Addressing ^{31}P and ^{29}Si nuclear spins in isotopically engineered silicon

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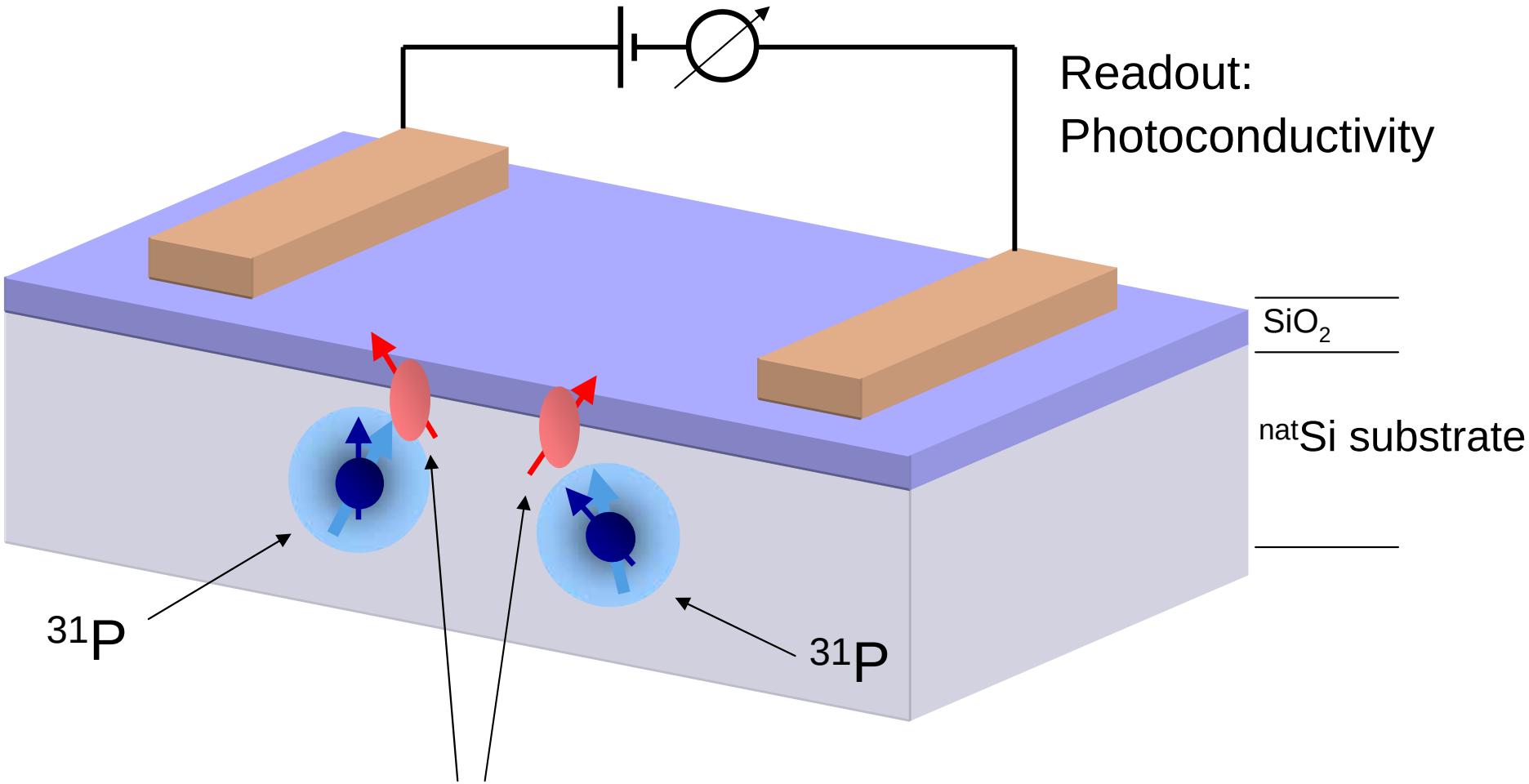
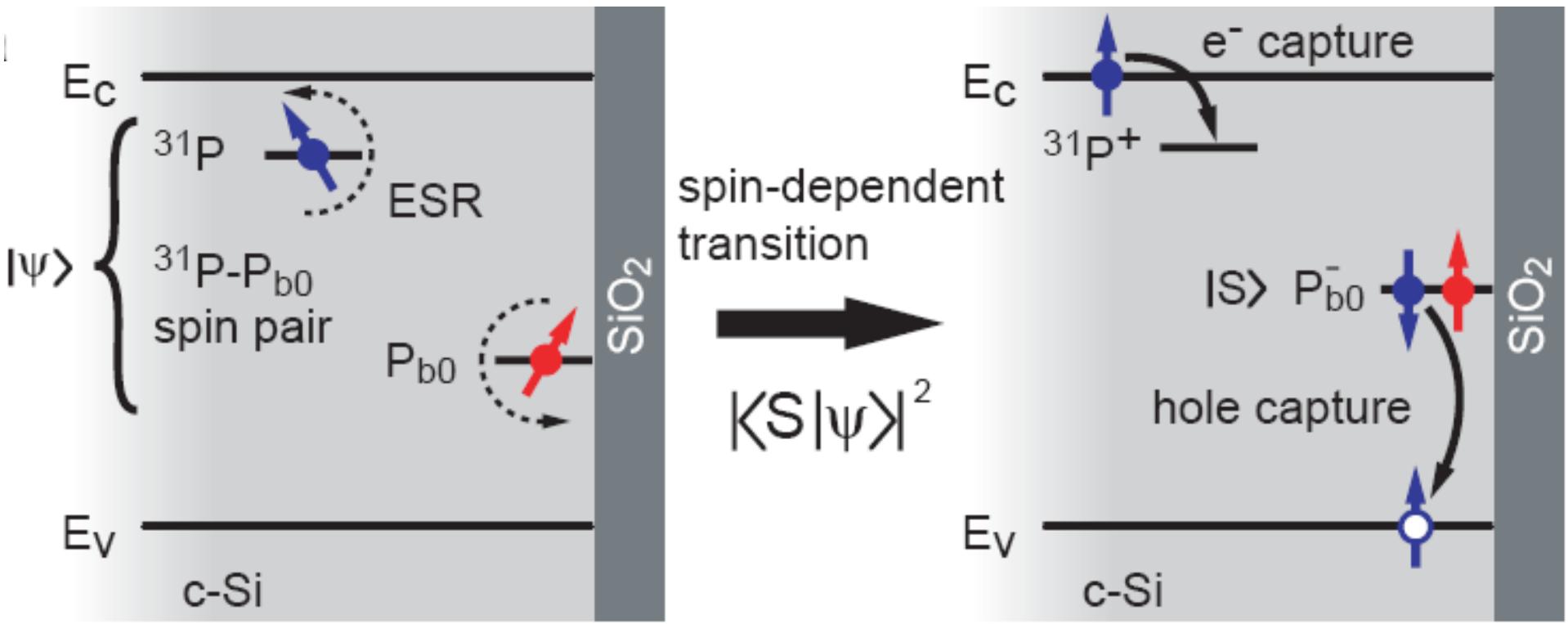
"Solid-State Based
Quantum Information Processing"

Spin-to-charge transfer at interface states



Paramagnetic interface states P_{b0}

Electrically detected magnetic resonance

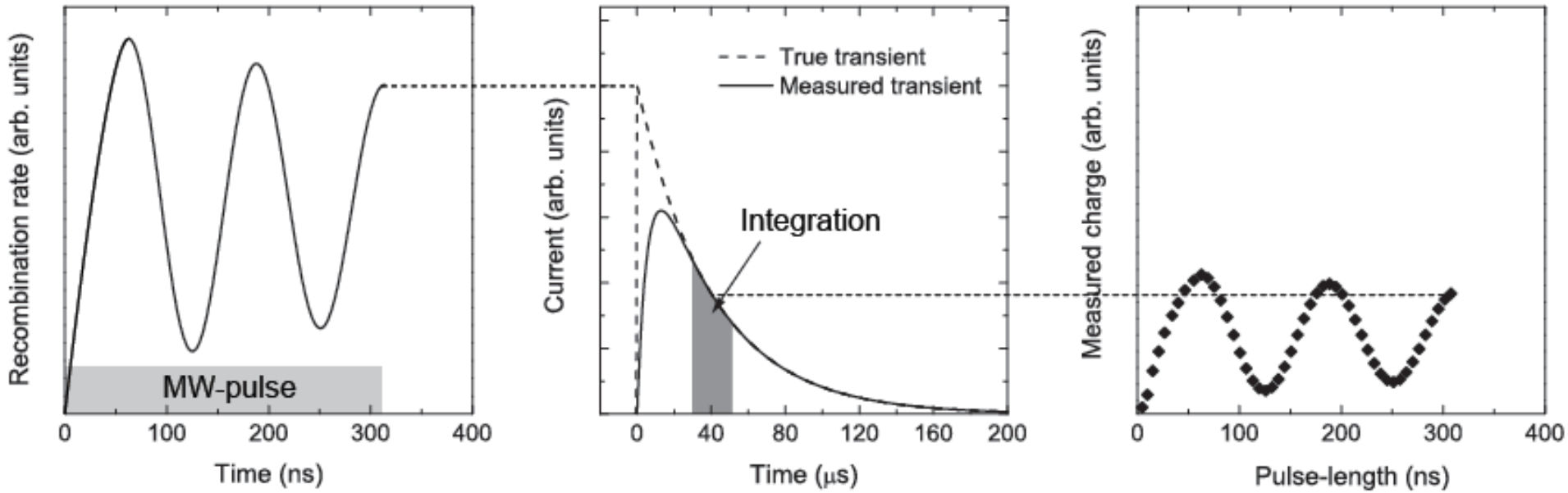


natSi, undoped

natSi, [P]=10^{17} cm^{-3}
15 nm

10^{10} P donors, 5 Kelvin

Pulsed EDMR



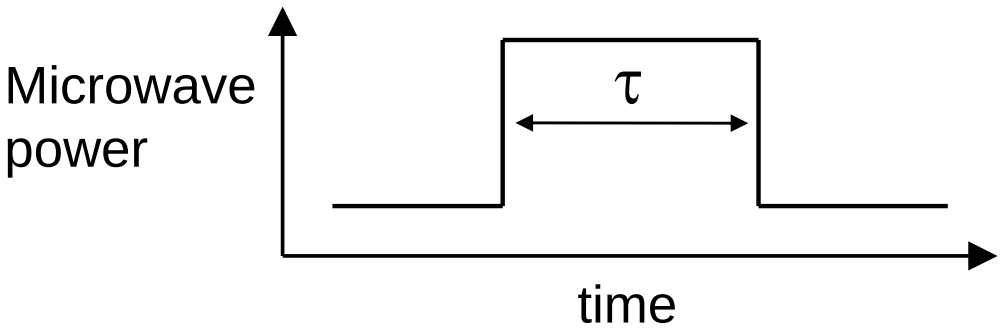
Recombination rate / Propagation of spin-ensemble

