

Report on Quantum Information and Quantum
Machine Learning
Laboratory 2

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Chapter 1

Task 1: Create Φ^+ and measure in ZZ

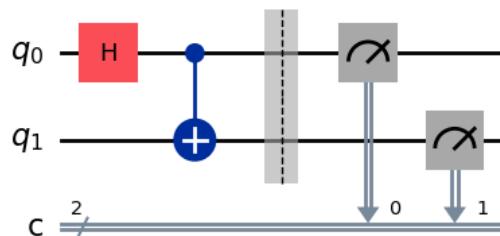


Figure 1.1: Circuit for Φ^+ with ZZ measurement.

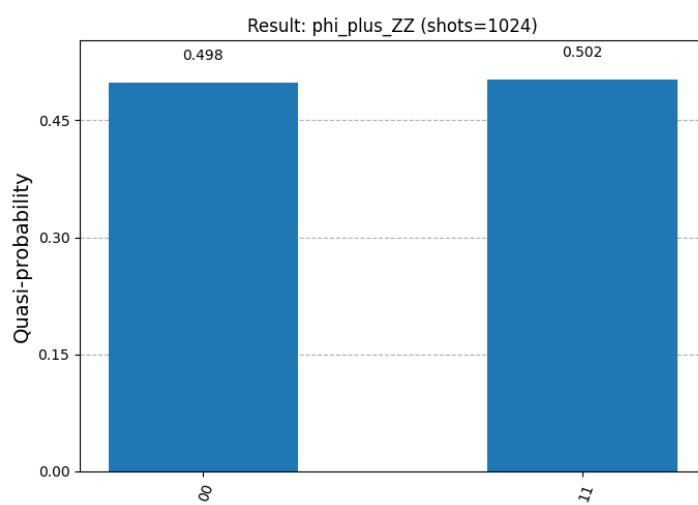


Figure 1.2: Measurement results for Φ^+ (ZZ).

Chapter 2

Task 2: Create Φ^- and measure in ZZ

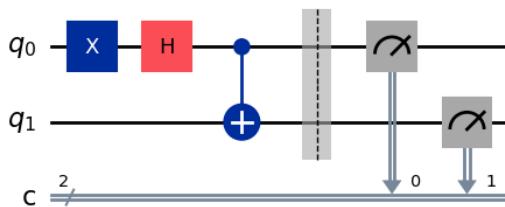


Figure 2.1: Circuit for Φ^- with ZZ measurement.

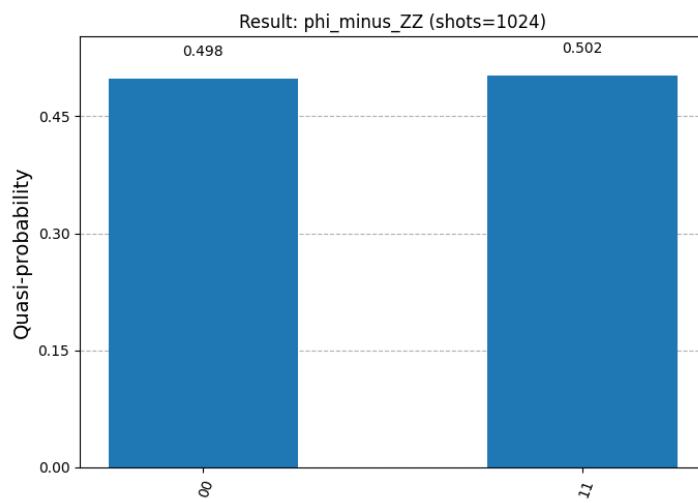


Figure 2.2: Measurement results for Φ^- (ZZ).

Mathematical calculation (Matrix form)

Bell state $|\Phi^-\rangle$ derivation - Matrix form

1. Negate the rightmost qubit ($I \otimes X$)
$$\begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$$
2. Apply Hadamard on the same qubit ($I \otimes H$)
$$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -1 \\ 0 \\ 0 \end{bmatrix}$$
3. Apply CNOT gate
$$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ -1 \\ 0 \\ 0 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 0 \\ 0 \\ -1 \end{bmatrix} = |\Phi^-\rangle$$

Figure 2.3: Handwritten derivation for Φ^- (matrix form).

