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^{20}NE-W REACTIONS AT 340 MEV/NUCLEON STUDIED IN WIRE-LOADED NUCLEAR EMULSIONS

B. JAKOBSSON,
DEPT. OF PHYSICS, UNIV. OF LUND, LUND, SWEDEN AND
CENTRE DE RECHERCHES NUCLÉAIRES, STRASBOURG, FRANCE.

B. LINDKVIST AND I. OTTERLUND,
DEPT. OF PHYSICS, UNIV. OF LUND, LUND, SWEDEN.

^{16}O-NUCLEUS INTERACTIONS AT 75-100 MEV/NUCLEON

R. KULLBERG, A. OSKARSSON AND I. OTTERLUND,
DEPT. OF PHYSICS, UNIV. OF LUND, LUND, SWEDEN.

$\pi^{\pm}$-MULTIPLICITY DISTRIBUTIONS IN 2 GEV/NUCLEON HEAVY ION INTERACTIONS

B. JAKOBSSON,
DEPT. OF PHYSICS, UNIV. OF LUND, LUND, SWEDEN AND
CENTRE DE RECHERCHES NUCLÉAIRES, STRASBOURG, FRANCE.

R. KULLBERG AND I. OTTERLUND,
DEPT. OF PHYSICS, UNIV. OF LUND, LUND, SWEDEN.

A. RUIZ,
DEPT. OF PHYSICS, UNIVERSITY OF SANTANDER, SANTANDER, SPAIN.

J.M. BOLTA AND E. HIGÓN,
INST. OF PHYSICS, UNIVERSITY OF VALENCIA, VALENCIA, SPAIN.

DEPARTMENT OF PHYSICS
UNIVERSITY OF LUND,
SÖLVEGATAN 14,
S-223 62 LUND, SWEDEN.

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B. Jakobsson
B. Lindkvist
I. Otterlund
R. Kullberg
A. Oskarsson
A. Ruiz
J.M. Bolta
E. Higón.

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^{20}Ne-W Reactions at 540 MeV/Nucleon Studied in Wire-Loaded Nuclear Emulsions.

^{16}O-Nucleus Interactions at 75-100 MeV/Nucleon.

$\pi^{\pm}$-Multiplicity Distribution in 2 GeV/Nucleon Heavy Ion Interactions

Referat (sammandrag)

We report on the first investigation of high energy heavy ion reactions in which the combination of nuclear emulsions as 4π-detectors and well-defined targets is used. In the experiment reported here Ilford K5 emulsions laminated with tungsten wires have been irradiated with 400 MeV/nucleon ^{20}Ne at the Berkeley Bevatron. The aim of the experiment is to study target and projectile fragmentation processes.

The degree of target and projectile disintegration is studied in ^{16}O-emulsion nucleus interactions at 0.075-0.100 GeV/nucleon. The results are compared with data from ^{16}O-emulsion nucleus interactions at 0.18 and 2.0 GeV/nucleon.

We have estimated the total $\pi^{\pm}$-multiplicity distribution in ^{12}C and ^{16}O induced interactions in nuclear emulsions at 2 GeV/nucleon by determining the energy loss of all charged particles. The experimental results are compared to a model in which we assume that only individual nucleon-nucleon scattering occurs. Thereby we find that the frequency of high $\pi^{\pm}$-multiplicity events is too large to be understood by this model, indicating that collective production phenomena are present.

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Pris

^{20}Ne-W Reactions at [illegible] MeV/Nucleon Studied in Wire-Loaded Nuclear Emulsions.

B. Jakobsson

Dept. of Physics, Univ, of Lund, Lund, Sweden, and

Centre de Recherches Nucléaires, Strasbourg, France.

B. Lindkvist and I. Otterlund

Dept. of Physics, Univ. of Lund, Lund, Sweden.

We report on the first investigation of high energy heavy ion reactions in which the combination of nuclear emulsions as 4π-detectors and well-defined targets is used. In the experiment reported here Ilford K5 emulsions laminated with tungsten wires have been irradiated with 400 MeV/nucleon ^{20}Ne at the Berkeley Bevatron. The aim of the experiment is to study target and projectile fragmentation processes.

