Production of Σ baryons as a function of multiplicity in pp collisions at the LHC with ALICE

Pavel Gordeev[1,*] for the ALICE Collaboration

[1]IUPAP

Abstract. In recent year, the production of charged Σ hyperons in pp and p–Pb collisions was measured by the ALICE collaboration using several techniques. Historically, the first one used the decay channel $\Sigma^+ \rightarrow p\pi^0$ with reconstruction of the proton with the tracking systems at mid-rapidity and the π^0 in the electromagnetic calorimeter EMCAL or via the photon conversion method. The second technique used the decay channel $\bar{\Sigma}^{\pm} \rightarrow \bar{n}\pi^{\pm}$ where charged pions are reconstructed with the tracking systems and the anti-neutron in the precise electromagnetic calorimeter PHOS. We present the transverse momentum spectra of charged Σ and its anti-particle measured in pp collisions at $\sqrt{s}$ = 13 and $\sqrt{s}$ = 5 TeV and compare them to predictions of several models. Finally, we discuss expectations from the Run 3 of LHC and in particular the possibility of Σ particle detection with the reconstruction of its decay after traversing several layers of the upgraded silicon tracker.

1 Introduction

The strangeness content of the final state in ultrarelativistic heavy-ion collisions has been studied so far through measurements of kaons, Λ, Ξ and Ω baryons in pp, pA and AA collisions, but not with Σ baryons yet. To date only Σ^0 in 7 TeV pp collisions have been measured by ALICE, while few other experiments have measured the charged states at lower pp (p$\bar{\text{p}}$) collision energies [1, 2].

Σ baryons contain a single strange quark and form a triplet, with the electric charge defined by its light quark content. In a thermal model, these states are abundant enough to carry a significant fraction of the strangeness produced in the collision. Therefore, the measurement of these states is interesting for the comparison with thermal model predictions. Measurement of the yield of Σ hyperons is also important to control feed-down to lighter states.

A reliable method of reconstructing and identifying Σ baryons is also important to the study of nucleon-Σ correlations, which will shed light on the presence of Σ-hyperons in neutron stars and constrain their Equation-of-State. So far, only p–Σ^0 interaction via femtoscopy was measured [3]. The measured correlation function is consistent with the p–($\Lambda\gamma$) baseline, which indicates the presence of an overall shallow strong potential, but with current uncertainties it is not possible to discriminate between different models. The experimental measurement is a challenging task because all decays of all Σ states involve neutral decay products, thus requiring high-resolution calorimeters or usage of photon conversion method (PCM).

*e-mail: pavel.gordeev@cern.ch

2 ALICE experiment in Run 2

The detailed description of the ALICE experiment can be found in [4]. The current analysis uses the Inner Tracking System (ITS) and Time Projection Chamber (TPC) for the reconstruction of tracks of charged particles. Charged particle identification is done via specific energy loss in TPC and with Time-Of-Flight (TOF) detector. The electromagnetic calorimeters, such as PHOton Spectrometer (PHOS), Electro Magnetic Calorimeter (EMCAL and DCAL), are used for reconstructing photons and anti-neutrons from decays. For multiplicity estimation, the V0 and Silicon Pixel Detectors (SPD) are used.

2.1 Σ^0 measurement in pp collisions at 7 TeV

Σ^0 is reconstructed via its decay into a photon and a Λ. Λ baryons are reconstructed by combining pairs of protons and pions, while photons are reconstructed via the PCM by electron-positron pair. Then, an invariant mass distribution is constructed using selected photon and Λ candidates (Fig. 1 (left panel)). This measurement provides a Σ^0 to Λ integrated yield ratio which complements world data from lower energies (Fig. 1 (right)).

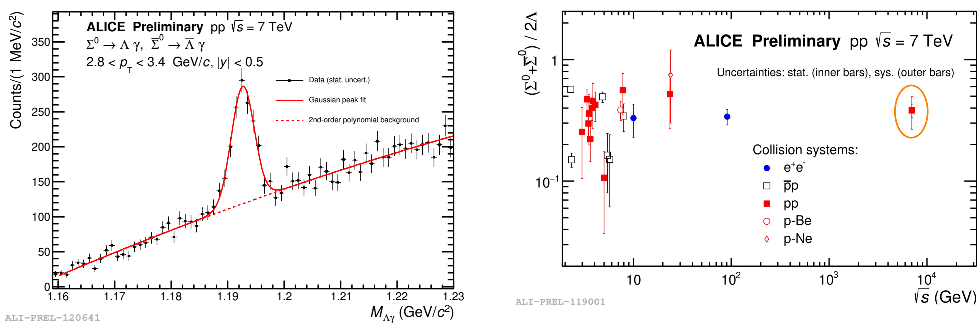

Figure 1. Left: invariant mass distribution of Λ and γ pairs in pp collisions at $\sqrt{s}$ = 7 TeV. Right: Σ^0 to Λ ratio as a function of $\sqrt{s}$ from different experiments

2.2 Σ^+ and $\bar{\Sigma}^-$ measurement in pp collisions at 13 TeV

The measurement of Σ^+ and $\bar{\Sigma}^-$ can be done via π^0 and p channel. The proton is detected directly in the tracking system, the π^0 is reconstructed through two-photon decay. Photons can be detected either in calorimeters or via PCM. Both PCM-Calo and PCM-PCM techniques give results that are in agreement with each other.

One can see comparison of resulting spectrum obtained in Minimum Bias pp collisions with different Monte-Carlo (MC) generators (Fig. 2). The spectrum is well reproduced by the EPOS LHC [5] generator, while PYTHIA8 [6] catches the shape, but underestimates the yield. PYTHIA6 does not describe the shape of the spectrum at low transverse momentum and underestimates the yield.

