Tera-Z phase of FCCee as a portal to composite dynamics

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Based on ongoing work with G. Cacciapaglia, A. Deandrea, K. Sridhar

Motivation of the talk

What are the signatures for composite models?

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 prompt decay channels in detail while commenting on the other two.

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

Source: symmetry magazine

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)

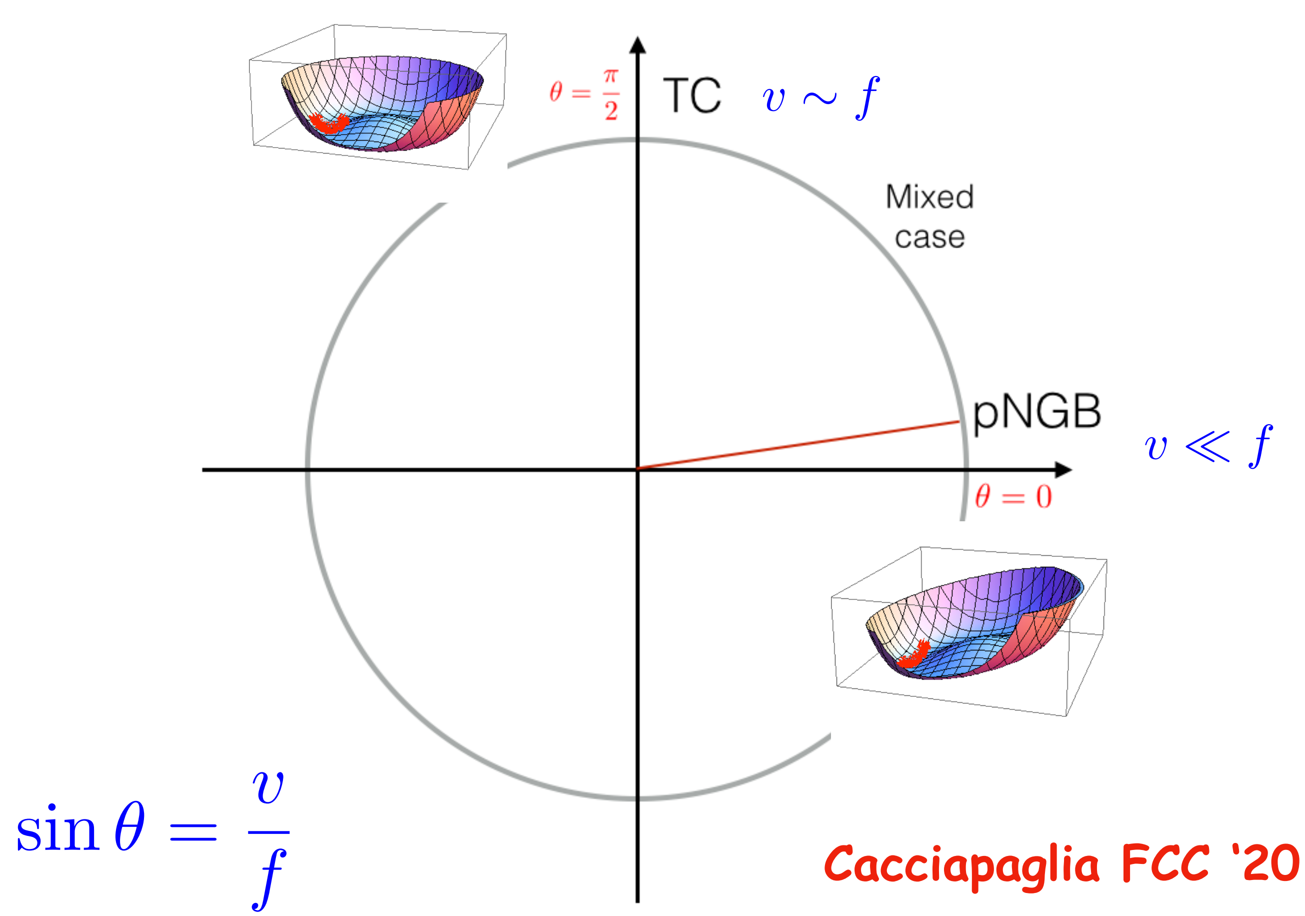
Technicolor:

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



Cacciapaglia FCC '20

Choice of global symmetries

Begin with single Dirac species of fermions: ψ

The possibilities for the flavour symmetry are SU(2Nf) or SU(Nf)xSU(Nf)

SU(Nf)xSU(Nf) : Fermions sitting in the complex representations. QCD like

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

Breaking of global symmetries and cosets

SU(2Nf)/SO(2Nf) :
Real

SU(2Nf)/SP(2Nf) :
Pseudo-Real

SU(Nf)xSU(Nf)/SU(Nf) :
Complex

"Minimal versions of each"

SU(6)/SO(6) :
20 GB~(3,3),(2,2)+(2,2)+3(1,1)

SU(4)/SP(4) :
5 GB~(2,2)+(1,1)

SU(4)xSU(4)/SU(4) :
15 GB~(2,2)+(2,2)+(1,3)+(3,1)+(1,1)

Most minimal from the matter content point of view

Spectrum:

Electroweak cosets: Higgs, triplets and singlets

Additional Spectrum:

QCD cosets: octets, triplets and sextets

Two U(1) singlets

We are interested in the singlets sitting in the electroweak coset.

For a detailed model zoology and classification see

Cacciapaglia, Flacke, Ferreti, Serrodio

Properties of the PNGB "a"

Coupling to Gauge bosons

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

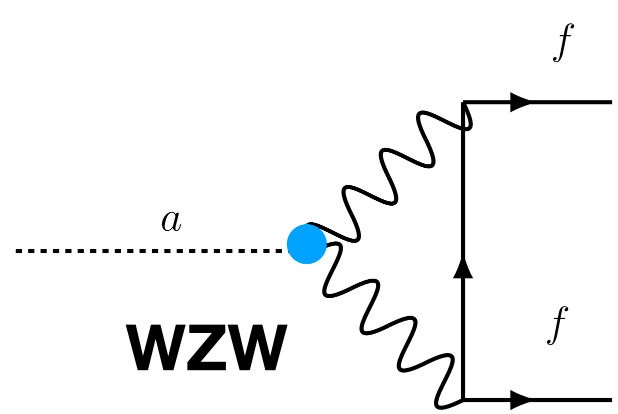
$$\mathcal{L} \supset \frac{g_i^2}{32\pi^2}\frac{\kappa_i}{f_a}\; a\; \epsilon^{\mu\nu\alpha\beta} G^i_{\mu\nu} G^i_{\alpha\beta}\,,$$

The underlying dynamics also fixes the co-efficients.

