中国科学院高能物理研究所
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NP search at the CEPC :

a General Perspective

(White paper: arXiv:2505.24810)

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On behalf of CEPC NP team

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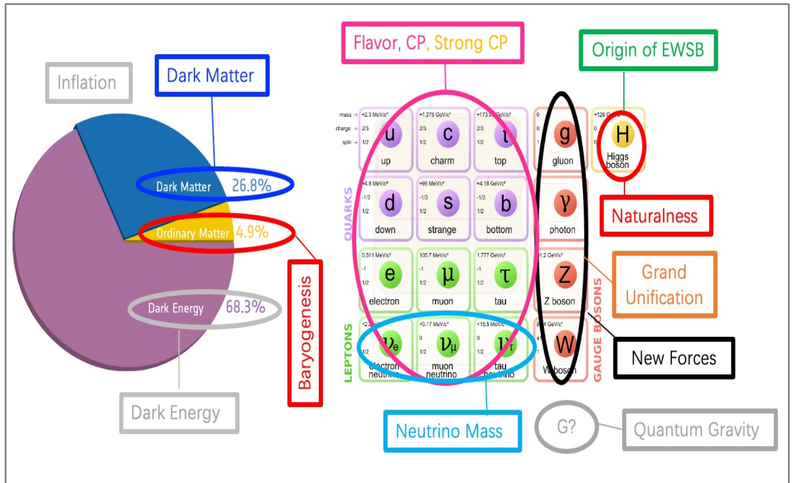
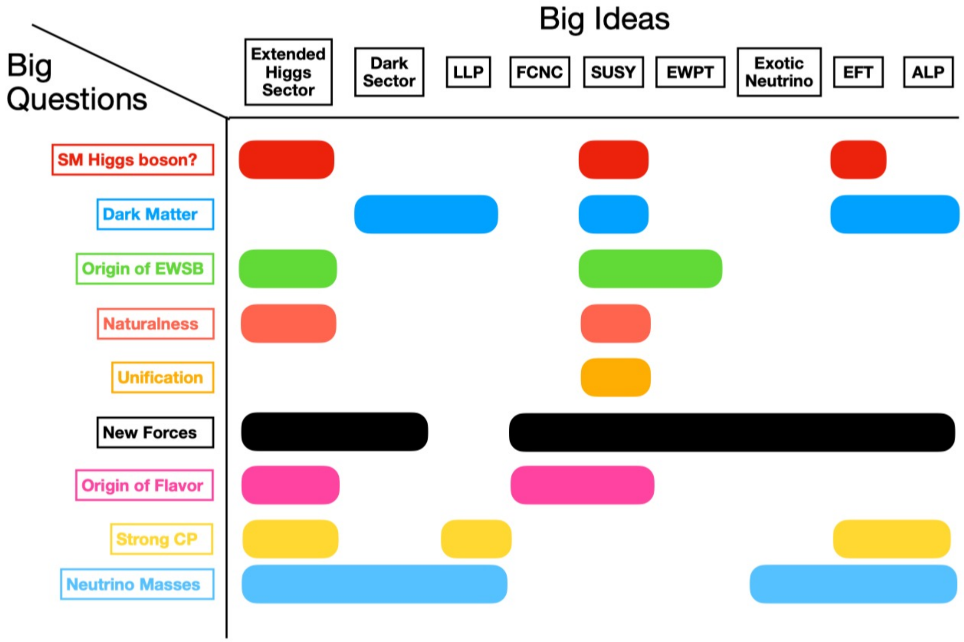
Big Questions and Ideas in particle physics



Picture modified from Jonathan Feng at 2017 ICFA Seminar, gray one not covered by cepc.



CEPC operation scheme

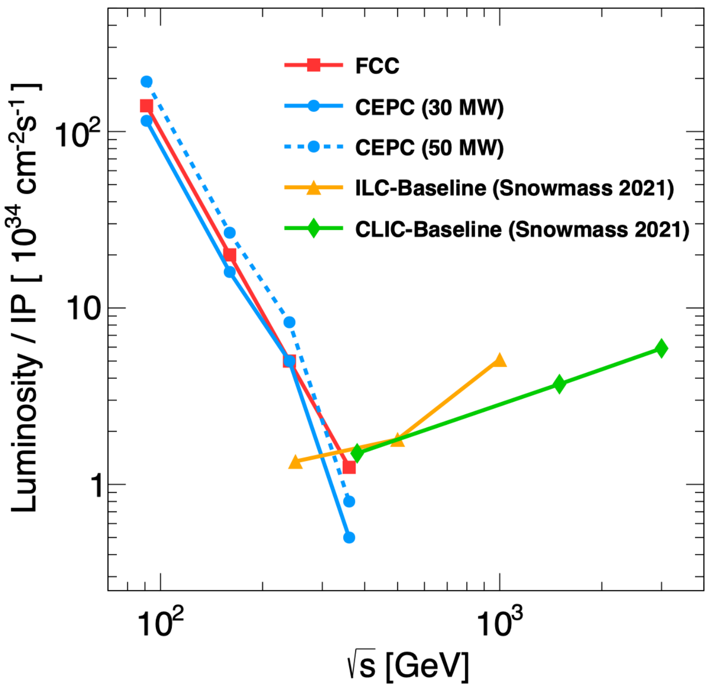


FIG. 2: The updated run plan of the CEPC, with the baseline and upgrade shown in solid and dashed blue curves, respectively. The run plans for several other proposals of the e^+e^- colliders are also shown for comparison. See [14] for details.

Operation mode	Z factory	WW threshold	Higgs factory	$t\bar{t}$
$\sqrt{s}$ (GeV)	91.2	160	240	360
Run time (year)	2	1	10	5
Instantaneous luminosity ($10^{34} cm^{-2} s^{-1}$, per IP)	191.7	26.6	8.3	0.83
Integrated luminosity (ab^{-1}, 2 IPs)	100	6	20	1
Event yields	4.1×10^{12}	2×10^8	4.3×10^6	0.6×10^6

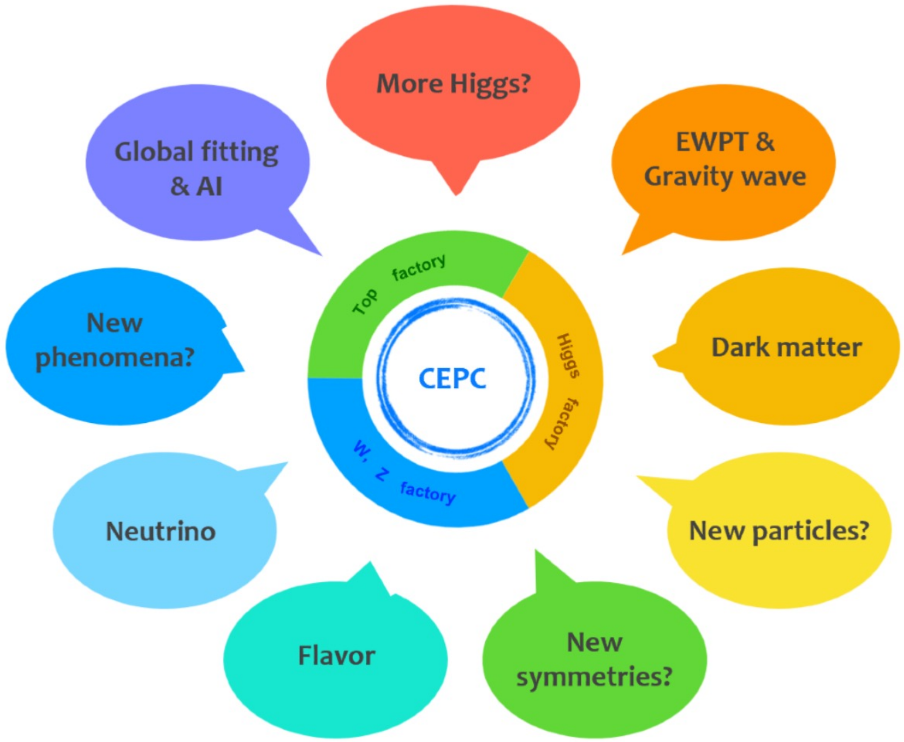
TABLE I: Nominal CEPC operation scheme, and the physics yield, of four different modes.

Executive Summary

As a Higgs (flavor, top) factory, CEPC will provide unprecedented opportunities for looking for new physics Beyond SM. CEPC could:

- **Identify the origin of matter, especially the mechanism related to the first-order EW phase transition (EWPT) in the early Universe, which could produce a detectable gravitational wave signal.**
- **Discover dark matter, particularly dark matter particles with a mass between one tenth and 100 times the proton mass.**
- **Observe an array of new physics smoking guns, with sensitivities orders of magnitude better than those of existing facilities.**

NP Program



- Intensity frontier of H/Z...:
  - Exotic Higgs/Z, EWPT,...
- Dark Matter and Dark Sector
- New particles/phenomena:
  - LLP, ALP, ...
- New symmetries:
  - SUSY
- Flavor frontier :
  - Flavor, Neutrino, ...
- Techniques:
  - Global fitting, AI,...

1. Exotic Higgs/Z/top decays

- ***Higgs*** **is connected to the origin of both visible and dark matter of the Universe, the origin of neutrino masses, the stability of the Universe, and the self-consistency of the particle physics theory at quantum level …**

  → A promising way towards NP.

- ***Higgs exotic decay*** **motivated by a large class of BSM physics, such as singlet extensions, two Higgs-doublet-models (2HDM), SUSY models, Higgs portals, gauge extensions of the SM …**

Exotic higgs

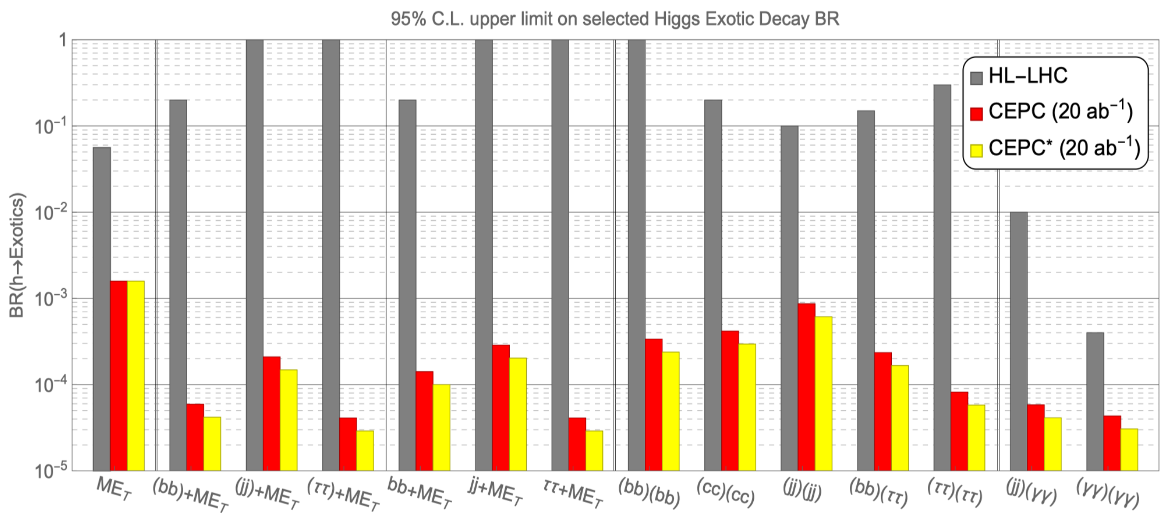


FIG. 9: The 95% C.L. upper limit on selected Higgs exotic decay branching fractions at HL-LHC and CEPC, based on Ref [45].

1. Exotic Higgs/Z/top decays

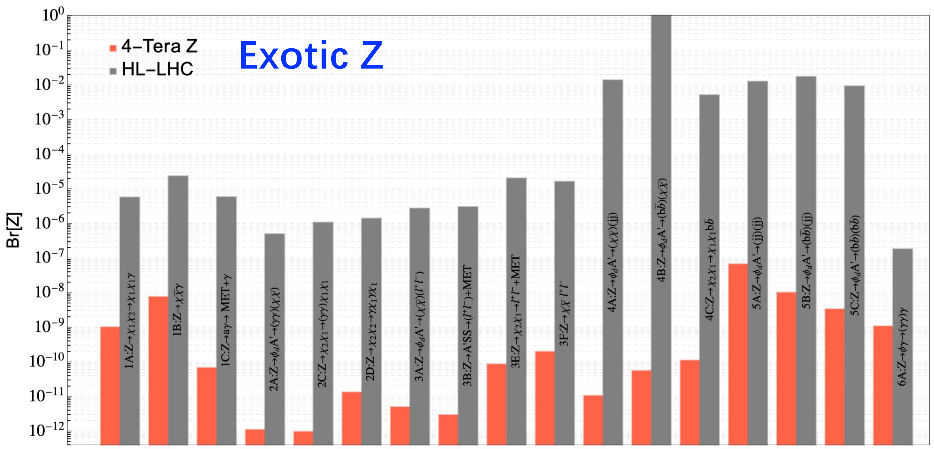
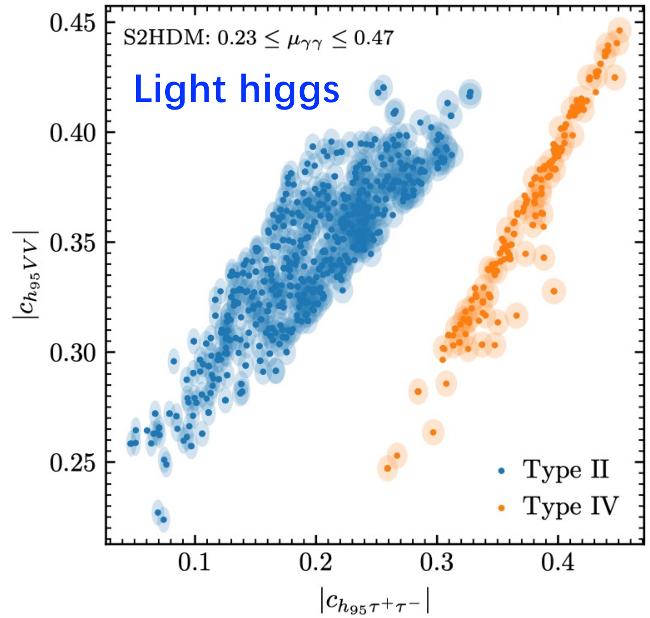


FIG. 12: The reach for the branching ratio of various exotic Z decay modes at the future Z-factories (rescaled to four Tera Z) and the HL-LHC at 13 TeV with $\mathcal{L} = 3\ \mathrm{ab}^{-1}$ [73]. The



- ***Exotic Z or top decays*** are also motivated by many BSM models (ED, **Heavy Vector Triplet , …**)
- ***Light Higgs*** **are motivated by 2HDM and Axion-like particle models.**

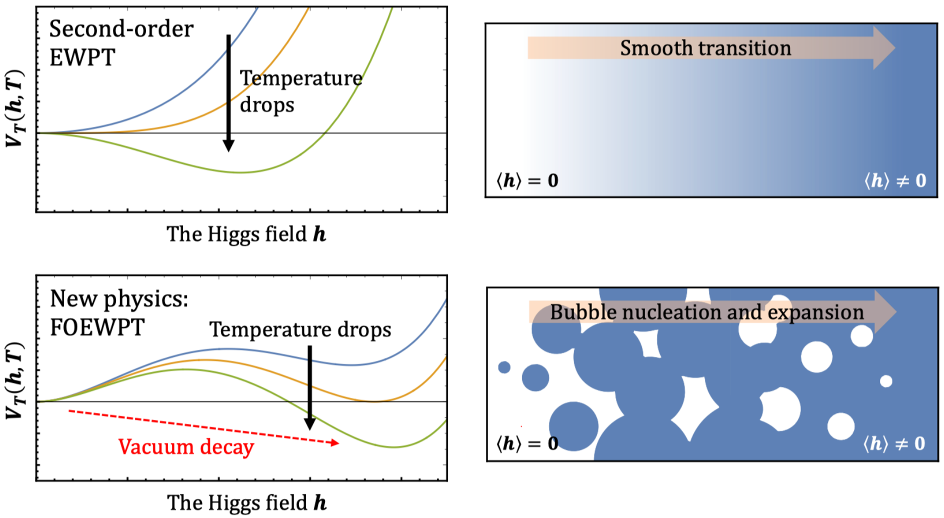
Light higgs can be searched at CEPC very well if exists.

➔ As a ***Higgs (flavor, top) factory***, CEPC could search for **exotic H/Z/top decays** with sensitivities **orders of magnitude better** than those of existing facilities.

