Non classical effects in light matter interaction

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fibre Kerr squeezing	non-classical coherent states	spontaneous emission
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J. Heersink,	C. Marquardt	R. Maiwald,
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J. Milanovic,	M. Yukawa[3],	M. Sondermann,
A. Huck,	H. Yonezawa[3],	U. Peschel
R.-F. Dong,	A. Furusawa[3]	
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fibre Kerr squeezing


Cadbury
Fudge

INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS B: ATOMIC, MOLECULAR AND OPTICAL PHYSICS

J. Phys. B: At. Mol. Opt. Phys. **35** (2002) 1555–1582 PII: S0953-4075(02)31806-6

The stochastic Gross–Pitaevskii equation

C W Gardiner[1], J R Anglin[2] and T I A Fudge[3]

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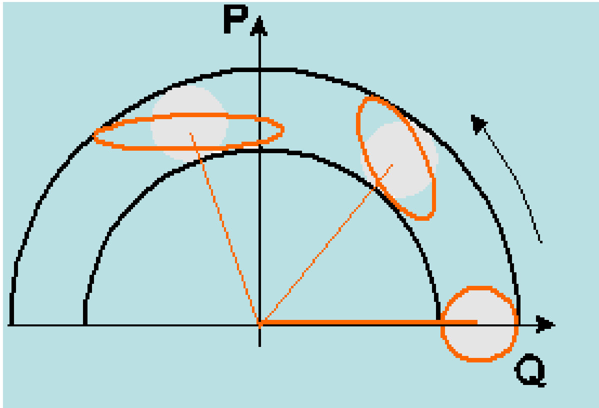
Received 10 December 2001, in final form 31 January 2002
Published 13 March 2002
Online at stacks.iop.org/JPhysB/35/1555

The interpretation of (43) as a genuine stochastic differential equation requires that the matrix of noise coefficients

$$\begin{pmatrix} G^{(-)}[x, \epsilon_C(x,t)] & -(iu/\hbar)\alpha^*(x)^2 \\ (iu/\hbar)\alpha(x)^2 & G^{(-)}[x, \epsilon_C(x,t)] \end{pmatrix} \tag{59}$$

should have only non-negative eigenvalues. For higher-temperature situations in which there is a substantial thermal component, this will certainly be true for all values of the variable $\alpha(x)$ which would turn up in a stochastic simulation. When this is not so, a positive P-representation would be necessary. The experience of Drummond and co-workers [35,36] has shown this is in principle feasible, but application to experimentally realistic problems would be very difficult.

Kerr squeezed states



$$n = n_0 + n_2 I$$

$$U(t) = e^{i\gamma t\, \hat{a}^{+} \hat{a}^{+} \hat{a}\, \hat{a}}$$

medium: optical fiber

communication wavelength

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Quantum dynamical model

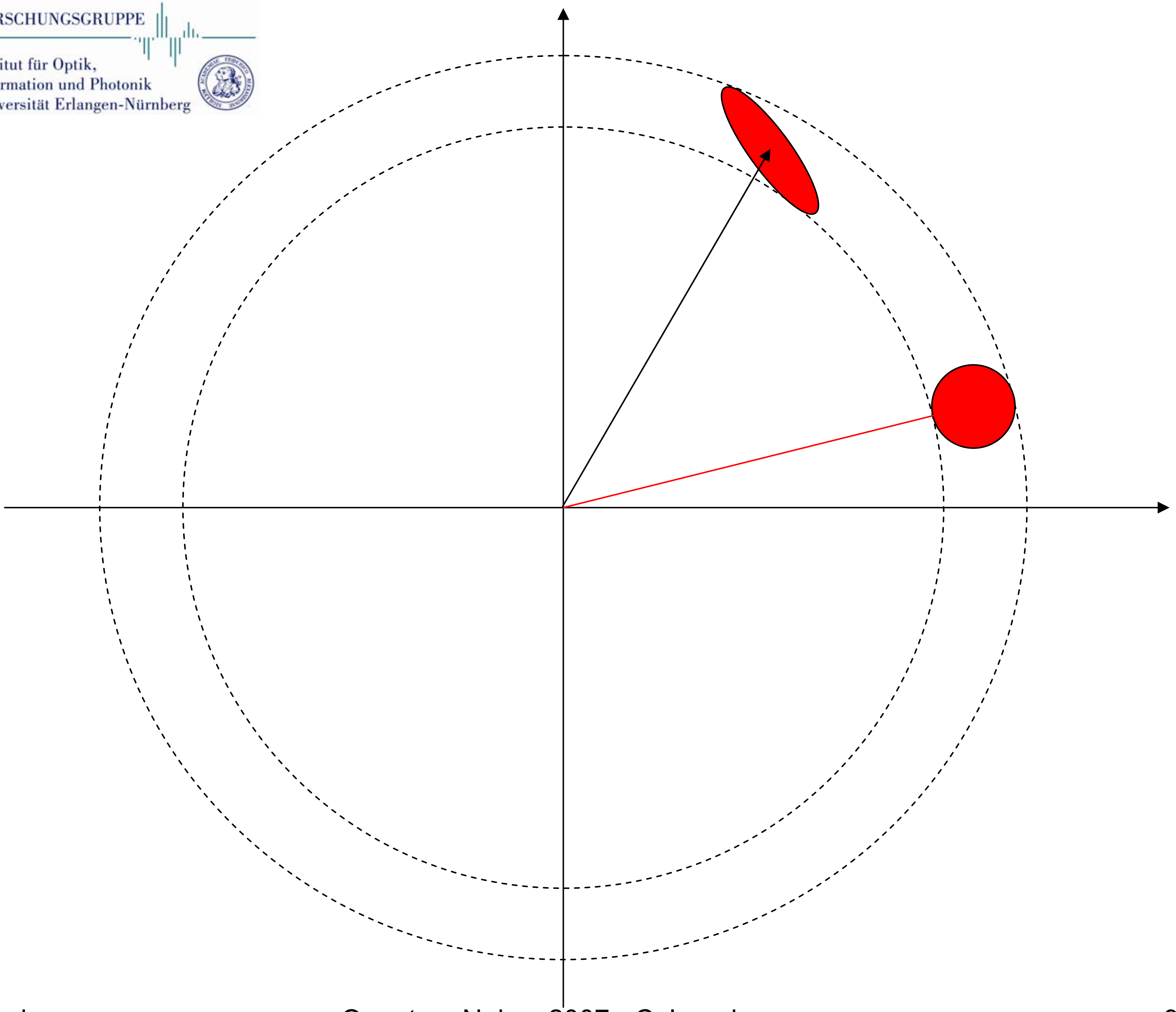
- Quantum pulse propagation model for silica fibers includes:
  - pulse envelope evolution (dispersion)
  - $\chi^{(3)}$ nonlinearity (Kerr effect)
  - coupling to phonons (e.g. Raman scattering)

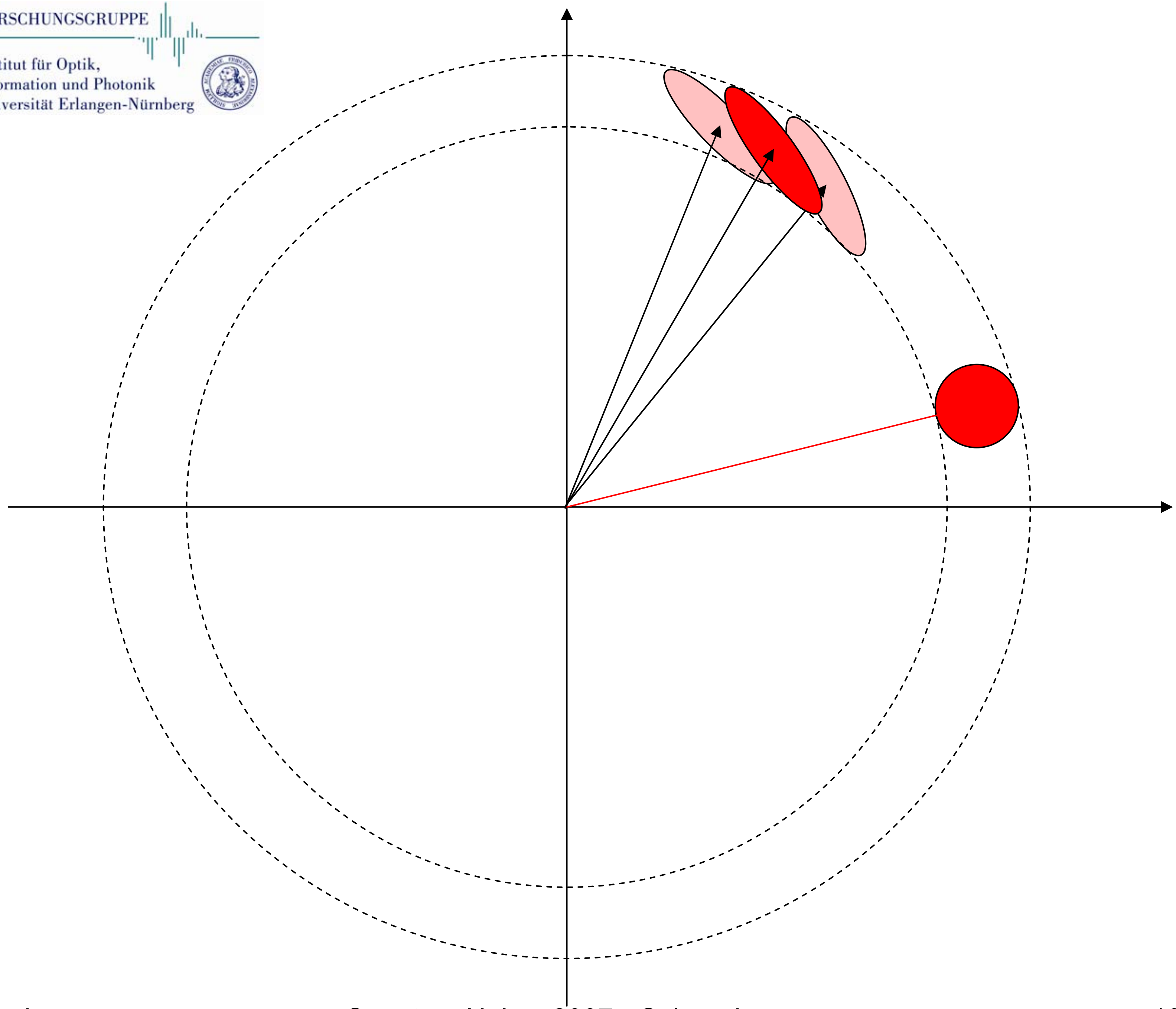
- Phonon coupling generates:
  - phase noise
  - delayed nonlinearity

