New Physics Scales @ Lepton Colliders

Shao-Feng Ge

(gesf02@gmail.com)

Max-Planck-Institut für Kernphysik, Heidelberg, Germany

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SFG, Hong-Jian He, Rui-Qing Xiao, JHEP 1610 (2016) 007 [arXiv:1603.03385]

CEPC preCDR

New Physics Scales

Ge, He, Xiao JHEP 1610 (2016) 007 [1603.03385]

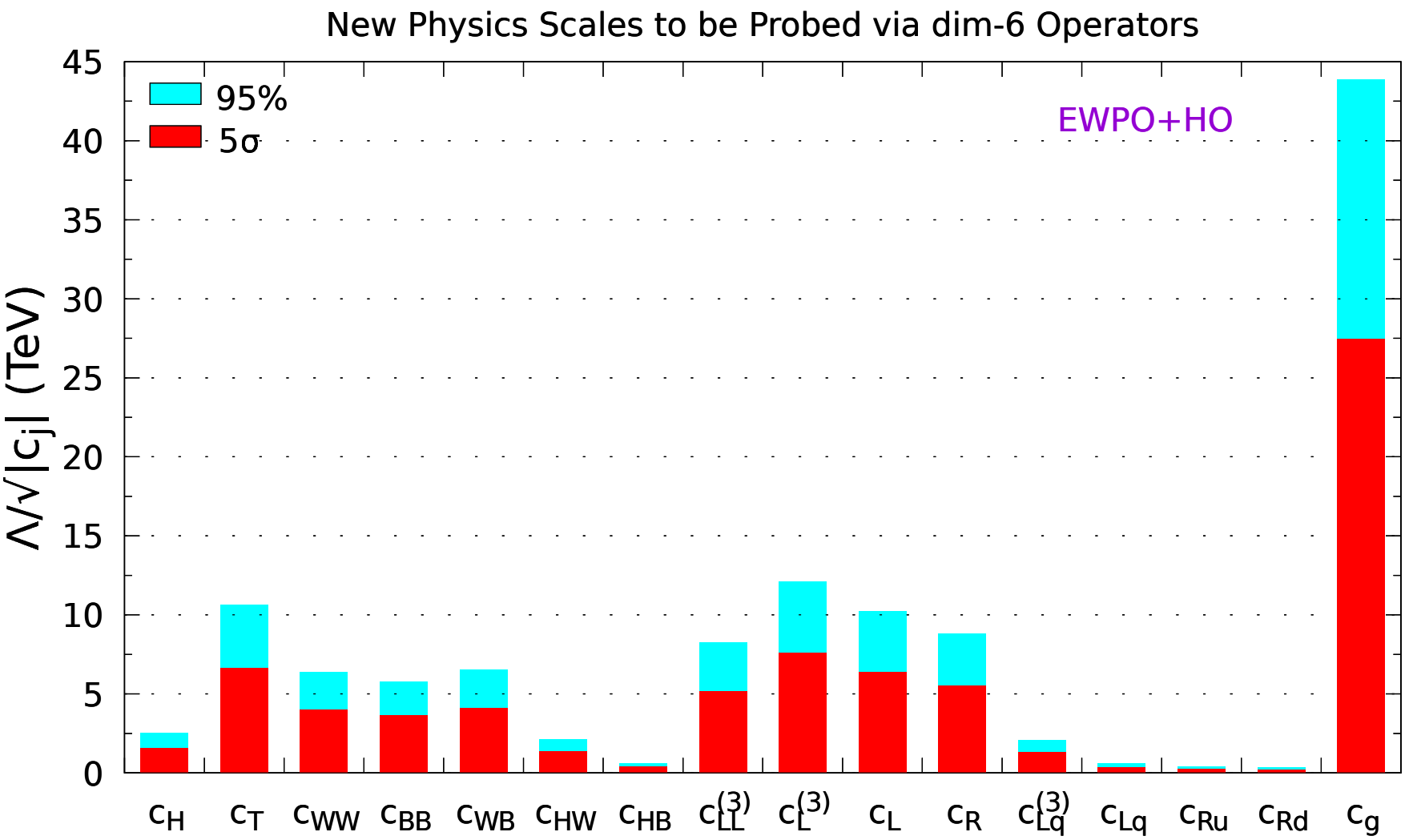
- New physics appears @ high energy scale & can only be probed **Indirectly**

