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Superfluid-insulator transitions of collective helical modes in the zero quantum Hall state of bilayer graphene

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We derive an effective field-theoretical model for the one-dimensional collective modes associated with domain walls in a quantum Hall ferromagnetic state, as realized in bilayer graphene systems at zero filling subject to a kink-like perpendicular electric field. In particular, it is demonstrated that two pairs of collective helical modes are formed at opposite sides of the kink, each pair consisting of modes with identical helicities. The coupling between modes implies a description in terms of anisotropic quantum spin-ladders, whose parameters are tunable by varying the magnetic and electric fields. We show that this system possesses a rich phase diagram, which due to the helical nature of the modes implies a diversity of charge conduction properties. Most notably, we find that the helical ladders may undergo a transition from a superfluid to an insulating phase, manifested by a jump in the two-terminal conductance as well as the drag trans-conductance.