PROCEEDINGS OF SCIENCE

Secondary nuclei from ^{16}O fragmentation at the LHC

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Fragmentation of relativistic ^{16}O in nuclear emulsions and in future runs at the LHC was simulated with the Abrasion-Ablation Monte Carlo for Colliders (AAMCC) model. The calculated probabilities of production of specific elements as spectators in ^{16}O–Em collisions were found in general agreement with measurements. However, the calculated multiplicity distributions of ^{4}He fragments have demonstrated the underestimation of channels with single ^{4}He and, especially with two and three ^{4}He. Such a deficiency of multiple production of ^{4}He can be attributed to α-clustering in initial ^{16}O. The cross sections of production of given numbers of spectator neutrons and nucleons as well as certain spectator nuclei were also calculated with AAMCC for ^{16}O–^{16}O collisions at the LHC.

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1. Introduction

It is planned to study ^{16}O–^{16}O collisions in future runs at the LHC [1]. Due to α-clusterisation of nucleons in ^{16}O an admixture of a tetrahedral state in the ground state of this nucleus is considered, see, in particular [2]. It was found much earlier [3] that α-core bound state in ^{16}O impacts α-transfer and knock-out nuclear reactions involving ^{16}O. However, it was shown only recently that the initial collision eccentricity [4], collective flow [5, 6] and the production of D-mesons [7] in relativistic ^{16}O–^{16}O collisions are partially affected by clustering. At the same time, the influence of the clusterisation in ^{16}O on the spectator matter produced in ^{16}O–^{16}O at the LHC energies was not considered so far and has to be investigated. In this work we made the first step in this direction. The composition of spectator matter in collisions of ^{16}O with ^{16}O and other nuclei was modelled by means of the Abrasion-Ablation Monte Carlo for Colliders (AAMCC) [8] model with two parameterisations of nuclear density distributions in ^{16}O without accounting for cluster effects. The probabilities and cross sections for the production of specific elements along with the probabilities to obtain one, two or three spectator α-particles in ^{16}O–Em (AgBr+CNO) collisions were calculated and compared with data [9, 10] to validate the model. The composition of spectator nuclei from ^{16}O–^{16}O collisions at $\sqrt{s_{\rm NN}}$ = 6.37 TeV the LHC as well as multiplicity distributions of neutrons and nucleons were calculated. These results can help to evaluate the performance of Zero Degree Calorimeters in experiments at the LHC and the impact of secondary nuclei on LHC components.

2. Abrasion-Ablation Monte Carlo for Colliders

In this work we supplemented our AAMCC model [8] with a pre-equilibrium decay mechanism based on the Minimum Spanning Tree (MST) clusterisation algorithm. Modelling of each event is proceeded via several stages. Firstly, the sizes and shapes of spectator prefragments from both colliding nuclei are defined at the abrasion stage using Glauber Monte Carlo (Glauber MC) model [11]. There are two options in Glauber MC to sample positions of nucleons in initial ^{16}O [12]: according to the density distributions based on the harmonic oscillator (HO) and direct (DW) wave functions. Two- and three-nucleon interactions are taken into account in DW distribution [4], but both distributions neglect α-clustering. Secondly, the excitation energy of the prefragments is calculated with a hybrid approach: Ericson formula [13] is used for peripheral collisions (with less than 15% of nucleons removed from ^{16}O), while ALADIN parameterization [14] is involved otherwise. Thirdly, the MST-clustering algorithm is applied to both prefragments at the ablation stage to define secondary clusters with their excitation energies depending on their size. Finally, cluster decays are simulated via the evaporation and Fermi Break-up models from Geant4 toolkit [15].

