FERMILAB-PUB-77-158-E

COMPARATIVE STUDY OF INCLUSIVE CORRELATION FUNCTIONS IN PROTON INTERACTIONS ON EMULSION NUCLEI

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Abstract. $R(\eta_1, \eta_2)$ and $C(\eta_1, \eta_2)$ inclusive correlation functions are studied in 300 GeV proton interactions on emulsion nuclei. Their dependence on nuclear excitation is investigated and some differences between their behaviours are pointed out.

The interpretation of experimental data is attempted in the framework of a repeated independent collision picture of hadron-nucleus interaction. The introduction of clustering patterns in produced hadronic matter provides a qualitative description of target dependence of correlations.

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1. Introduction.

A large amount of inclusive data on hadron-nucleus interactions at very high energy have been collected in the last few years[1]. At first sight, one is impressed by the rather small effects which nuclear targets produce as compared with proton target. As an example, the ratio R_A between the mean multiplicities in hadron-nucleus and hadron-proton collisions is surprisingly low with respect to the predictions of the old intranuclear cascade models.

These experimental facts have given rise to a new generation of theoretical models[2], which, though starting from different assumptions, explain, at least qualitatively, the most salient features of hadron-nucleus interaction.

Recently the main interest of experimentalists has been devoted to a more detailed analysis of inclusive distributions and their energy and target dependence, in order to stress the parameters that can differentiate between hadron-nucleus and hadron-proton behaviours.

Two particle inclusive rapidity correlations seem to be an useful tool in order to investigate these peculiarities of nuclear targets. Indeed a remarkable asymmetry was found [3,4] between projectile and target hemispheres, in proton collisions on emulsion nuclei.

The purpose of this paper is to extend the analysis of the previous investigations, through the comparison of two different correlation functions at various nuclear excitations and to discuss which kind of information they can give about particle production inside the nucleus. We shall make use a naive, though plausible, MonteCarlo calculation in order to analyse the effects of nuclear targets on correlations.

2. Experimental results.

The experimental data are based on 300 GeV proton interactions in nuclear emulsions exposed at FNAL. The events were collected in the Batavia-Belgrade-Lund-Lyon-Montreal-Nancy-Ottawa-Paris-Rome--Strasbourg-Valencia Collaboration and are approximately the same as quoted in Ref.3. The experimental details on scanning procedure and inclusive analysis are given elsewhere[5].

The data were divided into three groups: $N_h \leq 1$, $2 \leq N_h \leq 6$ and $6 < N_h$, where N_h is the number of heavily ionizing particles accompanying multihadron production in nuclei. The parameter N_h is usually interpreted as a relative measure of the mean number of collisions inside the nucleus[6].

The present analysis makes use of the inclusive correlation functions:

$$C(\eta_1,\eta_2) = \frac{1}{\sigma_{in}} \frac{d^2\sigma}{d\eta_1 d\eta_2} - \frac{1}{\sigma_{in}^2} \frac{d\sigma}{d\eta_1} \frac{d\sigma}{d\eta_2}$$

and

$$R(\eta_1,\eta_2) = C(\eta_1,\eta_2) \Big/ \left[\frac{1}{\sigma_{in}^2} \frac{d\sigma}{d\eta_1} \frac{d\sigma}{d\eta_2} \right]$$

where σ_{in}, $d\sigma/d\eta$ and $d^2\sigma/d\eta_1 d\eta_2$ are respectively the inelastic cross section, the single and two-particle inclusive distributions. η is the pseudo-rapidity of the emitted particle in the proton-nucleon c.m. system:

$$\eta = \eta_L - \ln\left(\gamma_c + \sqrt{\gamma_c^2 + 1}\right)$$

where γ_c is the relevant Lorentz factor ($\simeq 12.67$ at 300 GeV lab energy) and η_L is the laboratory pseudo-rapidity.

