CORRELATIONS OF SECONDARIES IN EVENTS WITH A FORWARD NEUTRON AT THE ISR

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ABSTRACT

Data, obtained from p-p collisions at centre-of-mass energies between 31 and 63 GeV, are presented on inclusive and semi-inclusive correlations between forward emitted neutrons and charged particles observed in an omnidirectional hodoscope. A total absorption spectrometer was used to detect the neutrons and to measure their energy. Significant correlations are observed over the whole rapidity range. The data suggest that neutrons result from the decay of clusters emitted in the fragmentation region.

Submitted to Physics Letters

9 June 1975

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Results of a study of the correlations between charged particles and a forward neutron produced in pp collisions at the CERN ISR are presented. These results supplement those reported in the previous letter[1], in which the correlations between charged particles and forward π^-, K^- and $\bar{p}$ were discussed.

The apparatus consisted of the same counter hodoscope system[2] which was used in the study[1] of the correlations with negatively charged particles and of a neutron detector[3]. The angular correlations between the neutrons and the over-all distribution of charged secondaries observed in the hodoscope were studied for centre-of-mass energies $\sqrt{s}$ of 31, 45, 53 and 63 GeV.

The neutron detector was a total absorption spectrometer placed to observe neutrons emitted at 0^o with respect to one of the circulating beams and passing through a thin window in a special vacuum chamber. This detector, described in detail elsewhere[3], consisted of a sandwich of 40 scintillators interspaced by 2 cm thick iron plates. The scintillators were viewed by a common photomultiplier S, which provided a linear signal proportional to the amount of energy deposited inside the detector itself. The interaction of the incident neutron was localised inside the first four iron plates (converter) which were followed by a trigger P_0. A second trigger counter P_1 was inserted in the sandwich at a depth of 12 cm of iron. In front of the system a lead absorber, 5 radiation lengths thick, was placed to filter out gamma-rays. It was followed by a counter A to veto charged particles. The coincidence $P_0 P_1 \bar{A}_1$ was used as a trigger to gate the signal from the photomultiplier S. The accepted solid angle, as determined by the size of the converter and of counter P_0, was about 5 μsr. The energy resolution, as measured with a proton beam, was about ±40% at 5 GeV and about ±10% at 30 GeV. The detection efficiency was almost constant and equal to about 40% for neutron energies above 5 GeV. The stability of the energy calibration was monitored by means of a pulsed photodiode and checked by a momentum selected π beam which was provided by the magnetic spectrometer[1] installed in the same intersection region. In the analysis of the data a lower cut was set on the pulse-height spectrum of counter S corresponding to a neutron energy E of about 5 GeV.

The minimum value of x, defined by

$$x = \frac{2E}{\sqrt{s}} \quad ,$$

varied from about 0.3 at $\sqrt{s}$ = 31 GeV to about 0.15 at $\sqrt{s}$ = 63 GeV. Consequently the rapidity of the observed neutrons differed from the maximum allowed value by less than two units and therefore the neutron always fell within the so-called fragmentation region.

Inclusive spectra of neutrons emitted at 0^o were measured using the same apparatus; the results are reported elsewhere[4]). The K^0 contamination was estimated to be about 15% at x = 0.2; it decreases with energy and becomes less than 5% at x = 0.6.

In order to measure the correlations between the neutron and the charged particles detected by the hodoscope, two different trigger conditions were used. The only requirement for the unbiased trigger (o) was, as in Ref. 1, the presence of at least one charged particle in each hemisphere of the hodoscope system. Trigger (c) required in addition the presence of the neutron trigger given by the combination $P_0 P_1 \bar{A}$.

For trigger (o), beam-beam events were selected by requiring the appropriate time-of-flight between hodoscope counters placed at opposite sides of the crossing point. For trigger (c) an additional requirement on the time-of-flight between the neutron detector and the hodoscope counters was imposed.

Trigger (o) was essentially fully inclusive in the sense that the fraction of undetected inelastic events was less than 3%.

Correlations between the neutron and the charged particles detected by the hodoscope will be expressed in terms of the standard two-body correlation function, defined as in Ref. 1. The events were selected by grouping the measured energy of the neutrons in intervals. For a given range of the x of the neutron, or of the corresponding rapidity y, the correlation function is given in terms of the variable η, referring to the charged particles detected by the hodoscope, which is defined by

$$\eta = -\ln \mathrm{tg}\ (\theta/2)\ ,$$

where θ is the polar angle with respect to the beam pointing toward the neutron detector. Positive η corresponds to particles emitted in the hemisphere containing the neutron counter and negative η to particles emitted in the opposite hemisphere. The explored range of the variable η was from -5 up to 5.