3. Spectator nuclei from ^{16}O–Em collisions

3.1 Production of specific elements

The calculated probabilities to obtain spectator He, Li, Be, B, C or N in collisions of 200 GeV/nucleon ^{16}O with light nuclei (CNO) in nuclear emulsion are presented in Fig. 1. As seen, the data [9] on the production of He and Li are described well by AAMCC with DW parametrization of nuclear density. The data on production of Be, B and N [9] are in a reasonable agreement with calculations with DW as well as with HO parameterizations. However, the production of carbon fragments is underestimated in both cases. A similar underestimation of secondary carbon nuclei is seen for the charge-changing cross section measured in ^{16}O–^{12}C collisions [10], while the production of nitrogen is described well by AAMCC with DW parametrization, see Fig. 1. The underestimation of carbon production can be explained by neglecting the existence of α-^{12}C bound state [3] in initial ^{16}O. Nucleons from the α particle can be abraded in collisions, thus leaving the ^{12}C core intact.

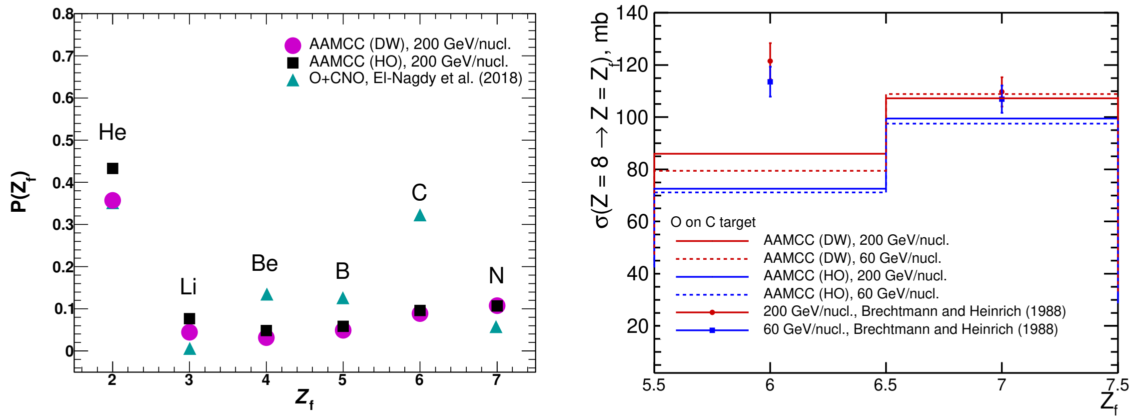

Figure 1: Left panel: calculated probabilities (circles and squares) of production of specific elements in collisions of 200 GeV/nucleon ^{16}O with light elements (CNO) of nuclear emulsion compared with data [9] (triangles). Right panel: Calculated charge changing cross sections (histograms) for 60 GeV/nucl. and 200 GeV/nucl. ^{16}O projectiles on carbon target compared with data [10] (points). DW and HO nuclear density distributions were used in calculations.

3.2 Production of ^{4}He

Another indication in favour of α-clustering in ^{16}O can be seen in Fig. 2, where the calculated probabilities of multiple production of α-particles in interactions of ^{16}O with different energies in nuclear emulsion are presented along with data [9]. The probabilities of production of one, two and three of α-particles at 3.7 GeV/nucl. calculated with HO and DW options of AAMCC underestimate the data. As one can also see from Fig. 2, calculated and as well as measured multiplicity distributions of α-particles demonstrate a very weak dependence on collision energy, from 2 GeV/nucl. till 200 GeV/nucl. However, the calculations systematically underestimate the data especially on 2α and 3α production, while the channel with single α is overestimated. Such a discrepancy can be attributed to neglecting virtual multiple-α cluster states in initial ^{16}O [2].

