data is from the 1982 sample of 6362 events.

$$\gamma_2 = \langle(n-\langle n\rangle)^2\rangle/\langle n\rangle^2, \quad \gamma_3 = \langle(n-\langle n\rangle)^3\rangle/\langle n\rangle^3$$

$$\gamma_4 = \langle(n-\langle n\rangle)^4\rangle/\langle n\rangle^4 - 3\gamma_2^2$$

	UA5	UA1[23]
$\langle n\rangle$	10.0 ± 0.1	9.8 ± 0.7
$\langle n\rangle/D$	1.38 ± 0.02	1.51 ± 0.05
γ_2	0.52 ± .01	0.441 ± 0.017
γ_3	0.53 ± .05	0.308 ± 0.021
γ_4	0.80 ± .18	0.216 ± 0.050

Figure Captions

Fig 1 (a) Distributions in charged multiplicity for non single-diffractive events obtained in the UA5 runs of 1981 (5547 events) and 1982 (6362 events). Except for 2-,4- and 6-prongs (see footnote) the errors shown are statistical only. (For the sake of clarity the 1981 data points have been slightly displaced to higher values of n_{ch}).

(b) Charged multiplicity distribution plotted as a function of z for merged 1981 and 1982 UA5 data (11909 events), compared with the distributions from the ISR [13], and from Serpukhov and FNAL [21].

Fig.2 The percentage of events having (a) $z>1.5$, (b) $z>2.0$ and (c) $z>2.5$ for the distributions shown in Fig 1(b). For the ISR data, and for UA5, statistical and systematic errors combined in quadrature are plotted.

Fig.3 Values of the moments $C_q = \langle n^q\rangle/\langle n\rangle^q$, $q = 2$ to 5, for non single-diffractive data from the experiments referred to in Fig 2. For the ISR data, and for UA5, statistical and systematic errors combined in quadrature are plotted. The dashed lines indicate the average of the ISR values [13]: these represent the expected magnitudes at Collider energies should KNO scaling hold.

Fig.4 (a) Charged multiplicity distribution for $|\eta|<1.5$ from UA5 and UA1 where only events with at least one track in $|\eta|<1.5$ have been included.

(b) Charged multiplicity distribution for $|\eta|<1.3$ from UA5 and for pp data at $\sqrt{s}$ = 53 GeV [24], where only events with at least one track in $|\eta|<1.3$ have been included.

The UA5 data is from the 1982 sample of 6362 events in both (a) and (b).

