Diagnosing the Offset

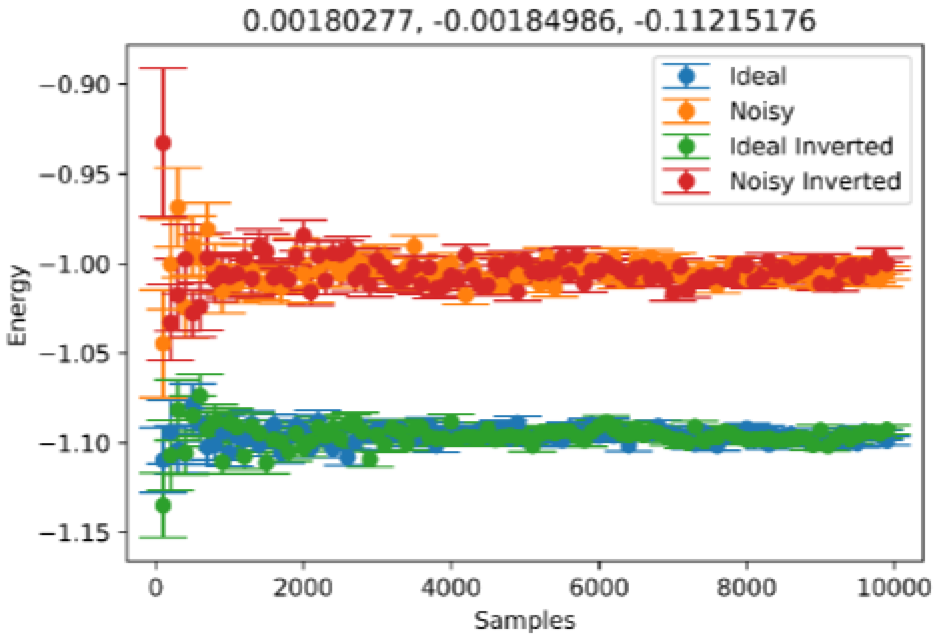
Meeting with Professor Schentzer

September 23, 2020

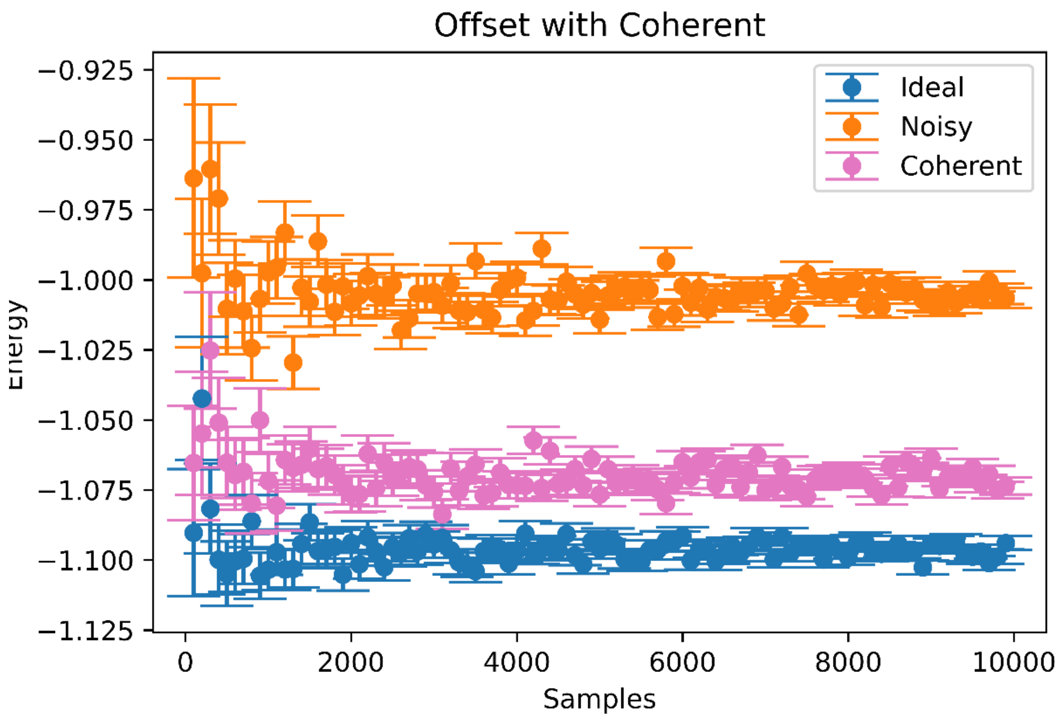
Last Week Recap

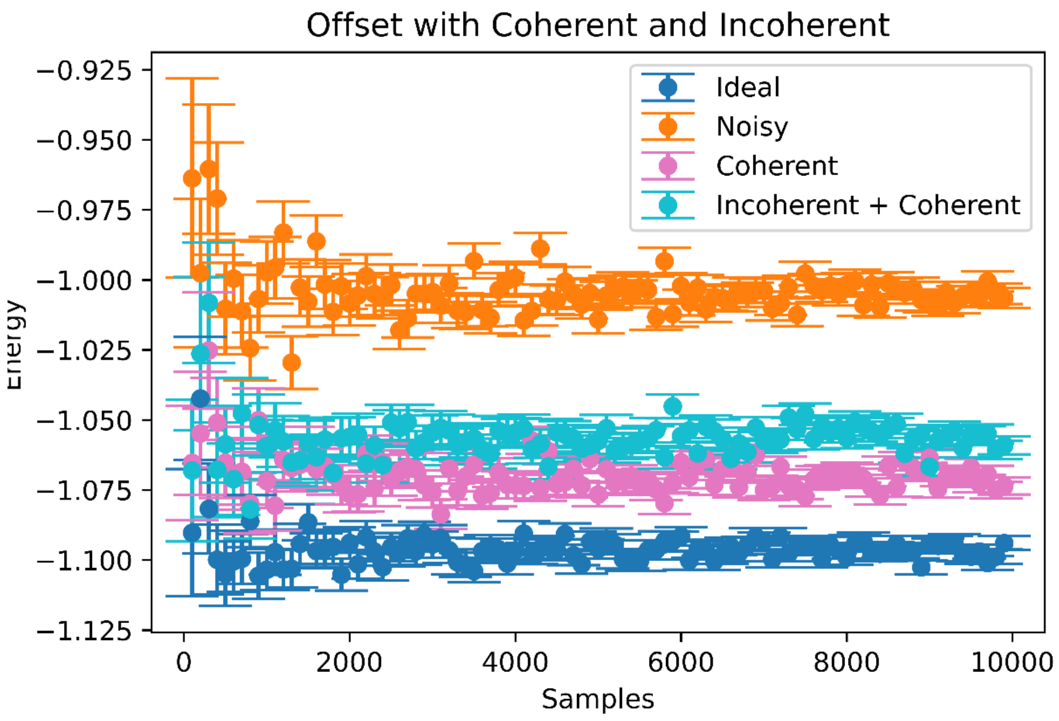
- Using the Inversion technique (flipping the 0s with 1s and vice versa), we tried to exploit the asymmetry
- However, this technique did not work, since inverting the circuit did nothing to energy computed by the noise model.
