Summary of Theory Study

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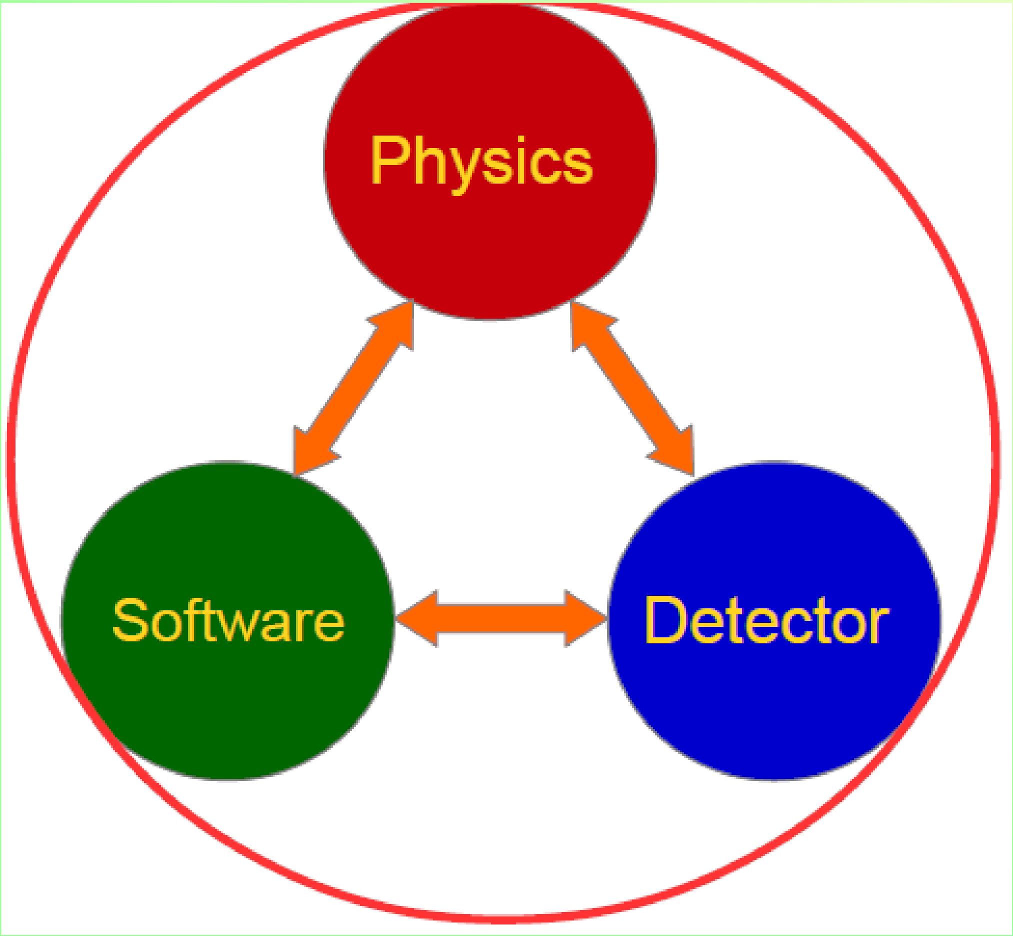
Goal : How to Prepare CDR (Theory) ?
— 3 Key Lessons —

- **Think about Real Physics Issues !**
  -- both Theory Side and Experimental Tests !

- **Closely watch out LHC Run-2 Results !**
  -- Any possible New Particle Discovery @ Run-2
  will give strong inputs to CDR Writing of CEPC

- **How to make Theory Studies Useful for EXP Simulations?!**
  -- Cooperate with Detector Group!
  -- Motivate and Help Detector Simulations!