2. EWPT at CEPC

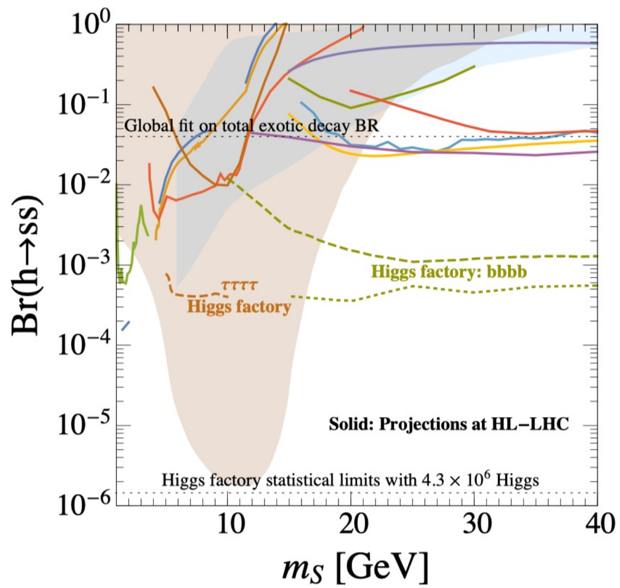
- **The nature of Electroweak Phase Transition (EWPT) deeply impacts the thermal history of the Universe, closely linked to puzzles of DM, matter-antimatter asymmetry**

In the **SM**, the transition is a **smooth crossover**



In **NP**, the scalar potential exhibits a barrier, allowing for a FOEWPT with **bubble nucleation and expansion**

- **Higgs precision measurements**
- **Higgs exotic decay**



Higgs exotic decay $h \to ss \to XXYY$ as a probe for the FOEWPT:

CEPC has the potential to probe almost the entire FOEWPT parameter space for 4b and 4tau channels

2. EWPT at CEPC

- **Higgs precision measurements**
- **Higgs exotic decay**

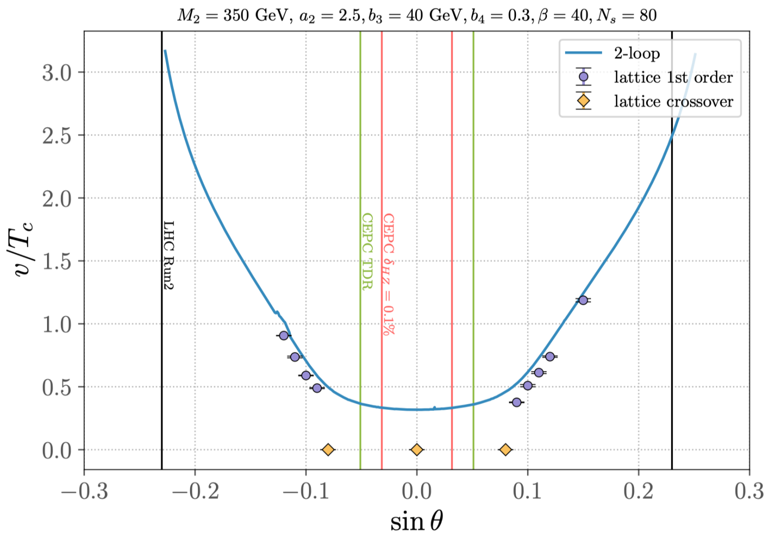


FIG. 17: Discontinuity in the Higgs vev (v) at the critical temperature (T_c) as function of the doublet-singlet mixing angle θ in the real scalar singlet extension of the SM (xSM).

CEPC will provide a powerful test of the xSM FOEWPT

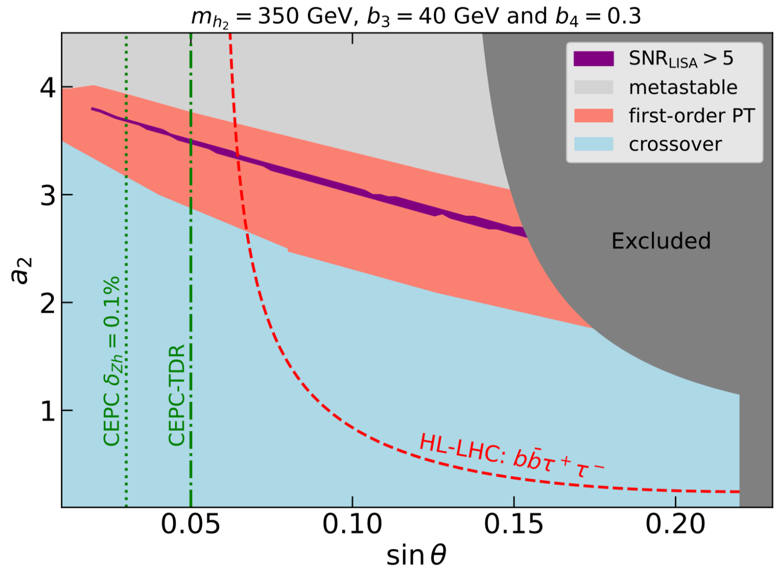


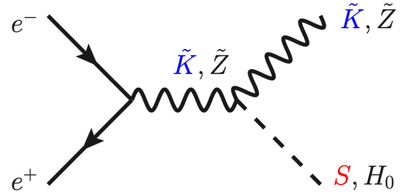
FIG. 18: Phase diagram for the real scalar singlet extension of the SM in the plane of the doublet-singlet mixing angle θ and double-singlet cross-quartic portal coupling a_2. Light

A FOEWPT could also generate detectable GW signals, CEPC measurements will coincide with next generation of GW detectors (LISA, Taiji, Tianqin)

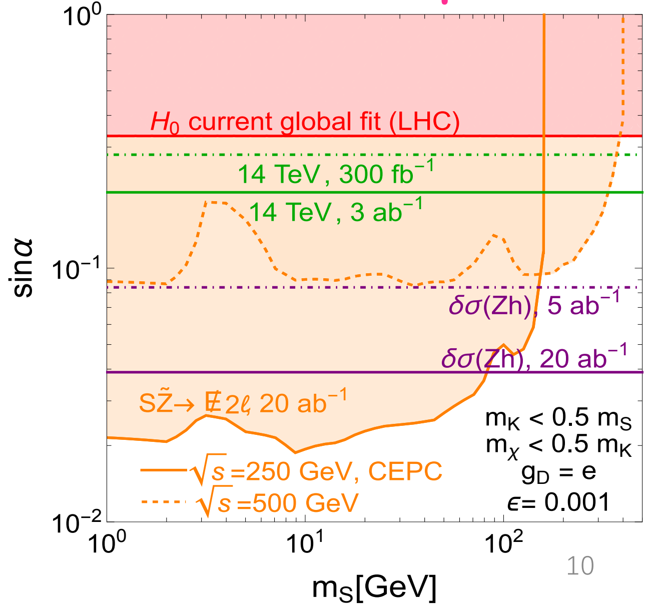
3. Dark Matter and Dark Sector

- **UV models DM:**
  - SUSY DM / Double dark portal model /……
- **Simplified models DM:**
  - Scalar / Fermion / Vector portal
- **EFT DM**

Dark Sector from Z/H associate production

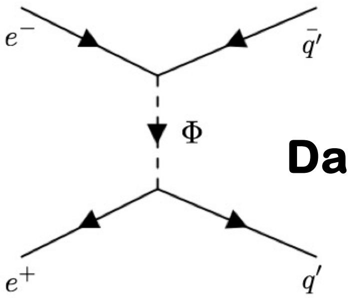


Double dark portal model: Scale and Vector-portal DM



Portal	Effective operator	$\sqrt{s}$ [GeV]	$\mathcal{L}[ab^{-1}]$	Sensitivity of CEPC (HL-LHC)	Figs.	Ref.
Scalar	$\lambda_{HP}\|H\|^2 S^2 \to$ scalar mixing $\sin\theta$	250	5	invisible S, $\sin\theta \approx 0.03$ (0.20 global-fits)	24	[220]
Fermion	$y_\ell \bar{\chi}_L S^\dagger \ell_R$ + H.c.	250	5	covering 100 GeV $< m_S <$ 170 GeV	25	[45]
	$\kappa\Phi\overline{q'_L}\ell_R$ + H.c. (dark QCD)	250	5	$m_\Phi \sim 10$ TeV for $c\tau_{\text{darkpion}} \in [1, 10^3]$ cm (Null)	27	[221]
	$y\Phi\bar{F}_L\ell_R$ + H.c.	240	5.6	$y\theta_L \in [10^{-11},\ 10^{-7}]$ ($\lesssim 10^{-8} - 10^{-9}$)	-	[222]
Vector	$A'_\mu\,(e\epsilon J^\mu_{\text{em}} + g_D\bar{\chi}\gamma^\mu\chi)$	250	5	$\epsilon \sim 10^{-3}$ for $g_D = e$ and $m_{A'} <$ 125 GeV ($\epsilon \sim 0.02$)	28, 29	[220]
	$\varepsilon A_\mu\bar{\chi}\gamma^\mu\chi$, (millicharge DM)	250	5	$\epsilon \sim 0.1$ for $m_\chi \sim 50$ GeV	-	[223]
		91.2	2.6	$\epsilon \sim 0.02$ for $m_\chi \sim 5$ GeV		
		160	16	$\epsilon \sim 0.5$ for $m_\chi \sim 10$ GeV		
	$\frac{1}{2}\mu_\chi\bar{\chi}\sigma^{\mu\nu}\chi F_{\mu\nu} + \frac{i}{2}d_\chi\bar{\chi}\sigma^{\mu\nu}\gamma^5\chi F_{\mu\nu}$	91.2	100	$\mu_\chi, d_\chi \sim 4\times10^{-7}$ $(4\times10^{-6})\mu_B$ for $m_\chi <$ 25 GeV	30	[224]
	$-a_\chi\bar{\chi}\gamma^\mu\gamma^5\chi\partial^\nu F_{\mu\nu} + b_\chi\bar{\chi}\gamma^\mu\chi\partial^\nu F_{\mu\nu}$	240	20	$a_\chi, b_\chi \sim 10^{-6}$ (2×10^{-6}) GeV^{-2} for $m_\chi <$ 80 GeV		
EFT	$\frac{1}{\Lambda^2}\sum_i (\bar{\chi}\gamma_\mu(1-\gamma_5)\chi)\,(\bar{\ell}\gamma^\mu(1-\gamma_5)\ell)$	250	5	$\Lambda_i \sim 2$ TeV ($m_\chi = 0$) (Null)	31	[225]
	$\frac{1}{\Lambda_A^2}\bar{\chi}\gamma_\mu\gamma_5\chi\bar{\ell}\gamma^\mu\gamma_5\ell$	250	5	$\Lambda_A \sim 1.5$ TeV (Null)	32	[223]
	$\sum_i \frac{1}{\Lambda_i^2}\,(\bar{e}\Gamma_\mu e)\,(\bar{\nu}_L\Gamma^\mu\chi_L)$ + H.c. $\Gamma_\mu = 1, \gamma_5, \gamma_\mu, \gamma_\mu\gamma_5, \sigma_{\mu\nu}$	240	20	$\Lambda_i \sim 1$ TeV ($m_\chi = 0$) (Null)	33	[226]

3. Dark Matter and Dark Sector

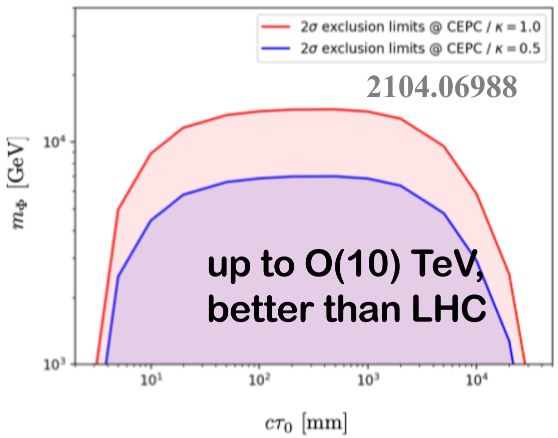


Decay to leptons

Dark quark q'

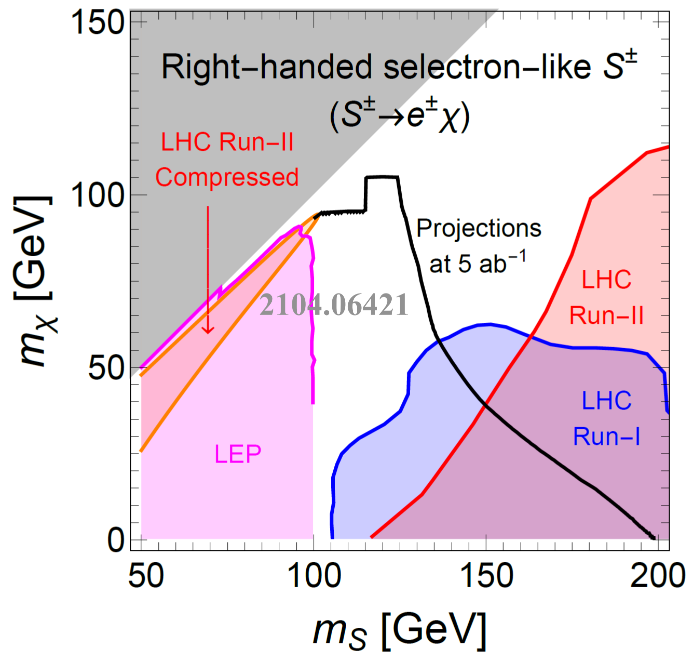
Jet-like

Signature:
Lepton + jet + MET



Lepton-portal DM

$$e^+e^- \to S^{\pm(*)}S^{\mp} \to \ell^+\chi\ell'^-\chi$$



$$m_S \sim 100 - 170\ GeV$$

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Fermion	$y_\ell\bar{\chi}_L S^\dagger \ell_R$ + H.c.	250	5	covering 100 GeV $< m_S <$ 170 GeV	25	[45]
	$\kappa\Phi\overline{q'_L}\ell_R$ + H.c. (dark QCD)	250	5	$m_\Phi \sim 10$ TeV for $c\tau_{\text{darkpion}} \in [1, 10^3]$ cm (Null)	27	[221]
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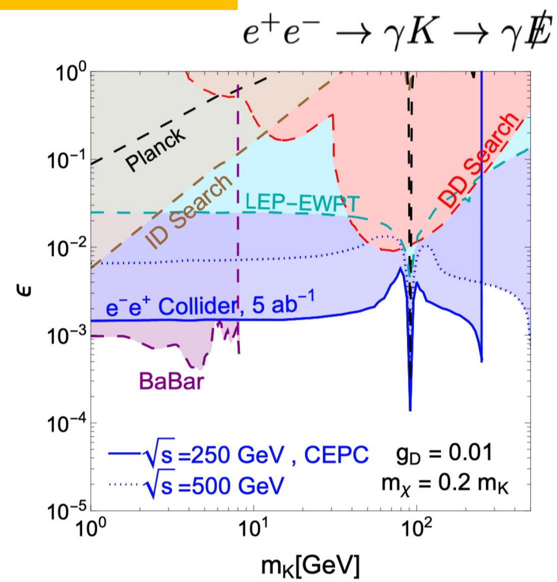
3. Dark Matter and Dark Sector

Vector-portal DM

→ CEPC can probe low-mass light dark states.



