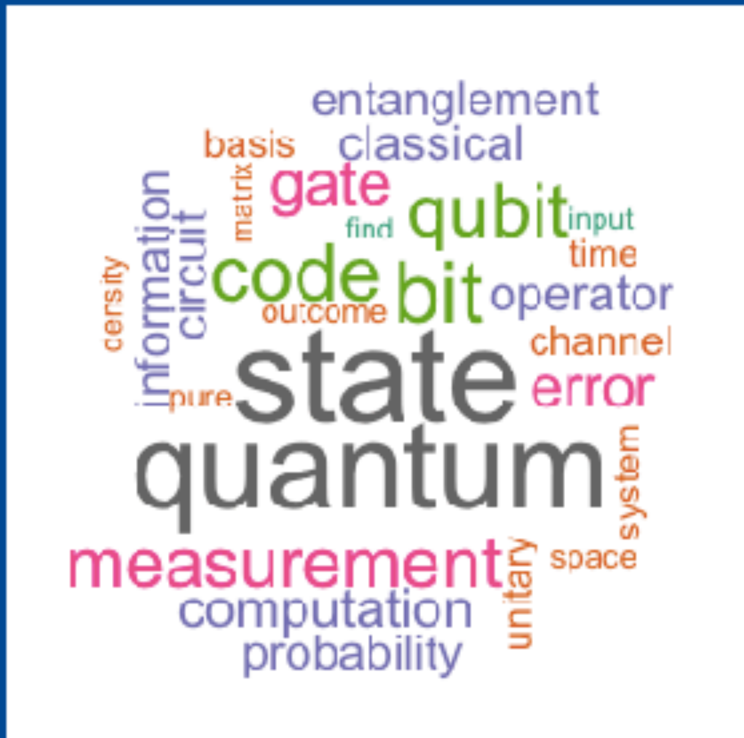
[https://indico.fnal.gov/event/15222/]



Near-term Applications of Quantum Computing

6-7 December 2017
Fermilab - Wilson Hall
US/Central timezone

Search

- Confirmed Speakers
- Timetable (with presentation material)
- Registration
  - Registration Form
- Participant List
- Accommodations
- General Information
- Wilson Hall

This meeting will bring together a small group of experts in high energy physics and quantum computing. The focus is to identify problems and algorithms that are expected to be feasible on quantum computing systems in the near term.

In particular, we hope to:

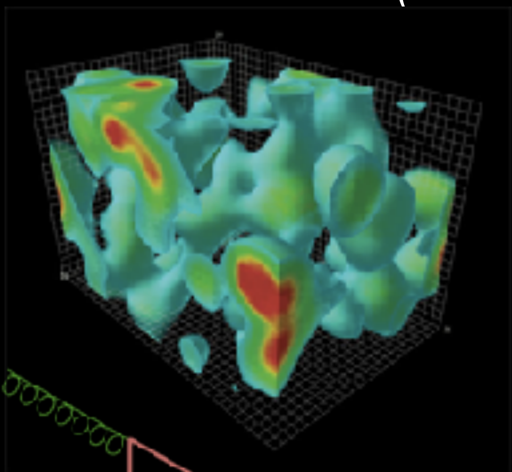
- discuss how different disciplines have cast their problems of interest into a form amenable to quantum computing
- discuss the complexity of problems that have been addressed with state-of-the art quantum architectures
- learn how quantum computing ties into the HEP computing model, and how existing code frameworks, languages and toolkits could be leveraged for HEP computing
- understand how current challenges in HEP computing / calculations (machine learning, dynamics of strongly interacting field theories and scattering amplitudes,experimental event reconstruction bottlenecks) could benefit from quantum algorithms and architectures, and how HEP could provide benchmark problems for quantum computers.

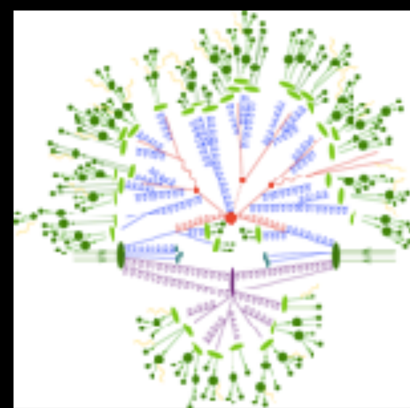
Summary Report

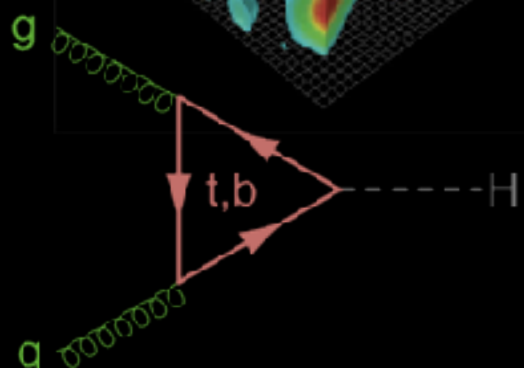
Kiel Howe, Fermilab, 3/5/18 for Jefferson Lab Computing Round Table
On behalf of the workshop organizers (Walter Giele, Stefan Prestel, James Simone, Marcela Carena, Joseph Lykken, K.H.)

Fermilab Theory

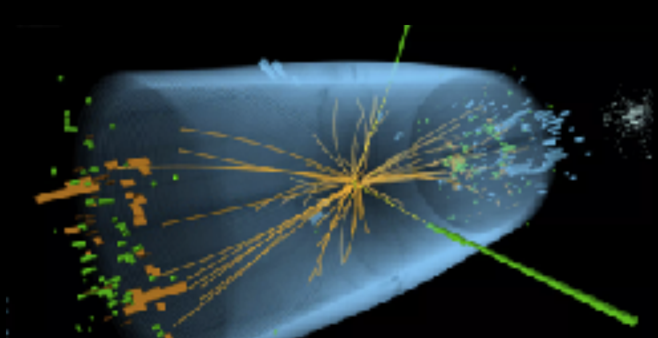
Finding the predictions of field theories (SM and Beyond)







backgrounds,
new searches,
new experiments

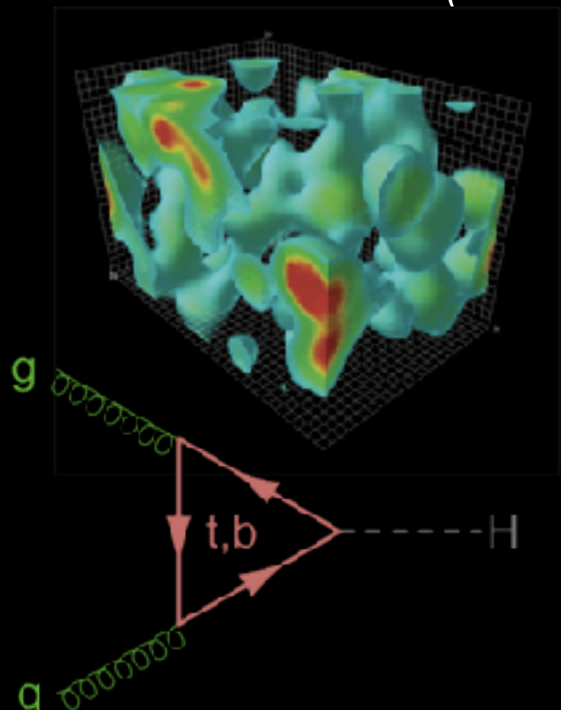


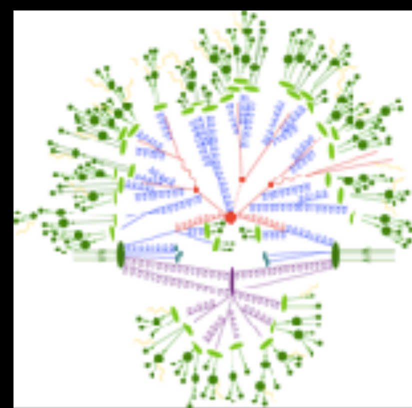
experiments on the universe

Fermilab Theory

QUANTUM

Finding the predictions of field theories (SM and Beyond)

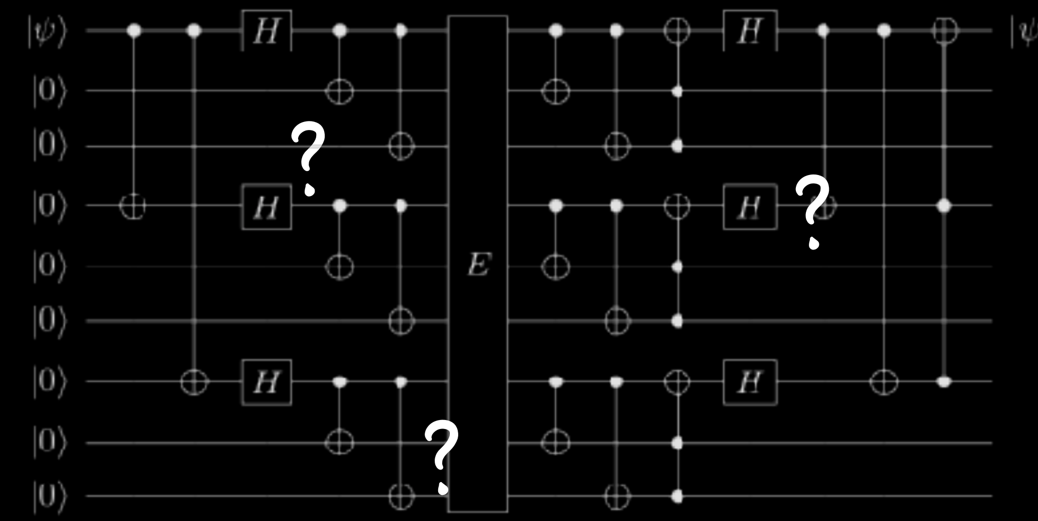




Quantum Gravity?

new BSM?

Mapping field theories (SM and Beyond) to controllable finite quantum systems

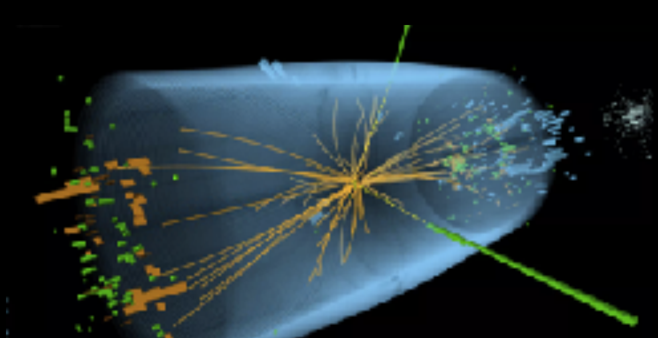


new algorithms?

backgrounds,
new searches,
new experiments

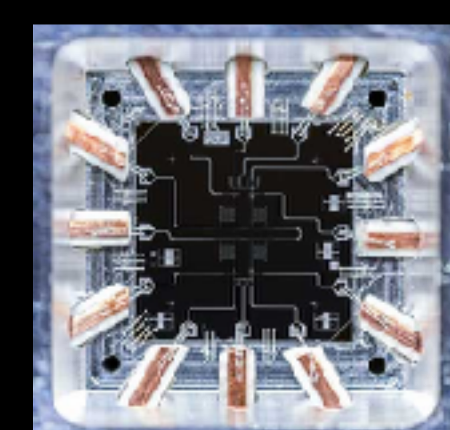
new algorithms?

new architectures?



experiments on the universe

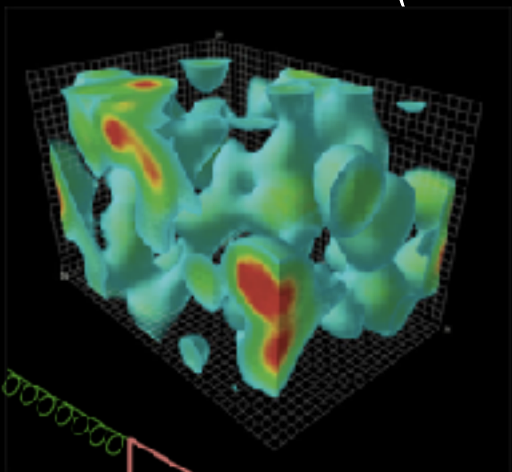
Quantum Sensors?

