Quantum computing for simulating high energy collisions

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Simulating high energy collisions with quantum computers

Towards a Quantum Computing Algorithm for Helicity Amplitudes and Parton Showers

Khadeejah Bepari, Sarah Malik, Michael Spannowsky, Simon Williams

arXiv:2010.00046

Phys. Rev. D 103, 076020 (2021)

A quantum walk approach to simulating parton showers

Khadeejah Bepari, Sarah Malik, Michael Spannowsky, Simon Williams

arxiv:2109.13975

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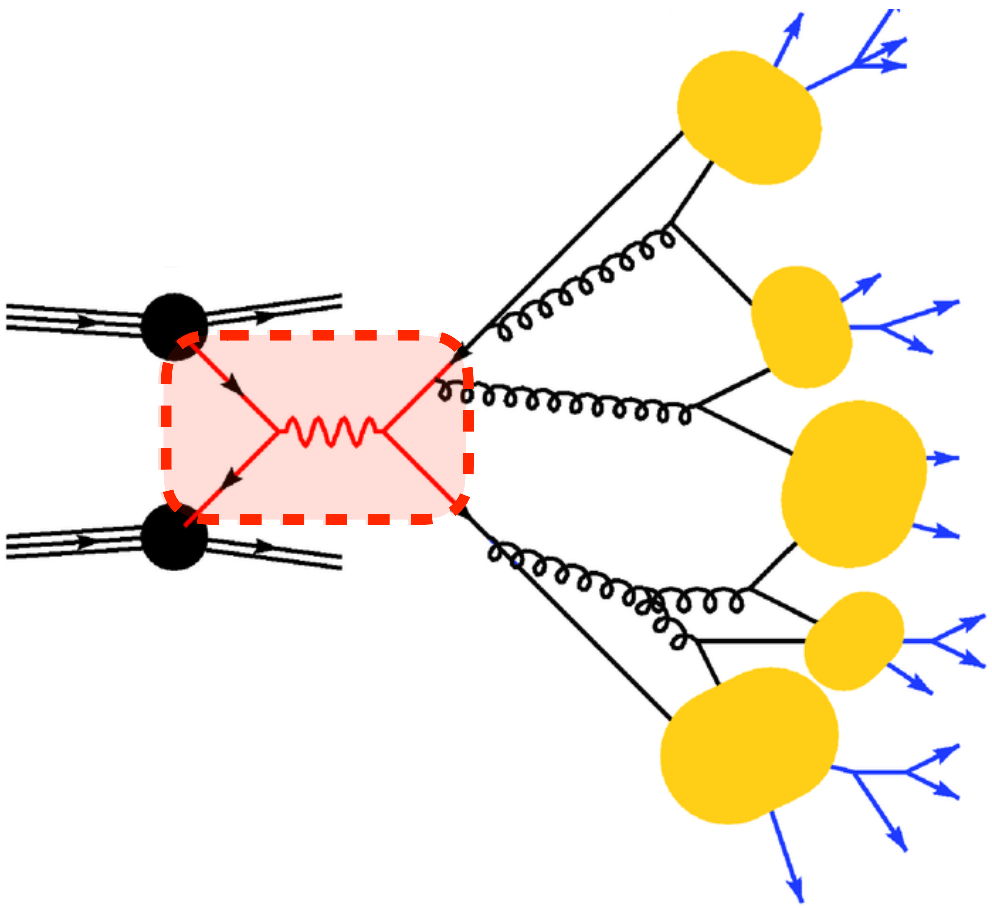
Calculating helicity amplitudes

arXiv:2010.00046

- Scattering amplitudes - **essential** for calculating predictions for collider experiments.



Spinor helicity formalism = tool for calculating scattering amplitudes much more efficiently than conventional approach

$$|p\rangle^{\dot{a}} = \sqrt{2E}\begin{pmatrix}\cos\frac{\theta}{2}\\ \sin\frac{\theta}{2}e^{i\phi}\end{pmatrix} \xrightarrow{\text{Equivalence between spinors and qubits}} |\psi\rangle = \begin{pmatrix}\cos\frac{\theta}{2}\\ \sin\frac{\theta}{2}e^{i\phi}\end{pmatrix}$$

Calculation of helicity amplitudes follows same structure as a quantum computing algorithm; quantum operators act on an initial state to transform it into a state that can be measured