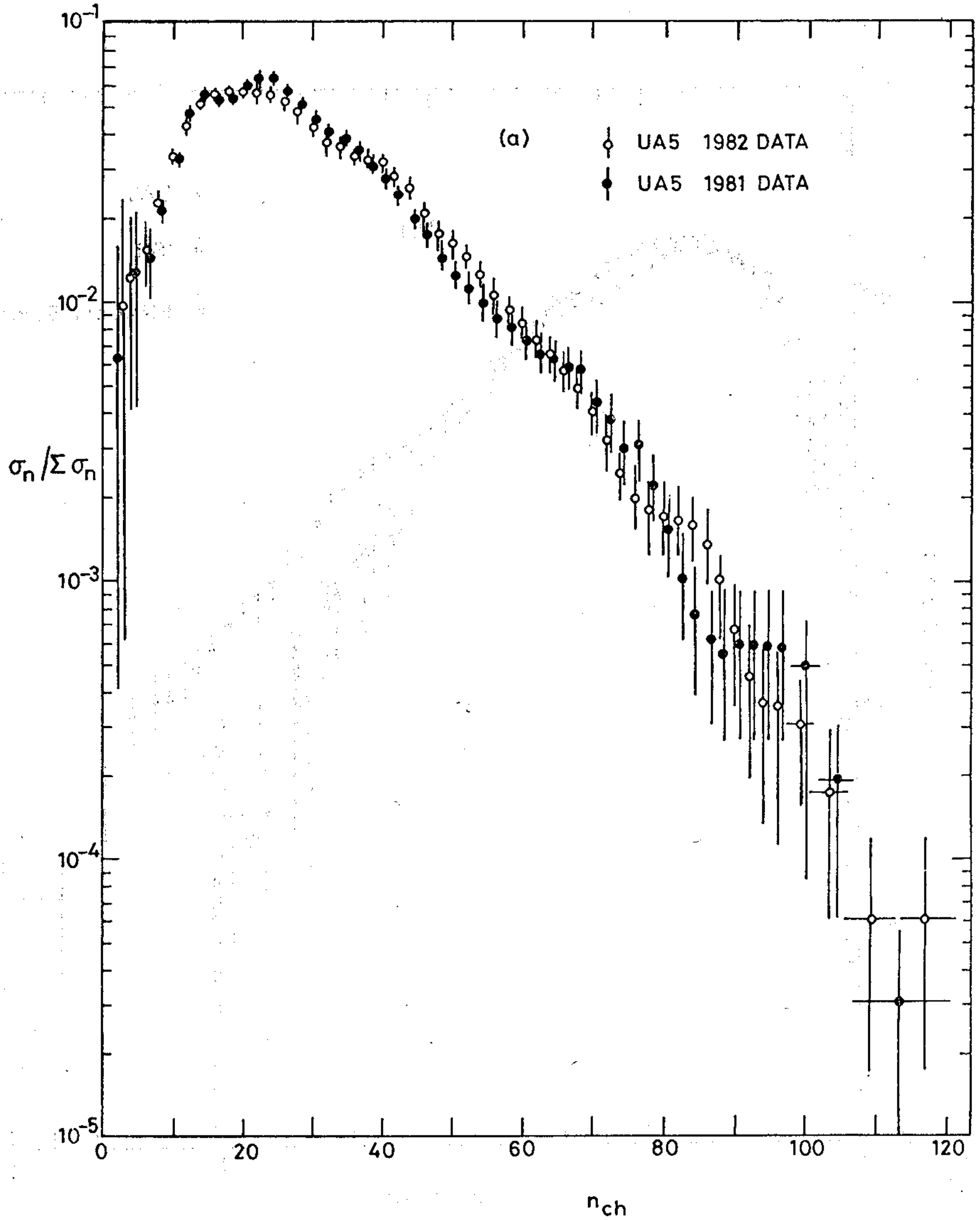
