Optimizing the Prioritization of Compiled Quantum Circuits by Machine Learning Approaches

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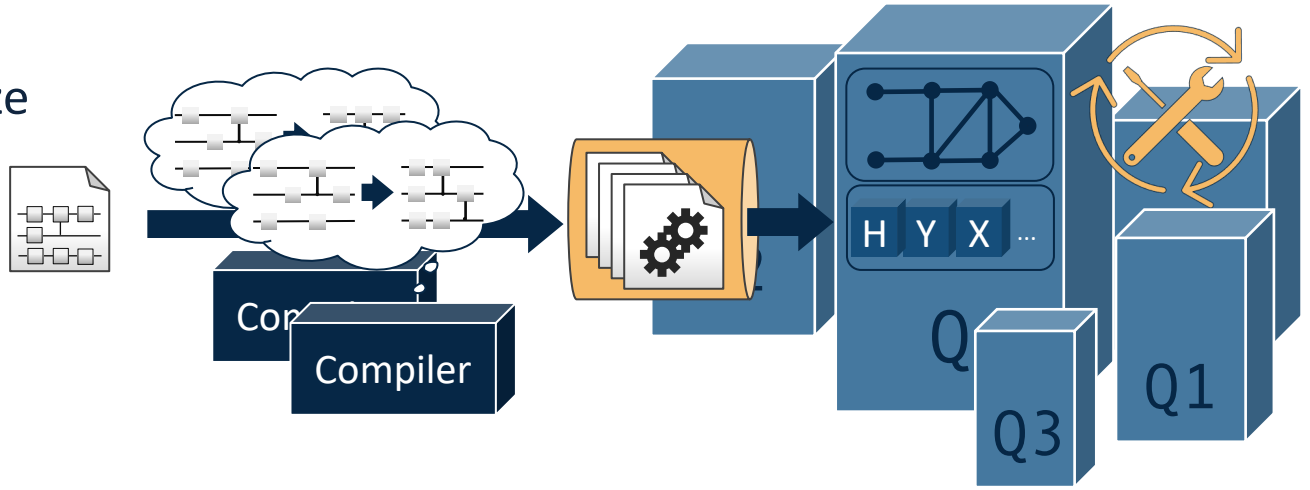
Structure

- motivation
- previous work
- approach
- system architecture
- case study
- conclusion & future work

Quantum computing is promising ...

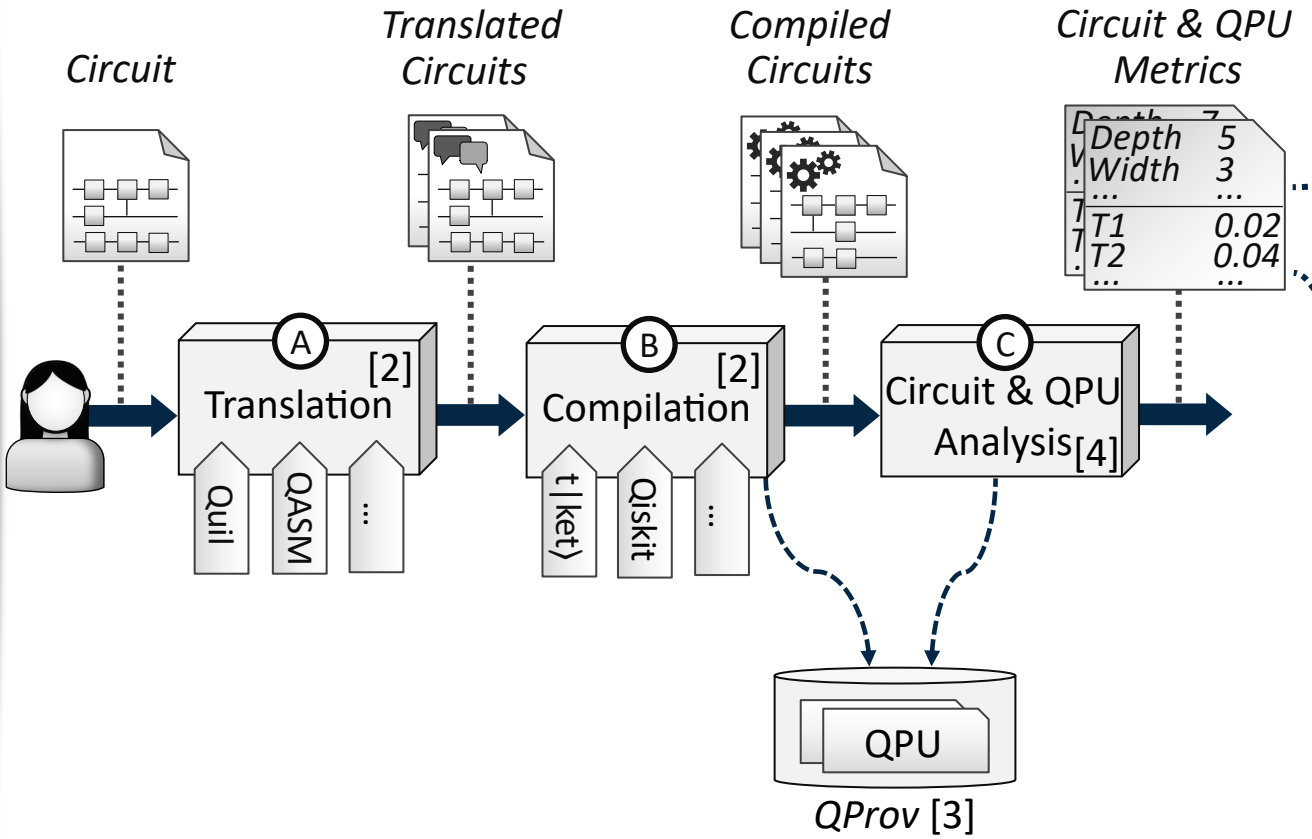
- number of QPUs increases
  - differ in hardware properties → influence execution results