Note: In this instance we are interested in scenarios where the tree-level. $a\gamma\gamma$ WZW interaction is zero-Photophobic

Coupling to Fermions:

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



Free parameters

f, m_a

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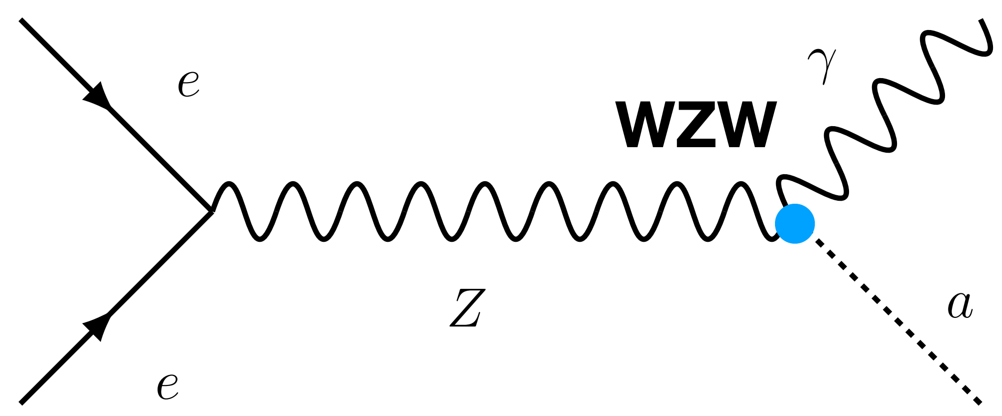
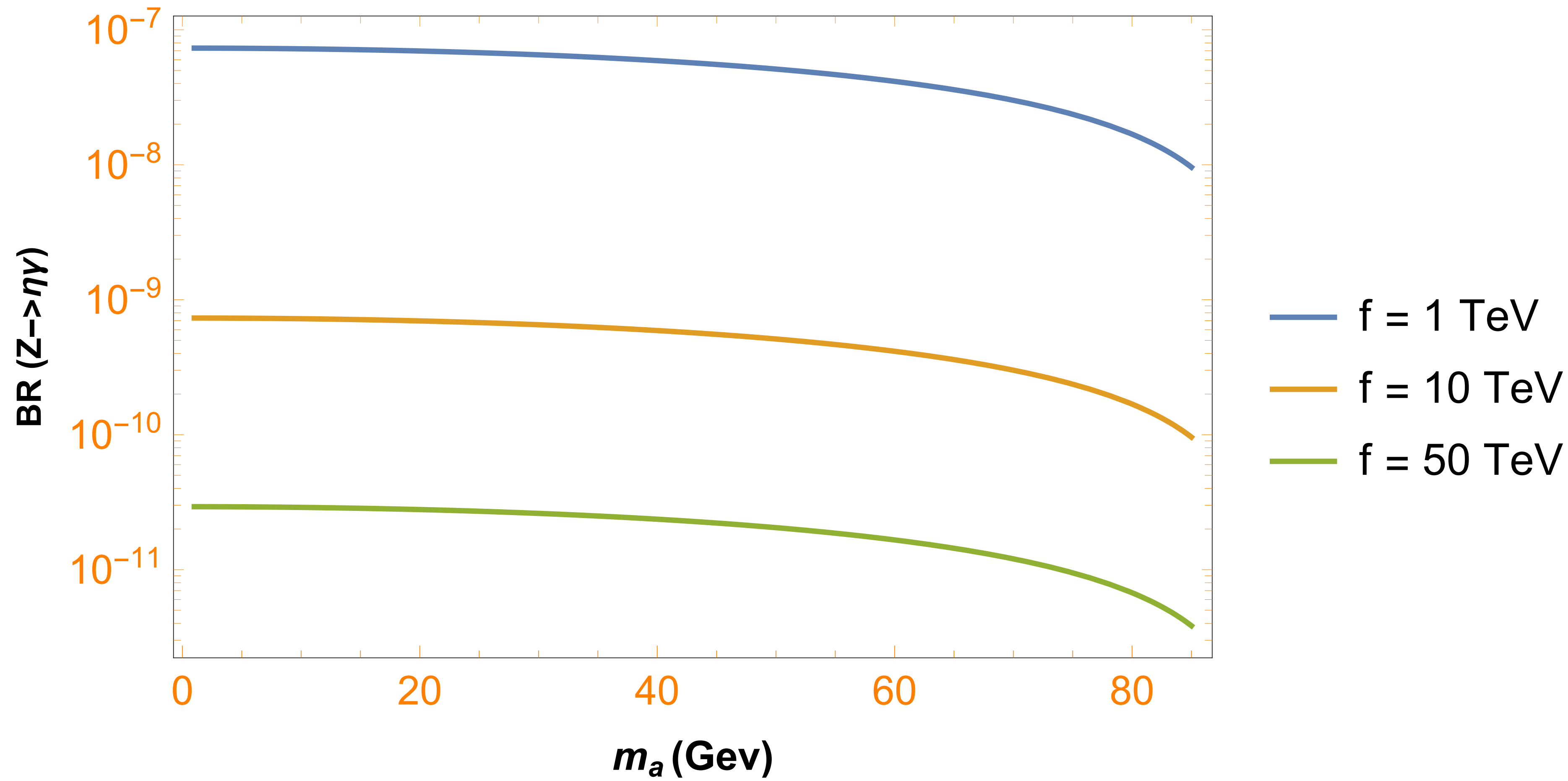
Terra-Z portals for compositeness

Preliminary



This process is always associated with a monochromatic photon.

