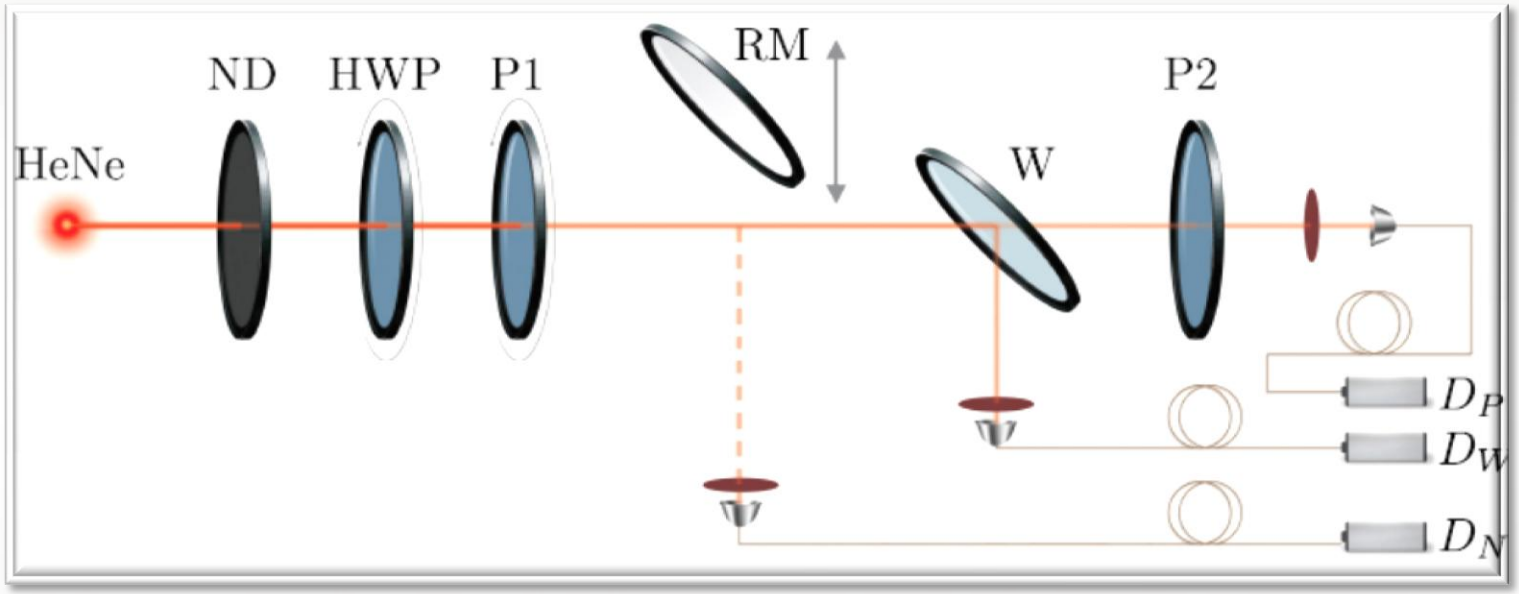
Null weak values in quantum dots and beyond



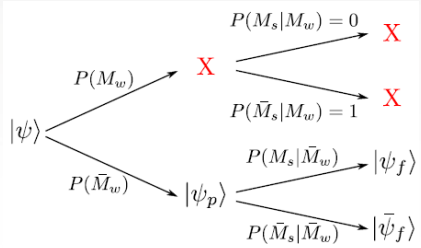
OZ, Alessandro Romito, and Yuval Gefen
and
Experiment: **OZ**, Alessandro Romito, D. J. Starling, G. A. Howland, J. C. Howell , and Yuval Gefen

arXiv:1205:3877

Outline

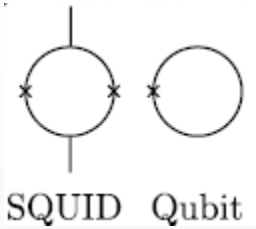
- (Null) Weak values

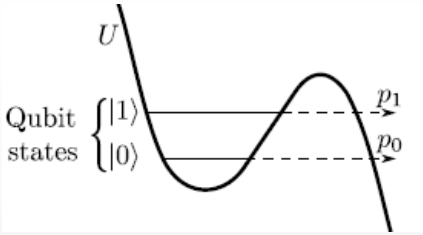
$$\frac{\langle \chi_f | \hat{A} | \chi_i \rangle}{\langle \chi_f | \chi_i \rangle}$$

