LIGHT NUCLEI AND ANTI-NUCLEI PRODUCTION IN *pp* AND Pb–Pb COLLISIONS WITH ALICE*

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The production of nuclei and anti-nuclei in *pp* collisions at $\sqrt{s} = 7$ TeV and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV has been studied using the ALICE experiment. These particles are identified using their specific energy loss (dE/dx) measurement in the Time Projection Chamber. The Inner Tracking System gives a precise determination of the event vertex, which helps to distinguish primary from secondary particles. The high statistics of over 380 million events for *pp* collisions and 17 million events for Pb–Pb collisions provides a significant number of light nuclei and anti-nuclei (Pb–Pb collisions: $\sim$ 700 anti-^{3}He and $\sim 4\overline{\alpha}$). In this paper, we report on light nuclei and anti-nuclei production at the LHC.

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1. Introduction

One of the goals of ultra-relativistic nuclear collision experiments is to understand the production mechanism of matter and anti-matter. These collisions produce hot and dense matter for a short duration (10^{-23} s), containing roughly equal numbers of quarks and anti-quarks. In contrast to the Big Bang, nuclear collisions produce negligible gravitational attraction and allows the plasma to expand rapidly. The hot and dense matter cools down and undergoes a transition into a hadron gas, producing nucleons and their anti-particles.

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2. Experiment and data analysis

The results presented in this paper are obtained from A Large Ion Collider Experiment (ALICE) [1] at the LHC. It has excellent particle identification capabilities using its various subsystems. Two main subsystems are used for the results presented here: Time Projection Chamber (TPC) [2] and Time-of-Flight (TOF) [3] detectors. The TPC has full azimuthal acceptance for tracks in the pseudo-rapidity region $|\eta| < 0.9$. The various particles are identified using their specific energy loss (dE/dx) measurements in the TPC. Figure 1 shows dE/dx *versus* rigidity (momentum/charge) for negatively charged TPC tracks for Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The various particles are clearly separated and identified in the TPC. The TOF detector uses the velocity information of the particles to identify them, with similar acceptance as the TPC. The combined use of TPC and TOF detectors helps to identify the particles up to a high momentum region. The Inner Tracking System (ITS) [4] is used for the precise determination of event vertex, by which primary and secondary particles are separated.

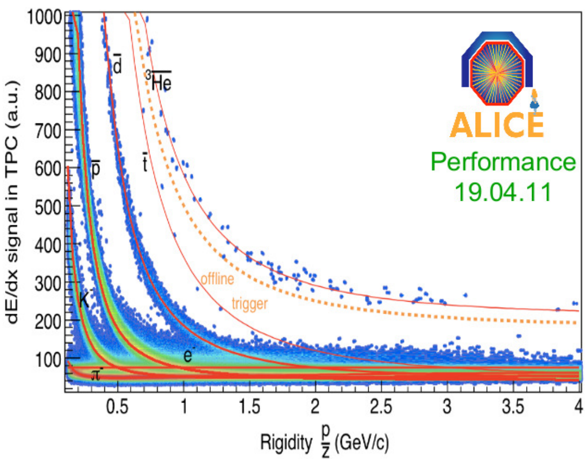

Fig. 1. Specific energy loss dE/dx *vs.* rigidity (momentum/charge) of negatively charged TPC tracks for 2.2 million Pb–Pb collisions ($\sqrt{s_{NN}} = 2.76$ TeV). The solid lines are parametrized Bethe–Bloch curves.

We present the results for identified nuclei and anti-nuclei in mid-rapidity region for *pp* collisions at $\sqrt{s} = 7$ TeV and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. To select primary tracks, a vertex cut along the z-axis is applied as $|v_z| < 10$ cm. The total number of events analysed is about 381.5 M for *pp* collisions and about 17 M for Pb–Pb collisions. The track selections used for our analysis are the number of clusters measured in the TPC for track reconstruction ≥ 80, and χ^2 per cluster ≤ 4. In addition, we also make sure that there is at least one cluster in the ITS associated to the track.

Particles produced in the collisions interact with the detector material or the beam pipe to produce the secondary particles. The probability of anti-nuclei production from interactions of produced particles with detector material is very small, whereas the nuclei sample may include primary as well as secondary particles from these interaction. Most of the secondary particles have large distance-of-closest approach (DCA) to the primary vertex and hence this information is used to reject this background.

A cut in $|\mathrm{DCA}_Z| < 1.0$ cm reduces large fraction of nuclei background without affecting primary particles [5]. To obtain the final counts, we study the DCA_{XY} distributions for particles and anti-particles for various transverse momentum (p_t) intervals. We assume that the DCA_{XY} distribution for particles should be similar to anti-particles plus background due to interaction with material. Figure 2 shows a typical example of these distributions for $d(\bar{d})$ for 0.55 GeV/$c < p_\mathrm{t} < 0.65$ GeV/c in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The left panel ($\bar{d}$) shows no significant number of tracks in $|\mathrm{DCA}_{XY}| > 1.0$ cm region and is nicely explained with the two Gaussian fit. The parameters obtained from this fit are used in the fit for deuteron (right panel) which are two Gaussians plus almost flat background. The raw yield is obtained from the area under the peak after background subtraction. A similar procedure is applied to obtain the raw yields for different (anti-) nuclei in different p_t bins for pp and Pb–Pb collisions.