- Possible Issues:
    1. The offset between noisy energy and ideal energy is caused by a different source of noise. ***Why should this noise be asymmetrical though?***
    2. The inversion technique may work but number of gates in VQE circuit for H2 atom is too small

Gate Inversion of VQE Optimized Circuit for H2 molecule *Optimized on Noise Model*



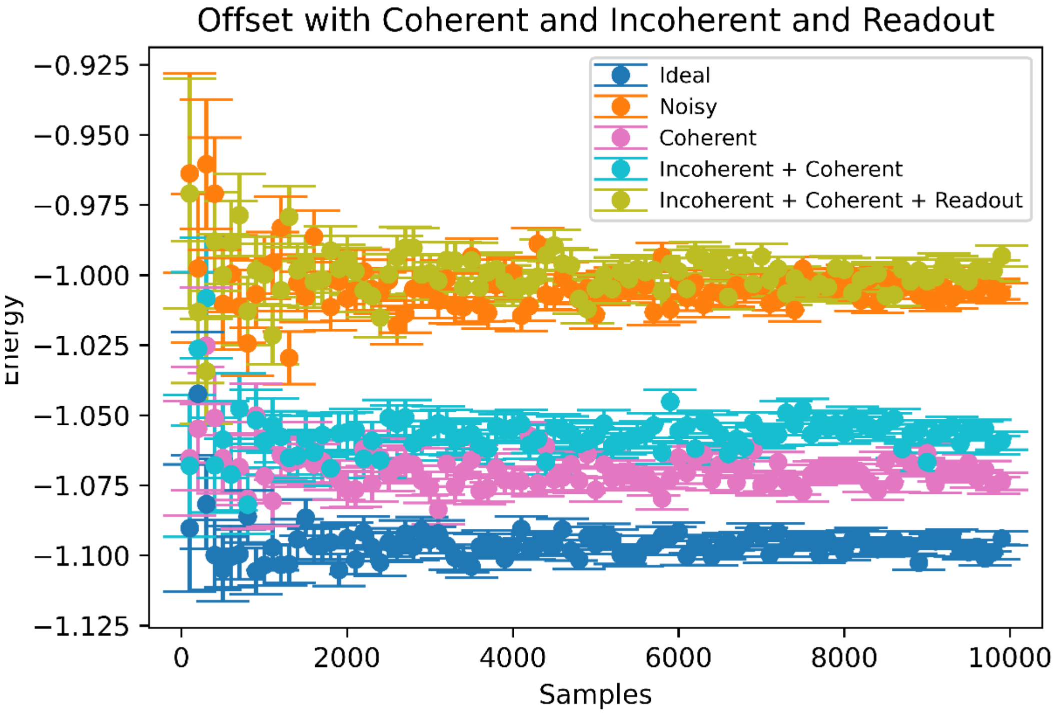
Issue 1: Coherent Errors and Incoherent Errors





