Robust EPR entangled light from room temperature atomic vapour

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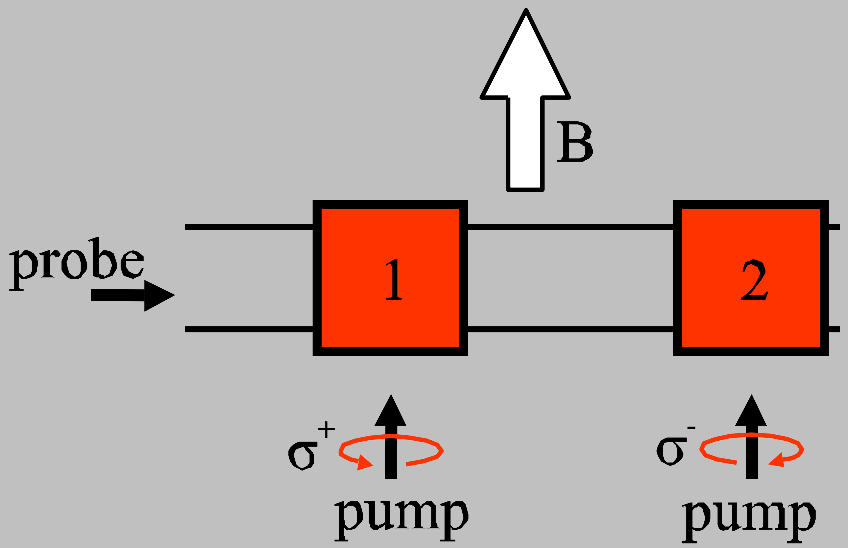
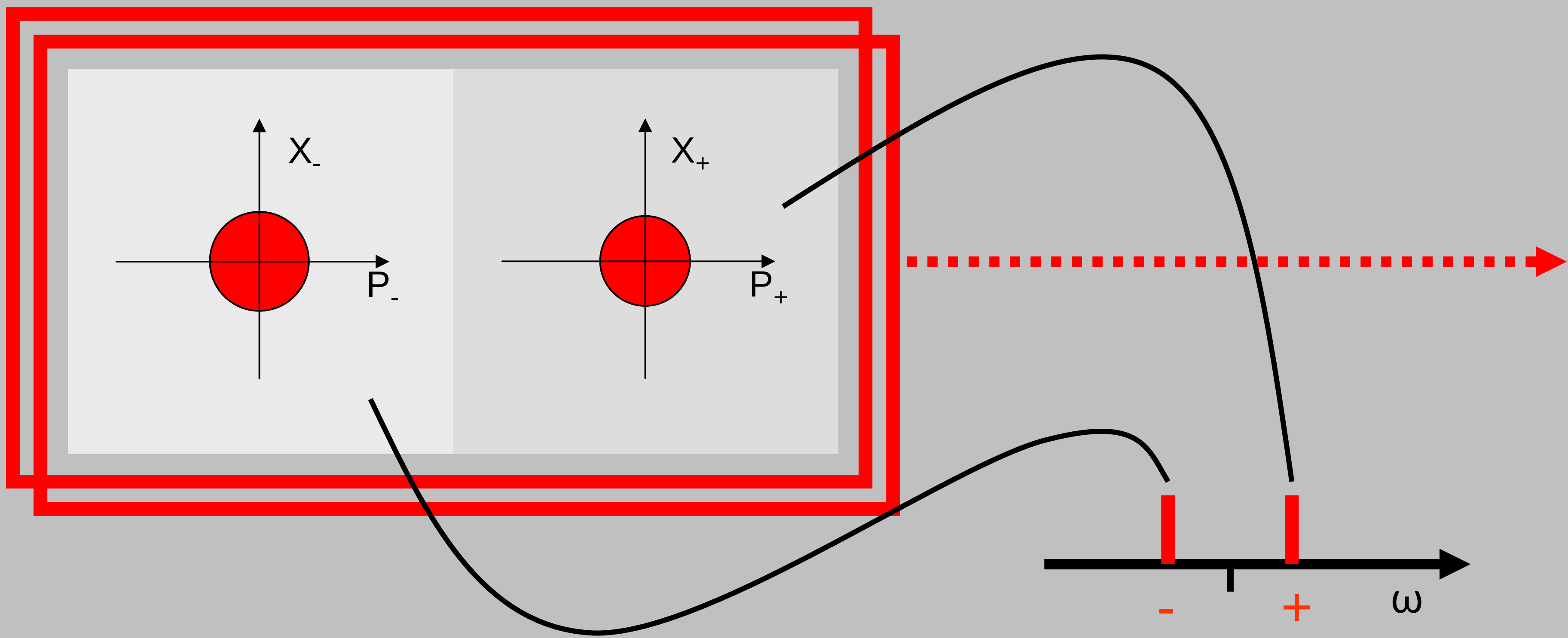
Outline

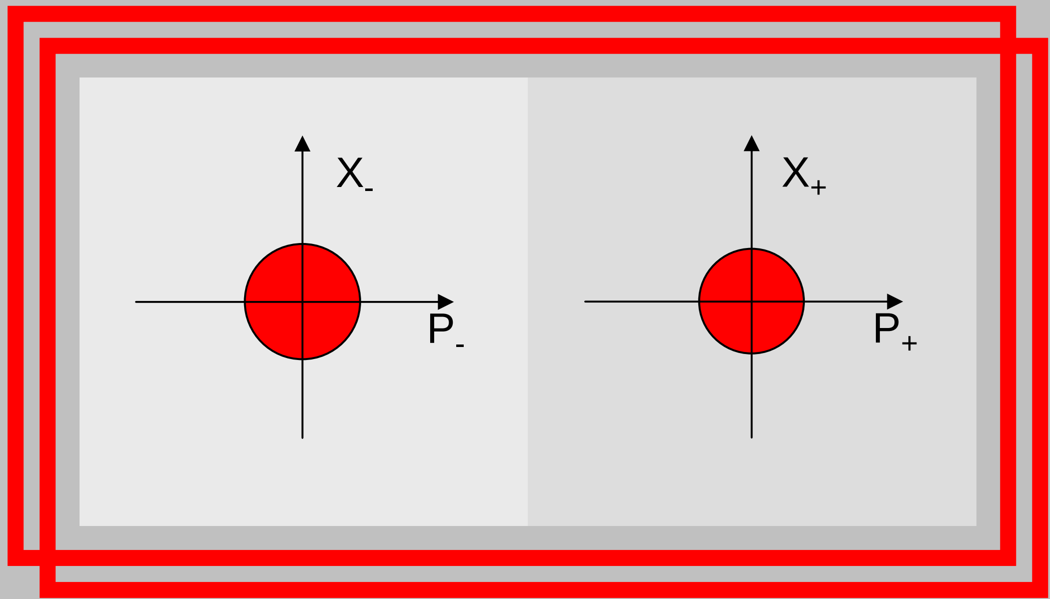
- EPR entanglement: single- vs. multimode
- Faraday interaction with tensorial correction
- Results with mode analysis