$$\mathcal{L} = \mathcal{L}_{\mathbf{SM}} + \sum_{ij} \frac{\mathbf{y_{ij}} \sim \mathcal{O}(1)}{\mathbf{\Lambda} \sim 10^{14}\mathrm{GeV}} (\bar{L}_i \tilde{\mathbf{H}})(\tilde{\mathbf{H}}^\dagger L_j) + \sum_i \frac{\mathbf{c_i}}{\mathbf{\Lambda}^2} \mathcal{O}_\mathbf{i} \,.$$

- **SM Gauge Invariance** is respected

Higgs	EW Gauge Bosons	Fermions
$\mathcal{O}_\mathbf{H} = \frac{1}{2}(\partial_\mu \lvert\mathbf{H}\rvert^2)^2$	$\mathcal{O}_\mathbf{WW} = g^2 \lvert\mathbf{H}\rvert^2 W^a_{\mu\nu} W^{a\mu\nu}$	$\mathcal{O}^{(3)}_\mathbf{L} = (i\mathbf{H}^\dagger \sigma^a \overleftrightarrow{D}_\mu \mathbf{H})(\overline{\Psi}_L \gamma^\mu \sigma^a \Psi_L)$
$\mathcal{O}_\mathbf{T} = \frac{1}{2}(\mathbf{H}^\dagger \overleftrightarrow{D}_\mu \mathbf{H})^2$	$\mathcal{O}_\mathbf{BB} = g^2 \lvert\mathbf{H}\rvert^2 B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}^{(3)}_\mathbf{LL} = (\overline{\Psi}_L \gamma_\mu \sigma^a \Psi_L)(\overline{\Psi}_L \gamma^\mu \sigma^a \Psi_L)$
	$\mathcal{O}_\mathbf{WB} = g g' \mathbf{H}^\dagger \sigma^a \mathbf{H} W^a_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_\mathbf{L} = (i\mathbf{H}^\dagger \overleftrightarrow{D}_\mu \mathbf{H})(\overline{\Psi}_L \gamma^\mu \Psi_L)$
Gluon	$\mathcal{O}_\mathbf{HW} = ig(D^\mu \mathbf{H})^\dagger \sigma^a (D^\nu \mathbf{H}) W^a_{\mu\nu}$	$\mathcal{O}_\mathbf{R} = (i\mathbf{H}^\dagger \overleftrightarrow{D}_\mu \mathbf{H})(\overline{\psi}_R \gamma^\mu \psi_R)$
$\mathcal{O}_\mathbf{g} = g_s^2 \lvert\mathbf{H}\rvert^2 G^a_{\mu\nu} G^{a\mu\nu}$	$\mathcal{O}_\mathbf{HB} = ig'(D^\mu \mathbf{H})^\dagger (D^\nu \mathbf{H}) B_{\mu\nu}$	$\mathcal{O}_\mathbf{f} = \lvert H\rvert^2 \overline{F}_L H f$

Sensitivities from Existing EWPO & Future HO



Ge, He, Xiao, **JHEP 1610 (2016) 007 [arXiv:1603.03385]**

Existing EWPO & Future HO

- **Observables**: **EWPO** (PDG14) + **HO** (preCDR)

