Multiplicity dependence of strange and multi-strange particle in jets in pp collisions at $\sqrt{s}\ =\ 7$ TeV

authors

Abstract

Comprehensive results on the production of unidentified charged particles, $\pi^{\pm}$, $K^{\pm}$, p, K^0_S, K^{*0}, ϕ, Λ, $\Xi^{\pm}$, $\Omega^{\pm}$ hadrons in jets in proton-proton (pp) collisions at $\sqrt{s}\ =\ 7$ TeV are presented with two developed colour reconnection models, the new colour reconnection model and the rope hadronization model, in PYTHIA 8 generator. The observables are ratios of identified hadron yields as a function of the transverse momentum (p_{T}) and the final-state activity (the charged multiplicity).

1 Introduction

In heavy-ion collisions at ultra-relativistic energies, it is well established that a strongly coupled Quark-Gluon-Plasma (QGP) is formed [**? ? ? ? ?**]. Recent measurements in high multiplicity pp, p–A and d–A collisions at different energies have revealed strong flow-like effects even in these small collision systems [**? ? ? ? ? ? ? ? ? ? ?**]. The baryon-to-meson ratios p/π and Λ/K^0_S, in pp and p–Pb collision systems, exhibit a characteristic depletion at $p_{\mathrm{T}} \sim 0.7$ GeV/c and an enhancement at intermediate p_{T} ($\sim$ 3 GeV/c), which is qualitatively similar to that observed in Pb–Pb collisions [**?**]. In a letter [**?**], the ALICE Collaboration reported the multiplicity dependent enhancement of strange (K^0_S, Λ and $\overline{\Lambda}$) and multi-strange (Ξ^-, $\overline{\Xi}^+$, Ω^- and $\overline{\Omega}^+$) particle in pp collisions at $\sqrt{s}\ =\ 7$ TeV. As well as, those results were complemented by the measurement of $\pi^{\pm}$, $K^{\pm}$, p, $\overline{\mathrm{p}}$, K^{*0} and ϕ with ALICE [**?**]. Such behaviour cannot be reproduced by any of the MC models commonly used, suggesting that further developments are needed to obtain a complete microscopic understanding of strangeness production and indicating the presence of a phenomenon novel in high-multiplicity pp collisions.

In a recent study, to provide further insight into the particle production mechanisms in high-multiplicity pp and p–Pb events, the ALICE Collaboration has studied baryon-to-meson ratios with a new method: by studying the ratios in two parts of the events separately – inside jets and in the event portion perpendicular to a jet cone [**?**]. In contrast to the inclusive distribution, the p_{T}-differential Λ/K^0_S ratio within jets in pp and p–Pb collisions does not exhibit baryon enhancement at intermediate p_{T}. It is plausible that the baryon enhancement may therefore be attributable to the soft (low Q^2) component of the collision as discussed in [**?**].

In this work, inspired by this paper [**?**], we study the "strangeness to pion ratio increase with multiplicity" and the "baryon-to-meson ratio enhancement at intermediate p_{T}" with charged-particle jet probe by PYTHIA model. In this contribution we consider two of the models: the new colour reconnection (CR) model [**? ?**] and the colour rope model [**? ? ?**] in the PYTHIA 8 generator. Both considered colour reconnection models are built upon the Lund model for string hadronization [**? ?**]. In these models, outgoing partons are connected with string-like colour fields, which fragment into hadrons when moving apart.

The paper is structured as follows:the results compared to data are provided in Sec. 2, the predictions results can be find in Sec. 3, and in the end, the paper will be summarized in Sec. 4,

2 Compare to data

The models perform as intended when comparing to existing data. An event and particle selection was implemented to mimic a possible experimental setup. The inclusive measurements on the charged particle pseudo-rapidity and multiplicity distributions are presented in Figure 1.

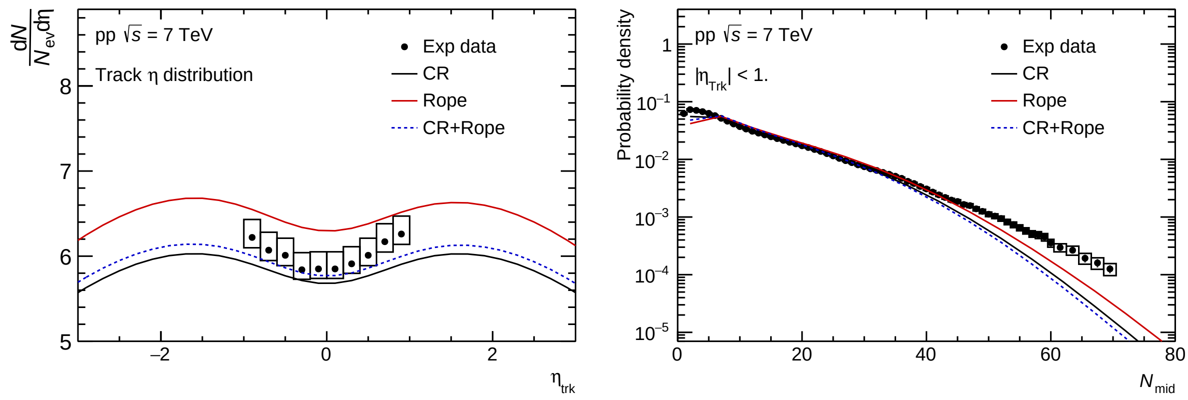

Figure 1: Charged particle pseudo-rapidity (η_{trk})(left) and number of mid-rapidity tracks (N_{mid}) (right) distribution for pp collisions at $\sqrt{s} = 7$ TeV. The experimental data are taken from [**?**].