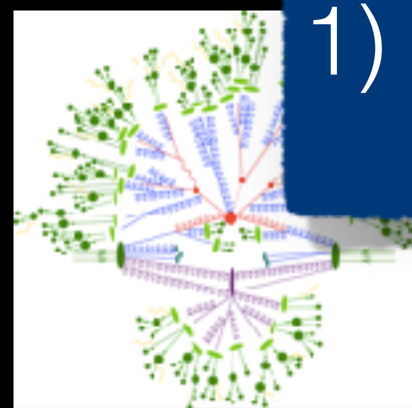


experiments on quantum hardware

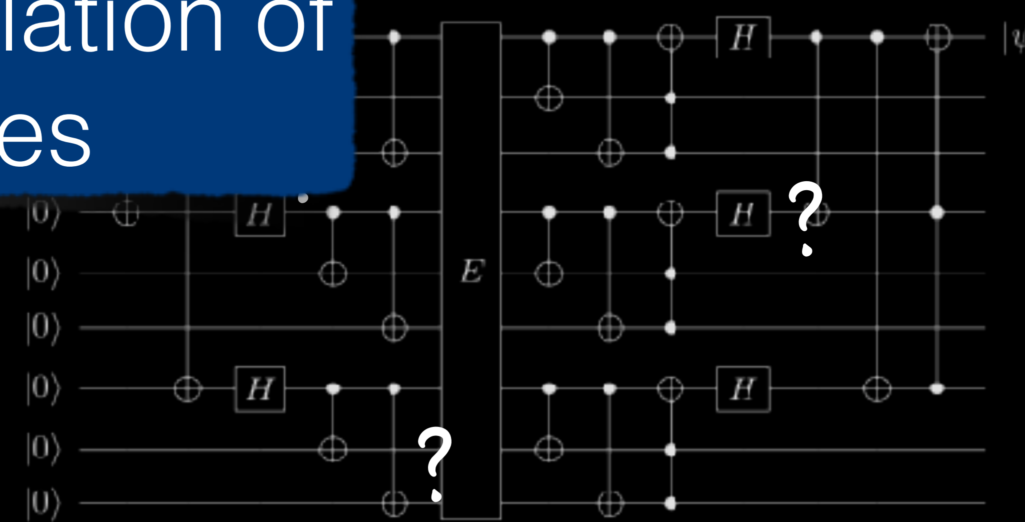
Fermilab ^QUANTUM Theory

Finding the predictions of field theories (SM and Beyond)





Mapping field theories (SM and Beyond) to controllable finite uantum systems



1) Quantum Simulation of Field Theories

2) Optimization problems on quantum annealers

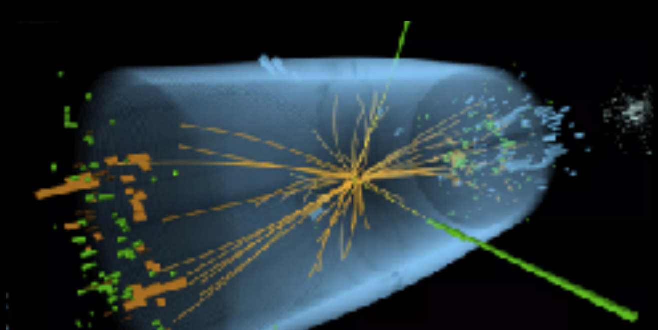
hms?

nds,
hes,
ments

3) Quantum Algorithm Development Stack

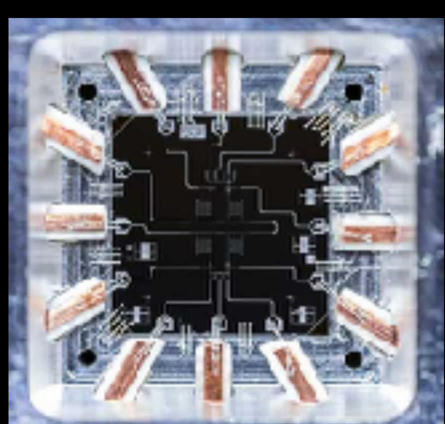
ithms?

ectures?



experiments on the universe

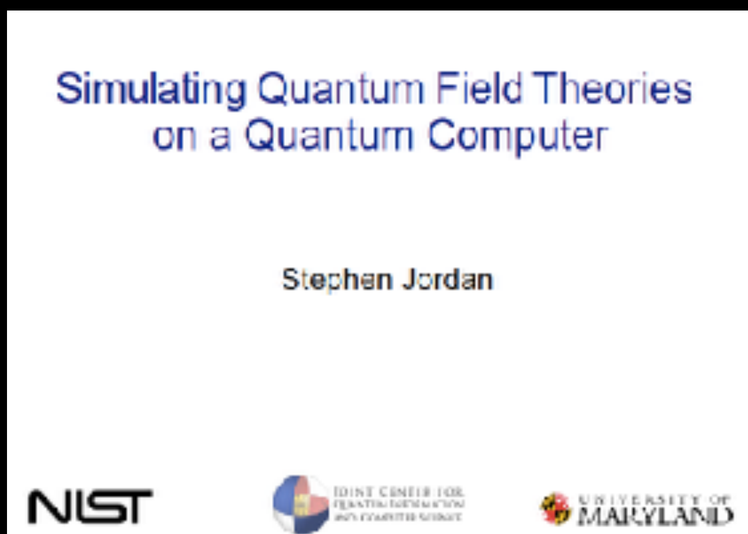
Quantum Sensors?



4) Fermilab Quantum Computing Testbed

ents on quantum hardware

Quantum Simulations of Field Theory…



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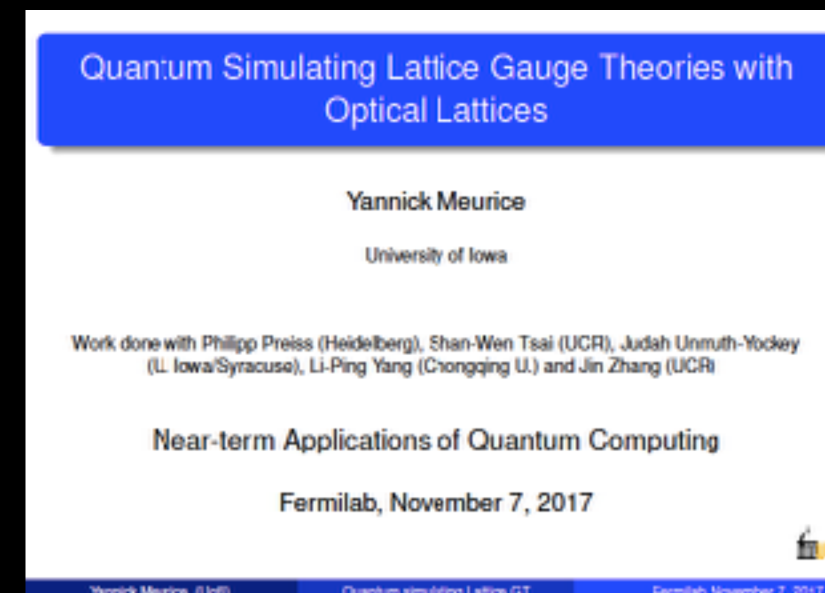


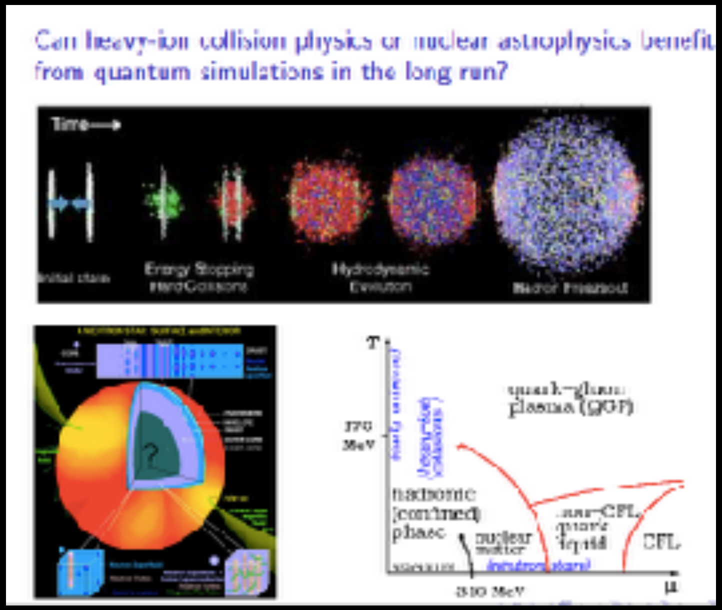
https://indico.fnal.gov/event/15222/contribution/13

universal quantum computer

analog quantum simulators

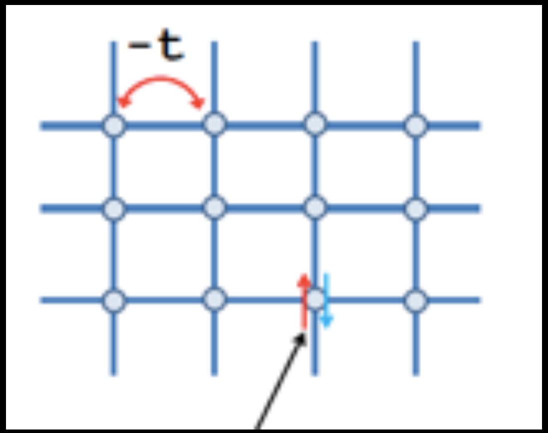
Quantum Advantage

- Fermionic Sign problem   *~~Lattice QCD~~*
  - Chemical potential (finite-density)
  - Real-time Processes (scattering, hadronization, fragmentation [jlab 12]…)
- Strong Coupling   *~~Perturbative Methods~~*



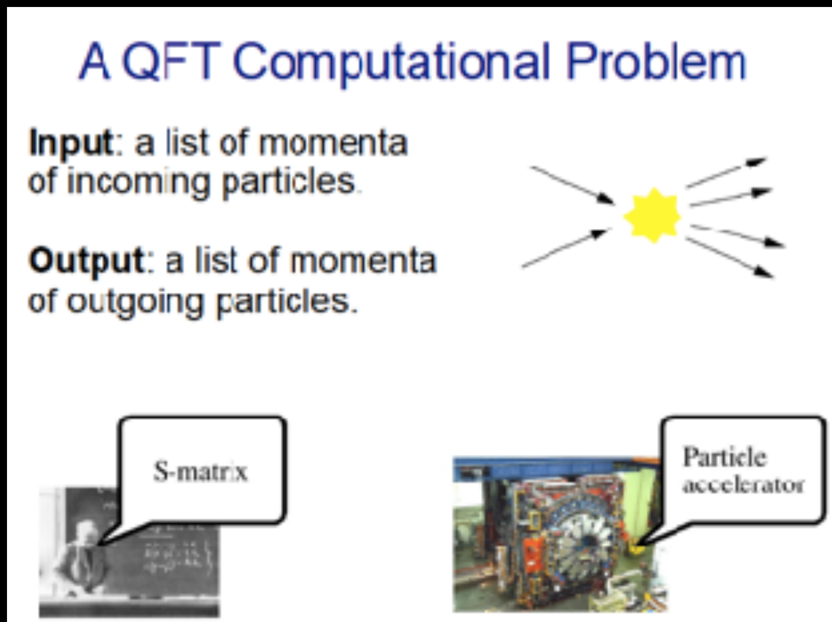
…and disadvantage

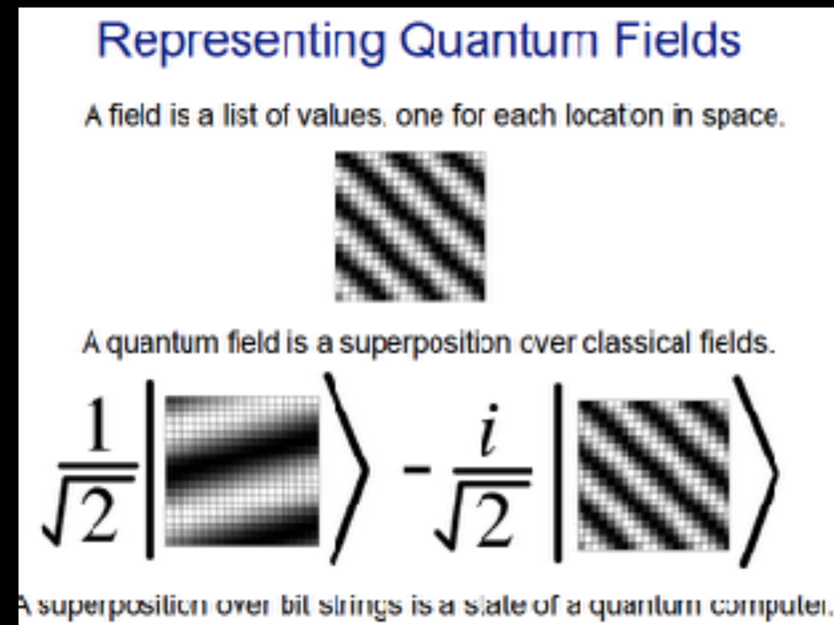
- Space(time) Latticization (same as lattice QCD)
  - analog = continuous time (optical lattice)
  - digital = discrete steps (gates / pulses)

