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# MEASUREMENT OF THE FRAGMENTATION OF HADRONIC SYSTEMS OF DIFFERENT FLAVOUR AND COLOUR SELECTED BY LEPTON PAIRS

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## ABSTRACT

A lepton-pair trigger was used to select a hadronic system in different flavour and colour states; properties of the transformation of this system into hadrons were measured in terms of charge flow, multiplicity distribution, and fragmentation function. It is observed that, while the effects of flavour are clearly seen, the colour degrees of freedom are not observed in the region of low $p_T$.

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## 1. INTRODUCTION

Considerable progress has been made in the understanding of the structure of matter in the last decade. It is generally assumed that matter is constructed of spin-$\frac{1}{2}$ quarks and leptons interacting through the exchange of spin-1 bosons. Leptons and quarks appear as point-like objects down to at least $10^{-16}$ cm [1]. However quarks are not observed as isolated point-like particles; instead they emerge as jets of hadrons.

Quantum Chromodynamics (QCD) is a strong candidate for the theory of strong interactions. In this theory colour is introduced as the charge of strong interactions giving an additional degree of freedom to different flavours of quarks. The coloured quarks interact through the exchange of coloured gluons, which in turn can also interact among themselves. As in Quantum Electrodynamics (QED) there is also a vacuum polarization giving rise to quark-antiquark pairs called "sea quarks". Therefore, hadrons, which are neutral in colour, are understood as being composed of many partons: valence quarks, gluons, and sea quarks.

In the hadron-hadron interactions, partons from one hadron interact with partons in the other one. As a result two or more hadronic systems composed of partons in different colour and flavour states emerge and fragment into colourless hadrons. Generally it is very difficult to interpret these interactions since the observed result is a mixture of many different parton-parton interactions.

The experiment described here uses a lepton-pair trigger in order to select fragmenting hadronic systems in a well-defined colour and flavour state.

In this experiment the $\mu^+\mu^-$ lepton pair was produced in $\pi^-N$ interactions at a mean energy of 190 GeV/c. The lepton pair mass spectrum is composed of a continuum and of a few narrow resonances. It is generally understood that the high-mass continuum is produced through the Drell-Yan mechanism in which the lepton pair is produced via a quark-antiquark annihilation into a virtual photon which in turn converts into the $\mu^+\mu^-$ pair (fig. 1). Here the dominant process is the annihilation of the $\bar{u}$ quark from the negative pion with the u quark from the nucleon. In this case the remaining quark system from the pion continues its trajectory in the forward direction and fragments into hadrons. It is important to realize that knowing x and the mass of the lepton pair one can obtain the fraction $(1 - x_1)$ of the longitudinal momentum carried by the forward d quark system for every event.

For $J/\psi$ production we expect a different situation (fig. 1). Since the $J/\psi$ is produced mostly through gluon-gluon fusion [2] at the energies of this experiment, the system of d quark plus $\bar{u}$ quark are fragmenting in the forward direction. Again, one knows the momentum of the fragmenting system for each event.

Therefore there are basic differences for these two cases. First of all, in the case of Drell-Yan production, it is a system with a charge of $1/3$ which is fragmenting, while in the case of $J/\psi$ production it is the whole -1 charge. Do we see this difference experimentally? Secondly, for the Drell-Yan production (quark fusion) the forward fragmenting system is in the three-colour state, while for the $J/\psi$ production (gluon fusion) the fragmenting system is in the eight-colour state. According to QCD predictions one could expect a higher multiplicity by a factor of $9/4$ for the fragmentation of the eight-colour state (section 5). Finally, what are the fragmentation functions? In particular, is the d quark accompanying Drell-Yan production fragmenting as a Field-Feynman jet [3]?

In order to investigate these questions, properties of hadrons associated with Drell-Yan and $J/\psi$ production were investigated and compared with the properties of hadrons produced in the normal hadronic interactions as measured in the same experiment. All these were compared with the properties of "standard jets". As a particular example of "standard jet" the so-called Lund Monte Carlo (jet MC) was used [4]. Since this MC describes very well properties of jets in $e^+e^-$ annihilation, any comparison of data presented here with this jet MC will be treated as the comparison with $e^+e^-$ annihilation data.

## 2. EXPERIMENTAL SET-UP AND PROCEDURE

The experiment was performed by the Saclay-Imperial College-Southampton-Indiana Collaboration (WA11-Goliath) in the CERN SPS West Hall. The experimental set-up is presented in fig. 2. Negative pions with momentum between 175 and 197 GeV/c interacted in three beryllium targets with a length of 3 + 4.2 + 3 cm.

Coordinates of outgoing particles were measured by 13 chambers placed in the magnetic field of the Goliath magnet and three downstream. Muons were identified as particles passing through 4 m of iron. Every chamber was desensitized in the region of the beam trajectory. This "beam killer" [5] was slightly displaced for every chamber in order to follow the beam curvature. In this way an asymmetry in the acceptance for positive and negative particles was built into the apparatus. Despite its geometrical smallness the "beam killer" had an important effect on the acceptance owing to the strong Lorentz boost of the outgoing particles at these high energies. In addition, it increased the difficulties of the pattern recognition program in the region of high-particle density.

In order to investigate the experimental acceptance a sophisticated Monte Carlo program was developed. In this program a uniform distribution in rapidity and $p_T$ was generated for both positive and negative particles. Each particle was traced through the set-up and the response of every detector was generated. This information, after taking into account chamber inefficiency was then mixed with a real event measured during a standard data-taking period. Afterwards, such a set of events was processed through the standard pattern-recognition program. Finally, the ratio of the number of tracks surviving this procedure to the number of generated events determined the efficiency for every bin in a table of rapidity versus $p_T$. This procedure determined efficiency in a model-independent way. Since the results were subject to large statistical fluctuations a smooth surface was fitted to the MC results.

During the data analysis every particle with a given rapidity and $p_T$ received a weight defined as an inverse of efficiency. A two-dimensional plot of the weight distribution is presented in fig. 3. One can see that at large rapidities (above two) there is a difference in acceptance between positive and negative particles. In addition, for rapidities where the acceptance was very small, the weight was set at zero.

## 3. EVENT SELECTION

Figure 4 shows the $\mu^+\mu^-$ invariant mass spectrum. It is worth noting the excellent mass resolution for the $J/\psi$ ($\sigma$ = 31 MeV). A total of 42,456 events with the lepton-pair mass between 2.95 and 3.25 GeV were defined as those accompanying $J/\psi$ production, while the 2126 events with the $\mu^+\mu^-$ mass between 3.85 and 9.3 GeV were selected to represent the Drell-Yan production. As can be seen in fig. 4, the background contamination below the $J/\psi$ peak is less than 15%. An analysis of like-sign $\mu$-pairs showed that the background below Drell-Yan events is even smaller. Finally, these two sets of data were compared with those from normal $\pi^-N$ interactions at 192 GeV/c in a beryllium target measured in the same experiment.

