中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

NP search at the CEPC :

a General Perspective

(White paper statues)

Xuai Zhuang (IHEP)

On behalf of CEPC NP team

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CEPC Day

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Introduction

CEPC NP white paper is almost ready for your review

- ~260 pages, 13 chapters, 37 editors, ~100(?) authors
- Proof reading version is ready, just let's know if you'd like to review

New Physics search at the CEPC: a General Perspective

AUTHOR LIST

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- Zhao Li

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- Fa Peng Huang
- Sai Wang
- Michael Ramsey Musolf
- Bruce Mellado Garcia

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- Yongchao Zhang
- Bhupal Dev
- Peiwen Wu

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- Yu Gao
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Global Fits

- Jiayin Gu
- Yang Zhang
- Yong Du
- Tao Han
- Shufang Su
- Wei Su
- Yongcheng Wu

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Acknowledgements

- Manqi Ruan

Glossary

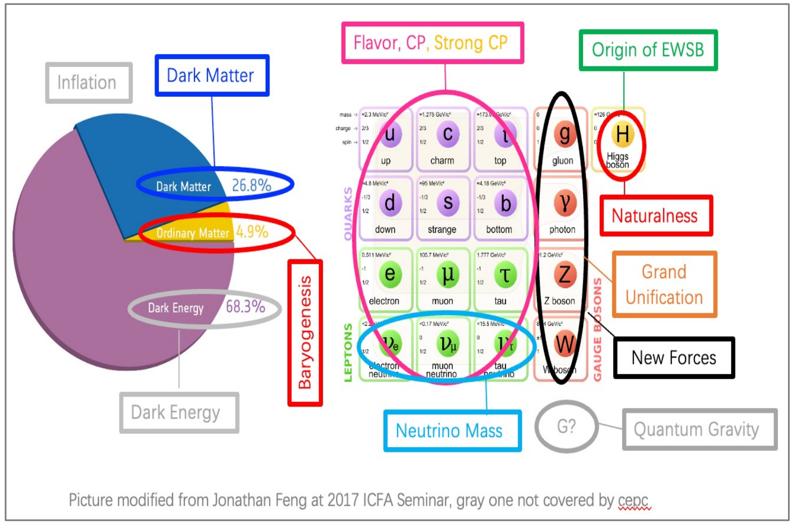
- Xuai Zhuang

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.**

Big Questions and Ideas in particle physics



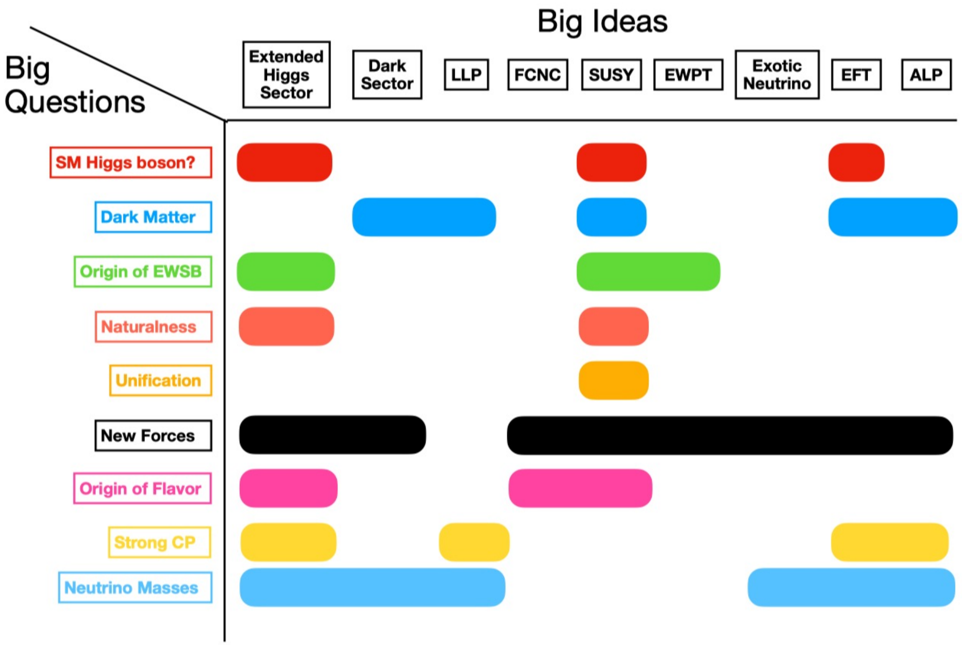


FIG. 1: Big questions and big ideas of the BSM landscape.

CEPC operation scheme

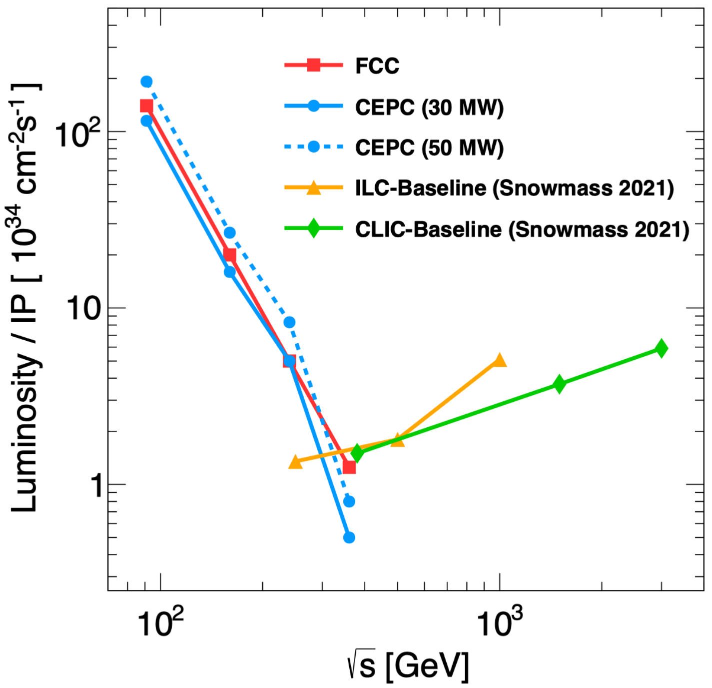


FIG. 2: The updated run plan of the CEPC, with the baseline and upgrade shown in solid and dashed blue curves, respectively. The run plans for several other proposals of the e^+e^- colliders are also shown for comparison. See [14] for details.

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.

NP Program

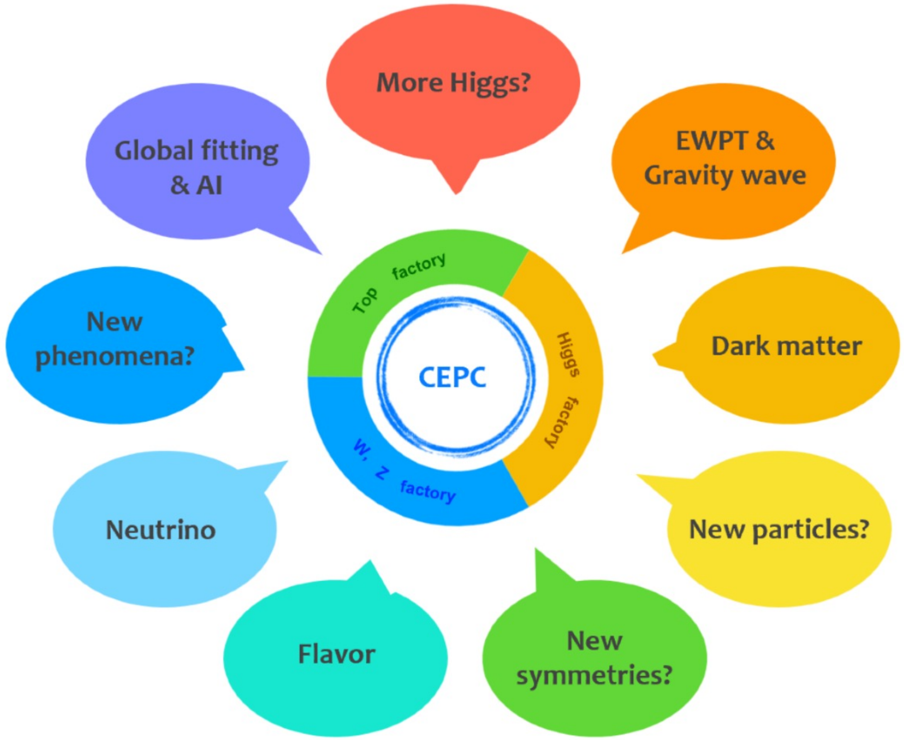


FIG. 2: A cartoon of new physics program at the CEPC.

- **Intensity frontier of H/Z...:**
  - Exotic Higgs/Z, EWPT, DM&DS,...
- **New particles/phenomena:**
  - LLP, ALP, ...
- **New symmetries:**
  - SUSY
- **Flavor frontier :**
  - Flavor, Neutrino, ...
- **Techniques:**
  - Global fitting, AI,...

Exotic Higgs/Z/top decays

IV. Exotic Higgs potential and Exotic Higgs/Z/top decays (Yaquan, Zhao)

A. Introduction

B. Model-independent Sensitivity to Exotic Higgs decays

C. Exotic Higgs potential

D. Higgs exotic decays in supersymmetry

E. Exotic Decays via Dark Sector

1. Higgs Exotic Decays via Dark Sector

2. Z Exotic Decays via Dark Sector

F. Higgs exotic invisible decays

G. Decays into Long-Lived Particles

1. Higgs exotic decays into Long-Lived Particles

2. Z exotic decays into Long-Lived Particles

H. The 95 GeV Higgs boson at the CEPC

I. Top quark exotic decays

J. Summary

Motivated by many BSM physics: singlet extensions, 2HDM, SUSY models, Higgs portals, gauge extensions of the SM …

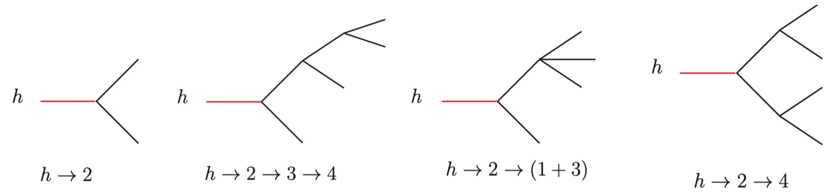


FIG. 8: Representative topologies of the Higgs exotic decays (from Ref.[45]).

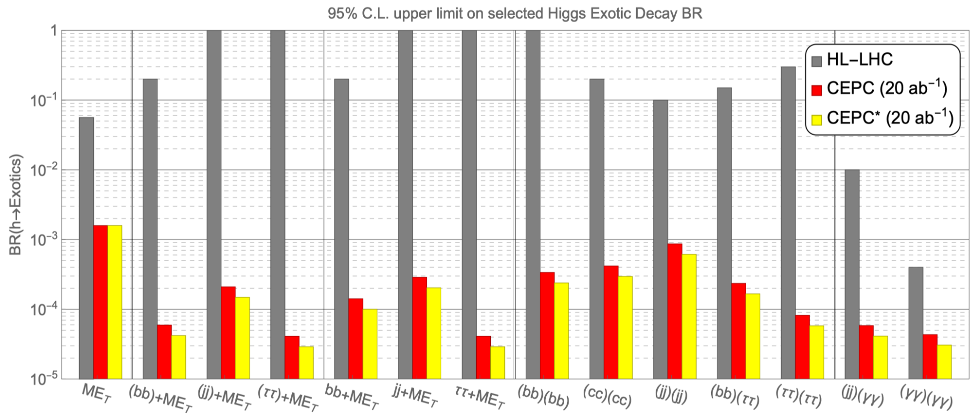


FIG. 9: The 95% C.L. upper limit on selected Higgs exotic decay branching fractions at HL-LHC and CEPC, based on Ref [45].