Observables	Central Value	Relative Error	SM Prediction
α	$7.2973525698\times10^{-3}$	3.29×10^{-10}	–
G_F	$1.1663787\times10^{-5}\text{GeV}^{-2}$	5.14×10^{-7}	–
M_Z	91.1876GeV	2.3×10^{-5}	–
M_W	80.385GeV	1.87×10^{-4}	–
$\sigma[Zh]$	–	0.50%	–
$\sigma[\nu\bar{\nu}h]$	–	2.86%	–
$\sigma[\nu\bar{\nu}h]_{350\text{GeV}}$	–	0.75%	–
Br$[WW]$	–	1.2%	22.5%
Br$[ZZ]$	–	4.3%	2.77%
Br$[bb]$	–	0.54%	58.1%
Br$[cc]$	–	2.5%	2.10%
Br$[gg]$	–	1.4%	7.40%
Br$[\tau\tau]$	–	1.1%	6.64%
Br$[\gamma\gamma]$	–	9.0%	0.243%
Br$[\mu\mu]$	–	17%	0.023%

- **Exclusion (95%) & Discovery (5σ) Reach** Ge, He, Xiao **JHEP 1610 (2016) 007** **[1603.03385]**

	$\mathcal{O}_H$	$\mathcal{O}_T$	$\mathcal{O}_{WW}$	$\mathcal{O}_{BB}$	$\mathcal{O}_{WB}$	$\mathcal{O}_{HW}$	$\mathcal{O}_{HB}$	$\mathcal{O}_{LL}^{(3)}$	$\mathcal{O}_{L}^{(3)}$	$\mathcal{O}_L$	$\mathcal{O}_R$	$\mathcal{O}_{L,q}^{(3)}$	$\mathcal{O}_{L,q}$	$\mathcal{O}_{R,u}$	$\mathcal{O}_{R,d}$	$\mathcal{O}_g$
95%	2.50	**10.6**	**6.38**	**5.78**	**6.53**	2.12	0.604	**8.23**	**12.1**	**10.2**	**8.78**	2.06	0.568	0.393	0.339	**43.8**
5σ	1.57	6.65	4.00	3.62	4.09	1.33	0.378	5.15	7.57	6.39	5.49	1.29	0.356	0.246	0.212	27.4

Enhancement from M_Z & M_W @ CEPC

Observables	Relative Error	
	Current	**CEPC**
M_Z	2.3×10^{-5}	$5.5 \times 10^{-6} \sim 1.1 \times 10^{-5}$
M_W	1.9×10^{-4}	$\mathbf{3.7 \times 10^{-5}} \sim 6.2 \times 10^{-5}$

Table: The M_Z & M_W @ CEPC [Z.Liang, "Z & W Physics @ CEPC" & preCDR].

Scheme-Independent Analysis

$\frac{\Lambda}{\sqrt{c_i}}$ [TeV]	$\mathcal{O}_H$	$\mathcal{O}_T$	$\mathcal{O}_{WW}$	$\mathcal{O}_{BB}$	$\mathcal{O}_{WB}$	$\mathcal{O}_{HW}$	$\mathcal{O}_{HB}$	$\mathcal{O}_{LL}^{(3)}$	$\mathcal{O}_L^{(3)}$	$\mathcal{O}_L$	$\mathcal{O}_R$	$\mathcal{O}_{L,q}^{(3)}$	$\mathcal{O}_{L,q}$	$\mathcal{O}_{R,u}$	$\mathcal{O}_{R,d}$	$\mathcal{O}_g$
HO+EWPO	2.74	10.6	6.38	5.78	6.53	2.16	0.604	8.58	12.1	10.2	8.78	2.06	0.568	0.393	0.339	43.8
+M_Z	2.74	**10.7**	6.38	5.78	**6.54**	2.16	0.604	**8.62**	12.1	10.2	8.78	2.06	0.568	0.393	0.339	43.8
+M_W	2.74	**21.0**	6.38	5.78	**10.4**	2.16	0.604	**15.5**	**16.4**	10.2	8.78	2.06	0.568	0.393	0.339	43.8
+$M_{Z,W}$	2.74	**23.7**	6.38	5.78	**11.6**	2.16	0.604	**17.4**	**18.1**	10.2	8.78	2.06	0.568	0.393	0.339	43.8

