Studying Hadronic Reactions

K_L Beam Production of Ξ^- Hyperons on a Deuterium Target at K_LF

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https://github.com/mayajovanovic/bscproject

Introduction

Hyperons are highly unstable baryons containing one or more strange quarks, and are hypothesised to exist in a stable form in extremely gravitationally massive and dense environments - such as the core of a neutron star [1]. There is a strong incentive to study hyperon-nucleon behaviour due to a strange occurrence dubbed as the "hyperon puzzle" (see Figure 1).

This experiment has a long term end goal of recording never-before seen data, thus furthering our understanding of these fundamental interaction events. The short term goal is determining whether the experiment itself is feasible to do at the Thomas Jefferson labs (JLab) in Virginia.

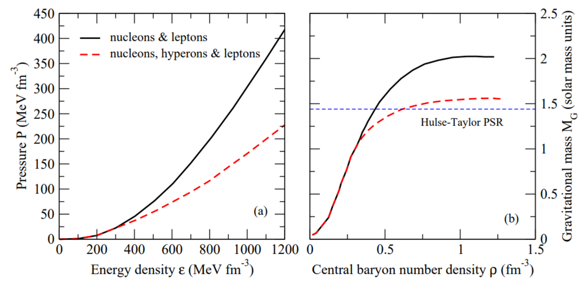


Figure 1: Hyperonic effect on the Equation of State and neutron star measured mass. Red dashed line means no hyperons present. Figure is from Ref [2].

The aim of this project is to simulate the scattering events that would occur when a neutral Kaon-long beam, K_L, hits a liquid deuterium target, producing a positively charged K^+, and a negatively charged Ξ^- hyperon. The Ξ^- would then scatter elastically with protons in the deuterium target. Finally, Ξ^- decays into $\Lambda^0 + \pi^-$, and Λ^0 decays to $\pi^- + p$.

Method

The project simulation is essentially done by using the Monte-Carlo (MC) method. MC methods can be especially useful for analysing particle scattering, due to the number of coupled degrees of freedom that need to be accounted for. ROOT is where the random sampling functions are utilised, using its selection of vast class libraries [3]. The three key elements of the fundamental mathematics of the interaction are the production cross section, the luminosity, and the length of the particle's trajectory. These need to be computed prior to any interaction event simulation occurring. The calculations are fundamental to the behaviour of the travelling hyperon.

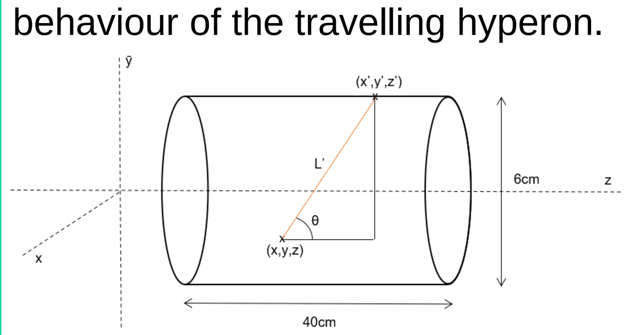


Figure 2: The target as seen from the (ỹ,z) plane.

The path length in the target is calculated component wise.

These two components are then joined together to calculate a three-dimensional representation of the path length. This is then programmed into the macro. The cross section and luminosity of the beam and interaction/production events allow for the calculation of the particle flux for each "vertex", where a vertex represents each step of the total $K_L + n \rightarrow K^+\Xi^-$ interaction.

