Experimental entanglement recovery by thermal environment probing

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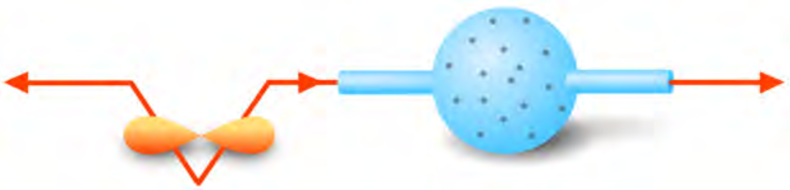
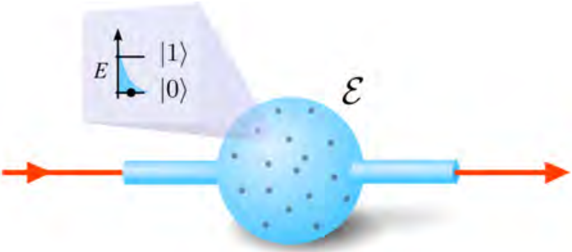
Entanglement transfer through noisy environment



Noisy environment

Multi-qubit environment $\mathcal{E}$:

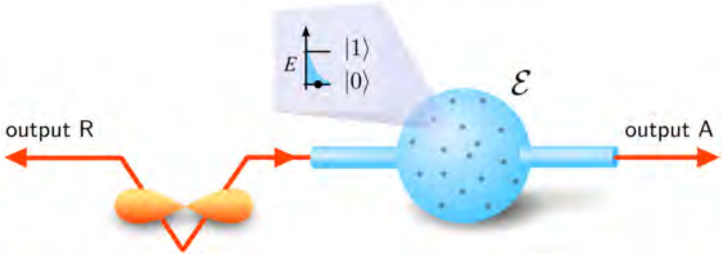
$$\mathcal{E} = (1 - p_T)|0\rangle\langle 0| + p_T|1\rangle\langle 1| \qquad p_T = \frac{\exp\left(-\frac{\Delta E}{k_B T}\right)}{1 + \exp\left(-\frac{\Delta E}{k_B T}\right)}$$



Incoherent environment:

qubits do not interfere or interact with another qubits

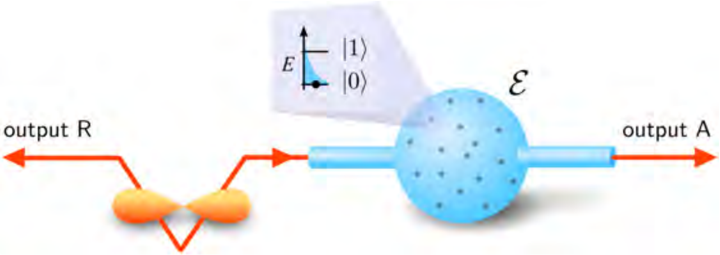
Entanglement transfer through incoherent environment—cooling limit



Input state $|\Psi^-\rangle = \frac{1}{\sqrt{2}}(|0\rangle|1\rangle - |1\rangle|0\rangle)$

Output state $\rho_{\mathrm{R,A}} = P_S|\Psi^-\rangle_{\mathrm{R,A}}\langle\Psi^-| + (1 - P_S)\frac{1_R}{2} \otimes \mathcal{E}_A$

Entanglement transfer through incoherent environment—cooling limit



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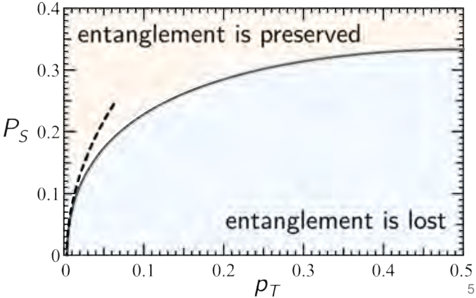
Output state $\rho_{\mathrm{R,A}} = P_S|\Psi^-\rangle_{\mathrm{R,A}}\langle\Psi^-| + (1-P_S)\frac{\mathbb{1}_R}{2}\otimes\mathcal{E}_A$