It is convenient to define the longitudinal momentum of the forward hadronic system in the units of $\sqrt{s}/2$ as $x_{tot} = 1 - x$ (fig. 1). The measured distributions of $x_{tot}$ are given in fig. 5.

One problem of the analysis of the properties of hadrons in this experiment was the fact that the interactions took place not with a proton target but with a beryllium target. The results of the Heidelberg-Lund [6] experiment at CERN show that while in the backward direction one is studying basically nuclear effects, in the forward direction one can measure properties of hadrons produced in the elementary interaction. However, one should not forget that even in the forward direction, the small (< 15%) nuclear effects are not excluded.

Bearing in mind all these considerations, we will investigate properties of hadrons in terms of the following variables: charge flow, multiplicity, and fragmentation functions. The properties of the hadronic system are measured here through its fragmentation into charged hadrons in the forward direction of the $\pi N$ c.m.s. It is essential to note that all the experimental and MC curves and numbers presented in this paper are normalized to one (experimental or MC) event.

## 4. FRAGMENTATION FUNCTION

The fragmentation function describes the way in which a parton or system of partons fragments into hadrons observed in the experiment. The simplest function describing the fragmentation is the z-distribution, where z is the ratio of the x of each hadron to the $x_{tot}$ of the hadronic system as defined in section 3. In this way fragmentation in the forward longitudinal momentum is investigated.

What fragmentation function can we expect for the three different sets of data presented here? How should they compare with the jet MC calculations? There are many reasons why they could be different:

i) The quark contents of the forward hadronic systems are different. In the case of the Drell-Yan production it is the d quark which is fragmenting, while in the case of the $J/\psi$ or normal hadronic interactions, both the d and $\bar{u}$ quarks may be fragmenting.

ii) The colour charges are different. The forward hadronic system is in the three-colour state in the case of Drell-Yan production, mostly in the eight-colour state for the $J/\psi$ production, and in an unknown mixture of different colour states in the case of normal hadronic interactions.

iii) Valence quarks are not the only partons in the hadrons. There are many gluons and sea partons in the hadrons fragmenting together with the valence quarks. In the case of $e^+e^-$ annihilation we start with point-like quarks, or "current quarks", while in the soft fragmentation described here we have a system of fragmenting partons (quarks with a form factor on "constituent quarks").

The measured z-distribution in the forward direction is given in fig. 6 for each of the three different data sets. Both linear and logarithmic scales are shown. For each set a comparison with MC is made. The jet MC was generated by the Lund Monte Carlo [4] program with the standard parameters for the fragmentation which made it equivalent to the Field-Feynman jet generation. The jet momentum was chosen according to the experimental $x_{tot}$ distribution in fig. 5 for $J/\psi$ and Drell-Yan events; $x_{tot} = 1$ was used for $\pi N$ interactions. The fragmentation of the d quark was generated for the Drell-Yan events, while for the $J/\psi$ and $\pi N$ events, the fragmentation of the d or $\bar{u}$ quark was used with equal probability. However, it is important to realize that, since the fragmentation function of the d and $\bar{u}$ quarks are practically identical, all the experimental z-distributions presented here are compared with the fragmentation function of one quark jet. Generated particles with y and $p_T$ for which the weight was set at zero (section 2) were removed.

Careful examination of fig. 6 reveals the large enhancement of slow particle production (below $z = 0.2$) over the MC prediction. However, above $z = 0.2$ good agreement between the data and the jet MC calculation can be seen for all three data sets. Therefore, above $z = 0.2$ there is no significant difference between any of the fragmentation functions for the three sets of data presented here.

## 5. MULTIPLICITY

This experiment allows a study of how the multiplicity of the fragmenting low-$p_T$ hadronic system depends on its colour. What can QCD predict about this dependence? Quantum Chromodynamics works well for short-distance phenomena. Brodsky and Gunion [7], however, used QCD for long-distance phenomena and predicted that the multiplicity of a fragmenting octet should be $^9/_4$ times the multiplicity of a fragmenting triplet.

The experimentally measured multiplicity data are presented in fig. 7.

Since the mean energy of the forward hadronic system is lowest for Drell-Yan production, higher for $J/\psi$ production, and finally highest for normal hadronic interactions (fig. 5), it is important to take into account this energy-dependence property. Therefore, fig. 7 shows the mean measured multiplicity of the forward hadronic system as a function of its $x_{tot}$. In this way multiplicity of jets with the same momentum are compared. It is seen that the multiplicity is very similar for both the Drell-Yan and the $J/\psi$ production and is approaching the multiplicity of the normal hadronic interactions for $x = 1$. One can therefore conclude that the QCD colour effects, which predict a multiplicity ratio of $^9/_4$, are not observed in the energy region of this experiment.

## 6. CHARGE FLOW

It is very difficult to interpret the charge distribution of the fragmenting hadronic system. Even in the case of a fragmentation of an idealized d quark one should not observe a net charge of $-^1/_3$. The problem is presented in fig. 8. Before the interaction, the negative pion and proton approach from opposite directions in the c.m.s. During the interaction the $\bar{u}$ and u quarks annihilate. Afterwards the diquark from the proton and the d quark from the pion continue their trajectories in opposite directions. A string of colour is created and mesons are produced when the string breaks creating quark-antiquark pairs. The net charge is calculated by summing up charges of all mesons from a certain range of rapidity (here all positive rapidity).

One should realize that for the balance of charge only the first (d) quark and the last antiquark in the fragmentation chain are important (the others cancel). If the last one is the $\bar{d}$, the $\bar{u}$, or the $\bar{s}$ with equal probability, then the net charge is really $-1/3$. On the other hand, if only the first two are produced, then the integrated charge is -0.5, while in the case of their production with the probability of 0.4, 0.4, and 0.2 (as in the case of standard Field-Feynman fragmentation), one can expect to observe a net charge of -0.4.

The charge flow data are presented in fig. 9.

Figure 9a shows the distribution of charge as a function of rapidity in the $\pi^-N$ c.m.s. for $J/\psi$ production (dashed line). The solid line represents the same distribution without the acceptance correction. It is clearly seen that the corrected distribution is dominated by the positive particles in the backward direction, while in the forward direction the distribution is dominated by the negative charge with the crossover at rapidity zero. Since the positive charge is strongly rising in the backward direction, clearly showing the fragmentation of the beryllium nucleus, only the physics in the forward direction is analysed in what follows. In addition, fig. 9b shows the charge-flow distribution of the forward hadronic system accompanying the $J/\psi$ production, fig. 9c the Drell-Yan production, and fig. 9d the charge-flow observed in the normal hadronic interactions. These experimental spectra are compared with the same distribution of the jet MC calculation generated for the $\bar{u}$ or d quarks.

Table 1 lists the integrated charge in the forward direction.