Issue 1: Readout Errors

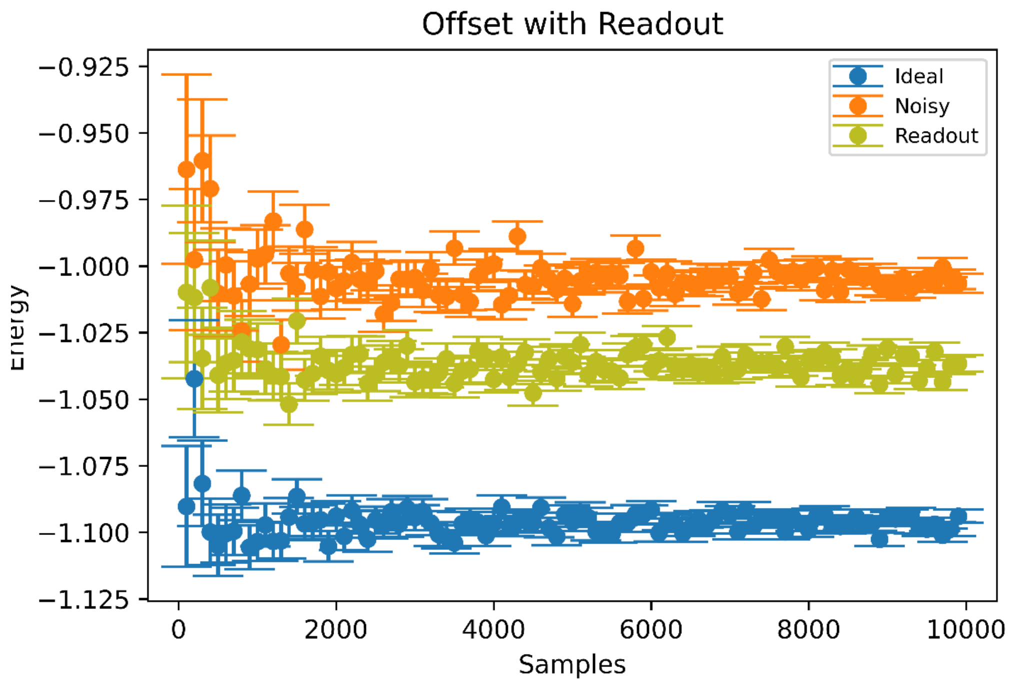
- After adding in all 3 kind of errors, we do get close to the noise model's energy calculation.
- Clearly, readout errors cause the greatest deviation.
- Something Interesting: the measurement error rates are asymmetric
- What happens when we switch them? Do we get the same results, for example, if for qubit 0 , P(0|1) = 0.05 and P(1|0) = 0.05?
    - Let's call this Issue 1.1: Measurement Assymetry