Let us look at the production of these states "a"



Branching fractions

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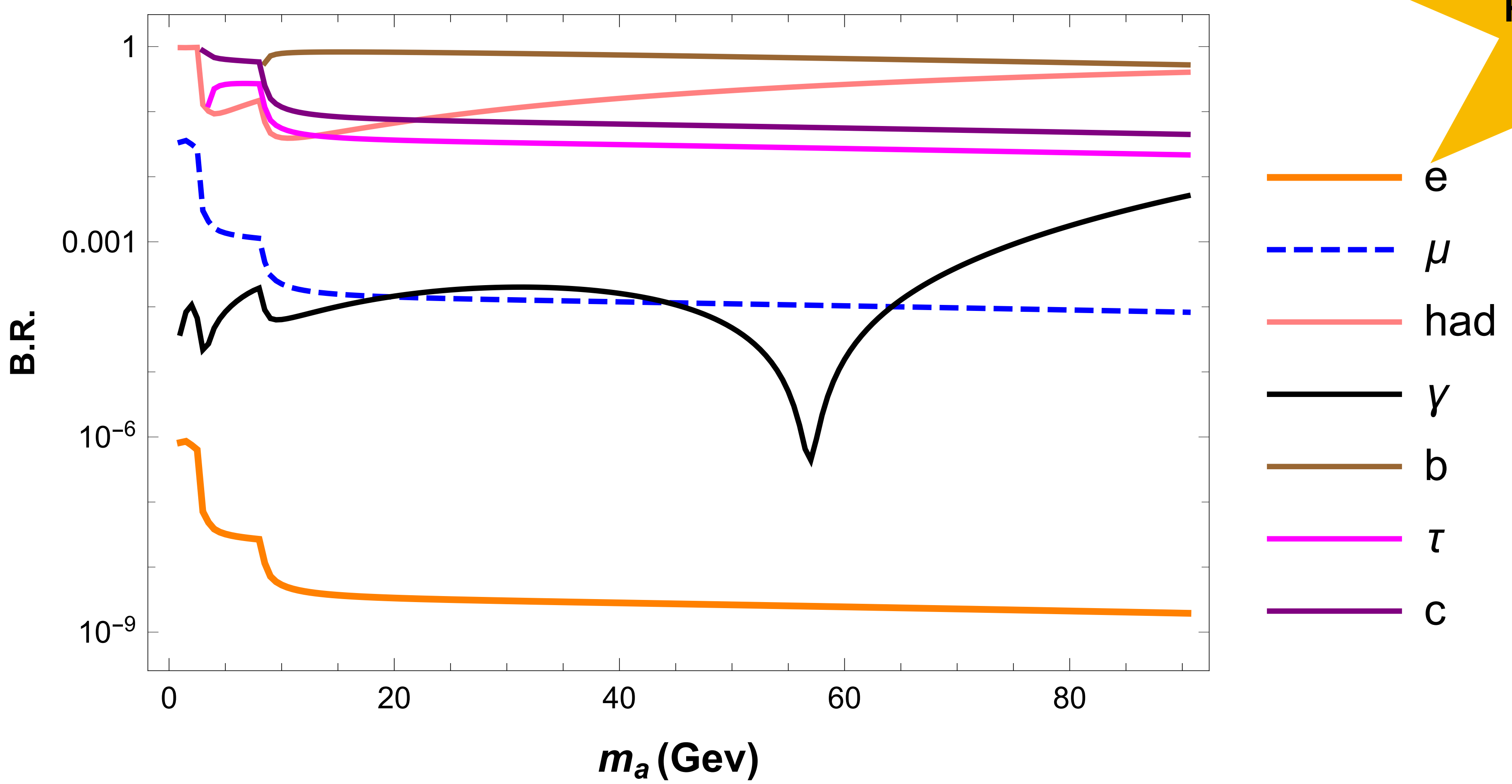
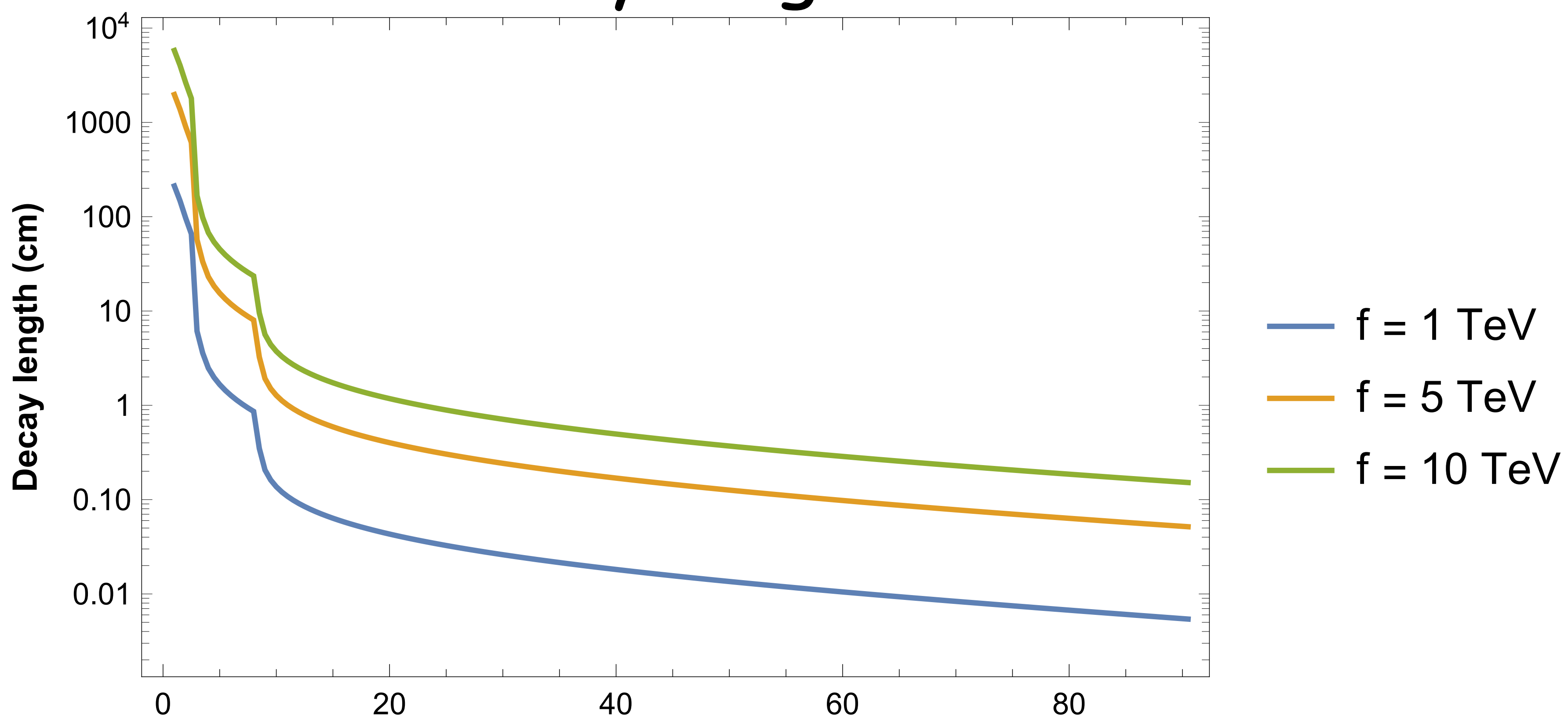
Preliminary

