The following Green function is obtained by solving equation (30)

$$G(r,r') = \frac{2\mu_{\Lambda^* p}}{\hbar^2} \sum_{\ell=0}^{\infty} \sum_{M} Y_{\ell M}(\hat{r}) \frac{u^0_{\ell(r<)}\, u^+_{\ell(r>)}}{r r' \, W(u^0_\ell u^+_\ell)} Y^*_{\ell M}(\hat{r}') \tag{31}$$

We substituted the values of $G(r,r'), f^*(r)$ and $f(r')$ into equation (28).

Finally, we obtained the production differential cross section of $\Lambda^* p$ as

$$\frac{d^6\sigma}{dE_1 d^2\Omega_1 dE_3 d^2\Omega_3} = \left(\frac{2\pi}{\hbar c}\right)^4 |\bar{v}_0|^2 \frac{k_1 k_3 E_0 E_3}{2k_0} \left|\langle -k_3|\Phi_i\rangle\right|^2$$
$$\left(-\frac{1}{\pi}\right) \mathrm{Im}\left[\iint \frac{2\mu_{\Lambda^* p}}{\hbar^2} 4\pi(2\ell+1)\, e^{\frac{r}{\beta}} e^{-\frac{r'}{\beta}}\, j_\ell(Qr) j_\ell(Qr') \frac{u^0_\ell(r_<) u^+_\ell(r_>)}{W(u^0_\ell, u^+_\ell)}\, dr dr'\right] \tag{32}$$

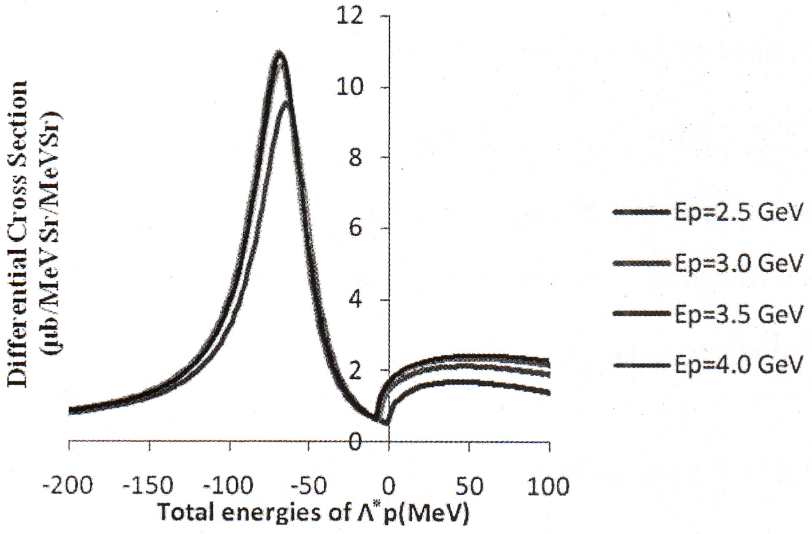
We solved above equation numerically by using forton code to get differential cross section and binding energy of $ppK^-$ . Before determine the differential cross section, firstly we solved $u_\ell(r)$'s by difference method. We do necessary calculation to determine reaction differential cross section. The results are discussed in the following section.

## III. Results and Discussion

### A. Energy Dependence of $p(d, K^0p)ppK^-$ Reaction Differential Cross Section

We calculated the differential cross sections of $p(d, K^0p)ppK^-$ reaction by solving the equation (32). In this equation, input parameters are the incident energy $E_0$, outgoing kaon energy $E_1$ and spectator proton energy $E_3$. First, we calculated the threshold energy of the reaction to know the minimum incident energy value to be input to our program. The threshold energy above reaction is $E_{th}$= 1.7 GeV.

Then we give various incident energies of proton from 2.0 GeV to 6.0 GeV with 0.5 GeV interval. For a particular value of the projectile proton incident energy, there are many possible ways of sharing the energy among the outgoing kaon, spectator proton $P_s$ and $\Lambda^*p$ system. Thus we calculated the maximum energy of outgoing kaon for each incident energy $E_0$ at a particular spectator proton momentum $P_s$. Then we change various kaon energy $E_1$ starting from the maximum value and then uniformly decreasing 5 MeV at a time. The energy of spectator proton $E_3$ is fixed at a specified value. For each pair of $E_0$ and $P_s$ , we obtained differential cross sections corresponding to various $E_1$. The energy of $\Lambda^*p$ is obtained from the values of $E_0$, $P_s$ and $E_1$. The results are shown in the following figure. It shows that the peak is the largest at incident kinetic energy 3.5 GeV . The differential cross section is 10.95 μb/(MeV Sr)/(MeV Sr) and the full width at half maximum is 41 MeV which is the level width of $ppK^-$ bound state. The width arises from $ppK^-$ decaying to $p\Sigma\pi$. Then we calculated the maximum differential cross section values corresponding the incident kinetic energies for each spectator momentum. The figure shows that differential cross section at peak position is highest at incident kinetic energy 3.5 GeV.




