Optomechanics for particle physics

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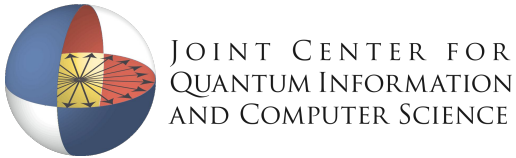
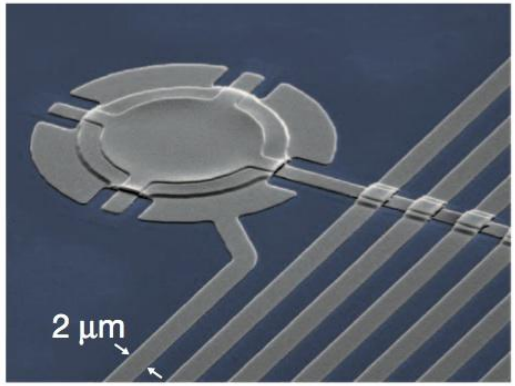
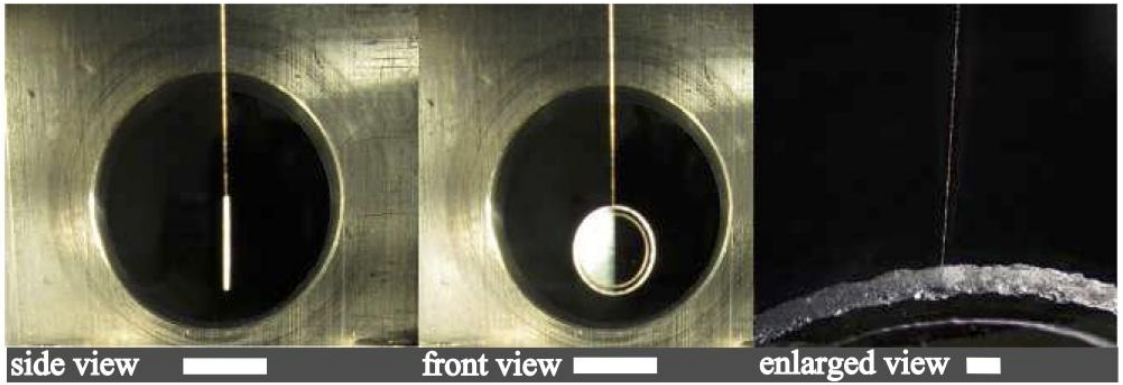
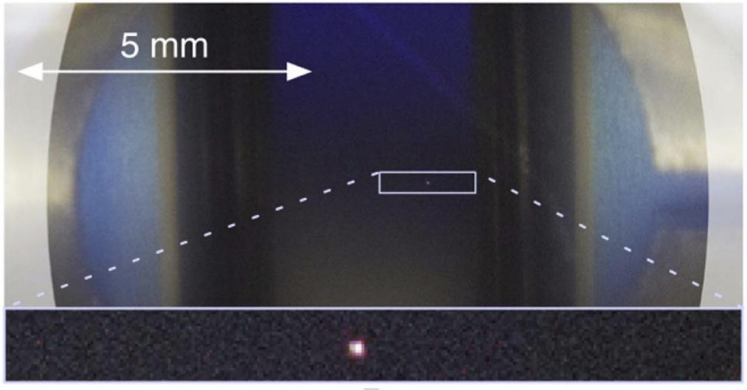




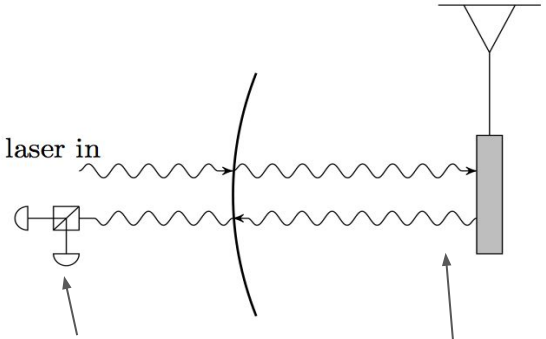
Teufel et al, Nature 2011



Matsumoto et al, PRA 2015



Aspelmeyer ICTP slides 2013

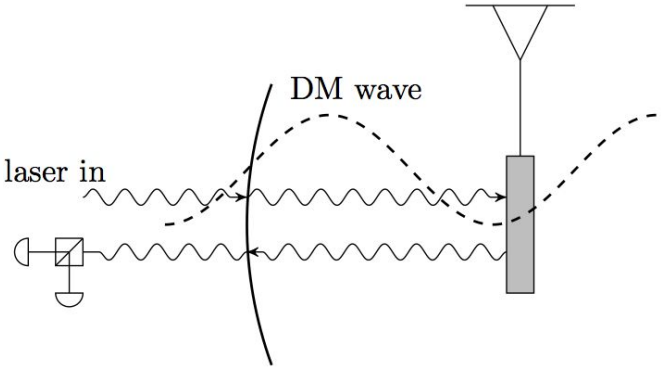


Quantum-limited: sensitivity set by vacuum fluctuations (of light + mechanics)