Fig. 1 shows the correlation functions $R(\eta_1,\eta_2)$ and $C(\eta_1,\eta_2)$ along the $\eta_1 = \eta_2$ diagonal, for the different N_h groups. The most striking effect is the asymmetry about $\eta_1 = \eta_2 = 0$, which is more pronounced for $R(\eta_1,\eta_2)$ than for $C(\eta_1,\eta_2)$.

A comparison with the available pp data from FNAL[7] and CERN--ISR[8] experiments, respectively at ~ 200 and ~ 300 GeV lab energy(*), is also given in Fig. 1 for R-function. $N_h \leq 1$ interactions (which are usually interpreted as collisions against quasi-free nucleons) show a quite different behaviour from proton-proton correlations, expecially in the backward rapidity region. In the forward region, the difference is less pronounced, though nuclear data seem to show somewhat lower correlations.

$N_h \leq 1$ events show a remarkable deviation from pp data even for C-function. In this case, the shape is similar to pp, but the central value $\left[C(0,0)\right]_{N_h \leq 1} = 3.5 \pm .4$ is considerably higher than that coming from ISR measurement, $\left[C(0,0)\right]_{pp} = 1.69 \pm .01$.

In order to make the N_h-dependence of correlation functions more evident, in Fig. 2 $R(\eta_1,\eta_2)$ and $C(\eta_1,\eta_2)$ are given for different η_2 slices.

First of all we emphasize that, for each N_h group, both correlation functions show a maximum at $\eta_1 \approx \eta_2$, thus displaying a typical short range behaviour.

Another interesting feature emerging from Fig. 2 is the different N_h-dependence of correlations in the three kinematical regions. No

(*) Though both pp data show the same qualitative features, in more detail they exhibit appreciable differences. In our opinion, these differences are not completely justified by their energy separation, on the basis of the smooth energy dependence given in Ref. 9.
Incidentally, we observe that our experimental technique is more directly comparable with the one used in the FNAL investigation, whose results better agree with our data points.

appreciable N_h-dependence is observed in the forward region ($1.2 \leqslant \eta_2 \leqslant 2.0$) for both $R(\eta_1, \eta_2)$ and $C(\eta_1, \eta_2)$, whereas an increasing separation among the different N_h data points is shown when the backward region ($-2.0 \leqslant \eta_2 \leqslant -1.2$) is approached.

Finally, it is worthwhile to notice the difference between the behaviours of $R(\eta_1, \eta_2)$ and $C(\eta_1, \eta_2)$ as a function of N_h. As it can be seen from both Figs. 1 and 2, R-function shows the maximum asymmetry just for events with $N_h \leqslant 1$ and flattens in the target hemisphere for higher values of N_h. On the contrary, $C(\eta_1, \eta_2)$ exhibit a slight backward shifting of its mid point, associated with a pronounced growth of its maximum, with incresing N_h. Here we remind that C-function is strongly related to the f_2 moment , which is found to be an increasing function of the multiplicity of emitted particles. This fact could justify, at least partially, the observed enhancement of $C(\eta_1, \eta_2)$ with increasing N_h, owing to the observed correlation between N_h and n_s [1] (n_s is the multiplicity of shower tracks in emulsion).

In summary, within the statistical accuracy of experimental data, the following features of inclusive rapidity correlations are clearly drawn from the presented emulsion data:

1) Target independence in the projectile hemisphere. Both R- and C--functions exhibit an evident N_h-dependence and remarkable deviations from pp data in the backward rapidity region; however, no appreciable N_h-dependence and a pp-like general trend is observed in the forward hemisphere.

2) Different N_h-dependence of correlation functions. $R(\eta_1, \eta_2)$ and $C(\eta_1, \eta_2)$ show different behaviours as a function of N_h. In particular, R-function flattens with increasing N_h, whereas $C(\eta_1, \eta_2)$ shows increasing height and asymmetry.

3) Strong deviations of low-N_h correlations from pp data. The usual procedure of considering low N_h emulsion events as equivalent to pp data seems to fail if correlation functions are compared. Indeed $N_h \leqslant 1$ correlations show some unexpected differences from pp data.

