CERN-PRE 88-016
HEN-291

MULTIPLICITY DISTRIBUTIONS IN SEPARATED PHASE SPACE INTERVALS OF π^+p COLLISIONS AT 250 GeV/c

EHS/NA22 Collaboration

Aachen- Antwerp/Brussels- Berlin (Zeuthen)- Helsinki- Krakow- Moscow- Nijmegen- Rio de Janeiro- Serpukhov- Warsaw- Yerevan

M. ADAMUS[a], N.M. AGABABYAN[b], I.V. AJINENKO[c], Yu.A. BELOKOPYTOV[c], H. BIAŁKOWSKA[a], H. BÖTTCHER[d], P.V. CHLIAPNIKOV[c], F. CRIJNS[e], A. DE ROECK[f1], E.A. DE WOLF[f2], C. DREHER[d], K. DZIUNIKOWSKA[g], A.M.F. ENDLER[h], H. GRAESSLER[j], P. van HAL[e3], T. HAUPT[e4], J.K. KARAMYAN[b], W. KITTEL[e], A.I. KURNOSENKO[c], B.B. LEVCHENKO[i], J. MÄKELÄ[k], F. MEIJERS[e5], M. MERK[e], A.B. MICHALOWSKA[f], V.I. NIKOLAENKO[c], L.C.S. OLIVEIRA[h], K. OLKIEWICZ[g], V.M. RONJIN[c], A.M. RYBIN[c], H.M.T. SAARIKKO[k], W. SCHMITZ[j], L. SCHOLTEN[e], N.A. SOTNIKOVA[i], J. STEPANIAK[a], O.G. TCHIKILEV[c], L.A. TIKHONOVA[i], V.A. UVAROV[c], F. VERBEURE[f], R. WISCHNEWSKI[d], W. ZIELINSKI[g]

[a] University of Warsaw and Institute of Nuclear Problems[6], PL-00681 Warsaw, Poland
[b] Institute of Physics, SU-375036 Yerevan, USSR
[c] Institute for High Energy Physics, SU-142284 Serpukhov, USSR
[d] Institut für Hochenergiephysik der Akademie der Wissenschaften der DDR, DDR-1615 Berlin-Zeuthen, German Dem. Rep.
[e] University of Nijmegen and NIKHEF-H, NL-6525 ED Nijmegen, The Netherlands
[f] Universitaire Instelling Antwerpen, B-2610 Wilrijk and Inter-University Institute for High Energies, VUB/ULB, B-1050 Brussels, Belgium
[g] Institute of Physics and Nuclear Techniques of the Academy of Mining and Metallurgy and Institute of Nuclear Physics[6], PL-30055 Krakow, Poland
[h] Centro Brasileiro de Pesquisas Fisicas, 22290 Rio de Janeiro, Brazil
[i] Moscow State University, SU-117234 Moscow, USSR
[j] III. Physikalisches Institut B [7], RWTH, D-5100 Aachen, Fed. Rep. Germany
[k] Department of High Energy Physics, Helsinki University, SF-00170 Helsinki, Finland

ABSTRACT

The charged particle multiplicity distribution is studied for non-single-diffractive π^+p collisions at $\sqrt{s} = 22$ GeV, in central rapidity intervals separated from the outer regions by empty gaps. A priori unexpectedly, also these distributions yield good negative binomial fits. The variation of the parameter $1/k$ as a function of the gap size can be understood in terms of cascading clans of limited rapidity range if events with a large number of clans preferably contribute to the central region. The Fritiof-3 model agrees quantitatively with the data.

[1] Onderzoeker IIKW, Brussels, Belgium
[2] Bevoegdverklaard Navorser NFWO, Belgium
[3] Now with Ericsson Telecommunicatie B.V., Ri [redacted]
[4] On leave from Institute of Nuclear Physics, Krak
[5] Now at CERN, Geneva, Switzerland
[6] Partially supported by grants from CPBP 01.06 and
[7] Partially funded by the German Federal Minister for
the contract number 053AC41P

In a multiparticle final state, information is already contained in the distribution of the number of (charged) particles produced, the (charge) multiplicity n. This distribution has been studied at various energies in hadron-hadron, lepton-hadron and e^+e^- collisions and important differences have been observed (see [1] for recent reviews). Of particular interest is the distribution in limited parts of phase-space. There, distortions due to conservation laws are less important than for full phase space and the influence from various kinds of production mechanism is better isolated.

