CF6: Quantum Computing (and Technology)

Snowmass Plenary : Computational Frontier

August 10-11, 2020
CF6 Coveners : Travis Humble, Gabriel Perdue and Martin J. Savage

Why Quantum Computing / Quantum Information Science

✤ Quantum information science (QIS) is a major area of research emphasis in the DOE and for the nation at large.

✤ HEP has historically had a number of important roles in this field and we continue to play an important role in theoretical developments.

✤ We are becoming more important on the hardware side and have important contributions to make to QIS.

✤ Furthermore, there are a number of deeply interesting science questions quantum technologies enable us to ask in HEP.

  ✤ In short - we can play an important role in this endeavor and our science will benefit.

Toward a Quantum Ecosystem

National Laboratories

Universities

Government Agencies

Technology Companies,Startups

Investors

Manufacturing Sector

Quantum Economic Development Consortium [QED-C]

Areas for Snowmass

Thank you to all who are presenting LOIs and contributing !

- This is a new area for Snowmass, HEP long-range planning

- Looking to identify and assess all "quantum" areas impacting and advancing HEP during the next decade

  ✤ Quantum networks
  ✤ Data analysis in HEP with quantum computers
  ✤ NISQ-era quantum devices for HEP
  ✤ Simulation of quantum field theories
  ✤ Quantum simulation and hardware co-design
  ✤ Tensor networks
  ✤ Quantum information, error correction and holography
  ✤ QFTs on AdS
  ✤ Search strategies for new particles using SRF cavities
  ✤ Quantum computing for event generators
  ✤ Quantum algorithms for quantum sensing
 ✤ Algorithm development for beyond NISQ-era devices
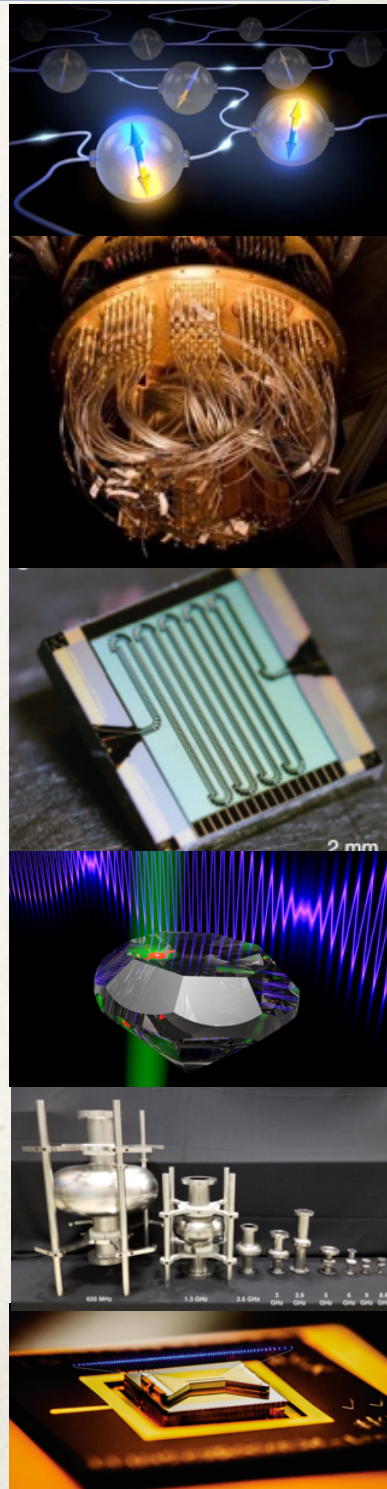
Observations

✤ This is a new, emerging area for HEP research activities
    ✤ expected to start impacting HEP experiment, computing and theory
    ✤ priority in DOE and other agencies, rapidly growing in general

✤ Taking first steps to understand and assess impacts and potential contributions to QIS

✤ Highly cross-disciplinary collaboration is key
    ✤ within HEP
    ✤ with QIS, domain sciences and HPC outside of HEP

✤ Next ~5 years will assess, benchmark, project and integrate into HEP research activities
    ✤ HEP specific quantum advancements and impacts expected to be identified
    ✤ anticipate significant acceleration in activity, impact and integration during the next 10 years
        ✤ flexibility should be integrated into planning

✤ Quantum-HEP workforce development essential
    ✤ requires coherent and deliberate planning and implementation, i.e. universities, labs, tech companies,
    ✤ scientists, developers, engineers, …