f=10 TeV

Does not depend on f



Decay length



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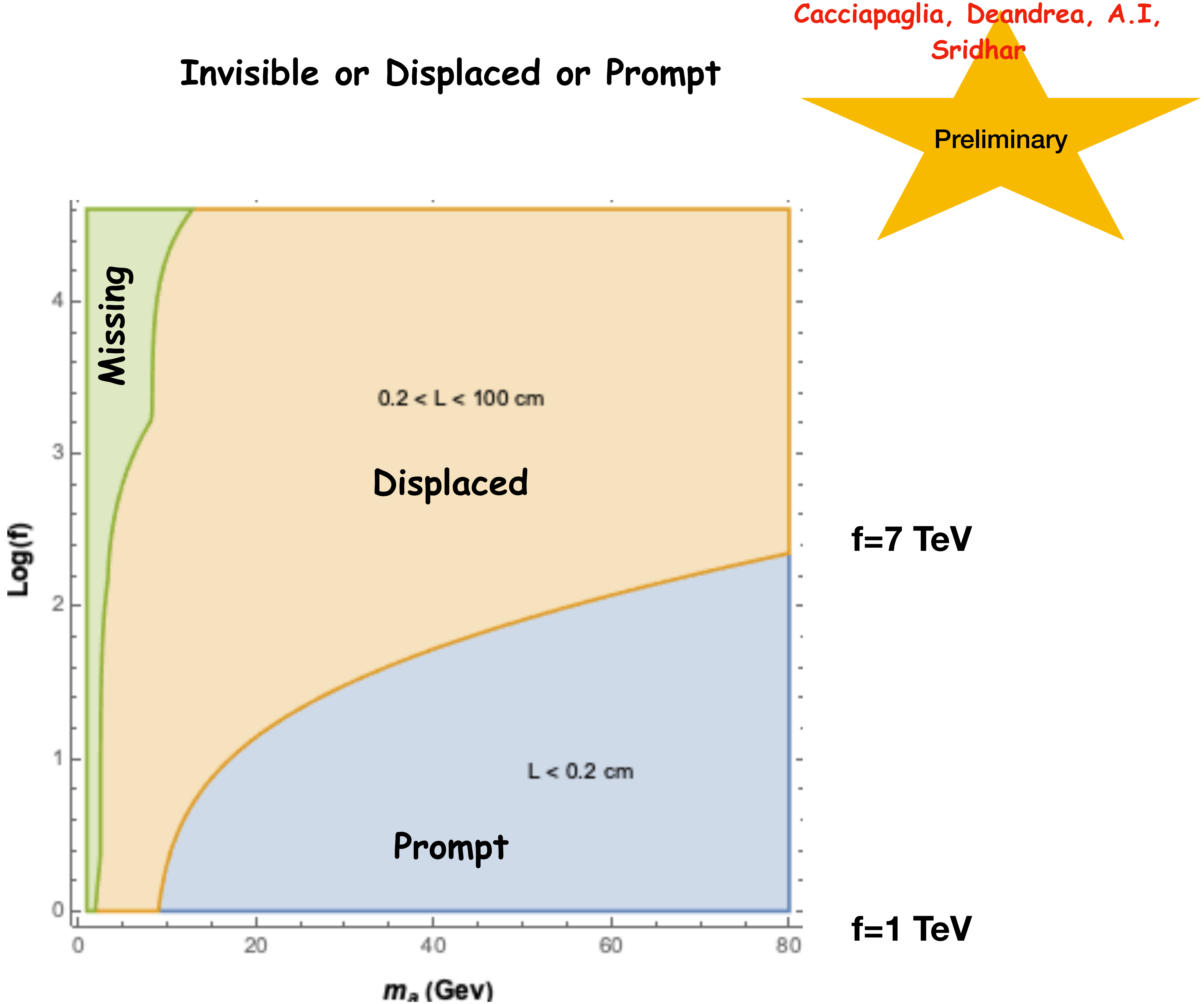
Invisible or Displaced or Prompt



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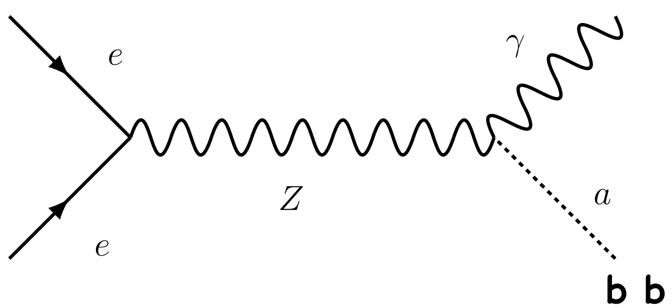
Phenomenology-Prompt Decays

Tera Z phase of FCCee will lead to 8×10^{12} visible Z bosons at the end of the run.

