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by

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INTRODUCTION.

This communication is a report on some aspects of the investigations into the interactions of negative pions of 14, 16 and 17 GeV which are being carried out in collaboration by the emulsion groups at Bari, Bristol, CERN, Karachi and Milan. The main object of this work is the analysis of those types of events in which the target nucleus remains a "spectator", that is events in which nuclear excitation cannot be detected experimentally. One is thus concerned with elastic scattering, diffraction dissociation and Coulomb dissociation of the incident pion and any exchanges of virtual particles which do not disrupt the target nucleus. Nuclear emulsion is a particularly suitable medium for this kind of work as the emulsion of charged particles of low-energy, electrons even, can be detected with high efficiency, and as angles can be measured with very good accuracy.

Possible mechanisms for the multiple production of pions (and, perhaps, other particles also) by pions in interactions in which the target nucleus acts coherently and does not absorb an appreciable amount of energy have been suggested by a number of authors [1,2,3], and early results obtained by the present collaboration have already been published [4]. In this report we present some further evidence concerning the existence of events in which a pair of pions is produced coherently by a fast negative pion (14, 16 and 17 GeV). Events of this type will be referred to as "pion tridents".

CHARACTERISTICS OF COHERENT EVENTS.

The processes to be considered are the following:

a) production of a pion pair in the Coulomb field of the target (Coulomb dissociation) [2,3], and

b) production of a pion pair by diffraction dissociation of the incident pion in the nuclear field of the target [1,2].

In both these cases the requirements of coherence results in the requirement that the point of interaction must not be localized in a region which is much less than the entire target nucleus.

Thus, by the uncertainty principle, the longitudinal momentum transfer to the target should not exceed the value $q_{llmax} \simeq R^{-1} \simeq m_{\pi} A^{-1/3}$ where R is the nuclear radius and $\hbar = c = 1$[5] For Coulomb dissociation this limit applies to the total momentum transfer also.

In diffraction dissociation one would expect that the angular distribution of the vector sum of the momenta of the outgoing particles is the same as the angular distribution in ordinary elastic diffraction scattering [2]. From this angular distribution the expected transverse-momentum distribution for pion tridents can be calculated, or vice-versa.

As mentioned already, coherence also implies the complete absence of evidence of nuclear excitation or disintegration (the events must be "clean"), and, in addition, the sum of the measured energies of the three secondary particles, assumed to be pions, must be consistent with the primary energy.

The errors made in the determination of the momenta of the momenta of the secondaries by multiple-scattering measurements are large, generally of the order of 20%, whilst angles can be measured with high accuracy. It is therefore desirable to rely as much as possible on criteria which do not depend on the results of scattering measurements. A particularly useful relation between the upper limit to the longitudinal momentum transfer q_{llmax} and the space angles α_i between the direction of the primary and those of the three secondaries has been derived by members of the Bristol group [6].

It is

$$\Sigma \sin \alpha_i \leq \frac{1}{m_\pi} q_{llmax}$$

The cross section for Coulomb dissociation may be expected to increase rapidly with increasing atomic number Z of the target nucleus. In nuclear emulsion the dominant contribution to pion tridents produced by this process will therefore come from collisions with silver and bromine nuclei for which $q_{llmax} \simeq 30$ MeV/c. Thus we have the condition

$$\Sigma \sin \alpha_i \leq 0.22 \quad \text{for Coulomb dissociation.}$$

For diffraction dissociation, on the other hand, semi-transparent nuclei are likely to be more effective [2] so that the major part of the events would come from the carbon, nitrogen and oxygen in the emulsion. For these,

$$q_{llmax} \simeq 60 \text{ MeV/c, giving}$$

$\Sigma \sin \alpha_i \leqslant 0.44$ for diffraction dissociation.

EXPERIMENTAL DETAILS AND RESULTS.