Since rope and colour reconnection effects will rise with increasing event activity in pp, it is desirable to use a discriminator for event activity which can both be measured in experiments and be sensible reproduced theoretically. Here we use the number of charged particles in the forward ($2 < |\eta| < 5$) direction. The average charged densities in each event for different string tension implementations are presented in Table A.3.

The p_{T}-integrated yields of $\mathrm{K}^0_{\mathrm{S}}$, K^{*0}, ϕ, Λ, Ξ and Ω in pp collisions at $\sqrt{s} = 7$ TeV with three configurations, are shown in Figure 2. All of those three configurations can show an increase of all species as a function of multiplicity. The simulations are shown to compare well to the data in Ref [**? ?**]. The simulation results of mesons, $\mathrm{K}^0_{\mathrm{S}}$, K^{*0}, and ϕ, show that the p_{T}-integrated yields are increasing faster for Rope mode than CR ones. In the contrary, the p_{T}-integrated yields of baryons, Λ, Ξ, and Ω, got by Rope are increasing slower than CR ones. The CR + Rope is the fastest in most cases, and can predict data the best. In addiction, only the CR + Rope can predict the multi-strange baryons (Ξ and Ω) well. These phenomena, above all, hint that the Rope mechanism will give larger production rates for strangeness in high multiplicity events, and the CR mode will give larger recombination rates for partons recombined to baryons.

The corresponding hadrons to π p_{T}-integrated ratios, $\mathrm{K}^0_{\mathrm{S}}/\pi$, ϕ/π, Λ/π, Ξ/π, and Ω/π as functions of $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle_{|\eta|<0.5}$ distributions in pp collisions at $\sqrt{s} = 7$ TeV are studied in Figure 3. The simulation results of mesons to π ratio, $\mathrm{K}^0_{\mathrm{S}}/\pi$, ϕ/π ,show that the models underestimate the experiment results, which also show the prediction of Rope mode is larger than the prediction of CR mode. In the contrary, the baryon to π ratios, Λ/π, Ξ/π, and Ω/π, got by Rope are less than CR ones. In addiction, only the CR + Rope gives the best prediction of the multi-strange baryons to π ratios.

The p_{T}-differential spectra of hadrons at midrapidity ($|y| < 0.5$) in minimum bias pp collisions at $\sqrt{s} = 7$ TeV are presented in Figure 4. All those models can predict the experimental data. Prediction results are almost no different among those three configurations. Only for Ω (sss) particle, the CR + Rope can

