Exotic Higgs Decays at Future Colliders

FCC Higgs/EWSB WG meeting
@
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Exotic Higgs Decays

Motivation

- The couplings of the SM-like higgs will be determined by **coupling fits** with ~10% precision by the end of the LHC program.

  Br(h→invisible) can be constrained to only ~ 10% with 3000/fb

1310.8361 Dawson et al

- Imagine an exotic higgs decay with 10% Br.

  Run 1 data could contain O(50,000) exotic higgs decays per experiment.
  Run 2: O(1 million)
  HL-LHC: O(10 million)

If we do not look, we will not find!

- Important theoretical motivations to consider exotic higgs decays:

1. The higgs width is extremely narrow (~ 4 MeV).
   Tiny couplings ~ 0.01 can give Br ~ 10%.
2. New physics can easily couple to SM via Higgs Portal $\Delta\mathcal{L} = \frac{\mu}{\Lambda^2}|H|^2\bar{\psi}\psi$ $\Delta\mathcal{L} = \frac{\zeta}{2}s^2|H|^2$
3. Vast theory literature on models with light BSM sectors coupling to the Higgs.

For survey, see DC, Essig, Gori, Jaiswal, Katz, Liu, Liu, McKeen, Shelton, Strassler, Surujon, Tweedie, Zhong, arXiv:1312.4992

Naive Reach Estimates

e.g. $h \to Z_D Z_D \to 4l$

e.g. $h \to 2a \to 4b$ or even $h \to$ jets

	E (Tev)	lumi (/fb)	N_{higgs} (all)	N_{higgs} (clean)	Br sensitivity for very **conspicuous** decays	Br sensitivity for very **difficult** decays
LHC run 1	7,8	25	500k	0	10^{-4}	O(1) or worse
LHC run 2	14	300	10 million	0	10^{-5}	O(0.1) - O(1)
HL-LHC	14	3000	100 million	0	10^{-6}	?
ILC	0.25 - 1	7000	1 million	40k	10^{-4} - 10^{-5}	10^{-2}
TLEP	0.25ish	10000	3 million	300k	10^{-5}	10^{-3}
100 TeV	100	3000	few billion	0	10^{-7} - 10^{-8}	10^{-2} ????

100 TeV collider is an intensity frontier experiment to study the Higgs!

Good example: Dark Photons

Simplified Model Lagrangian

- Many motivations for considering this: arises as part of UV complete models, hidden valleys, can help with anomalies, etc...
- Add a new *higgsed* $U(1)_D$ gauge group. Get SM singlet scalar (mix with Higgs) and dark photon (mix with hypercharge)

$$\mathcal{L}_{\text{gauge}} = -\frac{1}{4}\hat{B}_{\mu\nu}\hat{B}^{\mu\nu} - \frac{1}{4}\hat{Z}_{D\mu\nu}Z_D^{\mu\nu} + \frac{1}{2}\frac{\epsilon}{\cos\theta_W}\hat{B}_{\mu\nu}\hat{Z}_D^{\mu\nu}$$

Hypercharge Portal

$$V_0 = -\mu^2|H|^2 + \lambda|H|^4 - \mu_D^2|S|^2 + \lambda_D|S|^4 + \zeta|S|^2|H|^2$$

Higgs Portal

- Recently studied prospects of probing these two portals at future colliders. DC, Rouven Essig, Stefania Gori, Jessie Shelton, 1412.0018

