Probing pseud Nambu-Goldstone Boson by stimulated photon colliders in the mass range 0.1eV ~ 10keV

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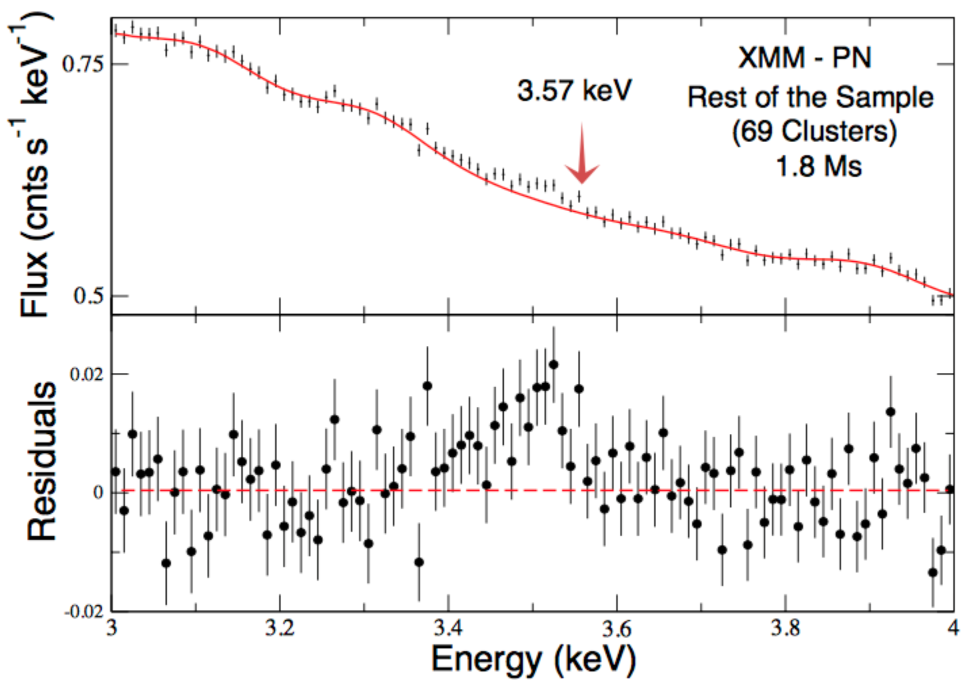
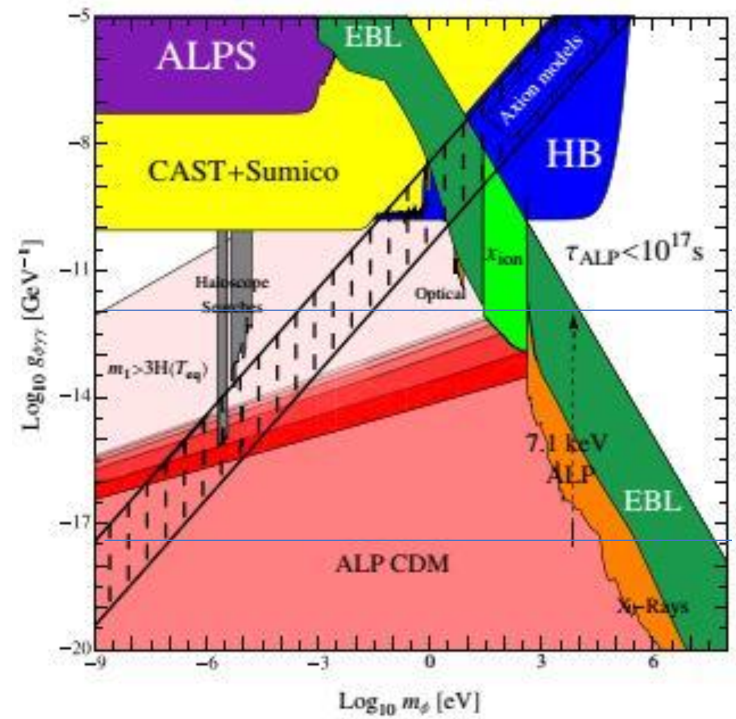
Unidentified emission in 3.5keV



arXiv:1402.2301v2



PHYSICAL REVIEW D 89, 103511 (2014)