EPR entanglement



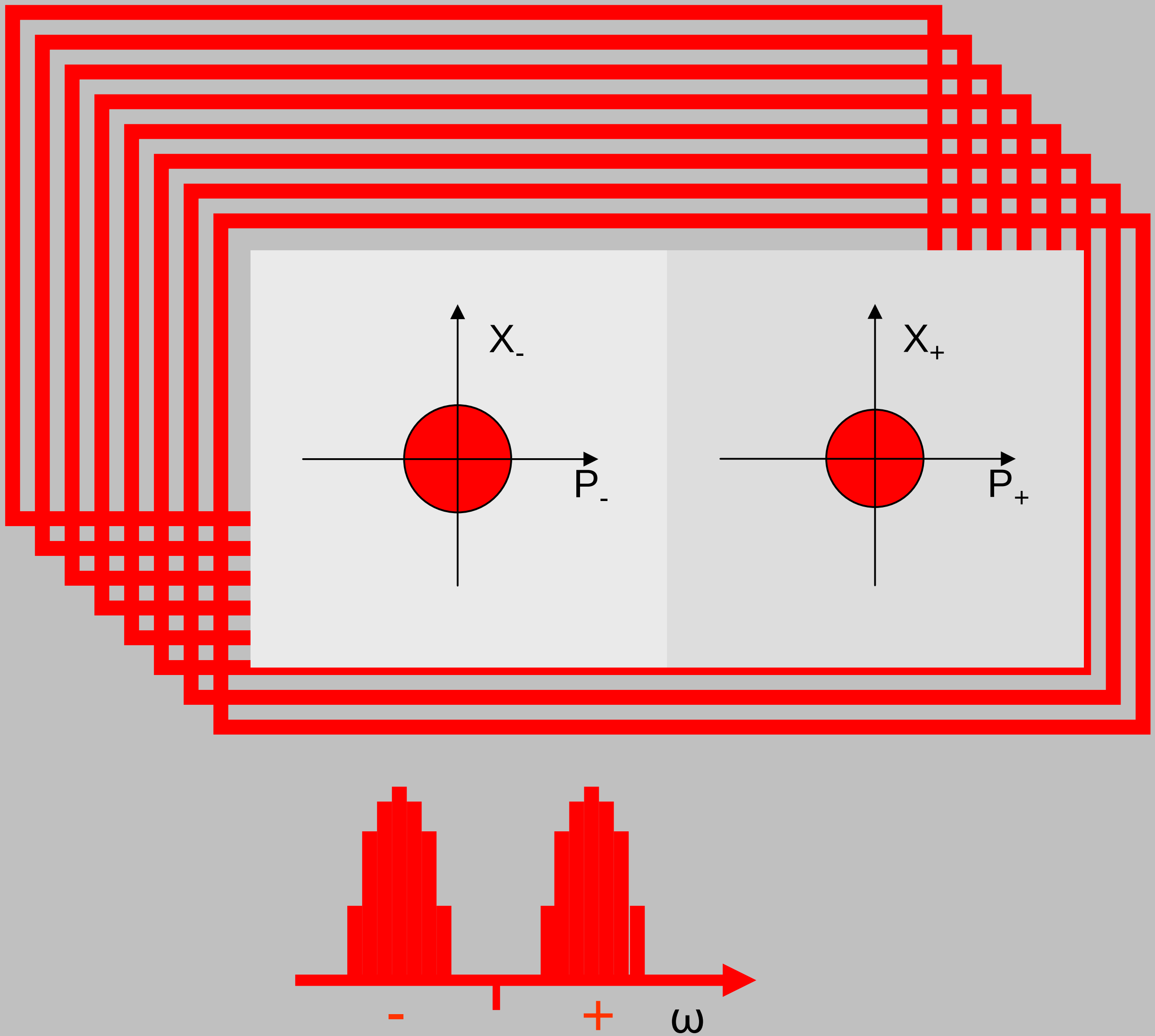
EPR entanglement



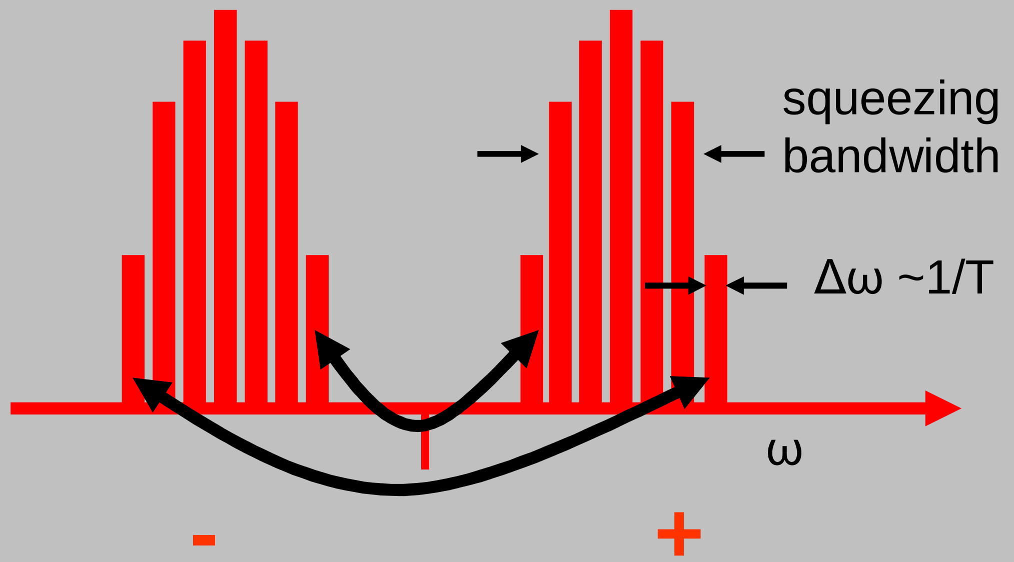
$$\mathrm{Var}(X_- + X_+) + \mathrm{Var}(P_- - P_+) < 2$$

$$|\mathrm{out}\rangle = (1-r)\left(|\mathrm{vac}\rangle + r|1,1\rangle + r^2|2,2\rangle + \ldots\right)$$