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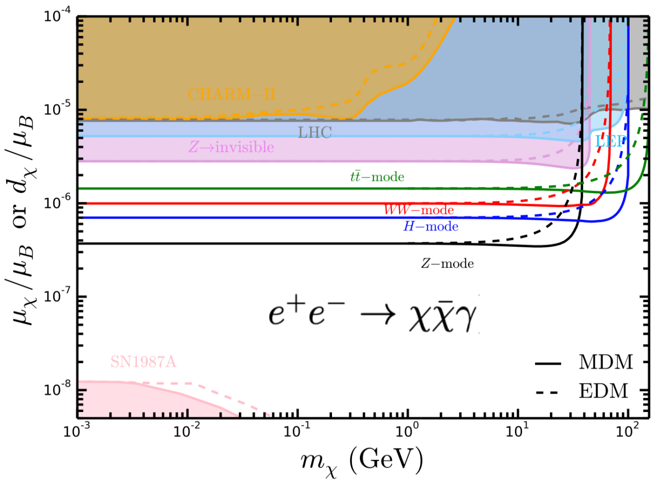


3. Dark Matter and Dark Sector

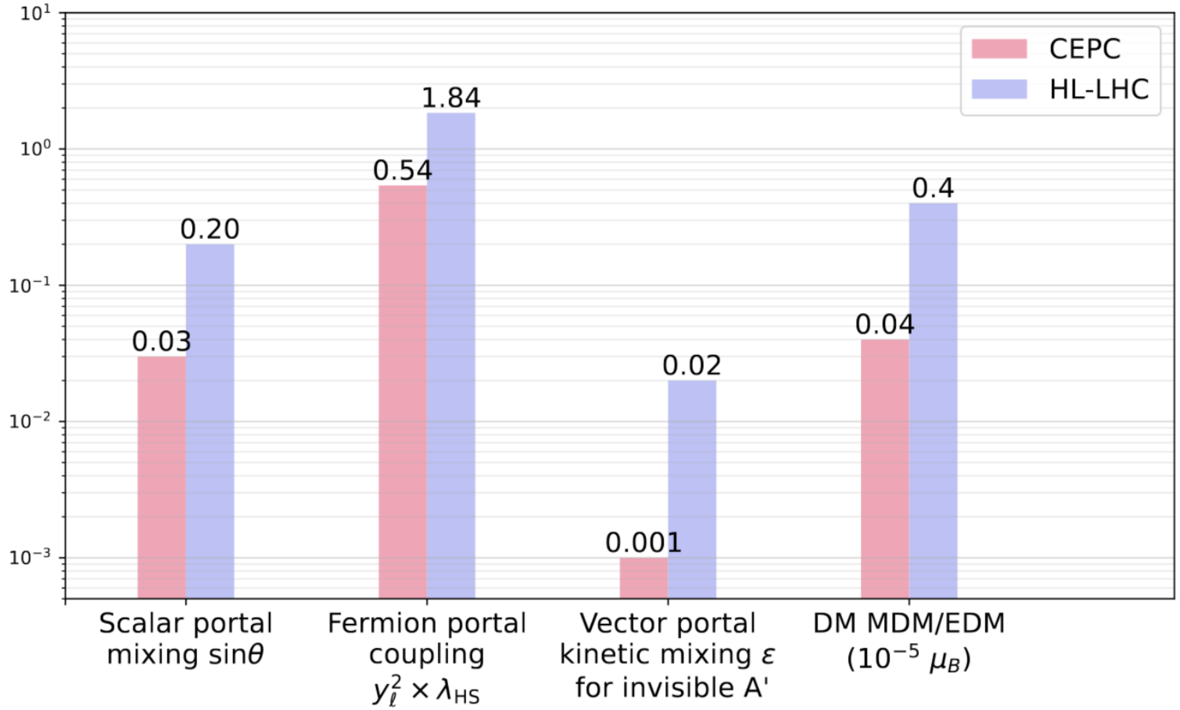


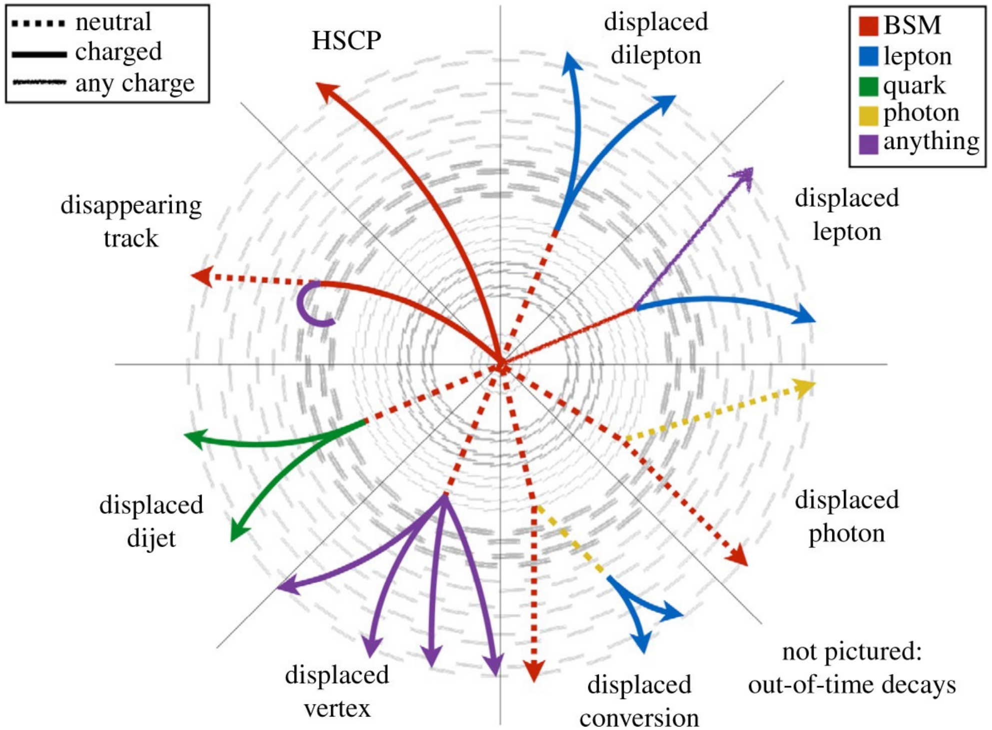
FIG. 35: The sensitivities for scalar, fermion, and vector portals, as well as dark matter magnetic dipole moment and electric dipole moment operators for CEPC and HL-LHC.

CEPC can improve the sensitivities by roughly one order of magnitude (vs LHC)

4. Long-lived particles (LLP)

Long lifetimes result from a few simple physical mechanisms:

- **Small couplings (ex. RPV SUSY)**
- **Limited phase space: small mass splitting (ex. compressed SUSY, …)**
- **Heavy intermediate states**
- ……

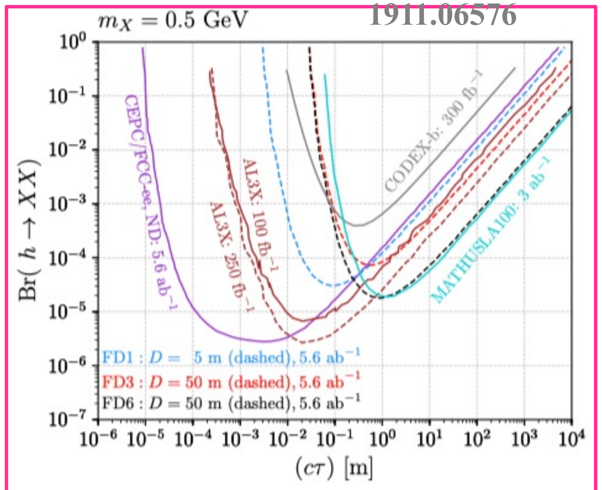


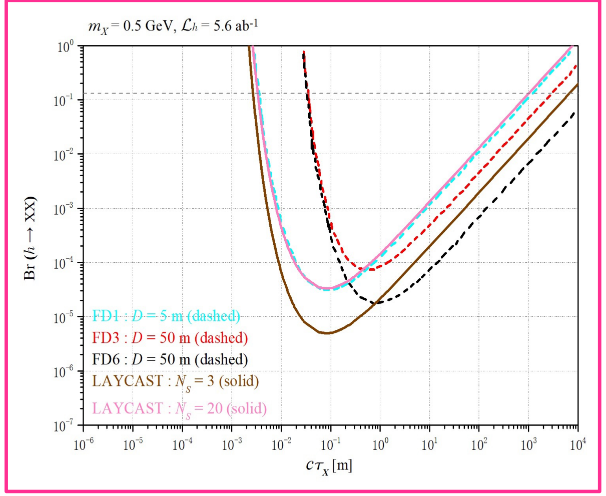
- **New scale particles from higgs decay**
- **SUSY RPV N1 from Z-boson decays**
- **ALP**
- **Dark photons**
- …

→ Far Detector can help a lot!

4. Long-lived particles (LLP)

LLP Type	Signal Signature	$\sqrt{s}$ [GeV]	$\mathcal{L}$ [ab^{-1}]	Detector	Sensitivities on parameters [Assumptions]	Figs.	Refs.
New scalar particles (X)	$Z(\to \text{incl.})\, h(\to XX)$, $X \to q\bar{q}/\nu\bar{\nu}$	240	20	MD	$\text{Br}(h \to XX) \sim 10^{-6}$ [$m \in (1, 50)$ GeV, $\tau \in (10^{-3}, 10^{-1})$ ns]	38	[82]
	$Z(\to \text{incl.})\, h(\to XX)$, $X \to \text{incl.}$	240	5.6	MD	$\text{Br}(h \to XX) \sim 3 \times 10^{-6}$ [$m = 0.5$ GeV, $c\tau \sim 5 \times 10^{-3}$ m]	50	[88]
				FD3	$\text{Br}(h \to XX) \sim 7 \times 10^{-5}$ [$m = 0.5$ GeV, $c\tau \sim 1$ m]	50	[88]
				LAYCAST	$\text{Br}(h \to XX) \sim 5 \times 10^{-6}$ [$m = 0.5$ GeV, $c\tau \sim 10^{-1}$ m]	50	[258]
RPV-SUSY neutralinos ($\tilde{\chi}_1^0$)	$Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to \text{incl.}$	91.2	150	MD	$\lambda'_{112}/m_{\tilde{f}}^2 \in (2 \times 10^{-14}, 10^{-8})$ GeV^{-2} [$m \sim 40$ GeV, $\text{Br}(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) = 10^{-3}$]	44	[88]
				FD3	$\lambda'_{112}/m_{\tilde{f}}^2 \in (10^{-14},\ 10^{-9})$ GeV^{-2} [$m \sim 40$ GeV, $\text{Br}(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) = 10^{-3}$]	51	[88]
				LAYCAST	$\lambda'_{112}/m_{\tilde{f}}^2 \in (7 \times 10^{-15},\ 10^{-9})$ GeV^{-2} [$m \sim 40$ GeV, $\text{Br}(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) = 10^{-3}$]	51	[258]
ALPs (a)	$Z^{(*)} \to \mu^- \mu^+ a$	91	150	MD	$f_a/C^A_{\mu\mu} \lesssim 950$ GeV	45	[87]
	$e^+e^- \to \gamma\, a$, $a \to \gamma\gamma$	91.2	150	MD	$C_{\gamma\gamma}/\Lambda \sim 10^{-3}$ TeV^{-1} [$C_{\gamma Z} = 0$, $m \sim 2$ GeV]	52	[258]
				FD3	$C_{\gamma\gamma}/\Lambda \sim 6 \times 10^{-3}$ TeV^{-1} [$C_{\gamma Z} = 0$, $m \sim 0.3$ GeV]	52	[259]
				LAYCAST	$C_{\gamma\gamma}/\Lambda \sim 2 \times 10^{-3}$ TeV^{-1} [$C_{\gamma Z} = 0$, $m \sim 0.7$ GeV]	52	[258]
Hidden valley particles (π_V^0)	$Z\, h(\to \pi_V^0 \pi_V^0)$, $\pi_V^0 \to b\bar{b}$	350	1.0	MD	$\sigma(h) \times \text{BR}(h \to \pi_v^0 \pi_v^0) \sim 10^{-4}$ pb [$m \in (25, 50)$ GeV, $\tau \sim 10^2$ ps]	42	[260]
Dark photons (γ_D)	$Z(\to q\bar{q})\, h(\to \gamma_D \gamma_D)$, $\gamma_D \to \ell^- \ell^+/q\bar{q}$	250	2.0	MD	$\text{Br}(h \to \gamma_D \gamma_D) \sim 10^{-5}$, [$m \in (5, 10)$ GeV, $\tau \sim 10^2$ ps, $\epsilon \in (10^{-6}, 10^{-7})$]	43	[85]





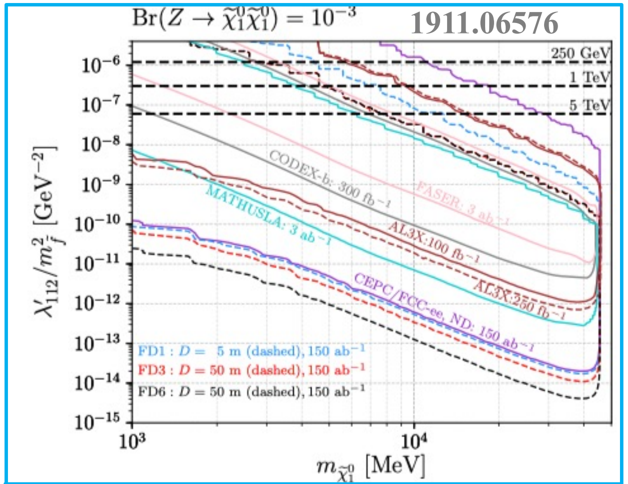
Light Scalars from Exotic Higgs Decays

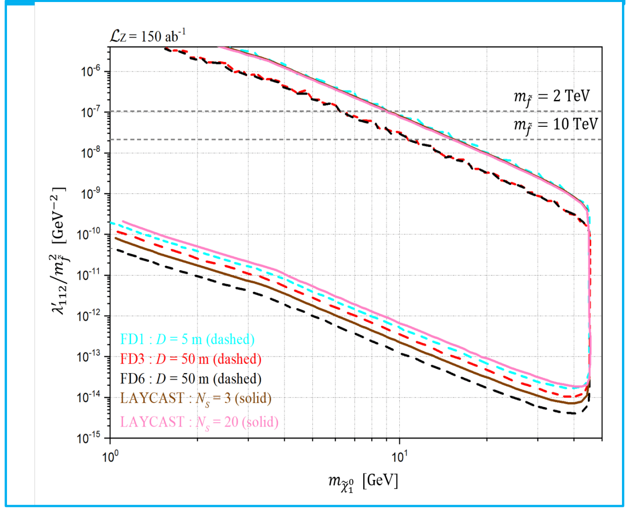
FD can extend and complement the sensitivity to the LLPs compared with Main Detector

arXiv:1911.06576
arXiv:2406.05770

4. Long-lived particles (LLP)

LLP Type	Signal Signature	$\sqrt{s}$ [GeV]	$\mathcal{L}$ [ab^{-1}]	Detector	Sensitivities on parameters [Assumptions]	Figs.	Refs.
New scalar particles (X)	$Z(\to \text{incl.})\, h(\to XX)$, $X \to q\bar{q}/\nu\bar{\nu}$	240	20	MD	$\text{Br}(h \to XX) \sim 10^{-6}$ [$m \in (1, 50)$ GeV, $\tau \in (10^{-3}, 10^{-1})$ ns]	38	[82]
	$Z(\to \text{incl.})\, h(\to XX)$, $X \to \text{incl.}$	240	5.6	MD	$\text{Br}(h \to XX) \sim 3 \times 10^{-6}$ [$m = 0.5$ GeV, $c\tau \sim 5 \times 10^{-3}$ m]	50	[88]
				FD3	$\text{Br}(h \to XX) \sim 7 \times 10^{-5}$ [$m = 0.5$ GeV, $c\tau \sim 1$ m]	50	[88]
				LAYCAST	$\text{Br}(h \to XX) \sim 5 \times 10^{-6}$ [$m = 0.5$ GeV, $c\tau \sim 10^{-1}$ m]	50	[258]
RPV-SUSY neutralinos ($\tilde{\chi}_1^0$)	$Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to \text{incl.}$	91.2	150	MD	$\lambda'_{112}/m_{\tilde{f}}^2 \in (2 \times 10^{-14}, 10^{-8})$ GeV^{-2} [$m \sim 40$ GeV, $\text{Br}(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) = 10^{-3}$]	44	[88]
				FD3	$\lambda'_{112}/m_{\tilde{f}}^2 \in (10^{-14},\ 10^{-9})$ GeV^{-2} [$m \sim 40$ GeV, $\text{Br}(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) = 10^{-3}$]	51	[88]
				LAYCAST	$\lambda'_{112}/m_{\tilde{f}}^2 \in (7 \times 10^{-15},\ 10^{-9})$ GeV^{-2} [$m \sim 40$ GeV, $\text{Br}(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) = 10^{-3}$]	51	[258]
ALPs (a)	$Z^{(*)} \to \mu^- \mu^+ a$	91	150	MD	$f_a/C^A_{\mu\mu} \lesssim 950$ GeV	45	[87]
	$e^+e^- \to \gamma\, a$, $a \to \gamma\gamma$	91.2	150	MD	$C_{\gamma\gamma}/\Lambda \sim 10^{-3}$ TeV^{-1} [$C_{\gamma Z} = 0$, $m \sim 2$ GeV]	52	[258]
				FD3	$C_{\gamma\gamma}/\Lambda \sim 6 \times 10^{-3}$ TeV^{-1} [$C_{\gamma Z} = 0$, $m \sim 0.3$ GeV]	52	[259]
				LAYCAST	$C_{\gamma\gamma}/\Lambda \sim 2 \times 10^{-3}$ TeV^{-1} [$C_{\gamma Z} = 0$, $m \sim 0.7$ GeV]	52	[258]
Hidden valley particles (π_V^0)	$Z\, h(\to \pi_V^0 \pi_V^0)$, $\pi_V^0 \to b\bar{b}$	350	1.0	MD	$\sigma(h) \times \text{BR}(h \to \pi_v^0 \pi_v^0) \sim 10^{-4}$ pb [$m \in (25, 50)$ GeV, $\tau \sim 10^2$ ps]	42	[260]
Dark photons (γ_D)	$Z(\to q\bar{q})\, h(\to \gamma_D \gamma_D)$, $\gamma_D \to \ell^- \ell^+/q\bar{q}$	250	2.0	MD	$\text{Br}(h \to \gamma_D \gamma_D) \sim 10^{-5}$, [$m \in (5, 10)$ GeV, $\tau \sim 10^2$ ps, $\epsilon \in (10^{-6}, 10^{-7})$]	43	[85]





