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?

Is there a way to distinguish them from other BSM scenarios: elementary BSM frameworks

NO-GO signatures?

Not possible in elementary but only in composite models

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

Several realisations of such phenomenon

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

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

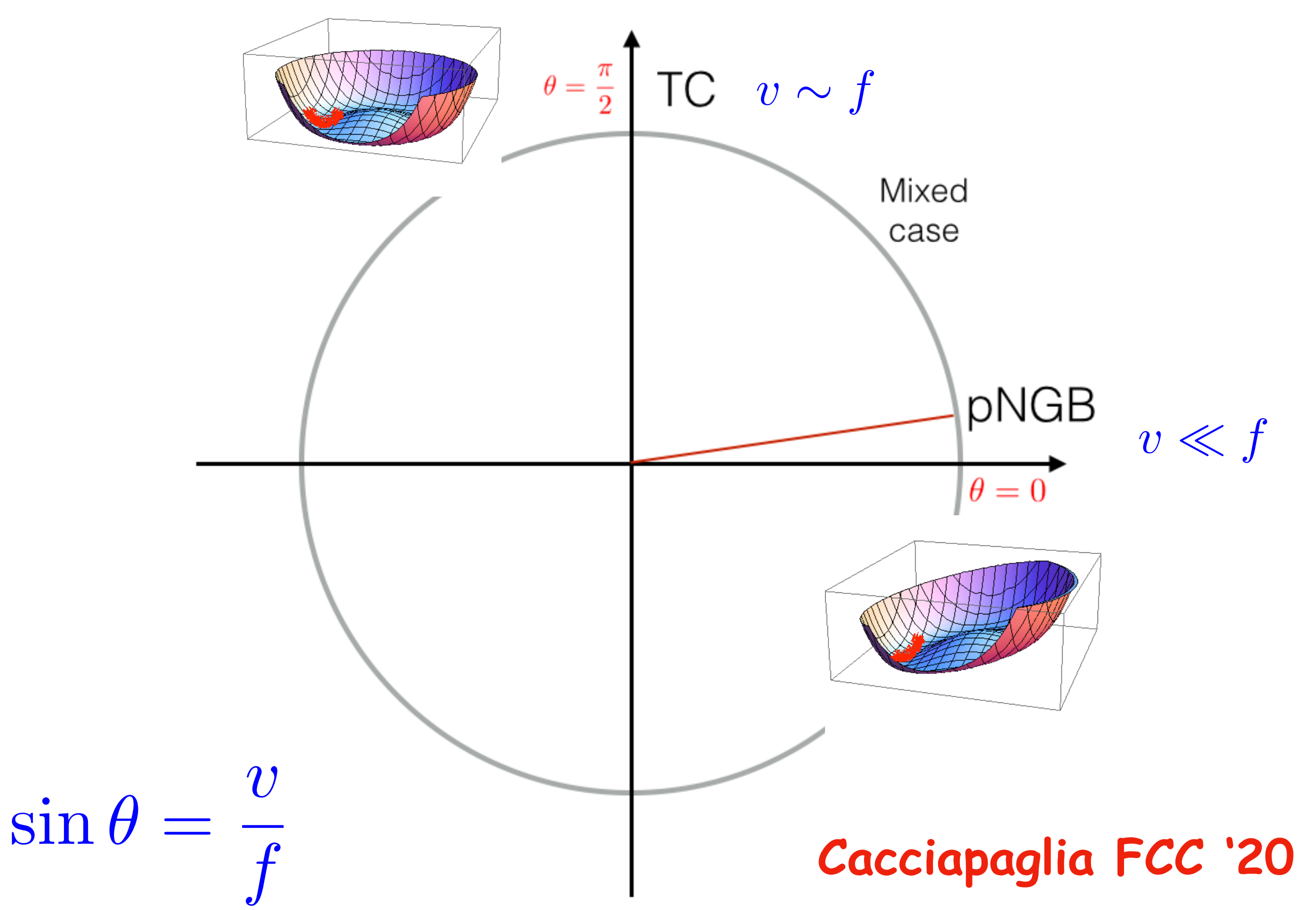
Technicolor:

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

Partial compositeness for the top.

Requirement of partial compositeness makes it convenient to add another species of fermion: ψ and χ . They transform under different representation of the Confining group

The introduction of a new coloured state allows us to construct coloured top partners. They are a bound state of three quarks $< \psi\chi\chi >$ or $< \psi\psi\chi >$

The introduction of a new coloured state allows us to construct coloured top partners and Separating the possibility of light coloured PNGB in the Higgs sector.