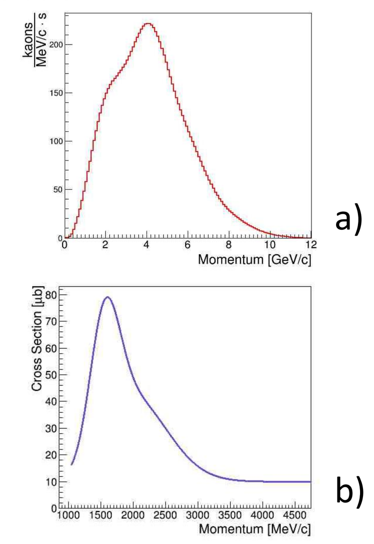
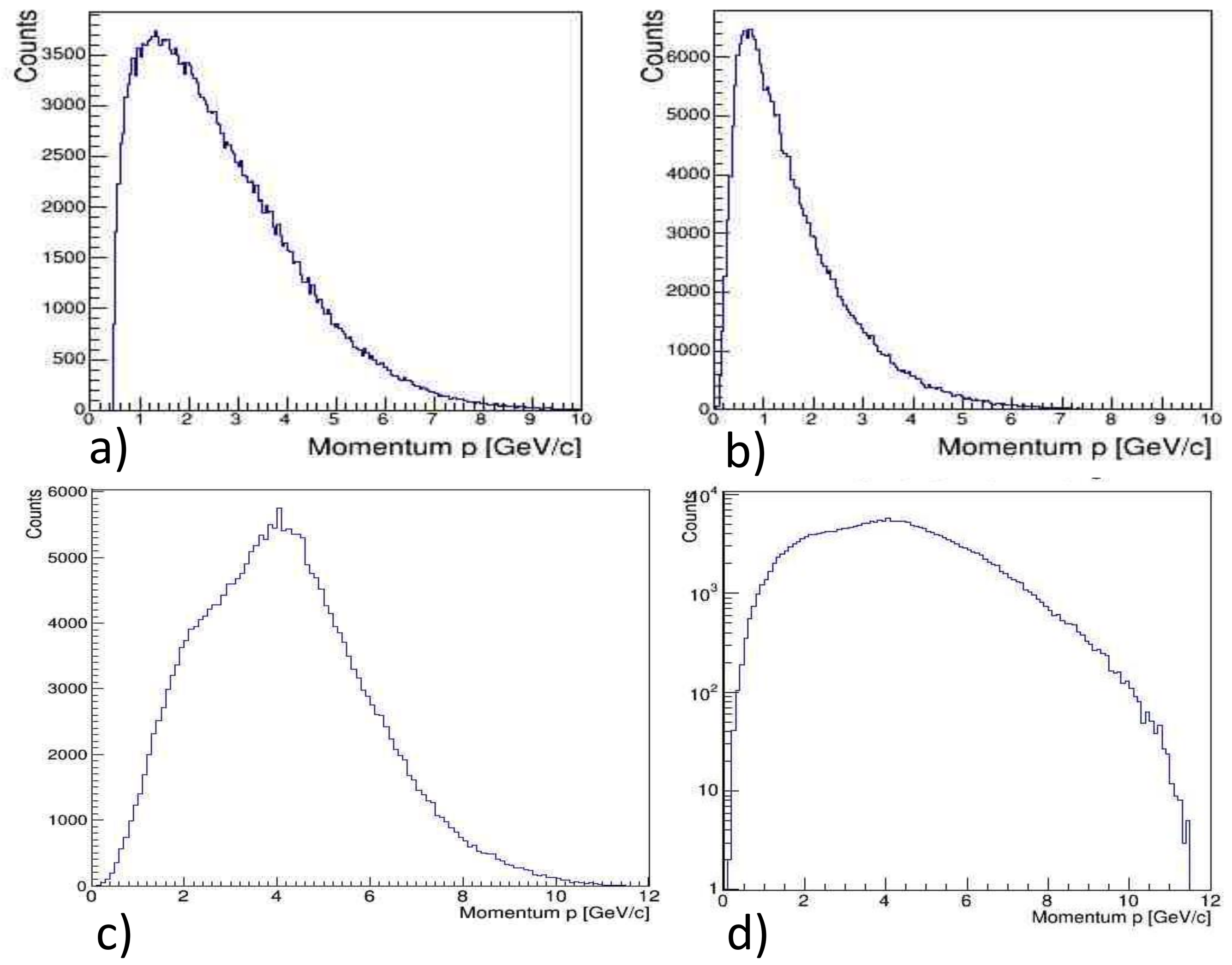
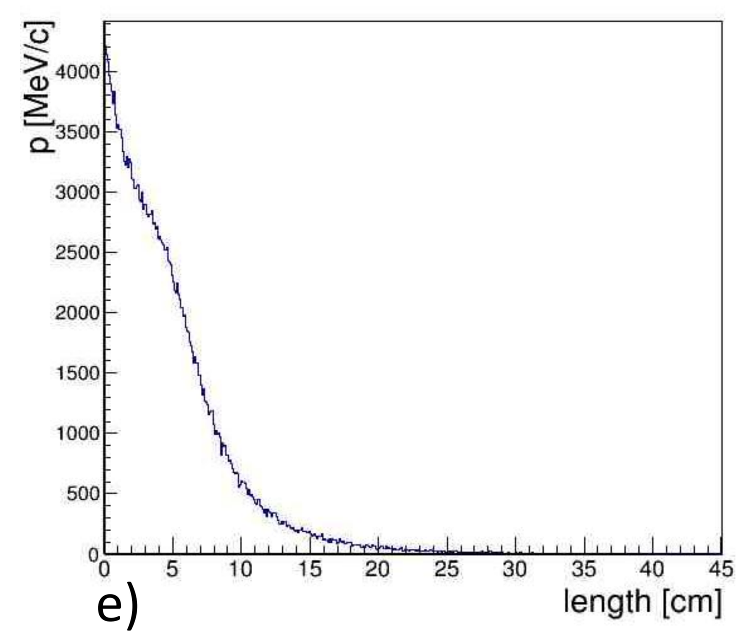