- always choose the same QPU!?
  - regular QPU re-calibration
  - compilation changes circuit size
  - quantum compilers differ
  - regulated computing access



➢ deep & versatile analysis
to choose between compilers, QPUs & compiled circuits
regarding, e.g., precise & fast executions

Approach of our previous work [1]



compiled quantum circuit		width
		depth
		multi-qubit gate depth
		# of operations
		# single-qubit gates
		# multi-qubit gates
		# measurement operations
target quantum computer	hardware	avg. single-qubit gate error
		avg. multi-qubit gate error
		avg. single-qubit gate time
		avg. multi-qubit gate time
		avg. readout error
		avg. T1
		avg. T2
	cloud provider	waiting time

[1] Marie Salm, Johanna Barzen, Frank Leymann, Benjamin Weder: Prioritization of Compiled Quantum Circuits for Different Quantum Computers. In: The 1st International Workshop on Quantum Software Analysis, Evolution and Reengineering (Q-SANER 2022) co-located with IEEE International Conference on Software Analysis, Evolution and Reengineering (SANER), 2022.
[2] Marie Salm, Johanna Barzen, Frank Leymann, Benjamin Weder, Karoline Wild. 2021. Automating the Comparison of Quantum Compilers for Quantum Circuits. In: Proceedings of the 15th Symposium and Summer School on Service-Oriented Computing (SummerSOC 2021), Springer International Publishing, 2021
[3] Benjamin Weder, Johanna Barzen, Frank Leymann, Marie Salm, Karoline Wild. 2021. QProv: A provenance system for quantum computing. In: IET Quantum Communications, Wiley, 2021
[4] Marie Salm, Johanna Barzen, Uwe Breitenbücher, Frank Leymann, Benjamin Weder, et al. 2020. The NISQ Analyzer: Automating the Selection of Quantum Computers for Quantum Algorithms. In: Proceedings of the 14th Symposium and Summer School on Service-Oriented Computing (SummerSOC 2020), Springer International Publishing, 2020

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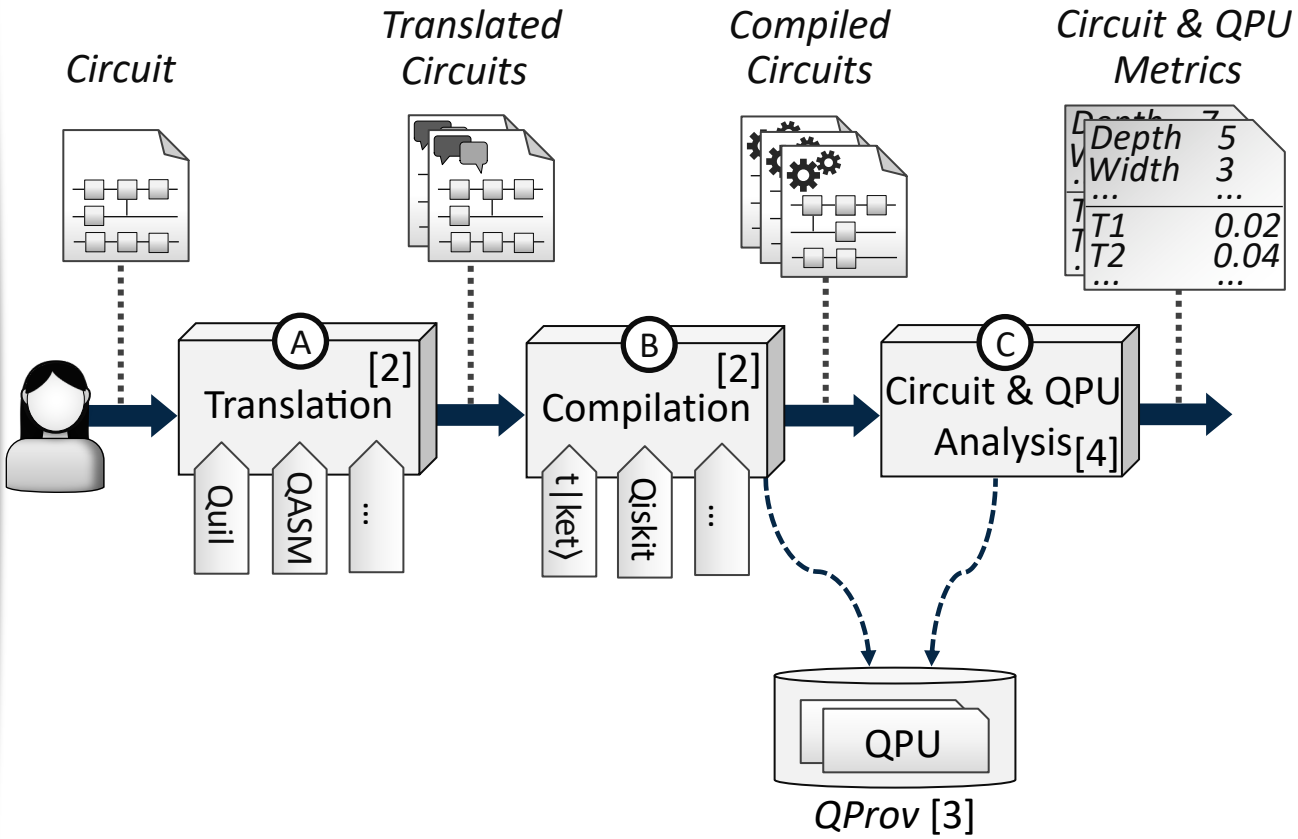

