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Enhanced deuteron coalescence probability in jets

Supplemental Material: a model based on PYTHIA 8 and simple nucleon coalescence

ALICE Collaboration*

Abstract

This Note contains a detailed description of a simple nucleon coalescence model, where the phase space distributions of nucleons are generated using PYTHIA 8 with the Monash 2013 tuning. The predictions of this model can be compared to measurements of the transverse-momentum (p_{T}) spectra and coalescence parameters B_2 of (anti)deuterons in pp collisions at $\sqrt{s}$ =13 TeV, in and out of jets.

*See Appendix A for the list of collaboration members

The coalescence model assumes that deuterons are formed by coalescence of protons and neutrons that are close in phase space. The space coordinates are ignored in the most simple implementation of the coalescence model and only momentum correlations are considered, i.e., a deuteron is formed if the momentum difference of a proton–neutron pair is smaller than a given threshold p_0, which is a free parameter of the model.

The first step in the simulation of deuteron coalescence is the tuning of the input p_{T} distributions of protons and neutrons in PYTHIA 8 with the Monash 2013 tune, which are different from the measured distributions. The input spectra are reweighted using p_{T}-dependent weights calculated as the ratio between the p_{T} distributions in data and in PYTHIA 8. This tuning is done for each azimuthal region (Toward, Away, and Transverse) since the reweighting based on the minimum-bias spectra resulted in residual deviations when comparing the proton spectra from PYTHIA 8 with the measurements in the three different regions. The unmodified p_{T} distributions of protons from PYTHIA 8 are compared with the data in Fig. 1.

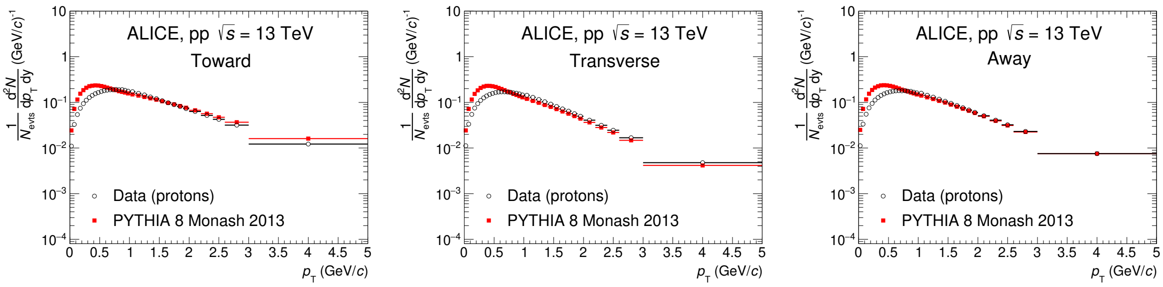

Fig. 1: Transverse momentum spectra of protons in the three different azimuthal regions in data and PYTHIA 8 with the Monash 2013 tune. The data-to-model ratio is shown in Fig. 3.

The measured proton spectra are extrapolated to $p_{\mathrm{T}} = 0$ by adding data points following an m_{T}-exponential function that is first fitted to the data at low p_{T}. Different functional forms are also used to estimate the systematic uncertainties due to the input p_{T} shapes from PYTHIA 8. The proton spectrum and the fit functions are shown for the Toward region as an example in Fig. 2.

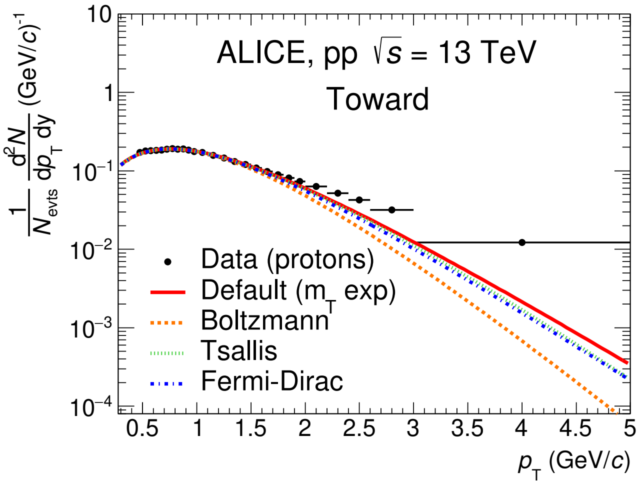

Fig. 2: Transverse momentum spectrum of protons in the Toward region fitted with different functions used for the extrapolation to $p_{\mathrm{T}} = 0$.