FD can extend and complement the sensitivity to the LLPs compared with Main Detector

SUSY RPV Neutralino1 from Z Decays

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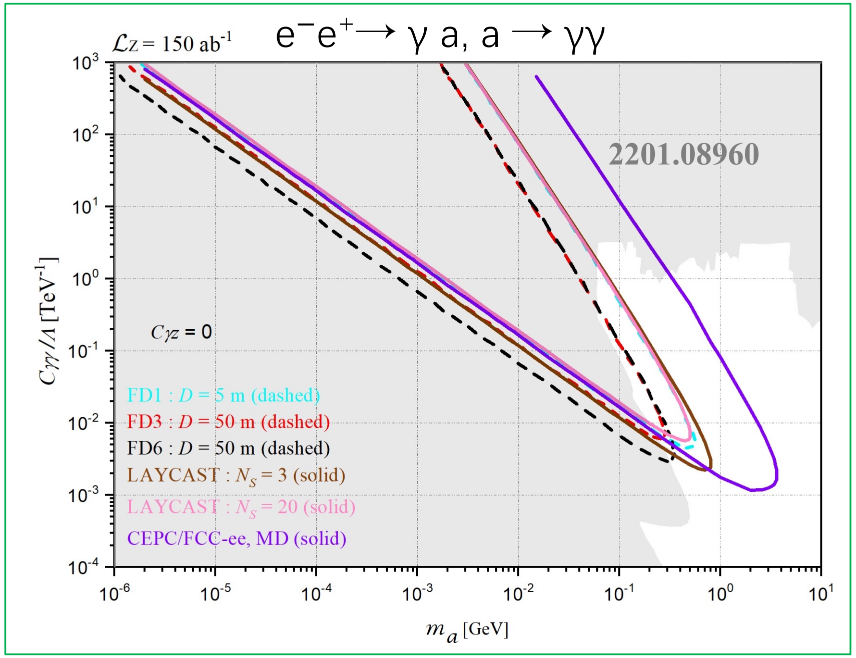
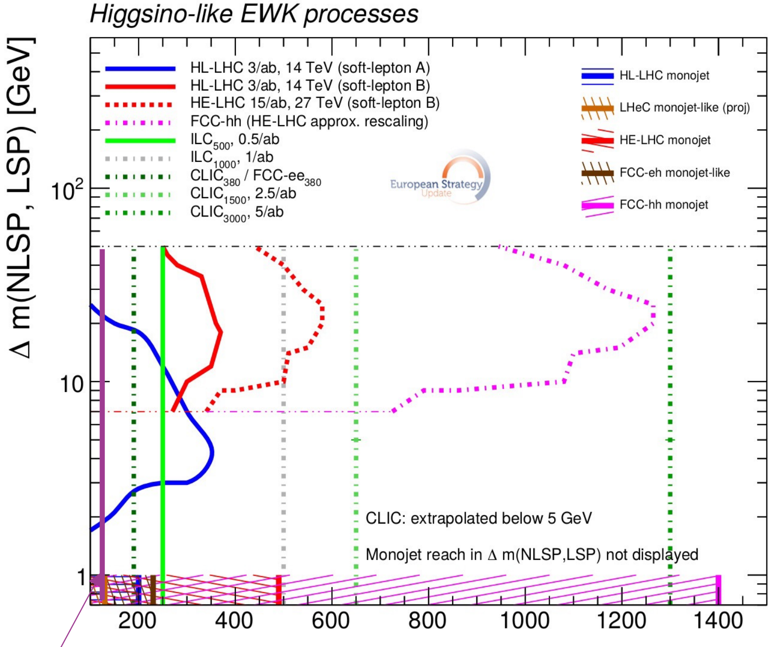
Good sensitivity for ALP

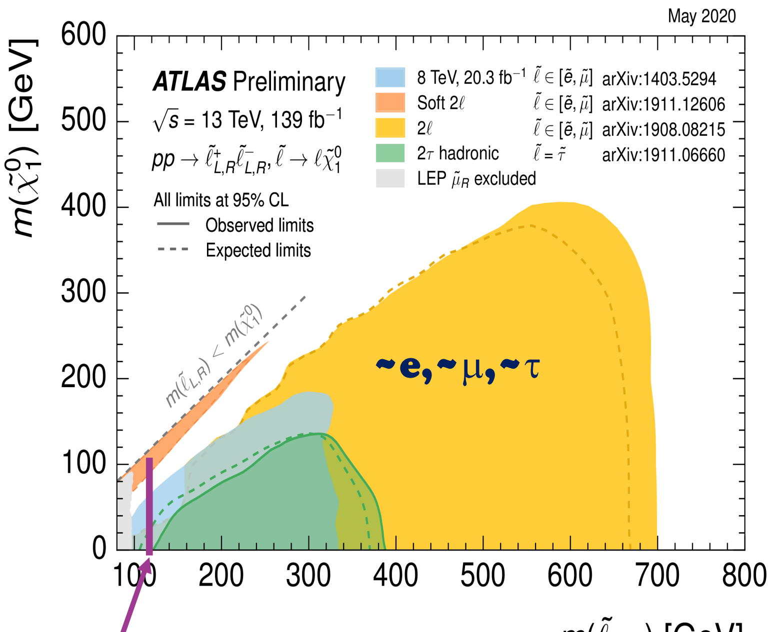


Axion-like Particles

5. SUSY Searches at CEPC

- **SUSY: establishes a symmetry between fermions and bosons, solve many big questions: unification, DM, Hierarchy, ……**
- **Complementary with LHC: lower mass/soft energy region**
  - ✓ **Mainly light EWKino and slepton for CEPC**

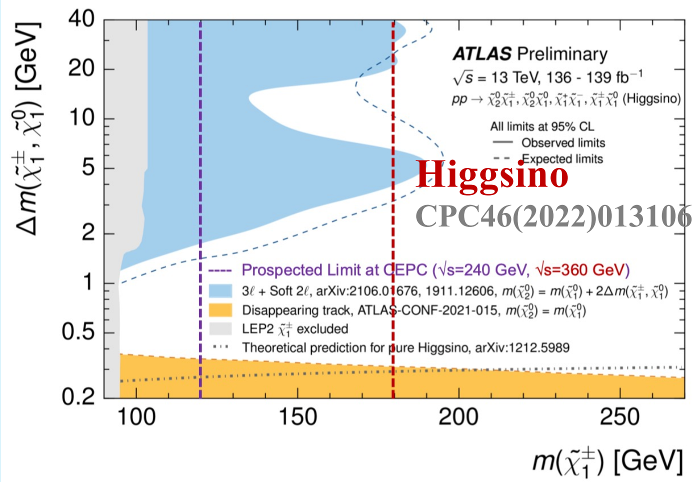




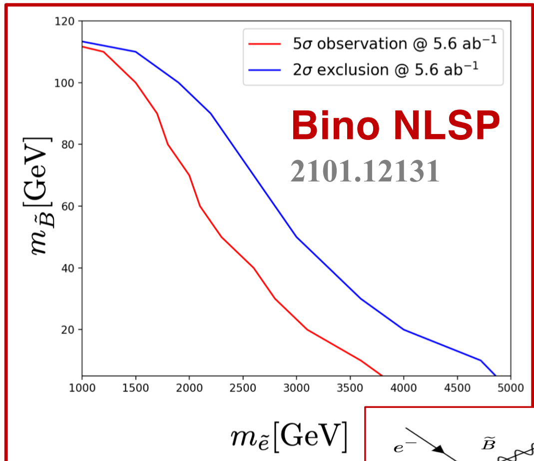
Lepton collider: discovery in all scenarios up to kinematic limit: √s/2

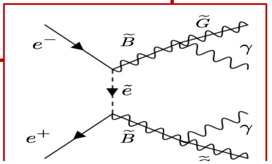
5. SUSY Searches at CEPC

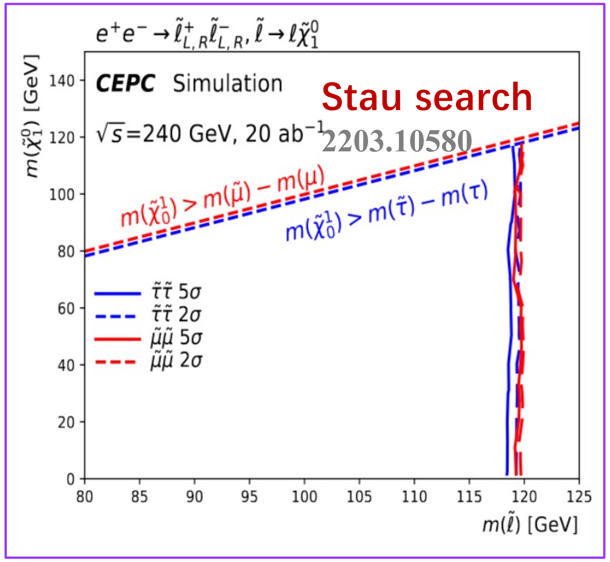
Search	Production	$\sqrt{s}$ [GeV]	$\mathcal{L}[ab^{-1}]$	Sensitivity	Figs.	Ref.
Light electroweakino	chargino pair	240	5.05	chargino excluded up to 120 GeV	59	[465]
	$e^+e^- \to BB \to \gamma\gamma GG.$	240	5.6	selectron excluded up to 4.5 TeV	60	[467]
Light slepton	smuon pair	240	20	smuon excluded up 119 GeV	61	[468]
	stau pair	240	20	stau excluded up 119 GeV	61	[468]
	smuon pair	360	1	smuon excluded up 177 GeV	61	[469]
	stau pair	360	1	stau excluded up 176 GeV	61	[469]
	$e_R^+e_R^- \to \tilde{\chi}_1^0(\text{bino}) + \tilde{\chi}_1^0(\text{bino}) + \gamma$	240	3	right-handed selectron excluded up to 210 GeV	62	[470]
	off-shell smuon pair	240	5	smuon excluded up 126 GeV	63	[471]
	$\mathcal{F}$-$SU(5)$	-	-	upper limits on $\tilde{\tau}_1$ up to 115 GeV	64	[472]
	$\mathcal{F}$-$SU(5)$	-	-	upper limits on $\tilde{e}_R$ up to 150 GeV	64	[472]

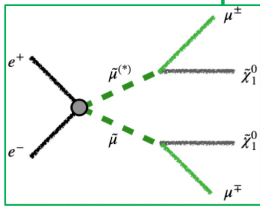


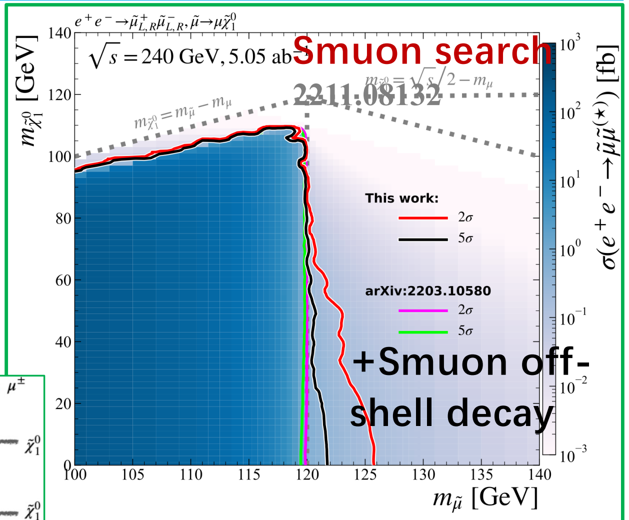
$$\tilde{B} \to \tilde{G}/\tilde{a} + \gamma$$



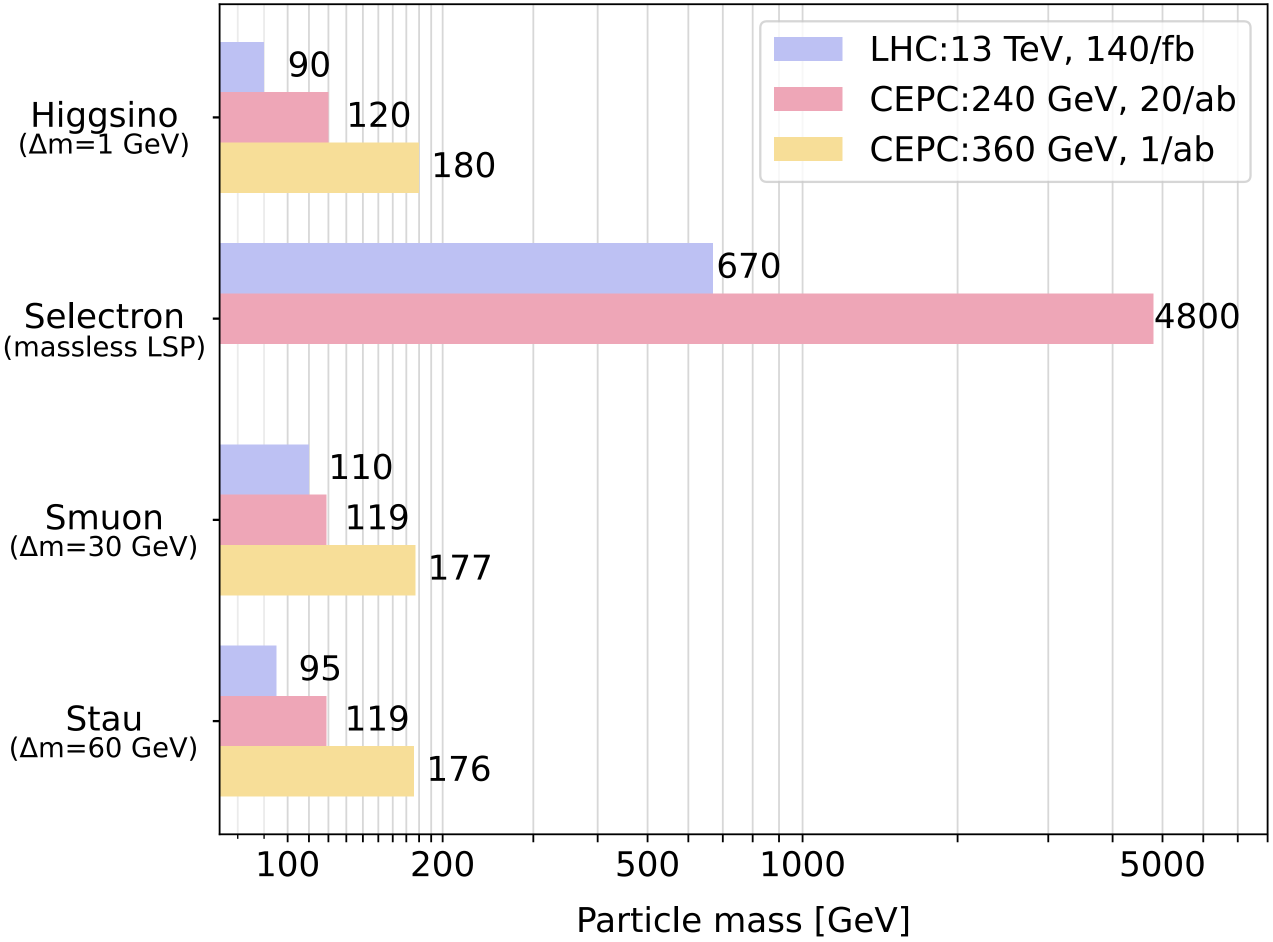




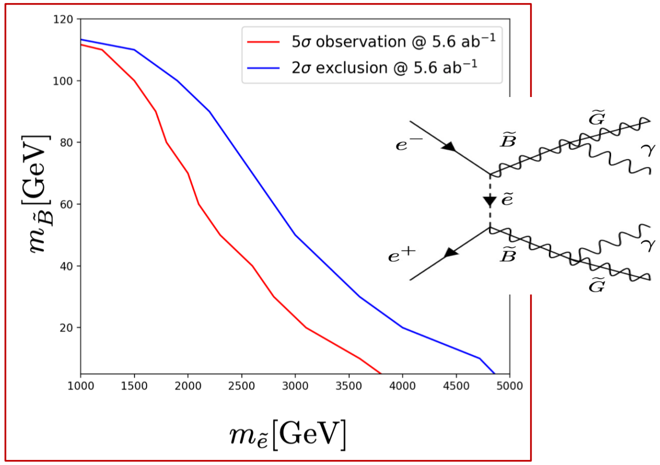




5. SUSY Searches at CEPC



- **Light EWKinos/sleptons: discovery in all scenarios up to kinematic limit √s/2**
- **Heavy selectron from t-channel**



