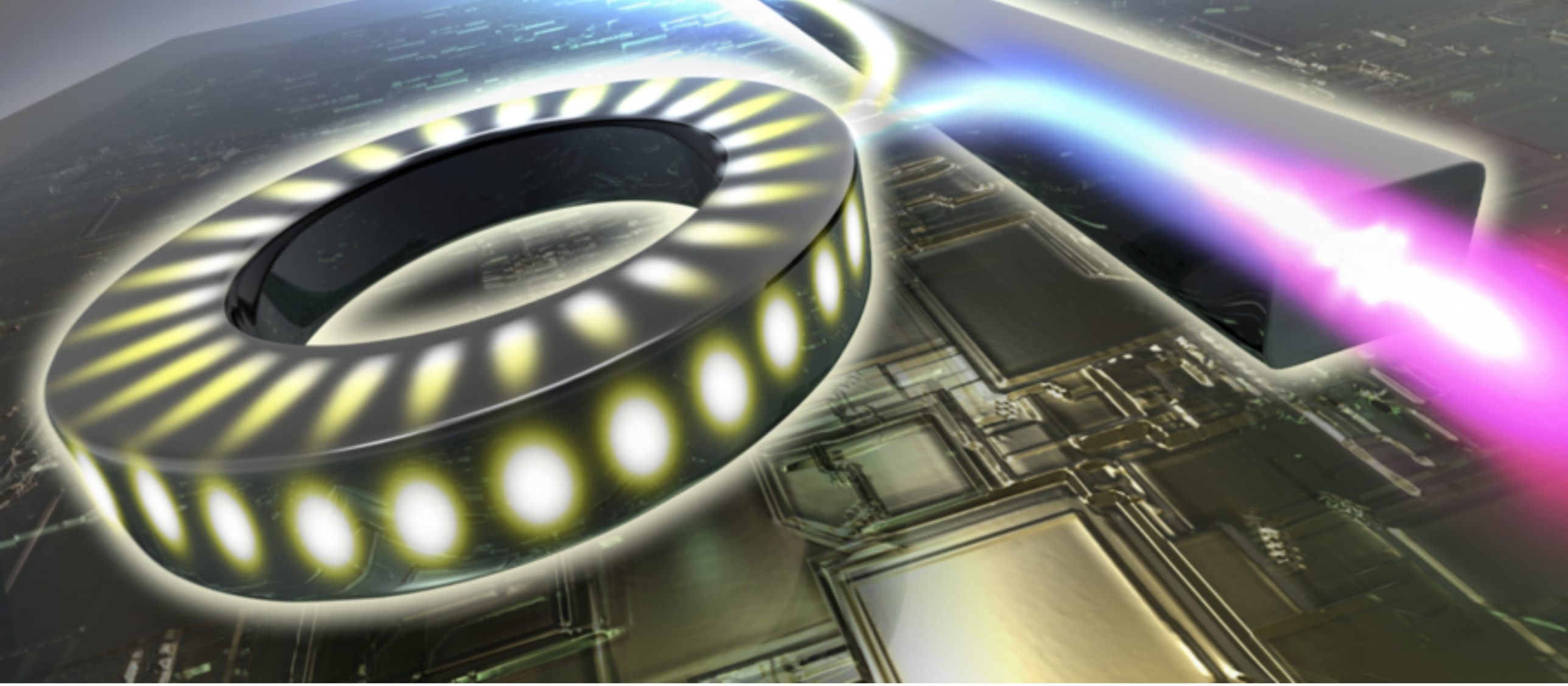

Searching for Ultralight Dark Matter with Light

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PIKIMO 12

04/30/22

Fermilab

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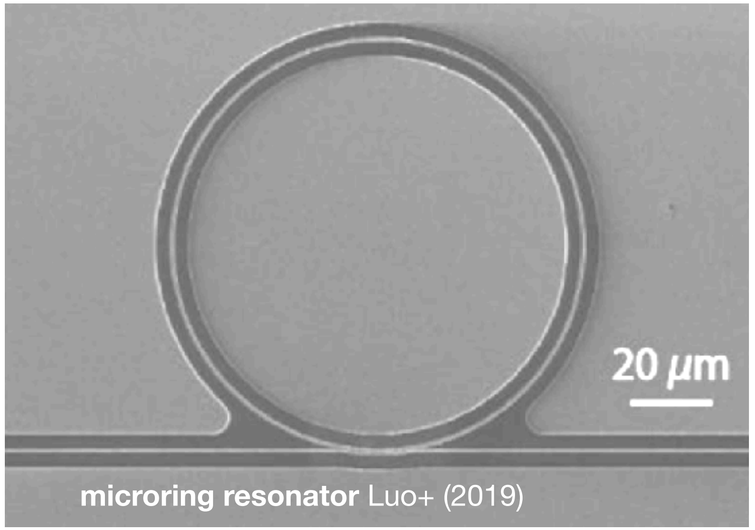
eV and Sub-eV Dark Matter

