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Olomouc

Quantum nonlinearities induced in an oscillator

Radim Filip, **Petr Marek, Kimin Park, LukášLachman, Lukáš Slodička**

Department of Optics, Faculty of Science, Palacky University, Olomouc

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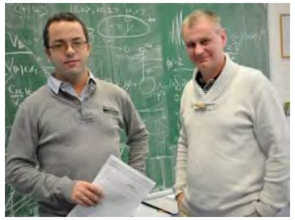








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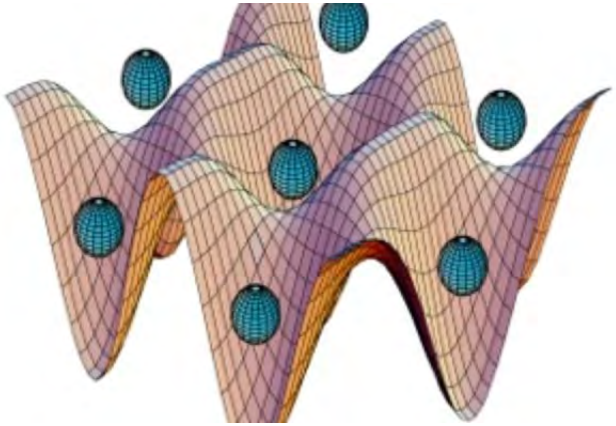
QUANTUM NONLINEAR DYNAMICS

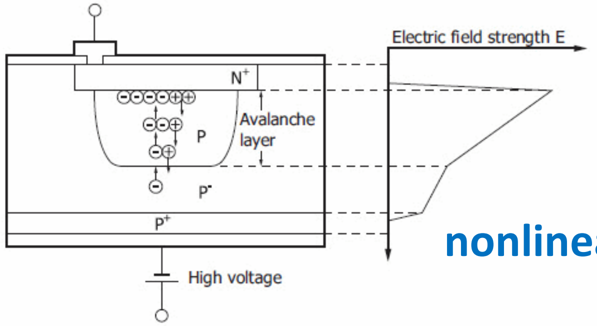
analog quantum simulators

I.H. Deutsch, Scientific American (2015)



quantum metrology

APD structure

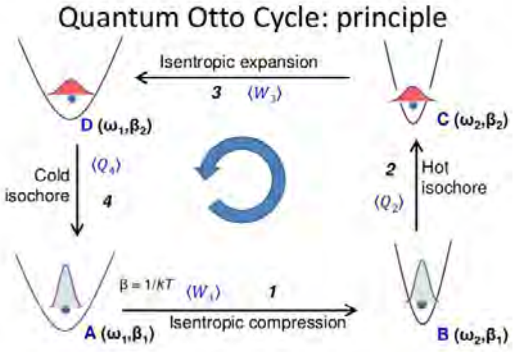


nonlinear

Laszlo Ruppert (poster)

analog quantum engines

J. Millen, A. Xuereb, NJP (2016)



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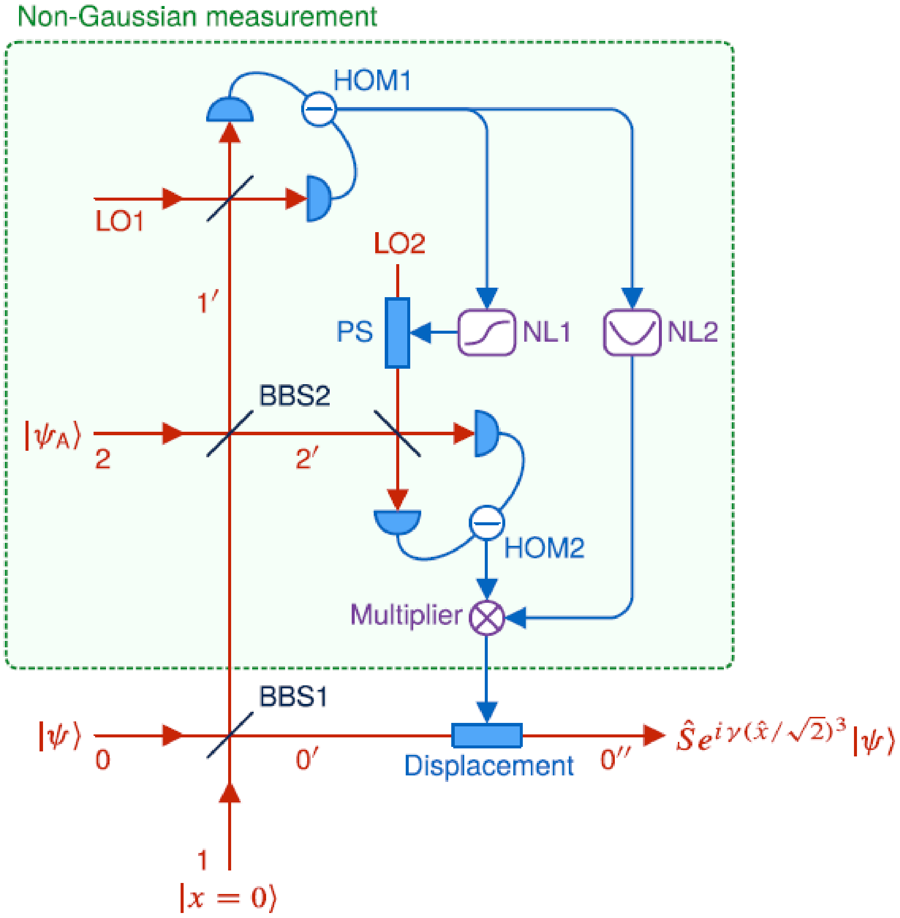
DETERMINISTIC CUBIC NONLINEARITY

$$\hat{U} = e^{i\gamma\hat{x}^3} \qquad \hat{x}' = \hat{x}, \quad \hat{p}' = \hat{p} + 3\gamma\hat{x}^2$$

