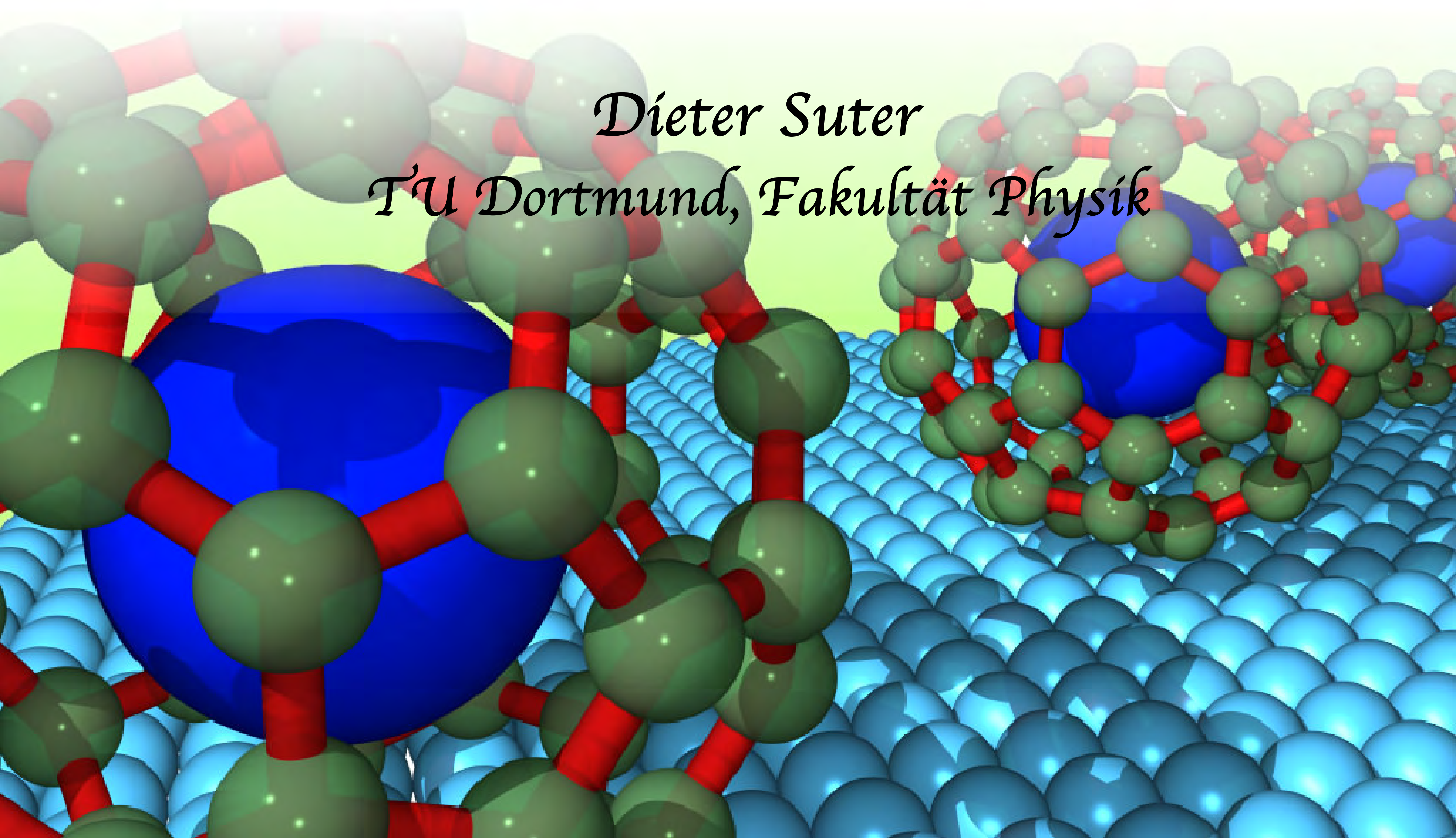
Robust Control in RF-Optical Double Resonance Experiments

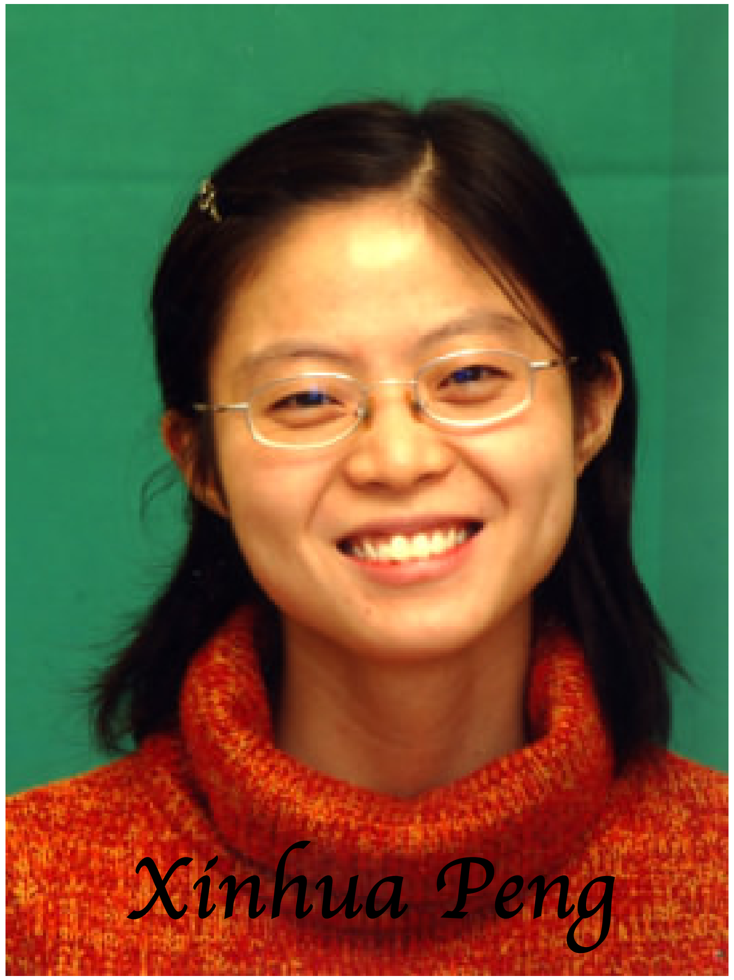
Dieter Suter
TU Dortmund, Fakultät Physik

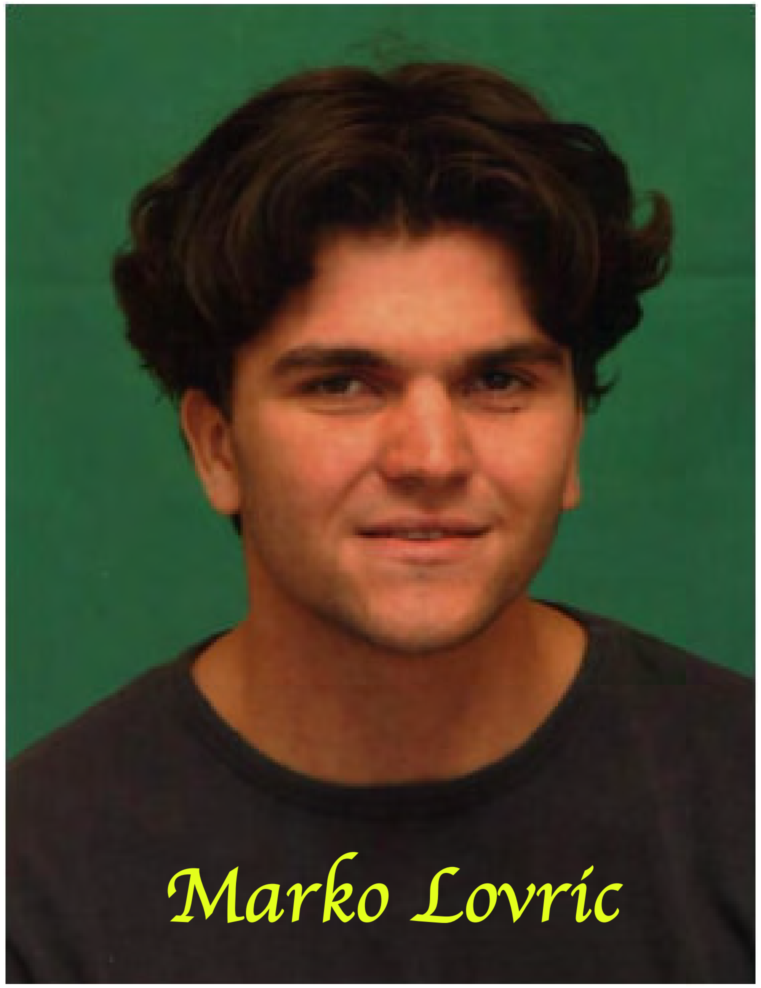


The Team


Mahesh
Tirthahalli


Christina Hopfgarten

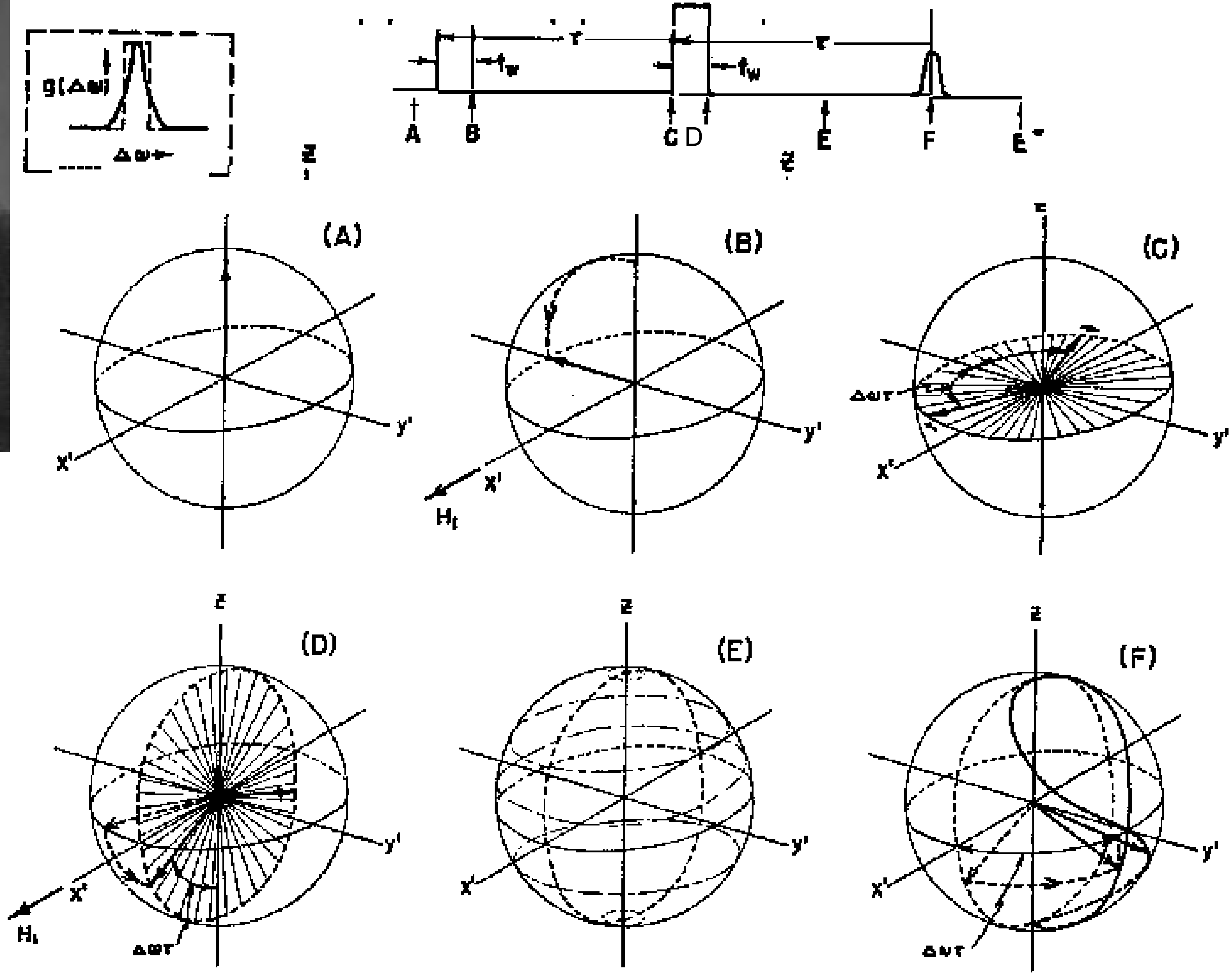

Xinhua Peng


Marko Lovric

Erwin Hahn

Bits of History

1950@Berkeley



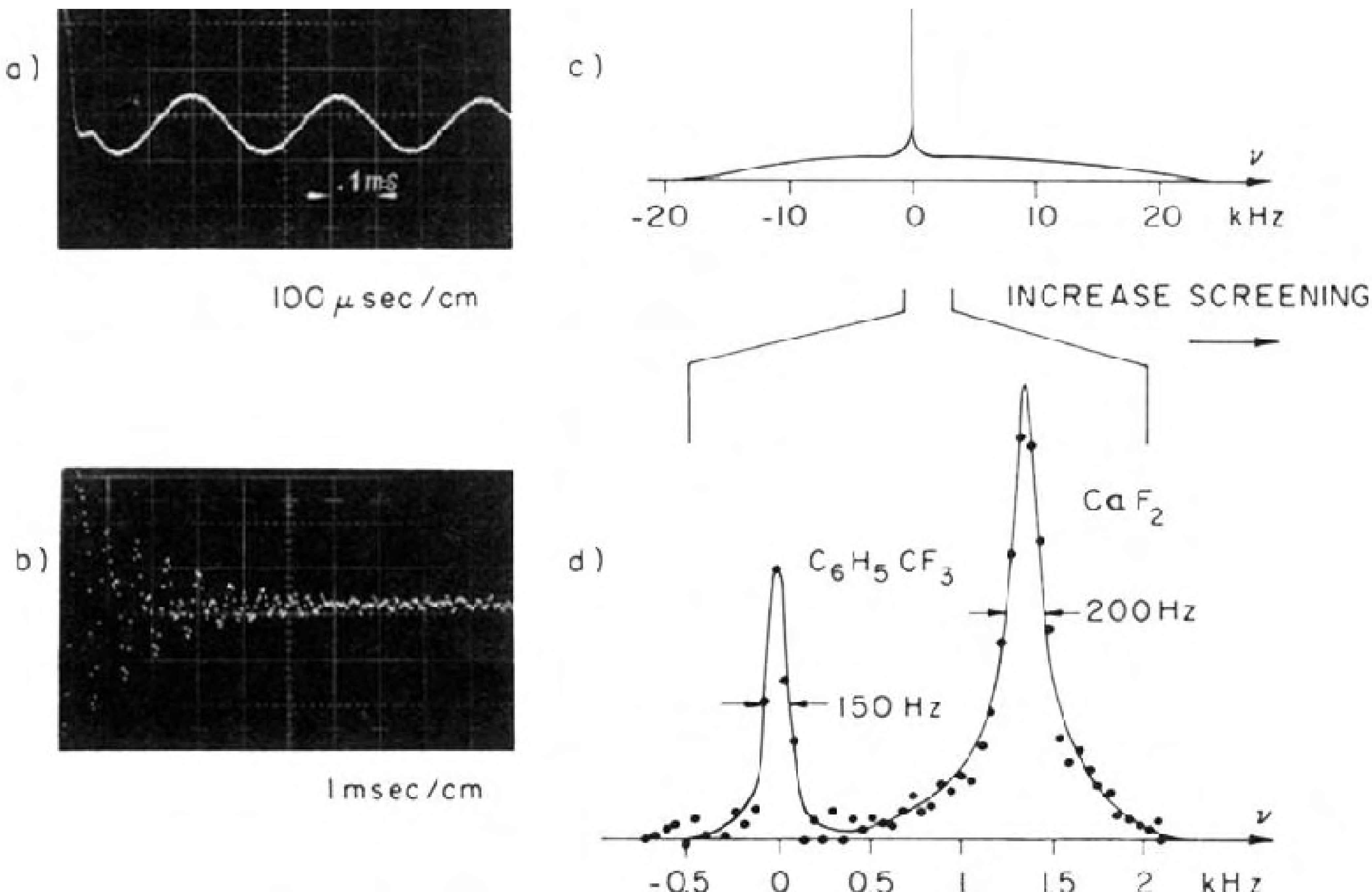
Bits of History

APPROACH TO HIGH-RESOLUTION nmr IN SOLIDS*

1968@MIT

J. S. Waugh, L. M. Huber, and U. Haeberlen†
Department of Chemistry and Research Laboratory of Electronics,
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

(Received 27 December 1967)



