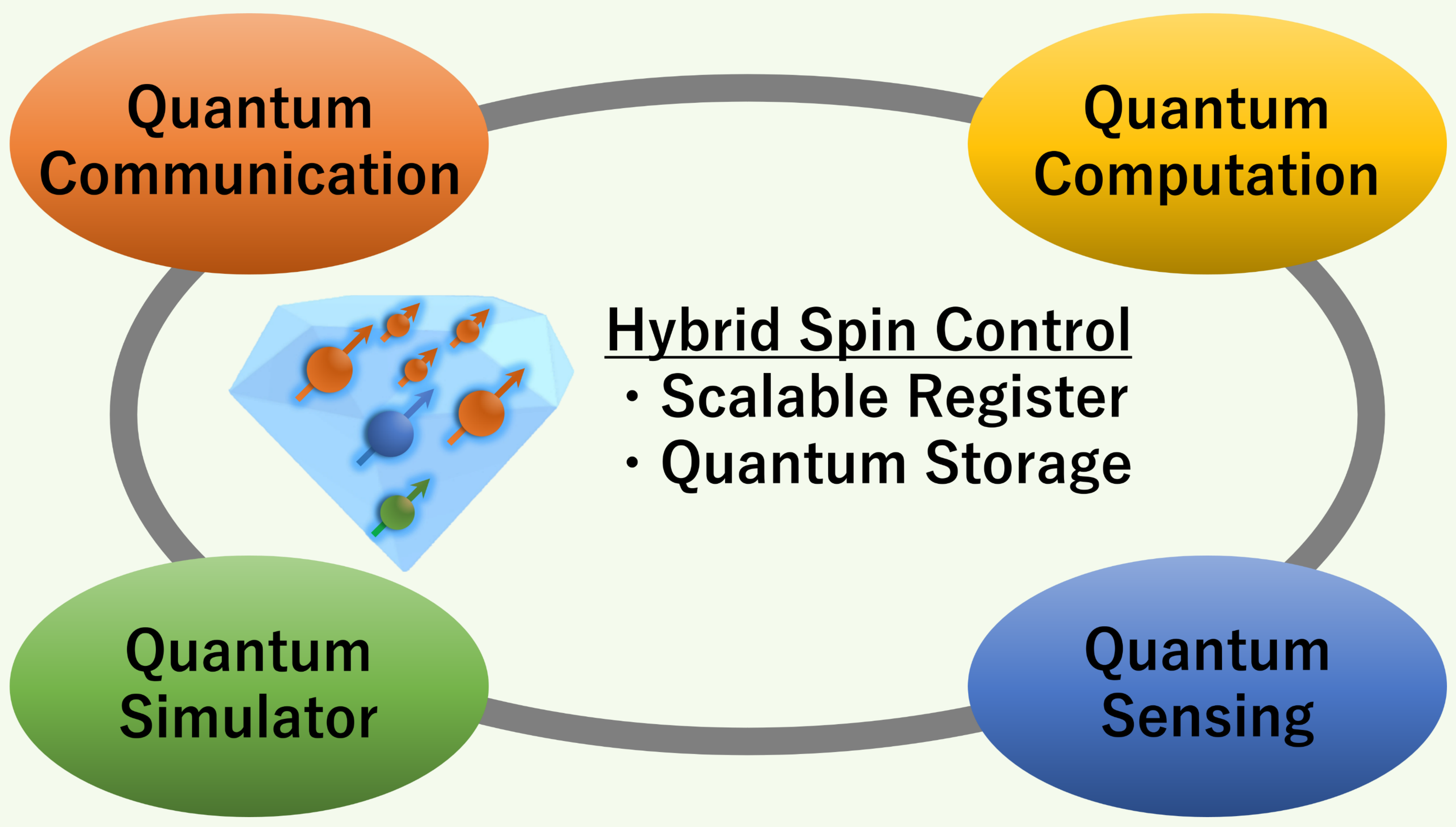
ゼロ磁場ダイヤモンド NV 中心における弱結合核スピン検出・操作手法の研究

江川直也[1], 田宮志郎[2], 渡辺幹成[1], 小坂英男[1]
横国大院理工[1], 東大院工[2]

