Quantum control of spin correlations in ultracold lattice gases

P. Hauke
(IQOQI)

P.Hauke, R.J.S., M.W.Mitchell & M.Lewenstein,
PRA 87, 021601 (2013).

M.Lewenstein

M.W.Mitchell

ICFO Institut de Ciències Fotòniques

MG roup itchell

MINISTERIO DE CIENCIA E INNOVACIÓN

Generalitat de Catalunya

erc

MARIE CURIE ACTIONS

Fundació Privada CELLEX

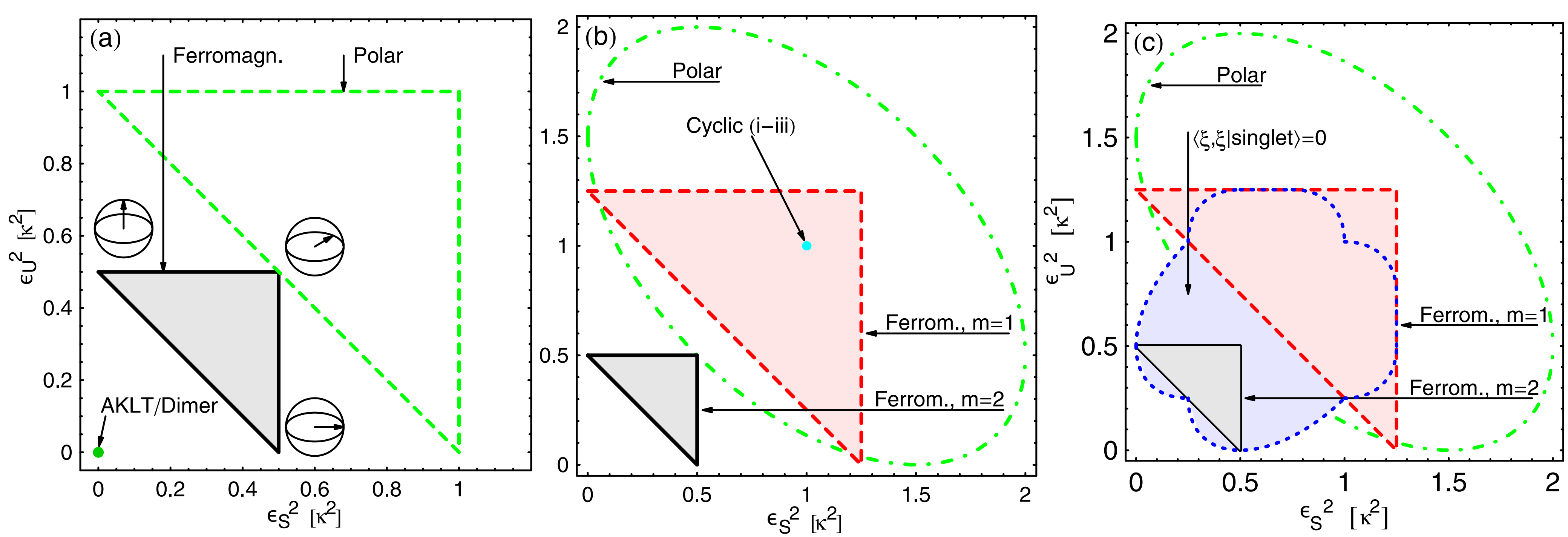
icrea Institució Catalana de Recerca i Estudis Avançats

Quantum Polarization Spectroscopy

PRL **98,** 100404 (2007) PHYSICAL REVIEW LETTERS week ending 9 MARCH 2007

Quantum Polarization Spectroscopy of Ultracold Spinor Gases

K. Eckert,[1] Ł. Zawitkowski,[2] A. Sanpera,[3] M. Lewenstein,[4] and E. S. Polzik[5,6]

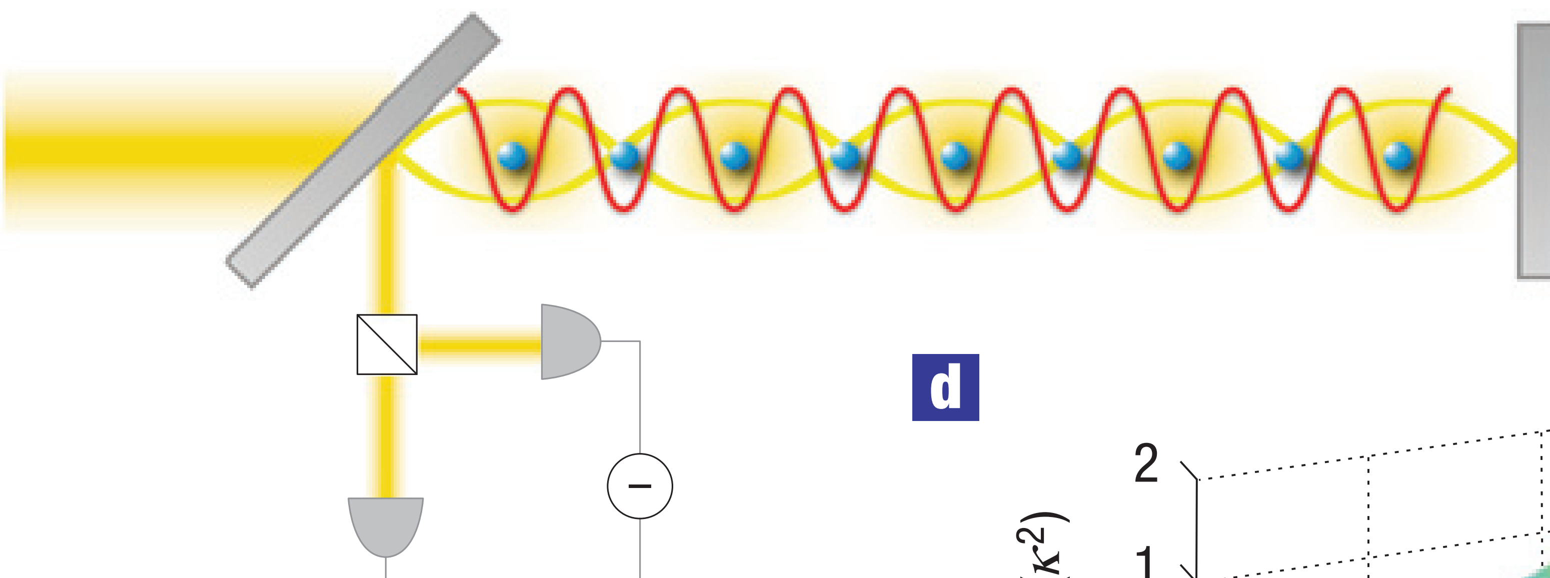


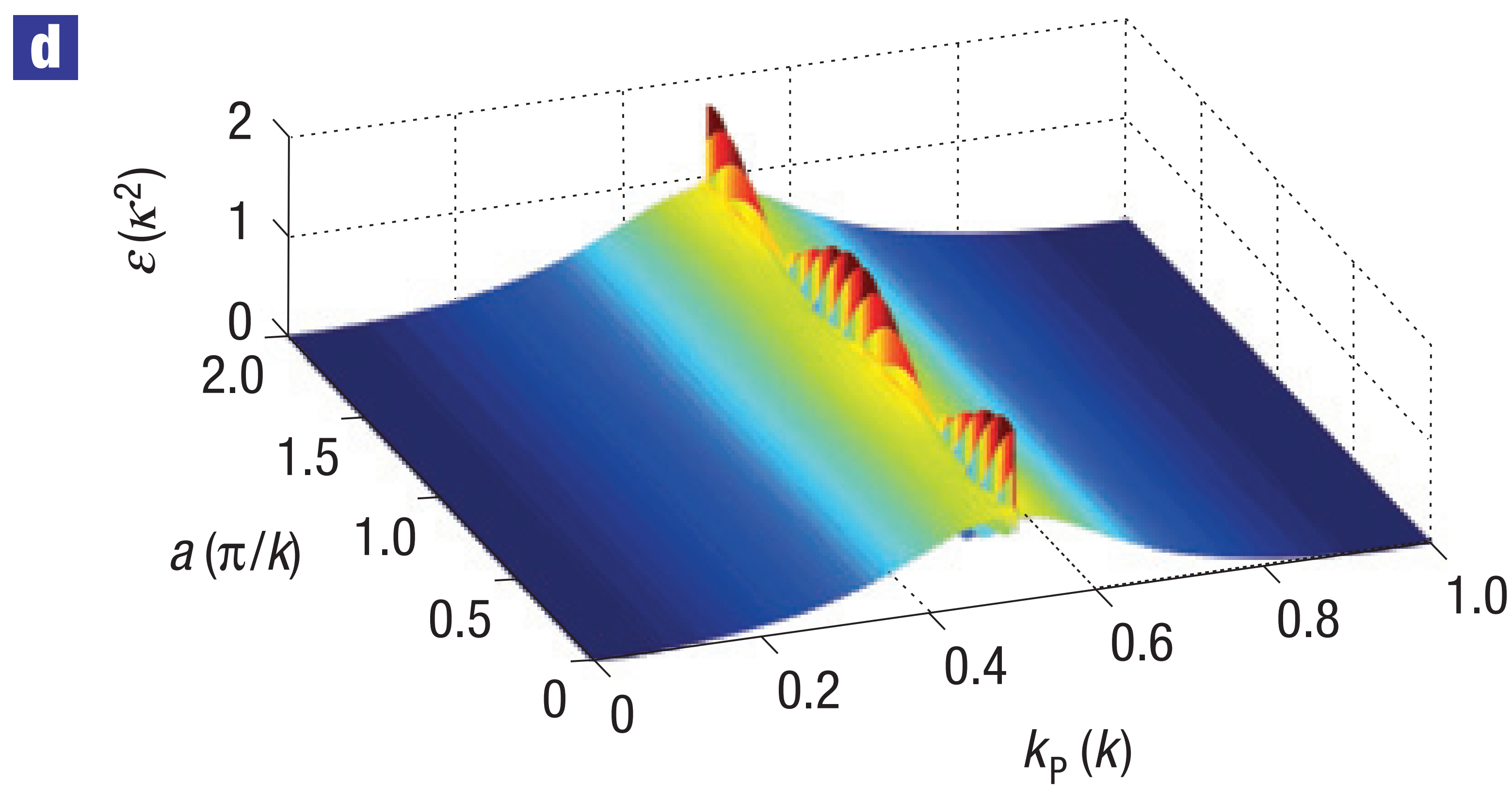
Eckert, PRL 98, 100404 (2007)

Quantum Polarization Spectroscopy

Quantum non-demolition detection of strongly correlated systems

KAI ECKERT[1], ORIOL ROMERO-ISART[1], MIRTA RODRIGUEZ[2], MACIEJ LEWENSTEIN[2,3],
EUGENE S. POLZIK[4] AND ANNA SANPERA[1,3]*

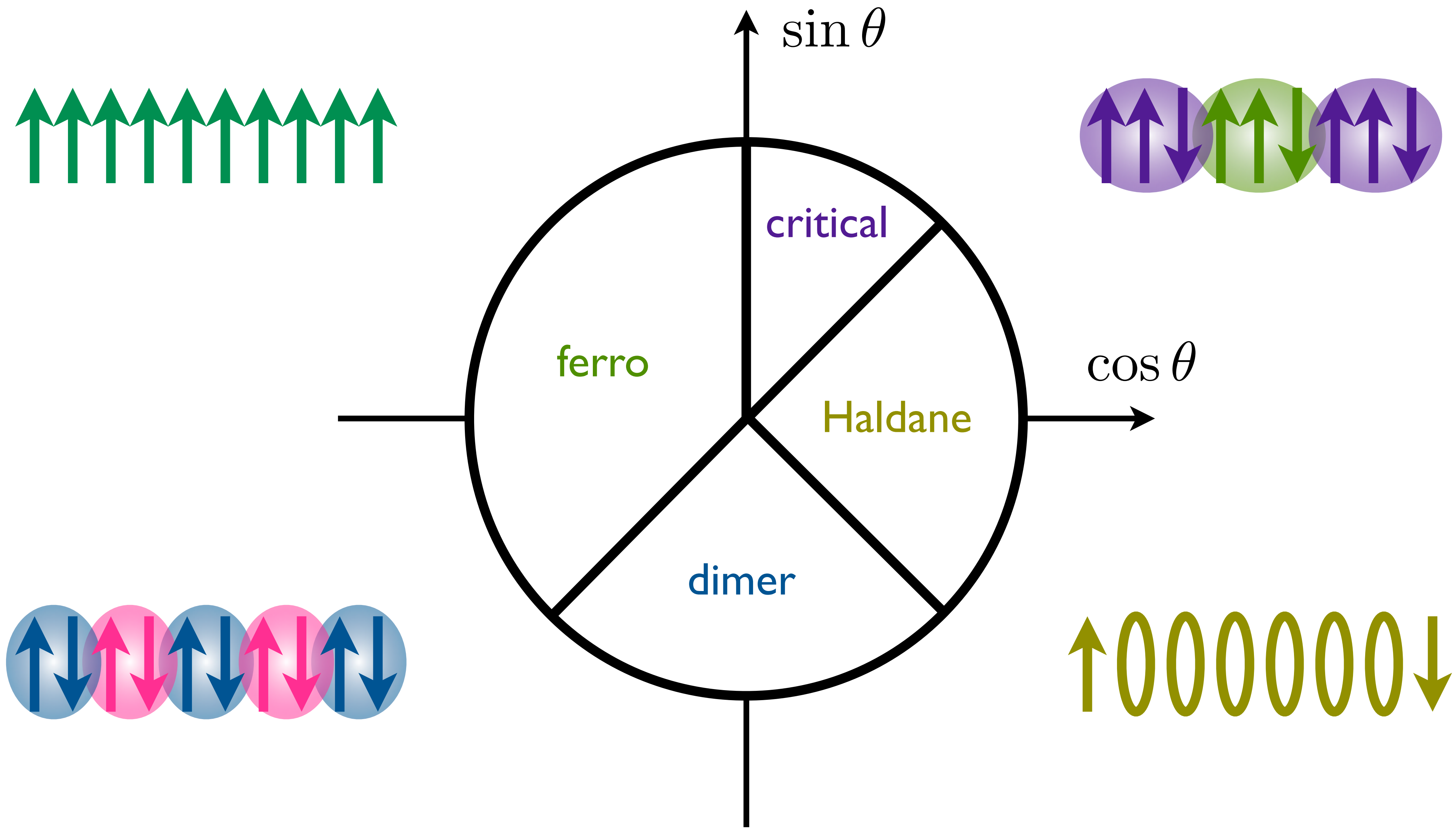




Eckert, Nat. Phys. 4, 50 (2008)

Example: 1D chain of spin-1 atoms described by the bilinear-biquadratic Hamiltonian