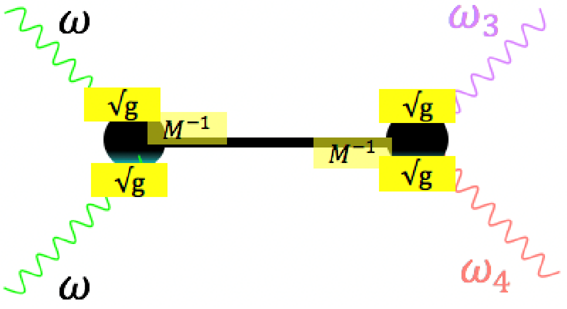
- Recently, an unidentified emission line, ω ~ 3.5 keV, was reported in the photon energy spectra from a single galaxy and galaxy clusters.
- <u>If we assume a resonance state, the resonance state of 7 keV decay into two photons which has 3.5 keV.</u>

Feature of this method

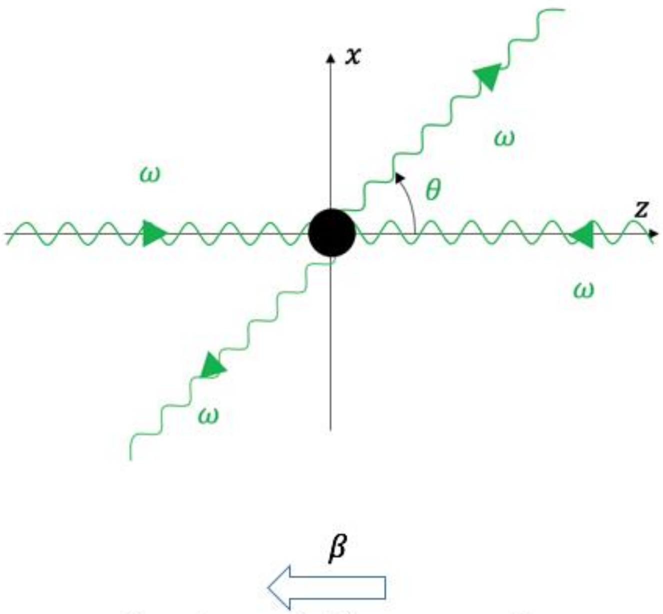
Effective Interaction Lagrangian

$$-L = gM^{-1}\frac{1}{4}F_{\mu\nu}F^{\mu\nu}\phi$$

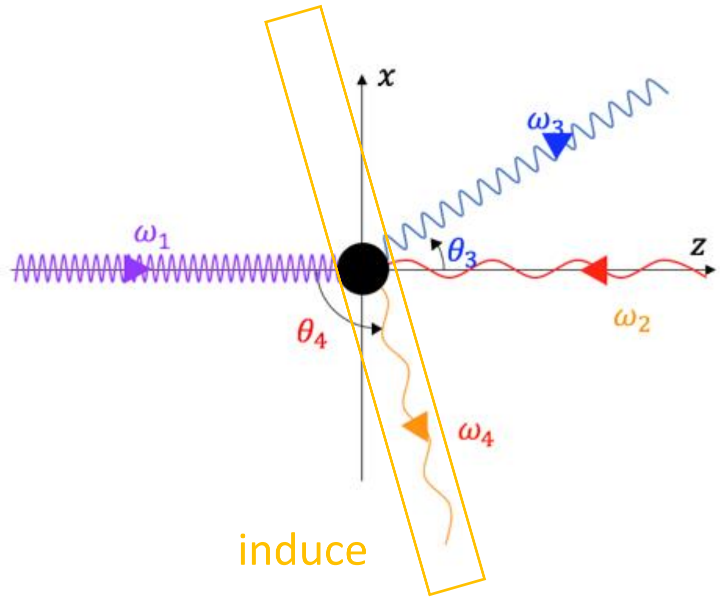
・s-channel resonant pNGB exchange.
・Utilizing the coherent nature of induction laser.
・head-on-collision



