Physics
OSAKA UNIVERSITY

初期空間位相を用いた原子ニュートリノ過程における誘電体導波路によるQED背景過程の抑制

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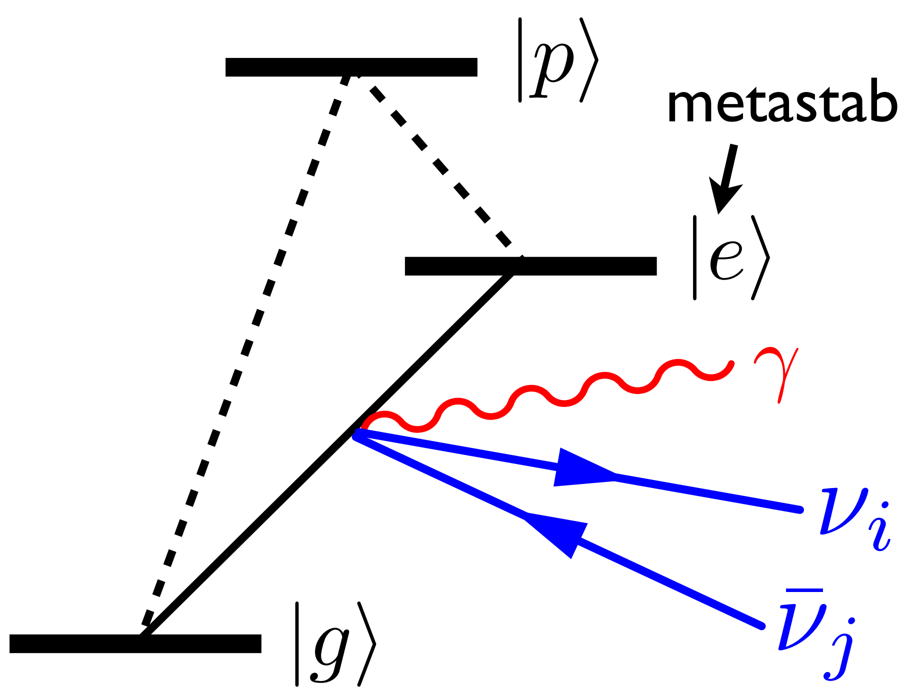
科研費
KAKENHI

Radiative Emission of Neutrino Pair (RENP)

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



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

Atomic energy scale
~ eV or less
close to neutrino mass scale

cf. nuclear processes ~ MeV

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

Enhancement by macrocoherence Yoshimura et al. arXiv:0805.1970

Energy scale reduction by initial spatial phase

MT, Tsumura, Sasao, Uetake, Yoshimura, PRD96, 113005 (2017), arXiv:1710.07136

Initial spatial phase (ISP)