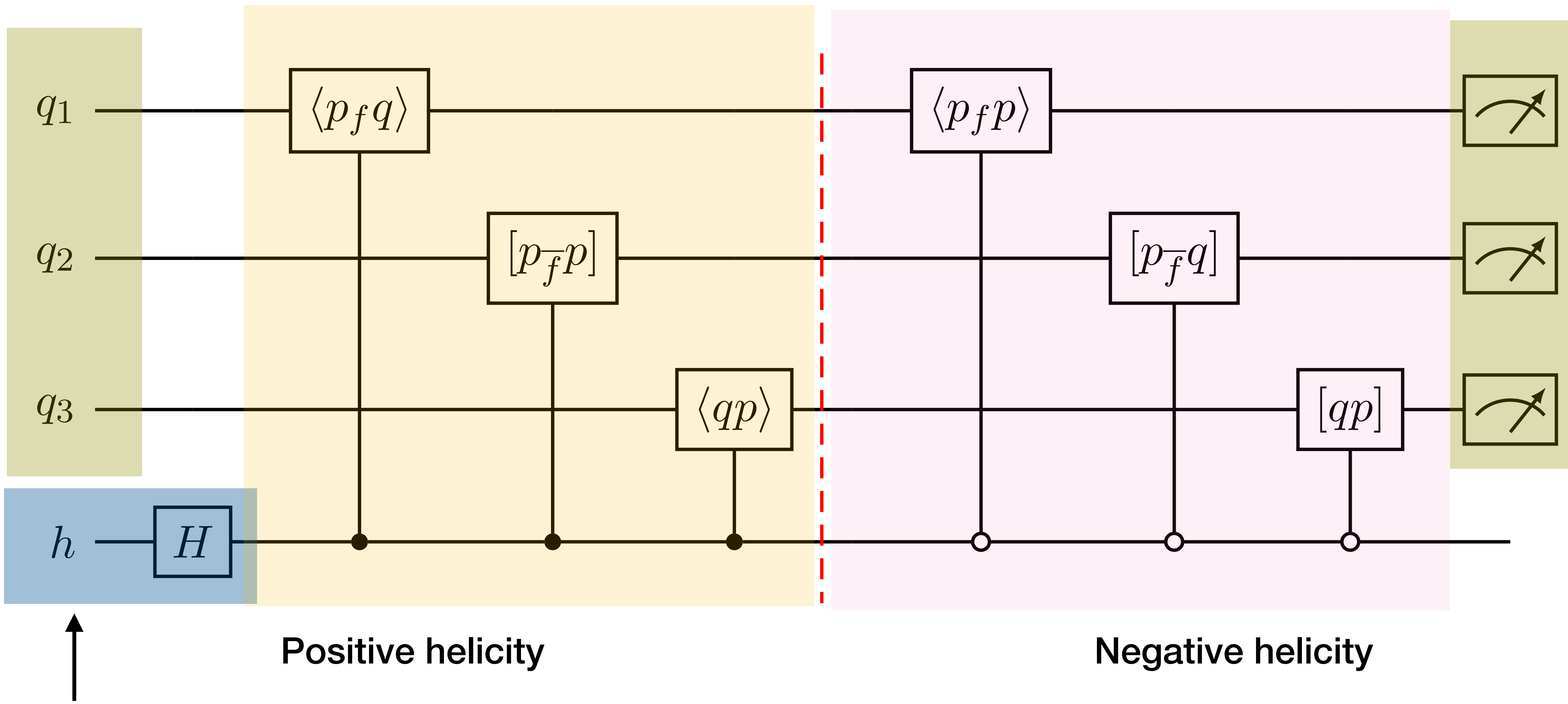
Operators acting on spinors == series of quantum gates applied to qubits

Helicity amplitude circuit

arXiv:2010.00046

$$\mathcal{M}_+ = -\sqrt{2}\frac{\langle p_f q\rangle [p_{\bar{f}} p]}{\langle qp\rangle}, \qquad \mathcal{M}_- = -\sqrt{2}\frac{\langle p_f p\rangle [p_{\bar{f}} q]}{[qp]}.$$

qubits calculate the 3 scalar products for each helicity amplitude



Measure these qubits at end of algorithm

Helicity amplitude algorithm exploit equivalence of spinors and qubits, encodes operators as unitary operations in a quantum circuit. Using Hadamard gates to introduce a superposition between helicity qubits, it enables simultaneous calculation of the + and − helicity states of each particle AND the s- and t-channel amplitudes for a 2→2 process

