Quantum trajectories and feedback based on the measurement of decoherence channels in a qubit

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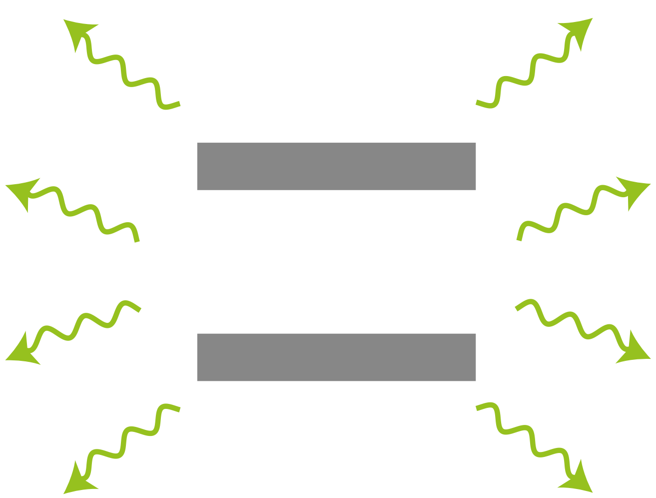
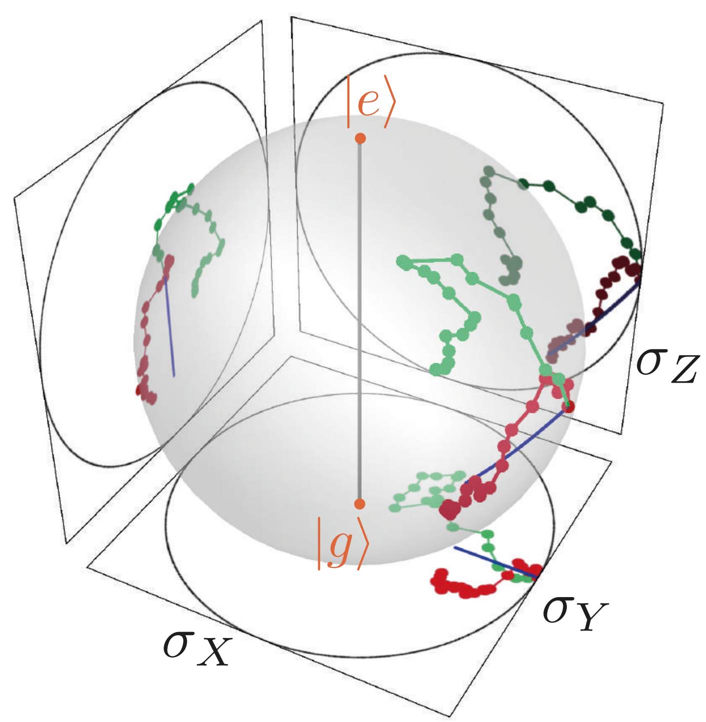
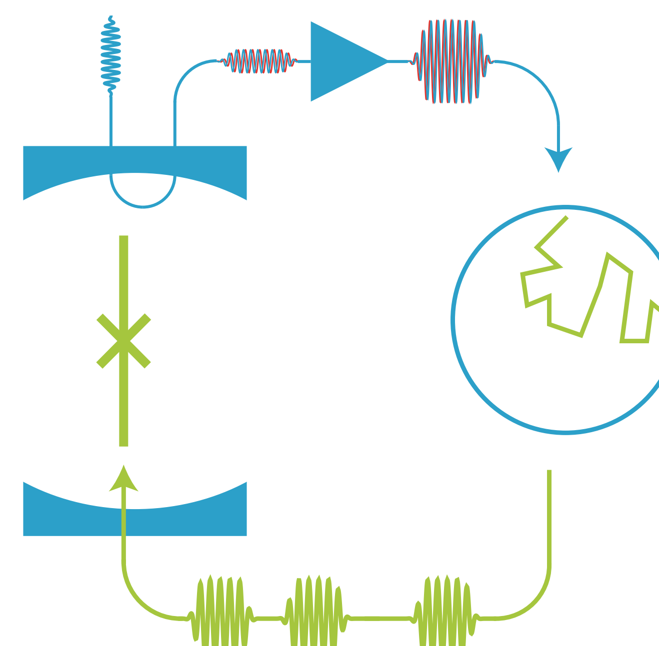
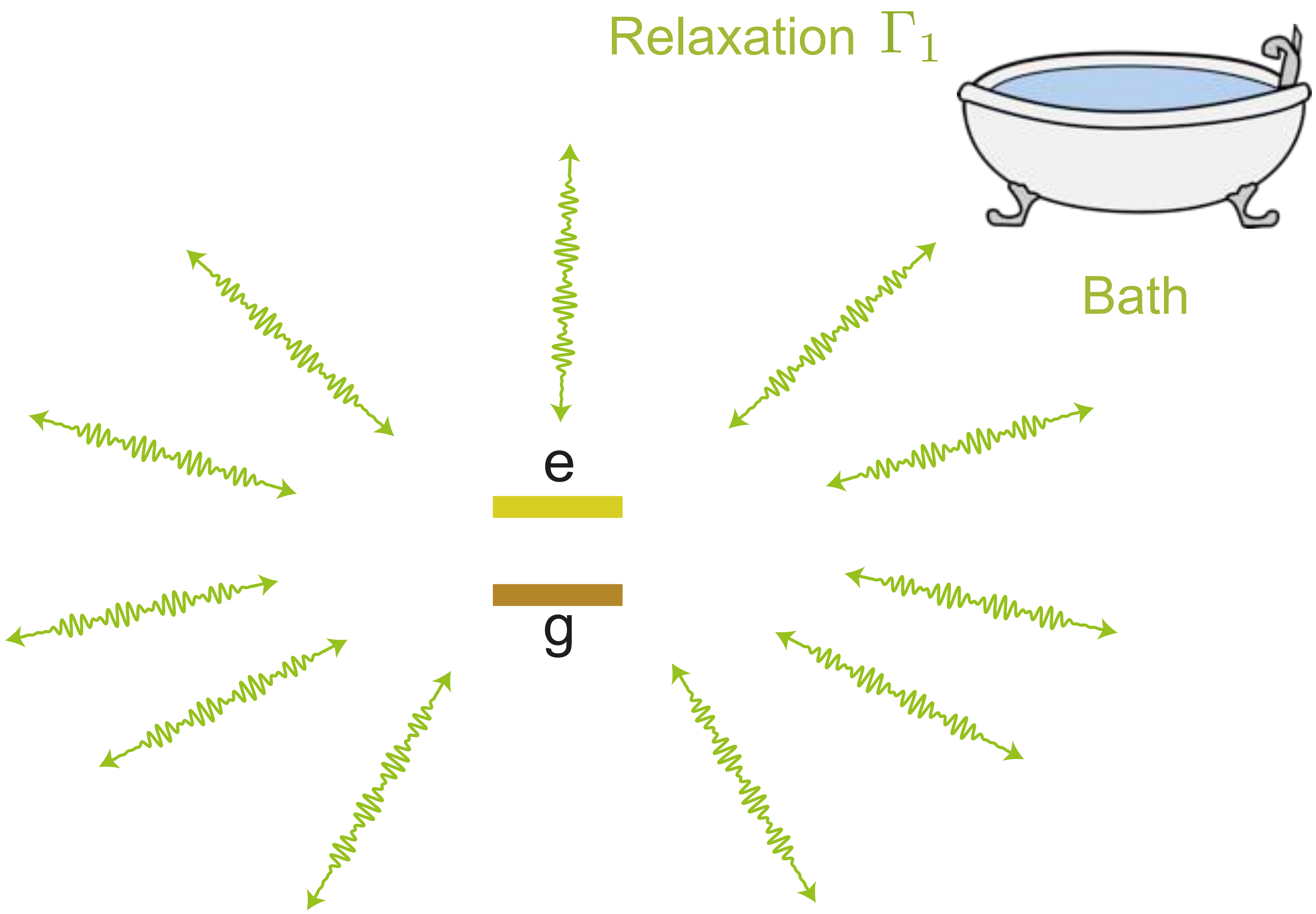




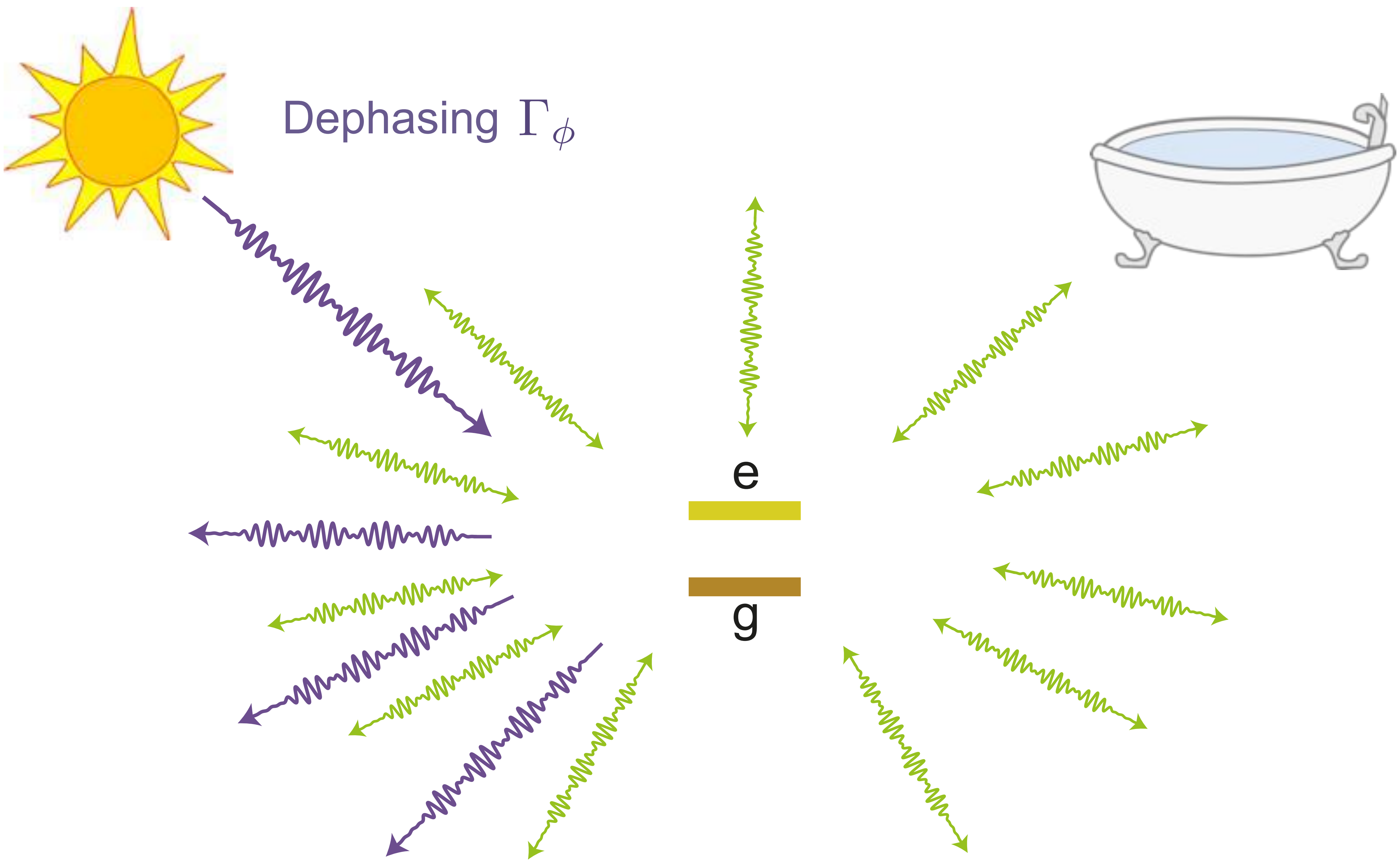


Decoherence channels of a qubit

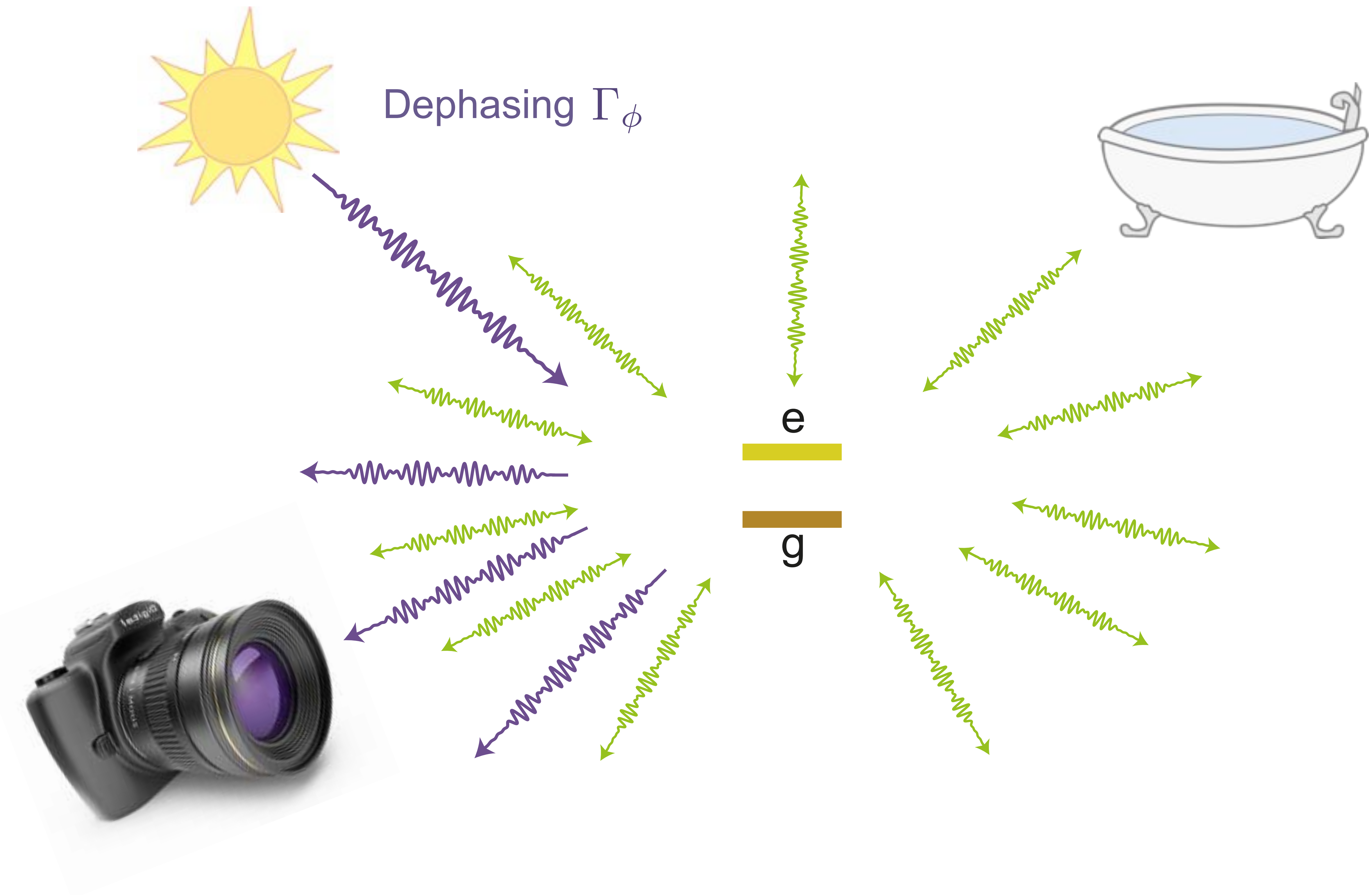
Decoherence channels of a qubit



Decoherence channels of a qubit

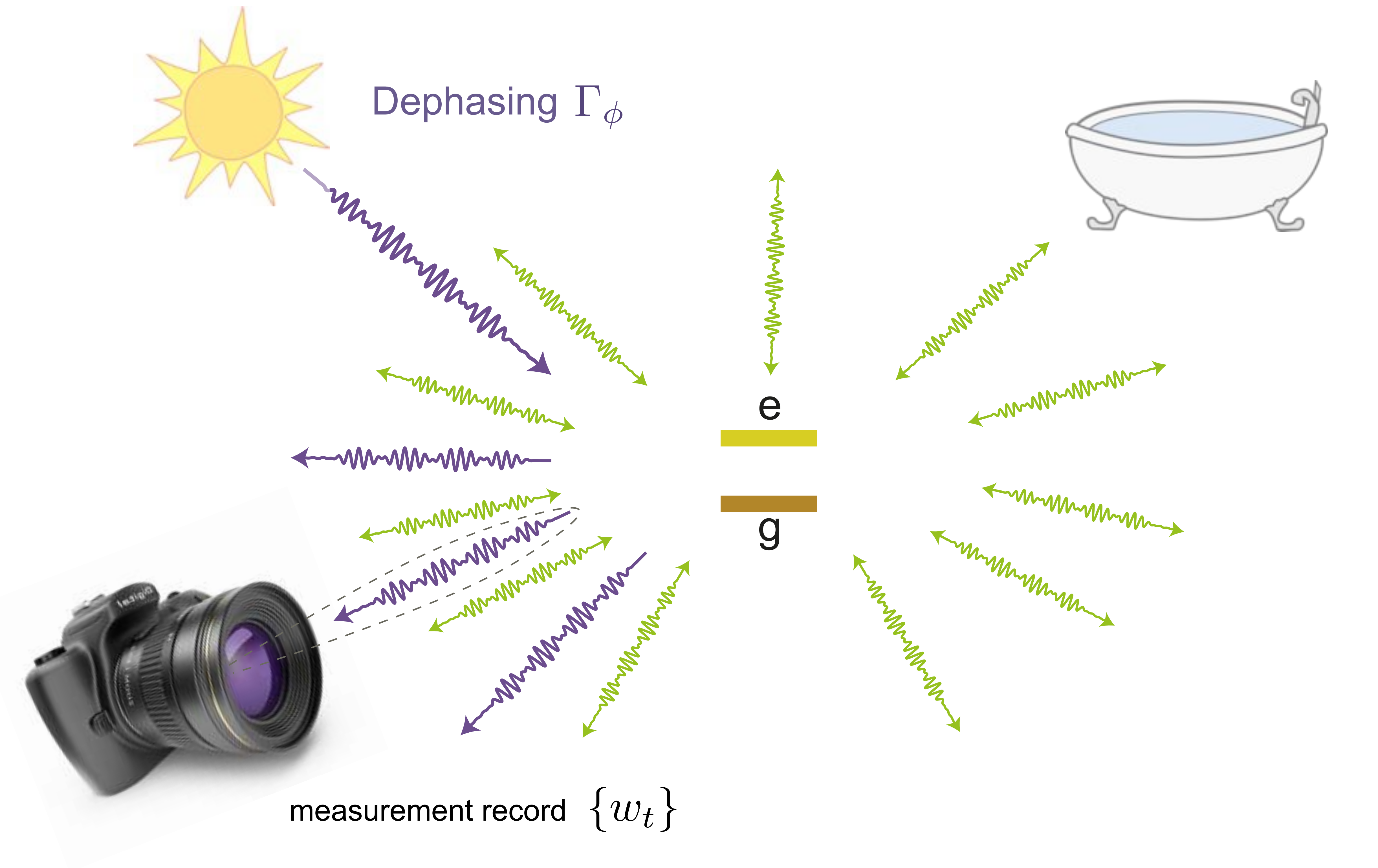


Measurement of decoherence channels of a qubit



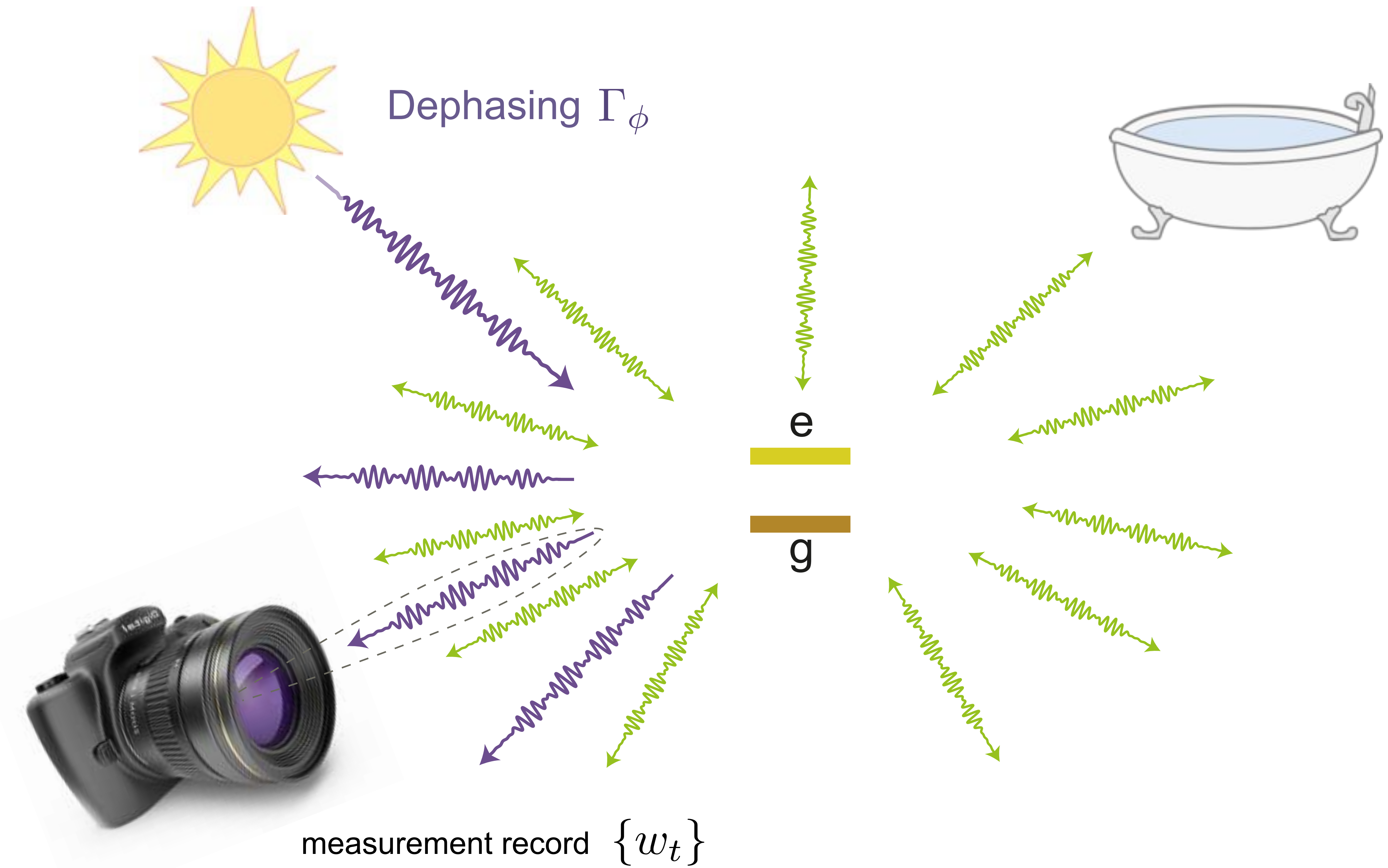
measurement A

Measurement of decoherence channels of a qubit



measurement A

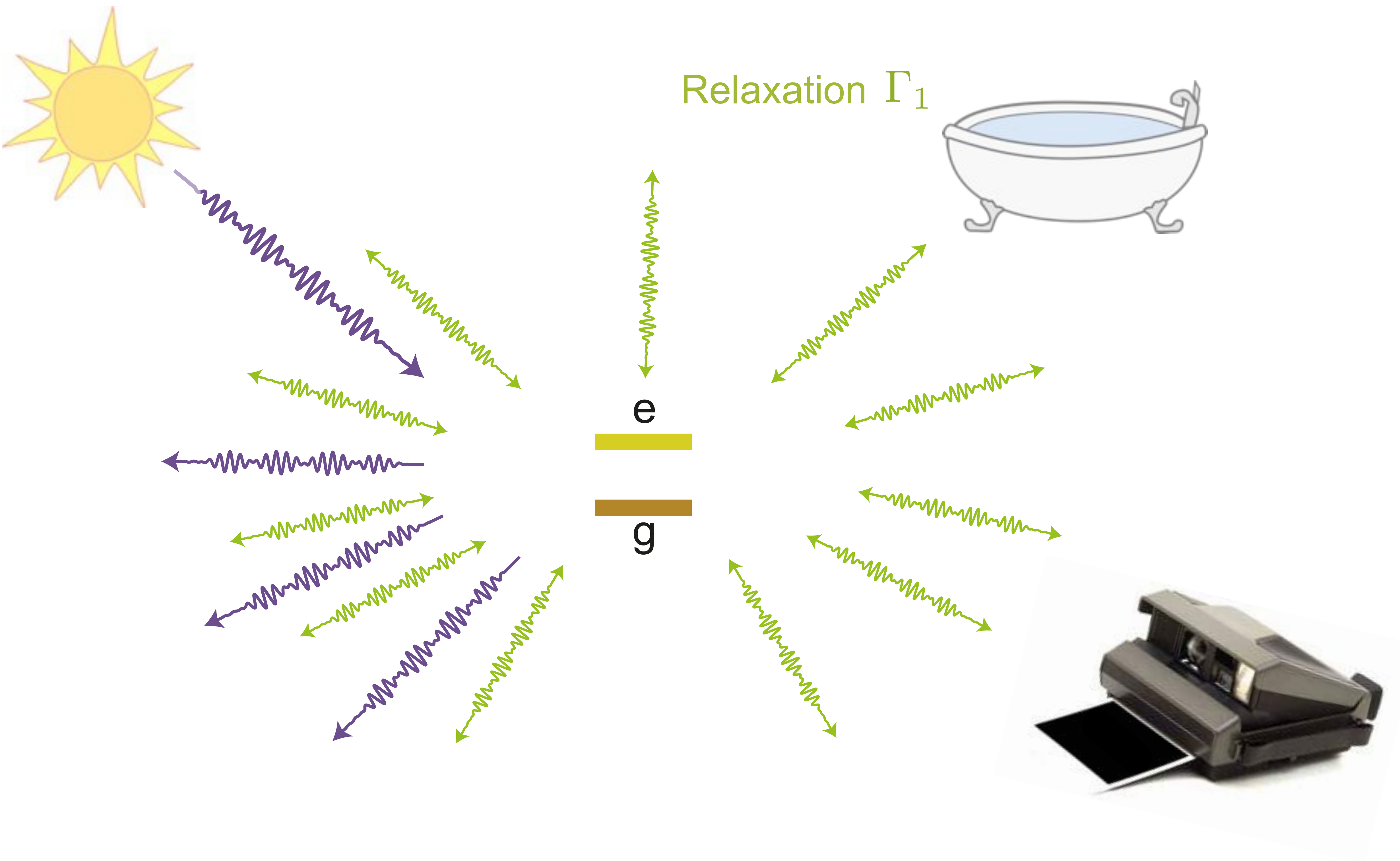
Measurement of decoherence channels of a qubit



Quantum trajectory = $\{\rho_t^{\mathrm{A}}\}$

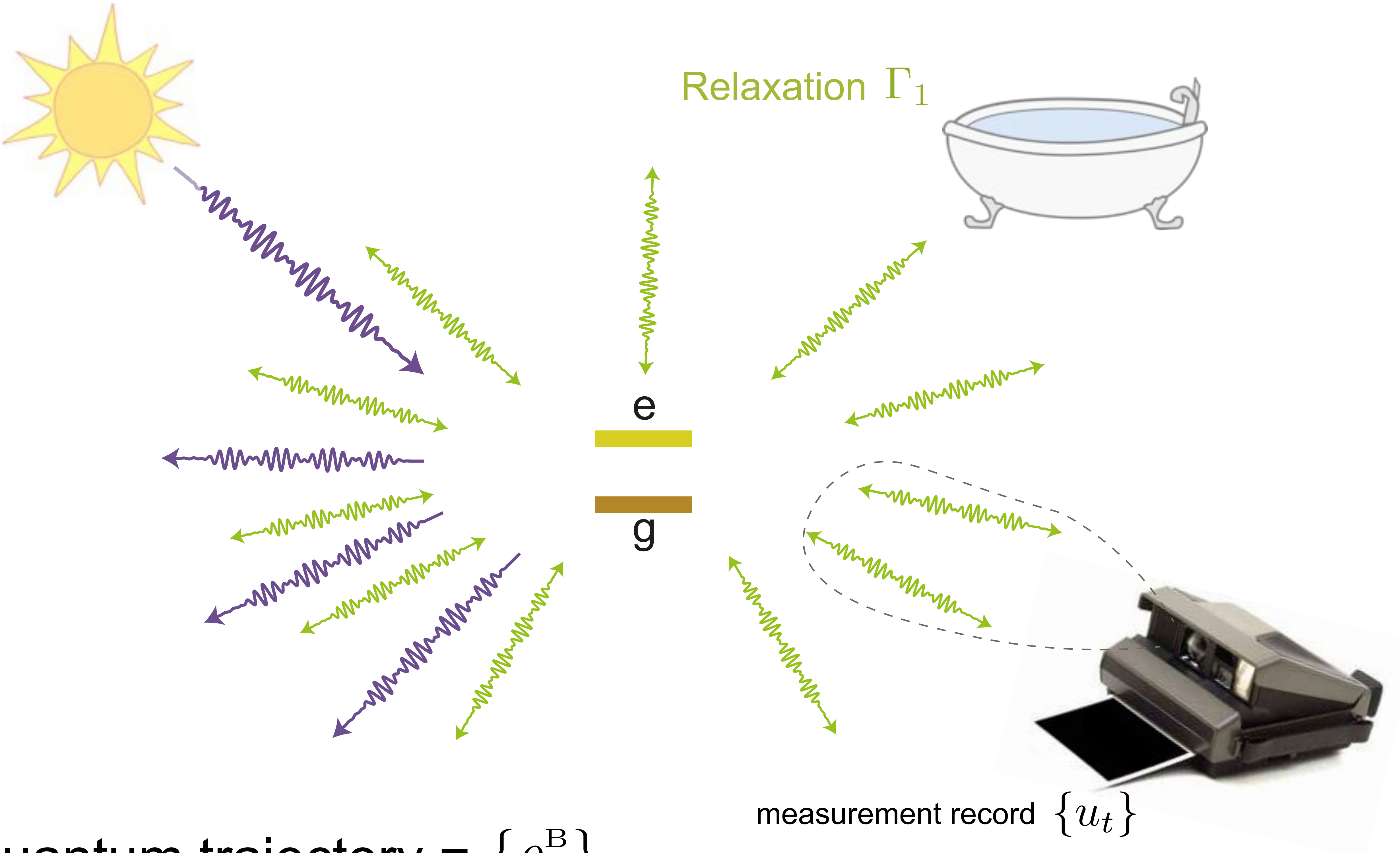
measurement A

Measurement of decoherence channels of a qubit



measurement B

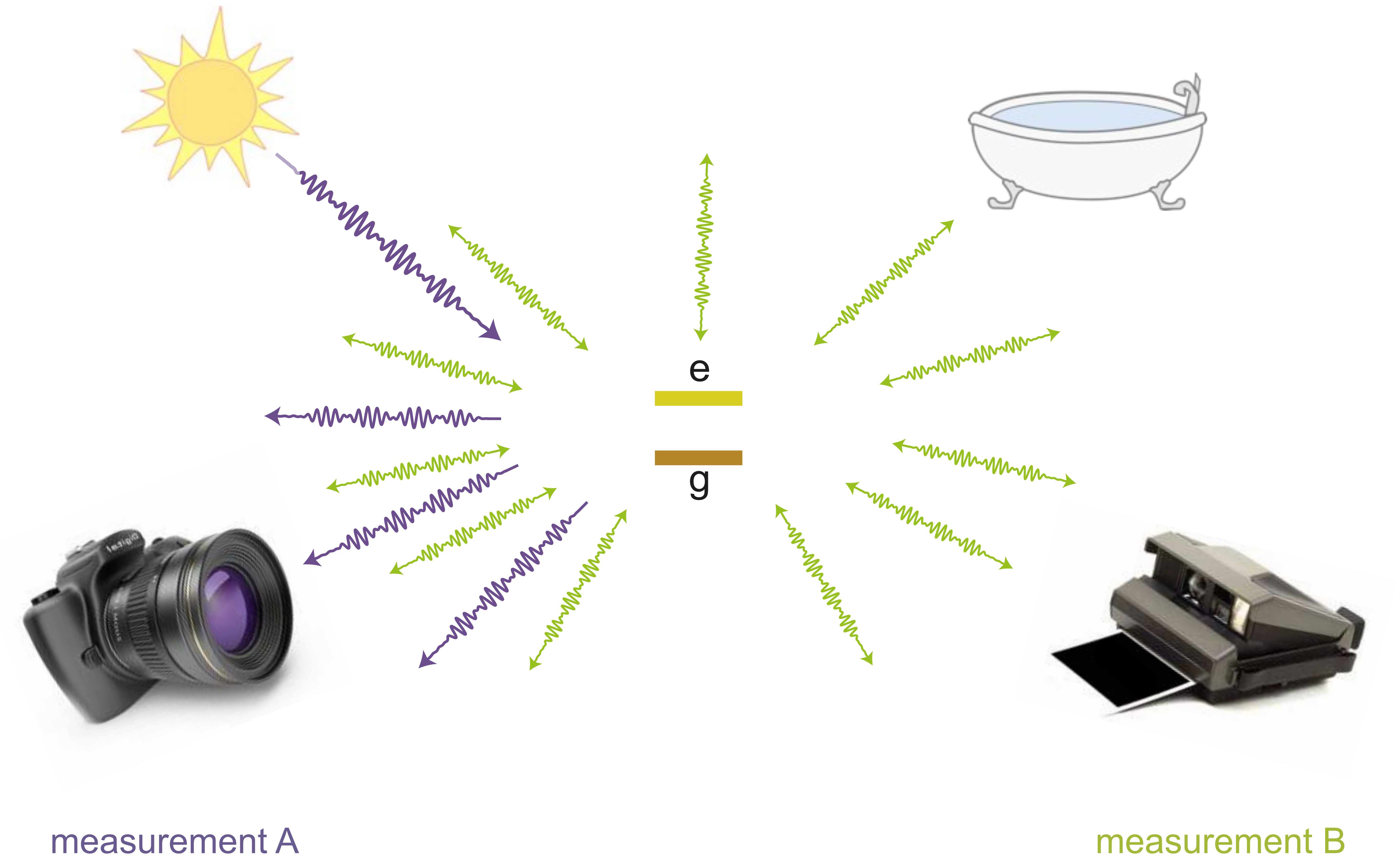
Measurement of decoherence channels of a qubit



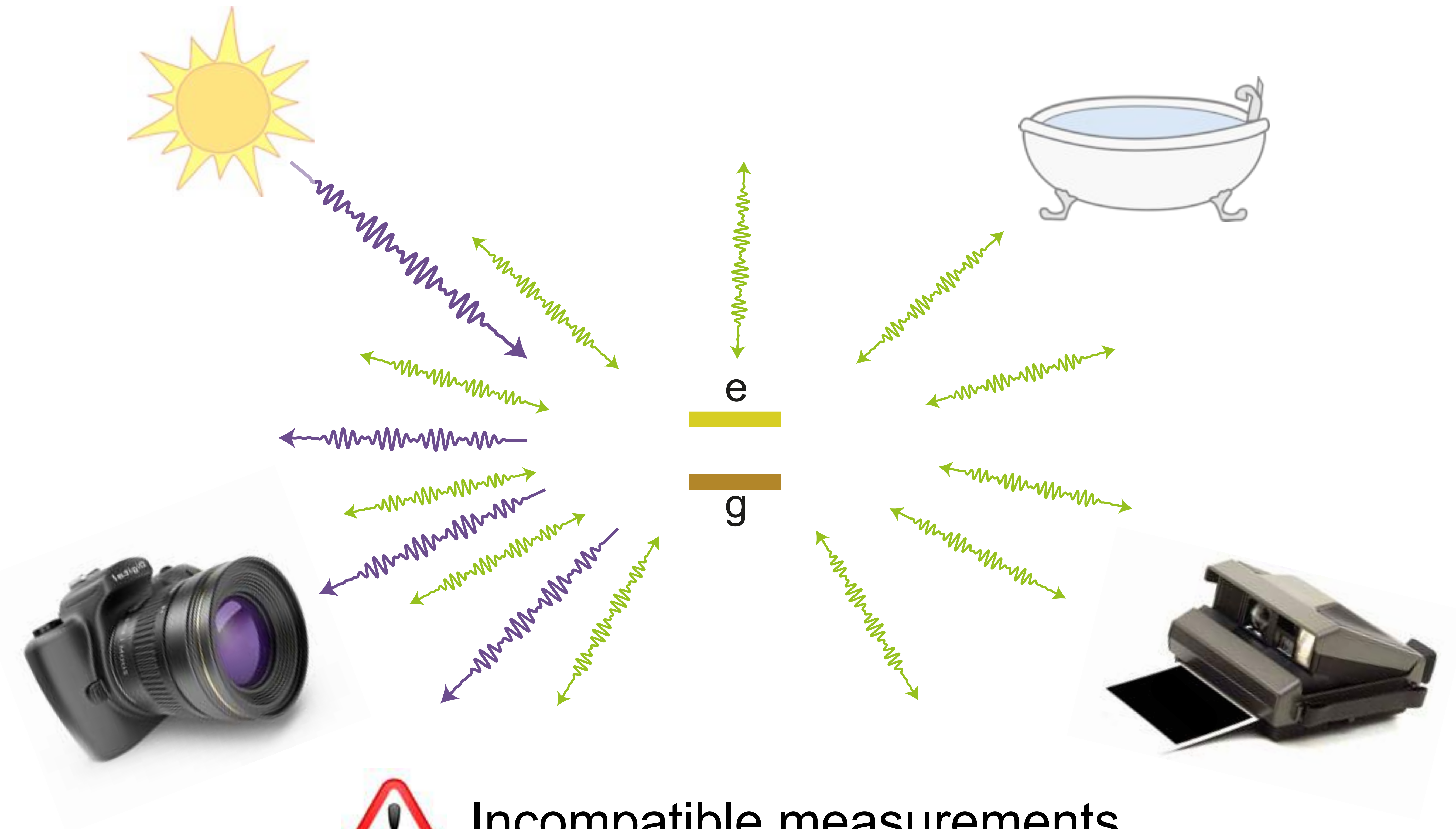
Quantum trajectory = $\{\rho_t^{\mathrm{B}}\}$

measurement B

Measurement of decoherence channels of a qubit



Measurement of decoherence channels of a qubit



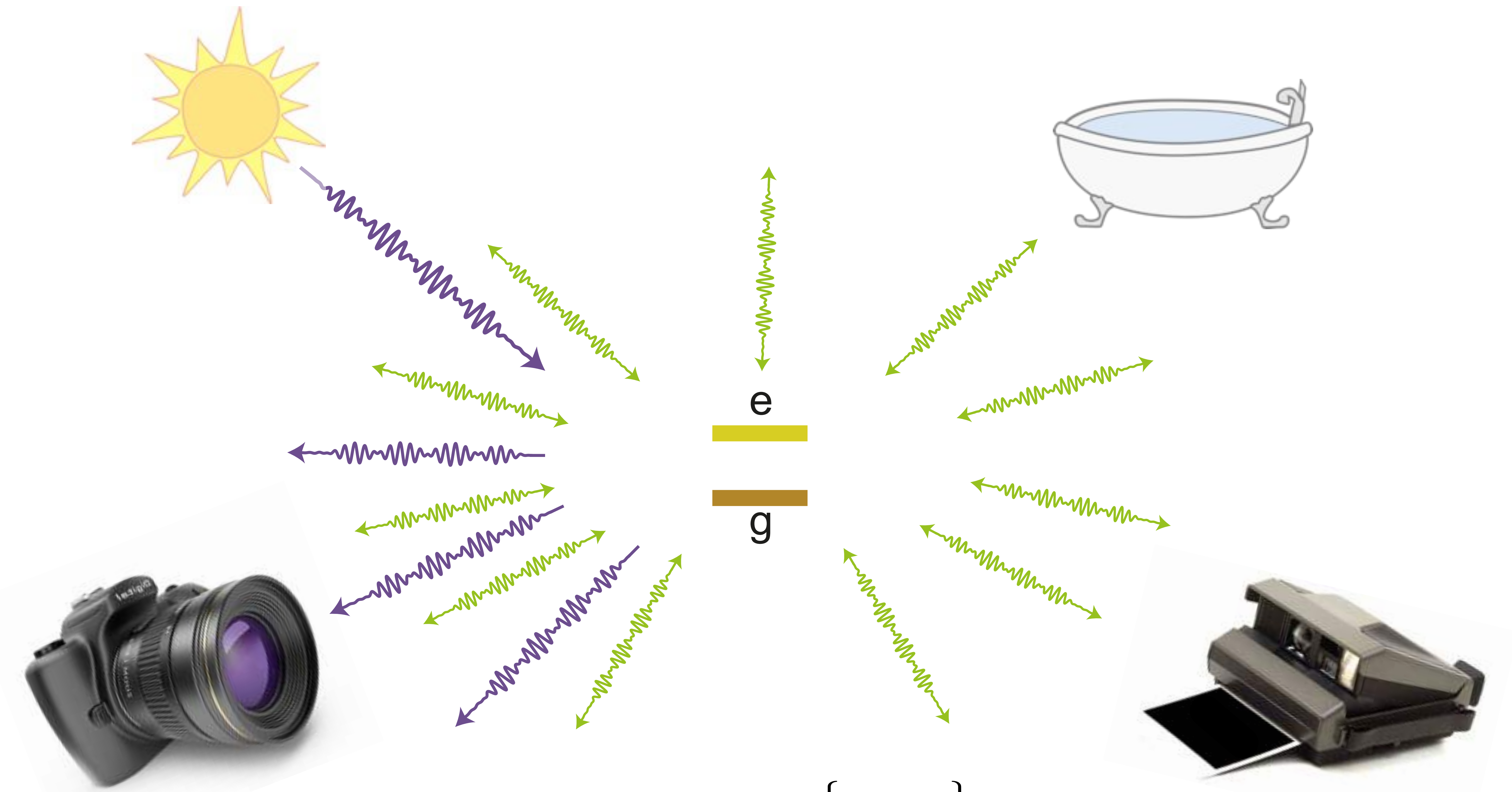
Incompatible measurements

measurement A

[Hacohen-Gourgy *et al.*, Nature 2016]

measurement B

Measurement of decoherence channels of a qubit



measurement records $\{u_t, w_t\}$

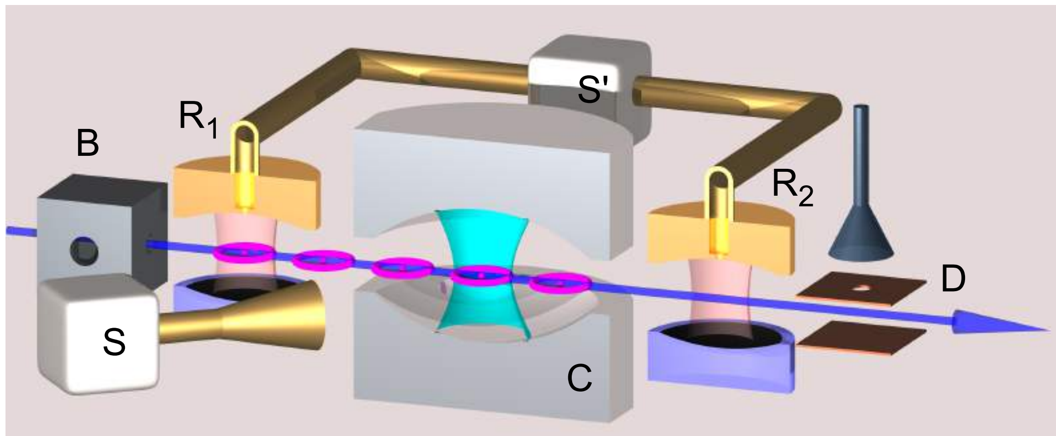
Quantum trajectory = $\{\rho_t^{\mathrm{A+B}}\}$

measurement A

measurement B

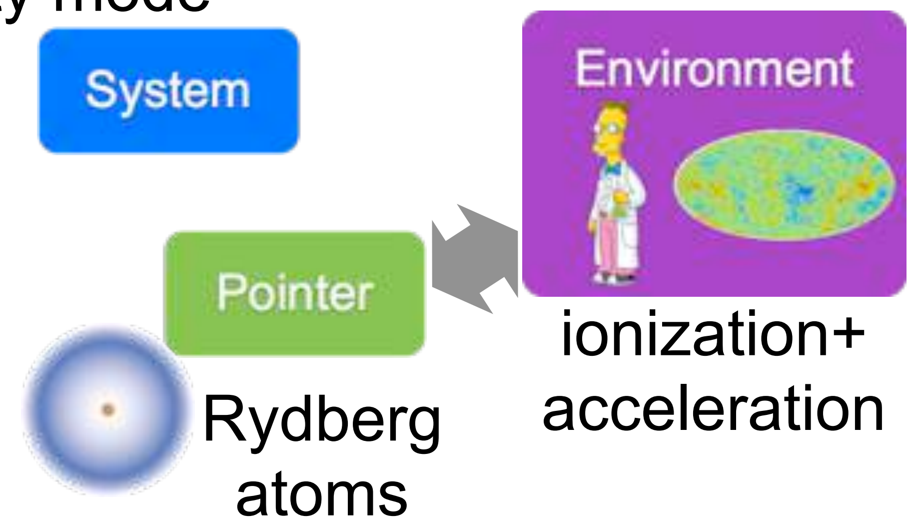
Quantum trajectories already measured in...