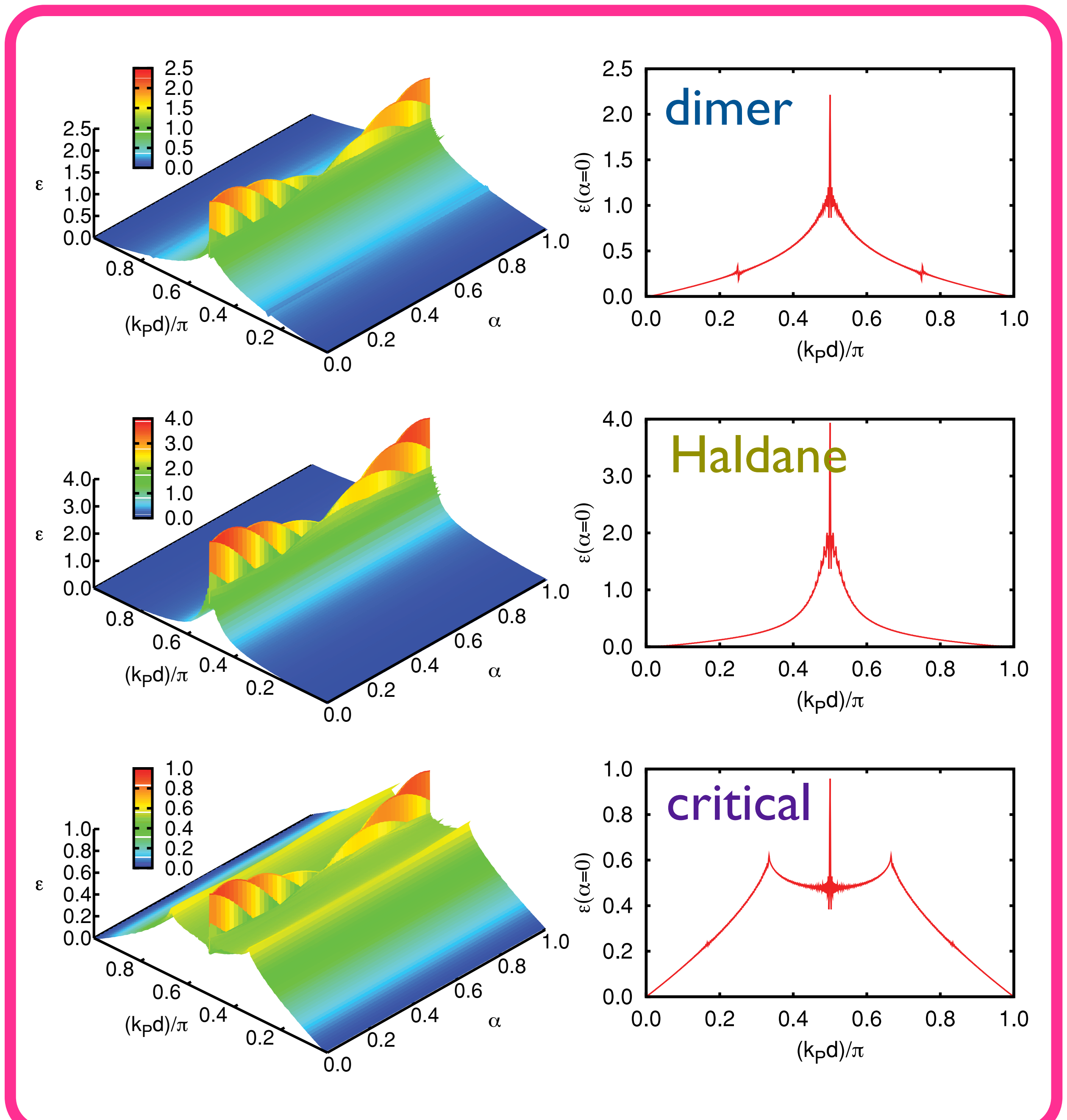
$$H = \sum_i \cos\theta \mathbf{S}_i \cdot \mathbf{S}_{i+1} + \sin\theta \left(\mathbf{S}_i \cdot \mathbf{S}_{i+1}\right)^2$$

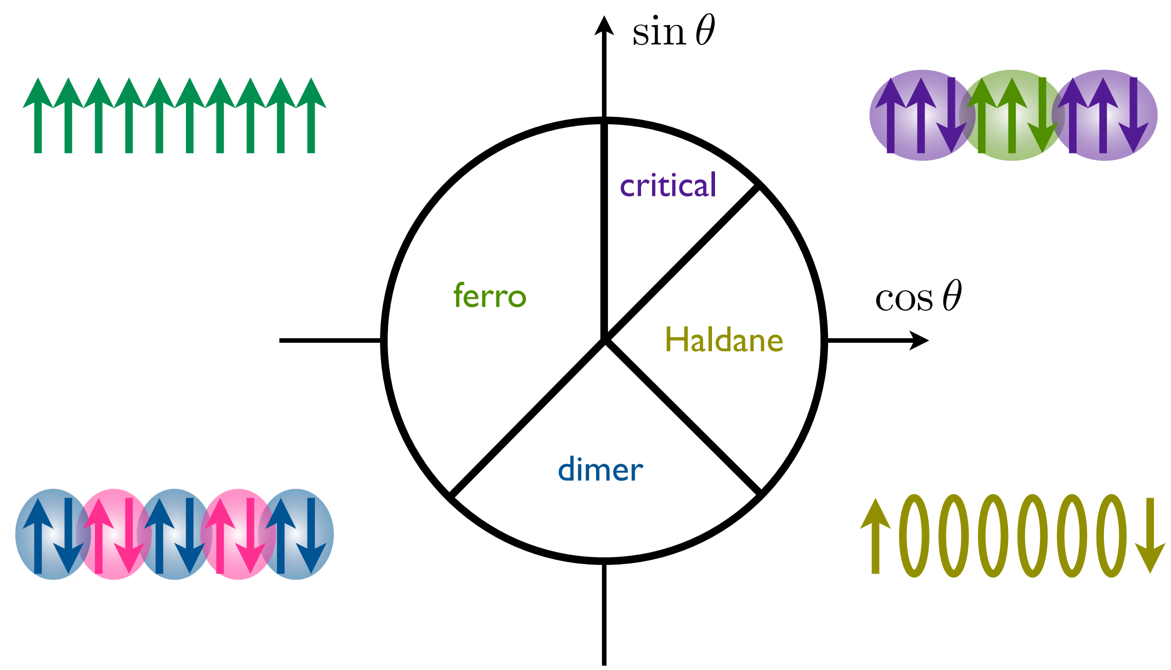


De Chiara, PRA 83, 021604 (2011)

Example: 1D chain of spin-1 atoms described by the bilinear-biquadratic Hamiltonian

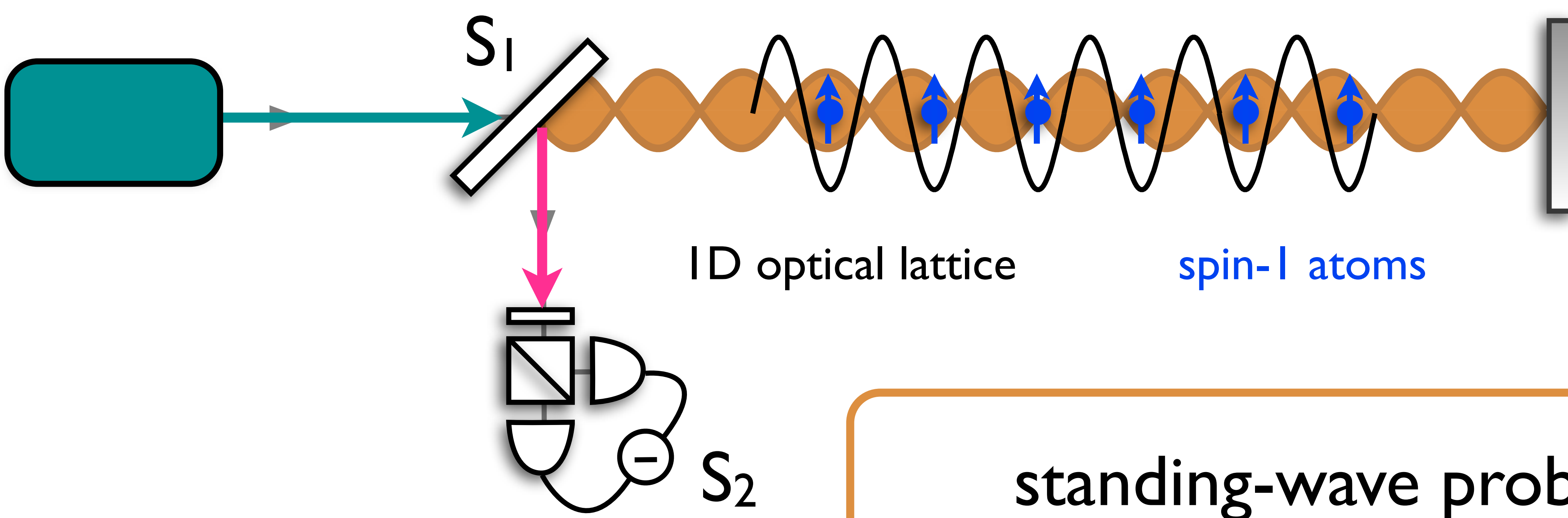
$$H = \sum_i \cos\theta \mathbf{S}_i \cdot \mathbf{S}_{i+1} + \sin\theta \left(\mathbf{S}_i \cdot \mathbf{S}_{i+1}\right)^2$$





De Chiara, PRA 83, 021604 (2011)

Quantum Polarization Spectroscopy



standing-wave probe

$$c_i(k_p) = (1 + \cos(2k_p r_i))/2$$

atom-light interaction

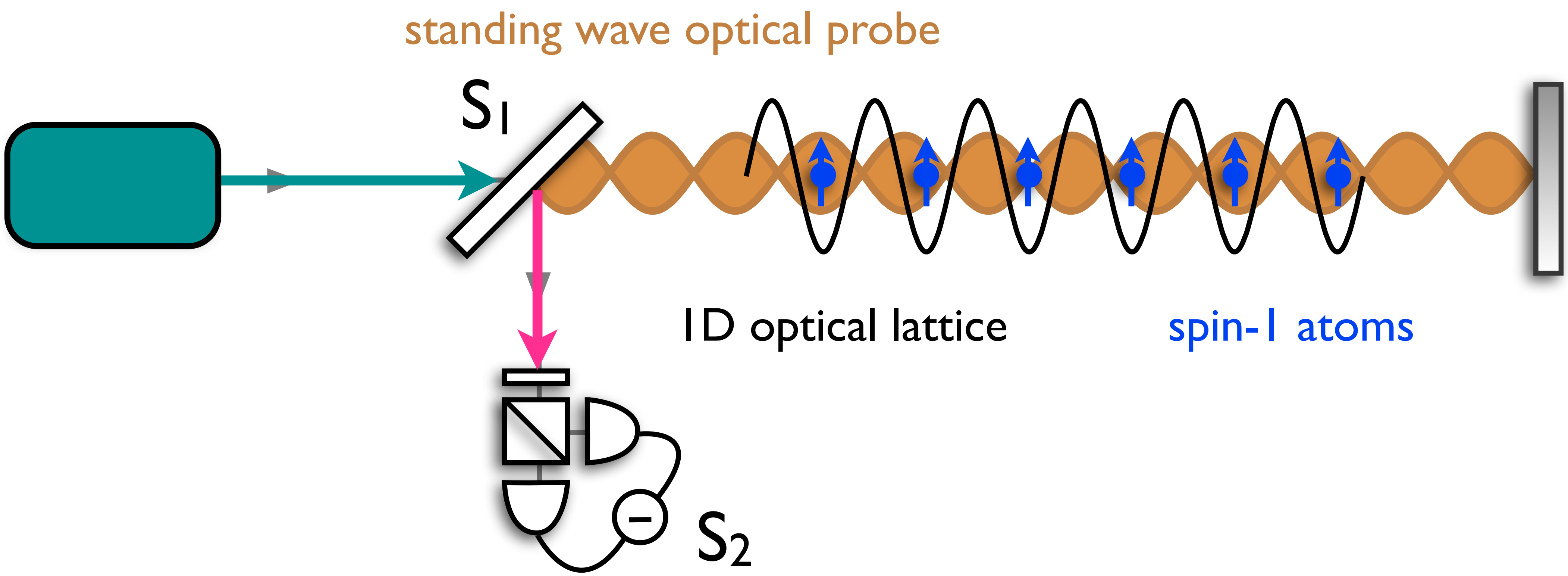
$$H_p = \Omega_p \sum_i c_i(k_p) J_{z,i} S_3$$

measurement

$$S_2^{(\mathrm{out})} = S_2^{(\mathrm{in})} + \kappa_p \sum_i c_i(k_p) J_{z,i}$$

$$J_{\alpha,i} \equiv \sum_{n=1}^{n_a} j_{\alpha,i}^{(n)} \qquad \Omega_p \equiv \frac{\sigma(\Delta)}{A}$$

Quantum Polarization Spectroscopy



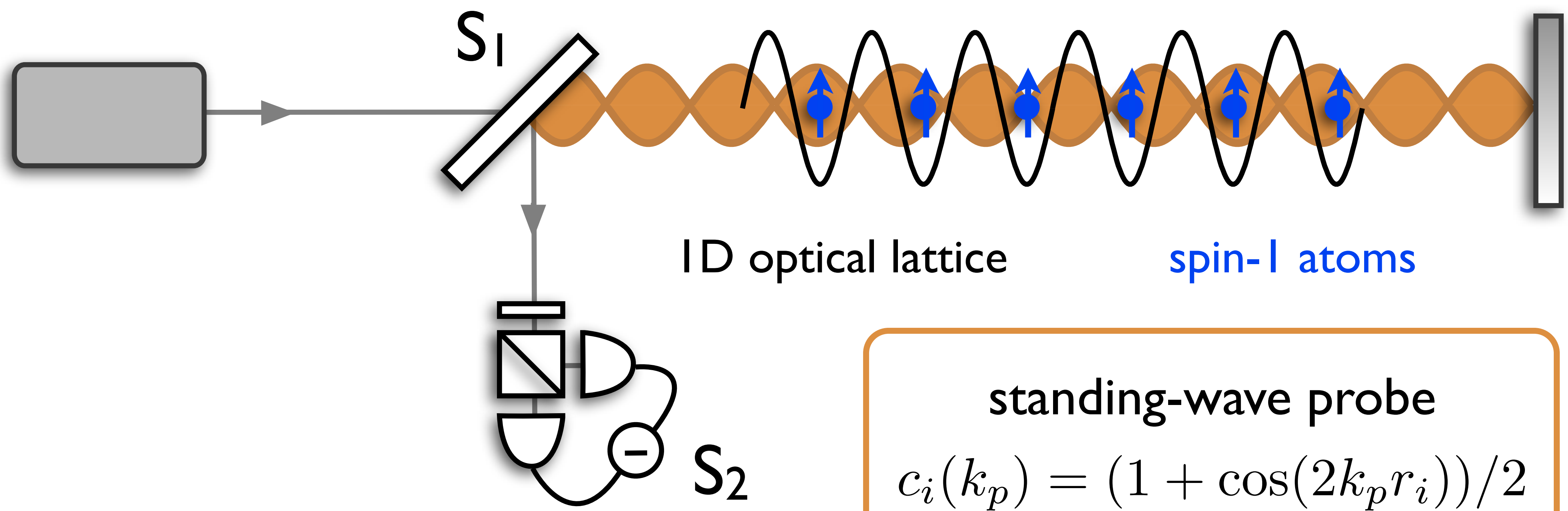
detected variance

$$\Delta^2 S_2^{(\mathrm{out})} = \Delta^2 S_2^{(\mathrm{in})} + \kappa_p^2 \sum_{i,j} c_i(k_p) c_j(k_p) G_{ij}$$

spin correlation function

$$G_{ij} \equiv \langle J_z(r_i) J_z(r_j) \rangle - \langle J_z(r_i) \rangle \langle J_z(r_j) \rangle$$

