原子ニュートリノ観測のための誘電体導波路中のQED過程の解析

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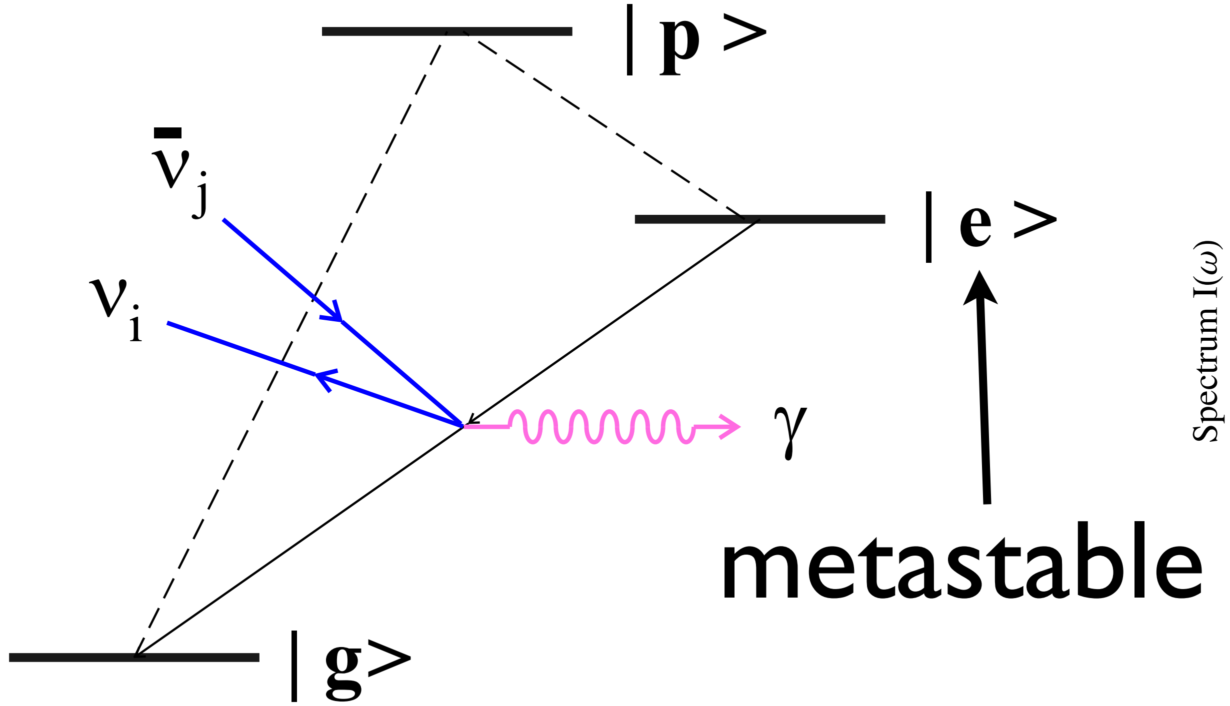
