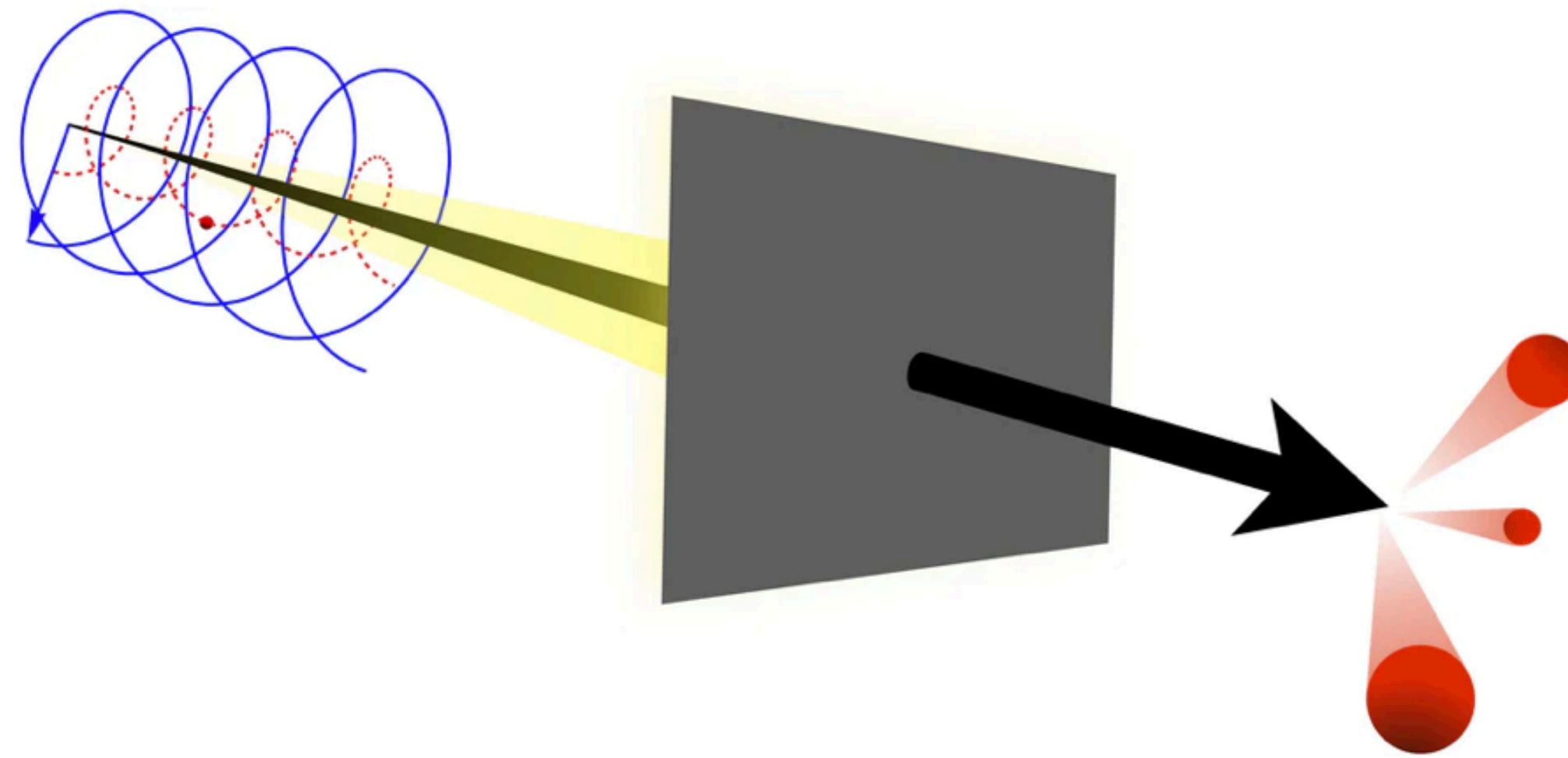


Synchrotron Radiation Facilities as Dark Photon Factories: A Parasitic Search for WISPs



TOKYO METROPOLITAN UNIVERSITY

東京都立大学

Press release: <https://www.tmu.ac.jp/news/topics/38563.html>

@2026/4/15, E-lab, Nagoya Univ.

Based on WY, 2507.22055, 2508.14885
and WY, Yoshida, 2408.17451

Wen Yin (Tokyo Metropolitan University)

Contents

- 1. Introduction
- 2. Proposal of a parasitic search of dark photon
- 3. Matter and quantum effects in dark photon-photon conversion
- 4. Dark photon limit from radiation safety monitoring
- 5. Conclusions

- 1. Introduction

What is the direction for new physics before new colliders?

- Low-cost experiment to gather hints, making the background solid.
- Technology 🤝 Particle physics.
- The particles of focus is Weakly Interacting Slim Particles (WISPs) that has good motivation.

See the [White Paper](#), 2603.03433, for the outlook for the next 10 years, as well as [WISPEdia](#), 2602.09089, a theoretical model encyclopedia for WISPs by groups in COSMIC WISPErs.

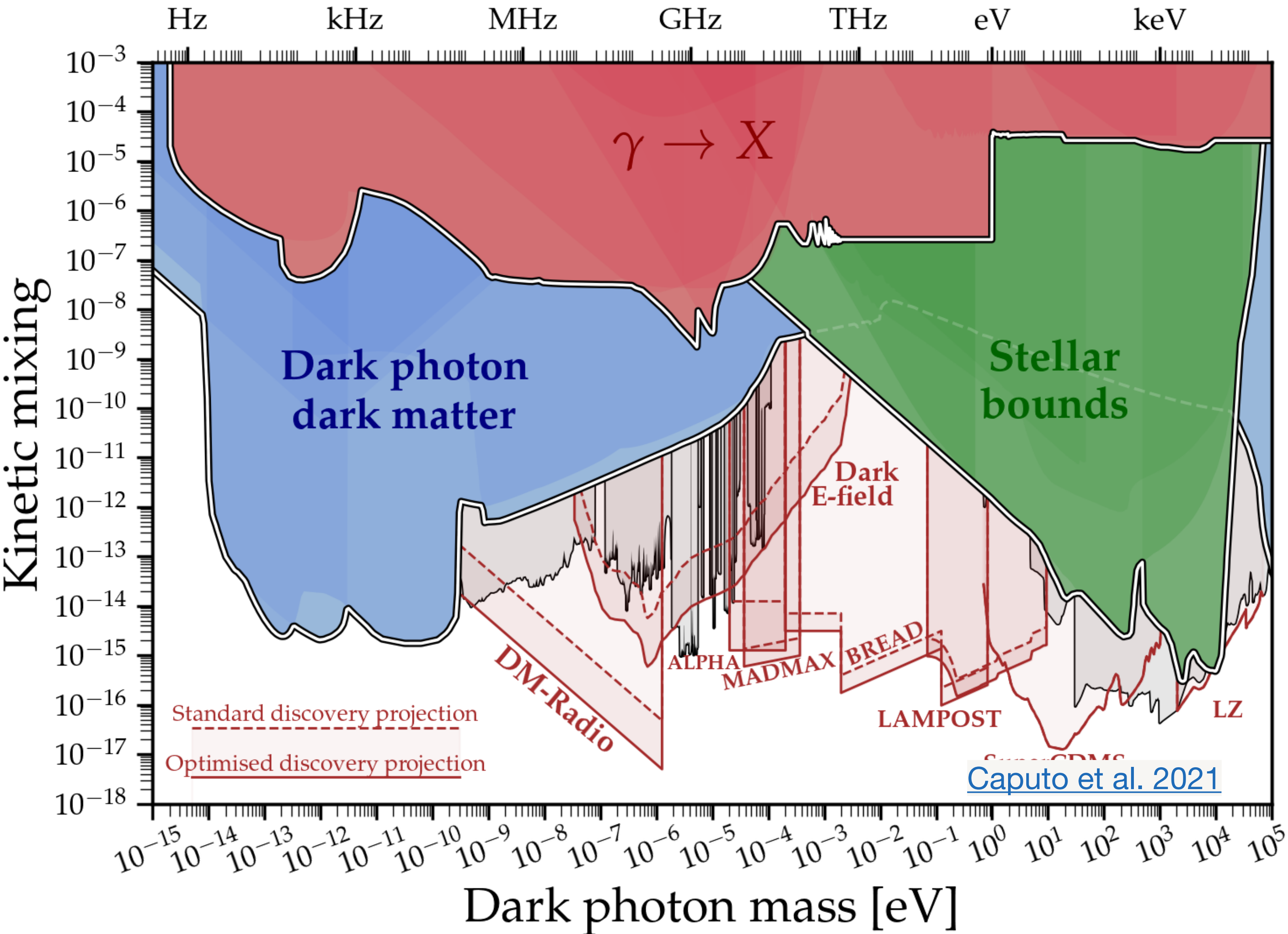
Dark Photon Model

See e.g. Jaeckel, Ringwald, 1002.0329, for UV model and Ruegg, Ruiz-Altaba, 0304245 for renormalizability

$$\Delta\mathcal{L} \supset \underline{-\frac{\chi}{2}F'_{\mu\nu}F^{\mu\nu}} - \frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} - \frac{m_{\gamma'}^2}{2}A'_\mu A'^\mu$$

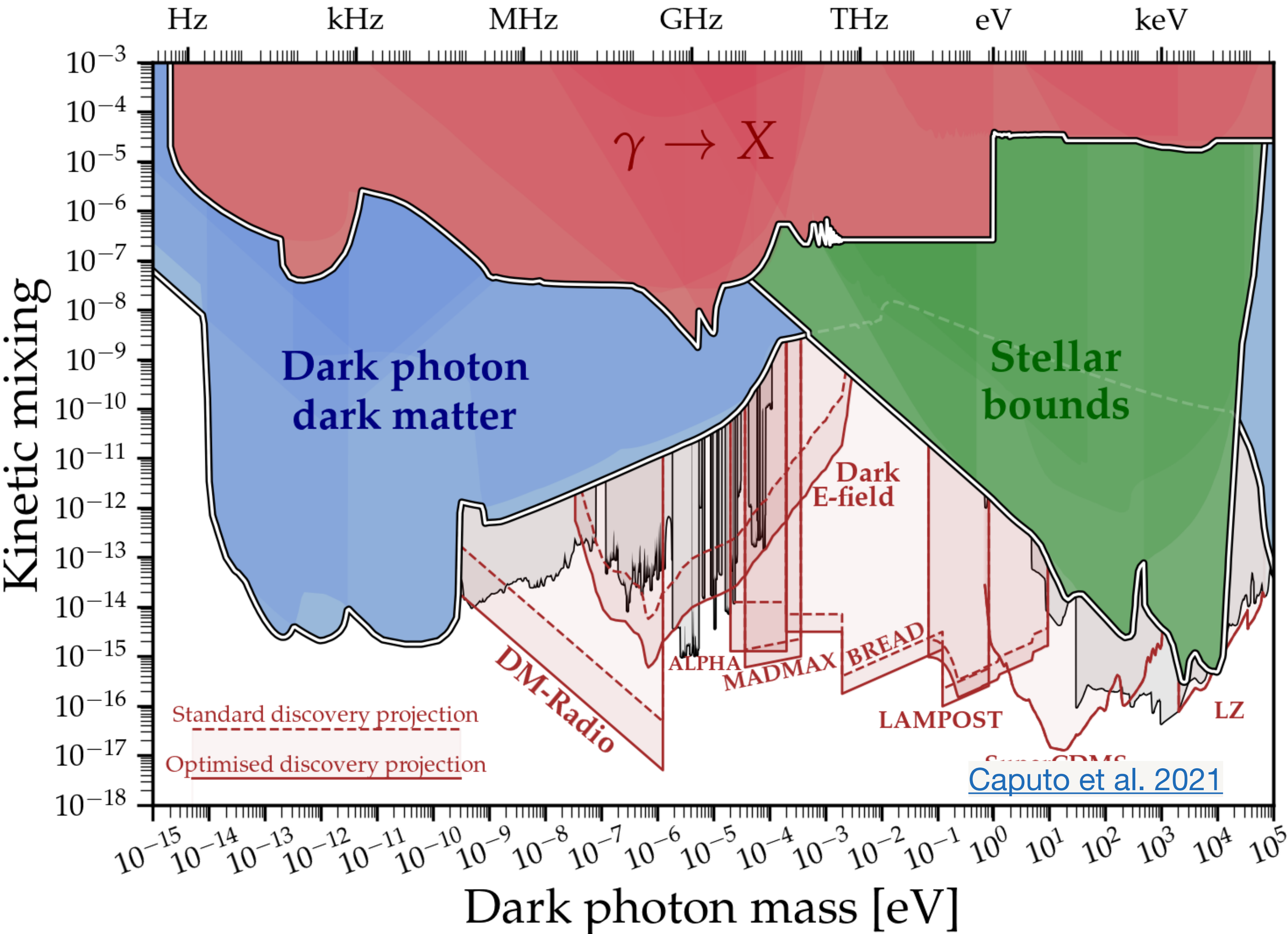
- One of the simplest extensions of Standard Model.
- Dark photon couples to electron via the mixing with ordinary photon: $e' = \chi e$.
- Photon-dark-photon oscillation occurs similar to neutrino oscillation.

Generic dark photon parameter region



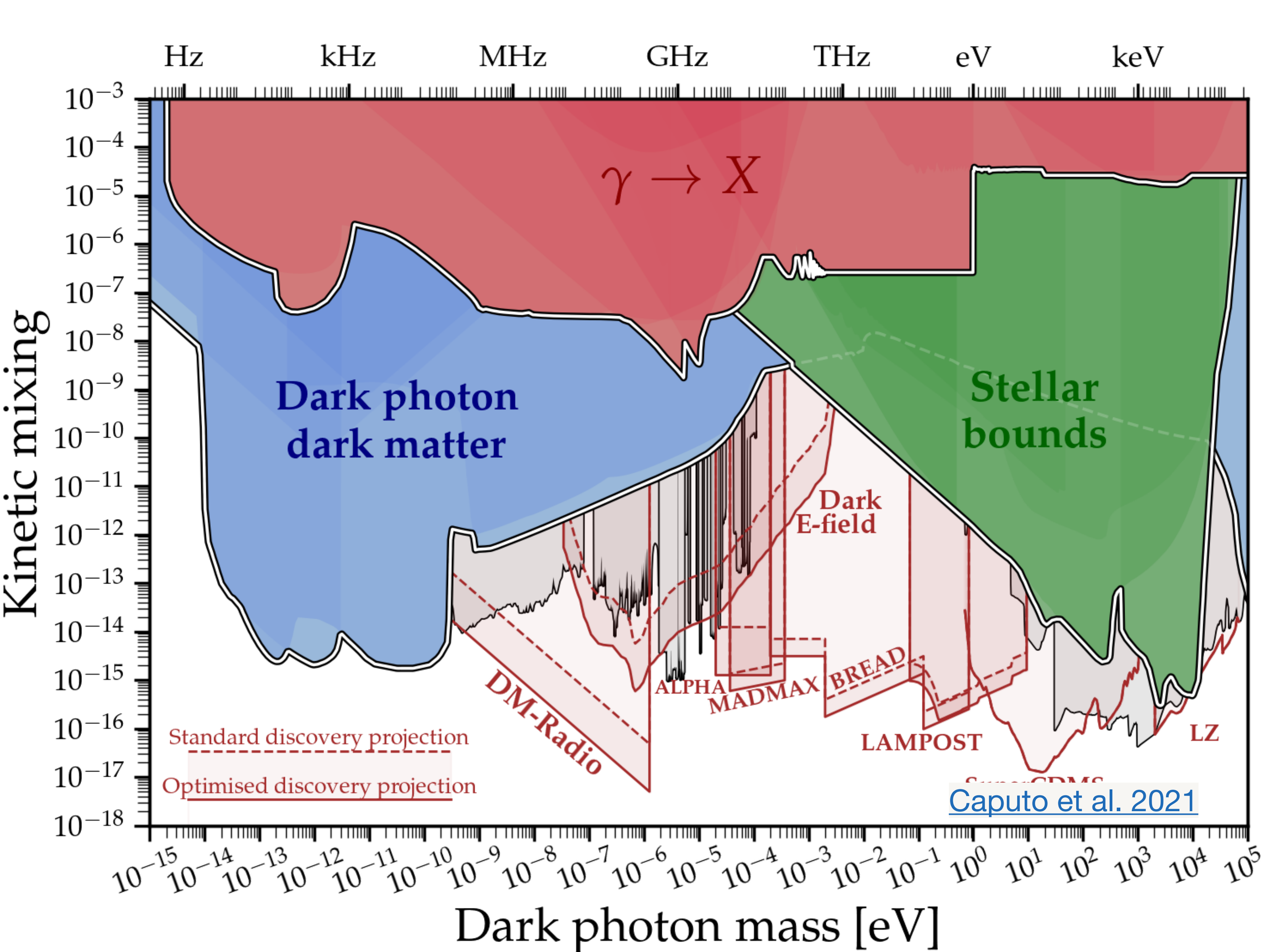
Generic dark photon parameter region

Today's focus



- Laboratory produced dark photon

Generic dark photon parameter region



Today's focus

- Laboratory produced dark photon

Other limits

- Astrophysically produced dark photon
- Cosmologically produced dark photon

Search of dark photon

- **Laboratory**

- Both production and detection are conducted in laboratories.
- Usually **weaker limit**. ALPS-(II), Spring-8 LSW etc
- **Less systematics** and thus **more robust**.

There is also a series of models that can only be probed in laboratories.

[Masso and Redondo, 0504202](#); [Jaeckel et al. 0610203](#); [Brax, 0703243](#); [Chakraborty et al, 2008.10610](#).

-
- Only detection is conducted in laboratories.
 - Usually **stronger limit**.
 - **More systematics** usually exist.
 - **Astrophysics** • **Cosmology**

Search of dark photon

- **Laboratory**

- Both production and detection are conducted in laboratories.

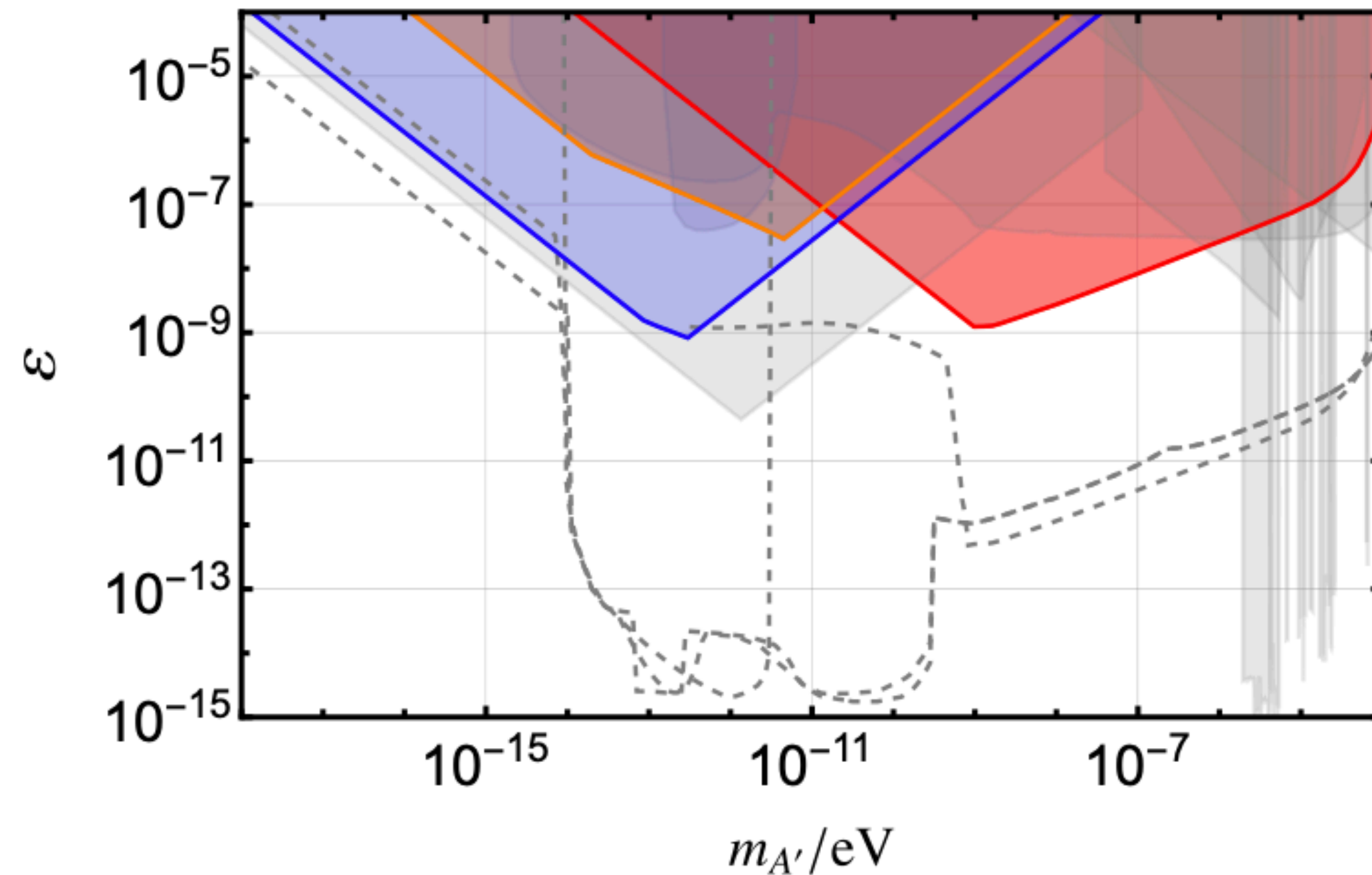
“No cosmological constraints on dark photon dark matter from resonant conversion”: [Hook et al, 2510.13956](#)

Spring-8 LSW etc

are robust.

are probed in laboratories.

[Chakraborty et al, 2008.10610.](#)



laboratories.

