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SCALING VIOLATIONS IN MULTIPLICITY DISTRIBUTIONS AT 200 AND 900 GeV

UA5 Collaboration

Bonn[1], Brussels[2], Cambridge[3], CERN[4] and Stockholm[5]

G.J. Alner[3*], R.E. Ansorge[3], B. Åsman[5], K. Böckmann[1†], C.N. Booth[3+], L. Burow[1], P. Carlson[5], C. DeClercq[2], R.S. DeWolf[3], B. Eckart[1], G. Ekspong[5,4], I. Evangelou[4$], A. Eyring[1], J.-P. Fabre[4], L. Fröbel[1], C. Fuglesang[5], J. Gaudaen[2#+], C. Geich-Gimbel[1], G. von Holtey[4], R. Hospes[1], K. Jon-And[5], Th. Kokott[1], F. Lotse[5], N. Manthos[4$], R. Meinke[1], D.J. Munday[3], J.E.V. Ovens[3], W. Pelzer[1], J. Reidy[4×], J.G. Rushbrooke[3], H. Schmickler[1], F. Triantis[4$], L. Van hamme[2], Ch. Walck[5], C.P. Ward[3], D.R. Ward[3], C.J.S. Webber[3], T.O. White[3], G. Wilquet[2] and N. Yamdagni[5].

1 Physikalisches Institut der Universität Bonn, Germany
2 Inter-University Institute for High Energies (ULB-VUB), Brussels, Belgium
3 Cavendish Laboratory, Department of Physics, Cambridge University, UK
4 CERN, Geneva, Switzerland
5 Institute of Physics, University of Stockholm, Sweden

ABSTRACT

New data are presented on charged particle multiplicity distributions for non single-diffractive events produced at c. m. energies $\sqrt{s}$ = 200 and 900 GeV. The data were obtained at the CERN antiproton proton collider operated in a new pulsed mode. The multiplicity distributions are very well described by a negative binomial distribution. The highest energy data show no sign of approaching scaling, confirming our earlier results on the breaking of KNO scaling. The energy variation of the average charged multiplicity can be fitted to a quadratic in ln s or a $s^{0.13}$ dependence.

† Deceased
* Member of Rutherford Appleton Laboratory, Chilton, Didcot, UK.
# Also at the Universitaire Instellingen Antwerpen, Antwerp, Belgium.
$ Also at the University of Ioannina, Greece.
+ Now at CERN
× Visiting scientist from University of Mississippi

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INTRODUCTION

Asymptotic scaling of multiplicity distributions in hadron-hadron collisions, KNO scaling, was predicted in 1972 [1]. If P_n is the probability for n charged particles in the final state of the interaction and $\langle n \rangle$ the mean multiplicity, the scaling law states that $\langle n \rangle P_n = \psi(z)$ is an energy independent function of the scaled variable $z = n/\langle n \rangle$ at very high energy. Indeed the data from Fermilab (c. m. energy $\sqrt{s}$ = 10-30 GeV [2]) and the ISR ($\sqrt{s}$ = 30-60 GeV [3]) show approximate scaling.

The UA5 Collaboration published in 1983 first evidence for non scaling multiplicity distributions in the new energy region accessible at the CERN antiproton-proton collider [4]. The scaled multiplicity distribution at $\sqrt{s}$ = 546 GeV was significantly wider than at energies below 100 GeV.

Recently the UA5 Collaboration has shown [5,6] that the scaled multiplicity distributions for the non single-diffractive part of the inelastic interactions in the energy range 10 - 546 GeV is very well parametrized with a negative binomial distribution

$$P(n;\langle n \rangle,k) = \begin{bmatrix} n+k-1 \\ k-1 \end{bmatrix} \left[\frac{\langle n \rangle/k}{1+\langle n \rangle/k}\right]^{n} \frac{1}{(1+\langle n \rangle/k)^{k}} \qquad (1)$$

The parameters $\langle n \rangle$ (the average multiplicity) and k (a parameter affecting the shape) were found to depend on the c. m. energy in a regular manner. We recall that k=1 means a geometric (exponential) distribution and $k^{-1}=0$ a Poisson distribution. For large $\langle n \rangle$, i.e. $\langle n \rangle \gg k$, scaling would imply a constant k. However, the data showed that k^{-1} increases linearly with ln s over the entire energy range and showed no tendency towards scaling. The approximate scaling that was observed in the energy range 10 - 62 GeV was in this framework seen to be accidental [5,6].