ψ	χ
EW	**Colour+Hypercharge**
$< \psi\psi >$	$< \chi\chi >$
Higgs bosons	Coloured heavy bosons

U(1) PNGB's

Each fundamental fermion is associated with an underlying U(1) symmetry

The global is symmetry is then:

$$SU(N_\psi) \times SU(N_\chi) \times U(1)_\psi \times U(1)_\chi$$

The abelian symmetries are also spontaneously broken by the formation on condensates

One linear combination of the two U(1)'s is anomalous: Possibly heavy η'

The other linear combination of the two U(1)'s is non-anomalous: PNGB

The mass of this PNGB is unrelated to the mechanism of ew symmetry breaking.

Spectrum:

Electroweak cosets: Higgs, triplets and singlets

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

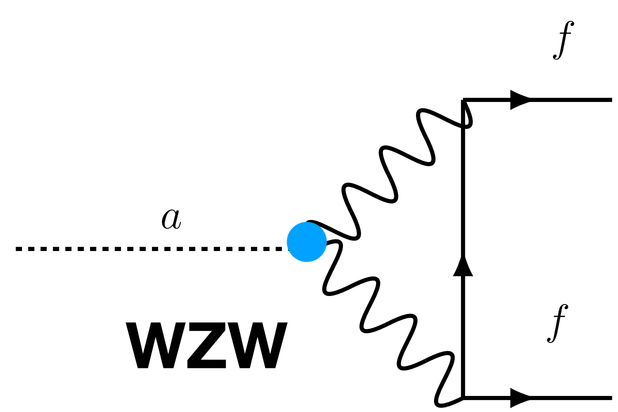
$$\mathcal{L} \supset \frac{g_i^2}{32\pi^2}\frac{\kappa_i}{f_a}\ a\ \epsilon^{\mu\nu\alpha\beta}G^i_{\mu\nu}G^i_{\alpha\beta}\ ,$$

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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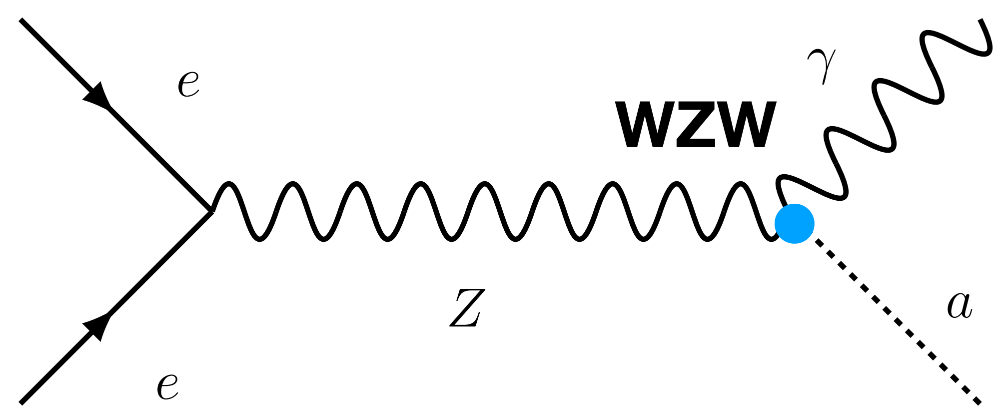
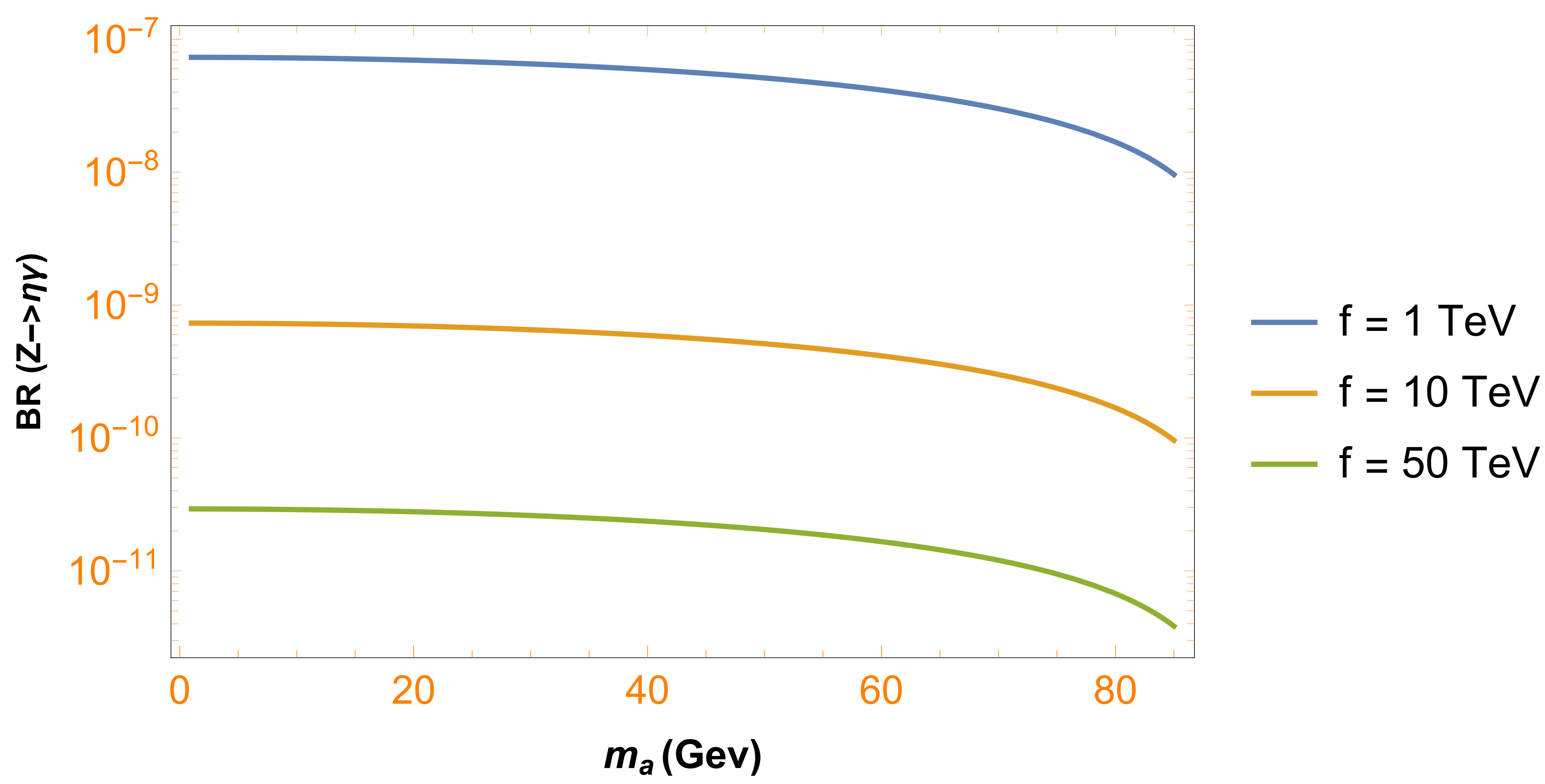
Terra-Z portals for compositeness