✤ Important that this area be identified within Snowmass process as "turning on" and accelerating during the next decade with HEP, with multi-pronged impacts
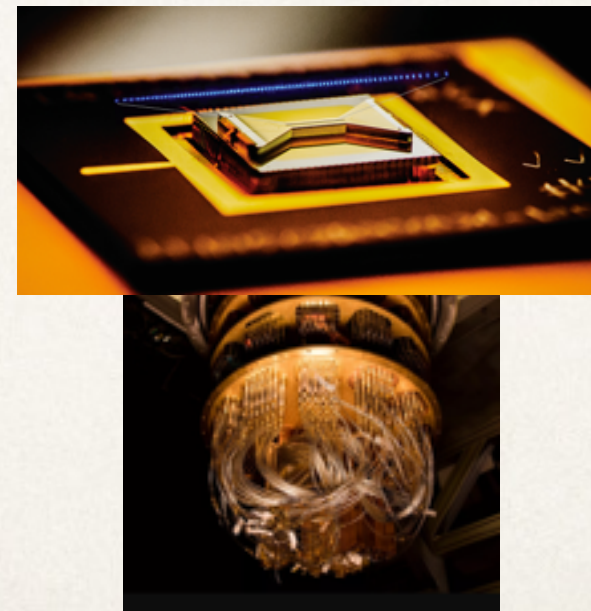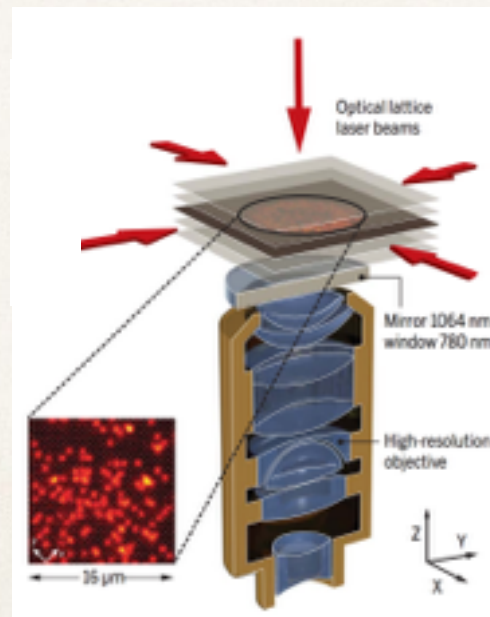
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Simulation

- Simulate quantum systems with quantum systems - Feynman 1980s
- Quantum devices are available for scientists to access
- Google's demonstrated quantum advantage/supremacy in 2019
- close interplay between theory, experiment and computing
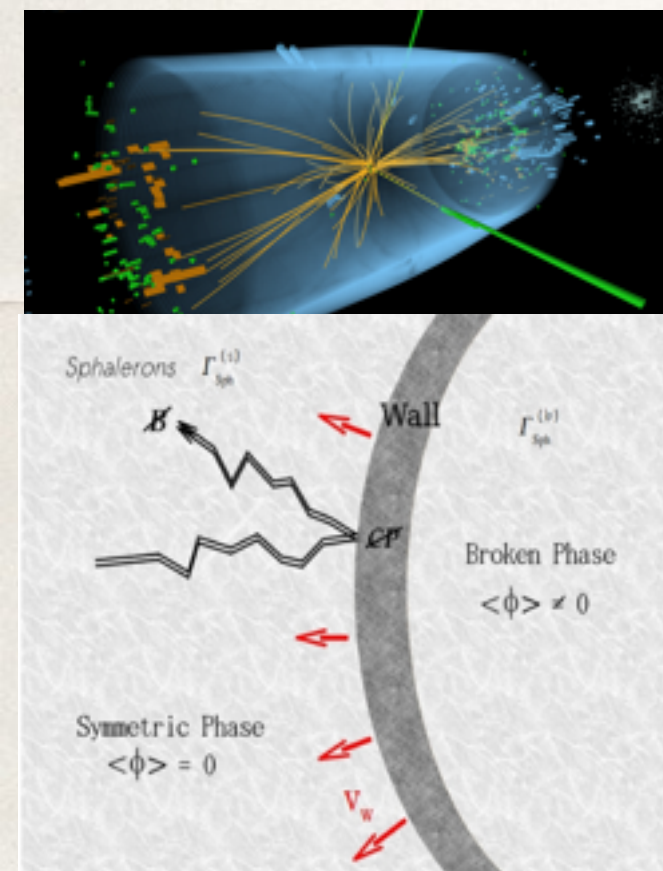
HEP challenges

Potential Quantum Computing "Solutions"

Quantum Comp. and Tech. for HEP
Simulation

Similar (but different trajectory?) to HPC for HEP ?

- including data pipelines, analysis, lattice QCD-specific hardware, event generators, …..

