JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE START PROGRAMME

A Monte Carlo Study of Hypertriton Production with the BM@N Experiment at NICA

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1 Abstract

Study of the strangeness production in the heavy ion collision is one of the most important tasks of the BM@N experiment at NICA. It can provide valuable information about the mechanism of birth of strange particles and properties of hyperonic interactions. Such information may be important in many areas of physics. In the present work the Monte Carlo study of hypertriton H_{Λ}^{3} production in the BM@N experiment with Xe beam on CsI target at 3.9 GeV energy was performed. Important numerical characteristics were obtained, such as the efficiency of hypernuclei reconstruction and the efficiency of He^{3} matching with the time-of-flight system TOF.

2 Introduction

NICA (Nuclotron-based Ion Collider fAcility) - is a new accelerator complex designed by the Joint Institute for Nuclear Research and located in Dubna, Russia. One of the main purposes of NICA is to provide favorable conditions to study properties of dense baryonic matter. BM@N (Baryonic Matter at Nuclotron) experiment is the important experiment performed at NICA. One of its tasks is to study the strangeness production in the heavy ion collision. This investigation may provide valuable information about the properties of hyperonic interaction, which in turn may be useful in different areas of physics, for instance in neutron stars study. Such experiment (as many others) requires the numerical simulation of its performance to be extensively carried out. In the present work the Monte Carlo study of hypernuclei production at the BM@N experiment was performed using the BmnRoot software framework.

3 Simulation procedure

The work consists of Monte Carlo simulation and the following reconstruction of hypernuclei, namely the H_{Λ}^{3} nuclei. For numerical modeling of the experiment the BmnRoot software framework of the BM@N experiment was used.

3.1 Hypernuclei production

First of all, the Monte Carlo simulation was performed using the DCMSMM generator performing the simulation of the experiment with Xe beam on CsI target at 3.9 GeV energy. However the birth of the H_{Λ}^{3} nucleus is rather rare event, only 224 hypernuclei are produced per 50000 events. Therefore, to generate a reasonable amount of hypernuclei, some enrichment procedure is required. This can be done by using a "hypernuclei generator", generating additional amount of hypernuclei with the same phase space distribution as the ones from the original generator [1]. For this study, one additional H_Λ^3 per 10 events on average was produced. Particles are generated with a given distribution of the transverse momentum p_t fitted by the function

$$dn/dp_t \sim p_t e^{(-m_t/T)} \tag{1}$$

and the rapidity y fitted by the Gaussian function. Therefore parameters required for this generator to work are σ and the mean value for Gaussian and T for function (1). These parameters were obtained by building histograms for p_t and y with the hypernuclear data from the original generator and fitting them with corresponding functions. Obtained distributions are presented in fig. 1.

