Magnetically amplified tunneling of the 3rd kind as a probe of minicharged particles*

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HELMHOLTZ ASSOCIATION GSI DESY

Outline

I. Light Propagation in the Quantum Vacuum
   within the Standard Model ($\rightarrow$ QED) and beyond

II. Light-shining-through-walls
   How to suppress the Standard Model “background”?

III. Tunneling of the 3rd kind
   Setting, Calculation and Parameters

IV. Results
   Exclusion Plot

V. Conclusions and Outlook

I. Light Propagation in the Quantum Vacuum

I. Light Propagation in the Quantum Vacuum

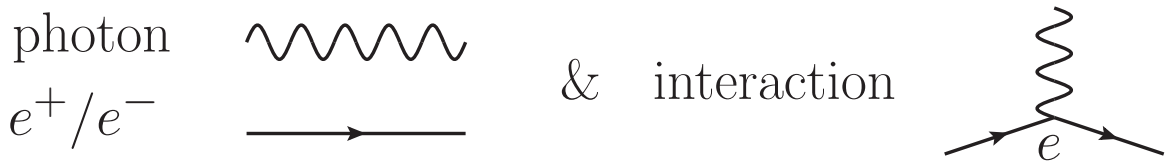
$\widehat{=}$ a photon starts as a photon and is detected (somewhere else) as a photon

in classical field theory:

- vacuum $\widehat{=}$ empty space, and this is trivial,
- here, a photon stays a photon, stays a photon ...

in quantum field theory ($\rightarrow$ QED) this is different:

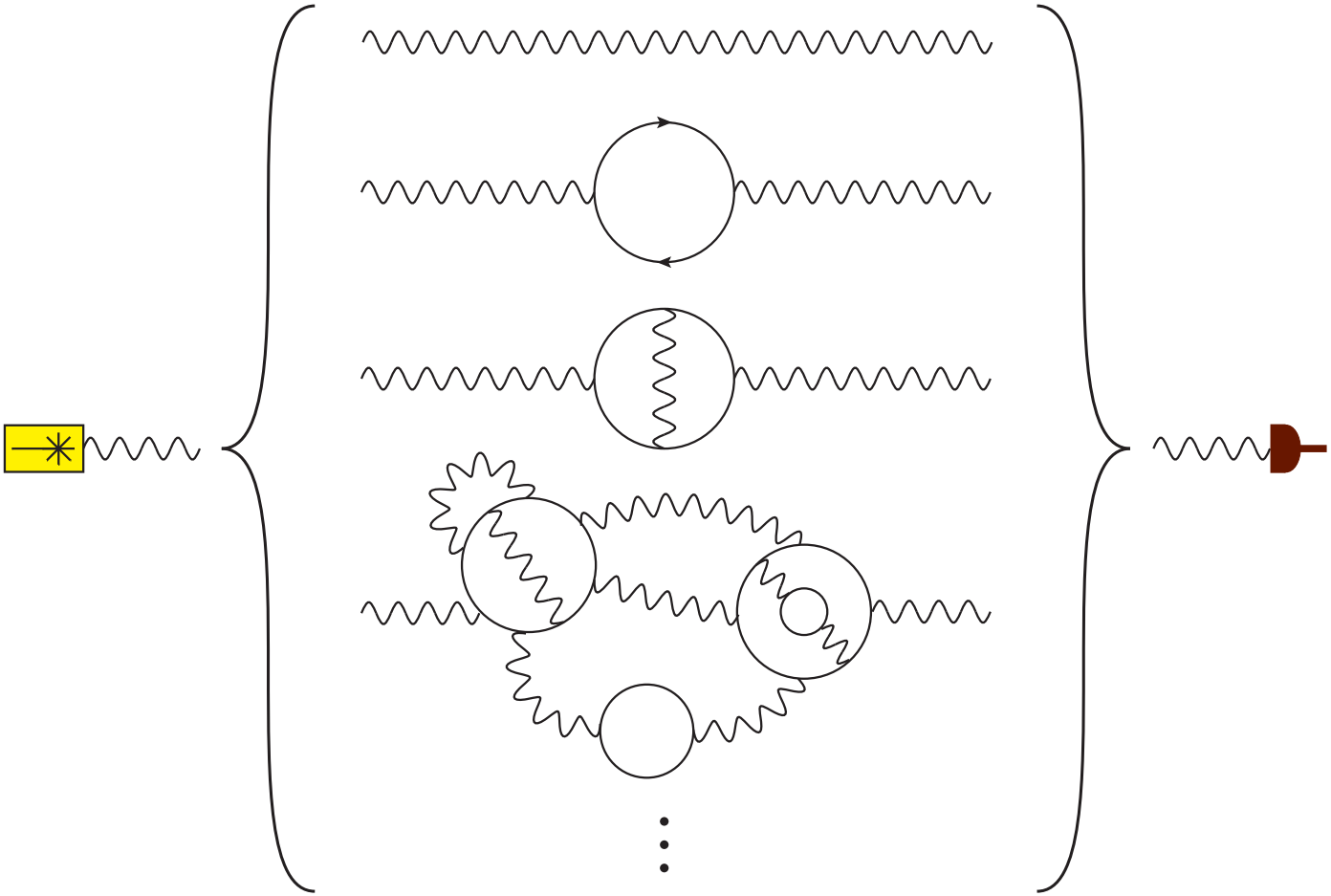
- building blocks:



- everything constructable can happen in-between

I. Light Propagation in the Quantum Vacuum

in pictures:



particles only within diagrams (not as external lines) $\equiv$ *virtual*

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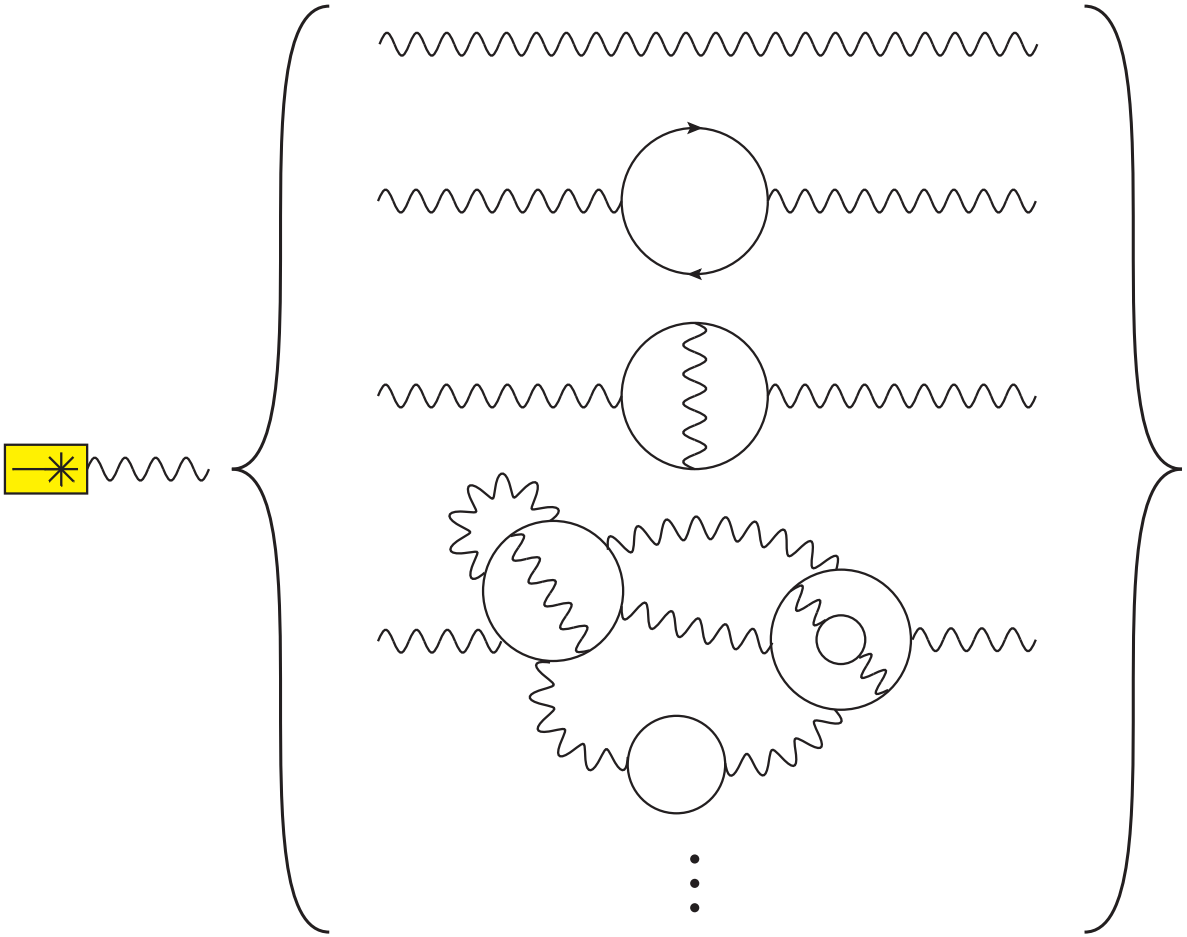

1-loop diagram
$\widehat{=}$ dominant
quantum corr.

↓ contributions
suppressed
with # of loops

I. Light Propagation in the Quantum Vacuum

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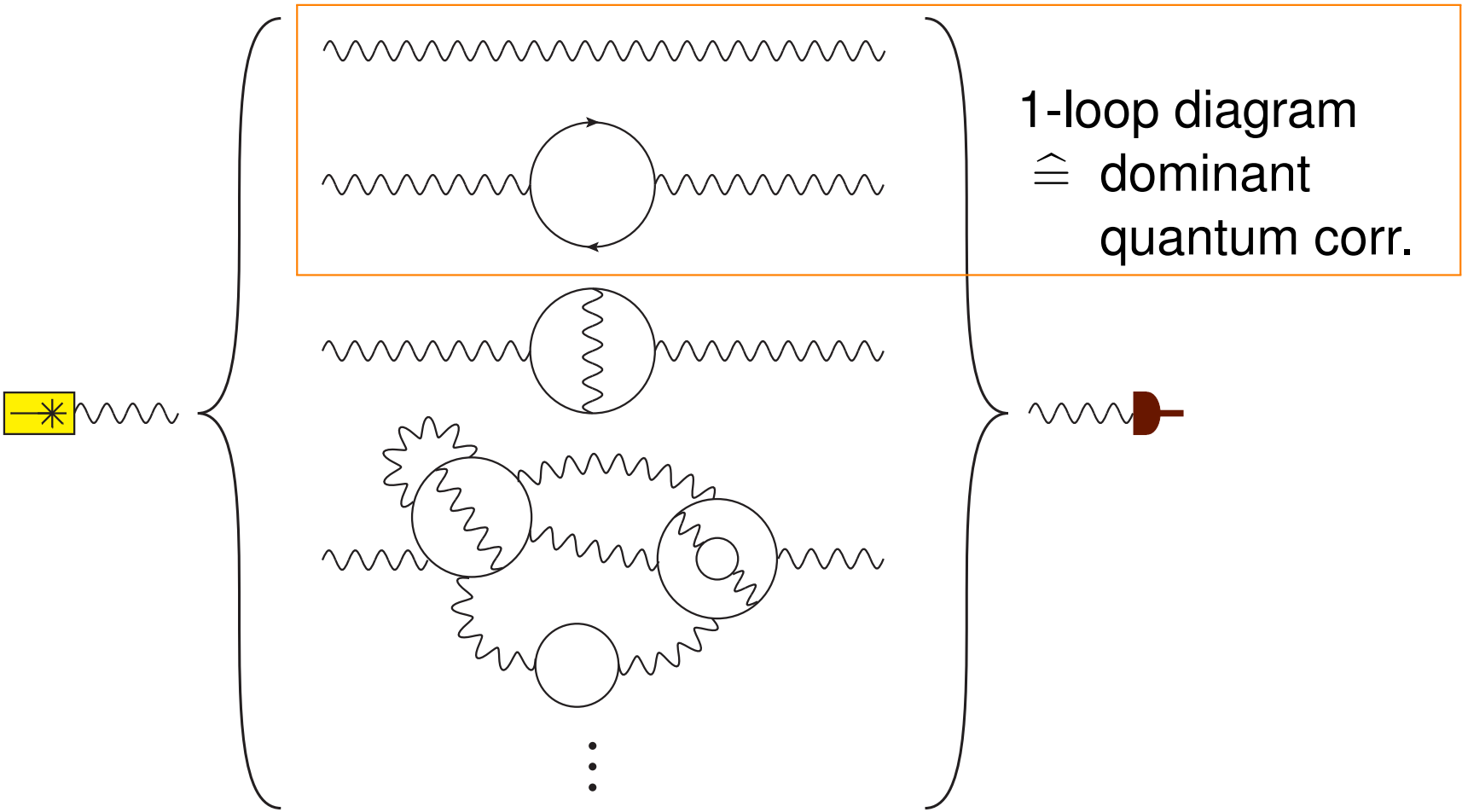
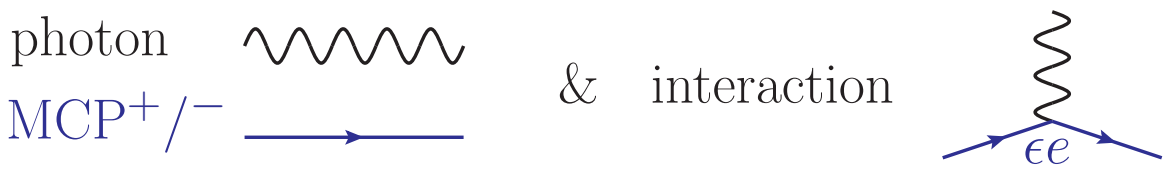


I. Light Propagation in the Quantum Vacuum

Quantum fluctuations involve all types of particles present.

