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Production of Strange Particles in Jets in Heavy-ion Collisions in ALICE

V. Kučera
Charles University in Prague, Faculty of Mathematics and Physics, Prague, Czech Republic.

Nuclear Physics Institute, The Academy of Sciences of the Czech Republic, Řež, Czech Republic.

Institut Pluridisciplinaire Hubert Curien, Ecole Doctorale de Physique et Chimie-Physique, Université de Strasbourg, Strasbourg, France.

Abstract. The current status of an analysis of production of strange particles in jets in heavy-ion collisions measured with the ALICE experiment at the LHC is presented. The main goal of the analysis is to investigate properties of hot and dense strongly interacting matter created in ultrarelativistic collisions of nuclei by studying hadronisation processes occuring in this medium. For this purpose, strange V0 particles (baryon Λ, meson K^0_S) are chosen to be studied. V0 candidates are reconstructed using selection criteria applied on the topological parameters of their decay. Jets are reconstructed from charged tracks using the anti-k_t algorithm. The uncorrected fragmentation functions are extracted for the strange particles found in the selected jets.

Introduction

Motivation

The theory of strong interaction, Quantum Chromodynamics (QCD), predicts a phase transition of hadronic matter at high temperatures and high energy densities. Under these conditions, quarks and gluons become deconfined and form a state called “quark–gluon plasma” (QGP). It is believed that hadronic matter existed in this state during an early stage of evolution of the Universe. According to the results of the latest experiments, it seems that ultrarelativistic collisions of heavy ions (HIC) enable to create a state of strongly interacting matter resembling QGP and to probe different regions of the phase diagram of hadronic matter. Studying properties of this matter at high temperatures and high energy densities is expected to improve our understanding of QCD.

Matter created in HIC at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) seems to have properties close to those of perfect liquid, manifests presence of partonic degrees of freedom and shows indications of suppression of particle production at high transverse momenta (p_T) which is observed for the jet constituents as “jet quenching”. Fig. 1 shows the nuclear modification factor R_AA which expresses how p_T spectra of hadrons produced in HIC differ from those in proton collisions.

Jet as a probe of strongly interacting medium

In a process involving hard scattering and strong interaction, there are partons produced with high p_T. Such parton created in hard scattering radiates softer partons, resulting in a cascade of partons. This set of partons is called a jet. Partons cannot be observed so at the experimental level, a jet is detected as a collimated spray of hadrons with high p_T. Production of jets in proton collisions is a process well described by perturbative QCD and jets can therefore be used as a probe to study collisions of nuclei.

As a jet propagates through the matter created in HIC, the jet properties are expected to be modified by strong interaction of jet constituents with the medium. This mechanism can modify the jet energy, its shape or particle composition.

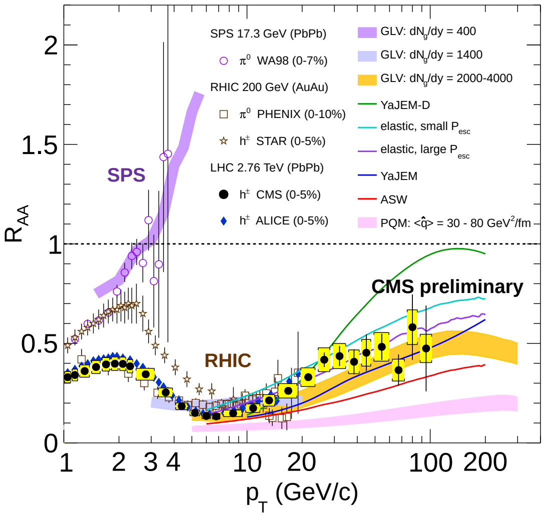

Figure 1. Measurements of modification of hadron production in HIC performed with different experiments [1].

The process where a hadron h is produced from a parton q is described in QCD by the fragmentation functions

$$D_q^h(z, j_{\mathrm{T}}), \quad z = E_h/E_q,$$

where E_h is the hadron energy and j_{T} is the transverse momentum of the hadron relative to the momentum of the parton with energy E_q.