D. Gottesman, A. Kitaev, J. Preskill, "Encoding a qubit in an oscillator", Phys. Rev. A 64, 012310 (2001)



- adaptive measurement strategy
- nonlinear feedforward control
- fast time-resolved regime

$$\hat{x}_0'' = \frac{1}{\sqrt{2}}\hat{x}_0 - \frac{1}{\sqrt{2}}\hat{x}_1,$$

$$\hat{p}_0'' = \sqrt{2}\left(\hat{p}_0 + \frac{3\gamma}{2\sqrt{2}}\hat{x}_0^2\right) + (\hat{p}_2 - 3\gamma\hat{x}_2^2) + 3\gamma\left(\hat{x}_0\hat{x}_1 + \frac{1}{2}\hat{x}_1^2\right)$$

mode 1

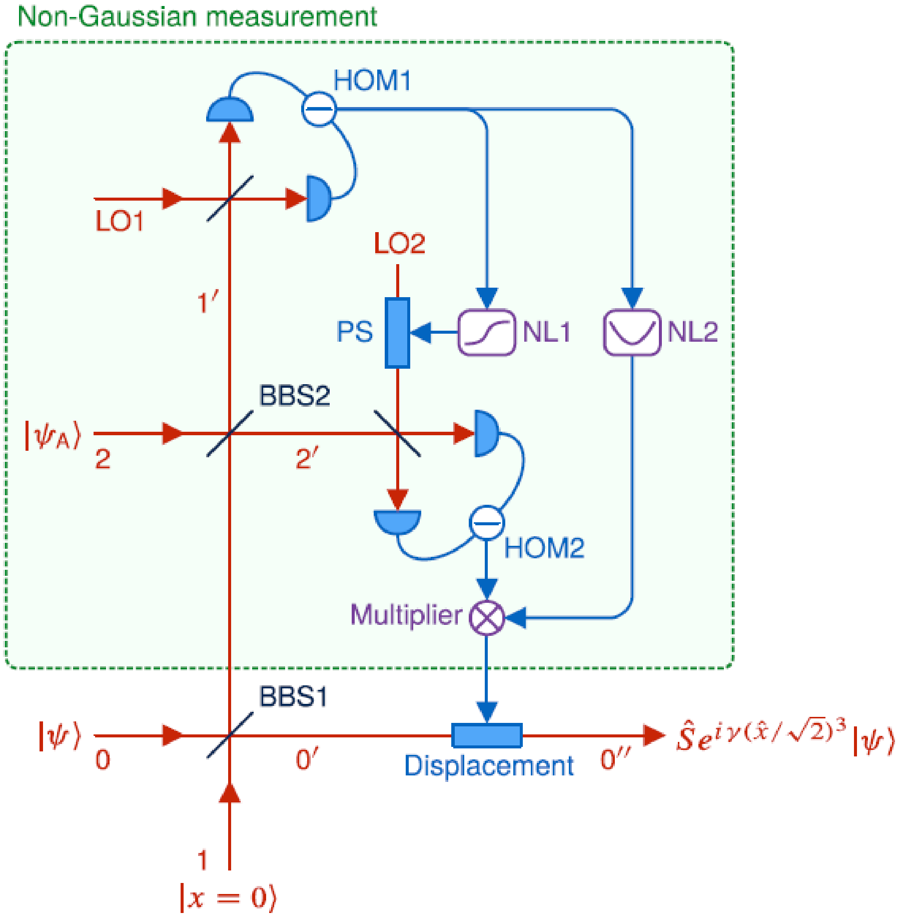
mode 0

mode 2

mode 1

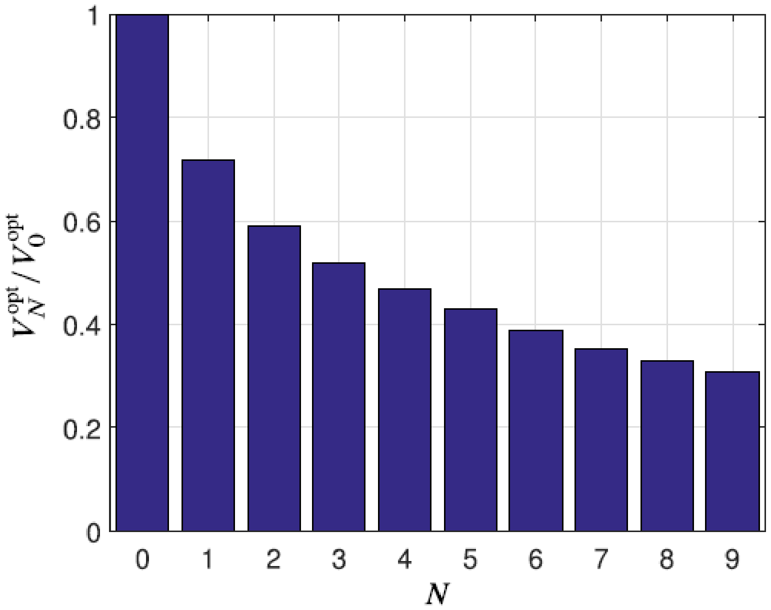
K. Miyata, H. Ogawa, P. Marek, R. Filip, H. Yonezawa, J. Yoshikawa, and A. Furusawa, Phys. Rev. A 93, 022301 (2016).

