Higgs portal & Exotic Higgs/Z/top decays

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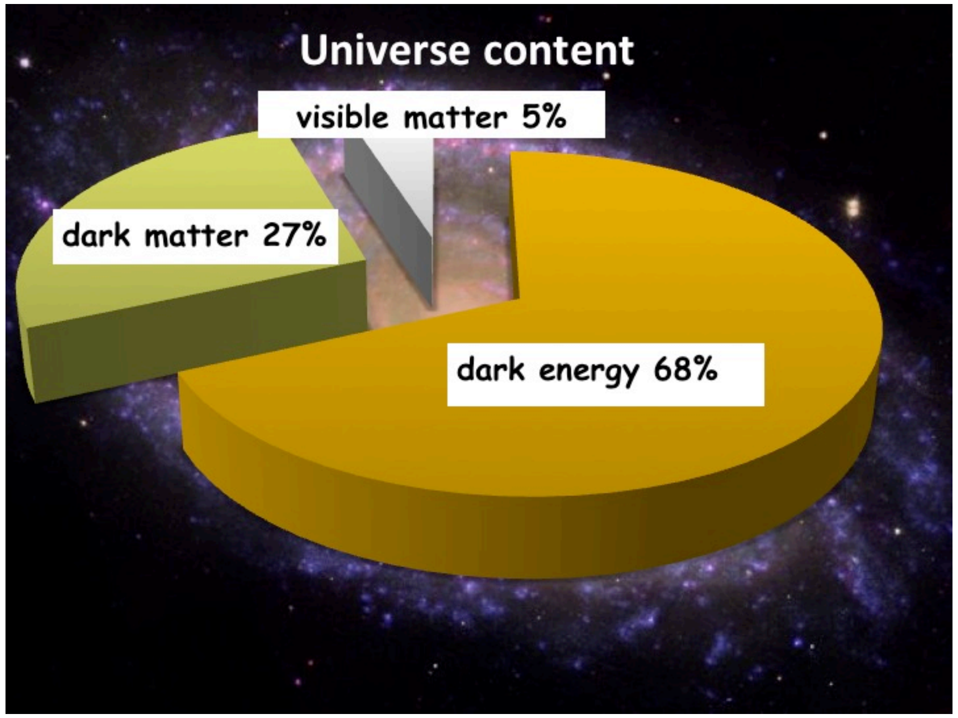
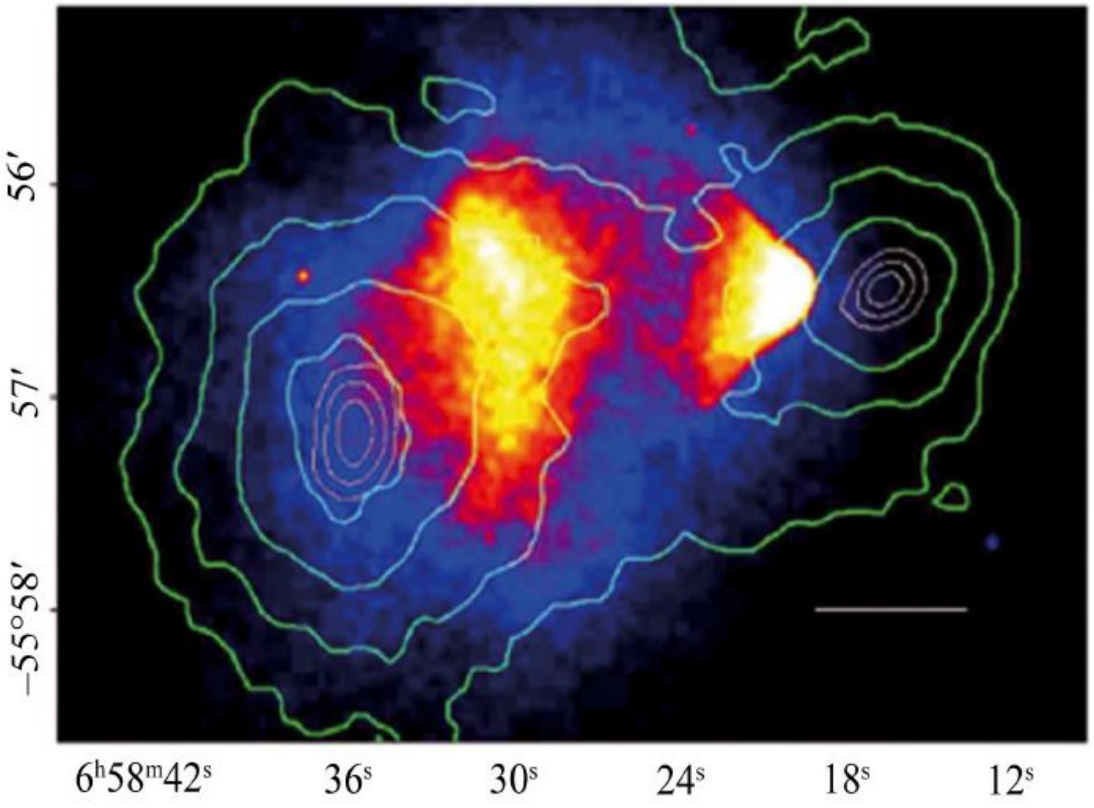
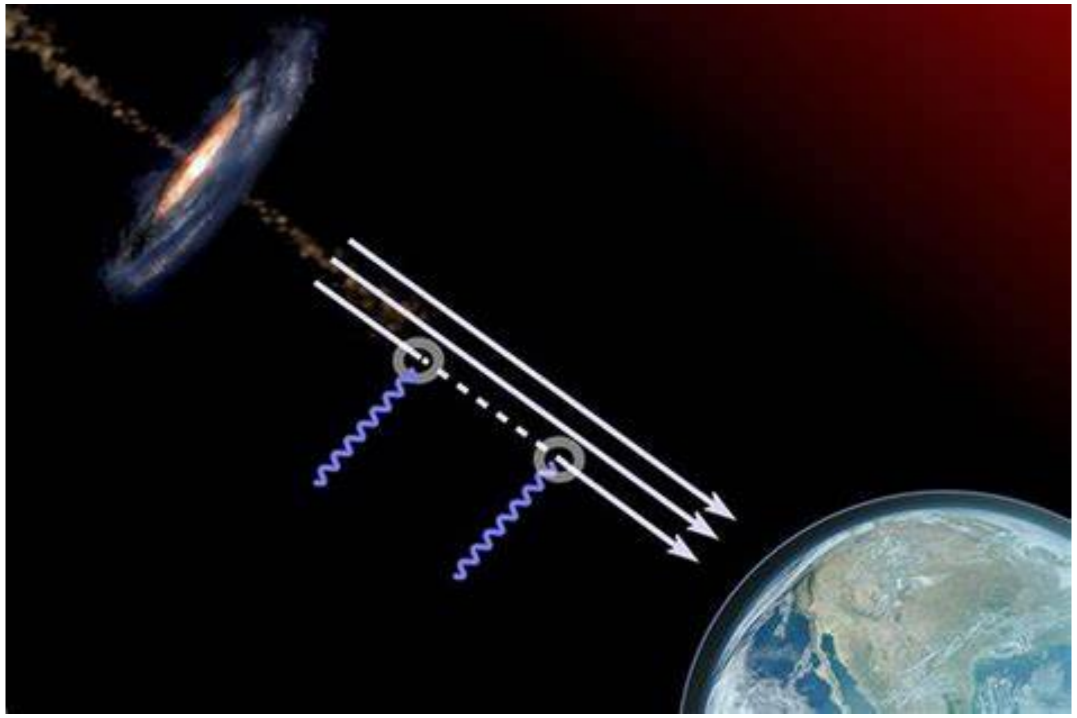
The 2023 International Workshop on the High Energy Circular Electron Positron Collider
2023 Oct 27