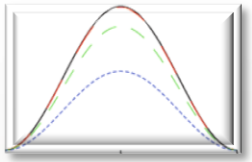


- Realistic implementations

Amplified quantum state discrimination

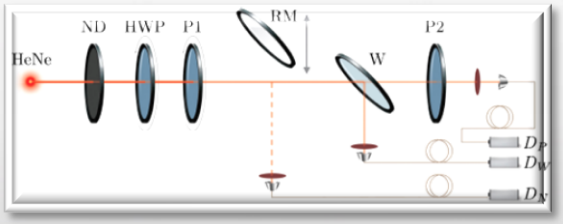






- Optical analogue =>

Experimental manisfestation



Motivation → Weak Values→ why ?

- Elucidates fundamentals & paradoxes of quantum mechanics
- Non-destructive measurement of (classically forbidden) virtual states
- Hyper-precision measurements
- Amplified quantum state discrimination

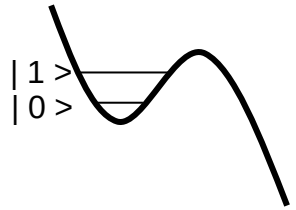
$$|\psi_0\rangle = \alpha_0 |0\rangle + \beta_0 |1\rangle$$

$$|\psi_\delta\rangle = \alpha_\delta |0\rangle + \beta_\delta |1\rangle$$

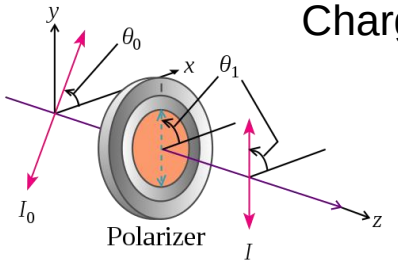
Measuring a qubit system

$$|i\rangle = \alpha_0 |0\rangle + \beta_0 |1\rangle$$

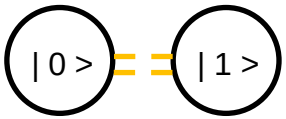
- How to measure $|\beta_0|^2$?



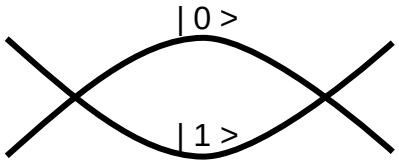
Josephson phase qubit



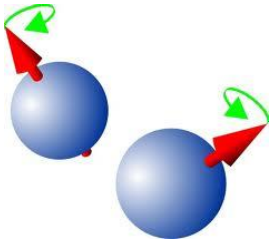
Polarization of light



Charge qubit



Which-path qubit



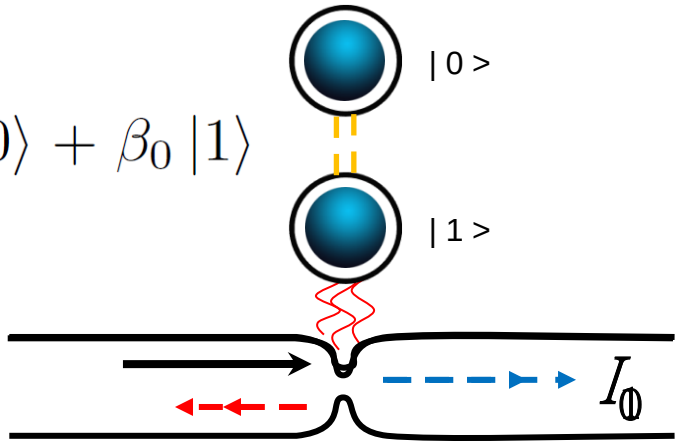
Spin qubit

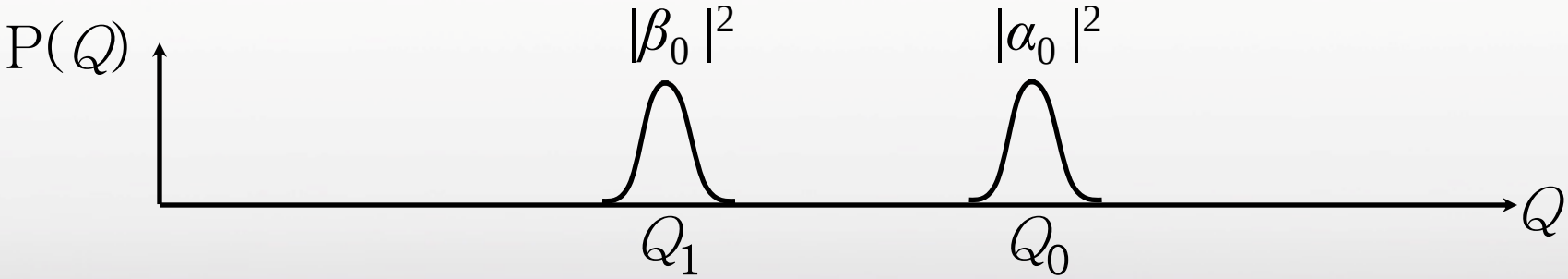
Measuring a charge qubit (strongly)

