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(Anti-)matter and hyper-matter production at the LHC with ALICE

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Abstract

The ALICE detector is ideally suited to study the production of anti- and hyper-matter due to its excellent particle identification capabilities. The measurement of the $^4\overline{\mathrm{He}}$-nucleus in Pb–Pb collisons at $\sqrt{s_{\mathrm{NN}}} = 2.76\,\mathrm{TeV}$ is presented. We further show the performance for the reconstruction of the (anti-)hypertriton in the decay to $^3\mathrm{He}+\pi^-$ ($^3\overline{\mathrm{He}}+\pi^+$). In addition to this, two searches have been performed, one for the H-Dibaryon $\rightarrow \Lambda \mathrm{p}\pi^-$ and one for the Λn bound state ($\overline{\Lambda\mathrm{n}} \rightarrow \overline{\mathrm{d}}\pi^+$). No signals are observed for these exotic states and upper limits have been determined.

1. Introduction

The unique particle identification capabilities of the ALICE detector [1, 2] allow for the measurement of rarely produced exotic states created in Pb–Pb collisions. This also gives the opportunity to search for hypothetical states. In particular we study anti-matter, such as light anti-nuclei and anti-hypernuclei, and search for states like the H-Dibaryon, a hexaquark state ($uuddss$), which was already predicted in 1977 by R. L. Jaffe [3] using a bag model calculation. Anti-matter studies have the advantage that the anti-particles suffer only from annihilation when detector material is crossed, whereas on the matter side a substantial background is created via knockout from the material. The energy regime reached at the LHC leads to large production probabilities of such particles, as described for example by thermal models [4, 5].

2. Anti-Alpha

The excellent performance of Time-Projection Chamber (TPC) [6] and Time-Of-Flight detector (TOF) [1] allows for the clear identification of all stable particles over a range of 0.15 to 5 GeV/c in rigidity $R = p/z$, where p is the track momentum and z is the charge number. Combining the specific energy loss ($\mathrm{d}E/\mathrm{d}x$) in the TPC and the TOF information, we identified 10 anti-alpha nuclei. Here we present results for 23 million Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76\,\mathrm{TeV}$, recorded in the heavy-ion run of November 2011 where a trigger mix of minimum bias, semi-central and central events was applied. We further apply an offline trigger selecting all $^3\overline{\mathrm{He}}$-nuclei

[1] A list of members of the ALICE Collaboration can be found at the end of this issue.

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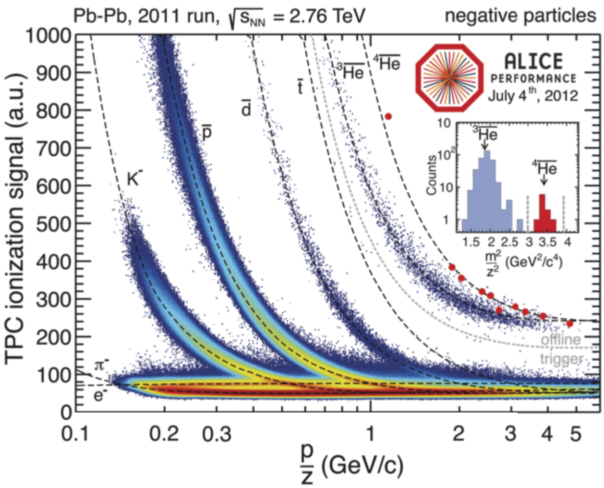

Figure 1: TPC dE/dx spectrum for negative particles after a selection of events that contain at least one $^{3}\overline{\mathrm{He}}$ or $^{4}\overline{\mathrm{He}}$ candidate. The inlet shows the m^2/z^2 distribution for this pre-selected data. The 10 anti-alphas clearly identified by TPC and TOF are indicated as red dots.

or heavier candidates. Figure 1 shows the dE/dx versus rigidity distribution for candidates after the offline selection for negative particles in the region where the bands of $^{3}\overline{\mathrm{He}}$ and $^{4}\overline{\mathrm{He}}$ are clearly visible. Below a rigidity of $p/z \approx 2\,\mathrm{GeV}/c$ three candidates are clearly identified based on the dE/dx information only. At higher p/z the energy-loss information of the candidates is combined with mass determination performed with the TOF detector following $m^2/z^2 = R^2/(\gamma^2 - 1)$. The inlet in Fig. 1 shows the m^2/z^2 distribution for all tracks within a 2σ-band around the expected dE/dx for $^{4}\overline{\mathrm{He}}$. The 10 identified anti-alphas are highlighted in both the m^2/z^2 and the dE/dx versus rigidity plot. A similar analysis had been performed for the 2010 data, which led to four anti-alpha candidates [7]. The work on the extraction of the corrected particle yield is currently ongoing.