6. Flavor NP

- CEPC is also a flavor factory (b,c,tau) when running at Z pole, which has a unique sensitivity for some **rare/SM–forbidden decays of leptons and heavy quarks**

- New Physics scenarios:
  - cLFV processes
  - Decays of b and c hadrons
  - Light BSM degrees of freedom from flavor transitions (cLFV or quark FCNC processes) with inv. BSM states or LLP

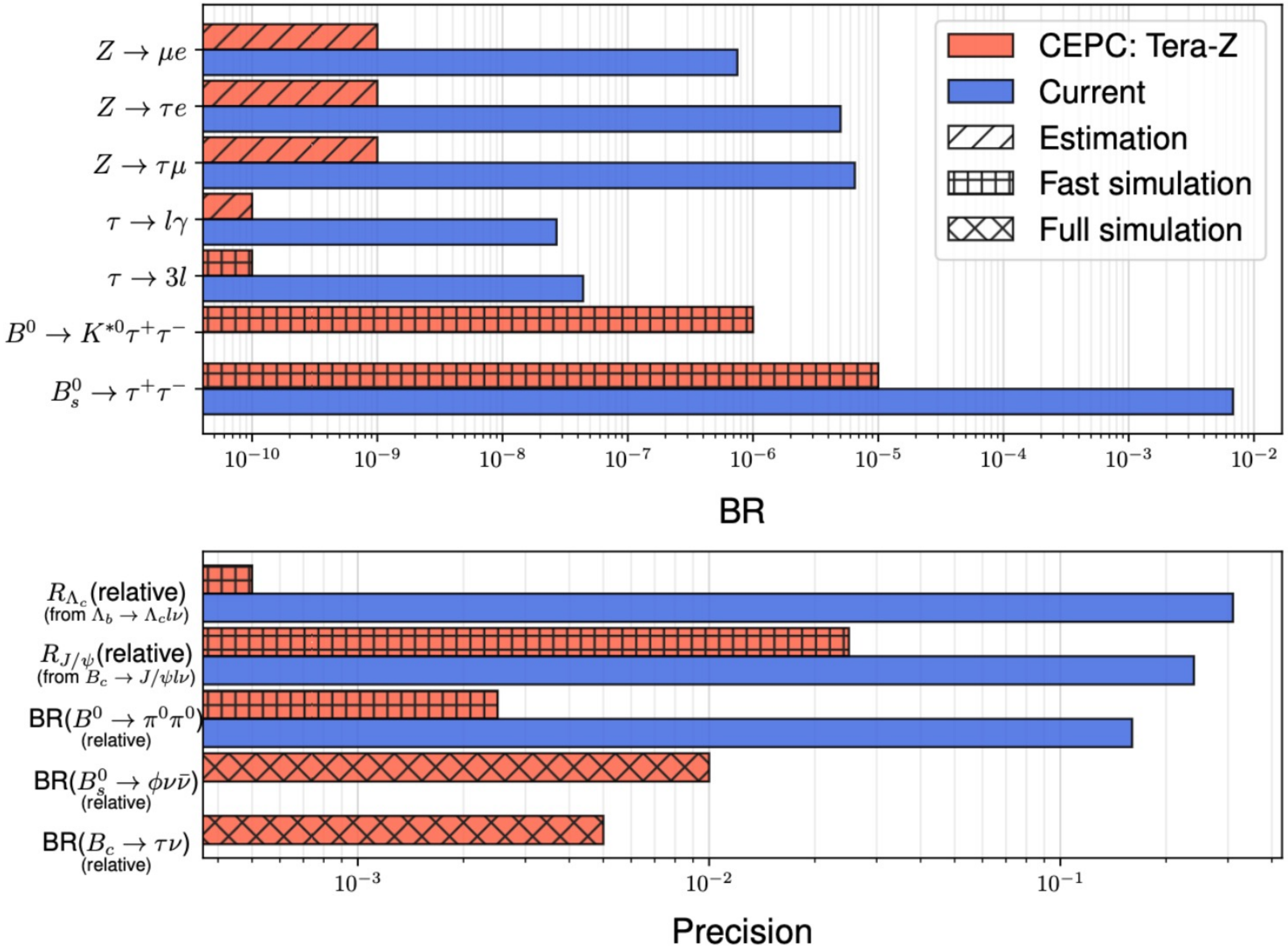
Measurement	Current Limit	CEPC [373]
$\mathrm{BR}(Z \to \tau\mu)$	$< 6.5 \times 10^{-6}$	$\mathcal{O}(10^{-9})$
$\mathrm{BR}(Z \to \tau e)$	$< 5.0 \times 10^{-6}$	$\mathcal{O}(10^{-9})$
$\mathrm{BR}(Z \to \mu e)$	$< 7.5 \times 10^{-7}$	$10^{-8} - 10^{-10}$
$\mathrm{BR}(\tau \to \mu\mu\mu)$	$< 2.1 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to eee)$	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to e\mu\mu)$	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to \mu ee)$	$< 1.8 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to e\gamma)$	$< 3.3 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(B_s \to \phi\nu\bar{\nu})$	$< 5.4 \times 10^{-3}$	$\lesssim 1\%$ (relative)
$\mathrm{BR}(B^0 \to K^{*0}\tau^+\tau^-)$	-	$\lesssim \mathcal{O}(10^{-6})$
$\mathrm{BR}(B_s \to \phi\tau^+\tau^-)$	-	$\lesssim \mathcal{O}(10^{-6})$
$\mathrm{BR}(B^+ \to K^+\tau^+\tau^-)$	$< 2.25 \times 10^{-3}$	$\lesssim \mathcal{O}(10^{-6})$
$\mathrm{BR}(B_s \to \tau^+\tau^-)$	$< 6.8 \times 10^{-3}$	$\lesssim \mathcal{O}(10^{-5})$
$\mathrm{BR}(B^0 \to 2\pi^0)$	$\pm 16\%$ (relative)	$\pm 0.25\%$ (relative)
$C_{CP}(B^0 \to 2\pi^0)$	± 0.22 (relative)	± 0.01 (relative)
$\mathrm{BR}(B_c \to \tau\nu)$	$\lesssim 30\%$	$\pm$ 0.5% (relative)
$\mathrm{BR}(B_c \to J/\psi\tau\nu)/\mathrm{BR}(B_c \to J/\psi\mu\nu)$	$\pm 0.17 \pm 0.18$	$\pm 2.5\%$ (relative)
$\mathrm{BR}(B_s \to D_s^{(*)}\tau\nu)/\mathrm{BR}(B_s \to D_s^{(*)}\mu\nu)$	-	$\pm 0.2\%$ (relative)
$\mathrm{BR}(\Lambda_b \to \Lambda_c\tau\nu)/\mathrm{BR}(B_c \to \Lambda_c\mu\nu)$	± 0.076	$\pm 0.05\%$ (relative)
$\mathrm{BR}(\tau \to \mu X_{\mathrm{inv.}})$	7×10^{-4}	$(3\text{-}5)\times 10^{-6}$
$\mathrm{BR}(B \to \mu X_{\mathrm{LLP}}(\to \mu\mu))$	-	$\mathcal{O}(10^{-10})$ (optimal)

Preliminary sensitivities of BSM flavor physics probes at CEPC

> two orders of magnitude improv.

6. Flavor NP

See Manqi's talk

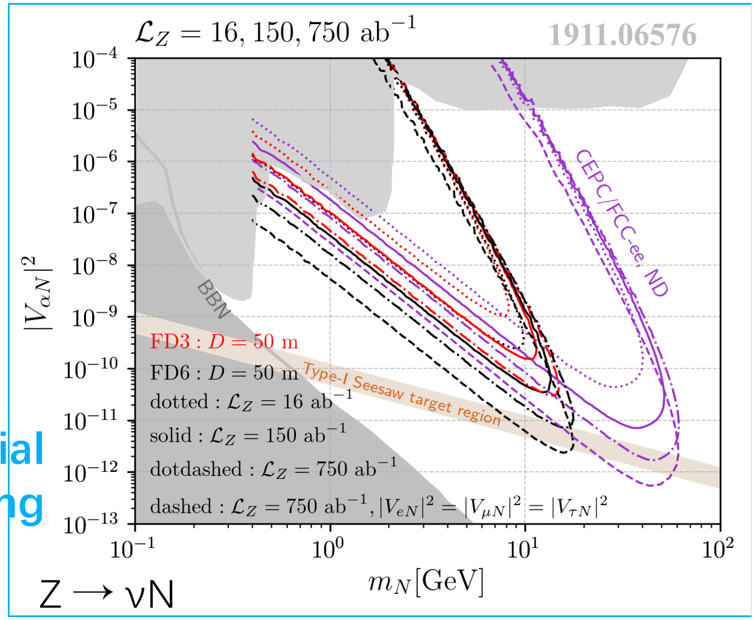


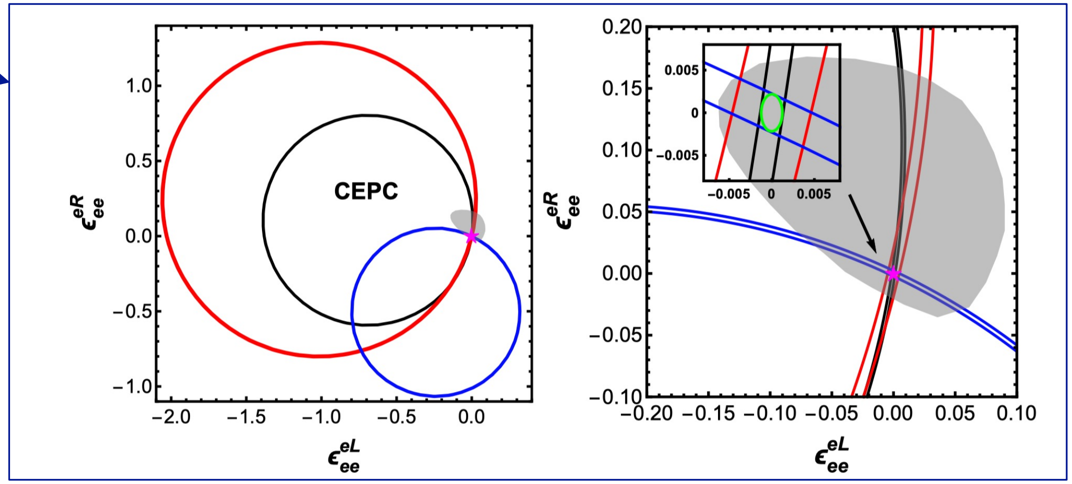
7. Neutrino physics

BSM related neutrino physics from neutrino mass mechanism, new messengers and interactions at EW scale:

- Heavy neutrino (@ND, FD)
- Non-standard neutrino interactions (NSI)
- Active-sterile neutrino transition magnetic moments
- Neutral and doubly-charged scalars in seesaw models
- Connection to leptogenesis (collider probes) and dark matter (sterile neutrino in the νMSM)

Discovery potential extends down to mixing values of O(10 $^{-11}$)





The allowed ranges can be constrained to be smaller than **0.002**.

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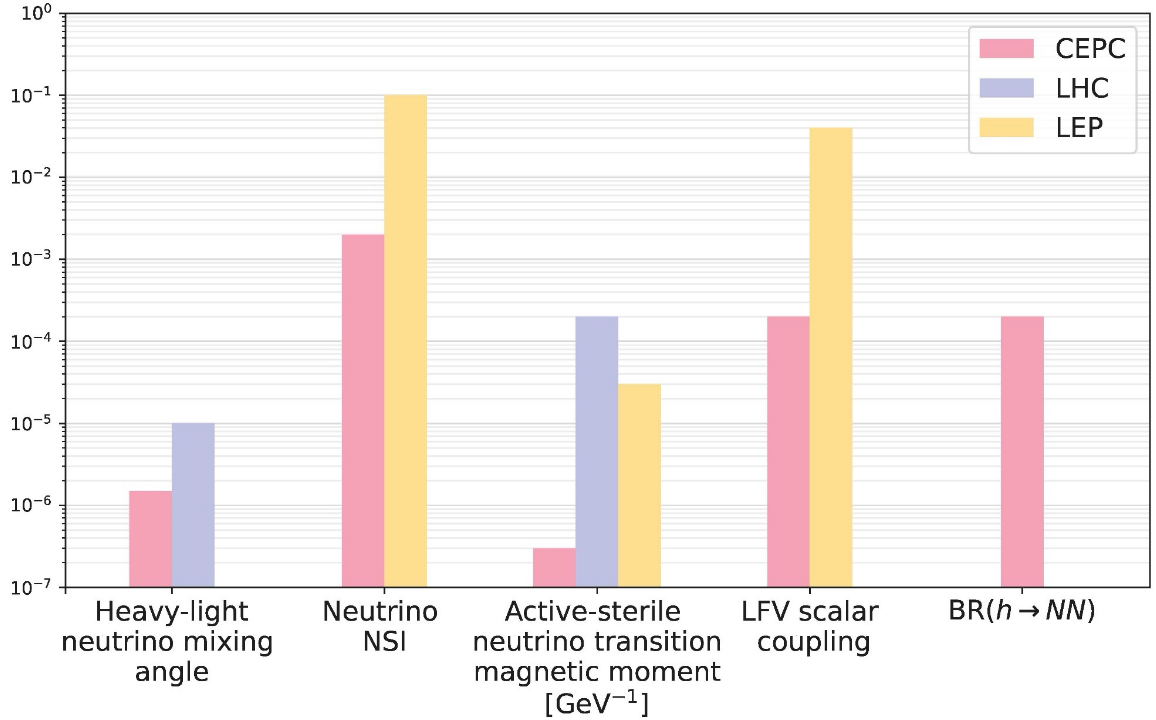
Summary plot of neutrino relevant models



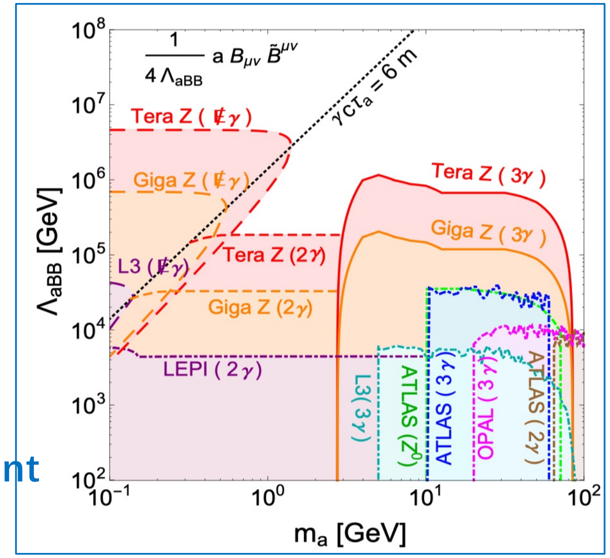
The sensitivities can be improved by roughly *1 to 2 (or more) orders of magnitude* (vs LHC & LEP).