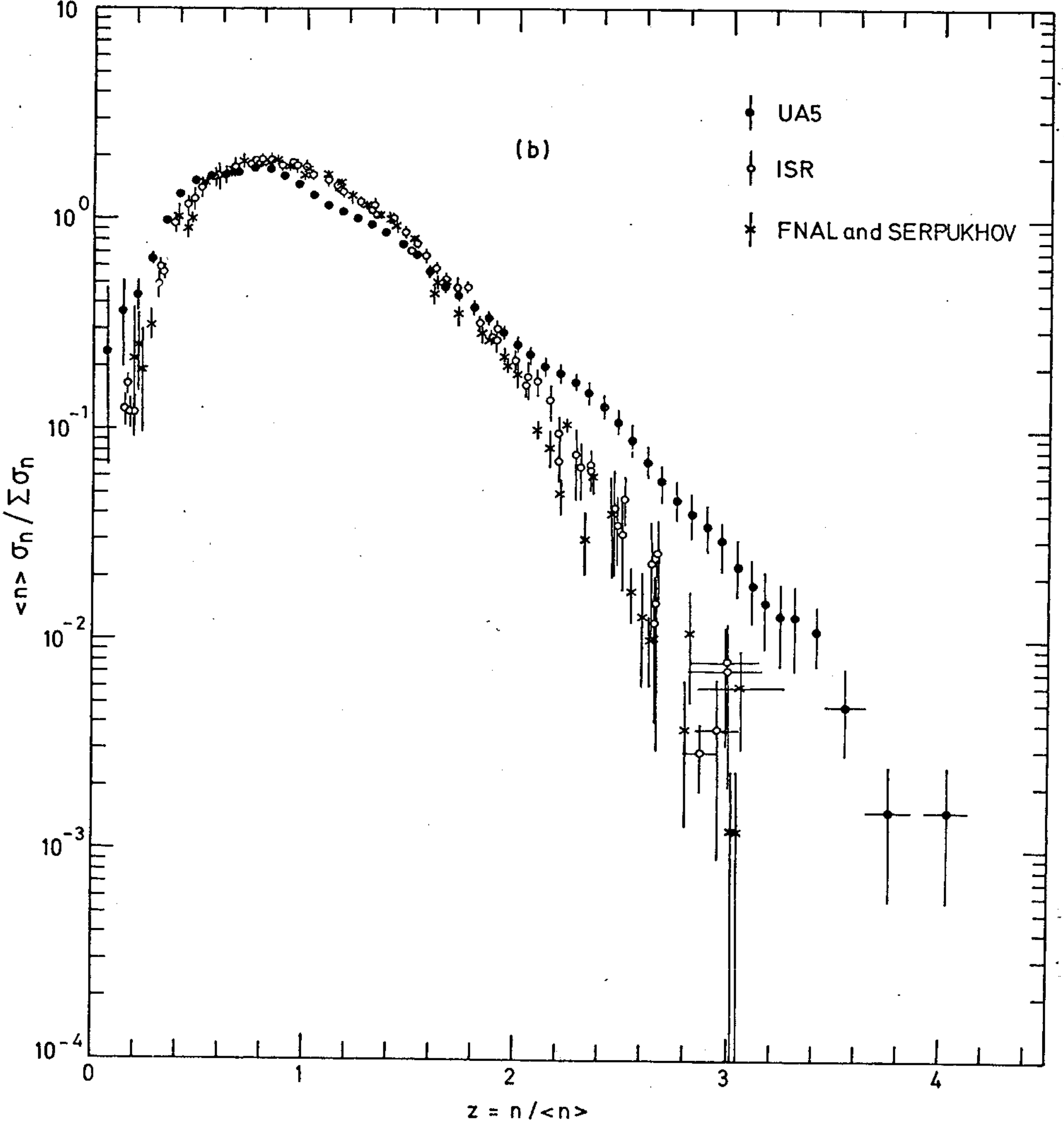