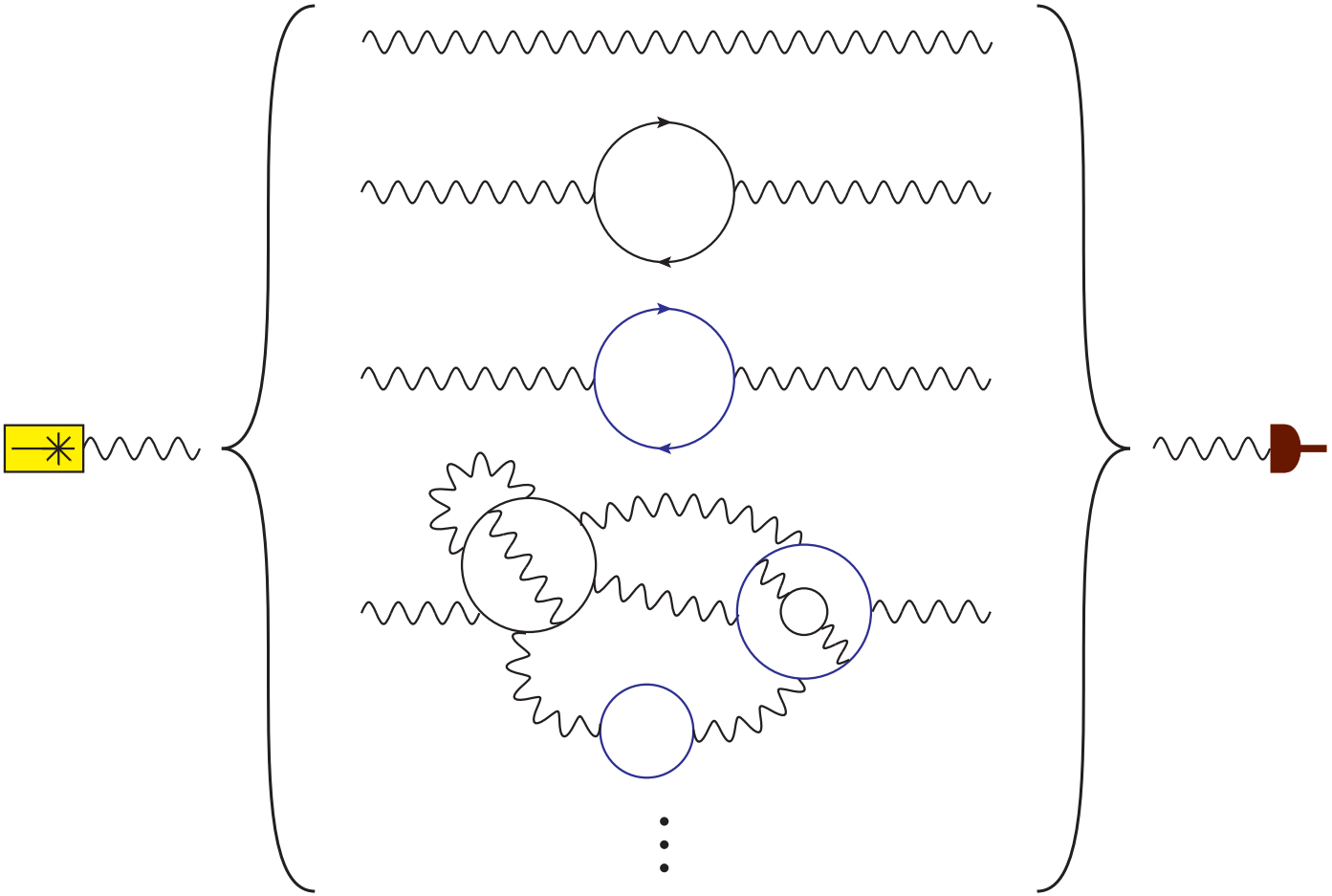
$\rightarrow$ Perhaps there are minicharged particles (MCPs),

- resembling e^+/e^-, with direct coupling to photons
- of charge ϵe, with ϵ "mini" $\leftrightarrow$ $\epsilon \ll 1$,
- mass m_ϵ
- beyond the Standard Model $\leftrightarrow$ hypothetical particles,
  $\rightarrow$ parameters (m_ϵ, ϵ) unknown.
- additional building blocks:



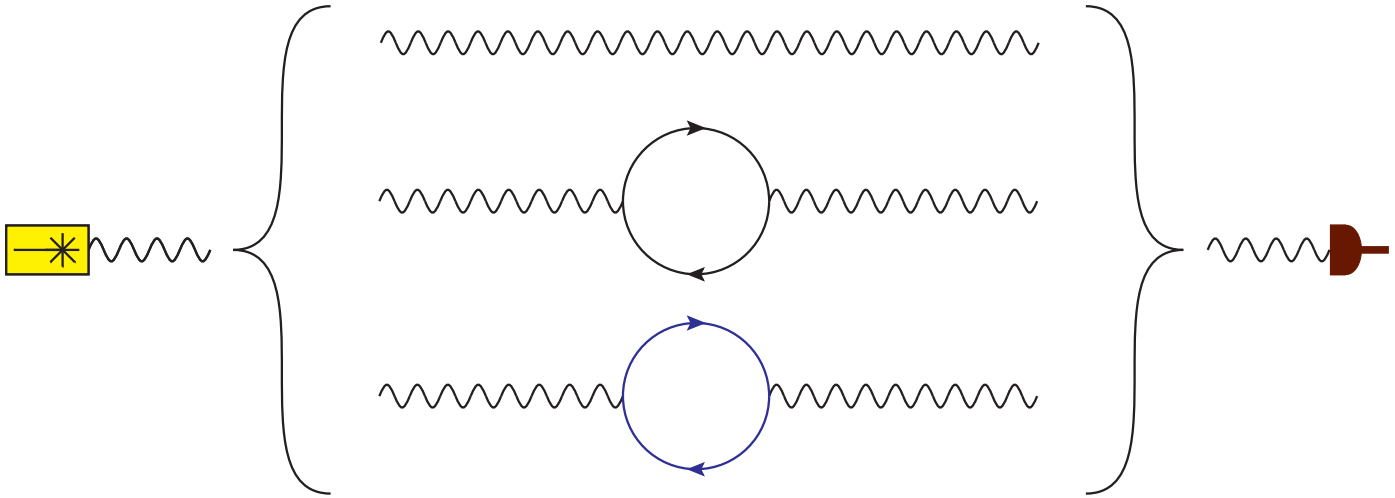
II. Light-Shining-Through-Walls

in pictures:



I. Light Propagation in the Quantum Vacuum

dominant contributions in pictures:



in formulae: effective action for photon propagation

$$S_{\text{eff}}[A] = \int_k \left[-\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{1}{2} A_\mu(k)\, \Pi^{\mu\nu}(k)\, A_\nu(k) \right]$$

free Maxwell quantum corrections

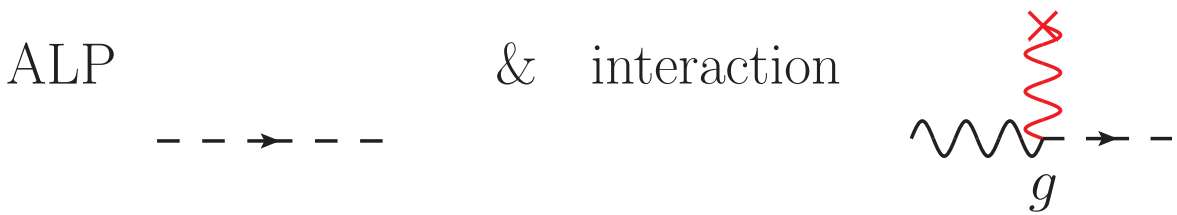
I. Light Propagation in the Quantum Vacuum

Let us account for an external electromagnetic field and repeat the previous discussion of light propagation.

building blocks as before, but in addition:

- new couplings,

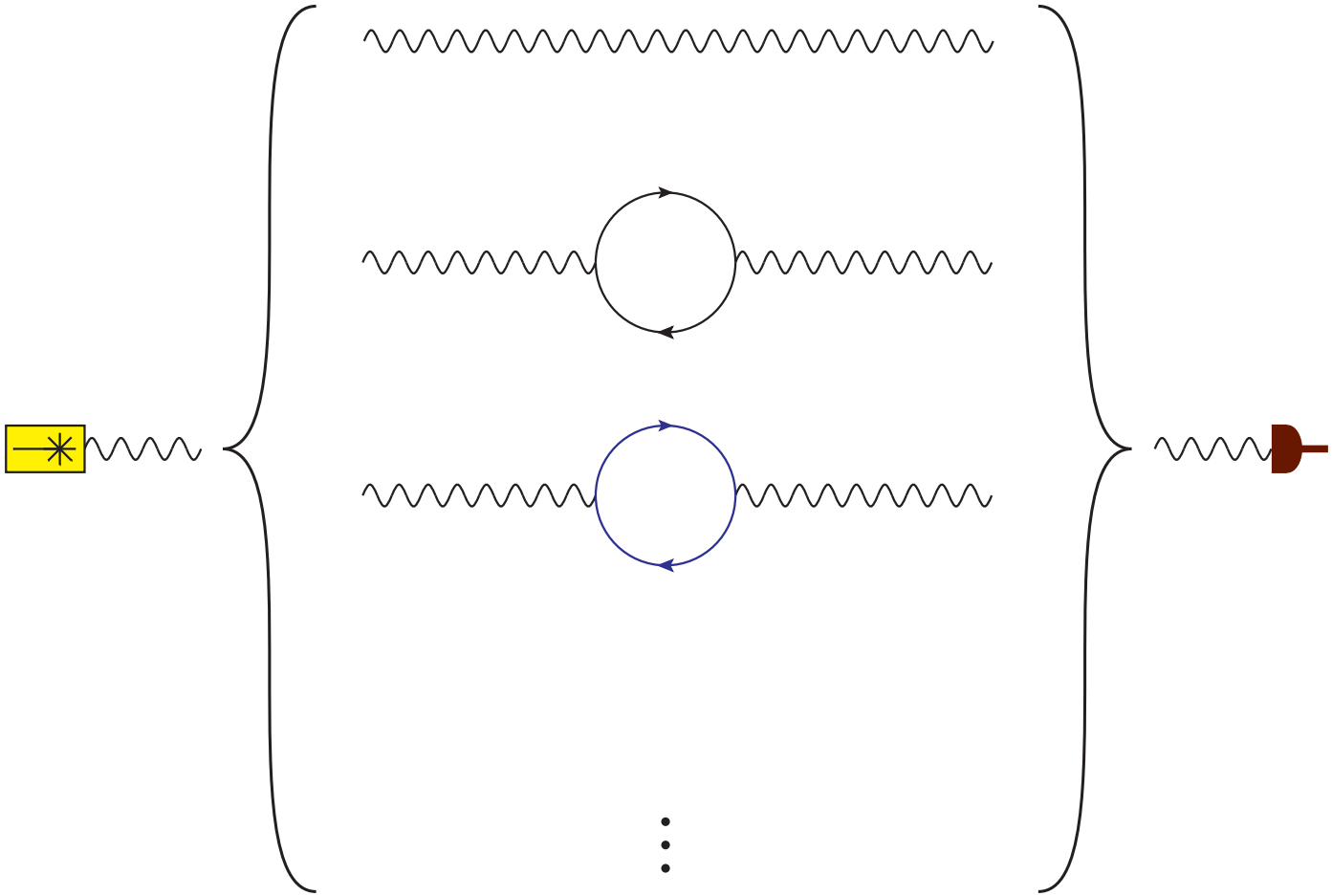
- the external field couples to the quantum fluctuations
- also other intermediate particles are possible, e.g., (pseudo-)scalar Axion-like particles (ALPs),



of unknown mass, tiny coupling g.