Rydberg atoms



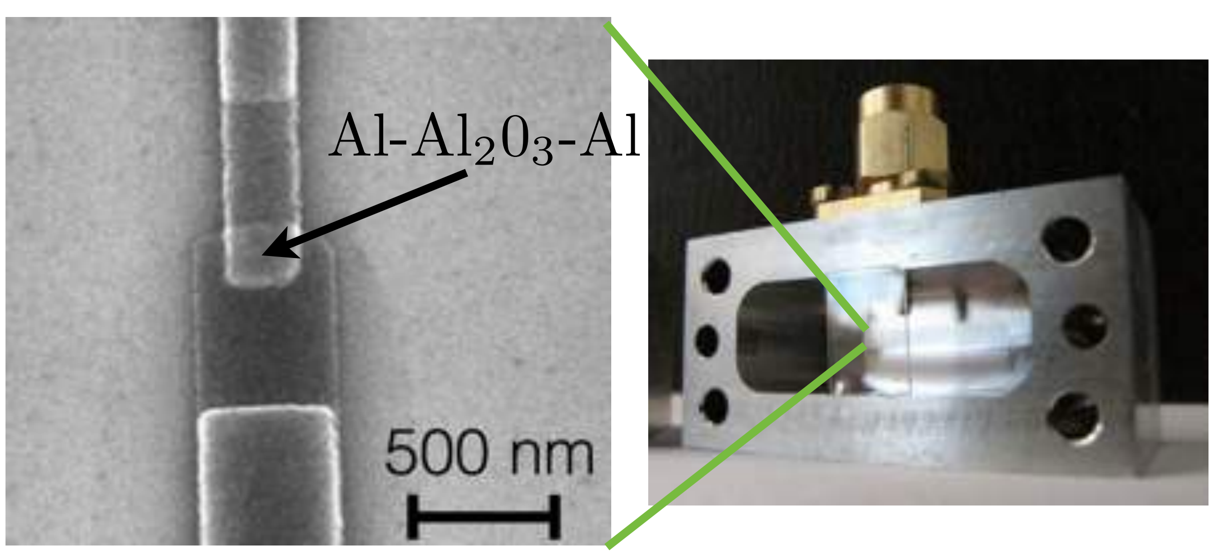
[pic from CQED group, College de France Paris]

Cavity mode

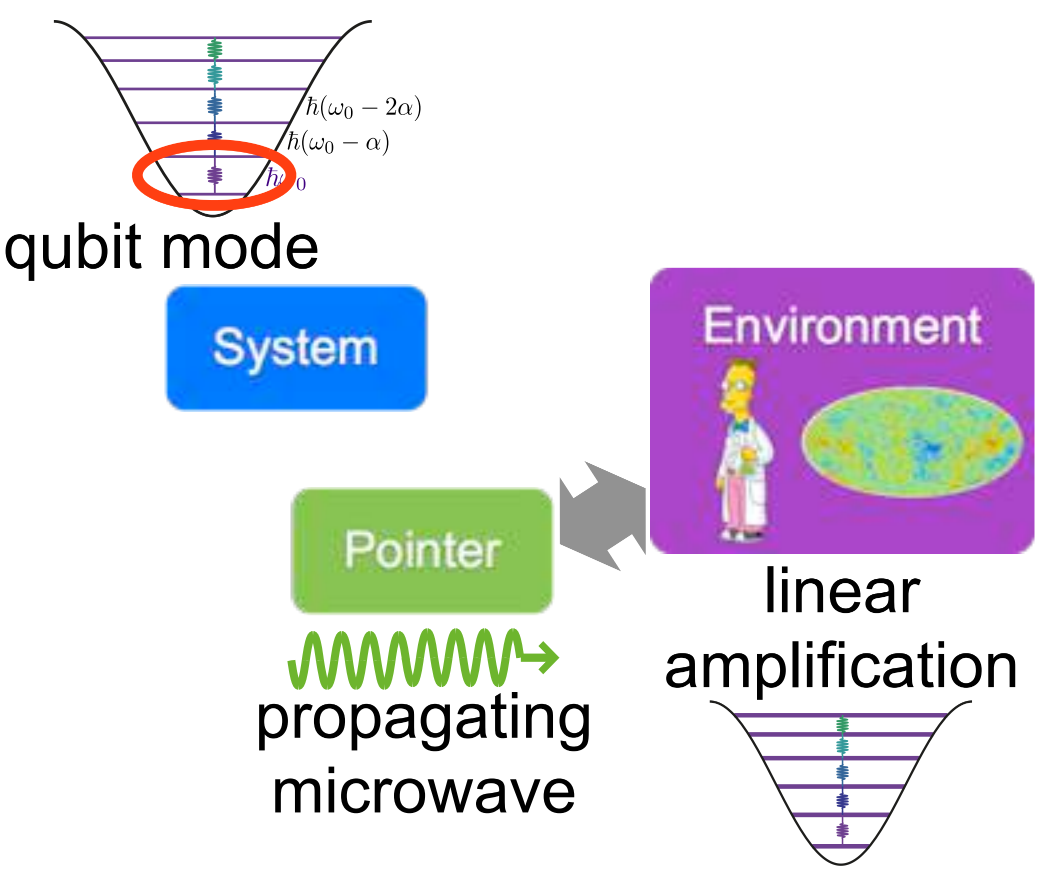


see talk by M. Brune

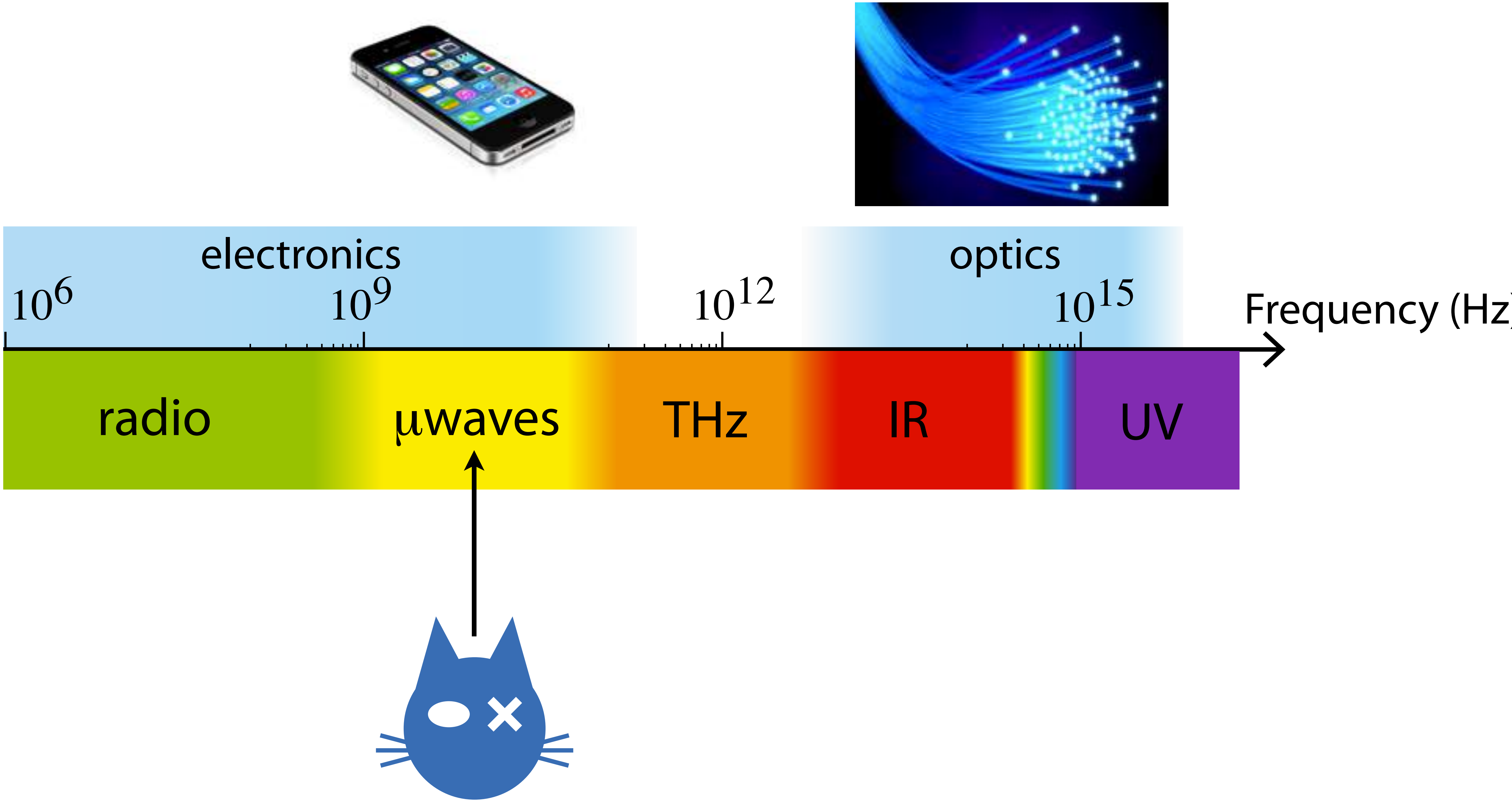
Superconducting circuits



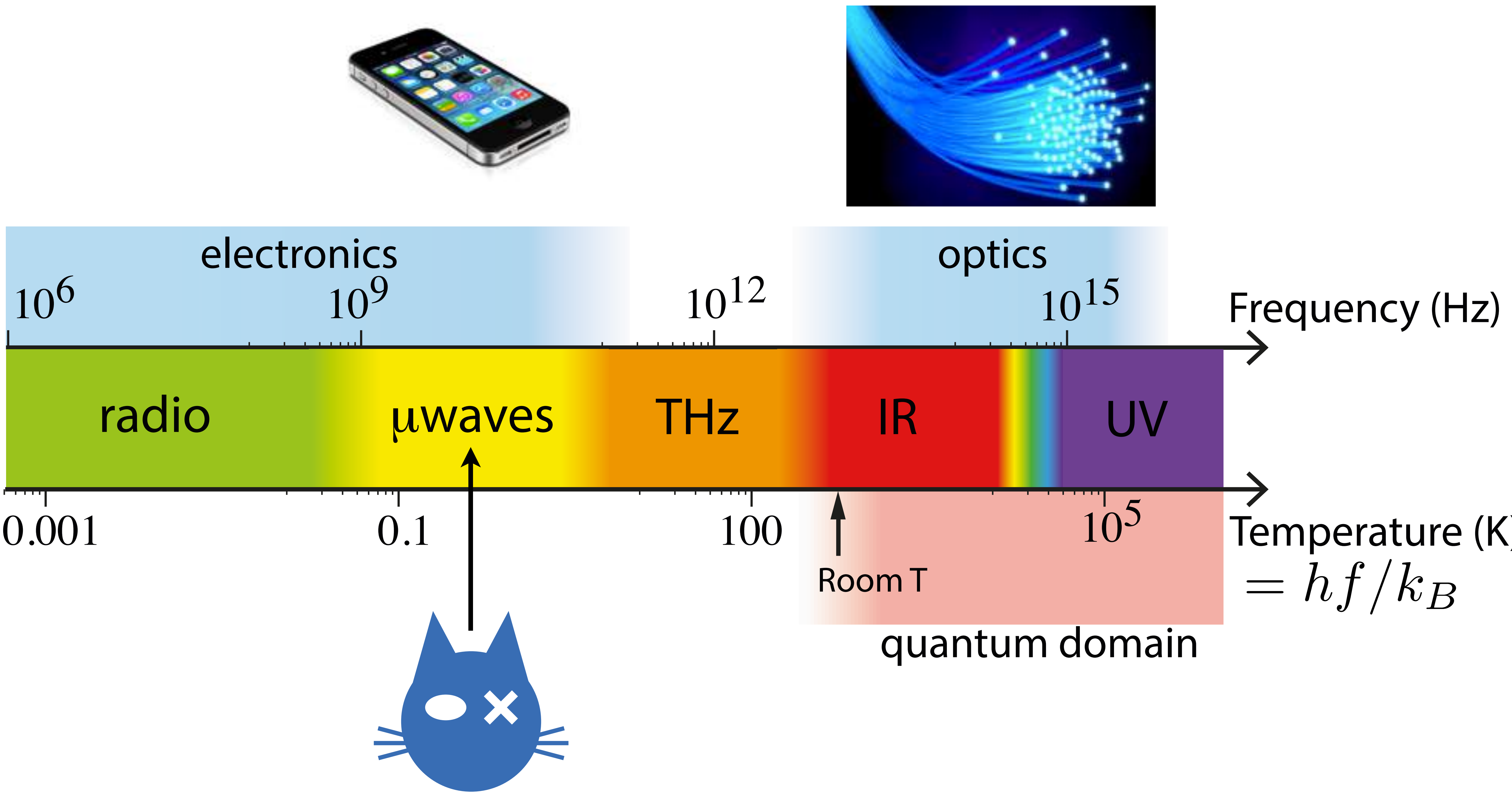
qubit mode



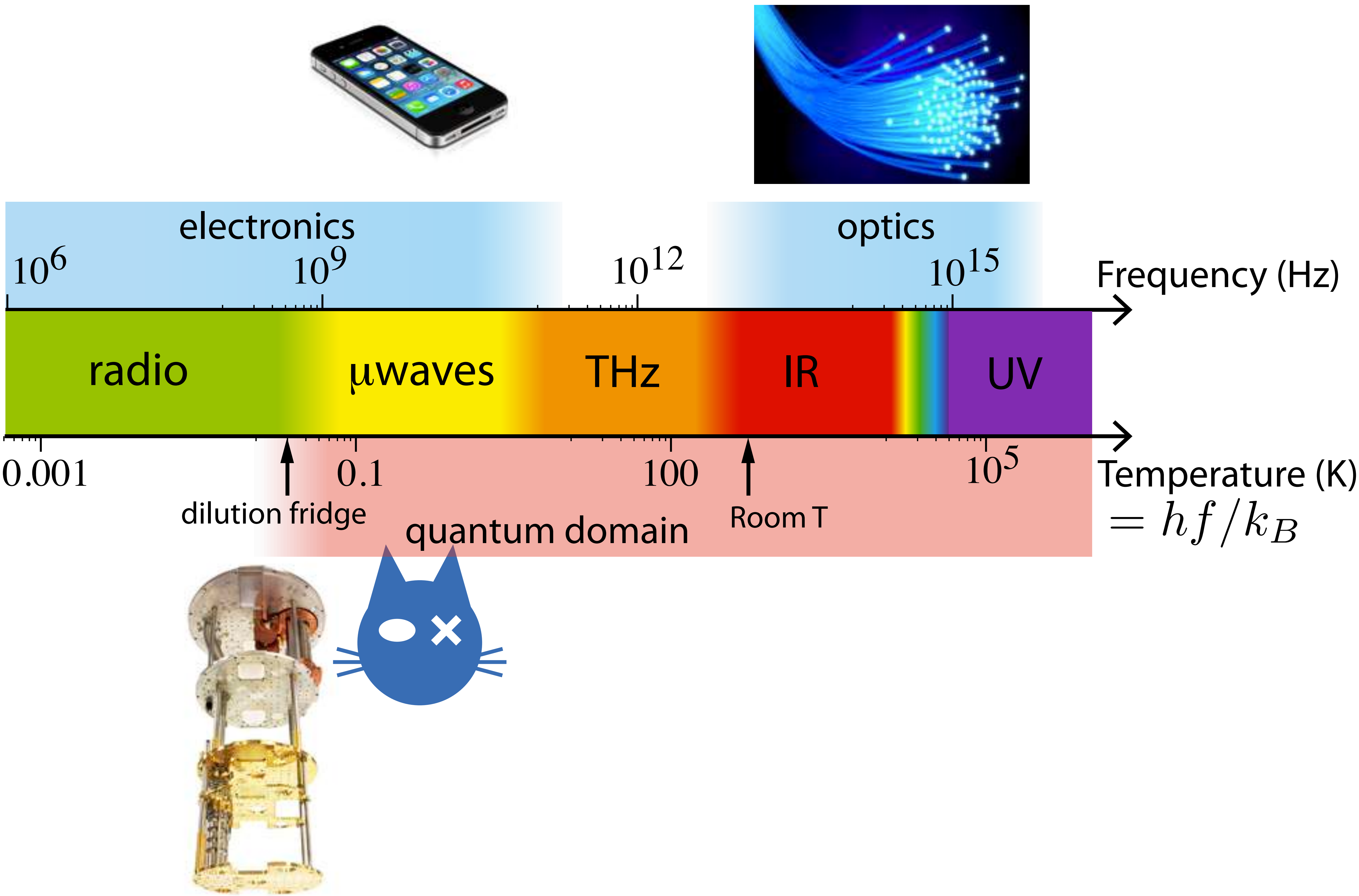
Microwave quantum optics



Microwave quantum optics

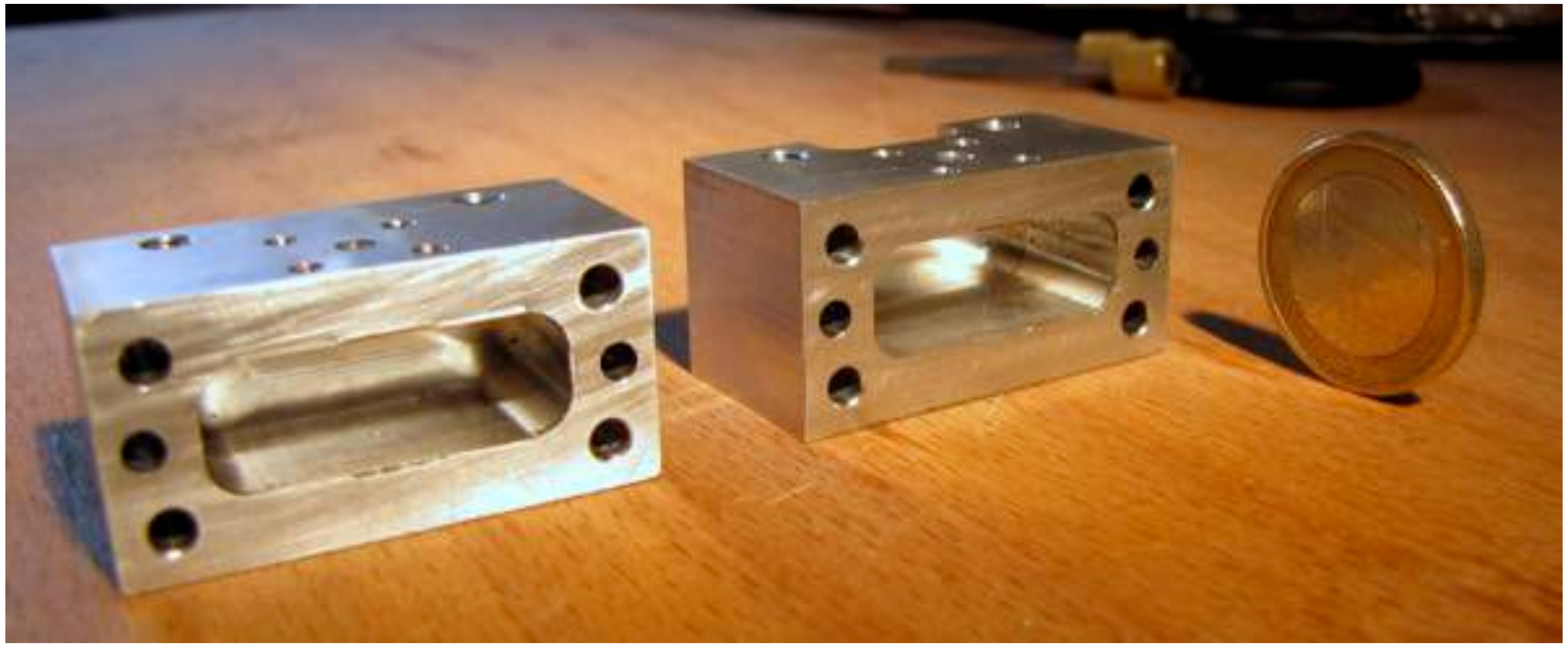


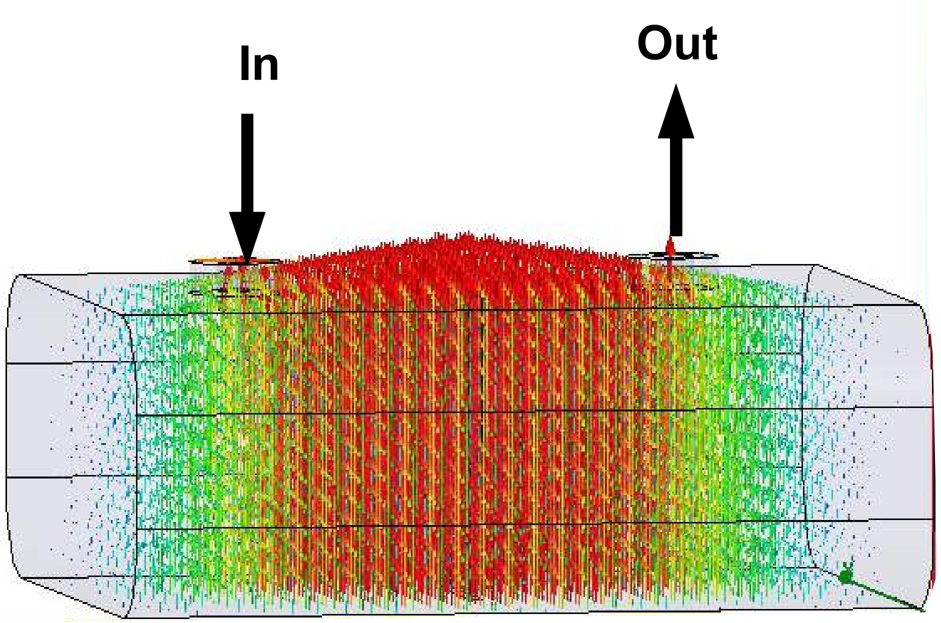
Microwave quantum optics



Superconducting circuits

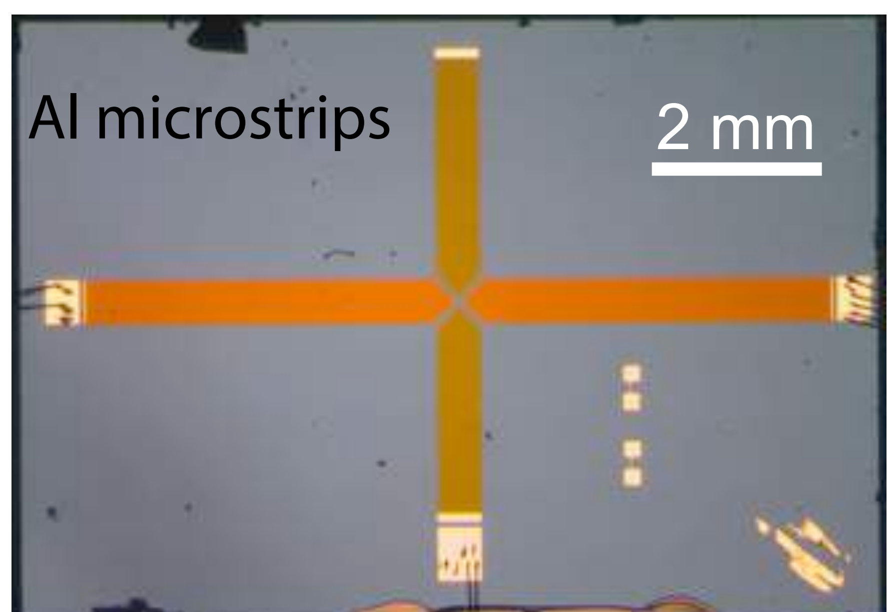
Al cavities



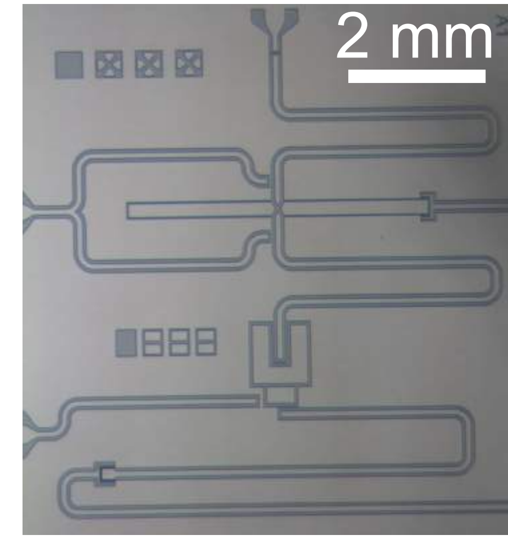


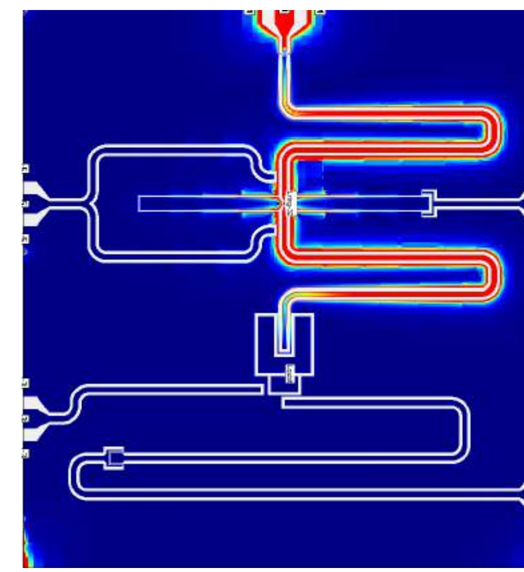
1st mode : 7.8 GHz

$Q \approx 10^6$



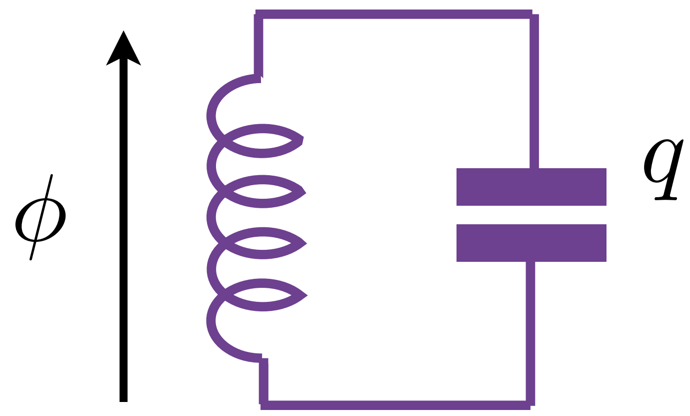
Nb Coplanar waveguides





Superconducting circuits

dissipationless LC circuit...

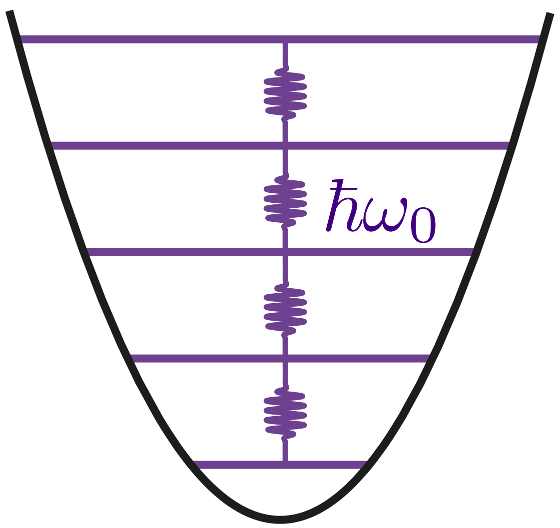


$$\omega_0 = 1/\sqrt{LC}$$

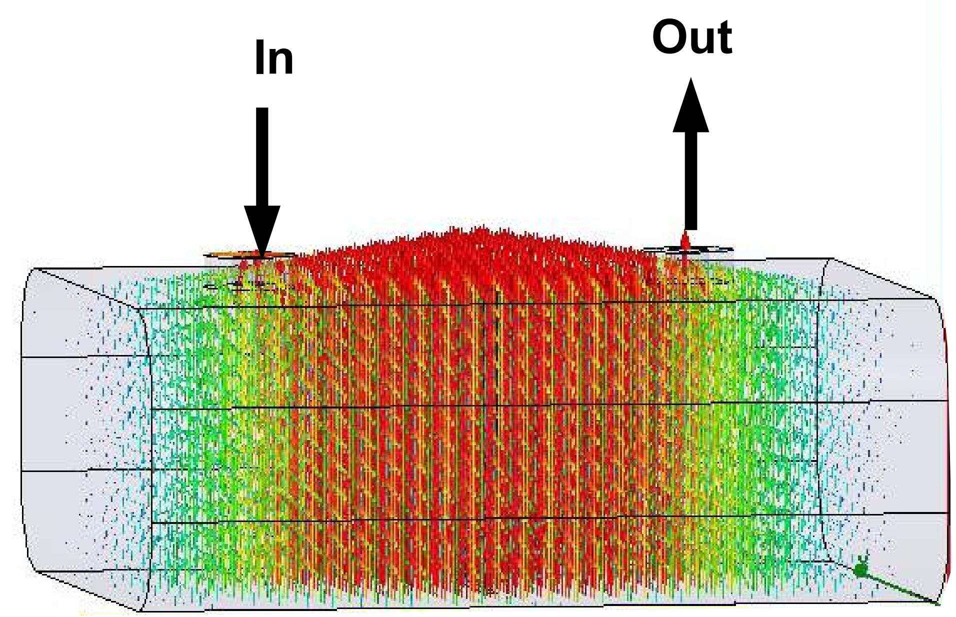
$$\hat{H} = \frac{\hat{q}^2}{2C} + \frac{\hat{\phi}^2}{2L}$$

$$[\hat{\phi}, \hat{q}] = i\hbar$$

....canonically quantized



$$\hat{H} = \hbar\omega_0(\frac{1}{2} + \hat{a}^\dagger \hat{a})$$

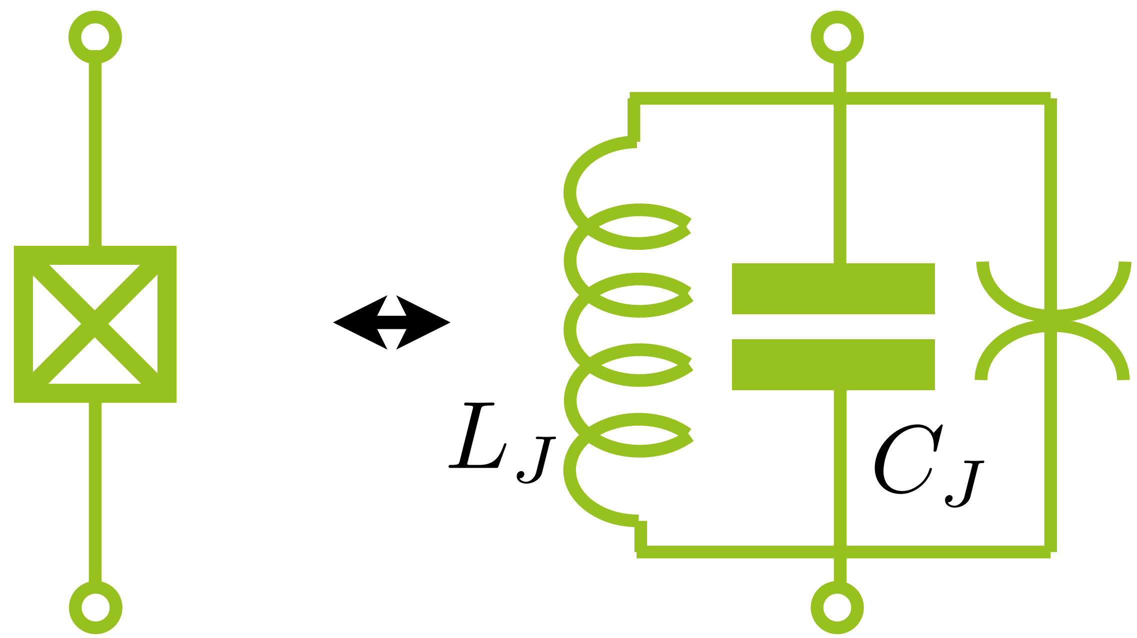


1st mode : 7.8 GHz

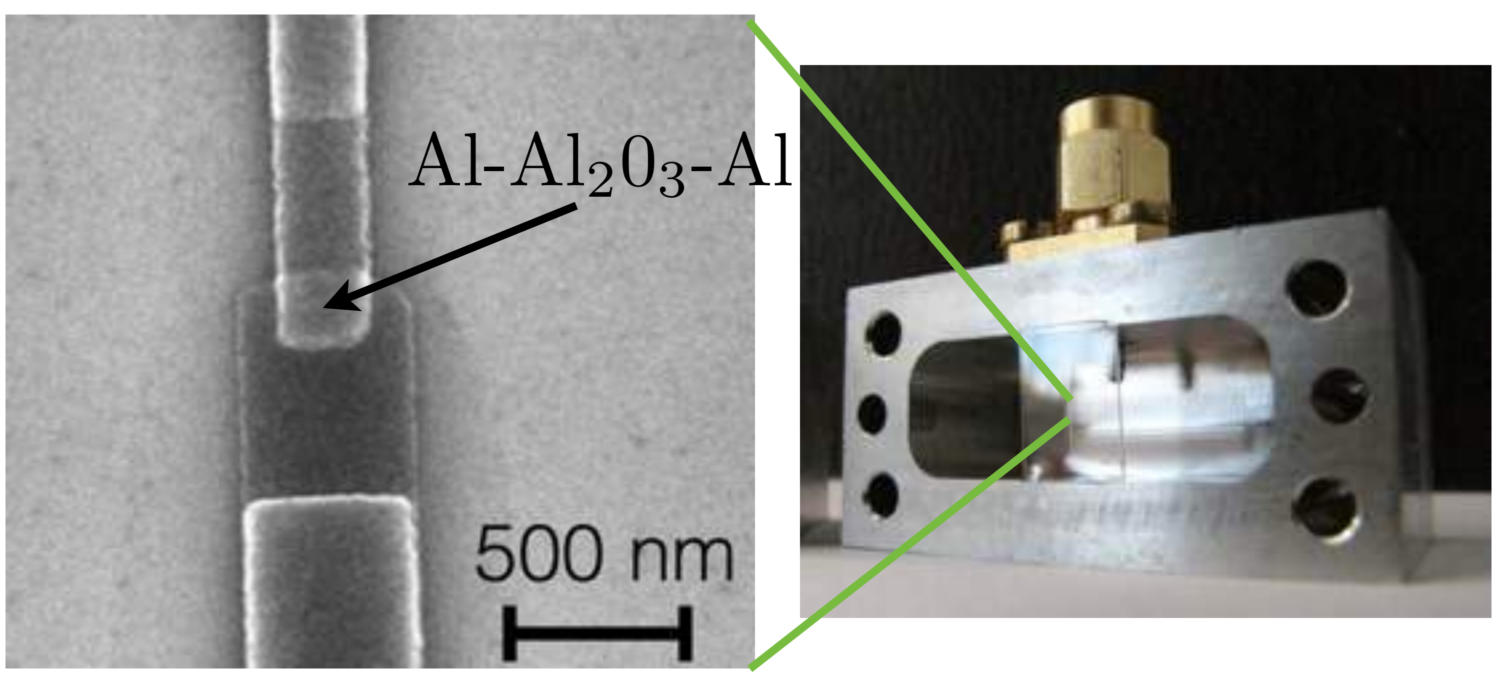
$$Q \approx 10^6$$

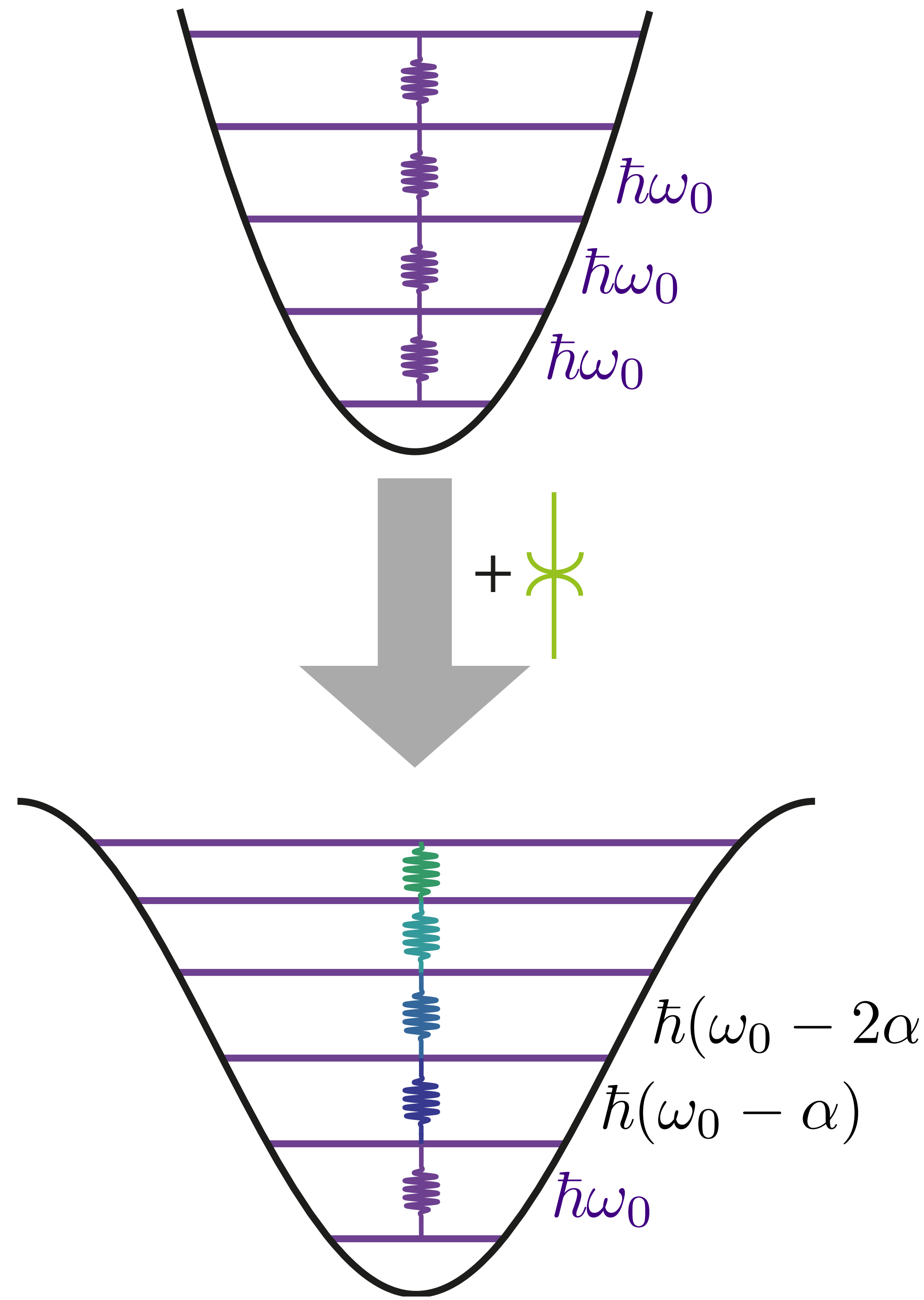
Superconducting circuits with Josephson junctions

dissipation-less non linear LC circuit



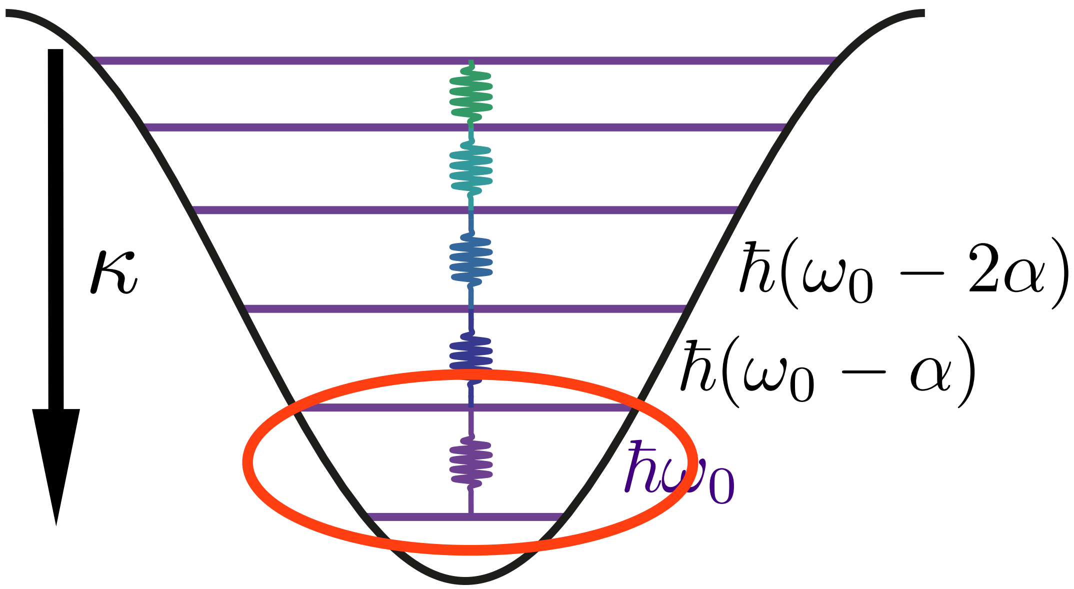
$$\hat{H} = \frac{\hat{q}^2}{2C_J} - E_J \cos\frac{\hat{\phi}}{\hbar/2e} = \frac{\hat{q}^2}{2C_J} + \frac{\hat{\phi}^2}{2L_J} + H_{\mathrm{non-lin}}(\hat{\phi})$$





transitions observed in 1980's [Berkeley & Saclay]
strong coupling regime of CQED in 2004 [Yale]

