Thoughts about Quantum Computing for HEP

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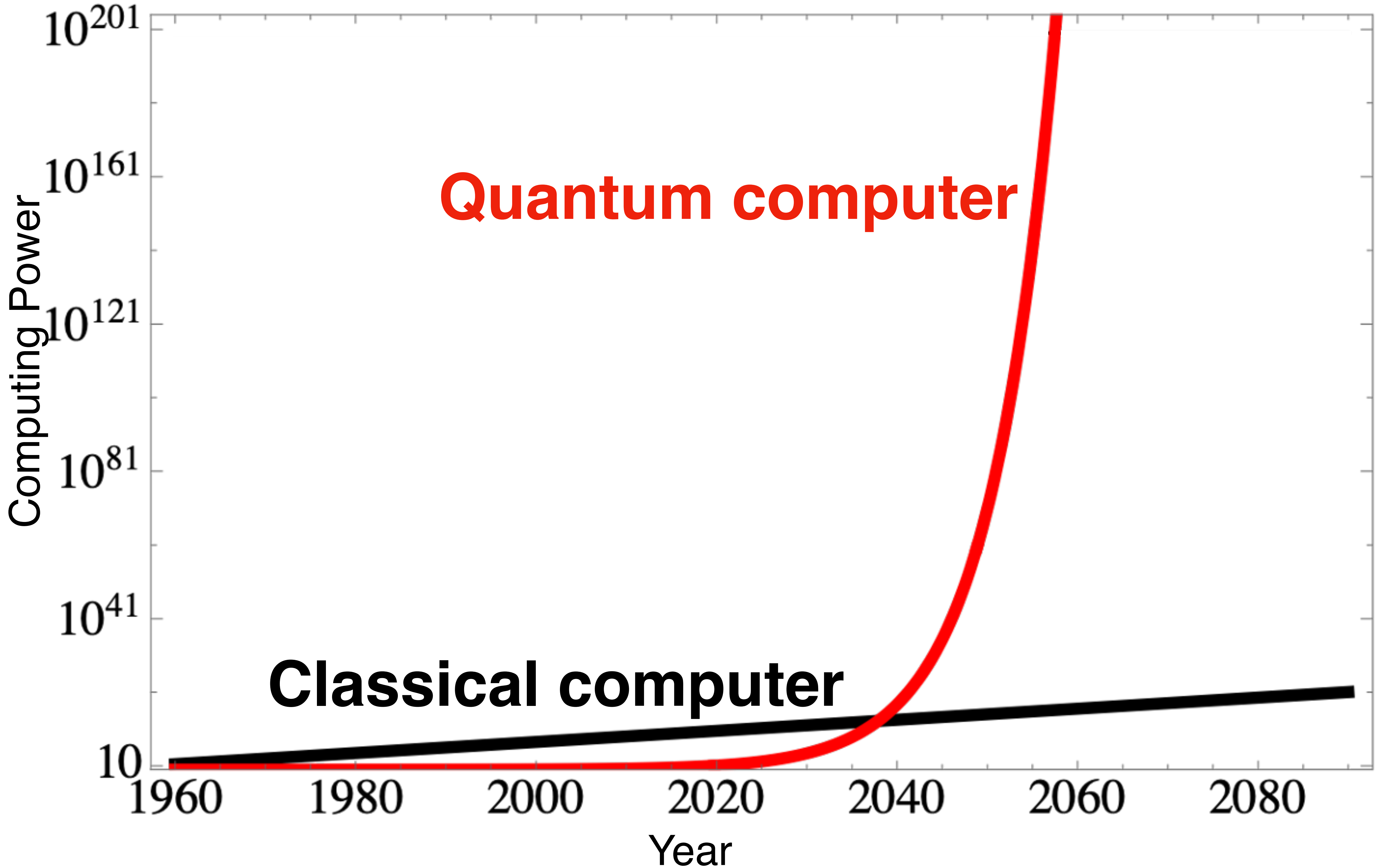
The standard argument for quantum computing is that it outperforms a classical computer exponentially



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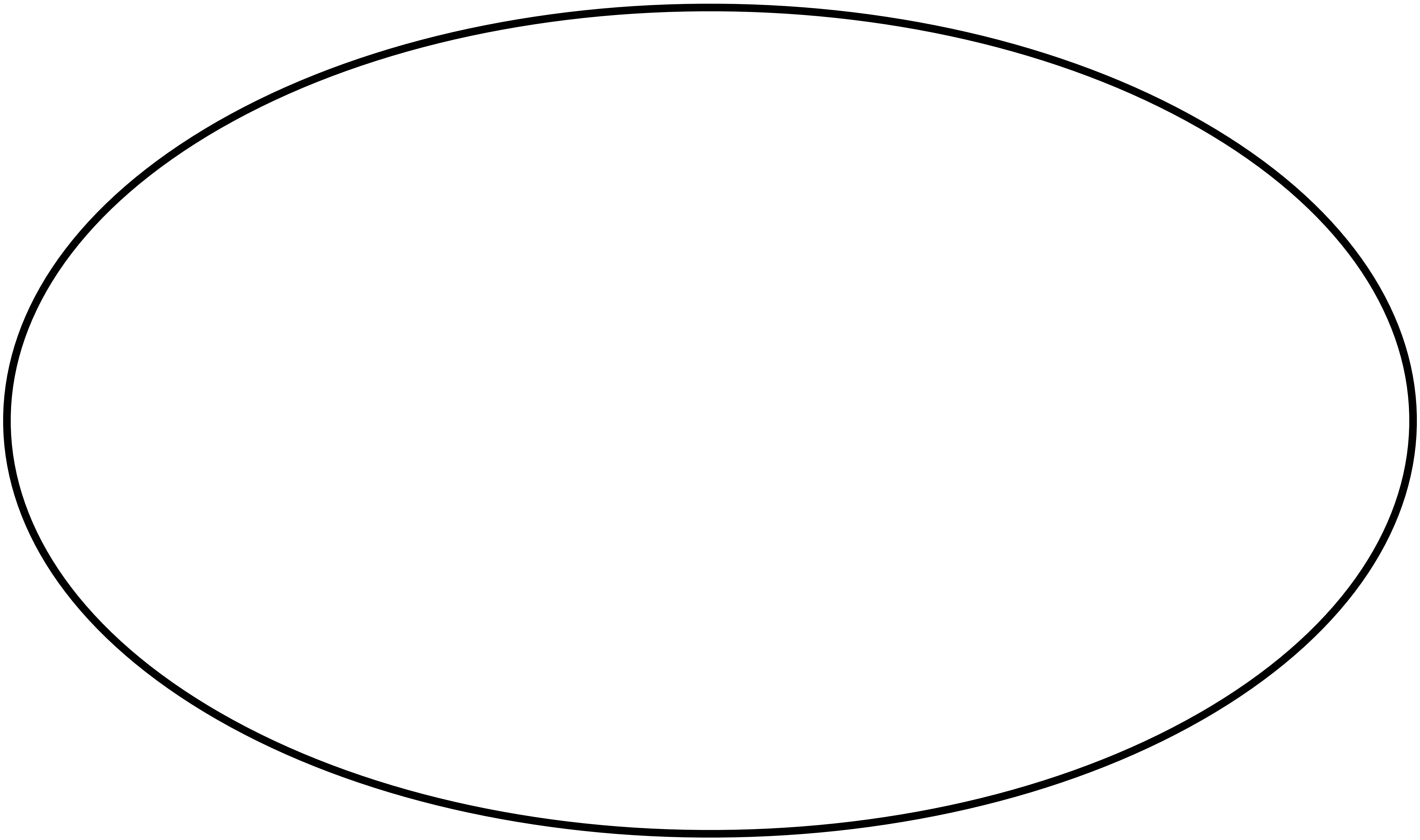

