Problem of narrow and wide momentum structures in ^{11}Li breakup

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It has been close to three decades that the radioactive ion beam research had posed a serious problem in the understanding of the narrow and wide Gaussian momentum distributions of ^9Li as breakup fragment from ^{11}Li projectile, on ^2H and ^{12}C targets[1–5]. The narrow width of $\sim 16MeV/c$ was however interpretted in terms of the small momentum fluctuations of the two valence neutrons forming the Halo in ^{11}Li[2, 3]. The presence of a much wider component of $\sim$60MeV/c has not been understood well even today. The transverse momentum distribution of neutrons in coincidence with ^9Li from ^{11}Li+Be at 29$MeV/nucleon$ showed a sharp momentum distribution with Gaussian width of $\sim$10MeV/c has however, been understood in terms of neutron halo of ^{11}Li[2]. It is well known that the two-neutron separation energy (S_{2n}=0.25MeV) is much smaller than the single-neutron separation energy of ^{11}Li (S_n=1.0MeV) and ^{10}Li is unbound clearly indicates that the two-neutrons are paired in ^{11}Li. In removing one-neutron one has to break the pair formed by the valence neutrons in ^{11}Li and thus supply extra 0.75MeV energy which goes as the relative energy of the n+n+^9Li as a scattering state. When two-neutrons are removed simultaneously from ^{11}Li then the same state of n+n+^9Li is produced at a lower energy. The pairing energy is thus 0.75MeV for the two valence neutrons of ^{11}Li.

In this pairing process the two neutrons of ^{11}Li are coupled to $J = 0$ with $S = 0$ and $L = 0$ and these neutrons enjoy the benefit of the short range n-n attractive pairing interaction thereby reducing the total ground state energy of ^{11}Li nucleus and producing a 3-dimensional structure of ^{11}Li. Since the valence neutrons are in ℓ=1-state hence they are mostly moving on opposite sides with respect to ^9Li (as shown in Figs.1 and 2), and when their centre of mass is faraway from ^9Li then they are closest to each other to feel the strong short range pairing interaction at P's. At the positions (P's in Fig. 1 and A and E in Fig.2) the n-n relative velocity is large hence their individual momenta are large but their momentum with respect to ^9Li is small. At this stage a single neutron removal from ^{11}Li is

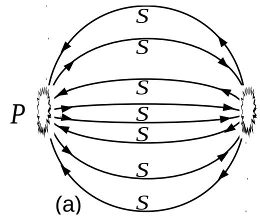

FIG. 1: 3-dimensional structure of ^{11}Li produced by the pairing of nucleons with strong short range n-n interaction at point P scattering the neutrons on to any of the shell model trajectories S.

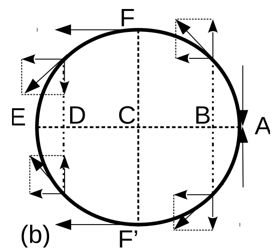

FIG. 2: Various positions of the paired valence neutrons in ^{11}Li, at point A the $c.m.$ of the two neutrons is at rest with respect to ^9Li but the relative momenta of the neutrons is largest. At this position it is difficult to remove a single neutron because of their close proximity hence the two neutron removal results in the narrow momentum component.

difficult because of the close proximity of the two-neutrons to each other. Here the small velocity of the 2-n-$c.m.$ with respect to ^9Li results in the narrow momentum component of ^9Li. When the c.m. of the two neutrons is close to ^9Li (shown by points FF' and C in Fig.2) then the n-n separation is larger than in the previous case, so that the pairing interaction is absent, but the n-^9Li relative velocity is large and the single neutron removal is easy but ^9Li momentum is large hence producing a wider momentum component of ^9Li fragment. In order to evaluate the two distributions we have taken recourse to the Brody-Moshinsky transformation to convert the two valence $p_{1/2}$-neutrons coordinates to the relative n-n coordinates $\vec{r}$ and the centre of mass the two neutrons with respect to the ^9Li nucleus coordinate $\vec{R}$. The two oscillator ℓ=1 gives one oscillator quanta each for the two $p_{1/2}$-neutrons is taken into account by the one radial quantum number N=1 which corresponds to two oscillator quanta. We then solve the Schrodinger equations for the two $\vec{r}$ and $\vec{R}$ motions. In this we insert the strong short range pairing n-n interaction of the Argonne $v18$ [6] type along with a long range interaction of shell model type. The wave function is generated for the pairing interaction energy of $0.75 MeV$. The strength of the long range shell model interaction is varied to fit the binding energy of $0.75 MeV$.

In this communication we present our calculations indicating that the two Gaussian distributions arise from the pairing superimposing the shell model space. As the 2-n removal gives rise to the narrow momentum distribution of the ^9Li fragment. The results presented in Fig. 3 are a natural consequence of the pairing interaction between the valence neutrons of ^{11}Li. Similarly as discussed above the single neutron removal fragmentation will result in the wider momentum distribution of $\sim 87 MeV/c$ shown in Fig3. In our case the results contain no uncertainties about the reaction mechanism because it is just the momentum distribution obtained from the bare single

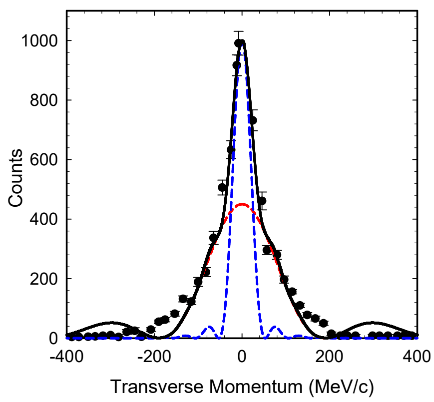

FIG. 3: The momentum distributions obtained from the two-neutron temoval and single neutron removal obtained with the pairing interaction included(in the form of $Argonne-v14$ interaction).

and the two-neutron wave functions which is the basic ingredient at large energies. It is seen that the $P_{||}$-components observed in the ^{24}O $\rightarrow$ ^{23}O in the one neutron removal reaction[7] process also should contain such wide momentum components arising due to pairing.

To conclude the pairing interaction has its appearence in the nuclear reactions involving shell closure nucleons and where high momentum components show up in the reaction dynamics.

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