Figure(2) The spectral shapes of $\Lambda^*p$ for incident energy 2.5,3.0,3.5 and 4.0 GeV

### B. $\Lambda^*p$ ($ppK^-$) Size Effect on Differential Cross Section

We investigated $\Lambda^*p(ppK^-)$ size effect on differential cross section by changing the rms distance of $\Lambda^*$-p. In order to carry out this analysis, we determined parameters of $\Lambda^*p$ potential which gives the binding energy value 64 MeV. To do so, we consider $ppK^-$ as a two-body system which is composed of $\Lambda^*$ and proton. We solved the two-body Schrodinger equation by using Gaussian wave function to find the potential strengths and range parameters which gives the binding energy 64 MeV. For different pairs of potential strength and range parameter we calculated the binding energy and root mean square distance of $\Lambda^*p$ system. We select the potential strength which gives the binding energy of $\Lambda^*p$ system as 64 MeV. It is shown in table (1).

| $\Lambda^*p$ Potential Strength (MeV) | $\Lambda^*p$ Energy (MeV) | Range Parameter (fm) | Root Mean Square Distance (fm) | Differential Cross Section (μb/MeV Sr/MeV Sr) |
|---|---|---|---|---|
| (-714.50, -59.00) | -63.9719 | 0.50 | 0.80 | 40.5401 |
| (-413.30, -35.33) | -63.9719 | 0.75 | 0.93 | 25.1493 |
| **(-295.00, -42.00)** | **-63.9719** | **1.00** | **1.05** | 10.9592 |
| (-155.00, -20.00) | -63.9719 | 2.00 | 1.46 | 5.099 |
| (-119.00, -25.00) | -63.9719 | 3.00 | 1.79 | 2.1602 |
| (-93.08, -20.72) | -63.9719 | 5.00 | 2.33 | 1.2843 |

Table(1) Various potential strengths and range parameters corresponding to various sizes and differential cross sections.

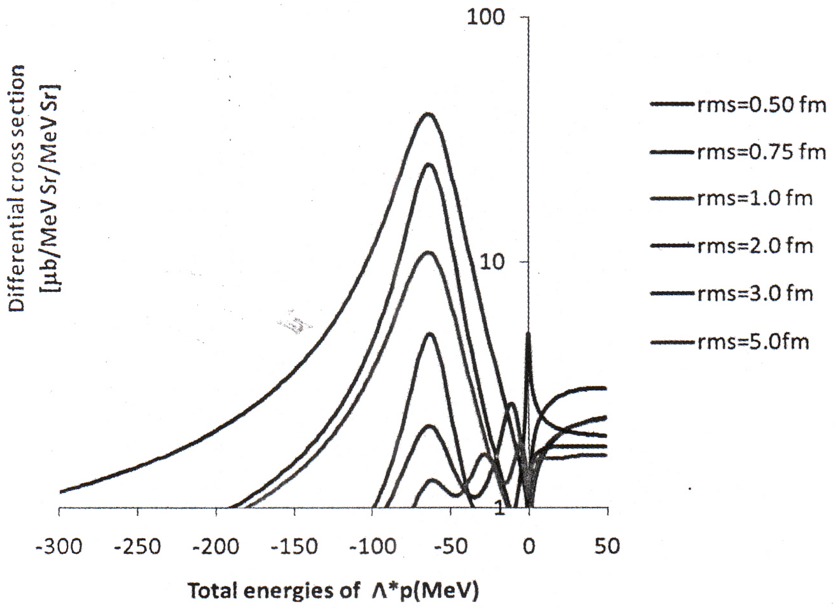



Figure (3) Differential cross sections for various incident kinetic energies.

The figure (3) shows that the bound-state peak decreases dramatically, we increase the rms size $R(\Lambda^*p)$ from 1.05 fm (the predicted size of the dense $ppK^-$) to 1.46 and 2.33 fm. It also shows that with a denser system ($R(\Lambda^*p)$ = 0.93 and 0.80 fm) the peak height increases. So, the dominant sticking of $\Lambda^*p$ is the result of the dense $\bar{K}$ system to be formed.