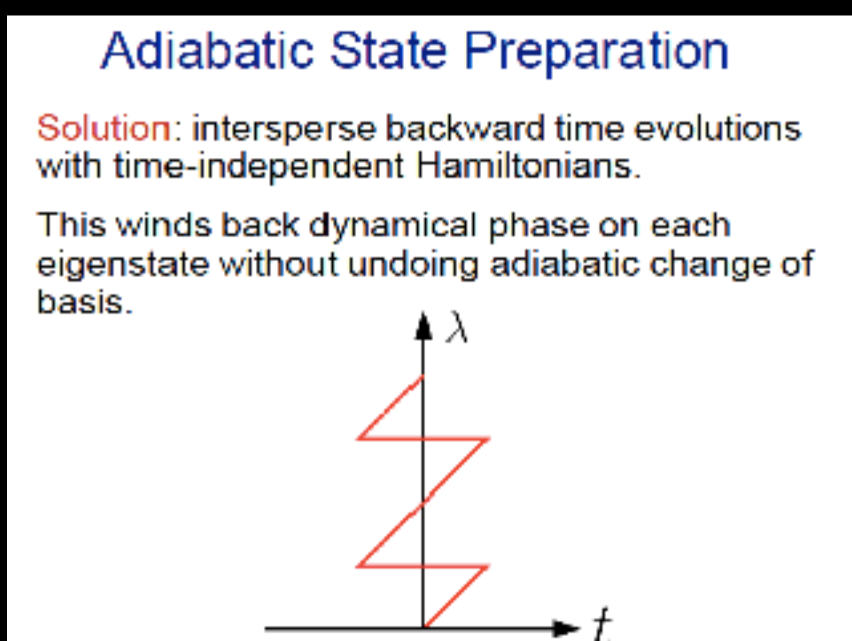


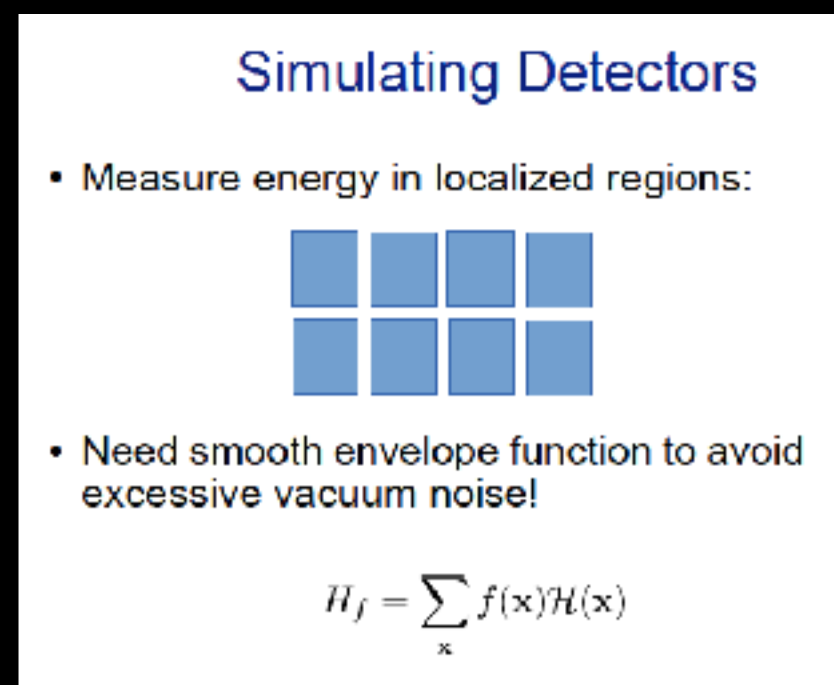
- Field/particle number space discretization
  - Quantum Link Models (Wiese),
  - Spin Truncation (Meurice),
  - Discrete Field Space (Jordan)

LHC in a Quantum Computer









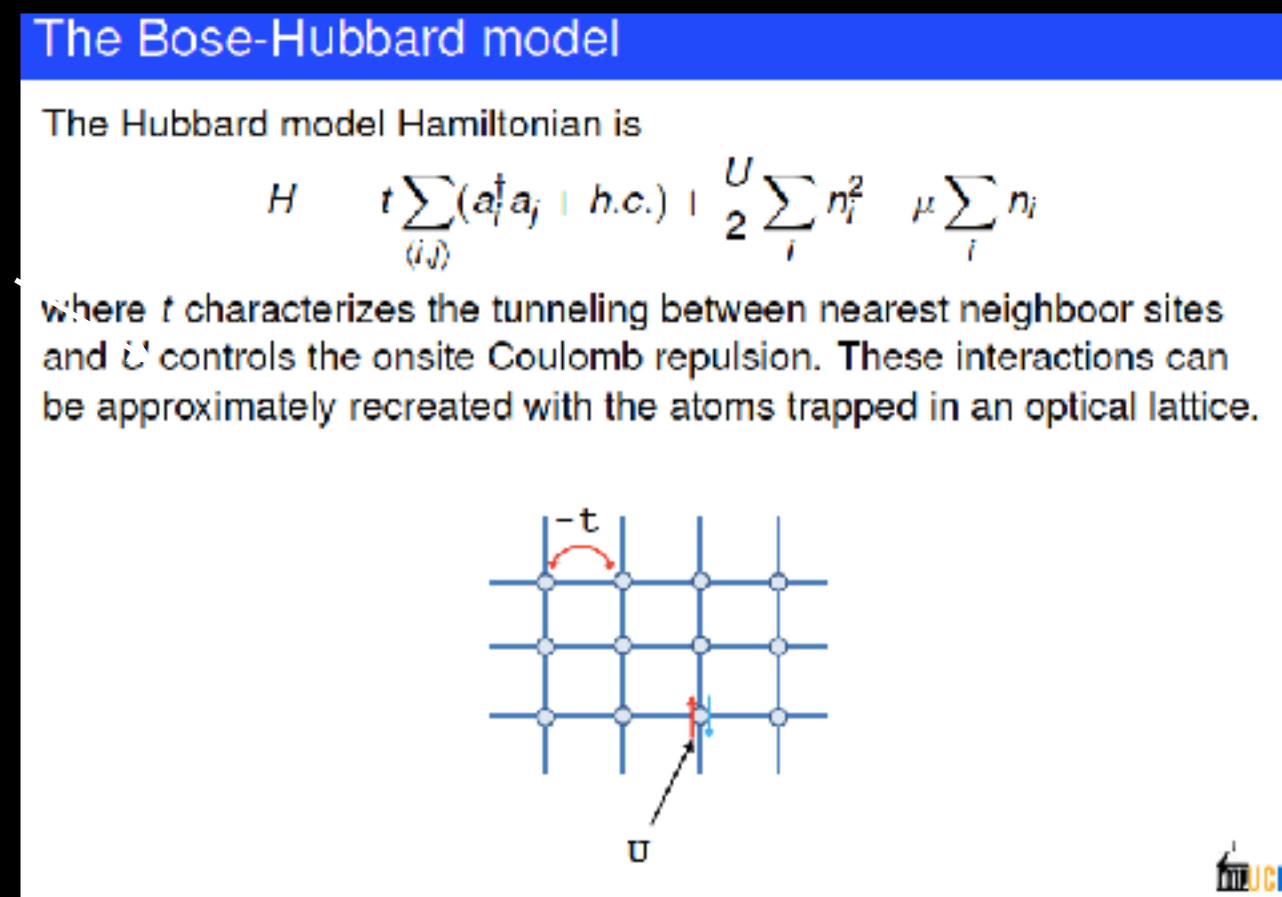
Quantum Info
inspired detectors
-> See Dan Carney's Talk
https://indico.fnal.gov/event/15222/contribution/10

Near-term? variation eigensolver & MERA

See also recent Fermilab work: https://arxiv.org/abs/1802.07347 A. Macridin, P. Spentzouris, J Amundson, R. Harnik