In this letter we report on new measurements of the multiplicity distributions at c. m. energies of 200 and 900 GeV, the latter representing the highest energy available at any accelerator. We also report on the energy variation of the average charged multiplicity. The data presented here are based on 1248 (608) fully reconstructed events at 900 (200) GeV from a run at the CERN Collider during its first operation in pulsed mode in March and April 1985. Details on the excellent performance of the accelerator and other running conditions are given in ref [7].

EXPERIMENTAL DETAILS

The UA5 detector and standard analysis procedures have been described previously [4,8]. Two large streamer chambers, 6m×1.25m×0.5m, were placed above and below the SPS beryllium beam pipe. This gave a geometrical acceptance of about 95% for $|\eta|<3$, falling to zero at $|\eta|=5$ (η is the pseudorapidity, $\eta=-\ln\tan\theta/2$ where θ is the c. m. emission angle). The trigger for the chambers was provided by scintillation counter hodoscopes at each end of the chambers covering the pseudorapidity range $2<|\eta|<5.6$. For the data presented here at least one hit in each arm was required, i.e. a two arm trigger. Using Monte Carlo simulations we estimate that this trigger accepts 95% (91%) of the non single-diffractive cross section at 900 (200) GeV.

The streamer chambers were photographed and the tracks were measured, geometrically reconstructed and associated with primary or secondary vertices as explained in ref. [4,8].

The event generator in the simulation programme was tuned to correctly reproduce the observed features of particle production at 546 GeV: multiplicity and rapidity distributions [4,9], observed yields of strange particles and baryons [10-12] and of photons [13]. The results were then parametrized as a function of c. m. energy [6,8,10] and calculations performed at 200 and 900 GeV. Produced particles were tracked through the detector allowing for interactions and scattering. Measurement errors were taken into account. The 3000 simulated events at each energy were used to determine the trigger efficiency ε_n (the probability that an event with true multiplicity n gives a two arm trigger) and a probability matrix P (the probability that a true multiplicity n results in an observed multiplicity m is given by the matrix element P_{mn}). This matrix is used to correct for the effects of geometrical acceptance losses and residual contamination of primary tracks by secondaries [8].

RESULTS

In fig. 1 a and b are shown the distributions of observed multiplicities at 200 and 900 GeV c. m. energy, respectively. The data have been subject to a vertex finding procedure which makes a first order correction for secondary interactions, gamma conversions and short-lived decays, but not for geometrical acceptance or trigger efficiency. The solid line in each figure is the result of a fit to the observed data of a negative binomial multiplicity distribution (1) transformed to an observed distribution using the matrix elements P_{mn} and trigger efficiences ε_n mentioned above. As can be seen from the figures there is an excellent agreement which is also borne out by the χ^2/NDF values of 22/33 and 52/58 for the 200 and 900 GeV fits, respectively. The parameters of the fit are given in table 1 together with the results from 546 GeV [4,6].

Figure 2 shows the parameter k^{-1} as a function of the logarithm of the c. m. energy. The new data at 200 and 900 GeV confirm our earlier observation that the shape of the scaled multiplicity distribution varies in a regular manner. There is no tendency of an approach to scaling, i. e. constant k. We have fitted the parameter k^{-1} to a linear function of $\ln\sqrt{s}$ ($\sqrt{s}$ in GeV):

$$k^{-1} = a + b \ln\sqrt{s} \qquad (2)$$

and obtain these new values for the parameters a and b (earlier values [6] in parenthesis): a = −0.104±0.004 (−0.098±0.008) and b = 0.058±0.001 (0.056±0.002).

