Team Quantum ETS

QuEra technical challenge

https://github.com/QuantumETS/QueraTechnical2026/tree/main

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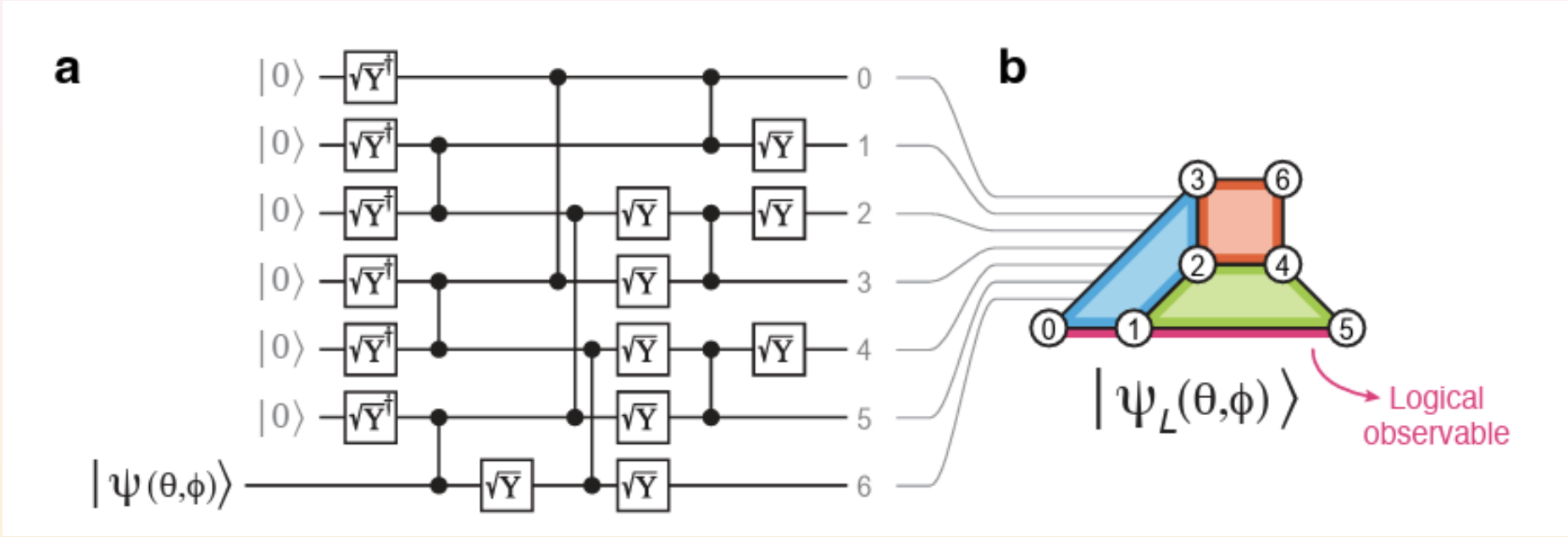
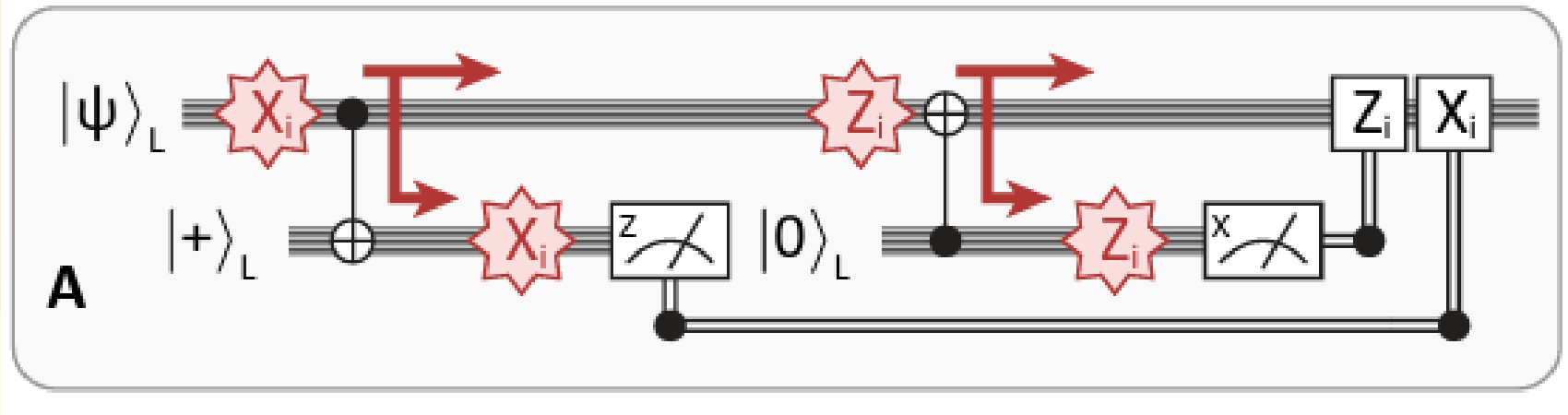
Context of the challenge



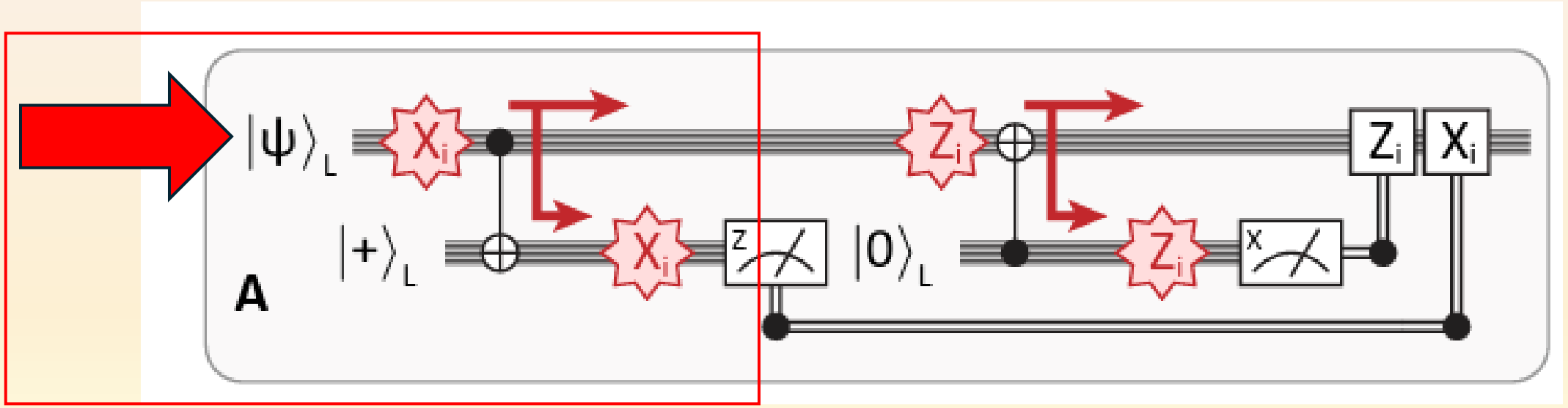


How did we implement Steane code

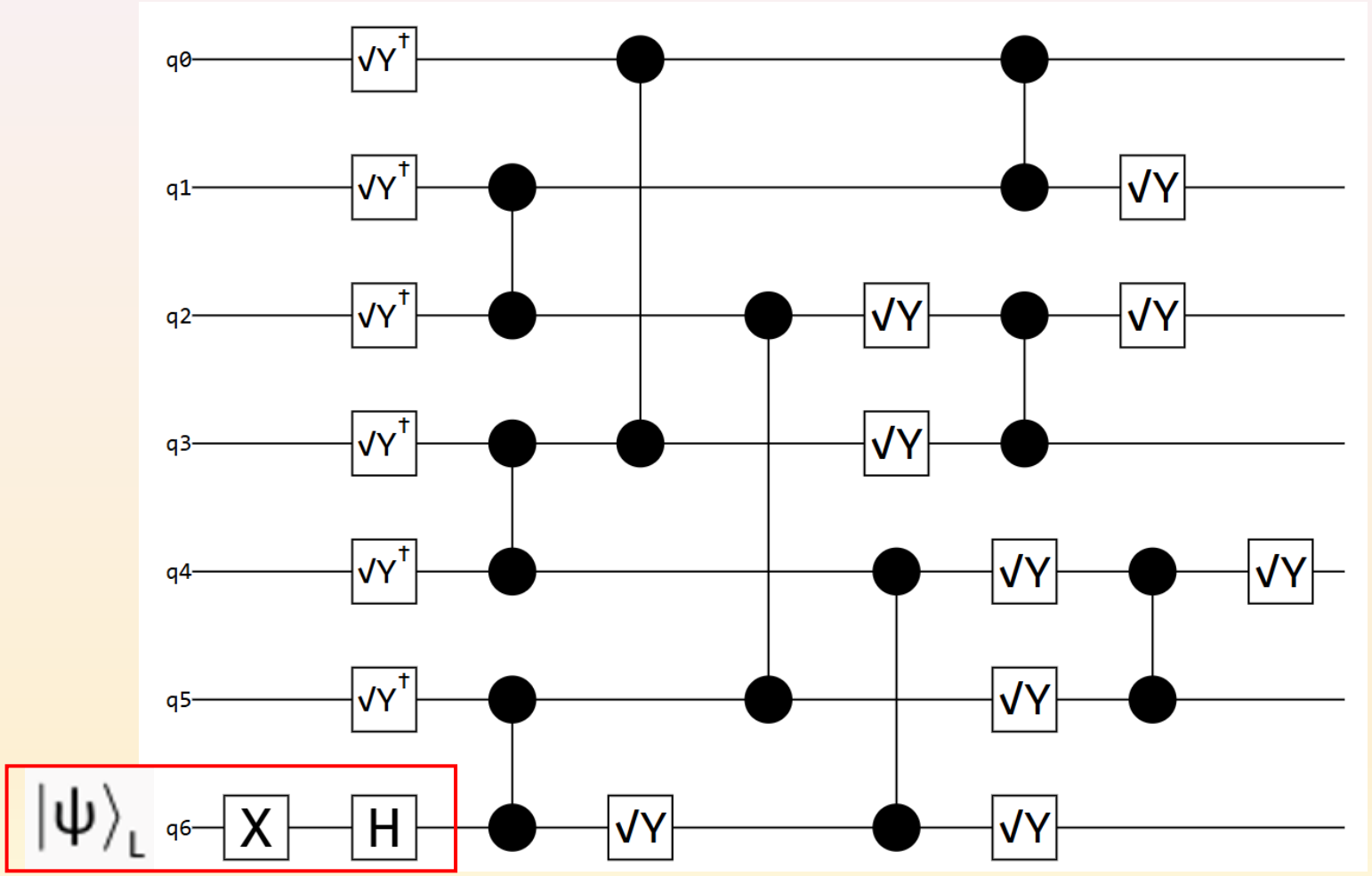
- Step one, encode the state that we want in the steane code

```
qubits_1 = squin.qalloc(n_sean_qubits)
# put arbitrary state
squin.x(qubits_1[-1])
squin.h(qubits_1[-1])
qubits_1 = color_code_factory(qubits_1)
```

