

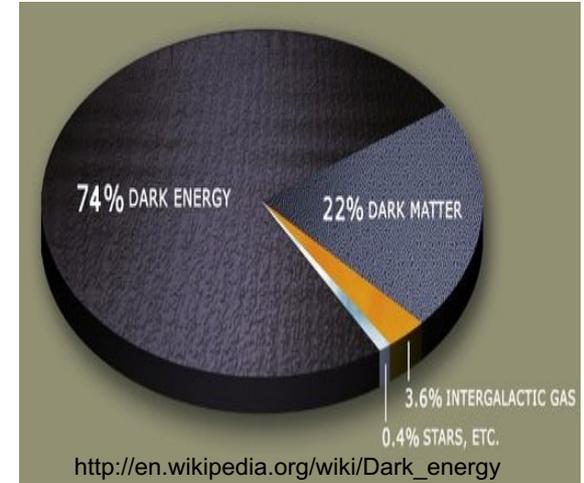
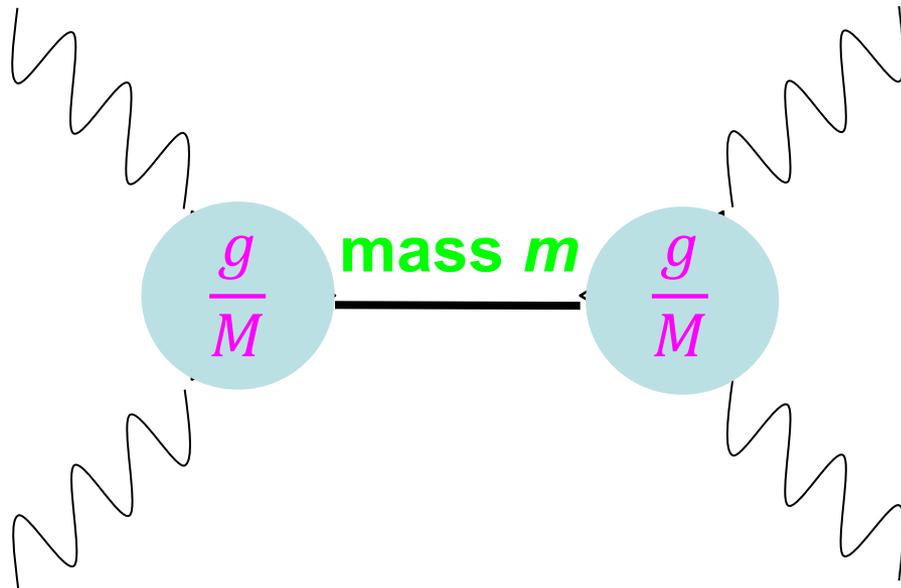
Laboratory searches for pseudo Nambu-Goldstone bosons with stimulated photon-photon colliders

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On behalf of the SAPPHIRES collaboration



pNGBs can be dark components of the Universe



Scale symmetry breaking

$$-\frac{1}{4} \frac{g}{M} F_{\mu\nu} F^{\mu\nu} \phi$$

If $M \sim M_{\text{Planck}}$, dilaton (Dark Energy)

mass $1.5-5.9 \cdot 10^{-7} \text{ eV}$

PQ U(1) symmetry breaking

$$-\frac{1}{4} \frac{g}{M} F_{\mu\nu} \tilde{F}^{\mu\nu} \sigma$$

If $M \sim M_{\text{GUT}}$, axion (Cold Dark Matter)

mass $10^{-4}-10^{-6} \text{ eV}$

Two-loop self-energy correction

arXiv:1512.01360 [gr-qc]