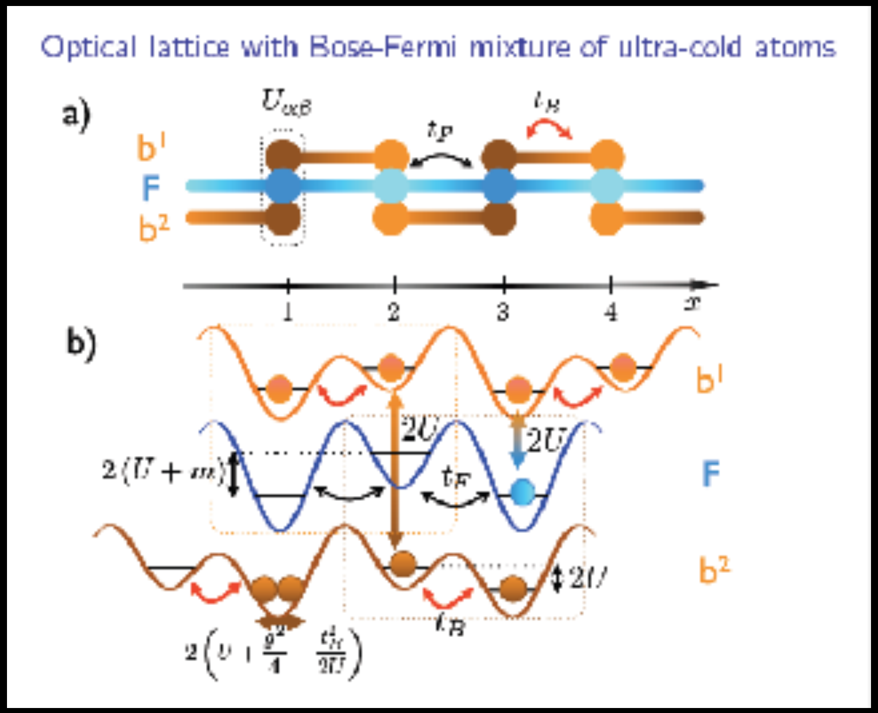
Optical Lattice

Meurice - Bloch Group



Meurice

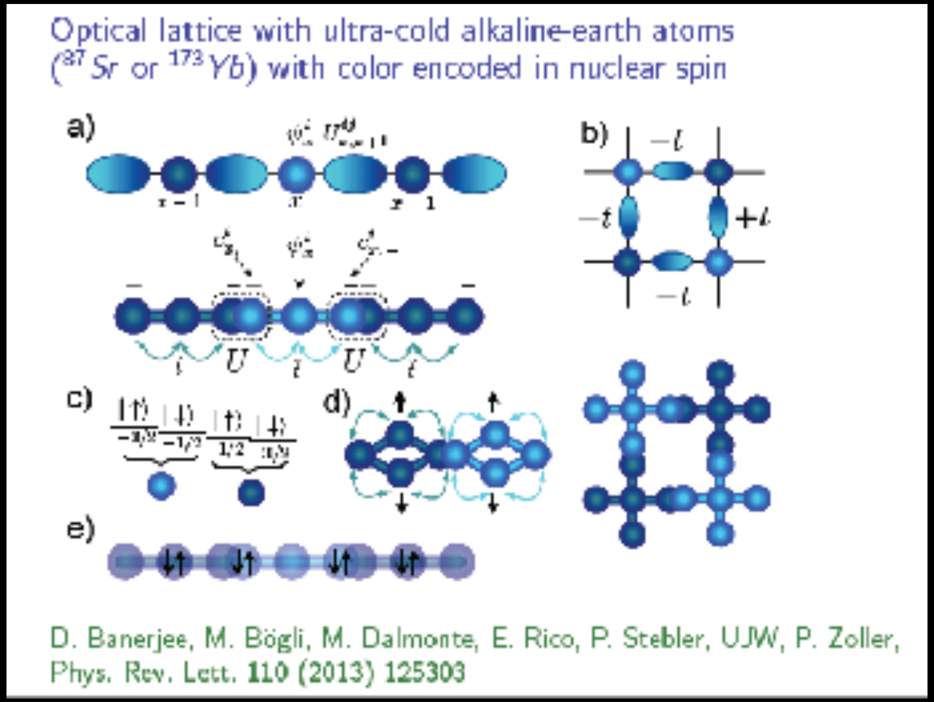
Fields as atoms



Weise

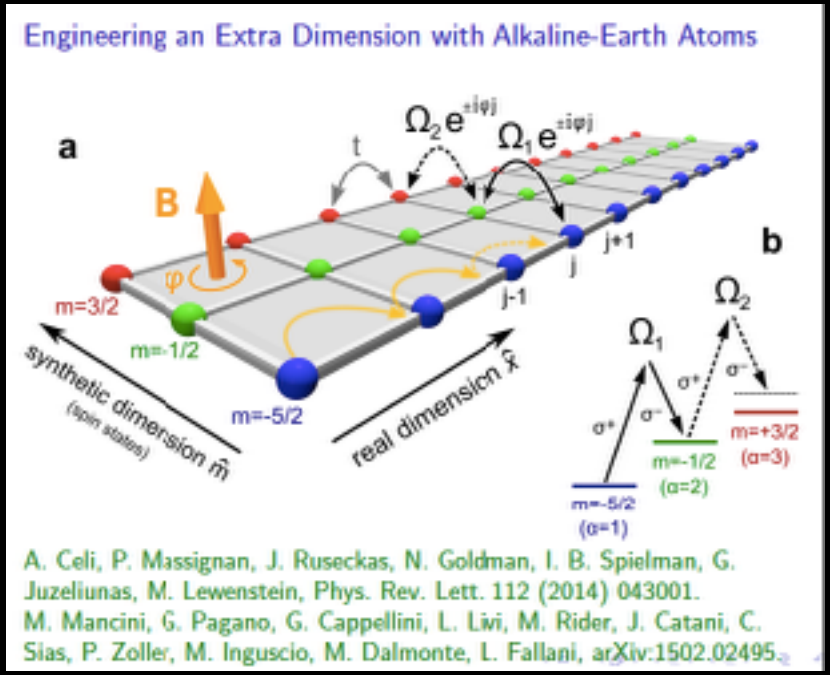
Mixtures of bosonic and fermonic atoms (U(1) link theory)

Weise



Encoding non-abelian interactions in spin

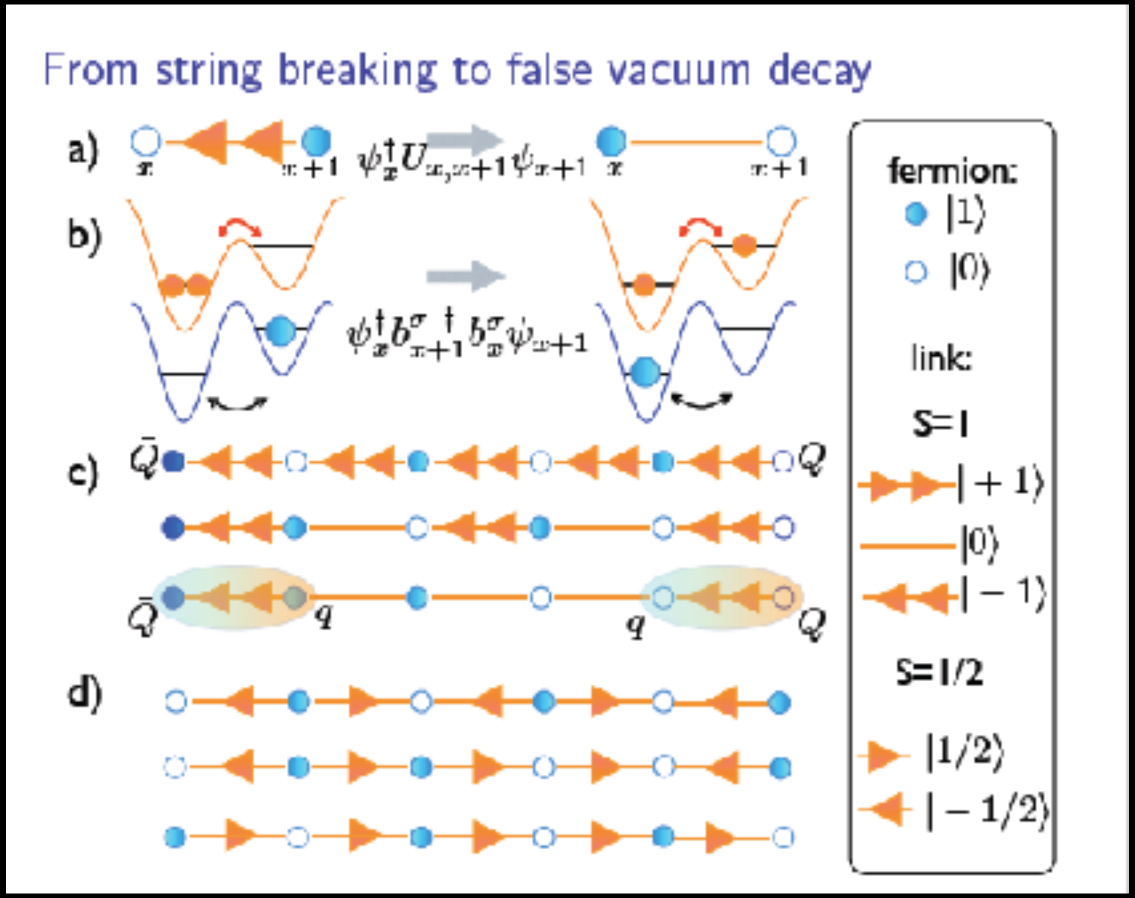
Weise



Encoding extra dimensions in spin

Toy Problems

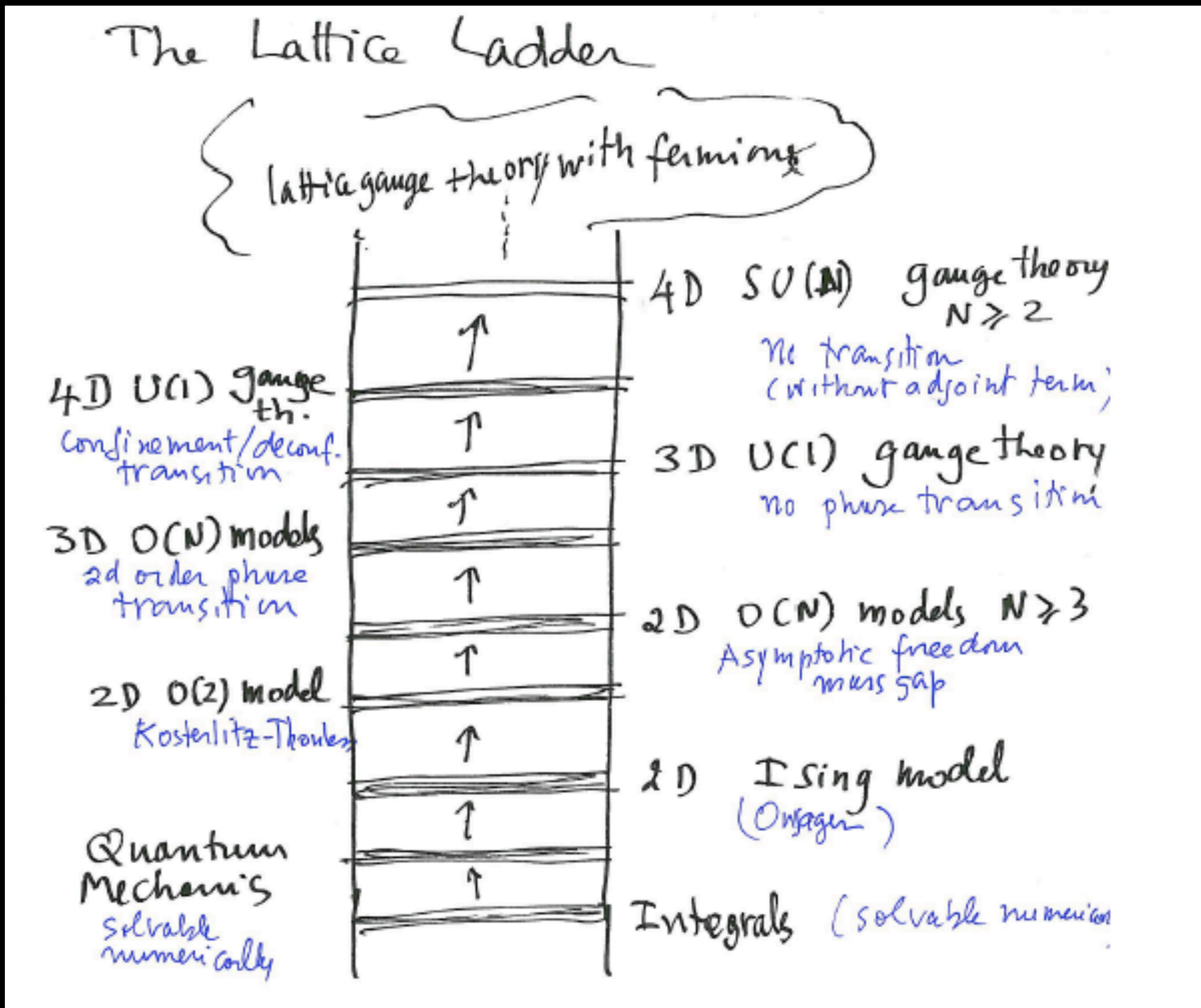
“Real-time evolution of gauge string breaking”



Weise

Toy Model + Toy Gauge Theory -> Real Problem + SU(3)

Ladder to the future…



Meurice

Meurice

“Large optical lattices (L~1000) are part of the future”

