Section XI: more exotics

Mostly non-susy BSM (last WP)

↓

Anything different from Section IV –X (this WP)

(On behalf of)
Yu Gao, Zuowei Liu
& contributors

CEPC NewPhysics WP meeting
Zhengzhou 2024/09/01

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(Multi-lepton + LNV RHN search),
(Neutrino form factors) → Section X
(Neutrino NSI)

Contributor list

- Kingman Cheung [Ntnl Tsinghua], C.J. Ouseph [Ntnl Tsinghua], Chih-Ting Lu[NJNU], Shuo Yang [LNU], Chong-Xing Yue[LNU], Peter Athron[NJNU] (Collider Axion-like particle search)
- Craig D. Roberts [NJU] (QCD mass mechanism & hadron FF)
- Fei Wang[ZZ.U.],Peter Athron[NJNU] (Lepton g-2), Long Chen[], Yu Zhang[Anhui U.], Wei Liu[NJUST](Neutrino trans. Mag. Moment, NSI), Jiajun Liao[SYSU] (Neutrino NSI),
- Zheng Sun [Sichuan U.] (Exotic lepton mass mechanism)
- Tong Li [Nankai], Kai Ma [UCAS], Roberto A. Morales [IFLP] (Quantum Spin Entanglement)
- Yu Gao[IHEP], Kechen Wang[WHUT], Arindam Das[Hokkaido U.](Heavy neutrino)

All current material are collected from invited contributors since Fudan conference (**Gracias!**)

CEPC good for exotic search.

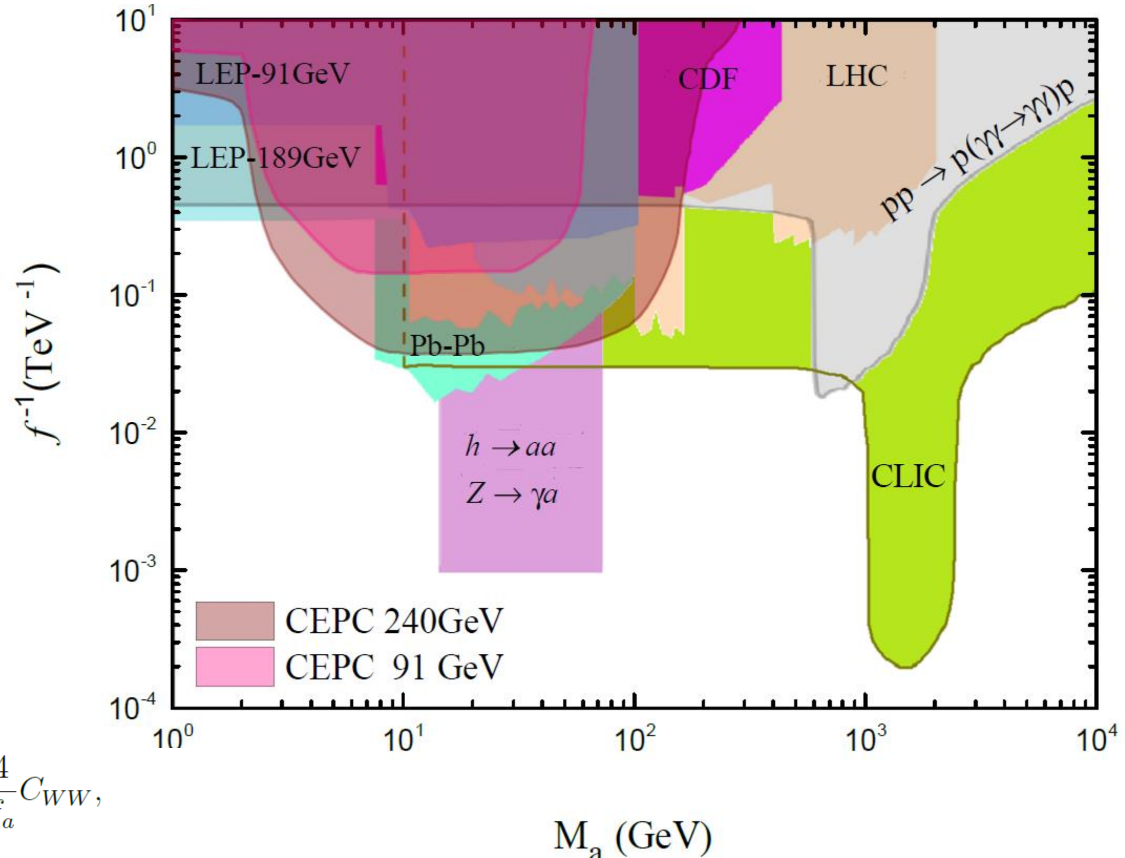
- Soft stuff are visible (low E photons, leptons, jets)
- Good particle identification
- Less necessity with large tigger
- Lepton connection
- Z-pole, Higgs Z (Higgs factory) runs