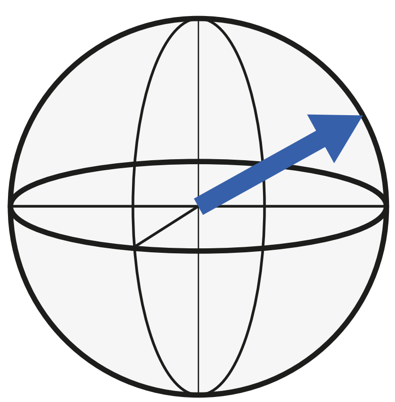
Non-linear superconducting circuits

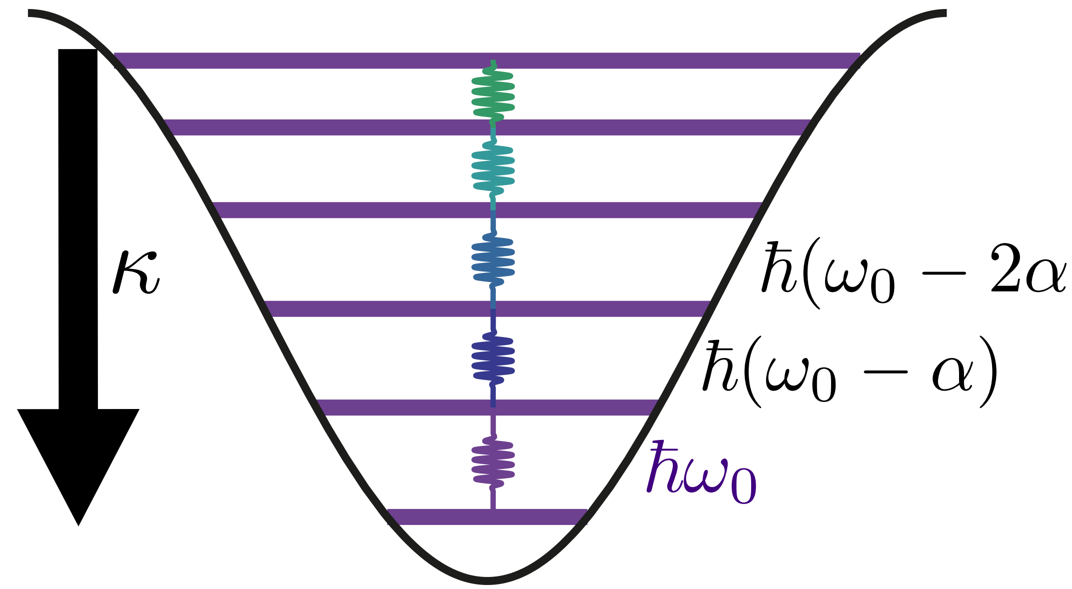


Strongly anharmonic

$\alpha \gg \kappa$

qubit $\hbar\omega\hat{\sigma}_z/2$

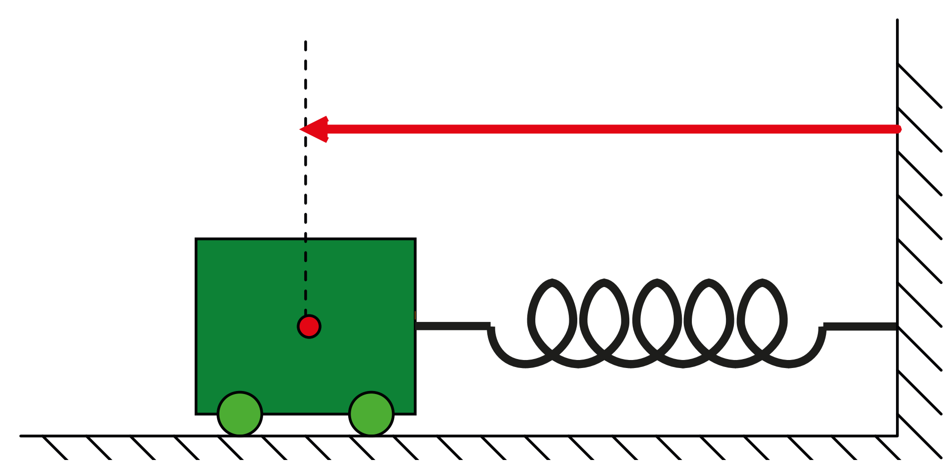




Weakly anharmonic

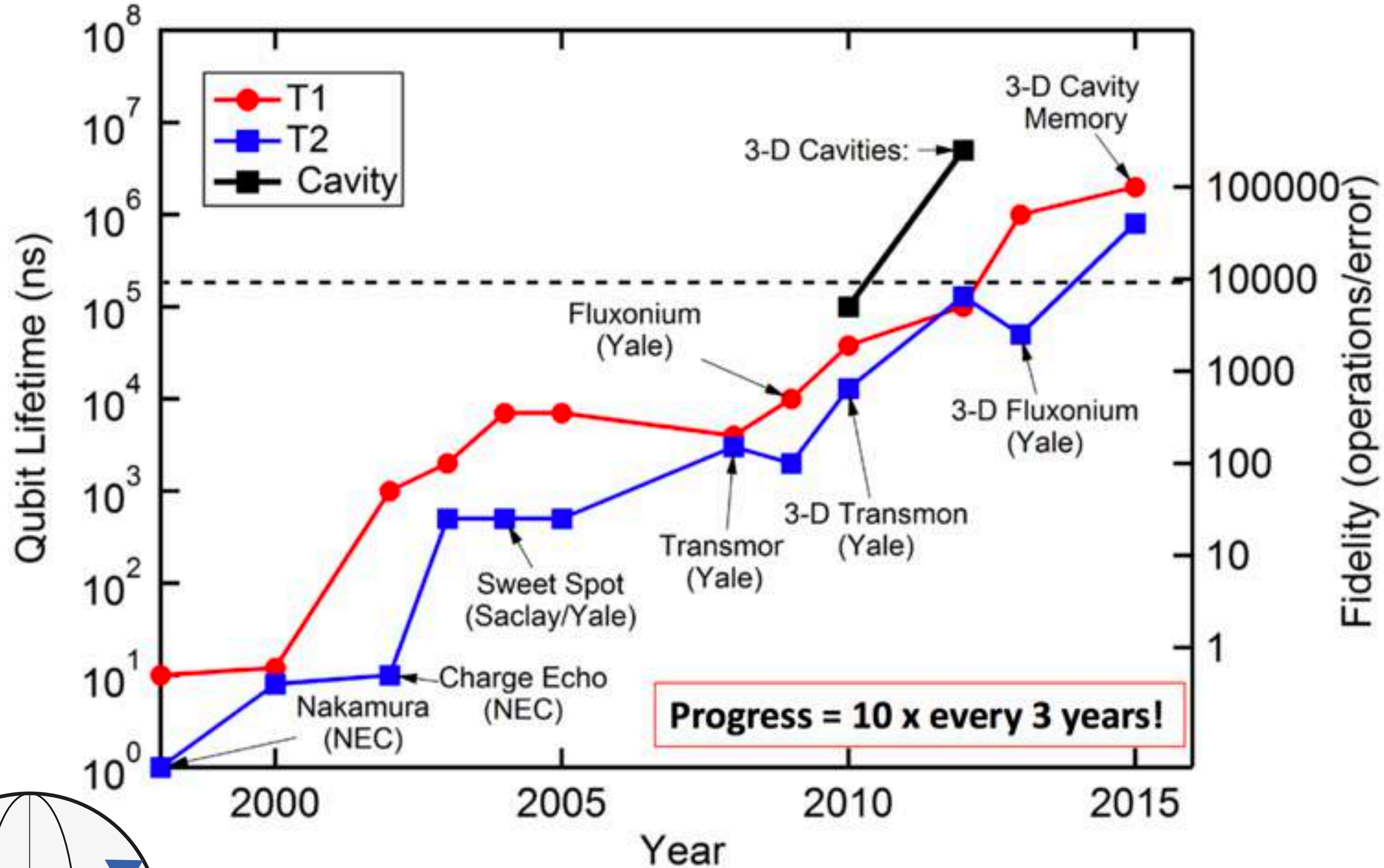
$\alpha \ll \kappa$

oscillator $\hbar\omega\hat{a}^\dagger\hat{a}$

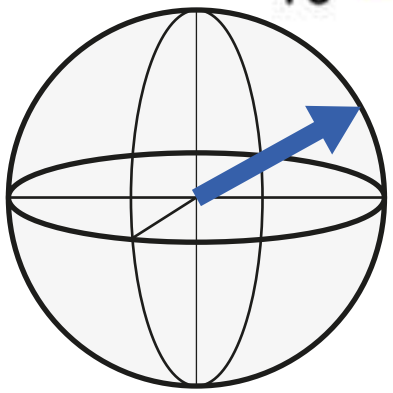


Parametric amplifiers & squeezing
in 1980’s [Bell Labs]

Superconducting qubits



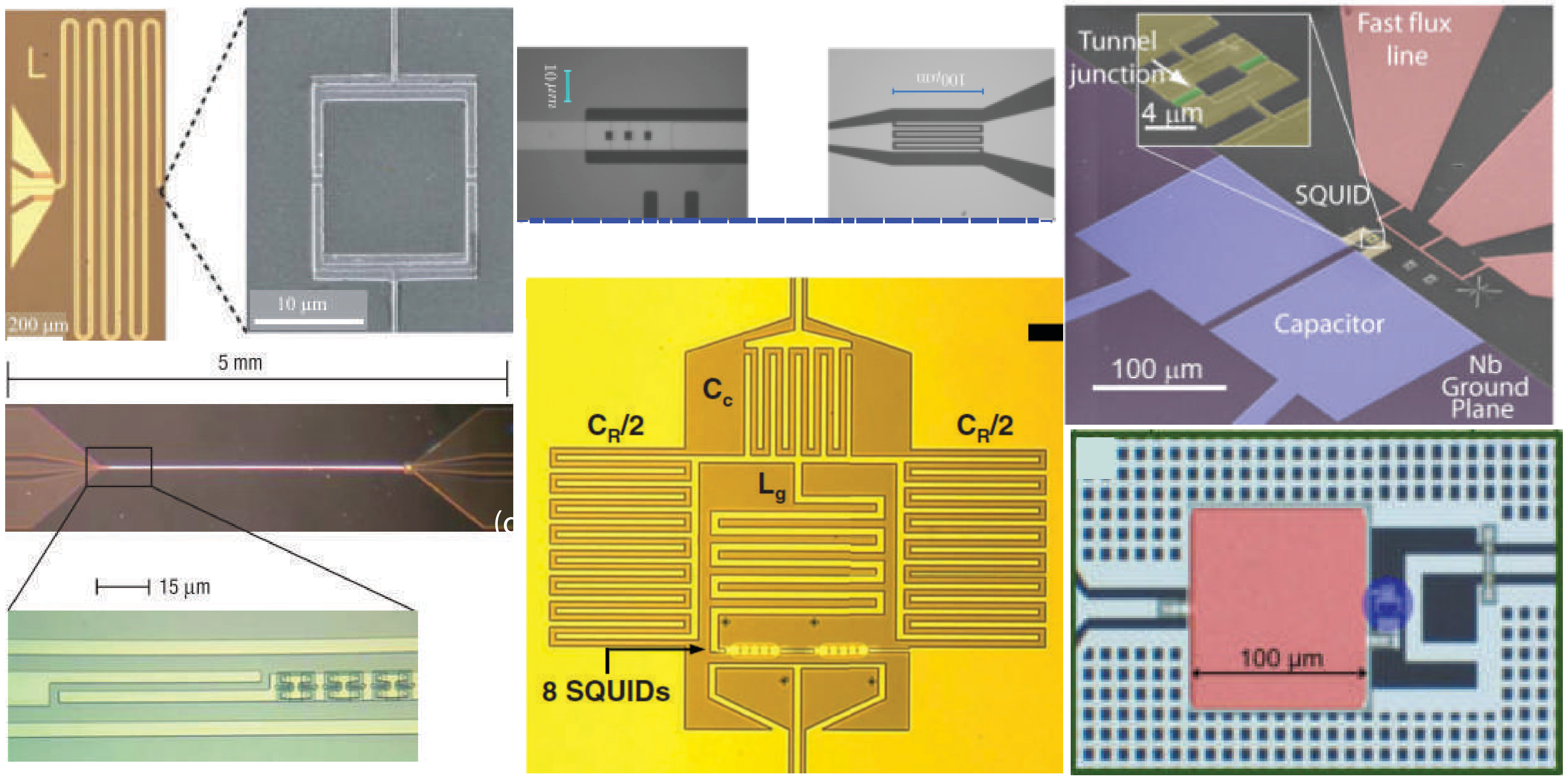
[courtesy of M. Devoret]



First Rabi oscillations in 1999 [Nakamura et al., Tsukuba]
Quantronium in 2002 [Vion et al., Saclay]
Charge qubit, phase qubit, flux qubit,
transmon, fluxonium, Xmon...

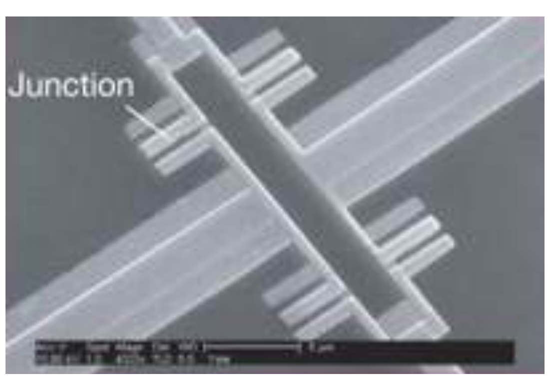
Quantum limited amplifiers

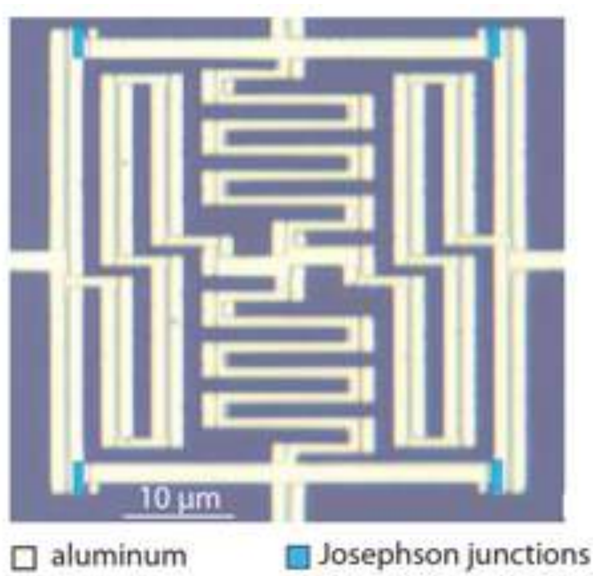
Degenerate amplifiers



(Bell Labs, 1989)
(NEC Tokyo, 2008)
(Boulder, 2008)
(Yale, 2009)
(Zurich, 2011)
(Berkeley, 2011)
(Santa Barbara, 2013)
(Saclay, 2014)

Non degenerate amplifiers

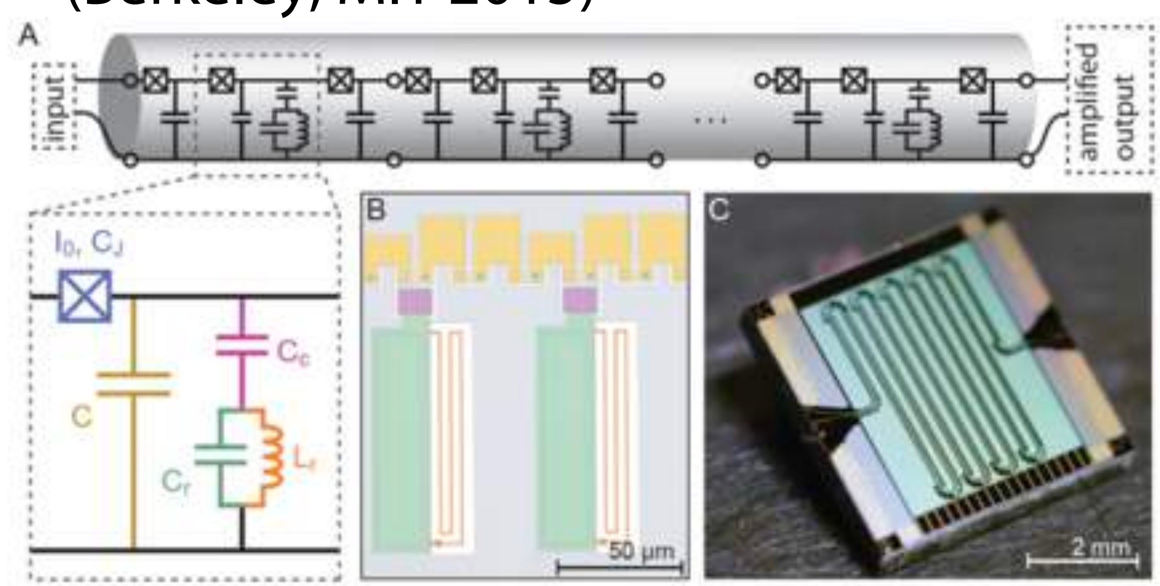




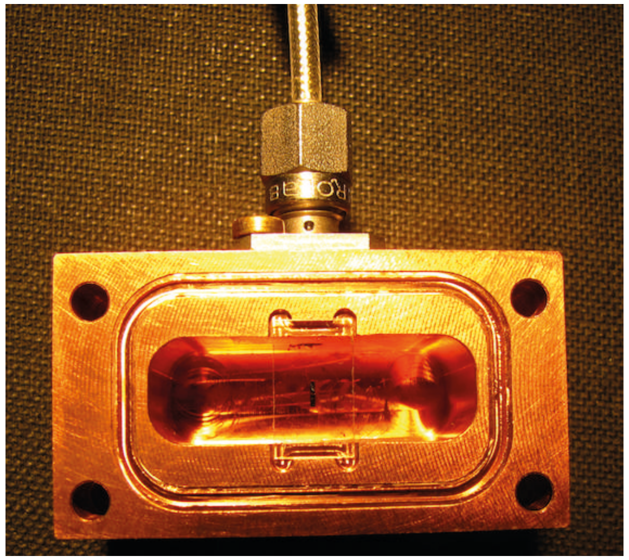
(Yale, 2010)

(ENS Paris, 2012)

Traveling wave amplifier
(Berkeley, MIT 2015)

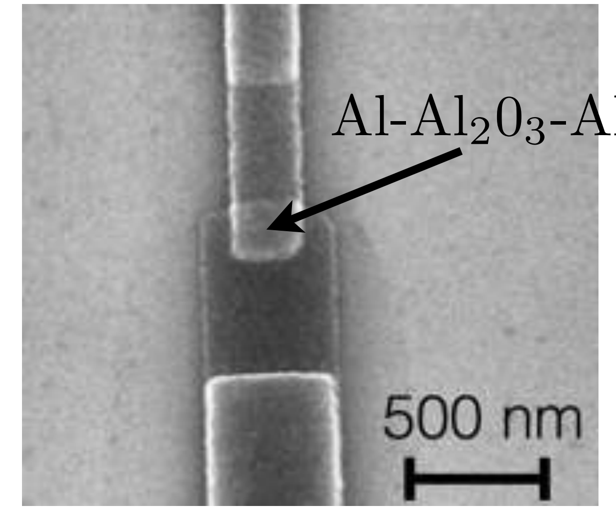


3D transmon architecture



$$H_{\mathrm{disp}} = h\chi\frac{\sigma_z}{2}a^\dagger a$$

$$\frac{\chi}{2\pi} = 4\ \mathrm{MHz}$$

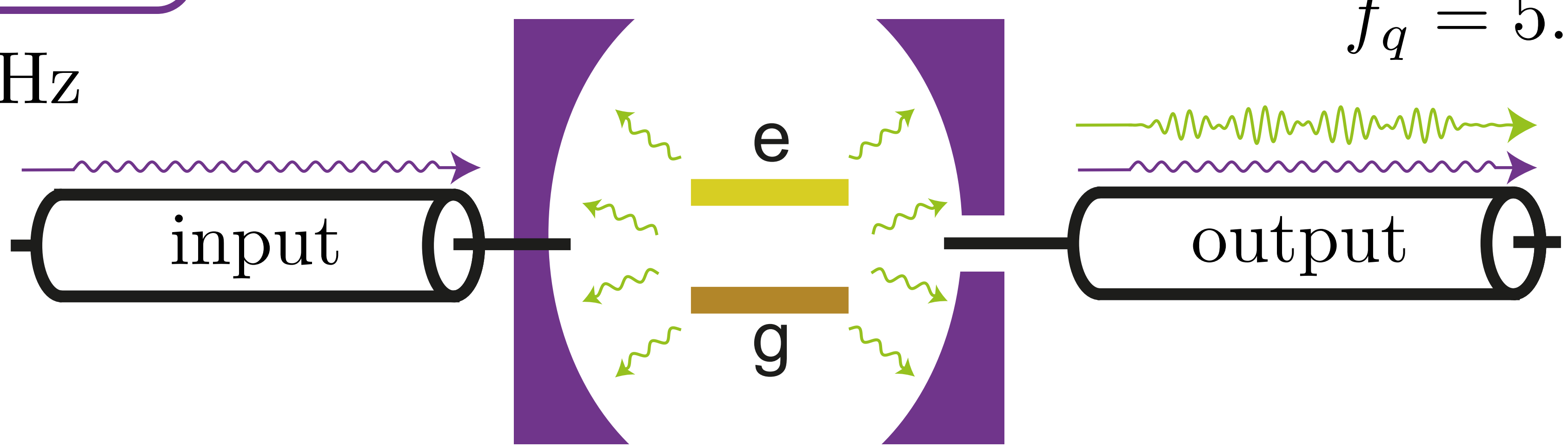


$$H_c = hf_c(a^\dagger a + \frac{1}{2})$$

$$f_c = 7.8\ \mathrm{GHz}$$

$$H_q = hf_q\frac{\sigma_z}{2}$$

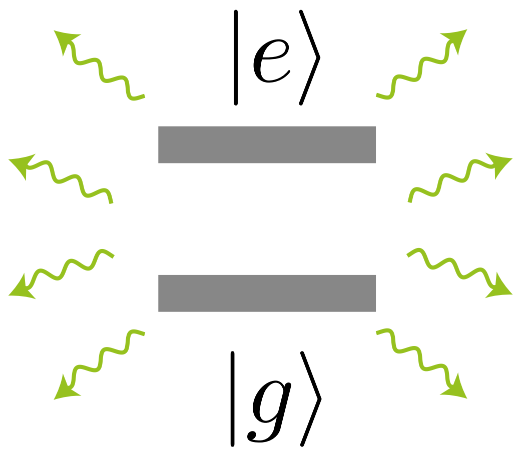
$$f_q = 5.4\ \mathrm{GHz}$$

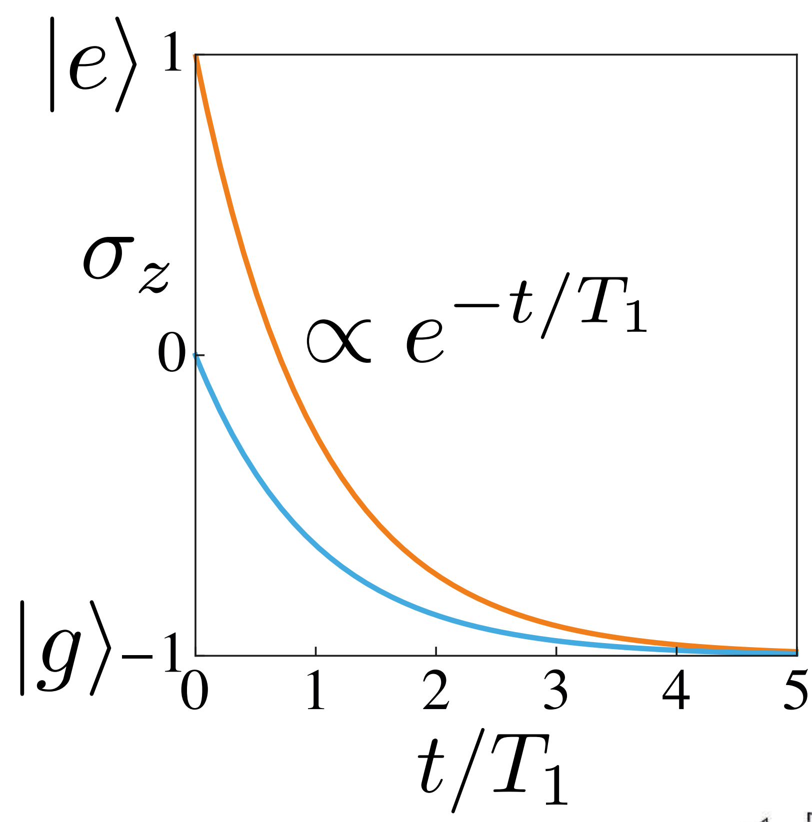


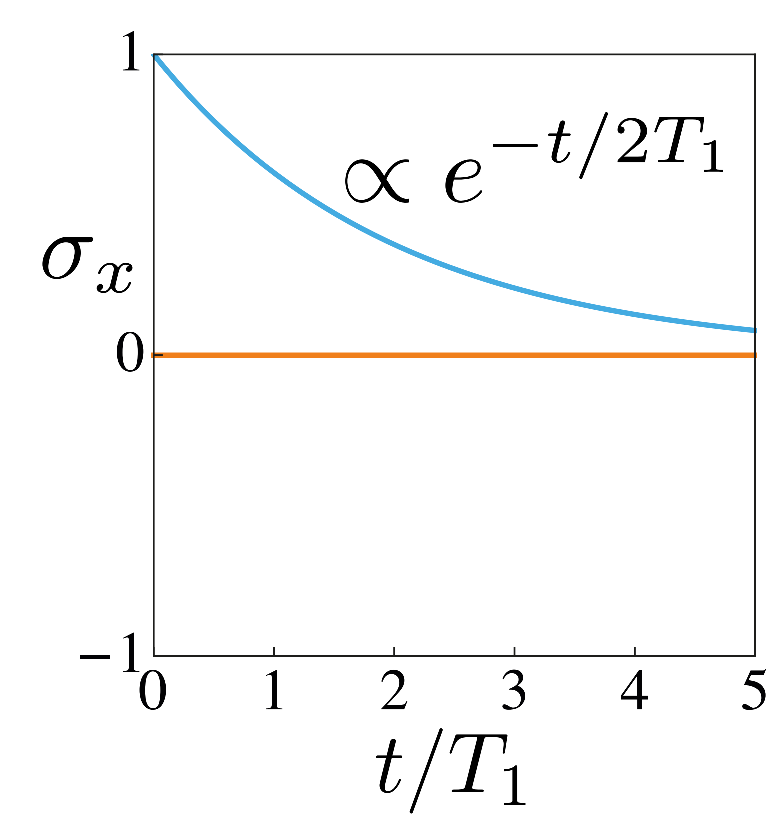
Dispersive Hamiltonian

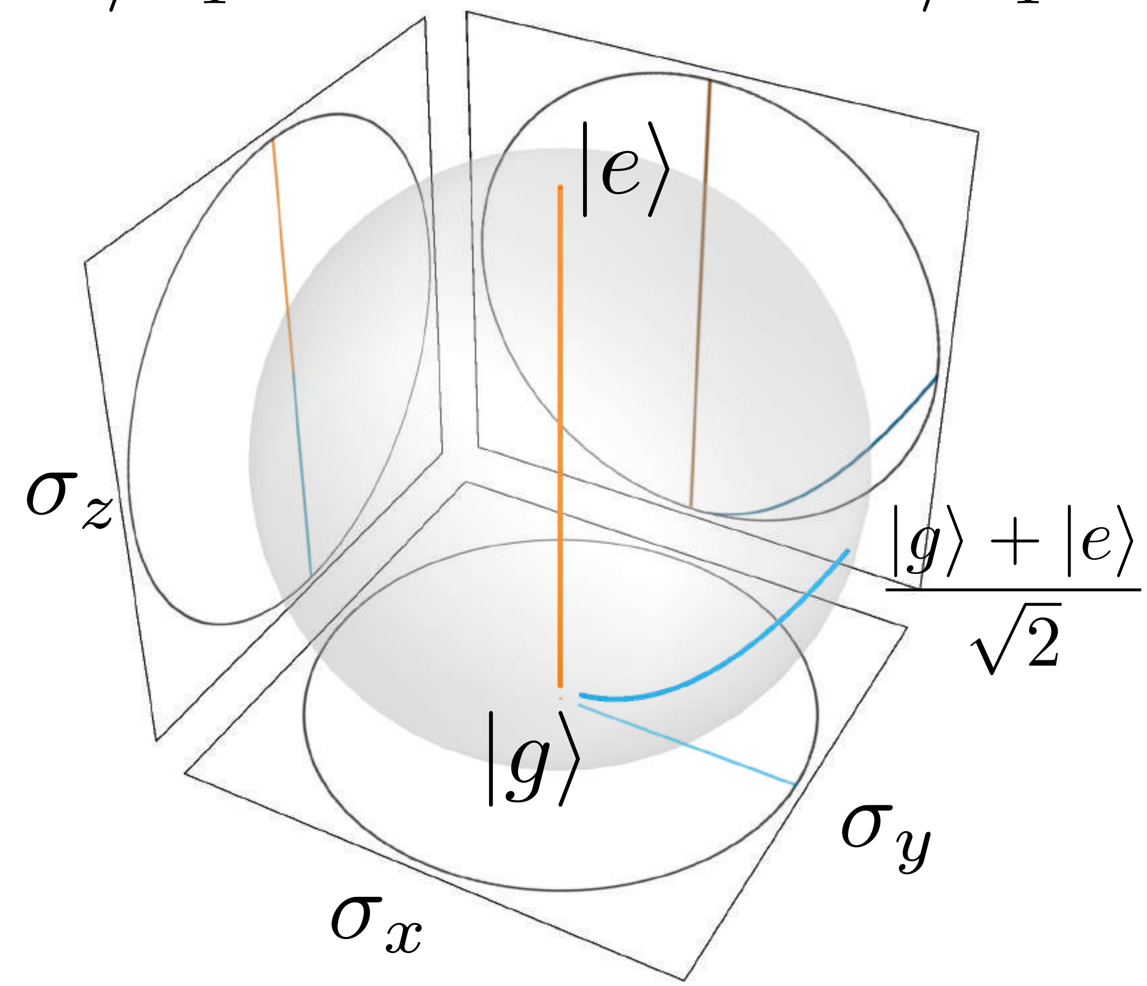
$$H = hf_c(a^\dagger a + \frac{1}{2}) - h\frac{\chi}{2}\sigma_Z a^\dagger a + hf_q\frac{\sigma_Z}{2}$$

Ideal quantum jump of an atom

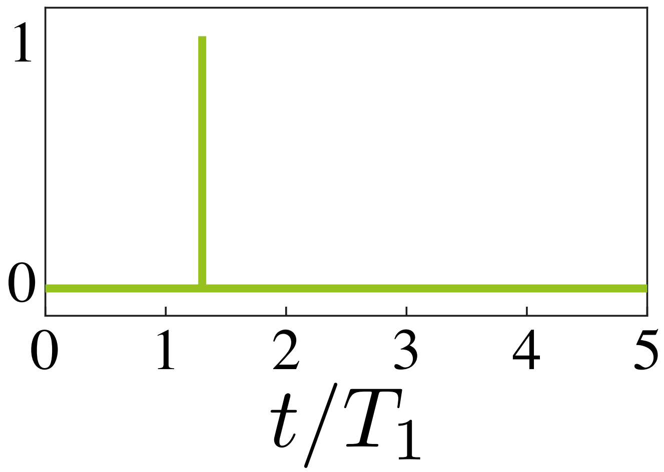


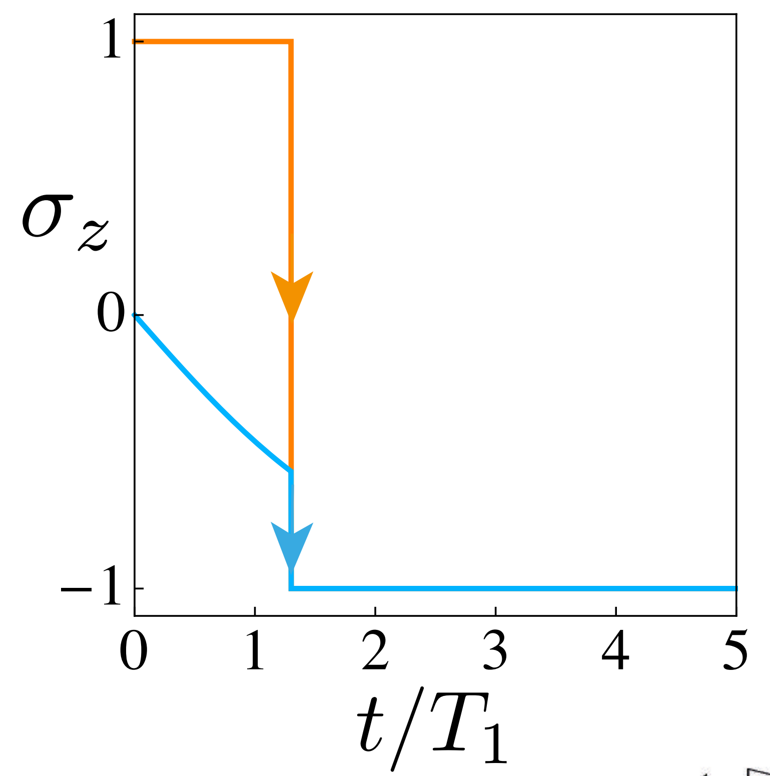


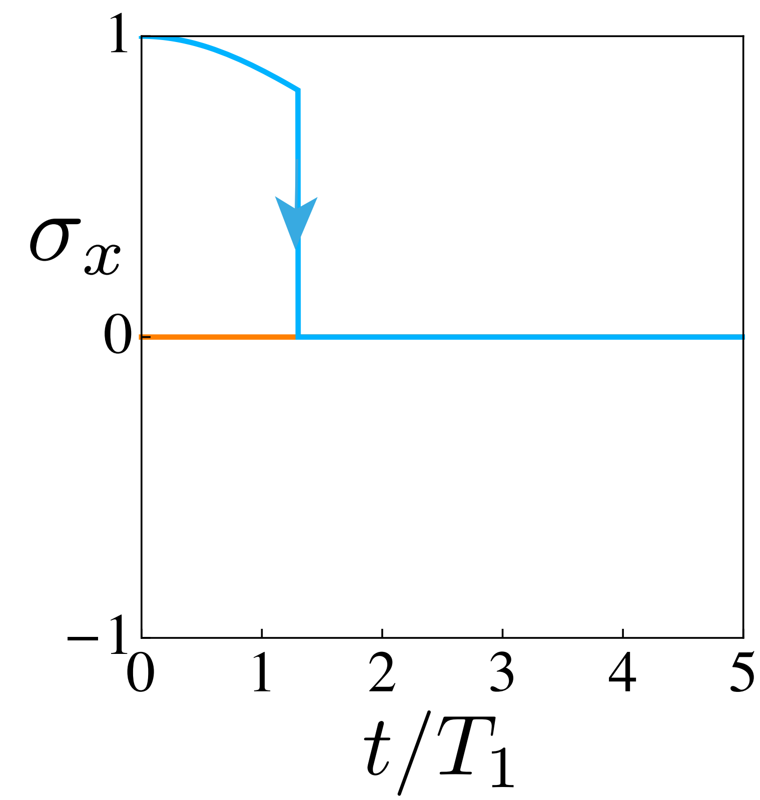


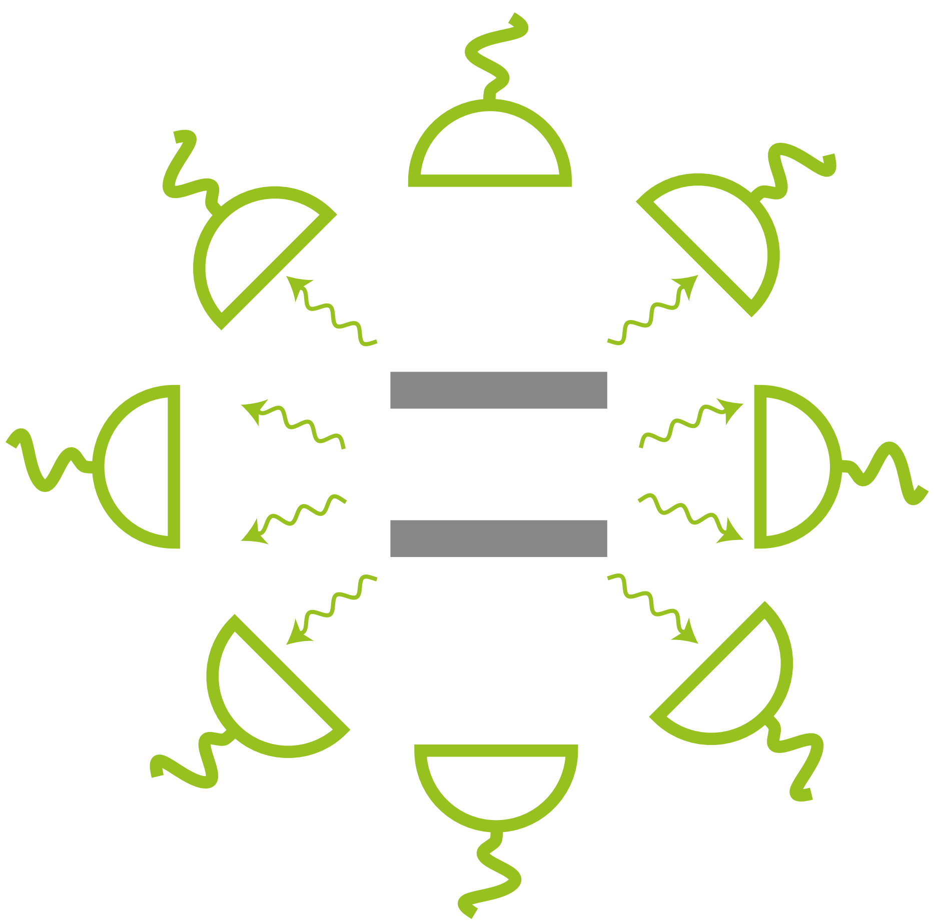


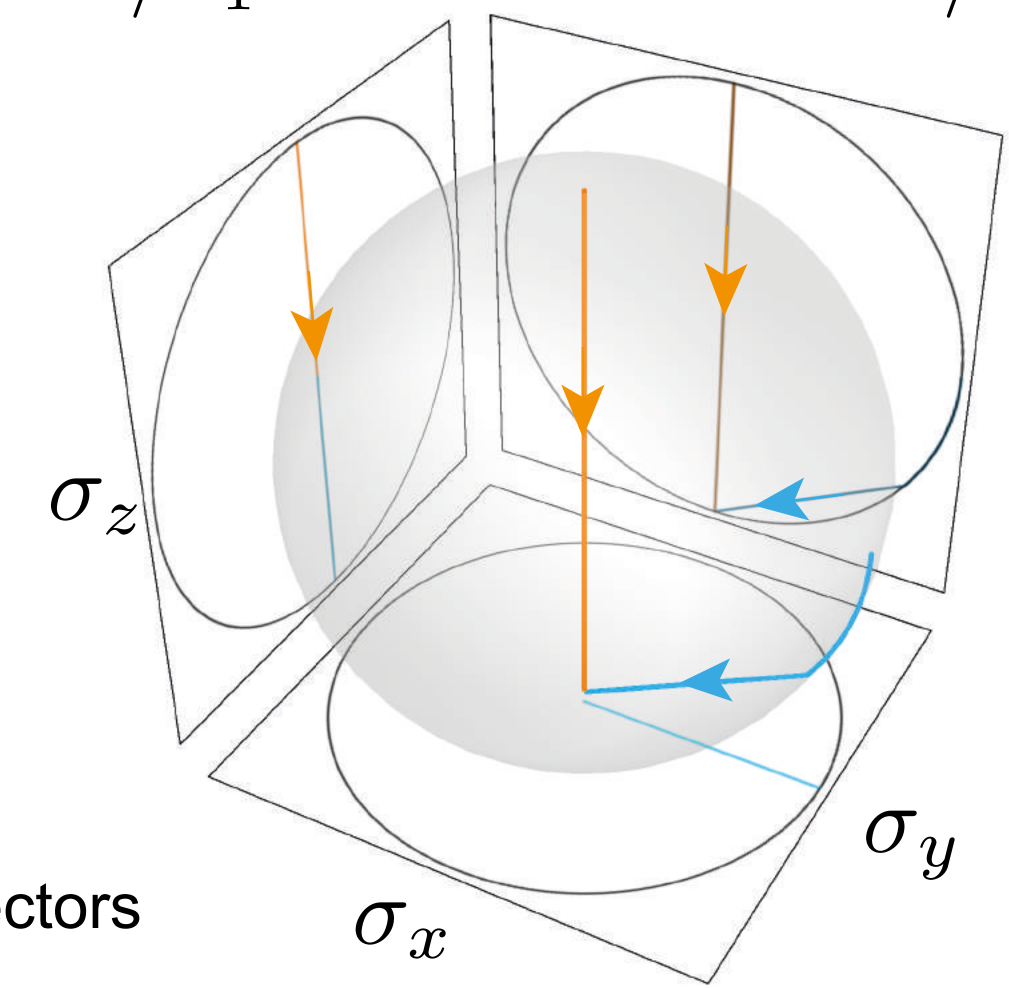
Ideal quantum jump of an atom







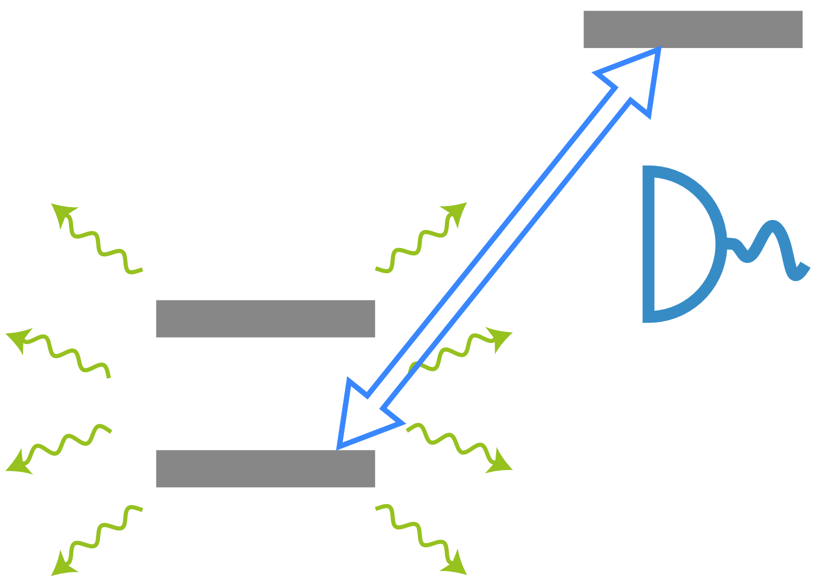




Note: purity of state is 1 only for perfect detectors

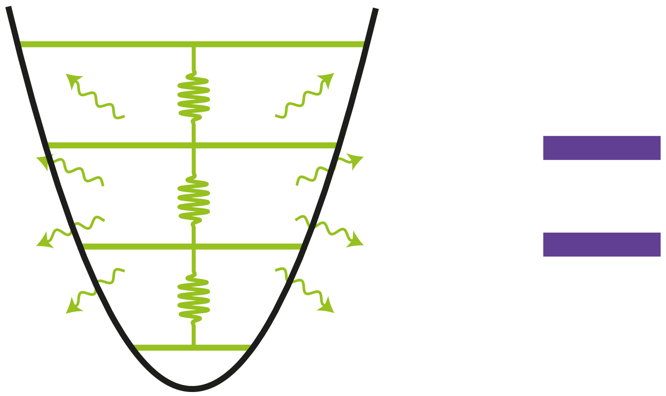
Ideal quantum jump

hard to collect → use an ancillary detector



since 1986 in trapped ions

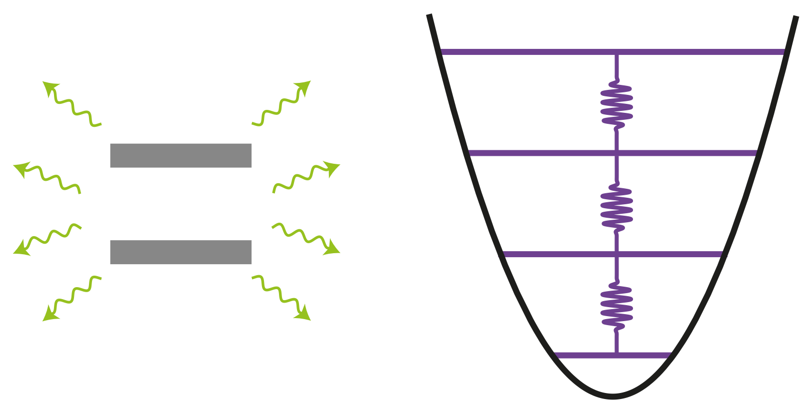
[Wineland group, Boulder
Dehmelt groupe, Seattle
Toschek group, Hambourg]