We have corrected the observed multiplicity distribution using our standard techniques [4,8,14,15]. The results are summarized by moments, given in table 1. Fig. 3 shows the variation of the average charged particle multiplicity $\langle n \rangle$ for non single-diffractive events with the c. m. energy. Lower energy data are from refs [2,3]. Two parametrizations have been used to fit the data in the energy range 10 to 900 GeV (s in GeV^2):

$$\langle n \rangle = A + B \ln s + C(\ln s)^2 \qquad (3)$$

$$\langle n \rangle = \alpha + \beta s^{\gamma} \qquad (4)$$

The parameters for (3) are $A = 2.7\pm0.7$, $B = -0.03\pm0.21$ and $C = 0.167\pm0.016$ with correlation coefficients $\rho_{AB} = -0.992$, $\rho_{AC} = 0.964$ and $\rho_{BC} = -0.990$. For fit (4) the parameters are $\alpha = -7.0\pm1.3$, $\beta = 7.2\pm1.0$ and $\gamma = 0.127\pm0.009$ with correlation coefficients $\rho_{\alpha\beta} = -0.997$, $\rho_{\alpha\gamma} = 0.984$ and $\rho_{\beta\gamma} = -0.994$. The χ^2/NDF values for the two fits are 17/9 and 11/9, respectively. Thus either form gives a satisfactory fit to the data, both being shown in fig. 3.

The energy variation of the $C_2 - C_5$ moments ($C_q = \langle n^q \rangle / \langle n \rangle^q$) is shown in fig. 4 and given in table 1. Scaling would lead to constant moments. The new data at 200 and 900 GeV confirm our earlier conclusion [6] of non-KNO scaling between ISR and Collider energies with moments significantly larger at the Collider than at the ISR.

Equation (2) for the energy variation of k^{-1} and equations (3) and (4) for the energy variation of $\langle n \rangle$ can be used to predict parameters of the multiplicity distribution at higher energies as was done in our earlier work on fitting multiplicity distributions to the negative binomial distribution [6]. The new fits to k^{-1} and to $\langle n \rangle$ given above do not change those results significantly.

In conclusion, we have presented new data on charged particle multiplicity distributions at 200 and 900 GeV c. m. energy. The data confirm our earlier conclusion of non-scaling multiplicity distributions when the c. m. energy is increased sufficiently above the ISR energy range. The distributions are very well described by the negative binomial distribution with parameters smoothly varying with energy.

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Table 1. Moments of the corrected multiplicity distribution at 200, 546 [4,6] and 900 GeV c. m. energy. The errors in (a) are statistical only whereas the errors in (b) contain also a systematic part. The C moments are defined as $C_q = \langle n^q \rangle / \langle n \rangle^q$.

$\sqrt{s}$ (GeV)	200	546	900
(a) Fit to negative binomial			
Number of events	608	7344	1248
$\langle n \rangle$	21.6±0.5	28.3±0.2	35.1±0.6
k	4.6±0.4	3.69±0.09	3.2±0.2
(b) Moments calculated from corrected data			
Number of events	608	11909	1248
$\langle n \rangle$	21.4±0.8	29.1±0.9	34.6±1.2
D	10.9±0.4	16.3±0.4	20.2±0.6
$\langle n \rangle$/D	1.96±0.09	1.79±0.06	1.72±0.07
C_2	1.26±0.03	1.31±0.03	1.34±0.03
C_3	1.91±0.12	2.12±0.11	2.22±0.13
C_4	3.3±0.3	4.1±0.3	4.3±0.4
C_5	6.6±0.9	8.8±1.0	9.3±1.1