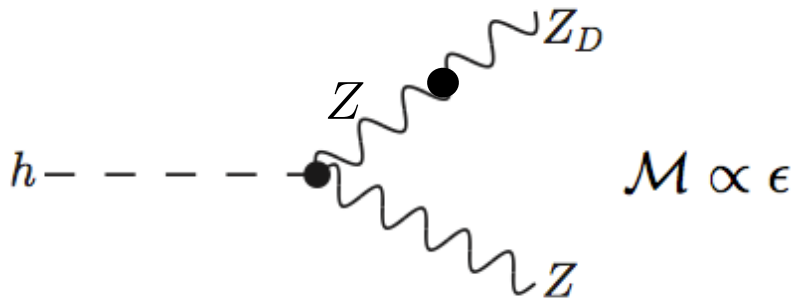
Higgs → Dark Vector

Two kinds of exotic higgs decays to dark photons

via kinetic mixing

$\epsilon >> \zeta$

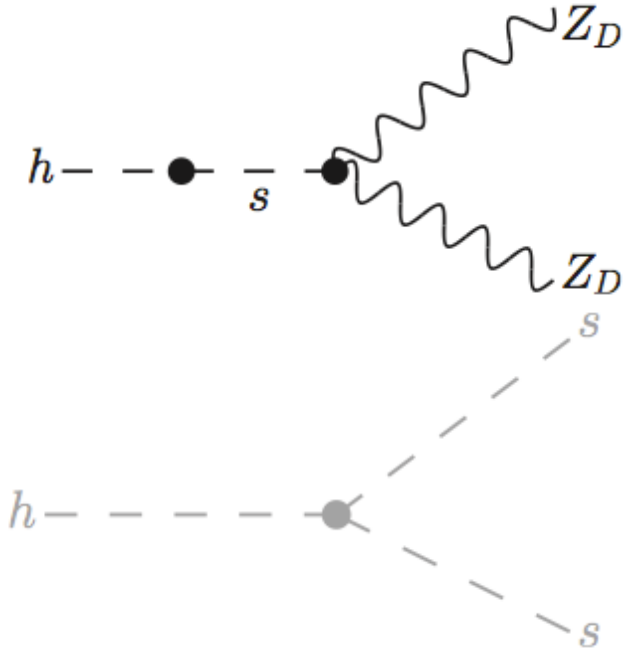
$Br(h \to Z\, Z_D) \propto \epsilon^2$



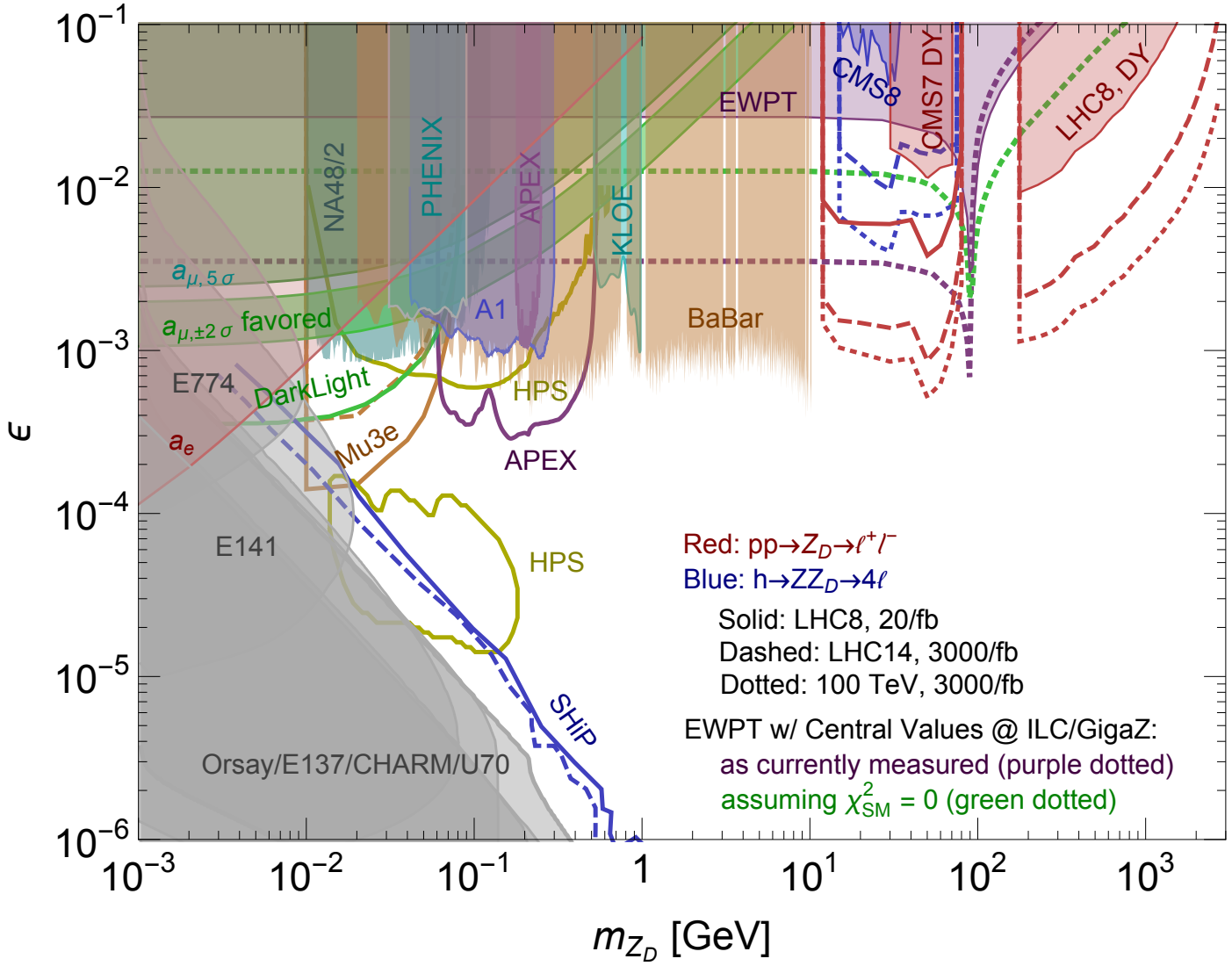
via higgs mixing

$\zeta >> \epsilon \neq 0$ (to let Z_D decay)

