PROCEEDINGS OF SCIENCE

Soft QCD results from ALICE

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Most of the processes in high-energy hadronic collisions are dominated by soft interactions with low momentum transfer. The description of these processes typically relies on phenomenological models and soft QCD measurements provide important constraints on the model parameters. The results presented in this contribution include recent ALICE measurements of the underlying event properties in pp collisions at $\sqrt{s}$ = 13 TeV, searches of jet quenching effects in small collision systems, (multi-)strange hadron production as a function of multiplicity, hadronic interaction via correlation measurements, and first results on light antinuclei inelastic cross sections. Comparisons with existing models and lattice QCD calculations are shown and discussed.

The Eighth Annual Conference on Large Hadron Collider Physics-LHCP2020
25-30 May, 2020
online

*Speaker

PoS(LHCP2020)147

1. Introduction

In high-energy hadronic collisions, most of the processes are dominated by interactions with low momentum transfer. The description of these processes using quantum chromodynamics (QCD), the fundamental theory of strong interactions, is extremely difficult due to their non-perturbative regime and is mostly based on phenomenological models implemented in Monte Carlo event generators. Soft QCD measurements are fundamental for tuning the model parameters and for a better understanding of non-perturbative QCD.

The measurements presented in the following paragraphs are done using the ALICE detectors. A detailed description of the ALICE apparatus and its performance can be found in Refs. [1] and [2]. The event activity classification is based on the signal amplitude measured by two plastic scintillator arrays, V0A and V0C [3], located on both sides of the interaction point. Trajectories of charged particles are reconstructed in the ALICE central barrel with the Inner Tracking System (ITS) [1] and the Time Projection Chamber (TPC) [4]. These detectors are also used for particle identification together with the Time-Of-Flight (TOF) detector [5]. Measurements of particle production using the dimuon decay channel at forward rapidity are done using the muon tracker [1].

2. The underlying event

The underlying event properties in pp collisions at $\sqrt{s}$ = 13 TeV are characterized using the leading track method [6]. Charged particles are measured in three different azimuthal regions defined considering the particle with maximum transverse momentum ($p_{\mathrm{T}}^{\mathrm{leading}}$) as a reference. The toward and away regions include particles produced by parton fragmentation and from the underlying event, while the transverse region is expected to contain predominantly particles from the underlying event. The charged-particle density increases rapidly as a function of $p_{\mathrm{T}}^{\mathrm{leading}}$ until a plateau is reached at about 5 GeV/c. This dependence is qualitatively described by EPOS LHC [7] and PYTHIA 8 [8] for the three azimuthal regions. The saturation of the underlying event activity is reached at smaller $p_{\mathrm{T}}^{\mathrm{leading}}$ for lower center-of-mass energies, as observed when comparing the results in pp collisions at $\sqrt{s}$ = 13 TeV with those at $\sqrt{s}$ = 7 TeV and 0.9 TeV [9]. The plateau in the transverse region is further characterized by the probability distribution of its charged-particle multiplicity normalized to its average value (R_{T}) and the mean transverse momentum $\langle p_{\mathrm{T}} \rangle$ as a function of R_{T}. The experimental results are described by EPOS LHC and PYTHIA 8 with an overall agreement of 30% [6].

3. Jet quenching in small collision systems

The study of collectivity and energy loss effects in pp and p–Pb collisions is important to shed light on the possible formation of the quark-gluon plasma (QGP), a state of deconfined quarks and gluons, also in these collision systems. Energy loss effects are quantified by the ratio $I_{\mathrm{pp,pA,AA}} = Y_{\mathrm{pp,pA,AA}} / \langle Y_{\mathrm{pp,pA,AA}} \rangle$, where $Y_{\mathrm{pp,pA,AA}}$ is the yield of charged particles measured for a given multiplicity interval in the transverse region in different collision systems. The ratios $I_{\mathrm{pp,pA,AA}}$ measured in pp, p–Pb and Pb–Pb at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV are shown in Fig. 1 for the toward (left) and away regions (right). A clear enhancement (suppression) is observed in Pb–Pb collisions in the near (away) side, due to parton energy loss in the created QGP, while no evidence for a similar effect is observed for small collision systems in the measured multiplicity range.

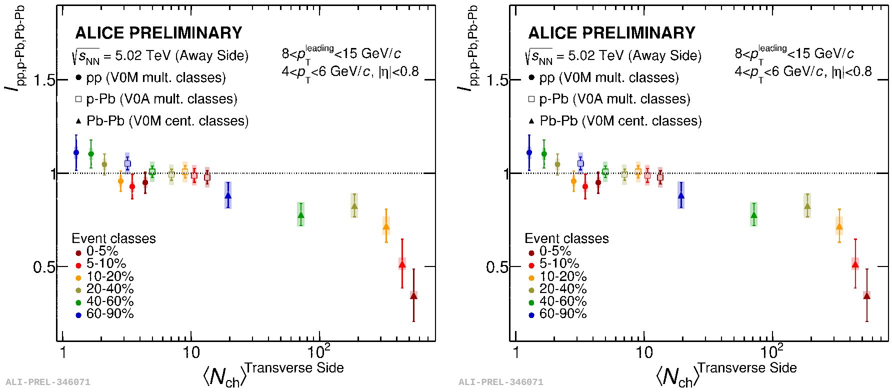

Figure 1: Ratio of the charged-particle yield in a given transverse multiplicity interval and its average for pp, p–Pb and Pb–Pb at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV for the toward (left) and away (right) regions.