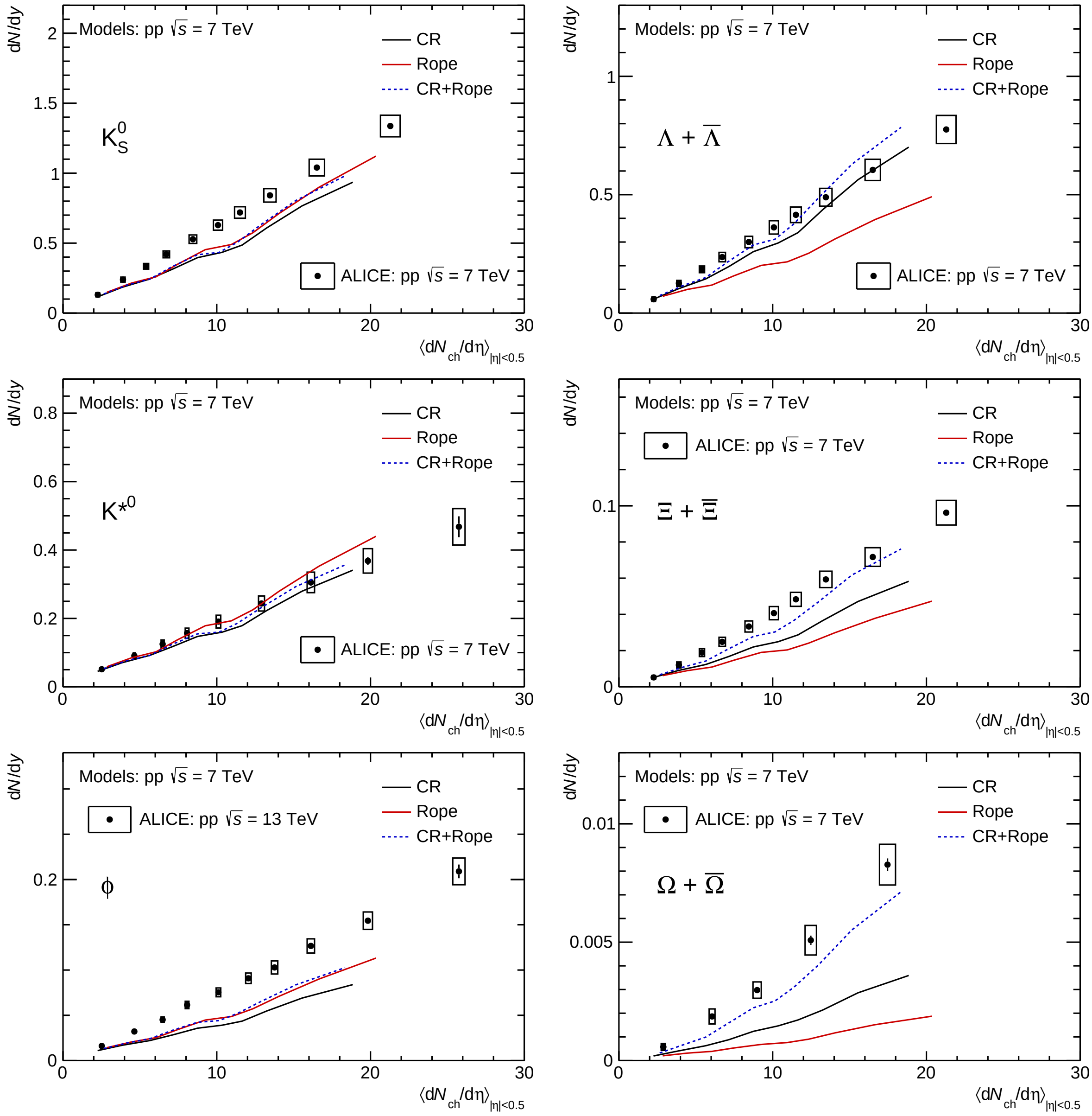

Figure 2: p_T-integrated yields dN/dy of various hadrons, K^0_S, K^{*0}, ϕ, Λ, Ξ, and Ω, as functions of $dN_{ch}/d\eta_{|\eta|<0.5}$. The mesons yields are shown in the left plots, and the baryons yields are shown in the right plots. Model results are show for pp collisions at $\sqrt{s} = 7$ TeV, data for pp collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 13$ TeV (only for ϕ particle). The data point are taken from [**? ?**].

68 simulate well.