Theory & Exp Interface



Manqi Ruan's talk

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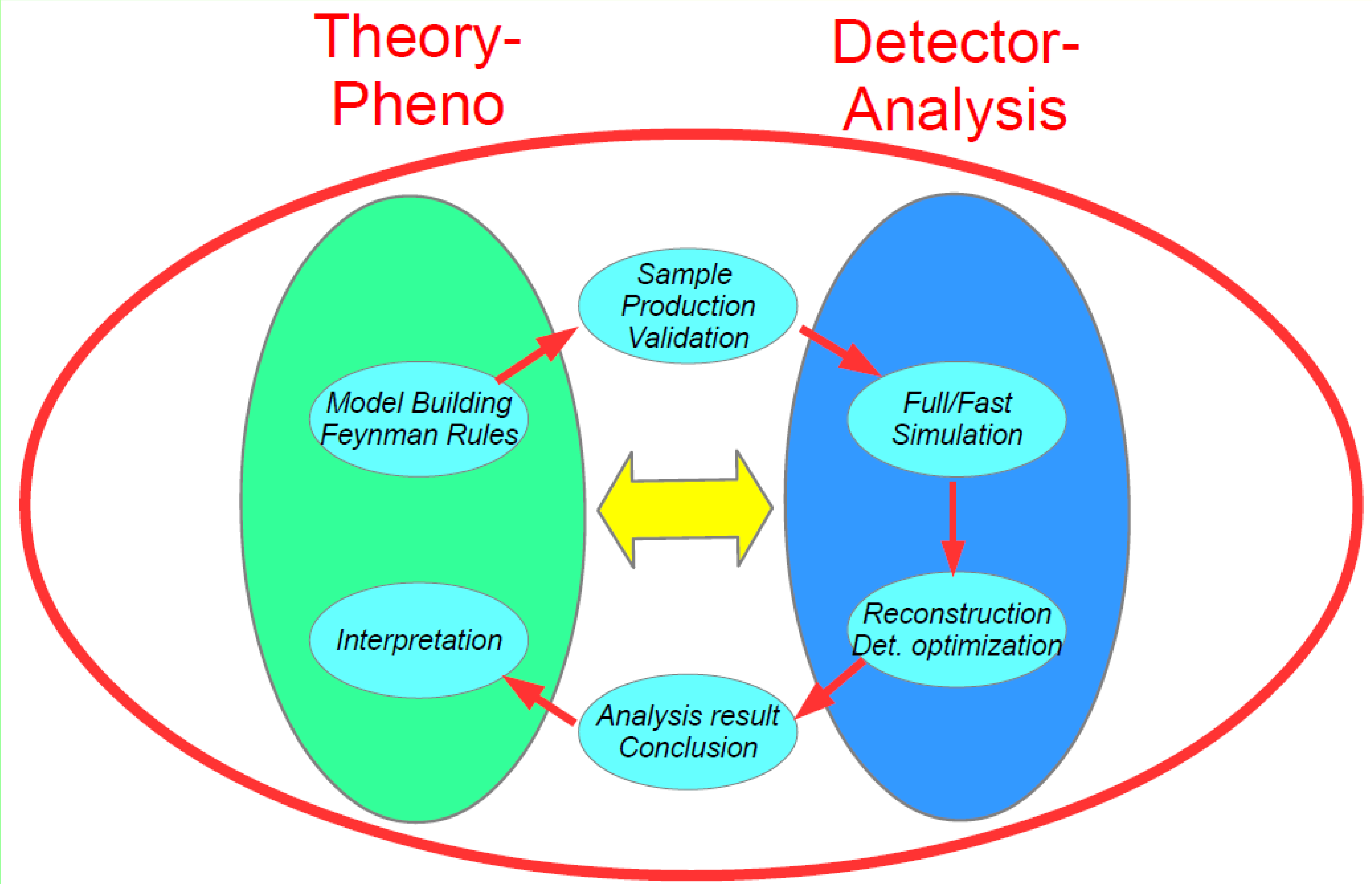


Many good progresses from last year ……

Probing New Physics Scales at CEPC	Shao-Feng Ge
Probing the nature of electroweak phase transition from CEPC to gravitational waves detectors	Fa-Peng Huang
Searching for dark matter at future e+e- and pp colliders	Peng-Fei Yin
Searching exotic decay channels of the SM Higgs boson at CEPC	Hao Zhang

A roadmap to reconstruct the Higgs potential at e+e- and pp colliders	Qi-Shu Yan (UCAS)
Interaction between Theory-Phenomenology & Detector Simulation Studies	Manqi Ruan (IHEP)

Phenomenology of the Georgi-Machacek model at future electron-positron colliders	Cheng-Wei Chiang
Constraining Natural Supersymmetry at the HL-LHC, ILC and CEPC	Tian-Jun Li,

B Physics Anomalies and High Energy Collider	Ying Li
Understanding the quarkonium production mechanism from polarization measurements	Yan-Qing Ma,
Interference effects on Higgs mass measurement at CEPC	Yu-Jie Zhang

Probing new physics inside Loops at electron-positron colliders	Qing-Hong Cao,
The effective operator analysis of CEPC and CEPC 400	Jing Shu,

Physics Motivations

LHC New Discovery →
High Energy Physics at Turning Point

- Run-1 Higgs Discovery h(125GeV) in 2012
- Run-2 New Particle Discovery in 2016 ?!