One of the most striking observations is that in all types of collision the multiplicity distribution can, with few exceptions, be well described by a negative binomial [2],

$$P_n(\bar{n},k) = \binom{n+k-1}{n} \left(\frac{\bar{n}/k}{1+\bar{n}/k}\right)^n (1+\bar{n}/k)^{-k} \quad , \tag{1}$$

with $\bar{n}$ the average multiplicity and $1/k$ a parameter to be defined below. This observation holds for full phase space as well as for central rapidity intervals [3-8].

To explain this observation, a large variety of mechanisms have been proposed (for a recent review see [9]). Particularly successful is the concept of "clans", groups of particles of common ancestry, introduced by Ekspong [10] and Giovannini and Van Hove [11]. Clans produced according to a Poisson distribution yield a negative binomial in n if the decay multiplicity distribution of an average clan is of the logarithmic type. From a comparison of the distribution for negative or positive particles to that of all charged particles [5] a clan cascading mechanism is, indeed, favoured over purely stimulated emission [9]. Clans are found [11] to grow in particle content (average number of charged particles) and probably also in rapidity range as the energy increases, but not in number. At given energy, they are bigger in particle content and range, but less numerous in hadron-hadron than in e^+e^- collisions.

As shown in [12], the above clan concept may be formulated in a context of greater generality and good indications exist that the clan decomposition may be more than a mathematical parametrization of the data and indeed have dynamical significance [13].

Until now, little is known about the rapidity structure of clans. In [14] an attempt is made to estimate directly the clan particle content and rapidity range, using simple parametrizations in rapidity. Good agreement is found for the rapidity dependence of the multiplicity distribution in the central region, but the model fails to describe the observed forward-backward multiplicity correlations, if clans are assumed to be identical in all phase space regions. More differential information is required from experiment to decide if the clan decomposition formalism has wider practical applicability and predictive power.

Here, we present for the first time information on the behaviour of the multiplicity distribution in central rapidity intervals when these are separated from the outer regions by empty gaps of varying size Δy. The analysis on these "conditional" distributions is done for a sample of all charged particles produced in π^+p collisions at $\sqrt{s} = 22$ GeV, as well as for a sample of negative particles from the same experiment. The results are confirmed by an analysis of our K^+p sample at the same energy (not shown here).

The experiment (NA22) has been performed at the CERN SPS in the European Hybrid Spectrometer (EHS). The hydrogen filled Rapid Cycling Bubble Chamber (RCBC) is used as an active vertex detector and exposed to a meson enriched positive beam. The experimental set-up and the trigger conditions are described in [5] and references quoted therein.

The data have been taken with a minimum bias interaction trigger. Secondary charged particle tracks are reconstructed from hits in the wire- and drift-chambers of the two lever-arm magnetic spectrometer and from measurements in the bubble chamber. The momentum resolution $\Delta p/p$ varies from a maximum of 2.5% at 30 GeV/c to less than 1% above 100 GeV/c.

Events are accepted when measured and reconstructed charge multiplicity are consistent, charge balance is satisfied, no electron is detected among the secondary tracks, all tracks are well reconstructed and particle identification from RCBC is available for $p_{LAB} < 1.2$ GeV.

An inelastic sample is defined by a simultaneous cut on missing transverse and missing longitudinal momentum. A "non-(single)-diffractive" (NSD) sample is defined by excluding low multiplicity events ($n \leq 6$) with a positive particle having $|x_F| > 0.88$. This NSD $\pi^+ p$ sample used in the analysis comprises 8954 events.

To correct for losses, each event is assigned an acceptance weight. The distributions presented below are, furthermore, corrected by Monte Carlo simulation for residual wrong mass assignment and event losses due to badly reconstructed tracks.

The errors given include an estimate of the systematic uncertainties due to the NSD selection. We estimate these to vary from 0 (large n and small interval) to 7.5% (low n and big interval). The systematic errors are added in quadrature to the statistical ones.

