LLPs at FCC-ee

Home

Oct 28th 2020

Matthew McCullough

CERN

Dark Sectors

Evidence for dark matter is now overwhelming

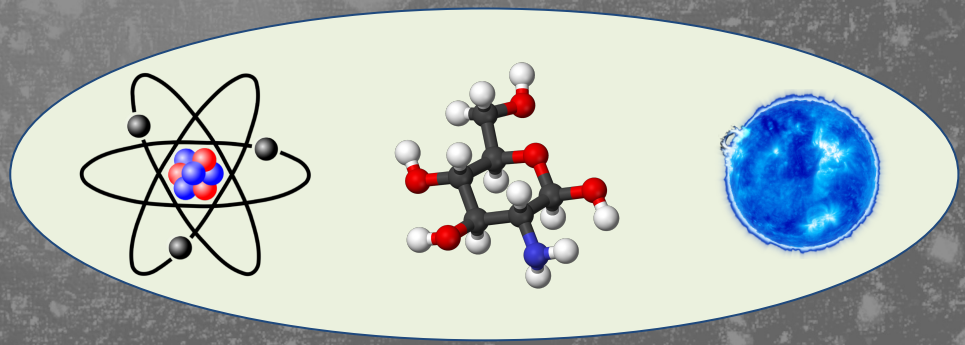
- Rotation curves
- CMB
- Large scale structure
- Velocity dispersions
- Gravitational lensing (Bullet Cluster)
- ....

Yet we have no clue what it is at the particle level!

Only 18% of all matter in Universe is visible.

e u d Z h
μ c s g
τ t b γ W

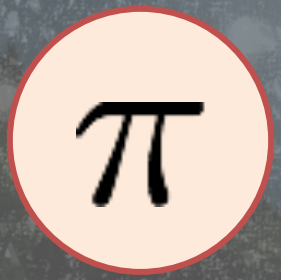
Within that 18% we observe extraordinary complexity.

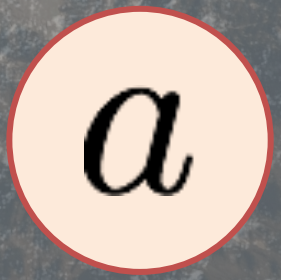


Similarly, it may be the light mediators, or other states, that open the window to the dark sector.

Windows

The standard model provides two examples of neutral bosons which can comfortably be light and have arbitrarily weak interactions:





Standard Model

Dark Sector

ALPs

I will here focus on this case:

π

Standard Model

a

Dark Sector

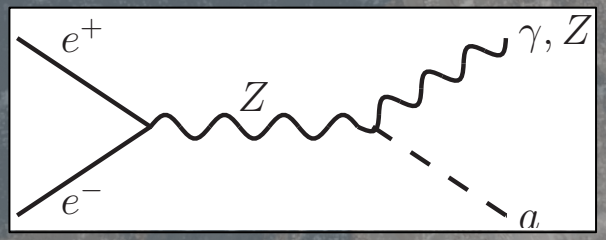
Pseudo-Goldstone Bosons can be naturally light.
Typically called “Axion-Like Particles (ALPs)”.

$$\mathcal{L}_{\text{eff}} \ni e^2\, C_{\gamma\gamma}\, \frac{a}{\Lambda}\, F_{\mu\nu}\, \tilde{F}^{\mu\nu} + \frac{2e^2}{s_w c_w}\, C_{\gamma Z}\, \frac{a}{\Lambda}\, F_{\mu\nu}\, \tilde{Z}^{\mu\nu} + \frac{e^2}{s_w^2 c_w^2}\, C_{ZZ}\, \frac{a}{\Lambda}\, Z_{\mu\nu}\, \tilde{Z}^{\mu\nu}$$

Many possible interactions, but focus on these.

ALPs: FCC-ee

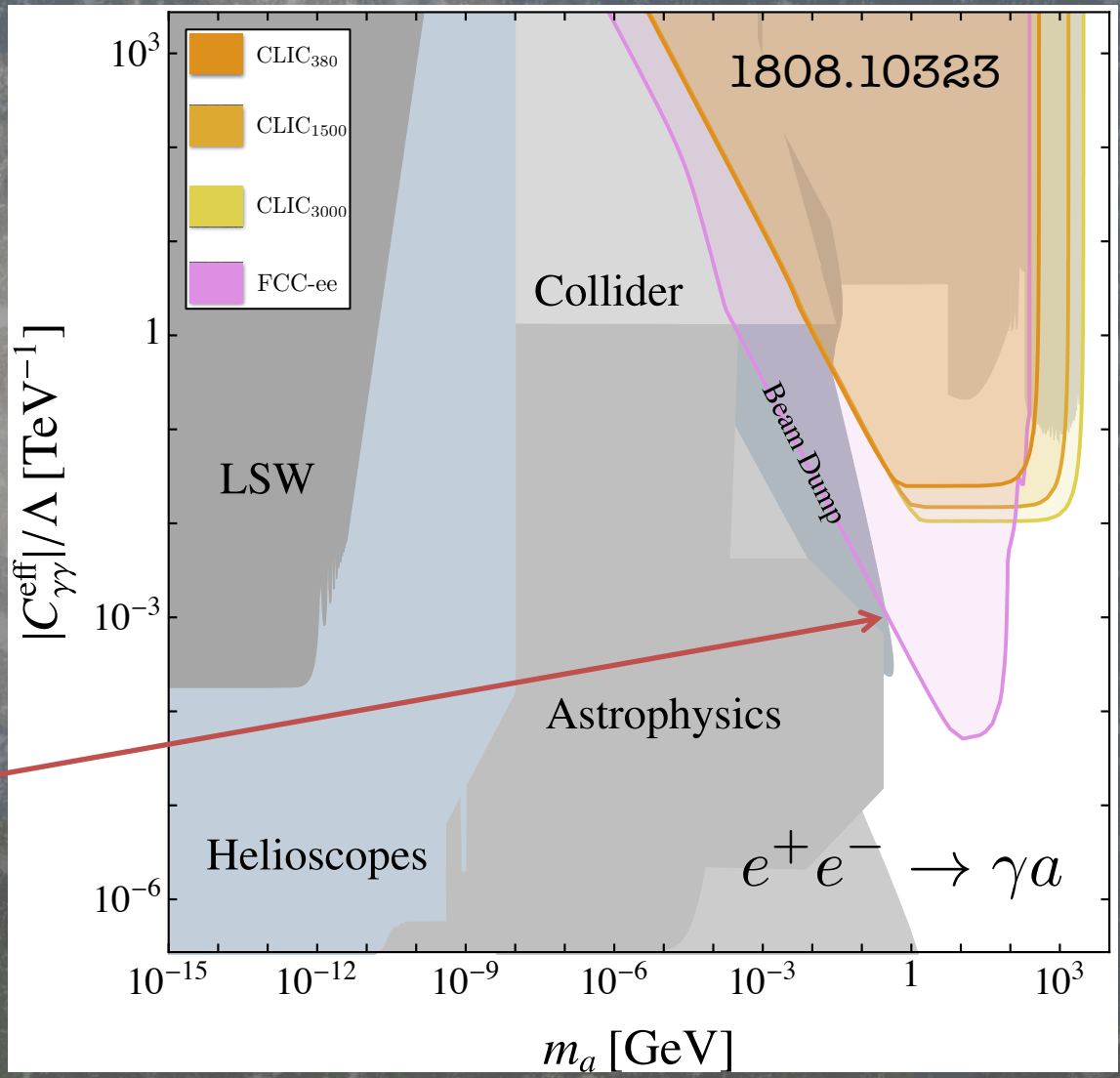
Key production channel:



Followed by:

$$a \to \gamma\gamma$$

FCC-ee is an intensity frontier machine!!!



ALPs

We will here focus on this case:

π

Standard Model

a

Dark Sector

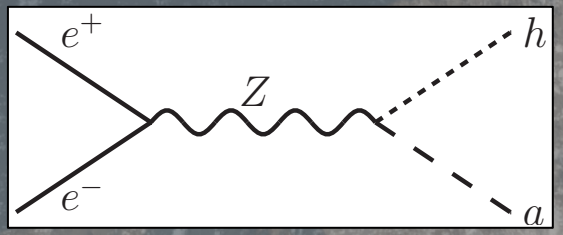
Pseudo-Goldstone Bosons can be naturally light.
Typically called “Axion-Like Particles (ALPs)”.

$$\mathcal{L}_{\text{eff}}^{D\geq 6} = \frac{C_{ah}}{\Lambda^2}\,(\partial_\mu a)(\partial^\mu a)\,\phi^\dagger\phi + \frac{C_{Zh}}{\Lambda^3}\,(\partial^\mu a)\left(\phi^\dagger\, iD_\mu\,\phi + \text{h.c.}\right)\phi^\dagger\phi + \dots\,,$$

Can also have interactions with the Higgs.