Couple a quantum point contact to one of the quantum dots

$$\alpha_0 |0\rangle + \beta_0 |1\rangle$$

$$Q = \int_0^{\Delta t} I dt \Rightarrow \hat{n}_1 = |1\rangle \langle 1|$$



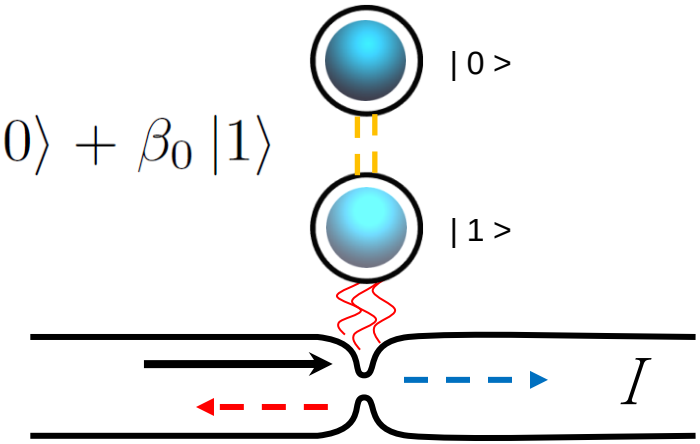


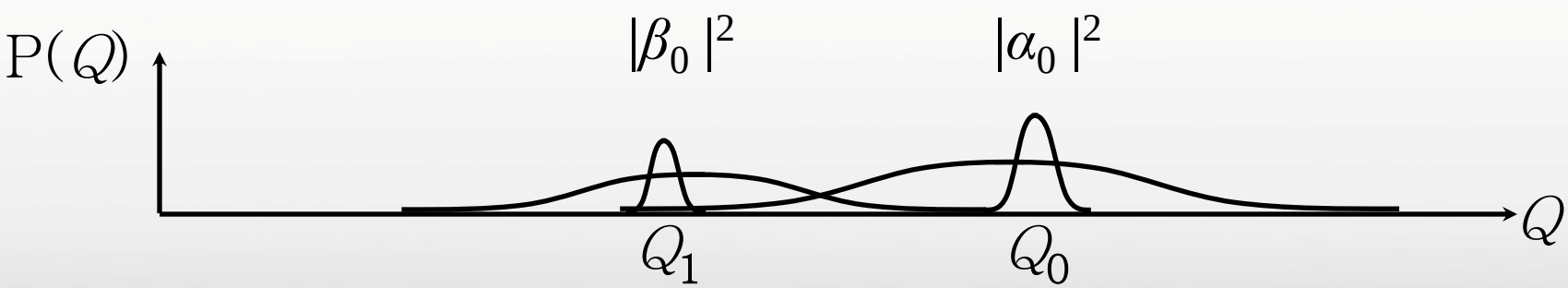
Measuring a charge qubit (weakly)

Couple a quantum point contact to one of the quantum dots

$$\alpha_0 |0\rangle + \beta_0 |1\rangle$$

$$Q = \int_0^{\Delta t} I dt \Rightarrow \hat{n}_1 = |1\rangle \langle 1|$$



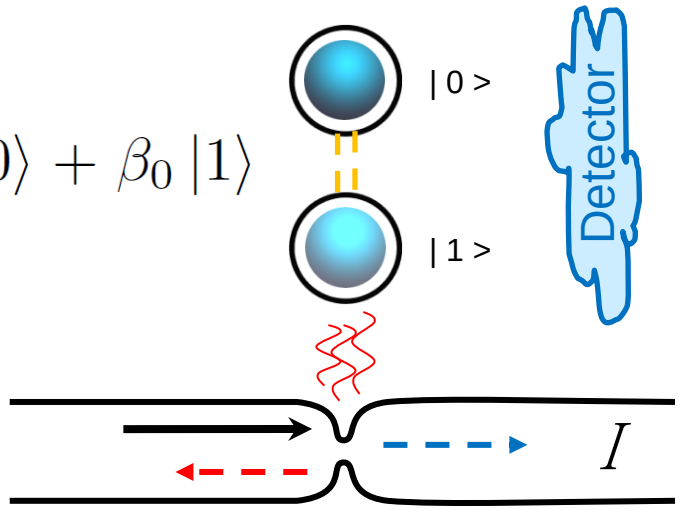


Weak Value Protocol

- Preparation | i >
- Weak measurement of $\hat{n}_1$ — Keep
- (later) Strong measurement of $\hat{B}$ on final state | f >