- de Broglie wavelength $\frac{h}{mv} \sim 1\ \text{mm} \times \frac{\text{eV}}{m} \frac{10^{-3}c}{v}$
- Local number density $\frac{\rho}{m} \sim 10^8/\text{cm}^3$
- Example: axion or axion-like particles $-\frac{g}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu}$

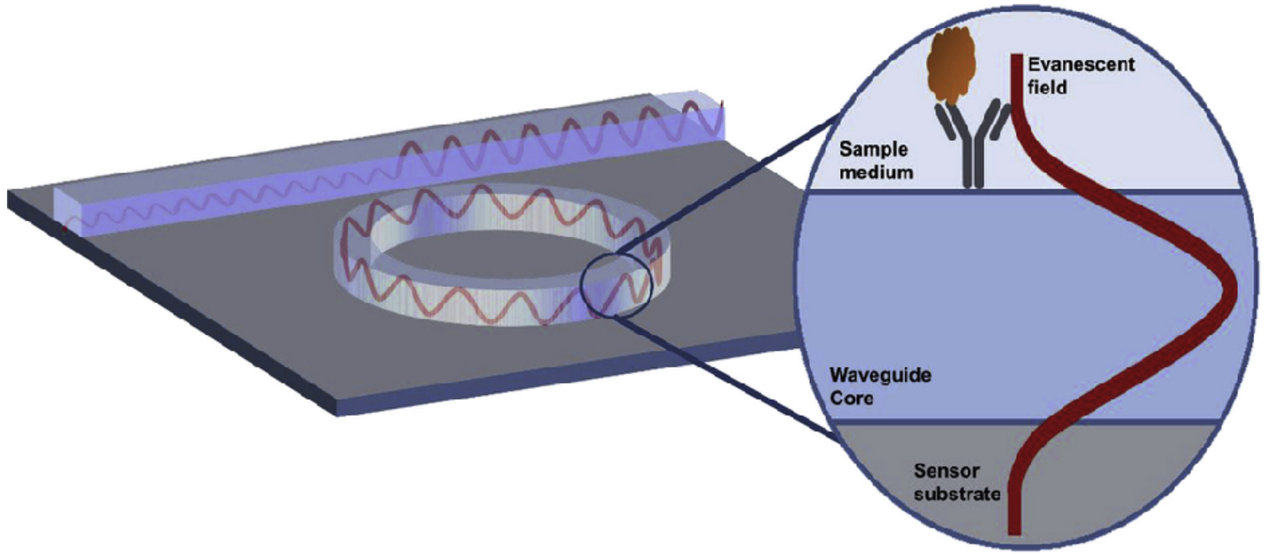
  dark photon $-\frac{1}{2} \epsilon F'_{\mu\nu} F^{\mu\nu}$

Searches at Optical Frequency

Optical Cavity: eV



microring resonator Luo+ (2019)



