QCD Axion Search with ILC Beam Facility

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1. Axion Search

QCD Axion
Light Shining through Walls (LSW) experiments
Need of high-energy and high-intensity photons

2. Photon Source from ILC Beam

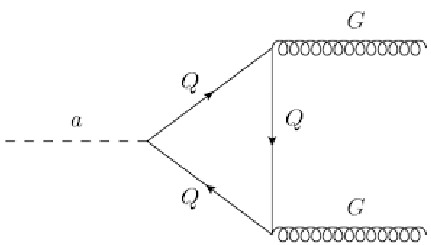
Beam
Positron Source
Undulator photon

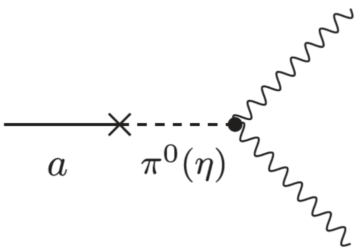
3. LSW Experiments at ILC

Axion reach at ILC

QCD Axions

- Nambu-Goldston boson to solve the strong CP problem.
- Light CP odd particle coupling to gauge bosons.





At low energy,

$$\mathcal{L} = \frac{1}{2}(\partial a)^2 - \frac{1}{2}m_a^2 a^2 - \frac{1}{4}g_{a\gamma\gamma} a F_{\mu\nu}\tilde{F}^{\mu\nu} + \cdots$$

Axion-Photon Conversion

With photon field background, there is mixing between axion and photon.

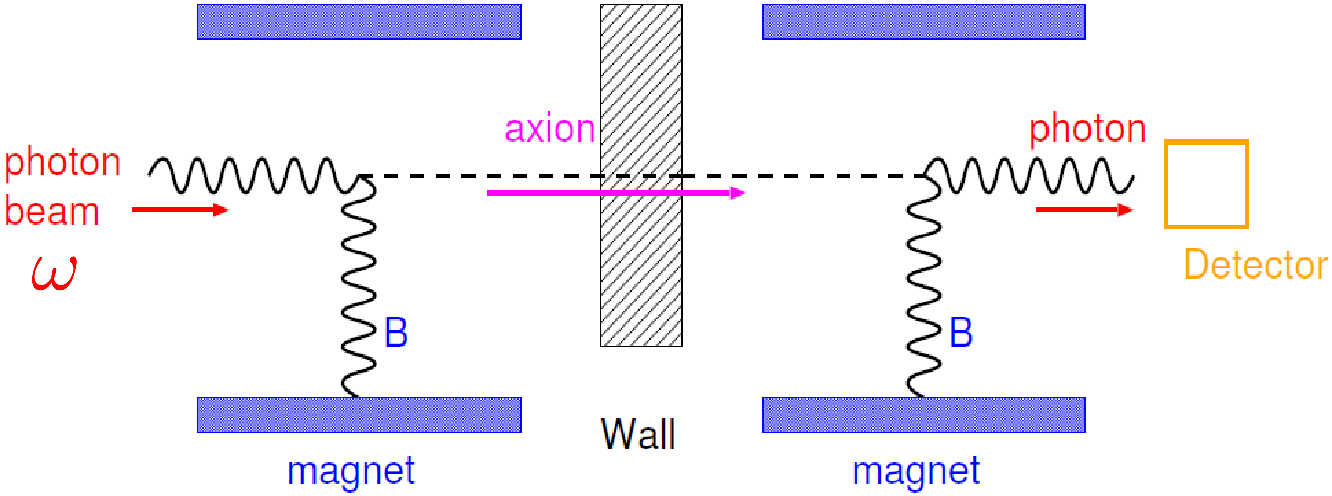
$$g_{a\gamma\gamma} a \langle F_{\mu\nu} \rangle \tilde{F}^{\mu\nu}$$

This provides axion-photon oscillation with strong magnetic field.
The conversion is important for

- Cosmology.
- Astrophysics.
  - Detection of solar axion.
- Terrestrial axion search.
  - LSW-type experiments.