- **Cosmology**

Search of dark photon

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“No cosmological constraints on dark photon dark matter from resonant conversion”: [Hook et al, 2510.13956](#)

Spring-8 LSW etc

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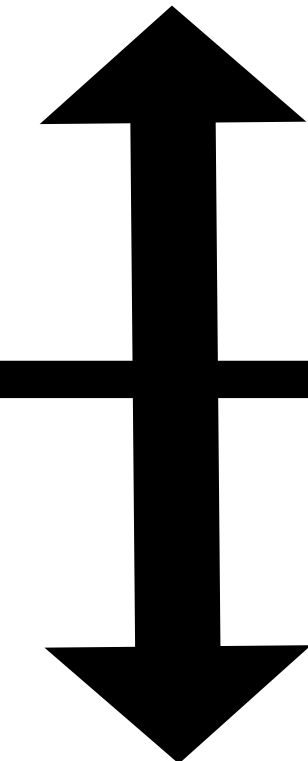
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[Chakraborty et al, 2008.10610.](#)

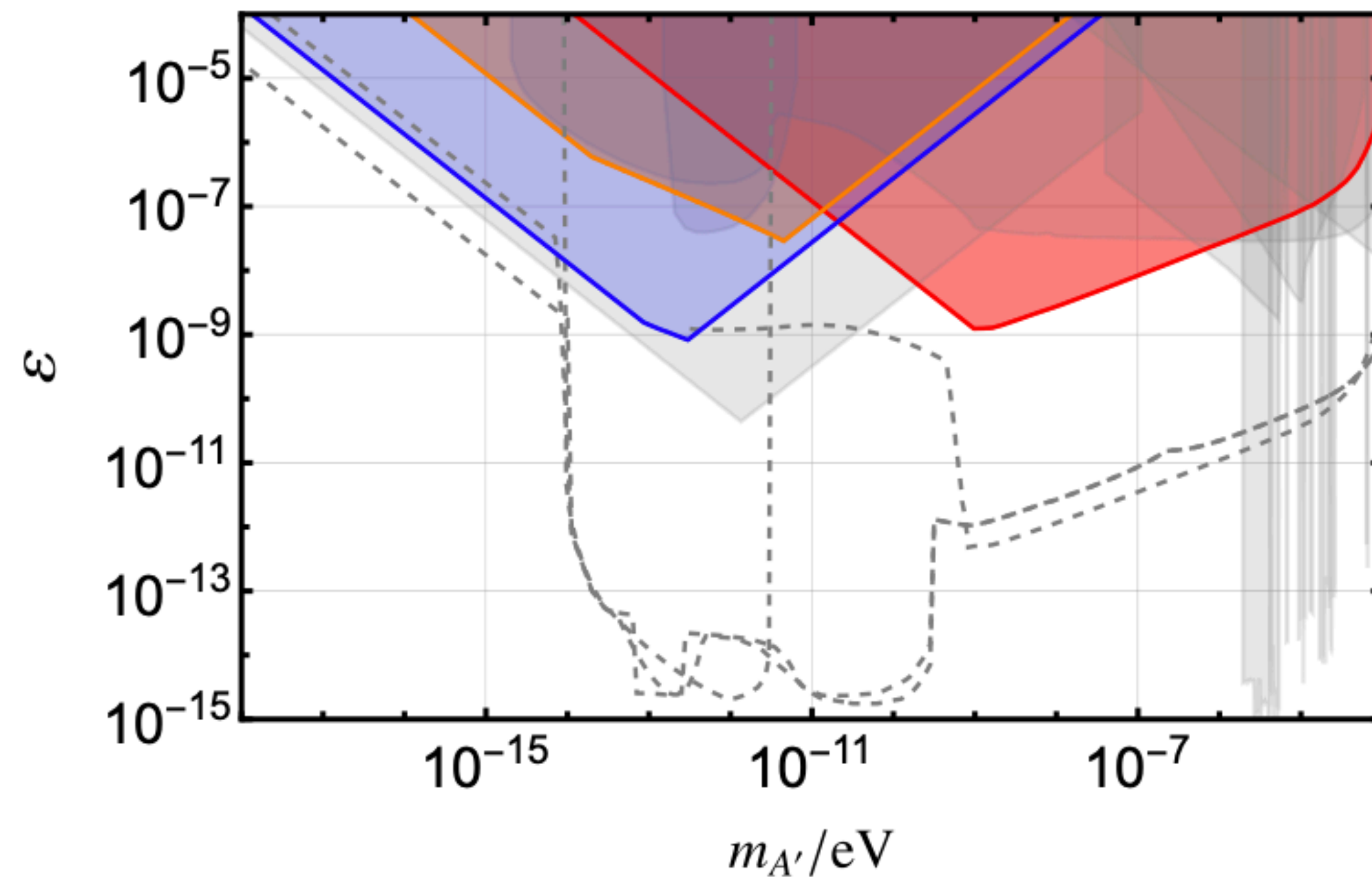
laboratories.

- **Cosmology**

Robustness



Sensitivity

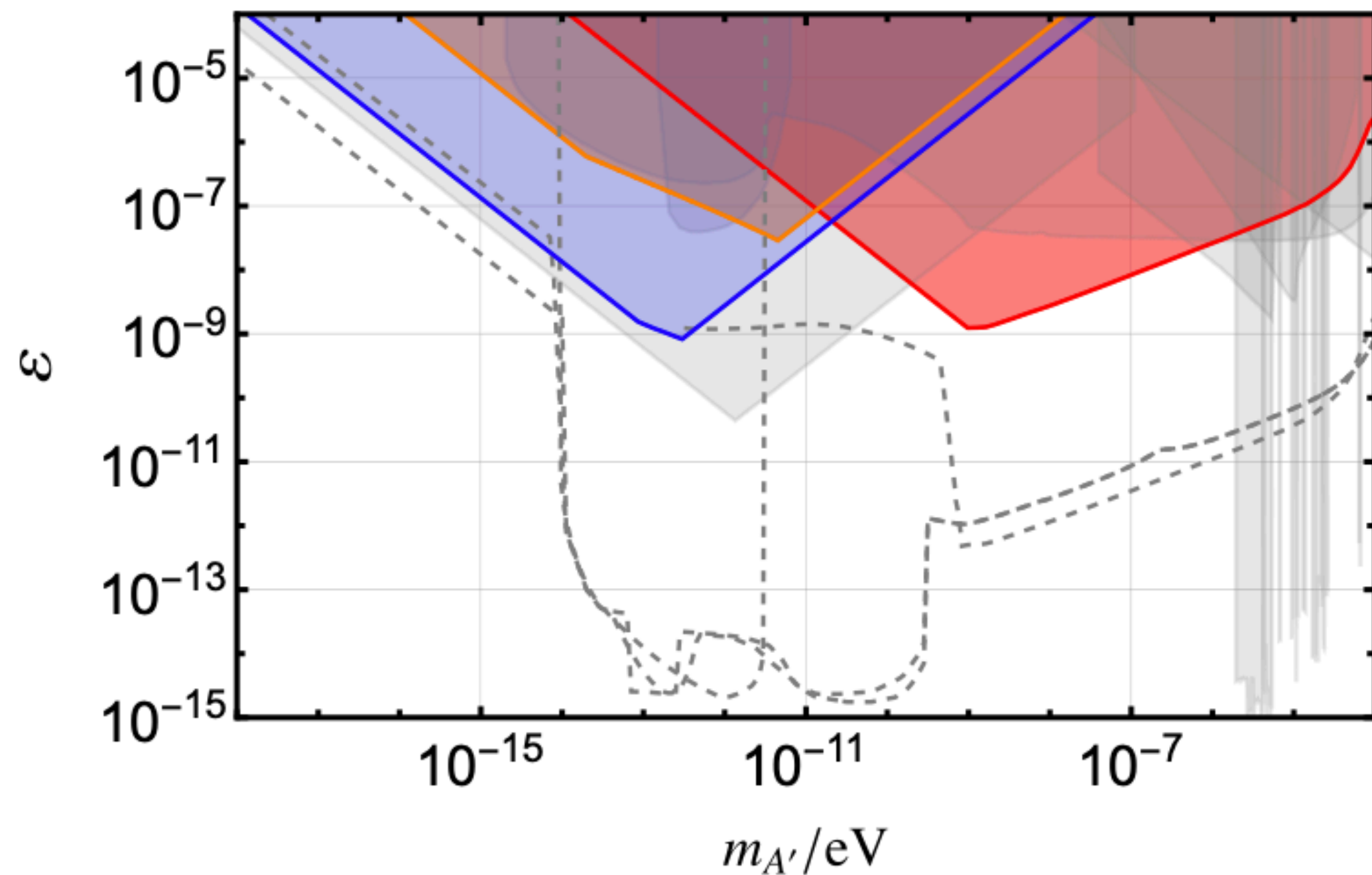


Search of dark photon

- **Laboratory**

- Both production and detection are conducted in laboratories.

“No cosmological constraints on dark photon dark matter from resonant conversion”: Hook et al, 2510.13956



Spring-8 LSW etc

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are probed in laboratories.

Chakraborty et al, 2008.10610.

laboratories.

- **Cosmology**

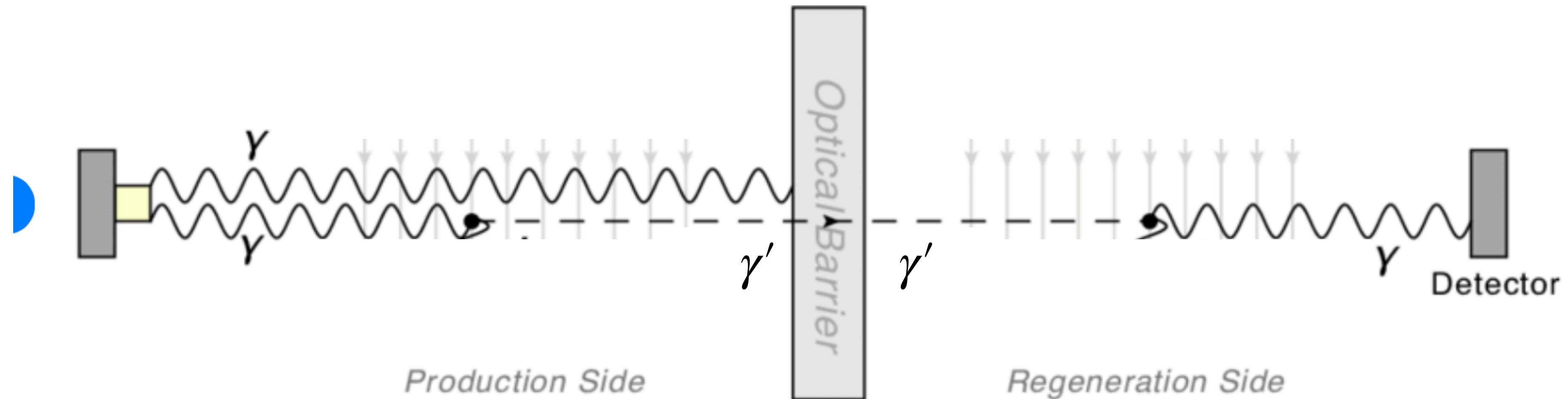
Robustness

Today's talk

Sensitivity

Light-Shining-Through-a-Wall (LSW) experiment

Sikivie, 1983; Anselm, 1985; VanBibber, 1987;



[Battesti et al](#) *Physics Reports* 765-766(15)

Light source

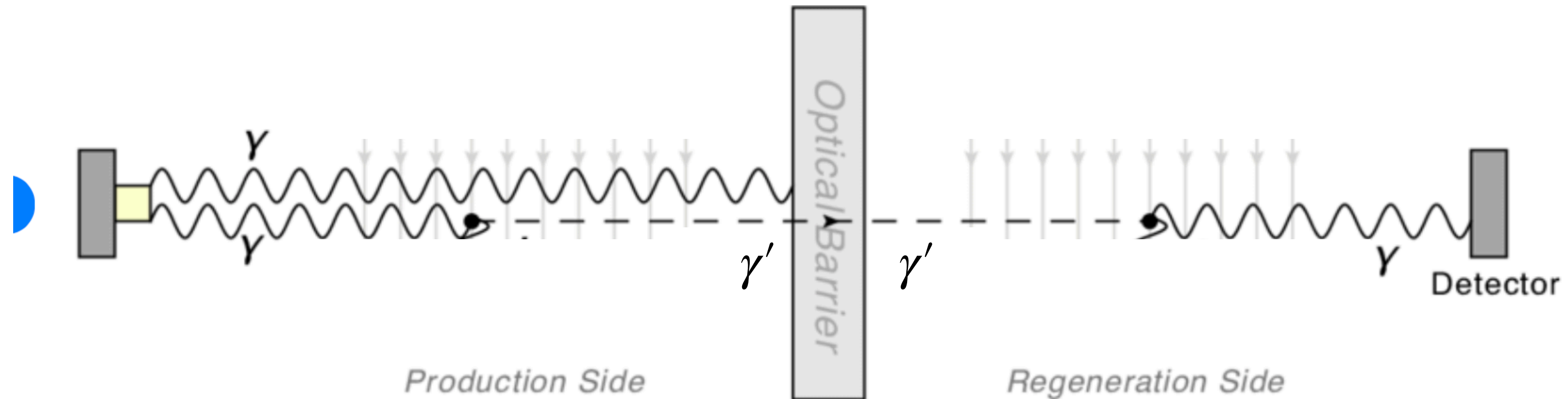
Wall

Detector

Light-Shining-Through-a-Wall (LSW) experiment

Sikivie, 1983; Anselm, 1985; VanBibber, 1987;

Photon-dark-photon oscillation:
$$P_{\gamma-\gamma'} = 16\chi^4 \left(\sin\left(\frac{\Delta k L_1}{2}\right) \sin\left(\frac{\Delta k L_2}{2}\right) \right)^2$$



[Battesti et al](#) *Physics Reports* 765-766(15)

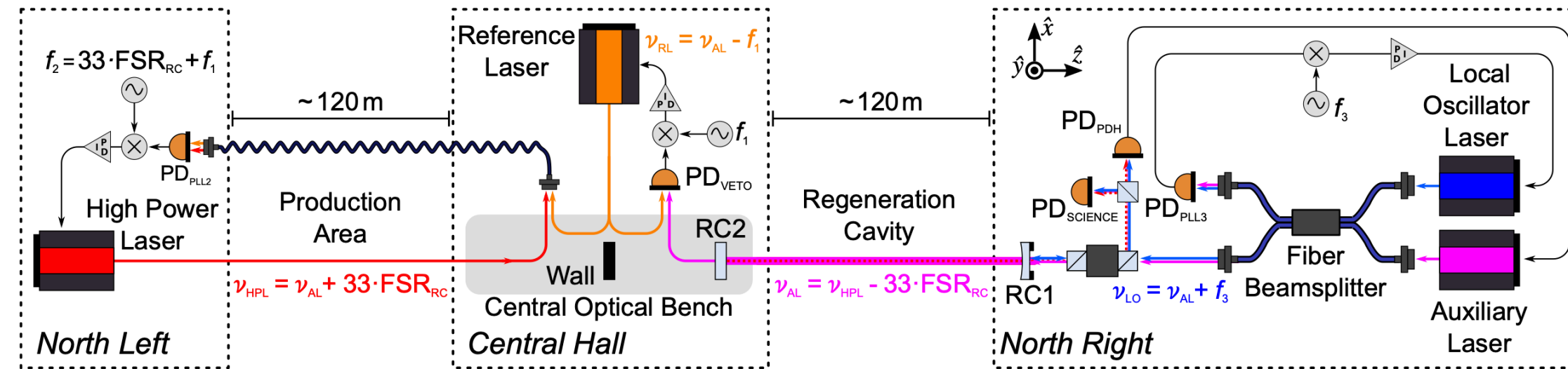
Light source

Wall

Detector

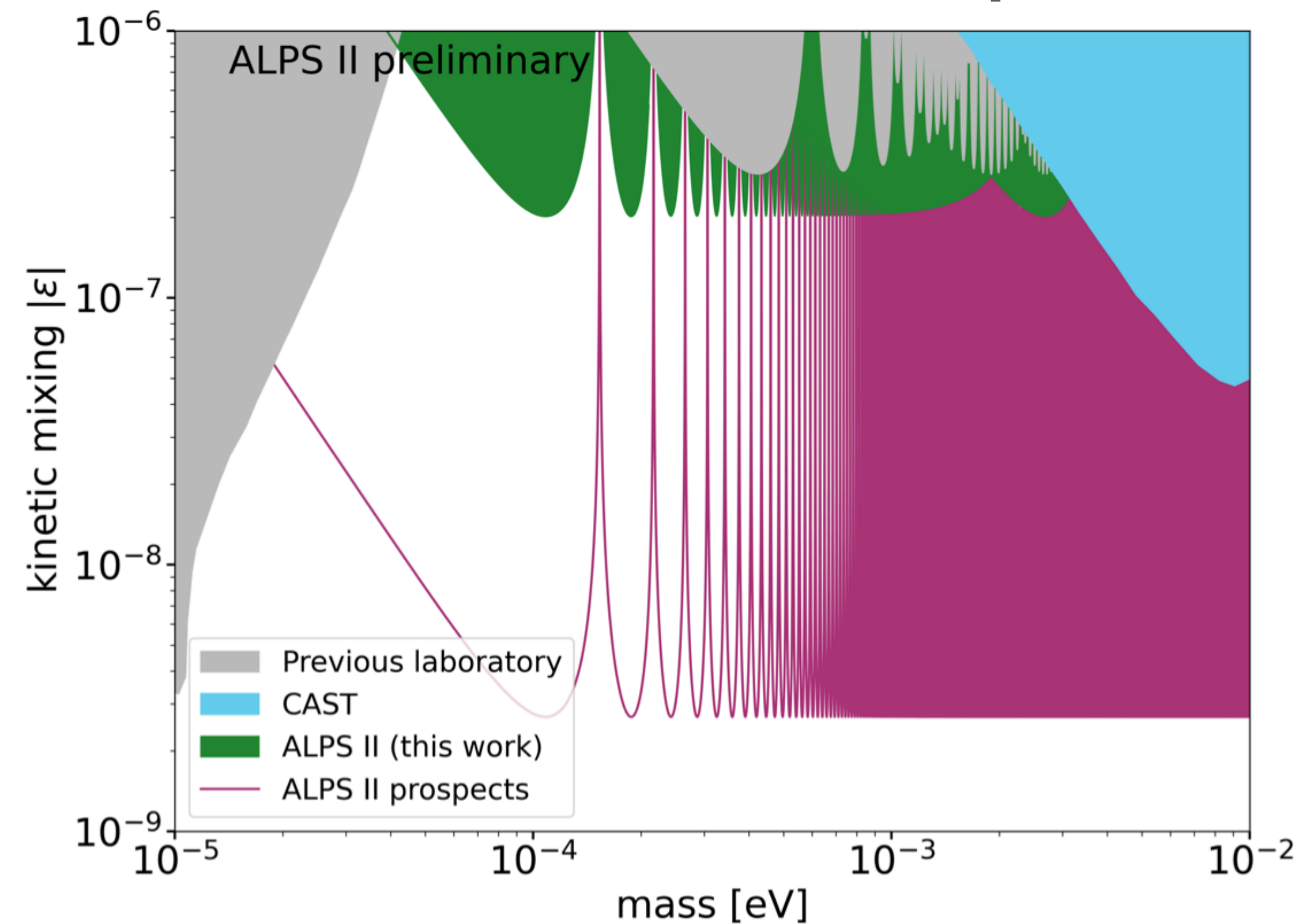
World record for laboratory wisps in the (sub-)eV region (3month's run). Light source= near-infrared Laser (eV)

4



2512.14110, ALPS II collaboration

Dark photon



LSW experiment in Japan in SPring-8

Light source= undulator (keV)

Inada et al 1301.6557

Side view

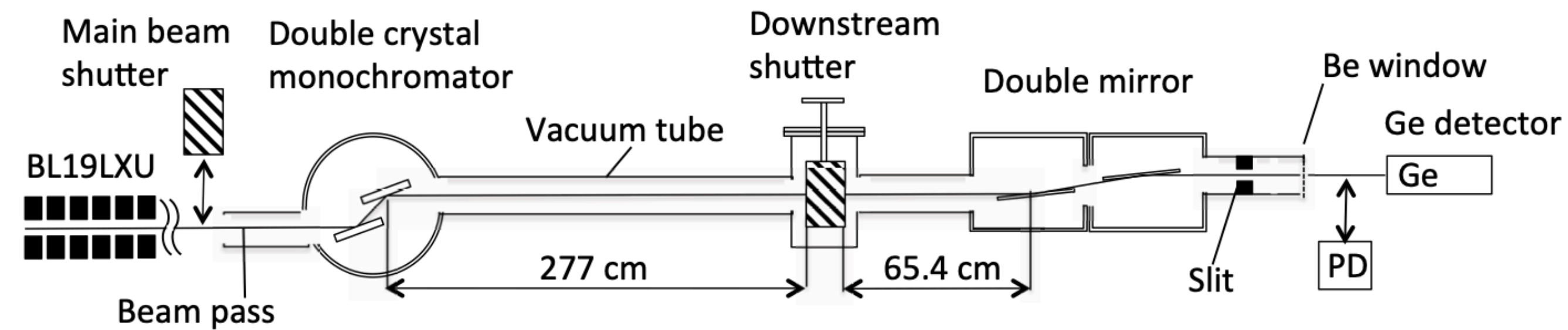
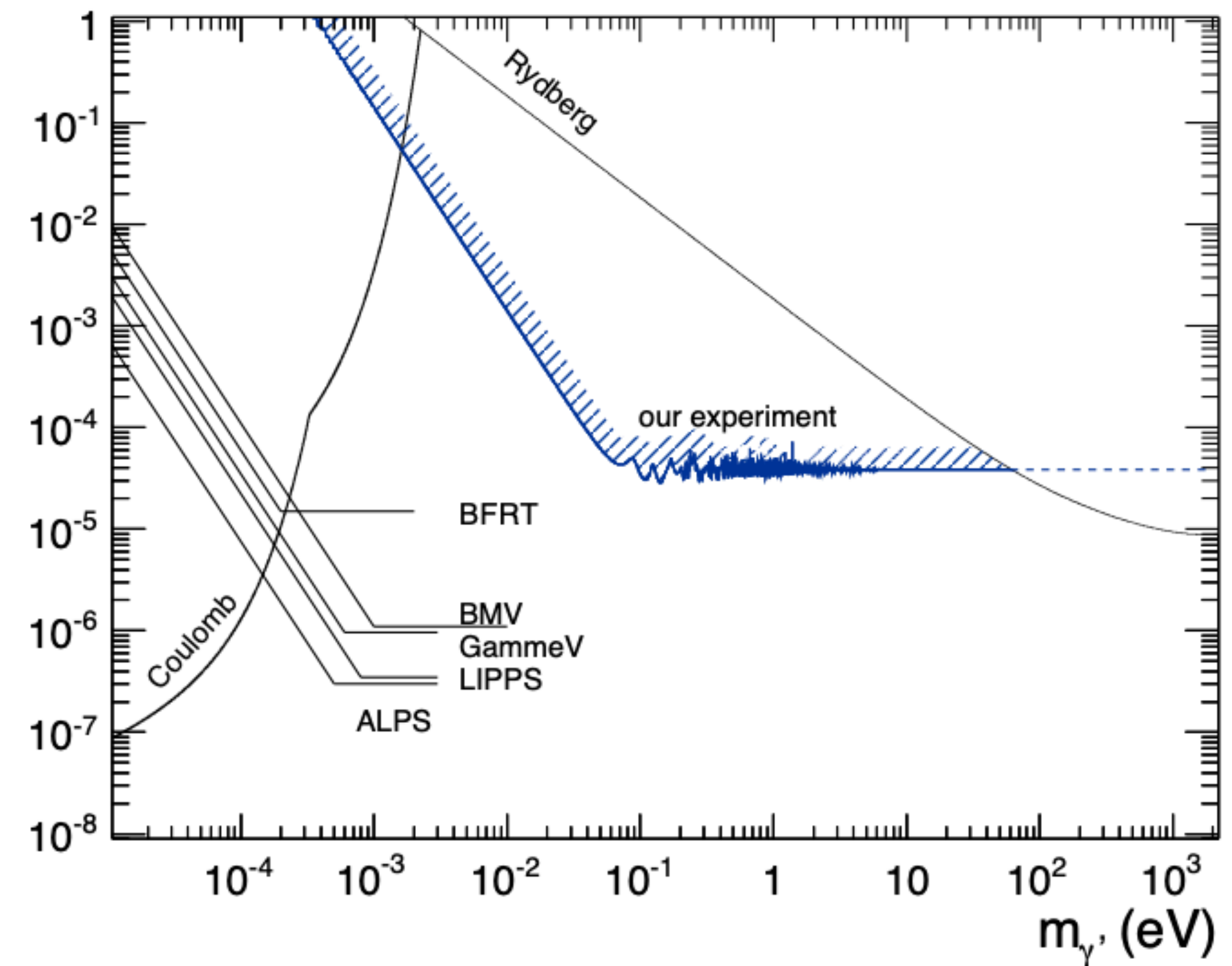


Figure 1: Schematic view of our experimental setup.



