PROSPECTS FOR ALPs SEARCHES

FEDERICA GIACCHINO

PADME

General Meeting

8-9 January 2019

PADME PHYSICS: looking for …

DARK PHOTON: vector particle coming from new extra U(1). Coupled with SM by mixing with SM photon or vector interaction with fermions.

M. Raggi & V. Kozhuharov already analysed (looking in the PROPOSAL)

SIMILAR RESEARCH IN PADME FOR

AXION-LIKE PARTICLE: pseudo-scalar particle as axion but alp mass and decay constant are independent parameters because not any CP strong violation to solve.

ALP Analysis

Lagrangian: $$\mathcal{L} \supset -\frac{1}{4} g_{a\gamma\gamma} F_{\mu\nu}\tilde{F}^{\mu\nu} - i g_{aee} m_e a \bar{\psi}\gamma^5\psi$$

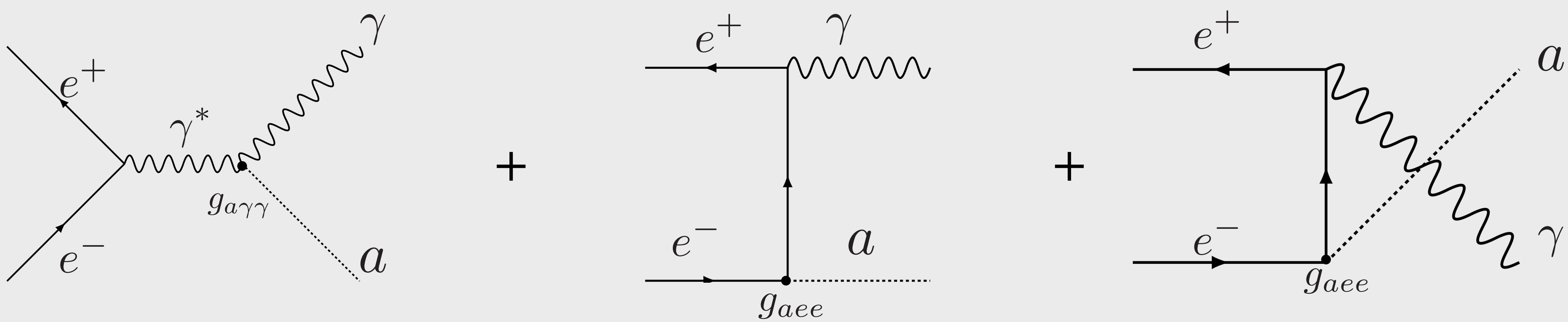
electron mass

Two type of processes studied for PADME analysis:

- Production of alp-photon: $e^+e^- \to a\gamma$
- Production photon-photon: $e^+e^- \to \gamma\gamma$

Annihilation into alp-photon

Cross-section $e^+e^- \to a\gamma$



FREE PARAMETERS to test: **m_a, g_{aee}, $g_{a\gamma\gamma}$**

$$\sigma = \alpha\, g_{a\gamma\gamma}^2 \frac{(s+2m_e^2)(s-m_a^2)^3}{24\,\beta\, s^4} + \alpha\, g_{aee}^2 m_e^2 \frac{-2m_a^2\,\beta\, s + (s^2+m_a^4-4m_a^2m_e^2)\log\frac{1+\beta}{1-\beta}}{2(s-m_a^2)s^2\beta^2}$$

$$+\ \alpha\, g_{a\gamma\gamma}\, g_{aee}\, m_e^2 \frac{(s-m_a^2)^2}{2\,\beta^2\, s^3} \log\frac{1+\beta}{1-\beta}$$

with $\beta = \sqrt{1-\frac{4m_e^2}{s}}$. $\quad s = 2m_e(E+m_e)$

Annihilation into alp-photon

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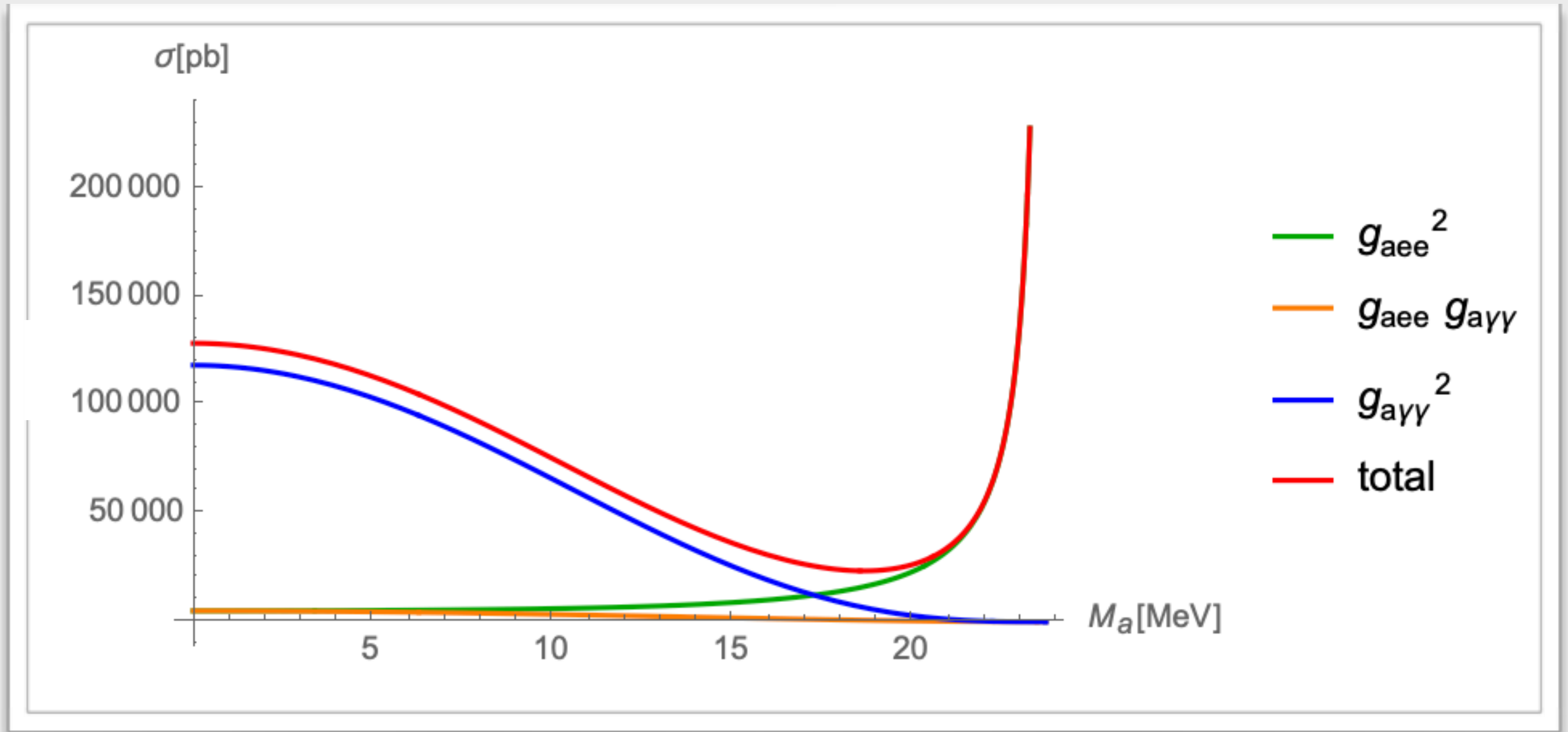
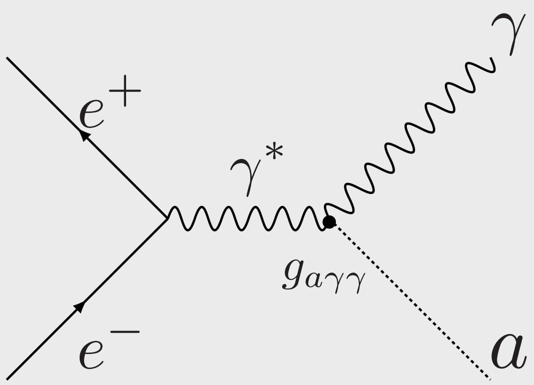
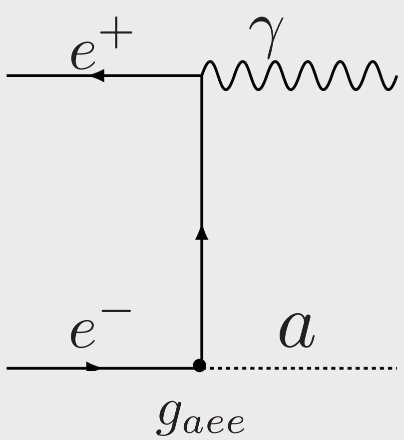


