Physics
OSAKA UNIVERSITY

Radiative emission of neutrino pair free of QED backgrounds

M. TANAKA
Osaka University

in collaboration with K. Tsumura, N. Sasao, M. Yoshimura

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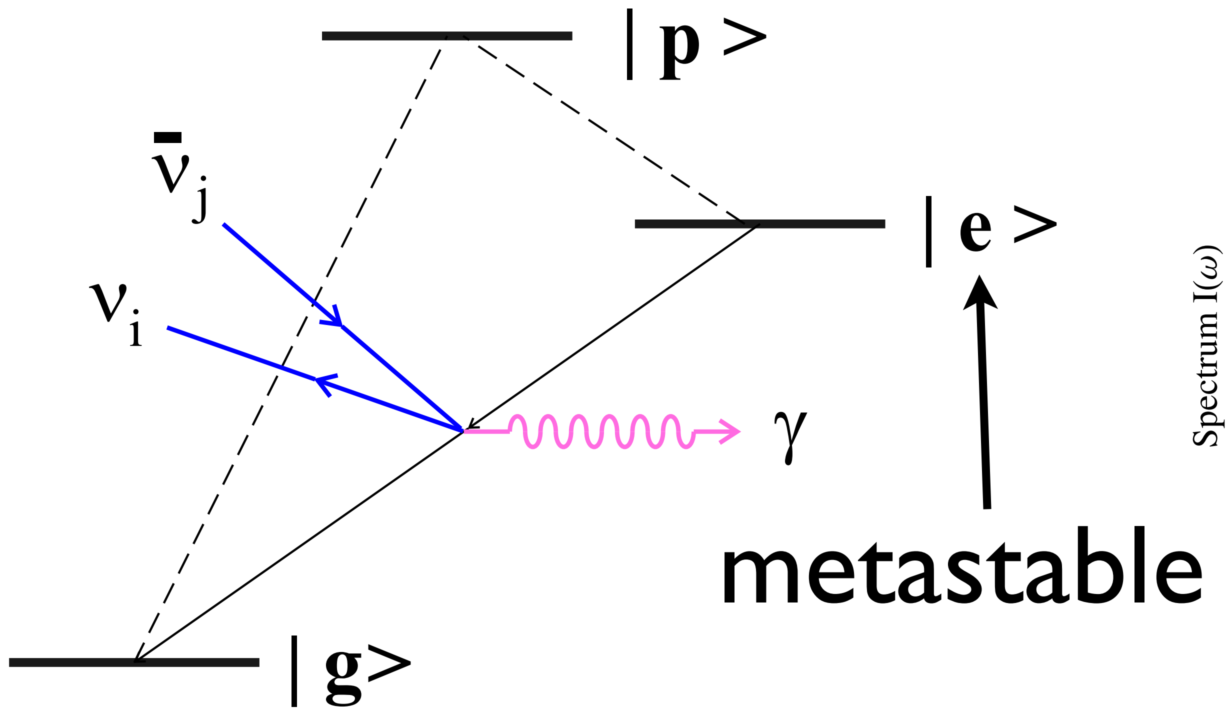
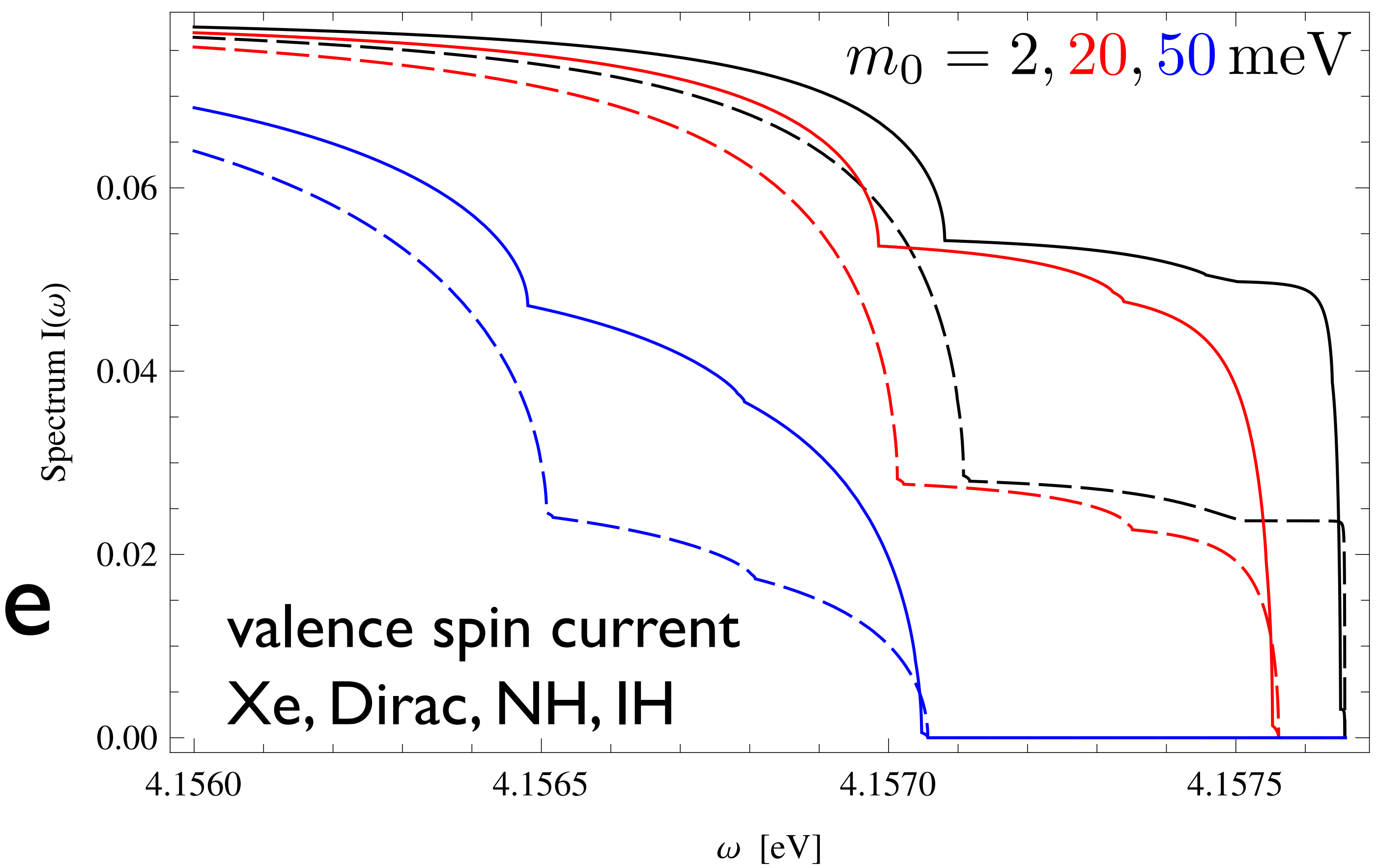
Radiative Emission of Neutrino Pair (RENP)