$$Q \sim 10^7$$

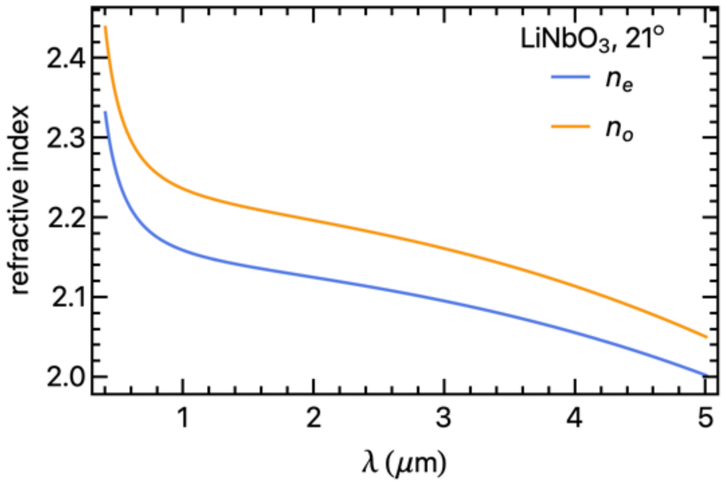
can be mass produced

Dark Photon Dark Matter Search w. Optical Cavities

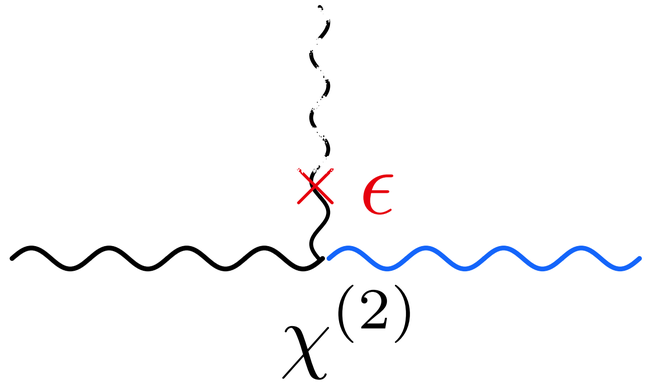
Nikita Blinov, Roni Harnik, Ryan Janish, Neil Sinclair

$$\int d\mathbf{x}\; 2\chi^{(2)}_{ijk} E_i E_j E_k \supset \epsilon \int d\mathbf{x}\; 2\chi^{(2)}_{ijk} \left(E'_i E_j E_k + E_i E'_j E_k + E_i E_j E'_k\right)$$