LSW Experiments

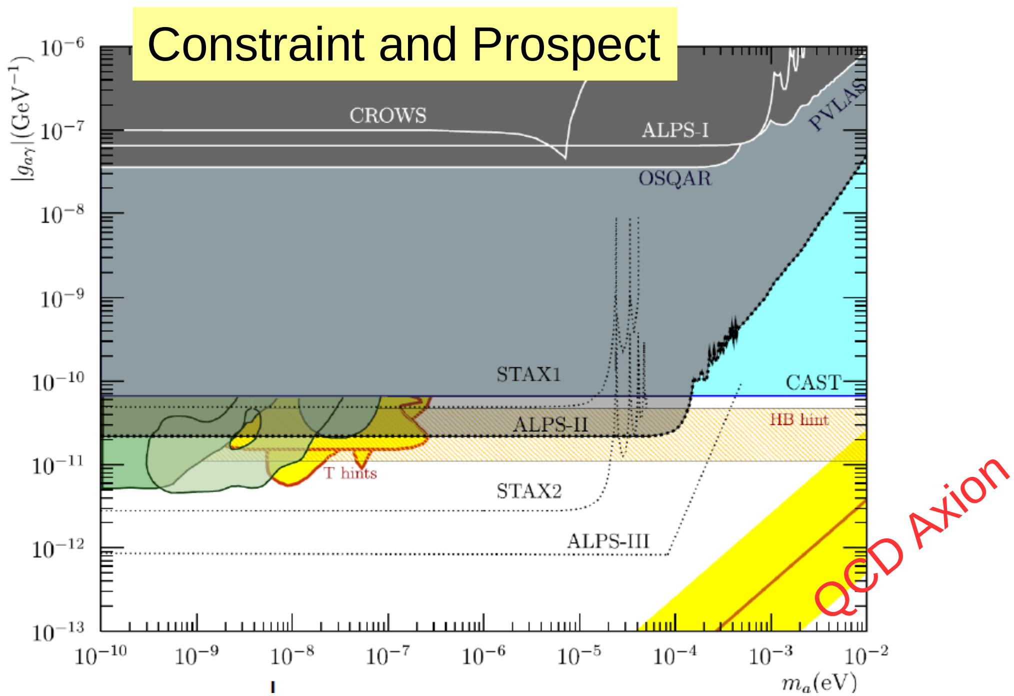
Light Shining through a Wall



LSW Experiments

Taken from 1801.08127

Experiment	Status	B (T)	L (m)	Input power (W)	β_P	β_R	$g_{a\gamma}$ [GeV^{-1}]
ALPS-I [433]	Completed	5	4.3	4	300	1	5×10^{-8}
CROWS [435]	Completed	3	0.15	50	10^4	10^4	9.9×10^{-8} (a)
OSQAR [434]	Ongoing	9	14.3	18.5	-	-	3.5×10^{-8}
ALPS-II [436]	In preparation	5	100	30	5000	40000	2×10^{-11}
ALPS-III [437]	Concept	13	426	200	12500	10^5	10^{-12}
STAX1 [438]	Concept	15	0.5	10^5	10^4	–	5×10^{-11}
STAX2 [438]	Concept	15	0.5	10^6	10^4	10^4	3×10^{-12}



Photon Conversion

$$P_{\gamma\leftrightarrow a} = \frac{1}{4} g_{a\gamma\gamma}^2 B_0^2 L^2 \left[\frac{\sin(qL/2)}{qL/2} \right]^2$$

q is momentum transfer between axion and photon.

$$q = \omega - \sqrt{\omega^2 - m_a^2} \simeq \frac{m_a^2}{2\omega}$$

q → 0 or massless axion:

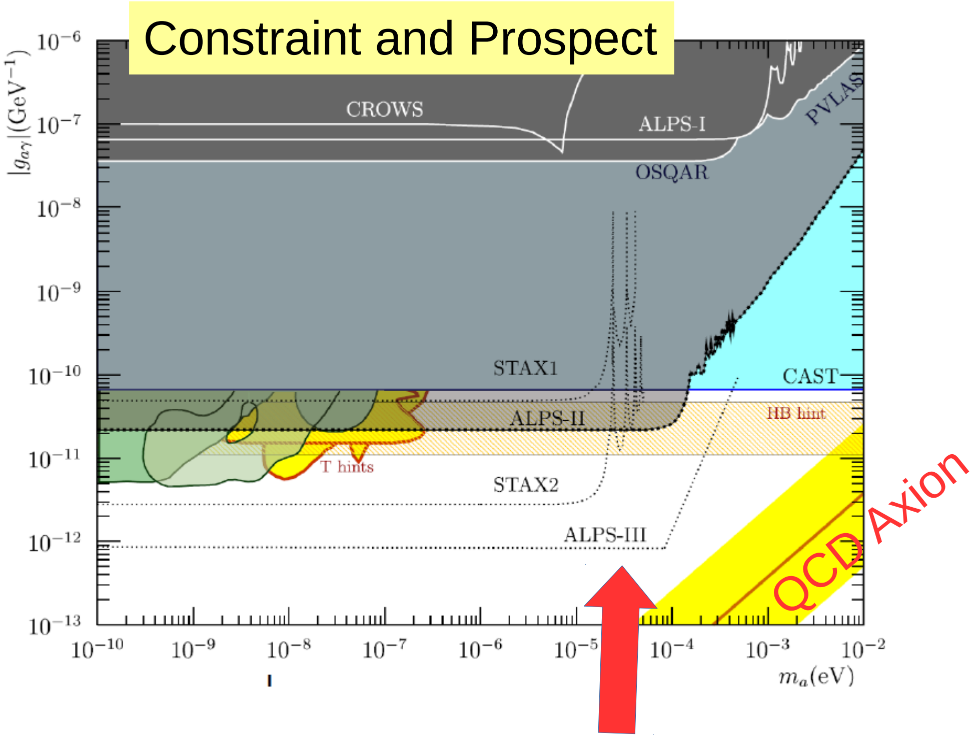
$$P_{\gamma\leftrightarrow a} \to \frac{1}{4} g_{a\gamma\gamma}^2 B_0^2 L^2$$

qL > O(1) i.e., $m_a > \sqrt{\omega/L}$

$$P_{\gamma\leftrightarrow a} \sim g_{a\gamma\gamma}^2 B_0^2 \omega^2 m_a^{-4}$$

suppression for high mass axion

LSW Experiments



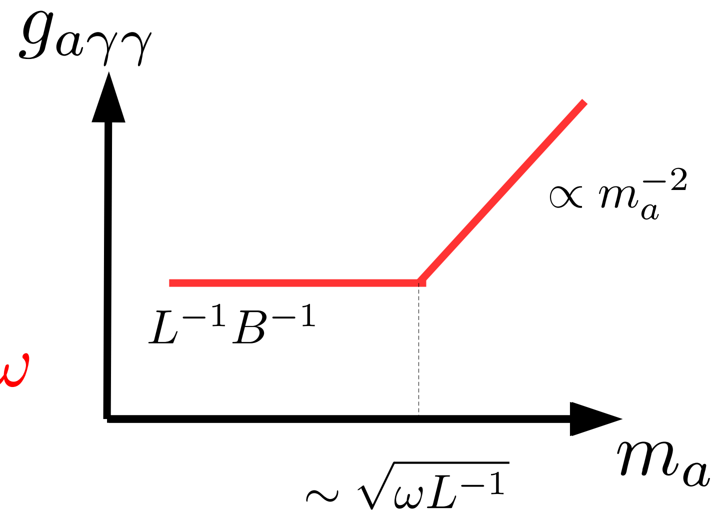
$$\sqrt{\omega L^{-1}} \sim 10^{-4}\ \mathrm{eV} \left(\frac{\omega}{1\ \mathrm{eV}}\right)^{1/2} \left(\frac{L}{1\ \mathrm{m}}\right)^{-1/2}$$

Sensitivity

$$P_{\gamma\leftrightarrow a} = \frac{1}{4} g_{a\gamma\gamma}^2 B_0^2 L^2 \left[\frac{\sin(qL/2)}{qL/2}\right]^2$$

