Tera-Zooming in on light (composite) ALPS

Giacomo Cacciapaglia
IP2I Lyon, France

@ ECFA HF WG1 first workshop

with A. Deandrea, A.Iyer, K. Sridhar and A.Pinto
Based on: 2104.11064 (PRD) + work in preparation

Motivation

- The TeraZ option will produce 10^12 Z's: like a telescope pointing to high-scale physics.

multi-TeV mountain

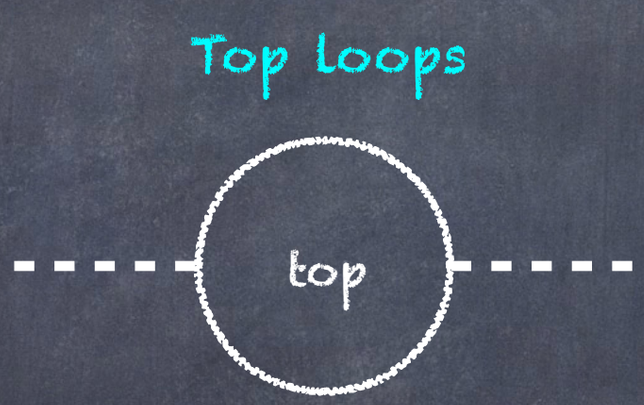
- What are we looking for?

-> Precision EW observables

-> light composite scalars

Composite Higgs models 101

How can light states emerge?



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!

Typical ALP Lagrangian:

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

Composite Higgs scenario:

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

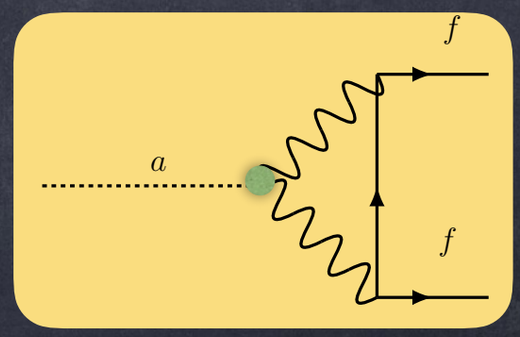
$$\frac{C_{GG}}{\Lambda} = 0$$

(Poor bounds at the LHC)

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

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

M.Bauer et al, 1708.00443



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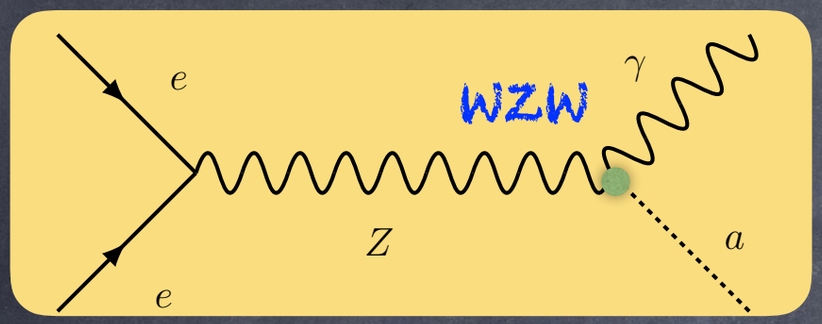
We will consider two scenarios:
Photo-philic and
Photo-phobic

Free parameters:

f, m_a

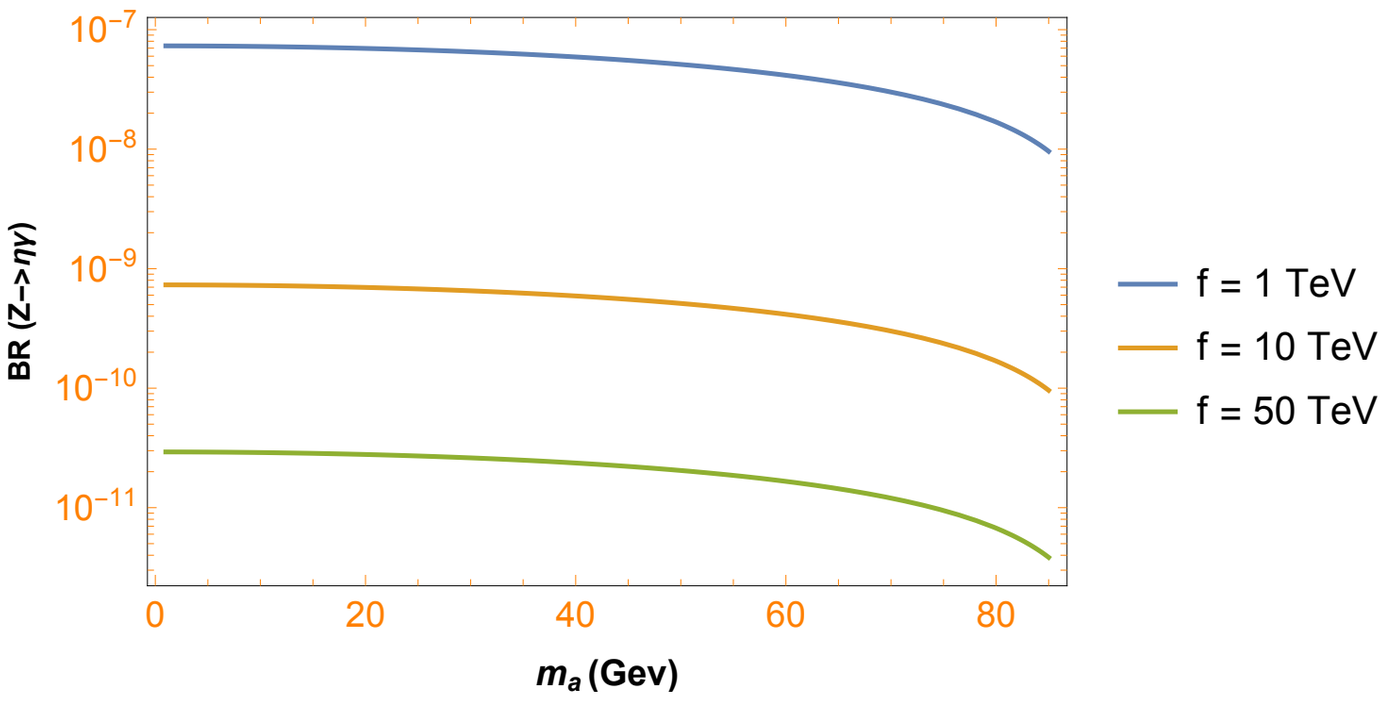
Tera-Z portal to compositeness (via ALPs)