Contribution 1: ALP search

$$\mathcal{L} = -C_{BB}\frac{a}{f_a}B_{\mu\nu}\tilde{B}^{\mu\nu} - C_{WW}\frac{a}{f_a}W^i_{\mu\nu}\tilde{W}^{\mu\nu,i}.$$

H.-Y. Zhang, C.-X. Yue, Y.-C. Guo, and **S. Yang**,
Phys. Rev. D 104 (2021) no. 9, 096008

"light-by-light scattering"
e e -> e e γ γ
(ISR photons exchange an ALP: 90/240 GeV analysis)



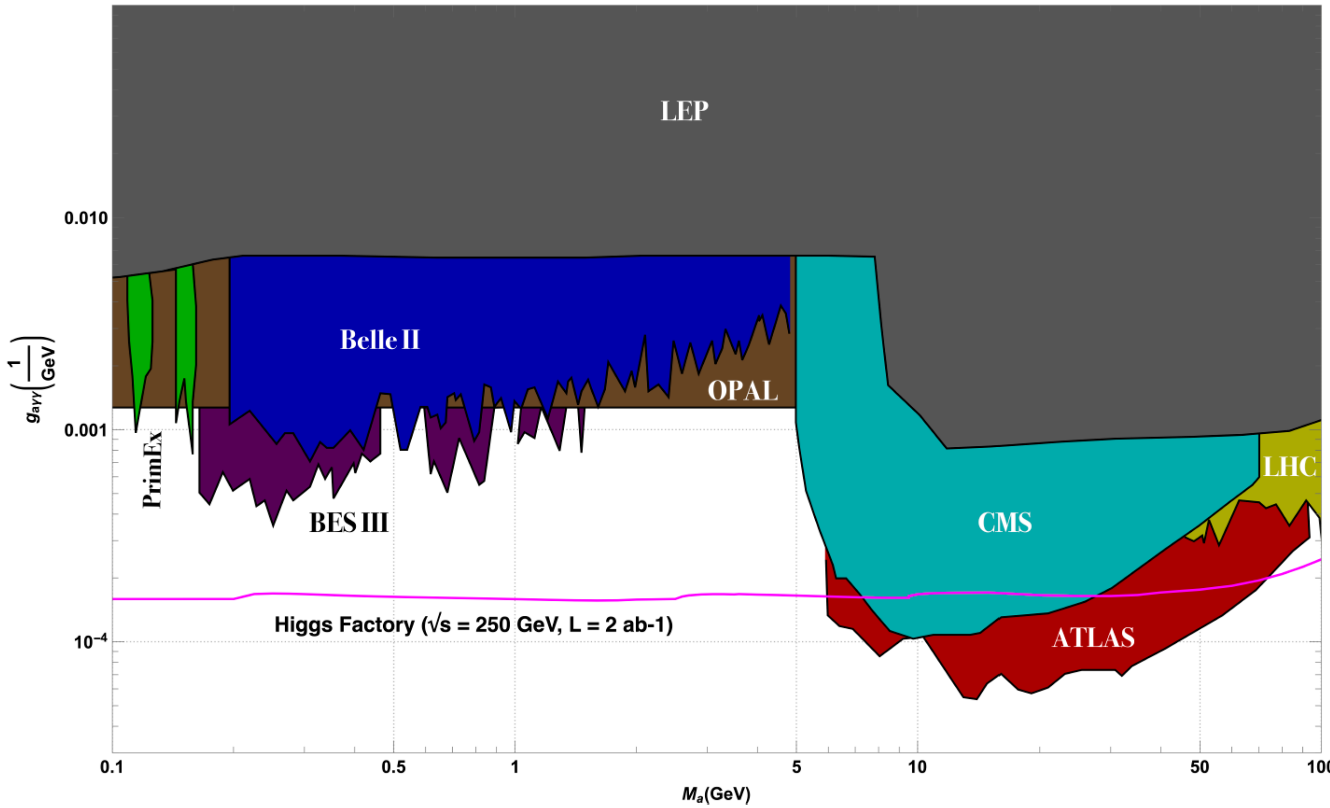
Rotate into $g_{a\gamma}, g_{aZ}$ by θ_W

