Global fit with operators in W/Z-pole and 4-fermion

Yong Du

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In collaboration with Jorge de Blas, Christophe Grojean, Jiayin Gu, Michael Peskin, Junping Tian, Marcel Vos, Eleni Vryonidou

Overview

Number of operators is large, but usually it is $\mathcal{O}(10)$ if focusing on specific sectors (will see specific examples shortly).

In this talk, I will present our preliminary results from Z/W-pole observables and with the inclusion of 4-fermion operators from a personal view.

The big picture of this ongoing project? See, for example, Jiayin's recent talk @ILCX2021

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14:00 **Anomalous HZZ, HWW couplings** *18′*
Speaker: Tomohisa Ogawa (KEK), (k)

14:18 **Global measurement for Higgs** *18′*
Speaker: Gang Li (IHEP)

16:00 **Higgs bosons below 125 GeV at CEPC** *22′*
Speaker: Tania Robens (R)

16:22 **Theory precision for CEPC Higgs measurements** *22′*
Speaker: Sebastian Passehr (RWTH Aachen University)

16:44 **H125 coupling measurement: what to expect and what can we do with it** *22′*
Speaker: Prof. Shinya Kanemura (University of Toyama)

17:06 **Top yukawa couplings and related EFT at 360 GeV** *22′*
Speaker: Zhen Liu (FNAL)

10:30 **Towards complete two-loop EW e+e- to ZH** *30′*
Speaker: Dr. Qian Song (University of Pittsburgh)

12:00 **Use machine learning to study aQGCs** *30′*
Speaker: 冀翀 杨 (辽宁师范大学)

(Not covered)

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Barklow et al, PRD 97, 053003 (2013), Di Vita et al, JHEP02(2018)178
Han and Skiba, PRD 71, 075009(2005), de Blas et al, JHEP12(2019)117
Ethier et al, 2105.00006, Vryonidou and Zhang, JHEP 08 (2018)036
....

Overview

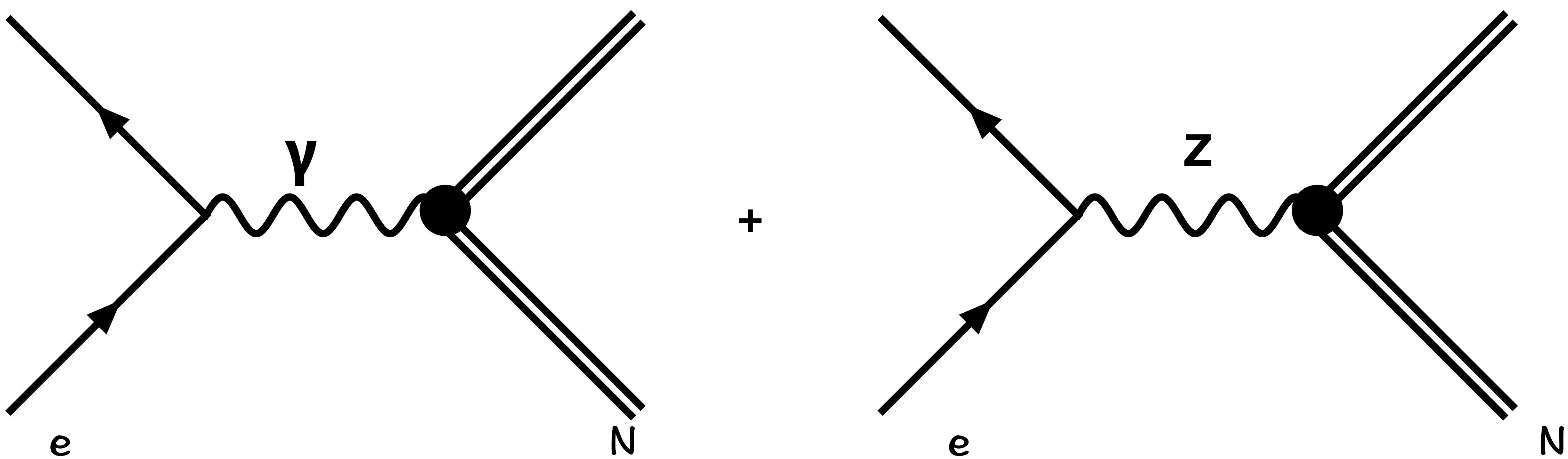
Question:

Why 4-fermion operators?

Short answer: It has not yet been done for future colliders.

Overview: ***PVES***

Parity-violating electron scattering (PVES) has played an essential role in establishing the SM.

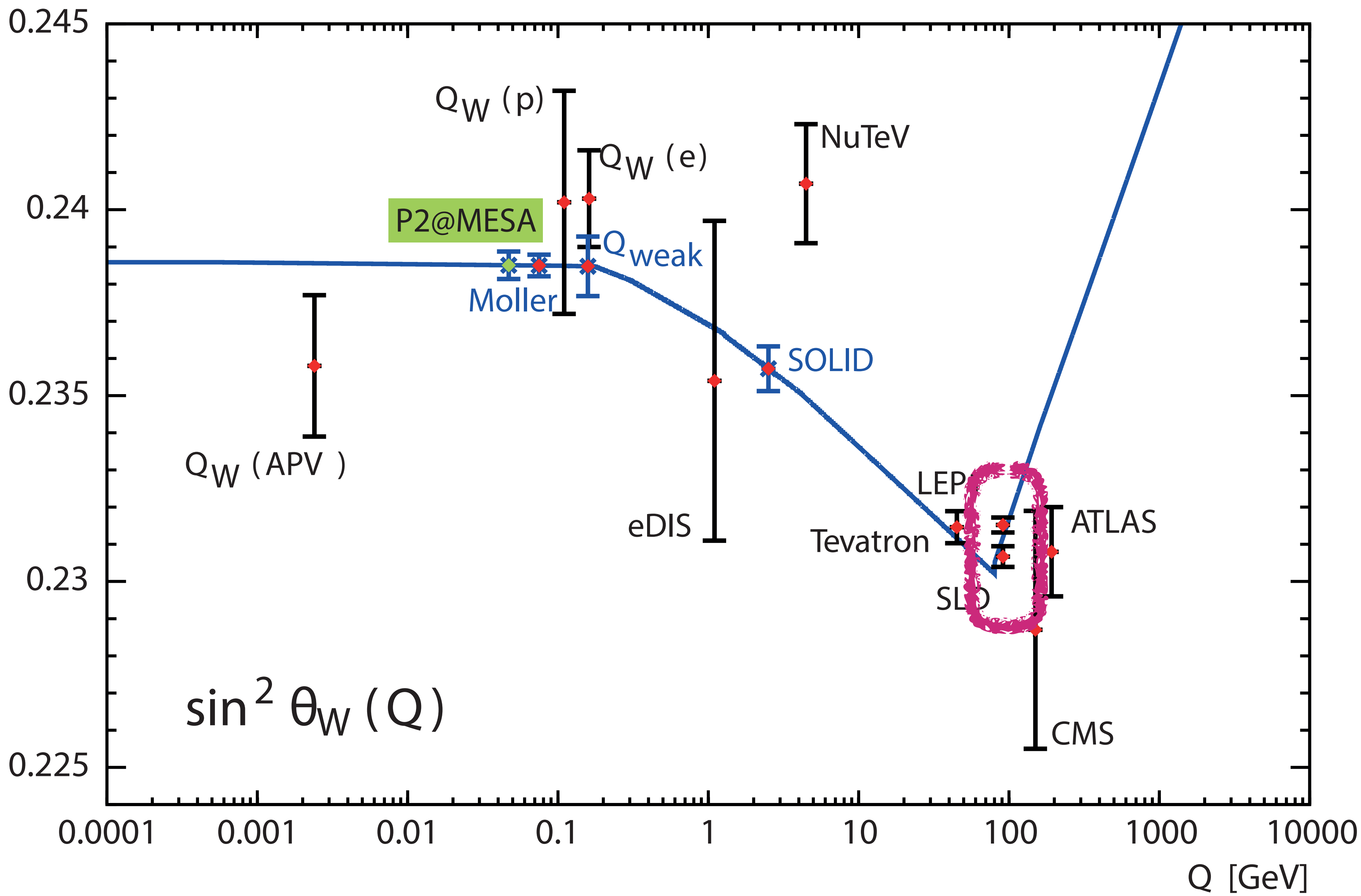


14:00 **AFB measurement at hadron colliders & weak mixing angle at CEPC** *25′*
Speaker: 思奇 杨 (University of Science and Technology of China)

Overview: ***PVES***

Future prospects

Aleksejevs et al, 2011, 2012, 2015



Berger et al, 1511.03934

Overview: ***PVES***

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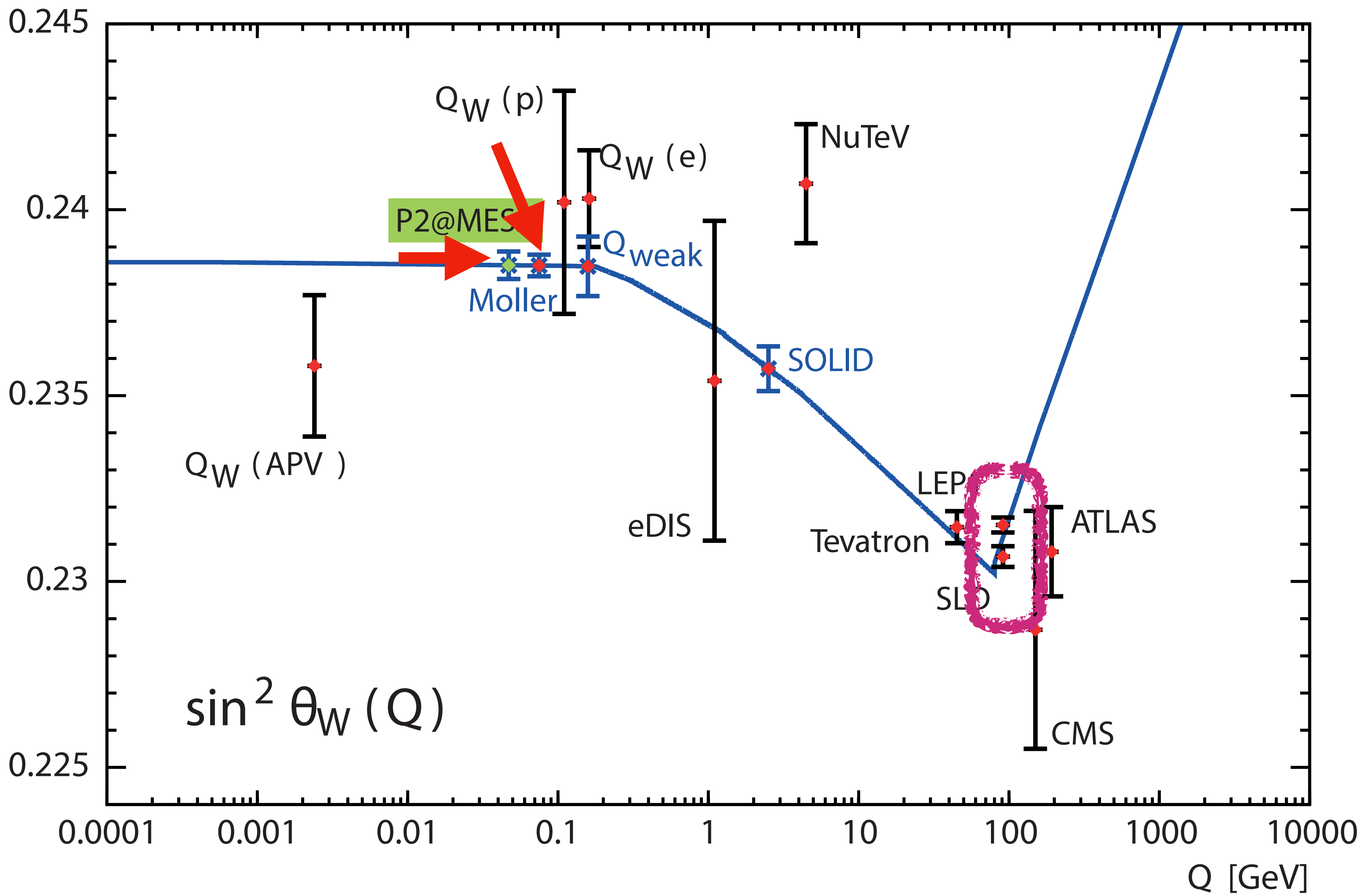