Laboratory world records over 10 years in eV mass range.

2. Proposal of a parasitic search of dark photon (and other wisps)

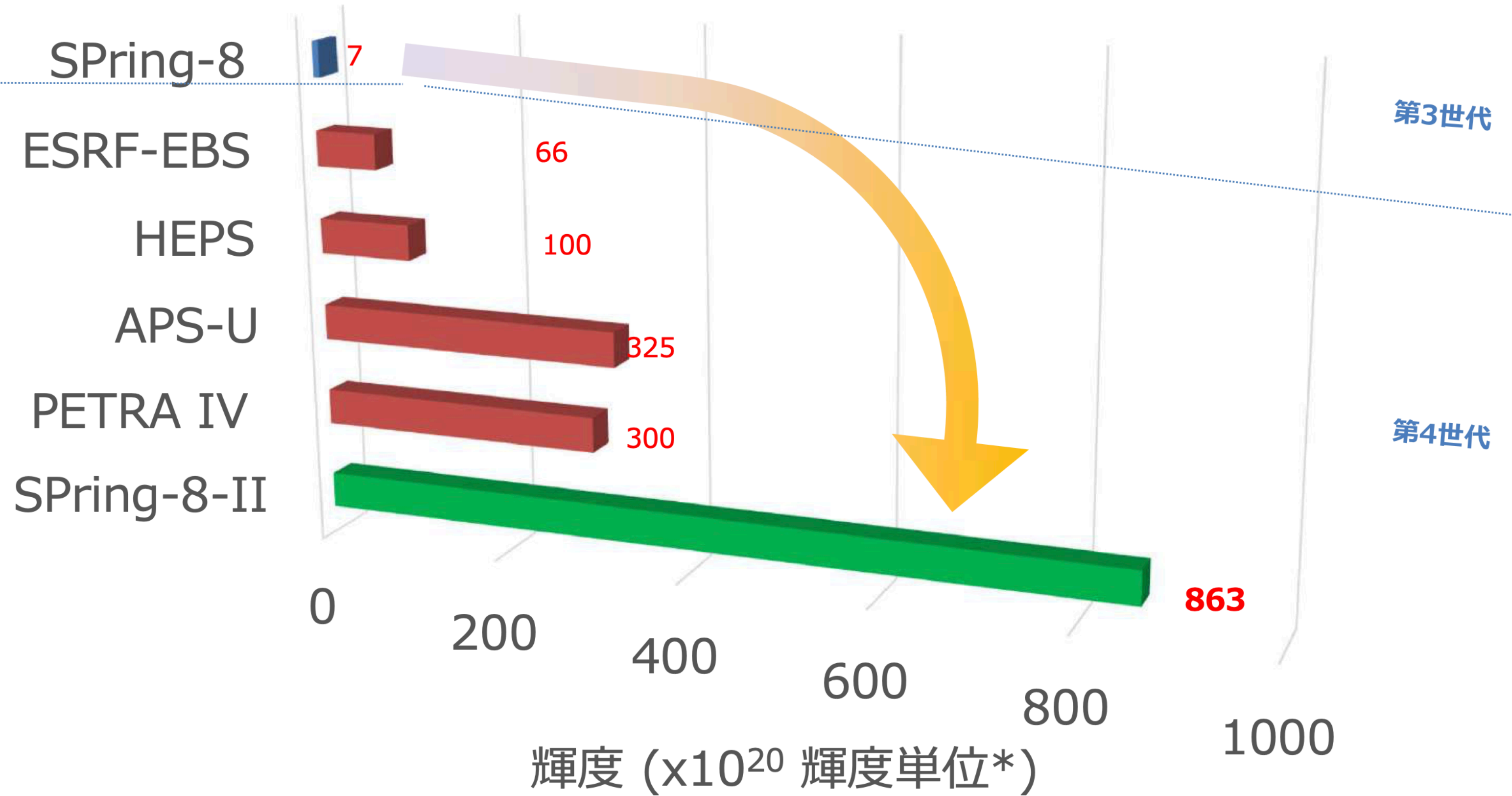
WY, Yoshida, 2408.17451; Yoshida, WY, preliminary

Japan has excellent synchrotron radiation facilities for condensed matter, chemistry, materials science, and structural biology, but they have scarcely been used for particle physics.



SPring-8-II (2029-) <https://spring8.jp/mission/symposium/>

最高輝度の比較

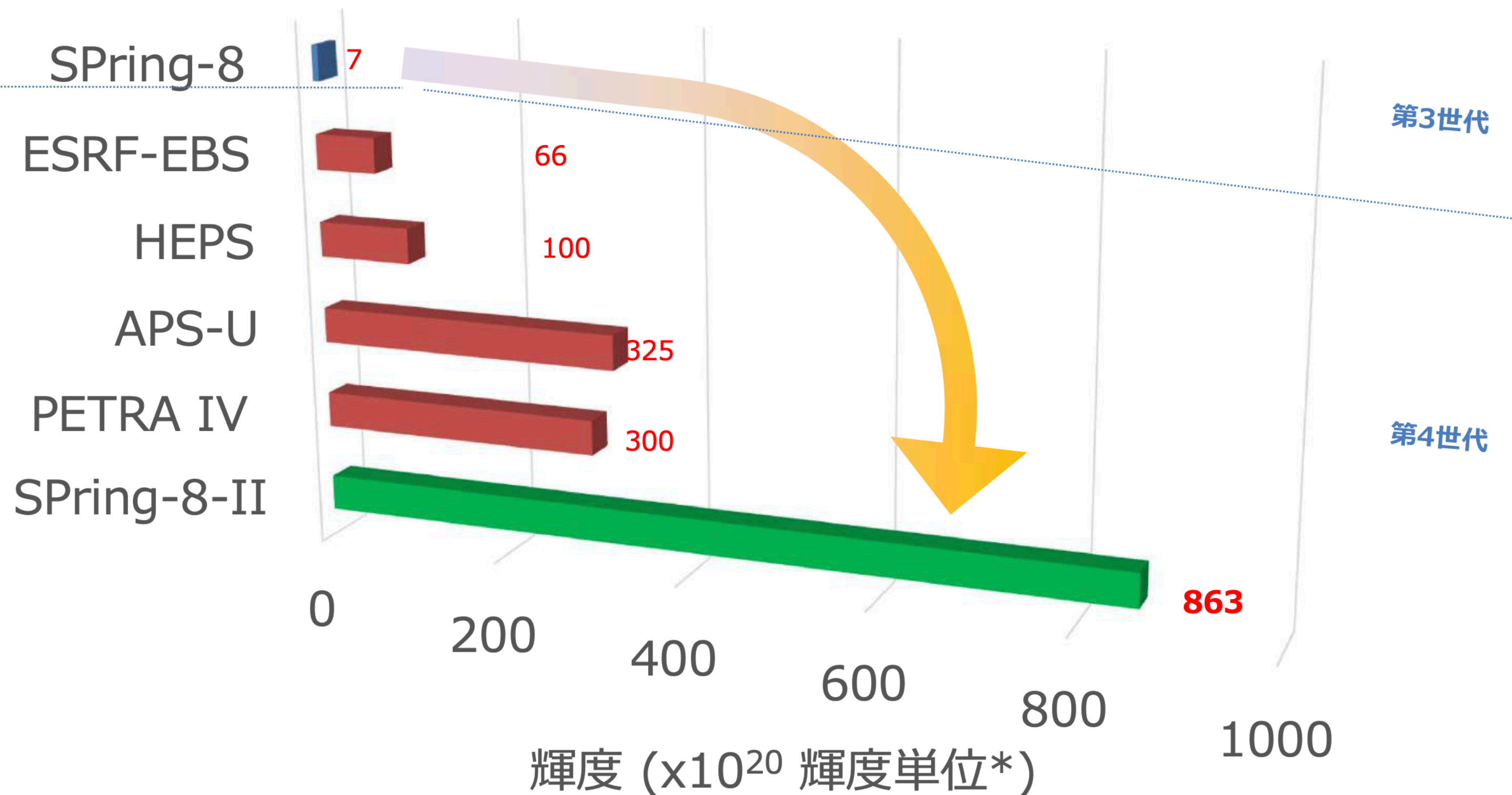


radiation
mistry,
ology, but they
e physics.



SPring-8-II (2029-) <https://spring8.jp/mission/symposium/>

最高輝度の比較

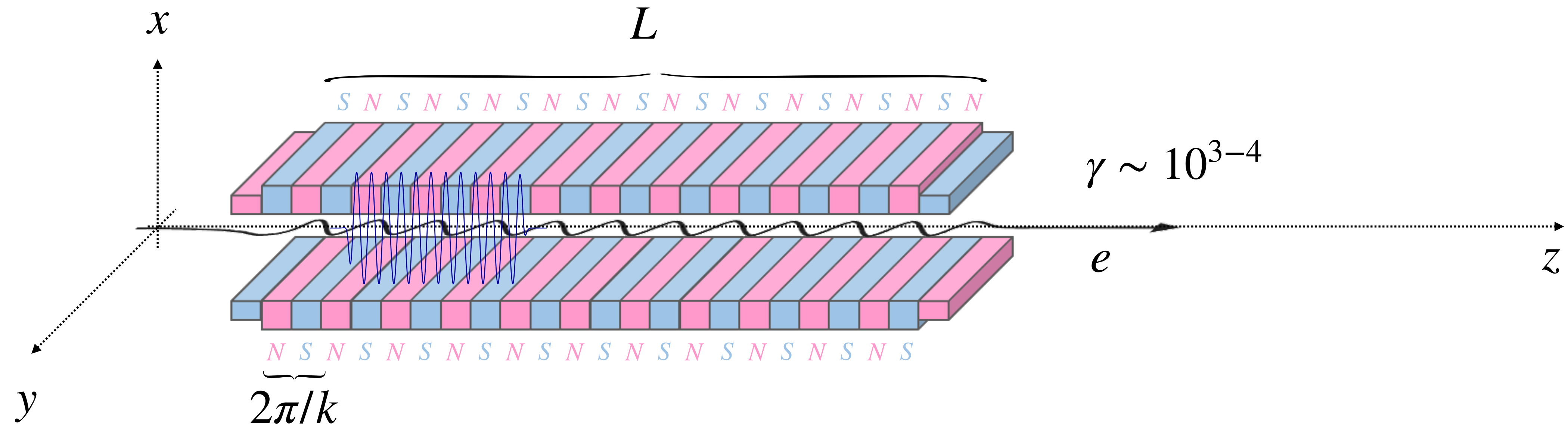


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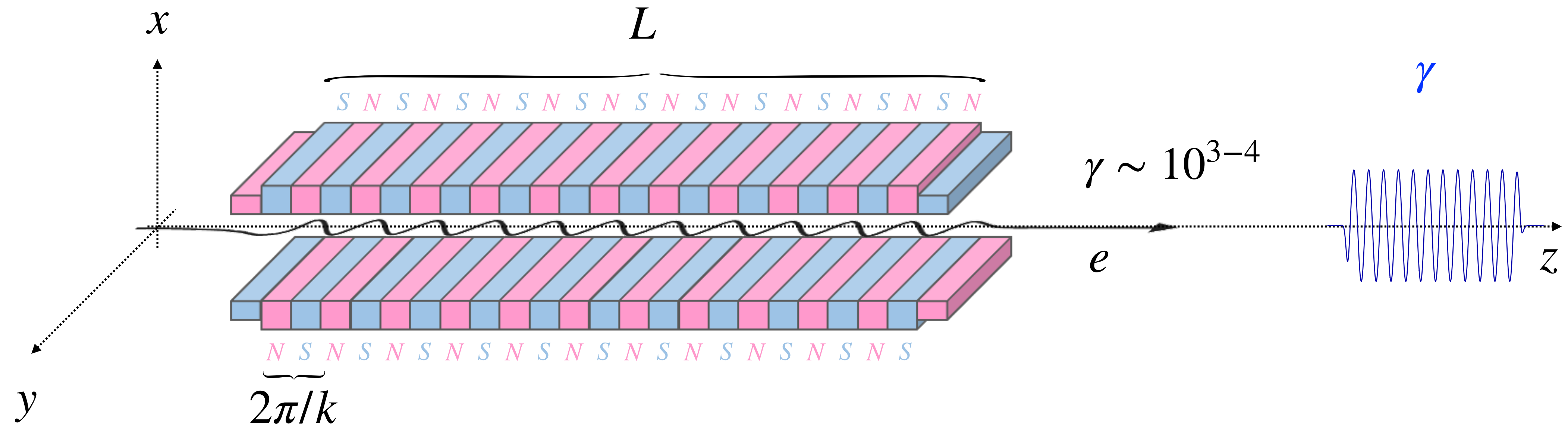
Light sources
= undulators (or wiggler)

What is undulator?



- Intense and concentrated photons in narrow lines.
- Controllable photon energy and polarization.
- Used in synchrotron radiation facilities, free-electron laser, and in the design of ILC, etc

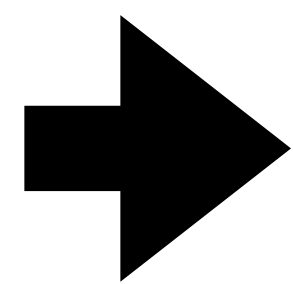
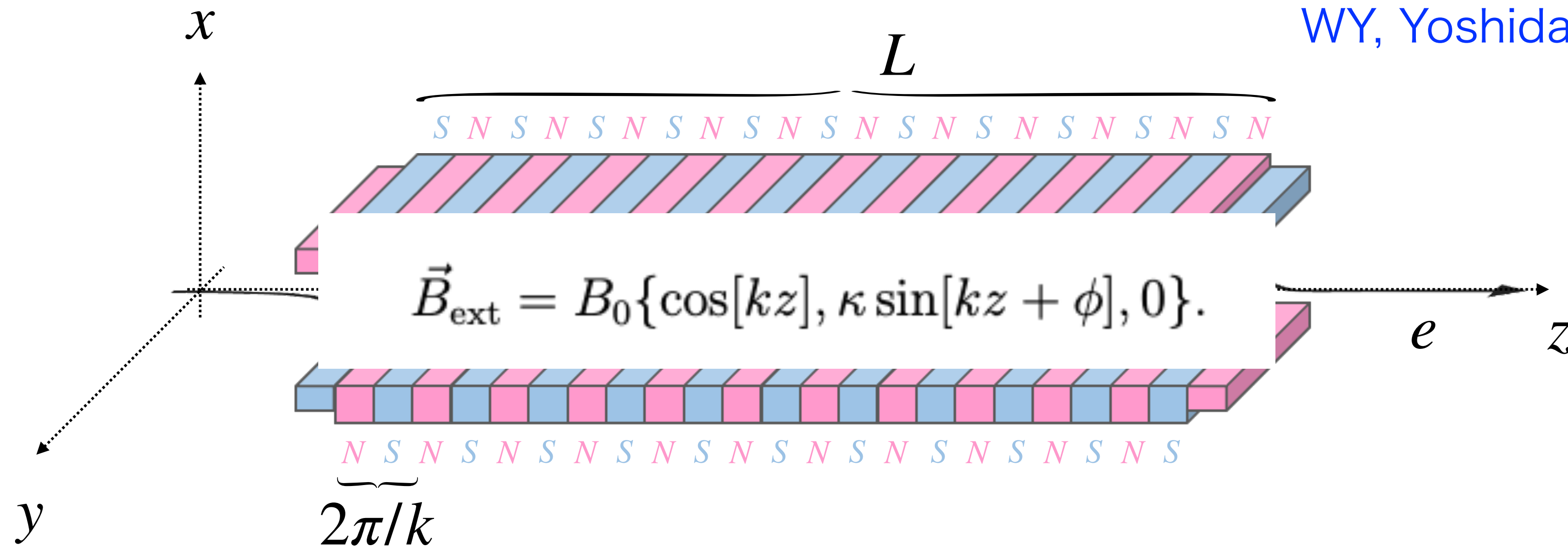
What is undulator?



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Modeling the undulator and electron motion

WY, Yoshida, 2408.17451;



$$\vec{\beta} \simeq \left(-\frac{K\kappa}{\gamma} \cos[k\beta^z t_e + \phi], -\frac{K}{\gamma} \sin[k\beta^z t_e], \beta^z \right), \quad \beta^z \simeq \sqrt{1 - \gamma^{-2} \left(1 + \frac{1}{2}(1 + \kappa^2) K^2 \right)},$$

$$K \equiv \frac{B_0 e}{k m_e}.$$

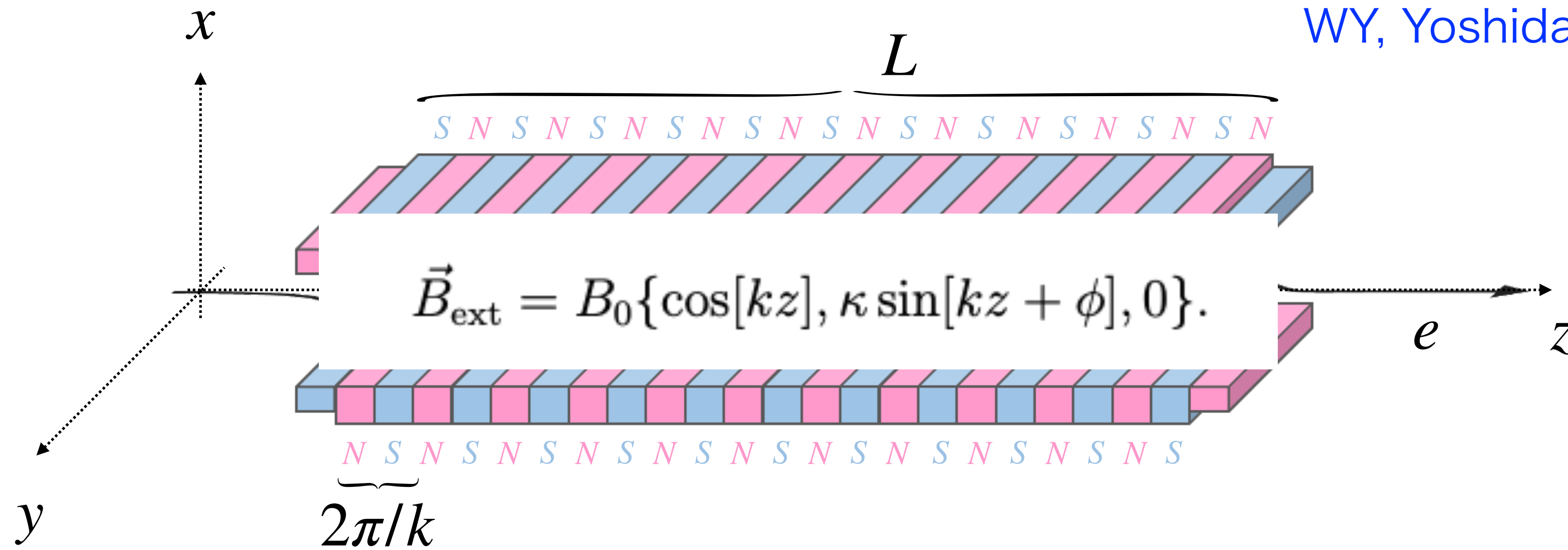
With $K \lesssim 1$, it is called undulator. ($K \gg 1$ is called Wiggler.)

