Interplay & synergies between the Cosmic/X Frontier and CEPC

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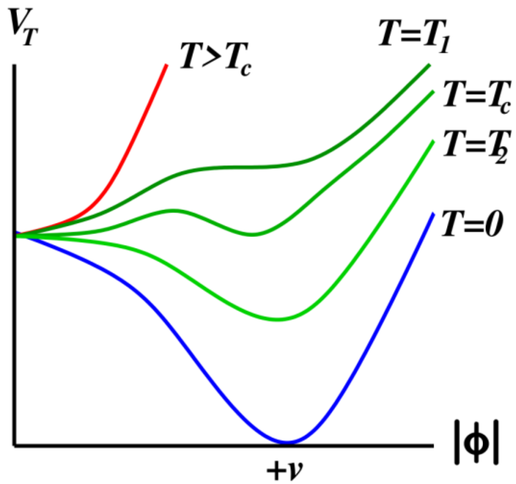
[contain adapted slides and summary]

高能大会2022-BSM
2022-8-11

- EWPT & the Higgs machine
- Other connections: DM, neutrino/lepton properties

Early universe: EWPT

- V(H) gets finite-T corrections at very high z.



FOPT needs a lower minimum and a barrier
(fig. from 2008.09136)

$$V(H,T) = m^2(T)H^2 + E(T)H^3 + \lambda(T)H^4 + \ldots$$

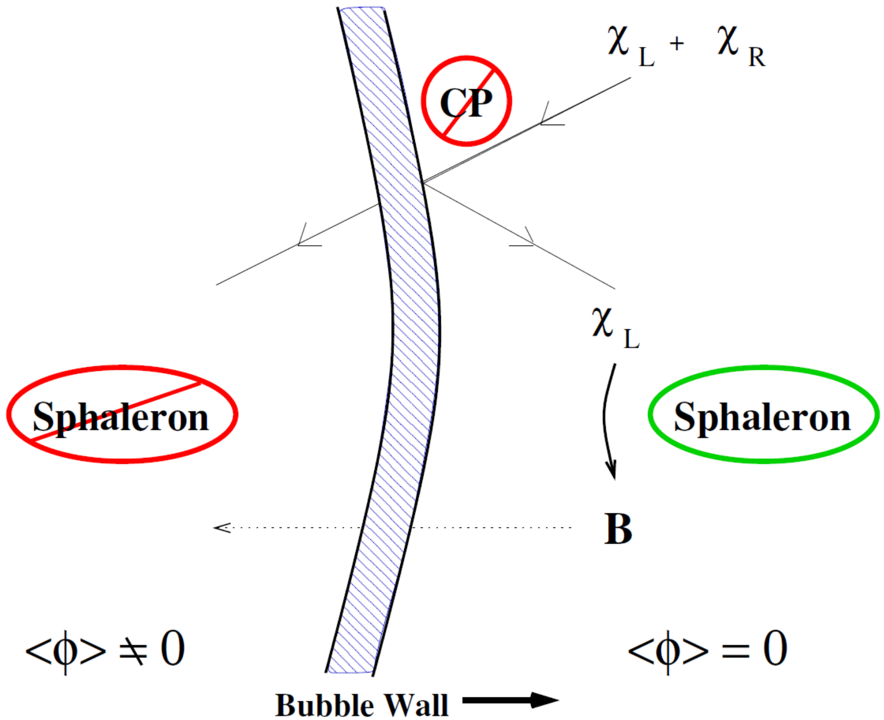
Contributions:

Loop level: gauge boson (SM), stops (Susy), extra coupled stuff (extend Higgs, etc.)

Tree level: extra scalars: $S|H|^2$, $|S|^2|H|^2$, NMSSM, etc.

…

FOEWPT can create vacuum bubbles and mediate baryogenesis.



$$\partial_\mu J^\mu_B = -\frac{g_2^2}{64\pi^2}\epsilon^{\mu\nu\rho\sigma}W^a_{\mu\nu}W^a_{\rho\sigma}$$

BNV by anomaly, in presence of $SU(2)_L$ field

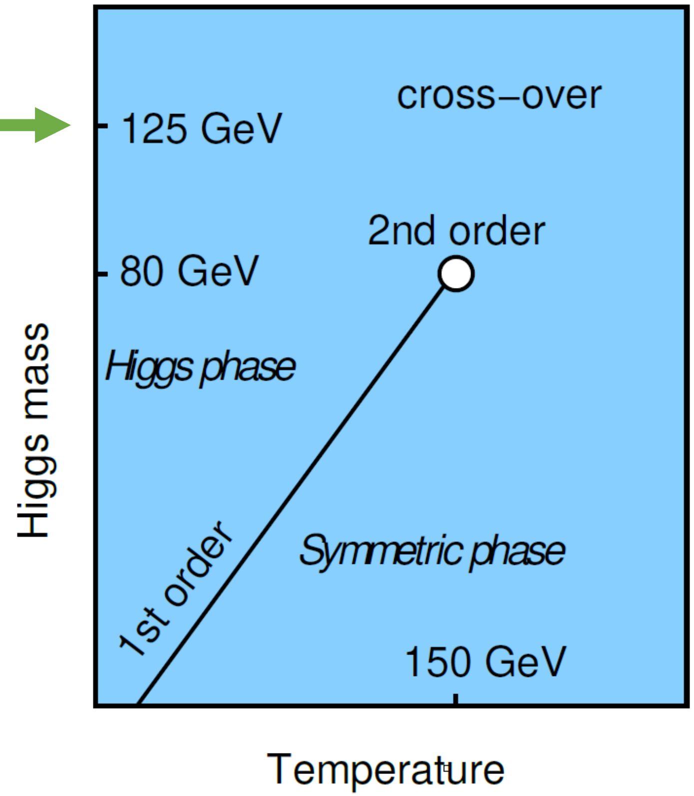
t'Hooft, 1976

D. Morrissey, M. Ramsey-Musolf, 12'

Figure 2. Baryon production in front of the bubble walls.