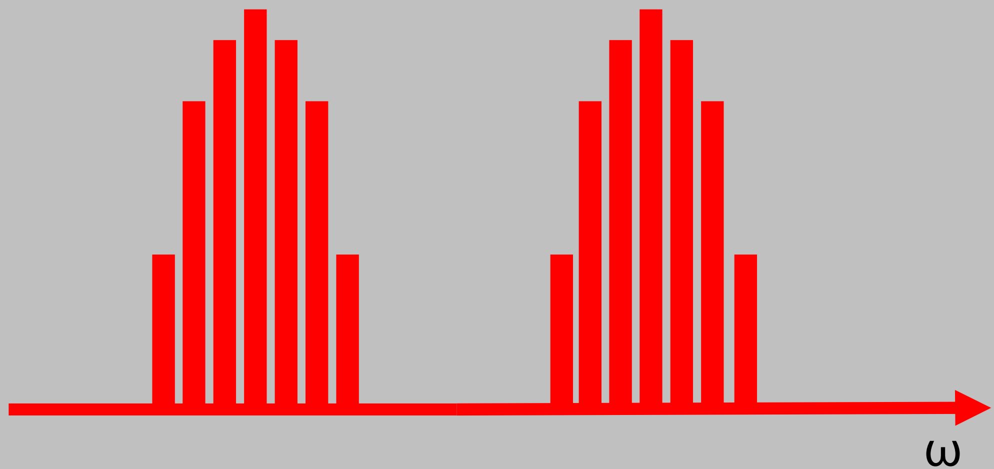
Multimode entanglement

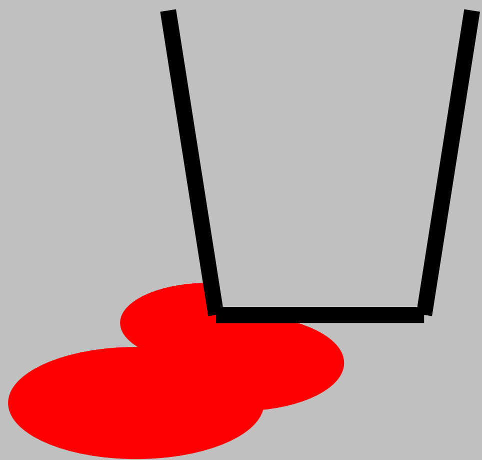


Multimode entanglement

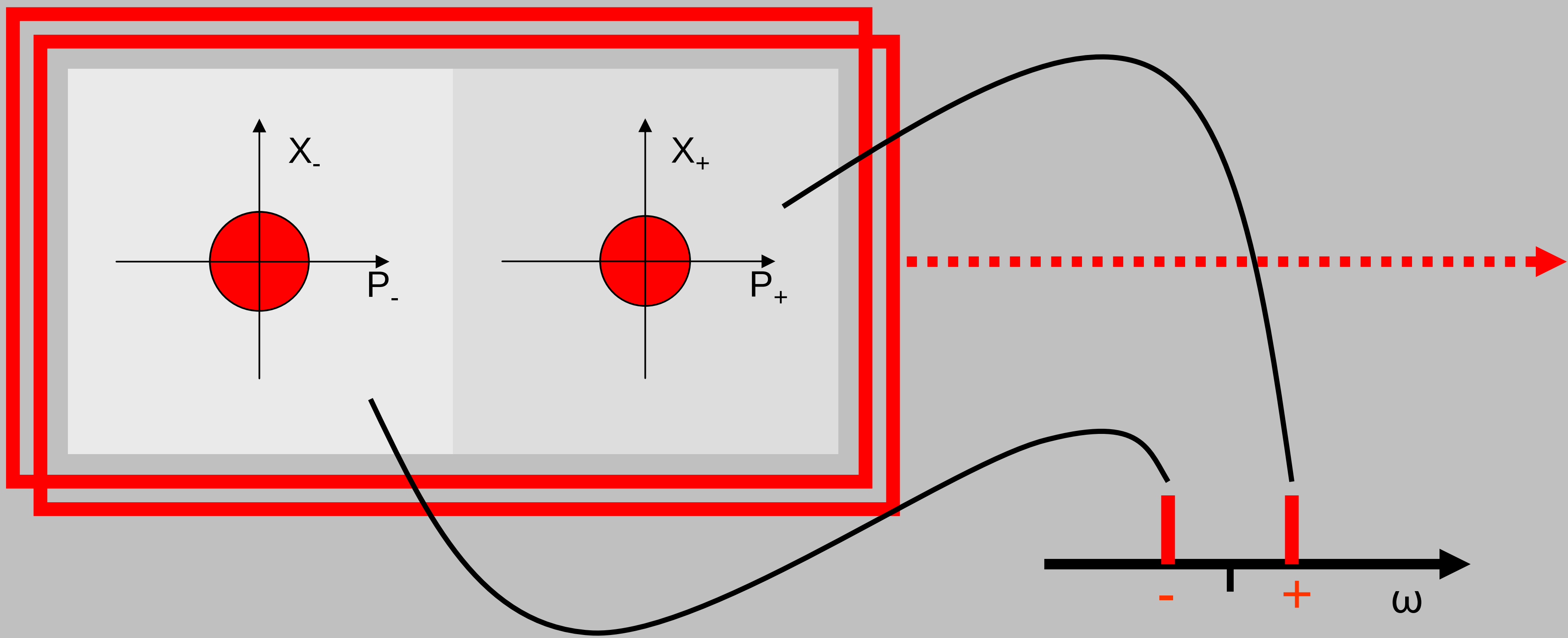


Multimode entanglement

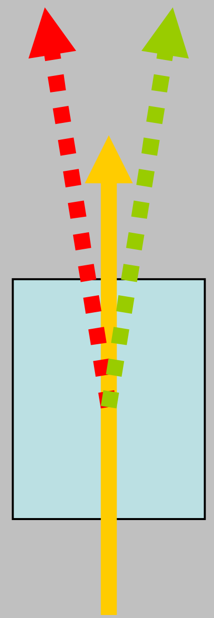




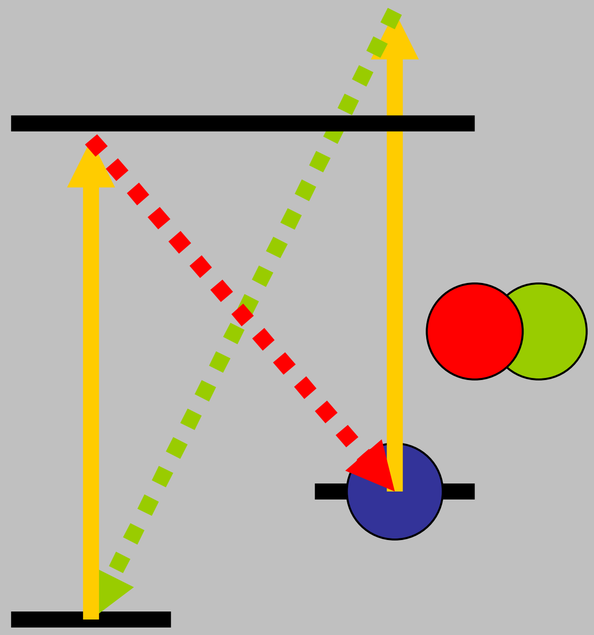
EPR entanglement



Twin beams from atomic vapour

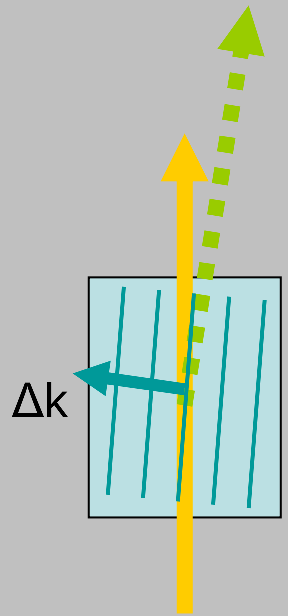


Spectrally & spatially
multimode

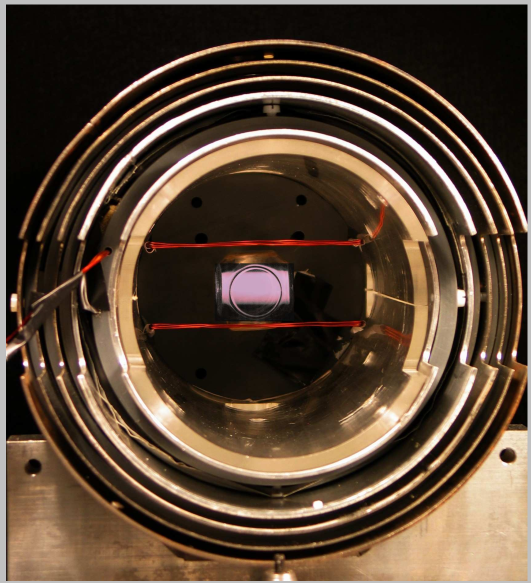


Boyer, V.; Marino, A. M.; Pooser, R. C. & Lett, P. D.
Science, **2008**, 1158275

Suppressing spatial modes

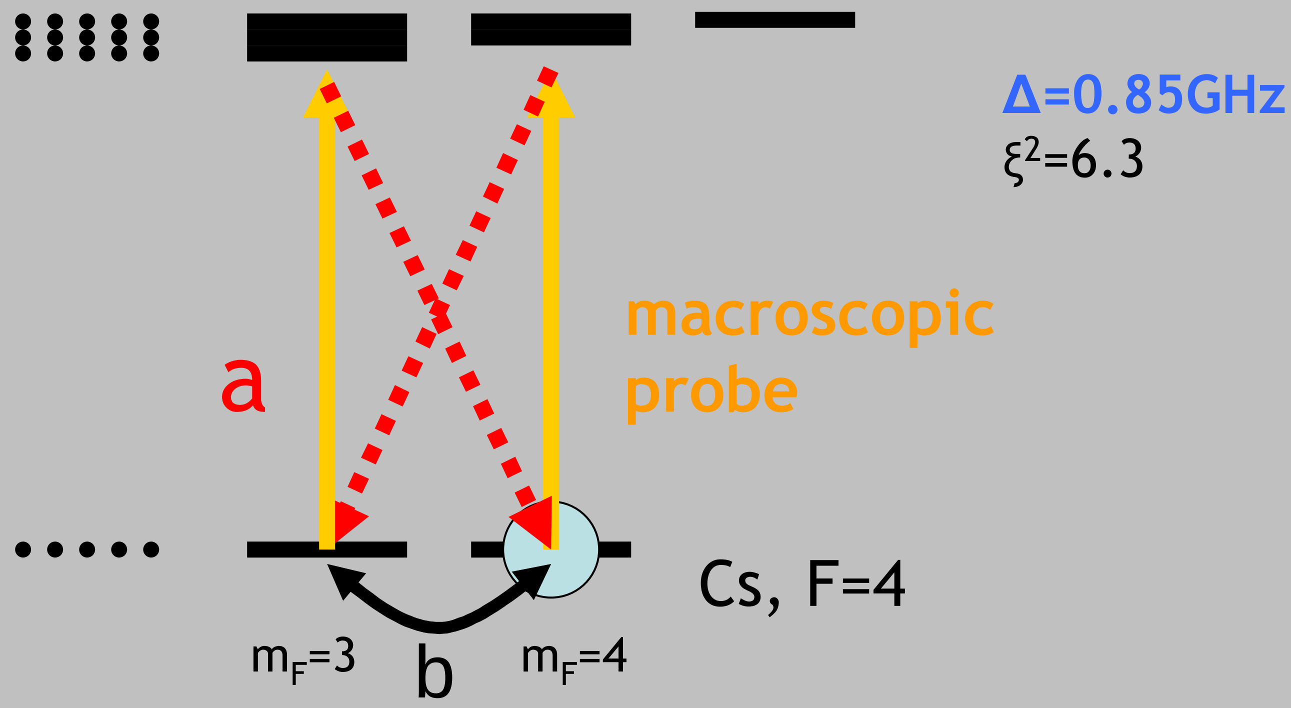


T_2 ~ 30ms



Only forward scattering can built up coherently
+ life is easy: one spin wave, one spatial light mode