Backend Name	Provider	SDK	Width	Depth	Multi-Qubit Gate Depth	Total Number of Operations
ibmq_qasm_simulator	ibmq	pytket	3	14	6	21
ibmq_qasm_simulator	ibmq	qiskit	3	14	6	21
ibmq_bogota	ibmq	pytket	3	27	9	45
ibmq_bogota	ibmq	qiskit	3	30	13	51
ibmq_lima	ibmq	pytket	3	27	9	45
ibmq_lima	ibmq	qiskit	3	40	11	62
ibmq_belem	ibmq	pytket	3	29	9	45
ibmq_belem	ibmq	qiskit	3	41	11	63
ibmq_quito	ibmq	pytket	3	27	9	45

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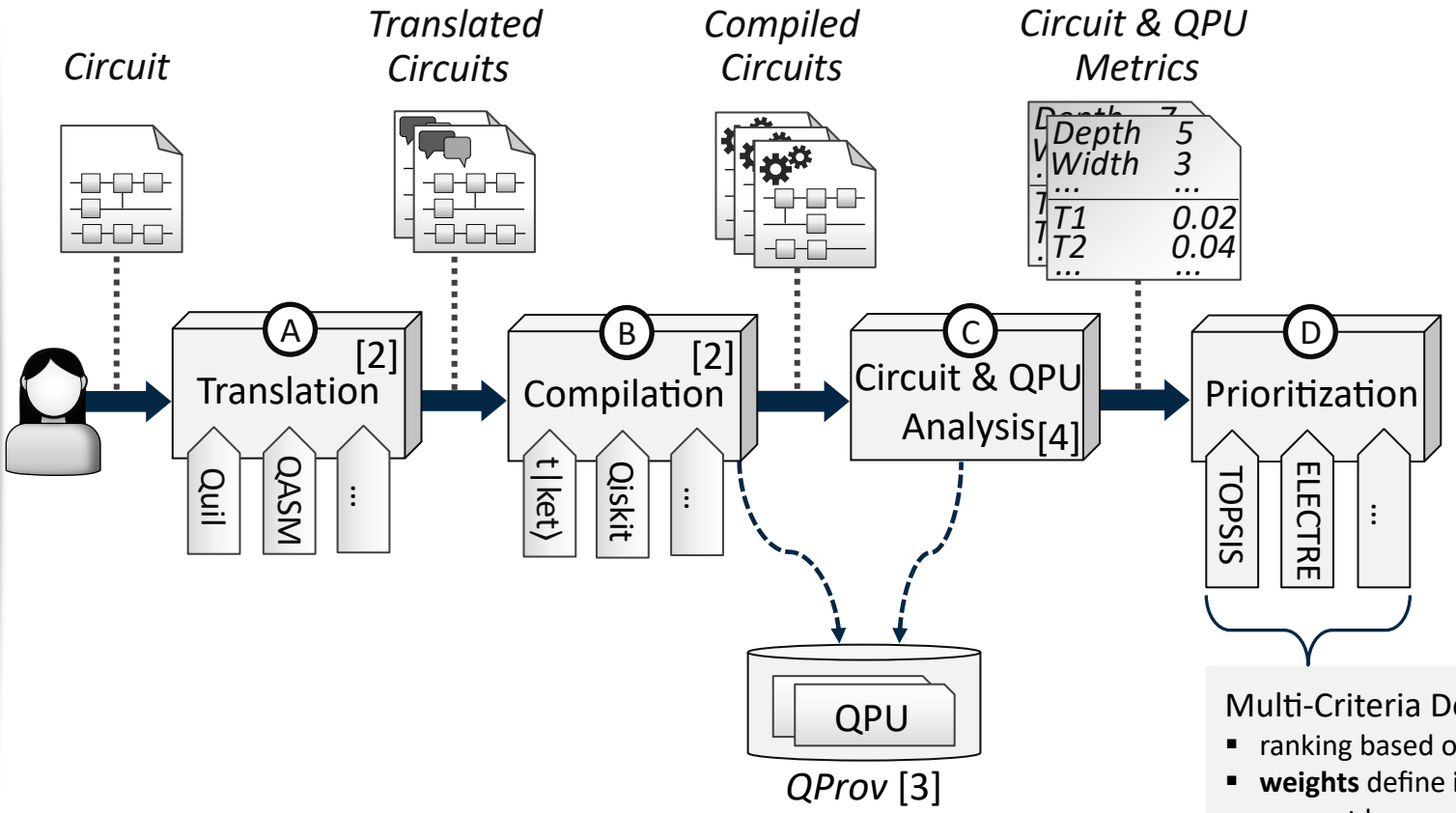

