



Tera-Zooming into compositeness

Abhishek Iyer
IP2I Lyon France
a.iyer@ipnl.in2p3.fr
abhishekiyer1@gmail.com

LCWS2021

International Workshop on Future Linear Colliders 2021

15 March 2021

Based on work to appear with *G. Cacciapaglia, A. Deandrea, K. Sridhar*

Motivation of the talk

What are the signatures for light pseudo scalars in composite models

Depart from the conventional $O(1)$ parametrization: Hierarchy is good!!

Depending on the parameter space, the light composite states can have a different imprint on the detector: Prompt, Displaced or Missing energy

In this talk we will discuss the coverage of the parameter space for each of these scenarios

The Higgs sector of the SM is still a mystery:

Spontaneous symmetry breaking is not explained: simply modelled

Shielding of the electroweak scale from higher scales: Naturalness

Elementary or Composite?

A solution to the above two questions: Compositeness



Several motivations to consider these kind of models:

Use lessons from QCD: chiral symmetry breaking

Lightness of the "pion"

New states implies new signatures

#win

Global symmetry and its breaking: G/H

Disclaimer: We are interested in models with fundamental fermions charged under new confining group. Motivated by QCD, we have a global symmetry for fermions.

~~SO(5)/SO(4)~~

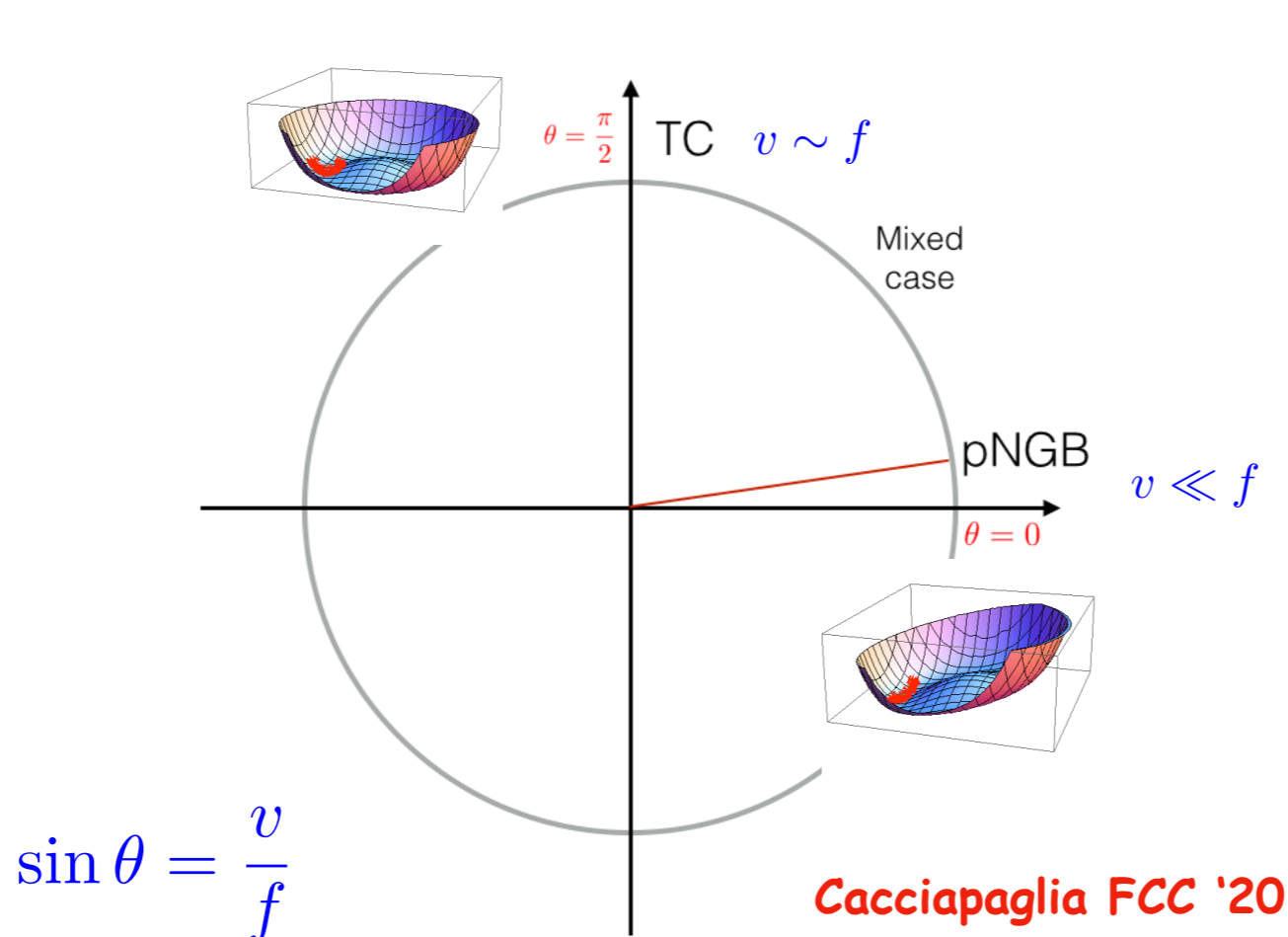
Technicolor:

Electroweak symmetry breaks due to the formation of condensates. Higgs is the lightest

PNGB Higgs:

Underlying dynamics breaks only the global symmetry of underlying fermions

In a generic vacuum alignment, the Higgs is neither a PNGB or a TC-Higgs



Typical pseudo scalar Lagrangian

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

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

By giving examples, we will demonstrate how a departure from the conventional parametrisation can lead to interesting phenomenology

This analysis is also applicable to ALP's which exhibit similar properties!

Properties of the PNGB "a"

Coupling to Gauge bosons

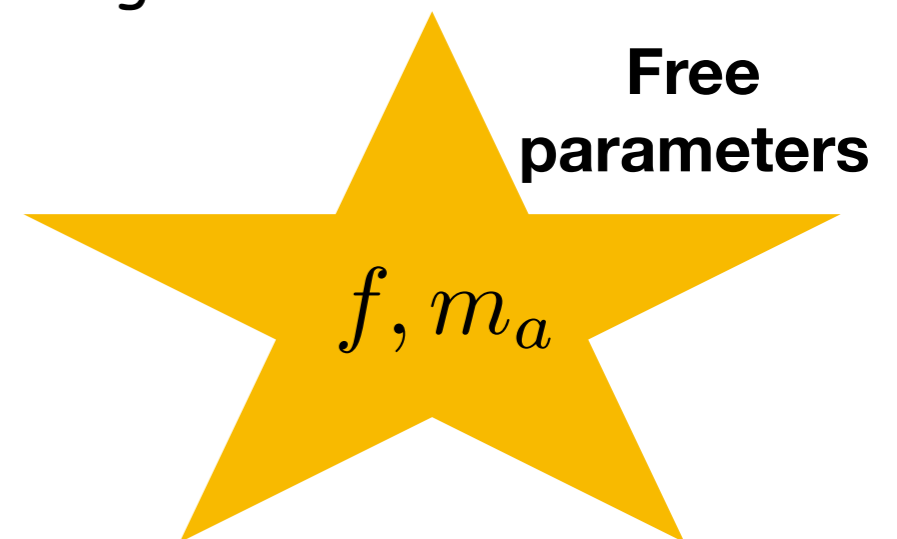
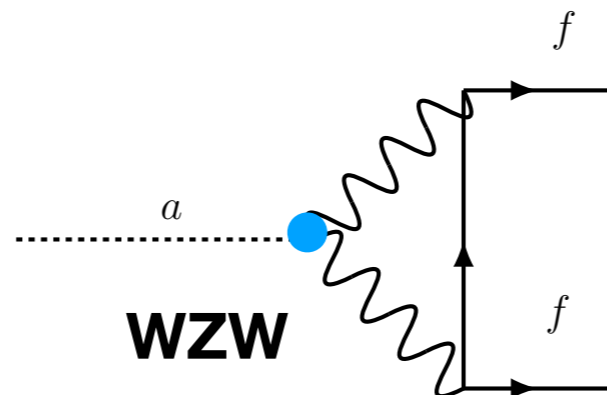
The coupling to a pair of gauge bosons are through the anomalous WZW interactions