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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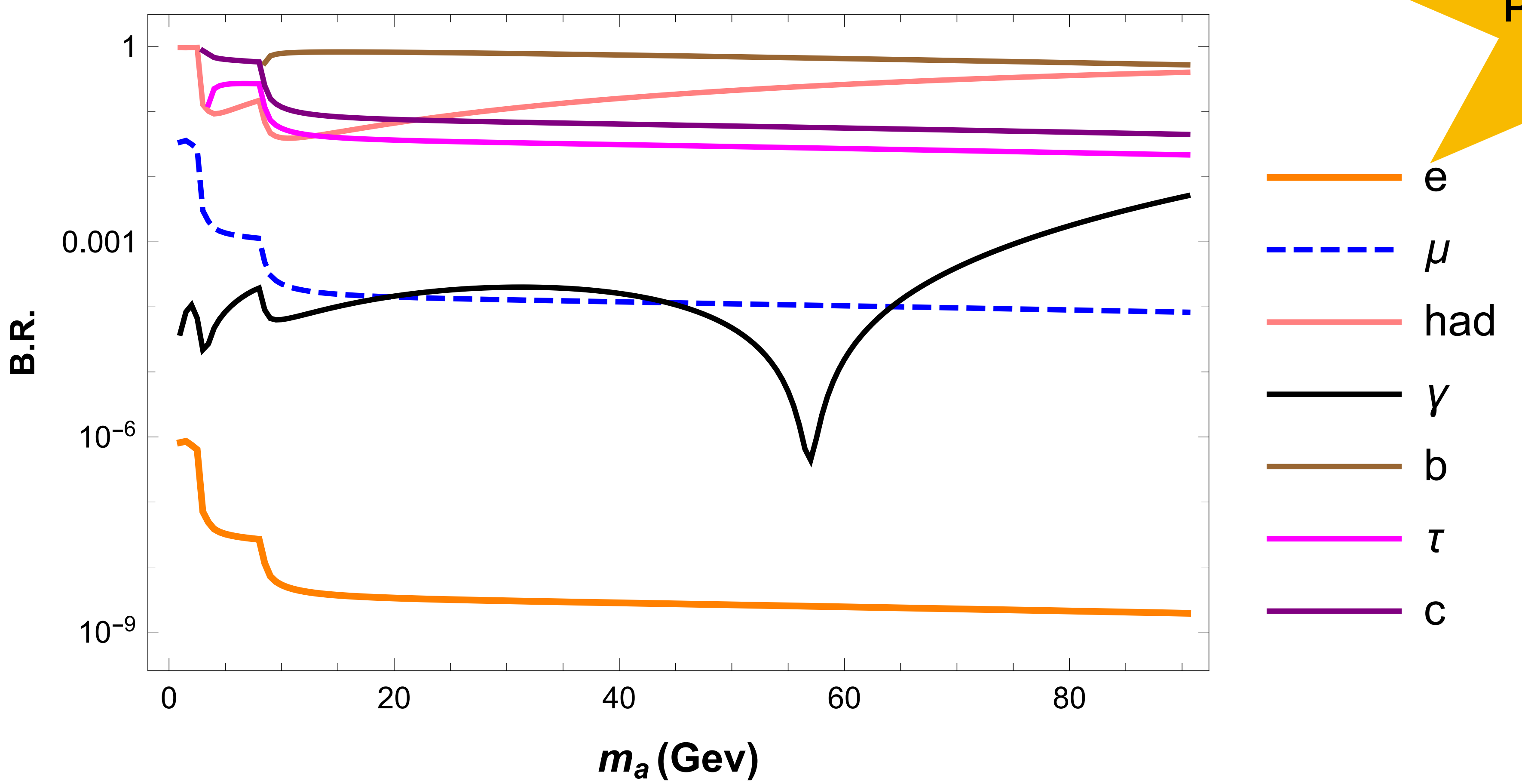
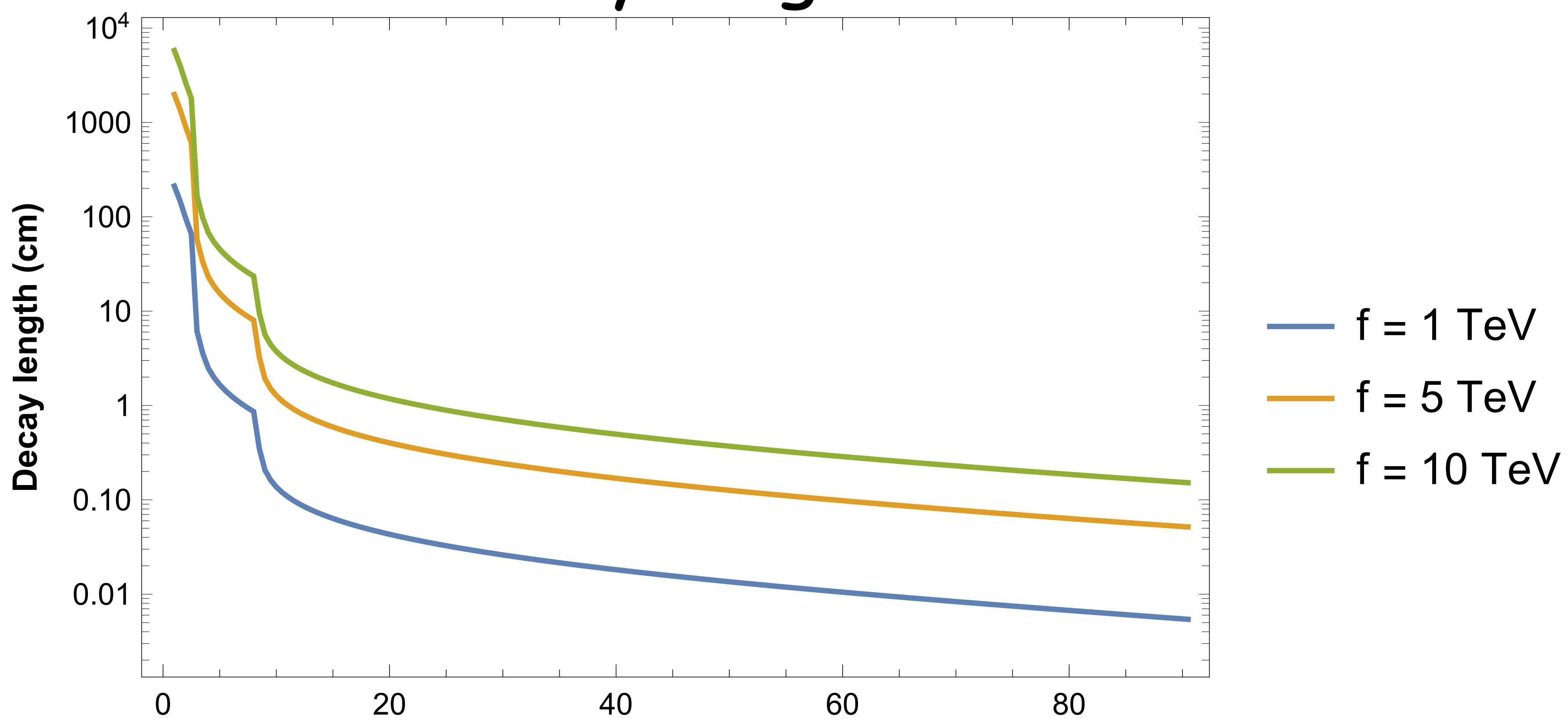
Preliminary