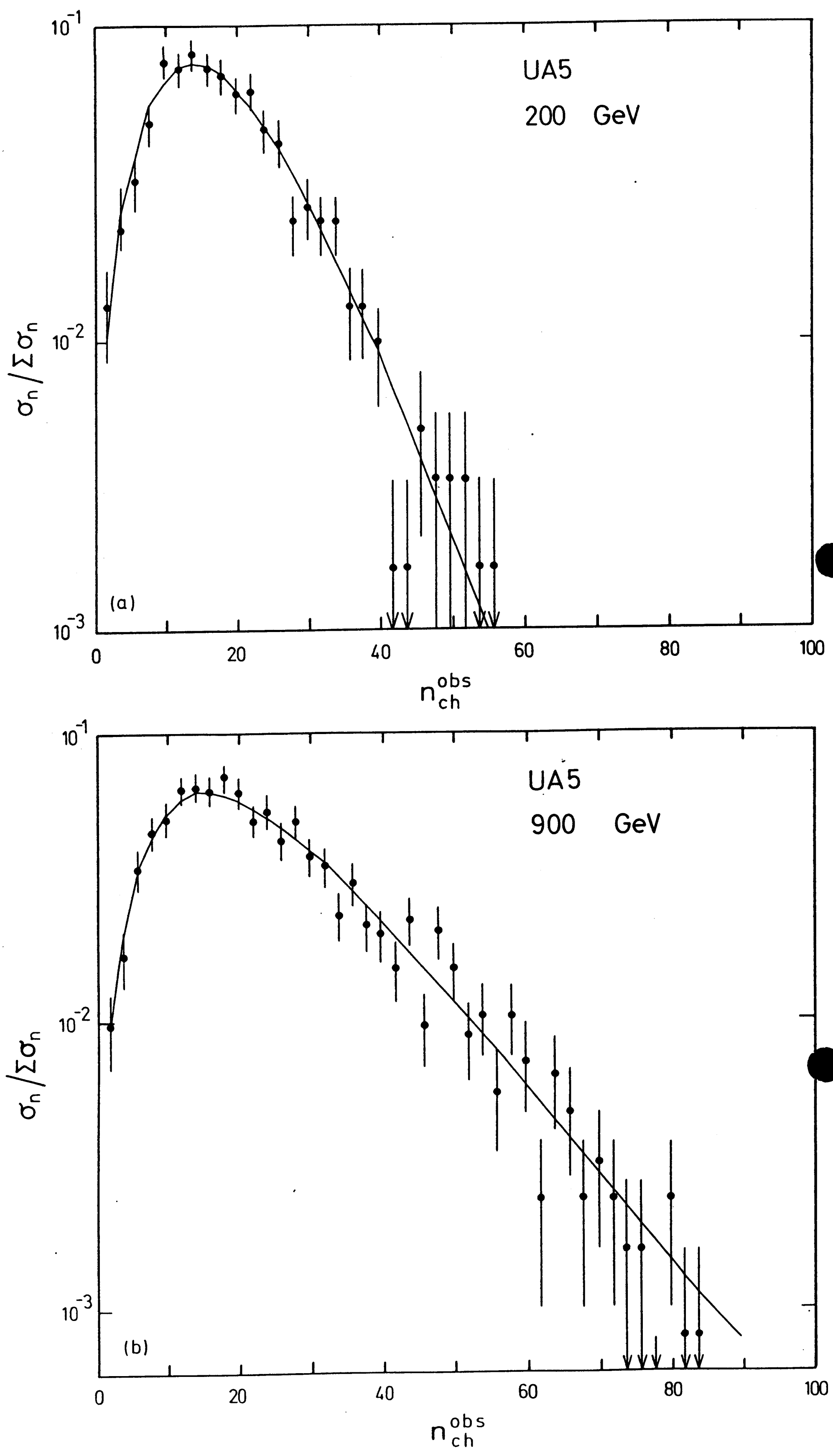
FIGURE CAPTIONS

Fig. 1 The distributions of observed multiplicities at 200 (a) and 900 (b) GeV c. m. energy. The full line in each figure is the result of a fit where the true acceptance corrected multiplicity distribution is assumed to be a negative binomial.

Fig. 2 The energy variation of the parameter k^{-1}.