(a)
UA5 1982 DATA
UA5 1981 DATA
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$\sigma_n / \Sigma \sigma_n$
0
20
40
60
80
100
120
n_{ch}

FIG.1a



10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$\langle n \rangle \; \sigma_n / \sum \sigma_n$
0
1
2
3
4
$z = n / \langle n \rangle$
(b)
UA5
ISR
FNAL and SERPUKHOV

FIG. 1b

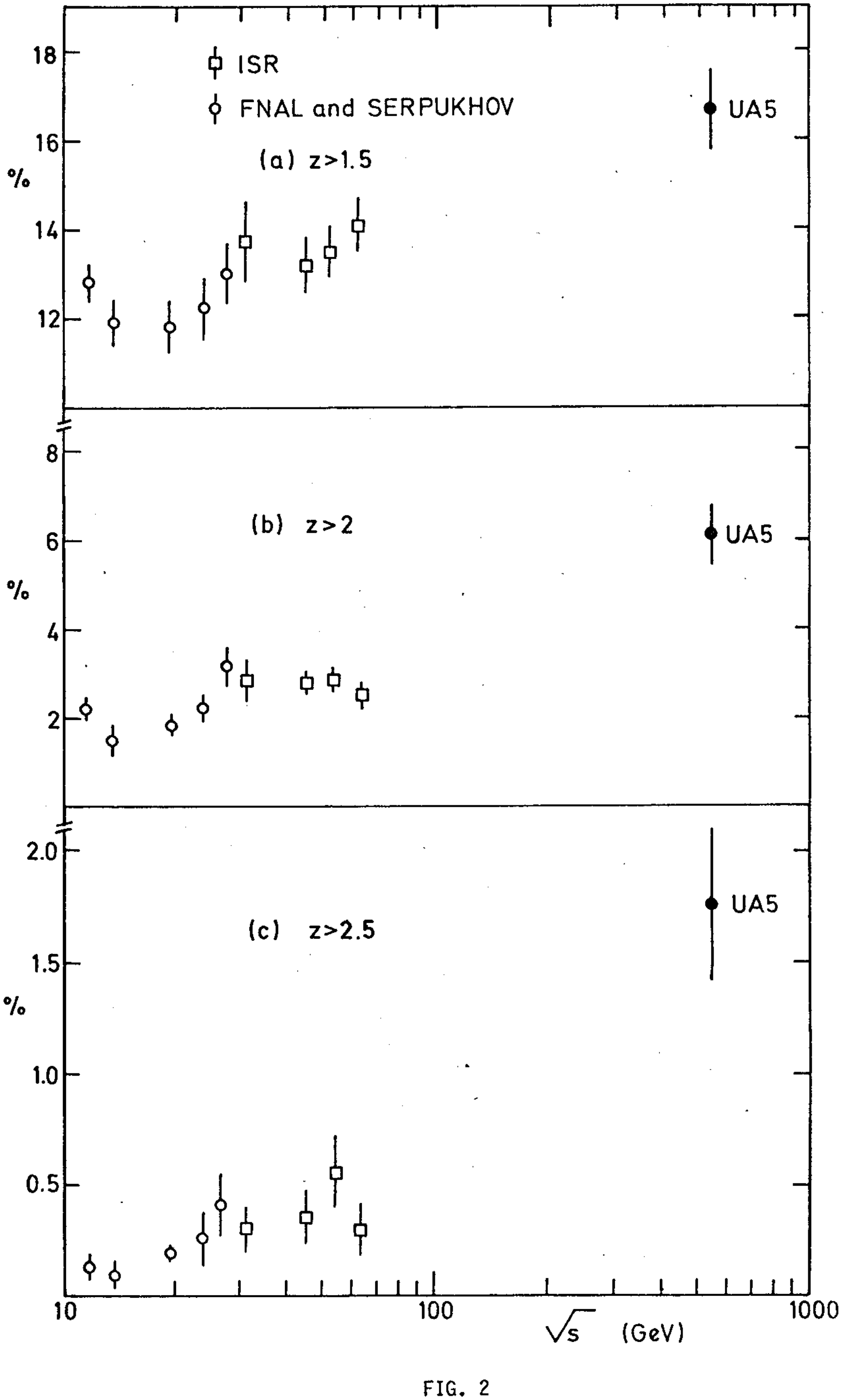
ISR
FNAL and SERPUKHOV
UA5
(a) z>1.5
18
16
14
12
%
(b) z>2
8
6
4
2
(c) z>2.5
2.0
1.5
1.0
0.5
10
100
1000
√s (GeV)

