

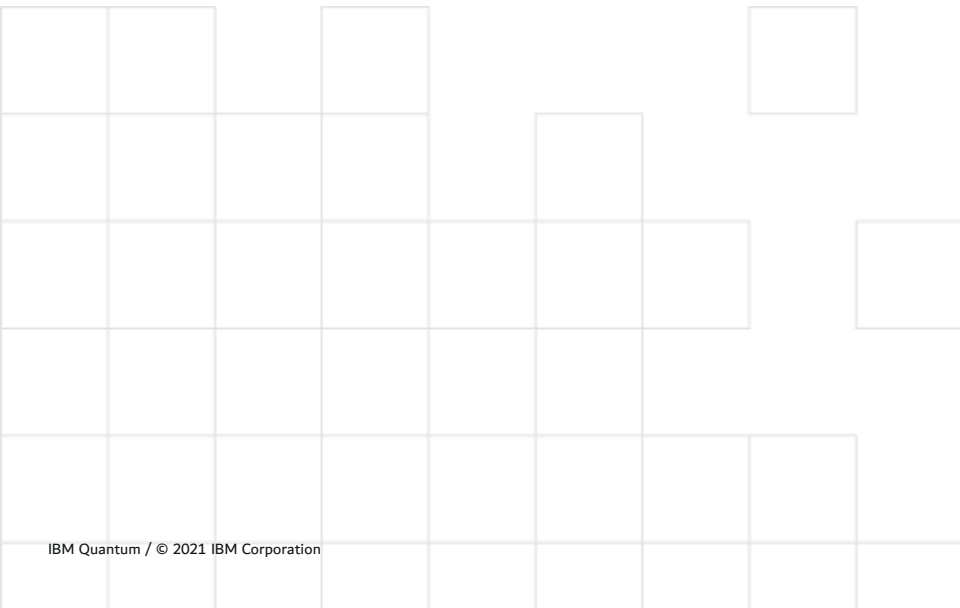
#17

Interleaved Randomized Benchmarking of gates with delay

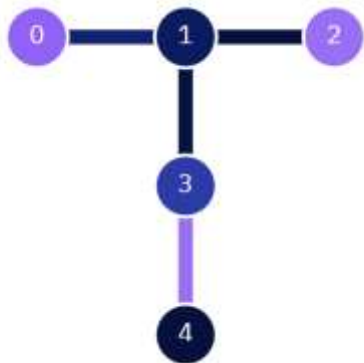
Mentee : Jeongwon Kim

Sungkyunkwan University, Masters in Nanoscience & Technology

Mentor : Toshinari Itoko

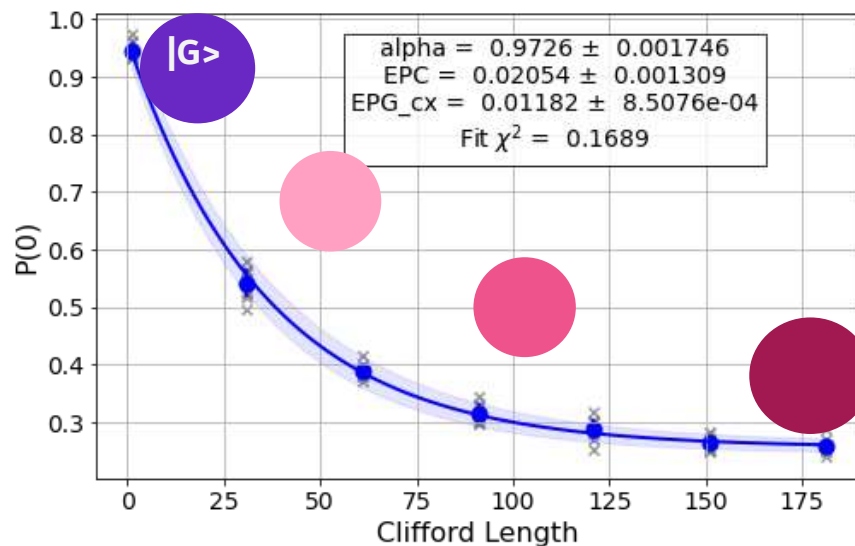
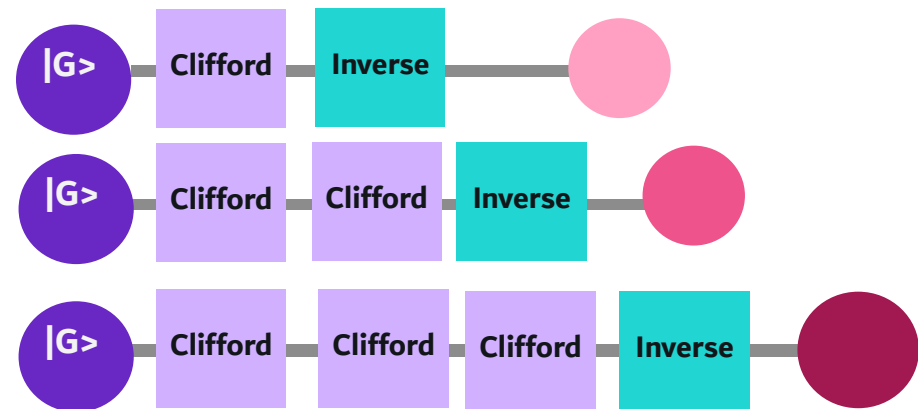
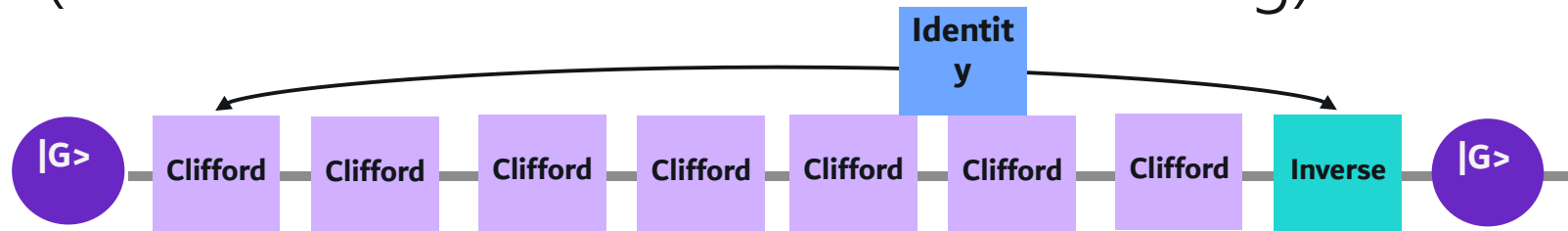


