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PION PRODUCTION IN ^{4}He-NUCLEUS REACTIONS FROM 200 TO 800 MeV/nucleon

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Introduction

One of the major challenges of relativistic heavy ion physics is the determination of the nuclear equation of state for densities up to several times normal density. During the last years, several methods have been suggested in order to extract the equation of state from experimental data [1]. For instance, it has been proposed a few years ago [2] to use the pion multiplicity. The question whether this observable is sensitive or not to the equation of state has been abundantly discussed [3-8], and it is clear that new experimental data would help to clarify the situation.

We report here π^+ and π^- measurements at the SATURNE synchrotron in Saclay for ^{4}He+(C,Cu,Pb) at 200, 600 and 800 A.MeV, and ^{4}He+(C,Cu) at 400 A.MeV, using the large solid angle detector "Diogene" [9]. Those results are the first ones from our heavy ion program at Diogene. Data have also been taken with neon beams, and are presently under analysis. Data taking with argon beams are planned for this year.

Diogene is an electronic 4π detector which can measure simultaneously π^+, π^-, p, d, t, and He between 20° and 132°, and above energy thresholds of ~23 MeV for pions and ~42 MeV for protons. Its forward angular range (0°-6°) is covered by telescopes which provide charge identification (not used in the ^{4}He experiments). In order to select non peripheral events for ^{4}He+A collisions, the detector was triggered by the requirement that one charged particle at least was emitted between 37° and 119°, with an energy above ~43 MeV for pions and ~70 A.MeV for baryons.

Our results are compared to the Cugnon's intra-nuclear cascade predictions [10]. For this purpose, the theoretical results are "filtered" by the detector and trigger acceptances. The model used here has been improved : first the charge dependence of elementary cross-sections has been implemented, and second, the spectator nucleons are "frozen" in the way described in ref. [11]

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Pion multiplicities

Fig. 1 shows the total pion multiplicities. For a given incident energy, $<M(\pi^+)>$ decreases and $<M(\pi^-)>$ stays constant when the target mass increases. The model overpredicts the experimental values and does not account for the target mass dependence. The ratios between the theoretical and experimental results increase with the target mass. It is worthwhile to notice that those ratios are roughly the sames for π^+ and π^- : the π^- are only 5 to 20% larger than the π^+ values.

The fact that the pion yield does not increase with the target mass may seem surprising, since for heavy ion collisions it generally increases with the mass of the system. But in our case, the projectile is much smaller than the target, and this has two consequences. First, for a given incident energy, the energy per participant nucleon (in the participants C.M.) will significantly decrease when the target mass increases. Second, it is likely that the interactions between the ejected particles and the target spectators are significant, specially for heavy targets. In fact, the ^{4}He+A reactions are intermediate between p+A and A+A cases. From the p+A→π^++X experimental data, it has been shown [12] that the π^+ production cross-section is proportional to $Z^{1/3}$. If we assume that the reaction cross-section is proportional to $A^{2/3}$, we find that $<M(\pi^+)>$ decreases when the target mass A increases.

It is interesting to study the pion yield as a function of impact parameter. We used the proton-like multiplicity M("p") as a rough estimate of the impact parameter. M("p") is the total number of measured protons, no matter they are free or bound in a light nucleus. The cascade shows that M("p") is somewhat correlated to the impact parameter. For instance, in the ^{4}He+Cu (800 A.MeV) reaction, the mean impact parameter selected by M("p")≥6 is ~2.1 fm, while it is 4.6 fm for M("p")≤1.

Fig. 2 shows the pion mean multiplicities as a function of M("p") for the incident energy 800 A.MeV. The general trends visible on Fig. 2 are also observed at 400 and 600 A.MeV. We see that $<M(\pi^+)>$ decreases with increasing M("p"), while $<M(\pi^-)>$ increases, stays constant, or decreases, respectively for the C,Cu, or Pb targets. At the same time, the ratio between the theoretical prediction and the experimental result always increases with M("p"). The model never predicts a decrease of $<M(\pi)>$, neither for π^+, nor for π^-. For "high" values of M("p"), the ratios between the $<M(\pi)>$ values predicted by the model and those experimentally measured are still almost independent of the pion charge.

The $<M(\pi)>$ decrease (when M("p") increases) has not been observed in the A+A collisions: in the Ar+KCl reactions [13] for instance, $<M(\pi)>$ increases with M("p"). But the fact that our systems are highly asymmetrical plays probably an important role, as it has already been noticed in our discussion on the $<M(\pi)>$ target mass dependence. The effect of charge conservation has also to be considered. For instance, for the C target, the total charge is 8 : when M("p") approaches this value $<M(\pi^+)>$ decreases, while $<M(\pi^-)>$ increases.