New Physics Beyond SM



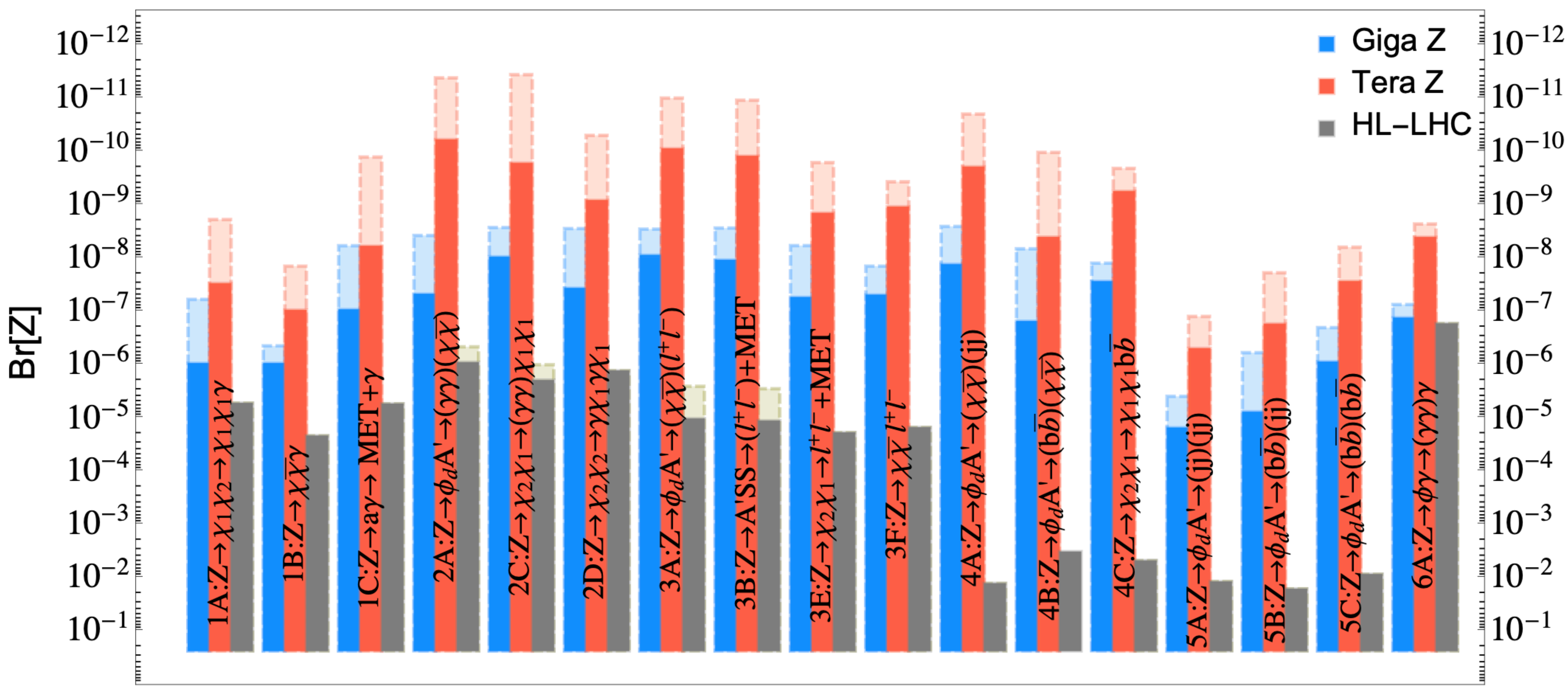




Dark sector @ future Z factories

- Giga-Z (Tera-Z) at Z pole: $10^9 (10^{12})$ Z bosons

Jia Liu, Lian-Tao Wang, Xiao-Ping Wang, Wei Xue, Phys.Rev.D 97 (2018) 9, 095044

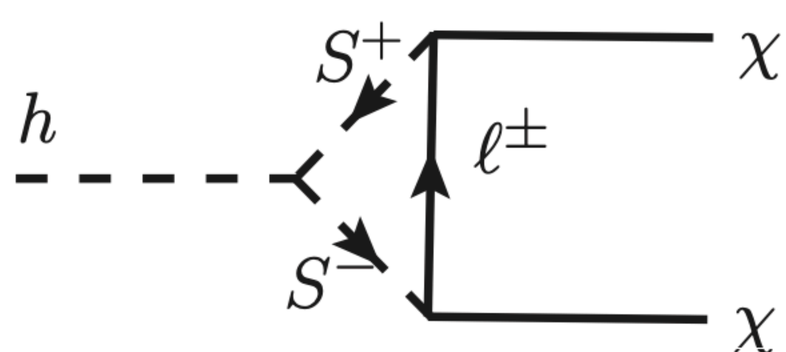


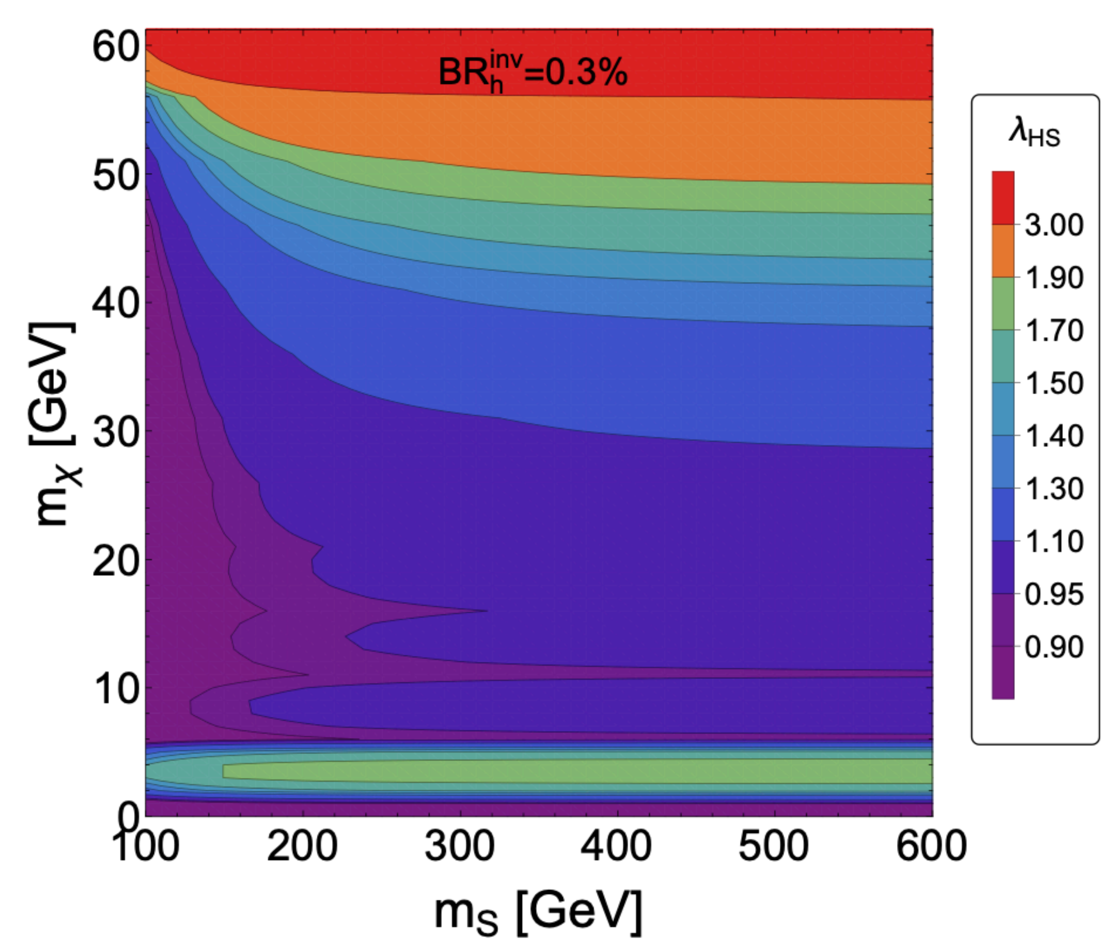
DM @ Higgs invisible decays

- ATLAS Run-II (139fb^{-1}): Br(h → inv) < 13%[93].
- HL-LHC: ~3.5%[94].
- CEPC: ~0.3% [86].