We begin with the prompt decays of the pseudo scalar “a” into a pair of b quarks

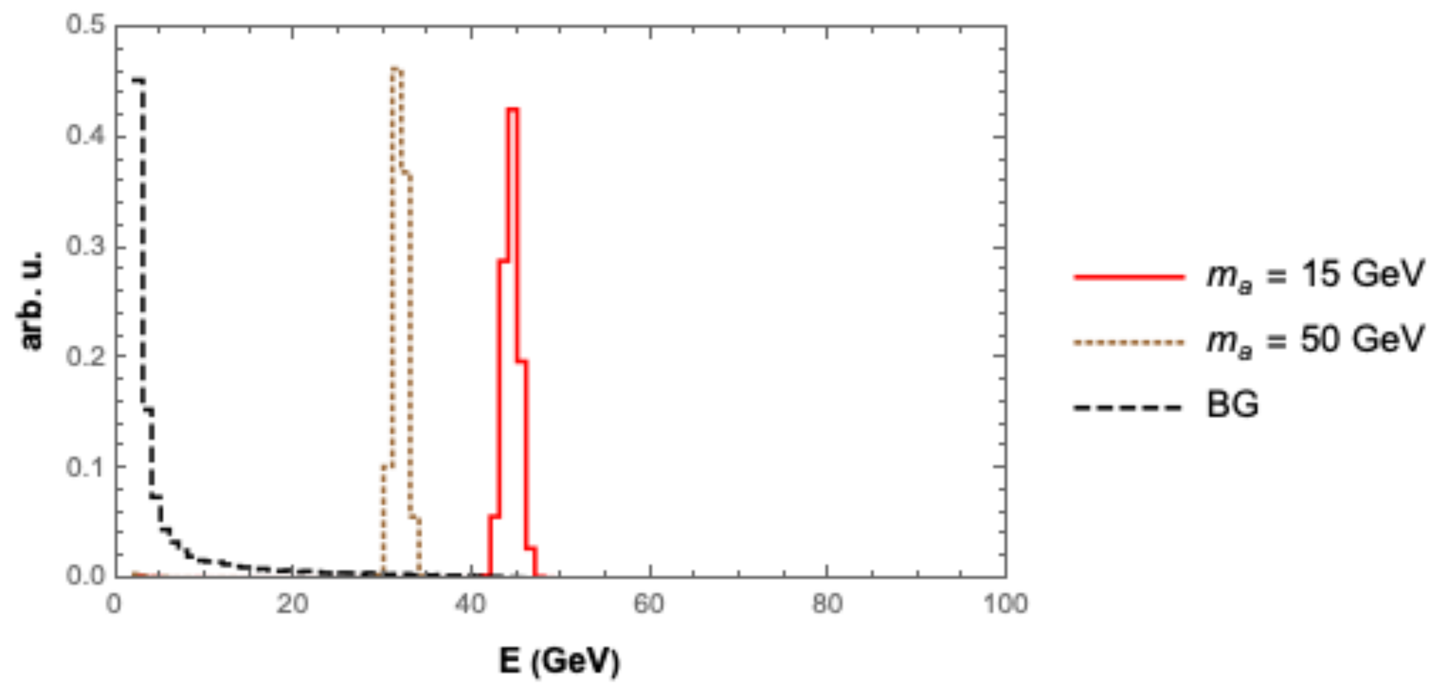


Preliminary

Signal selection

One isolated photon + at least one b tagged jet

Discriminating variable-Energy of the photon



Events are binned in the photon energy (E) of bin sizes 2 GeV. The signal sensitivity is computed using:

$$Z = \sqrt{q_0} = \sqrt{\sum_{i=1}^{N} \left(2(s_i + b_i) \log \left[1 + \frac{s_i}{b_i} \right] - 2s_i \right)}$$

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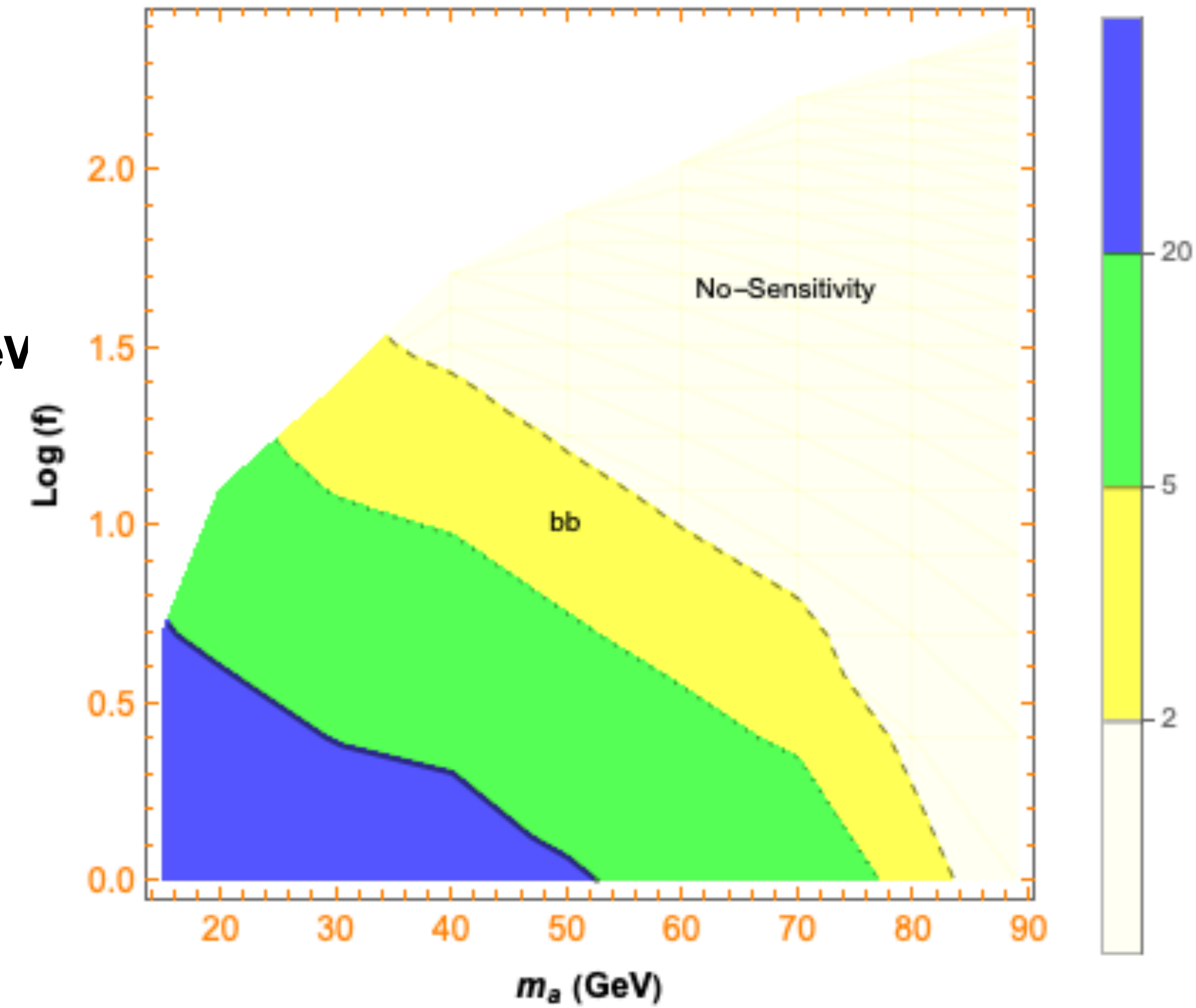
Preliminary