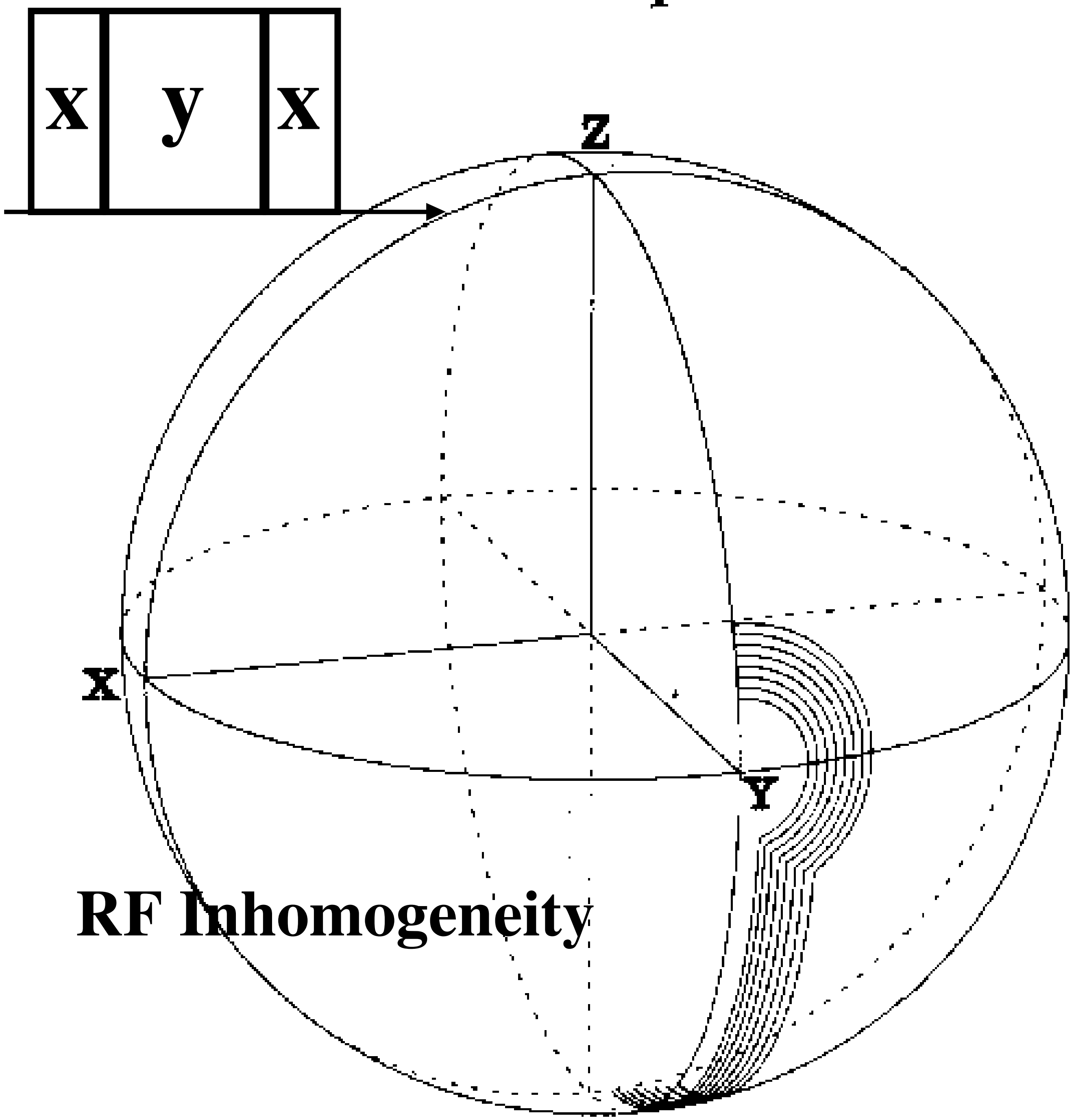
Composite Pulses

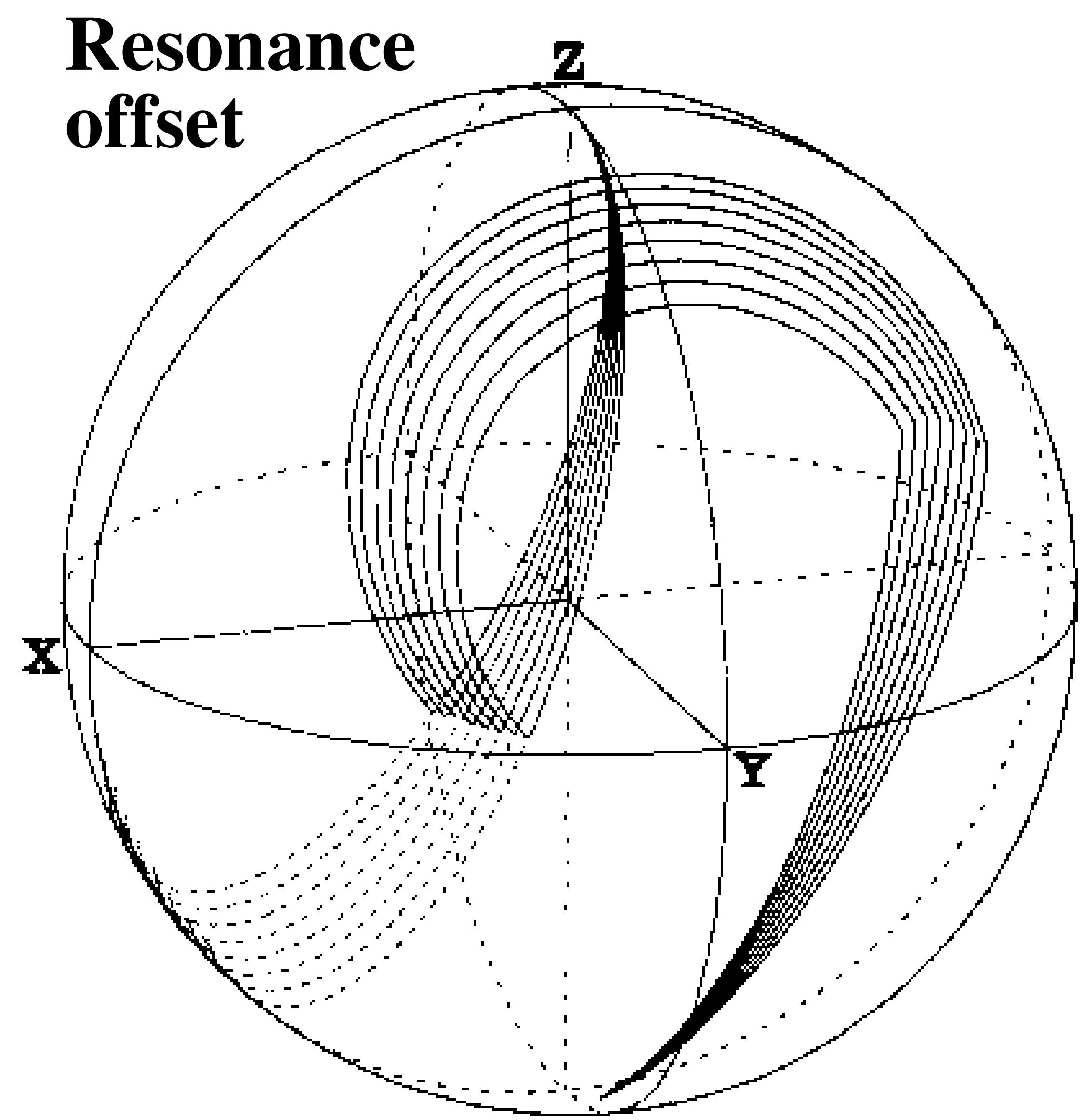
1979@Oxford

JOURNAL OF MAGNETIC RESONANCE 33, 473–476 (1979)

NMR Population Inversion Using a Composite Pulse

MALCOLM H. LEVITT
RAY FREEMAN

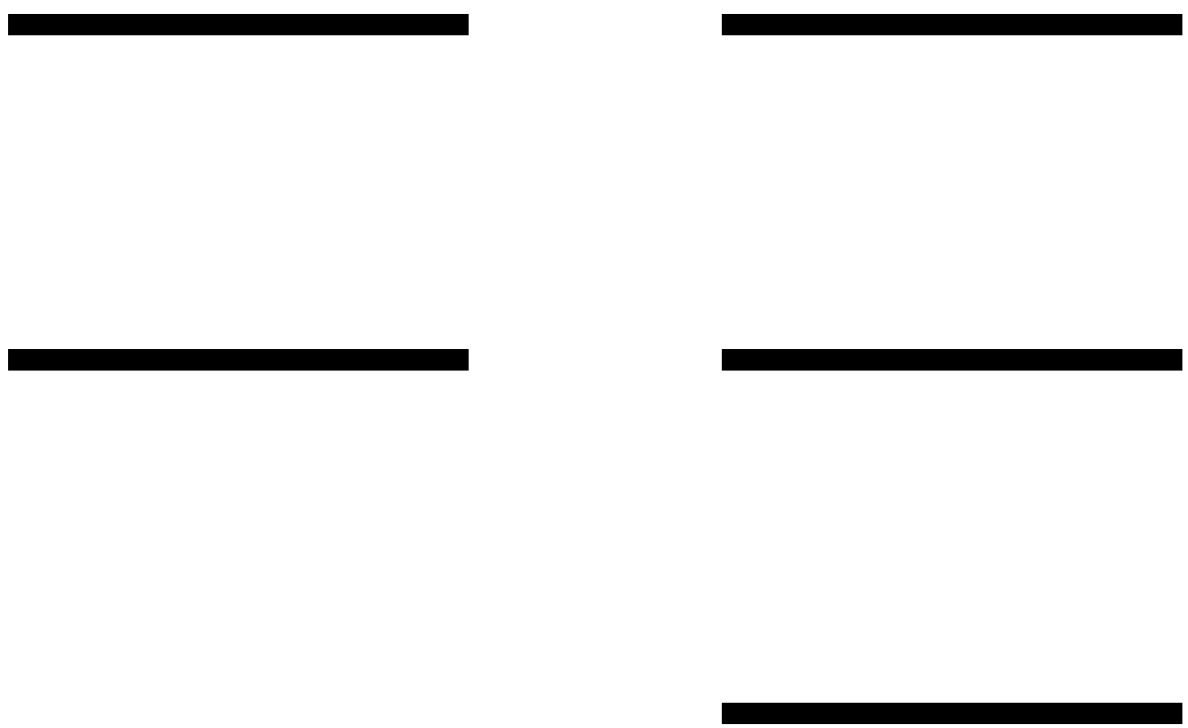




Larger Systems

Before: 2 levels

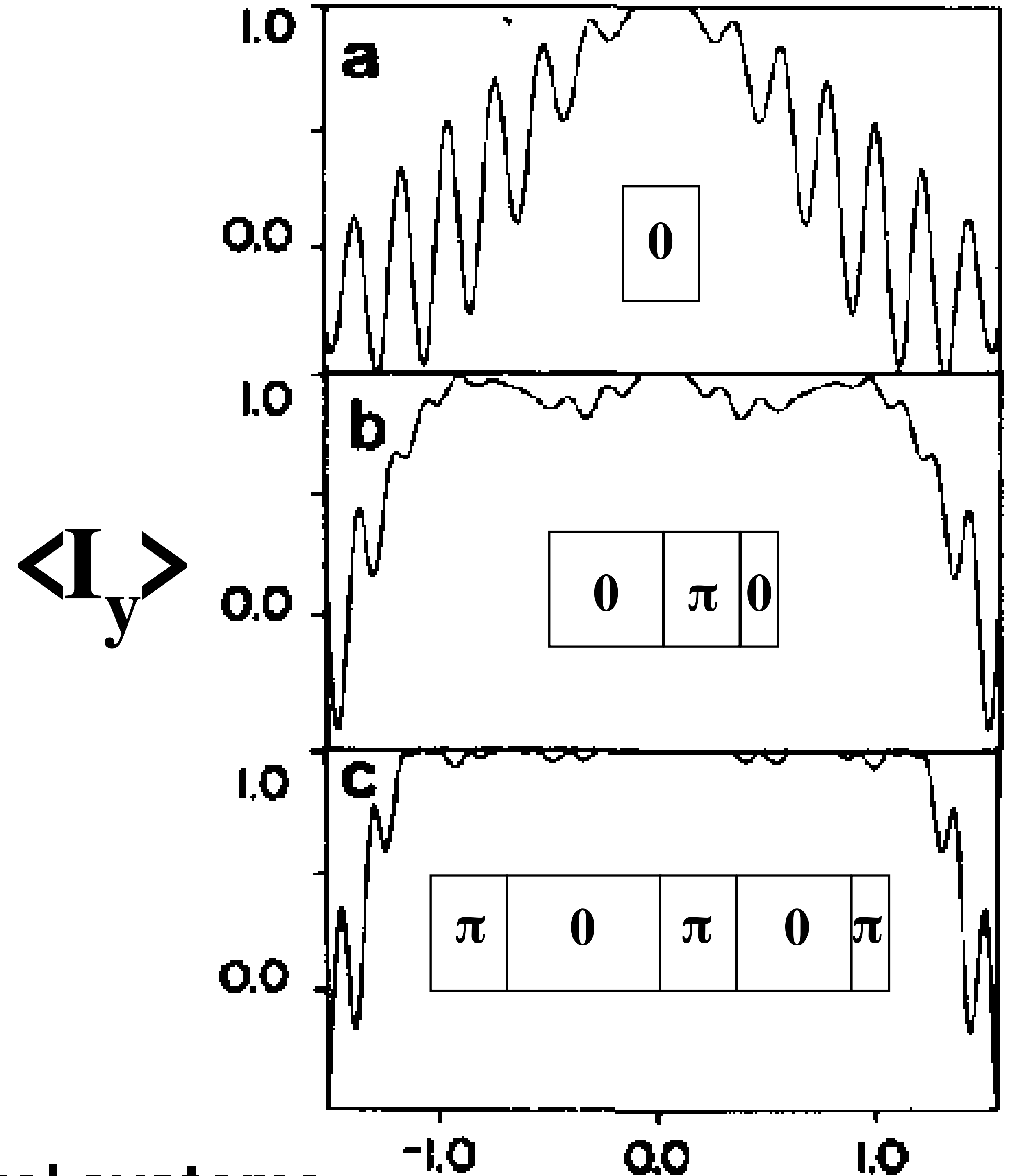
3 levels



Spin 1/2 ^1H

Spin 1 ^2D

1984@Zürich



Composite pulse excitation in three-level systems

M. H. Levitt, D. Suter, and R. R. Ernst

J. Chem. Phys. 80, 3064 (1984).

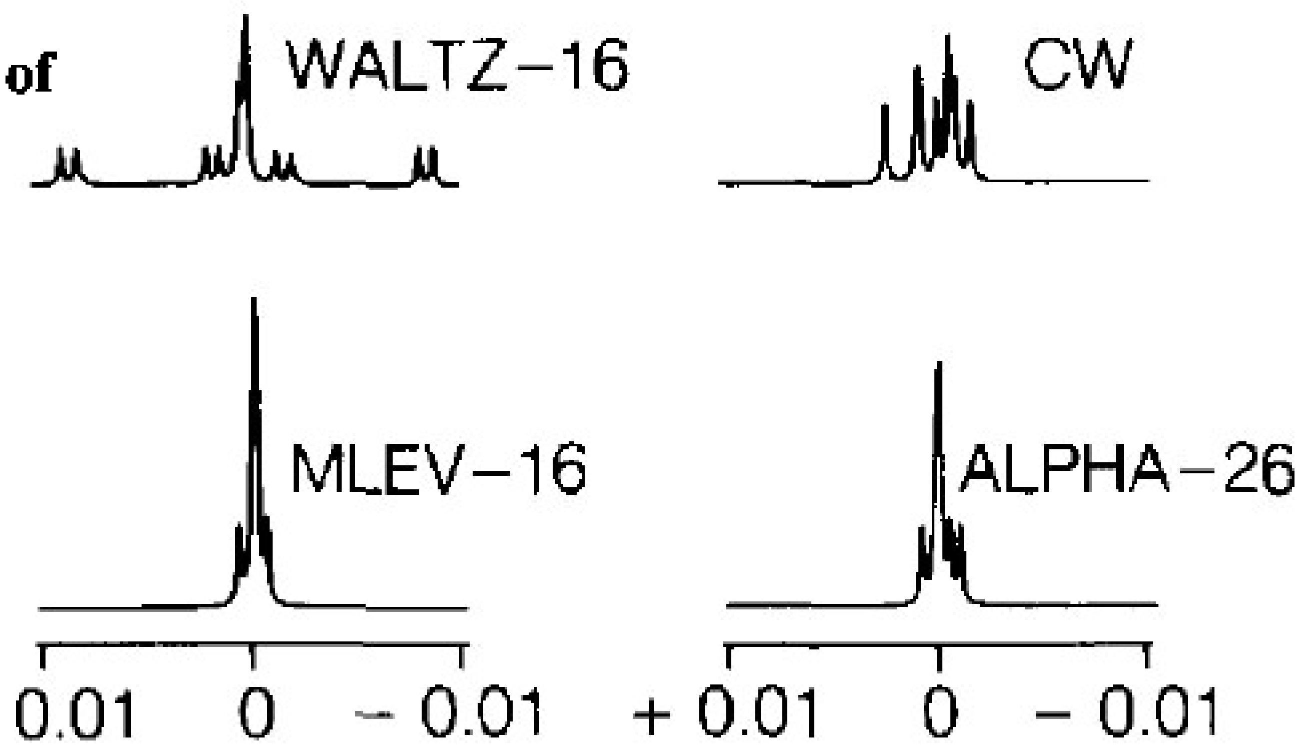
Larger Systems

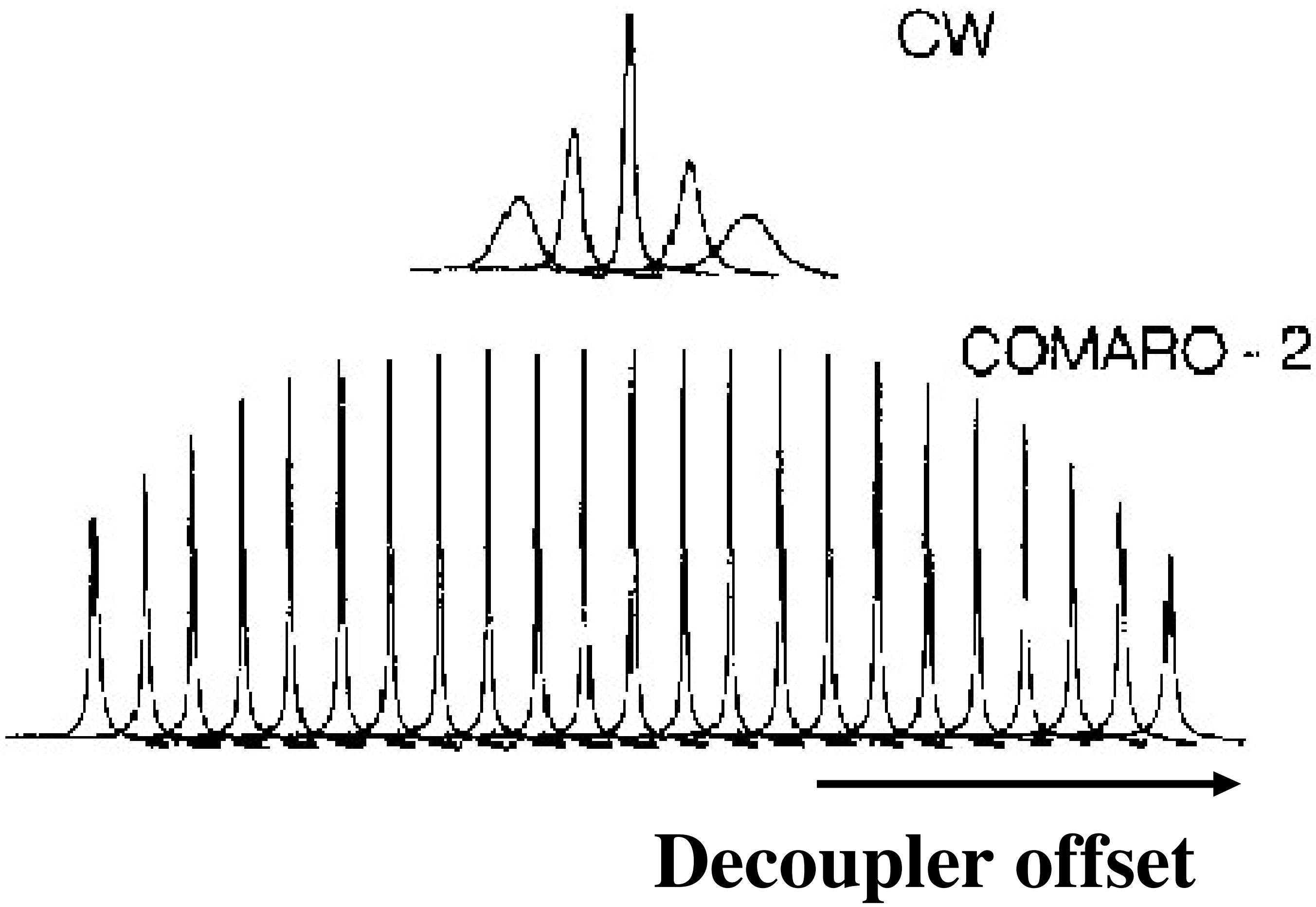
Multiple Spins
Multiple Interactions

1987@Berkeley

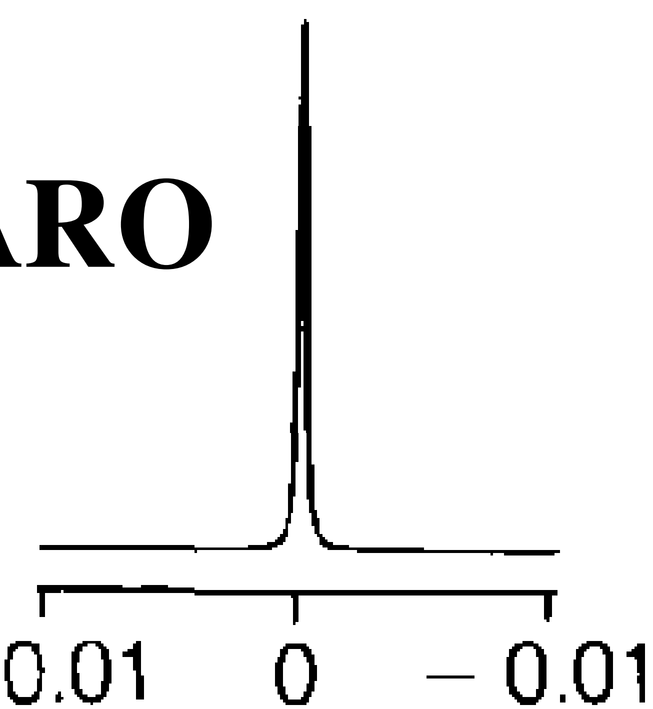
Broadband Heteronuclear Decoupling in the Presence of Homonuclear Dipolar and Quadrupolar Interactions