Inclusive and semi-inclusive correlation functions were evaluated. The inclusive correlation function $R(\eta)$ was obtained from the full sample of events. The semi-inclusive correlation functions $R_n(\eta)$ were obtained by selecting events having the observed charged particle multiplicity equal to n.

The correlation function $R(\eta)$ at $\sqrt{s}$ = 63 GeV is shown in Fig. 1 for four different intervals of the x of the neutron. The $R(\eta)$ function appears to be essentially smooth but for a modest bump around $\eta \simeq 3.0$; at high values of x there is also an enhancement at large negative η. The interpretation of the bump indicating the production of a cluster of particles accompanying the neutron will be discussed below.

For the lowest value of x, the function $R(\eta)$ is flat and close to zero in the whole η range except in the fragmentation region of the observed neutron. As x increases, however, the correlation function starts to exhibit a slope which becomes more and more pronounced. When x is close to the kinematical limit ($x > 0.78$), the emission of secondaries at positive η, i.e. on the hodoscope hemisphere which is on the same side as the neutron detector, is strongly reduced. This effect can be qualitatively understood as a consequence of energy-momentum conservation.

For a fixed value of x the shape of the correlation function is essentially the same from $\sqrt{s}$ = 31 GeV up to $\sqrt{s}$ = 63 GeV.

Semi-inclusive correlation functions were evaluated at $\sqrt{s}$ = 53 GeV by selecting the observed multiplicity n of the charged secondaries, as measured by the hodoscope. The events were grouped in the following four intervals of multiplicity: n = 3-4, n = 5-8, n = 9-16 and $n > 16$. Three different ranges of the neutron energy were selected, corresponding to low values of x (x = 0.20-0.45), medium values (x = 0.45-0.71) and high values ($x > 0.71$). The mean neutron rapidities corresponding to these three x intervals are 2.8, 3.5 and 3.9, respectively.

In Fig. 2 the unbiased η-distribution of the secondaries, as measured by the hodoscope with trigger (0) at $\sqrt{s}$ = 53 GeV are shown for the four classes of multiplicity together with the semi-inclusive correlation functions for the three different ranges of the x of the neutron. On the top line of Fig. 2 the inclusive unbiased η distribution is presented together with the inclusive correlation functions.

A very prominent bump at positive η is seen in the semi-inclusive correlation function for the smallest multiplicities (n = 3-4). The bump becomes less pronounced in the correlation functions for the next multiplicity interval (n = 5-8). The simplest interpretation is that in the low-multiplicity events the neutron is emitted in association with other particles. These data therefore suggest the production of a baryonic cluster in the fragmentation region ("leading" cluster) which results from the fragmentation of one of the incident protons into a small number of particles amongst which there is the detected neutron.

The bump in the function $R_n(\eta)$ for n = 3-4 is centred at $\eta \simeq 2.3$, $\eta \simeq 1.7$ and $\eta \simeq 1.2$ for the three ranges of low, medium and high x, respectively. As the neutron rapidity increases, the bump moves to lower values of η by approximately the same amount. Consequently the sum of the mean neutron rapidity and of the most likely η value of the accompanying charged particles remains almost constant. This observation supports the interpretation of the bump as resulting from the production of a cluster in the fragmentation region. In fact the sum of the η values of extremely relativistic particles produced in the decay of a system has a mean value which only depends on the Lorentz factor γ of the system itself, and is actually proportional to ln γ. It may be concluded, therefore, that in low-multiplicity events neutrons detected in the fragmentation region are often associated with charged particles in a "leading" cluster. The bump at positive η, which is very pronounced in the semi-inclusive correlation functions at low-multiplicity (n = 3-4), is still prominent in the next multiplicity interval (n = 5-8), but completely disappears in the high-multiplicity correlation functions.

The production of "leading" clusters is then a process typical of the low-multiplicity events. This same feature has been observed[1)] for the clusters containing a π^- meson in the fragmentation region.

By means of the same method used in Ref.1 to evaluate the multiplicity of clusters containing a π^-, the average charged multiplicity of the leading clusters observed in the present experiment was estimated and found to be 1.3 ± 0.3, which can be compared to the value of about 4 obtained[1)] for clusters containing a π^-.