2008.09136

SM is here.



w/o top, SM would need $m_H < 40$ GeV

The phase diagram of the Standard model.
Higgs masses of $m_H <\sim 80$ GeV (excluded) the Standard Model undergoes a FOEWPT

Lattice: Kajantie, et.al, 96', Csikor, Fordor, Heitger, 98'

SM:

SM Higgs mass too low
for FOPT. (<70~80 GeV)
Bochkarev and M. E. Shaposhnikov, 87'

Even w FOPT, SM's CKM
insufficient for baryogenesis
see hep-ph/9312215, /9404302,/9406289

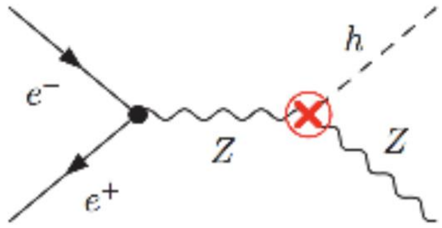
BSM (is necessary!):

Must exist in abundance
around transition Tc
(-> close to EW scale)

Moderately (at least) coupled
to the SM
(-> coupled sectors)

- 2HDM: $m_H \geq 300$ (transport by tops)
- SM with a dim-6 Higgs potential for M<800 GeV (EDMs similar to 2HDM)
- MSSM: light stops (LHC search), charginos (EDMs)
- Singlet models (NMSSM, SM+S): cubic terms in the tree-level potential induce a strong phase transition EDM constraints somewhat relaxed

Collider: hVV, hhh coupling measurements.



Craig, Englert, McCullough, 13'

A Very Inert (Z_2) Example:

SM + real singlet scalar

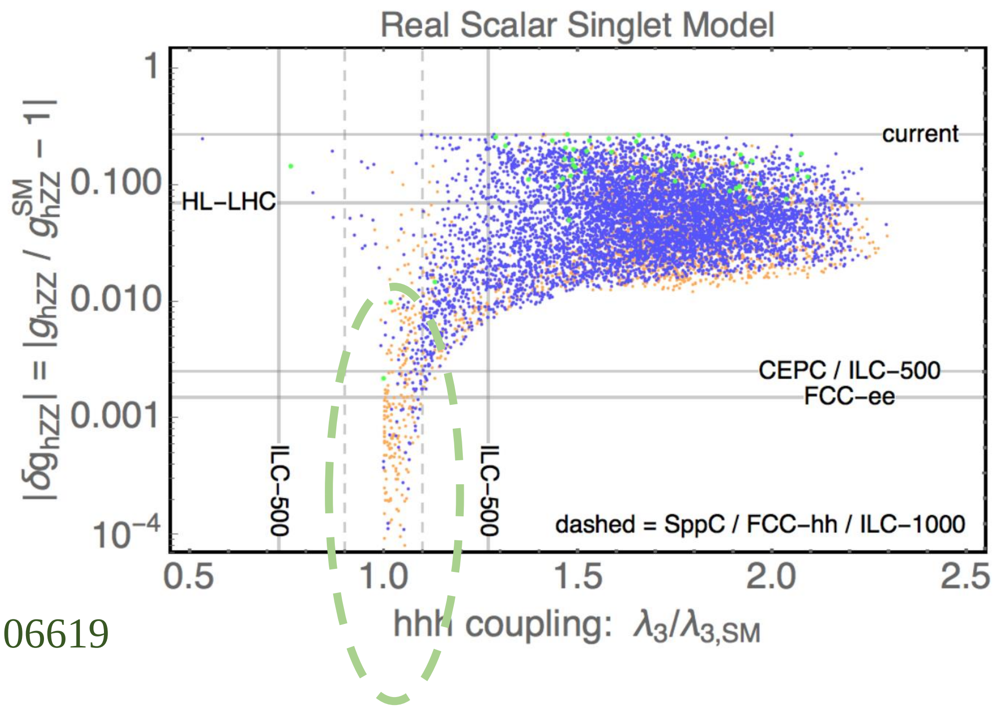
BSM singlet carries odd parity

$$\lambda_{hs} \Phi^\dagger \Phi S^2$$

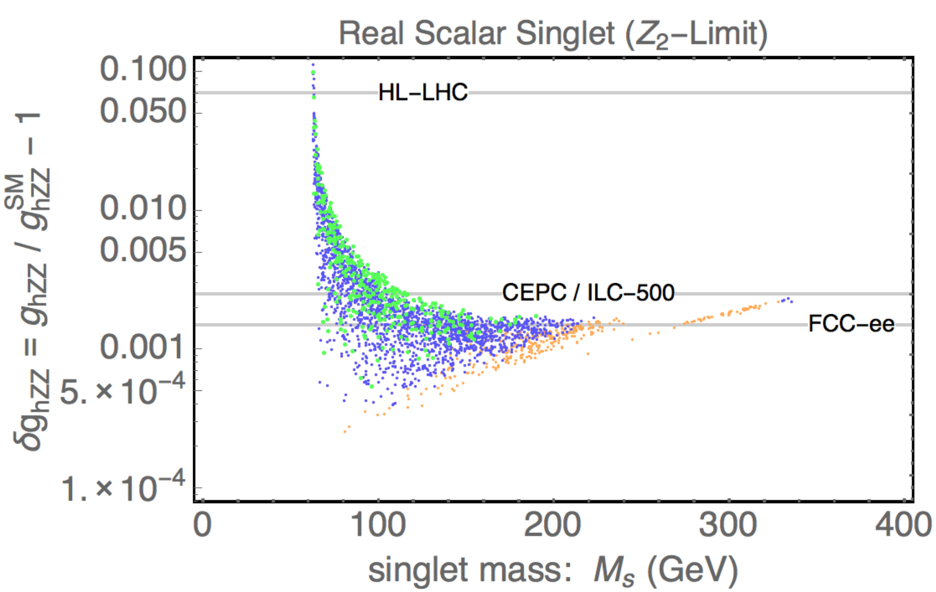
-> h-s mixing forbidden by Z_2

-> modified Higgs (125GeV) branching & couplings at loop level

P. Huang, et.al. 1608.06619



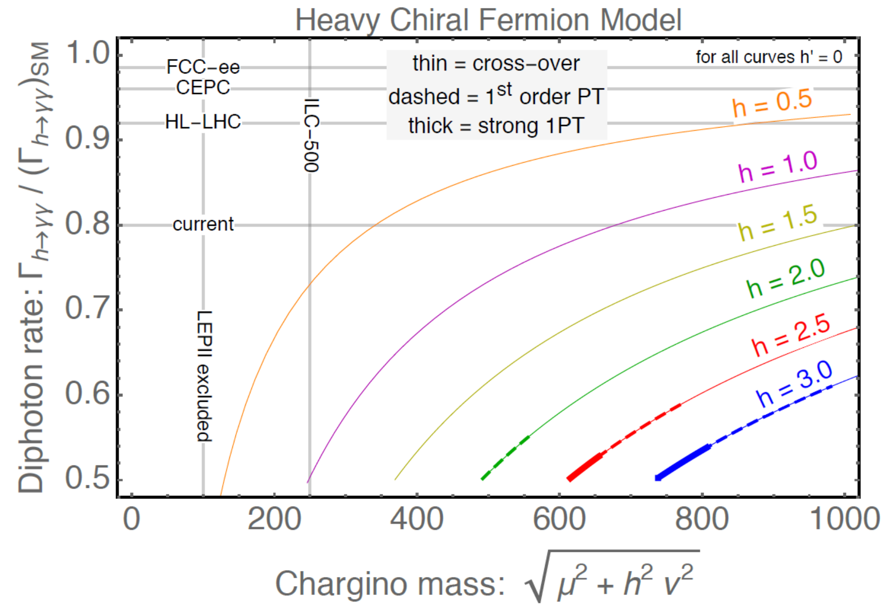
FOPT even at `SM-like' region



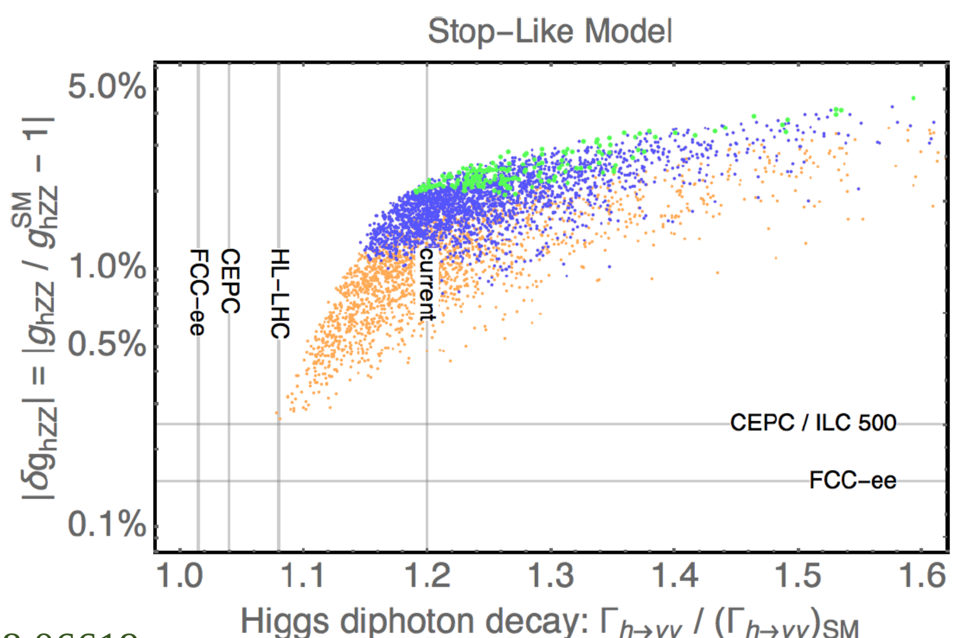
Yield hzz correction up to 30% (of SM)

Large range of hhh cubic coupling (compared to SM) gives FOEWPT

New charged doublet/fermions



Loop correction to Higgs branching into diphotons.



P.Huang, et.al. 1608.06619

Highlights from CEPC - Astro/Cosmic connection

From PT： Gravitational Wave

Three sources of energy

$$h^2\Omega_{\rm GW} \simeq h^2\Omega_\phi + h^2\Omega_{\rm sw} + h^2\Omega_{\rm turb}$$

① Bubble collision
② Sound wave in plasma
③ Magnetic Turbulence

BSM Phenomena cross-check need a model interpretation.

GW: See Ligong Bian's talk yesterday.

Joint Workshop(s) of the CEPC Physics, Software and New Detector Concept in 202X

→ Join the discussion←
https://indico.ihep.ac.cn/event/16509/
https://indico.ihep.ac.cn/event/14938
https://indico.ihep.ac.cn/event/13888/

Take-home Msg：

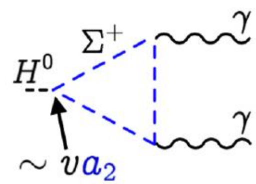
CEPC can probe BSM potentials that yield SFOEWPT, w precision *Higgs* measurements. Can cross-test with GW data

Doublet + Triplet Higgs (w/o Z_2)

Friedrich, MJRM, Tenkanen, Tran, 2203.05889
(fig. adapted from V.Q.Tran's talk)