$\kappa = 1, \phi = 0$ Helical undulator

$\kappa = 0$ Linear undulator(Fig)

Modeling the undulator and electron motion

WY, Yoshida, 2408.17451;



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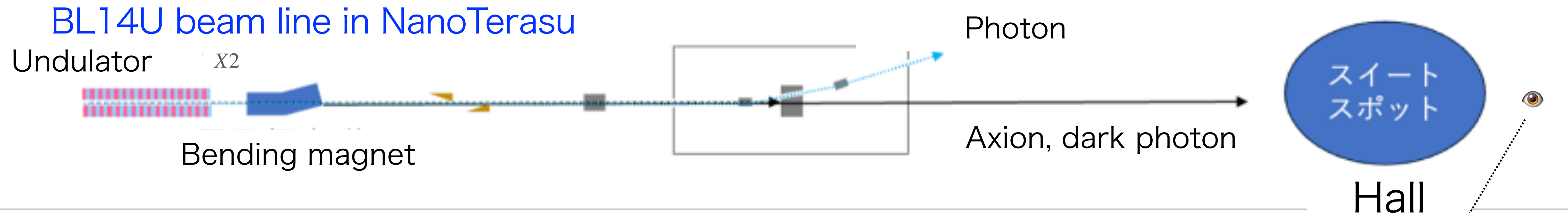
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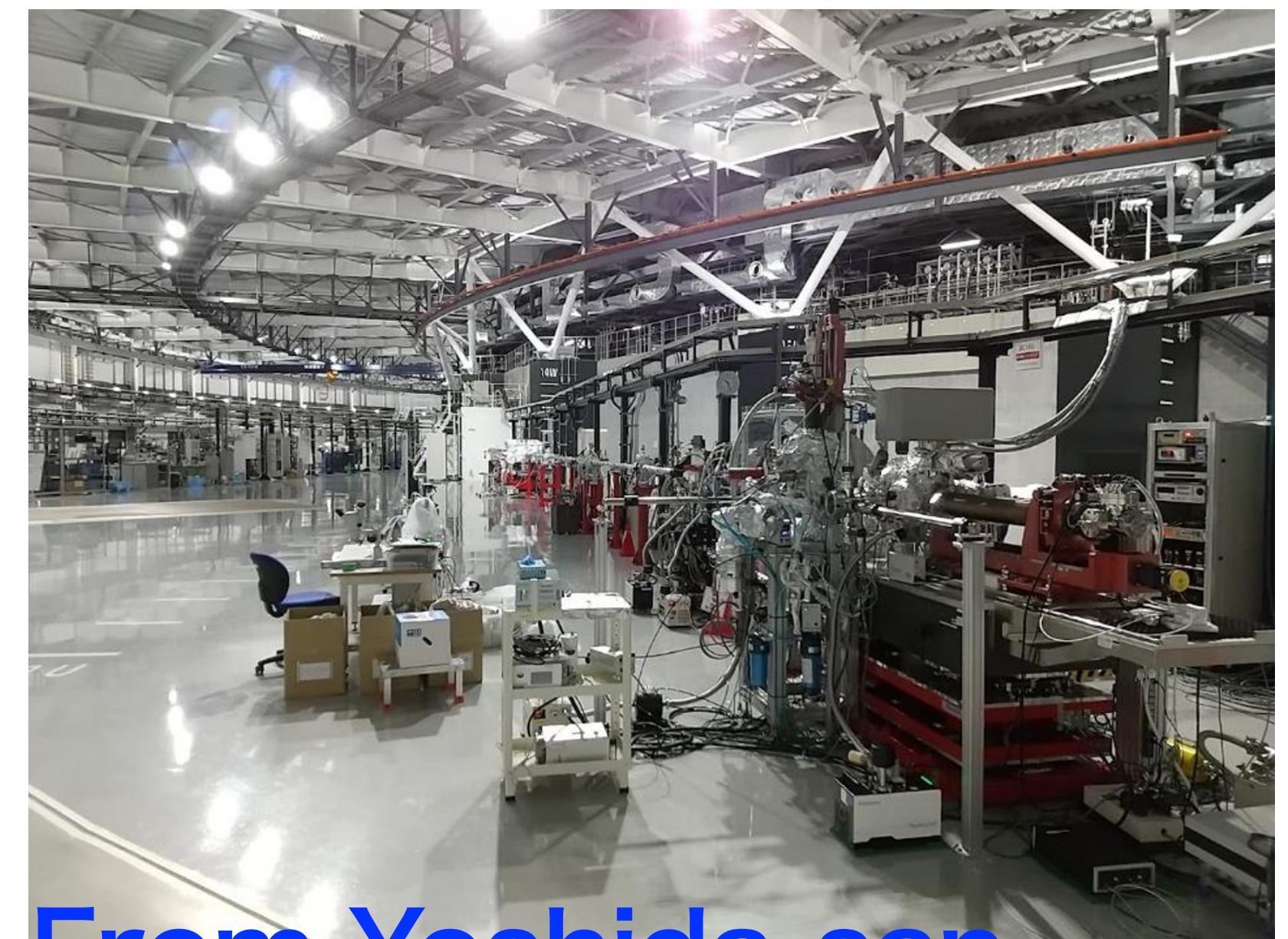
$\kappa = 0$ Linear undulator(Fig)

Our proposals in case of NanoTerasu,

WY, Yoshida, 2408.17451; Yoshida, WY, preliminary



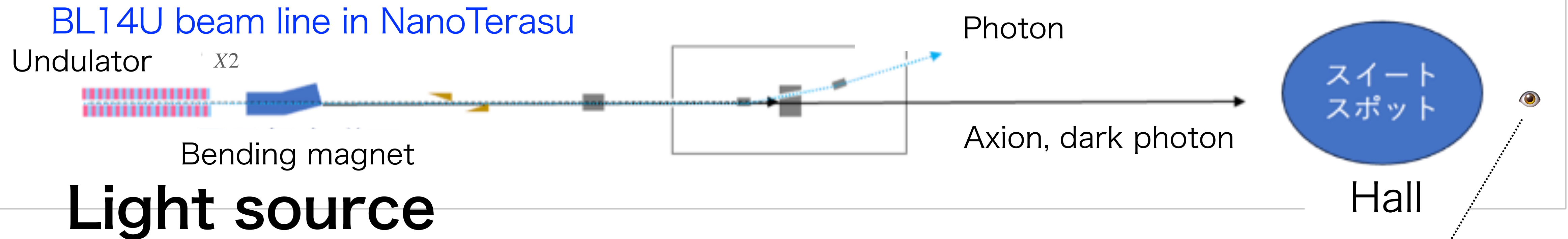
- Dark photon is automatically generated.
- Beam spread $\Delta\theta \sim 1/\gamma \sim 1/10^4$.
- Distance to sweet spot $O(10m)$
- Detector with scale $\gg 10m \times 1/10000 \sim 1mm$ will cover the interesting directions.



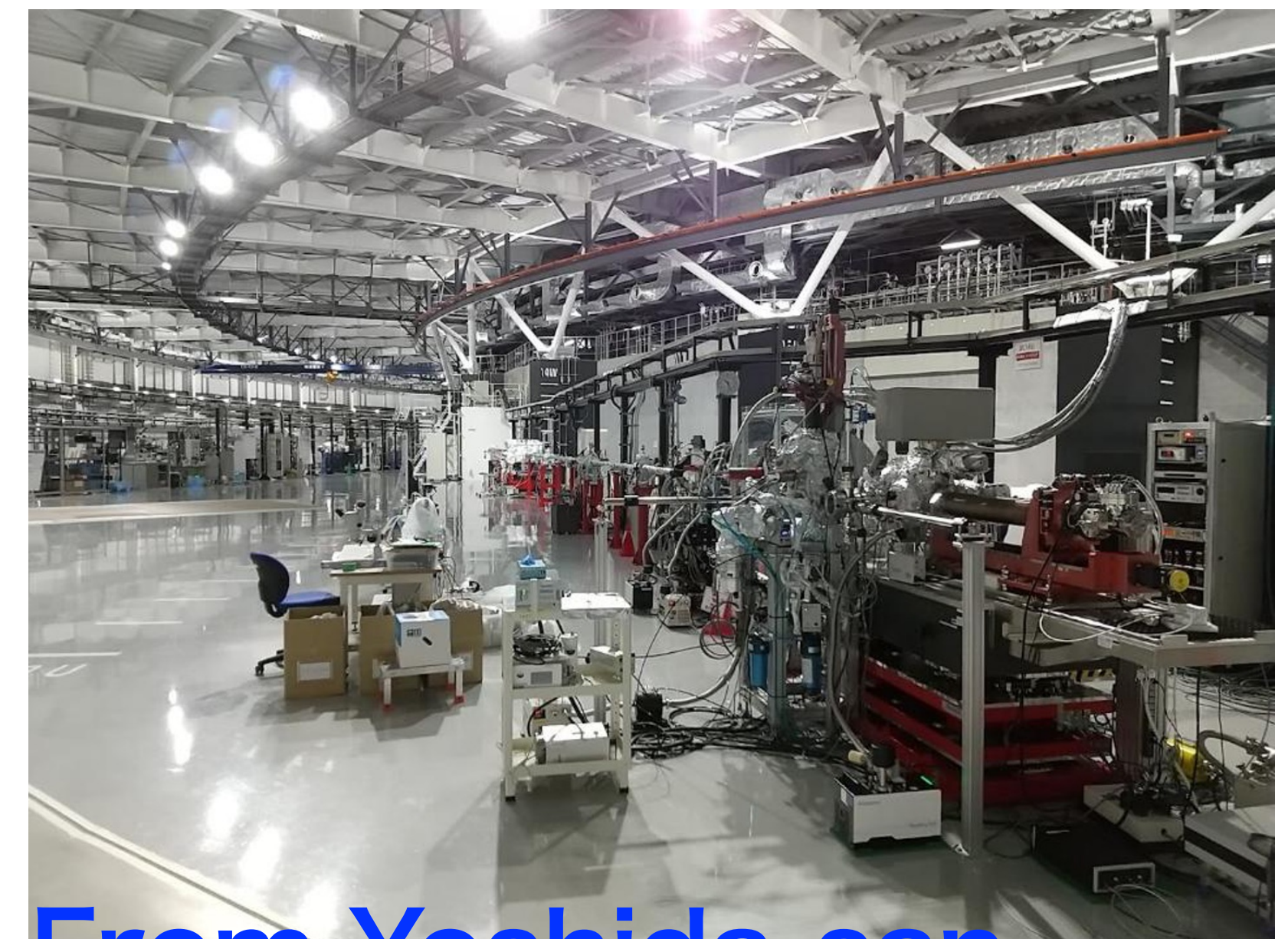
From Yoshida-san

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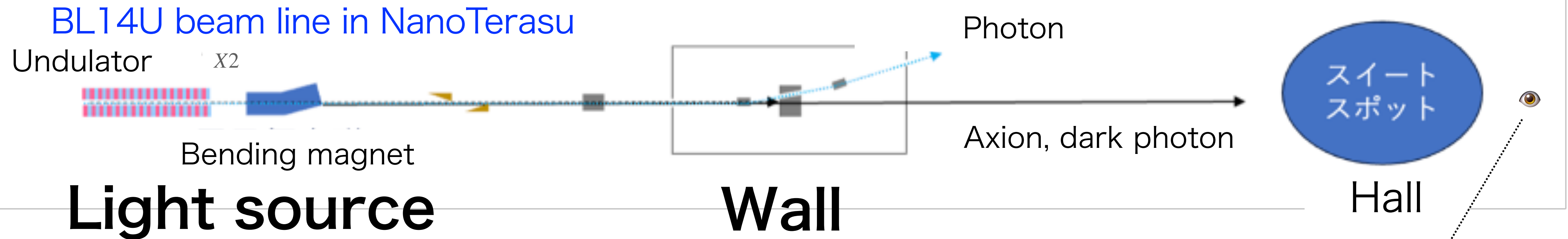
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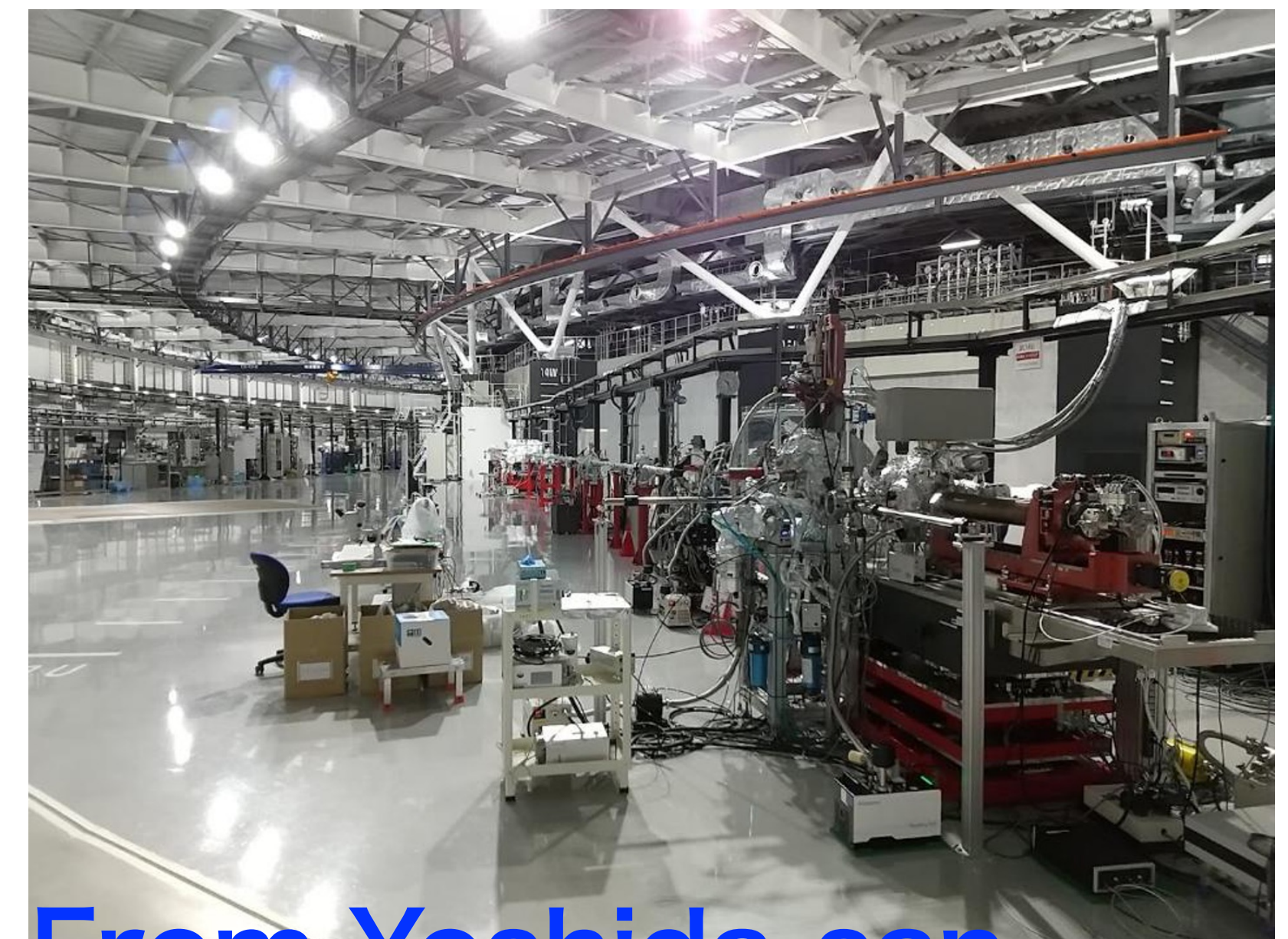
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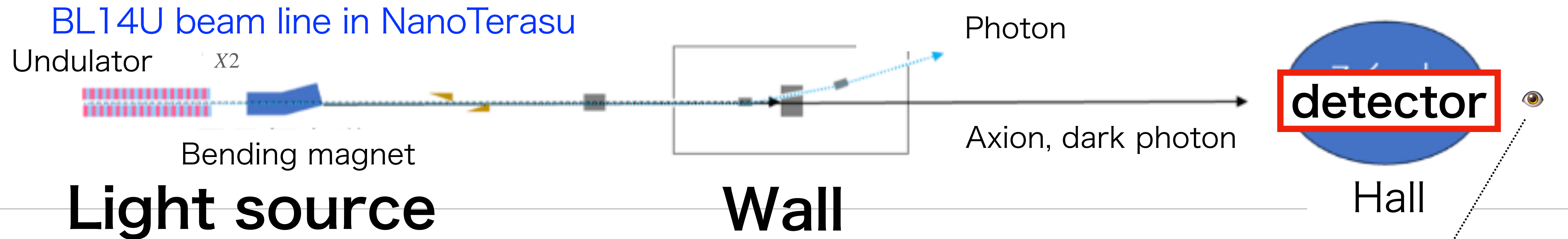


From Yoshida-san

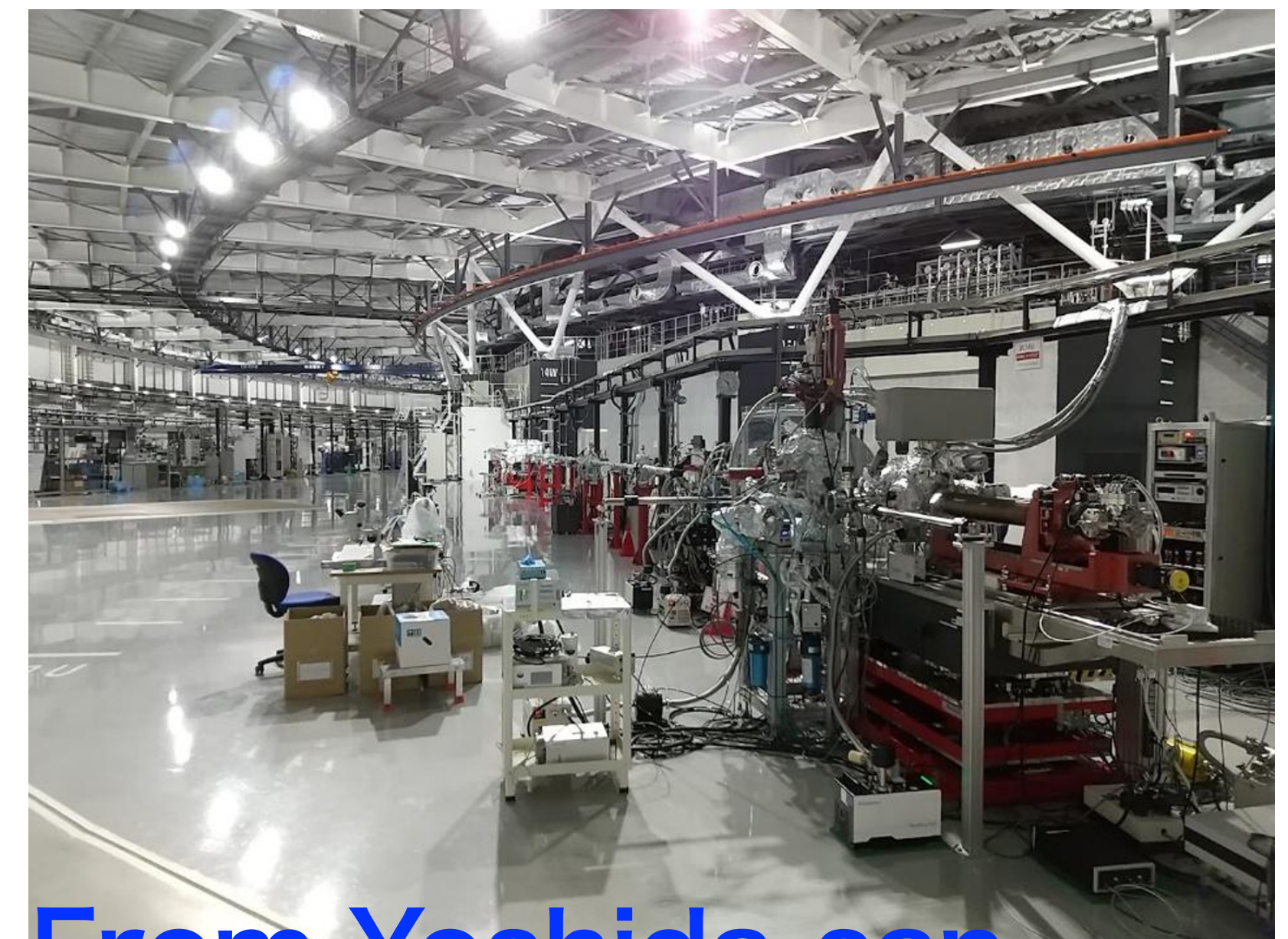
Our proposals in case of NanoTerasu,

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Put a detector and wait!