What is IRB? (Interleaved Randomized Benchmarking)

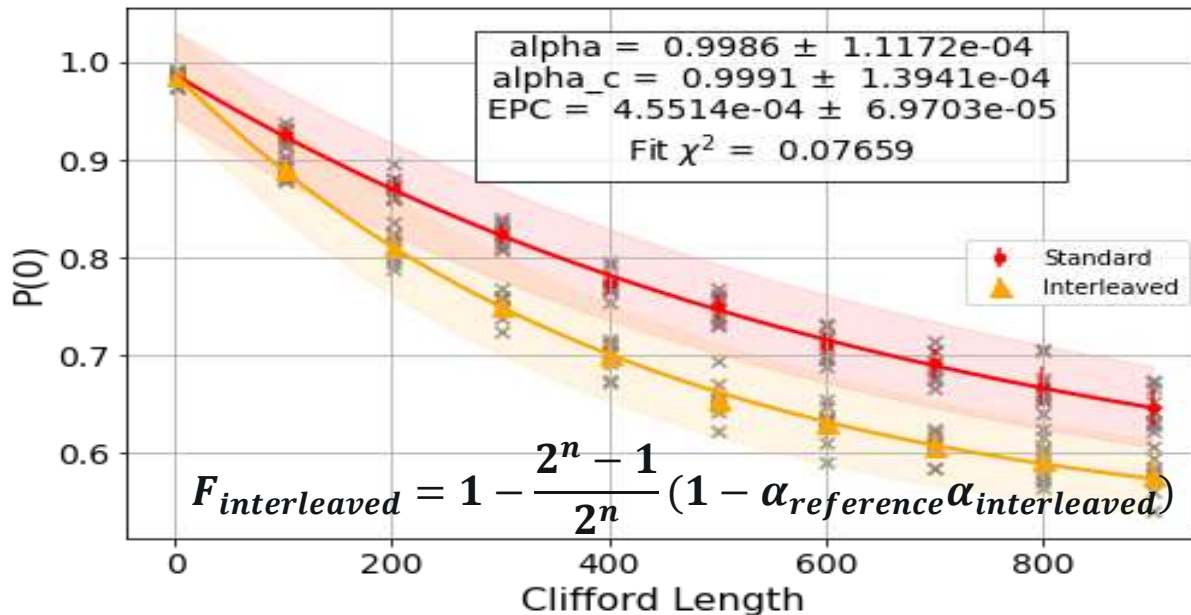
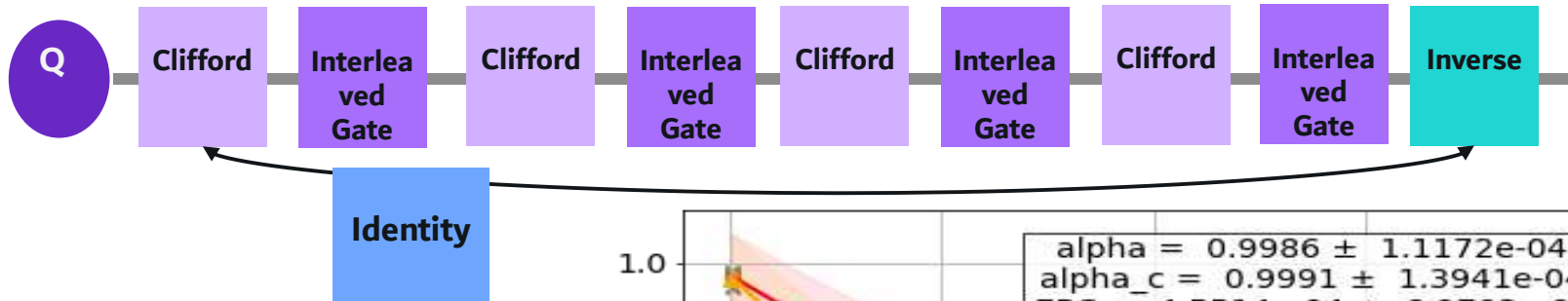