Y. Fujii

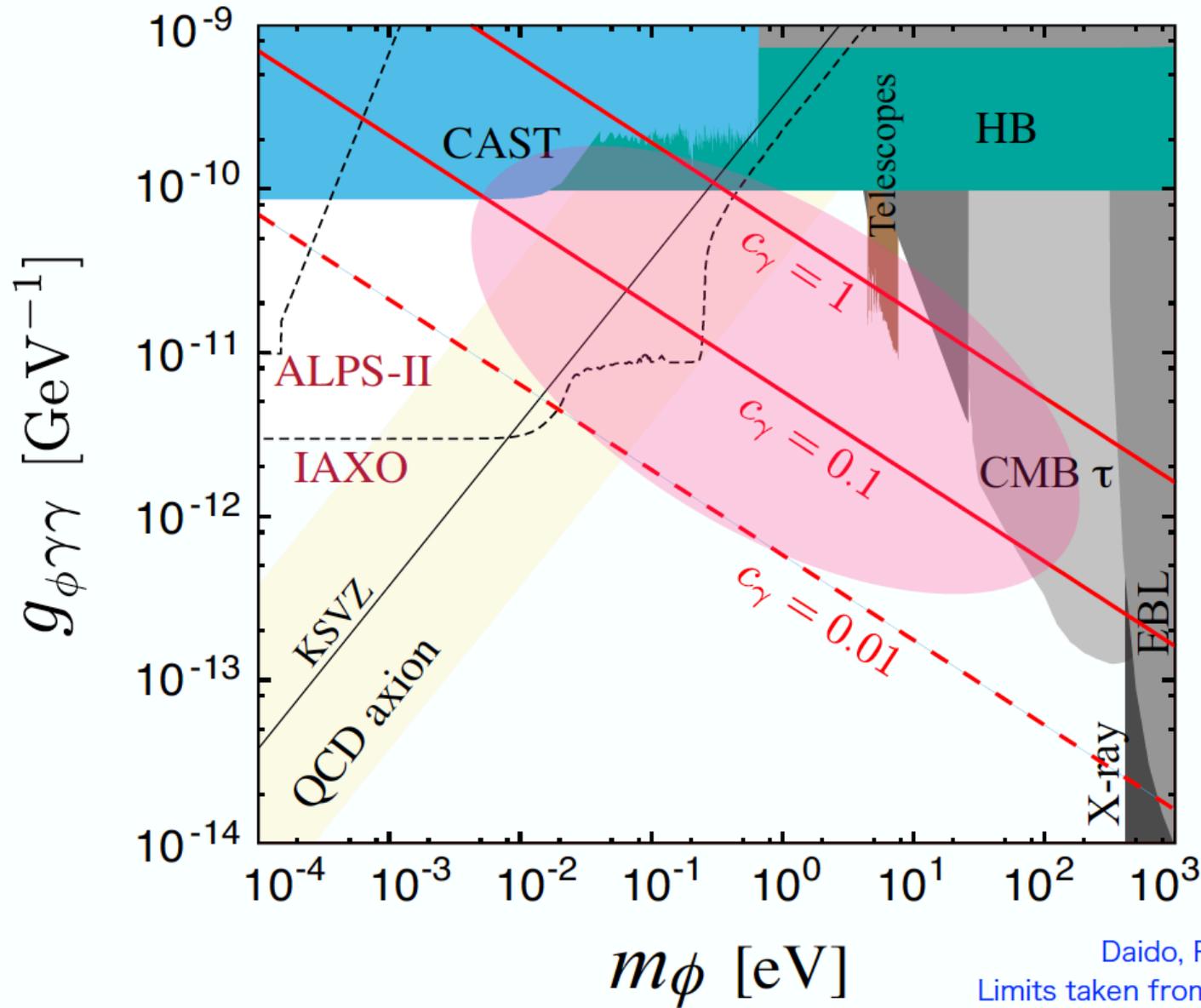
Target region for ALP searches

$$\mathcal{L} = \frac{g_{\phi\gamma\gamma}}{4} \phi F_{\mu\nu} \tilde{F}^{\mu\nu} \quad g_{\phi\gamma\gamma} = \frac{c_\gamma \alpha}{\pi f}$$

