LIGHT HYPERNUCLEI PRODUCTION IN Pb–Pb COLLISIONS AT $\sqrt{s_{NN}} = 2.76$ TeV WITH ALICE AT LHC*

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Relativistic heavy-ion collisions offer a method to produce strangeness, hyperons, and also hyperon–baryon bound systems called hypernuclei. Thanks to its excellent performance for the reconstruction and identification of low $p_{\rm t}$ particles and light ions, the ALICE detector is ideally suited for this kind of measurements. In this paper, preliminary results of hypertriton production in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV will be reported using the data sample collected by the ALICE experiment during the first LHC heavy-ion run at the end of 2010. The ${}^{3}_{\Lambda}\mathrm{H}$ (${}^{3}_{\Lambda}\overline{\mathrm{H}}$) signal is extracted from the study of its mesonic decay ${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}({}^{3}_{\Lambda}\overline{\mathrm{H}} \rightarrow {}^{3}\overline{\mathrm{He}} + \pi^{+})$. Different background evaluation methods will be discussed.

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1. Introduction

A hypernucleus is a nucleus which contains at least one hyperon, namely a baryon containing one or more strange quarks, in addition to nucleons. Hypernuclear physics was born in 1952 when the Polish scientists Danysz and Pniewski observed the first hypernuclear decay event in a photographic emulsion exposed to cosmic rays at around 26 km above the ground [1]. Hypernuclei can be produced both at low energy and in high-energy heavy-ion collisions. At low energy, hypernuclei can be produced by collision of hadrons or photons with a nucleus. Since strangeness has to be conserved, three processes can be used: processes with strangeness exchange, processes with associated production of strange hadrons, or reactions in which exchange

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and associated production of strangeness are combined [2]. In heavy-ion collisions hypernuclei can be produced mostly by coalescence. The coalescence model describes the hypernucleus production cross section in terms of the product of the hyperon and nucleus inclusive cross section at the same rapidity [3].

Relativistic heavy-ion collisions offer a unique opportunity for hypernuclear studies, in fact it is possible to produce at the same time and with equal abundance matter and anti-matter [4, 5], therefore hypernuclei and their associated anti-hypernuclei.

The hypertriton ${}^{3}_{\Lambda}\mathrm{H}$ is the lightest known hypernucleus and is formed by a proton, a neutron and a Λ. ${}^{3}_{\Lambda}\mathrm{H}$ decays mesonically into the following channels [6]:

$$ {}^{3}_{\Lambda}\mathrm{H} \rightarrow \pi^{-}\left(\pi^{0}\right) + {}^{3}\mathrm{He}\left({}^{3}\mathrm{H}\right) , \tag{1} $$

$$ {}^{3}_{\Lambda}\mathrm{H} \rightarrow \pi^{-}\left(\pi^{0}\right) + d + p(n) , \tag{2} $$

$$ {}^{3}_{\Lambda}\mathrm{H} \rightarrow \pi^{-}\left(\pi^{0}\right) + p + n + p(n) . \tag{3} $$

The study of the production of ${}^{3}_{\Lambda}\mathrm{H}$ detected via its decay ${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$ using ALICE is presented in this paper.

2. Analysis

For the present study, nearly 15 million of minimum-bias events from Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV collected by ALICE during 2010 are analysed.

The main detector used in the analysis is the Time Projection Chamber (TPC) which has a full azimuthal acceptance for tracks in the pseudorapidity region $|\eta| < 0.9$ [7,8,9]. Figure 1 shows the measured specific energy loss (dE/dx) *versus* rigidity $R = p/z$, where p is the track momentum and z is the charge number. The lines superimposed are Bethe–Bloch curves for the different particle species.

Both daughter tracks of the ${}^{3}_{\Lambda}\mathrm{H}$ can be clearly identified using TPC over a wide range of momentum.

However, nuclei can be produced by secondary interactions of the outgoing particles with the different materials traversed in their way out. In order to reduce such a contamination, it is needed to apply further cuts on the tracks used for the analysis. The distribution of the distance of closest approach along the beam axis, (DCA_Z), for anti-nuclei shows a negligible number of tracks with DCA_Z value greater than 1 cm; a DCA_Z cut of 1 cm is applied in addition to the standard track selections.