4. Spectator matter from ^{16}O–^{16}O collisions at the LHC

Two pairs of Zero Degree Calorimeters (ZN and ZP) are available in the ALICE experiment at the LHC on each side of the interaction point for detecting, respectively, forward neutrons and protons [16]. In this experiment ZN were used, in particular, for estimating centrality in ^{208}Pb–^{208}Pb

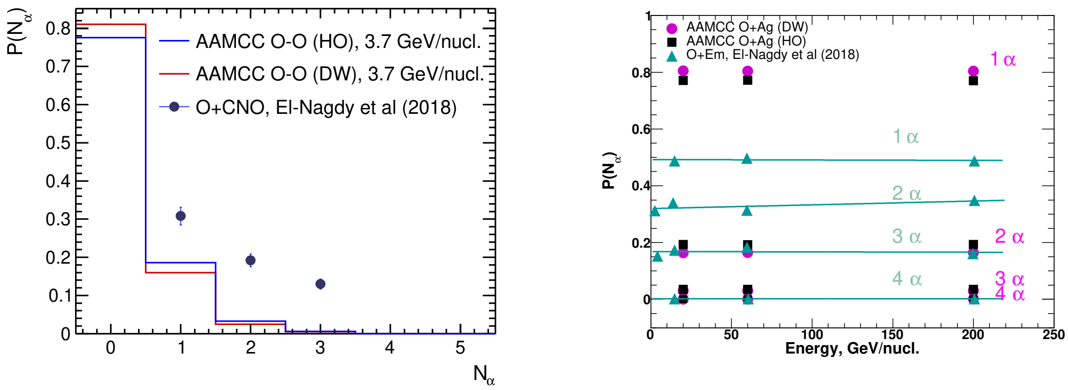

Figure 2: Left panel: calculated multiplicity distributions of ^{4}He spectator fragments from collisions of 3.7 GeV/nucl. ^{16}O with light nuclei (CNO) in nuclear emulsion. Right panel: calculated multiplicity distributions of ^{4}He from collisions of 2–200 GeV/nucl. ^{16}O with nuclear emulsion. Data from Ref. [9] are shown in both panels.

collisions. Therefore, it is necessary to estimate the performance of ZN also for future ^{16}O–^{16}O runs. Moreover, it is important to estimate the cross sections of production of specific secondary nuclei. Those of them which have their charge-to-mass ratio Z/M_F close to ^{16}O will propagate in the LHC magnetic field far from the interaction point and potentially impact collider components.

4.1 Free spectator neutrons and nucleons

The calculated cross sections of production of given numbers of spectator neutrons and nucleons (neutrons + protons) in ^{16}O–^{16}O collisions at $\sqrt{s_{\rm NN}}$ = 6.37 TeV are presented in Fig. 3. Calculations were performed with HO and DW parameterizations of density distributions in ^{16}O. As seen, higher spectator multiplicity is predicted with DW option in comparison to HO. This is caused by the extension of the DW density distribution to larger radii. In contrast to ^{208}Pb–^{208}Pb collisions which always accompanied by the emission of spectator neutrons, ^{16}O–^{16}O events without neutrons or even without nucleons are most probable. In such events all spectator nucleons remain bound in fragments and neither ZN nor ZP will be suitable for centrality determination.

4.2 Spectator nuclei

The cross sections of production of spectator nuclei with given charge Z and charge-to-mass ratio Z/M_F in ^{16}O–^{16}O collisions at $\sqrt{s_{\rm NN}}$ = 6.37 TeV were calculated with HO and DW parametrizations of nuclear density in ^{16}O. These cross sections are presented in Fig. 4. Calculations with HW and DW predict the production of same spectator nuclei in ^{16}O–^{16}O, namely, $^{13-15}$O, $^{13-15}$N, $^{10-14}$C, $^{10-13}$B, ^{7,9,10}Be, $^{6-8}$Li, ^{3,4,6}He, $^{1-3}$H, but with different cross sections. As predicted by AAMCC, the most abundant spectator nuclei are ^{2}H and ^{4}He. Deuterons and α-particles along with other nuclei with their magnetic rigidity close to that of ^{16}O, in particular, ^{6}Li, ^{10}B, ^{12}C, ^{14}N, have to be separated from ^{16}O beam by the LHC collimator system in order to avoid collisions of nuclei other than ^{16}O and also to reduce possible impact of secondary nuclei on sensitive collider components.