Optimization Problems on Quantum Annealers

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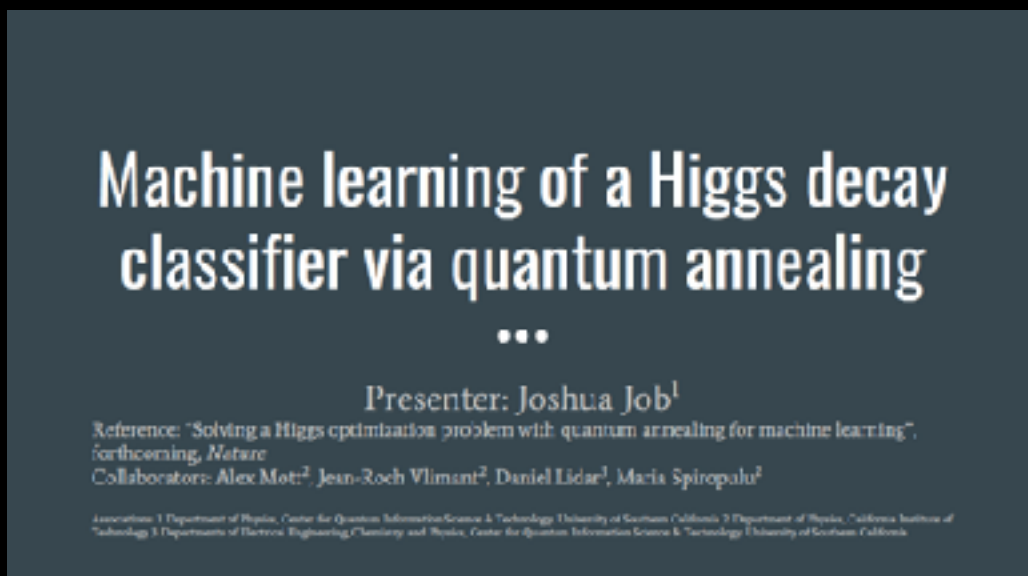
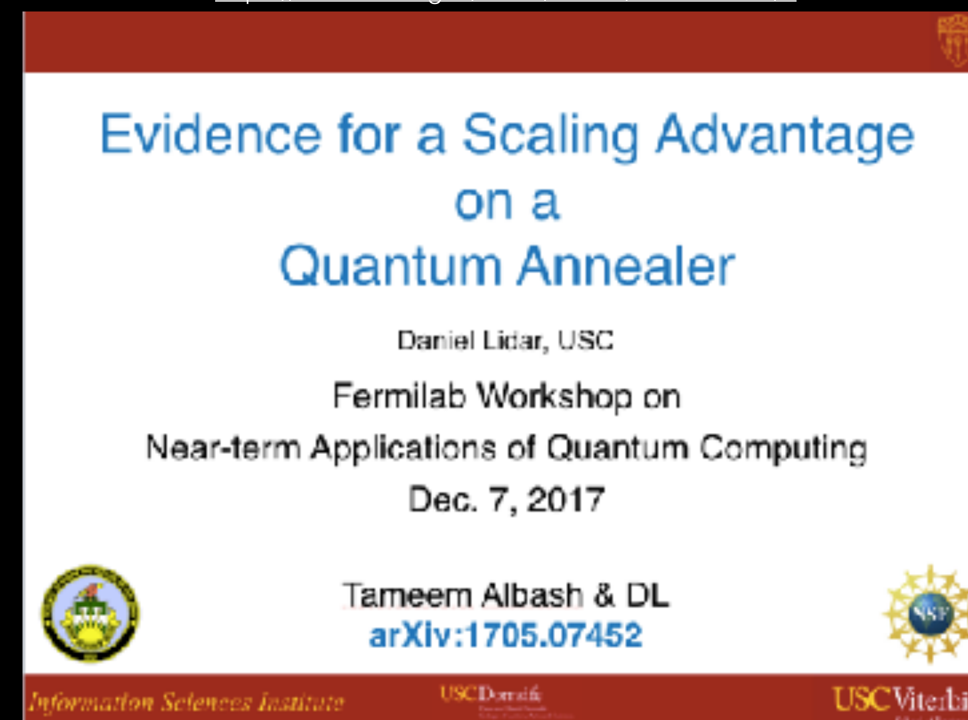


Can the D-wave architecture work for real HEP problems?

Yes

https://indico.fnal.gov/event/15222/contribution/6

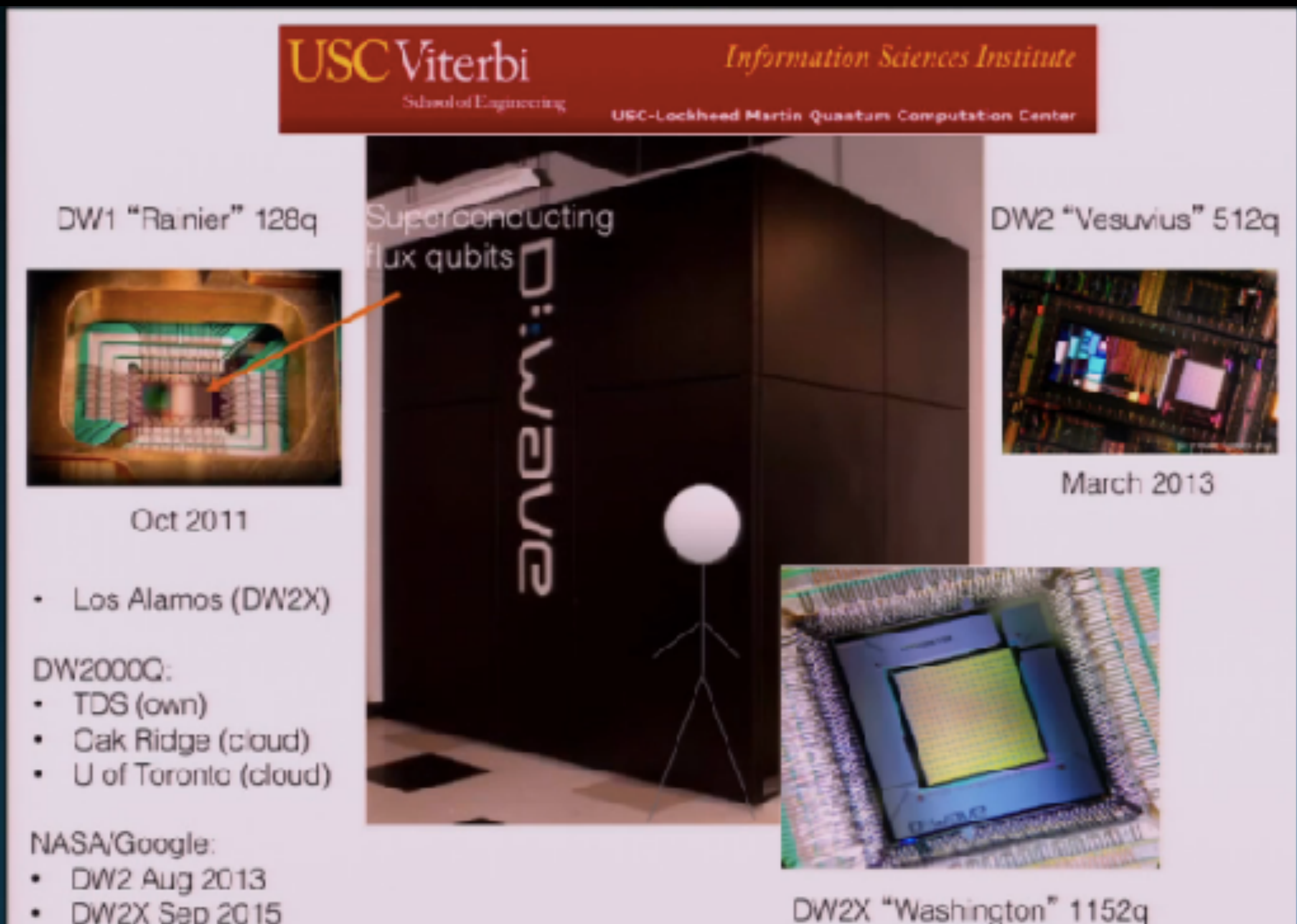
https://indico.fnal.gov/event/15222/contribution/9



Will it be worth putting HEP problems on the D-wave?

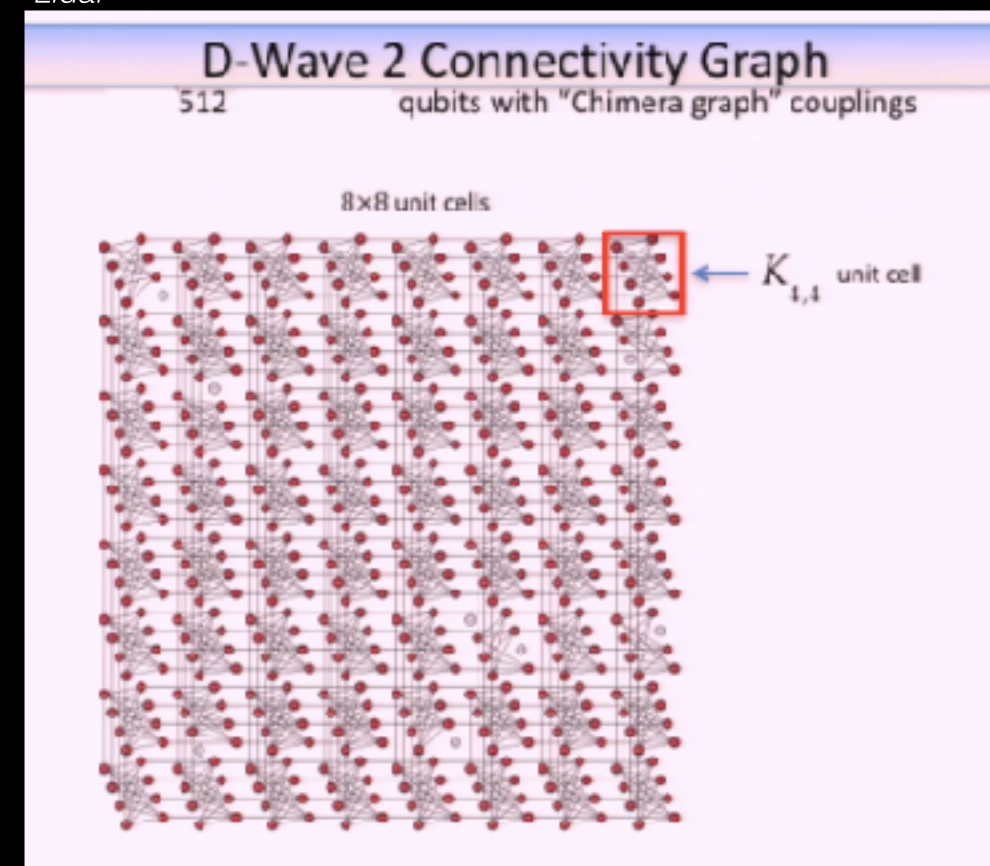
Not yet?

D-Wave



Lidar

Lidar



Goal:
find the ground state energy, or sample from the Gibbs distribution of the classical Ising model:

$$H_{\text{Ising}} = \sum_{j \in V} h_j \sigma_j^z + \sum_{(i,j) \in E} J_{ij} \sigma_i^z \sigma_j^z$$

$\{\sigma_j^z = \pm 1\}_{j=1}^N$ (later Pauli matrices)

$\{J_{ij}, h_j\}$ are "program parameters"

Lidar

Finding a speed-up

Certifiable speedup requires optimality

- An experimental demonstration of even a **limited** scaling advantage did not exist until now
- Culprit for quantum annealers:
  - Decoherence and noise
  - Annealing times too long:

    the curse of sub-optimality(1,2)

