PROCEEDINGS OF SCIENCE

Multi-differential studies to explore strangeness enhancement in pp collisions with ALICE at the LHC

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The relative production rate of (multi-)strange hadrons in high multiplicity hadronic interactions is enhanced with respect to the one measured at lower multiplicities and reaches values observed in heavy-ion collisions. The microscopic origin of this striking phenomenon, historically interpreted as a signature of quark-gluon plasma (QGP) formation in heavy-ion collisions, is still unknown: is it related to soft particle production or to hard scattering events, such as jets? Is it related to final particle multiplicity only or does it also depend on initial state effects? The ALICE experiment has addressed these questions by performing dedicated measurements in pp collisions at $\sqrt{s}$ = 13 TeV. To separate strange hadrons produced in jets from those produced in soft processes, the angular correlation between high-p_{T} charged particles and strange hadrons has been exploited. The near-side jet yield and the out-of-jet yield of $\mathrm{K}^0_{\mathrm{S}}$ and Ξ have been studied as a function of the multiplicity of charged particles produced in pp collisions.

Moreover, a multi-differential analysis has been carried out to disentangle the contribution of final state multiplicity from the one of effective energy available for strange particle production. The effective energy has been estimated by subtracting the energy measured in the Zero Degree Calorimeters (ZDC) from the centre-of-mass energy.

The results suggest that soft (i.e. out-of-jet) processes are the dominant contribution to strange particle production and that initial state properties do not play a significant role in strangeness production, which is mainly driven by final particle multiplicity.

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1. Introduction

Heavy-ion collisions are a unique tool to study the quark-gluon plasma (QGP) [1], a state of matter in which quarks and gluons are not bound within hadrons by the strong force. QGP is expected to form in heavy-ion collisions, where high energy density and temperatures are reached, leading to quark and gluon deconfinement. One proposed signature of QGP formation is the strangeness enhancement effect [2], which consists in an increase of the ratio of strange to non-strange hadron yields in Pb–Pb collisions with respect to minimum bias pp collisions. This effect has been investigated by studying its dependence on the multiplicity (i.e., the number) of charged particles produced in the collisions [3–6]. Results show that the ratios of different strange hadron yields to pion yields increase with the multiplicity of charged particles, revealing a smooth transition between different collision systems, from low multiplicity pp to high multiplicity Pb–Pb collisions. This behaviour is striking as different particle production mechanisms are expected to be involved in the different collision systems.

In these proceedings, recent results exploring the origin of strangeness enhancement in pp collisions are presented.

To understand if strangeness enhancement in pp collisions is driven only by final state effects, or if initial state effects also play a role, $\Xi^{\pm}$ production in pp collisions at $\sqrt{s}$ = 13 TeV is studied using a multi-differential approach in order to factor out the contribution of the effective energy available for particle production.

To investigate if strangeness enhancement is related to hard scattering processes or to soft particle production mechanisms, the $\mathrm{K^0_S}$ and $\Xi^{\pm}$ yields are studied in jets and out of jets as a function of the final state charged particle multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV. The near-side jet and out-of-jet production yields are studied exploiting the correlation between the direction of high-p_{T} charged particles and the one of strange hadrons.

2. Analysis strategies

Strange hadrons are identified with the ALICE detector [7] by exploiting their weak decay topology into charged hadrons. The decay products are reconstructed and identified using the Time Projection Chamber (TPC) [8] of the ALICE detector and topological and kinematic selections are applied to reduce the combinatorial background. Multiplicity classes are defined starting from the distribution of the signal amplitude measured by the two V0 detectors placed at forward rapidity [9]. For each V0M multiplicity class, an average number of charged particles produced at midrapidity $\langle \mathrm{d}N/\mathrm{d}\eta \rangle_{|\eta|<0.5}$ is measured.

In order to study the role of initial state effects the concept of effective energy available for particle production is exploited. The effective energy is smaller than the centre-of-mass energy because of the leading baryon effect [10], which consists in a high probability of emitting baryons with large longitudinal momenta along the direction of the proton beams. An estimate of the energy carried away by the leading baryons is provided by the energy deposited in the two Zero Degree Calorimeters (ZDC) [7] placed at forward rapidity on both sides of the interaction point. Effective energy classes (labelled as $\sqrt{\mathrm{s}}$ – ZDC in the Figures) are defined starting from the signal amplitude in the ZDC calorimeters.

