quantum measurement cooling

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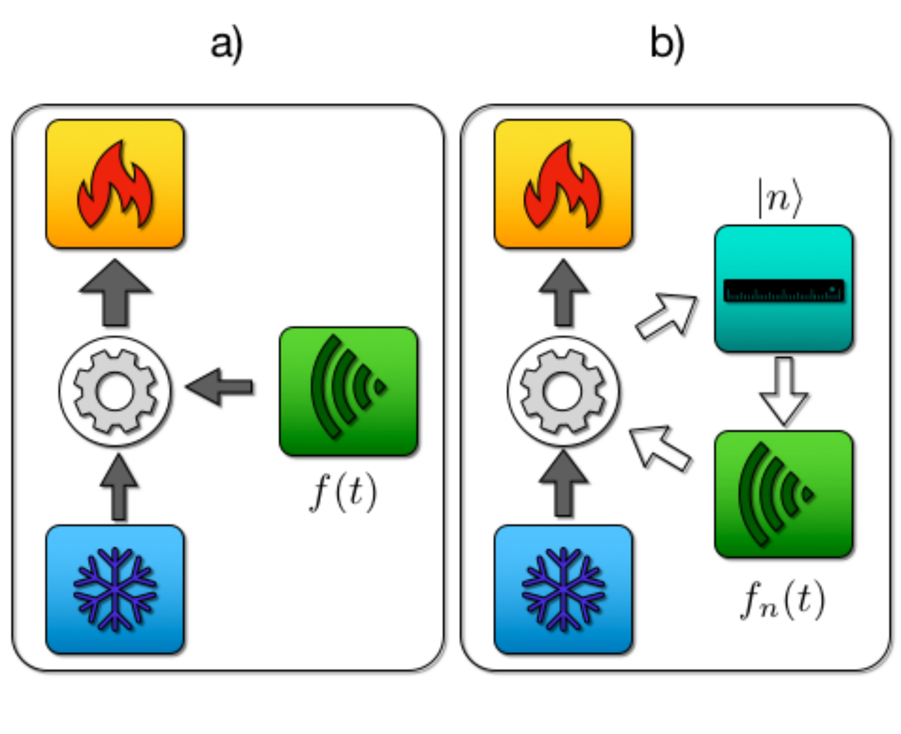
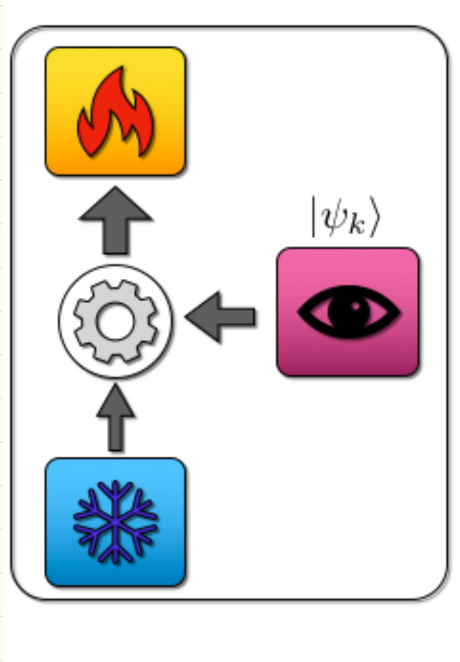
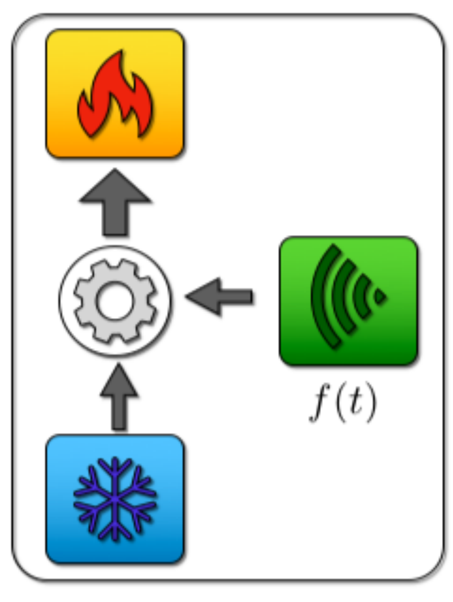
Standard cooling concepts