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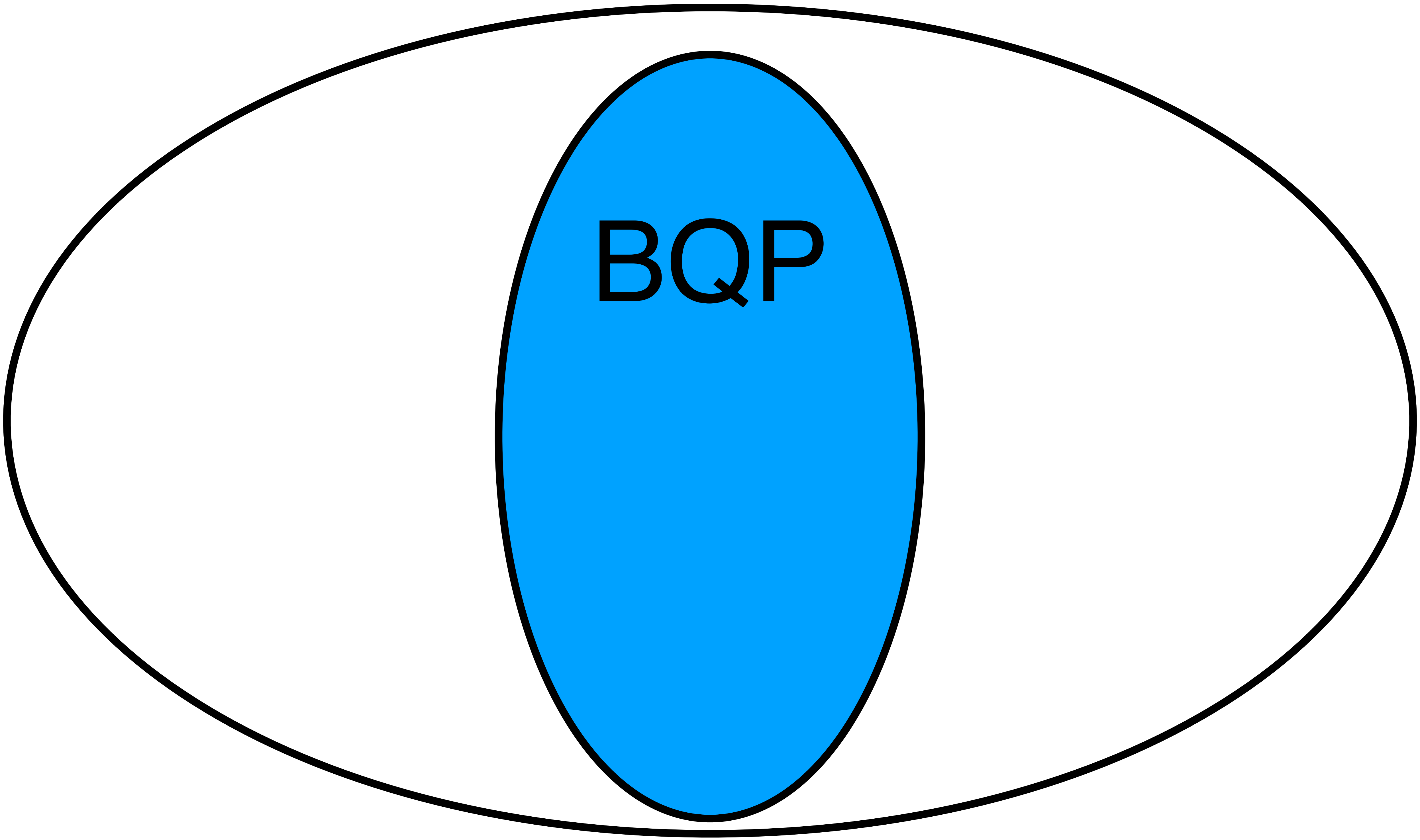

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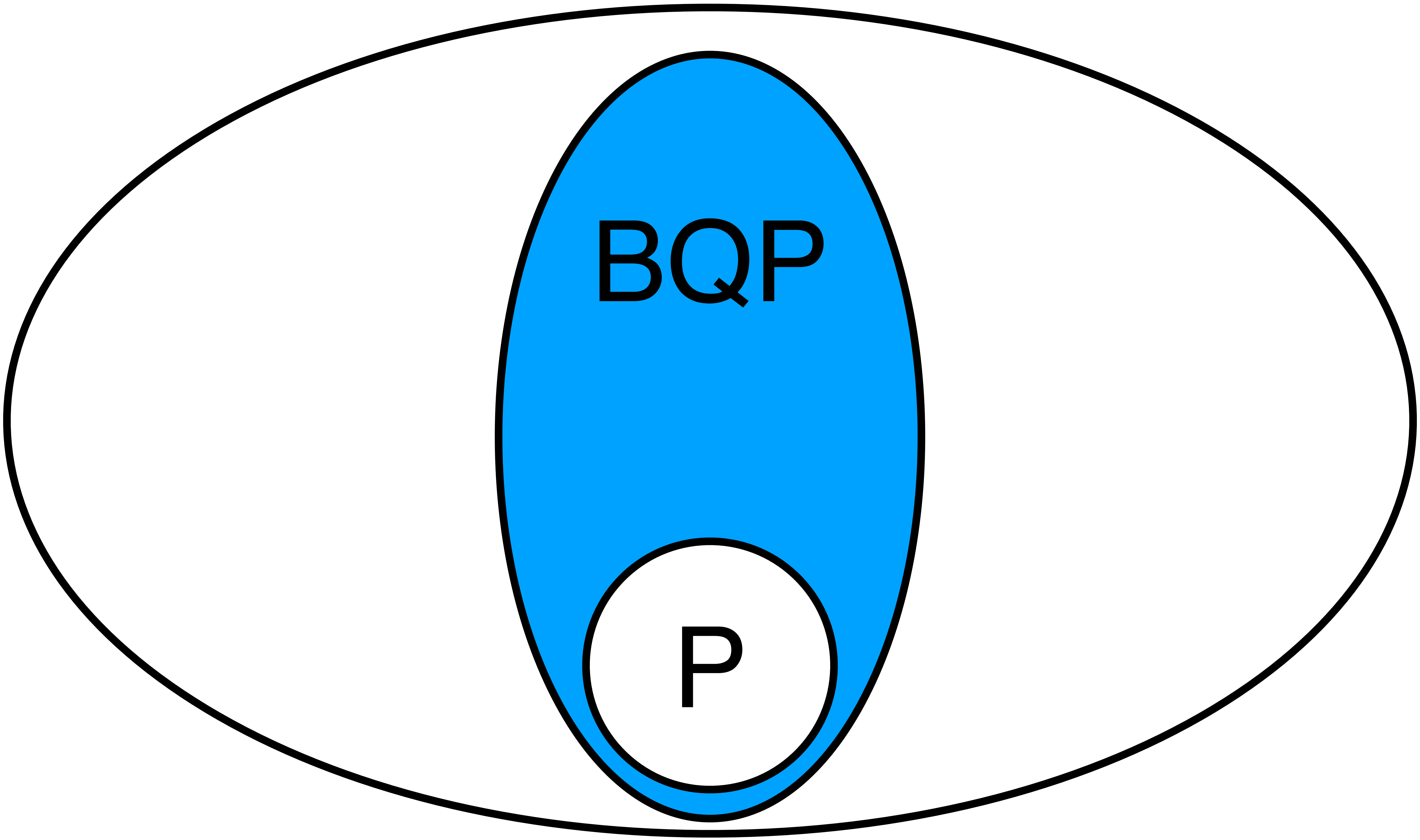

