Axion-like particle at CEνNS experiments

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Outline

Axion-like particle

Current constraints

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Axion-like particle

Axion-like particle (ALP)

Axion is:

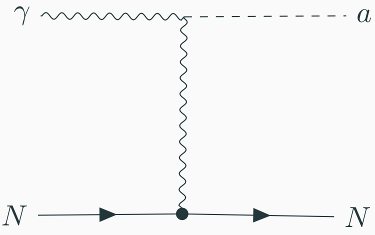
- proposed to solve strong CP problem
- a pseudo-Nambu–Goldstone boson arise from spontaneous breaking of a global symmetry
- weakly coupled to photons, electrons and nucleons, etc.

This talk focus on the ALP couplings to photon and electron:

$$\mathcal{L} \supset \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2}m_a^2 a^2 - \frac{1}{4}g_{a\gamma\gamma} a F_{\mu\nu}F^{\mu\nu} - g_{ae} a \bar{\psi}_e \gamma_5 \psi_e$$

ALP production

Through Primakoff process:

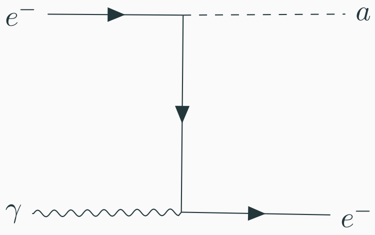


Enhanced by Z^2 because of coherence.

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta} = \frac{1}{4} g_{a\gamma\gamma}^2 \alpha Z^2 F^2(t) \frac{p_a^4 \sin^2\theta}{t^2}$$

ALP production

Through Compton-like process:

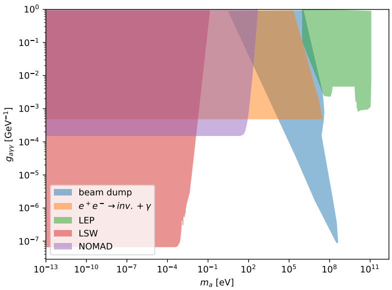


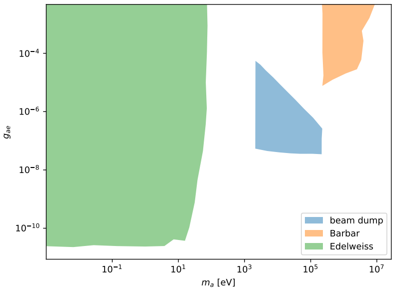
Enhanced by Z.

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{g_{ae}^2 \alpha E_\gamma}{8\pi m_e^2 p_a}\left(1 + \frac{4m_e^2 E_\gamma^2}{(2m_e E_a + m_a^2)^2} - \frac{4m_e E_\gamma}{(2m_e E_a + m_a^2)} - \frac{4m_a^2 p_a^2 m_e E_\gamma}{(2m_e E_a + m_a^2)^3} \sin^2\theta\right)$$

Current constraints

Current constraints from lab based experiments



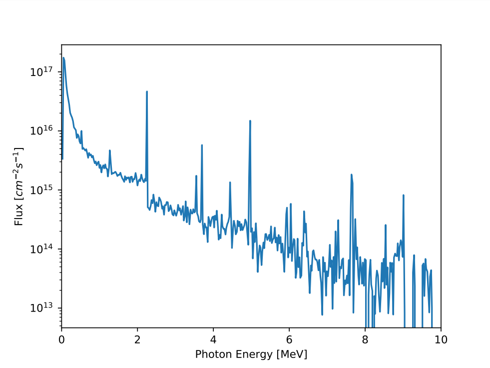


Lab-based searches are more conservative and robust while astrophysical searches depend on a host of environmental parameters such as the temperature, matter density, or plasma frequency, as well as the momentum transfer at the ALP-photon vertex.

ALP detection at CEνNS experiment

Reactor source

For a MWatt reactor (10^{19} photons/s):



With $g_{a\gamma\gamma} = 10^{-6}\,\mathrm{MeV}^{-1}$ and $m_a = 1\,\mathrm{MeV}$:

- Expected photon flux from axion decay: $13.6/(\mathrm{cm}^2\mathrm{s})$
- Expected axion flux arrived at detector: $72.0/(\mathrm{cm}^2\mathrm{s})$

Beam source

Possible source of photons:

1. Stopped π^- to photon via $\pi^- + p \to n + \gamma$
2. π^0 decay to two photons
3. Brem photons
4. Cascade photons

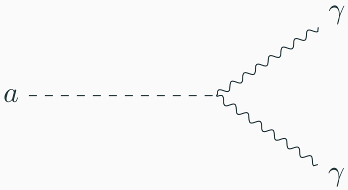
And more. Under calculation.

With $g_{a\gamma\gamma} = 10^{-6}\,\mathrm{MeV}^{-1}$, $m_a = 1\,\mathrm{MeV}$ and $\pi^- + p \to n + \gamma$, beam intensity 5×10^{20} POT/day:

- Expected photon flux from axion decay: $5 \times 10^{-3}/(\mathrm{cm}^2\mathrm{s})$
- Expected axion flux arrived at detector: $6 \times 10^{-3}/(\mathrm{cm}^2\mathrm{s})$

This is underestimation. (Using COHERENT beam source)

Detection: ALP decay to photons



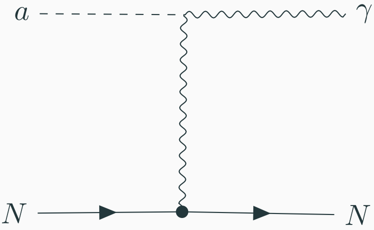
ALP decays in flight to two photons, and detector detects photons.