Asymmetric Collision System(ACS)



Center of Mass system



Asymmetric collision system

u, u^+, u^- *are* constant related β

0-axis: $\omega_1 + \omega_2 = \omega_3 + \omega_4$
z-axis: $\omega_3 \sin\theta_3 = \omega_4 \sin\theta_4$
x-axis: $\omega_1 - \omega_2 = \omega_3 \cos\theta_3 - \omega_4 \cos\theta_4$

$$\omega_1 = u\omega, \qquad \omega_2 = u^{-1}\omega$$
$$\omega_3 = \frac{2\omega}{u^+ - u^- \cos\theta_3}$$

Short pulsing effect

$$|\mathcal{M}| = -(gM^{-1})^2 \frac{\omega^4(\cos 2\vartheta - 1)^2}{2\omega^2(\cos 2\vartheta - 1) + m^2},$$

Then we introduce the imaginary part,

$$m^2 \to (m - i\Gamma/2)^2 \approx m^2 - im\Gamma \quad ,\Gamma = (16\pi)^{-1}(gM^{-1})^2 m^3,$$

Beam energy fluctuation occurs because of short pulsing, so we integrate and take the average value.

$$|\bar{M}|^2 = \frac{1}{\chi_+ - \chi_-}\int_{\chi_-}^{\chi_+} |M|^2 d\chi$$

$$\omega_\pm = \frac{m}{2} \pm \Delta\omega, \omega = \frac{m}{2}$$

$$\chi_\pm = \omega_\pm^2 - \left(\frac{m}{2}\right) = \Delta\omega^2 \pm m\Delta\omega \sim \pm \Delta\omega$$

$$\overline{|M|^2} \sim 8\pi^3 \frac{a}{m\Delta\omega} = \frac{\pi^2}{4\Delta\omega}\left(\frac{g}{M}\right)^2 m^3,$$

Mean value of the squared amplitude

$$\overline{|M|^2} \sim 8\pi^3 \frac{a}{m\Delta\omega} = \frac{\pi^2}{4\Delta\omega}\left(\frac{g}{M}\right)^2 m^3,$$

Here, energy resolution R defined as ,

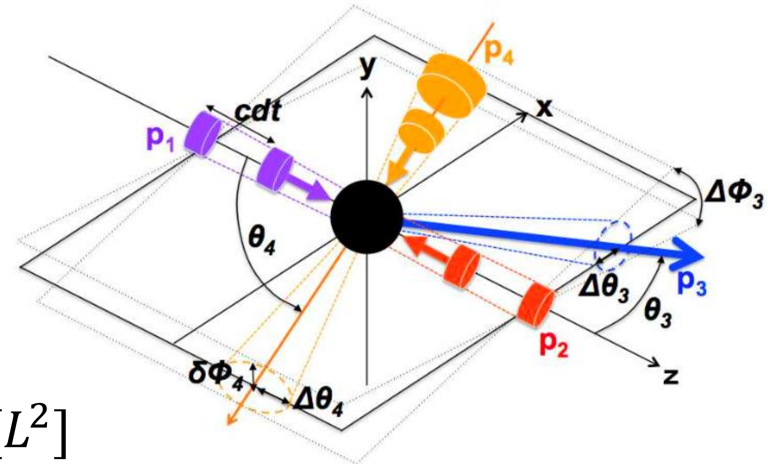
$$\Delta\omega = \sqrt{\omega_1\omega_2}\sqrt{\left(\frac{\delta\omega_1}{\omega_1}\right)^2 + \left(\frac{\delta\omega_2}{\omega_2}\right)^2} \equiv \frac{mR}{\sqrt{2}},$$

Mean value is,

$$\overline{|\mathcal{M}|^2} \sim \frac{\sqrt{2}\pi^2}{8R}\left(\frac{g}{M}\right)^2 m^2$$

Yield

Y_s: *spontaneous yield*, Y_i: *induction yield*



Collision geometry between three pulsed photon beams.