Jia Liu, Xiao-Ping Wang, Ke-Pan Xie, JHEP 06 (2021) 149

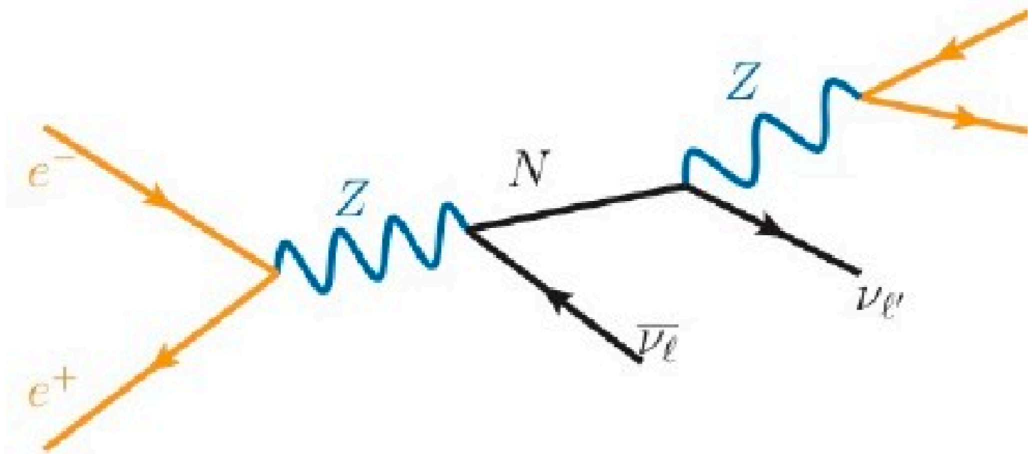
$$\mathcal{L}_\chi = \frac{1}{2}\bar{\chi} i\partial\!\!\!/ \chi - \frac{1}{2} m_\chi \bar{\chi}\chi + y_\ell \left(\bar{\chi}_L S^\dagger \ell_R + \text{h.c.} \right),$$
$$\mathcal{L}_S = \left(D^\mu S\right)^\dagger D_\mu S - V(H,S),$$
$$V(H,S) = \mu_H^2 |H|^2 + \mu_S^2 |S|^2 + \lambda_H |H|^4 + \lambda_S |S|^4 + 2\lambda_{HS} |H|^2 |S|^2,$$

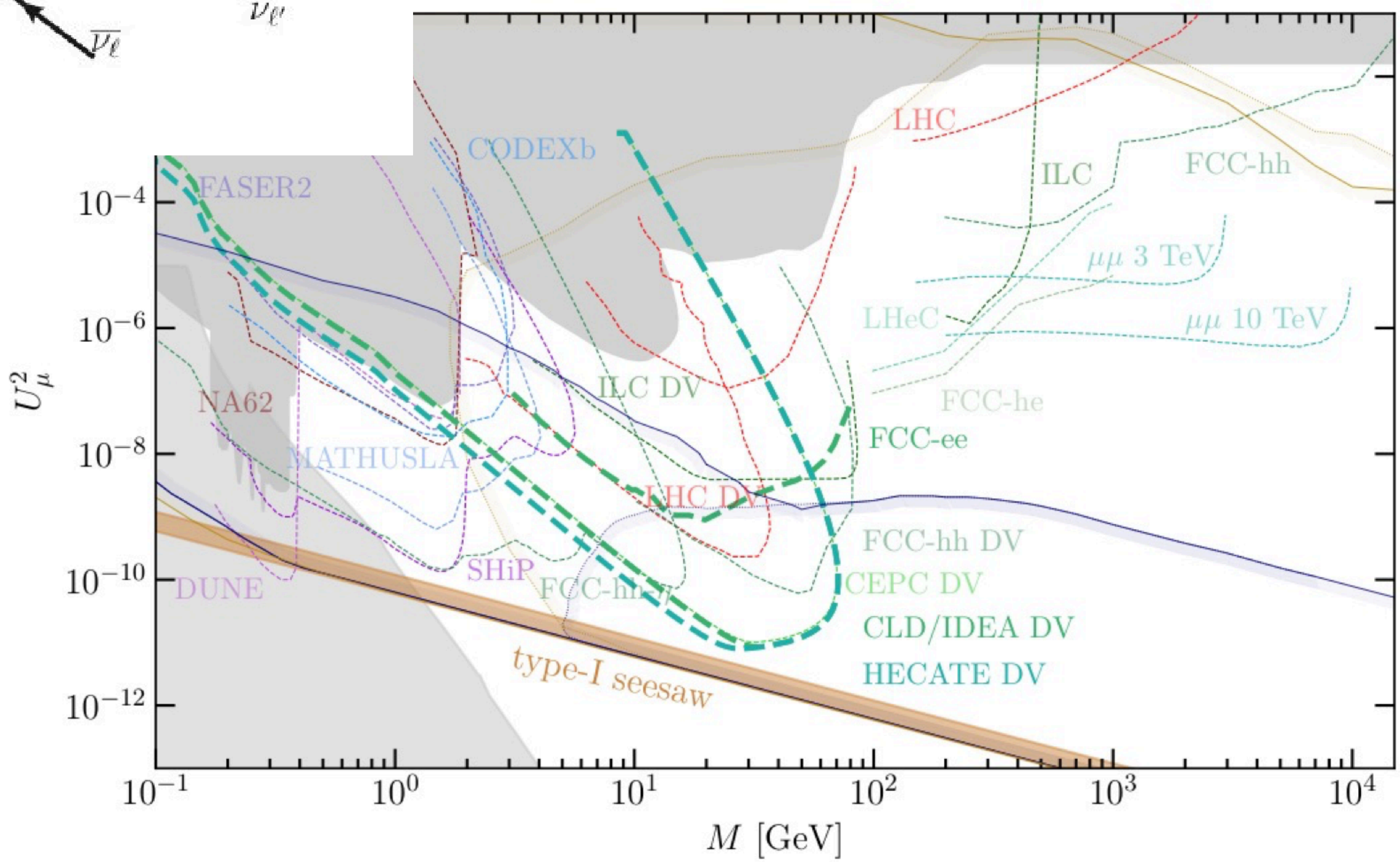




Heavy Neutral Lepton (HNL)

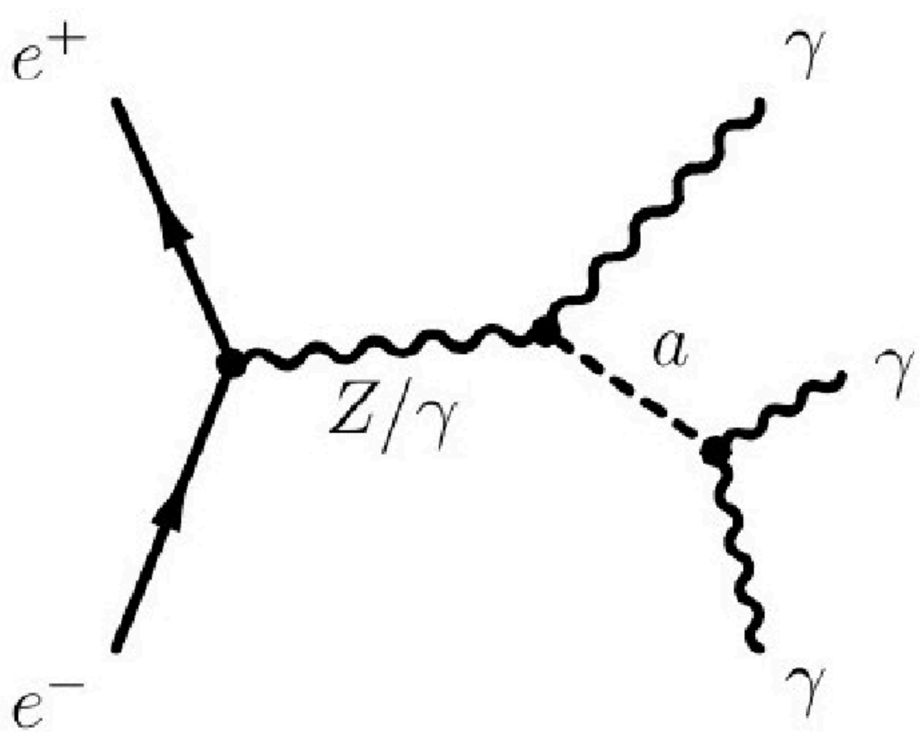
A. Blondel, et. al., Front.in Phys. 10 (2022) 967881