Lidar

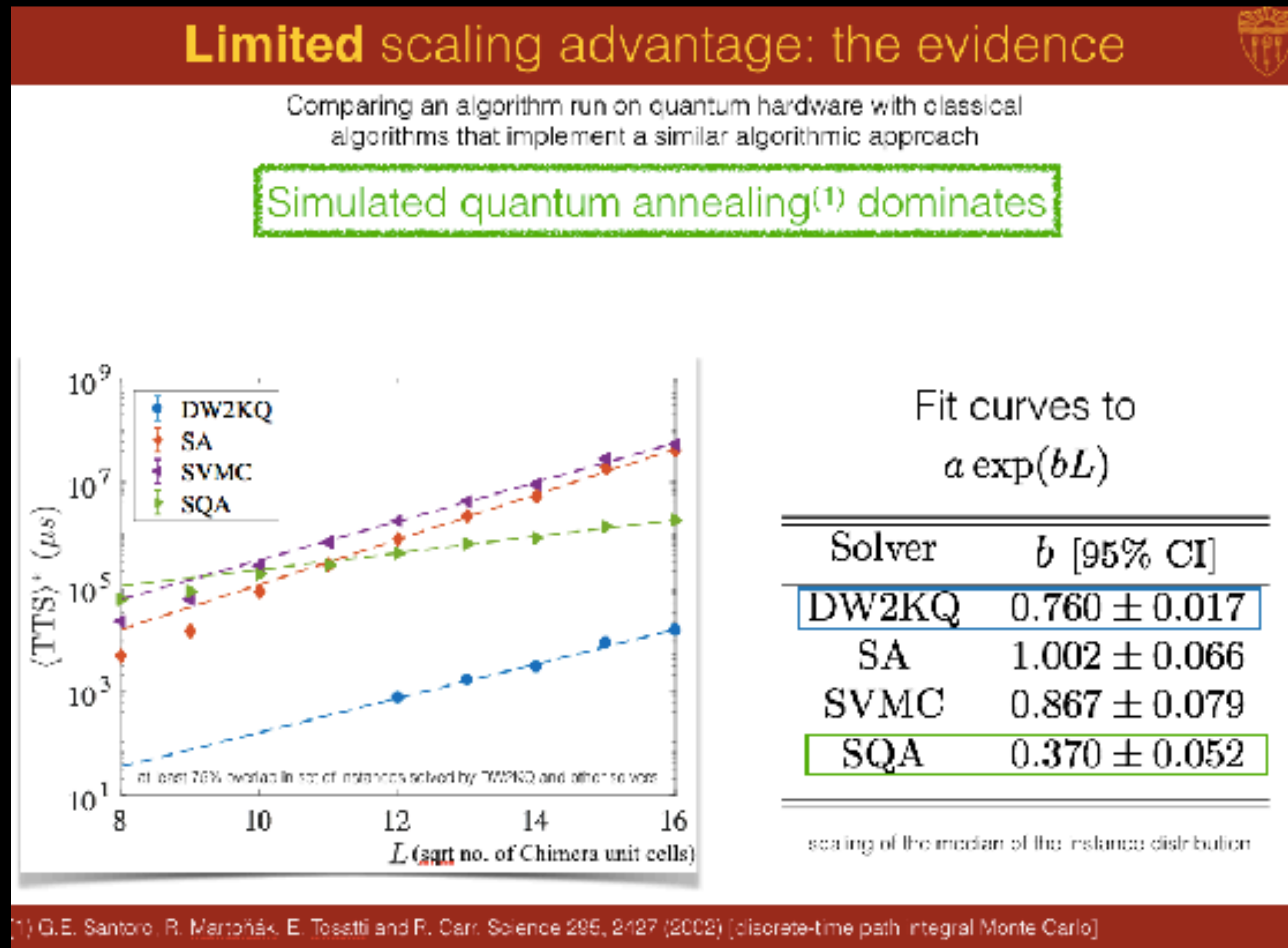
$$\mathrm{TTS} = t_a \times (\text{no. of repetitions to get to } 99\%) = t_a \, \frac{\log(1-0.99)}{\log(1-p_{\mathrm{GS}}(t_a))}$$

The optimal annealing time t_a is that which minimizes the TTS for fixed problem size N

Scaling *cannot be trusted* unless optimal t_a has been identified(1,2).

Lidar

Scaling Advantage

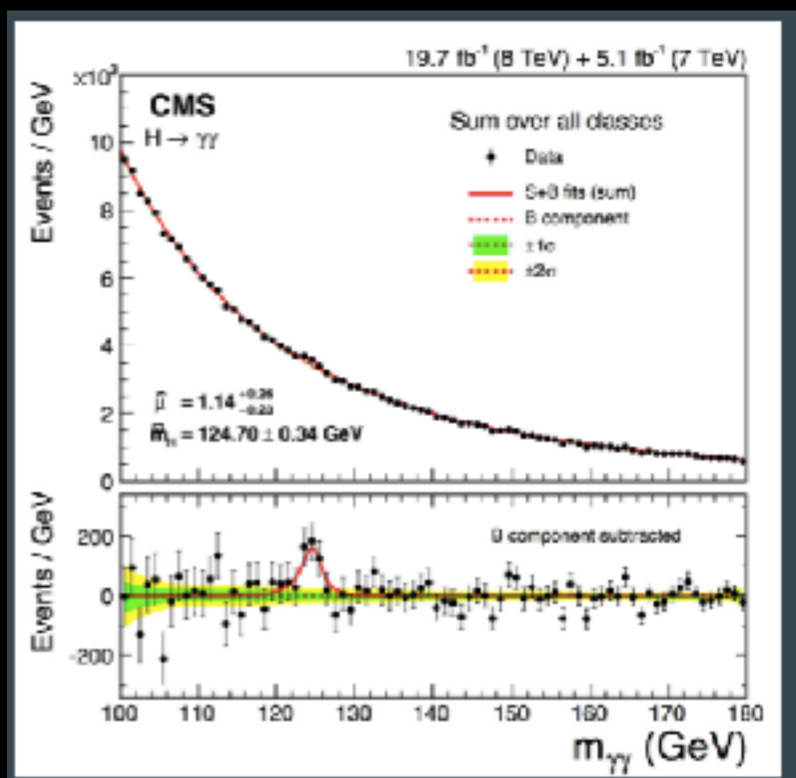


Lidar

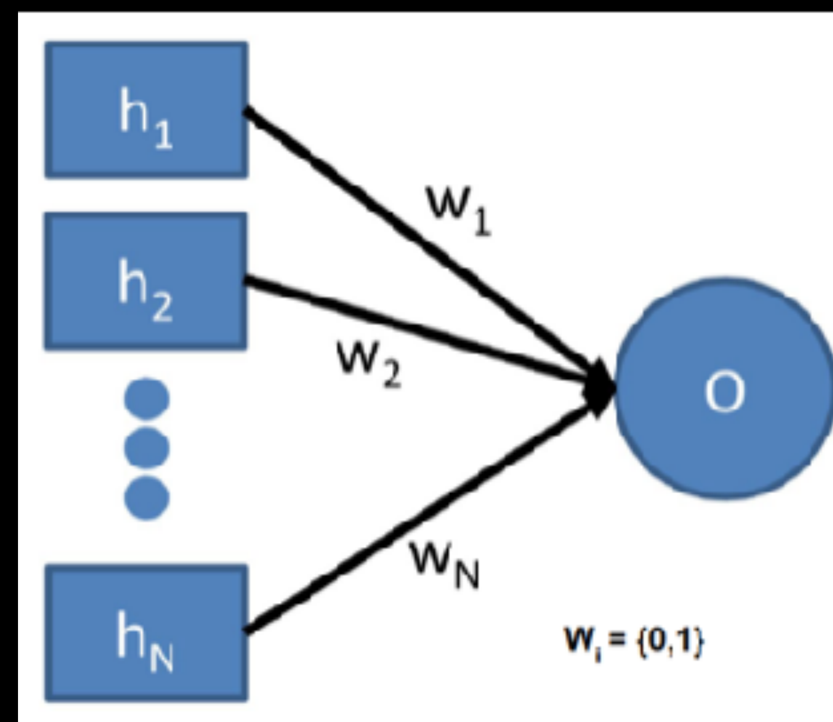
->Future of QC depends on scaling advantages