ALP decay width:

$$\Gamma_a = \frac{g_{a\gamma\gamma}^2 m_a^3}{64\pi}$$

e.g. with $E_a = 20\,\mathrm{MeV}$, $m_a = 1\,\mathrm{MeV}$ and $g_{a\gamma\gamma} = 10^{-5}$, the mean decay length is 7.9 meters.

Detection: ALP scattering in detector

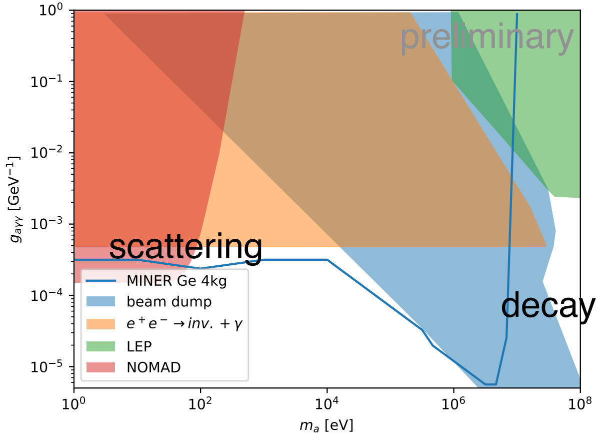


The detector detects photon through inverse Primakoff process.

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta} = \frac{1}{2} g_{a\gamma\gamma}^2 \alpha Z^2 F^2(t) \frac{p_a^4 \sin^2\theta}{t^2}$$

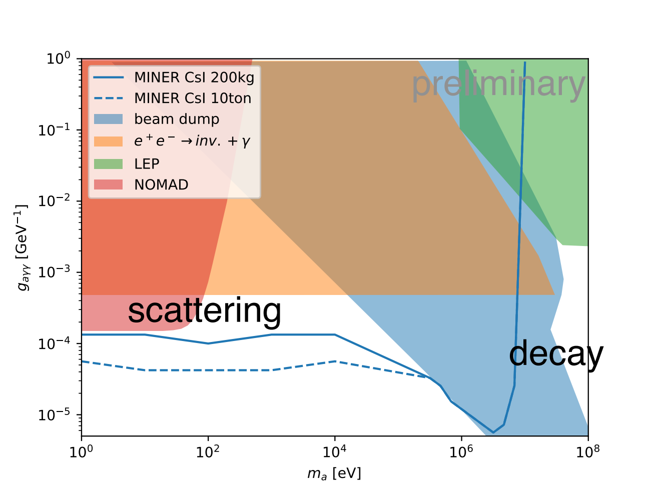
Results

ALP-photon coupling, MINER Ge detector 10 events per day



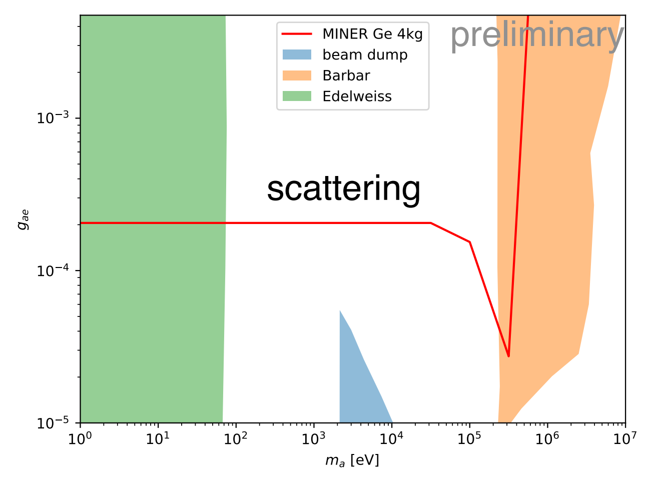
Reactor

ALP-photon coupling, MINER CsI detector 10 events per day

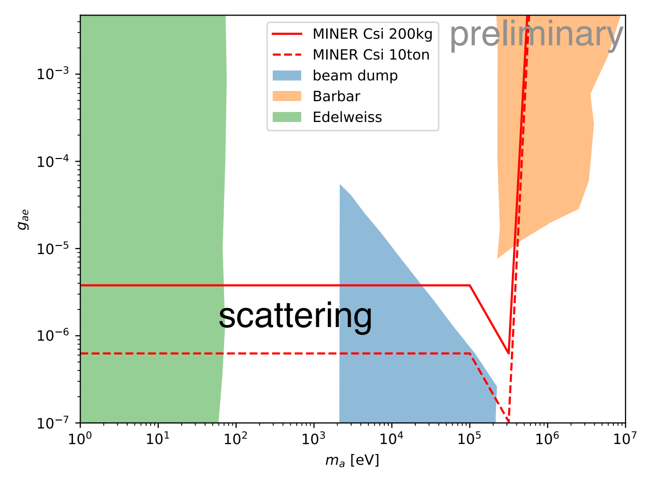


Reactor

ALP-electron coupling, MINER Ge detector 10 events per day



ALP-electron coupling, MINER CsI detector 10 events per day



Conclusions

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- CEνNS experiments that comes with large amount of photon flux can be turned into an ALP experiment.
- Current facilities at CEνNS experiments can already beat other lab based ALP experiments.