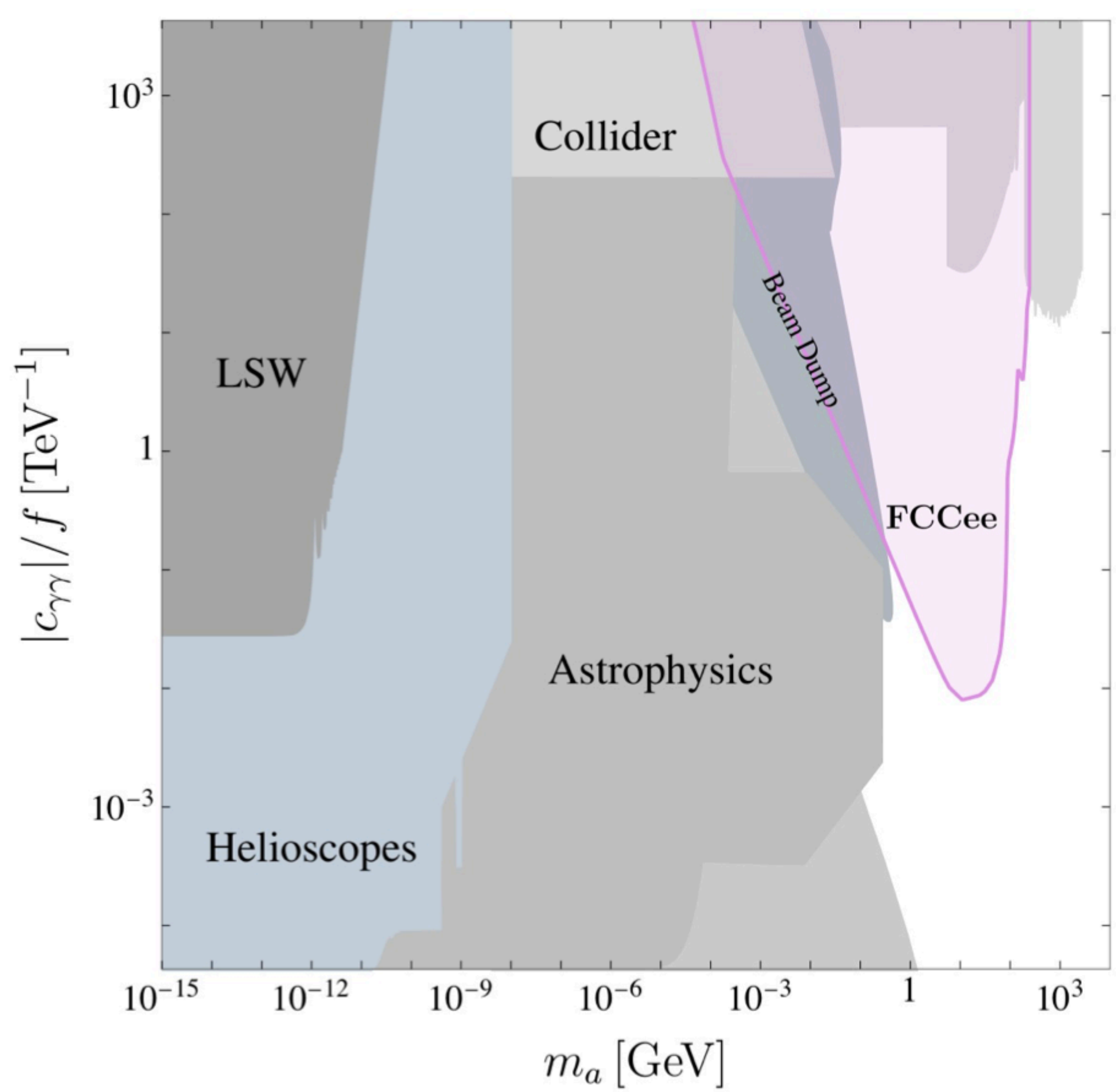




Axion Like Particle (ALP)

A. Blondel, et. al., Front.in Phys. 10 (2022) 967881

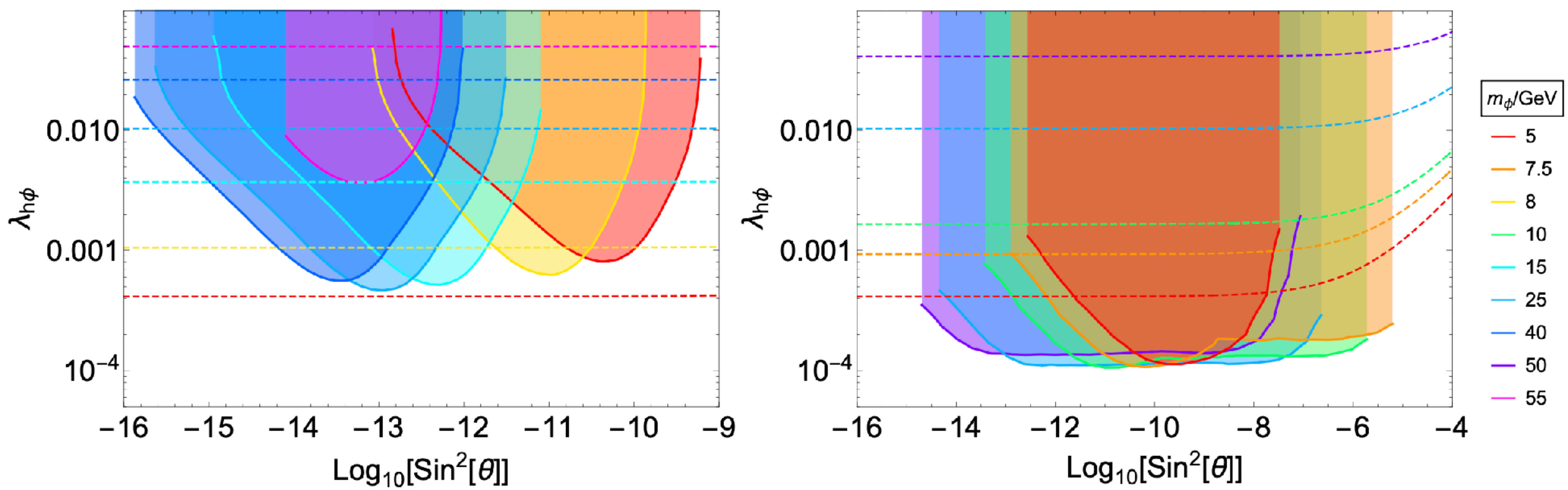




Long Lived Particle (LLP) in Higgs Decay

Elina Fuchs, et. al., JHEP 04 (2021) 019

Long Lived New Scalar: $h \to \phi\phi @ \sqrt{s} = 240$ **GeV**



(a) ATLAS $\sqrt{s} = 13$ TeV with 36 fb^{-1}.

(b) FCC-ee $\sqrt{s} = 240$ GeV with 5 ab^{-1}.