By considering the π^- correlation data[1)] and the present neutron data together, the following picture emerges. Clusters in the fragmentation region are "leading" clusters having the same charge and baryonic number as the incoming proton. The lowest configuration of these clusters is either $(p\pi^+\pi^-)$

or ($n\pi^+$), depending on whether the signature is provided by the observation of a pion[1] or of a neutron, respectively. The estimated values of the average charged multiplicity indeed confirm this interpretation, indicating that the configurations which are close to the lowest ones, i.e. those containing the smallest number of particles, are preferred. In addition, the production of leading clusters is found to be typical of the low-multiplicity events, which are dominated by single and double fragmentation, while it is strongly depressed in the high-multiplicity events which are, on the average, highly inelastic.

In Fig. 3 the charged multiplicity distributions at $\sqrt{s}$ = 53 GeV, associated with neutrons of low, medium and high x, are shown together with the unbiased distribution obtained by triggering on the hodoscope only. The average value of the associated multiplicity decreases as the x of the neutron increases, as expected from energy-momentum conservation. In addition, a strong peak is seen at n = 2 which becomes more prominent at high x. This peak closely resembles that observed in the multiplicity distribution associated with π^- [1] at a value of the total charged multiplicity n = 4.

The events with charged multiplicity n = 2 correspond to the reaction

$$pp \rightarrow pn\pi^+ \qquad (1)$$

The momentum transfer to the proton and the effective mass of the $n\pi^+$ system could be extracted from the data by using the measured values of the production angle of the two observed charged particles. It was found that the momentum transfer distribution has a forward peak with a slope of about 10 GeV^{-2}, the ($n\pi^+$) mass distribution peaks around 1.5 GeV and the production cross-section is of the order of 0.2 mb. These values agree with the results of a measurement[5] of the diffractive-like reaction (1) made at the same energy.

From the previous discussion the following conclusions can be drawn.

i) Neutrons produced at 0° in the fragmentation region are, in low-multiplicity events, often associated with a cluster. This cluster has, most likely, the same charge and baryonic number as the proton, i.e. it is a leading cluster. In the special case of multiplicity n = 2, the leading cluster is probably to be identified with a $n\pi^+$ system diffractively produced at these energies[5].

ii) In high-multiplicity events the production of leading clusters is strongly depressed. In such circumstances no evidence for clustering emerges from the present data.

iii) In high-multiplicity events, the observation of a neutron at high x strongly affects the probability of emission of the secondaries in the whole rapidity range. This long-range effect can be qualitatively understood in terms of energy-momentum conservation as discussed in Ref. 1.

The conclusions listed above on the production of leading clusters are similar to those reached in Ref. 1 concerning the production of clusters containing a π^-. It appears that the observation of a neutron or of a π^- in the fragmentation region represent two complementary ways for demonstrating the production of leading clusters.

We are indebted to the personnel of the ISR Department for their many contributions to this experiment. In particular we are grateful to G. Kantardjian for his co-ordination of technical services and to M. Wensveen for installations. J-C. Brunet, J-C. Godot and E. Jones are to be thanked for their work on the special vacuum chamber. We are grateful to M. Busi for much effort in the data reduction and to J.V. Allaby, C. Bosio, J. Dorenbosch and W. Duinker for help in various phases of the experiment. We thank A. Bechini, R. Donnet and M. Ferrat for their excellent technical support.

References

1) U. Amaldi et al., Physics Letters B, preceding letter.

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3) J. Engler et al., Nuclear Instrum. and Methods 106 (1973) 189.
V. Böhmer et al., Nuclear Instrum and Methods 122 (1974) 313.

4) W. Flauger et al. (to be published).

