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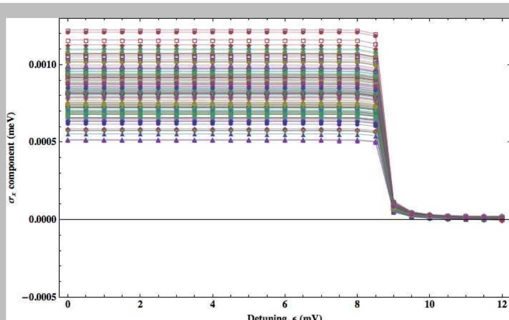

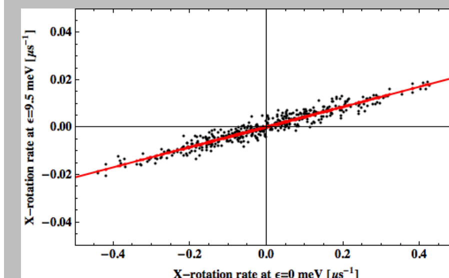

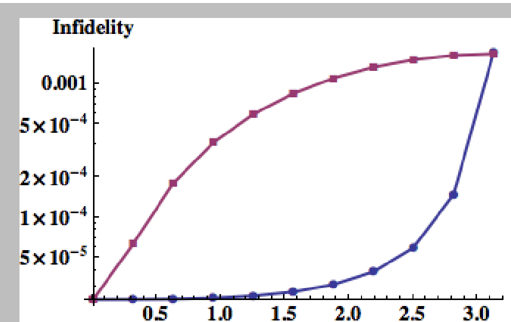

Dynamically corrected gates for singlet-triplet spin qubits with control-dependent errors

Joint work with:
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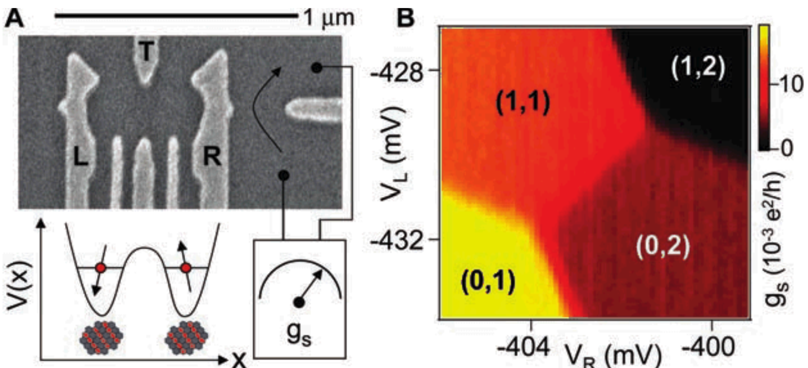
DQD singlet/triplet (S/T_0) spin qubits

Inhomogeneous **B** field (e.g. Overhauser field) contributes to spin qubit dephasing
Goal: Design Hamiltonian controls to suppress these errors



[*Petta, et al., Science* ***309****, 2180 (2005)*]

Treat field inhomogeneity as a classical Hamiltonian error (slow bath variation during gate time)

exchange energy

component due to B-field inhomogeneity

Effective qubit Hamiltonian: $H(\epsilon) = -\frac{1}{2}J(\epsilon)\sigma_z + h_x(\epsilon)\sigma_x$

Intuition: Singlet and triplet states vary spatial distribution with ϵ, hence experience different perturbation from environment

Our results:
-Control-dependent Hamiltonian errors may have a significant influence on gate fidelity
-In certain operating regimes, this dependence is predictable
-Dynamically-corrected gate (DCG) sequences can be modified straightforwardly to account for these systematic errors, providing improved gate fidelity