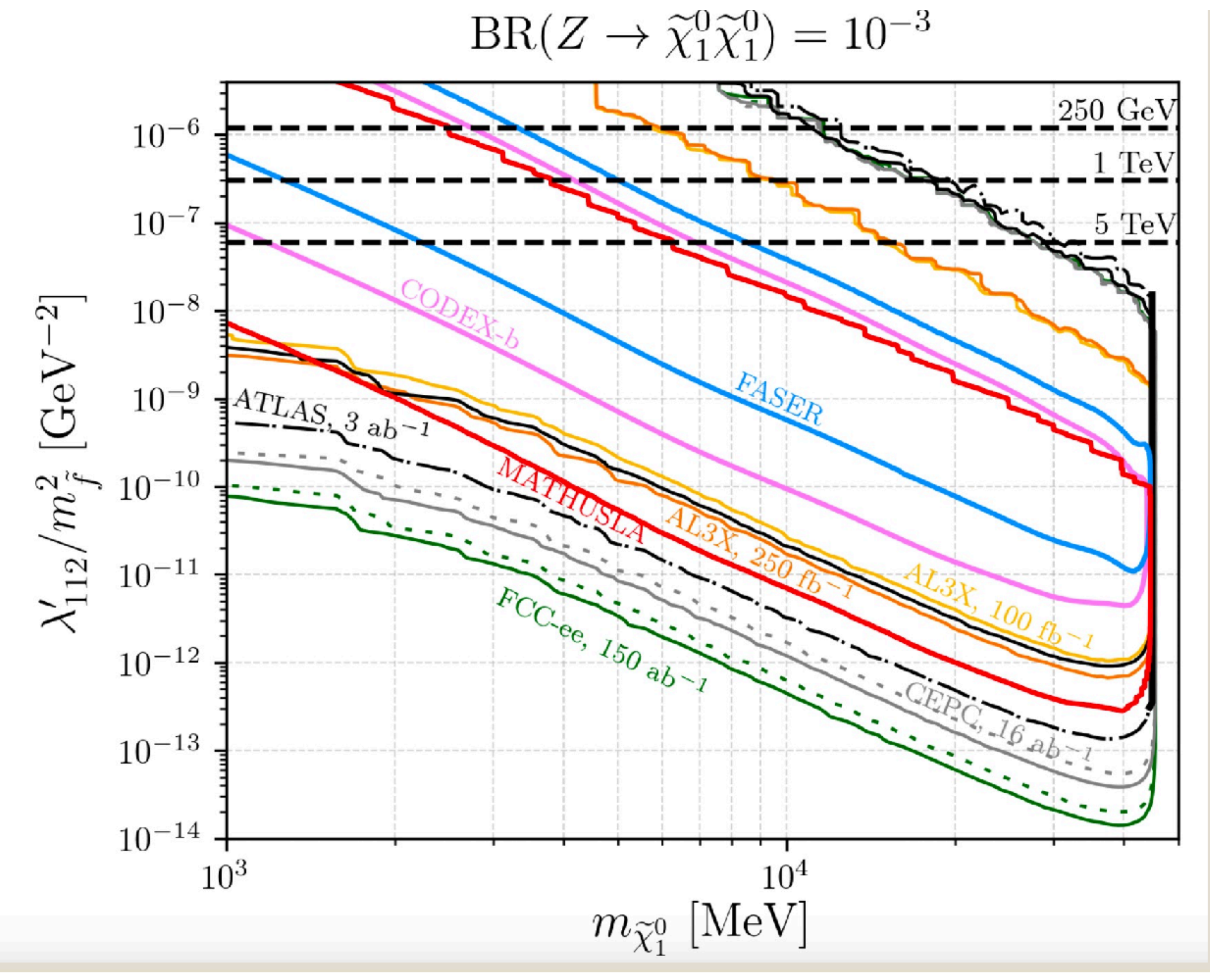
Figure 4. Bounds on $\lambda_{h\phi}$ and $\sin^2\theta$ for various singlet masses arising from searches for displaced jets in Higgs decays. The dashed lines show the upper naturalness limit $\lambda_{h\phi}^{\max} = m_\phi^2/v^2 + 4\pi m_\phi s_\theta/v$.

Long Lived Particle (LLP) in Z Decay

Z. Wang, Kechen Wang, PRD 101 (2020) 11, 115018

RPV-SUSY neutralinos:

$$Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0, \tilde{\chi}_1^0 \to e^{\mp} K^{(*)\pm}, e^{\mp} jj @ \sqrt{s} = 91.2\text{GeV}$$



Light Higgs Search ~ 95GeV

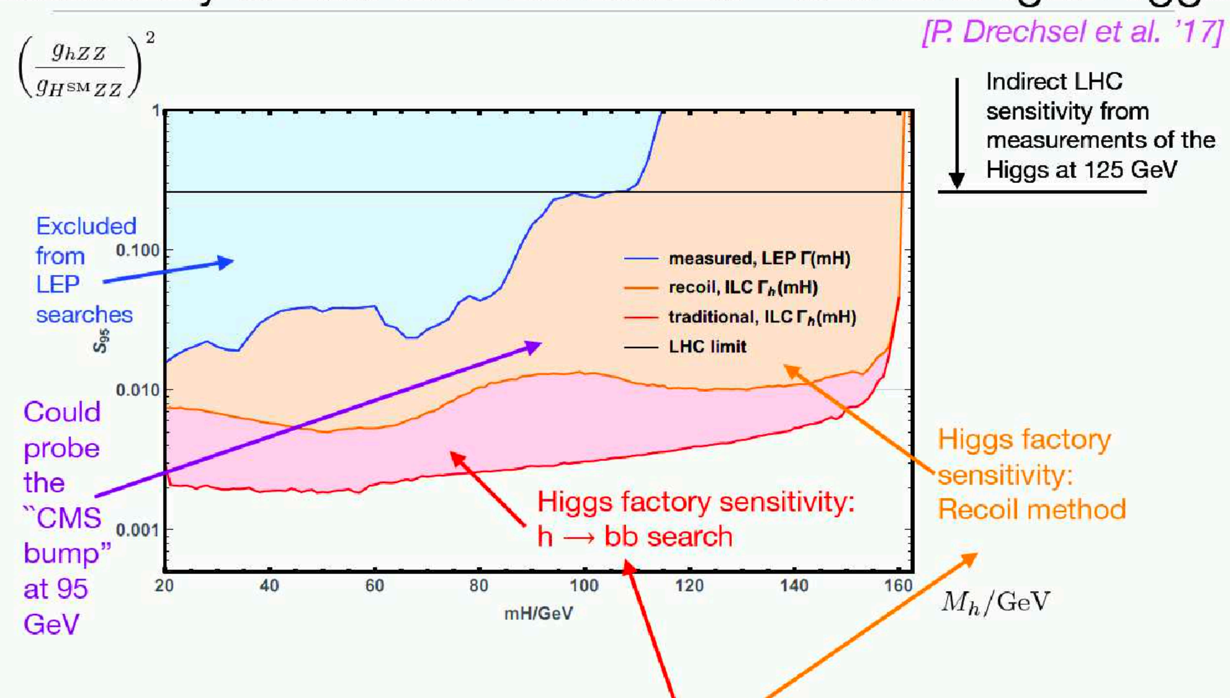
Sven Heinemeyer at CEPC workshop Edinburgh, 2023

Evidence for a Higgs boson at ~ 95.4 GeV

- $pp \to h_{95} \to \gamma\gamma \quad \Rightarrow \quad$ CMS: $2.9\,\sigma$, ATLAS: $1.7\,\sigma$
- $e^+e^- \to Zh_{95} \to Zb\bar{b} \quad \Rightarrow \quad$ LEP: $2\,\sigma$
- $pp \to h_{95} \to \tau\tau \quad \Rightarrow \quad$ CMS: $2.4\,\sigma$

3. Physics opportunities at CEPC (originally for ILC, but equivalent!)

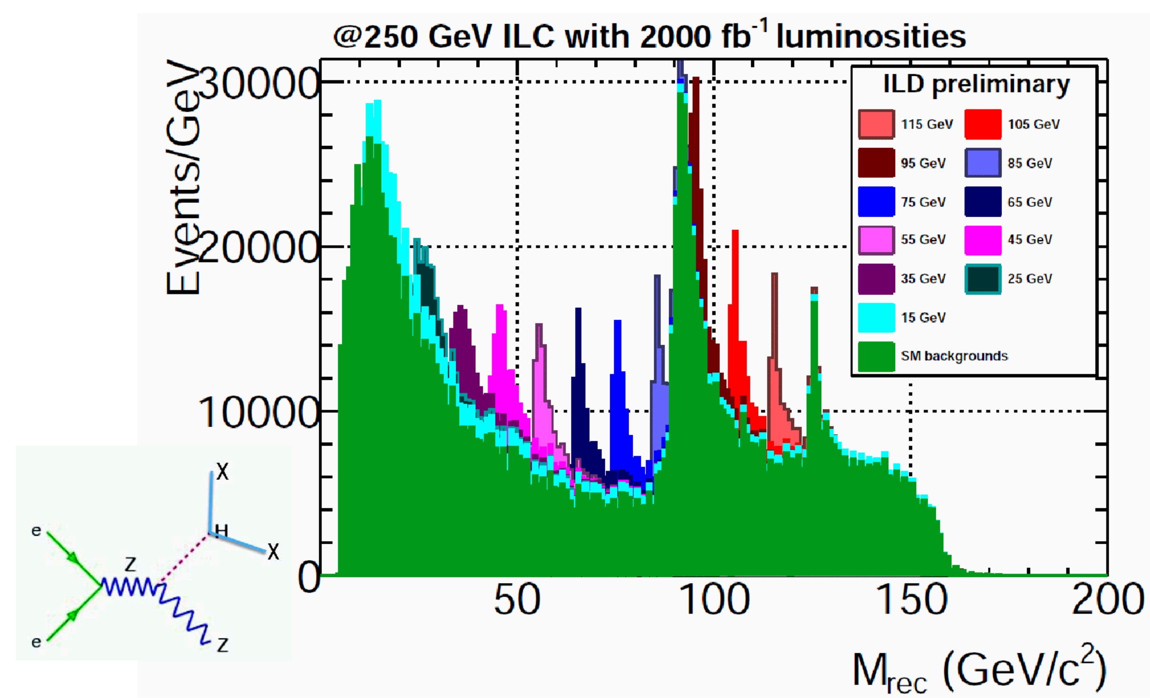
Example for discovery potential for new light states:
Sensitivity at 250 GeV with 500 fb^{-1} to a new light Higgs



⇒ Higgs factory at 250 GeV will explore a large untested region!

