PhD THESIS DEFENSE: Quantum Adventures From Analog to Digital: Gauge, Scars and Laughlin

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10:00
ICFO Auditorium and Online (Teams)

This is a thesis in theoretical physics about analog quantum simulations, digital quantum simulations (quantum computing), and quantum state preparation using different quantum platforms (neutral atoms, trapped ions, and superconducting circuits). We live in a quantum era with such a wide variety of platforms available, however performing experiments on existing quantum devices remains challenging due to limitations in control, scale, and connectivity. Therefore, innovative strategies must be developed to achieve quantum advantage using current quantum technology. We are primarily interested in applications to high-energy physics, as quantum computing provides a natural framework for simulating the real-time evolution of gauge theories. While the field of quantum simulations and quantum computing is still in its infancy and may be far from uncovering relevant insights about the

Standard Model in regimes inaccessible to analytical methods, classical simulations, or direct experiments, interesting discoveries are emerging. Significant developments include the observation of quantum many-body scar states and the reformulation of quantum field theories as quantum link models.?

Most part of the thesis is dedicated to the quantum simulations of lattice gauge theories which we explore under different lenses. First, we propose a scheme to effectively generat three body interactions in trapped-ion platforms which consists of a generalization of th Molmer-Sorensen scheme for three spins. In this project, we envision the quantum simulatio of the spin 1/2 quantum link model description of the massless Schwinger model, whic features a three-body interaction. Such interaction requires at least 12 two-qubit gates to b performed, which in principle accumulates more errors than a single three-qubit gate. This i what makes analog quantum simulations so powerful: We can tailor the platform to generat interactions of a specific target model, potentially reducing quantum errors.

? Next, assuming the existence of a perfect three-body gate, we study quantum many-bo y scar states in the Schwinger model. We use a mapping from the spin 1/2 Schwinger quant m link model to the PXP model to identify the relevant physical configurations. Then, e compare the evolution of thermal and non-thermal states under sequential Trotteriz d quantum circuits to their evolution under randomized quantum circuits. Our results indica e that the non-thermal sector of the Hilbert space, which includes the quantum many-bo y scars, are more sensitive to randomization

Then, on a more realistic note, we use real quantum devices from IBMQ to perform digi al quantum simulations of the Schwinger model. These quantum computers are based on superconducting circuits, and we currently have access to up to 156-qubits together wit a basis of single and two-qubit gates. The devices impose strong limitations on connectiv ty and depth of the quantum circuits, hence we propose using gauge invariance, in the form of the Gauss' law, for quantum error detecti n. In the last part of this thesis, we shift focus to study an interesting many-body behavior t at emerges from the presence of a static gauge field. Specifically, we propose a protocol for he quasi-adiabatic preparation of the 1/2-Laughlin state, a fractional quantum Hall state, us ng rotating ultracold atoms to create artificial gauge fields. From the condensate phase to he Laughlin state there are three points of closed gaps, and we make trap largely anisotropic to cross these regions without losing fidelity. We improved the preparation times by a factor of ten compared to previous studi

Tuesday May 27, 10:00 h. ICFO Auditorium

Thesis Directors: Prof. Dr. Maciej Lewenstein and Dr. Tobias Daniel Grass.

Hosted by: Prof. Dr. Maciej Lewenstein