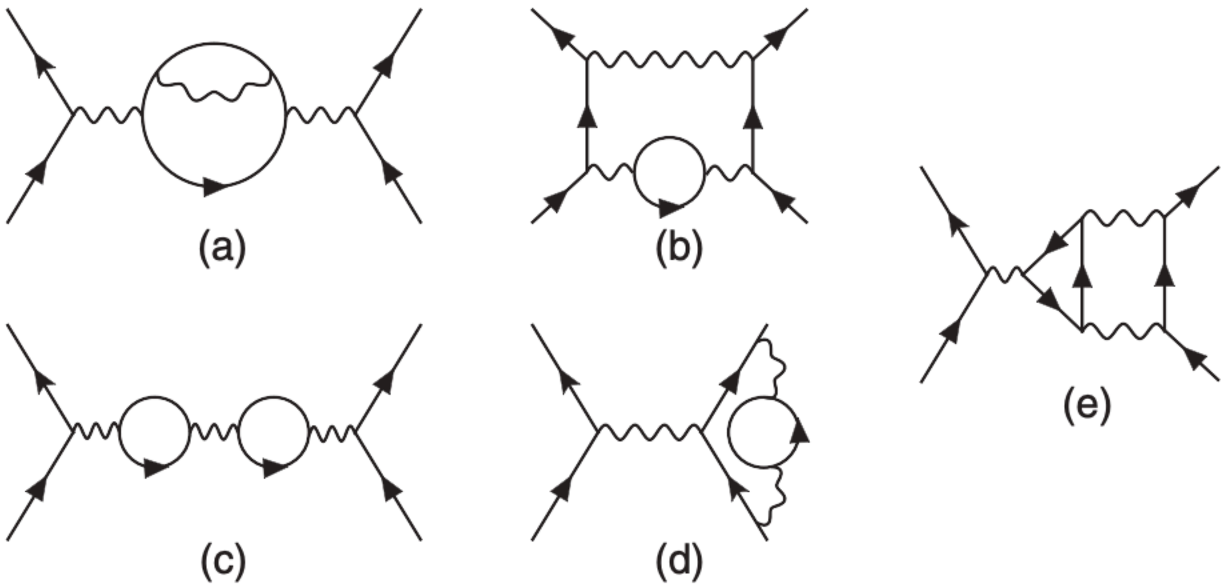
Berger et al, 1511.03934

Overview: *PVES*

LO: Derman and Marciano, 1979

NLO: Czarnecki and Marciano, 1996

NNLO: **YD**, Freitas, Patel, Ramsey-Musolf, PRL 2020



Quantity	Contribution ($\times 10^{-3}$)
1–4 $\sin^2\theta_W$	+74.4
$\Delta Q^e_{W(1,1)}$	–29.0
$\Delta Q^e_{W(1,0)}$	+3.1
$\Delta Q^e_{W(2,2)}$	$-0.18^{+0.0024}_{-0.0040}$
$\Delta Q^e_{W(2,1)}$	$+1.18^{+0.015}_{-0.010}$
$\Delta Q^e_{W(2,0)}$	± 0.13 (estimate)

$\Delta Q^e_{W\,(i,j)}$

i: Number of loops

j: Number of closed fermion

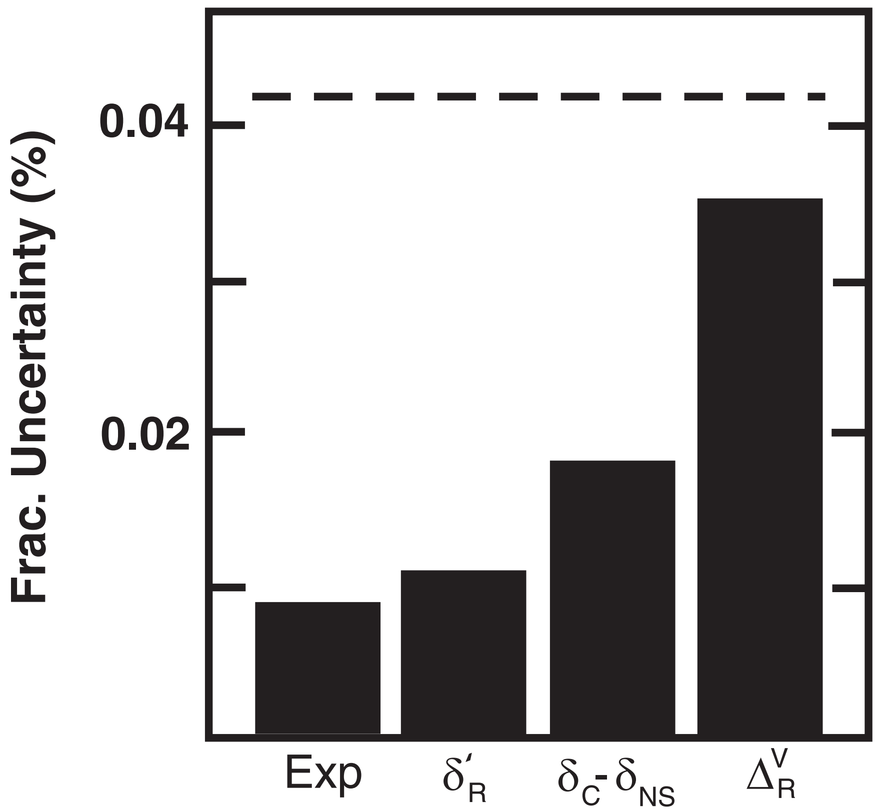
$$\Delta Q^e_{W(2,2)} + \Delta Q^e_{W(2,1)} = 1.00^{+0.012}_{-0.008} \times 10^{-3}$$

$$\Delta_{\exp} Q^e_W = 1.1 \times 10^{-3}$$

Overview: ***CKM unitarity***

Super-allowed β decay or free neutron decay

Towner & Hardy, 2015



Exp. : Experiment

$\delta_{\rm C} - \delta_{\rm NS}$: Nuclear structure dependent

$\delta'_{\rm R}$: transition dependent radiative corrections

$\Delta_{\rm R}^{\rm V}$: transition independent radiative corrections

Overview: *CKM unitarity*

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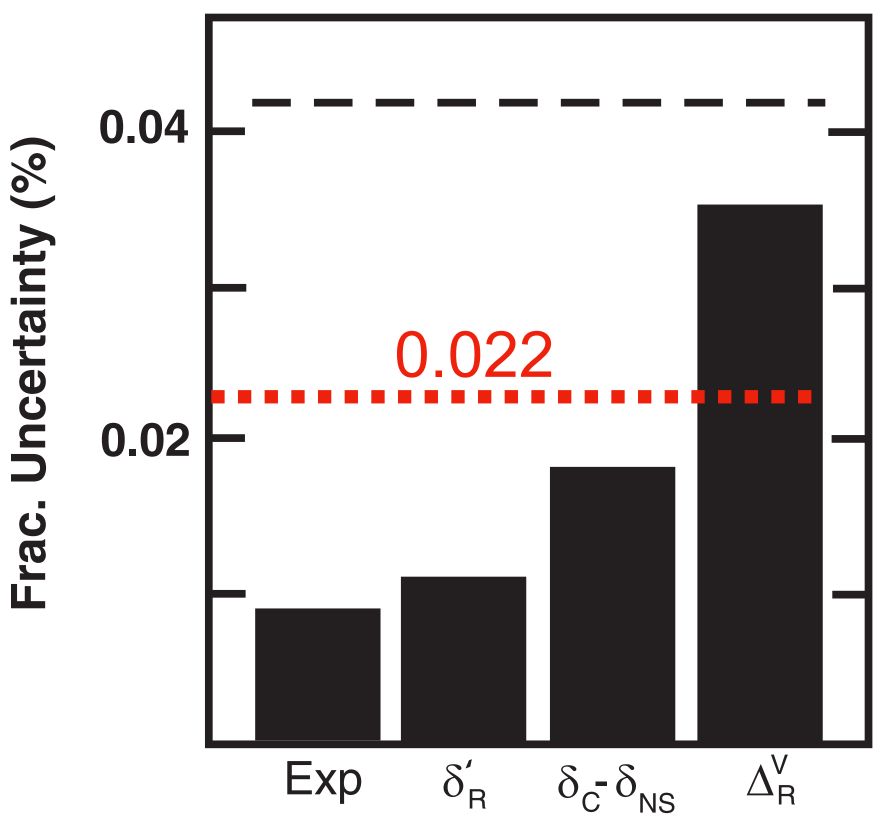

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$\Delta^{\rm V}_{\rm R}$: transition independent radiative corrections