$$\mathcal{L} \supset \frac{g_i^2}{32\pi^2} \frac{\kappa_i}{f_a} a \epsilon^{\mu\nu\alpha\beta} G_{\mu\nu}^i G_{\alpha\beta}^i,$$

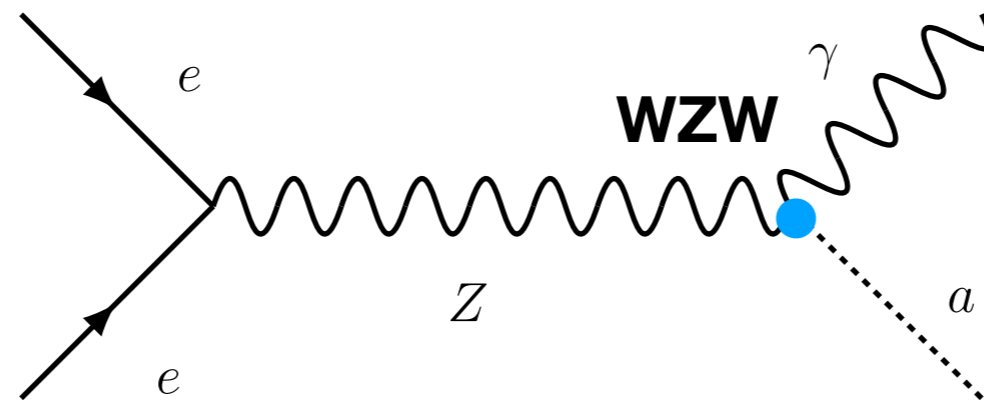
The underlying dynamics also fixes the co-efficients.

Coupling to Fermions:

No tree level interaction. They are loop induced and also through the WZW interaction.



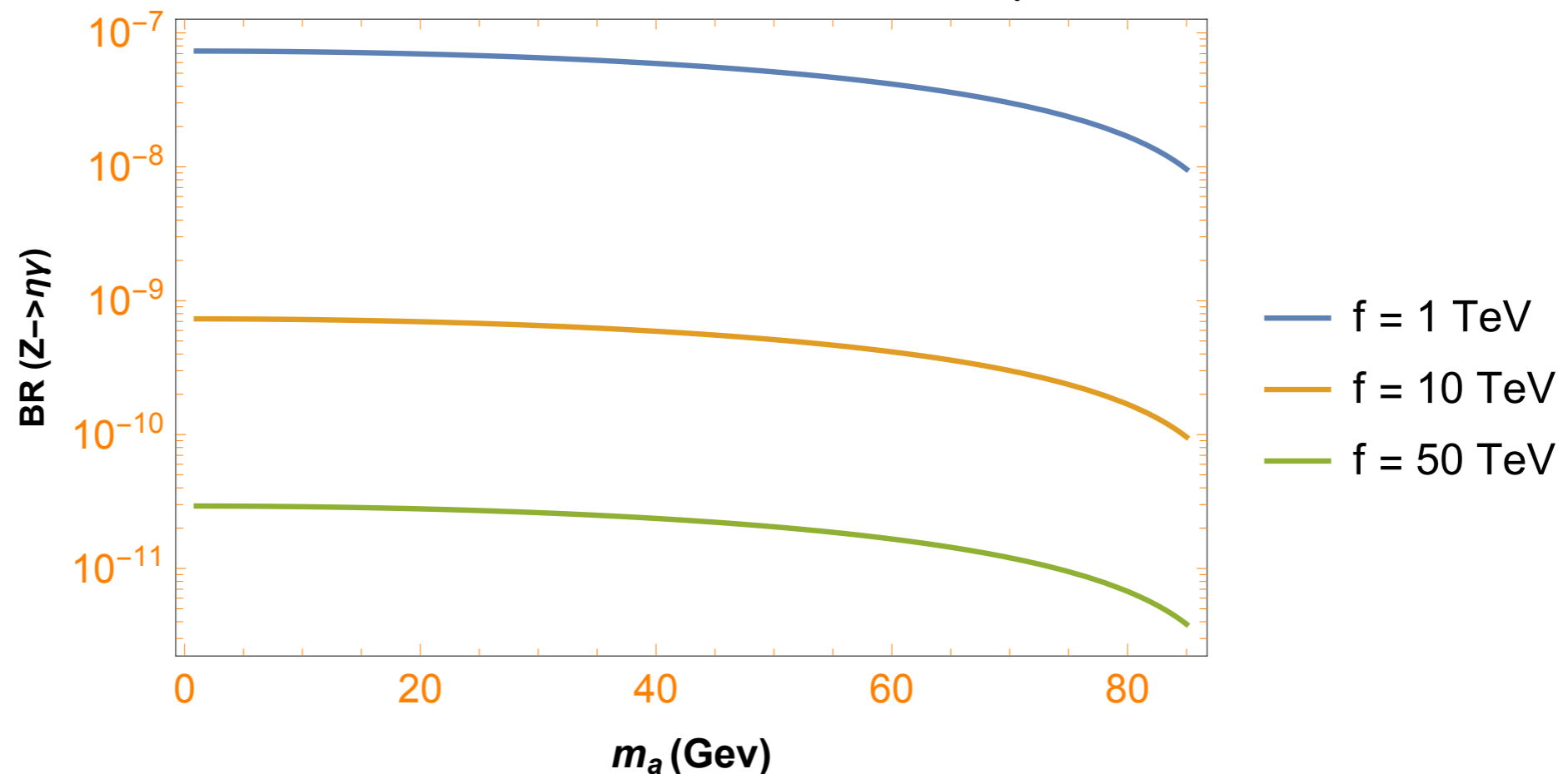
Terra-Z portals for compositeness



This process is always associated with a monochromatic photon.