Spin Squeezing



standing-wave probe

$$c_i(k_p) = (1 + \cos(2k_p r_i))/2$$

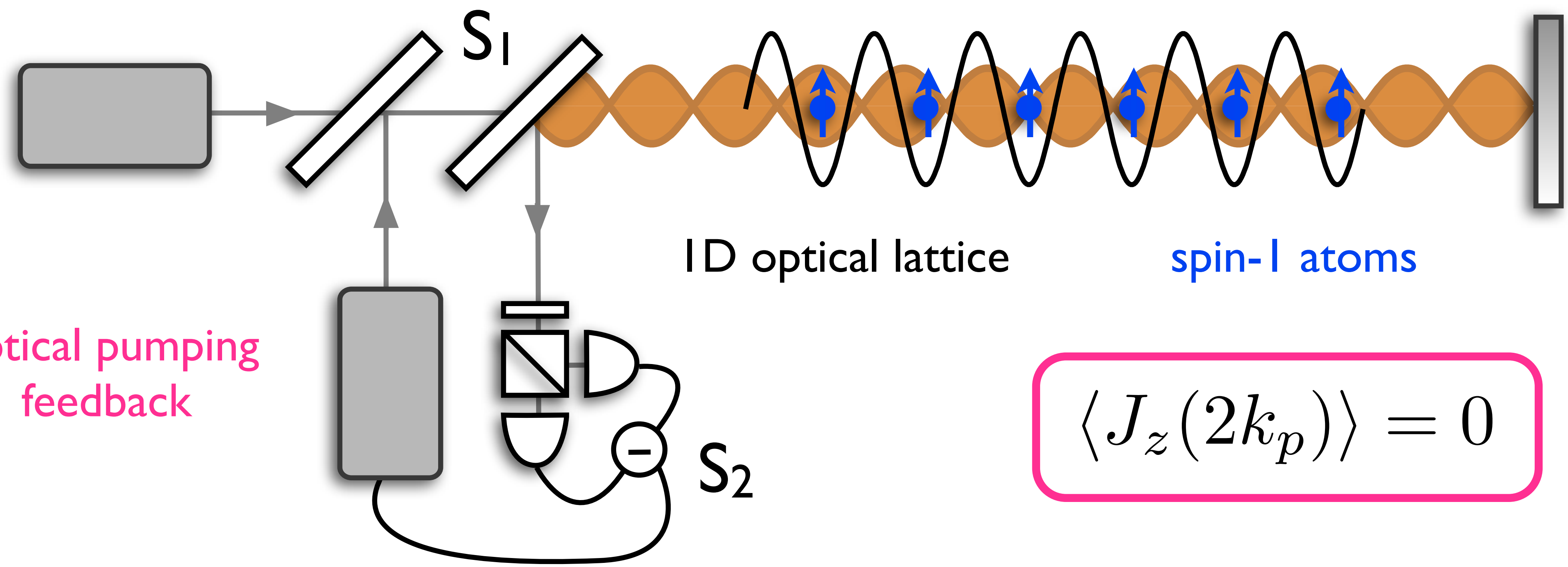
squeeze atomic spin wave

$$\Delta^2 J_z^{(\mathrm{out})}(\pm 2k_p) \simeq \frac{\Delta^2 J_z^{(\mathrm{in})}(\pm 2k_p)}{1+\kappa_p^2}$$

Hauke, PRA 87, 021601 (2013)

$$J_\alpha(k) \equiv \frac{1}{\sqrt{n_\mathrm{s}}} \sum_i J_{\alpha,i} \exp(ikr_i)$$

Feedback control



$$\langle J_z(2k_p)\rangle = 0$$

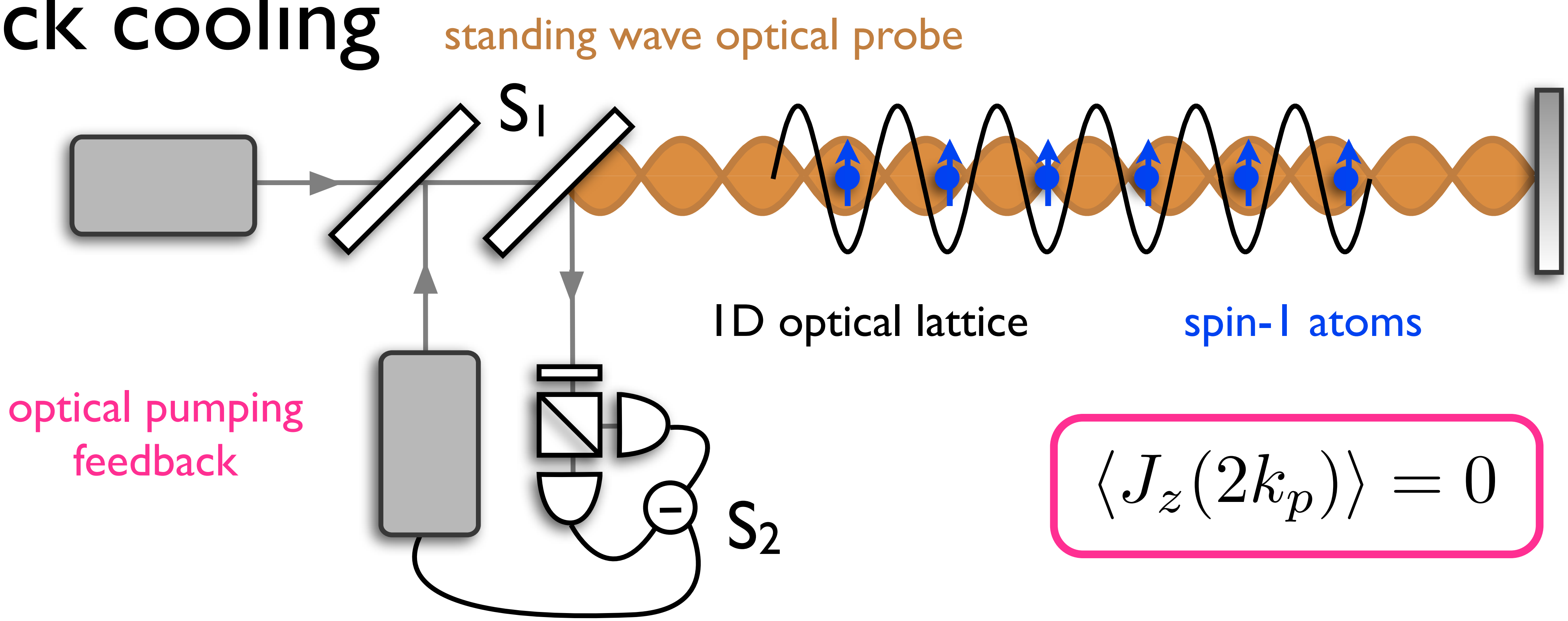
squeeze atomic spin wave

$$\Delta^2 J_z^{(\mathrm{out})}(\pm 2k_p) \simeq \frac{\Delta^2 J_z^{(\mathrm{in})}(\pm 2k_p)}{1+\kappa_p^2}$$

Hauke, PRA 87, 021601 (2013)

$$J_\alpha(k) \equiv \frac{1}{\sqrt{n_\mathrm{s}}}\sum_i J_{\alpha,i}\exp(ikr_i)$$

Feedback cooling



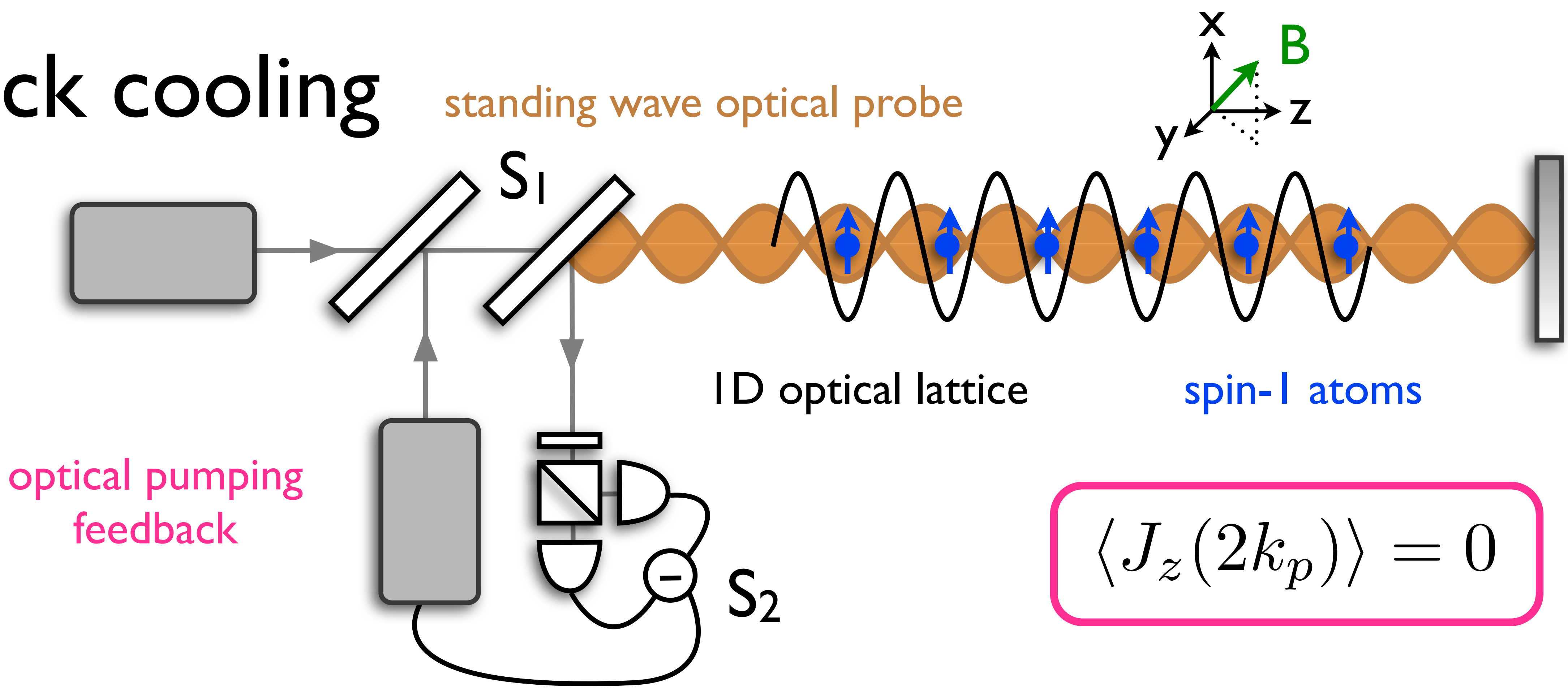
$$\langle J_z(2k_p)\rangle = 0$$

Heisenberg uncertainty relation

$$\Delta J_\alpha(k_1)\Delta J_\beta(k_2) \geq \frac{1}{4}|\langle J_\gamma(k_1+k_2)\rangle|$$

Hauke, PRA 87, 021601 (2013)

Feedback cooling



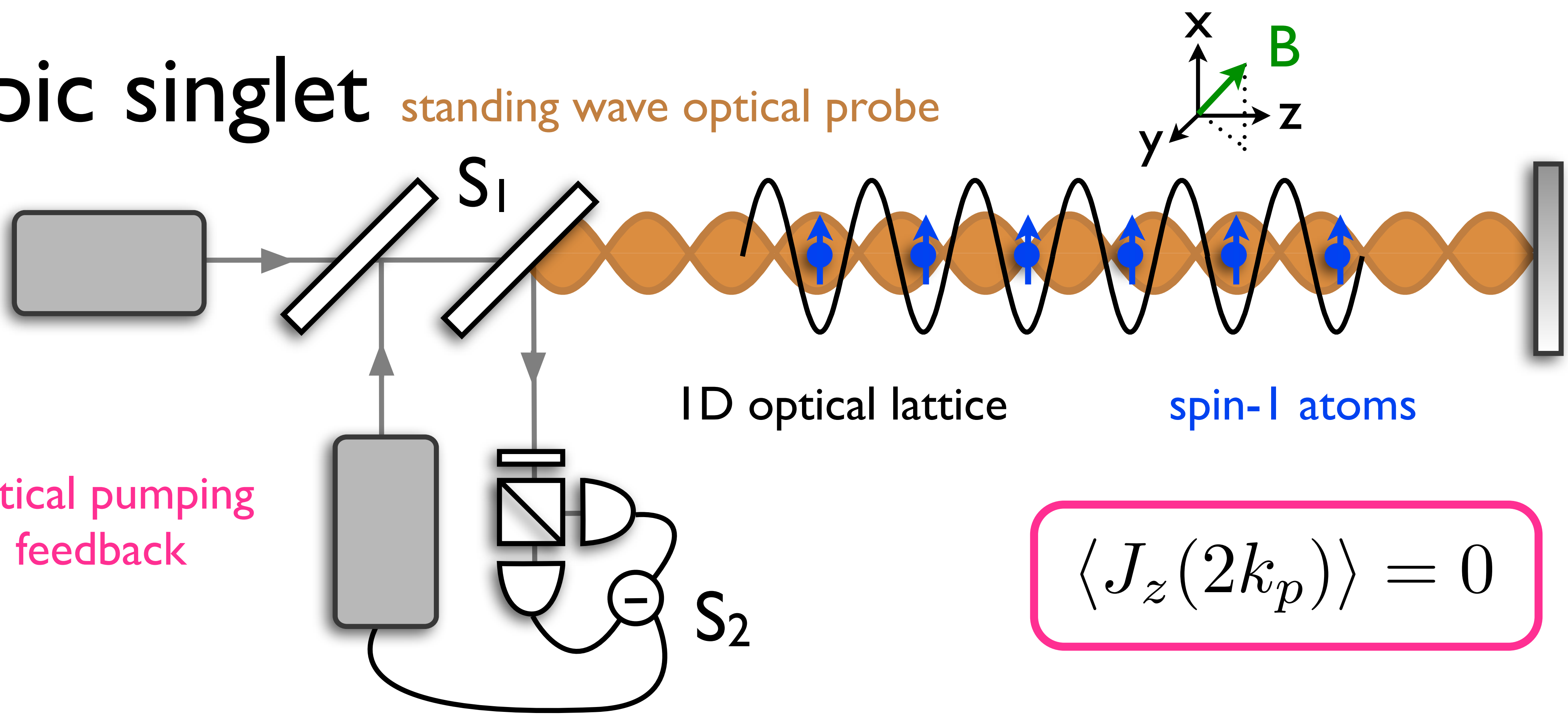
$$\langle J_z(2k_p)\rangle = 0$$

Heisenberg uncertainty relation

$$\Delta J_\alpha(k_1)\Delta J_\beta(k_2) \geq \frac{1}{4}|\langle J_\gamma(k_1+k_2)\rangle|$$