K. V. SCHENKER, D. SUTER, AND A. PINES





COMARO

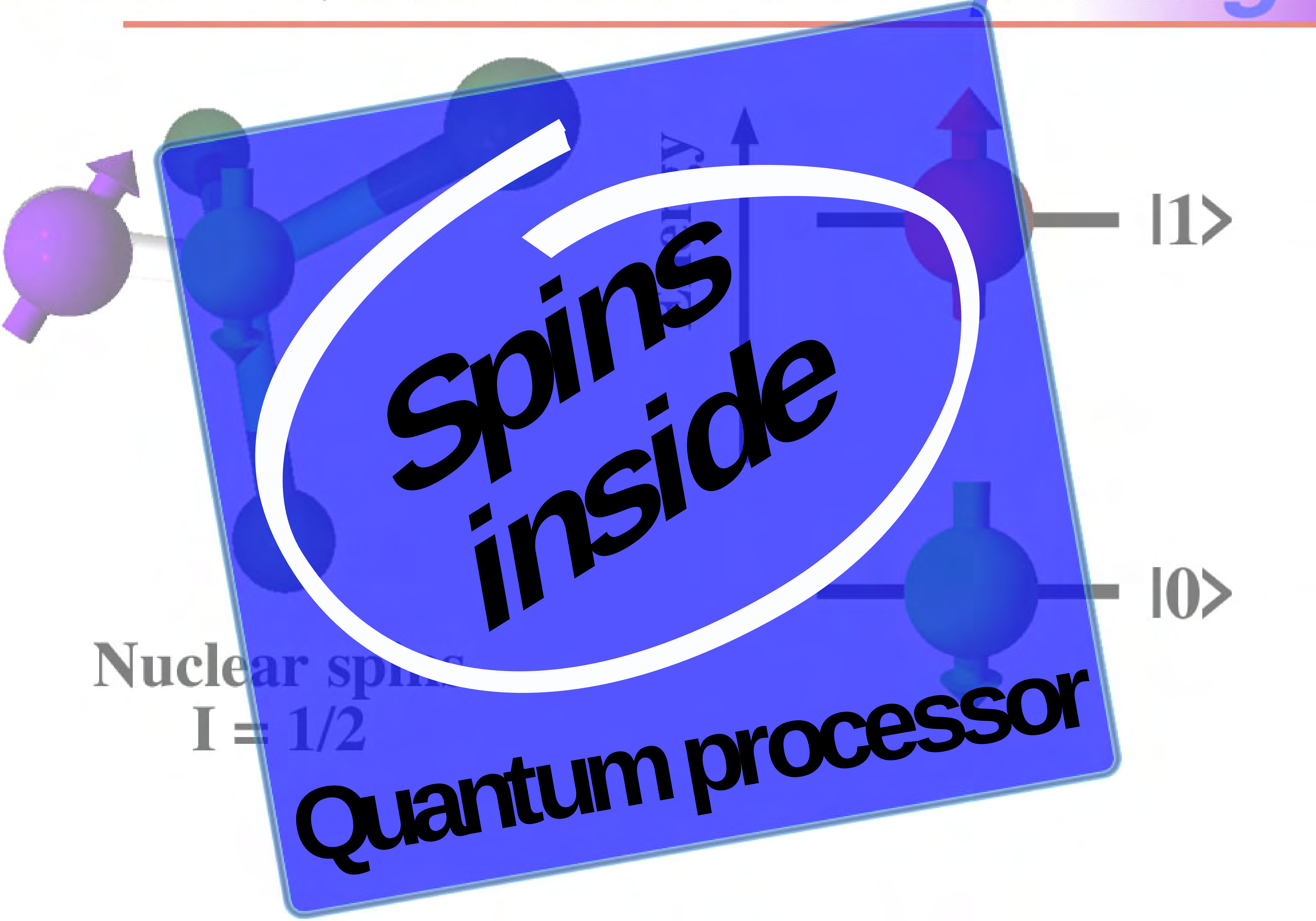


1st Conclusion

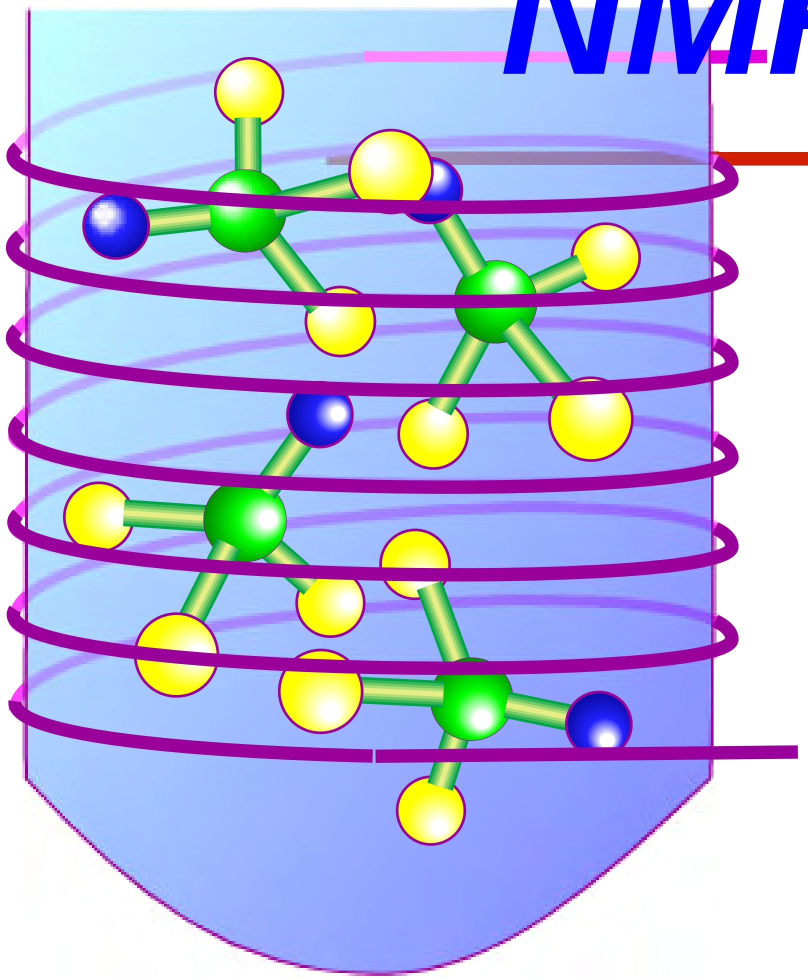
Quantum Control =
Teaching spins new tricks

... even in the presence of distraction

NMR Quantum Computing

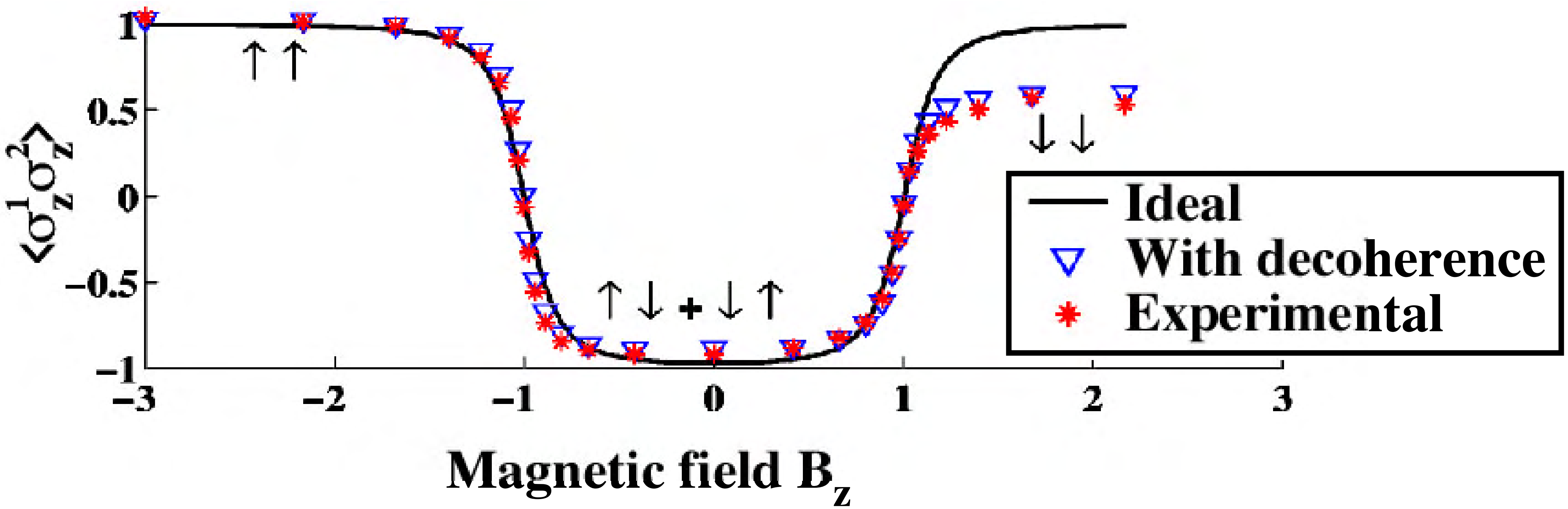


NMR Quantum Computing



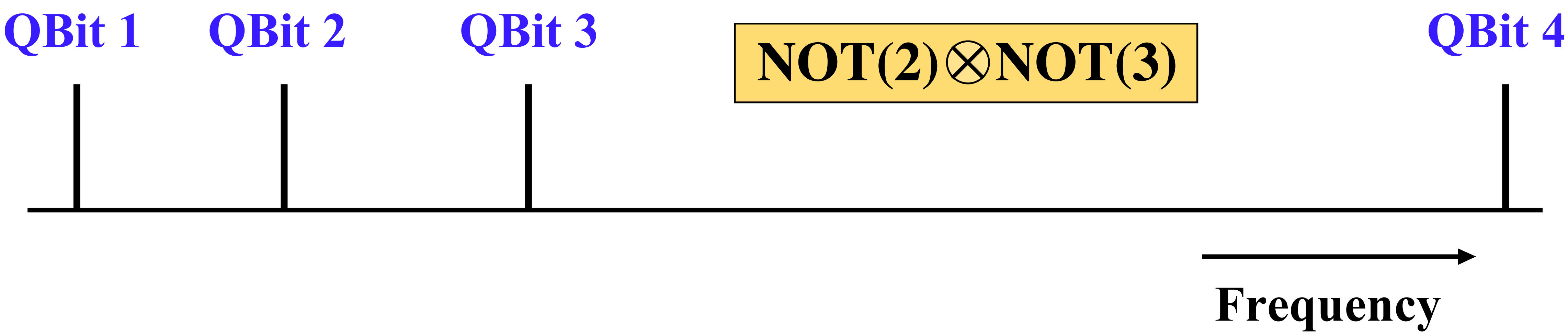
- **Liquid state NMR is an excellent system for small quantum registers.**

e.g. Simulation of Quantum Phase Transition

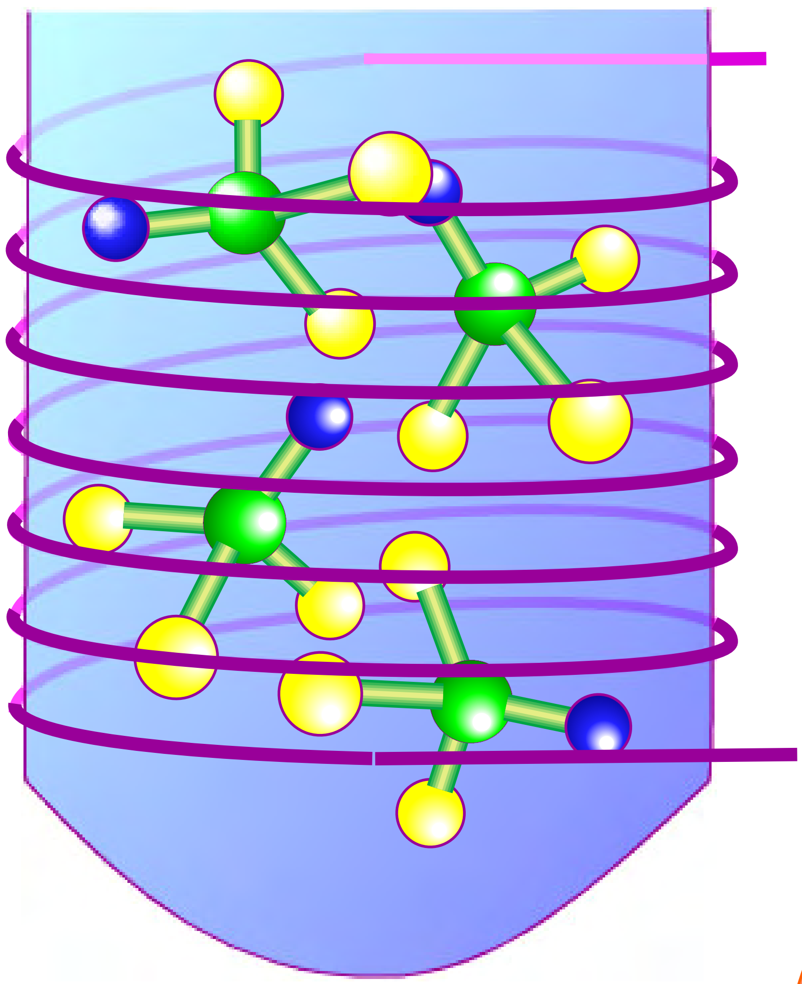


X. Peng, J. Du, and D. Suter, Phys. Rev. A 71, 012307 (2005).

NMR Quantum Computing



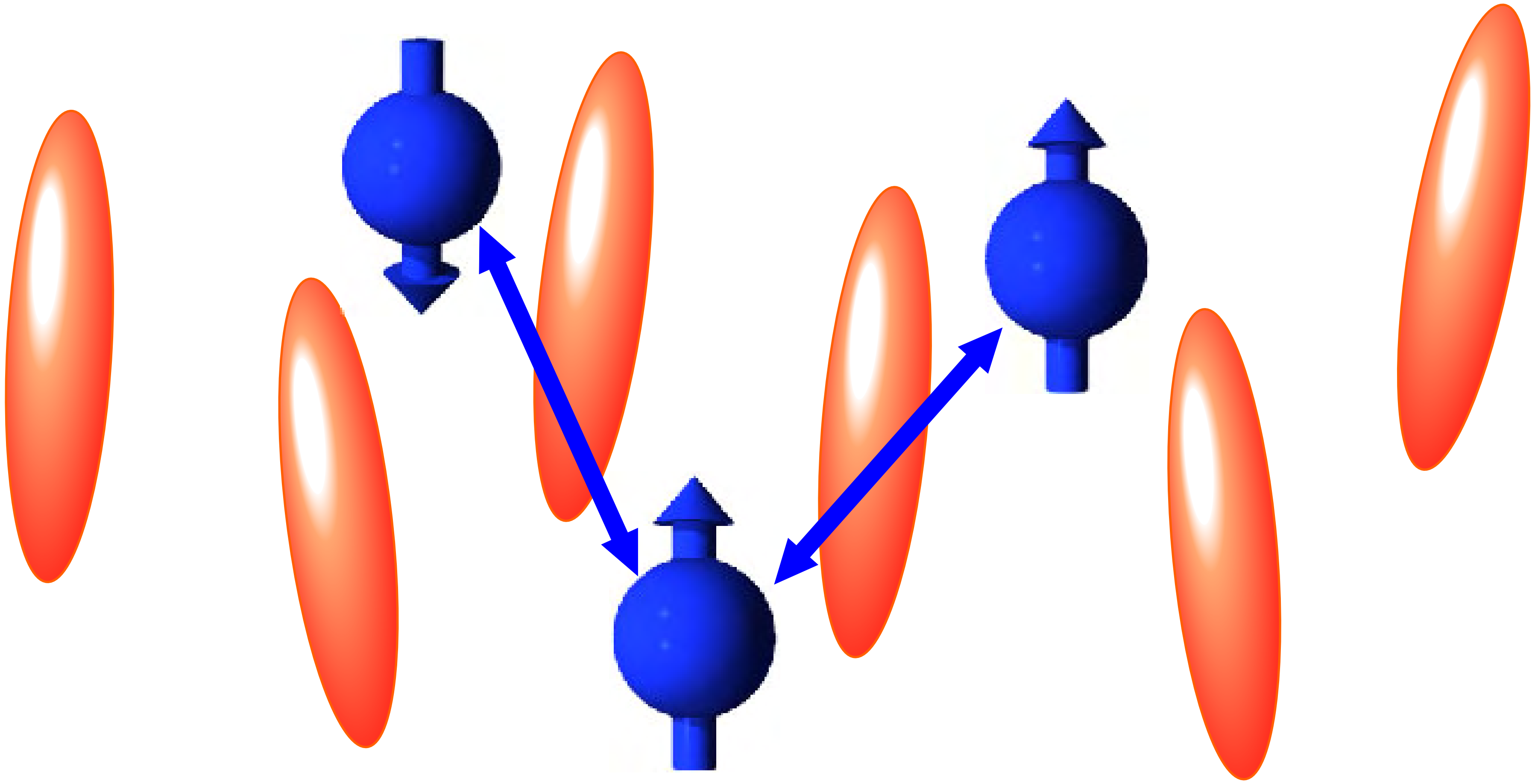
Liquid Crystal NMR



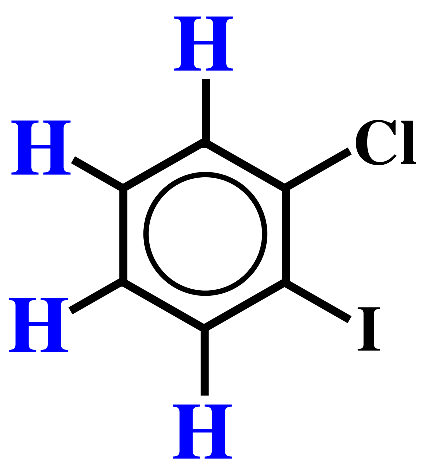
Liquids are simple, easy to handle

Main problem: couplings are weak (~10 Hz)