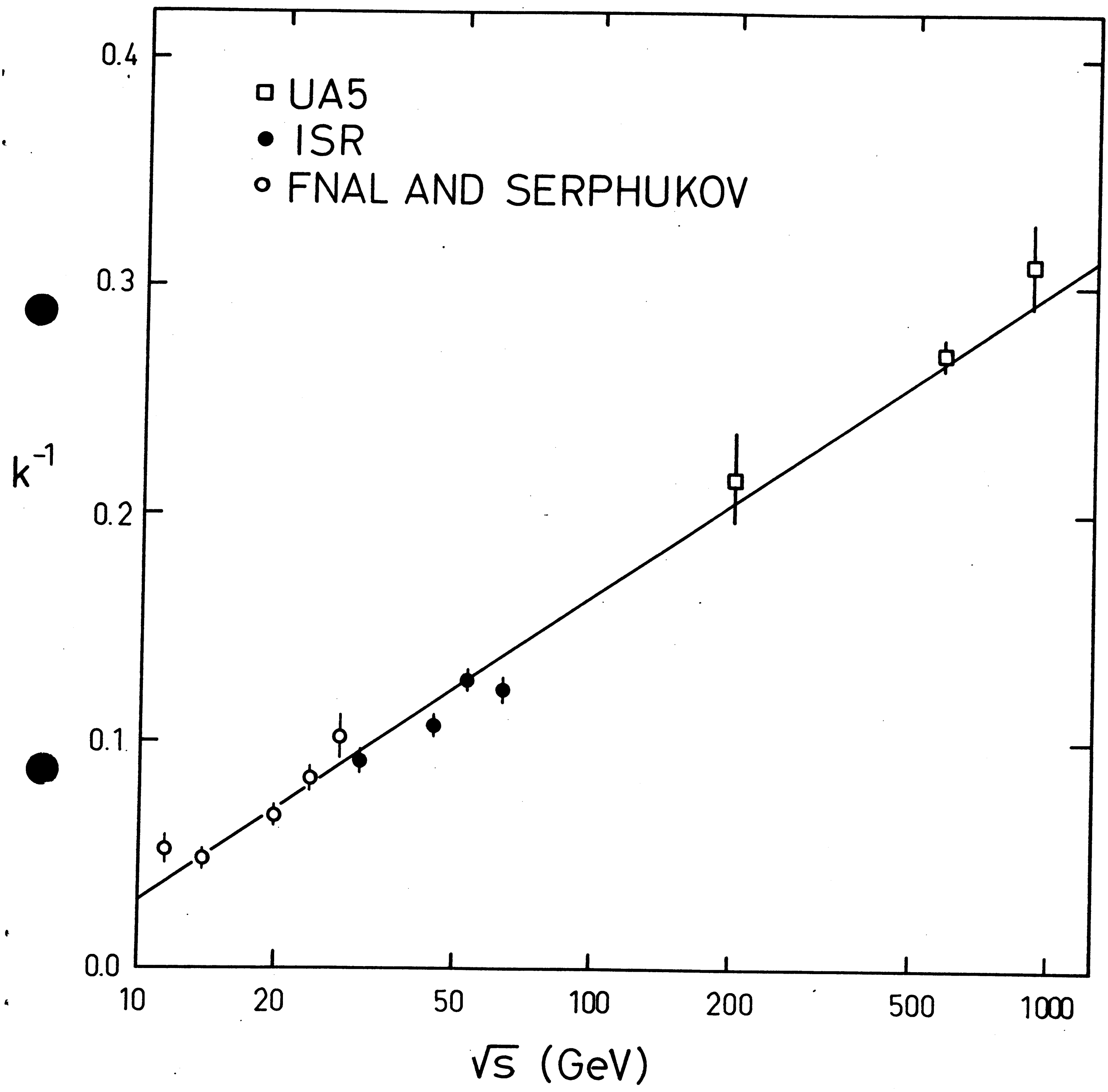
Fig. 3 The energy variation of the average charged multiplicity for non single-diffractive events. The solid and dashed lines are fits to the data explained in the text.

Fig. 4 The energy variation of the C-moments of the multiplicity distributions. For the UA5 points the smaller error bar indicates the size of the statistical error. The full error is the statistical and systematic errors added in quadrature.



UA5
200 GeV
(a)
10^{-1}
10^{-2}
10^{-3}
$\sigma_n/\Sigma\sigma_n$
0
20
40
60
80
100
n_{ch}^{obs}
UA5
900 GeV
(b)
10^{-1}
10^{-2}
10^{-3}
$\sigma_n/\Sigma\sigma_n$
0
20
40
60
80
100
n_{ch}^{obs}

Fig. 1



UA5
ISR
FNAL AND SERPHUKOV
0.4
0.3
0.2
0.1
0.0
k-1
10
20
50
100
200
500
1000
√s (GeV)