$$Y_s = \int dt \int dx^i \rho_1(t,x^i)\rho_2(t,x^i)K\left[\frac{1}{L^2}\right]\tilde{\sigma}_{dm}[L^2]$$

$$\mathrm{Y_i} = \int dt \int dx^i \rho_1(t,x^i)\rho_2(t,x^i)KP_4(t,x^i)\,\tilde{\sigma}_{dm}$$

$$\equiv K\tilde{\sigma}_{dm}N_1N_2N_4G$$

$$G = \left(\frac{2}{\pi}\right)^{\frac{2}{3}}\left(\frac{\omega_{04}}{c\tau}\right)^2\int_{-\tau L}^{\tau L} dt(\omega_1\omega_2\omega_4)^{-2} \times \left\{A\left(\frac{1}{\omega_1^2}+\frac{1}{\omega_2^2}+\frac{1}{\omega_4^2}\right)B\right\}^{-\frac{1}{2}} \mathrm{e}^{-2Dt^2}$$

$$\tilde{\sigma}_{ngb} = \frac{\overline{|M|^2}}{(8\pi\omega)^2}\int_{\underline{\phi_3}}^{\overline{\phi_3}} d\phi_3 \int_{\underline{\theta_3}}^{\overline{\theta_3}}\left(\frac{\omega_3}{2\omega}\right)^2 \sin\theta_3\, d\theta_3 = \frac{\sqrt{2}}{128R}\left(\frac{g}{M}\right)^2 I,$$

$$I \equiv \frac{\Delta\phi_3(\cos\underline{\theta_3} - \cos\overline{\theta_3})}{(u^+ - u^-\cos\underline{\theta_3})(u^+ - u^-\cos\overline{\theta_3})}$$

Coupling

Detected signal photon Number is,

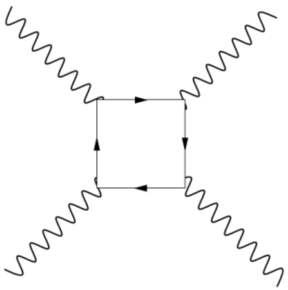
$$Y = fT\epsilon Y_i,$$

f:collision repetition rate(Hz)
T:accumulation time (s)
ϵ:efficiency

finally a reachable coupling strength is

$$\frac{g}{M} = 2^{1/4}8\sqrt{\frac{RY}{IfT\epsilon KGN_1N_2N_4}}$$

QED Background



- Above the keV range, we must consider QED Background from the standard model.
  This calculation are based on Euler-Heisenberg equation.