3. A few considerations on theoretical models.

Theoretical work on multiparticle production in hadron-nucleus interaction has been mainly devoted to provide a mechanism which can justify the gross features of experimental data. Most of theoretical models give accurate predictions only for the simplest parameters as the average multiplicities or related quantities, but they are generally very crude for a more detailed description of the production phenomenon . Therefore higher momenta and inclusive distributions are obtained in a merely qualitative way and often only in the asymptotic regime.

It is beyond doubt that the interpretation of proton-nucleus correlation data is very difficult within this framework; nevertheless some simple information can be inferred on the basis of the general structure of the proposed production mechanisms.

A wide class of theoretical models include as a common feature that forward emitted hadronic matter, arising from hadron-nucleus interaction, is not affected from the size of the target. As a consequence of this fact, which can be reached even using different assumptions, all inclusive distributions are expected to be target independent in the forward rapidity region and then all the differences from hadron-proton interactions are confined within the backward hemisphere.

This prediction finds an evident support in the N_h-independence of correlation functions in the projectile hemisphere, which was pointed out from our experimental data (see sentence 1 of the previous section).

For what concerns the behaviour of correlations in the target hemisphere, the interpretation of experimental data is obviously more difficult and cannot be obtained from simple arguments on the general features of theoretical models.

On the other hand, it is well established that evidence of short--range correlations in hadron-proton interaction is connected with some clustering phenomenon in the multiperipheral chain. Many models[10] have been proposed but their common feature is the assumption of an independent production of average-zero charge clusters of 3 to 4 pions.

The observed short-range effects even in proton-nucleus interactions suggested to us that a simple approach to the problem of interpreting experimental data could be to insert clusters in a naive nuclear production scheme.

In order to go forward in the interpretation of experimental data a Monte Carlo calculation has been done using this picture.

4. Monte Carlo general lay-out.

Our Monte Carlo calculation is based upon an independent cluster picture of proton-proton interaction. Proton-nucleus collision is viewed as an incoherent sum of independent elementary processes, of which:

a) the collision with the first encountered nucleon is assumed to be quite equivalent to a proton-proton or proton-neutron interaction;

b) subsequent collisions with downstream nucleons are assumed to produce new hadronic matter only in the backward rapidity region.

It should be noted here that the hypothesis that only a fraction of hadronic matter is emitted in the repeated collisions inside the nucleus is a common feature of both EFC[11] and Multiperipheral[12] models. Our particular choice - ½ of the full rapidity interval - of the cutoff of "reproducing" part is not crucial for the following conclusions, which will be merely qualitative, taking into account the simplifying assumptions we made.

The adopted cluster model for pp interaction is a slightly simplified version of Ranft and Ranft model[13], where both cluster and pion multiplicities are Poisson-like distributions, clusters are emitted, within a mass-dependent rapidity interval, from a flat distribution and pions from a Gaussian-like distribution. No dependence on mass and pion multiplicity was introduced into the width of emitted particle spectrum.

Unfortunately, at 300 GeV lab energy the central rapidity region is not much developed and then it is not possible to study the multihadron production process in terms of only central clusters. Moreover diffractive produced events are not sufficiently separated from multiperipheral ones. As a consequence, both diffractive events and leading clusters in multiperipheral processes have been introduced, in spite of the difficulties connected with the choice of the relevant distributions. Therefore most of the distribution parameters had to be adjusted in order to give a satisfactory, though qualitative, agreement with proton-proton experimental data.

In addition to pp interactions, proton-neutron collisions had to be considered, on account of their important role in nuclear data. For lack of unbiased experimental data on pn single- and two-particle inclusive distributions a reasonable introduction of neutron target collision was made, taking into account the general framework of the adopted cluster model. Central cluster were supposed to be neutral and with

zero total baryonic number. As a consequence of this peripheral characteristic, only target leading clusters "remember" the type of encountered nucleon. Therefore it was assumed that n-type leading clusters obey the same decay scheme of p-type ones - i.e. into one baryon plus a number of pions extracted from a Poisson-like distribution, with mean multiplicity ranging from 0.5 to 1.5, according to the different trials - but have zero total charge instead of one.