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





Atomic/molecular energy scale ~ eV or less

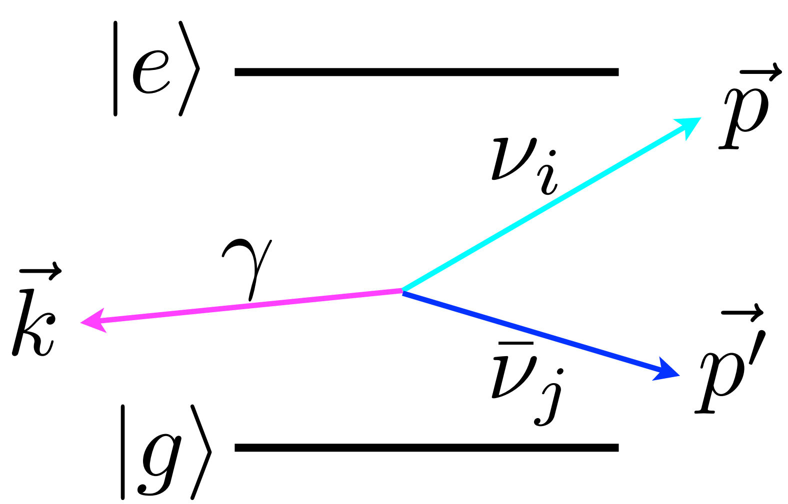
close to the neutrino mass scale

Rate $\sim \alpha G_F^2 E^5 \sim 1/(10^{33}\,\mathrm{s})$

enhancement by macrocoherence

Macrocoherence

Yoshimura et al. (2008)