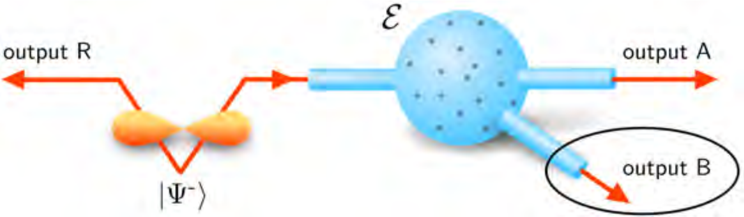
The state remains entangled if

$$P_S > \frac{\sqrt{p_T(1-p_T)}}{1+\sqrt{p_T(1-p_T)}}$$

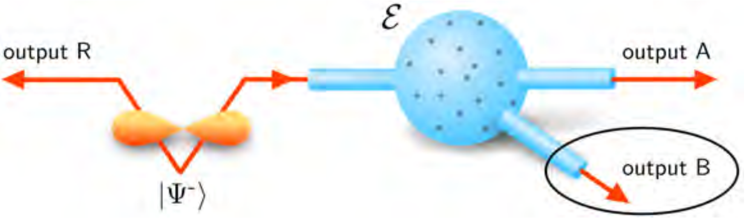
$$\frac{p_T}{P_S^2} < 1 \quad \text{for} \quad p_T \ll 1$$



Using additional environment probing



Using additional environment probing

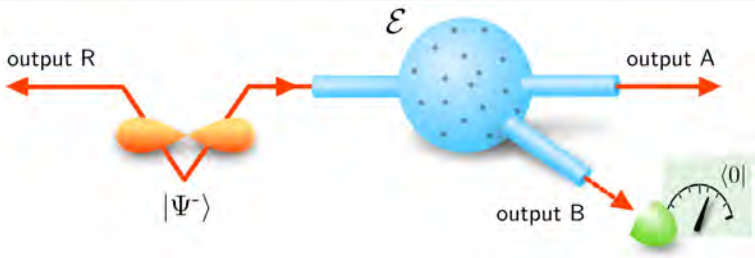


Three possible processes—**success, flip, and loss**

	R	A	B	state
P_S	● (red)	● (red)	● (blue)	$\vert\Psi^-\rangle_{RA}\langle\Psi^-\vert \otimes \mathcal{E}_B$
P_F	● (red)	● (blue)	● (red)	$\vert\Psi^-\rangle_{RB}\langle\Psi^-\vert \otimes \mathcal{E}_A$
P_L	● (red)	● (blue)	● (blue)	$\frac{1}{2}1_R \otimes \mathcal{E}_A \otimes \mathcal{E}_B$

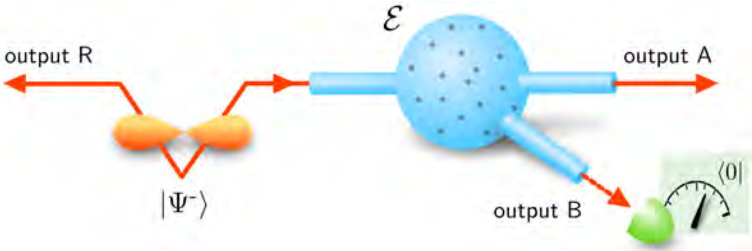
$$P_S + P_F + P_L = 1$$

Conditional cooling limit



Projecting channel *A* to environment's ground state gives

$$\rho_{\mathrm{R,A}} \propto (1 - p_T) P_S |\Psi^-\rangle_{\mathrm{R,A}}\langle\Psi^-| + \frac{1}{2} P_F |1\rangle_{\mathrm{R}}\langle 1| \otimes \mathcal{E}_{\mathrm{A}} + (1 - p_T) P_L \frac{1}{2} 1_{\mathrm{R}} \otimes \mathcal{E}_{\mathrm{A}}$$



Projecting channel A to environment's ground state gives

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The state remains entangled if

$$P_S > \frac{1}{2}\left(\sqrt{p_T P_L(4 - 3p_T P_L)} - p_T P_L\right)$$

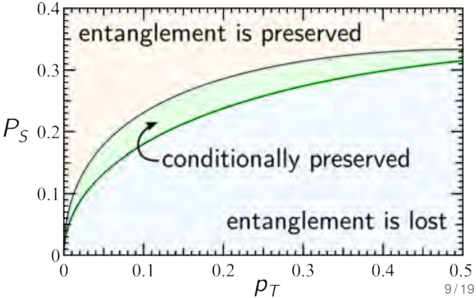
$$\frac{p_T P_L}{P_S^2} < 1 \quad \text{for} \quad p_T \ll 1$$

$P_L = 0$ for single particle environment

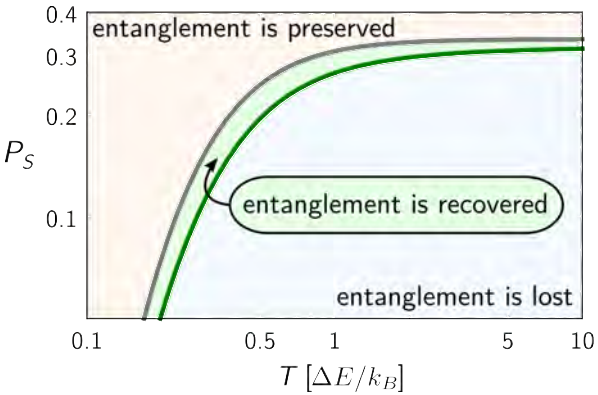
[F. Sciarrino et al., PRA 79, 060304(R) (2009)]