To see small coupling,
Large B and ;arge L

To see high-mass axion,
Small L and large photon energy ω

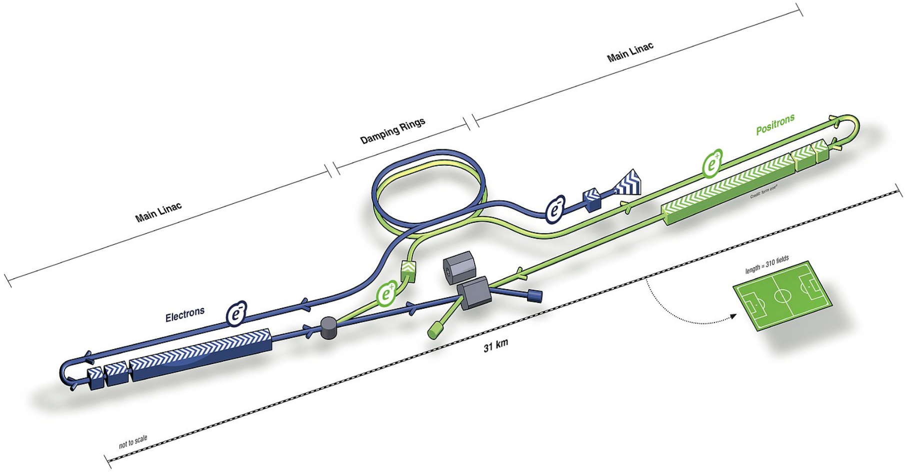


We need high-energy photons.

Photon Source from ILC Beam

Axion Search at ILC

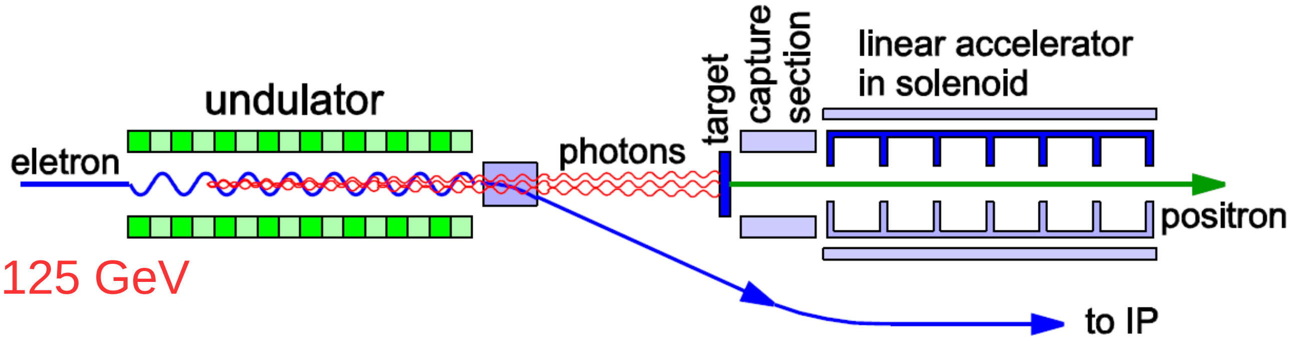
International Linear Collider is e^+e^- Collider.



Axion search at the ILC is possible?