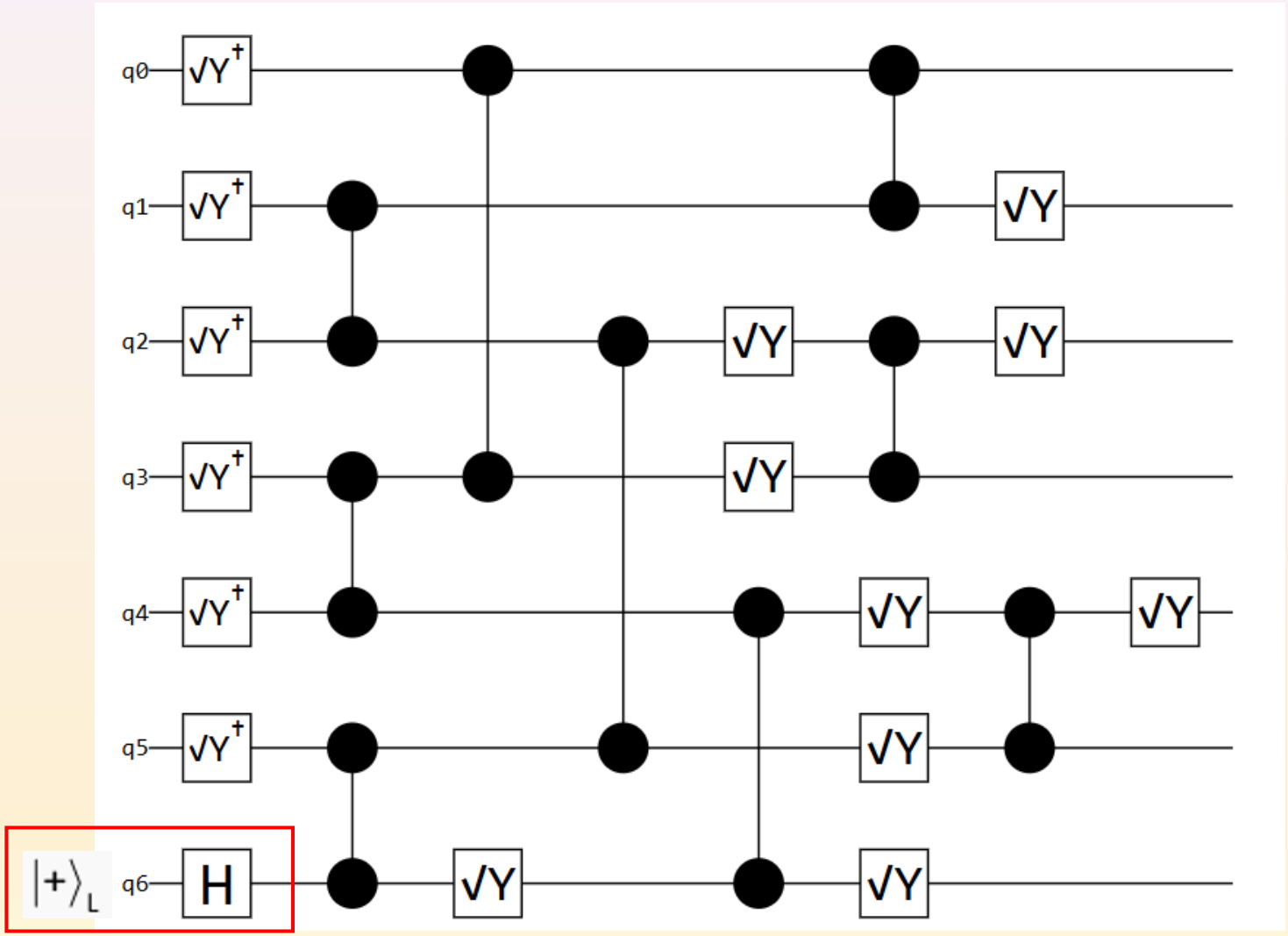
```
# put state + on ancillary registers
qubits_2 = squin.qalloc(n_sean_qubits)
squin.h(qubits_2[-1])
qubits_2 = color_code_factory(qubits_2)
```



Steane code for arbitraty |Ψ> state



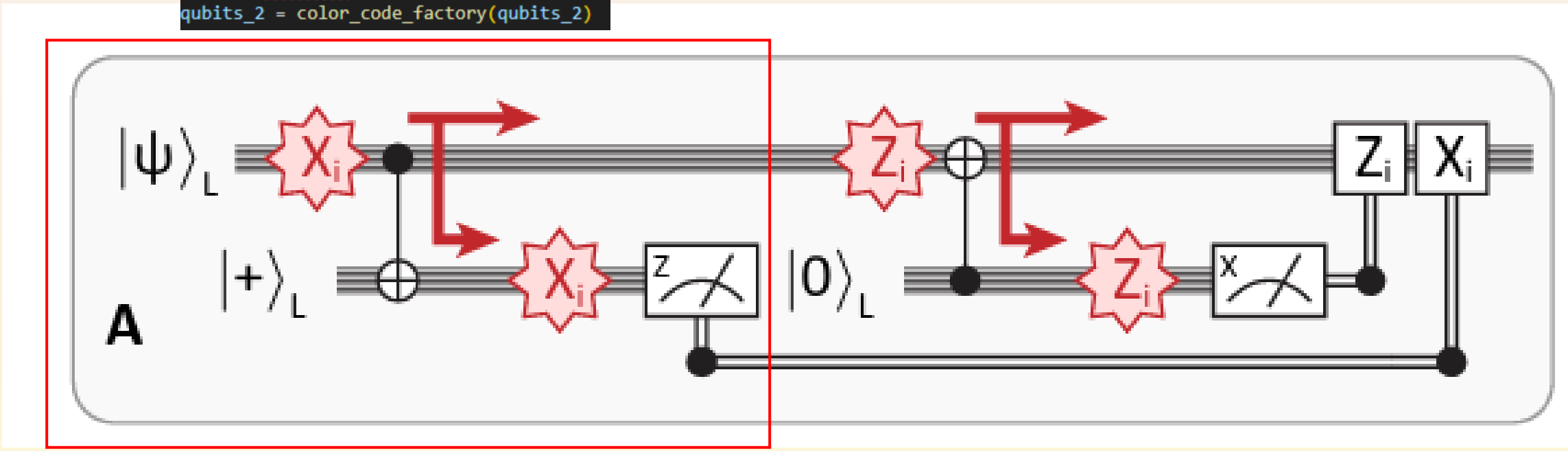
Steane code X error detection with |+> state



Lets look at post-selecting when there's X error

```
qubits_1 = squin.qalloc(n_sean_qubits)
# put arbitrary state
squin.x(qubits_1[-1])
squin.h(qubits_1[-1])
qubits_1 = color_code_factory(qubits_1)

# put state + on ancillary registers
qubits_2 = squin.qalloc(n_sean_qubits)
squin.h(qubits_2[-1])
qubits_2 = color_code_factory(qubits_2)
```