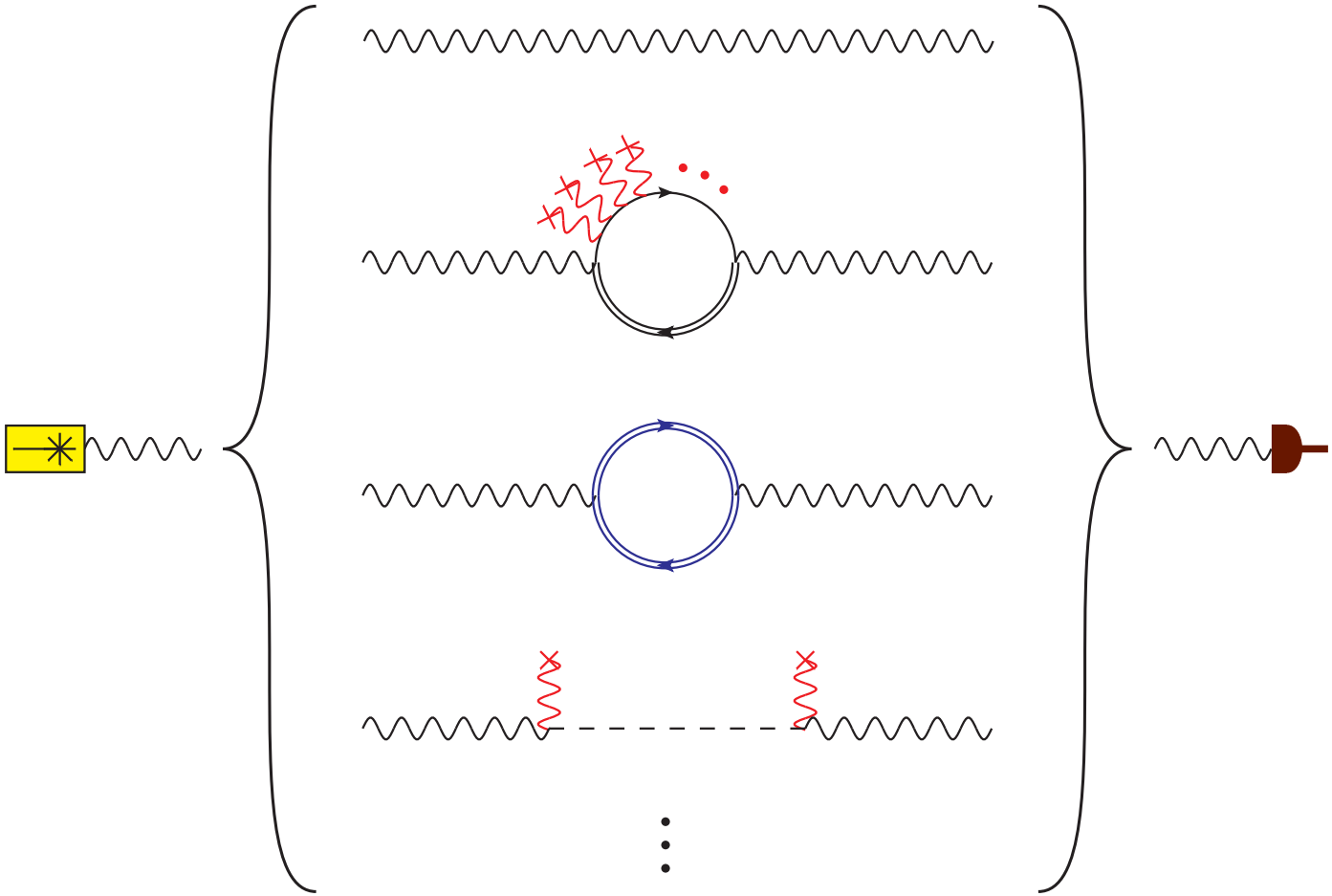
I. Light Propagation in the Quantum Vacuum

dominant contributions in pictures: without external field



I. Light Propagation in the Quantum Vacuum

dominant contributions in pictures: with external field



How to disentangle QED and beyond-the-Standard-Model contributions?

NEUES DEUTSCHLAND

„Ich verstehe Ihre Frage so, daß es in Westdeutschland Menschen gibt, die wünschen, daß wir die Bauarbeiter der Hauptstadt der DDR dazu mobilisieren, eine Mauer aufzurichten. Mir ist nicht bekannt, daß eine solche Absicht besteht. Die Bauarbeiter unserer Hauptstadt beschäftigen sich hauptsächlich mit Wohnungsbau, und ihre Arbeitskraft wird dafür voll eingesetzt.

Niemand hat die Absicht, eine Mauer zu errichten!“

Ulbricht am 15. Juni 1961
auf einer internationalen Pressekonferenz in Ostberlin

Use a wall to suppress the Standard Model “background”!

II. Light-shining-through-walls

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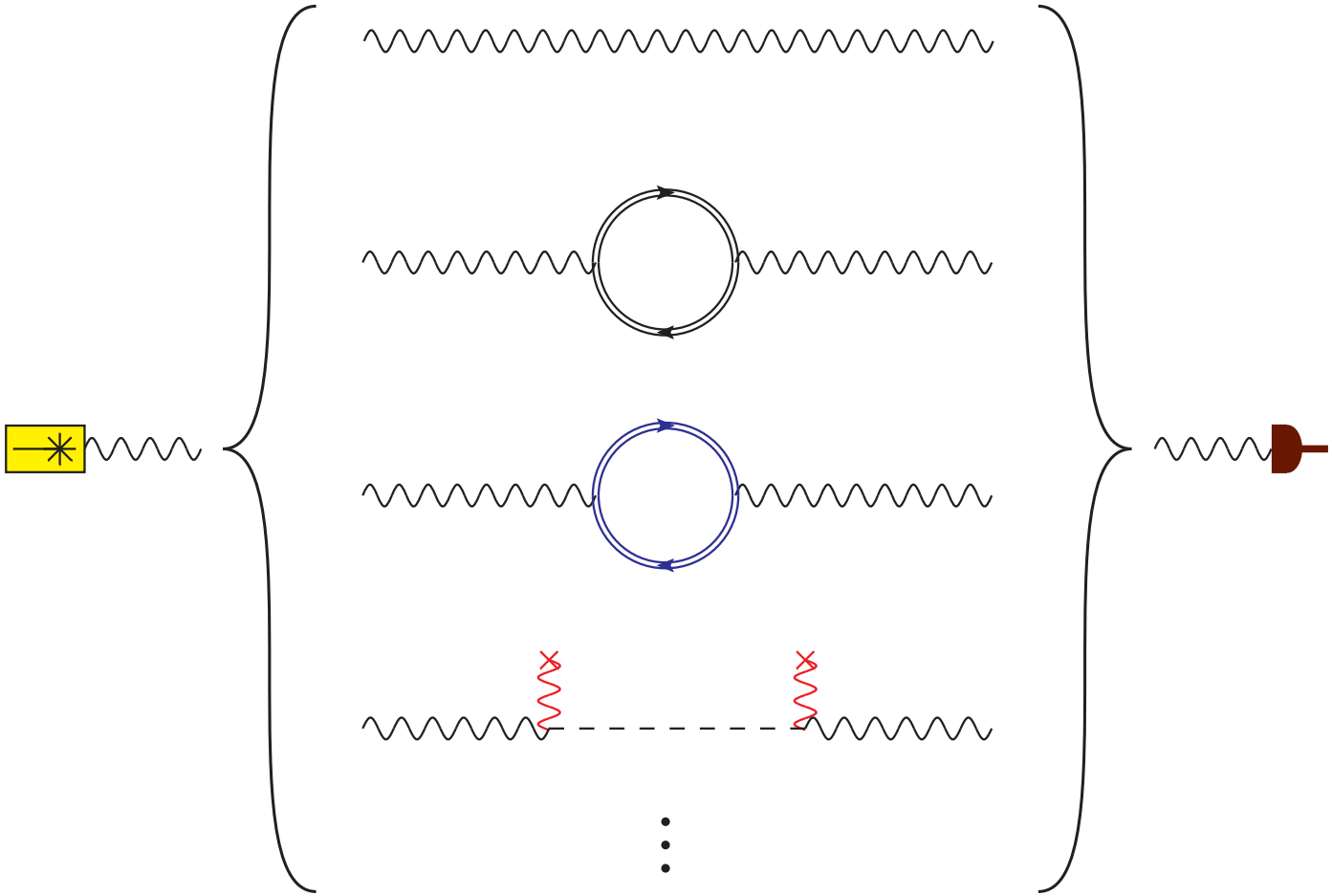
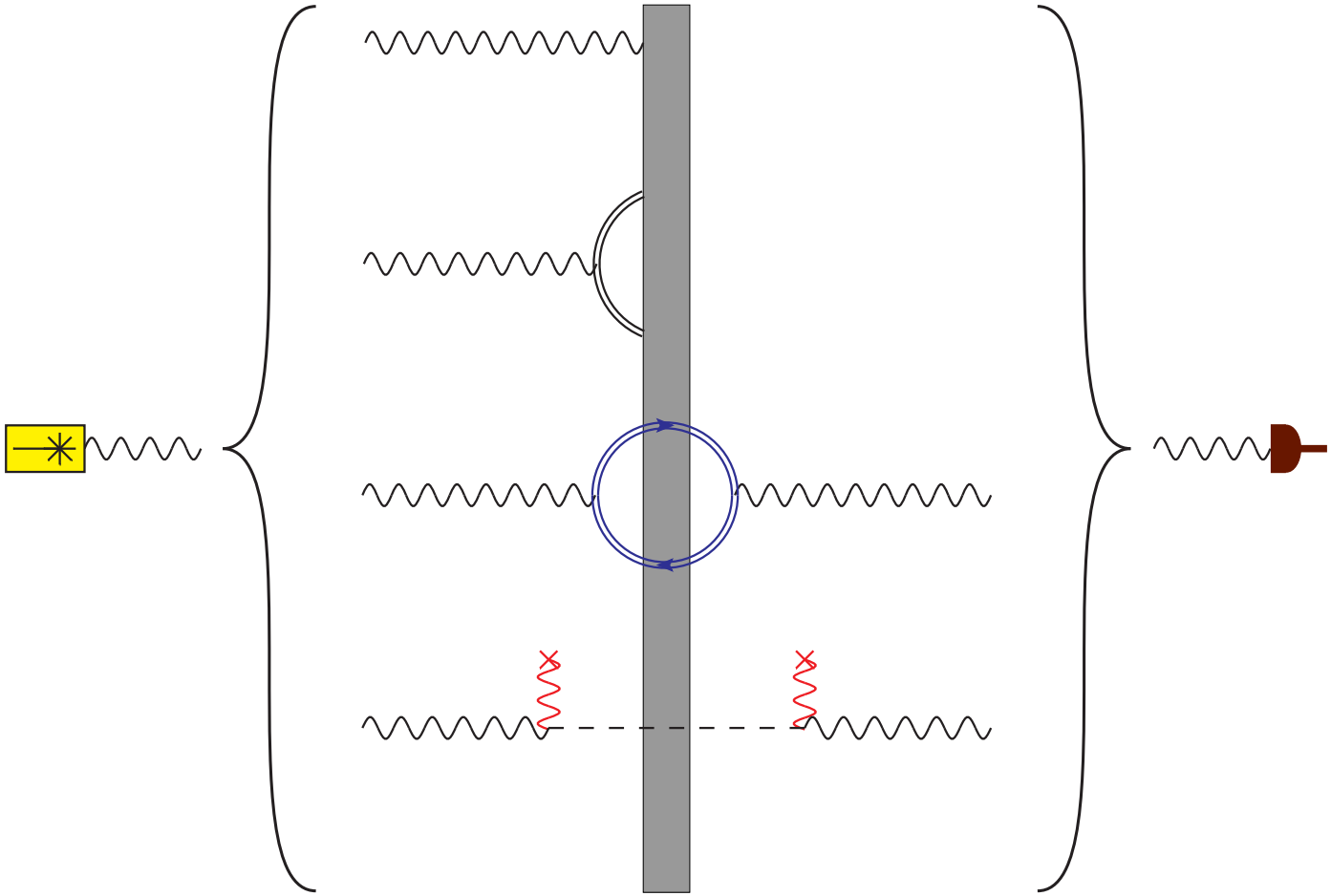
dominant contributions in pictures: with external field