[Taken from G. Weiglein '18]

Search for invisibly decaying light Higgses via recoil method: [Y. Wang et al. '18]



Higgs CPV @ CEPC

Qiyu sha, et. al., Eur.Phys.J.C 82 (2022) 11, 981

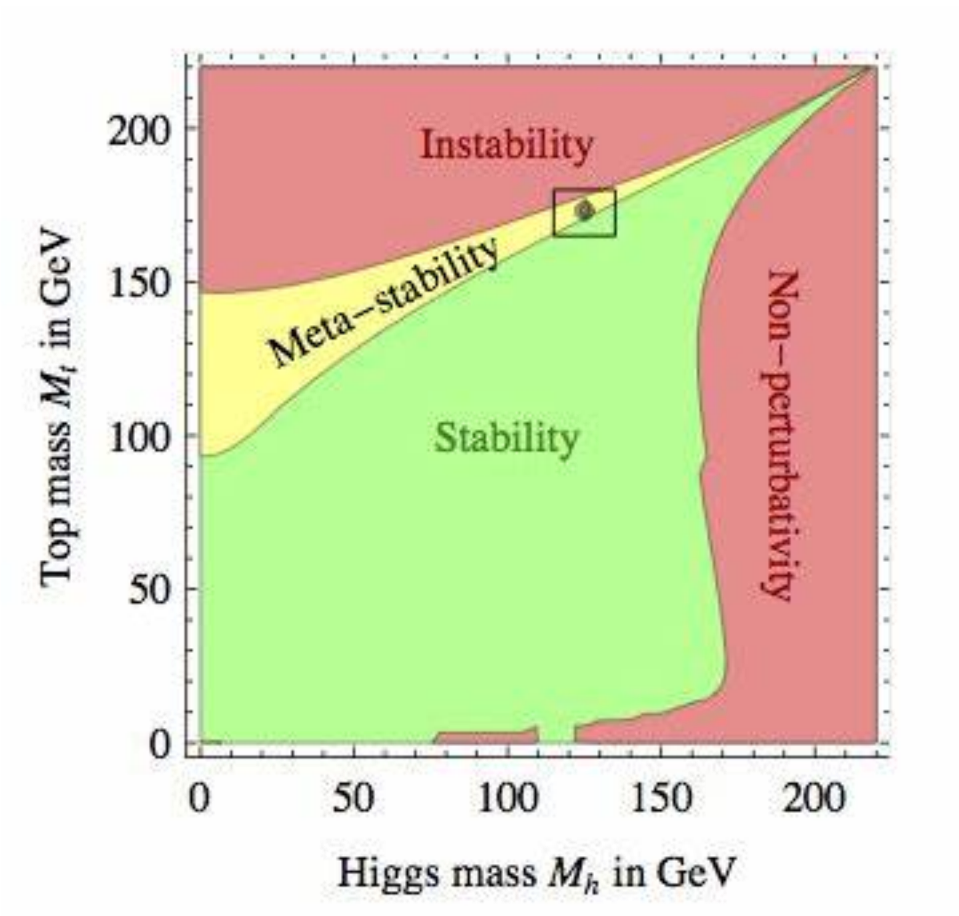
$$\mathcal{L}_{\mathrm{CPV}} = \frac{H}{v}\left[\tilde{c}_{\gamma\gamma}\frac{e^2}{4}A_{\mu\nu}\tilde{A}^{\mu\nu} + \tilde{c}_{Z\gamma}\frac{e\sqrt{g_1^2+g_2^2}}{2}Z_{\mu\nu}\tilde{A}^{\mu\nu} + \tilde{c}_{ZZ}\frac{g_1^2+g_2^2}{4}Z_{\mu\nu}\tilde{Z}^{\mu\nu} + \tilde{c}_{WW}\frac{g_2^2}{2}W^+_{\mu\nu}\tilde{W}^{-\mu\nu}\right],$$

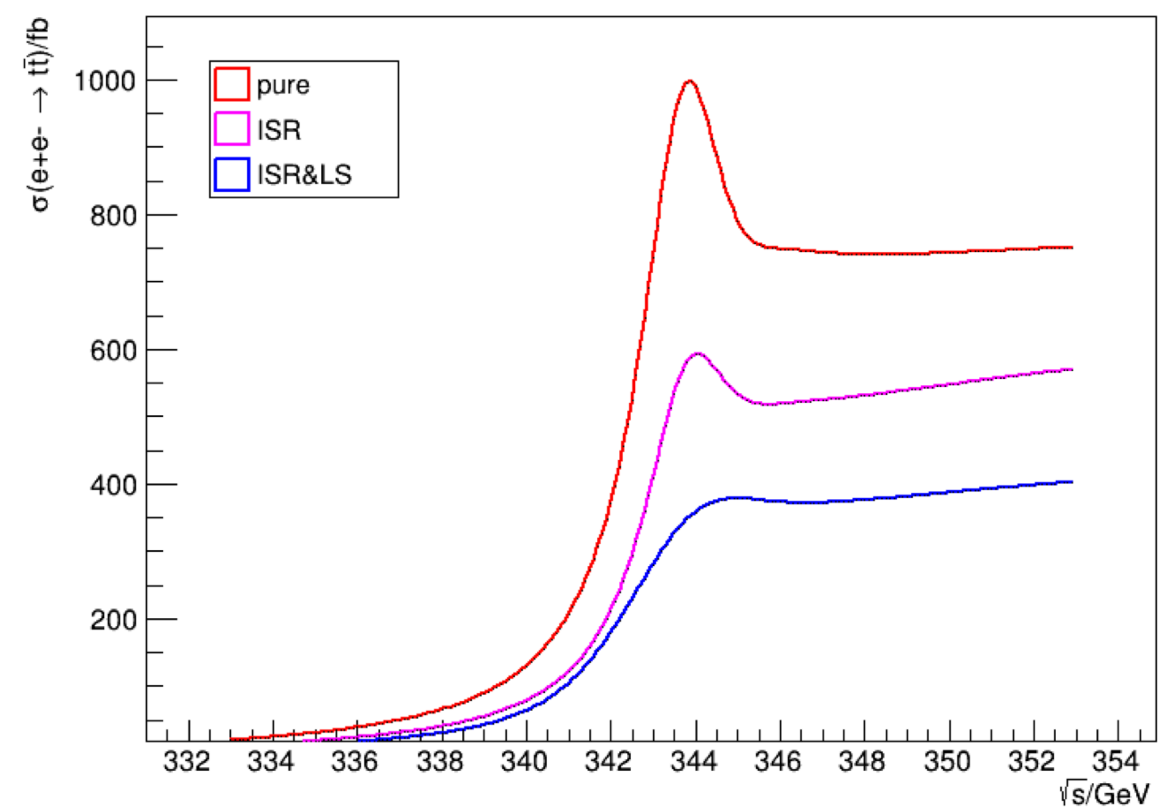
$$\widetilde{X}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma}X^{\rho\sigma}$$

Collider	pp	e^+e^-	e^+e^-
$E\,(\mathrm{GeV})$	14000	240	240
$\mathcal{L}\,(\mathrm{fb}^{-1})$	3000	5600	20000
$\tilde{c}_{Z\gamma}\,(1\sigma)$	$[-0.22, 0.22]$	$[-0.30, 0.27]$	$[-0.16, 0.14]$
$\tilde{c}_{ZZ}\,(1\sigma)$	$[-0.33, 0.33]$	$[-0.06, 0.06]$	$[-0.03, 0.03]$

Top mass @ CEPC (tt threshold)