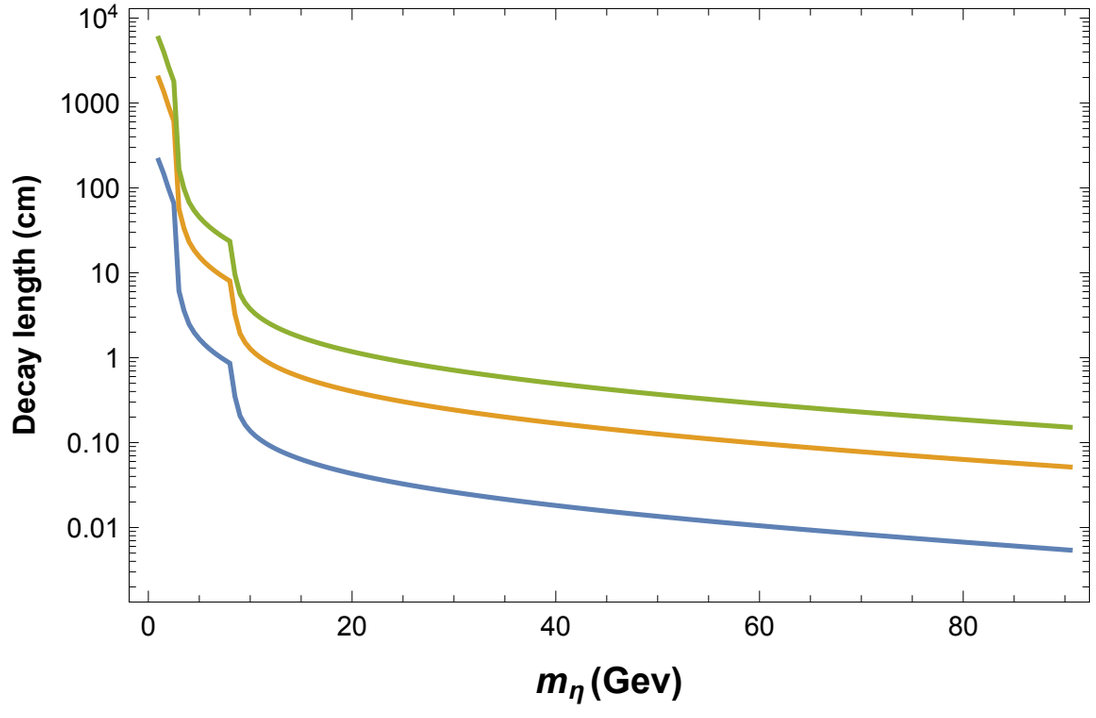


This process is always associated with a monochromatic photon.

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

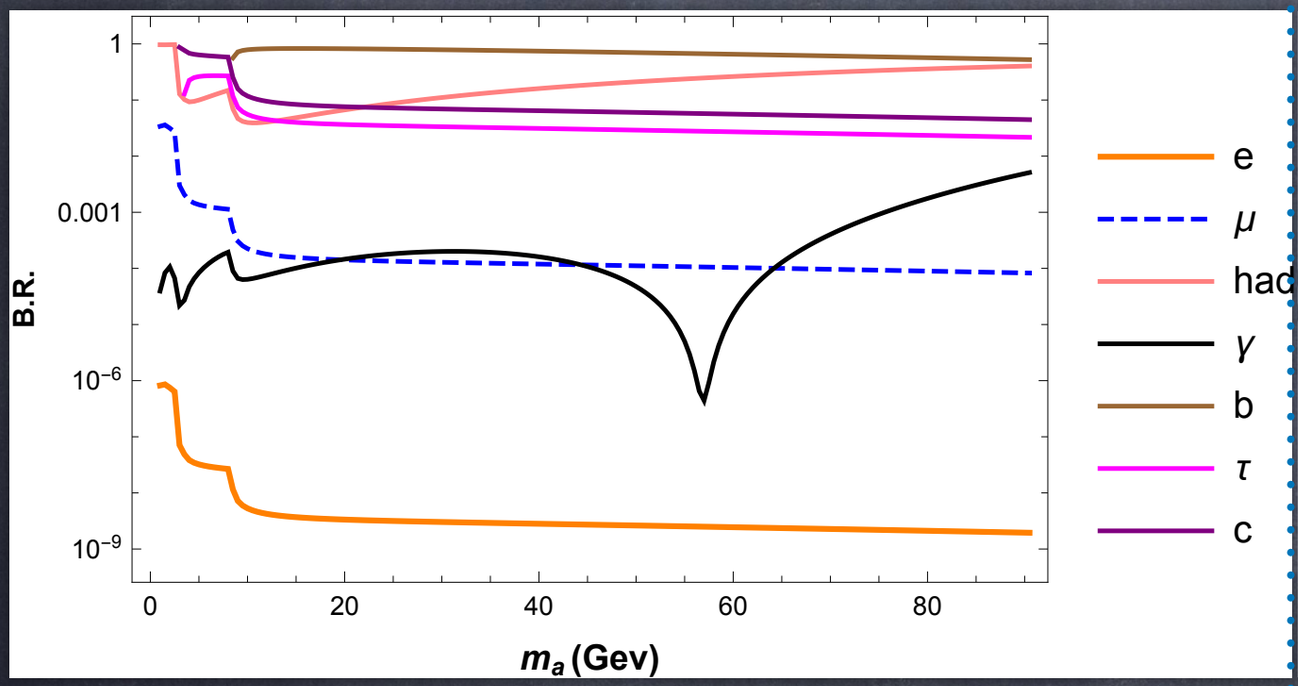
Ideal test for rare Z decays!!





Tera-Z portal to compositeness (via ALPs)