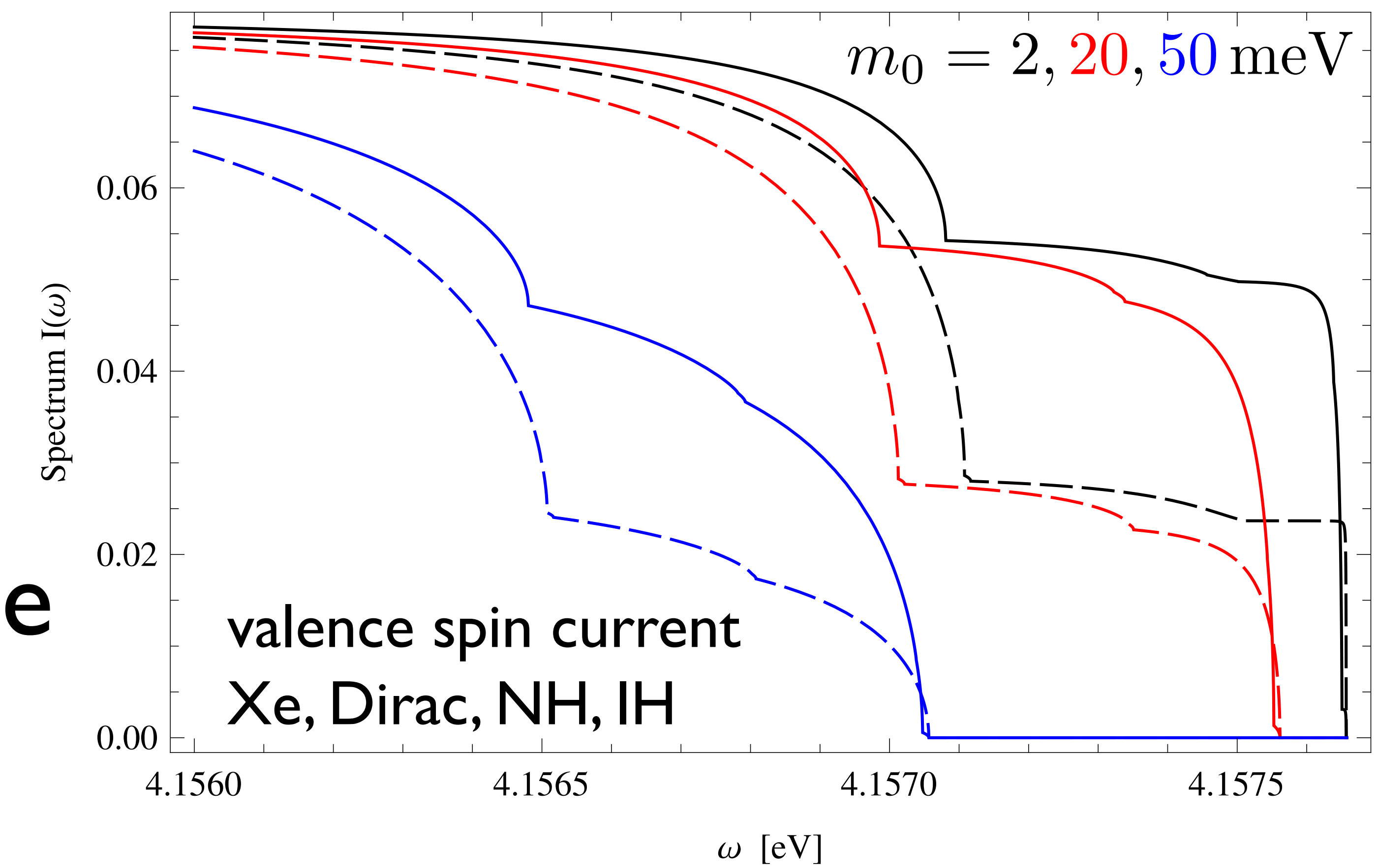
Radiative Emission of Neutrino Pair (RENP)