Raman modified, quantum nonlinear Schrödinger equation

$$\frac{\partial}{\partial \zeta}\hat{\phi}_\iota(\tau,\zeta) = \frac{i}{2}\frac{\partial^2}{\partial \tau^2}\hat{\phi}_\iota(\tau,\zeta) + i\hat{\Gamma}_\iota^R(\tau,\zeta)\hat{\phi}_\iota(\tau,\zeta) + i\int_{-\infty}^{\infty} d\tau'\, h(\tau-\tau')\hat{\phi}_\iota^\dagger(\tau',\zeta)\hat{\phi}_\iota(\tau',\zeta)\hat{\phi}_\iota(\tau,\zeta)$$

P.D. Drummond and J.F. Corney J. Opt. Soc. Am. B **18**, 139 (2001)





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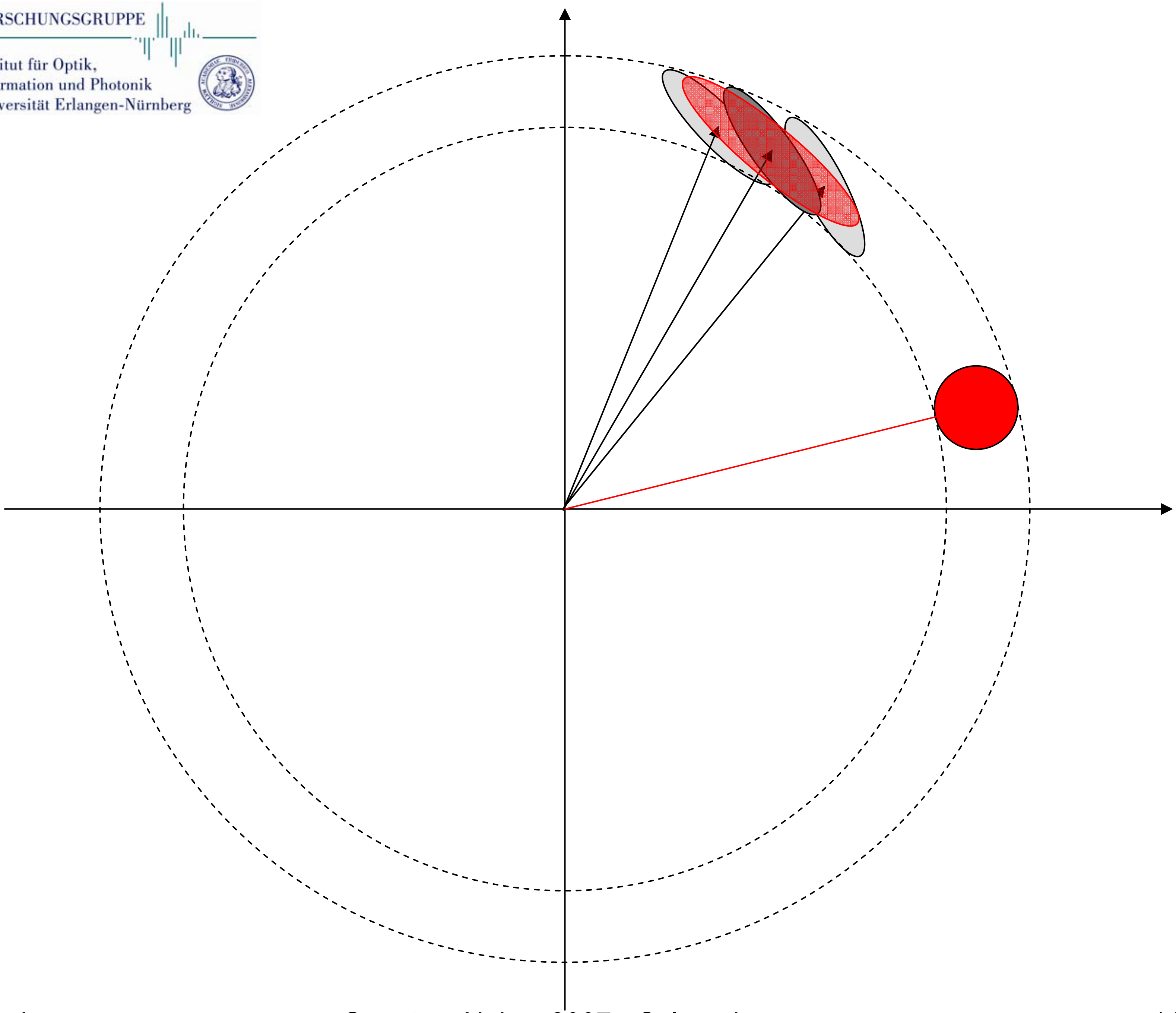