$$H_{\mathrm{coupl}} = \hbar\chi a^{\dagger} a \frac{\sigma_Z}{2}$$

Rydberg atom probing cavity jumps

[Haroche group, Paris (2007)]



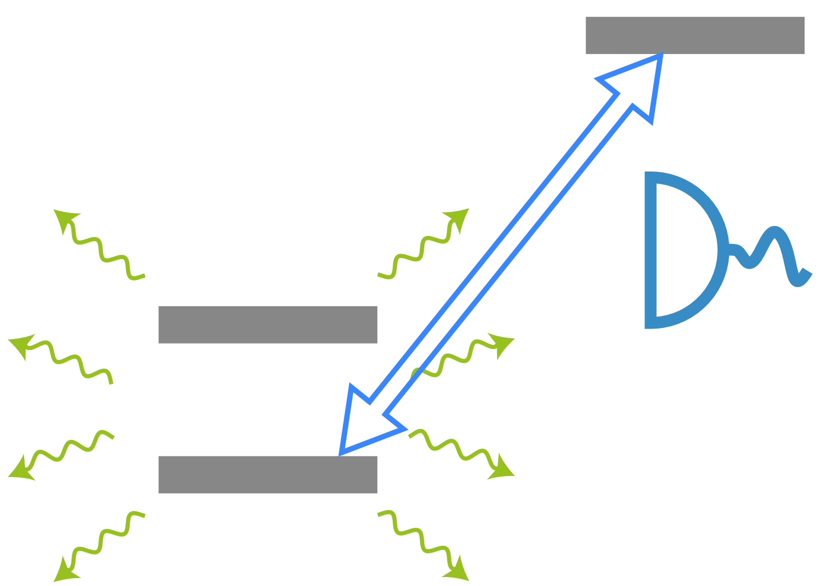
$$H_{\mathrm{coupl}} = \hbar\chi a^{\dagger} a \frac{\sigma_Z}{2}$$

Cavity probing qubit jumps

[Siddiqi group, Berkeley (2011)]

Ideal quantum jump

hard to collect → use an ancillary detector



since 1986 in trapped ions

[Wineland group, Boulder
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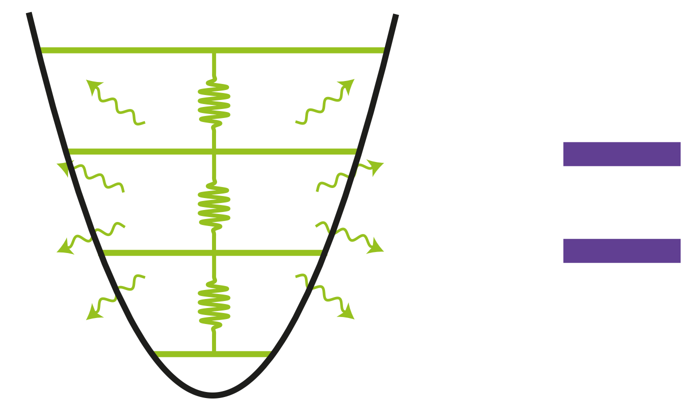

$$H_{\mathrm{coupl}} = \hbar\chi a^{\dagger} a \frac{\sigma_Z}{2}$$

Rydberg atom probing cavity jumps

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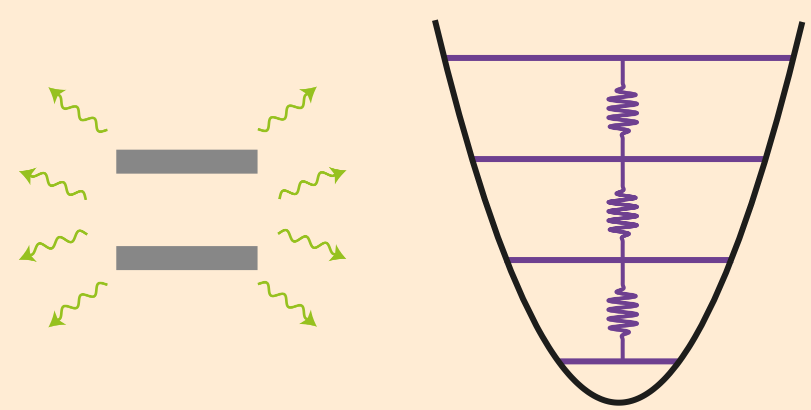


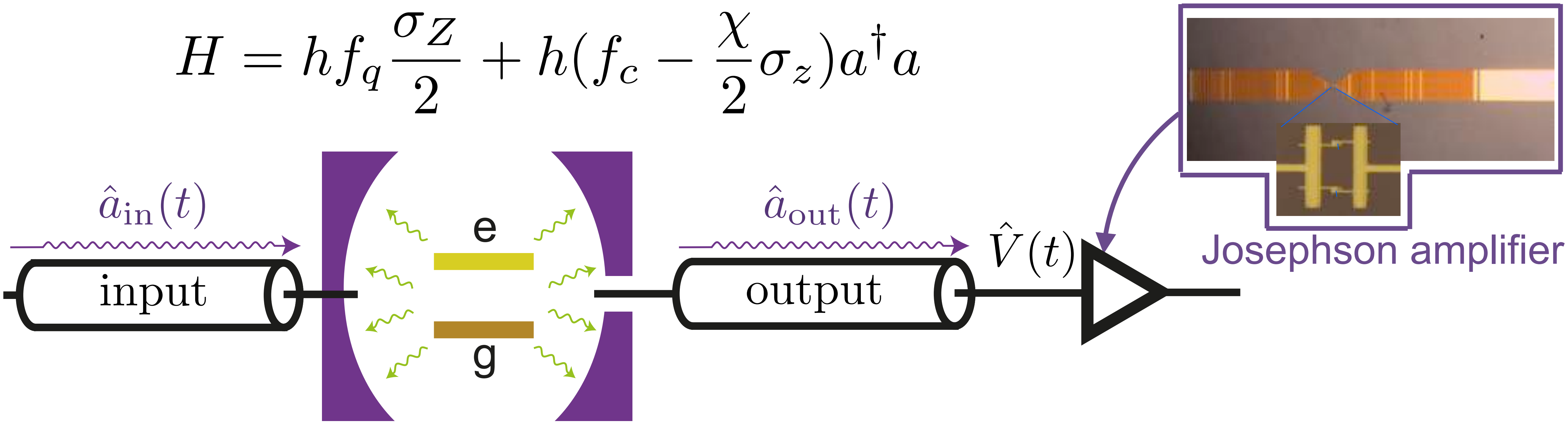
$$H_{\mathrm{coupl}} = \hbar\chi a^{\dagger} a \frac{\sigma_Z}{2}$$

Cavity probing qubit jumps

[Siddiqi group, Berkeley (2011)]

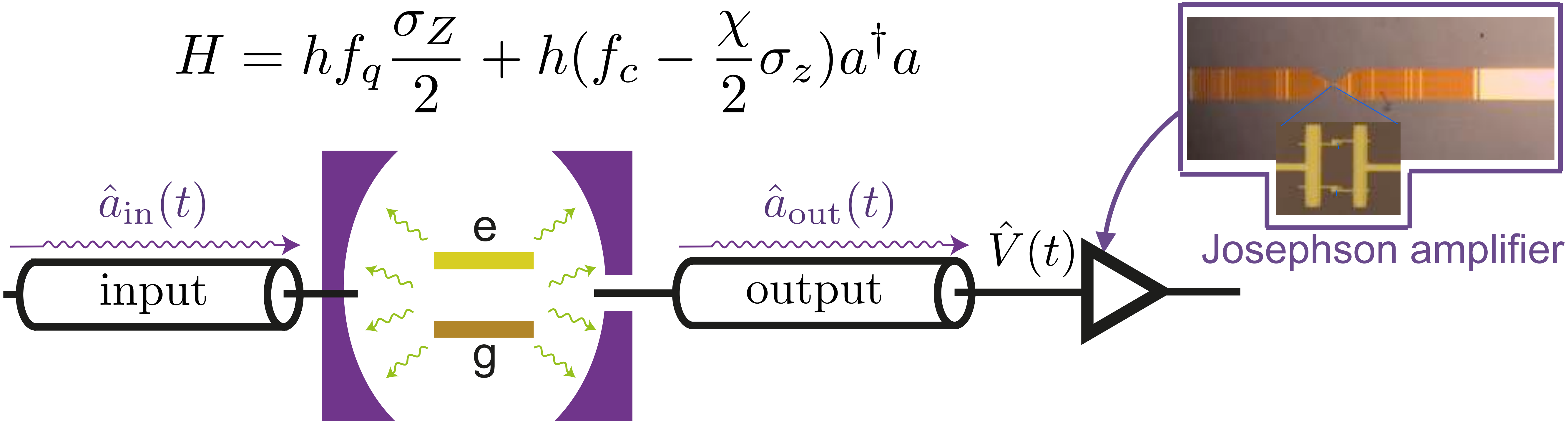
Dispersive Measurement

$$H = hf_q \frac{\sigma_Z}{2} + h(f_c - \frac{\chi}{2}\sigma_z)a^\dagger a$$



Dispersive Measurement

$$H = hf_q \frac{\sigma_Z}{2} + h(f_c - \frac{\chi}{2}\sigma_z)a^\dagger a$$



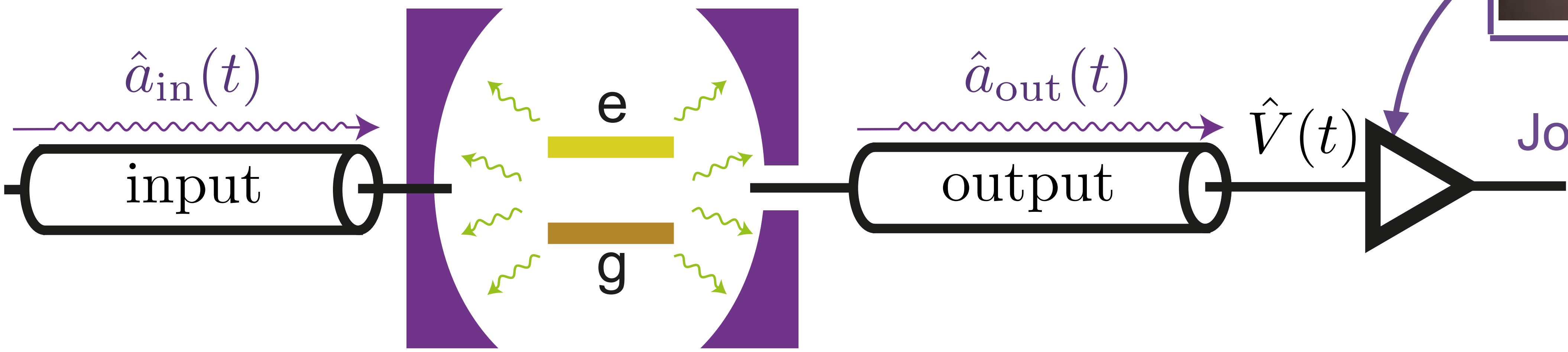
Classically $V(t) = I(t)\cos(2\pi f_c t) + Q(t)\sin(2\pi f_c t)$

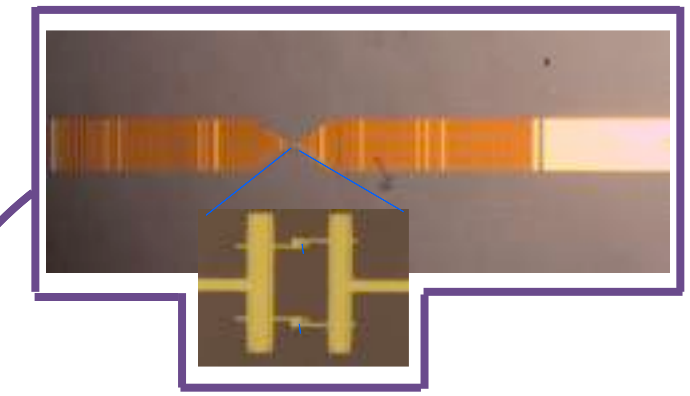
$$I_t \to \hat{I}_t \propto \frac{\hat{a}_{\text{out}} + \hat{a}_{\text{out}}^\dagger}{2} = \text{Re}(\hat{a}_{\text{out}})$$

$$Q_t \to \hat{Q}_t \propto \frac{\hat{a}_{\text{out}} - \hat{a}_{\text{out}}^\dagger}{2i} = \text{Im}(\hat{a}_{\text{out}})$$

Dispersive Measurement

$$H = hf_q\frac{\sigma_Z}{2} + h(f_c - \frac{\chi}{2}\sigma_z)a^\dagger a$$

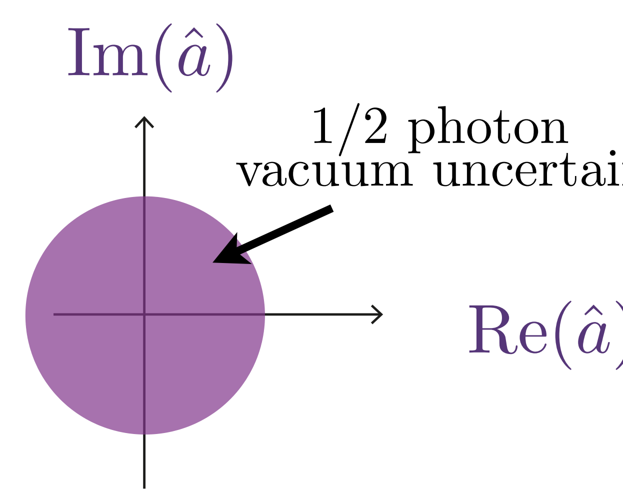




Classically $V(t) = I(t)\cos(2\pi f_c t) + Q(t)\sin(2\pi f_c t)$

$$I_t \to \hat{I}_t \propto \frac{\hat{a}_{\text{out}} + \hat{a}_{\text{out}}^\dagger}{2} = \text{Re}(\hat{a}_{\text{out}})$$

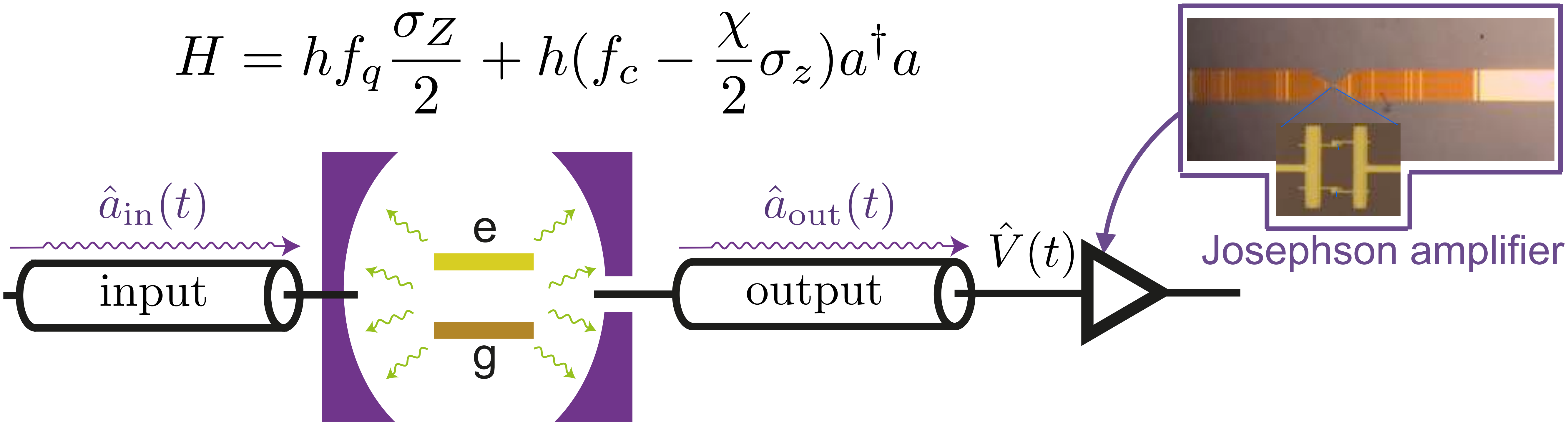
$$Q_t \to \hat{Q}_t \propto \frac{\hat{a}_{\text{out}} - \hat{a}_{\text{out}}^\dagger}{2i} = \text{Im}(\hat{a}_{\text{out}})$$



Zero-point fluctuations $|0\rangle$

Dispersive Measurement

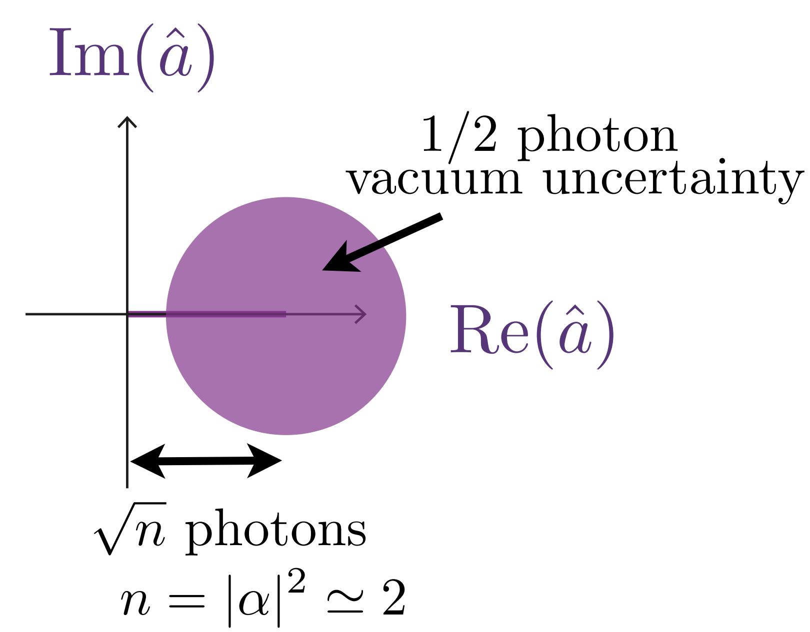
$$H = hf_q\frac{\sigma_Z}{2} + h(f_c - \frac{\chi}{2}\sigma_z)a^\dagger a$$



Classically $V(t) = I(t)\cos(2\pi f_c t) + Q(t)\sin(2\pi f_c t)$

$$I_t \to \hat{I}_t \propto \frac{\hat{a}_{\text{out}} + \hat{a}^\dagger_{\text{out}}}{2} = \text{Re}(\hat{a}_{\text{out}})$$

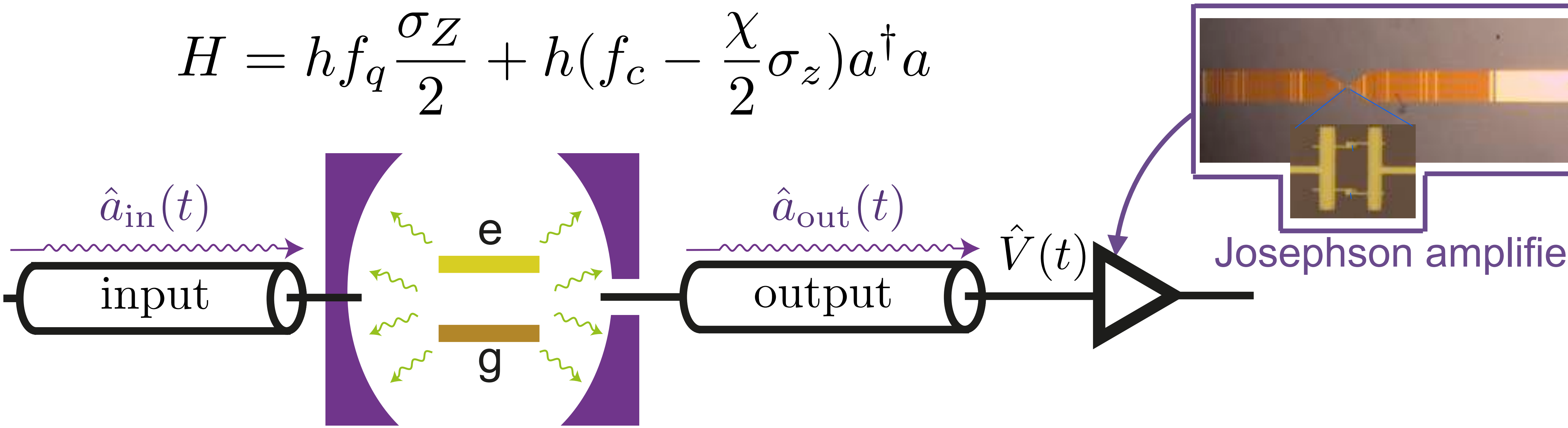
$$Q_t \to \hat{Q}_t \propto \frac{\hat{a}_{\text{out}} - \hat{a}^\dagger_{\text{out}}}{2i} = \text{Im}(\hat{a}_{\text{out}})$$

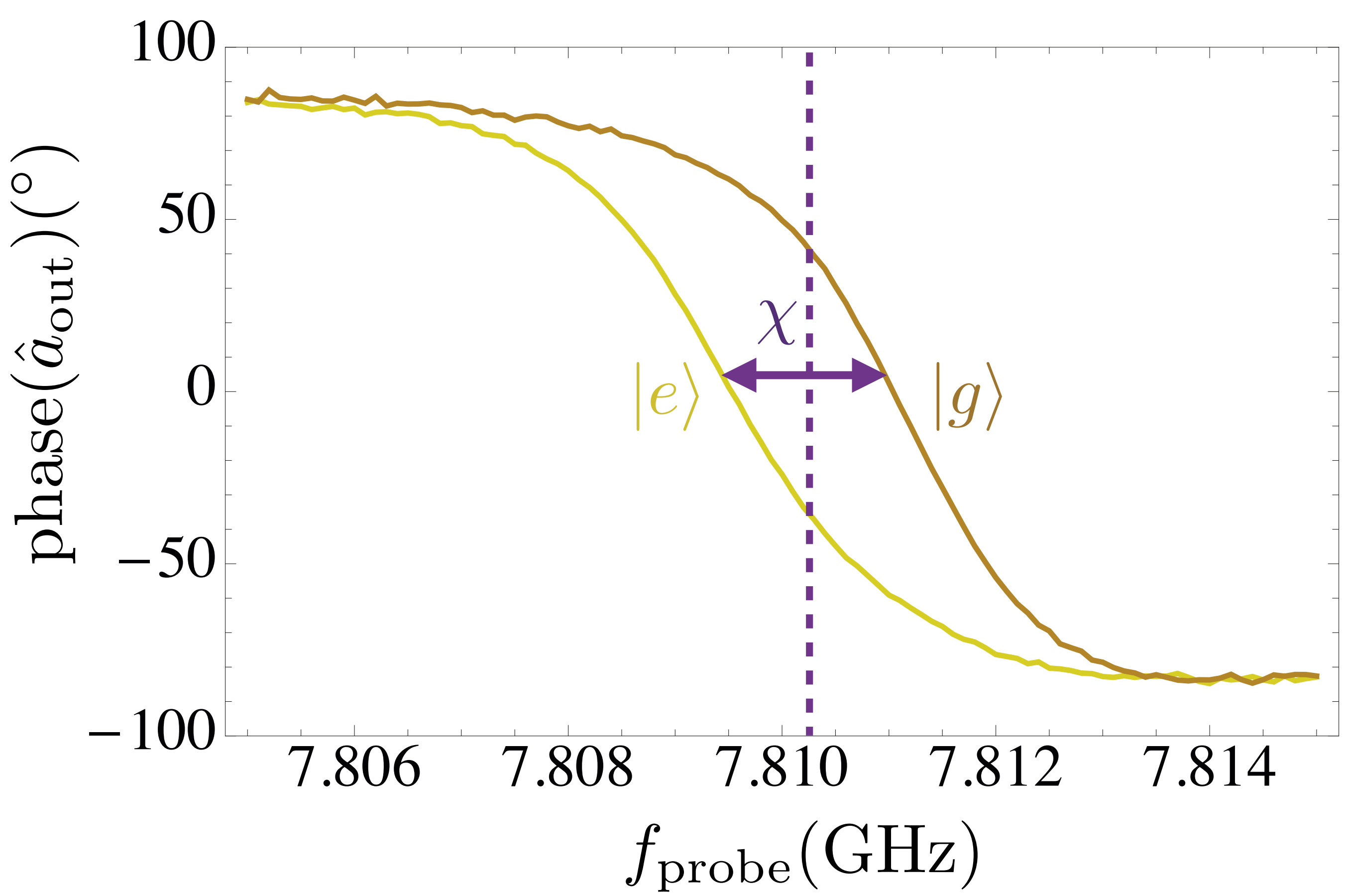


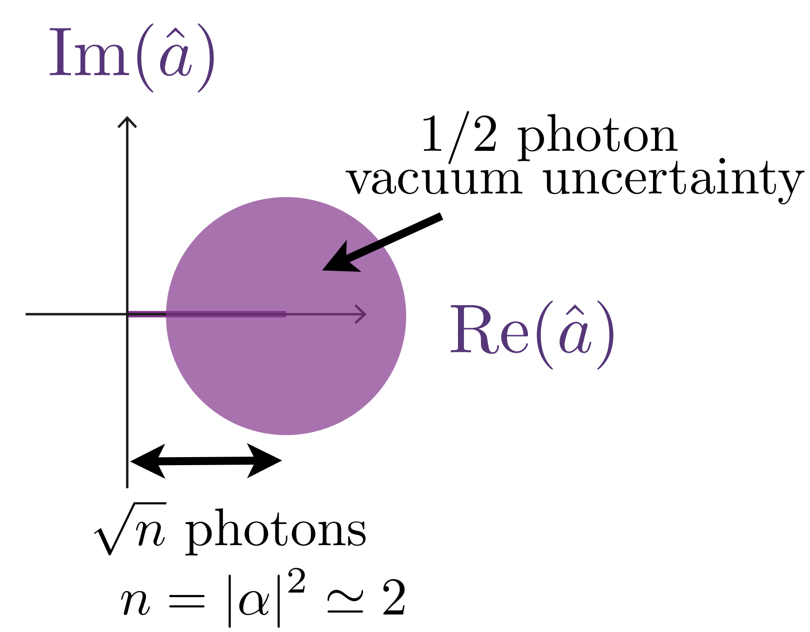
Coherent field $|\alpha\rangle$

Dispersive Measurement

$$H = hf_q \frac{\sigma_Z}{2} + h(f_c - \frac{\chi}{2}\sigma_z)a^\dagger a$$



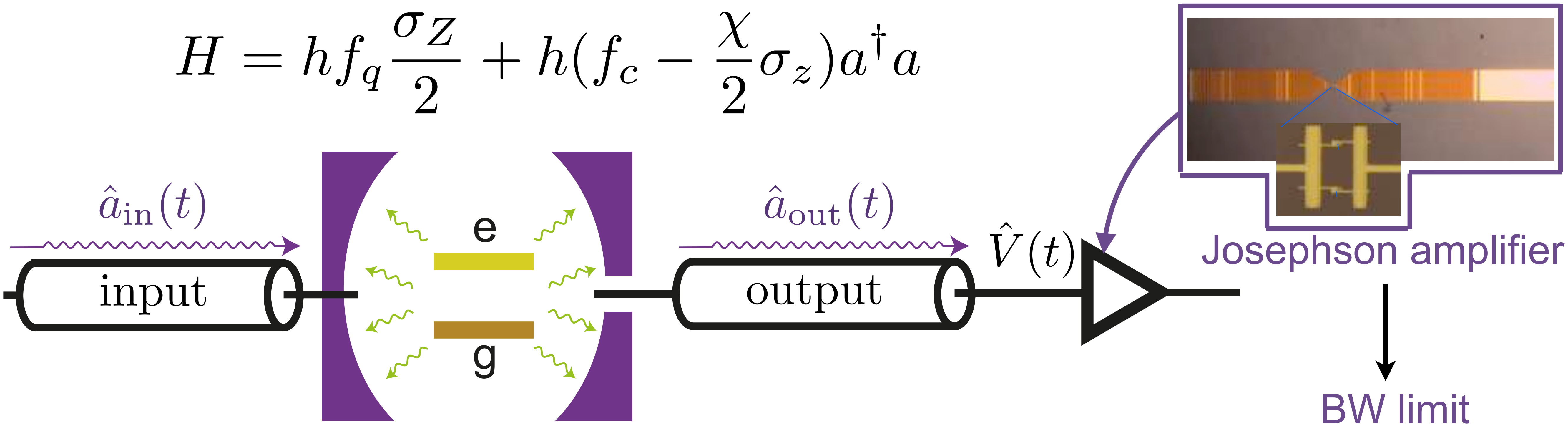




Coherent field $|\alpha\rangle$

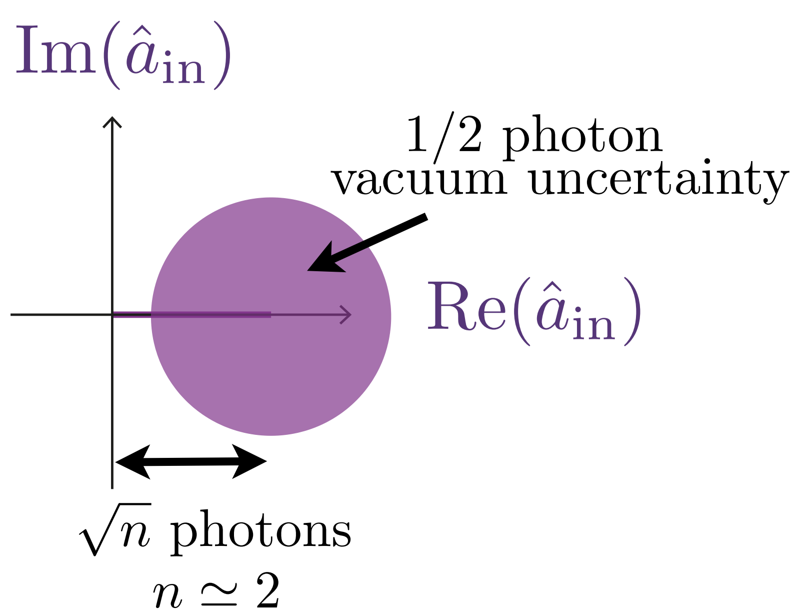
Dispersive Measurement

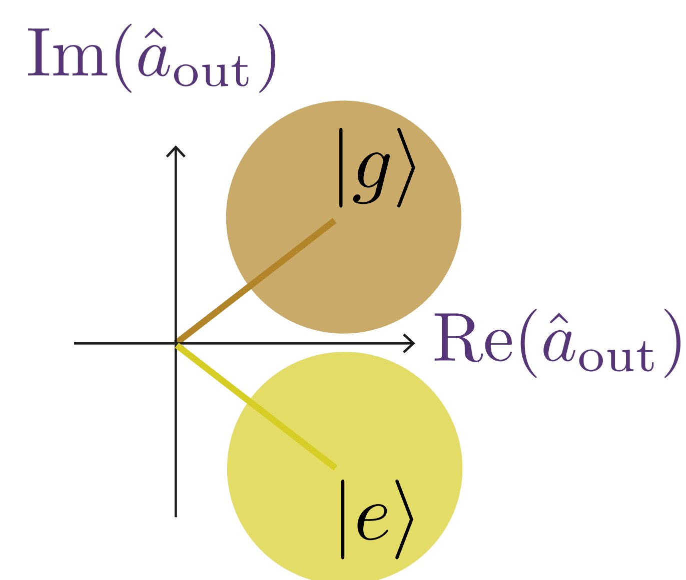
$$H = hf_q \frac{\sigma_Z}{2} + h(f_c - \frac{\chi}{2}\sigma_z)a^\dagger a$$



field going in ...