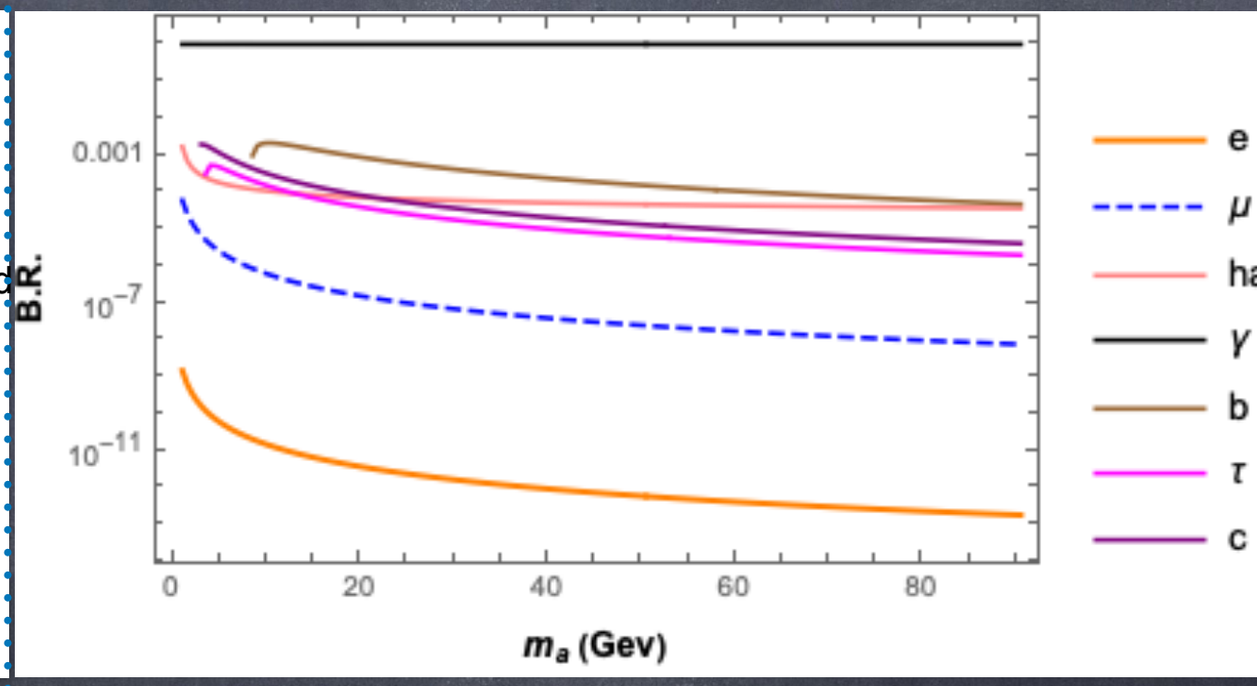
Photo-phobic



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

eg. SU(4)/SP(4), SU(4)×SU(4)/SU(4)

Photo-philic

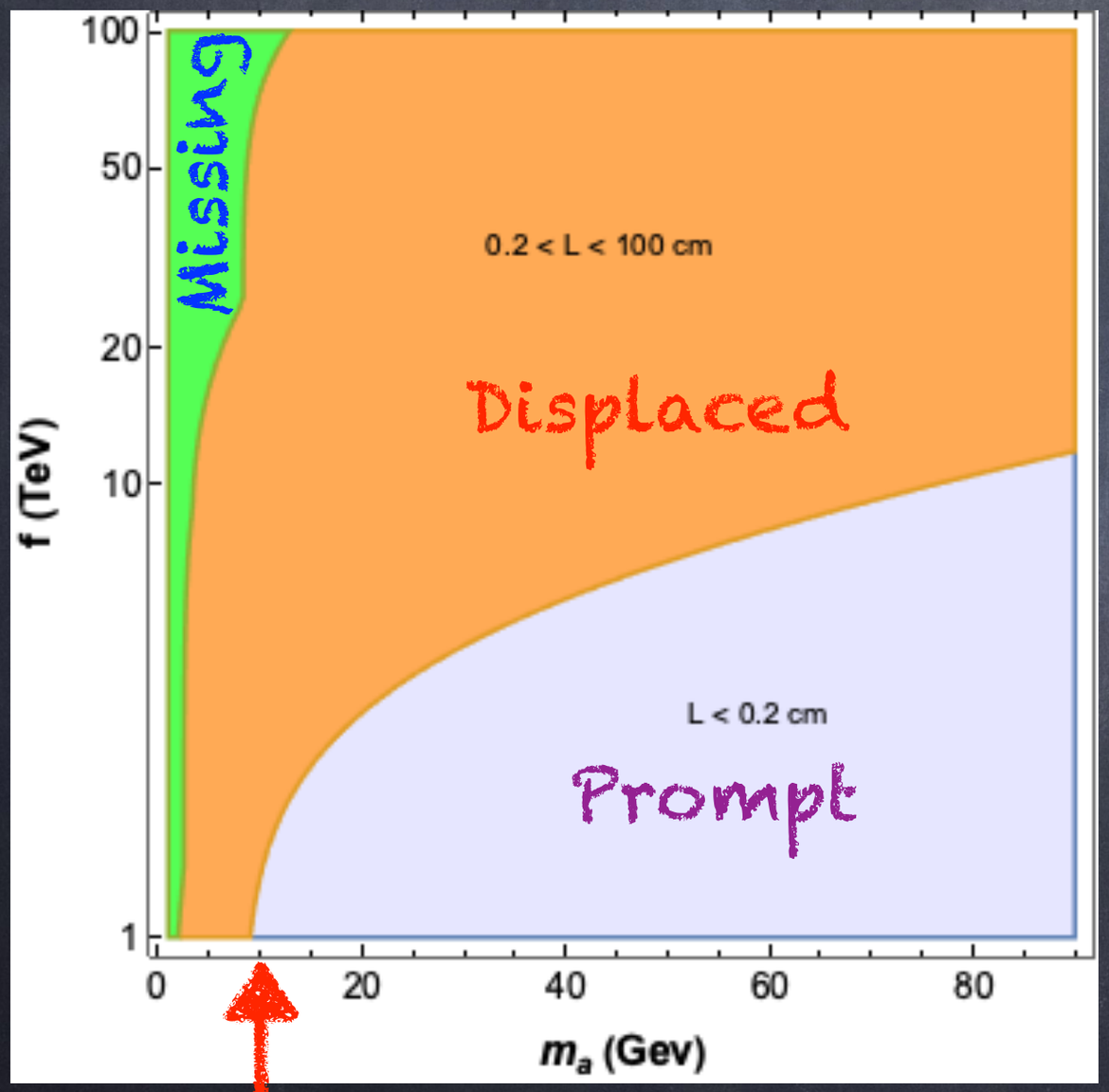


WZW interaction to photons (like the pion)

eg. SU(5)/SO(5), SU(6)/SO(6)