- requires resources for collaboration with technology companies and national laboratories, access to "commodity" hardware, and for designing, building running HEP specific hardware

  - SciDAC-like community focused collaborative efforts (see Travis Humble presentation)

- Strong integration with HPC [ASCR] , BES , NP

- Strong couplings between National Labs, Tech Companies and Startups and Universities

- Anticipate integration with HPC

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Sensing

Quantum Sensing
for
High Energy Physics

Report of the first workshop to identify approaches and techniques in the domain of quantum sensing that can be utilized by future High Energy Physics applications to further the scientific goals of High Energy Physics.

Organized by the Coordinating Panel for Advanced Detectors of the Division of Particles and Fields of the American Physical Society
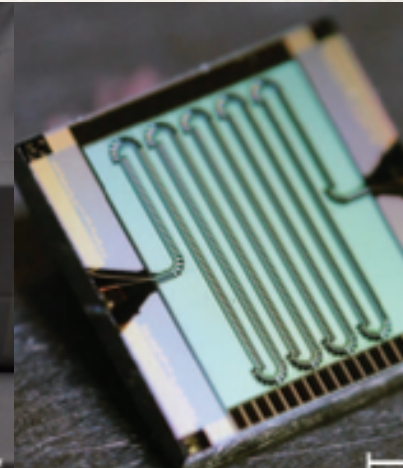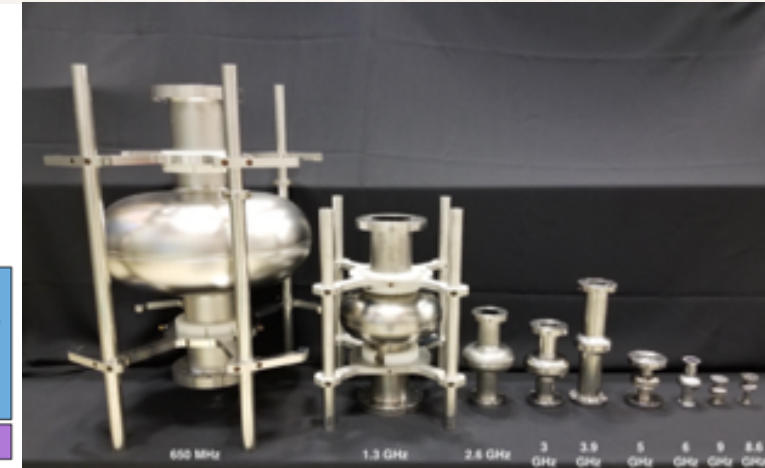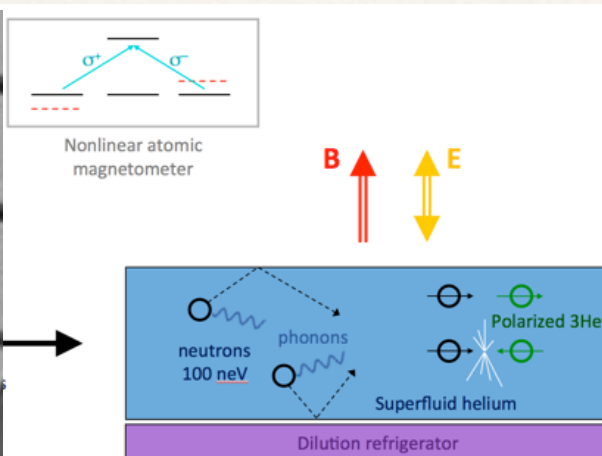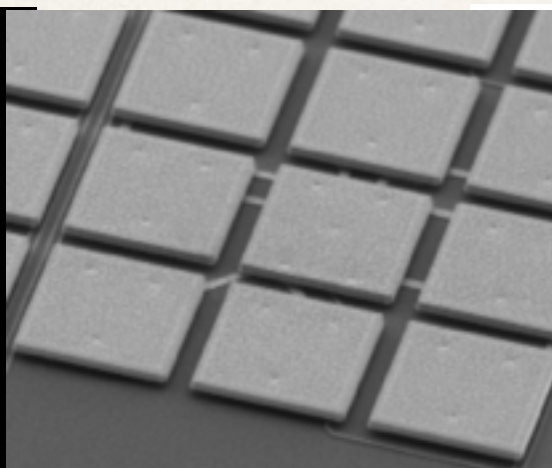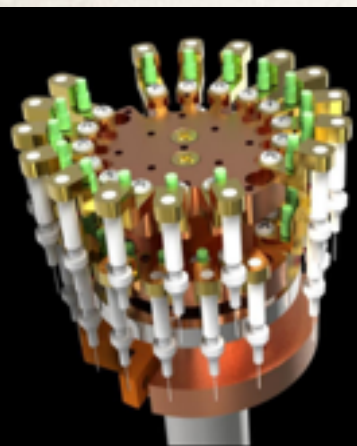
March 27, 2018