DETERMINISTIC CUBIC NONLINEARITY



- cubic states

variance of added noise



N-photon superposition for ancilla $|\psi_A>$

K. Miyata, H. Ogawa, P. Marek, R. Filip, H. Yonezawa, J. Yoshikawa, and A. Furusawa, Phys. Rev. A 93, 022301 (2016).

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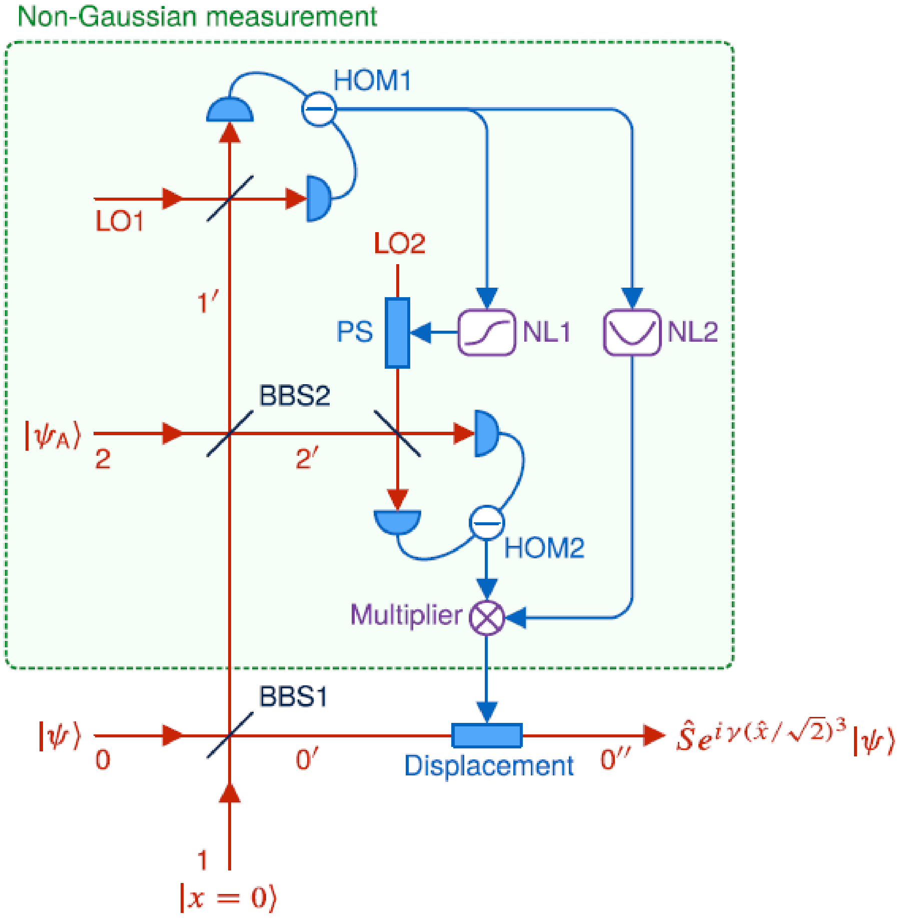
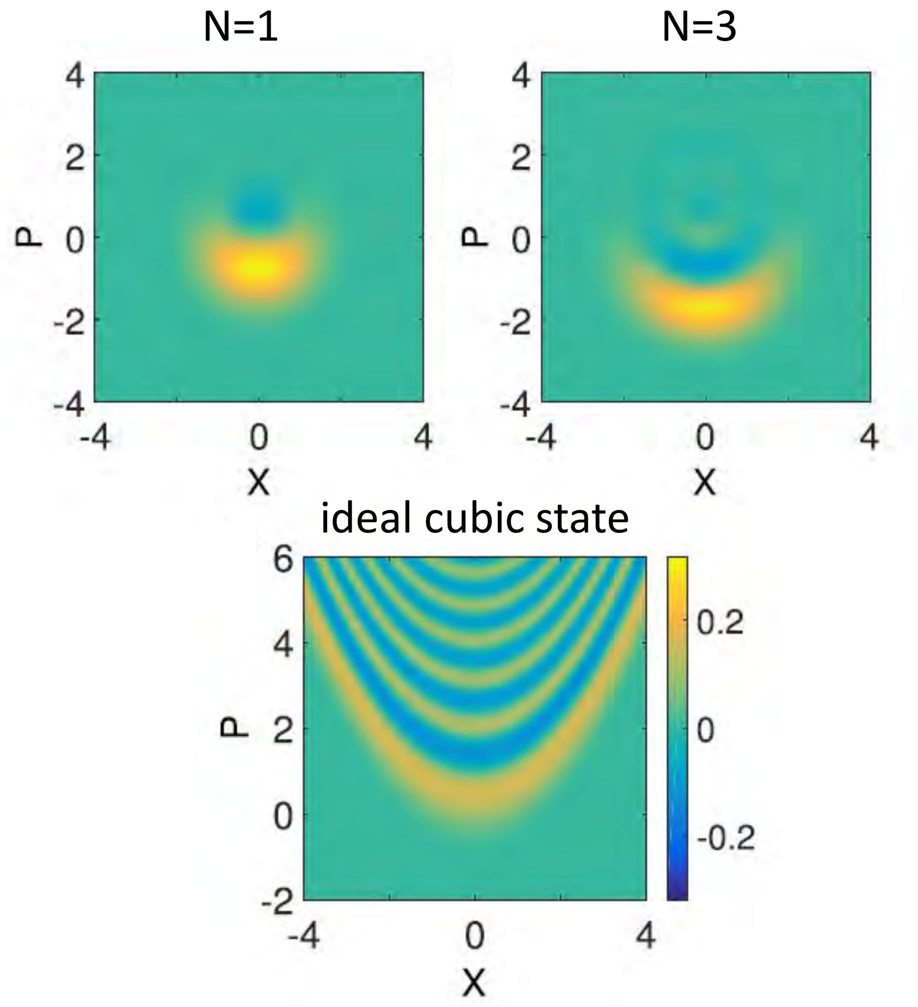
DETERMINISTIC CUBIC NONLINEARITY

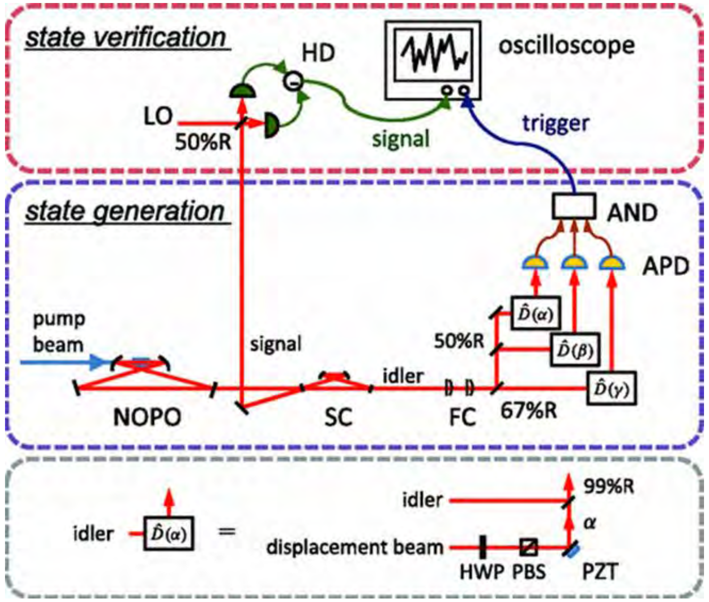
K. Miyata, H. Ogawa, P. Marek, R. Filip, H. Yonezawa, J. Yoshikawa, and A. Furusawa, Phys. Rev. A 93, 022301 (2016).