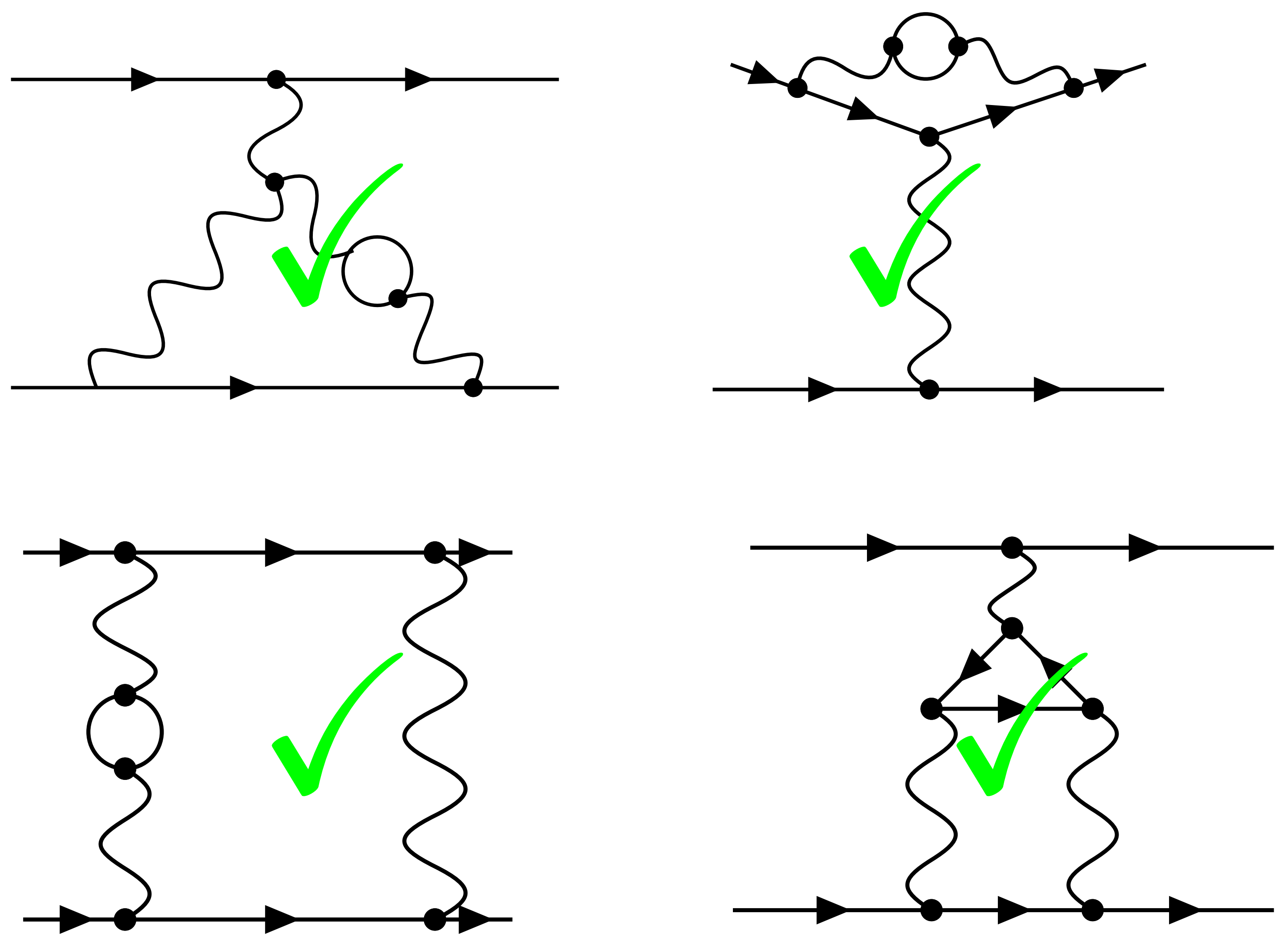
Seng, Gorchtein, Patel, Ramsey-Musolf, PRL 2018

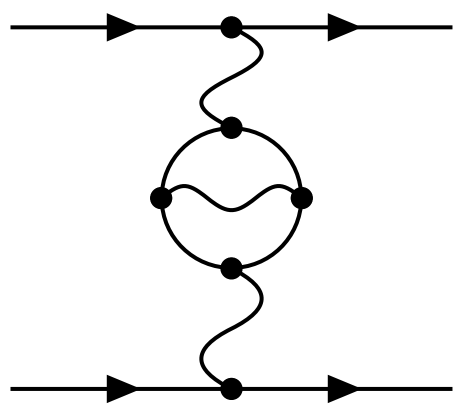
Seng, Gorchtein, Ramsey-Musolf, PRD 2019

Overview: ***CKM unitarity***

Current status:

* in progress, with Michael Ramsey-Musolf, Jia Zhou





Trivial and not necessary.

Remaining: Non-trivial $W\gamma$ boxes on the quark line.

Overview

What in common for PVES and neutron decay? *4-fermion operators!*

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PVES

$$\mathcal{O}_{le} = \frac{c_{\ell e}}{\Lambda^2}\left(\bar{\ell}\gamma_\mu \ell\right)\left(\bar{e}\gamma^\mu e\right)$$

Ignore flavor indices. Left-right symmetric model

$$\Lambda^{\rm Moller} \gtrsim 10 \sim 50\,{\rm TeV}$$

The MOLLER collaboration, 1411.4088

Overview

What in common for PVES and neutron decay? *4-fermion operators!*

PVES

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Ignore flavor indices. Left-right symmetric model

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The MOLLER collaboration, 1411.4088

Neutron decay

$$\mathcal{O}^{(3)}_{lq} = \frac{c^{(3)}_{\ell q}}{\Lambda^2}\left(\bar{\ell}\gamma_\mu \tau^I \ell\right)\left(\bar{q}\gamma^\mu \tau^I q\right)$$

Ignore flavor indices. Lepto-quark model

$$\Lambda^{\nu_\alpha \leftrightarrow \nu_\beta} \gtrsim \mathcal{O}(10)\,\text{TeV}$$

YD, Li, Tang, Vihonen, Yu, 2011.14292

Overview

Including our recent three papers (neutrino oscillation + N_{eff} + CEvNS)

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Non-standard interactions in SMEFT confronted with terrestrial neutrino experiments

Yong Du,[a,b] Hao-Lin Li,[a] Jian Tang,[c] Sampsa Vihonen[c] and Jiang-Hao Yu[a,d,e,f]

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[c] *School of Physics, Sun Yat-sen University, Guangzhou 510275, China*
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Neutrino non-standard interactions meet precision measurements of N_{eff}

Yong Du[a] and Jiang-Hao Yu[a,b,c,d,e]

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[b] *School of Physical Sciences, University of Chinese Academy of Sciences,*

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PREPARED FOR SUBMISSION TO JHEP

Exploring SMEFT Induced Non-Standard Interactions from COHERENT to Neutrino Oscillations

Yong Du,[a] Hao-Lin Li,[a] Jian Tang,[c] Sampsa Vihonen,[c] Jiang-Hao Yu[a,d,e,f,g]

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[c] *School of Physics, Sun Yat-sen University, Guangzhou 510275, China*
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ABSTRACT: We investigate the prospects of next-generation neutrino oscillation experiments DUNE, T2HK and JUNO including TAO within Standard Model Effective Field Theory (SMEFT). We also re-interpret COHERENT data in this framework. Considering both charged and neutral current neutrino Non-Standard Interactions (NSIs), we analyse dimension-6 SMEFT operators and derive lower bounds to UV scale Λ. The most powerful probe is obtained on $\mathcal{O}_{ledq_{1211}}$ with $\Lambda \gtrsim 450\,\mathrm{TeV}$ due to the electron neutrino sample in

:2106.15800v2 [hep-ph] 27 Sep 2021

Overview

Questions:

Why 4-fermion operators?

So the long answer is: Great potential in exploring new physics indirectly. More importantly, we have many experiments for them.

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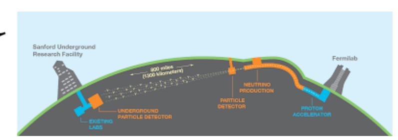
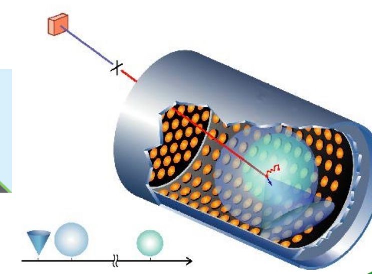
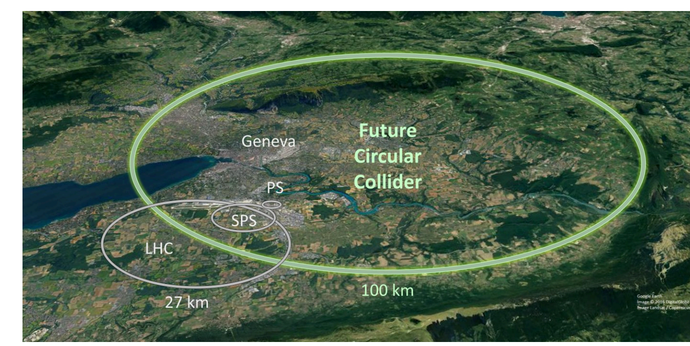
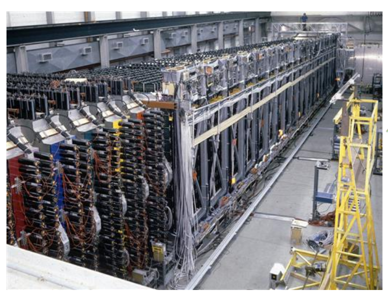
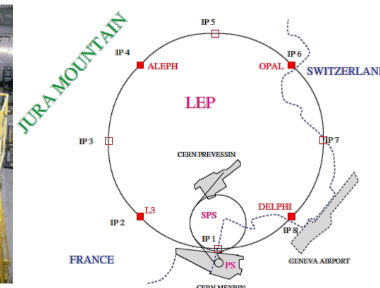
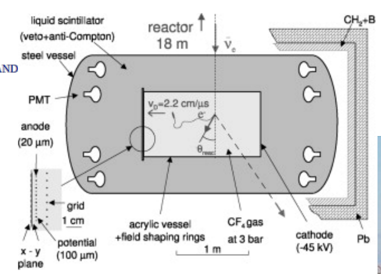