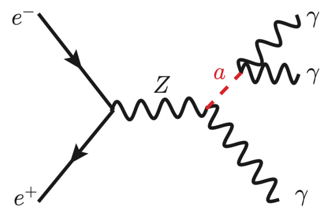
8. More exotics

High precision of Z, h width offers power test of exotics process of
Lepton number/flavor violation, Sterile states, Axion-like particles …

- Axion-like particles (solve "strong-CP" problem)
- Emergent Hadron Mass
- Lepton form factors (μ /e g-2, μ /e dipole moments in SUSY, τ weak-electric dipole moments)
- Exotic lepton mass models
- Spin entanglement
- ……

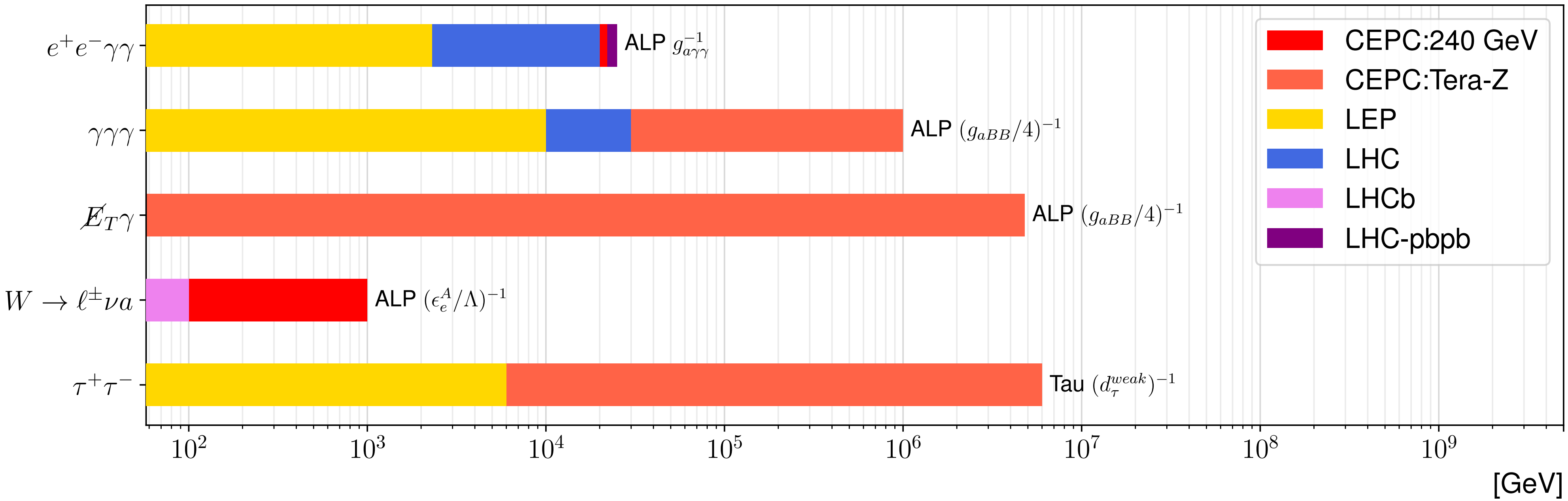
Quantity	Channel	Sensitivity scale (GeV)	CEPC Run
ALP $g_{a\gamma\gamma}^{-1}$	$e^+e^-\gamma\gamma$	6.7×10^3 [668]	Tera-Z
	$e^+e^-\gamma\gamma$	2.2×10^4 [668]	240 GeV
	$\bar{f}fa$	6.5×10^3 [668]	250 GeV
ALP $(g_{aBB}/4)^{-1}$	3γ	10^6 [61]	Tera-Z
	$\not{E}_T\gamma$	4.8×10^6 [61]	Tera-Z
ALP $(\epsilon_e^A/\Lambda)^{-1}$	$W\to\ell^\pm\nu a$	10^3 [669]	240 GeV
Tau $(d_\tau^{weak})^{-1}$	$\tau^+\tau^-$	6×10^6 [711]	Tera-Z
Bell Inequality	$Z,h\to\tau^+\tau^-$	1σ [718]	240 GeV





m_a ranges from 0.1 to 100 GeV, extending current limits by more than two orders of magnitude

8. More exotics



Energy reach in representative exotic search channels at the CEPC. Note the maximal energy reach may apply to different model parameter regions between experiments.

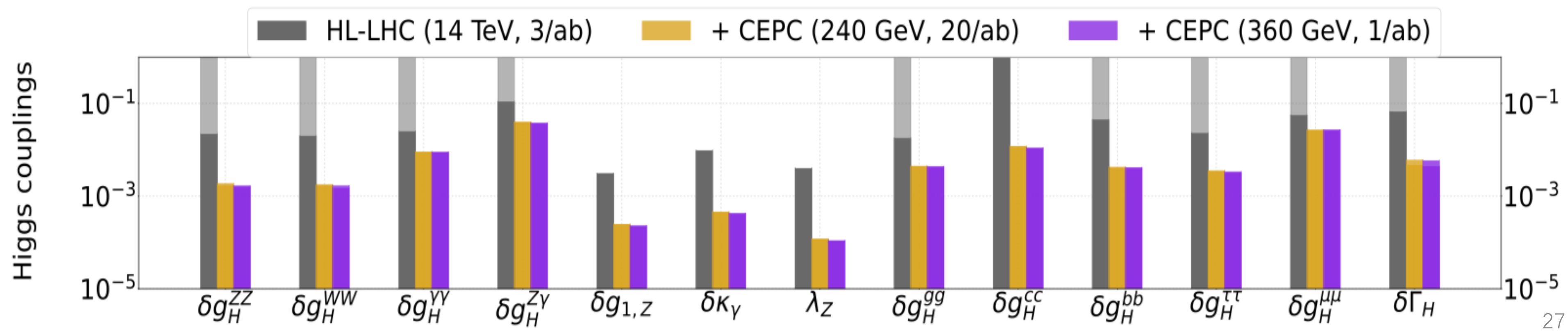
9. Global fits

Global fits: an essential tool to obtaining a thorough understanding of a NP model, and the implications and predictions of the models for future searches and experiments.

- **SMEFT**
- **2HDM**
- **SUSY**

Global fit for SMEFT operators at future colliders

- **CEPC can improve the Higgs couplings by a factor of a few, or even orders of magnitude ($\delta g_{1,Z}$, $\delta\kappa_\gamma$, and λ_Z.)**
- **CEPC can dramatically increase the sensitivity to Higgs, electroweak, and 4fermion operators by the 10~70 TeV scale**



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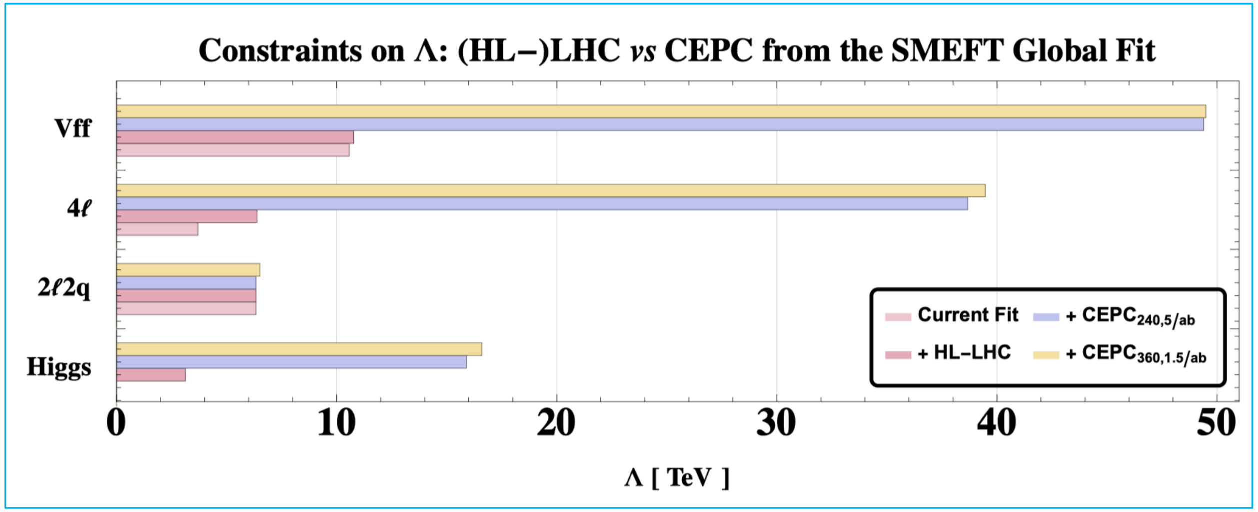
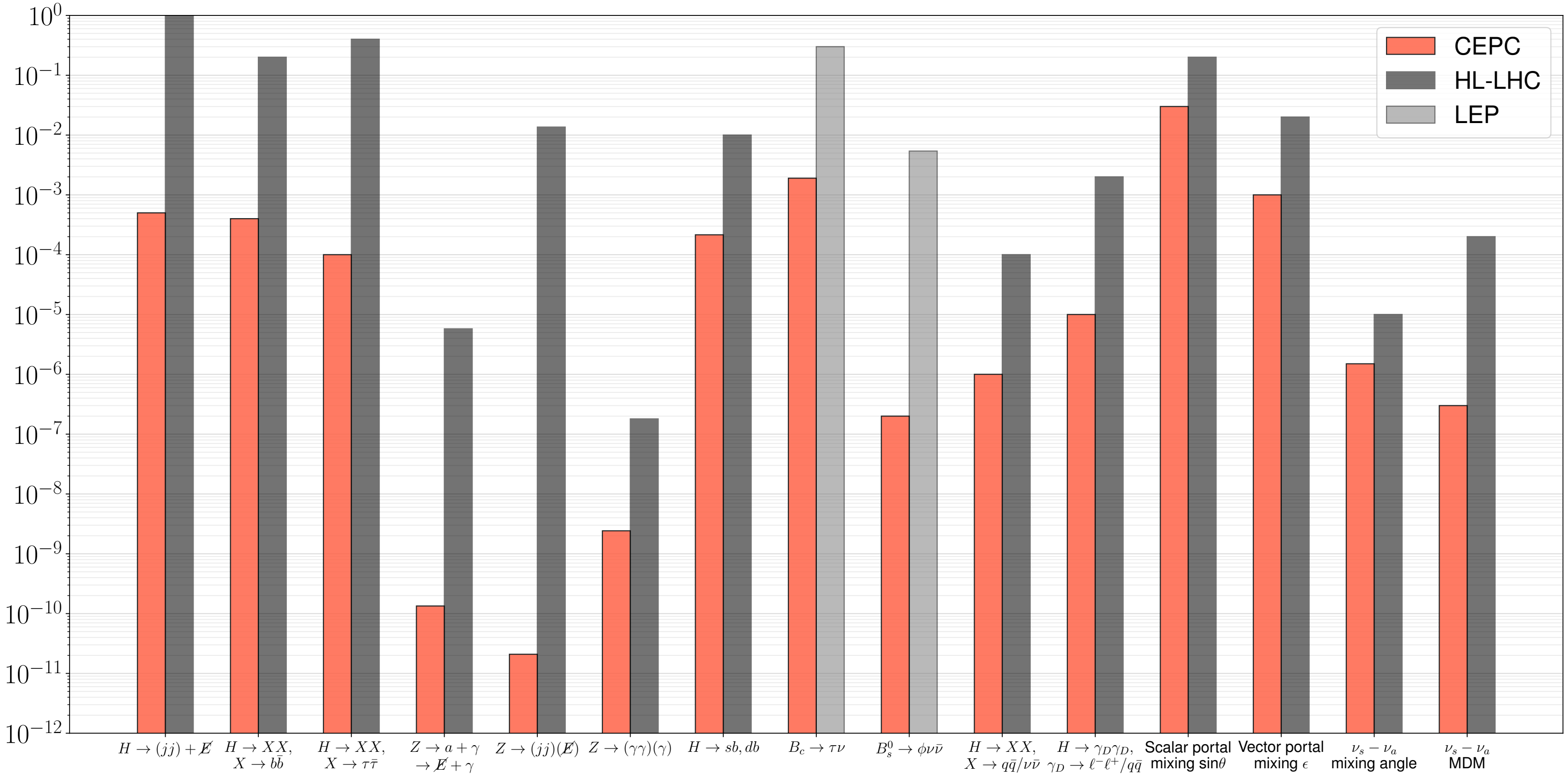


Projected sensitivities of the CEPC and HL-LHC for various new physics scenarios



exotic Higgs

exotic Z

Flavor
flavor-violating Higgs and and B-meson decays

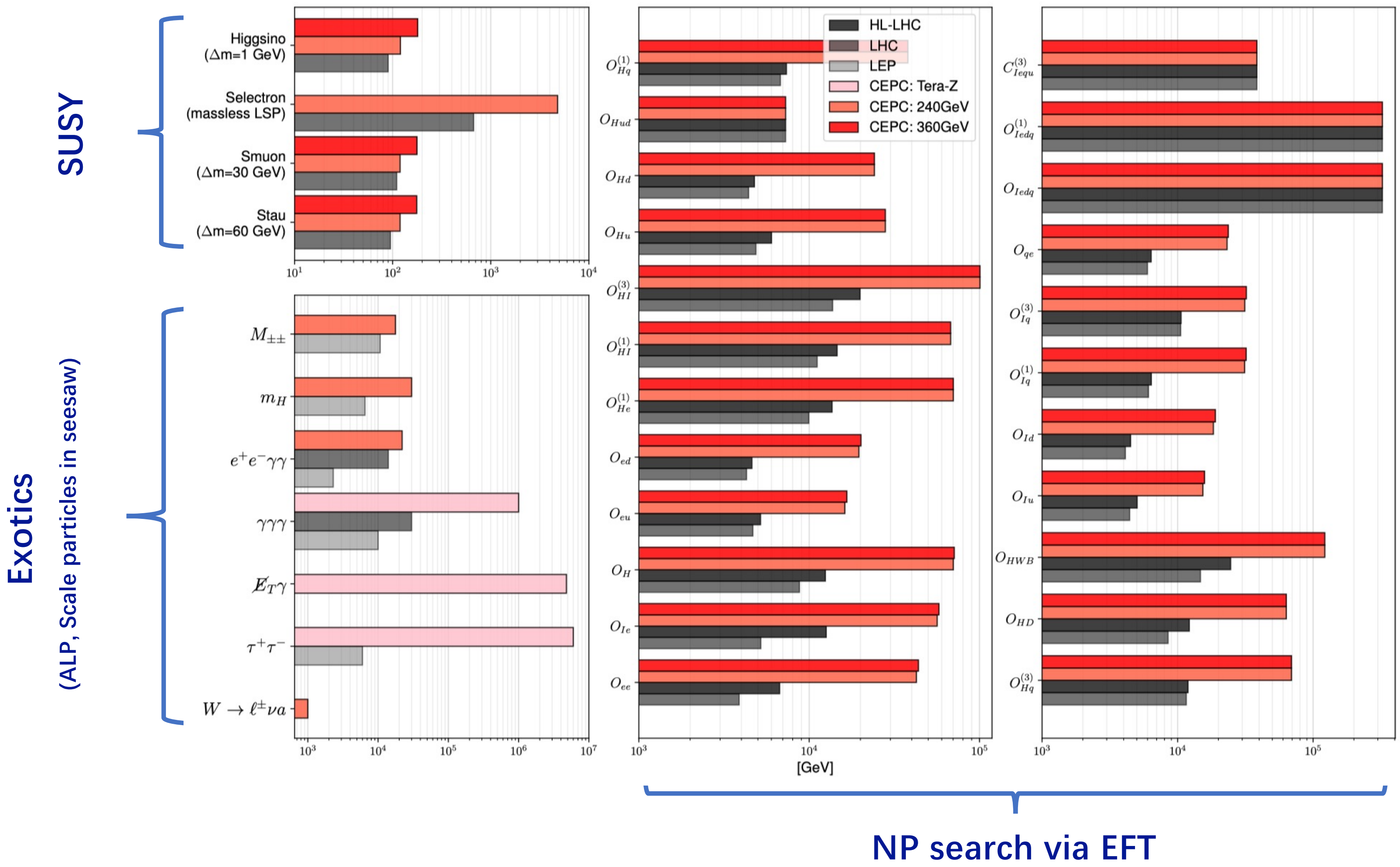
LLP

DM&DS
scalar and vector portal mixing

Neutrino
sterile-active neutrino mixing and magnetic dipole moment interactions

The sensitivities are orders of magnitude better than the existing facility

Sensitivity scale of the CEPC and other Exp. for various new physics scenarios



The new physics discovery power could also be expressed in the explorable energy range:

- SMEFT: up to 10-100 TeV, improve NP scale by a factor of 3~10
- SUSY/exotics: from half beam energy to TeV scale

Summary and Outlook

- CEPC has excellent discovery potential for NP, especially for light new particles at low energy/mass scale, which is complementary to hadron colliders
- CEPC NP white paper is on [arXiv:2505.24810](https://arxiv.org/abs/2505.24810), your comments/suggestions are very appreciated!

arXiv:2505.24810v1 [hep-ex] 30 May 2025

New Physics Search at the CEPC: a General Perspective

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Thanks for your attention!