f=10 TeV

Does not depend on f



Decay length



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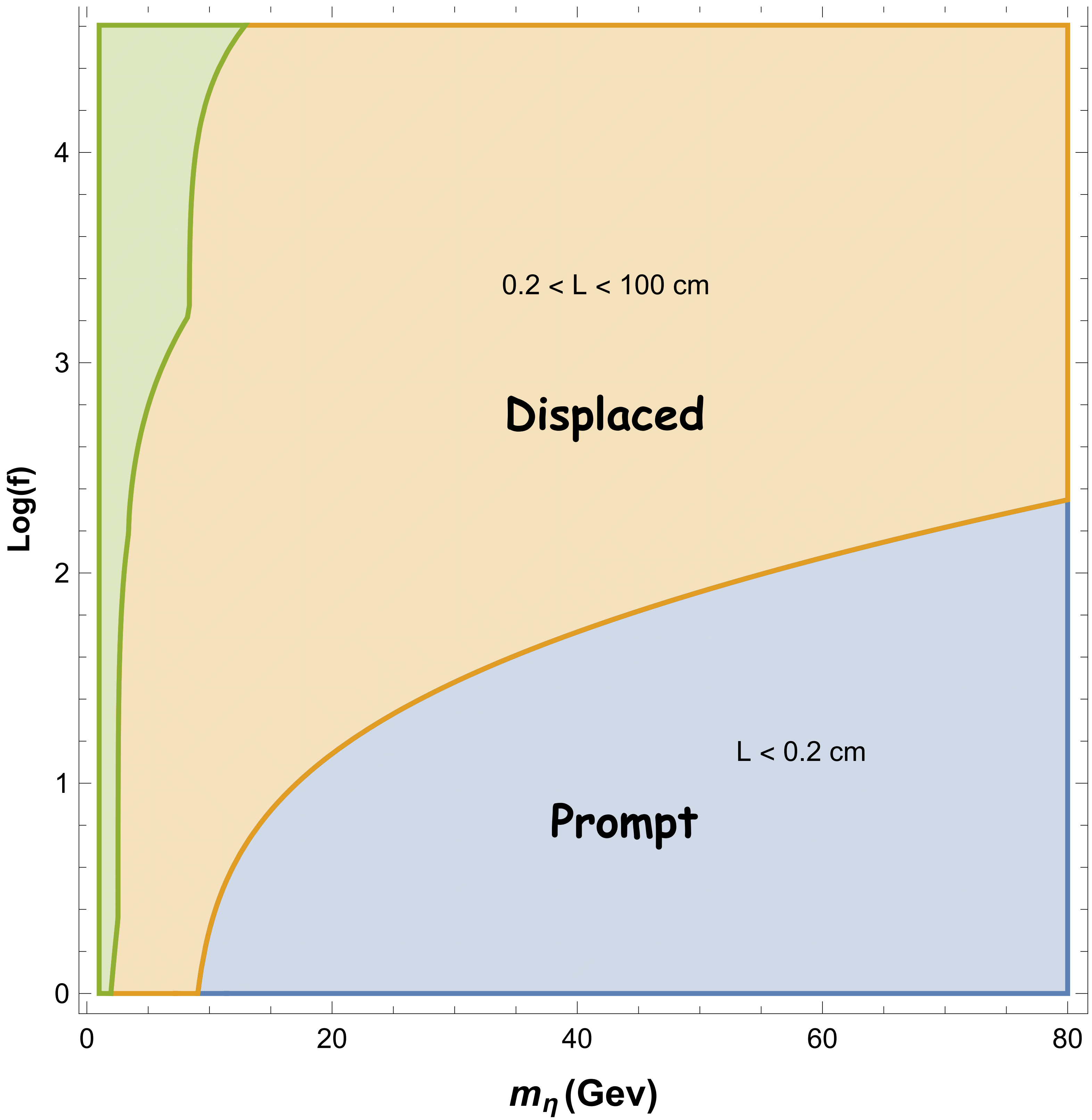
Invisible or Displaced or Prompt

Preliminary



Are displaces vertices possible with elementary scalars?

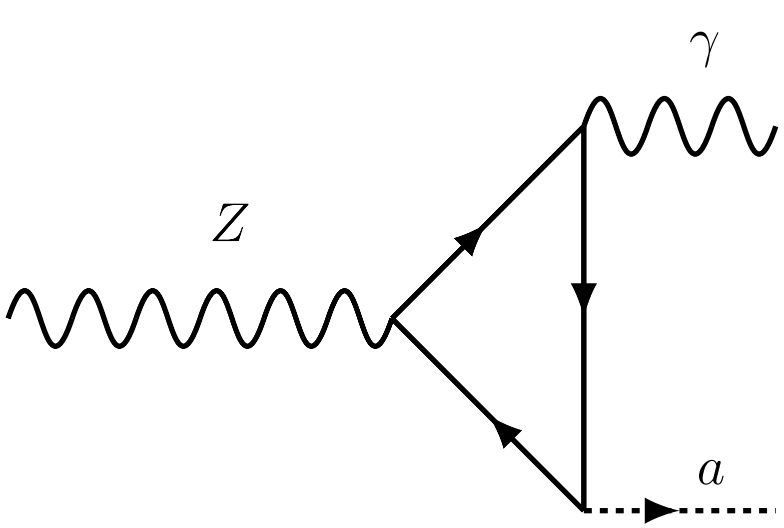
Let us consider a simple extension with a singlet scalar