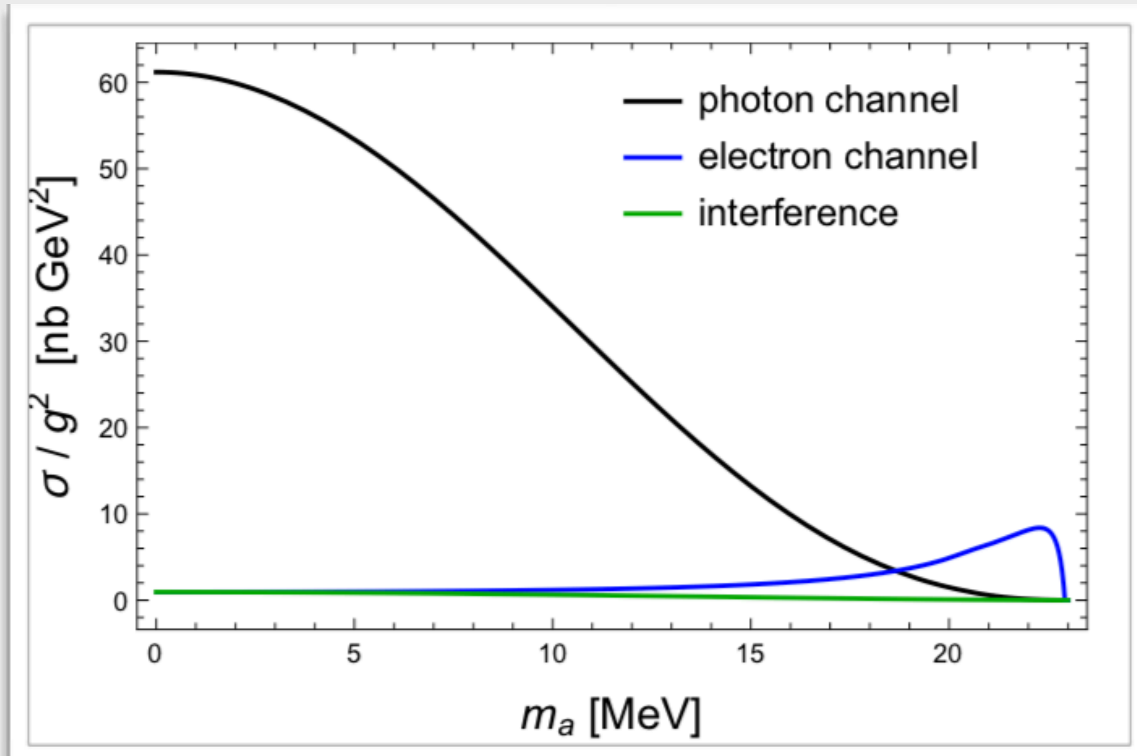




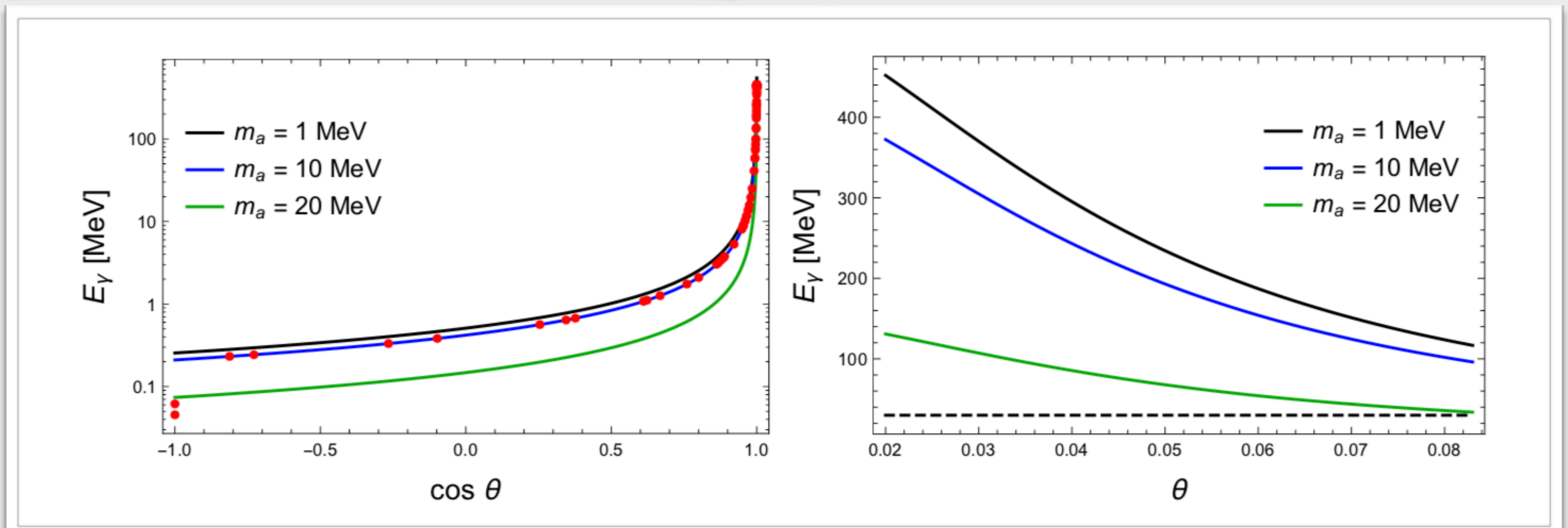
$g_{aXX} = 1$	$M_a = 1\,MeV$	$M_a = 10\,MeV$	$M_a = 20\,MeV$
$\sigma_f(pb)$	5077.77	6074.66	23141.7
$\sigma_\gamma(pb)$	118013	65959.4	2865.08
$\sigma_{int}(pb)$	5053.09	3428.63	423.67
$\sigma_{tot}(pb)$	128144	75462.69	26430.45

M_a alp mass

Annihilation into alp-photon



Cross-section $e^+e^- \to a\gamma$ with cuts 0.02< θ <0.083 and E_γ >30 GeV



Annihilation into alp-photon

$$e^+e^- \to a\gamma$$

Estimation of probability that **one single positron** annihilate in photon-alp

#$_{tot}$ of e$^-$ on target

Avogadro Number

$$P = N_e\sigma_{tot}(cm^2) = 6d_{target}Na\frac{\rho}{A}\sigma_{tot}$$

diamond density = 3.5 g/cm^3

atomic number= 12 g/mol

target thickness=100μm

$M_a = 1\,MeV$	1.34551×10^{-9}
$M_a = 10\,MeV$	7.92358×10^{-10}
$M_a = 20\,MeV$	2.77519×10^{-10}