Chapter 3

Task 3: Create Ψ^+ and measure in ZZ

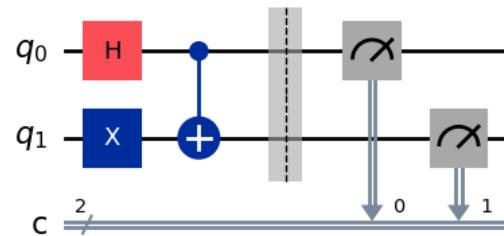


Figure 3.1: Circuit for Ψ^+ with ZZ measurement.

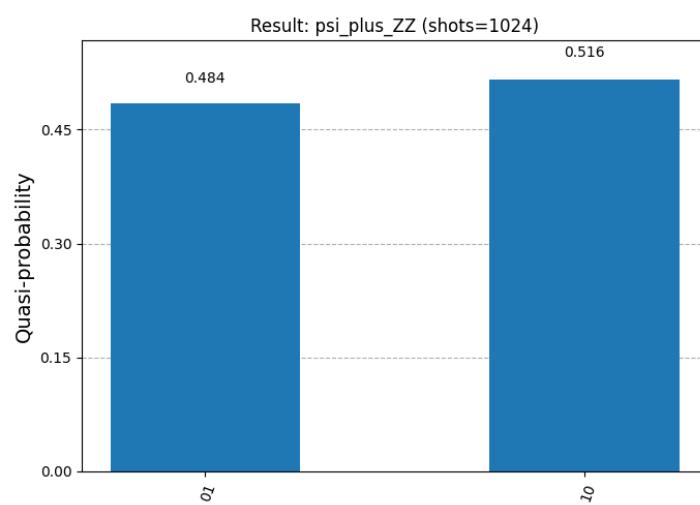


Figure 3.2: Measurement results for Ψ^+ (ZZ).

Mathematical calculation (Operator form)

Bell state $|\Psi^+\rangle$ derivation - Operators form

$$|100\rangle = |0\rangle \otimes |0\rangle$$

X_1 : negate second (rightmost) qubit

$$\xrightarrow{(X \otimes I)} |X|0\rangle \otimes |0\rangle = |1\rangle \otimes |0\rangle$$

H_0 : apply Hadamard to the first qubit

$$\xrightarrow{(I \otimes H)} |1\rangle \otimes (H|0\rangle) = |1\rangle \otimes \left(\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)\right) =$$
$$= \frac{1}{\sqrt{2}}(|11\rangle \otimes |0\rangle + |1\rangle \otimes |1\rangle)$$

C_X : apply controlled-NOT

$$\xrightarrow{C_X} \frac{1}{\sqrt{2}}(C_X(|10\rangle) + C_X(|11\rangle)) =$$
$$= \frac{1}{\sqrt{2}}(|10\rangle + |01\rangle) = |\Psi^+\rangle$$

Figure 3.3: Handwritten derivation for Ψ^+ (operator form).

Chapter 4

Task 4: Create Ψ^- and measure in ZZ

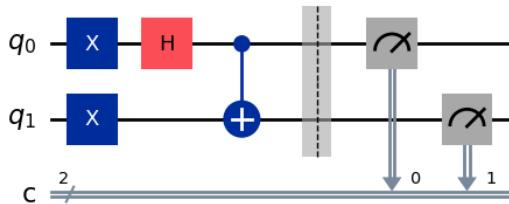


Figure 4.1: Circuit for Ψ^- with ZZ measurement.

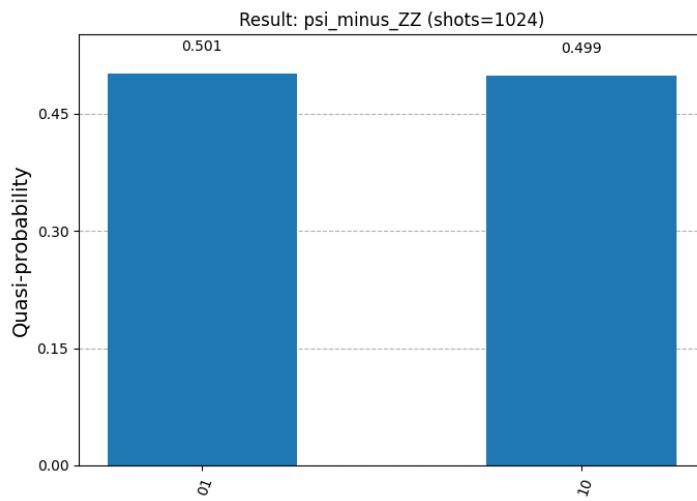


Figure 4.2: Measurement results for Ψ^- (ZZ).