The cascade pion excess

How can one account for the discrepancy between our results and the cascade predictions ? One has to keep in mind that in the standard Cugnon's cascade used here, the potential binding energies of the two nuclei are not included. Therefore, we recalculated the cascade pion yields, with the addition of the Cahay et al. [7] binding energy prescription. In this approach, the nucleons

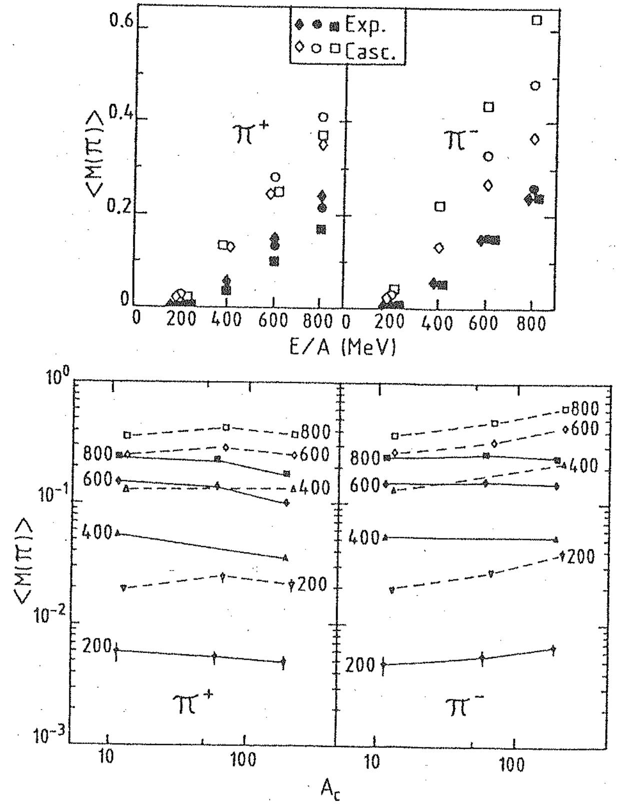

Fig.1 Mean π^+ and π^- total multiplicities measured in Diogene for the ^{4}He+(C,Cu,Pb) reactions from 200 to 800 A.MeV. The experimental results (full symbols) are compared to the cascade predictions (open symbols). The two upper plots show the results as functions of the ^{4}He incident energy for the C (losanges), Cu (circles), and Pb (squares) targets. The two lower plots show the same results, but as functions of the target mass for the following incident energies (A.MeV): 200 (▼ and ▽), 400 (▲ and △) , 600 (◆ and ◇) , 800 (■ and □).

suddenly loose 40 MeV just before their first collision. We found that the Cahay et al. prescription strongly reduces the discrepancy between the cascade and the experimental total pion multiplicities. For instance, in the reaction ^{4}He+Cu (800 A.MeV), the ratios (casc./exp.) were ~1.8, and become ~1.1. However, a study of the M("p") dependence (at 800 A.MeV incident energy) shows that the model still overpredicts the experimental data for "high" M("p"). In this case, the ratio (casc./exp.) increases with increasing target mass. For instance, in ^{4}He+Pb (800 A.MeV, M("p")≥7), the cascade <M(π^+)> and <M(π^-)> values are ~2.3

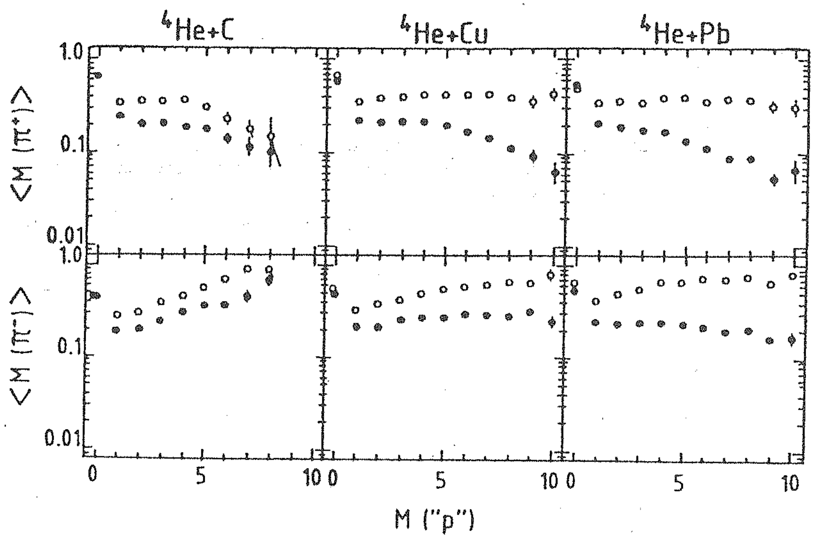

Fig.2 Mean π^+ and π^- multiplicities as functions of the proton-like multiplicity M("p"), for the ^{4}He+(C,Cu,Pb) reactions at 800 A.MeV incident energy. The three upper plots correspond to the π^+, and the three lower ones to the π^-. The experimental results (full circles) are compared to the cascade predictions (open circles).