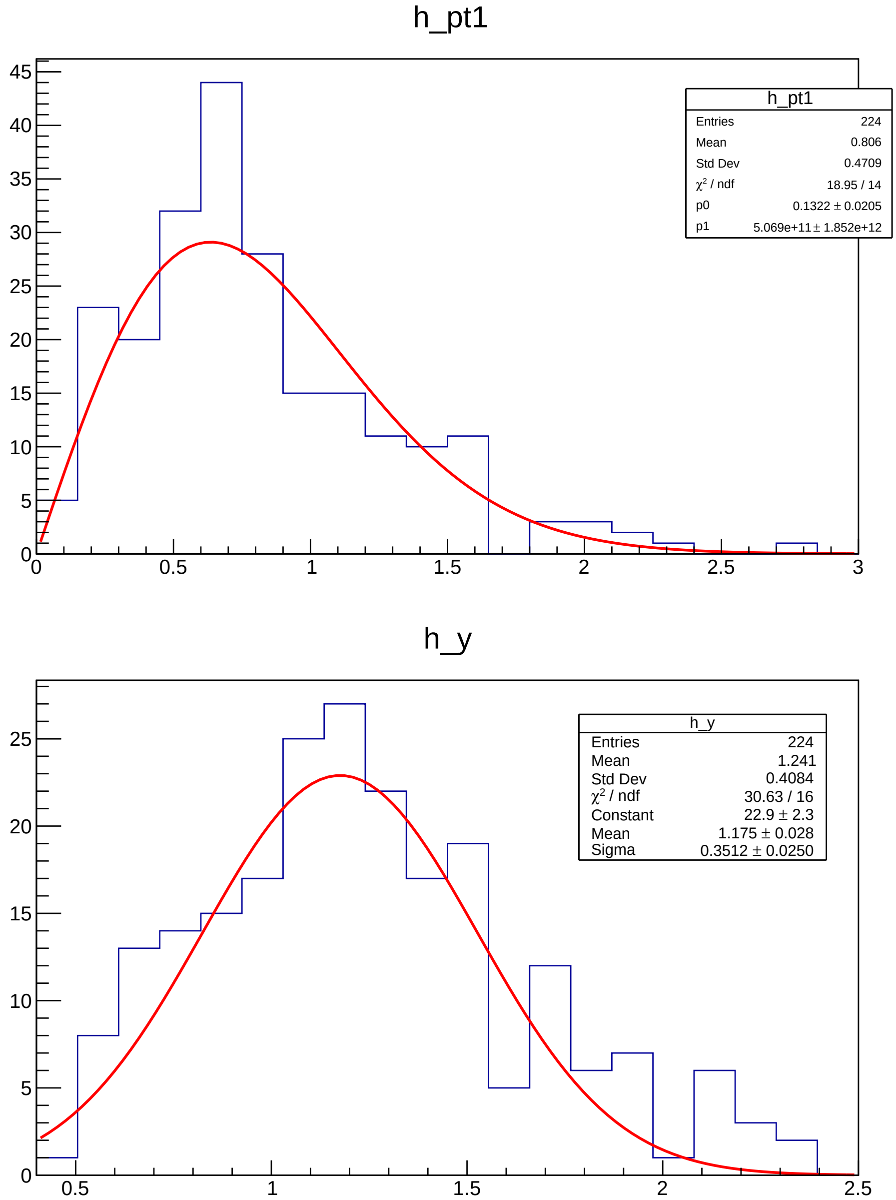

Figure 1: Distributions of transverse momentum and rapidity for H_Λ^3 fitted with function (1) and Gaussian, respectively

As a result of this step, Monte Carlo simulation for 50000 events in total and

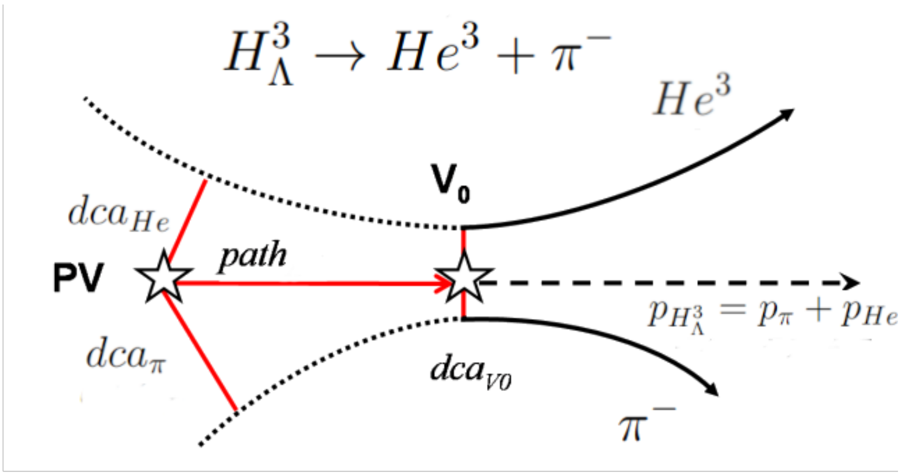

Figure 2: Scheme of hypertriton decay topology in the bending plane of the magnetic field. Here, dca_{He} , and dca_π are the distances of the closest approach (DCA) of the decay tracks to the primary vertex **PV**; dca_{V0} is the distance between daughter tracks in the mother decay vertex **V0** ; path is the mother particle decay length; and $p_{H^3_\Lambda}$, p_{He} and p_π are momenta of particles.

5 different generator files was performed providing needed data for hypernuclei reconstruction.

3.2 H^3_Λ reconstruction

Hypernuclei are identified via their weak decays to charged particles in the final state. In the case of H^3_Λ these particles are He^3 and π^-. The decay topology of H^3_Λ in the bending plane of the magnetic field schematically shown in the fig. 2 [2].

Such topology is selected by making use of the secondary vertex reconstruction method, which is based on finding secondary vertices separated from the primary one. The selection is checked by applying different selection criteria on the relevant kinematic and topological variables. First two criteria restrict the distance of closest approach of the decay tracks to the primary vertex (dca_{He}, dca_π). It should be greater than some value, which helps to suppress the combinatorial background. At the same time the distance of closest approach between the daughter track candidates ((dca_{V0}) should be less than some value in order to ensure that the tracks originate from the same mother particle. Next cut is the requirement for the secondary vertex position to be located farther than some distance (*path*) from the the primary vertex in order to ensure that decay correspond to the long-lived particle. Finally the angle between decayed particle momentum and the direction vector from the primary to the secondary vertex should be smaller than some value to ensure that the topology is correct.