The p_{T}-dependent weights used to tune the input p_{T} distributions of both protons and neutrons are shown in Fig 3.

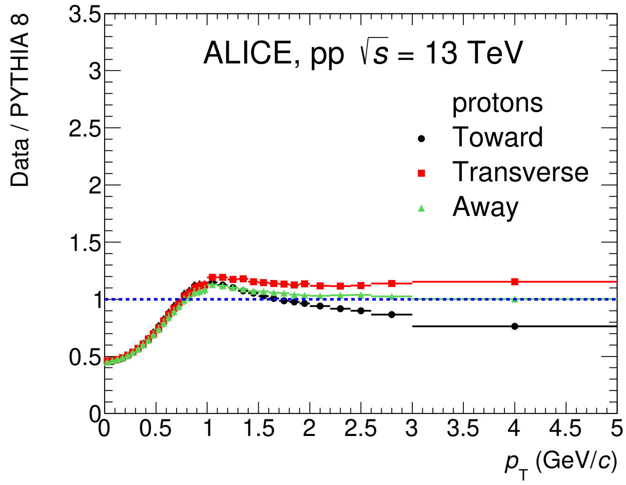

Fig. 3: p_{T}-dependent weights used to adjust the input spectra of protons and neutrons in PYTHIA 8 with the Monash 2013 tune.

The simulation of deuteron coalescence can be summarized in the following steps:

1. Primary protons and neutrons with rapidity $-1 < y_{\mathrm{p,n}} < 1$ are selected and saved in two separate arrays;
2. Loop over all proton–neutron pairs;
3. If a proton-neutron pair fulfills the coalescence condition $|\vec{p}_{\mathrm{p}} - \vec{p}_{\mathrm{n}}| < p_0$, with momenta calculated in the deuteron rest frame:
   (a) a deuteron with momentum $\vec{p}_{\mathrm{d}} = \vec{p}_{\mathrm{p}} + \vec{p}_{\mathrm{n}}$ is created.
   (b) both proton and neutron are removed from the arrays
   (c) a statistical factor = 3/8 (spin and isospin) is applied as a weight
4. The deuteron spectrum is filled if its rapidity is $|y| < 0.5$.

The rapidity distributions of protons and neutrons with $|\vec{p}_{\mathrm{p}} - \vec{p}_{\mathrm{n}}| < p_0$ that form a deuteron with $|y| < 0.5$ are shown in Fig. 4.

The measured p_{T}-differential yield of deuterons is compared to the coalescence calculation in the left panel of Fig. 5. The coalescence momentum and its uncertainty (Δp_0) are obtained by fitting the (anti)deuteron spectrum taken from coalescence simulations to the measured (anti)deuteron p_{T} spectrum in MB pp collisions at 13 TeV [1], with p_0 as a free parameter. A discrete scan using 50 different values of p_0 is executed for this fit and the best agreement is found by searching for the minimum in the χ^2 curve as a function of p_0 (see right panel of Fig. 5). The best estimate of the coalescence momentum threshold is $p_0 = 285 \pm 1$ MeV/c, where the uncertainty is obtained by a local cubic polynomial regression to the χ^2 curve around its minimum and searching for the p_0 interval corresponding to a variation of one unit in the χ^2. As stated above, the obtained (anti)deuteron spectrum is scaled by a statistical factor 3/8 that accounts for the probability for forming a spin-1 and isospin-0 (anti)deuteron from spin-1/2 and isospin-1/2 (anti)protons and (anti)neutrons. The difference between the coalescence momentum threshold value found in this work and that used in Ref. [2] ($p_0 = 110$ MeV/c) is attributed to the isospin