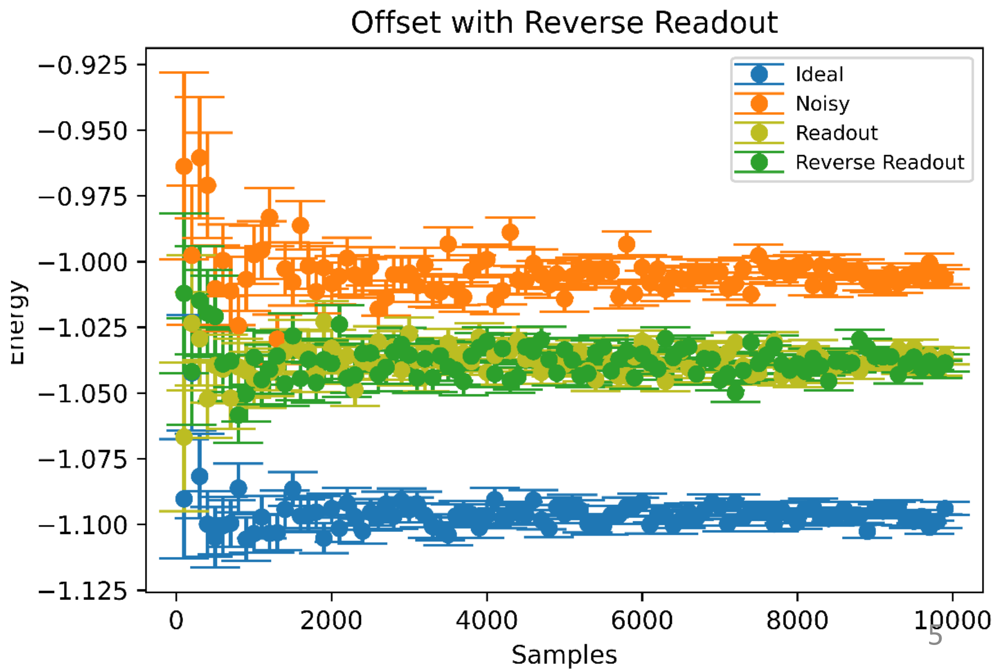



```
Fake London
Qubit: 0 ----------------------------------
 P(1|0) = 0.01
 P(0|1) = 0.050000000000000044
Qubit: 1 ----------------------------------
 P(1|0) = 0.02
 P(0|1) = 0.07666666666666666
Qubit: 2 ----------------------------------
 P(1|0) = 0.14
 P(0|1) = 0.18999999999999995
Qubit: 3 ----------------------------------
 P(1|0) = 0.0033333333333332993
 P(0|1) = 0.03
Qubit: 4 ----------------------------------
 P(1|0) = 0.006666666666666667
 P(0|1) = 0.043333333333333335
```

Issue 1.1: Measurement Asymmetry

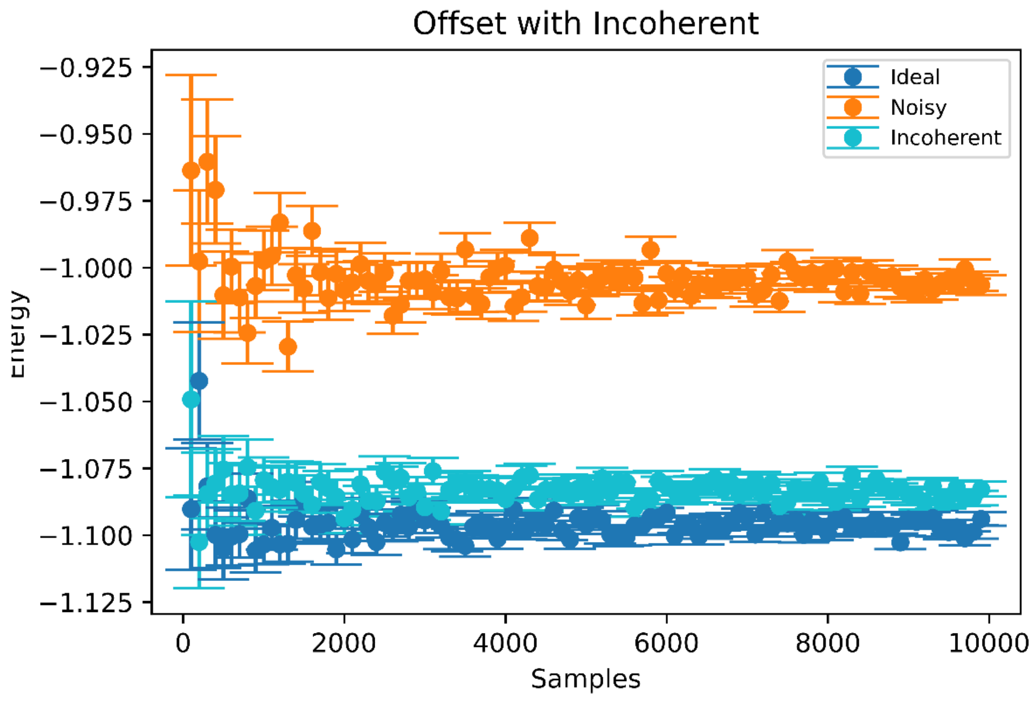
- Reversing the qubit error rates, however, does nothing to the energy value
- **Possible Explanation?**