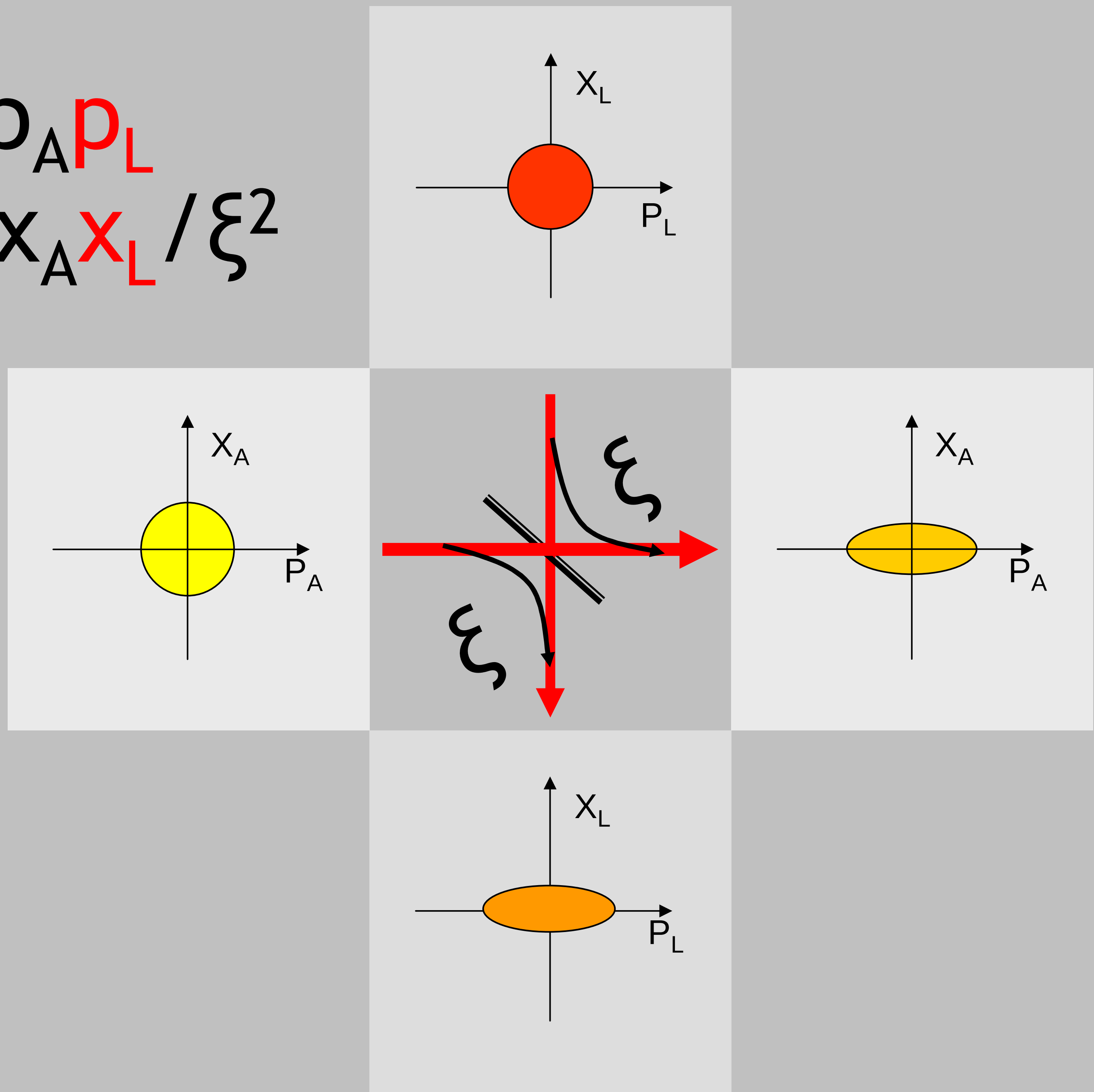
Our atomic system



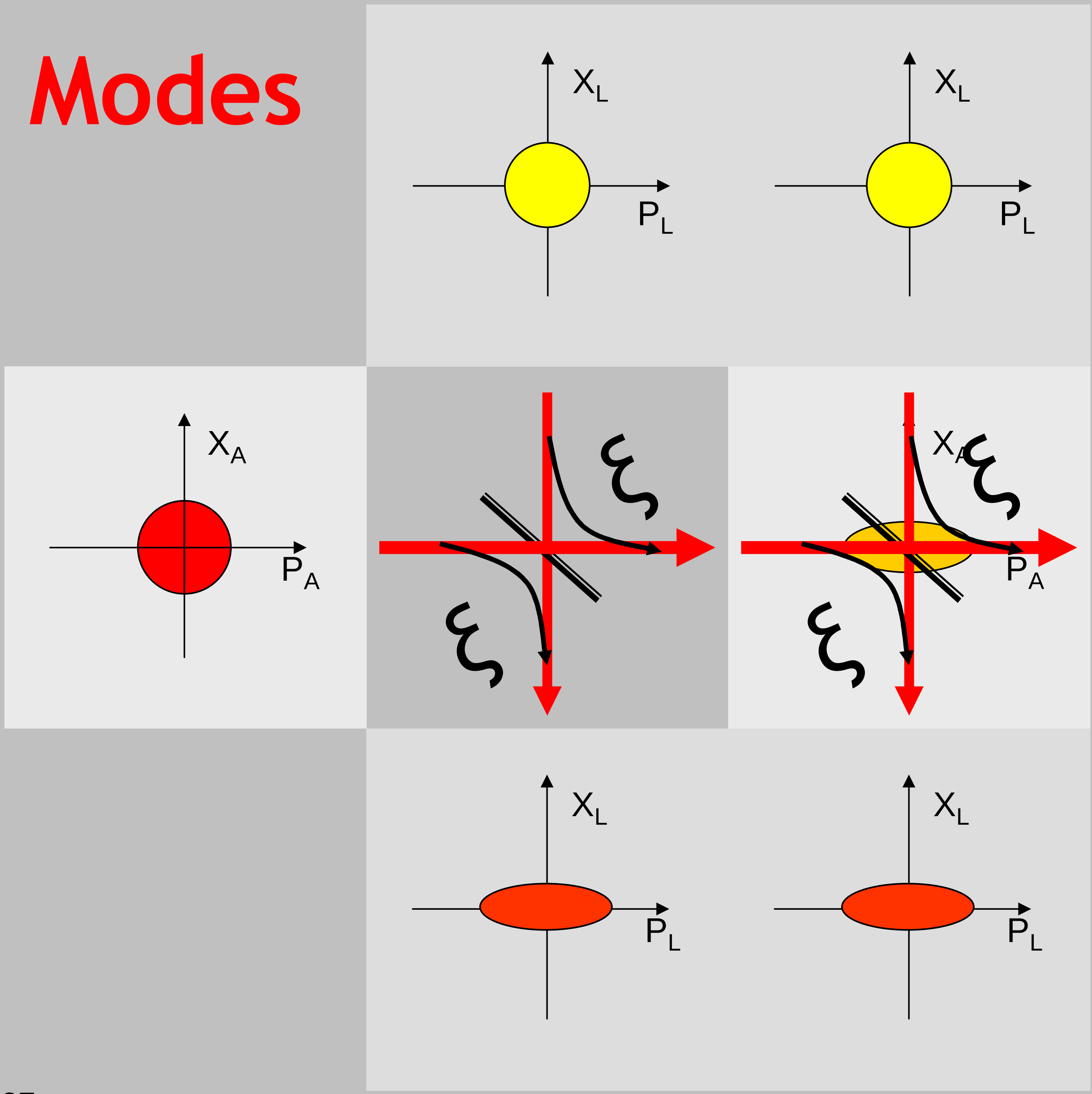
$$H_{int} \propto \chi_a a^\dagger b^\dagger + \chi_p a^\dagger b + H.c.$$