Higgs portal interaction

$$+a_1 H^\dagger \Sigma H + \frac{a_2}{2} H^\dagger H \vec{\Sigma}^2$$

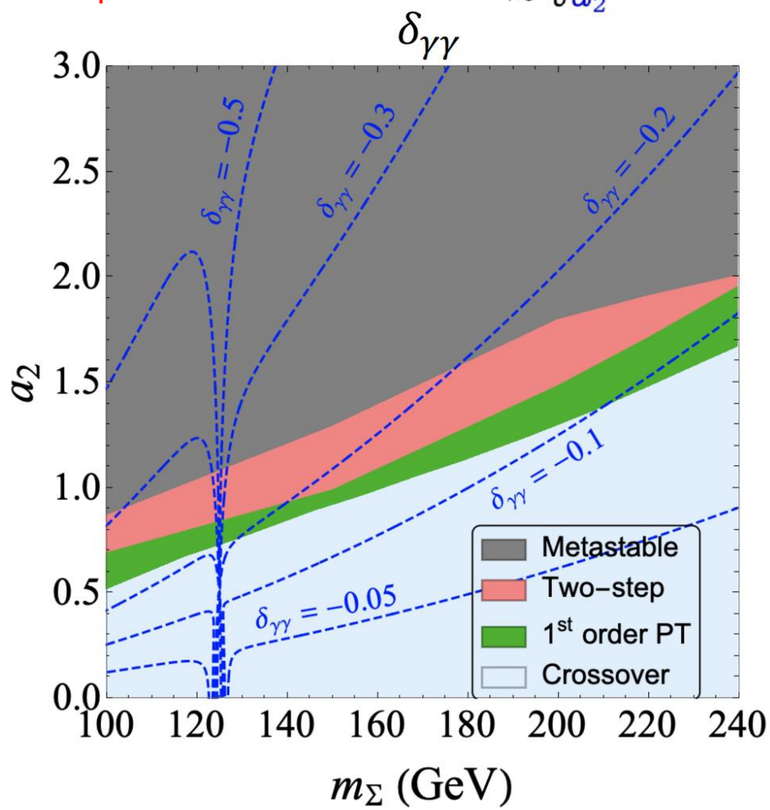


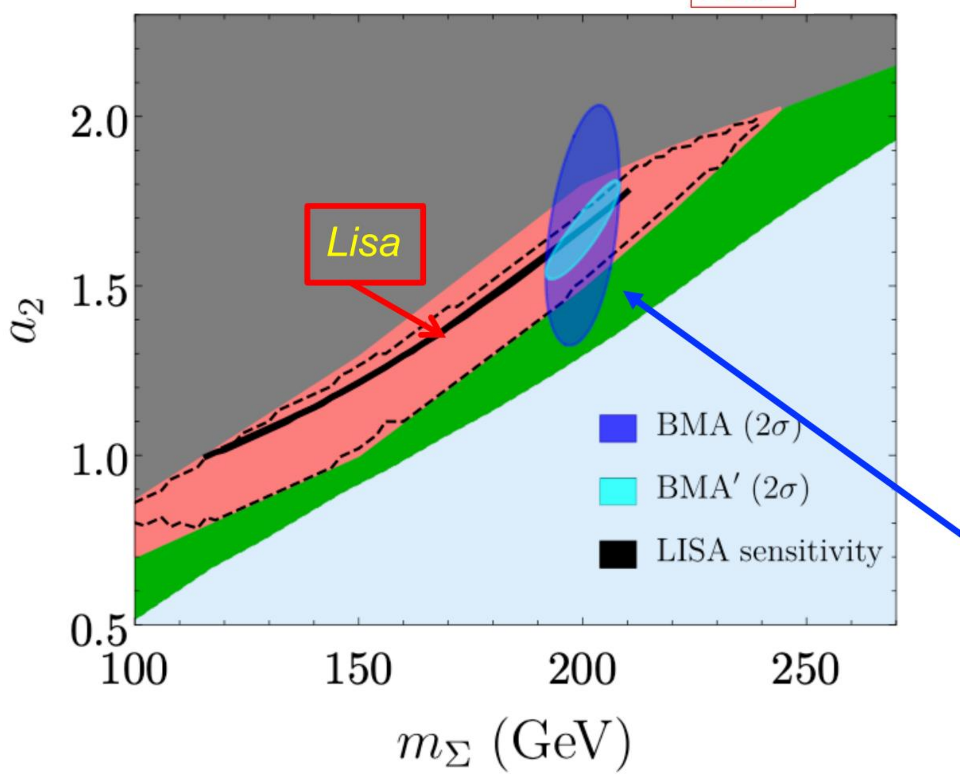
$$\delta_{\gamma\gamma} \equiv \frac{\Gamma^{\Sigma SM}_{h\to\gamma\gamma}}{\Gamma^{SM}_{h\to\gamma\gamma}} - 1$$

Hypothetical set of measurements:

$$\delta_{\gamma\gamma} = -0.132 \pm 0.015,$$
$$m_\Sigma = (200 \pm 5)\ \text{GeV}$$
$$\text{BR}(\Sigma^0 \to ZZ) = 0.01 \pm 0.002\ ,$$

FCC-ee





SFOEWPT model & Gravitational Wave Signal

Classical Scale invariance (tree) and broken (@ loop)

Higgs doublet (H) + Z_2 Singlet (S) + Scalar Dark Matter (X)

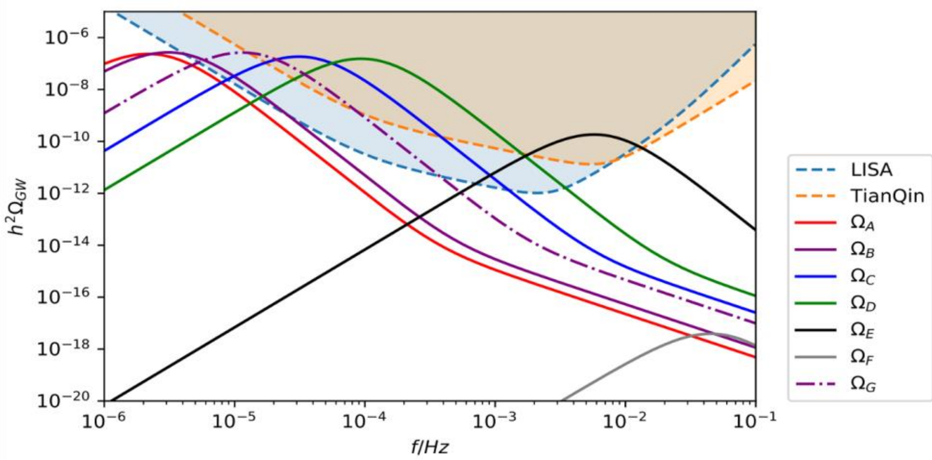
Z. Kang and J. Zhu, Phys. Rev. D 102 (2020) no.5, 053011