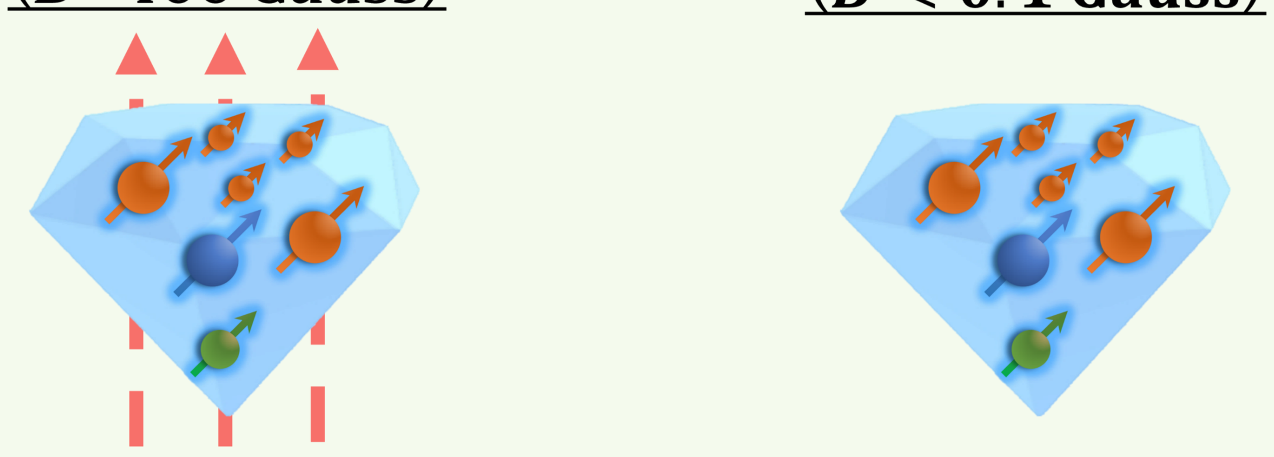
Motivation

Diamond-Based Quantum Information Processing



Zero-Field Spin Register

High Magnetic Field ($B\sim400$ Gauss) | Zero Magnetic Field ($B<0.1$ Gauss)



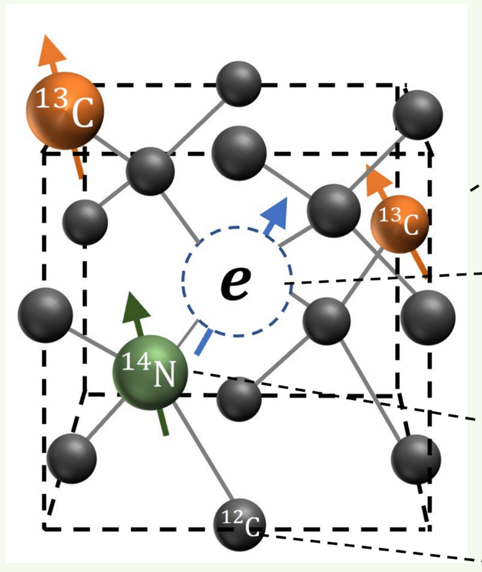
Spin control constraints caused by the application of a magnetic field [1, 2]

Possibility of constraint exclusion

Foundation

Nitrogen-Vacancy (NV) Center in Diamond

$$H=\underbrace{D_0S_z^2}_{\text{ZFS}}+\underbrace{\sum_i A^{(i)}S_z\otimes I_z^{(i)}}_{\text{Hyperfine couplings}}$$



Carbon-13 Nuclear Spins(spin-1/2)

Electron Spin (spin-1)

Spin-Triplet
$|+1\rangle:=|\uparrow\uparrow\rangle$
$|0\rangle:=(|\uparrow\downarrow\rangle+|\downarrow\uparrow\rangle)/\sqrt{2}$
$|-1\rangle:=|\downarrow\downarrow\rangle$

Nitrogen Nuclear Spin(spin-1)