Hauke, PRA 87, 021601 (2013)

Macroscopic singlet



$$\langle J_z(2k_p)\rangle = 0$$

mascroscopic spin singlet

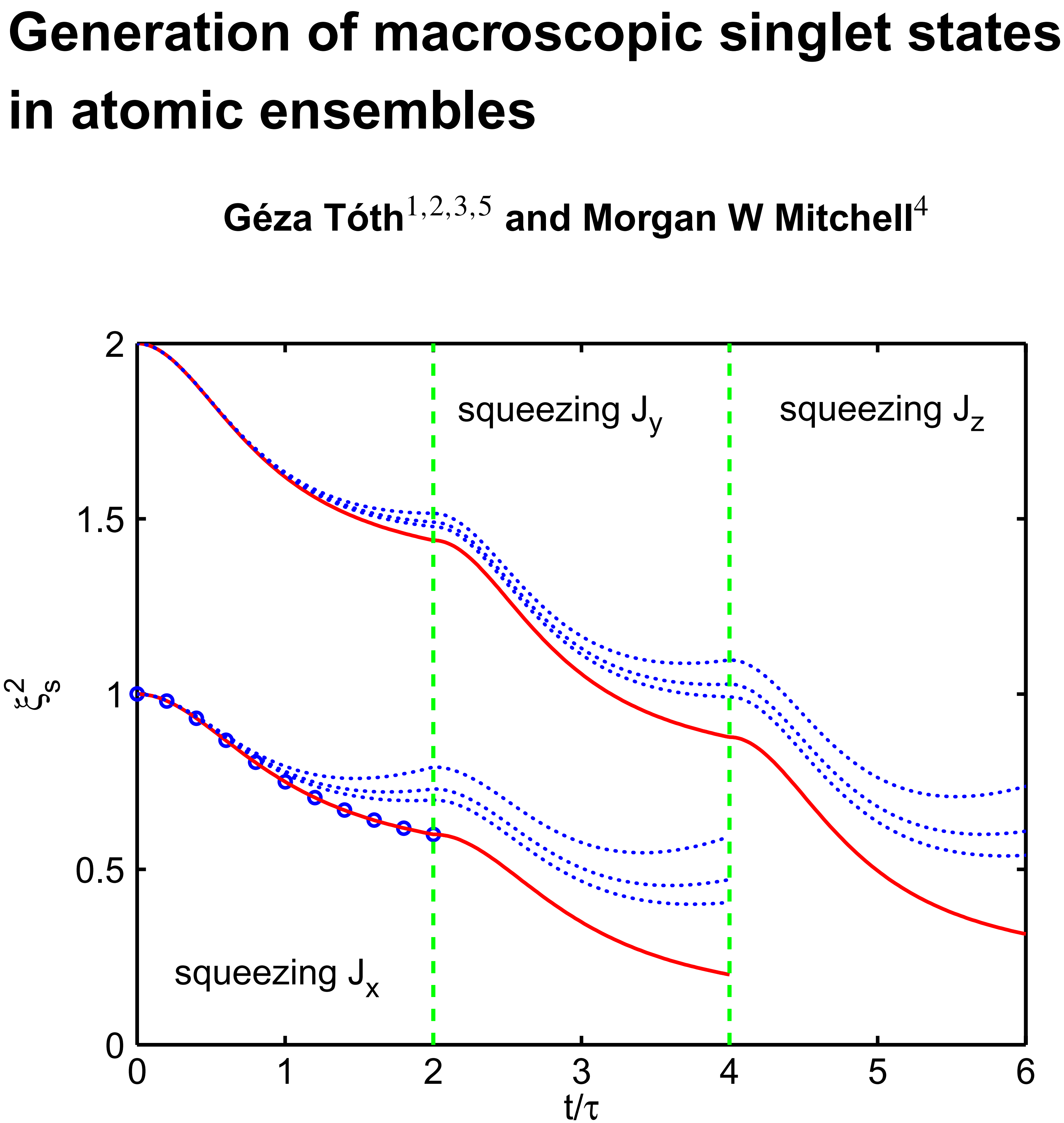
$$\Delta^2 J_\alpha(2k_p) \to 0 \quad \& \quad \langle J_\alpha(2k_p)\rangle = 0$$

$$|\mathbf{J}(2k_p)| \to 0$$

Hauke, PRA 87, 021601 (2013)

G.Tóth, NJP 12, 053007 (2010)

I. Urizar-Lanz, PRA 88, 013626 (2013)



spin squeezing via QND measurement

$$\Delta^2 J_z^{(\mathrm{out})} = \frac{\Delta^2 J_z^{(\mathrm{in})}}{1+\kappa}$$

+

quantum control

$$\langle J_z(2k_p) \rangle = 0$$

=

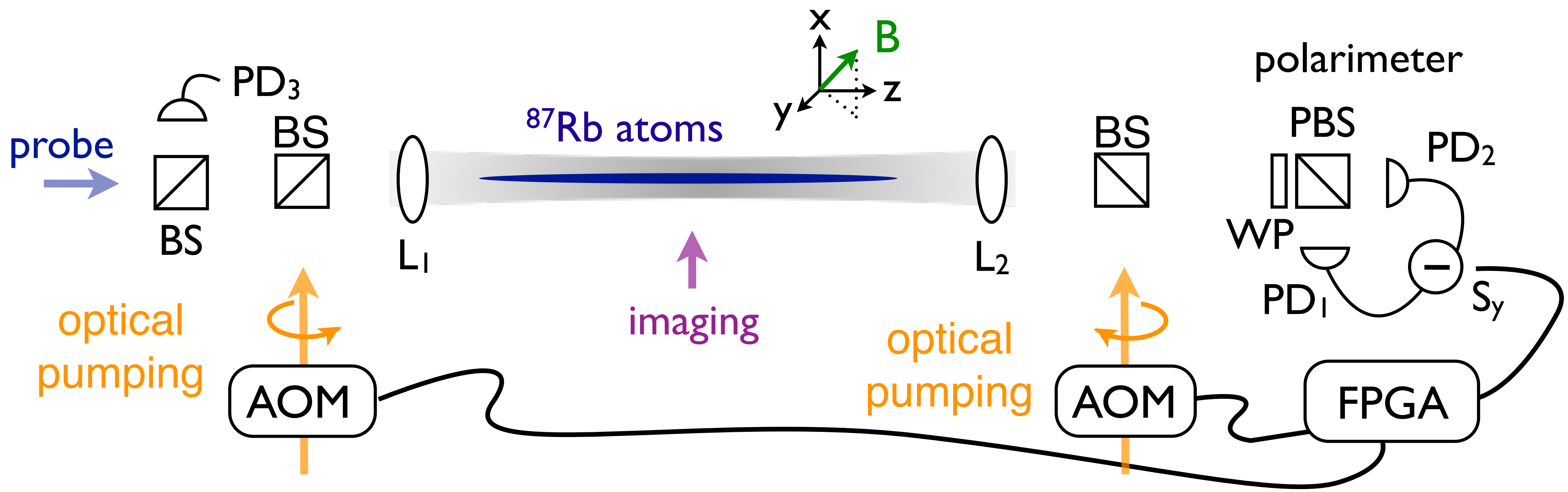
macroscopic singlet

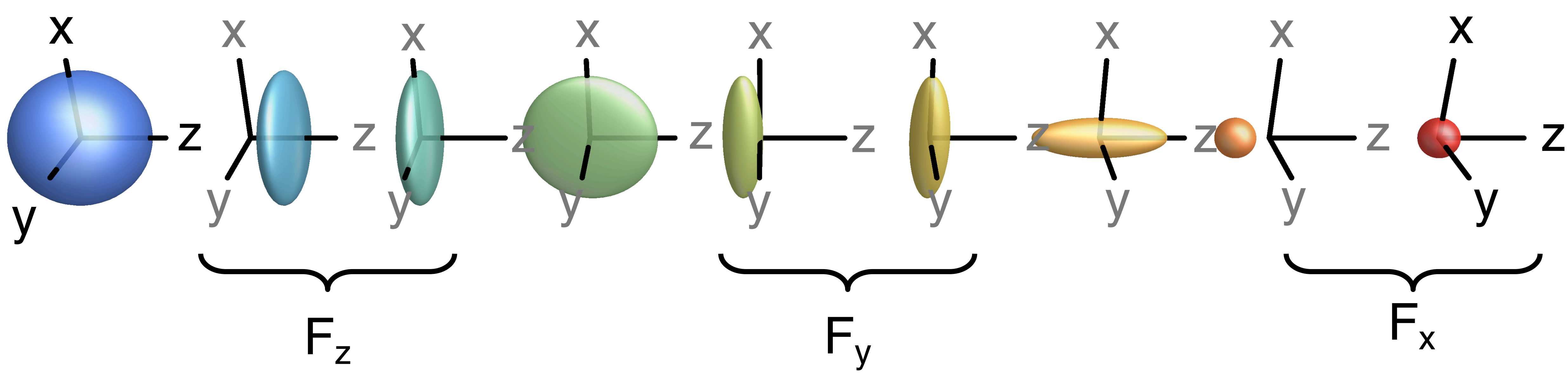
$$|\mathbf{J}| \rightarrow 0$$

G.Tóth, NJP 12, 053007 (2010)