1. Introduction. When investigating possible existence of extreme phenomena in high energy heavy ion reactions as for instance abnormal densities leading to shock waves or collective pion production it is necessary to distinguish between central and peripheral reactions. For this purpose nuclear emulsions are suitable because they are 4π geometry detectors. The disadvantege in conventional experiments, where the emulsion is used both as target and detector, is that the target is composed of different nuclei (H, C, N, O, Ag, Br). The technique of loading emulsions with thin wires, first suggested for hadron-nucleus reactions by Dr. J. Herz, CERN, has been developed in Lund and at CERN by B. Lindkvist [1]. In the experiment reported here the usefulness of this new emulsion technique in high energy heavy ion experiments will be tested.

2. Method. The wire-loaded detector is shown in Fig. 1. Two emulsions - one pellicle (stripped emulsion) and one plate (emulsion on glass) - are laminated with thin wires in a grid between the emulsions. The emulsions are exposed to Ne with the beam impinging horizontally to the emulsion surface and perpendicular to the wires. The plates are scanned along the wires. The scanning

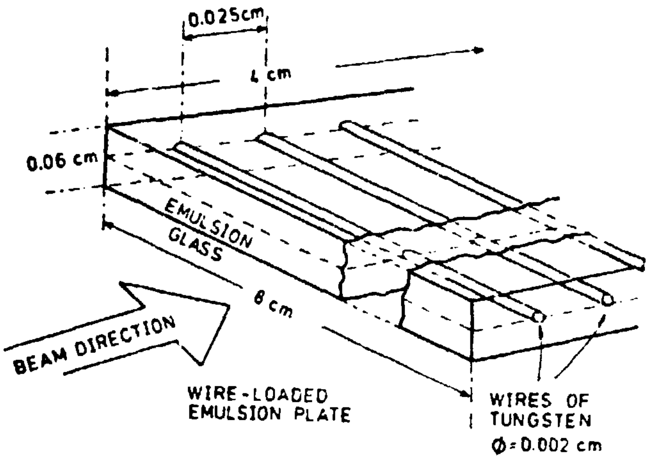

Fig. 1. Wire-loaded emulsion.

method has been found to be both efficient (> 95% scanning efficiency) and fast compared to normal emulsion scanning.

Measurements of energy-loss parameters and emission angles have been performed on the semi-automatic digitalized TRICO coordinate measurement system at the Centre de Recherches Nucléaires, Strasbourg. A final test of whether the scanned star is a "wire-star" or an "emulsion-star" has been performed by a method where the paths of all tracks are extrapolated to the interaction centre. Thereby about 10% of the scanned stars are found to be emulsion stars. After this process 94 stars have been accepted and further analysed.

3. Discussion. The analysis of the data has just started why only a few preliminary results will be mentioned in this report.

Figure 2 shows the angular distribution of black track producing particles ($E_p \leq 44$ MeV, $E_{He} < 310$ MeV, all $Z \geq 3$ projectile fragments) in peripheral ($N_{ch} \leq 10$) and central ($N_{ch} \geq 25$) reactions. N_{ch} = the total number of charged particles observed.

The pronounced forward peak in reactions with $N_{ch} \leq 10$ contains projectile fragments. The background of target-fragments is almost isotropic which is expected in peripheral reactions if these particles are emitted in thermal processes from slowly recoiling nuclei. In central reactions ($N_{ch} \geq 25$) on the other hand the distribution is more anisotropic. In the latter distribution there seems to be a comparatively large contribution of projectile protons with angles > 10^{o}. The isotropic background if any, is small.

Fig. 3 shows the angular distribution of all black tracks together with the distribution expected from the fireball model + + final state interactions with the emission of fragments produ-