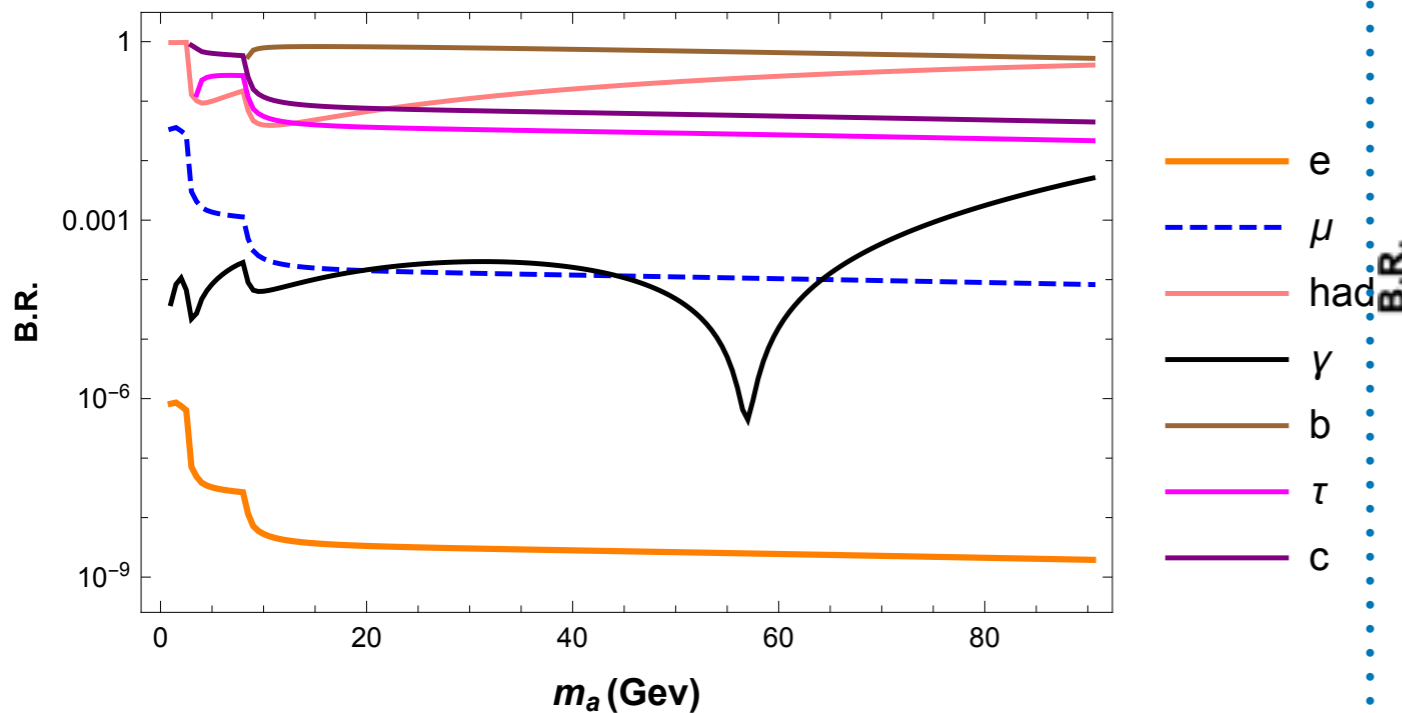
Tera Z phase of FCCee will lead to $\sim 5 - 6 \times 10^{12}$ visible Z bosons at the end of the run.

Good for rare decays!!



Based on the coupling of pseudoscalars to the photons, photons,
the discussion can be split into two scenarios:

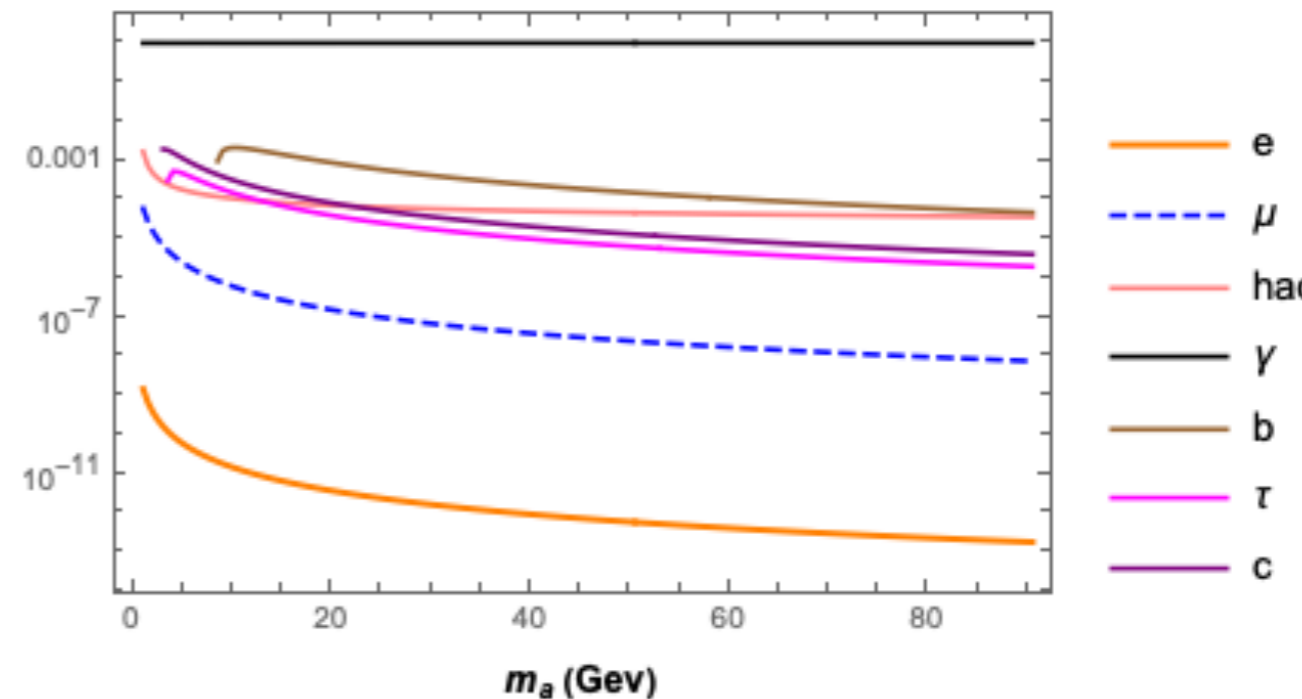
Photo-Phobic



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

eg. $SU(4)/SP(4)$,
 $SU(4) \times SU(4)/SU(4)$:

Photo-Phillic



WZW interaction to photons (like the pion)

eg. $SU(6)/SO(6)$:

Cacciapaglia, Deandrea, A.I.,
Sridhar

Invisible or Displaced or Prompt

Cacciapaglia, Deandrea, A.I., Sridhar

Photo-Phobic

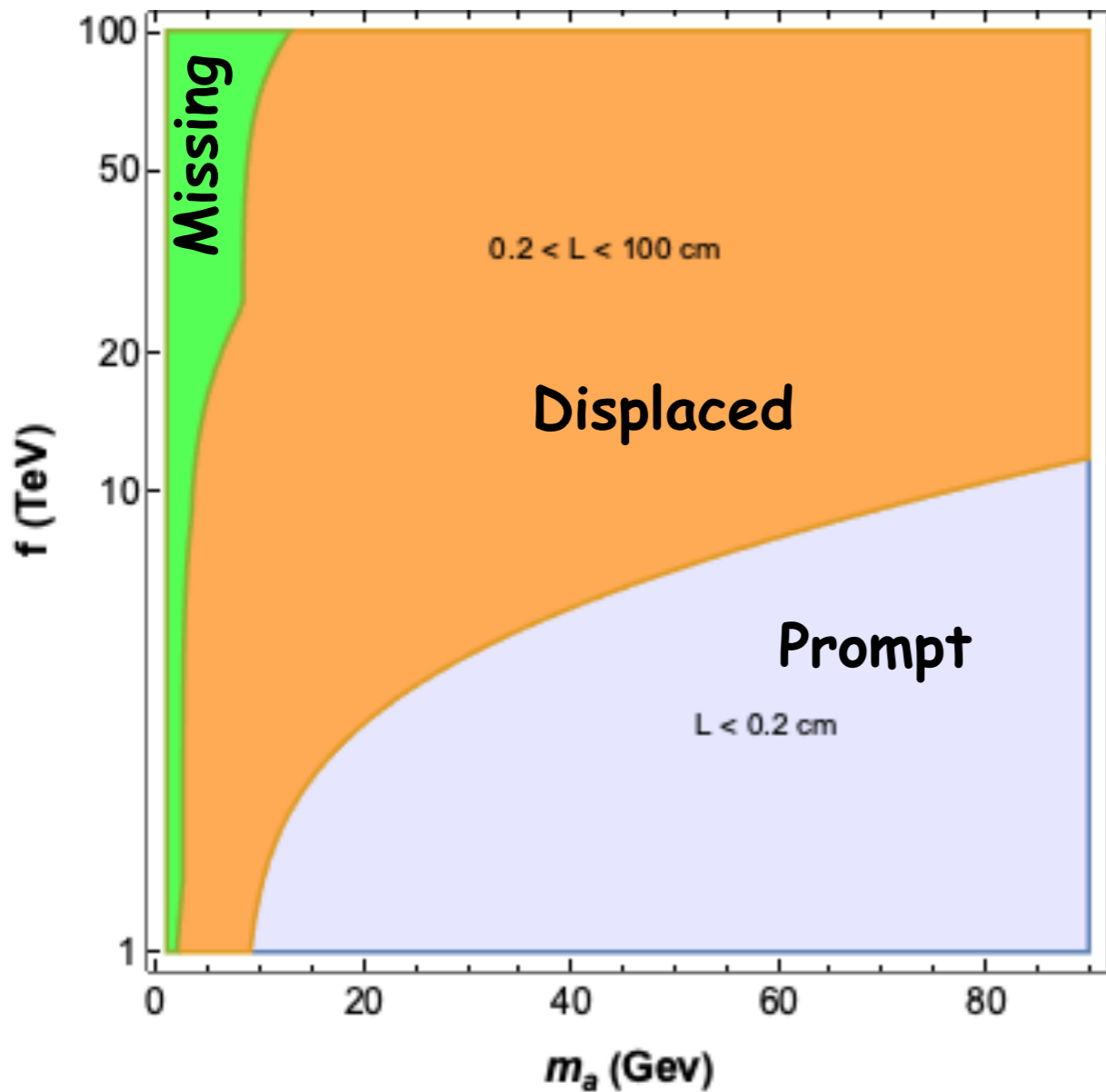
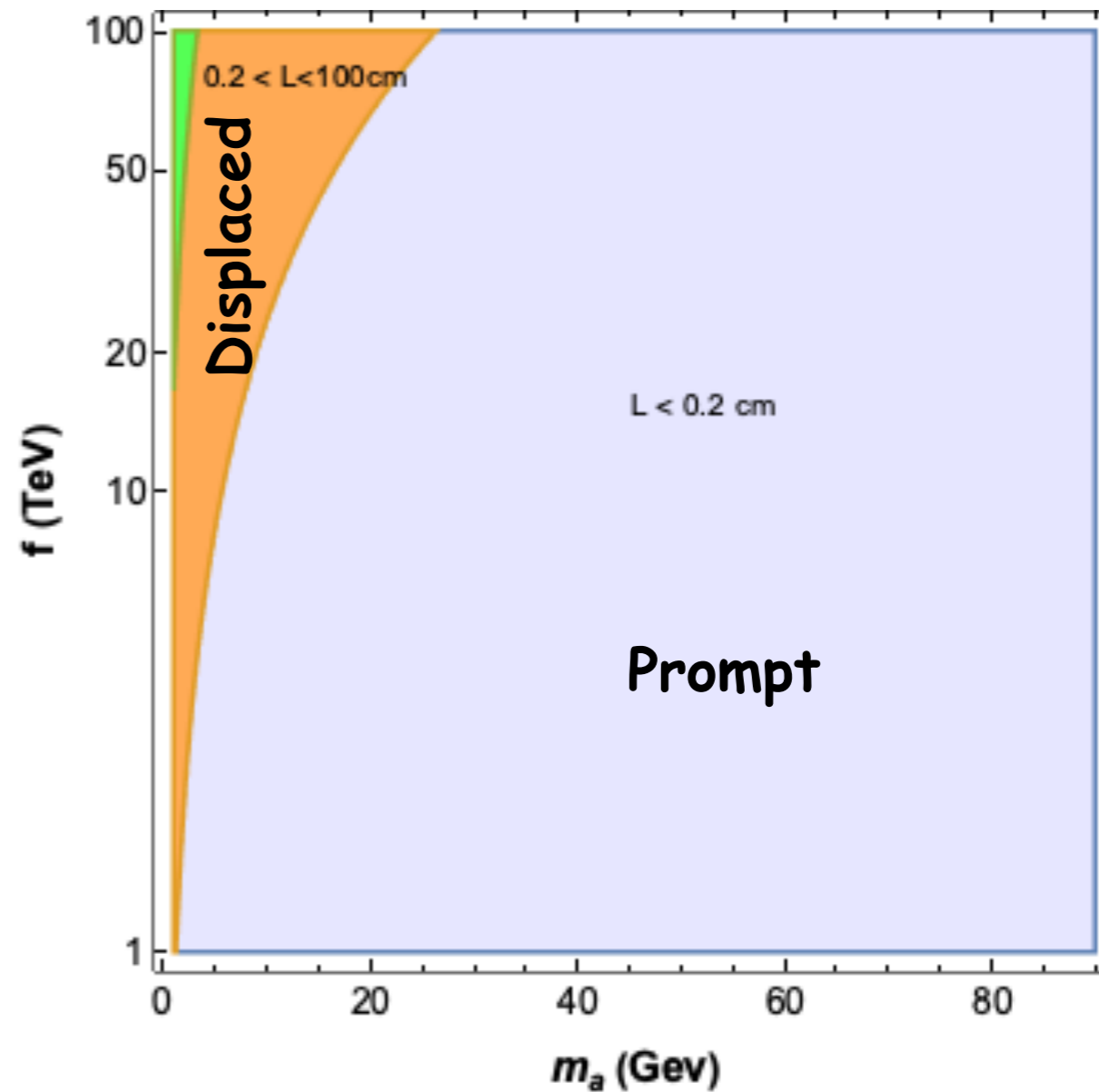
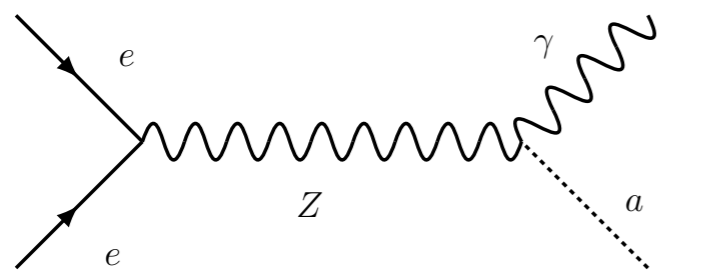