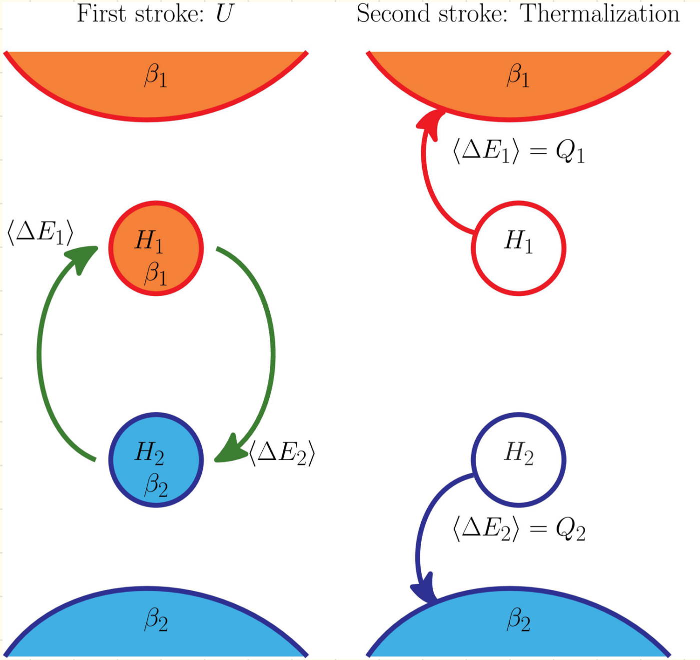
Quantum measurement cooling





Cooling by time-dependent driving





$$H = \underbrace{H_1}_{\frac{w_1}{2}\sigma_1^z} + \underbrace{H_2}_{\frac{w_2}{2}\sigma_2^z} + V(t) \rightarrow U$$

