Referee Report

On "Strangeness production as a function of charged-particle multiplicity in pp at 5.02 TeV"

(ALICE Collaboration)

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Summary

The manuscript reports high-quality measurements of strange and multi-strange hadron yields in proton–proton collisions at 5.02 TeV as a function of charged-particle multiplicity. The experimental analysis is technically sound and the data are clearly presented.

However, the physical interpretation and the main conclusions of the paper suffer from a serious logical flaw. The authors systematically conflate empirical scaling with event multiplicity and evidence for collective or partonic dynamics. This over-interpretation is not supported by the data and renders the main claims of the manuscript misleading.

Major issues

1. Multiplicity is not an independent physical control variable

Charged-particle multiplicity is a derived, stochastic outcome of the collision process. It is strongly correlated with effective volume, number of multi-parton interactions, and selection biases introduced by event classifiers.

Treating multiplicity as a fundamental control parameter and interpreting smooth yield scaling as evidence of underlying collectivity is logically circular. The manuscript does not identify any observable independent of multiplicity that could discriminate between different microscopic mechanisms.

2. Scaling does not imply collectivity

The observed smooth increase of strange-hadron yields with multiplicity across pp, p–Pb, and Pb–Pb systems is fully consistent with volume-driven statistical production, including canonical suppression effects.

No discontinuity, threshold behavior, or non-trivial structure is observed that would indicate the onset of collective dynamics. The data exhibit precisely the behavior expected from statistical scaling with an effective volume.

3. Model comparison is not discriminating

The manuscript repeatedly argues that models reproduce the data only when collective effects are introduced. This argument is a non sequitur.

Different models (PYTHIA with color reconnection or ropes, EPOS with hydrodynamics, statistical hadronization approaches) reproduce the observed trends for entirely different physical reasons. Agreement with data therefore does not constitute evidence for any specific underlying mechanism.

No observable is presented that falsifies non-collective explanations.

4. Overstated conclusions

Statements suggesting that the results provide evidence for collectivity or partonic dynamics in high-multiplicity pp collisions go well beyond what the data support. The manuscript effectively promotes a descriptive scaling variable to the status of a physical mechanism.

The correct interpretation is that strange-hadron production correlates with event activity in a manner consistent with effective volume scaling. The microscopic origin of this behavior remains undetermined.

Recommendation

While the experimental measurements themselves are valuable, the current interpretation is not justified. The manuscript requires substantial revision.

At a minimum, all claims linking multiplicity scaling to collective or partonic dynamics must be removed or significantly weakened, and the conclusions must explicitly state the model-dependent and non-discriminating nature of the interpretation.

In its present form, the manuscript is misleading.

Recommendation: Major revision / Reject

Appendix A: Derivation from the wave function psi

In this Appendix the scaling of strange hadron yields with charged-particle multiplicity is derived starting from the quantum state of the produced system. It is shown that the observed behavior follows from effective volume scaling and does not imply collective or partonic dynamics.

A.1 Quantum description of the produced system

Consider a many-particle final state produced in a proton–proton collision, described by a normalized wave function

$$\Psi(\{x_i\}),$$

where x_i denote the space-time coordinates of the produced particles. The corresponding probability density is

$$P(\{x_i\}) = |\Psi(\{x_i\})|^2.$$

All observable yields are obtained by integrating this density over the accessible phase space.

A.2 Single-particle density and effective volume

The single-particle density for hadrons of species h is defined as

$$n_h(x) = \int \prod_{j \neq h} d^3x_j \, |\Psi(\{x_i\})|^2.$$

The total yield of species h is then

$$N_h = \int d^3x \, n_h(x).$$

Define the effective production volume V_{eff} as the support of $n_h(x)$. For systems of increasing activity, V_{eff} increases monotonically.

A.3 Statistical production and canonical suppression

In a finite volume, conservation of quantum numbers leads to canonical suppression of rare species. For strange hadrons one obtains

$$N_h \propto V_{\text{eff}}\, S(V_{\text{eff}}),$$

where $S(V_{\text{eff}})$ is a suppression factor satisfying

$$S(V_{\text{eff}}) \to 1 \quad \text{for} \quad V_{\text{eff}} \to \infty.$$

For small volumes $S(V_{\text{eff}}) < 1$, leading to a faster than linear increase of multi-strange yields with V_{eff}.

A.4 Relation to charged-particle multiplicity

The charged-particle multiplicity N_{ch} is given by

$$N_{\text{ch}} = \int d^3x\, n_{\text{ch}}(x),$$

where $n_{\text{ch}}(x)$ is the charged-particle density.

Since both N_h and N_{ch} scale with the same effective volume, one obtains the functional dependence

$$N_h = f_h(N_{\text{ch}}),$$

with f_h determined by statistical suppression factors.

This relation is purely kinematic and statistical and does not encode any information about the microscopic dynamics of the system.

A.5 Absence of collective dynamics

No assumption about thermalization, hydrodynamic flow, or partonic collectivity has been made in the derivation above.

The observed smooth scaling of strange hadron yields with charged-particle multiplicity follows directly from the increase of the effective production volume and from conservation laws.

Therefore, multiplicity scaling alone cannot be interpreted as evidence for collective or partonic dynamics.

A.6 Final statement

Starting from the wave function psi and applying minimal statistical assumptions, the experimentally observed scaling behavior is reproduced.

The data constrain the effective volume of the produced system but do not discriminate between microscopic production mechanisms.

Claims of collectivity based solely on multiplicity scaling are therefore not justified.