A.Fukumi et al. PTEP (2012) 04D002; arXiv:1211.4904

D.N. Dinh, S.T. Petcov, N. Sasao, M.T., M.Yoshimura, PLB719(2013)154; arXiv:1209.4808

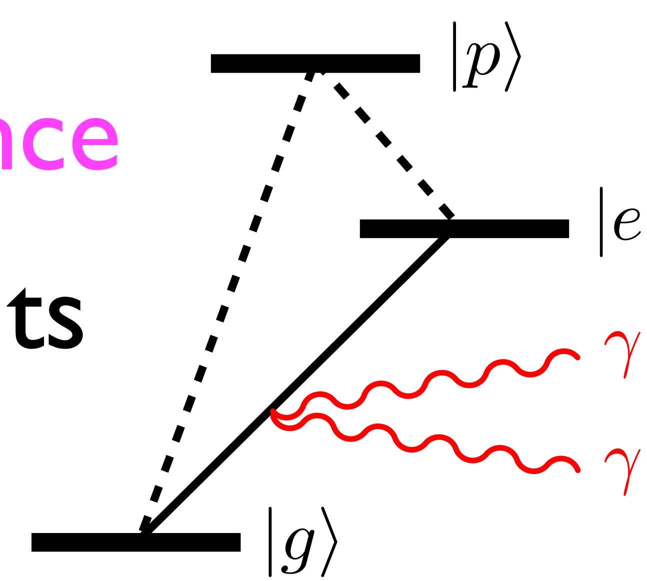




Rate enhancement by macrocoherence

→ Confirmed by PSR experiments

10^{18} amplification



QED backgrounds

M.Yoshimura, N. Sasao, MT
PTEP (2015) 053B06; arXiv:15010571

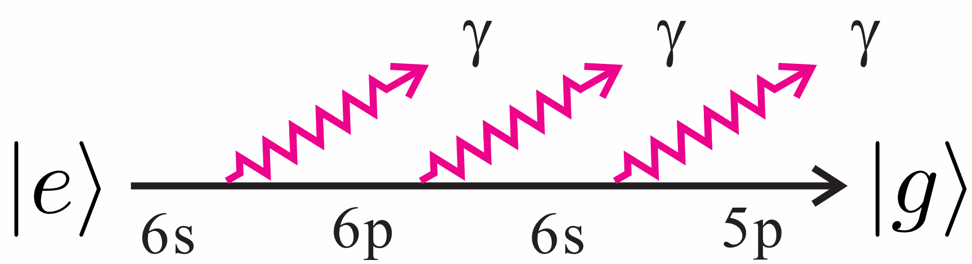
Macrocoherent amplification of RENP

$$|e\rangle \to |g\rangle + \gamma + \nu_i \bar{\nu}_j$$

Macrocoherent amplification of QED processes

$$|e\rangle \to |g\rangle + \gamma_0 + \gamma_1 \gamma_2$$ **McQ3**

Ex. Xe



$$\Gamma(\mathrm{McQ3}) \sim 10^{20}\ \mathrm{Hz} \left(\frac{n}{10^{20}/\mathrm{cm}^3}\right)^3 \frac{V}{\mathrm{cm}^3} \frac{\eta_3(t)}{10^{-3}}$$

cf. $$\Gamma(\mathrm{RENP}) \sim 1\ \mathrm{mHz} \left(\frac{n}{10^{20}/\mathrm{cm}^3}\right)^3 \frac{V}{\mathrm{cm}^3} \frac{\eta_\omega(t)}{10^{-3}}$$

serious BG though reducible

Radiation in waveguide/cavity

Purcell, Phys. Rev. 69, 681 (1964)

Emission rate (of single mode)

$\Gamma \propto \text{density of states}$ ⟵ depends on environment

Purcell factor

$$F_p := \frac{\Gamma}{\Gamma_{\mathrm{FS}}} = \frac{\mathrm{DoS}}{\text{DoS in Free Space}}$$ (quantum)

$$= \frac{P}{P_{\mathrm{FS}}}$$ Ratio of powers (classical)

$F_p < 1$ ⟶ Rate suppression

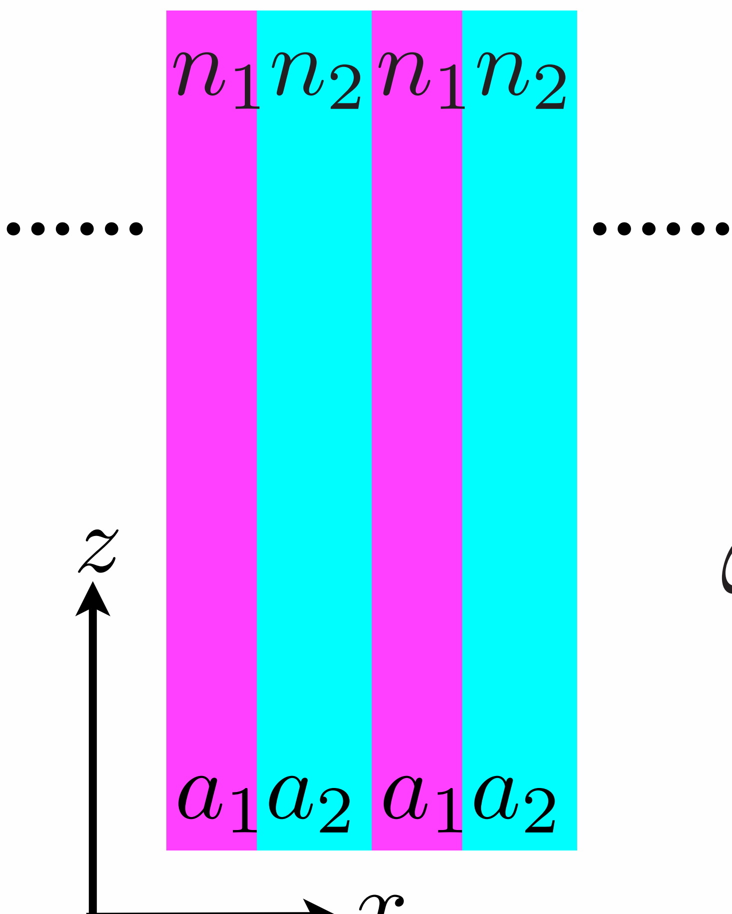
E. Yablonovitch, PRL58, 2059 (1987)
S. John, ibid., 2486 (1987)