$$g_{a\gamma\gamma} = \frac{4}{f_a}(C_{BB}c_w^2 + C_{WW}s_w^2), \qquad g_{aWW} = \frac{4}{f_a}C_{WW},$$

$$g_{aZZ} = \frac{4}{f_a}(C_{BB}s_w^2 + C_{WW}c_w^2), \qquad g_{aZ\gamma} = \frac{8}{f_a}s_w c_w(C_{WW} - C_{BB}).$$

K. Cheung and C. J. Ouseph, Phys. Rev. D 108 (2023) no. 3, 035003, arXiv:2303.16514 [hep-ph].

$e^+e^- \to f^+f^-a$ and final state $a \to \gamma\gamma$, (talk given at Fudan & HK-IAS)

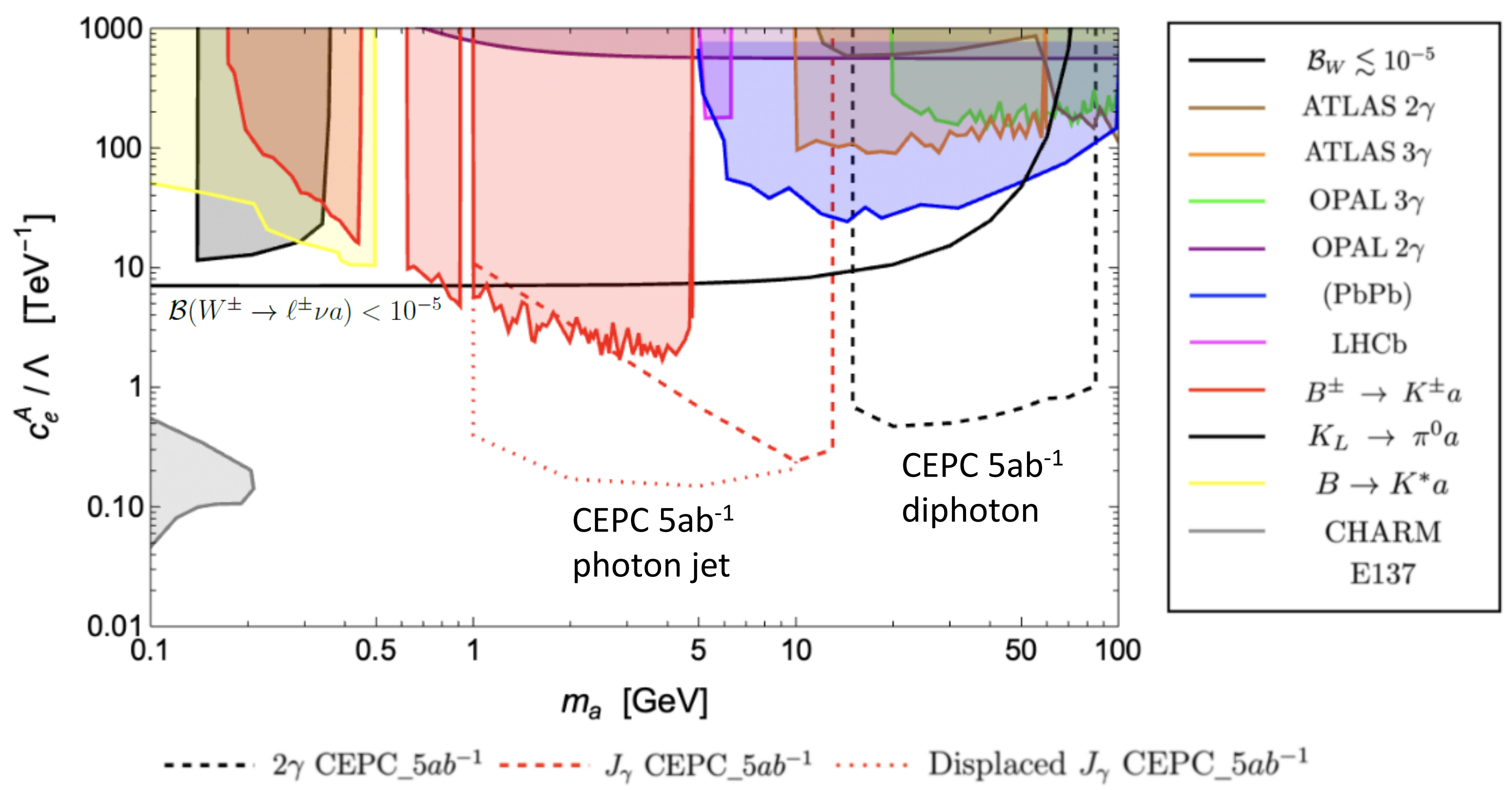


Analysis done for Higgs factory √s = 250 GeV with an integrated luminosity 2 ab^{-1}. Sensitivity scales as luminosity sqrt.