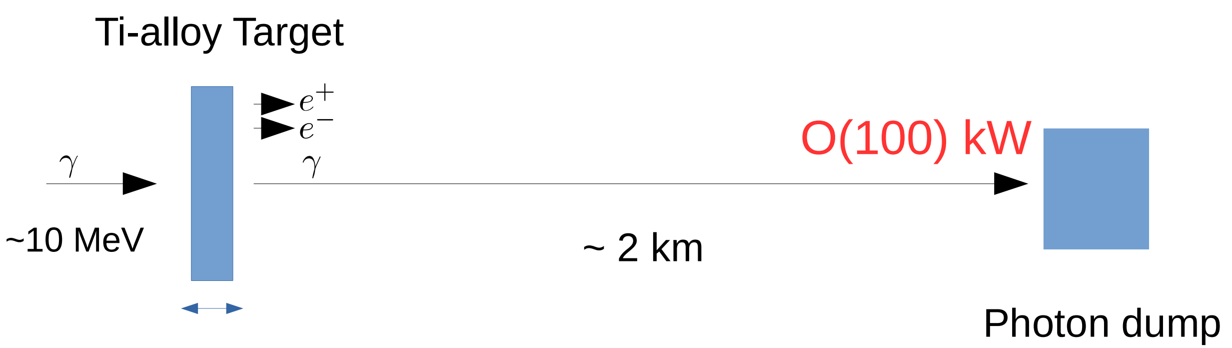
Positron Source

Baseline plan for positron source is based on undulator photon



main beam: 125 GeV

Undulator photon

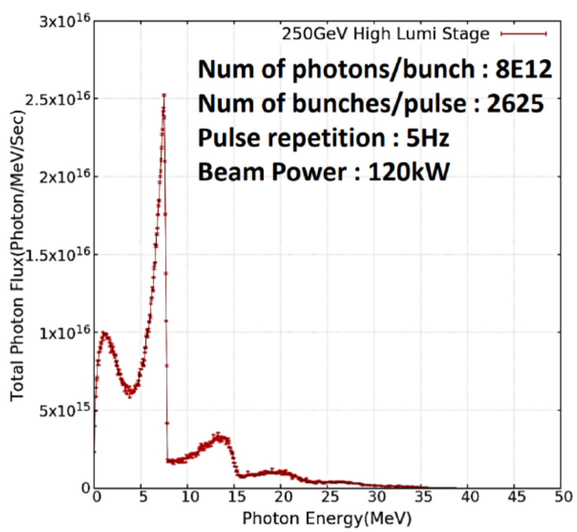


~ 7 mm ~ $0.4X_0$

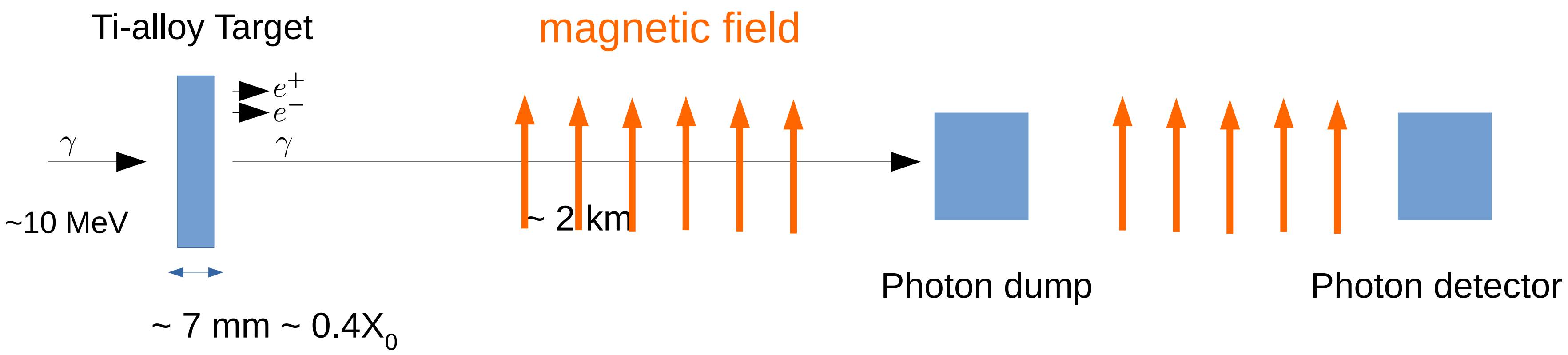
Most of photons are not used.