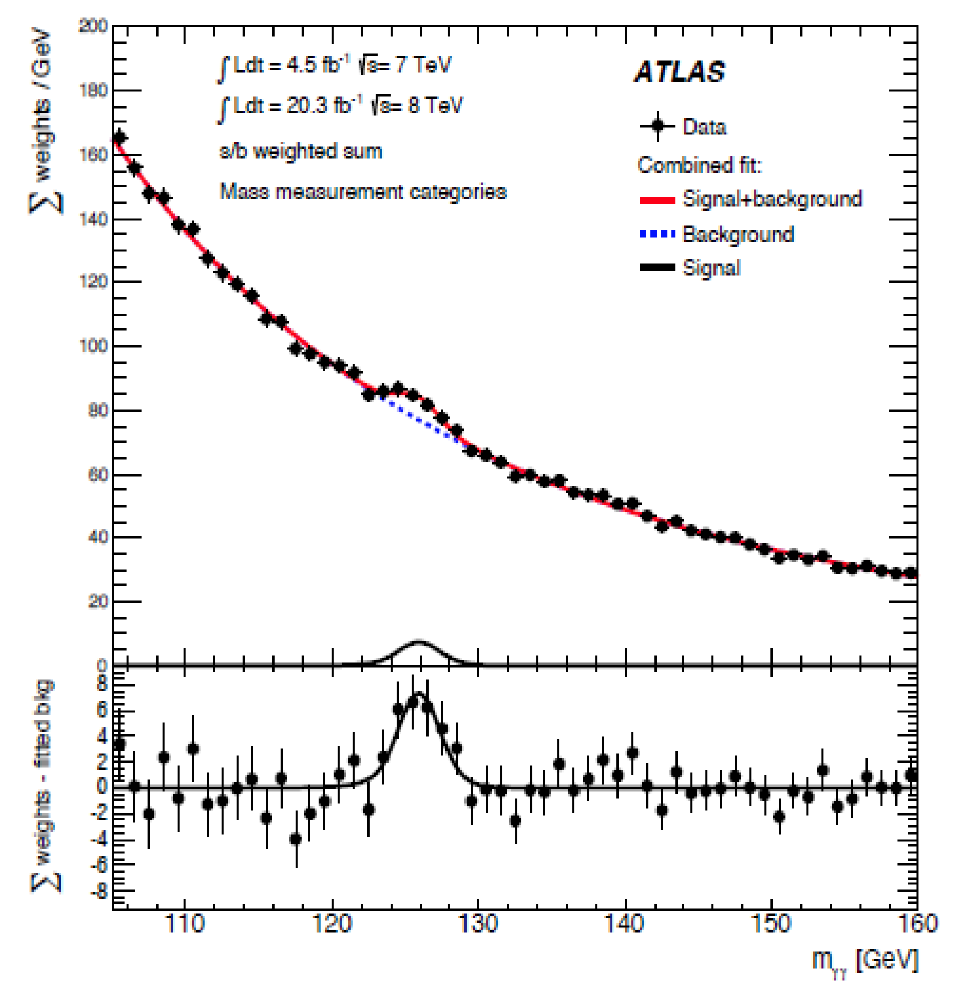
These will lead to

New Set of Key Physics Questions
for Future Colliders to answer!!

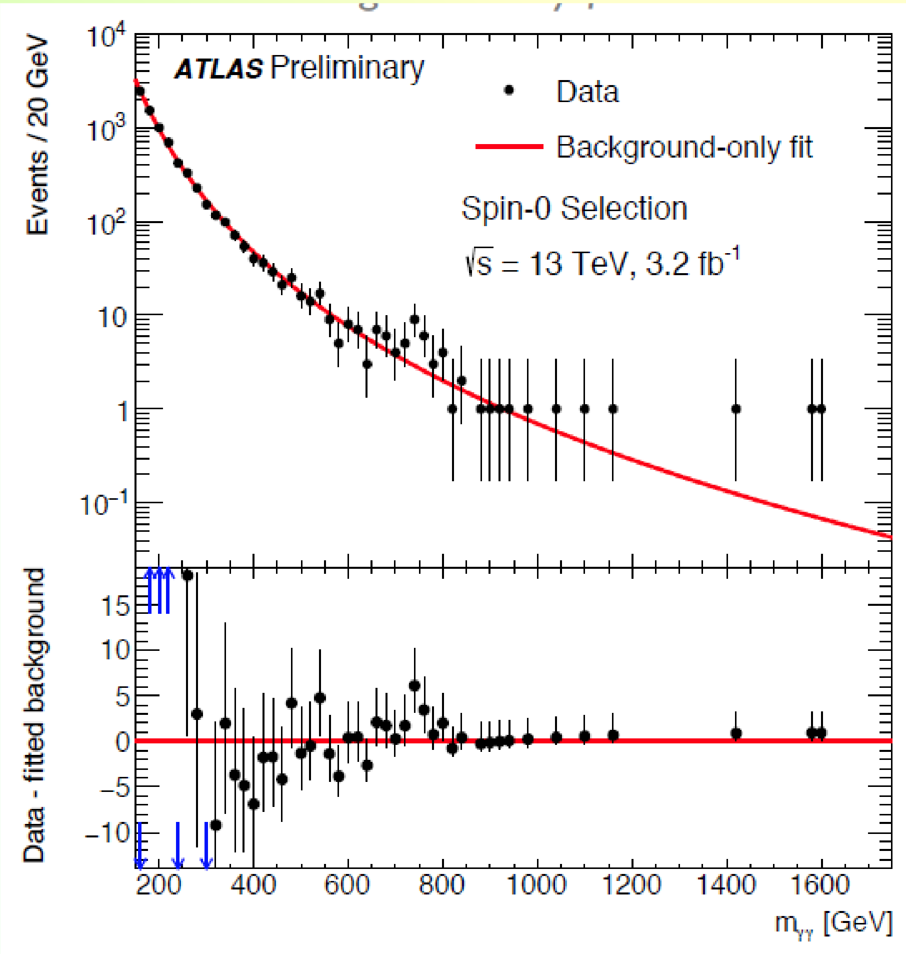
➢ h(125GeV) Discovery at LHC Run-1

➢ X(750GeV) New Resonance at LHC Run-2 ?!

✓ h(125GeV)



X(750GeV) ??