With the unconditional distribution ($\Delta y = 0$) following a negative binomial, the conditional ones ($\Delta y > 0$), in general, are not expected to follow a negative binomial. Nevertheless, the results of negative binomial fits to the conditional multiplicity distribution in rapidity intervals $|y| < y_1$, separated by two empty gaps $y_1 < |y| < y_2$ from the outer regions are given in table 1. For each of the three values of y_2, five values of y_1/y_2 are used ranging from an empty gap Δy of 80% ($y_1/y_2 = 0.2$) to zero ($y_1/y_2 = 1.0$). From the χ^2/NDF values of table 1, it is seen that not only the unconditional distribution ($y_1/y_2 = 1.0$) gives good fits, but, at our present statistics, also the conditional ones. This holds for all charged as well as for negative particles. Since independent emission (Poisson) corresponds to a negative binomial with $1/k = 0$, we use $1/k$ ($= \frac{D^2}{\bar{n}^2} - \frac{1}{\bar{n}}$ with $D^2 = \overline{n^2} - \bar{n}^2$) as a measure of the multiplicity correlation also in the conditional distribution.

In Fig.1, the values of the parameter $1/k$ are shown as a function of y_1 for the three values of y_2, for all charged particles (Fig.1a) and for negatives (Fig.1b). For given y_2, the $1/k$ value rises above the value of the unconditional distribution ($y_1/y_2 = 1.0$, open symbols) as y_1 is reduced in favour of the size of $\Delta y = y_2 - y_1$. But, more importantly, $1/k$ also increases for given y_1, when y_2 is increased from 0.5 to 1.5, i.e. the gap is increased outwards. Selecting events by the criterion of having no particles in the gap, the multiplicity correlation $1/k$ between the particles in the inner region grows when the criterion gets more severe. (The lines will be discussed further down.) For negatives (Fig.1b), the dependence of the parameter $1/k$ on the gap size is weaker than for all charged particles.

What can be concluded from this behaviour?

We start from a situation where the multiplicity distribution is negative binomial with parameter value $1/k_2$ in the interval $|y| < y_2$, but there is no correlation between the particles in rapidity. In this case, the distribution in the sub-interval $|y| < y_1$ follows from a composition [9] of the negative binomial for n particles in $|y| < y_2$ with the binomial

$$P(n|n_1) = \binom{n}{n_1} p^{n_1} q^{n-n_1}, \tag{2}$$

for n_1 in $|y| < y_1$. Here, p is the probability for a particle of $|y| < y_2$ to fall into $|y| < y_1$ and $q = 1 - p$ that for the same particle to fall into the gap $y_1 < |y| < y_2$. For both the unconditional distribution ($0 \leq n - n_1 \leq n$) in $|y| < y_1$ and the conditional distribution ($n - n_1 = 0$) in $|y| < y_1$, this gives a negative binomial with $1/k_1 = 1/k_2$. So, when no rapidity correlation is assumed, $1/k$ is expected equal for conditional and unconditional distributions. This is different from the behaviour observed in Fig.1.

In a second step, we assume a clan cascading mechanism with various parametrizations of the rapidity density of clans and their decay, including the parametrization of [14]. Numerical calculations show that the unconditional and conditional distributions are only approximately negative binomial and that, depending on the particular parametrization, $1/k$ is either equal to or even smaller than that of the unconditional one.

An increase of $1/k$ with the gap size can, however, be obtained if, in addition to the multiplicity correlation of the negative binomial and the clustering in y as introduced above, we use the fact that events with a large number of particles (and therefore a large average number of clans) preferably contribute to the central region.

To understand the increase of $1/k$ with increasing gap size, we consider the two events schematically shown in Fig.2. Both consist of 4 clans, but the clans are distributed differently in rapidity. In the case that a track is allowed in $y_1 < |y| < y_2$ (unconditional distribution), both event 1 and 2 contribute to the multiplicity distribution. If no track is allowed in $y_1 < |y| < y_2$ (conditional distribution), only event 2 contributes. Event 1 gives a contribution with particles from 4 separate clans, while in event 2 the contribution is only from 2 separate clans. So, in the conditional distribution events with a large number N of clans in $|y| < y_2$ are suppressed. In [10,11] N follows a Poisson distribution and the only correlation in n is within a clan. The parameter $1/k$ can then be interpreted as a measure of "aggregation" of particles in clans [11], $1/k = P_1(2)/P_2(2)$, i.e. the probability for two particles to come from one clan divided by that for the two to come from different clans. It is natural to expect that the aggregation in a conditional distribution is larger than in an unconditional one. The effect will be the stronger, the more clans lie in the central region.