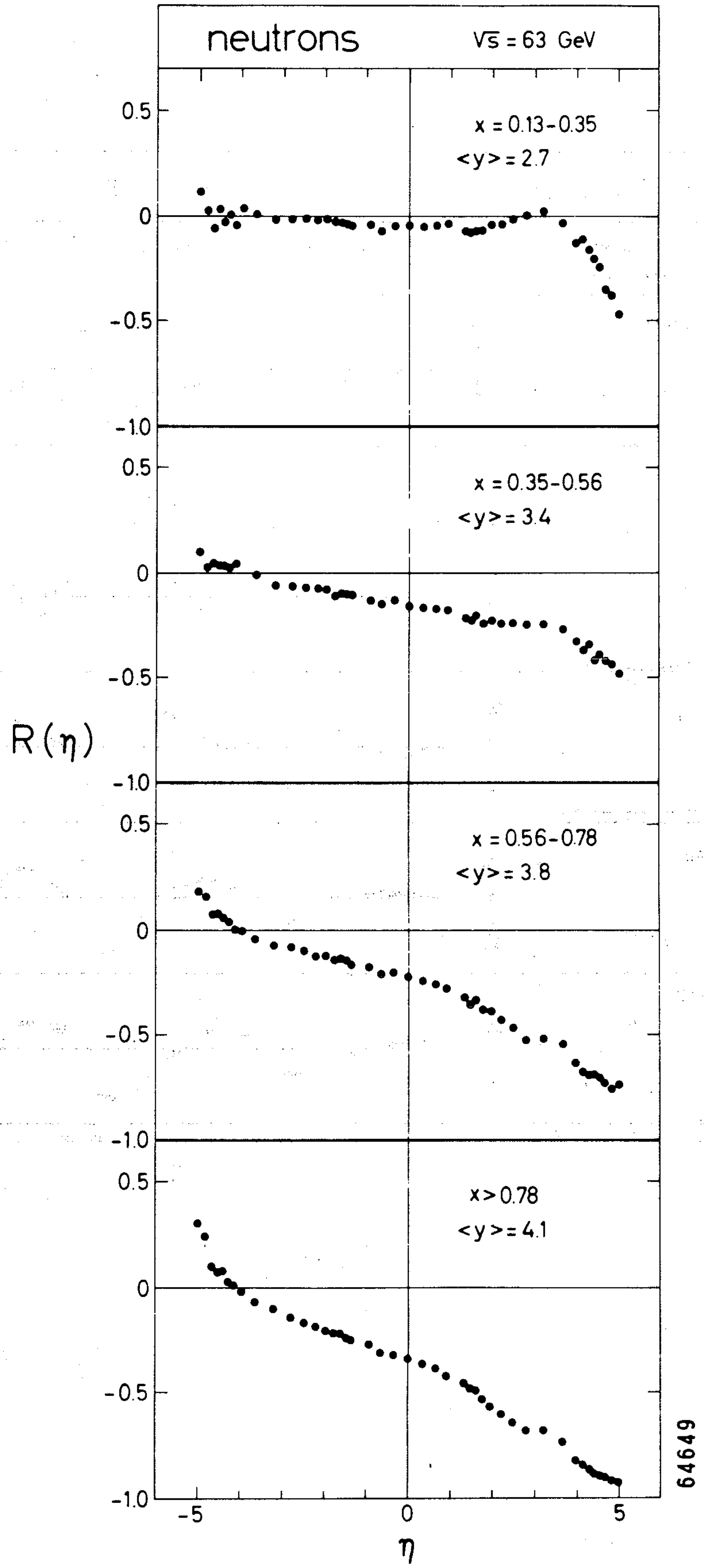
5) E. Nagy et al. presented by C. Broll, Proc. XVII International Conference on High Energy Physics, London (1974), p.I-13. See also the report of A.N. Diddens p.I-41.

Figure captions

Fig. 1: The inclusive correlation function $R(\eta)$ at $\sqrt{s} = 63$ GeV for four different intervals of the neutron energy, $x = 0.13-0.35$, $x = 0.35-0.56$, $x = 0.56-0.78$ and $x > 0.78$, is plotted as a function of the variable η referring to the charged particles detected by the hodoscope. The mean neutron rapidity for each x interval is also given.