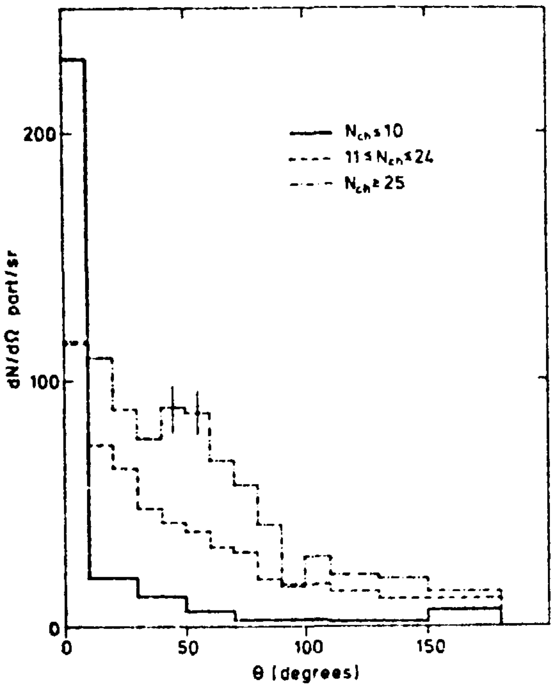

Fig. 2. Angular distribution of black tracks in 340 MeV/nucleon ^{20}Ne-W collisions with a number of charged particles $N_{ch} \leq 10$, 11-24 and ≥ 25.

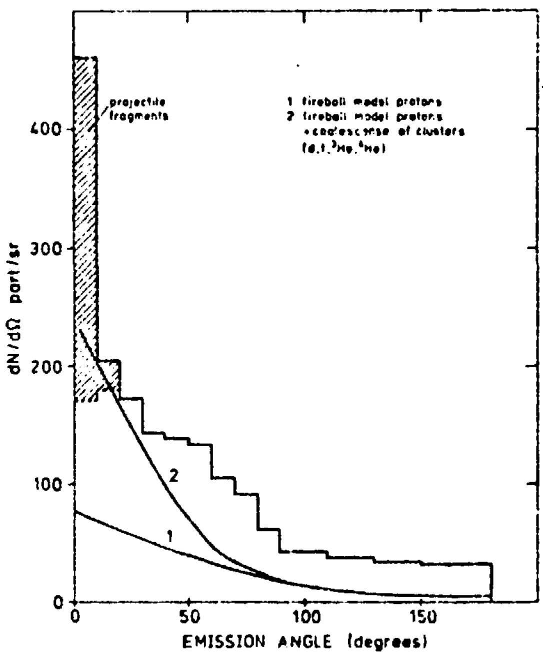

Fig. 3. The angular distribution of black tracks in 340 MeV/nucleon ^{20}Ne-W collisions together with the predictions from the fireball-model (curves).

ced by coalescenses with the emission of fragments produced by nucleons. This model has been developed by the Poskanzer Gutbrod group in Berkeley [2,3]. A somewhat too large forward peaking in curve 2 seems to be the only discrepancy from the experimental data if one assumes that an isotropic evaporation contribution should be added to the fireball distribution.

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^{16}O-Nucleus Interactions at 75-100 MeV/Nucleon

R. Kullberg, A. Oskarsson and I. Otterlund
Department of Physics, University of Lund,
Sölvegatan 14, S-223 62 LUND, Sweden.

Abstract. The degree of target and projectile disintegration is studied in ^{16}O-emulsion nucleus interactions at 0.075-0.100 GeV/ /nucleon. The results are compared with data from ^{16}O-emulsion nucleus interactions at 0.18 and 2.0 GeV/nucleon.

1. Introduction. In this investigation we study heavy ion interactions induced by 75-100 MeV/nucleon ^{16}O. The results are compared to earlier studies of ^{16}O-emulsion nucleus interactions at 2.0 and 0.175 GeV/nucleon (1,2).

2. Experimental details. A stack of Ilford G5 nuclear emulsions, 26 pellicles 10x10x0.06 cm^3 in size, was irradiated with 250 MeV/ /nucleon ^{16}O and ^{12}C at the Berkeley Bevatron in 1972. The beams of ^{16}O and ^{12}C were exposed parallel to the emulsion surface, but from opposite directions of the stack. Stopping beam tracks of ^{12}C and ^{16}O are used for calibration purposes and improve extentially the accuracy of identification of multiply charged projectile fragments.

Up to now 154 ^{16}O-emulsion nucleus interactions have been found in the scanned volume. This volume contains interactions with energies in the region 75-100 MeV/nucleon. All primaries were followed from the interaction point to the edge of the emulsion. The angles are measured for all particles leaving the interaction point. For all secondary particles stopping in the stack the range is measured. The identity of the particles is determined by energy loss and scattering measurements. Particles leaving the stack or interacting in the stack are identified by energy loss measurements in some segments along the track.