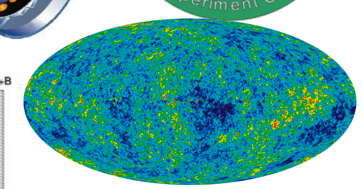


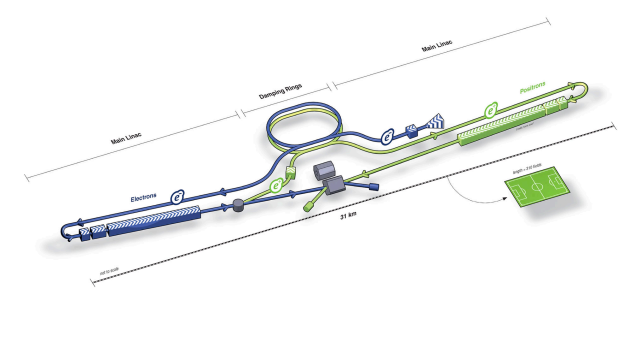




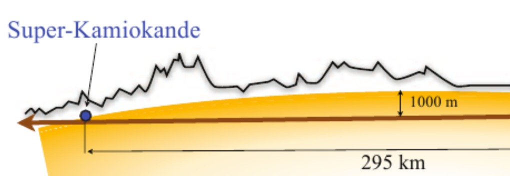


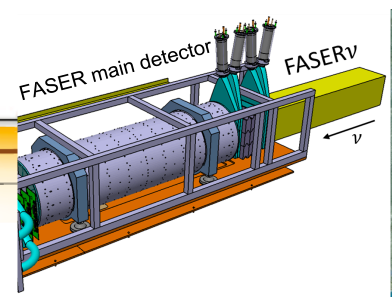


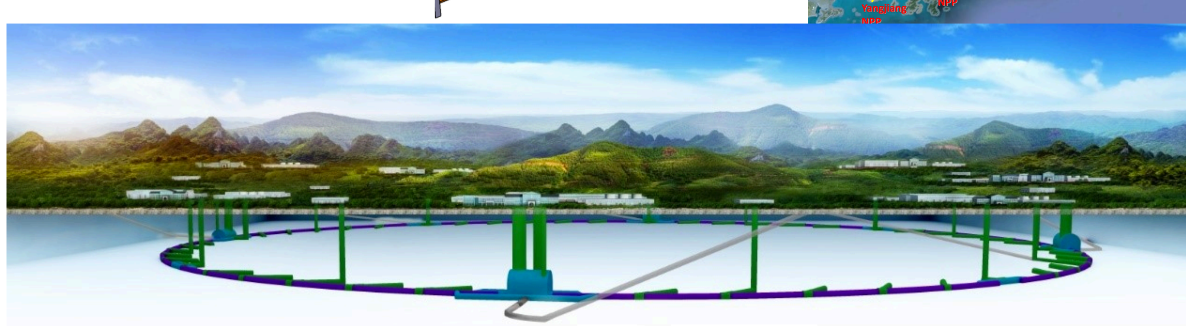


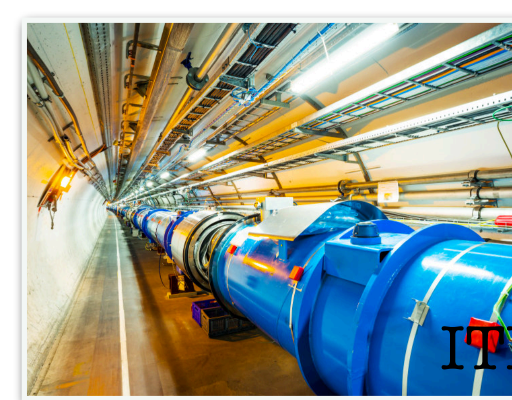


* with many more exps.









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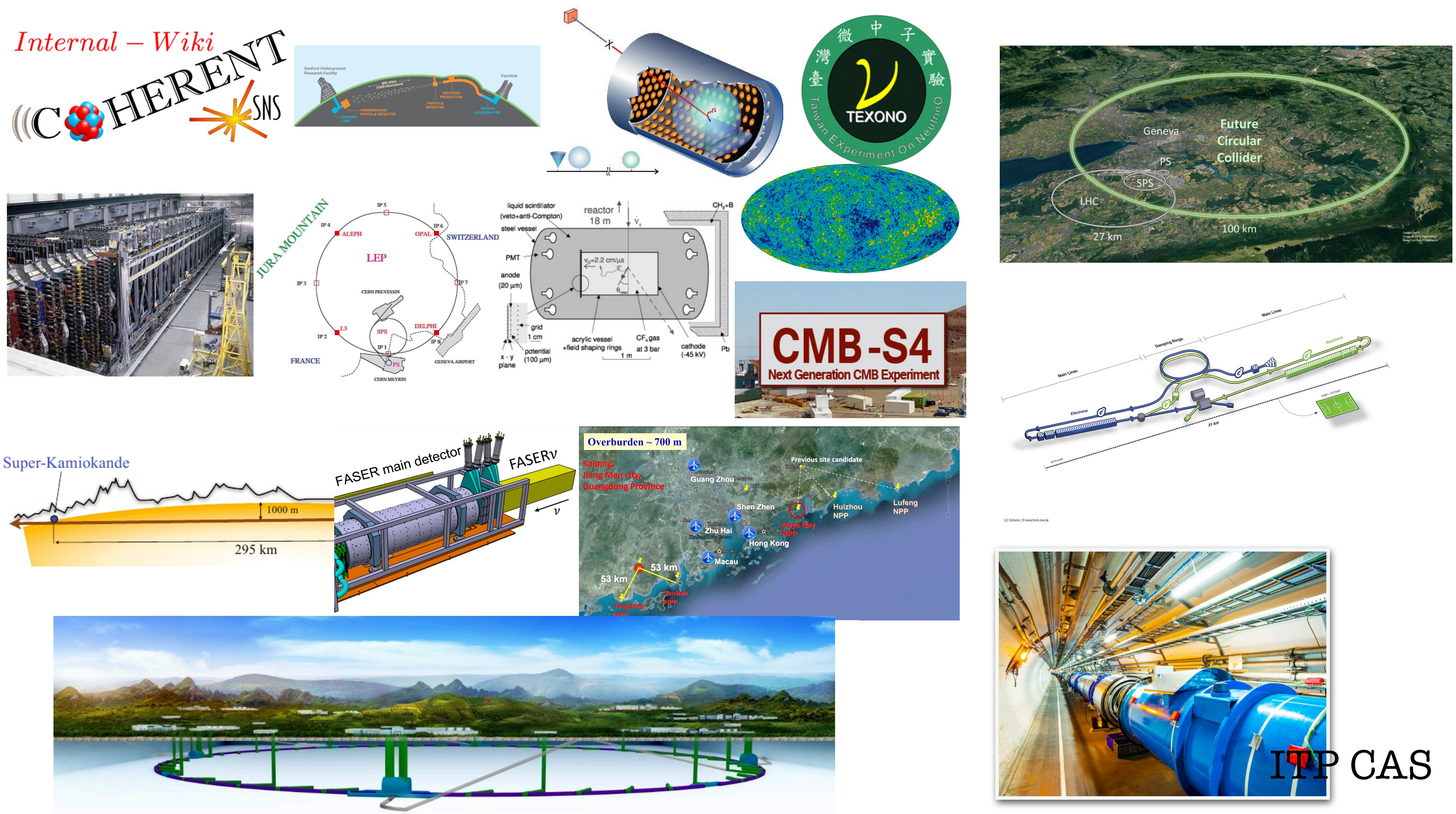
Why 4-fermion operators?

20:05 **Overview of the CEPC** *25′*
Speaker: Haijun Yang (Shanghai Jiao Tong University)

20:30 **CEPC Higgs Physics Opportunities after the HL-LHC** *30′*
Speaker: Sven Heinemeyer (IFT (CSIC))

21:00 **Status and Perspectives of the FCC** *30′*
Speaker: Dr. Frank Zimmermann (CERN)

So the long answer is: Great potential in exploring new physics indirectly. More importantly, we have many experiments for them.



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ITP CAS

Framework

This ongoing project is devoted to a global fit of 4-fermion operators for future colliders.

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$$\mathscr{L}_{\text{eff}}^{vff} = eA_\mu \sum_{f\in u,d,e} Q_f \left(\bar{f}\bar{\sigma}_\mu f + f^c \sigma_\mu \bar{f}^c\right) + g_s G_\mu^a \sum_{f\in u,d} \left(\bar{f}\bar{\sigma}_\mu T^a f + f^c \sigma_\mu T^a \bar{f}^c\right)$$

$$+\frac{g_L}{\sqrt{2}}\left(W_\mu^+ \bar{u}\bar{\sigma}_\mu \left(V + \delta g_L^{Wq}\right) d + W_\mu^+ \bar{u}\bar{\sigma}_\mu \delta g_R^{Wq} d_R + W_\mu^+ \bar{\nu}\bar{\sigma}_\mu \left(\square + \delta g_L^{W\ell}\right) e + \textbf{h.c.} \right)$$

$$+\sqrt{g_L^2 + g_Y^2} Z_\mu \left[\sum_{f\in u,d,e,\nu} \bar{f}\bar{\sigma}_\mu \left(\square T_f^3 - \square s_\theta^2 Q_f + \delta g_L^{Zf}\right) f + \sum_{f^c \in u^c,d^c,e^c} f^c \sigma_\mu \left(-\square s_\theta^2 Q_f + \delta g_R^{Zf}\right) \bar{f}^c \right]$$

$$m_W \rightarrow (1 + \delta m) m_W$$

Extra corrections to both Z/W-pole observables and fermion-pair production.

LHC Higgs Cross Section Working Group, 2017

Framework

One flavor $(I = 1 \ldots 3)$	Two flavors $(I < J = 1 \ldots 3)$
$[O_{\ell\ell}]_{IIII} = \frac{1}{2}\left(\bar{\ell}_I \bar{\sigma}_\mu \ell_I\right)\left(\bar{\ell}_I \bar{\sigma}_\mu \ell_I\right)$	$[O_{\ell\ell}]_{IIJJ} = \left(\bar{\ell}_I \bar{\sigma}_\mu \ell_I\right)\left(\bar{\ell}_J \bar{\sigma}_\mu \ell_J\right)$
$[O_{\ell e}]_{IIII} = \left(\bar{\ell}_I \bar{\sigma}_\mu \ell_I\right)\left(e_I^c \sigma_\mu \bar{e}_I^c\right)$	$[O_{\ell\ell}]_{IJJI} = \left(\bar{\ell}_I \bar{\sigma}_\mu \ell_J\right)\left(\bar{\ell}_J \bar{\sigma}_\mu \ell_I\right)$
	$[O_{\ell e}]_{IIJJ} = \left(\bar{\ell}_I \bar{\sigma}_\mu \ell_I\right)\left(e_J^c \sigma_\mu \bar{e}_J^c\right)$
$[O_{ee}]_{IIII} = \frac{1}{2}\left(e_I^c \sigma_\mu \bar{e}_I^c\right)\left(e_I^c \sigma_\mu \bar{e}_I^c\right)$	$[O_{\ell e}]_{JJII} = \left(\bar{\ell}_J \bar{\sigma}_\mu \ell_J\right)\left(e_I^c \sigma_\mu \bar{e}_I^c\right)$
	$[O_{\ell e}]_{IJJI} = \left(\bar{\ell}_I \bar{\sigma}_\mu \ell_J\right)\left(e_J^c \sigma_\mu \bar{e}_I^c\right)$
	$[O_{ee}]_{IIJJ} = \left(e_I^c \sigma_\mu \bar{e}_I^c\right)\left(e_J^c \sigma_\mu \bar{e}_J^c\right)$

Extra corrections to fermion-pair production

*Currently only flavor-conserving observables/operators are included in our fit.