ALPs: FCC-ee

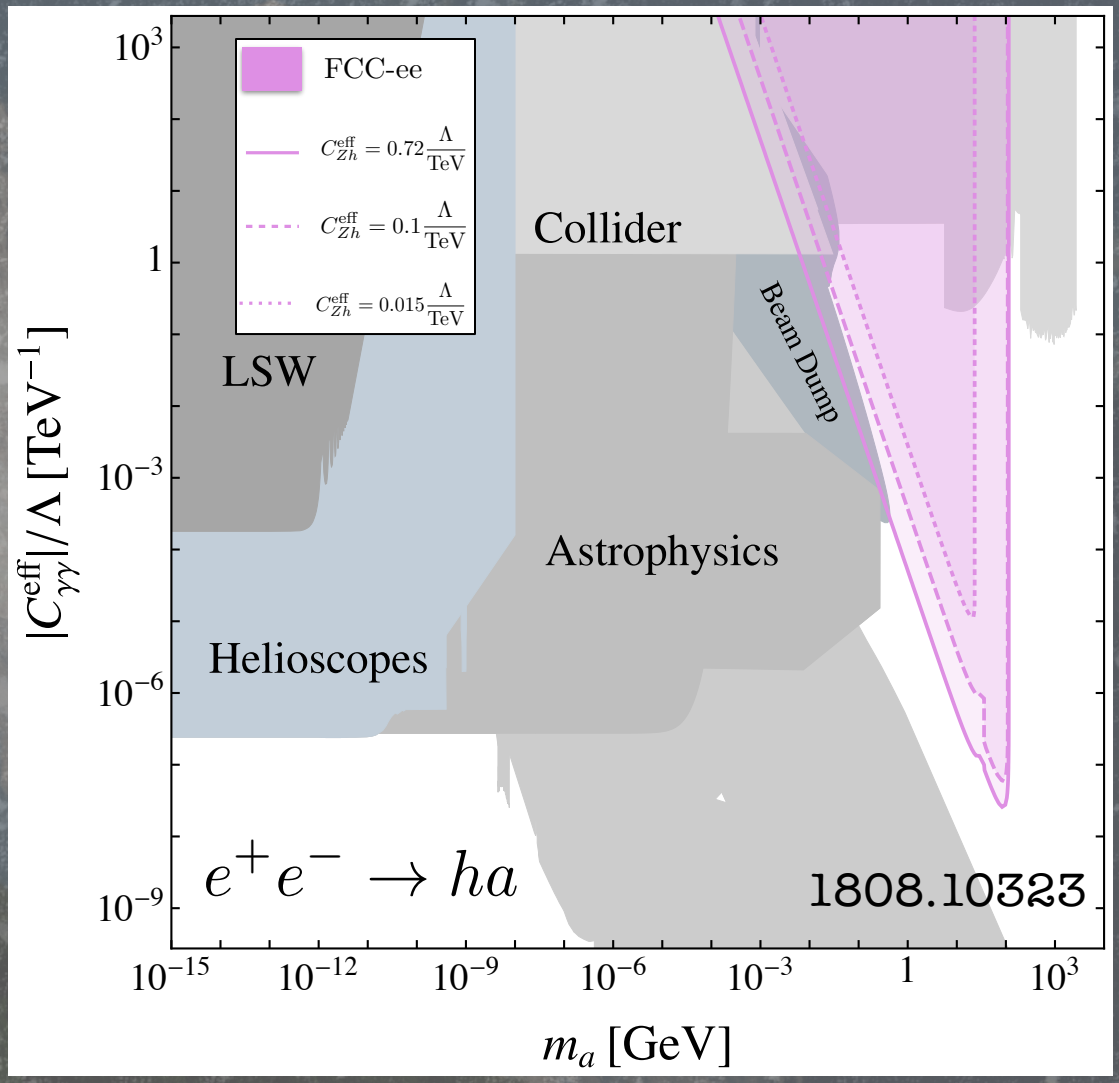
The Higgs is a key player:



Followed by:

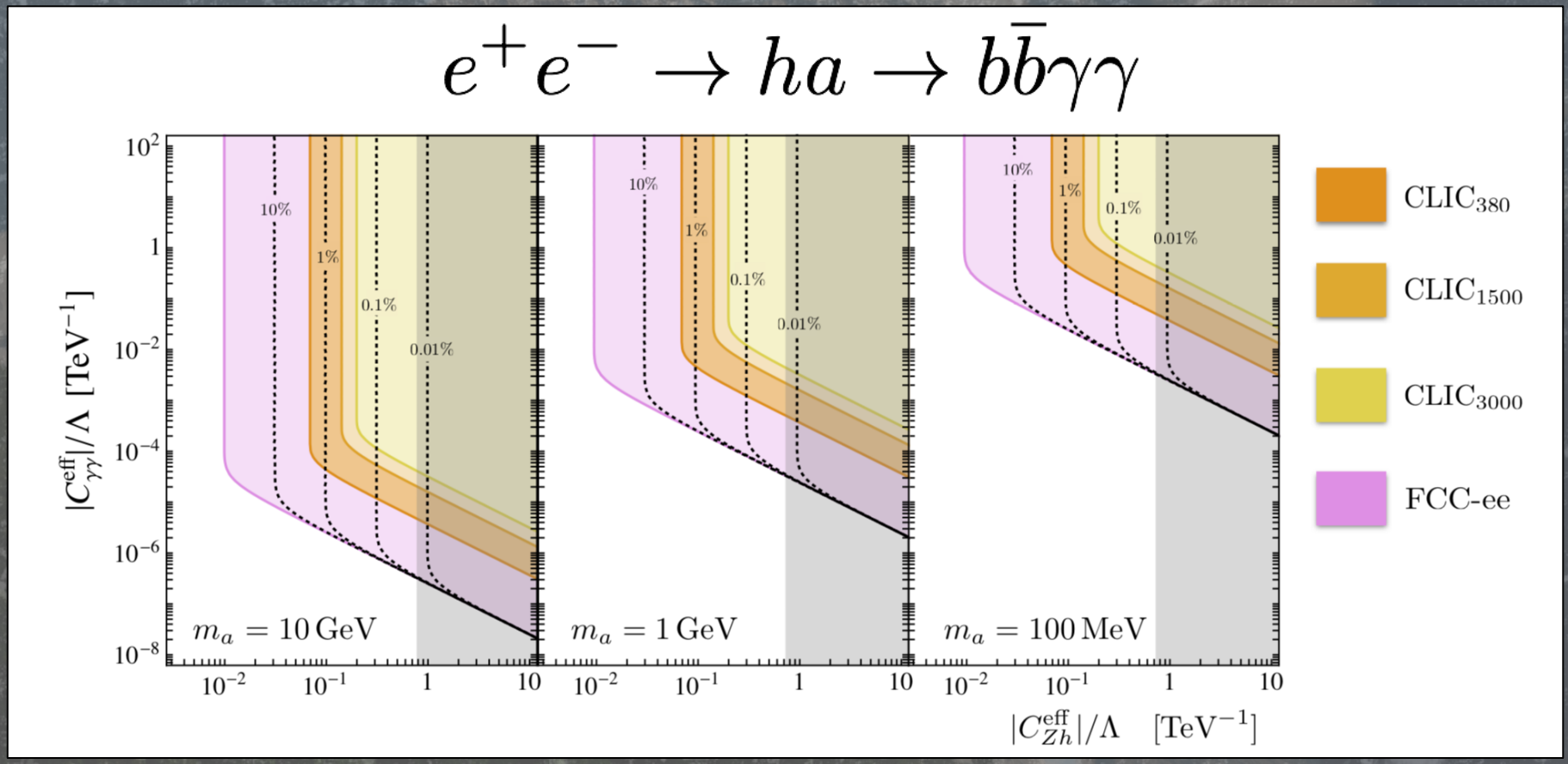
$$a \to \gamma\gamma$$

FCC-ee/CEPC can probe extremely high scales through the Higgs.



ALPs: FCC-ee/CEPC

Possible to probe multi-TeV couplings across a range of parameter space:



Revealing light remnants of high scale physics!

ALPs + Dark Photon

What about an ALP and a dark photon?