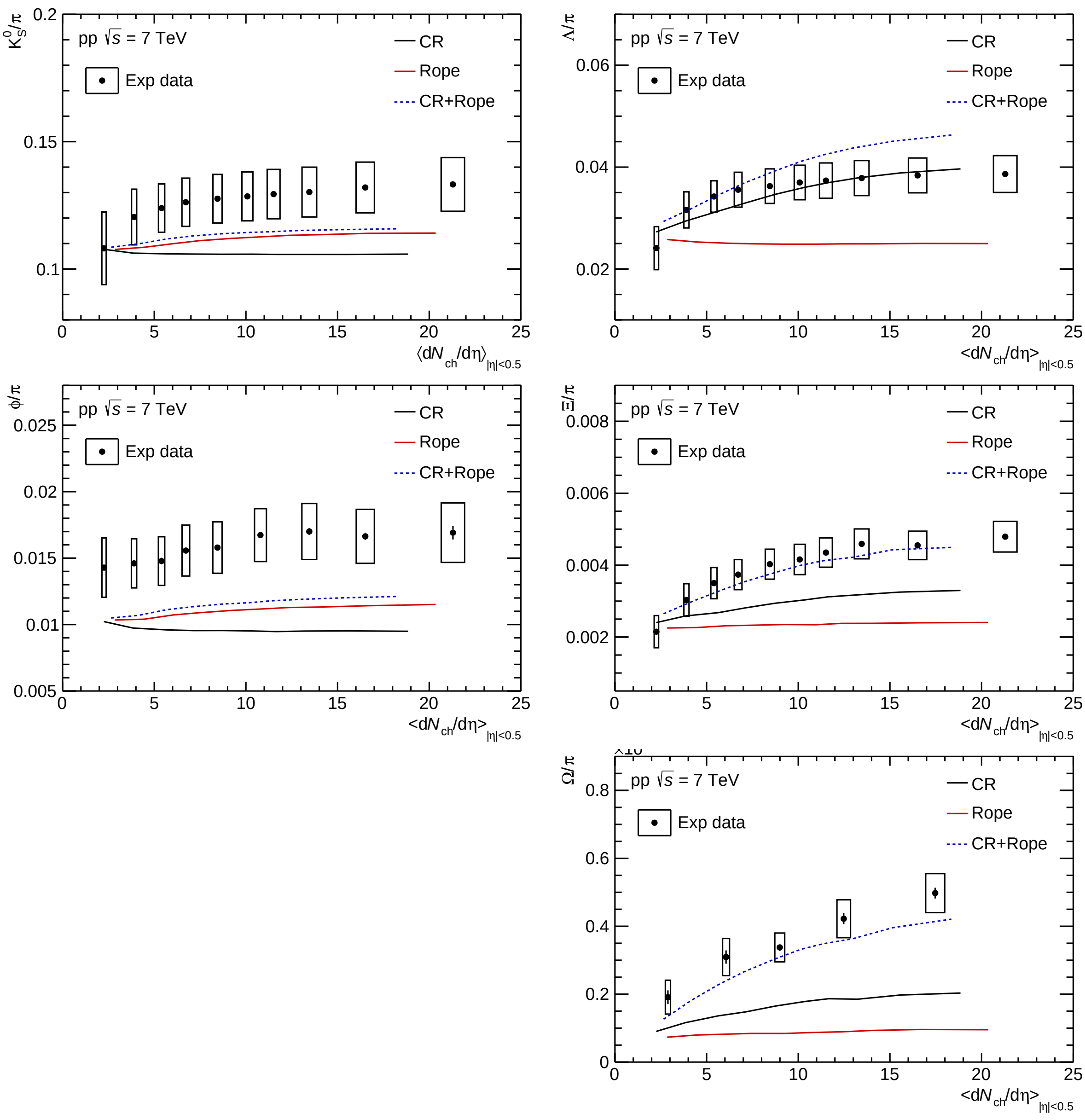

Figure 3: Hadrons to π p_{T}-integrated ratios, $\mathrm{K}^0_{\mathrm{S}}/\pi$, ϕ/π, Λ/π, Ξ/π, and Ω/π, as function of $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta_{|\eta|<0.5}$ distributions in pp collisions at $\sqrt{s}$ = 7 TeV. The mesons to π ratios are shown in the left plots, and the baryons to π ratios are shown is the right plots. The data point are taken from [**? ?**].

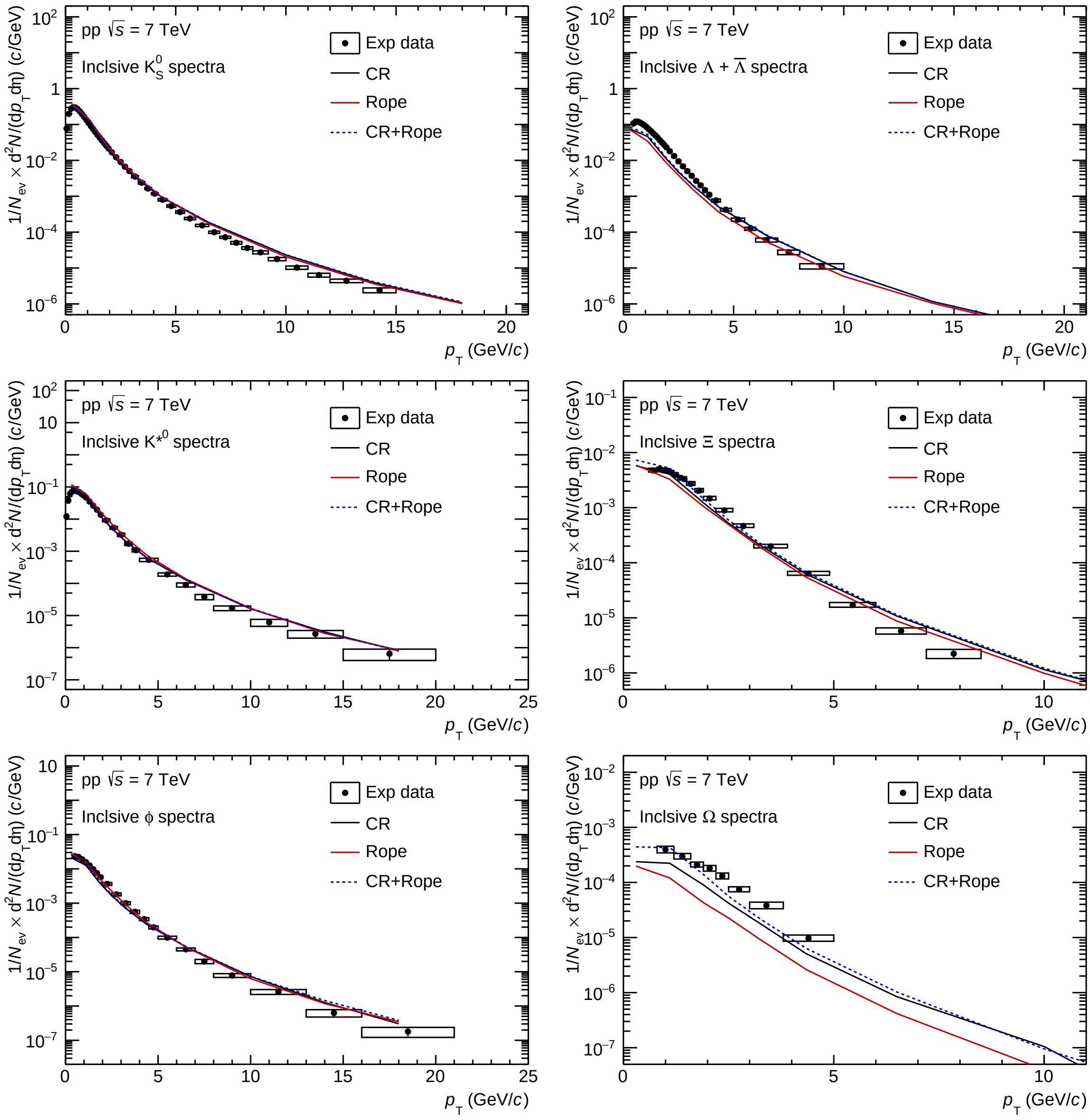

Figure 4: Transverse momentum spectra of strange hadrons measured at midrapidity $|y| < 0.5$ in pp collisions at $\sqrt{s}$ = 7 TeV TeV. Data taken from [**? ? ?**].