Qubit	T1 (us)	T2 (us)	Frequency (GHz)	Single-qubit Pauli-X error	CNOT error
Q0	110.84	142.61	5.301	3.093e-4	0_1: 1.089e-2
Q1	102.43	86.56	5.081	6.154e-4	1_3: 9.034e-3 1_2: 8.858e-3 1_0: 1.089e-2
Q2	108.84	169.83	5.322	2.517e-4	2_1: 8.858e-3
Q3	115.04	23.93	5.164	2.847e-4	3_4: 2.135e-2 3_1: 9.034e-3
Q4	119.2	146.01	5.052	4.357e-4	4_3: 2.135e-2

What is IRB? (Interleaved Randomized Benchmarking)



What is IRB? (Interleaved Randomized Benchmarking)



'Delay' Interleaved Randomized Benchmarking



0. Interleave Arbitrary duration of Delay

1. Delay IRB vs Theoretical Coherence Limit Error(CLE)

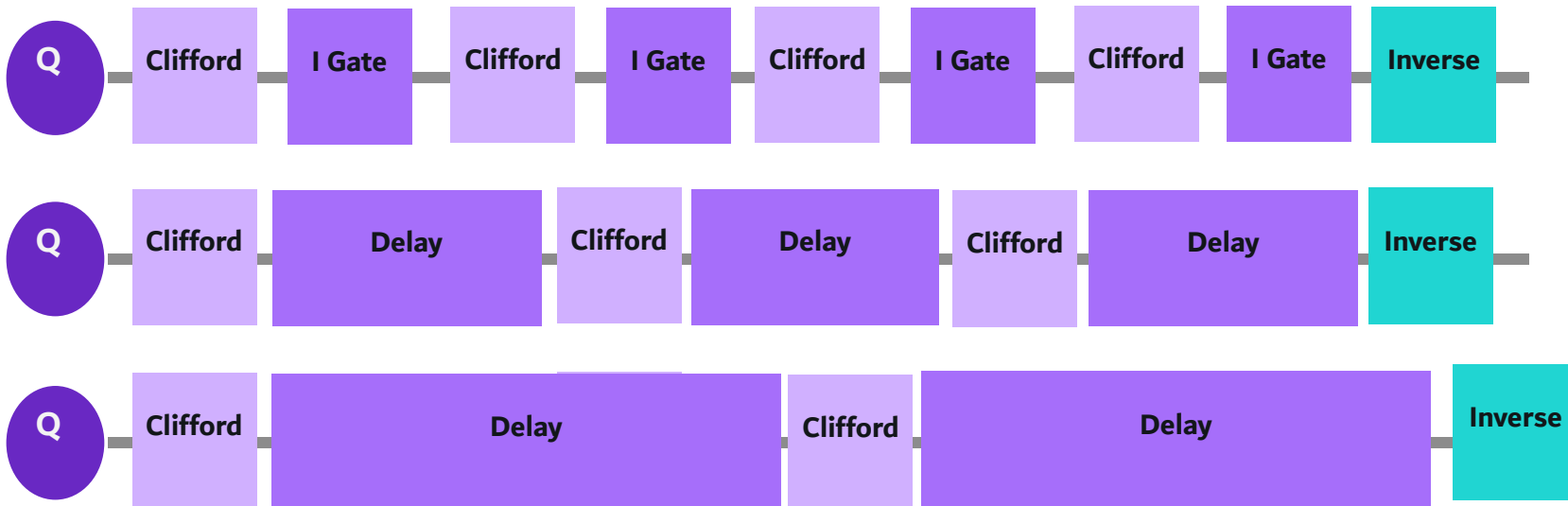
2. Spectator qubit's effect on other qubit's gate operation