5. Discussion on Monte Carlo results.

In this section we shall discuss the main results that can be obtained from the previously described picture of hadron-nucleus interaction, taking into account the experimental facts given in Section 2.

5.1. $N_h \leqslant 1$ correlations.

The peculiarities exhibited in low-N_h interactions are perhaps the most surprising feature of experimental data. Both multiplicity and single-particle inclusive distributions do not show strong difference between $N_h \leqslant 1$ emulsion events and pp interactions, at approximately the same energy. Thus two-particle rapidity correlations give the first strong disagreement between these interactions.

In a previous paper[3] kinematical effects (i.e. Fermi motion and η-variable definition) were discussed and no crucial influence on correlations was argued.

On the other hand the strongest disagreement with pp data occurs in the target fragmentation region and then it could be suspected that the characteristics of nuclear target can affect $N_h \leqslant 1$ correlations.

In order to estimate this effect, it was roughly assumed that $N_h \leqslant 1$ emulsion events consists of mere $\nu = 1$ interactions: here ν stands for the number of intranuclear collisions. For simplicity, nucleon target was supposed to be a proton or a neutron with equal probabilities for each kind of struck nucleus.

All inclusive distributions obtained using neutron target give results very close to the pure-proton target elaboration, with the exception of R-correlation function. Fig. 3 shows $R(\eta_1, \eta_2)$ along the $\eta_1 = \eta_2$ diagonal for $\nu = 1$, compared with pure pp and pure pn collisions. It should be noted that R-function is highly sensitive to the choice of the n-type leading cluster in the target fragmentation region. Thus the corresponding drawing line (dashed curve) is an average of several trials, within a region where the difference among them is not too strong.

As seen in Fig. 3, proton-neutron collisions exhibit some tendency to increase R-correlation function in the target hemisphere. Nevertheless the mixture of the two types of collisions (solid curve) does not succeed in describing $N_h \leqslant 1$ experimental data.

Since the hypothesis that this class of events include only proton-neutron interactions does not seem very credible, we conclude that collisions with neutron target can justify only partially the observed features of R-function and then some sort of "nuclear effect" on backward produced hadronic matter must be invoked to give a full account for the $N_h \leqslant 1$ behaviour of correlation functions. To add more reliability to this statement, we observe that our Monte Carlo results on C-function give the same maximum height ($\sim 1.5 \div 1.6$) for pp, pn and $\nu = 1$ cases, which clearly disagrees with N_h 1 experimental data.

It should be observed that $N_h \leqslant 1$ interactions come only in a small fraction from collisions with emulsion hydrogen nuclei, the remaining part consisting of peripheral interactions on light and heavy

nuclei. Thus it can be thought that the observed anomalies of $N_h \leqslant 1$ interactions arise just from these latter interactions. As a matter of fact the part of hadronic matter which suffers more the nuclear influence is the backward emitted one, which spends more time, for both geometrical and kinematical reasons, inside the nucleus. Hence our calculation can indicate that nucleus affects the dynamical structure of this part of hadronic matter, changing some characteristics of its clusters.

5.2. Target dependence of correlations.

In order to interpret the observed N_h-dependence of correlations, repeated collisions inside the nucleus were introduced, as described in the previous section.

Fig. 4 a-c show a comparison between $\nu = 1$ and $\nu = 2$ Monte Carlo results for inclusive rapidity distribution and for R- and C-correlation functions along the $\eta_1 = \eta_2$ diagonal. These curves have to be considered only for their general features and particularly for their ν-dependence; any comparison with experimental data is prevented from the fact that $\nu = 1$ curves do not account for $N_h \leqslant 1$ events.

Single particle inclusive distribution shows the expected enhancement in the backward rapidity region, due to the piling up of pions in that interval. It should be noted that the separation between the two curves occurs at $\eta \approx 1.5$ (corresponding to $\eta_L \approx 4.7$) which is in good agreement with experimental data[1].