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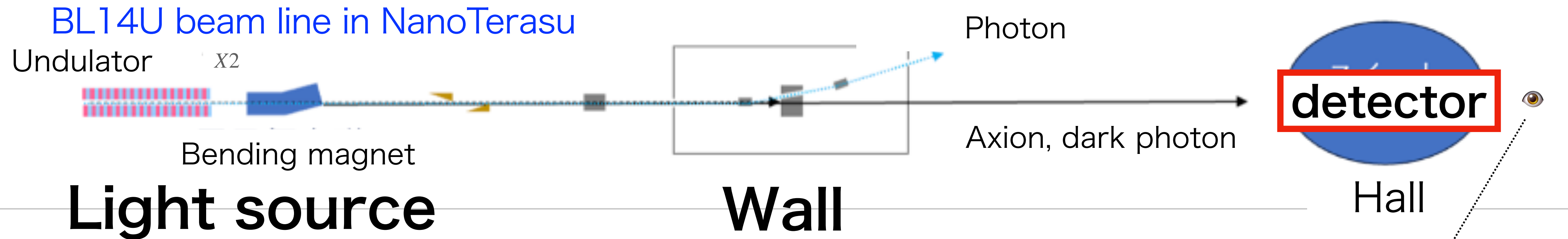


From Yoshida-san

Our proposals in case of NanoTerasu,

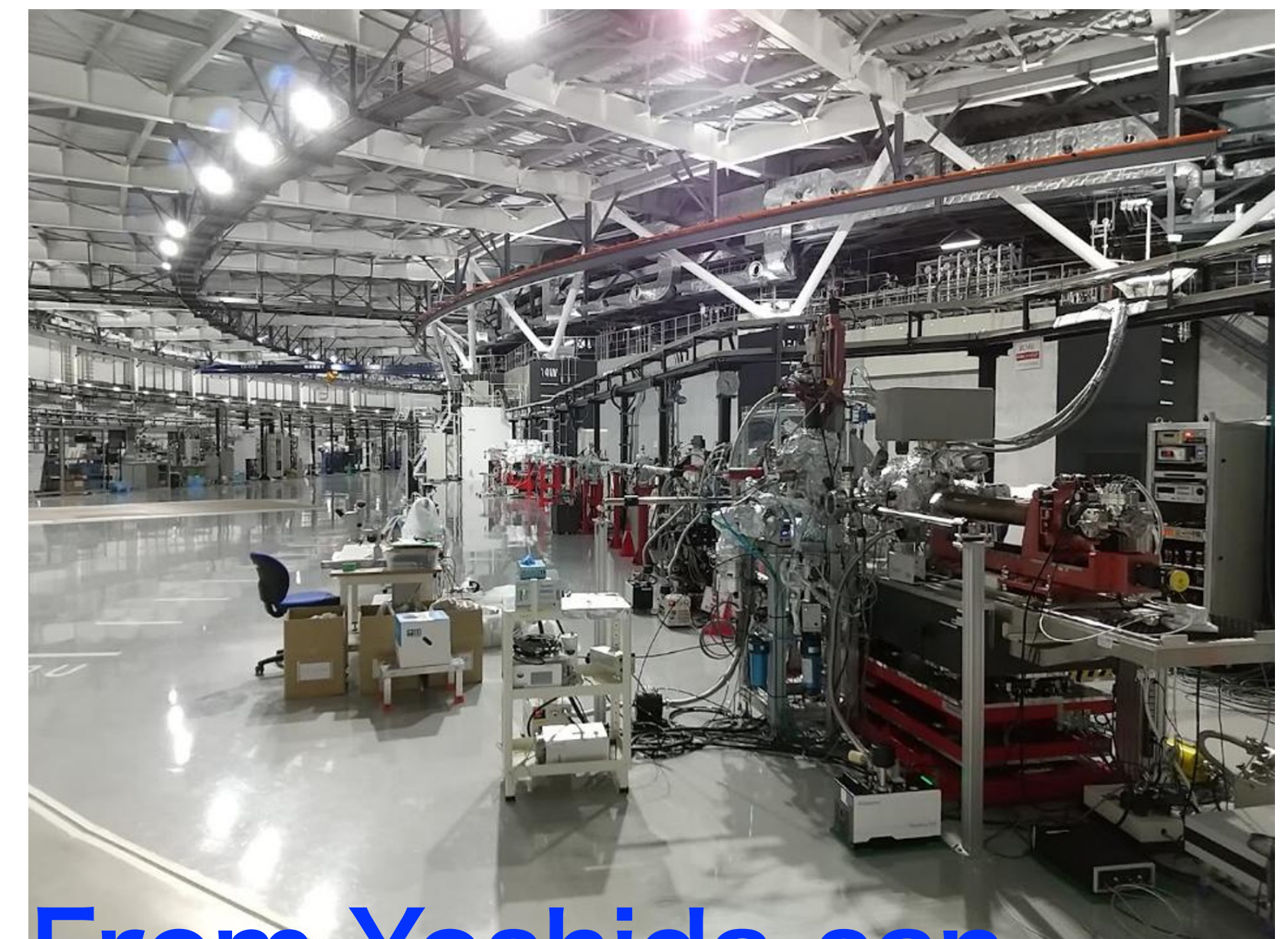
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Put a detector and wait!



- Dark photon is automatically generated.
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- Detector with scale $\gg 10m \times 1/10000 \sim 1mm$ will cover the interesting directions.

Next topic



From Yoshida-san

Advantages of the parasitic experiment compared to usual LSW experiments

- Long experimental time (yrs)&large space without occupying the beam-lines.
- Many more photons.
Case of BL43LXU of SPring-8 :

$$n_{\gamma}^{\text{undulator}} > 10^4 n_{\gamma}^{\text{used in exps.}}$$

3. Quantum and matter effects of dark photons

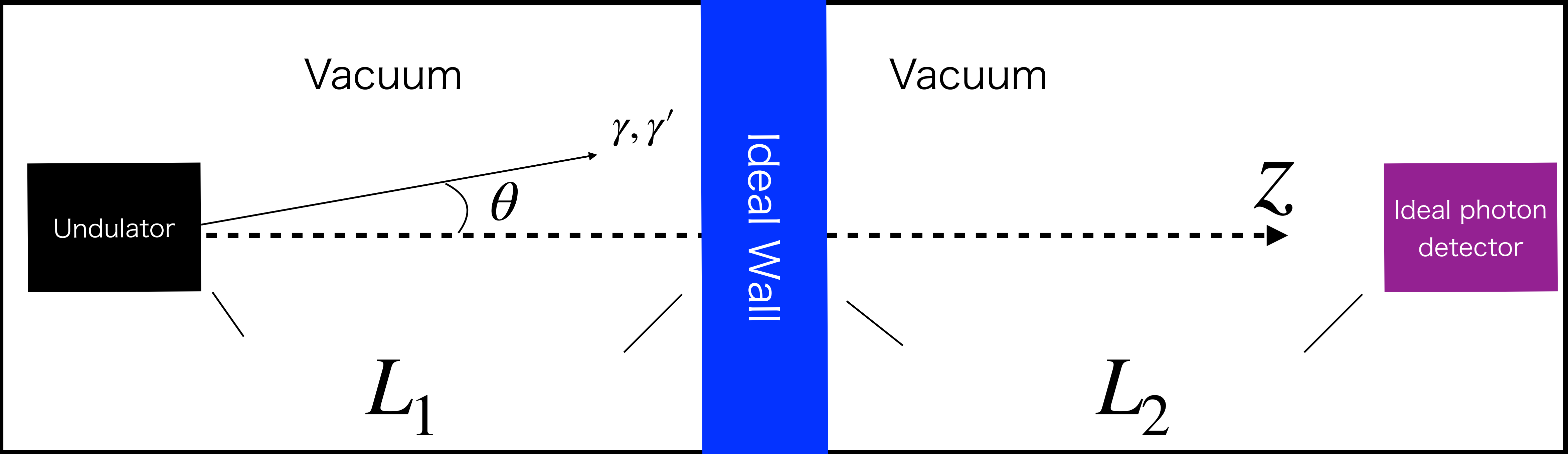
[WY,2507.22055,](#)

—Oscillation formula, $P_{\gamma-\gamma} = 16\chi^4 \left(\sin \left(\frac{\Delta k L_1}{2} \right) \sin \left(\frac{\Delta k L_2}{2} \right) \right)^2$,

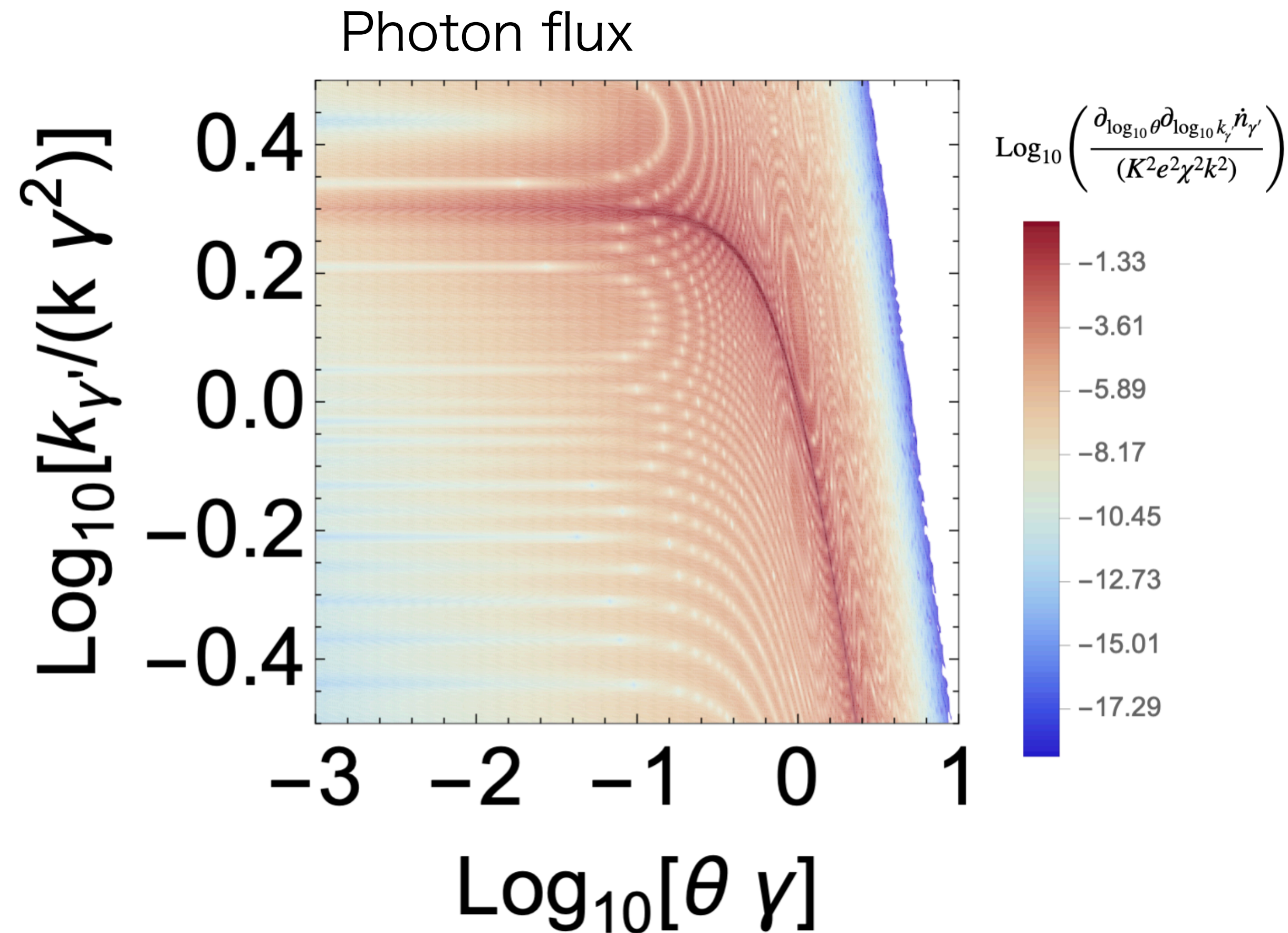
is not a very good approximation —

- Wave packet (not completely narrow line)
- Undulator structure
- Matter effect during propagation

Assume undulator similar to BL14U beam-line in NanoTerasu, $E_\gamma \simeq keV$



Following QFT approach, photon wave packet from undulator is obtained as [WY, Yoshida, 2408.17451](#); [WY, 2507.22055](#),



$$\Delta E_\gamma \sim \mathcal{O}(0.1) E_\gamma$$

and E_γ changes

with $\theta \gtrsim 1/\gamma$.

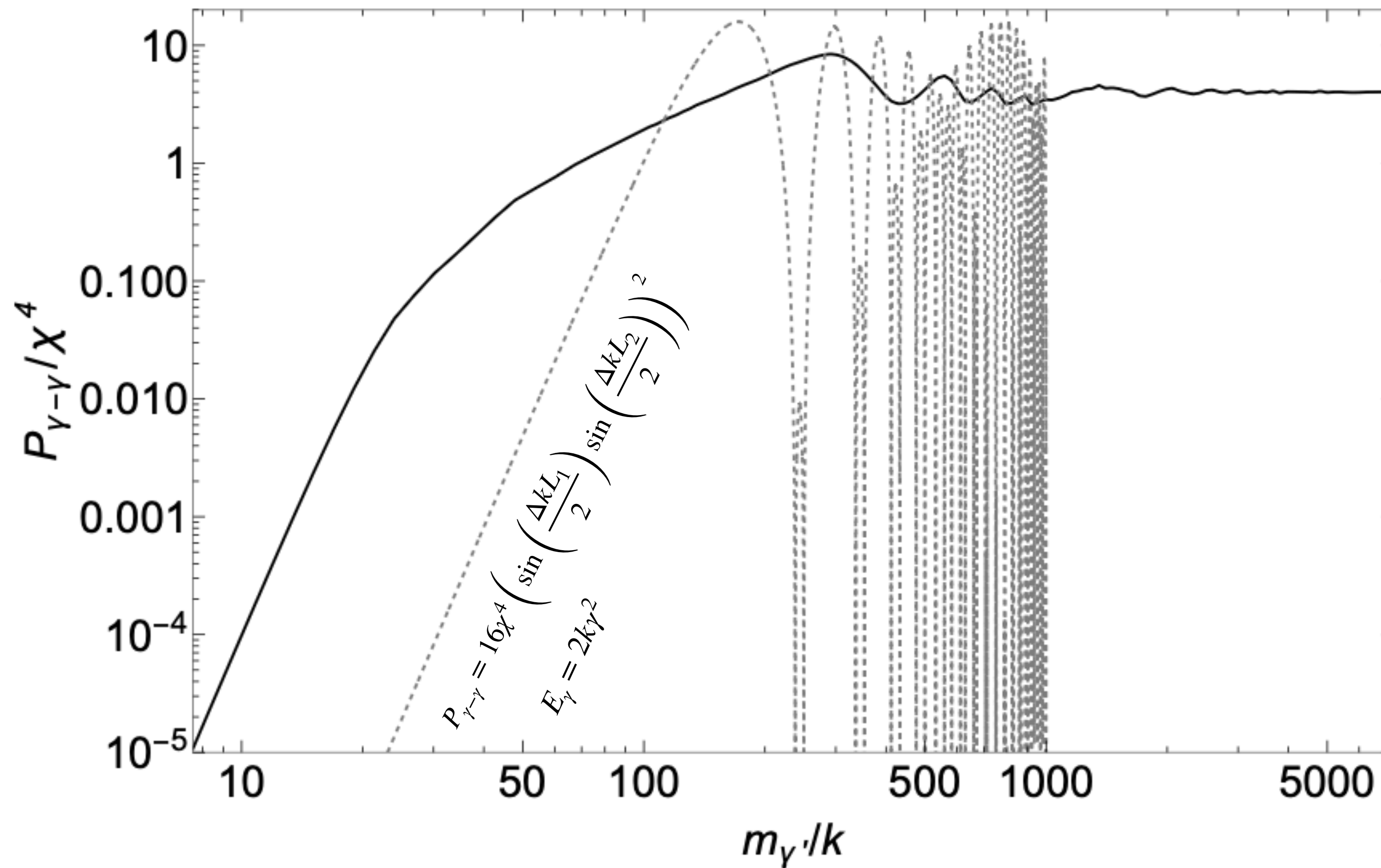
In reality, the photon spectrum is not complete monochromatic, it is not too narrow and the energy depends on (tiny) direction.

Transmitting probability with $m_{\gamma'} < k\gamma$

$$P_{\gamma \rightarrow \gamma}^{\text{eff, light}} \approx \frac{1}{L \dot{n}_\gamma} \chi^4 \sum_{\epsilon^\pm} \int \frac{d^3 \vec{k}_{\gamma'}}{(2\pi)^3} \left| \tilde{\Phi}(\epsilon, \gamma, \vec{k}_{\gamma'}) \right|^2 4 \sin^2 \left(\frac{m_{\gamma'}^2}{4k_{\gamma'}} L_1 \right) \times 4 \sin^2 \left(\frac{m_{\gamma'}^2}{4k_{\gamma'}} L_2 \right).$$

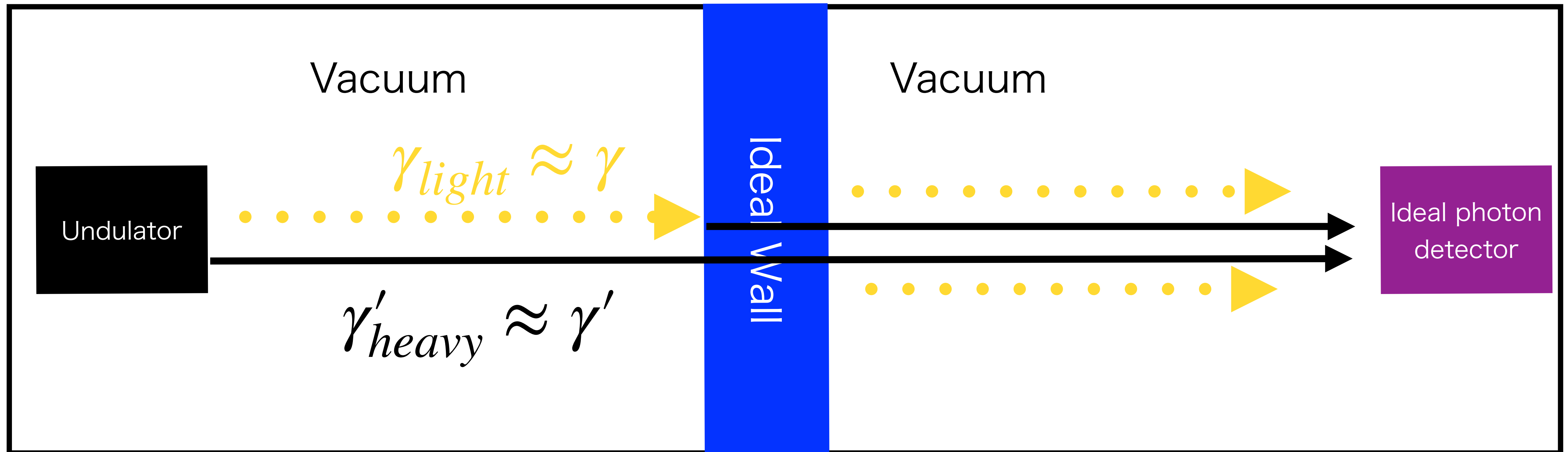
Photon wave packet

[WY,2507.22055,](#)



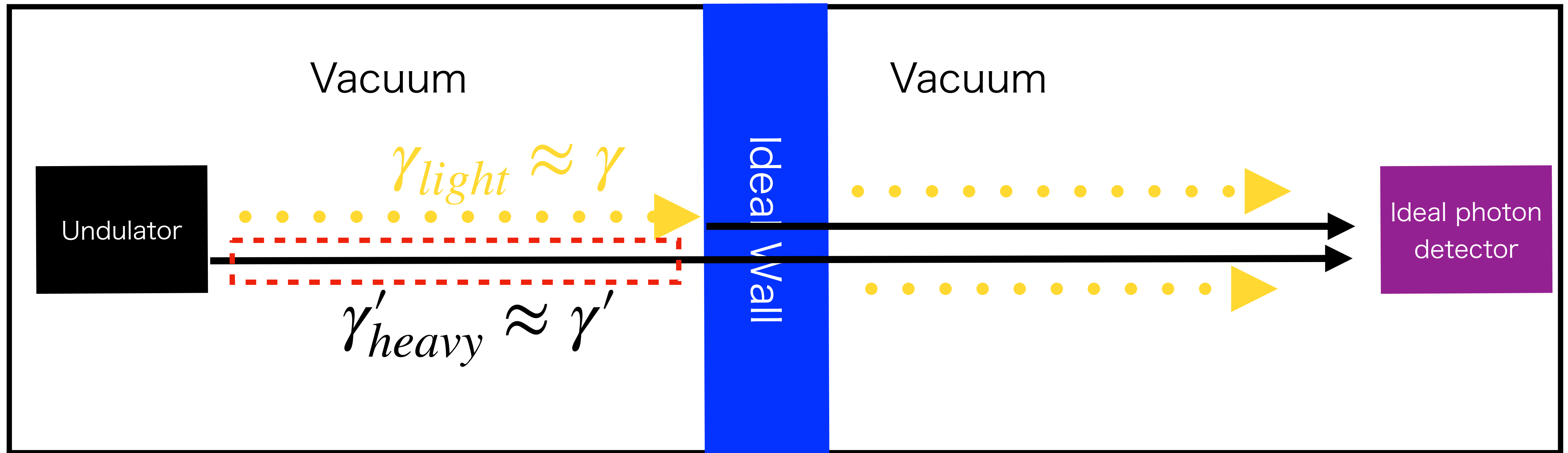
In **heavy mass** range, $\Delta E_\gamma \partial_{E_\gamma} \frac{m_{\gamma'}^2 L_i}{2E_\gamma} \sim \frac{m_{\gamma'}^2 L_i}{2E_\gamma} \frac{\Delta E_\gamma}{E_\gamma} \gg 1$,

asymptotic states give good estimate.