$Br(h \to Z_D\, Z_D) \propto \zeta' \equiv \zeta \left| \frac{m_h^2}{m_h^2 - m_s^2} \right|$



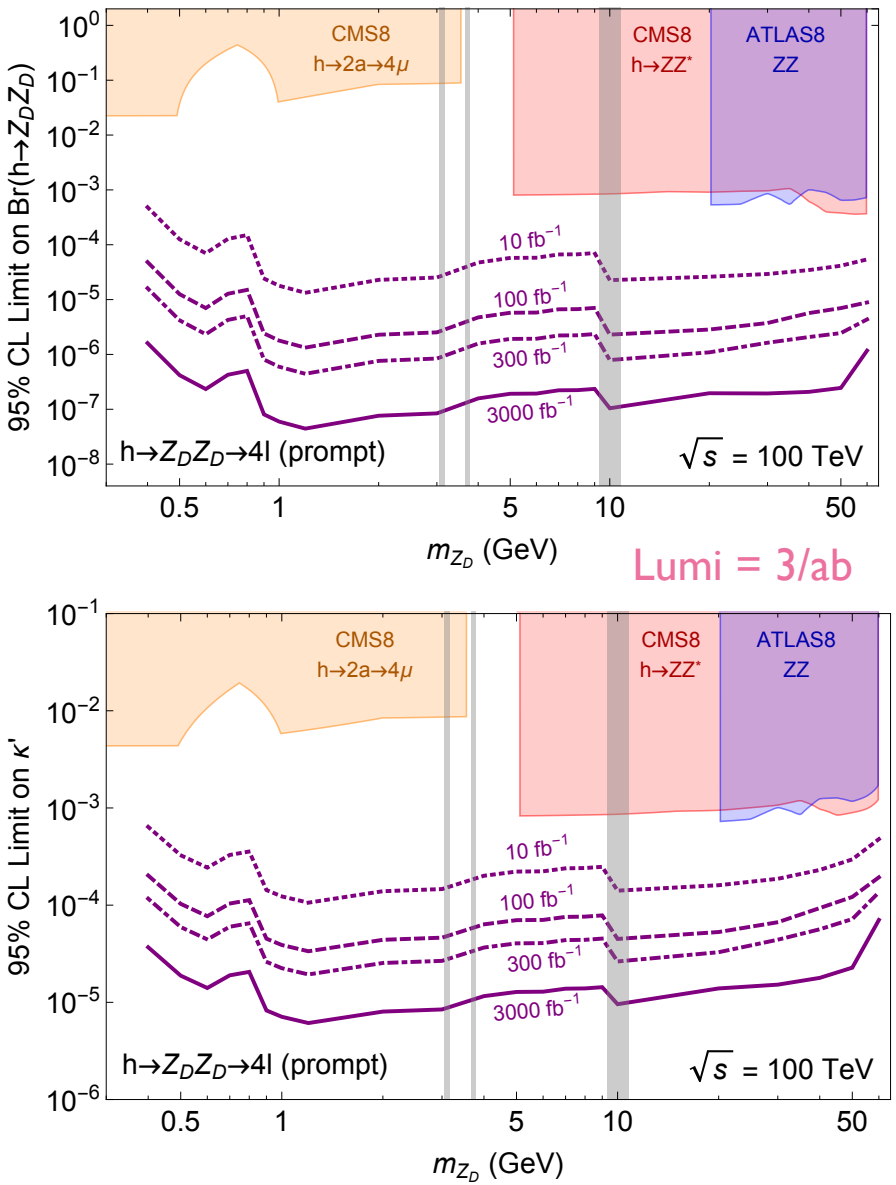
Probing Kinetic Mixing



DY production
$pp \rightarrow Z_D$
and exotic Higgs decay
$h \rightarrow Z^{(*)}Z_D$
are both needed to characterize the dark photon and can probe $\epsilon \sim 10^{-3}$.

Direct searches beat EWPT.