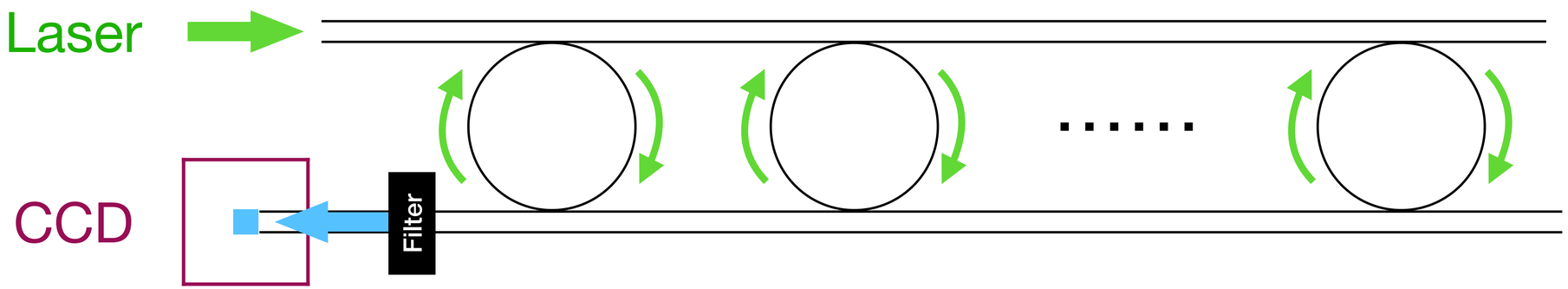
Birefringence



Non-linear susceptibility,
e.g. Lithium Niobate



Dark Photon Dark Matter Search w. Optical Cavities



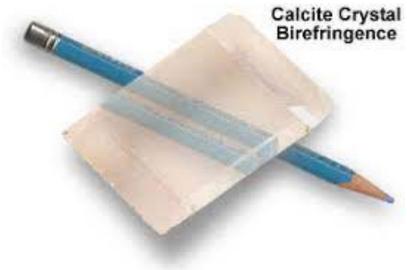
Signal photons can be resonantly produced if frequency and momentum match.

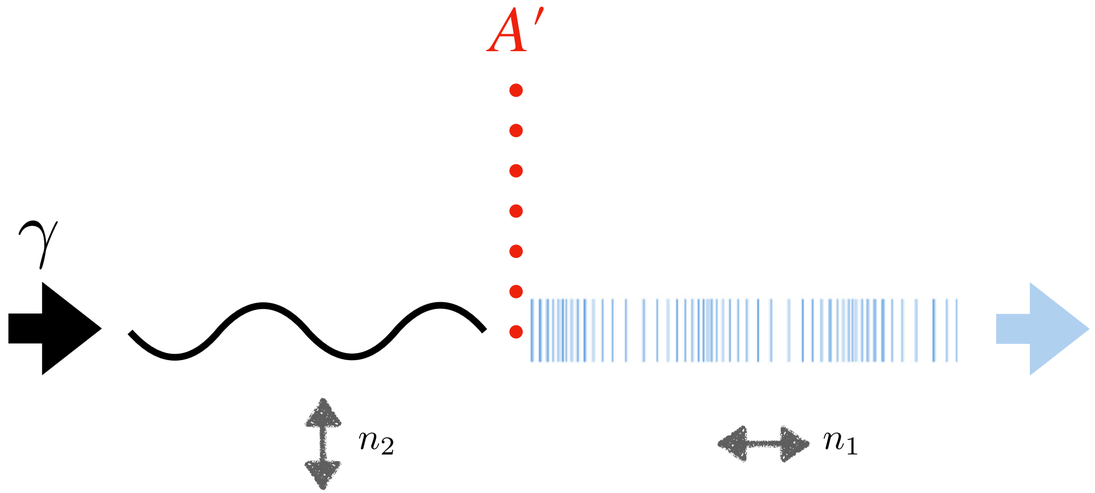
$$\omega_p + \omega_d = \omega_s$$
$$k_p + k_d = k_s, \text{but } k_d \approx 0$$