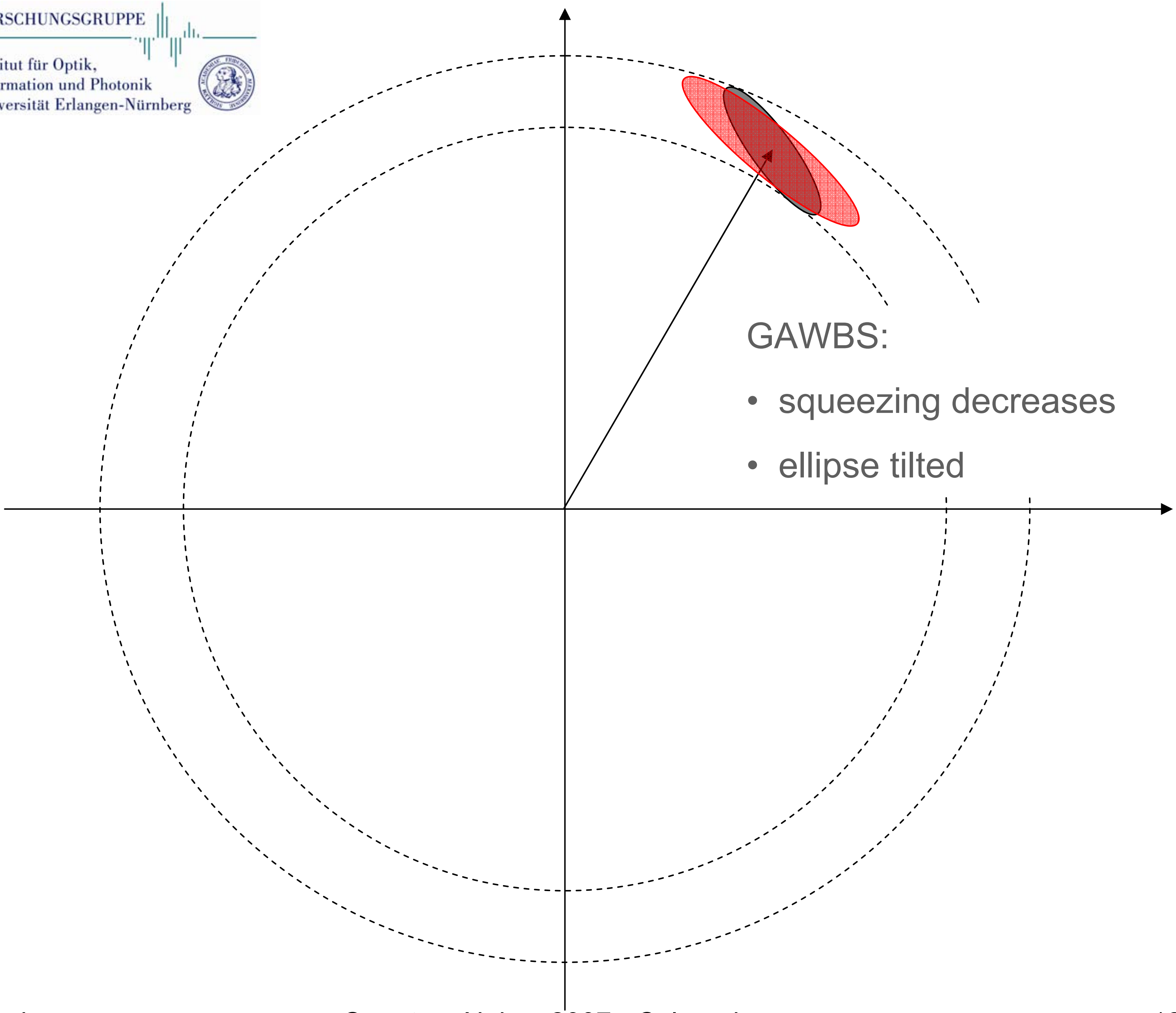

GAWBS:

- squeezing decreases
- ellipse tilted

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attempts to compensate GAWBS with pulses and differential techniques:

symmetric Sagnac loop → squeezed vacuum

- M. Rosenbluh, R.M. Shelby, PRL 66,153 (1991)
- K. Bergman Opt.Lett. 19, 290 (1994)

spectral filtering → amplitude squeezing of bright beams

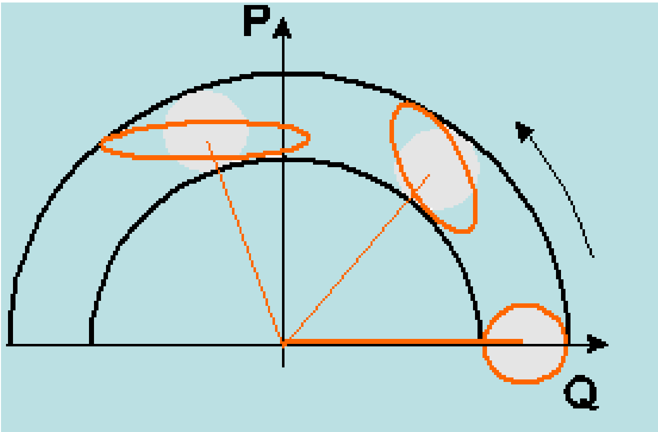
- S.R. Friberg et al. PRL 77, 3775 (1996)
- S. Spälter et al. Europhys. Lett. 38, 335 (1997)

asymmetric Sagnac loop → amplitude squeezing of bright beams

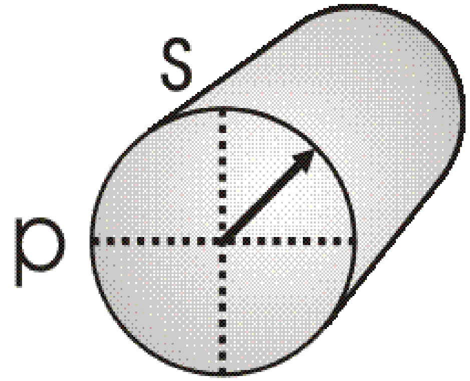
- S. Schmitt et al. PRL 81, 2446 (1998)
- D. Krylov, K. Bergman, Opt. Lett. 23, 1390 (1998)

theory P.D. Drummond, C.W. Gardiner, J.Phys.A 13, 2353 (1980)
H.A. Haus, Y. Lai, JOSA B7, 386 (1990)
N. Korolkova, R. Loudon et al., J. Mod. Opt. 48, 1339 (2001)
… P.D. Drummond, J.F. Corney, JOSA B18, 139 (2001)

Kerr squeezed states



Two optical axes in the fiber.

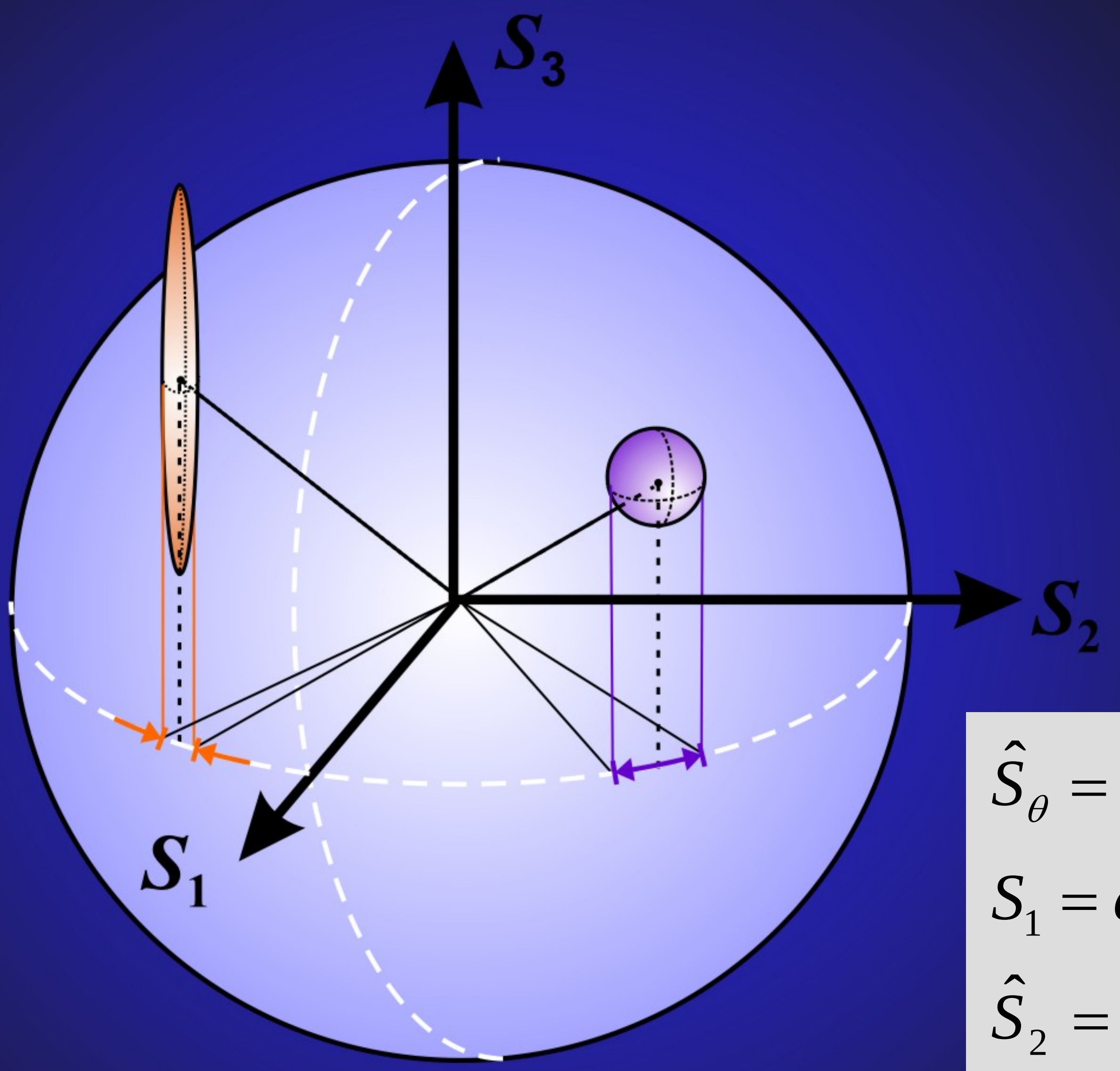


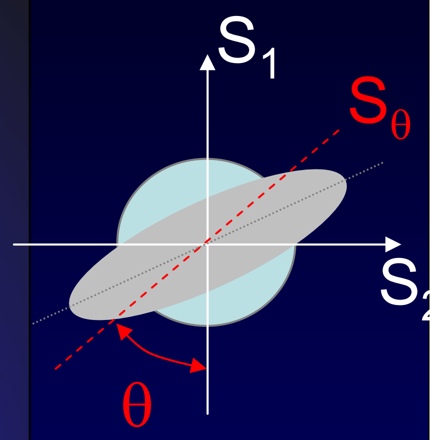
→ squeezing in two orthogonal polarisation modes.

Polarization squeezing!