$$\propto p_A p_L + x_A x_L / \xi^2$$

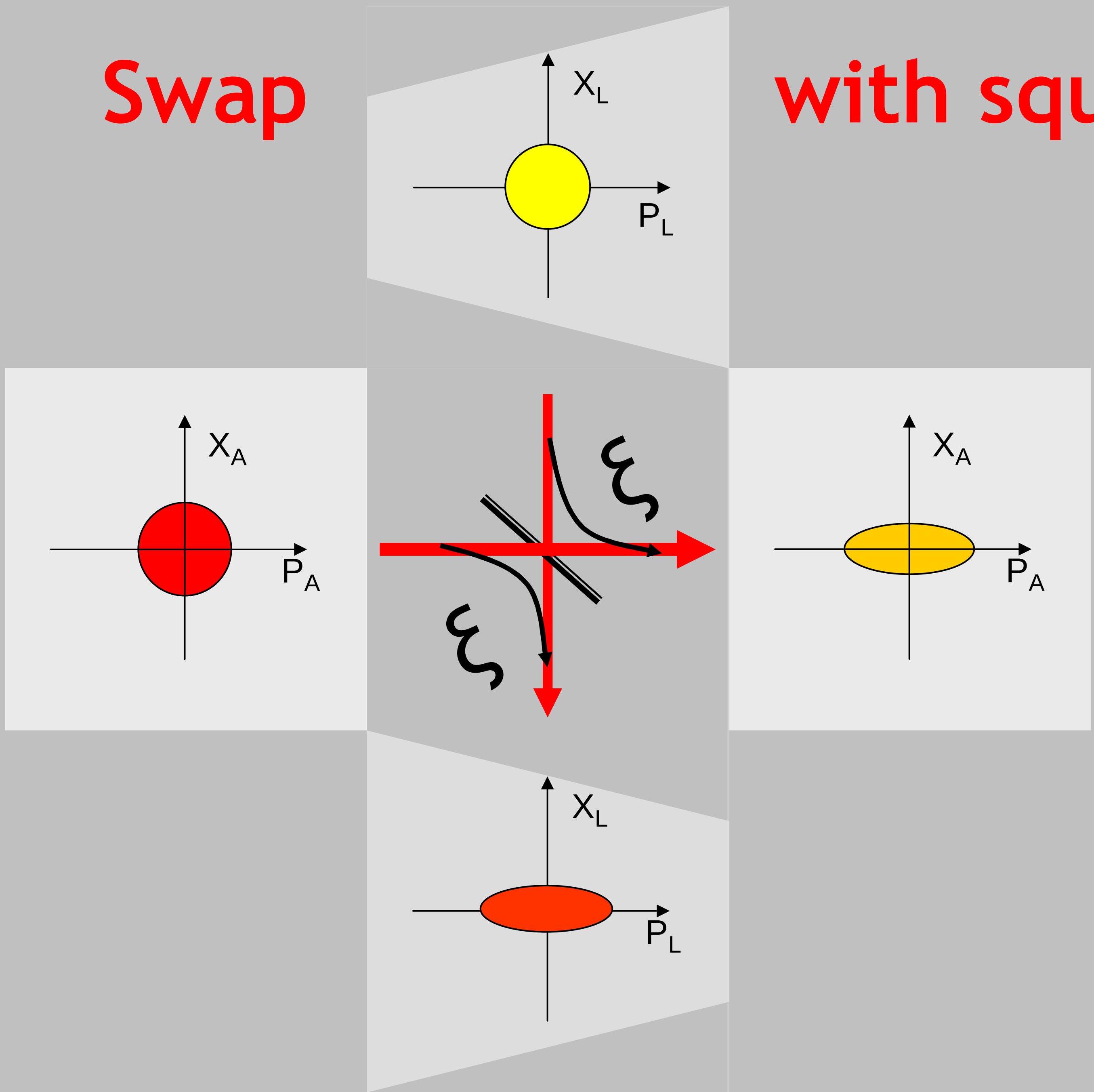
$$H_{int} \propto p_A p_L + x_A x_L / \xi^2$$



Modes



Swap with squeezing



Phase sensitive beamspliter

$$X_A^{out} = \sqrt{t}X_A^{in} + \sqrt{1-t}\xi^{-1}P_L^{in} \qquad X_L^{out} = \sqrt{t}X_L^{in} + \sqrt{1-t}\xi^{-1}P_A^{in}$$

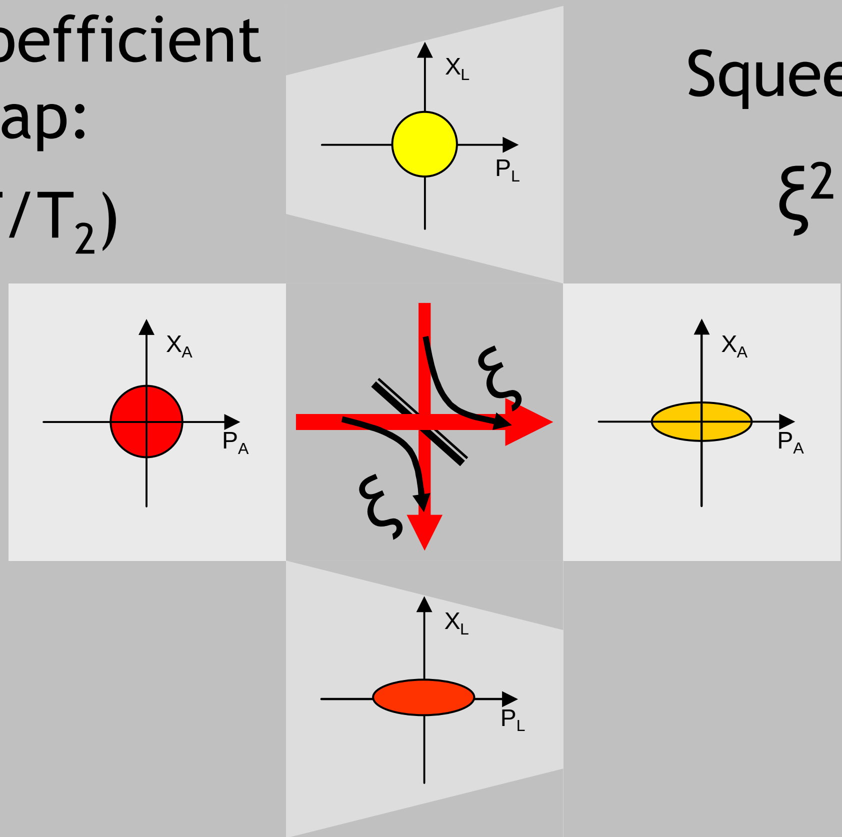
$$P_A^{out} = \sqrt{t}P_A^{in} - \sqrt{1-t}\xi X_L^{in} \qquad P_L^{out} = \sqrt{t}P_L^{in} - \sqrt{1-t}\xi X_A^{in}$$

Transmission coefficient of the swap:

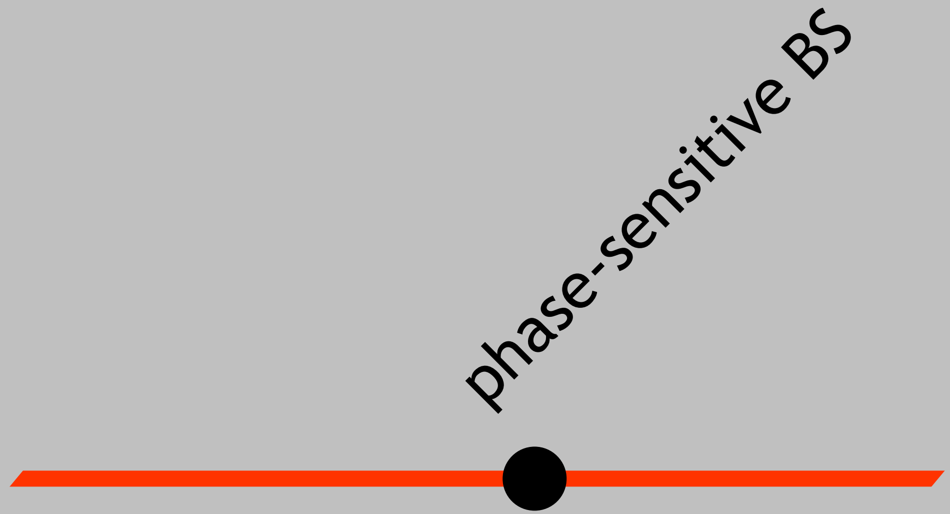
$t=\exp(-2T/T_2)$

Squeezing parameter:

$\xi^2 \propto$ Detuning



Limits

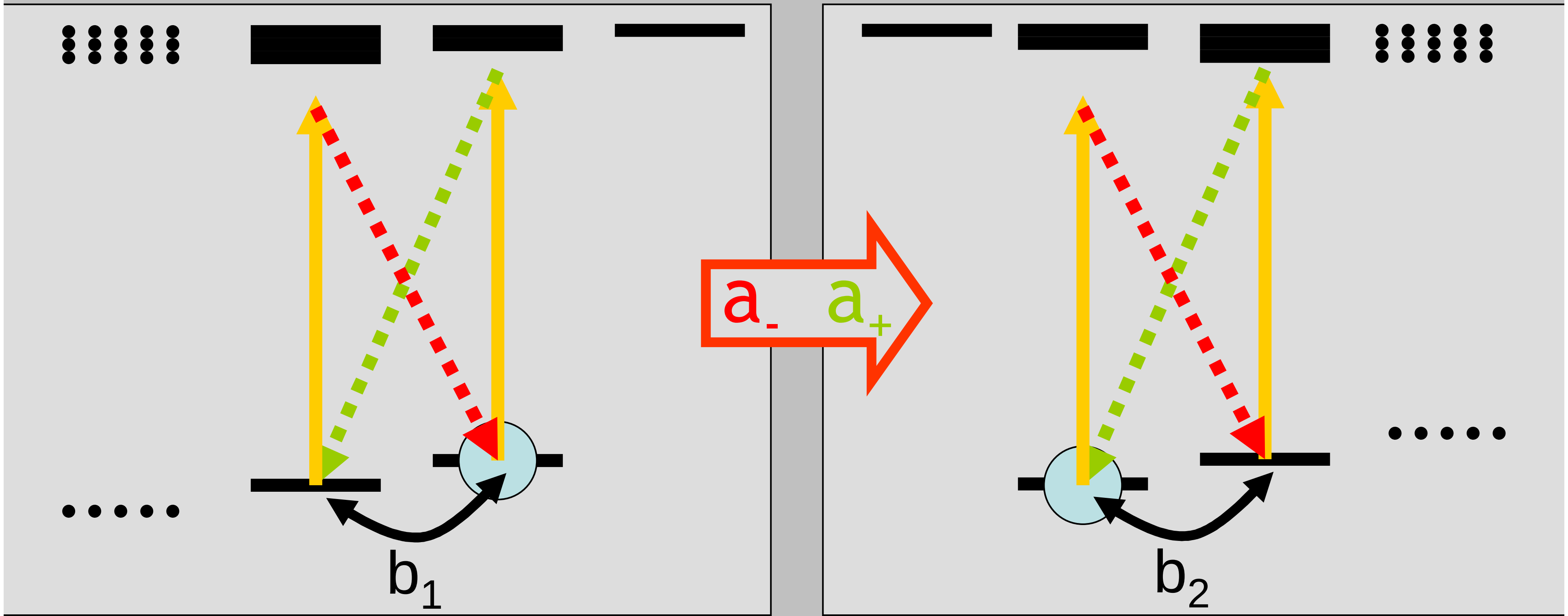


$\xi^2 = 6.3$

$\Delta = 0.85\mathrm{GHz}$

$\xi^2 \propto$ Detuning

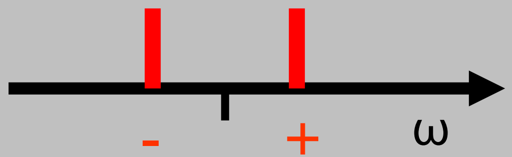
Our true atomic system



$$H_{int} \propto p_{Ac}p_{Lc} + x_{Ac}x_{Lc}/\xi^2$$
$$+p_{As}p_{Ls} + x_{As}x_{Ls}/\xi^2$$