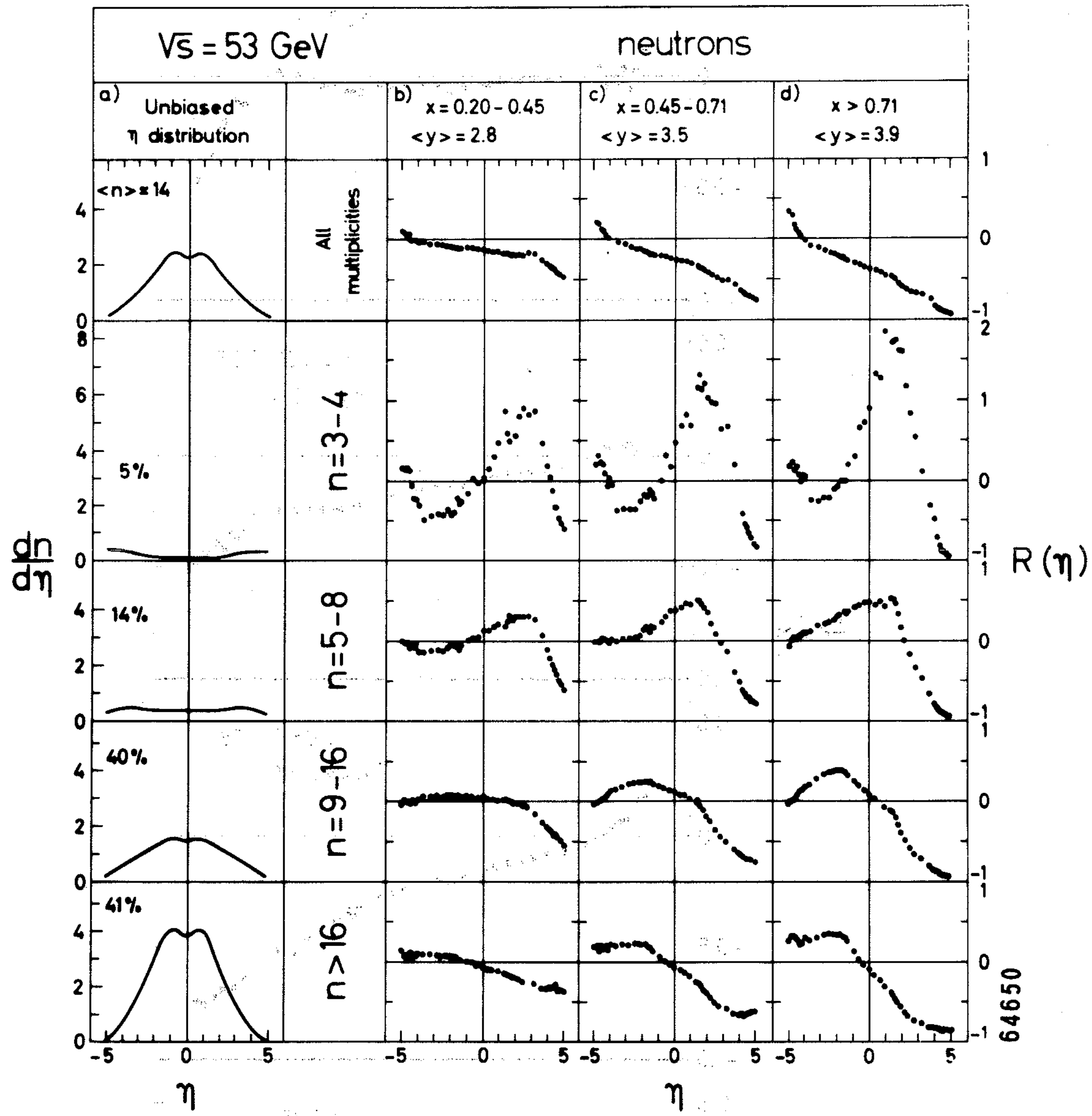
Fig. 2: The unbiased η-distributions of the charged secondaries as measured by the hodoscope with trigger (o) at $\sqrt{s} = 53$ GeV are shown in Fig. 2a. These distributions have been smoothed and should be regarded as qualitative. The correlation functions for neutrons having x in the intervals $x = 0.20-0.45$, $x = 0.45-0.71$ and $x > 0.71$ are shown in Figs. 2b, 2c and 2d, respectively. The top line contains the inclusive, unbiased, η-distribution and the inclusive $R(\eta)$ functions. The other lines contain the semi-inclusive, unbiased, η-distributions and the corresponding semi-inclusive $R_n(\eta)$ functions for the following intervals of charged multiplicity: $n = 3-4$, $n = 5-8$, $n = 9-16$ and $n > 16$.