$$c_\gamma = \sum_i q_i Q_i^2$$

$$\psi_i \rightarrow e^{i\beta q_i \gamma_5 / 2} \psi_i$$

$$\phi \rightarrow \phi + \beta f$$



Two-body interactions in stimulated resonant scattering

$$S^{(2)} = \frac{i^2}{2} \int d^4x \int d^4y T[F_{\mu\nu}(x)F^{\mu\nu}\phi(x)F_{\rho\sigma}(y)F^{\rho\sigma}(y)\phi(y)]$$

$$N[F_{\mu\nu}(x)F^{\mu\nu}(x)F_{\sigma\rho}(y)F^{\sigma\rho}(y)\langle 0|T[\phi(x)\phi(y)]|0\rangle]$$

$$\propto a_{\vec{i}}^\dagger a_{\vec{j}}^\dagger a_{\vec{k}} a_{\vec{l}} \quad \text{Scalar - propagator}$$

Coherent state:

$$|N\rangle\rangle \equiv \exp(-N/2) \sum_{n=0}^{\infty} \frac{N^{n/2}}{\sqrt{n!}} |n\rangle \quad |n\rangle = \frac{1}{\sqrt{n!}} (a^\dagger)^n |0\rangle$$

$$\langle\langle N|N\rangle\rangle = 1 \quad \langle\langle N|(a^\dagger a)|N\rangle\rangle = N \quad \boxed{a|N\rangle\rangle = \sqrt{N}|N\rangle\rangle, \quad \text{and} \quad \langle\langle N|a^\dagger = \sqrt{N}\langle\langle N|}$$

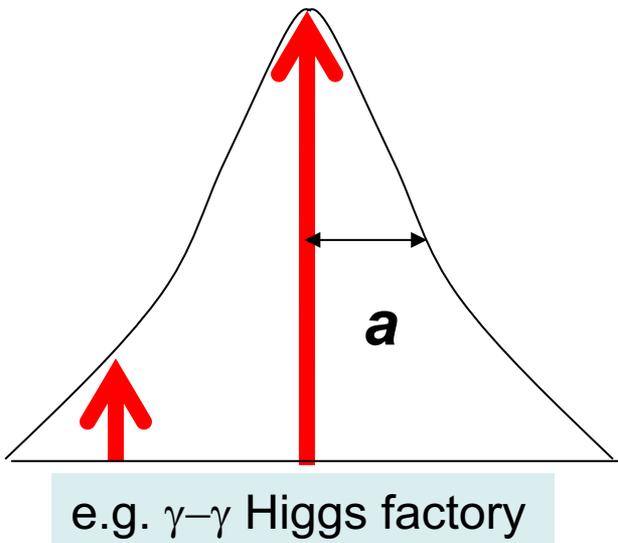
Transition amplitude: $1 + 1 \rightarrow 3 + 4$

$$\langle\langle N_1| \langle\langle N_4| \langle\langle 1_3| S^{(2)} |N_1\rangle\rangle |N_4\rangle\rangle |0\rangle$$

$$\propto \langle\langle N_1| \langle\langle N_4| \langle\langle 1_3| a_{\vec{i}}^\dagger a_{\vec{j}}^\dagger a_{\vec{k}} a_{\vec{l}} |N_1\rangle\rangle |N_4\rangle\rangle |0\rangle$$

$$\propto \sqrt{N_1} \sqrt{N_1} \sqrt{N_4} \langle\langle N_1|N_1\rangle\rangle \langle\langle N_4|N_4\rangle\rangle \langle 0|0\rangle$$

s-channel scattering contains resonance



$$|\mathcal{M}|^2 \approx (4\pi)^2 \frac{a^2}{\chi^2 + a^2}$$

$$a = \frac{\omega_r^2}{16\pi} \left(\frac{gm}{M} \right)^2$$

$$\chi = \omega^2 - \omega_r^2 \quad \omega_r^2 = \frac{m^2/2}{1 - \cos 2\vartheta}$$

$$\chi \gg a \rightarrow |\mathcal{M}|^2 \propto a^2 \propto M^{-4}$$

$$\omega = \omega_r \rightarrow |\mathcal{M}|^2 \propto (4\pi)^2$$

$$\chi_{\pm} \equiv \pm \eta a \text{ with } \eta \gg 1$$

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

$$= \frac{(4\pi)^2}{2\eta a} 2a \tan^{-1}(\eta) = (4\pi)^2 \eta^{-1} \tan^{-1}(\eta)$$