Band structure of photonic crystal

Periodic dielectric structure → band

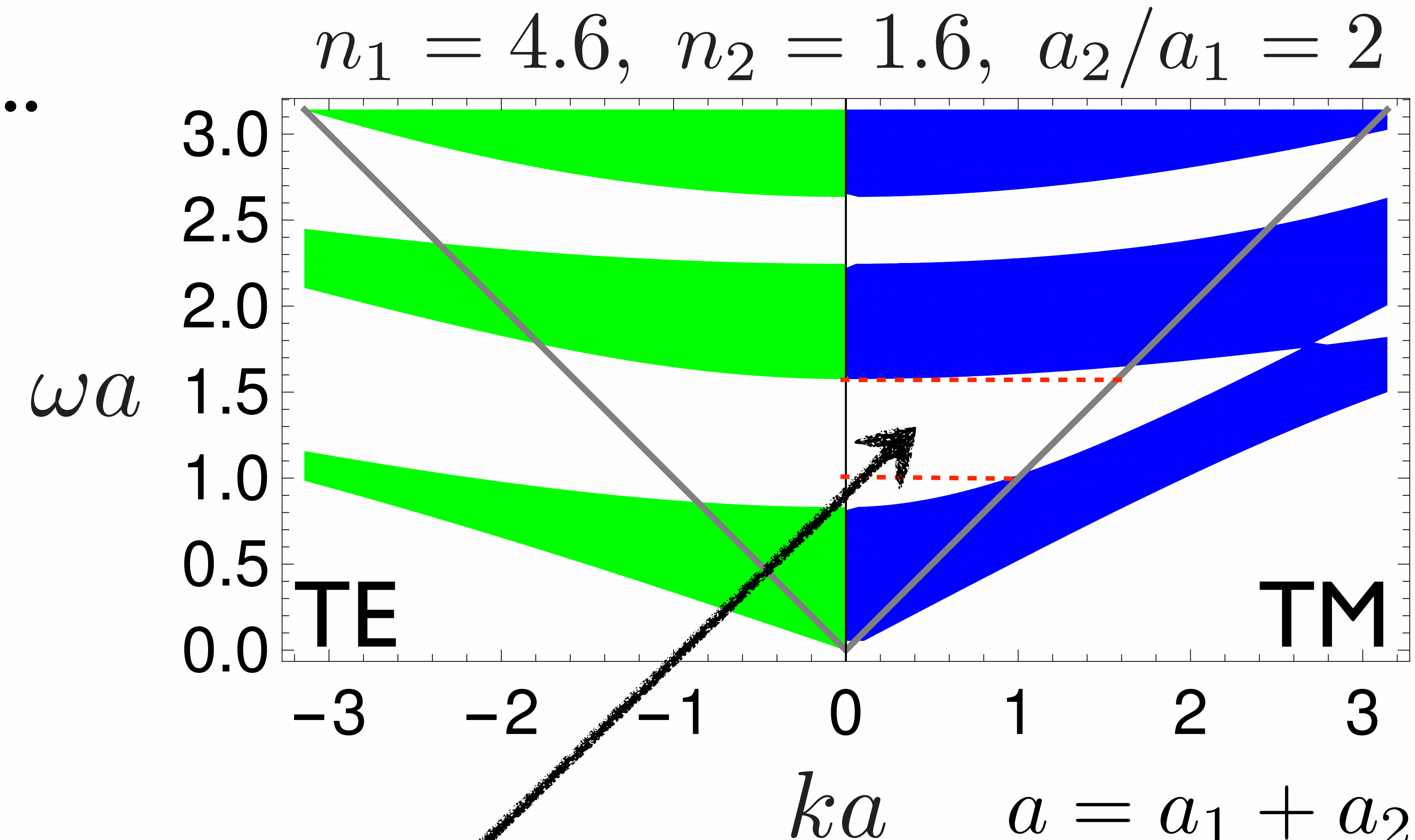
manipulating photon propagation

cf. electronic band structure in solid



Field

$$E(x)e^{i(kz-\omega t)}$$