Its couplings to the SM is through mixing with the Higgs

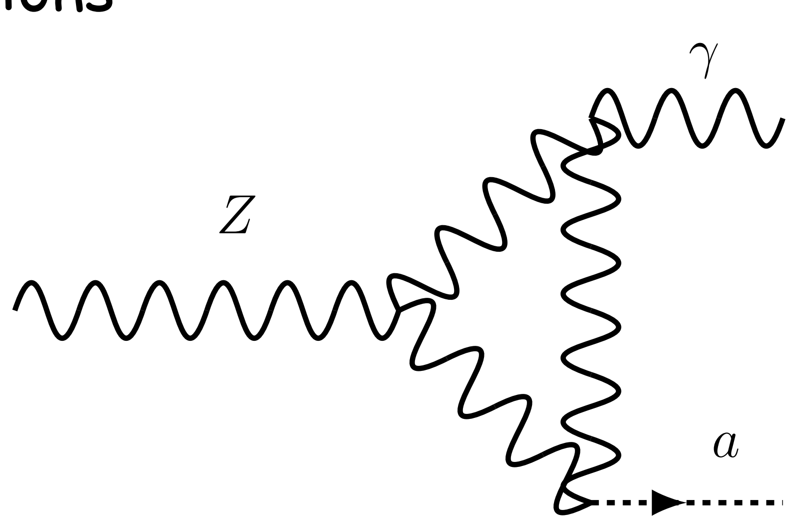
$$\mathscr{L} = \mathscr{L}_{\rm SM} + \frac{1}{2}(\partial_\mu S)^2 - \frac{m_S^2}{2}S^2 - \frac{\lambda_{HS}}{2}S^2|H|^2 - a_{HS}S|H|^2 - V(S),$$

$$h = h^0 \cos\theta + s^0 \sin\theta$$
$$a = -h^0 \sin\theta + s^0 \cos\theta$$

Unlike the composite case, its production with a photon is only through loops of gauge Bosons and fermions