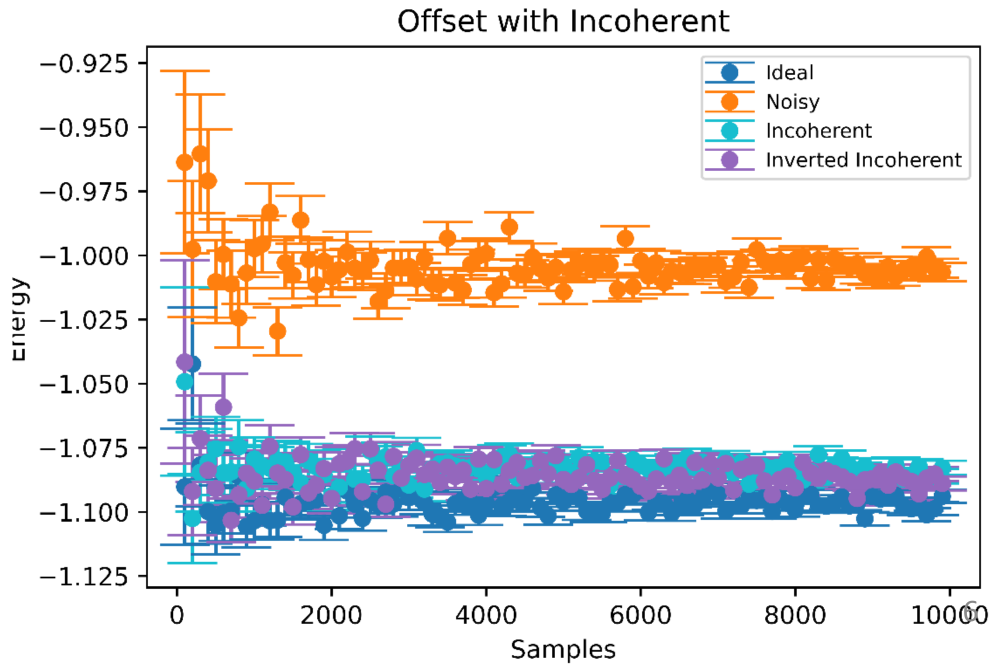




Issue 1.2: Incoherent Errors Asymmetry

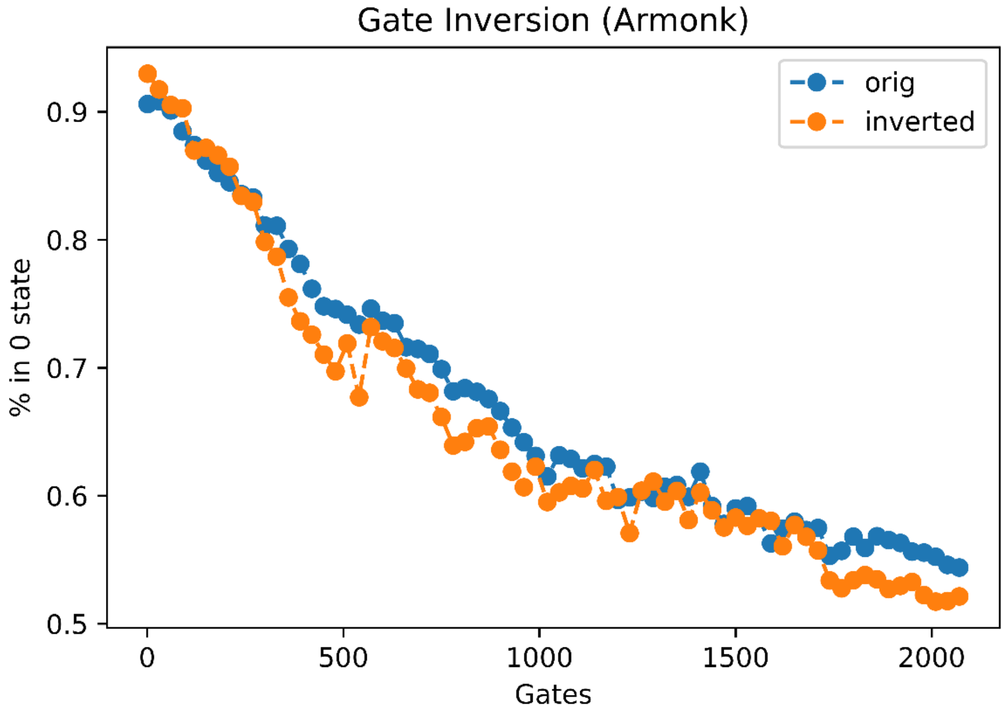
- Lets try to see if we invert our circuit, does the energy change if our noise model is made of purely incoherent errors?
- The purple and cyan points are slightly off balance but no significant shift in energy.
- Failure to get any change in energy ties into issue 2--- is the gate length the reason why we don't get this shift?





Issue 2: Gate Length and Inversion

- Let's invert a 1 qubit circuit by changing sign of angles of U3 gates and inserting 2 X gates , one before and after the circuit
- Also, suppose our original circuit is equivalent to identity (so we should get a 0 state at the end)
- Figure shows that inverting a circuit as described doesn't change decay rate.
- Possible Issue: Maybe measurement error asymmetry interfering?

