Particle Physics with Quantum Sensors

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Grand Challenge of High Energy Physics

Standard Model experimentally established

We know there is new physics out there

Matter? Universe?

Dark Matter

Dark Energy

Hierarchy

Where is this new physics?
Where is this New Physics?
Mass? Strength?

$10^{19}$ GeV
(Quantum Gravity)

Colliders

Dark Matter, Dark Energy, Inflation…

Neutrinos, Gravitational Waves

Strong Physics Case

How?

Precision $\Rightarrow$ Quantum Sensors
Quantum Tools for HEP

Questions

- Dark Matter
- Dark Energy
- Inflation
- New Interactions/Symmetries

Tools

- Photons
- Spins
- Atoms
- Molecules

Opportunities?
Dark Matter

Study a/c effects of dark matter on electrons, nucleons and photons

- (e.g. axion)
- Magnetic Field \( \lesssim 10^{-16} \frac{T}{\sqrt{\text{Hz}}} \) \( \cos (m_a t) \)
- SQUID Sensor

Dark Matter

- (neutrino masses?)

Direct force on atoms, measure acceleration

- Accelerations \( \lesssim 10^{-13} \frac{g}{\sqrt{\text{Hz}}} \) \( \cos (m_a t) \)

Sensitivity scales with size (volume, time…)
Direct Detection of Dark Energy

What is it?
Constant? Does it have a kinetic energy?

\[ \frac{\partial \phi}{\partial t} \bar{\psi} \gamma^\mu \gamma_5 \psi \rightarrow \frac{\dot{\phi}}{f} \vec{v}.\vec{S} \rightarrow \vec{v} \]

Similar to axion dark matter, but harder
Less dark energy in galaxy and signal is dc

Bonus

Neutrino current not Energy.
Calibrate reactor output + low energy neutrino detection

Enhanced Sensitivity with Quantum Acceleration
Inflation

Direct

Gravitational Waves

Two Frequencies: CMB, 1 - 10 Hz

Probe Inflationary Potential

(optical and atom interferometry)

Indirect

Produce ultra-light particles

Lab detectable dark matter

(e.g. vector bosons)

(electromagnetic sensors, interferometers)
New Interactions and Symmetries

Photon Qubits/Single Photon Detectors

Optical and Atom Interferometry

CP Violation? Dark Matter?

Ultra-cold molecules with actinides
Roadmap

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Technologies are a direct contribution to the National Quantum Initiative
QIS contribution to major HEP goals