Z Z'

π a

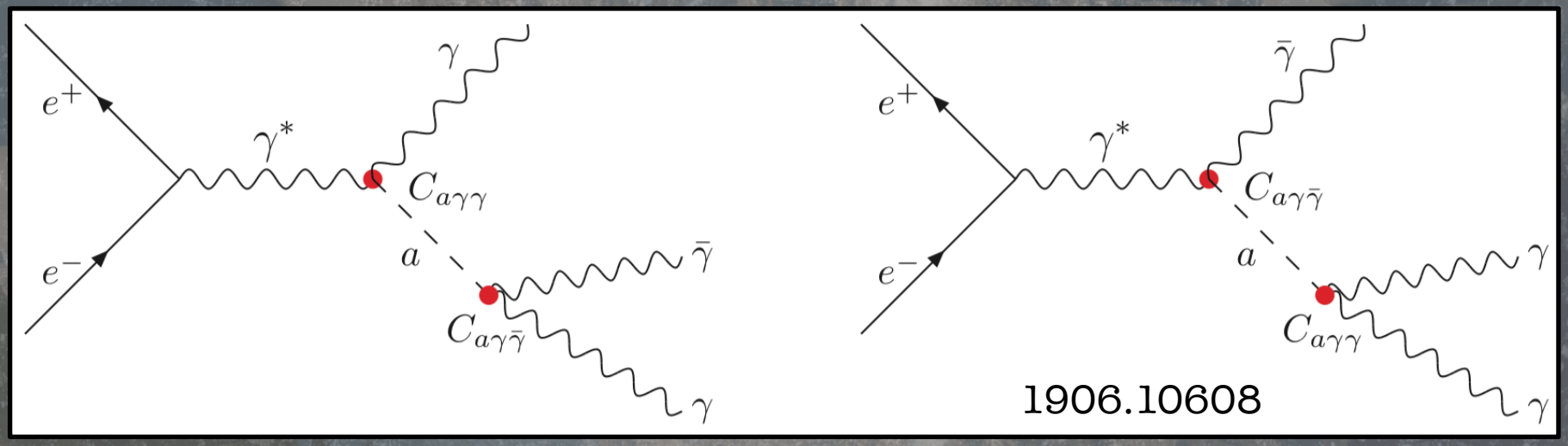
Standard Model

Dark Sector

$$\mathcal{L}_{eff} = \frac{C_{a\gamma\gamma}}{\Lambda} a F^{\mu\nu}\tilde{F}_{\mu\nu} + 2\frac{C_{a\gamma\bar{\gamma}}}{\Lambda} a F^{\mu\nu}\tilde{\bar{F}}_{\mu\nu}$$

ALPs + Dark Photon

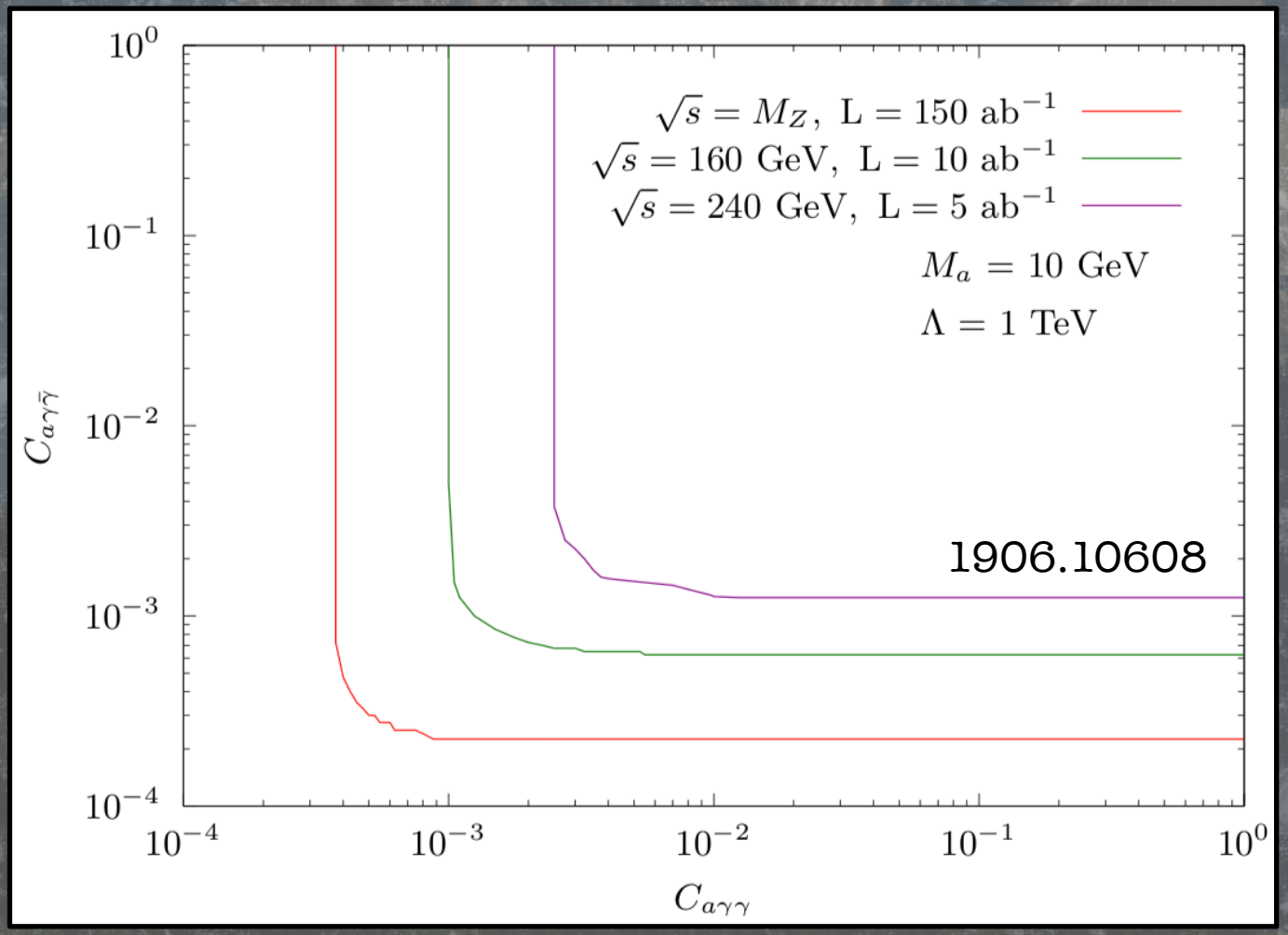
With this addition the signatures change somewhat:



Leading to the additional handle of missing energy!

ALPs + Dark Photon

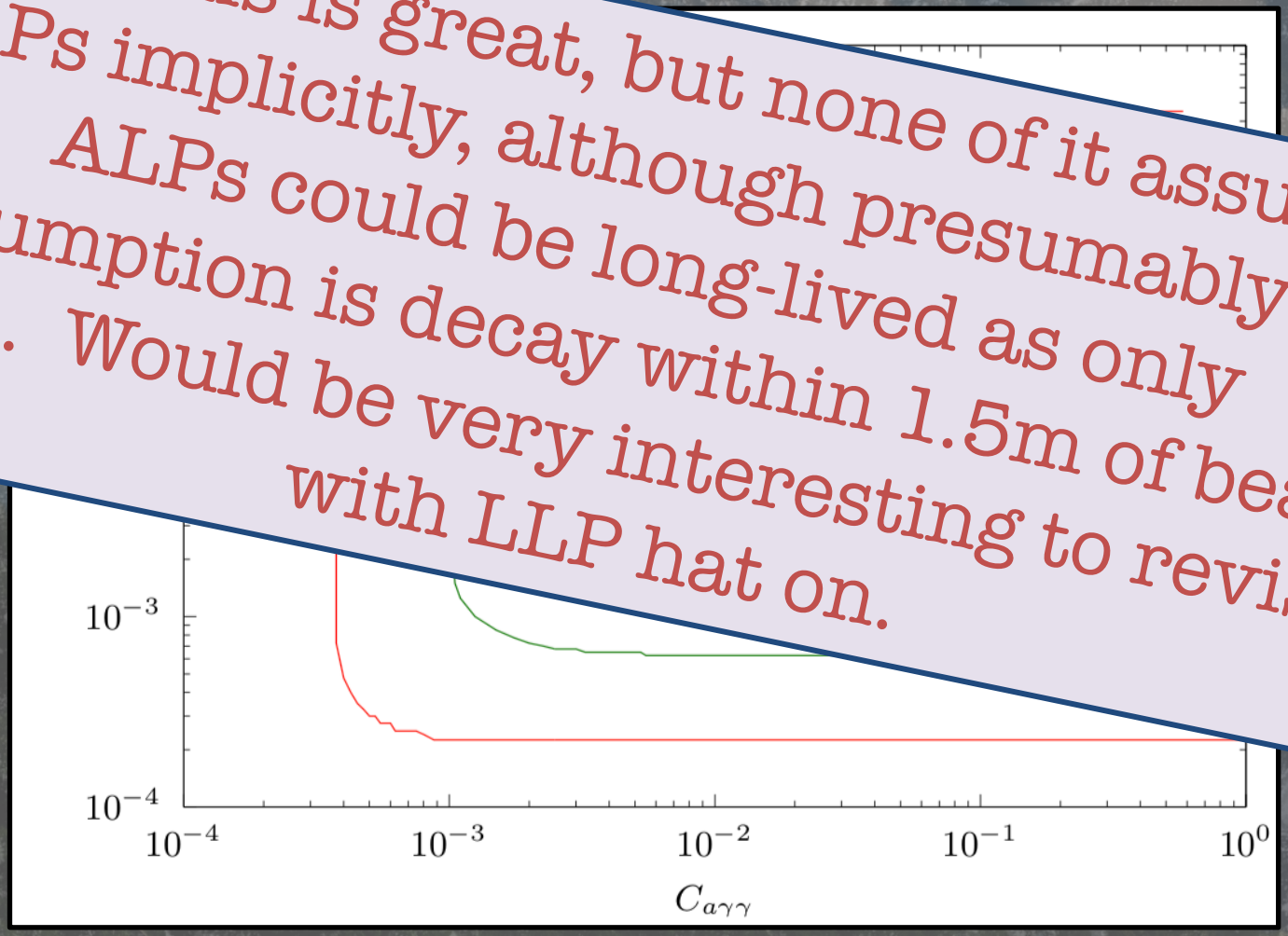
Future lepton colliders also have extreme sensitivity to high scale physics in this case:



ALPs + Dark Photon

Futu lepton colliders also have extreme
sens scale physics in this case:

All of this is great, but none of it assumes LLPs implicitly, although presumably the ALPs could be long-lived as only assumption is decay within 1.5m of beam pipe. Would be very interesting to revisit with LLP hat on.



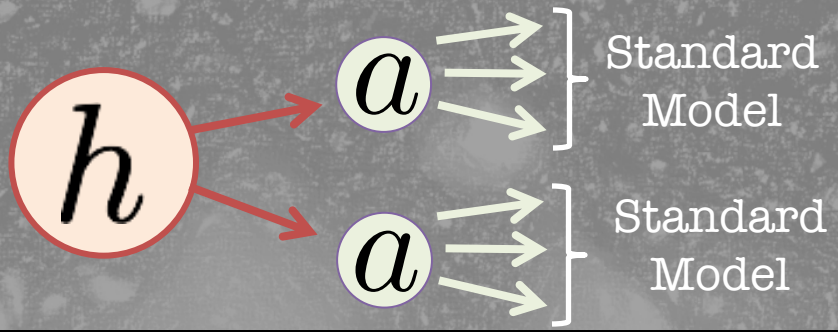
Comment: On Energy

It is tempting to associate the weakly coupled frontier with the low mass range. Why?

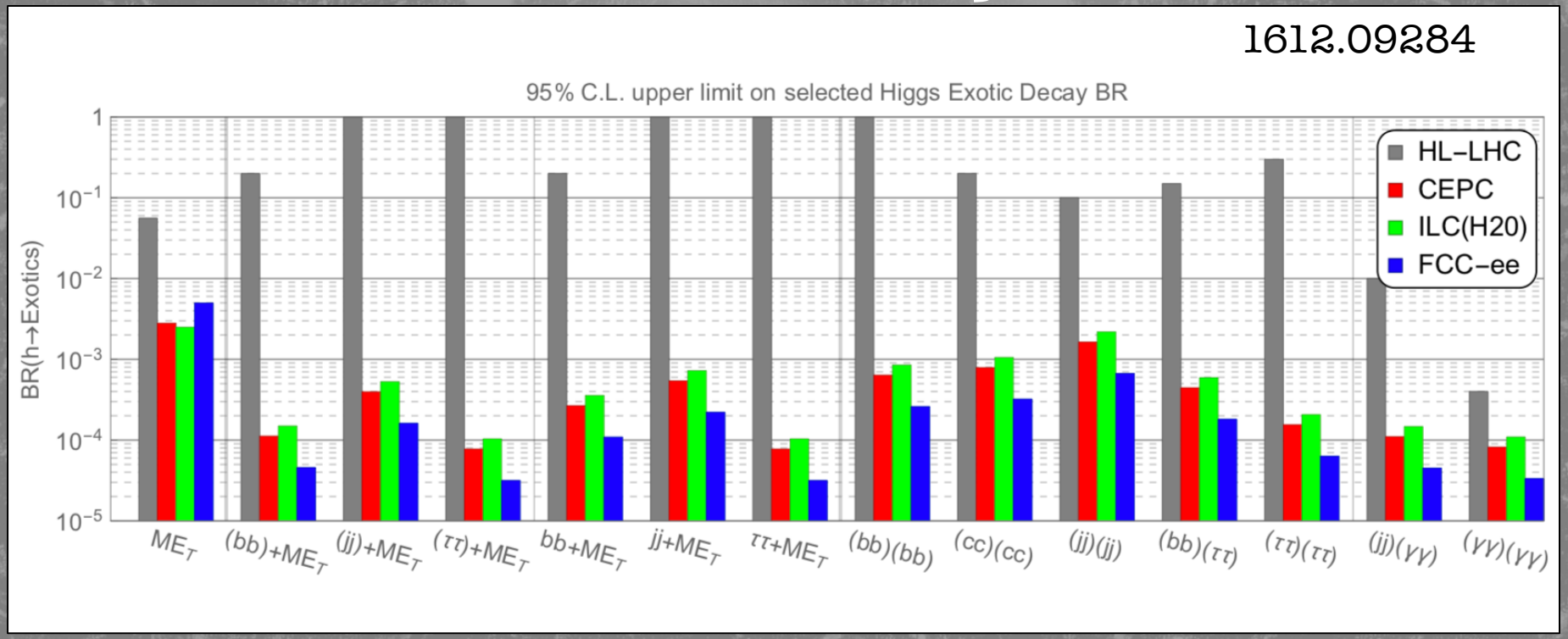
Case study: The Higgs boson is the most mysterious particle in nature. If it has rare decays then the only shot at discovering them is through Higgs boson decays.

Higgs

The Higgs is totally different from other particles and could be our new window to the dark sector:



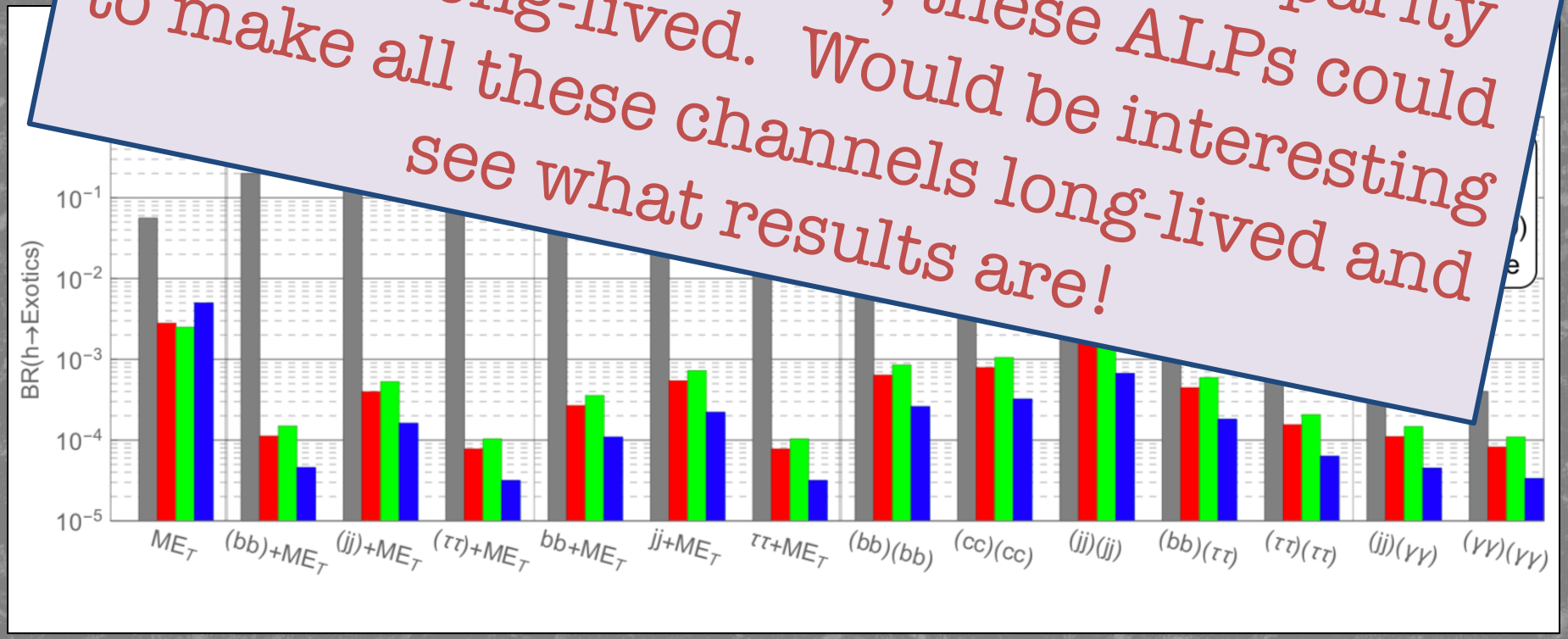
1612.09284



Higgs

The Higgs is totally different from other particles and could be our new window to the dark sector:

Since the Higgs decay respects a parity symmetry for the ALP, these ALPs could be easily long-lived. Would be interesting to make all these channels long-lived and see what results are!



1812.05588 – Higgs to LLP

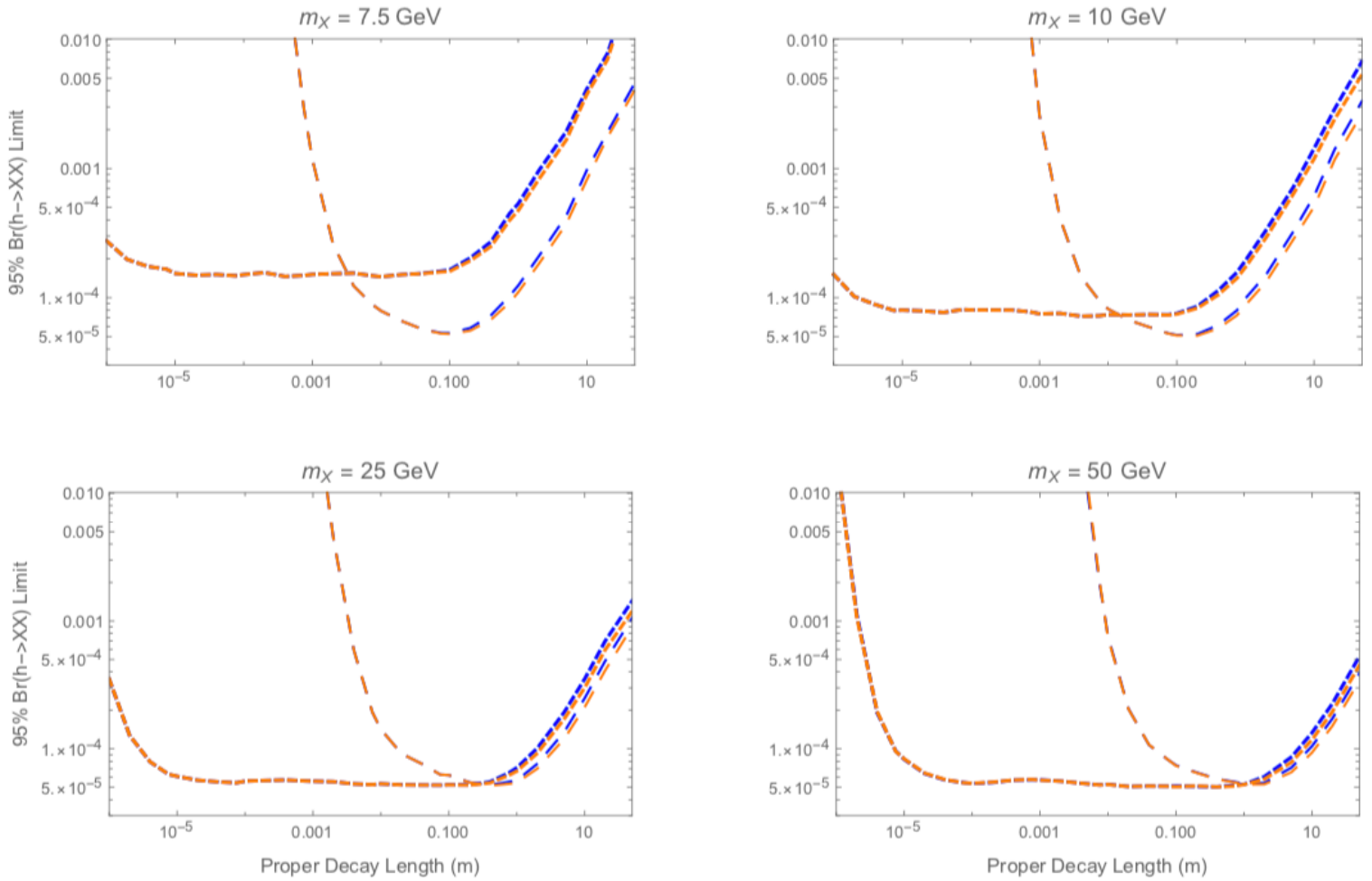
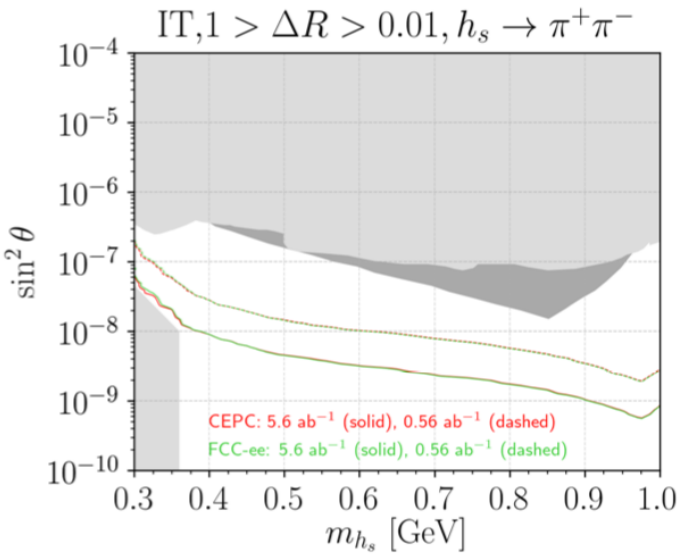
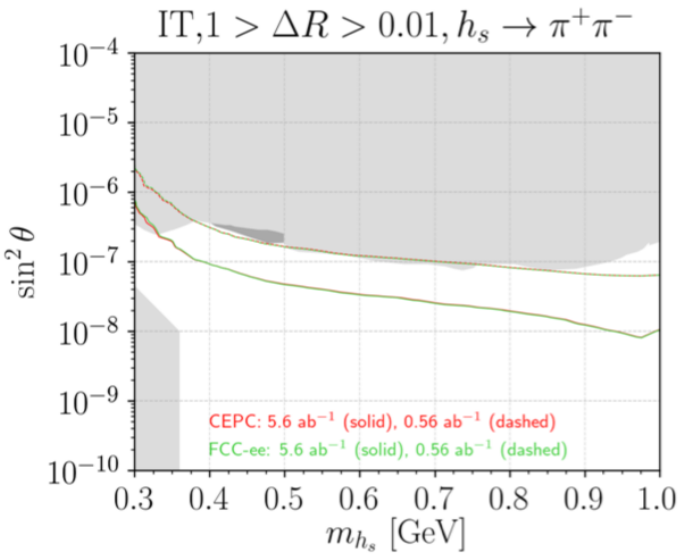
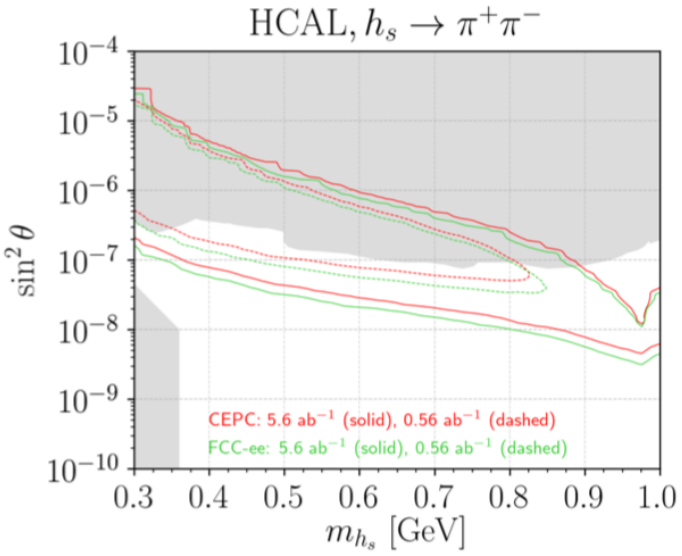