Stronger couplings
in liquid crystals : ~ 1 kHz



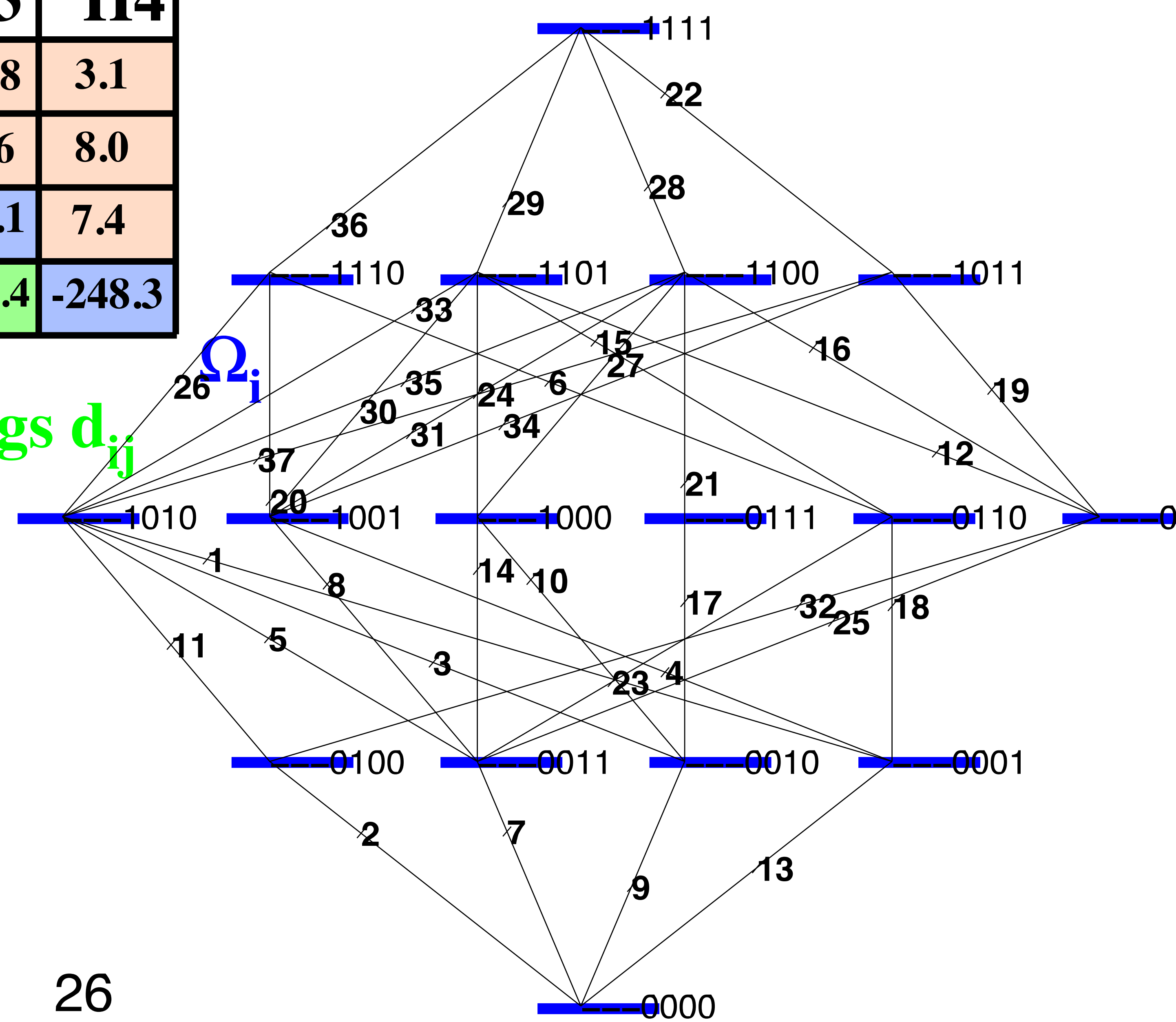
Dipolar Coupled System



in ZLI-1132

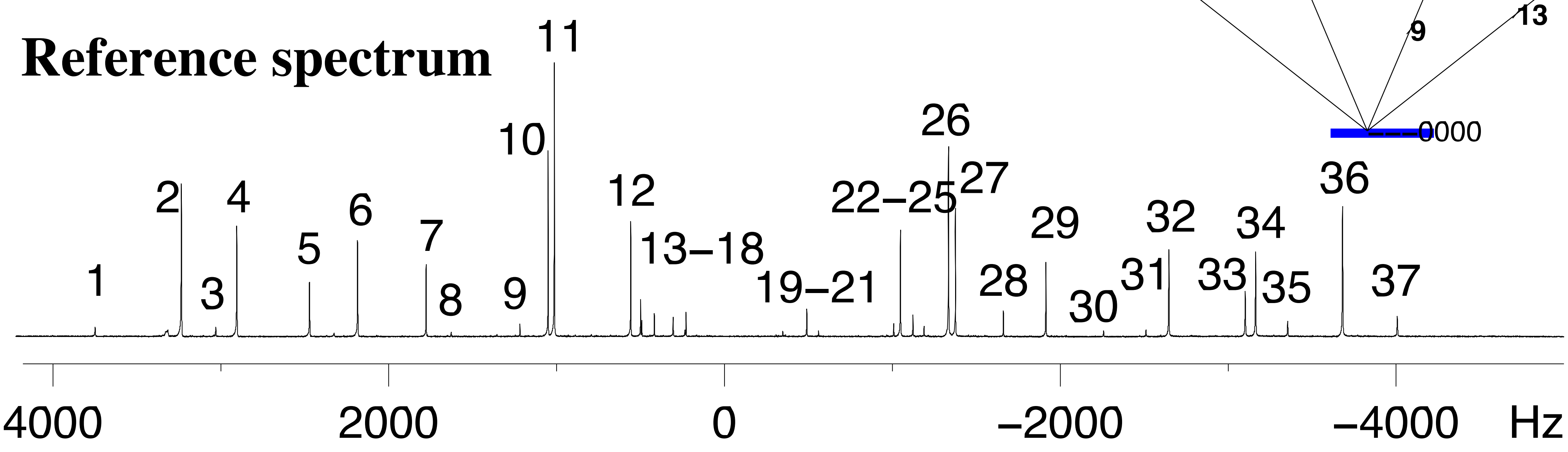
	H1	H2	H3	H4
H1	-303.7	7.7	0.8	3.1
H2	-788.0	-3.5	7.6	8.0
H3	85.7	-278.5	-208.1	7.4
H4	71.0	-667.2	-1873.4	-248.3

dipolar couplings d_{ij}



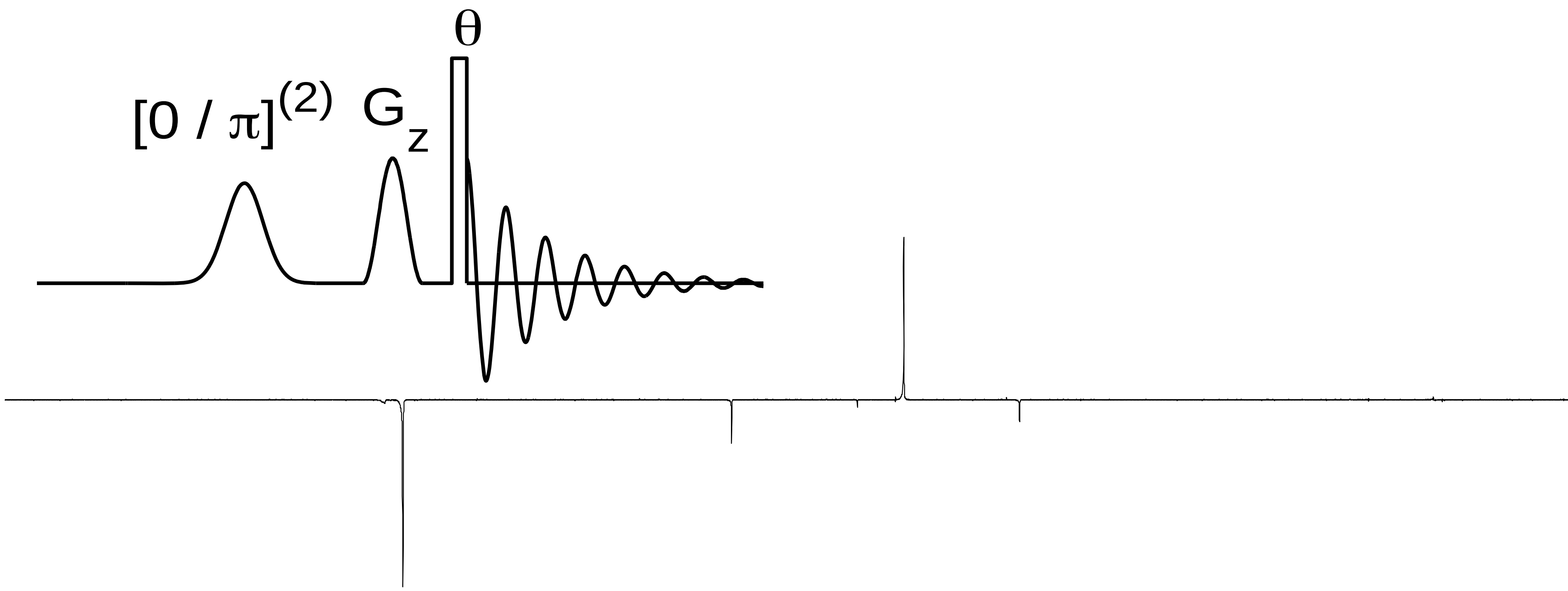
How do we implement quantum gates ?

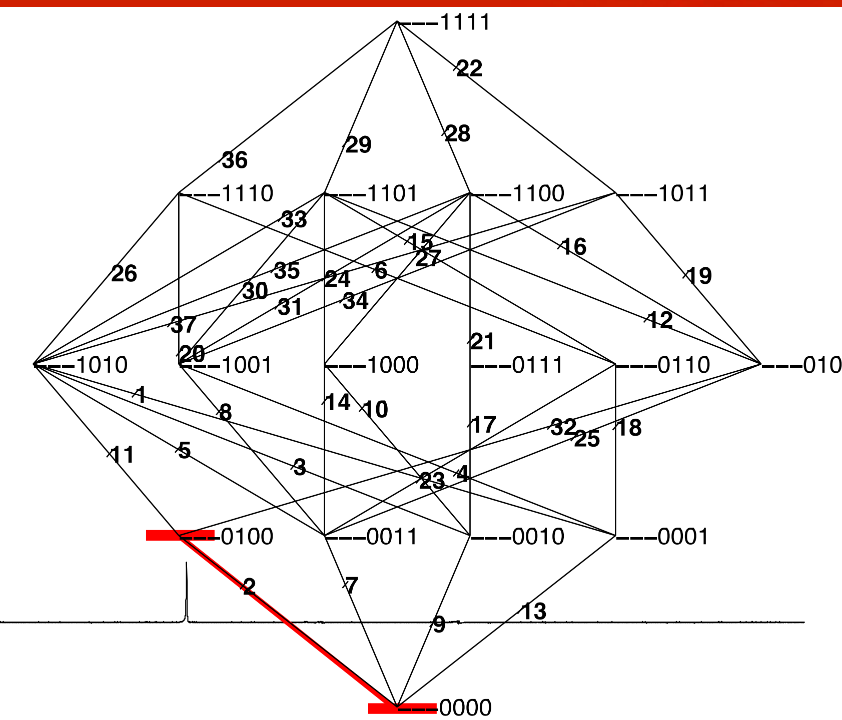
Reference spectrum



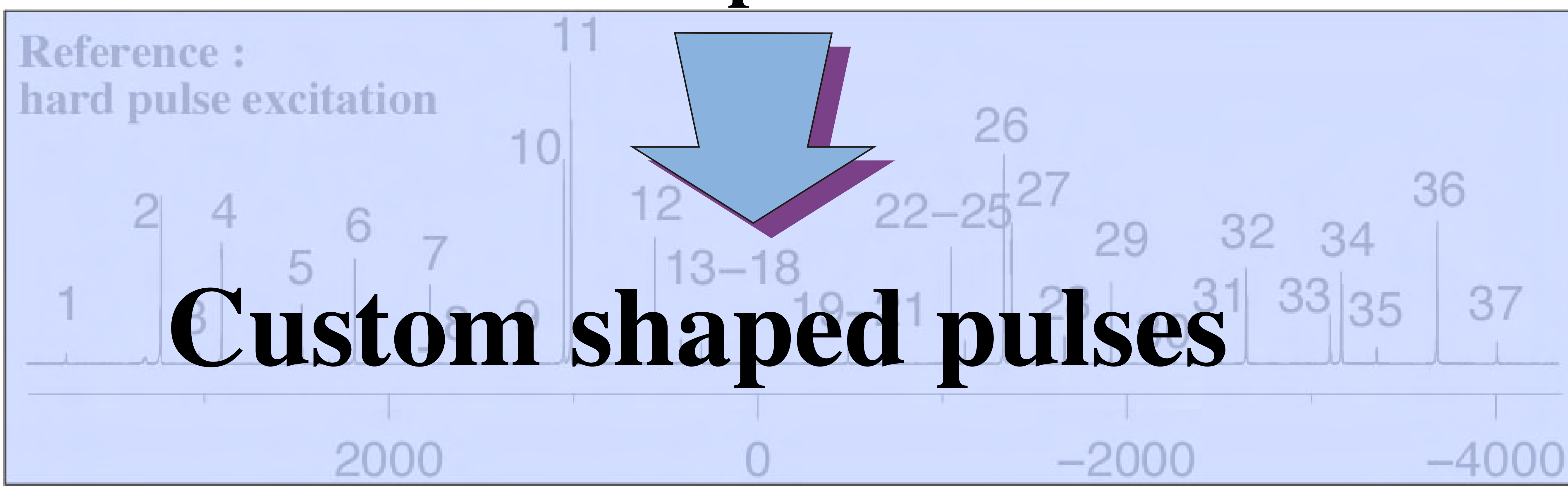
Gate Operations

e.g State Preparation (POPS)