Zhan Li, et. al., *Eur.Phys.J.C* 83 (2023) 4, 269

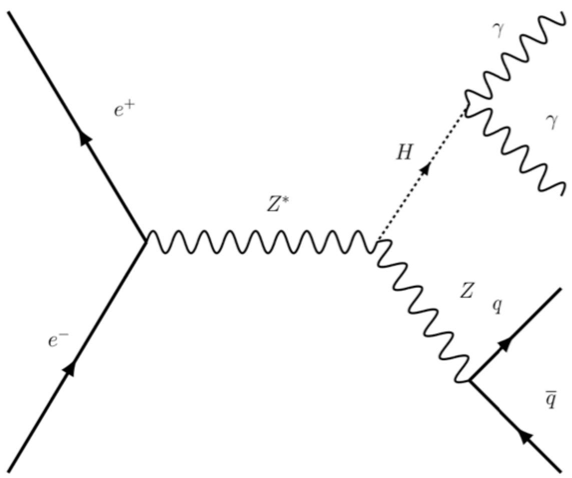


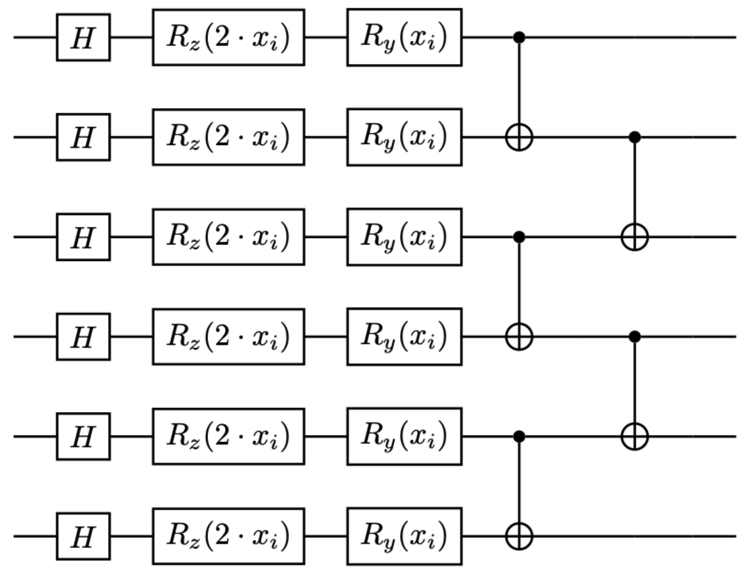


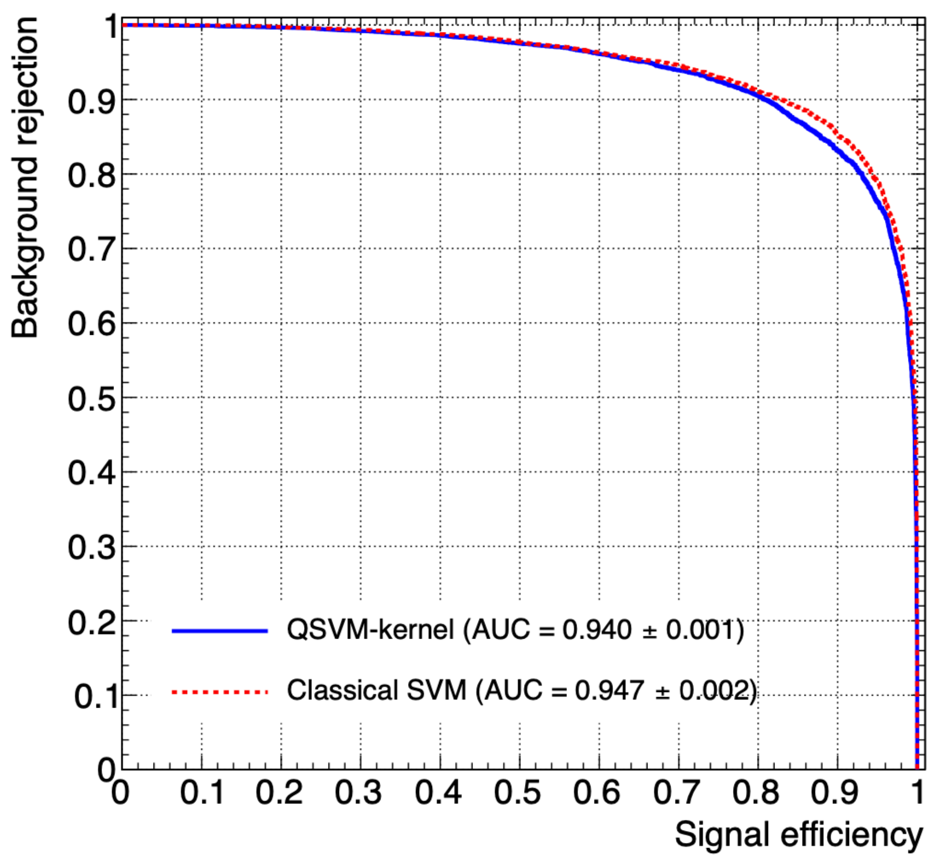
Centre-of-mass energy	Precision of m_{top}	Precision of Γ_{top}	Precision of α_S
342.75 GeV optimal for m_{top}	9 MeV	343 MeV	0.00041
344.00 GeV optimal for Γ_{top}	> 50 MeV	26 MeV	0.00047
343.25 GeV optimal for α_S	15 MeV	40 MeV	0.00040

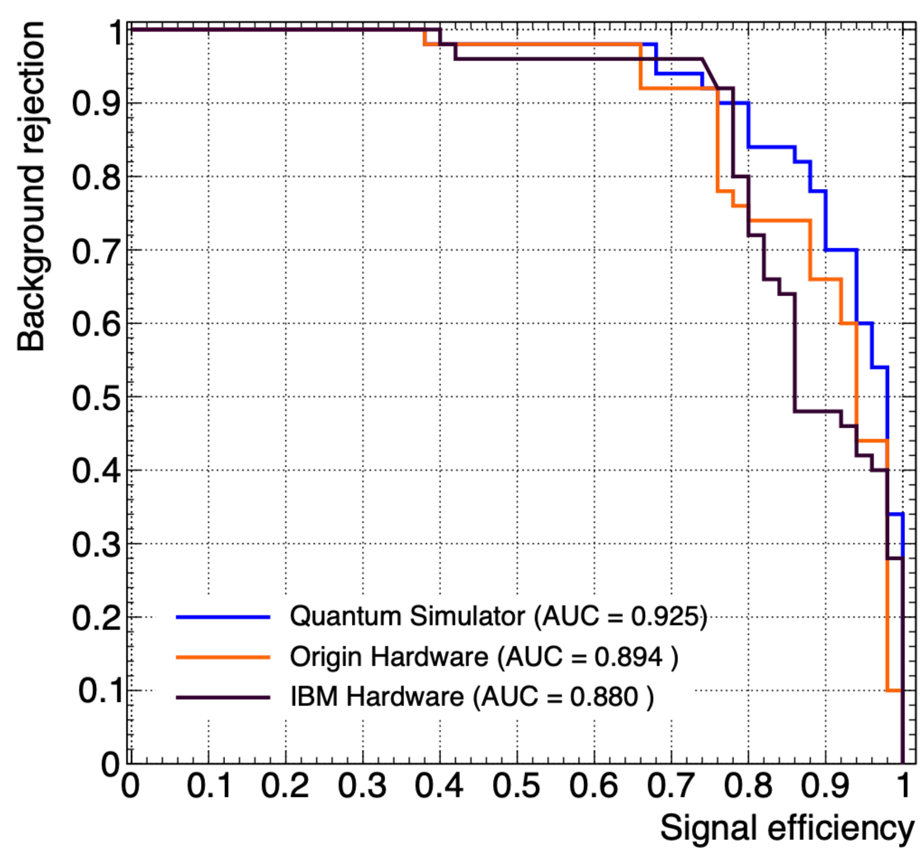
Quantum Machine Learning in $H \to \gamma\gamma$ @ CEPC

Qiyu Sha, et. al., 2209.12788 [hep-ex]









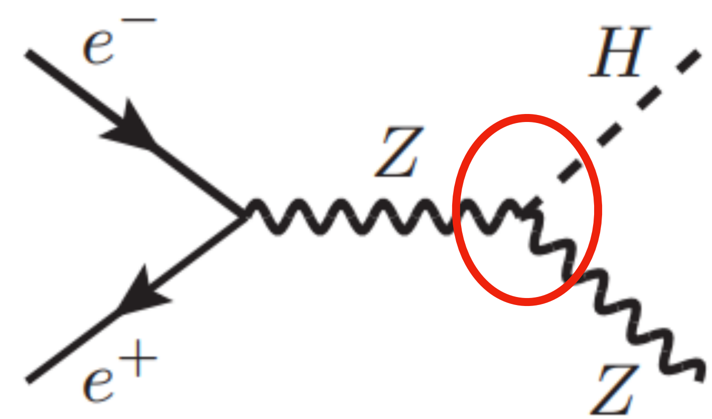
Precise Theoretical Prediction for $e^+e^- \to HZ$