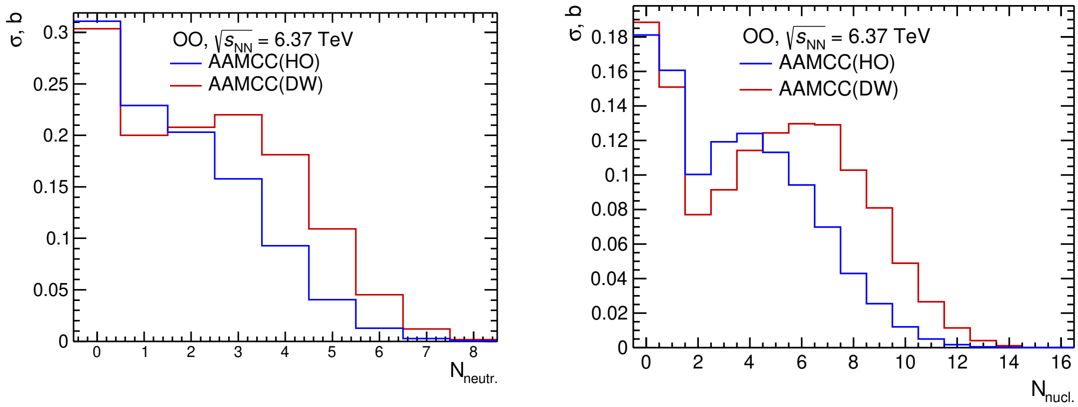

Figure 3: Calculated cross sections of production of given numbers of spectator neutrons (left) and nucleons (neutrons + protons) (right) in ^{16}O–^{16}O collisions at $\sqrt{s_{NN}}$ = 6.37 TeV at the LHC. The cross sections were obtained with HO and DW parametrizations of nuclear density in ^{16}O.

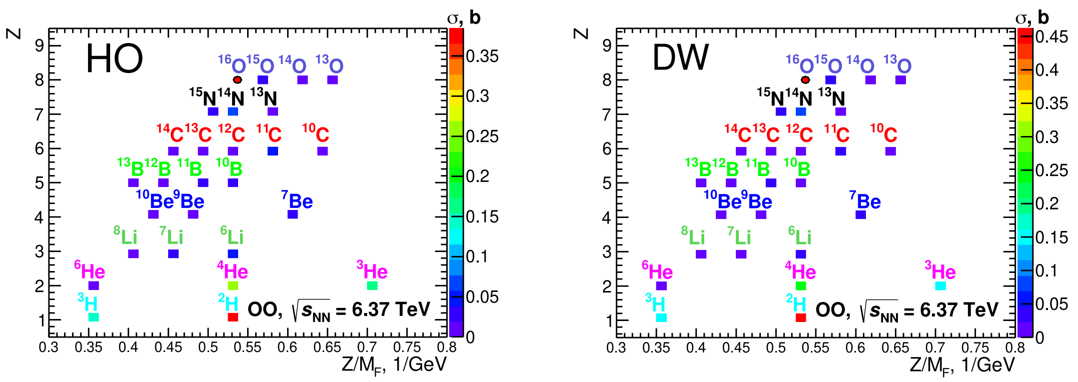

Figure 4: Calculated cross sections of production of spectator nuclei with given charge Z and charge-to-mass ratio Z/M_F in ^{16}O–^{16}O collisions at $\sqrt{s_{NN}}$ = 6.37 TeV at the LHC. The cross sections were obtained with HO (left) and DW (right) parametrizations of nuclear density in ^{16}O. Red circles denote initial ^{16}O.

5. Conclusion

The cross sections of the production of certain spectator nuclei (Li, Be, B and N) in interactions of relativistic ^{16}O in nuclear emulsion are described in general with AAMCC. However, the underestimation of production of carbon and especially events with multiple helium nuclei indicates the importance of taking into account α-clusterization in initial ^{16}O. Such effects are planned to be considered in the further development of the model. According to AAMCC, in a part of ^{16}O–^{16}O collisions at the LHC all spectator nucleons remain bound in nuclear fragments and thus can not be detected by Zero Degree Calorimeters to determine collision centrality.

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