Figure 3: a) The K_L beam flux. b) The cross section for $K_L + p \rightarrow K^+\Xi^0$.





Momentum histograms of the first vertex interaction.

a) Momentum of produced Ξ^-
b) Momentum of rescattered Ξ^-
c) Momentum distribution of the K_L beam
d) Logarithmic plot of c)
e) Momentum distribution of the path length at which Ξ^- decays

Results

The simulation is run for 250,000 events in order to obtain more accurate results. For each vertex event simulated, an interaction phase space was generated. These vertices require their own phase spaces due to the momentum and mass four-vectors differing in each vertex.

The first vertex is the hyperon production. The momentum of the produced particle and the K_L beam is observed. This is shown in plots a)-d). When the hyperon is produced, it scatters off a proton and travels some length in the target. This is the second vertex. The angles of the production vertex are shown in plots f)-i). From here, the path length is determined. The path length is affected by the decay of Ξ^- - see plots j)-k). Plot e) is the momentum distribution of the path length. It follows the exponential decay of Ξ^-, shown in Figure 4.

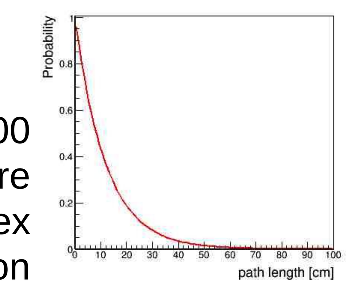
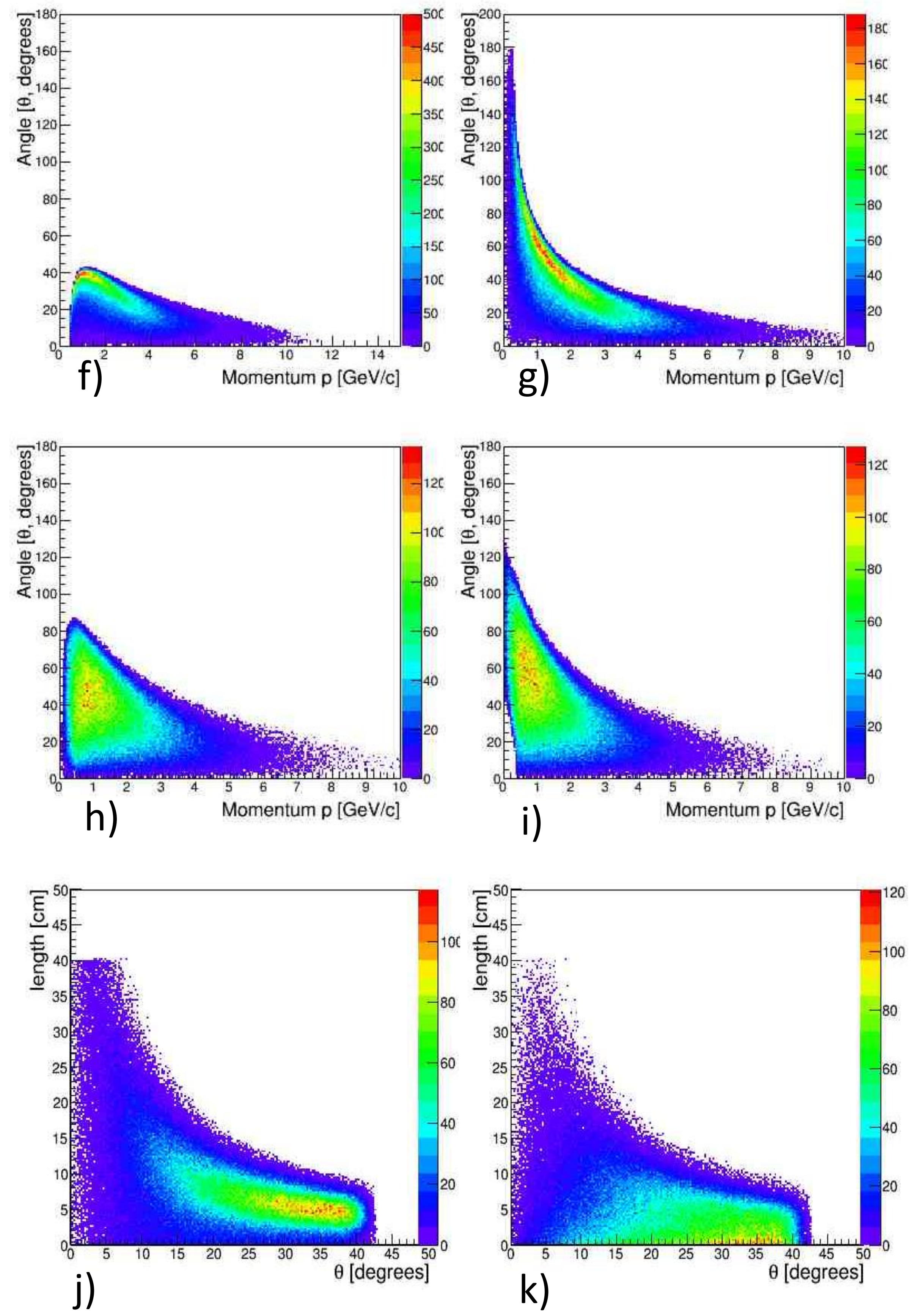
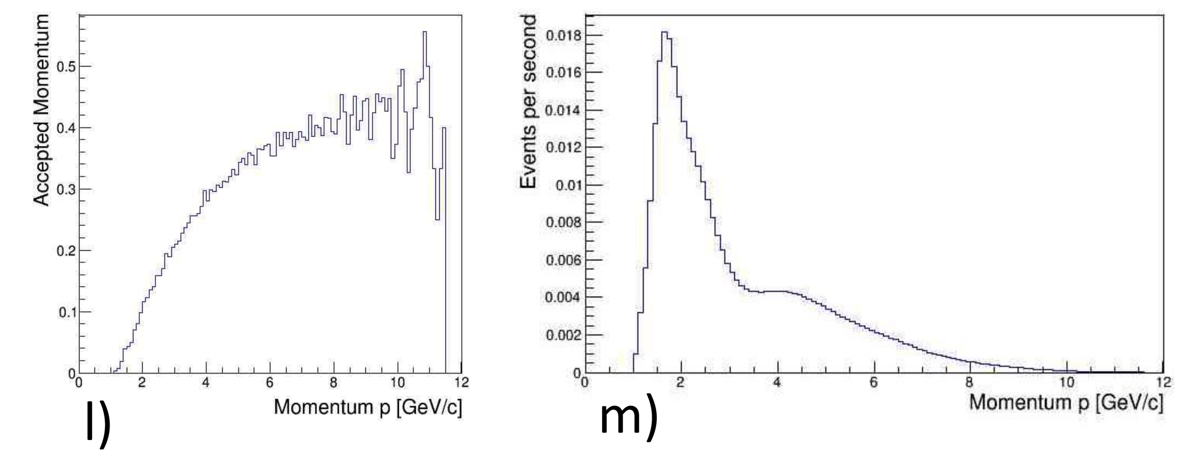


Figure 4: The exponential decay of Ξ^-.

