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Quark counting rules for the production of cumulative pions with large transverse momenta

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This work focuses on the calculation of quark counting rules for the inclusive production of pions at large transverse momenta in the cumulative region—a kinematic domain forbidden for single nucleon-nucleon interactions. This region, which cannot be accessed through single nucleon-nucleon interactions, becomes relevant in nuclear collisions and can be observed using the MPD and SPD detectors at the NICA complex. Unlike high-energy colliders like RHIC and LHC, where this phenomenon cannot be studied due to kinematic limitations, the intermediate energy collisions at NICA provide a distinctive opportunity to investigate these cumulative effects in detail.

The concept of the flucton, a cluster of cold, dense quark-gluon matter with high baryon density, plays a central role in this context. From a modern perspective, fluctons are seen as temporary, highly localized concentrations of quarks and gluons within the colliding nuclei, and their presence enables the production of cumulative particles during the collision. If a flucton is present during nucleon collisions, it can trigger the production of particles that exhibit unusual kinematic properties, including those with large transverse momenta at mid-rapidities.

Building on the earlier work of V. V. Vechernin and M. A. Braun [1-4], who developed a microscopic quark-parton model for particle production in the fragmentation region of one of the colliding nuclei, we extend this framework to the new kinematic region characterized by high transverse momentum. In this extended region, we observe a shift in the proton-to-pion yield ratio when compared to cumulative particle production in the traditional fragmentation region. This is largely due to the different underlying mechanisms of particle formation: while cumulative protons are predominantly formed through the coherent recombination of three quarks from a flucton, cumulative pions are primarily produced via the fragmentation of a single quark [3, 4, 9]. We compare the obtained theoretical results with the results of our preliminary estimates of particle yields in this region based on a more phenomenological approach [5-7].

Moreover, our work reveals the potential for studying flucton-flucton interactions—a rare and intriguing process—in the new cumulative region at mid-rapidities. Unlike the fragmentation region, where such interactions are impossible to observe, this region opens up the possibility for detailed experimental investigation. Notably, this process can be explored in detail using dd (deuteron-deuteron) collisions at the NICA SPD, where both deuterons may exist as flucton states at the moment of collision. In this scenario, the absence of additional nucleon-nucleon interactions reduces background, simplifying the detection of cumulative particles in correlation with those originating from flucton fragmentation [8]. The higher collision rate at SPD compared to MPD also enhances the likelihood of observing rare cumulative events, making SPD a particularly valuable tool for these studies.

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