W. Altmannshofer, J. A. Dror, and S. Gori,
Phys. Rev. Lett. 130 (2023) no. 24, 241801;
C.-T. Lu, arXiv:2210.15648 [hep-ph].

"an opportunity to explore electrophilic ALPs (eALPs) at the GeV scale"

Probe four-point interaction W-ℓ-ν-a in the process $e^+e^- \to \nu_e\, a\, \bar{\nu}_e$



Contribution 2: lepton EM Form factors

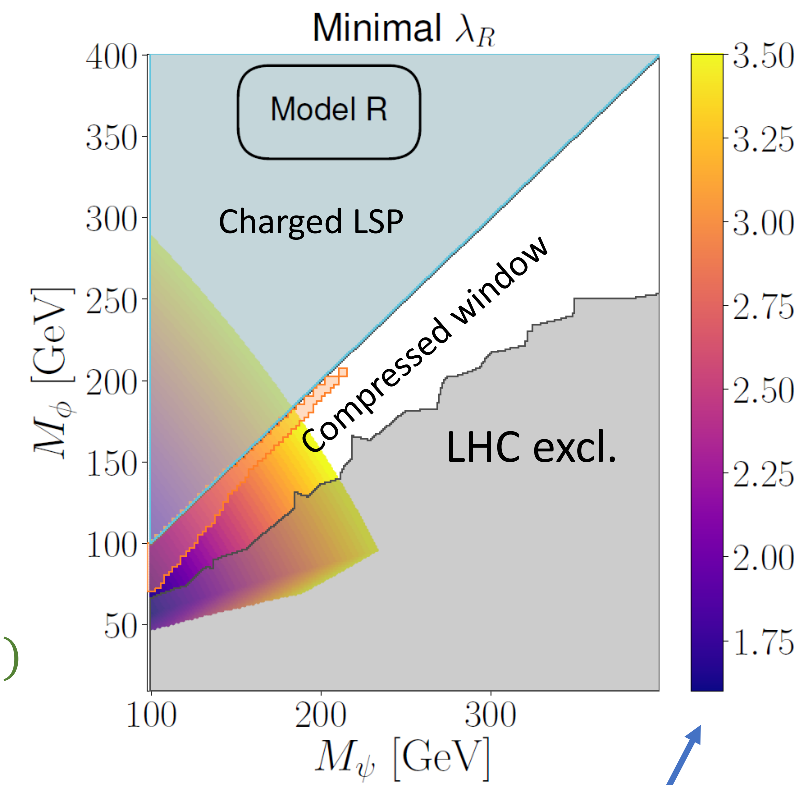
Section X.2.1

Muon/electron g − 2:
general remarks, collected writings from by Peter Athron (NJNU)

