Weak measurements with an ensemble quantum processor.

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Experimental realization of post-selected weak measurements on an NMR quantum processor

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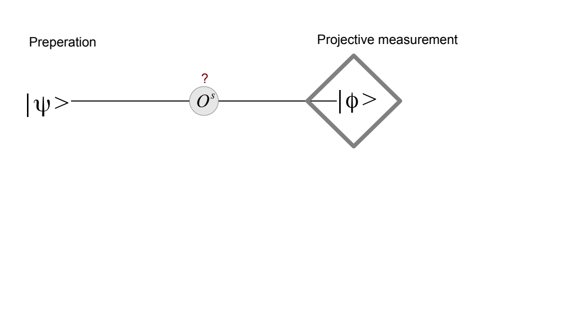
What can we say about a quantum system between two measurements?



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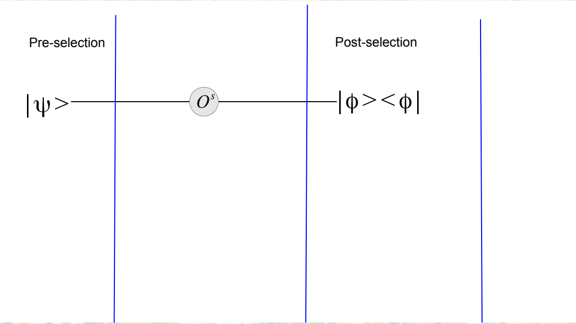

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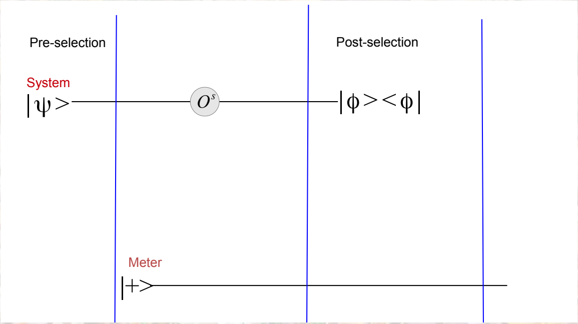

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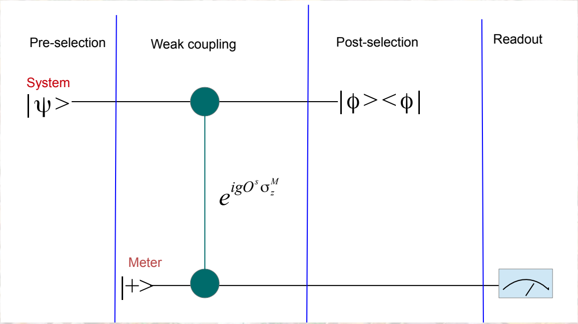

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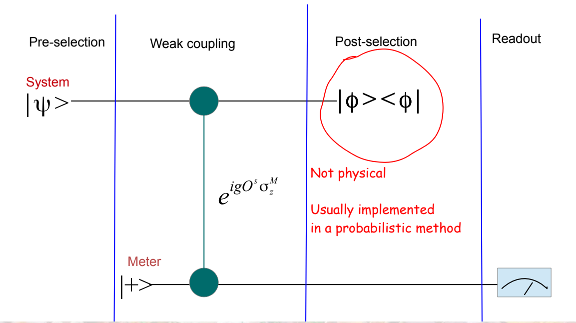

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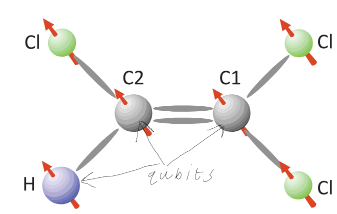
Why weak measurements?

- Weak values are observable[Aharonov Albert Vaidman, PRL 1989; Vaidman, FoP 1991]
- Post selection paradoxes: 3box [Aharonov Vaidman, JPA 1991] Hardy's [Aharonov et al., PLA 2002]
- Measurement without disturbance [Rozema et al., PRL 2012]
- Improved precision [Jordan Martinez-Rincon Howell, arXiv 2013]

Post selection is also useful elsewhere

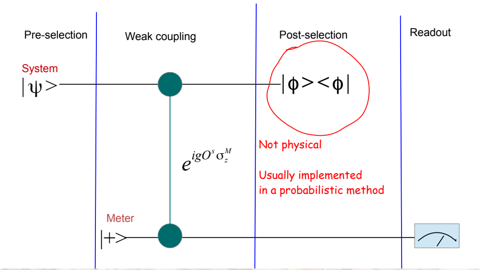
Molecules as quantum processors



$$\mathcal{H} = \sum_{j=1}^{3} \pi\nu_j\sigma_z^j + \frac{\pi}{2}(J_{13}\sigma_z^1\sigma_z^3 + J_{23}\sigma_z^2\sigma_z^3) + \frac{\pi}{2}J_{12}(\sigma_x^1\sigma_x^2 + \sigma_y^1\sigma_y^2 + \sigma_z^1\sigma_z^2),$$

- Control dynamics by rotating individual qubits
- Readout is an average over all molecules

Why is it hard to post-select in NMR?