Cahn et al. '79



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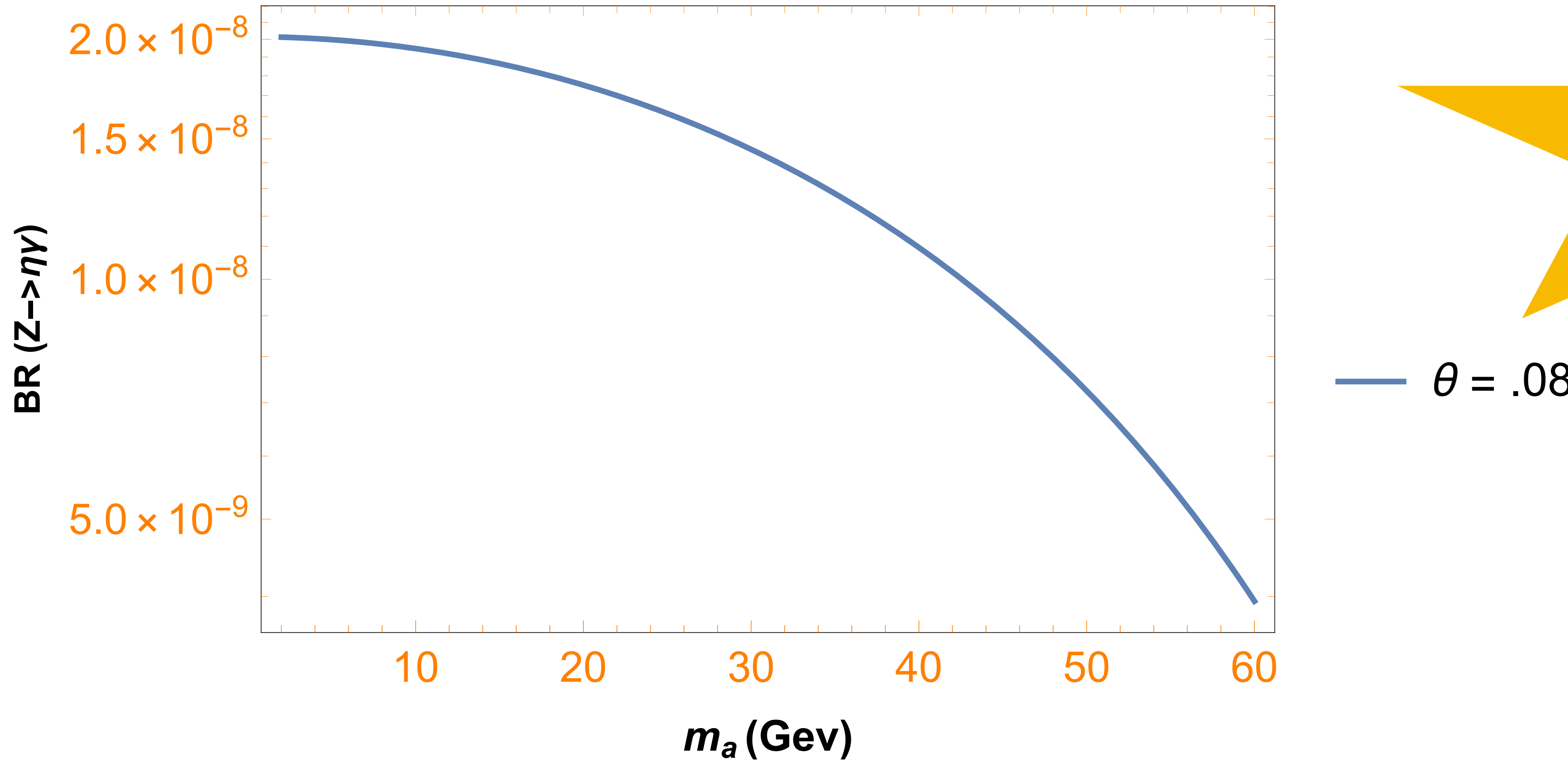
