Consequence of strangeness enhancement at LHC on excess muon production in cosmic ray air showers

Ronald Scaria[1],* Captain R. Singh[1], Suman Deb[2], and Raghunath Sahoo[1]
[1] *Department of Physics, Indian Institute of Technology Indore, Simrol, Indore-453552, India and*
[2] *Laboratoire de Physique des 2 infinis Irene Joliot-Curie, Universite Paris-Saclay, CNRS-IN2P3, F-91405 Orsay, France*

Introduction

Primary cosmic rays (PCRs) can have energies up to 10^{20} eV and provide the unique opportunity to study particle production dynamics at center-of-mass energies and kinematic regions inaccessible at particle accelerators. On interacting with atmospheric nuclei, they produce a multitude of particles that further interact or decay based on their energies. This produces a cascade of particles known as extensive air showers (EAS). Multiple cosmic ray experiments have observed an excess of muons at the ground level in EAS produced by ultra-high-energy PCRs compared to estimates of various models. This is termed the "*muon puzzle*" because adjusting model parameters alone cannot account for the observed excess of muons. To address this issue, a modification of the electromagnetic energy fraction in EAS has been suggested as a possible solution to explain the observed muon yield. We explore possible reasons for such modification by studying the mid-rapidity and forward rapidity K/π integrated yield ratio and the electromagnetic to hadronic energy fraction (R), given by [1]

$$R(\eta) = \frac{\langle dE_{em}/d\eta \rangle}{\langle dE_{had}/d\eta \rangle}. \quad (1)$$

Here, the numerator and denominator give the average energy carried by photons and $e^{\pm}$ and all hadrons in pseudorapidity bins, η, respectively. An increase of K/π ratio indicates less energy provided to the electromagnetic cascade through π^0 production, reducing R. This work explores the multiplicity and pseudorapidity dependence of K/π and R using EPOS-LHC, SYBILL 2.3d, QGSJET-II 04, and PYTHIA 8 models. The methodology, details of the models and the tunes used, and the collision species considered can be found in Ref.[1].

*Electronic address: ronaldscaria.rony@gmail.com

Results and Discussion

It can be seen in the left panel of Fig.1 that the EPOS-LHC model gives a consistent description of the experimentally observed K/π values as a function of multiplicity, while PYTHIA 8 and QGSJET-II 04 fail. The SYBILL 2.3d model shows a nonmonotonous trend, initially decreasing and then increasing with multiplicity, a behavior not observed in experimental data. This might be an indication of the importance of the core-corona picture employed in the EPOS-LHC model, in contrast to the Lund string fragmentation followed in the other models considered. The dependence of R on multiplicity is shown in the middle panel of Fig.1. R is seen to decrease as a function of multiplicity for the EPOS-LHC model, whereas it remains constant for the PYTHIA 8 and QGSJET-II 04 models. The SYBILL 2.3d model initially shows a decreasing trend for R, which reverses at higher multiplicity to an increasing behavior. The right panel of Fig.1 shows the correlation between K/π and R for various models and collision species. It can be seen that the EPOS-LHC model shows an anti-correlation between the two parameters considered before getting saturated in both K/π and R at the high-multiplicity region. For all the other models, a clear trend is not discernible.

In the left panel of Fig.2, we explore the pseudorapidity dependence of R in pp collisions at 7 TeV using the various models. All

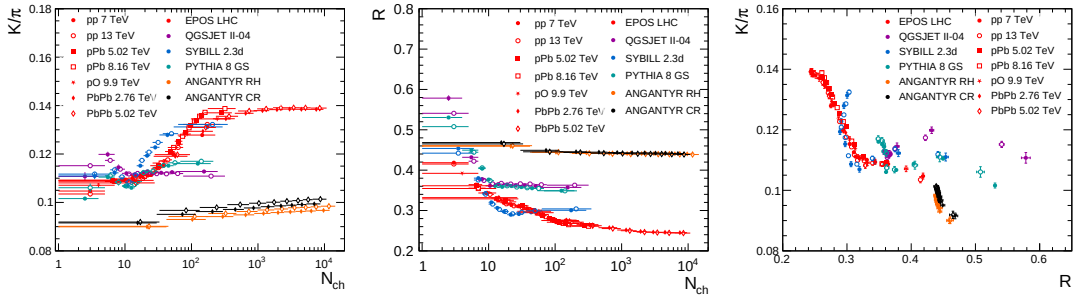

FIG. 1: Multiplicity dependence of mid-rapidity K/π yield ratio (left panel) and R value (middle panel) comparing multiple models across various colliding species and center of mass energies. The right panel shows the correlation between K/π and R at mid-rapidity obtained using the different models [1].

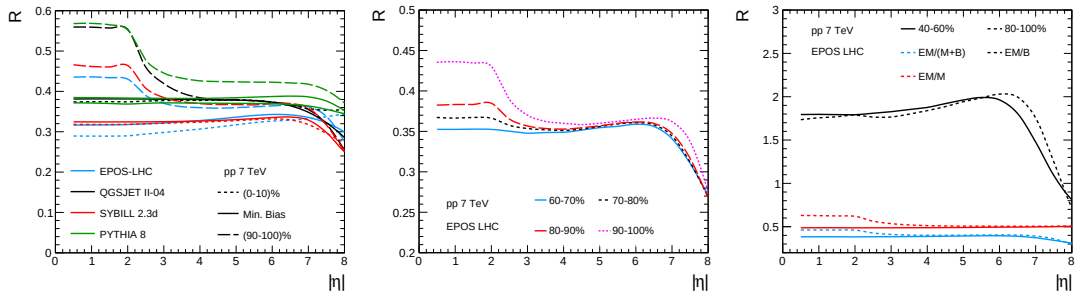

FIG. 2: (Left panel) Variation of R as a function of pseudorapidity using different models for pp collisions at $\sqrt{s} = 7$ TeV [1]. The middle panel shows the onset of electromagnetic dominance in the mid-rapidity region in peripheral collisions, while the right panel compares the electromagnetic (EM) energy fraction with the energy carried by hadrons (Mesons (M) and Baryons (B)).

the models show that R value jumps in the mid-rapidity region for the lowest multiplicity class ((90-100)%). This can be attributed to the dominance of photon-photon or other photon-induced interactions in the most peripheral collisions. Such interactions dominate particle production in mid-rapidity when the nuclei are close by compared to the forward rapidity regions. The forward rapidity region is dominated by nuclear fragmentation or spectator effects. We explore the onset of this dominance through the middle and right panels of Fig.2. As seen in the middle panel, R value increases in the mid-rapidity region as a function of the centrality class. This rise can be explained from the right panel of Fig.2, which shows that the energy transferred to the electromagnetic particles is larger in the mid-rapidity region.

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References

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