Preparation of initial coherent state

Two-photon absorption: $\gamma_1(k_1) + \gamma_2(k_2) + |g\rangle \to |e\rangle$

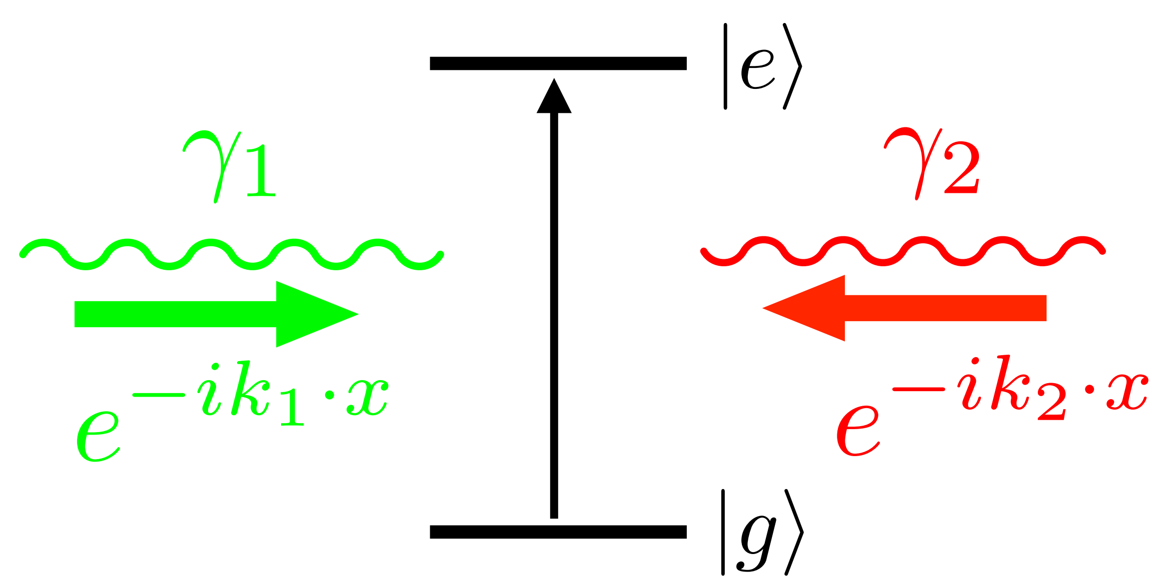
Initial spatial phase (ISP)

$$\langle e|\rho|g\rangle \propto e^{i\vec{p}_{eg}\cdot\vec{x}}$$

$$\vec{p}_{eg} = \vec{k}_1 + \vec{k}_2$$

$$|\vec{p}_{eg}| = |\omega_1 - \omega_2|$$

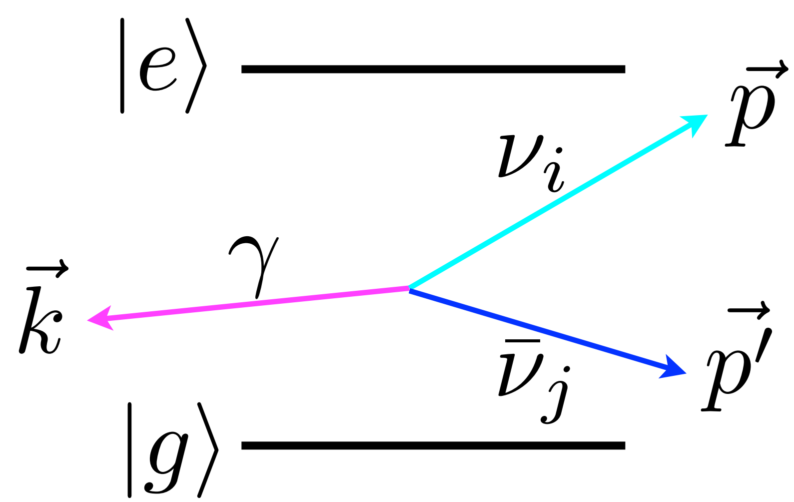
counter-propagating



$E_{eg} = E_e - E_g$ ~ initial energy

$\vec{p}_{eg}$ ~ initial momentum = boost

Macrocoherence with ISP



position of atom

$$\propto e^{i(\vec{p}_{eg}-\vec{k}-\vec{p}-\vec{p}')\cdot\vec{x}_a}$$

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

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

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

macrocoherent amplification

→ energy-momentum conservation

$$(E_{eg},\vec{p}_{eg})=(E_\gamma,\vec{k})+(E_\nu,\vec{p})+(E'_\nu,\vec{p})$$

$E_{eq}^2-\vec{p}_{eg}^2<E_{eg}^2$ energy scale reduction

QED backgrounds

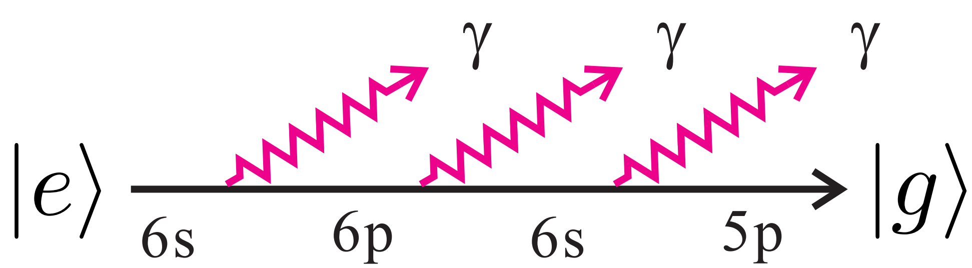
M.Yoshimura, N. Sasao, MT
PTEP (2015) 053B06; arXiv:15010571