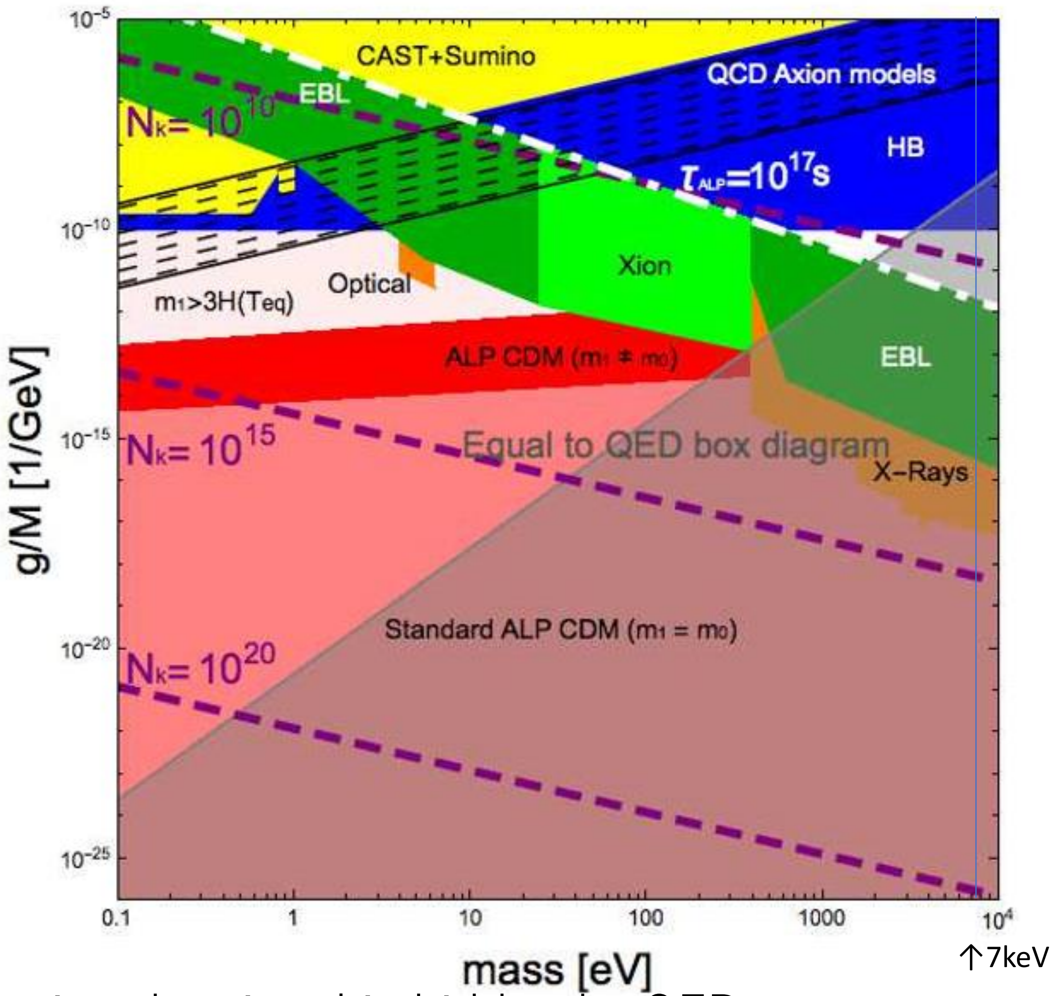
$$d\sigma_{qed} = \frac{(\alpha r_0)^2}{4\pi^2}\frac{139}{90^2}\boldsymbol{\omega^6}\left(3+\frac{\gamma^2(\cos\theta_3-\beta)^2}{\gamma^2(\cos\theta_3-\beta)^2+\sin\theta_3}\right)^2$$

$$\times\left(1+\frac{160}{90^2}\frac{\omega^2\sin^2\theta_3}{4\gamma^2(\cos\theta_3-\beta)^2+3\sin^2\theta_3}\right)$$

$$\times\frac{\gamma(1-\beta\cos\theta_3)}{\gamma^2(\cos\theta_3-\beta)^2+\sin^2\theta_3}d\theta_3 d\phi_3$$

Ref.[3]

Sensitivity to mass-coupling domain

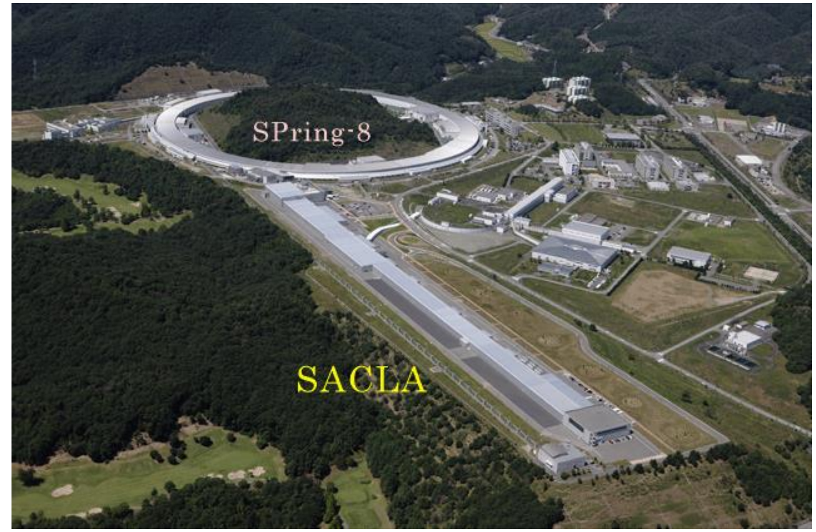


- In keV region the signal is hidden by QED.
- In the low energy region the signal is dominate than QED

Light source

- In the 10 eV–1 keV range
  The generation of higher harmonics by shooting high-intensity laser pulses into material targets.
- In the 0.1–10 eV range
  variable-wavelength lasers based on optical parametric amplification.