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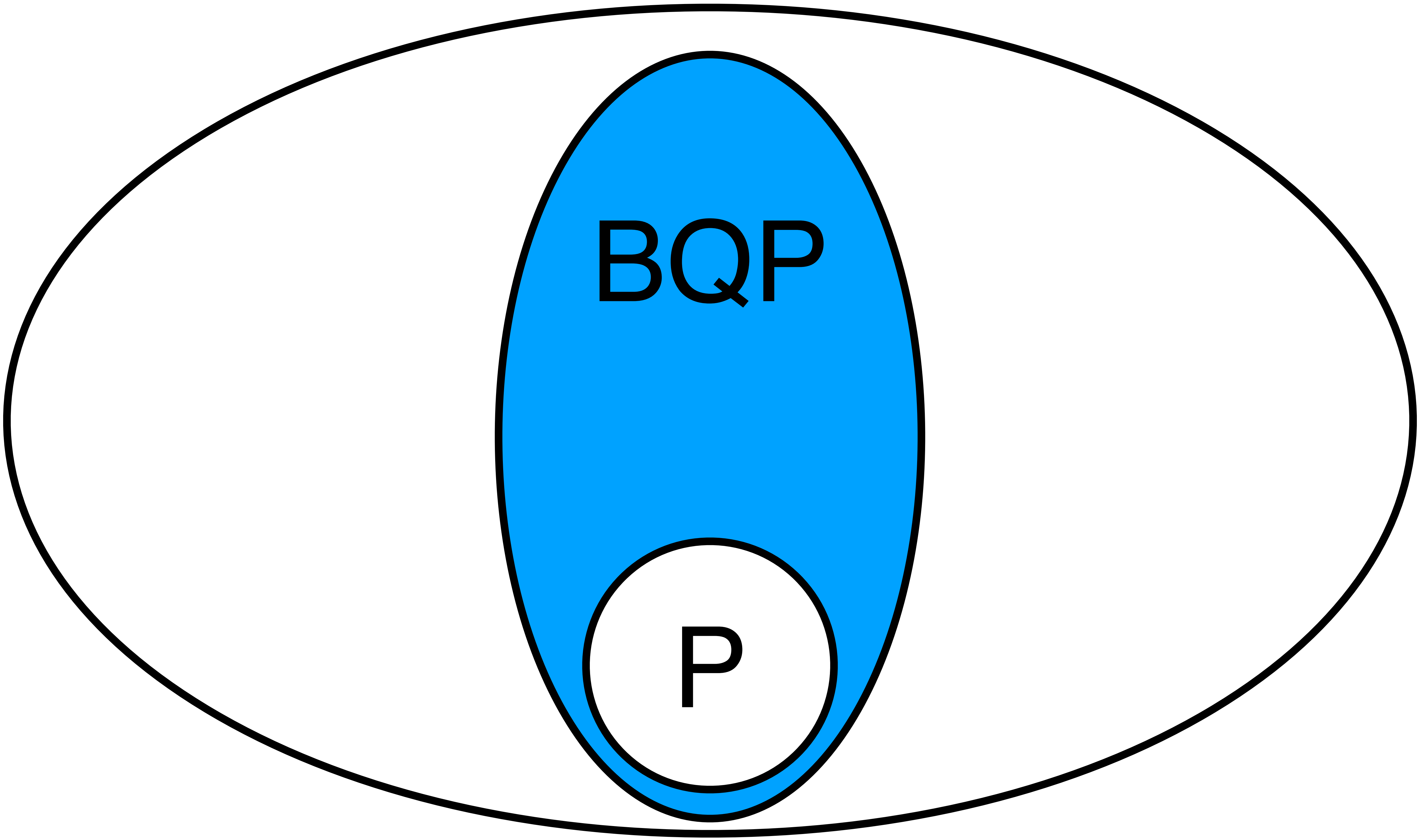