Multi-Criteria Decision Analysis (MCDA) methods

- ranking based on **multiple** metrics
- **weights** define **importance** of metrics
- e.g., set by user for their requirements

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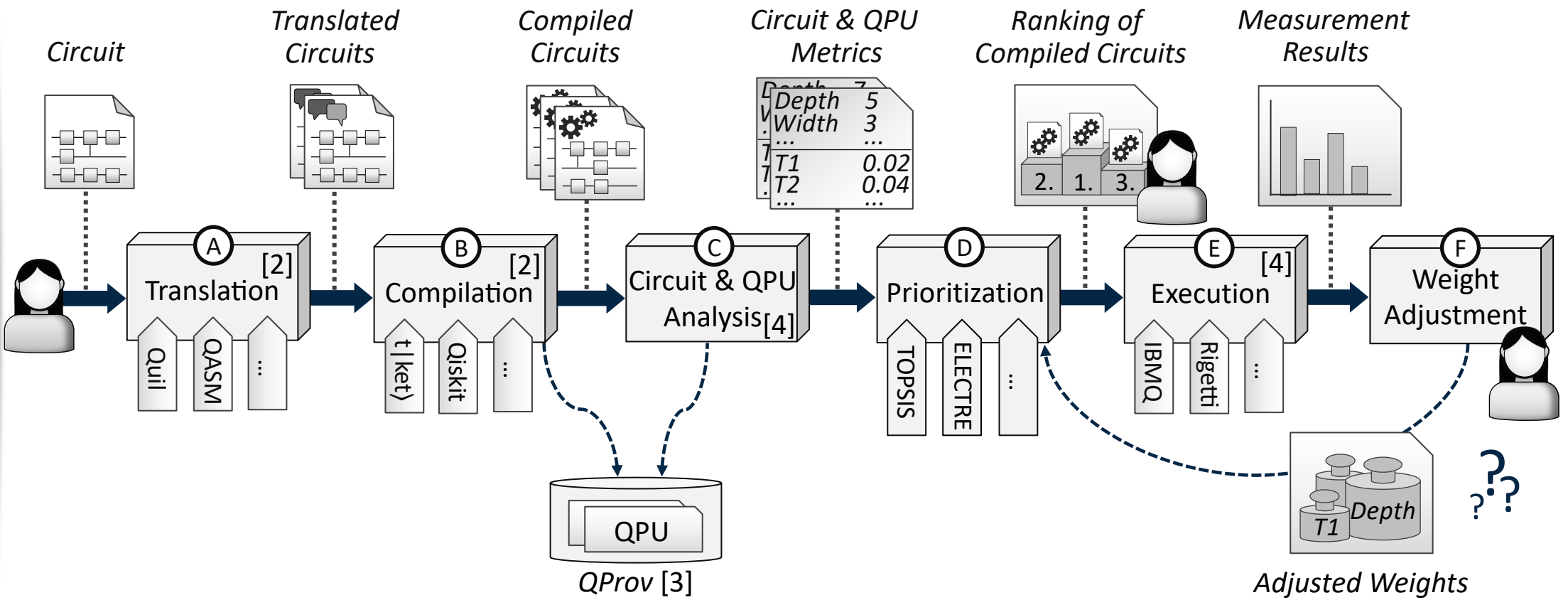