The experimental conditions and methods were, on the whole, similar to those described in the previous paper [4]. The events were obtained by along-the-line scanning on a total of 807 metres of pion track at 14 GeV/c (207 m), 16 GeV/c (423 m) and 17 GeV/c (175 m). It was assumed that for the purposes of this analysis the events obtained at the primary energies can be lumped together.

A total of 68 clean pion tridents were found among 1932 interactions (interaction mean free path 42 cm). 58 of these were suitable for measurement.

Fig. 1 shows the distribution of $\Sigma \sin \alpha_i$ for an unbiased sample of events in which at least 2/3 of the primary energy reappears in the three charged secondaries, assumed to be pions*.

These events we label "events with energy balance". It can be seen that while only a few of the events are consistent with the criterion for Coulomb dissociation, almost all of them fall inside the range of $\Sigma \sin \alpha_i \leqslant 44$ for possible diffraction events.

The question immediately arises whether the distribution

* Detailed ionization and multiple-scattering measurements on a sample of secondaries suggest that at least about 75% are pions; all the secondaries which could be identified with certainty were pions.

of Fig. 1 is characteristic of clean events with energy balance or not. In spite of the low statistics this seems clear from figs. 2 and 3 which give the distribution of $\sum \sin \alpha_i$ for events which are not "clean" (they have a small evaporation star at the origin) and for events in which less than 2/3 of the total primary energy reappears in the secondaries.

To pursue the question of diffraction dissociation further we must now compare the angular distribution of the vector sum of the momenta of the three outgoing pions with both optical--model calculations and with the experimental angular distribution for elastic small-angle scattering of pions in identical conditions. Fig. 4 shows this comparison. The top line shows the calculated angular distribution for diffraction scattering of 16 GeV/c pions from nucleons. Underneath is plotted the calculated angular distribution for scattering from a nucleus with A = 29, the arithmetic mean atomic weight of nuclear emulsion.

The histogram immediately below gives the angular distribution of elastic scatters of pions, found in the examination of 27 metres of pion track (details to be published). The method of detection of the scatters is almost 100% efficient for angles in the range considered, and the accuracy of the measurements is very high. While the sample is small (15 scattering events), it is clear that the distribution is in agreement with what would be expected from for diffraction from nuclei. All the fifteen elastic scatters gave angles below 25 milliradians.

On the bottom line of Fig. 4 is plotted the angular distribution of the resultant momentum vectors of those clean pion tridents with energy balance for which this information was available at the time of writing. The distribution appears to have a much wider spread that that for elastic scattering, but the statistics are still too low to allow a definite conclusion.

From the above data we observe:

a) that the longitudinal momentum transfer to the target nucleus in clean pion trident events with energy balance is, on the average, significantly lower than in events without energy balance or accompanied by evaporation stars;

b) that in most clean trident events with energy balance the longitudinal momentum transfer to the target nucleus is low enough to ensure coherence even if the target is as heavy as oxygen, but it is not low enough for coherent interaction with silver or bromine-nuclei; and

c) that the angular distribution of the vector sums of the momenta of the secondaries of clean tridents with energy balance has a wider spread than that which would be expected if the majority of the events were due to diffraction dissociation. The statistics are low, however, and further work is in progress to clear up this point.