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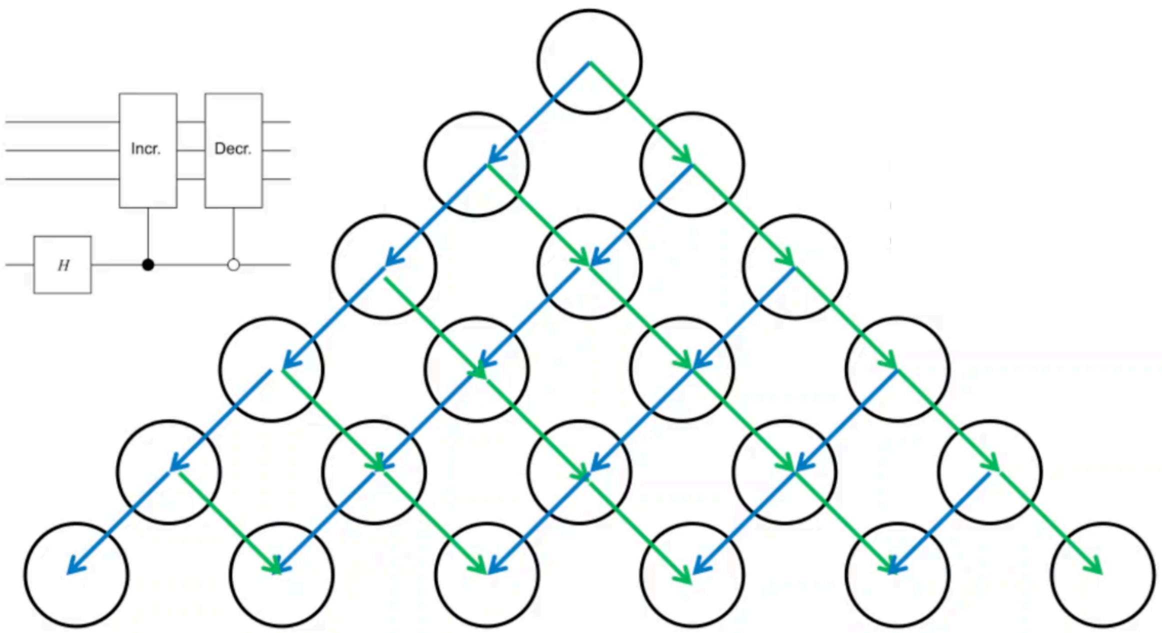
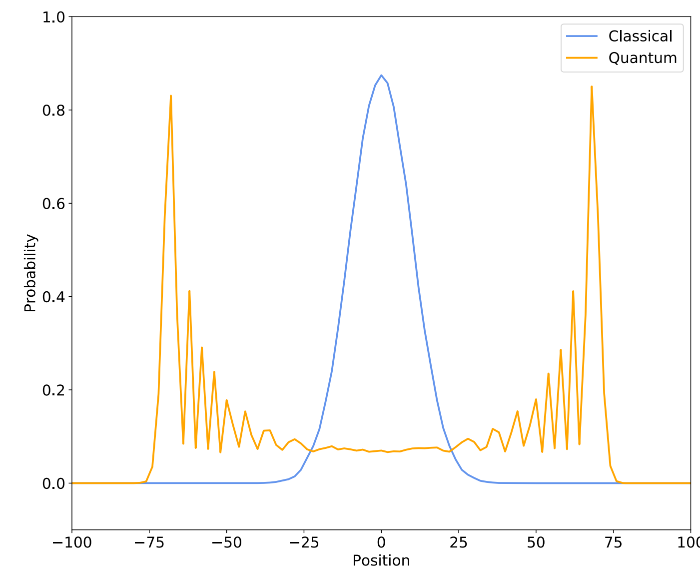
Quantum walk approach to parton showers