->Need *careful* comparison w/classical computing

Higgs Quantum Machine Learning



Job

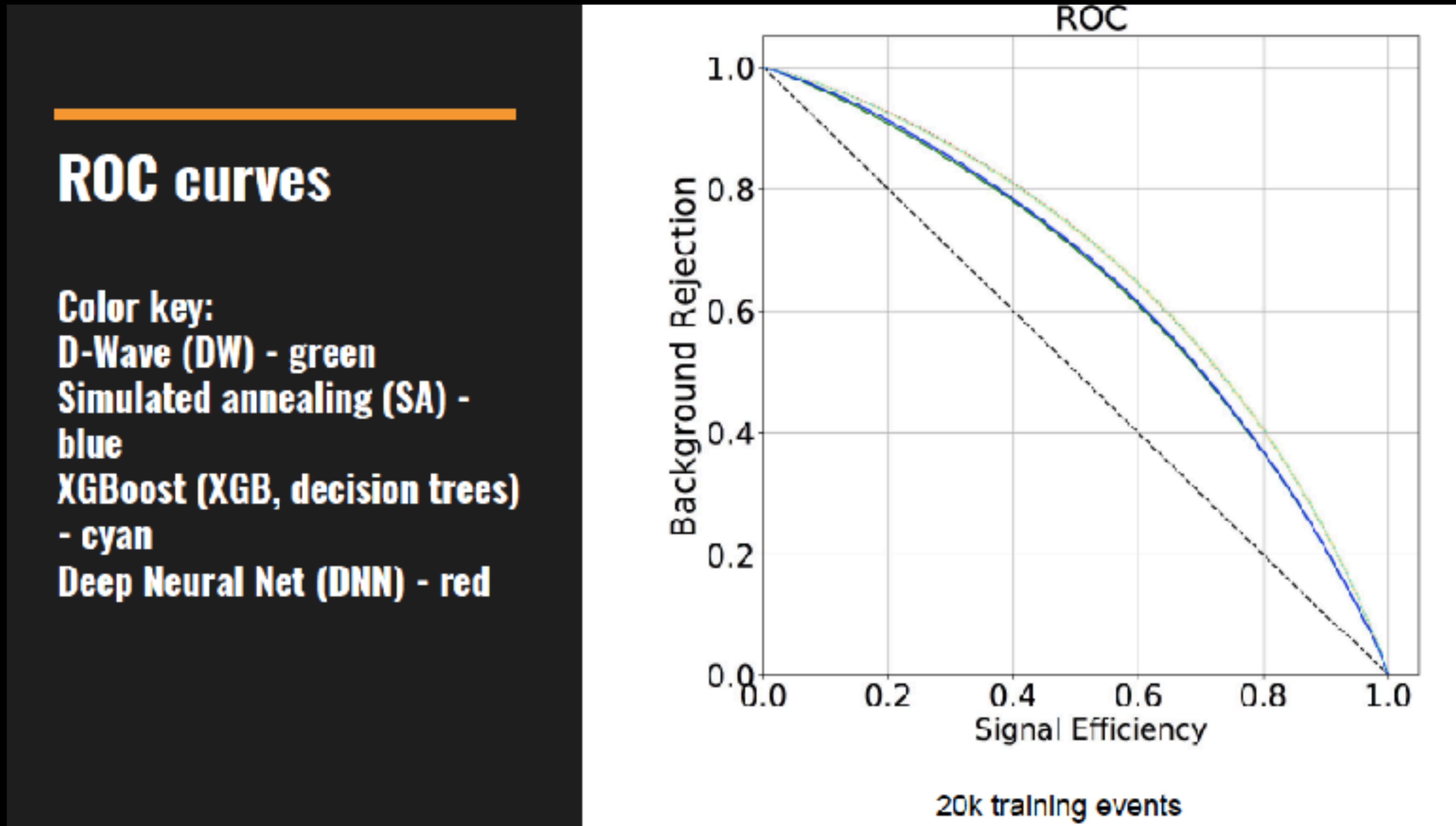


Job

Job

D-Wave: Map weights to spins

Training data error minimized by hamiltonian

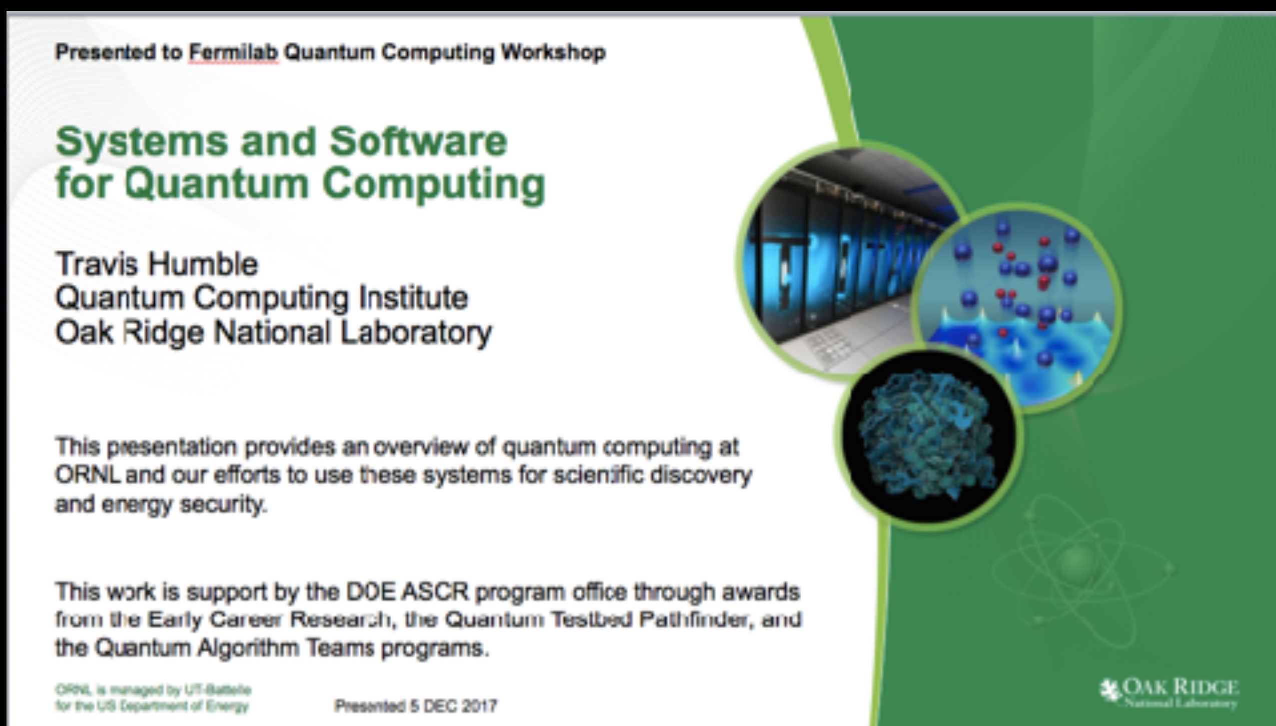


Job

-> Competitive w/classical computing
-> Applicable for other HEP optimization problems
-> Will there be a (quantum) scaling advantage?

Quantum Algorithm Development Stack

https://indico.fnal.gov/event/15222/contribution/7



How does QPU function as a scientific computing resource?

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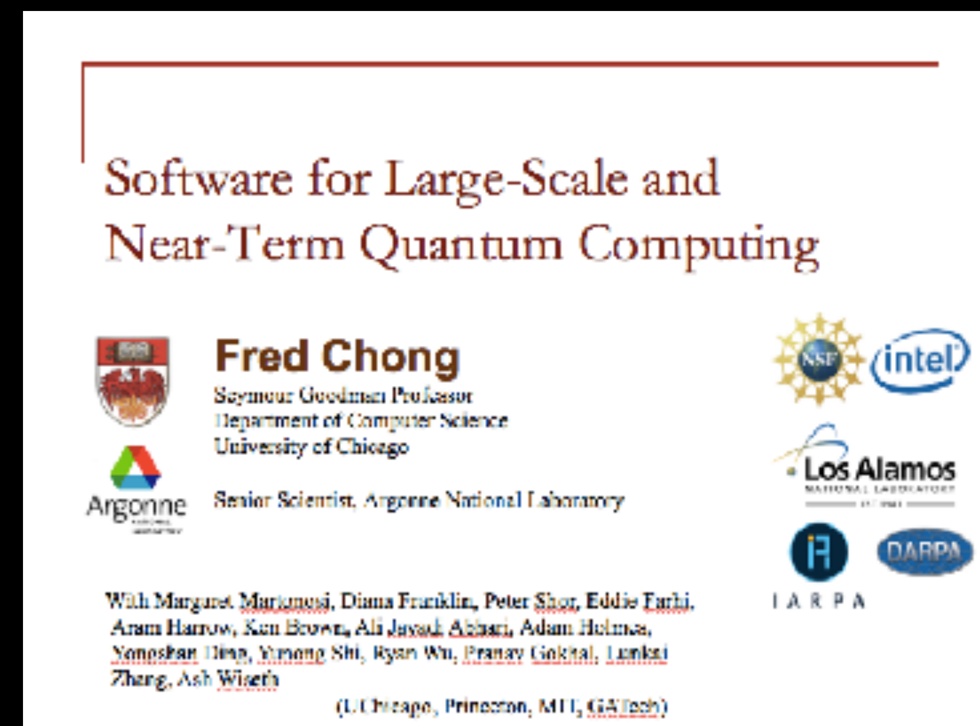
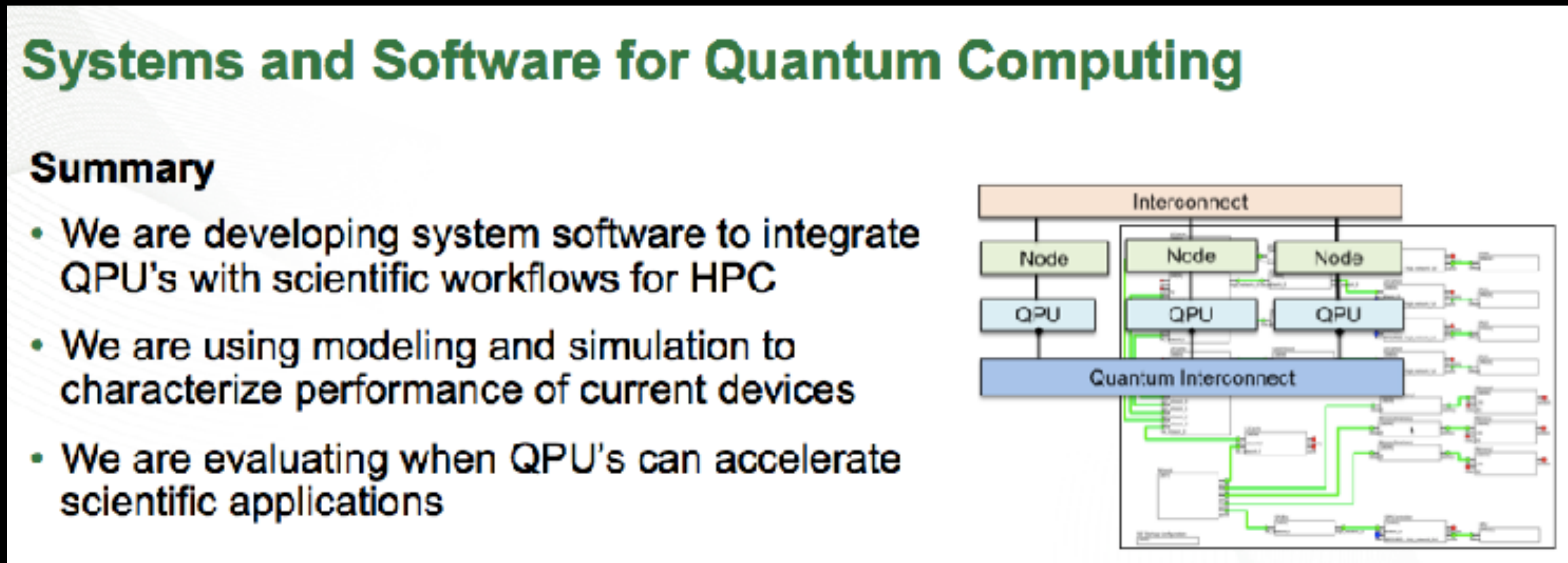
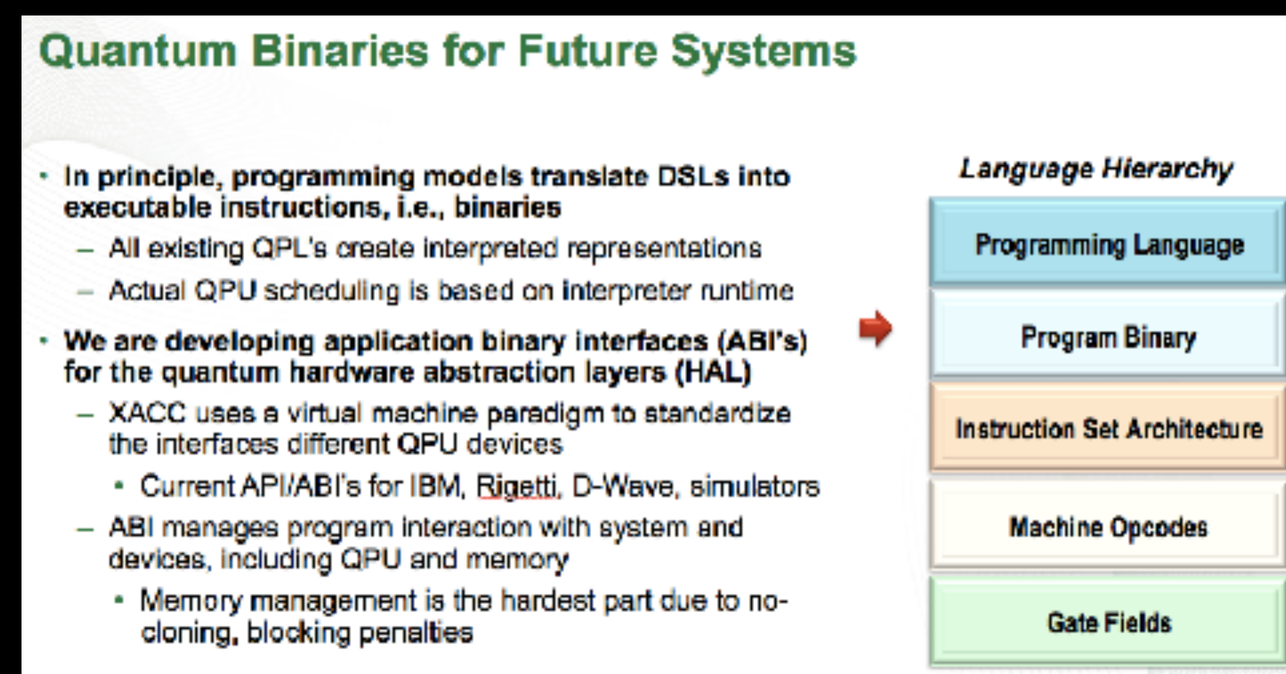


Can compilers and codesign optimize for limited near term resources?