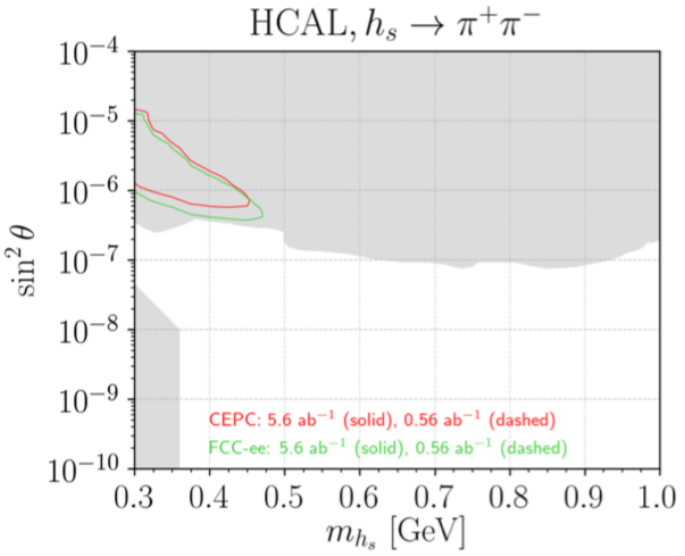
Figure 1: Projected 95% $h \to XX$ branching ratio limits as a function of proper decay length for a variety of X masses. Blue lines are for CEPC and orange lines are for FCC-ee, and where only one is visible they overlap. The larger dashes are the 'long lifetime' analysis and the smaller dashes are the 'large mass' analysis.

1911.08721 – Light Scalars





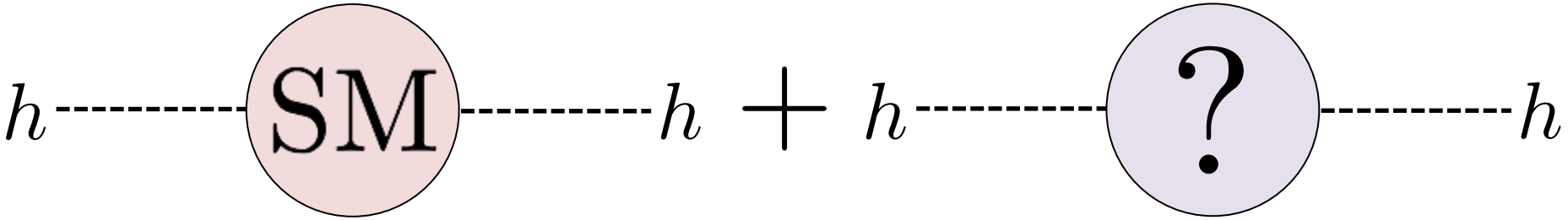




UV Motivations

Neutral Naturalness

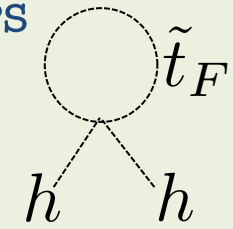
Could there be totally hidden states which tame sensitivity to physics at the cutoff?



Much attention now to alternative ideas:

Folded SUSY hep-ph/0609152

Theory where EW-charged uncoloured scalars are top partners

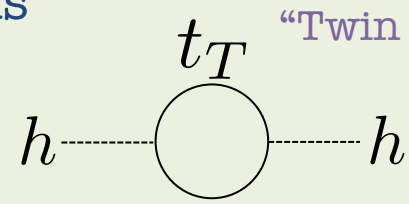


"Folded Stops"

...but they must be charged under new hidden QCD'.

Twin Higgs hep-ph/0506256

Theory where top partners are SM gauge neutral fermions



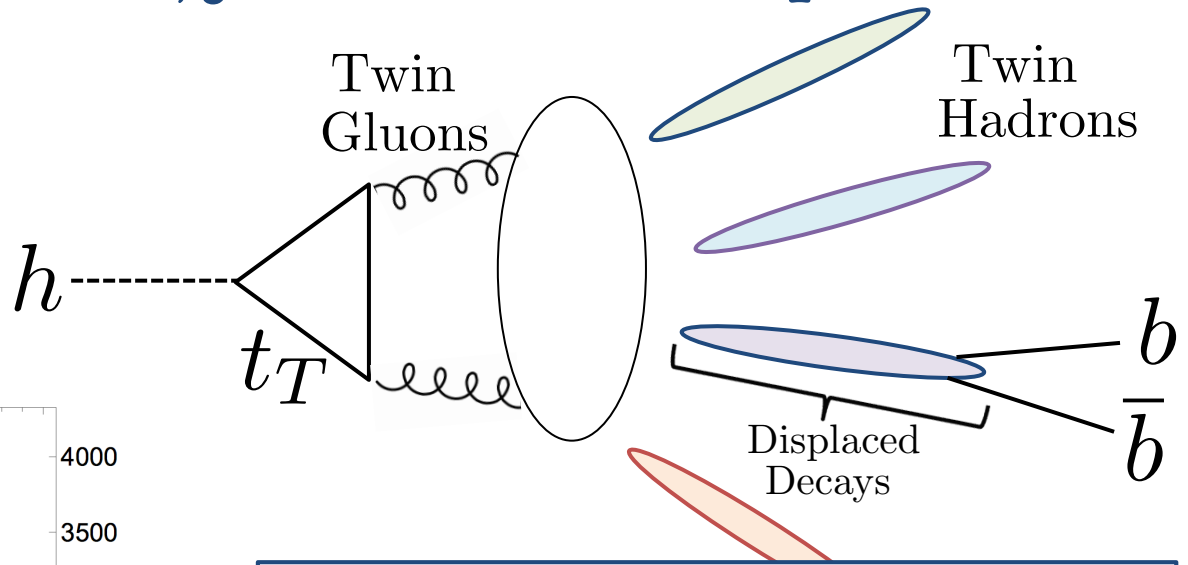
"Twin Tops"

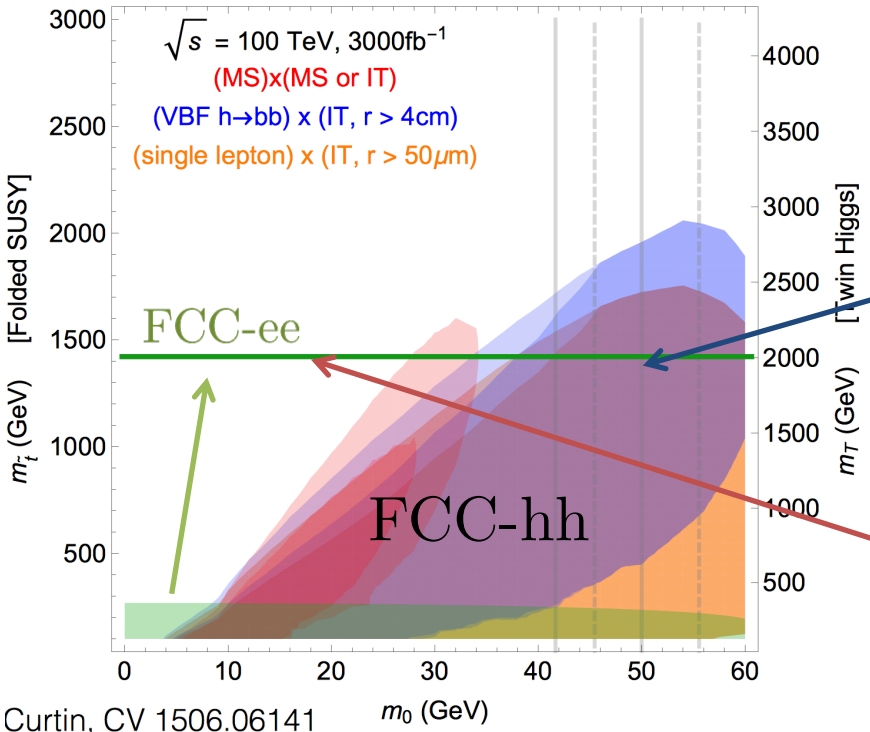
...but they must be charged under new hidden QCD'.