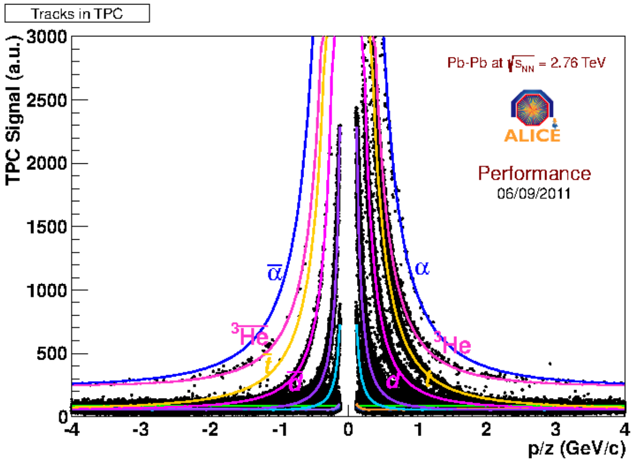

Fig. 1. (dE/dx) in the TPC *versus* rigidity $R = p/z$ with Bethe–Bloch curves superimposed.

In Fig. 2 (left panel) it is possible to observe the effect of the DCA_Z cut on the distribution of the distance of closest approach in the xy plane (DCA_{XY}) of ^{3}He: the DCA_{XY} background is effectively reduced without any significant signal loss.

As expected, a similar cut does not affect the $^3\overline{\mathrm{He}}$ DCA_{XY} distribution (Fig. 2, right panel) since there is no $^3\overline{\mathrm{He}}$ contamination from secondary collisions.

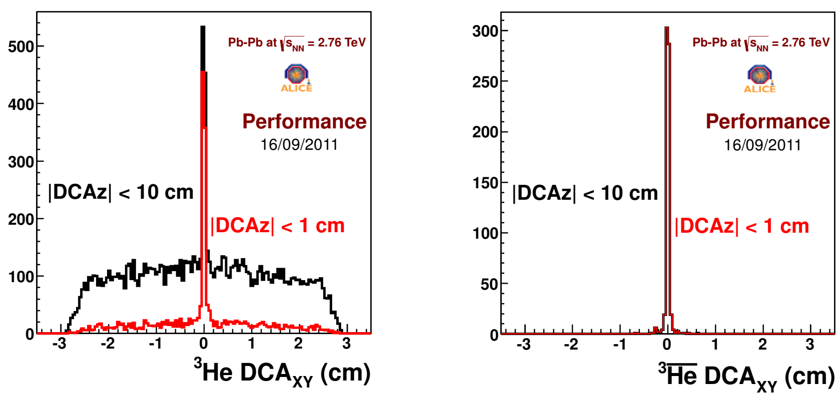

Fig. 2. DCA_{XY} distribution of identified ^{3}He (left panel) and $^3\overline{\mathrm{He}}$ (right panel) for Pb–Pb collisions.

Once both daughter tracks are identified, it is possible to reconstruct the hypertriton signal candidates by identifying their decay vertices. A set of topological cuts has been implemented in order to reduce the combinatorial background. These cuts include: distance of closest approach (DCA) between the two tracks (< 1 cm), DCA of the negative track from the primary vertex (> 0.4 cm) and cosine of the pointing angle between the primary and secondary vertex (> 0.9).

To extract the hypertriton signal, two methods to evaluate the background have been studied.

The first is the "like sign" method which consists in the combination of two tracks with the same sign (*i.e.* ${}^3\mathrm{He}+\pi^+$), and the second is the combined fit (third degree polynomial function for the background and a Gaussian for the signal) of the invariant mass spectrum.

The like sign method is very sensitive to statistical fluctuations, while the combined fit method seems to provide a smoother background subtraction.

The left panel of Fig. 3 shows two histograms illustrating the first method. The empty one is the invariant mass of (${}^3\mathrm{He}+\pi^-$), which represents the sum of the signal and the background, while the shaded one is the invariant mass of (${}^3\mathrm{He}+\pi^+$), used to evaluate the background.

In the right part of Fig. 3, it is possible to observe the bin-by-bin subtraction of the two histograms, fitted with a Gaussian function. The Gaussian mean is $\mu = 2.994 \pm 0.001$ GeV/c^2 and its width is $w = (3.4 \pm 1.5) \times 10^{-3}$ GeV/c^2. The mean value is compatible within $2\,\sigma$ with the value of hypertriton mass from the literature [10]. The integral of the Gaussian function is 104 ± 27.