Studying fragmentation functions of particles in jets allows to investigate the effect of the medium on hadronisation mechanisms in jets, as function of quark flavour.

Since the momentum of the initial parton cannot be measured, the parton energy is commonly replaced by the energy of the measured jet. Modification of fragmentation functions by the medium is expected to be pronounced mostly for softer jet constituents, i.e. for low z. In order to focus on this region, fragmentation in jets in HIC is described using distribution of a variable

$$\xi = \ln\left(p_{\mathrm{T}}^{\mathrm{jet}}/p_{\mathrm{T}}^{h}\right).$$

Hadron production

Spectra of hadrons measured at the LHC manifest a strong increase of baryon/meson ratio in HIC relative to pp collisions at intermediate p_{T}. This behaviour has been observed at lower collision energies at RHIC and is also present at the LHC energies [2]. Maximum of the ratio increases with increasing centrality (quantity directly related to the impact parameter of colliding nuclei). The phenomenon is observed for hadrons containing the lightest quarks (u, d) and also for strange hadrons (containing the quark s). Fig. 2 shows the ratios of spectra of baryon Λ and meson $\mathrm{K}_{\mathrm{S}}^{0}$ measured with ALICE.

Hadron production by fragmentation cannot explain this anomaly of baryon/meson ratio. A scenario, proposed to describe it, assumes that hadrons are produced by coalescence and parton recombination in the region of low p_{T}. In the region of intermediate p_{T} these mechanisms are supposed to compete with fragmentation which is a process dominating at high p_{T}.

Particles suitable for investigating these processes are the V0 particles. These are strange neutral particles decaying into two charged particles (daughters). Mother particle is reconstructed using the topology of its V-shaped decay. This procedure is using various parameters describing the spatial configuration of the decay as it is displayed in Fig. 3.

Presented analysis is focused on the reconstruction of baryon Λ ($\overline{\Lambda}$) and meson $\mathrm{K}_{\mathrm{S}}^{0}$ using

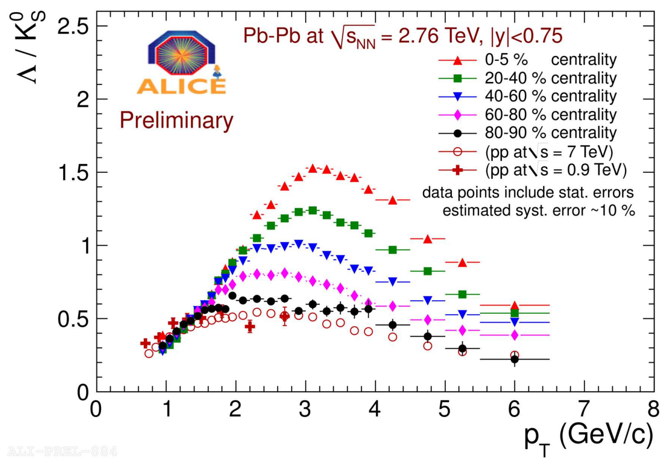

Figure 2. Baryon/meson enhancement observed with ALICE for baryon Λ and meson K^0_S [3].

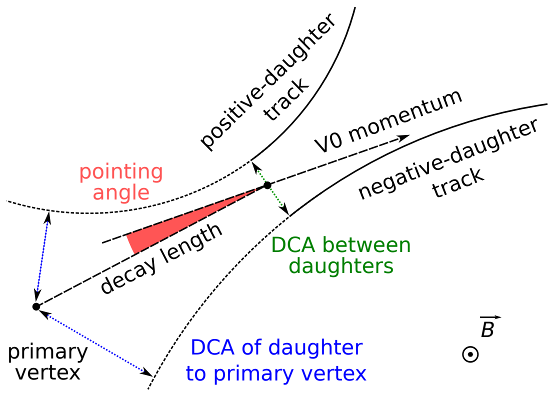

Figure 3. Topological parameters used in the reconstruction of V0 particles.