The values of the clan-model parameters, the average population of a clan $\bar{n}_c$ and the average number of clans $\bar{N}$, can be calculated as [10,11]

$$\bar{n}_c = \frac{\bar{n}}{k} / \ln\left(1 + \frac{\bar{n}}{k}\right) \text{ and } \bar{N} = k \, \ln\left(1 + \frac{\bar{n}}{k}\right) . \tag{3}$$

The results for our intervals are shown in Fig.3, for all charged particles as well as for negatives. While for given y_1 the average population $\bar{n}_c$ of the clans is approximately independent of y_2, the number of clans indeed decreases as the empty gap gets larger. This is just what we expect from the reasoning above.

At first sight, it may seem surprising that the effect is much weaker for the negatives than for all charged particles. If clans consist of a mixture of negative and positive particles, the condition introduced becomes weaker for negatives, because no restriction is imposed on positive particles in the gap. On the other hand, such a reduction of the effect is not expected in purely stimulated emission of identical particles.

It can be seen for small y_1 in Fig.1a that, at our energies, the effect of y_2 is particularly big when the gap $\Delta y = y_2 - y_1$ becomes larger than $\Delta y \approx 1.0$. Since from Fig.2, only clans longer than Δy would be able to span the gap and contribute to the conditional distribution from the outside, clans seem to be limited to about that range in rapidity. At our energies, this range happens to be of similar size as that of the well-known short range order. Indication exists, however, that centrally produced clans are considerably more extended in rapidity at the Collider [3,10] and shorter in e^+e^- collisions [4,5] than in hh collisions at similar energies. For a confirmation of this important difference between clan development and short range order, repetition of our analysis at higher energies and for other types of collision would be extremely useful.

We now come back to the lines in Fig.1. The full and dash-dotted ones correspond to, respectively, the unconditional and conditional distribution from the Fritiof-3 model [15]. While we still have difficulties [5] in reproducing the full phase space multiplicity distribution (too narrow, not shown), the central region is described to the detail of our present analysis. This indicates that the model, in terms of a partonic branching process, contains the proper features of cascading. On the other hand, a two-chain version [16] of the Dual Parton Model (dashed and dotted) gives bad fits (large χ^2) and too low $1/k$ values. More (central) chains are needed, but are believed to only contribute at the level of a few percent at our energy.

We conclude that the multiplicity distribution in the central region widens not only if the region is reduced, but also if forbidden gaps on both sides are introduced and increased. With our present statistics, also the conditional distributions can be described by negative binomials. The increase of correlation deduced from the widening of the distributions can be understood from the clan picture (with clans of limited range in y and events with a large number of clans preferably contributing to the central region) and from the Fritiof-3 model. A similar analysis at higher energies and for other types of collision would be important and provide more information on the rapidity structure of clans and its development with energy.

ACKNOWLEDGEMENTS

It is a pleasure to thank the operating crews and staffs of the EHS, the SPS and the $H2$ beam, as well as the scanning and processing teams of our laboratories for their invaluable help with this experiment. We particularly thank L. Van Hove and A. Giovannini for drawing our attention to this type of analysis.

REFERENCES

[1] G. Gustafson, "Soft Hadronic Interactions", Rapporteur talk at the Int. Europhys. Conf. on High Energy Physics, Uppsala 1987, Lund preprint LU TP 87-15 (1987);
W. Kittel, "Soft and Semi-Hard Hadronic Compared to e^+e^- and lh Collisions", Invited Review at the XVIIIth Int. Symp. on Multiparticle Dynamics, Tashkent 1987, Nijmegen preprint HEN-292 (1987).