LHC Higgs Cross Section Working Group, 2017

Input

$$G_F = 1.1663787 \times 10^{-5}\ \text{GeV}^{-2}$$

$$m_Z = 91.1882\ \text{GeV}$$

$$\alpha(m_Z) = \frac{1}{127.952}$$

Observables: LEP-Z, W

Z-pole observables

$\Gamma_Z, \sigma_{\text{had}}, R_{e,\mu,\tau}, A_{\text{FB}}^{0,\{e,\mu,\tau\}}$

$R_b, R_c, A_b^{\text{FB}}, A_c^{\text{FB}}$

A_e, A_μ, A_τ

A_e, A_τ

A_b, A_c

A_s (SLD)

R_{uc} (PDG)

W-pole observables

m_W, Γ_W

$\text{Br}(W \to \ell\nu)$

$R_{W,c}$

R_σ

Observables: LEP-Z, W

Z-pole observables

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A_s (SLD)

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$g_{V,A}^{u,d}$ (D0)

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Observables: LEP-Z, W

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W-pole observables

m_W, Γ_W

$\text{Br}(W \to \ell\nu)$

$R_{W,c}$

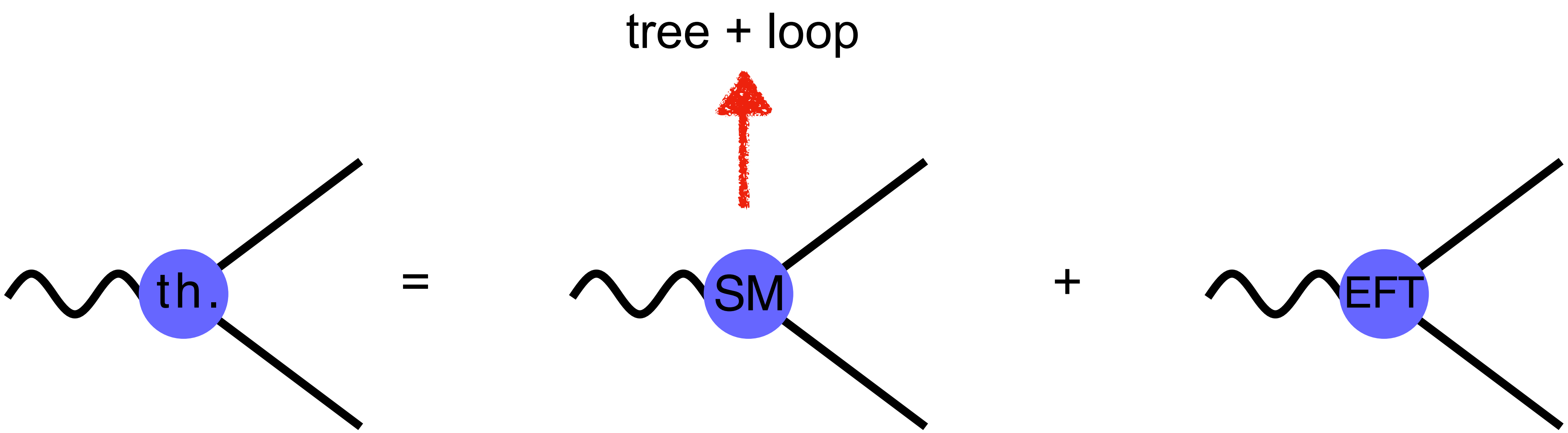
R_σ

15:15 **Electroweak precision pseudo-observables at the e+e− Z-resonance peak** *25′*
Speaker: Dr. Johann Usovitsch (Mainz University)

11:00 **SMEFT at Z pole** *30′*
Speaker: Jia Zhou (UMass Amherst)

11:30 **Z-mass measurement at CEPC** *30′*
Speaker: LI Gang (EPC.IHEP)

Strategy: *exemplified by pole observables*



$$\mathscr{M}^2_{\text{th.}} = \mathscr{M}^2_{\text{SM}} + 2\text{Re}\left(\mathscr{M}_{\text{SM}}\mathscr{M}^\dagger_{\text{EFT}}\right) + \mathscr{M}^2_{\text{EFT}}$$

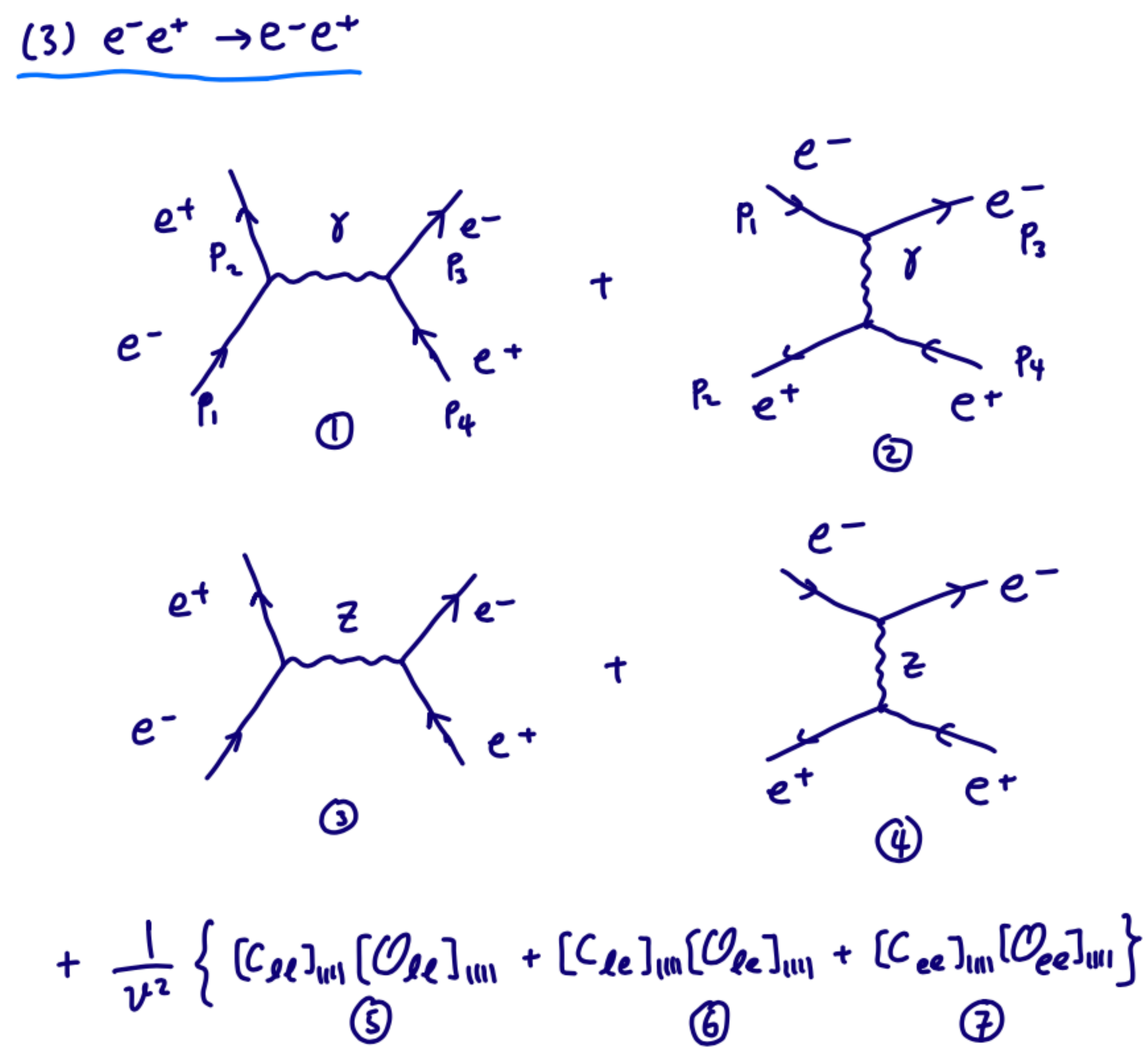
$$\simeq \mathscr{M}^2_{\text{SM}} + 2\text{Re}\left(\mathscr{M}^{\text{tree}}_{\text{SM}}\mathscr{M}^\dagger_{\text{EFT}}\right) + \mathscr{O}\left(\alpha^2\delta g, \delta g^2\right)$$

$$\chi^2 = \sum_{ij}\left[O_{i,\text{exp}} - O_{i,\text{th}}\right]\sigma^{-2}_{ij}\left[O_{j,\text{exp}} - O_{j,\text{th}}\right]$$

Observables: LEP-Z, W

Fermion-pair production: Bhabha scattering for example

$$\frac{d\sigma}{d\cos\theta}(\text{Bhabha})$$



Accidental flat direction for unpolarized beams at LEP lifted by PVES (SLAC-E158)

Observables: LEP-Z, W

Fermion-pair production

$$\sigma(e^+e^- \to \mu^+\mu^-), \quad \sigma_{\rm FB}(e^+e^- \to \mu^+\mu^-)$$

— Flat direction lifted by $\overset{(-)}{\nu}_\mu e^-$ (CHARM-II)

$$\sigma(e^+e^- \to \tau^+\tau^-), \quad \sigma_{\rm FB}(e^+e^- \to \tau^+\tau^-)$$

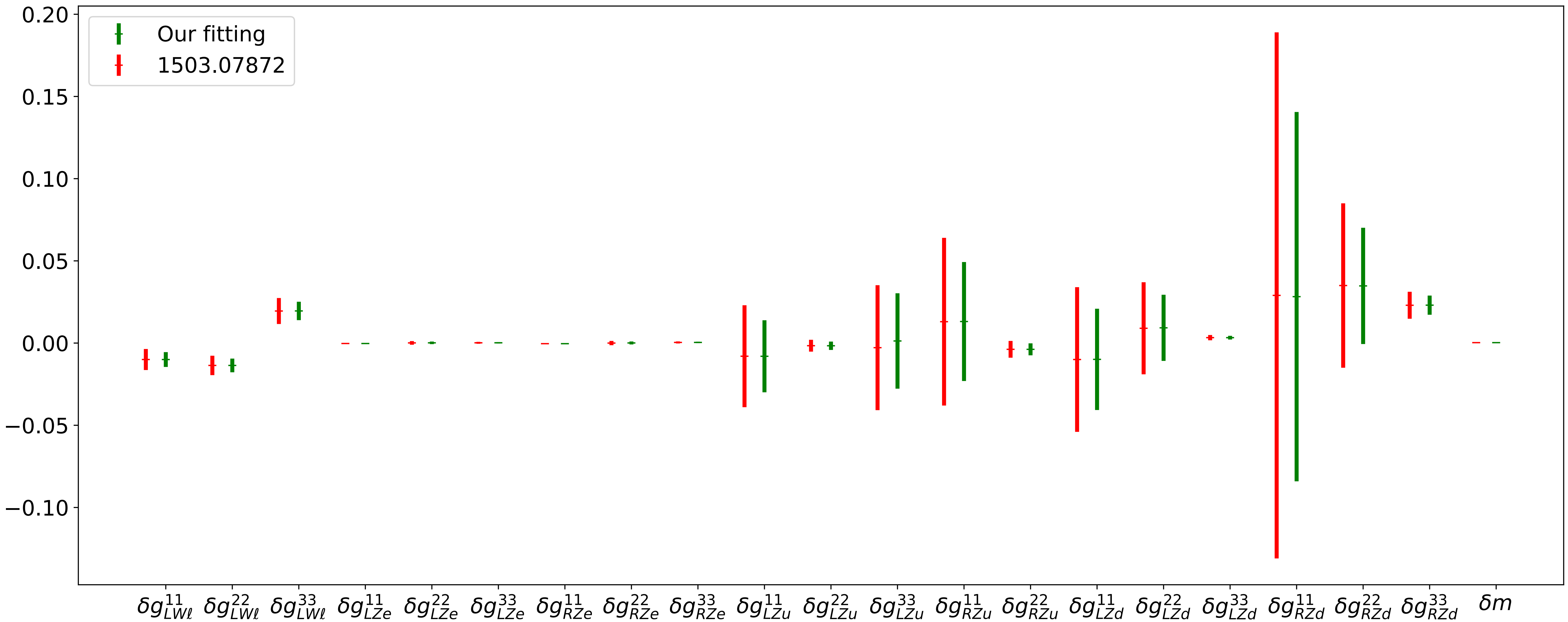
GF from τ decay (PDG)

