Non-Abelian Berry phase induced entanglement between qubits in QED cavity

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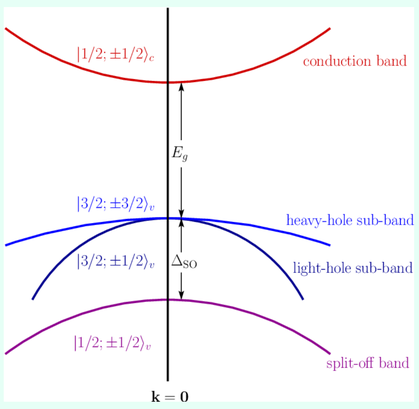
Non-Abelian holonomy group:

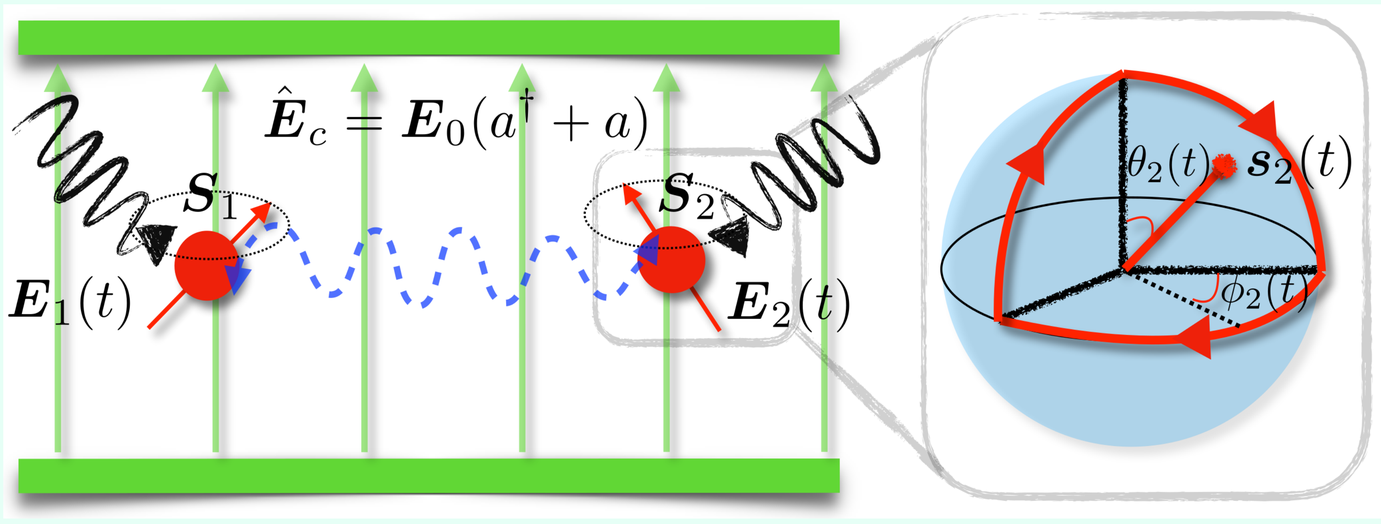
degenerate groundstate + auxiliary states $|1\rangle$ $|0\rangle$



Working example:

hole-spin 3/2 immersed in QED cavity

1. Platform
2. Control
3. Read-out
4. Entanglement
5. Protection



$$H(t) = \sum_{j=1,2} \sum_{\alpha=x,y,z} \Big(E_{j,\alpha}(t) + g_j(a^\dagger + a) \Big) \Gamma^\alpha + \omega_0 a^\dagger a$$

Gamma matrices (4x4) are generators of the SO(5) Clifford algebra

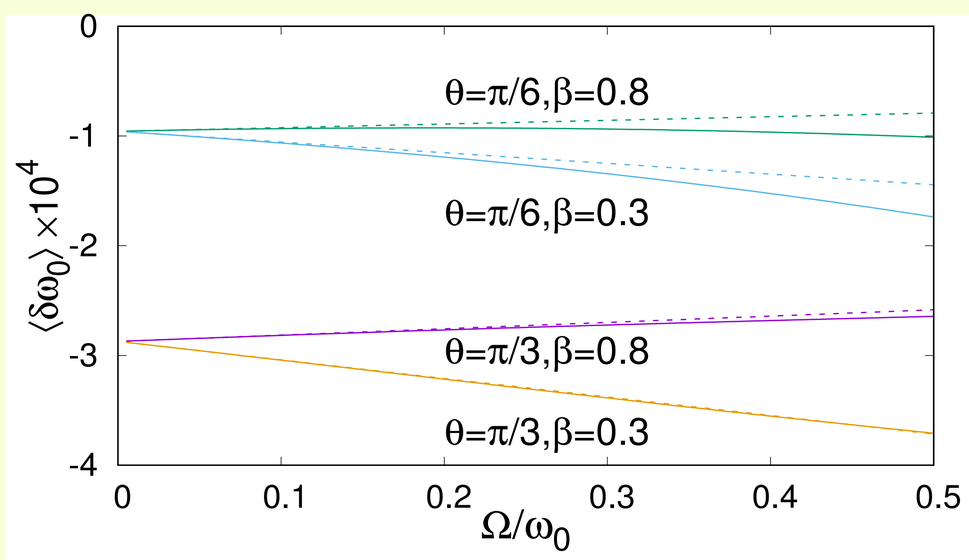
Single qubit model: H(t) rotated to **instanteous spectrum** by *U* and projected on the **low-energy sector** in dispersive regime:

$$h_j = \sum_{\alpha=x,y,z} \dot{E}_{j,\alpha} \underbrace{\mathcal{A}^l_{j,\alpha}}_{\text{projected Berry connection}} + \Big(\omega_0 + \underbrace{\sum_{\alpha\beta\gamma} \dot{E}_{j,\alpha}\, g_{j,\beta}\, g_{j,\gamma}\, \mathcal{O}^l_{j,\alpha\beta\gamma}}_{\delta\omega_{0,j}} \Big) a^\dagger a$$