orders of magnitude improvement

Exotic Higgs/Z/top decays

IV. Exotic Higgs potential and Exotic Higgs/Z/top decays (Yaquan, Zhao)

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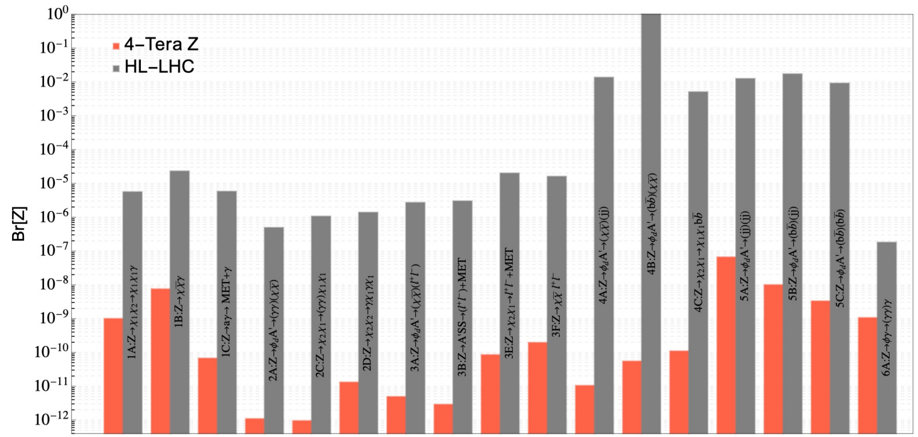
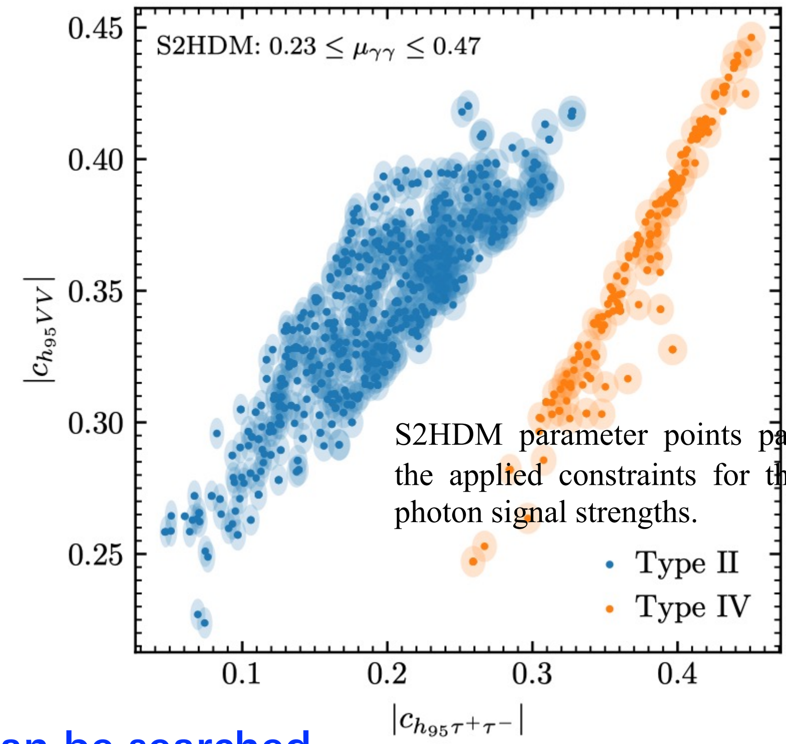


FIG. 12: The reach for the branching ratio of various exotic Z decay modes at the future Z-factories (rescaled to four Tera Z) and the HL-LHC at 13 TeV with $\mathcal{L} = 3\ \mathrm{ab}^{-1}$ [73]. The

Light Higgs

motivated by 2HDM and Axion-like particle models



S2HDM parameter points passing the applied constraints for the di-photon signal strengths.

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

2. EWPT at CEPC

V. Electroweak phase transition and gravitational waves (Ke-Pan Xie, Fa Peng Huang, Sai Wang, Michael Ramsey Musolf, Bruce)

A. Introduction

B. Higgs precision measurements

C. Higgs exotic decay

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

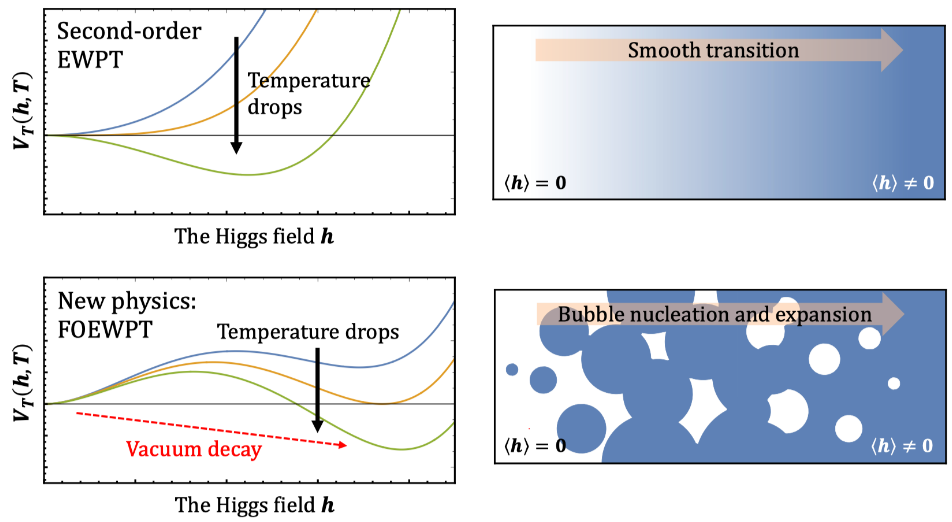


FIG. 15: Illustration of electroweak phase transition patterns. Top: in the SM, the transition is a smooth crossover. Bottom: in many new physics models, the scalar potential exhibits a barrier, allowing for a FOEWPT with bubble nucleation and expansion.

2. EWPT at CEPC

V. Electroweak phase transition and gravitational waves (Ke-Huang, Sai Wang, Michael Ramsey Musolf, Bruce)

A. Introduction

B. Higgs precision measurements

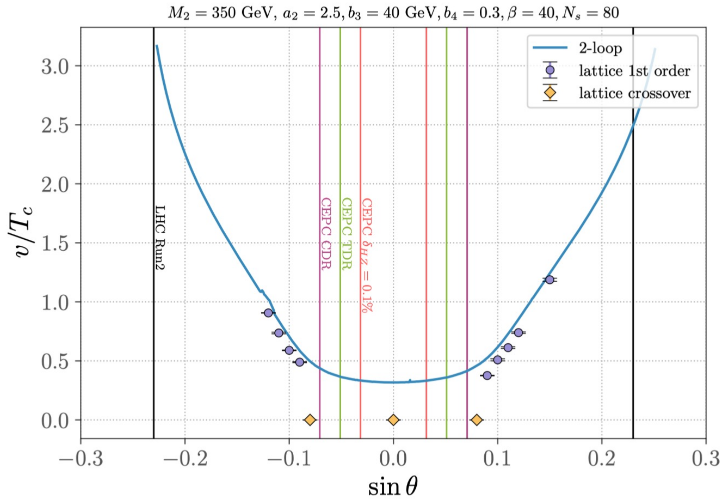


FIG. 17: Discontinuity in the Higgs VEV (v) at the critical temperature (T_c) as function of the doublet-singlet mixing angle θ in the real scalar singlet extension of the SM (xSM). Blue circles (yellow diamonds) give lattice results for a first order (crossover) transition, while blue curve is obtained 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. [190] by G. Xia).

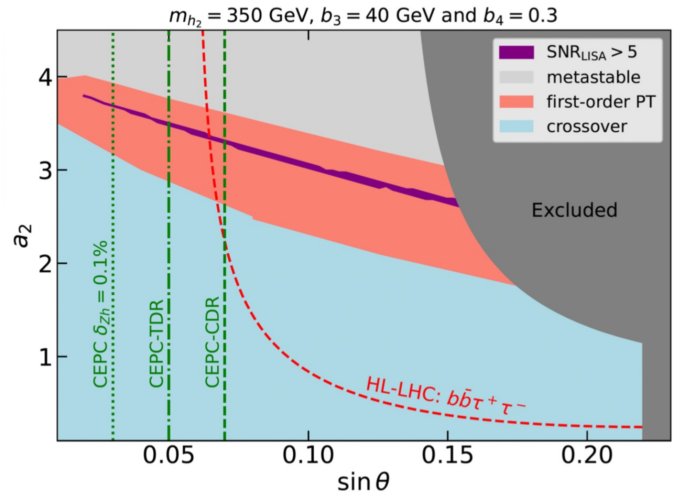


FIG. 18: Phase diagram for the real scalar singlet extension of the SM in the plane of the doublet-singlet mixing angle θ and double-singlet cross-quartic portal coupling a_2. Light blue and red regions indicate cross over and two-step EWPT regions, respectively, while the light grey region corresponds 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.

In the event of a GW observation, and assuming the xSM is realized in nature, one could **either anticipate a CEPC discovery of a significant singlet-doublet mixing or identify the narrow region of xSM parameter space consistent with both sets of experiments.**

2. EWPT at CEPC

V. Electroweak phase transition and gravitational waves (Ke-Pan Xie, Fa Peng Huang, Sai Wang, Michael Ramsey Musolf, Bruce)

A. Introduction

B. Higgs precision measurements

C. Higgs exotic decay

Higgs exotic decay

h→ss→XXYY as a probe for the FOEWPT:

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

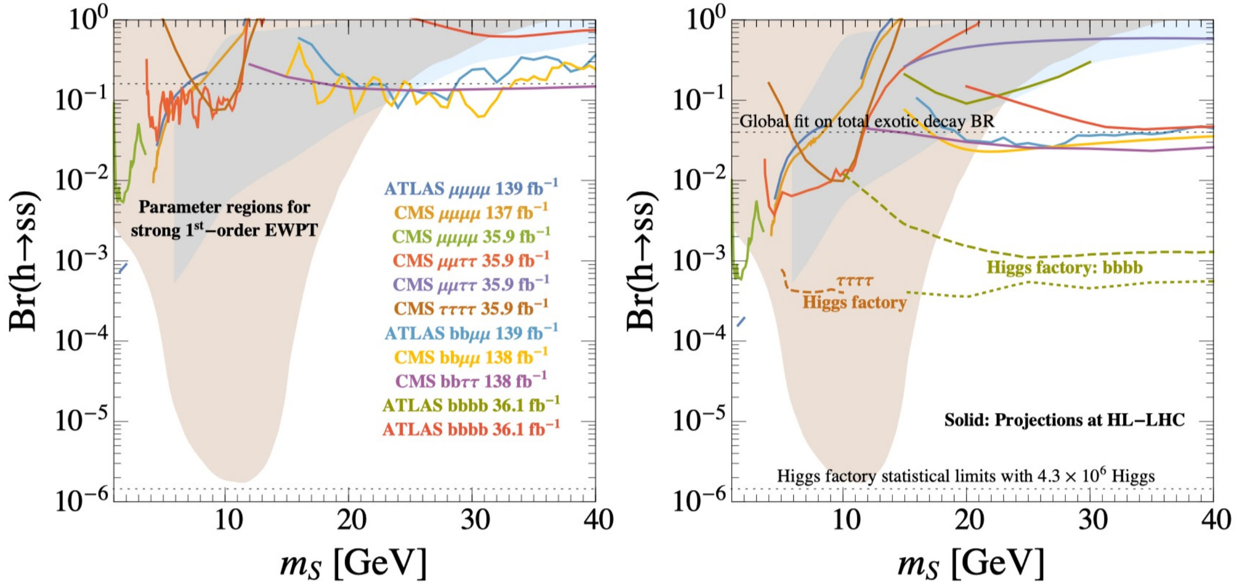
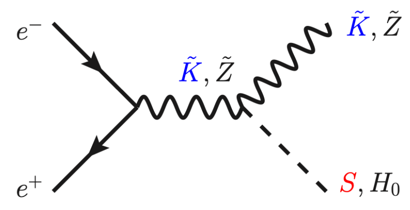


FIG. 22: Updated version of figure from Ref. [52], the Higgs exotic decay $h \to ss \to XXYY$ as a probe for the FOEWPT, where X and Y denote the SM particles.

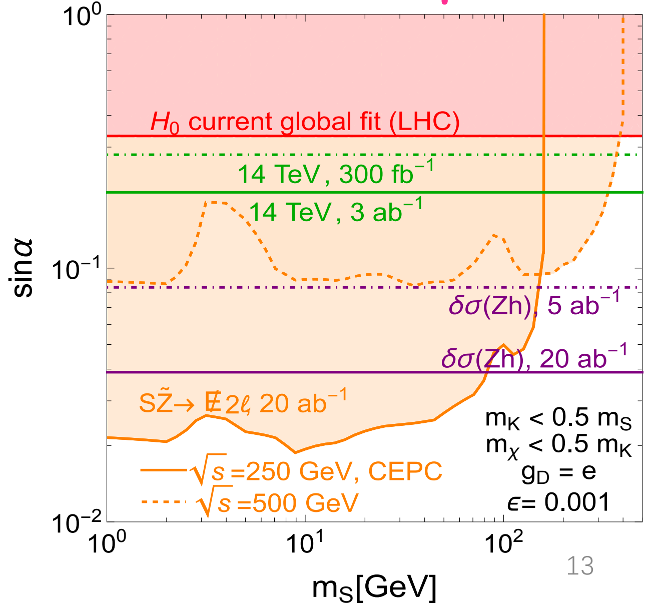
3. Dark Matter and Dark Sector

- **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

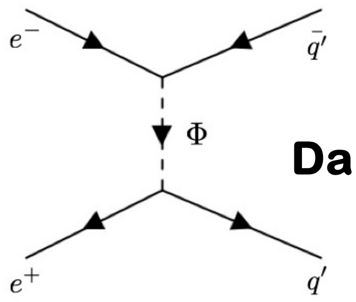


Double dark portal model: Scale and Vector-portal DM



Portal	Effective operator	$\sqrt{s}$ [GeV]	$\mathcal{L}[ab^{-1}]$	Sensitivity of CEPC (HL-LHC)	Figs.	Ref.
Scalar	$\lambda_{HP}\lvert H\rvert^2 S^2 \to$ 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	$A'_\mu\left(e\epsilon J^\mu_{\text{em}} + g_D\bar{\chi}\gamma^\mu\chi\right)$	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	$\mu_\chi, d_\chi \sim 4\times10^{-7}$ (4×10^{-6})μ_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	$\frac{1}{\Lambda^2}\sum_i\left(\bar{\chi}\gamma_\mu(1-\gamma_5)\chi\right)\left(\bar{\ell}\gamma^\mu(1-\gamma_5)\ell\right)$	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]
	$\sum_i \frac{1}{\Lambda_i^2}\left(\bar{e}\Gamma_\mu e\right)\left(\bar{\nu}_L\Gamma^\mu\chi_L\right)$ + 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