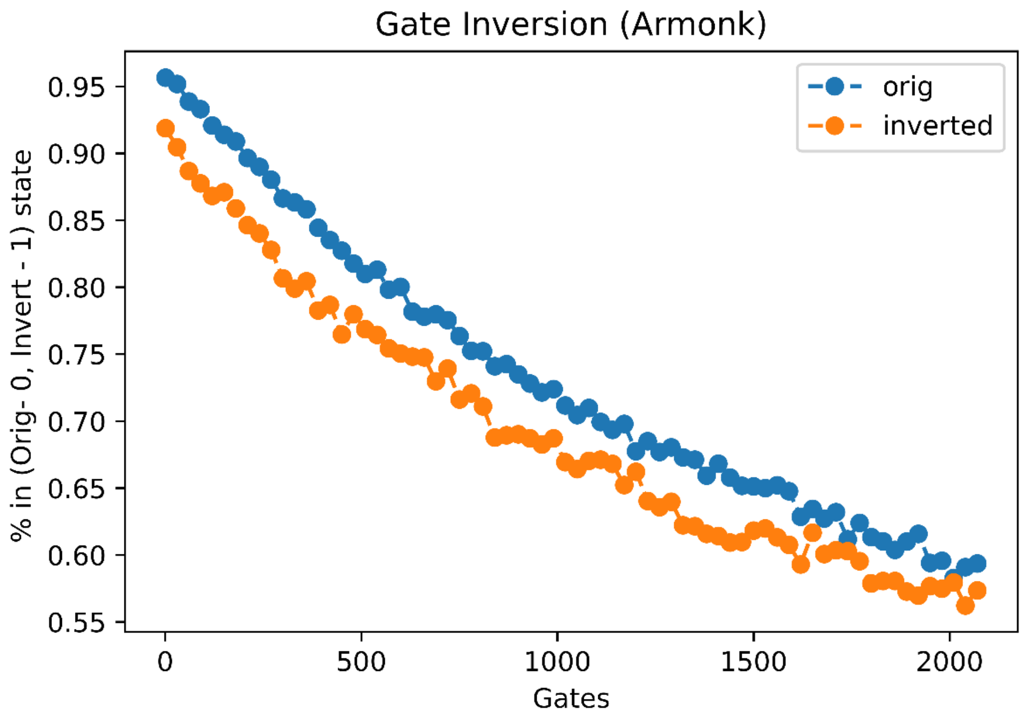


Ran on Armonk Device since 1 qubit circuits

```
Armonk
 P(1|0) = 0.04620000000000002
 P(0|1) = 0.0684
```

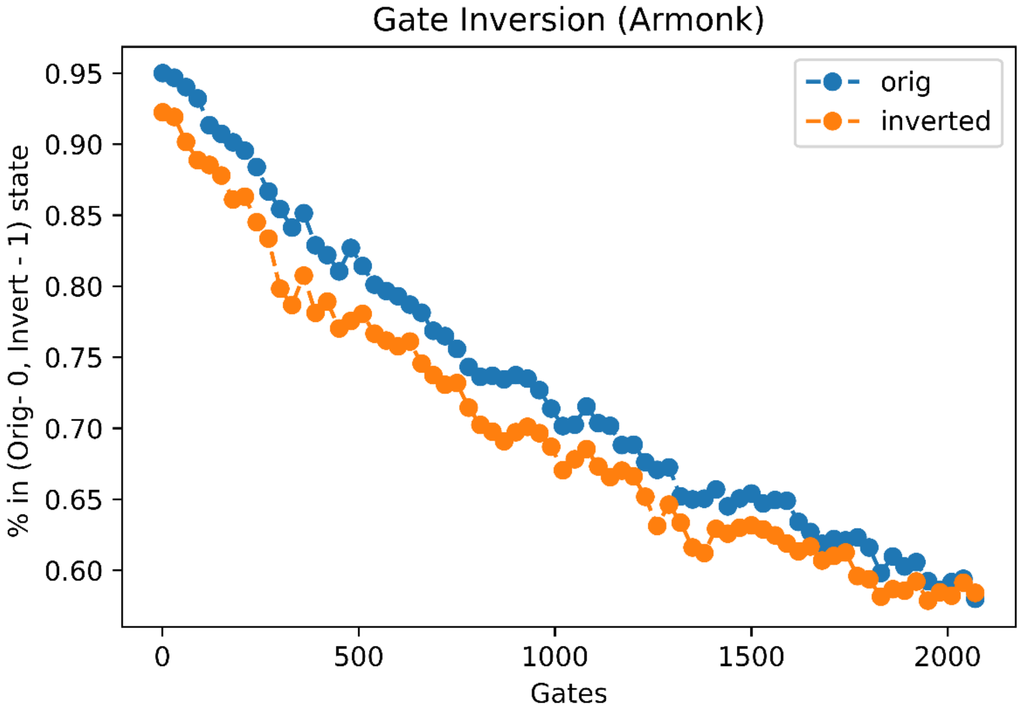
Issue 2: Gate Length and Inversion

- Repeat previous procedure but in the end of inverted circuit, don't insert the X gate
- So for inverted circuit, on ideal quantum computer, we should get only 1 state
- We do so to avoid the measurement error interfering with results
- Result: There is an offset but inverted is decaying on the same "pace" as original.