[2] M. Garetto and A. Giovannini, Lett. Nuovo Cimento 7 (1973) 35;
A. Giovannini et al., Nuovo Cimento 24A (1974) 421;
N. Suzuki, Prog. Theor. Phys. 51 (1974) 1629;
W.J. Knox, Phys. Rev. D 10 (1974) 65.

[3] G.J. Alner et al. (UA5), Phys. Lett. B 160 (1985) 199; B 160 (1985) 193; B 167 (1986) 476.

[4] M. Derrick et al. (HRS), Phys. Lett. B 168 (1986) 299; Phys. Rev. D 34 (1986) 3304.

[5] M. Adamus et al. (NA22), Phys. Lett. B 177 (1986) 239; Z. Phys. C 32 (1986) 475; "Phase Space Dependence of the Multiplicity Distribution in π^+p and pp Collisions at 250 GeV/c", to be published in Z. Phys. C.

[6] F. Dengler et al., Z. Phys. C 33 (1986) 187.

[7] R. Ammer et al. (LEBC-MPS), Phys. Lett. B 178 (1986) 124.

[8] M. Arneodo et al. (EMC), Z. Phys. C 35 (1987) 335.

[9] P. Carruthers and C.C. Shih, Int. J. Mod. Phys. A2 (1987) 1447.

[10] G. Ekspong, Proc. XVI Int. Symp. on Multiparticle Dynamics, Kiryat Anavim (1985), ed. J. Grunhaus (Editions Frontières, World Scientific 1985) p.309.

[11] A. Giovannini and L. Van Hove, Z. Phys. C 30 (1986) 391;
L. Van Hove and A. Giovannini, Proc. of XVII Int. Symp. on Multiparticle Dynamics, Seewinkel (1986), eds. M. Markytan et al., (World Scientific, Singapore 1987) p.561;
A. Giovannini and L. Van Hove, "Negative Binomial Properties and Clan Structure in Multiplicity Distributions", CERN-TH 4894/87 (1987).

[12] L. Van Hove, Physica 147A (1987) 19.

[13] L. Van Hove and A. Giovannini, "Multiplicity Distributions in the Lund Shower Model of e^+e^- Annihilation", CERN-TH 4885/87 (1987).

[14] A. Bialas and A. Szczerba, Acta Phys. Pol. B17 (1986) 1085 and Acta Phys. Pol. B18 (1987) 681.

[15] B. Andersson et al., Nucl. Phys. B281 (1987) 289 and "A High Energy String Dynamics Model for Hadronic Interactions", Lund preprint TP87-6 (1987).

[16] E.A. De Wolf, Proc. XV-th Int. Symp. on Multiparticle Dynamics, Lund, eds. G. Gustafson and C. Peterson (World Scientific, Singapore 1984) p.2.

Table 1

Negative Binomial parameters of the multiplicity distributions.

	y_1/y_2	y_2=0.5	y_2=1.0	y_2=1.5
charged				
$1/k$	0.2	0.672±0.187	0.549±0.137	0.966±0.216
	0.4	0.432±0.066	0.352±0.052	0.710±0.082
	0.6	0.376±0.034	0.407±0.034	0.508±0.039
	0.8	0.366±0.025	0.360±0.020	0.345±0.018
	1.0	0.357±0.021	0.279±0.012	0.234±0.009
$\bar{n}$	0.2	0.224±0.009	0.323±0.015	0.417±0.026
	0.4	0.509±0.014	0.823±0.024	1.112±0.038
	0.6	0.876±0.014	1.546±0.029	2.216±0.047
	0.8	1.332±0.018	2.504±0.034	3.724±0.048
	1.0	1.866±0.024	3.673±0.036	5.415±0.045
χ^2/NDF	0.2	2.19/ 2	1.43/3	2.93/4
	0.4	2.15/ 4	7.87/5	0.84/8
	0.6	7.50/ 6	5.70/9	11.42/11
	0.8	7.31/ 8	8.25/13	13.45/18
	1.0	6.35/11	24.68/17	22.47/21
negatives				
$1/k$	0.2	0.364±0.122	0.259±0.080	0.257±0.059
	0.4	0.205±0.058	0.218±0.046	0.275±0.046
	0.6	0.194±0.041	0.177±0.027	0.169±0.022
	0.8	0.198±0.035	0.174±0.020	0.127±0.014
	1.0	0.164±0.025	0.151±0.015	0.111±0.011
$\bar{n}$	0.2	0.155±0.005	0.291±0.009	0.400±0.014
	0.4	0.320±0.008	0.598±0.013	0.894±0.019
	0.6	0.495±0.009	0.951±0.015	1.395±0.021
	0.8	0.688±0.011	1.321±0.017	1.920±0.022
	1.0	0.876±0.012	1.692±0.018	2.406±0.022
χ^2/NDF	0.2	0.64/2	2.17/3	8.80/ 4
	0.4	2.13/3	3.60/4	8.65/ 5
	0.6	6.99/4	10.27/6	5.36/ 7
	0.8	3.28/4	8.51/7	9.96/ 9
	1.0	2.55/6	3.27/8	5.41/10