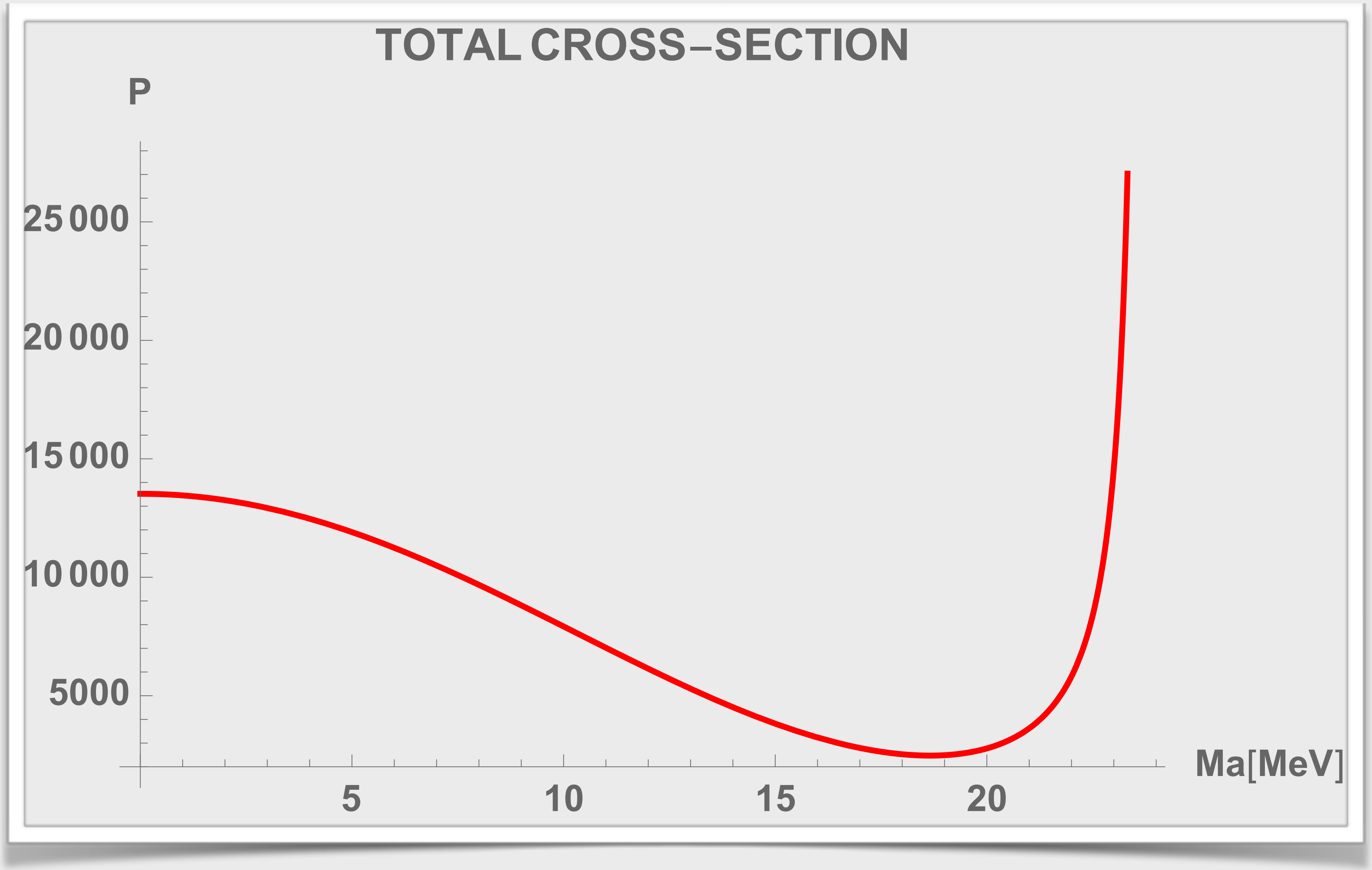
$$g_{aXX} = 1GeV^{-1}$$

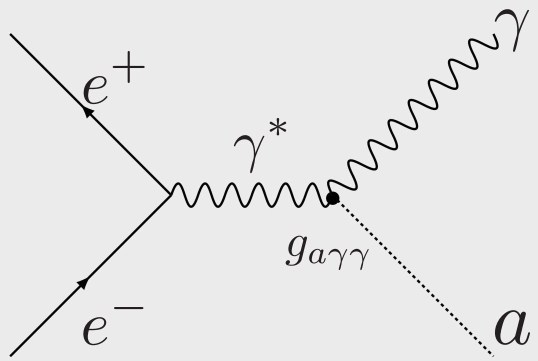
Annihilation into alp-photon

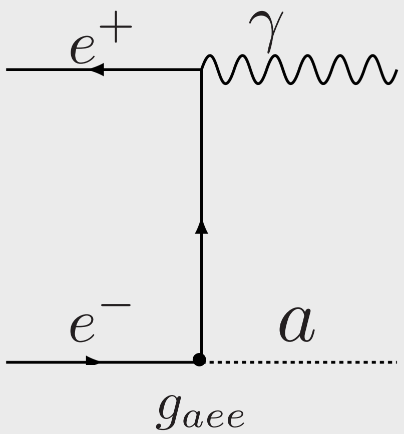
$$e^+e^- \rightarrow a\gamma$$

Estimation of probability that 10^{13} positrons annihilate in photon-alp

QUESTION: we have 10^{13} Positron On Target?







$$g_{aXX} = 1GeV^{-1}$$

Annihilation into alp-photon

$$e^+e^- \to a\gamma$$

OBSERVABLE: missing mass as A'

