Tera-Zooming in on light (composite) ALPS

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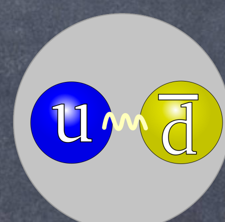
Based on: 2104.11064, GC, A. Deandrea, A.Iyer, K. Sridhar

Motivation

- The TeraZ option will produce 10^12 Z's: does it make sense to search for new light states in Z decays?
- In composite Higgs models, light (pseudo)scalars are allowed and likely to exist!
- Composite ALP Lagrangian is "calculable": predictive power! Access to high composite scales.
- Ideal physics case for FCC-ee @ 90 GeV! [Synergy with EWPTs]

Composite Higgs models 101

- Symmetry broken by a condensate (of TC-fermions)
- Higgs and longitudinal Z/W emerge as mesons (pions)



Scales:

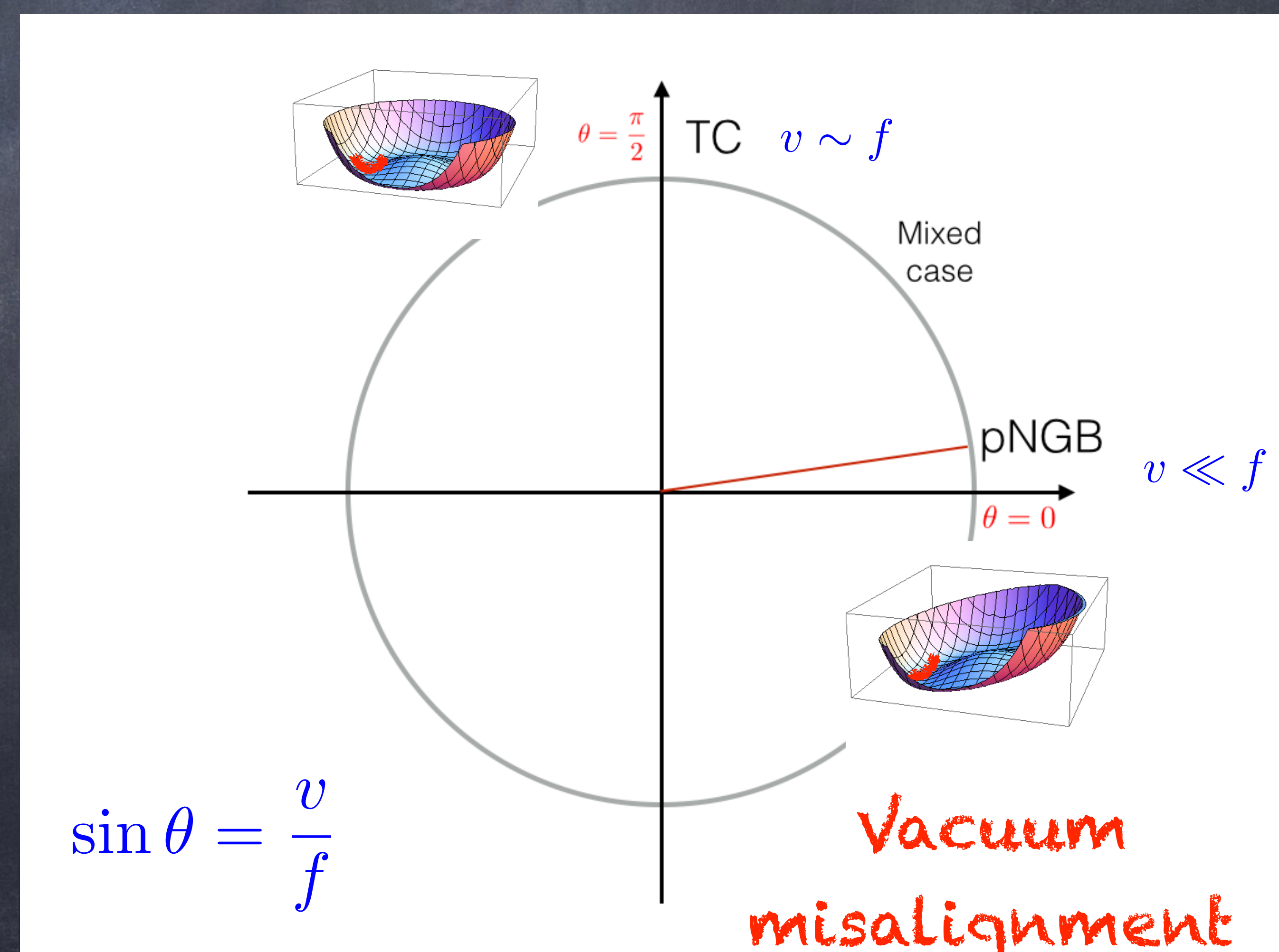
f : Higgs decay constant

v : EW scale

$m_\rho \sim 4\pi f$

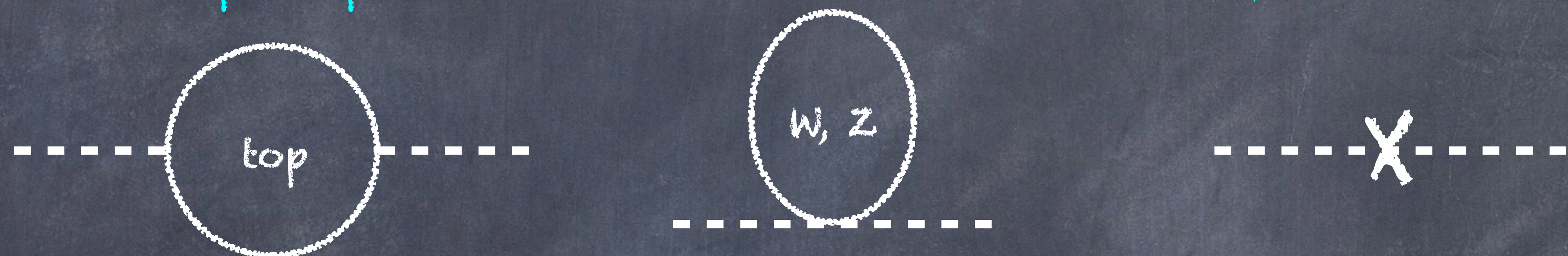
EWPTs + Higgs coupl. limit:

$$f \gtrsim 4v \sim 1\ \mathrm{TeV}$$



Composite Higgs models 101

How can light states emerge?