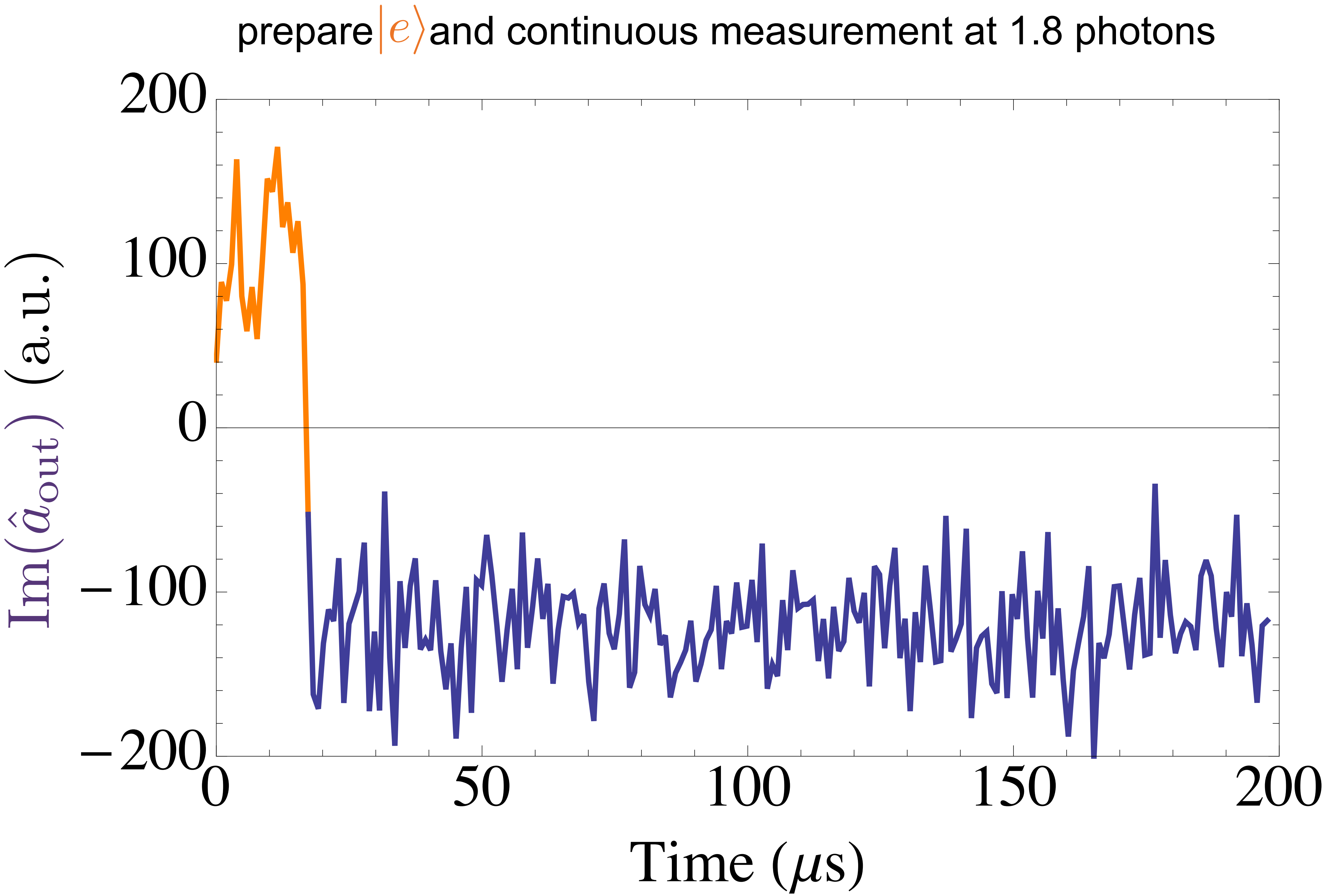
... field coming out





measuring $\text{Im}(\hat{a}_{\text{out}})$ → Strong QND measurement

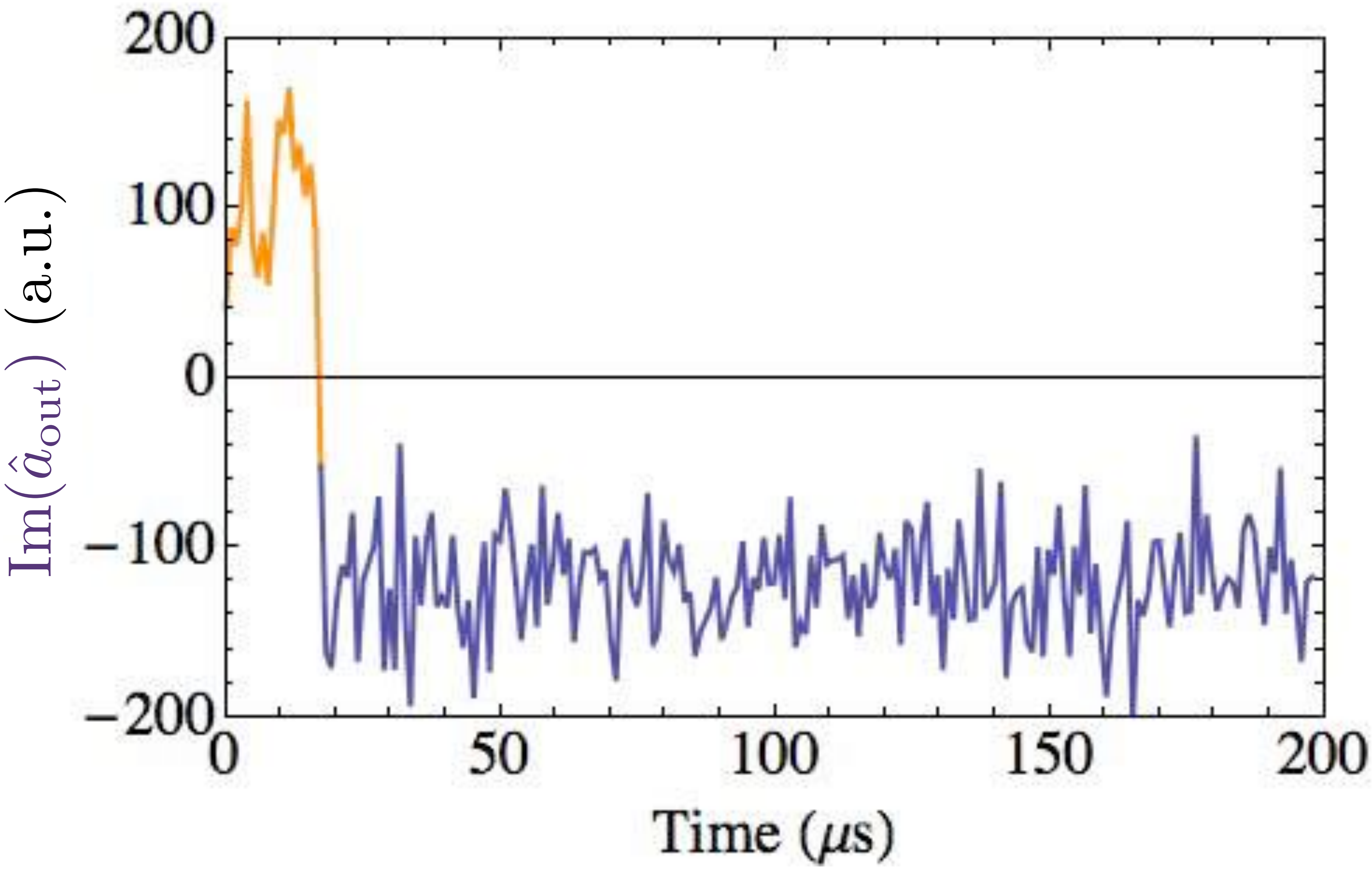
Quantum jumps



similar to [Vijay et al., PRL 2011 (Berkeley)]

Quantum jumps

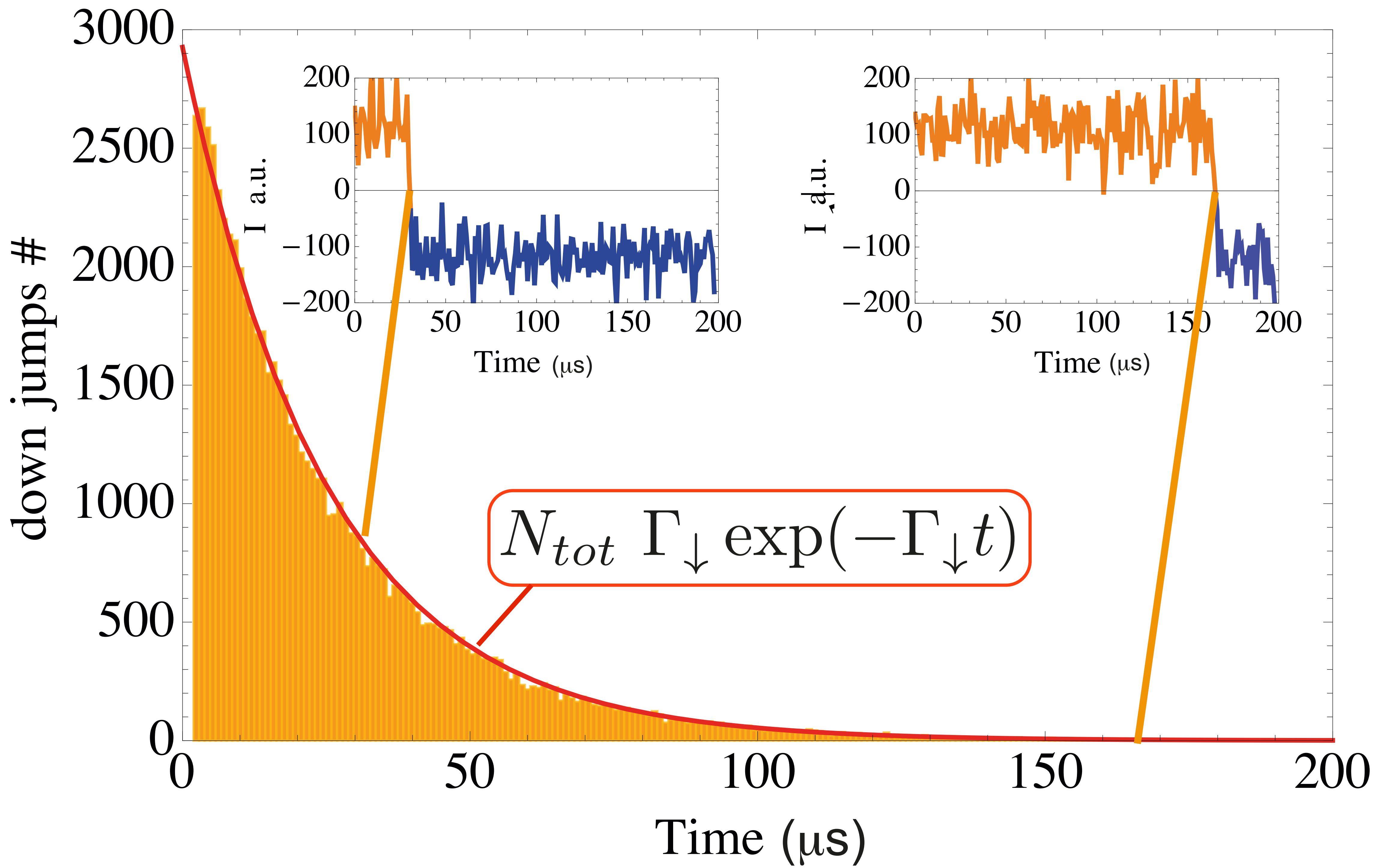
prepare $|e\rangle$ and continuous measurement at 1.8 photons



similar to [Vijay et al., PRL 2011 (Berkeley)]

Quantum jumps

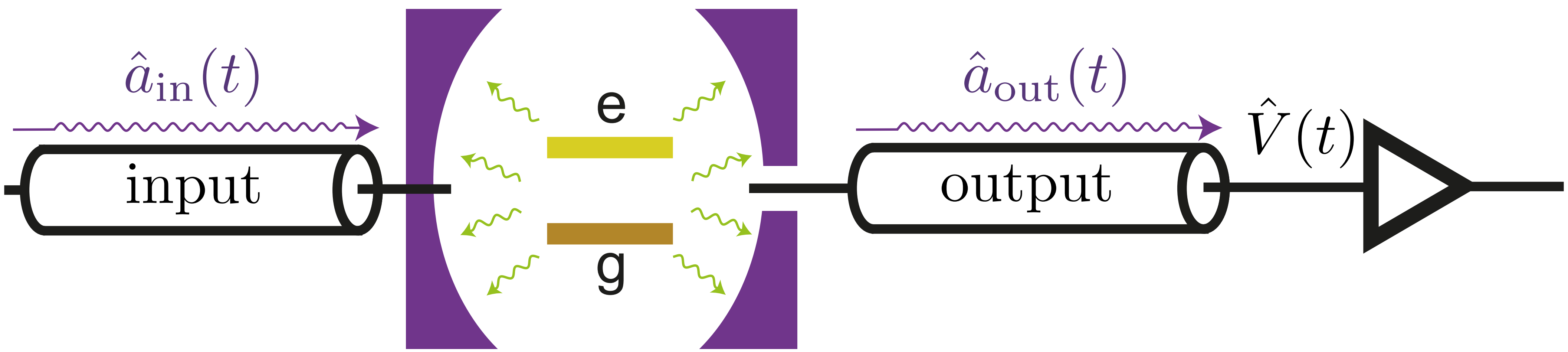
continuous measurement at 1.8 photons



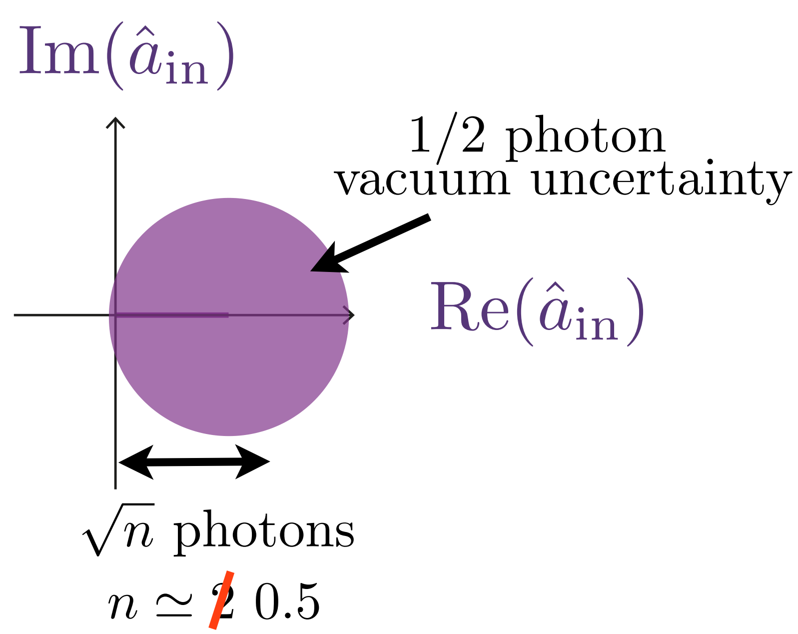
$$\frac{1}{\Gamma\downarrow} \simeq T_1 = 26\ \mu s$$

[Campagne-Ibarcq et al., PRX 2013 (ENS Paris)]

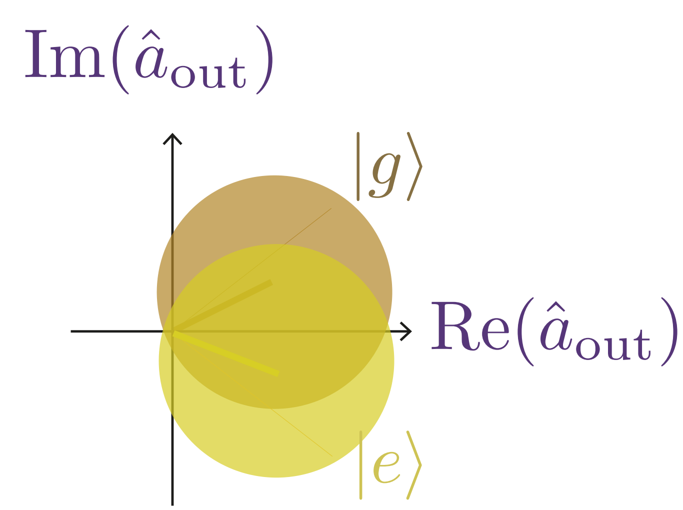
Weak measurement



field going in ...



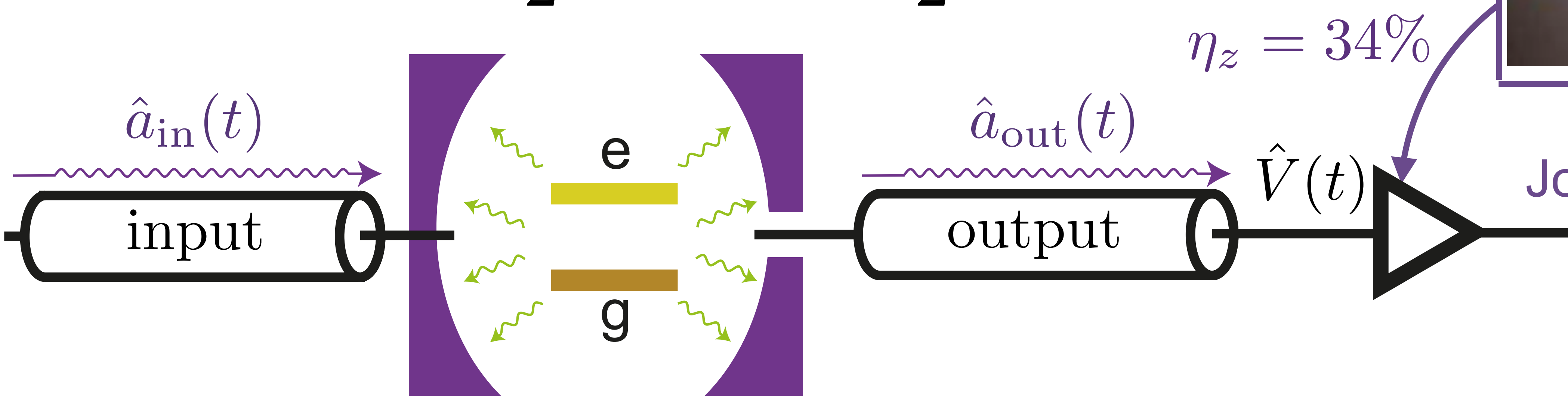
... field coming out

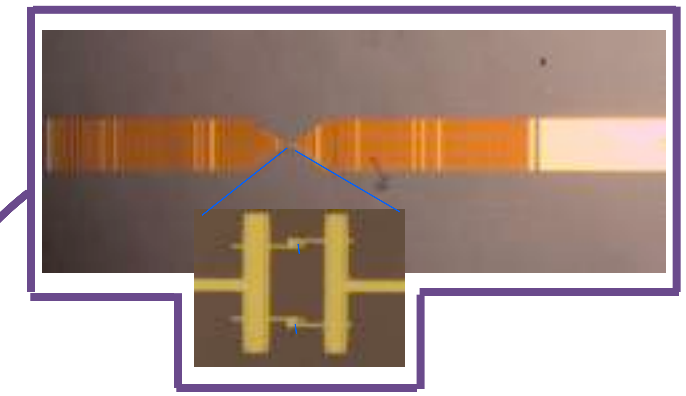


measuring $\mathrm{Im}(\hat{a}_{\mathrm{out}})$ $\longrightarrow$ Weak QND measurement

Dispersive Measurement

$$H = hf_q \frac{\sigma_Z}{2} + h(f_c - \frac{\chi}{2}\sigma_z)a^\dagger a$$





Josephson amplifier

[Kamal *et al.*, PRB 2009]

jump operator $L_z = \sqrt{\frac{\Gamma_d}{2}}\sigma_z$

$$dw_t = \sqrt{2\eta_z\Gamma_d}\,\langle\sigma_z\rangle_{\rho_t}\,dt + dW_{t,3}$$

average outcome

noise (Wiener)

Wiener Process

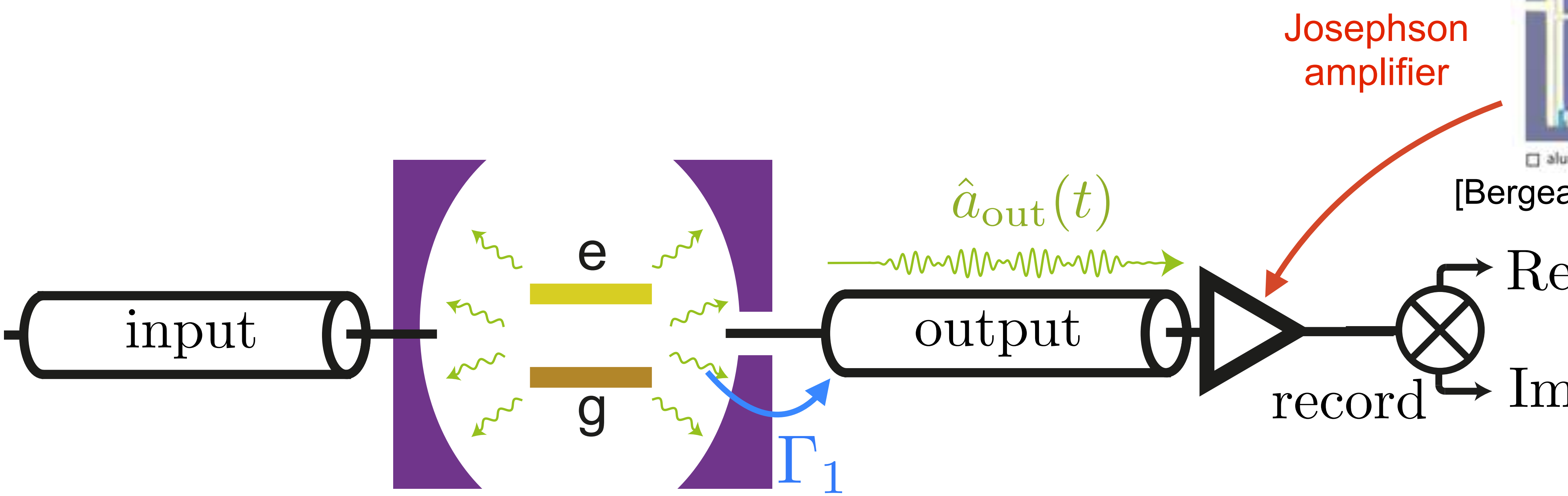
$$\mathbb{E}(dW_{t,i}) = 0$$

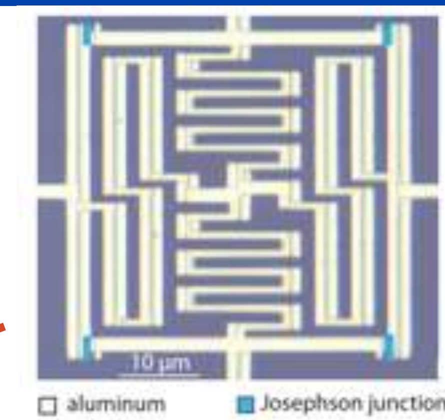
$$dW_{t,i}{}^2 = dt$$

$$\{dw_t\} \xrightarrow{\text{stochastic master equation}} \rho_t^{\mathrm{A}}$$

[Murch *et al.*, Nature 2013]
[Hatridge *et al.*, Science 2013]

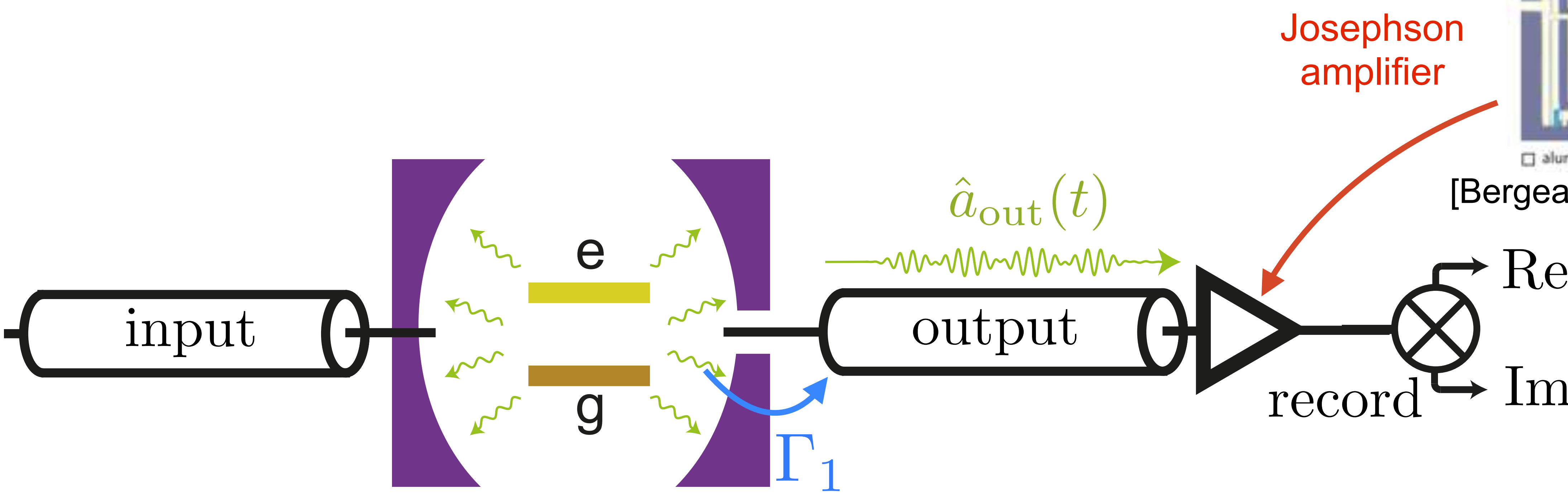
Fluorescence Measurement

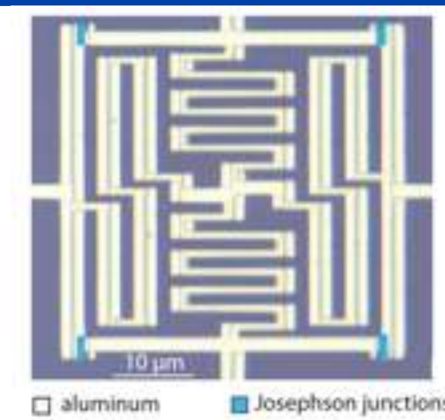




[Bergeal *et al.*, Nature 2010]

Fluorescence Measurement





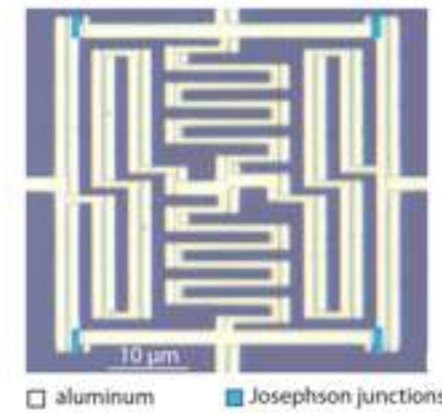
[Bergeal *et al.*, Nature 2010]

mean signal $\langle \hat{a}_{\text{out}} \rangle \propto \sqrt{\Gamma_1} \langle \sigma_- \rangle$

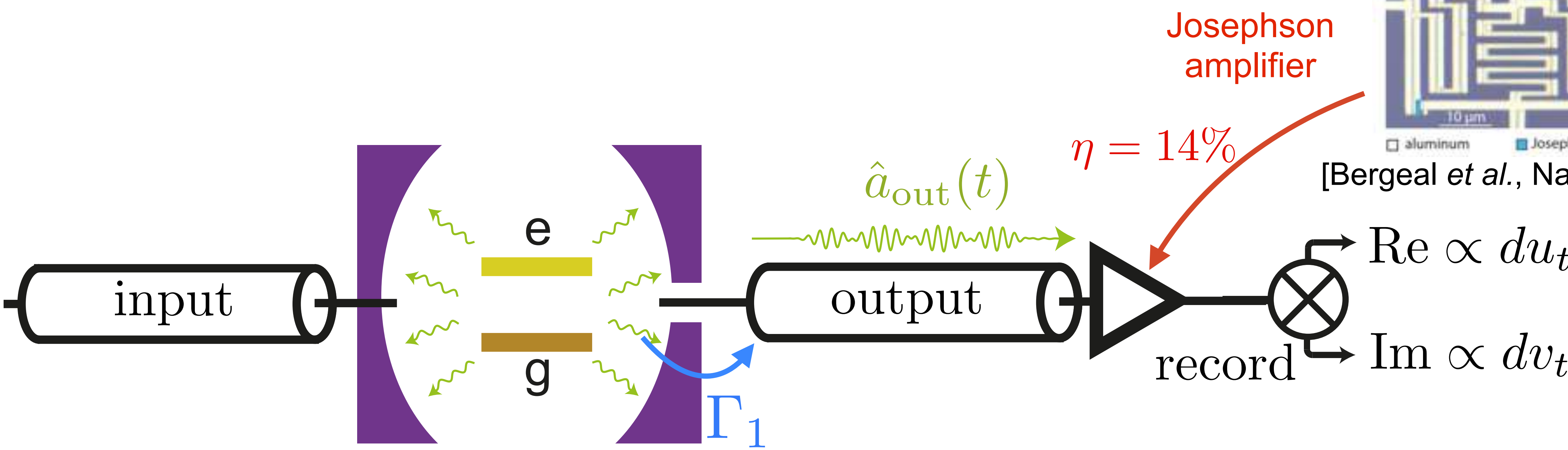
jump operator $\propto \sigma_- = |g\rangle \langle e| = \dfrac{\sigma_x - i\sigma_y}{2}$

$\Gamma_1 = (12.5\ \mu\text{s})^{-1}$

Fluorescence Measurement



[Bergeal *et al.*, Nature 2010]

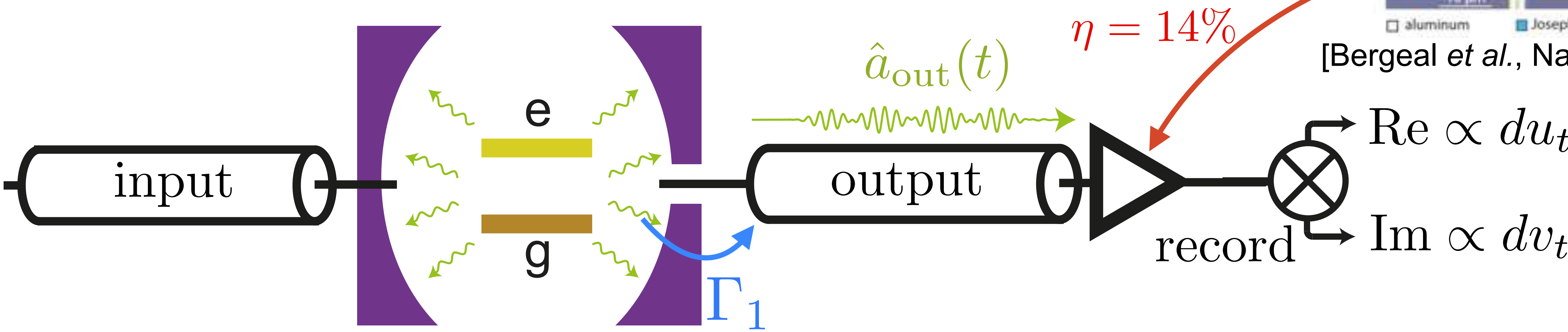


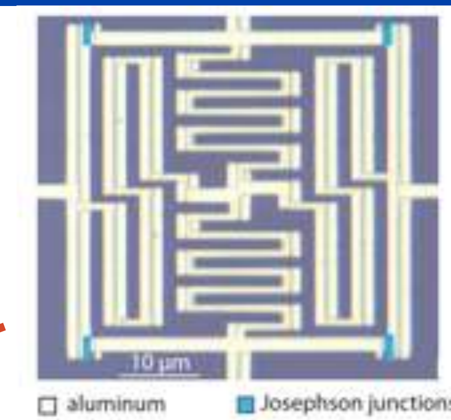
$$du_t = \sqrt{\frac{\eta\Gamma_1}{2}} \langle \sigma_X \rangle_{\rho_t} dt + dW_{t,1}$$

$$dv_t = \sqrt{\frac{\eta\Gamma_1}{2}} \langle \sigma_Y \rangle_{\rho_t} dt + dW_{t,2}$$

Fluorescence Measurement

Josephson amplifier





[Bergeal *et al.*, Nature 2010]

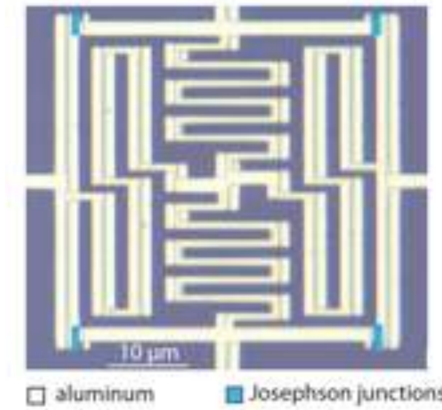
$$du_t = \sqrt{\frac{\eta\Gamma_1}{2}} \langle \sigma_X \rangle_{\rho_t} \, dt + dW_{t,1}$$

$$dv_t = \sqrt{\frac{\eta\Gamma_1}{2}} \langle \sigma_Y \rangle_{\rho_t} \, dt + dW_{t,2}$$

average outcome

noise
(Wiener)

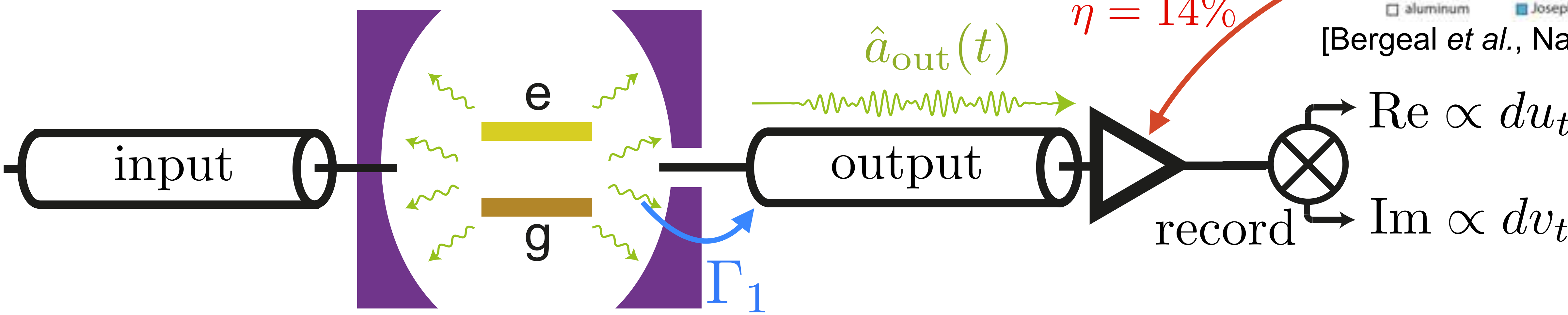
Fluorescence Measurement



Josephson amplifier

[Bergeal *et al.*, Nature 2010]

$\eta = 14\%$



$$du_t = \sqrt{\frac{\eta\Gamma_1}{2}} \langle \sigma_X \rangle_{\rho_t} dt + dW_{t,1}$$

$$dv_t = \sqrt{\frac{\eta\Gamma_1}{2}} \langle \sigma_Y \rangle_{\rho_t} dt + dW_{t,2}$$

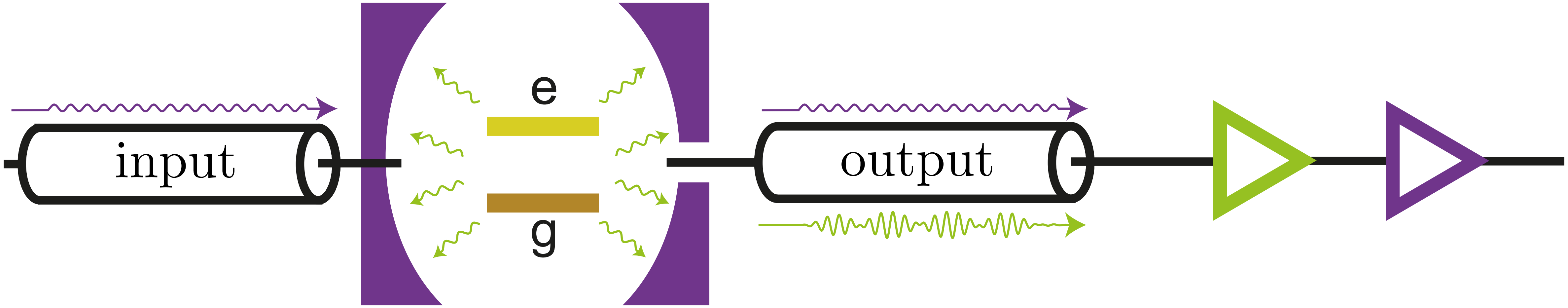
average outcome

noise (Wiener)

$$\{du_t, dv_t\} \xrightarrow{\text{stochastic master equation}} \rho_t^{\mathrm{B}}$$

[Campagne-Ibarcq *et al.*, PRX 2016]
[Naghiloo *et al.*, Nat. Comm. 2016]

Records of simultaneous X, Y and Z



full measurement records

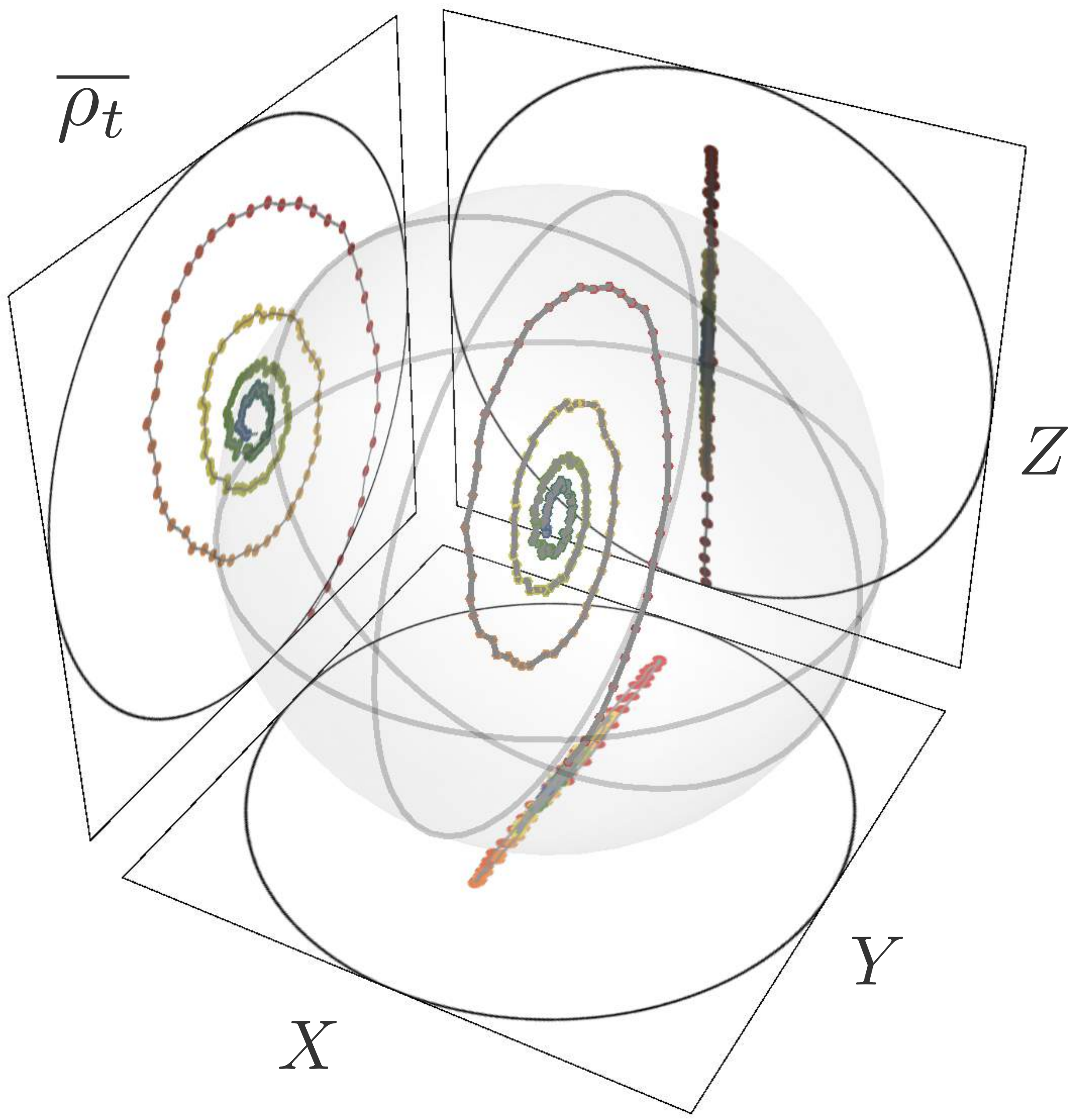
$$du_t = \sqrt{\eta_{\text{fluo}}\Gamma_1/2}\,\langle\sigma_X\rangle_{\rho_t}\,dt + dW_{t,1}$$
$$dv_t = \sqrt{\eta_{\text{fluo}}\Gamma_1/2}\,\langle\sigma_Y\rangle_{\rho_t}\,dt + dW_{t,2}$$
$$dw_t = \sqrt{2\eta_{\text{disp}}\Gamma_d}\,\langle\sigma_Z\rangle_{\rho_t}\,dt + dW_{t,3}$$

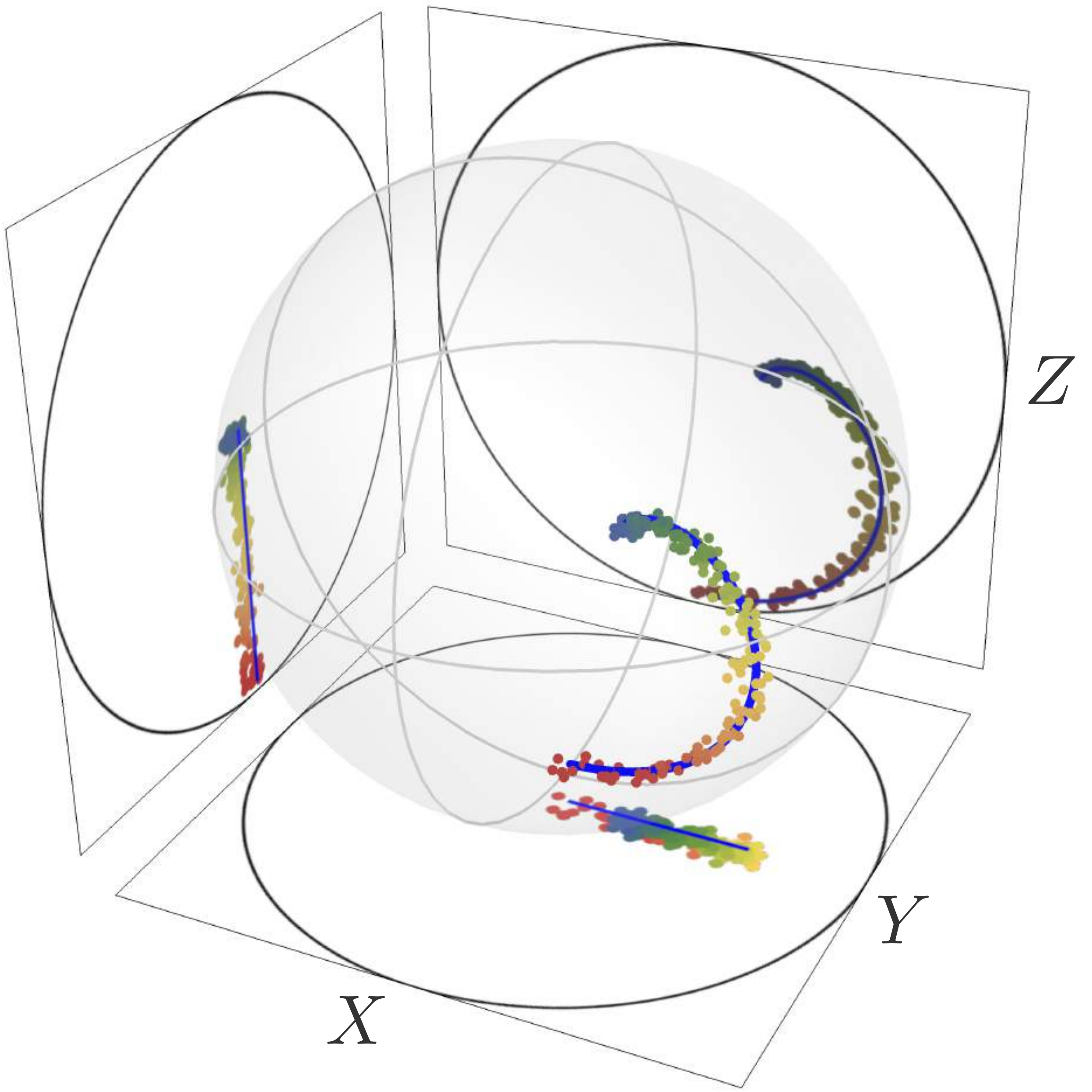
average outcome

noise (Wiener)

raw averaging directly gives Bloch vector

Average trajectory



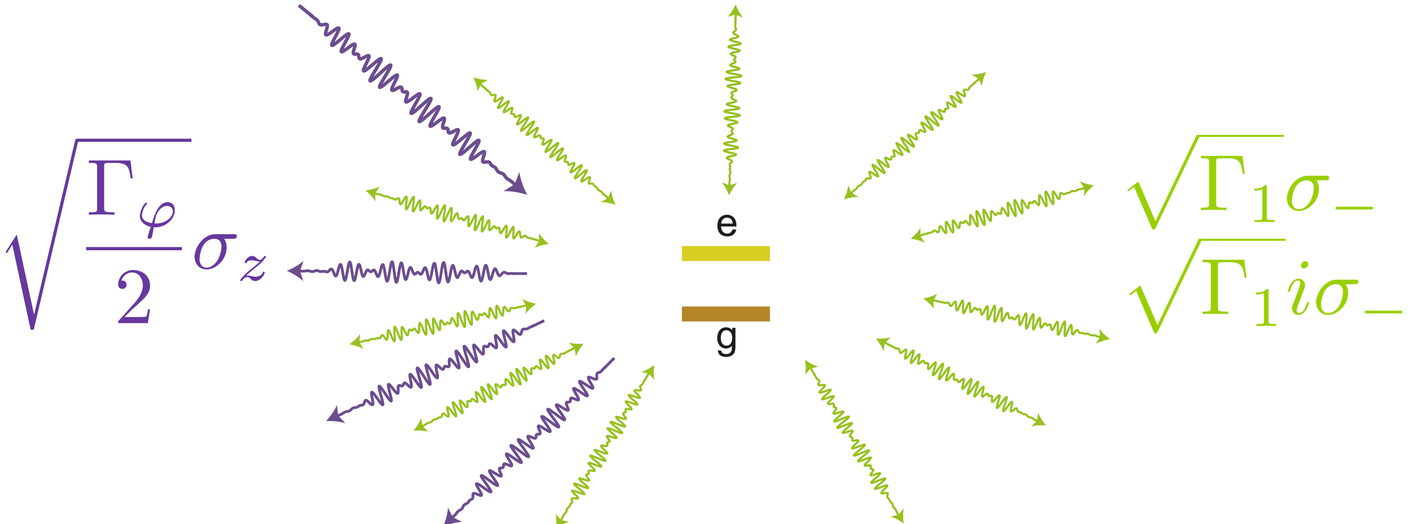


Quantum Trajectories - SME

Stochastic Master Equation for a continuous and weak measurement

$$d\rho_t = -\frac{i}{\hbar}[H,\rho_t]dt + \sum_{i=1}^{m} \mathcal{D}_i(\rho_t)dt$$