Fig. 2

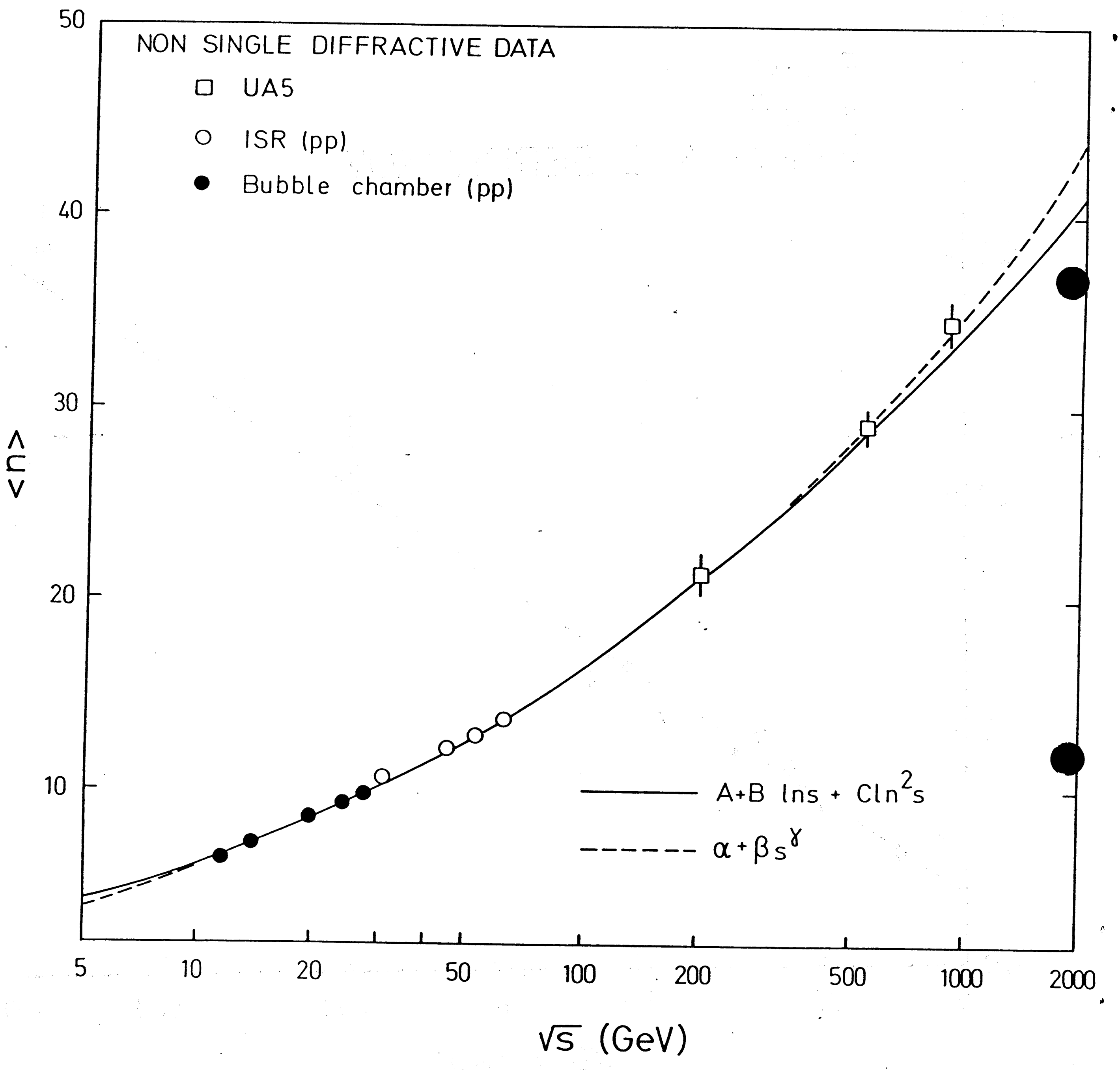
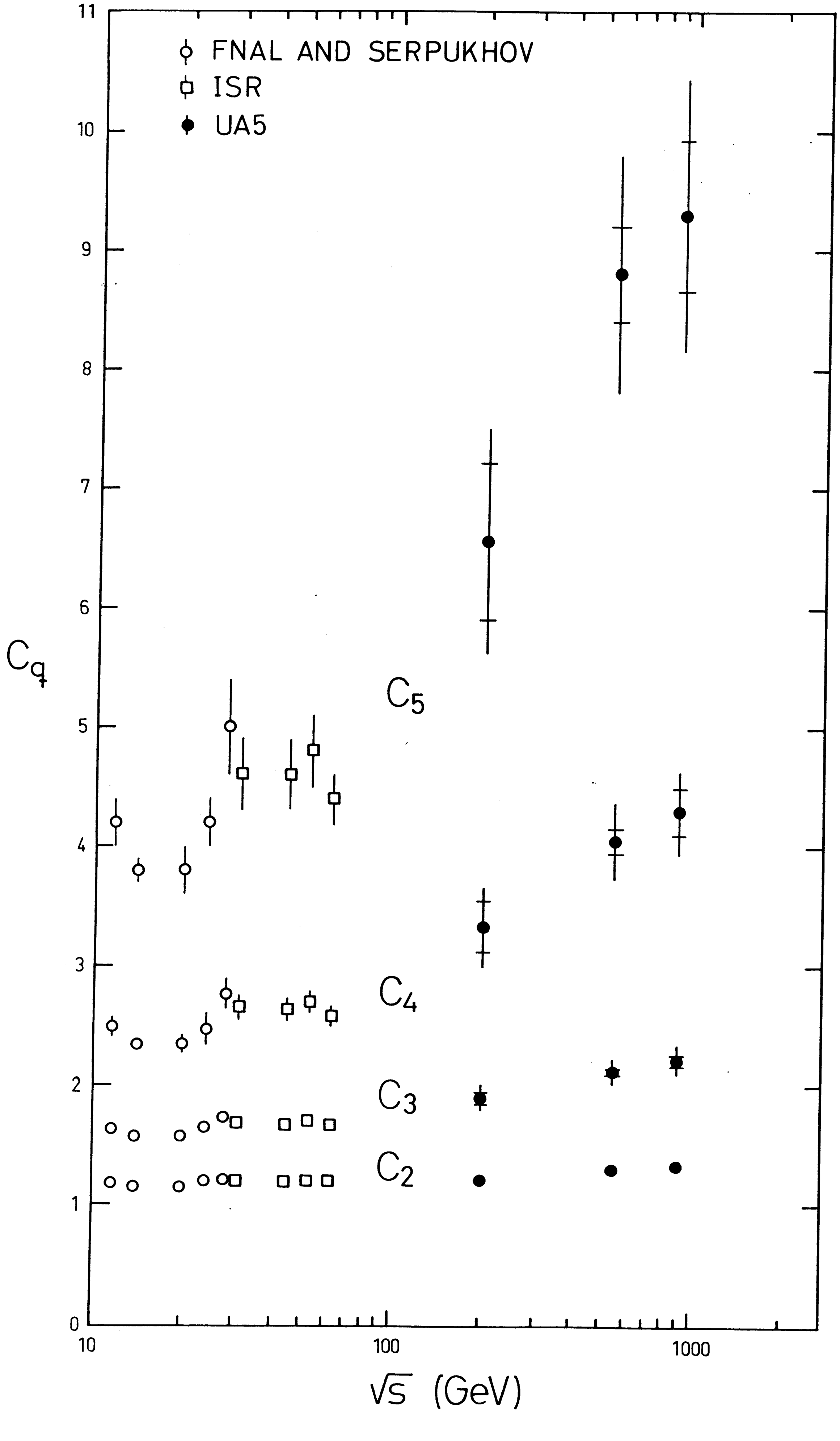

NON SINGLE DIFFRACTIVE DATA
UA5
ISR (pp)
Bubble chamber (pp)
A+B lns + Cln^{2}s
$\alpha+\beta s^\gamma$
50
40
30
20
10
<n>
5
10
20
50
100
200
500
1000
2000
√s (GeV)

Fig. 3



FNAL AND SERPUKHOV
ISR
UA5
C_q
C_5
C_4
C_3
C_2
0
1
2
3
4
5
6
7
8
9
10
11
10
100
1000
$\sqrt{s}$ (GeV)

Fig. 4