FIG. 2

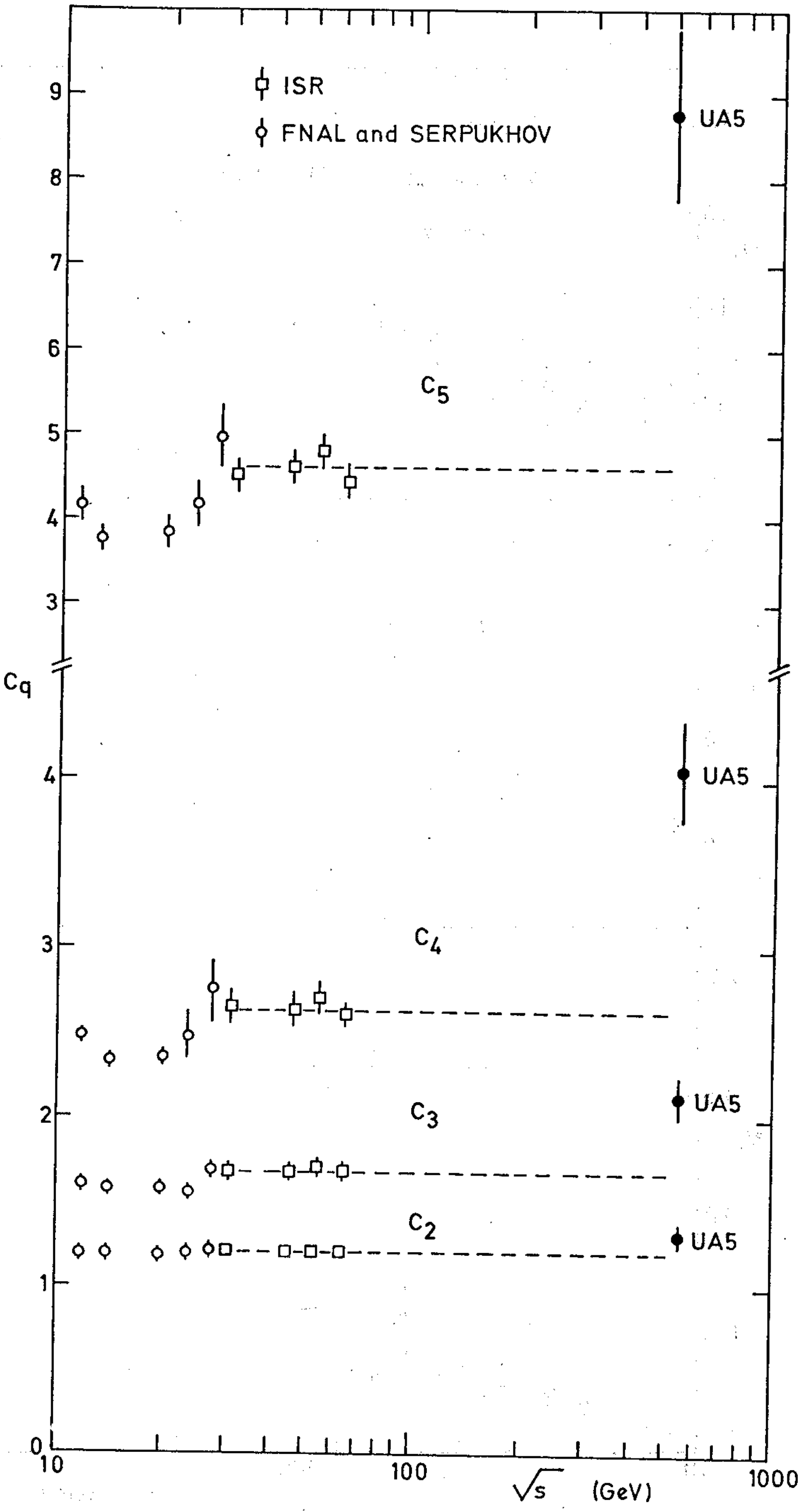

ISR
FNAL and SERPUKHOV
UA5
C5
C4
C3
C2
Cq
0
1
2
3
4
5
6
7
8
9
10
100
1000
$\sqrt{s}$ (GeV)