$$\rho = \frac{e^{-\beta_1 H_1}}{Z_1} \otimes \frac{e^{-\beta_2 H_2}}{Z_2}$$

$$\boxed{\rho \rightarrow U \rho U^\dagger}$$

$$\langle \Delta E_1 \rangle = \mathrm{Tr}\, H_1 (U \rho U^\dagger - \rho)$$

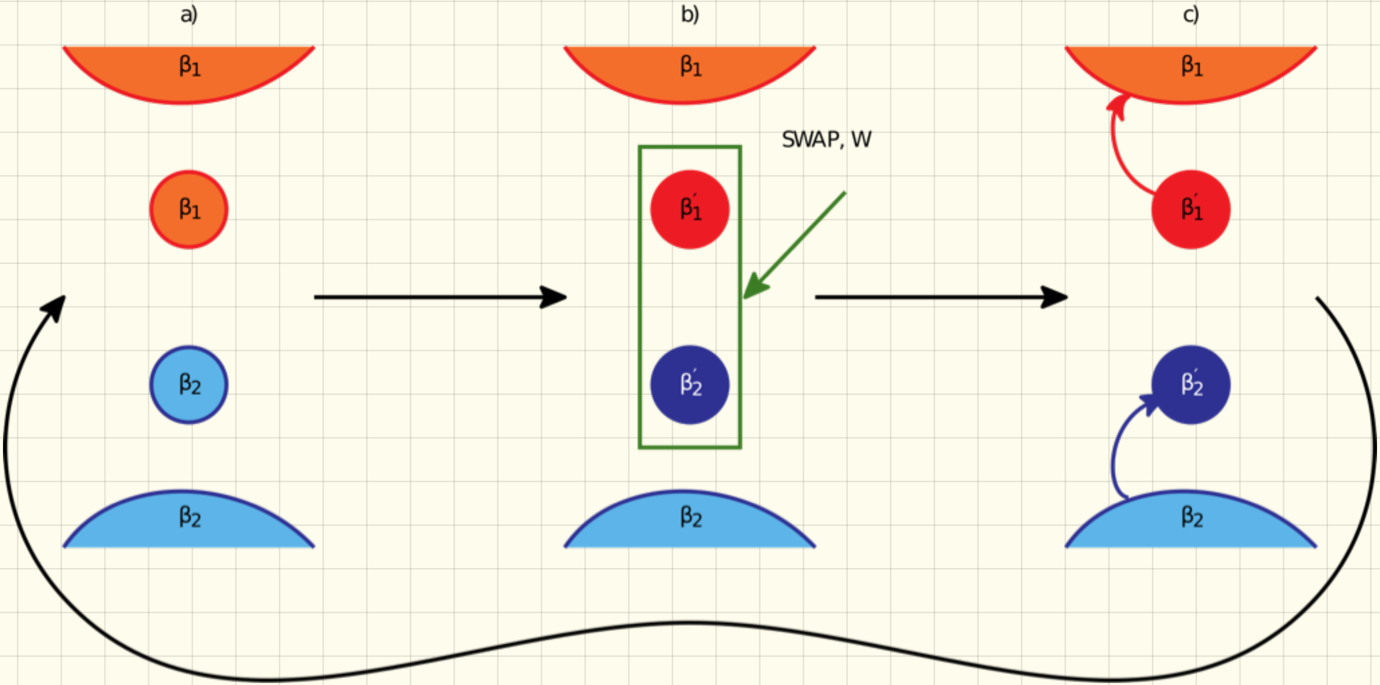
$$+$$

$$\langle \Delta E_2 \rangle = \mathrm{Tr}\, H_2 (U \rho U^\dagger - \rho)$$

$$=$$

$$\langle W \rangle$$

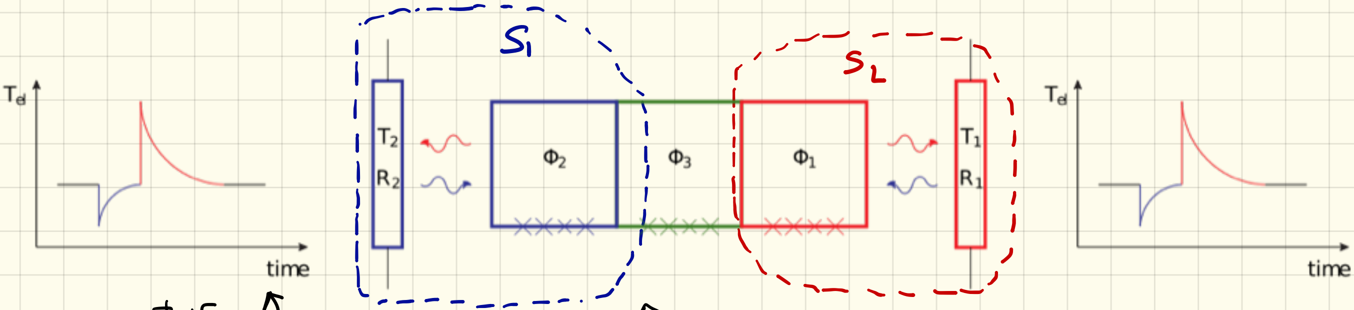
Campisi, Pekola, Fazio, NJP 17 035012 (2015)



$$\beta_1' = \beta_2 \frac{\omega_2}{\omega_1} \qquad \beta_2' = \beta_1 \frac{\omega_1}{\omega_2} \qquad \frac{\omega_2}{\omega_1} < \frac{\beta_1}{\beta_2}$$