$$k_{p,s} = \frac{2\pi}{\lambda} = n\omega_{p,s}$$

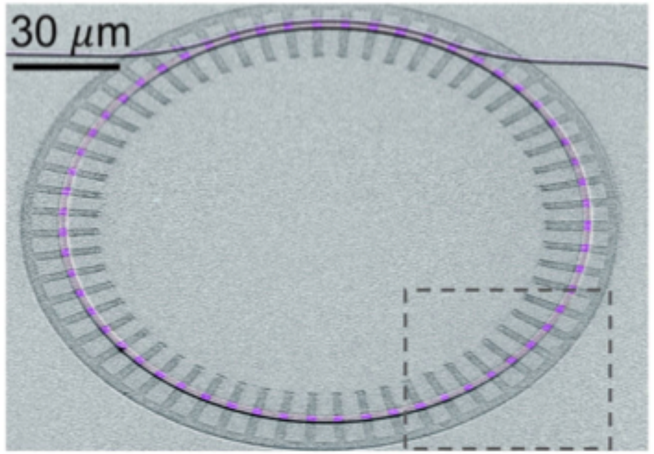
Dark Photon Dark Matter Search w. Optical Cavities

- Through **birefringence**



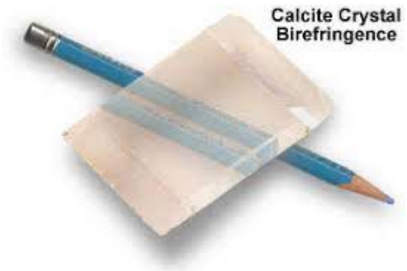


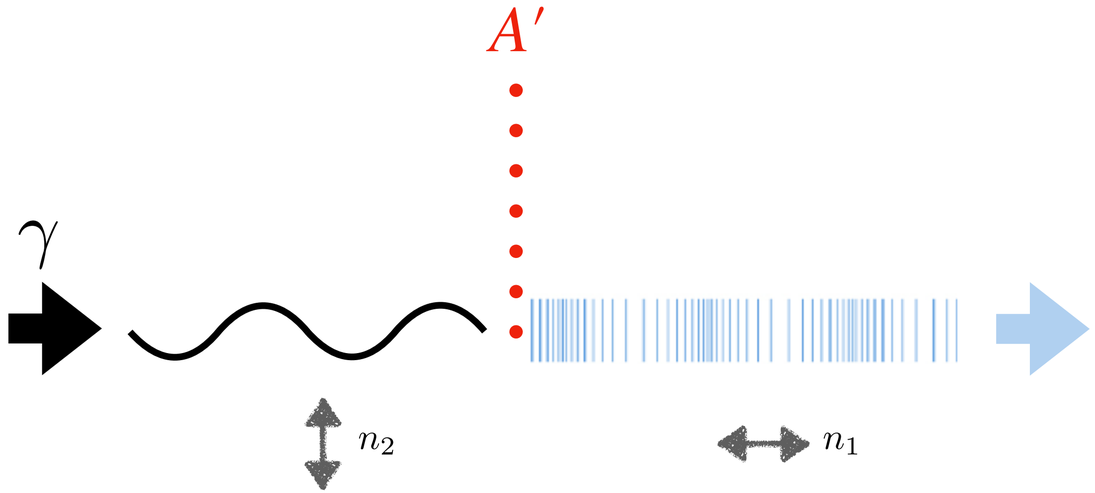
- Through **quasi phase matching**



Dark Photon Dark Matter Search w. Optical Cavities

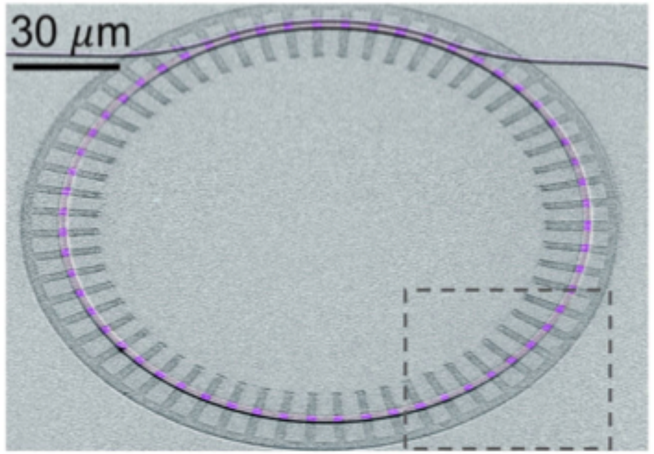
- Through **birefringence** $\chi^{(2)}_{xxy}$