3 Predictions

In this work, we used CR, Rope and CR + Rope models to predict the particles produced in charged-particle jets distributions in pp collisions at $\sqrt{s}\ =\ 7$ TeV. The analysis strategy is following the Ref [**?**] which is studied the production of K^0_S and Λ in jets by ALICE experiment. The strange hadrons studied in this paper are generated within $|\eta| < 0.75$. The charged-particle jets are reconstructed using the anti-k_T algorithm [**?**] from the FastJet package [**? ?**], which is a commonly used jet finding algorithm with resolution parameter $R = 0.4$. A cut on transverse momentum of reconstructed charged-particle jet ($p_{\mathrm{T,jet}} > 10$ GeV/c) is applied according the ALICE study [**?**]. To obtain the yields of hadrons within the charged-particle jet, the particles are selected based on their distance from the jet axis in the pseudo-rapidity and azimuthal angle plane ($\eta - \varphi$)

$$R(\mathrm{Par,\ jets}) = \sqrt{\left(\eta_\mathrm{jet} - \eta_\mathrm{Par}\right)^2 + \left(\varphi_\mathrm{jet} - \varphi_\mathrm{Par}\right)^2}. \tag{1}$$

A particle with a radial distance from a given jet $R(\mathrm{Par,\ jet}) < 0.4$ is considered matched to the charged-particle jets.

p_T-integrated yield and corresponding ratios as functions of $\mathrm{d}N_\mathrm{ch}/\mathrm{d}\eta$, the p_T-differential yields and corresponding ratios will be shown in this section. The jet selection criteria is the same as [**?**].