Fig. 3: The percentage fraction of events having charged multiplicity equal to n is plotted as a function of n at $\sqrt{s} = 53$ GeV. The unbiased multiplicity distribution obtained with trigger (o) is shown together with those measured by requiring the coincidence with a neutron of low, medium and high x. The distributions are raw data and have not been corrected for secondary interaction of the produced particles. The solid lines represent a smooth interpolation of the unbiased distribution.



neutrons
$\sqrt{s}$ = 63 GeV
x = 0.13-0.35
<y> = 2.7
x = 0.35-0.56
<y> = 3.4
x = 0.56-0.78
<y> = 3.8
x > 0.78
<y> = 4.1
R(η)
η
64649

FIG: 1



√s = 53 GeV
neutrons
a) Unbiased η distribution
b) x = 0.20 - 0.45 <y> = 2.8
c) x = 0.45 - 0.71 <y> = 3.5
d) x > 0.71 <y> = 3.9
<n> ≈ 14
All multiplicities
5%
n=3-4
14%
n=5-8
40%
n=9-16
41%
n>16
dn/dη
R(η)
η
64650

FIG:2

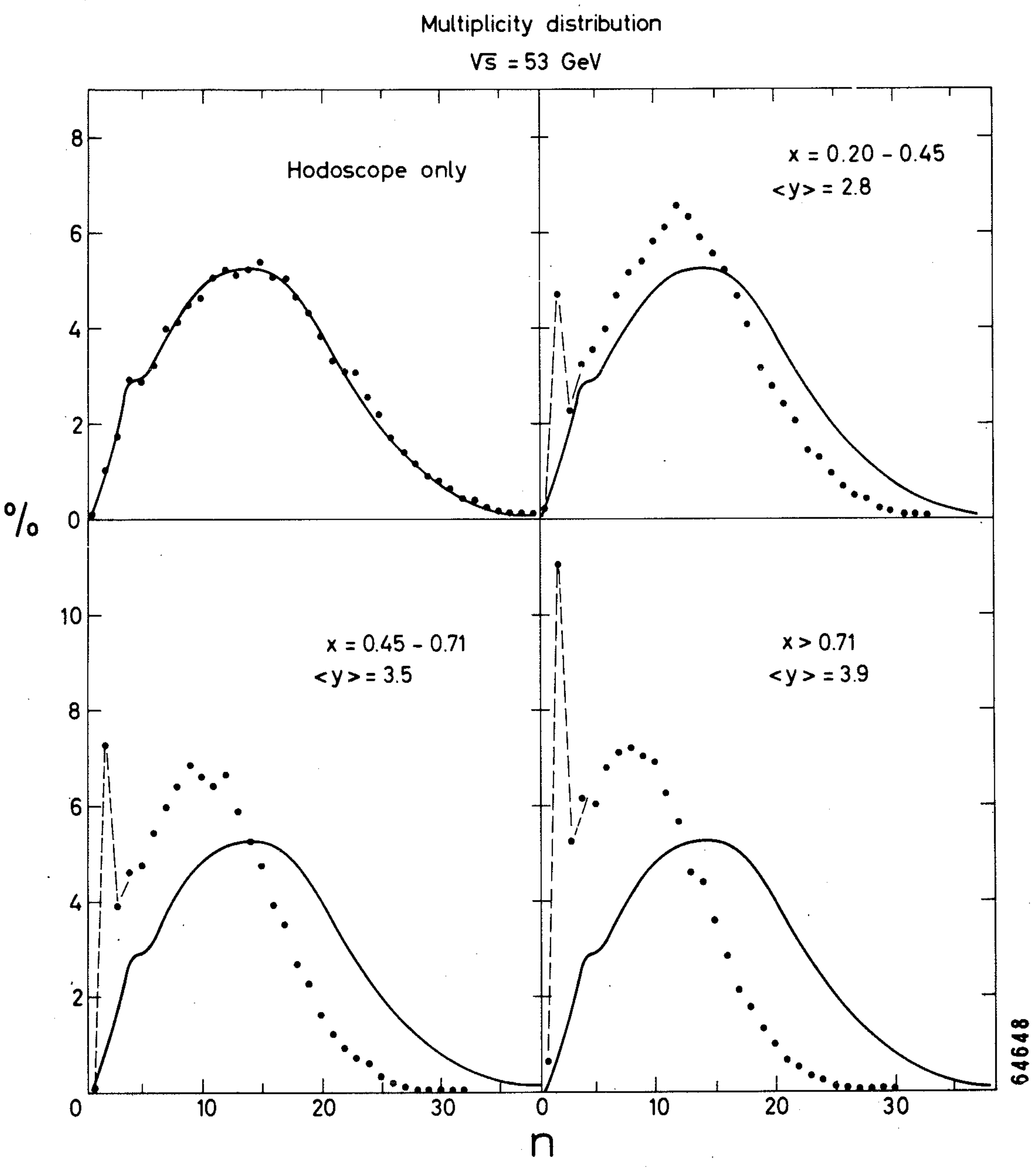

Multiplicity distribution
$\sqrt{s}$ = 53 GeV
Hodoscope only
x = 0.20 - 0.45
<y> = 2.8
x = 0.45 - 0.71
<y> = 3.5
x > 0.71
<y> = 3.9
%
n
64648