2.3 $\bar{\Sigma}^+$ and $\bar{\Sigma}^-$ measurement in pp and p–Pb collisions at 5 TeV

A more challenging experimental task is the measurement of $\bar{\Sigma}^{\pm}$ through the anti-neutron and charged pion channel. There is no hadron calorimeter to capture neutrons in the ALICE experiment, but one can try to use electromagnetic calorimeter to reconstruct anti-neutrons.

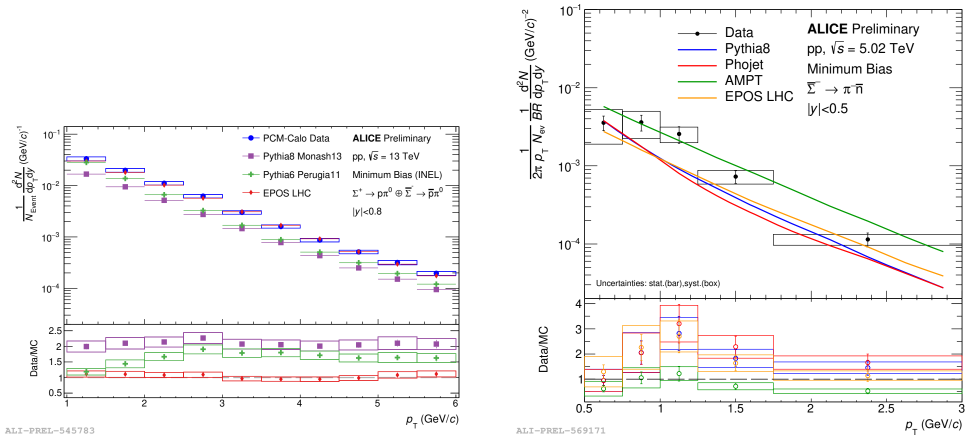

Figure 2. Left: Σ^+ ($\bar{\Sigma}^-$) spectrum in pp collisions at $\sqrt{s}$ = 13 TeV and comparison with different MC models. Right: $\bar{\Sigma}^-$ spectrum in pp collisions at $\sqrt{s}$ = 5.02 TeV and comparison with different MC models

Anti-neutron identification is done using the following parameters: the energy released during annihilation in the calorimeter, the neutrality of the cluster (clusters from charged particles are suppressed), and the dispersion of the cluster (shape of the cluster and number of cells).

However, it is not possible to measure an antineutron momentum directly. Therefore, time-of-flight information from PHOS is used to reconstruct the momentum. After that, $\bar{n}$ and $\pi^\pm$ candidates are combined to reconstruct secondary vertices to apply the topological selections that are used to increase the signal to background ratio.

$\bar{\Sigma}^\pm$ were measured both in pp and p–Pb collisions at 5.02 TeV. In Fig. 2 one can see $\bar{\Sigma}^-$ spectrum with different MC predictions in pp collisions at 5.02 TeV. EPOS LHC, PYTHIA8 and PHOJET [7] show good agreement with data points within large uncertainties. The AMPT [8] model have a good agreement at low p_{T} and overestimates the yield at high p_{T}.

3 Kink topology method in Run 3

The main changes from Run 2 to Run 3 are upgraded detectors to handle continuous readout and improved vertexing capabilities in the central barrel. In addition, an increase of statistics allows more precise measurements.

Σ-hyperons can be reconstructed making use of their kink-topology, reconstructed in the upgraded ITS (ITS2). The new ITS2 uses CMOS Monolithic Active Pixel Sensors, which significantly improve the impact parameter resolution and the tracking efficiency, especially for particles with low transverse momenta, as well as the readout-rate capability. This method is based on searching signals from particles in different detector layers, and requires more statistics to be effective, which Run 3 can provide. In Fig. 3 one can see invariant mass distributions of charged Σ baryons obtained for differently charged pions. However, two differently charged Σ cannot be distinguished from each other using this method. The ITS3 upgrade will help to reduce the width of the signal peaks.

4 Conclusion

For the first time at the LHC, the production of charged Σ-hyperons was measured. The method for anti-neutron reconstruction was proposed, which opens up a variety of new observables. Obtained results are consistent within uncertainties with EPOS LHC predictions and can be used to constrain other MC generators. More precise measurement of Σ-hyperons, Σ-hypernuclei search and hadron-Σ interactions measurement is foreseen at LHC with ALICE in Run 3 in 2022–2025.

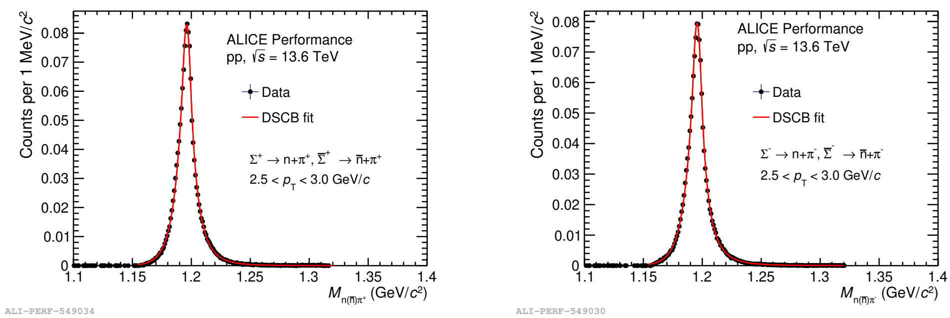

Figure 3. Invariant mass distribution of $n(\bar{n})$ and $\pi^{\pm}$ pairs in pp collisions at $\sqrt{s}$ = 13.6 TeV

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