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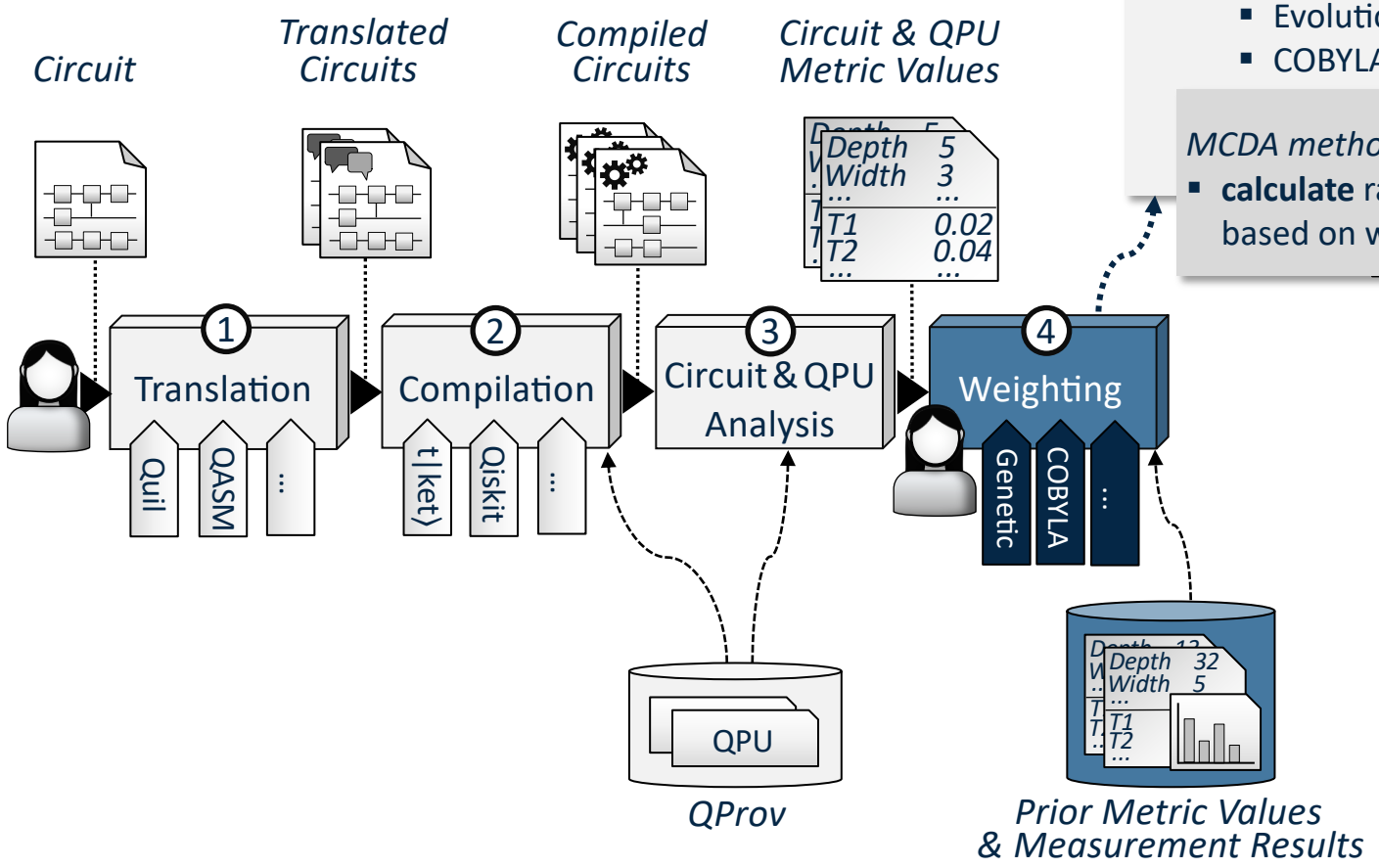
RQ1

How can the determination of **metric weights** be **automated**
to **prioritize** compiled quantum circuits and
associated quantum computers
targeting **precise results** of future quantum circuit executions?

