NSF CYBER-PHYSICAL SYSTEMS · BREAKOUT GROUP

Quantum in CPS

From Physics Demonstrations to Dependable Decisions

Breakout of October 22, 2026 · Moderator Vishal Sharma, Phasecraft · Scribe Abhishek Dubey, Vanderbilt University

FRAMING

The question for NSF

Then

Feynman (1982) asked for a machine built from quantum parts to simulate nature. Shor (1994) showed that factoring, a non-quantum problem, gets an exponential speedup, and sustained federal R&D followed.

Now

Machines of about 100-1000 physical qubits run a few thousand gates before noise wins. Error correction works but consumes most of the qubits. Advantage has been shown in physics, theoretically proven in cryptography, not yet in optimization.

Next 10 years

Invest where CPS problems can be recast for hybrid quantum–classical computation off the real-time path, and where CPS methods make the quantum machines themselves work.

CONTEXT

What the breakout focused on

01 Three technologies, three maturities. Quantum sensing is in field pilots; quantum networking is approaching field tests, with Chattanooga as one site; quantum computing is where classical computing was in the 1950s. Superconducting, trapped-ion, neutral-atom and photonic architectures trade speed against precision.

02 Speedups are selective. Exponential gains are certain for molecular and materials simulation and for cryptography; optimization and machine learning remain open. Polynomial and constant-factor gains already matter to airlines and trading desks, and hybrid warm starts of classical solvers show them on small instances.

03 **The bottleneck for CPS is the classical–quantum interface.** About 90 percent of an algorithm is device-independent, yet there is no agreed instruction-level abstraction or operating-system layer, and the dimensions of the hand-off (time, precision, certainty, locality, scale, representation, energy) are still undefined.

WHY CPS

Why this is a CPS problem, not simply a quantum problem

Problem	Quantum answers are probabilistic and repeated, the machines are cryogenic and slow to load, and error correction consumes capacity. They will not sit on a real-time control path in the near-term, yet CPS decisions still happen on deadlines in the physical world.
CPS role	Design the whole loop: what is computed offline (futures, policies, certified bounds), what is looked up in real time, and how anytime algorithms, buffers and scheduling absorb stale or probabilistic answers. The quantum machine is a co-processor, not a controller.
Investment direction	Fund the interface: abstractions and middleware with hooks across the boundary (a quantum analogue of eBPF was suggested), together with measurement of latency, precision and certainty at the hand-off.

PLANNING AND CONTROL

Practice on Friday, race on Sunday

Problem	Scenario explosion. A system with many interacting stochastic inputs faces exponentially many trajectories; a thousand logical qubits would encode 2^{1000} states. This is the state-explosion problem that limits planning and verification today.
CPS role	Encode the decision space in qubits, let entanglement prune impossible trajectories (going left rules out going right), sample the value of what remains, and train a policy on the samples in the style of AlphaZero. Precompute offline, look up in real time.
High-impact investment	Surface the computationally hard CPS planning and optimization problems where faster time-to-solution changes a decision (grid restoration, fleet and crew scheduling, multi-stage allocation), each with a classical baseline. Forget exponential speedups.

VERIFICATION AND DIGITAL TWINS

Model checking over superposed futures

Problem	Reachability analysis and model checking stay offline because state spaces explode, and digital twins must weigh many futures quickly. Multi-stage probabilistic answers compound error after two or three steps.
CPS role	Optimization is the quantum task closest to verification (SAT and SMT solving). Treat reachability as pruning, move model checking toward online use over superposed scenarios, and let mixed-criticality and clairvoyant scheduling decide which world lines to carry.
High-impact investment	A CPS benchmark track aligned with QOBLIB, run as hybrid pipelines against the strongest classical baselines at matched budgets, with results published whether or not they favor the quantum path.

SENSING AND NETWORKING

Precision and long-range interdependence

Problem	Sensing is the most mature quantum technology and networking is close to field deployment, but the semantics of a probabilistic sensor's output, and how it crosses into classical control at the right time and precision, are unsettled.
CPS role	Three gains to engineer together: precision from sensing, speed from computing, long-range interdependence from networking. Timing and synchronization in distributed CPS, and closing the loop at sensor precision, are CPS questions.
High-impact investment	Field testbeds, Chattanooga among them, with CPS applications running on them; quantum timing and synchronization for distributed CPS; the April 2027 workshop on quantum sensing and networking for CPS.

SECURITY

Post-quantum cryptography cannot wait

Problem	A cryptographically relevant quantum computer is now expected in five to ten years, and data captured today can be decrypted then. Post-quantum standards exist (NIST FIPS 203, 204, 205) but carry more computation and larger keys than the schemes they replace.
CPS role	Fielded CPS devices are constrained and long-lived. Measure what the overhead does to latency, energy and lifetime on real platforms, design for crypto-agility across the classical–quantum boundary, and treat forensics and self-probing as part of the system.
High-impact investment	Fund post-quantum cryptography cost measurements on representative CPS platforms in the first year, and migration paths for fielded fleets. This is the one item from the breakout with a hard deadline.

CPS FOR QUANTUM

A quantum computer is itself a cyber-physical system

Problem	Today's machines are noisy physical plants: calibration drifts, experiments are stochastic and repeated, cryogenics and data transfer dominate, and no operating-system layer exists. Physicists are building this instrumentation themselves.
CPS role	Automate and repeat stochastic experiments (the LHC trigger pipeline is the model), apply control to the physical processes inside the machine, and verify compiled circuits and hybrid workflows with the tools CPS already has.
High-impact investment	Cross-funded teams that pair CPS engineers with quantum hardware groups on calibration, control and verification.

RESEARCH INFRASTRUCTURE

Get ahead of the hardware

Problem	Fault-tolerant machines are on commercial developer roadmaps for 2029 to 2033. If CPS abstractions, interfaces and benchmark problems are not ready, the machines will arrive before the community can use them.
CPS role	Explore now on simulators such as Qiskit, on small problems, to build the abstractions and interfaces. Nobody at the early CPS weeks saw the GPU coming; being early is cheaper than catching up.
High-impact investment	Two NSF mini-workshops with one roadmap: Quantum Algorithms and Optimization for CPS (second week of January 2027, Phasecraft, Arlington) and Quantum Sensing and Networking for CPS (April 2027); report-out at CPS-IoT Week, May 2027, then a journal article.

OUTCOMES

What NSF should be able to measure in 10 years

Scientific progress

An agreed classical–quantum interface model with measured latency, precision and certainty; a theory of anytime hybrid computation; verification methods that scale by pruning the state space.

Application progress

Catalog problems run as hybrid pipelines against classical baselines at matched budgets, with demonstrated decision gains in application areas like grid restoration, scheduling and digital twins, and post-quantum cryptography overhead quantified on fielded CPS.

Research-community progress

Cross-funded CPS–quantum teams, shared benchmarks and testbeds.

CLOSING MESSAGE

Quantum changes what CPS computes offline before it changes what CPS does in the loop.

The next CPS program should be ready with the right problems, the right interfaces and the right measurements when the machines arrive.