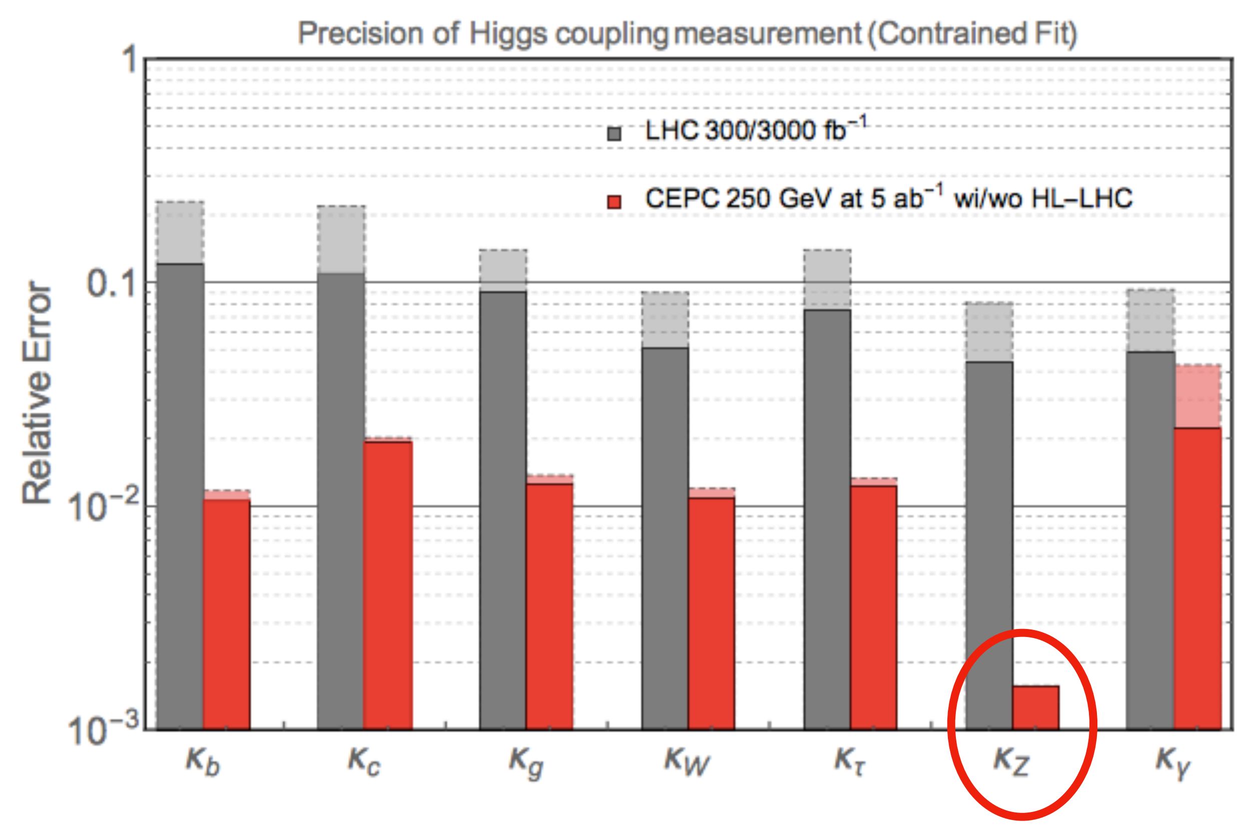
$\delta\sigma_{HZ}$ < 0.5% with millions of Higgs bosons

NLO-EW corr. err. ~ 6%

$\delta\kappa_Z$ ~ 3%

Go beyond NLO!





Mixed QCD-EW for $e^+e^- \to HZ$

PHYSICAL REVIEW D **95,** 093003 (2017)

Mixed QCD-electroweak corrections for Higgs boson production at e^+e^- colliders

Yinqiang Gong,[1,*] Zhao Li,[2,†] Xiaofeng Xu,[1,‡] Li Lin Yang,[1,3,4,§] and Xiaoran Zhao[5,‖]

PHYSICAL REVIEW D **96,** 051301(R) (2017)

Mixed electroweak-QCD corrections to $e^+e^- \to HZ$ at Higgs factories

Qing-Feng Sun,[1,2] Feng Feng,[3,2] Yu Jia,[2,4,5] and Wen-Long Sang[6,*]

$\sqrt{s}$	Schemes	σ_{LO} (fb)	σ_{NLO} (fb)	σ_{NNLO} (fb)
240	$\alpha(0)$	223.14 ± 0.47	229.78 ± 0.77	$232.21^{+0.75+0.10}_{-0.75-0.21}$
	$\alpha(M_Z)$	252.03 ± 0.60	$228.36^{+0.82}_{-0.81}$	$231.28^{+0.80+0.12}_{-0.79-0.25}$
	G_μ	239.64 ± 0.06	$232.46^{+0.07}_{-0.07}$	$233.29^{+0.07+0.03}_{-0.06-0.07}$
250	$\alpha(0)$	223.12 ± 0.47	229.20 ± 0.77	$231.63^{+0.75+0.12}_{-0.75-0.21}$
	$\alpha(M_Z)$	252.01 ± 0.60	$227.67^{+0.82}_{-0.81}$	$230.58^{+0.80+0.14}_{-0.79-0.25}$
	G_μ	239.62 ± 0.06	231.82 ± 0.07	$232.65^{+0.07+0.04}_{-0.07-0.07}$

$\delta\sigma_{HZ}^{\text{mixed}} > 1\%$

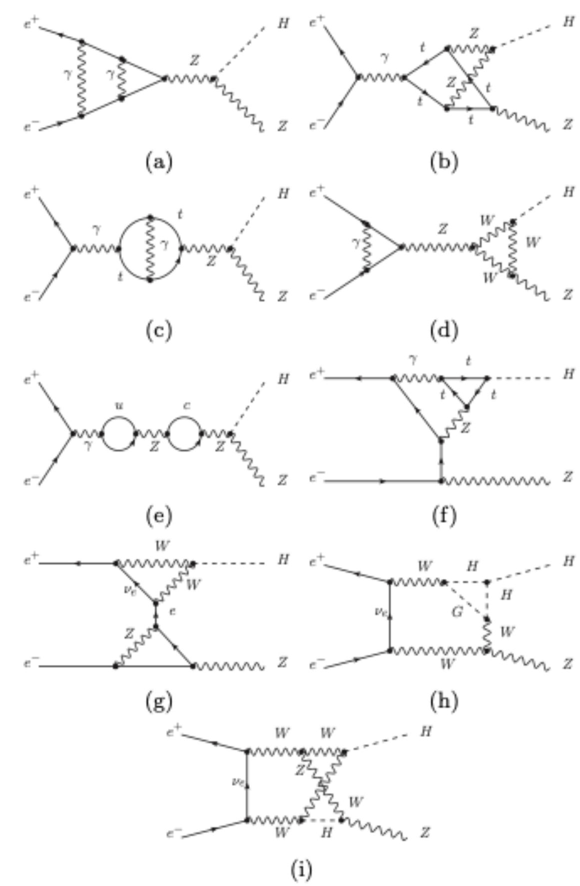
NNLO-EW for $e^+e^- \to HZ$

Complete two-loop electroweak corrections to $e^+e^- \to HZ$

Xiang Chen,[1,*] Xin Guan,[1,†] Chuan-Qi He,[1,‡] Zhao Li,[2,3,4,§] Xiao Liu,[5,¶] and Yan-Qing Ma[1,4,**]

arXiv:2209.14953v1 [hep-ph]

$$
\begin{aligned}
\mathcal{A}^{(2)} = \alpha^4 (75548.083\epsilon^{-4} \\
&-3.1962821 \times 10^6 \epsilon^{-3} \\
&+1.1548893 \times 10^7 \epsilon^{-2} \\
&+2.6990603 \times 10^8 \epsilon^{-1} \\
&+1.5608903 \times 10^9 + \mathcal{O}(\epsilon)),
\end{aligned}
$$



Complete analysis on theoretical uncertainty is upcoming.

Prospects

- Many works have shown the great potential for the new physics probing at CEPC via exotic Higgs/Z/top decay and production.

- Further investigations are still needed.

- Synergy between theorists and experimentalists is crucial.

- Lots of works are not shown here yet.