* * *

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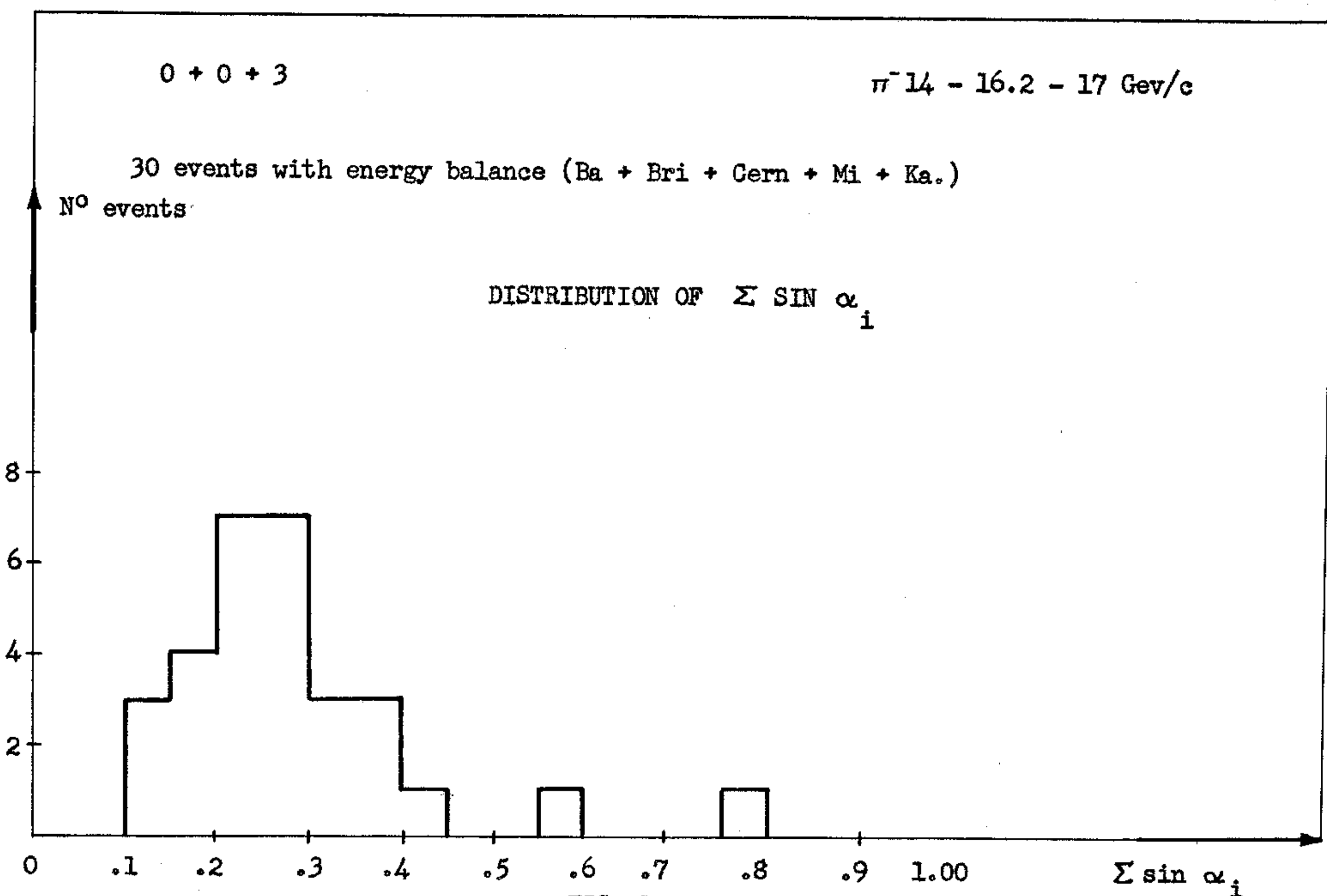

0 + 0 + 3
π⁻ 14 - 16.2 - 17 Gev/c
30 events with energy balance (Ba + Bri + Cern + Mi + Ka.)
N° events
DISTRIBUTION OF Σ SIN α_i
8
6
4
2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.00
Σ sin α_i