[N. Korolkova et al., Nonlinear Opt. **24**, 223 (2000)]
Heersink et al., PRA **68**, 013815 (2003)

N. Korolkova et al., Phys. Rev. A 65, 052306 (2002)





$$\hat{S}_\theta = \cos\theta\,\hat{S}_1 + \sin\theta\,\hat{S}_2$$

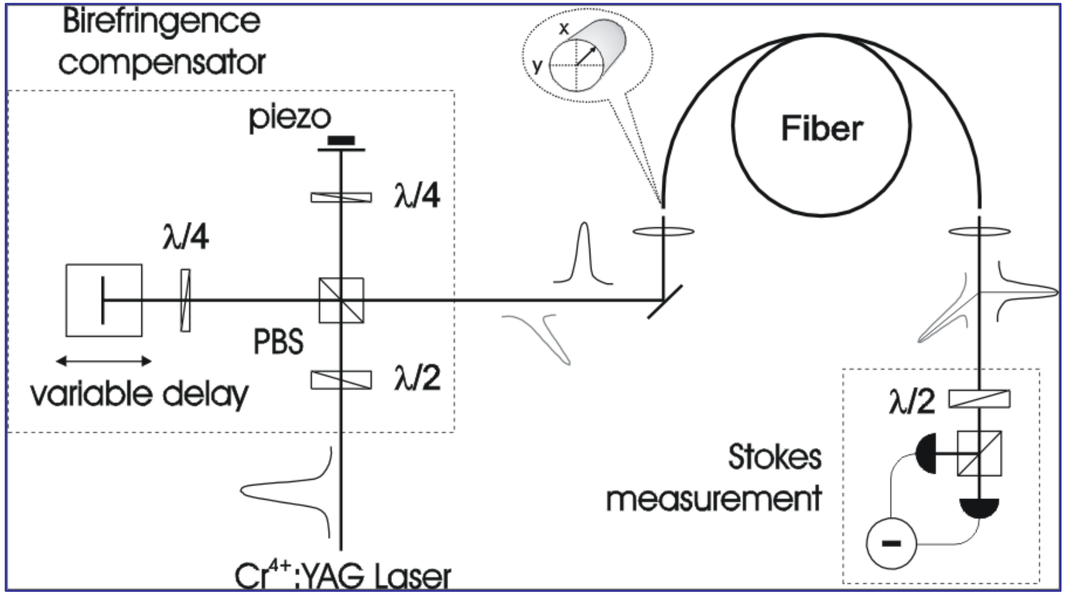
$$S_1 = \hat{a}_x{}^+\hat{a}_x - \hat{a}_y{}^+\hat{a}_y$$

$$\hat{S}_2 = \hat{a}_y^+\hat{a}_x + \hat{a}_x^+\hat{a}_y$$

$$\hat{S}_3 = i(\hat{a}_y^+\hat{a}_x - \hat{a}_x^+\hat{a}_y)$$

Experimental polarization squeezing

❖ A ***polarization squeezed*** source obtained using optical fiber:



J. Heersink, et al., Opt. Lett. 30, 1192 (2005).

Pulse properties:

- t_0 = 77 fs sech pulse
- λ_0 = 1499.5 nm,
- $\Delta\lambda$ ~ 19 nm
- τ_{rep} = 163 MHz

Fiber properties:

- $n_2 = 2.9\times10^{-20}$ m^2/W
- β_2 = -11.1 fs^2/mm
- Mode field diameter = 5.69 μm
- Attenuation = 1.9dB/km
- L = 13.2 m

6.8 dB squeezing was measured at energy of 100.7 pJ!