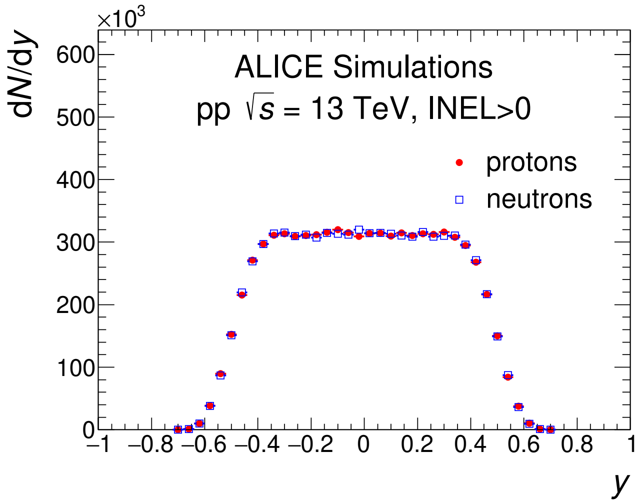

Fig. 4: Rapidity distributions of protons and neutrons with $|\vec{p}_\mathrm{p} - \vec{p}_\mathrm{n}| < p_0$ that form a deuteron with $|y| < 0.5$ in Pythia 8 with the Monash 2013 tune.

degeneracy factor 3/8 that was ignored in the previous work. The value reported here is instead consistent with Ref. [3], where the isospin factor is correctly taken into account and $p_0 = 285$ MeV/c. Additionally, in Ref. [2], the proton spectra from PYTHIA 8 were not reweighted in order to match the data.

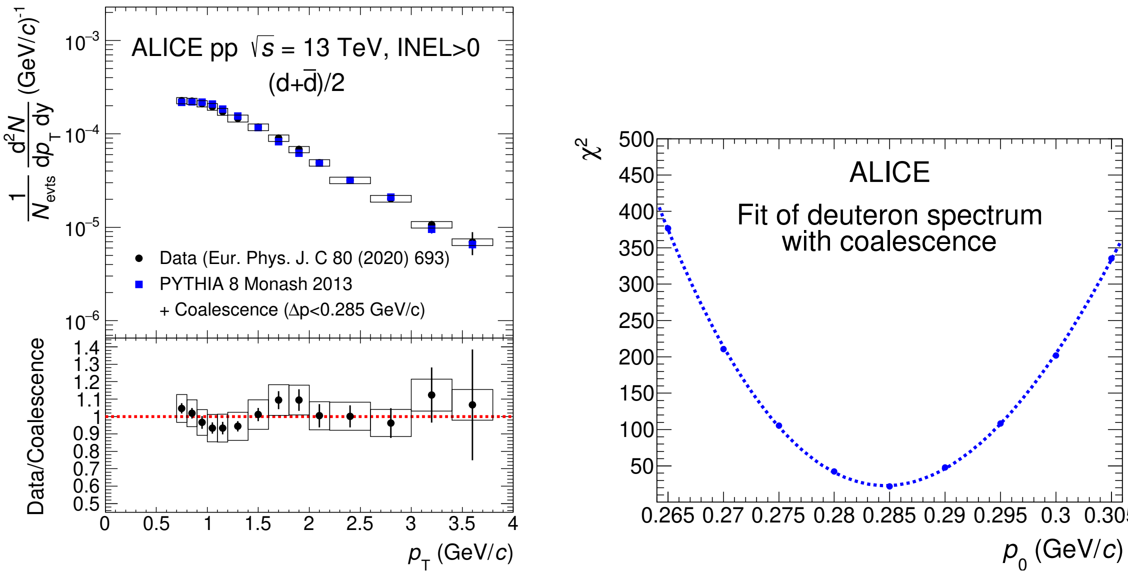

Fig. 5: (Anti)deuteron p_T spectrum measured in minimum-bias pp collisions at 13 TeV [1] in comparison with the simple coalescence calculation (left). Model-to-data χ^2 curve as a function of p_0 used to determine the best value of the coalescence momentum threshold and its uncertainty (right). See text for details.

Three sources of uncertainties are considered for the coalescence predictions: the experimental uncertainties in the proton measurement, the extrapolation to $p_\mathrm{T} = 0$, and the uncertainty on the coalescence momentum threshold, p_0. The first uncertainty is obtained by re-calculating the p_T-dependent weights of protons by shifting each data point in the measured p_T distribution up and down by the corresponding uncertainty. The second contribution, which affects only the extrapolated part of the spectrum, is calculated as the maximum difference between the different fit functions used for the extrapolation. The last contribution is calculated as the difference between the deuteron spectra obtained using the coalescence momenta $p_0 - \Delta p_0$ and $p_0 + \Delta p_0$.

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