

# $K_S^0$ & $\Lambda$ Production in ALICE

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**Abstract.** The production of  $\Lambda$  and  $K_S^0$  hadrons at the LHC can be measured through the reconstruction of their weak decay topologies via decay channels with only charged particles in the final state. The tracking and particle identification capabilities of the ALICE detector allow us to measure the spectra of these particles over a wide transverse momentum range ( $0.4 < p_T < 12$  GeV/c), and to precisely determine the behaviour of the baryon-to-meson ratio  $\Lambda/K_S^0$ .

Transverse momentum spectra and production yields at mid-rapidity ( $|y| < 0.5$ ) for  $\Lambda$  and  $K_S^0$  are presented for  $\sqrt{s_{NN}} = 2.76$  TeV Pb–Pb collisions as a function of centrality. The evolution of the  $\Lambda/K_S^0$  ratio is discussed, in comparison with corresponding results in pp collisions at the LHC and in  $\sqrt{s_{NN}} = 200$  GeV Au–Au collisions at RHIC. Comparisons to theoretical models will also be outlined.

## 1. Introduction

Relativistic collisions of heavy ions can be used to study the behaviour of strongly-interacting matter as it undergoes a phase transition from a quark-gluon plasma to a hadronic phase. By studying the transverse momentum ( $p_T$ ) of hadrons emitted from the collisions, information about the production mechanisms of these hadrons can be inferred.

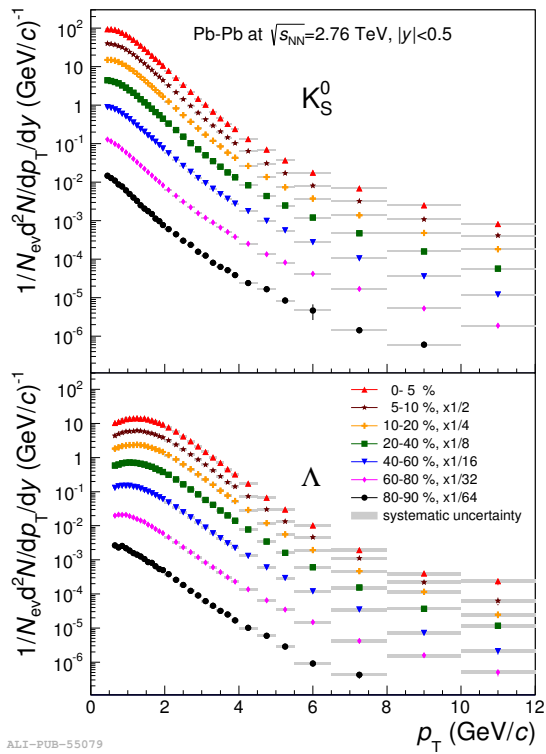
It was observed at the Super Proton Synchrotron (SPS) [1] and at the Relativistic Heavy Ion Collider (RHIC) [2, 3] that ratios of  $p_T$  spectra for baryons and mesons, such as  $p/\pi$  and  $\Lambda/K_S^0$  are enhanced at intermediate  $p_T$ , when compared to the corresponding ratios in pp collisions. At low  $p_T$ , the hydrodynamical flow of the medium could contribute to this effect, as the heavier baryons are pushed to higher momentum than the lighter mesons. However, such models are typically only applicable to  $p_T \sim 2$  GeV/c, while the enhancement is still evident at  $\sim 4$  GeV/c. Another potentially contributing effect is coalescence, in which multiple soft quarks from the medium combine to form hadrons. The momentum of a baryon will then be given by the sum of the momenta of three quarks, and thus be typically higher than mesons formed from two quarks. This mechanism could extend up to higher  $p_T$  values (10 - 20 GeV/c) [4] at LHC energies, if the quarks from jet fragmentation also undergo recombination [5]. Above  $\sim 6$  GeV/c the ratio is compatible with that measured in pp collisions, and so it is expected that vacuum-like fragmentation will dominate hadron production. A precise measurement of these ratios over a broad transverse momentum range for a wide selection of energies and centrality intervals is thus important for examining the interplay between these different mechanisms.