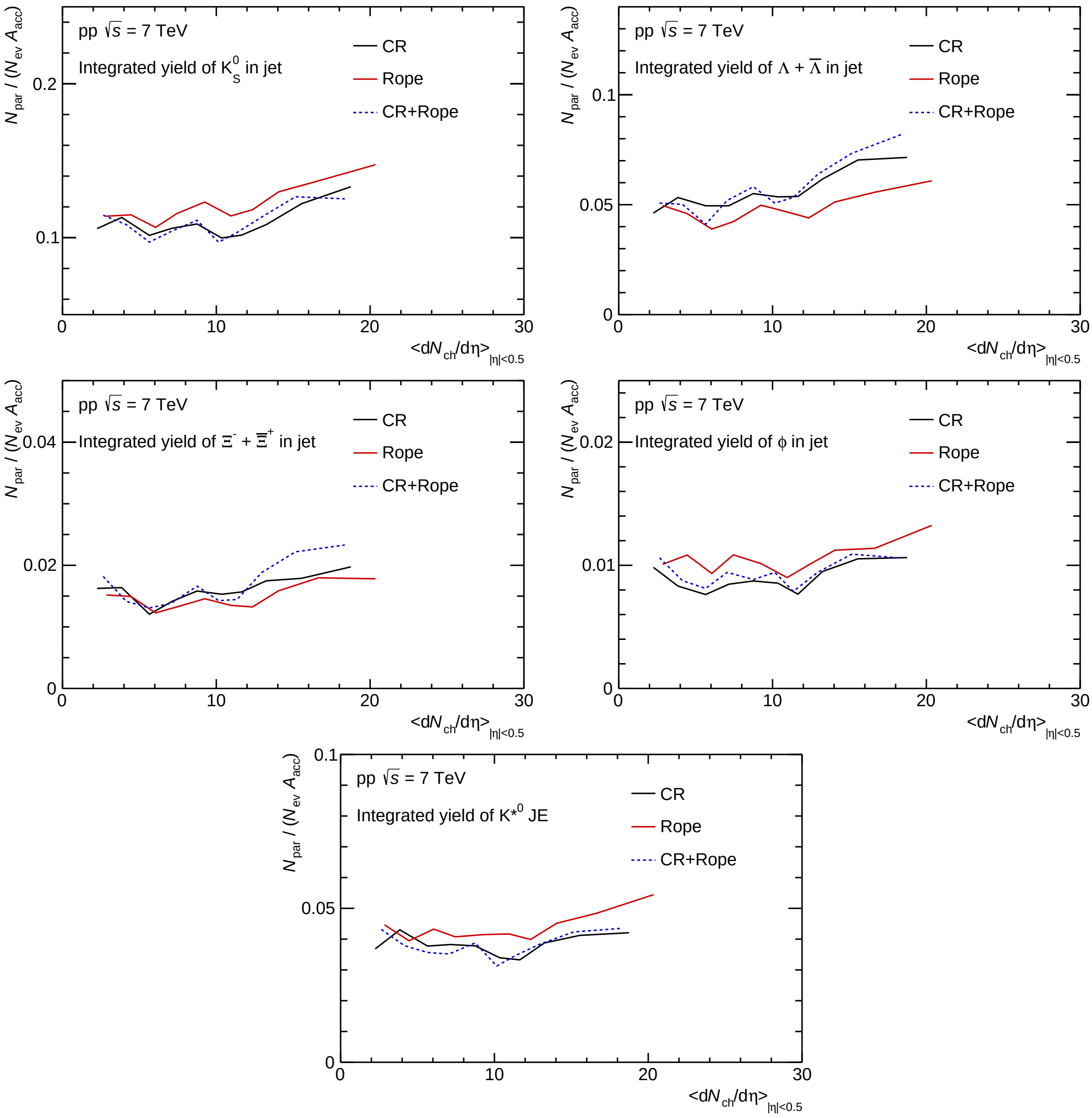

Figure 5: Integrated yields of particles in jet with $\langle dN_{\mathrm{ch}}/d\eta\rangle$.(Data point at 13 TeV is used hadron-strange correlation method)

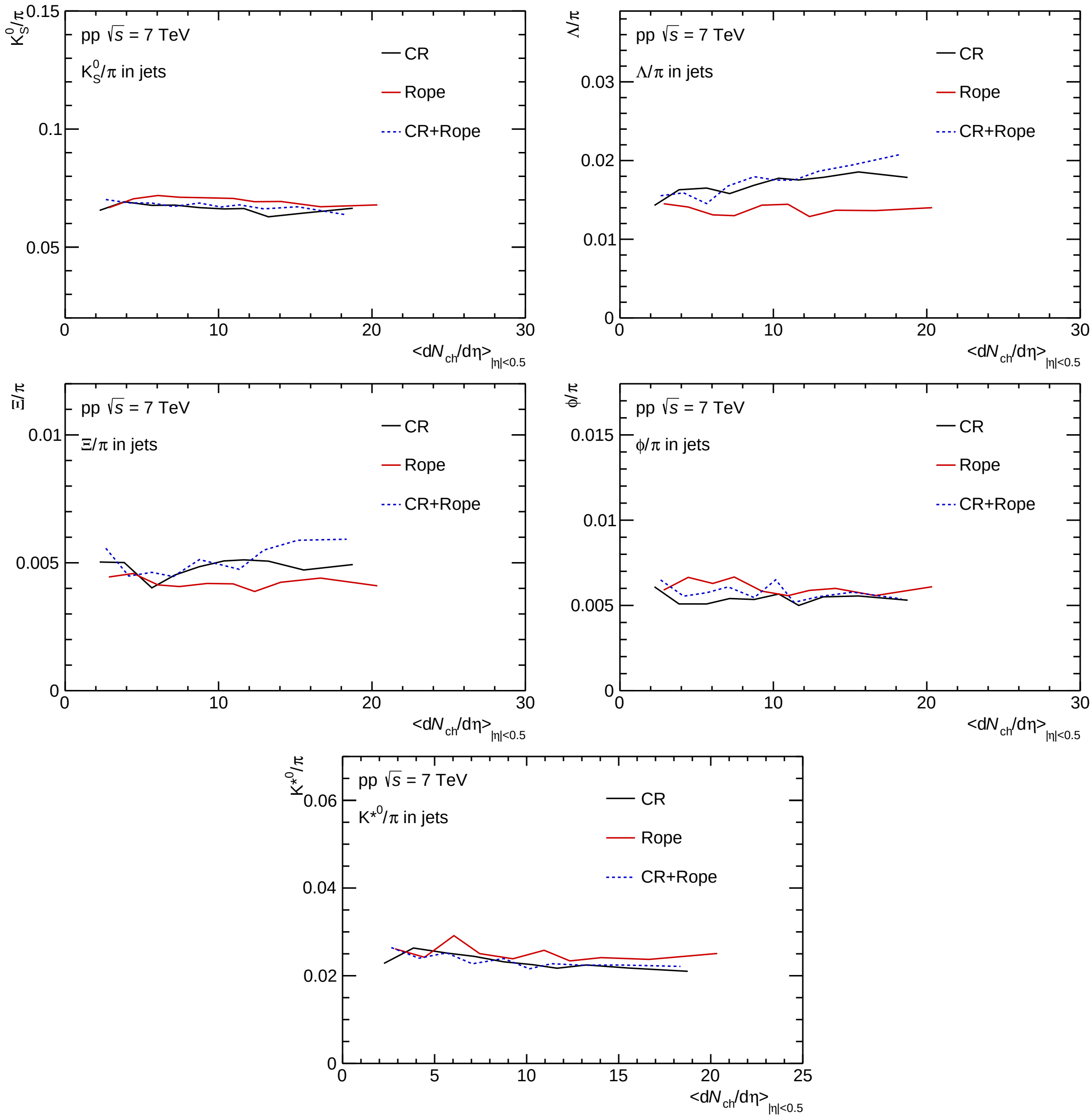

Figure 6: Integrated yields ratios in jet of strange particle to π with $\langle dN_{ch}/d\eta \rangle$. (Data taken from arXiv:1606.07424v2 and arXiv:1807.11321v2)