3. Hypertriton

Hypertriton and anti-hypertriton are identified via their weak decays ($^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{+}$ and $^{3}_{\overline{\Lambda}}\overline{\mathrm{H}} \rightarrow {}^{3}\overline{\mathrm{He}} + \pi^{-}$), for details of the signal reconstruction see also [8]. Using the data of 2011, a signal for hypertrition (anti-hypertriton) with a significance of 4.6 (2.6) has been obtained. The background was evaluated with two different methods, i.e. like-sign and a combined fit (Gaussian on top of a third order polynomial, where the Gaussian describes the signal and the polynomial the background shape), shown in Fig. 2. Combining the information from the fits we extract for the mass a mean value of $\mu = (2.992 \pm 0.001)\,\mathrm{GeV}/c^2$ (only statistical error), which agrees with the world data, and a width of 2-3.4$\times 10^{-3}\,\mathrm{GeV}/c^2$, which reflects the resolution over the covered momentum range. Currently, the work on efficiency correction, where the main issue is connected to the poorly known $^{3}\overline{\mathrm{He}}$ matter interaction, and the connected study of systematics is ongoing.

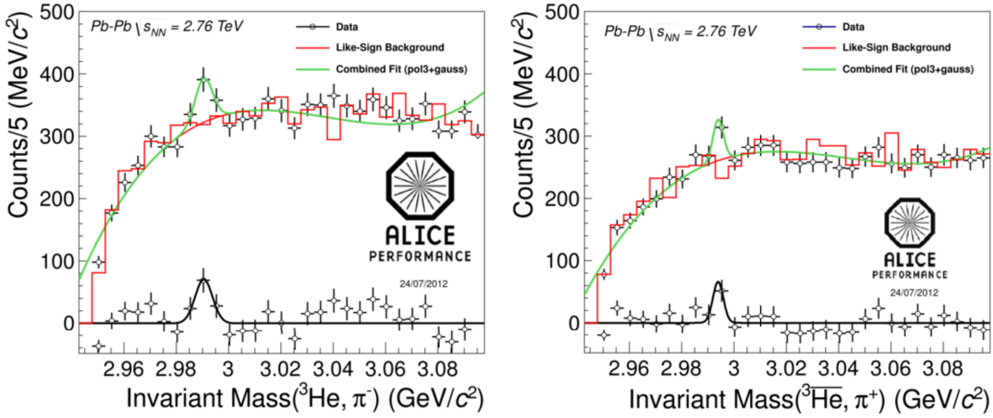

Figure 2: Invariant-mass analyses for hypertriton (left) and anti-hypertriton (right). Both figures show data (black), like-sign background (red) and a combined fit of a Gaussian on top of a third order polynomial (green).

4. Searches for H-Dibaryon and $(\overline{\Lambda \mathrm{n}})$ bound state

Recently, lattice calculations [9, 10] have been performed showing evidence for a bound H-Dibaryon, although these calculations have been done at an unphysical pion mass ($m_\pi \approx$ 390 GeV/c^2). When those results are extrapolated chiraly [11, 12] the H is rather unbound: either by 13 ± 14 MeV/c^2 (so it could still be bound by 1 MeV/c^2) above the $\Lambda\Lambda$ (2.231 GeV/c^2) threshold or even close to the Ξp threshold (2.26 GeV/c^2). A binding energy of around 1 MeV/c^2 is also favoured from the observed double Λ hypernuclei, which gives the current constraints on the $\Lambda\Lambda$ interaction, for a recent discussion see [13]. For the H-Dibaryon we investigated the