$$M^2_{\text{miss}} = \left(P_{e^-} + P_{\text{beam}} - P_\gamma\right)^2.$$

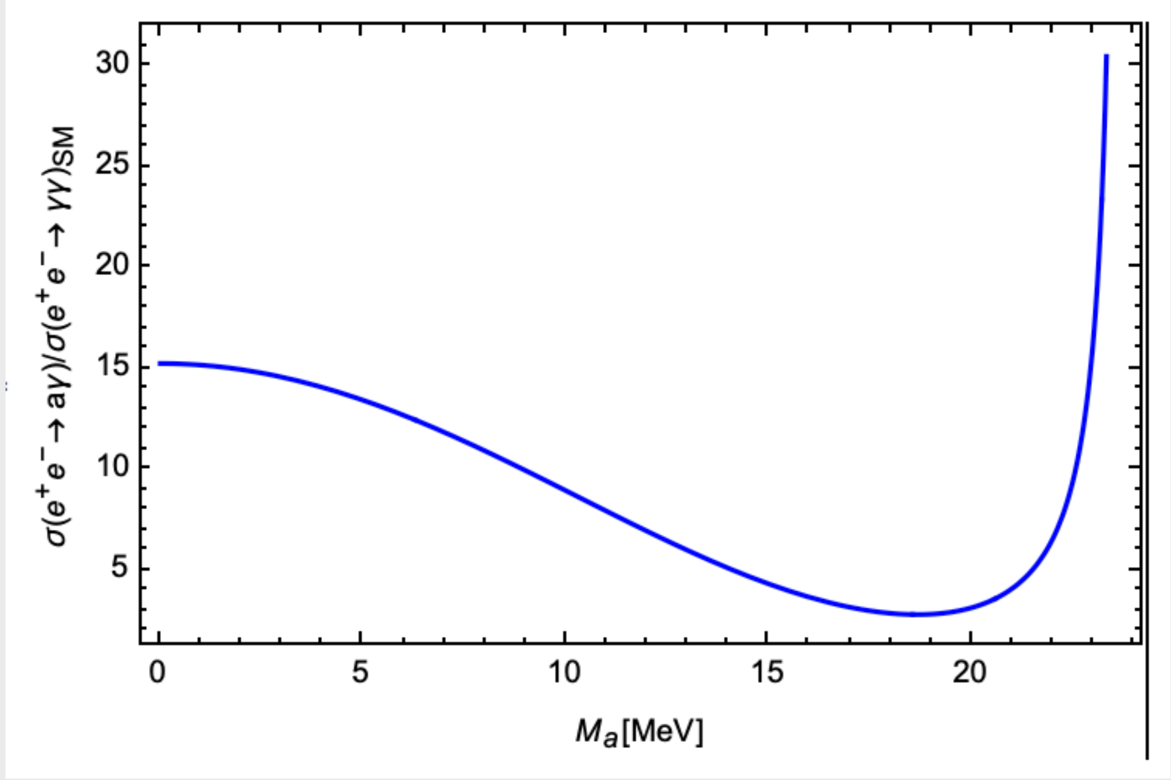
BACKGROUND: bremsstrahlung

pile-up

γγ

γγγ

$g_{aXX} = 1GeV^{-1}$



Annihilation into photon-photon

Cross-section $e^+e^- \to \gamma\gamma$

$$
\begin{aligned}
|\mathcal{M}_{e^+e^-\to\gamma\gamma}|^2 &= \frac{1}{4}\sum|\mathcal{M}|^2 \\
&+ 2e^4\frac{1}{(t-m_e^2)^2(u-m_e^2)^2}\left[tu(t^2+u^2)+m_e^2 s(t^2+6tu+u^2)+m_e^4(t+u)^2-6m_e^8\right] \\
&+ e^2\, g_{aee}\, g_{a\gamma\gamma}\frac{m_e^2\, s^3}{(s-m_a^2)(t-m_e^2)(u-m_e^2)} \\
&+ g_{aee}^2\, g_{a\gamma\gamma}^2\frac{m_e^2\, s^3}{4(s-m_a^2)^2}
\end{aligned}
$$

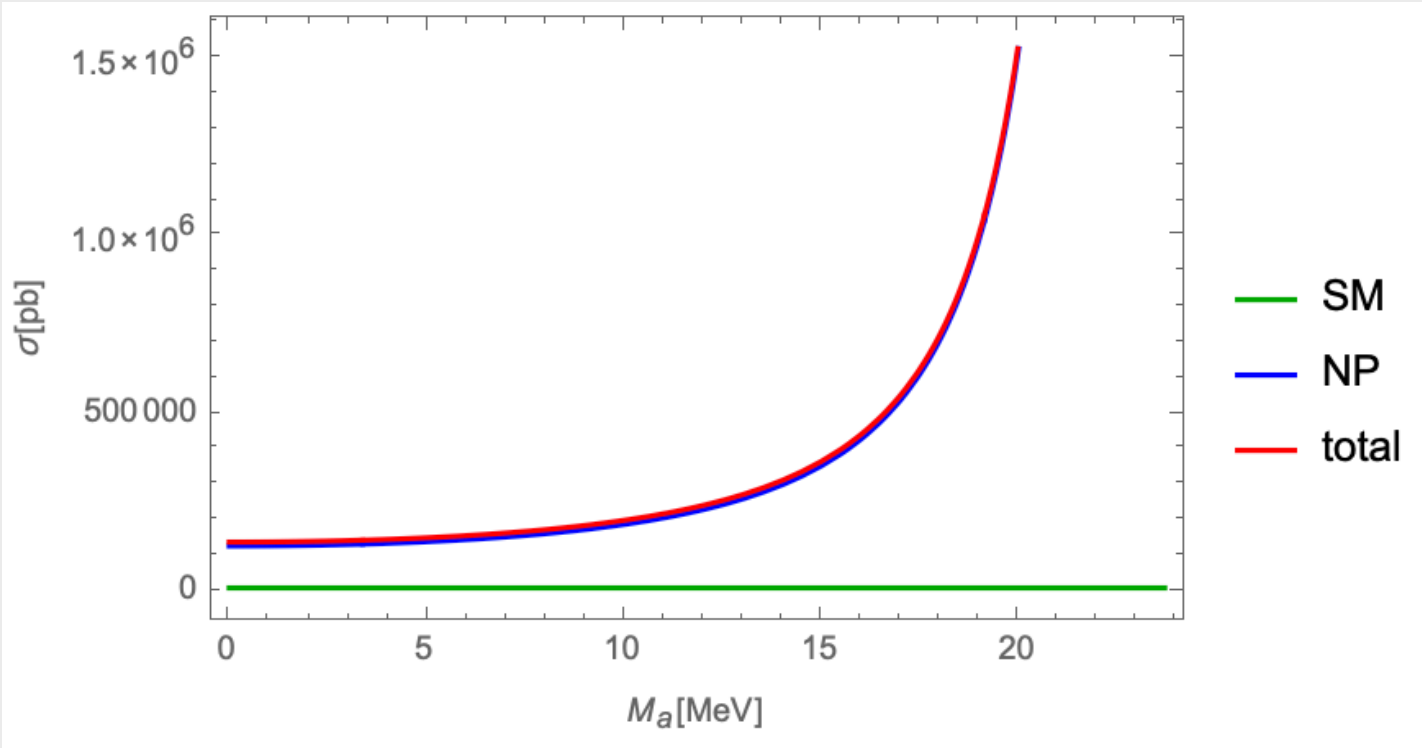
SM

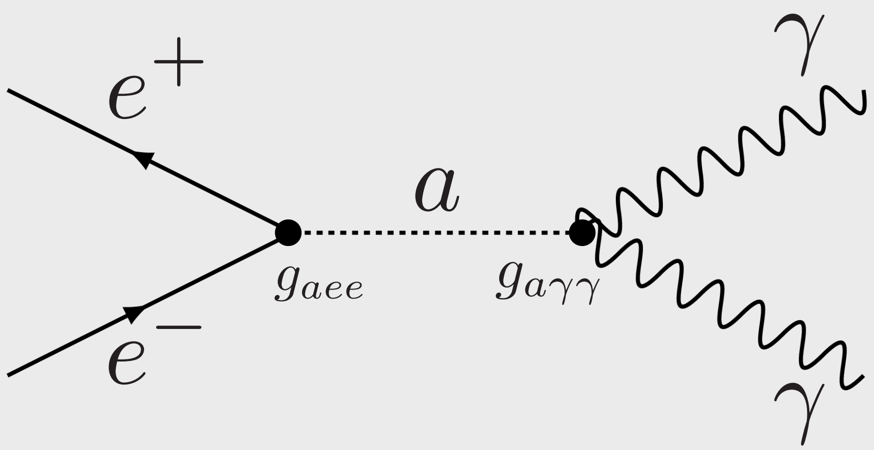
Mix

NP

The cross section in the $E_e \gg m_e, m_a$ limit is

$$
\left.\frac{d\sigma}{d\Omega}\right|_{E_e\gg m_e,m_a} \simeq \frac{1}{4E_e\, m_e(1-\cos\theta)}\left[\alpha^2+\frac{\alpha}{8\pi}g_{aee}\, g_{a\gamma\gamma}\, m_e^2+\frac{1}{64\pi^2}g_{aee}^2\, g_{a\gamma\gamma}^2\frac{m_e^4}{1-\cos\theta}\right]
$$