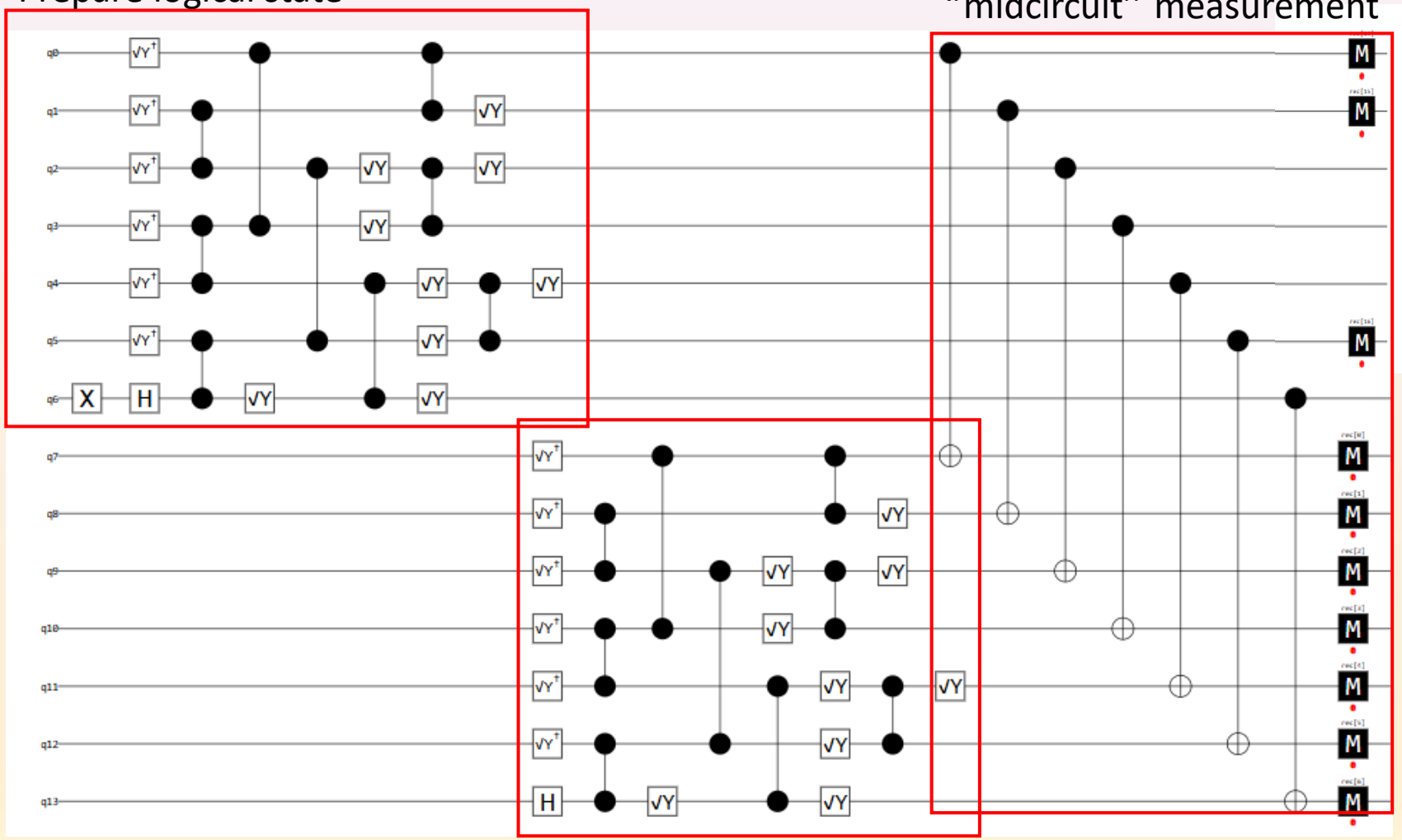
```
# transversal CX
for index in range(len(qubits_1)):
    squin.cx(qubits_1[index], qubits_2[index])

bits = squin.broadcast.measure(qubits_2)
return bits
```



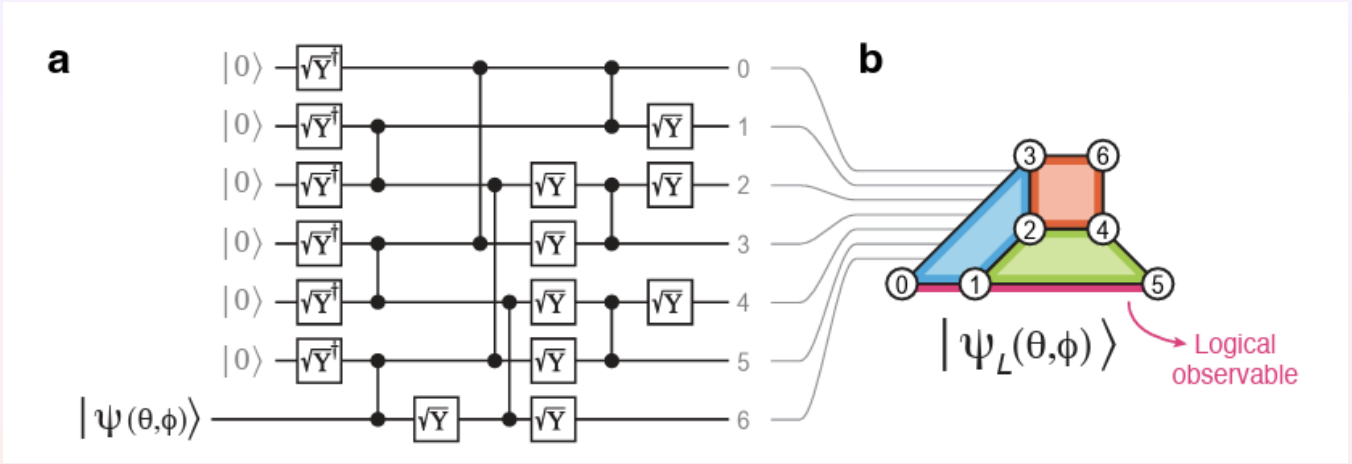
Post-selecting for X errors only

Prepare logical state

Transversal cnot for x error and
‘’midcircuit’’ measurement



Prepare logical |+> state



Extraction of syndromes and classification

```python
def extract_syndrome(group, log_expectation=False) -> int:
    """Compute the parity of measurement results in a plaquette group.

    This function calculates the syndrome for a plaquette by summing all
    measurement results in the group and returning the parity (mod 2).
    A return value of 0 indicates even parity (no error detected), while
    1 indicates odd parity (error detected).

    :param group: List of measurement results (0 or 1) for qubits in a plaquette
    :param log_expectation: If True, logs the -1/+1 mapping of 1/0 results
    :return: Parity of the group (0 for even, 1 for odd)
    :rtype: int

    :Example:

    >>> extract_syndrome([0, 1, 0, 1])
    0
    >>> extract_syndrome([1, 1, 1])
    1
    """
    if log_expectation:      Scirelgar, 7 hours ago • Add logging to syndrome evaluation and update e…
        for i in group:
            logger.debug(f"Measurement result {i} mapped to expectation value {1 if i == 0 else -1}")
    t = 0
    for i in group:
        t = t + i
    return (t % 2)
```

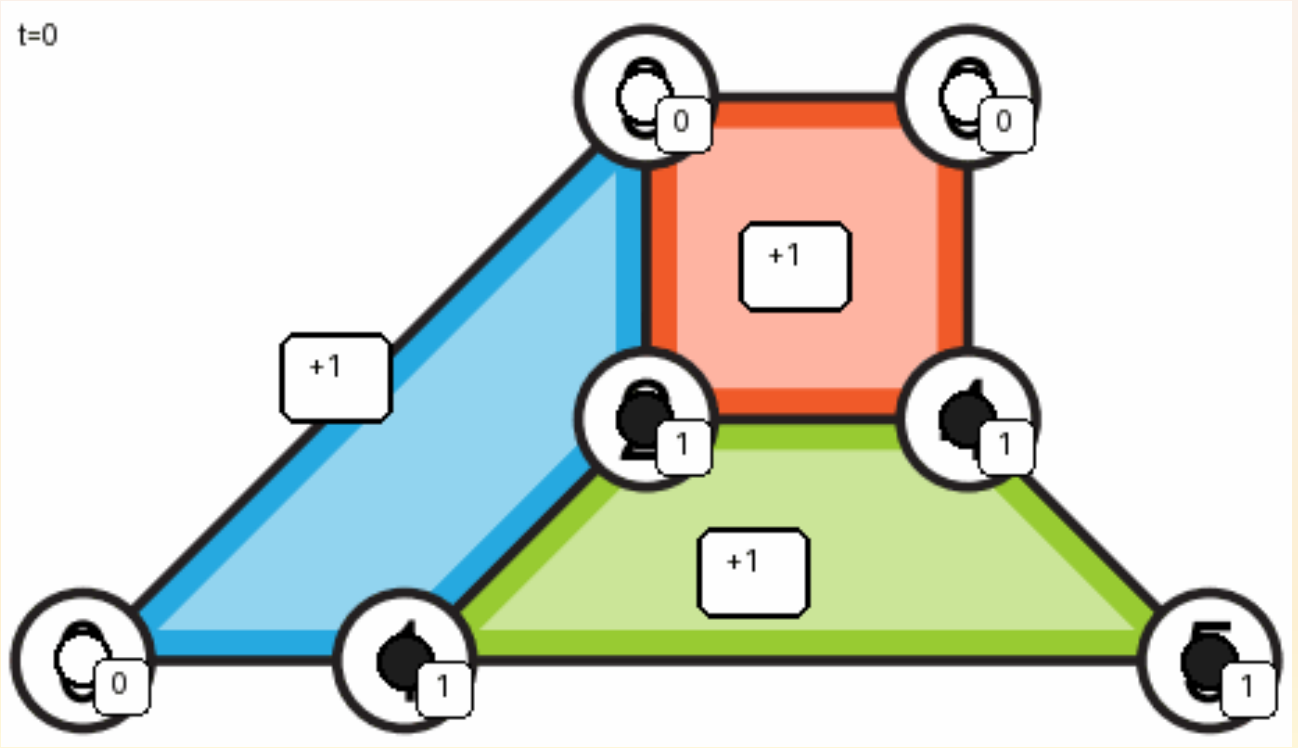
```python
def evaluate_syndromes(results: IList[MeasurementResult, Any]) -> tuple[int, int, int]:
    """Evaluate and return syndromes for all three color code plaquettes.

    This function evaluates the syndromes for blue, red, and green plaquettes
    of a 7-qubit color code. Each syndrome is computed as the parity of its
    respective plaquette measurements. A syndrome of 0 indicates even parity
    (no error detected), while 1 indicates odd parity (error detected).

    :param results: Measurement results from all 7 qubits in the color code
    :type results: IList[MeasurementResult, Any]
    :return: Tuple of (blue_syndrome, red_syndrome, green_syndrome)
    :rtype: tuple[int, int, int]

    :Example:

    >>> results = IList([0, 0, 0, 0, 0, 0, 0])
    >>> syndromes = evaluate_syndromes(results)
    >>> print(syndromes)
    (0, 0, 0)
    """
    blue = [results[0], results[1], results[2], results[3]]
    red = [results[2], results[3], results[4], results[6]]
    green = [results[1], results[2], results[4], results[5]]

    blue_plaquette_syndrome = extract_syndrome(blue)
    red_plaquette_syndrome = extract_syndrome(red)
    green_plaquette_syndrome = extract_syndrome(green)

    return (blue_plaquette_syndrome, red_plaquette_syndrome, green_plaquette_syndrome)
```