complete Bragg reflection

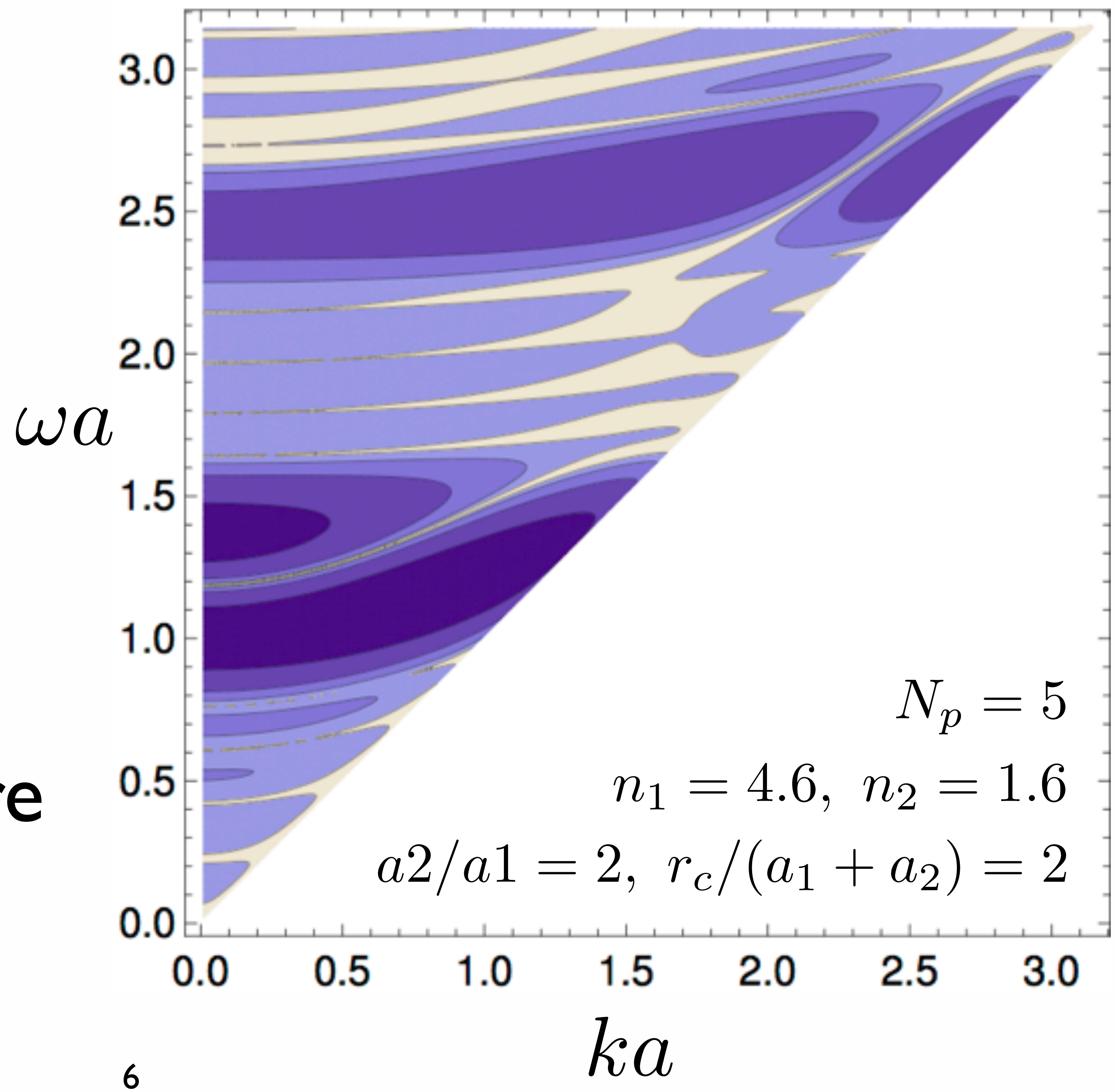
Winn et al., Opt. Lett. 23, 1573 (1998)

Bragg fiber

Yeh, Yariv, Marom, J. Opt. Soc. Am. 68, 1196 (1977)
Fink et al., J. Lightwave Technol. 17, 2039 (1999)