After applying all this cuts it is possible to distinguish peaks in the invariant mass distributions at the right particle mass values, which serve as a clear signature of the right particle decay under study. Searching for right cuts can by done manually, however it is much more convenient to obtain exact cuts by performing a multidimensional scan over the whole set of selection criteria with a requirement to maximize the invariant mass peak significance. Significance is defined as $S/\sqrt{S+B}$, where S is the total number of signal and B - is the total number of background combinations.

4 Results

Using the scan described in previous section the set of cuts for H^3_Λ reconstruction was found. Obtained cuts are presented in the table 1. Figure 3 shows the invariant mass spectrum with these cuts applied. Maximal significance calculated during scan equals to **12.63**.

Table 1: Selection criteria used for H^3_Λ reconstruction. Cuts on DCAs are imposed in the χ^2-space, i.e., after normalization to respective parameter errors.

Cut	Value
DCA of π to primary vertex	> 1.4
DCA of He^3 to primary vertex	> 0.1
DCA between daughters	< 5.0
Decay length, cm	> 3.7
Mother pointing angle, rad	< 0.33

Table 2: Parameters written in hFlag. First column of values contains results obtained before the matching with TOF was applied, second contains the ones with TOF matching.

Bin	Parameter	Value	
		Without TOF	With TOF
0	Total number of hypernuclei	5079	5079
1	Number of decays	4528	4528
2	Reconstructible mothers	1679	1679
5	Reconstructed mothers	1611	889

Another result, which may be important in the future is calculation of the efficiency of H^3_Λ reconstruction and the effectiveness of TOF matching. During the analysis of hypernuclei reconstruction the matching of He^3 with TOF (time

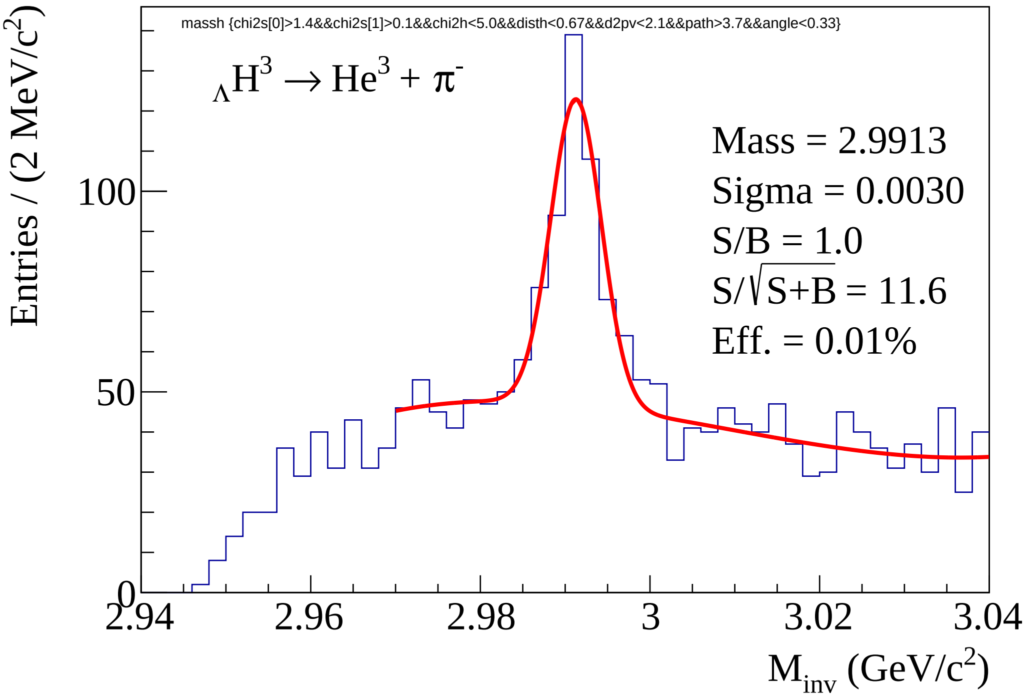

Figure 3: Reconstructed invariant mass spectrum of H^3_Λ decay products. Cuts from the table 1 are applied.

of flight detector) was applied meaning that only tracks with at least one TOF hit were accepted. The data about TOF hits was taken from Global Tracks.

Figure 4 represents the histograms with parameters describing the hypernuclei reconstruction for two cases: without TOF matching applied and with TOF matching. Important parameters represented in this histogram are following: the total number of hypernuclei, the number of decayed particles, the number of reconstructible mother nuclei (calculated using the loop over decay products) and the number of reconstructed hypernuclei with He^3 identified using internal Monte Carlo identification process. Other parameters (bins 3 and 4 in fig. 4) are irrelevant for this study. Table 2 represents numerical values for described parameters. Using this data some important characteristics of the reconstruction process can be calculated. First, the efficiency of H^3_Λ reconstruction equals to the ratio of the number of reconstructed hypernuclei to the number of reconstructible hypernuclei (both in case without TOF matching applied) and equals to **0.959**. Another important characteristic is the efficiency of TOF matching which can be calculated as the ratio of number of identified tracks with TOF matching to the number of identified tracks without TOF matching. In this work it equals to **0.552**.