The first four entries in this table give the integrated charge for the d and $\bar{u}$ jet MC calculation both as generated and after rejection of particles for which the weight was set at zero (section 2). Then the measured numbers and those corrected for acceptance are presented. The correction was made according to the weight presented in fig. 3. Since for the experimental data the correction in the region of the "beam killer" was not made, an extrapolated number is also given. For this extrapolation an assumption was made that the distributions in y and $p_T$ for the jet MC calculation and data had the same shape, so the extrapolation was done for the percentage of the charge loss in the MC calculation in the "beam killer" region.

It is interesting to note that the forward charge for the $\pi^-N$ interactions is not −1 as one could naïvely expect from a model where the forward fragmenting $\pi^-$ is completely separated from a backward fragmenting nucleon; instead it is −0.76 ± 0.1. Results of bubble-chamber measurements [8] show that this value is changing with energy, having the above value at the energy of this experiment, showing that the acceptance corrections are made properly. The change of the forward charge with energy may be due to the charge "leak" through the region of rapidity zero [9].

The forward charge of about $-\frac{1}{3}$ accompanying the Drell-Yan production may also vary with energy. Therefore more interesting numbers are ratios of charges after normalizing the charge in $\pi^-N$ interactions to −1. This approach is justified if the charge "leak" through the region of rapidity zero is proportional to the charge "leak" in the elementary $\pi N$ interaction. It is, of course, less justified if the "leak" depends on the energy of the hadronic system [9]. For the Drell-Yan production we obtain in this way a number −0.47 ± 0.05, in approximate agreement with the number −0.4 predicted above for the fragmentation of the d quark. In a similar way, for the $J/\psi$ production one gets the value of −0.79 ± 0.08. Assuming that the $J/\psi$ is produced partly through gluon-gluon fusion -- giving the charge seen in the $\pi^-N$ interactions -- and partly through quark-quark fusion -- giving the charge accompanying the Drell-Yan production -- one finds that the fraction of $J/\psi$ produced through quark-quark fusion is about 40% at the energy of this experiment.

This result may be in disagreement with the evidence from the fit to other variables of $J/\psi$ production. For example, the preliminary results show [2] that it is unlikely that the production of $J/\psi$ through the quark-antiquark fusion is larger than 25%.

It is difficult to discuss a precise value of the forward charge in this experiment, because one has to deal with many poorly known numbers such as the details of the $J/\psi$ production mechanism and the dependence of the charge "leak" on energy. However, the important conclusion is that the forward charge is clearly different for the different sets of experimental data presented here, and therefore, the effects of flavour are indeed observed.

## 7. CONCLUSIONS

The results of this experiment show that the colour effects are not observed in low-$p_T$ physics while the flavour degrees of freedom are clearly seen. This conclusion is based on the comparison among three experimental sets of data presented here and the jet MC. It was observed that the fragmentation functions are identical above $z = 0.2$ and that the multiplicities are identical, while the integrated forward charges are different.

The hadronic system may be described by many variables: its flavour (and correlated electric charge), its colour charge, its geometrical size, and its set of structure functions. In this work different hadronic systems have been investigated: three- and eight-colour objects, fragmentation starting from a point-like object ($e^+e^-$ annihilation seen through the jet MC calculation) and from a large system (all the data presented here), and fragmenting systems of unit or fractional charge.

No colour effects in the multiplicity were observed. Fragmentation of a point-like system or a large system, of current quarks or constituent quarks, and of three- or eight-colour systems is surprisingly the same in the first approximation.

However, one major difference is observed in the charge flow. The presence of the d quark in the fragmentation of the forward hadronic system accompanying the Drell-Yan production is clearly seen. The balance of charge is different there from that of normal hadronic interactions and from that accompanying $J/\psi$ production.

The results of this experiment also allow one to interpret better the results of $e^+e^-$ annihilation into hadrons. There, parton-QCD effects are observed on the level of angular distribution and flavour degrees of freedom, while the fragmentation function is universal.

High-$p_T$ experiments in hadron-hadron collisions are likely to be more difficult to design since it will be difficult to distinguish a gluon jet from a quark jet by its fragmentation function. Most probably they will be identical since according to present ideas the gluon turns into an eight-colour quark-antiquark pair before converting into hadrons; thus it should fragment like the eight-colour system presented here. Therefore one concludes that the flavour degrees of freedom provide a more favourable identification technique for future jet studies.

## REFERENCES AND FOOTNOTES

[1] H. Harari, Phys. Lett. 86B (1979) 83.

[2] The fraction of J/ψ produced through the quark-antiquark annihilation is probably not larger than 25% in this experiment. The preliminary data of WA11 based on the J/ψ x-distribution are compatible with 100% gluon fusion [R. Barate et al., Proc. 20th Int. Conf. on High Energy Physics, Madison, 1980 (Eds L. Durand and L.G. Pondrom) (Amer. Inst. Phys., New York, 1981), p. 197]. NA3 preliminary data indicate 65% of gluon-gluon fusion [A. Romana, p. 99, Ph. Charpentier, p. 61, *in* Proc. 1st Moriond Workshop on the Lepton Pair Production, Les Arc, 1981 (Ed. J. Tran Thanh Van)]. About 30% of J/ψ is produced by χ radiative decays (WA11 results -- Y. Lemoigne et al., to be published in Phys. Lett. B). For the conclusions of this paper it has no importance if X's are produced through gluon-gluon fusion. It is worth noting that for the first-order analysis presented in this paper a small contribution of quark-antiquark annihilation to J/ψ production is not important.

[3] R.D. Field and R.P. Feynman, Nucl. Phys. 136B (1978) 1.

[4] T. Sjöstrand and B. Söderberg, Lund preprint LU TP 78-18 (1978).

[5] R.R. Crittenden and J.C. Krider, Nucl. Instrum. Methods 128 (1975) 599.

[6] M. Faessler, Ann. Phys. (USA) 137 (1981) 44, Fig. 12.
It is shown there that the ratio of the number of fast particles ($\beta > 0.7$) produced in the hadron-very-heavy-nucleus interaction to the number of fast particles produced in the hadron-nucleon interaction is close to one in the forward direction, while it is strongly rising in the backward direction in the hadron-hadron c.m.s., which may be interpreted as indicating that the forward-going particles do not reinteract in the nucleus. Noting in addition that beryllium is a very small nucleus one can conclude that while in

the backward direction one is studying basically nuclear effects, in the forward direction one can measure properties of hadrons produced in the elementary interaction.

[7] S.J. Brodsky and J.F. Gunion, Phys. Rev. Lett. 37 (1976) 402.

In QED the multiplicity of soft photons emitted in charged particle scattering is well known. They are produced through the bremsstrahlung from charged particles, and the average multiplicity consists of a sum over charged particle pairs, each contribution depending only on the product of charges times the general function.

The arguments for QCD are made in analogy to QED. Here an electric charge is replaced by a colour charge. The radiation of coloured gluons occurs only when two coloured objects are separated in momenta. Then the radiated coloured gluons materialize as hadrons so the soft hadron multiplicity is a direct function of the gluon multiplicity. Since the coupling constant of the gluon to separating colour octets is $9/4$ times the coupling constant to separating colour triplets, the multiplicity of a fragmenting octet should be $9/4$ times the multiplicity of a fragmenting triplet.