f=5 TeV



More Prompt Decays-diphoton

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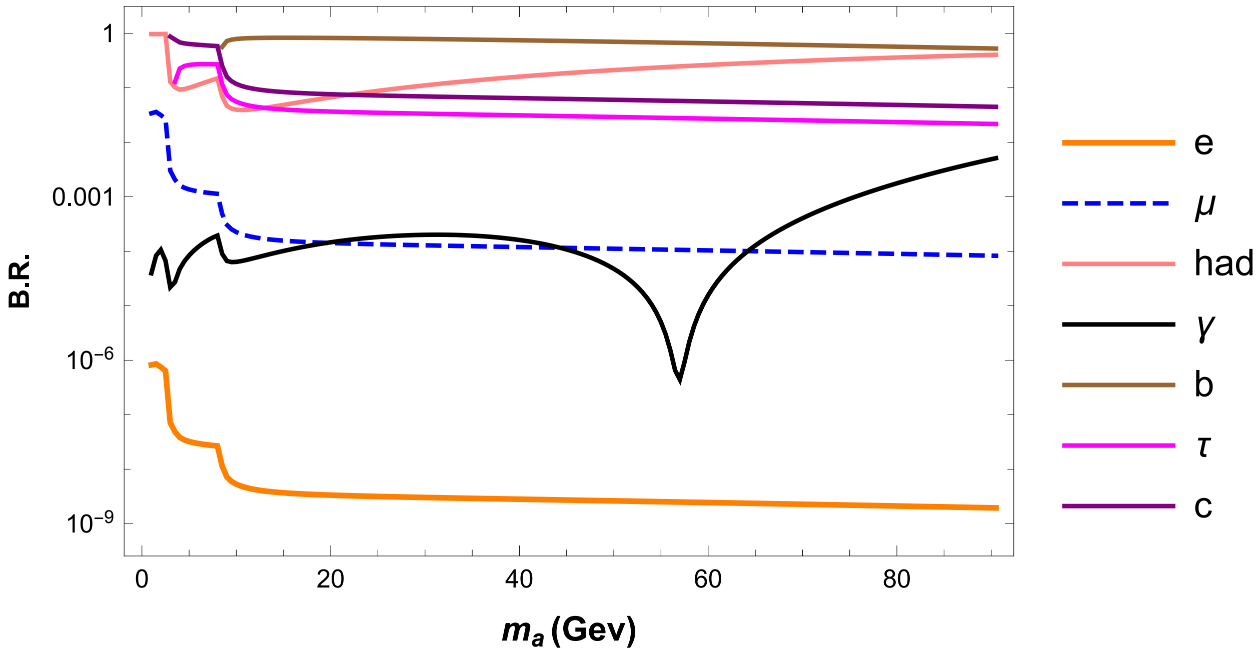
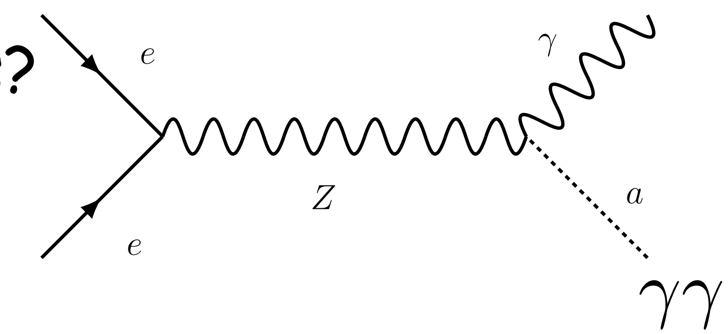


"bb" mode demonstrated progressively decreasing sensitivity with the mass of "a" approaching the Z pole

Mainly because of the associated softer photon.

Is there any hope for heavier masses?

