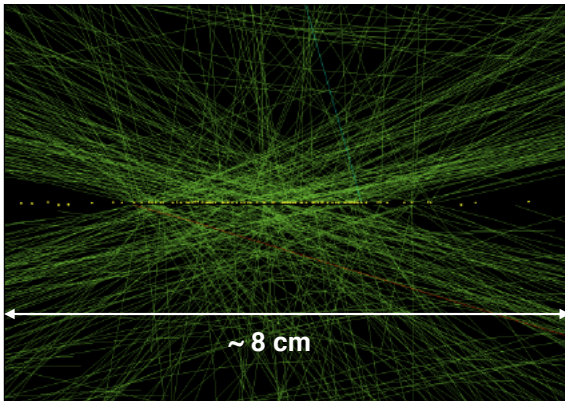# Summary: Primary Vertexing with a Quantum Annealer



**~ 8 cm**

**Which tracks originate together from a p-p collision?**



**D-Wave QPU at the end of a dilution refrigerator**



p-p collision number: 0 1 2

Tracks "cutting" beam axis at physical positions

$p_{i0}$ $p_{j0}$

$z_i$ $z_j$ LHC beam axis

$D(i, j)$

Schematic of primary vertexing formulation for the quantum annealer. Elements of $p_{ik}$ matrix are qubits. i = track number, k = vertex number
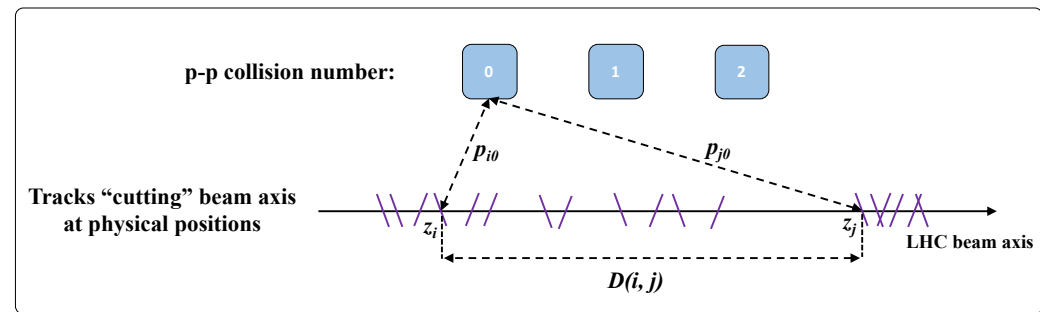
**MOTIVATION:**
- Find a HEP-ex problem that can be solved *today* using a quantum computer (annealer)
- Target problem: Primary vertexing. 1D clustering of tracks to p-p collision points
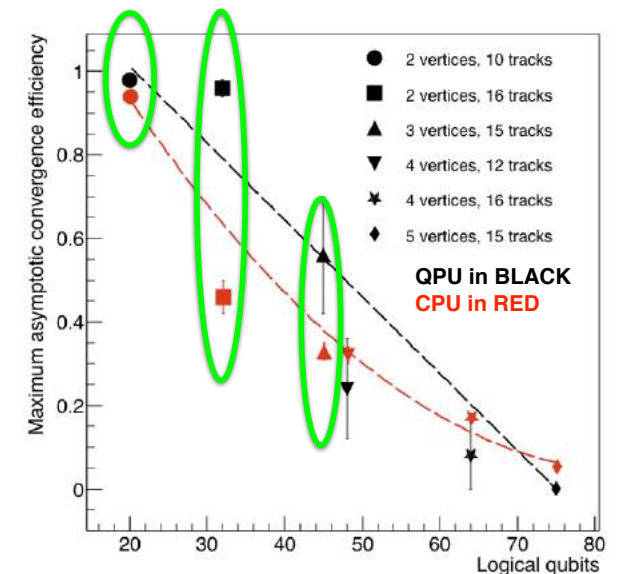
**EXPERIMENTS**:
- Formulated primary vertexing for the D-Wave 2,000+ qubit system
- Threw artificial primary vertices and tracks using published data distributions
- The D-Wave QPU returns "true" clustering of tracks into primary vertices with some efficiency
- Efficiency drops with increasing problem size due to qubit instabilities
- Benchmarking against simulated annealing reveals some quantum advantage

**OUTLOOK**:
- Pursuing improvements in quantum formulation and execution
- Exponential increase in qubits and connectivity encourage more realistic applications soon



- 2 vertices, 10 tracks
- 2 vertices, 16 tracks
- 3 vertices, 15 tracks
- 4 vertices, 12 tracks
- 4 vertices, 16 tracks
- 5 vertices, 15 tracks

**QPU in BLACK**
**CPU in RED**

**QPU performance comparable to a modern CPU**