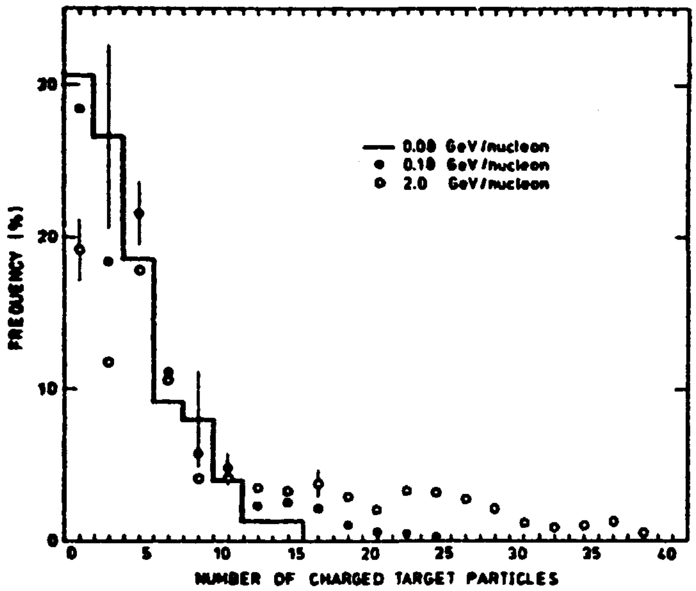

Fig. 1. The frequency of interactions with different multiplicity of charged target particles in ^{16}O-emulsion nucleus interactions.

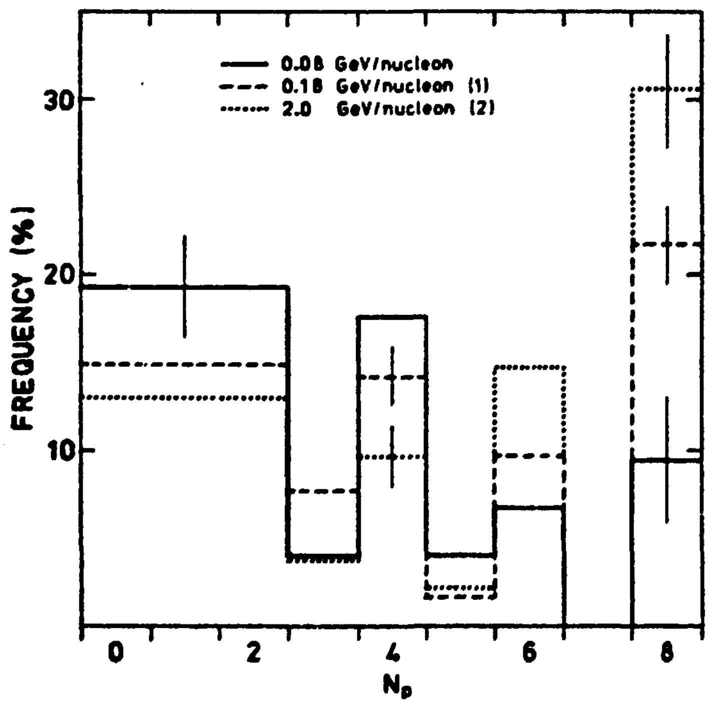

Fig. 2. The frequency of interactions with different multiplicity of hydorgen isotopes in ^{16}O-emulsion nucleus interactions, emitted from the projectile ^{16}O nucleus.

3. Experimental results.

a. Target disintegration: Fig. 1 shows the number of charged target particles in ^{16}O-emulsion nucleus interactions at 0.08, 0.18 (Ref. 1) and 2.0 (Ref. 2) GeV/nucleon. There is a marked trend towards increased target disintegration with increased incident energy. However, even at 0.08 GeV/nucleon there is a comparatively large target disintegration in some events.

b. Projectile disintegration: The multiplicity of hydrogen nuclei, N_p, ($N_p = 8 - \Sigma Z_i$, where Z_i is the charge of projectile fragments with charge ≥ 2) emitted from the incident ^{16}O nucleus is shown in Fig. 2. At 2 GeV/nucleon about 30 % of the interactions, result in total breakup of the ^{16}O nucleus into protons, deuterons or tritons. At 0.08 GeV/nucleon this happens only in about 10 % of the interactions. It is also worth noting the frequent emission of one and two helium nuclei from the projectile nucleus. This is indicated by the maxima for $N_p = 6$ and $N_p = 4$.