Modeling of the DQD

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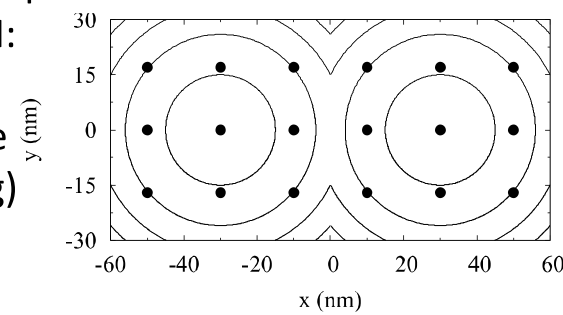
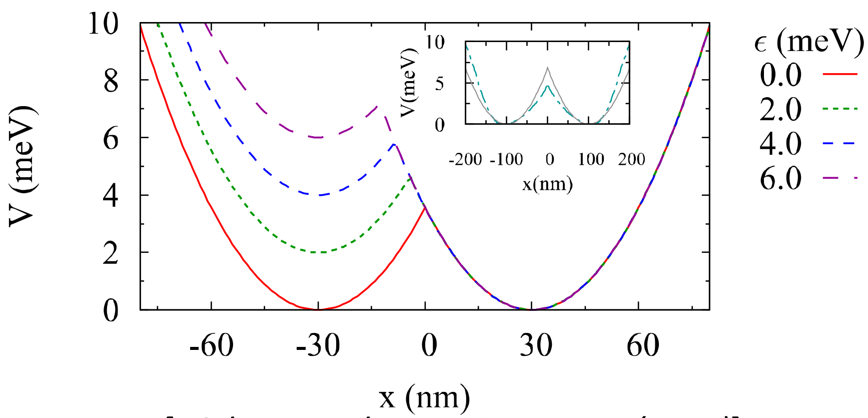
Computational basis: lowest-energy singlet (S) and unpolarized triplet (T_0) states of the unperturbed ($\Delta B = 0$) Hamiltonian

Configuration interaction (CI) basis for wavefunctions, with variationally-defined positions and sizes (Heitler-London or Hund-Mulliken approximations inadequate for accurately describing doubly-occupied regime)

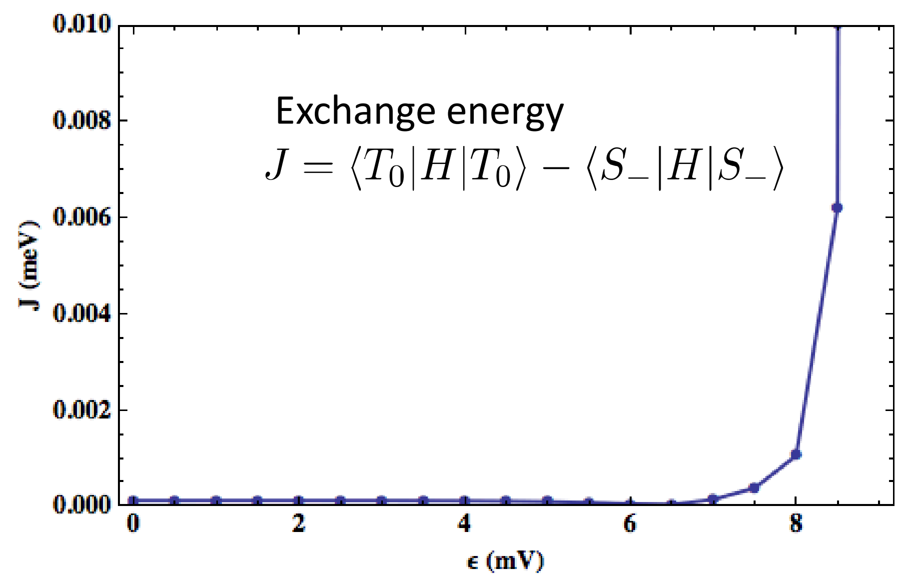
Representation of positions of Gaussian basis states for CI: (9 states per dot here, but we take 4 in the following)



Parabolic confinement potential:



[*Nielsen, et al. PRB* ***82****, 075319 (2010)*]