HEP has significant sensing needs
Dark Matter detection, axions
Enhanced charged particle detection

Advanced Quantum-1 sensors
Quantum-2 sensors
utilize quantum coherence and entanglement
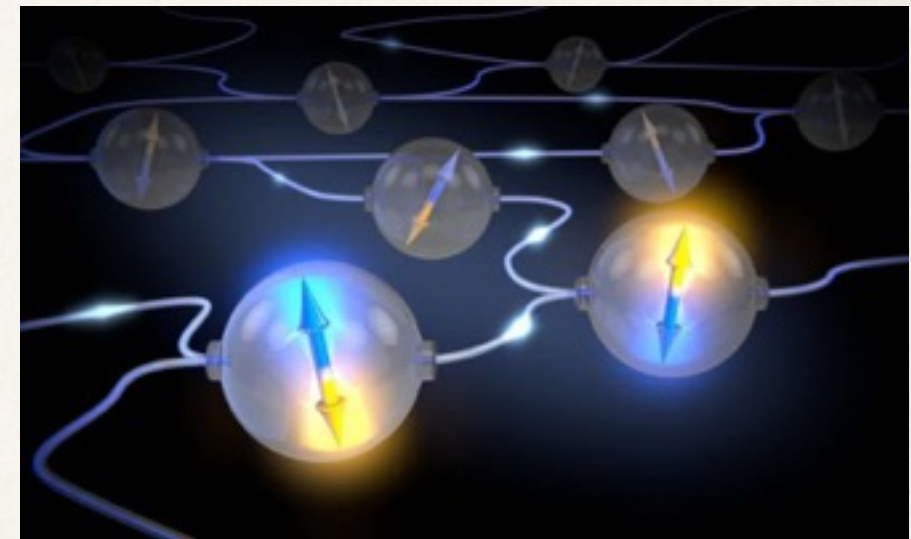
Impacts quantum computing

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Networking

The quantum internet
- collaboration among national labs, universities and companies
- HEP is a key partner in this development
- Important for thee US, for QIS and for HEP
- Networking quantum-2 sensors over large (international) distances - new physics detection capabilities

Maria Spiropulu captures this effort well (11/19):

"We will be using state-of-the-art sources and photodetectors in nodes we have built ……. to co-distribute classical and quantum information …… ,"

"We want to identify and address the challenges toward nontrivial, long-distance multilayered architectures that support multiple end-users and test various protocols."

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Data

Track, event reconstruction ?

- Ideal quantum registers support exponentially large Hilbert spaces

- "Potential" to process large data sets …. hurdle = state preparation

- Early studies are underway
  - Annealing, Digital, Hybrid, quantum-machine learning

Heather Gray
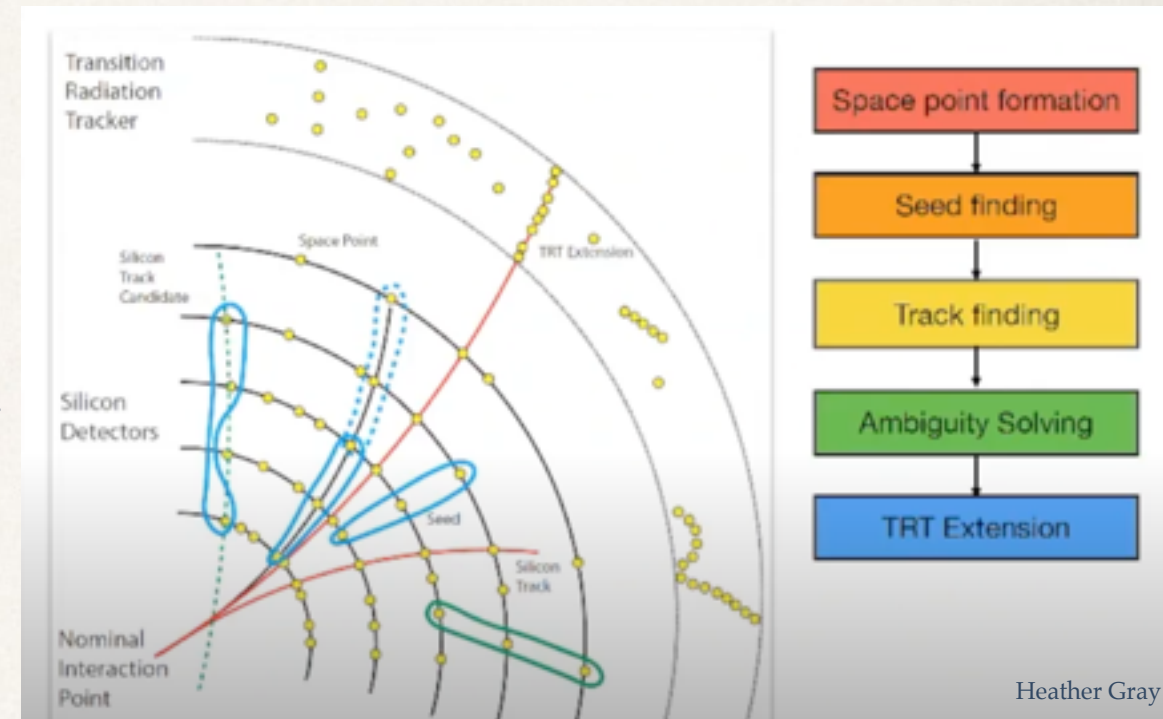
Is there a quantum advantage for handling LHC-scale data sets ?

