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Probing Pion-Nucleon and Proton-Nucleon Production Channels for Millicharged Particles in the SuperFGD Detector at T2K

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The T2K experiment uses a high-intensity muon neutrino beam produced at the J-PARC accelerator facility to study neutrino properties and search for physics beyond the Standard Model. Recently, the near detector ND280 was upgraded with a high-performance scintillator detector, the SuperFGD. Composed of approximately 2 million 1 cm^3 scintillator cubes read out by wavelength-shifting (WLS) fibers in three dimensions, the SuperFGD enables improved 3D tracking of stopping protons and pions, enhanced electron/photon separation, and neutron detection. This makes the SuperFGD sensitive to feebly interacting exotic particles. In this study, we investigate the potential of the detector to observe millicharged particles (mCPs) with masses up to several GeV, as predicted by various hidden-sector models.

Previous studies have primarily focused on mCP production from neutral unflavoured mesons, while this work extends the production model to include additional hadronic channels. We evaluate the contribution of mCPs generated through charged pion-nucleon scattering and elastic proton-neutron scattering within the target material. These production mechanisms may constitute a non-negligible source of mCPs at T2K energies. Using realistic performance characteristics of the SuperFGD, we estimate the expected signal rates for the topology of double consecutive scatterings of mCPs on atomic electrons. The study will provide an assessment of how pion-nucleon and proton-neutron processes extend the detector's sensitivity in the (mass, millicharge) parameter space.

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