arXiv:2109.13975

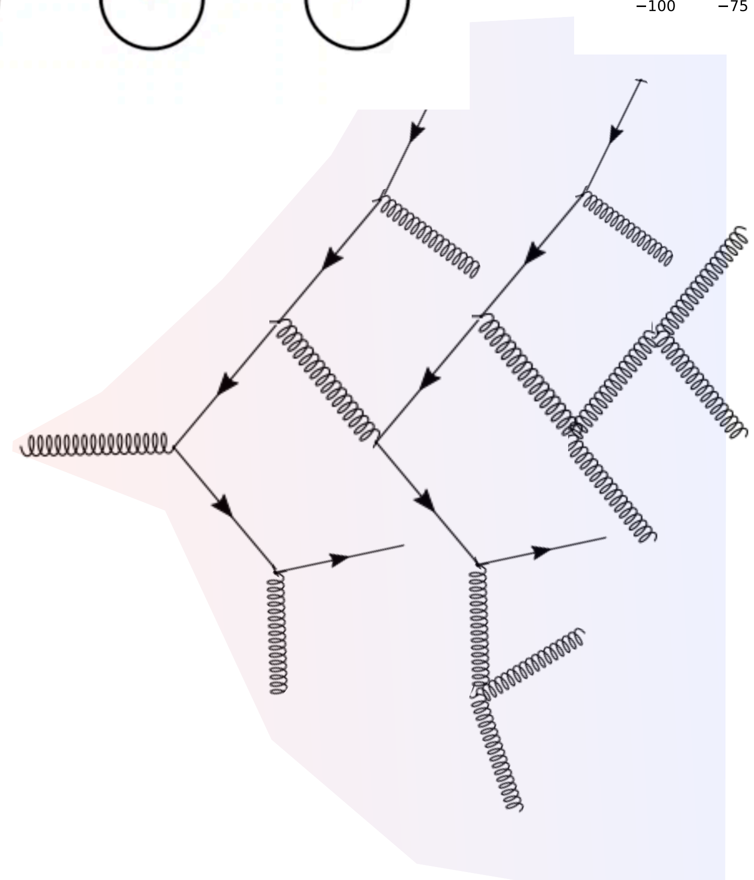
A novel quantum walk approach to simulating parton showers on a quantum computer.

- emission probabilities implemented as coin flip for walker
- particle emissions to either gluons or quark pairs = movement of the walker in 2D





Quantum walker propagates quadratically faster than classical walker



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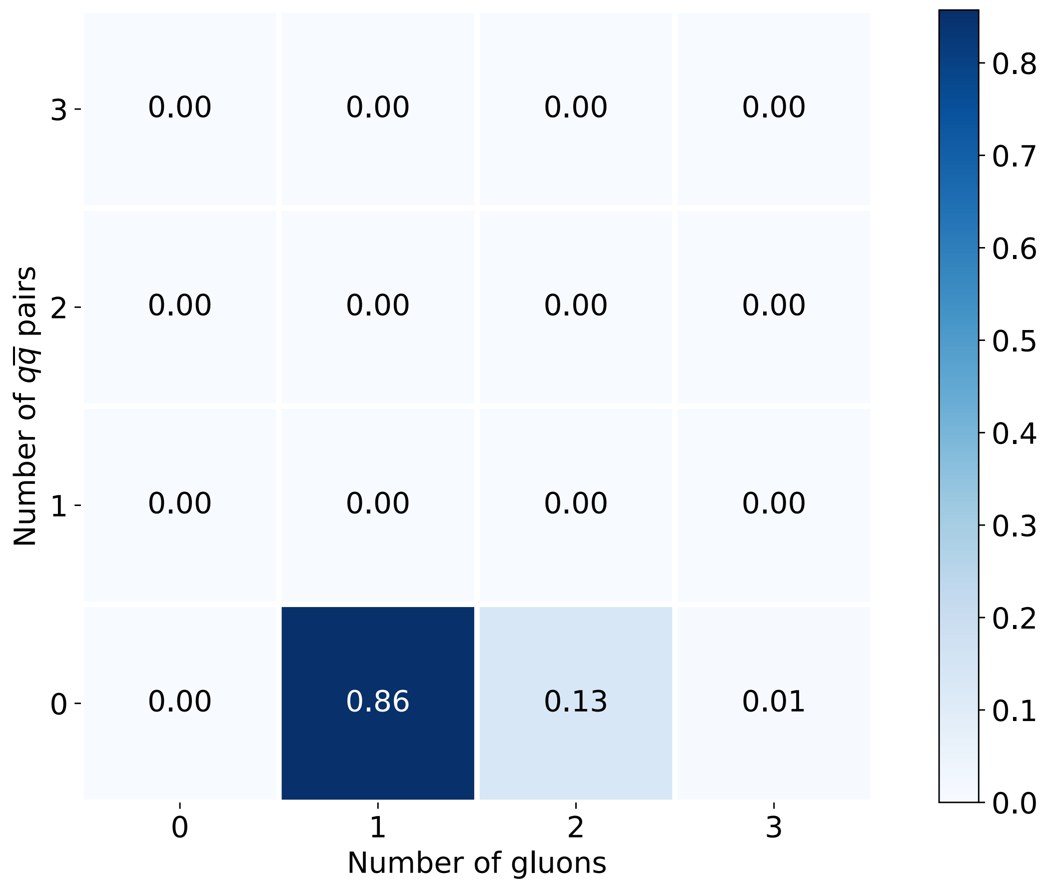