The third vertex is the decay, which is only relevant in order to calculate the interaction acceptance to determine feasibility. The beam momentum acceptance is also calculated, shown in plot l).

Finally, the true feasibility is drawn from the number of particles produced, scattered and detected. Figures 3a) and 3b) are multiplied together to get roughly **3 million production events**. The $K_L + p \rightarrow K^+\Xi^0$ cross section data to find the scattered/detected value has to be used in place of the $K_L + n \rightarrow K^+\Xi^-$ data, because there is limited knowledge of kaon interactions on a neutron target. Plot l) is then multiplied with plot m) in order to obtain plot n), which produces **692 detected scattering events** out of **3718** calculated to occur.





l) The acceptance histogram of the KL beam momentum.
m) The flux of the beam plotted with respect to the momentum of the particles.

Plots f)-i): The angular dependence plots of the first vertex.
f) Initially produced Ξ^-,
g) Initially produced K+,
h) Rescattered Ξ^-,
i) Rescattered proton.
Plots j) and k): The histograms pertaining to the path length of the travelling hyperon.
j) Path length of Ξ^- trajectory in the target.
k) Path length of Ξ^-, accounting for its decay process.

Conclusion

Ultimately, the end goal was to determine whether this experiment is feasible to do at JLab. Due to the minimal knowledge of $K_L + n$ interactions, running this high cost experiment without simulating it first would be unwise. The simulation did return some satisfactory results – 692 detected events out of 3718 is a roughly 19% detection rate. This is a higher statistic than what is currently available for this interaction, which is roughly 3 events. The uncertainty of the detection is merely 1%, which decreases as the simulation is run multiple times consecutively.

After analysis of the produced data and the number of events being calculated to a workable amount, it can be determined that this experiment is feasible to complete. It would be an excellent opportunity to gather valuable research on hyperon-nucleon interactions which we know so little about. The measurements will lead to data that provides roughly 40 times the available statistics on hyperonic photoproduction [4]. Doing so would enable more constructive work to commence on solving the hyperon puzzle. This experiment will lead to a new insight into the accuracy of quantum chromodynamics of hyperons, as well enabling precise partial-wave analysis of resonances in the spectra of a variety of hyperons [5].

References

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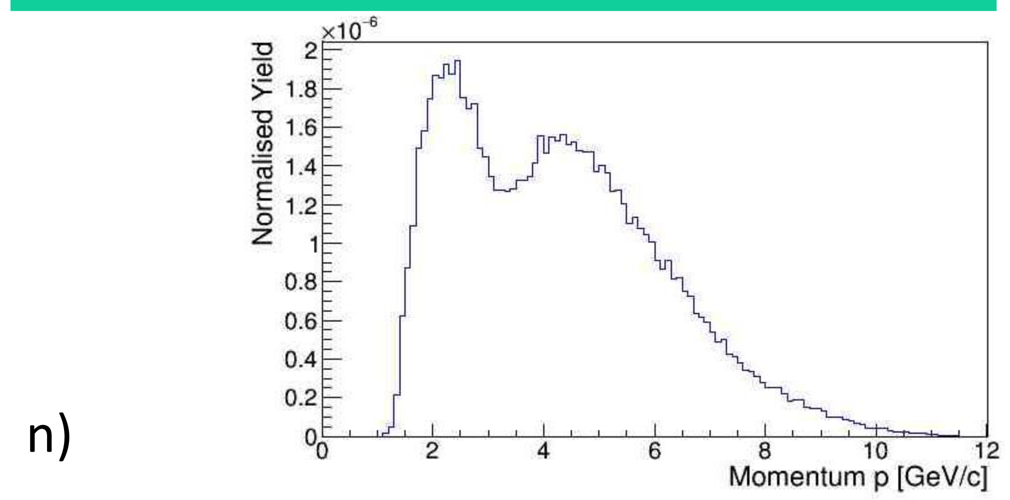

The beam flux is multiplied with the beam momentum acceptance to produce this plot. The integration of this histogram yields the number of scattered particles that are detected.