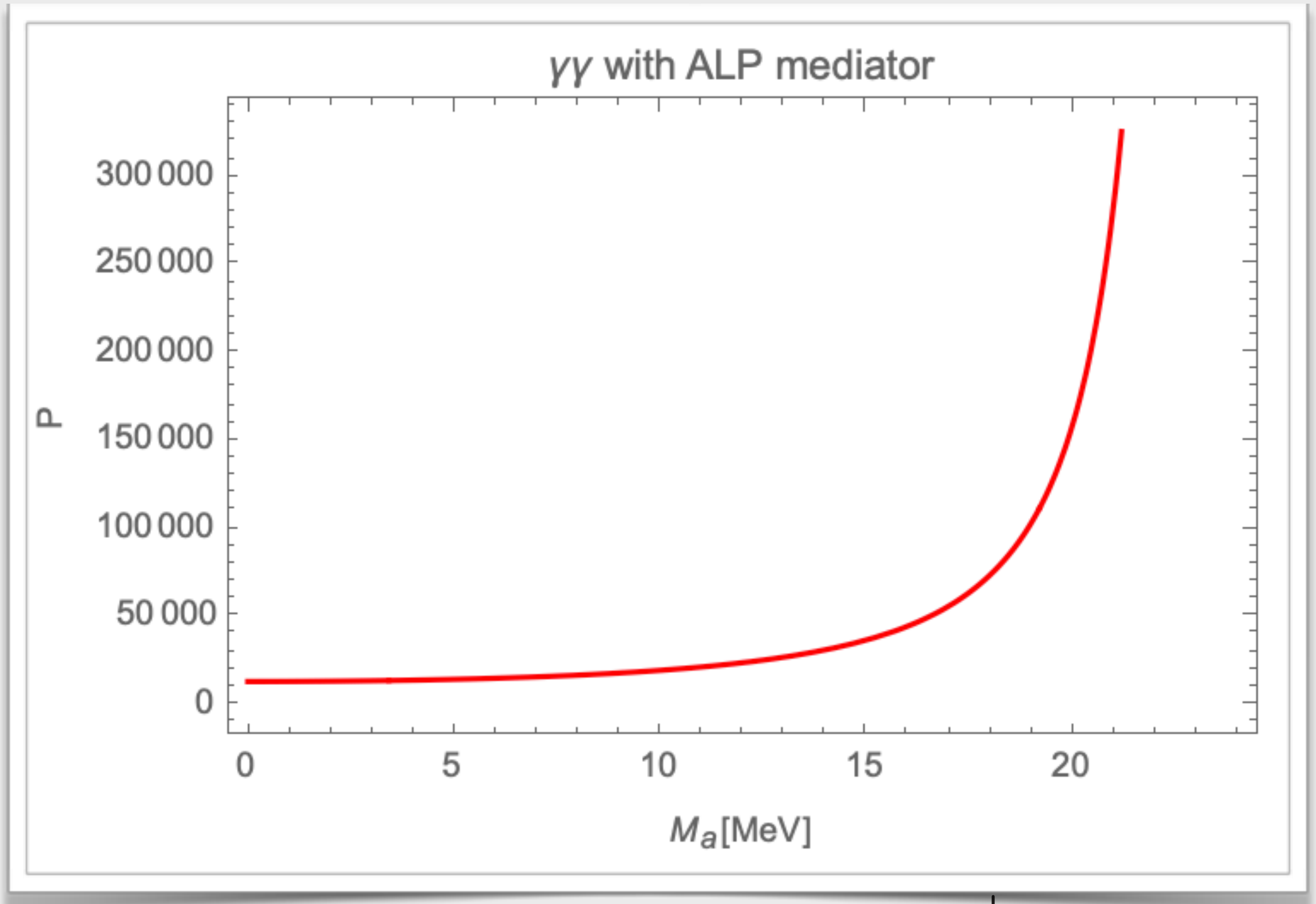




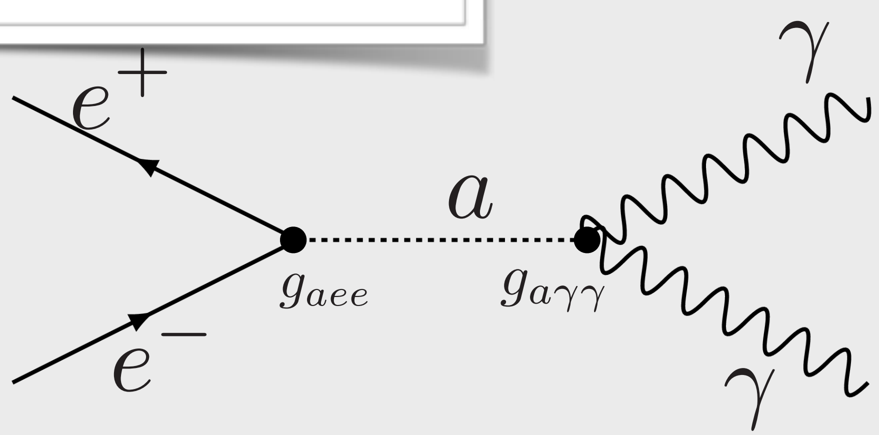
Annihilation into photon-photon

$$e^+e^- \to \gamma\gamma$$

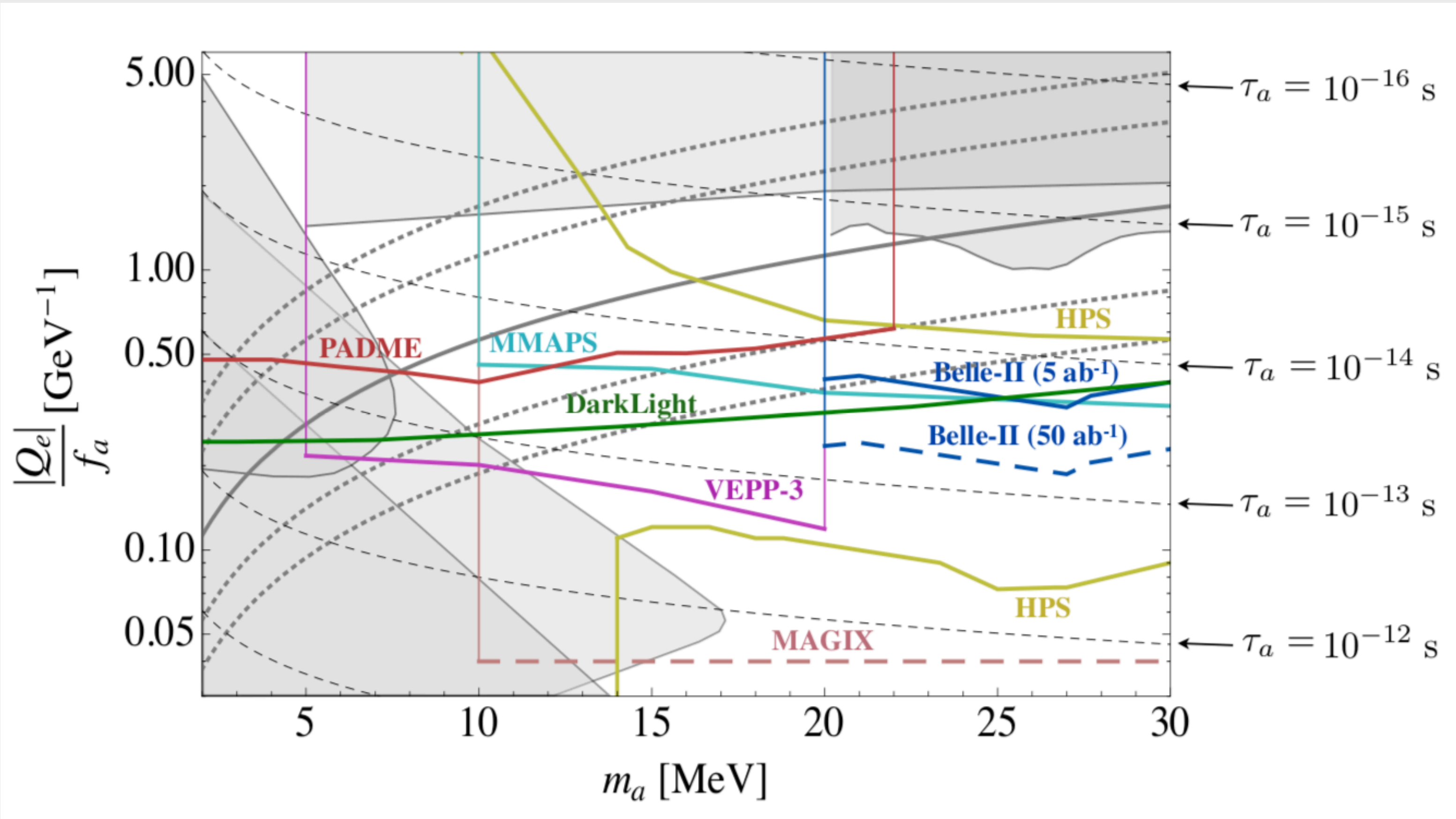
Probability that 10^{13} positrons annihilate in photon-photon