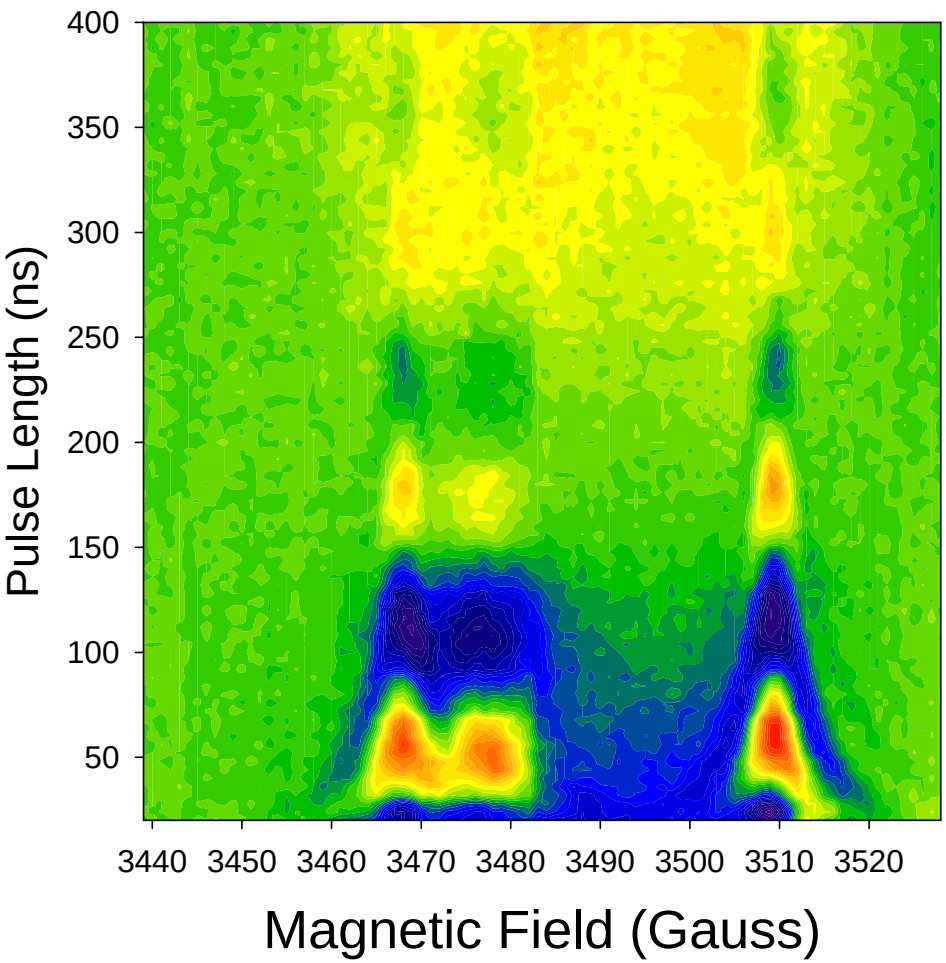
Current transient after pulse

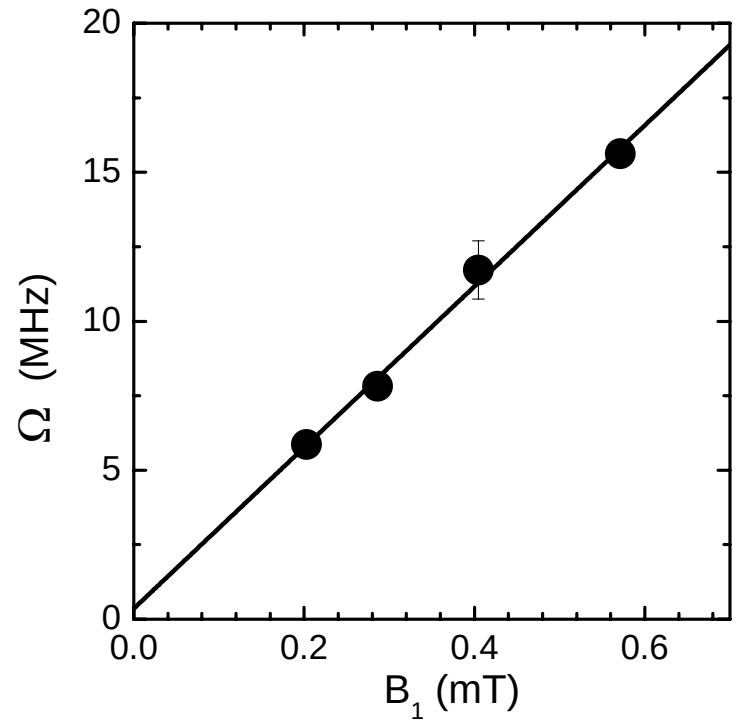
Reconstruction from PLD of the transient

C. Boehme and K. Lips,
Phys. Rev. B **28**, 245105 (2003)

Rabi Oscillations







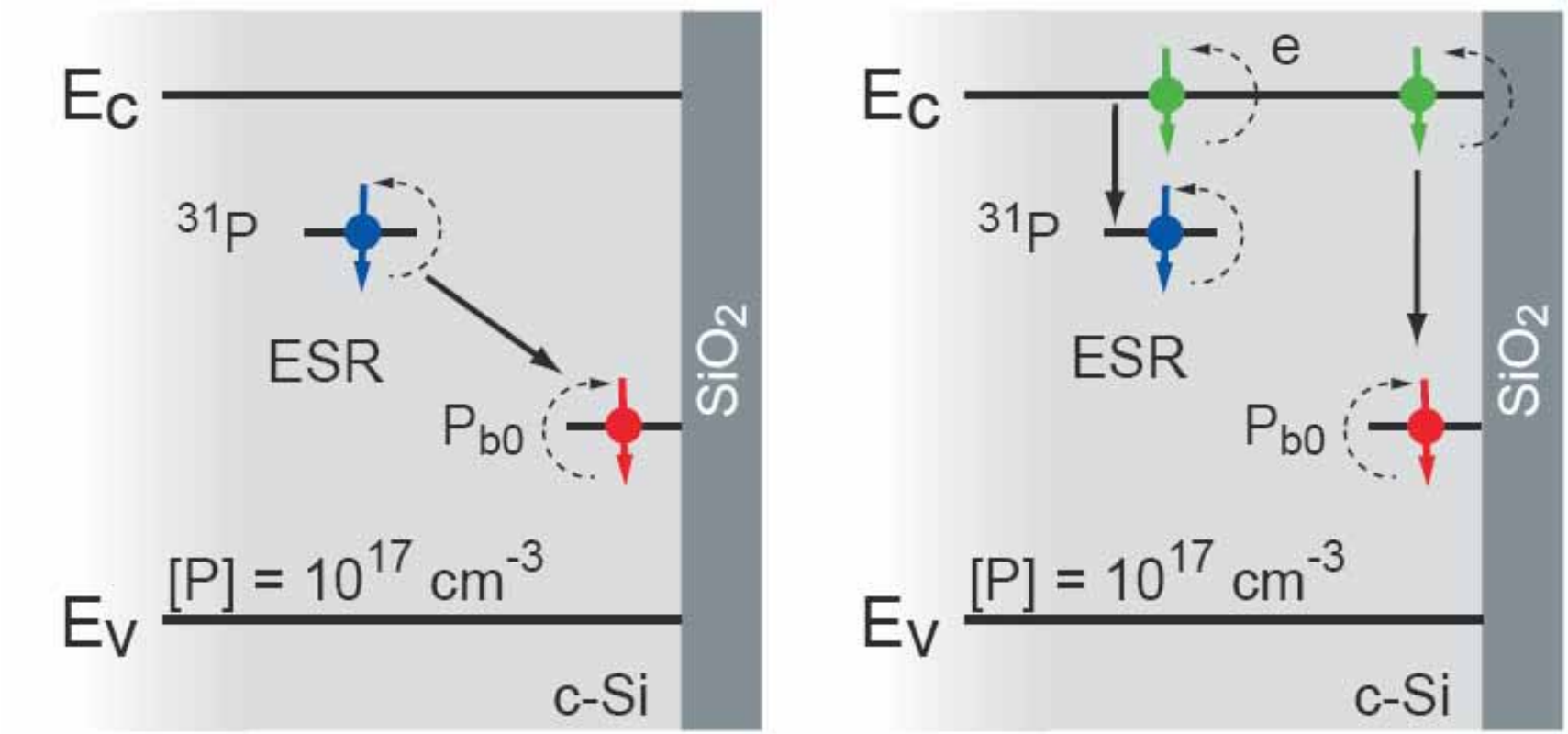
→ $\Omega = 1.03 \frac{g\mu_B}{\hbar} B_1 = 1.03 \gamma B_1$

→ weakly coupled spin pair

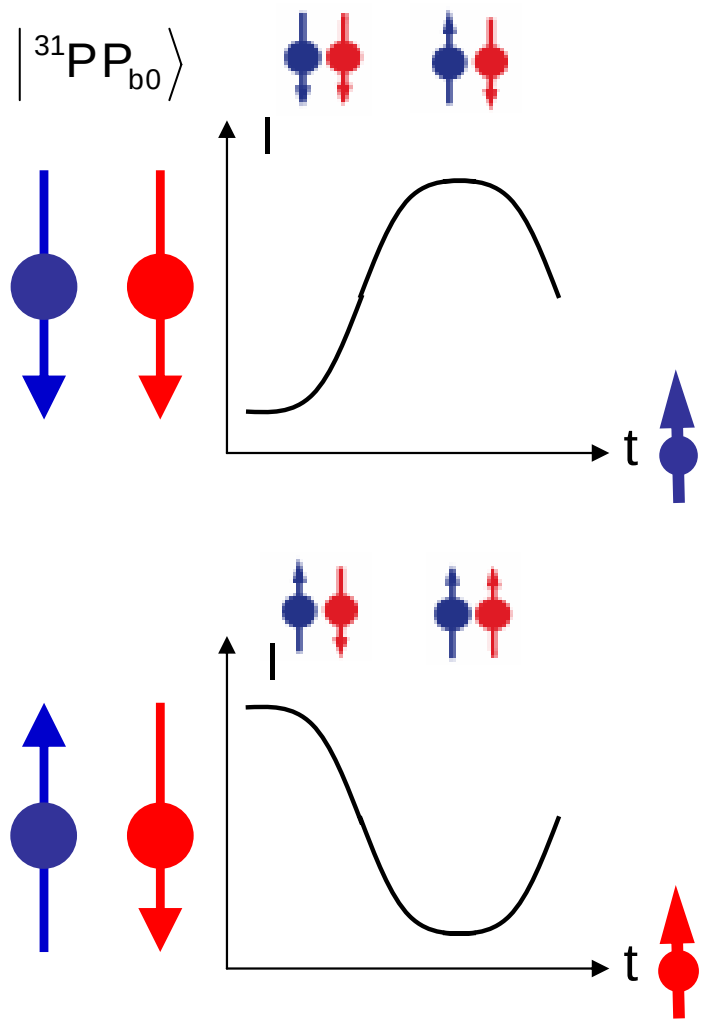
Nature Physics **2**, 835 (2006)