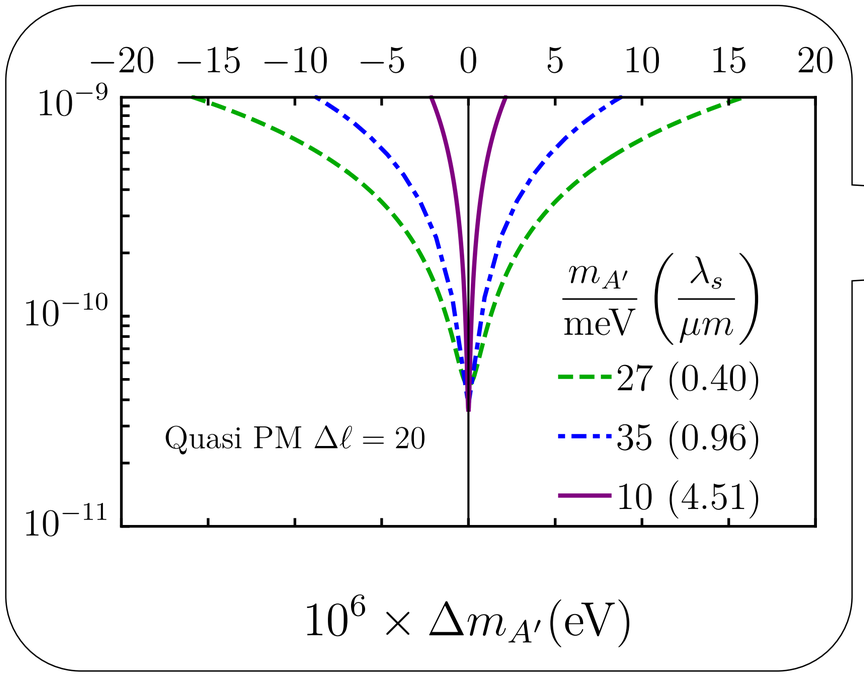


- Through **quasi phase matching** $\chi^{(2)}_{xxx}$

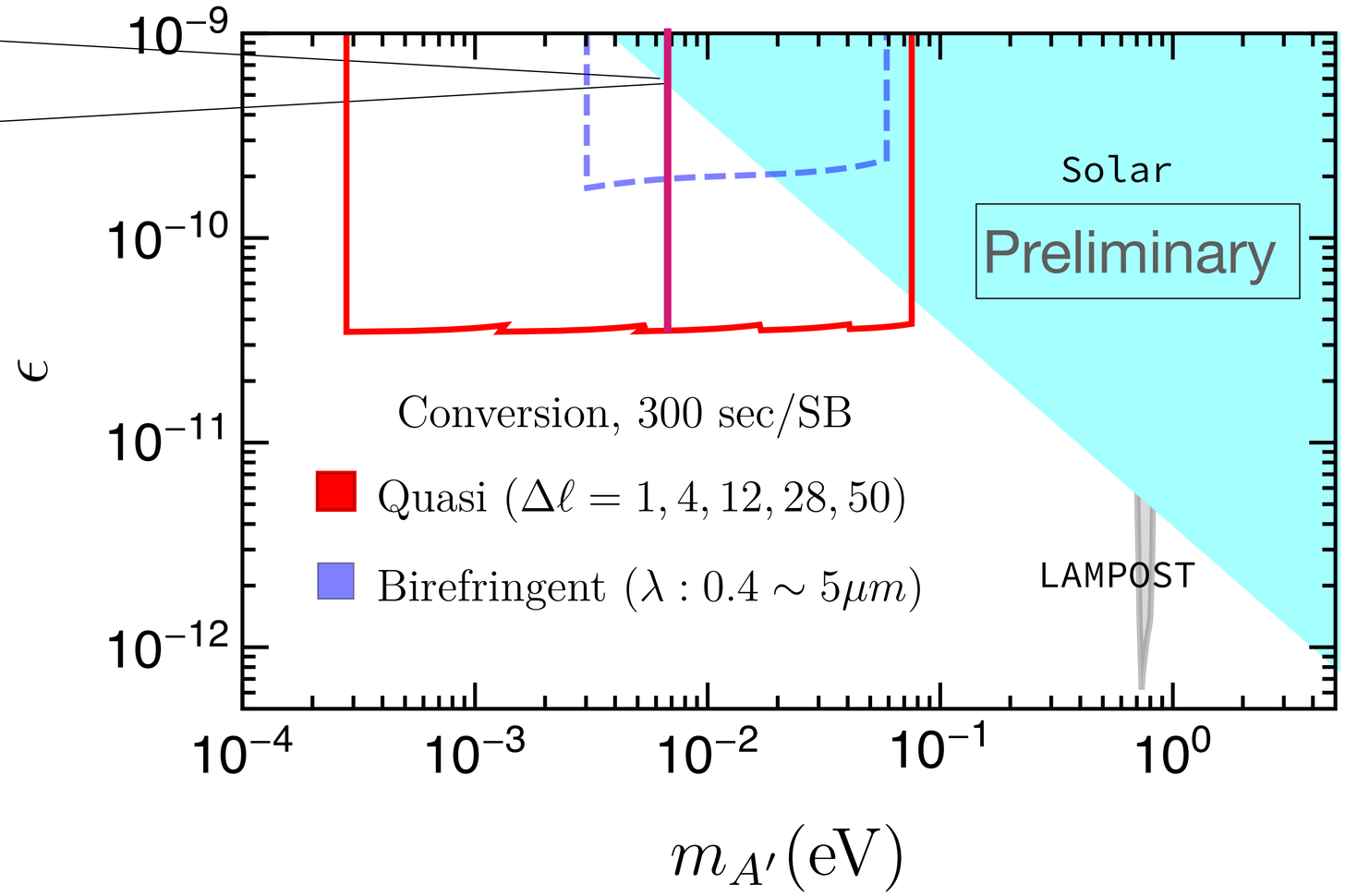
$$\varepsilon = \mathrm{diag}(n_e^2, n_o^2, n_o^2)$$