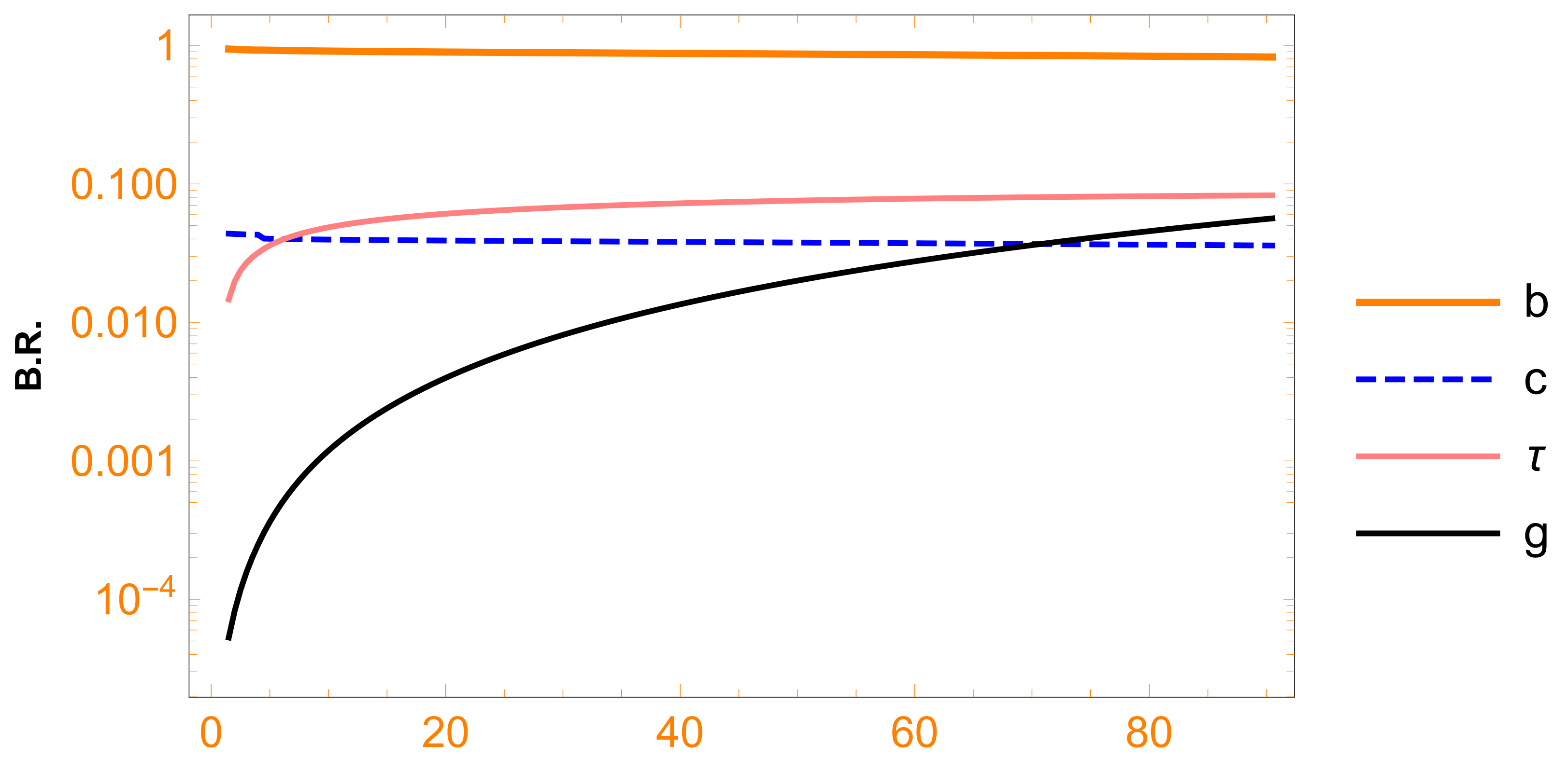
Enhancement of its production requires an enhancement of the mixing angles.