FIG:3

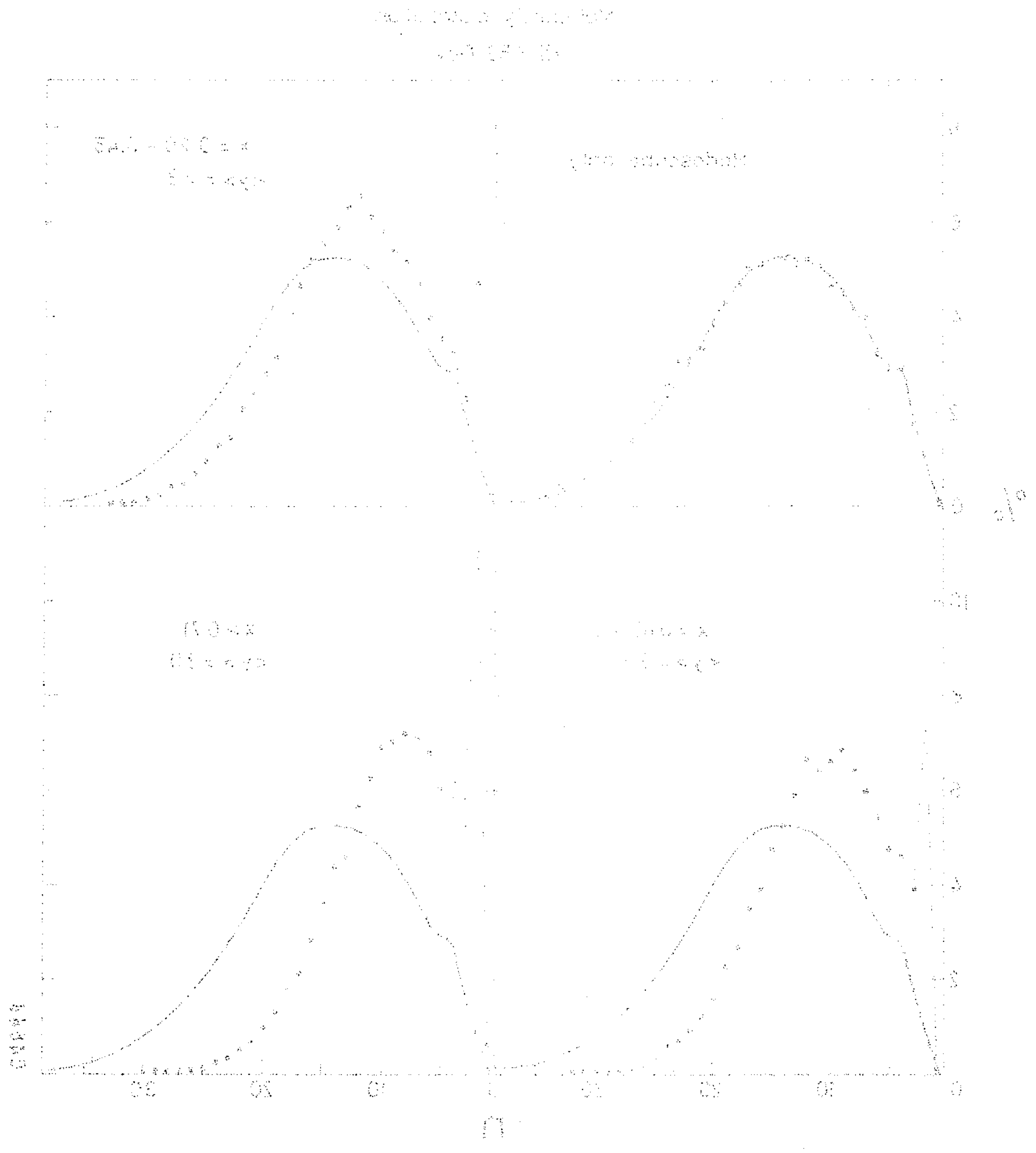


FIG 13