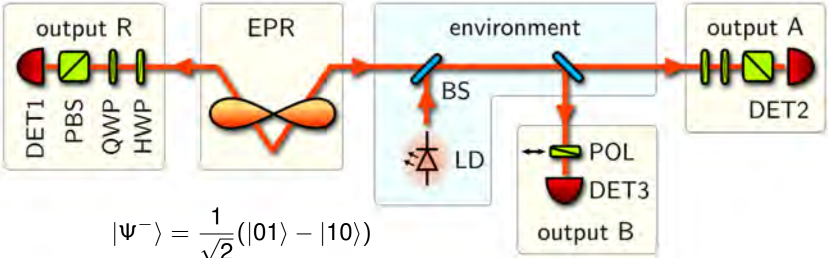
[M. Gavenda et al., PRA 81, 022313 (2010)]

[M. Gavenda et al., PRA 83, 042320 (2011)]

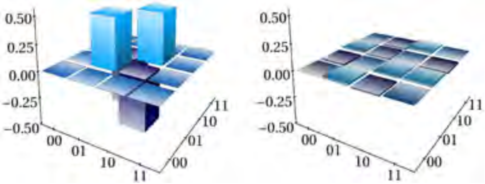


Conditional entanglement recovery at low temperature limit





$$|\Psi^-\rangle = \frac{1}{\sqrt{2}}(|01\rangle - |10\rangle)$$



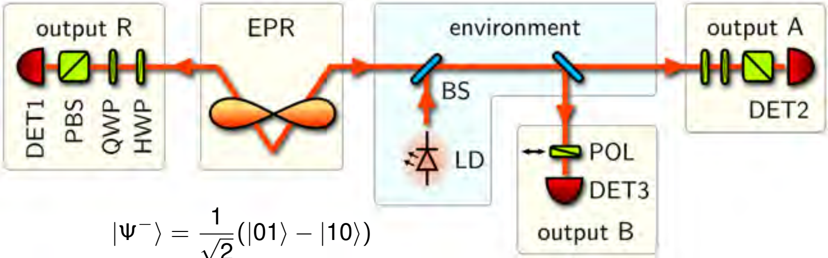
$(\mathcal{P}, \mathcal{F}, \mathcal{C}) \gtrsim 98\%$

$|0\rangle$ conditioning (or Tr)

Experimental features:

– 3-fold coincidences of independent sources
– Full tomography
– Coincidence window
– Noise depolarization

Photonic simulator



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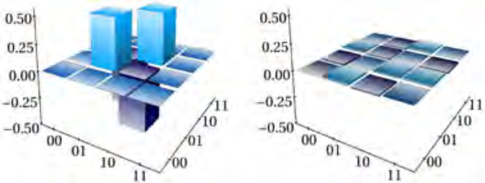

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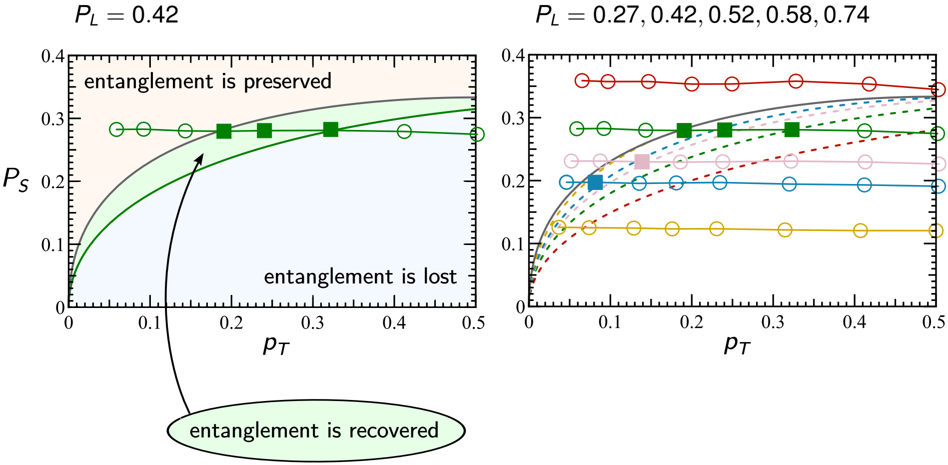
Model of the simulator:

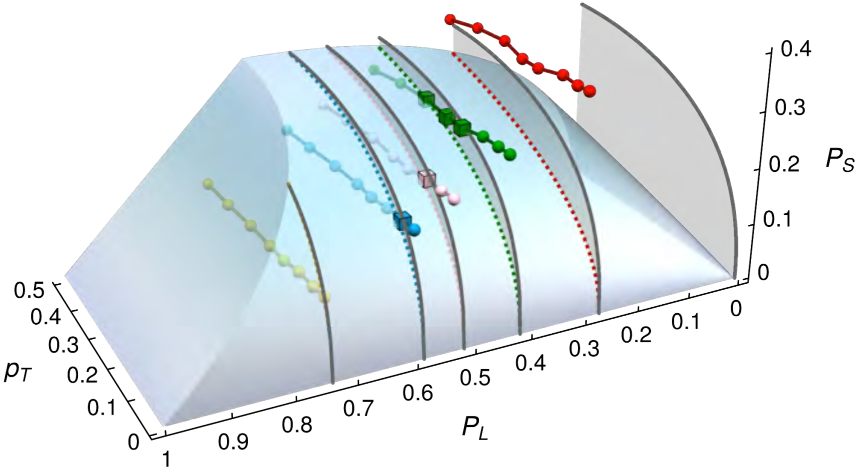
$$\rho_{RS} \propto (1-p_T)|\Psi^-\rangle_{RA}\langle\Psi^-| + \frac{1}{2}|1\rangle\langle 1| \otimes \mathcal{E}_A + (1-p_T)\widetilde{P}_L \frac{1_R}{2} \otimes \mathcal{E}_A, \quad \widetilde{P}_L \propto \frac{\tau R_S R_N}{R_{\psi^-}}$$

Results of the photonic simulation



I. Straka et al., **arXiv:1509.03144** (2015)

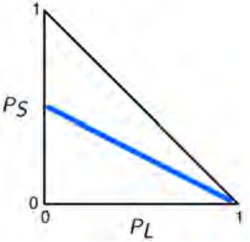
Simulation rusults—full parametric space

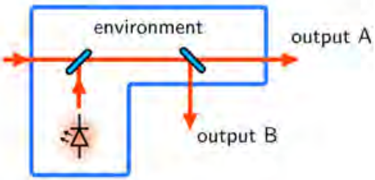


Model of the simulator:

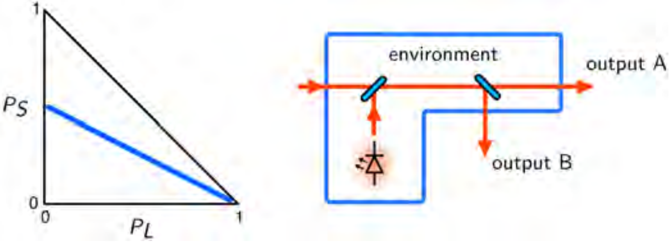
$$\rho_{RS} \propto (1-p_T)|\Psi^-\rangle_{\mathrm{RA}}\langle\Psi^-| + \frac{1}{2}|1\rangle\langle 1| \otimes \mathcal{E}_{\mathrm{A}} + (1-p_T)\widetilde{P}_L \frac{1_{\mathrm{R}}}{2} \otimes \mathcal{E}_{\mathrm{A}}, \quad \widetilde{P}_L \propto \frac{\tau R_S R_N}{R_{\psi^-}}$$

Basic simulator

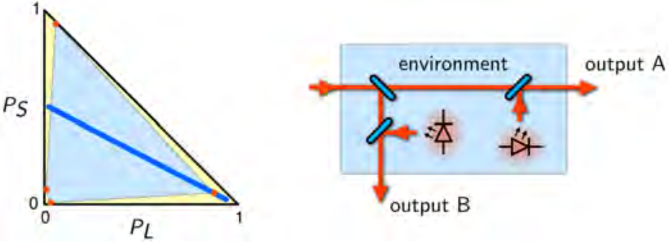




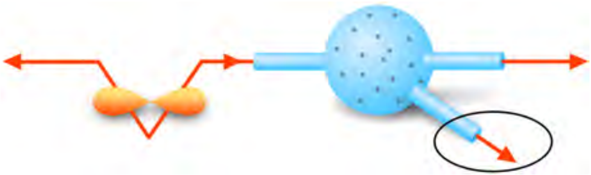
Basic simulator



Extended simulator



Entanglement transfer through noisy environment



- Multi-qubit incoherent environment
- Environment probing
- Unconditional and conditional cooling limits
- Photonic simulator
- Channel parameters accessible to the simulation

I. Straka et al., **arXiv:1509.03144** (2015)

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Thank you for your attention