adapted from J.Zhu's talk

Lagrangian: $\mathcal{L} = \mathcal{L}_{\mathcal{SM}}|_{\lambda=0,\mu=0} + K_{scalar} - V_{scalar}$

$$V_{scalar} = \lambda_1 (H^\dagger H)^2 + \frac{1}{4}\lambda_2 S^4 + \frac{1}{4}\lambda_3 X^4 + \frac{1}{2}\lambda_{12} S^2 H^\dagger H + \frac{1}{2}\lambda_{13} X^2 H^\dagger H + \frac{1}{4}\lambda_{23} S^2 X^2$$

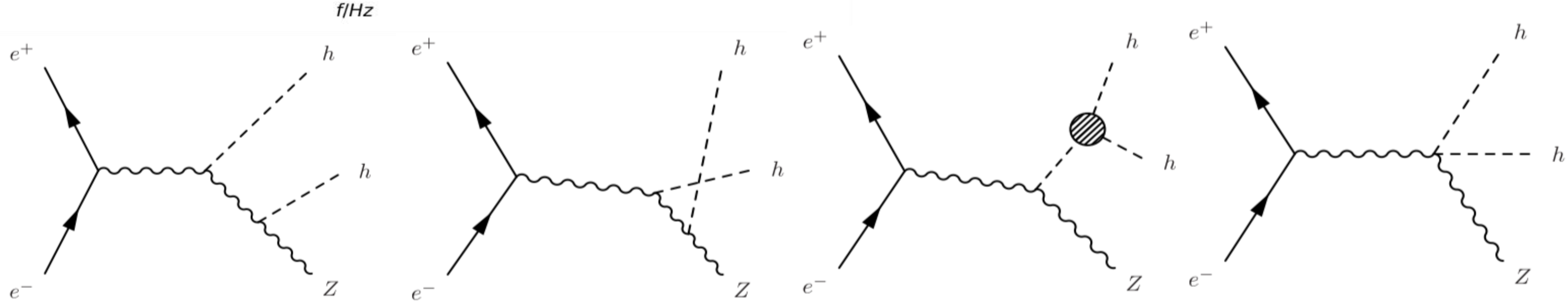
$$H = \begin{pmatrix} \phi_1 + i\phi_2 \\ \frac{H_0 + i\phi_3}{\sqrt{2}} \end{pmatrix} \qquad H_0 = (v+h) \text{ and } S = (v_s + s)$$



Modified Higgs cubic and quartic couplings.

$\lambda_{hhhh} = A_4 \lambda_{hh}$
$\lambda_{hhh} = A_3 \lambda_{hh}$

$e^+e^- \to Zhh$ *Channel:*



Neutrino connection: CEPC's complementary NSI measurement

Modification of matter potential

SM

$$i\frac{\mathrm{d}}{\mathrm{d}t}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \frac{1}{2E}\left[U\begin{pmatrix}0 & 0 & 0\\ 0 & \Delta m^2_{21} & 0\\ 0 & 0 & \Delta m^2_{31}\end{pmatrix}U^\dagger + A\begin{pmatrix}1+\varepsilon_{ee} & \varepsilon_{e\mu} & \varepsilon_{e\tau}\\ \varepsilon^*_{e\mu} & \varepsilon_{\mu\mu} & \varepsilon_{\mu\tau}\\ \varepsilon^*_{e\tau} & \varepsilon^*_{\mu\tau} & \varepsilon_{\tau\tau}\end{pmatrix}\right]\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}$$

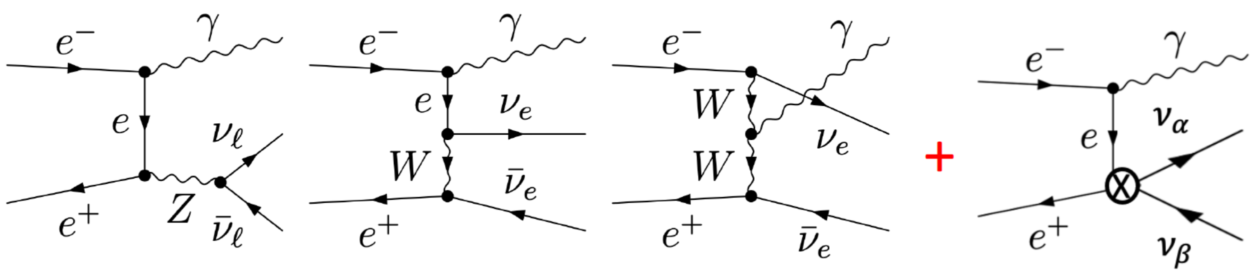
Jiajun Liao, Yu Zhang
2105.11215

Effective coefficient $\varepsilon_{\alpha\beta} \equiv \sum_{f,C} \varepsilon^{fC}_{\alpha\beta}\frac{N_f}{N_e}$

$A \equiv 2\sqrt{2}G_F N_e E$

On earth $N_u = N_d = 3N_e$

Neutrino NSI has impact on extreme astro phenomena.