The analysis is still in progress. An interesting result is that pions are observed in ^{16}O-emulsion nucleus interactions at least at as low energy as 0.08 GeV/nucleon. Angular and energy distributions of secondary particles will be presented at the conference.

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$\pi^{\pm}$-Multiplicity Distributions in 2 GeV/Nucleon Heavy Ion Interactions

B. Jakobsson
Dept. of Physics, University of Lund, Lund, Sweden, and
Centre de Recherches Nucléaires, Strasbourg, France.

R. Kullberg and I. Otterlund
Dept. of Physics, University of Lund, Lund, Sweden.

A. Ruiz
Dept. of Physics, University of Santander, Santander, Spain.

J.M. Bolta and E. Higón
Inst. of Physics, University of Valencia, Valencia, Spain.

Abstract: We have estimated the total $\pi^{\pm}$ multiplicity distributions in ^{12}C and ^{16}O induced interactions in nuclear emulsions at 2 GeV/nucleon by determining the energy loss of all charged particles. The experimental results are compared to a model in which we assume that only individual nucleon-nucleon scattering occurs. Thereby we find that the frequency of high $\pi^{\pm}$ multiplicity events is too large to be understood by this model, indicating that collective production phenomena are present.

1. Introduction. We report on an attempt to determine the total charged pion multiplicity distributions in ^{12}C and ^{16}O induced reactions in nuclear emulsions at 2 GeV/nucleon. The motivation is to determine whether these distributions could be completely understood by nucleon-nucleon scattering or if collective phenomena are involved in the pion production. Previous inclusive experiments on π^{+} and π^{-} production in d, α, ^{12}C, ^{14}N induced heavy ion reactions have resulted in different conclusions concerning this problem. Papp et al. [1] find that the Lorenz invariant $E/p^2\, d^2\sigma/d\Omega dp$ cross sections (E=energy and p=momentum of the pion) at 2.5^{0} lab. angle are well reproduced by the nucleon-nucleon scattering hypotheses. Baldin et al.[2] and Schimmerling et al. [3] have however found that pions are frequently produced with such high energies that the beam nucleons must interact in a cooperative way.

2. Method. In our experiment we used Ilford K5 emulsions exposed to 2.1 GeV//nucleon ^{12}C and ^{16}O beams from the Lawrence Berkeley Laboratory Bevatron. The average fluxes were in both cases 10^{4} cm^{-2}. The plates have been area scanned twice and the mean free path is found to be 14.9 cm for ^{12}C and 14.0 cm for ^{16}O in agreement with other measurements [4]. 192 ^{12}C-events and 421 ^{16}O-events have so far been analysed.

The energy loss of all outgoing tracks from an event in the emulsion have been determined by gap counting. A dip angle correction for the gap density of the type discussed in appendix 2 in Ref. 4 has been applied. All candidates for relativistic multiply charged fragments i.e. tracks with $dE/dx \geq$ $\geq 4(dE/dx)_{min}$ and emission angle $\theta \lesssim 5^{o}$, have been followed until they interact or leave the stack. In cases of He candidates, repeated gap density measurements have been made and in cases of $Z \geq 3$ fragments, we have determined the charge with an error of ± 1 unit by opacity measurements with photometers. By these measurements we have been able to separate the events into the H-, CNO- and AgBr target groups according to the scheme given in Ref. 4. This method gives for ^{12}C interactions 13±3% H, 27±4% CNO and 60±6% AgBr and for ^{16}O interactions 11±2% H, 29±3% CNO and 60±4% AgBr roughly in agreement with calculations using presently known reaction cross sections [4]. The parameter representing the pion multiplicity which we determine is:

$$N^{Em}_{\pi^\pm} = N_s - \left(Z_{beam} - \Sigma Z_{fr}\right) \quad (1)$$

where N_s = the number of shower particles $\left(\frac{dE}{dx} \leq 1.4\left(\frac{dE}{dx}\right)_{min}\right)$, Z_{beam} and Z_{fr} are the charges of the beam respectively multiply charged relativistic fragments.