Mathematical calculation (Operator form)

Bell state $|\Psi^-\rangle$ derivation - Operators form

$$|00\rangle = |0\rangle \otimes |0\rangle$$

1. Apply X gates on both qubits (X_0, X_1)

$$(X \otimes X)(|00\rangle) = |11\rangle$$

2. Apply Hadamard on the first qubit (H_0)

$$(I \otimes H)|11\rangle = |1\rangle \otimes \left(\frac{1}{\sqrt{2}}(|10\rangle - |11\rangle)\right) =$$

$$\frac{1}{\sqrt{2}}(|1\rangle \otimes |0\rangle - |1\rangle \otimes |1\rangle)$$

3. Apply controlled-NOT

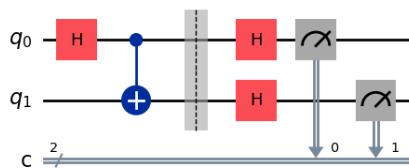
$$C_X \frac{1}{\sqrt{2}}(C_X(|10\rangle) - C_X(|11\rangle)) =$$

$$= \frac{1}{\sqrt{2}}(|10\rangle - |01\rangle) = |\Psi^-\rangle$$

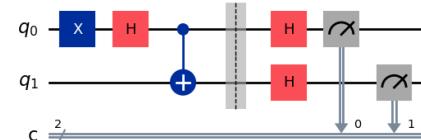
Figure 4.3: Handwritten derivation for Ψ^- (operator form).

Chapter 5

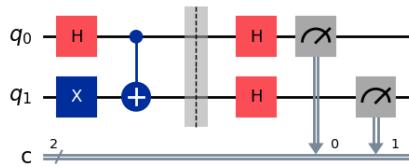
Task 5: XX measurements for Tasks 1–4



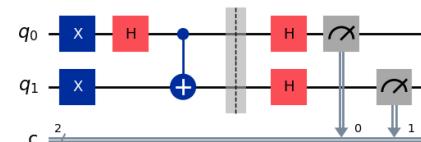
(a) Φ^+



(b) Φ^-



(c) Ψ^+



(d) Ψ^-

Figure 5.1: Circuits for XX measurements.