Decoherence $\mathcal{D}_i(\rho_t) = L_i \rho_t L_i^\dagger - \frac{1}{2}\rho_t L_i^\dagger L_i - \frac{1}{2} L_i^\dagger L_i \rho_t$



$L_i \rightarrow$ jump operator

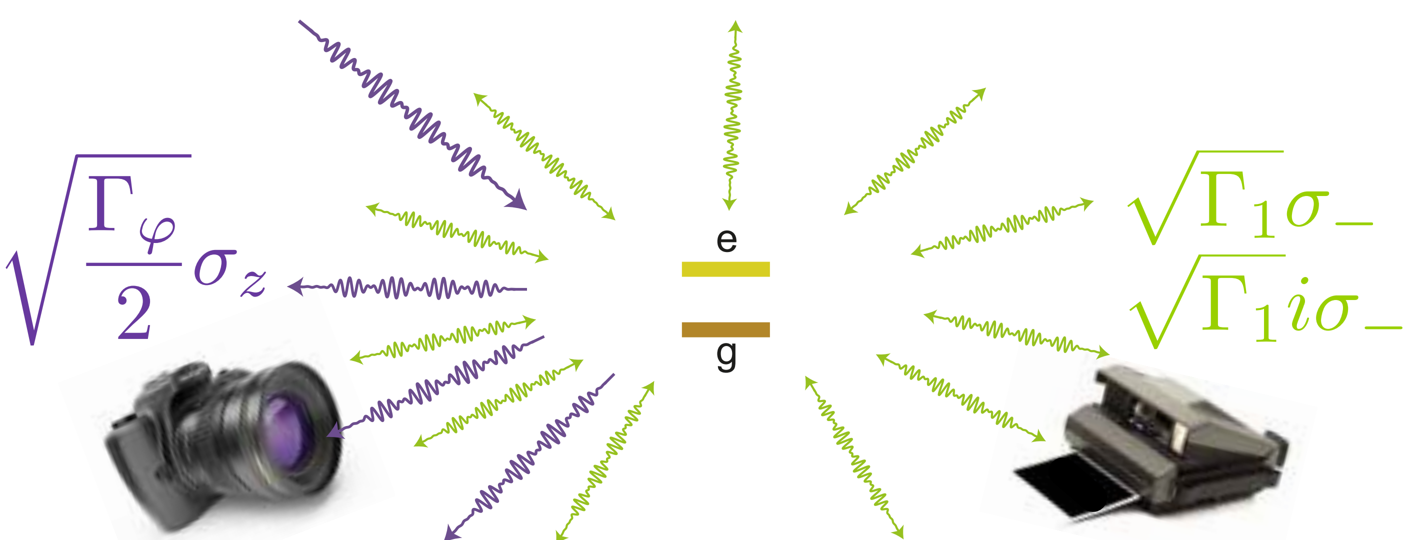
Quantum Trajectories - SME

Stochastic Master Equation for a continuous and weak measurement

$$d\rho_t = -\frac{i}{\hbar}[H,\rho_t]dt + \sum_{i=1}^{m} \mathcal{D}_i(\rho_t)dt + \sum_{i=1}^{m} \sqrt{\eta_i}\mathcal{M}_i(\rho_t)dW_{t,i}$$

Decoherence $\quad \mathcal{D}_i(\rho_t) = L_i\rho_t L_i^\dagger - \frac{1}{2}\rho_t L_i^\dagger L_i - \frac{1}{2}L_i^\dagger L_i \rho_t$

Innovation $\quad \mathcal{M}_i(\rho_t) = L_i\rho_t + \rho_t L_i^\dagger - \mathrm{Tr}(L_i\rho_t + \rho_t L_i^\dagger)\rho_t$



$L_i \rightarrow$ jump operator

$\eta_i \rightarrow$ measurement efficiency

Quantum Trajectories - SME

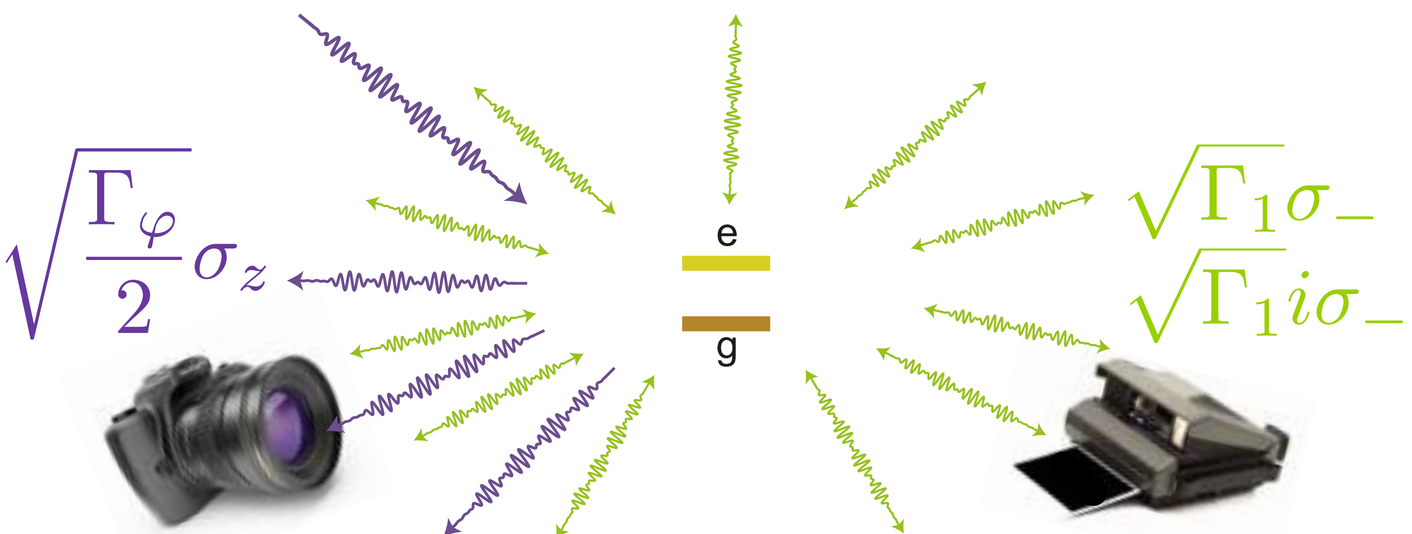
Stochastic Master Equation for a continuous and weak measurement

$$d\rho_t = -\frac{i}{\hbar}[H,\rho_t]dt + \sum_{i=1}^{m} \mathcal{D}_i(\rho_t)dt + \sum_{i=1}^{m} \sqrt{\eta_i}\mathcal{M}_i(\rho_t)dW_{t,i}$$

Decoherence $\mathcal{D}_i(\rho_t) = L_i\rho_t L_i^\dagger - \frac{1}{2}\rho_t L_i^\dagger L_i - \frac{1}{2}L_i^\dagger L_i \rho_t$

Innovation $\mathcal{M}_i(\rho_t) = L_i\rho_t + \rho_t L_i^\dagger - \mathrm{Tr}(L_i\rho_t + \rho_t L_i^\dagger)\rho_t$

Measurement records $dy_t^i = \sqrt{\eta_i}\mathrm{Tr}(L_i\rho_t + \rho_t L_i^\dagger)dt + dW_{t,i}$



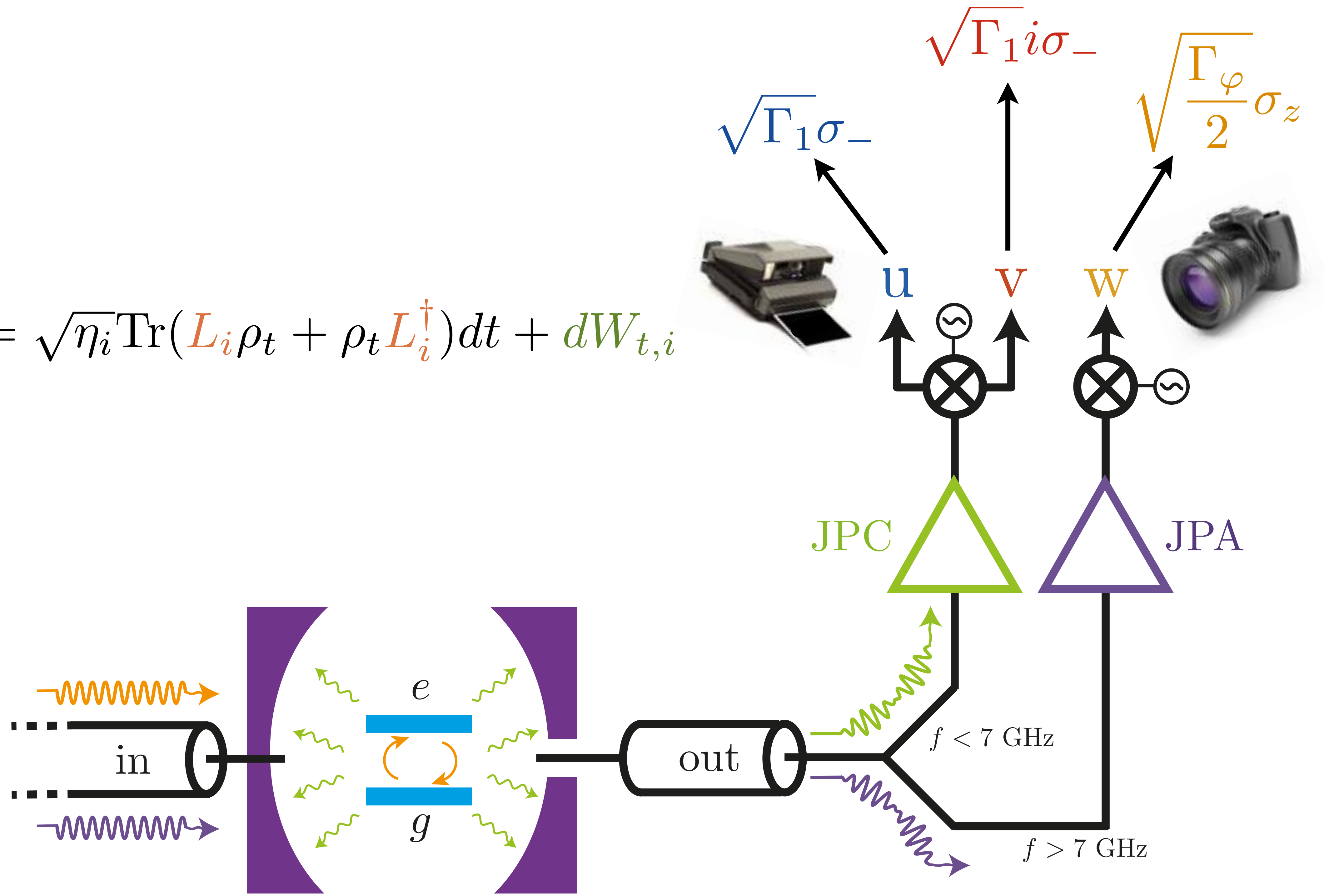
$L_i \rightarrow$ jump operator

$\eta_i \rightarrow$ measurement efficiency

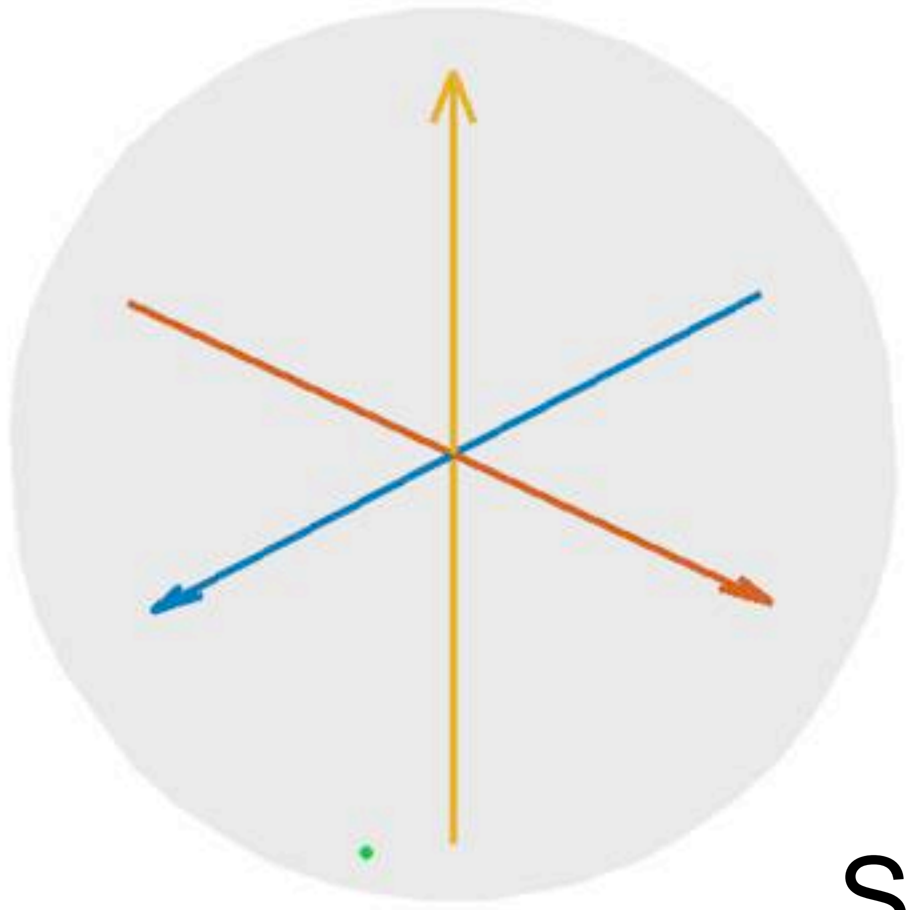
$dt \rightarrow$ limited by amplifier bandwith

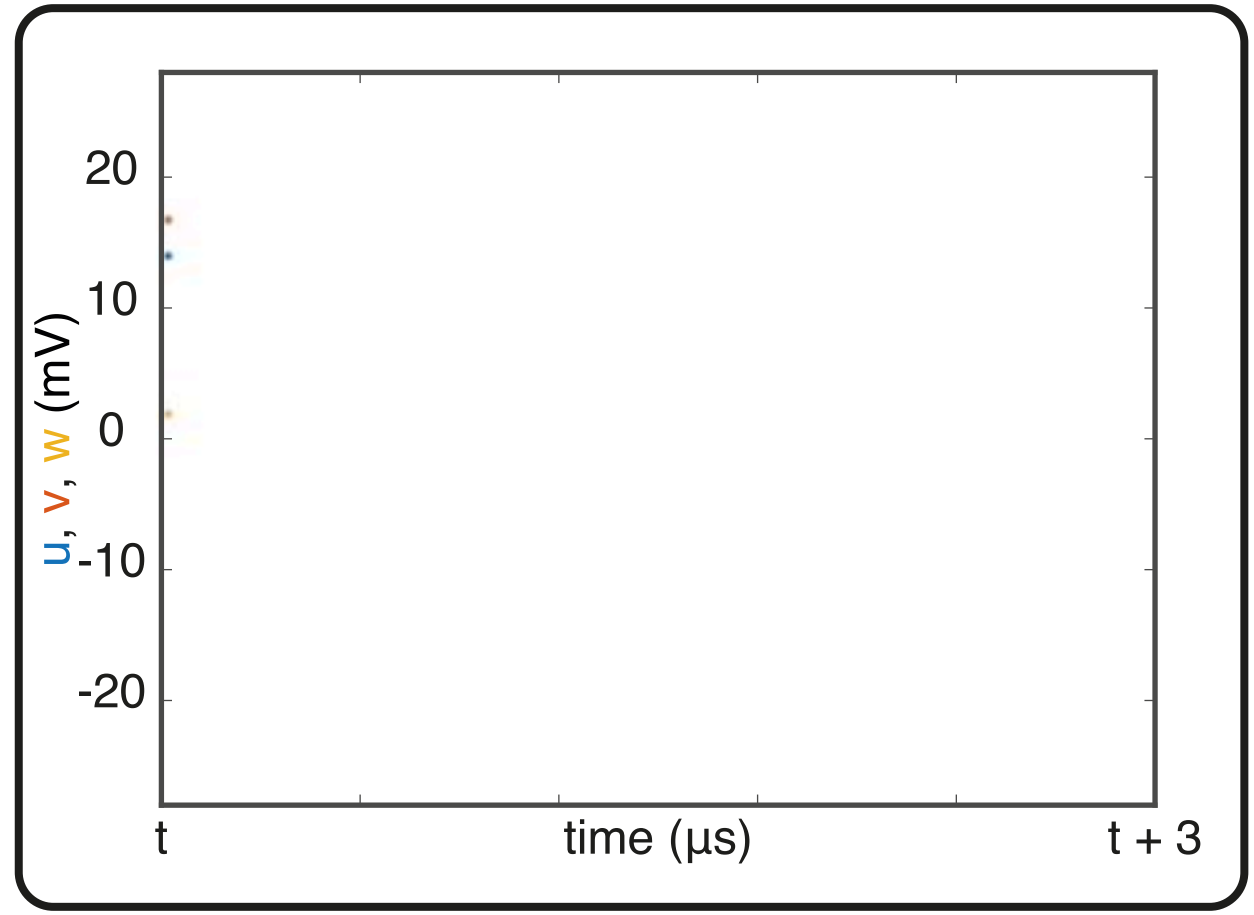
Measurement setup

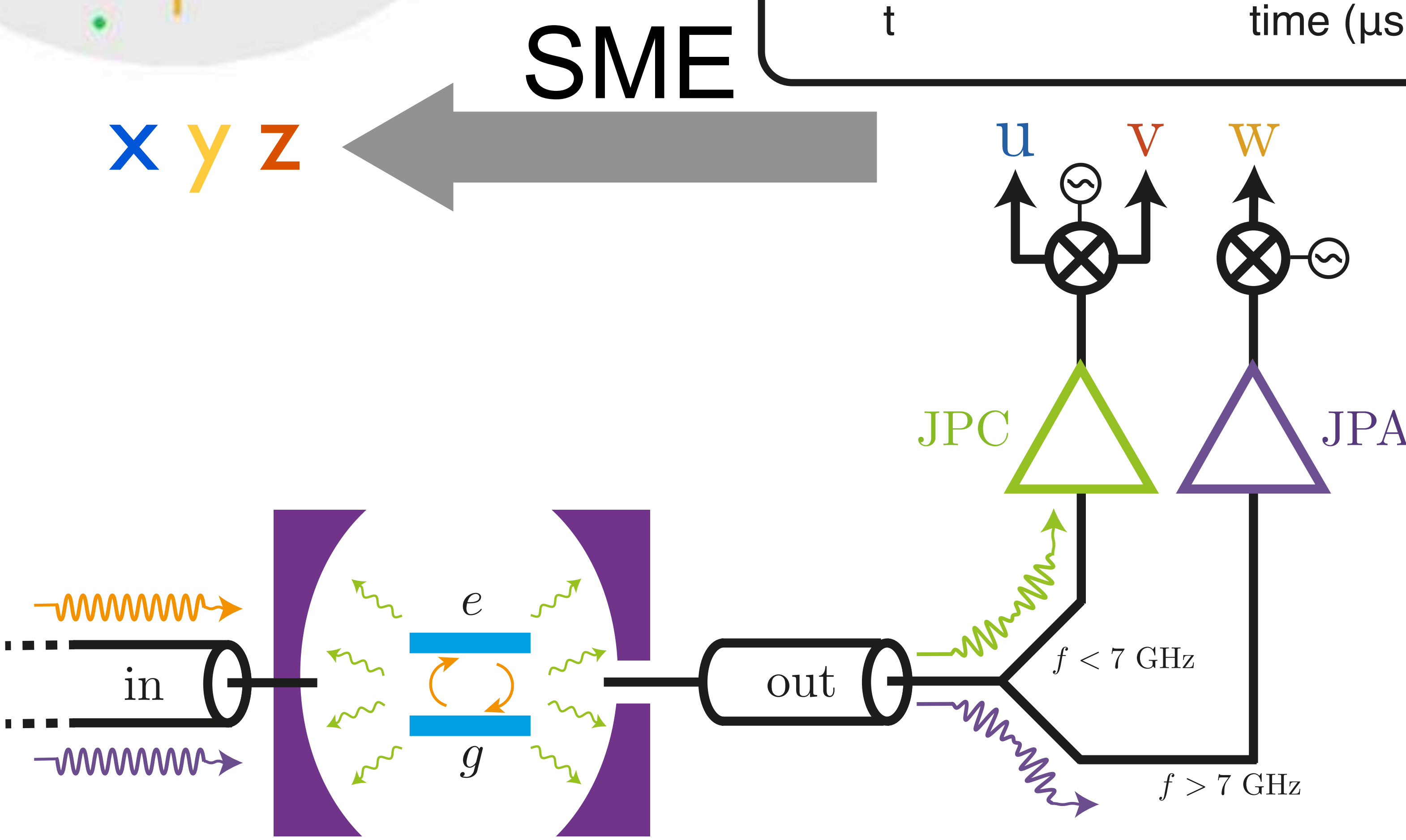
$$dy_t^i = \sqrt{\eta_i}\mathrm{Tr}(L_i \rho_t + \rho_t L_i^\dagger)dt + dW_{t,i}$$