II. Light-Shining-Through-Walls

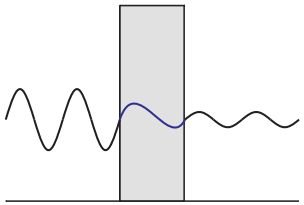
dominant contributions in pictures: with external field and wall



II. Light-shining-through-walls

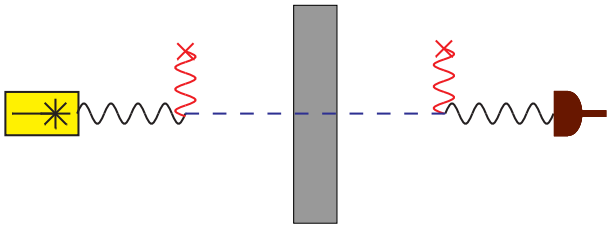
short detour $\rightarrow$ classification of “tunneling mechanisms”:

1st



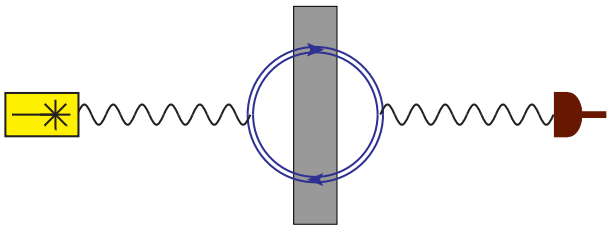
QM tunneling
of potential barrier
(finite height and width)

2nd



on-shell tunneling
classical field theory

3rd kind



off-shell tunneling
“manifestly quantum”

[H. Gies & J. Jaeckel; JHEP 0908:063 (2009)]

III. Tunneling of the 3rd kind

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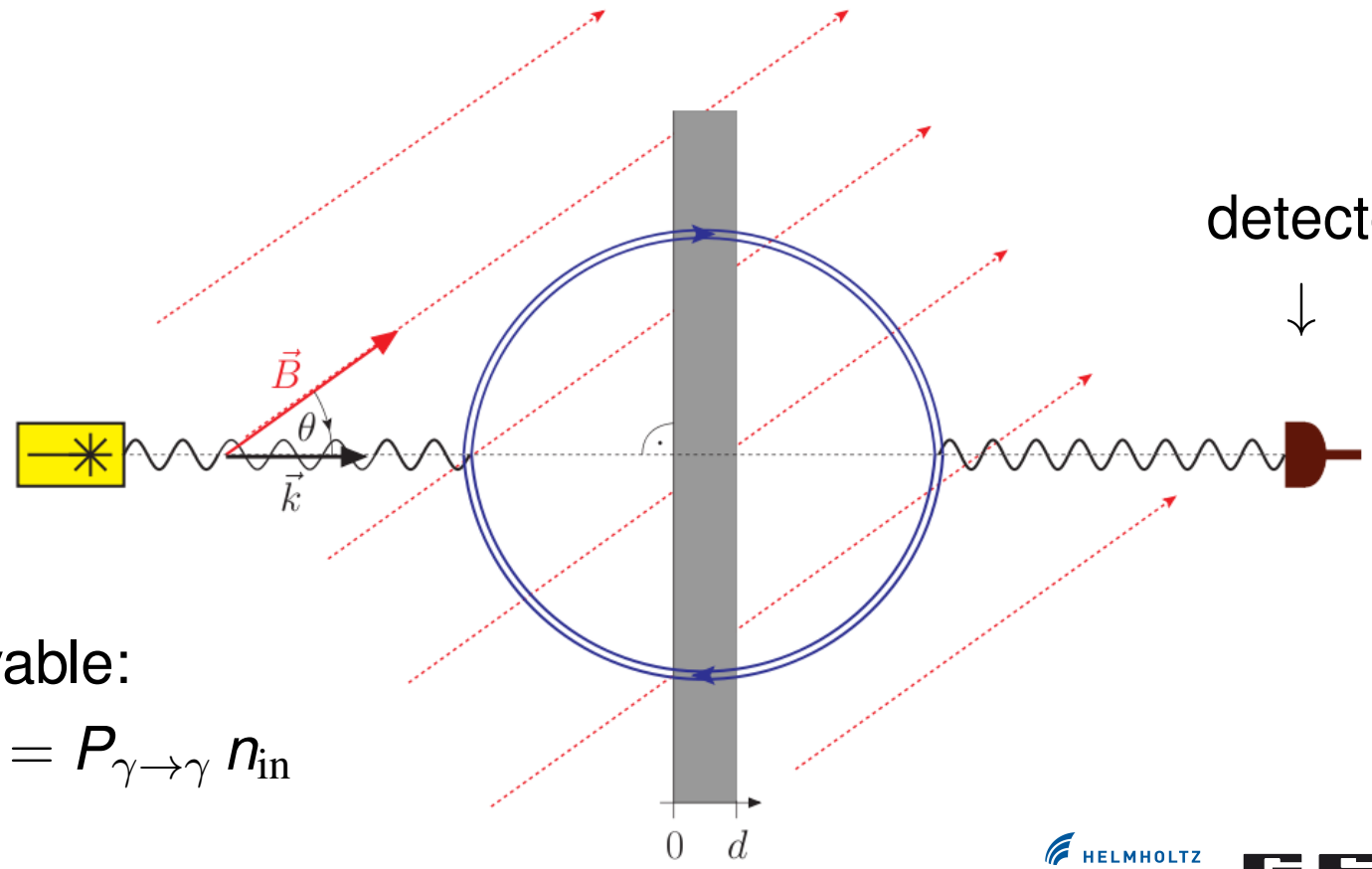
the setting:

- adjustable parameters: $\vec{B}$, $\hat{\vec{k}}$, ω, d and also $n_{\rm in}/n_{\rm out}$
- to be explored: (m_ϵ, ϵ) – "plane"



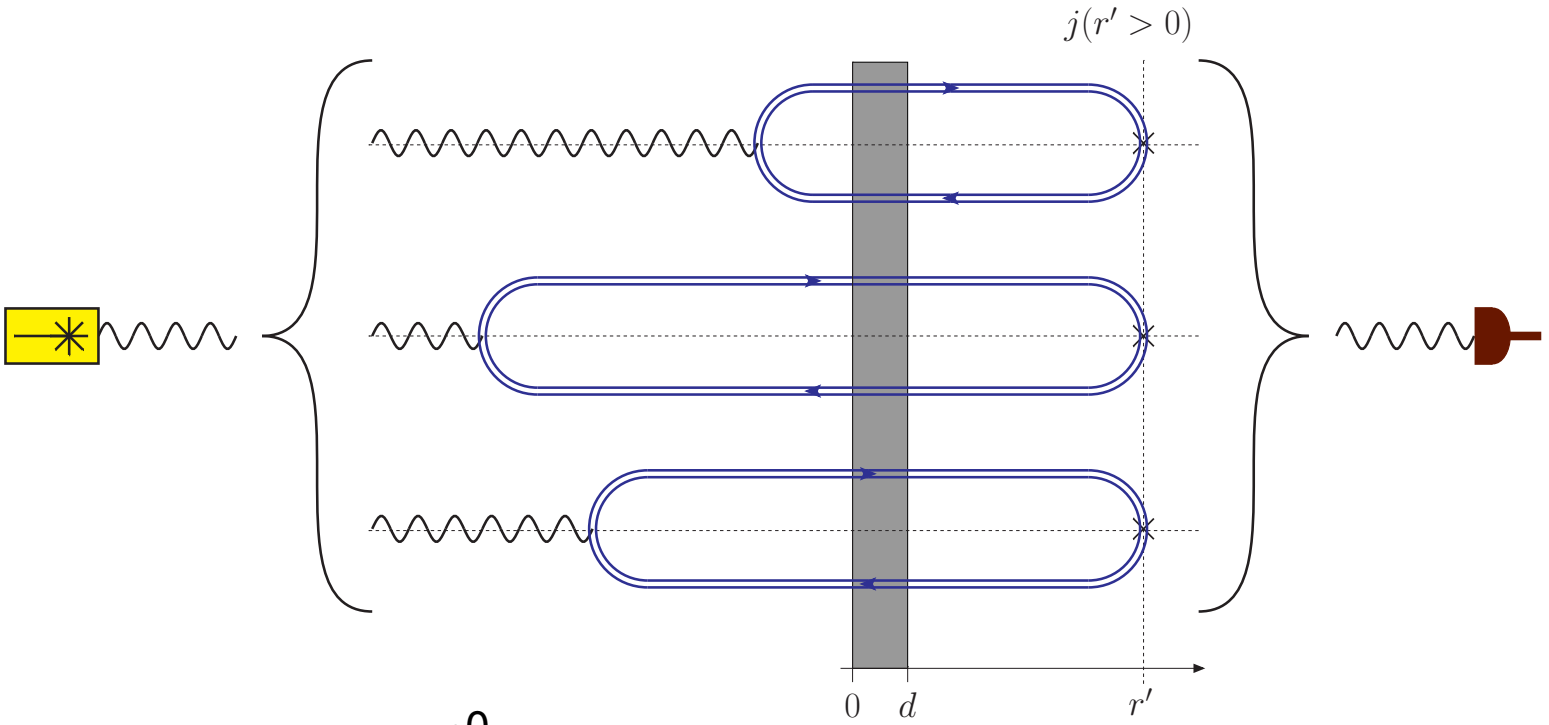
observable:

$$n_{\rm out} = P_{\gamma\to\gamma}\, n_{\rm in}$$

III. Tunneling of the 3rd kind

the calculation: $\rightarrow \quad P_{\gamma\to\gamma}(d, \vec{B}, \hat{\vec{k}}, \omega, m_\epsilon, \epsilon e)$

1. determine the induced current $j(r' > 0)$, for reflecting boundary conditions on the left hand side of the wall,



$$j_p(r', \omega|\vec{B}) = \int_{-\infty}^{0} \mathrm{d}r\, a(\omega) \sin(\omega\, r)\, \Pi_p(r'-r, \omega|\vec{B})\,, \quad (p = 1, 2, 3)\,.$$

III. Tunneling of the 3rd kind

2. determine the outgoing photon wave, assuming absorbing boundary conditions on the right hand side of the wall,

$$A_p^{\text{out}}(r'' \gg d, \omega|\vec{B}) = i \int_d^\infty \mathrm{d}r' \, \frac{e^{i\omega(r''-r')}}{2\omega} \, j_p(r', \omega|\vec{B}) \,,$$

3. evaluate the photon-to-photon transition probability,

$$P_{p,\gamma\to\gamma} = \lim_{r''\to\infty} \left| \frac{A_p^{\text{out}}(r'', \omega|\vec{B})}{a(\omega)} \right|^2 ,$$

4. and finally use it in the equation

$$n_{\text{out}} = P_{p,\gamma\to\gamma} \, n_{\text{in}} \quad \leftrightarrow \quad 1 = \left(\frac{n_{\text{in}}}{n_{\text{out}}} \right) P_{p,\gamma\to\gamma}$$

to obtain the exclusion plot.