position of atom

$$\propto e^{-i(\vec{k}+\vec{p}+\vec{p'})\cdot\vec{x}_a}(2\pi)\delta(\epsilon_{eg}-\omega-E_p-E_{p'})$$

$$(\epsilon_{eg}=\epsilon_e-\epsilon_g,\ \omega=|\vec{k}|)$$

Macroscopic target of N atoms, volume V (n=N/V)

$$\text{total amp.} \propto \sum_a e^{-i(\vec{k}+\vec{p}+\vec{p'})\cdot\vec{x}_a} \simeq \frac{N}{V}(2\pi)^3\delta^3(\vec{k}+\vec{p}+\vec{p'})$$

$$d\Gamma \propto \boxed{n^2V}(2\pi)^4\delta^4(q-p-p') \qquad q^\mu=(\epsilon_{eg}-\omega,-\vec{k})$$

macrocoherent amplification

→ Confirmed by PSR experiments 10^{18} amp.

QED backgrounds

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

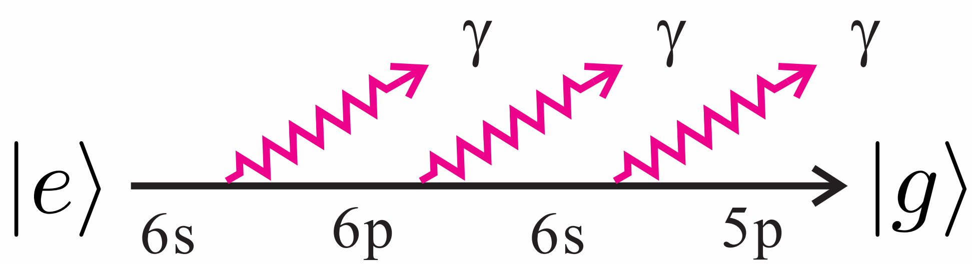
Macrocoherent amplification of RENP

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

Macrocoherent amplification of QED processes

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

Ex. Xe

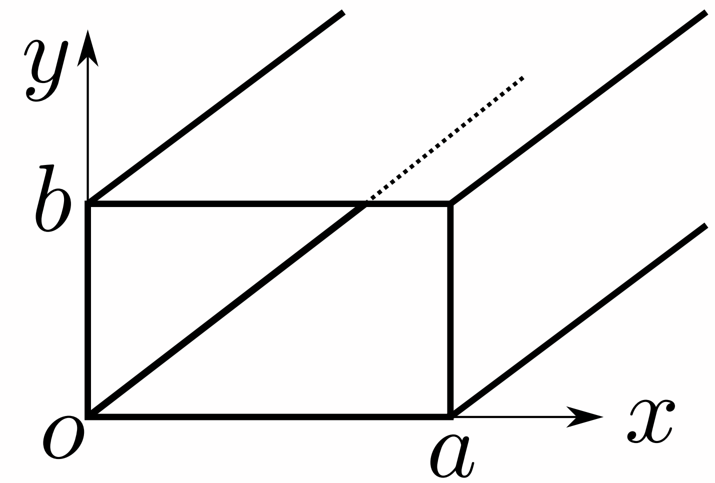


$$\Gamma(\mathrm{McQ3}) \sim 10^{20}\ \mathrm{Hz} \left(\frac{n}{10^{20}/\mathrm{cm}^3}\right)^3 \frac{V}{\mathrm{cm}^3} \frac{\eta_3(t)}{10^{-3}}$$

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

McQn vs. RENP in a waveguide



TE modes

$$E_y \sim \sin\left(\frac{n_x \pi}{a} x\right) \cos\left(\frac{n_y \pi}{b} y\right) e^{i(kz - \omega t)}$$