$$g_{a\gamma\gamma} = g_{aee} = 1GeV^{-1}$$



CONSTRAINTS FOR COUPLING



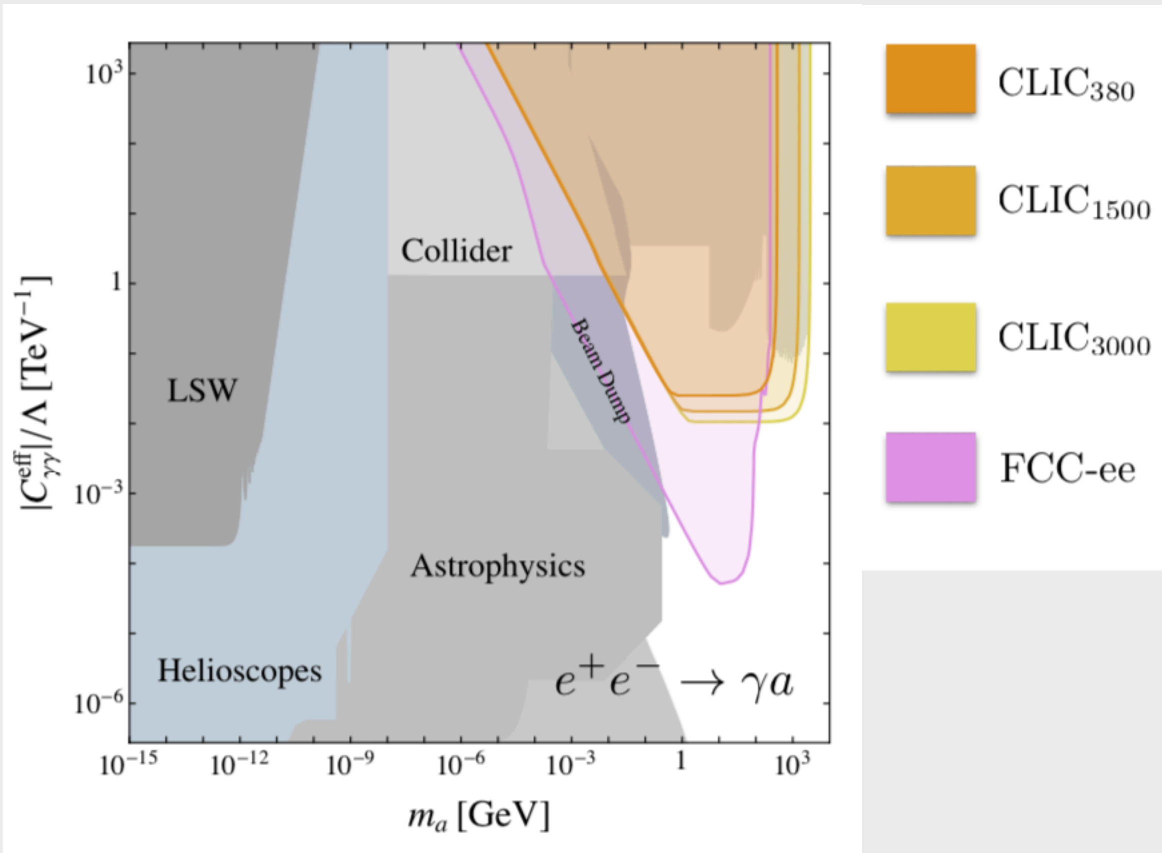
paper on g_{aee} coupling constraints ref. Alves and Weiner JHEP07(2018)092

In Fig. 2, we translate the projected reach of several planned dark photon experiments into the MeV axion parameter space, using the following rule of thumb relating the dark photon kinetic mixing parameter $\epsilon_{A'}$ and the axion-electron coupling that would yield comparable signal strengths:

$$\epsilon_{A'}^2\,\alpha \quad \sim \quad \frac{1}{4\pi}\left(\frac{Q_e}{f_a}\,m_e\right)^2 . \tag{7.17}$$

We emphasize that (7.17) is only approximate, since the angular dependence of pseudoscalar cross-sections differs from that of vectors. Fig. 2 includes ongoing and proposed dark photon searches via e^+e^- annihilation (VEPP-3 at BINP [155, 156], PADME in Frascati [157], MMAPS at Cornell [151] and Belle-II at KEK [158]), as well as dark photon bremsstrahlung from electrons scattering off of heavy fixed targets (HPS [159] and DarkLight [160, 161] at