One quantum trajectory







η_{fluo} = 14 %

η_{disp} = 34 %

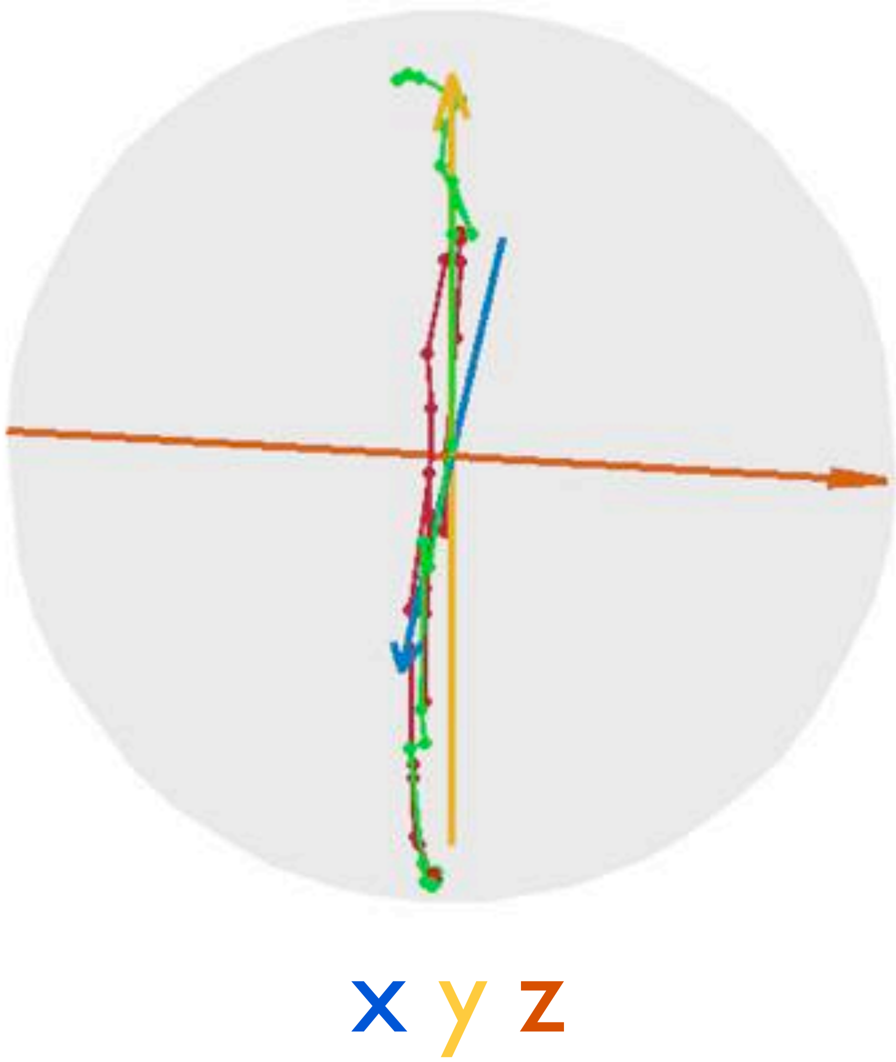
T_1 = 15.0 µs

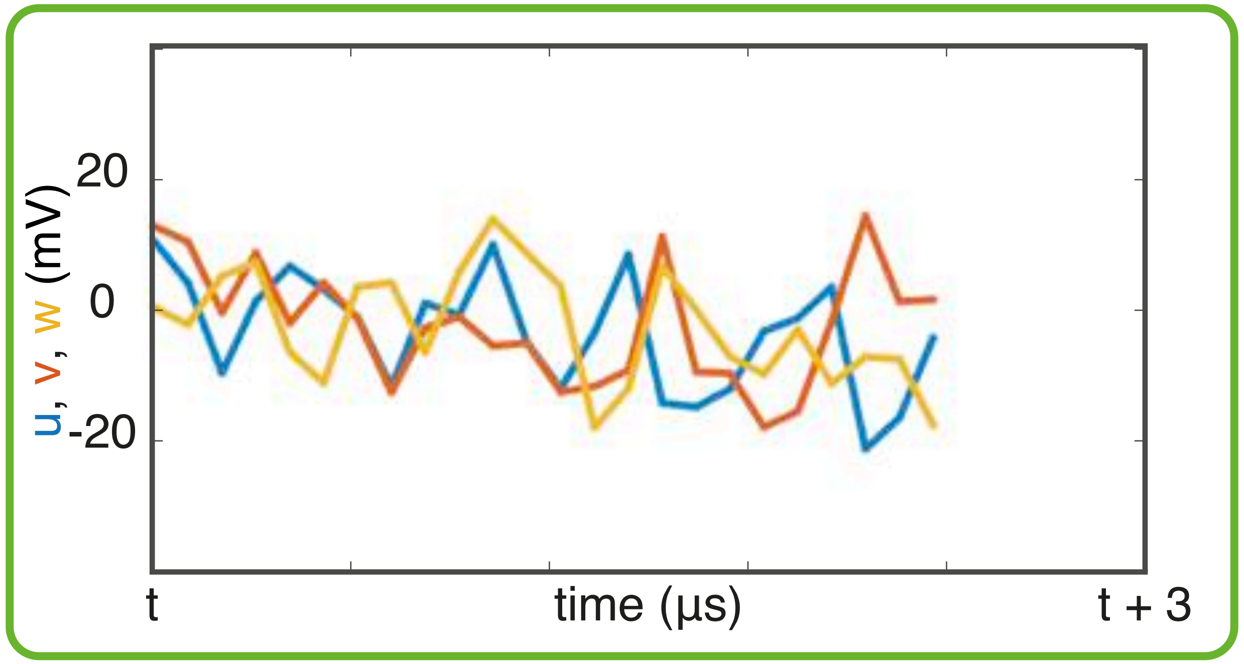
T_2 = 11.2 µs

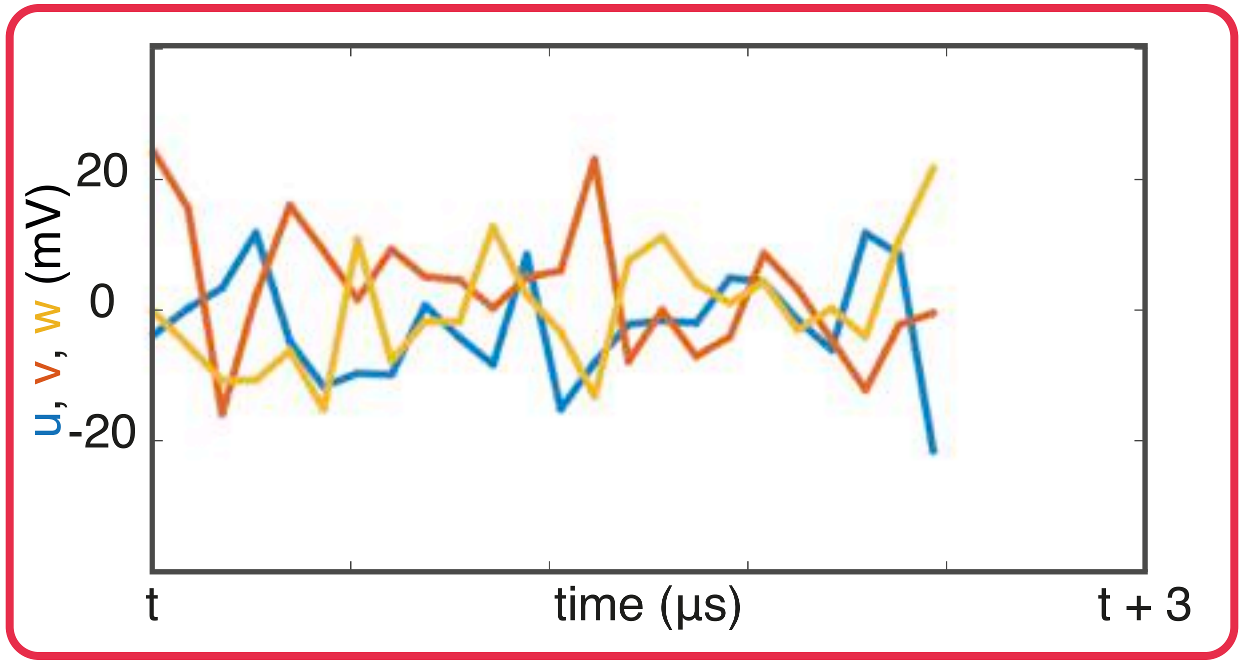
T_d = 0.9 µs

T_R = 5.2 µs

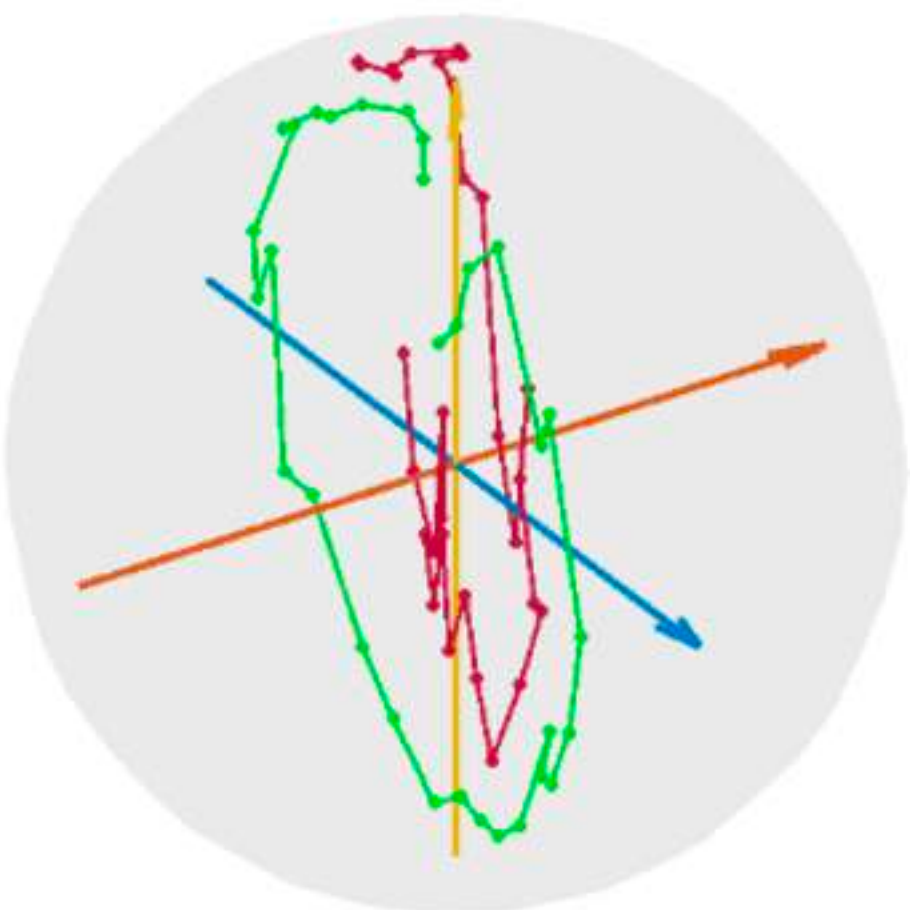
Two quantum trajectories



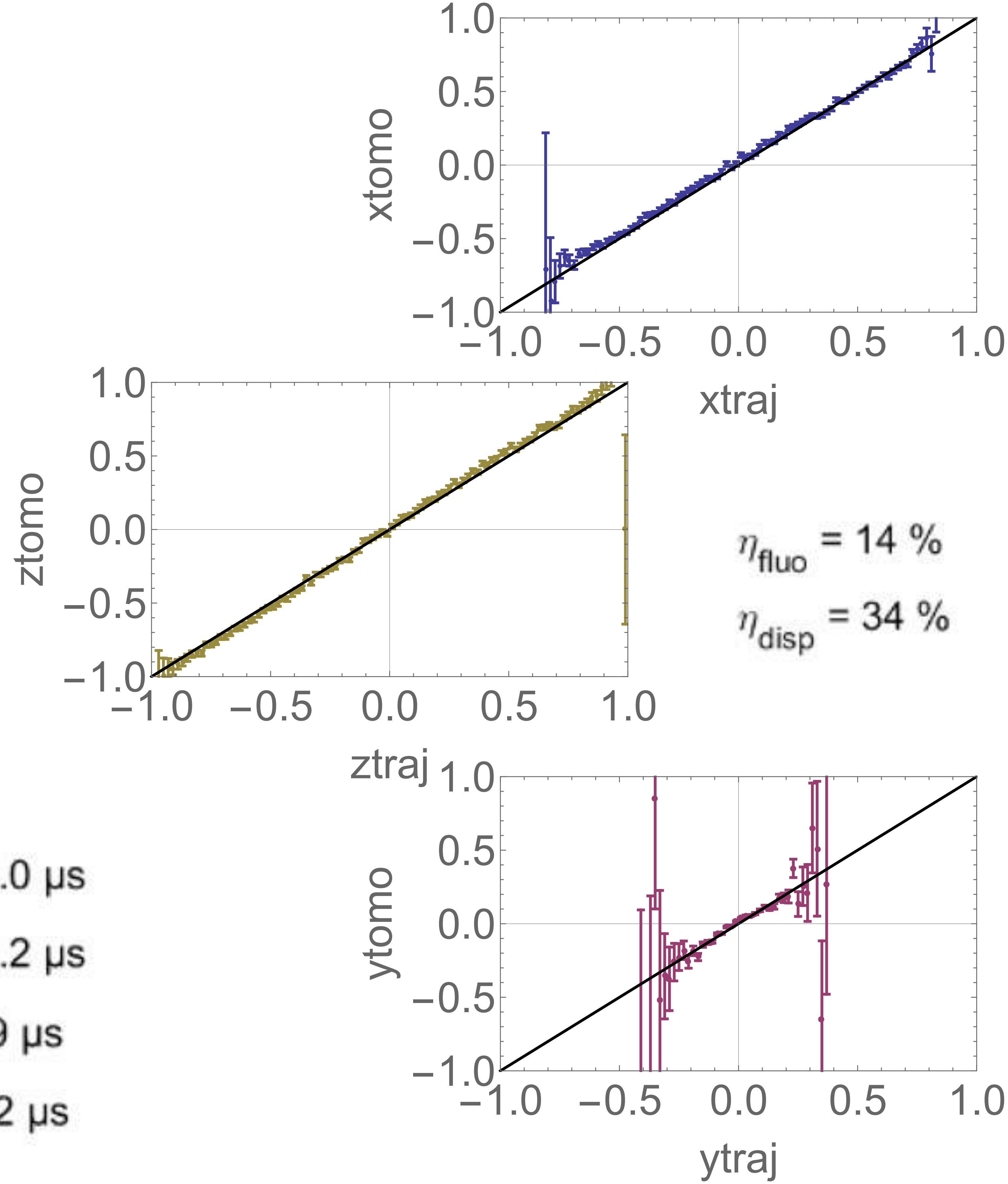




Control trajectories by tomography



x y z



η_{fluo} = 14 %

η_{disp} = 34 %

T_1 = 15.0 μs

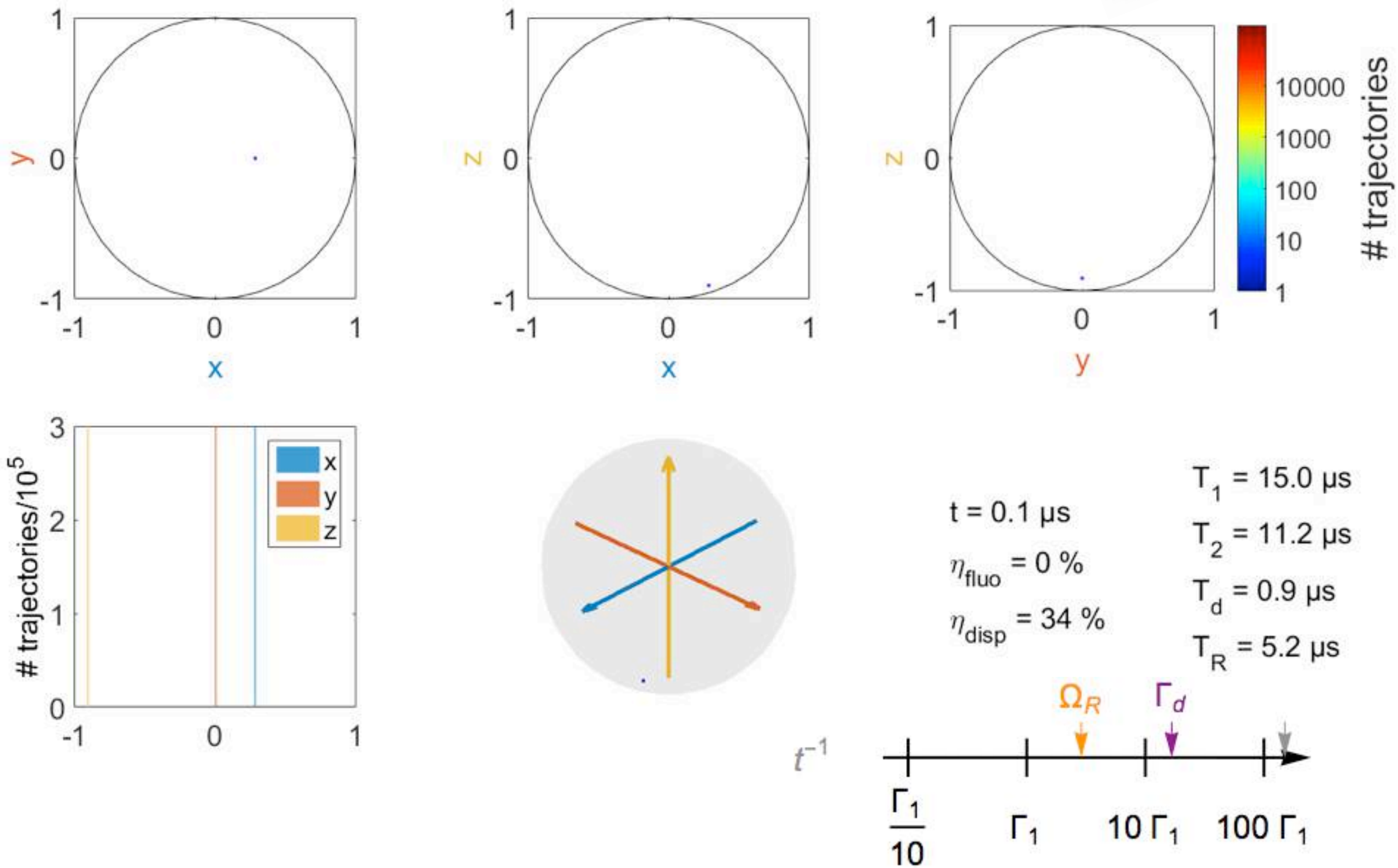
T_2 = 11.2 μs

T_d = 0.9 μs

T_R = 5.2 μs

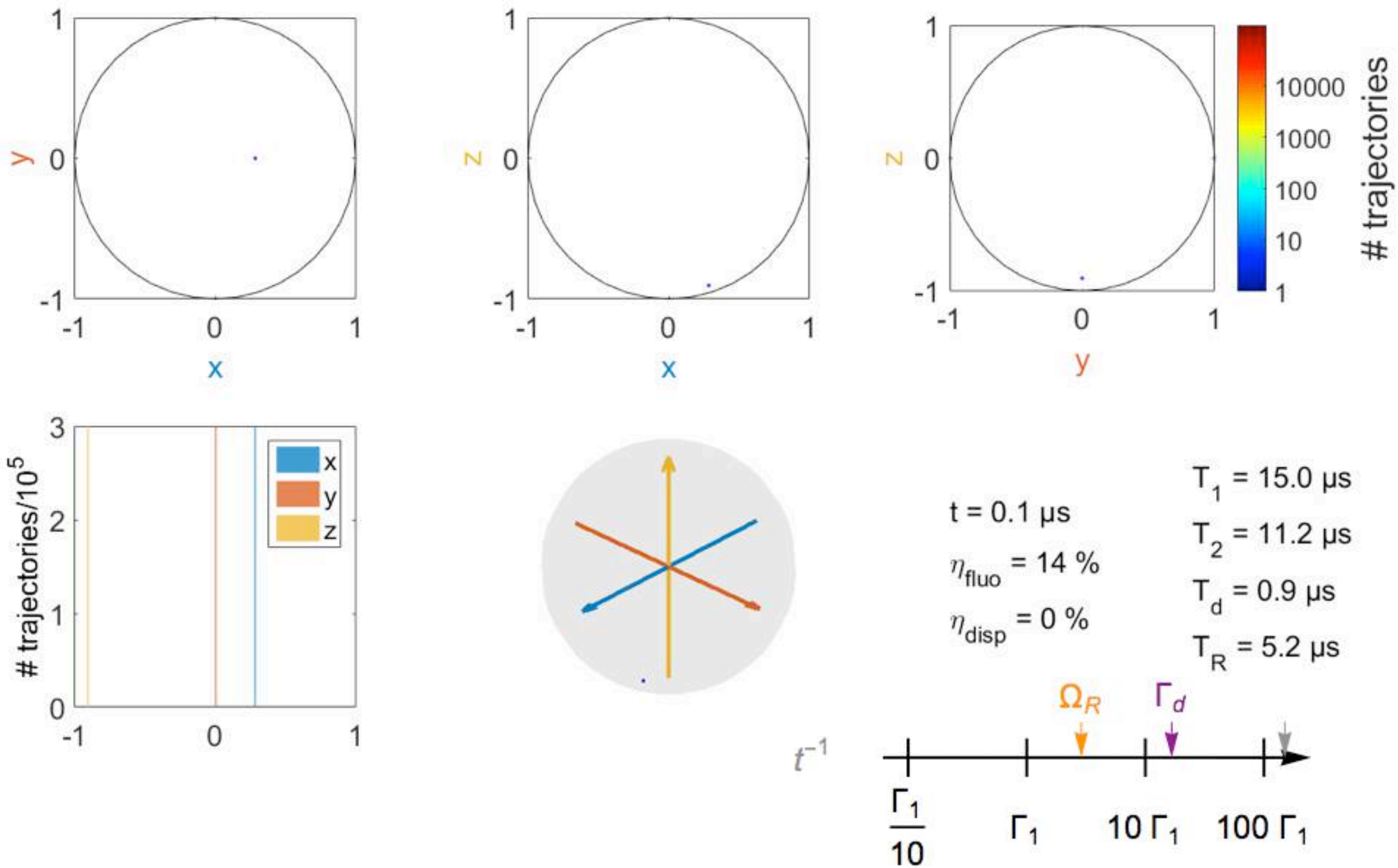
statistics in the Zeno regime

σ_Z measurement only



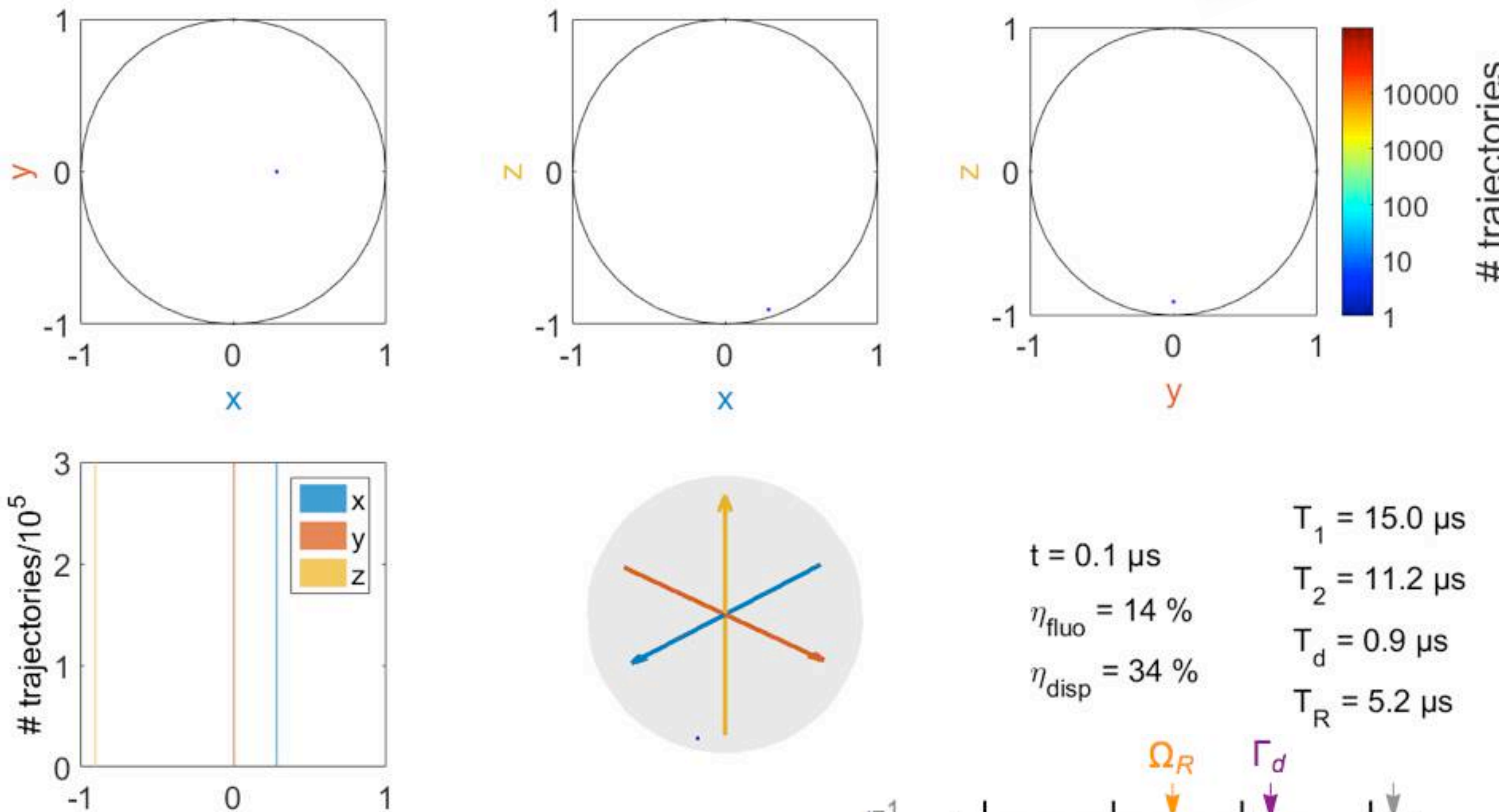
statistics in the Zeno regime

σ_- measurement only



statistics in the Zeno regime

σ_- and σ_Z measurements at the same time



t = 0.1 µs

η_{fluo} = 14 %

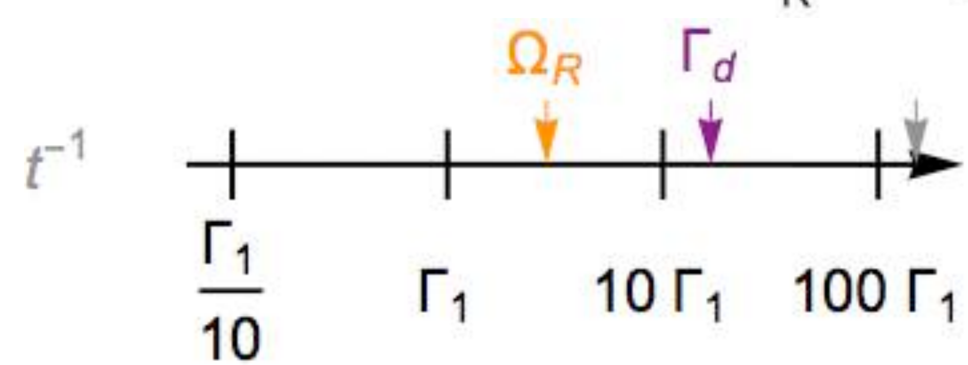
η_{disp} = 34 %

T_1 = 15.0 µs

T_2 = 11.2 µs

T_d = 0.9 µs

T_R = 5.2 µs

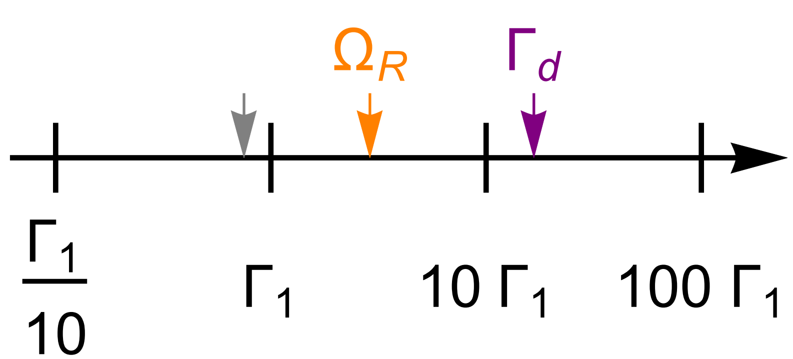


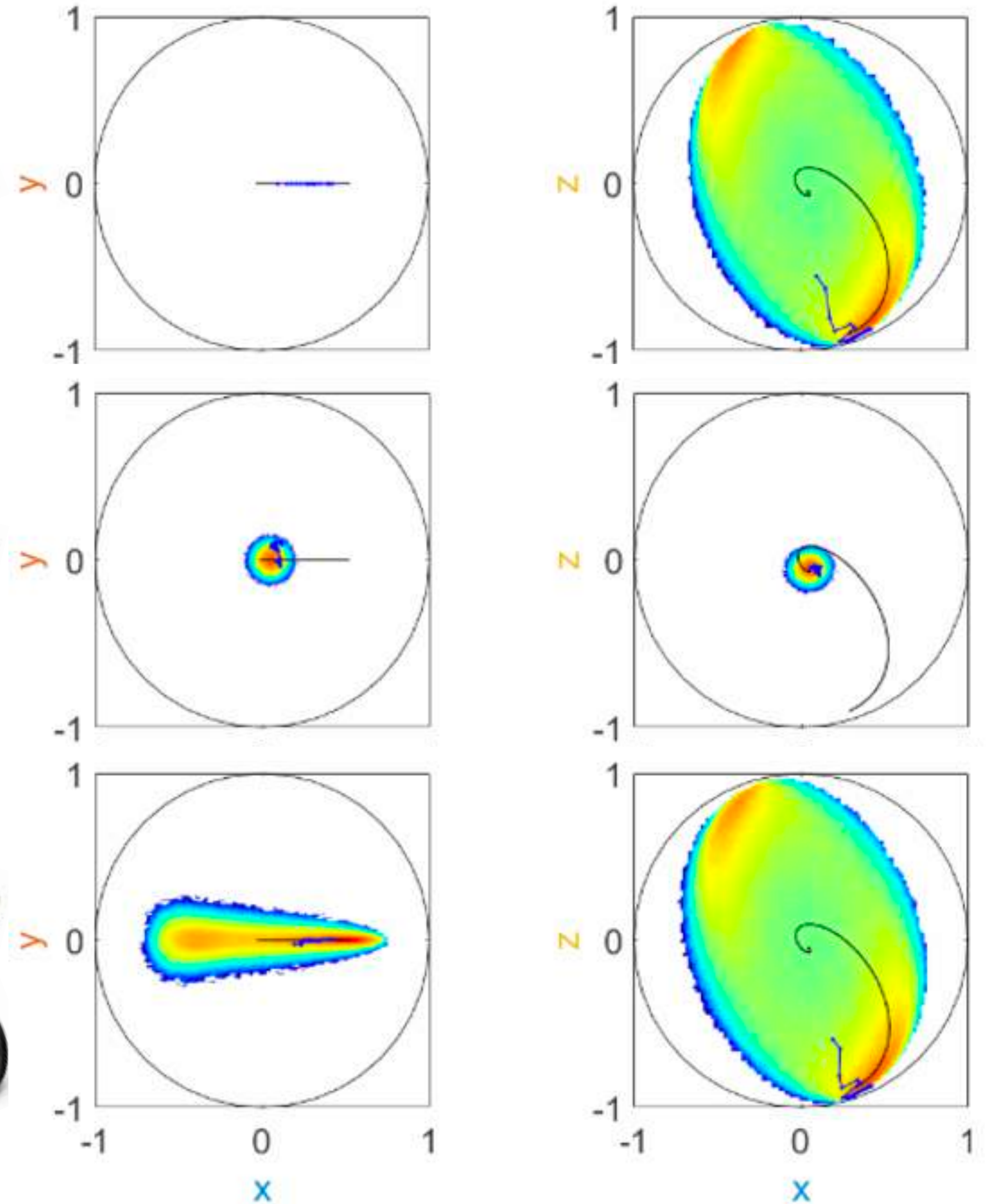
statistics in the Zeno regime

σ_Z measurement only

σ_- measurement only

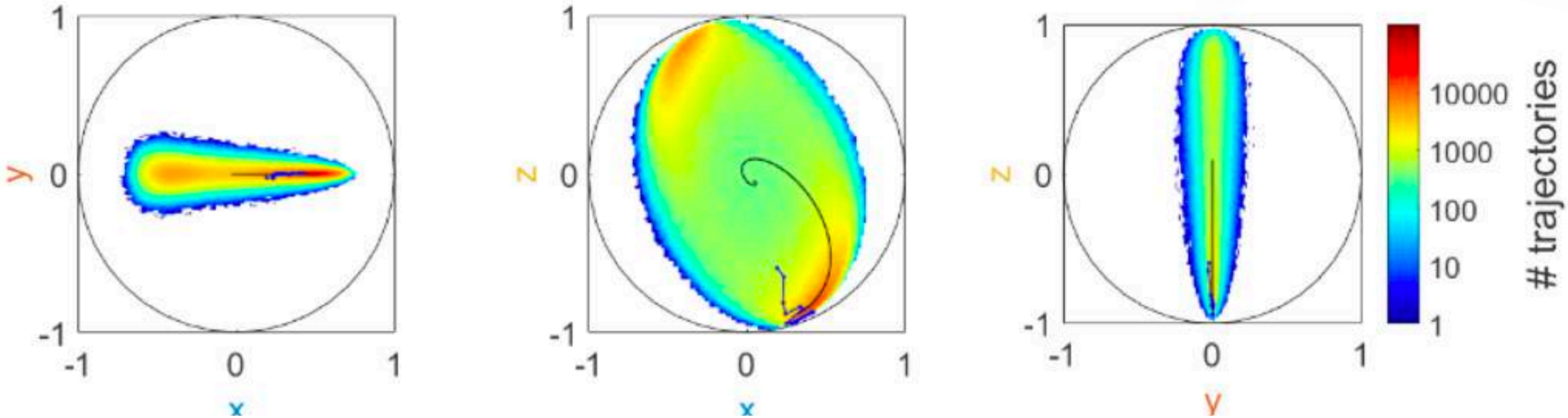
σ_- and σ_Z measurements





statistics in the Zeno regime

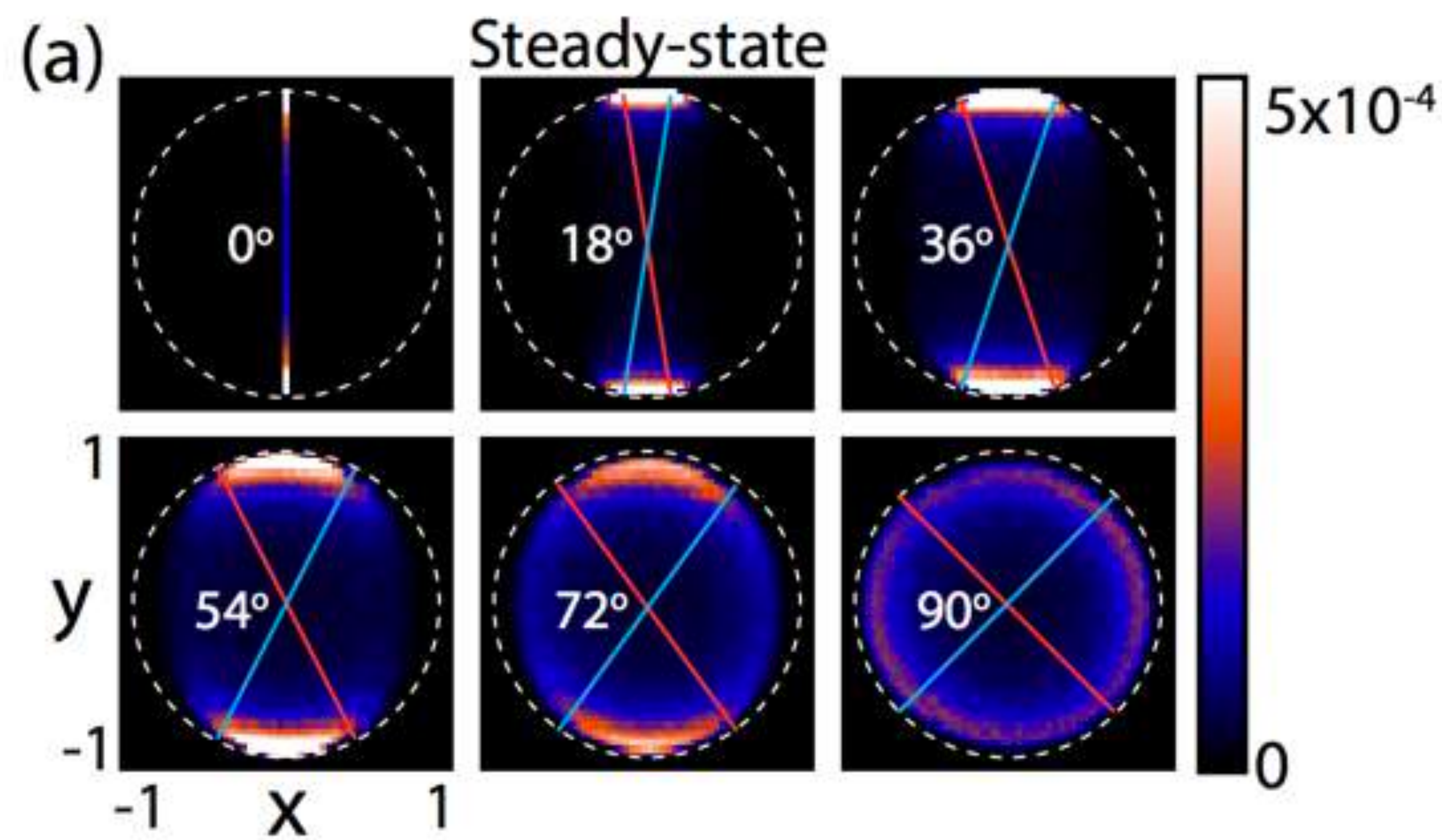
σ_- and σ_Z measurements at the same time



differs from the case of

σ_x and σ_y

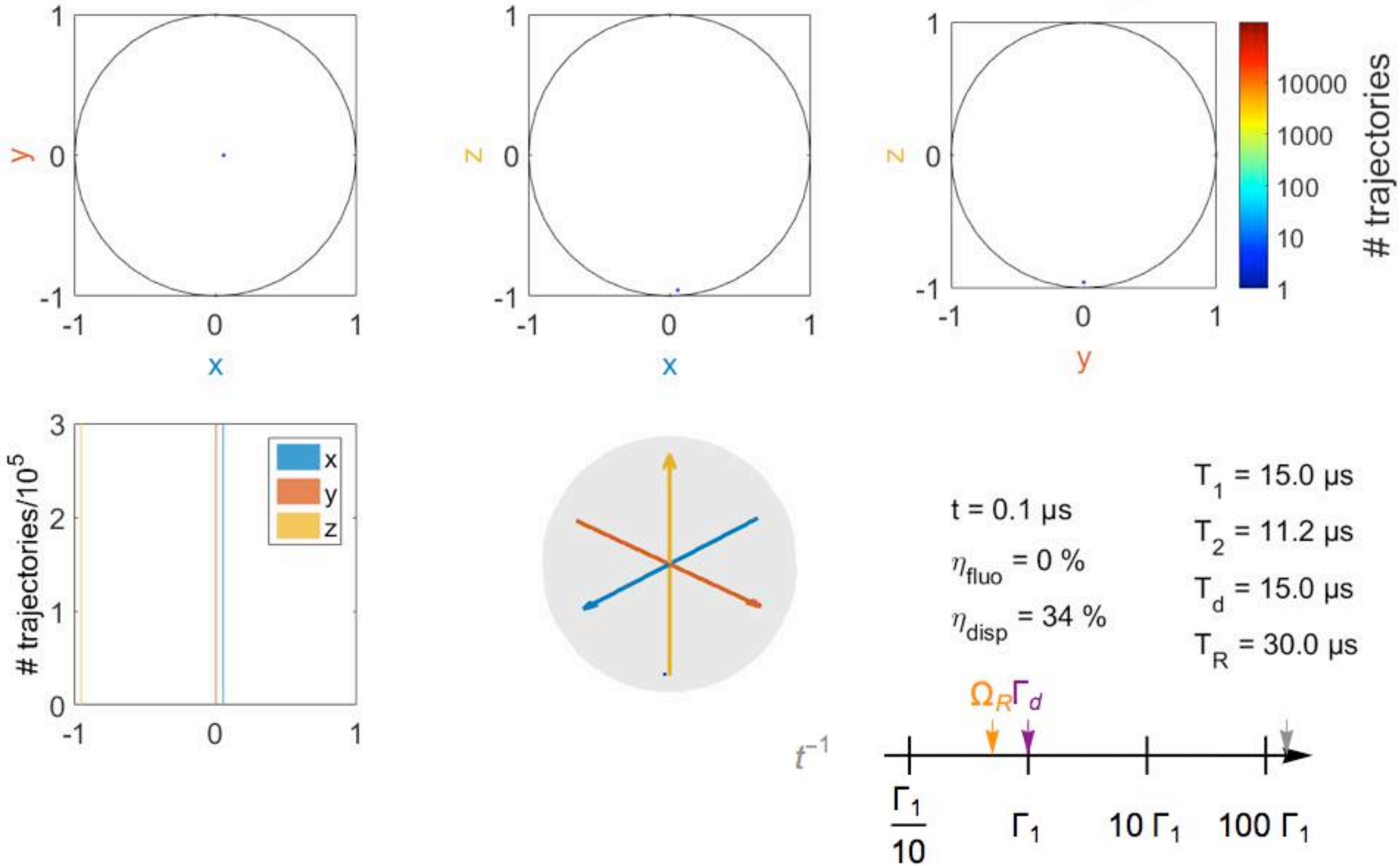
measurement



[Hacohen-Gourgy *et al.*, Nature 2016]

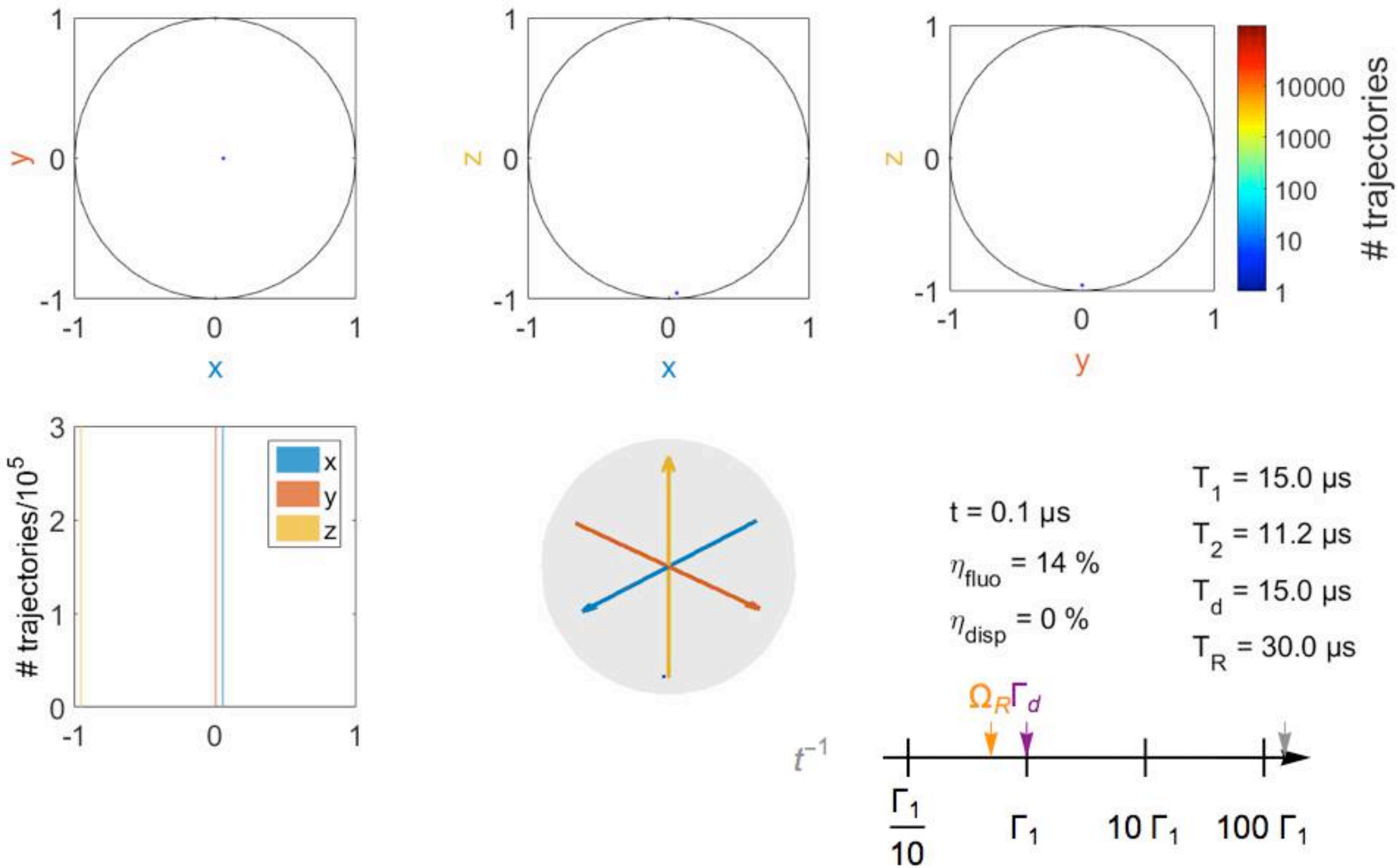
statistics with weak fluo and dispersive

σ_Z measurement only



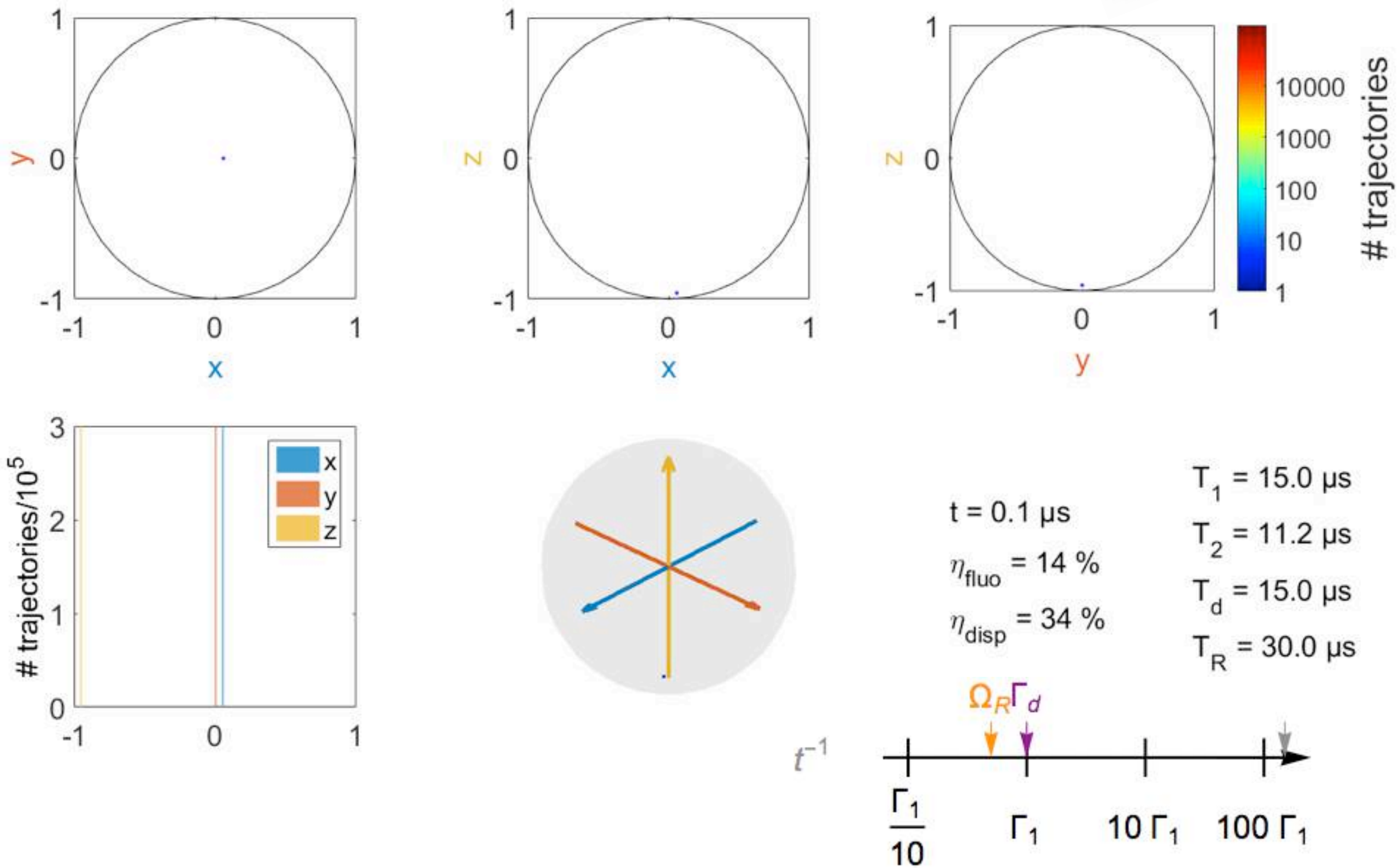
statistics with weak fluo and dispersive

σ_- measurement only



statistics with weak fluo and dispersive

σ_- and σ_Z measurements at the same time

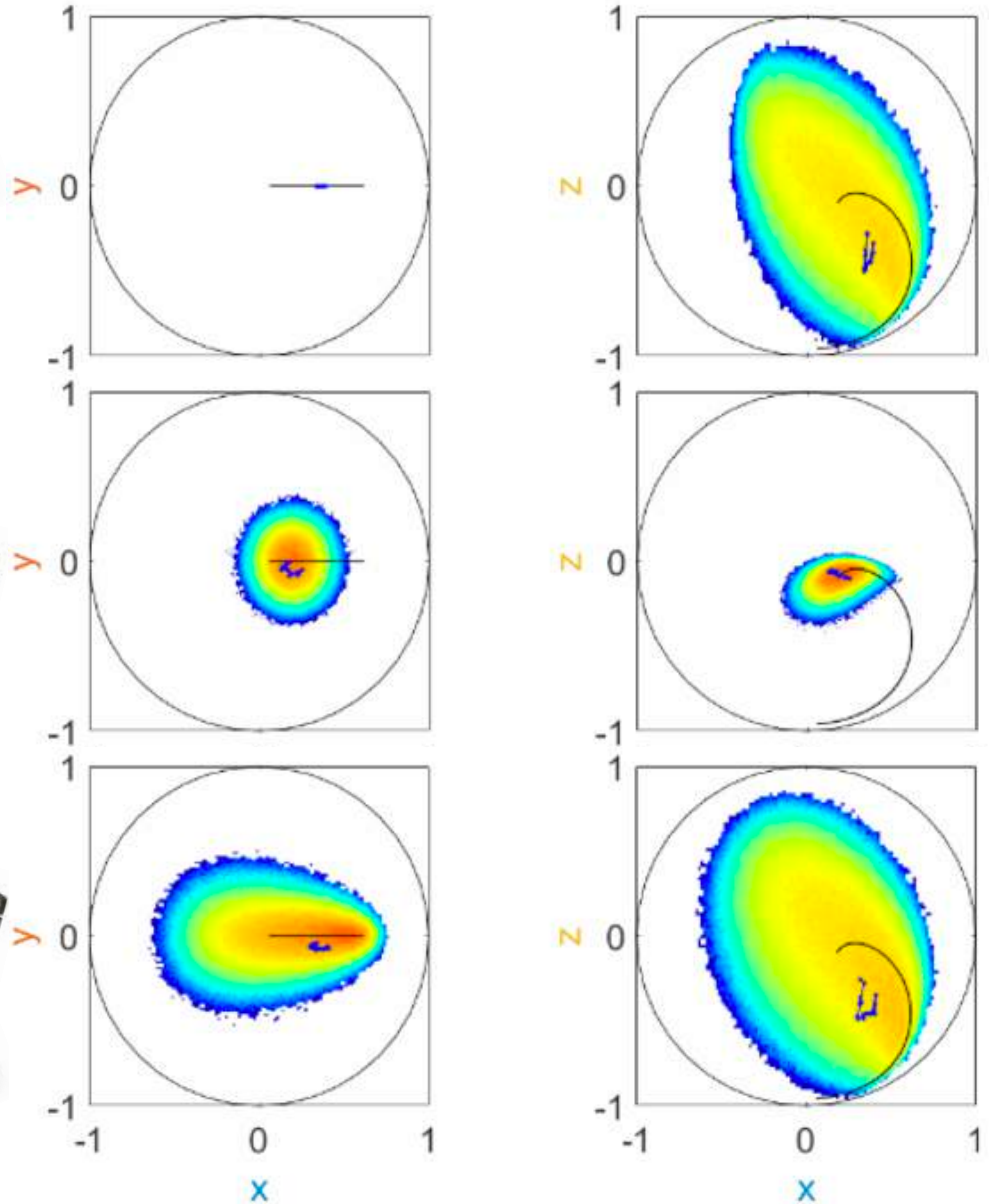


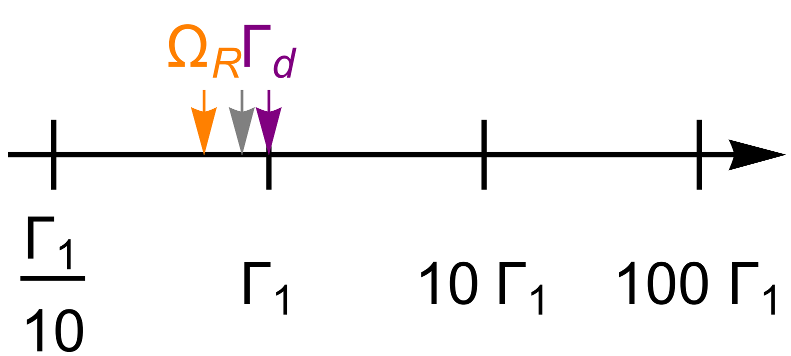
statistics in the Zeno regime

σ_Z measurement only

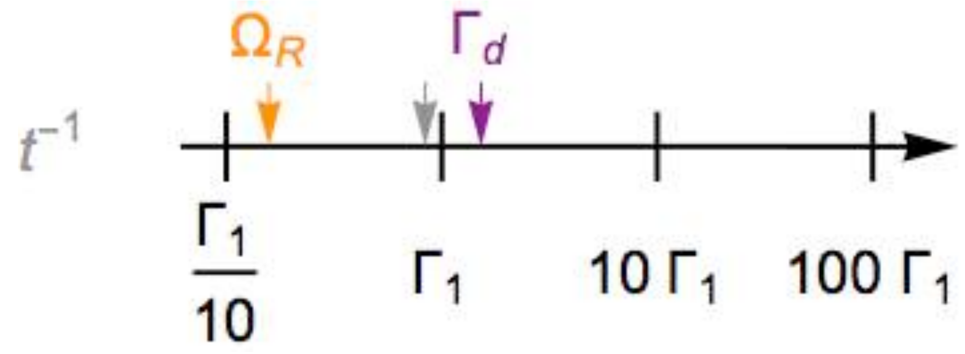
σ_- measurement only

σ_- and σ_Z measurements





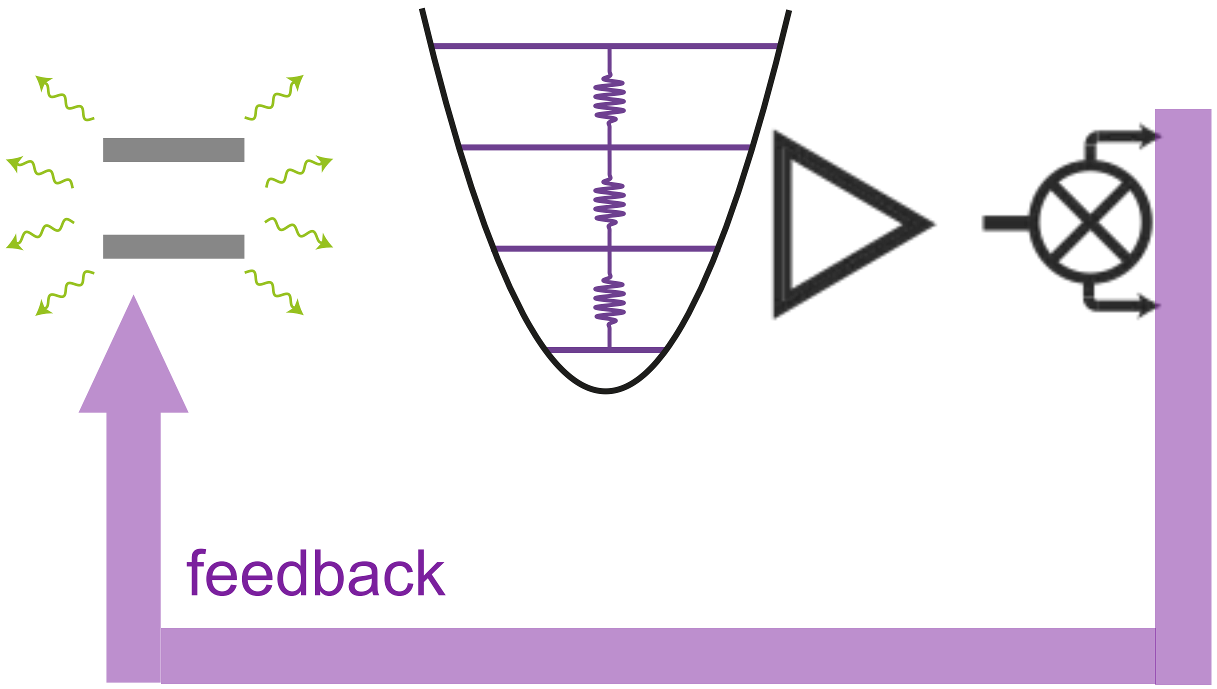
Any configuration



to appear at http://www.physinfo.fr soon

Measurement based feedback

based on dispersive measurement



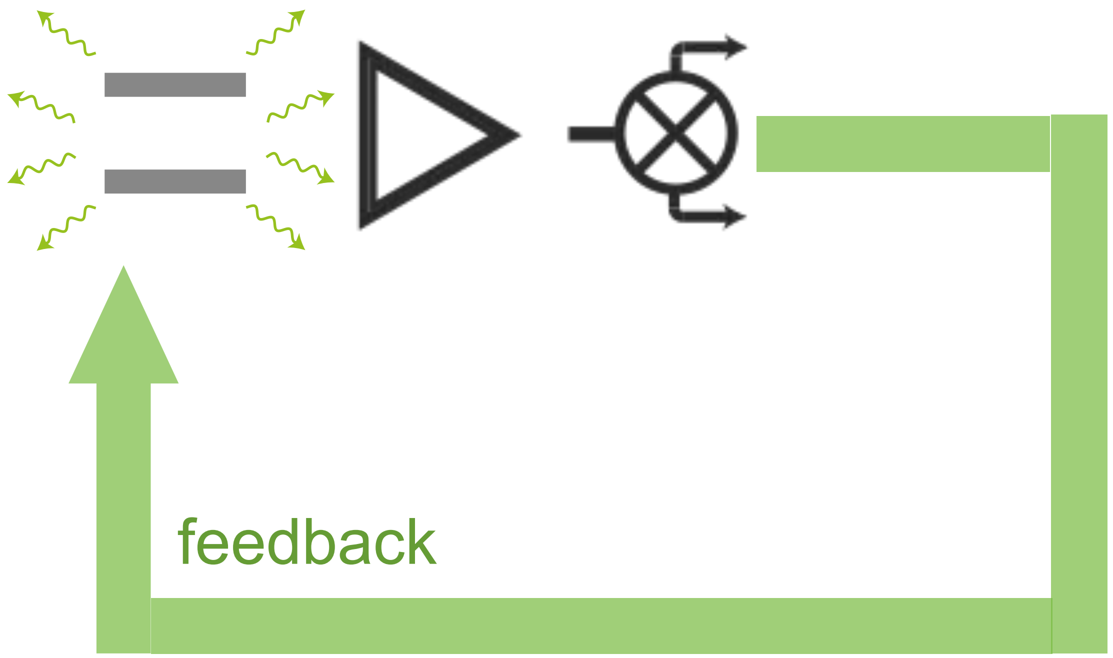
[Vijay et al., Nature 2012 (Berkeley)]

[Ristè et al., PRL 2012 (Delft)]

[Campagne-Ibarcq et al., PRX 2013 (ENS Paris)]