the following decay channels:

$$K^0_S \to \pi^+ + \pi^- \text{ (b. r. 69 \%)}, \qquad \Lambda \to p + \pi^- \text{ (b. r. 64 \%)}, \qquad \overline{\Lambda} \to \overline{p} + \pi^+ \text{ (b. r. 64 \%)}.$$

Analysis

Experiment

A Large Ion Collider Experiment (ALICE) is one of the four main experiments at the LHC at CERN and the one dedicated to study extreme states of strongly interacting matter. It provides a unique particle identification performance given by using various specific detectors as the Time Projection Chamber (TPC), the Inner Tracking System (ITS), the Time Of Flight detector (TOF) etc. Another important feature of the apparatus is detection of events with high multiplicity of tracks ($\approx 10^4$). The central tracking detectors, operating in a moderate magnetic field of induction of 0.5 T, enable measurement of momenta of charged particles down to $p_T \approx 100$ MeV/c.

Jets

Jets need to be reconstructed using a jet algorithm. The most popular class of jet algorithms, used in the current analyses, are sequential recombination algorithms. Examples of them are k_t [4], anti-k_t [5], Cambridge/Aachen. They all use the same formalism and differ in value of the parameter p:

$$d_{ij} = \min\left({p_{\mathrm{T}}}_i^{2p}, {p_{\mathrm{T}}}_j^{2p}\right)\frac{\Delta_{ij}^2}{R^2}, \qquad \Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

$$p = \begin{cases} 1 & k_{\mathrm{t}} \\ 0 & \text{Cambridge/Aachen} \\ -1 & \text{anti-}k_{\mathrm{t}} \end{cases}$$

where ${p_{\mathrm{T}}}_i, y_i, \phi_i$ are respectively transverse momentum, rapidity and azimuth of a particle i and R is the resolution parameter of the jet algorithm. The procedure of clustering particles into jets starts with high-p_{T} particles for the anti-k_{t} algorithm whereas the k_{t} algorithm clusters low-p_{T} particles first which makes the former suitable for reconstruction of signal jets and the latter for background estimation.

Presented results have been obtained using data from the Pb + Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV measured with ALICE in 2010. Input for the jet algorithm are charged tracks measured in the ITS and the TPC. Signal jets are reconstructed by the anti-k_{t} algorithm with $R = 0.4$ and a threshold for minimum p_{T} of charged tracks $p_{\mathrm{T}}^{\mathrm{min}} = 150\,\mathrm{MeV}/c$ [6].

In a collision of nuclei there is an important contribution of background consisting of soft particles coming from underlying event. The average density of p_{T} corresponding to this background is estimated using the k_{t} jets with the same setting as for the signal jets, where 2 hardest jets are excluded from each event [7]. The density ρ is estimated as

$$\rho = \mathrm{median}\left\{\frac{p_{\mathrm{T}}^{\mathrm{jet}}}{A_{\mathrm{jet}}}\right\}$$

where A_{jet} is area of jet. Raw p_{T} of a reconstructed signal jet is corrected by subtracting p_{T} corresponding to the background in the jet area, using a 4-vector formalism:

$$\mathbf{P}_{\mathrm{bg}} = \rho\mathbf{A}_{\mathrm{jet}}, \qquad \mathbf{P}_{\mathrm{jet}}^{\mathrm{corr}} = \mathbf{P}_{\mathrm{jet}} - \mathbf{P}_{\mathrm{bg}}.$$

The signal jets are selected from the leading jets in a range of pseudorapidity $|\eta| < 0.35$ and are required to have the hardest charged track with $p_{\mathrm{T}} > 5\,\mathrm{GeV}/c$ to reduce contribution of fake jets. Fig. 4 shows the background-subtracted p_{T} spectra of selected leading charged jets in different centrality bins. These spectra still have to undergo corrections for background fluctuations and detector effects, using an unfolding procedure.

Strange particles

Selection criteria used for the reconstructed V0 candidates are tuned to reduce contribution of fake candidates from the combinatorial background. The procedure enables to obtain a very clean peak in the invariant-mass spectrum.