R-correlation function is considerably lowered in the target hemisphere with increasing ν, whereas this effect is much reduced in the forward region.

C-function increases very strongly with ν and shifts its maximum towards the backward direction. No difference is seen in the projectile fragmentation region.

All these trends give a satisfactory account for the observed behaviours of inclusive distributions with N_h.

6. Concluding remarks.

I - The experimental results presented in this paper have shown that two-particle rapidity correlations exhibit a considerable variety of characteristic features, which make possible a more detailed differentiation between proton-nucleus and proton-proton interactions.

Three interesting features were pointed out in Section 2, in order to clarify the different roles of $R(\eta_1, \eta_2)$ and $C(\eta_1, \eta_2)$ with respect to nuclear excitation. In particular a remarkable behaviour was observed in low N_h interactions, which give correlations strongly different from pp data. This fact should suggest to revise the traditional interpretation of this kind of interactions.

II - The interpretation of experimental data seems to be possible on the basis of current nuclear production models with the introduction of an independent cluster mechanism. This framework provides a correct though qualitative, description of target-dependence of correlations. However, further assumptions are required to account for low N_h interactions.

We conclude that the study of hadron-nucleus two-particle correlations is of great importance to investigate multiparticle production mechanism inside the nucleus. Therefore higher statistical accuracy experiments and the use of pure targets, which give less inadequate ν-dependence, would be of great interest.

Acknowledgments.

We would like to thank all the participants of the Batavia--Belgrade-Lund-Lyon-Montreal-Nancy-Ottawa-Paris-Rome-Strasbourg--Valencia Collaboration for use of the commonly scanned material. We also wish to thank Prof. E.Amaldi for suggestions and helpful discussions. Finally, we are greatly indebted to Drs. A.M.Cecchetti and C.Sgarbi for their valuable effort in the collection of all experimental data and the computer analysis.

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Figure Captions.

Fig. 1 - $R(\eta_1, \eta_2)$ and $C(\eta_1, \eta_2)$ along the $\eta_1 = \eta_2$ diagonal: ■ $N_h \leq 1$, ● $2 \leq N_h \leq 6$, ▲ $6 < N_h$.
Typical errors are shown: it should be noted that errors on R-function are roughly constant, whereas errors on C-function increase approximately with statistical law (i.e. $\propto \sqrt{C}$).
Solid curves show R-function for pp data: 1 is obtained from a 205 GeV/c HBC investigation at FNAL (Ref. 7), 2 from a counter experiment at CERN-ISR at c.m.s. energy $\sqrt{s} = 23$ GeV (Ref. 8). The arrows at the lower edge of C-function figure show the $C(\eta, \eta)$ mid points corresponding to the two extreme N_h groups.

Fig. 2 - Correlation functions: a) $R(\eta_1, \eta_2)$ and b) $C(\eta_1, \eta_2)$ as a function of η_1, for different η_2 slices. ■ $N_h \leq 1$, ● $2 \leq N_h \leq 6$, ▲ $6 < N_h$.

Fig. 3 - Monte Carlo results showing $R(\eta_1, \eta_2)$ along the $\eta_1 = \eta_2$ diagonal. The solid line refers to the $\nu = 1$ elaboration (i.e. 50% pp + 50% pn interactions), the dotted line to the pp elaboration and the dashed line to the pn elaboration.

Fig. 4 - Monte Carlo results showing the ν-dependence of inclusive distributions:
a) rapidity distribution $dN/d\eta$;
b) R-function and c) C-function along the $\eta_1 = \eta_2$ diagonal.