Photo-Phillic



Phenomenology-Prompt Decays

Photo-Phobic



One isolated photon +
at least one b tagged jet **b b**

Discriminating variable:
Energy of the photon

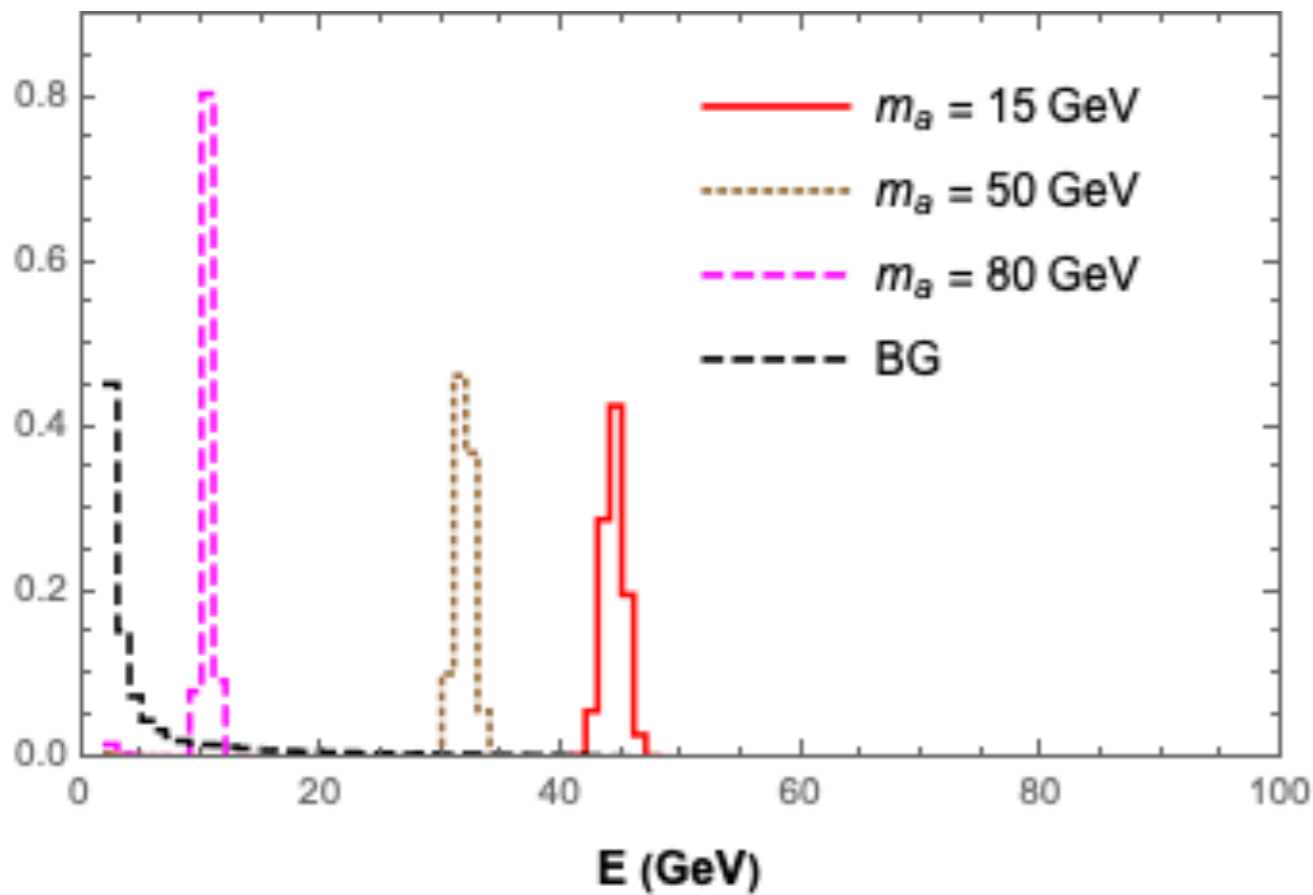
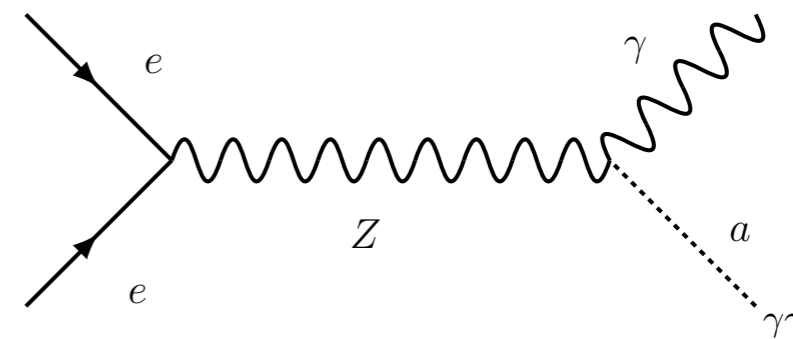
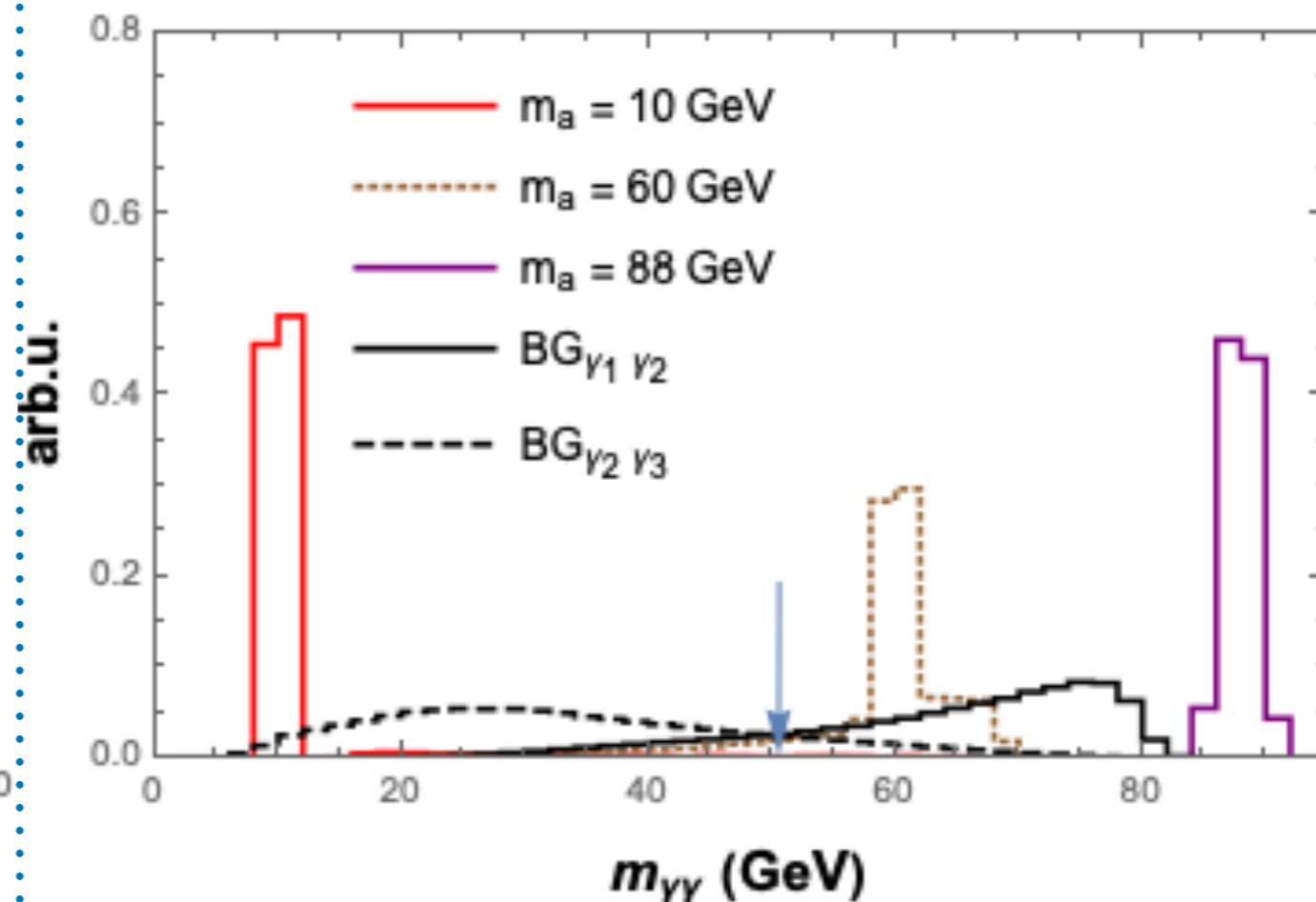