III. Tunneling of the 3rd kind

explicit parameter values in our analysis: (cf. ALPS@DESY)

$$|\vec{B}| = 5\mathrm{T}$$

$$\omega = 2.33\mathrm{eV}\ (\widehat{=}\ \lambda = 532\mathrm{nm})$$

$$n_{\mathrm{in}}/n_{\mathrm{out}} = 10^{25}$$

$$d = \mathcal{O}(\mu\mathrm{m}) \ldots \mathcal{O}(\mathrm{cm})$$

$$\theta = \sphericalangle(\vec{k}, \vec{B}) \gtrapprox 0$$

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$\leftrightarrow$ "on-shell" effects typically minimal for $\theta = 0$

$\leftrightarrow$ **but** we tunnel the wall "off-shell"

IV. Results

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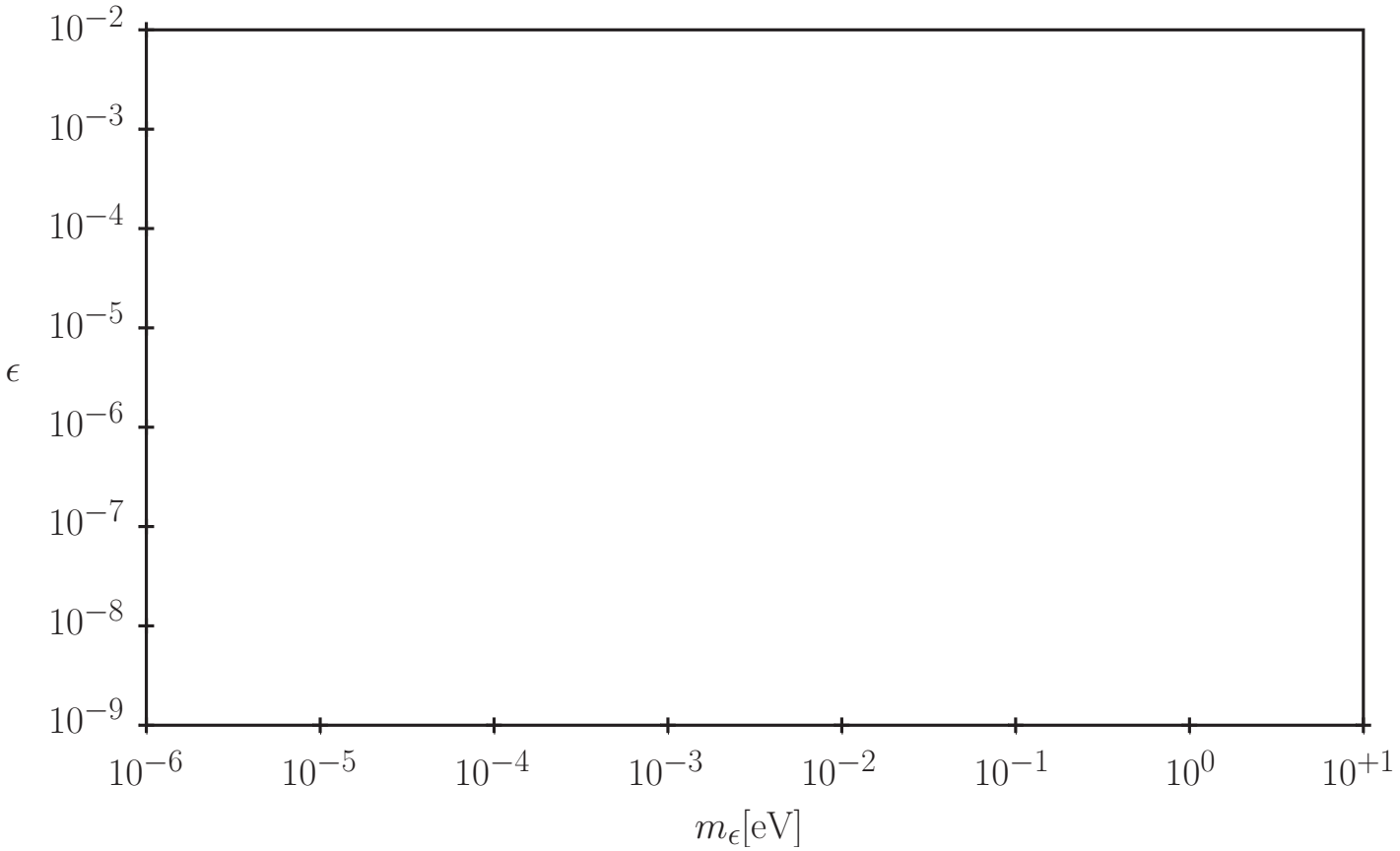
Exclusion Plot: (for Dirac-fermionic MCPs)



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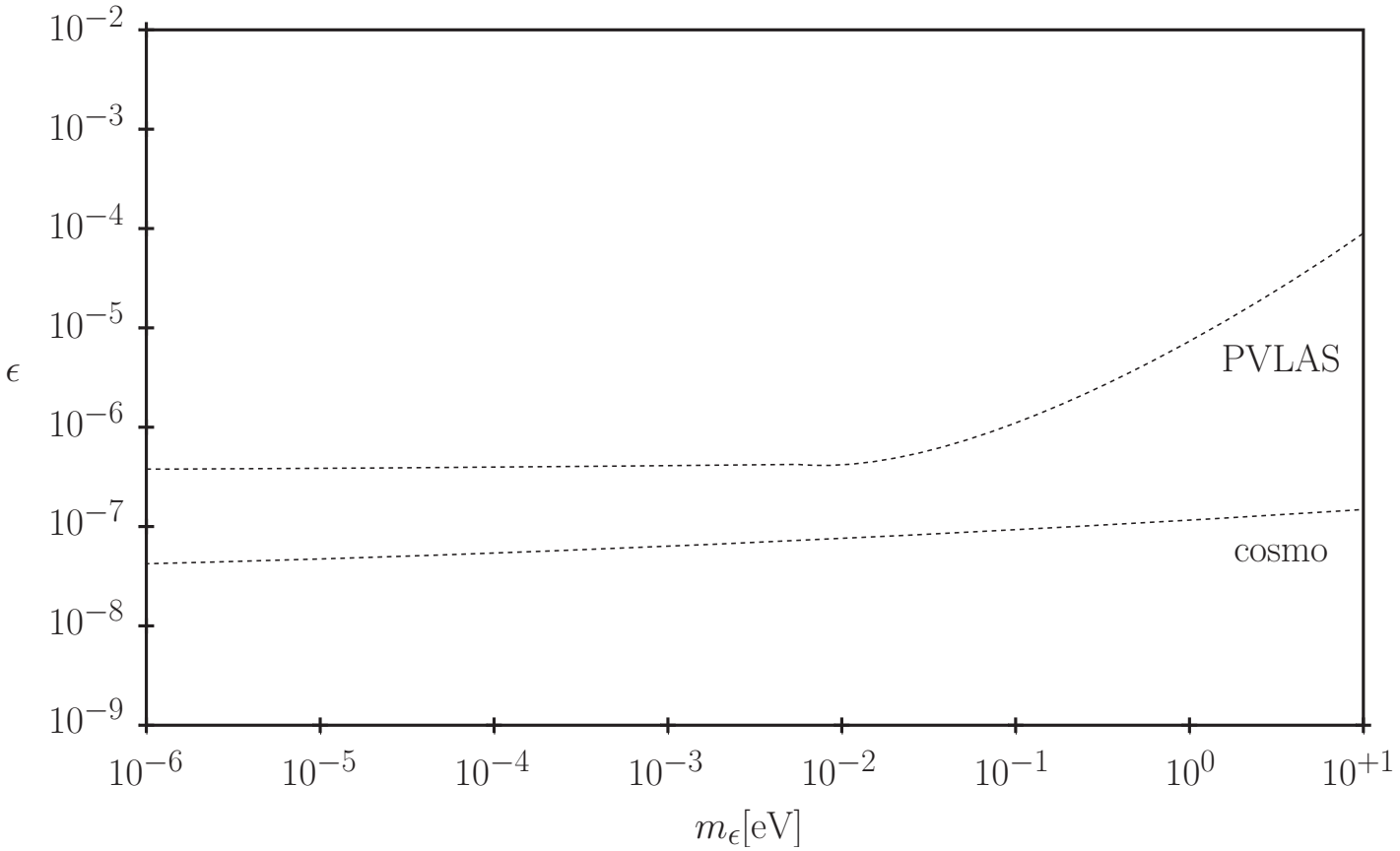

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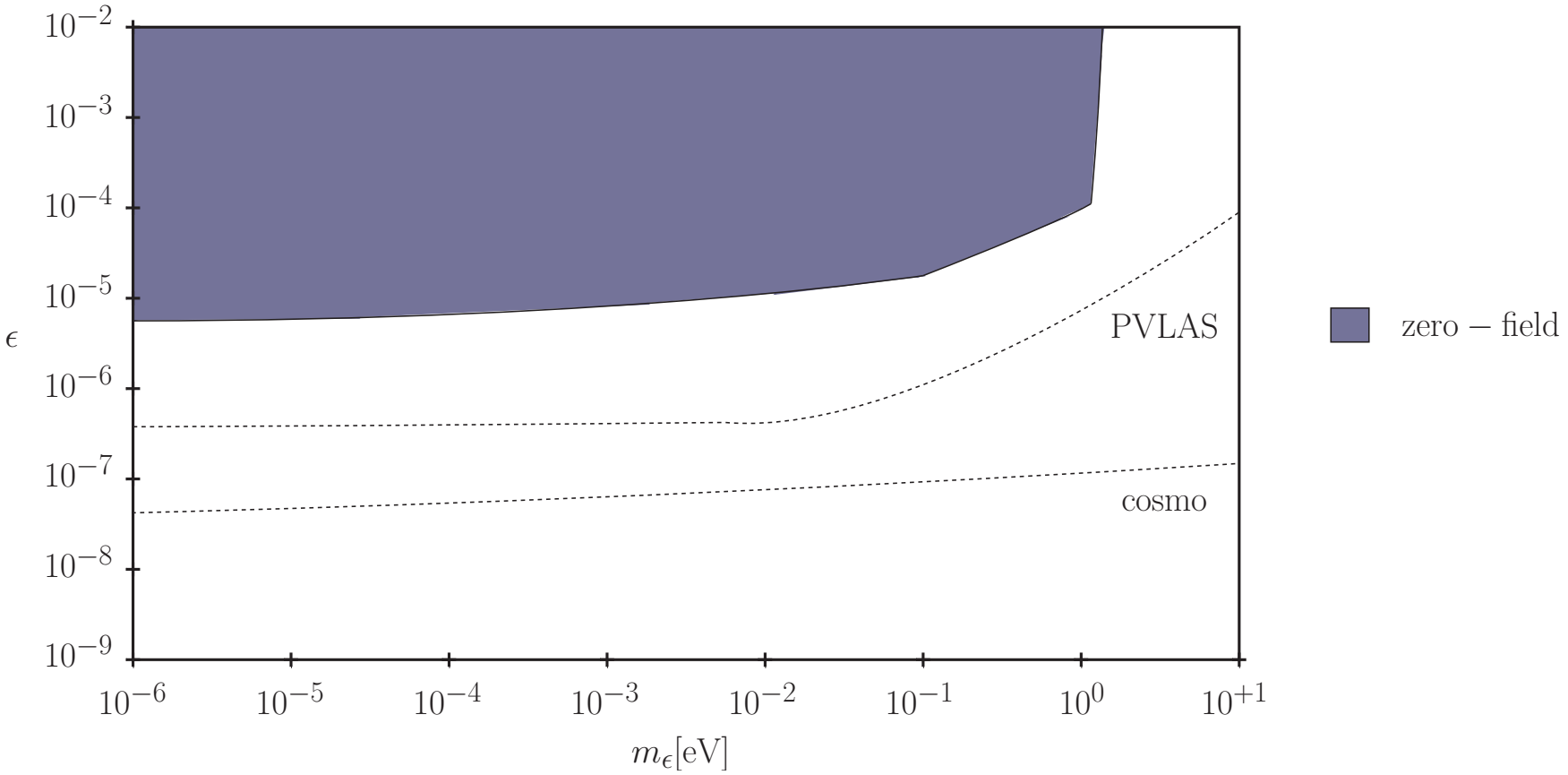