4. (Multi)strange hadron production

Measurements of particle production at forward rapidities provide important information on soft QCD processes considering that these particles originate on average from softer collisions. The self-normalized yields of ω and ϕ are measured in pp collisions at $\sqrt{s}$ = 13 TeV as a function of the self-normalized charged-particle multiplicity in the rapidity interval $2.5 < y < 4$ using the dimuon channel (Fig. 2). At low p_{T}, only PYTHIA 8 with hadron rescattering is consistent with the ϕ measurement over the full multiplicity interval while all implementations of PYTHIA 8 overestimate the ω measurement at high multiplicity. At high p_{T} the different versions of PYTHIA 8 are consistent with the data.

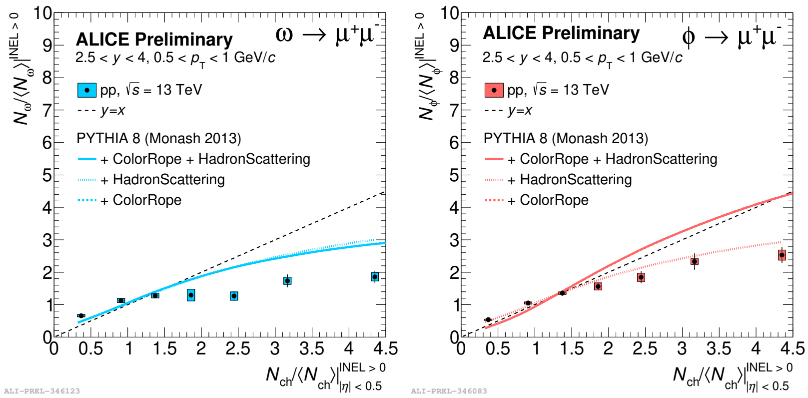

Figure 2: Self-normalized yields of ω (left) and ϕ (right) measured in pp collisions at $\sqrt{s}$ = 13 TeV in comparison with different implementations of PYTHIA 8.

The self-normalized yields of $\mathrm{K}^0_{\mathrm{S}}$, Λ, Ξ and Ω measured at midrapidity in pp collisions at $\sqrt{s}$ = 13 TeV show a faster than linear increase with the self-normalized multiplicity at high p_{T} [10].

This trend is well reproduced by both PYTHIA 8 and EPOS-LHC. The latter assumes a collective expansion of the medium created in these collisions described by hydrodynamics. A further effect that could be connected to a collective expansion is the more pronounced increase of the $\langle p_{\mathrm{T}} \rangle$ with multiplicity for heavier hadrons [10]. When considering the total yield, i.e. including also the low p_{T} contribution, all existing models fail in providing a consistent description of (multi-)strange hadron production as a function of multiplicity, which indicates that the origin of the strangeness enhancement observed going from low to high multiplicity is still not fully understood. A further experimental contribution is provided by ALICE with the measurement of (multi-)strange hadron production in pp collisions at $\sqrt{s}$ = 5.02 TeV as a function of multiplicity, which complements the existing picture with better precision and finer granularity.

5. Hadronic interaction

A new experimental method to study the hadronic interaction is via correlations. The measurements of the correlation functions of p-Ξ and p-Ω [11] are compared to lattice QCD calculations and important information on the interaction potential is obtained. More specifically, while the p-Ξ correlation function is consistent with lattice QCD calculations, the data are underestimated in the relative-momentum interval $100 < k^* < 300$ MeV/c for p-Ω. This important observation has implications on the possible existence of a p-Ω bound state which will be further studied with higher precision in the LHC Run 3.

The study of hadronic interactions is extended by ALICE to antimatter nuclei with the first measurement of the antideuteron [12] and anti-^{3}He inelastic cross sections at low momentum. The measured cross section of antideuterons is consistent with the Glauber model implemented in GEANT 4 [13] for momenta $p > 1$ GeV/c, while the data suggest a steeper rise going to lower momenta although the deviations with respect to GEANT4 are within the experimental uncertainties. Similarly, the anti-^{3}He inelastic cross section is consistent with GEANT4 at high momentum ($p >$ 2 GeV/c) and deviates significantly at lower momenta. These results have important applications to astrophysics for the description of the propagation of antinuclei, which could be produced by dark matter annihilation in the interstellar medium.

6. Summary

The ALICE measurements presented at this conference have substantially contributed to the characterization of the underlying event in pp collisions at $\sqrt{s}$ = 13 TeV. The agreement with the MC models is within 30%. No evidence for jet quenching effects in small collision systems is observed in the multiplicity range covered by the current measurement. Particle production at forward rapidity and (multi-)strange hadron measurements challenge the existing models which do not yet provide a consistent description of hadron production as a function of multiplicity. Experimental validation of lattice QCD calculations of hyperon-nucleon interactions is obtained via correlation measurements thus opening a new avenue for high-precision tests of QCD at the LHC. The first measurements of light antinuclei inelastic cross sections indicate deviations at low momentum with respect to the expectations from the Glauber model which are not understood. These measurements provide important input for indirect searches of dark matter.

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