5 Conclusion

In the present work the full cycle of hypernuclei simulation and reconstruction in the BM@N experiment simulation was successfully performed. Characteristics,

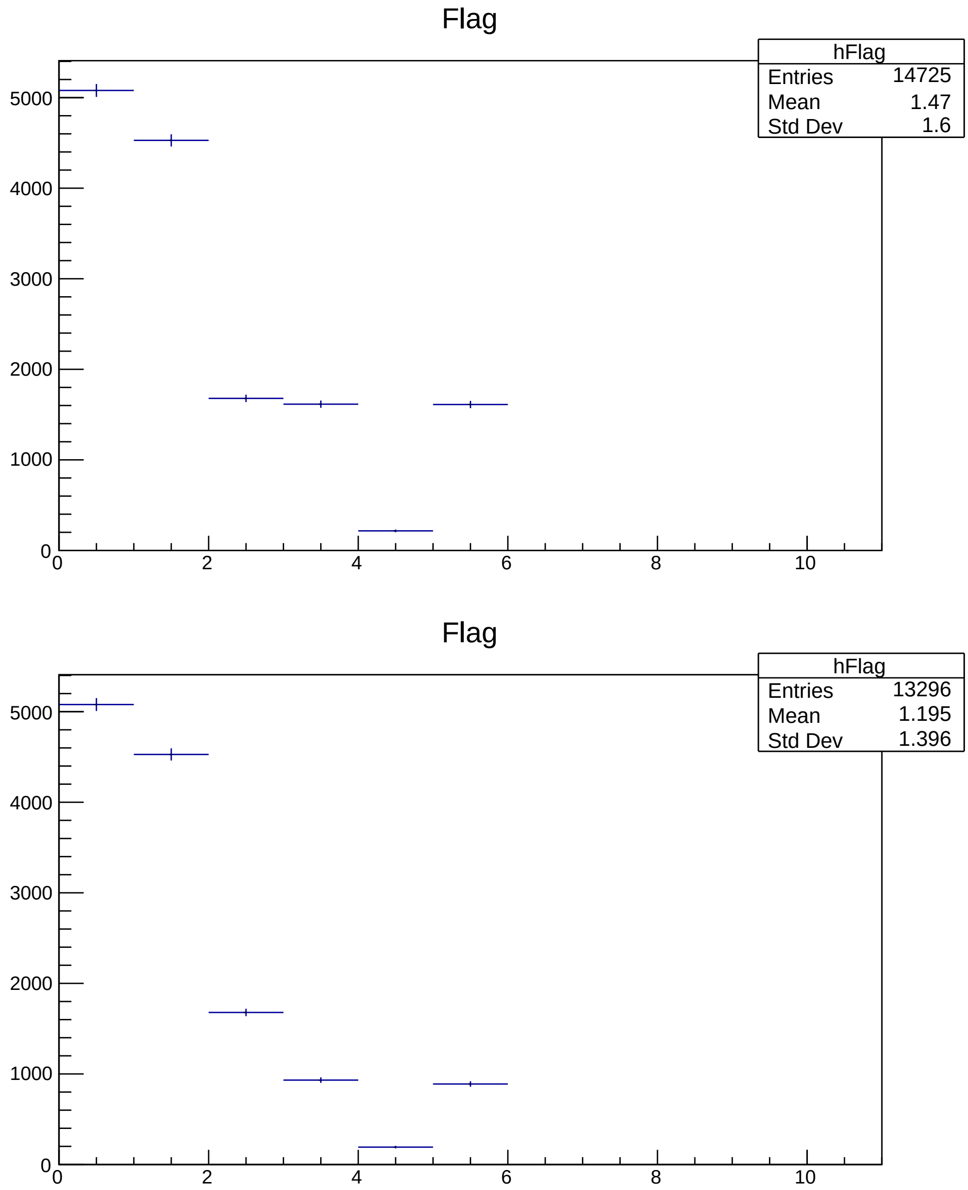

Figure 4: Histogram of parameters describing hypernuclei reconstruction for two cases: without TOF matching of He^3 (up) and with TOF matching (down)

which can be important for future investigations were obtained: the efficiency of H_Λ^3 reconstruction equals to **0.959**, the efficiency of matching of He^3 with TOF equals to **0.552**.

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References

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