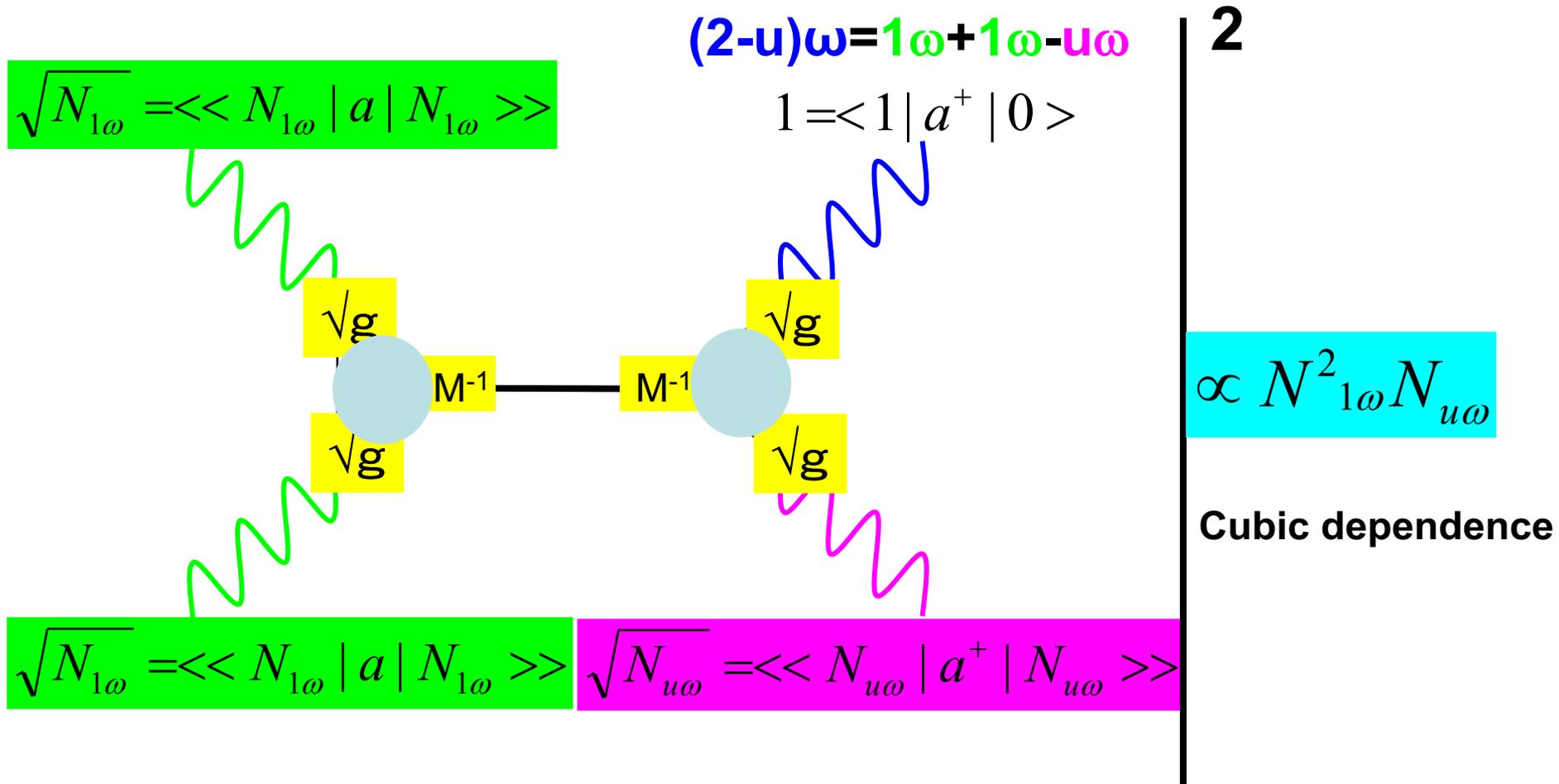
$$\approx (4\pi)^2 \eta^{-1} \frac{\pi}{2} = 8\pi^3 \frac{a}{|\chi_{\pm}|}$$