FIGURE CAPTIONS

Fig. 1: The $1/k$ parameter of the negative binomial fit as function of y_1 for $y_2 = 0.5, 1.0, 1.5$, a) for all charged particles, b) for negatives. The open symbols correspond to the unconditional distribution ($y_1 = y_2$). The dash-dotted lines correspond to the Fritiof-3 model predictions for conditional distributions, the solid line for unconditional ones, the dashed and dotted ones to a 2-chain DPM. The statistical errors in the model are about 75% of those in the data.

Fig. 2: Schematic view of two events, both consisting of 4 clans, but their clans distributed differently in rapidity.

Fig. 3: The clan model parameters $\bar{N}$ and $\bar{n}_c$ as functions of y_1 for $y_2 = 0.5, 1.0, 1.5$, a) and c) for all charged particles, b) and d) for the negatives. The open symbols correspond to the unconditional distribution. The lines are to guide the eye.

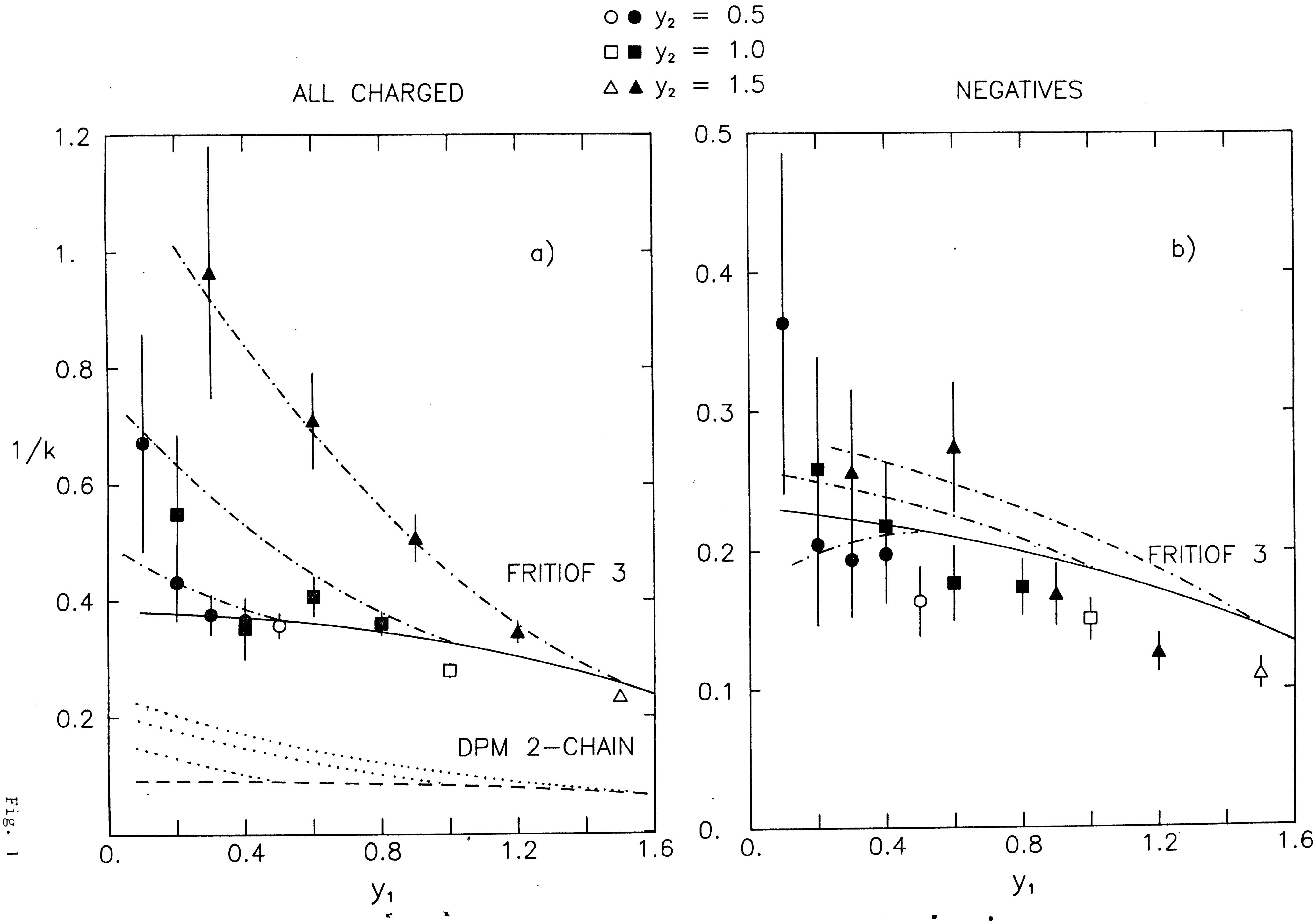
○ ● y_2 = 0.5
□ ■ y_2 = 1.0
△ ▲ y_2 = 1.5
ALL CHARGED
NEGATIVES
a)
b)
FRITIOF 3
FRITIOF 3
DPM 2-CHAIN
1/k
y_1
y_1
0.
0.4
0.8
1.2
1.6
0.2
0.6
1.
0.1
0.3
0.5