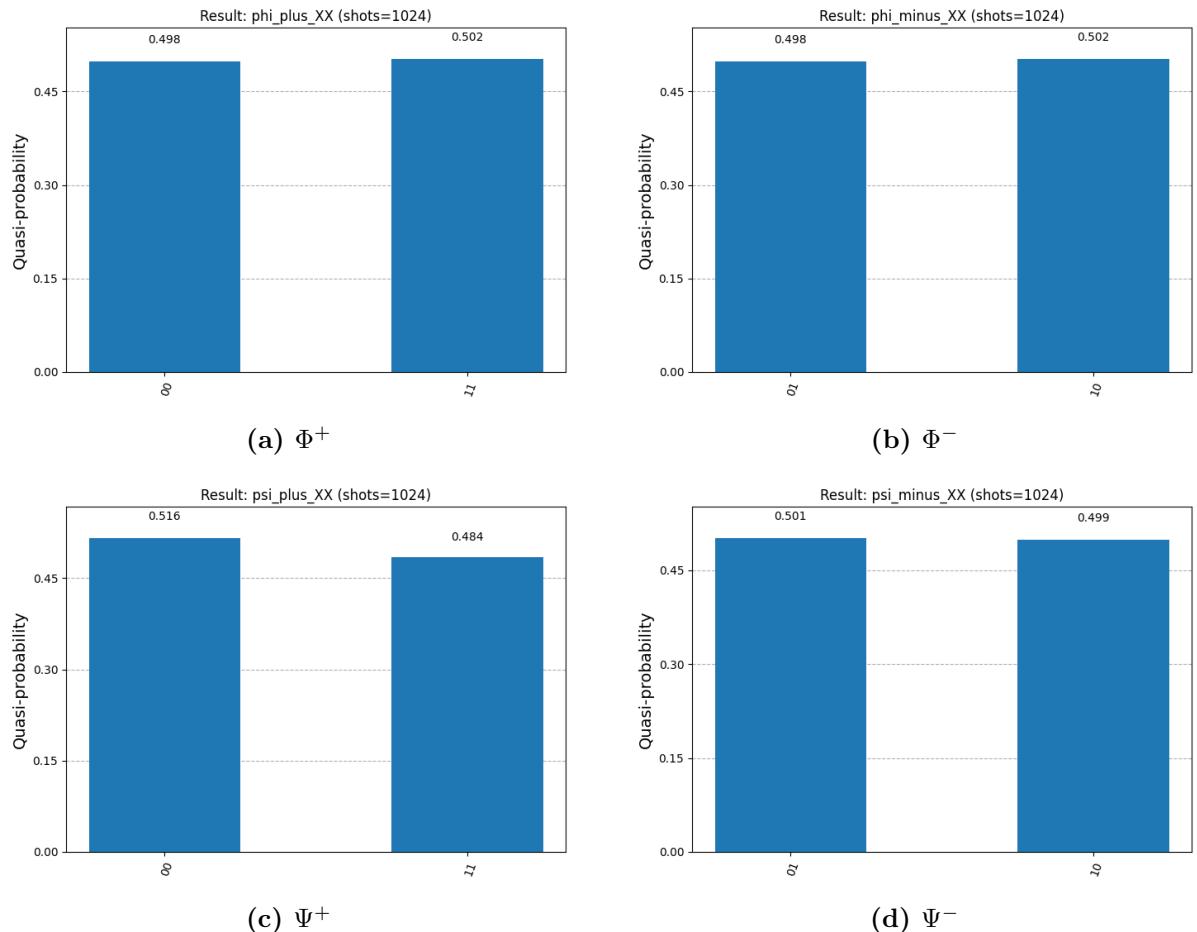


Figure 5.2: Measurement results for XX basis.

Chapter 6

Task 6: YY measurements for Tasks 1–4

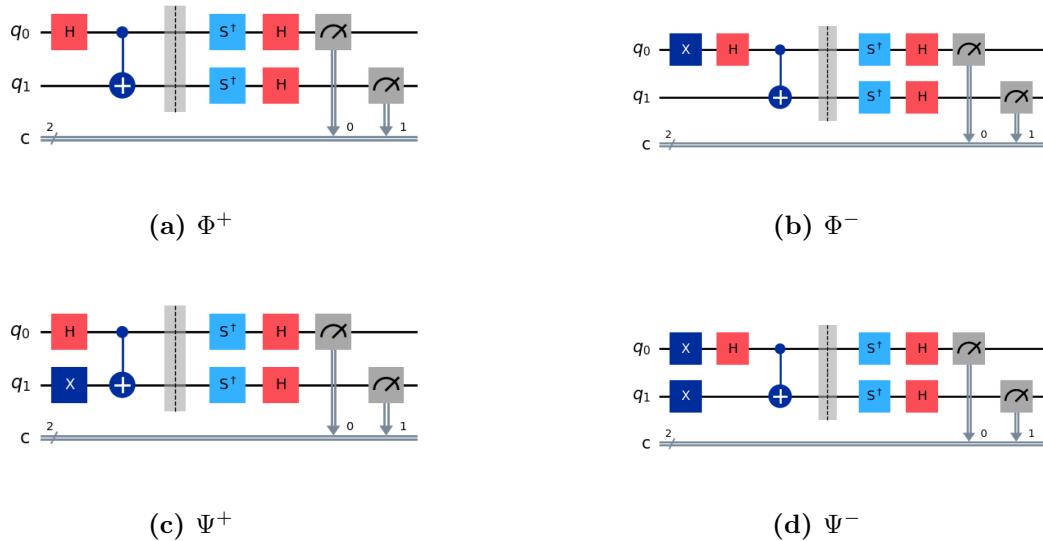


Figure 6.1: Circuits for YY measurements.