$e^+e^- \to \nu\bar{\nu}\gamma \qquad \frac{d^2\sigma}{dx_\gamma dz_\gamma} = H\left(x_\gamma, z_\gamma; s\right)\sigma_0(s_\gamma)$

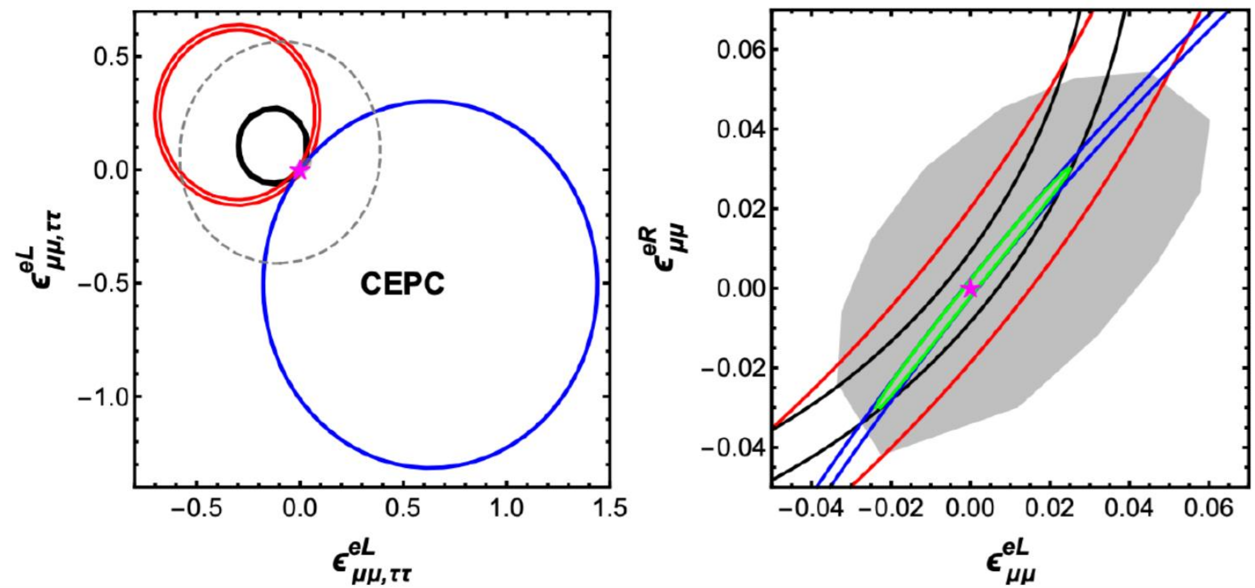
Berezhiania , Rossi, Phys.Lett.B 535 (2002)

$$\sigma_0^{\mathrm{NSI}}(s) = \sum_{\alpha,\beta=e,\mu,\tau}\frac{G_F^2}{6\pi}s\left[\left((\epsilon^{eL}_{\alpha\beta})^2 + (\epsilon^{eR}_{\alpha\beta})^2\right) - 2\left(g_L\epsilon^{eL}_{\alpha\beta} + g_R\epsilon^{eR}_{\alpha\beta}\right)\frac{M_Z^2\left(s-M_Z^2\right)}{\left(s-M_Z^2\right)^2 + \left(M_Z\Gamma_Z\right)^2}\right]$$

$$+\frac{G_F^2}{\pi}\epsilon^{eL}_{ee}M_W^2\left[\frac{\left(s+M_W^2\right)^2}{s^2}\log\left(\frac{s+M_W^2}{M_W^2}\right) - \frac{M_W^2}{s} - \frac{3}{2}\right]. \qquad \alpha,\beta = e,\mu,\tau$$

12 independent NSI parameters

CEPC can probe NSI to 10^{-3}



	CEPC-91.2 $L = 16$ ab^{-1}	CEPC-160 $L = 2.6$ ab^{-1}	CEPC-240 $L = 5.6$ ab^{-1}	CEPC-combined $L = 24.2$ ab^{-1}	Previous Limit 90% Allowed [45]
ϵ^{eL}_{ee}	[-0.0037,0.0037]	[-0.0036,0.0035]	[-0.0010,0.0010]	[-0.00095,0.00095]	[-0.03,0.08]
ϵ^{eR}_{ee}	[-0.0017,0.0017]	[-0.014,0.015]	[-0.0065,0.0070]	[-0.0017,0.0017]	[0.004,0.15]
$\epsilon^{eL}_{\mu\mu/\tau\tau}$	[-0.0014,0.0014]	[-0.012,0.012]	[-0.0055,0.0053]	[-0.0013,0.0013]	[-0.03,0.03]/[-0.5,0.3]
$\epsilon^{eR}_{\mu\mu/\tau\tau}$	[-0.0017,0.0017]	[-0.014,0.015]	[-0.0065,0.0070]	[-0.0017,0.0017]	[-0.03,0.03]/[-0.3,0.4]

Lepton connection: tau g-2

PDG 2022

$\mu_\tau/(e\hbar/2m_\tau)-1 = (g_\tau-2)/2$

For a theoretical calculation $[(g_\tau-2)/2 = 117\,721(5)\times10^{-8}]$, see EIDELMAN 2007 .

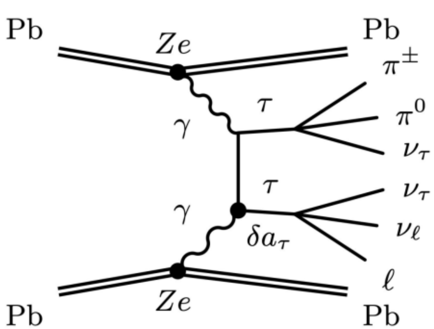
VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>-0.052 and <0.013 OUR LIMIT					
>-0.052 and <0.013	95	[1] ABDALLAH	2004K	DLPH	$e^+ e^- \to e^+ e^- \tau^+ \tau^-$ at LEP2
• • We do not use the following data for averages, fits, limits, etc. • •					
< 0.107	95	[2] ACHARD	2004G	L3	$e^+ e^- \to e^+ e^- \tau^+ \tau^-$ at LEP2

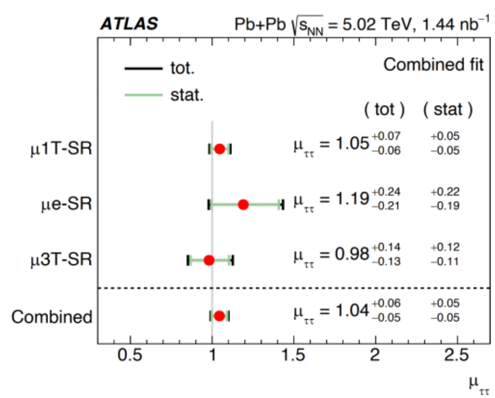
Muon seems to have anomalies. How about tau?