Identity vs Delay

```
backend.properties().gate_length('id',0)
```

✓ 0.6s

3.555555555555554e-08



'Delay' Interleaved Randomized Benchmarking

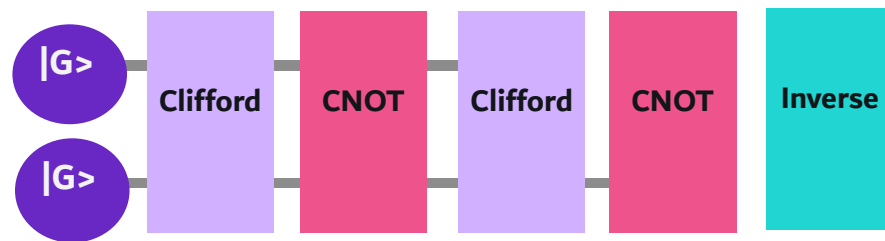
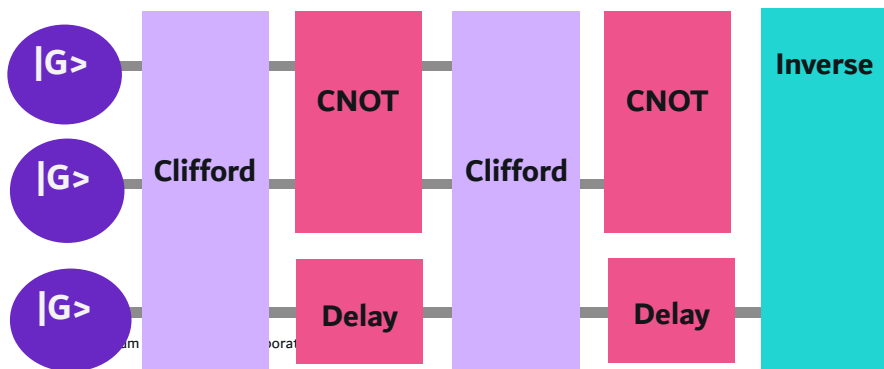
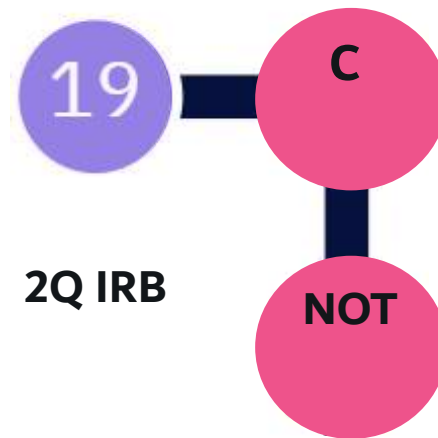
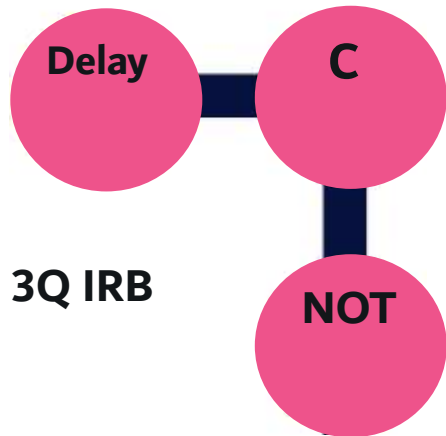


0. Interleave Arbitrary duration of Delay

1. Spectator qubit's effect on other qubit's gate operation

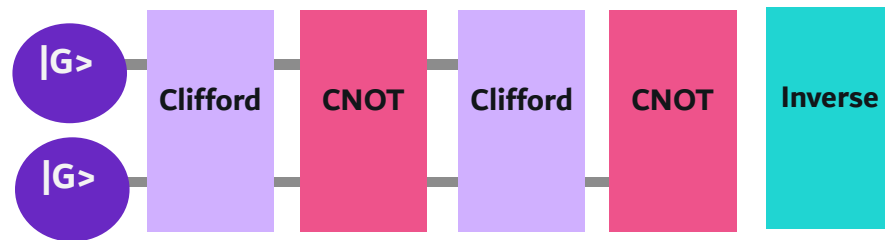
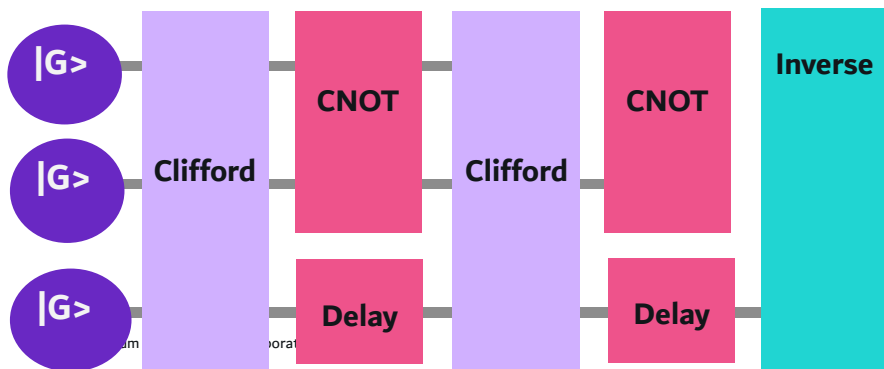
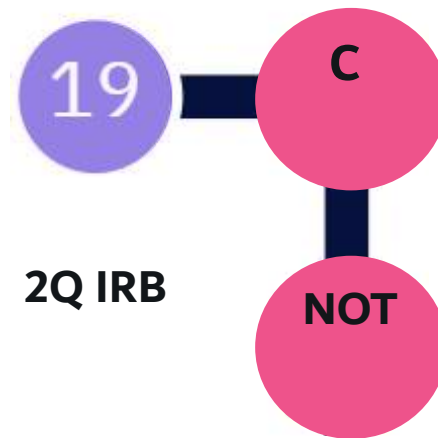
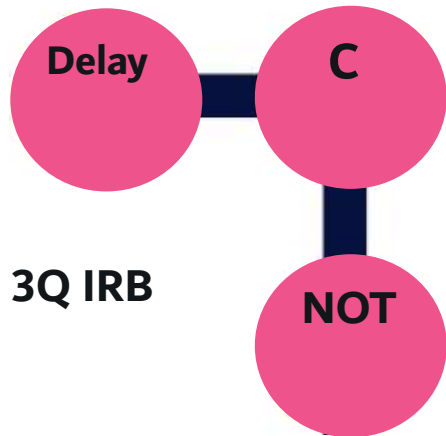
2. Delay IRB vs Theoretical Coherence Limit Error(CLE)