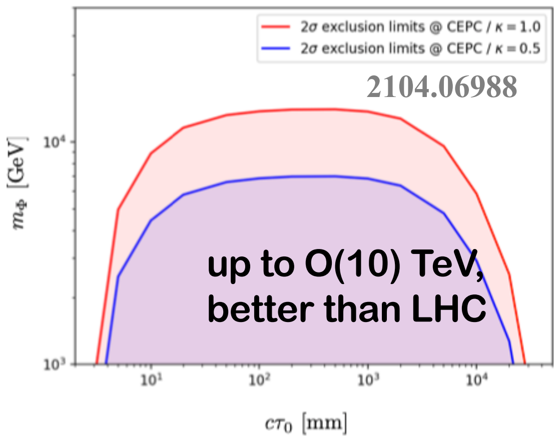


Decay to leptons

Dark quark q′

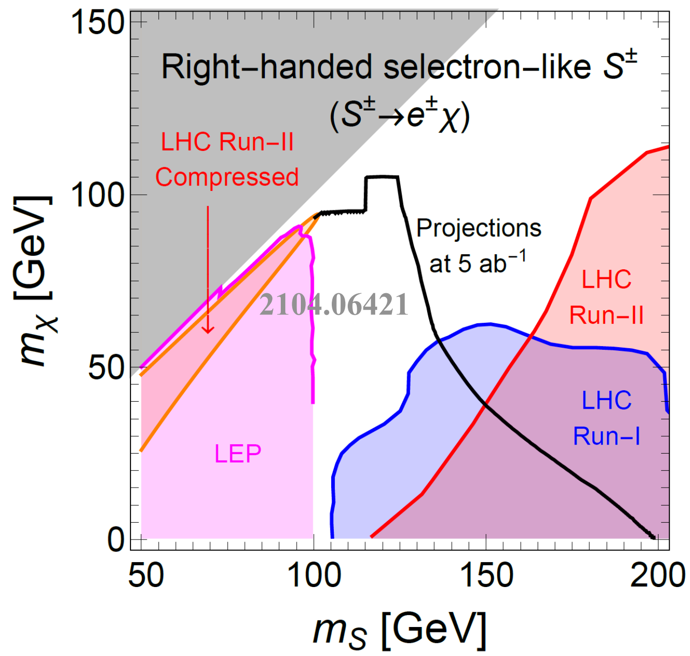
Jet-like

Signature:
Lepton + jet + MET



Lepton-portal DM

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



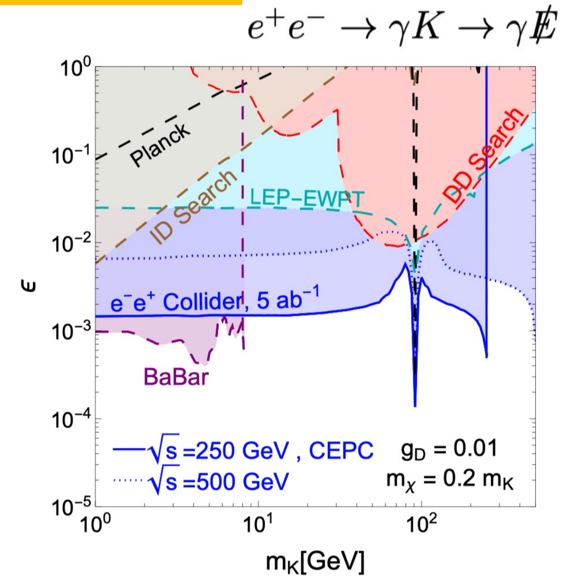
$$m_S \sim 100 - 170\ GeV$$

Portal	Effective operator	$\sqrt{s}$ [GeV]	$\mathcal{L}[ab^{-1}]$	Sensitivity of CEPC (HL-LHC)	Figs.	Ref.
Scalar	$\lambda_{HP}\lvert H\rvert^2 S^2 \to$ 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 $c\tau_{\rm darkpion} \in [1, 10^3]$ 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	$A'_\mu\left(e\epsilon J^\mu_{\rm em} + g_D\bar{\chi}\gamma^\mu\chi\right)$	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	$\mu_\chi, d_\chi \sim 4\times10^{-7}$ (4×10^{-6})μ_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	$\frac{1}{\Lambda^2}\sum_i\left(\bar{\chi}\gamma_\mu(1-\gamma_5)\chi\right)\left(\bar{\ell}\gamma^\mu(1-\gamma_5)\ell\right)$	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]
	$\sum_i \frac{1}{\Lambda_i^2}\left(\bar{e}\Gamma_\mu e\right)\left(\bar{\nu}_L\Gamma^\mu\chi_L\right)$ + 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

Vector-portal DM

→ CEPC can probe low-mass light dark states.



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Vector	$A'_\mu\,(e\epsilon J^\mu_{\rm em} + g_D\bar{\chi}\gamma^\mu\chi)$	250	5	$\epsilon \sim 10^{-3}$ for $g_D = e$ and $m_{A'} <$ 125 GeV ($\epsilon \sim 0.02$)	28, 29	[220]
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	$\frac{1}{2}\mu_\chi\bar{\chi}\sigma^{\mu\nu}\chi F_{\mu\nu} + \frac{i}{2}d_\chi\bar{\chi}\sigma^{\mu\nu}\gamma^5\chi F_{\mu\nu}$	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]
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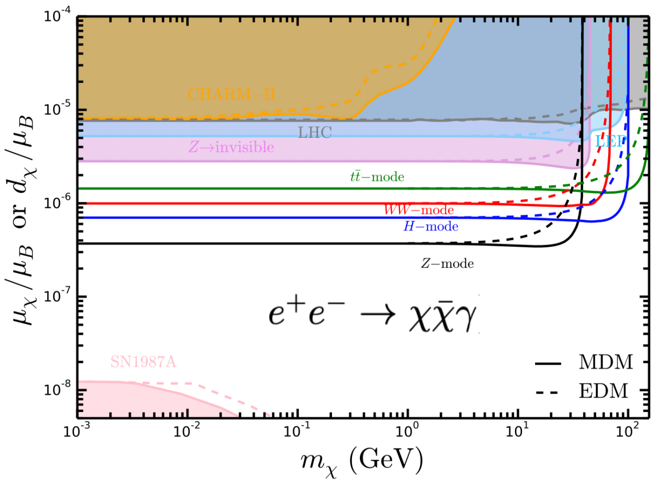


3. Dark Matter and Dark Sector

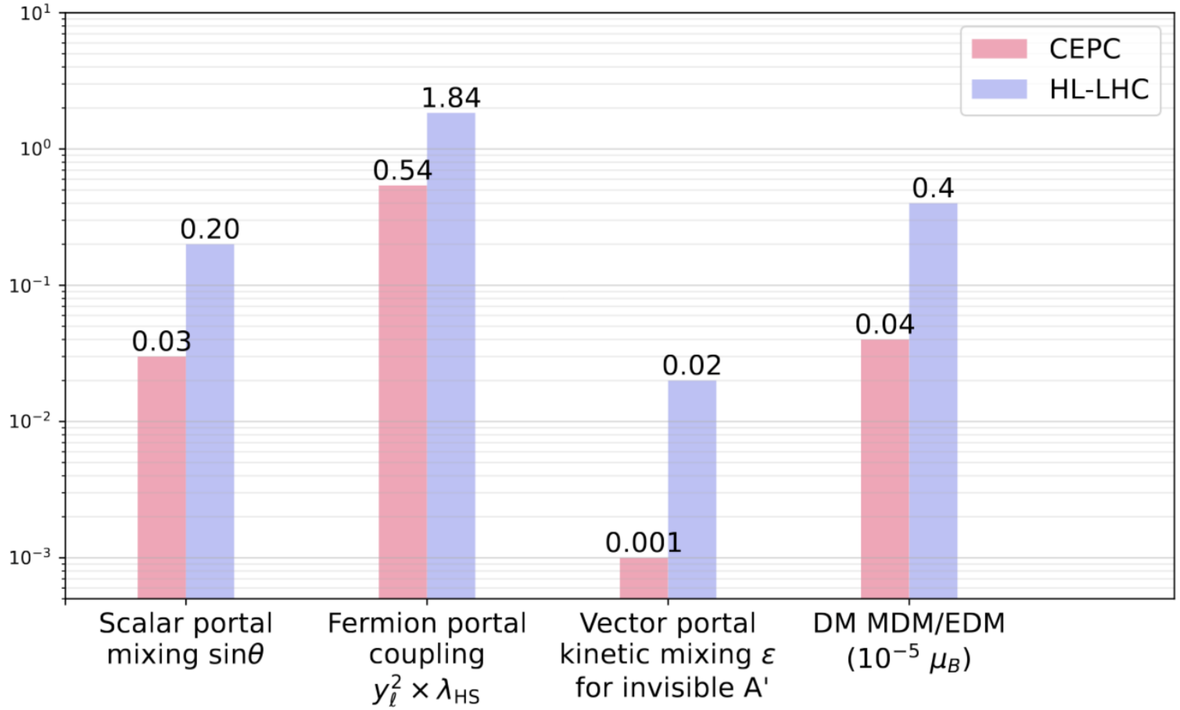


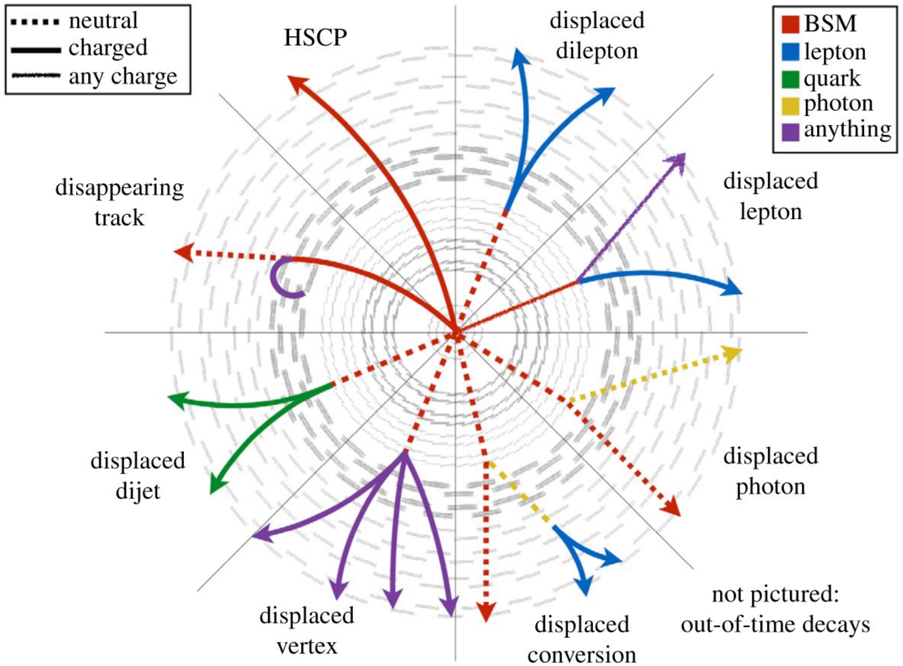
FIG. 35: The sensitivities for scalar, fermion, and vector portals, as well as dark matter magnetic dipole moment and electric dipole moment operators for CEPC and HL-LHC.

CEPC can improve the sensitivities by roughly one order of magnitude (vs LHC), for some cases.