Gain by M^2

Collision with momentum-energy uncertainty

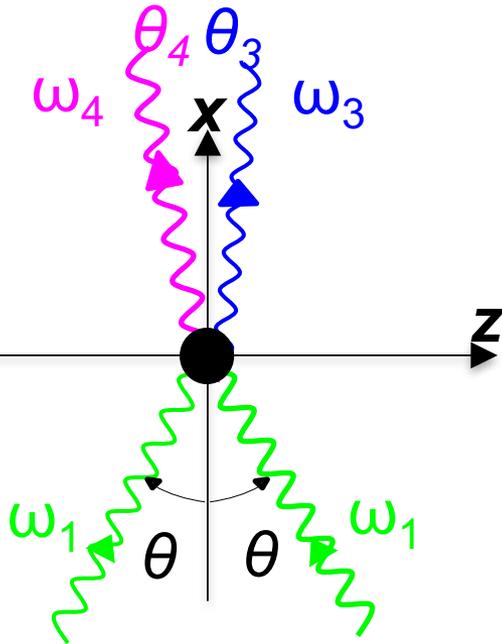
Enhanced rate by inducing laser field

- stimulated scattering in bkg laser field-



Photon-photon collision systems

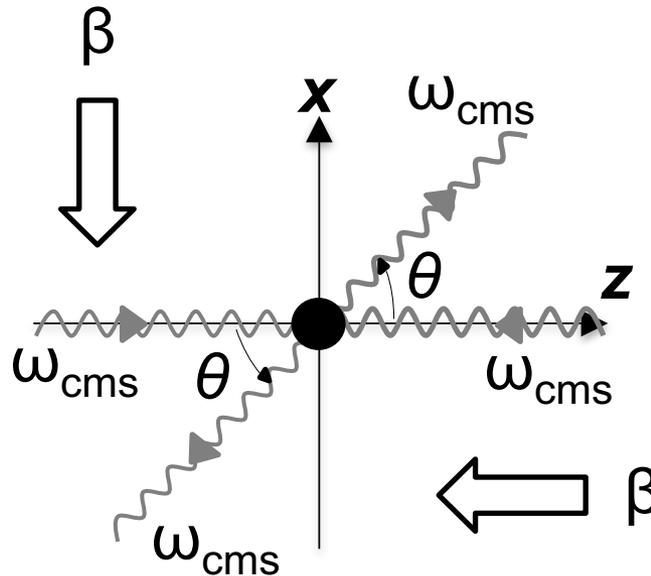
Quasi-Parallel collision System



$$E_{cms} = 2\omega_1 \sin \theta$$

Low mass search