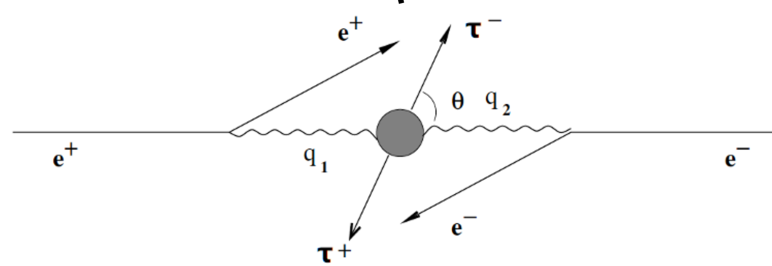
Collider offers a test on μ_τ

γ γ fusion @ Pb-Pb:
xsec enhanced by $Z^4 \sim 10^5$ with Z_{Pb} = 82.

Haifeng Li, et.al. 2204.13478







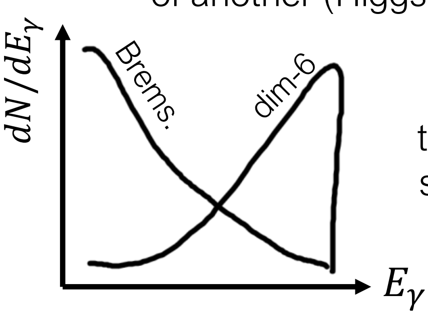
Photon fusion process:
Can produce tau with a dipole coupling $\sim \bar{\tau}\sigma^{\mu\nu}\tau F_{\mu\nu}$

Lepton dipole moment @ Higgs factory

$h \to \tau\tau\gamma$ stems from the SMEFT prescription of tau's Dim-6 dipole moment operators.

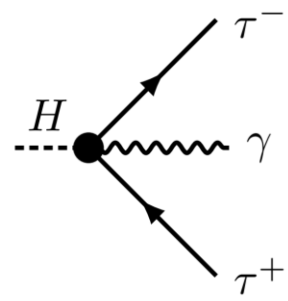
$$O_{e_iW} = (\bar{L}_i \sigma^{\mu\nu} \tau^I e_i)\phi W^I_{\mu\nu},$$
$$O_{e_iB} = (\bar{L}_i \sigma^{\mu\nu} e_i)\phi B_{\mu\nu},$$

Dipole moment is a L-R coupling that requires the presence of another (Higgs,say) doublet.

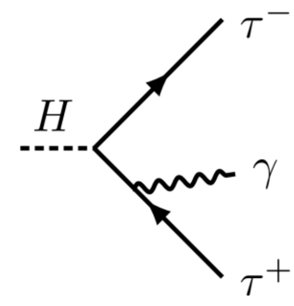


Emits a hard photon to lift angular momentum suppression (h is spin-0) → hard spectrum with a high-E endpoint.

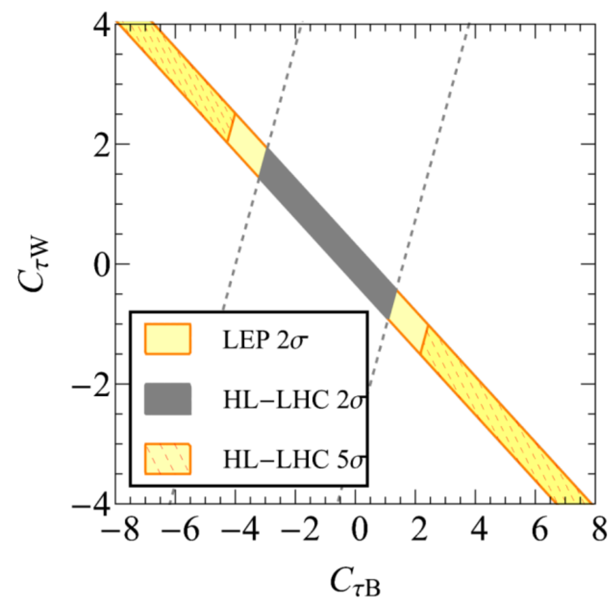
$h\tau\tau\gamma$ coupling ~ (effective μ_τ) $/v_H$



Dipole-coupling: hard photon spectrum with endpoint~ $m_h/2$



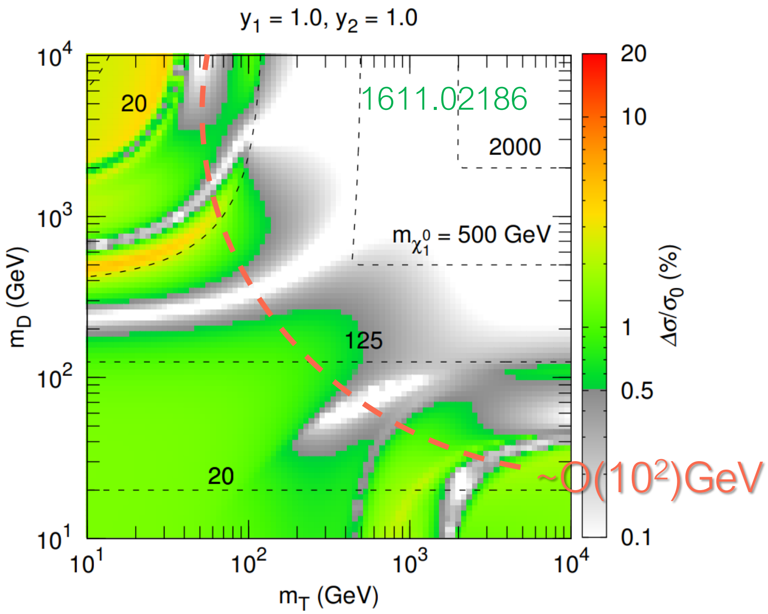
SM brems. with soft spectrum ~ $\log(E/m_\tau)$