Candidates within a defined range of invariant mass are selected as signal in further analysis. Fig. 5 shows the uncorrected inclusive p_{T} spectra of strange particles for different centrality ranges.

Next step is to search for the V0 particles within the jet cone. This requirement has a significant impact on the statistics of candidates. The ratio of number of V0s found in jets to number of inclusive V0s is $\approx 1:300$. The uncorrected spectra of strange particles in jets in the most central collisions are shown in Fig. 6 for different ranges of jet momentum.

Statistical uncertainties will be reduced when using data measured in 2011, where a much higher statistics is available.

Another step in the analysis is to calculate the value of $\xi = \ln\left(p_{\mathrm{T}}^{\mathrm{jet}}/p_{\mathrm{T}}^{h}\right)$ for each V0 candidate and obtain the distribution $\mathrm{d}N/\mathrm{d}\xi$. The uncorrected fragmentation functions for different jet momenta are shown in Fig. 7.

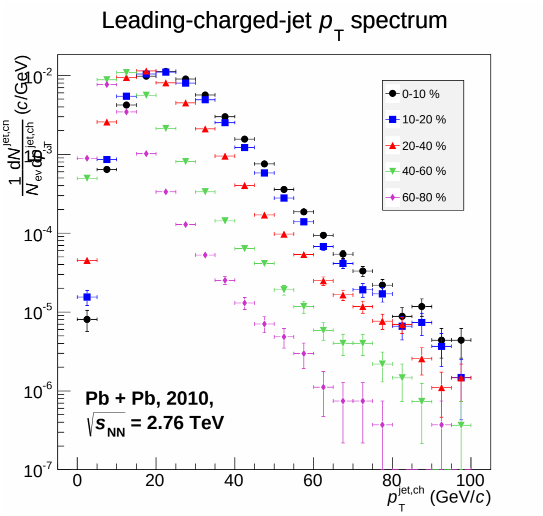

Figure 4. Spectrum of leading charged jets in different centrality bins, corrected for average background density.

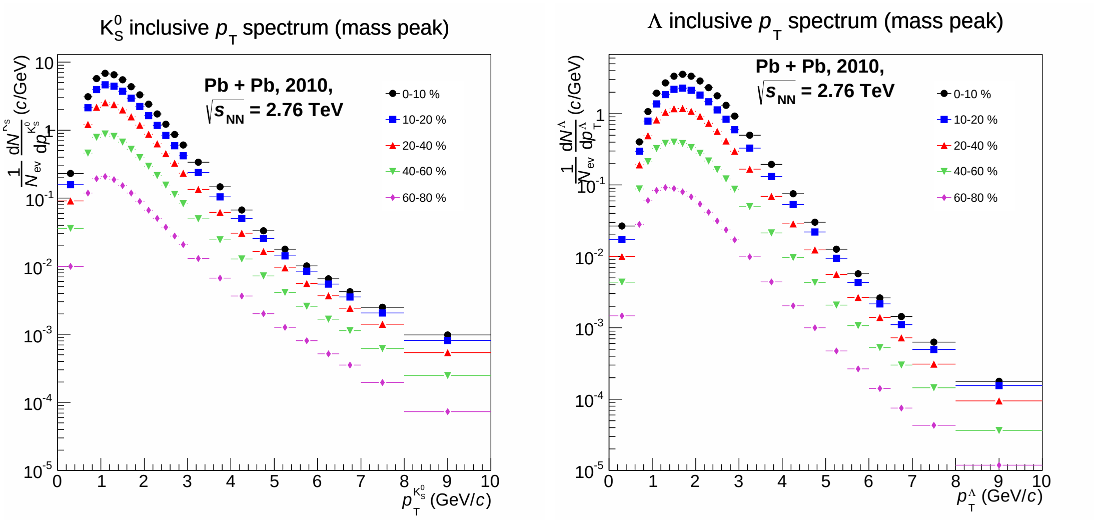

Figure 5. Uncorrected inclusive p_{T} spectra of strange particles in different centrality bins.

Hard jet constituents are plotted in the low ξ region. These particles should be produced mainly by fragmentation. Soft particles populating the high ξ region might be produced with participation of other hadronisation mechanisms like coalescence and parton recombination.