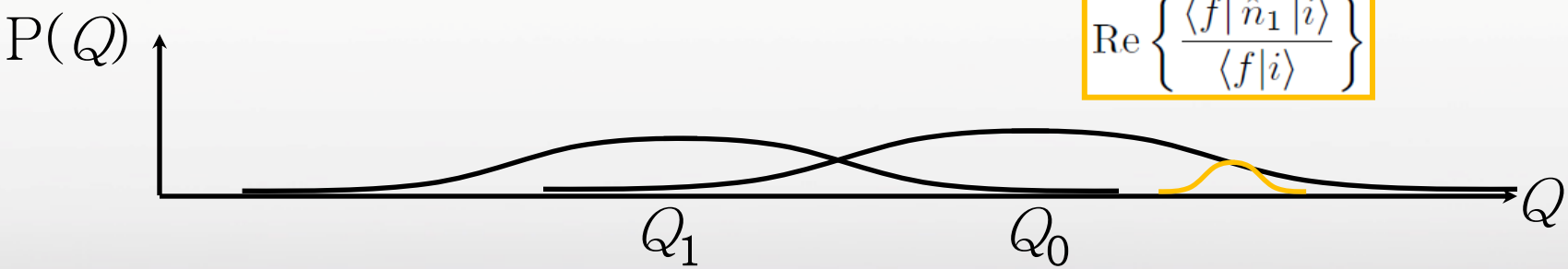
Provided $\hat{B} = B_0$ Postselection

$$\alpha_0 |0\rangle + \beta_0 |1\rangle$$



Weak value

$$\mathrm{Re}\left\{\frac{\langle f|\,\hat{n}_1\,|i\rangle}{\langle f|i\rangle}\right\}$$



Y. Aharonov, D. Albert, L. Vaidman, Phys. Rev. Lett. 60, 1351 (1988)

Null Weak Value Protocol

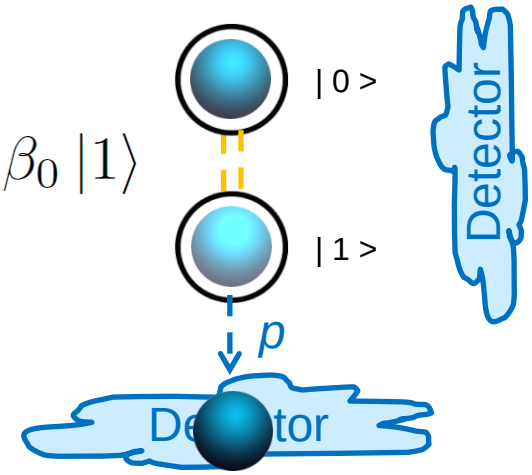
- Preparation | i >
- ~~Weak measurement of~~ $\hat{n}_1$ ~~with small probability *p<<1*~~
- (later) Strong measurement of $\hat{B}$ on final state | f >

Keep

Provided $\hat{B}$="no click"