Extended approach

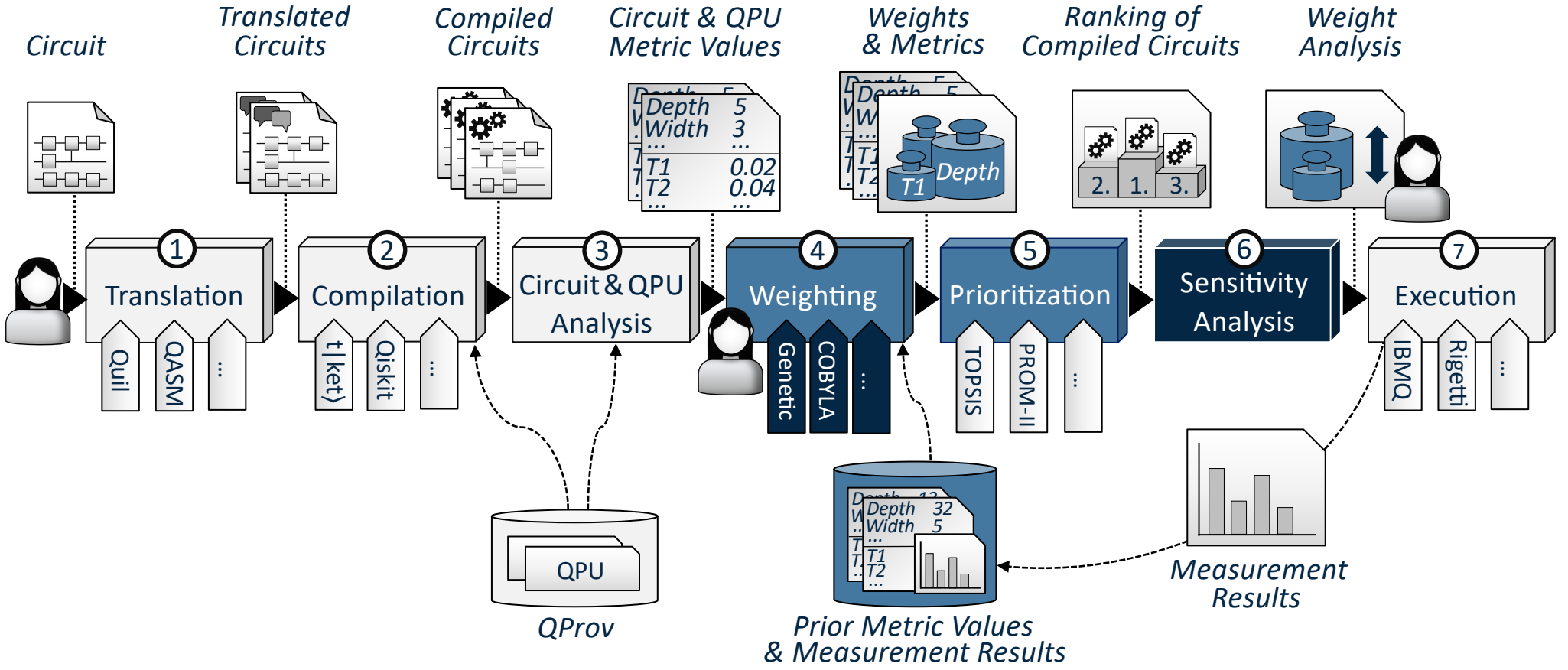


- optimizers
  - Genetic Algorithm
  - Evolution Strategy
  - COBYLA

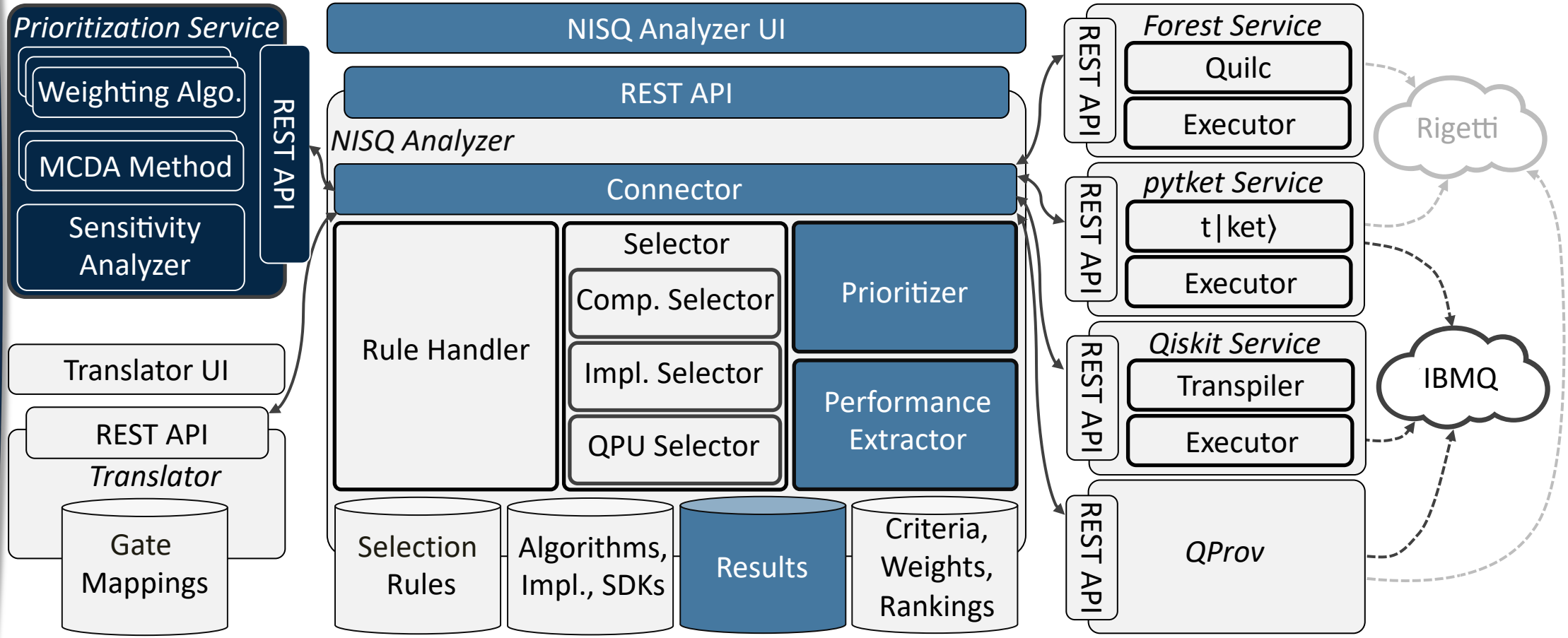
MCDA method:
- **calculate** rankings based on weights

Optimizer:
- **compare** rankings with histogram intersection values
- **adapt** weights