In these proceedings, the measurement of the  $\Lambda/K_S^0$  ratio by ALICE will be discussed. These singly-strange particles can be identified with a single technique over a wide momentum range, which allows for a precise measurement of the ratio.

## 2. Analysis Technique

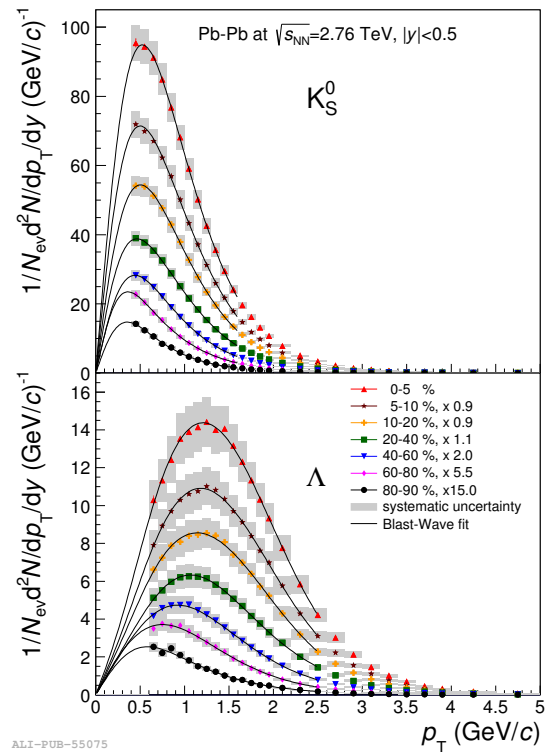
ALICE is designed for excellent particle identification in high-multiplicity collisions. For this analysis, a two-station scintillator detector at forward rapidity (VZERO) was used for event and centrality selection, the Inner Tracking System (ITS) for vertex identification and particle tracking, and the Time Projection Chamber (TPC) for further particle tracking and particle identification (PID) through energy loss measurements. About  $1.5 \times 10^7$  events from the 2010 Pb–Pb run were analysed in 7 different centrality bins spanning from 0-90% of the most central nuclear collisions.

$\Lambda$  and  $K_S^0$  were identified by the topology of their decays into  $p\pi^-$  and  $\pi^+\pi^-$  respectively, with branching ratios of 63.9% and 69.2% [6]. Pairs of oppositely charged tracks which could emerge from a common secondary vertex were considered ‘V0 candidates’, as described in [7]. More stringent cuts were applied to reduce the large level of combinatorial background present in Pb–Pb collisions [8]. Cuts on the distance of closest approach between the two daughter tracks and also to the primary vertex were tightened, as were cuts on the decay radius and the cosine of the pointing angle (the angle between the V0s position and momentum vectors.) In addition, the rate of energy loss in the TPC for positive daughters of  $\Lambda$  candidates with  $p_T$  below 1.2 GeV/c was required to be within  $3\sigma$  of that expected for a proton. A cut was further applied on the Armenteros-Podolanski diagram [9] in order to exclude  $\Lambda$  and  $\bar{\Lambda}$  from being reconstructed as background to the  $K_S^0$ .



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**Figure 1.**  $\Lambda$  and  $K_S^0$  spectra in log scale.



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**Figure 2.**  $\Lambda$  and  $K_S^0$  spectra in linear scale.