	Top loops	Gauge loops	TC-fermion masses
ϕ	$\sim y_t^2 f^2$	$\sim g^2 f^2$	$\sim m_\psi f$
h (h massless for vanishing v)	$\sim y_t^2 f^2 s_\theta^2 = y_t^2 v^2$	$\sim g^2 f^2 s_\theta^2 = g^2 v^2$	X
a	X	X	$\sim m_\psi f$ This can be small!

Composite Higgs models 101

T.Ryttov, F.Sannino 0809.0713
Galloway, Evans, Luty, Tacchi 1001.1361

	$SU(2)_{TC}$	$SU(4)_\psi$	$SU(2)_L$	$U(1)_Y$
$\begin{pmatrix}\psi^1\\ \psi^2\end{pmatrix}$	$\square$	$\square$	**2**	0
ψ^3	$\square$		**1**	-1/2
ψ^4	$\square$		**1**	1/2

The EW symmetry
is embedded in the global
flavour symmetry
SU(4) !

- The global symmetry is broken: SU(4)/Sp(4)

Witten, Kosower

- 5 Goldstones (pions) arise:

$$\mathbf{5}_{\mathrm{Sp}(4)} \to (2,2) \oplus (1,1)$$

Higgs — additional singlet

Typical ALP Lagrangian:

$$\mathcal{L}_{\text{eff}}^{D\leq 5} = \frac{1}{2}\,(\partial_\mu a)(\partial^\mu a) - \frac{m_{a,0}^2}{2}\,a^2 + \frac{\partial^\mu a}{\Lambda}\sum_F \bar{\psi}_F\,\boldsymbol{C}_F\,\gamma_\mu\,\psi_F$$
$$+\,g_s^2\,C_{GG}\,\frac{a}{\Lambda}\,G_{\mu\nu}^A\,\tilde{G}^{\mu\nu,A} + g^2\,C_{WW}\,\frac{a}{\Lambda}\,W_{\mu\nu}^A\,\tilde{W}^{\mu\nu,A} + g'^2\,C_{BB}\,\frac{a}{\Lambda}\,B_{\mu\nu}\,\tilde{B}^{\mu\nu}\,,$$

The couplings C's are typically chosen to be O(1)

Composite models demonstrate how a departure from the conventional "generic" values can lead to interesting phenomenology

This analysis is also applicable to ALPs that exhibit similar properties!

Typical ALP Lagrangian:

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$$+ g_s^2 C_{GG}\frac{a}{\Lambda}G_{\mu\nu}^A \tilde{G}^{\mu\nu,A} + g^2 C_{WW}\frac{a}{\Lambda}W_{\mu\nu}^A \tilde{W}^{\mu\nu,A} + g'^2 C_{BB}\frac{a}{\Lambda}B_{\mu\nu}\tilde{B}^{\mu\nu},$$

Composite Higgs scenario:

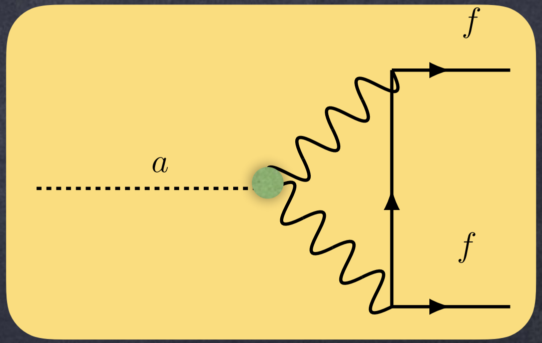
$$\frac{C_{WW}}{\Lambda} \sim \frac{C_{BB}}{\Lambda} \sim \frac{N_{\rm TC}}{64\sqrt{2}\,\pi^2 f}$$

$$(C_{\gamma\gamma} = C_{WW} + C_{BB})$$

$$\frac{C_{GG}}{\Lambda} = 0$$

(Poor bounds at the LHC)

$\mathbf{C}_F$ is loop-induced:



M.Bauer et al, 1708.00443

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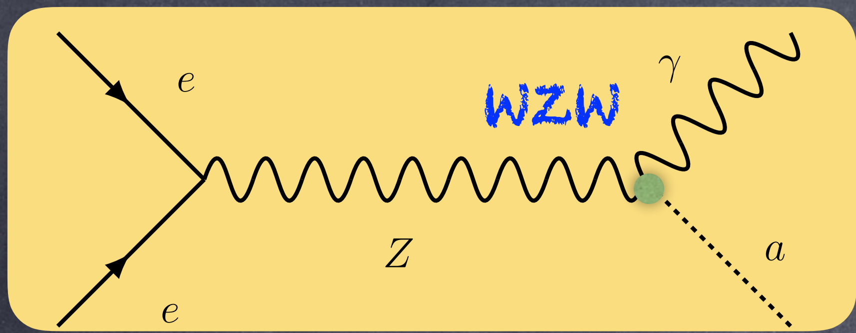
Free parameters:

f, m_a

We will consider two scenarios:
Photo-philic and
Photo-phobic

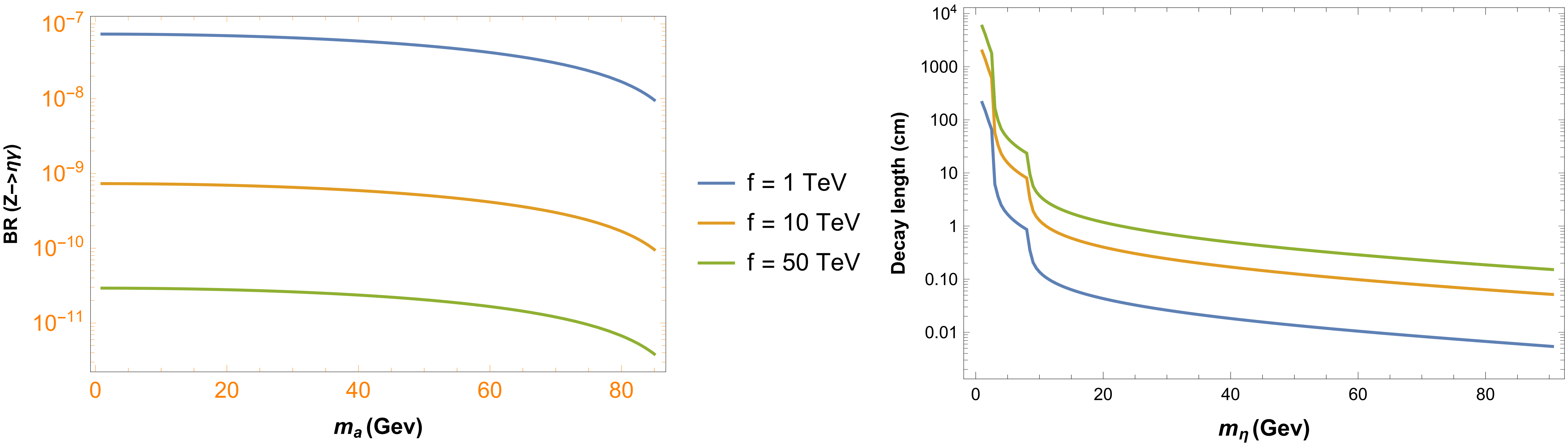
Tera-Z portal to compositeness (via ALPs)



This process is always associated with a monochromatic photon.

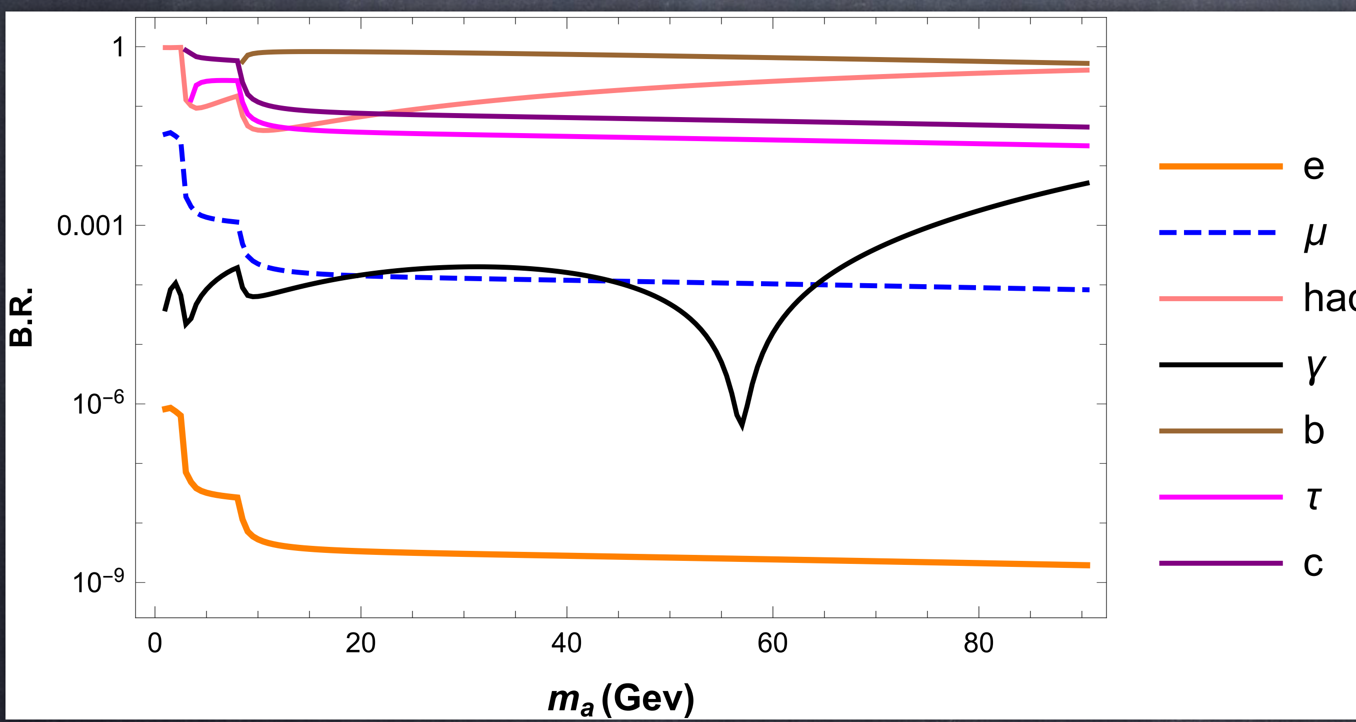
Tera Z phase of FCC-ee will lead to 5-6 10^12 Z bosons at the end of the run.

Ideal test for rare Z decays!!



Tera-Z portal to compositeness (via ALPs)