Neutral Naturalness

Naturalness not hidden, just look in new places...

New hidden sector introduces exotic Higgs decays:



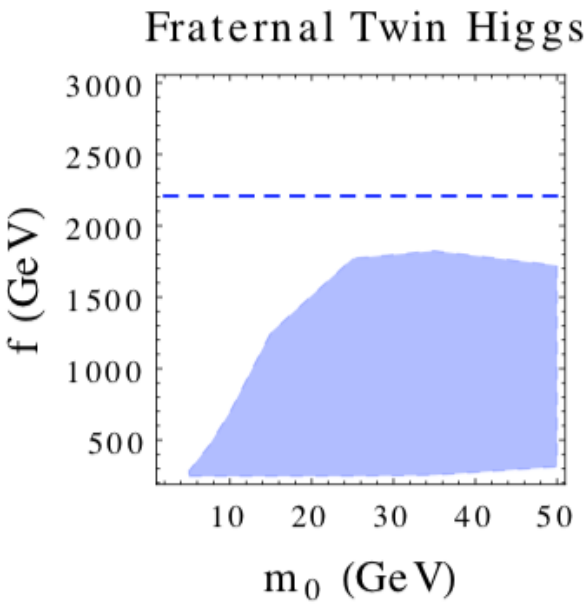


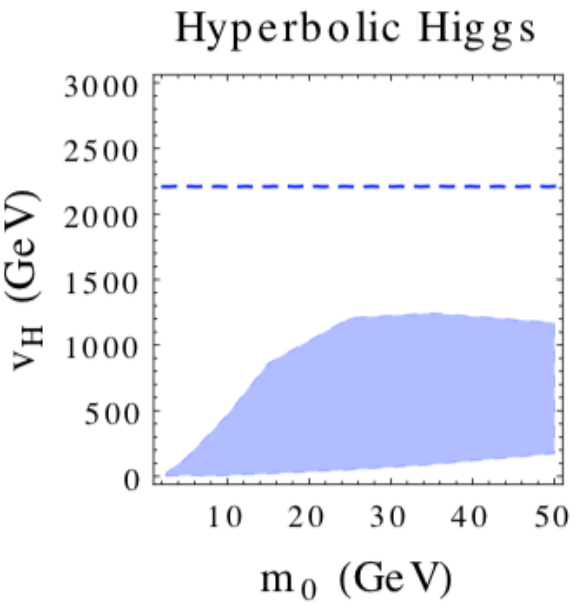
Curtin, CV 1506.06141

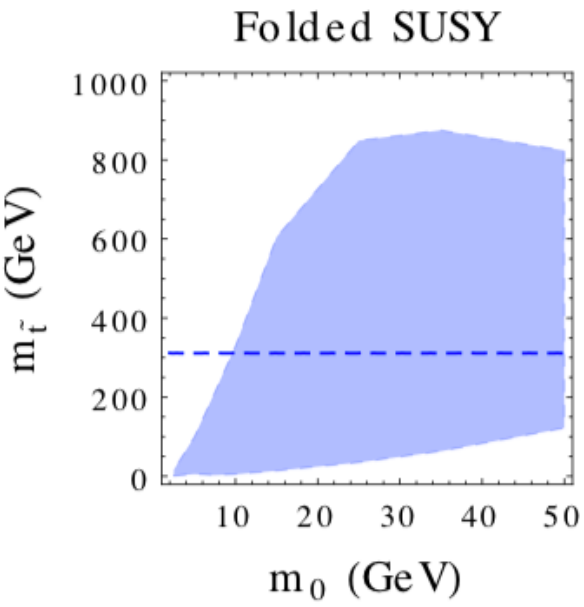
FCC-hh can thoroughly probe larger Twin scales through displaced searches.

FCC-ee/CEPC has indirect access for top partners, including for low confinement scales.