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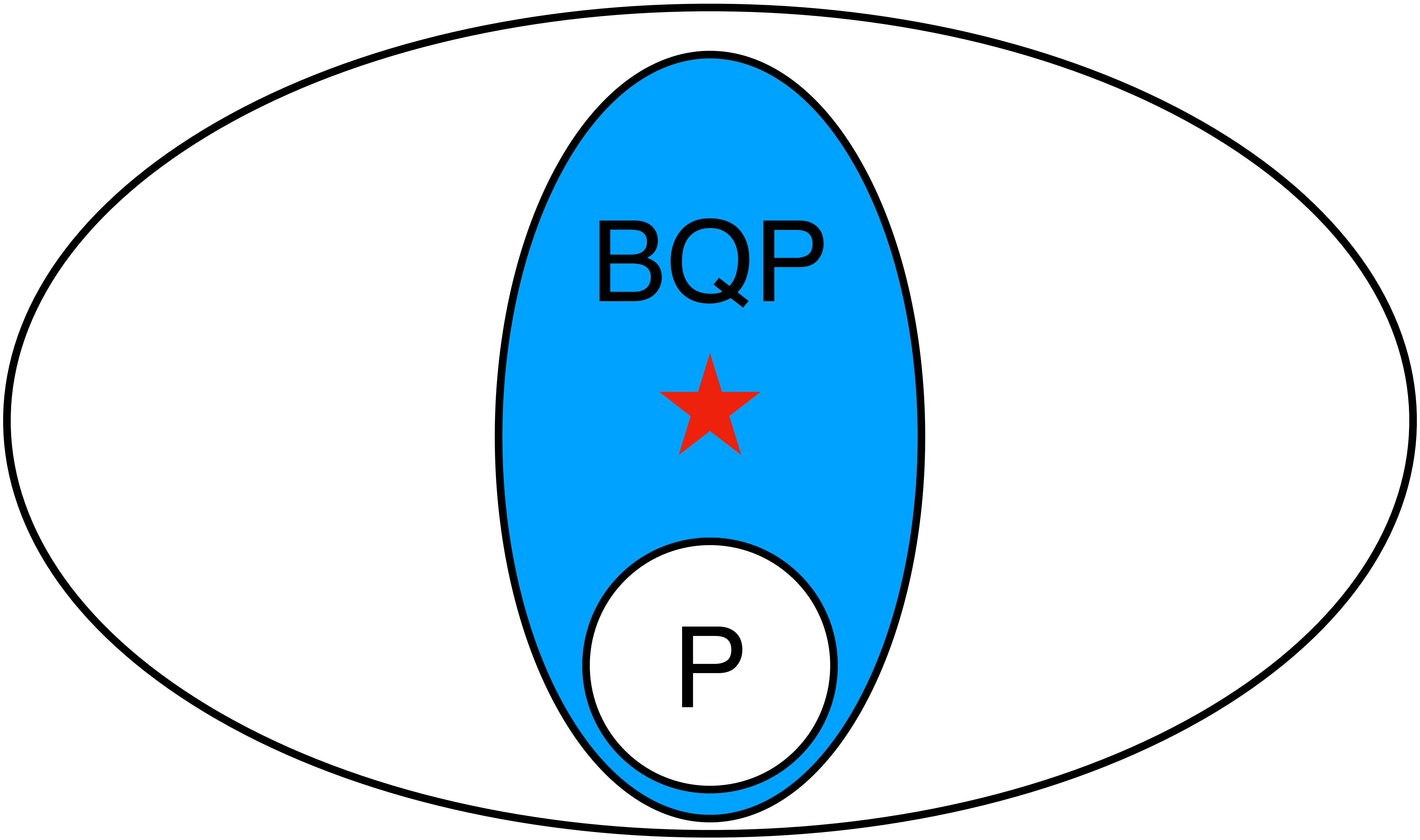
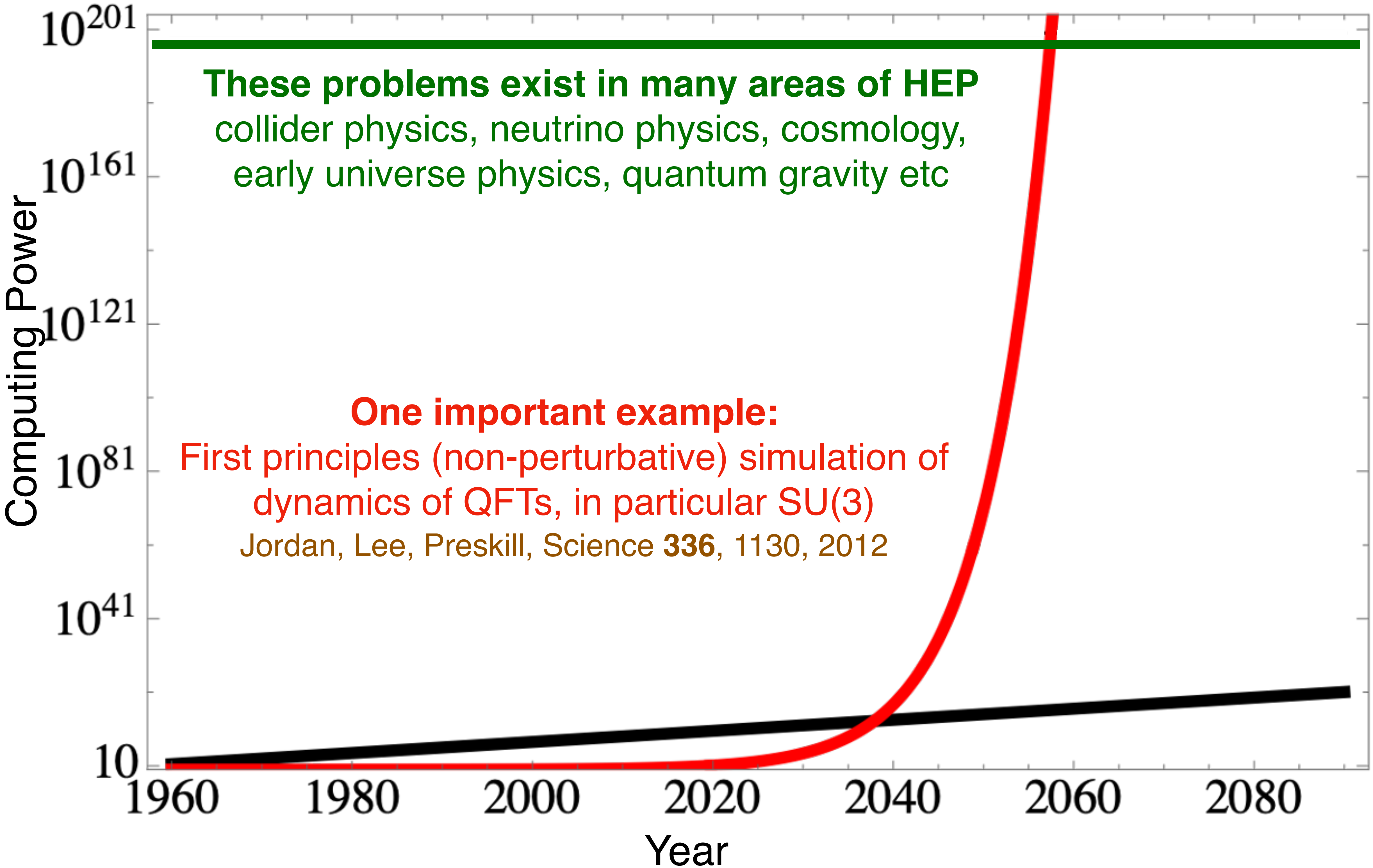
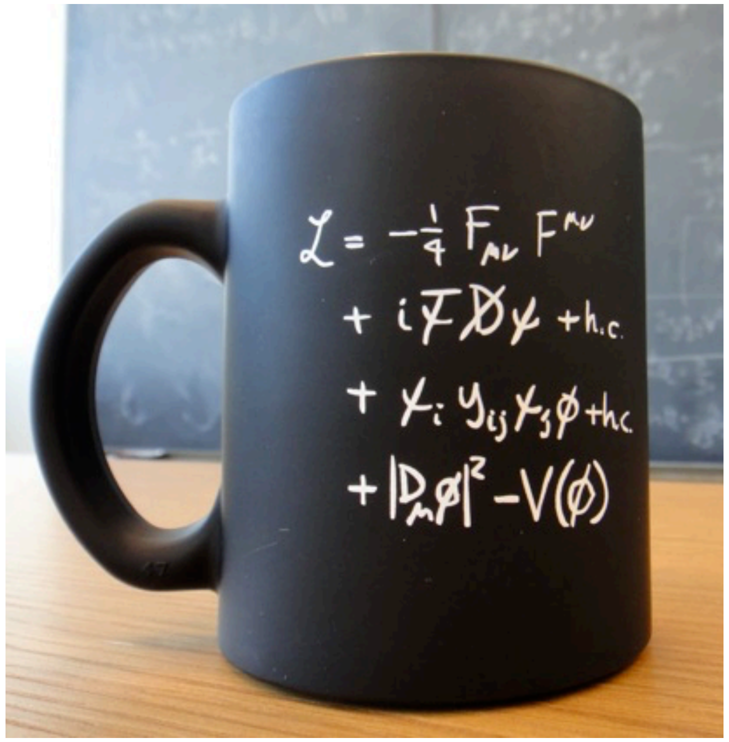
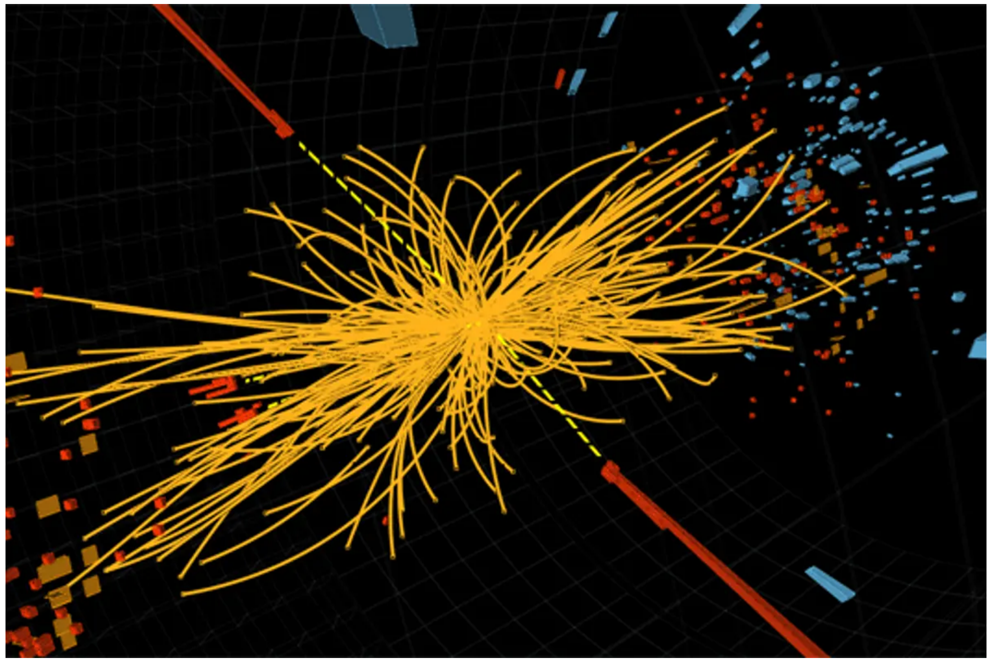
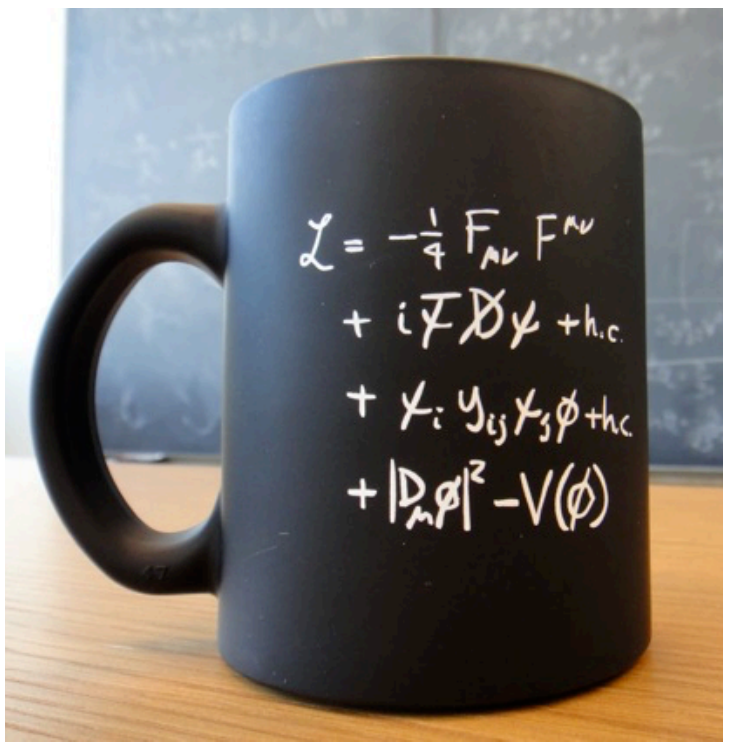