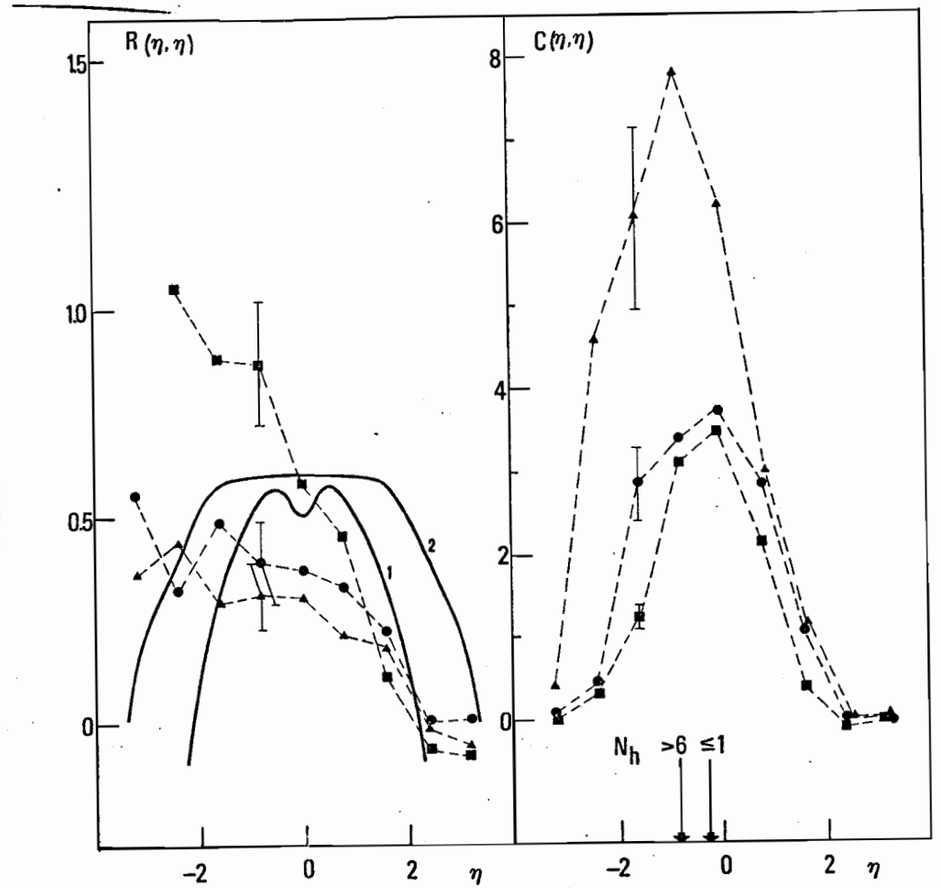

Fig. 1

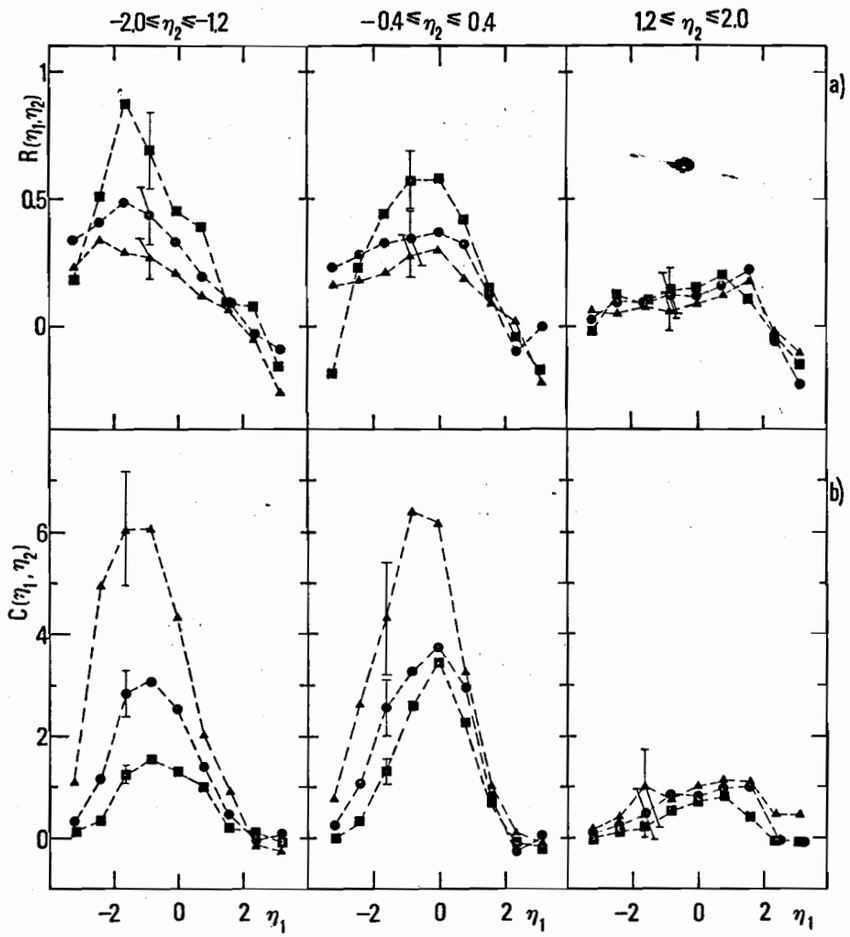
-2.0≤η2≤-1.2
-0.4≤η2≤0.4
1.2≤η2≤2.0
a)
b)
R(η1,η2)
C(η1,η2)
η1