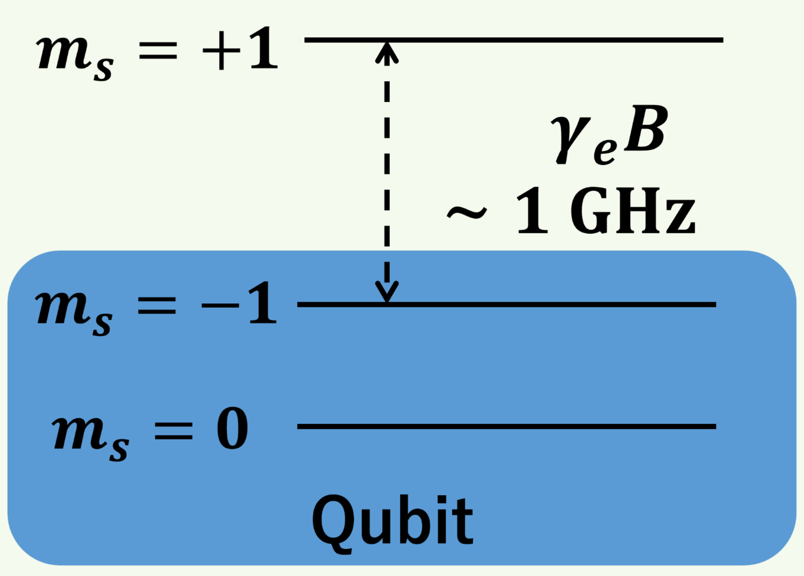
Carbon

Electron Spin: Optically detectable, Microwave control (~ns)
Dephasing time (~μs)
Nuclear Spin: Quantum memory (~1min), Dephasing time (~ms)

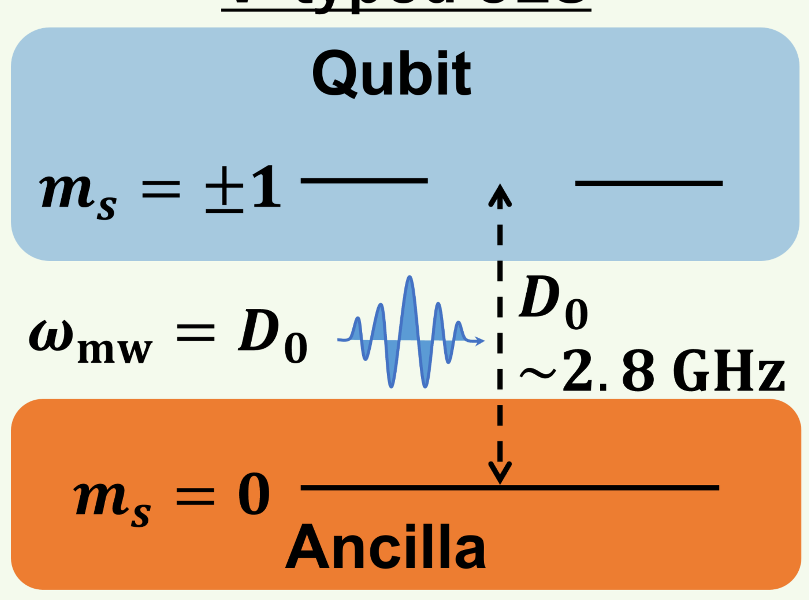
Electron Spin Control

$$H=\underbrace{D_0S_z^2}_{\text{ZFS}}+\underbrace{BS_z}_{\text{Zeeman}}+\underbrace{\Omega_x\cos(\omega_{\text{mw}}t+\phi_{\text{mw}})S_x}_{\text{Microwave driving}}$$