[8] R. Göttgens et al., Z. Phys. C 9 (1981) 17.

[9] D.R.O. Morrison, Charge distribution in $\nu p$ and $\bar{\nu} p$ interactions, to be published in Proc. 12th Int. Symposium on Multiparticle Dynamics, Notre Dame, USA, 1981.

Table 1

Integrated charge in the forward direction

| | Drell-Yan | J/ψ | $\pi^-N$ |
|---|---|---|---|
| Monte Carlo a) | | | |
| d corrected | -0.29 | -0.30 | -0.28 |
| d total | -0.33 | -0.35 | -0.35 |
| $\bar{u}$ corrected | -0.45 | -0.45 | -0.43 |
| $\bar{u}$ total | -0.49 | -0.51 | -0.52 |
| Data b) | | | |
| Measured | -0.20 | -0.29 | -0.33 |
| Corrected | -0.32 | -0.52 | -0.62 |
| Corrected + extrapolated (total) | -0.36 ± 0.05 | -0.60 ± 0.08 | -0.76 ± 0.1 |
| $\pi^-N$ normalized to -1 | -0.47 ± 0.05 | -0.79 ± 0.08 | -1 |

a) Monte Carlo: total -- as generated by jet MC; corrected -- particles for which the weight was set to zero were removed (those going in the "beam killer" region).

b) Data: measured -- without any corrections; corrected -- the weight correction was applied; corrected + extrapolated -- extrapolation for the loss in the "beam killer" region was made according to the ratio total/corrected of the Monte Carlo events in this table.

Figure captions

Fig. 1 : Graphs describing the parameters of a hadronic system accompanying the Drell-Yan and the $J/\psi$ production.

Fig. 2 : The WA11-Goliath experimental set-up.

Fig. 3 : Distribution of weight used in the evaluation of this experiment. Regions where the weight was set at zero are clearly seen.

Fig. 4 : $\mu^+\mu^-$ invariant mass spectrum measured in this experiment. Dashed line shows the same spectrum in a linear scale. The dotted lines show the experimental selection of the $\mu^+\mu^-$ invariant mass for the $J/\psi$ and the Drell-Yan production.

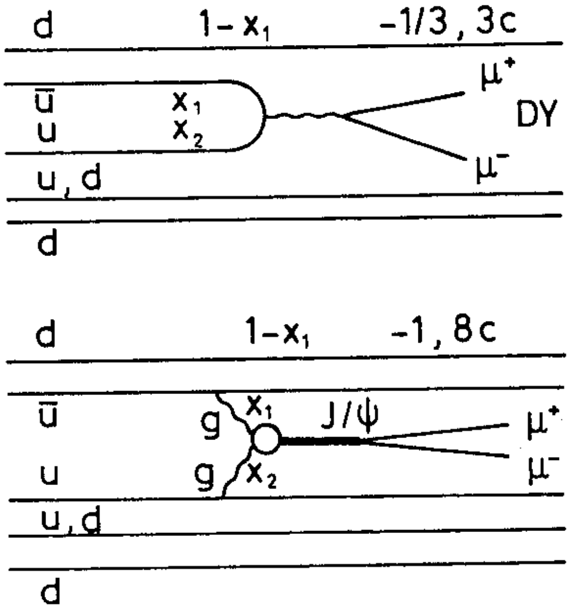
Fig. 5 : Distribution of the total longitudinal momentum $x_{tot}$ of the forward hadronic system accompanying the $J/\psi$ (solid line) and the Drell-Yan (dashed line) production.

Fig. 6 : z-distribution describing the fragmentation both in the linear and the logarithmic scale. Linear scale: data (solid line), q MC (dashed line). Logarithmic scale: data (dash-dotted line); q MC (dotted line). All curves have absolute normalization to one experimental (or MC) event.

Fig. 7 : The measured multiplicity distribution versus longitudinal momentum of the forward-going hadronic system; $J/\psi$ production -- solid line, Drell-Yan production -- dashed line. $x_{tot}$ = 1 corresponds to 9.3 GeV/c.

Fig. 8 : The schematic description of the charge flow in the production of the Drell-Yan continuum in this experiment.

Fig. 9 : Distribution of charge versus rapidity. a) Distribution corrected for acceptance (dashed line) and not corrected for acceptance (solid line). b), c), and d) Data corrected for acceptance (solid line), d quark MC (dashed line), and $\bar{u}$ quark MC (dashed-dotted line).