Postselection

$$\alpha_0 |0\rangle + \beta_0 |1\rangle$$



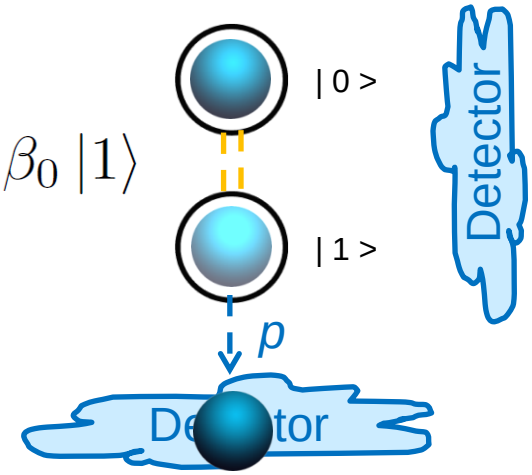
Null Weak Value Protocol

- Preparation | i >

Keep

- Strong measurement of $\hat{n}_1$ with small probability *p<<1*

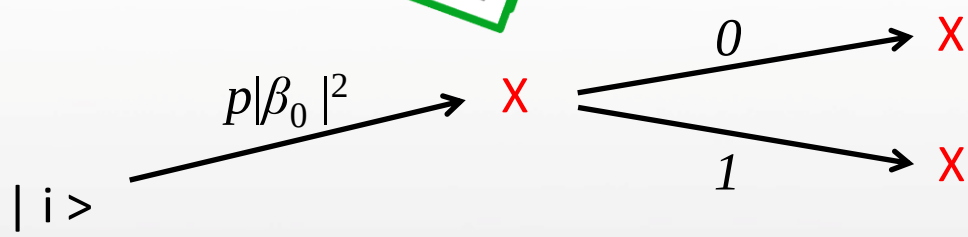
$$\alpha_0 |0\rangle + \beta_0 |1\rangle$$



- (later) Strong measurement of $\hat{B}$ on final state | f >

Provided $\hat{B}$="no click"

Postselection



Null Weak Value Protocol

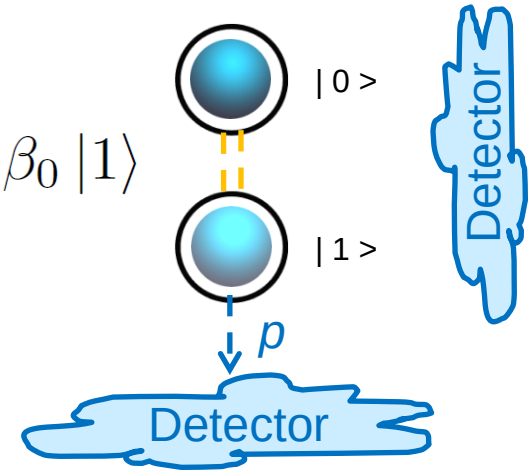
- Preparation | i >
- Strong measurement of $\hat{n}_1$ with small probability *p<<1*
- (later) Strong measurement of $\hat{B}$ on final state | f >

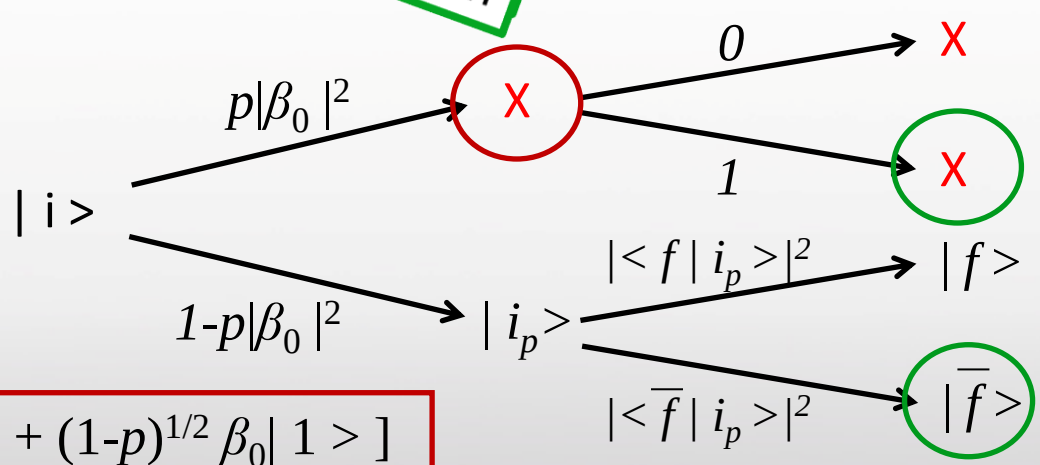
Keep

Provided $\hat{B}$="no click"