CONTRAINTS FOR COUPLING



Bauer, Heilas, Neubert, Thamm 1808.10323

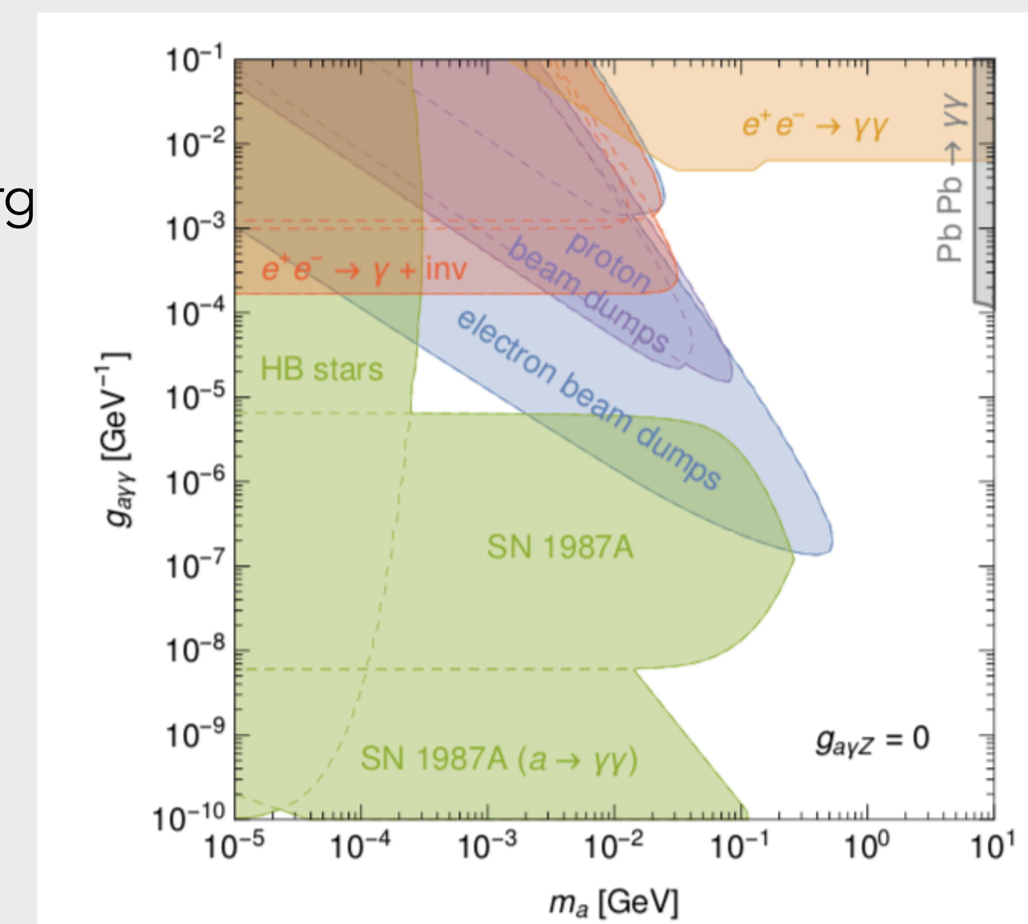
Constraints on $g_{a\gamma\gamma}$

JHEP12(2017)094 Dolan, Ferber, Kahlohefer and Schmidt-Hoberg

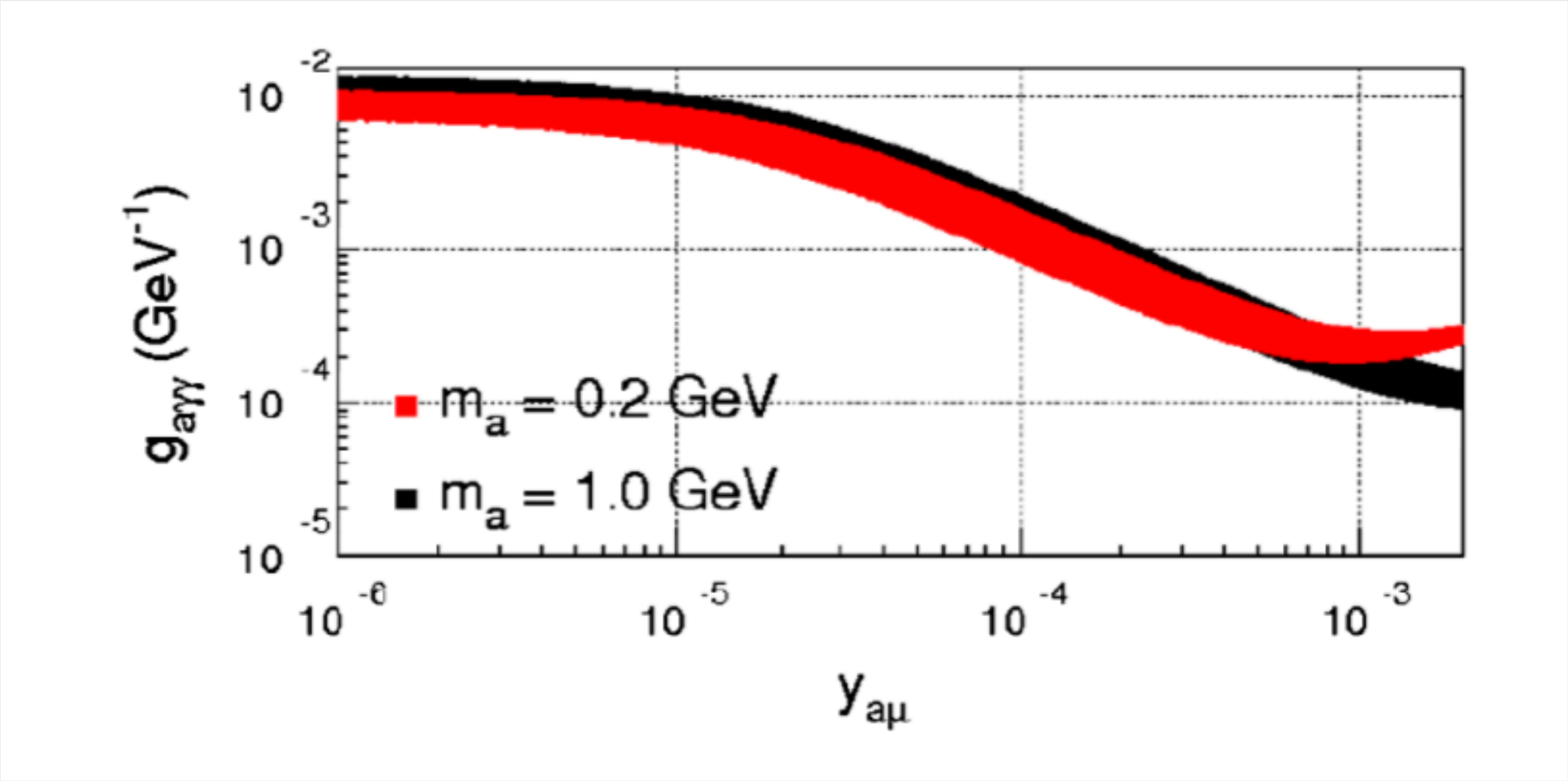
The BaBar analysis considers $-0.6 < \cos\theta < 0.6$ for $m_{A'} > 5.5\,\mathrm{GeV}$ and $-0.4 < \cos\theta < 0.6$ for $m_{A'} < 5.5\,\mathrm{GeV}$. By integrating the respective differential cross sections for ALP production and Dark Photon production over these ranges we obtain the fiducial cross section including geometric acceptance. Using these numbers, we can translate bounds on Dark Photons into the ALP parameter space under the assumption that all other selection cuts have the same efficiency for the two models. For very small masses of the invisibly decaying particle, we find that the translation is given by

$$g_{a\gamma\gamma} = 1.8 \times 10^{-4}\,\mathrm{GeV}^{-1} \left(\frac{\epsilon}{10^{-3}}\right) . \tag{3.3}$$

Repeating this calculation for finite ALP masses and taking into account the probability that the ALP decays before leaving the detector (see above) using a detector length of $L_D = 275\,\mathrm{cm}$ [59], we can then reinterpret the full BaBar bound in the context of ALPs.