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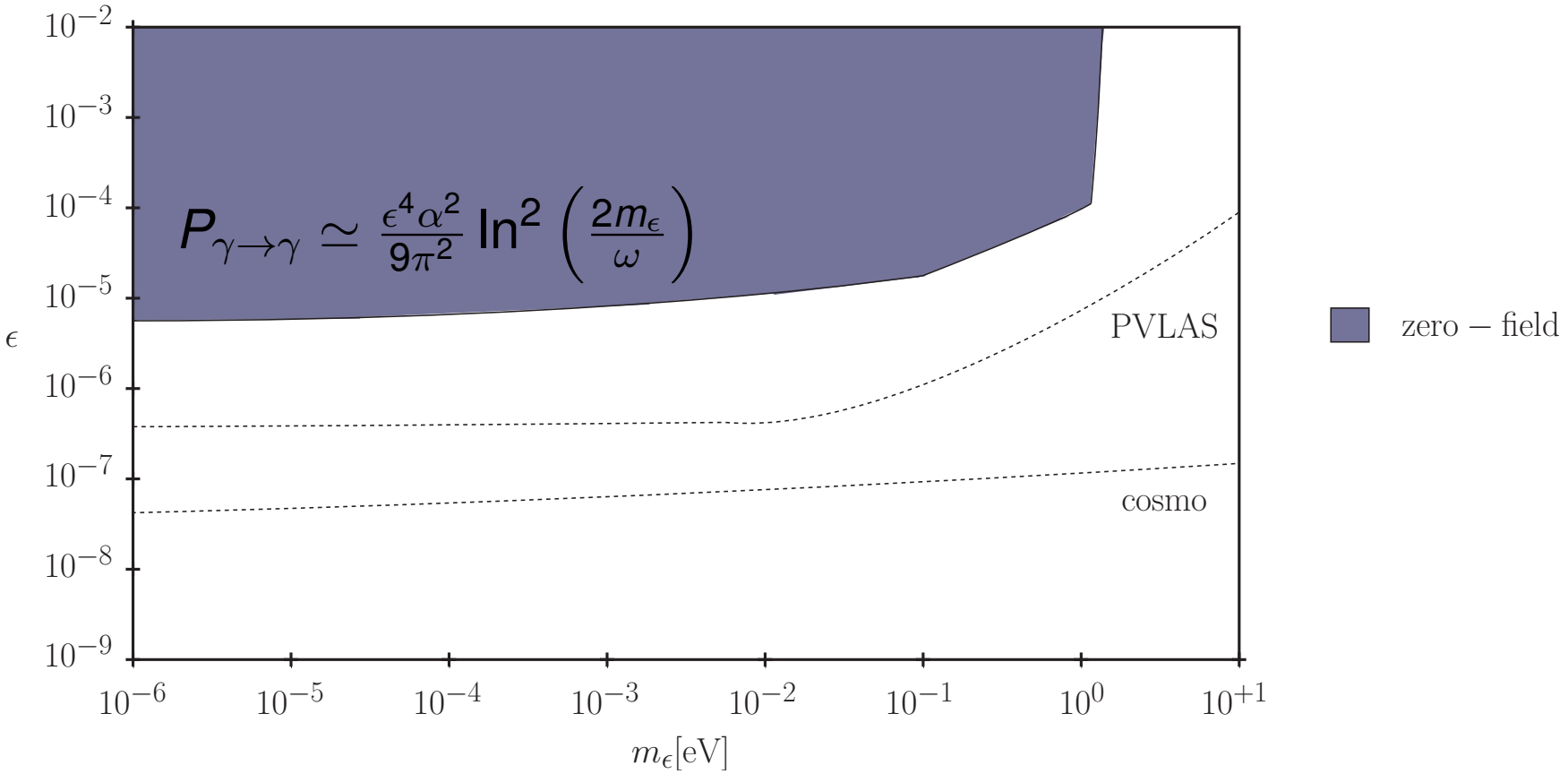

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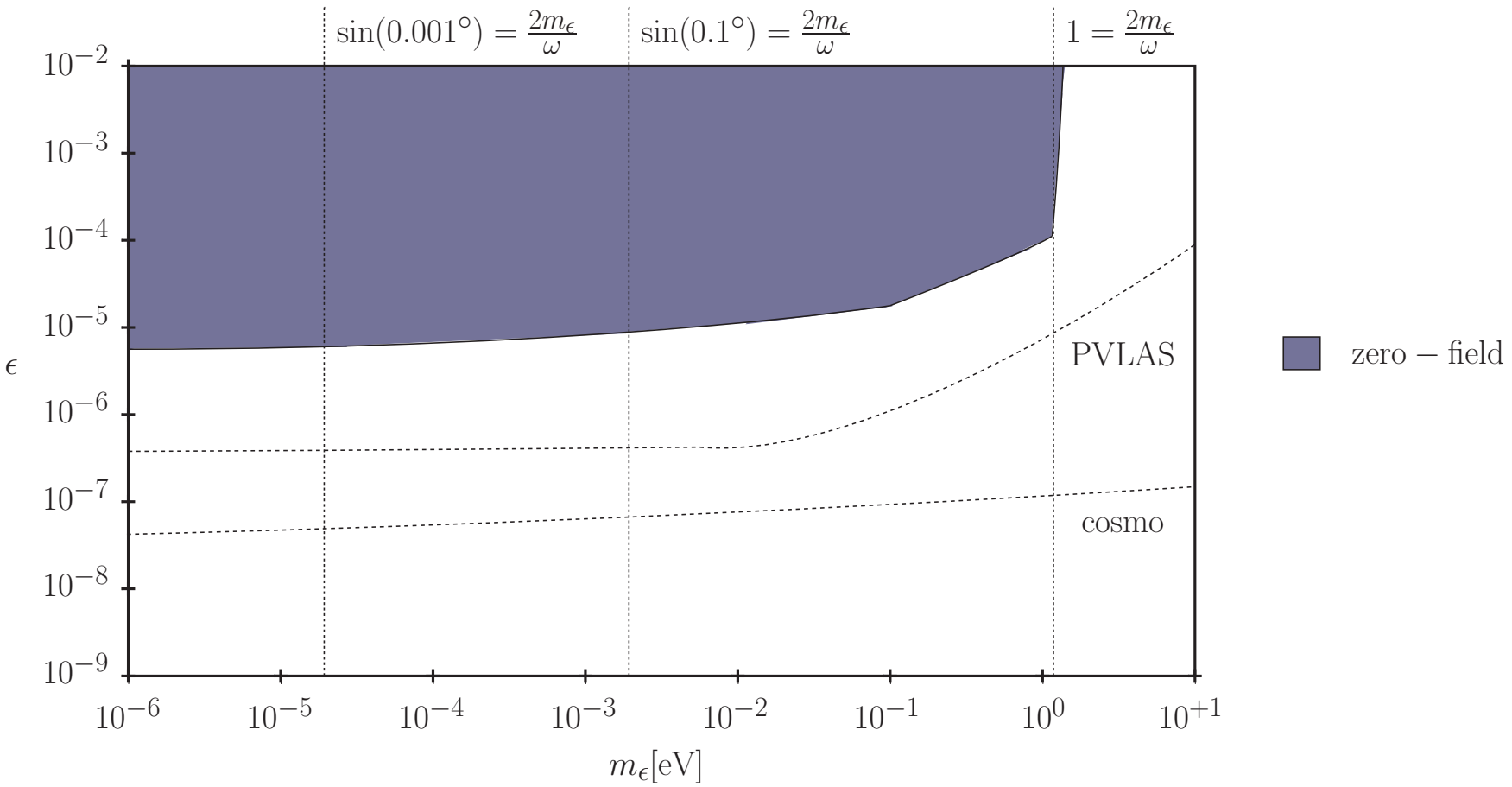

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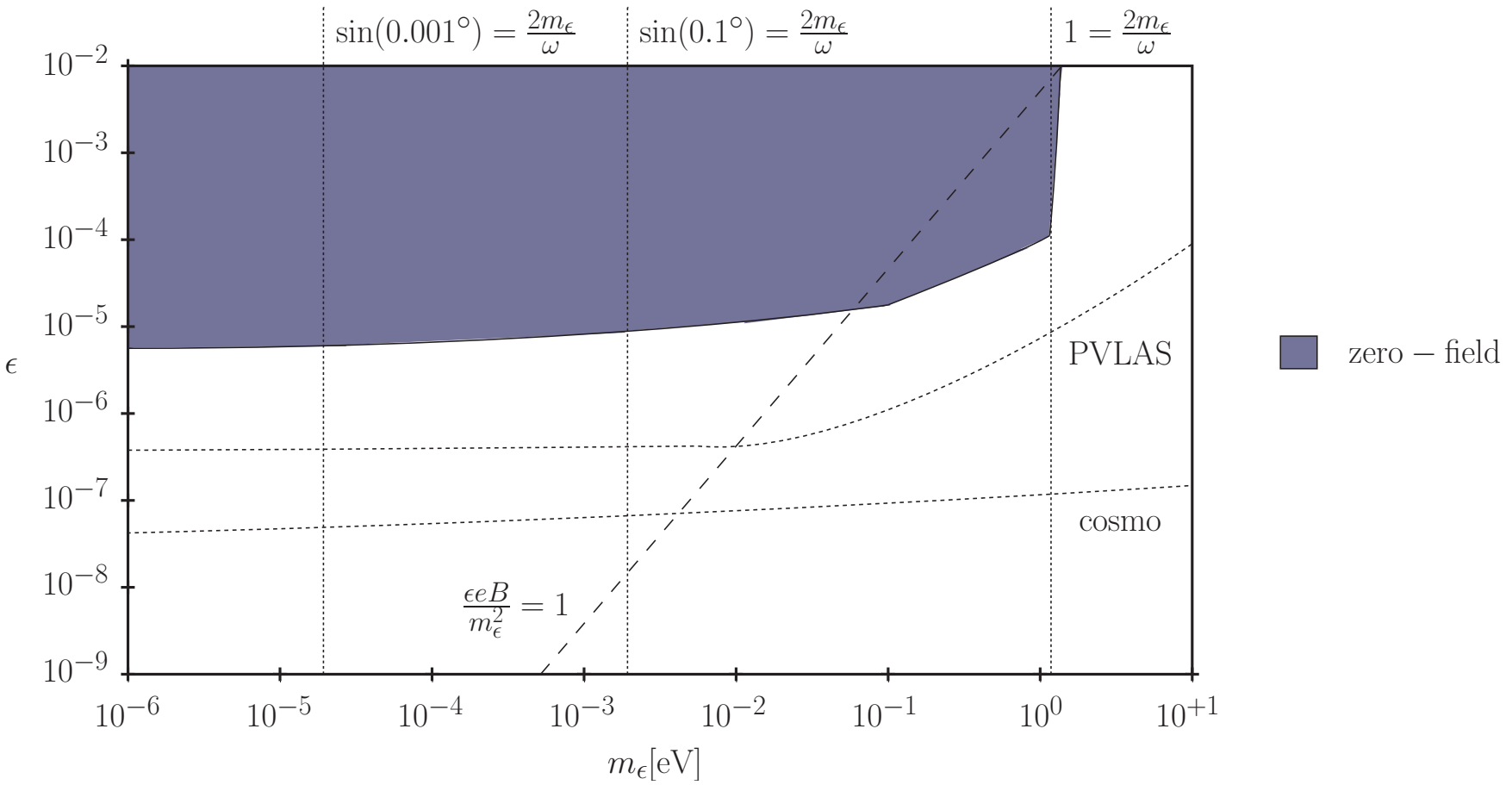