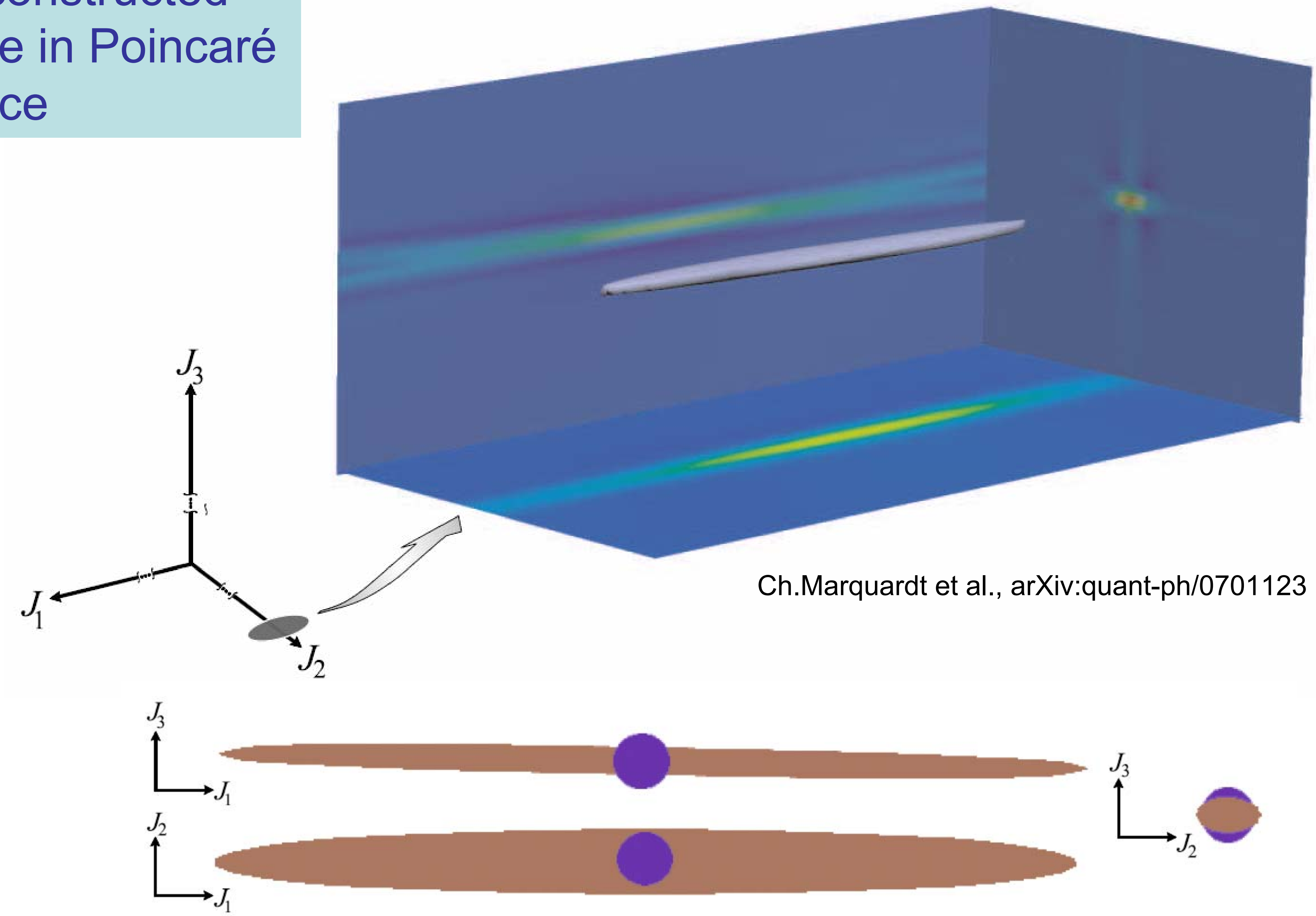
Loss 10%

Measurement frequency 17.5 MHz

RBW 300 kHz

VBW 30 Hz

Reconstructed state in Poincaré space



Ch.Marquardt et al., arXiv:quant-ph/0701123

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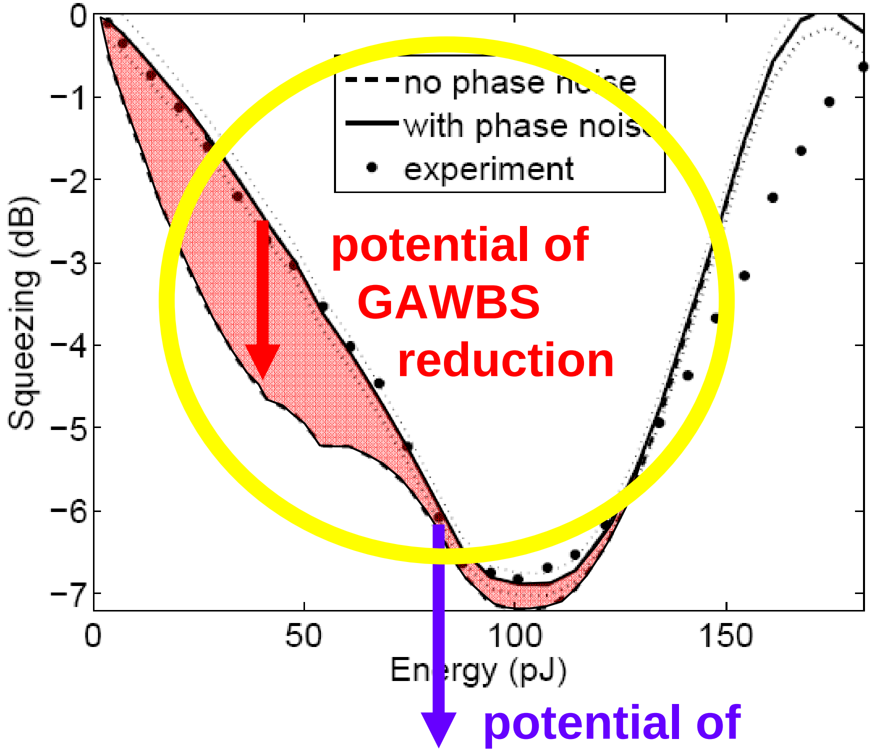
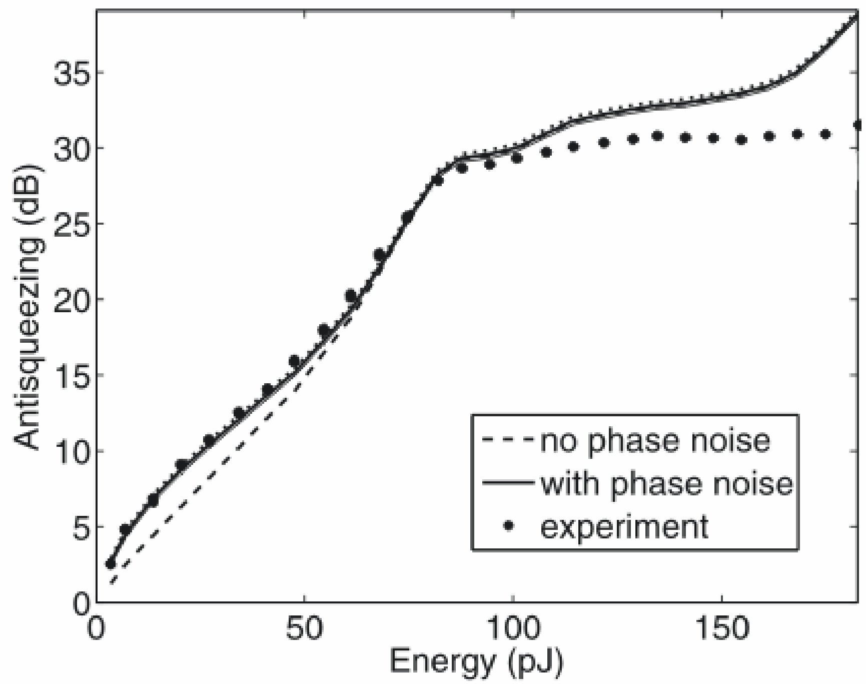
Squeezing and anti-squeezing

- Squeezing and anti-squeezing for a 13.2m fiber are simulated.
- Linear loss of 13% is taken into account by theory





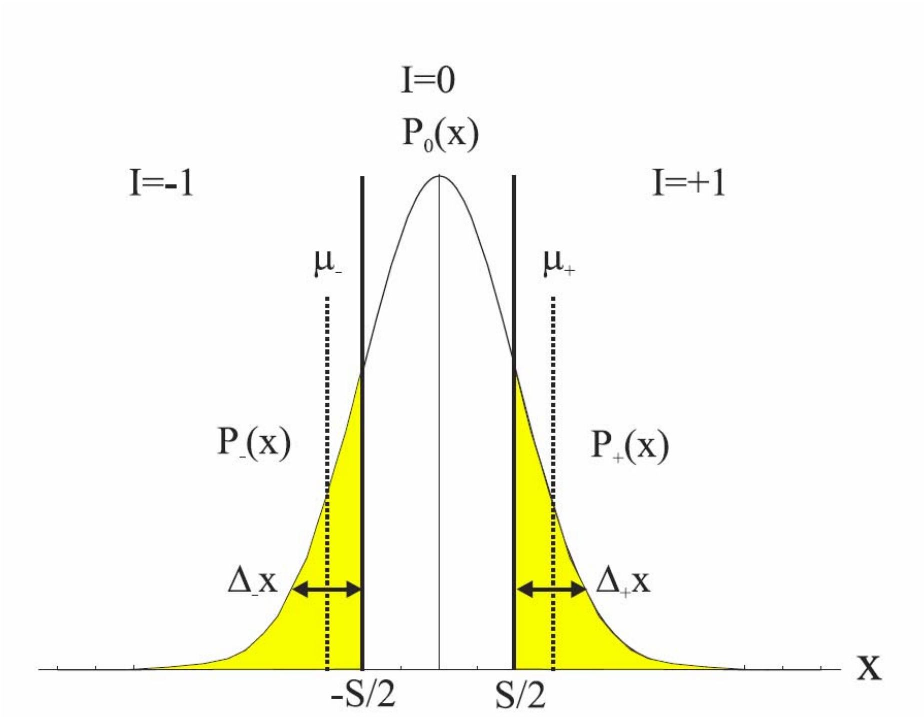
J.F.Corney, P.D.Drummond, J.Heersink, V.Josse, G.L., U.L.Andersen,
Phys. Rev. Lett. 97, 023606 (2006)

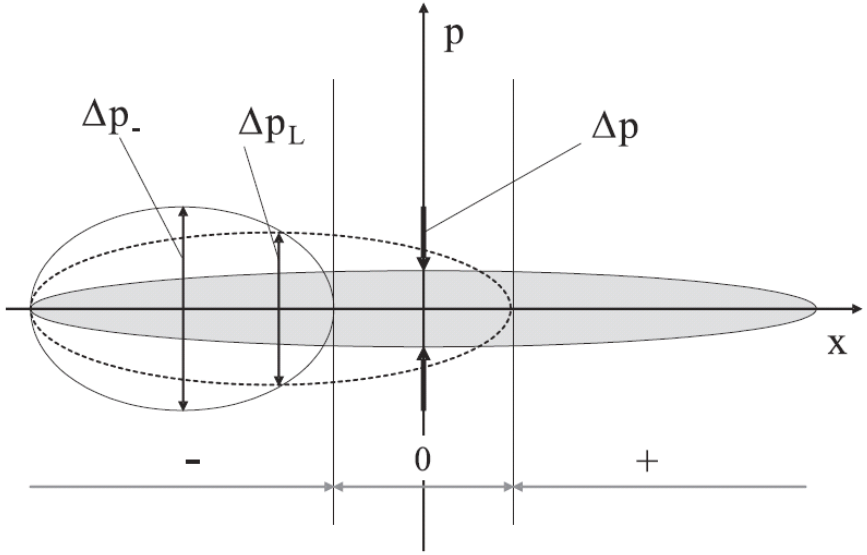
the non-classical property of a

coherent state

E.G. Cavalcanti & M.D. Reid, PRL97, 170405 (2006)

$$\Delta^2_{mixed} p \geq P_- \Delta^2_- p + P_0 \Delta^2_0 p + P_+ \Delta^2_+ p$$





$$(\Delta^2_{ave} x + P_0 \delta)\Delta^2 p \geq 1$$

$$\delta = \{(\mu_+ + S/2)^2 + (\mu_- - S/2)^2 + S/2\} + \Delta^2_+ x + \Delta^2_- x$$