- In an experiment post-selection is not always successful.
- Usually post selection is done by discarding experiments which fail post selection.
- Requires access to individual outcomes.
- But we can only access an average over many simultaneous runs of the experiment.

Post selection with ensemble averages

The idea is to reset the meter when post selection is unsuccessful

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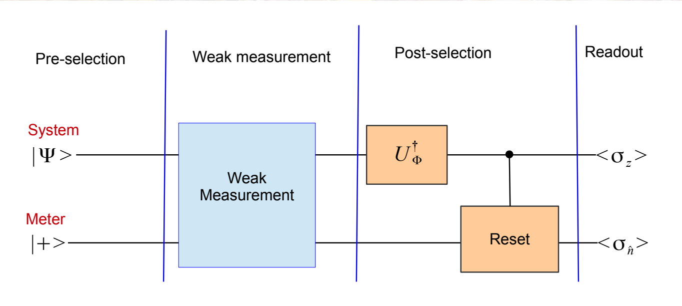


The reset R is conditioned on the system being in $|1\rangle$ and obeys $Tr[\sigma_n R(\rho)] = 0$ for all ρ.

Choosing $\hat{n} = \hat{y}$ we find: $Re(\{\sigma_x\}_w) \approx \frac{\langle \sigma_y^{\mathcal{M}} \rangle}{g(\langle \sigma_z^{\mathcal{S}} \rangle + 1)}$

Note: R is not unitary.

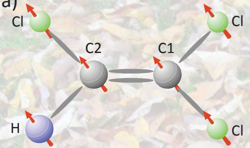
Aims for the experiment

The first experimental implementation of weak measurements without optics

- As proof of principle we wanted to show measure two main features of weak measurements
  1. Weak values beyond the range of eigenvalues
  2. Complex weak values

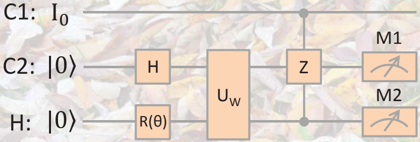
Experimental circuit

(a)



	C1	C2	H	T_1(s)	T_2(s)
C1	21784.6			13.0±0.3	0.45±0.02
C2	103.03	20528.0		8.9±0.3	1.18±0.02
H	8.52	201.45	4546.9	8.9±0.3	1.7±0.2

(b) C1-Ancilla; C2-Measuring Device; H-System.

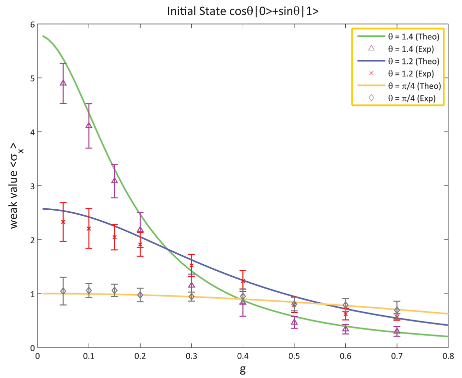


H	Hadamard	Z	$\exp(-i\,\pi/2\,\sigma_z)$
R(θ)	$\exp(-i\,\theta\,\sigma_y)$	M1	$\langle\sigma_y\rangle$
U_W	$\exp(-i\,g\,\sigma_x\,\sigma_z)$	M2	$\langle\sigma_z\rangle$

To perform the reset operation we prepare an ancilla in the maximally mixed state and use a control control σ_z with both system and ancilla as controls.

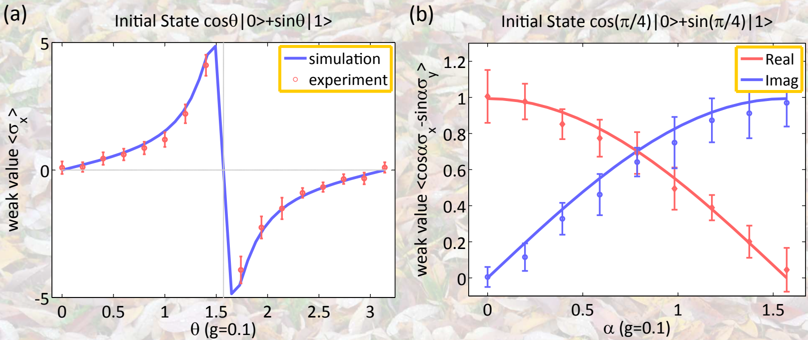
Real weak values

The observed 'weak value' as a function of the coupling strength



The initial state is $\cos(\theta)\,|0\rangle^{\mathcal{S}} + \sin(\theta)\,|1\rangle^{\mathcal{S}}$, the weak measurement is of σ_x and the post-selection was $|0\rangle^{\mathcal{S}}$

More weak values



Conclusions and outlook

- We measured weak values outside the range of eigenvalues and complex weak values
- Measurements of large weak values are limited by decoherence and weak signal
- Can we still use this scheme for precision measurements?
- Realization of weak measurement experiments on more qubits than other platforms
- More fun with post-selection