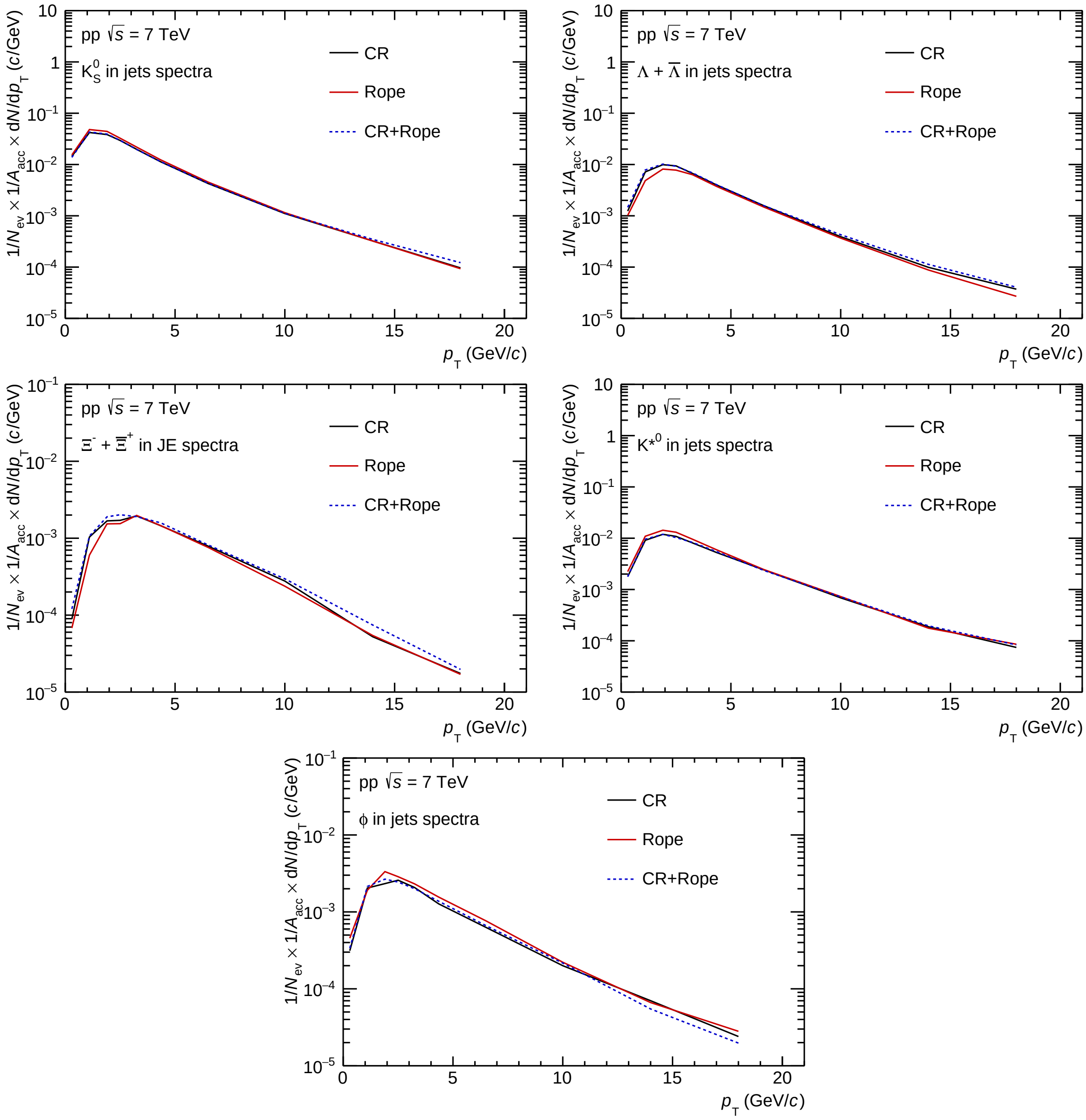

Figure 7: Particle in jet p_T spectra.