A short review on experimental limits of muon and electron's g-2 value.

$$\Delta a_\mu^{\mathrm{BSM}} \approx C_{\mathrm{BSM}} \frac{m_\mu^2}{M_{\mathrm{BSM}}^2},$$

Generic NP contribution to the dipole moment:
* mass scale of the new physics expected at ≲ 200 – 300 GeV



Coupling size for g-2 in a toy model with an extra scalar and fermion [Athron]

Section X.2.2

SUSY aspects on muon g − 2, by Fei Wang (ZZ. U.)

AMSB,Gauge/Yukawa-MSB models: Possible to explain the electron g – 2 @ 2σ && muon g – 2 @1σ

mSUGRA challenging for muon g-2; Gluino-SUGRA (~gSUGRA) extension: possible to explain muon g-2 @ 1σ

Section X.2.3

W. Bernreuther, **L. Chen**, and O. Nachtmann, Phys. Rev. D 103 (2021) no. 9, 096011, arXiv:2101.08071 [hep-ph]:
A *Z*-pole analysis on effective tau weak dipole moment

TABLE X: Ideal 1 s.d. statistical errors on $\mathrm{Re}[d_\tau^w]$ and $\mathrm{Im}[d_\tau^w]$.

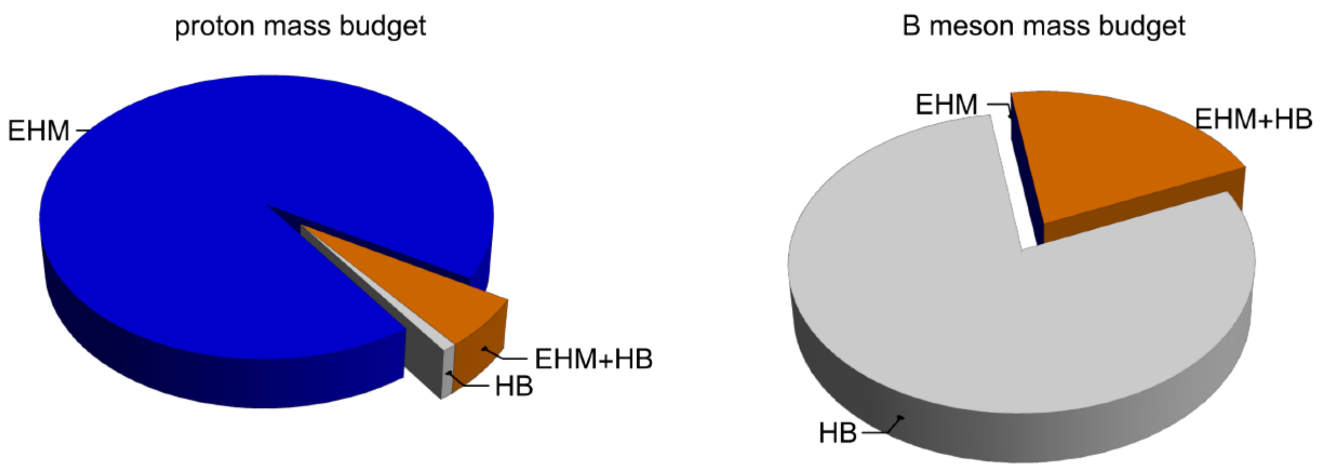
$\delta\mathrm{Re}[d_\tau^w]$ [e cm]			$\delta\mathrm{Im}[d_\tau^w]$ [e cm]		
$\langle T_{33}\rangle$	$\langle \hat{T}_{33}\rangle$	$\langle O_R\rangle$	$\langle Q_{33}\rangle$	$\langle \hat{Q}_{33}\rangle$	$\langle O_I\rangle$
3.4×10^{-21}	3.4×10^{-21}	1.4×10^{-21}	3.2×10^{-19}	4.0×10^{-20}	2.1×10^{-21}