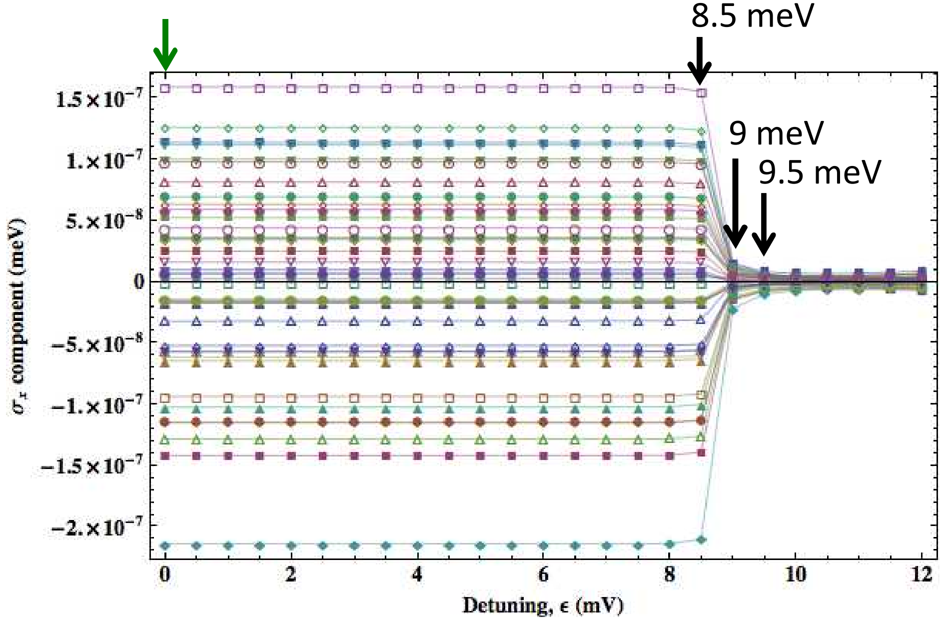
Approximations:

-Neglecting spin-orbit interaction (can contribute to σ_y term) [Stepanenko, et al. PRB **85**, 075416 (2012)]

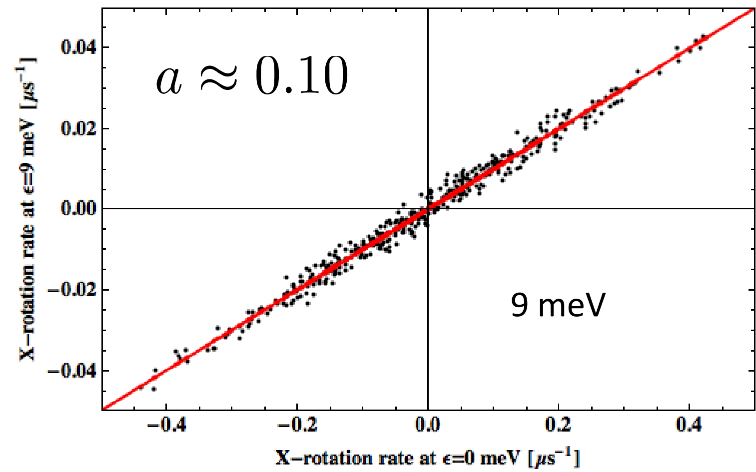
-Assuming $\mathbf{B} = B\hat{z}$ and $\Delta\mathbf{B} = \Delta B\hat{z}$

Detuning-dependent errors

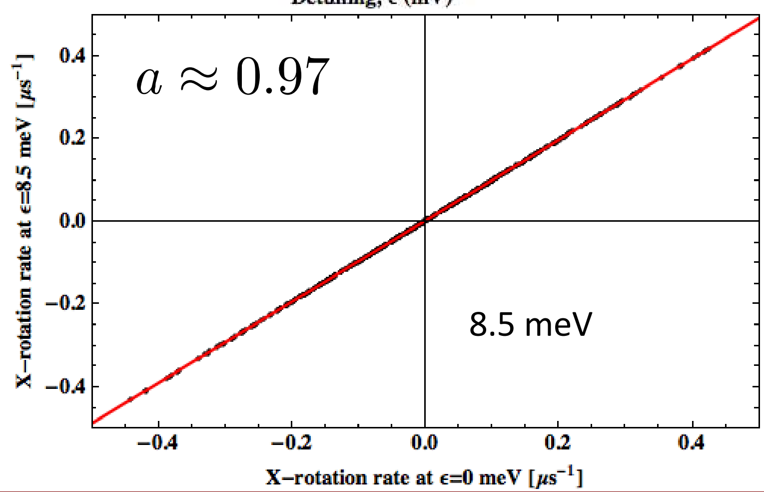
Error in σ_x due to B-field inhomogeneity is commonly assumed to be independent of the applied controls, but variation with controls may be significant:

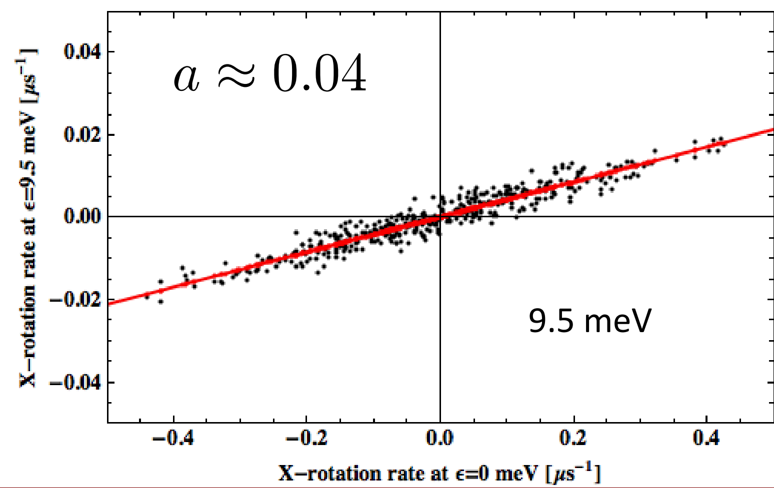


Correlation factor:
$a = \langle h_x(\epsilon_1)/h_x(\epsilon_0) \rangle$



$h_x(\epsilon)$correlations:





DCGs on S/T_0 spin qubits

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Dynamically-corrected gates (DCGs) [refs for Kodjasteh & Viola, others]:

If $h_x(\epsilon)$is known, the DCG sequence can be adapted straightforwardly

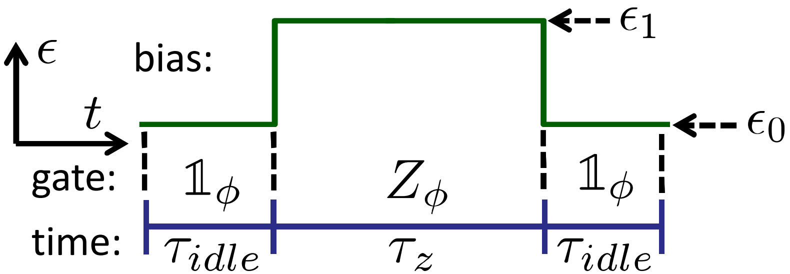
Want to cancel the first-order error per gate (EPG): $\Phi_{tot}^{[1]} = \sum_{k=1}^{N} P_{k-1}^{\dagger}\Phi_k^{[1]}P_{k-1}$, where

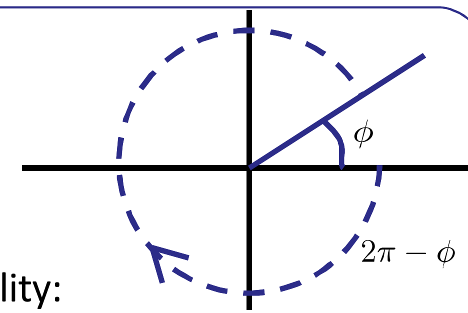
$P_k \equiv \hat{U}_k\hat{U}_{k-1}\cdots\hat{U}_1\hat{U}_0$ and

$$\Phi_k^{[1]} = \frac{1}{\hbar}\int_{t_{k-1}}^{t_k} ds\ \hat{U}^{\dagger}(s,t_{k-1})H_{err}(t)\hat{U}(s,t_{k-1})$$

Idea: Given $h_x(\epsilon)$, adjust operating points and gate times so that "uncompensated" $U_k$are implemented

Example: Dynamically-corrected $Z_\phi = e^{-i\sigma_z\phi/2}$gate ($\mathbb{1}Z_\phi\mathbb{1}$sequence)

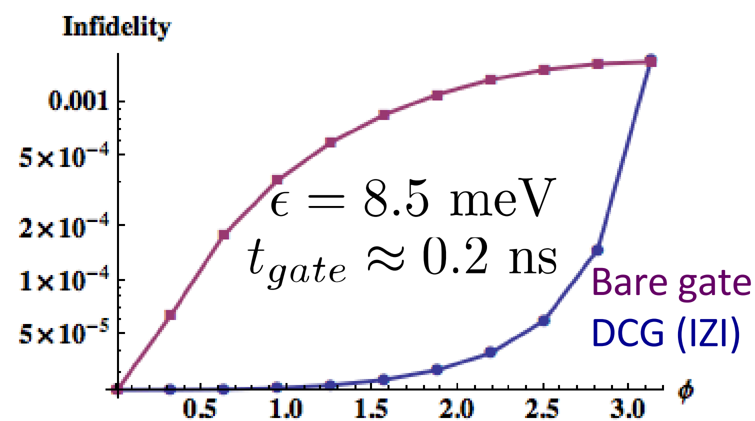




$$\tau_z = \frac{(2\pi-\phi)\hbar}{J_{op}}$$

$$\tau_{idle} = -\tau_z a\frac{\tan[(2\pi-\phi)/2]}{2\pi-\phi},\ \phi \in [0,\pi)$$