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The correlation between effective energy and charged particle multiplicity $\langle dN/d\eta \rangle_{|\eta|<0.5}$ is studied using Monte Carlo simulations based on PYTHIA 8 [11]. Events selected according to standalone V0M multiplicity classes or ZDC energy classes show the same correlation between $\langle dN/d\eta \rangle_{|\eta|<0.5}$ and effective energy. To disentangle initial from final state effects a multi-differential analysis in effective energy and multiplicity classes is needed.

To study the production of strange hadrons in jets and out of jets, the angular correlation between high-p_T charged tracks (trigger particles) and strange hadrons is exploited [12]. The trigger particle is defined as the charged particle with the highest-p_T found in the event and satisfying the kinematic selection $p_T > 3$ GeV/c. The trigger particle direction is considered as a proxy for the jet axis. Strange hadrons produced in jets are expected to be found at a small angular distance from the trigger particles, and therefore the angular correlation distribution in a ($\Delta\eta$, $\Delta\varphi$) region centred at (0, 0) is used to extract the near-side jet yield, after proper subtraction of the out-of-jet contribution. The out-of-jet contribution is evaluated at larger values of $\Delta\eta$ and $\Delta\varphi$, where no contribution from jet production is expected. The whole angular correlation distribution is used to obtain the full production yield.

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3. Results

The left panel of Fig. 1 shows the ratio between the $\Xi^{\pm}$ yield and the charged particle multiplicity at midrapidity $\langle dN/d\eta \rangle_{|\eta|<0.5}$ (self-normalised to INEL>0[1]) as a function of $\langle dN/d\eta \rangle_{|\eta|<0.5}$. Events are classified in V0M multiplicity classes after fixing the effective energy to high values (full markers) or low values (open markers). The two sets of points are compatible with each other, suggesting that the observed strangeness enhancement with multiplicity is driven by the final state multiplicity, while initial state effects do not play a significant role. This observation is confirmed by the results shown in the right panel of Fig. 1. In this case, events are classified in ZDC energy classes, after fixing the multiplicity to high values (full markers) or to low values (open markers). No significant dependence on the effective energy percentile is observed.

To investigate the different contributions of hard scattering events and of soft processes, the full, out-of-jet and near-side jet p_T spectra of K^0_S and $\Xi^{\pm}$ are studied in different V0M multiplicity classes. As expected, the near-side jet spectra (right panel) are harder than the out-of-jet spectra (left panel), with the latter being related to soft particle production. The same is observed for the K^0_S meson. The p_T spectra are interpolated in order to extract the yield in the p_T intervals were it cannot be measured.

The left panel of Fig. 2 shows the Ξ yield per trigger particle normalised to the corresponding $\Delta\eta\Delta\varphi$ area as a function of $\langle dN/d\eta \rangle_{|\eta|<0.5}$. For both K^0_S and Ξ, the full and out-of-jet yields increase with the multiplicity of charged particles, while the near-side jet yield shows a much milder evolution, suggesting that the relative contribution of soft processes increases with the multiplicity.

The strangeness enhancement effect can be studied by looking at the Ξ/K^0_S yield ratio as a function of $\langle dN/d\eta \rangle_{|\eta|<0.5}$ (right panel of Fig. 2). The increase with multiplicity of the ratio of full yields is attributed to the larger strangeness content of the Ξ ($|S| = 2$) with respect to the K^0_S ($|S| =$

[1] INEL>0 is a class of inelastic events having at least one charged particle in $|\eta|< 1$

