In [1]:

```
import matplotlib.pyplot as plt
from IPython.display import clear_output

#Import Qiskit classes
import qiskit
from qiskit import assemble, transpile
from qiskit.providers.aer.noise import NoiseModel
from qiskit.providers.aer.noise.errors.standard_errors import depolarizing_error, th

#Import the qv function
import qiskit.ignis.verification.quantum_volume as qv
```

Step 1: Generate QV sequences

In the following example we have 6 qubits Q0,Q1,Q3,Q5,Q7,Q10. We are going to look at subsets up to the full set (each volume circuit will be depth equal to the number of qubits in the subset).

In [9]:

```
# qubit_lists: list of list of qubit subsets to generate QV circuits
qubit_lists = [[0,1,3],[0,1,3,5],[0,1,3,5,7],[0,1,3,5,7,10]]
# ntrials: Number of random circuits to create for each subset
ntrials = 100
```

We generate the quantum volume sequences. We start with a small example (so it doesn't take too long to run).

In [10]:

```
import warnings
warnings.filterwarnings('ignore')
qv_circs, qv_circs_nomeas = qv.qv_circuits(qubit_lists, ntrials)
```

As an example, we print the circuit corresponding to the first QV sequence. Note that the ideal circuits are run on the first n qubits (where n is the number of qubits in the subset).

In [11]:

```
# pass the first trial of the nomeas through the transpiler to illustrate the circui
qv_circs_nomeas[0] = qiskit.compiler.transpile(qv_circs_nomeas[0], basis_gates=['u1'
```

In [12]:

```
qv_circs_nomeas[0][0].draw(fold=-1)
```

Out[12]:

```
global phase: 2.7077
     ┌──────────────────────────┐┌───┐┌──────────────────────────┐
q_0: ┤ U3(0.46782,-1.0711,1.4297) ├┤ X ├┤ U3(1.0507,0.52698,0.70689) ├
     ├─────────────────────────┬┘└─┬─┘└───┬─────────────────────┬───┘
q_1: ┤ U3(2.5797,2.0183,1.1996) ├───■──────┤ U3(0.86036,-π/2,π/2) ├────
     ├─────────────────────────┴┐         └─────────────────────┘
q_2: ┤ U3(0.26782,-1.4674,1.5617) ├──────────────────────────────────────
     └──────────────────────────┘
```

Step 2: Simulate the ideal QV circuits

The quantum volume method requires that we know the ideal output for each circuit, so we use the Aer simulator to get the ideal result.

In [13]:

```
sv_sim = qiskit.Aer.get_backend('aer_simulator')
ideal_results = []
```

```
for trial in range(ntrials):
    clear_output(wait=True)
    for qc in qv_circs_nomeas[trial]:
        qc.save_statevector()
    result = qiskit.execute(qv_circs_nomeas[trial], backend=sv_sim).result()
    ideal_results.append(result)
    print(f'Simulated trial {trial+1}/{ntrials}')
```

```
Simulated trial 100/100
```

Next, we load the ideal results into a quantum volume fitter

In [14]:
```
qv_fitter = qv.QVFitter(qubit_lists=qubit_lists)
qv_fitter.add_statevectors(ideal_results)
```

Step 3: Calculate the heavy outputs

As an illustration, we print the heavy outputs from various depths and their probabilities (for trial 0):

In [15]:
```
for qubit_list in qubit_lists:
    l = len(qubit_list)
    print ('qv_depth_'+str(l)+'_trial_0:', qv_fitter._heavy_outputs['qv_depth_'+str(
```

```
qv_depth_3_trial_0: ['010', '011', '100', '110']
qv_depth_4_trial_0: ['0000', '0001', '0011', '0111', '1000', '1010', '1011', '1111']
qv_depth_5_trial_0: ['00010', '00011', '00100', '00101', '00110', '00111', '01011',
'01100', '01101', '01110', '01111', '10000', '11001', '11011', '11110', '11111']
qv_depth_6_trial_0: ['000000', '000011', '000100', '000101', '000110', '000111', '00
1000', '001001', '001010', '001100', '001110', '010001', '010010', '010110', '01011
1', '011000', '011001', '011010', '011101', '011110', '100000', '100010', '100011',
'100110', '101100', '110010', '110100', '110101', '110111', '111100', '111101', '111
111']
```