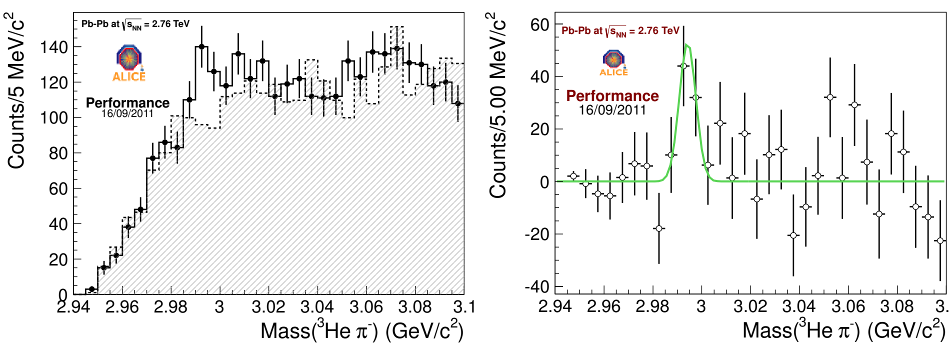

Fig. 3. Left panel: Full circles represent the invariant mass of (${}^3\mathrm{He}+\pi^-$); dashed line is the (${}^3\mathrm{He}+\pi^+$) like sign combination used to evaluate the background. Right panel: Bin-by-bin subtraction fitted with a Gaussian function.

In Fig. 4, it is possible to observe the (${}^3\mathrm{He}$, π^-) invariant mass distribution fitted with a function which is the combination of a third degree polynomial and a Gaussian.

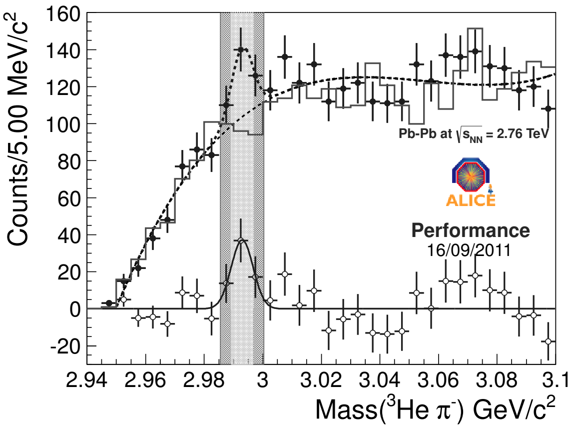

Fig. 4. Invariant mass distribution of identified ^{3}He and π^- for nearly 15 millions minimum-bias Pb–Pb events at $\sqrt{s_{NN}} = 2.76$ TeV. The dashed curve is the combination of a third degree polynomial and a Gaussian. The lighter box is the $1\,\sigma$ region around the peak, while the darker one represent the $2\,\sigma$ region.

The value of the Gaussian mean is $\mu = 2.993 \pm 0.001$ GeV$/c^2$, and the width is $w = (4.4 \pm 1.8) \times 10^{-3}$ GeV$/c^2$. Also in this case the value of the mean from the fit is compatible within $2\,\sigma$ with the one from literature [10]. The integral of the signal in a region of $2\,\sigma$ around the peak is 83 ± 26. The significance of the signal extracted, when calculated as Significance $=$ $\mathrm{S}/\sqrt{\mathrm{S}+\mathrm{B}}$, where S is the value of the signal integral and B the one of the background, is 4.

The two methods used to evaluate the background provide comparable yield, mean and width for the hypertriton signal.

3. Summary

The invariant mass distribution of (^{3}He, π^-) was studied in nearly 15 millions minimum-bias Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, and a $^3_\Lambda$H signal was observed.

The background was evaluated with two different methods. The first method, the "like sign" method, provides a raw signal of 104 ± 27 counts, a mean and a width respectively $\mu = 2.994 \pm 0.001$ GeV$/c^2$ and $w = (3.4 \pm 1.5) \times 10^{-3}$ GeV$/c^2$. The second method, the combined fit (third degree polynomial function for the background and a Gaussian for the signal) of the invariant mass spectrum, gives a raw signal count of 83 ± 26, a mean $\mu = 2.993 \pm 0.001$ GeV$/c^2$ and a width $w = (4.4 \pm 1.8) \times 10^{-3}$ GeV$/c^2$. The $^3_\Lambda$H signal is assessed with a significance of 4.

The same analysis was performed on $^3\overline{\mathrm{He}}$ and π^+: the $^3_{\overline{\Lambda}}\overline{\mathrm{H}}$ signal is visible but has to be confirmed with higher statistics.

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