I. Urizar-Lanz, PRA 88, 013626 (2013)

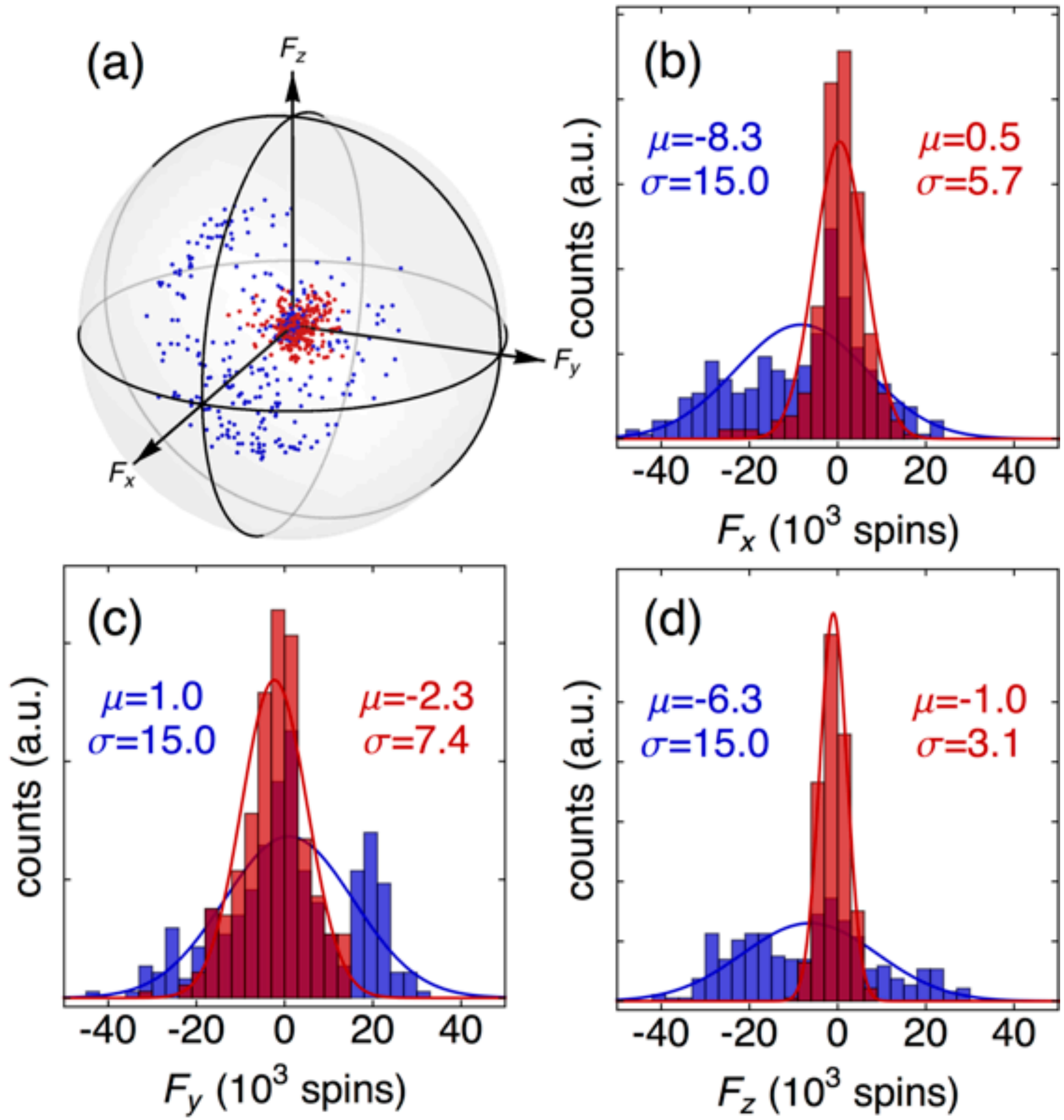
Feedback cooling of atomic spins





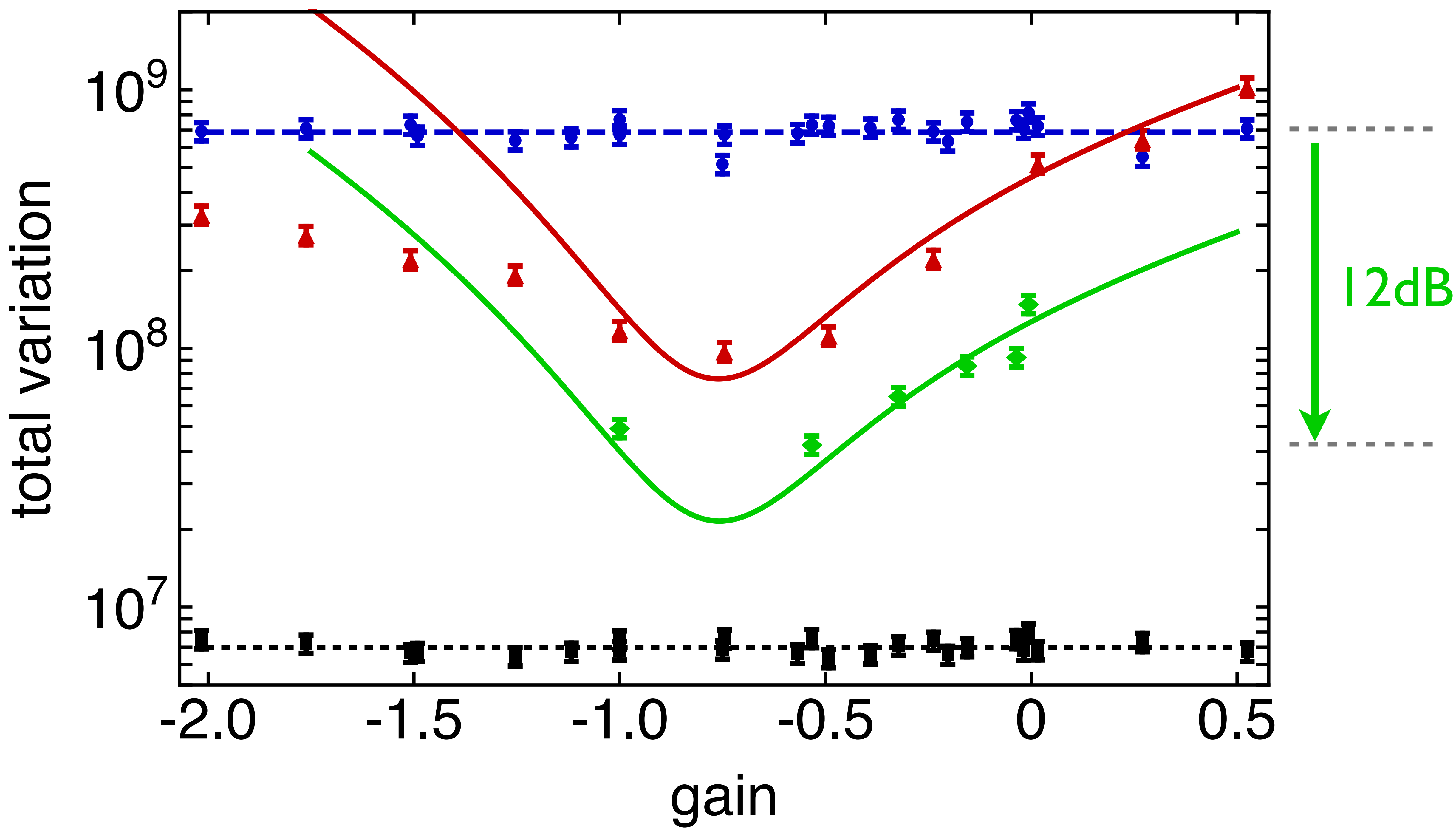
Behbood et al. PRL 111, 103601 (2013)

Feedback cooling of atomic spins



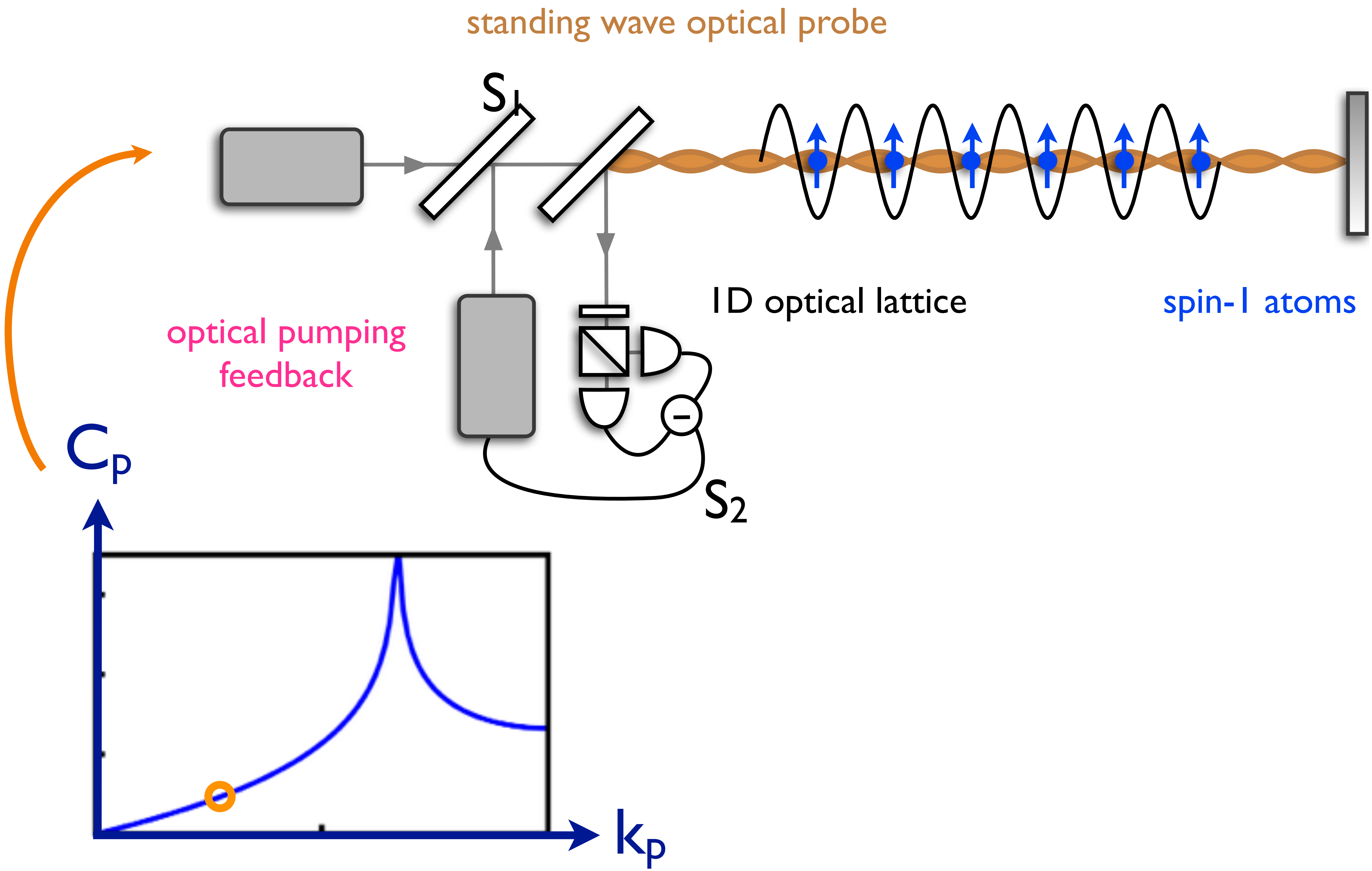
Behbood et al. PRL in press (2013)

Feedback cooling of atomic spins



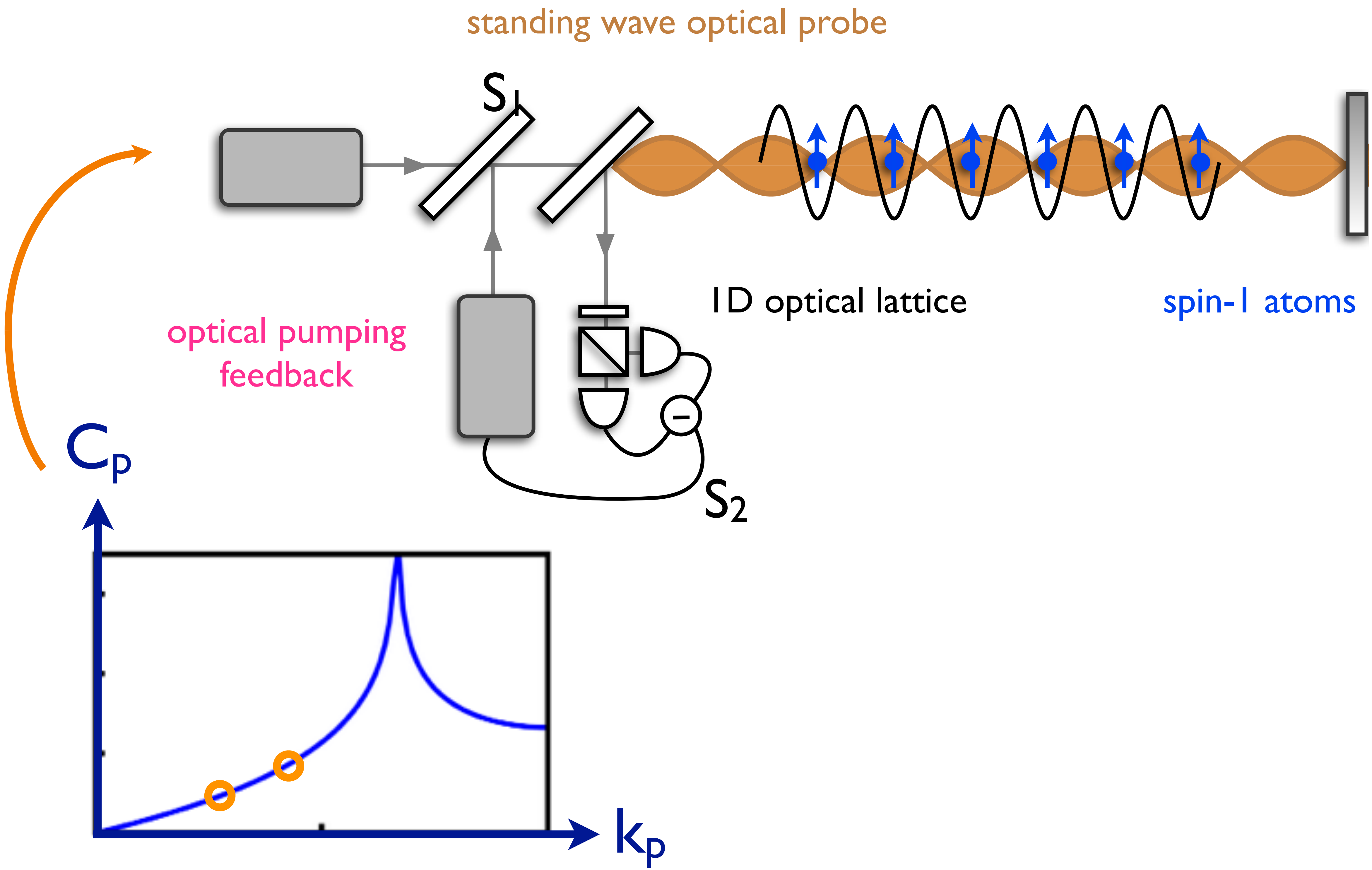
Behbood et al. PRL 111, 103601 (2013)

Engineering quantum spin correlations



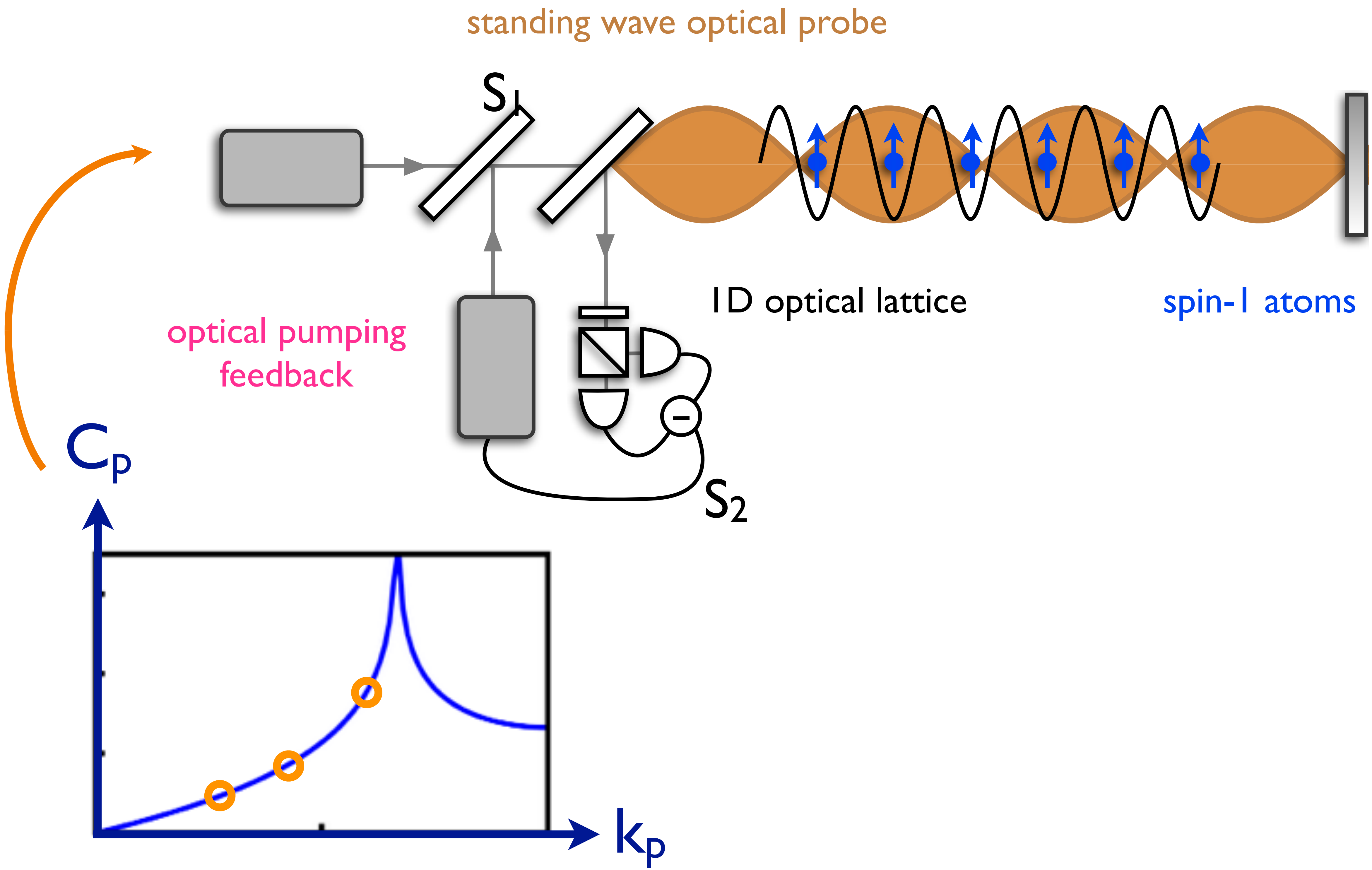
Hauke, PRA 87, 021601 (2013)