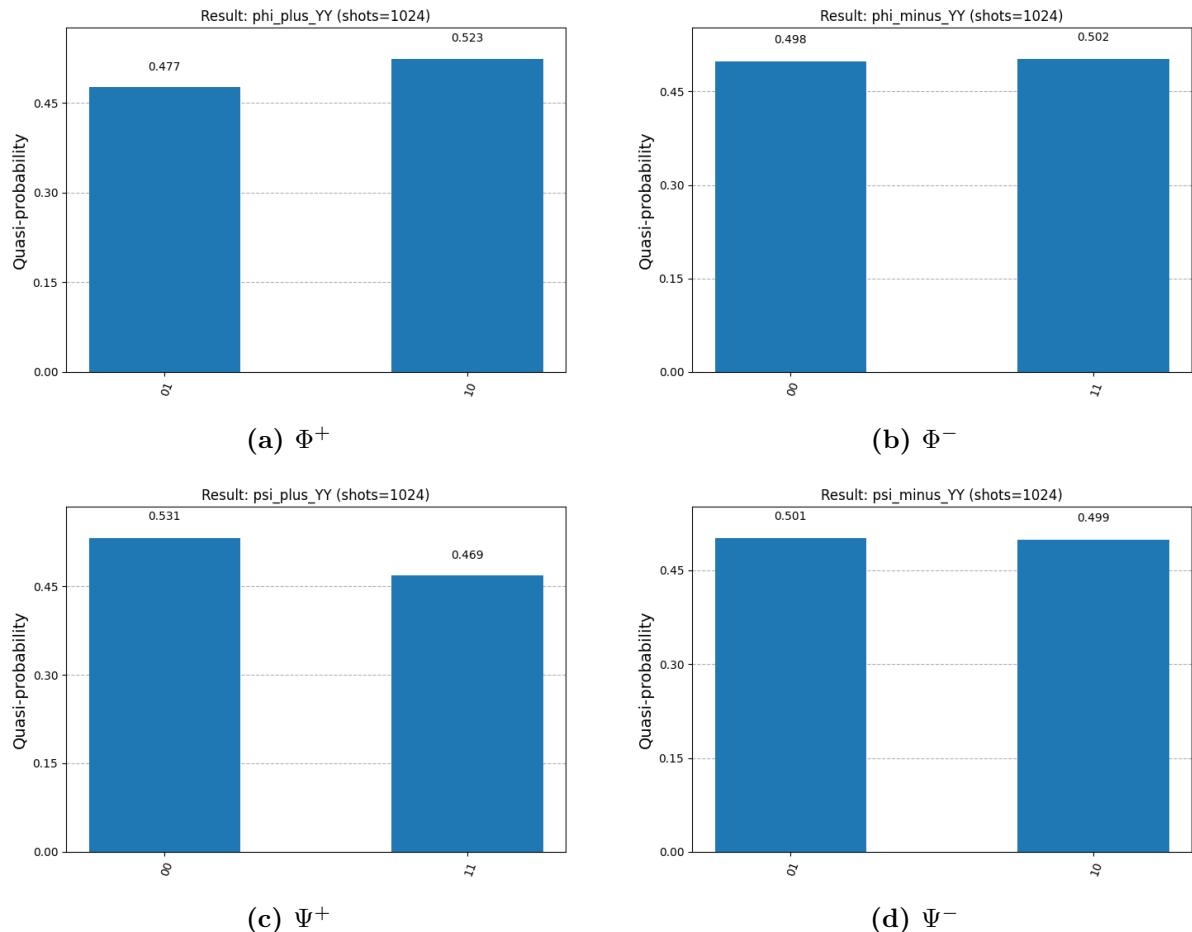


Figure 6.2: Measurement results for YY basis.