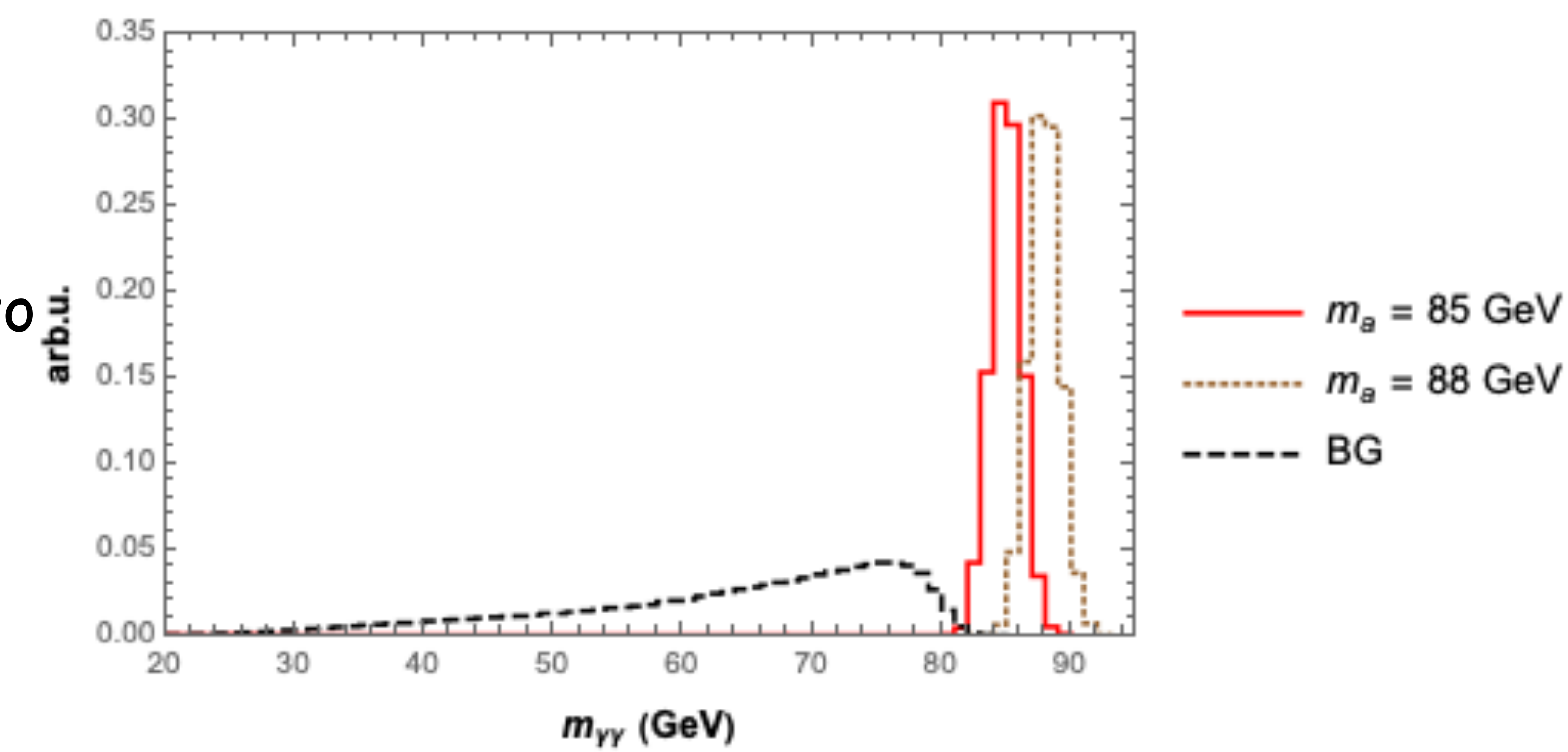
YES!! The diphoton mode



Event selection: 3 isolated photons

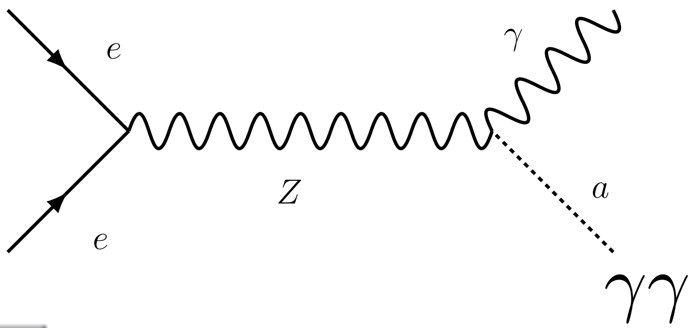
Reconstruct inv. mass of two leading photons