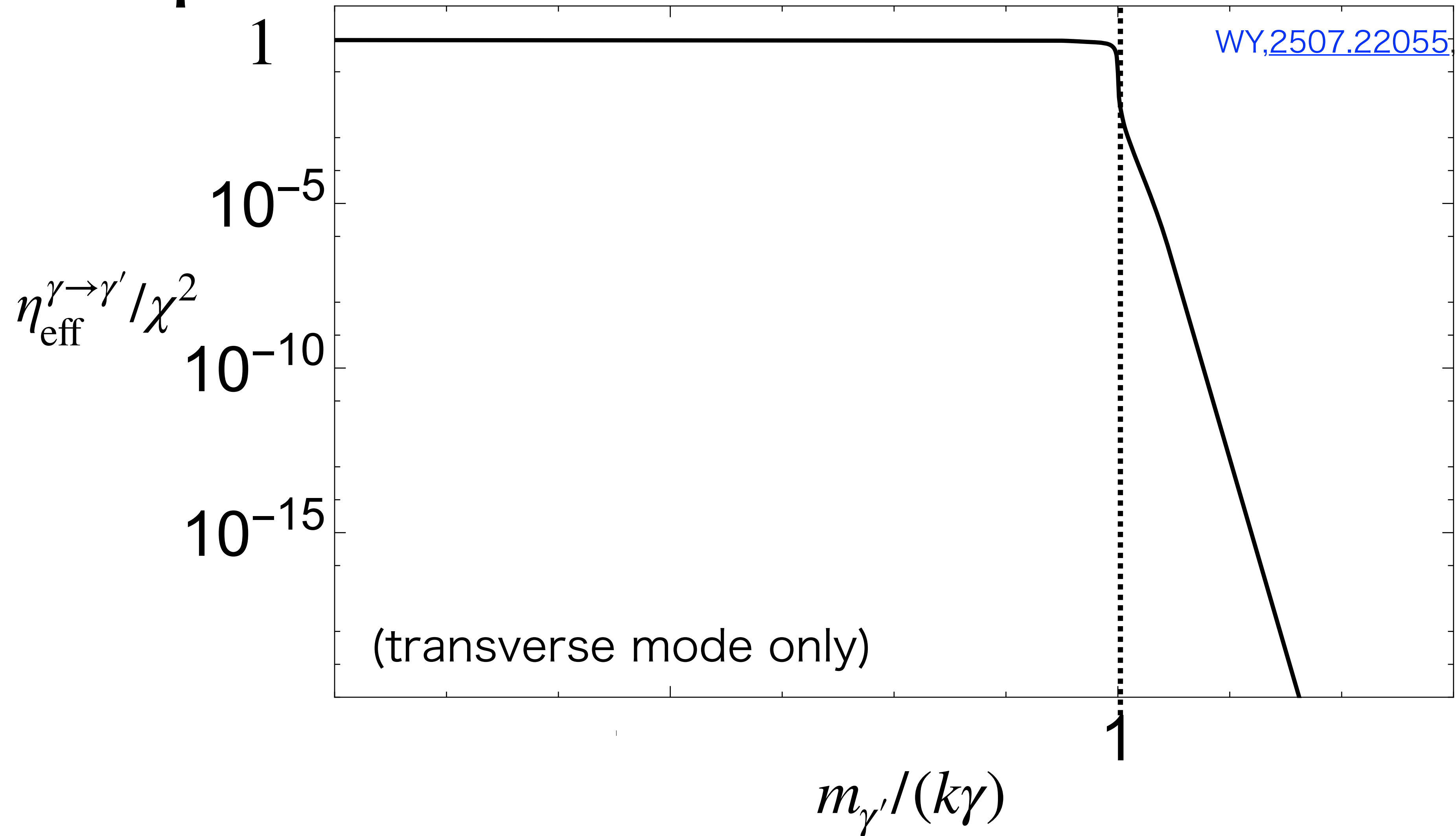


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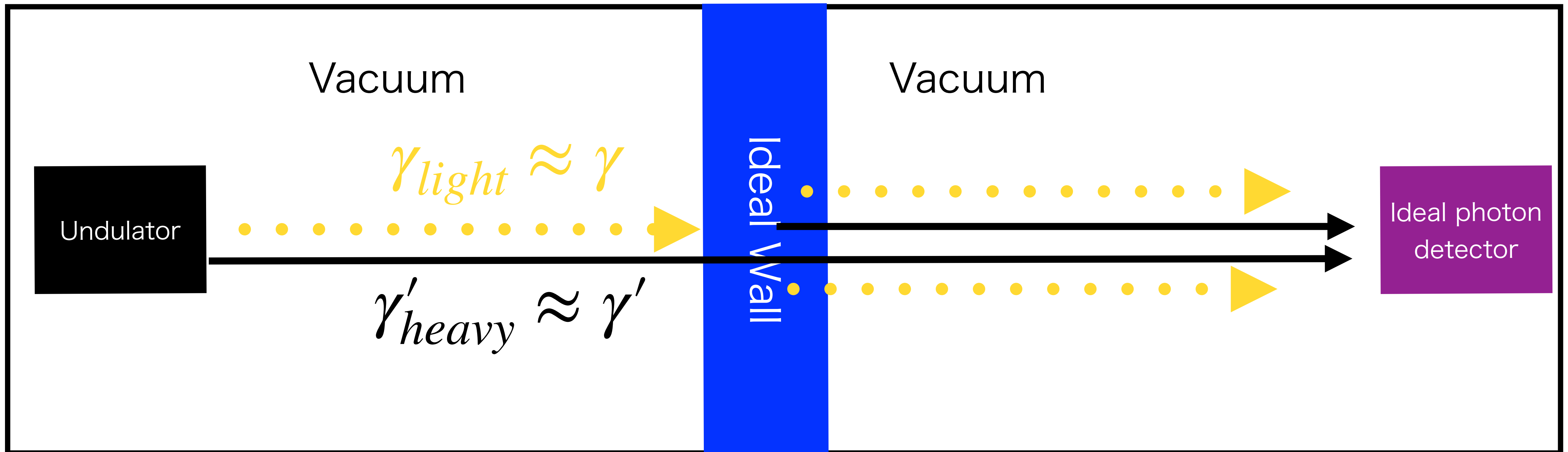


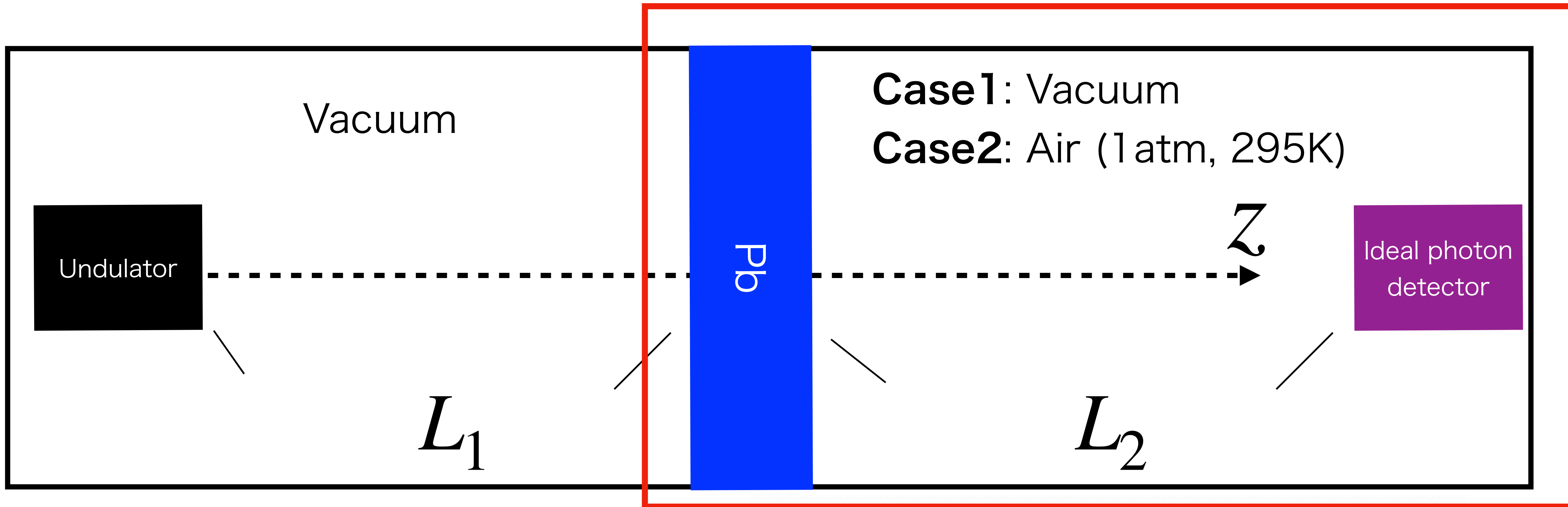
Heavy asymptotic state production from undulator.



In heavy mass range, $\Delta E_\gamma \partial_{E_\gamma} \frac{m_{\gamma'}^2 L_i}{2E_\gamma} \sim \frac{m_{\gamma'}^2 L_i}{2E_\gamma} \frac{\Delta E_\gamma}{E_\gamma} \gg 1,$

$$P_{\gamma \rightarrow \gamma}^{\text{eff,heavy}} \simeq (\eta_{\text{eff}}(m_{\gamma'}) + \chi^2) \times 2\chi^2.$$



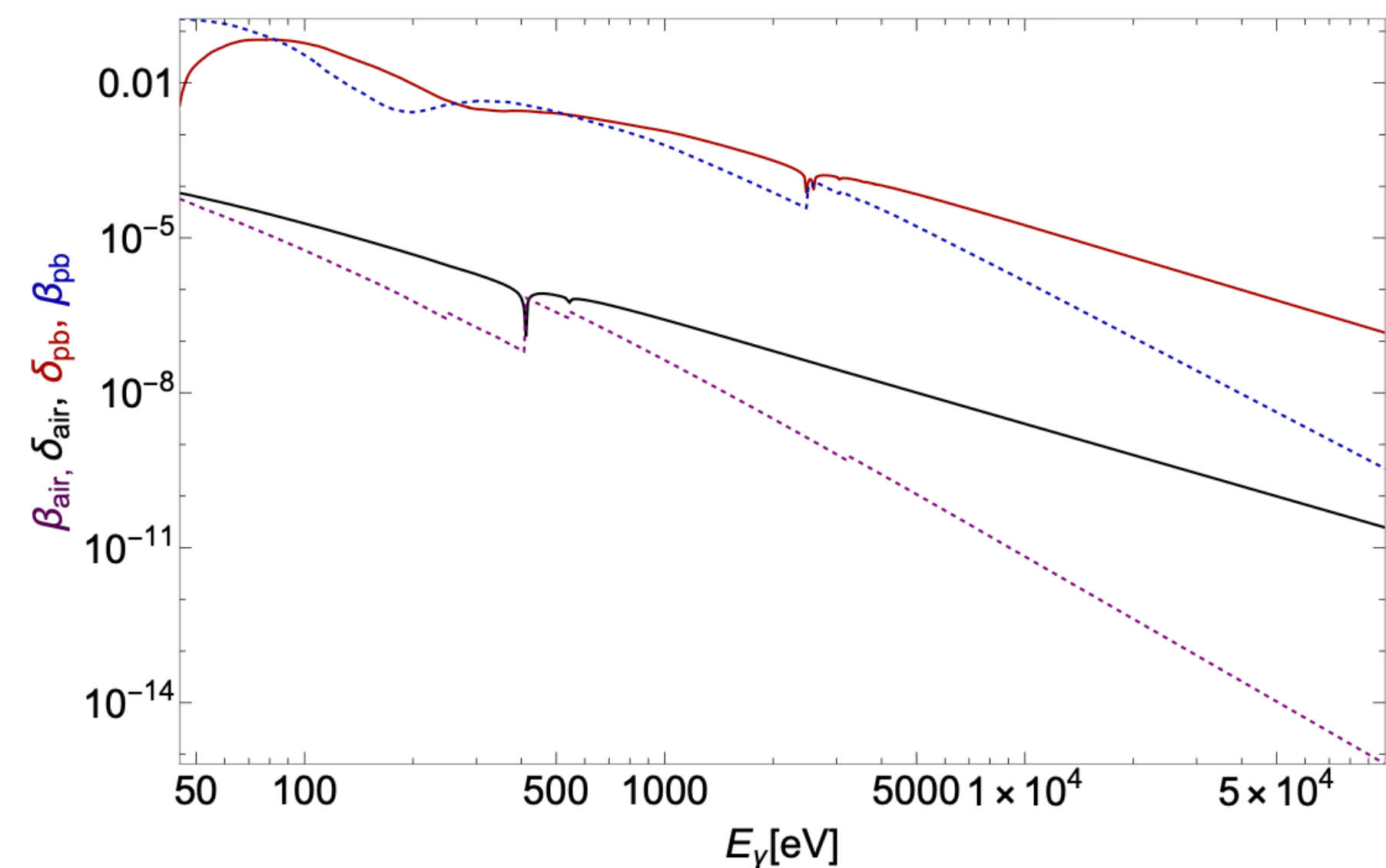


Kinetic equation is employed to study the propagation of the system.

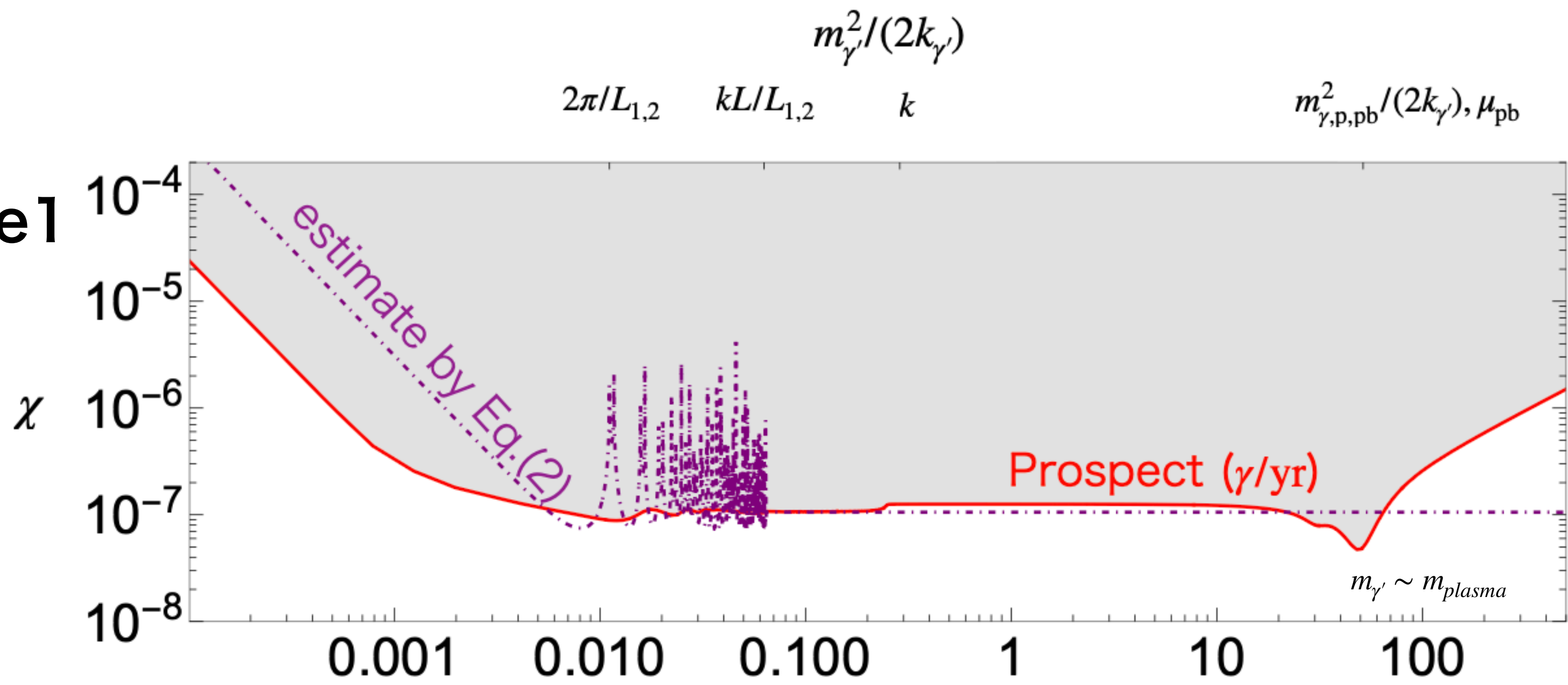
$$\dot{\rho} = -i[H, \rho] - \frac{1}{2}\{\Gamma, \rho\},$$

$$H = \begin{pmatrix} 0 & 0 \\ 0 & m_{\gamma'}^2/(2k_{\gamma'}) \end{pmatrix} + \begin{pmatrix} m_{\gamma,p}^2/(2k_{\gamma'}) & \chi m_{\gamma,p}^2/(2k_{\gamma'}) \\ \chi m_{\gamma,p}^2/(2k_{\gamma'}) & \chi^2 m_{\gamma,p}^2/(2k_{\gamma'}) \end{pmatrix}, \quad \Gamma(k) = \begin{pmatrix} \mu & \mu\chi \\ \mu\chi & \mu\chi^2 \end{pmatrix}. \quad (40)$$

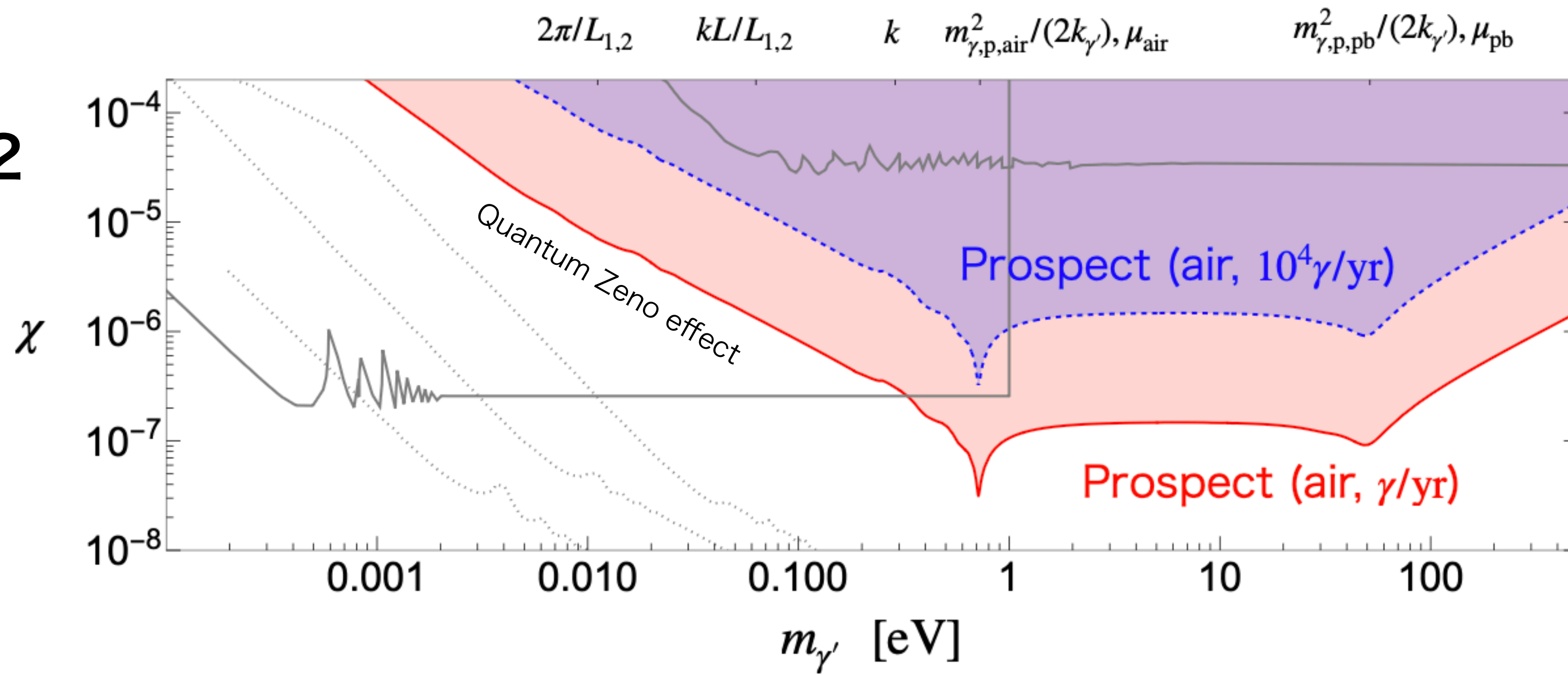
Complex reflective indices $n = 1 - \delta + i\beta$