Photo-Phillic



Three isolated photons

Discriminating variable:
Invariant mass



Long lived vertex

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

Monochromatic photon +
displaced hadrons

Photo-Phillic

Monochromatic photon +
At least one displaced photon

Missing energy

We use an existing analysis which estimates the lower bound for

$$B(Z \rightarrow \gamma \bar{\gamma}) < 2.3 \times 10^{-11}$$

Where $\bar{\gamma}$ is the dark photon

Photo-Phobic

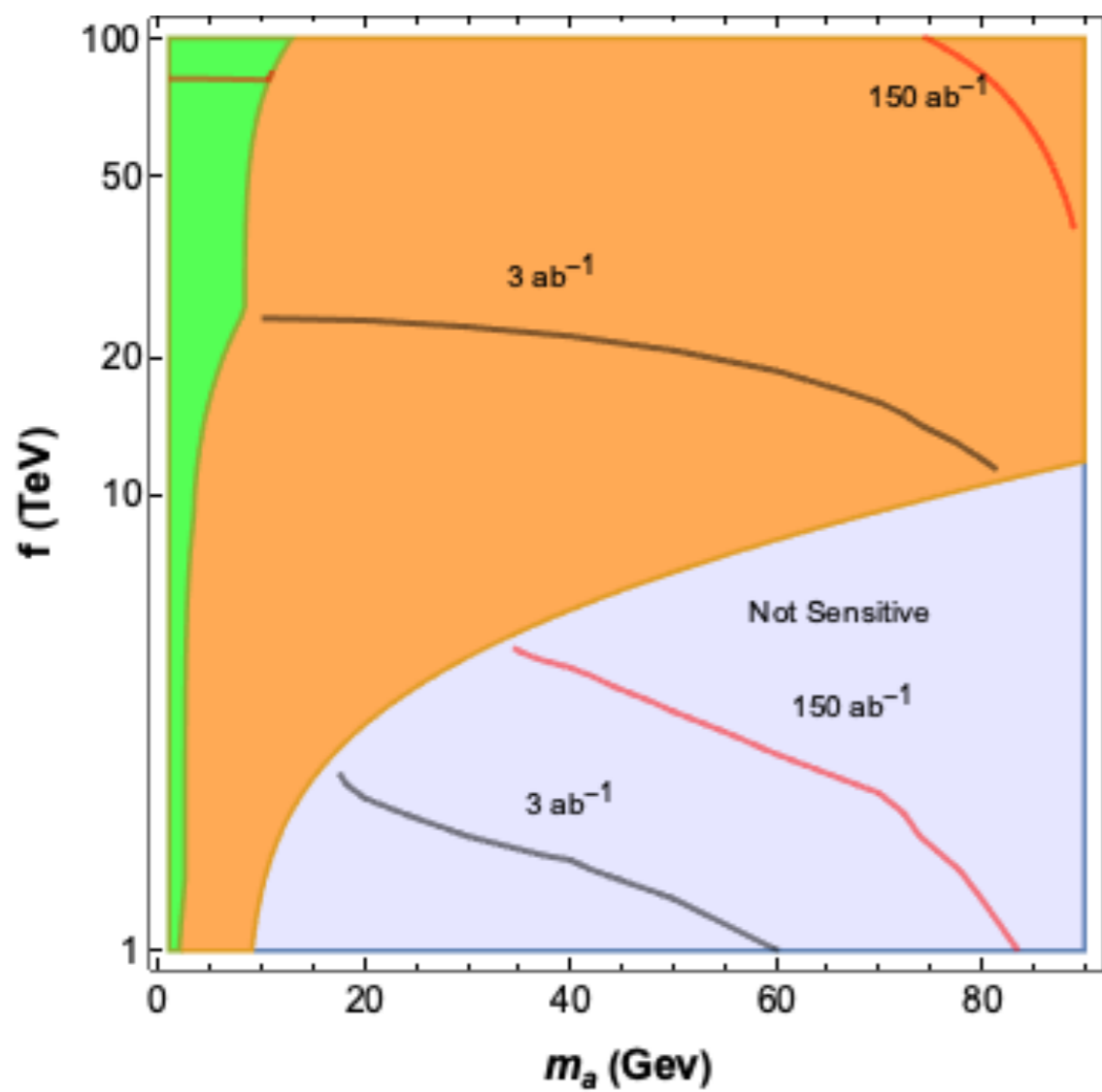
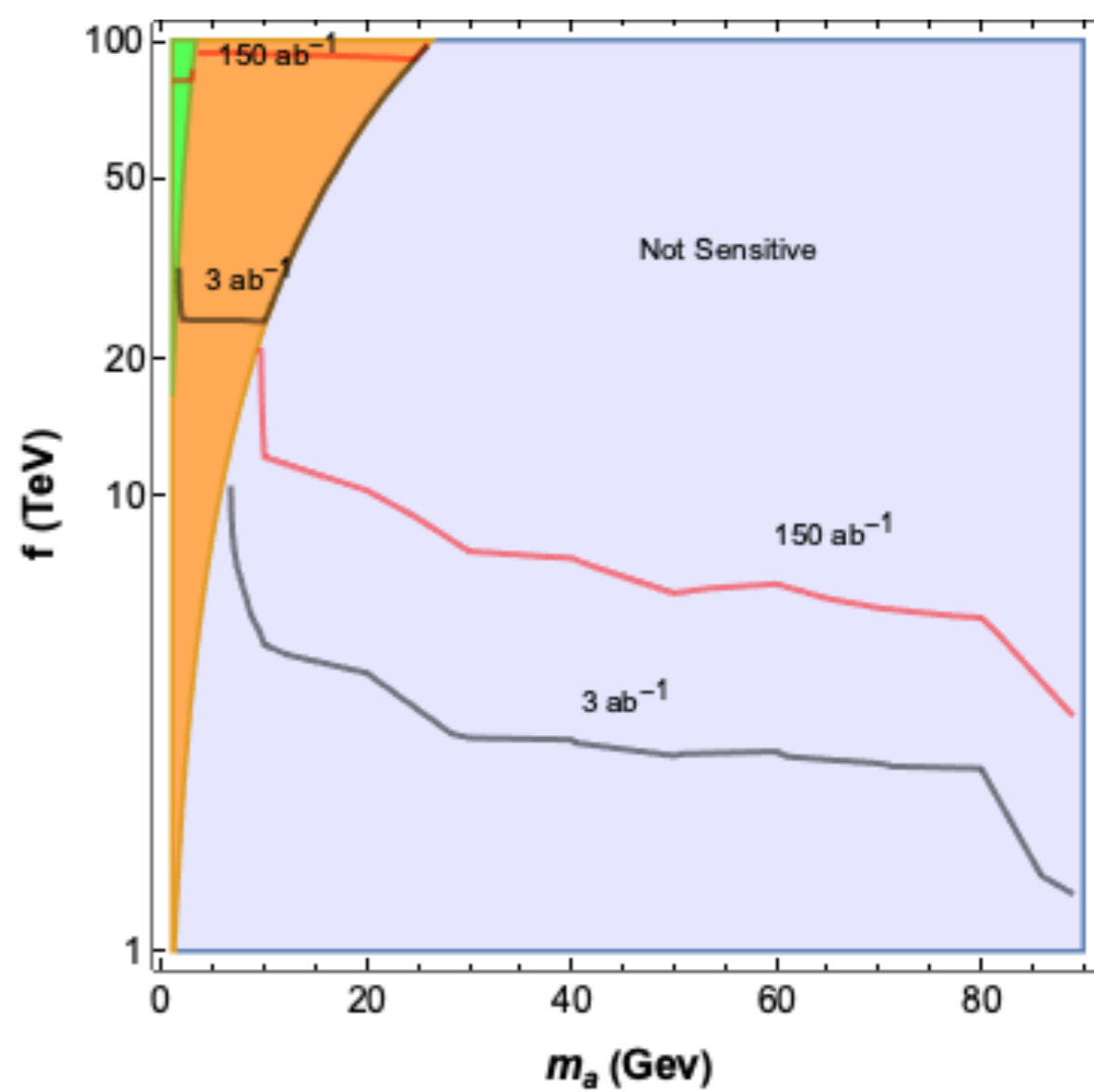


Photo-Phillic



Diphoton decay at the Z pole?

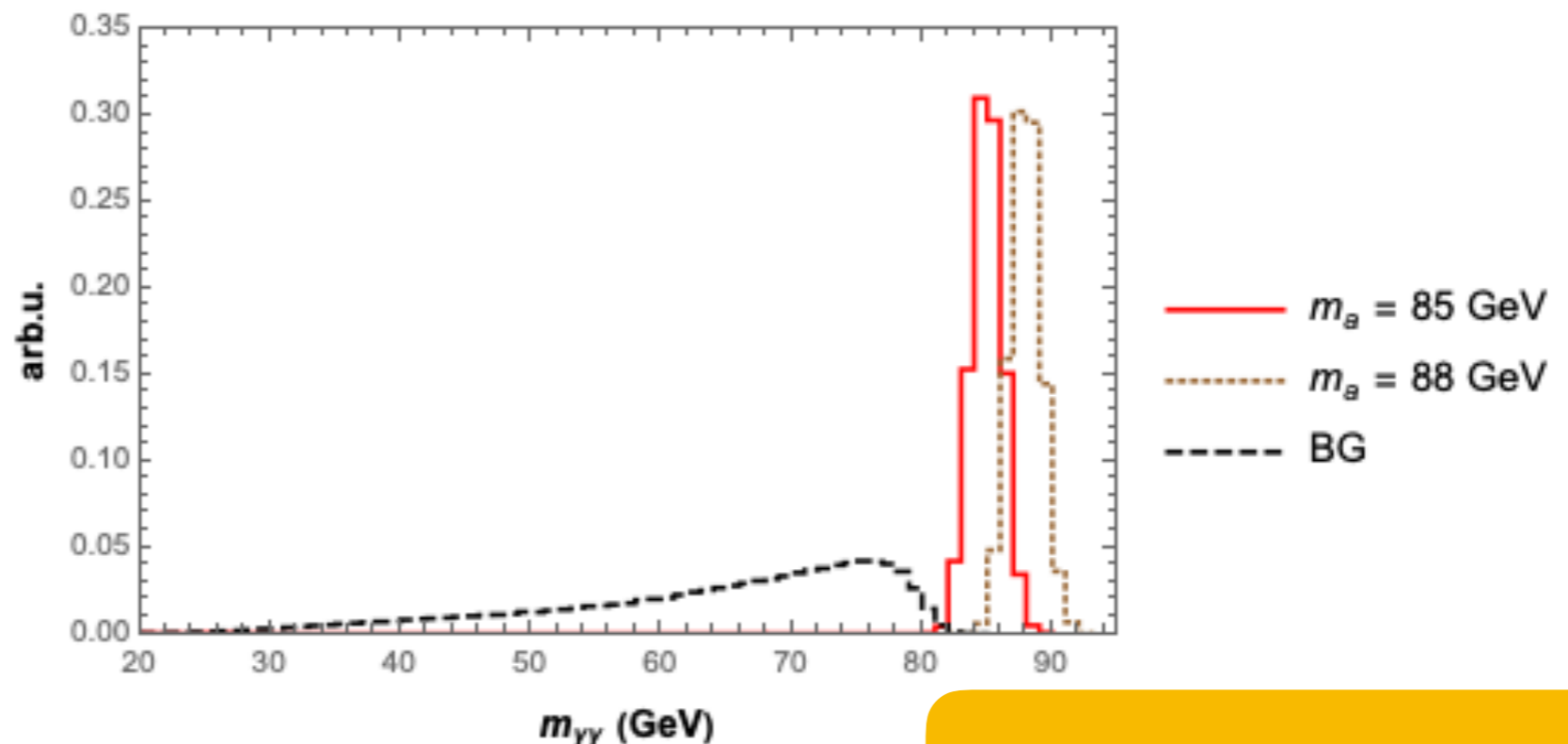
Cacciapaglia, Deandrea, A.I., Sridhar

The three photon background exhibits a rapid decline after 80 GeV

Possibility of zero background bins at the tail for pseudo scalar masses between 87-93 GeV