Engineering quantum spin correlations



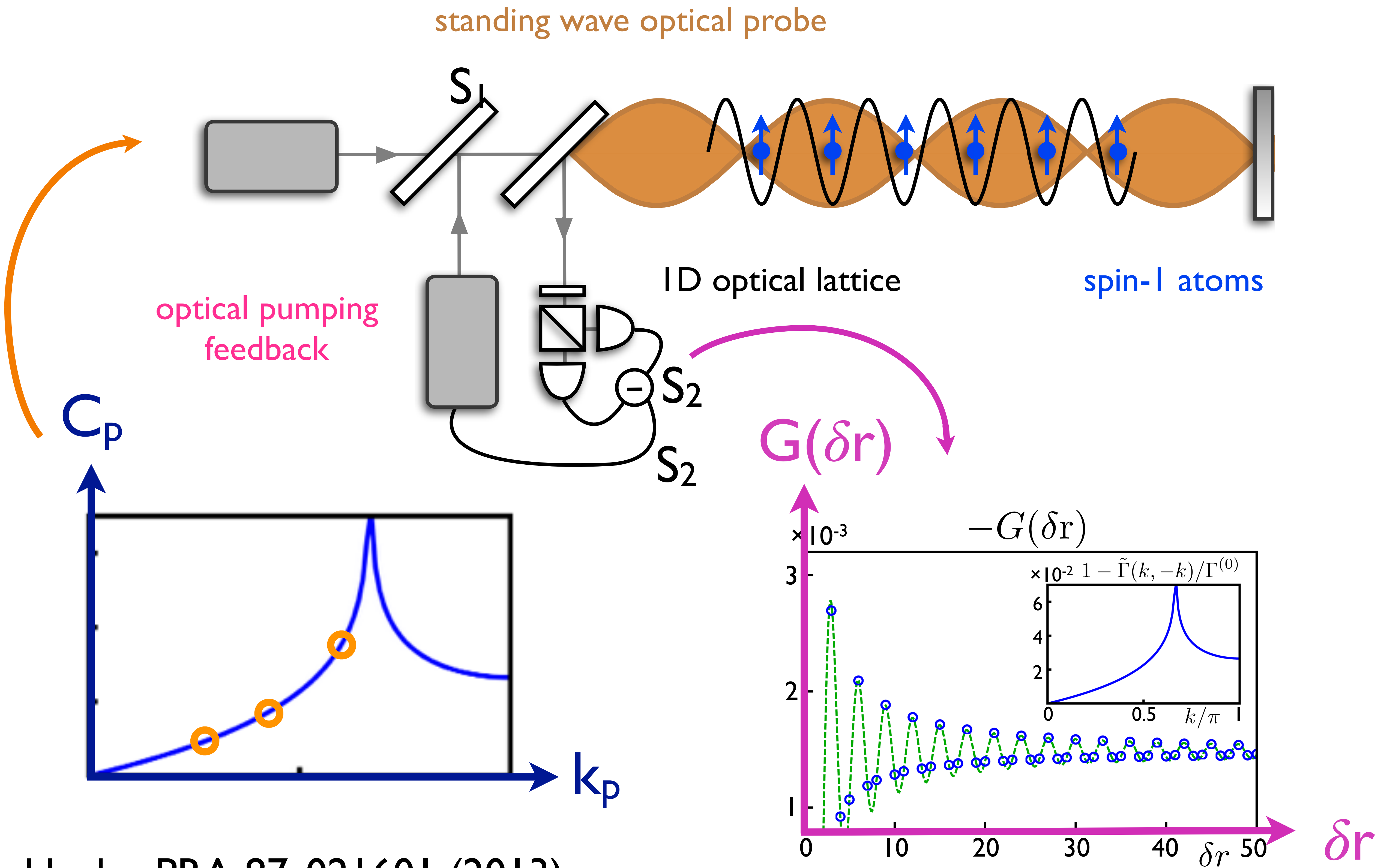
Hauke, PRA 87, 021601 (2013)

Engineering quantum spin correlations

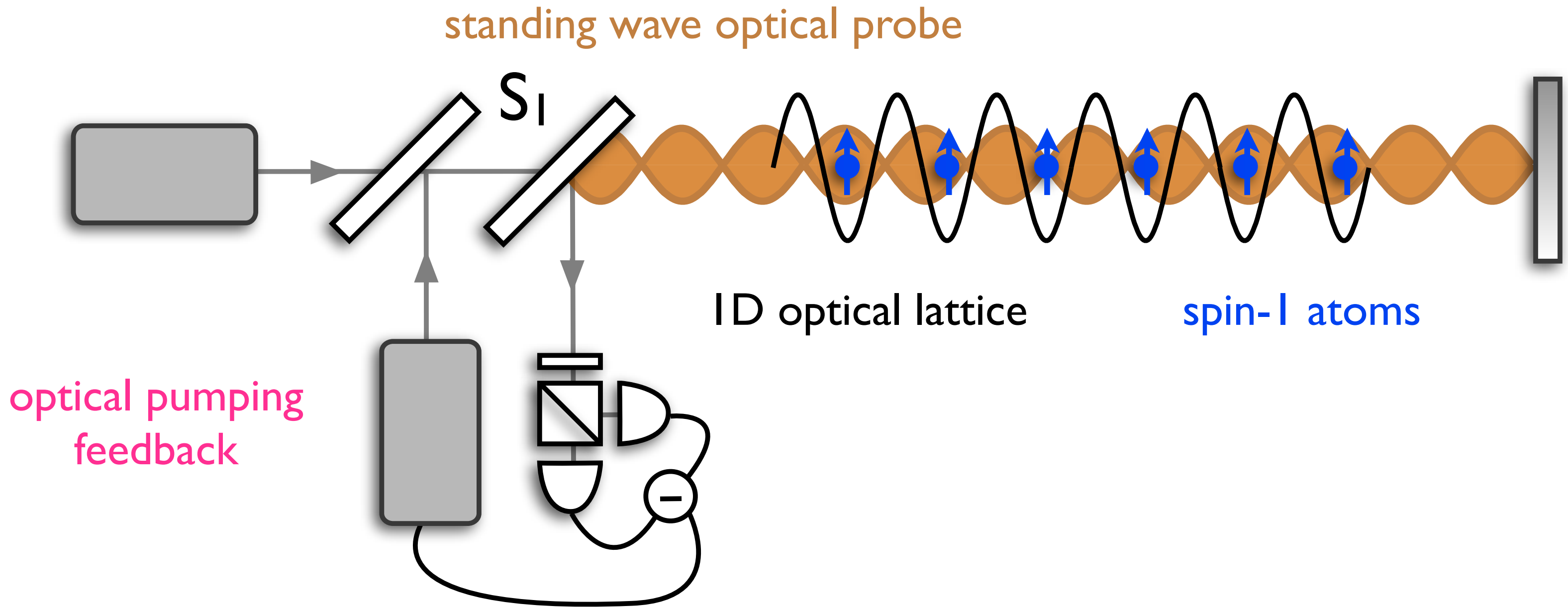


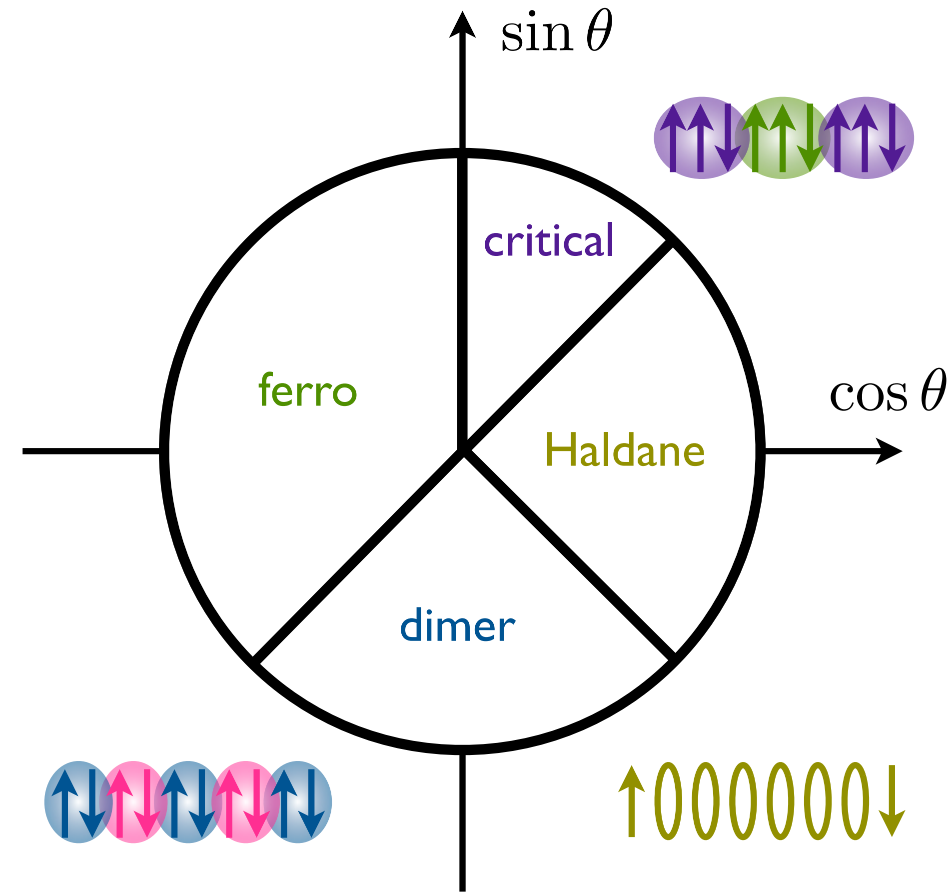
Hauke, PRA 87, 021601 (2013)

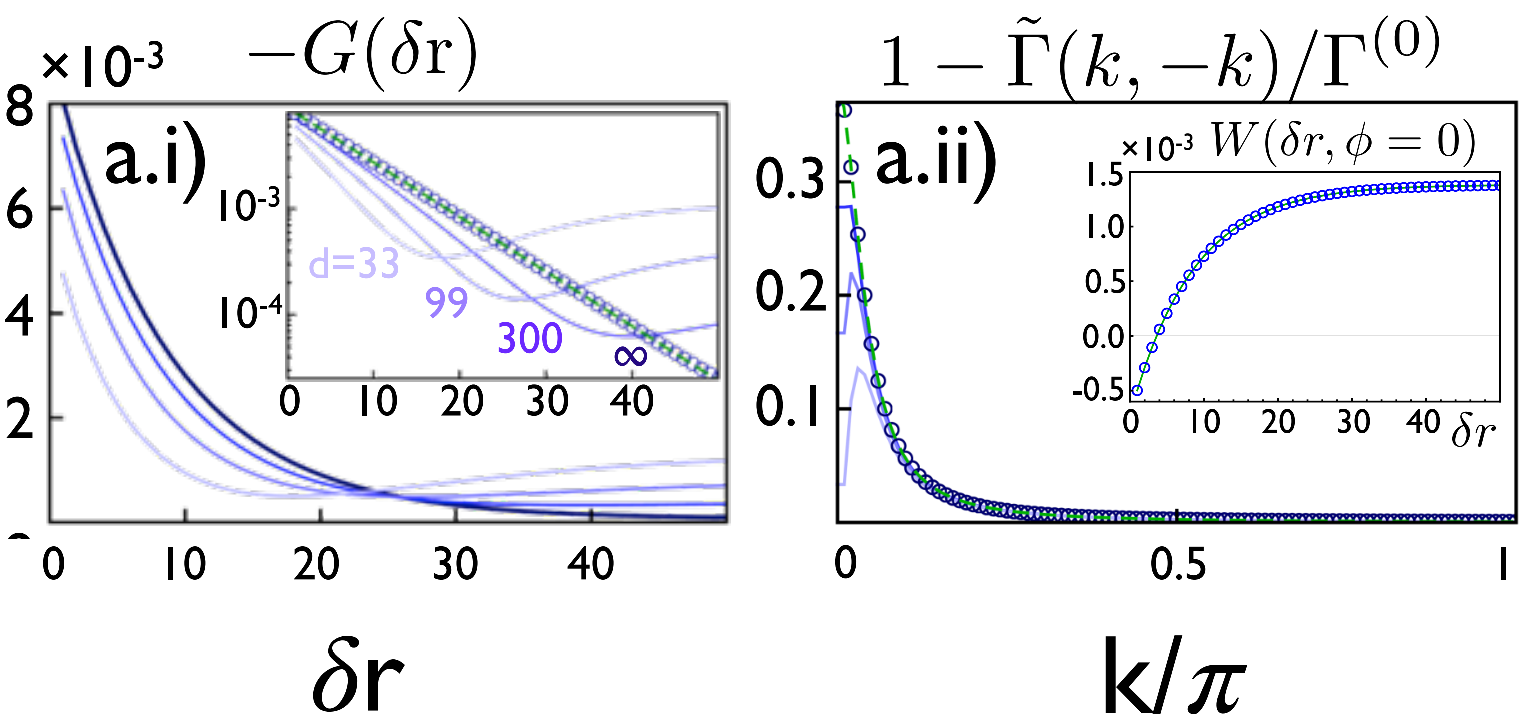
Engineering quantum spin correlations



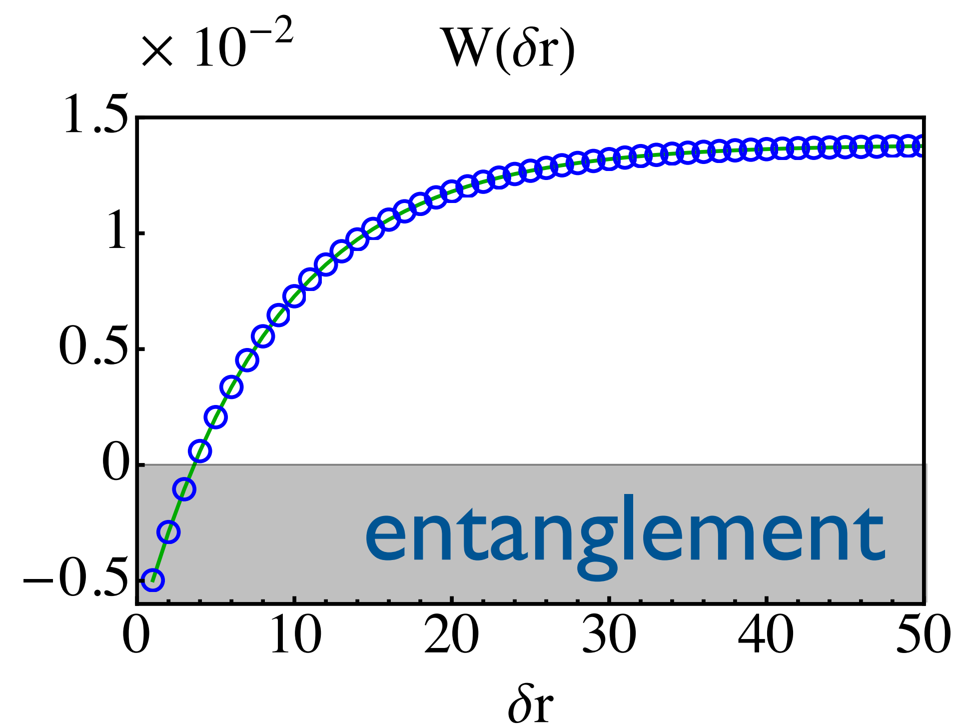
Hauke, PRA 87, 021601 (2013)