Extended approach



System architecture



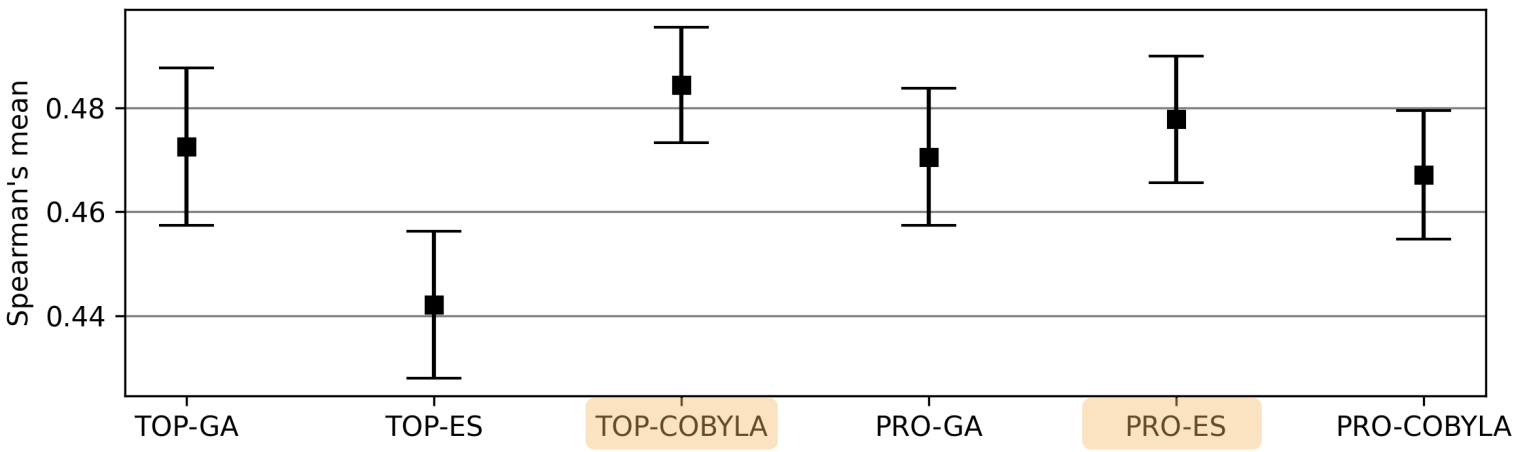
RQ2

Which quantum computer and quantum circuit **metrics** **influence** the **execution results** of compiled quantum circuits the most?

Case study – setup

- IBMQ 5-qubit QPUs & simulator
- Qiskit transpiler & t|ket⟩ compiler
- > 50 input circuits
  - 3 algorithmic circuits
  - randomized circuits with Clifford gates
  - ➢ > 220 compiled & executed circuits
- split circuits in 70 % training + 30 % test data
  - randomly
  - repeated 100 times
- (TOPSIS, PROMETHEE II) x (COBYLA, Genetic Algorithm, Evolution Strategy)

Case study – performance of MCDA + ML combinations



= 1: identical rankings

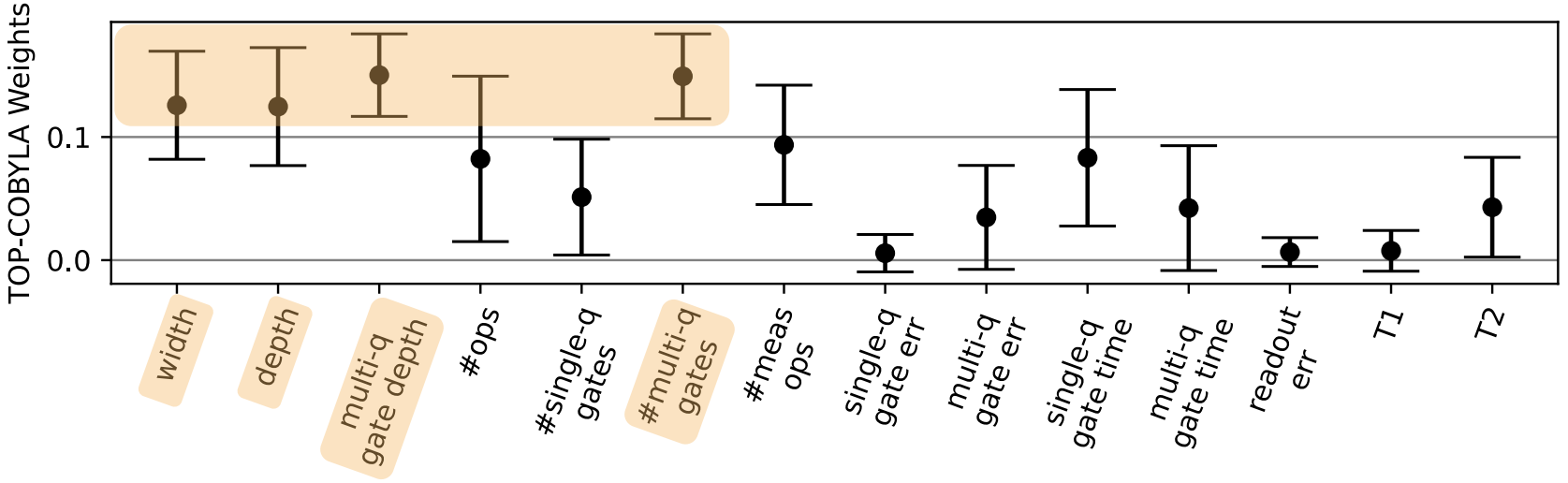
= 0: don't correlate

- performance evaluation with *Spearman rank correlation coefficient* [5]