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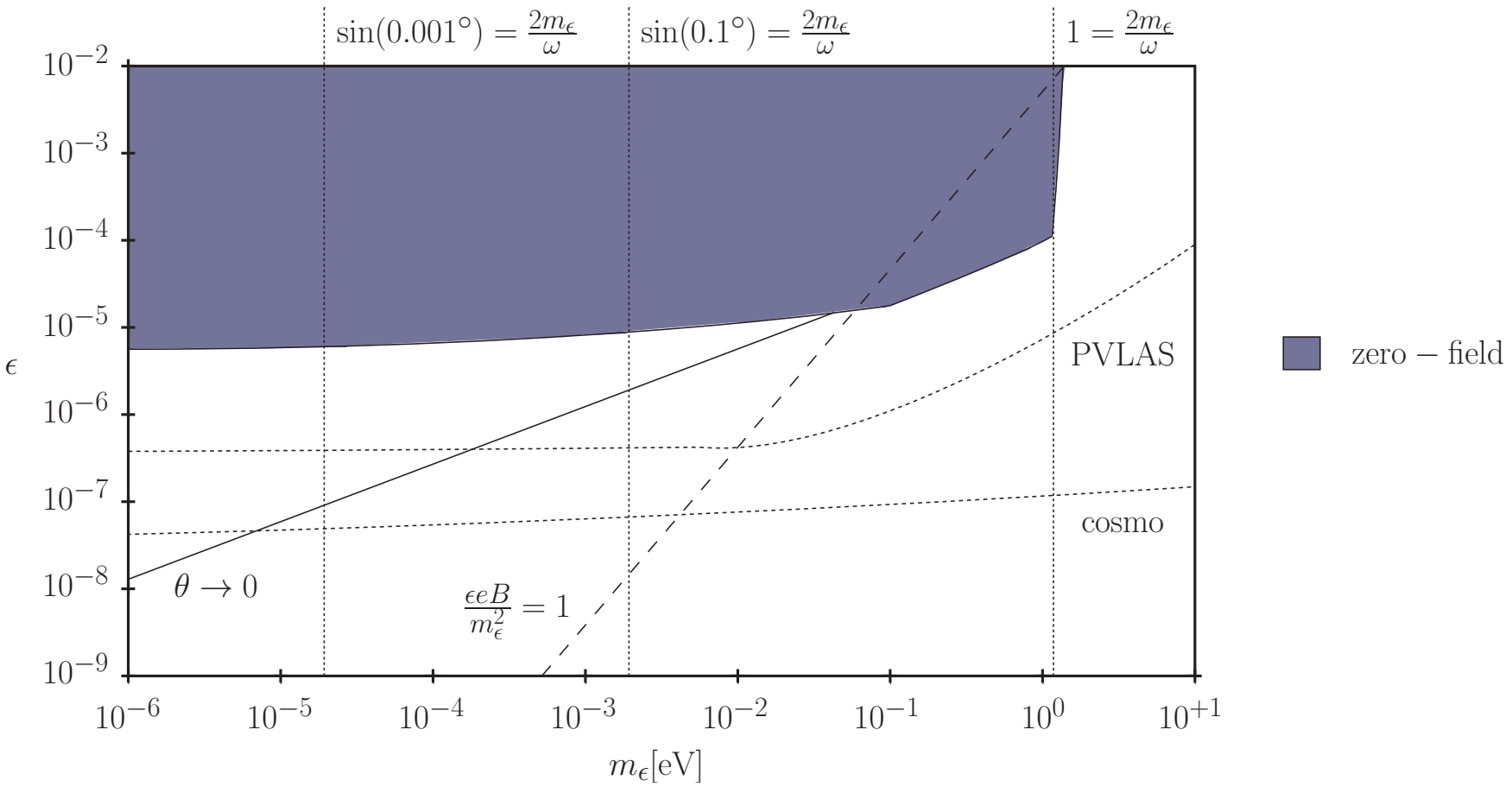

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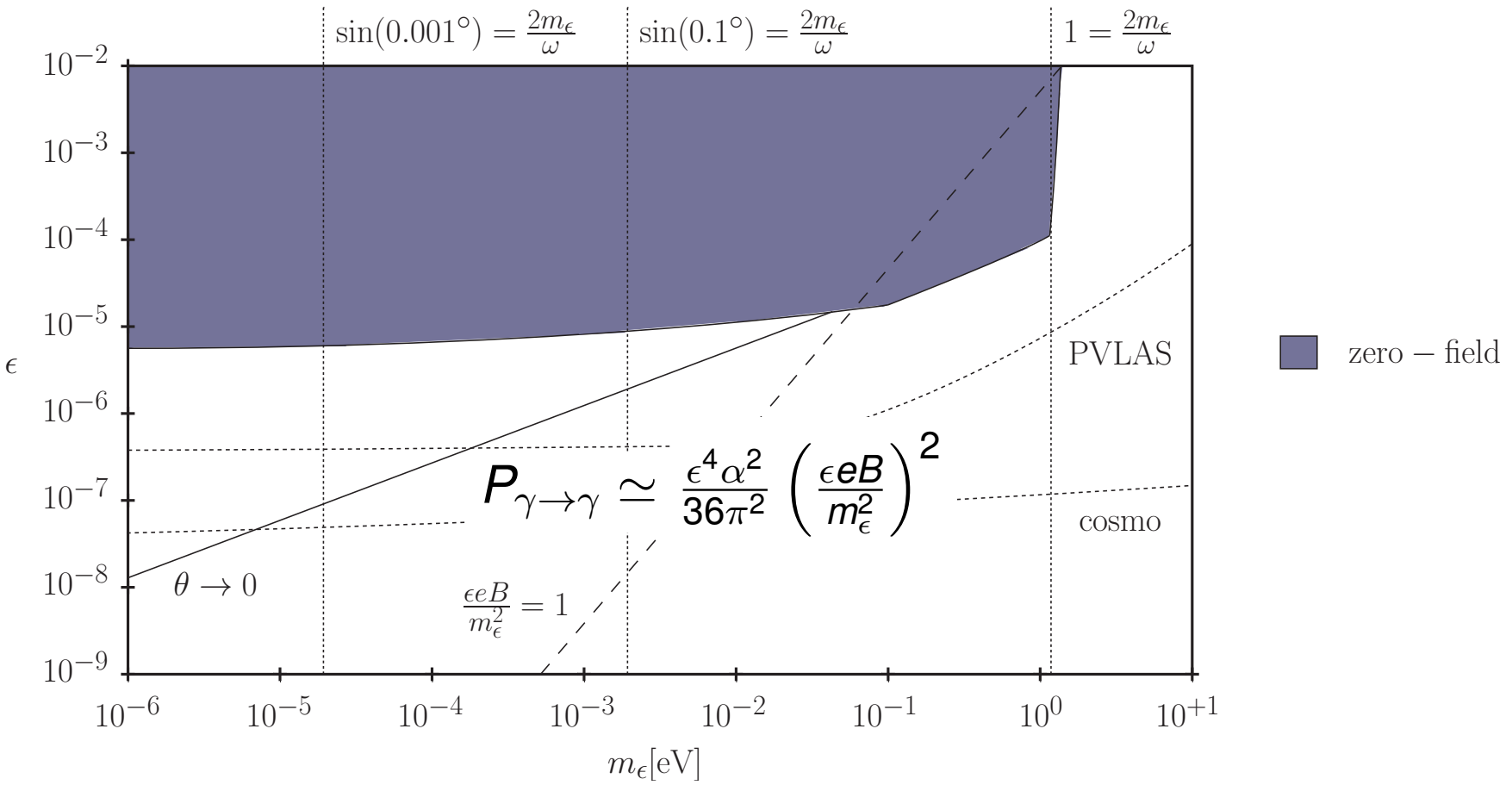

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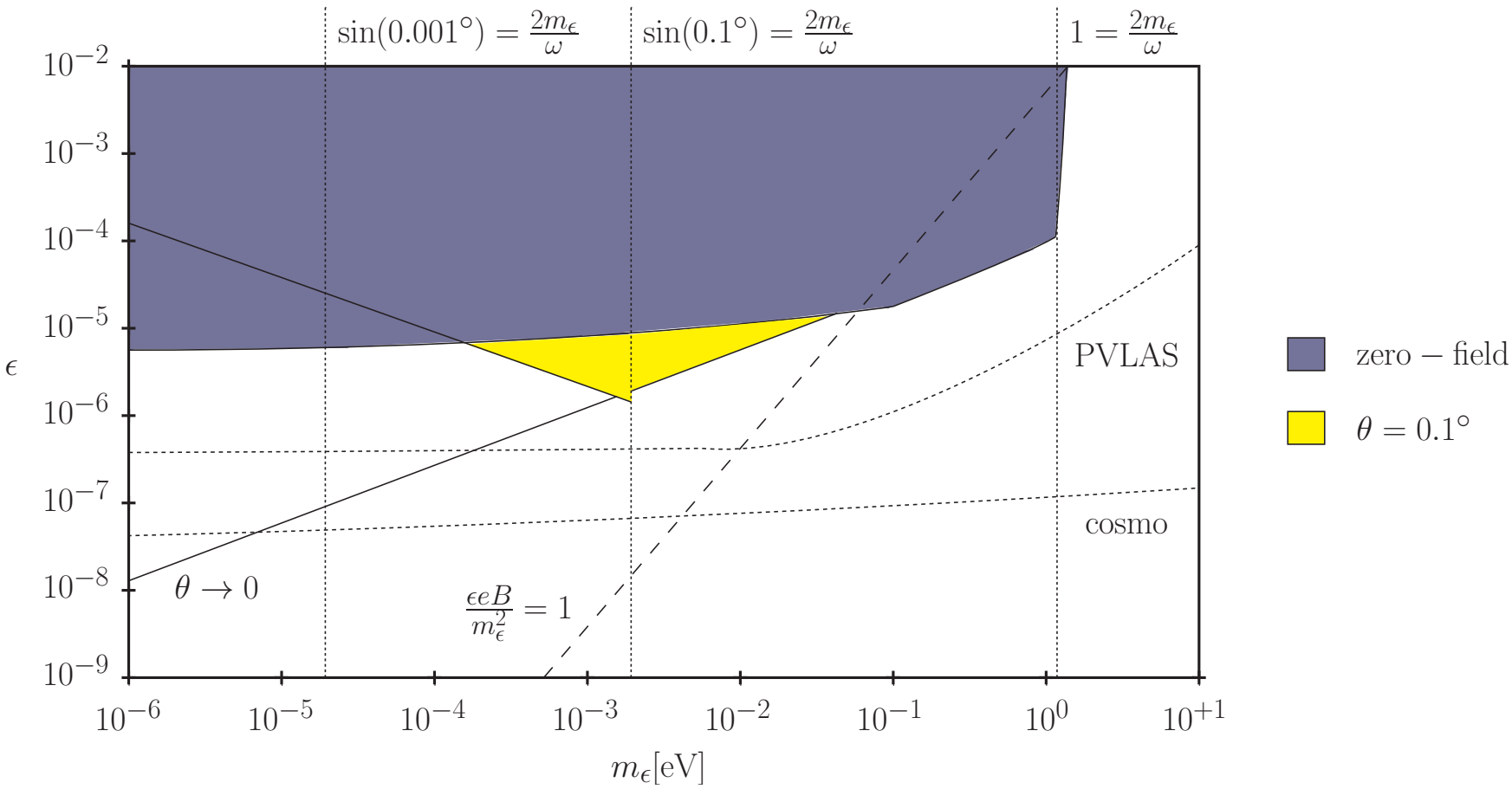