Humble

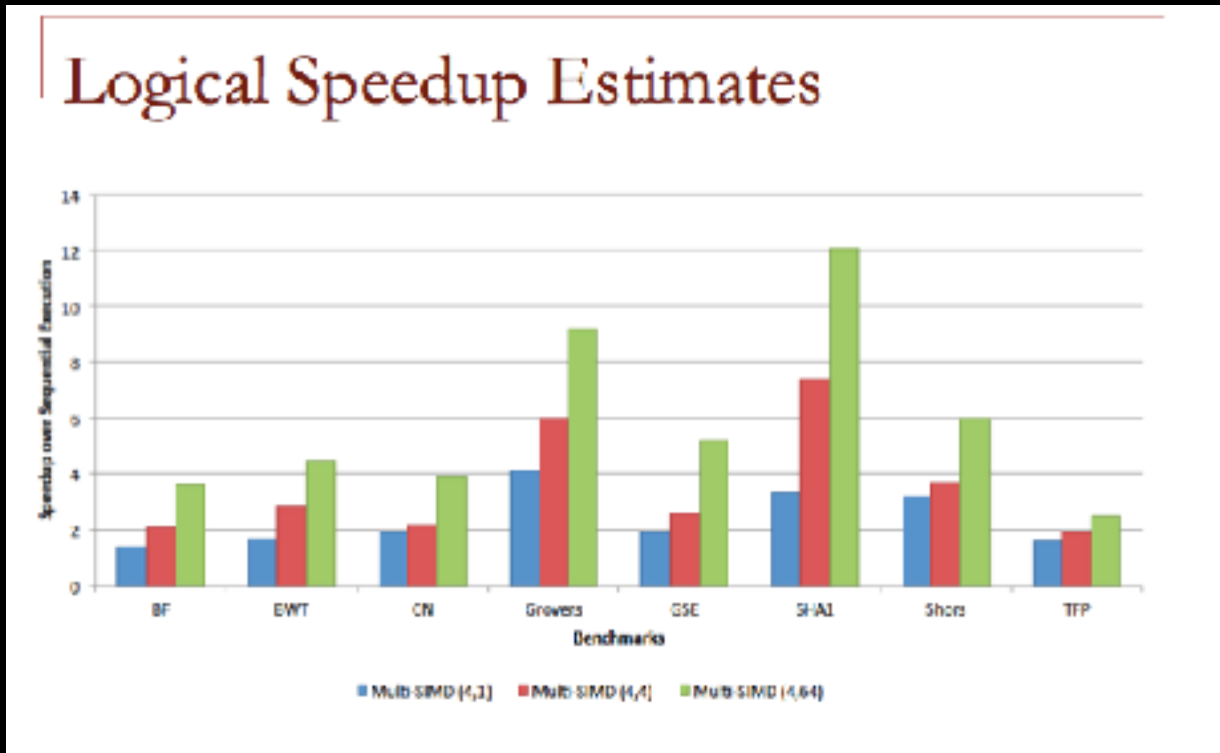


Humble

-standardized abstraction layer for different hardware

-enabling codesign and robust instruction sets

-framework for benchmarking and simulation of devices



Chong

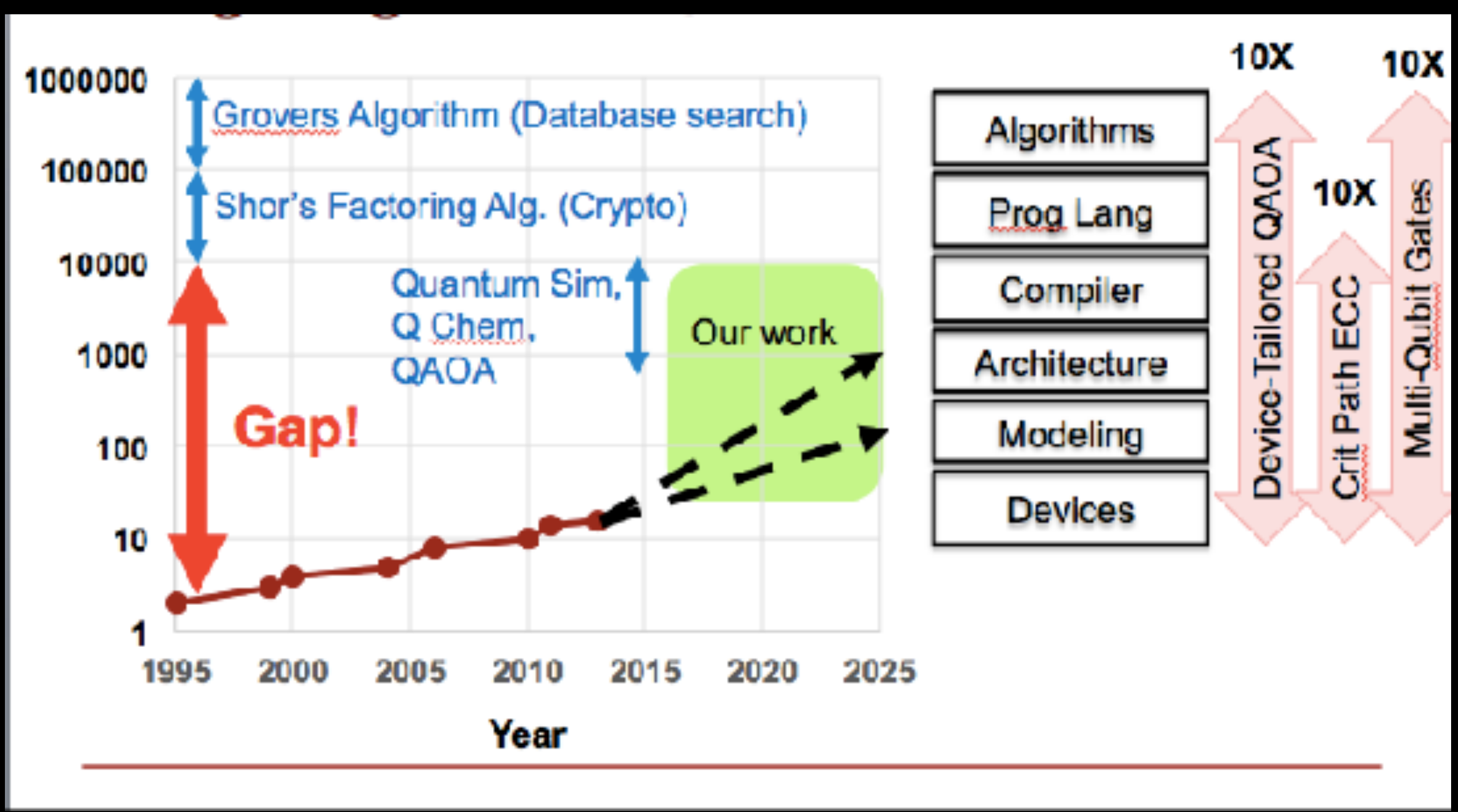
Speedup algorithms with compilation:
parallel gates (MIMD)
optimal rotations

Optimize Target Problem

Tailored gates

Optimize error correcting

…



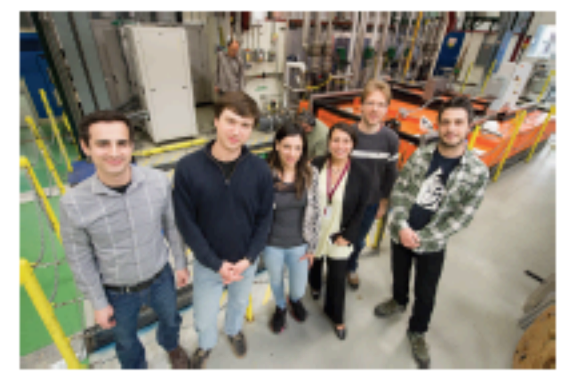
Chong

Fermilab Quantum Computing Testbed

Fermilab Quantum Hardware Initiatives

- Quantum sensors
  - Adapting quantum devices for use as quantum sensors for particle physics experiments such as direct dark matter detection
- Superconducting technologies
  - Some quantum computers use superconducting cavities similar to those we develop for accelerators.
- Quantum networks
  - We have agreed to host a quantum network on site in collaboration with Caltech and AT&T

Quantum sensors for axion search LDRD by Aaron Chou, Andrew Sonnenschein, and Dan Bowring



Fermilab SRF group is in a R&D collaboration with U. Chicago and Argonne

Quantum networks visit with John Donovan of AT&T

Fermilab

J. Amundson - https://indico.fnal.gov/event/15222/contribution/2/material/slides/0.pdf

Fermilab ^QUANTUM Theory

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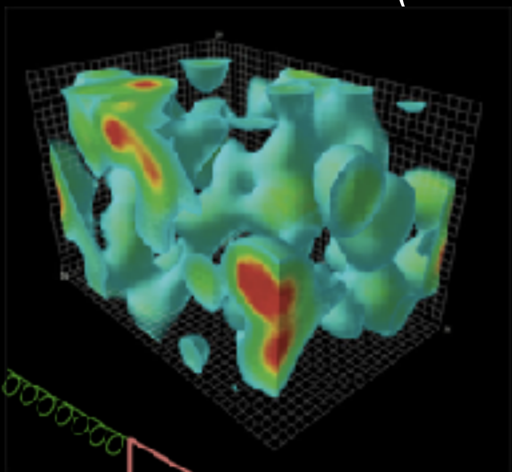
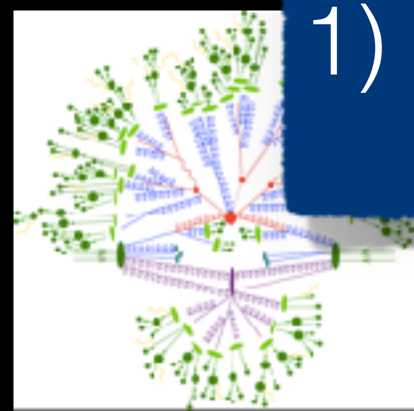
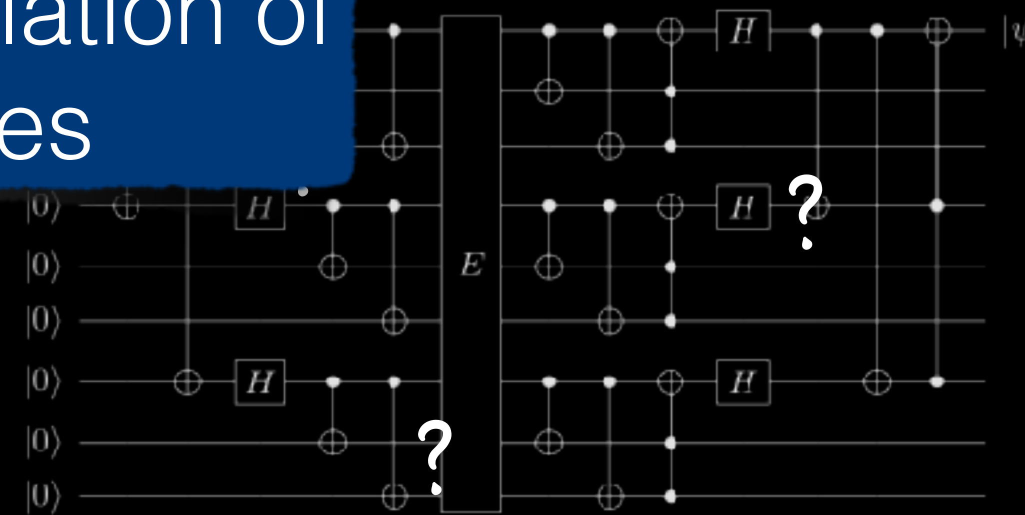




Mapping field theories (SM and Beyond) to controllable finite …uantum systems



1) Quantum Simulation of Field Theories

2) Optimization problems on quantum annealers

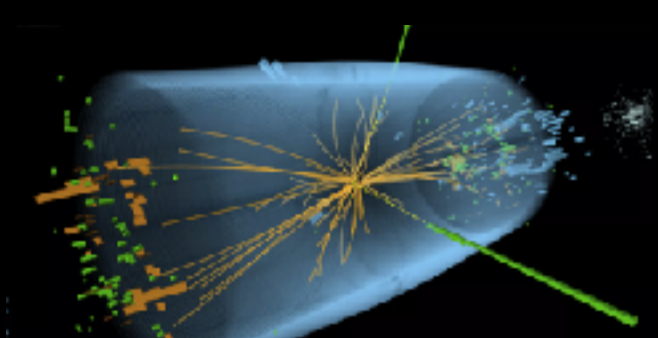
…hms?

…nds, …hes, …ments

3) Quantum Algorithm Development Stack

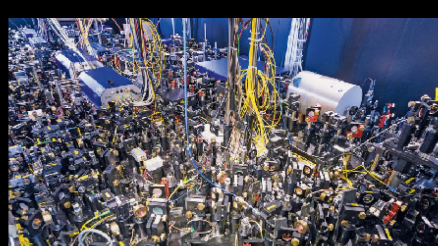
…ithms?

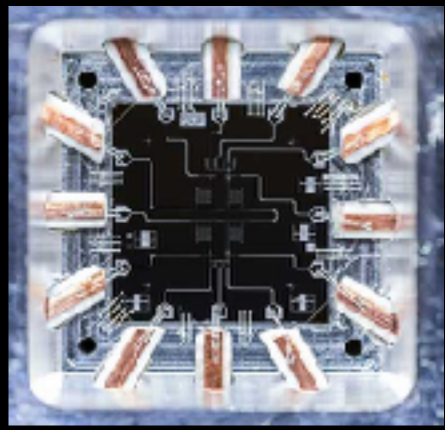
…ectures?



experiments on the universe

Quantum Sensors?





4) Fermilab Quantum Computing Testbed

…ents on quantum hardware

Next Steps

Next steps in Quantum Science for HEP

21-22 May 2018
Fermilab - Wilson Hall
US/Central timezone

https://indico.fnal.gov/event/16467/