Michel parameters from polarized muon decay (PSI)

— Michel parameters from polarized tau decay with upgraded SuperKEKB (Banerjee and Roney's talk at EF04 meeting last Friday)

Setup validation

Vertex part from pole observables

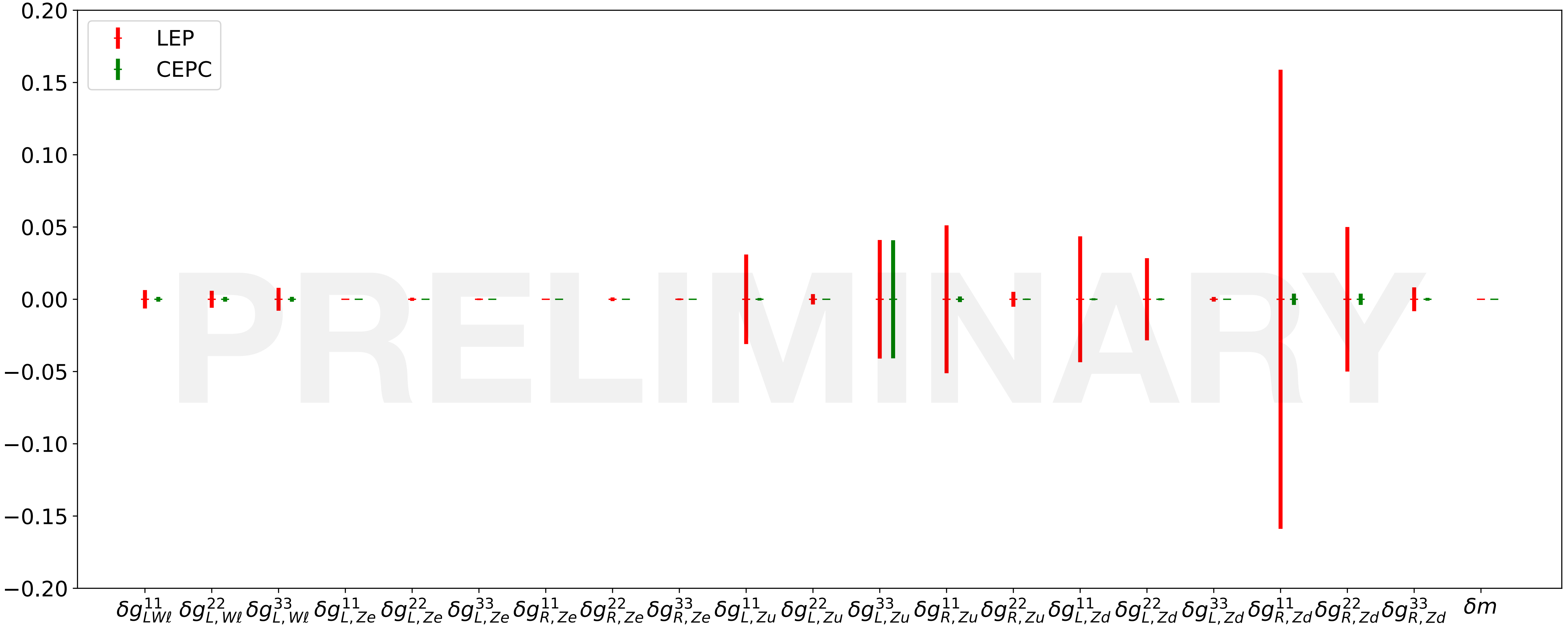


Observables: CEPC

CEPC CDR
de Blas, Durieux, Grojean, Gu, Paul, JHEP 2019

(10^{-3})	L/S	CEPC	(10^{-3})	L/S	CEPC
M_Z (GeV)	2.1	0.5	A_e**	14.3	—
Γ_Z (GeV)	2.3	0.5	A_μ**	102.0	—
σ_{had} (nb)	37.0	5.0	A_τ**	102.0	—
R_e	2.41	0.6	R_b	3.06	0.2
R_μ	1.59	0.1	R_c	17.4	1.13
R_τ	2.17	0.2	$A_{\mathrm{FB}}^{0,b}$	15.5	1.0
$A_{\mathrm{FB}}^{0,e}$	154.0	5.0	$A_{\mathrm{FB}}^{0,c}$	47.5	3.08
$A_{\mathrm{FB}}^{0,\mu}$	80.1	3.0	A_b	21.4	—
$A_{\mathrm{FB}}^{0,\tau}$	104.8	5.0	A_c	40.4	—
A_e*	33.3	—	A_s	97.3	—
A_τ*	29.2	—	source:	[60, 101]	[69]

Results: Vertex only



* No flavor assumption

Correlation matrix: Vertex only

δgLZd33	δgLZe11	δgLZe22	δgLZe33
1	-0.0359	-0.131	**0.603**
-0.0359	1	-0.39	-0.249
-0.131	-0.39	1	0.285
0.603	-0.249	0.285	1

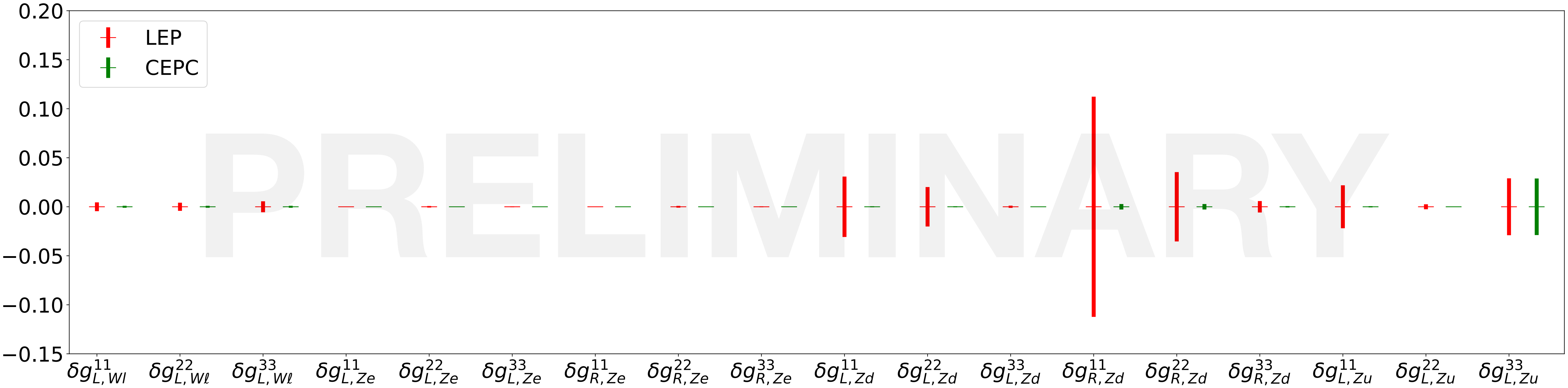
δgLWl11	δgLWl22	δgLWl33	δgLZd11	δgLZd22	δgLZd33	δgLZe11	δgLZe22	δgLZe33	δgLZu11	δgLZu22	δgLZu33	δgRZd11	δgRZd22	δgRZd33	δgRZe11	δgRZe22	δgRZe33	δgRZu11	δgRZu22	δm
1	-0.447	-0.477	-0.11	0.0485	0.0225	0.106	-0.0579	-0.0487	-0.00657	-0.0139	0.000135	0.00328	0.0104	0.00874	0.00301	0.0288	-0.00262	-0.00375	-0.0083	0.0000107
-0.447	1	-0.471	-0.11	0.0476	0.0216	0.112	-0.0595	-0.0501	-0.00449	-0.0146	0.000108	0.00621	0.0118	-0.00088	0.00381	0.023	-0.00501	-0.00893	-0.0147	-0.0000476
-0.477	-0.471	1	-0.11	0.0494	0.024	0.108	-0.0579	-0.0477	-0.00253	-0.0164	0.000127	0.00552	0.00989	0.00518	0.00678	0.0271	-0.00582	-0.00173	-0.0105	$-1.\times 10^{-6}$
-0.11	-0.11	-0.11	1	-0.331	-0.224	-0.32	-0.0842	-0.0548	0.011	0.223	-0.00231	-0.0149	0.226	-0.00803	-0.0156	-0.492	0.0107	0.0118	-0.435	0.0000218
0.0485	0.0476	0.0494	-0.331	1	0.34	-0.0626	0.281	-0.124	-0.0317	-0.234	0.00226	0.0321	-0.113	0.0287	0.0355	0.483	-0.0284	-0.0291	0.26	0.0000686
0.0225	0.0216	0.024	-0.224	0.34	1	-0.0359	-0.131	**0.603**	-0.0218	-0.157	0.00151	0.0217	-0.0733	0.019	0.0237	0.322	-0.0196	-0.0204	0.171	0.0000583
0.106	0.112	0.108	-0.32	-0.0626	-0.0359	1	-0.39	-0.249	-0.0117	0.171	-0.00195	0.0136	0.322	0.0143	0.00918	-0.415	-0.0131	-0.0145	-0.564	-0.000139
-0.0579	-0.0595	-0.0579	-0.0842	0.281	-0.131	-0.39	1	0.285	0.027	-0.0378	0.000637	-0.0268	-0.232	-0.0273	-0.021	0.136	0.0275	0.0285	0.376	0.0000512
-0.0487	-0.0501	-0.0477	-0.0548	-0.124	**0.603**	-0.249	0.285	1	0.0173	-0.0233	0.000399	-0.0177	-0.149	-0.0185	-0.0141	0.0851	0.0175	0.0179	0.242	0.0000459
-0.00657	-0.00449	-0.00253	0.011	-0.0317	-0.0218	-0.0117	0.027	0.0173	1	-0.0196	-0.0000729	0.195	0.00473	0.195	0.194	-0.0155	-0.19	-0.197	0.00282	-0.000315
-0.0139	-0.0146	-0.0164	0.223	-0.234	-0.157	0.171	-0.0378	-0.0233	-0.0196	1	-0.00155	0.0179	0.578	0.0217	0.0188	-0.331	-0.0178	-0.0183	-0.281	-0.000149
0.000135	0.000108	0.000127	-0.00231	0.00226	0.00151	-0.00195	0.000637	0.000399	-0.0000729	-0.00155	1	0.0000815	-0.0016	0.0000462	0.0001	0.00469	-0.0000588	-0.0000598	0.00418	2.7×10^{-6}
0.00328	0.00621	0.00552	-0.0149	0.0321	0.0217	0.0136	-0.0268	-0.0177	0.195	0.0179	0.0000815	1	-0.00589	-0.195	-0.189	0.0174	0.197	0.195	-0.000765	-0.000234
0.0104	0.0118	0.00989	0.226	-0.113	-0.0733	0.322	-0.232	-0.149	0.00473	0.578	-0.0016	-0.00589	1	-0.00196	-0.00657	-0.342	0.00487	0.00466	-0.409	-0.000135
0.00874	-0.00088	0.00518	-0.00803	0.0287	0.019	0.0143	-0.0273	-0.0185	0.195	0.0217	0.0000462	-0.195	-0.00196	1	-0.194	0.00988	0.196	0.191	-0.0077	0.000234
0.00301	0.00381	0.00678	-0.0156	0.0355	0.0237	0.00918	-0.021	-0.0141	0.194	0.0188	0.0001	-0.189	-0.00657	-0.194	1	0.0214	0.199	0.198	0.00445	0.000263
0.0288	0.023	0.0271	-0.492	0.483	0.322	-0.415	0.136	0.0851	-0.0155	-0.331	0.00469	0.0174	-0.342	0.00988	0.0214	1	-0.0126	-0.0128	**0.892**	0.000105
-0.00262	-0.00501	-0.00582	0.0107	-0.0284	-0.0196	-0.0131	0.0275	0.0175	-0.19	-0.0178	-0.0000588	0.197	0.00487	0.196	0.199	-0.0126	1	-0.193	0.00491	0.00029
-0.00375	-0.00893	-0.00173	0.0118	-0.0291	-0.0204	-0.0145	0.0285	0.0179	-0.197	-0.0183	-0.0000598	0.195	0.00466	0.191	0.198	-0.0128	-0.193	1	0.00525	0.000295
-0.0083	-0.0147	-0.0105	-0.435	0.26	0.171	-0.564	0.376	0.242	0.00282	-0.281	0.00418	-0.000765	-0.409	-0.0077	0.00445	**0.892**	0.00491	0.00525	1	0.000108
0.0000107	-0.0000476	$-1.\times 10^{-6}$	0.0000218	0.0000686	0.0000583	-0.000139	0.0000512	0.0000459	-0.000315	-0.000149	2.7×10^{-6}	-0.000234	-0.000135	0.000234	0.000263	0.000105	0.00029	0.000295	0.000108	1