Fig. 1

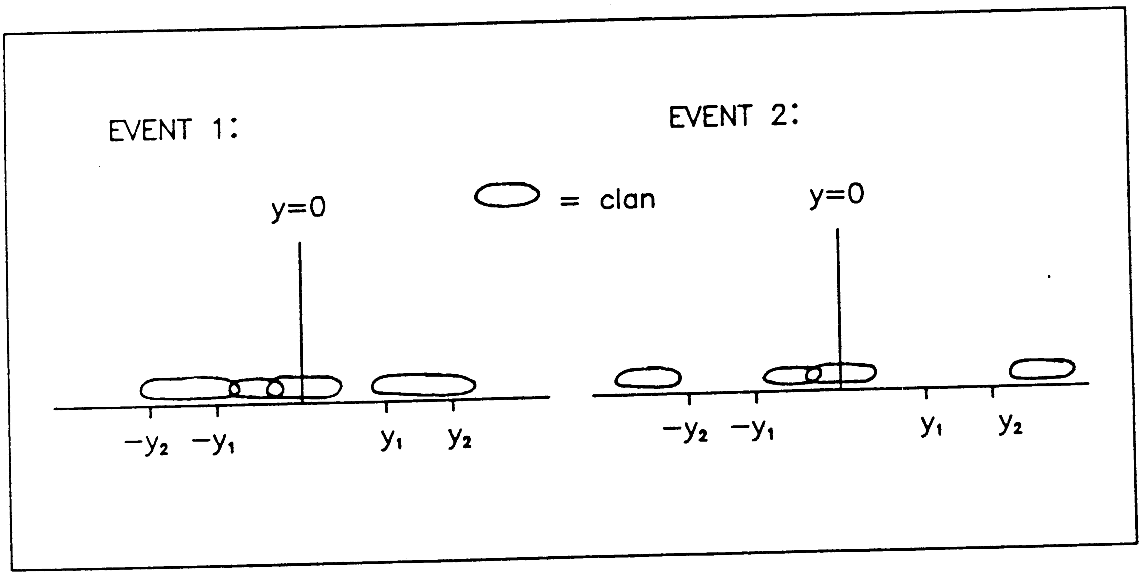

Fig. 2

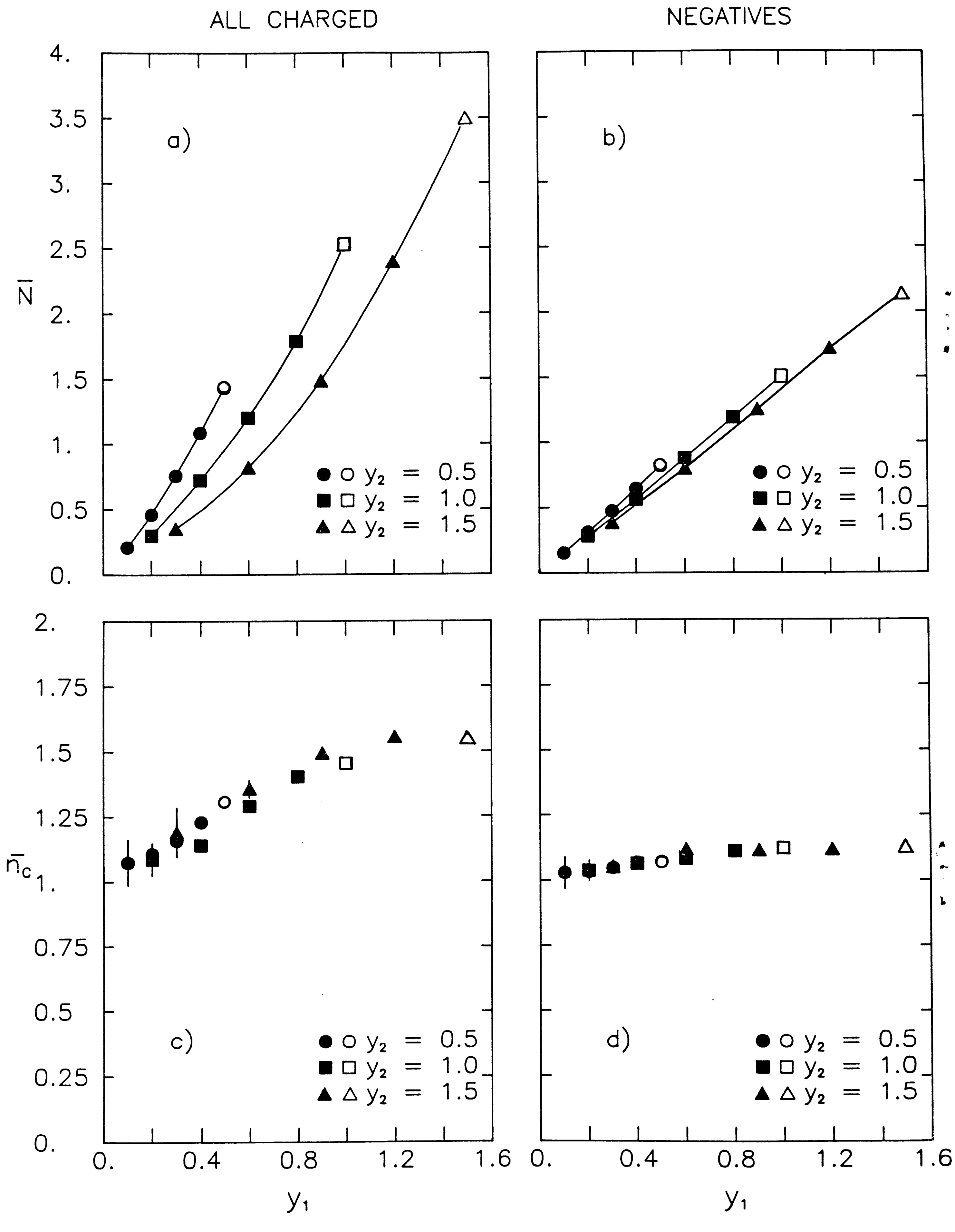
ALL CHARGED
NEGATIVES
a)
b)
c)
d)
$\bar{N}$
$\bar{n}_c$
y_1
● ○ y_2 = 0.5
■ □ y_2 = 1.0
▲ △ y_2 = 1.5
0.
0.5
1.
1.5
2.
2.5
3.
3.5
4.
0.25
0.75
1.25
1.75
0.4
0.8
1.2
1.6

Fig. 3