Event selection: 3 isolated photons

Reconstruct inv. mass of two leading photons



Need for a detailed analysis!!

The only possibility is the double fake from $Z \rightarrow ee \gamma$

The current fake rate from CMS searches is 0.0015: Detector and collider specific

One can expect significantly reduced numbers for FCCee

Summary

We argued the need to go beyond the conventional $O(1)$ parametrisation
Of couplings: *A HIERARCHY is not bad after all*

Scales deep into the UV can be probed at the FCCee

This analysis is also applicable to ALP's which exhibit similar properties!

Is a monochromatic photon associated with a displaced vertex a definite hint for compositeness? Maybe! Look for distinctions with elementary models

BACKUP

Choice of global symmetries

Begin with single Dirac species of fermions: ψ

The possibilities for the flavour symmetry are $SU(2N_f)$ or $SU(N_f) \times SU(N_f)$

$SU(N_f) \times SU(N_f)$: Fermions sitting in the complex representations. QCD like

$SU(2N_f)$: Fermions sitting in the (pseudo-)real representations.

Breaking of global symmetries and cosets

$SU(2N_f)/SO(2N_f)$:
Real

$SU(2N_f)/SP(2N_f)$:
Pseudo-Real

$SU(N_f) \times SU(N_f)/SU(N_f)$:
Complex

"Minimal versions of each"

$SU(6)/SO(6)$:

20 GB $\sim (3,3), (2,2) + (2,2) + 3(1,1)$

$SU(4)/SP(4)$:

5 GB $\sim (2,2) + (1,1)$

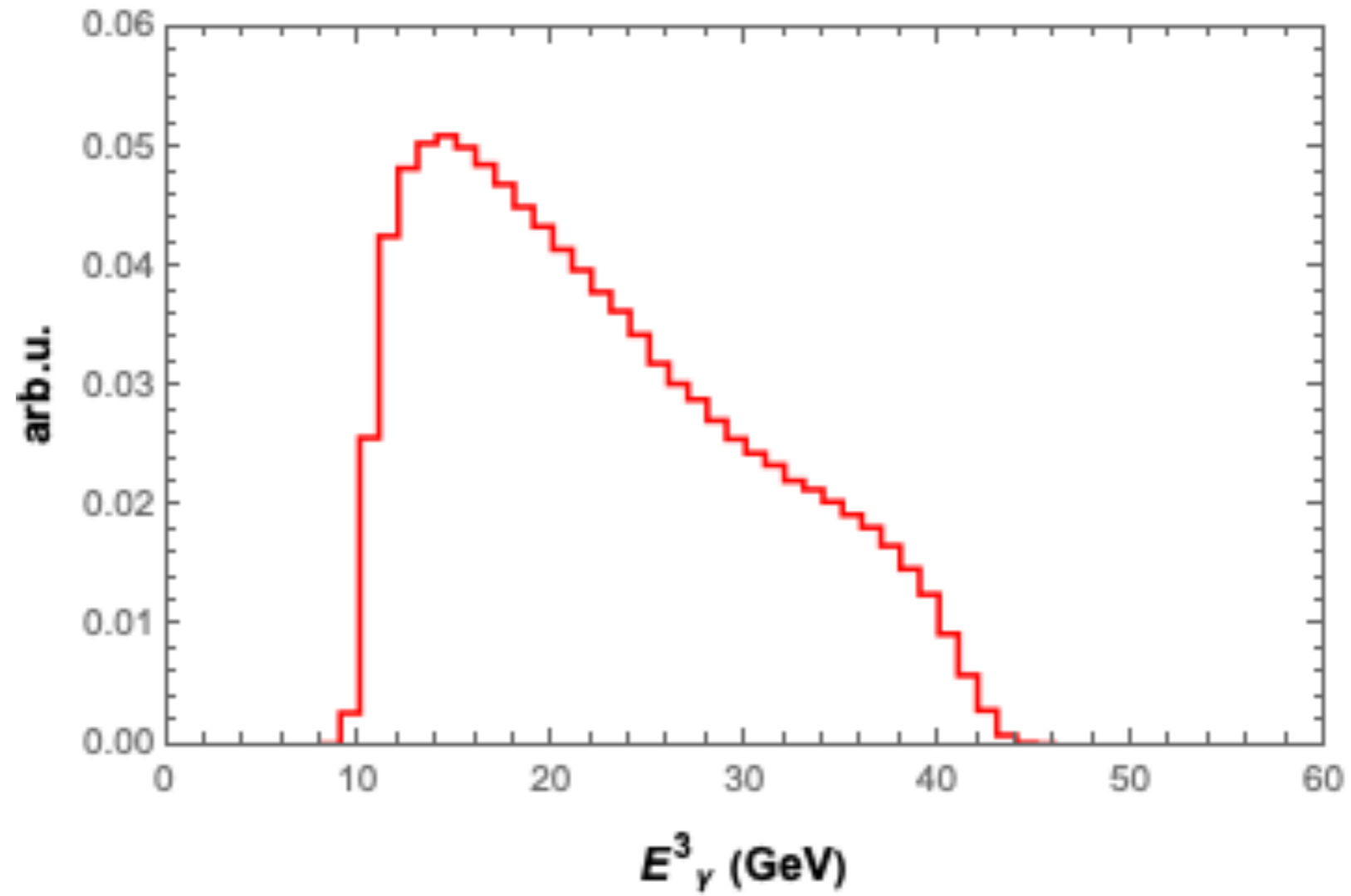
$SU(4) \times SU(4)/SU(4)$:

15 GB $\sim (2,2) + (2,2) + (1,3) + (3,1) + (1,1)$



Most minimal from the matter content
point of view

Energy of the third photon for the background



Axion Like particles

$$\mathcal{L}_{\text{eff}}^{D \leq 5} = \frac{1}{2} (\partial_\mu a)(\partial^\mu a) - \frac{m_{a,0}^2}{2} a^2 + \frac{\partial^\mu a}{\Lambda} \sum_F \bar{\psi}_F \mathbf{C}_F \gamma_\mu \psi_F$$

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