The important message is that there are transformational problems in HEP for which QC outperforms CC




$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$
$+ i \bar{\psi} \not{D} \psi + h.c.$
$+ \psi_i y_{ij} \psi_j \phi + h.c.$
$+ |D_\mu \phi|^2 - V(\phi)$

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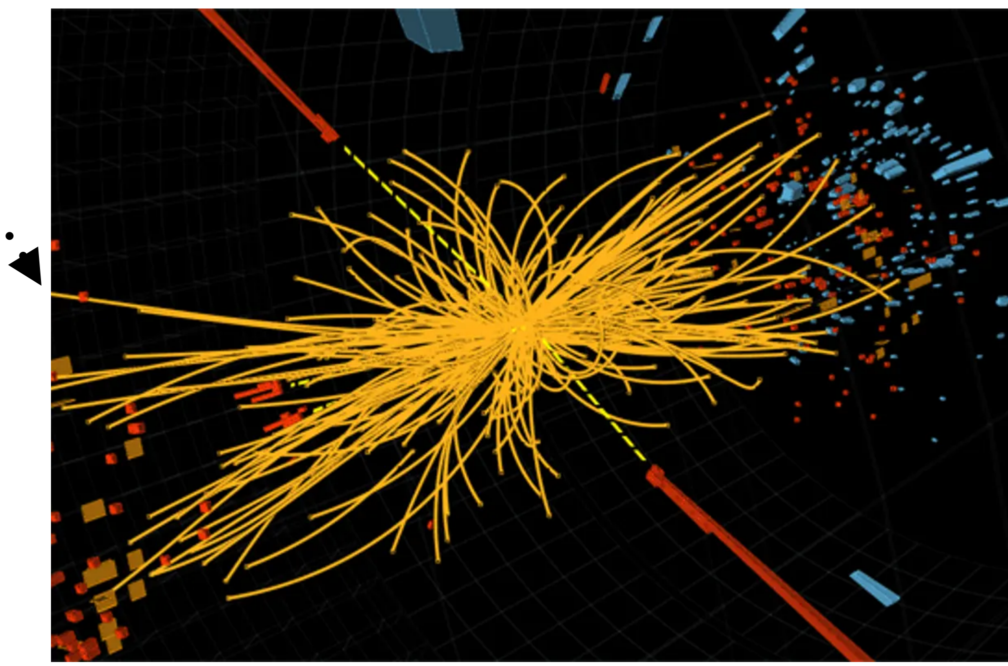
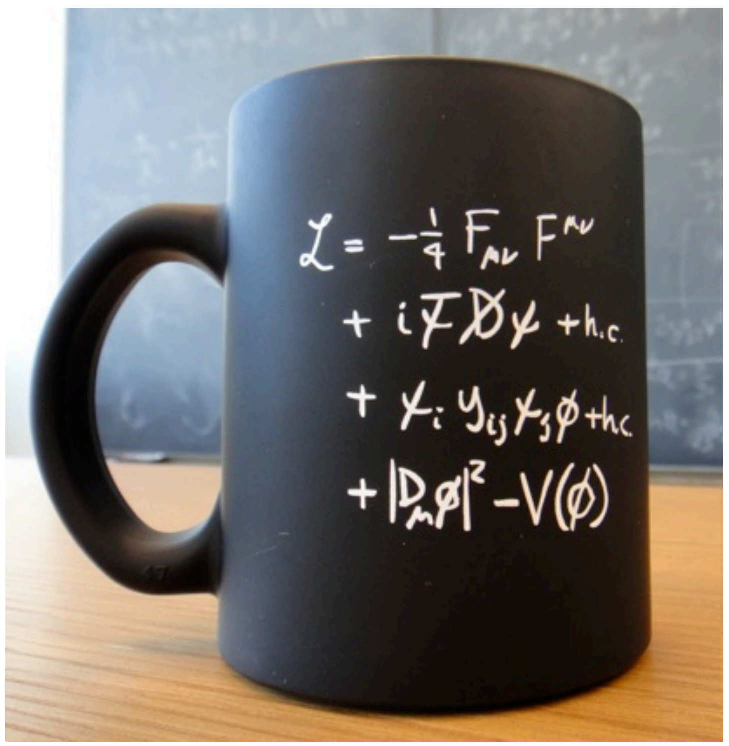


Only very limited information about non-perturbative quantities



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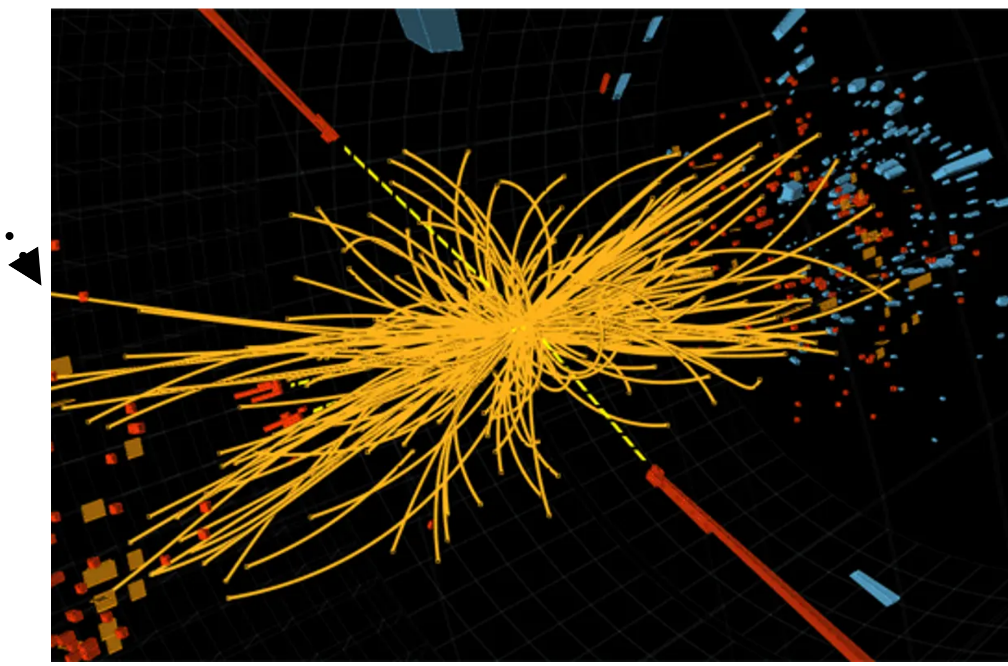

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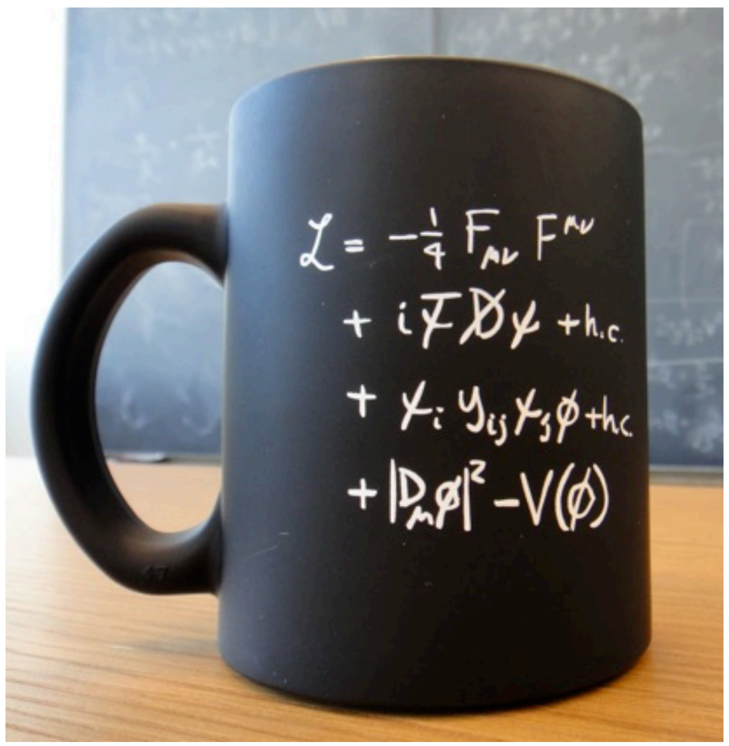