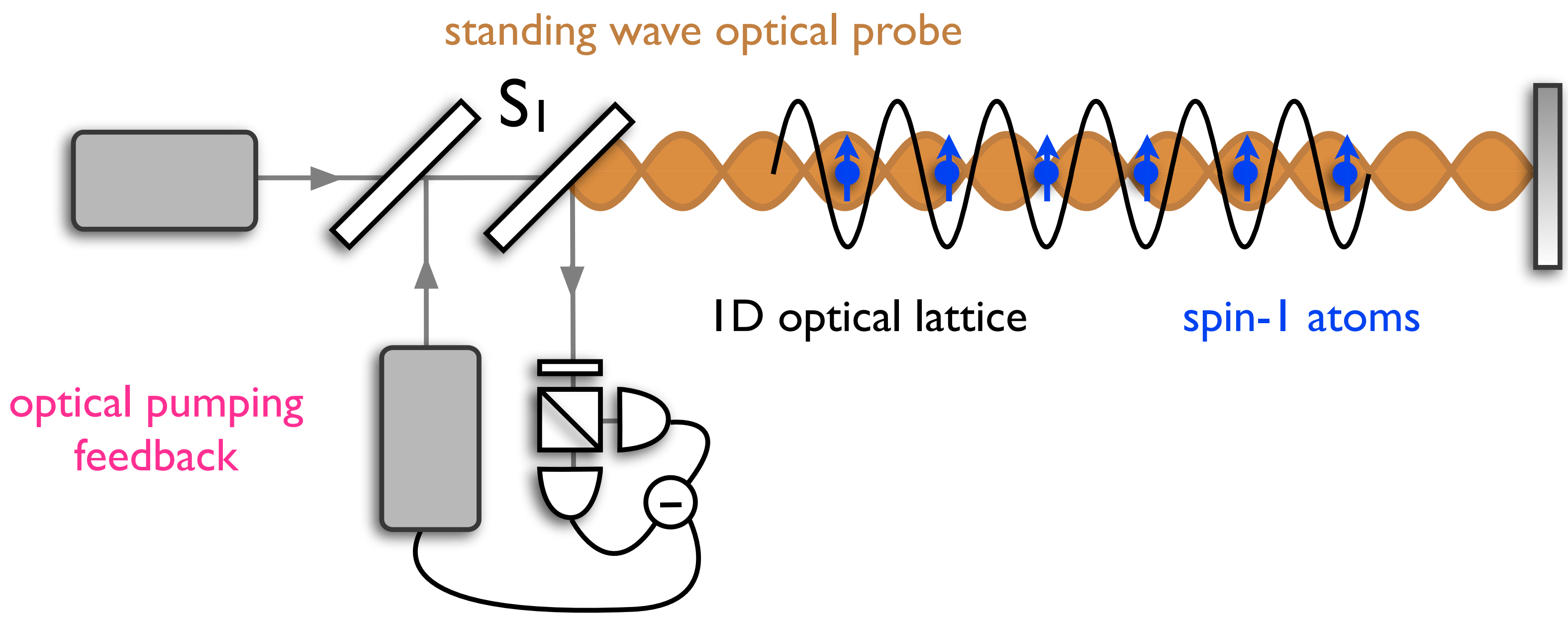


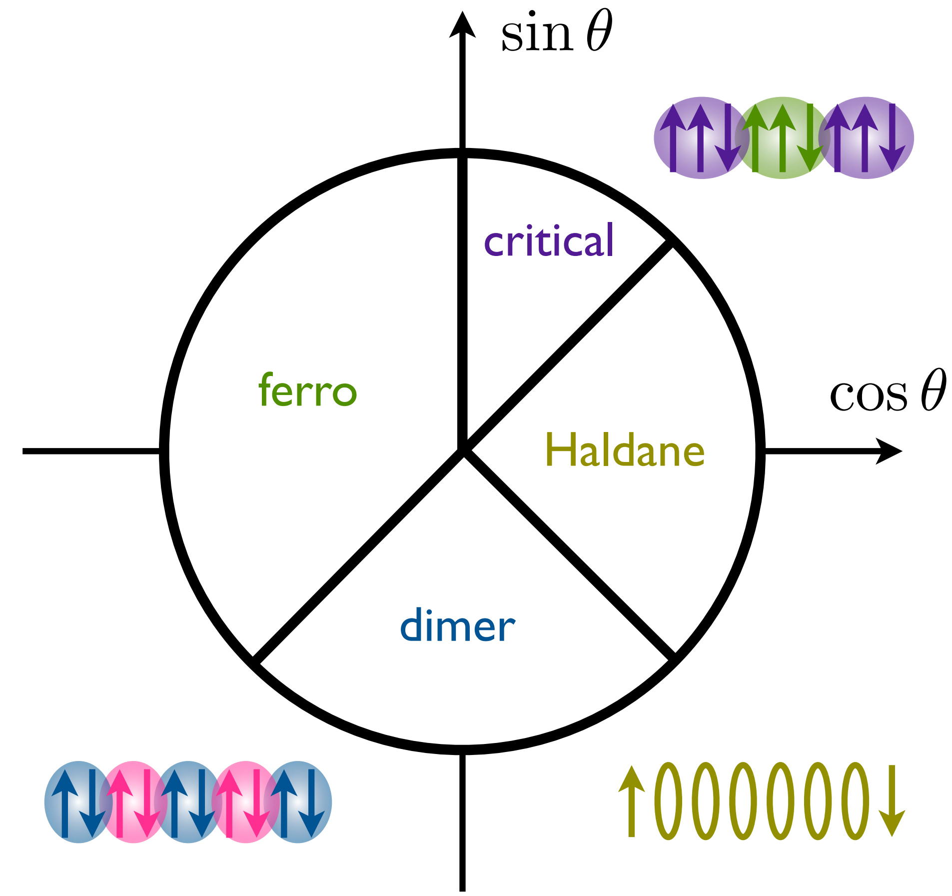


dimer phase

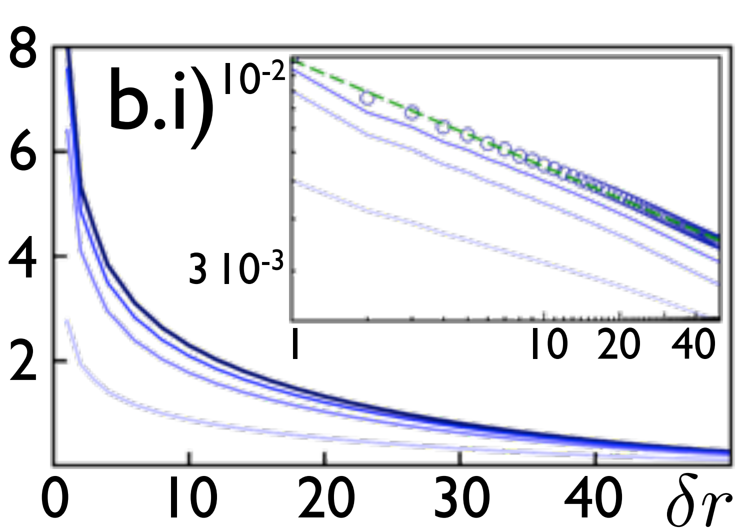


Hauke, PRA 87, 021601 (2013)