CEPC Z-pole sensitivity on d_{weak}^{τ} can reach the level of 10^{-21} e cm
"sufficient to be sensitive to certain beyond-SM models that predict values for d_{weak} of the order 10^{-19} e cm"

Dedicated & systematic study of tau dipole moment for CEPC is still in need

Tau lepton dipole moment measurement @ collider
Traditional channel $e^+e^- \to \tau^+\tau^-$, (Low E / Z Res.), $\gamma\,\gamma \to \tau^+\tau^-$ (ISR fusion)
+ Higgs/Z couplings via SMEFT Dim-6 operators

Contribution 3: mass emergence (QCD)



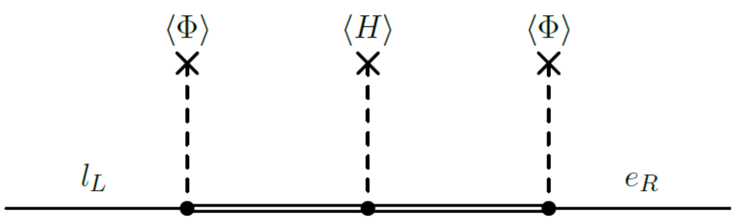
Blue: gluon effective mass   Gray: <H> contribution   Brown: interference

Writeup from **Craig Roberts** (NJU), with a proposal: precision measurement on the transition between `Emergent hadron mass (EHM)' particles and `Higgs Boson (HB)' particles. CEPC also has significant hadron production and can contribute to form factor measurements

Contribution 4: exotic mass relations

Models aiming the mass patterns:

Froggatt-Nielson(1979), seesaw-type Yukawaon models



Introduce SU(3) nonet scalar Φ and flavor nonets Y, A, plus heavier fermions that generate Dim-5 terms

$$\mathcal{L}^{(5)} = -\frac{y_0}{\Lambda}\bar{l}_L Y H e_R + \text{h.c.}, \quad W = \mu\,\mathrm{Tr}\,(YA) + \lambda\,\mathrm{Tr}\,(\Phi\Phi A)\,,$$

F-term equation leads $\langle Y\rangle \sim \langle\Phi\Phi\rangle$,
generate mass relations $K \sim Tr\langle\Phi\Phi\rangle/(Tr\langle\Phi\rangle)^2$

Koide invented a parametrization (1982):

$$K = \frac{m_e + m_\mu + m_\tau}{\left(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau}\right)^2} = \frac{2}{3},$$

Z. Liang and **Z. Sun**,
Nucl. Phys. B 972 (2021) 115546,

Potential searches for CEPC:

*** Induced effective Higgs-lepton couplings
New scalars / lepton mass

Contribution 5: QM entanglement

- QFT is quantum, no doubt.

$$\Psi(x,t) * \{Entangled\ \Psi(s_i)\} \xrightarrow[\text{measurement}]{\text{Polarization}} \Psi(x,t) * \{Collapsed\ \Psi(s_i)\}$$