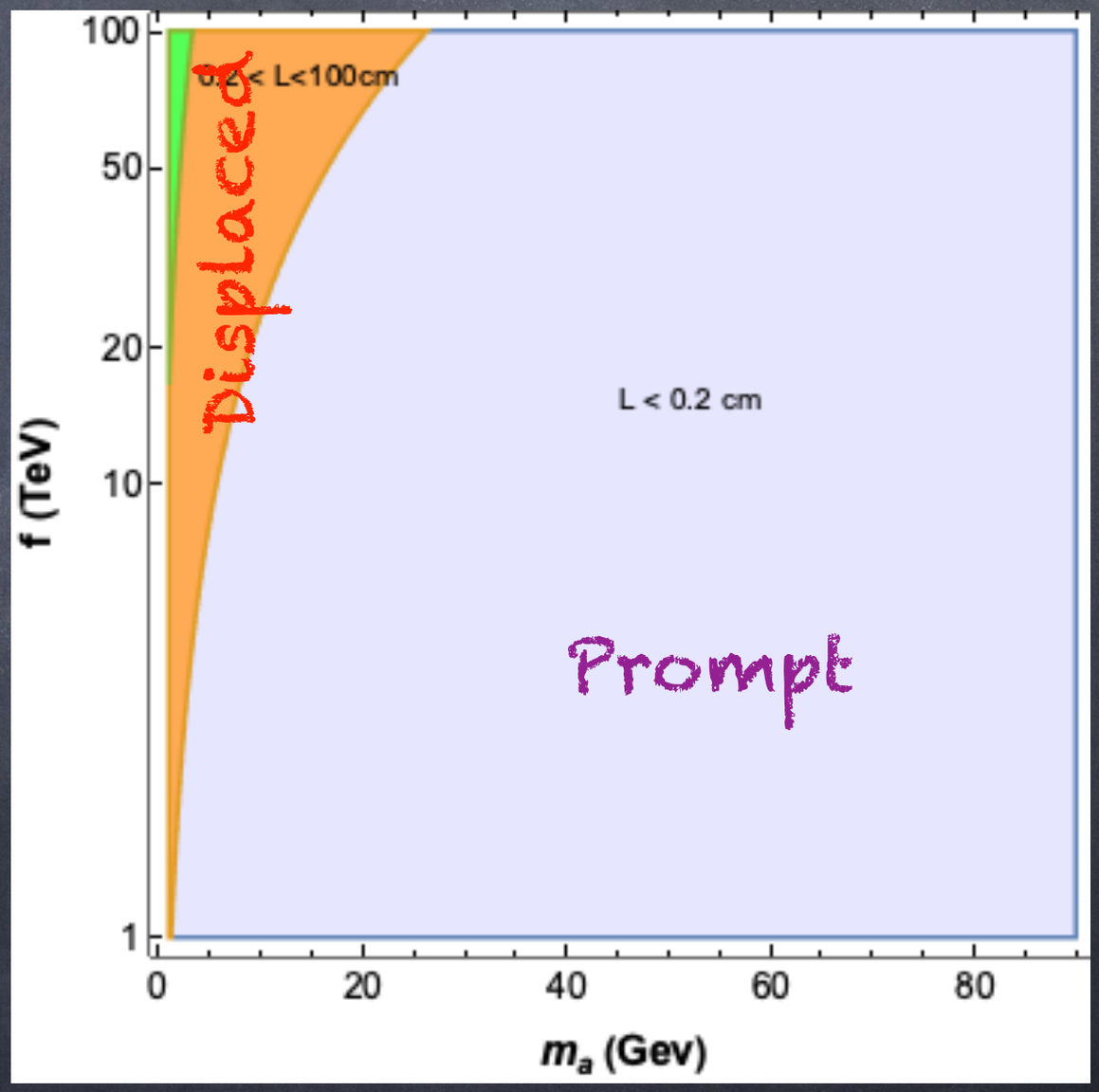
Signatures:
Invisible or Displaced or Prompt

