QUANTUM COMPUTING TECHNOLOGY DEEP DIVE
ColdQuanta will be a Leader in Quantum Computing...

As the leader in Cold Atom quantum technology, the most SCALABLE, VERSATILE, and COMMERCIALY VIABLE quantum approach, ColdQuanta is positioned to be a juggernaut in quantum computing.

Our Opportunity

>$65B

TAM by 2030

ColdQuanta’s quantum computers will be used broadly for quantum computing applications.

Our Position

100 QUBIT

Computer in 2021

Hilbert, our 2021 cloud-based quantum computer will deliver 100 QUBITS and unparalleled future scalability.

Targeting >1000 QUBITS WITHIN 3 YEARS with strong connectivity, fidelity, and miniaturization.

Room temperature; no refrigeration.
Expected Phases of Quantum Computing

ColdQuanta expects to win the race to quantum advantage, representing a prime opportunity to participate in a technology on the brink of extraordinary growth and commercial adoption.

**Expected Phases**

- **3-5: NISQ Era**
  - Material simulations that reduce expensive and time-consuming trial-and-error lab testing
  - Impact: $2 billion - $5 billion

- **10+: Broad Quantum Advantage**
  - Near-real-time risk assessment for financial services firms (e.g., Quant hedge funds)
  - Impact: $25 billion - $50 billion

- **20+: Full-Scale Fault Tolerance**
  - De novo drug design with large biologics that have minimal off-target effects
  - Impact: $450 billion - $850 billion

Sources: BCG analysis
ColdQuanta’s Hilbert Will Set the Stage for the Cold Atom Approach to Quantum Computing

Hilbert Quantum Processing Unit (QPU) Today

2Q 2020
$7.4M DARPA Award

2020
64 qubit prototype

3Q 2021
Target completion for 100 qubit computer

Late 2021
Cloud-based computing service offered

2022
2nd unit sold to customer

2024
DARPA award milestone for 1,000 qubit computer

Hilbert Commercial Version
ColdQuanta’s Quantum Computer is Differentiated by an Attractive Combination of Attributes

- **Qubit Count**: High qubit count greater than 100 by 3Q21
- **Temperature**: Cold Atom computers operate at room temperature
- **Miniaturization**: $10^6$ qubits on a thumbnail, with a footprint 1 / 200,000th the size of superconducting qubits
- **Cloud Based**: Albert (Cold Matter Machine) is currently accessible via Cloud
- **Gate Fidelity**: Achieve high gate fidelity
- **Connectivity**: The # of qubits that can interact with one another is high
- **Gate Duration**: Quantum operations can be performed rapidly
- **Coherence**: Duration of time that quantum properties are maintained is long
ColdQuanta Expects to Achieve High Qubit Quantity in a Very Small Way

- >100 Qubit Arrays in 2021
- Scalable to >1000 qubits in one cell in 3 years
- $10^6$ qubits require only 4 square mm
- System operates at room temperature while only atoms are cooled with lasers

- Superconducting computers with $10^6$ qubit count will require square meters of size
- The size cryostat (refrigeration) required for entire system does not exist today
ColdQuanta’s Connectivity Roadmap Provides Clear Path to Quantum Advantage

- Connectivity is based on long range Rydberg interaction
- Physics supports industry leading scaling
- Low-to-Medium risk
Coherence and Gate Duration Overview

- Coherence means the quantum properties are being maintained.
- The longer coherence persists, the more time a Quantum Computer has to perform a set of operations.
- The Gate Duration is the time for an individual computational operation (referred to as a gate) to be performed.
- The number of gate operations that can be performed while coherence is maintained is a key to enabling deep quantum circuits.
Cold Atom Approach Will Set the Benchmark in Quantum Volume

- ColdQuanta’s roadmap advances qubit count, connectivity, and gate fidelities
- When combined these advancements push forward quantum volume
- ColdQuanta's approach enables wide circuits to focus on performance for customer applications
## Quantum Computing Benchmark vs. Competitors