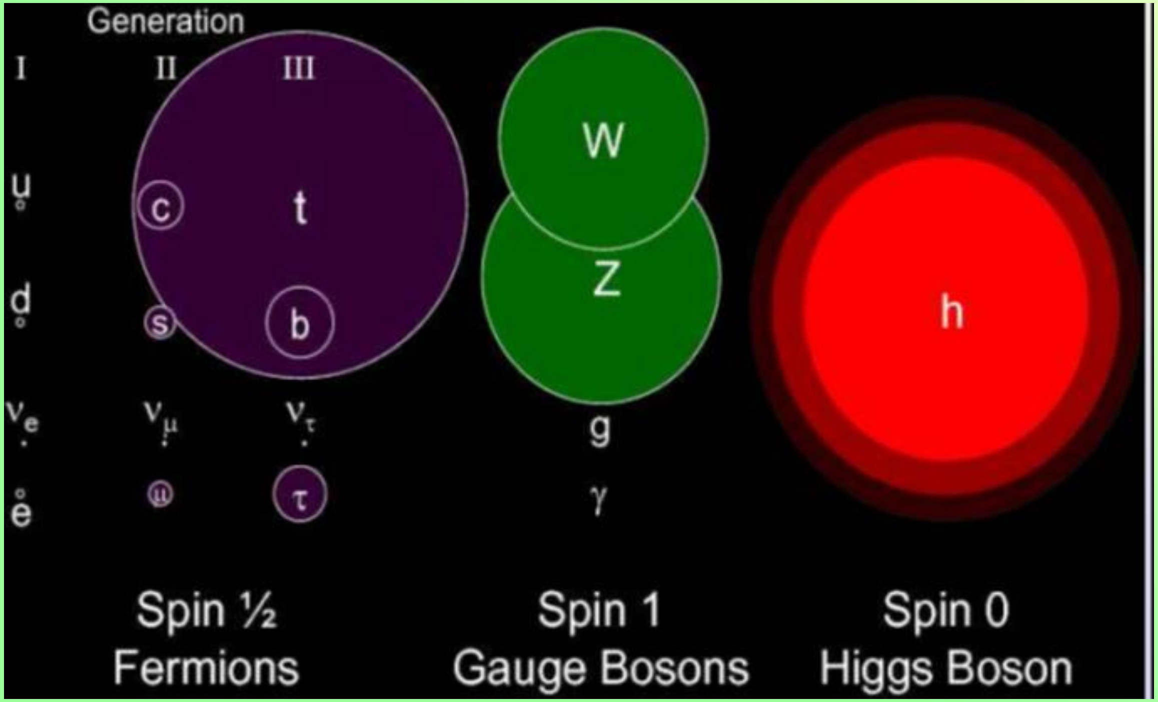
2878 events ($m_{\gamma\gamma}$ > 200 GeV)

SM *is* Incomplete: Mass Puzzle

— Yukawa Force is Flavor-dependent & Unnatural !
Why Quark/Lepton Masses differ so much at Tree Level?

— What are underlying Scales of Fermion Mass Generations?

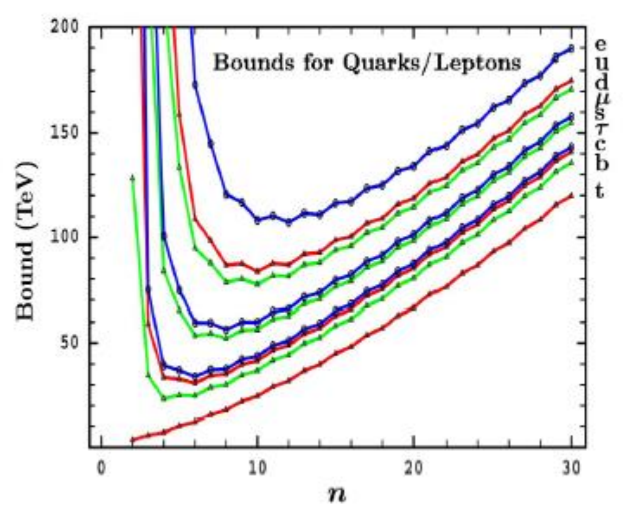
— Why is Higgs Mass itself Unnatural under Loop Corrections?

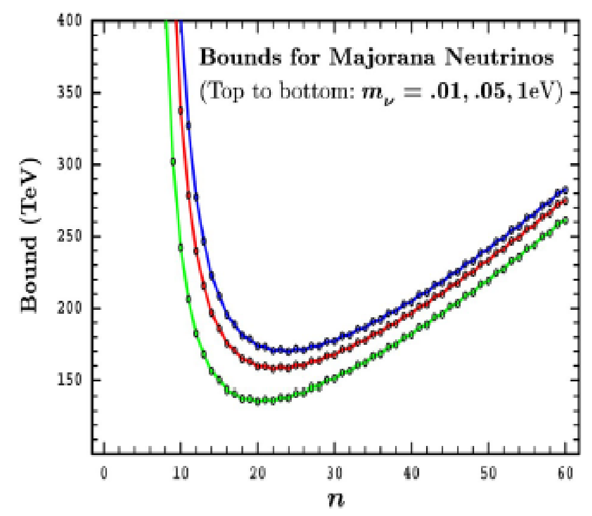


SM *is* Incomplete: Fermion Mass Puzzle

— **Yukawa Force is Flavor-dependent & Unnatural !**
Why Quark/Lepton Masses differ so much at Tree Level?

— **What are underlying Scales of Fermion Mass Generations?**





Upper Bounds on Scales of Fermion Mass Generations:

2nd+3rd Families: 3.5-56 TeV
1st Family: 77-107 TeV

— All these bounds Tied to O(3-100TeV) Scales !

