Target Neutron Skin Effect on Projectile Fragmentation

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The projectile fragmentation mechanism has long been debated whether to be sequential or prompt. Sequential decay of the projectile assumes a breakup after the excitation process [1]. Recently, experimental data showed that projectile fragmentation occurs at very close proximity to the target [2] and moreover, origin of fragments was observed to be a mixture of sequential decay and of promptly emitted particles when the impinging nucleus is still in contact with the target. Indeed, it was observed that neutron rich fragments are emitted with a slower velocity than what would be predicted by a sudden breakup of the projectile at very close proximity with the target. This suggest that the neutron rich fragments have encountered a stronger nuclear potential. This raises a lot of question on the magnitude of this effect and on the isospin dependence of the equation of state.

In this report, we present projectile fragmentation data obtained from the reaction of $^{28}\text{Si}$ on targets of $^{112,124}\text{Sn}$ at 50A MeV. If projectile breakup is a separate process from the excitation, both targets should give identical results. But, since projectile fragmentation results from a grazing collision with the target, targets having the same charge but differing by the number of neutron at their surface should give us some information on energy dissipation and mechanism of fragment production in nuclear collisions. The silicon nucleus which has an alpha structure will decay mostly by alpha particle emission, the relative yield of other isotopes should depend more on the interaction with the target nucleus.

Light charged particles and fragments produce by the breakup of the projectile were detected by the FAUST multi-detector array [3]. The angular coverage and granularity at forward angles of this device provide an excellent tool for projectile fragmentation studies. This arrangement was complemented with two silicon telescopes at intermediate and backward angles.

Projectile fragmentation events were selected by requiring a detection of a total charge of at least 12, and no more that 15. This allows for the study of events where approximately all the charge of the projectile was detected.

Figure 1 presents the charge, multiplicity of charged fragments and the isotope distribution for the reaction of 50A MeV $^{28}\text{Si}$ with the two targets. These distributions were normalized to the same number of events. In general, the target with more neutrons produces a smaller number of light charged particles ($Z=1$ and 2) and more heavier fragments like Ne of Na. Consequently, the multiplicity distribution is different. Smaller fragment multiplicities result from the interaction with the $^{124}\text{Sn}$ target. The last panel showing the isotope distribution reveals different yields of isotopes for the two targets. Especially, we can see that the number of hydrogen isotopes and $^3\text{He}$ are different. The relative numbers of $^7\text{Be}$ and $^9\text{Be}$ are also very different. These observables show that the isotopes of light charged particles and
light fragments are more neutron rich when the target is itself more neutron rich. The neutron number of the target is a thus relevant parameter in projectile fragmentation studies.

![Figure 1. Charge, multiplicity and isotope distribution for the reaction $^{38}$Si+$^{112,124}$Sn at 50A MeV.](image)

The degree of violence of the collision was measured by the sum of the pseudo-momentum along the beam direction. The pseudo-momentum is defined as the charge multiplied by the velocity. In more violent collision, more particles will be emitted transverse to the beam. This quantity was preferred to the projectile excitation energy since at this point we do not know which particles are emitted by the quasi-projectile, and which ones are promptly emitted.

Figure 2 presents the ratios of different isotopes for ten slices of forward pseudo-momentum. Each slice corresponds to approximately 500 GeV/c. Each panel on this figure shows that the fragments are more neutron rich for the neutron rich target at all level of dissipation. Even the least dissipative collisions show an enhanced yield of neutron rich fragments.

![Figure 2. Ratios of yield of isotopes plotted for different dissipation windows.](image)
Gemini calculation were performed to study the decay of $^{28}$Si and the result of the calculation are shown by the solid line on figure 2. For the purpose of the calculation and as a first approximation, all the particles were assumed to come from the decay of the projectile. The experimental excitation energy and laboratory quasi-projectile velocity distribution were extracted from the data on an event by event basis. These distributions were used as input parameters for the calculation.

The agreement with the data is better for A=3 isobars and Li isotopes. However, the predictions are not as good for heavier fragments. The ratios of $^7$Be over $^7$Be are overestimated by the calculation and the predicted ratios of $^{11}$B over $^{10}$B are much smaller than the data. For A=3 isobars, experimental data show larger ratios for dissipation bins 7 and 8 for both targets. A Gemini calculation of the decay of $^{28}$Si showed that a small admixture of neutron pickup can reproduce this increased ratios of yield of $^3$H and $^3$He. However, the ratios of $^7$Li over $^6$Li are insensitive to the mass of the projectile even though a difference is seen in the data.

These ratios show us that the interaction with the target is important and that quasi-projectile decay is not independent of the target.

The ratios simply consider the yields of fragments and not their energies. The figure 3 shows parallel velocity spectra for three breakup channels $\text{Ne} + ^4\text{He} + ^2\text{H} + ^1\text{H}$, $\text{O} + ^3\text{He}$ and $\text{O} + \text{C}$. These channels are typical and define three categories: $\alpha$-like, mixed and 2 IMF channels. $\alpha$-like channels correspond to channels containing only $\alpha$ particles and alpha-clustered nuclei. It was observed that all channels is this category have approximately the same yield for both targets. On the other hand, mixed channels, channels containing other species than $\alpha$ particles, have a larger yield for the $^{124}$Sn target. Except for protons, the velocity spectra are identical for the two targets. Proton velocity spectra show a slightly higher yield at low velocities for the $^{124}$Sn target. Notice that the H isotopes have a lower velocity compared to heavier particles.

![Fig. 3 Parallel velocity spectra of the different species composing three breakup channels, left Ne+$^4$He+$^2$H+$^1$H, middle O+$^3$He and right O+C. Data are shown in solid and dash line for $^{124}$Sn and $^{112}$Sn target respectively and dotted for the Gemini calculation for the decay of $^{28}$Si. The spectra were normalized to the same number of events per channel.](image)

Along with the data, the result of Gemini calculation for the decay of $^{28}$Si is plotted as dotted lines. For the first channel, the velocity
spectra of the residue is very well reproduced but
the calculation can only reproduce the high
velocity component of the alpha velocity spectra.
The calculation cannot reproduce the velocity
spectra of H isotopes. For the channel, O + 3
^4He, only the high velocity component of the
spectra is well reproduced for both residue and
light charged particles. In the case of a “2 IMF”
breakup channel, again only the high velocity
component of the spectra is reproduced.
Although these channels are specific, they are
typical of all the channel for each category.
From this we can thus observe a general behavior
that heavy residue velocity spectra are well
reproduce by sequential decay of the projectile,
but for light residues and light charged particles,
another mechanism must be introduce to explain
the velocity spectra. The rupture of the neck, the
overlapping nuclear matter between the projectile
and the target, could account for a substantial
part of fragments and light charged particles.

Taking into account the previous
observations on the isotope yields and these
velocity spectra, we are led to observe that a
more neutron rich target will produce more
breakup channel containing neutron rich isotopes
and channels with smaller multiplicities will be
favored. The velocity spectra of the fragments
are very similar for both target although a small
increase in proton yield at low velocity was
observed.

References:
360, and references therein.

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