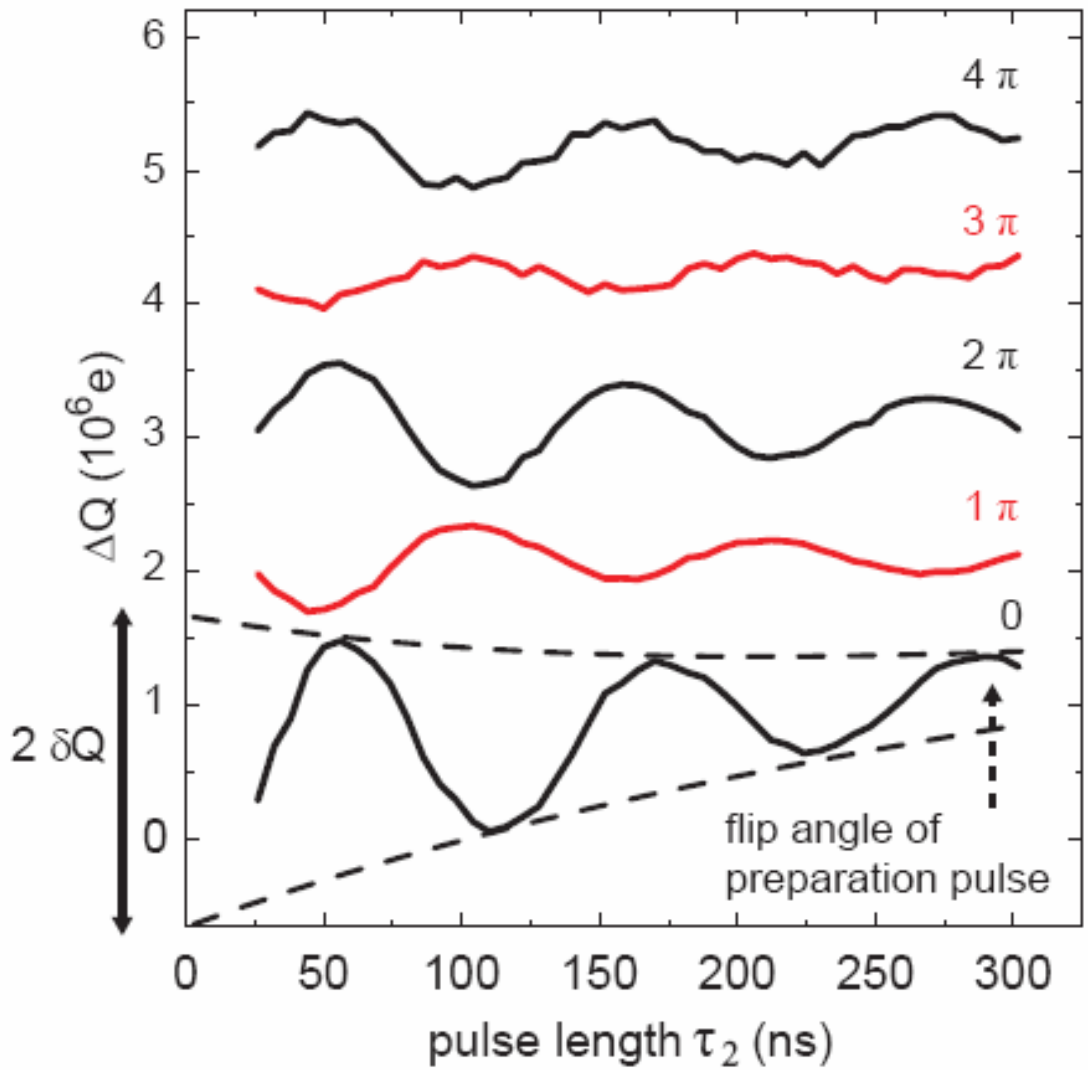
Electrically detected magnetic resonance

Do we really observe a ^{31}P-P_{b0} pair?



Electron Double Resonance (ELDOR)

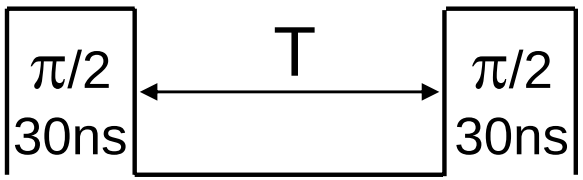




F. Hoehne, arXiv:0908.3612

Dynamics I: Dephasing

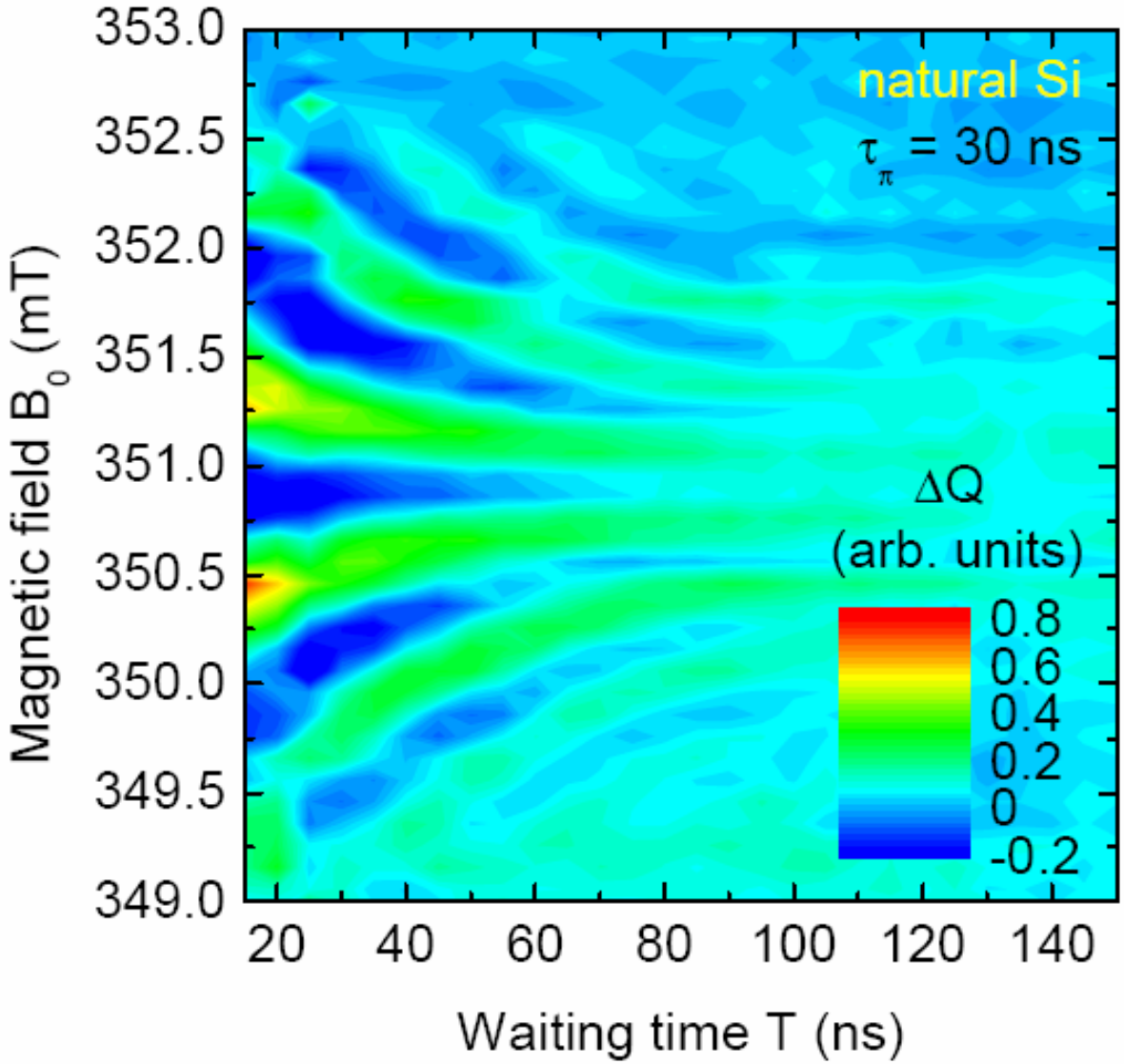
Ramsey fringes



→ Dephasing time:
60 ns

↕

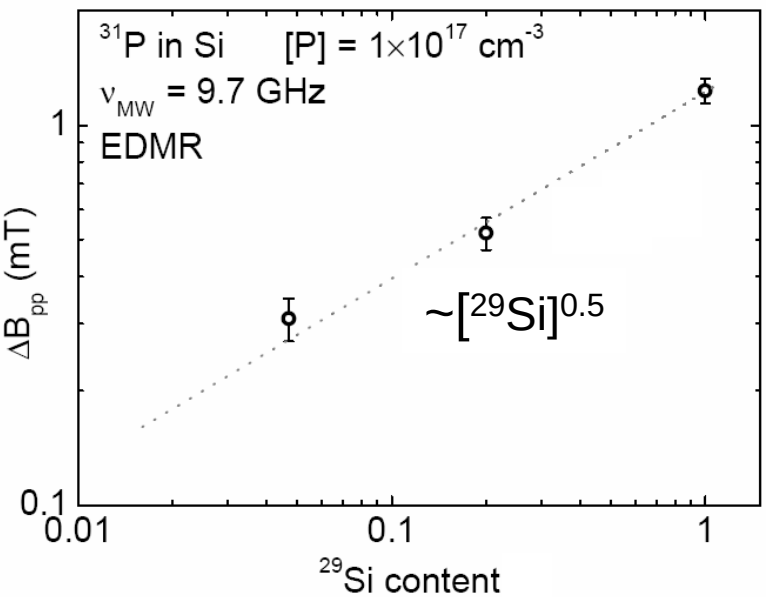
inhomogeneous
line width
(^{29}Si in ^{nat}Si)