Macrocoherent amplification

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

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

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

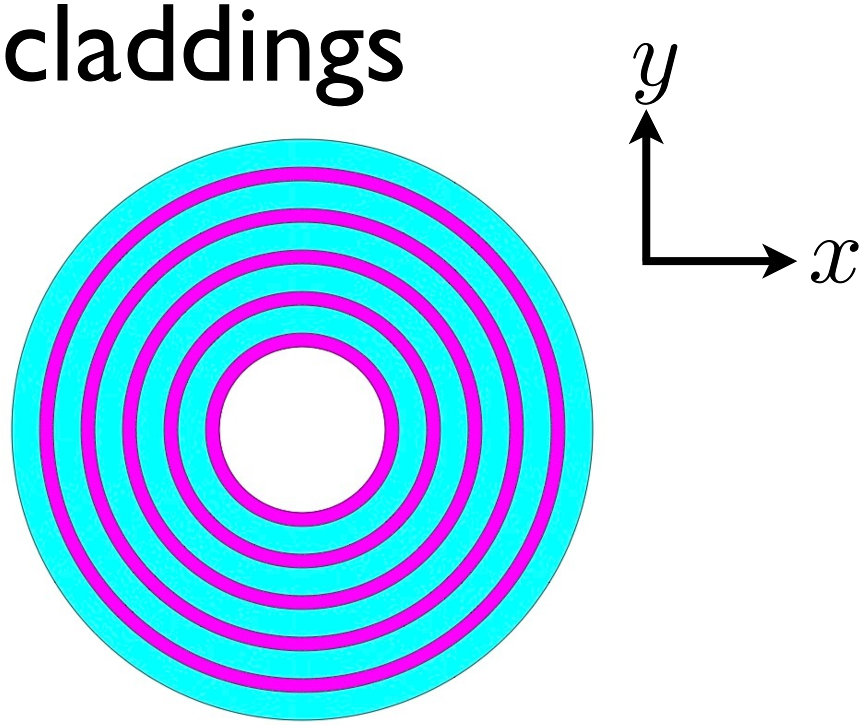
BG suppression by photonic band structure