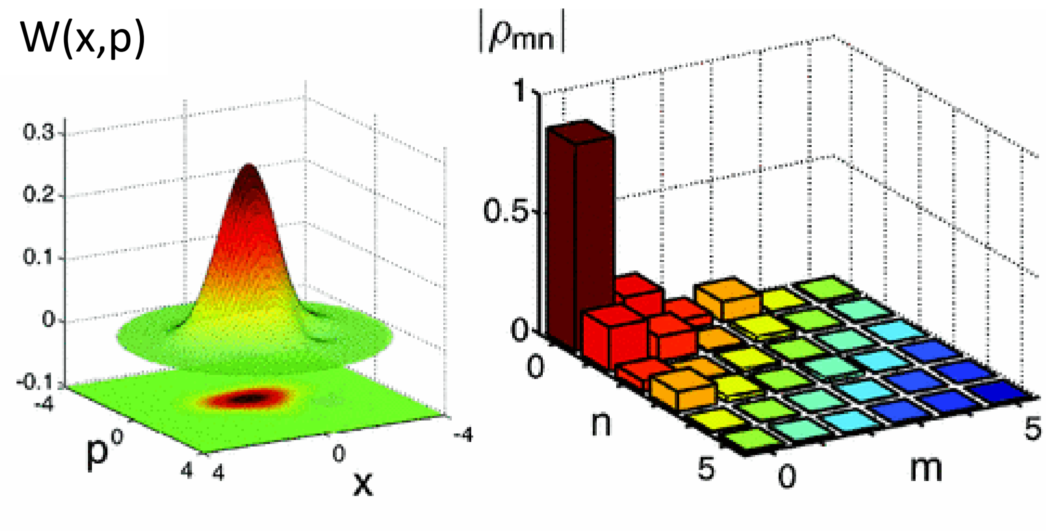


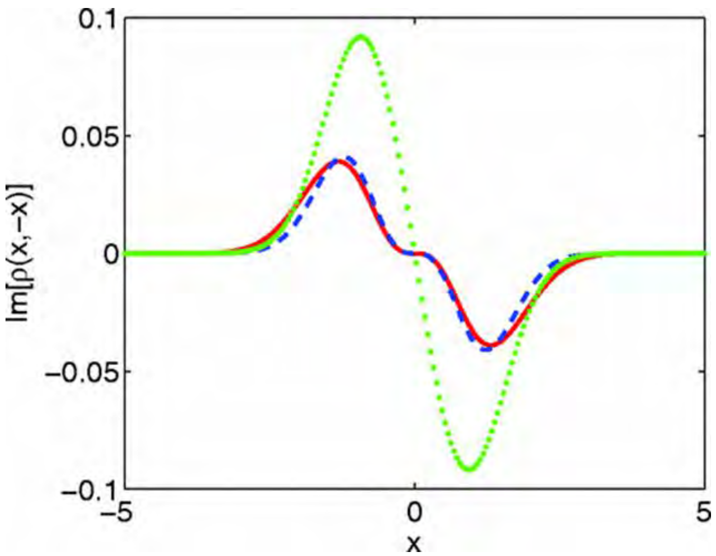


ALL OPTICAL PREPARATION

$$|0\rangle + \chi' \frac{3}{2\sqrt{2}} |1\rangle + \chi' \frac{\sqrt{3}}{2} |3\rangle$$







χ=0.090

M. Yukawa, K. Miyata, H. Yonezawa, P. Marek, R. Filip, and A. Furusawa, Phys. Rev. A 88, 053816 (2013).

ALL OPTICAL PREPARATION

$$U(\hat{X},\tau) = \sum_{k=0}^{\infty} \frac{U^{(k)}(\bar{X})}{k!}(\hat{X} - \bar{X})^k$$

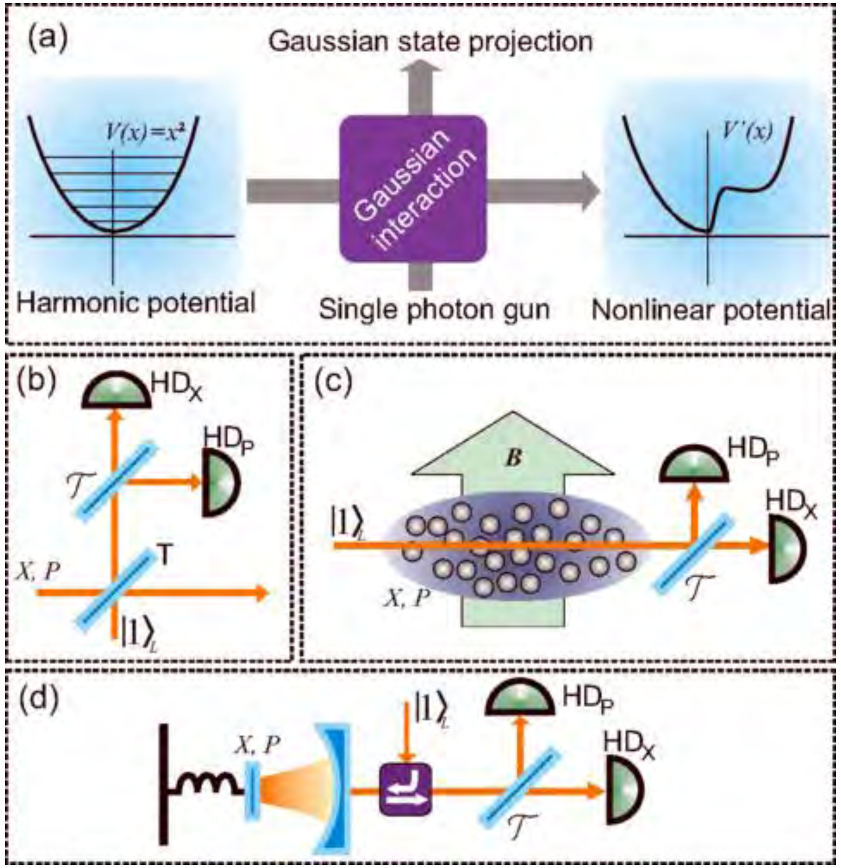
$$U(\hat{X},\tau) = \prod_{k=0}^{N}(1 + \lambda_k \hat{X})$$ X-gates

$$\exp[i\chi\hat{X}^3] \approx 1 + i\chi\hat{X}^3 - \frac{\chi^2}{2}\hat{X}^6 \propto$$

$$(1 - (\tfrac{\chi}{-1+i})^{1/3}\hat{X})(1 + (\tfrac{\chi}{1-i})^{1/3}\hat{X})$$

$$(1 - (-1)^{-2/3}(\tfrac{\chi}{-1+i})^{1/3}\hat{X})(1 - (\tfrac{\chi}{1+i})^{1/3}\hat{X})$$

$$(1 + (\tfrac{\chi}{-1-i})^{1/3}\hat{X})(1 - (-1)^{-2/3}(\tfrac{\chi}{1+i})^{1/3}\hat{X})$$



Kimin Park, Petr Marek, and Radim Filip, Phys. Rev. A 90, 013804 (2014).