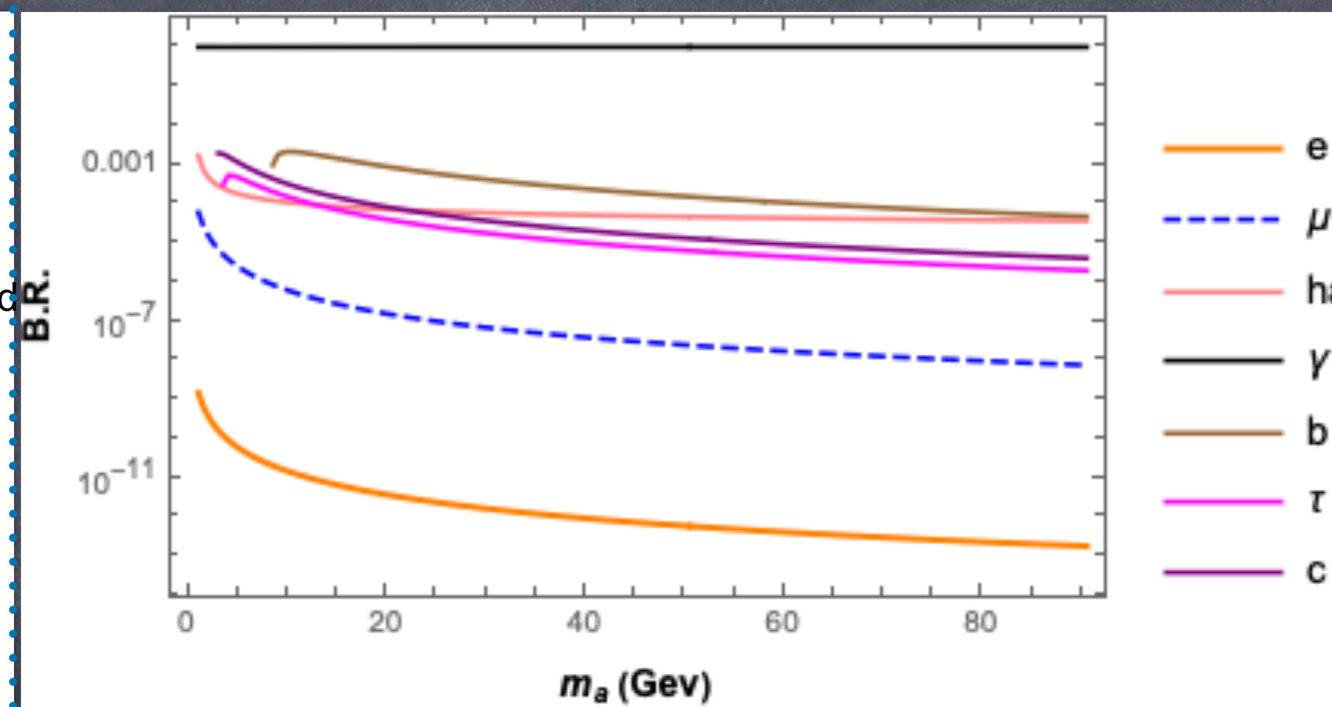
Photo-phobic



No leading order coupling to Photons (WZW interaction is Zero!!)

eg. SU(4)/SP(4), SU(4)xSU(4)/SU(4)

Photo-philic

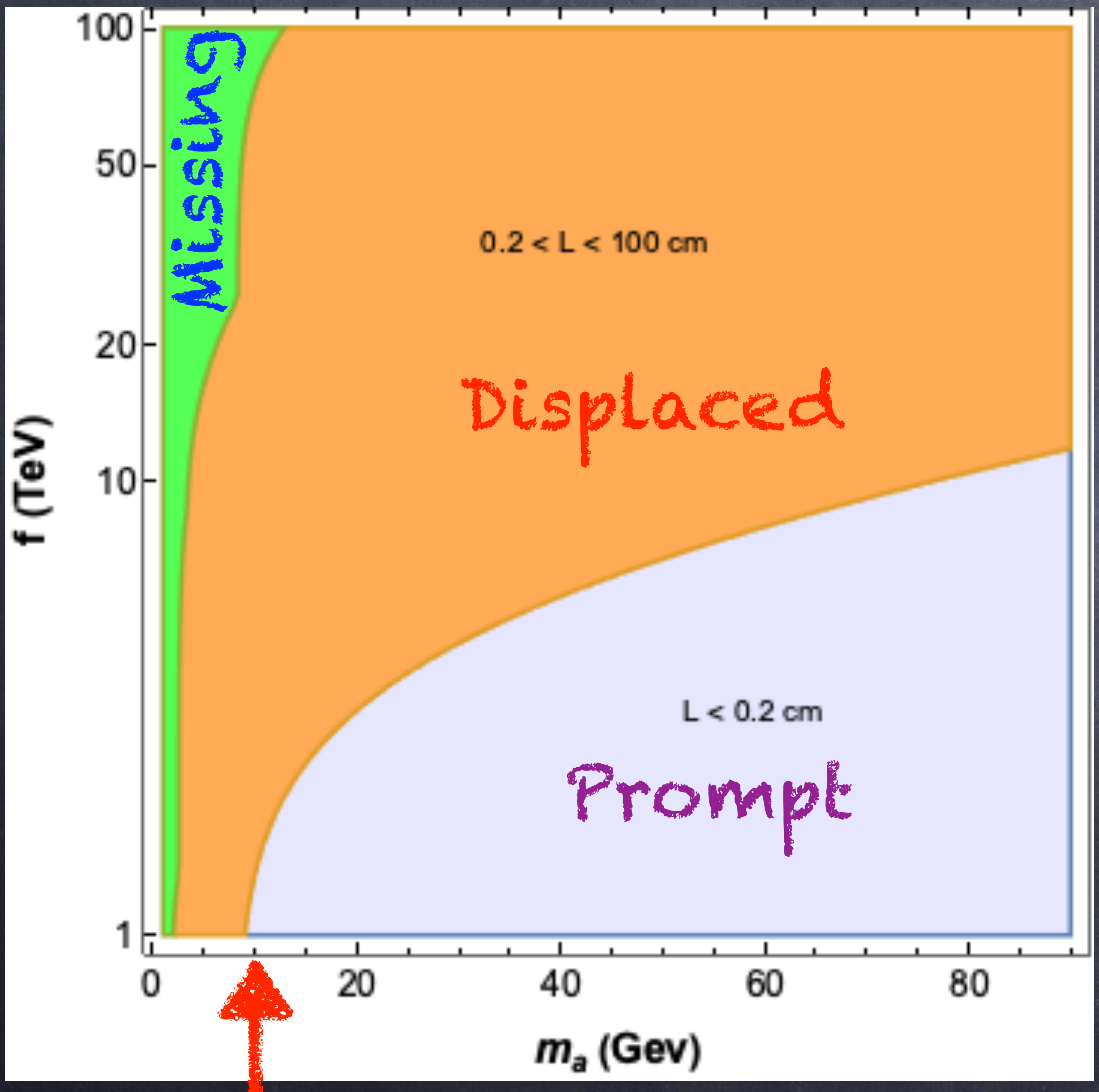


WZW interaction to photons (like the pion)

eg. SU(6)/SO(6)