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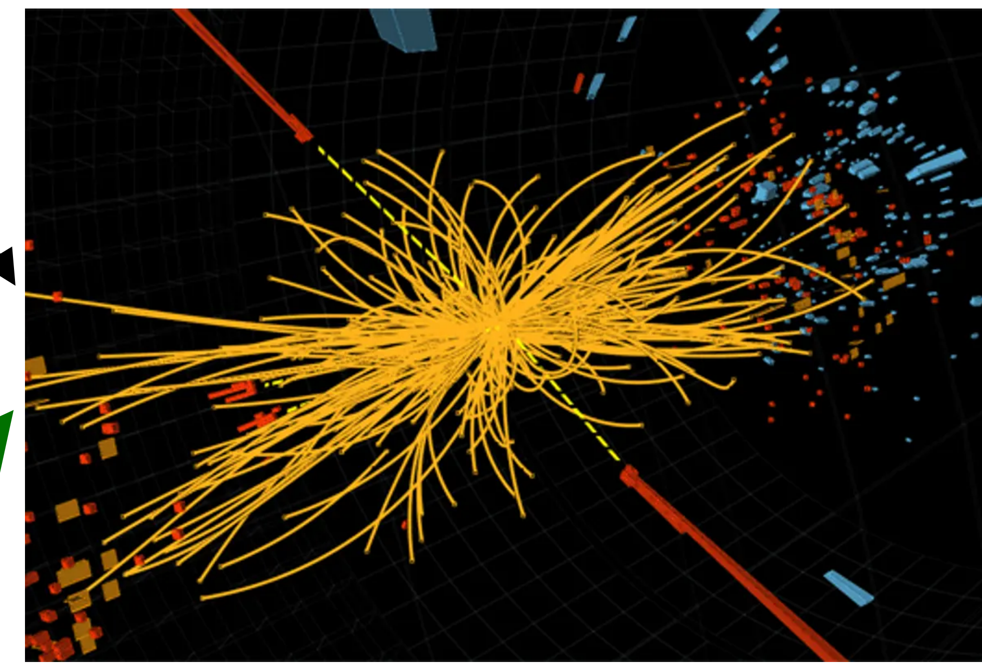

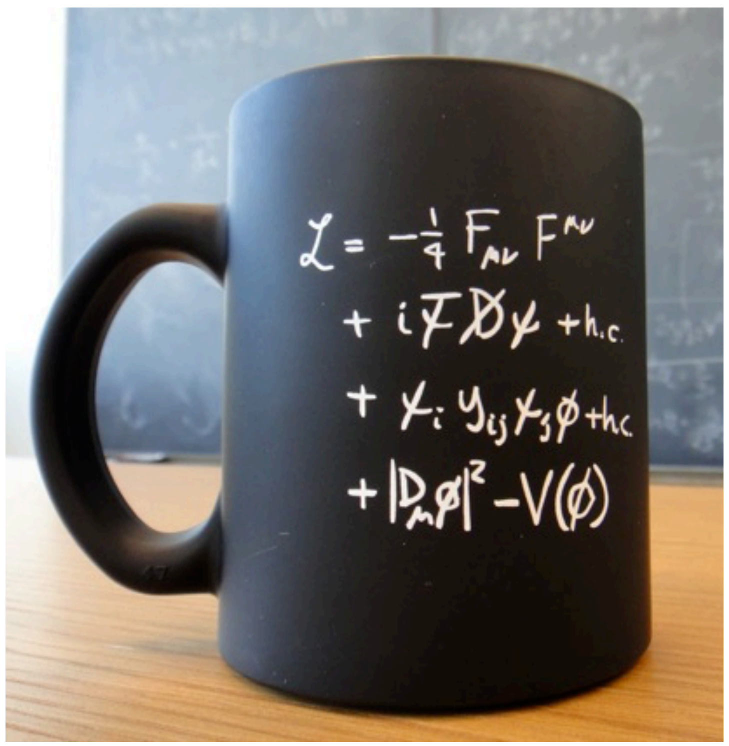

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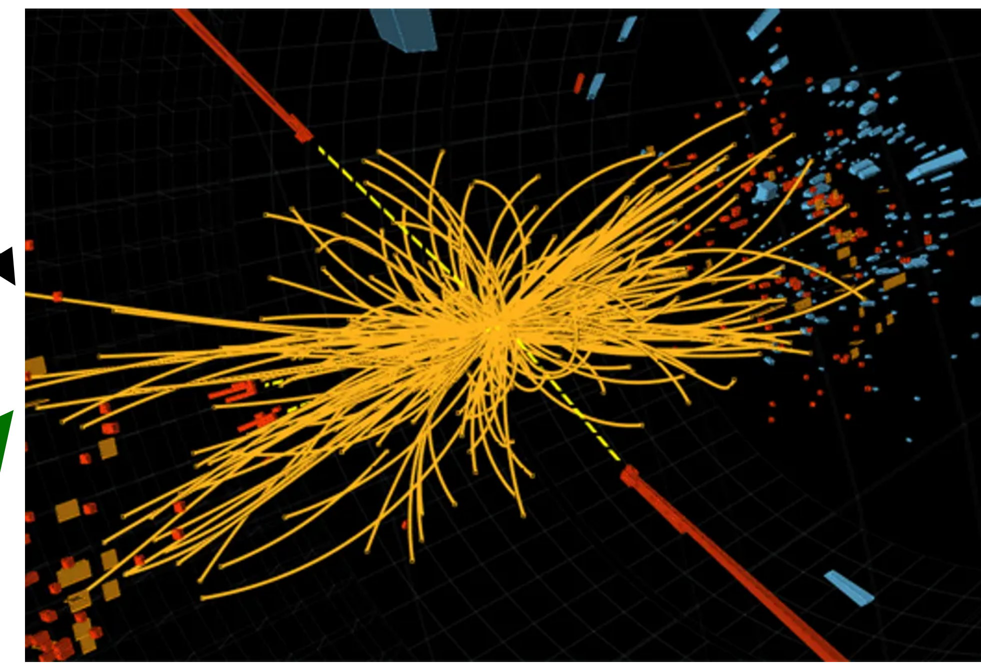

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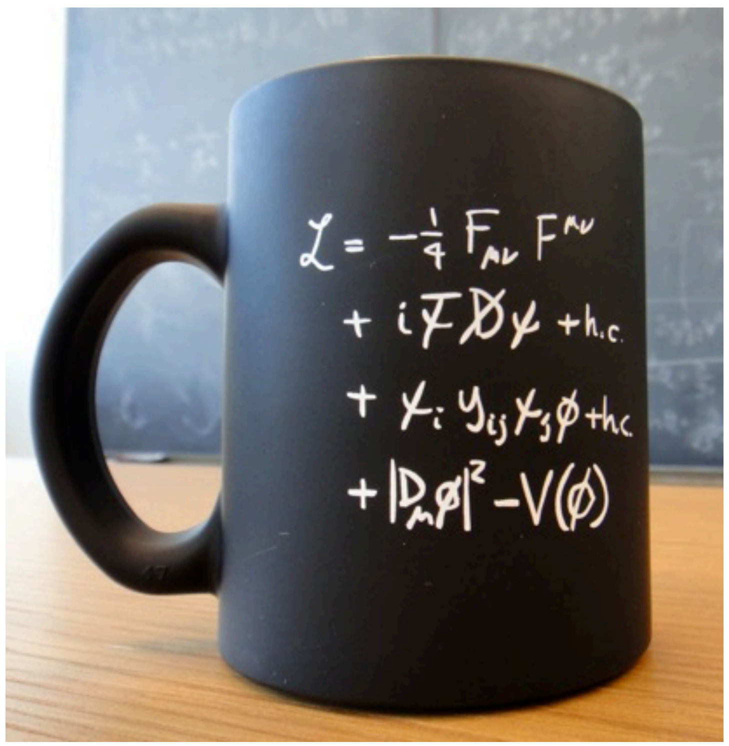