$$x = \frac{2P_{\parallel}}{\sqrt{s}} \qquad x_{\mu\mu} = x_1 - x_2$$

$$x_1 x_2 = \frac{\mathrm{mass}^2_{\mu\mu}}{s}$$

$$x_{tot} = 1 - x_1$$

Fig. 1

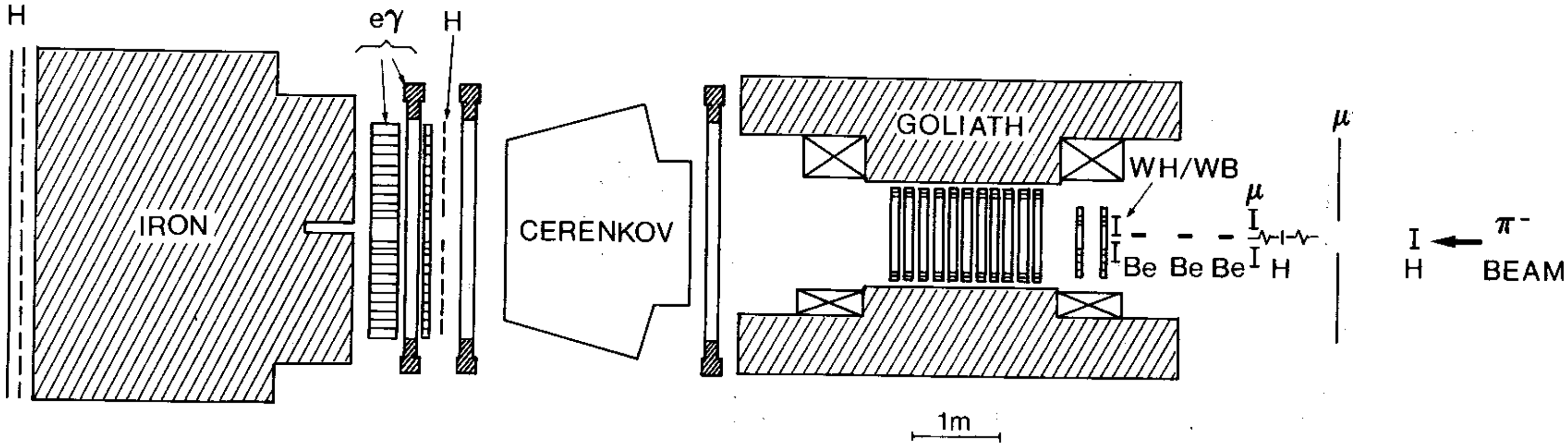
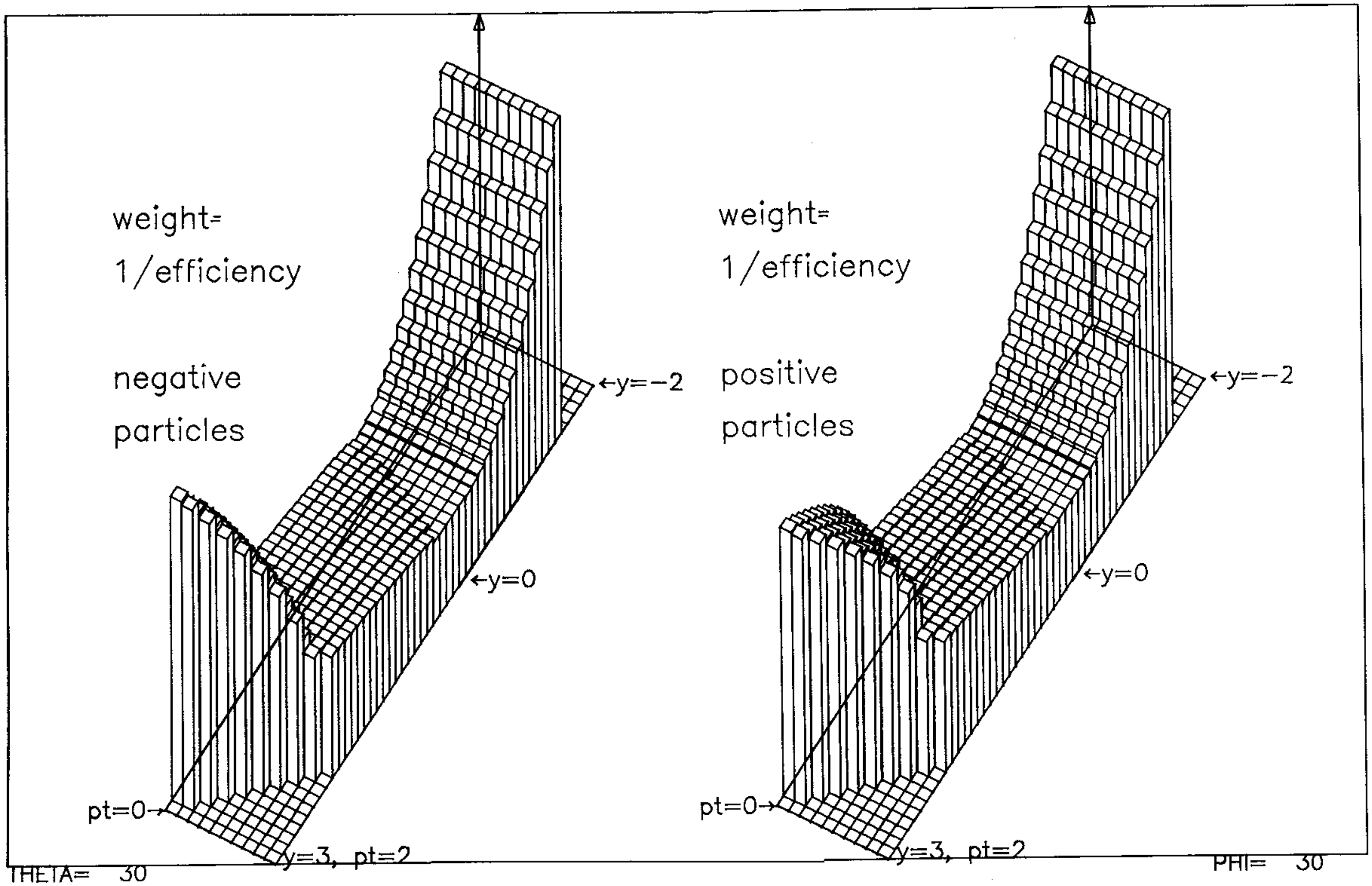
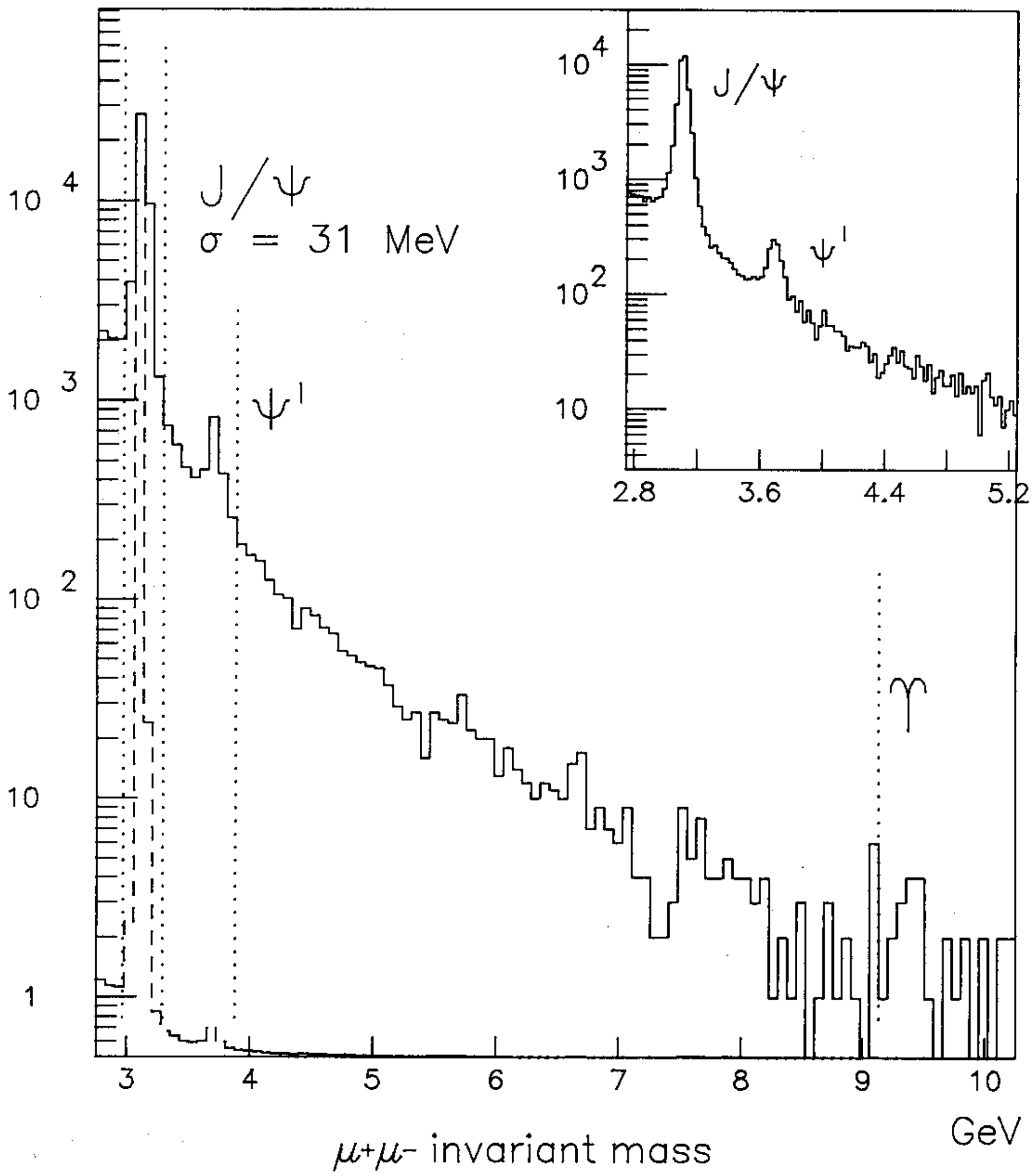