Average gate infidelity:



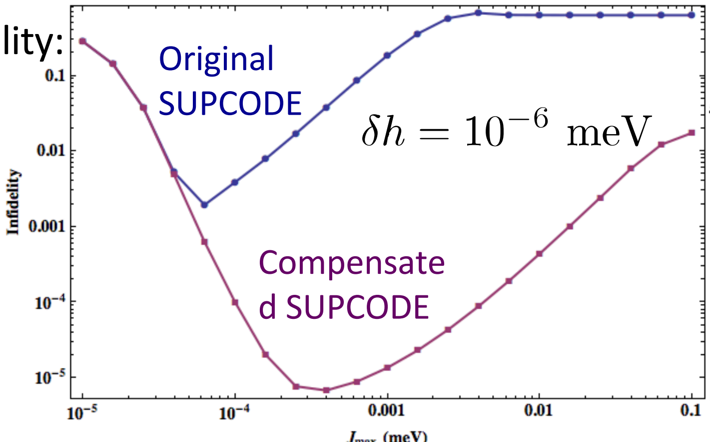
Compensated DCG

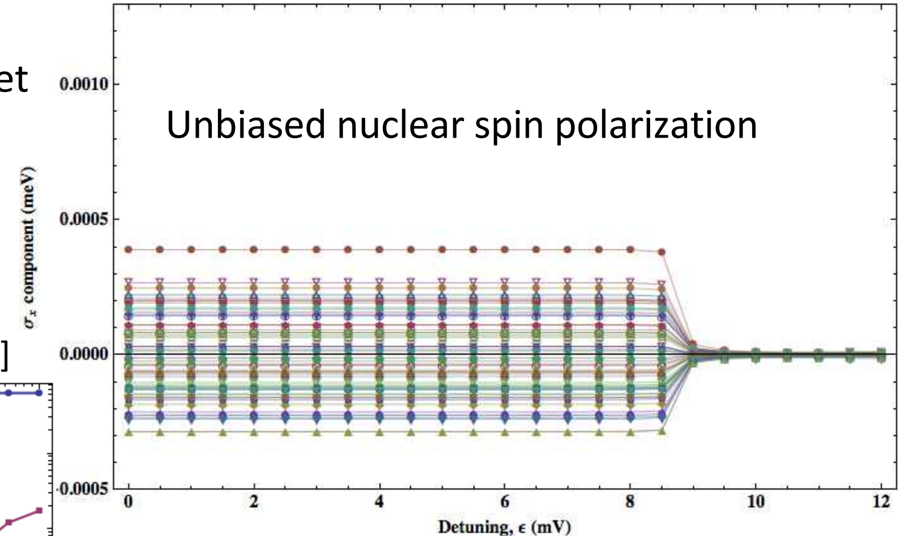
Universal single-qubit gates: Engineer a field inhomogeneity to perform X-gates: e.g. via nearby magnet [*Brunner, et al. PRL* ***107****, 146801 (2011)*] or dynamic nuclear spin polarization [*Foletti, et al. Nature Phys.* ***5****, 903 (2009)*]

Dynamic nuclear spin polarization: (designed-in nuclear spin polarization inhomogeneity)

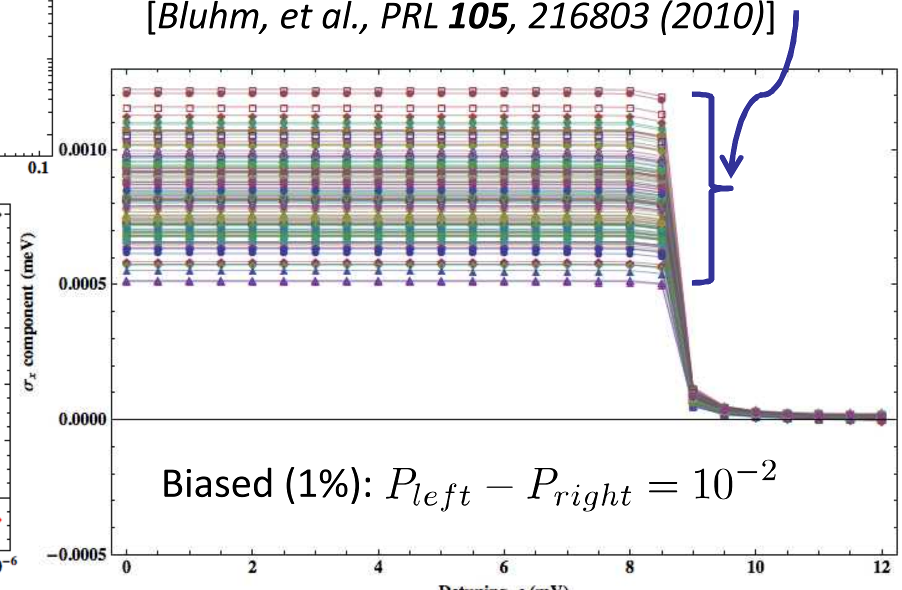
SUPCODE sequence [*Wang, et al. Nat. Commun.* ***3****, 997 (2012)*]