refrigerator

IMPLEMENTATION



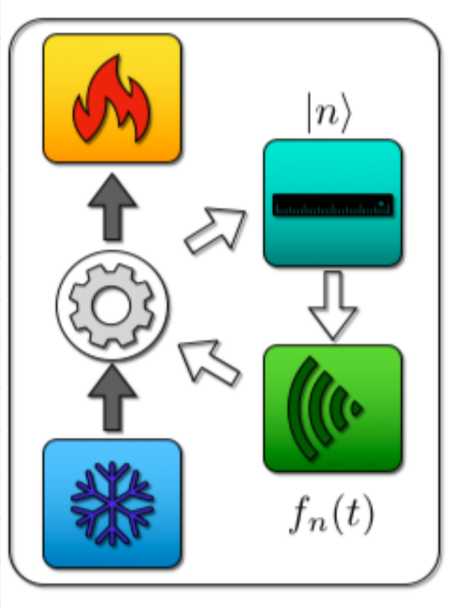
Calorimeter

Flux qubits

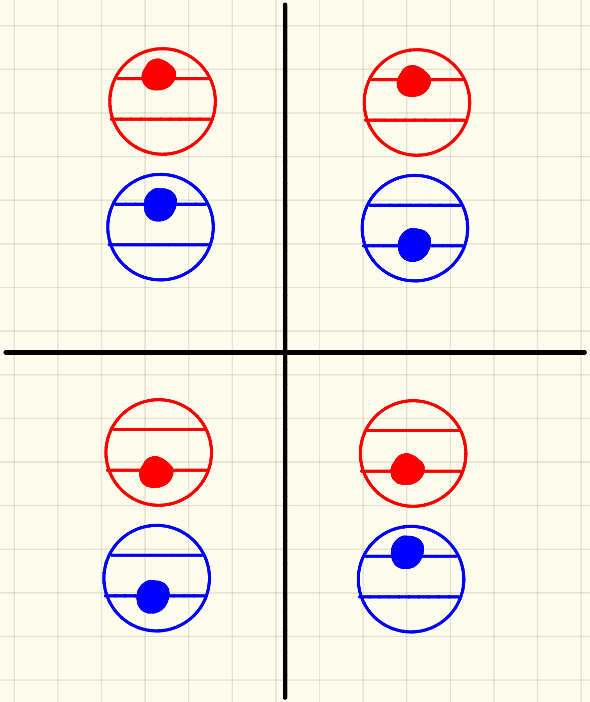
GASPARINETTI et al
Phys. Rev. App. $\underline{3}$ 014007 (2015)

NISKANEN et al
Science $\underline{316}$ 723 (2007)

Cooling by feedback control

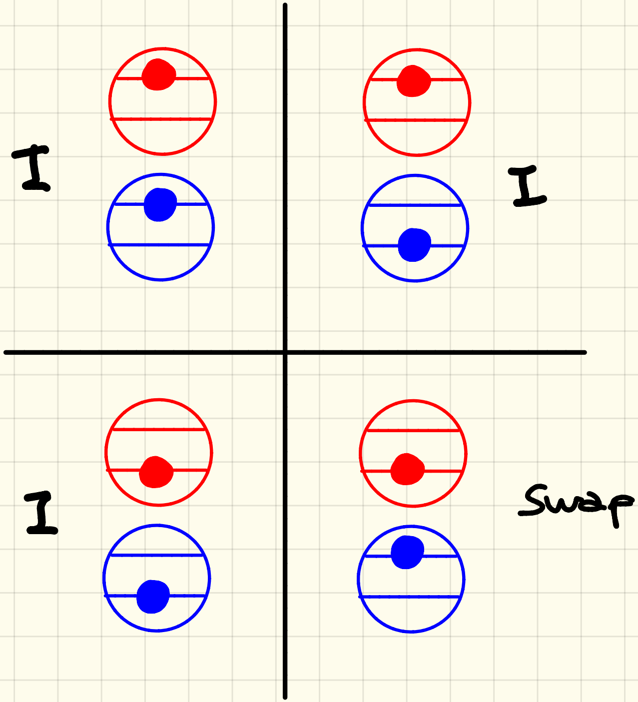


First stroke conditional



Campisi, Pekola, Fazio, NJP 19 053027 (2015)