Probing Higgs Mixing

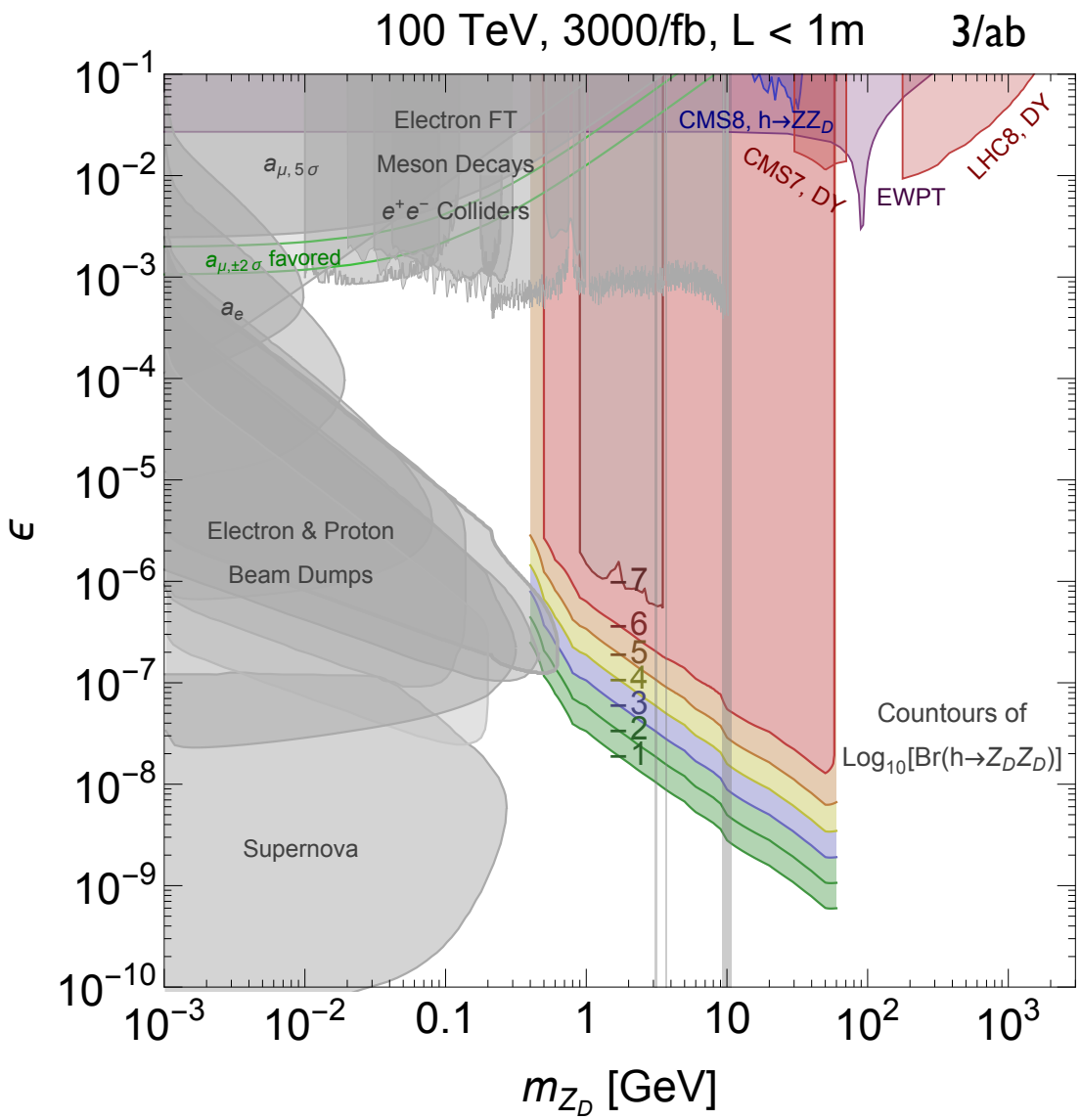


The only* way to probe higgs mixing is via the exotic Higgs decay $h \rightarrow Z_D Z_D$.

At 100 TeV, get expected ~ 10^{-8} Br sensitivity for a conspicuous decay.

Probe couplings smaller than 10^{-5}.

Probing Kinetic Mixing *via* Higgs Mixing



If there is Higgs mixing, have exotic Higgs decay
$h \rightarrow Z_D Z_D$.

However, kinetic mixing ϵ has to be nonzero to allow decay of Z_D.

If we detect $h \rightarrow Z_D Z_D$ via prompt decay, then we have detected
$\epsilon > 10^{-6}$
(much better than direct probe of ϵ)

Enormous signal rates at pp colliders allow detection of extremely long-lived particles.

Can probe $\epsilon \sim 10^{-10}$ if Higgs mixing is sizable!

Conclusions

- Exotic Higgs decays are well-motivated theoretically and experimentally and may be the only window into new physics.
- A 100 TeV collider is uniquely well suited to look for rare Higgs decays due to the enormous number of produced Higgs particles.
- The large rates can probe extremely small couplings, and/or extremely long life-times of produced particles.
- Underlines importance of triggering on and reconstructing low-pT objects at 100 TeV.
- For exotic Higgs decays with difficult final states (hadronic, MET, ...), future lepton colliders provide best discovery avenue.