When the measured fragmentation functions are fully corrected, the results will be compared with theoretical predictions (see Fig. 8) which expect the modification of fragmentation functions by medium in HIC to be sensitive to the type of particle.

Fig. 9 shows uncorrected baryon/meson ratio for inclusive candidates and for candidates found in jets in range $p_{\mathrm{T}}^{\mathrm{jet}} \in 10\text{–}20\ \mathrm{GeV}/c$. The ratio enhancement and its centrality dependence are well visible for inclusive particles. Higher statistics will enable comparison of ratio of inclusive particles with that of particles in jets.

Conclusion

An analysis of strange particles in jets in heavy-ion collisions in ALICE has been presented together with its first results. Charged jets were reconstructed and corrected for average contribution of background. Strange particles $\mathrm{K}^0_{\mathrm{S}}$ and Λ were reconstructed and found in jets.

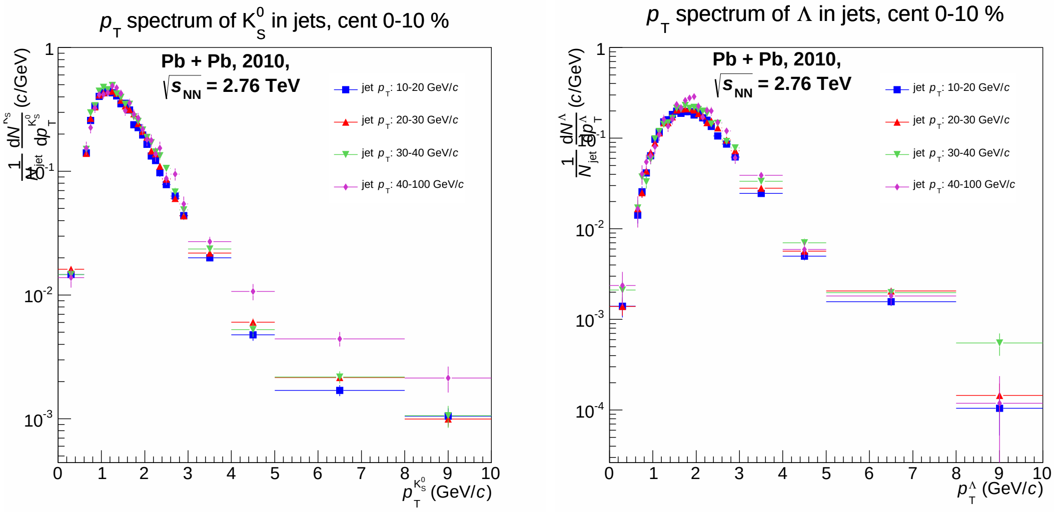

Figure 6. Uncorrected spectra of strange particles in jets in the most central collisions.