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**
- **……**



VII. Long-lived Particle Searches (Xiang Chen, Liang Li, Ying-nan Mao, Kechen Wang, Zeren Simon Wang, Peiwen Wu)

A. Introduction

B. Computation of LLP signal-event rates

C. Studies with the main detector

1. Higgs boson decays
2. Z-boson decays
3. Supersymmetry (SUSY)
4. Vector-like leptons with scalar

D. Studies with far detectors

1. Far detectors at hadron colliders
2. Proposed far detectors at lepton co
3. Higgs boson decays
4. $Z-$boson decays
5. Axion-like particles

E. Studies with beam dumps

1. ALPs and new scalar particles
2. New neutral gauge bosons

F. Summary and Discussion

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

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]
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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]
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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]
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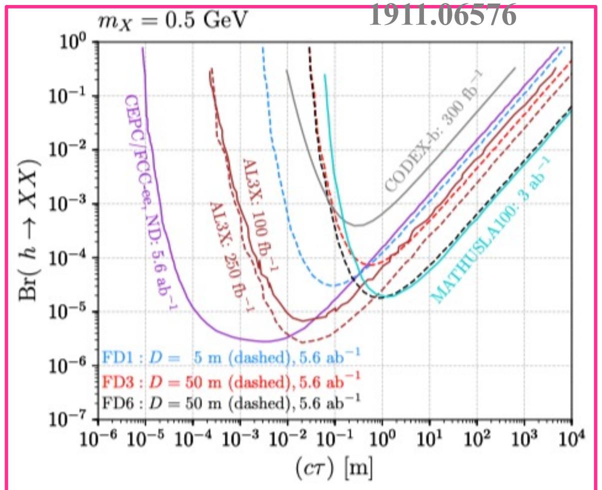
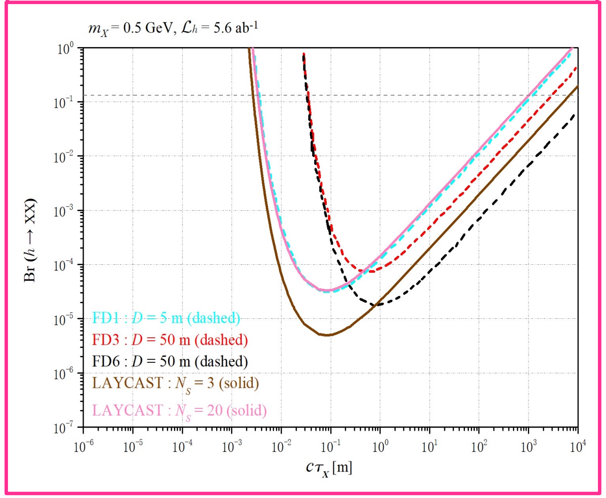
Hidden valley particles (π_V^0)	$Z\, h(\to \pi_V^0 \pi_V^0)$, $\pi_V^0 \to b\bar{b}$	350	1.0	MD	$\sigma(h) \times \text{BR}(h \to \pi_v^0 \pi_v^0) \sim 10^{-4}$ pb [$m \in (25, 50)$ GeV, $\tau \sim 10^2$ ps]	42	[260]
Dark photons (γ_D)	$Z(\to q\bar{q})\, h(\to \gamma_D \gamma_D)$, $\gamma_D \to \ell^- \ell^+ / q\bar{q}$	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

4. Long-lived particles (LLP)

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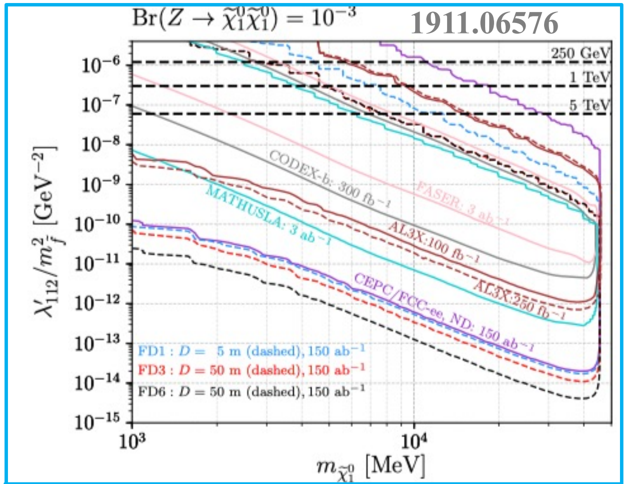

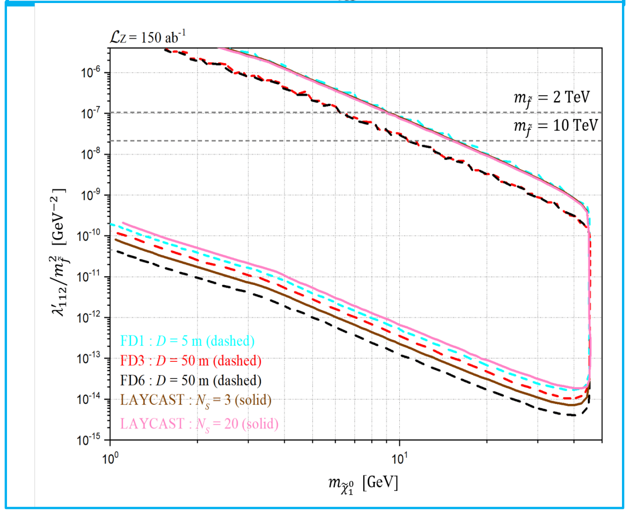

FD can extend and complement the sensitivity to the LLPs compared with Main Detector

SUSY RPV Neutralino1 from Z Decays

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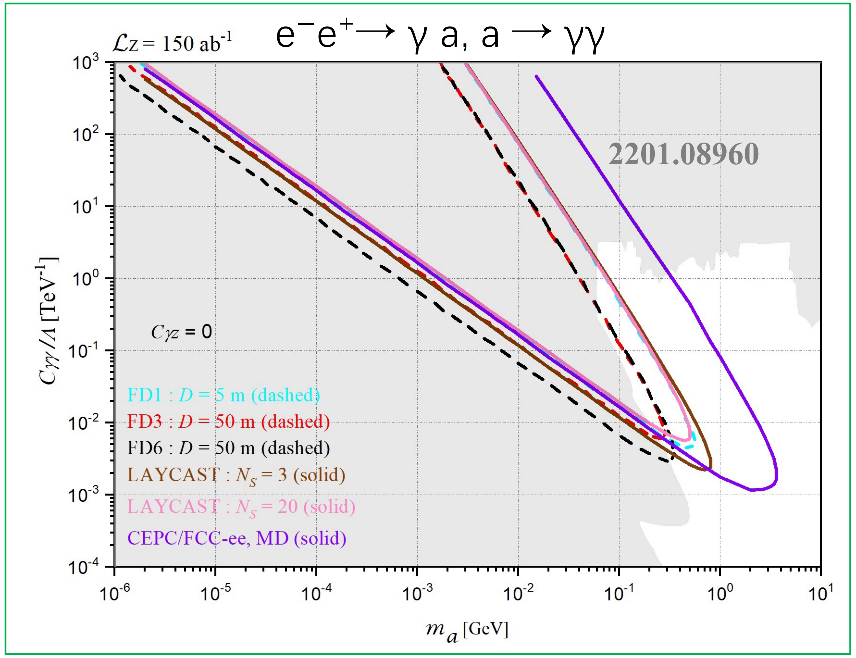
Good sensitivity for ALP



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**

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]
	$e^+e^- \to \tilde{B}\tilde{B} \to \gamma\gamma\tilde{G}\tilde{G}$.	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]
	$e^+_R e^-_R \to \tilde{\chi}^0_1(\text{bino}) + \tilde{\chi}^0_1(\text{bino}) + \gamma$	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]

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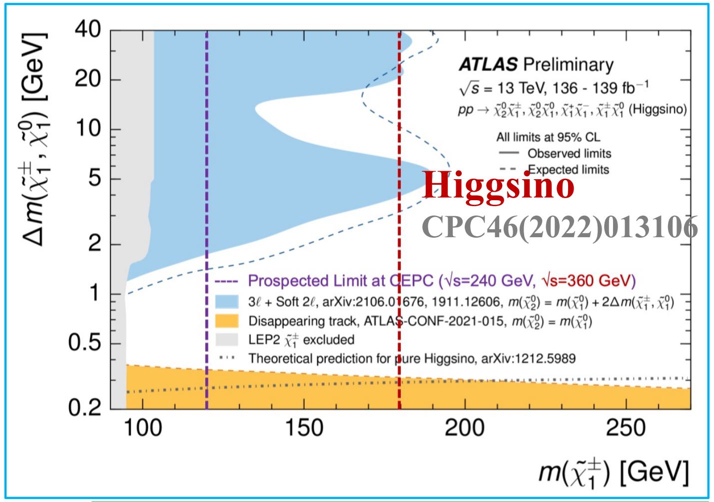
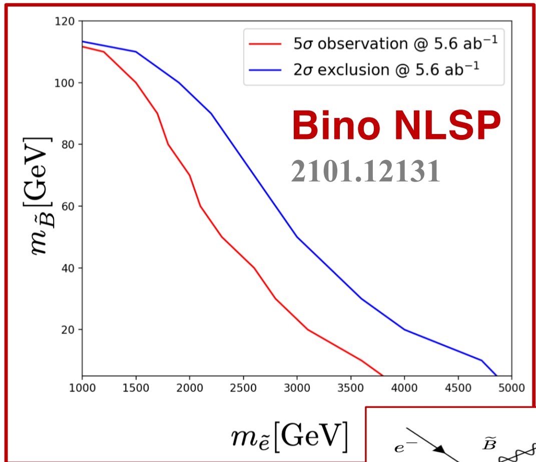
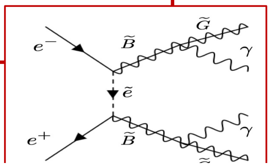
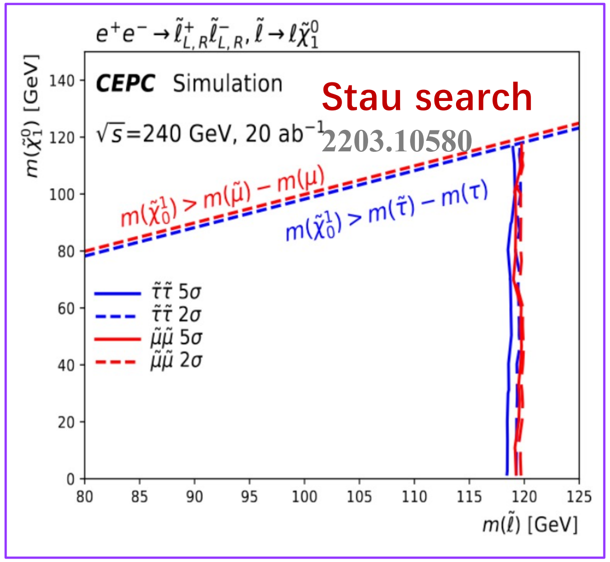
	smuon pair	360	1	smuon excluded up 177 GeV	61	[469]
	stau pair	360	1	stau excluded up 176 GeV	61	[469]
	$e_R^+e_R^- \to \tilde{\chi}_1^0(\text{bino}) + \tilde{\chi}_1^0(\text{bino}) + \gamma$	240	3	right-handed selectron excluded up to 210 GeV	62	[470]
	off-shell smuon pair	240	5	smuon excluded up 126 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]

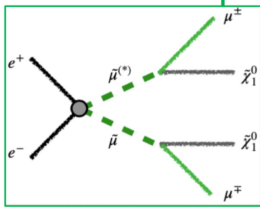


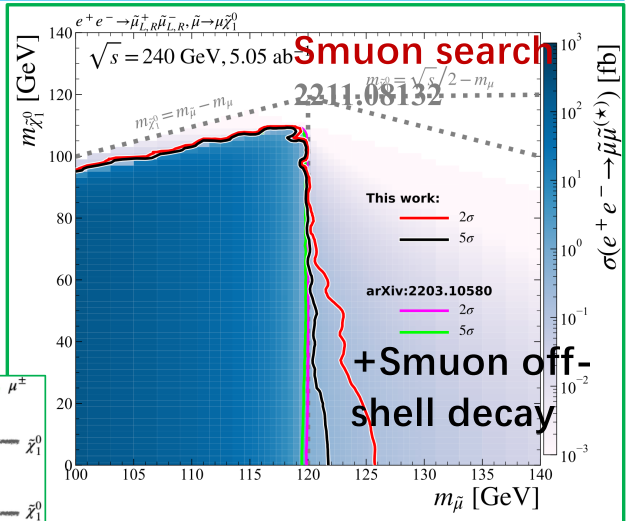
$$\tilde{B} \to \tilde{G}/\tilde{a} + \gamma$$