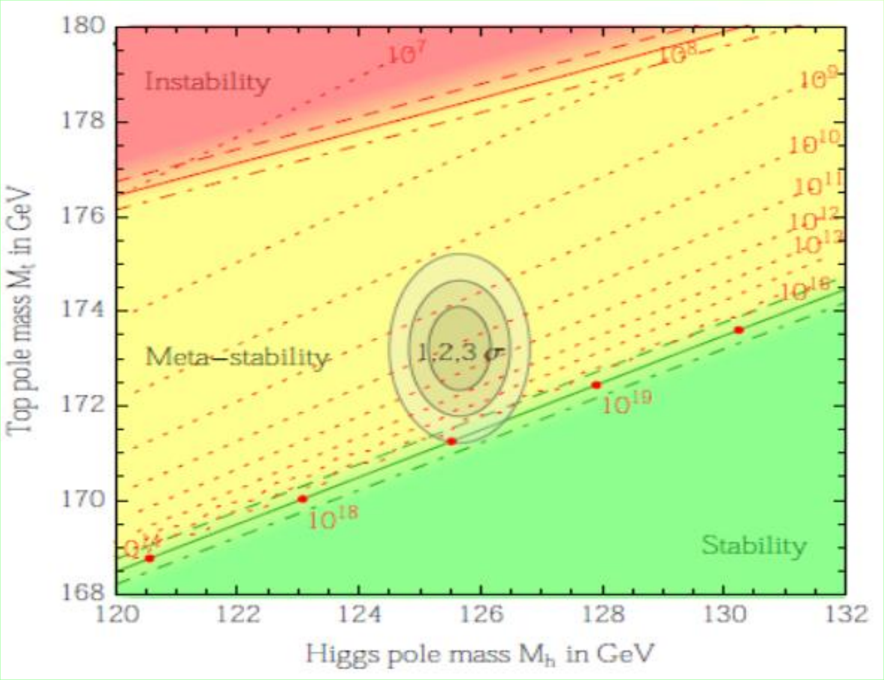
$\xi_1\xi_2$	V_LV_L	$t\bar{t}$	$b\bar{b}$	$c\bar{c}$	$s\bar{s}$	$d\bar{d}$	$u\bar{u}$	$\tau^-\tau^+$	$\mu^-\mu^+$	e^-e^+	$\nu_L\nu_L$
Mass (GeV)	80.4	178	4.85	1.65	0.105	0.006	0.003	1.777	0.106	5.11×10^{-4}	5×10^{-11}
n_s	2	2	4	6	8	10	10	6	8	12	22
$E^{\star(\min)}_{2\to n}$ (TeV)	1.2	3.49	23.4	30.8	52.1	77.4	83.6	33.9	56.3	107	158
$E^{\star}_{2\to 2}$ (TeV)	1.2	3.49	128	377	6×10^3	10^5	2×10^5	606	10^4	2×10^6	1.1×10^{13}

Dicus and He,
PRL.94 (2005) 221802
PRD.71 (2005) 093009

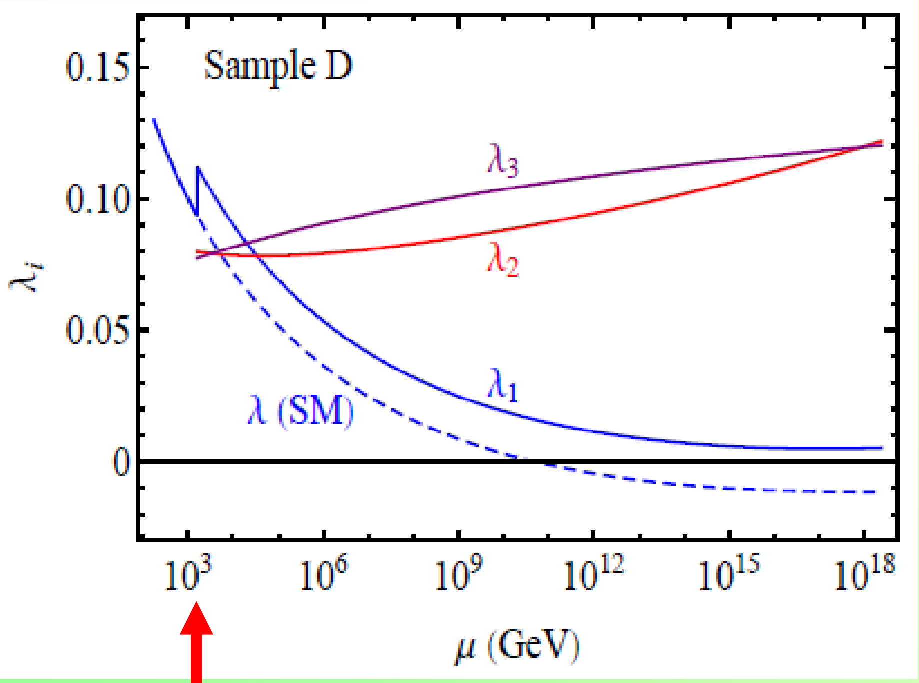
See: Nima's Overview in preCDR

SM *is* Incomplete: Vacuum, BA, DM, Inflation??

