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Theoretical modeling of pp collision-induced neutrino emission from astrophysical sources

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Understanding the origin of high-energy astrophysical neutrinos is one of the key challenges in modern multi-messenger astronomy. In this study, we present a comprehensive theoretical model to estimate the neutrino flux from various astrophysical sources, including starburst galaxies [1], galaxy clusters [2], and supernova remnants (SNRs). Our approach is grounded in diffusive shock acceleration (DSA) theory, through which we calculate the energy spectrum of cosmic-ray protons accelerated at shock fronts within these environments [3,4]. These high-energy protons are assumed to interact with ambient matter via inelastic proton-proton (pp) collisions, producing charged pions that subsequently decay into neutrinos. By incorporating realistic astrophysical parameters and environmental conditions for each source type, we evaluate the resulting neutrino energy spectra and fluxes. The analysis shows that, for extragalactic sources such as starburst galaxies and galaxy clusters, the predicted neutrino fluxes are below the current detection thresholds of existing neutrino observatories like IceCube and KM3NeT [1,2]. However, in the case of SNRs within our Galaxy, while individual sources may still produce weak neutrino signals, the cumulative signal from multiple remnants analyzed through stacking techniques could yield detectable signatures. This suggests that SNRs remain promising targets for neutrino detection efforts. Our findings highlight the importance of source selection and observational strategies when searching for astrophysical neutrinos and provide theoretical guidance for future observations and mission planning in the era of multi-messenger astrophysics.

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