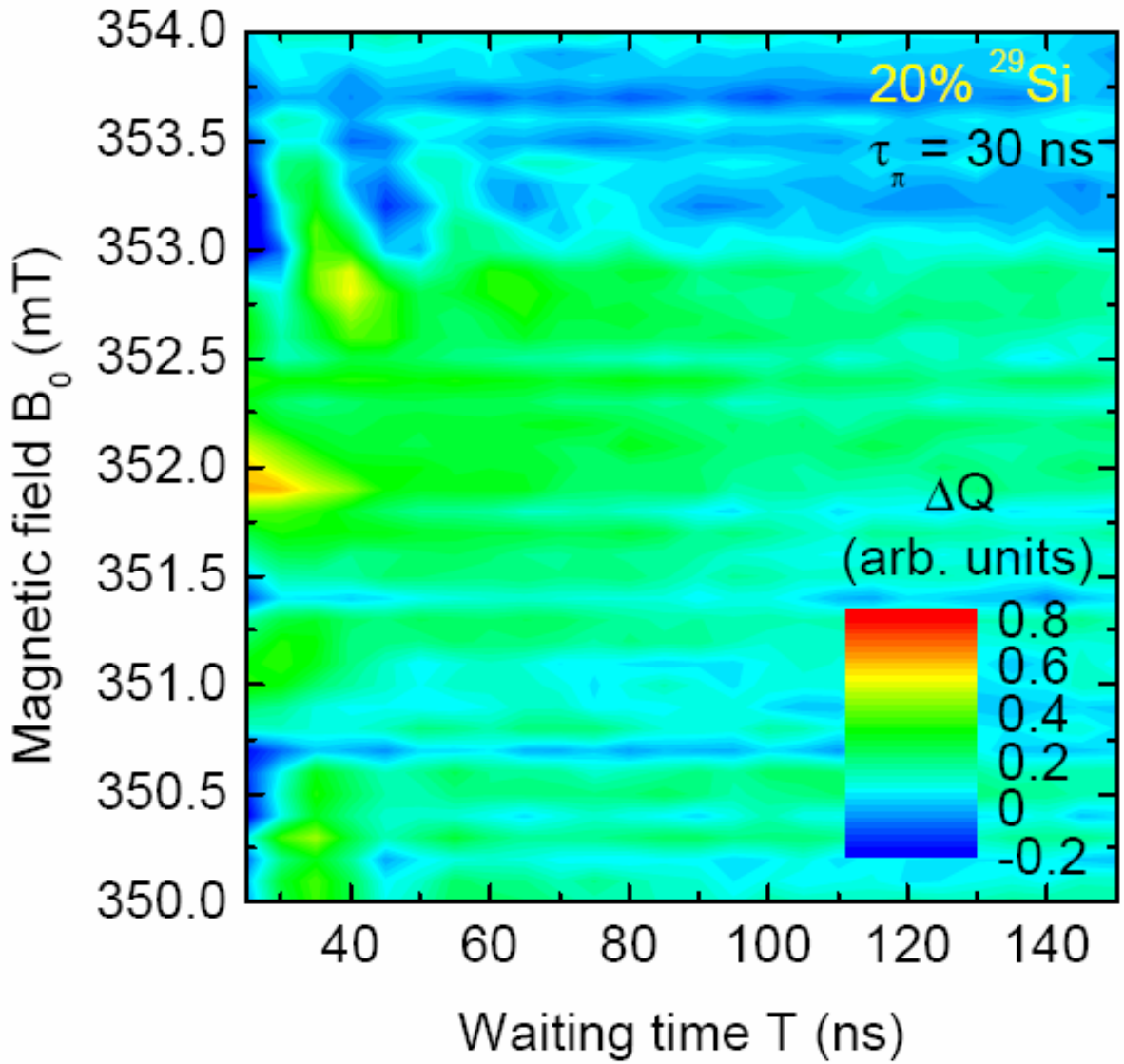


Dynamics I: Isotope engineering

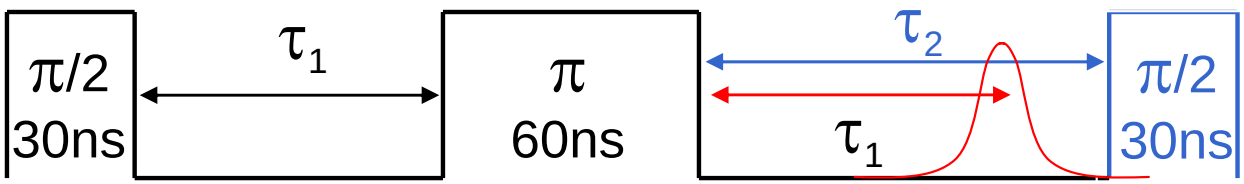
20% ^{29}Si in epilayer

$$\rightarrow T_2^* \propto \frac{1}{\Delta B^2} \propto \frac{1}{[^{29}\mathrm{Si}]}$$



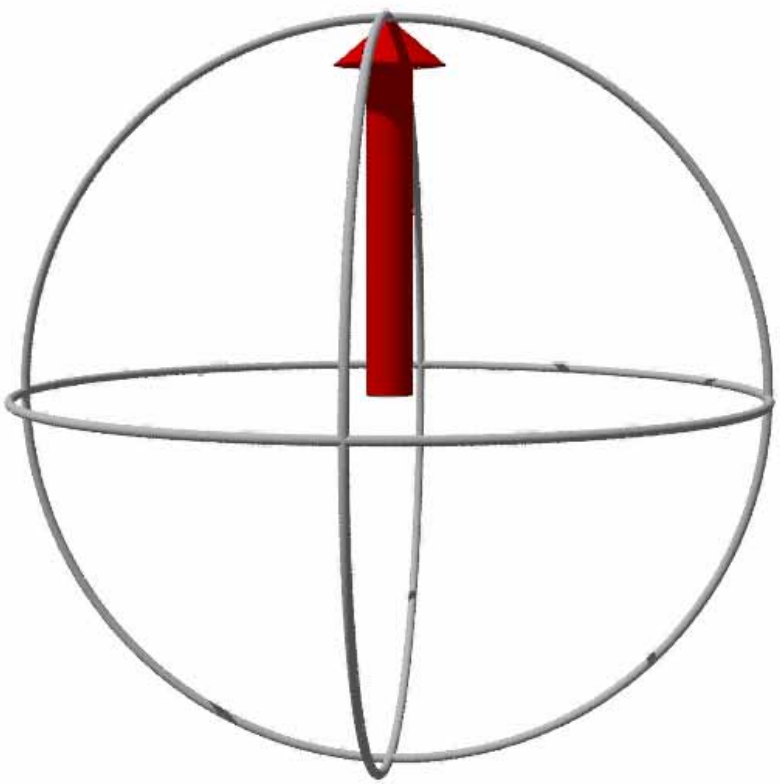


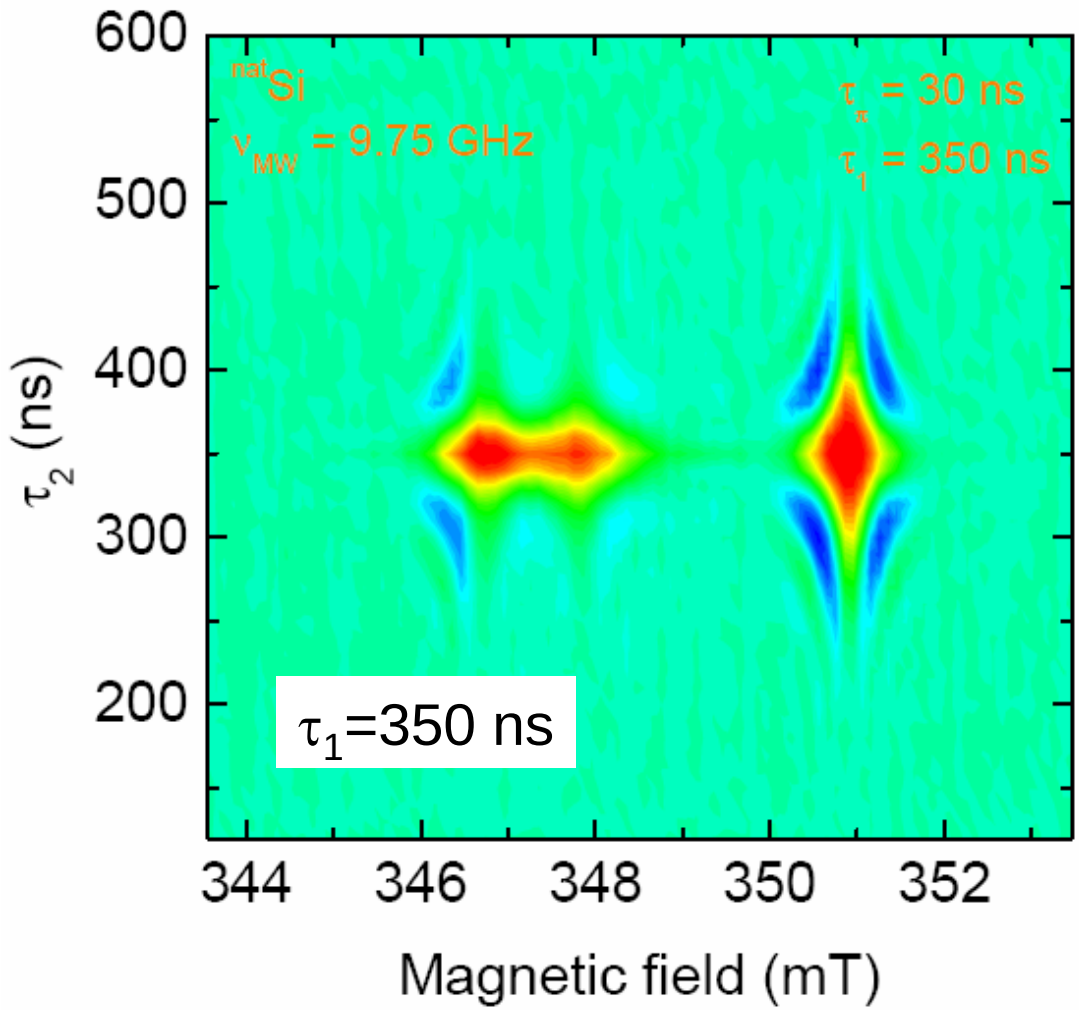
Dynamics II: Spin echos



Carr-Purcell echo

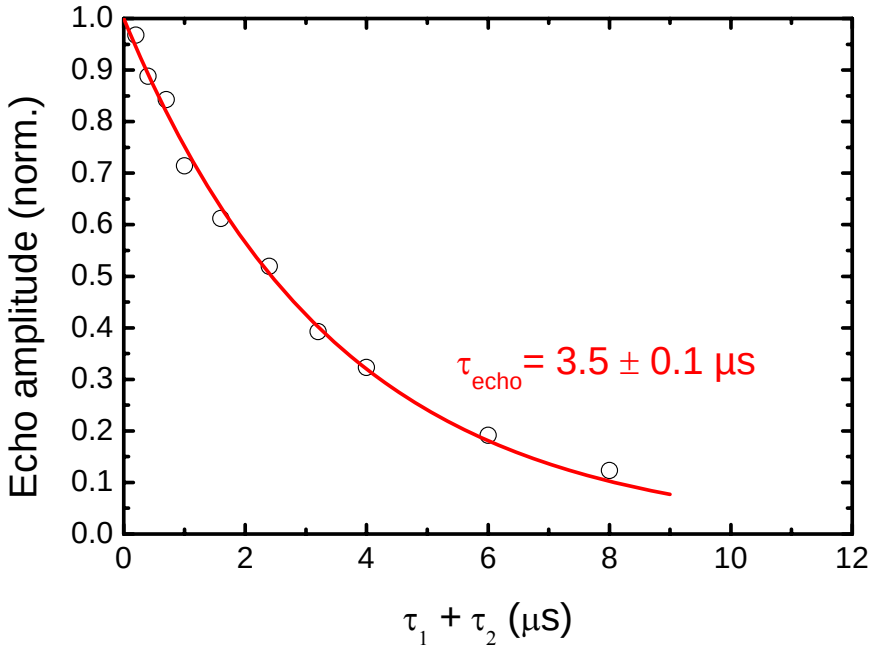
Echo tomography





Phys. Rev. Lett. **100**, 177602 (2008)