Postselection

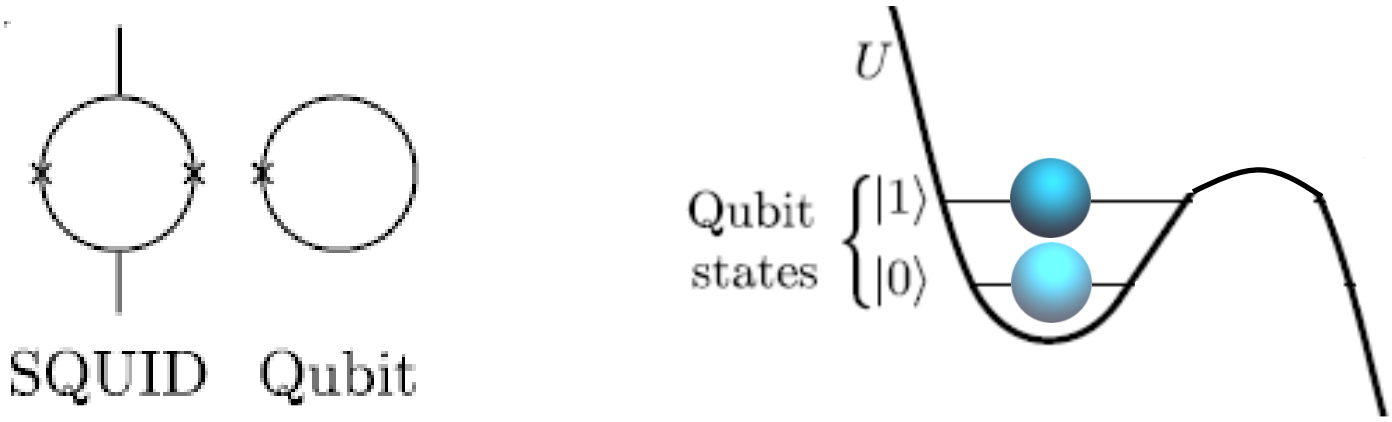
$$\alpha_0 |0\rangle + \beta_0 |1\rangle$$

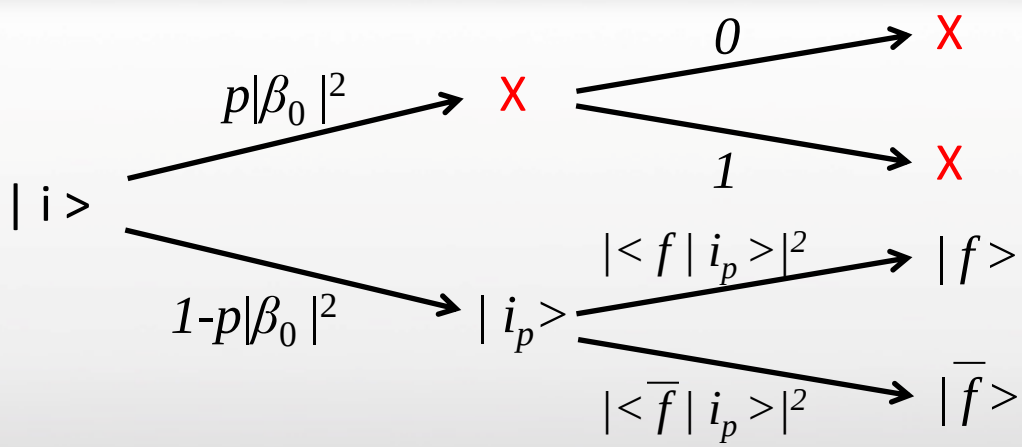




$$|i_p> = N\,[\,\alpha_0|0> + (1\text{-}p)^{1/2}\,\beta_0|1>\,]$$

Josephson phase qubit





N. Katz et al., Science 312, 1498 (2006); L. P. Pryadko and A. N. Korotkov, Phys. Rev. B 76, 100503 (2007).

What is it good for?

- Amplified quantum state discrimination

$$|\psi_0\rangle = \alpha_0 |0\rangle + \beta_0 |1\rangle \equiv \cos[\theta_0] |0\rangle + \sin[\theta_0] \exp[i\phi_0] |1\rangle$$

$$|\psi_\delta\rangle = \alpha_\delta |0\rangle + \beta_\delta |1\rangle \equiv \cos[\theta_0 + \delta_1] |0\rangle + \sin[\theta_0 + \delta_1] \exp[i(\phi_0 + \delta_2)] |1\rangle$$

<u>Option 1</u>

Measure $\hat{n}_1$ strongly

$$SNR_{std} = \frac{|\,|\beta_\delta|^2 - |\beta_0|^2\,|}{\sqrt{|\beta_\delta|^2 (1 - |\beta_\delta|^2)}} \sqrt{N}$$