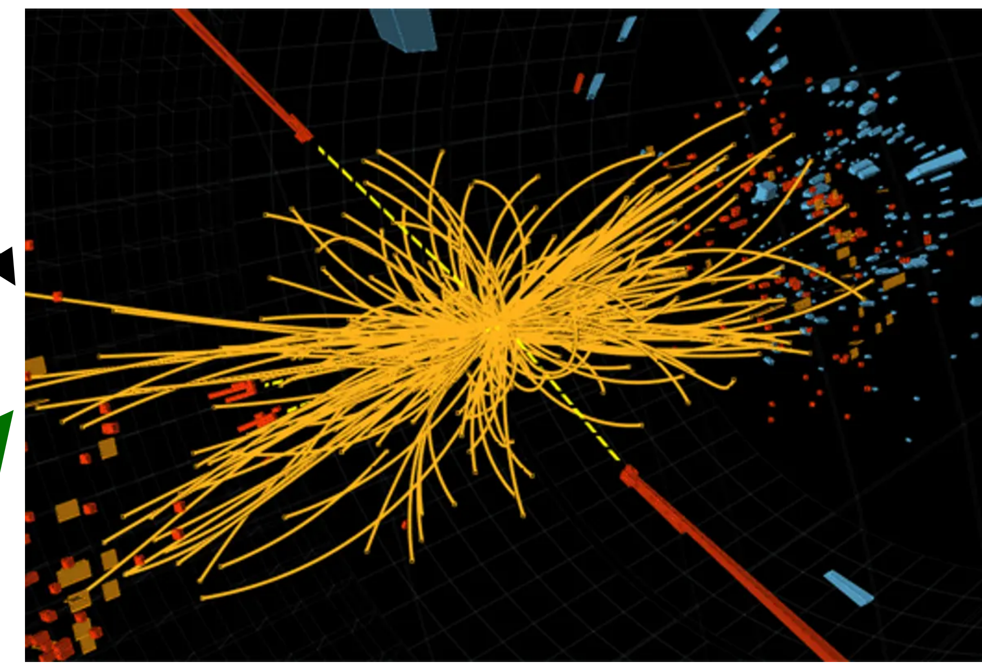

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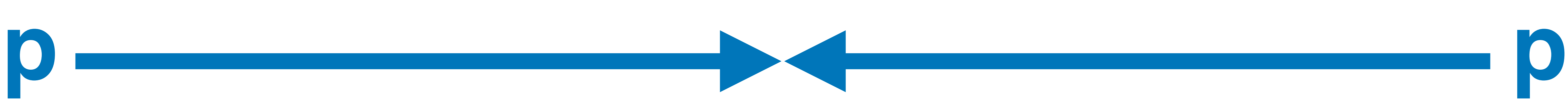

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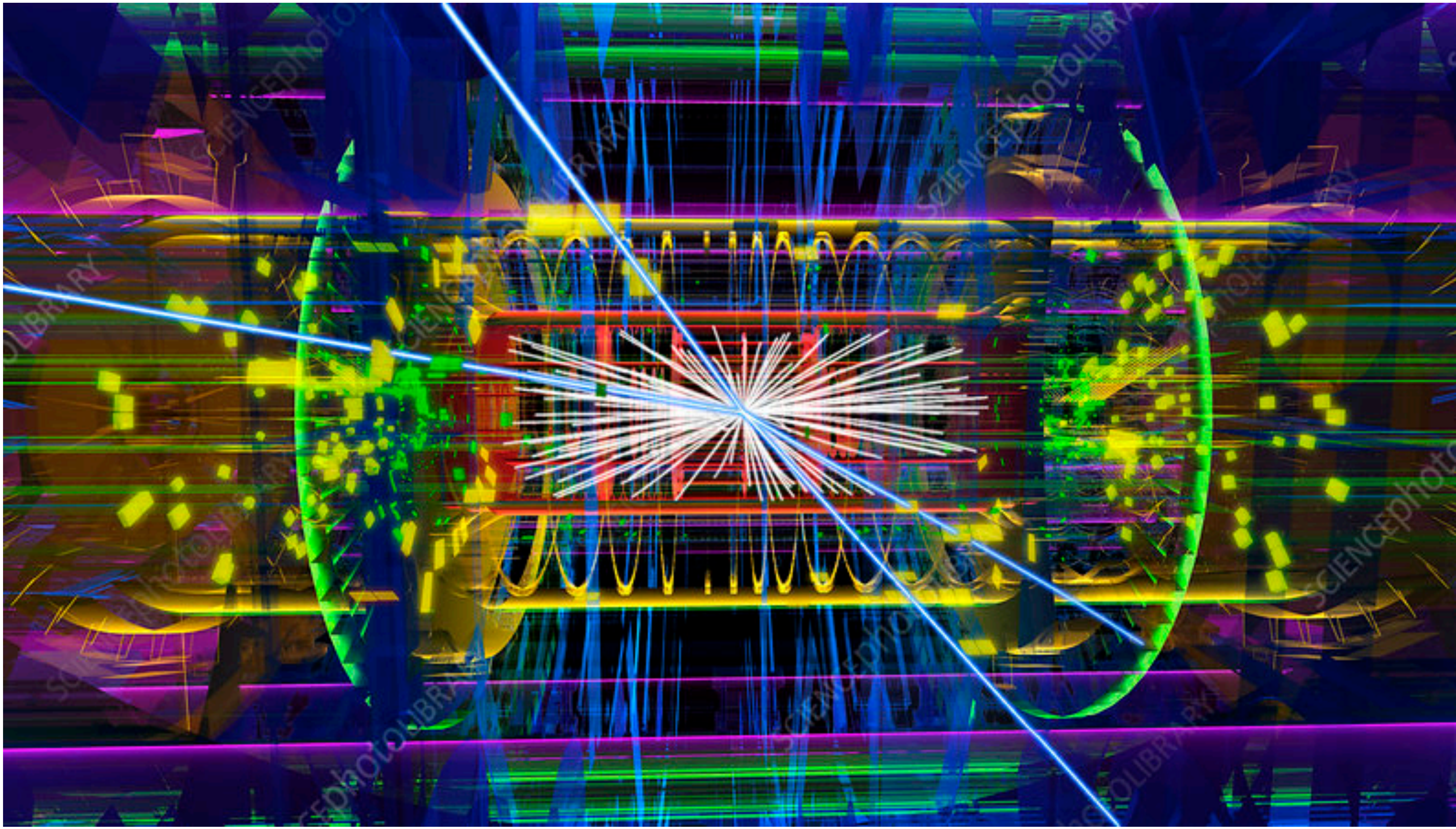

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All elements in this expression in terms of fields $\phi(x)$

Both position x and field $\phi(x)$ are continuous

Need to turn the infinite dimensional Hilbert space into finite dimensional one

Achieved by sampling space on a lattice and digitizing fields

Basic idea is to map the infinite Hilbert space of QFT on a finite dimensional HS making this a QM problem

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3 basic steps:

1. Create an initial state vector at time (-T) of two proton wave packets
2. Evolve this state forward in time from to time T using the Hamiltonian of the full interacting field theory
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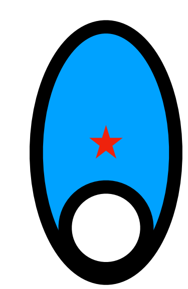
Exciting prospect is that 3 of these steps are 