Fig. 2



weight=
1/efficiency
negative
particles
←y=−2
←y=0
pt=0→
y=3, pt=2
THETA= 30
weight=
1/efficiency
positive
particles
←y=−2
←y=0
pt=0→
y=3, pt=2
PHI= 30


Fig. 3



J/ψ
σ = 31 MeV
ψ'
ϒ
10 4
10 3
10 2
10
1
3
4
5
6
7
8
9
10
GeV
μ+μ- invariant mass
10^4
10^3
10^2
10
2.8
3.6
4.4
5.2


Fig. 4

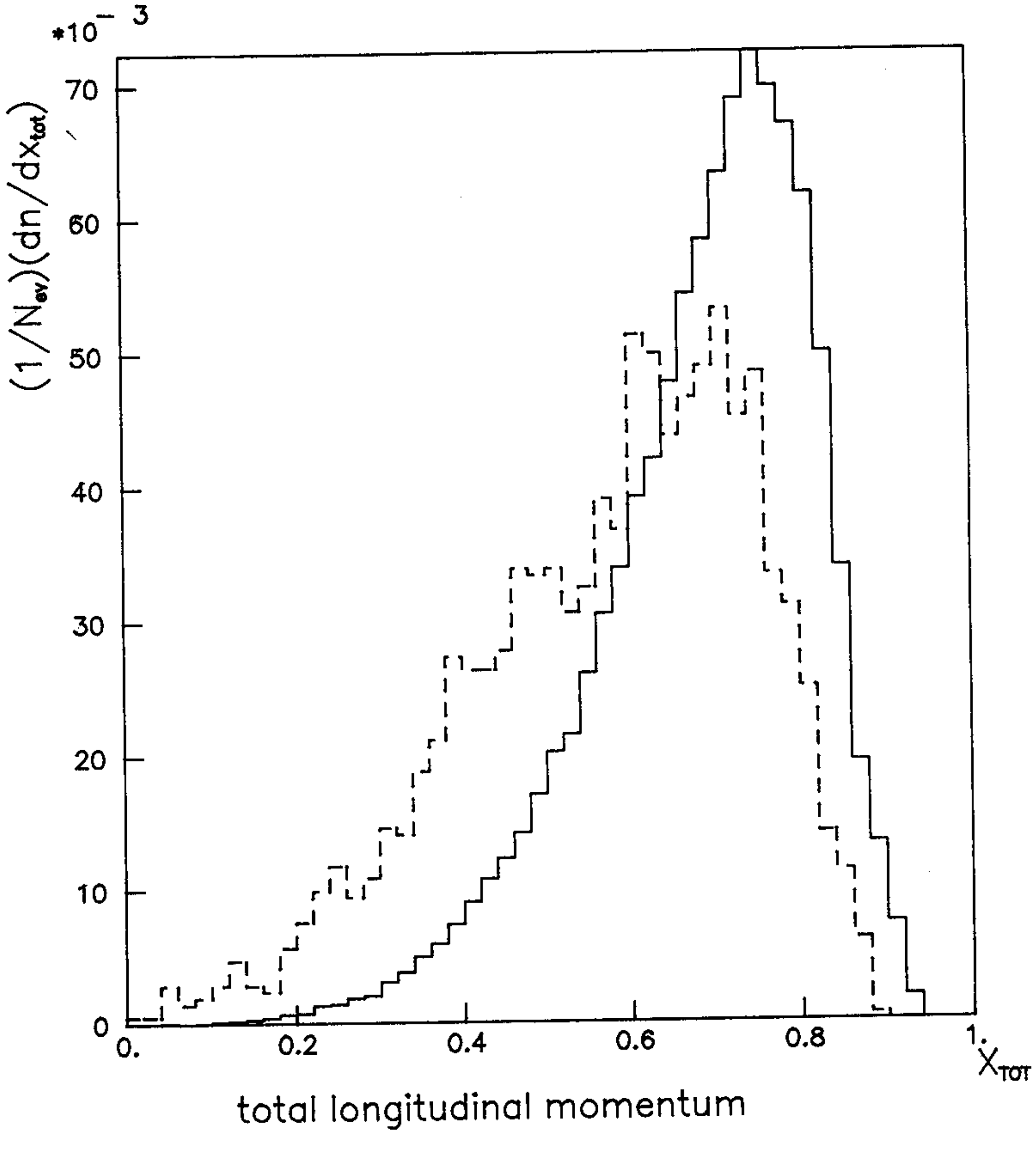

*10^-3
(1/N_ev)(dn/dx_tot)
70
60
50
40
30
20
10
0
0.
0.2
0.4
0.6
0.8
1.
X_TOT
total longitudinal momentum

