Measurement of strangeness production in OH_2 and pNe collisions using SMOG2

Theodor Zies
TU Dortmund

When highly energetic particles coming from the cosmos, also referred to as cosmic rays, interact with the Earth's atmosphere, they create cascades of secondary particles. Understanding these particle showers in the atmosphere, also called air showers, requires precise simulations describing all interactions, including the hadronic scattering. When nuclei are broken up in high-energy collisions as they occur in air showers, the produced quarks and gluons recombine into colour-neutral hadrons in a process called hadronization. In the SM, such nuclear processes are explained via the strong interaction, which is one of the three fundamental interactions. The strong interaction is described by quantum chromodynamics (QCD). In QCD, quarks form bound states at low energies called hadrons, e.g., a proton. Hadronization processes in cosmic-ray-induced air showers cannot be calculated analytically because of the non-perturbativity of QCD at low energies. Thus, simulating hadronization processes in air showers requires complex data-driven models. Measurements of particles produced in air showers can be used to test the simulations using such models. A significant surplus of muons is observed in comparison to the predictions of current models, hinting at an insufficient understanding of the hadronization process. A possible explanation for this discrepancy, also called the muon puzzle, is strangeness enhancement, referring to a greater production of hadrons containing strange quarks in collisions with high energy densities. The ALICE collaboration observed such an effect in centrally produced strange hadrons in high-multiplicity pp collisions, but it remains to be studied whether this enhancement is also present in the forward rapidity region relevant for air showers.

One approach to testing and tuning current models of hadronization is the SMOG system used at the LHCb experiment located at the LHC. By enabling collisions between the particles in the beam and stationary gases, fixed-target collisions can be recorded with the LHCb detector. In its first iteration, the SMOG system simply enabled gas to be injected into the beam pipe. In contrast, the newly developed SMOG2 system consists of an independent storage cell that contains the gas. It produced a unique set of ion collision samples during Run 3 of the LHC. The higher areal density of SMOG2 compared to SMOG, combined with the upgraded LHCb detector in Run 3, results in improved statistical precision and data quality. Measurements of strangeness production using the SMOG2 system are crucial to see whether the new data reveal effects that could explain the observed muon discrepancies in air showers. In this analysis, collisions of oxygen nuclei with hydrogen as well as those of protons with neon nuclei are studied with respect to the production of strange baryons and mesons. With an atomic number of 8 (oxygen) and 10 (neon), the nuclei are the closest available matches to nitrogen, which is the main constituent of the Earth's atmosphere. Consequently, the conditions in these high-energy hadronic interactions closely resemble those of cosmic rays interacting with the atmosphere. The pNe and OH_2 collisions differ in that in one case the heavy ion is the fixed target, while in the other case it forms the beam. Therefore, the two samples allow for individually probing the proton and ion side of the collision, as the LHCb detector's acceptance lies only in the backward center-of-mass rapidity region. By measuring the production cross-section ratios $R(\Lambda^0, K_S^0)$ and $R(\bar{\Lambda}^0, \Lambda^0)$, the production of strange mesons, baryons, and anti-baryons can be studied. The results are compared with predictions from common event generators used to model the hadronic interactions in air shower simulations. Therefore, this analysis provides a unique, first-of-its-kind test of how accurately the models describe the hadronization process under the conditions present in air showers.