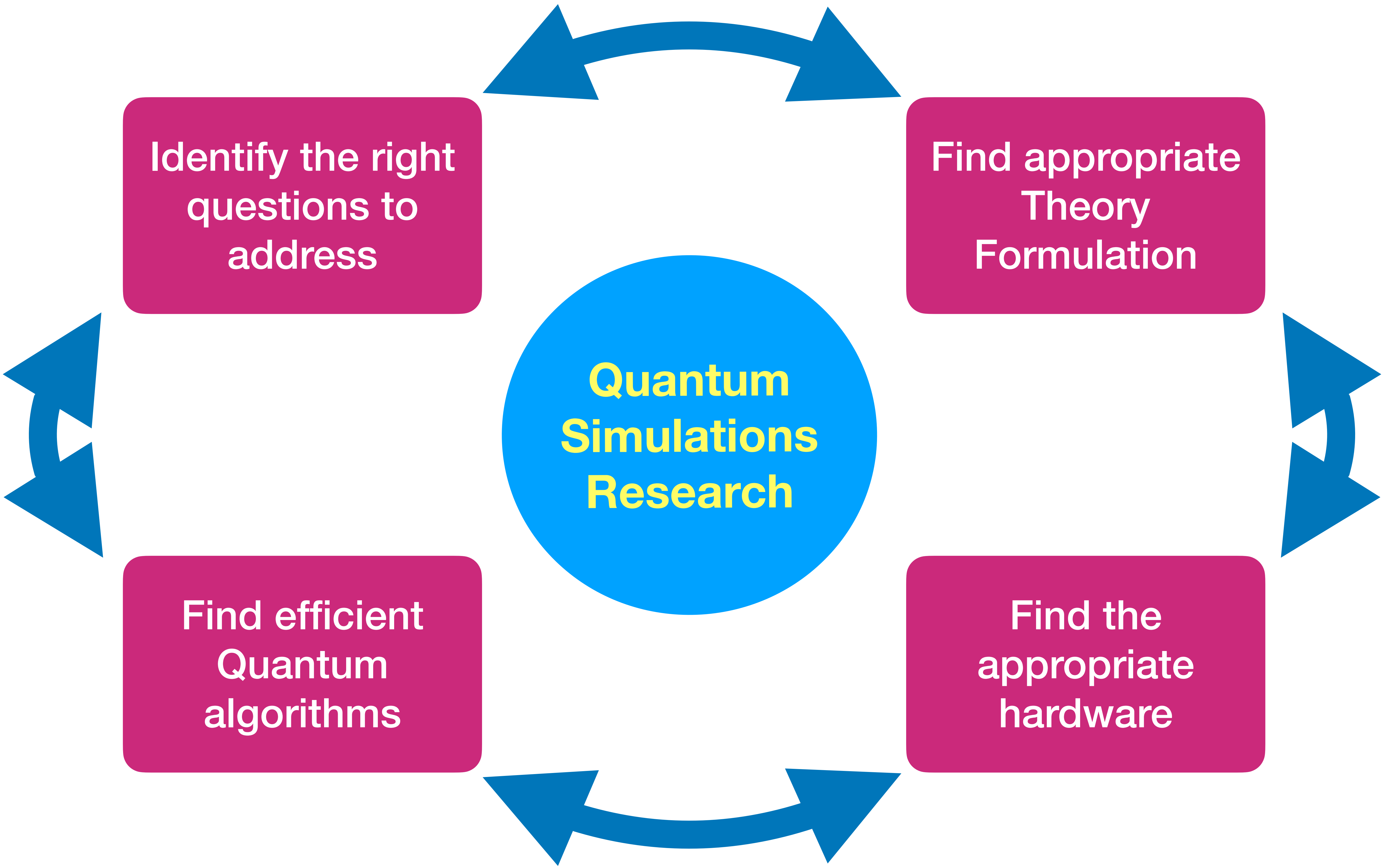
Identify the right questions to address

Find appropriate Theory Formulation

Quantum Simulations Research

Find efficient Quantum algorithms

Find the appropriate hardware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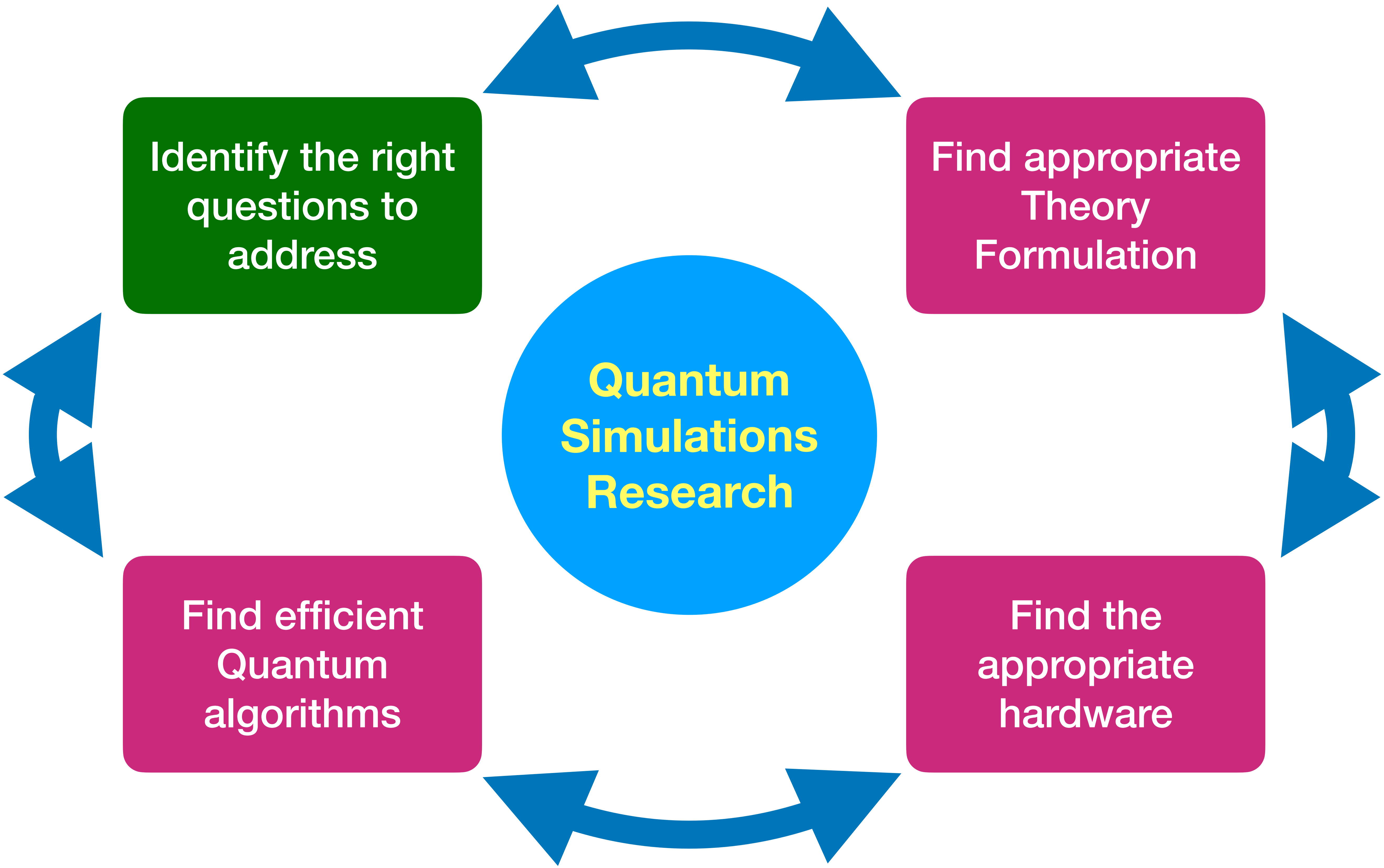
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Since quantum computers are typically behind classical computers in size, should find optimal problems

Energy range that can be described by lattice is given by $\frac{1}{Nl} \lesssim E \lesssim \frac{1}{l}$

Size of system scales as $\sim \left(E_{\text{high}}/E_{\text{low}}\right)^3$

Should attempt to use Quantum computer to only address those questions that are impossible using classical computers (non-perturbative)

Effective Theories are proven tool to isolate certain energy ranges of a problem

Likely better to compute non-perturbative objects defined in EFTs than the full scattering process

Quantum computers have the potential to revolutionize what simulations are possible in HEP

Need to spend the effort to study this in detail to see if / how / when this can become a reality