FIG. 3

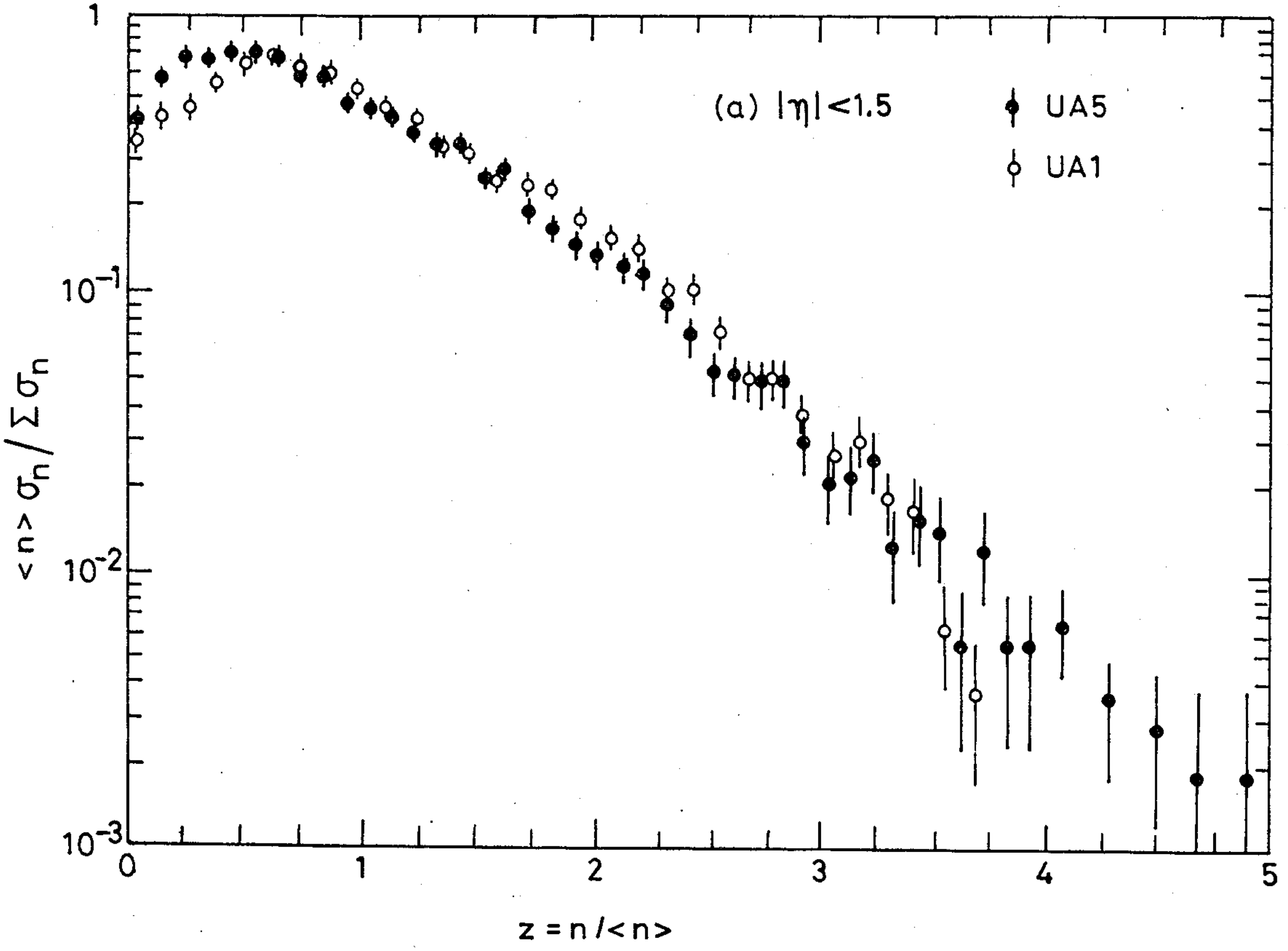

(a) $|\eta|<1.5$
UA5
UA1
$\langle n \rangle \sigma_n / \Sigma \sigma_n$
1
10^{-1}
10^{-2}
10^{-3}
0
1
2
3
4
5
$z = n/\langle n \rangle$