Backup

7. Neutrino physics

BSM related neutrino physics from neutrino mass mechanism, new messengers and interactions at EW scale:

X. Neutrino Physics (Bhupal, Wei, Yongchao)

A. Prospects of heavy neutrinos

1. Heavy neutrinos at the main detector
2. Heavy neutrinos at far detectors
3. SM Higgs decay $h \to NN$
4. Prospects of heavy neutrinos in $U(1)$ models
5. Prospects of heavy neutrinos in the LRSM

B. Non-standard neutrino interactions

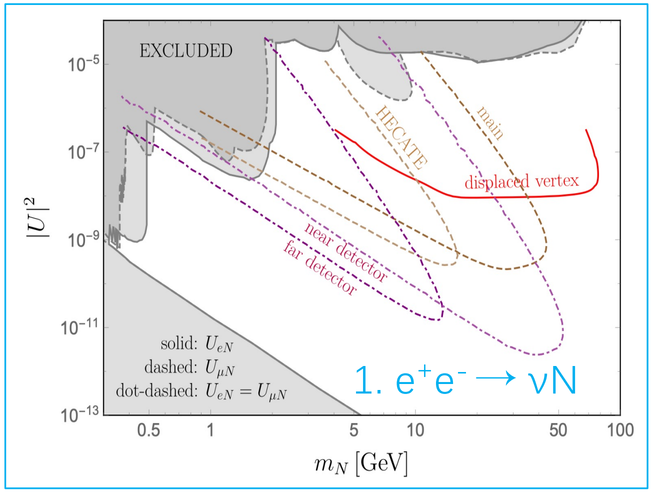
C. Active-sterile neutrino transition magnetic moments

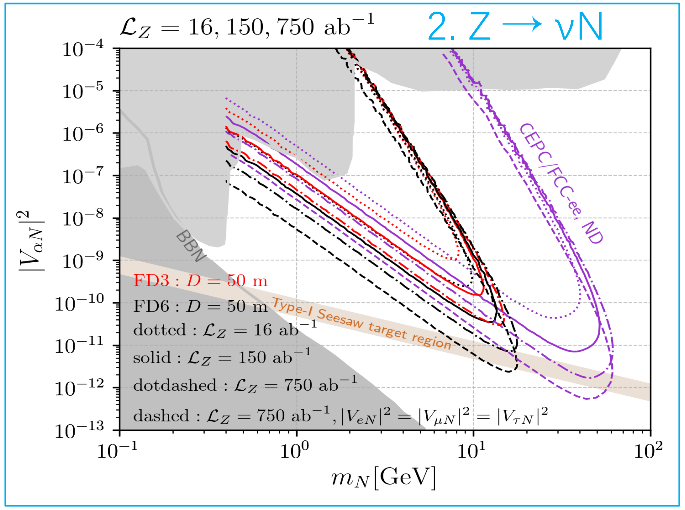
D. Neutral and doubly-charged scalars in seesaw models

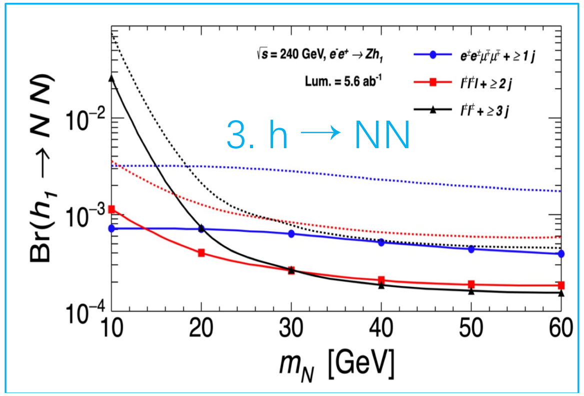
E. Connection to Leptogenesis and Dark Matter

F. Summary

Discovery potential extends down to mixing values of O(10 $^{-11}$)







7. Neutrino physics

The allowed ranges can be constrained to be smaller than **0.002**.

$$e^+e^- \to \nu\bar{\nu}\gamma$$

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- B. Non-standard neutrino interactions (NSI)
- C. Active-sterile neutrino transition magnetic moments
- D. Neutral and doubly-charged scalars in seesaw models
- E. Connection to Leptogenesis and Dark Matter
- F. Summary

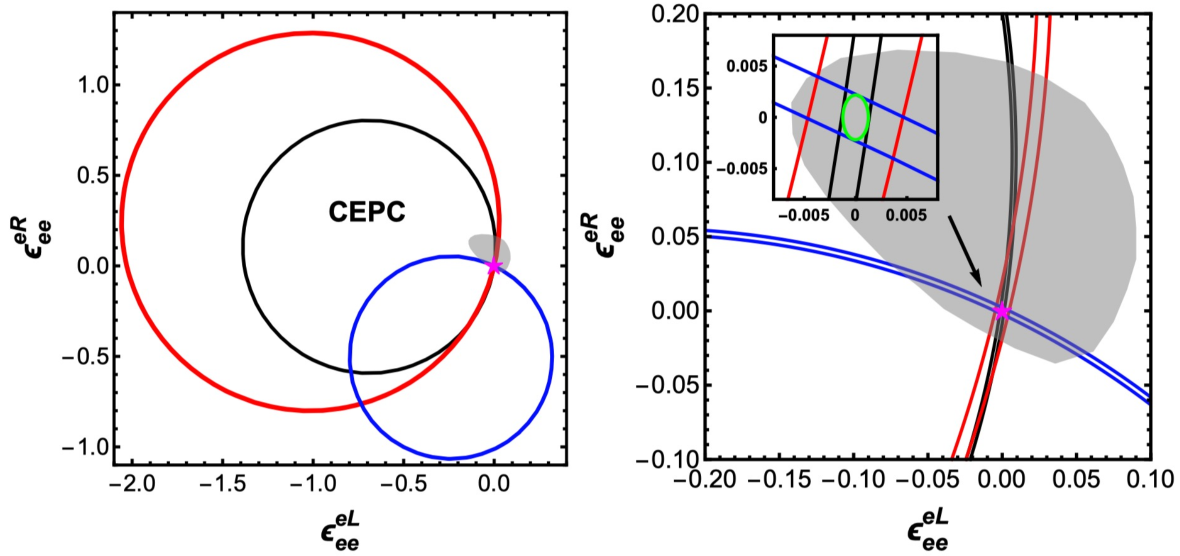

FIG. 76: *Left panel*: The allowed 90% C.L. region for electron-type neutrino NSI in the planes of (ϵ_{ee}^{eL}, ϵ_{ee}^{eR}) at future CEPC with 5.6 ab^{-1} data of $\sqrt{s} = 240$ GeV (Black), with 2.6 ab^{-1} data of $\sqrt{s} = 160$ GeV (Red), and with 16 ab^{-1} data of $\sqrt{s} = 91.2$ GeV (Blue), respectively. The allowed 90% C.L. regions arising from the global analysis of the LEP, CHARM, LSND, and reactor data [586], are shown in the shaded gray regions. *Right panel*: With all the data collected in all three running modes, the combined result is shown as the green region. Figure from Ref. [549]

7. Neutrino physics

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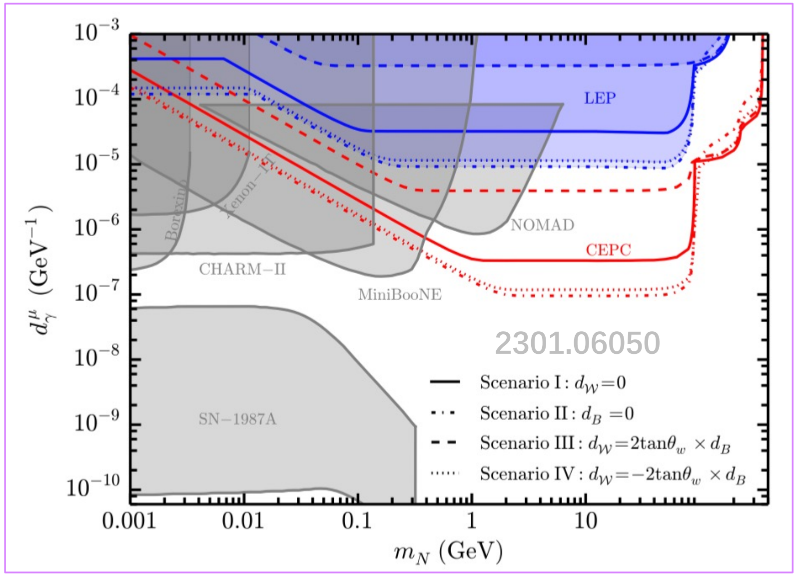
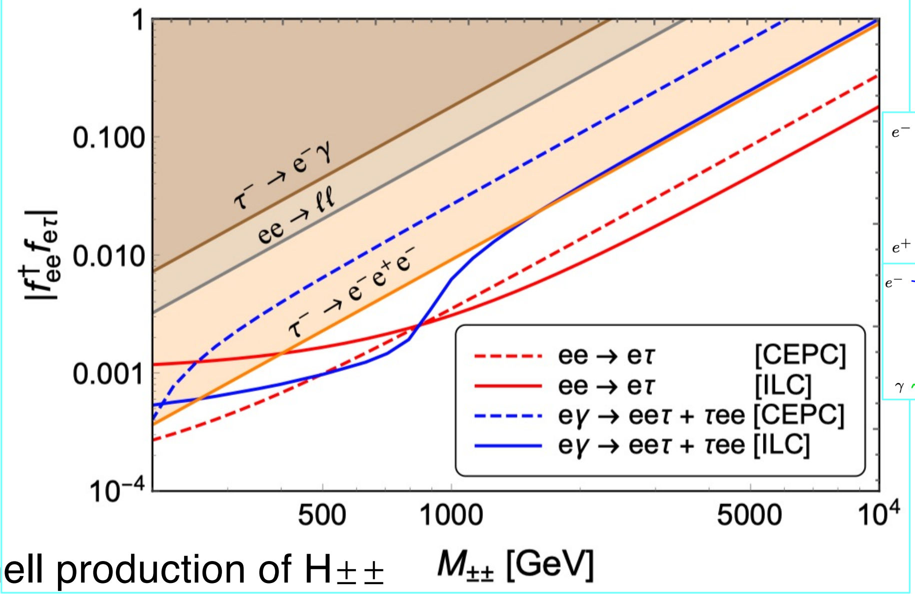
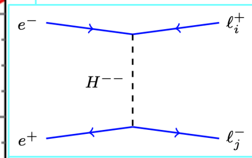
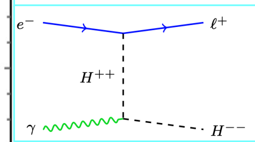
dipole portal couplings d^k_γ









off-shell production of H±±

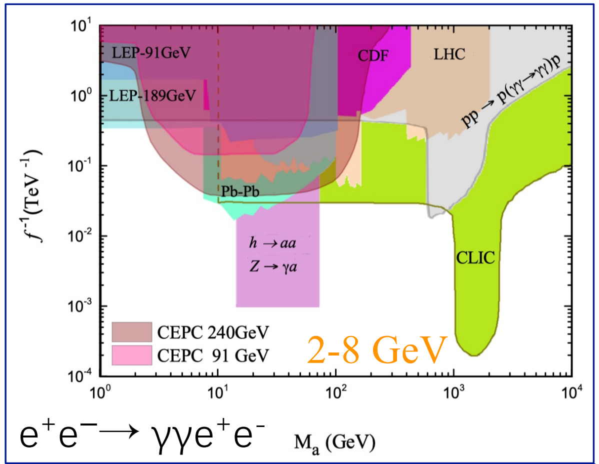
8. More exotics

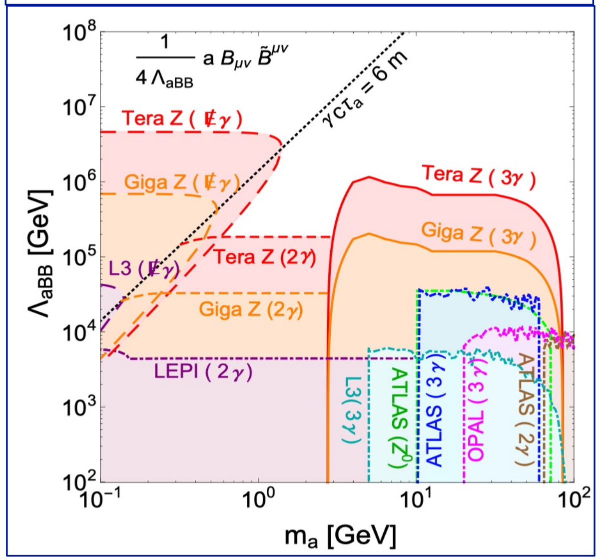
High precision of Z, h width offers power test of exotics process of

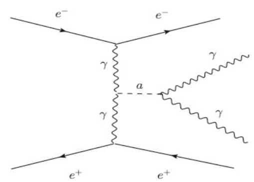
Lepton number/flavor violation, Sterile states, Axion-like particles …

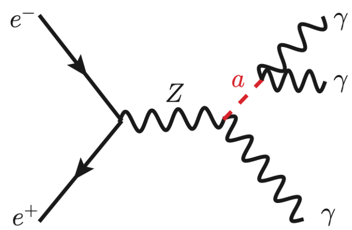
XI. More Exotics (Yu, Zuowei)

- A. Axion-like particles (solve "strong-CP" problem)
- B. Emergent Hadron Mass
- C. Lepton form factors
  1. General remarks on $\mu/e\ g-2$
  2. μ/e dipole moments in SUSY
  3. τ weak-electric dipole moments
- D. Spin entanglement
- E. Exotic lepton mass models
- F. Summary









m_a ranges from 0.1 to 100 GeV, extending current limits by more than two orders of magnitude

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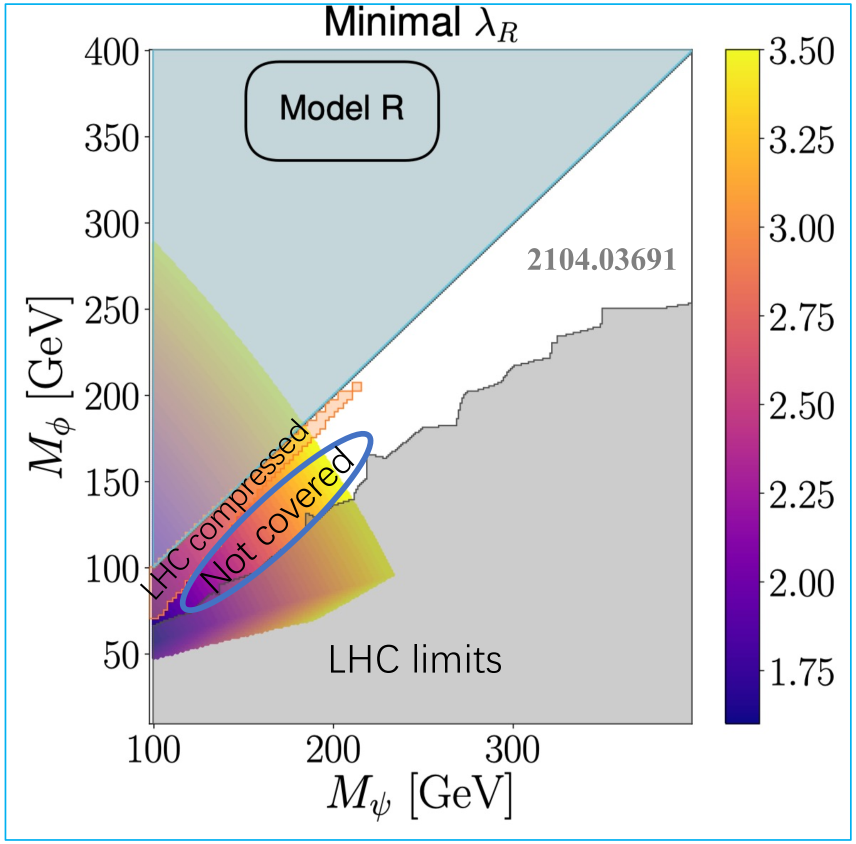


- Light EWKinos, smuon, stau co-annihilation can explain mu g-2 excess
- Gaps from LHC, can cover by CEPC

A simple model with a new scalar and and a new fermion

9. Global fits

Improve the new physics scale by a factor of 3~10

Global fits: an essentia obtaining a thorough unde of a NP model, and the im and predictions of the n future searches and exper

- SMEFT
- 2HDM
- SUSY

As a Higgs factory, CEPC is expected to improve significantly the SMEFT global analysis due to its high energy and luminosity.