Center of Mass System

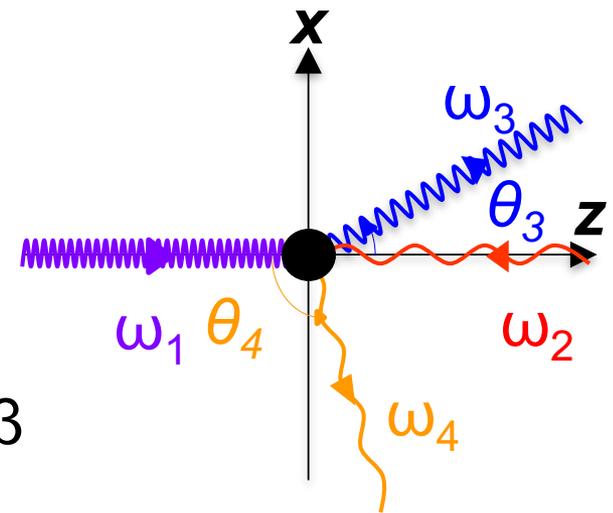


Lorentz boost

$$E_{cms} = 2\omega_{cms}$$

High mass search

Asymmetric Head-on collision System

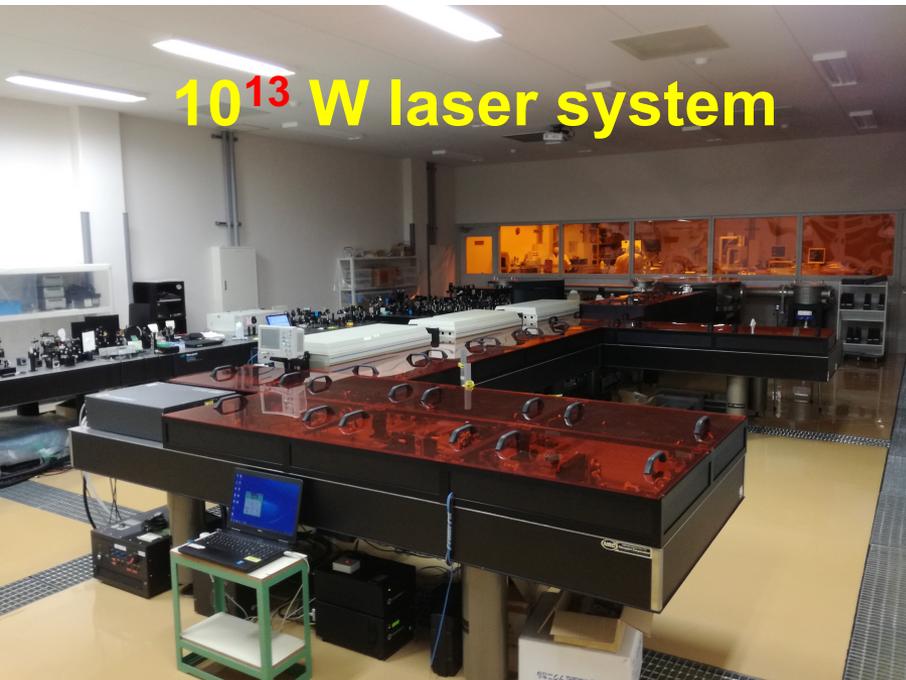


$$E_{cms} = 2\sqrt{\omega_1 \omega_2}$$

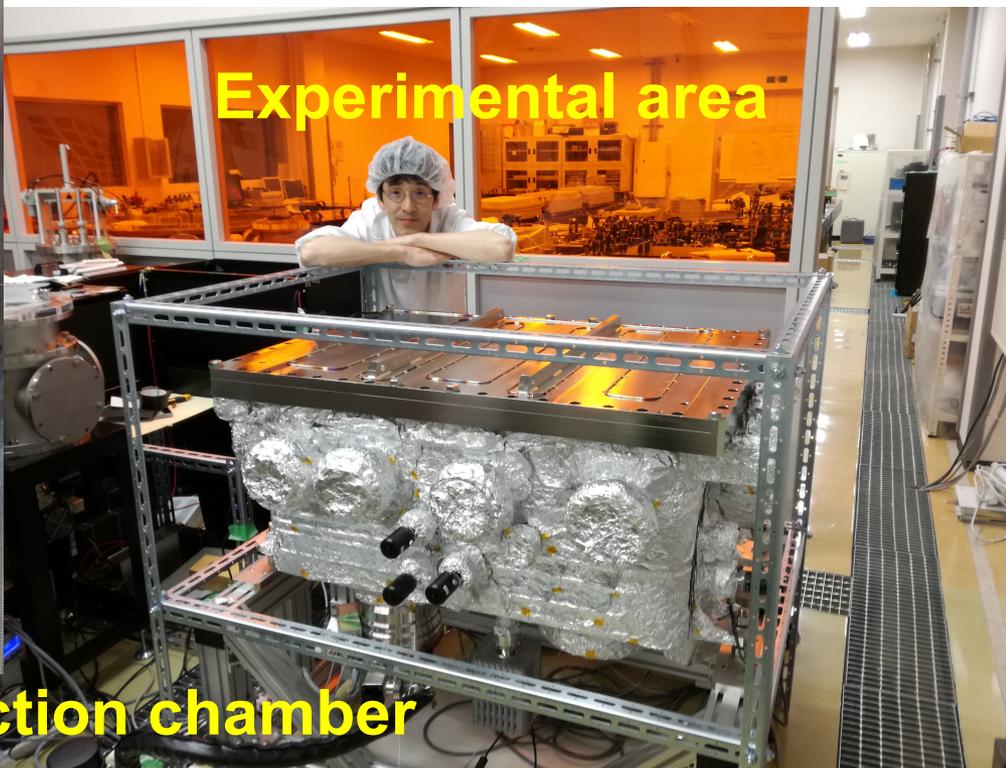
High mass search

Searches at Ins. Chem. Res. in Kyoto Univ.