In [16]:
```
for qubit_list in qubit_lists:
    l = len(qubit_list)
    print ('qv_depth_'+str(l)+'_trial_0:', qv_fitter._heavy_output_prob_ideal['qv_de
```

```
qv_depth_3_trial_0: 0.8711716544781744
qv_depth_4_trial_0: 0.829774868953036
qv_depth_5_trial_0: 0.8543419735543087
qv_depth_6_trial_0: 0.8234087763709976
```

Step 4: Define the noise model

We define a noise model for the simulator. To simulate decay, we add depolarizing error probabilities to the CNOT and U gates.

In [17]:
```
noise_model = NoiseModel()
p1Q = 0.002
p2Q = 0.02
noise_model.add_all_qubit_quantum_error(depolarizing_error(p1Q, 1), 'u2')
noise_model.add_all_qubit_quantum_error(depolarizing_error(2*p1Q, 1), 'u3')
noise_model.add_all_qubit_quantum_error(depolarizing_error(p2Q, 2), 'cx')
```

We can execute the QV sequences either using Qiskit Aer Simulator (with some noise model) or using IBMQ provider, and obtain a list of exp_results.

In [18]:
```
aer_sim = qiskit.Aer.get_backend('aer_simulator')
basis_gates = ['u1','u2','u3','cx'] # use U,CX for now
```

```
shots = 1024
exp_results = []
for trial in range(ntrials):
    clear_output(wait=True)
    t_qcs = transpile(qv_circs[trial], basis_gates=basis_gates, optimization_level=3
    qobj = assemble(t_qcs)
    result = aer_sim.run(qobj, noise_model=noise_model, max_parallel_experiments=0).
    exp_results.append(result)
    print(f'Completed trial {trial+1}/{ntrials}')
```

```
Completed trial 100/100
```

Step 5: Calculate the average gate fidelity

As an illustration, we print the heavy output counts from various depths (for trial 0):

In [19]:

```
qv_fitter.add_data(exp_results)
for qubit_list in qubit_lists:
    l = len(qubit_list)
    print ('qv_depth_'+str(l)+'_trial_0:', qv_fitter._heavy_output_counts['qv_depth_
```

```
qv_depth_3_trial_0: 832
qv_depth_4_trial_0: 686
qv_depth_5_trial_0: 767
qv_depth_6_trial_0: 671
```

Step 6: Calculate the achievable depth

We now convert the heavy outputs in the different trials and calculate the mean h_d and the error for plotting the graph.

