Contribution ID: **130** Type: **poster**

Minimal SU(2) models for analog simulation in small-scale superconducting quantum devices

Lattice gauge theories (LGTs) are essential tools for studying fundamental interactions in particle physics and have broad applications in condensed matter physics and quantum information. While many aspects of Abelian and non-Abelian gauge theories can be simulated efficiently with classical numerical methods, their intrinsic quantum nature makes other relevant phenomena hard to reproduce. Quantum simulators offer a promising approach to address these challenges, with successful simulations of Abelian theories in different quantum platforms demonstrating their potential in the last decades. Despite these advances, quantum simulation of non-Abelian theories remains challenging. Recent research efforts aimed at the analog simulation of LGTs has focused on scalable quantum platforms, such as ultracold atoms and trapped ions. In contrast, we propose alternative minimal SU(2) lattice gauge theory models for analog simulation, tailored for small-scale superconducting quantum hardware. By adopting concepts from quantum optics, our approach emphasizes coarse-grained systems that capture internal degrees of freedom and relevant non-Abelian properties with just a few qubits, bypassing the scalability demands of fine-grained models. We explore unique features of these non-Abelian systems and provide a circuit design for their experimental realization. This work advances the study of non-Abelian gauge theories and introduces a novel method for implementation of LGTs using superconducting qubits.

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Short summary

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Session Classification: Networking cocktail and Poster Session