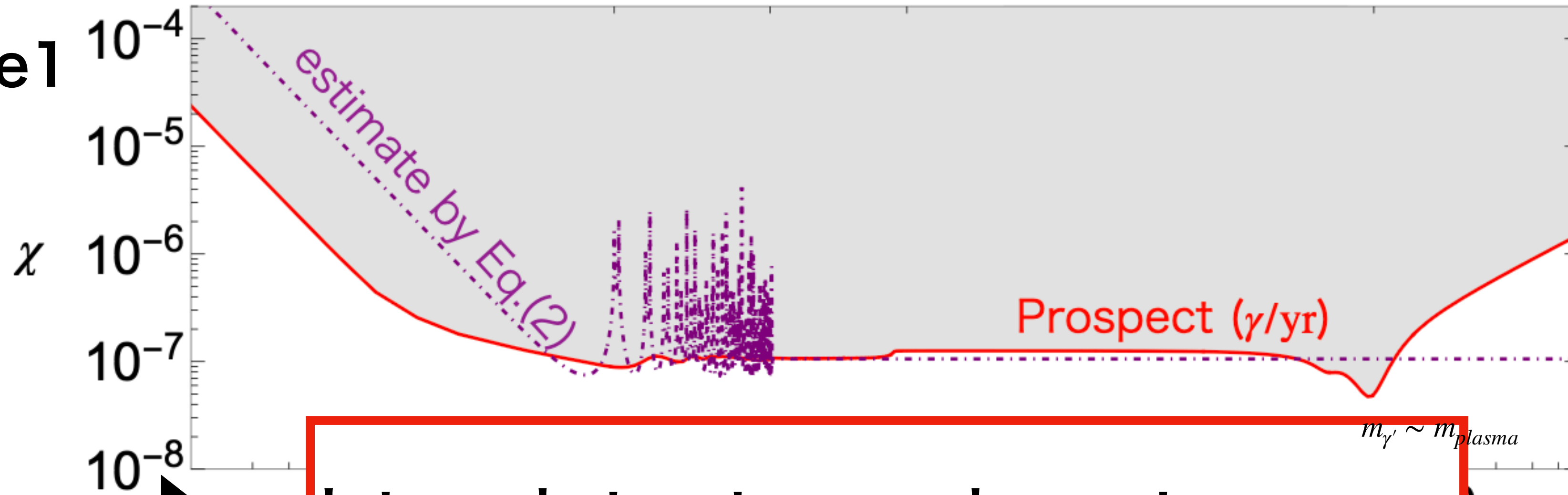
Case 1



Case 2

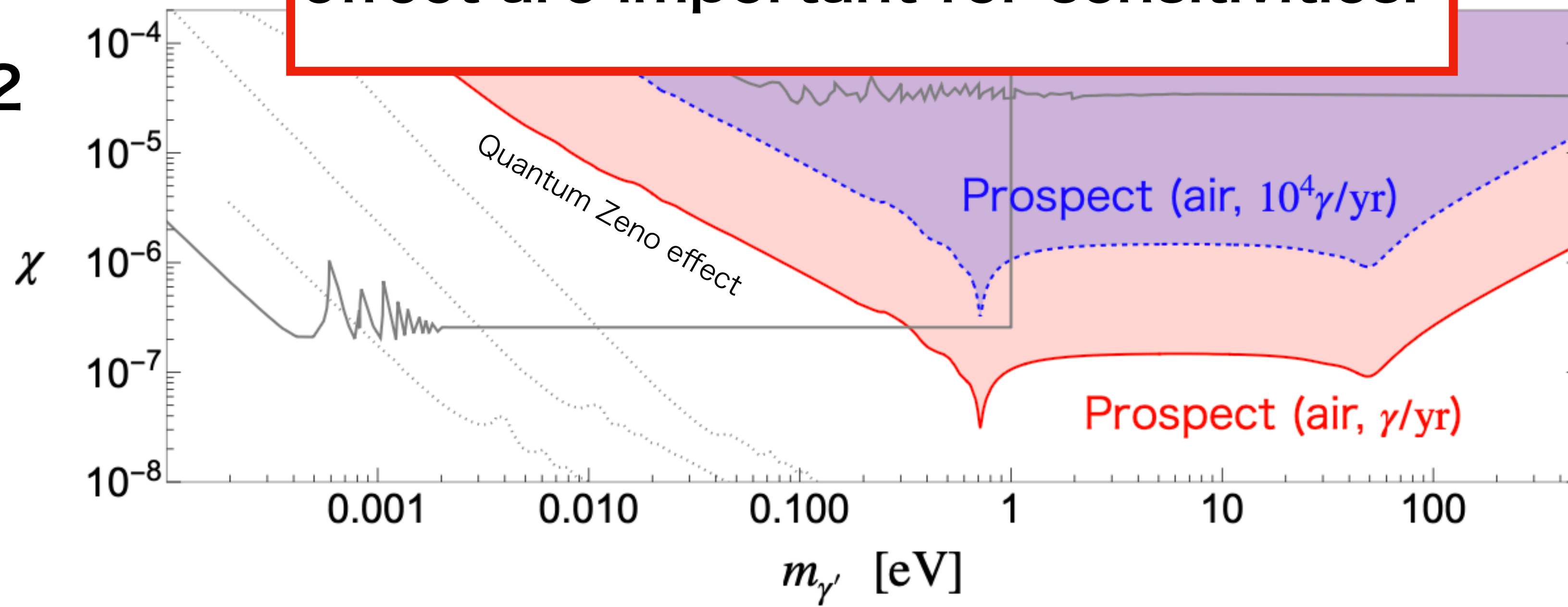


Case 1



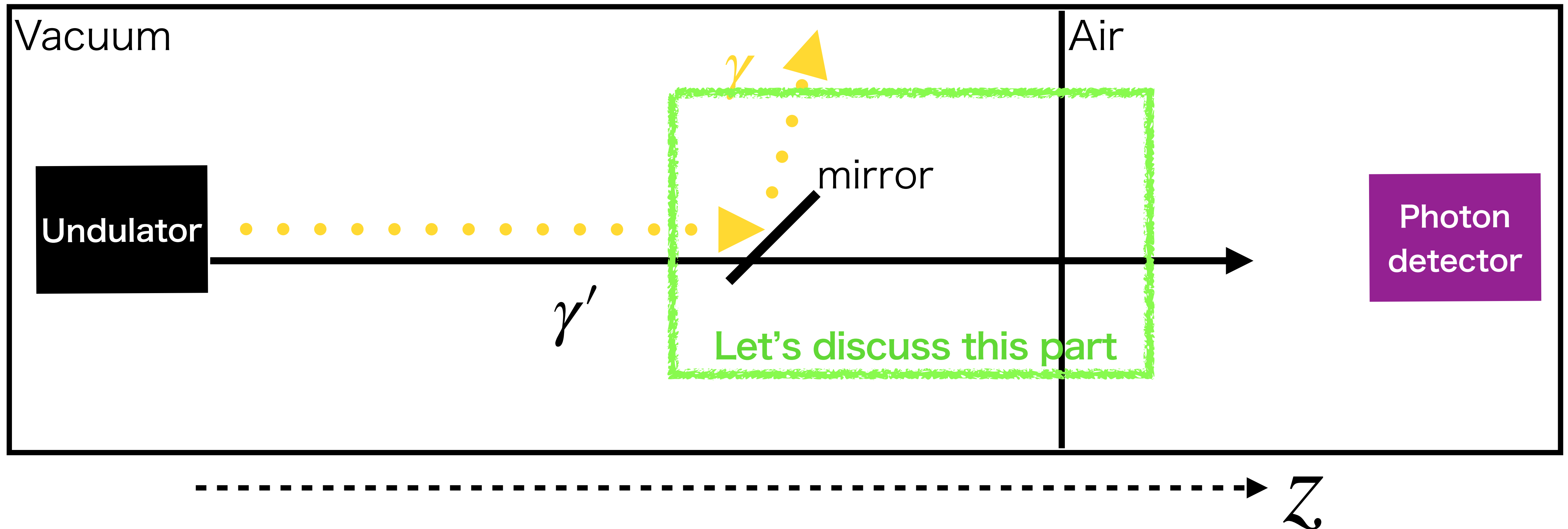
Internal structure and quantum effect are important for sensitivities.

Case 2



4. Dark Photon Limit from Radiation Safety Monitoring

Let us assume more realistic setup.



The boundary conditions imply

$\gamma \rightarrow \gamma'$ by mirror

WY, 2508.14885

$$\left[\omega^2 + \partial_{\perp}^2 - \vec{k}_{\parallel}^2 - \Pi_i(\omega) \right] A_{\mu} + \chi m^2 A'_{\mu} = 0,$$

$$\left[\omega^2 + \partial_{\perp}^2 - \vec{k}_{\parallel}^2 - m^2 \right] A'_{\mu} + \chi m^2 A_{\mu} = 0,$$

$$\Pi_i(\omega) = \omega^2 \left[1 - n_i^2(\omega) \right].$$

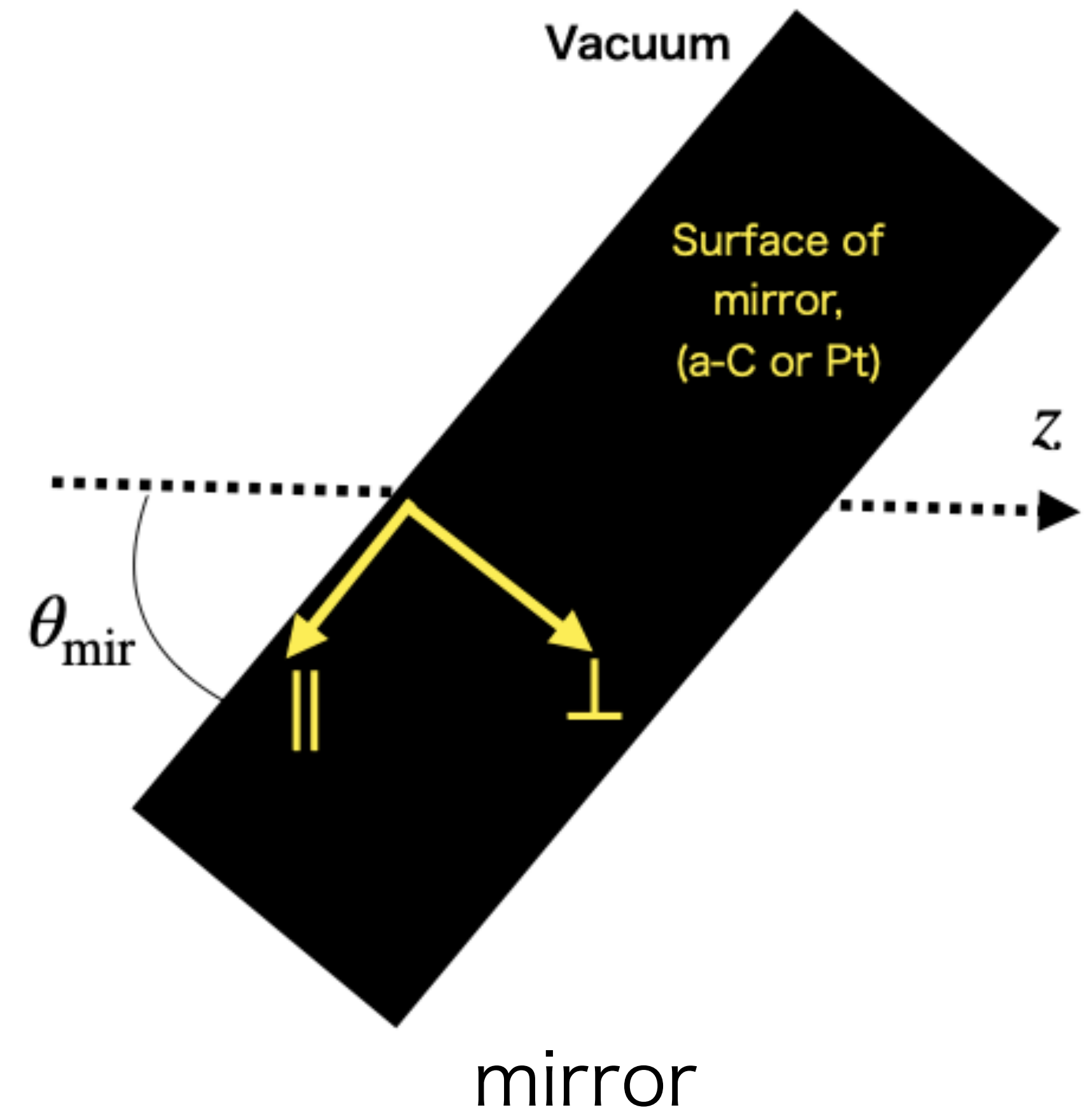
For n_i , https://henke.lbl.gov/optical_constants/getdb2.html

\therefore the probability we get a dark photon after the mirror:

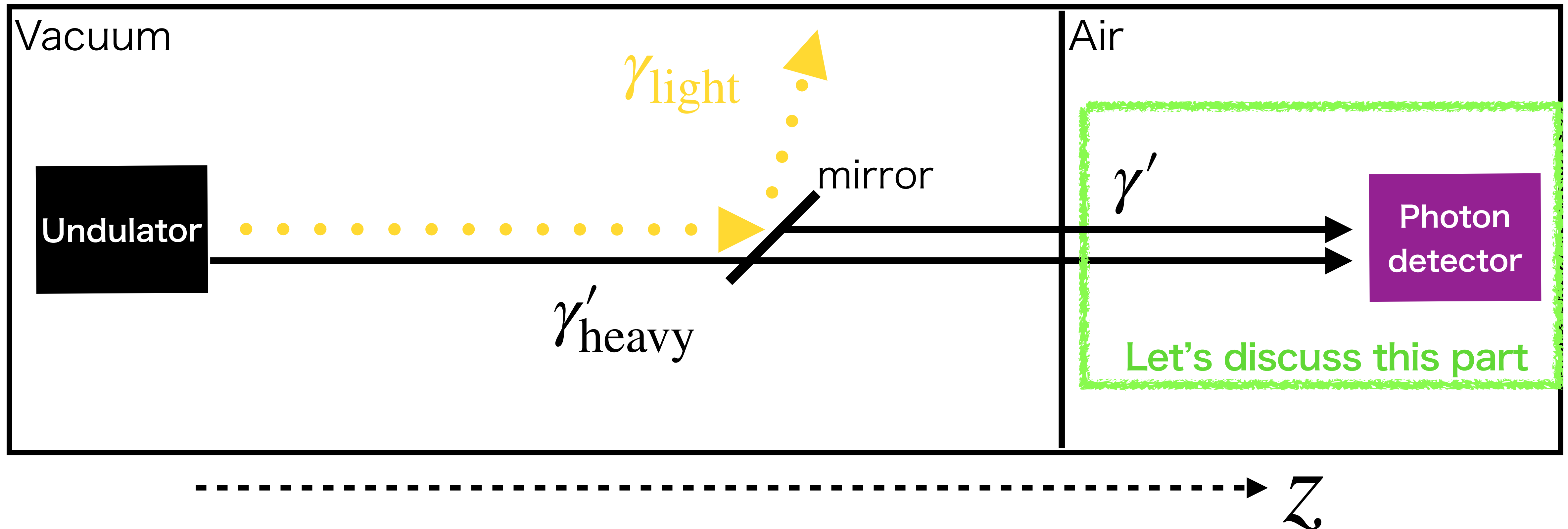
$$N_{\text{mir}}^{(2)} \simeq \sum_{e^{\pm}} \int \frac{d^3 k_{\text{mir}}^{(2)}}{(2\pi)^3} |\mathcal{M}|^2,$$

$$\Delta\chi^{\text{eff}} = \chi_{\text{mir}}^{\text{eff}} - \chi_{\text{vac}}^{\text{eff}},$$

$$\mathcal{M} \simeq \left(\frac{k_{\perp,\text{vac}}^{(1)} (k_{\perp,\text{mir}}^{(1)} + k_{\perp,\text{vac}}^{(2)})}{k_{\perp,\text{vac}}^{(2)} (k_{\perp,\text{mir}}^{(1)} + k_{\perp,\text{vac}}^{(1)})} \Delta\chi^{\text{eff}} \Theta(m_{\gamma'} - |\vec{k}_{\perp,\text{mir}}^{(2)}|) + e^{-i\frac{m^2}{2\omega}L_1} \chi \Theta(k\gamma - m_{\gamma'}) \right) f_{\gamma}$$



To study in more detail let me assume the setup.



Suppose the detector is a Geiger-Müller counter with Ar.

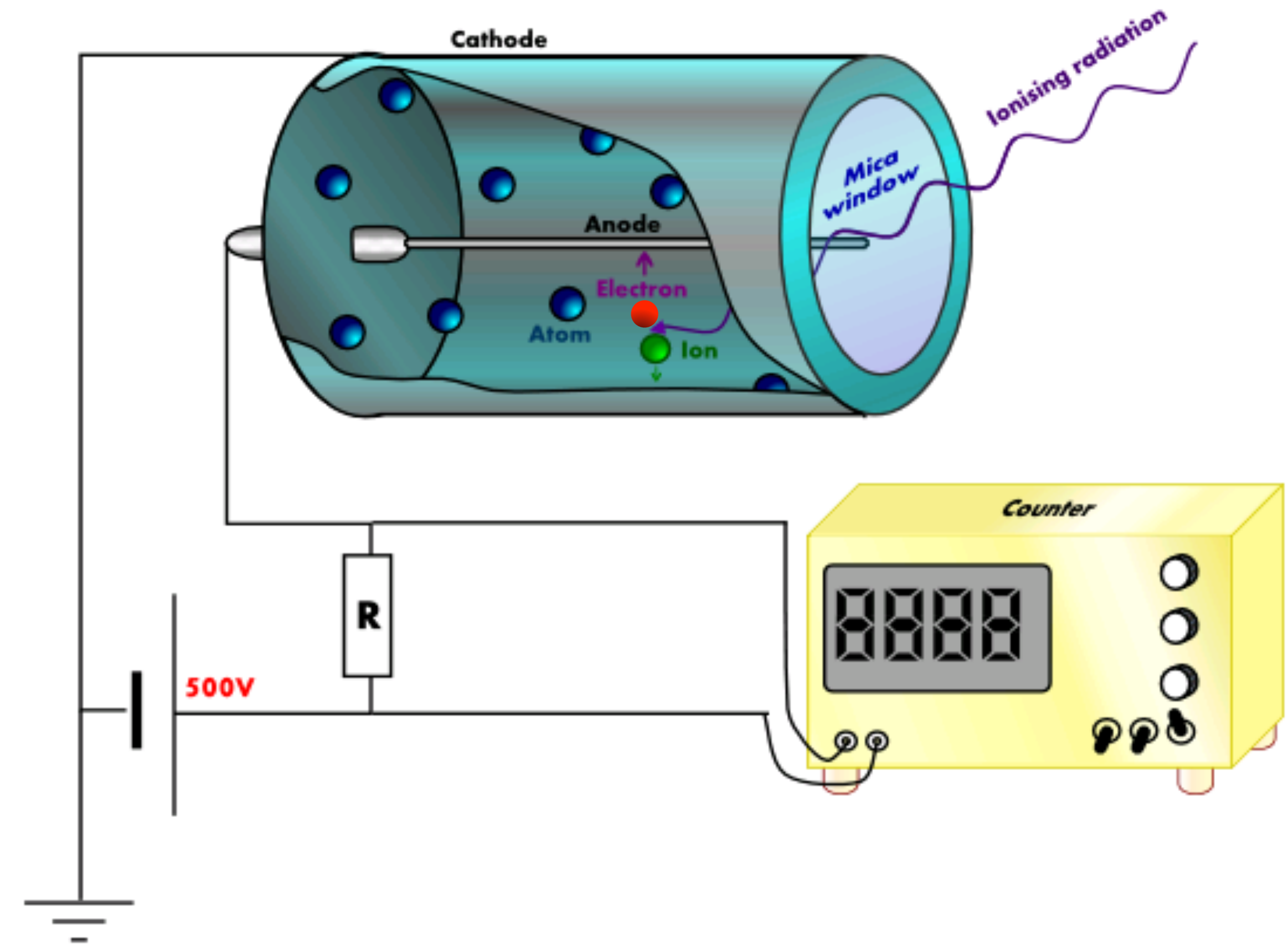


- It does not work for keV photon but works for dark photon!

[An, Pospelov, 1304.3461; 1412.8378;](#)
[WY, 2507.22055,](#)

$$P_{\text{det}}^{\text{eff}} = \chi^2 \times \frac{m^4}{|m^2 - \Pi_{\text{Ar}}|^2} \times \frac{-\Im \Pi_{\text{Ar}}}{2\omega} \times L_{\text{det}},$$

Wikipedia



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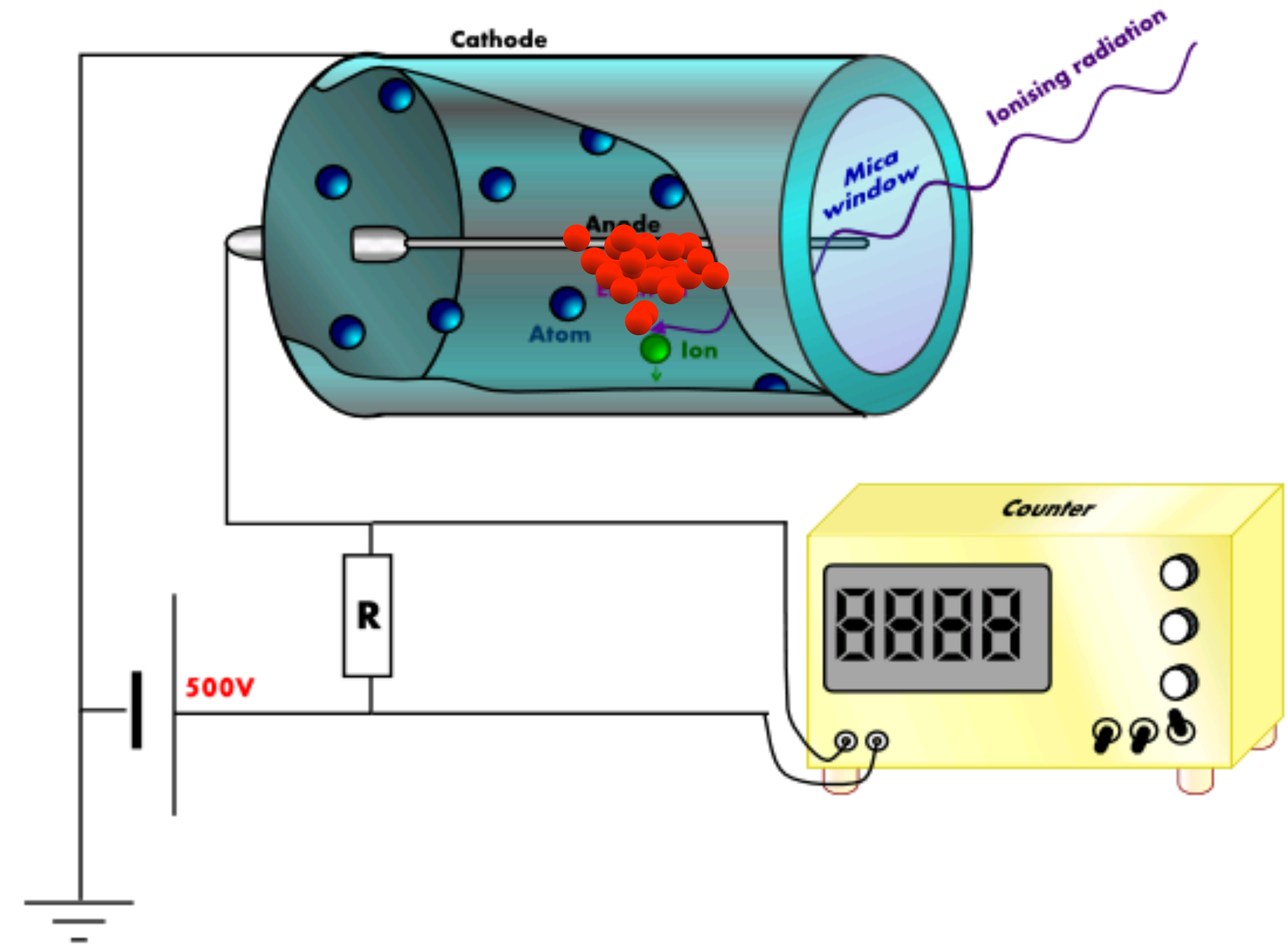