Table: Impacts of the projected M_Z and M_W measurements at CEPC on the reach of new physics scale $\Lambda/\sqrt{|c_j|}$ (in TeV) at 95% C.L. The Higgs observables (including $\sigma(\nu\bar{\nu}h)$ at 350 GeV) and the existing electroweak precision observables are always included in each row. The differences among the four rows arise from whether taking into account the measurements of M_Z and M_W or not. The second (third) row contains the measurement of M_Z (M_W) alone, while the first (last) row contains none (both) of them. We mark the entries of the most significant improvements from M_Z/M_W measurements in red color.

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Enhancement from Z-Pole Observables @ CEPC

N_ν	$A_{FB}(b)$	R^b	R^μ	R^τ	$\sin^2\theta_w$
1.8×10^{-3}	1.5×10^{-3}	8×10^{-4}	5×10^{-4}	5×10^{-4}	1×10^{-4}

Table: The Z-pole measurements at CEPC [Z.Liang, "Z & W Physics @ CEPC" & preCDR].

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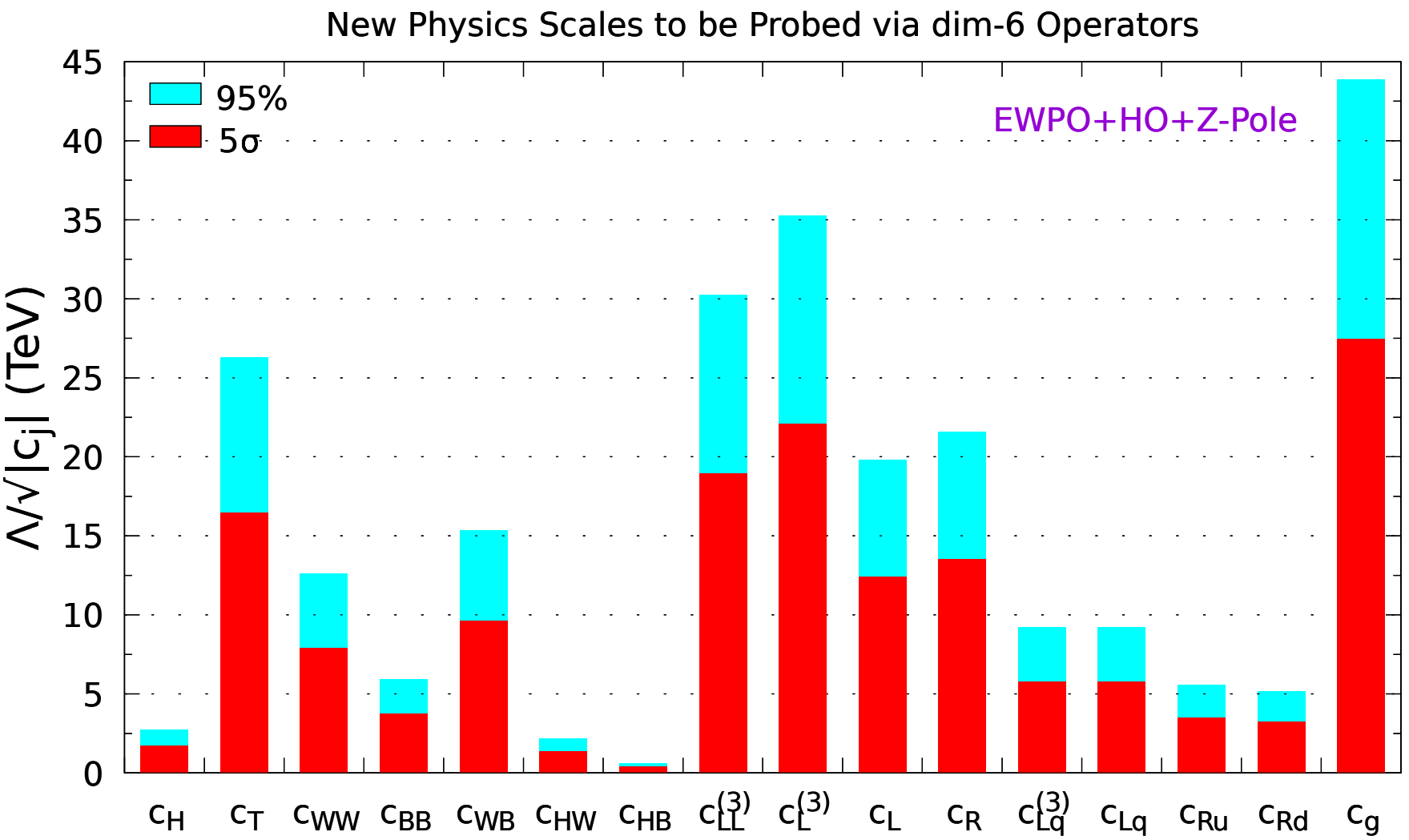
Z-Pole Observables are **IMPORTANT** for New Physics Scale Probe