High-Field 2LS



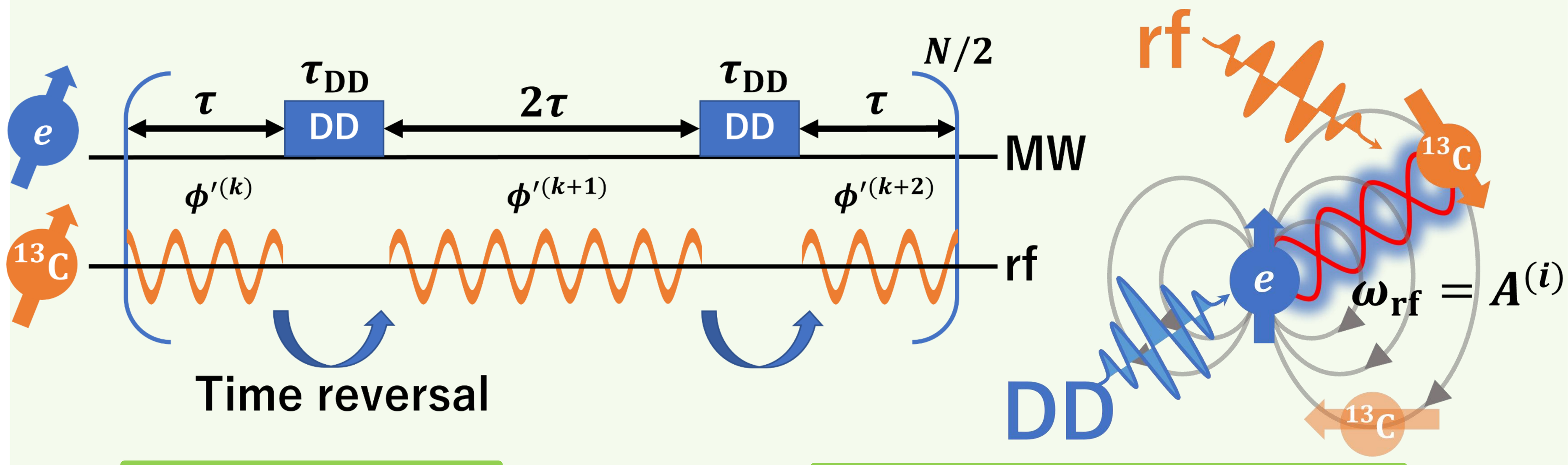
Zero-Field V-typed 3LS



Method

Zero-Field DDrf gate

Dynamical Decoupling (DD): Preserving electron spin coherence
radio-frequency (rf): Individual control of nuclear spins