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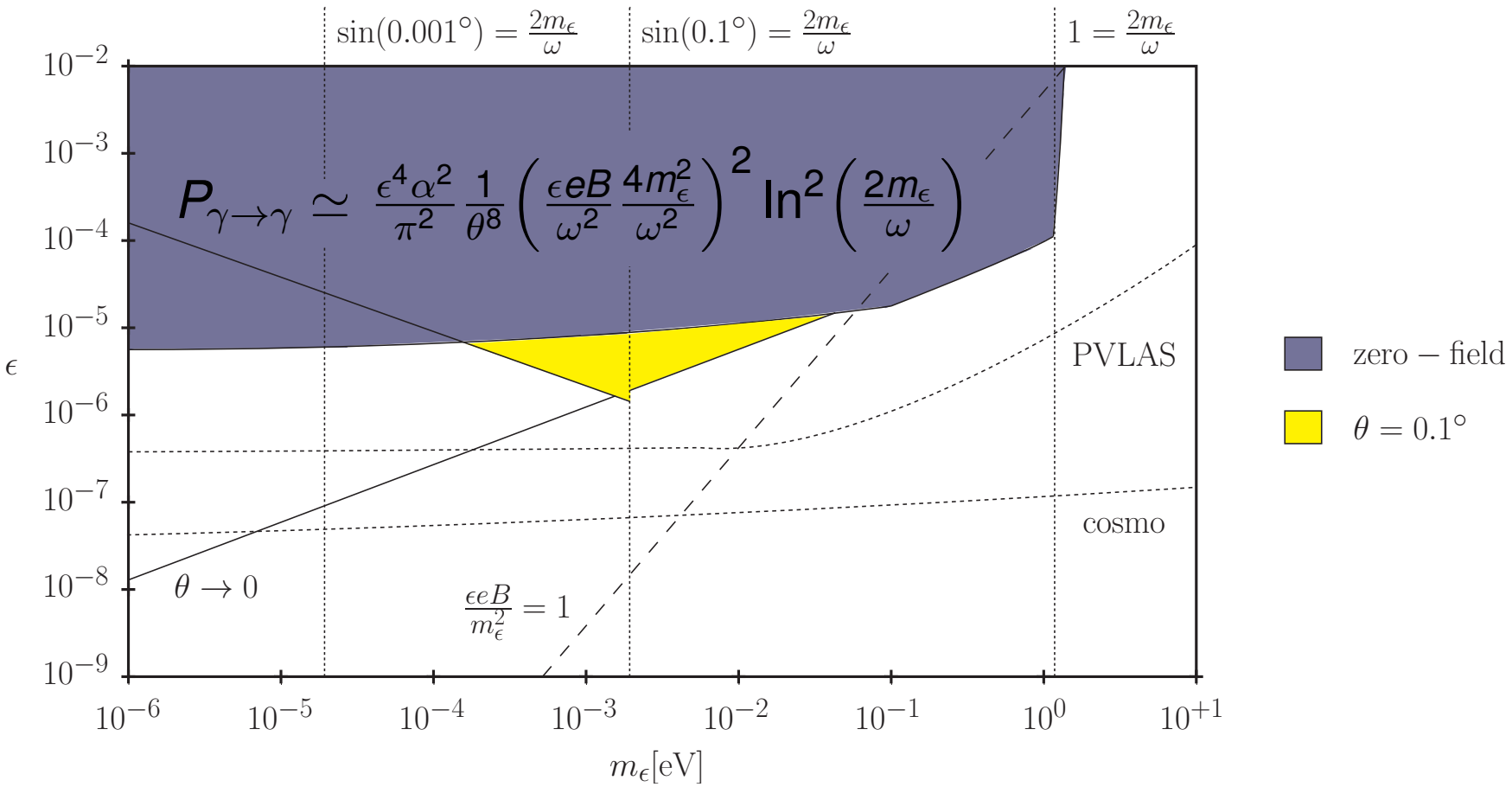

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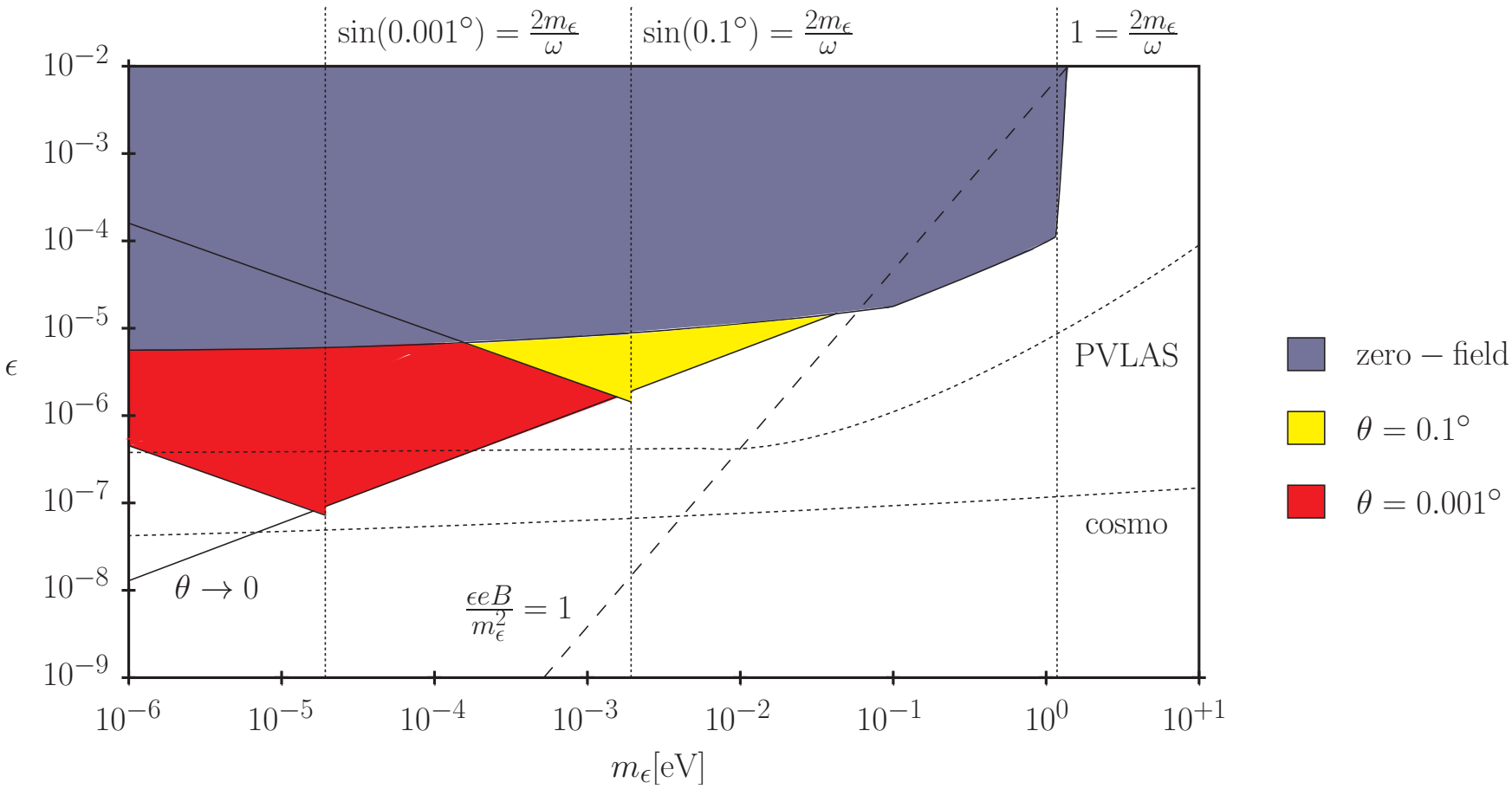

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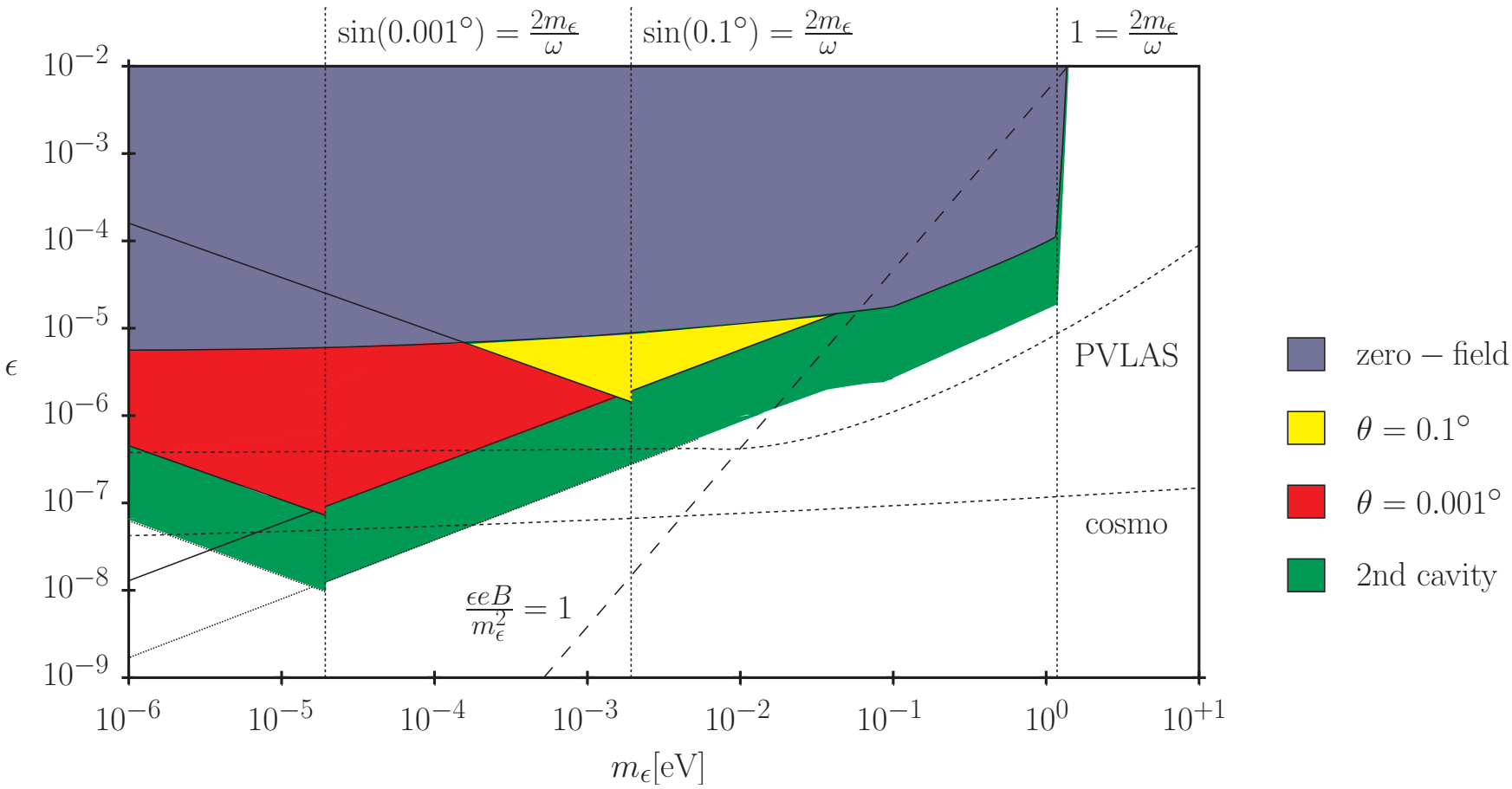

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We have generalized the tunneling of the 3rd kind scenario for MCPs to account for a homogeneous external magnetic field,

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- the photon polarization tensor $\Pi^{\mu\nu}(k|\vec{B})$ at 1-loop accuracy is a complicated object.
- As our scenario involves a Fourier transform of this object, information in the full momentum regime is required.

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Awaiting its experimental realization!

The End ...

Thank you for your attention!

References:

B. Döbrich, H. Gies, N. Neitz, F.K.;

arXiv:1203.2533 [hep-ph] & arXiv:1203.4986 [hep-ph].