The above parameter is of course only an approximation of the real number of produced charged pions in the individual case for reasons which will be discussed later. It is used because we consider Coulomb scattering methods for identifying all charged pions too uncertain and time-consuming. Furthermore we can estimate the corresponding parameter from our nucleon-nucleon model calculations. The $N^{Em}_{\pi^\pm}$ distributions for ^{16}O-H, ^{16}O-CNO, and ^{16}O-AgBr collisions are shown in Fig. 1 together with predictions from the nucleon-nucleon model discussed in the next section. Very similar distributions are found for ^{12}C induced reactions.

3. Individual Nucleon-Nucleon Model. In an attempt to find out if some kind of collective phenomena are involved in the pion production we have developed an individual nucleon-nucleon scattering model. Thereby we start with nucleon--nucleon cross sections, consider Fermi-motion and inelasticity distributions to receive a distribution of available centre of mass energy in each reaction step. Then we determine $P(\nu, n_{inc})$, which is the probability distribution for a nucleon to make ν scatterings when n_{inc} projectile nucleons participate in the reaction. Finally we estimate the corrections for changing the $P(n_{\pi^\pm})$ distribution into a $P(N^{Em}_{\pi^\pm})$ distribution.

In determining the $\pi^\pm$ distributions for nucleon-nucleon scattering in the

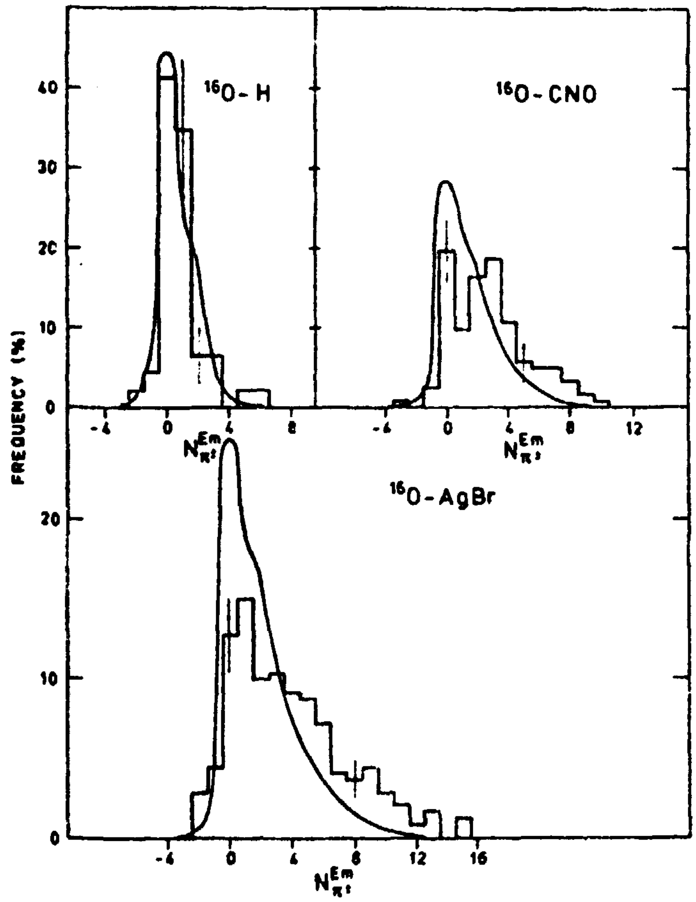

Fig. 1. $N^{Em}_{\pi^\pm}$ distributions in ^{16}O induced reactions at 2 GeV nucleon. The curves show the results of the individual nucleon-nucleon model calculations described in the text.

energy interval 0.4 - 3 GeV we use all reaction channels having a cross-section above 0.1 mb. The data are taken from Refs. 5 and 6. A sum up over all channels giving the total $\pi^\pm$ multiplicity in pp-reactions as a function of incident energy fits very well with bubble chamber data (we get for instance $\langle N_{\pi^\pm}\rangle_{pp}$ = 0.57 at 2 GeV).

In order to transform $\pi^\pm$ multiplicities into $\pi^\pm_{Em}$ multiplicities according to (1) we have to make the following corrections:

1. Slow pions ($E \lesssim 50$ MeV) will not be registered as shower tracks. The amount of such pions in each nucleon-nucleon reaction channel is estimated using energy distributions of pions from Monte Carlo phase-space simulations with the FOWL program [7].