Spectator qubit Effect



$$Error_{CX} * Error_{Delay} ? Error_{CX}$$

Spectator qubit Effect



'Delay' IRB vs CLE

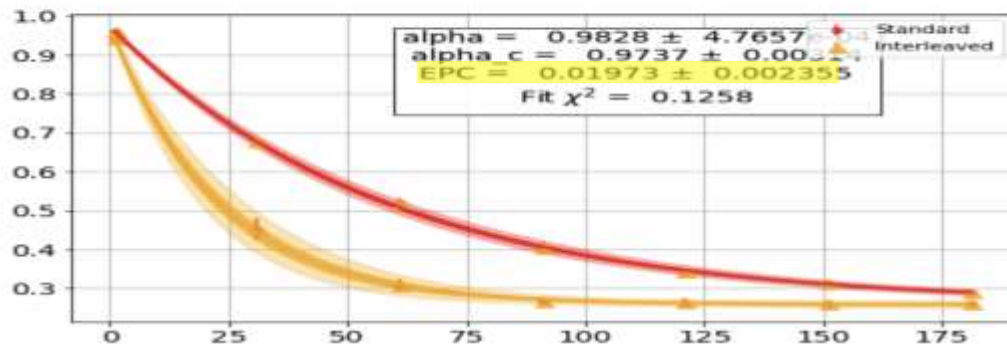
Coherence Limit Error (Theoretical)

```
nairobi_q45=RBUtils.coherence_limit_error(2,
backend.properties().gate_length('cx',(4,5)),
t1s=[backend.properties().t1(4),backend.properties().t1(5)],
t2s=[backend.properties().t1(4),backend.properties().t1(5)])
print(f'{qubit} CLE is {nairobi_q45} on {date}')
```

nairobi_q45 CLE is 0.0027267824762555294 on 2022-05-30 11:11:13.53!

Delay IRB (Experimental)

2q Delay
2022-05-28 15:23:31.548325
1407.9999999999999

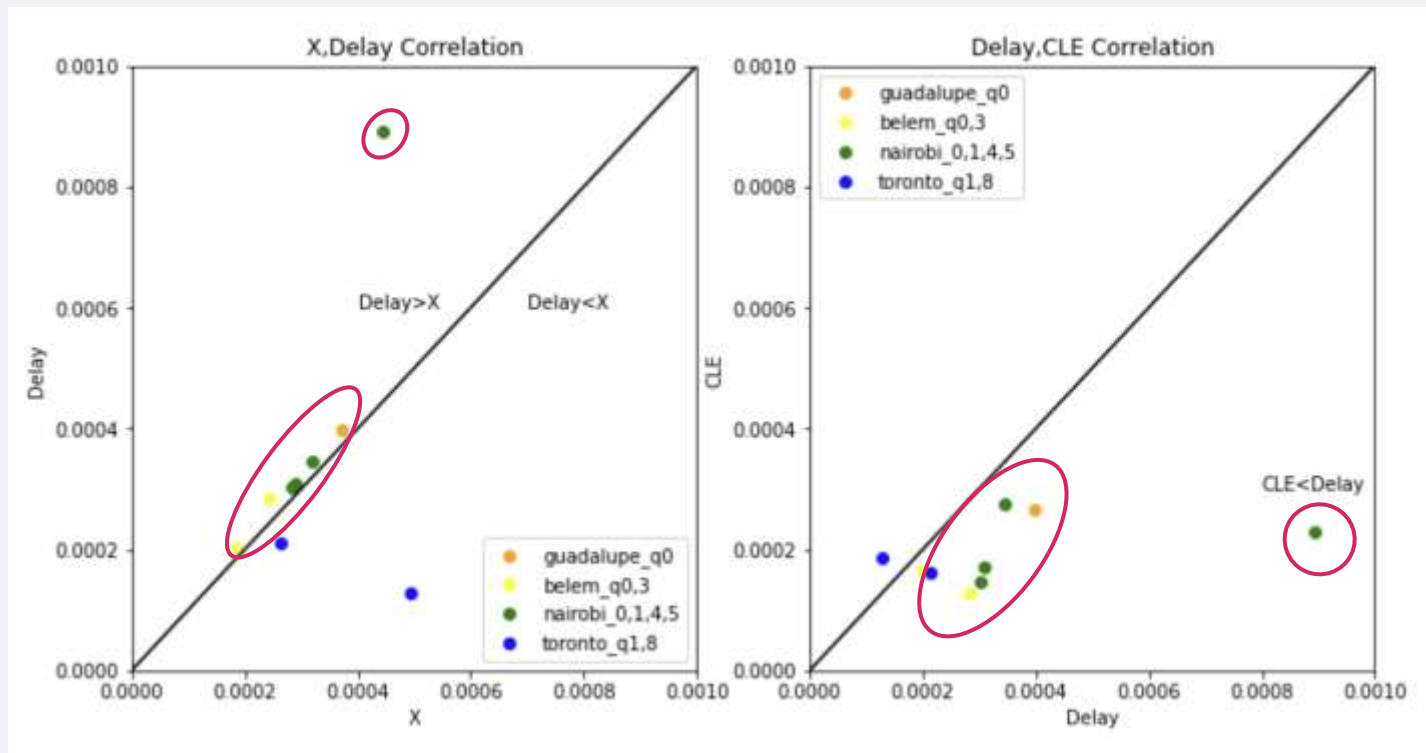


Gate = Incoherent(qubit)+coherent (gate)

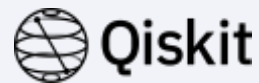
Delay = Incoherent(qubit)+coherent (gate)