background is ee-aa and ee- aaa

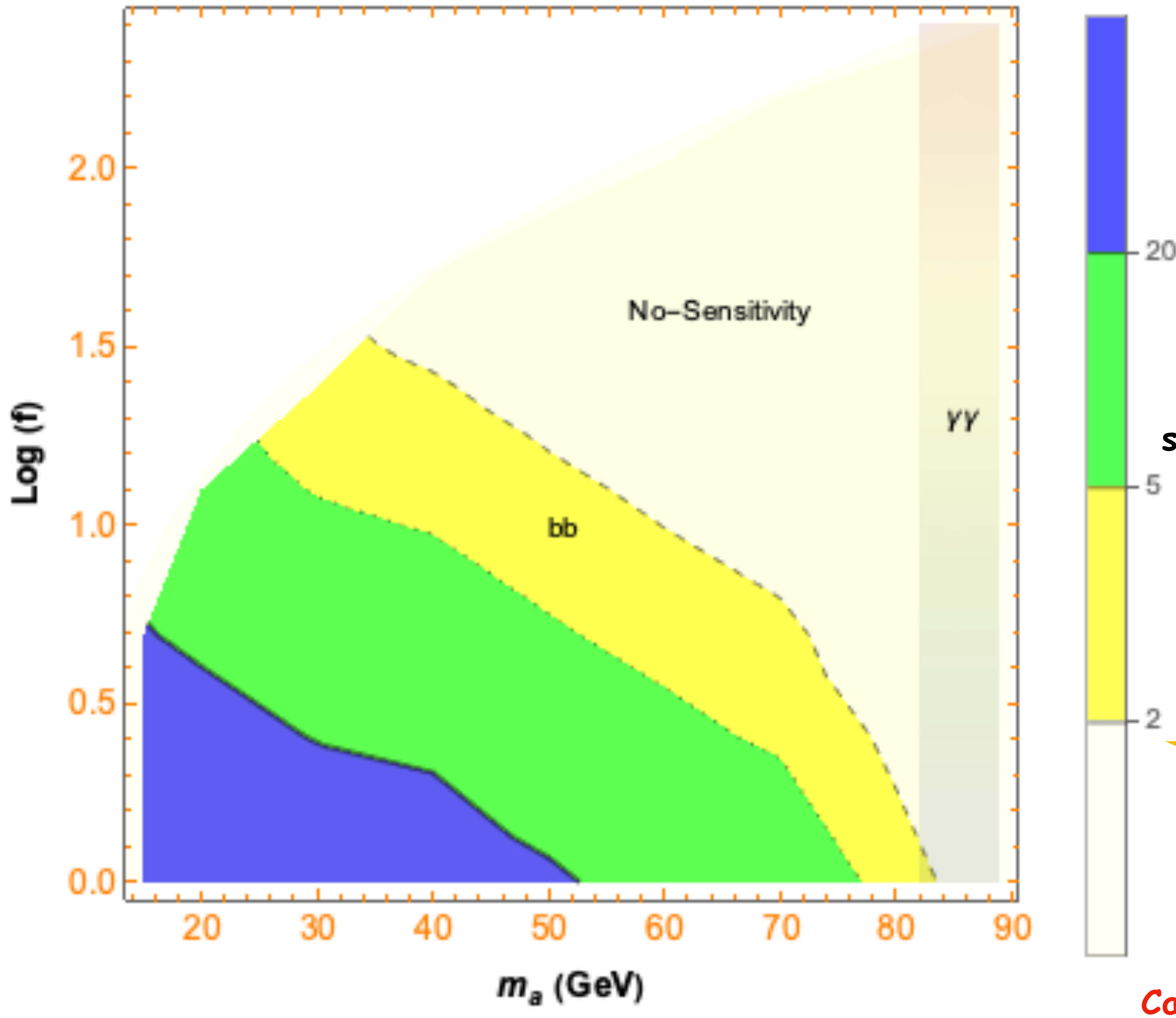


Background Free (?) between 87-93 GeV

The maximum limit on the mass of the pseudo-scalar in the di-photon mode is 89.5 GeV. Beyond that the third photon candidate is not reconstructed as a photon



4 million MC events for the BG



BG free zones are very promising. Mandates a detailed study with significantly more statistics and eventual data.

Preliminary

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Summary

FCCee is useful to study the WZW interactions of the pseudo scalar

Prompt decay modes of the pseudo scalar into bb and di-photon is very promising

Such signatures could also be studied at the HL-LHC, FCChh

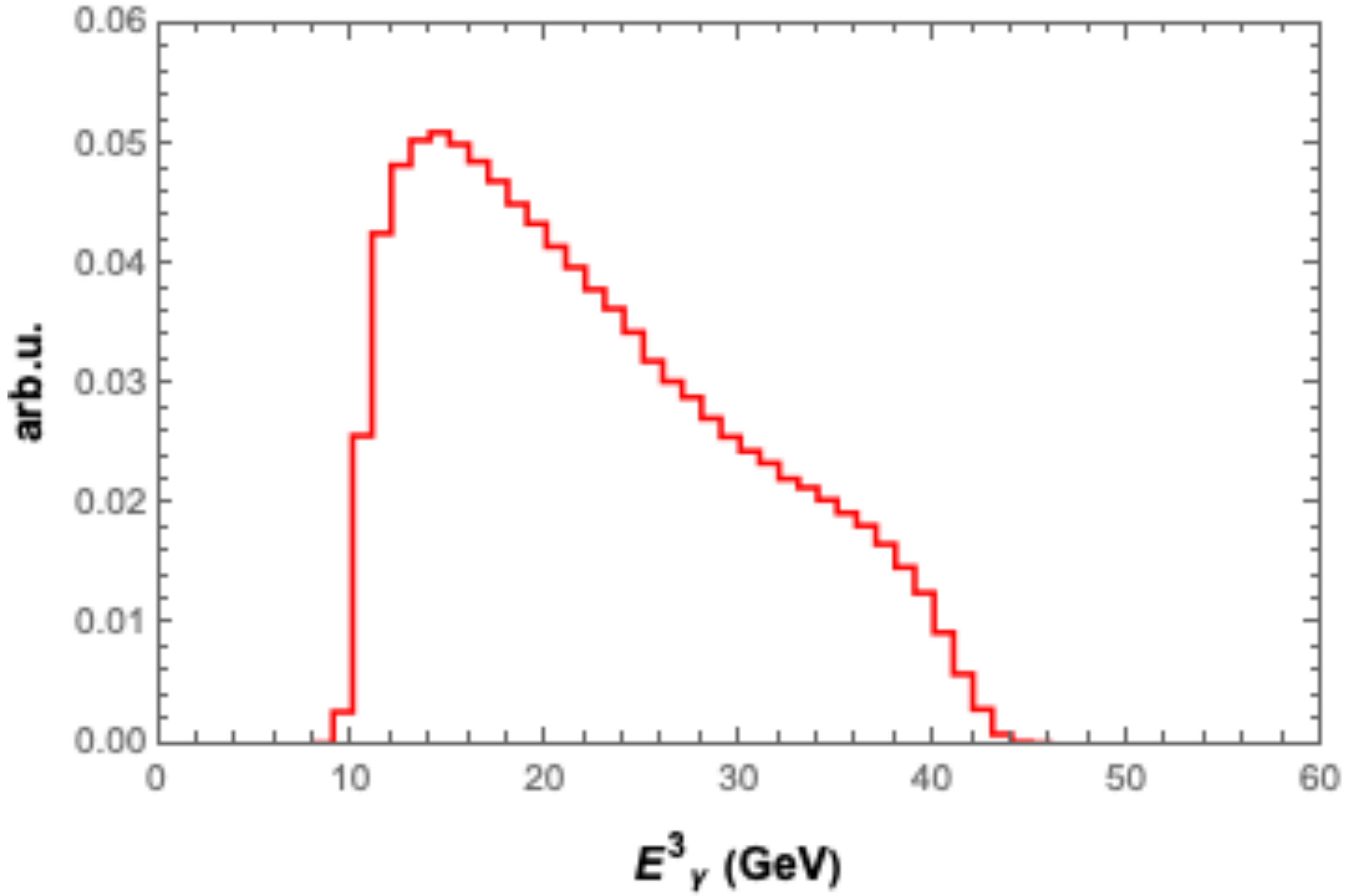
Probe the region with single photon and missing energy-Ongoing

There are plethora of processes to be explored in both the current and the future experiments: NA62, BELLE-II, KOTO..

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

BACKUP

Energy of the third photon for the background



Bauer, Neubert, Thamm '17

Axion Like particles

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