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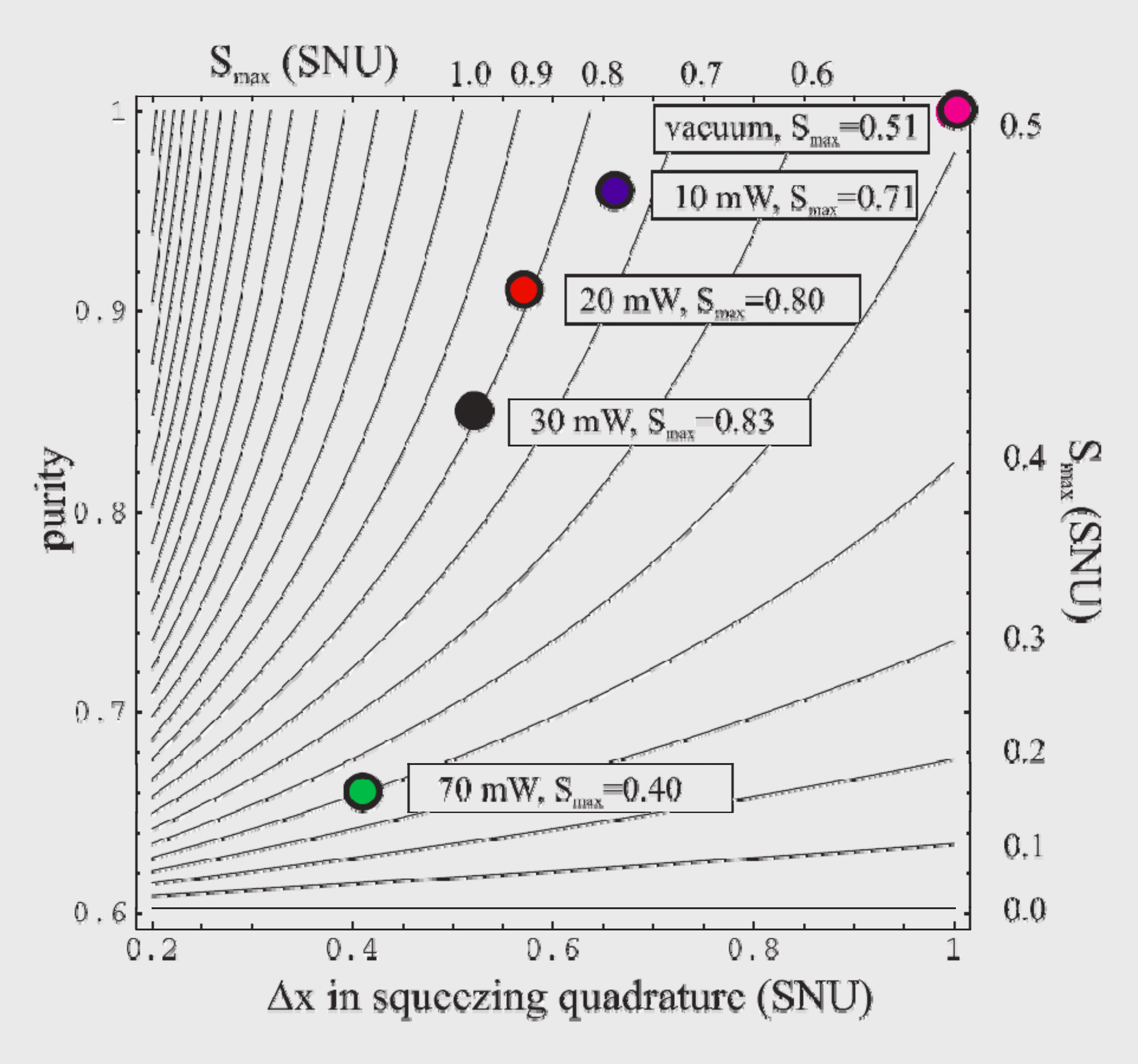

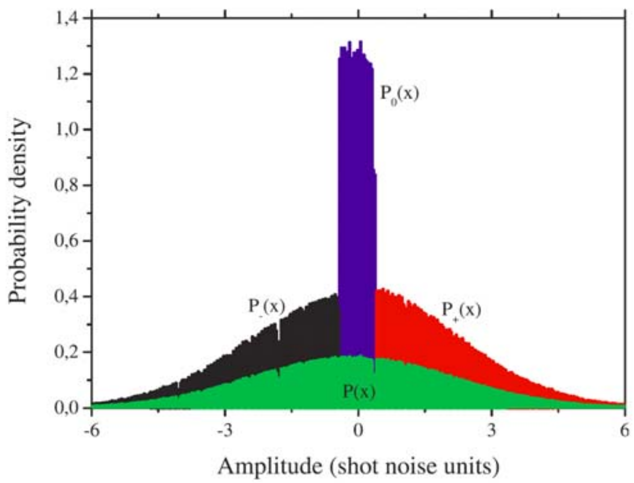

Ch. Marquardt, U.L. Andersen, G. Leuchs, Y. Takeno, M. Yukawa, H. Yonezawa, A. Furusawa, arXiv:quant-ph/0702215

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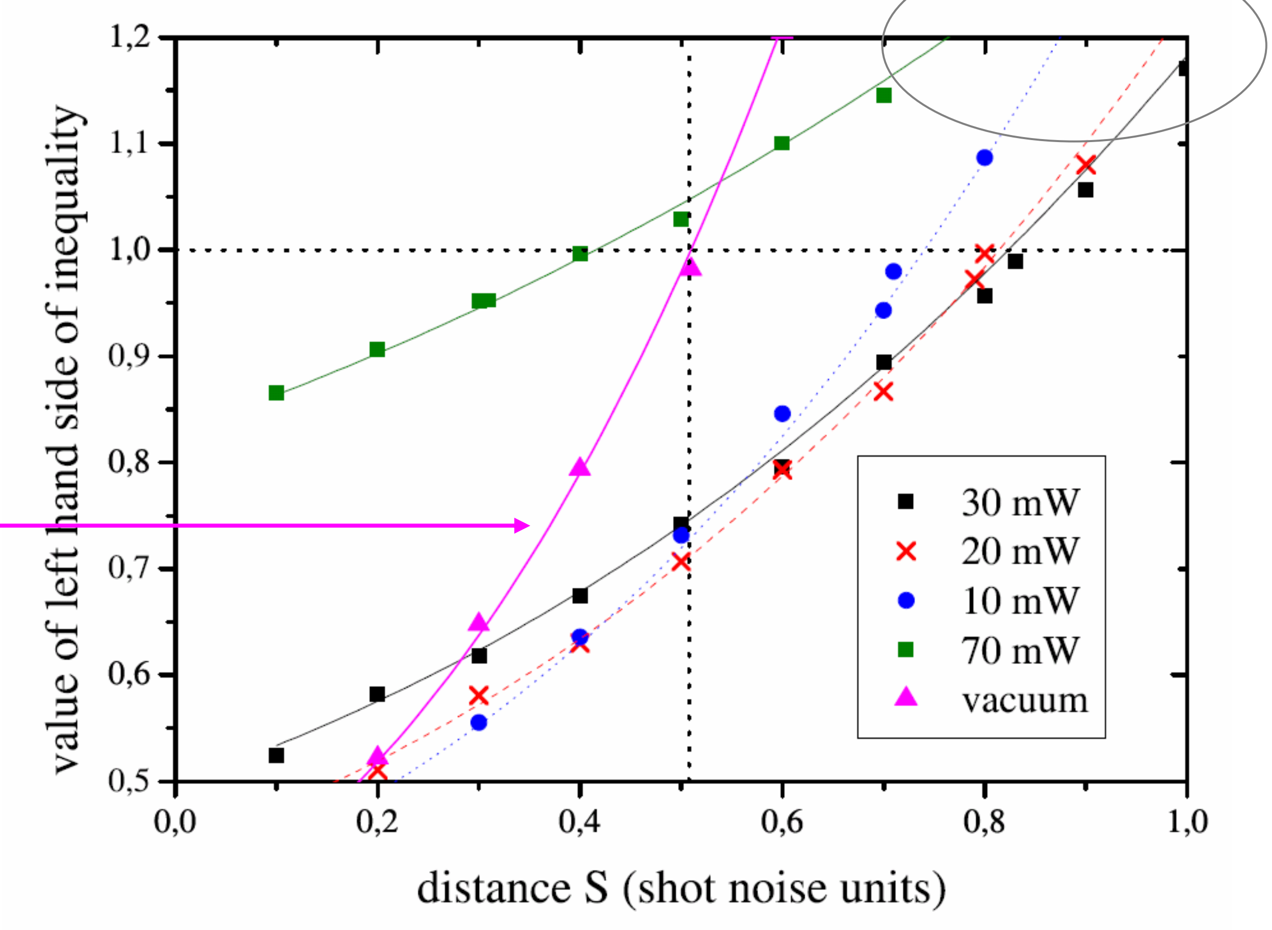
squeezed states