Dispersion: $\omega^2 = k^2 + \omega_c^2$

Cutoff freq. (Mass): $\omega_c^2 = M^2 = \pi^2 \left(\frac{n_x^2}{a^2} + \frac{n_y^2}{b^2}\right)$

The lowest mode: $\mathrm{TE}_{1,0}$ $M = \pi / a$

Threshold

McQn $\omega \le \epsilon_{eg}/2 - n(n-2)M^2/2\epsilon_{eg}$

RENP $\omega \le \epsilon_{eg}/2 - [(m_i + m_j)^2 - M^2]/2\epsilon_{eg}$

→ $(n-1)M > m_i + m_j$ BG-free RENP

McQ3

$M > (m_i + m_j)/2 \ge m_0$ (the smallest neutrino mass)

$$M = \frac{\pi}{a} \simeq 0.6 \text{ meV} \left(\frac{1\text{mm}}{a}\right)$$

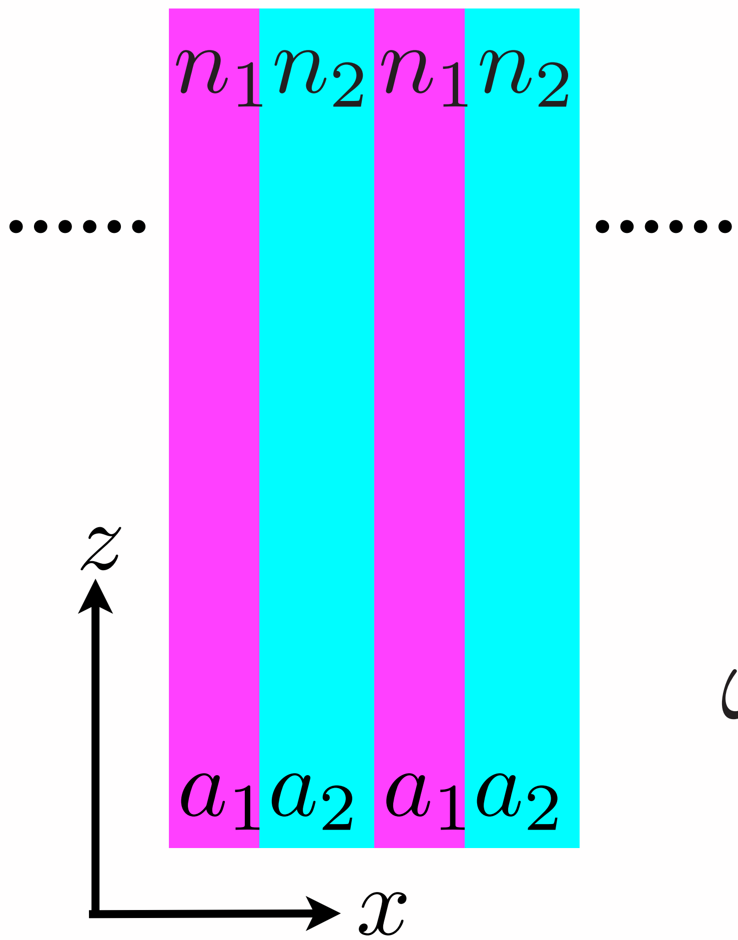
Ex. Xe $\epsilon_{eg} = 8.3153 \text{ eV} \quad m_0 = 1 \text{ meV}, \ a = 10 \ \mu\text{m}$

$$\omega_{\max}(\text{McQ3}) = 4.1570 \text{ eV}$$
$$\omega_{\max}(\text{RENP}) = 4.1579 \text{ eV}$$

Photonic crystals may be realistic.