2x Degenerate squeezing

$$\mathrm{Var}(P_C)<\tfrac{1}{2}, \quad \mathrm{Var}(P_S)<\tfrac{1}{2}$$

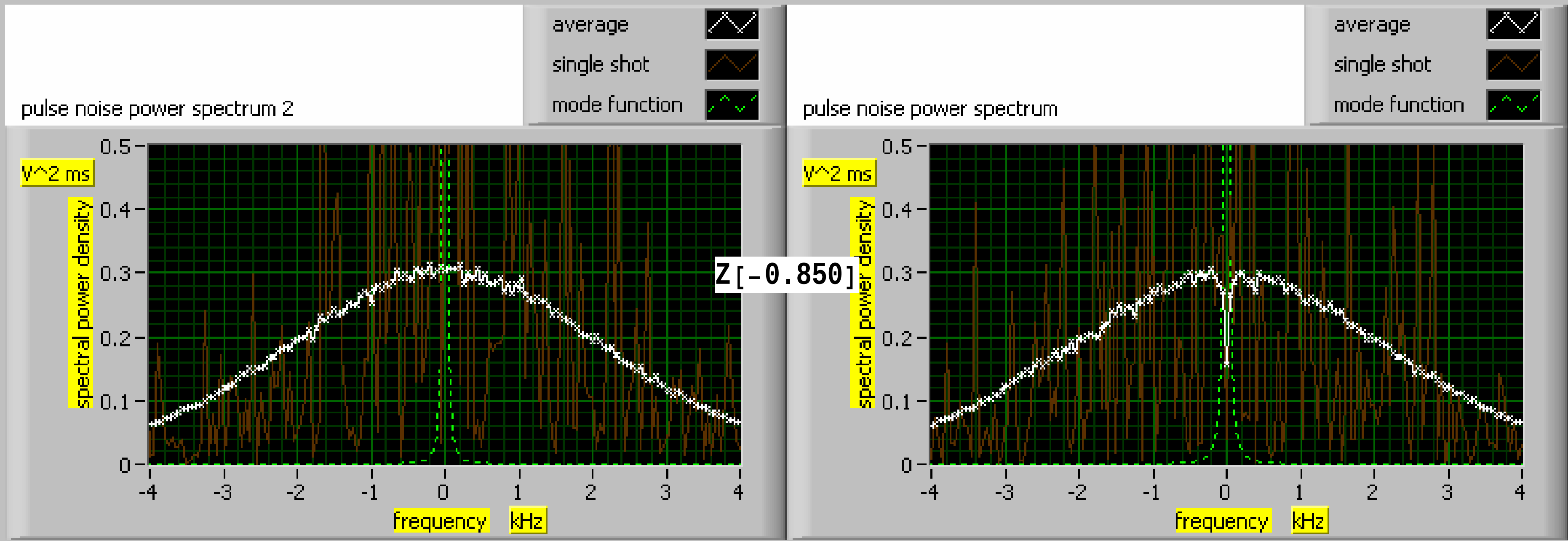


$$P_C=P_- - P_+/\sqrt{2} \qquad P_S=X_- + X_+/\sqrt{2}$$

$$\mathrm{Var}(X_- + X_+)+\mathrm{Var}(P_- - P_+)<2$$

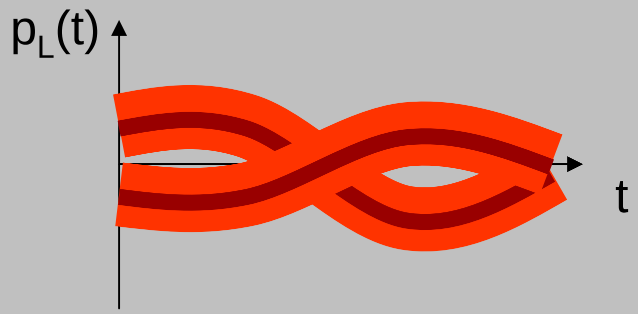
EPR entanglement

Atoms as robust, ultranarrowband squeezers



over 50% noise reduction

Analysing multimode nature



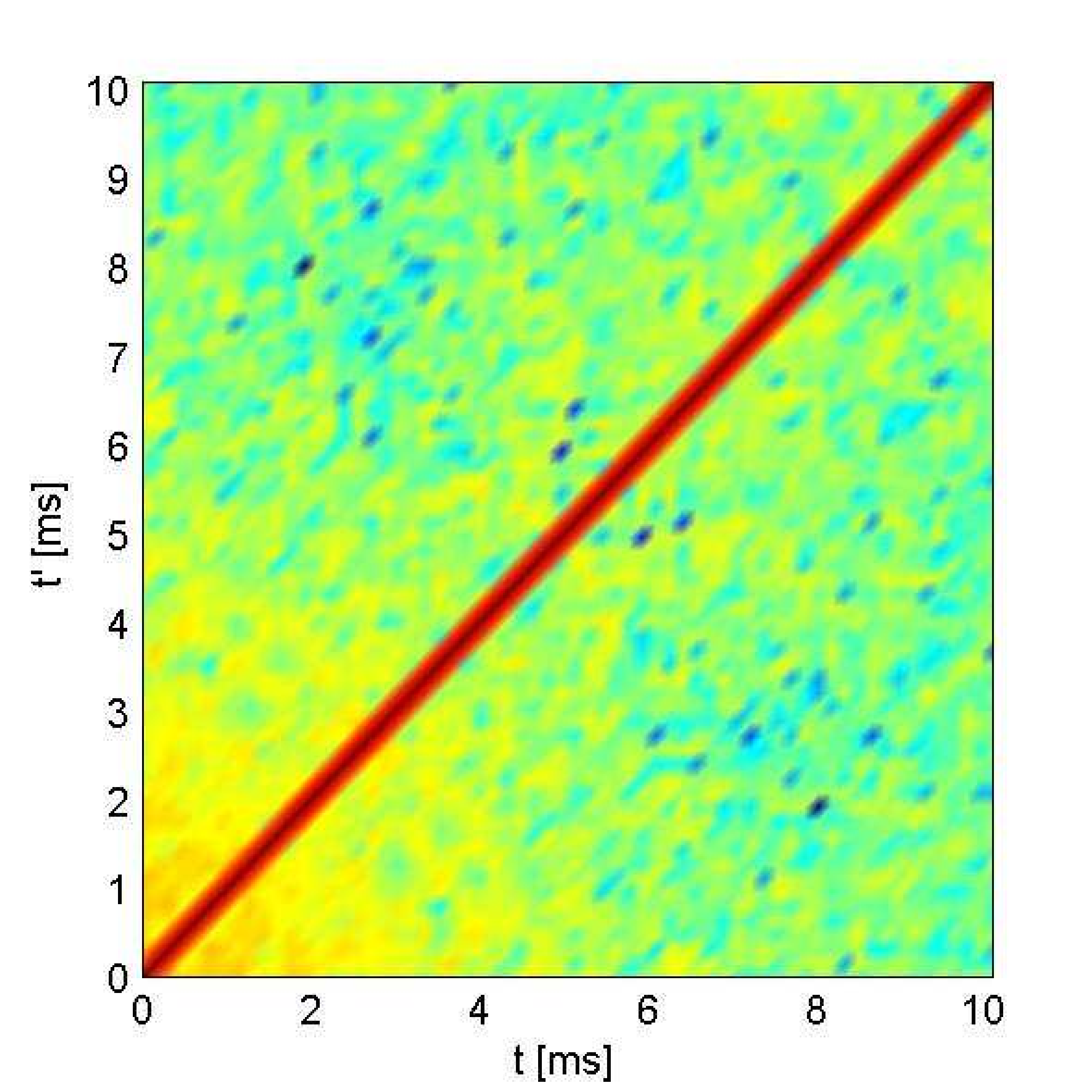
$P = \int dt\, u(t)\, p(t)$

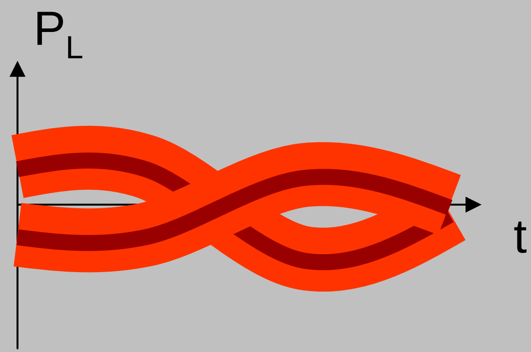
$Var(P)$

$Covar(P_1, P_2)$

How to find a set of independent modes $u_n(t)$?

