**Snowmass LOI: Front-form calculations on near-term and far-future quantum computers.**

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Over the last decade quantum algorithms for quantum simulation of electronic structure have become accepted as the most promising early application of quantum computing. They form a major focus of both Google and IBMs commercial efforts to construct a medium-scale quantum computer. The refinement of these algorithms has involved the development of numerous new quantum algorithmic techniques and small-scale experimental demonstrations in various quantum computing hardware platforms. Quantum algorithms for HEP problems, including algorithms for the simulation of quantum field theory, remain in a more nascent state. The algorithms proposed to date require many more error-corrected qubits than are likely to be available in the foreseeable future [6].

Can the ideas explored for quantum chemistry over the last 10 years be used or adapted to reduce the resource requirements for simulating QFT? Fortunately we can be guided by Wilson, who noted the possibly fruitful relationship between computational approaches to chemistry and gauge theory in 1990 [13]. The use of compact basis function representations in chemistry contrasts strongly with the use of lattice regulators for QCD [3]. Wilson proposed that the light front basis [4, 12, 2, 10, 1] could provide the right formulation for such a basis function approach.

Some of us recently investigated this idea as a route to use optimal quantum simulation methods for the simulation of quantum field theories in the light front [7]. We investigated in detail a simple example in $1 + 1$ dimensions containing coupled fermion and scalar fields [9]. We developed an algorithm which is optimal in both qubits and gates, where by 'optimal' we mean asymptotic scaling in momentum cutoffs, Hamiltonian sparsity, Hamiltonian norm, and error. This allowed us to significantly reduce the necessary computational resources as compared with the space-time lattices used in [6].

The algorithms proposed in [7] require a fault tolerant quantum computer for their implementation. Quantities that may be computed include the parton distribution functions (PDFs) of composite particles. The advantage of using the light front is that the qubit requirements are reduced by around two orders of magnitude [7]. This means that the quantum computer required is comparable in logical qubit requirements to that for Shor's algorithm. Such machines have been the subject of serious engineering studies [5].

The light-front also allows us to map problems in HEP and NP to noisy intermediate scale quantum (NISQ) devices. This is the topic on which some of us are currently working [8]. The basis light-front approach [11] allows us to reduce the quantum resources required for calculations to those suitable for the current era of NISQ devices, indeed we have already performed some example calculations using the IBM quantum computers [8].

**Summary:** The light-front approach is a very promising avenue for developing applications of quantum computers to quantum field theory, enabling one to get most of the available quantum-computational resources. Such computations may be performed on either NISQ devices or future fault-tolerant quantum computers.

# References


[1] Stanley J. Brodsky, Hans-Christian Pauli, and Stephen S. Pinsky. Quantum chromodynamics and other field theories on the light cone. *Phys. Rep.*, 301(4):299 – 486, 1998.

[2] J. Carbonell, B. Desplanques, V.A. Karmanov, and J.-F. Mathiot. Explicitly covariant light-front dynamics and relativistic few-body systems. *Phys. Rep.*, 300(5):215 – 347, 1998.

[3] Michael Creutz. *Quarks, gluons and lattices*, volume 8. Cambridge University Press, 1985.

[4] P. A. M. Dirac. Forms of relativistic dynamics. *Rev. Mod. Phys.*, 21:392–399, 7 1949.

[5] Craig Gidney and Martin Ekerå. How to factor 2048 bit rsa integers in 8 hours using 20 million noisy qubits. 2019.

[6] Stephen P. Jordan, Keith S. M. Lee, and John Preskill. Quantum algorithms for quantum field theories. *Science*, 336(6085):1130–1133, 2012.

[7] M. Kreshchuk, William M. Kirby, Gary Goldstein, Hugo Beauchemin, and Peter J. Love. Quantum Simulation of Quantum Field Theory in the Light-Front Formulation. *arXiv:2002.04016*, 2020.

[8] Michael Kreshchuk, Shaoyang Jia, William M. Kirby, Gary Goldstein, James P. Vary, and Peter J. Love. Simulating high energy physics on NISQ devices using basis light-front quantization (manuscript in preparation). 2020.

[9] Hans-Christian Pauli and Stanley J. Brodsky. Solving field theory in one space and one time dimension. *Phys. Rev. D*, 32(8):1993–2000, 1985.

[10] Leonard Susskind. Model of self-induced strong interactions. *Phys. Rev.*, 165:1535–1546, 1968.

[11] J. P. Vary, H. Honkanen, Jun Li, P. Maris, S. J. Brodsky, A. Harindranath, G. F. de Teramond, P. Sternberg, E. G. Ng, and C. Yang. Hamiltonian light-front field theory in a basis function approach. *Phys. Rev. C*, 81:035205, 3 2010.

[12] Steven Weinberg. Dynamics at infinite momentum. *Phys. Rev.*, 150:1313–1318, 10 1966.

[13] Kenneth G Wilson. Ab initio quantum chemistry: A source of ideas for lattice gauge theorists. *Nucl. Phys. B – Proc. Suppl.*, 17:82–92, 1990.