Sequential Decay Distortion of Goldhaber Model Widths for Spectator Fragments

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If A_0-K nucleons are suddenly removed from a nucleus that originally has A_0 nucleons, a nucleus consisting of K nucleons will emerge. For this fragment of K nucleons, Goldhaber [1] showed that the momentum width, σ, could be expressed as: $\sigma = \sigma_0$ sqrt $[K(A_0 - K)/(A_0 - 1)]$, where σ_0, the reduced momentum width, is related to the intrinsic Fermi motion of a single nucleon, i.e.,: σ_0 = sqrt $(1/5)P_F$. Based upon electron scattering measurements of Fermi momenta, σ_0 is expected to be ≈ 112-116 MeV/c. However, experimental results favor values of $\sigma_0 \approx 90$ MeV/c [2]. Some theoretical works [3] have attempted to explain this difference. However, the answers were still absent.

In this work, we studied peripheral collisions of 200 MeV/nucleon $^{40}Ar + {}^{27}Al$ with AMD-V model [4] and followed with the afterbuner (GEMINI) [5]. In the AMD-V model, initial width of the nucleon momentum distribution is ~ 105 MeV/c for ^{40}Ar and ~ 101 MeV/c for ^{27}Al. These values are less than expected from electron scattering measurements, but are still in a reasonable range.

The primary fragment momentum distributions from AMD-V can be described by a Gaussian shape characterized by a width σ.

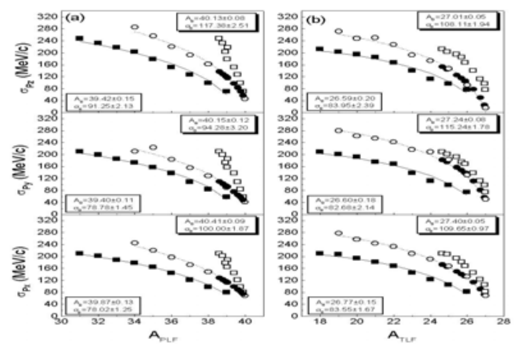

Figure 1: The three momentum widths, σ_{Px}, σ_{Py}, σ_{Pz}, as a function of the mass of PLF (left) and TLF (right) fragments. The open circles depict the momentum widths of the AMD-V primary fragments as a function of the mass of primary fragments and the dashed lines indicate the Goldhaber Model fits. The solid squares show the momentum widths of final fragments as a function of the mass of final fragment and the solid lines represent Goldhaber Model fits to those results. The open squares represent the momentum widths of final fragments as a function of the reconstructed average mass of the primary fragment. The solid circles depict the reconstructed momentum widths as a function of the reconstructed average mass of the primary fragment. See details in text.

The fragment mass numbers and the three momentum widths, σ_{Px}, σ_{Py}, σ_{Pz}, are plotted in Fig. 1 as a function of the PLF and TLF fragment masses at b = 6-8 fm. The widths of the primary fragments are denoted by open circles and the dashed lines represent the results of fits to the Goldhaber Model expression (Eq. 1). The fit parameters σ_0 are shown in upper-right corner. The initial masses are close to the original masses of projectile or target and the average of the reduced widths of the three momentum components is ~ 105 MeV/c for PLFs and 110 MeV/c for TLFs. The values of σ_0 are very close to the initial nucleon Fermi momentum widths of the AMD-V ground states as mentioned before. Consequently, it appears that the Goldhaber model works well for the primary fragments.

However, the primary fragments are excited. To evaluate the effect of secondary particle emission on the masses and momentum widths we used the AMD-V results as input to the GEMINI calculation.

The solid squares in Fig. 1 represent the momentum widths of the final fragments, observed after the secondary de-excitation. The results also fit with the Goldhaber Model expression (the solid line) and the extracted apparent primary mass A_0 and width σ_0 is shown in the lower-left corner. The mass parameters remain close to the initial masses of the projectile and target but the σ_0 values become significantly smaller, manifesting mean values ~ 83 MeV/c. Obviously, these values approach the typical values of ~ 90MeV/c observed experimentally (recall that the AMD-V ground state has a slightly lower Fermi momentum than those from experiments). It appears that the sequential decay plays an important role in causing the reduced momentum width of the final fragments to be narrower than that of the intrinsic nucleon momentum width. This leads us to a relatively simple explanation for the experimentally reported momentum widths of PLF fragments. Why does the sequential decay make the reduced width decrease and not increase? To answer this question, we have tracked the secondary decay paths and obtained the distribution of parent nuclei (primary fragments) which lead to each of the observed final fragments. If we plot the observed momentum width for the final fragments as a function of their average primary fragment masses, as represented by the open squares in Fig. 1, we immediately see that there is a large increase of momentum width compared to the original primary fragment width, denoted by open circles. It is, of course, natural that the sequential decay will make the momentum distribution wider.

Knowing the parentage of a final fragment, we can reconstruct the primary width distribution leading to it. The reconstructed width for the average parent fragments can be written as: $\sigma_{recons} \equiv \mathrm{sqrt}\,[\Sigma_i\, p_i \sigma_{Prim}(i)^2]$ where p_i is the fractional contribution of primary fragments to the final observed fragments. The results are indicated by the solid circles in Fig. 1. As required by this procedure, the results fall on the curves defining the primary fragment momentum widths. The difference in widths represented by these points and those represented by the open squares reflect evaporation effects.

In summary, the momentum widths of the primary fragments are related to the initial Fermi momenta in the projectile or target. However, since the primary fragments are excited, they are de-excited by light particle evaporation. This secondary decay decreases the observed masses and increases the observed momentum widths of the primary fragments. As a consquence, it makes the reduced width parameter σ_0, derived from a Goldhaber Model fit to the data, narrower by almost 20 MeV/c than the initial Fermi momentum width, consistent with many experimental observations. For details, see [6].

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