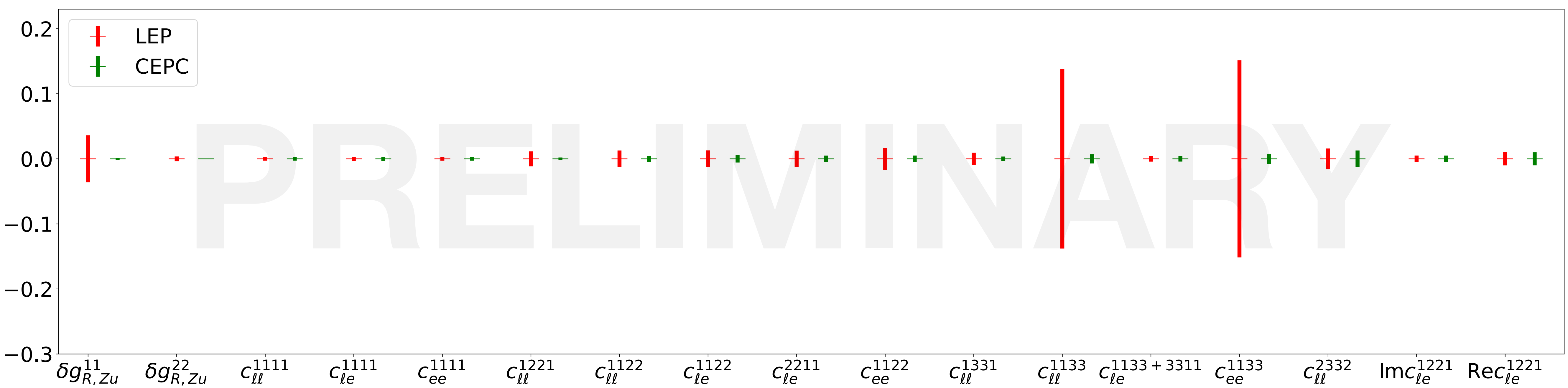
Correlation matrix: Vertex only

δgRZe22	δgRZe33	δgRZu11	δgRZu22
1	-0.0126	-0.0128	**0.892**
-0.0126	1	-0.193	0.00491
-0.0128	-0.193	1	0.00525
0.892	0.00491	0.00525	1

δgLWl11	δgLWl22	δgLWl33	δgLZd11	δgLZd22	δgLZd33	δgLZe11	δgLZe22	δgLZe33	δgLZu11	δgLZu22	δgLZu33	δgRZd11	δgRZd22	δgRZd33	δgRZe11	δgRZe22	δgRZe33	δgRZu11	δgRZu22	δm
1	-0.447	-0.477	-0.11	0.0485	0.0225	0.106	-0.0579	-0.0487	-0.00657	-0.0139	0.000135	0.00328	0.0104	0.00874	0.00301	0.0288	-0.00262	[illegible]	-0.0083	0.0000107
-0.447	1	-0.471	-0.11	0.0476	0.0216	0.112	-0.0595	-0.0501	-0.00449	-0.0146	0.000108	0.00621	0.0118	-0.00088	0.00381	0.023	-0.00501	[illegible]	-0.0147	-0.0000476
-0.477	-0.471	1	-0.11	0.0494	0.024	0.108	-0.0579	-0.0477	-0.00253	-0.0164	0.000127	0.00552	0.00989	0.00518	0.00678	0.0271	-0.00582	[illegible]	-0.0105	$-1.\times 10^{-6}$
-0.11	-0.11	-0.11	1	-0.331	-0.224	-0.32	-0.0842	-0.0548	0.011	0.223	-0.00231	-0.0149	0.226	-0.00803	-0.0156	-0.492	0.0107	[illegible]	-0.435	0.0000218
0.0485	0.0476	0.0494	-0.331	1	0.34	-0.0626	0.281	-0.124	-0.0317	-0.234	0.00226	0.0321	-0.113	0.0287	0.0355	0.483	-0.0284	[illegible]	0.26	0.0000686
0.0225	0.0216	0.024	-0.224	0.34	1	-0.0359	-0.131	**0.603**	-0.0218	-0.157	0.00151	0.0217	-0.0733	0.019	0.0237	0.322	-0.0196	[illegible]	0.171	0.0000583
0.106	0.112	0.108	-0.32	-0.0626	-0.0359	1	-0.39	-0.249	-0.0117	0.171	-0.00195	0.0136	0.322	0.0143	0.00918	-0.415	-0.0131	[illegible]	-0.564	-0.000139
-0.0579	-0.0595	-0.0579	-0.0842	0.281	-0.131	-0.39	1	0.285	0.027	-0.0378	0.000637	-0.0268	-0.232	-0.0273	-0.021	0.136	0.0275	[illegible]	0.376	0.0000512
-0.0487	-0.0501	-0.0477	-0.0548	-0.124	**0.603**	-0.249	0.285	1	0.0173	-0.0233	0.000399	-0.0177	-0.149	-0.0185	-0.0141	0.0851	0.0175	[illegible]	0.242	0.0000459
-0.00657	-0.00449	-0.00253	0.011	-0.0317	-0.0218	-0.0117	0.027	0.0173	1	-0.0196	-0.0000729	0.195	0.00473	0.195	0.194	-0.0155	-0.19	[illegible]	0.00282	-0.000315
-0.0139	-0.0146	-0.0164	0.223	-0.234	-0.157	0.171	-0.0378	-0.0233	-0.0196	1	-0.00155	0.0179	0.578	0.0217	0.0188	-0.331	-0.0178	[illegible]	-0.281	-0.000149
0.000135	0.000108	0.000127	-0.00231	0.00226	0.00151	-0.00195	0.000637	0.000399	-0.0000729	-0.00155	1	0.0000815	-0.0016	0.0000462	0.0001	0.00469	-0.0000588	-0.0000598	0.00418	2.7×10^{-6}
0.00328	0.00621	0.00552	-0.0149	0.0321	0.0217	0.0136	-0.0268	-0.0177	0.195	0.0179	0.0000815	1	-0.00589	-0.195	-0.189	0.0174	0.197	0.195	-0.000765	-0.000234
0.0104	0.0118	0.00989	0.226	-0.113	-0.0733	0.322	-0.232	-0.149	0.00473	0.578	-0.0016	-0.00589	1	-0.00196	-0.00657	-0.342	0.00487	0.00466	-0.409	-0.000135
0.00874	-0.00088	0.00518	-0.00803	0.0287	0.019	0.0143	-0.0273	-0.0185	0.195	0.0217	0.0000462	-0.195	-0.00196	1	-0.194	0.00988	0.196	0.191	-0.0077	0.000234
0.00301	0.00381	0.00678	-0.0156	0.0355	0.0237	0.00918	-0.021	-0.0141	0.194	0.0188	0.0001	-0.189	-0.00657	-0.194	1	0.0214	0.199	0.198	0.00445	0.000263
0.0288	0.023	0.0271	-0.492	0.483	0.322	-0.415	0.136	0.0851	-0.0155	-0.331	0.00469	0.0174	-0.342	0.00988	0.0214	1	-0.0126	-0.0128	**0.892**	0.000105
-0.00262	-0.00501	-0.00582	0.0107	-0.0284	-0.0196	-0.0131	0.0275	0.0175	-0.19	-0.0178	-0.0000588	0.197	0.00487	0.196	0.199	-0.0126	1	-0.193	0.00491	0.00029
-0.00375	-0.00893	-0.00173	0.0118	-0.0291	-0.0204	-0.0145	0.0285	0.0179	-0.197	-0.0183	-0.0000598	0.195	0.00466	0.191	0.198	-0.0128	-0.193	1	0.00525	0.000295
-0.0083	-0.0147	-0.0105	-0.435	0.26	0.171	-0.564	0.376	0.242	0.00282	-0.281	0.00418	-0.000765	-0.409	-0.0077	0.00445	**0.892**	0.00491	0.00525	1	0.000108
0.0000107	-0.0000476	$-1.\times 10^{-6}$	0.0000218	0.0000686	0.0000583	-0.000139	0.0000512	0.0000459	-0.000315	-0.000149	2.7×10^{-6}	-0.000234	-0.000135	0.000234	0.000263	0.000105	0.00029	0.000295	0.000108	1