larger than the experimental ones. The Pauli blocking effect has also been tested, using a new version of the Cugnon's cascade : the elementary NN collisions (or Δ decays) can be suppressed in a way that is similar to the prescription used in the "VUU" [5] or "BUU" [8,14] models in order to simulate the Uehling-Uhlenbeck blocking factors. At 800 A.MeV, the influence of this new prescription on the total mean pion multiplicities is smaller than the statistical uncertainties.

The lack of compressional energy in the cascade model [2] can also contribute to the observed discrepancy. The cascade calculations show that in ^{4}He+A collisions at 800 A.MeV, densities up to $\rho=4\rho_0$ can be reached, but in a very small zone: its diameter is about 2 fm . The meaning of a density calculated in such a small area is questionable, but this high value of ρ shows that the compressional energy effects cannot be completely neglected. On an other hand, the fact that the ratios of pion yields (casc./exp.) increase with increasing target mass or M("p") multiplicity suggests that the pion absorption in nuclear matter could be underestimated within the cascade code.

Pion multiplicity distributions and pion spectra

Concerning the pion multiplicity distribution, Gyulassy and Kauffmann had shown that any deviation from a simple Poisson form (at a given impact parameter) would be a significant signal of unusual coherent pion process [15]. We have compared the mean and the variance of the π^+ and π^- multiplicity distributions, at given values of M("p"). We found that the two values are close to each other.

We have investigated the pion spectra, namely the π^+ and π^- invariant cross-section as a function of the lab. pion momentum and angle, in different proton-like multiplicity bins. The general aspects of the spectra do not depend strongly on the M("p") selection. The cascade model gives a rather good prediction of the momentum and angle dependences.

The π^-/π^+ ratio between the two differential cross-sections has been studied as a function of pion momentum : when the latter increases, the π^-/π^+ ratio first decreases, then stays constant. The decrease is steeper for the Pb target than for the C one. These results can be qualitatively explained by the Coulomb forces due to the target remnants.

References

1) *Proc. 7th High Energy Heavy Ion Study, Darmstadt, Oct. 1984, GSI-85-10.*
2) *R. Stock et al., Phys. Rev. Lett. 49 (1982) 1236 ; and J.W. Harris et al., Phys. Lett. 153B (1985) 377.*
3) *J. Aichelin et al., UFTP preprint 188/1986, Institut fur Theoretische Physik der Universitat Frankfurt, D-6000 Frankfurt am Main (W. Germany).*
4) *Y. Kitazoe et al., Phys. Lett. 166B (1986) 35.*
5) *H. Kruse, B. V. Jacak, and H. Stocker, Phys. Rev. Lett. 54 (1985) 289*
6) *M. Sano et al., Phys. Lett. 156B (1985) 27.*
7) *M. Cahay, J. Cugnon, and J. Vandermeulen, Nucl. Phys. A411 (1983) 524.*
8) *G. F. Bertsch, H. Kruse, and S. Das Gupta, Phys. Rev. C29 (1984) 673*
9) *J. Poitou, Lect. Notes in Phys. 178 (1983) 202 ; and J. P. Alard et al., "The Diogene Detector", submitted to Nucl. Inst. & Meth. (1987).*
10) *J. Cugnon, D. Kinet, and J. Vandermeulen, Nucl. Phys. A379 (1982) 553.*
11) *J. Cugnon and D. L'hote, Nucl. Phys. A452 (1986) 738.*
12) *D. R. F. Cochran et al., Phys. Rev. D6 (1972) 3085 ; and J. F. Crawford et al., Phys. Rev. C22 (1980) 1184.*
13) *A. Sandoval et al., Phys. Rev. Lett. 45 (1980) 874 ; and J. W. Harris et al. in Ref. 1), p. 5.*
14) *J. Aichelin, Phys. Rev. C33 (86) 537.*
15) *M. Gyulassy and S. K. Kauffmann, Phys. Rev. Lett. 40 (1978) 298.*
16) *P. Danielewicz and G. Odyniec, Phys. Lett. 157B (1985) 146.*