Chapter 7

Task 7: XZ measurements for Tasks 1–4

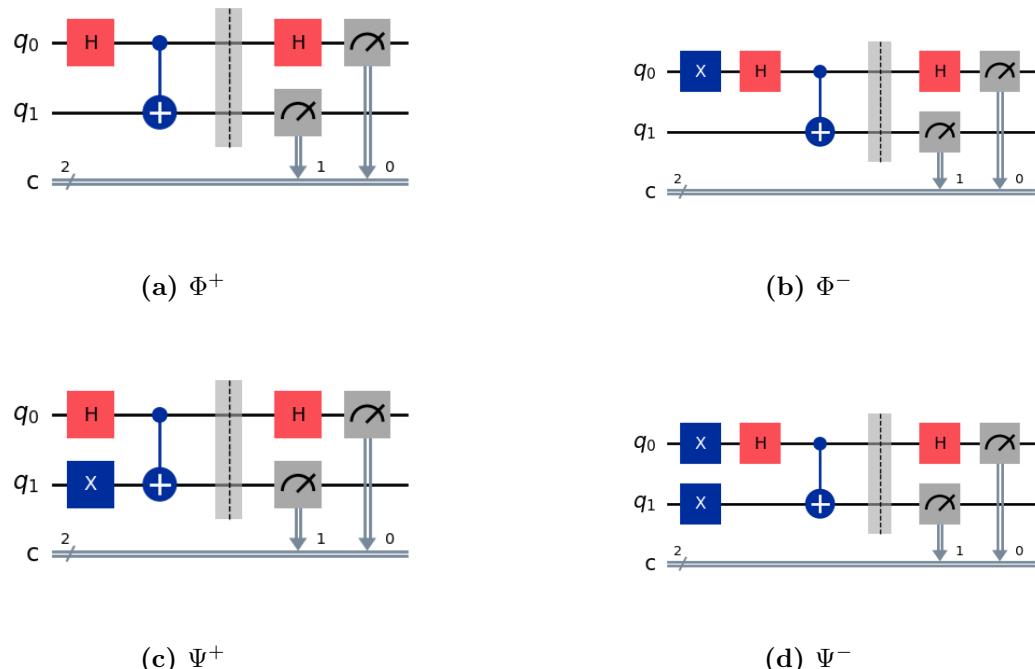


Figure 7.1: Circuits for XZ measurements.

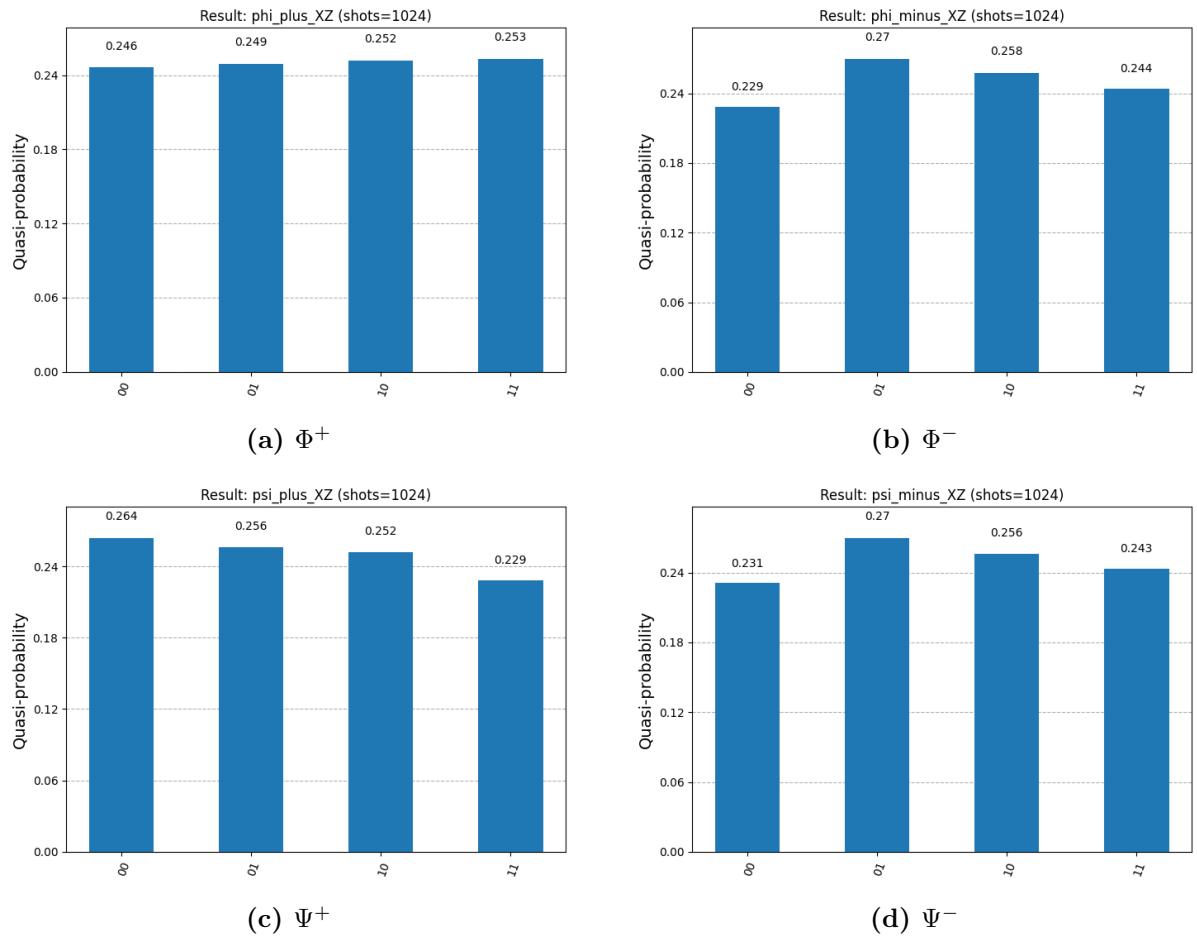


Figure 7.2: Measurement results for XZ basis.