Fig. 5

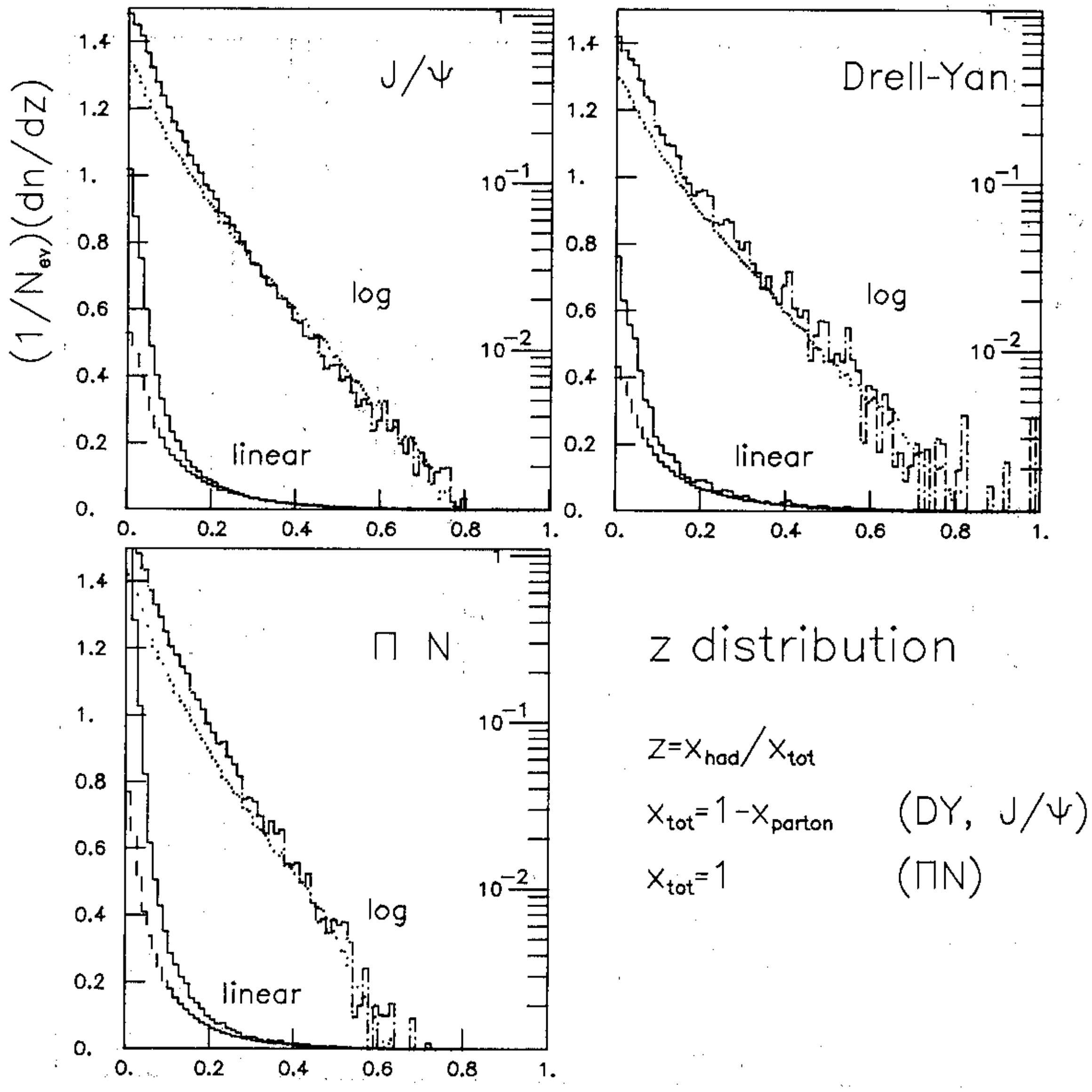

(1/N_ev)(dn/dz)
J/Ψ
Drell-Yan
Π N
log
linear
z distribution
Z=X_had/X_tot
X_tot=1-X_parton (DY, J/Ψ)
X_tot=1 (ΠN)

Fig. 6

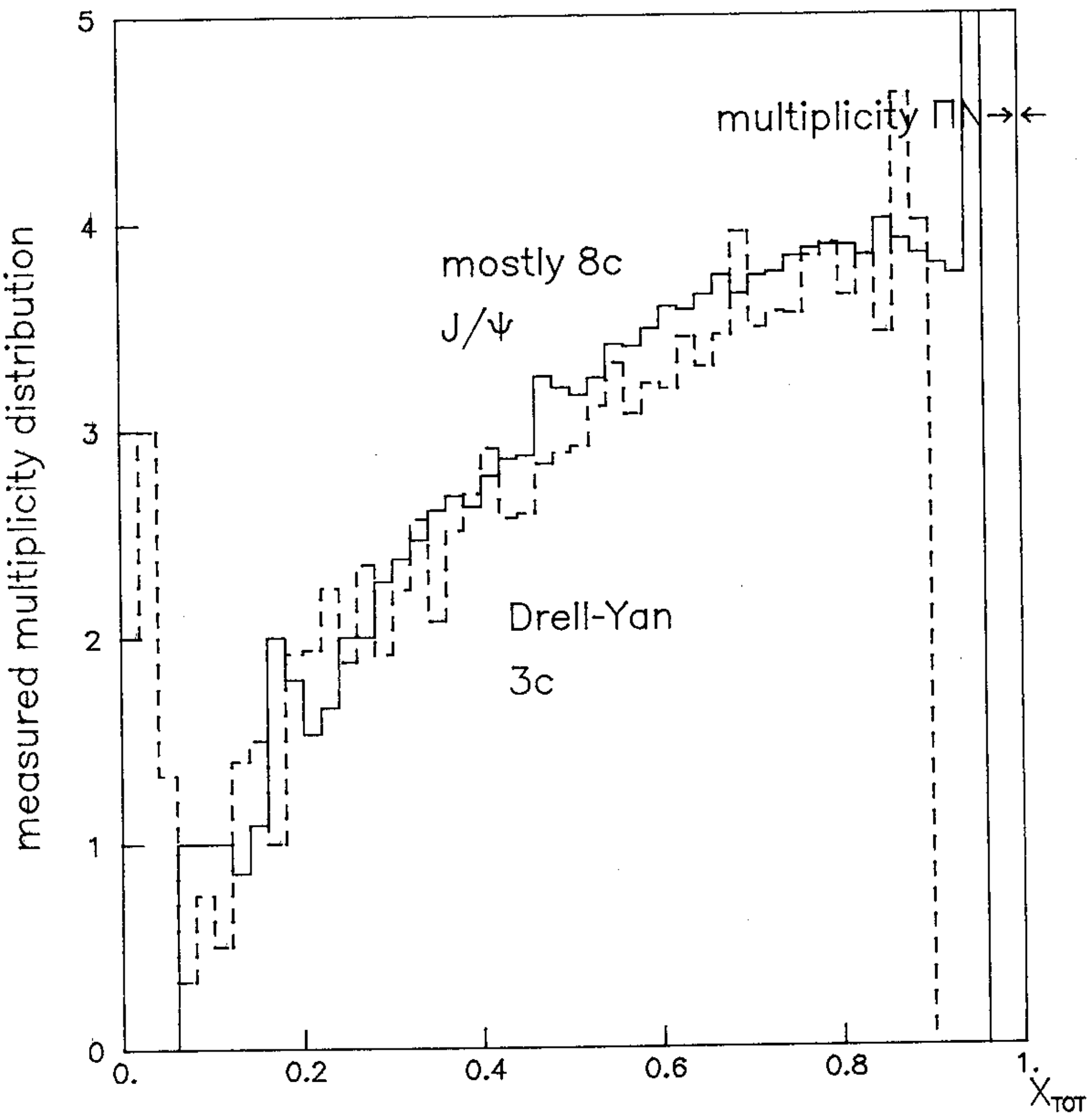
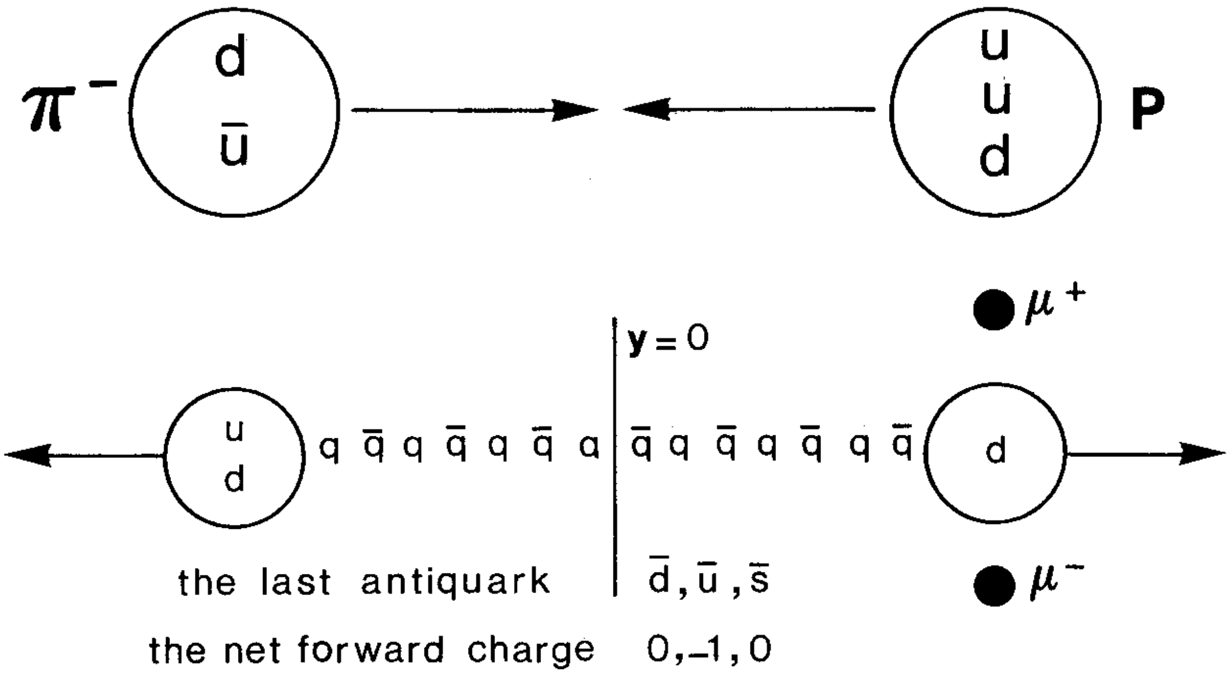