Parity Checking X error – Noiseless Simulation Data

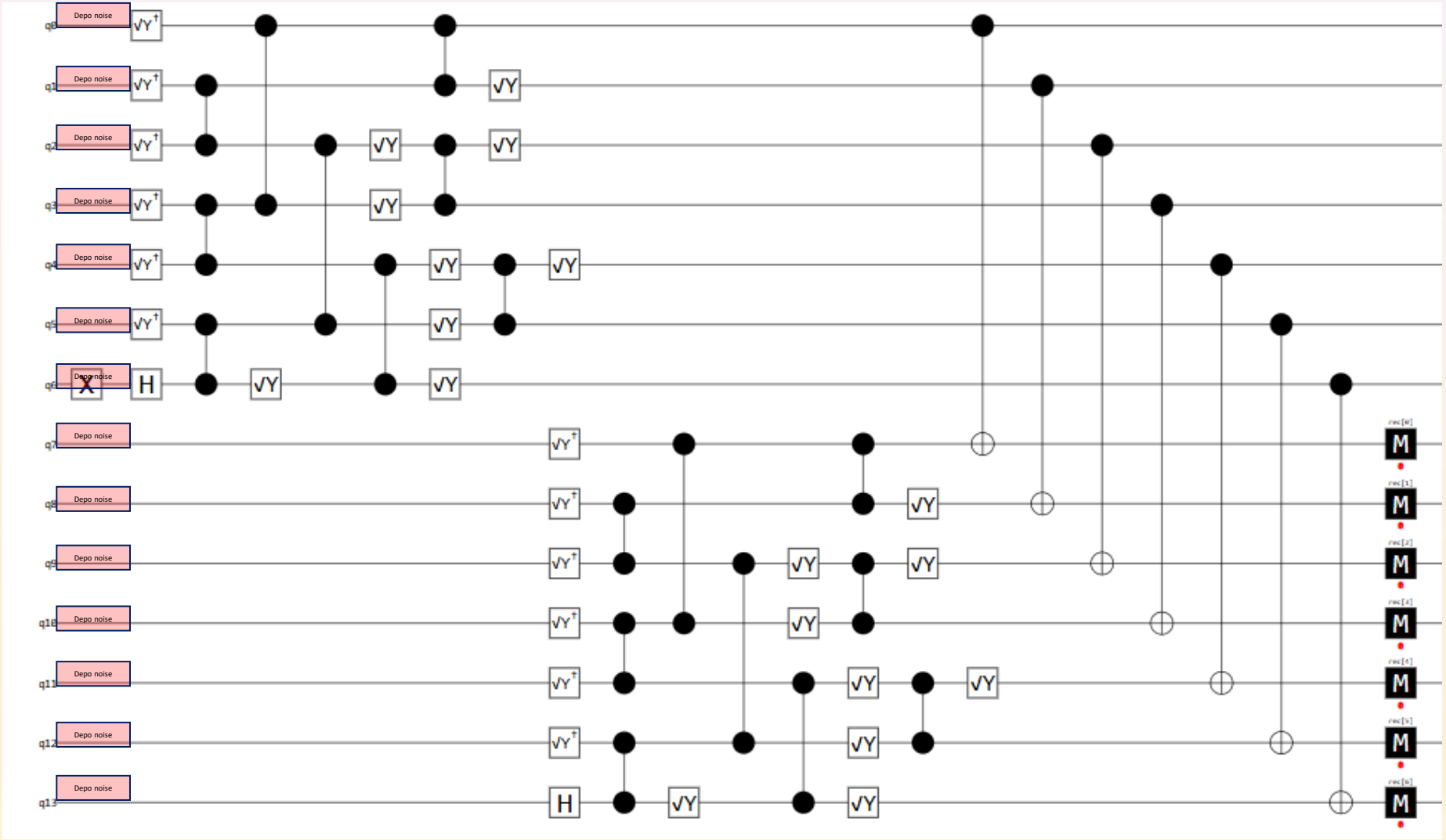

```
[
  {
    "blue": 0,
    "red": 0,
    "green": 0,
    "results": [
      0,
      1,
      1,
      0,
      1,
      1,
      0
    ]
  },
  {
    "blue": 0,
    "red": 0,
    "green": 0,
    "results": [
      1
```


100% success rate!

