Multi-strange particle measurements in 7 TeV proton-proton and 2.76 TeV PbPb collisions with the ALICE experiment at the LHC

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Abstract. The production of charged multi-strange particles is studied with the ALICE experiment at the CERN LHC. Measurements of the central rapidity yields of $\Xi^-$ and $\Omega^-$ baryons, as well as their antiparticles, are presented as a function of transverse momentum ($p_t$) for inelastic pp collisions at $\sqrt{s} = 7$ TeV and compared to existing measurements performed at the same and/or at lower energies. The results are also compared to predictions from two different tunes of the PYTHIA event generator. We find that data significantly exceed the production rates from those models. Finally, we present the status of the multi-strange particle production studies in Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV performed as a function of collision centrality.

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1. Introduction

The study of charged multi-strange particles in high-energy proton-proton collisions serves not only as an important benchmark for heavy-ion collisions, but it can also provide us with information pertinent to the interplay between different particle production mechanisms. At low transverse momenta, soft interactions are the dominant source of particle production, while at high $p_t$ perturbative quantum chromodynamics (pQCD) processes take over as the most significant mechanism. Information on these mechanisms can be used to constrain the phenomenology of QCD-inspired models and event generators such as PYTHIA [1]. The multi-strange baryons are of particular interest as the colliding particles have no net strangeness content, so that any open strangeness must have been created in the collision.

In heavy-ion collisions, multi-strange baryon measurements can reveal information about the early partonic stages of the event, since these baryons have small hadronic cross-sections. In Au-Au systems at $\sqrt{s_{NN}} = 200$ GeV at RHIC, radial flow was observed for the $\Omega$ that must have been accumulated prior to chemical freezeout [2].
2. Data Analysis

For this work, we studied multi-strange baryon production using a sample of $130 \times 10^6$ pp events measured by the ALICE experiment in 2010. The cascade decay candidates at mid-rapidity ($|y| \leq 0.5$) are reconstructed out of combinations of high-quality tracks as measured by the ALICE time projection chamber (TPC) and the silicon Inner Tracking System (ITS) [3]. Further selections applied to these candidates include topological cuts and particle identification by energy loss while traversing the TPC gas. In addition, for the $\Omega$, we reject all candidates whose invariant mass under the $\Xi$ mass hypothesis is less than $8 \text{ MeV}/c^2$ from the $\Xi$ nominal mass.

The number of counts in each $p_t$ bin is taken within $4.5\sigma$ from the invariant mass peak after background subtraction, where we determine the background in the regions from $4.5\sigma$ up to $9\sigma$ away from the peak. In order to compute detection efficiency, we used $\Xi^\pm$ or $\Omega^\pm$ enhanced Monte Carlo event generators such that every simulated event has at least one $\Xi$ or $\Omega$ baryon, and subsequent propagation of the particles is performed through the full ALICE geometry with GEANT3 [4, 5].

Systematic errors are deduced point-by-point for the topological selections, signal extraction and track quality cuts; the $p_t$-independent uncertainties contributing to the systematic error are normalization, material budget, GEANT3 (anti-)proton cross-section, TPC particle identification and mass under the $\Xi^\pm$ hypothesis rejection for the $\Omega^\pm$.

3. Results and Discussion

The $\Xi^\pm$ and $\Omega^\pm$ efficiency-corrected spectra are shown in Fig. 1. The anti-particle to particle ratios are consistent with unity throughout the measured $p_t$ region for both multi-strange baryon species. We fit the spectra with Lévy functions as done previously in the ALICE $\sqrt{s} = 900 \text{ GeV}$ pp strangeness analyses [6]. An additional 8% normalization uncertainty is not shown in Fig. 1.

The wide range in observed transverse momentum leads to an extrapolated area of only 22% for the $\Xi^\pm$ and 26% for the $\Omega^\pm$. The $\Xi^\pm$ integrated yield is approximately 60% higher than the one measured by ALICE at $\sqrt{s} = 900 \text{ GeV}$ for inelastic events [6]. The mean $p_t$ of $\Omega^\pm$ is about 20% higher than for $\Xi^\pm$.

When compared to Monte Carlo event generators, the total yields within the inelastic event category are $2.5 \pm 0.3$ times higher than the PYTHIA 6.4 Perugia-0 [7] predictions for $\Xi^\pm$ and $8.0 \pm 1.1$ times higher for $\Omega^\pm$. Newer tunes have been altered to match charged particle production measurements from pp collisions at 7 TeV, such as the Z2 tune [8]; however, the Z2 tune still underpredicts total $\Xi^\pm$ production by a factor of $1.9 \pm 0.2$ and $\Omega^\pm$ production by a factor of $6.0 \pm 0.8$. In either tune used, the shape of the $p_t$ spectra is not well described, as shown in Fig. 1 for the Z2 tune, and the $\langle p_t \rangle$ is larger in data by about 20%. The one notable exception is the $\Xi^\pm$ spectrum at high $p_t$, where the predictions and the data seem to converge.
When compared to other experiments, the measured yield for the $\Xi^\pm$ is smaller than the one measured by CMS \cite{9}. This is due to the difference in normalization, as the ALICE results are normalized to inelastic events and CMS results are normalized to non-single-diffractive (NSD) events. Under the assumption that the multi-strange baryon production at mid-rapidity is negligible in single-diffractive events, the difference is solely due to the cross-section ratio $\sigma_{\text{NSD}}/\sigma_{\text{inelastic}}$, which the comparison shows to be $76\pm13\%$. The $\langle p_t \rangle$ measured by ALICE and CMS for $\Xi^\pm$ is in agreement.

In order to compute the ratio of $\Omega^\pm/\Xi^\pm$ as a function of $p_t$, the $\Xi^\pm$ analysis was also performed in the same transverse momentum binning as the $\Omega^\pm$. The resulting ratio can be seen in Fig. 2 and is shown to rise with momentum, which is consistent with the different slopes observed in Fig. 1. PYTHIA predictions are also shown and do not reproduce this ratio well in any of the tunes used. This information could be used to further tune PYTHIA to reproduce the strangeness production rates seen in pp collisions at LHC energies.
4. Status of the analysis of Pb-Pb data

Using a data sample of $15 \times 10^6$ lead-lead (Pb-Pb) collisions as measured by ALICE in 2010, we show in Fig. 3 the invariant mass distributions for the multi-strange baryons. A clear signal can be seen in both a wide transverse momentum range (from 1.0 – 6.0 GeV/$c$ for the $\Xi^-$ and $\overline{\Xi}^+$ and 1.0 – 5.0 GeV/$c$ for the $\Omega^-$ and $\overline{\Omega}^+$) and a large reach in centrality, making it possible to perform spectrum extraction even in peripheral event categories such as 60-80%. The combinatorial background is significantly larger than in pp collisions, so that topological cuts had to be tightened to improve the signal to background ratio. Comparisons to pp systems will be drawn once the proper efficiency corrections have been applied.

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