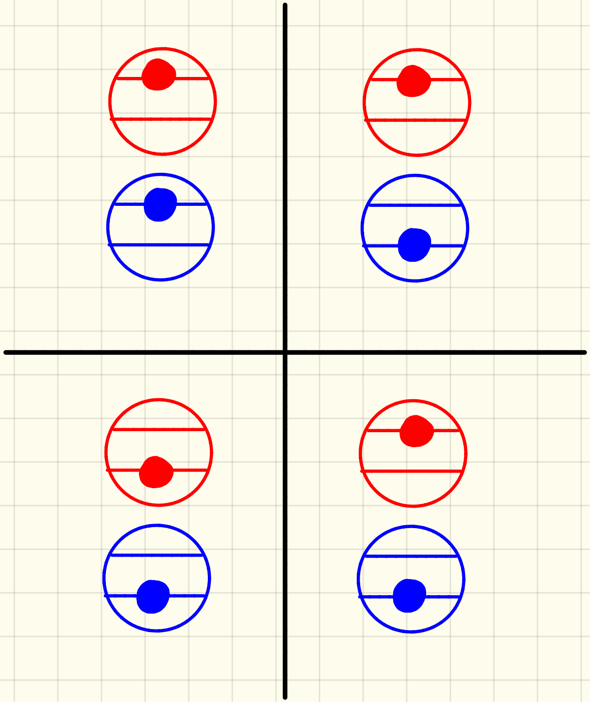
First stroke conditional



Campisi, Pekola, Fazio, NJP 19 053027 (2015)

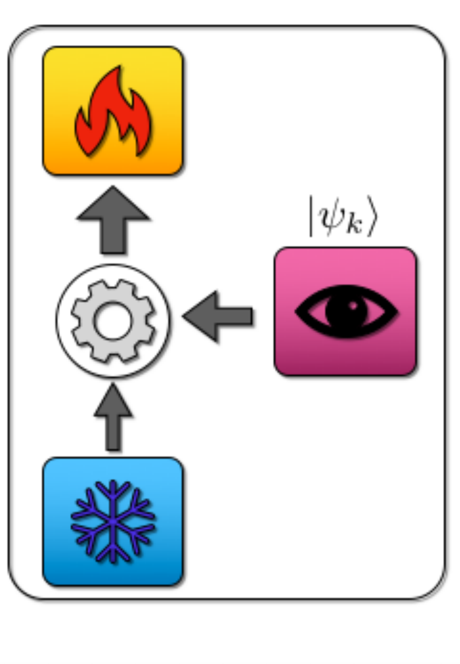
First stroke conditional

$$\boxed{\rho \to \sum_n U_n^\dagger P_n \rho P_n U_n}$$

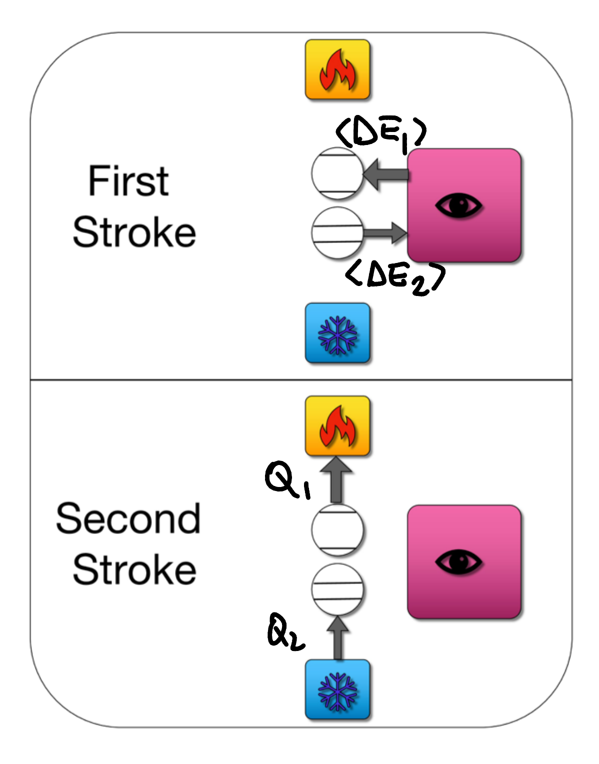


Campisi, Pekola, Fazio, NJP 19 053027 (2015)

quantum measurement cooling



$\Pi_k = |\psi_k\rangle\langle\psi_k|$



$$\boxed{\rho \rightarrow \rho' = \sum_k \Pi_k \, \rho \, \Pi_k}$$

$$\langle \Delta E \rangle = \langle \Delta E_1 \rangle + \langle \Delta E_2 \rangle$$

$$= Q_1 + Q_2$$

"quantum heat"