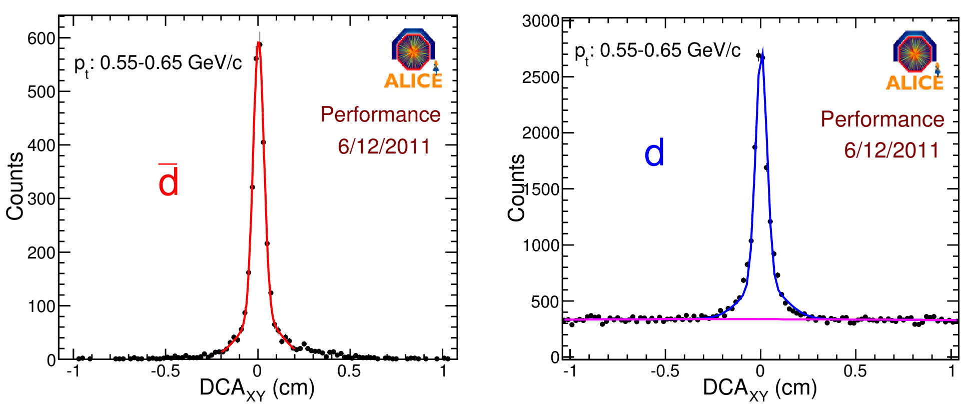

Fig. 2. DCA_{XY} distribution of identified anti-deuterons (left panel) and deuterons (right panel) in the transverse momentum range 0.55 GeV/$c < p_\mathrm{t} < 0.65$ GeV/c for Pb–Pb collisions ($\sqrt{s_{NN}} = 2.76$ TeV).

To obtain the final p_t spectra, the raw spectra of (anti-) nuclei should be corrected for the tracking efficiency and acceptance. The (anti-) nuclei are generated using the event generators and propagated through the detector material. The ratio of reconstructed to incident particles gives the combined efficiency and acceptance. It also takes into account the annihilation for anti-nuclei. The simulation of nuclei and anti-nuclei is performed in the AliRoot framework. The interaction of nuclei with the detector material is included in the Geant3 transport code. However, the annihilation effect of anti-nuclei in the detector material has not yet been implemented in Geant3. So we present only the corrected spectra for deuterons in *pp* collisions. The (anti-) nuclei efficiency for Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV is calculated by generating minimum-bias HIJING events. For *pp* collisions minimum-bias PYTHIA event generator is used. Figure 3 shows the efficiency of deuterons (left) and of ^{3}He (right) as a function of $p_{\rm t}$ for *pp* collisions and Pb–Pb collisions, respectively.

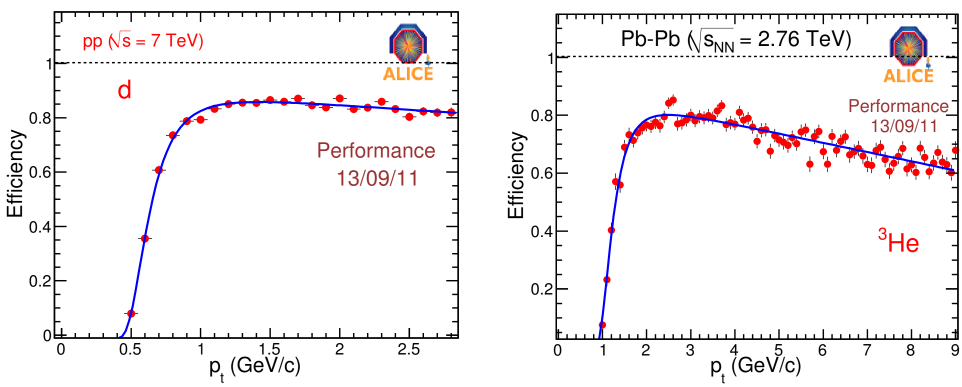

Fig. 3. Left panel: Efficiency of deuteron as a function of transverse momentum ($p_{\rm t}$) for *pp* collisions at $\sqrt{s} = 7$ TeV. Right panel: Efficiency of ^{3}He as a function of transverse momentum ($p_{\rm t}$) for Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

The low momentum particles loose energy while traversing the detector material. The track reconstruction algorithm takes into account the Coulomb scattering and energy loss, assuming the pion mass for each particle. Therefore, a track-by-track correction for the energy loss of heavier particles is needed. This correction is obtained from Monte Carlo (MC) simulations, in which the $p_{\rm t}$ difference of reconstructed and MC track is plotted as a function of $p_{\rm t}$ of reconstructed track. This track-by-track momentum correction has been applied for the (anti-) nuclei.