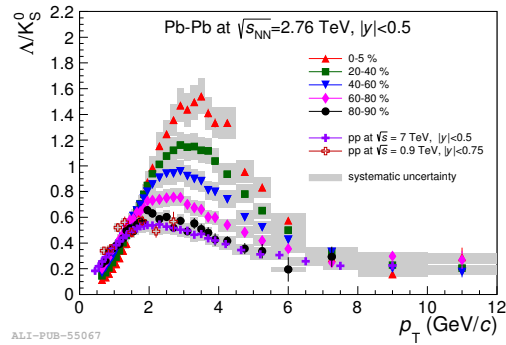
An invariant mass distribution was created for  $\Lambda$  and  $K_S^0$  by assuming that the decay daughters for each V0 candidate were  $p\pi^-$  and  $\pi^+\pi^-$  respectively. The yield of each particle could then be extracted by subtracting the background from the revealed peak. The background was estimated by first using a Gaussian plus 2nd degree polynomial fit to identify the peak region, and then fitting the area to either side of the peak and extrapolating into the ‘peak region’ to estimate

the background under the peak. The signal is then defined as the difference between the total number of counts in the 'peak region' and the background fit in the same region.

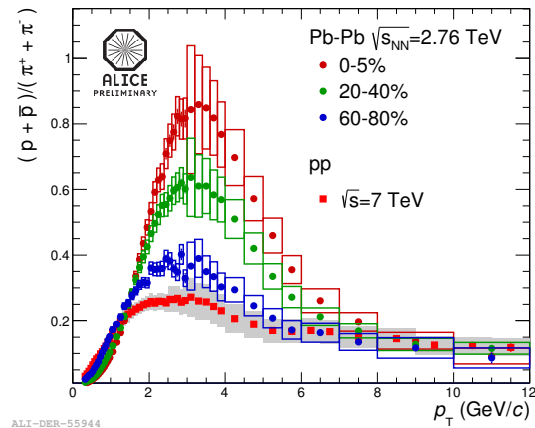
A Monte-Carlo study was used to correct these signals for efficiency and acceptance. Further, the yield of  $\Lambda$  was corrected to remove  $\Lambda$ 's coming from weak decays of  $\Xi^-$  and  $\Xi^0$ , using the  $\Xi^-$  yields measured by ALICE [10]. The final spectra are shown in Figures 1 and 2.

### 3. Results

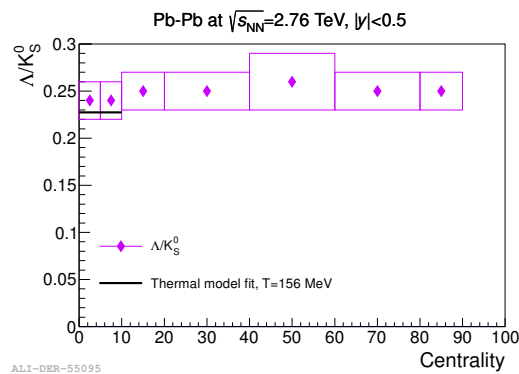
The  $\Lambda/K_S^0$  ratio as measured by ALICE is shown in Figure 3 for different centralities [8]. The figure also includes the ratio measured in pp collisions at energies which bracket the  $\sqrt{s_{NN}} = 2.76$  TeV energy of the Pb–Pb collisions. It can be seen that the ratio in pp collisions does not appear to depend upon the collision energy, and also that the ratio in the most peripheral Pb–Pb collisions (80–90% centrality) is consistent with that measured in pp collisions. All centralities give a comparable result for  $p_T \sim 1.5$  GeV/c, and for  $p_T > 7$  GeV/c, while at the peak of the enhancement, the most central (0–5%) ratio is approximately 3 times that measured in pp collisions. This factor of 3, as well as the  $p_T$  range of the enhancement, is consistent with what is observed for the  $p/\pi$  ratio as shown in Figure 4 [11].



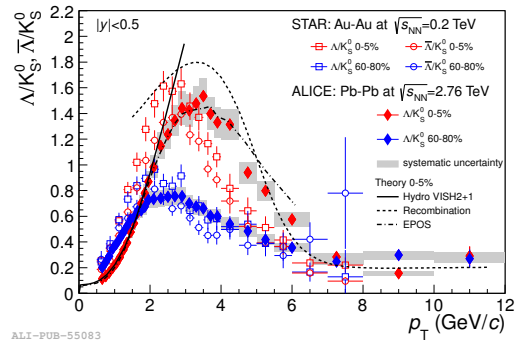
**Figure 3.**  $\Lambda/K_S^0$  ratio for different centrality selections in Pb–Pb, and for pp.



