Emergent Causality and the N-photon Scattering Matrix in Waveguide QED

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In this talk we discuss the emergence of approximate causality in a general setup from waveguide QED ---i.e. a one-dimensional propagating field interacting with a scatterer. We discuss that this emergent causality fixes the form for the N-photon scattering matrix. Our theory builds on the derivaton of a Lieb-Robinson-type bounds for the continuum and for all coupling strengths and other intermediate results, of which we remark (i) the asymptotic independence of space-like separated wavepackets, (ii) the proper definition of input and output scattering states, and (iii) th characterization of the ground state and correlations in the model. We illustrate the formal results by analyzing the two-photon scattering from a quantum impurity in the ultrastrong coupling regime, verifying the cluster decomposition and ground-state nature. Besides, We generalize the cluster decomposition if inelastic or Raman scattering occurs. Finally, the decay of the fluorescence (photon-photon correlations) is discussed.