3. Results and discussions

Figure 4 shows the corrected deuteron spectra for *pp* collisions at $\sqrt{s} = 7$ TeV. The curve represents the Lévy (or Tsallis) function [6]

$$\frac{d^2N}{dp_{\rm t}dy} = p_{\rm t} \times \frac{dN}{dy} \frac{(n-1)(n-2)}{nC(nC + m_0(n-2))} \left(1 + \frac{m_{\rm t} - m_0}{nC}\right)^{-n} , \qquad (1)$$

where the fit parameters are C, n and the yield dN/dy. m_0 is the rest mass of the particle (deuteron) and $m_{\rm t}$ ($\sqrt{m_0^2 + p_{\rm t}^2}$) is its transverse mass. This function describes well the deuteron $p_{\rm t}$ spectrum within statistical uncertainties and is used to extract the dN/dy.

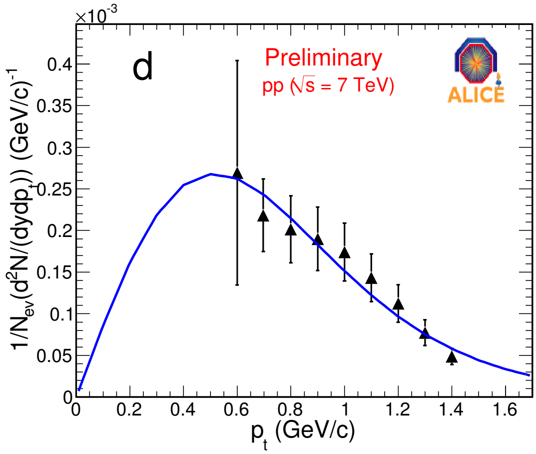

Fig. 4. Deuteron spectrum for *pp* collisions at $\sqrt{s} = 7$ TeV fitted with the Lévy function (see Eq. (1)).

Only 20 counts were obtained for the primary tritons and ^{3}He from the full statistics data in *pp* collisions at 7 TeV. In addition, the work is ongoing to obtain the corrected spectra for (anti-) nuclei in Pb–Pb collisions. The particle ratios with different masses will be compared to the statistical thermal model predictions [7].

The discovery of anti-alpha ($\overline{\alpha}$) has been first reported by the STAR experiment [8] and almost at the same time, also confirmed by the ALICE experiment [9]. We observed four $\overline{\alpha}$ candidates from about 17.8 millions events during the first heavy-ion run of the ALICE experiment in the year 2010 for Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Figure 5 shows negatively charged TPC tracks as blue points and the Bethe–Bloch curve parametrised for $\overline{\alpha}$ as orange solid line with dotted lines representing 2σ band around $\overline{\alpha}$ line. As illustrated in the figure, three $\overline{\alpha}$ candidates are clearly identified below 2.4 GeV$/c$ and are shown as red (light grey) points. The inset of Fig. 5 shows the final mass spectrum obtained with TPC and TOF showing four visible candidates of $\overline{\alpha}$.

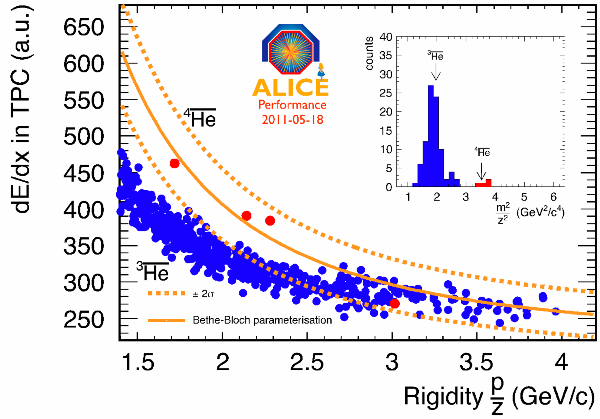

Fig. 5. Specific energy loss (dE/dx) *vs.* rigidity for TPC tracks, identified $\overline{\alpha}$ are shown as light grey (red) points; Inset plot: Mass spectrum obtained using TPC and TOF information.

4. Summary and outlook

In summary, we have presented the analysis for the nuclei and anti-nuclei production in pp collisions at $\sqrt{s} = 7$ TeV and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in the ALICE experiment. The corrected deuteron spectra for pp collisions at $\sqrt{s} = 7$ TeV is presented. We observed four $\overline{\alpha}$ candidates from the 17.8 millions events during the first heavy-ion run of the ALICE experiment in the year 2010 for Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. As an outlook, the work is ongoing to obtain the corrected spectra for (anti-) nuclei in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Furthermore, we will compare the particle ratios obtained from the data with statistical thermal model predictions and coalescence approaches.

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