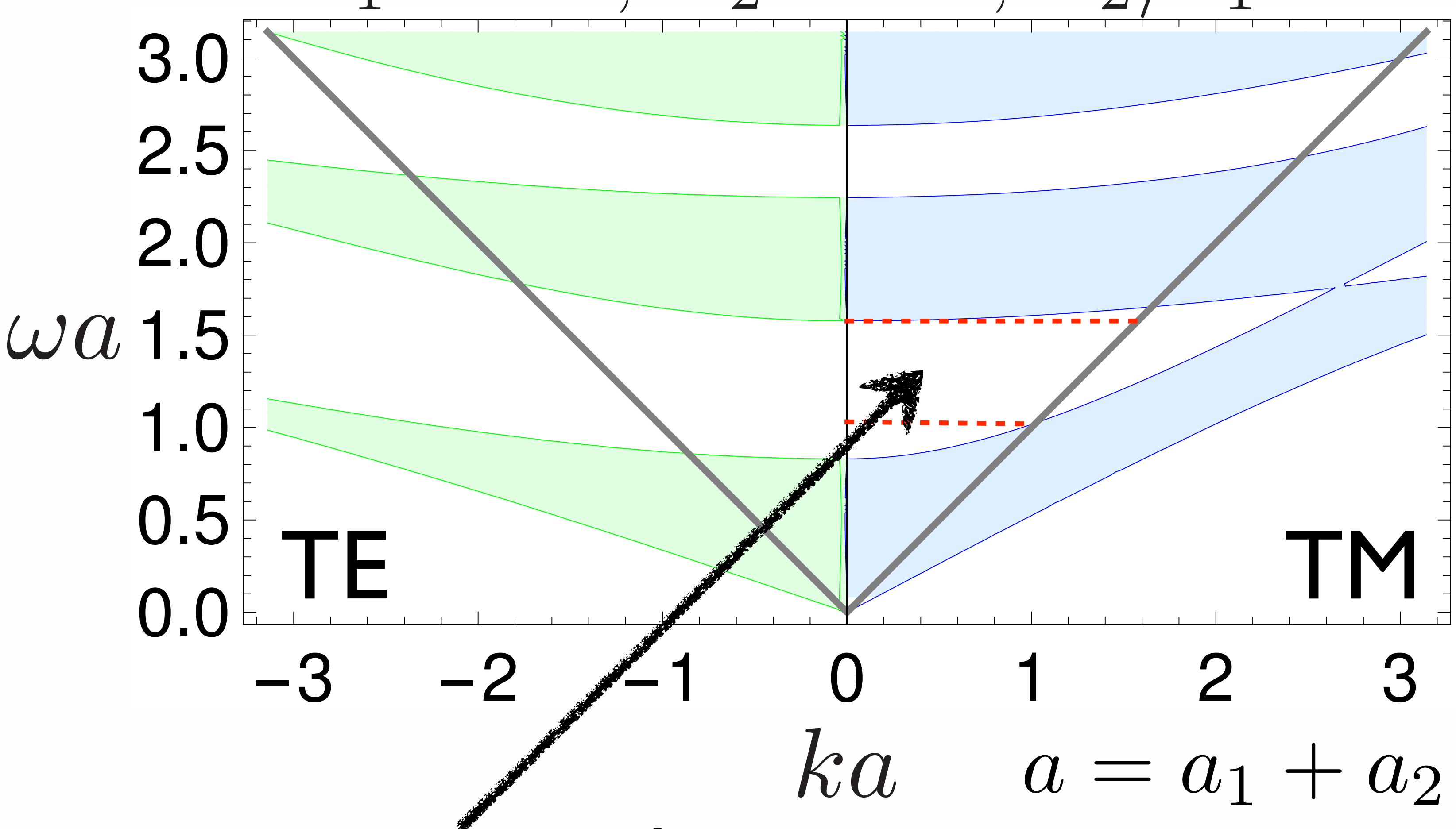
Band structure of photonic crystal

Slab layers = 1D photonic crystal



periodicity → band