Photo-phobic



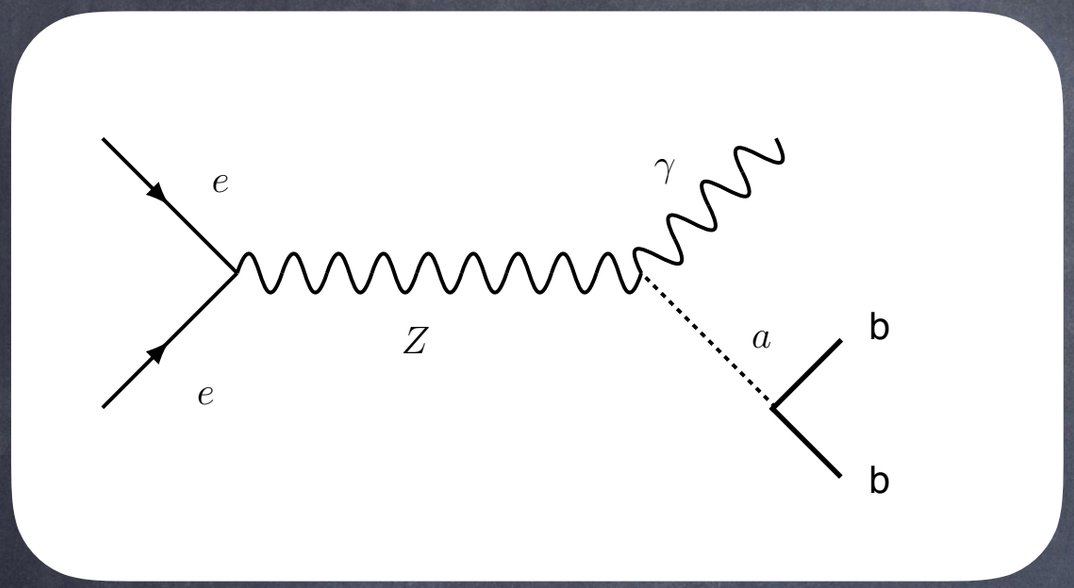
bb threshold

Photo-philic

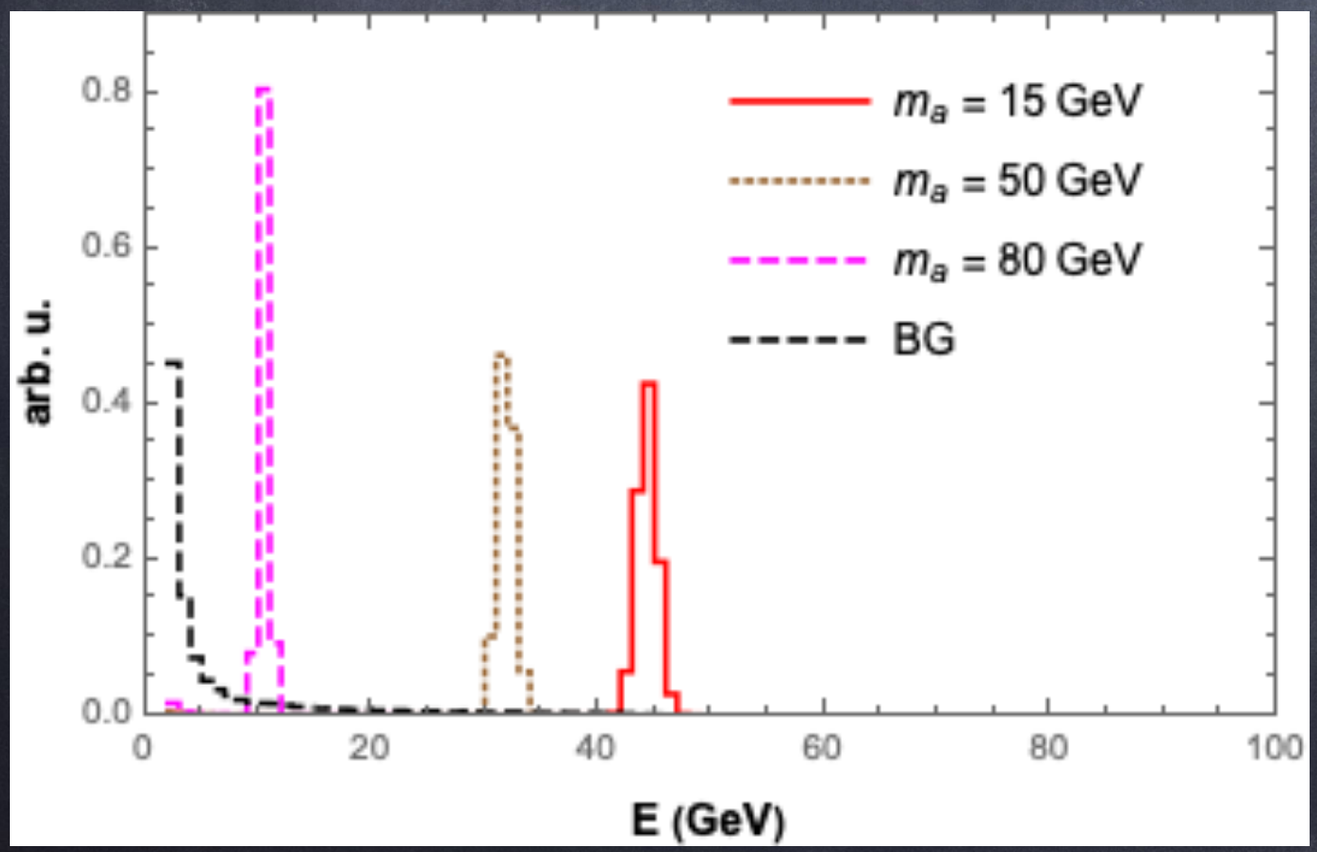


Phenomenology-Prompt Decays

Photo-phobic



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

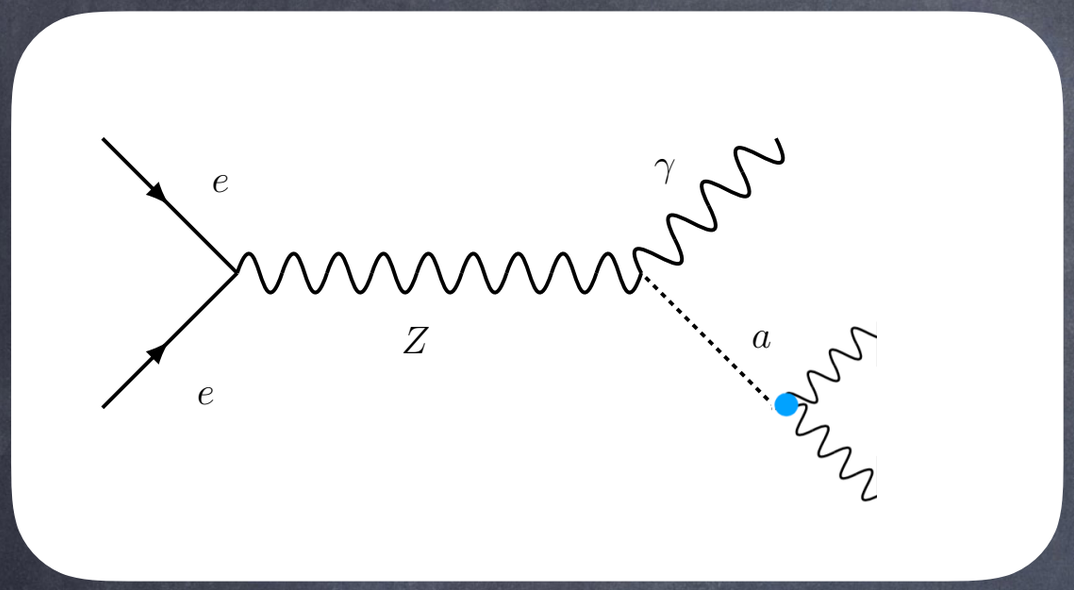


Discriminating variable:
photon energy

Best discrimination
for small ALP masses

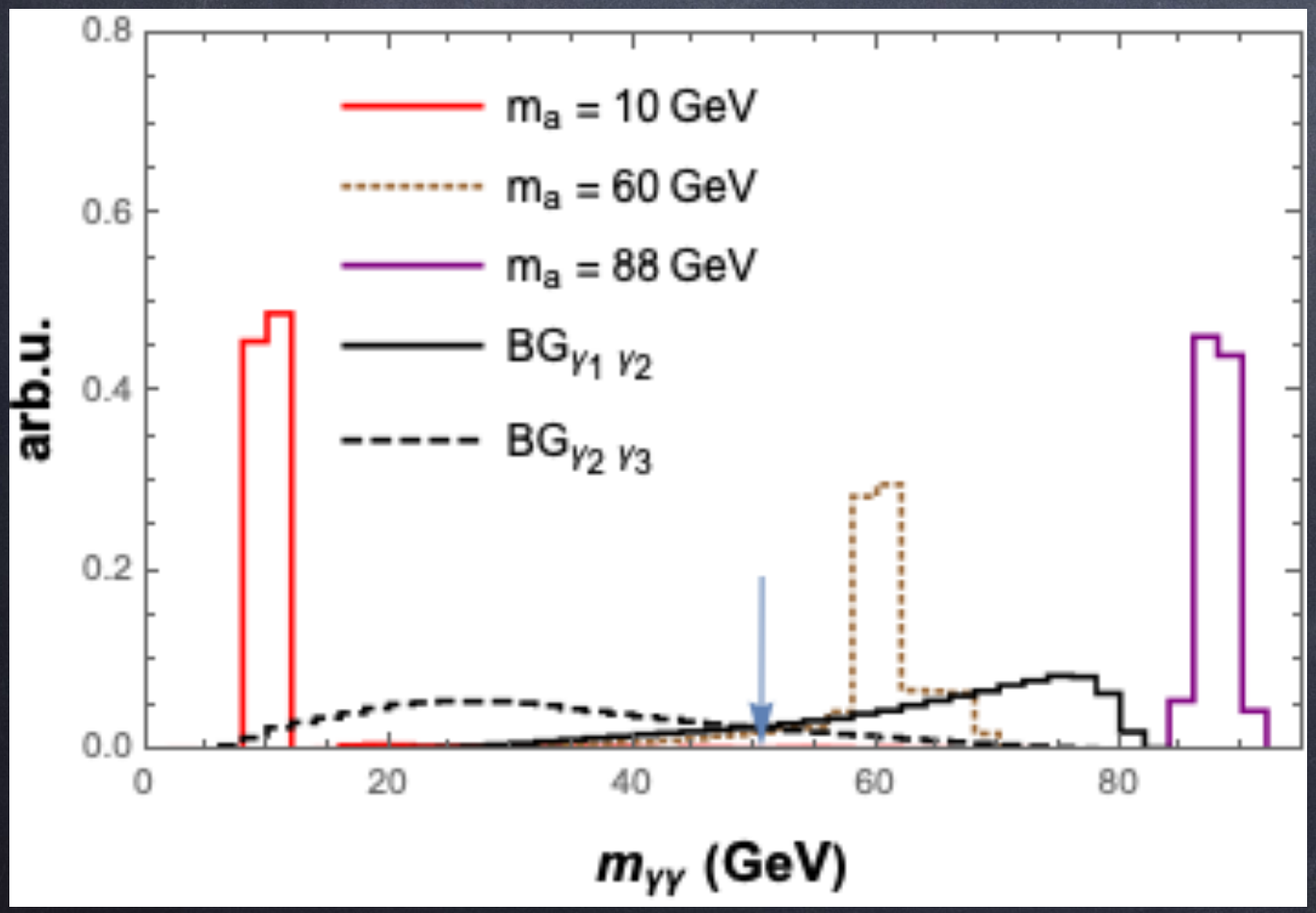