$\mathcal{O}_H$	$\mathcal{O}_T$	$\mathcal{O}_{WW}$	$\mathcal{O}_{BB}$	$\mathcal{O}_{WB}$	$\mathcal{O}_{HW}$	$\mathcal{O}_{HB}$	$\mathcal{O}_{LL}^{(3)}$	$\mathcal{O}_L^{(3)}$	$\mathcal{O}_L$	$\mathcal{O}_R$	$\mathcal{O}_{L,q}^{(3)}$	$\mathcal{O}_{L,q}$	$\mathcal{O}_{R,u}$	$\mathcal{O}_{R,d}$	$\mathcal{O}_g$
2.74	23.7	6.38	5.78	11.6	2.16	0.604	17.4	18.1	10.2	8.78	2.06	0.568	0.393	0.339	43.8
2.74	23.7	6.38	5.78	11.6	2.16	0.604	**17.5**	**18.3**	**10.5**	8.78	2.06	0.568	0.393	0.339	43.8
2.74	24.0	**8.32**	5.80	**12.2**	2.16	0.604	**20.7**	**23.0**	**12.5**	**13.0**	2.23	**1.62**	0.393	**3.97**	43.8
2.74	24.0	8.33	5.80	12.2	2.16	0.604	20.7	23.0	12.5	13.0	**7.90**	**7.89**	**3.55**	4.05	43.8
2.74	24.0	8.54	5.80	12.2	2.16	0.604	20.7	23.4	**14.4**	**14.0**	8.63	8.62	4.88	**4.71**	43.8
2.74	24.0	8.75	5.81	12.3	2.16	0.604	20.7	23.7	15.8	14.9	**9.21**	**9.21**	5.59	5.17	43.8
2.74	**26.3**	**12.6**	**5.93**	**15.3**	2.16	0.604	**30.2**	**35.2**	**19.8**	**21.6**	9.21	9.21	5.59	5.17	43.8

Table: Impacts of the projected Z-pole measurements at the CEPC on the reach of new physics scale $\Lambda/\sqrt{|c_j|}$ (in TeV) at 95% C.L. For comparison, the first row of this table repeats the last row of Table **??**, as our starting point of this table. For the $(n+1)$-th row, the first n observables are taken into account. In addition, the estimated M_Z and M_W measurements at the CEPC, the Higgs observables (HO), and the existing electroweak precision observables (EWPO) are always included for each row. The entries with major enhancements of the new physics scale limit are marked in red color.

Another factor of 2 enhancement from Z-Pole Observables

Sensitivity from EWPO+HO+Z-Pole



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