Not possible for all transitions

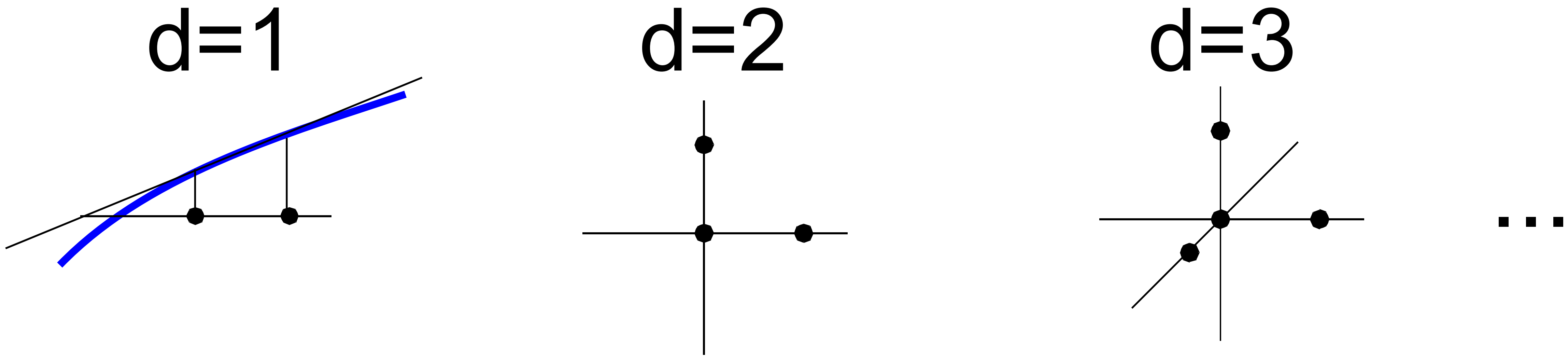


Custom shaped pulses

Gradient estimation

Classical

requires ≥ d+1 function evaluations in d dimensions

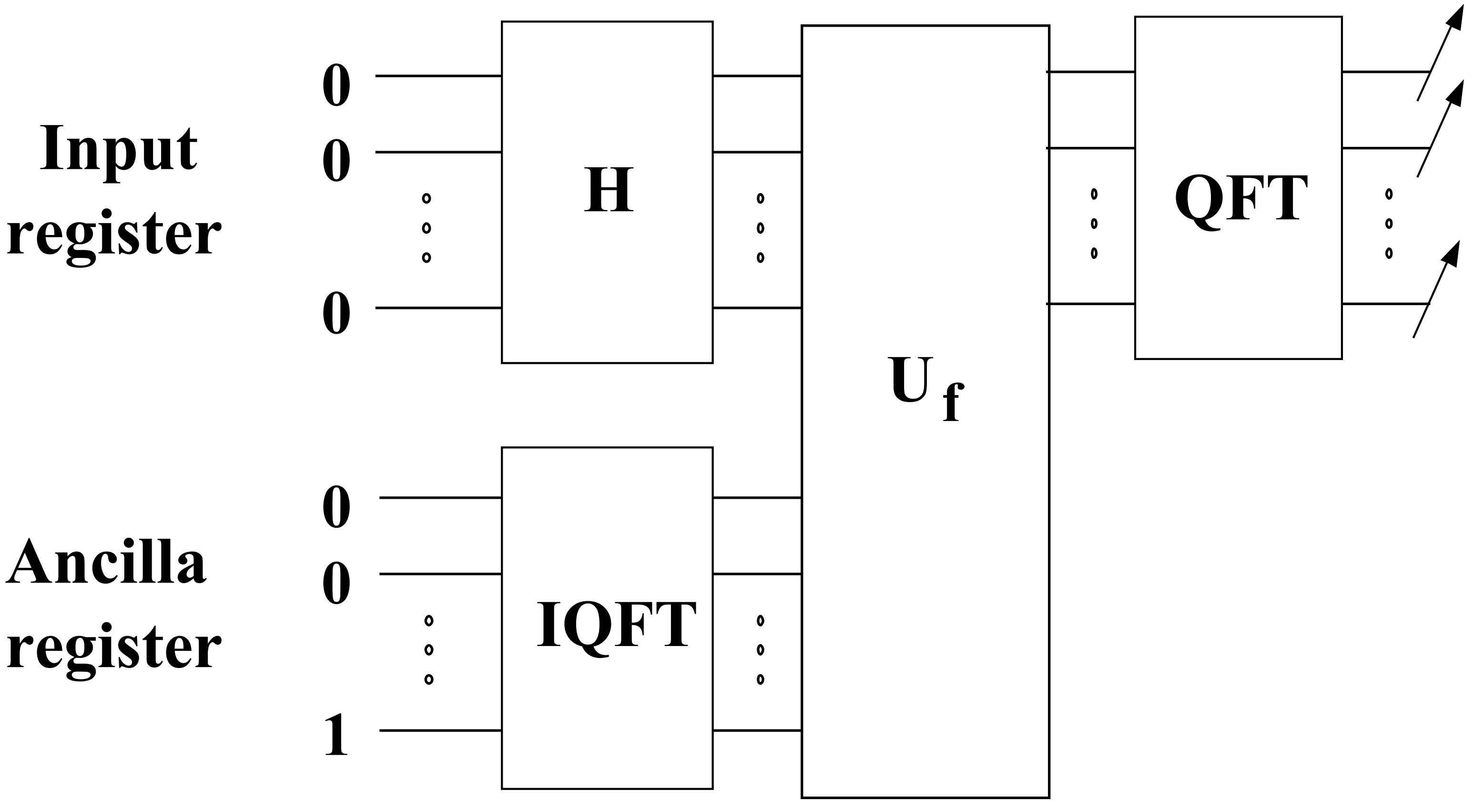


Quantum gradient estimation

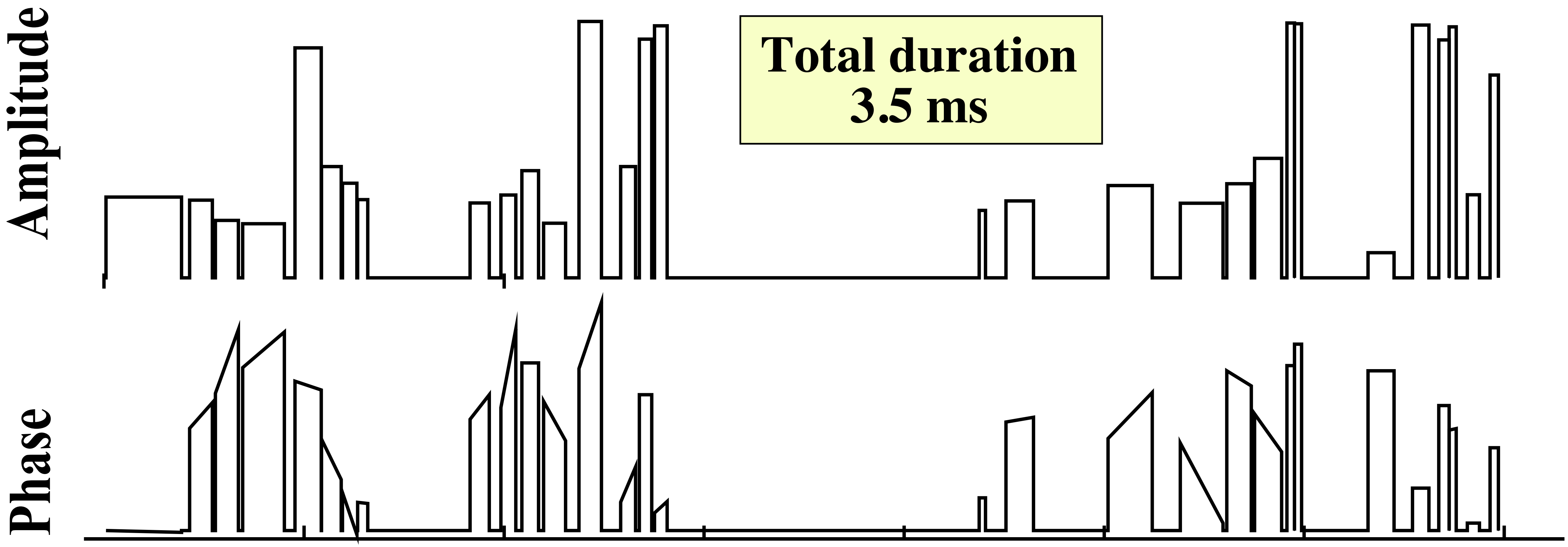
requires 1 function evaluation

S. P. Jordan,
Phys. Rev. Lett. 95*, 050501 (2005).*

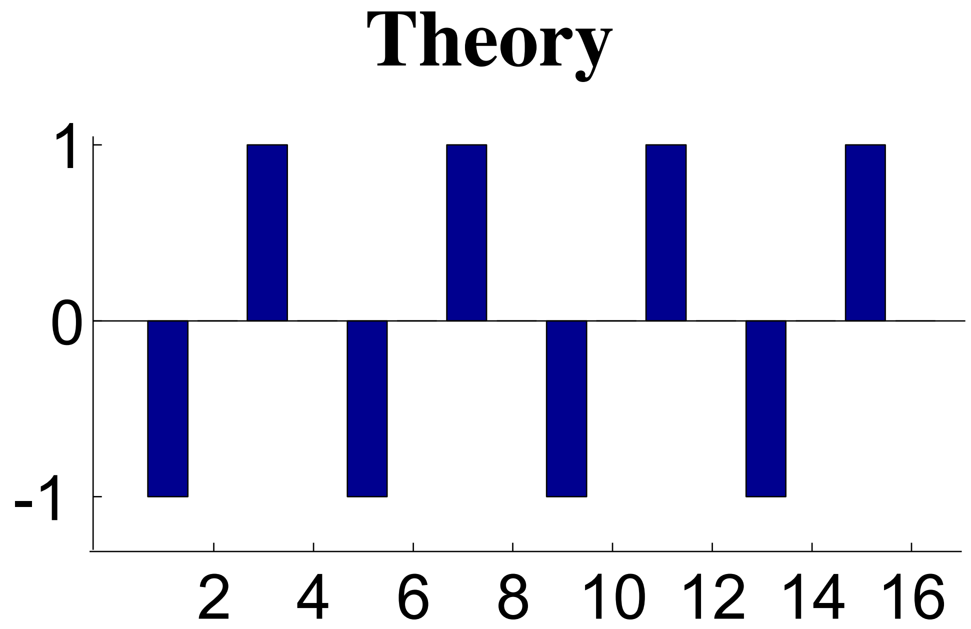
Here: d = 1

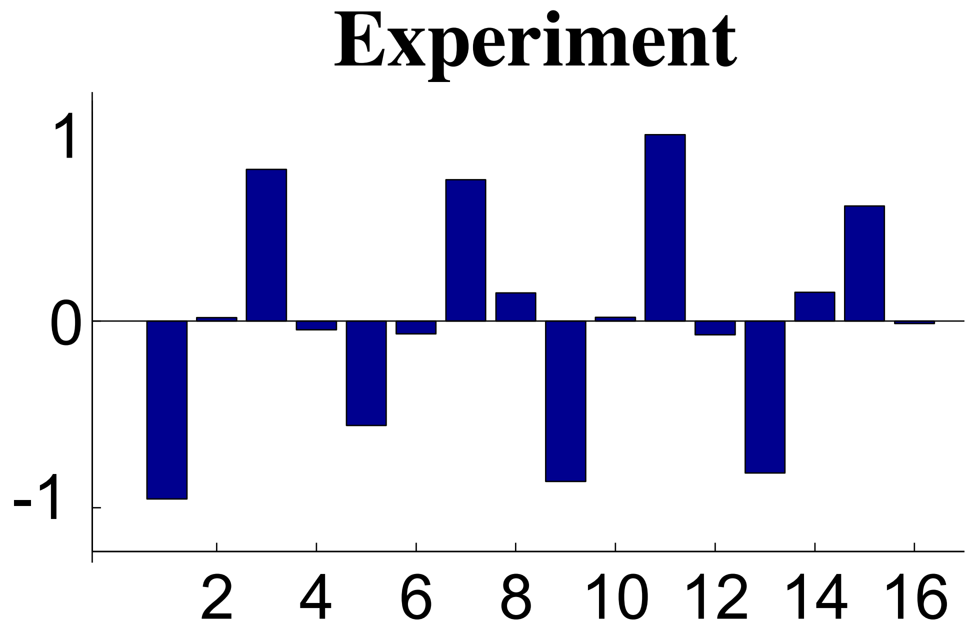


Optimized Sequence



Resulting populations



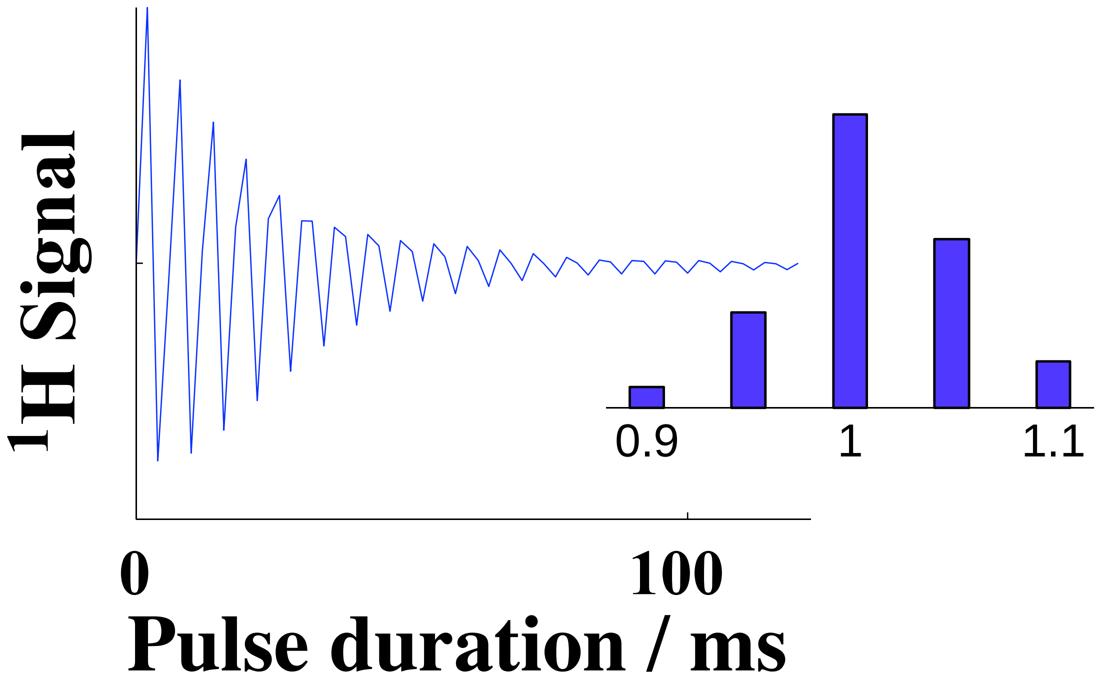


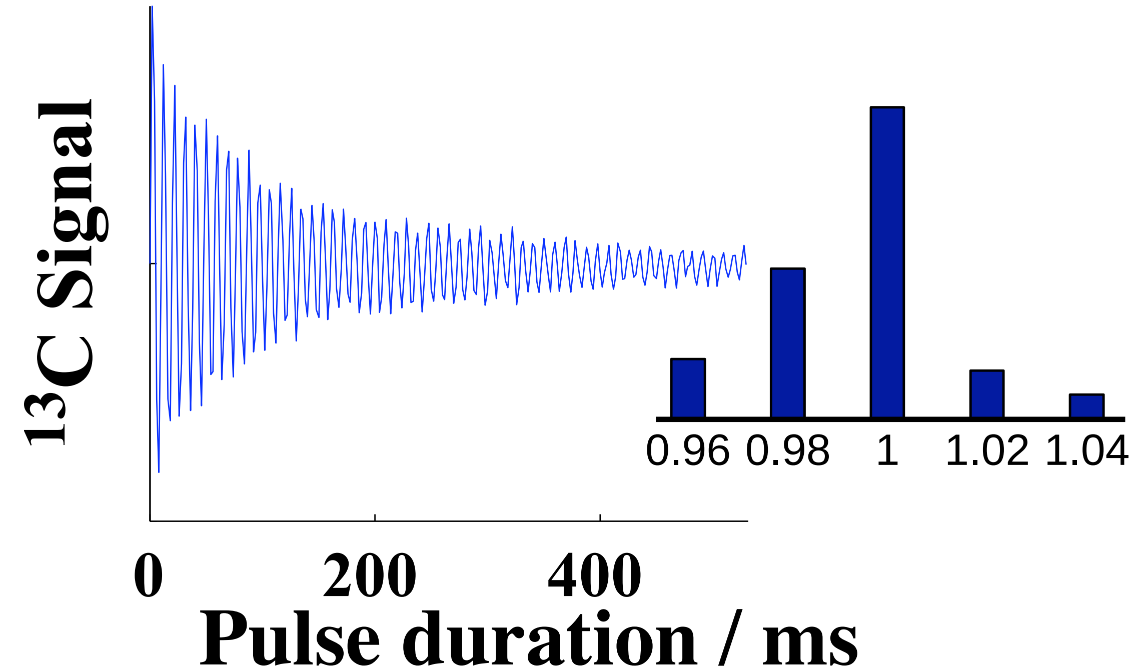
Result :
Input qubits
= |10>

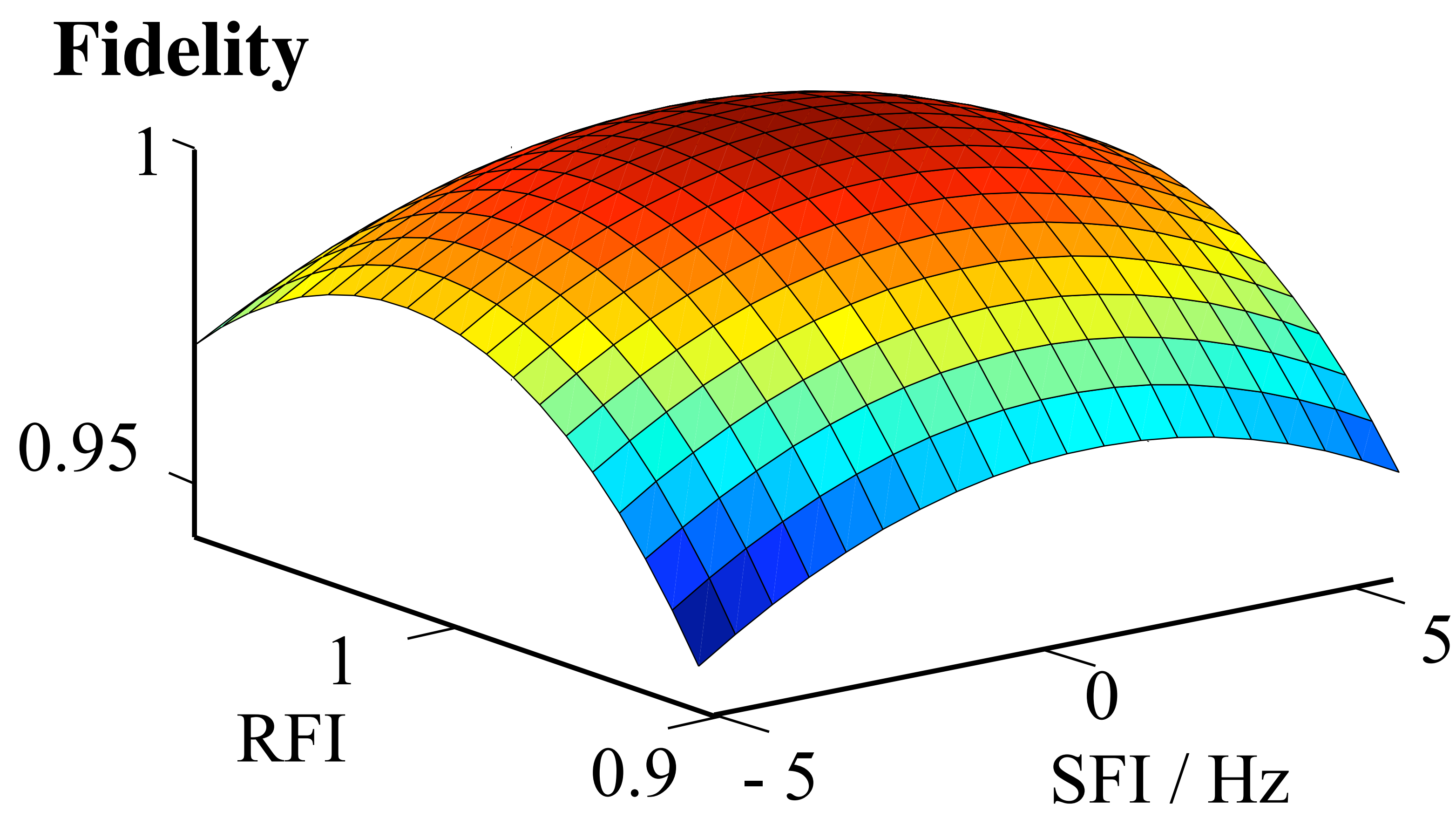
∇f = 2

Robustness

RF inhomogeneity

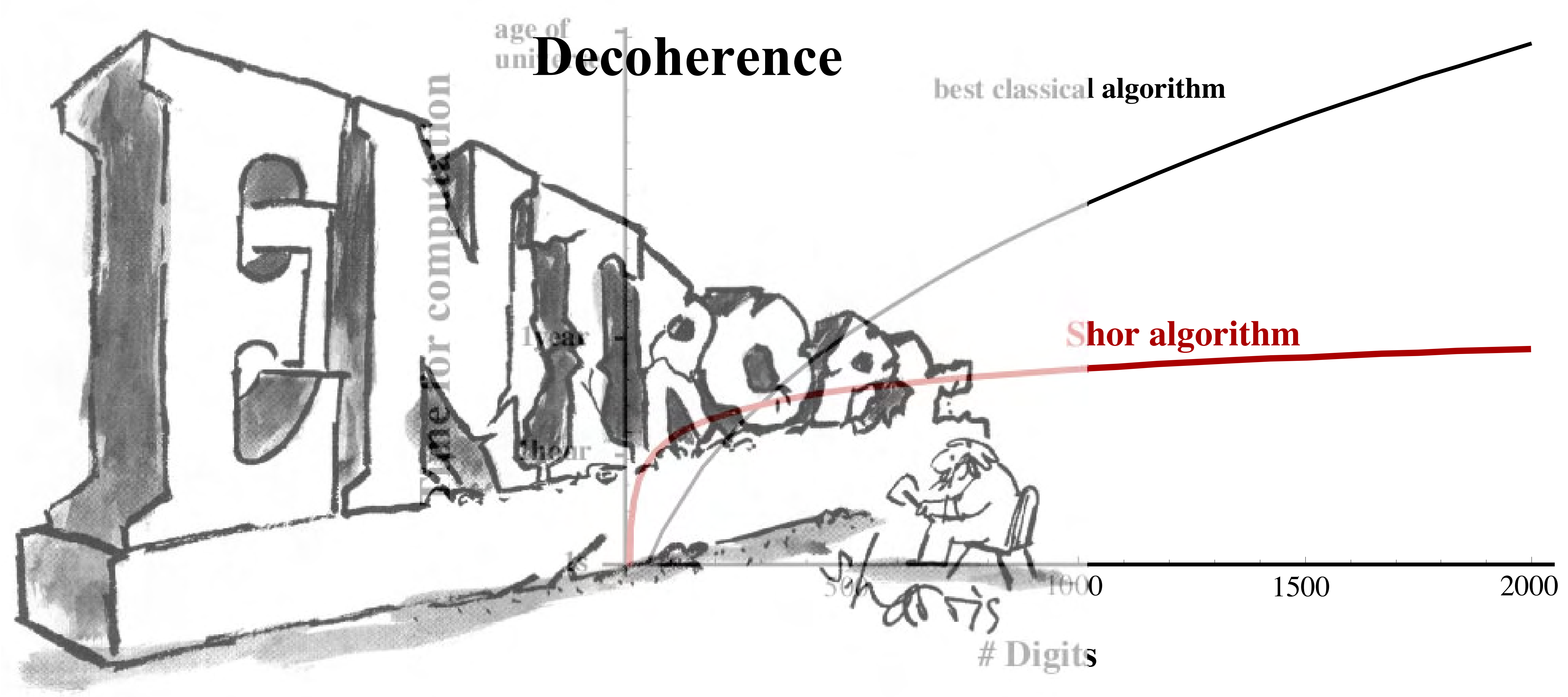






M.T. + D.S., Phys. Rev. A ***74**, 062312 (2006)*