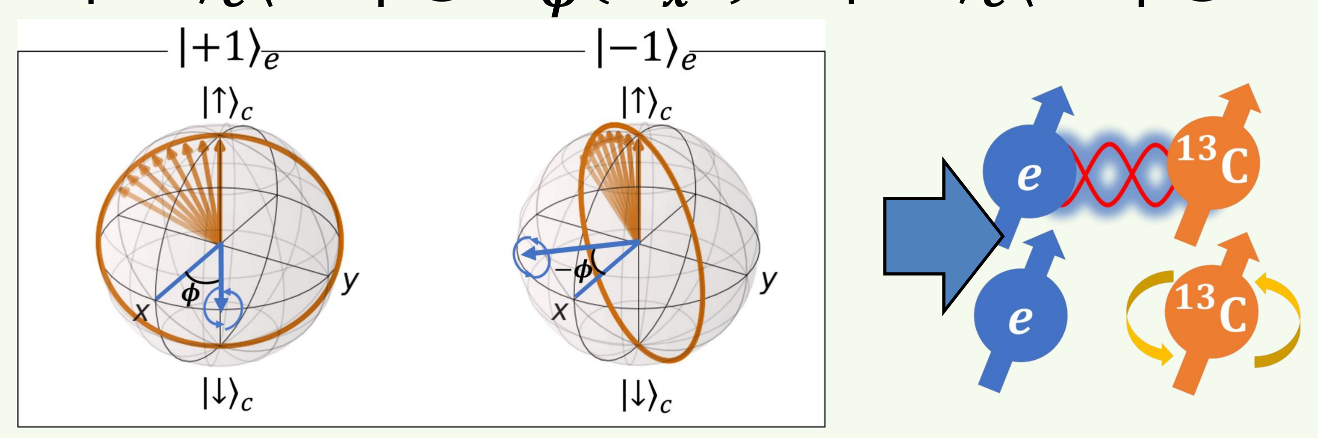


Postulate
Perfect DD pulse

rf phase condition
$$\phi^{(k)}=(-1)^k\phi-kA(2\tau+\tau_{\text{DD}})\phi$$

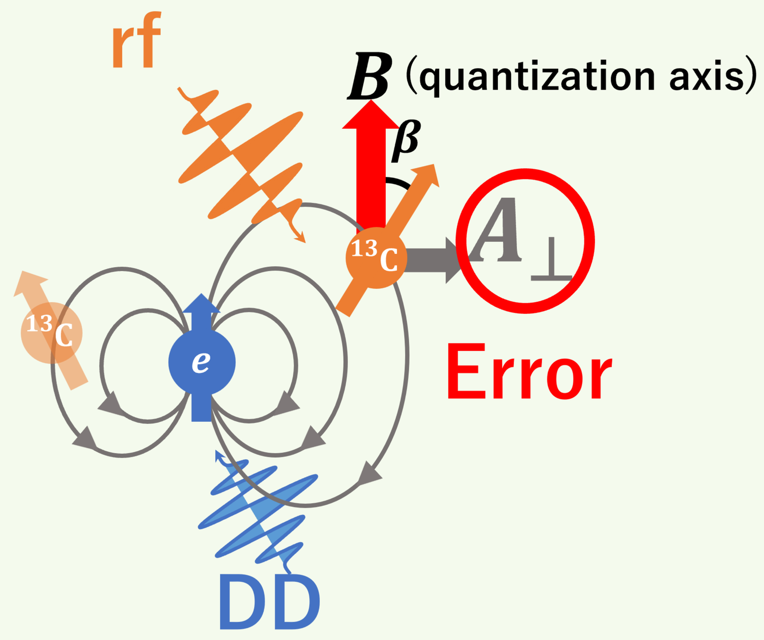
Zero-Field DDrf gate

$$U_{\text{DDrf}}=|+1\rangle_e\langle+1|\otimes R_\phi(\Omega_x\tau)+|-1\rangle_e\langle-1|\otimes R_{-\phi}(\Omega_x\tau)$$