Syndromes match expected results → No error on our logical observable



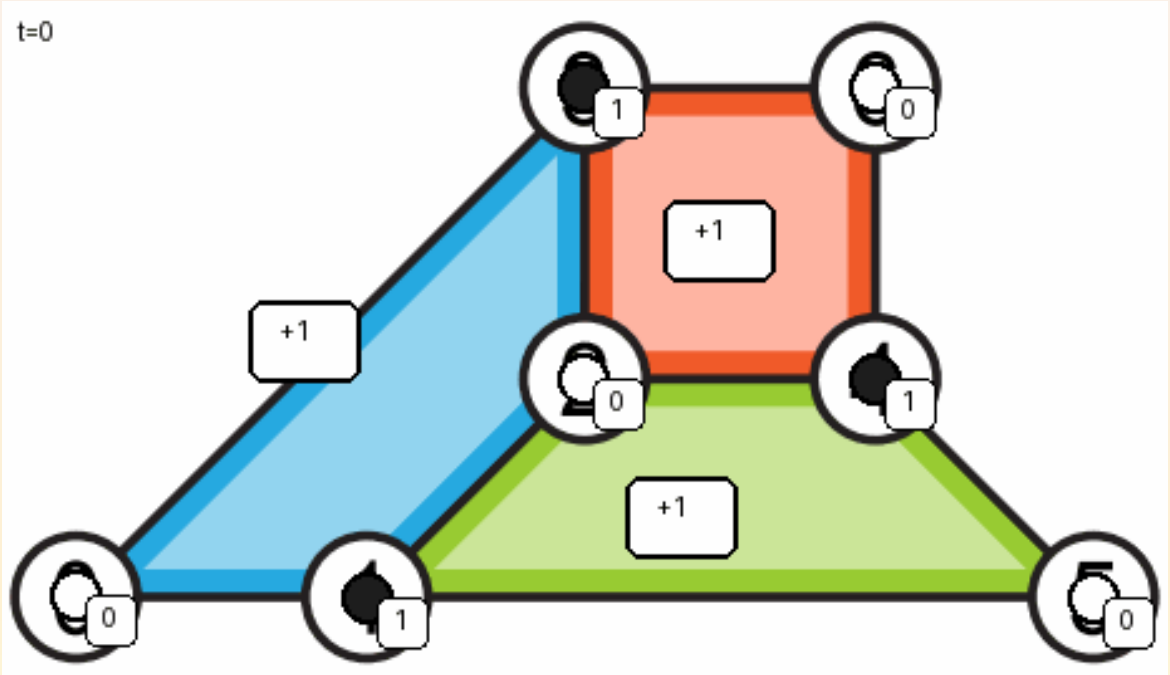
Lets add some noise, location = 0



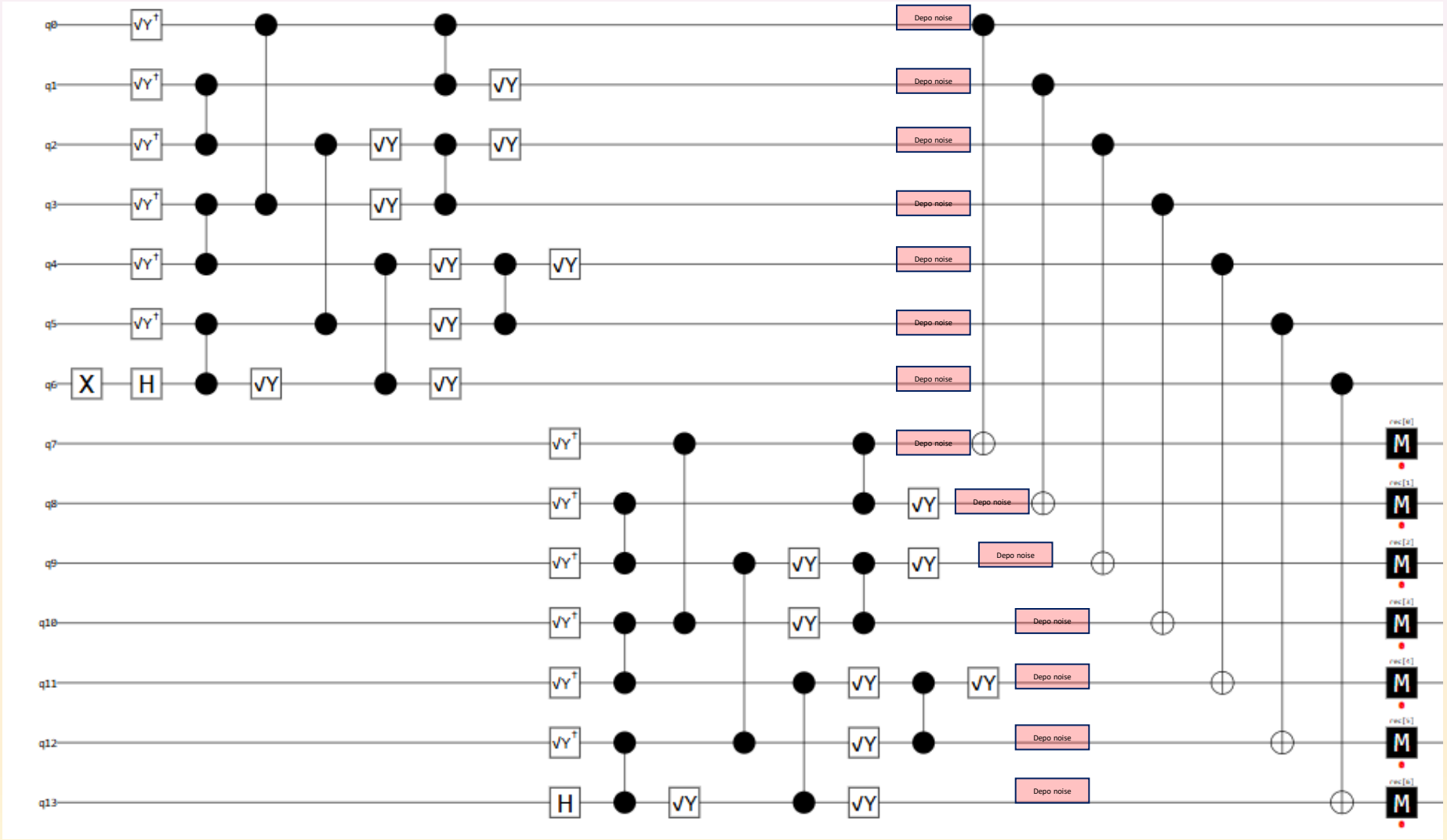
X post selection, p=0.1, location=0

```
def noisy_x_error_detection() -> IList[MeasurementResult, Any]:
    >>> emulator = StackMemorySimulator(min_qubits=14)
    >>> task = emulator.task(x_error_detection)
    >>> results = task.run()
    >>> print(results)
    """
    location = 0        You, now • Uncommitted changes
    p=0.1
    qubits_1 = squin.qalloc(n_sean_qubits)
    qubits_2 = squin.qalloc(n_sean_qubits)
    if location == 0:
        for i in range(len(qubits_1)):
            squin.depolarize(p,qubits_1[i])
            squin.depolarize(p,qubits_2[i])
    # put arbitrary state
    squin.x(qubits_1[-1])
    squin.h(qubits_1[-1])
    qubits_1 = color_code_factory(qubits_1)

    # put state + on ancillary registers
    squin.h(qubits_2[-1])
    qubits_2 = color_code_factory(qubits_2)
    if location == 1:
        for i in range(len(qubits_1)):
            squin.depolarize(p,qubits_1[i])
            squin.depolarize(p,qubits_2[i])
    # transversal CX
    for index in range(len(qubits_1)):
        squin.cx(qubits_1[index], qubits_2[index])
    if location == 2:
        for i in range(len(qubits_1)):
            squin.depolarize(p,qubits_1[i])
            squin.depolarize(p,qubits_2[i])
    bits = squin.broadcast.measure(qubits_2)
    return bits
```

~70% success rate with depolarizing noise on first location



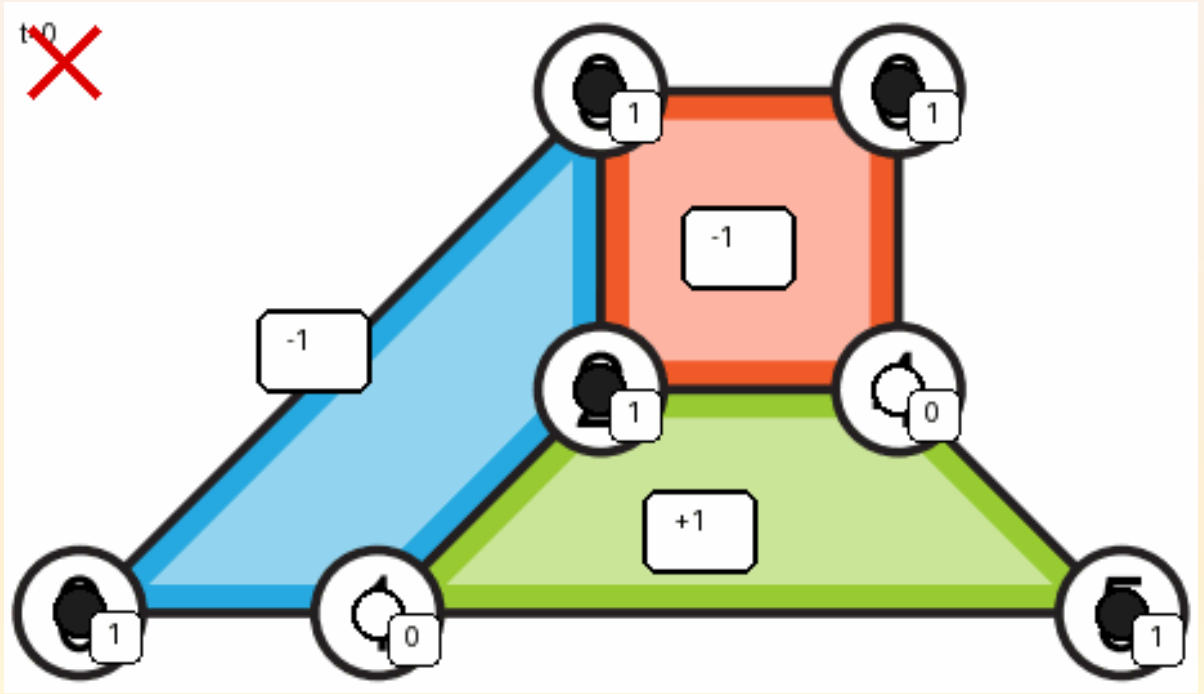
Lets add some noise, location = 1



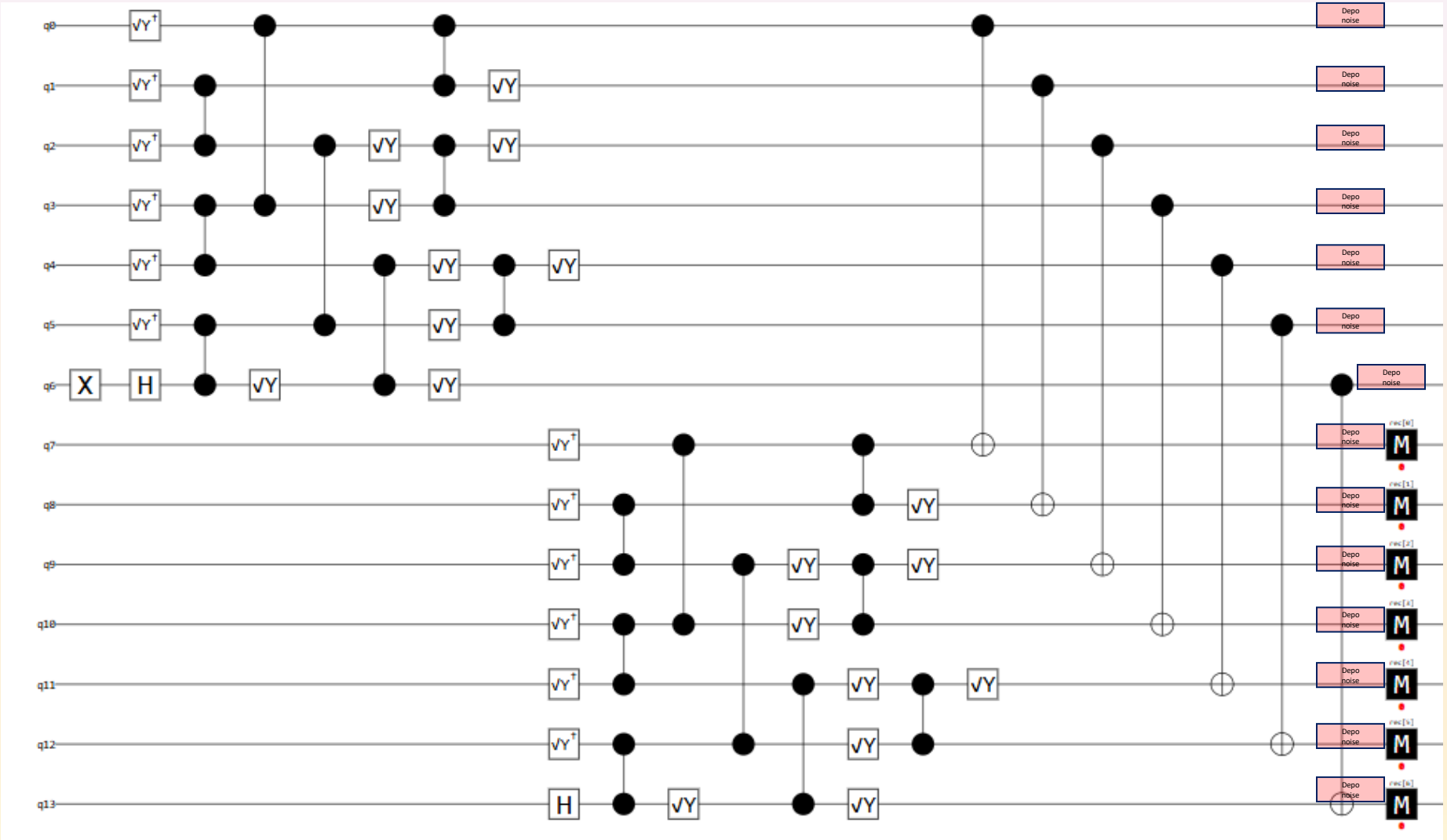
X post selection, p=0.1, location=1

```python
def noisy_x_error_detection() -> IList[MeasurementResult, Any]:
    >>> emulator = StackMemorySimulator(min_qubits=14)
    >>> task = emulator.task(x_error_detection)
    >>> results = task.run()
    >>> print(results)
    """
    location = 1        You, now • Uncommitted changes
    p=0.1
    qubits_1 = squin.qalloc(n_sean_qubits)
    qubits_2 = squin.qalloc(n_sean_qubits)
    if location == 0:
        for i in range(len(qubits_1)):
            squin.depolarize(p,qubits_1[i])
            squin.depolarize(p,qubits_2[i])
    # put arbitrary state
    squin.x(qubits_1[-1])
    squin.h(qubits_1[-1])
    qubits_1 = color_code_factory(qubits_1)

    # put state + on ancillary registers
    squin.h(qubits_2[-1])
    qubits_2 = color_code_factory(qubits_2)
    if location == 1:
        for i in range(len(qubits_1)):
            squin.depolarize(p,qubits_1[i])
            squin.depolarize(p,qubits_2[i])
    # transversal CX
    for index in range(len(qubits_1)):
        squin.cx(qubits_1[index], qubits_2[index])
    if location == 2:
        for i in range(len(qubits_1)):
            squin.depolarize(p,qubits_1[i])
            squin.depolarize(p,qubits_2[i])
    bits = squin.broadcast.measure(qubits_2)
    return bits
```