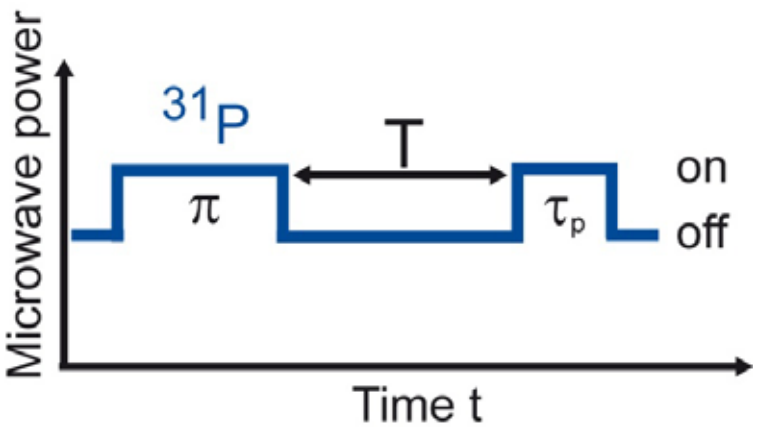
Dynamics II: Spin echos

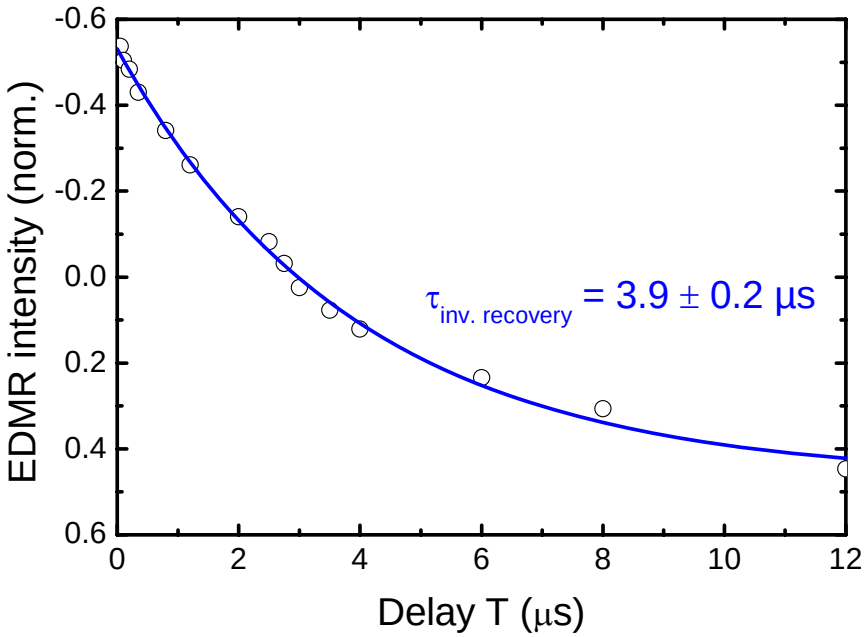


cf. Paik et al., arXiv:0905.0416

→ Increase of τ_{echo} by 2 compared to PRL **100** (2008)

Inversion recovery experiment



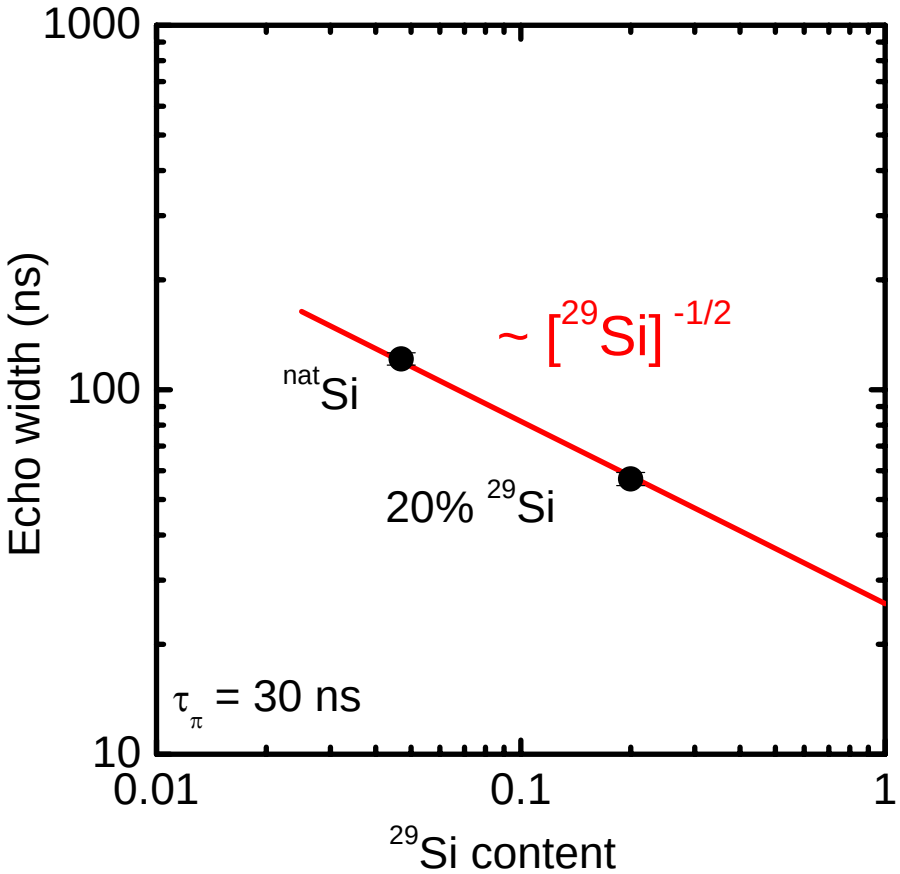


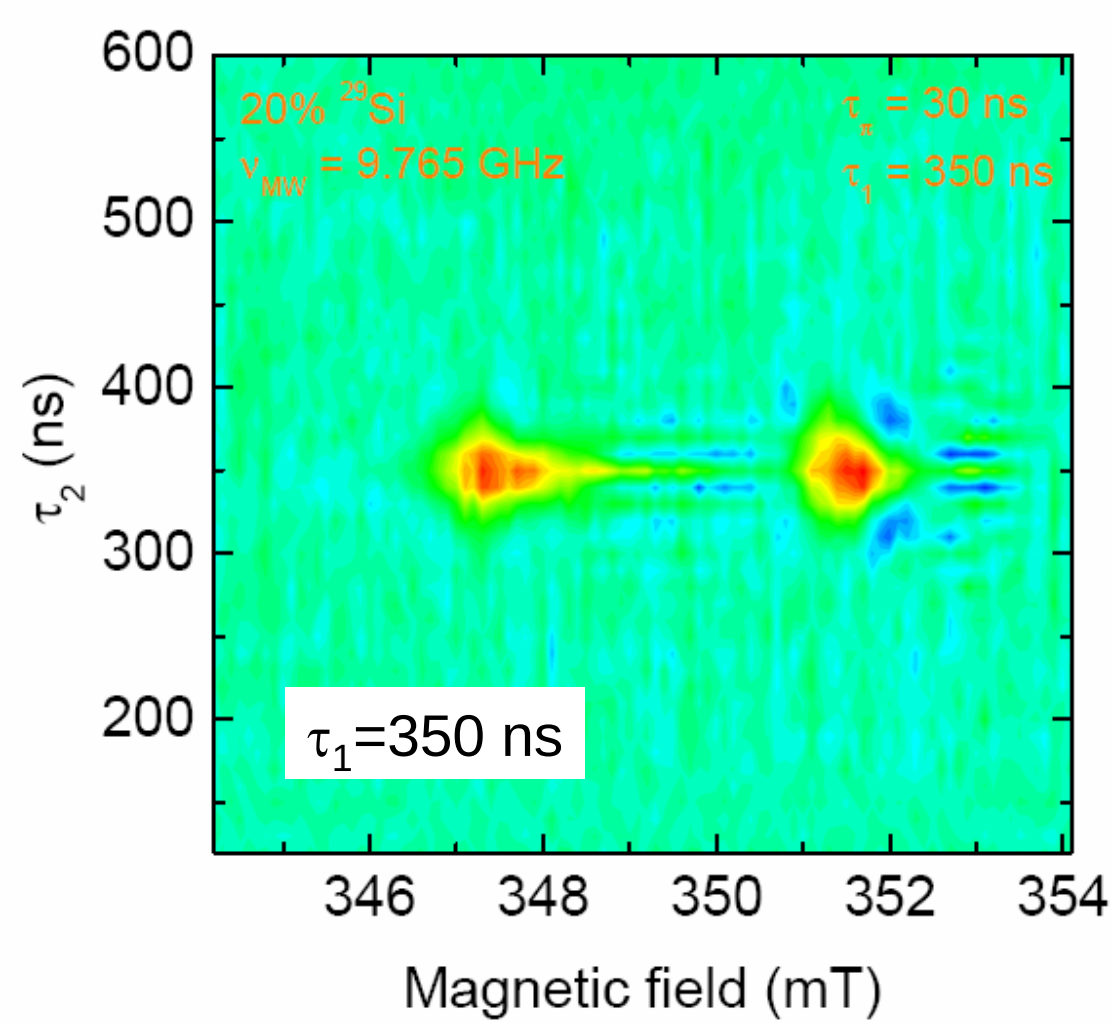
→ Echo decay determined by recombination kinetics