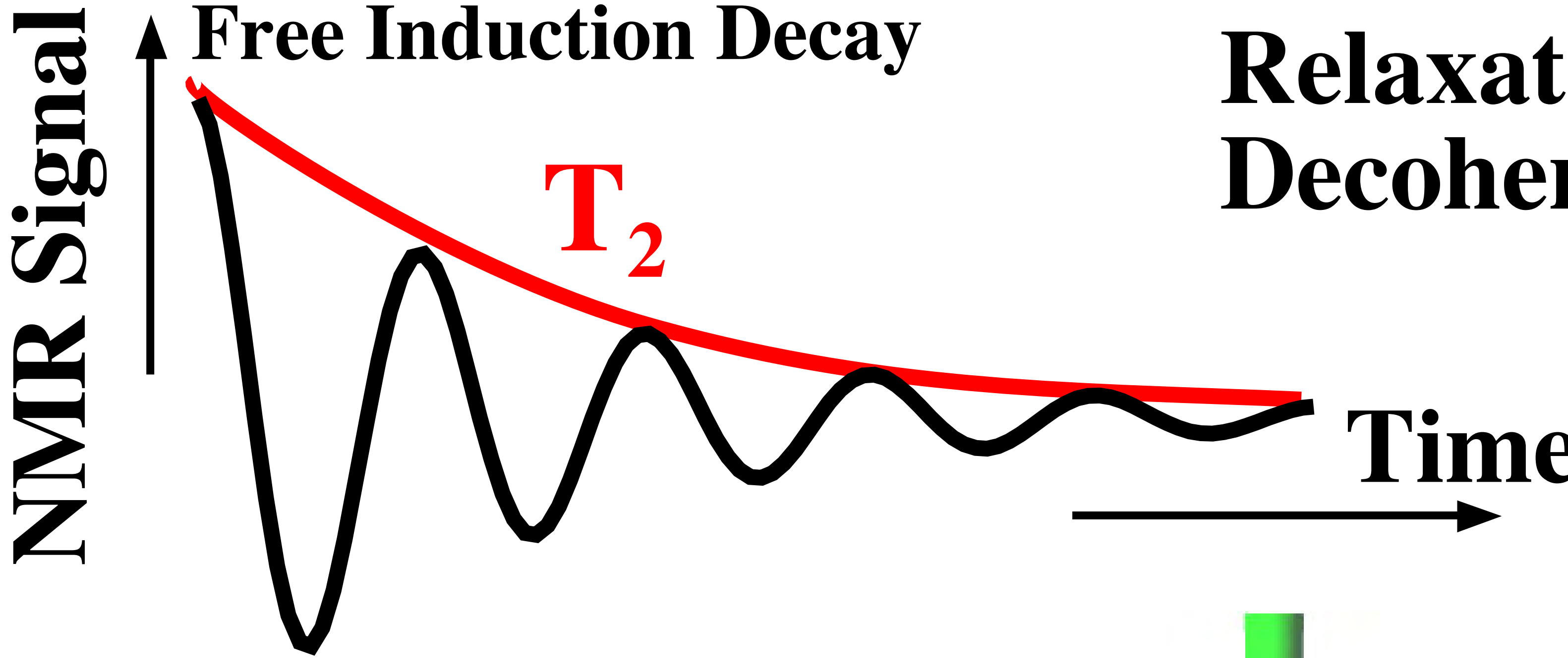
Scalability and Decoherence



Main source : coupling to environment

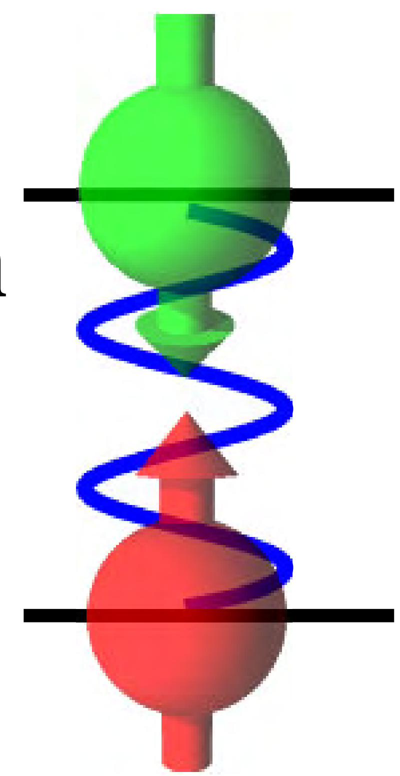
Decoherence

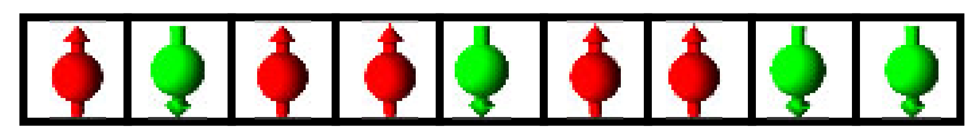
FID =
Free Induction Decay



**Relaxation =
Decoherence**

**observable magnetization
=
single qubit coherence**



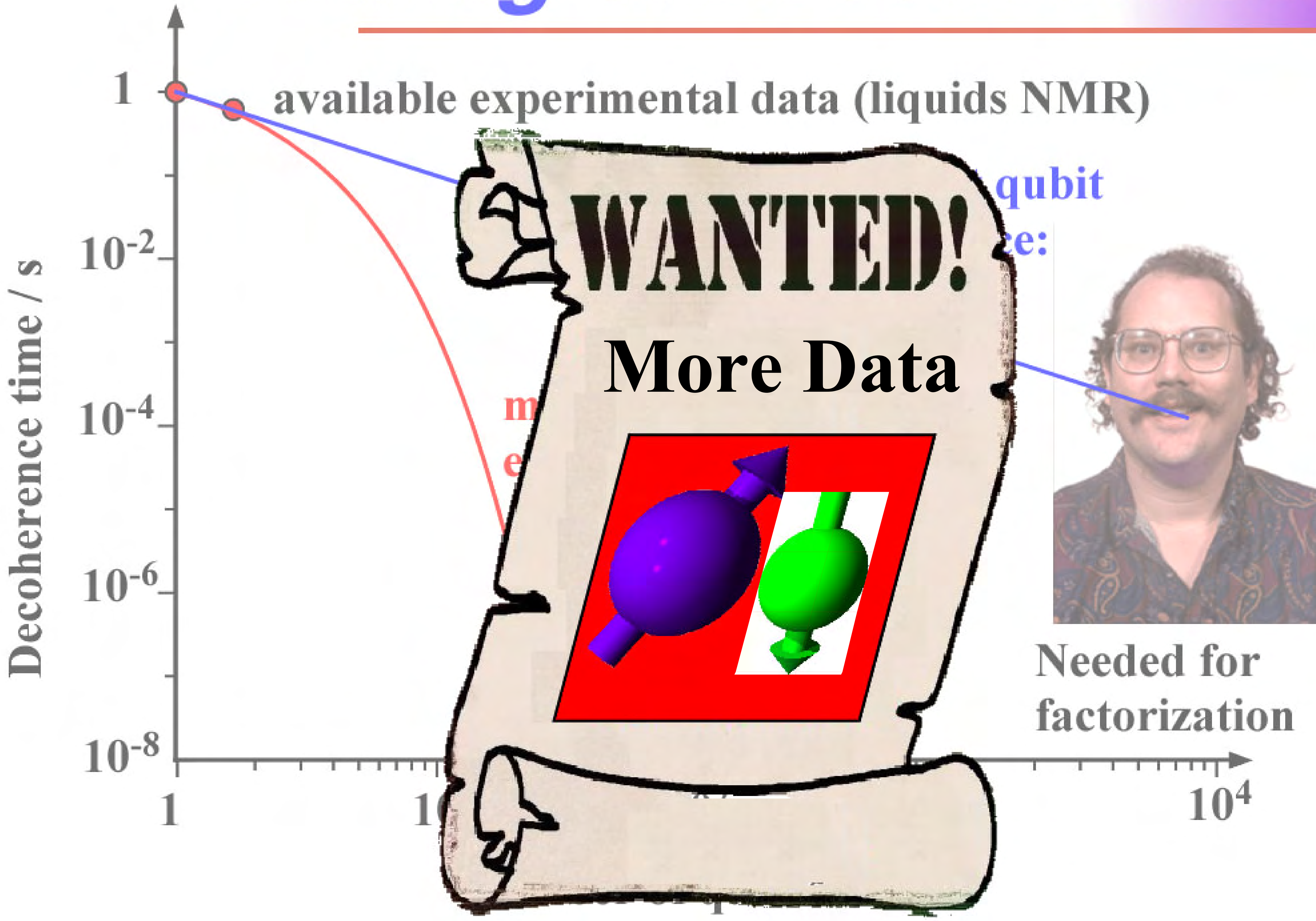


**Quantum register
involves coherence
of many qubits**

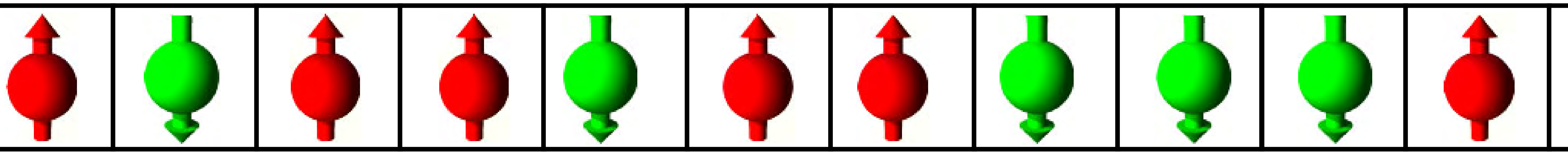
**How fast will a “useful” quantum register
loose information ?**

?

Scaling of Decoherence



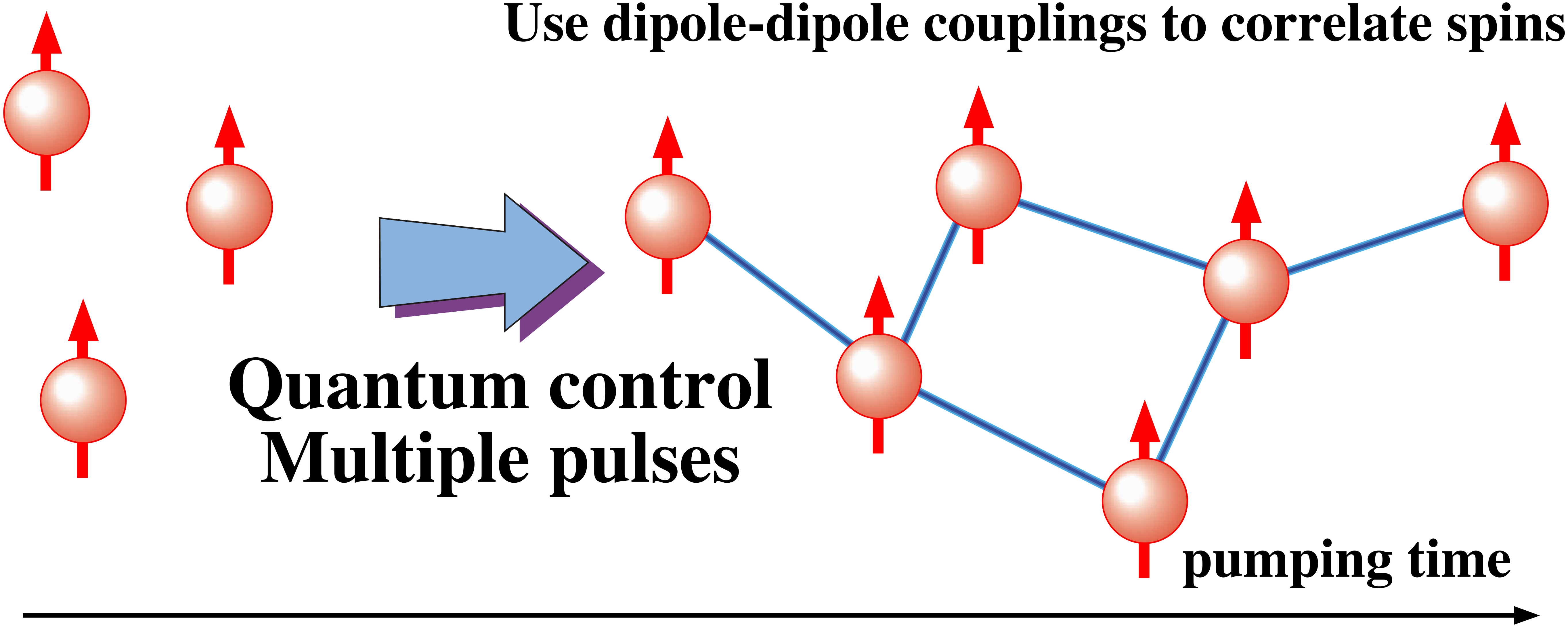
Wide Quantum Registers



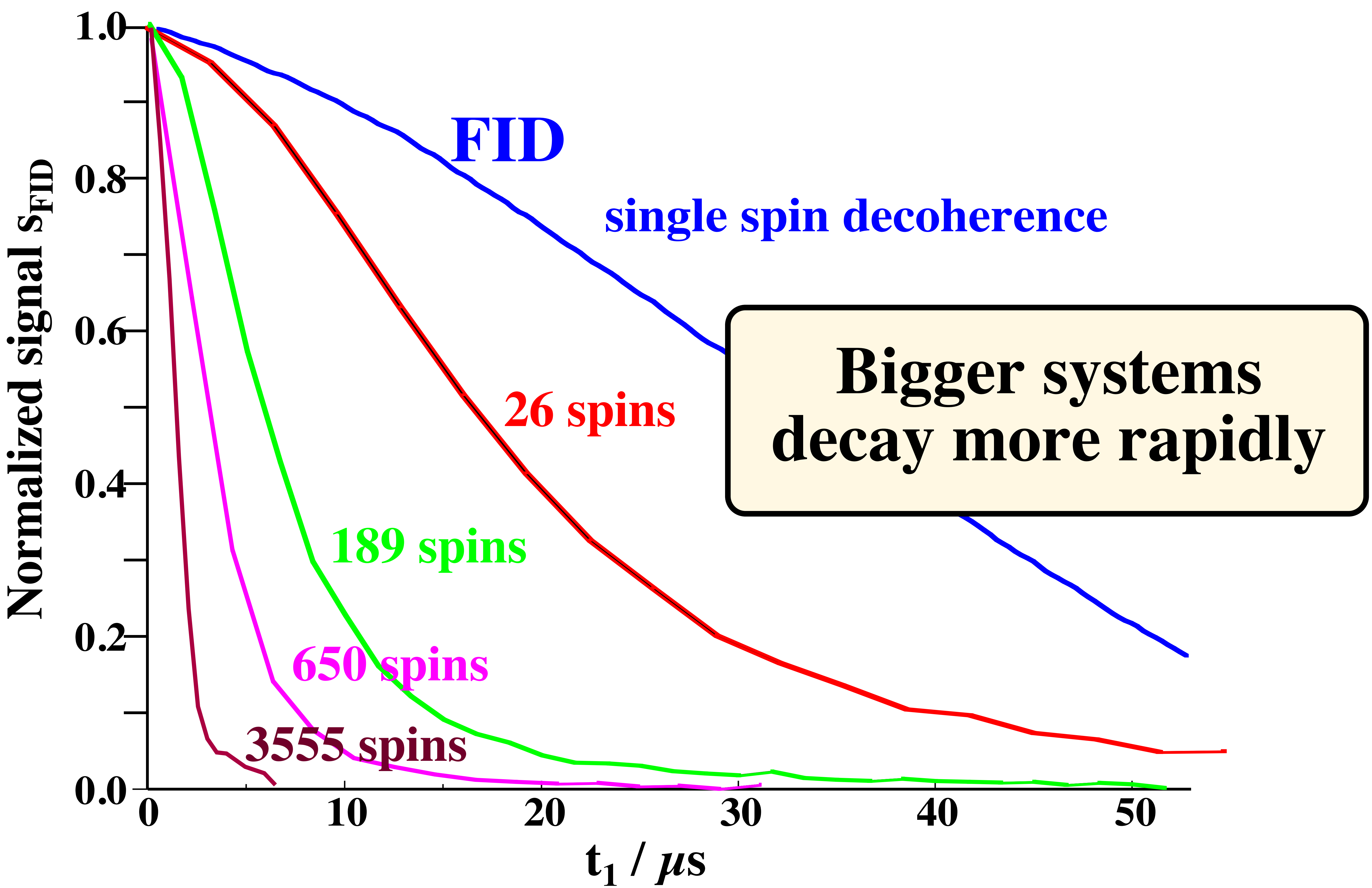
Model quantum register with 1000's of nuclear spin qubits

Thermal equilibrium: independent spins

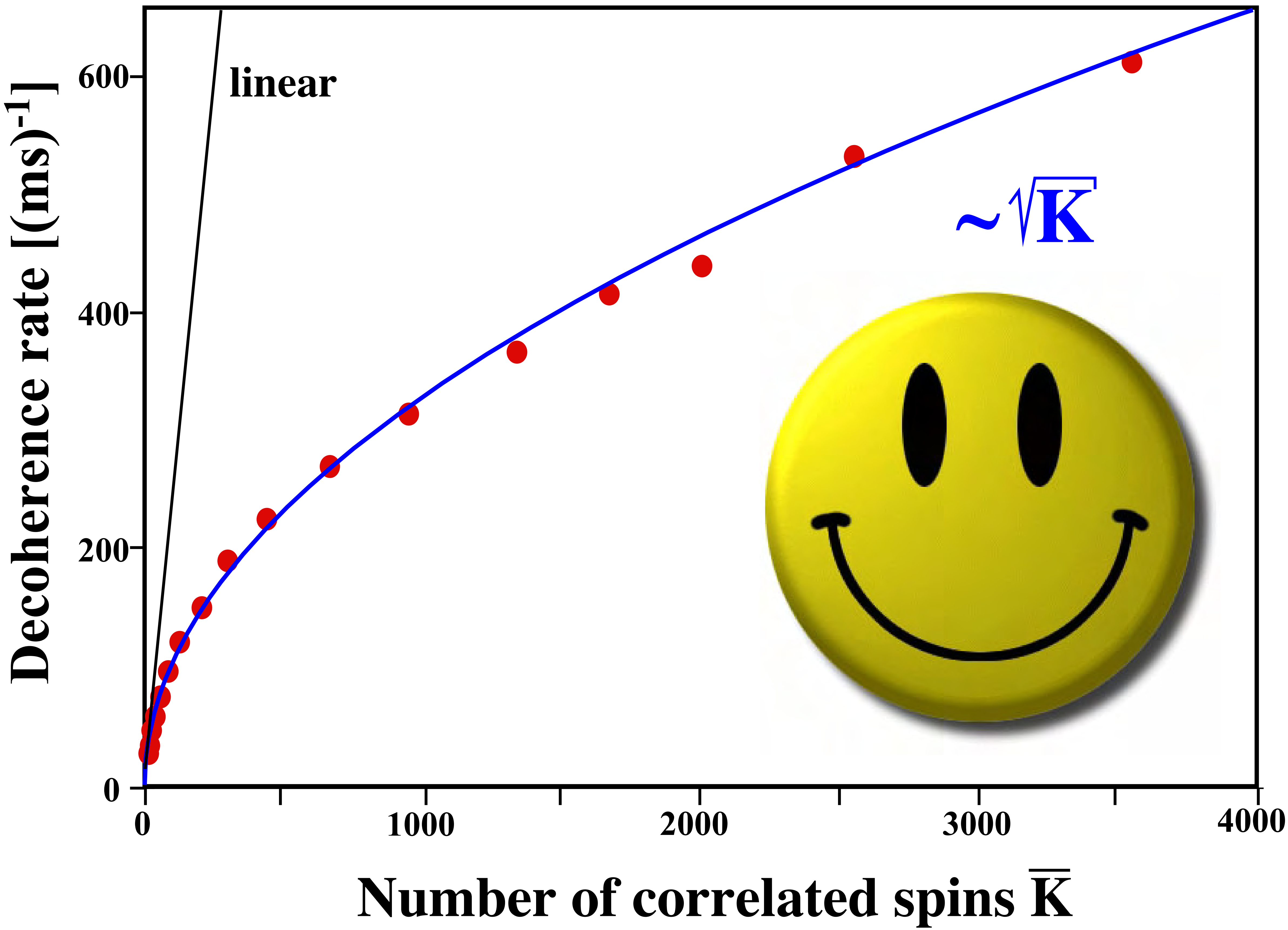
Use dipole-dipole couplings to correlate spins