LIGHT-ATOM PREPARATION

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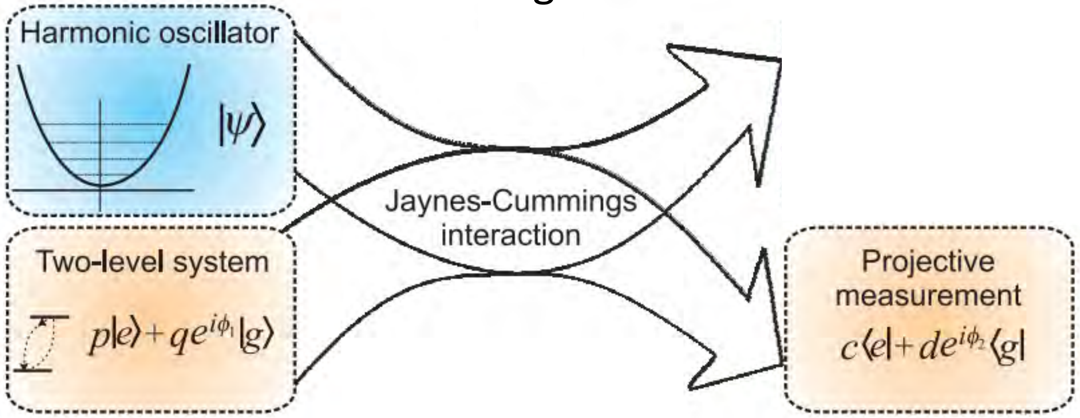
Jayness-Cummings interaction:

$$e^{i\chi\hat{x}^3} \approx \hat{O}_{\rm trig}^{(n_1\otimes n_2)}(\hat{X};t)$$
$$= \left(1 + i\left(\frac{(1+i\lambda\hat{X}/n_2)^{n_2} - (1-i\lambda\hat{X}/n_2)^{n_2}}{2i}\right)^3\right)^{n_1}$$

atomic X-gates

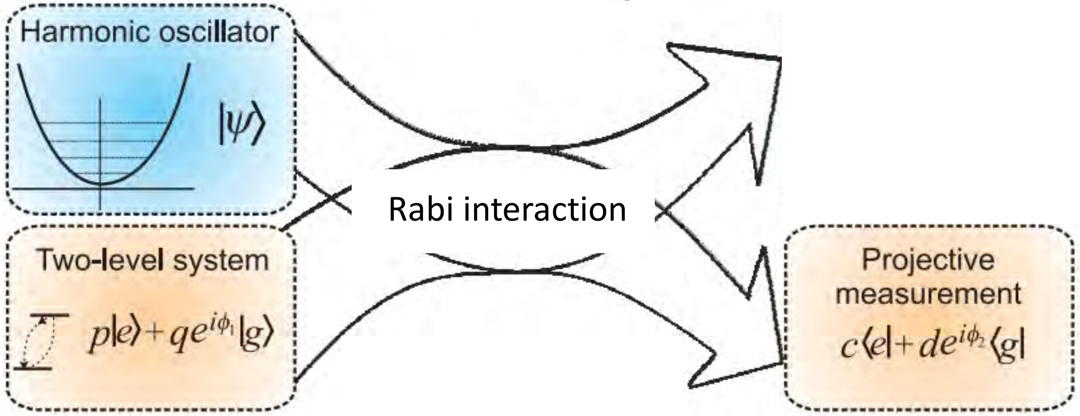


K. Park, P. Marek, and R. Filip, Phys. Rev. A 94, 012332 (2016)

Rabi interaction:

$$e^{i\chi\hat{x}^3} = \sum_{k=0}^{N} \frac{\{-i\sin^3[(zt)^{1/3}\hat{X}]\}^k}{z^k k!}$$

atomic Sin(X)-gates



K. Park, P. Marek, and R. Filip, Phys. Rev. A 94, 062308 (2016)

TRAPPED ION EXPERIMENTS

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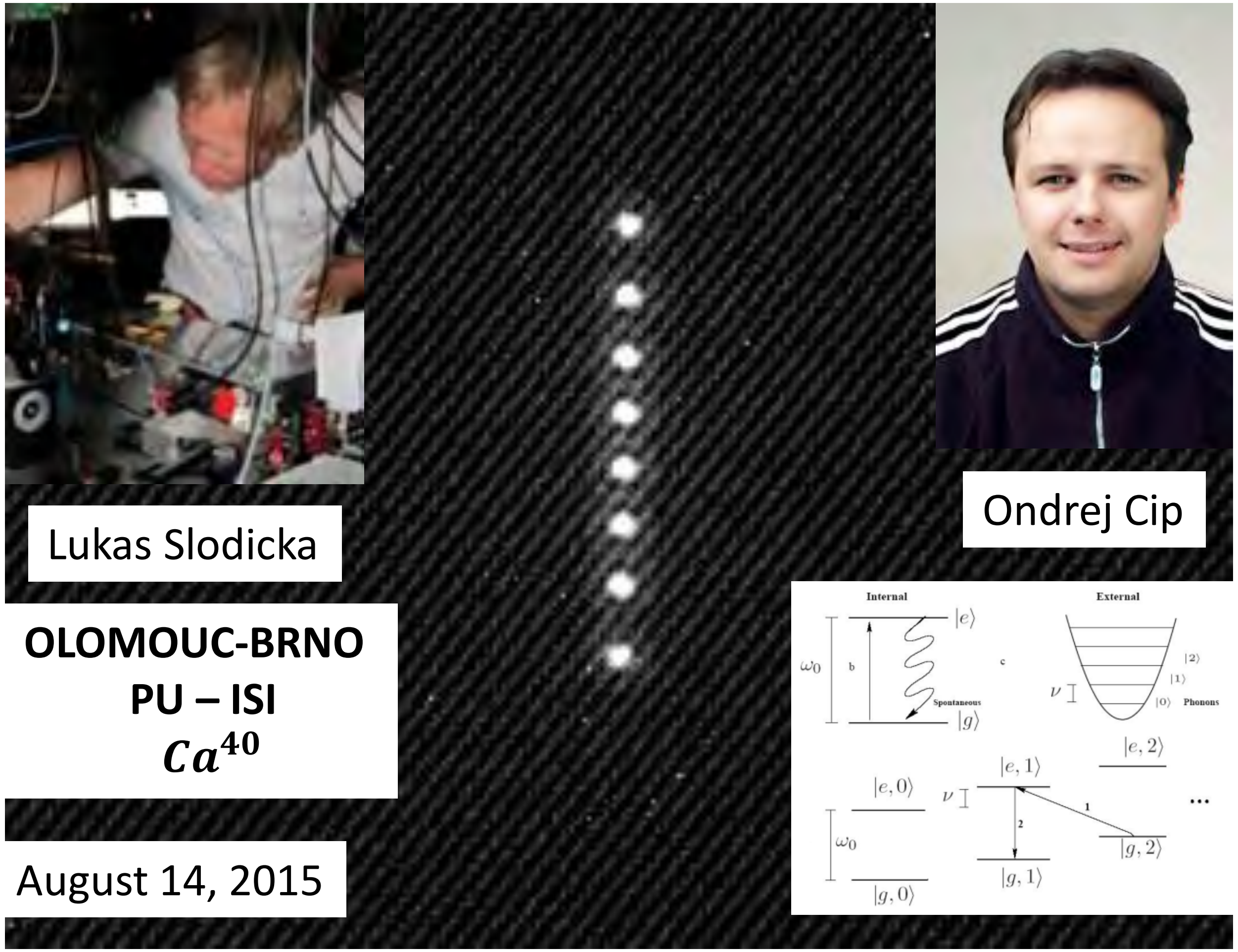