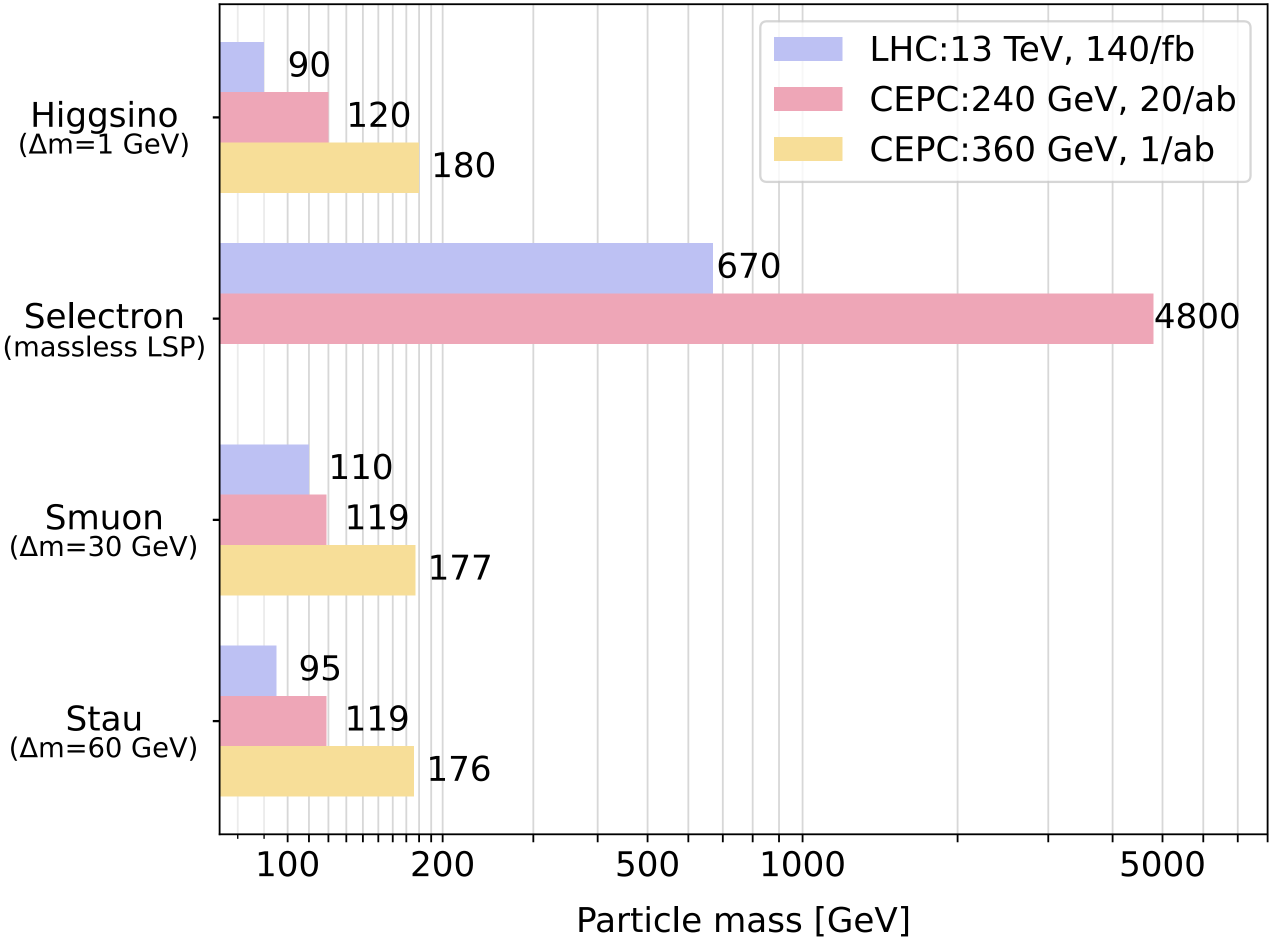




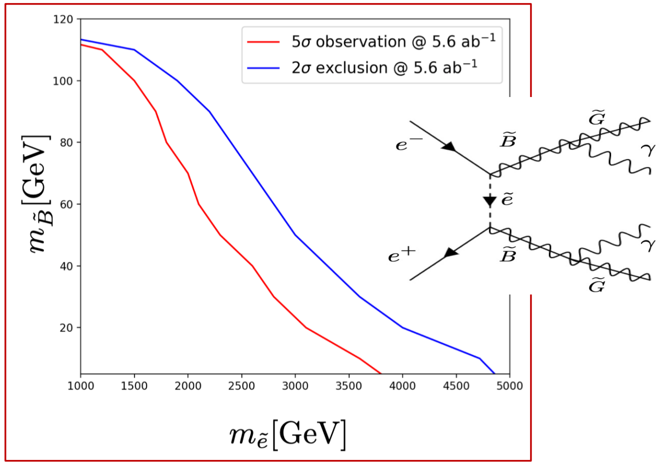




5. SUSY Searches at CEPC



- **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**

IX. Flavor Portal New Physics (Lingfeng, Xinqiang)

A. cLFV processes

B. Decays of b-flavored and charmed hadrons

C. Light BSM degrees of freedom from flavor transitions

D. Summary

- 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)
$\mathrm{BR}(\Lambda_b \to \Lambda_c\tau\nu)/\mathrm{BR}(B_c \to \Lambda_c\mu\nu)$	$\pm\ 0.076$	$\pm 0.05\%$ (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

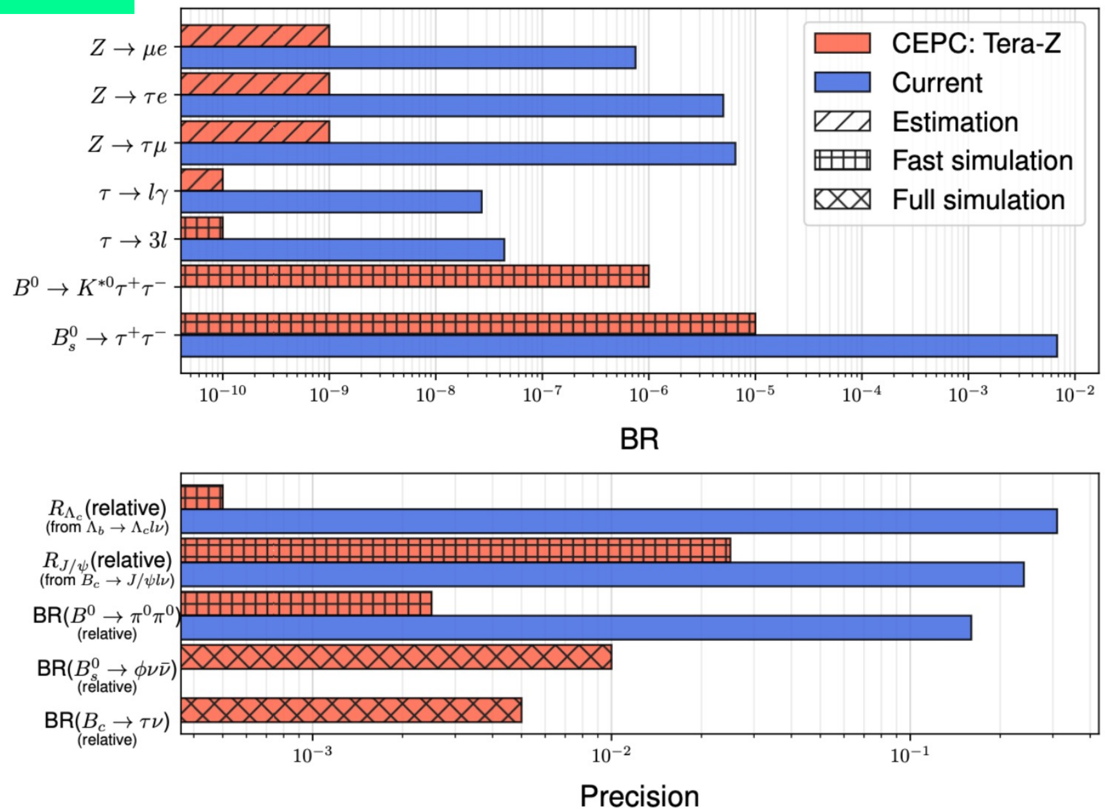


FIG. 67: Summary plot of relevant flavor physics probes at CEPC. The upper and lower parts of the plot correspond to the BR upper limits reached and the sensitivities of SM processes. The current limits of $\tau \to 3\ell$ and $\ell\gamma$ channels are taken as the best one among all lepton flavor combinations.

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

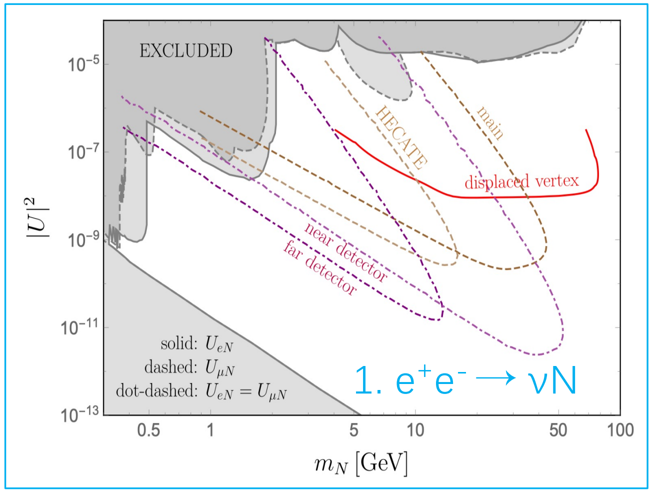
C. Active-sterile neutrino transition magnetic moments

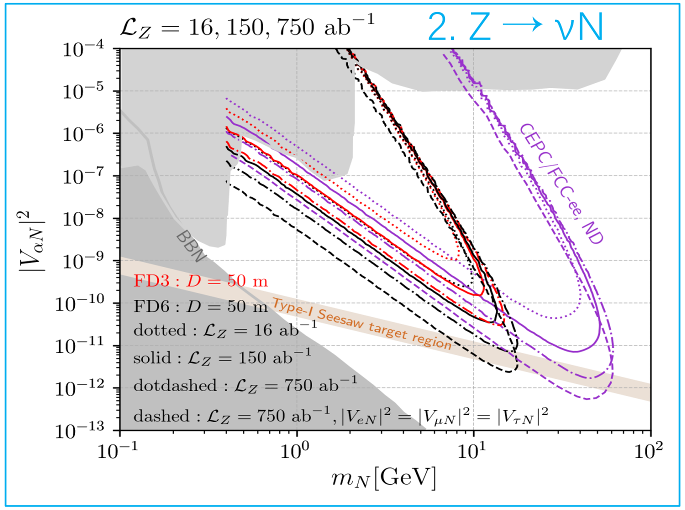
D. Neutral and doubly-charged scalars in seesaw models

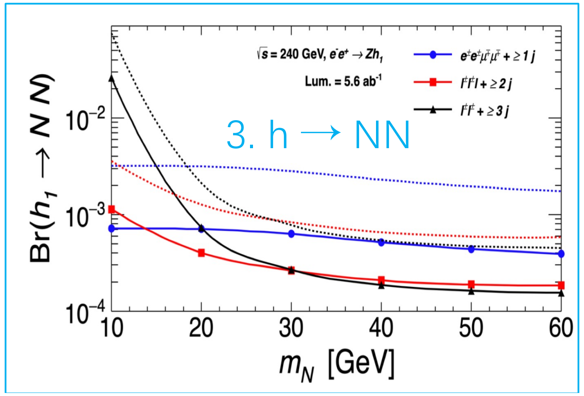
E. Connection to Leptogenesis and Dark Matter

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**.

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

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

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

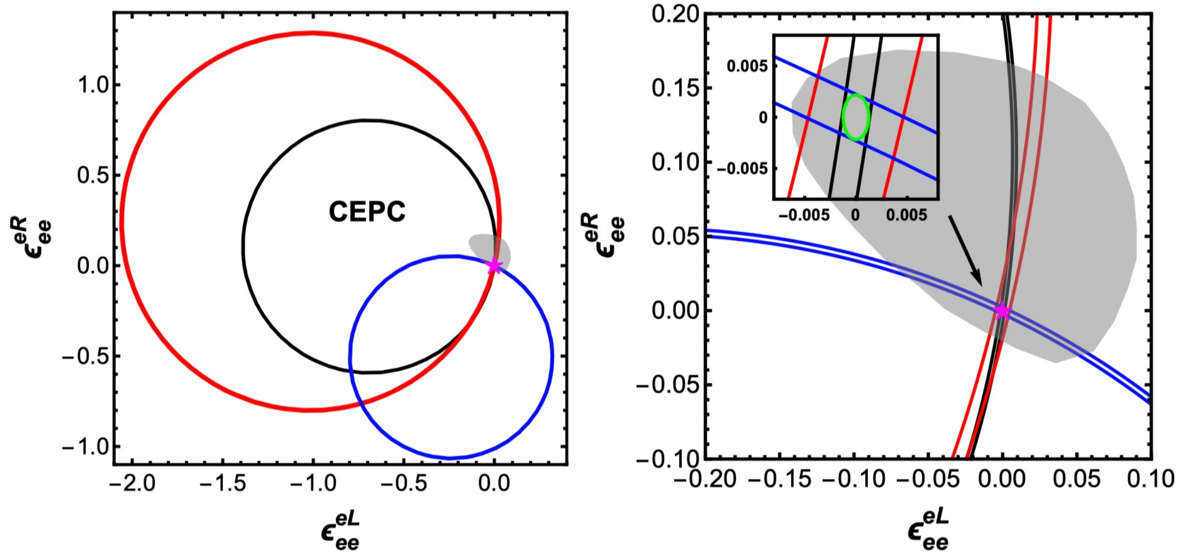


FIG. 76: *Left panel*: The allowed 90% C.L. region for electron-type neutrino NSI in the planes of (ϵ_{ee}^{eL}, ϵ_{ee}^{eR}) at future CEPC with 5.6 ab^{-1} data of $\sqrt{s} = 240$ GeV (Black), with 2.6 ab^{-1} data of $\sqrt{s} = 160$ GeV (Red), and with 16 ab^{-1} data of $\sqrt{s} = 91.2$ GeV (Blue), 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