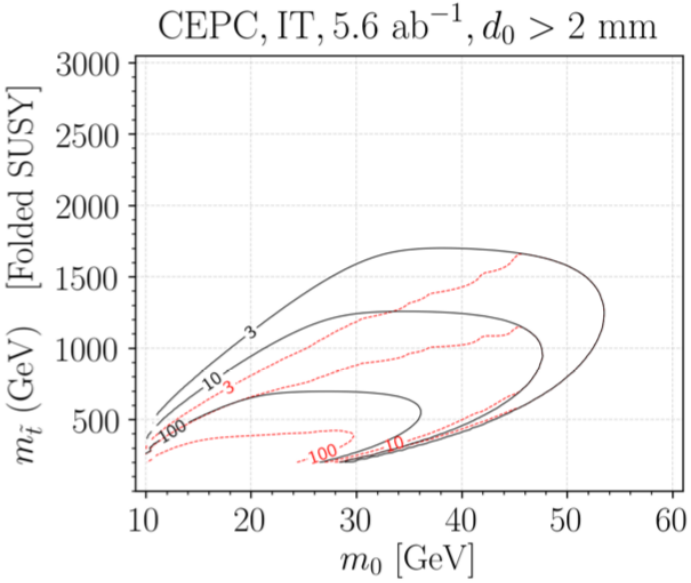
1812.05588 – Neutral Naturalness

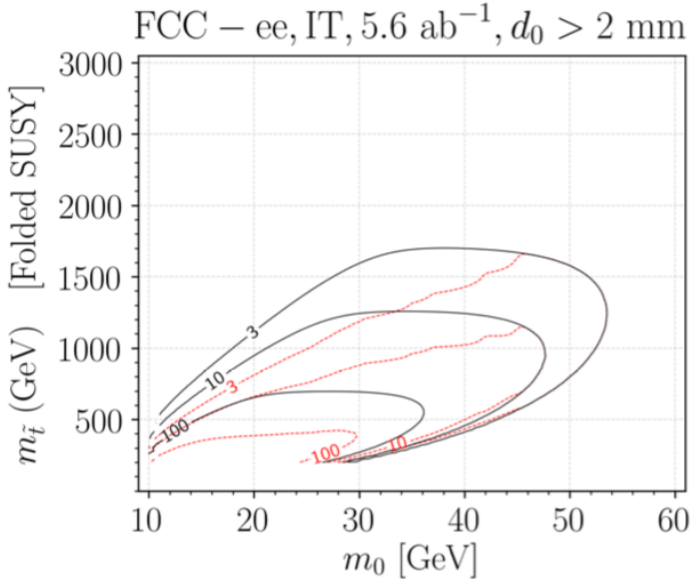


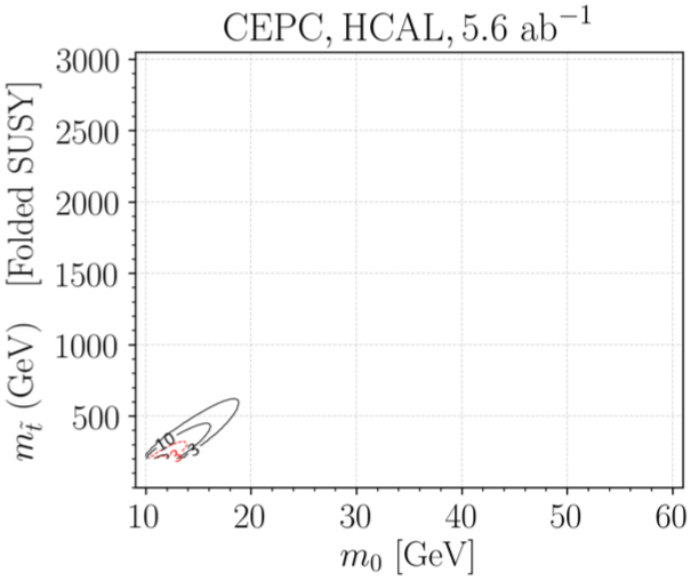


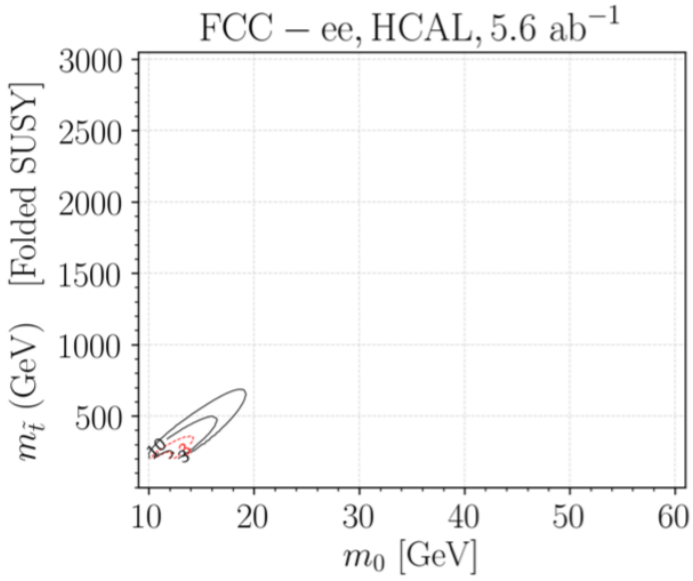


1911.08721 – Folded SUSY



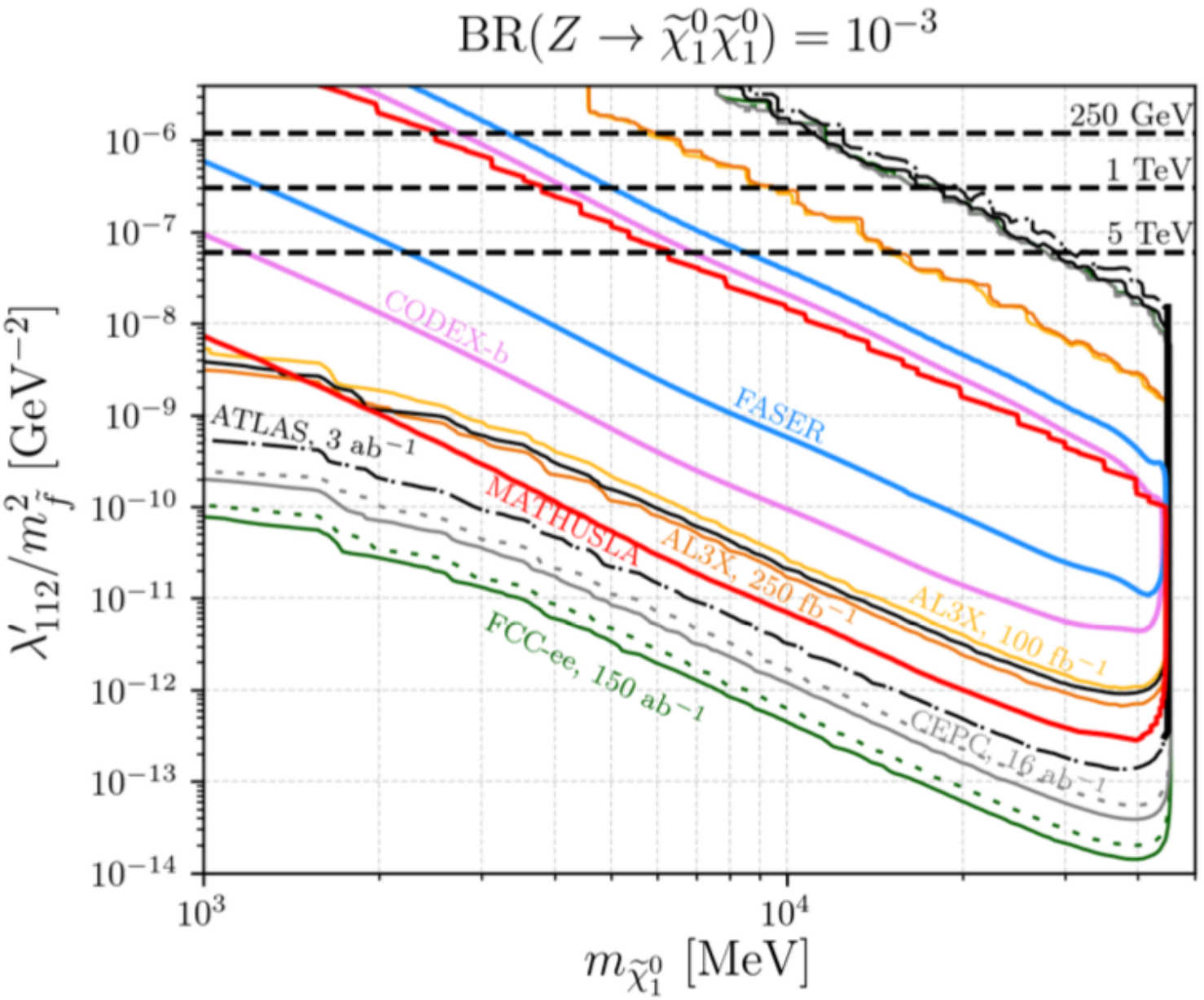






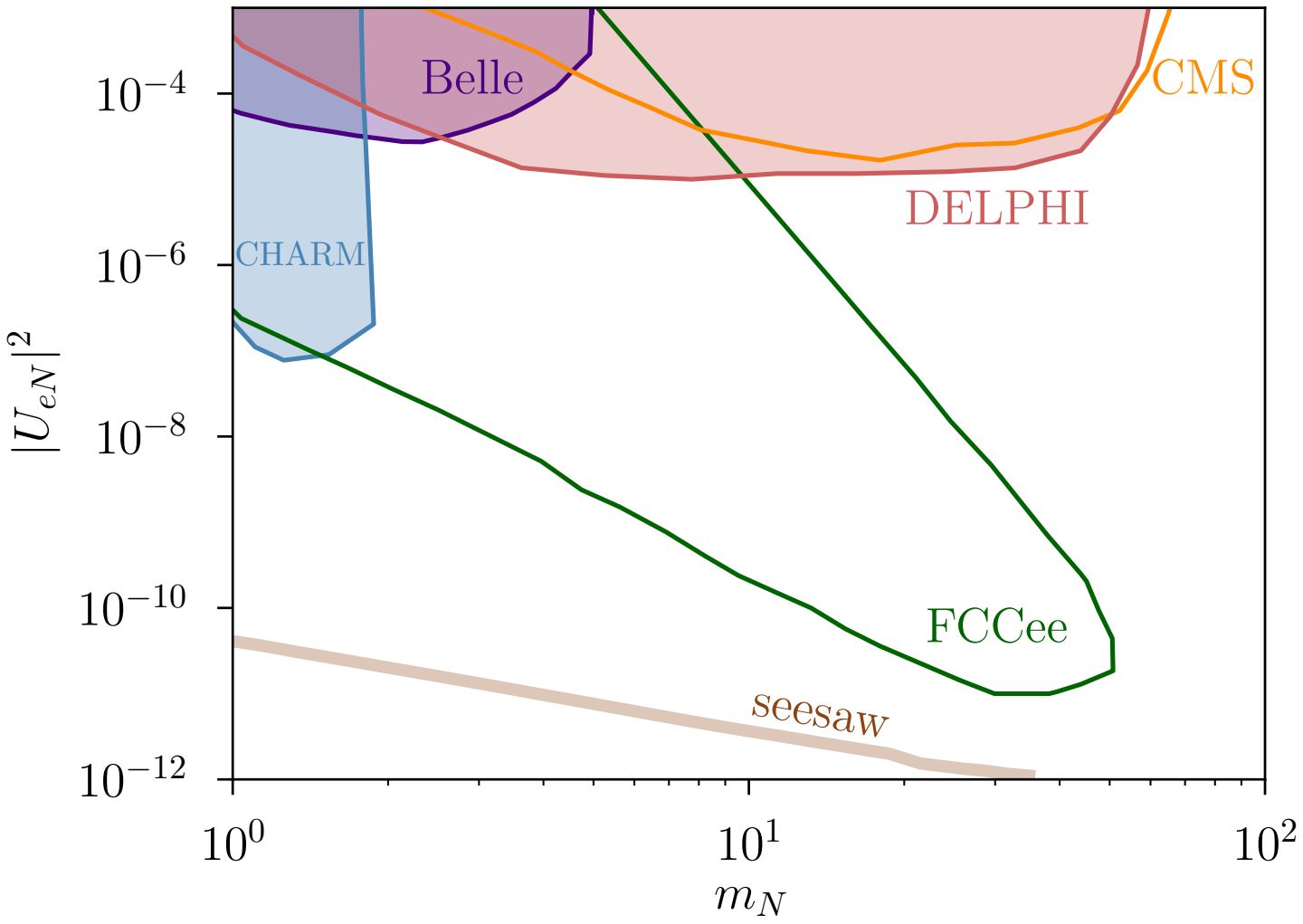
SUSY (ish)

1904.10661 - Neutralinos



Neutrinos

Simon Knapen - Neutrinos



There are clearly lots of interesting studies to do. Personal perspective...

Would prioritize decays of H or Z to pair of LLPs, which subsequently decay with range of final states.

This would cover a great range of UV scenarios.