~40% success rate with depolarizing noise on first location



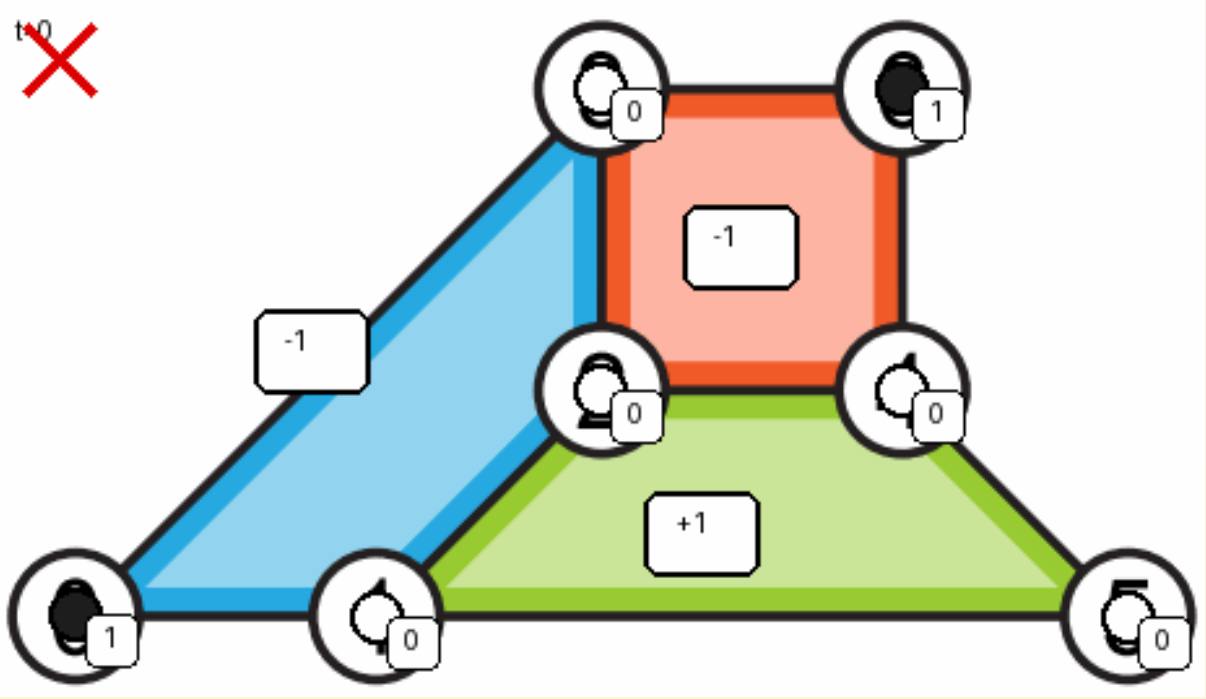
Lets add some noise, location = 2



X post selection, p=0.1, location=2

```python
def noisy_x_error_detection() -> IList[MeasurementResult, Any]:
    >>> emulator = StackMemorySimulator(min_qubits=14)
    >>> task = emulator.task(x_error_detection)
    >>> results = task.run()
    >>> print(results)
    """
    location = 2        You, now • Uncommitted changes
    p=0.1
    qubits_1 = squin.qalloc(n_sean_qubits)
    qubits_2 = squin.qalloc(n_sean_qubits)
    if location == 0:
        for i in range(len(qubits_1)):
            squin.depolarize(p,qubits_1[i])
            squin.depolarize(p,qubits_2[i])
    # put arbitrary state
    squin.x(qubits_1[-1])
    squin.h(qubits_1[-1])
    qubits_1 = color_code_factory(qubits_1)

    # put state + on ancillary registers
    squin.h(qubits_2[-1])
    qubits_2 = color_code_factory(qubits_2)
    if location == 1:
        for i in range(len(qubits_1)):
            squin.depolarize(p,qubits_1[i])
            squin.depolarize(p,qubits_2[i])
    # transversal CX
    for index in range(len(qubits_1)):
        squin.cx(qubits_1[index], qubits_2[index])
    if location == 2:
        for i in range(len(qubits_1)):
            squin.depolarize(p,qubits_1[i])
            squin.depolarize(p,qubits_2[i])
    bits = squin.broadcast.measure(qubits_2)
    return bits
```

~60% success rate with depolarizing noise on first location



Why did we choose this model for this part

- Allow to rapidly see where noise affect the results the most
- “Appropriately describe average noise for large circuits” (see https://arxiv.org/pdf/2103.08591)
- Simple and comprehensible; lots errors happen at the same time on real quantum systems
- Overall well studied and abstract specifics

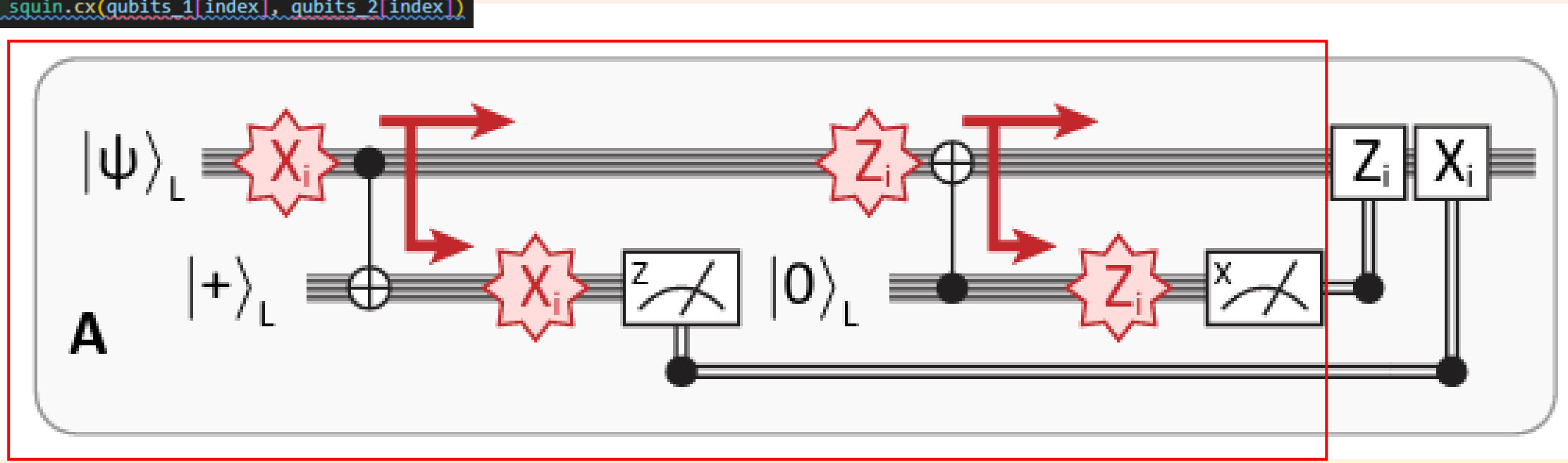
$$\Delta_\lambda(\rho) = (1-\lambda)\rho + \frac{\lambda}{d}(\mathrm{tr}(\rho))I = (1-\lambda)\rho + \frac{\lambda}{d}I$$