**Figure 4.**  $p/\pi$  ratio for different centrality selections in Pb–Pb, and for pp.



**Figure 5.**  $p_T$ -integrated  $\Lambda/K_S^0$  ratio.



**Figure 6.** Comparison of  $\Lambda/K_S^0$  ratio for central and peripheral collisions in ALICE, STAR, and theoretical predictions.

Studies of the  $p_T$ -integrated yields [8] of  $\Lambda$  and  $K_S^0$  suggest that a thermal model (with a temperature of 156 MeV) predicts accurately the total yields, and further that the ratio of

integrated yields is constant within errors across all centrality intervals, as shown in Figure 5. This would suggest that the enhancement of the ratio of  $p_T$  spectra is due to a redistribution of particles in  $p_T$ , rather than the introduction of additional production channels. This picture is supported by the low  $p_T$  region of the  $\Lambda/K_S^0$  ratio in Figure 3, where there is a change in the ratio with centrality consistent with a depletion of  $\Lambda$  with respect to  $K_S^0$ , which is strongest for the most central collisions.

Figure 6 shows the measured  $\Lambda/K_S^0$  for central (0-5%) and peripheral (60-80%) centrality classes, for  $\sqrt{s_{NN}} = 2.76$  TeV Pb–Pb collisions with ALICE and  $\sqrt{s_{NN}} = 200$  GeV Au–Au collisions with STAR [12]. While the antibaryon/baryon ratio approaches unity at the LHC, it is  $\sim 0.8$  at RHIC, so both  $\Lambda/K_S^0$  and  $\bar{\Lambda}/K_S^0$  ratios have been plotted separately for STAR. From this, it can be seen that the magnitude of the enhancement is very similar at both RHIC and LHC energies. The enhancement extends to slightly higher  $p_T$  at ALICE, but is still restricted to fairly modest  $p_T$ .

Also shown in Figure 6 are predictions by various theoretical models for the 0-5%  $\Lambda/K_S^0$  ratio. The viscous hydrodynamical model [13, 14, 15] describes the behaviour of the ratio accurately below 2 GeV/c, but then strongly deviates from the data as the ratio begins to turn over. A recombination model is also shown [16], which describes the general behaviour of the ratio well, but overestimates the magnitude of the data by approximately 15%. Finally, a result from the EPOS2.17v3 model is shown [17]. This model includes the interaction between jets and the hydrodynamical medium, and appears to describe well the behaviour of the  $\Lambda/K_S^0$  ratio over the full  $p_T$  range. It would be interesting to see how these and other models describe the variation of the ratio with energy and centrality.

#### 4. Conclusions

The  $\Lambda$  and  $K_S^0$  spectra and their ratios have been measured in  $\sqrt{s_{NN}} = 2.76$  TeV Pb–Pb collisions at ALICE over a wide range of centrality and  $p_T$  and compared to those measured in pp collisions at  $\sqrt{s} = 900$  GeV and 7 TeV. At high  $p_T$ , there is no discernible difference between the  $\Lambda/K_S^0$  ratio in pp and Pb–Pb collisions, suggesting that the relative production rates are dominated by vacuum-like fragmentation. In the intermediate  $p_T$  region however,  $\Lambda$  production is strongly enhanced in Pb–Pb relative to  $K_S^0$  for central collisions, while the  $p_T$ -integrated ratio appears to remain constant with respect to centrality. This would indicate that particles are redistributed in  $p_T$  in Pb–Pb as compared to pp collisions. The enhancement is similar at STAR and ALICE, suggesting that any collision energy dependence is weak.

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