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

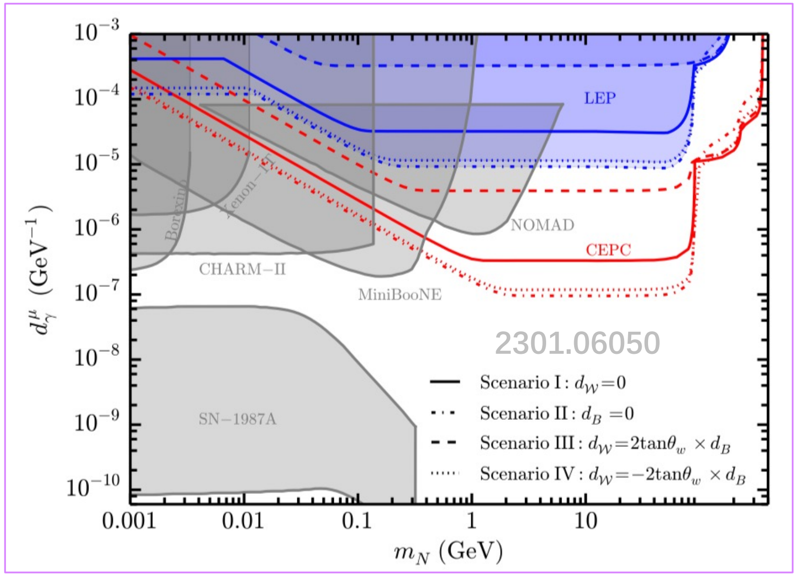
C. Active-sterile neutrino transition magnetic moments

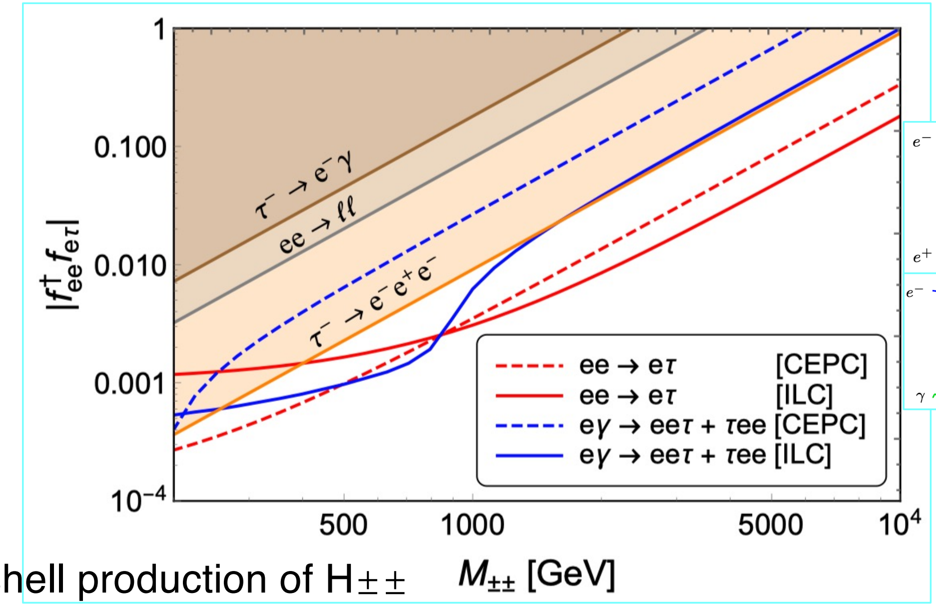
D. Neutral and doubly-charged scalars in seesaw models

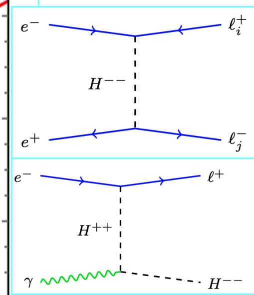
E. Connection to Leptogenesis and Dark Matter

F. Summary

dipole portal couplings d^k_γ







off-shell production of H±±

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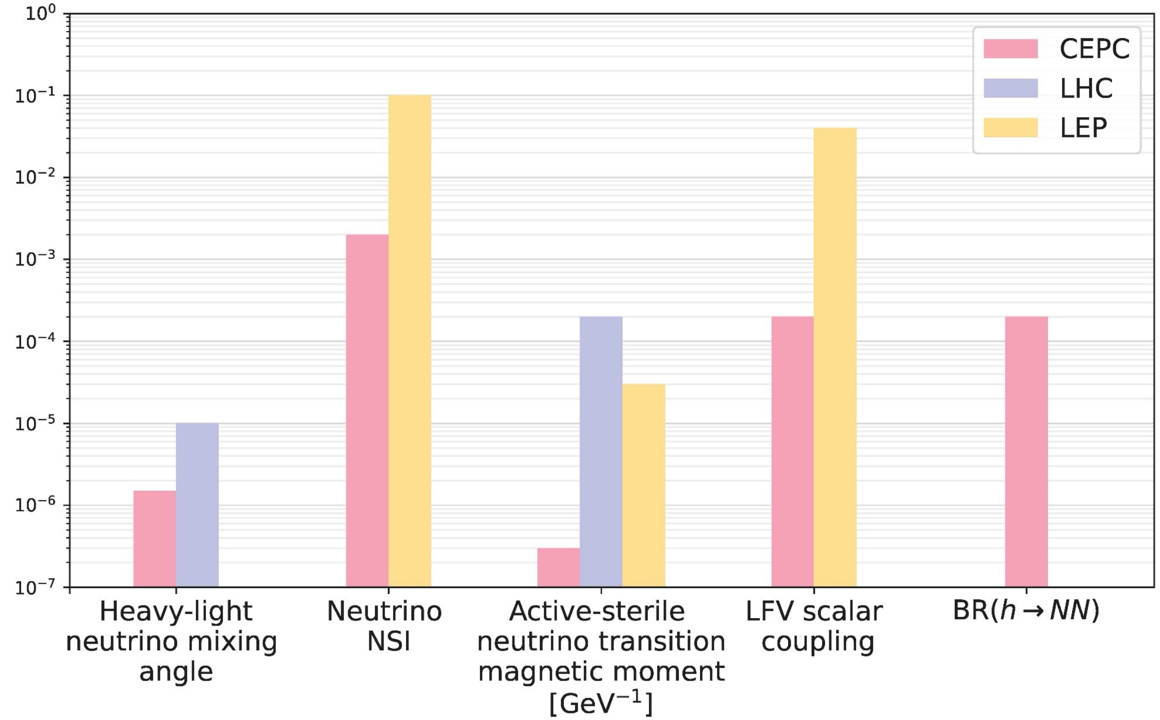
Summary plot of neutrino relevant models



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

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
- B. Emergent Hadron Mass
- C. Lepton form factors
  1. General remarks on μ/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

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

TABLE XIII: Projected energy scale sensitivities via exotic searches at the CEPC.

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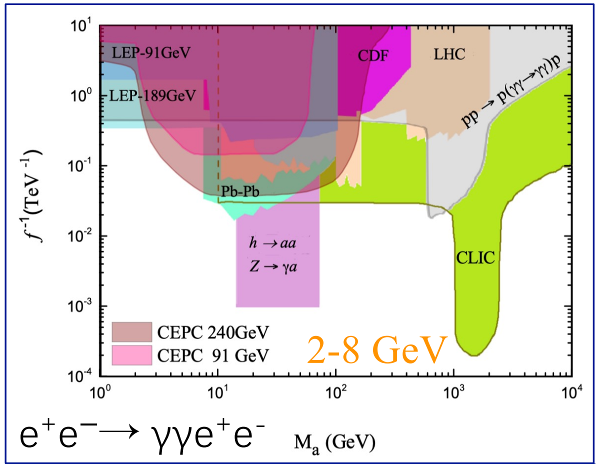

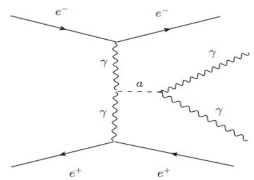

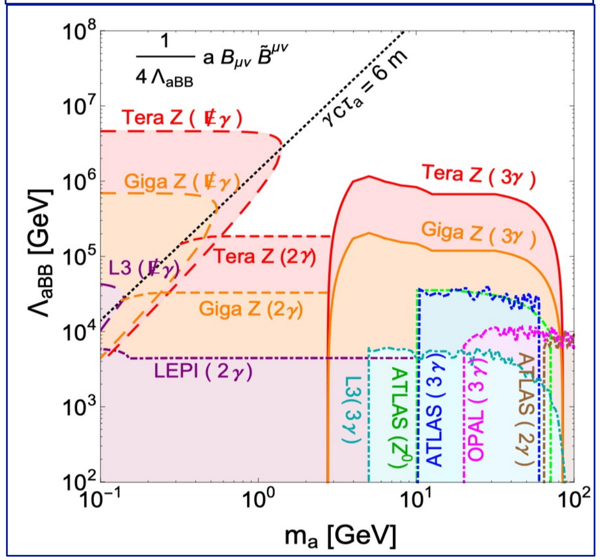

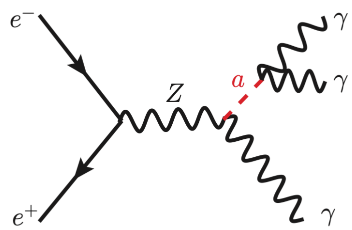

m_a ranges from 0.1 to 100 GeV, extending current limits by more than two orders of magnitude

8. More exotics

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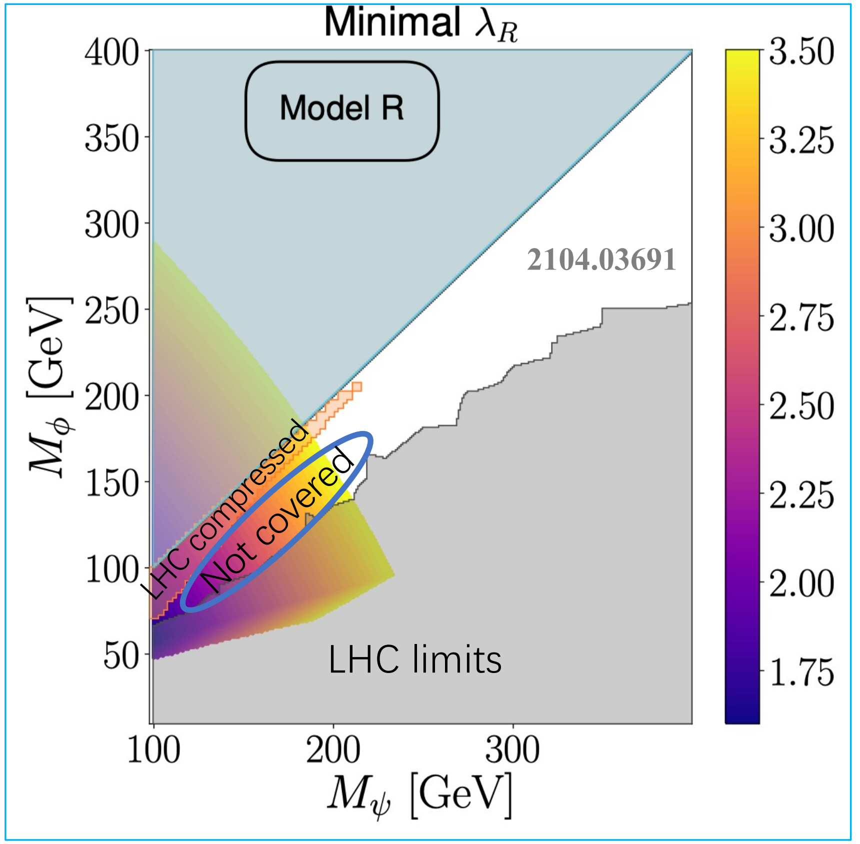
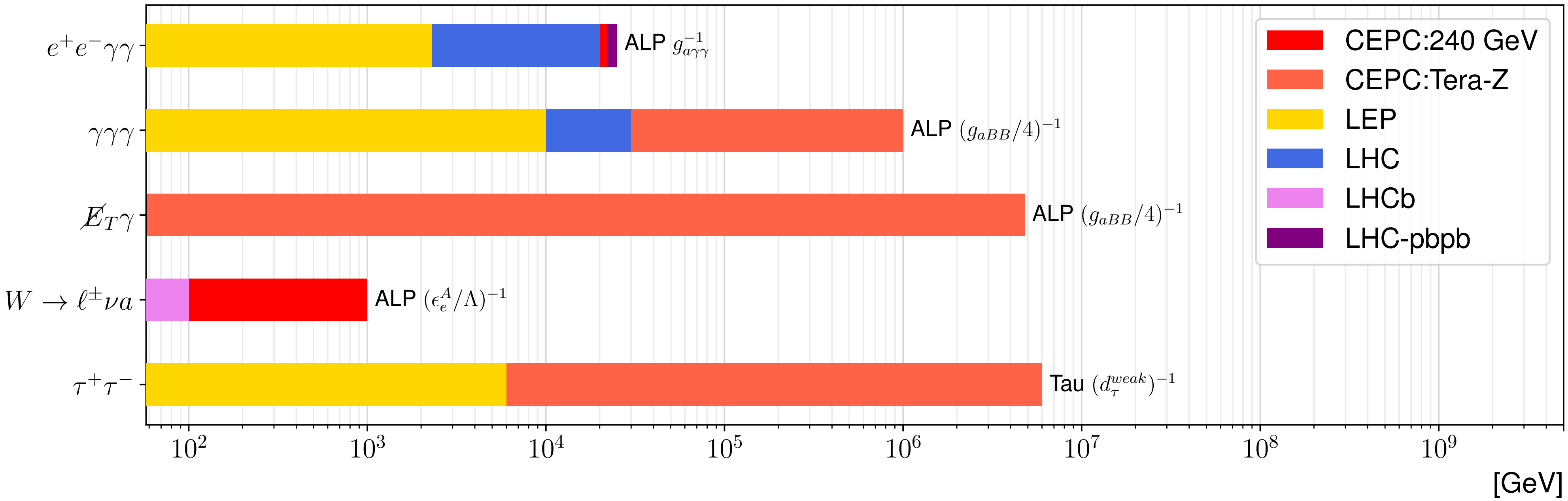