$n_1 = 4.6,\ n_2 = 1.6,\ a_2/a_1 = 2$



Field

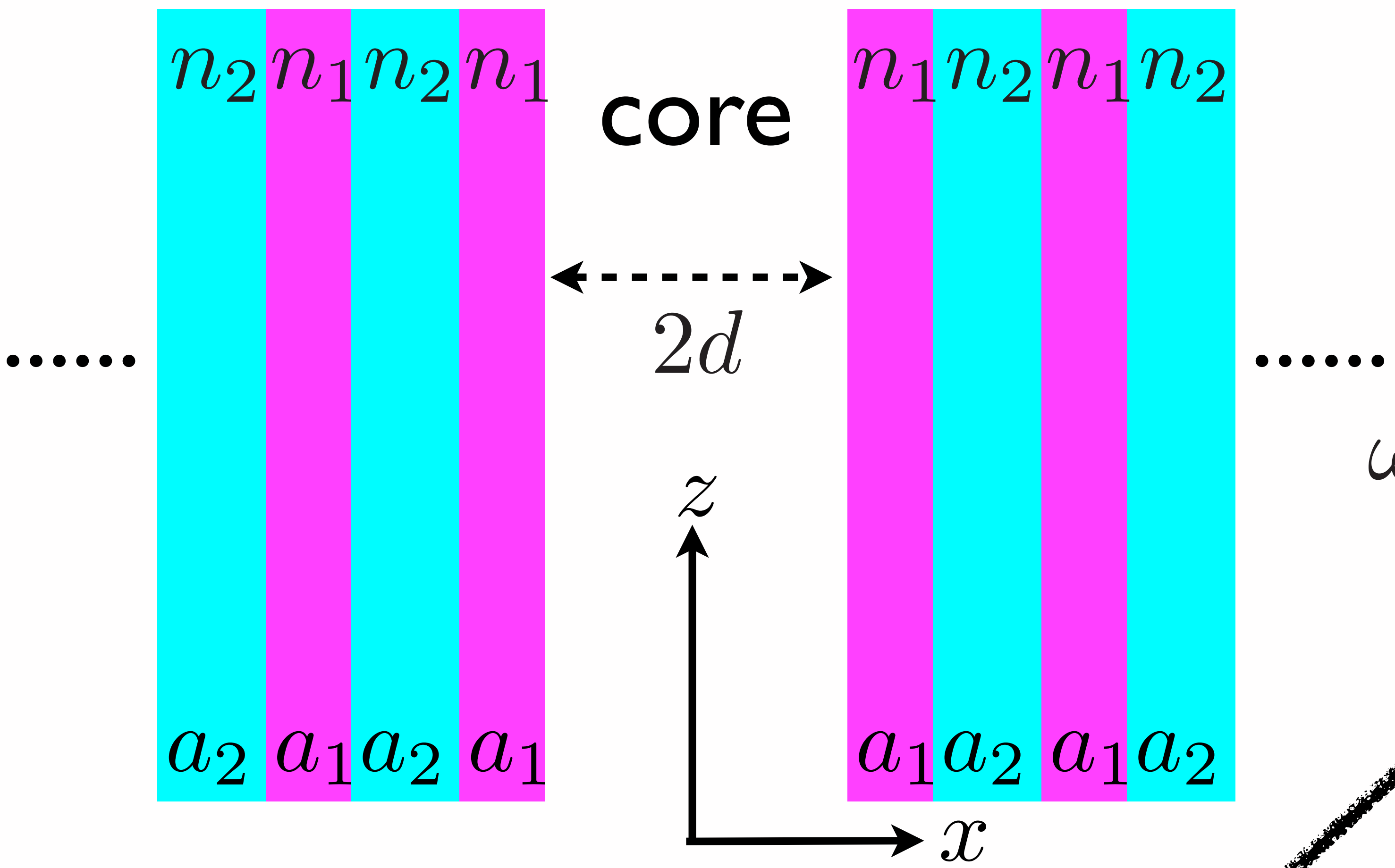
$$E(x)e^{i(kz-\omega t)}$$

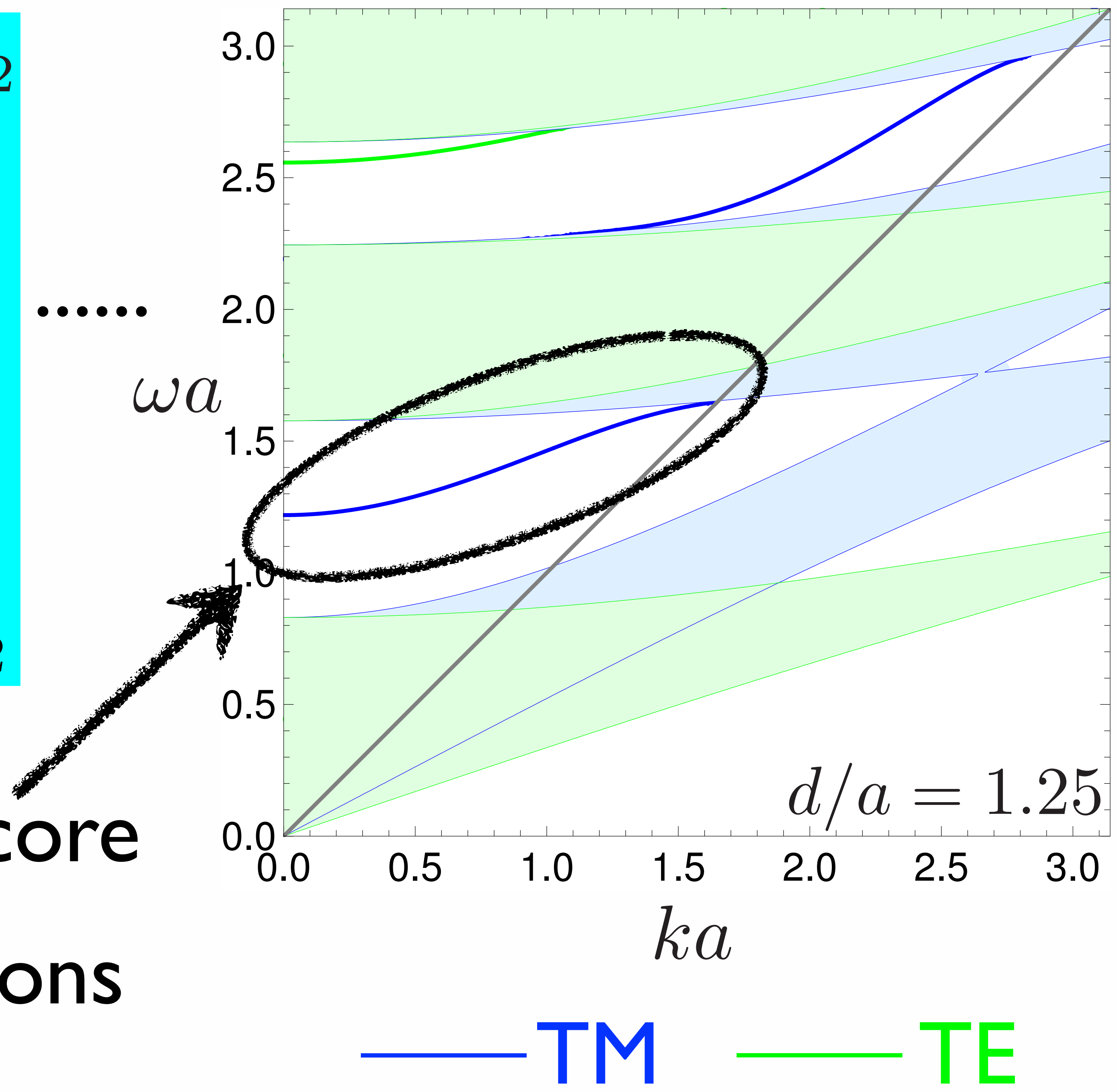
omnidirectional reflection

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

Slab waveguide

Yeh, Yariv, Hong, J. Opt. Soc. Am. 67, 423 (1977)