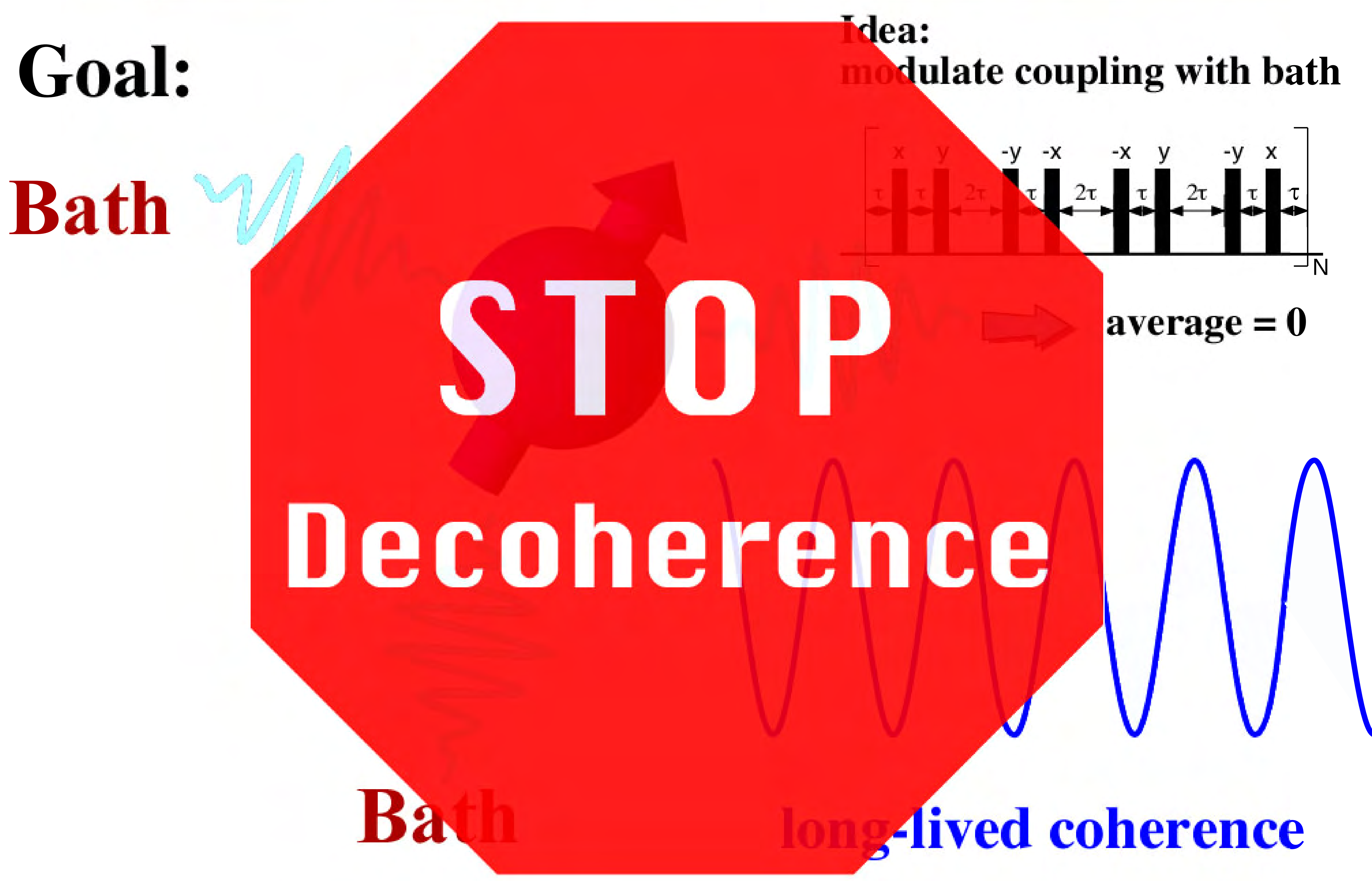
Observed Decays



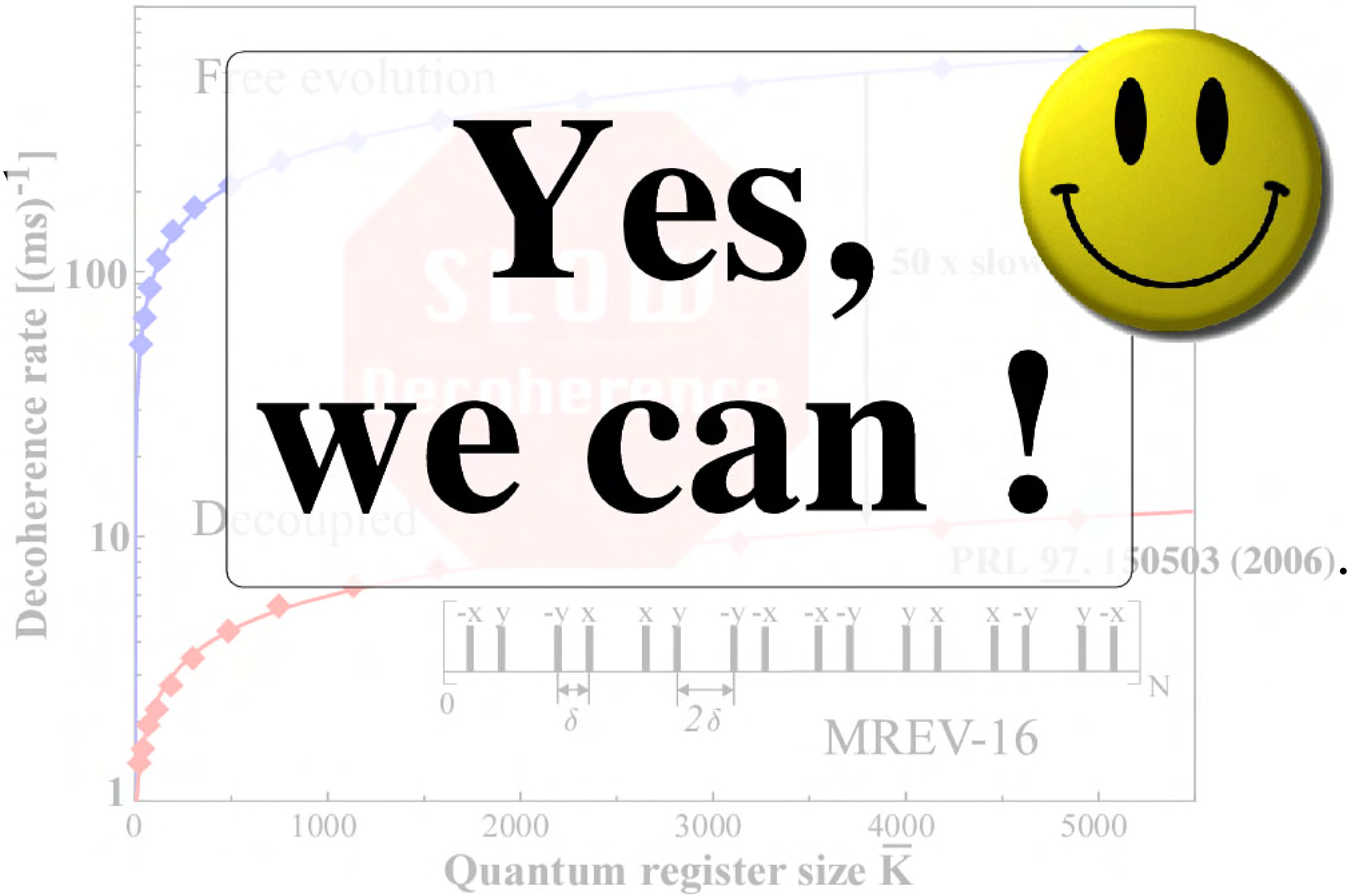
Decoherence Rates



Can We Reduce Decoherence ?