- Vacuum Puzzle: EW vacuum is Unstable at $10^{9\text{-}11}$ GeV !
- Puzzle of Missing Antimatter (Baryon Asymmetry) ?
- Dark Matter Puzzle (80% of all Matter): SM has no DM !
- Inflation Puzzle: naive SM provides no Inflaton !



Strumia et al, 1307.3536



He & Xianyu, JCAP 10(2014) 019.
See also: arXiv:1602.01801.

Eample: New Physics at TeV Scale:
New singlet scalar + New quark of masses ~ O(TeV)

3 Fundamental Forces Inside SM Itself

- 1. Gauge Forces： mediated by Spin-1 Vector Boson.
- 2. Yukawa Forces： mediated by Spin-0 Higgs Boson.
- 3. Higgs Self-Interaction Force： h^3 & h^4 forces,（concerns spontaneous EWSB and generating Higgs mass itself）.

- Type-2 & Type-3 Forces are New and Solely associated with Spin-0 Higgs, which were never seen before, despite they already exist in SM !

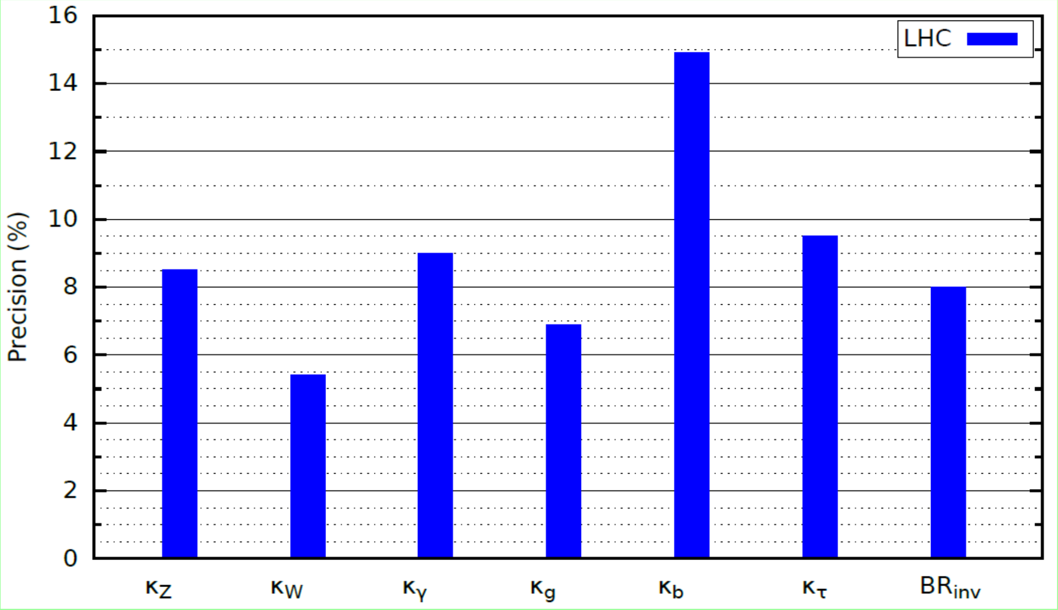
- In SM, Only Higgs can have Self-Interactions (involving exactly the same particle), but not all other fundamental particles (as forbiden by their spin & charge) !

- Spin-0 Higgs Boson is Unique in many ways, but all its associated forces are not yet directly tested, especially, the New Type-2 and Type-3 forces mediated by Higgs Itself !

3 Fundamental Forces inside SM Itself

Current Status:

- LEP/Tevatron/LHC only have good tests on Gauge Forces .
- LHC only has weak sensitivity to Yukawa couplings of h-τ-τ, h-b-b, h-t-t at order of 15% .
- LHC cannot probe Most Other Yukawa Couplings !
- LHC can hardly probe Higgs Self-Interaction !
- LHC cannot establish h(125GeV) as God Particle !



Higgs 125GeV and Beyond

Conclusion-1: Higgs is not only a New Particle, but also New Forces !!!

Even *within SM Forces*, strongly motivated to quantitatively test Type-2 & Type-3 New Forces (Higgs Yukawa Forces and Self-Interaction-Forces) mediated by Higgs Boson.

Conclusion-2: Any New Discovery of Run-2 (750GeV?) will require further Precision Tests.