10^{13} W laser system



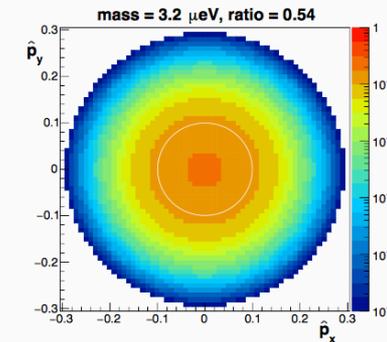
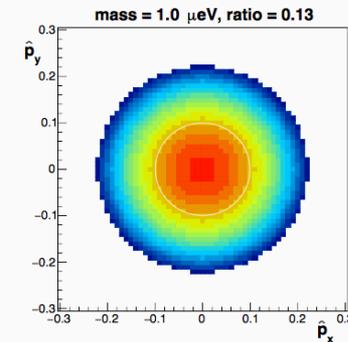
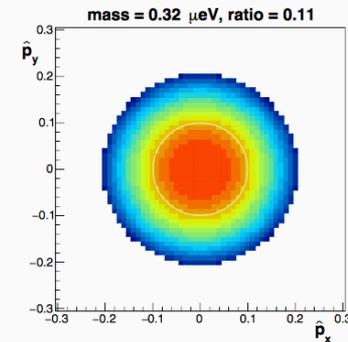
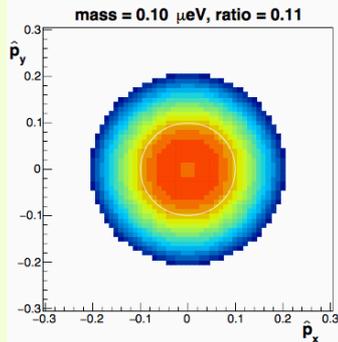
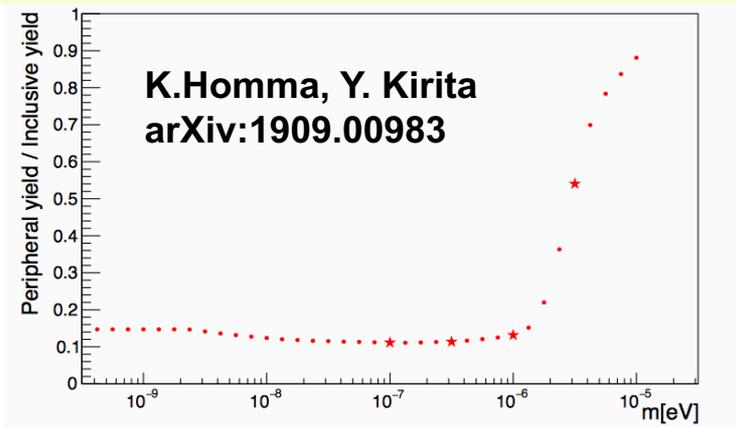
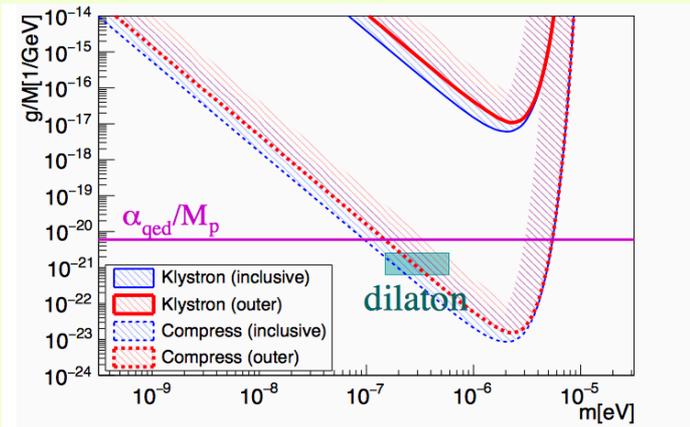
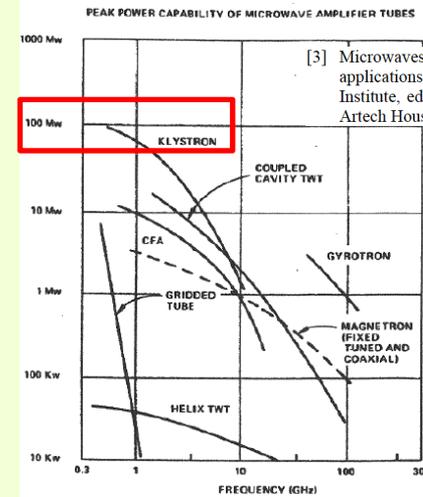
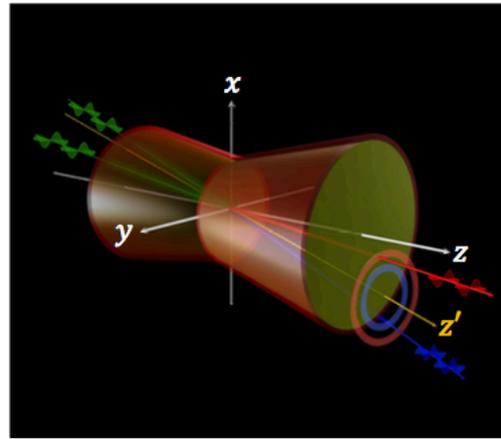
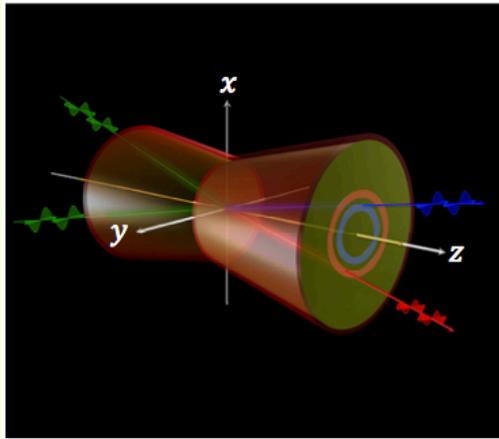
Experimental area



Interaction chamber



Can GHz source enable dilaton search?



Thank you for the support

- Two papers under review.
- Three searching data sets have been taken and analyzed for the future publication.
- We could get lots of knowledge to bridge to the ELI project.