Dark Photon Dark Matter Search w. Optical Cavities

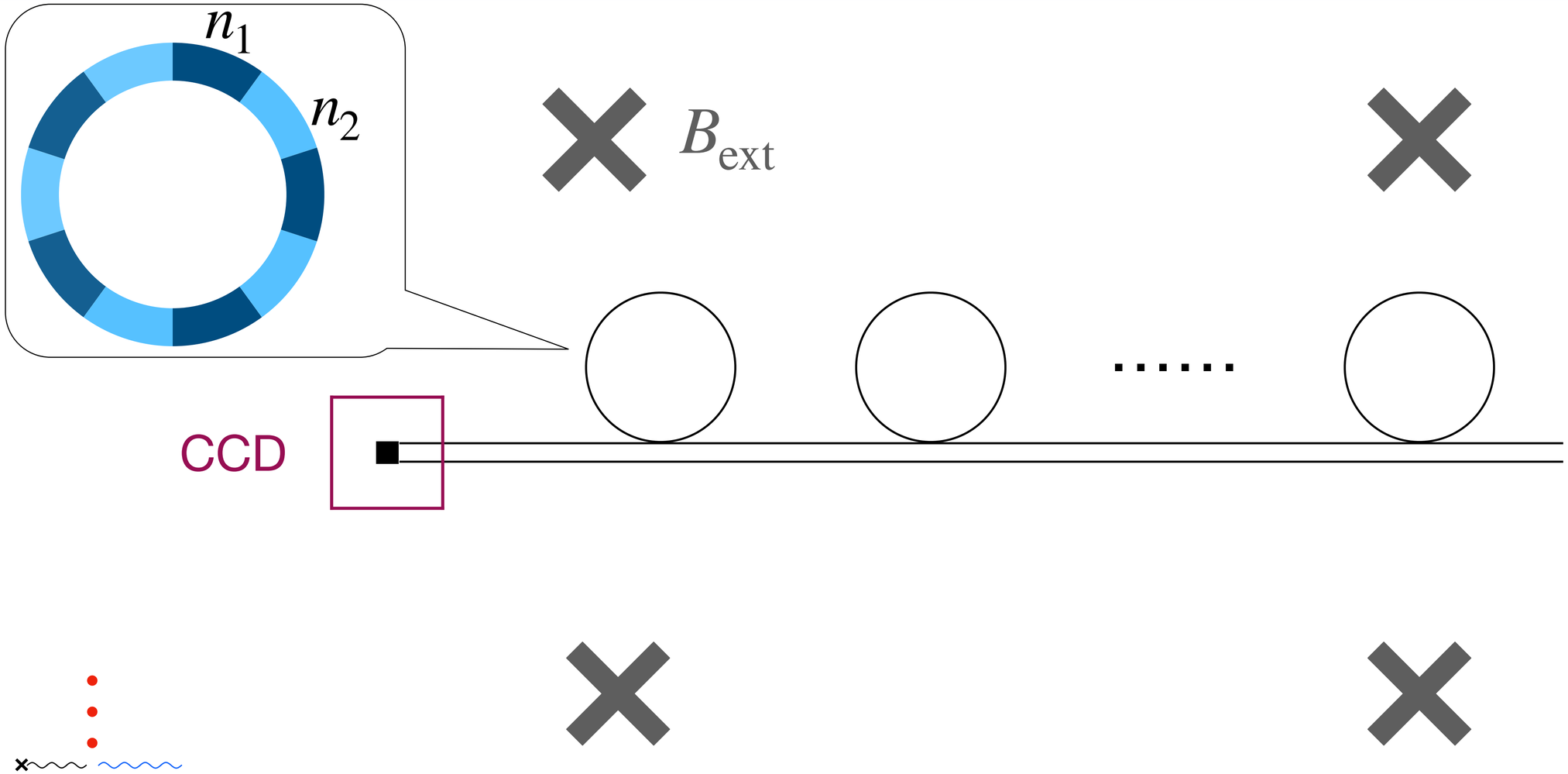


$$\Gamma_{\text{DPDM}} \sim \frac{10^{-1}}{\text{sec}}\left(\frac{N}{10^3}\right)\left(\frac{\rho_{\text{DM}}}{0.4\text{GeV/cm}^3}\right)\left(\frac{P_{\text{pump}}}{1\text{W}}\right)\left(\frac{L}{100\mu\text{m}}\right)\left(\frac{\mathcal{F}_p}{10^3}\right)\left(\frac{Q_s}{10^6}\right)\left(\frac{\epsilon}{10^{-9}}\right)^2\left(\frac{\chi^{(2)}}{10\text{pm/V}}\right)^2$$



$\Gamma_{\text{dark count}} = 10^{-4}\text{day}^{-1}$, $t_{\text{int}} = 300$ sec

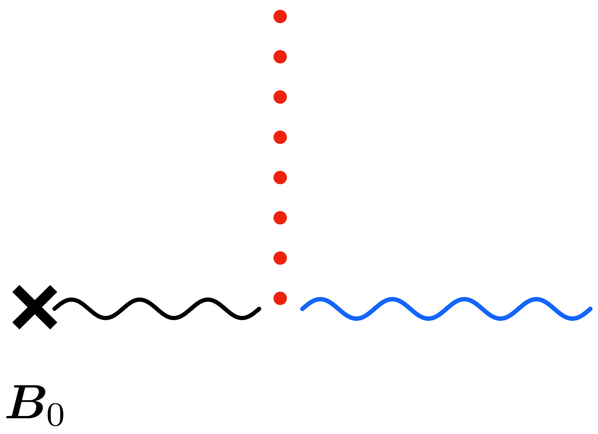
Axion Dark Matter Searches with Optical Cavities