Light sources



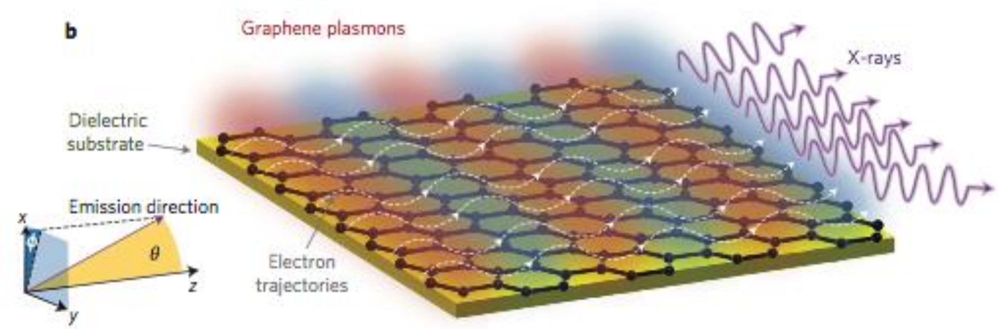
http://www.spring8.or.jp/ja/news_publications/press_release/2011/111005/

- X-ray laser $(1-10\ keV)$
  - SACLA : $N_k \sim 10^{11} at\ 60\ Hz$

    undulator length of 90 m
- Although introducing three long XFEL lines would likely be difficult.

  ↓

  Incoherent light source at the creation part.
- Graphene based laser



GP-based free-electron source Ref.[4]

Summary

- We formulated a stimulated photon–photon scattering process via an *s*-channel pNGB exchange in an asymmetric head-on collision system that would be applicable to the mass range of 0.1eV to 10keV.
- In the keV region, the effect of QED is dominant and resonance can not be observed, but there is a prospect of observation in a low region.

Reference

[1]K. Homma and Y, Toyota, arXiv:1701.04282, (2017).
[2]K. Homma, T. Hasebe, and K.Kume, Prog. Theor. Exp. Phys. 083C01 (2014).
[3] F. Moulin and D. Bernard, Opt. Commun. 164, 137 (1999); E. Lundstro¨m et al., Phys. Rev. Lett. 96, 083602 (2006); J. Lundin et al., Phys. Rev. A 74, 043821 (2006); D. Bernard et al., Eur. Phys. J. D 10, 141 (2000).
[4] L. J. Wong, I. Kaminer, O. Ilic, J. D. Joannopoulos, and M. Soljaˇcí c, Nature Photonics 10, 46 (2016).

Back up

Setting parameter

Lorentz factor to boost CMS energies	$\gamma = 1.5$
Scattering angle in CMS	$\theta = \pi/4$
Incident angle of induction beam	$\theta_4 = 1.65$ rad
Scattering angle of signal photons	$\theta_3 = 0.31$ rad
Common f-number of creation beams	$F = 100$
Induction beam f-number	$F_4 = 10$
Common duration time for creation beams	$\tau = Z_{R2}/c$
Integration time from longest Rayleigh length	$\tau_L = Z_{R2}/c$
Common energy uncertainty of creation beams	$R = 5\%$
Collision repetition rate	$f = 1$ Hz
Data accumulation time	$T = 10^6$ s
Total number of signal photons	$\mathrm{Y} = 100$
Detector efficiency to signal photons	$\epsilon = 100\%$
Creation beam energy in CMS	$\omega = 3.50$ keV
Higher creation beam energy in ACS	$\omega_1 = 9.16$ keV
Lower creation beam energy in ACS	$\omega_2 = 1.34$ keV
Induction beam energy in ACS	$\omega_4 = 2.48$ keV
Signal photon energy in ACS	$\omega_3 = 8.02$ keV