vacuum, coherent state



spontaneous emission

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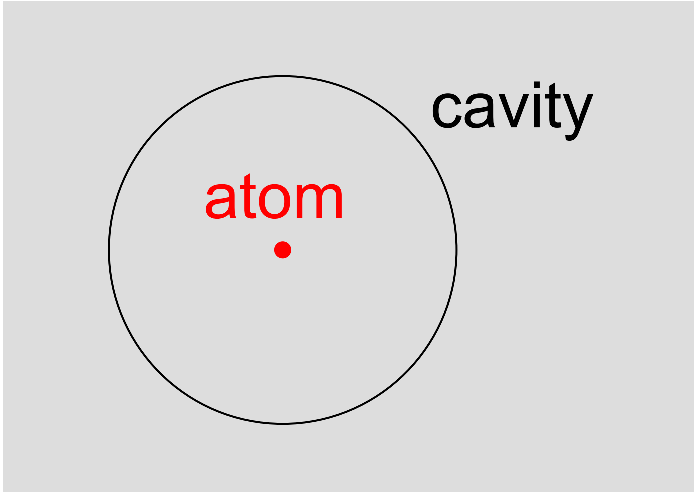
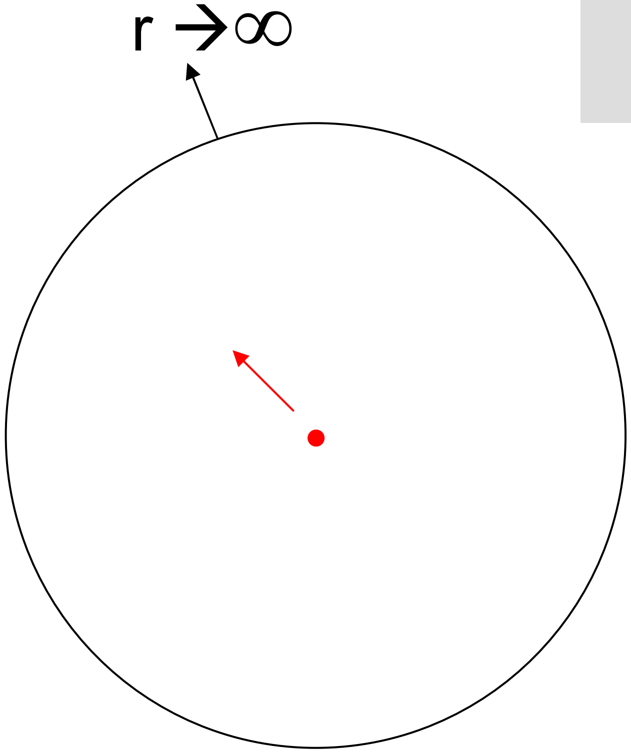
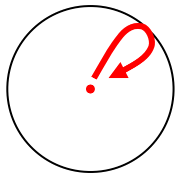




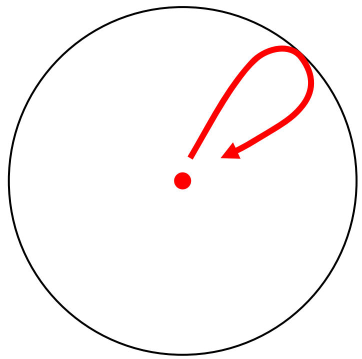
V. Weisskopf, E. Wigner, Z. Physik 63, 54 (1930)

one cavity mode



E.T. Jaynes, F.W. Cummings, Proc. IEEE 51, 89 (1963)

large r
many modes



G. Alber, Phys. Rev. A 46, R5338 (1992)

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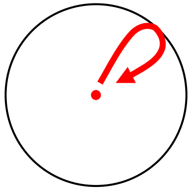
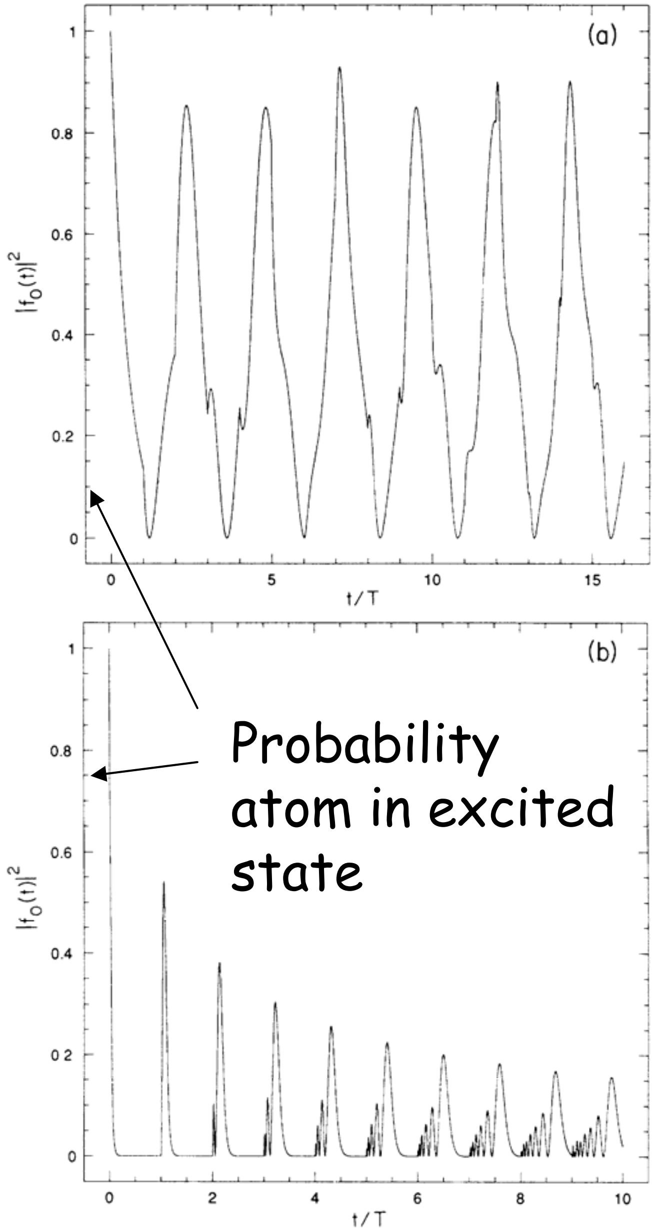
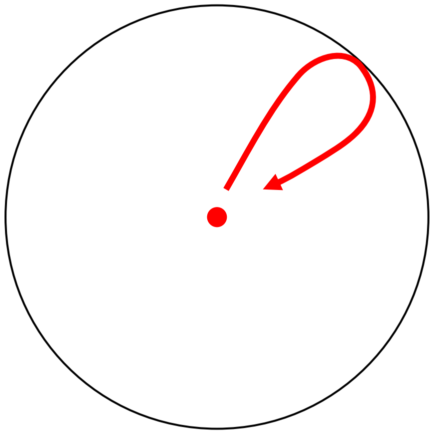




few modes

many modes

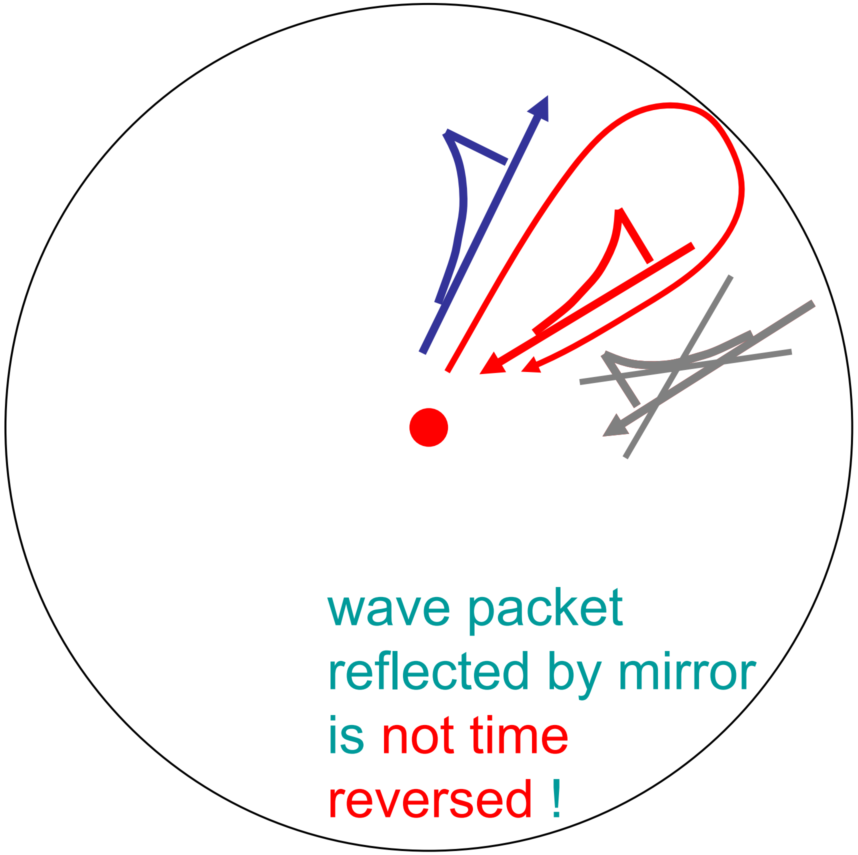
G. Alber, Phys. Rev. A 46, R5338 (1992)



what is wrong ?

properties to watch out for when time reversing:

- geometry
- polarization *
- timing →
- statistics



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* R. Dorn, S. Quabis, G.L., Phys.Rev.Lett. 91, 233901 (2003)