1qubit CLE vs Delay error vs Gate error

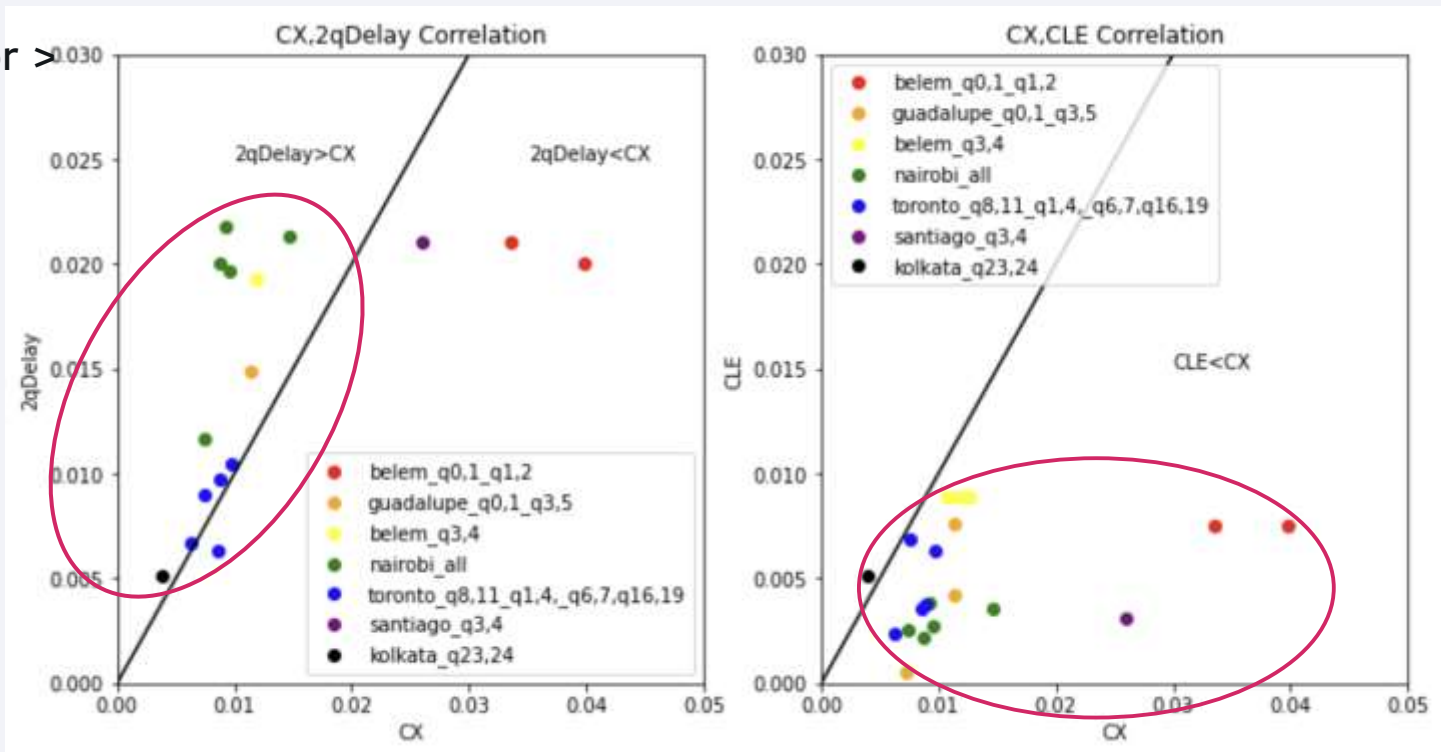
- ✓ Delay error > CLE
- ✓ Delay error > Gate(X) error