measured multiplicity distribution
multiplicity ΠN
mostly 8c
J/ψ
Drell-Yan
3c
$X_{TOT}$
0
1
2
3
4
5
0.
0.2
0.4
0.6
0.8
1.

Fig. 7



$\pi^-$
d
ū
u
u
d
P
$\mu^+$
y = 0
u
d
q q̄ q q̄ q q̄ q
q̄ q q̄ q q̄ q q̄
d
the last antiquark
d̄, ū, s̄
$\mu^-$
the net forward charge
0,–1,0


Fig. 8

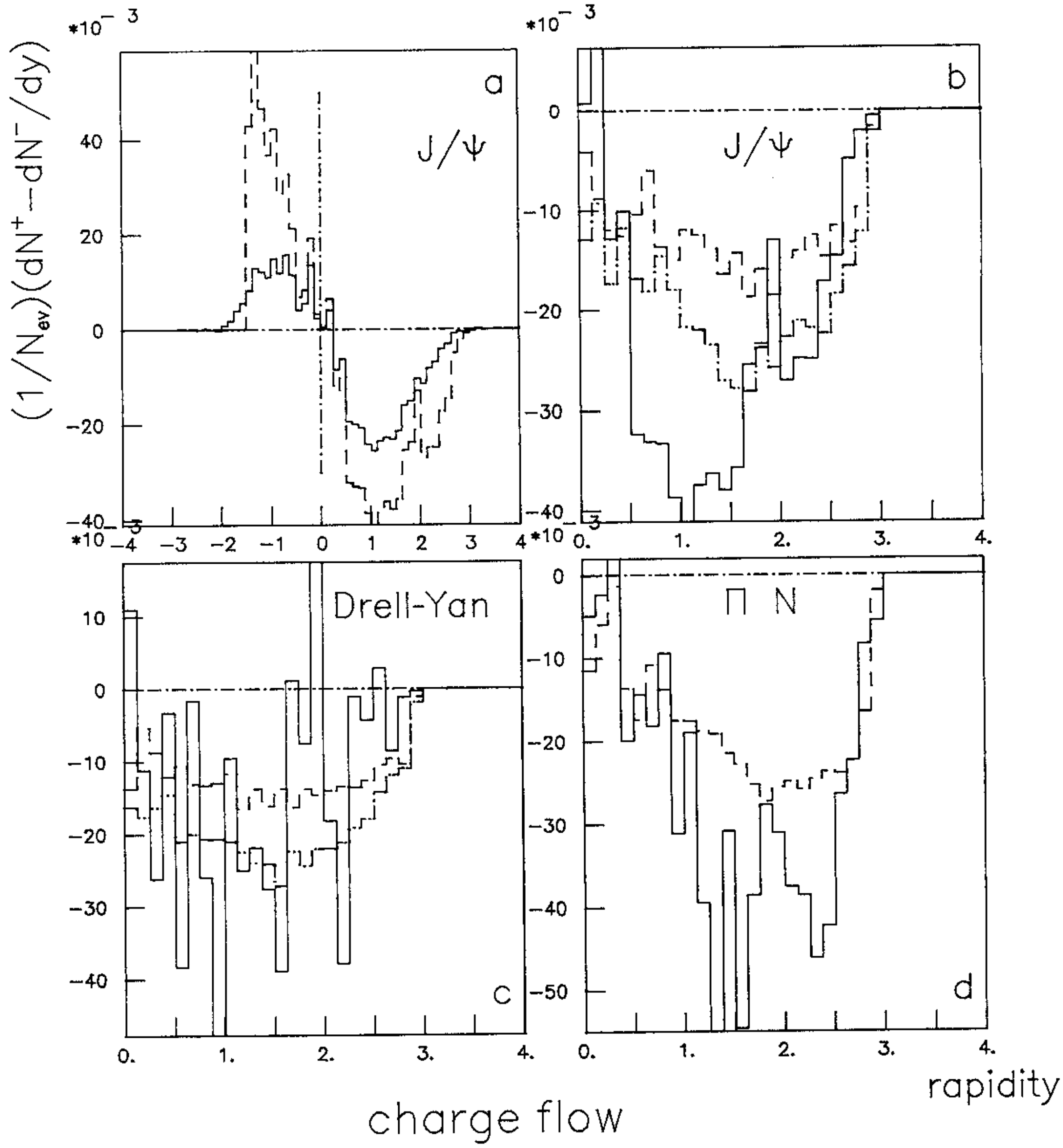



Fig. 9