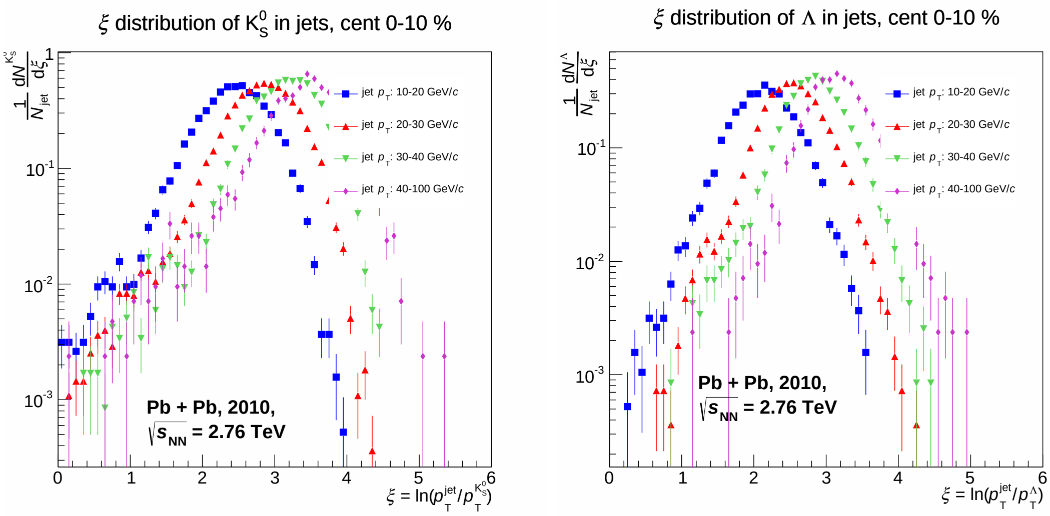

Figure 7. Uncorrected fragmentation functions of strange particles in the most central collisions.

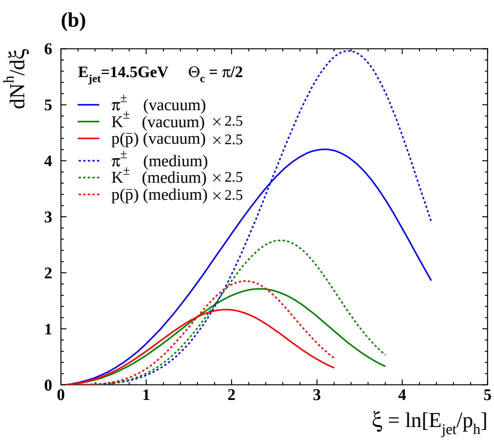

Figure 8. Theoretical prediction for fragmentation functions of different types of particles in vaccum and in medium [3].

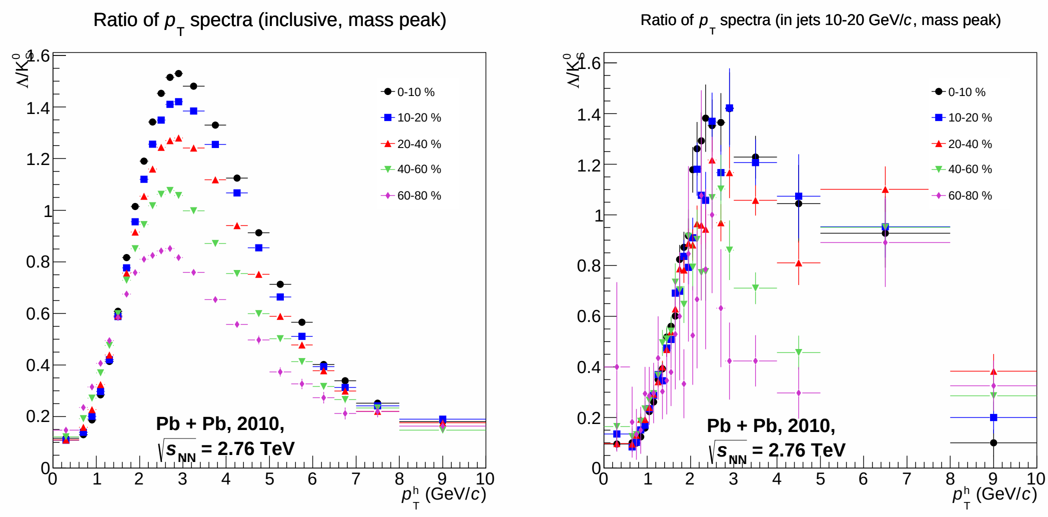

Figure 9. Uncorrected baryon/meson ratio of strange particles for inclusive candidates (left) and candidates in jets (right), in different centrality bins.

Uncorrected inclusive p_T spectra, p_T spectra of particles in jets and fragmentation functions were obtained.

Future analysis steps include optimisation of V0 reconstruction criteria and improvement of signal extraction. Further corrections need to be applied to the V0 reconstruction procedure and to the jet spectra. Another step in the analysis is using information from electromagnetic calorimeter. This would enable performing of reconstruction of full jets including their neutral component.

When the results are fully corrected, conclusions can be drawn from comparison of measured strange-particle spectra with predictions of fragmentation models.

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