FIG. 1

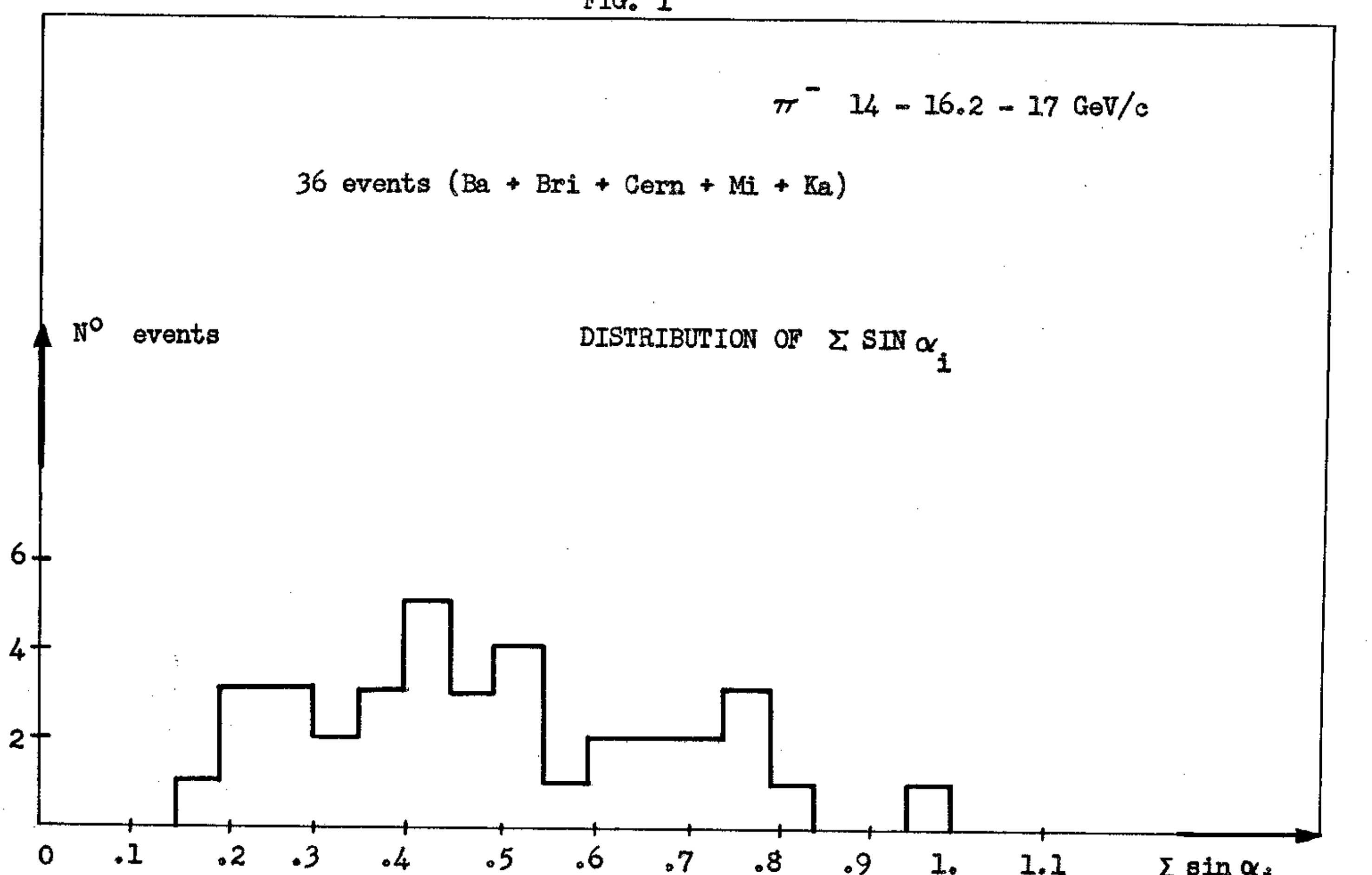

π⁻ 14 - 16.2 - 17 GeV/c
36 events (Ba + Bri + Cern + Mi + Ka)
N° events
DISTRIBUTION OF Σ SIN α_i
6
4
2
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.
1.1
Σ sin α_i

