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Pion Production in 4π-Neutron Reactions from 200 to 800 MeV/Neucleon

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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. For instance, it has been proposed a few years ago to use the pion multiplicity to determine whether this observable is sensitive or not to the equation of state has been abundantly discussed, and it is clear that new experimental data would help to clarify the situation.

We report here p and n measurements at the SARTHE Synchrotron in Saclay for \( \text{He}+\{\text{Cu,Pb}\} \) at 200, 600 and 800 A MeV, and \( \text{He}+\{\text{Cu}\} \) at 400 A MeV, using the large solid angle detector "Biogen". Those results are the first ones from our heavy ion program at Biogen. Data have also been taken with neutron beams, and are presently under analysis. Data taking with argon beams are planned for this year.

Biogen is an electronic 4m detector which can measure simultaneously p, n, p, d, t, and He between 20° and 130°, and above energy thresholds of 23 MeV for pions and 32 MeV for protons. Its forward angular range (0°-6°) is covered by telescopes which provide charge identification (not used in the \( \text{He} \) experiments). In order to select non peripheral events, \( \text{He}+\text{Cu, Pb} \) 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 heavy ions.

Our results are compared to the Cugnon's intra-nuclear cascade predictions. 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, \( \langle n_p \rangle \) decreases and \( \langle n_n \rangle \) 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 same for p and n: the \( n_p/n_n \) are only 5 to 20 larger than the \( n_p/n_n \) 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.E.N.) will significantly decrease when the target mass increases. Second, it is likely that the interactions between the projectile pions and the target spectators are significant, especially for heavy targets. In fact, the \( p+\text{Cu} \) reactions are intermediate between p+p and A+A cases. From the p+p\text{Cu} experiment data, it has been shown that the pion production cross-section is proportional to Zp. If we assume that the reaction cross-section is proportional to A, we find that \( \langle n_p \rangle \) 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 \( \langle M(p) \rangle \) as a rough estimate of the impact parameter. \( \langle M(p) \rangle \) is the total number of measured protons, no matter they are free or bound in a light nucleus. The cascade shows that \( \langle M(p) \rangle \) is somewhat correlated to the impact parameter. For instance, in the \( \text{He}+\text{Cu} \) reaction, the mean impact parameter selected by \( \langle M(p) \rangle \) is 2.1 fm, while it is 4.6 fm for \( \langle M(p) \rangle \).

Fig. 2 shows the pion mean multiplicities as a function of \( \langle M(p) \rangle \) 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 \( \langle n_p \rangle \) decreases with increasing \( \langle M(p) \rangle \), while \( \langle n_n \rangle \) increases, stays constant, or decreases, respectively, for the C,Cu, or Pb targets. At the same time, the ratio between the theoretical predictions and the experimental result always increases with \( \langle M(p) \rangle \). The model never predicts a decrease of \( \langle n_n \rangle \), neither for p, nor for n. For low values of \( \langle M(p) \rangle \), the ratio between the \( \langle n_n \rangle \) values predicted by the model and those experimentally measured are still almost independent of the pion charge.

The \( \langle n_n \rangle \) decrease (when \( \langle M(p) \rangle \) increases) has not been observed in the A+A collisions: in the Ar+XeCl reactions, for instance, \( \langle n_n \rangle \) increases with \( \langle M(p) \rangle \). 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 \( \langle n_n \rangle \) target mass dependence. The effect of charge conservation has also to be considered. For instance, for the C target, the total charge is B: When \( \langle M(p) \rangle \) approaches this value \( \langle n_n \rangle \) decreases, while \( \langle n_n \rangle \) 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 Canay et al. binding energy prescription. In this approach, the nucleons...
Fig. 1 Mean $\pi^+$ and $\pi^-$ 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 (\^\gamma and \^\gamma), 400 (\^\Delta and \^\Delta), 600 (\phi and \phi), 800 (\^\Pi and \^\Pi).

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^+)>20), the cascade $\langle M(\pi^+) \rangle$ and $\langle M(\pi^-) \rangle$ values are -2.3

Fig. 2 Mean $\pi^+$ and $\pi^-$ 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 $\pi^+$, and the three lower ones to the $\pi^-$. 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 Ochsenkohr's cascade: the elementary NN collisions (or $\Delta$ decays) can be suppressed in a way that is similar to the prescription used in the $^{\mu\mu\mu\mu}$ or $^{\mu\mu\mu\mu\mu}$ models in order to simulate the Uehling-Unsbeck 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 \cite{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 $\rho=\rho_0$ 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 $\rho$ shows that the compressional energy effects cannot be completely neglected. On the 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 14). We have compared the mean and the variance of the $\pi'$ and $\pi''$ multiplicity distributions, at given values of $M(\pi'\pi'')$. We found that the two values are close to each other.

We have investigated the pion spectra, namely the $\pi'$ and $\pi''$ 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 $M(\pi'\pi'')$ selection. The cascade model gives a rather good prediction of the momentum and angle dependences.

The $\pi''/\pi'$ ratio between the two differential cross-sections has been studied as a function of pion momentum: When the latter increases, the $\pi''/\pi'$ 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

3) J. Aichelin et al., UTF preprint 188/1986. Institut fur Theoretische Physik der Universitat Frankfurt, D-6000 Frankfurt am Main (W. Germany).
13) A. Sandoval et al., Phys. Rev. Lett. 45 (1980) 874 ; and J. W. Harris et al. in Ref. 11, p. 5.