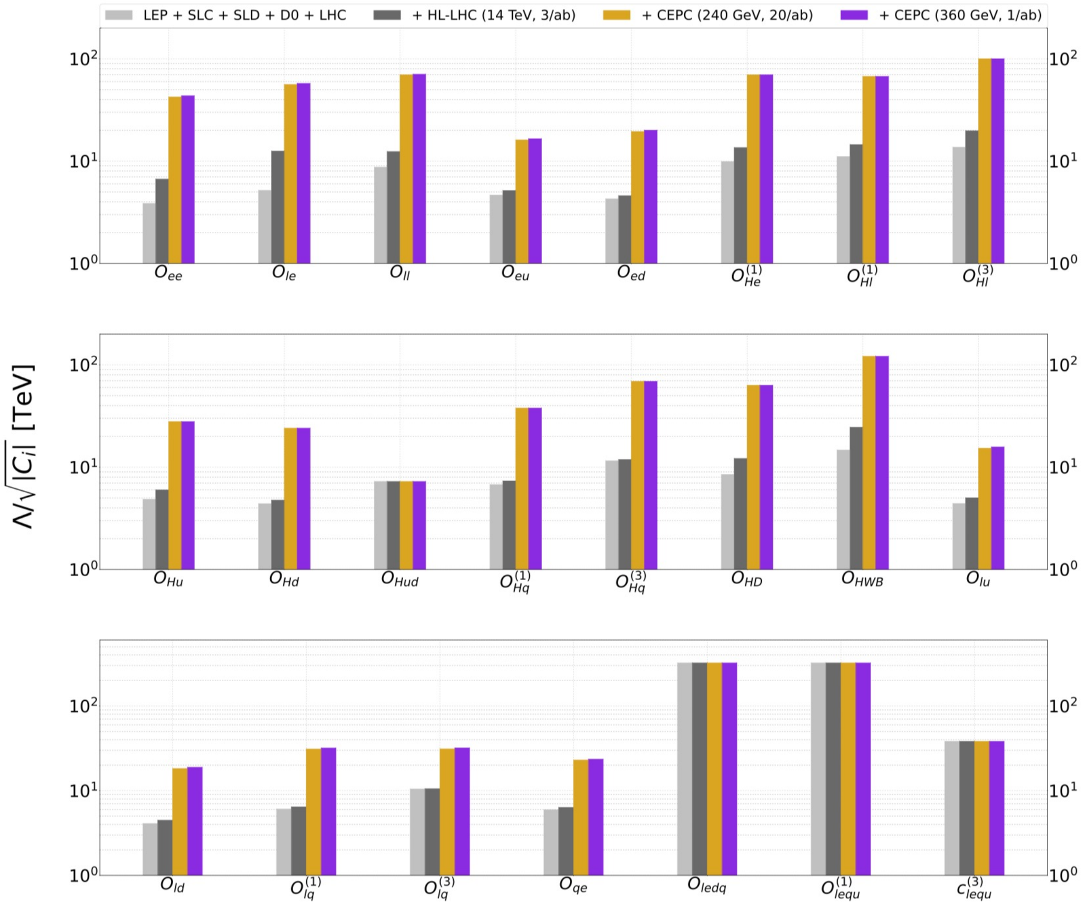


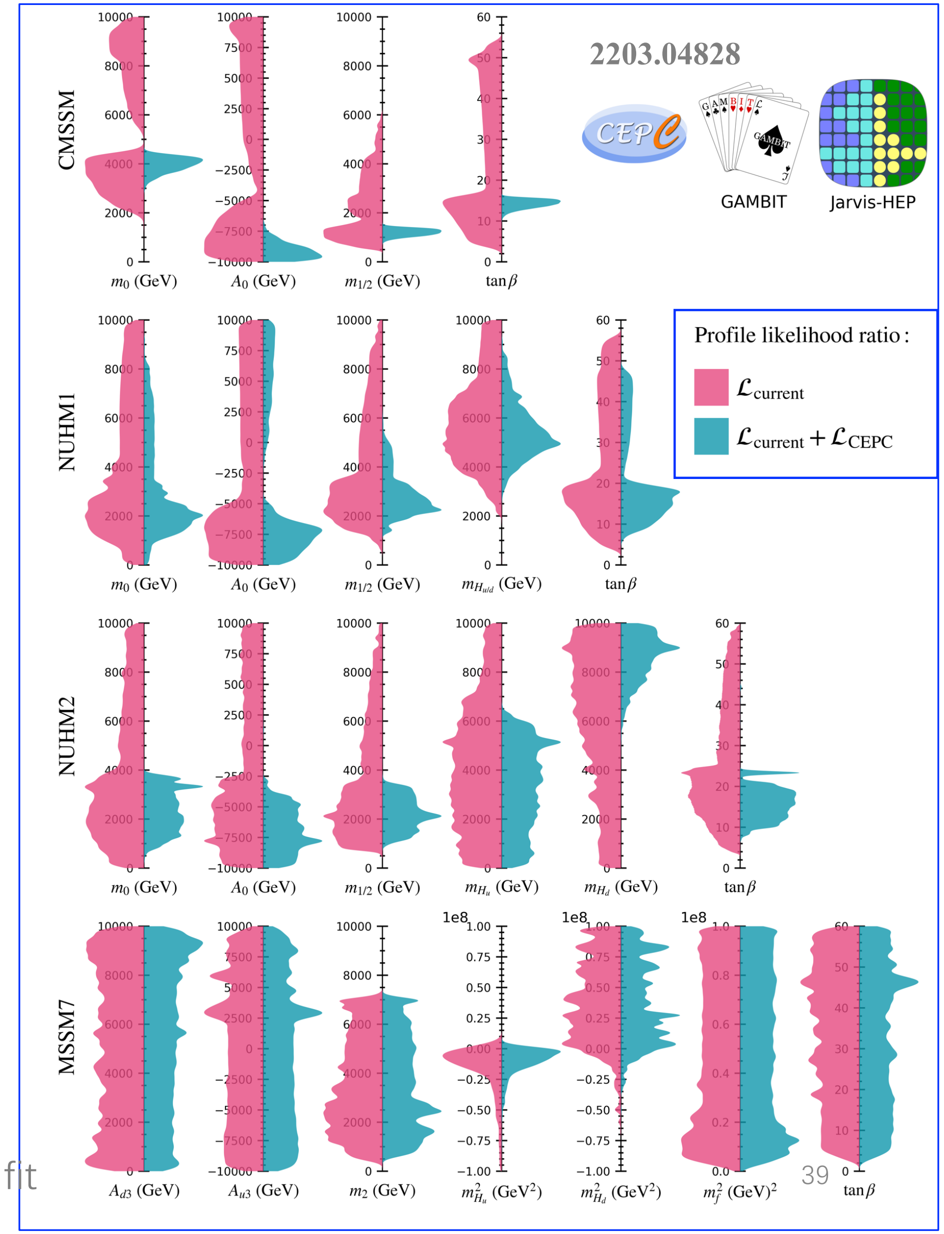
FIG. 95: Lower bounds on $\Lambda/\sqrt{|C_i|}$ at the 95% CL as presented in the Warsaw basis, assuming flavor universality and one operator at a time.

9. Global fits

Global fits: an essential tool to obtaining a thorough understanding of a NP model, and the implications and predictions of the models for future searches and experiments.

- **SMEFT**
- **2HDM**
- **SUSY**

CEPC has the potential to greatly enhance our understanding of the parameter space and mass spectrum in the MSSM.



One-dimensional profiled likelihood ratio for the global fit

2. EWPT at CEPC

V. Electroweak phase transition and gravitational waves

Huang, Sai Wang, Michael Ramsey Musolf, Bruce)

A. Introduction

B. Higgs precision measurements

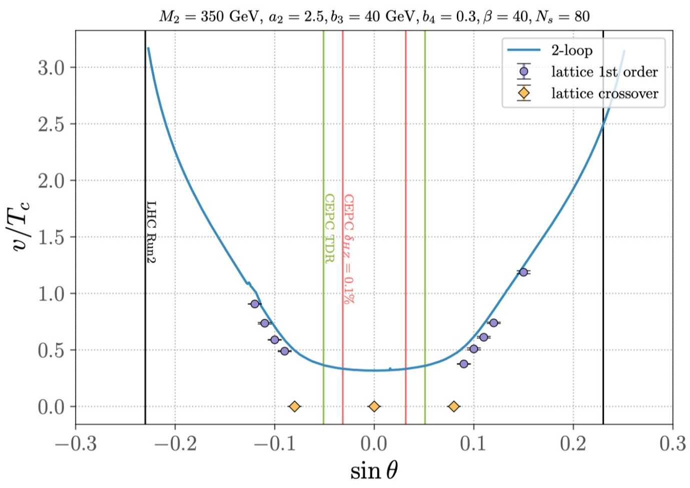


FIG. 17: Discontinuity in the Higgs vev (v) at the critical temperature (T_c) as function of the doublet-singlet mixing angle θ in the real scalar singlet extension of the SM (xSM). Blue circles (yellow diamonds) give lattice results for a first order (crossover) transition, while blue curve is obtained from a two-loop perturbative computation using the $T > 0$ EFT framework. Black and green vertical lines indicate $\sin\theta$ sensitivities of LHC Run 2 and the CEPC, respectively (adapted from Ref. [193] by G. Xia).

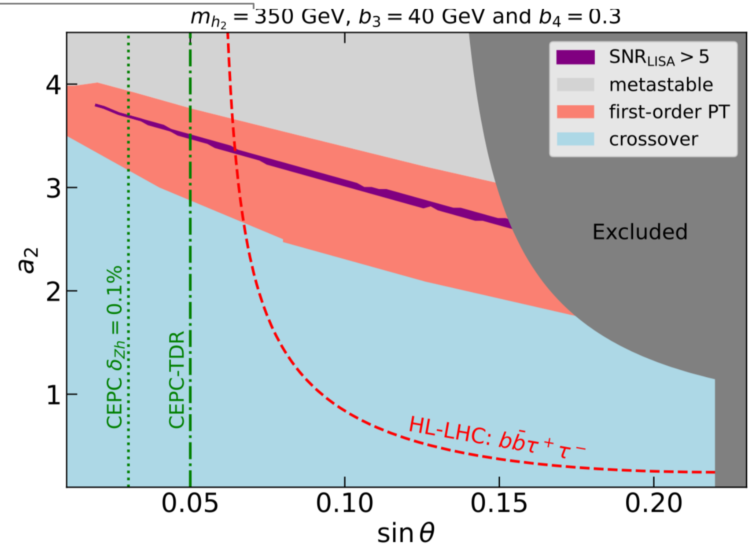
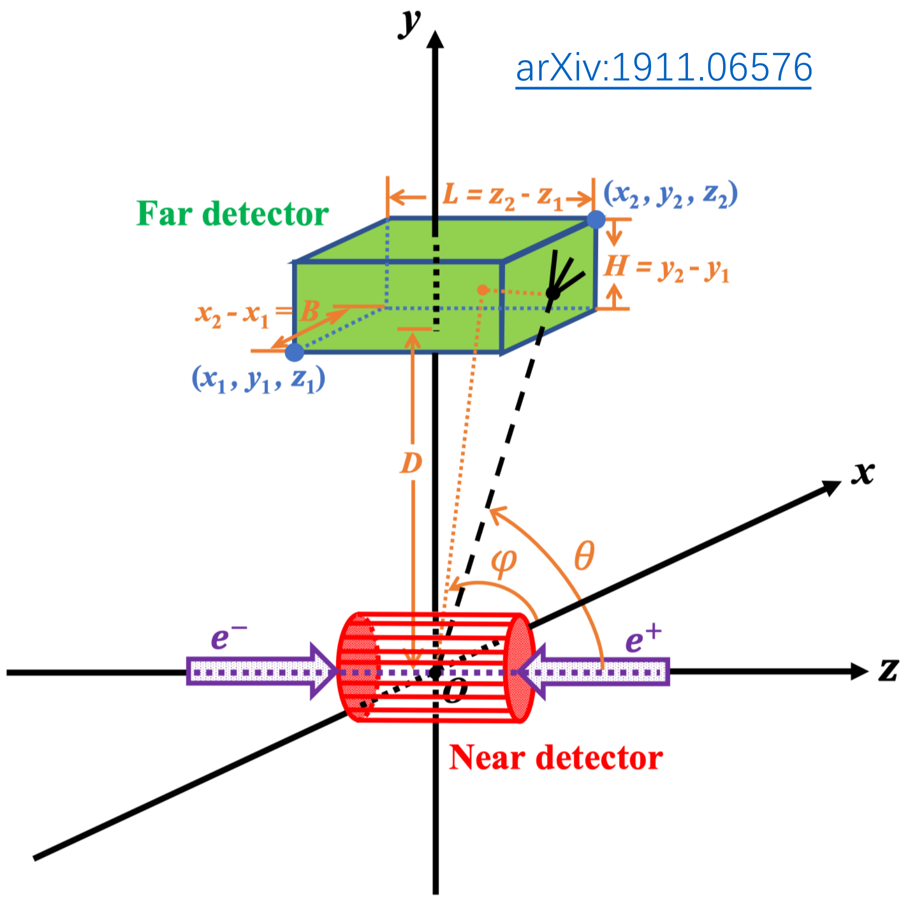
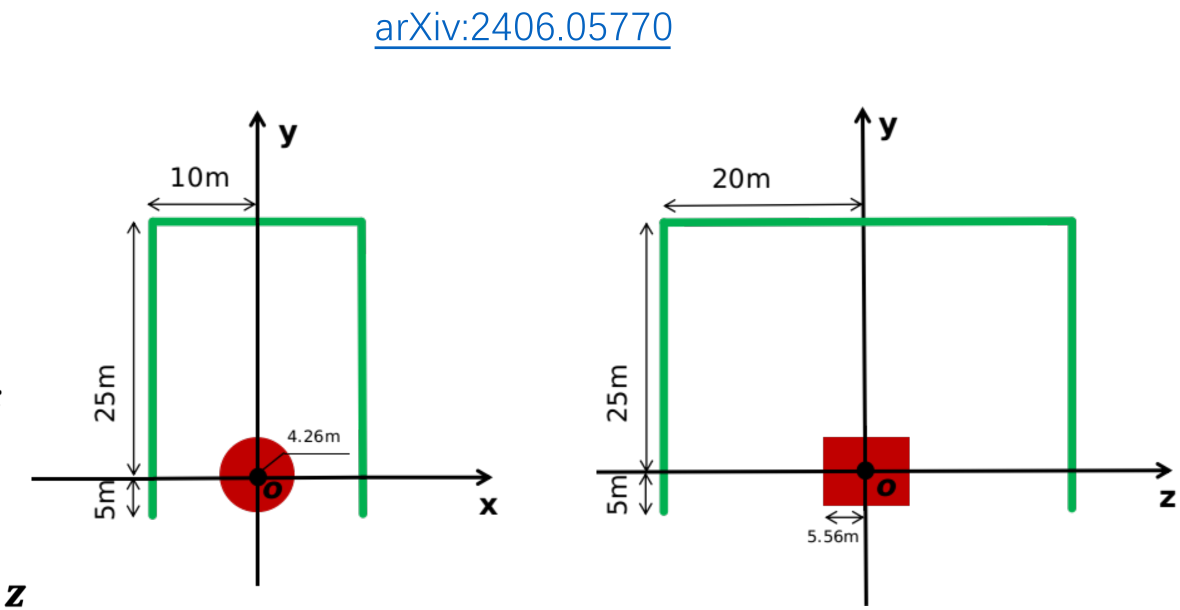


FIG. 18: Phase diagram for the real scalar singlet extension of the SM in the plane of the doublet-singlet mixing angle θ and double-singlet cross-quartic portal coupling a_2. Light blue and red regions indicate cross over and two-step EWPT regions, respectively, while the light grey region corresponds to a metastable electroweak vacuum. The dark grey region is experimentally excluded. Dashed red curve and dashed green lines indicate sensitivities of high luminosity LHC resonant di-Higgs searches in the $b\bar{b}\tau^+\tau^-$ channel and different scenarios of the CEPC precision $\sigma(e^+e^- \to Zh)$ exclusion reach, respectively. Purple band shows parameter region consistent with a LISA GW observation with SNR > 5. Dark grey region is experimentally excluded (adapted from Ref. [178] by V.Q. Tran)

FAR Detector





LAYCAST

LAYered CAvern Surface Tracker at future electron-positron colliders