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

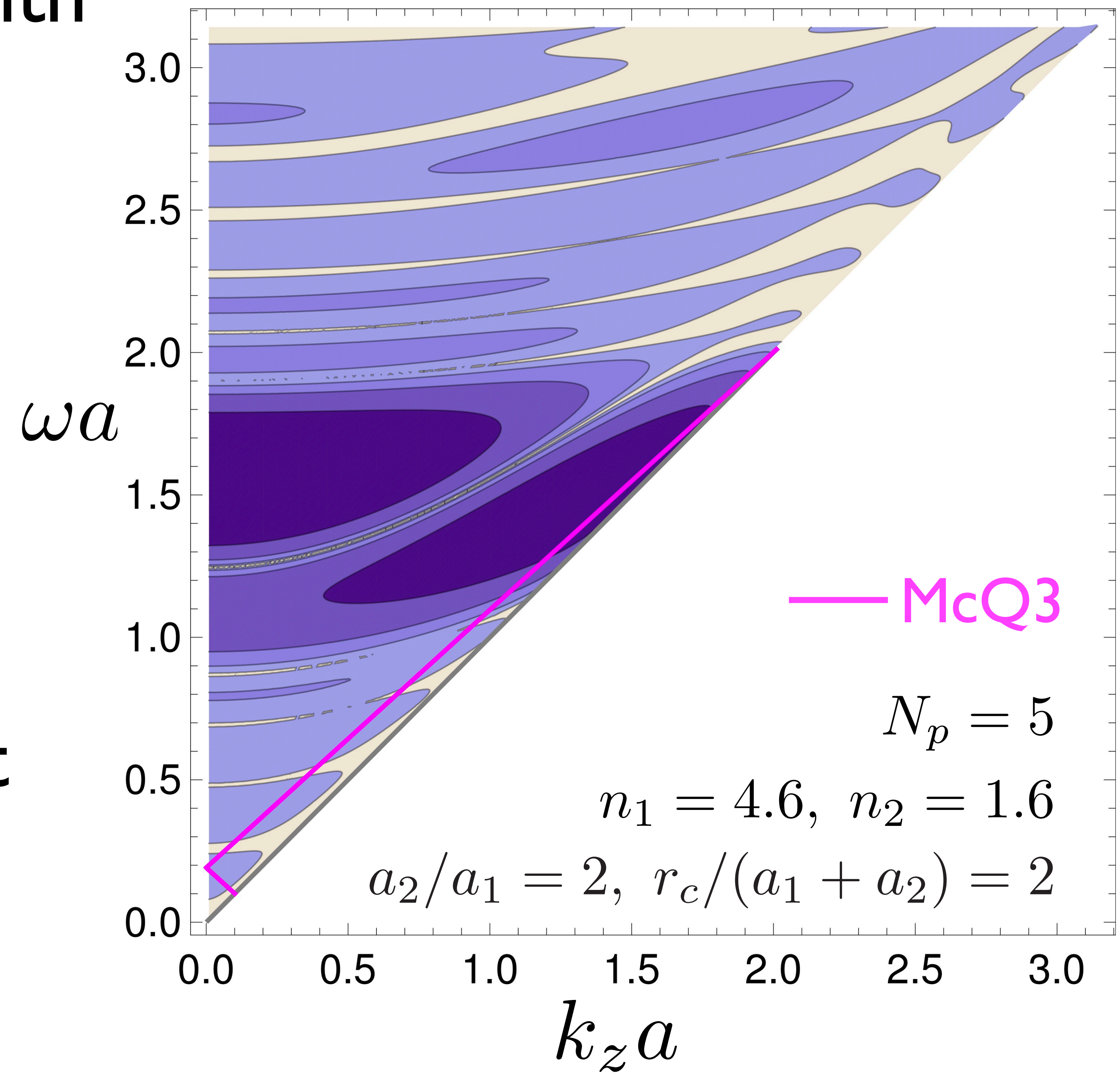
Bragg fiber

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

Hollow core fiber with alternating dielectric claddings



band structure



Confinement of light by Bragg reflection

Field

$$E(x, y)e^{i(k_z z - \omega t)}$$

M.T., K.Tsumura, N. Sasao, M.Yoshimura
PTEP(2017)043B03; arXiv:1612.02423

Boost-trigger lock (BTL)

$$(E_{eg}, \vec{p}_{eg}) = (E_\gamma, \vec{k}) + (E_1, \vec{k}_1) + (E_2, \vec{k}_2)$$