Fig. 2

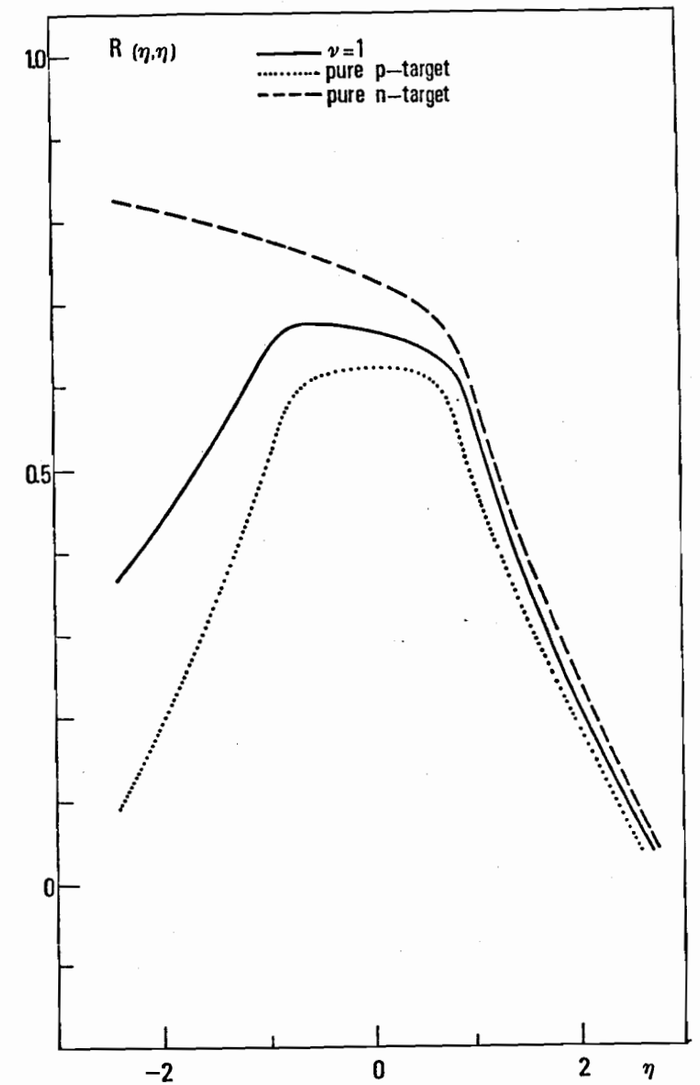
R (η,η)
ν=1
pure p–target
pure n–target
η