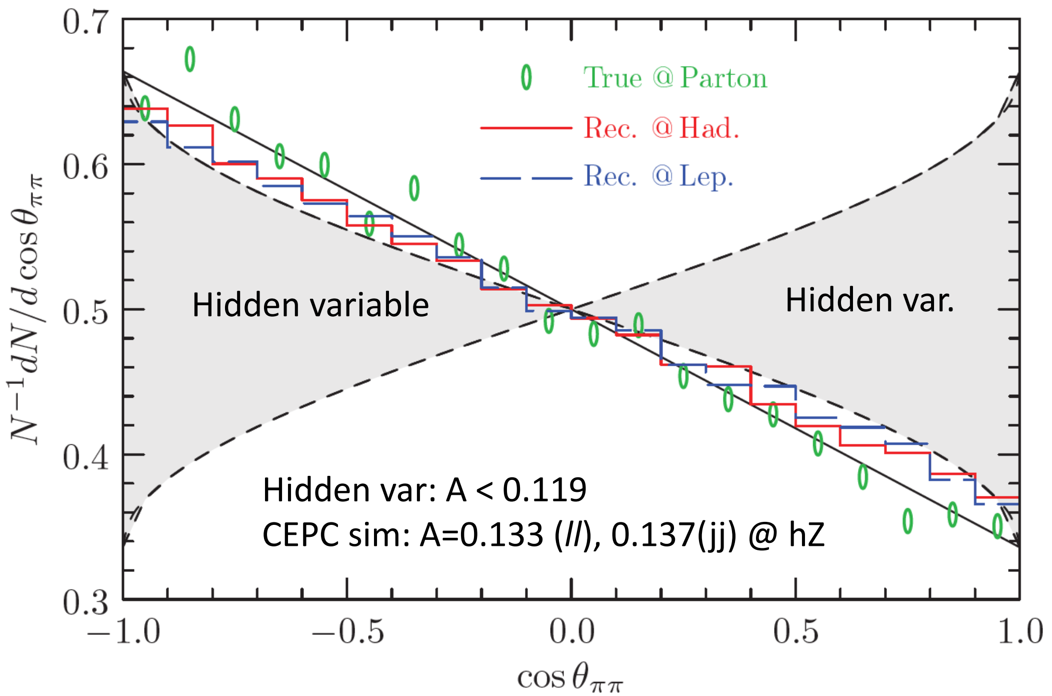
For CEPC: Spin-0 Higgs boson is a perfect entangler for multi- spin final state at the weak-scale energy.

K. Ma and T. Li, "Testing Bell inequality through h → τ τ at CEPC," Chinese Phys. C (2024) .

Tornqvist's approach in Higgs decay chain $h \to \tau^+\tau^- \to \pi^+\bar{\nu}_\tau\pi^-\nu_\tau$

$$\mathcal{A} = \frac{N(\cos\theta_{\pi\pi} < 0) - N(\cos\theta_{\pi\pi} > 0)}{N(\cos\theta_{\pi\pi} < 0) + N(\cos\theta_{\pi\pi} > 0)}$$

$$\cos\theta_{\pi\pi} = \vec{p}_{\pi^-} \cdot \vec{p}_{\pi^+} / (|\vec{p}_{\pi^-}||\vec{p}_{\pi^+}|)$$



“Bell inequality can be tested below 1σ level at the CEPC”

Ma & Li, Chinese Phys. C (2024) .

Channels	Observable	LHVT	CEPC @ 5.6 ab^{-1}	CEPC @ 20 ab^{-1}
$Z \to \ell\ell$	$\mathcal{A}$	≤ 0.119	0.133 ± 0.269	0.133 ± 0.142
	$m_1 + m_2$	≤ 1	1.04 ± 0.921	1.04 ± 0.481
$Z \to jj$	$\mathcal{A}$	≤ 0.119	0.137 ± 0.1	0.137 ± 0.053
	$m_1 + m_2$	≤ 1	1.05 ± 0.355	1.05 ± 0.188

TABLE XI: The results of observables testing the Bell inequality in Törnqvist's method and the CHSH approach. The experimental predictions are given for the CEPC with colliding energy $\sqrt{s} = 240$ GeV and total luminosities 5.6 ab^{-1} and 20 ab^{-1}.