- Light EWKinos, smuon, stau co-annihilation can explain mu g-2 excess
- Gaps from LHC, can cover by CEPC

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

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

XII. Global Fits (Jiayin, Yang, Yong Du)

A. SMEFT global fits

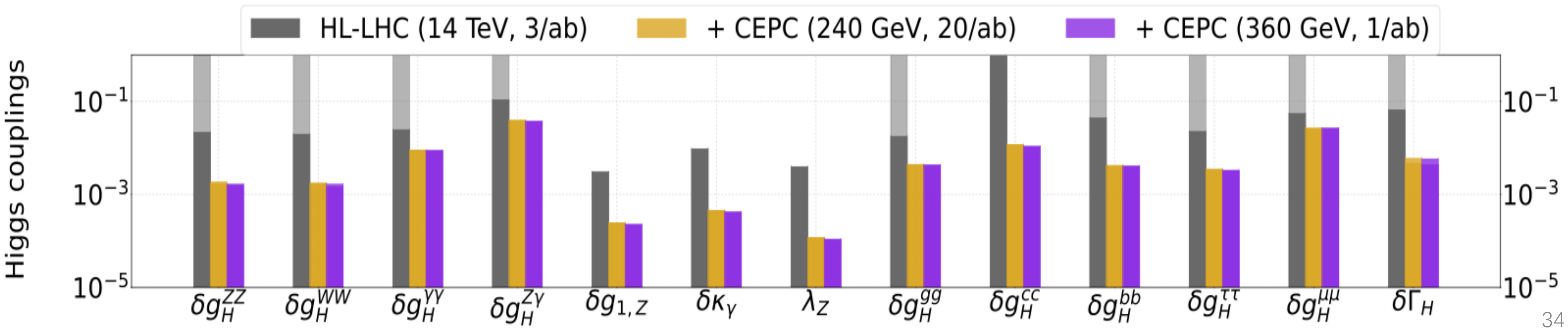
B. 2HDM global fits (Tao Han, Shufang Su, Wei Su, Yongcheng Wu)

C. SUSY 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**



9. Global fits

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- **2HDM**

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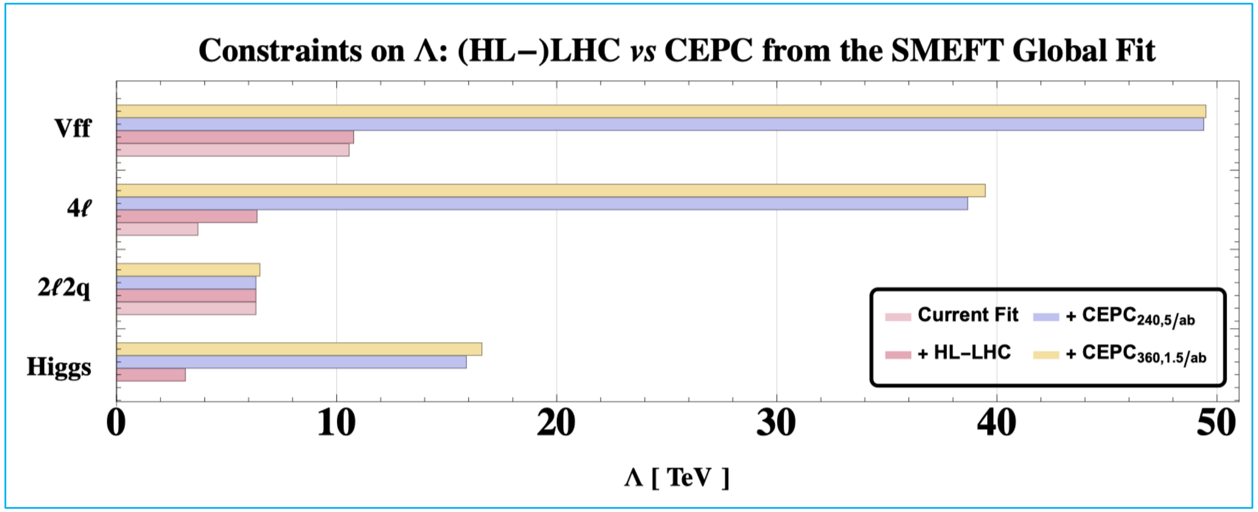

9. Global fits

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

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

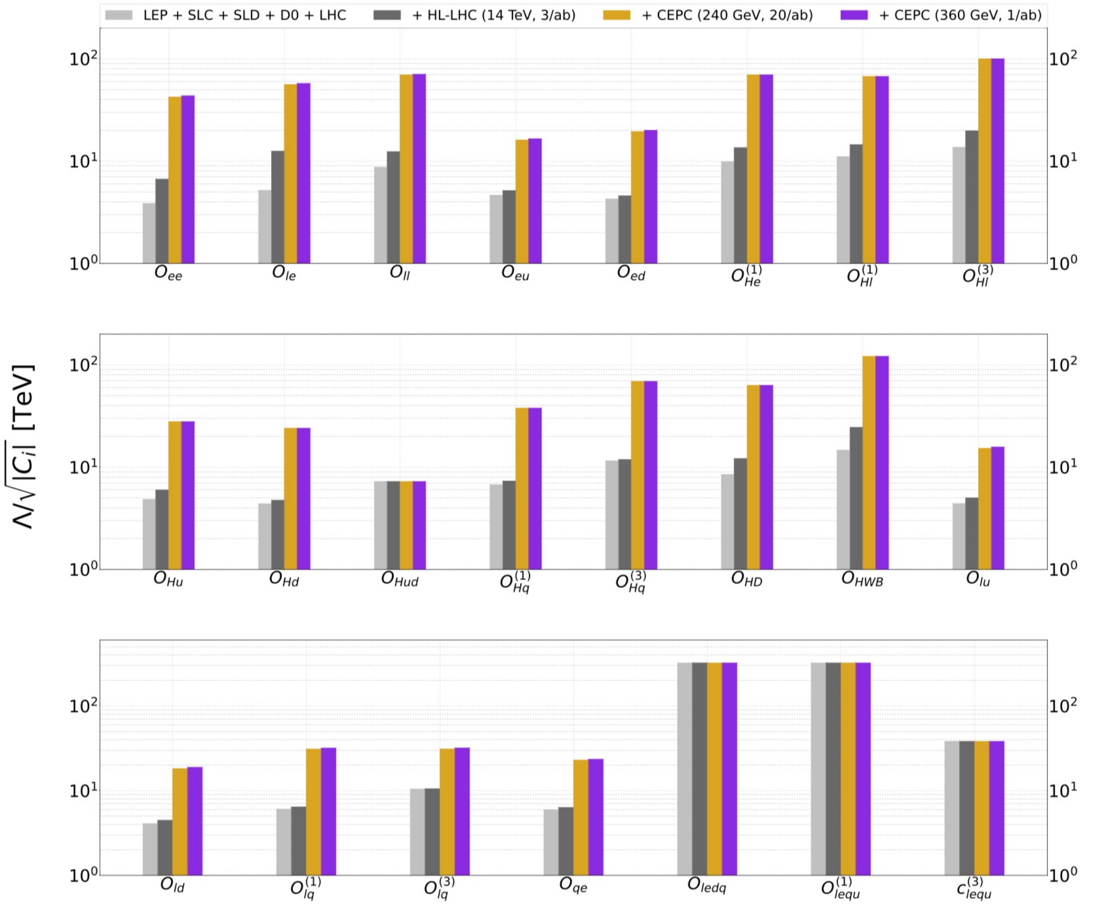


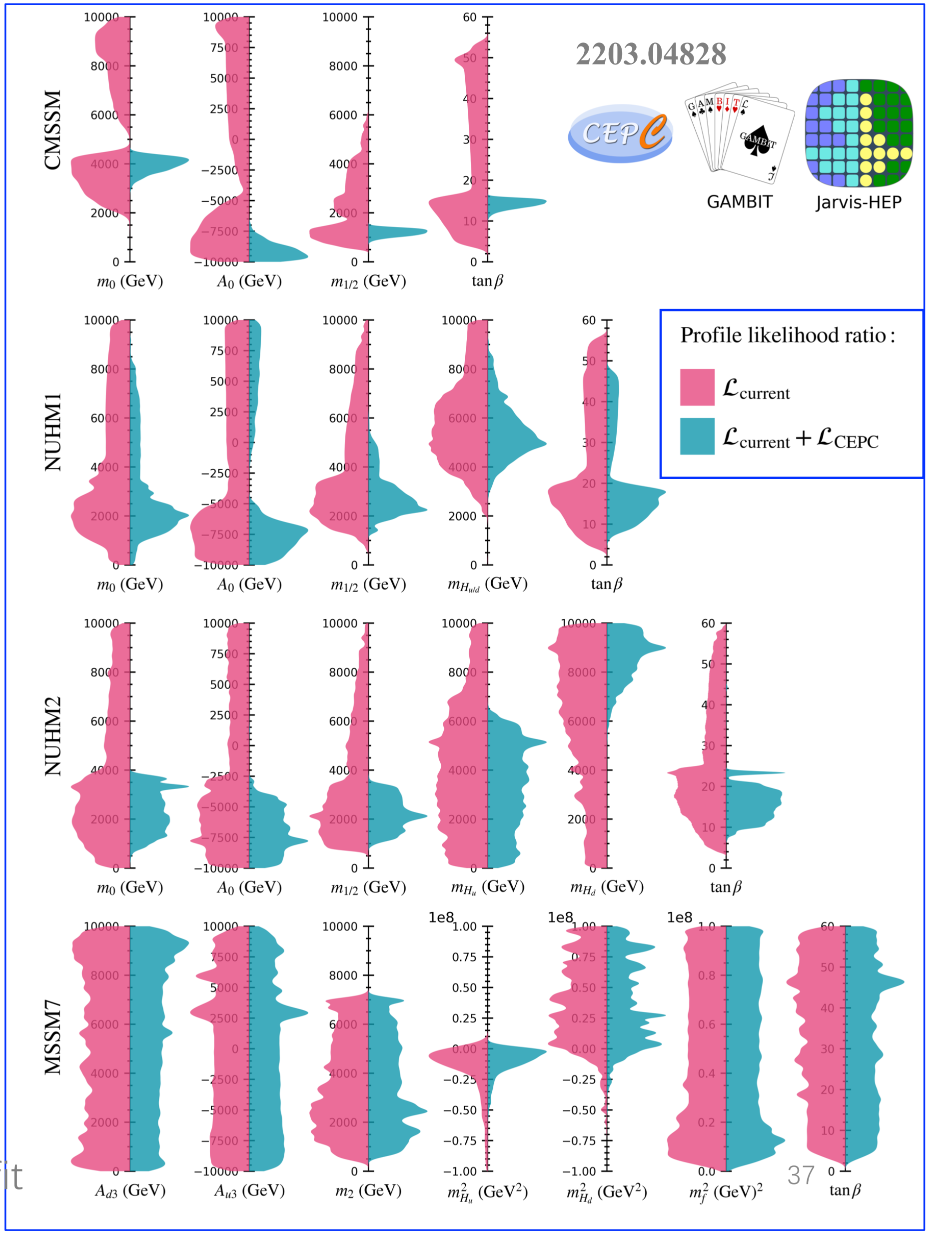
FIG. 95: Lower bounds on $\Lambda/\sqrt{|C_i|}$ at the 95% CL as presented in the Warsaw basis, assuming flavor universality and one operator at a time.

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.