hollow core fiber

Purcell factor



Confinement of light by Bragg reflection

Similar band structure as the slab

McQ3 rate in Bragg fiber

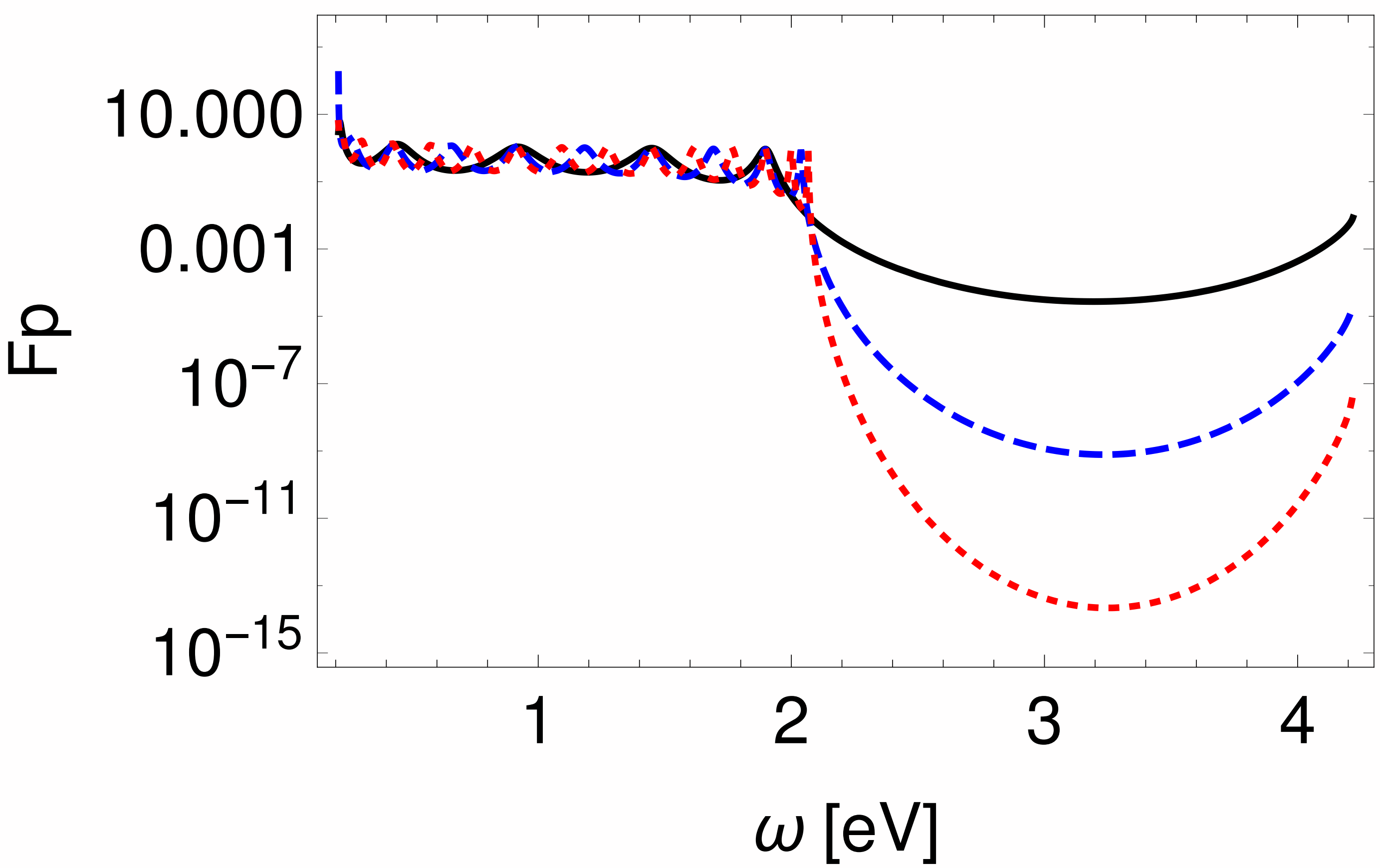
$$|e\rangle \to |g\rangle + \gamma_0(\omega_0) + \gamma_1(\omega_1) + \gamma_2(\omega_2)$$

↖trigger

Rate suppression factor

$$r_{\mathrm{BF/FS}}(\omega_0) := \frac{1}{\Gamma_{\mathrm{FS}}(\omega_0)} \int d\omega_1 \frac{d\Gamma_{\mathrm{FS}}}{d\omega_1} F_p(\omega_1, k_1) F_p(\omega_2, k_2)$$