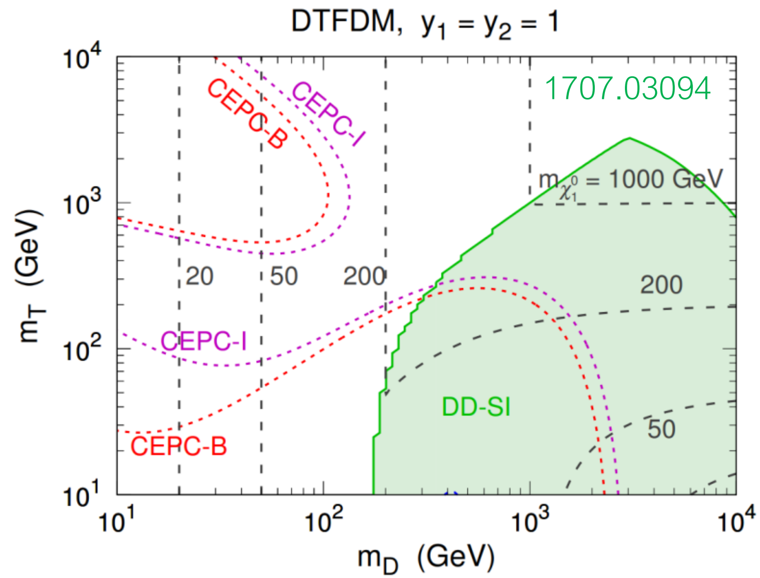


Qing-Hong Cao, Hao-Ran Jiang, Bin Li, Yandong Liu, Guojin Zeng, 2106.04143 (analysis for LHC)

WIMP @ CEPC

$$y_1(H\sigma^i D_1)T^i - y_2(H^\dagger \sigma^i D_2)T^i + \text{h.c.}\,.$$





CEPC $\sigma(ZH)$ limits on doublet-triplet fermion DM model + many others

1611.02186, 1705.02534
1711.04046, 1712.02140
1707.03094, 1711.05622…

CEPC Z pole (S,T) limits on doublet-triplet fermion DM model

less effective for a pure multiplet.

CEPC sensitive to 10^2 GeV Weak multiplet DM

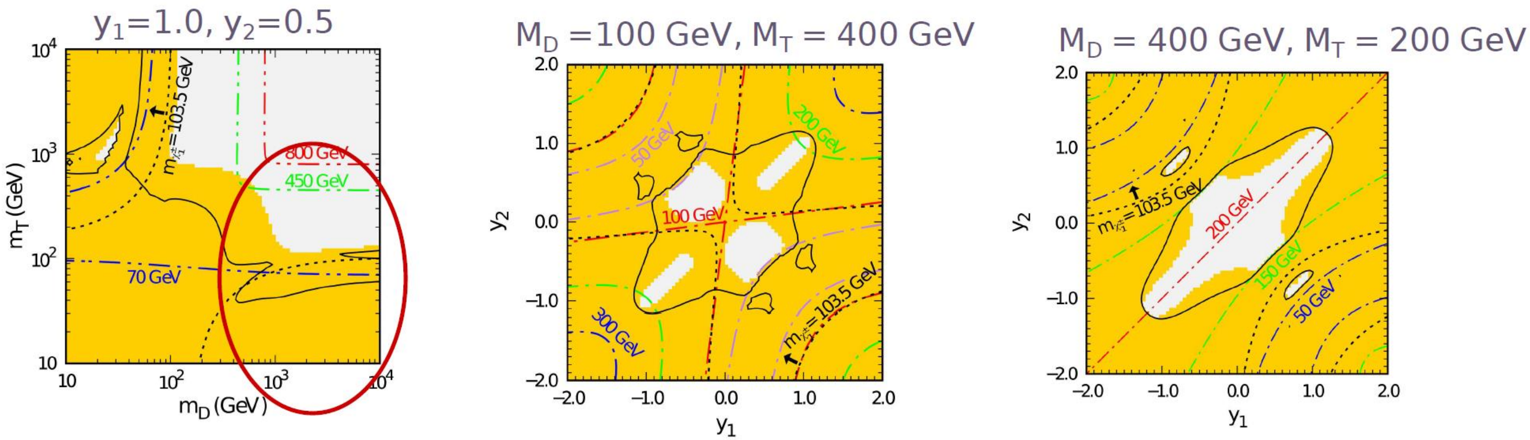
Combined one-(DM)-loop fit to ee → $\mu^+\mu^-$, Zh, W^+W^-,ZZ,Zγ @ CEPC

combined constraints

In mass plane and Yukawa coupling plane

$$\frac{\Delta\sigma}{\sigma_0} = \frac{|\sigma_{\mathrm{SDFDM}} - \sigma_{\mathrm{SM}}|}{\sigma_{\mathrm{SM}}}$$

Yellow region : exlusion region
solid black lines : exlusion region(~0.5%)
color lines : mass of χ_1^0



LEP : dashed black line
LHC : mass of χ_1^0 is less than ~100 GeV

some differences with SDFDM model :
1. constraints is more strigent
2. red loop region

Linqing Gao, et.al. 2112.02519

CEPC - Astro/Cosmic/X connection

Join the discussion!

Joint Workshop(s) of the CEPC Physics, Software and New Detector Concept in 202X

https://indico.ihep.ac.cn/event/16509/
https://indico.ihep.ac.cn/event/14938
https://indico.ihep.ac.cn/event/13888/

CEPC can probe BSM potentials that yield SFOEWPT, w precision *Higgs* measurements. Can cross-test with GW data

CEPC can offer precision test of lepton properties complementary to non-collider anomaly/measure-ments