<table>
<thead>
<tr>
<th>Company</th>
<th>Quantum Method</th>
<th>Other Quantum Technologies</th>
<th>Quantum Qubit Count</th>
<th>Connectivity</th>
<th>1Q Fidelity</th>
<th>2Q Fidelity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ColdQuanta</strong></td>
<td>Cold Atom</td>
<td>Navigation, Sensors, Signal Processing, AI / Machine Learning</td>
<td>100+</td>
<td>8 (2021)</td>
<td>0.991</td>
<td>0.95 (2021)</td>
</tr>
<tr>
<td><strong>IBM</strong></td>
<td>Superconducting</td>
<td>None</td>
<td>53</td>
<td>&lt;3</td>
<td>0.999</td>
<td>0.98</td>
</tr>
<tr>
<td><strong>rigetti</strong></td>
<td>Superconducting</td>
<td>None</td>
<td>32</td>
<td>&lt;3</td>
<td>0.987</td>
<td>0.95</td>
</tr>
<tr>
<td><strong>IONQ</strong></td>
<td>Trapped Ions</td>
<td>None</td>
<td>11</td>
<td>10</td>
<td>0.995</td>
<td>0.975</td>
</tr>
<tr>
<td><strong>PsiQuantum</strong></td>
<td>Photonic</td>
<td>None</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Google</strong></td>
<td>Superconducting</td>
<td>None</td>
<td>53</td>
<td>4</td>
<td>0.998</td>
<td>0.994</td>
</tr>
</tbody>
</table>

Note: ColdQuanta metrics are based on estimates for Hilbert’s target completion in 3Q21. Competitor metrics have been published.
DEEP DIVE

TECHNICAL

DEEP DIVE
Quantum Computing Operational Sequence

Qubit Register Preparation

- Cold Atoms
- Single Atom Array
- Filled Array

Laser cooling 852,894 nm lasers

Array 825 nm lasers
Deep Cooling

Rearrangement 1064 nm laser

Calculation Cycle

State Initialization

- Optical Pumping 895 nm laser

- Gates 1Q, 2Q
459 nm, 1040 nm lasers, mwaves

Quantum Circuit

- Measure Results

Cesium

\( |0\rangle \rightarrow |1\rangle \)

|0\rangle

|1\rangle

Calculation Cycle

Controlling the Mechanics

Controlling the Quantum

ColdQuanta
Exponential growth over the last decade

Testing new approach
>1000 site array

Enabling technologies:
- Pristine vacuum
- Laser power
- Optical beam scanning

Qubit Count Scaling

UWM experiments over the last 15 years

Qubit number


10 20 30 40 50 60 70 80 90 100

Qubit number

<25>/49 <30>/49 <65>/121 <110>/196

35^2=1225 trap sites
Gate Fidelity Over Time

- **All platforms have shown improved fidelity over time**
- Atomic physics supports 99.99% fidelity entangling gates
- Present limits are technical: laser noise, atom temperature, optical beam pointing stability
- With engineering improvements fidelity will steadily increase
- The $10^{12}$ on/off ratio of the cold atom Rydberg gate approach allows qubit count to scale in large arrays without suffering increased crosstalk or impacting gate fidelity

<table>
<thead>
<tr>
<th>Quantum Method</th>
<th>First Entangled Gate</th>
<th>Fidelity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapped Ions</td>
<td>1995</td>
<td>&gt;0.99 (2008)</td>
</tr>
<tr>
<td>Superconducting</td>
<td>2005</td>
<td>&gt;0.99 (2014)</td>
</tr>
<tr>
<td>Quantum Dots</td>
<td>2005</td>
<td>0.98 (2019)</td>
</tr>
<tr>
<td>Cold Atom</td>
<td>2010</td>
<td>&gt;0.99 (2020)</td>
</tr>
</tbody>
</table>
The combination of fidelity and connectivity enables algorithmic performance.

Moving quantum states requires a swap operation with 3 CNOT gates.

Connectivity compensates for low fidelity.

Entangling A-B requires 9 swaps & 1 CNOT = 28 gates.
At $F=0.99$, $F_{AB} = 0.99^{28} = 0.75$

Entangling A-B requires 1 swap & 1 CNOT = 4 gates.
At $F=0.99$, $F_{AB} = 0.99^4 = 0.96$
At $F=0.95$, $F_{AB} = 0.95^4 = 0.81$
Quantum Approximate Optimization Algorithm (QAOA)

ColdQuanta and ParityQC aim at Quantum Advantage with Optimization problems

Press release of ParityQC, Dec 16, 2020
MAKING QUANTUM A REALITY

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