S. Quabis, R. Dorn, M. Eberler, O. Glöckl, G.L., Opt. Commun. 179, 1 (2000)

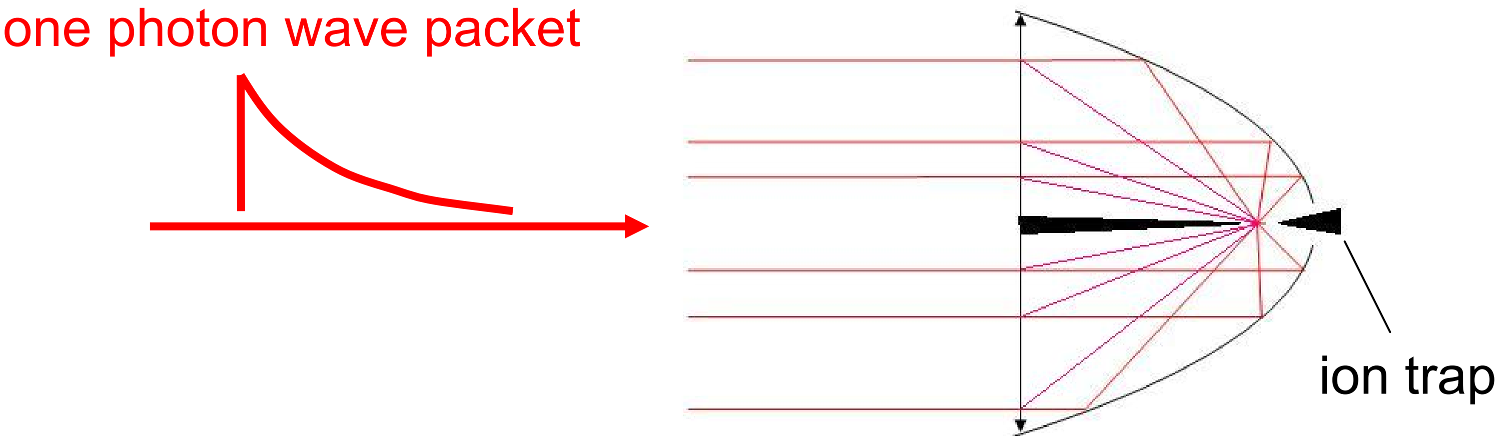
our expectation:

take guidance from photon emission

- angular pattern
- polarization pattern
- temporal shape

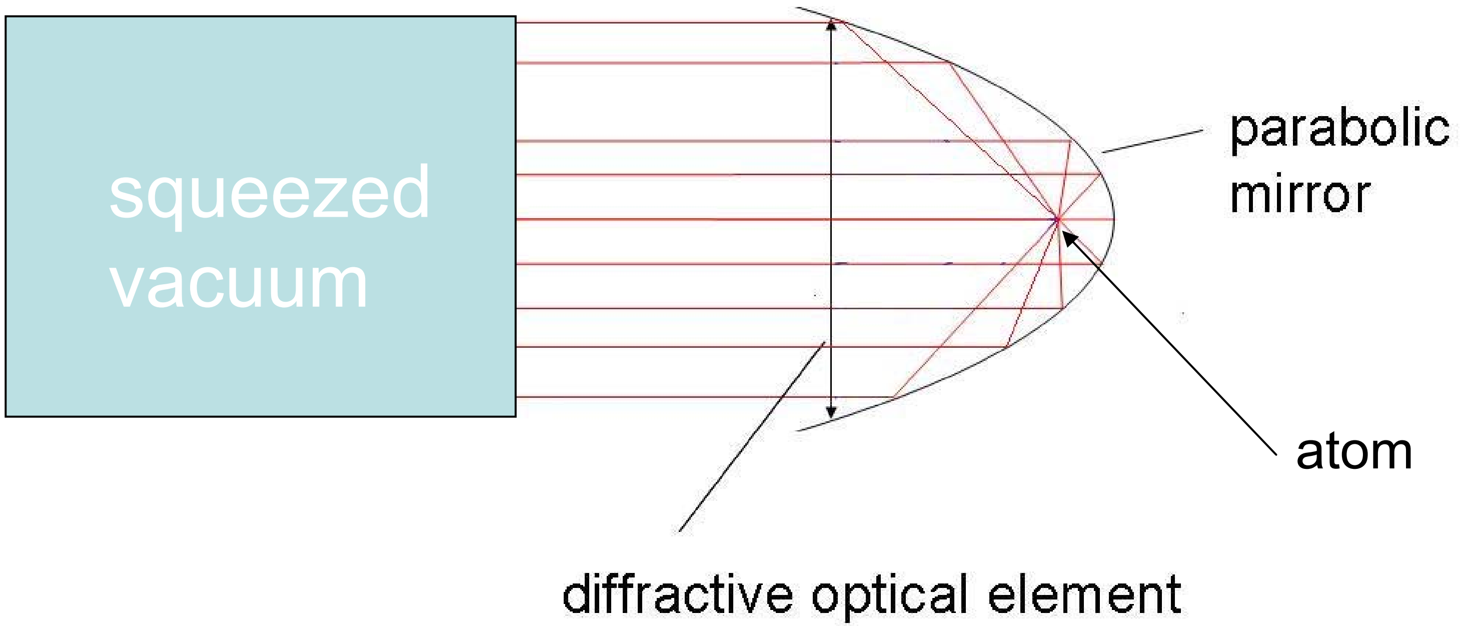
and offer time reversed single photon wave packet

→ 100%

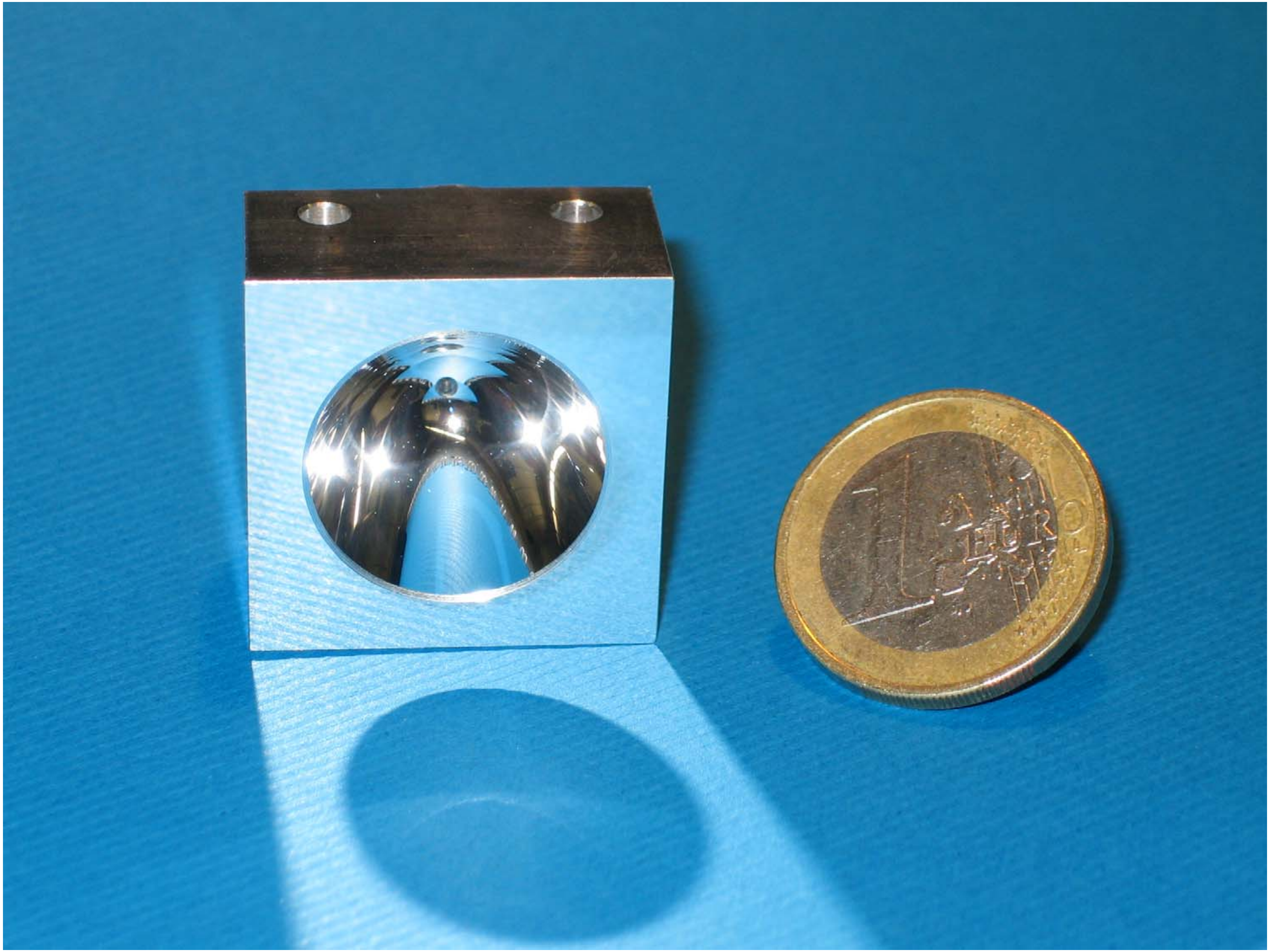


detection: time delayed emission & inversion of shape

geometry for 4π focusing



Excited atom in a squeezed vacuum:
C.W. Gardiner, Phys. Rev. Lett. 56, 1917 (1986)



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