2qubit CLE vs 2qDelay error vs CX Gate error

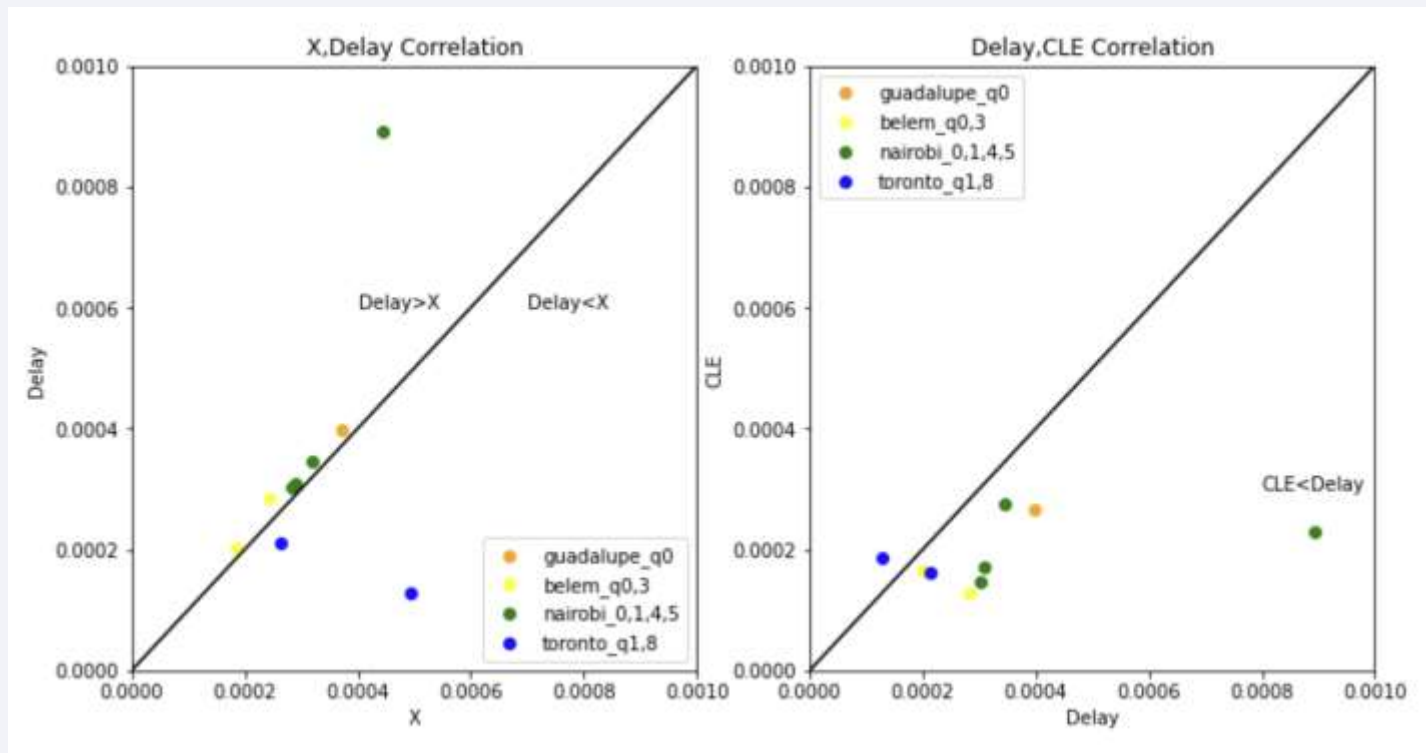


- ✓ 2qubit delay error > CLE
- ✓ 2qubit delay > CX Gate error



Cause of high Delay error

- ✓ Delay error > CLE
- ✓ Delay error > Gate(X) error
- ✓ **Cause :
Phase error
(Z error)**