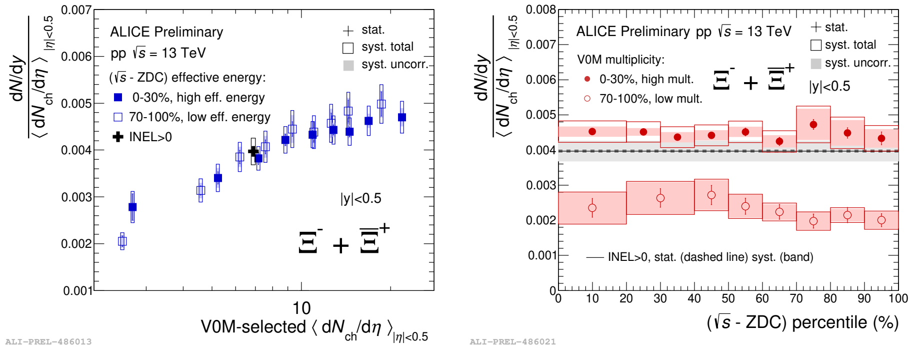

Figure 1: Ratio between the $\Xi^{\pm}$ yield and the charged particle multiplicity at midrapidity $\langle dN/d\eta\rangle_{|\eta|<0.5}$ as a function of $\langle dN/d\eta\rangle_{|\eta|<0.5}$ (left) and effective energy percentile (right). Events are classified in multiplicity classes after fixing the effective energy (left) or in effective energy classes after fixing the charged particle multiplicity (right).

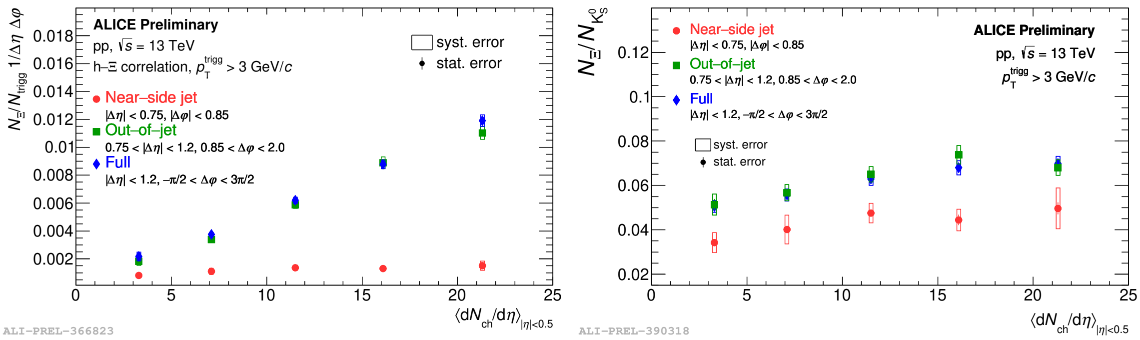

Figure 2: (Left) Ξ yields per trigger particle and per unit $\Delta\eta\Delta\varphi$ area vs charged particle multiplicity at midrapidity $\langle dN/d\eta\rangle_{|\eta|<0.5}$ for near-side jet (red markers), out-of-jet (green markers) and full (blue markers) production. (Right) Ξ/K^0_S yield ratio vs charged particle multiplicity at midrapidity $\langle dN/d\eta\rangle_{|\eta|<0.5}$ for near-side jet (red markers), out-of-jet (green markers) and full (blue markers) production. In both panels, the statistical uncertainties are represented by the error bars and the total systematic uncertainty by the empty boxes.

1). The out-of-jet ratio increases with multiplicity in a similar way, while firm conclusions about the multiplicity dependence of the near-side jet ratio cannot be drawn due to the large uncertainties. While the out-of-jet ratio is compatible with the ratio of full yields, the near-side jet ratio is smaller for all values of multiplicity, suggesting that soft particle production represents the dominant contribution to the strangeness enhancement effect in pp collisions.

4. Conclusions

The ALICE collaboration carried out several multi-differential analyses to investigate the origin of the strangeness enhancement effect in pp collisions. In these proceedings, a double-differential analysis of $\Xi^{\pm}$ production in combined multiplicity and effective energy classes was presented. Results suggest that the strangeness enhancement observed in pp collisions is driven by the final

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state particle multiplicity, whereas initial state effects do not play a significant role. Moreover, the near-side jet and out-of-jet production of K^0_S and $\Xi^{\pm}$ hadrons was presented as a function of the multiplicity of charged particles produced in pp collisions at $\sqrt{s}$ = 13 TeV. Results suggest that soft processes represent the dominant contribution to strange hadron production.

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