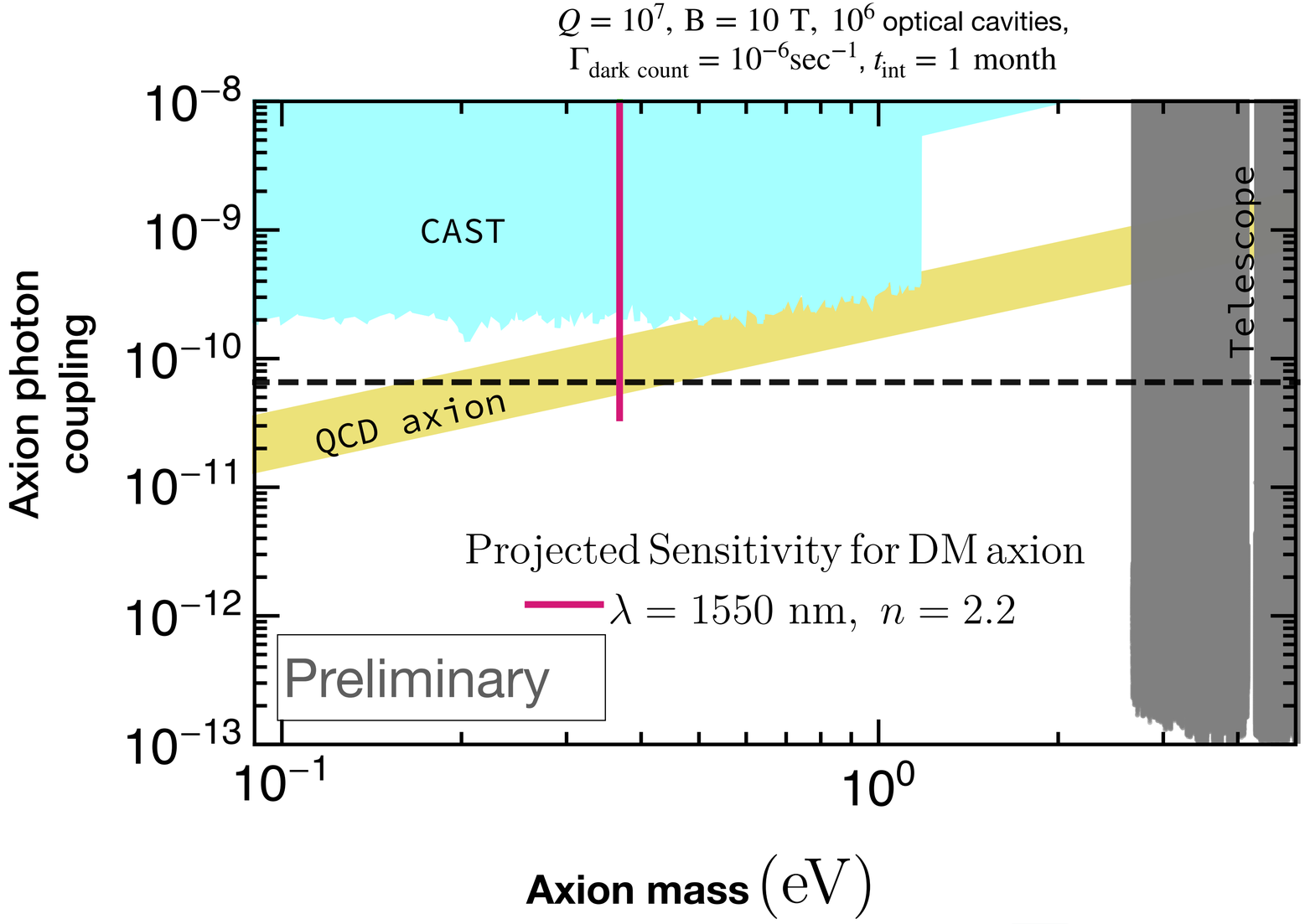


Signal photons can be resonantly produced if frequency and momentum match.

DM Axion Searches with Optical Cavities

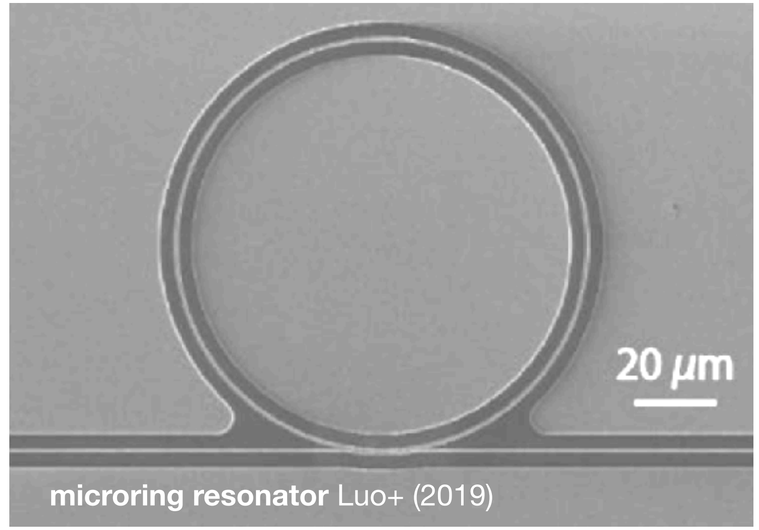
- through large B field
  + periodic structure





Summary

- Optical cavities $\Rightarrow$ ultralight dark matter $\lesssim \mathrm{eV}$
- Technologies of phase matching and mass production are quite mature in photonics.
- Exciting time to apply this technology to particle physics!



microring resonator Luo+ (2019)