<

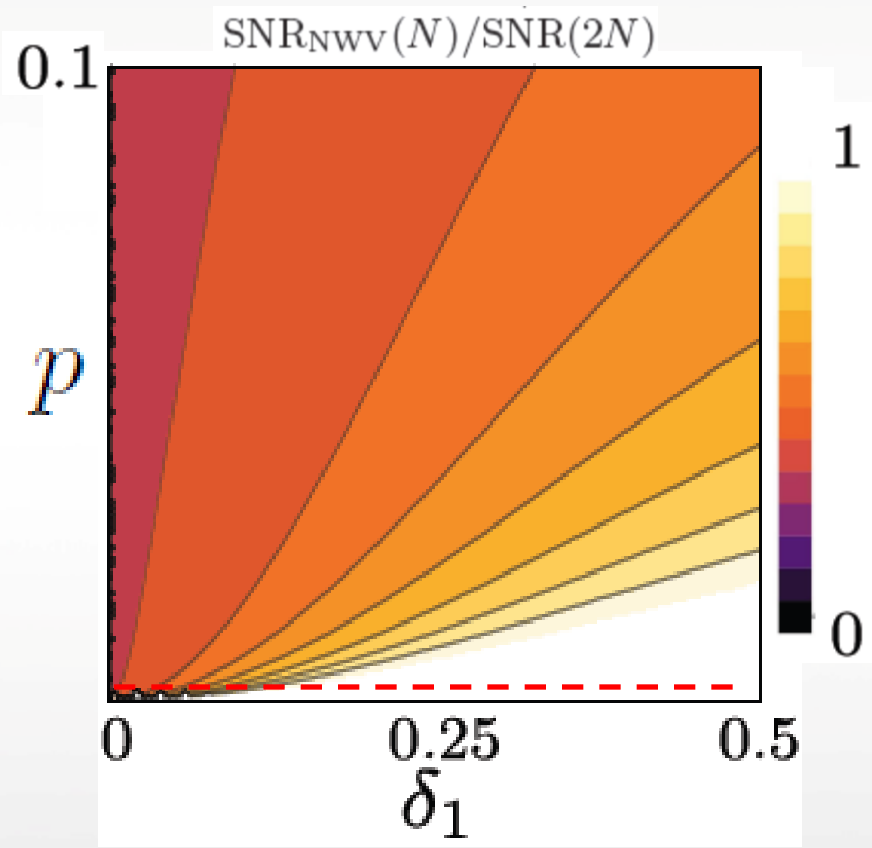
<u>Option 2</u>

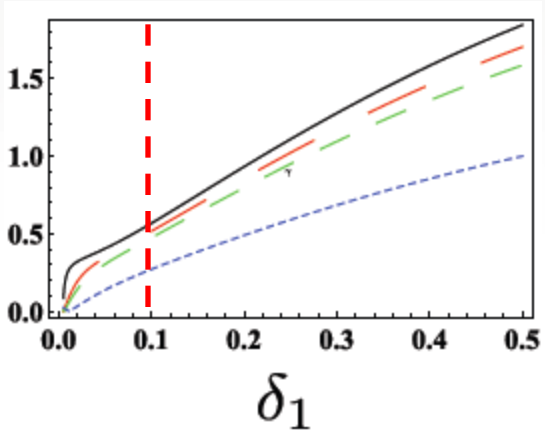
Compare Null Weak Values

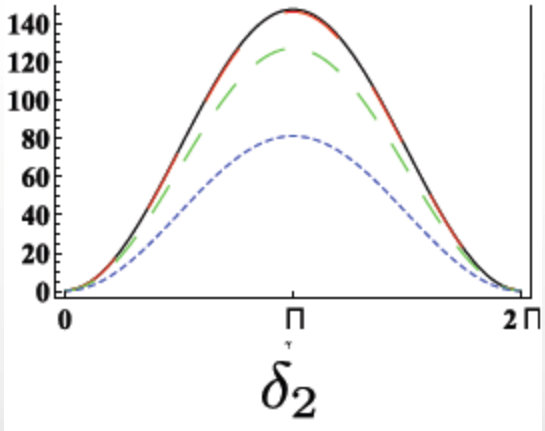
$$SNR_{NWV} = \frac{|\,P_\delta^{cond} - P_0^{cond}\,|}{\sqrt{P_\delta^{cond} (1 - P_\delta^{cond})}} \sqrt{N}$$

What is it good for?