Fig. 3

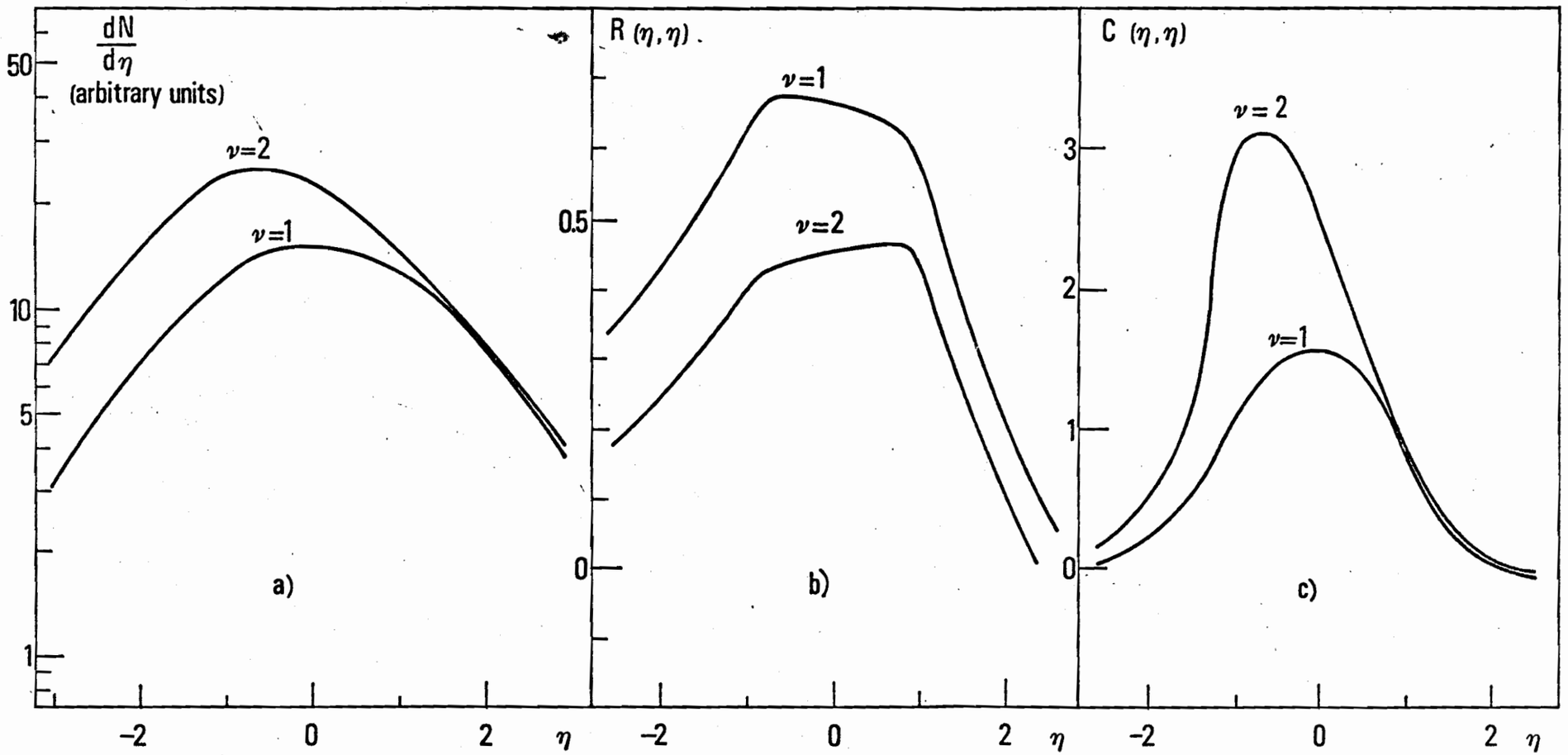
dN/dη
(arbitrary units)
50
10
5
1
ν=2
ν=1
a)
R (η, η)
0.5
0
ν=1
ν=2
b)
C (η, η)
3
2
1
0
ν = 2
ν=1
c)
−2
0
2
η

Fig 1