Phenomenology-Prompt Decays

Photo-philic



- Three isolated photons

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



Discriminating variable:
invariant mass

Photon ordering changes
at inv. mass 50 GeV

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

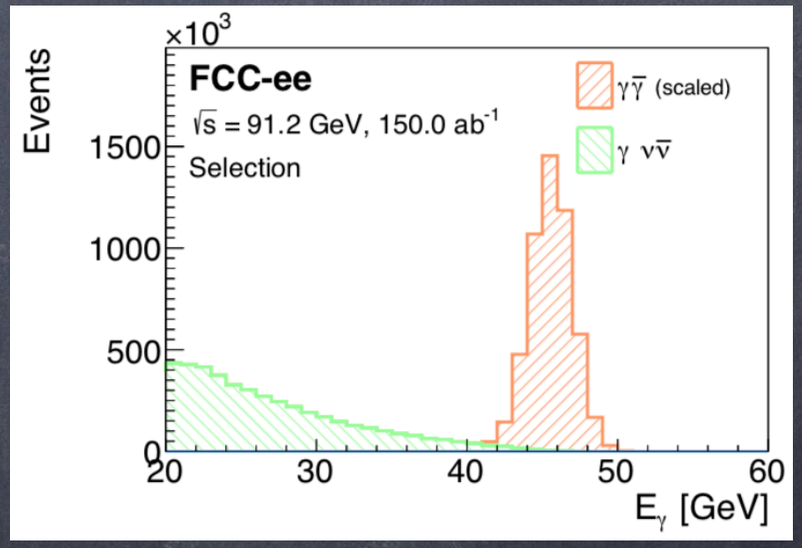
Phenomenology-Missing energy

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:



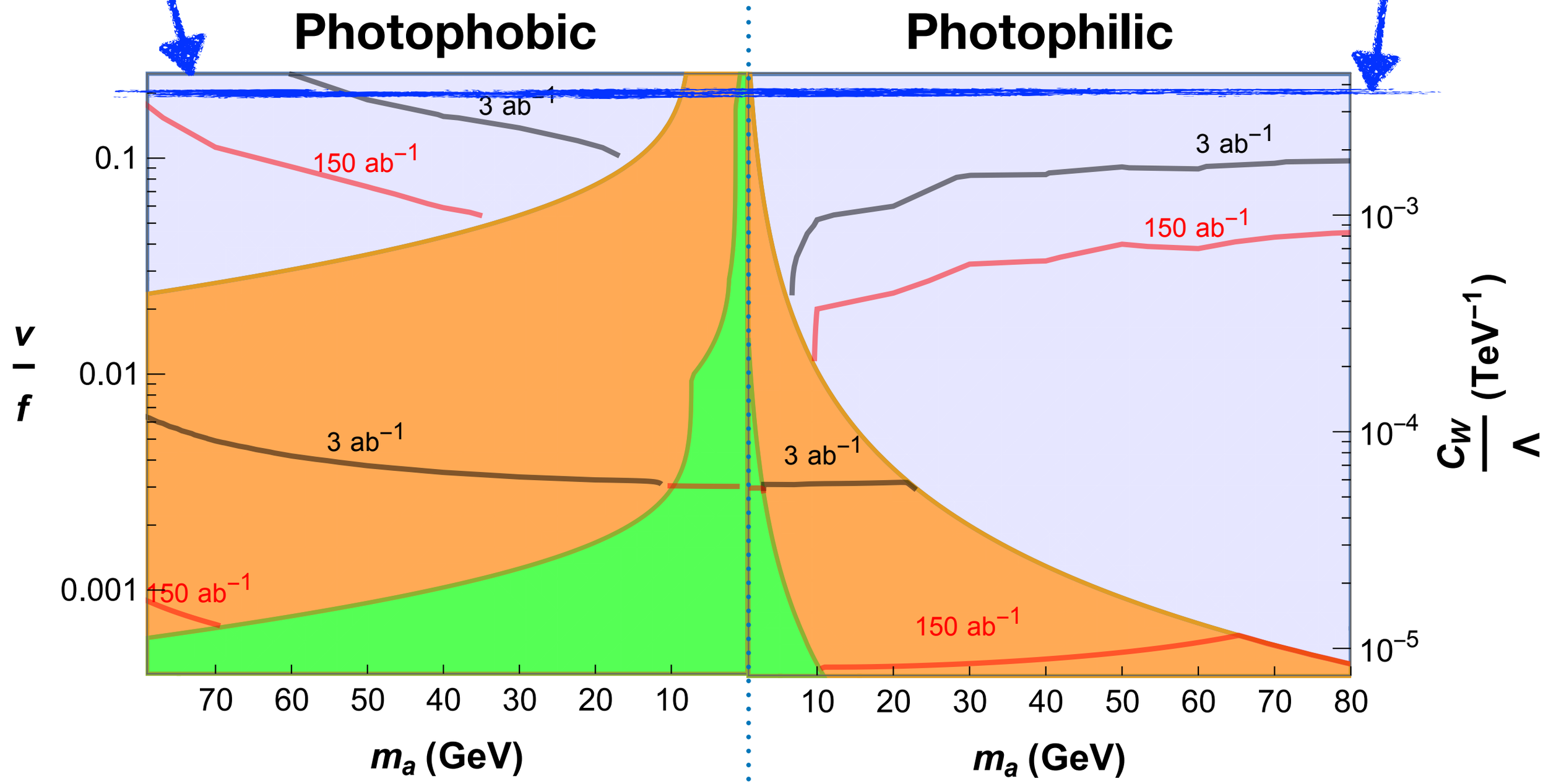
M.Cobal et al, 2006.15945

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

Money plot

Typical EWPT bound

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



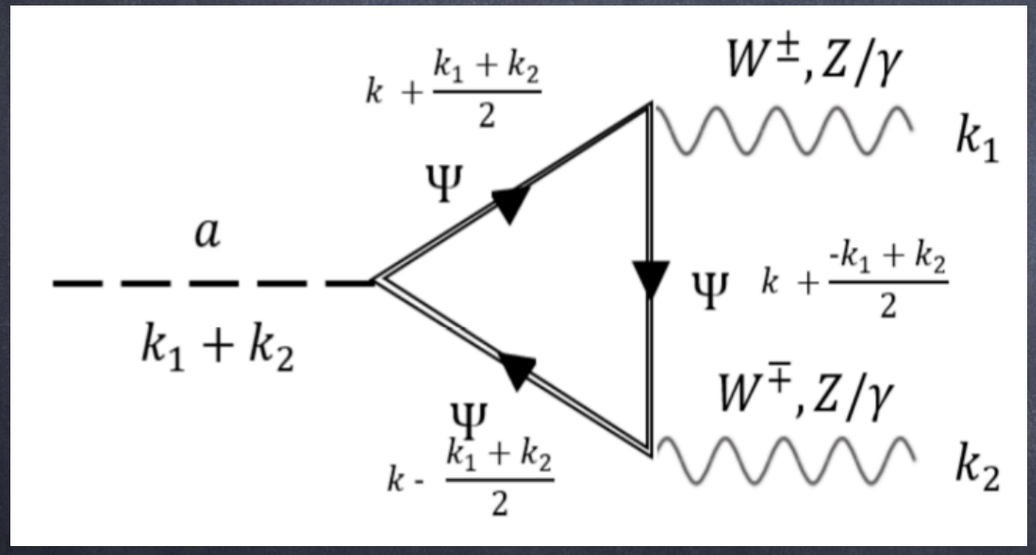
What if FCC-ee discovers Z > γa?

- Is it possible to distinguish the composite scenario, from an elementary mock-up model?

$\Phi = H + i\,a$

Singlet scalar

Ψ = doublet + singlet



Triangle loops can mimic the WZW interactions of the composite ALP:

doublet + singlet = photo-phobic case

- Note: fermion masses of the order of TeV, potentially discoverable at HL-LHC or FCC-hh (QCD-neutral)

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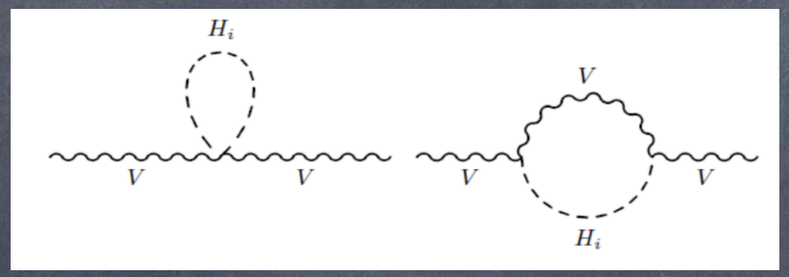
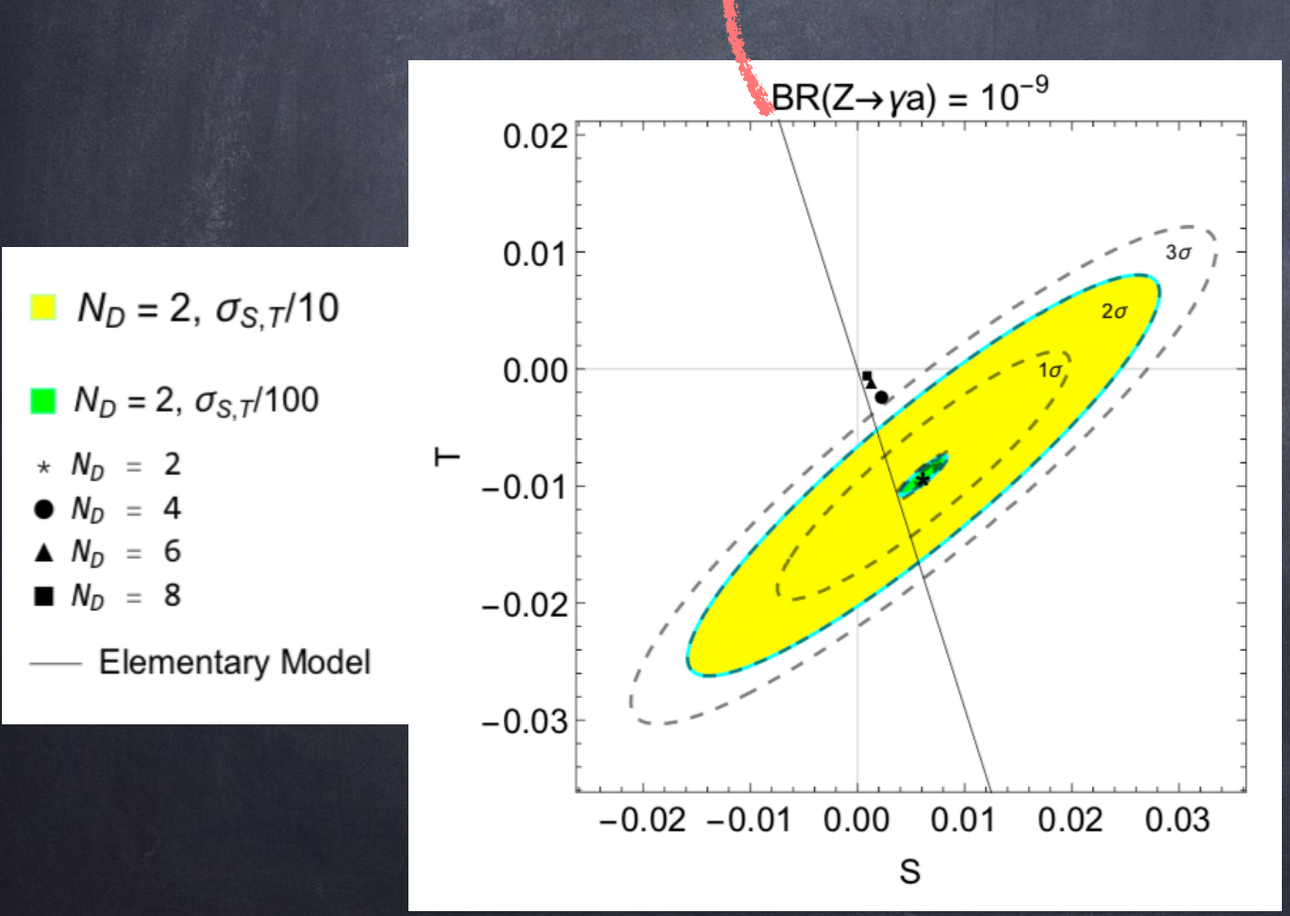
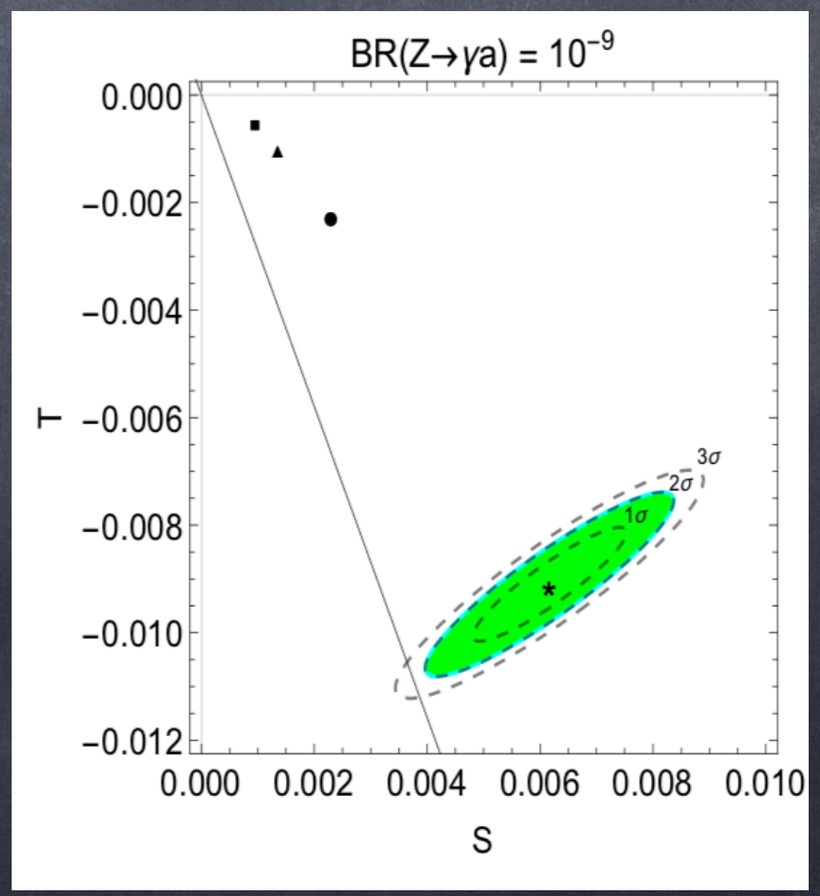
- Is it possible to distinguish the composite scenario, from an elementary mock-up model?