Preliminary





PS: Ignoring constraints on mixing angles as this is for purpose of illustration

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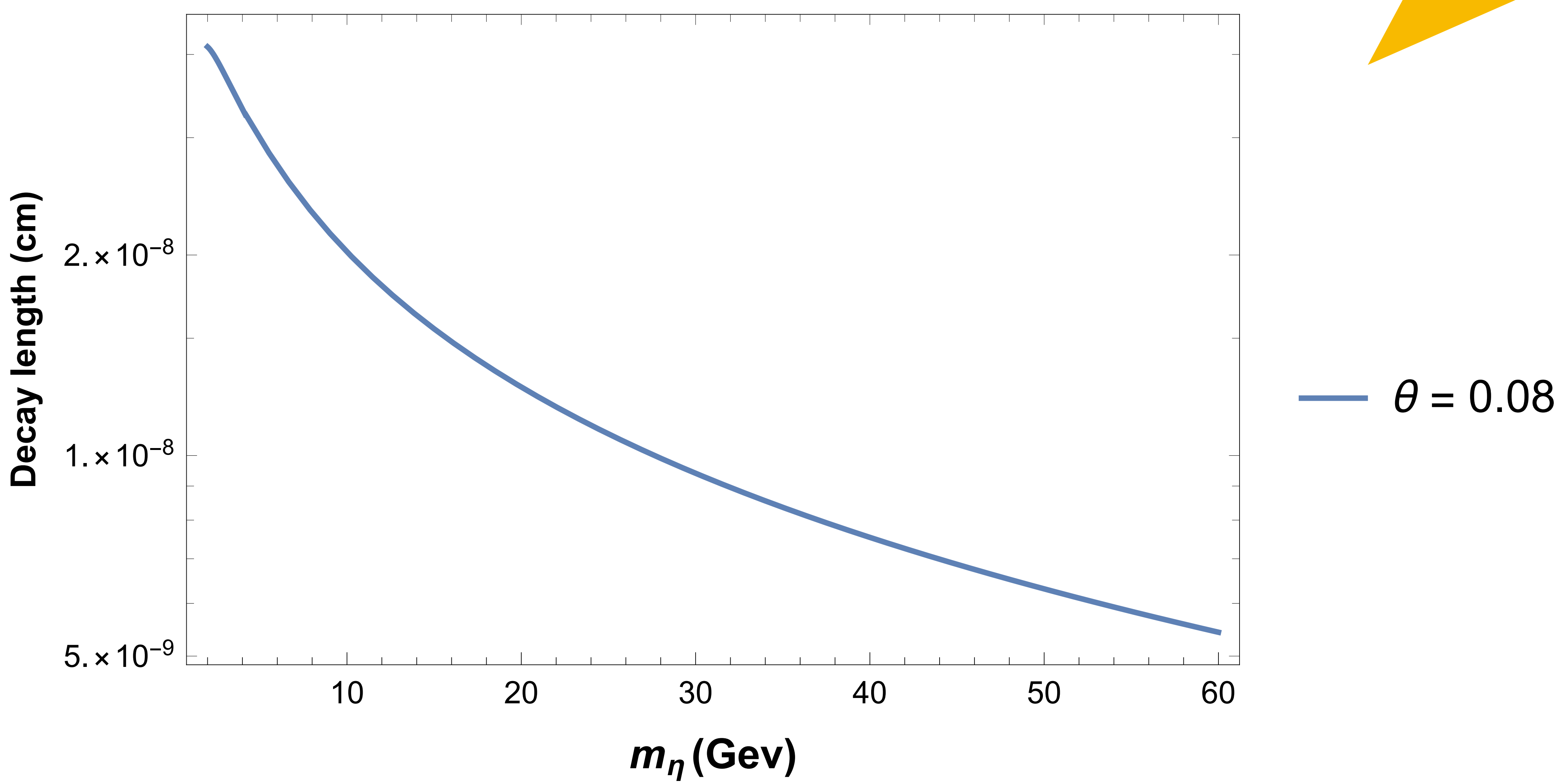
Enhancement of mixing angles implies- PROMPT Decays

Preliminary



The Beginning

Is a monochromatic photon associated with a displaced vertex a definite hint for compositeness? Maybe! But it is a positive direction to pursue.

Such signatures could also be studied at the HL-LHC

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

BACKUP

Axion Like particles

Bauer, Neubert, Thamm '17

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