Dynamics II: Isotope engineering

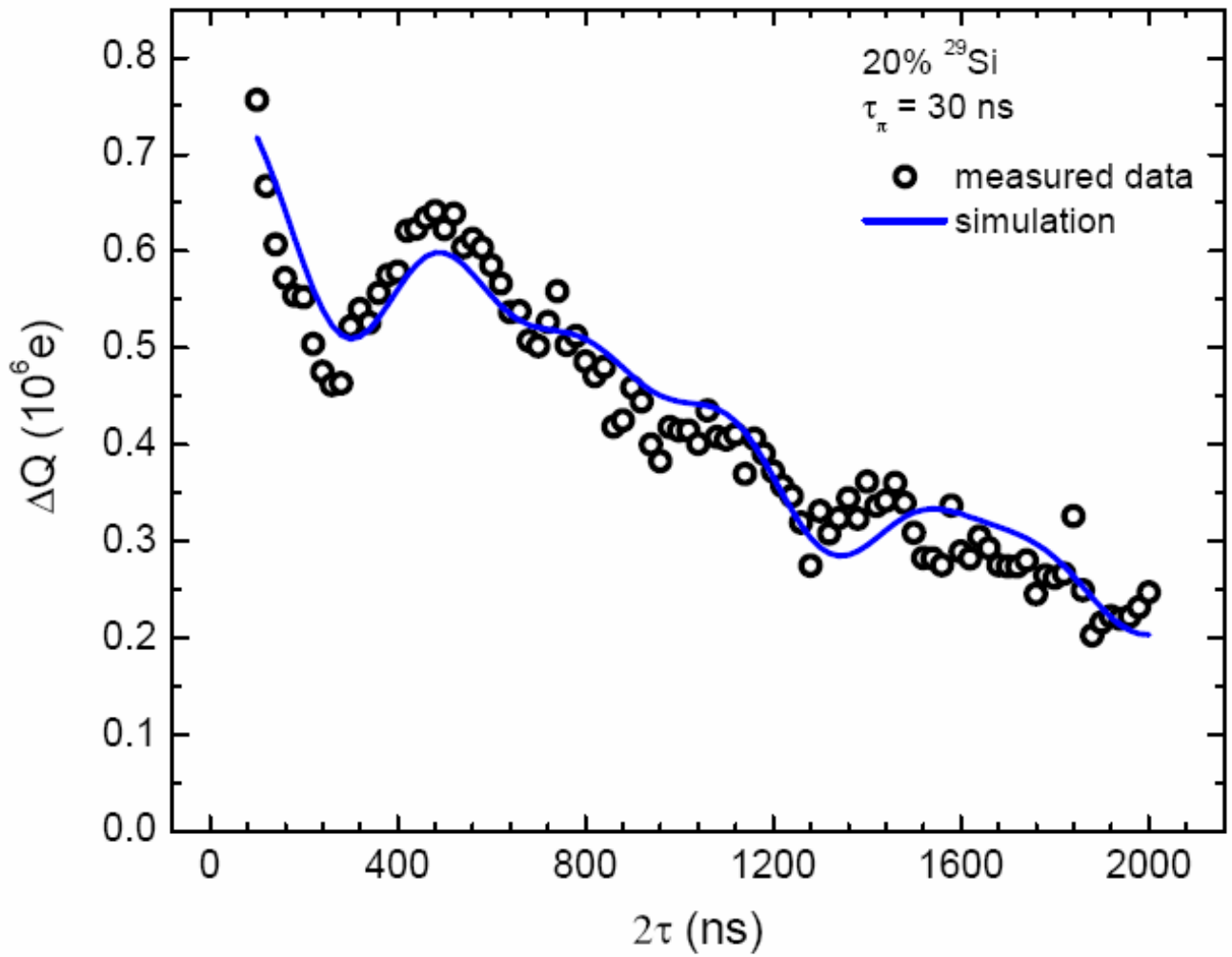
$$\text{Echo width} \propto \frac{1}{[^{29}\text{Si}]^{1/2}}$$

20% ^{29}Si in epilayer





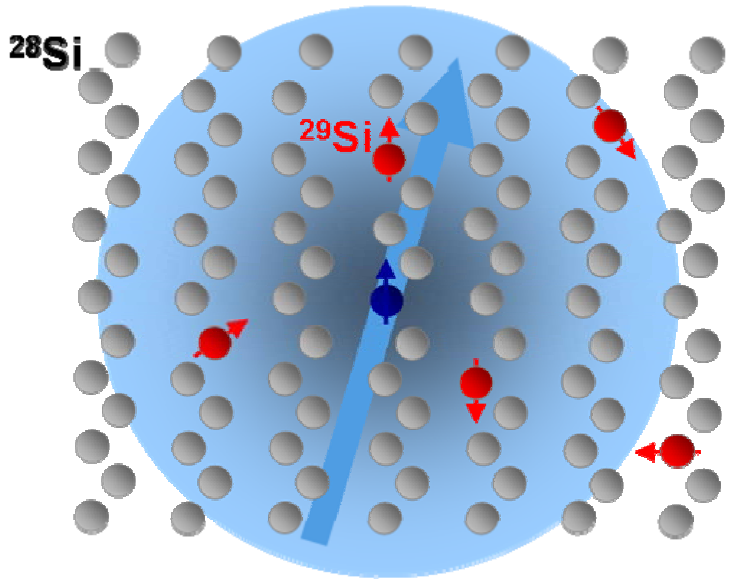
Dynamics II: Isotope engineering

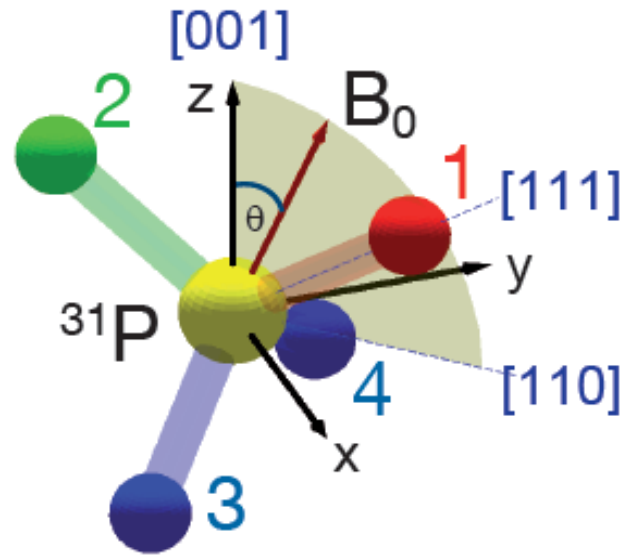


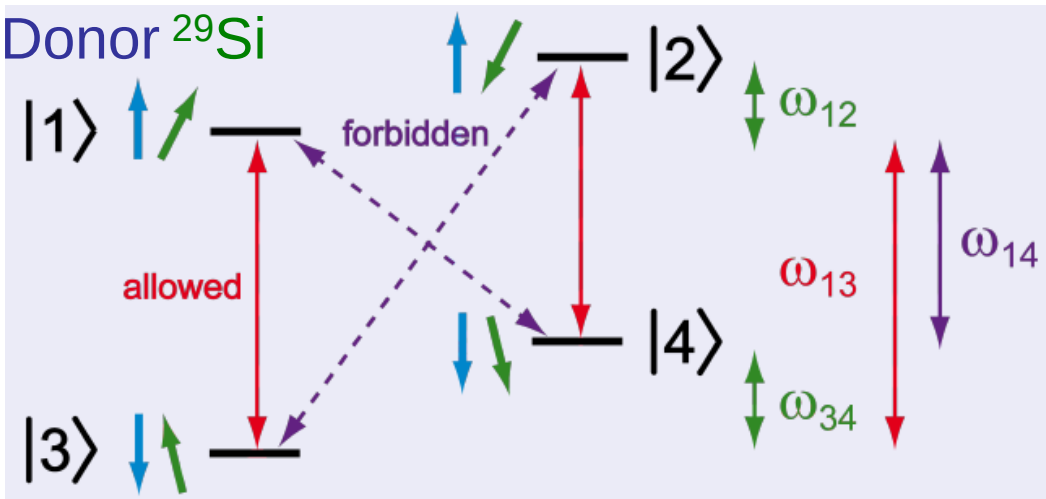
→ Electrical detection of Electron Spin Echo Enveloppe Modulation (ESEEM)

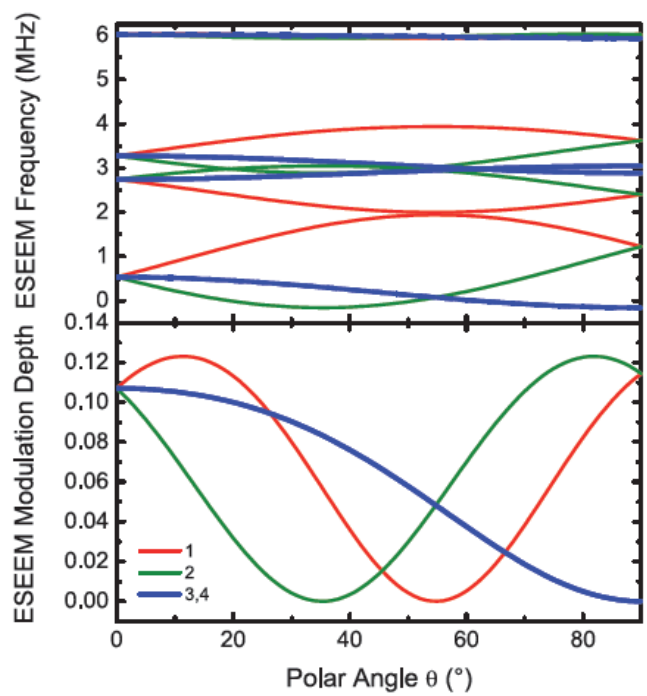
Rowan et al.,
Phys. Rev. **137** ,61 (1965)