- best performance
  - TOPSIS + COBYLA
  - PROMETHEE II + evolution strategy

[5] Spearman, C.: The Proof and Measurement of Association Between Two Things. Studies in individual differences: The search for intelligence. pp. 45–58 (1961). https://doi.org/10.1037/11491-005

Case study - avg. metric weights of TOPSIS + COBYLA

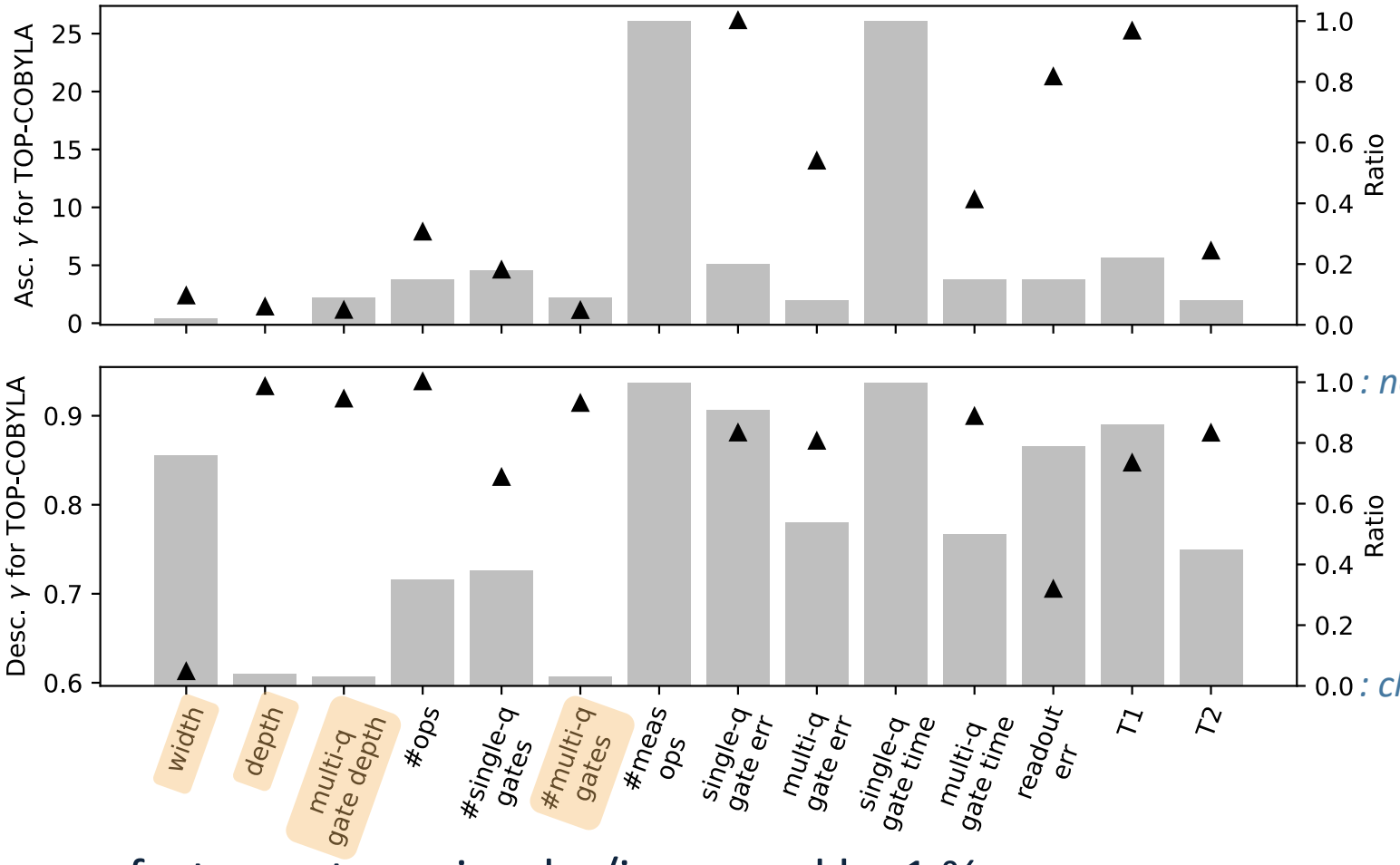


- *depth* & *number of multi-q-gates* influence result precision most
  - consider multiple metrics to estimate precision of execution results
  - consider different compilers

Case study – sensitivity analysis on weights of TOPSIS + COBYLA

$1 < \gamma \leq 1.01^{500}$

$1 > \gamma \geq 0.99^{500}$



: no change

: change always found

- disturbance factor γ step-wise de-/increased by 1 %
  - ▲: mean γ that changed rankings on avg.; **bar**: ratio
- metrics with high weights are, in general, more sensitive

Conclusion & future work

- limitations
  - not all shapes of circuits & existing QPUs covered
  - other machine learning & MCDA methods may perform better
    - ➢ results show importance of multi-qubit gates
- automated prioritization based on user's requirements
  - plug-in based, supports extensibility
  - estimates precise execution results
    - multiple metrics, different compilers & QPUs
- in the future
  - additional circuits, QPUs & metrics, e.g., monetary metrics
  - further MCDA & ML methods

Thank you!