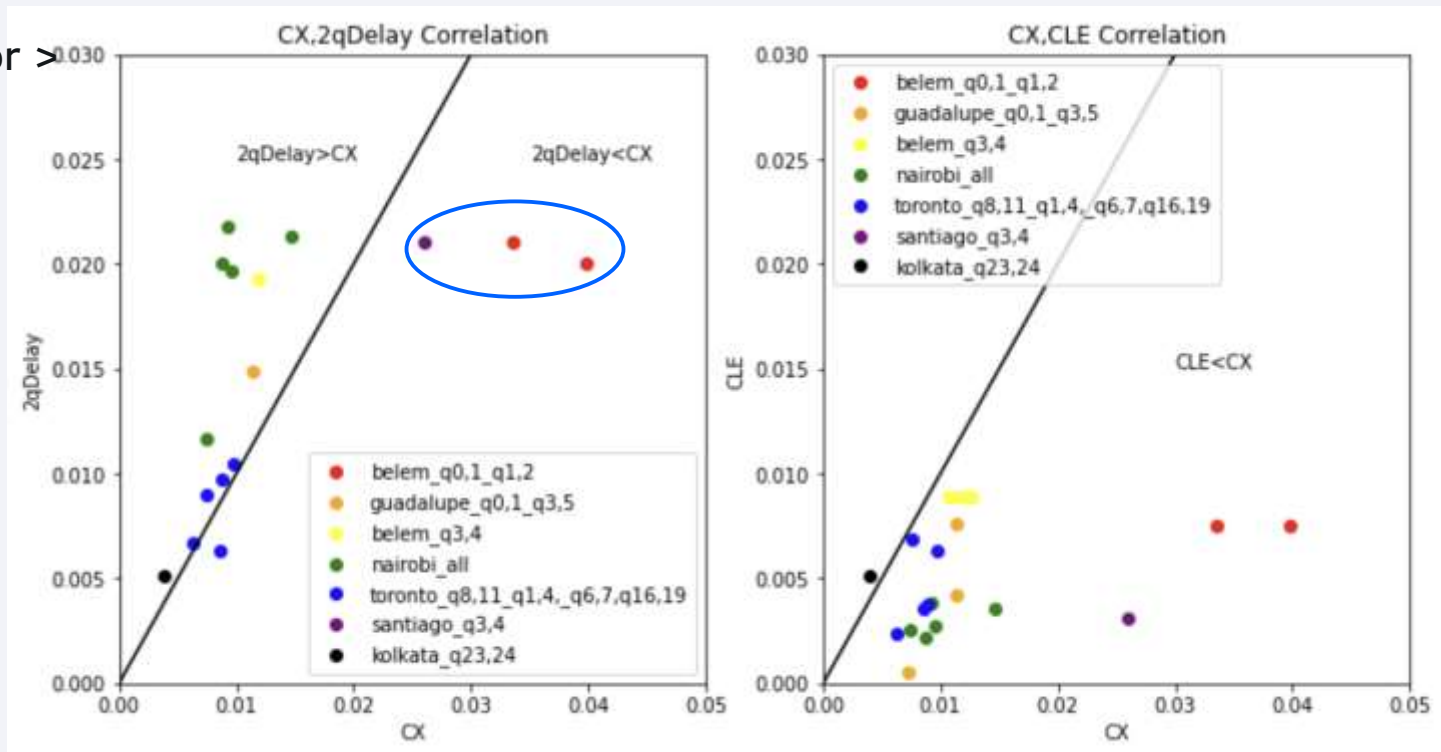


Cause of high 2q Delay error

✓ 2qubit delay error > CLE

✓ 2qubit delay > CX Gate error

✓ **Cause :**
Phase error
(ZI, IZ error) +
ZZ interaction



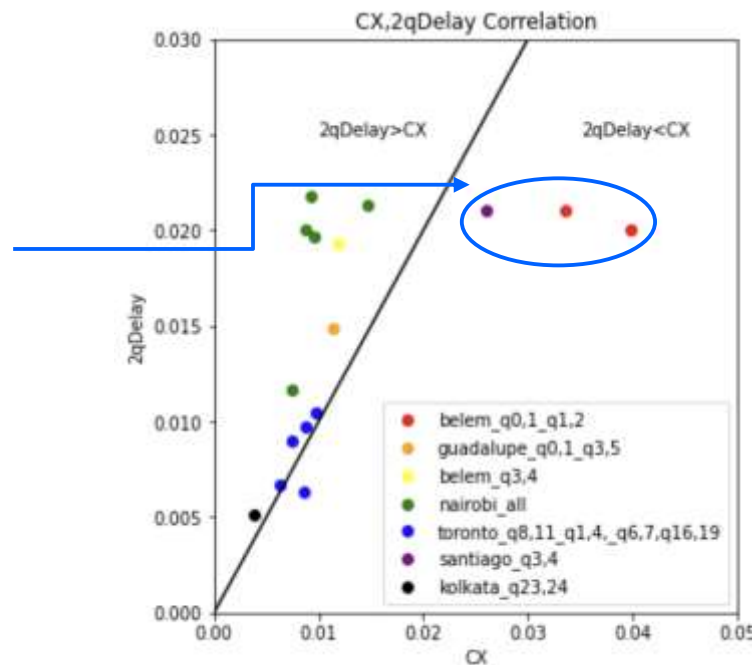
Error source

Coherence limit error = CLE(qubit decoherence)

Delay error (IRB) = CLE+ ZZ error(cross talk)

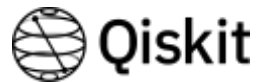
CX gate (IRB) = CLE+ ZZ'(suppressed ZZ error within the gate calibration)+gate calibration error

- ✓ CX error < 2q Delay
ZZ' +gate calibration < ZZ
- ✓ CX error > 2q Delay
ZZ'+gate calibration > ZZ





'Delay' Interleaved Randomized Benchmarking



Delay support in Interleaved Randomized Benchmarking #776

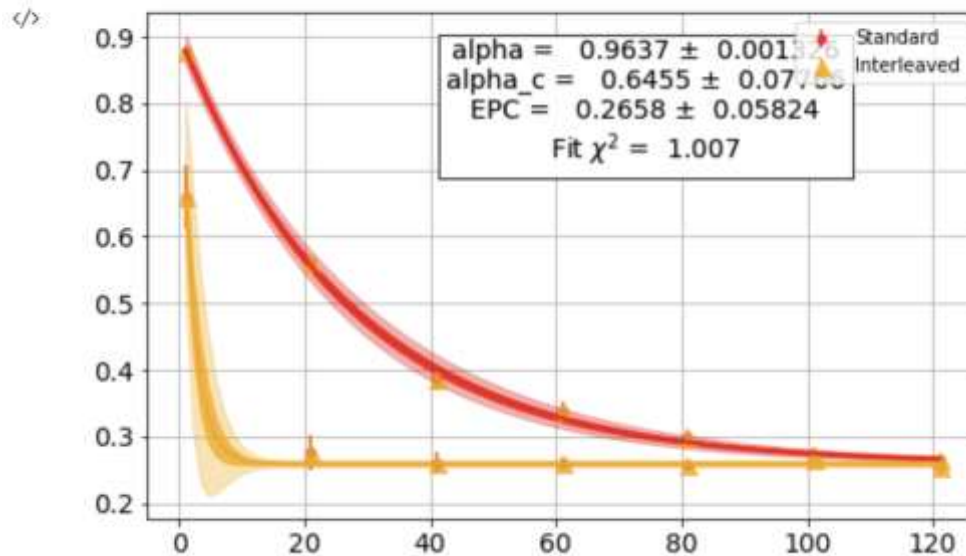
Merged

chriselectic merged 12 commits into `Qiskit:main` from `bicycle315:delay_IRB` on 28 Apr

```
duration=backend.properties().gate_length('cx',(1,3))/backend.configuration().dt
delay_qc = QuantumCircuit(2)
delay_qc.delay(round(duration), [0], unit="dt")
delay_qc.delay(round(duration), [1], unit="dt")
int_exp2 = InterleavedRB(
    interleaved_element=delay_qc, qubits=[1,3], lengths=lengths, num_samples=num_
int_exp2.set_transpile_options(scheduling_method='asap')
# Run
int_expdata2 = int_exp2.run(backend, shots=1000).block_for_results()
```

Belem_q3q4 : CXGate error < 2q Delay error

```
... ibmq_belem
2022-05-27 11:11:49.275614
```



This was the extreme case for me observing interleaving 2q Delay makes the channel more noisy than interleaving CXgate.

intuitively, doing nothing looks more stable but the result was not.

Even if we do nothing, there could be a significant unwanted interaction among qubits which induce qubit crosstalk error.