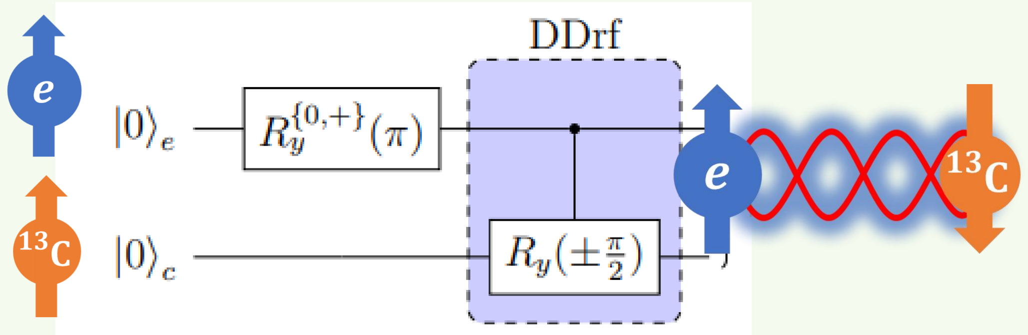
Key Property: Quantization Axis

Zero-field: Hyperfine coupling, High-field: Magnetic field



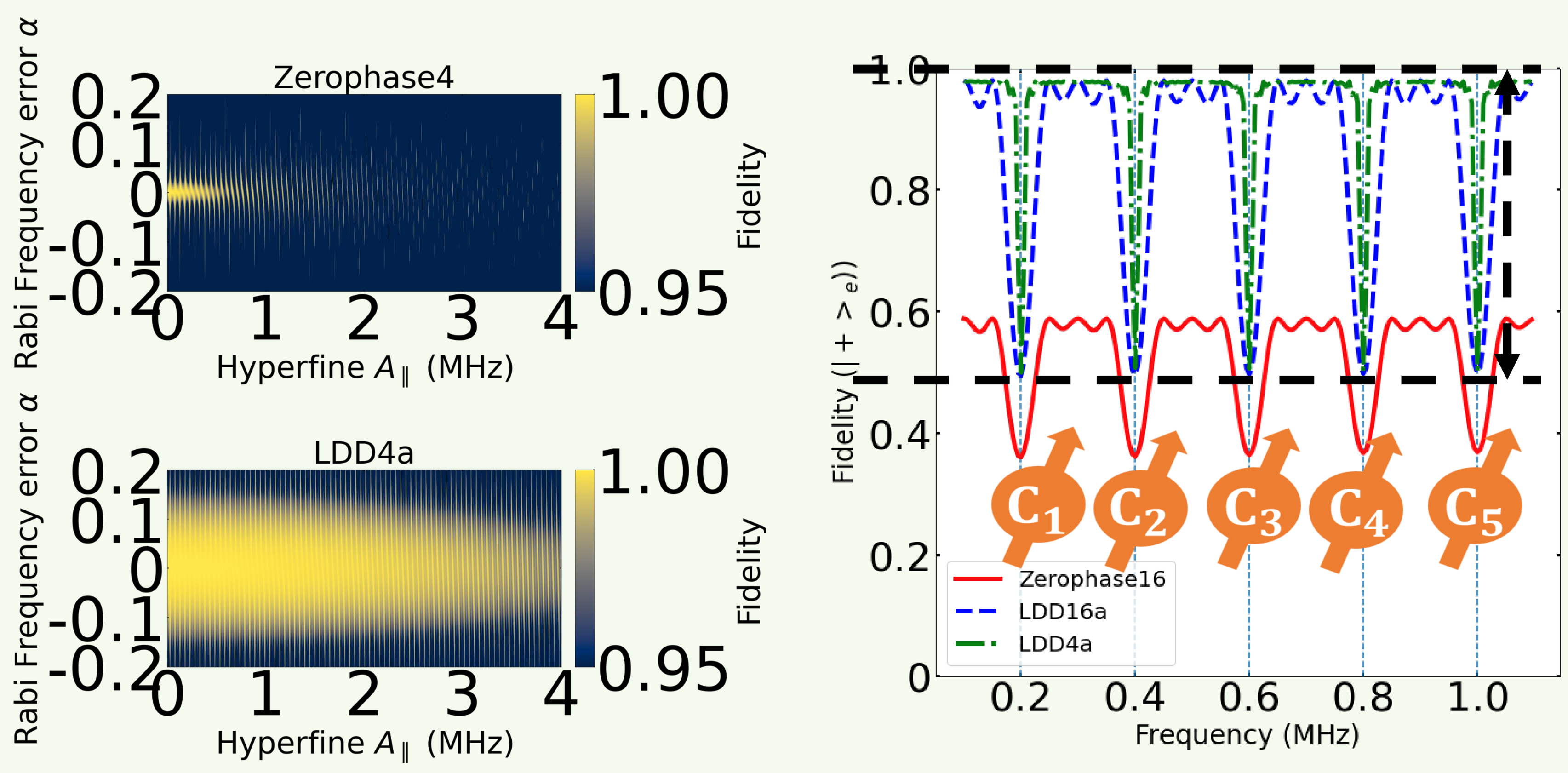
High-Field constraints

1. To achieve 99% Bell state fidelity, β must be less than 6°
2. Need to use with DD gate [1]
→ gate time is not adjustable



Detection & Control Simulations

Zero-Field DDrf + LDD [4] → Practical method



Conclusion and Outlook

1. Developed a new way for zero-field hybrid spin register
2. Overcome constraints in the conventional method

Future Application

Quantum network, Discrete time crystal, Quantum sensor

[1] T. H. Taminiau et al., Phys. Rev. Lett. 109, 137602 (2012)
[2] C. E. Bradley et al., Phys. Rev. X 9, 031045 (2019)
[3] Y. Sekiguchi et al., Nat Commun 7, 11668 (2016)
[4] P. J. Vetter et al., Phys. Rev. Applied 17, 044028 (2022)