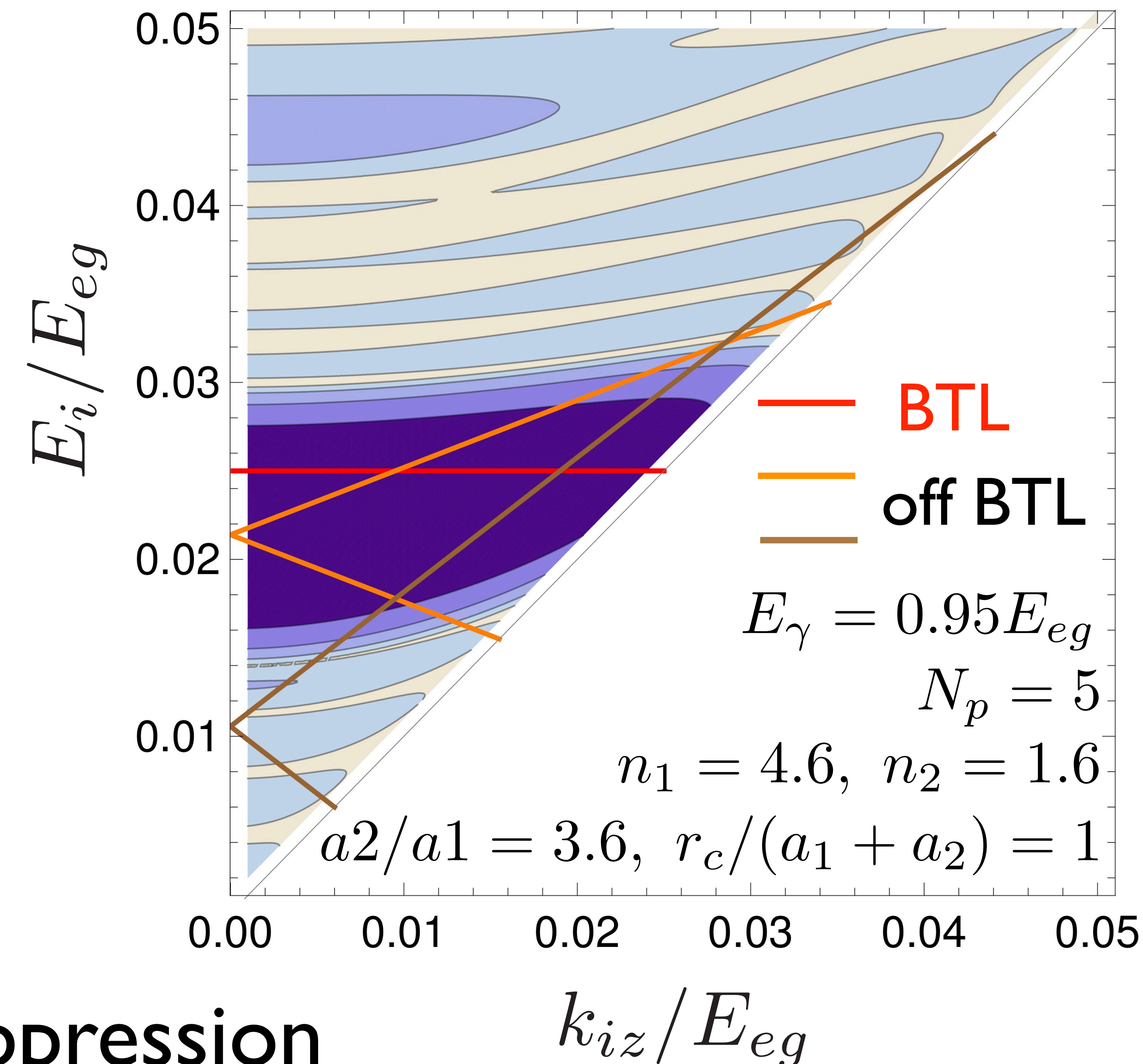
BTL: $\vec{p}_{eg} = \vec{k}$

$$\vec{k}_1 + \vec{k}_2 = 0$$

$\gamma_1 \gamma_2 \ (\nu_i \bar{\nu}_j)$ **at rest**

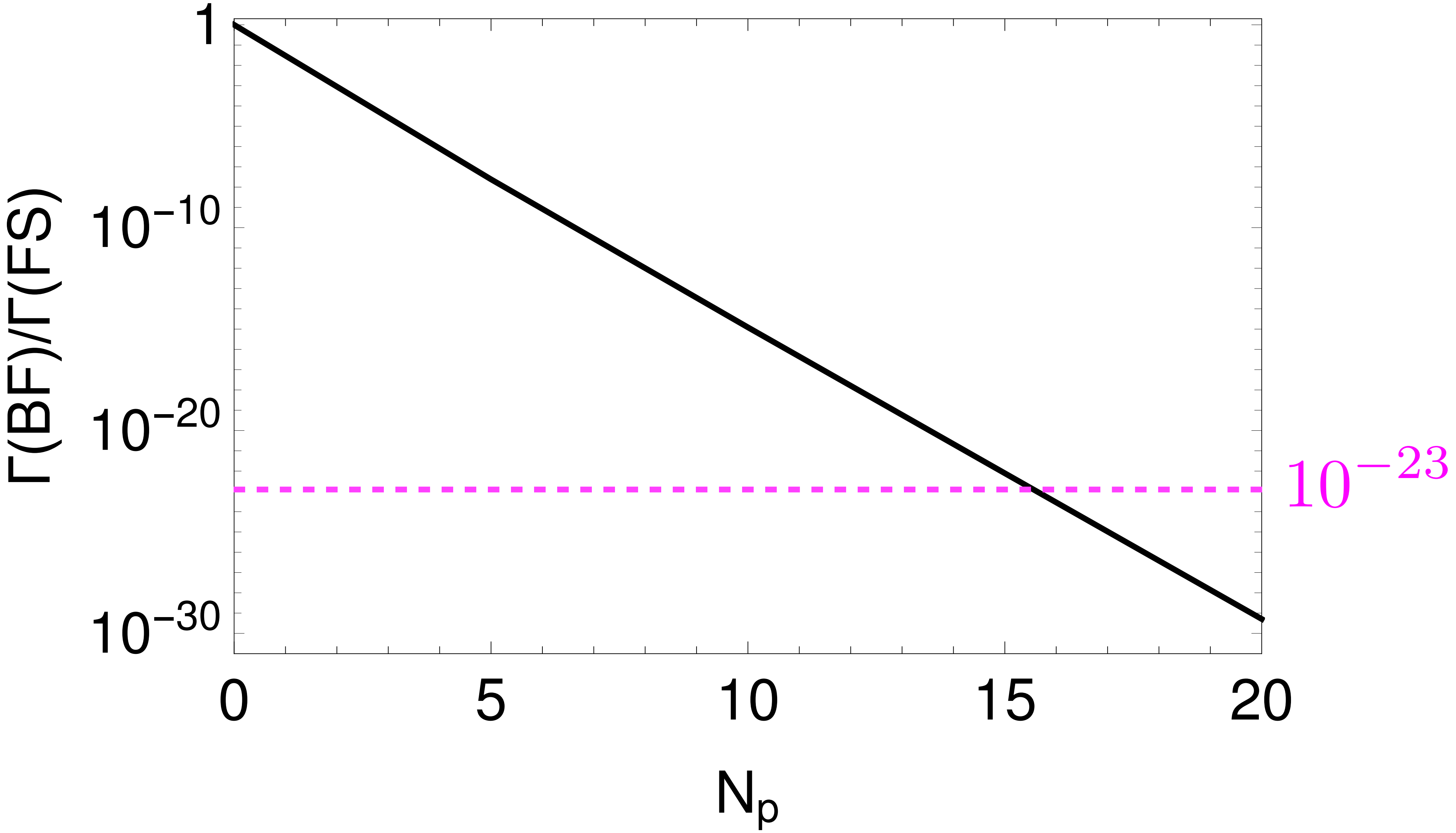
→ monochromatic BG photons

$$E_1 = E_2 = \frac{E_{eg} - E_\gamma}{2}$$



Favorable for BG suppression

McQ3 suppression in Bragg fiber with BTL



Sufficient suppression possible with a reasonable fiber spec

$$n_1 = 4.6,\ n_2 = 1.6$$

Summary

- ISP + macrocoherence: boosted RENP
  Improved sensitivity to neutrino parameters
- Suppression of QED BG (McQ3)
  Band gap of photonic crystal (Bragg fiber)
- Boost-trigger lock (BTL) $\vec{p}_{eg} = \vec{k}$
  Monochromatic BG photons
  Sufficient suppression by the band structure with realistic material $n_1 = 4.6,\ n_2 = 1.6$