DETERMINISTIC NONCLASSICALITY

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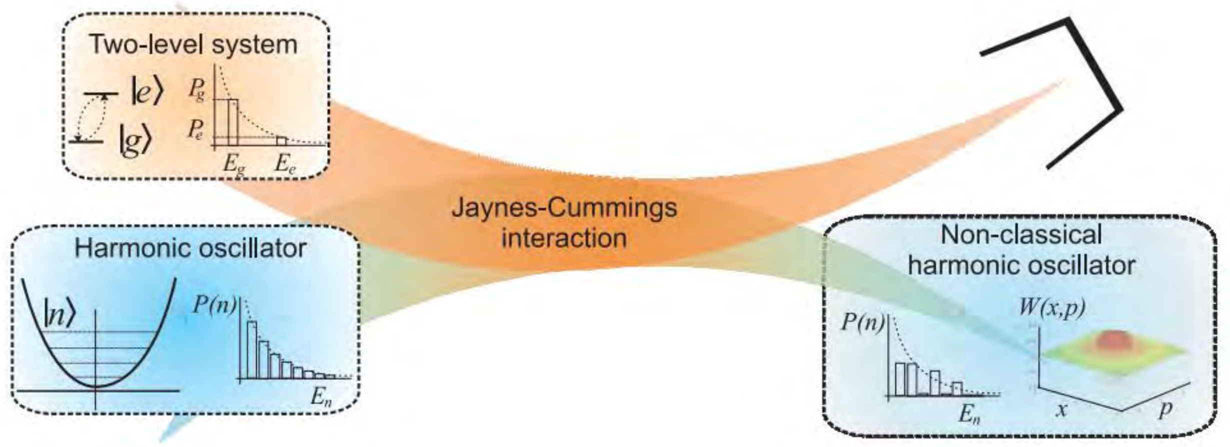
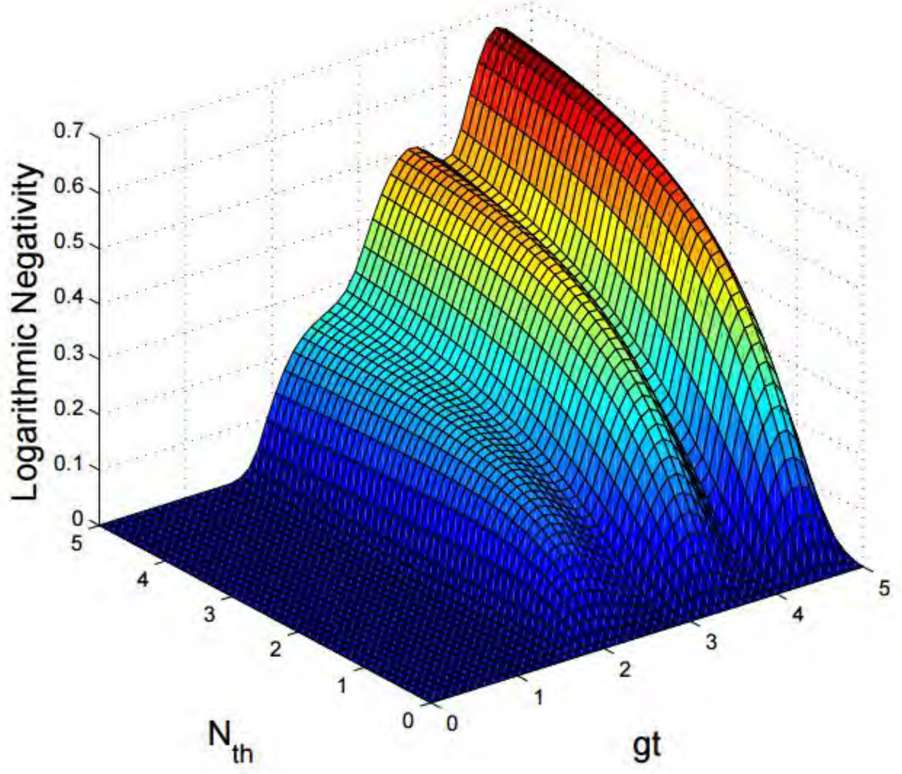
Energy-conserving resonant J-C interaction