## C. Momentum Transfer to $\Lambda^*p$ Relative Motion

Momentum transfer to $\Lambda^*p$ relative motion is the difference between the relative momentum of incident proton and the neutron in the target deuteron and that of outgoing kaon and centre of mass of $\Lambda^*$ and p. We want to investigate momentum transfer to $\Lambda^*p$ relative motion corresponding each maximum differential cross section, incident kinetic energy and spectator proton momentum.

Table (2) shows the values of momentum transfer with respect to various incident energies and spectator proton momenta. Although the spectator proton momentum changes, the momentum transfer to $\Lambda^*p$ relative motion does not change for each incident energy. Since the momentum transfer is large in this reaction, the process is realized only with a strongly attractive and short range nucleon-nucleon interaction. Such an interaction occurs through exchange of a heavy meson. But only $\rho^+$ meson can be exchanged between p-n since it obeys all the conservation laws for strong interaction.

| $KE_p$ (GeV) | $P_s$=10 (MeV/c) | $P_s$=100 (MeV/c) | $P_s$=200 (MeV/c) | $P_s$=300 (MeV/c) | $P_s$=400 (MeV/c) | $P_s$=500 (MeV/c) |
|---|---|---|---|---|---|---|
| 2.5 | 1.41 | 1.376 | 1.37 | 1.387 | 1.418 | 1.46 |
| 3 | 1.48 | 1.459 | 1.46 | 1.476 | 1.507 | 1.54 |
| 3.5 | 1.57 | 1.55 | 1.55 | 1.57 | 1.6 | 1.64 |
| 4 | 1.66 | 1.64 | 1.64 | 1.66 | 1.69 | 1.73 |
| 4.5 | 1.75 | 1.727 | 1.73 | 1.747 | 1.78 | 1.82 |
| 5 | 1.84 | 1.817 | 1.82 | 1.836 | 1.87 | 1.91 |

Table (2) Momentum transfer to $\Lambda^*p$ relative motion (GeV/c).

## IV. Conclusion

We investigated the differential cross sections for various incident energies and spectator proton momenta for p(d, $K^0$p)pp$K^-$ reaction. We have calculated differential cross section for different pairs of incident kinetic energy and spectator proton momentum. From our calculations, it is found that the differential cross section is the largest for each spectator proton momentum. The differential cross section of the peak position is maximum at $KE_p$= 4.0 GeV and $P_s$= 10 MeV/c. It is 6200 μb/(MeV Sr)/(MeV Sr). But we choose the differential cross section (10.95 μb/MeV Sr/MeV Sr ) at $P_s$ = 200 MeV/c and $KE_p$= 3.5 GeV because $P_s$ = 200 MeV/c is comparable to outgoing kaon momentum. These informations are very important for the experimentalists.

We also want to investigate the $\Lambda^*p$ size effect on the reaction process. To do so, we change the potential parameters of $V_{\Lambda^*p}$ which produces the same binding energy 64 MeV but different root mean square distance. The rms of $\Lambda^*p$ is 0.8 fm which gives the differential cross section 55.88 μb/MeV Sr/MeV Sr. The rms of $\Lambda^*p$ 2.33 fm gives the differential cross section 1.29 μb/MeV Sr/MeV Sr . Therefore, we found that the smaller the size of $\Lambda^*p$ , the larger the differential cross section is.

Momentum transferred to $\Lambda^*p$ relative motion in p(d,$K^0$p)pp$K^-$ reaction is found to be very large which is 1.6 GeV/c. When we consider the elementary process, final particles p, $K^0$, $K^-$ are transferred from incident proton. This process is highly off energy-shell with 1 GeV energy difference between initial and final states. It is physically realized with a large momentum transferred to the target neutron. Thus the interaction between proton and neutron must be short range and it can occur only through the exchange of heavy meson.

This work concerns the hot subject in frontiers of " hadron physics in nuclear medium", that is the possible existence of kaonic nuclei. The pp$K^-$ is the most basic kaonic nucleus. Presently, the quest for pp$K^-$ is pursued at major facilities like DAΦNE/Italy, GSI/Germany and J-PARC/Japan. We calculated theoretically the differential cross sections of the reaction at various incident-proton energies ranging 2.5-6.0 GeV and spectator proton momentum 10, 100-500 MeV/c, which is a significant contribution to actual design of experiment.

However, experimentally it is more feasible if spectator momentum $P_s$ is comparable to $P_l$ which is outgoing kaon momentum. Thus we would like to suggest that this reaction should be carried out with incident kinetic energy 3.5 GeV and spectator proton momentum 200 MeV/c.

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