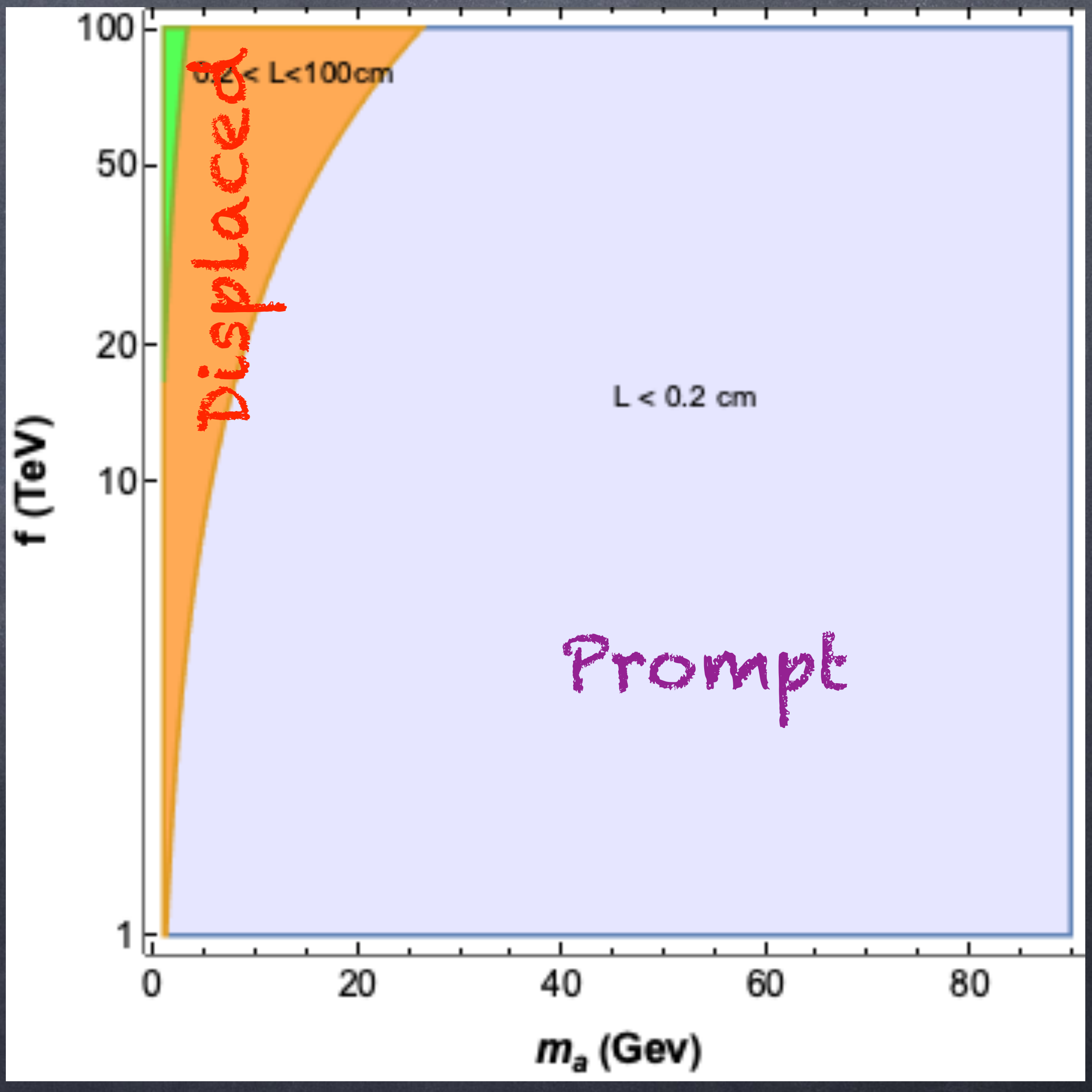
Signatures:
Invisible or Displaced or Prompt