Photon beam with:

- ~ 8 MeV Energy
- ~ 10^{16} photons / second

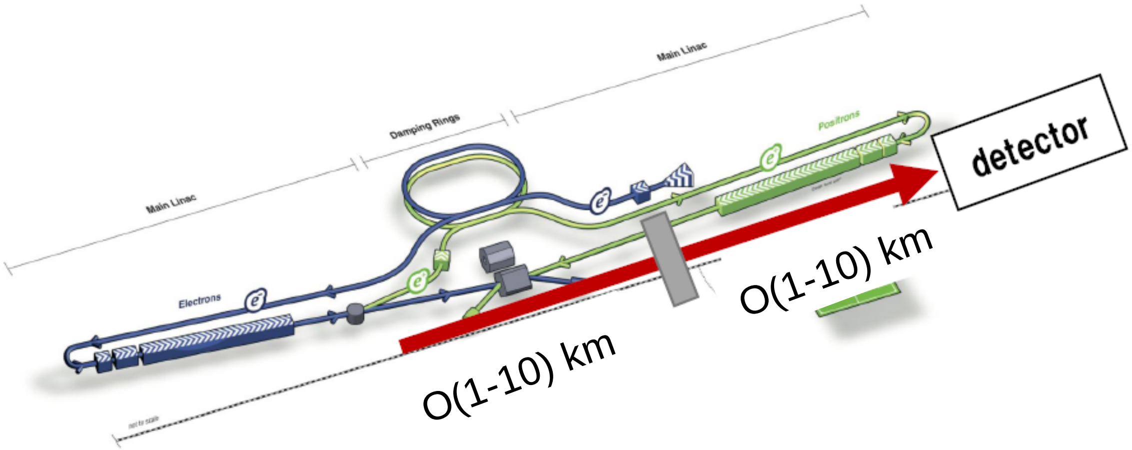


LSW Experiments at ILC



With high-energy photons, high mass axion can be probed.

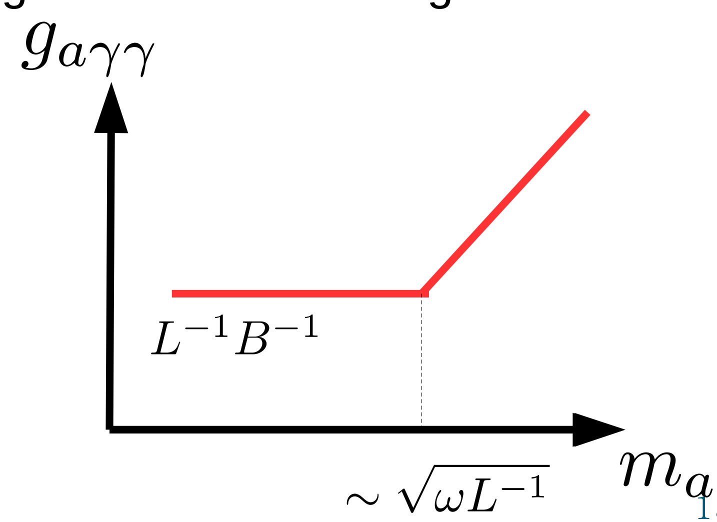
Proposal for LSW at ILC



In ILC tunnel or its extension, we may put long beam line with magnetic field.

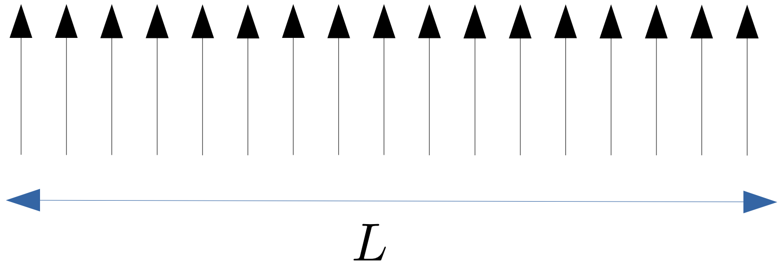
Thanks to MeV gamma, sub-eV axion can be probed.

$$\sqrt{\omega L^{-1}} \sim 10^{-1}\ \text{eV} \left(\frac{\omega}{10\ \text{MeV}}\right)^{1/2} \left(\frac{L}{1\ \text{km}}\right)^{-1/2}$$