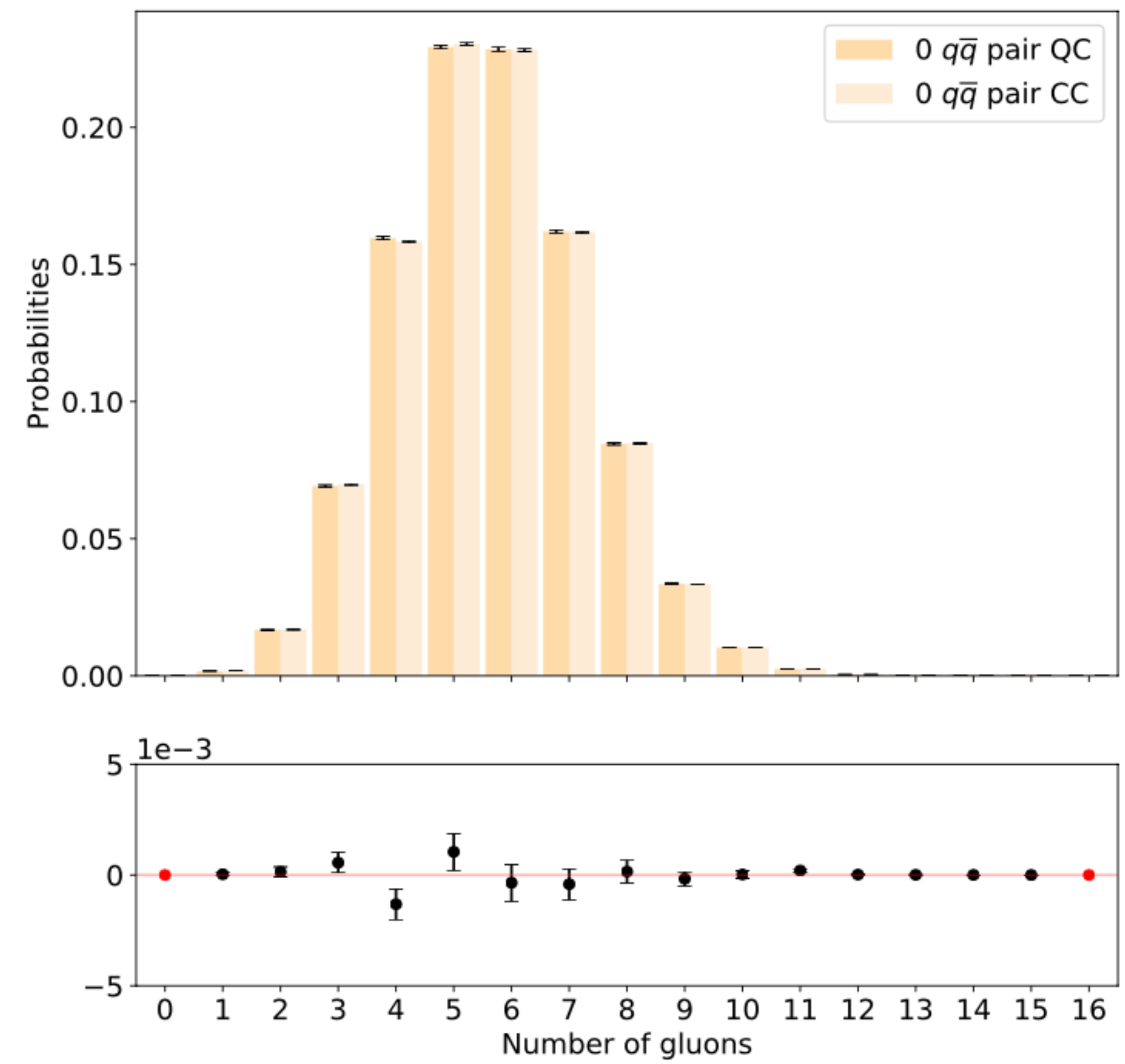

- Quantum walk paradigm offers a natural and much more efficient approach to simulating parton showers on quantum devices.
- Reframing parton shower within quantum walk framework dramatically increases the number of steps that can be simulated compared to previous quantum algorithms (31 steps with 16 qubits vs 2-step parton shower with 31 qubits)

Summary/thoughts

Current and near-term devices are excellent testbeds for proof-of-principle studies.

Porting over our classical algorithms on quantum computers may not optimally exploit the power of QC. Need a conceptual shift in the way we think about implementing problems on these devices.

Where else can we use quantum walks in High Energy Physics? Track reconstruction, jet clustering? Event classification?

Practical limitation : currently only have access to public devices which have a small number of qubits.

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