$$\hbar g(\sigma_+ a + a^\dagger \sigma_-)$$



Entanglement potential



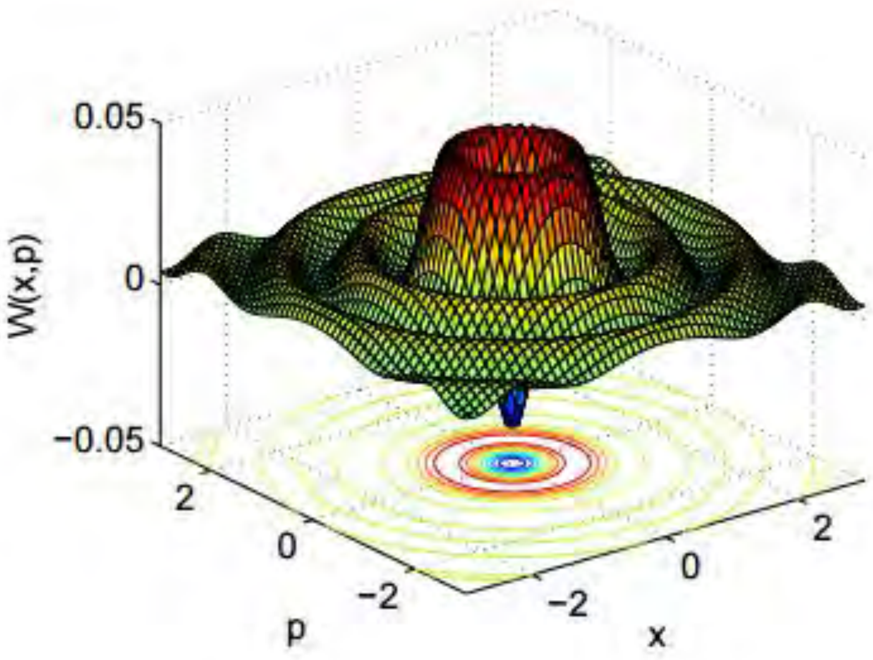
$$LN(\rho_{split}) = \log_2 ||\rho_{split}^{PT}||$$

L. Slodička, P. Marek and R. Filip, Optics Express 24, 7858 (2016)

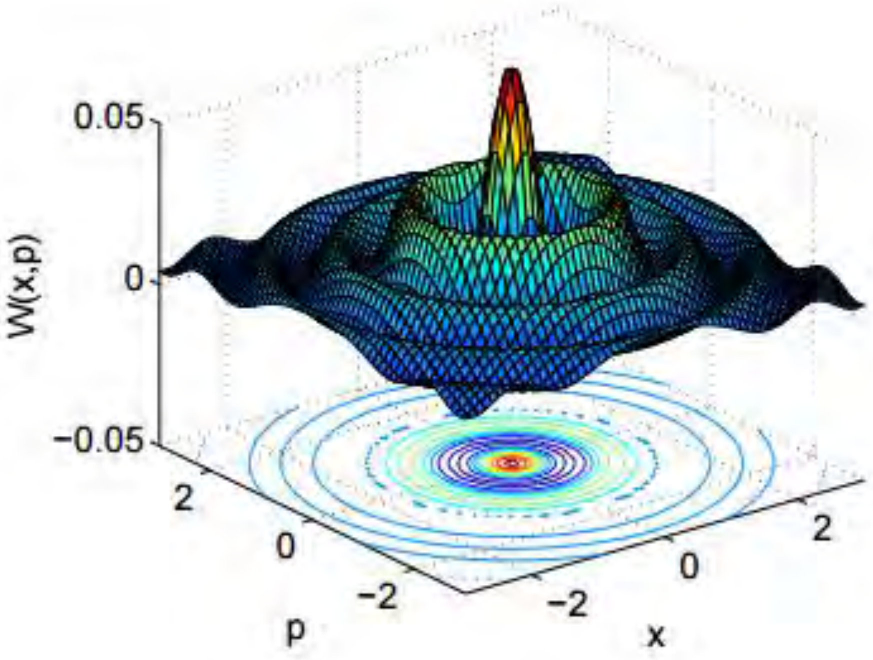
P. Marek, L. Lachman, L. Slodička, and R. Filip, Phys. Rev. A 94, 013850 (2016).

DETERMINISTIC NONCLASSICALITY

Negative Wigner function:



$\bar{n} = 10, gt = 5.5$



$\bar{n} = 10, gt = 2\pi$

L. Slodička, P. Marek and R. Filip, Optics Express 24, 7858 (2016)

P. Marek, L. Lachman, L. Slodička, and R. Filip, Phys. Rev. A 94, 013850 (2016)

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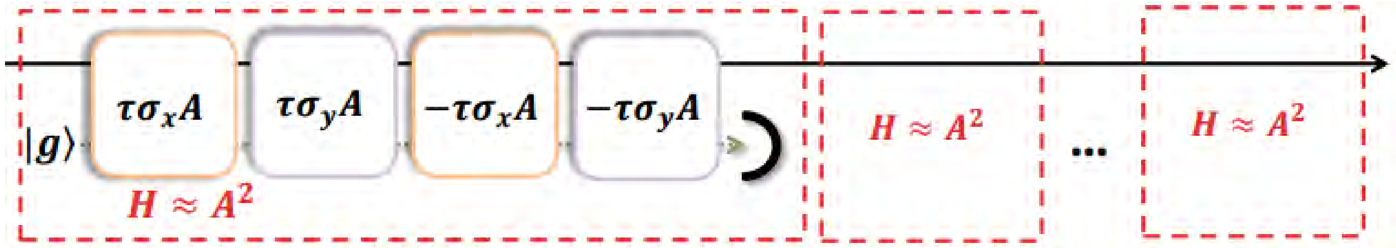
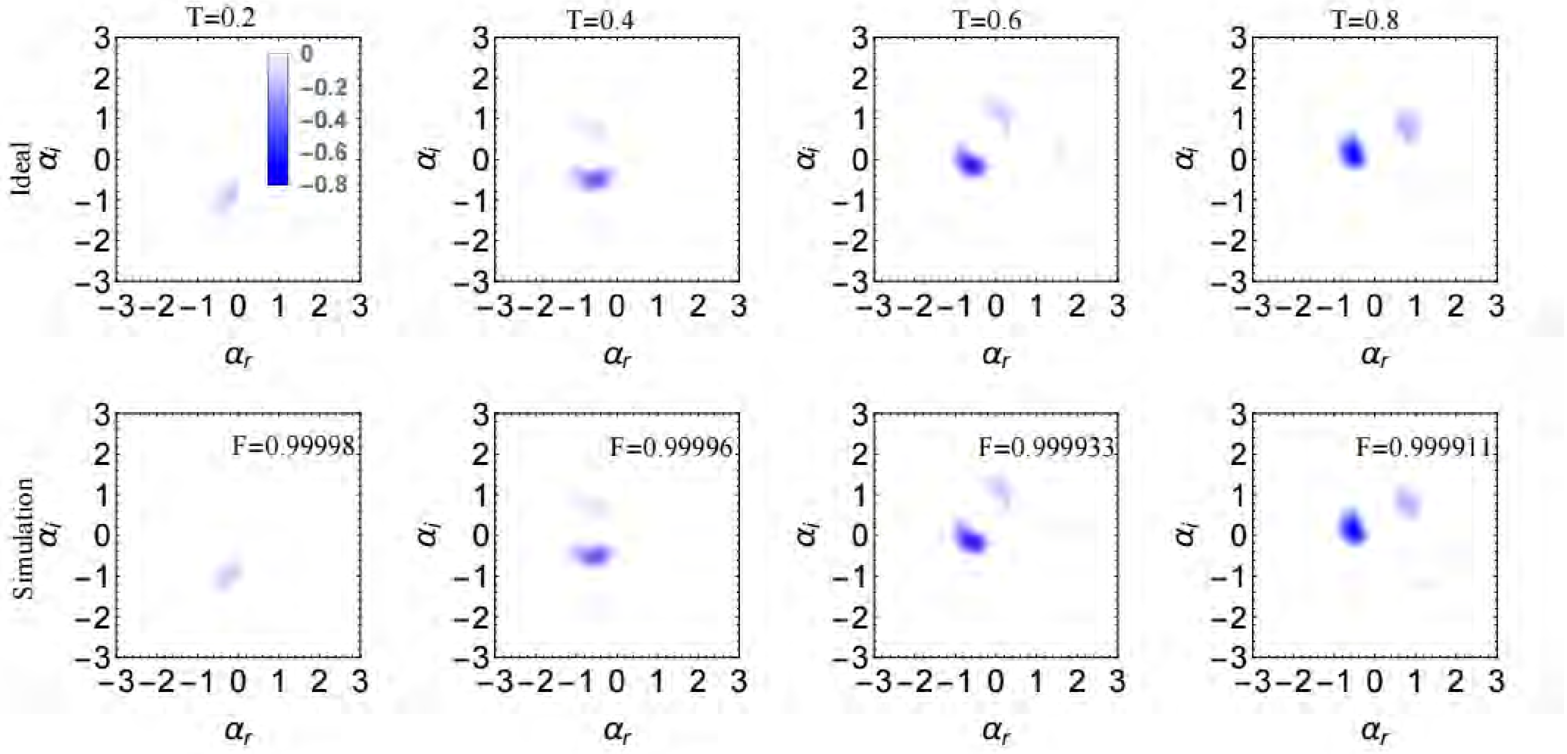
DETERMINISTIC NONLINEARITY