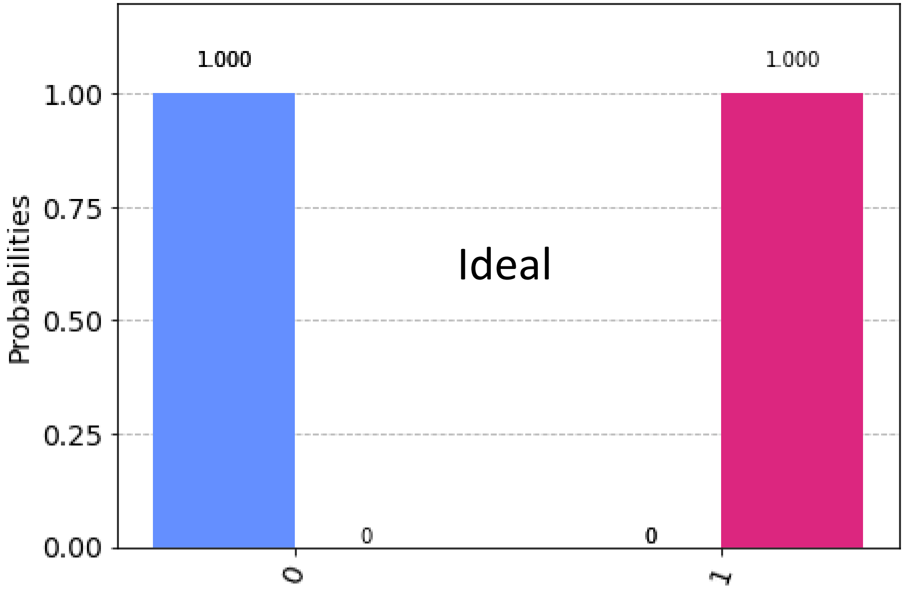
Issue 2: Gate Length and Inversion

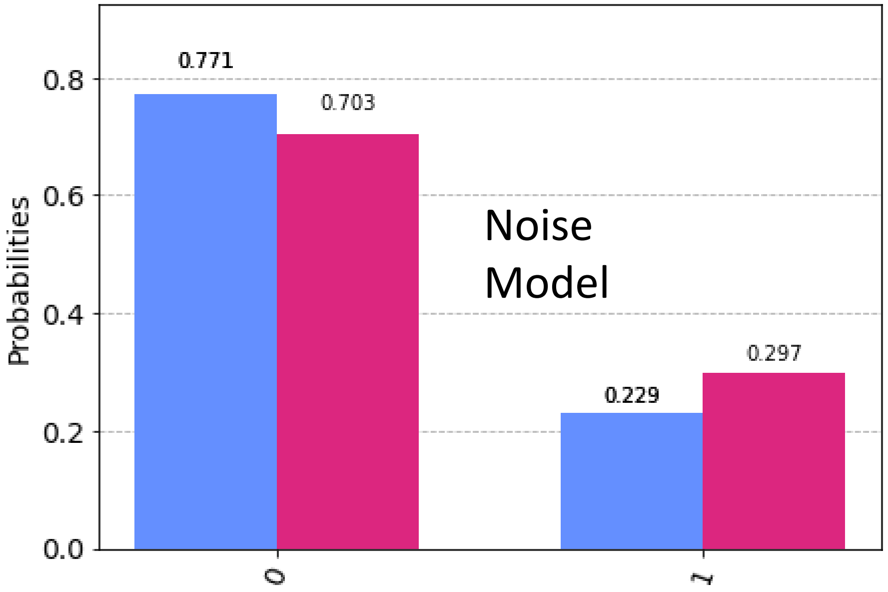
- Now in randomized benchmarking, all circuits are equivalent to the identity.
- So the inversion process can be made even simpler: Just insert an X gate in the beginning of the circuit.
- The result looks similar to the previous one where we also changed signs of angles of U3 gates but here, the offset is smaller.
- Coming back to the question: Why are both inverted and original decaying?
    - The answer may have to do with path dependence of incoherent-error-asymmetry.