...now standard technique

based on fluorescence

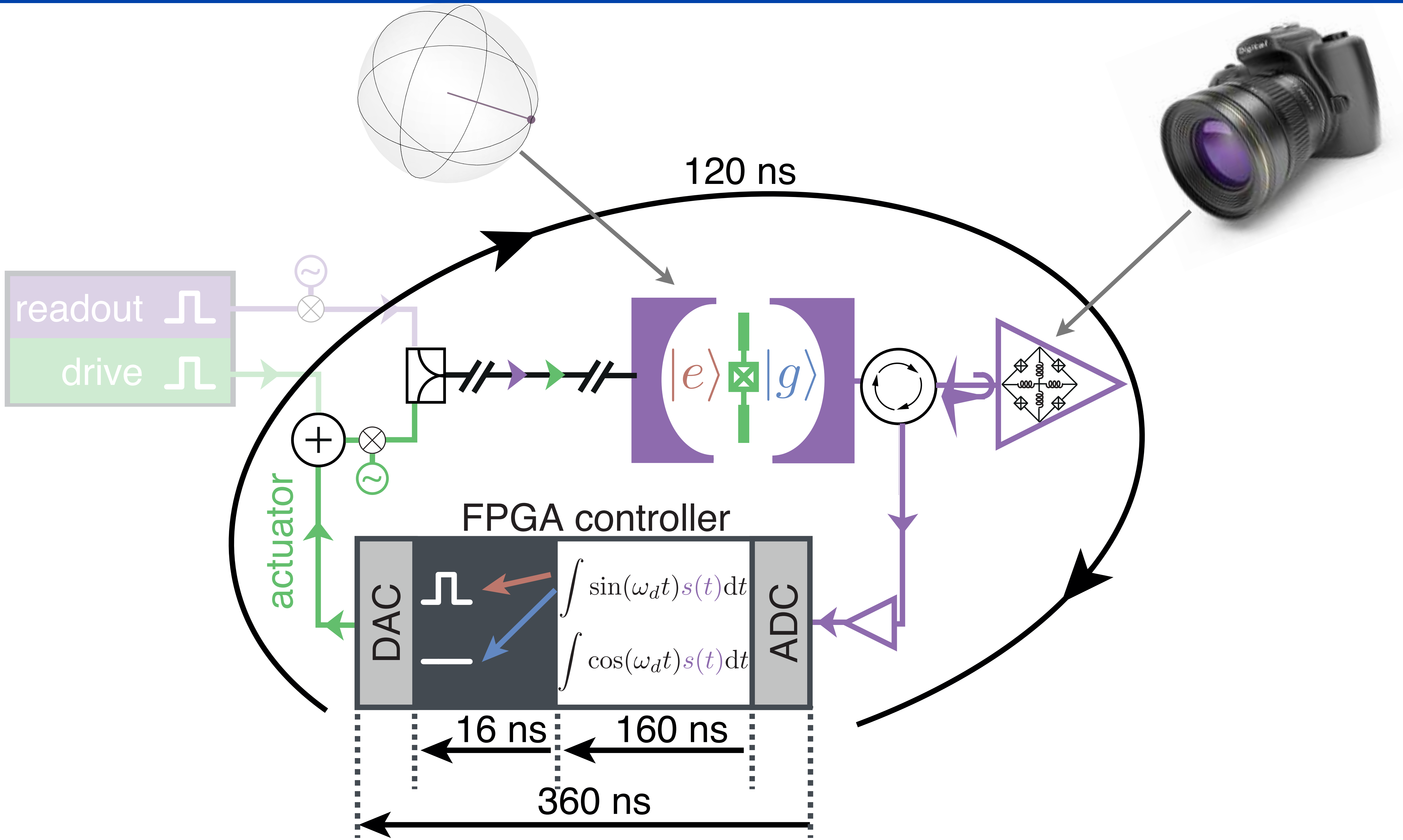


compatible with dispersive feedback

converges in T1 for any state

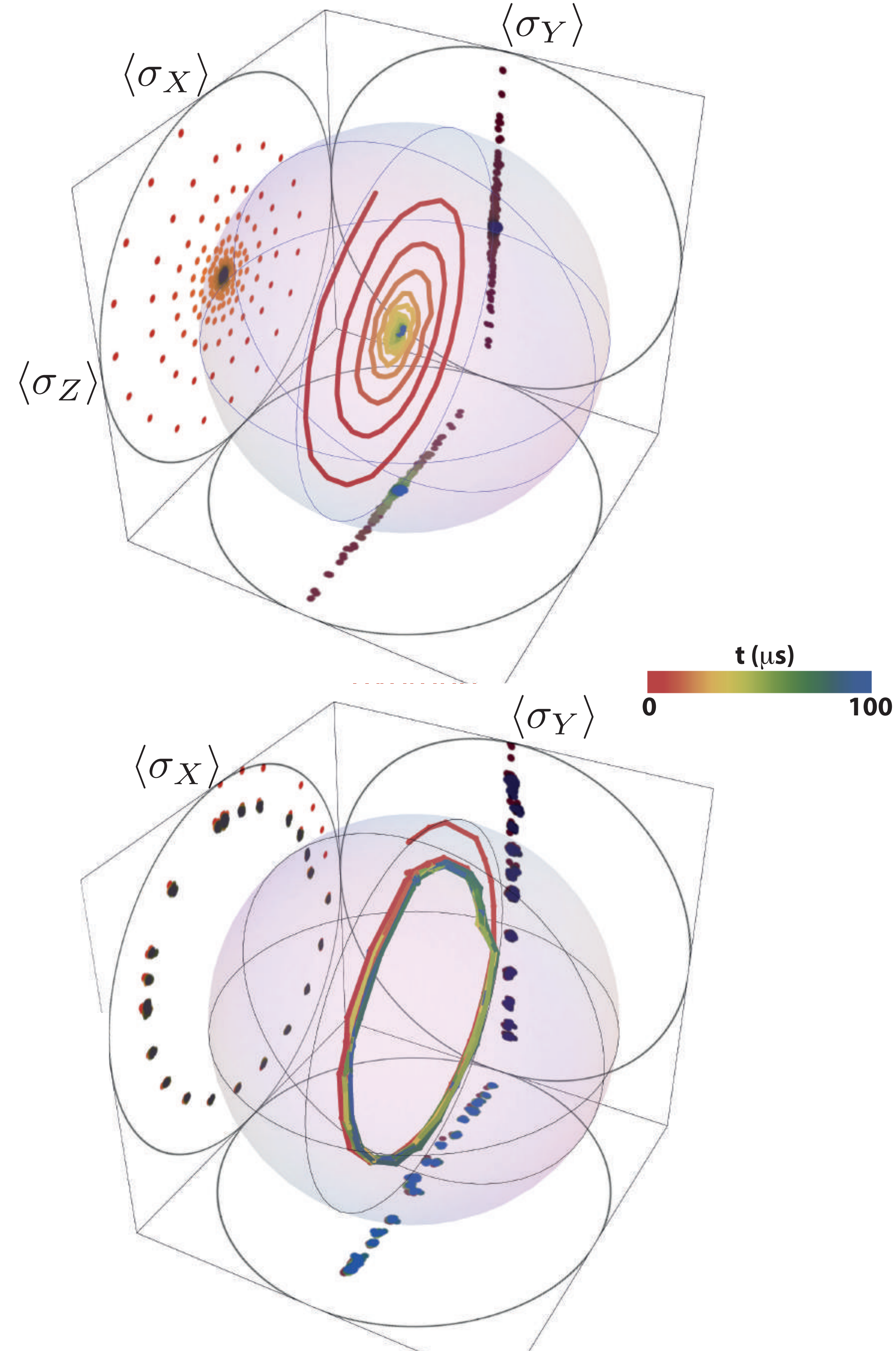
here continuous feedback qualitatively more efficient than stroboscopic

Measurement based feedback



[Campagne-Ibarcq et al., PRX 2013]

Measurement based feedback



Stabilization of Rabi and Ramsey oscillations

[Campagne-Ibarcq et al., PRX 2013 (ENS Paris)]

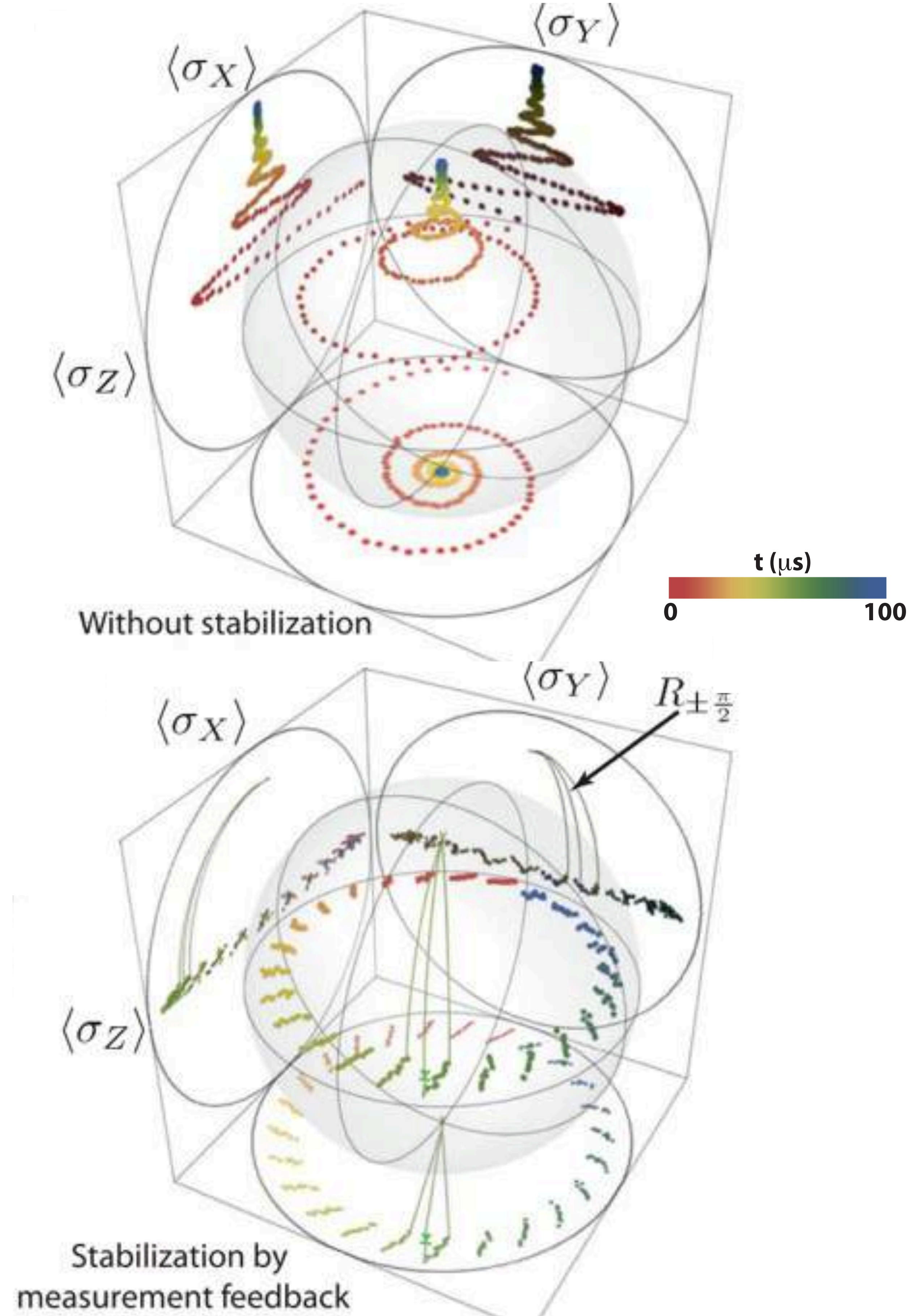
77% average Bloch vector length
vs 45% in constant measurement strength
[Vijay et al., Nature 2012 (Berkeley)]

Reset by feedback

[Ristè et al., PRL 2012 (Delft)]

Measurement based feedback

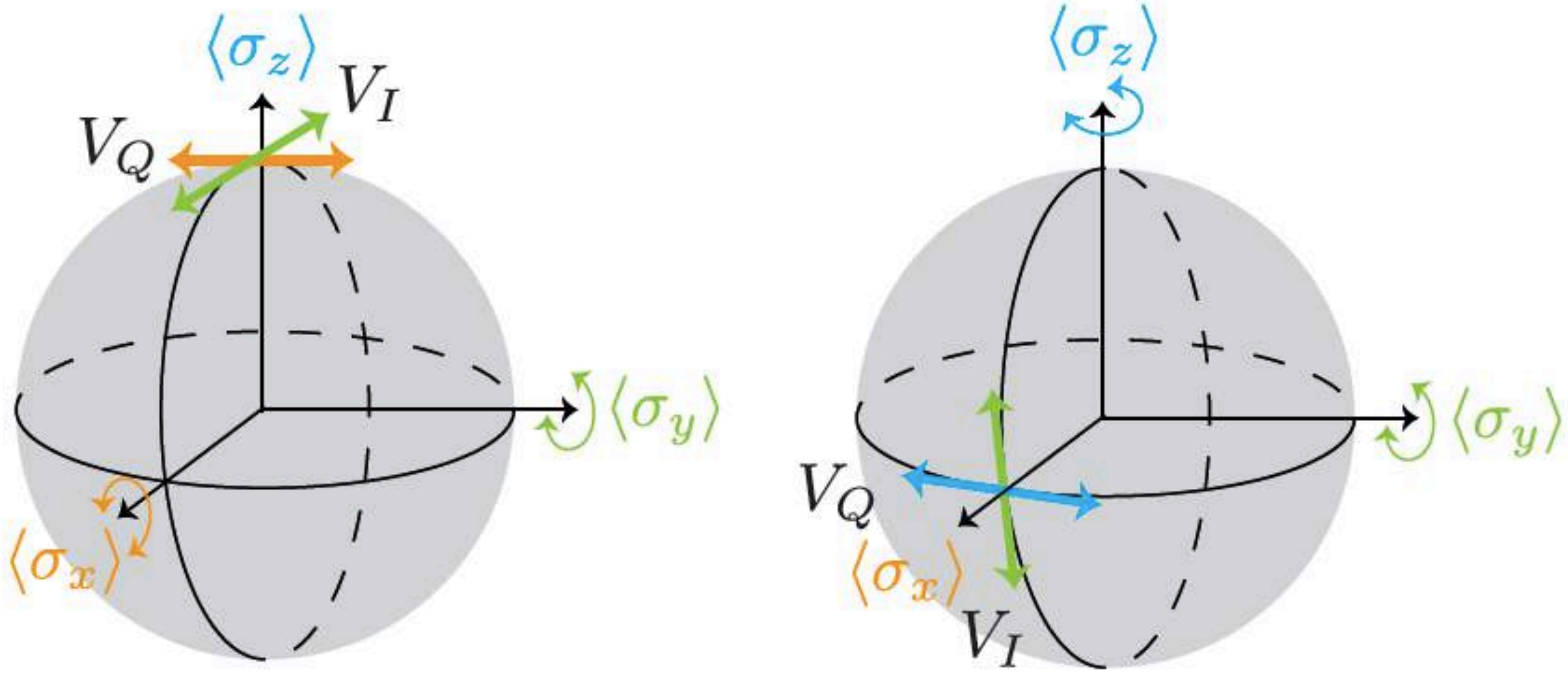
Stabilization of Rabi and Ramsey oscillations
[Campagne-Ibarcq et al., PRX 2013 (ENS Paris)]



Fluorescence based feedback

stabilize target $\cos\frac{\theta}{2}|e\rangle + \sin\frac{\theta}{2}e^{i\varphi}|g\rangle$

compensate stochastic kicks due to fluorescence?



use 3 rotation axes and Markovian feedback

[Campagne-Ibarcq *et al.*, PRL (2016)]

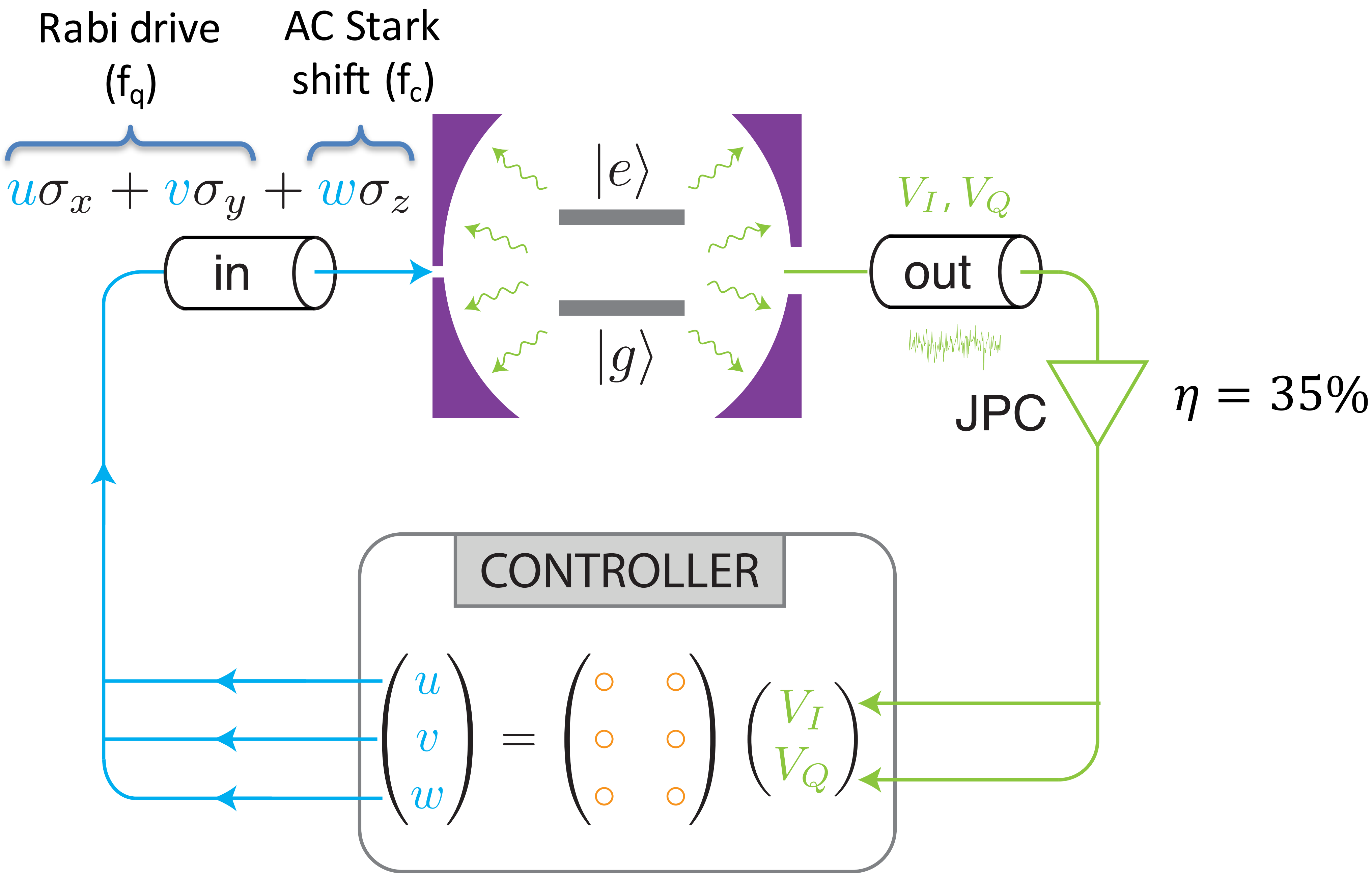
previous proposals

south hemisphere only [Hofmann, Mahler, Hess, PRA (1998)]

every state but equator [Wang, Wiseman, PRA (2001)]

Fluorescence based feedback

stabilize target $\cos\frac{\theta}{2}|e\rangle + \sin\frac{\theta}{2}e^{i\varphi}|g\rangle$



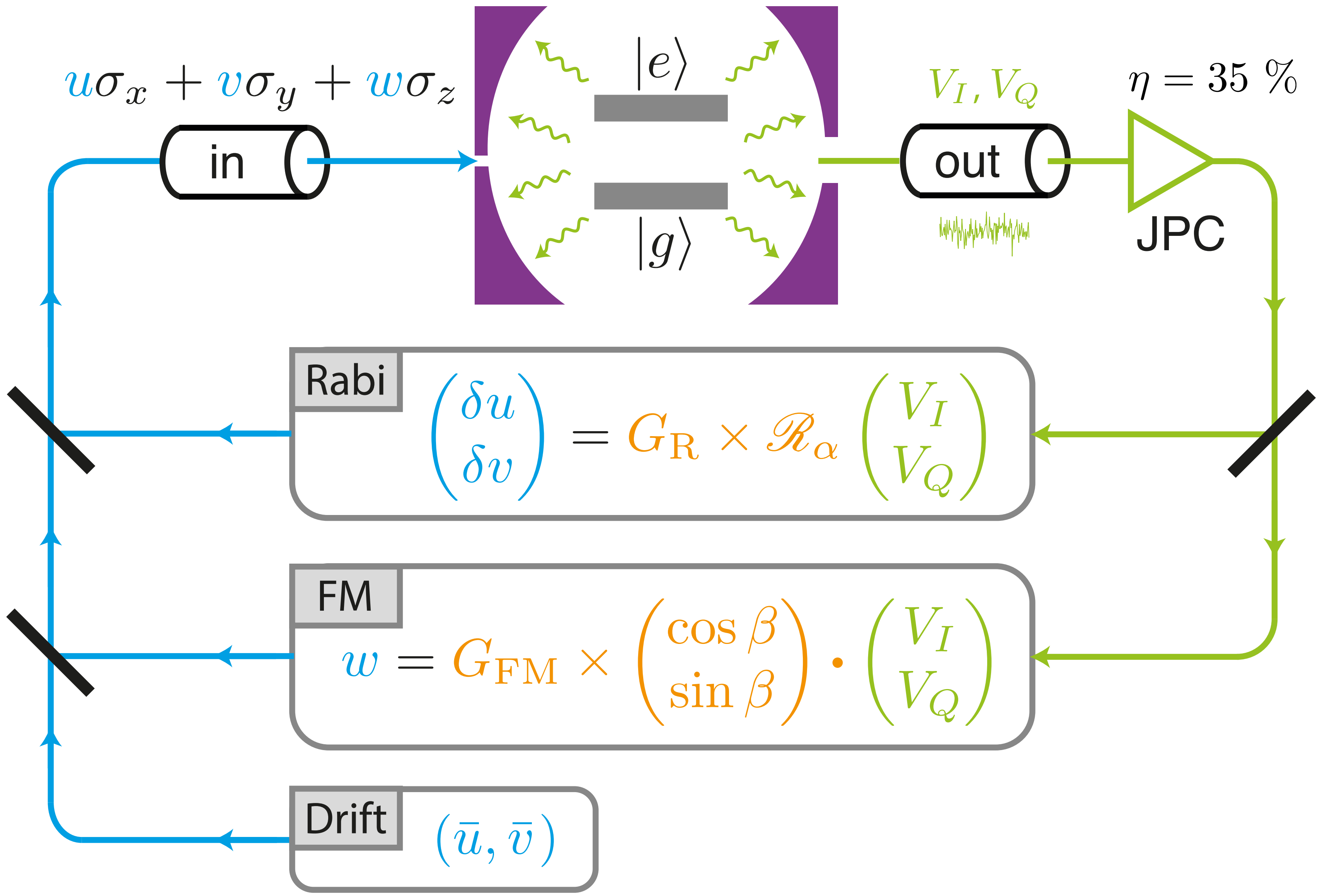
multi inputs and multi output Markovian feedback

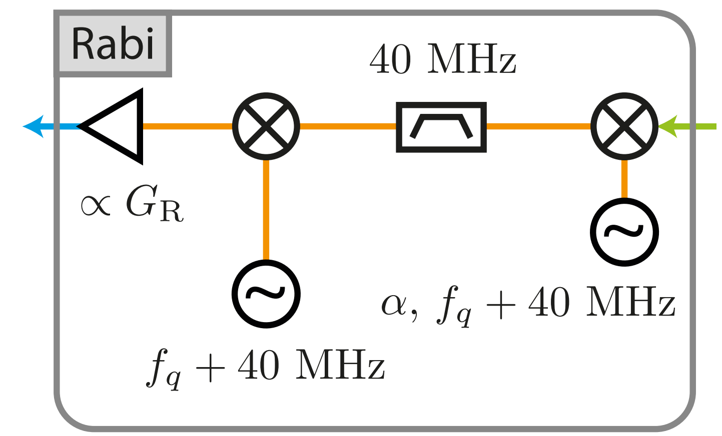
[Campagne-Ibarcq *et al.*, PRL (2016)]

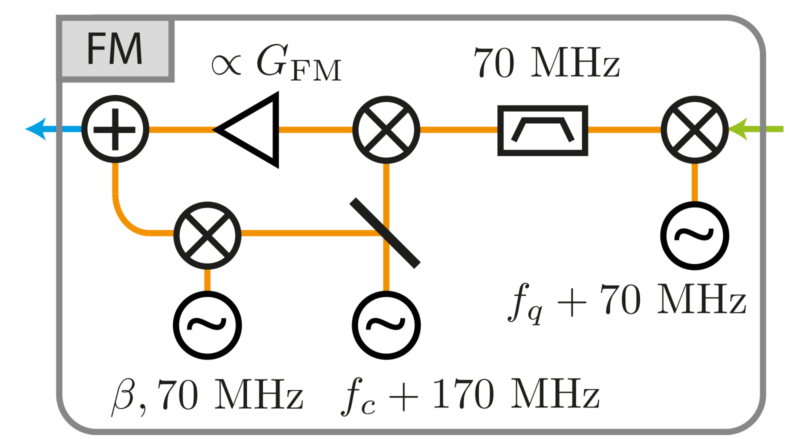
Fluorescence based feedback

stabilize target $\cos\frac{\theta}{2}|e\rangle + \sin\frac{\theta}{2}e^{i\varphi}|g\rangle$

$$
\begin{cases}
G_R = \sqrt{\frac{\gamma_1}{8\eta}}\,(1+\cos\theta)\,, & \alpha = \pi/2 \\
G_{FM} = \sqrt{\frac{\gamma_1}{8\eta}}\,\sin\theta, & \beta = \varphi - \pi/2 \\
-\frac{\bar{u}}{\sin\varphi} = \frac{\bar{v}}{\cos\varphi} = \frac{\gamma_1}{8\eta}\,(\cos\theta - \eta)\sin\theta &
\end{cases}
$$





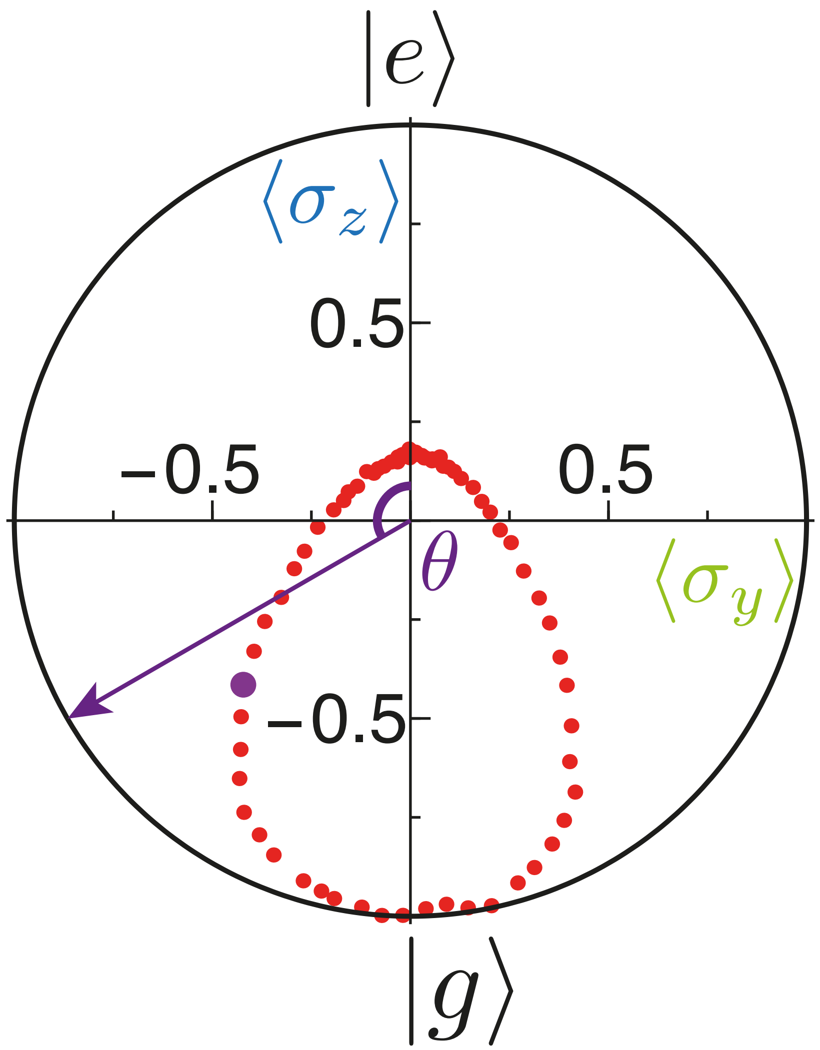


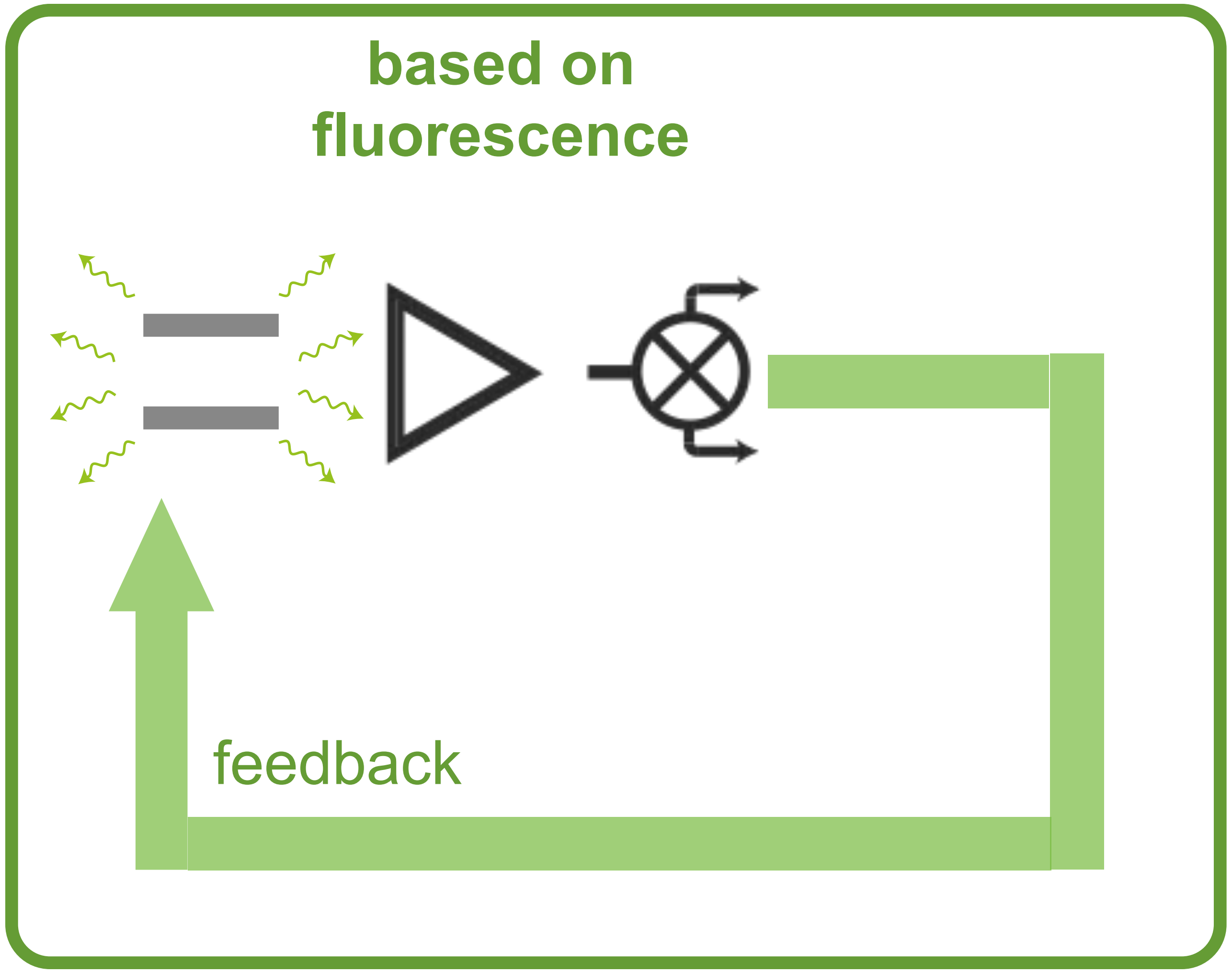
[Campagne-Ibarcq *et al.*, PRL (2016)]

Fluorescence based feedback

stabilize target $\cos\frac{\theta}{2}|e\rangle + \sin\frac{\theta}{2}e^{i\varphi}|g\rangle$

Stabilization of any state





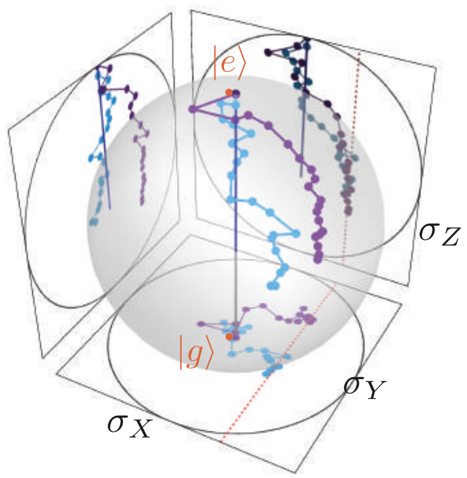
continuous measurement based feedback
with **multi inputs and multi outputs**
in the quantum regime

[Campagne-Ibarcq *et al.*, PRL (2016)]

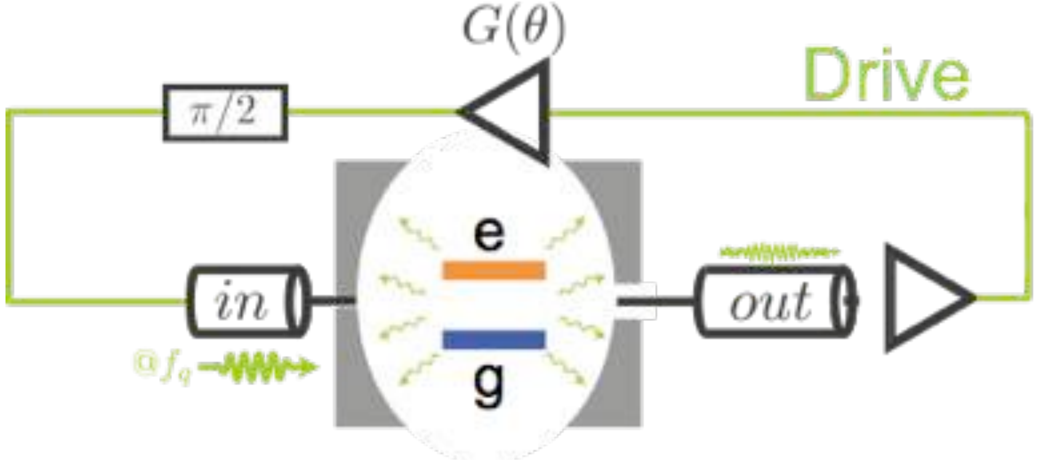
Conclusion

Superconducting circuits are a testbed for
quantum measurement backaction

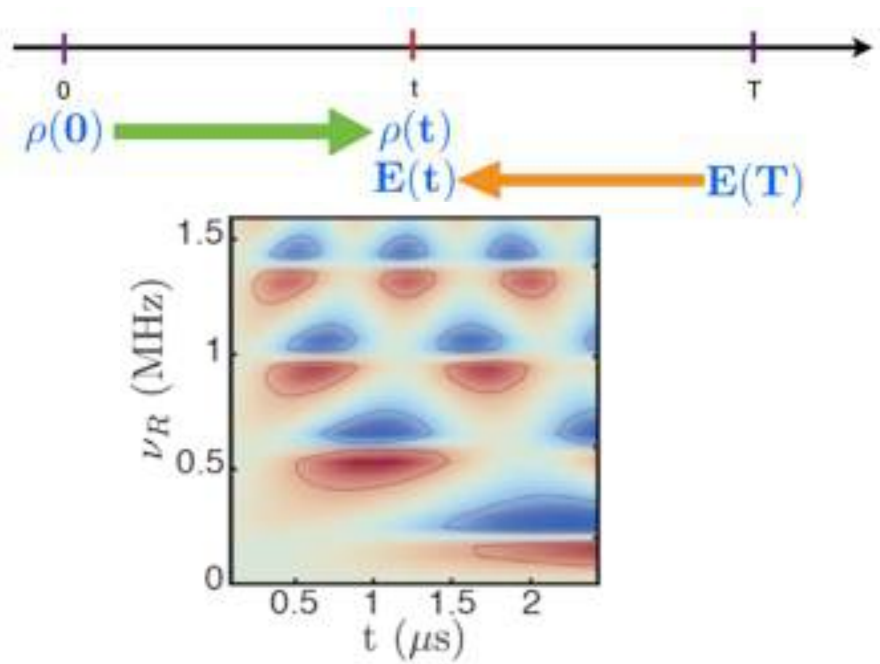
quantum trajectories



feedback

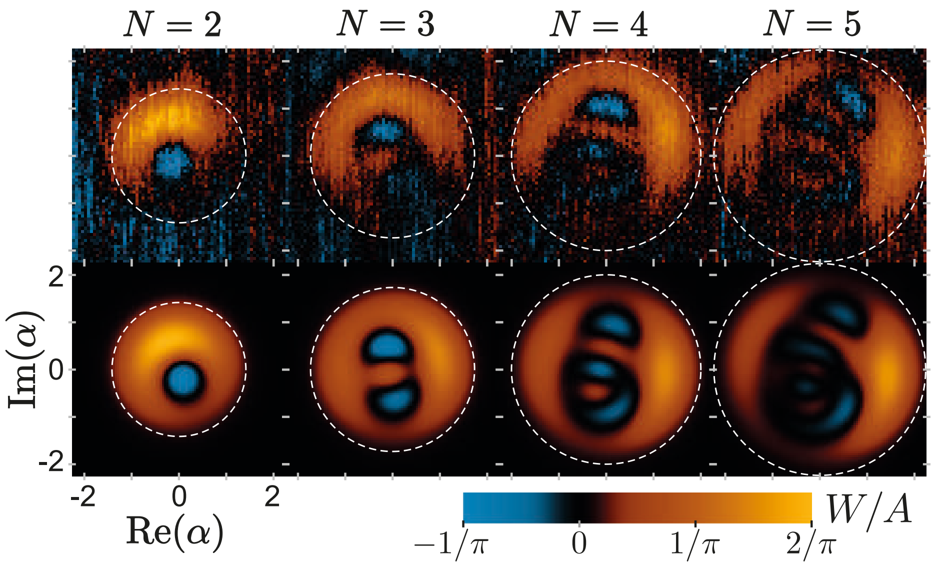


post-selection and quantum states



[Campagne-Ibarcq et al., PRL 2013]

quantum Zeno dynamics

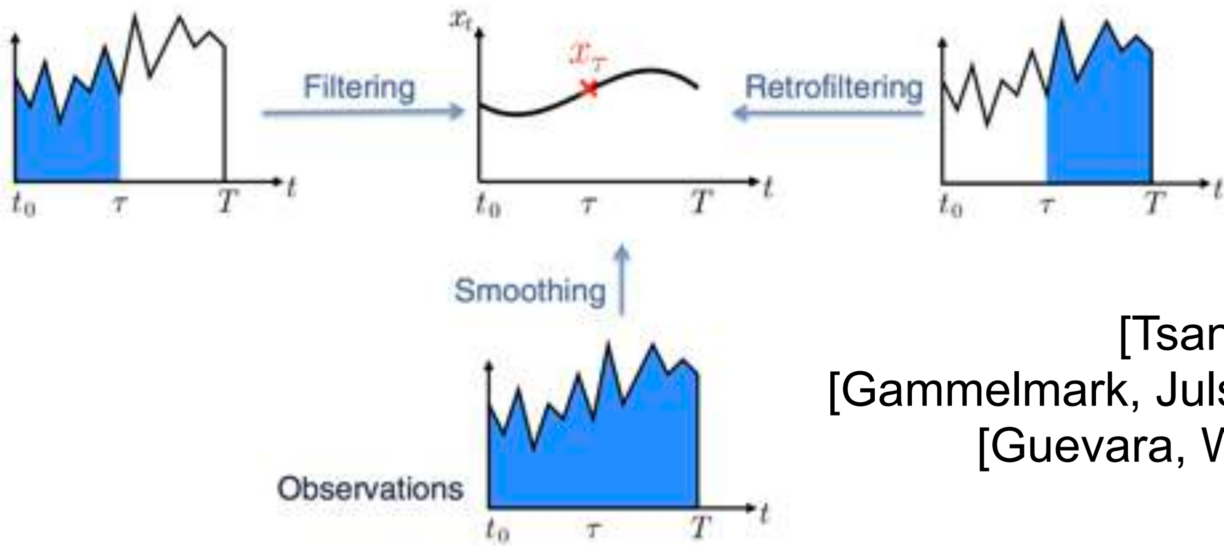


[Bretheau et al., Science 2016]

also: entanglement by measurement, link with thermodynamics...

Perspectives

quantum smoothing



[Tsang, PRL 2009]
[Gammelmark, Julsgaard, Mølmer, PRL 2013]
[Guevara, Wiseman, PRL 2015]

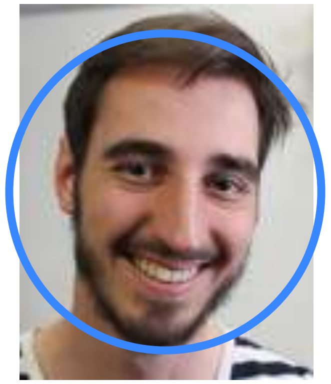
statistics of postselected outcomes

higher dimension

Quantum Circuit group


Zaki Leghtas


Sébastien Jezouin (now at Sherbrooke)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Quentin Ficheux


Danijela Markovic


Théau Peronnin


Raphaël Lescanne


Philippe Campagne-Ibarcq (now at Yale)


Landry Bretheau (now at MIT)

Quantic - Theory

Pierre Six


Joachim Cohen


Rémi Azouit


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Pierre Rouchon


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We are looking for postdocs!