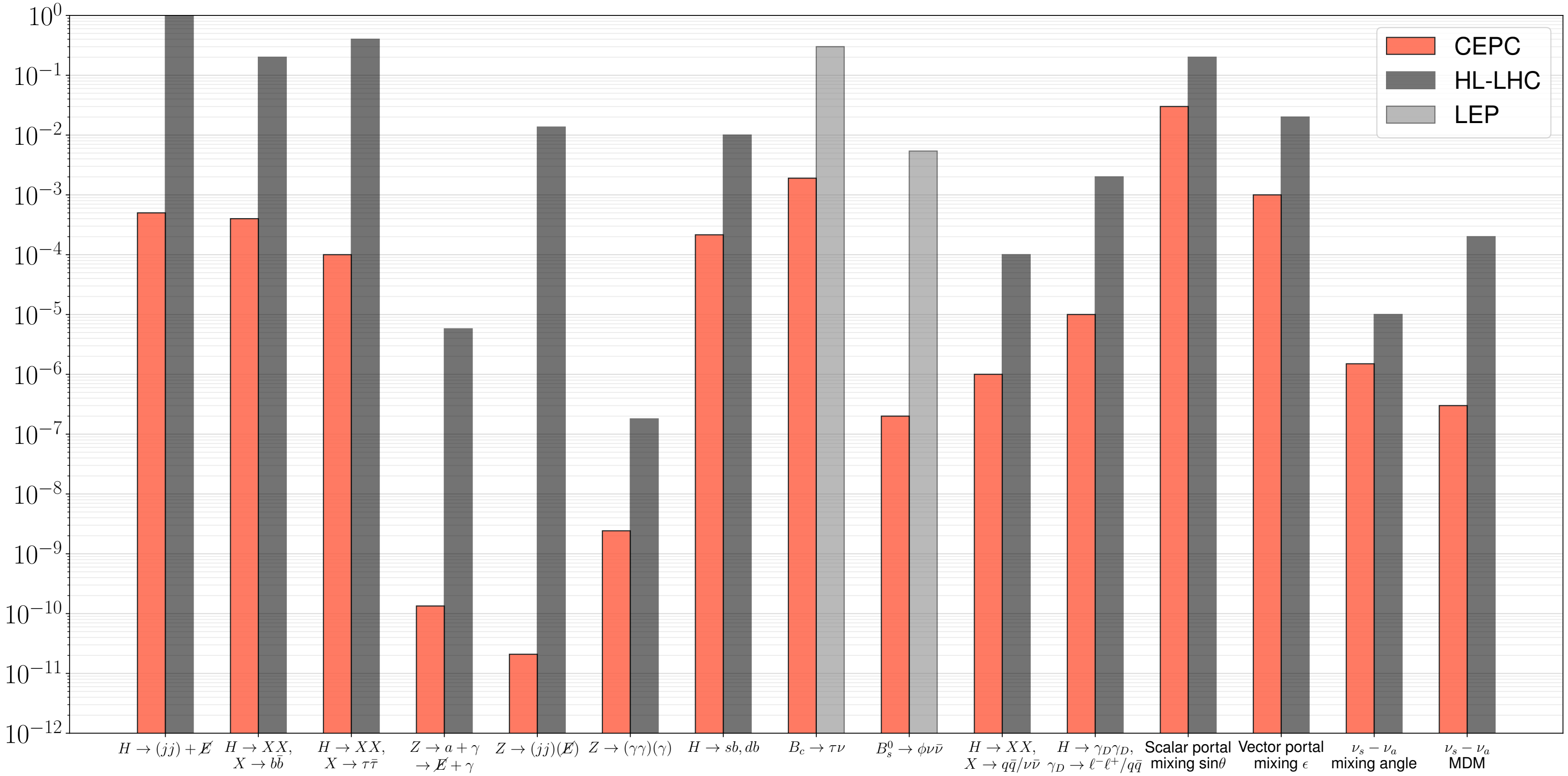


One-dimensional profiled likelihood ratio for the global fit

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

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

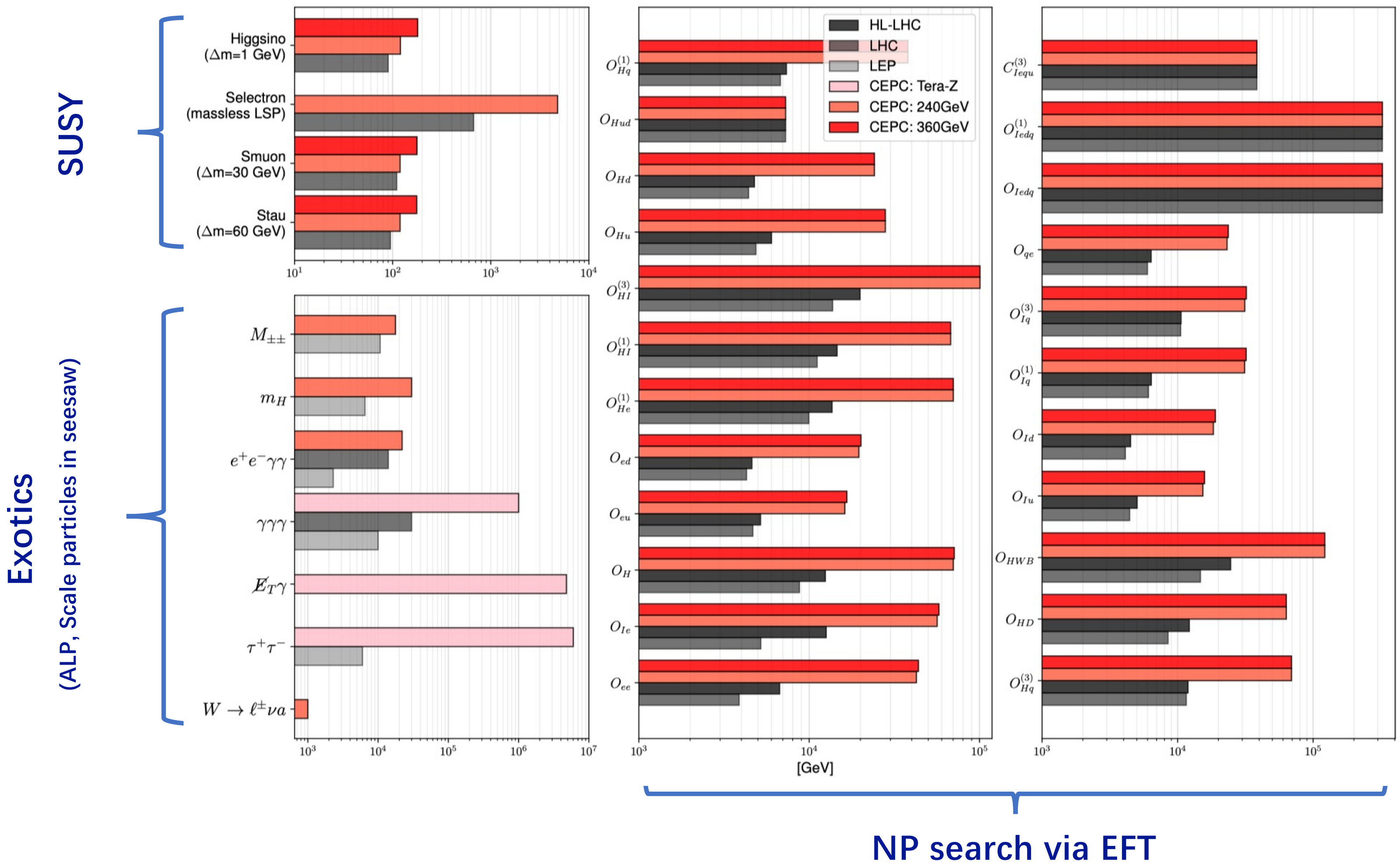
LLP

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

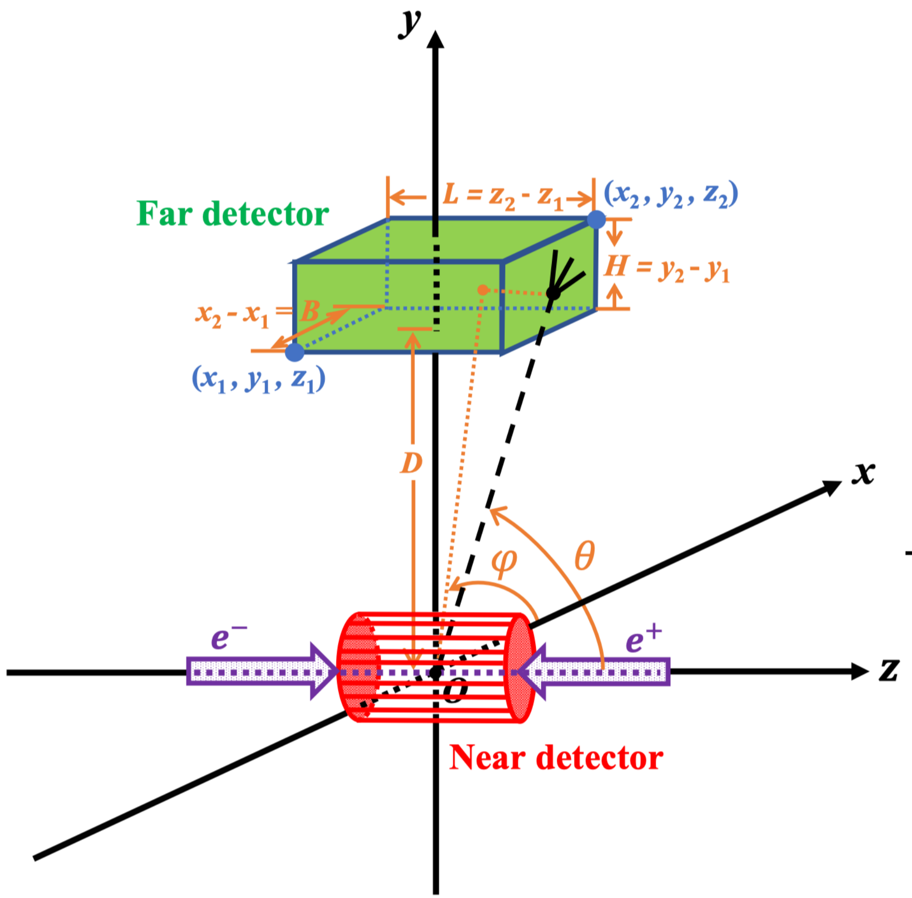


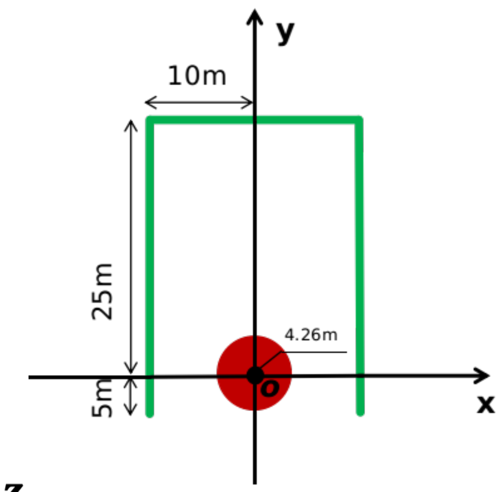
The new physics discovery power could also be expressed in the explorable energy range:

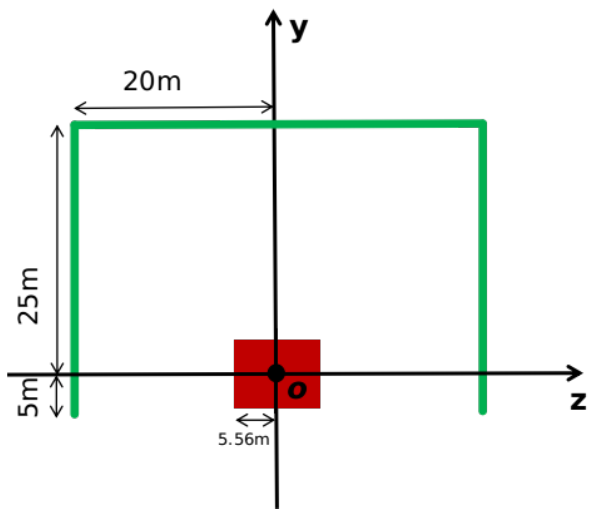
- SMEFT: up to 10-100 TeV, improve NP scale by a factor of 3~10
- SUSY/exotics: from half beam energy to TeV scale

Thanks for your attention!

FAR Detector







LAYCAST

SMEFT framework

The SMEFT framework—As has been previously addressed, the null result at the LHC since the Higgs discovery indicates that the SM is possibly a low-energy effective theory of some UV completed theories at a scale $\Lambda \gg \Lambda_{\mathrm{EW}}$, with $\Lambda_{\mathrm{EW}} = 246\,\mathrm{GeV}$ the electroweak scale. This large energy gap then naturally renders the EFT framework ideal for a model-independent study on new physics based on the decoupling theorem [732]. In this section, we focus on the SMEFT framework based on the same $\mathrm{SU}(3)_c \otimes \mathrm{SU}(2)_L \otimes \mathrm{U}(1)_Y$ *local* gauge symmetry as respected by the SM while relaxing the accidental *global* symmetries in the SM. Generically, the SMEFT can be obtained by extending the SM Lagrangian as

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \sum_{n=5}^{\infty} \sum_{i} \frac{\delta c_i}{\Lambda^{n-4}} \mathcal{O}_i^{(n)}, \tag{39}$$

where $\mathcal{O}^{(n)}$ represents operators with mass dimension n, the index i corresponds to the sum over the operator basis at dimension n, and δc_i is the associated Wilson coefficient. Clearly, contributions from the SMEFT operators will be generically suppressed by powers of p^2/Λ^2, with p^2 the momentum transfer and satisfying $p^2 \ll \Lambda^2$. Therefore, the dominant contribution will be coming from the dimension-5 operators, which are also known as the Weinberg operators [503]. These operators can induce non-vanishing neutrino masses after the electroweak spontaneous symmetry breaking (EWSSB), but will be otherwise irrelevant