Now lets look at adding Z error detection

```
qubits_1 = squin.qalloc(n_sean_qubits)
# put arbitrary state
squin.x(qubits_1[-1])
squin.h(qubits_1[-1])
qubits_1 = color_code_factory(qubits_1)

# put state + on ancillary registers
qubits_2 = squin.qalloc(n_sean_qubits)
squin.h(qubits_2[-1])
qubits_2 = color_code_factory(qubits_2)

# transversal CX
for index in range(len(qubits_1)):
    squin.cx(qubits_1[index], qubits_2[index])
```

```
bits_x = squin.broadcast.measure(qubits_2)

qubits_3 = squin.qalloc(n_sean_qubits)

qubits_3 = color_code_factory(qubits_3)

squin.z(qubits_3[0])

# transversal CX
for index in range(len(qubits_1)):
    squin.cx(qubits_3[index], qubits_1[index])
```

```
# Apply Hadamard gates for X-basis measurement
squin.broadcast.h(qubits_3)

bits_z = squin.broadcast.measure(qubits_3)
bits_psi = squin.broadcast.measure(IList([qubits_1[0], qub

return (bits_x, bits_z, bits_psi)
```

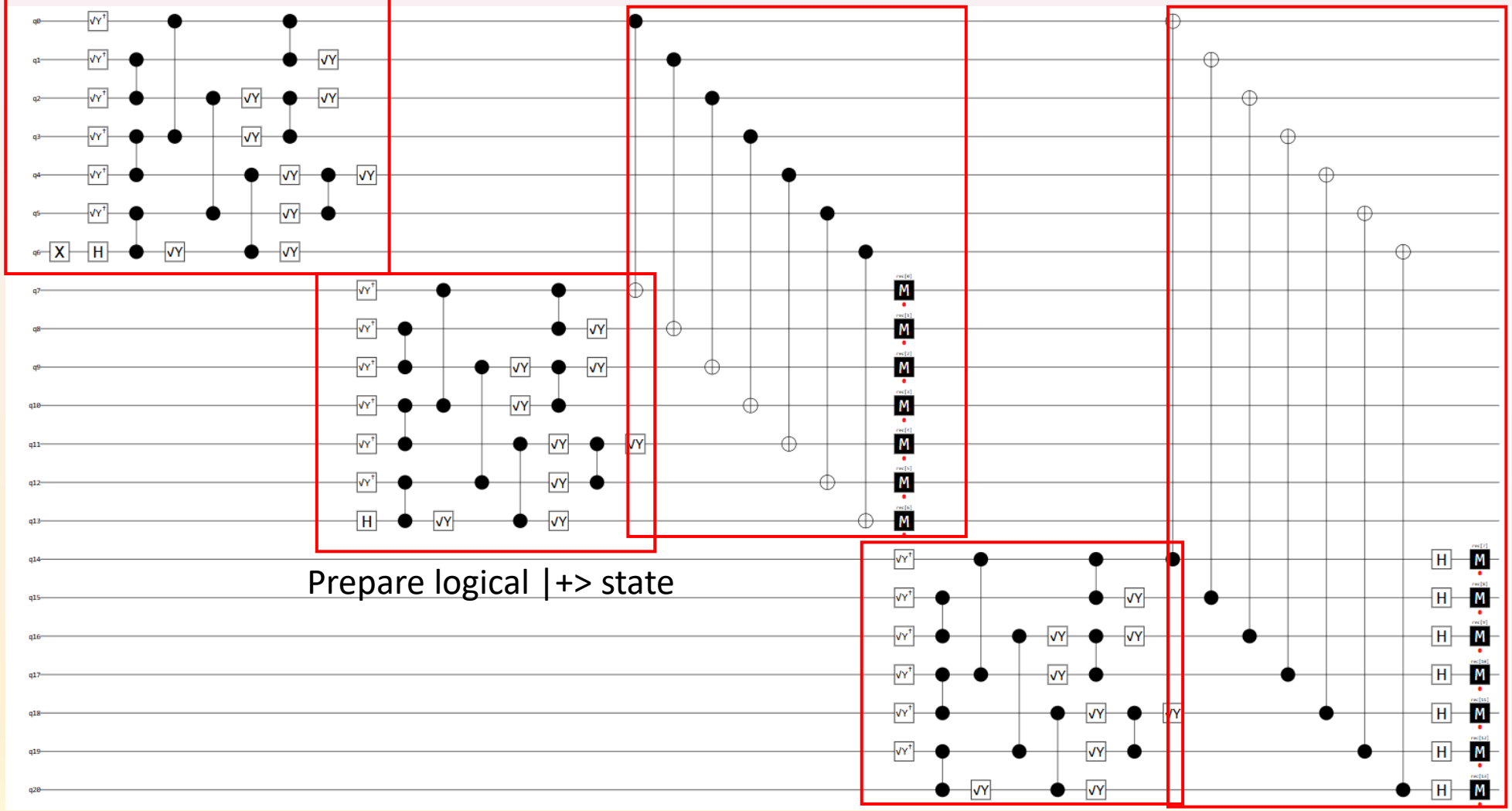


First iteration

Prepare logical state

Transversal cnot for x error and midcircuit measurement

Reversed transversal cnot for z error detection and midcircuit measurement



Prepare logical |+> state

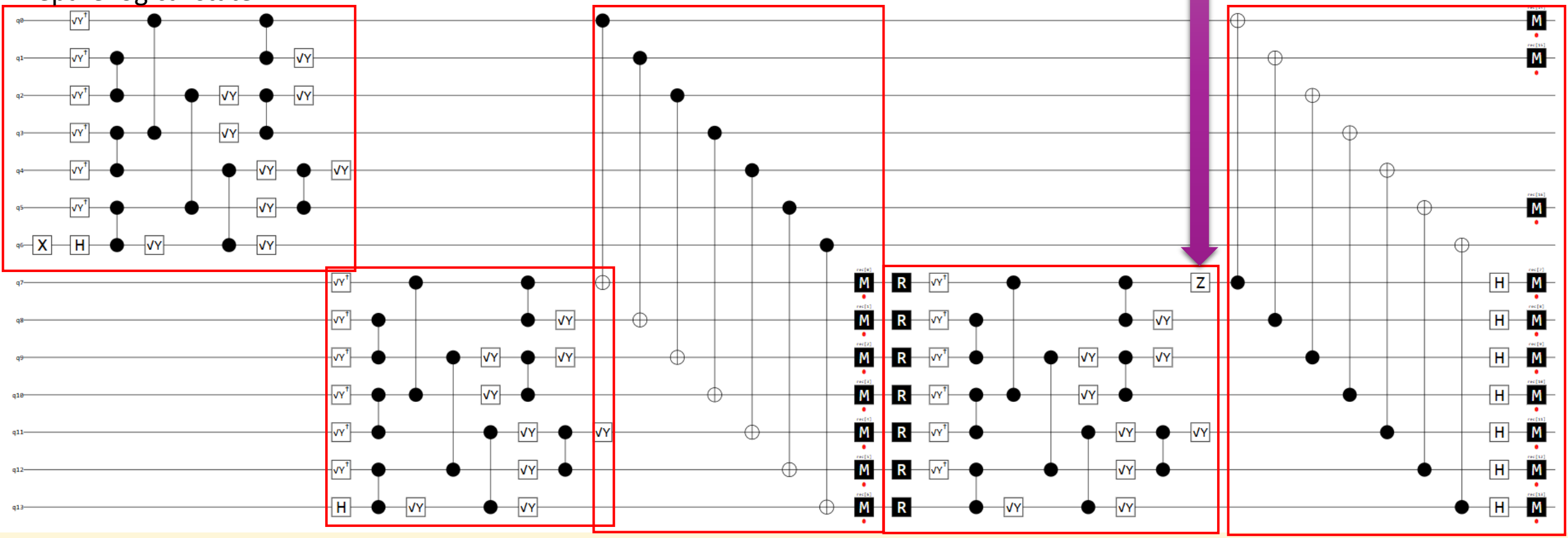
Prepare 0 logical state

Then figured we could reuse the qubits…

Prepare logical state

Transversal cnot for x error and midcircuit measurements

Reversed transversal cnot for z error detection and midcircuit measurements



Prepare logical |+> state

Prepare 0 logical state

Mid circuit measurement and error correction

With depolarizing on 1 channel on q0

```
valid : 331, invalid : 669
```

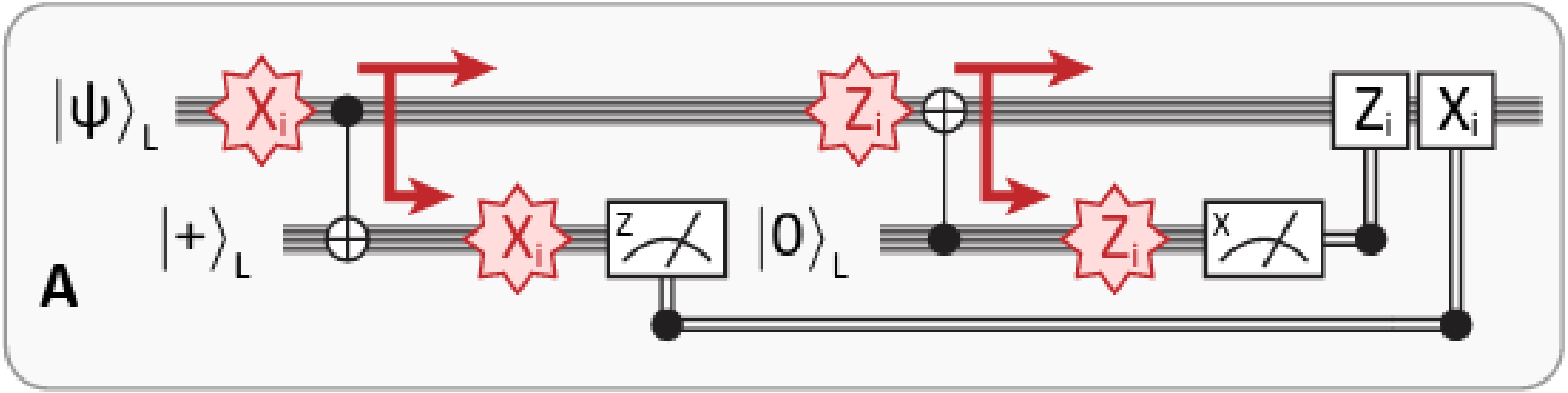
With no noise (implementation works!)

```
valid : 1000, invalid : 0
```