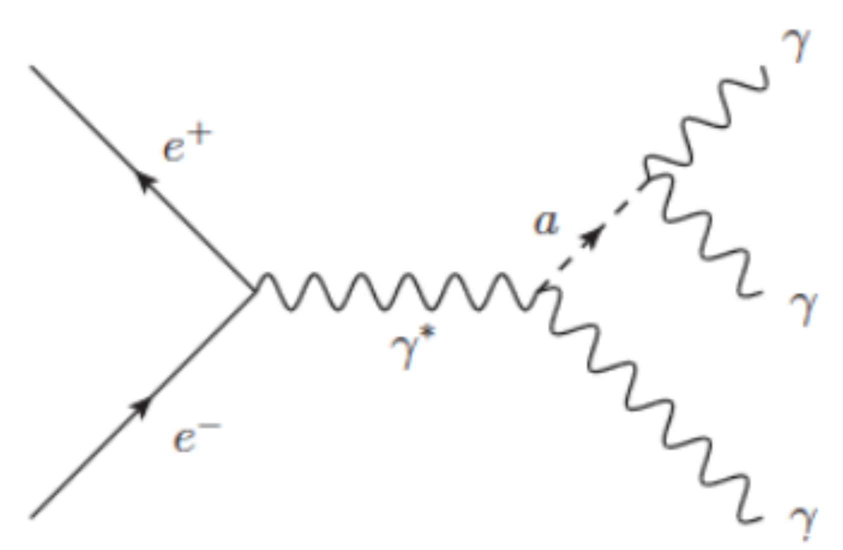


CONSTRAINTS FOR COUPLING

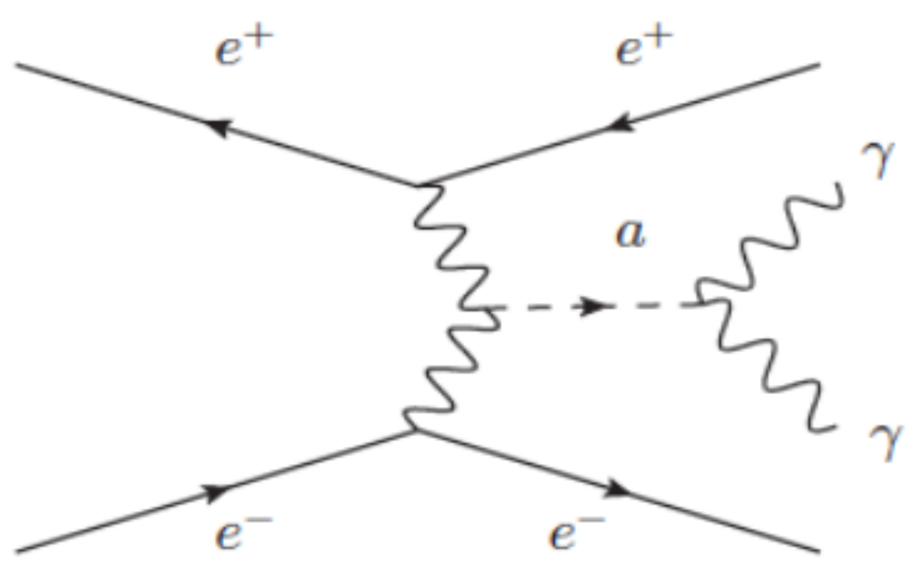


Marciano, Masiero, Paradisi e Passera

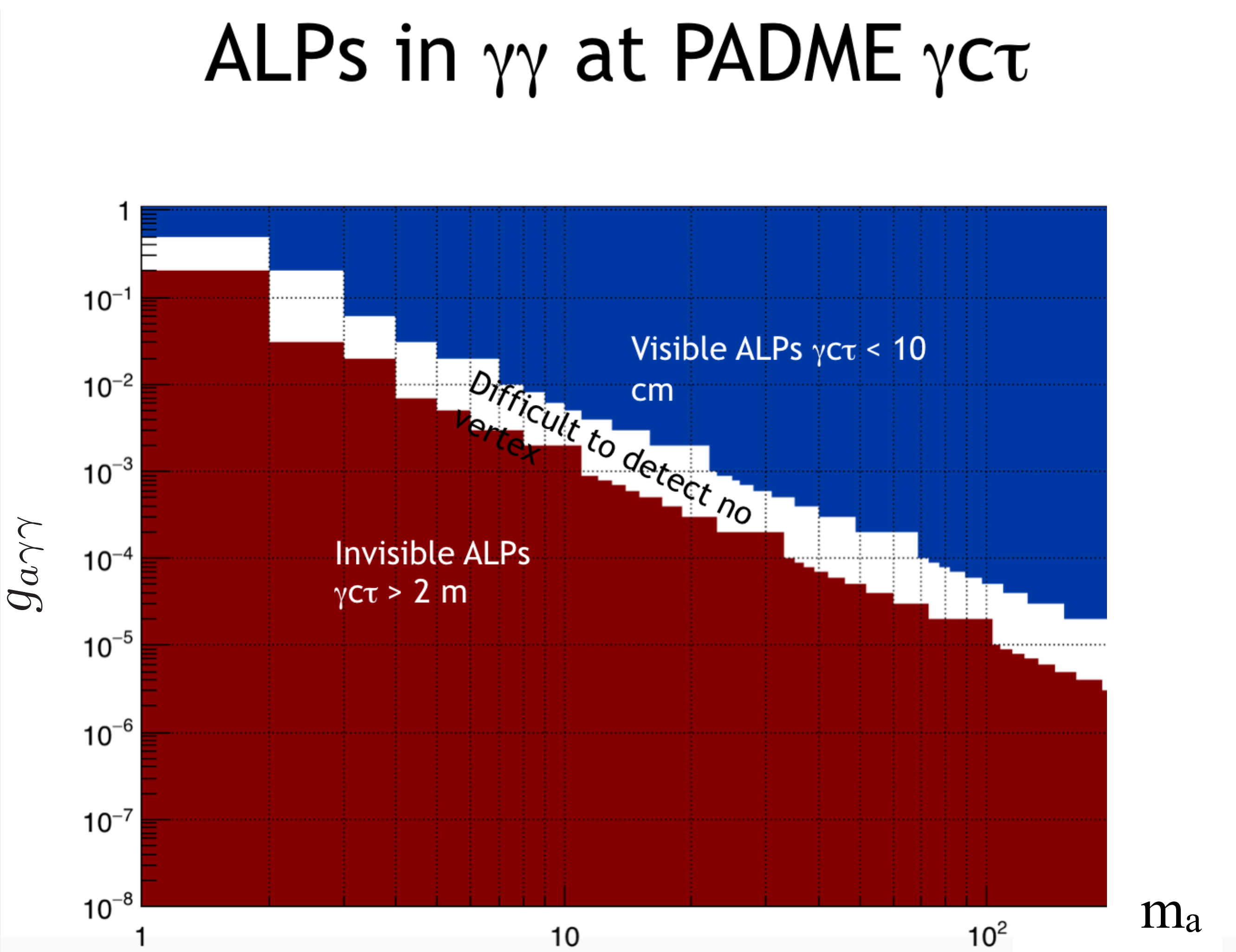
Other analysis from annihilation into alp-photon



$$(e^+e^- \to \gamma^* \to \gamma + a)$$



$$(e^+e^- \to e^+e^- + a)$$



FROM THEORY TO EXPERIMENT

WHAT WE HAVE TO DO:

- MONTE-CARLO OF ALP?
  - where
  - update MC for this process

OTHER TOOLS TO USE:

CALCHEP → MC generating .lhe useful for the implementation of cuts and in detector simulators

MADGRAPH → numerical simulations of σ

FROM THEORY TO EXPERIMENT

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TO TRANSLATE IN OUR MC


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#  Integrated weight (pb)  :       2.740351298
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2.740351e+00 1.064893e-01 2.740351e-02 1
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FROM THEORY TO EXPERIMENT

WHAT WE HAVE TO DO:

- ❑ **MONTE-CARLO OF ALP?**
  - where
  - update MC for this process

<u>OTHER TOOLS TO USE</u>:

CALCHEP → MC generating .lhe useful for the implementation of cuts and in detector simulators

MADGRAPH → numerical simulations of σ

- ❑ **SENSITIVITY?**
- ❑ **STATISTICS?**
- ❑ **ACCEPTANCE?**
- ❑ **IMPLEMENT PRECISES BEAM CARACTERISTICS**