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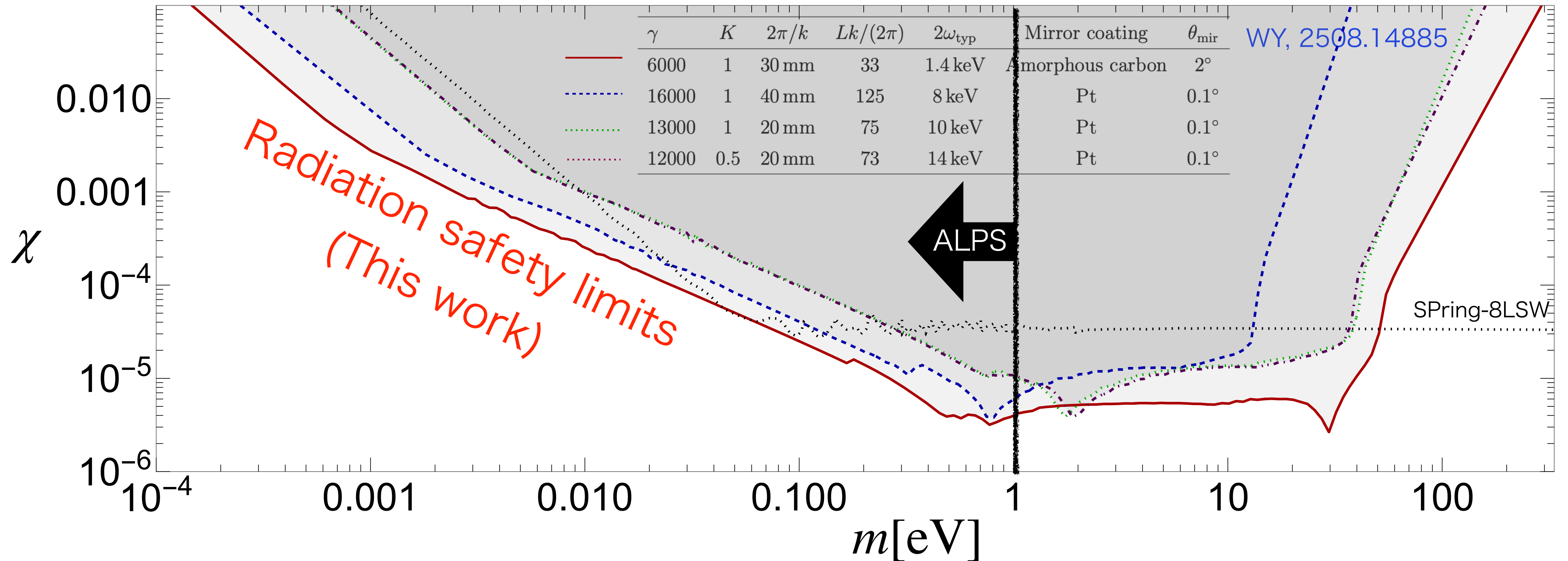
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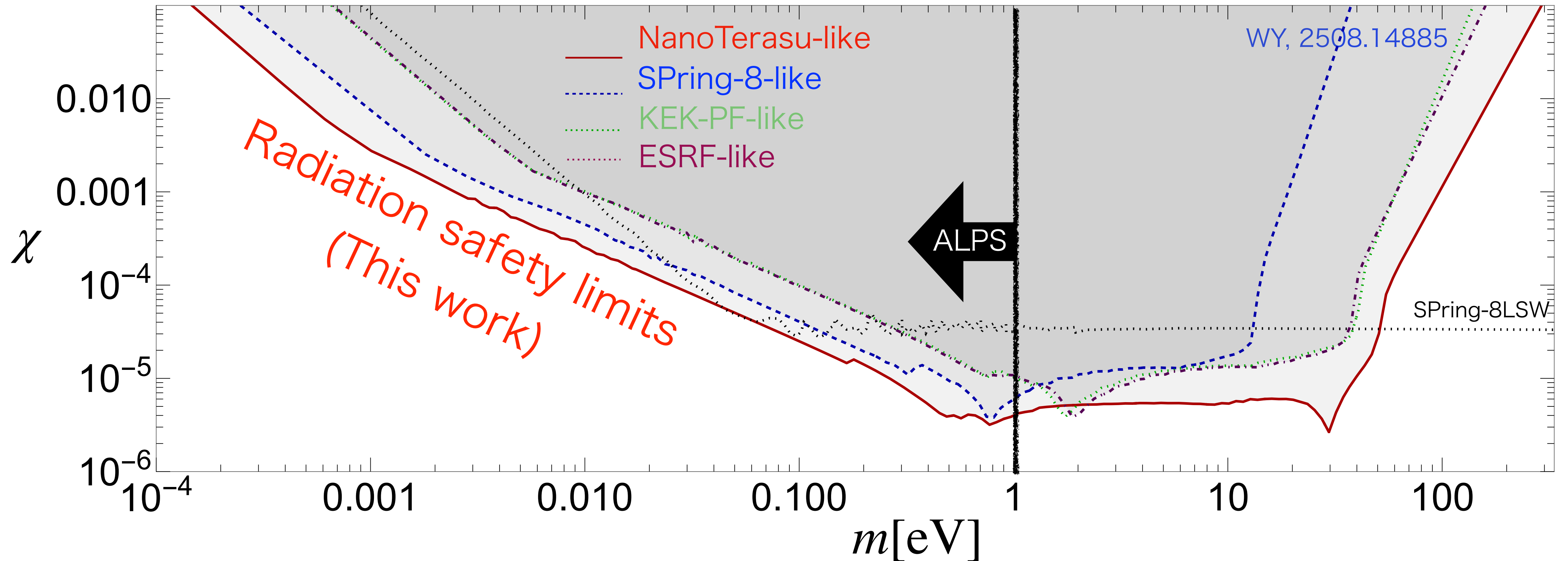


Combining all discussions and requiring $D < 10D_{\text{natural}} \sim 1\mu\text{Sv/h}$, I get



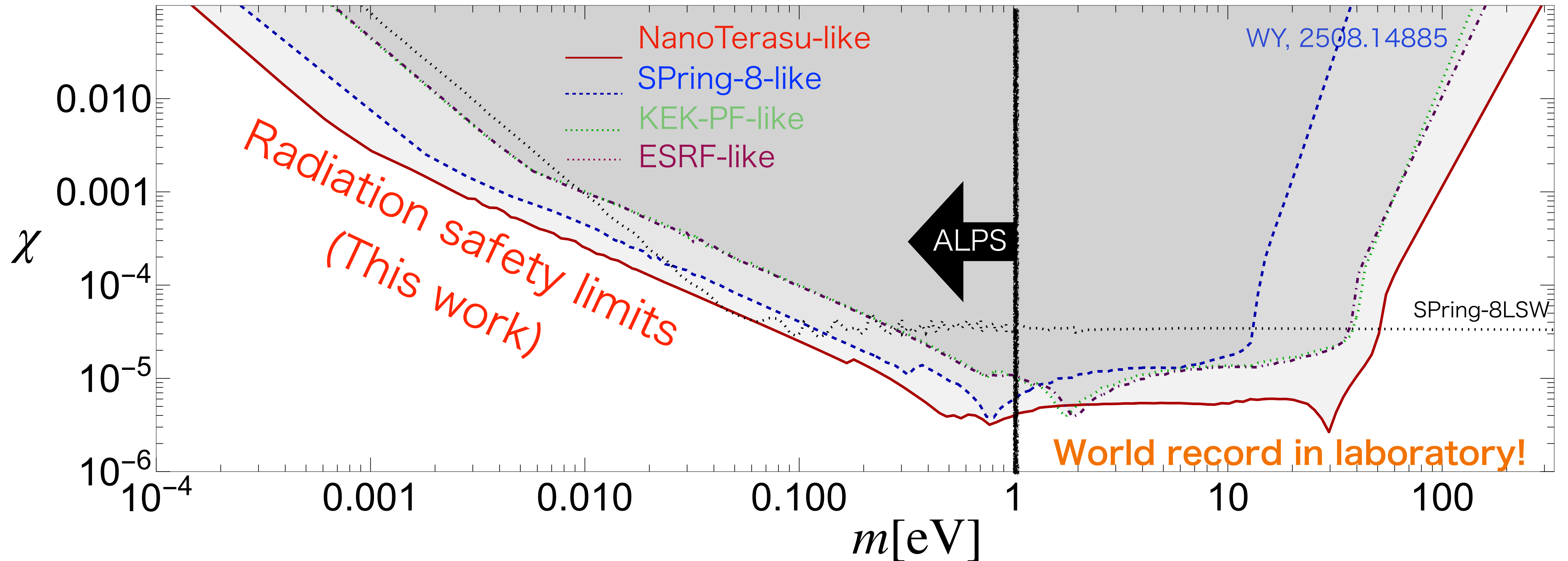
Notice that there are stronger astrophysical limits but astrophysical/cosmological model-dependent. c.f. [Hook et al, 2510.13956](#), [Chakraborty et al, 2008.10610](#).

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Conclusions:

• Parasitic Dark Photon Search at Synchrotron Radiation Facilities

| Item | Feature |
|---------------------|----------------------------|
| Beam time occupancy | None / minimal |
| Running time | Years |
| Photon flux | Much larger |
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- **More particle physics study featuring technology is warranted.**

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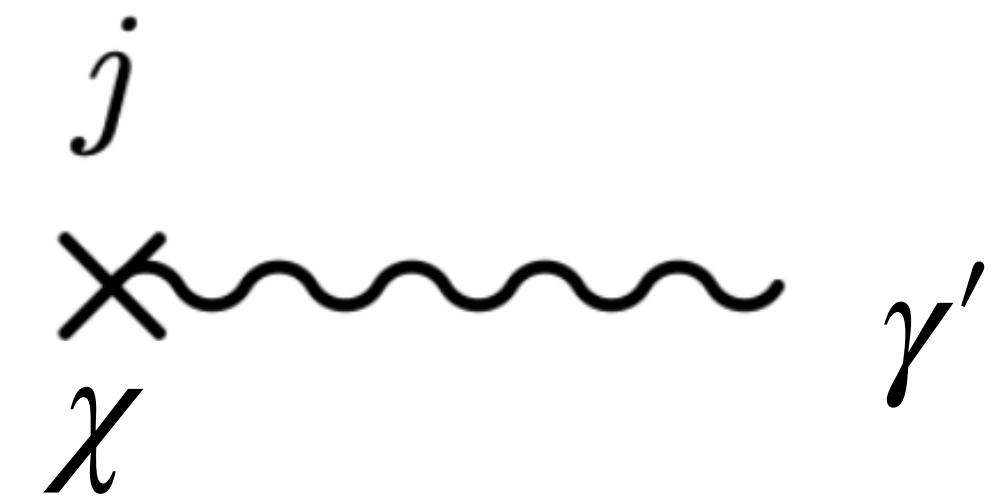
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Backups

(Dark) photon **wave packet** from undulator

$$\mathcal{L}_{\text{int}} = -\chi J_{\mu} A_{\text{dark}}^{\mu}$$

- (1) Draw Feynman Diagram
- (2) Calculate the amplitude



$$\pi\delta_{L/\beta}(X) \equiv \int_0^{L/\beta} dz e^{iXz}$$

$$\sqrt{2w_{\gamma'}} \frac{\text{out}\langle\gamma', \epsilon, k_{\gamma'} | 0_j\rangle_{\text{in}}}{\pi} \simeq i \frac{e\chi K}{2k\gamma} \left(k (\kappa e^{-i\phi} \epsilon^x + i\epsilon^y) + \epsilon^z (\kappa e^{-i\phi} k_{\gamma'}^x + i k_{\gamma'}^y) \beta^z \right) \delta_{\frac{L}{\beta^z}} \left(w_{\gamma'} - \beta^z k_{\gamma'} \cos[\theta] - k\beta^z \right) + O(K^2).$$

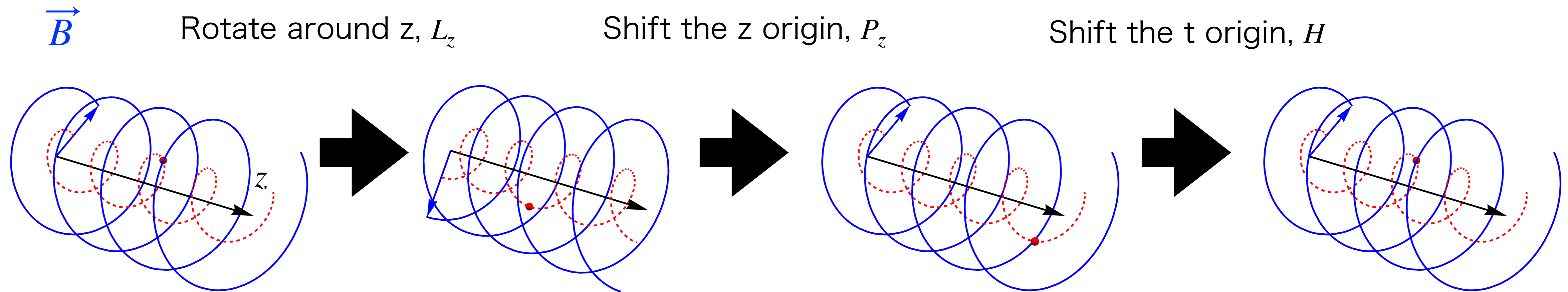
Neglecting terms $\delta_X(x)$ with $x \gg 2\pi/X$.

The difference from photon is not only $e \rightarrow e\chi$, but

also $w_{\gamma'} = \sqrt{k_{\gamma'}^2 + m_{\gamma'}^2}$.

Symmetry of (helical) undulator system

Consider the transformation leaving 'vacuum' with the background fields invariant.



A conserving charge (with $L \rightarrow \infty$):

$$\hat{Q} \equiv -\hat{H} + \beta^z \hat{P}^z + \beta^z k \hat{L}^z$$

Understanding from symmetry

Any particle produced from the helical undulator has

$$-\mathbf{w}_i + \beta^z \mathbf{p}_i^z + \beta^z \mathbf{k}(s_i^z + l_i^z) = \mathbf{0}$$

Undulator Photon

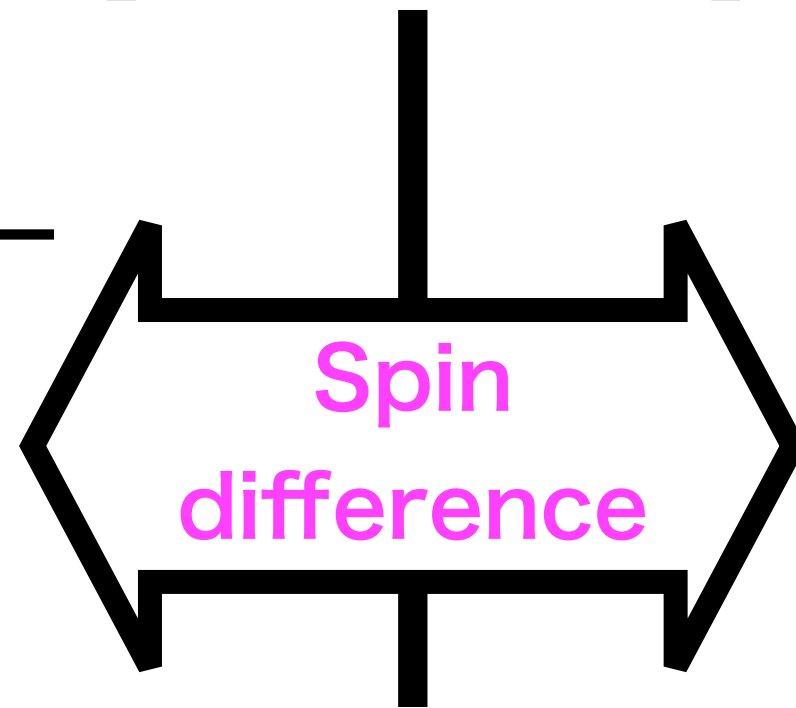
$$w_\gamma(1 - \cos \theta \beta^z) = \beta^z k(1 + l_\gamma^z)$$

$\therefore \theta = 0$ allowed

Undulator Axion

$$w_\phi(1 - \cos \theta \beta^z) = \beta^z k(0 + l_\phi^z)$$

$\therefore \theta \neq 0$



Nothing but the arguments
of the “delta functions”

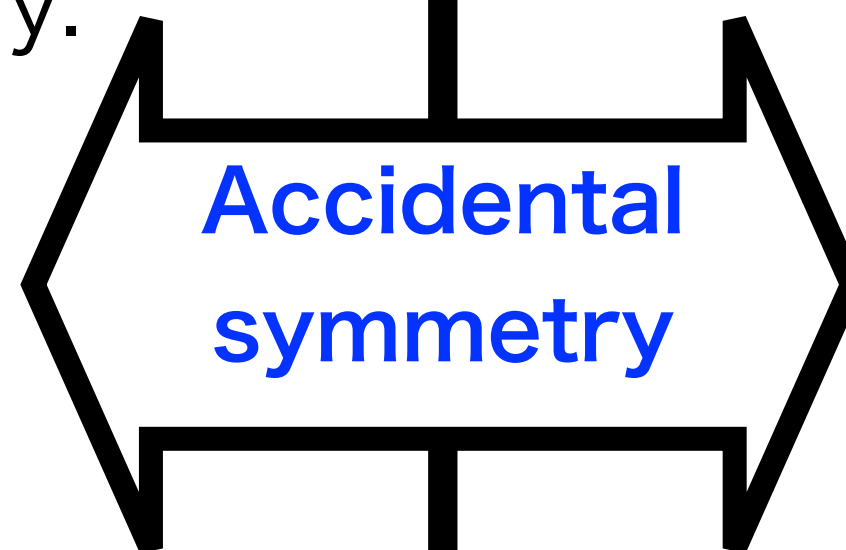
$$\mathcal{L}_{\text{int}} = -J_\mu A^\mu$$

At $K \rightarrow 0$, the electron moves straight,
we have additional accidental symmetry.

$$\hat{Q} \equiv -\hat{H} + \beta^z \hat{P}^z$$

which is never satisfied.

\Rightarrow K^0 contribution is forbidden.



$$\mathcal{L}_{\text{int}} = -g_{\phi\gamma\gamma} \phi \vec{E} \cdot \vec{B} - J_\mu A^\mu$$

At $K \rightarrow 0$, we do not have accidental symmetry
due to $\vec{B}_{\text{ext}} \neq 0$.

No symmetry forbids Coulomb Contribution.

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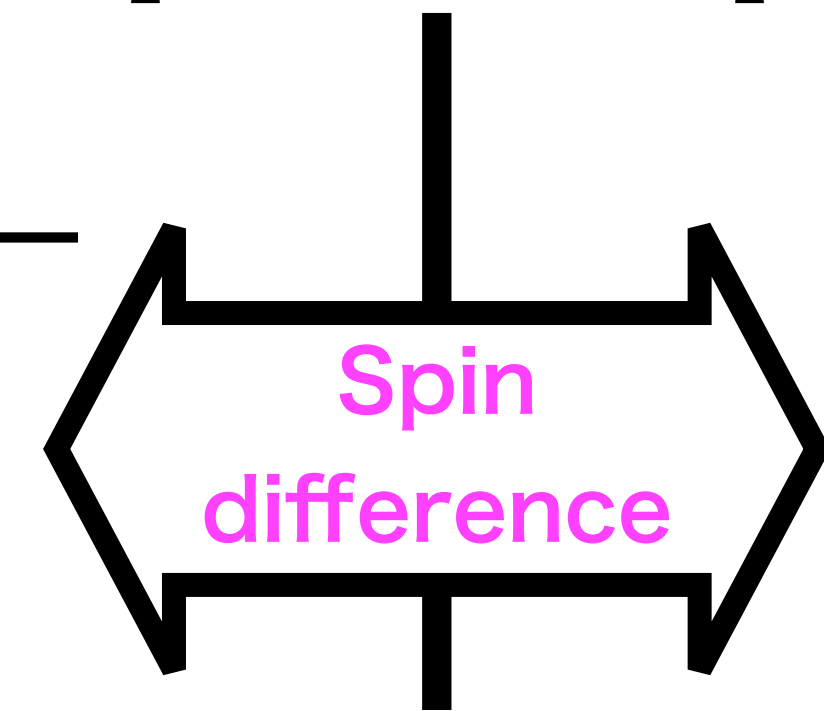
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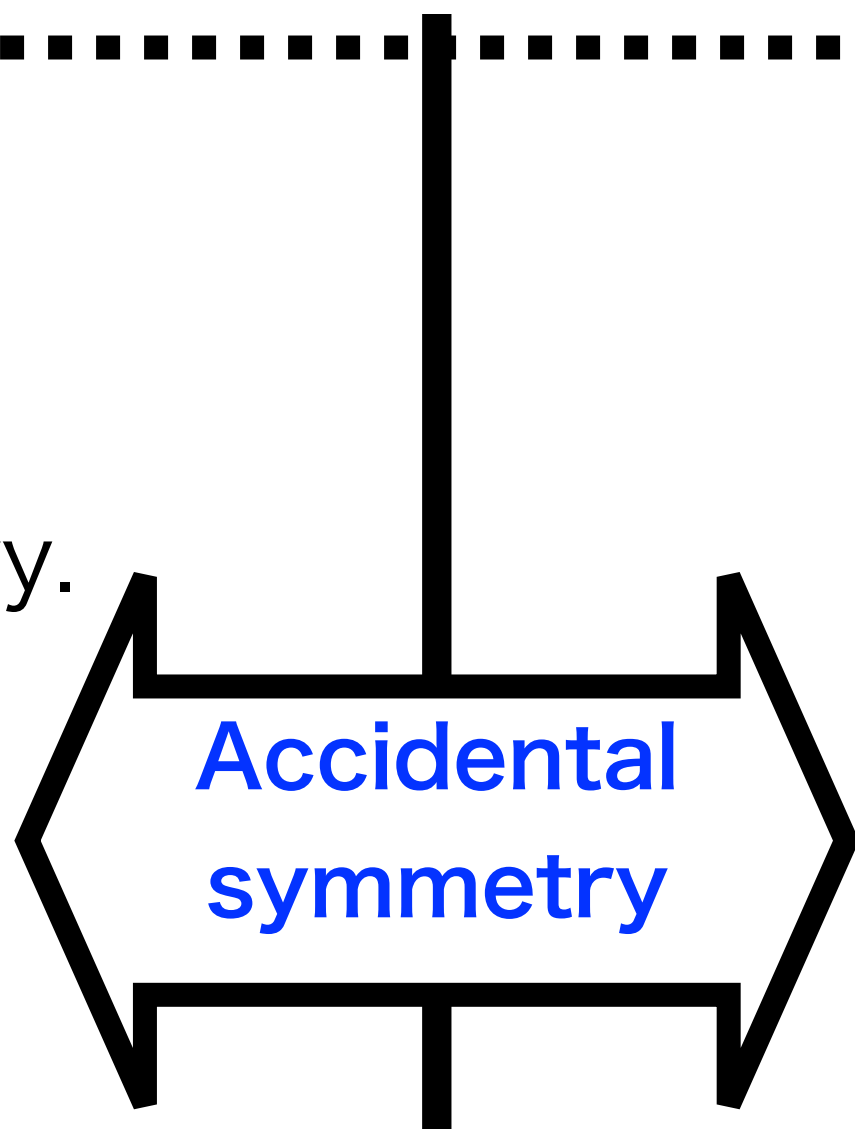
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->Measurement of spin!



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