FIG. 2

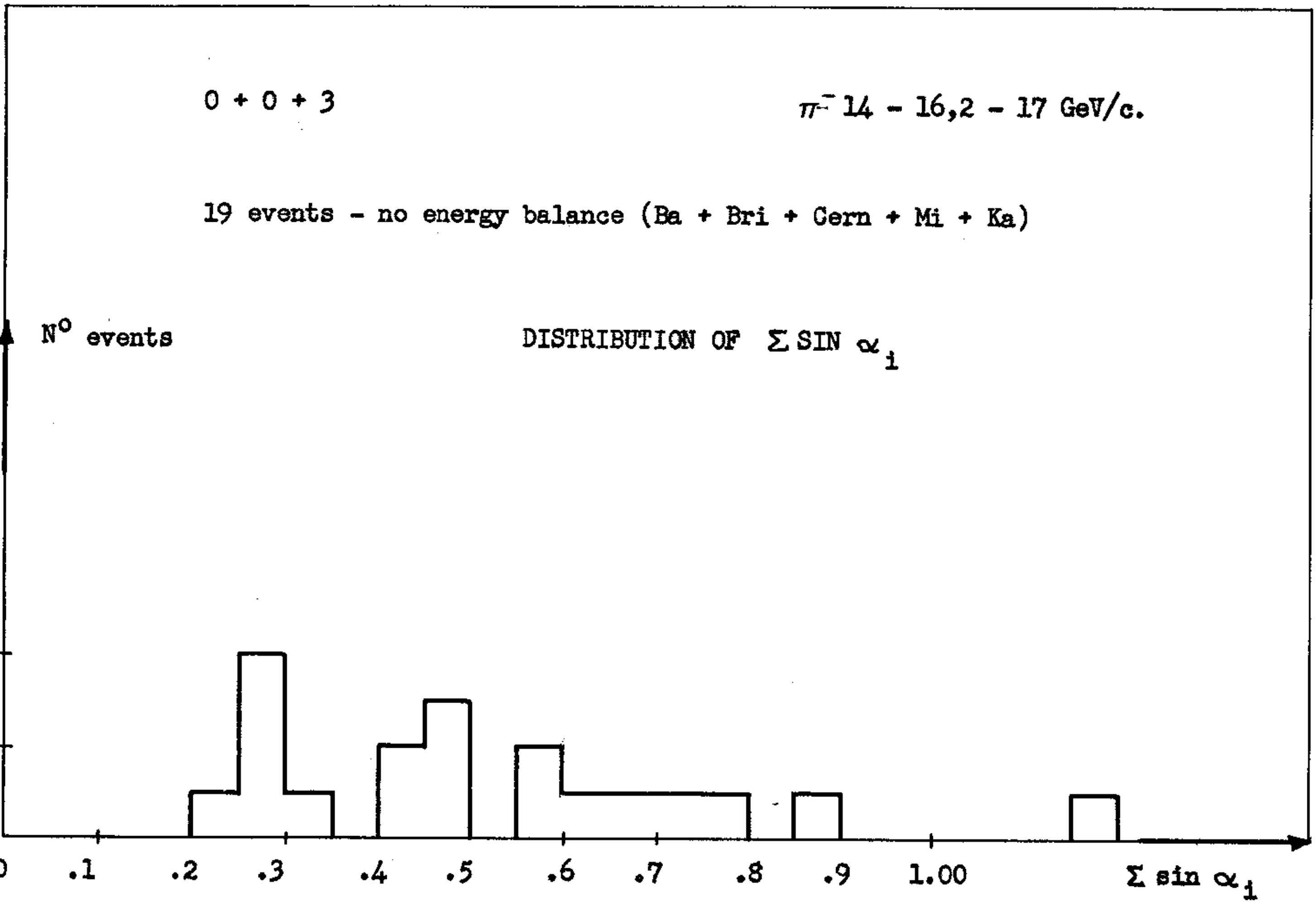
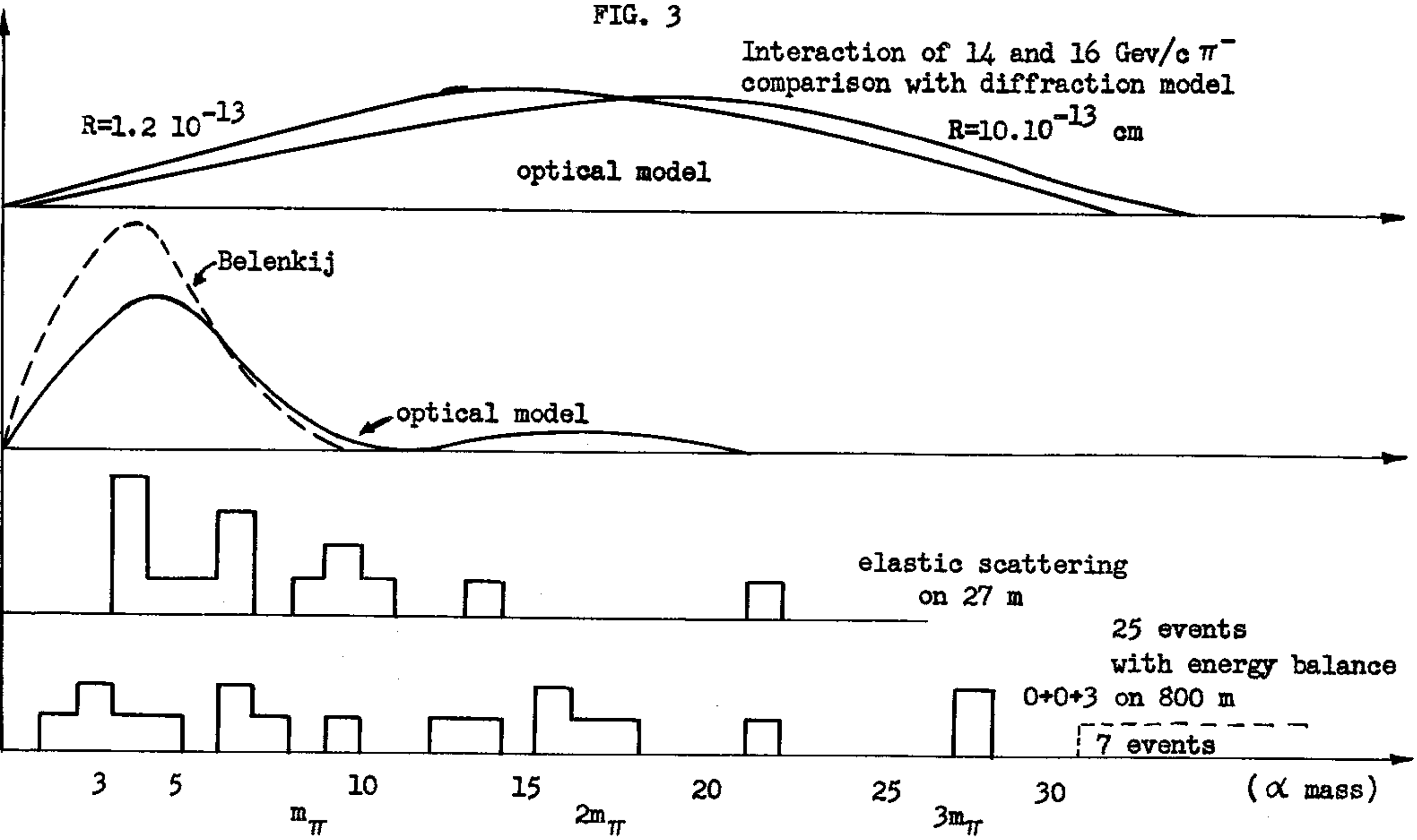

0 + 0 + 3
π⁻ 14 - 16,2 - 17 GeV/c.
19 events - no energy balance (Ba + Bri + Cern + Mi + Ka)
N° events
DISTRIBUTION OF Σ SIN α_i
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.00
Σ sin α_i

FIG. 3


Interaction of 14 and 16 Gev/c π⁻
comparison with diffraction model
R=1.2 10⁻¹³
R=10.10⁻¹³ cm
optical model
Belenkij
optical model
elastic scattering
on 27 m
25 events
with energy balance
0+0+3 on 800 m
7 events
3
5
10
15
20
25
30
(α mass)
m_π
2m_π
3m_π