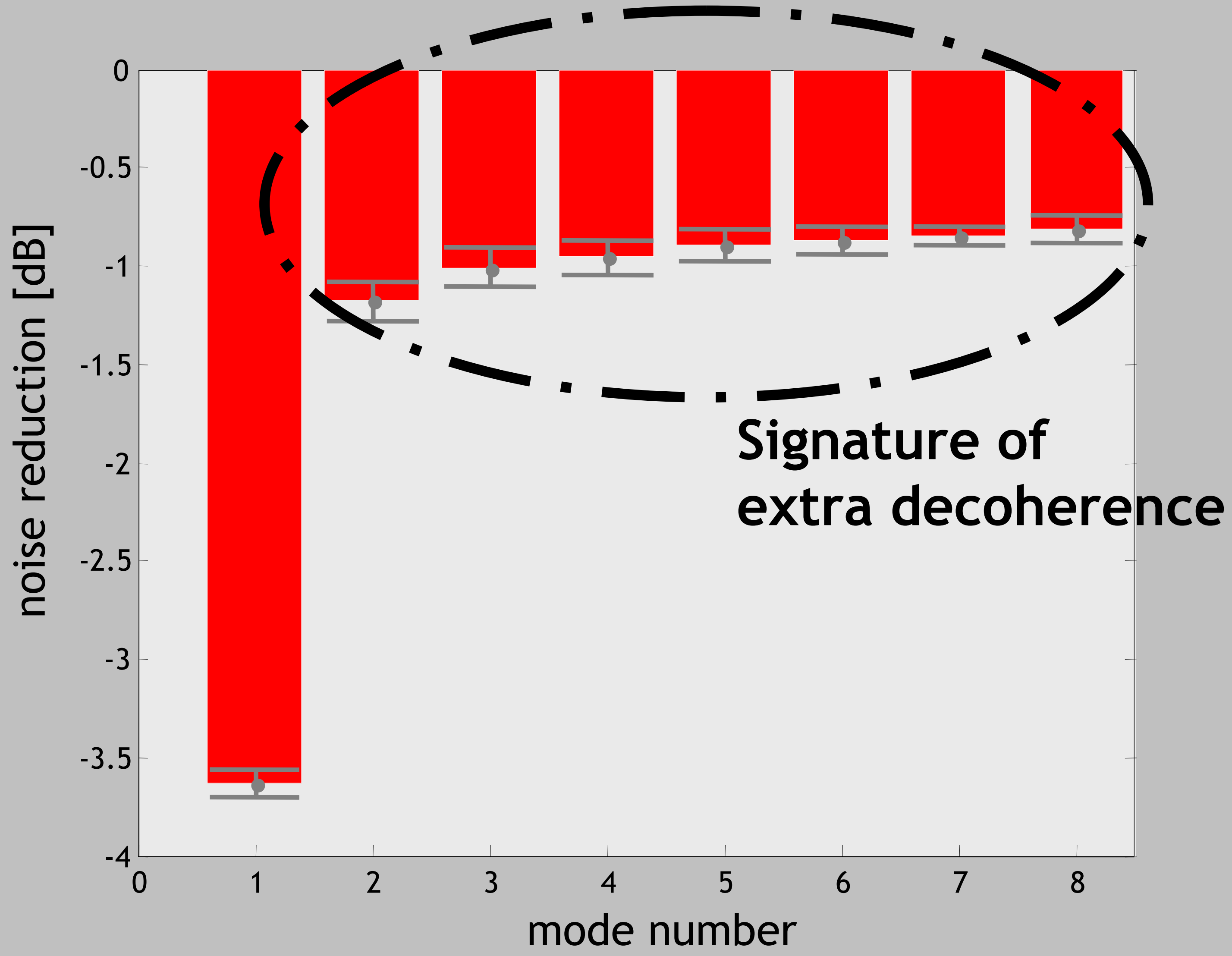
Correlation matrix



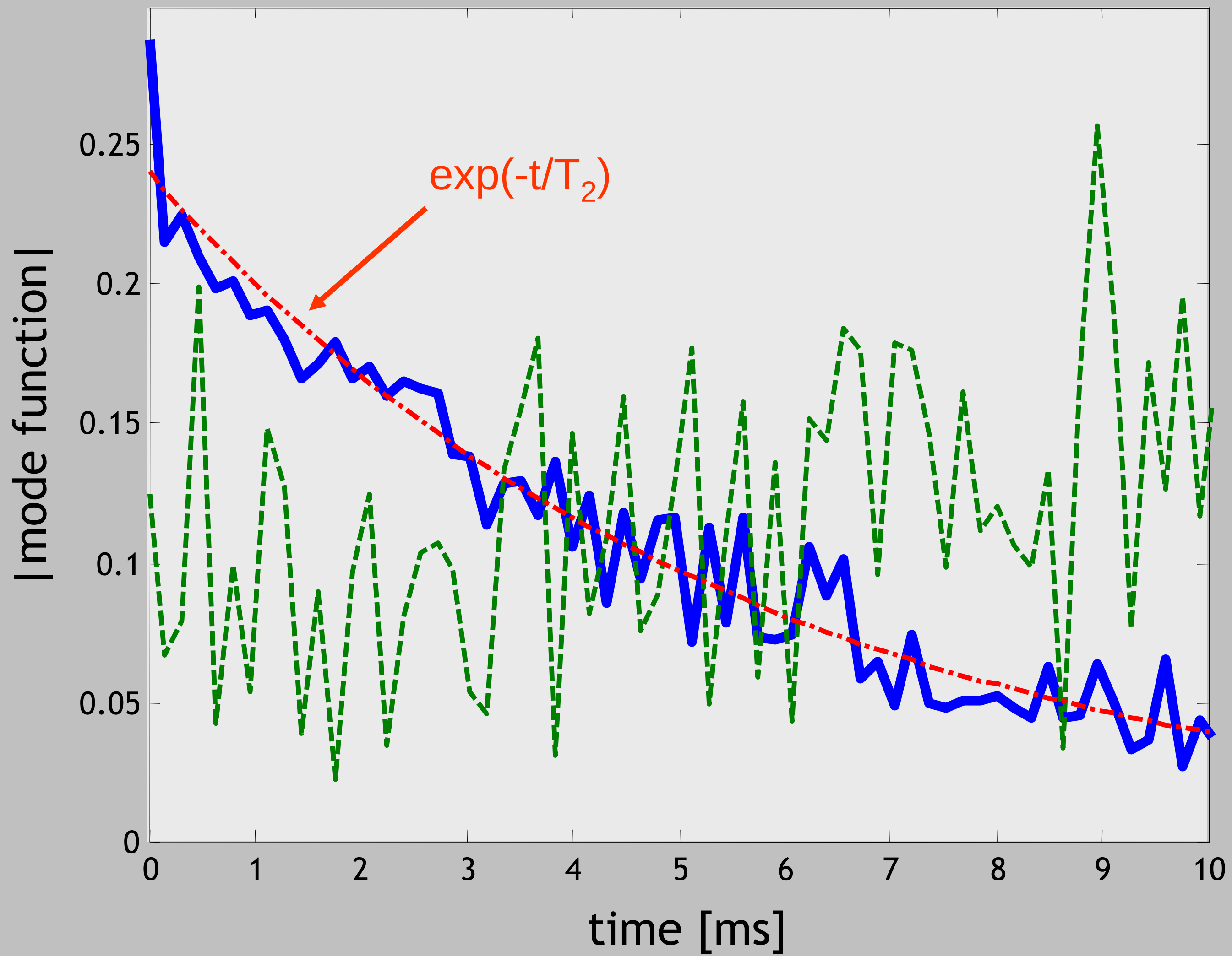


$\langle P_L(t) P_L(t') \rangle$

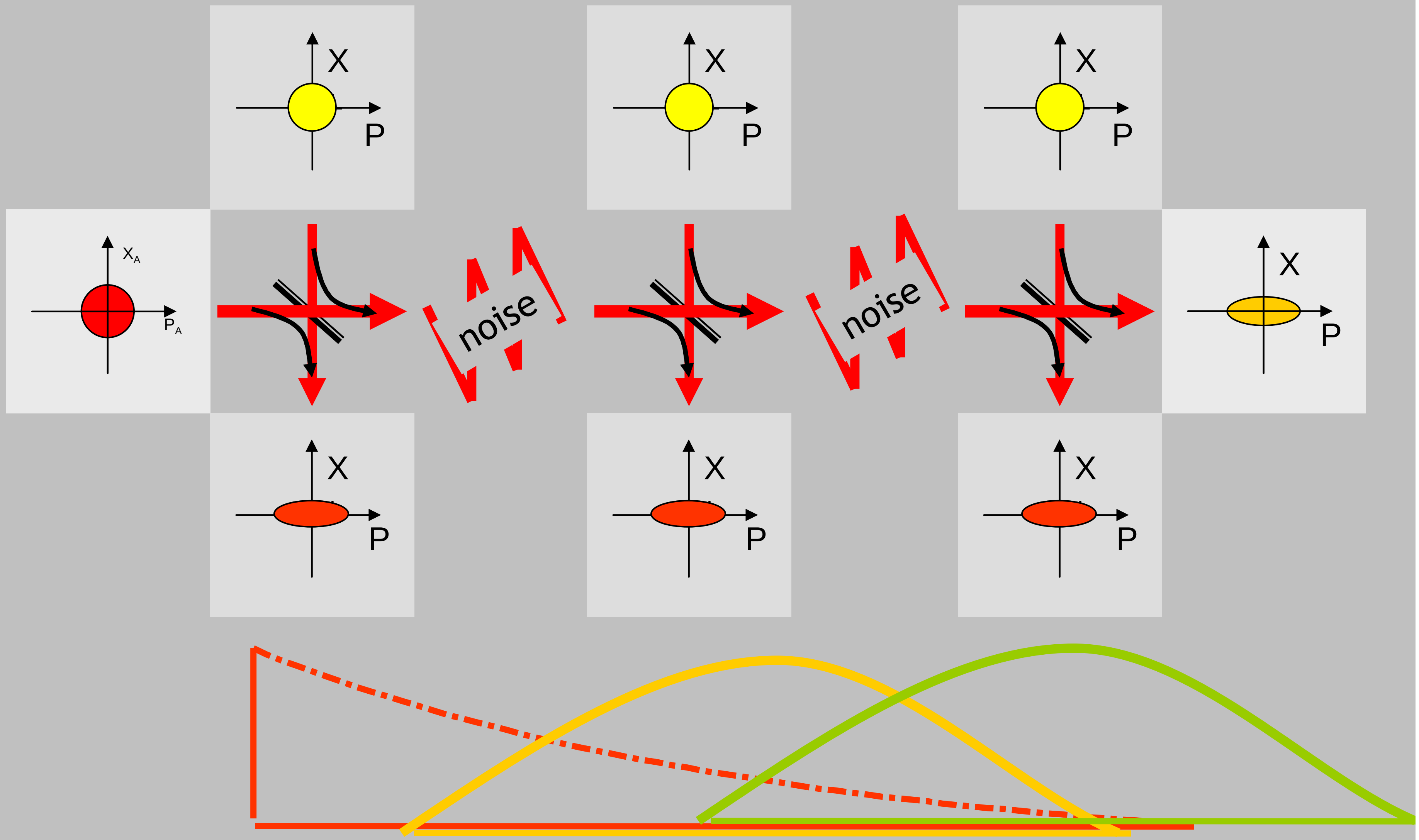
Eigenmodes & squeezing



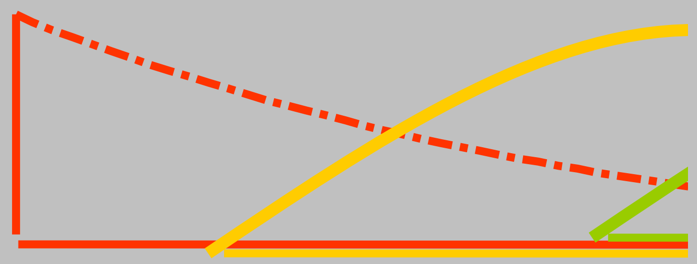
Eigenmodes & squeezing

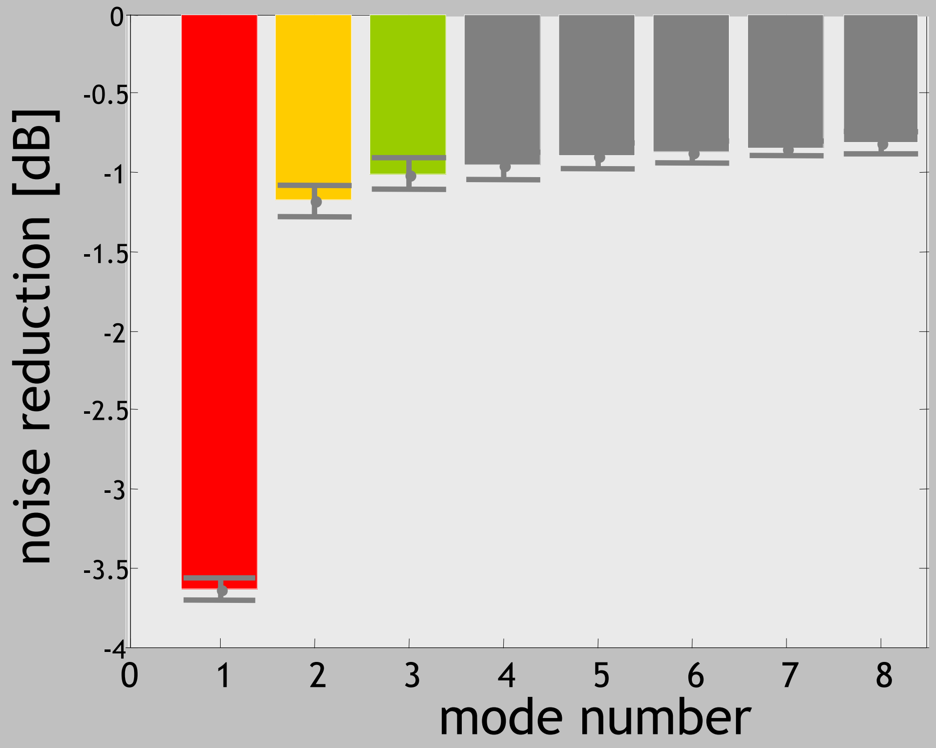


Transverse decoherence



Noise





Summary

- Robust source of EPR-entanglement
- Single spatial mode: motional avg.
- Almost single temporal mode: long T_2
- Compatible with atomic memories
- Modes can be frequency shifted & shaped

- Limited by transverse decoherence