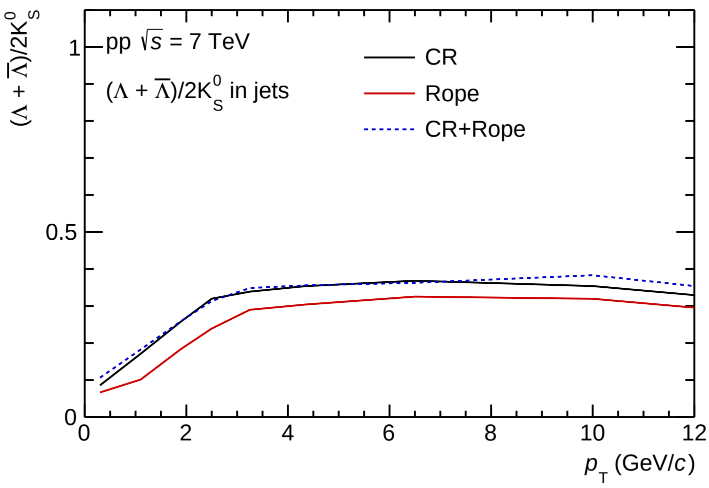

Figure 8: Particle ratios in jet with p_{T} distribution. (Data taken from arXiv:2005.11120)

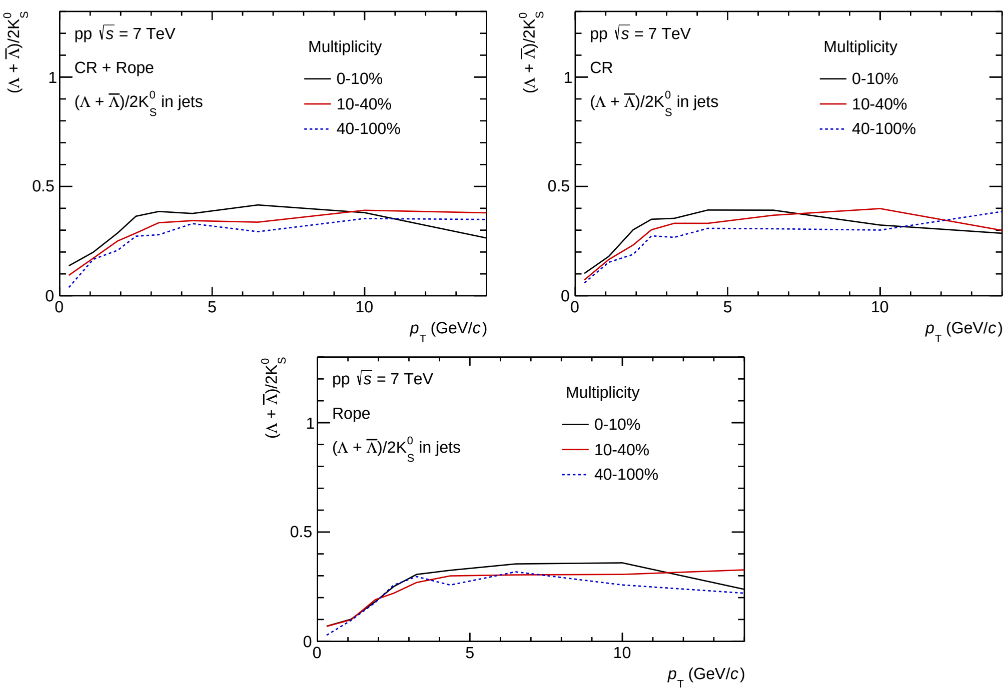

Figure 9: Particle ratios in jet with p_{T} distribution in different centrality bins.

4 Summary

References

85 # A Model parameters

Parameters	Values
MultiPartonInteractions:pT0Ref	2.15
BeamRemnants:remnantMode	1
BeamRemnants:saturation	5
ColourReconnection:reconnect	on
ColourReconnection:mode	1
ColourReconnection:allowDoubleJunRem	off
ColourReconnection:m0	0.3
ColourReconnection:allowJunctions	on
ColourReconnection:junctionCorrection	1.2
; ColourReconnection:timeDilationMode	2
ColourReconnection:timeDilationPar	0.18

Table A.1: Colour reconnection model parameters

Parameters	Values
Ropewalk:RopeHadronization	on
Ropewalk:doShoving	on
Ropewalk:tInit	1.5
Ropewalk:deltat	0.05
Ropewalk:tShove	0.1
Ropewalk:gAmplitude	0.
Ropewalk:doFlavour	on
Ropewalk:r0	0.5
Ropewalk:m0	0.2
Ropewalk:beta	0.1

Table A.2: Rope hadronization model parameters

Table A.3: Definition of the event classes as fractions of the analyzed event sample and their corresponding $dN_{ch}/d\eta$ within $|\eta_{lab}| < 0.5$.

Event class	I	II	III	IV	V	VI	VII	VIII	IX	X
$\sigma/\sigma_{INEL>0}$	0-0.95%	0.95-4.7%	4.7-9.5%	9.5-14%	14-19%	19-28%	28-38%	38-48%	48-68%	68-100%
Exp data	21.3 ± 0.6	16.5 ± 0.5	13.5 ± 0.4	11.5 ± 0.3	10.1 ± 0.3	8.45 ± 0.25	6.72 ± 0.21	5.40 ± 0.17	3.90 ± 0.14	2.26 ± 0.12
CR	18.8	15.6	13.3	11.7	10.4	8.8	7.1	5.7	3.9	2.3
Rope	20.3	16.6	14.1	12.3	10.9	9.2	7.5	6.1	4.5	2.9
CR + Rope	18.3	15.2	12.9	11.4	10.2	8.7	7.0	5.7	4.2	2.6