Photo-phobic



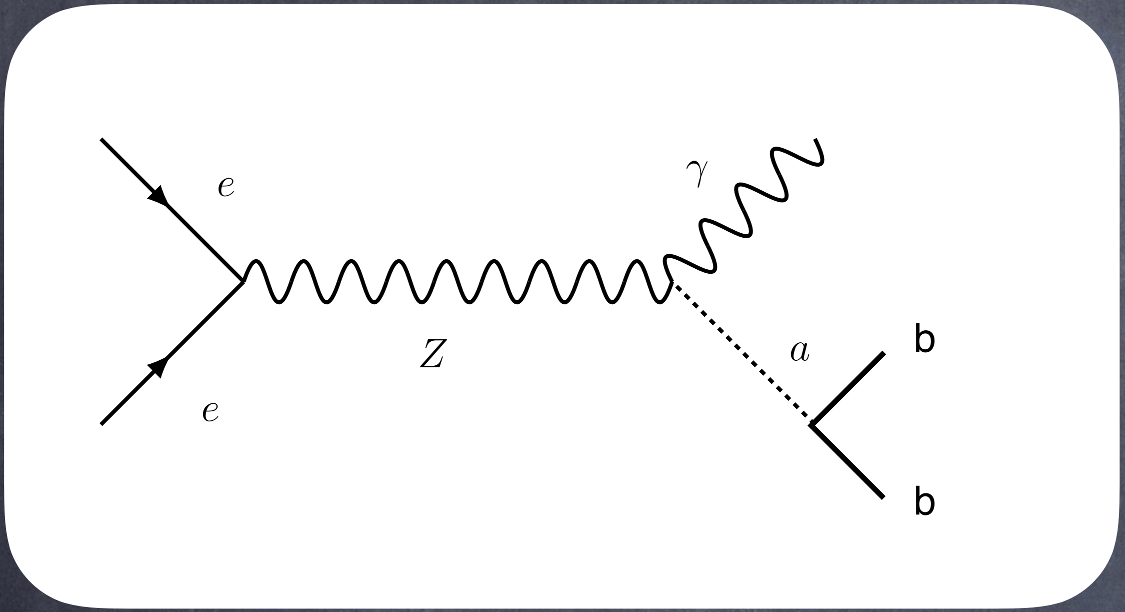
bb threshold

Photo-philic

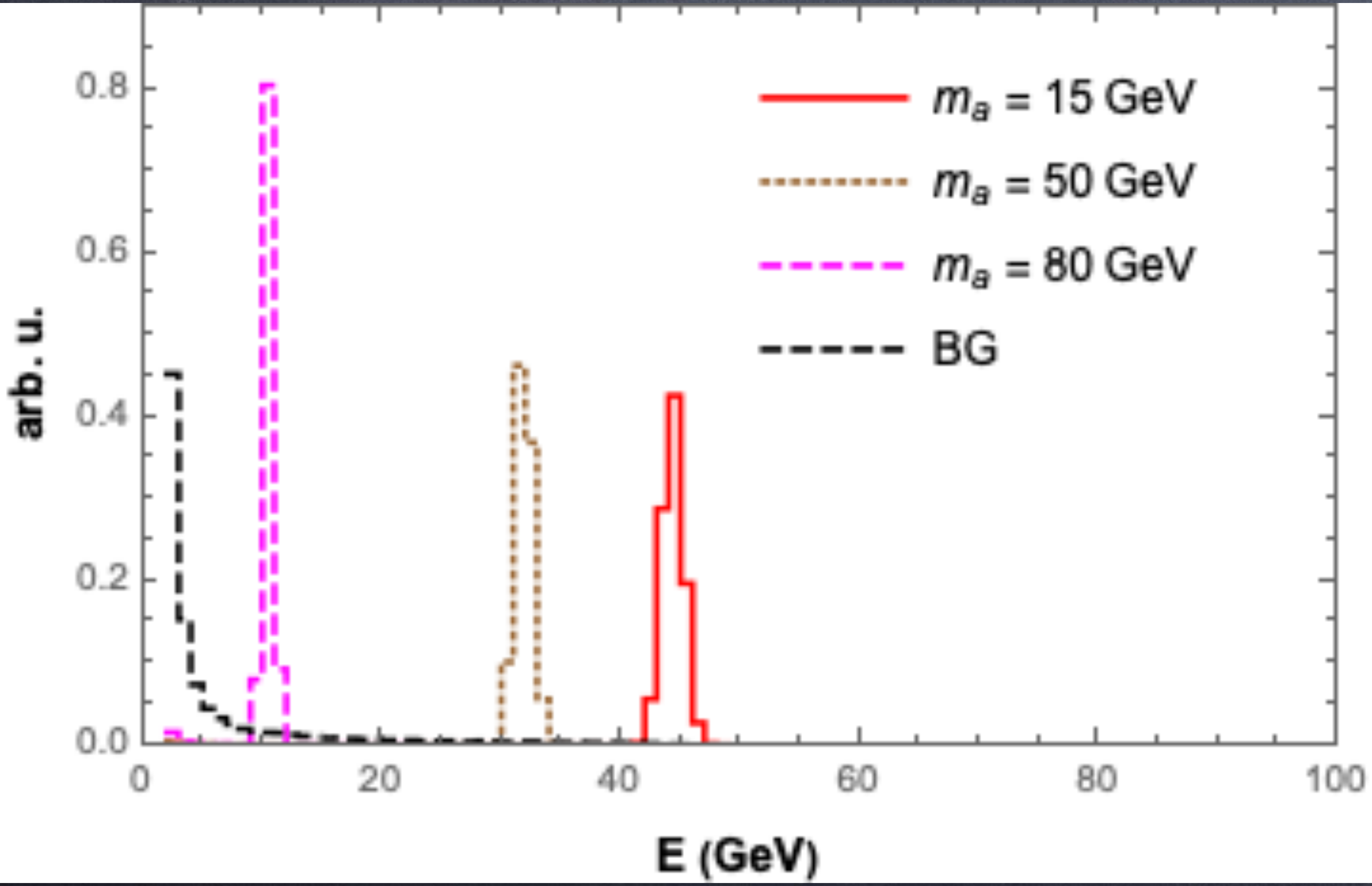


Phenomenology-Prompt Decays

Photo-phobic



- One isolated photon
- At least one b-tagged jet

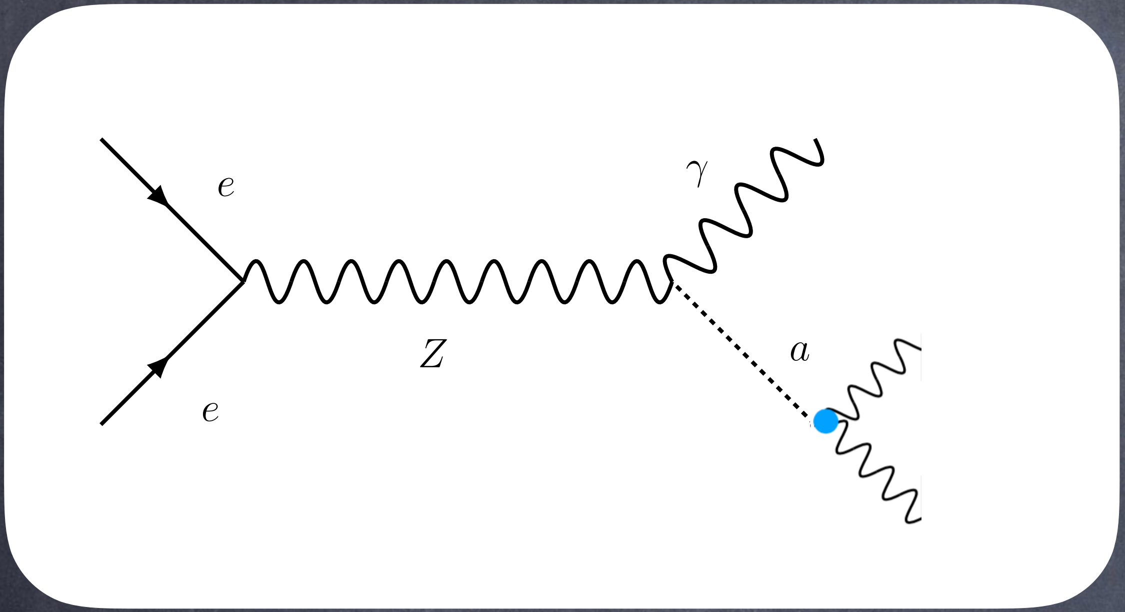


Discriminating variable: photon energy

Best discrimination for small ALP masses

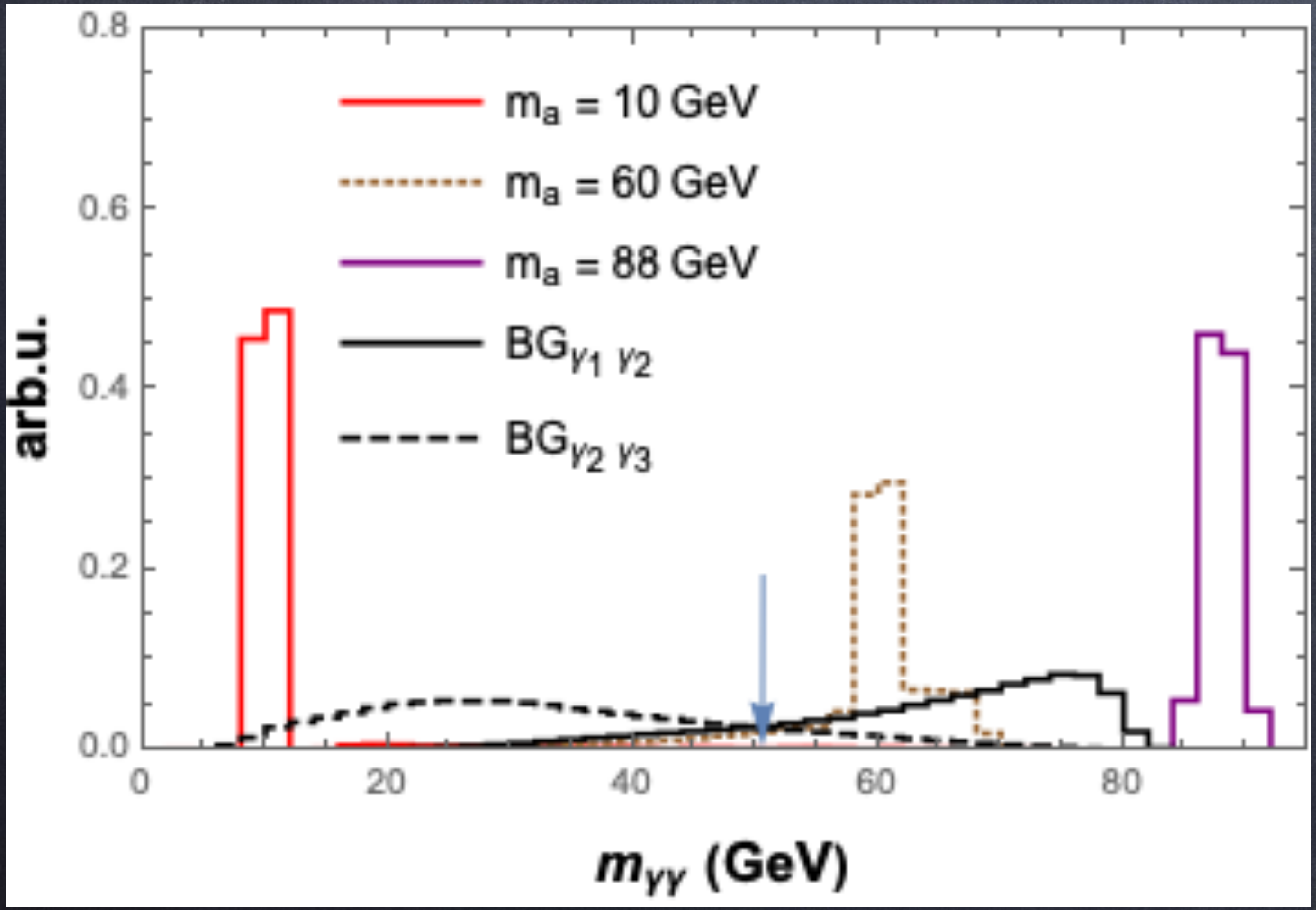
Phenomenology-Prompt Decays

Photo-philic



- Three isolated photons

$BR(Z \to 3\gamma)_{\rm LEP} < 2.2 \cdot 10^{-6}$



Discriminating variable: invariant mass

Photon ordering changes at inv. mass 50 GeV

Bins above 80 GeV populated by fakes: hard to estimate!

Phenomenology-Displaced vertices

In the absence of a detector card adapted to handle long lived particles, we simply count the number of displaced events.