Geometrical single qubit control [1]

Read-out due to geometrical cavity frequency shift [2]

$\mathcal{O}^l_{j,\alpha\beta\gamma}$ – geometrical object



$$\mathcal{A}^l_\alpha = -iP^\dagger_L U^\dagger \partial_{E_\alpha} U P_L$$

$$E_x = \sin\Omega t \sin\theta$$
$$E_y = \cos\Omega t \sin\theta$$
$$E_z = \cos\theta$$

$$\psi(0) = \begin{pmatrix} \sqrt{1-\beta^2} \\ \beta \end{pmatrix}$$

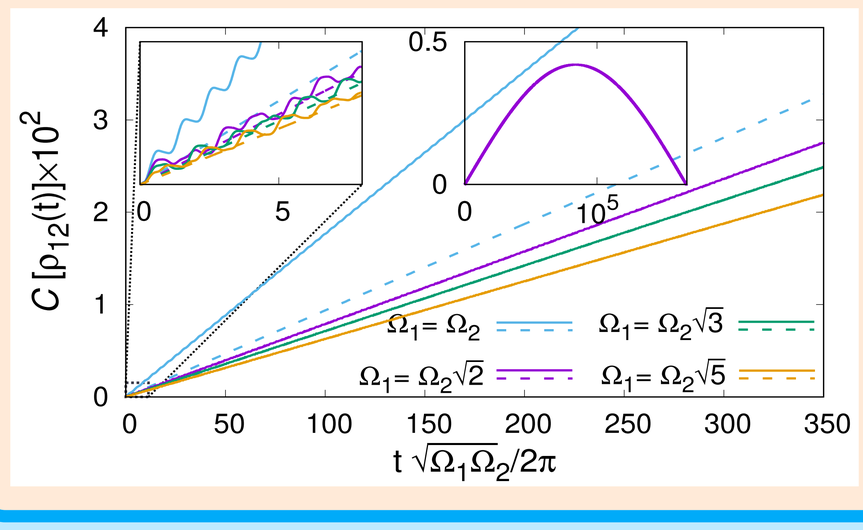
Cavity mediated **two-qubit interaction** in adiabatic and dispersive regime

$$h_{1-2} = \sum_{\alpha,\beta,\gamma,\delta} \frac{2 g_{1,\alpha} g_{2,\beta}}{\omega_0} \dot{E}_{1,\gamma} \dot{E}_{2,\delta} \underbrace{\mathcal{F}^l_{1,\alpha\gamma} \mathcal{F}^l_{2,\beta\delta}}_{\text{projected Berry curvature}}$$

Entanglement generation due to coupling between Berry curvatures [2]

$$\mathcal{F}^l_{\alpha,\beta} = \partial_\alpha \mathcal{A}^l_\beta - \partial_\beta \mathcal{A}^l_\alpha + i[\mathcal{A}^l_\alpha, \mathcal{A}^l_\beta]$$

Entanglement generation measured by conurrence



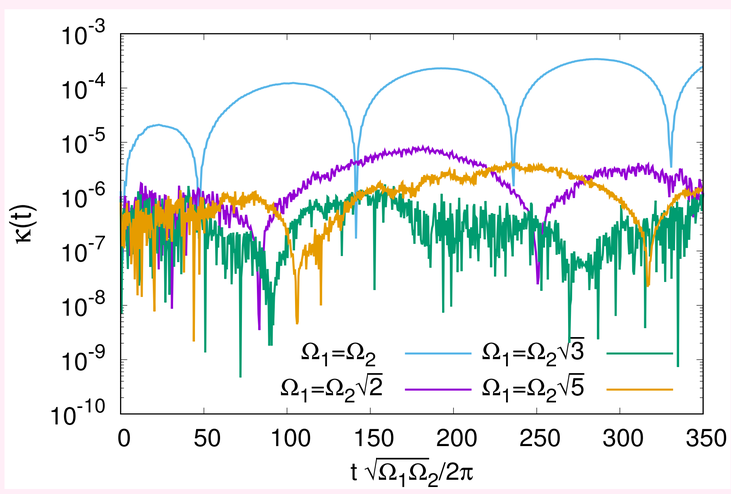
Noise $\Omega_j t \to \Omega_j t + \delta_j(t)$ is introduced with correlation function:

$$\langle \dot{\delta}_j(t) \dot{\delta}_j(t') \rangle = \gamma_j(|t-t'|) = \frac{2\eta_j}{\tau_j\sqrt{2\pi}} e^{-\frac{|t-t'|^2}{2\tau_j^2}}$$

$\kappa(t) = |\mathcal{C}_0(t) - \bar{\mathcal{C}(t)}|$

$\mathcal{C}_0(t)$ - noiseless conurrence

Protection is present for incommensurate frequencies [2]



[1] B. A. Bernevig, S.-C. Zhang, Phys. Rev. B **71**, 035303 (2005)

[2] M. M. Wysokiński, M. Płodzień, M. Trif Phys. Rev. B **104**, L041402 (2021)

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