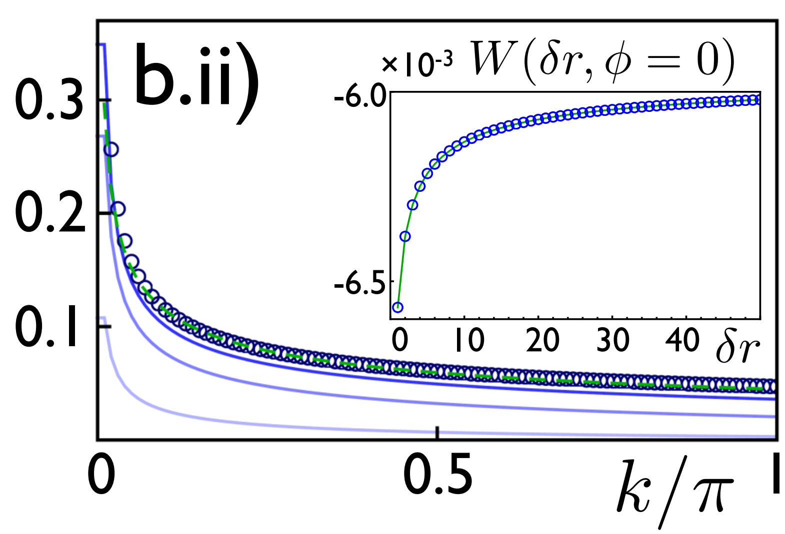




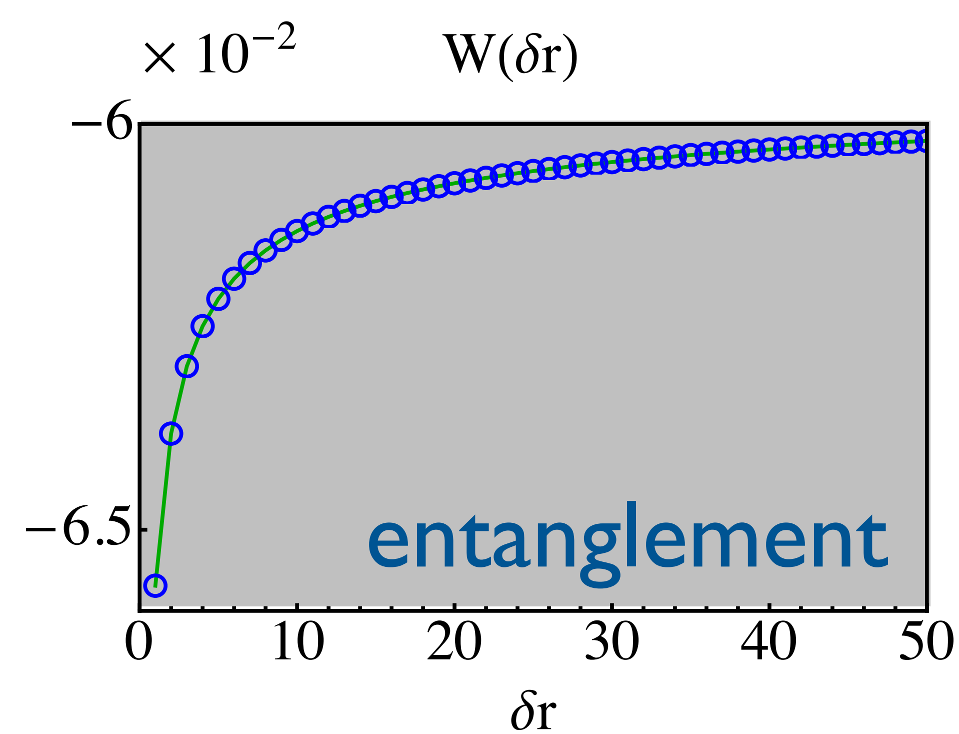
Haldane phase



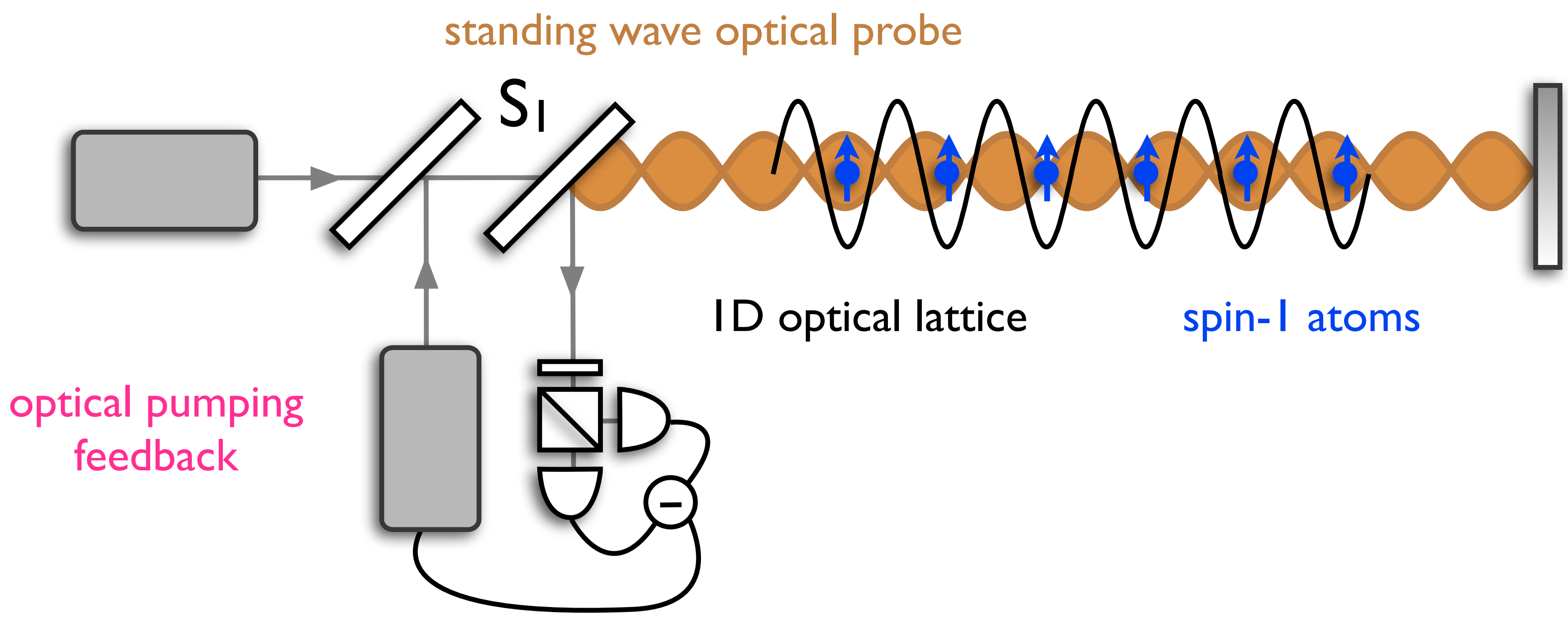
δr

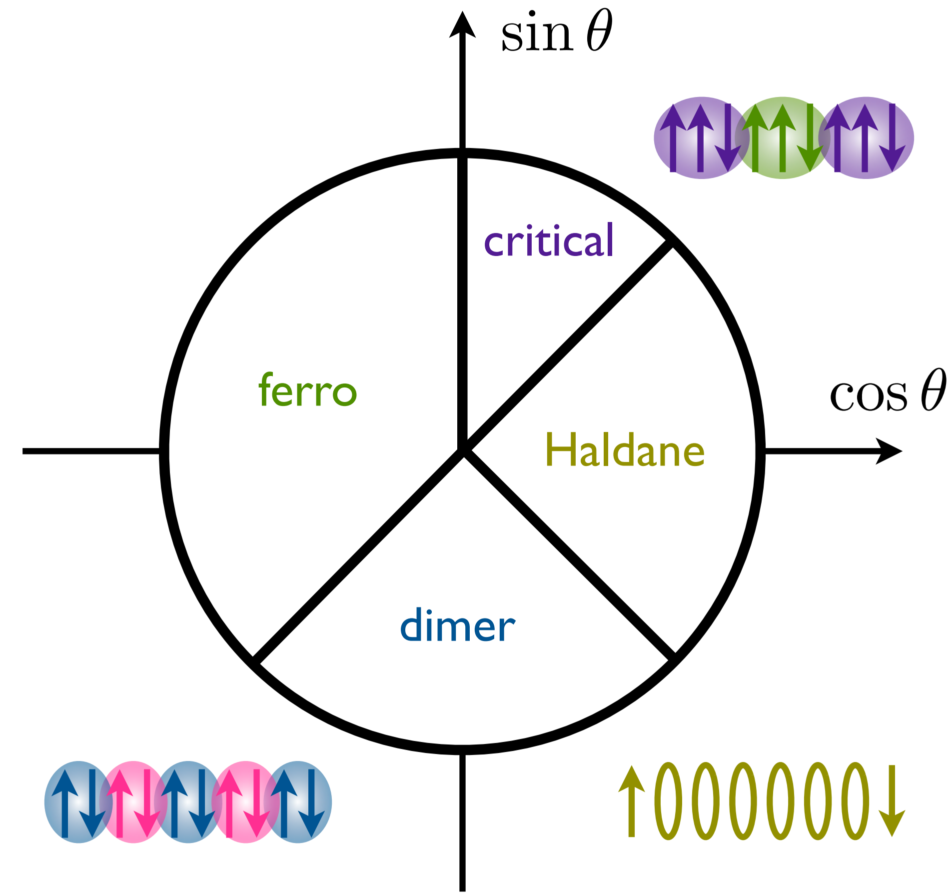


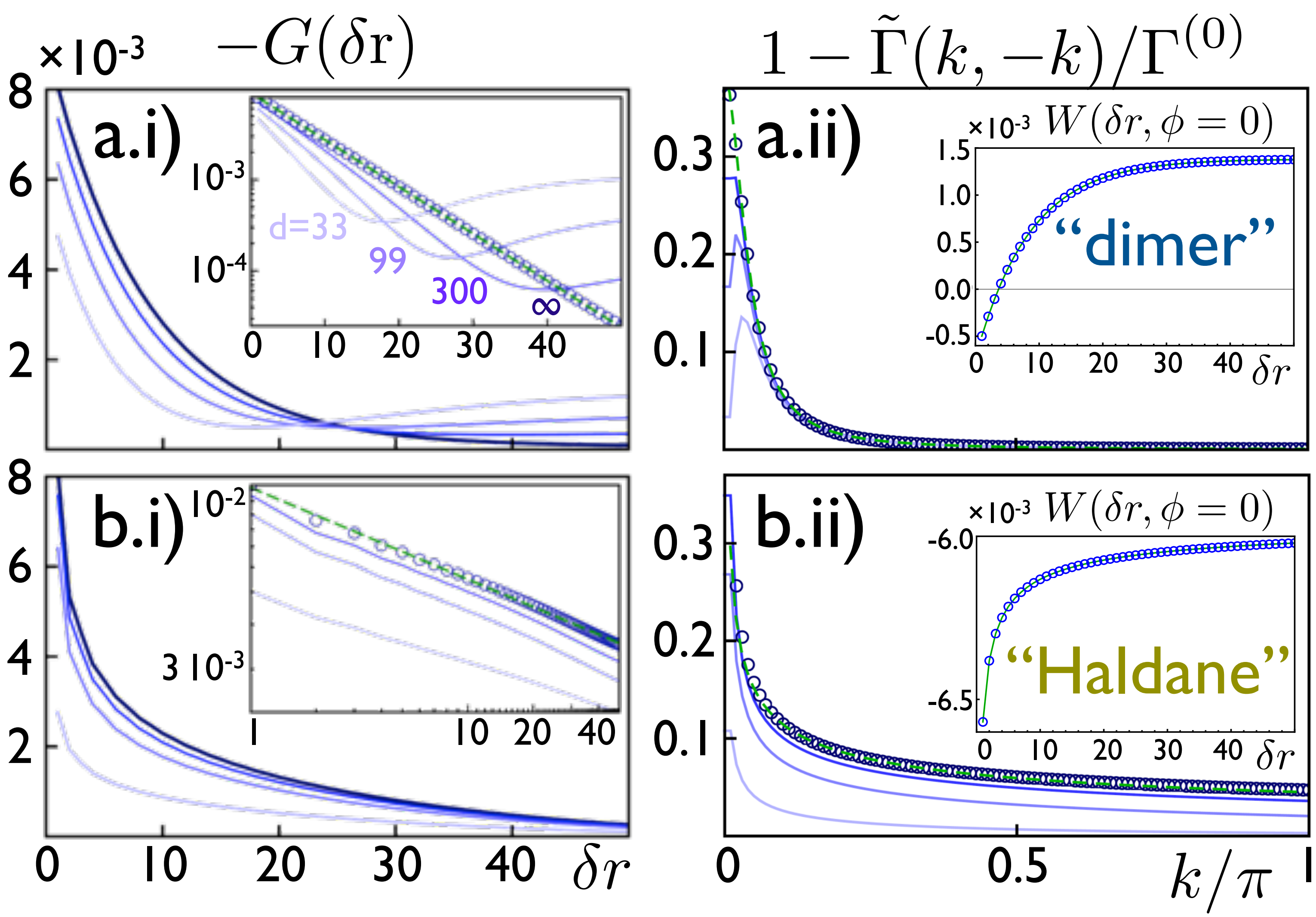
k/π



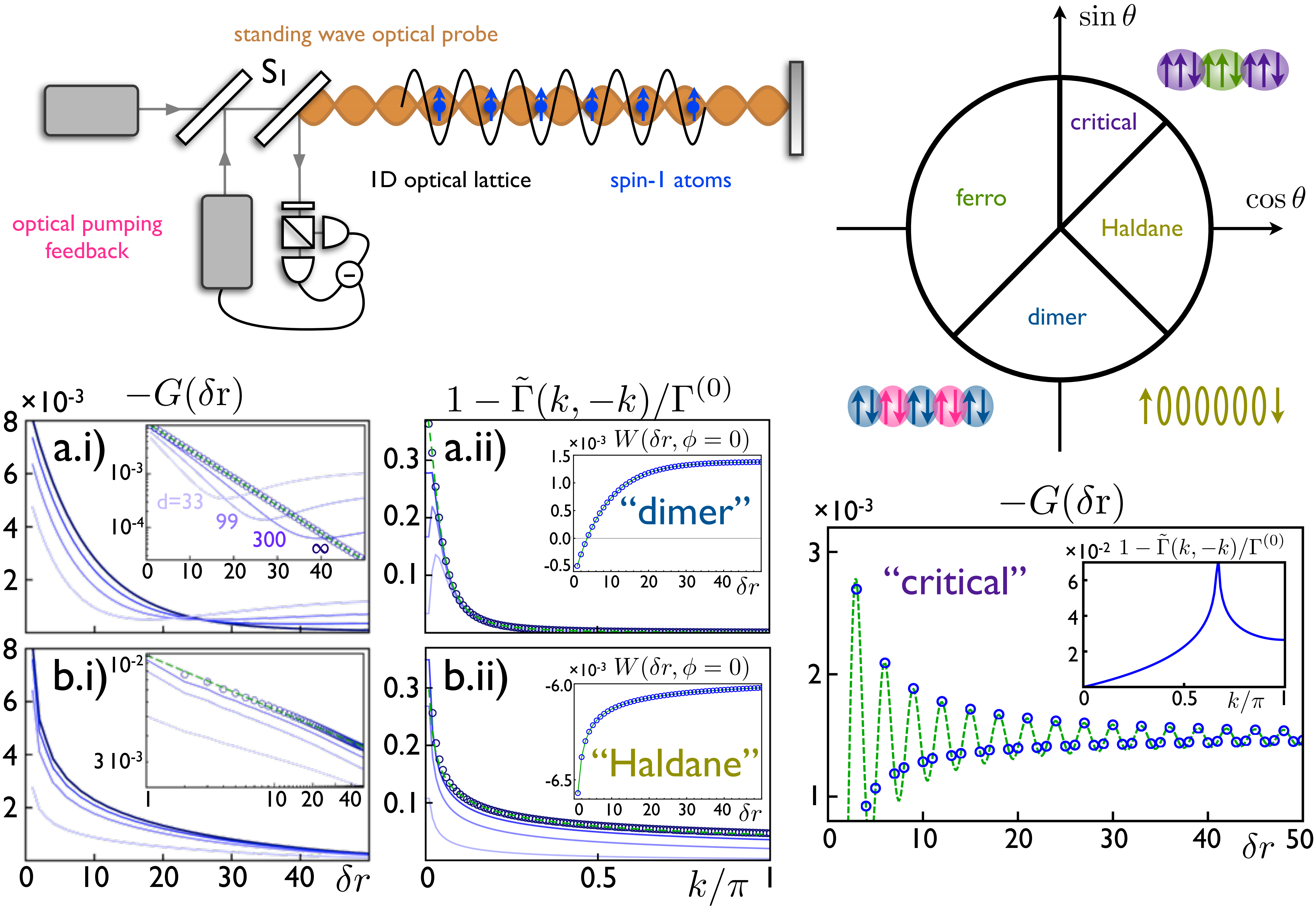
Hauke, PRA 87, 021601 (2013)





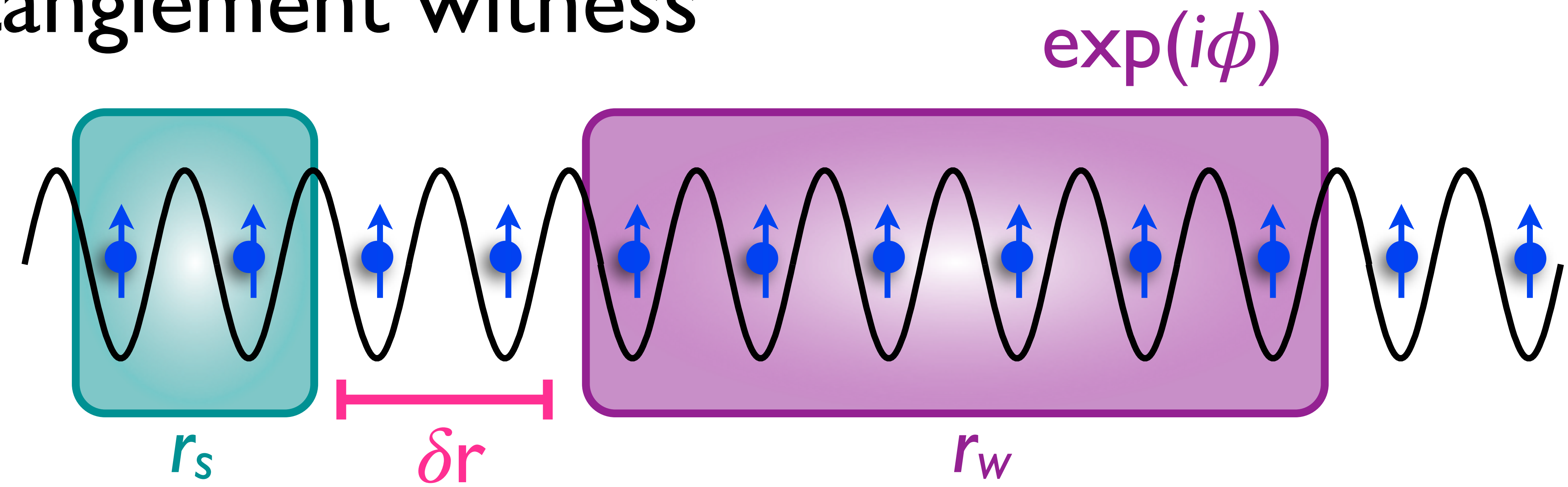


Hauke, PRA 87, 021601 (2013)



Hauke, PRA 87, 021601 (2013)

Entanglement witness



$$W \equiv \mathcal{S}/n_{\mathrm{a}} - 1 < 0$$

$$\mathcal{S} \equiv \sum_{\alpha} \mathcal{S}_{\alpha} = \sum_{\alpha} \sum_{i,j=1}^{n_{\mathrm{s}}} \langle J_{\alpha,i} J_{\alpha,j} \rangle f^*(r_i) f(r_j)$$

$$f(r_i) = \begin{cases} 1 & \text{if } r_i \in r_s, \\ \exp(i\phi) & \text{if } r_i \in r_w, \\ 0 & \text{otherwise.} \end{cases}$$

Cramer, PRL 106, 020401 (2011)

Quantum control of spin correlations in ultracold lattice gases

P. Hauke
(IQOQI)

P.Hauke, R.J.S., M.W.Mitchell & M.Lewenstein,
PRA 87, 021601 (2013).

M.Lewenstein

M.W.Mitchell

ICFO
Institut
de Ciències
Fotòniques

MGroup
itchell

MINISTERIO
DE CIENCIA
E INNOVACIÓN

Generalitat
de Catalunya

erc

MARIE CURIE ACTIONS

Fundació Privada
CELLEX

icrea
Institució Catalana de Recerca i Estudis Avançats