Parallel Session Preview

- ✤ Monday

  - ✤ Tensor Networks

  - ✤ Simulation of QFT

  - ✤ Quantum information, error correction, and holography

  - ✤ QFTs on AdS

  - ✤ Quantum computing software co-desisgn

  - ✤ Data analysis in HEP with quantum computers

- ✤ Tuesday

  - ✤ Quantum simulation and hardware co-design

  - ✤ Quantum computing for event generators

  - ✤ Quantum algorithms for quantum sensing

  - ✤ NISQ-era quantum devices for HEP

  - ✤ Algorithm development for beyond NISQ-era devices

  - ✤ Quantum networks

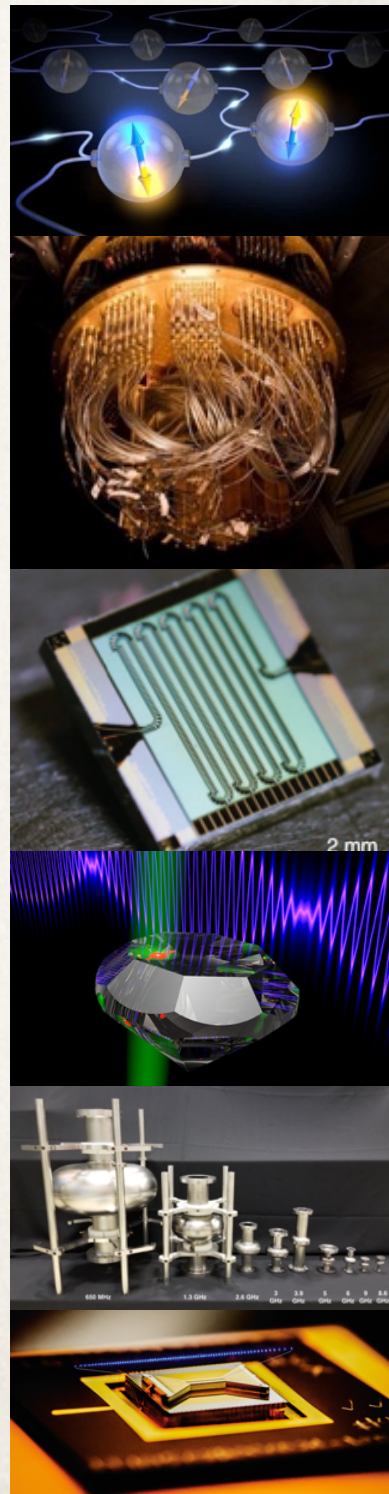 - ✤ Issues in HEP relevant to QML, decoherence, and quantum foundations

Goals for the parallel sessions

✤ We want to collect as much information and perspective as possible.

   ✤ Discussion focused!

✤ We further would like to identify individuals willing to write topical white papers in the next N months, and willing to help edit and compile these papers into a plan for QIS in HEP.

✤ The schedule is fairly full but we invite interested parties to contact us if you'd like to show a couple of slides and aren't on the agenda already.

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Summary

- QIS : an emerging and disruptive impact on HEP

- HEP anticipated to impact and be impacted

- Simulation, Communication, Sensing, Data

- Close collaboration with theory, HPC and experiment

- Close collaboration between Labs, Universities, Tech companies

- Close collaboration with other domain sciences, QIS

- New to Snowmass, next decade expected to be transformative

Thanks for listening!