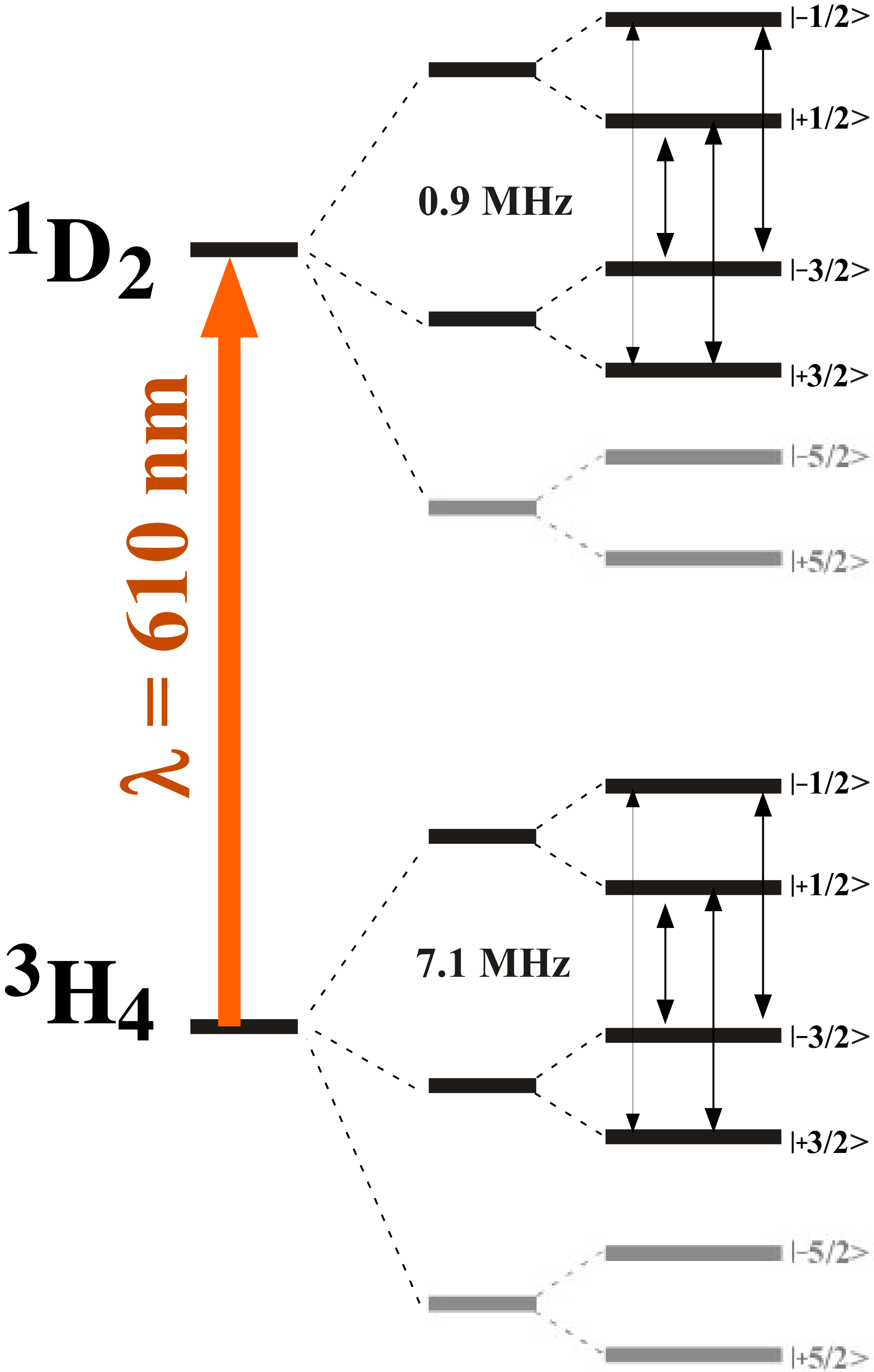


Decoupling Quantum Registers

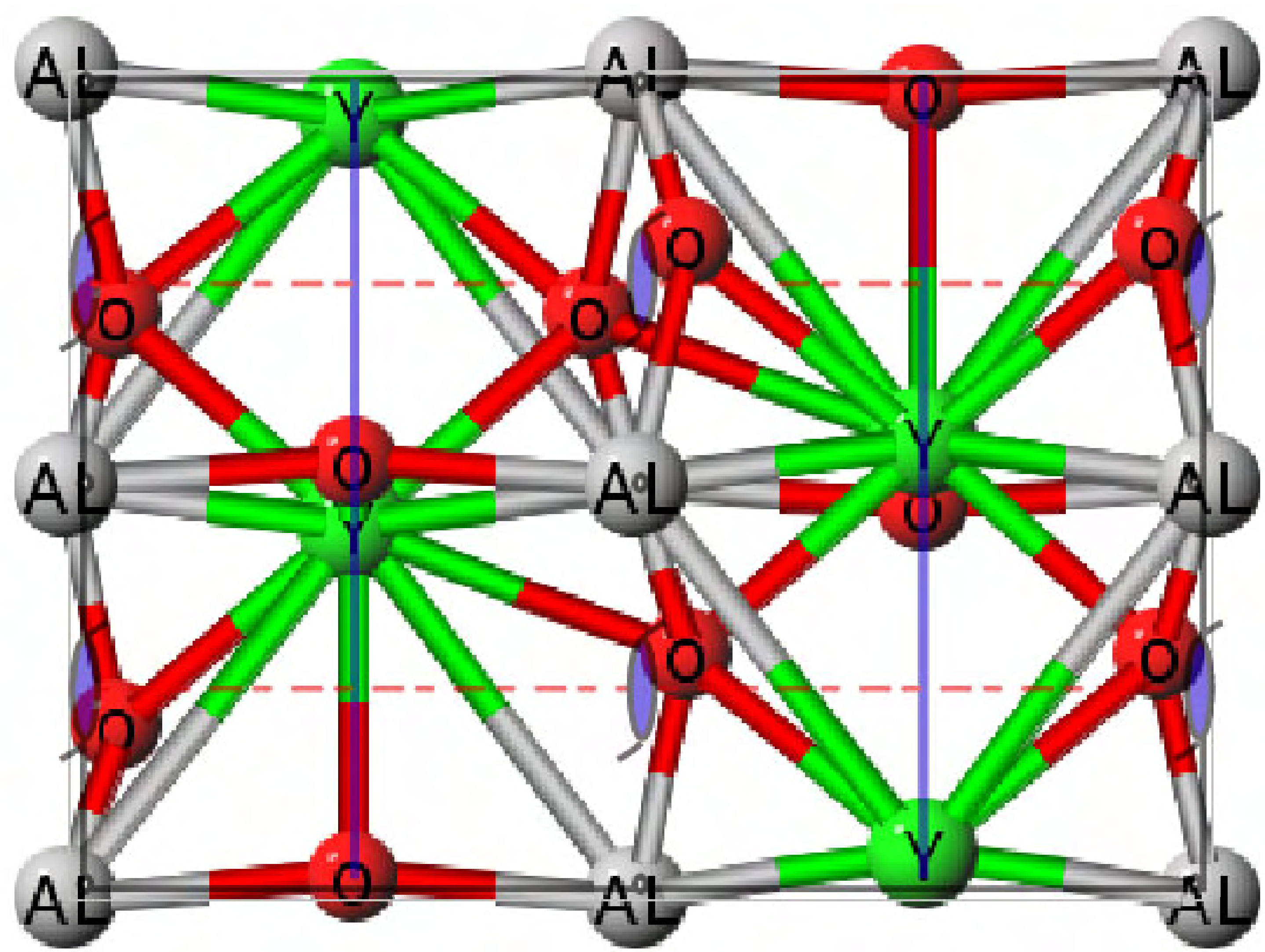


Magneto-Optics

$^{141}Pr : I = 5/2$

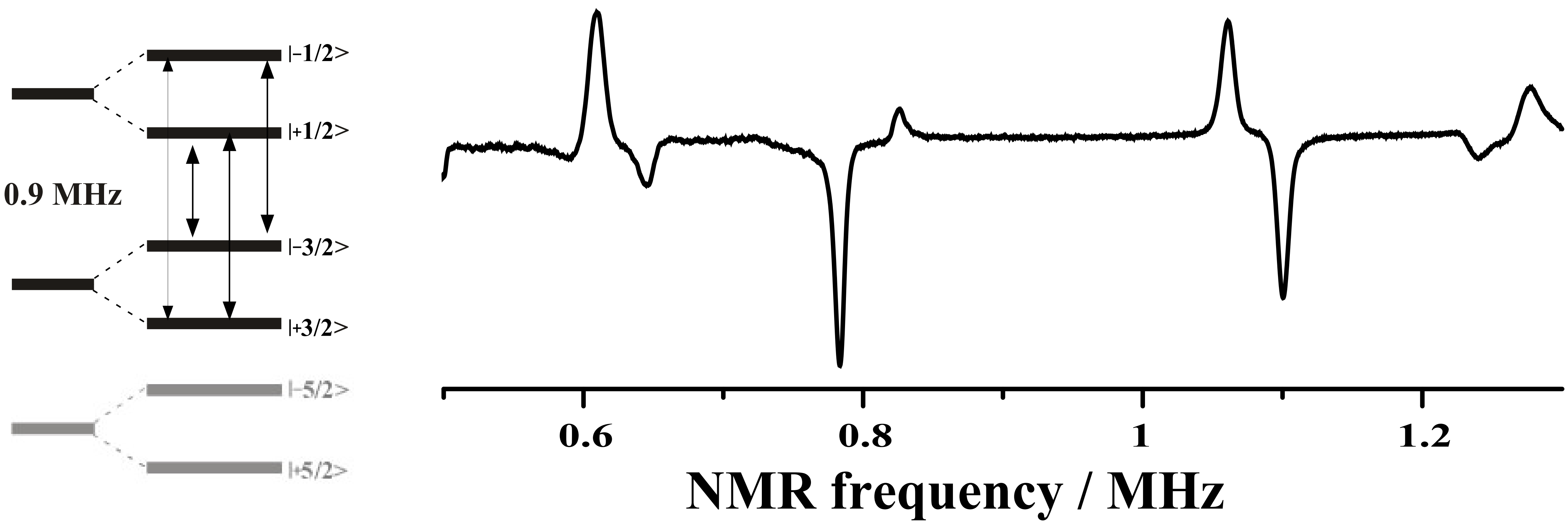


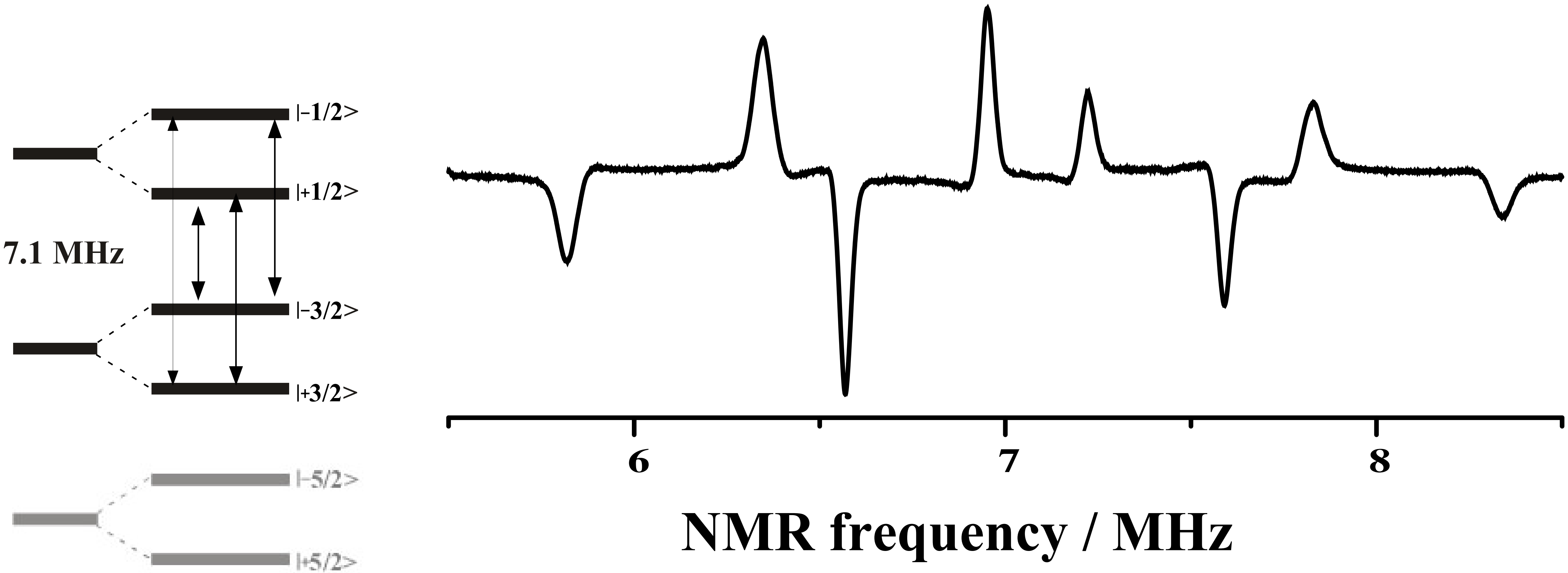
Pr:$YAlO_3$



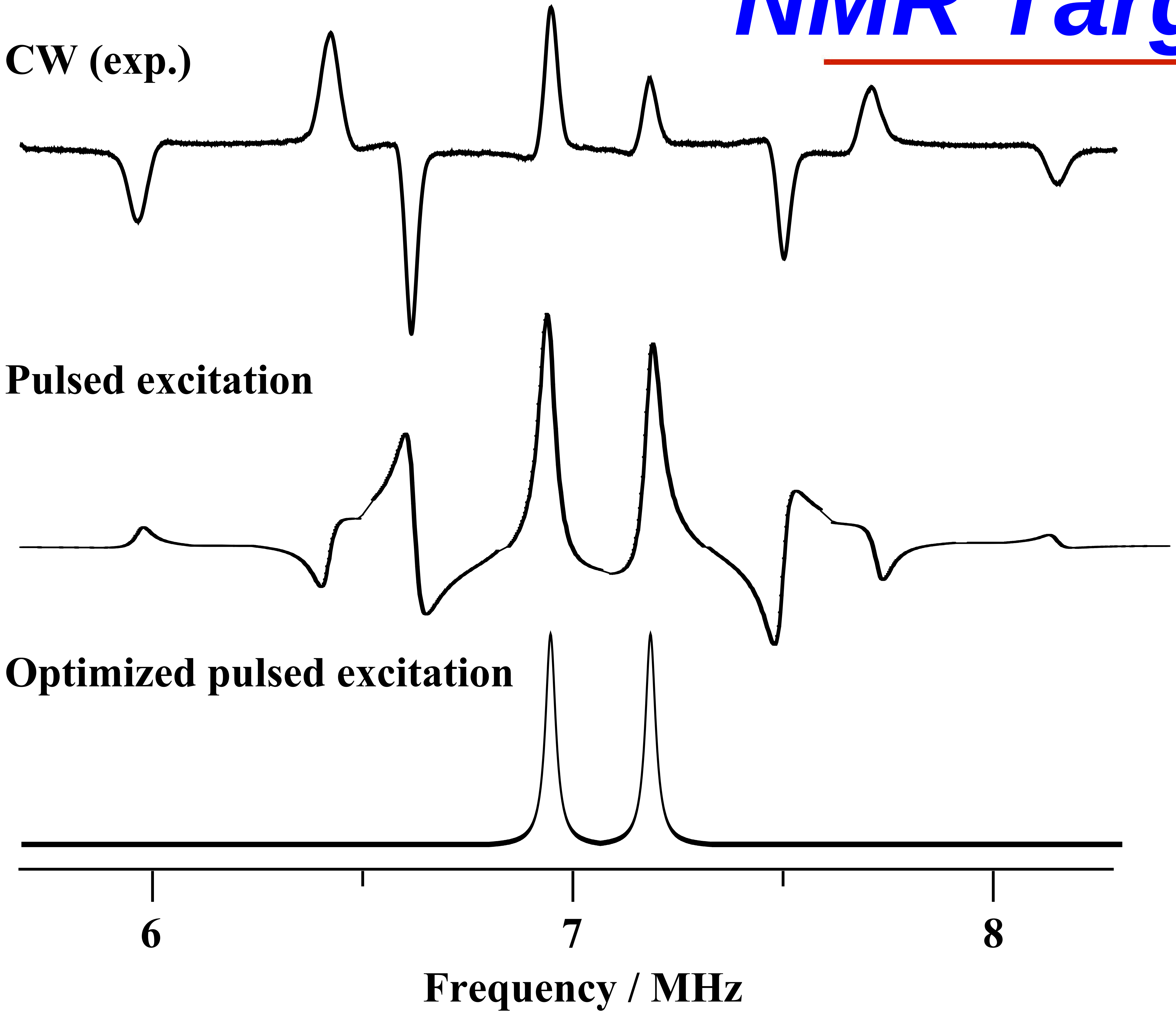
Spin Transitions

$^{141}Pr : I = 5/2$

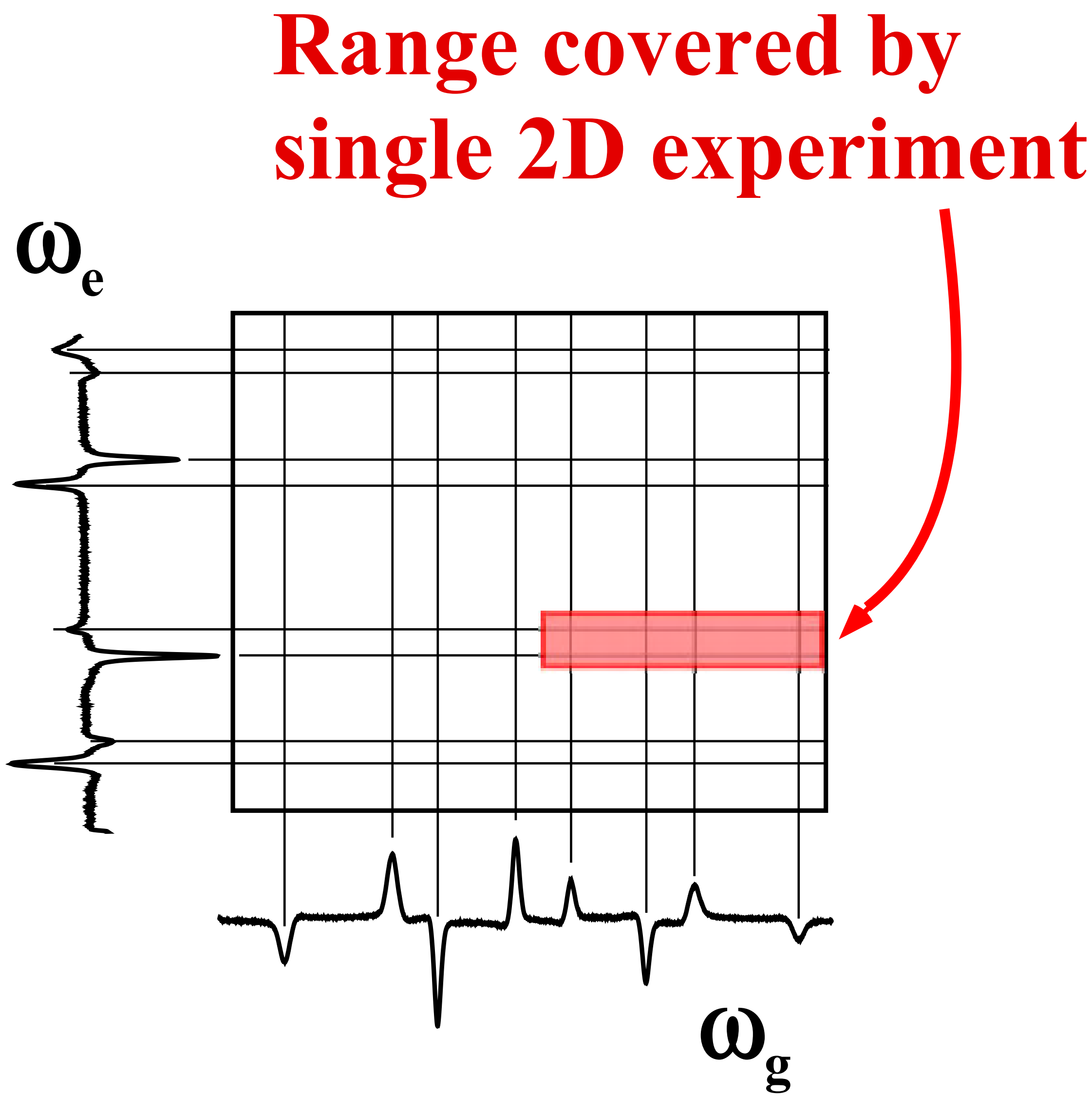




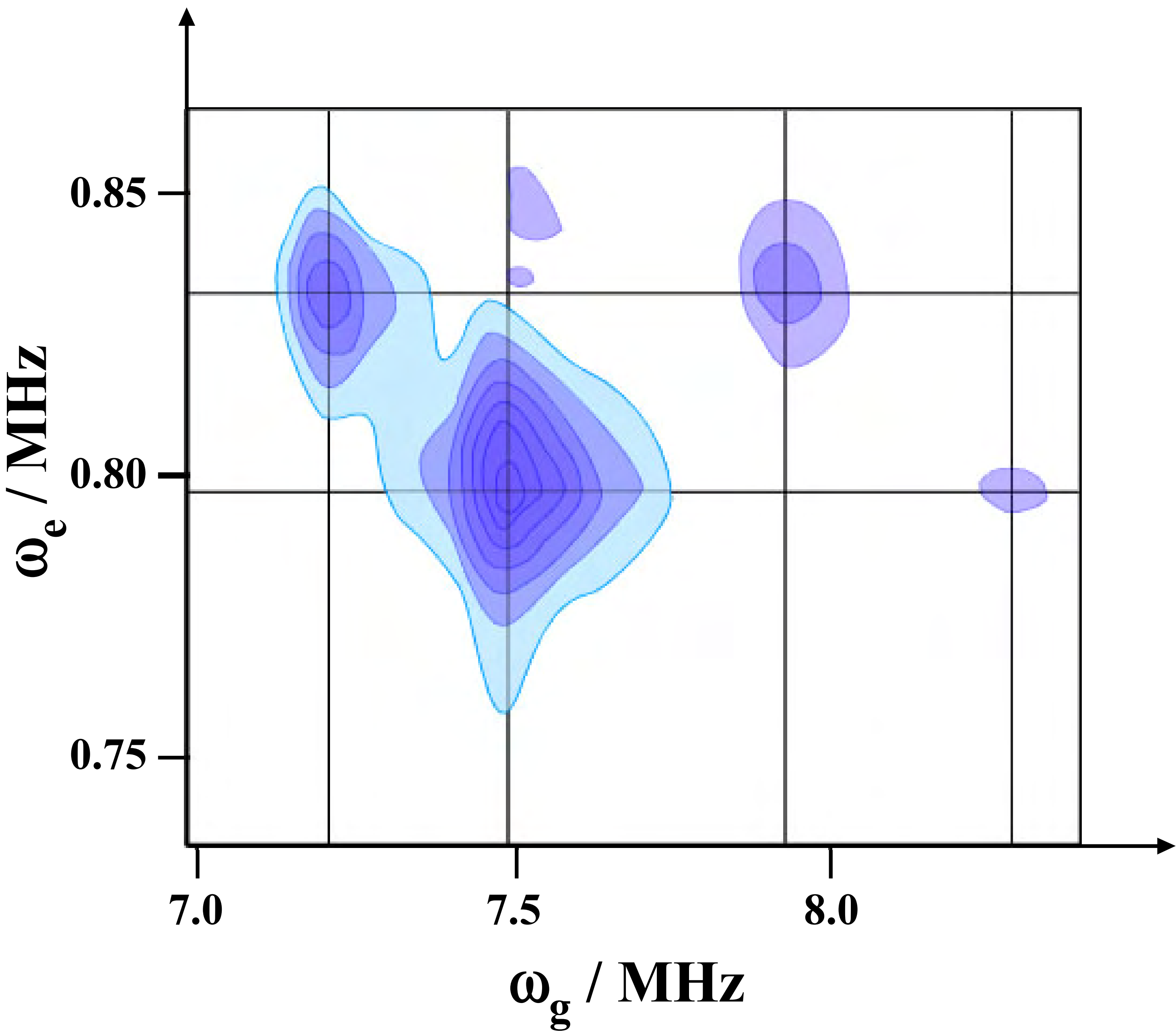
NMR Target


CW (exp.)
Pulsed excitation
Optimized pulsed excitation
6
7
8
Frequency / MHz

2D Spectrum

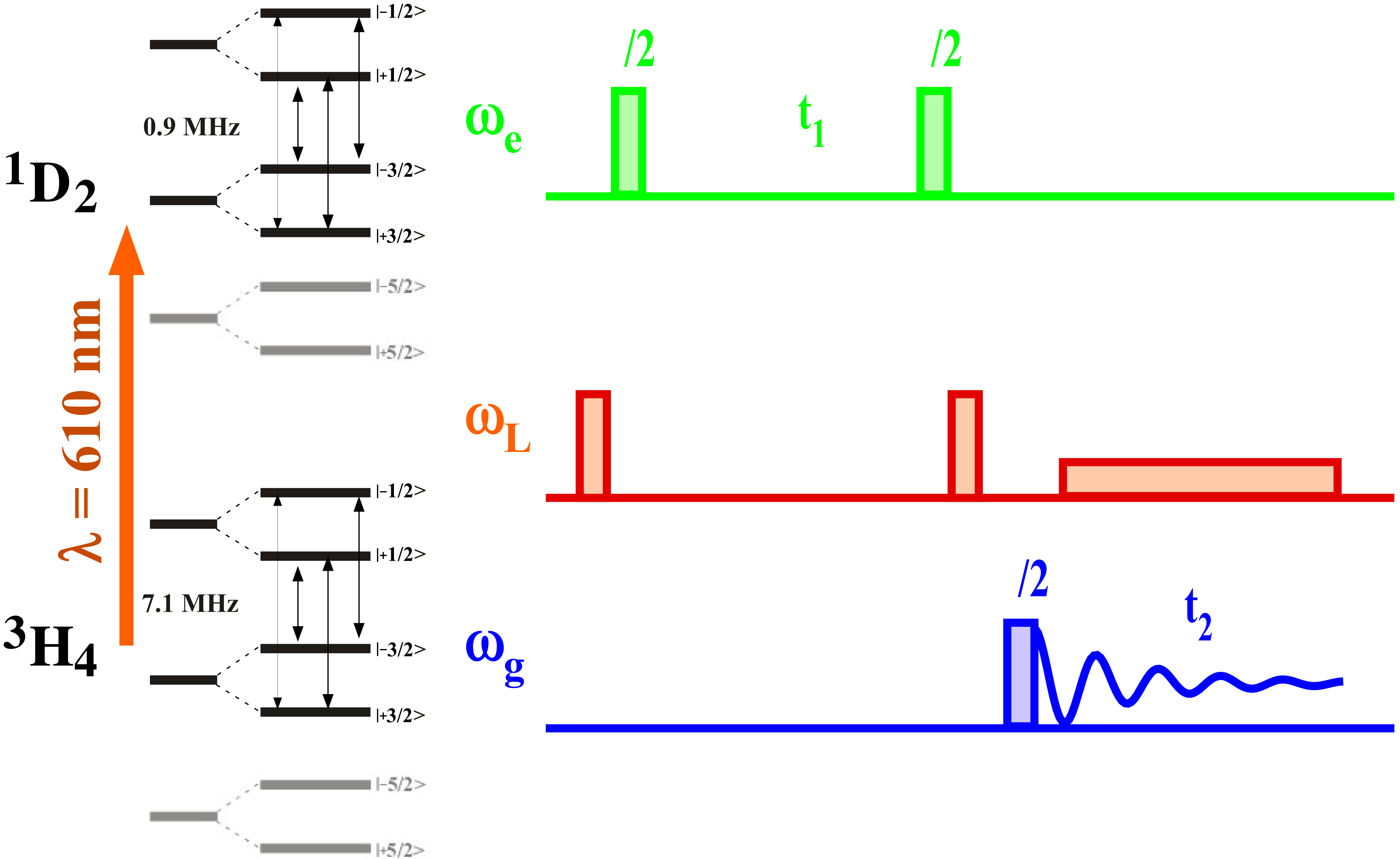


Range covered by single 2D experiment
ωe
ωg



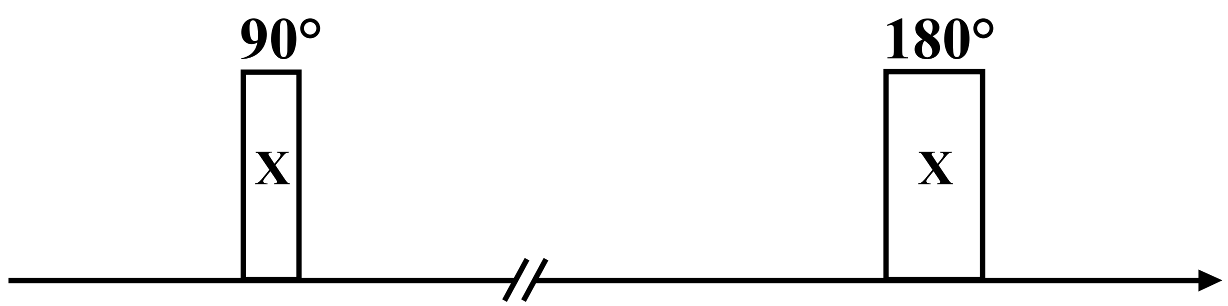
0.85
0.80
0.75
ωe / MHz
7.0
7.5
8.0
ωg / MHz

Pulsed Excitation



Composite Laser Pulses

Photon Echo **π-Pulse**



Offset-compensated π-pulse