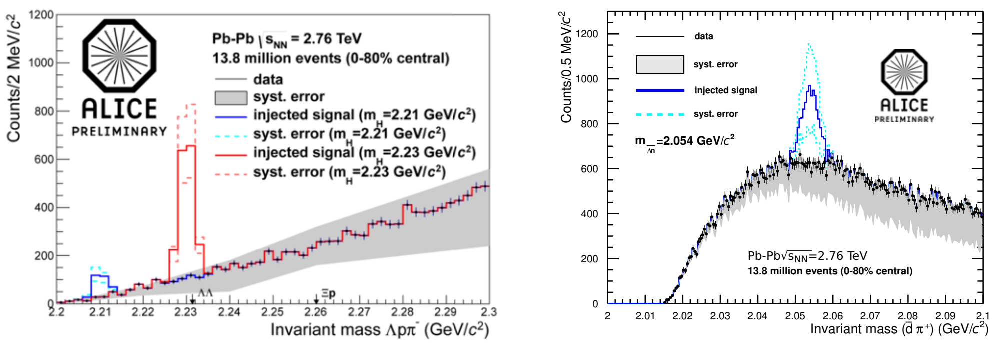

Figure 3: Invariant mass of $\Lambda + p + \pi^-$ (left) and invariant mass for $\overline{d} + \pi^+$ (right). The figures also show the expected signal using thermal-model predictions and the estimated acceptance x efficiency for two different possible bound states of the H-Dibaryon, respectively the expected signal for the $\overline{\Lambda \mathrm{n}}$ bound state.

decay into $\Lambda p \pi$. Other possible decay channels contain a neutron which is difficult to detect with the ALICE setup. The expected branching ratios depend on the binding energy, as shown in [14]. Since a low binding energy is favoured by the current theoretical discussions - if bound at all -

we concentrate on the mass region of 2.2-2.3 GeV/c^2 in the decay channel $\Lambda p\pi$. In this channel a signal for a bound state would result in a peak in the invariant mass or in a broad structure above the $\Lambda\Lambda$ threshold in case of a resonant state. In a similar way, we also study here the possible decay of a Λn bound state decaying into d+π^- which was observed at GSI by the HypHI collaboration [15] at a mass of 2.054 GeV/c^2.

The results shown here for the H-Dibaryon and the ($\overline{\Lambda\text{n}}$) bound state are based on the analysis of about 13.8 million Pb–Pb events in the centrality class of 0-80% taken with the ALICE apparatus in 2010. The reconstructed invariant mass distributions are shown in Fig. 3. No evidence for a signal, neither for the H-Dibaryon nor the ($\overline{\Lambda\text{n}}$) bound state was found. Figure 3 also shows the expected signal for the H-Dibaryon for two assumed masses of 2.21 GeV/c^2 and 2.23 GeV/c^2 (corresponding to binding energies of 21 MeV/c^2 and 1 MeV/c^2) and a possible ($\overline{\Lambda\text{n}}$) signal. We focus here on the $\overline{\Lambda\text{n}}$, since the background is much lower compared to Λn. The expected signal was computed estimating the acceptance × efficiency (from a Monte-Carlo simulation), the production rates as predicted by the thermal-model prediction [16] and the predicted branching ratios [14, 17]. For the Monte-Carlo simulation, involving full decay kinematics and transport in the material utilizing GEANT3, the lifetime of the free Λ hyperon was assumed for both exotic states.

We calculate upper limits for the yields shown in Table 1. The extracted limits are a factor of 10 lower than the thermal-model predictions [16] used to estimate the expected signal while these successfully describe the yields measured by STAR for the hypertriton [18] within uncertainties [4, 5].

Particle (Mass / GeV/c^2)	Upper limit of dN/dy (99% CL)
H-Dibaryon ($\Lambda\Lambda$) (2.21)	$\leq 8.4 \times 10^{-4}$
H-Dibaryon ($\Lambda\Lambda$) (2.23)	$\leq 2 \times 10^{-4}$
$\overline{\Lambda\text{n}}$ (2.054)	$\leq 1.5 \times 10^{-3}$

Table 1: Upper limits of dN/dy for the H-Dibaryon and the $\overline{\Lambda\text{n}}$ bound state at 99% confidence level.

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