2. If a nucleon-nucleon reaction leads to two protons above or below 400 MeV ($\sim 1.4\ (dE/dx)_{min}$) we introduce a discrepancy from the real number of charged pions by using formula (1). This effect is taken into consideration by using inelasticity distributions from Refs. 6 and 7.

3. Charge exchange reactions are considered in the case of the elastic pn → → np reaction by experimental data [5,6]. In other channels we assume that in 50% of the cases charge exchange between the nucleons occurs.

After these corrections which broaden the $N_{\pi^\pm}$ distributions a little and also result in the possibility of having $N^{Em}_{\pi^\pm} = {}^{\pi}-1$, we introduce the Fermi motion in both interacting nuclei ($E_{Fermi} = {}^{\pi}29$ MeV, Fermi-distribution of energies, isotropic angular distribution). This results of course in a spread of the available centre of mass energies and thereby in a further broadening of the $N_{\pm}^{Em}$ distributions. Energy distributions of scattered nucleons are introduced by using experimental dσ/dt distributions for elastic scattering [6] and the FOWL program for generating inelastic scattering [7]. In this way we can find the contribution to the multiplicity distributions from each reaction step.

The most important thing which is left now is to find $P(\nu,n_{inc})$ probability distributions. We have chosen to treat this problem in two ways. The first way is to use a Monte-Carlo simulation of the heavy ion reaction assuming the nucleons to be hard core particles. We distribute the nucleons in the nuclei with a Wood-Saxon distribution

$$\varphi(r) = \varphi_0(\exp((r-b)/a)+1)^{-1} \qquad (2)$$

with the parameters a = 0.55 fm and $b = 1.1\ A^{1/3}$, where A is the nucleon number. Furthermore we use a hard core radius of the nucleons in order to get <ν> in agreement with what is expected from the number of mean-free paths

$$\langle\nu\rangle = A\sigma_{pp}/\sigma_{pN} \qquad (3)$$

where σ_{pp} and σ_{pN} are the total cross sections for pp and p-Nucleus reactions.

The above mentioned parameters give also in the case of ^{12}C or ^{16}O interactions on CNO and AgBr, $P(\nu,n_{inc})$ distributions in good agreement with the results of our second approach.

This approach is a straightforward Glauber calculation. We use here Gaussian density distributions of the nuclei

$$\varphi(r) = (\frac{a}{\pi})^{3/2}\exp(-ar^2) \qquad (4)$$

to obtain the nucleon density as a function of the impact parameter $T(\bar{b})$ and finally the $T(\bar{b},\bar{s})$ function, where $\bar{s}$ is the position vector for the impact in the plane transvers to the beam.

Furthermore σ_{tot} = 44 mb is used. Straightforward Glauber calculations now give $P(\nu,n_{inc})$ distributions in close agreement with the Monte-Carlo simulation results.

The $\pi_{Em}^{\pm}$ multiplicity distributions for each reaction step are finally wieghted over the $P(\nu,n_{inc})$ probabilities for ^{12}C-CNO, ^{12}C-AgBr, ^{16}O-CNO and ^{16}O-AgBr reactions. The final $\pi_{Em}^{\pm}$ multiplicity distributions for ^{16}O-CNO and ^{16}O-AgBr reactions are shown as the curves in Fig. 1.

4. Discussion of the Results. The $\pi_{Em}^{\pm}$ multiplicity distributions for ^{12}C-H and ^{16}O-H reactions are very well reproduced by the calculations showing that

one has actually the broadening of the real $\pi^{\pm}$-distribution also to negative $n^{\pm}_{Em}$ values which is to be expected.

The low multiplicity parts of the CNO and AgBr distributions are well represented by the model but there seems to be a significant discrepancy for high $n^{\pm}_{Em}$ miltiplicities. Experimentally we have an overabundance of high multiplicity events even though we have been careful in our model always to choose alternatives giving as high multiplicities as possible. Furthermore the pion absorbtion not regarded here, must depress the high multiplicities somewhat.

We believe thus that the explanation of the discrepancies should be that some kind of collective phenomena, must be present at least in a part of the individual heavy ion events. The events with high $n^{\pm}_{Em}$ multiplicities are at present under further examination.

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