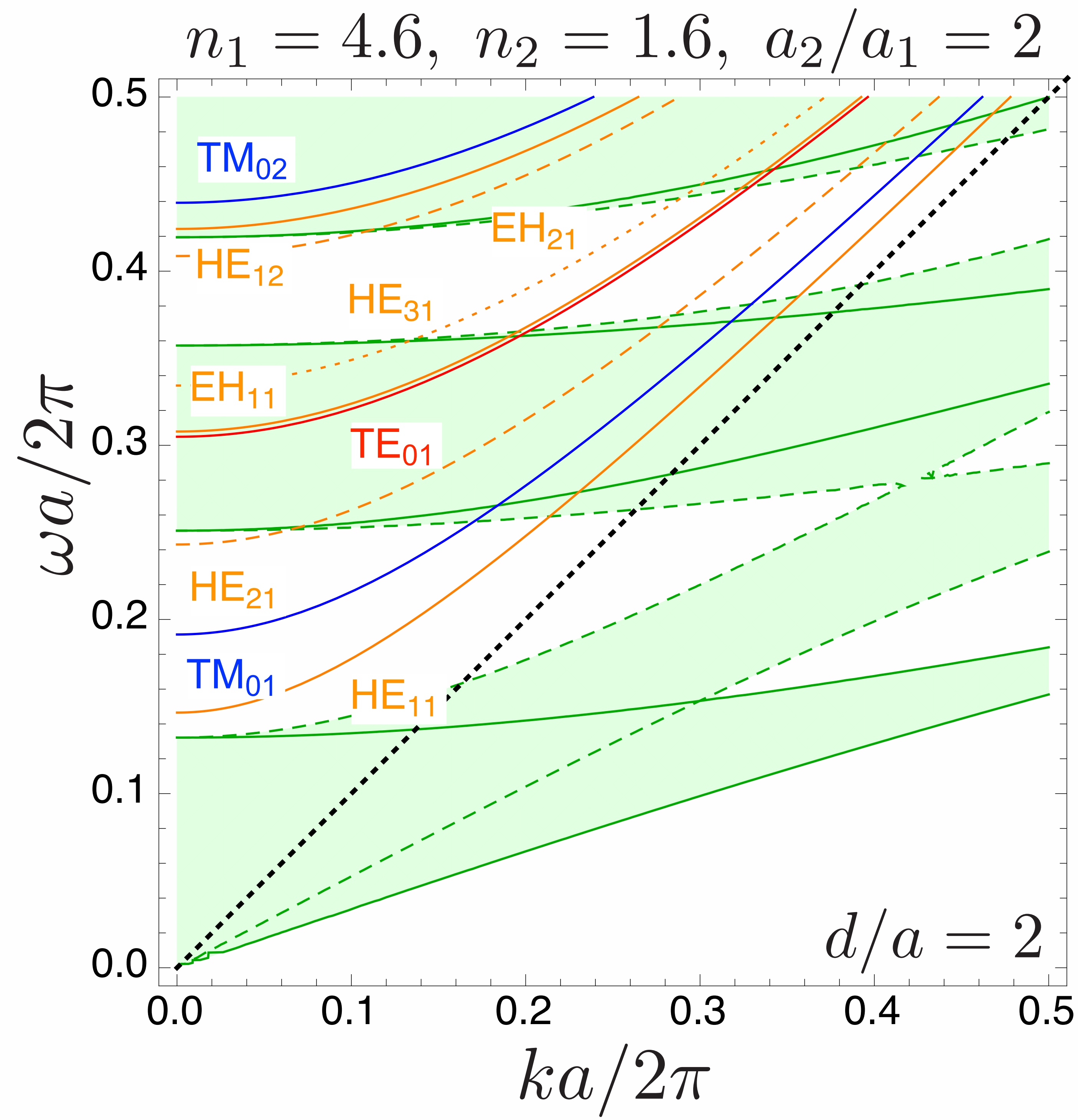


Localized modes in the core

similar dispersion relations
as metal waveguides

Bragg fiber

Yeh, Yariv, Marom, J. Opt. Soc. Am. 68, 1196 (1977)



Similar band structure as the slab

More localized modes

- HE (TE-like)
- EH (TM-like)

Neutrino Physics with Atoms/Molecules

- ✶ RENP spectra are sensitive to unknown neutrino parameters.
  - Absolute mass, Dirac or Majorana, NH or IH, CP
- ✶ Macrocoherent rate amplification is essential.
  - Demonstrated by a QED process, PSR.
- ✶ Background-free RENP
  - Waveguide, photonic crystals

A new frontier of neutrino physics