EDESEEM of ^{29}Si





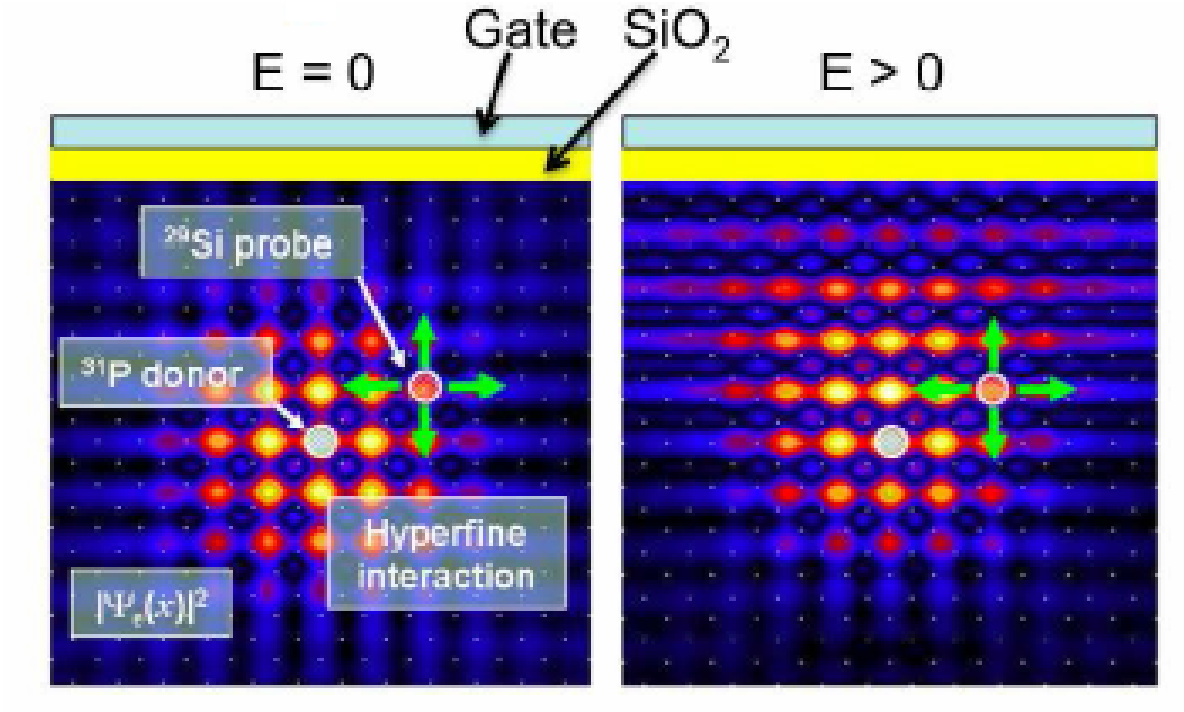




E. Abe et al., Phys. Rev. B. **70**, 033204 (2004)
A. Ferretti et al., Phys. Rev. B **72**, 235301 (2005)

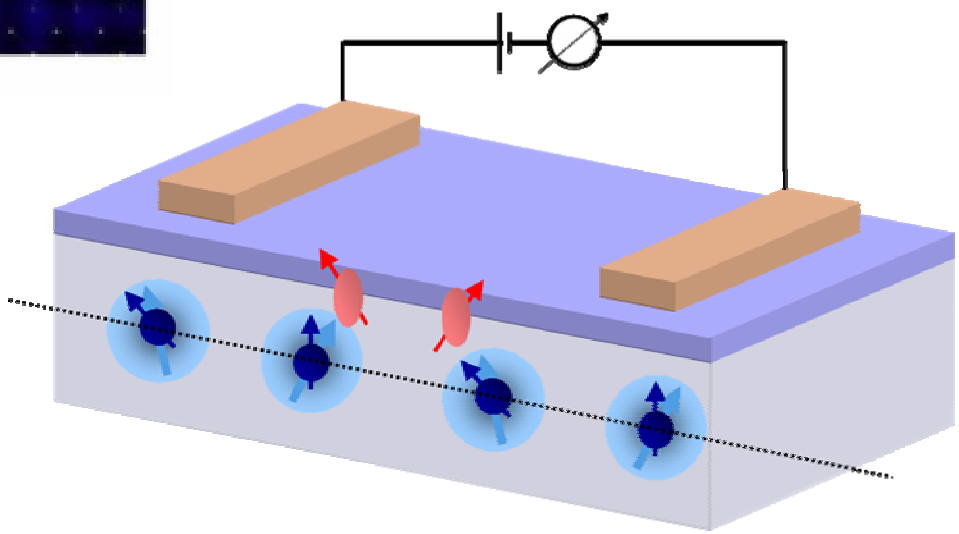
EDESEEM of ^{29}Si

Mapping of wavefunction



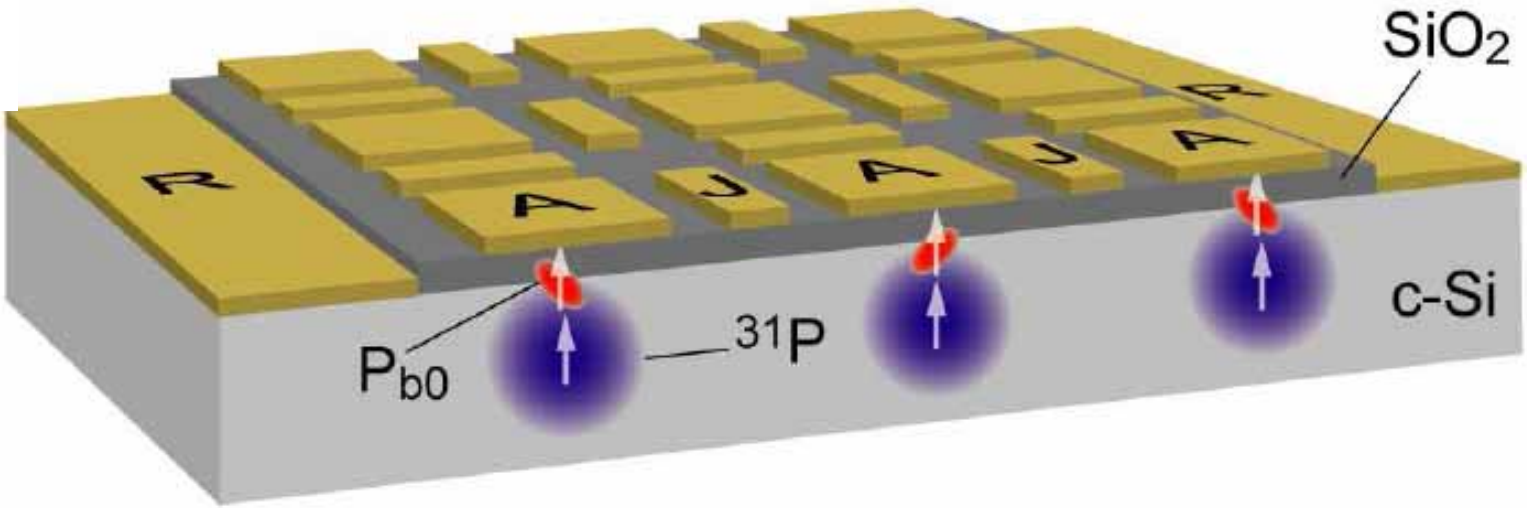
Park et al., arXiv:0902.1515

→ δ-doped layers in ^{29}Si



Selective read-out

Variation of ^{31}P-P_{b0} coupling by A gates

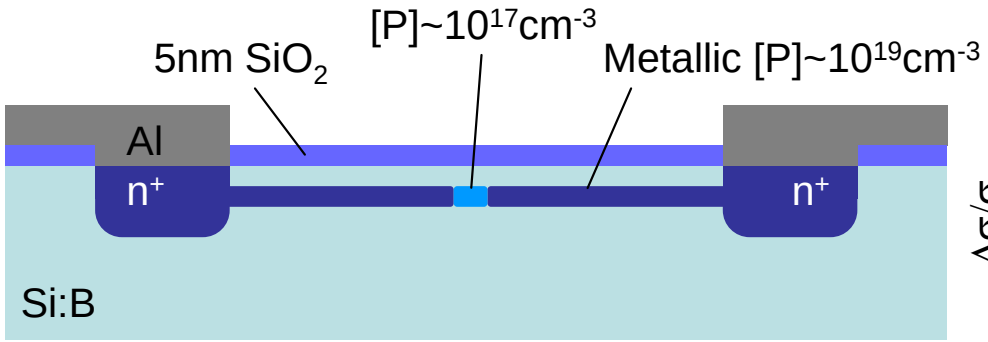


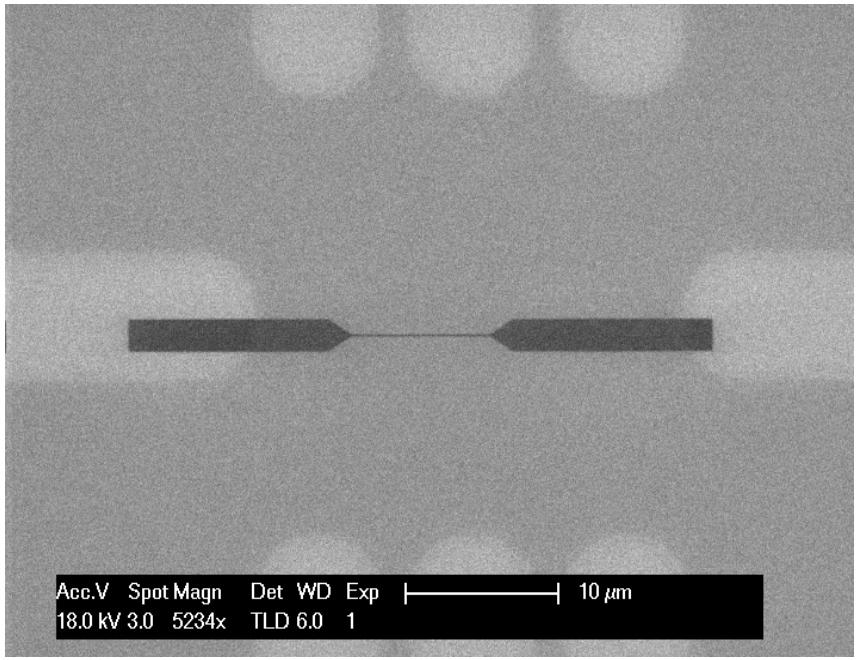
^{31}P-P_{b0} decoupled:
Spin manipulation