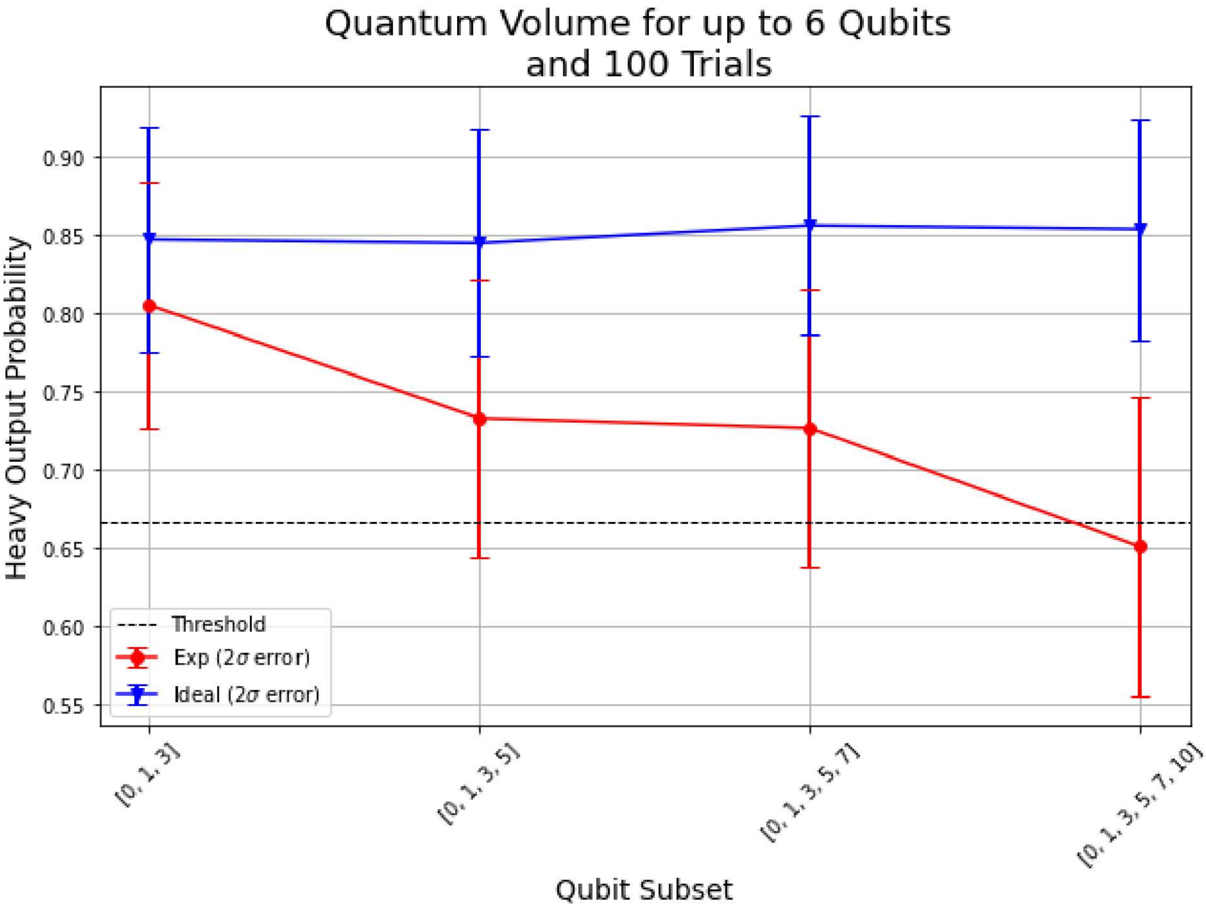
In [20]:

```
plt.figure(figsize=(10, 6))
ax = plt.gca()

# Plot the essence by calling plot_rb_data
qv_fitter.plot_qv_data(ax=ax, show_plt=False)

# Add title and label
ax.set_title('Quantum Volume for up to %d Qubits \n and %d Trials'%(len(qubit_lists[

plt.show()
```



Step 7: Calculate the Quantum Volume

We list the statistics for each depth. For each depth we list if the depth was successful or not and with what confidence interval. For a depth to be successful the confidence interval must be > 97.5%.

In [21]:

```
qv_success_list = qv_fitter.qv_success()
qv_list = qv_fitter.ydata
QV = 1
for qidx, qubit_list in enumerate(qubit_lists):
    if qv_list[0][qidx]>2/3:
        if qv_success_list[qidx][0]:
            print("Width/depth %d greater than 2/3 (%f) with confidence %f (successf
                  (len(qubit_list),qv_list[0][qidx],qv_success_list[qidx][1],qv_fitt
            QV = qv_fitter.quantum_volume()[qidx]
        else:
            print("Width/depth %d greater than 2/3 (%f) with confidence %f (unsucces
                  (len(qubit_list),qv_list[0][qidx],qv_success_list[qidx][1]))
    else:
        print("Width/depth %d less than 2/3 (unsuccessful)."%len(qubit_list))
```

```
Width/depth 3 greater than 2/3 (0.805469) with confidence 0.999773 (successful). Qua
ntum volume 8
Width/depth 4 greater than 2/3 (0.732861) with confidence 0.932679 (unsuccessful).
Width/depth 5 greater than 2/3 (0.726543) with confidence 0.910416 (unsuccessful).
Width/depth 6 less than 2/3 (unsuccessful).
```

In [22]:

```
print ("The Quantum Volume is:", QV)
```

```
The Quantum Volume is: 8
```

In [ ]:

```
```