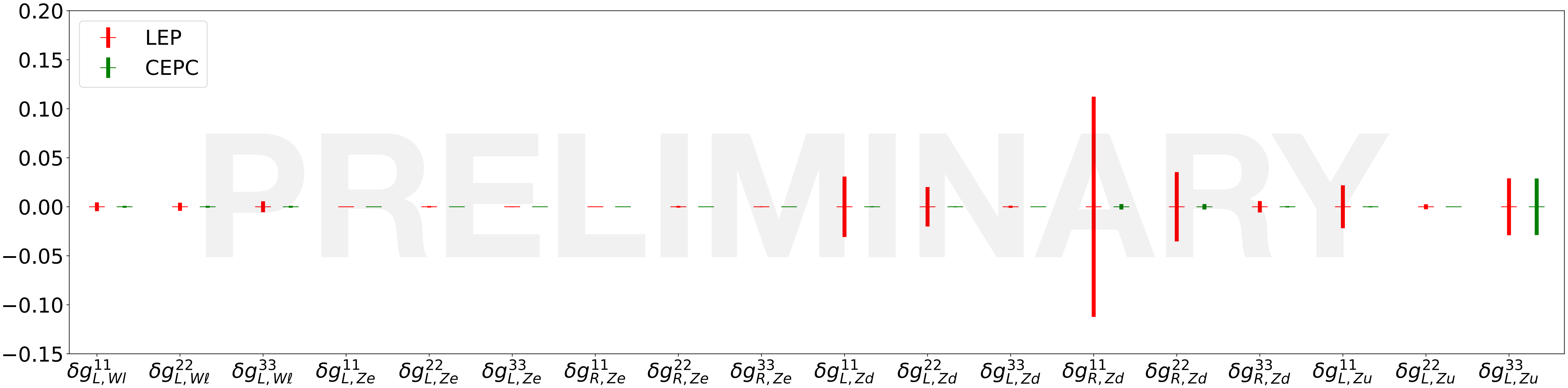
Results: Vertex + 4f

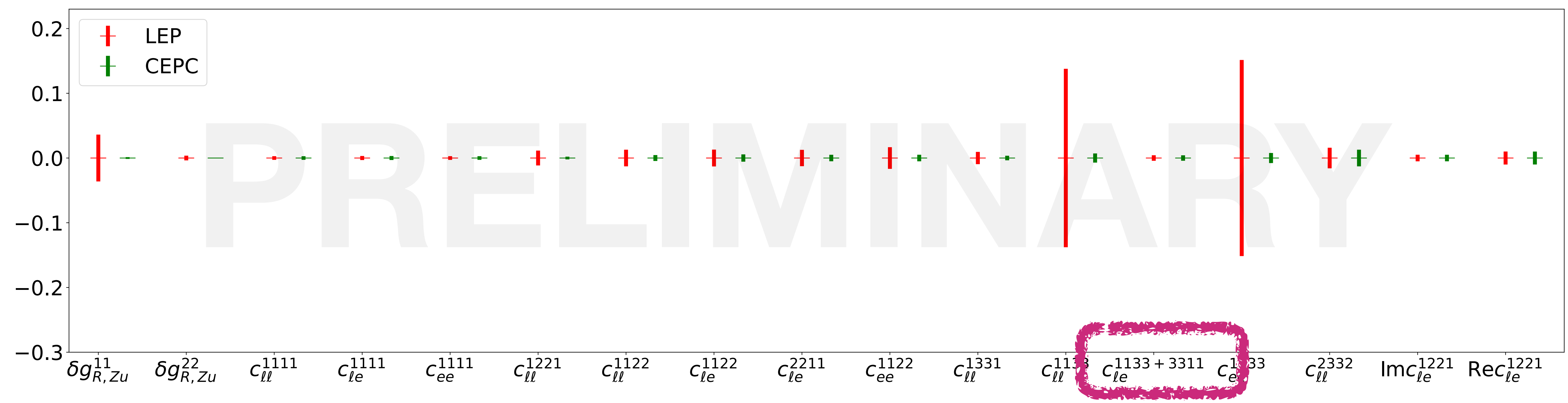




* No flavor assumption

Results: Vertex + 4f





* No flavor assumption

Beam polarization @ILC, CLIC

Summary and outlook

- 4-fermion operators are very interesting in exploring new physics indirectly (PVES, CKM unitarity, neutrino NSIs, $N_{\rm eff}$, etc)

- We validate our setup against results in literature for LEP and find excellent agreement.

- Preliminary results obtained using projections for CEPC, much smaller uncertainties would be expected as compared to those from LEP.

- More comprehensive results (with more operators) to be expected at the beginning of the coming year.

Backup

	δgLWl11	δgLWl22	δgLWl33	δgLZe11	δgLZe22	δgLZe33	δgRZe11	δgRZe22	δgRZe33	δgLZd11	δgLZd22	δgLZd33	δgRZd11	δgRZd22
δgLWl11	1	-0.485	-0.463	-0.0792	0.0357	0.0167	0.0779	-0.0416	-0.035	0.00291	0.00284	0.0189	-0.00396	-0.00398
δgLWl22	-0.485	1	-0.412	-0.103	0.0441	0.0205	0.103	-0.0553	-0.0459	0.00337	0.00361	0.0233	-0.00514	-0.00517
δgLWl33	-0.463	-0.412	1	-0.195	0.085	0.0398	0.193	-0.104	-0.0865	0.00866	0.00848	0.0451	-0.00735	-0.00742
δgLZe11	-0.0792	-0.103	-0.195	1	-0.327	-0.222	-0.306	-0.0949	-0.0635	-0.0103	-0.0102	-0.491	0.0123	0.0126
δgLZe22	0.0357	0.0441	0.085	-0.327	1	0.339	-0.0724	0.287	-0.121	0.0297	0.0297	0.481	-0.0311	-0.0314
δgLZe33	0.0167	0.0205	0.0398	-0.222	0.339	1	-0.0405	-0.129	0.606	0.0204	0.0203	0.321	-0.0211	-0.0214
δgRZe11	0.0779	0.103	0.193	-0.306	-0.0724	-0.0405	1	-0.387	-0.246	0.0114	0.0114	-0.427	-0.0129	-0.0129
δgRZe22	-0.0416	-0.0553	-0.104	-0.0949	0.287	-0.129	-0.387	1	0.282	-0.0254	-0.0254	0.141	0.0265	0.0265
δgRZe33	-0.035	-0.0459	-0.0865	-0.0635	-0.121	0.606	-0.246	0.282	1	-0.0164	-0.0164	0.0887	0.0173	0.0172
δgLZd11	0.00291	0.00337	0.00866	-0.0103	0.0297	0.0204	0.0114	-0.0254	-0.0164	1	-0.197	0.014	0.193	0.194
δgLZd22	0.00284	0.00361	0.00848	-0.0102	0.0297	0.0203	0.0114	-0.0254	-0.0164	-0.197	1	0.0139	0.194	0.194
δgLZd33	0.0189	0.0233	0.0451	-0.491	0.481	0.321	-0.427	0.141	0.0887	0.014	0.0139	1	-0.015	-0.0153
δgRZd11	-0.00396	-0.00514	-0.00735	0.0123	-0.0311	-0.0211	-0.0129	0.0265	0.0173	0.193	0.194	-0.015	1	-0.196
δgRZd22	-0.00398	-0.00517	-0.00742	0.0126	-0.0314	-0.0214	-0.0129	0.0265	0.0172	0.194	0.194	-0.0153	-0.196	1
δgRZd33	-0.00804	-0.0115	-0.0209	-0.439	0.261	0.17	-0.571	0.378	0.242	-0.003	-0.0031	0.893	0.00281	0.00257

cLe1111	cee1111	cLL1221	cLL1122	cLe1122	cLe2211	cee1122	cLL1331	cLL1133	cLe1133PcLe3311	cee1133	cLL2332	ImcLe1221	RecLe1221
1	-0.532	-0.00347	0.00085	0.000385	-0.000504	0.00075	-0.00269	0.000685	-9.69e-05	0.000671	-0.000944	1.91e-06	3.93e-06
-0.532	1	-0.000114	4.94e-05	7.68e-05	-9.1e-05	1.08e-05	-9.44e-05	2.76e-05	-3.06e-06	2.52e-05	-2.33e-05	-3.67e-06	-4.01e-06
-0.00347	-0.000114	1	-0.202	-0.00308	0.0132	-0.244	-0.142	0.0349	-0.00272	0.0347	-0.0511	1.06e-05	6.7e-07
0.00085	4.94e-05	-0.202	1	-0.667	0.799	-0.874	0.0576	-0.0143	0.00111	-0.014	0.000827	-5.31e-06	-2.12e-06
0.000385	7.68e-05	-0.00308	-0.667	1	-0.846	0.731	0.0983	-0.0242	0.00202	-0.0242	-0.0315	3.1e-07	4.31e-06
-0.000504	-9.1e-05	0.0132	0.799	-0.846	1	-0.772	-0.113	0.0277	-0.00232	0.0277	0.0353	-4.98e-06	-9.61e-06
0.00075	1.08e-05	-0.244	-0.874	0.731	-0.772	1	0.00573	-0.00126	8.23e-05	-0.0015	0.0218	-1.31e-06	-8.55e-08
-0.00269	-9.44e-05	-0.142	0.0576	0.0983	-0.113	0.00573	1	-0.247	0.0206	-0.245	-0.0193	7.01e-06	5.19e-06
0.000685	2.76e-05	0.0349	-0.0143	-0.0242	0.0277	-0.00126	-0.247	1	0.0716	-0.857	0.00472	-2.22e-06	-2.14e-06
-9.69e-05	-3.06e-06	-0.00272	0.00111	0.00202	-0.00232	8.23e-05	0.0206	0.0716	1	0.08	-0.000358	-3.46e-06	-8.19e-06
0.000671	2.52e-05	0.0347	-0.014	-0.0242	0.0277	-0.0015	-0.245	-0.857	0.08	1	0.00471	-2.24e-06	-2.19e-06
-0.000944	-2.33e-05	-0.0511	0.000827	-0.0315	0.0353	0.0218	-0.0193	0.00472	-0.000358	0.00471	1	-1.81e-06	-6.79e-06
1.91e-06	-3.67e-06	1.06e-05	-5.31e-06	3.1e-07	-4.98e-06	-1.31e-06	7.01e-06	-2.22e-06	-3.46e-06	-2.24e-06	-1.81e-06	1	-2.98e-06
3.93e-06	-4.01e-06	6.7e-07	-2.12e-06	4.31e-06	-9.61e-06	-8.55e-08	5.19e-06	-2.14e-06	-8.19e-06	-2.19e-06	-6.79e-06	-2.98e-06	1