Elouard et al., npj-quantum info, 3 (2017)

$$\boxed{\beta_1 Q_1 + \beta_2 Q_2 = D[\rho_t^1 \| \rho_0^1] + D[\rho_t^2 \| \rho_0^2] + I_{1/2}[\rho_t] + \Delta H}$$

$$\boxed{\beta_1 Q_1 + \beta_2 Q_2 \geq \Delta H \geq 0}$$

$$\rho \to \rho' = \sum_k \Pi_k \, \rho \, \Pi_k$$

unital !!

$$\Rightarrow \boxed{\Delta H \geq 0}$$

$$\mathrm{Tr}_i \left[H_i(\tau) \rho_t^i - H_i(0) \rho_0^i \right] = \langle \Delta E_i \rangle = Q_i$$

$$I_{1/2}[\rho_t] = \sum_i H[\rho_t^i] - H[\rho]$$

$$D[\rho \| \sigma] = \mathrm{Tr}\left(\rho \ln \rho - \rho \ln \sigma \right)$$

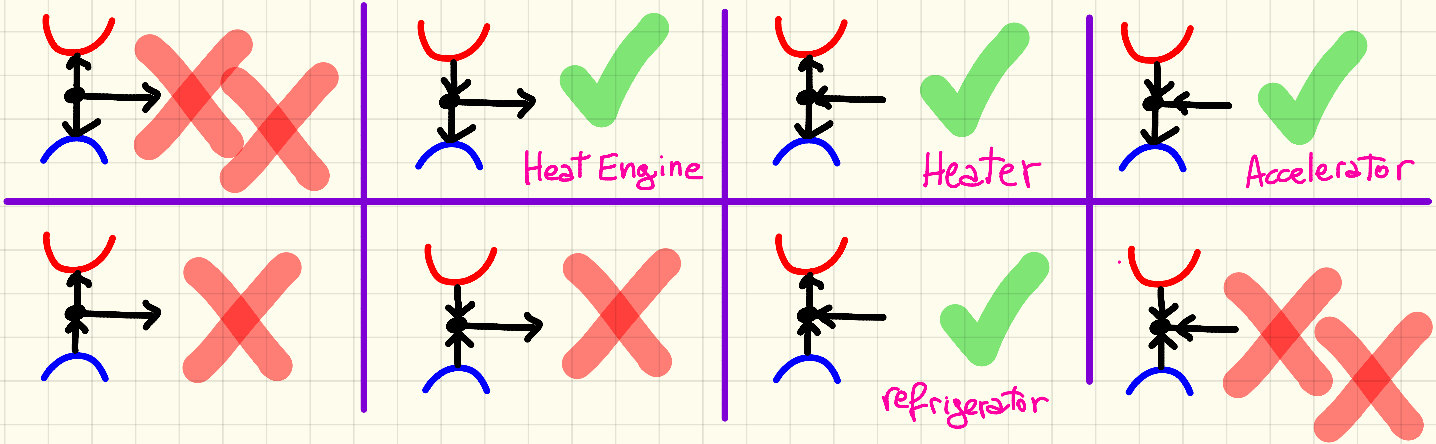
$$H[\rho] = -\mathrm{Tr}\, \rho \ln \rho$$