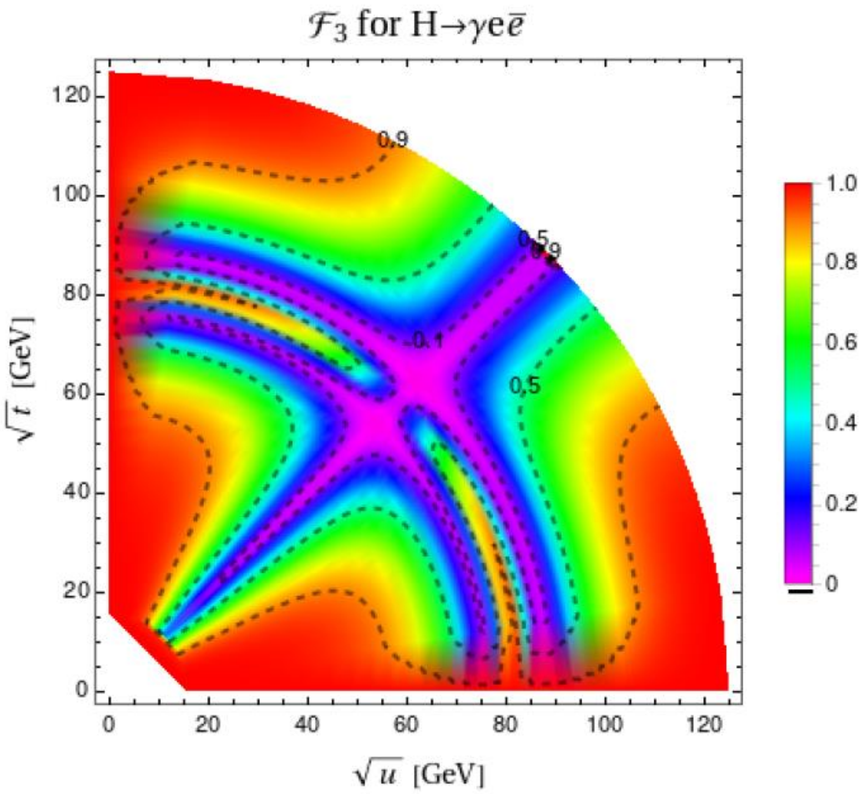
m: eigenvalue(s) of the $U=C^TC$ matrix,
C: spin correlation function.
In LHVT, m1+m2<1,

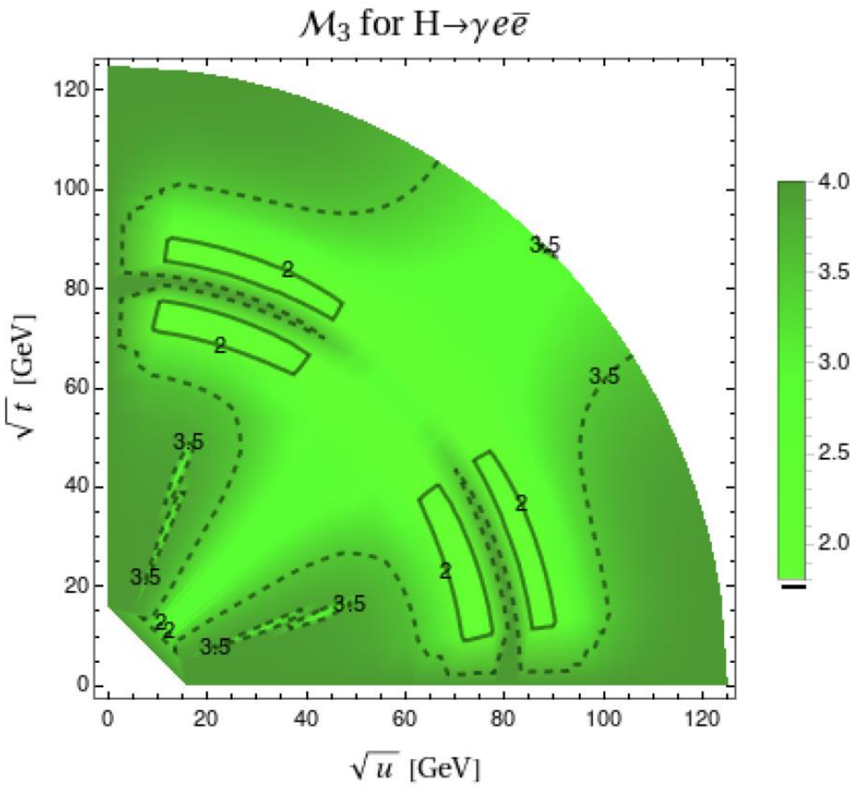
Tripartite entanglement measures in Higgs decay $h \to l\, l\, \gamma$

R. A. Morales, Eur. Phys. J. C 84 (2024) no. 6, 581

Theoretical evaluation of entanglement measures in sub-sys invar. parameter space ($\sqrt{u_{\gamma l^+}}, \sqrt{t_{\gamma l^-}}$)

Entanglement for three spins (total = 0).
Concurrence triangle (F_3)
Bell non-locality: Mermin (M_3)





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