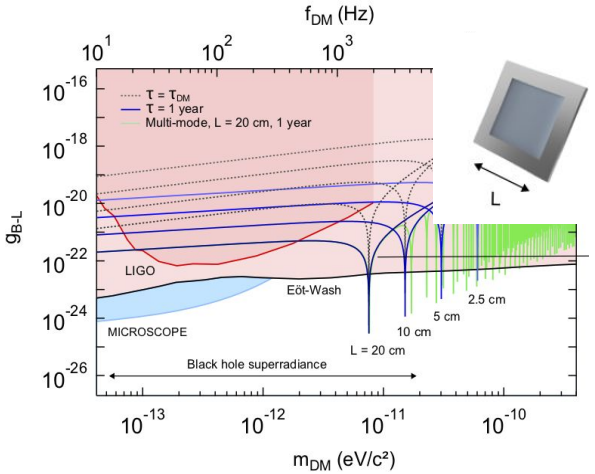
light phase shift ~ x(t)

Ultra-light DM detection

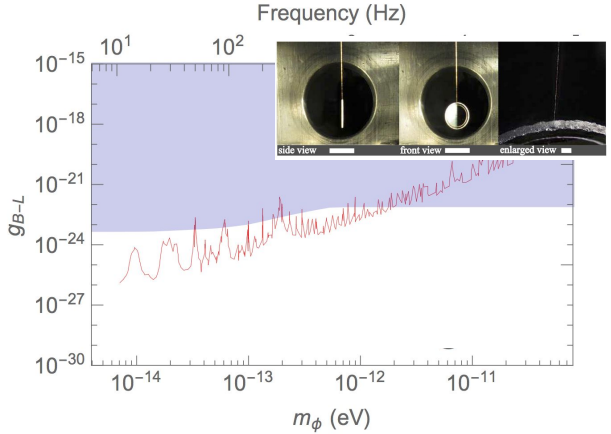
$$\mathcal{L}_{int} = g_{B-L} A \bar{n} n \longrightarrow F = g_{B-L} N_n F_0 \sin(\omega_s t)$$



Similar to QED cavity axion searches,
cavity mode → mechanical COM

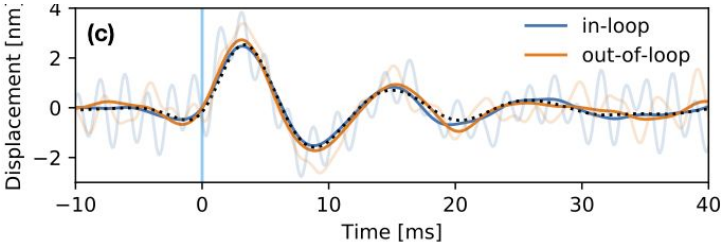


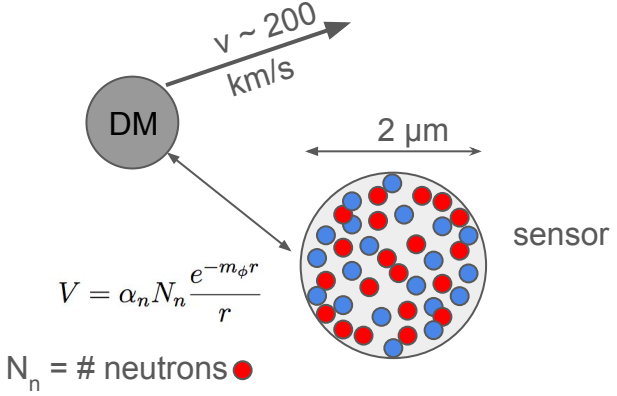
Manley, Chowdhury, Grin, Singh, Wilson 2007.04899