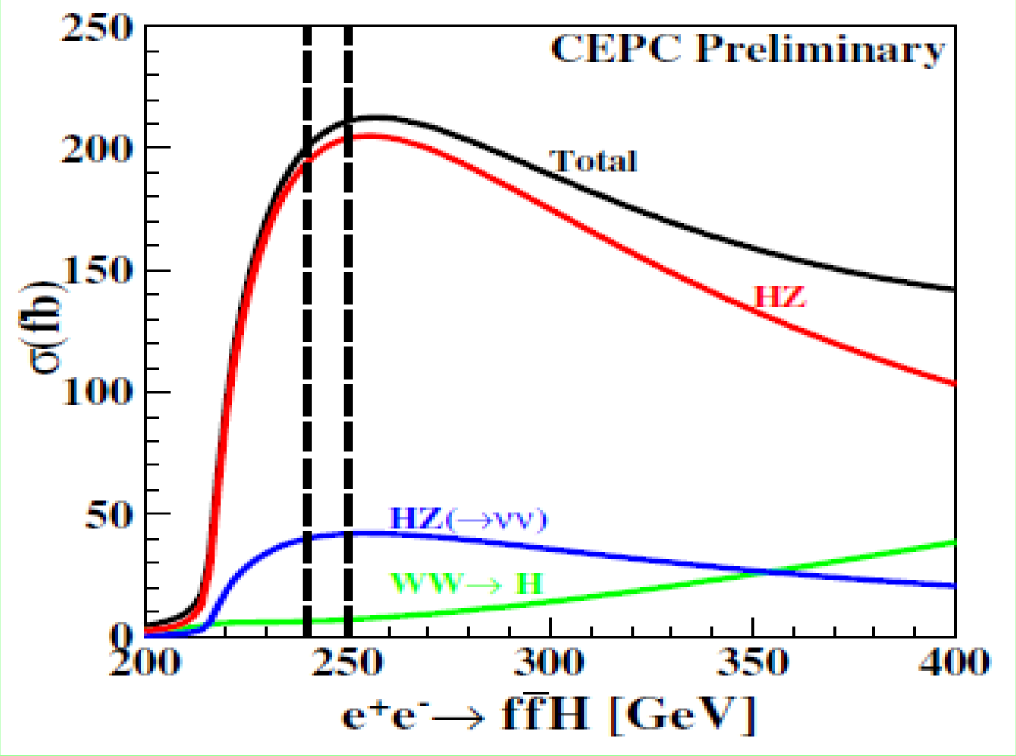
- → **This requires to Go Beyond the LHC !**
- → **High Energy Circular Colliders:**
  CEPC(ee, 90-250 GeV)
  SPPC(pp, 50-100TeV)

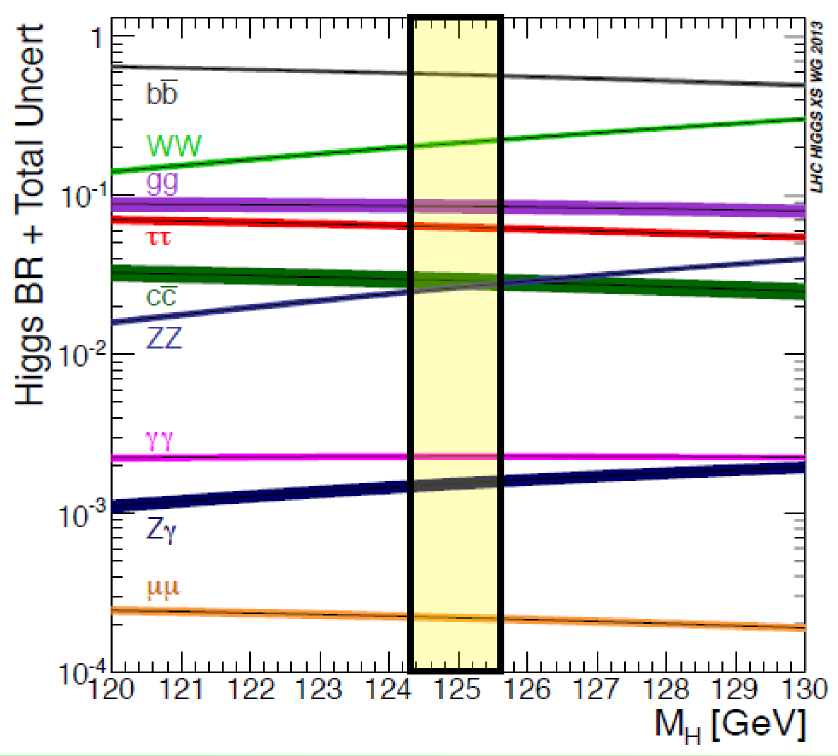
Physics Analyses

Higgs Factory: CEPC (240-250GeV)

- LHC-8 tells us: h(125) is SM-like. ⟶ *Precision Test is Crucial !*
- CEPC produces h(125) mainly via ee → hZ and ee →ννh .
- CEPC makes indirect probe to New Physics !

CEPC designed: 5/ab for 2 detectors in10y. ⟶ 10^6 Higgs Bosons !!





Inputs: Event Rate → Cross Section & BR

ΔM_h	Γ_h	$\sigma(Zh)$	$\sigma(\nu\bar{\nu}h) \times \mathrm{Br}(h \to bb)$
2.6 MeV	2.8%	**0.5%**	2.8%

Decay Mode	$\sigma(Zh) \times \mathrm{Br}$	Br
$h \to bb$	**0.21%**	0.54%
$h \to cc$	2.5%	2.5%
$h \to gg$	1.7%	1.8%
$h \to \tau\tau$	1.2%	1.3%
$h \to WW$	**1.4%**	1.5%
$h \to ZZ$	**4.3%**	4.3%
$h \to \gamma\gamma$	**9.0%**	9.0%
$h \to \mu\mu$	17%	17%
$h \to \mathrm{invisible}$	–	0.14%

latest 1σ uncertainty
Software WS, March 26

SM Predictions

$\mathrm{Br}(b\bar{b})$	$\mathrm{Br}(c\bar{c})$	$\mathrm{Br}(gg)$	$\mathrm{Br}(\tau\bar{\tau})$	$\mathrm{Br}(WW)$	$\mathrm{Br}(ZZ)$	$\mathrm{Br}(\gamma\gamma)$	$\mathrm{Br}(\mu\bar{\mu})$	$\mathrm{Br}(\mathrm{inv})$
58.1%	2.10%	7.40%	6.64%	22.5%	2.77%	0.243%	0.023%	0