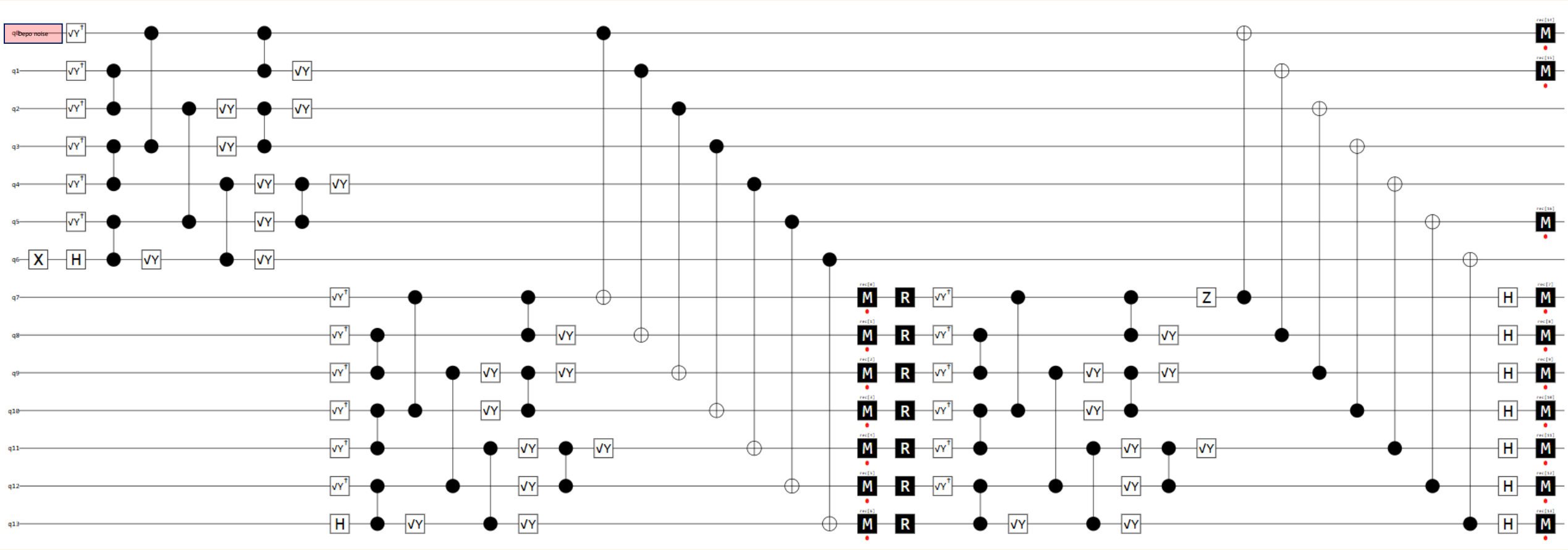
```python
# transversal CX
for index in range(len(qubits_1)):
    squin.cx(qubits_2[index], qubits_1[index])

# Apply Hadamard gates for X-basis measurement
squin.broadcast.h(qubits_2)

bits_z = squin.broadcast.measure(qubits_2)


blue = bits_x[0] ^ bits_x[1] ^ bits_x[2] ^ bits_x[3]
red = bits_x[2] ^ bits_x[3] ^ bits_x[4] ^ bits_x[6]
green = bits_x[1] ^ bits_x[2] ^ bits_x[4] ^ bits_x[5]

if blue == 1 and red == 0 and green == 0:
    squin.x(qubits_1[0])
elif blue == 1 and red == 0 and green == 1:
    squin.x(qubits_1[1])
elif blue == 1 and red == 1 and green == 1:
    squin.x(qubits_1[2])
elif blue == 1 and red == 1 and green == 0:
    squin.x(qubits_1[3])
elif blue == 0 and red == 1 and green == 1:
    squin.x(qubits_1[4])
elif blue == 0 and red == 0 and green == 1:
    squin.x(qubits_1[5])
elif blue == 0 and red == 1 and green == 0:
    squin.x(qubits_1[6])

blue = bits_z[0] ^ bits_z[1] ^ bits_z[2] ^ bits_z[3]
red = bits_z[2] ^ bits_z[3] ^ bits_z[4] ^ bits_z[6]
green = bits_z[1] ^ bits_z[2] ^ bits_z[4] ^ bits_z[5]

if blue == 1 and red == 0 and green == 0:
    squin.z(qubits_1[0])
elif blue == 1 and red == 0 and green == 1:
```

Final circuit

We do mid circuit measurement to figure out which gates to put and do put a Z_i or a X_i gate depending on the results of the mid circuit measurement. As to whether or not it improved the results is to be verified.

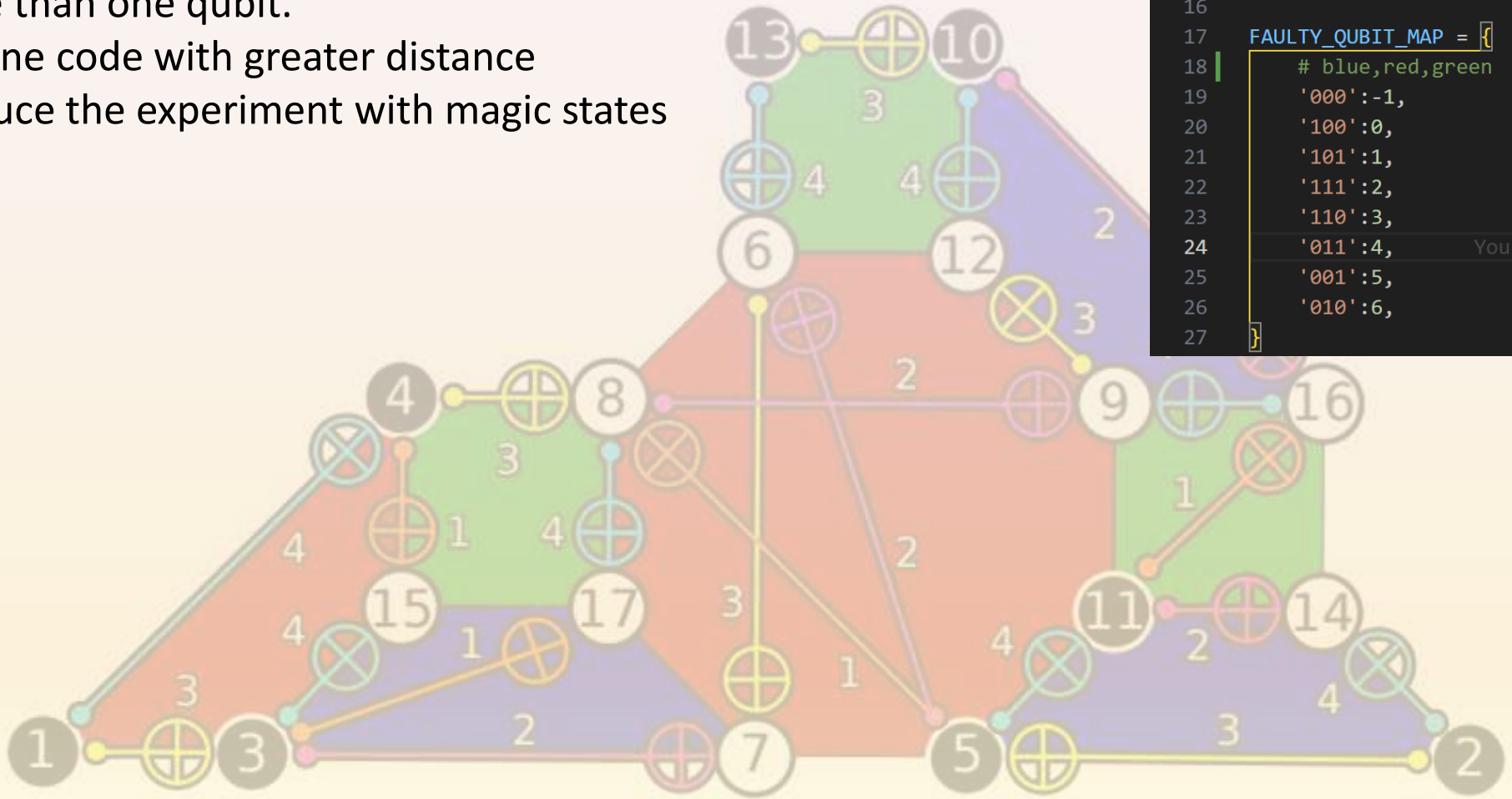


Final example



Next steps...

- Figure out heuristics that allows for the correction of more than one qubit.
- Try steane code with greater distance
- Reproduce the experiment with magic states



syndrome_evals.py M

src > syndrome_evals.py > ...

You, 9 seconds ago | 2 authors (You and one ot

```
1  """Syndrome evaluation and post-s
7
8  from typing import Any ···
14
15 logger = logging.getLogger(__name
16
17 FAULTY_QUBIT_MAP = {
18     # blue,red,green
19     '000':-1,
20     '100':0,
21     '101':1,
22     '111':2,
23     '110':3,
24     '011':4,        You, 7 hours a
25     '001':5,
26     '010':6,
27 }
```