Average gate infidelity:

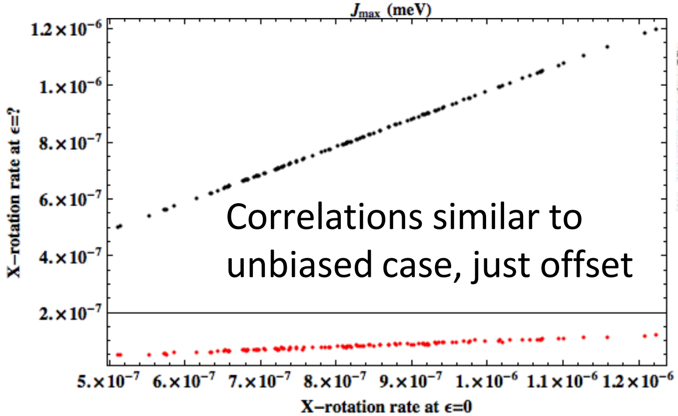




Polarization w/ feedback can narrow spread [*Bluhm, et al., PRL* ***105****, 216803 (2010)*]



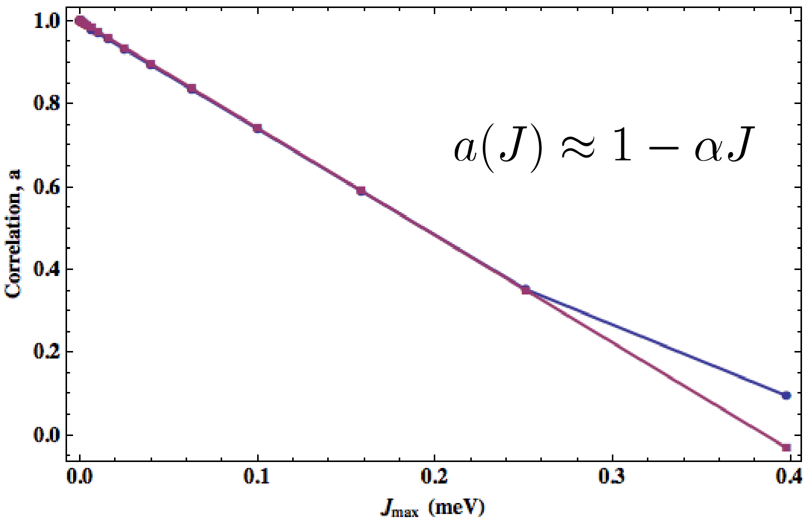
System parameters:
~10^6 GaAs nuclei in DQD,
L=30 nm, E_0=8.5 meV, B=1.5 T
Gaussian basis:16:8:4 (four Gaussians per dot)



Conclusions

Observe a linear dependence on exchange:

$$h_x(J) \approx (1 - \alpha J)(h_0 + \delta h)$$



Essentially, need to characterize the exchange $J(\epsilon)$ and only the single parameter α to obtain the σ_x component $h_x(\epsilon)$

To do:

See if our compensation scheme can be straightforwardly adapted to account for charge noise (errors in), a la the updated SUPCODE approach of [Kestner, et al. arXiv:1301.0826]

Conclusions:

Accounting for correlations in errors can lead to a significant improvement in gate fidelity

Improvement in fidelity gained by compensation is most significant when the field inhomogeneity ΔB is large. (Especially important in context of dynamic nuclear spin polarization)

See (preceding) talks:
C26.00007 [Wang, et al.]
and
C26.00008 [Kestner, et al.]