FIG. 4a

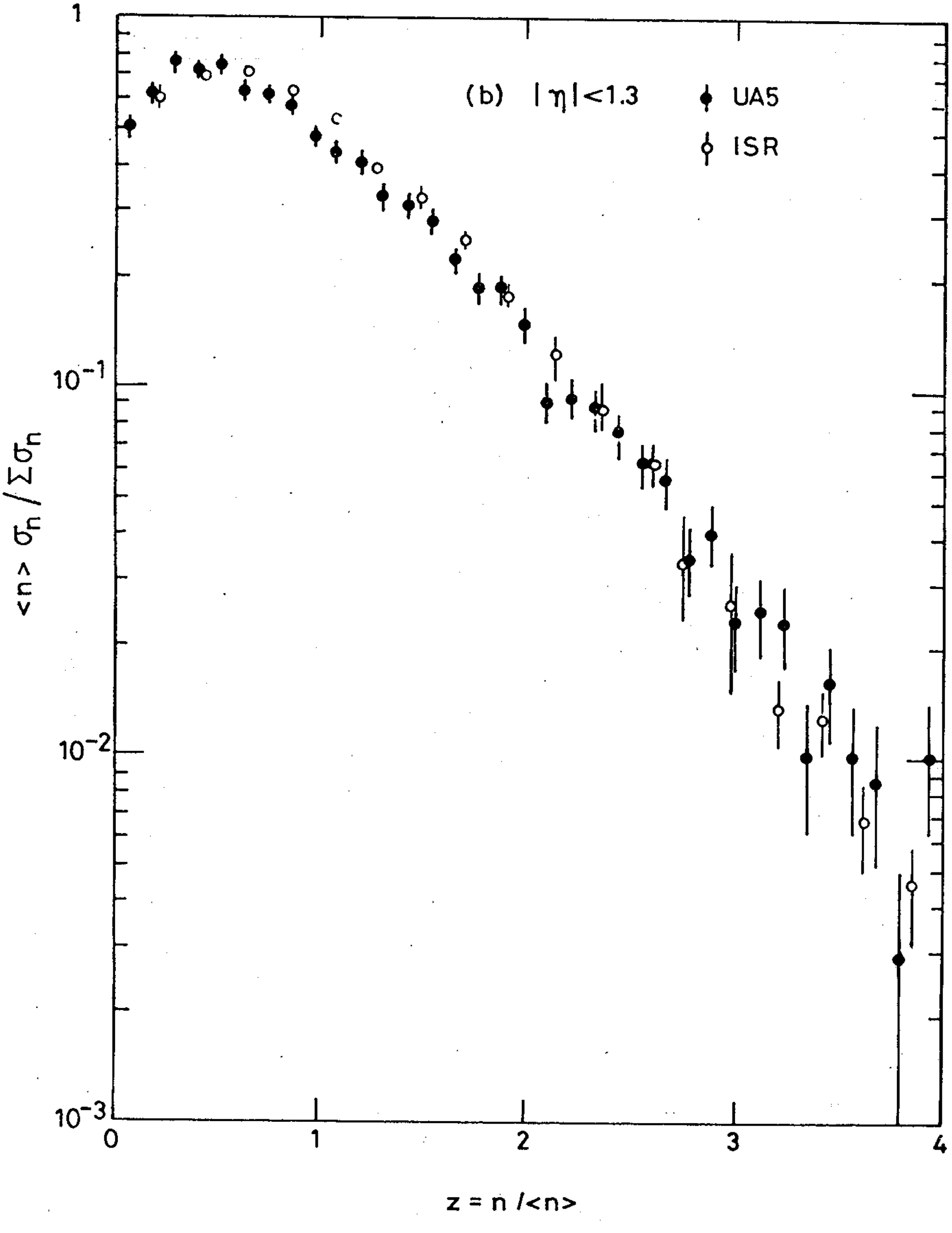

1
10^{-1}
10^{-2}
10^{-3}
0
1
2
3
4
$\langle n \rangle \, \sigma_n / \Sigma \sigma_n$
$z = n / \langle n \rangle$
(b) $|\eta| < 1.3$
UA5
ISR

FIG. 4b