Purcell factor (TM), Np=5,10,15



Xe $6\mathrm{s}\,{}^3P_1 \to 5\mathrm{p}\,{}^1S_0$

$$\omega_{\max} = \omega_{eg}/2 \simeq 4.22 \text{ eV}$$

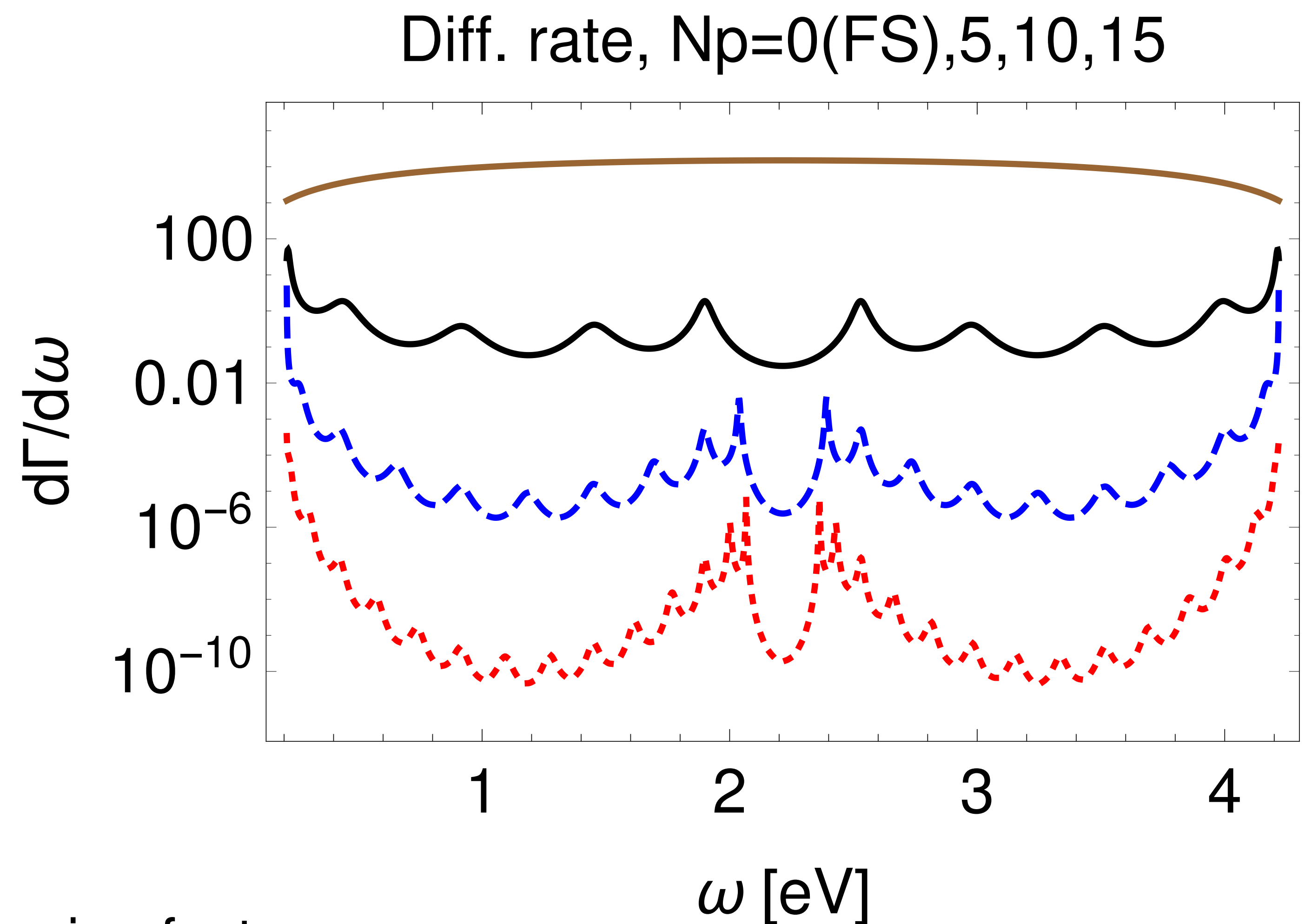
$$n_1 = 5.5, \;\; n_2 = 1.3$$

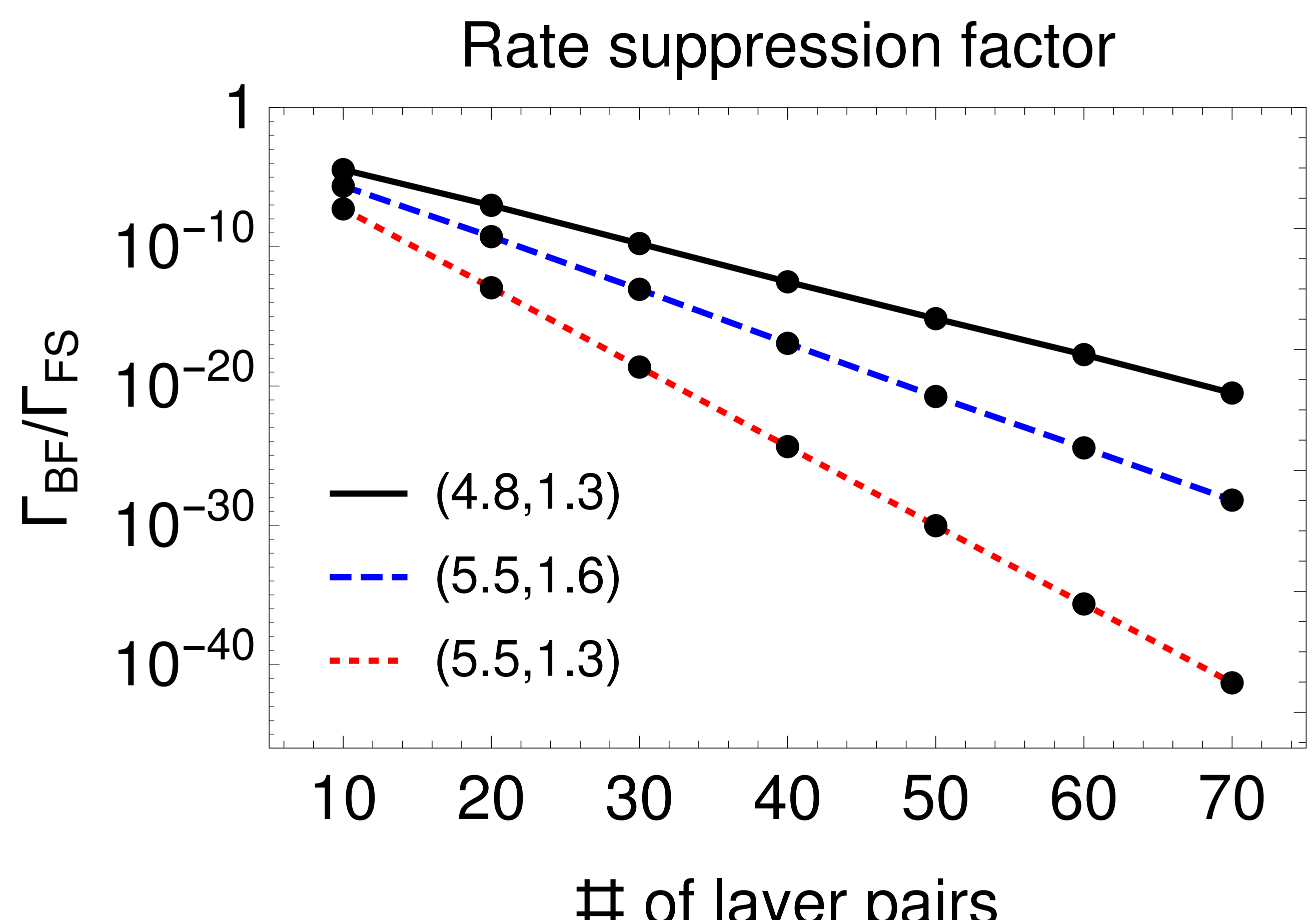
$$a = 0.126 \;\mu\mathrm{m}, r_c = 2a$$

$$\frac{a_2}{a_1} = \frac{\sqrt{n_1^2 - 1}}{\sqrt{n_2^2 - 1}} = 6.51$$

$$\omega_0 = 0.95\omega_{eg}/2$$

$$\frac{d\Gamma_{\mathrm{FS}}}{d\omega_1} F_{p1} F_{p2}$$





$$r_{\mathrm{BF/FS}} \propto \exp(-c N_p)$$

Suppression of QED process in Bragg fiber

- Photonic crystal ~ periodic dielectric structure

  → Band gap ~ vanishing DoS

- Purcell factor $F_p = \mathrm{DoS}/(\mathrm{DoS\ in\ free\ space})$

  $F_p < 1$ → Rate suppression

  Exponential rate suppression in the band gap for large index contrast

  $\Gamma_{\mathrm{BF}}/\Gamma_{FS} \sim 10^{-25}$ for $n_1 = 5.5,\ n_2 = 1.3,\ N_p = 40$

- To do

  Is $n_1 \gtrsim 4.8 \text{ or } 5.5$ necessary?

  Rate of McQ4 or higher