- Amplified quantum state discrimination

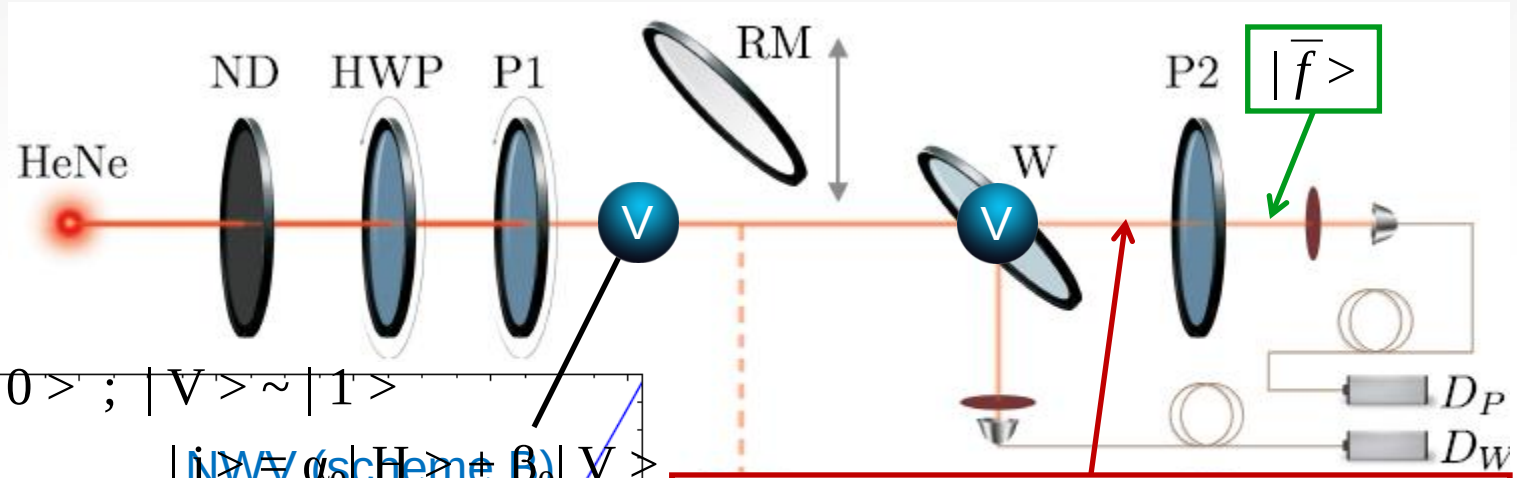






Optical experiment

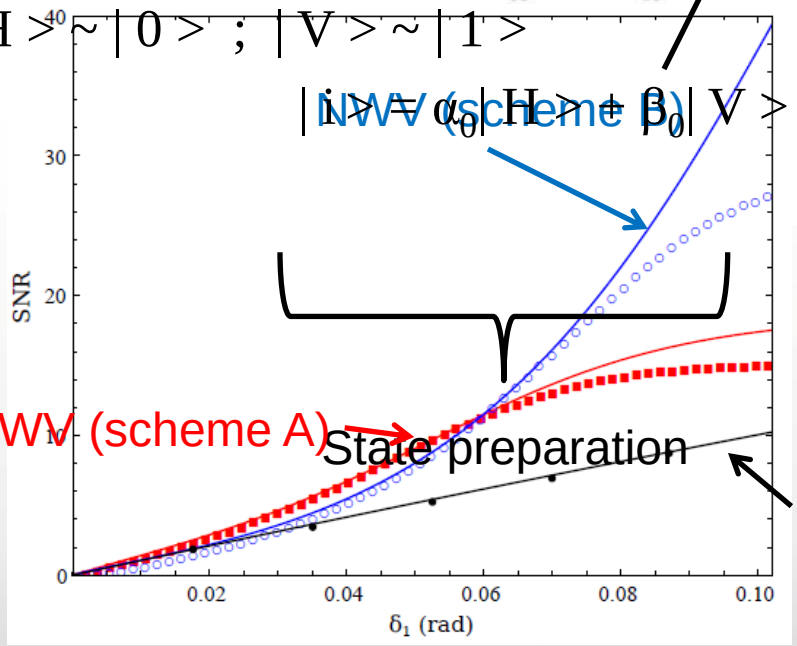
- Amplified quantum state discrimination



$|H> \sim |0>$; $|V> \sim |1>$

$|i> = \alpha_0|H> + \beta_0|V>$

$|i_p> = N[\alpha_0|H> + (1-p)^{1/2}\beta_0|V>]$



Null weak value = #w / (#w + #p)

Partial collapse

Postselection

O. Zilberberg , A. Romito, D. J. Starling, G. A. Howland, J. C. Howell, and Y. Gefen, arXiv: 1205.3877 (2012)

Summary

- Correlated measurements (and HOW you measure)
  => new observables

- Novel protocol: partial collapse + strong measurement
  (≠ Weak value protocol)

- Amplified quantum state discrimination
  (+ experiment)

Thank you!