$$\beta_1 Q_1 + \beta_2 Q_2 \geq 0$$

$$\langle \Delta E \rangle = Q_1 + Q_2$$

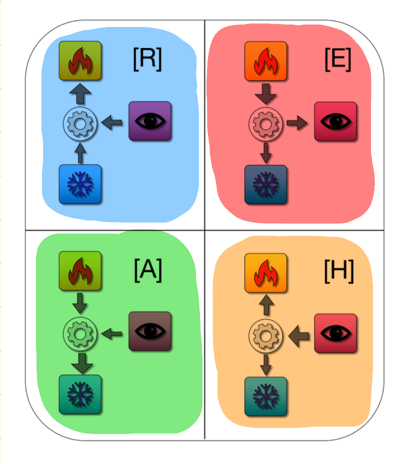
A. Solfanelli

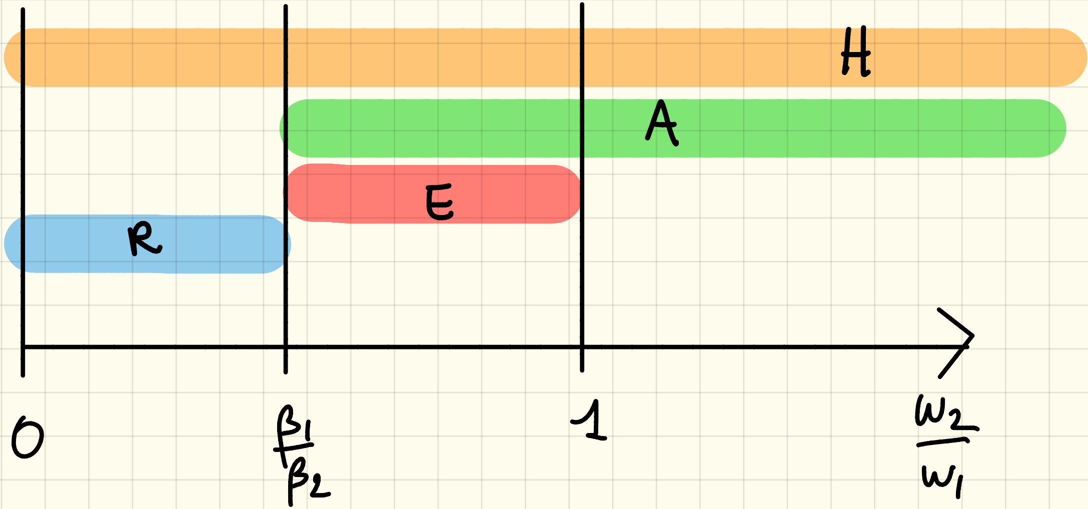
B. Sc. thesis UNIFI



Results

1





Results

2

$$\begin{cases} |\psi_1^*\rangle = |\uparrow\uparrow\rangle \\ |\psi_2^*\rangle = \frac{|\uparrow\downarrow\rangle+|\downarrow\uparrow\rangle}{\sqrt{2}} \\ |\psi_3^*\rangle = \frac{|\uparrow\downarrow\rangle-|\downarrow\uparrow\rangle}{\sqrt{2}} \\ |\psi_4^*\rangle = |\downarrow\downarrow\rangle \end{cases}$$

maximises

$\eta^{[R]}$, $-Q_2$ in [R]-range

$\eta^{[E]}$, $\langle \Delta E \rangle$ in [E]-range

$$\langle \Delta E_{1,2} \rangle = \frac{\pm\omega_i}{2}\left(\frac{1}{1+e^{\beta_1\omega_1}} - \frac{1}{1+e^{\beta_2\omega_2}}\right)$$