Signatures are likely to be background free

Photo-phobic

Main signature:

Monochromatic photon + displaced hadrons

We require at least 2 events

Photo-philic

Main signature:

Monochromatic photon + At least one displaced photon

We require at least 20 events

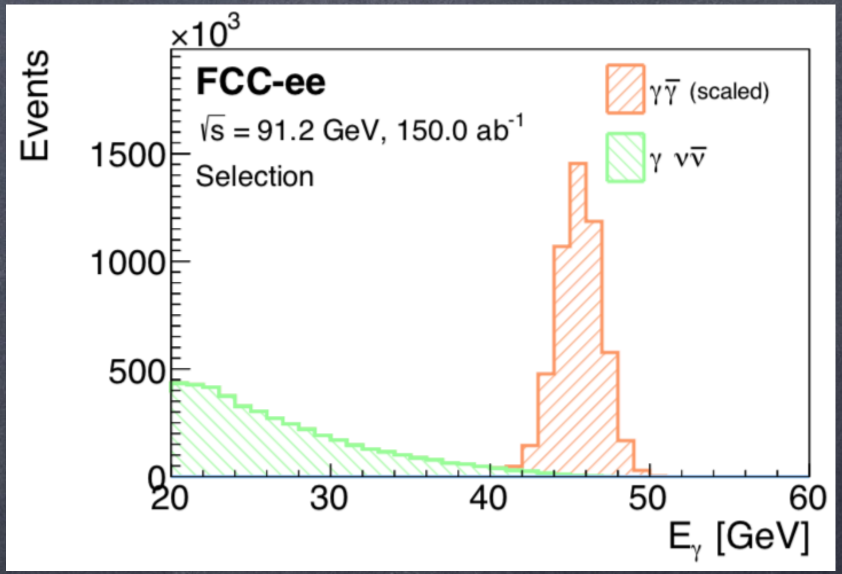
Phenomenology-Missing energy

The ALP decays outside of the detector reach,
thus the signature is MET for both cases.

The signature is a single monochromatic photon.

$BR(Z \to \gamma + X_{\rm inv})_{\rm LEP} < 10^{-6}$

We use the results from a recent analysis of decays into a dark photon, yielding:



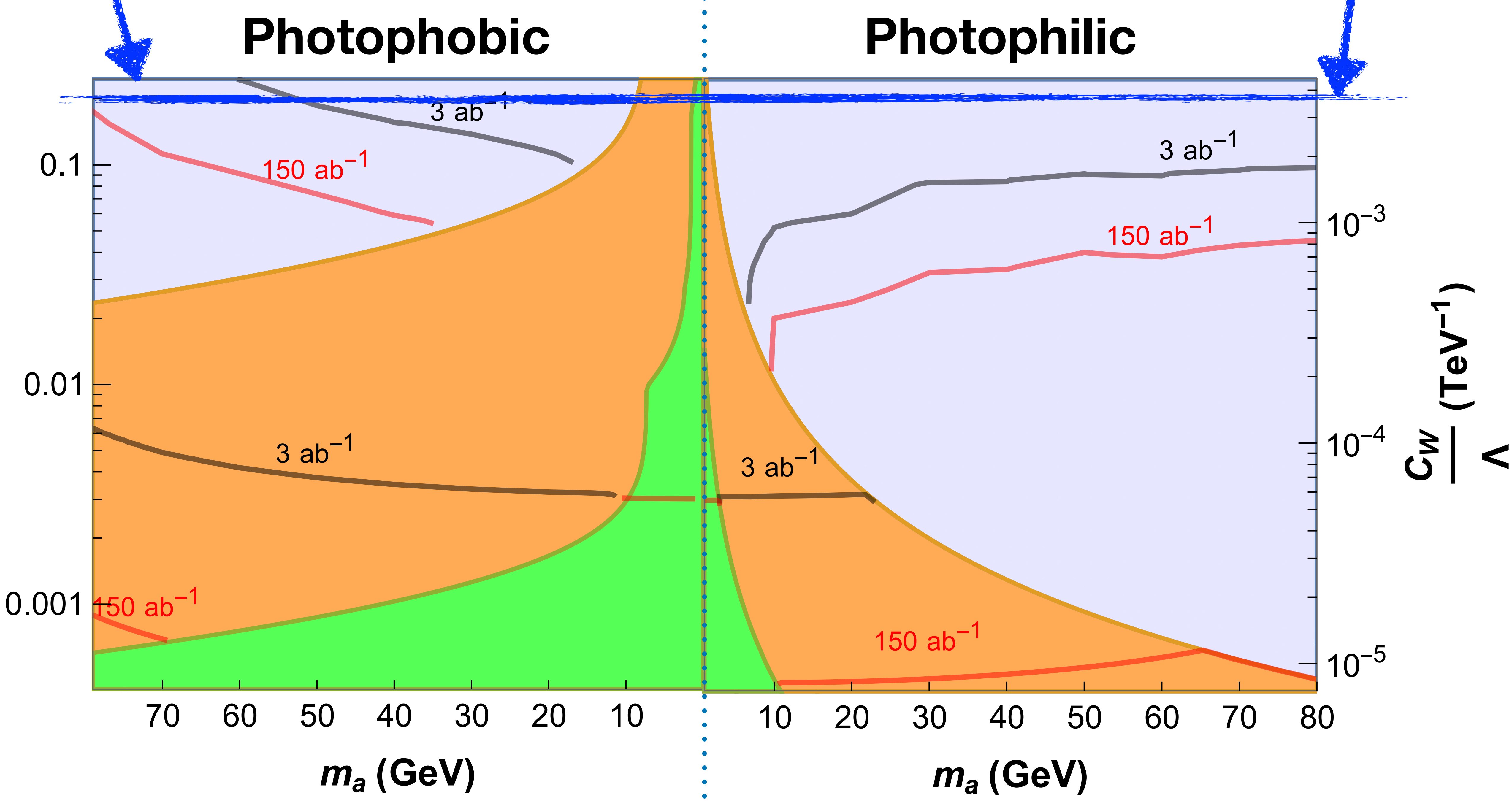
M.Cobal et al, 2006.15945

$$BR(Z \to \gamma + X_{\rm inv})_{\rm FCC-ee} < 2.3 \cdot 10^{-11} \quad at \quad 150\ {\rm ab}^{-1}$$

Final results

Typical EWPT bound

Too small to explain the muon g-2 anomaly!
M.Bauer et al, 1704.08207



Outlook and Conclusions

- The TeraZ run is ideal for searching for light composite ALP: reach well above EWPT limits
- The long-lived parameter space needs further analysis (displaced vertex reconstruction)
- A study of the EWPT at the TeraZ is underway (stage M2 Andrés Pinto)
- Can EWPT + Z decays distinguish composite from elementary ALPs? (work in progress)