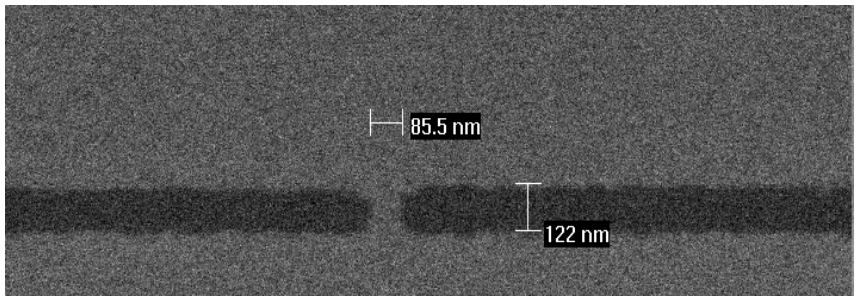
^{31}P-P_{b0} coupled:
Spin read-out

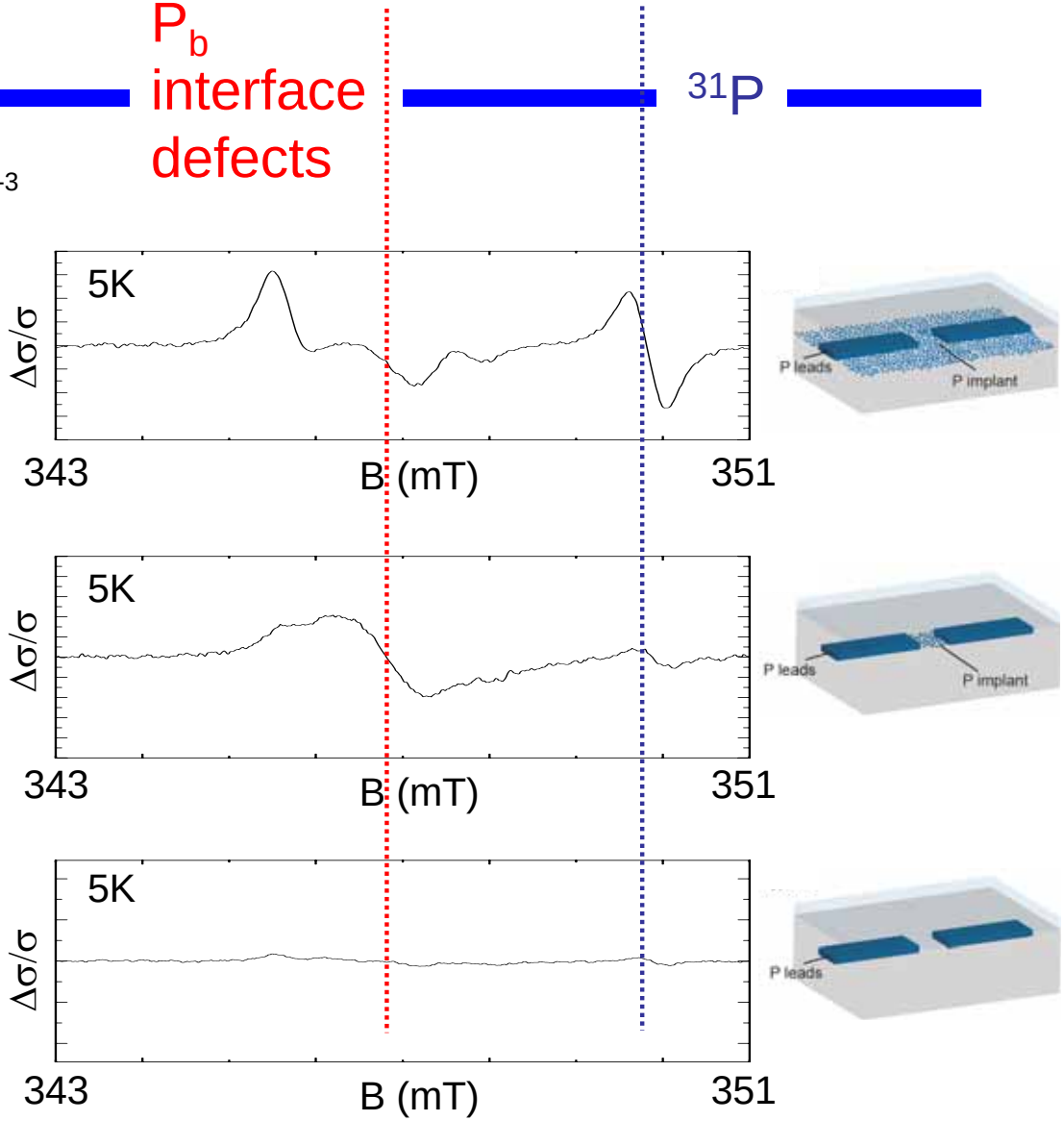
arXiv:quant-ph/0607178 (2006)

Sensitivity of EDMR







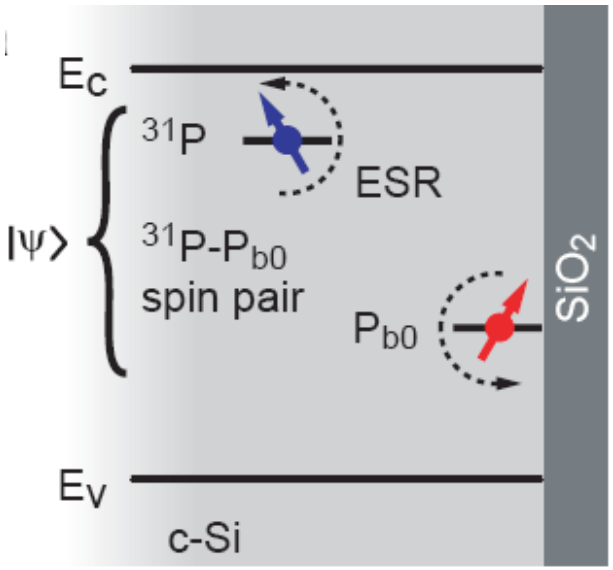


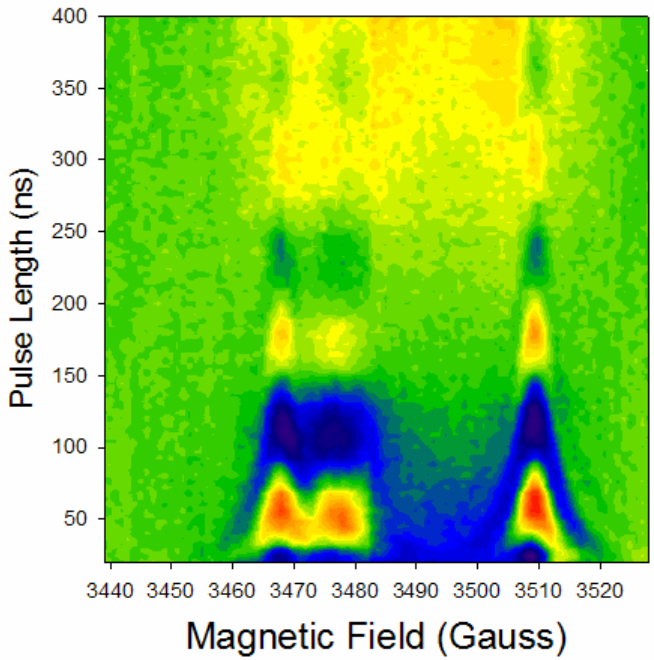
→ 100 P atoms $/\sqrt{\text{sweeps}}$

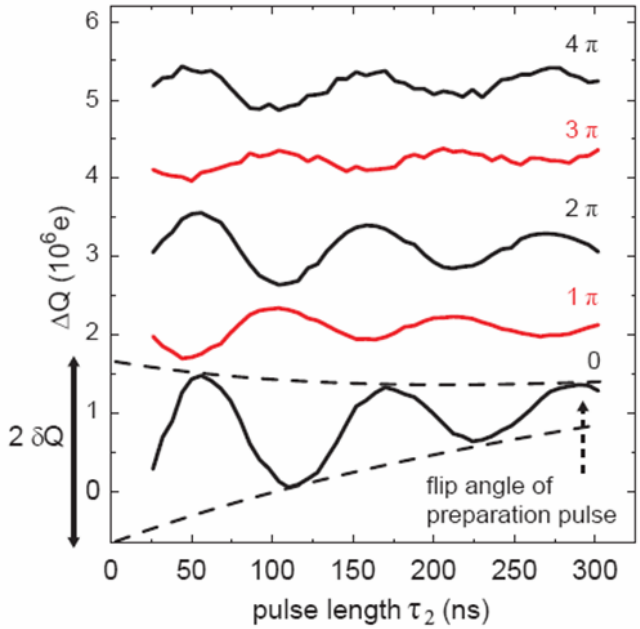
at signal/noise=1

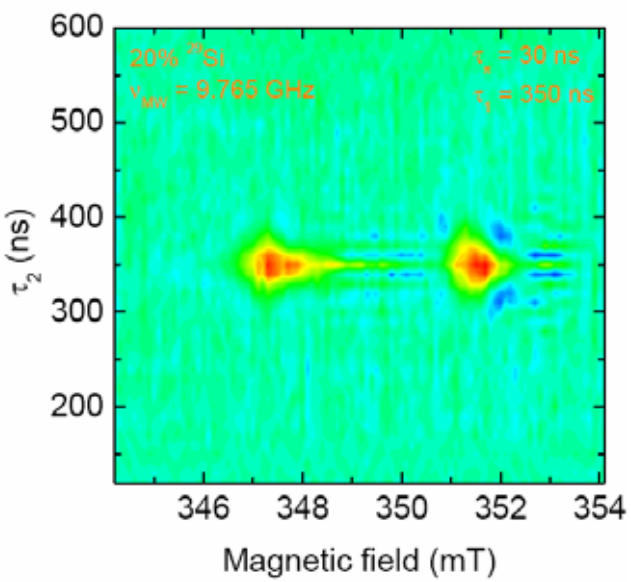
Appl. Phys. Lett. **89**, 182115 (2006)

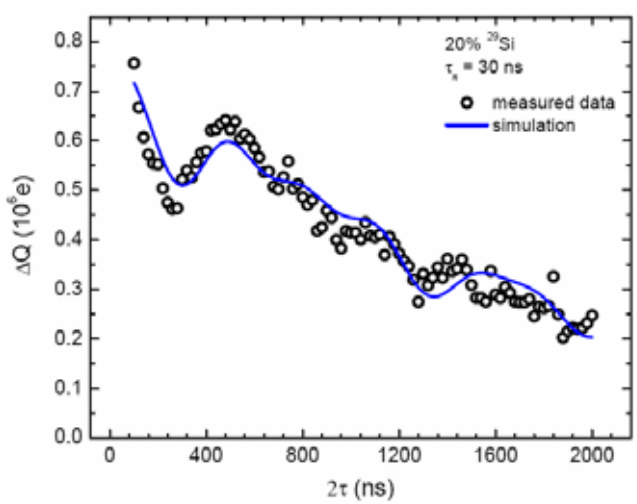
Summary

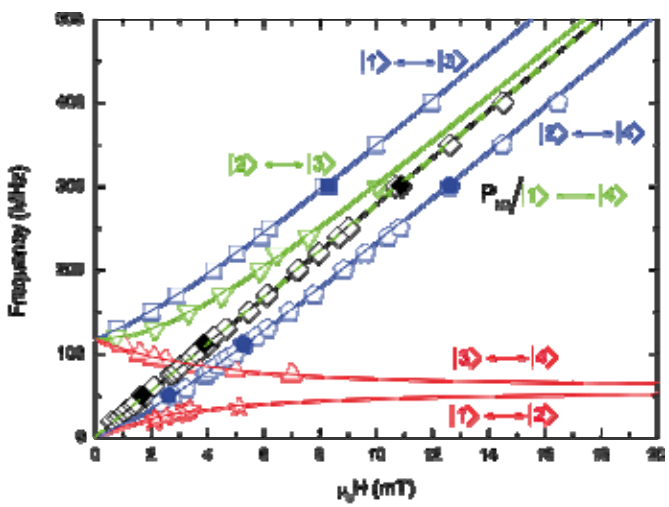

Ec
31P
ESR
|ψ>
31P-Pb0
spin pair
Pb0
SiO2
Ev
c-Si


Pulse Length (ns)
Magnetic Field (Gauss)


ΔQ (10^6 e)
4 π
3 π
2 π
1 π
0
2 δQ
flip angle of
preparation pulse
pulse length τ2 (ns)


20% 29Si
νMW = 9.765 GHz
τx = 30 ns
τy = 350 ns
τ2 (ns)
Magnetic field (mT)


20% 29Si
τx = 30 ns
measured data
simulation
ΔQ (10^6 e)
2τ (ns)


Frequency (MHz)
μBH (mT)