Path Dependence of Asymmetry

- Suppose we have a qubit initialized in the zero state (blue) and over 1000 steps, it makes a pi/8 rotation about the x axis of bloch sphere. After those 1000 steps, qubit is reverted back to its initial state.
- In other words, over the course of 1001 gate operations, its in the same hemisphere.
- Inverting this situation, we get the red qubit which is initialized in 1 state and over the 1000 steps, it stays in that lower hemisphere of the bloch sphere.
- Amplitude damping (caused by incoherent errors) will act differently on the qubits:
  - In the blue case, the damping will try to shift the vector towards the 0 state (north pole)
  - In the red case, the damping will try to shift the vector towards the equator and hence away from the 1 state i.e. south pole
- Because amplitude damping is different in both cases, the noise model show that there will be an asymmetry





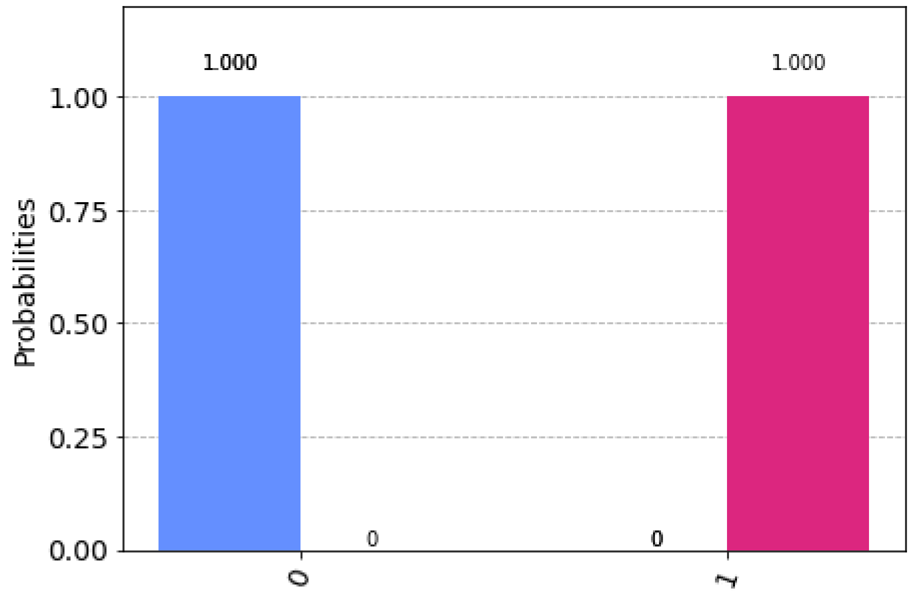
Path Dependence of Asymmetry

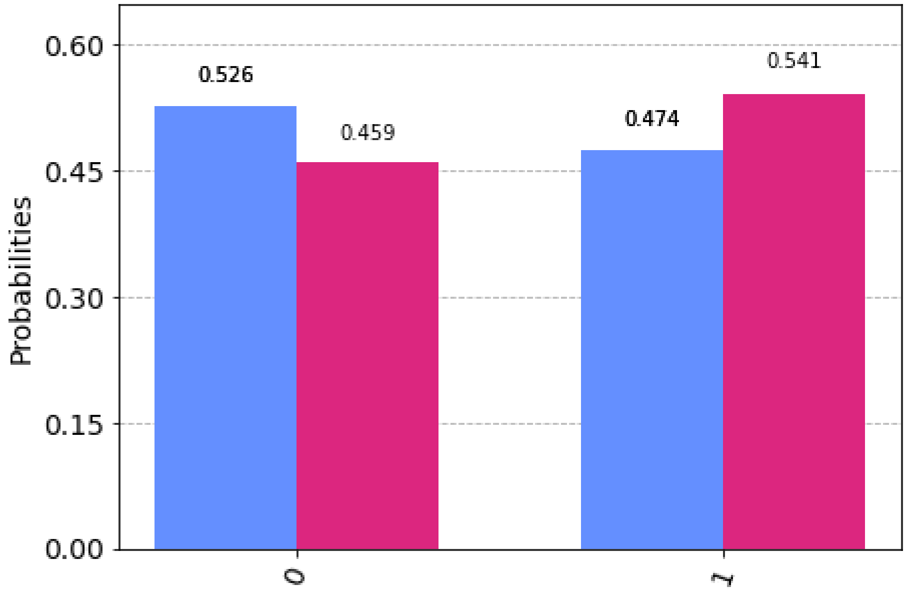
- Now suppose the blue and red qubits don't spend their time in the same hemisphere.

-In this experiment, the blue and red qubits do 1000 bit flips. At the end, they return back to their initial state.

-Since qubits are regularly visiting both hemispheres, the effect of amplitude damping will not be asymmetric

-What this shows: Asymmetry of incoherent errors may be more apparent if qubit spends disproportionate time in one of the 2 hemispheres





Doing the same experiment as Slide 10 but for integer multiples of pi/8

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