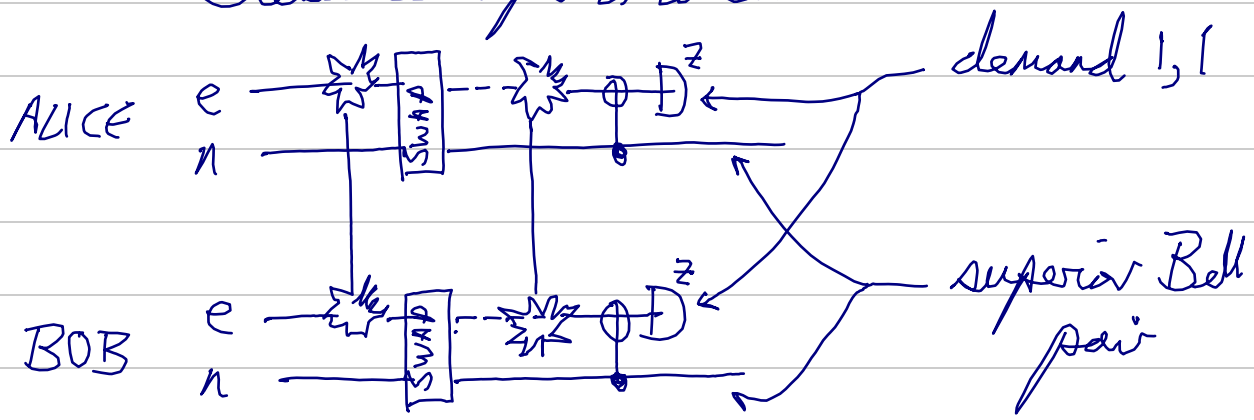
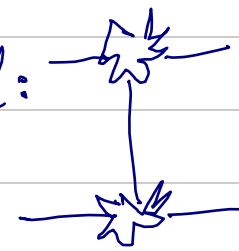
Performing Extreme Photon Loss protocol with NV^- Centres

Notes after Norbert's visit to Oxford Nov. '15 with Earl C. and Naomi C. participating

BACKGROUND

Basic concept is to do this



This symbol:  means create remote Bell pair

- start from $|s\rangle|s\rangle$ where $|s\rangle = \sin\vartheta|0\rangle + \cos\vartheta|1\rangle$
- detect one photon,

$\Rightarrow$ mixed state $(1-\eta)\,|\psi^+\rangle\langle\psi^+| + \eta\,|00\rangle\langle 00|$

Note:

① we can actually create any state instead of $|\psi^+\rangle$ with different internal phase eg $\frac{|01\rangle + e^{i\phi}|10\rangle}{\sqrt{2}}$ as long as ϕ is the same for both pairs (it cancels).

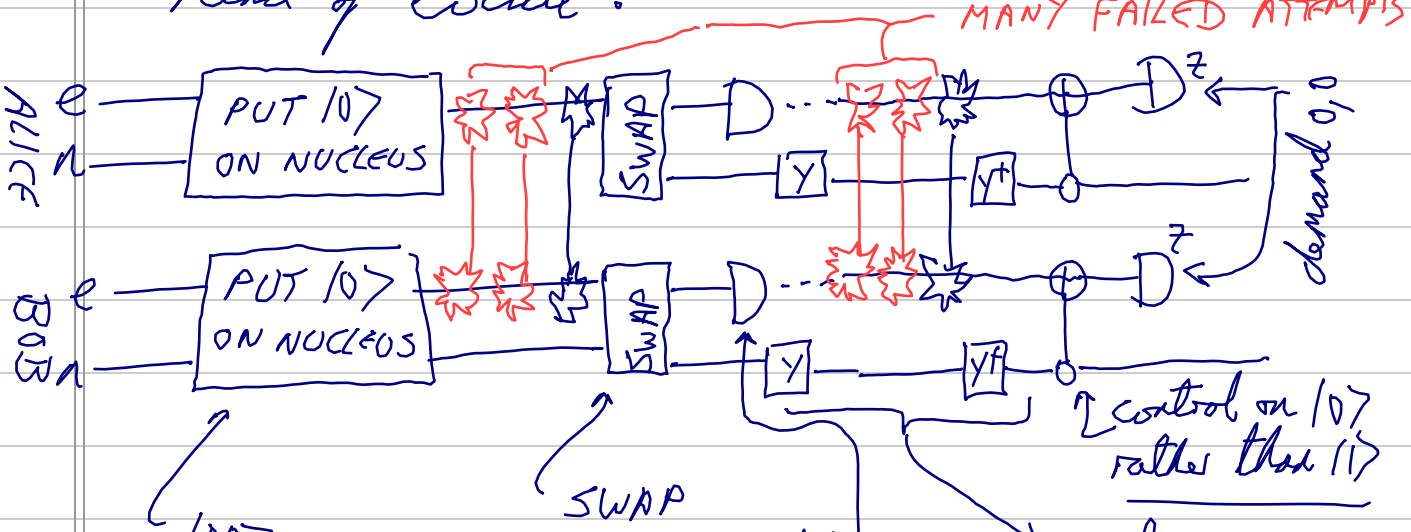
② This circuit is easy to verify by just working through the four cases,

Pair 1 = $|\psi\rangle$ & Pair 2 = $|\psi\rangle$, Pair 1 = $|\psi\rangle$ Pair 2 = $|10\rangle$

Pair 1 = $|01\rangle$ & Pair 2 = $|\psi\rangle$, Pair 1 = $|01\rangle$ Pair 2 = $|00\rangle$

PRESENT CASE

① Our local electron-nucleus gates are noisy (maybe 2.5% noise) and moreover we will need to try many times to get the second Bell pair and this process will put phase noise on the stored Bell state. Therefore use this general kind of circuit:



107 state not corrupted by subsequent e⁻ activity

SWAP can be implemented with only two e-n gates if we know nucleus is 107

encode memory, $|01\rangle + |10\rangle \rightarrow |+-\rangle + |-+\rangle$ then reverse later ⇒ phase error becomes flip *

demand "0" "0" on these measurements this verifies the SWAP.

See next page for same circuit using NATURAL gates.

* this encoding means that phase noise eventually becomes flip, taking eg $|01\rangle + |10\rangle \rightarrow |00\rangle + |11\rangle$ which is detected by the purification. But, the bad 00 part of mixture can then be

turned into $|10\rangle$ or $|01\rangle$ (or rarely, $|11\rangle$) by the same encode-phase error-decode process. When the bad part of the mixture $|00\rangle\langle 00|$ indeed flips to $|01\rangle\langle 01|$, say, then this will reduce the fidelity of the process, but generally the gain from filtering phase noise from the "good" part outweighs this

$$(1-\eta)|\psi\rangle\langle\psi| + \eta|00\rangle\langle 00|$$

more protected ☺ ← → spawns $|01\rangle\langle 01|$ etc. ☹

The merit of doing the memory encoding is greater for smaller η!

REAL GATES
- Can do any single qubit gate on electron.
- Can only do phase single qubit on nucleus.
- Can do electron-nuclear gate

basically a nuclear root-of with direction controlled by e^-.

$$G = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & 1 \end{pmatrix}$$

in basis $|e,n\rangle = 00, 01, 10, 11$

Circuit below uses Hayward Hard $X_R = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & -i \\ -i & 1 \end{pmatrix}$, $Y_R = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix}$, $Z_R = \frac{1}{\sqrt{2}}\begin{pmatrix} 1+i & 0 \\ 0 & 1-i \end{pmatrix}$.