EWPT only depend on H loops



composite case: see 1502.04718





Outlook and Conclusions

- The TeraZ run is ideal for searching for light composite ALP: reach well above EWPT limits

- Direct discovery + EW precision can help disentangling composite scenario from elementary mock-ups (relies on theoretical improvements)

- The long-lived parameter space needs further analysis (displaced vertex reconstruction)
  * FCC Master internship in 2022 *

BACK UP

Composite Higgs models 101

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

Scales:

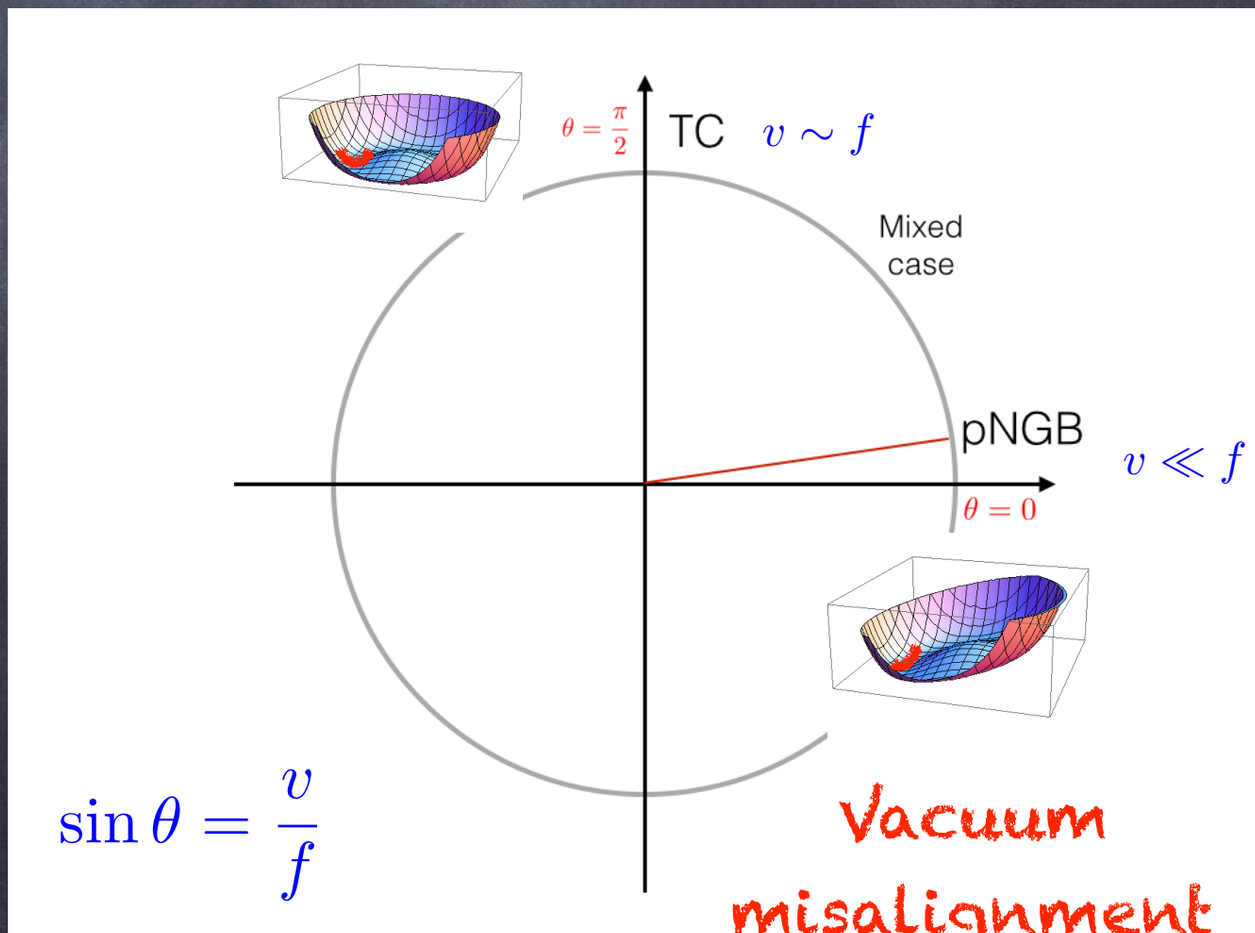
f : Higgs decay constant

v : EW scale

$m_\rho \sim 4\pi f$

EWPTs + Higgs coupl. limit:

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



Composite Higgs models 101

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

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

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