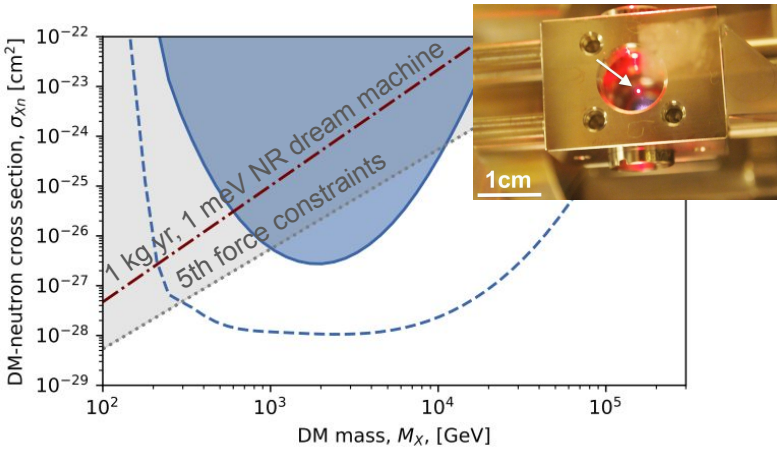


Cataño-Lopez, Santiago-Condori, Edamatsu, Matsumoto PRL 2019

Particle collision detection







Monteiro, Afek, Carney, Krnjaic, Wang, Moore 2007.12067

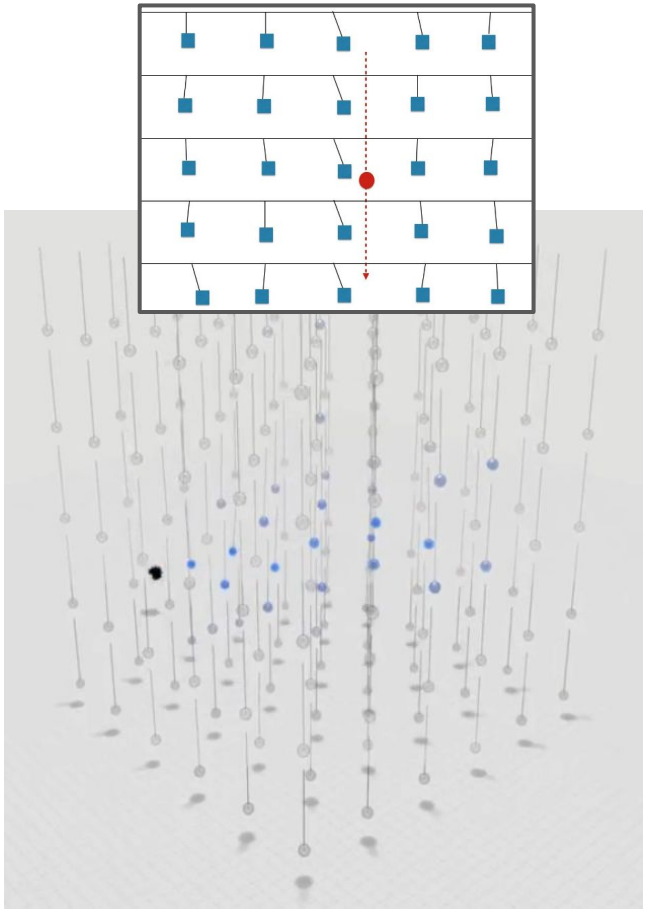
21st century swiss army knife/bubble chamber

Array of many detectors → enhanced SNR, background rejection, exquisite directional detection

Eg. gravitational direct detection of very heavy (~m_{Pl}) dark matter, or lighter DM coupled via long range force

Signal = correlated track of macroscopic motion

See talk by Juehang Qin on a testbed system



Carney, Ghosh, Krnjaic, Taylor 1903.00492

Overview + next steps

- Mechanical sensing = robust set of sensing platforms for many HEP signals of interest (especially those with coherence length ~ micron or larger), also applications to gravity (review on tabletop experiments: 1807.11494), metrology

- Complementary to atom interferometry, other quantum sensing techniques, often in different frequency domains

- Next steps: approaches to sub-SQL detection (th + exp); pathfinder experiments: ultralight, particle, array (exp); advanced quantum techniques eg. quantum coherent readout/track reconstruction (th)

- HEP-PH input--what else can be detected with this stuff?

See also: our LOI (“Optomechanics for particle detection”, w/ G. Krnjaic, R. F. Lang, Z. Liu, J. Lykken, D. C. Moore, R. Pooser, C. Regal, M. Spinrath, and J. M. Taylor)

Overview/white paper: 2008.06074 broad picture, examples, extensive refs

Feel free to contact me: carney@umd.edu

Backup slide: quantum limits in impulse sensing

Standard quantum limit for momentum transfer:

$$\Delta p_{SQL} = \sqrt{\hbar m_s \omega}$$

1.5 MeV (m = 1 ng, ω = 1 kHz)

1.5 μeV (m = 1 m_e, ω = 1 kHz)

Again this is just a benchmark. “Simple” and natural ways to go below this level:

- Squeezing
- Non-demolition/backaction-evasion

Back-action evading impulse measurements with mechanical quantum sensors
S. Ghosh, **D. Carney**, P. Shawhan, J. M. Taylor 1910.11892

See A. Clerk, PRB 2004 for review