$$\eta^{[R]} = \frac{1}{\frac{w_1}{w_2} - 1}$$

$$\eta^{[E]} = 1 - \frac{w_2}{w_1}$$

Results

3

Let $|\psi_k\rangle = U|k\rangle$

Pick U randomly from the invariant $SU(4)$ measure

then

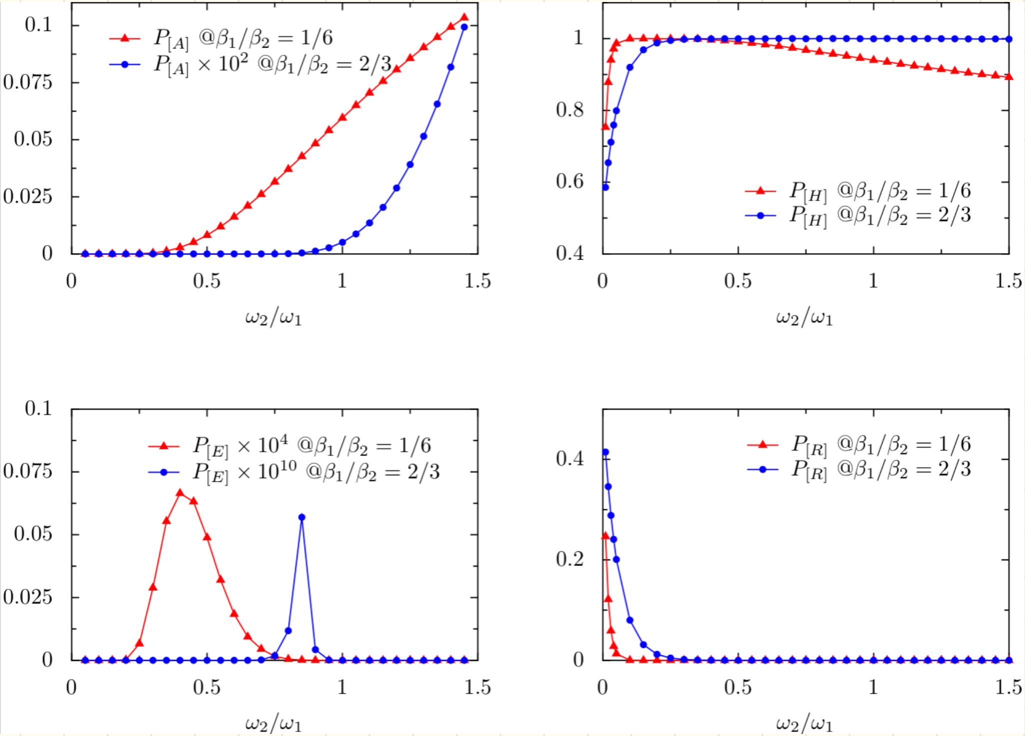
$$\overline{\langle \Delta E_i \rangle} \geq 0 \Rightarrow [H]$$

$$\left(\bar{f} = \int_{SU(4)} dm\, f \right)$$

Results

④

Monte Carlo Sampling of SU(4)



Experiment ....

circuit QED + circuit QTD

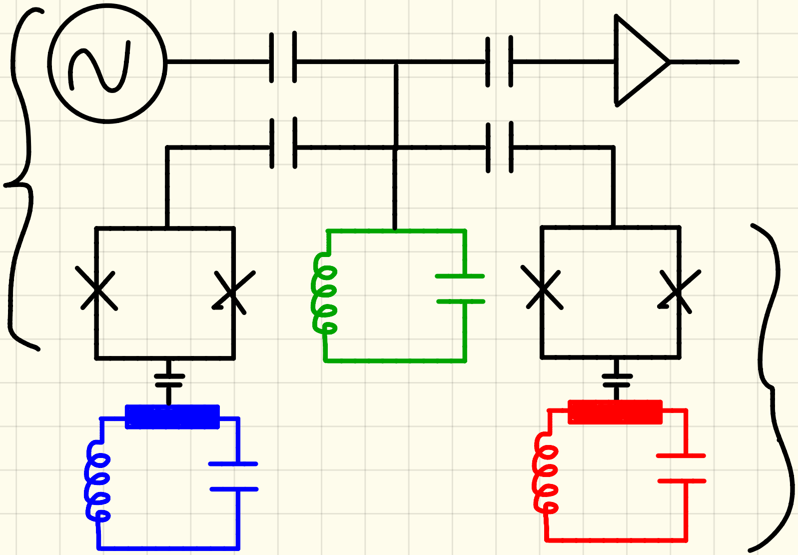
↓

circuit Quantum Thermo Dynamics → Pekola, Giazotto....

$$\rho' = \sum_k \Pi_k \, \rho \, \Pi_k$$

$$= \sum_k U P_k U^\dagger \rho \, U P_k U^\dagger$$

Filipp et al., PRL 102 200402 (2009)

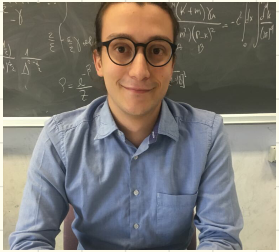


Ronzani et al

arXiv:1801.09312

Lorenzo Buffoni

Paola Verrucchi



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Q-TIF quantum theory in Florence

qtif.weebly.com

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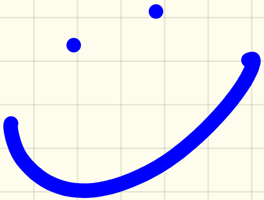
Prof Jukka Pekola, Aalto, Helsinki

thank you



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