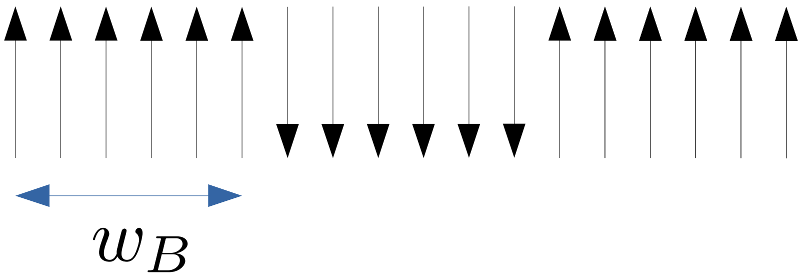


More on High-mass Axion

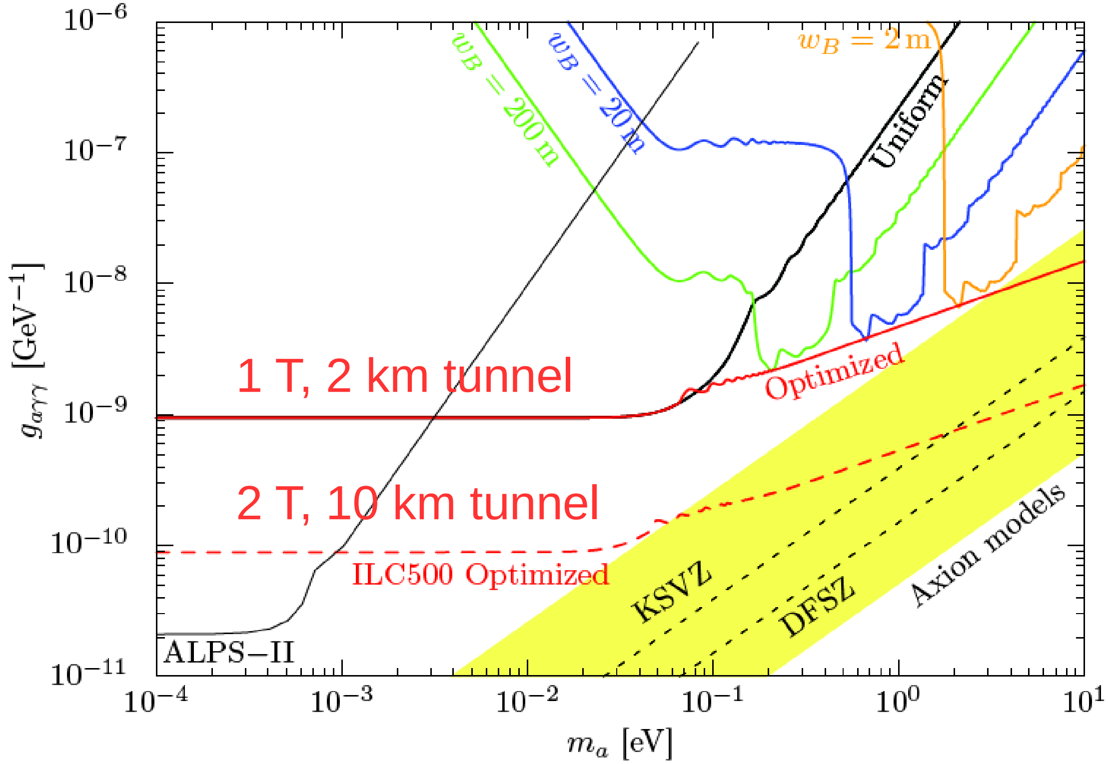
Usually, we consider uniform magnetic field,



With wiggled configuration, more higher-mass axion can be probed.



Expected Sensitivity



Summary and Discussion

- Axion is an important target with various theoretical and experimental challenges.
  - LSW experiments provide robust constraint/discovery parameter regions.
  - We need high-energy photons.

- ILC will provide a good source of high-quality photons.
  - Undulator photons from positron productions.

- ILC can improve the sensitivity for high mass axion.

- Application to dark photons.

Improving High Mass Range

$$P(\gamma \to a; \omega) \simeq \frac{g_{a\gamma\gamma}^2}{4} \left| \int dz e^{iqz} B_1(z) \right|^2$$