- deterministic without measurement
- many rounds with pulsed control
- we can already use dispersive and Rabi coupling

KERR EFFECT

(dispersive)



K. Park, P. Marek, and R. Filip, Deterministic nonlinear gates with oscillators mediated by a qubit, submitted.

DETERMINISTIC NONLINEARITY

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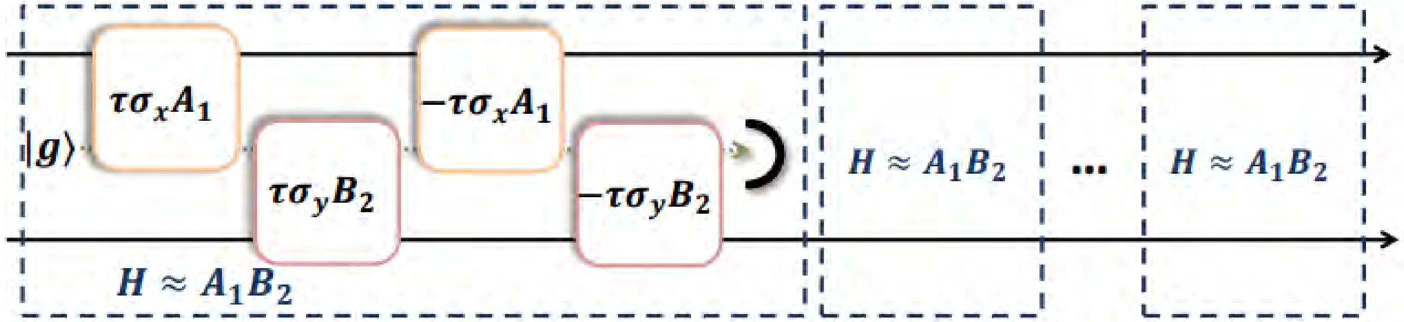
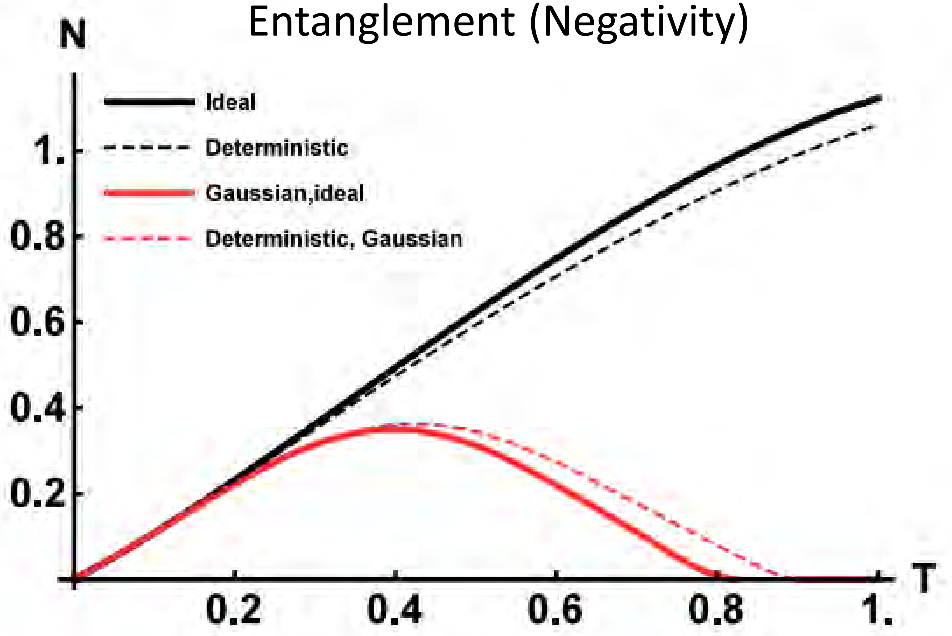


- deterministic without measurement
- many rounds with pulsed control
- we can already use dispersive and Rabi coupling

CROSS-KERR EFFECT

(dispersive)

Entanglement (Negativity)



Circuit QED:
S. Krastanov, V. V. Albert, C. Shen, C.-L. Zou, R. W. Heeres, B. Vlastakis, R. J. Schoelkopf, and L. Jiang, Phys. Rev. A 92, 040303 (R) (2015).

K. Park, P. Marek, and R. Filip, Deterministic nonlinear gates with oscillators mediated by a qubit, submitted.

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NONLINEAR QUANTUM DYNAMICS