Talks of Ge and Ruan

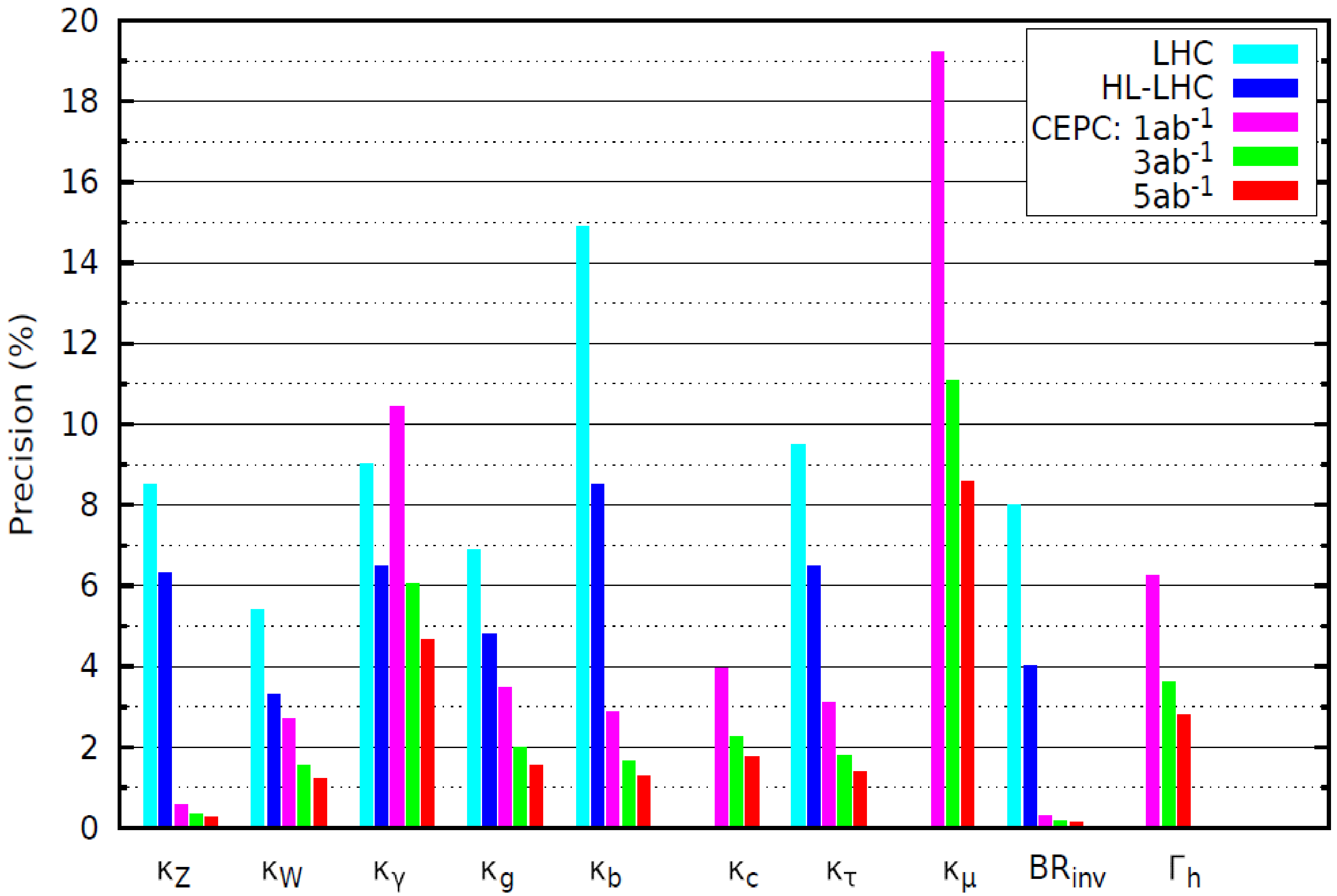
Effective Higgs Couplings: Gauge & Yukawa

$$\mathcal{L} = \kappa_3 \frac{m_H^2}{2v} H^3 + \kappa_Z \frac{m_Z^2}{v} Z_\mu Z^\mu H + \kappa_W \frac{2m_W^2}{v} W_\mu^+ W^{-\mu} H$$
$$+ \kappa_g \frac{\alpha_s}{12\pi v} G_{\mu\nu}^a G^{a\mu\nu} H + \kappa_\gamma \frac{\alpha}{2\pi v} A_{\mu\nu} A^{\mu\nu} H + \kappa_{Z\gamma} \frac{\alpha}{\pi v} A_{\mu\nu} Z^{\mu\nu} H$$
$$- \left(\kappa_t \sum_{f=u,c,t} \frac{m_f}{v} f\bar{f} + \kappa_b \sum_{f=d,s,b} \frac{m_f}{v} f\bar{f} + \kappa_\tau \sum_{f=e,\mu,\tau} \frac{m_f}{v} f\bar{f} \right) H$$

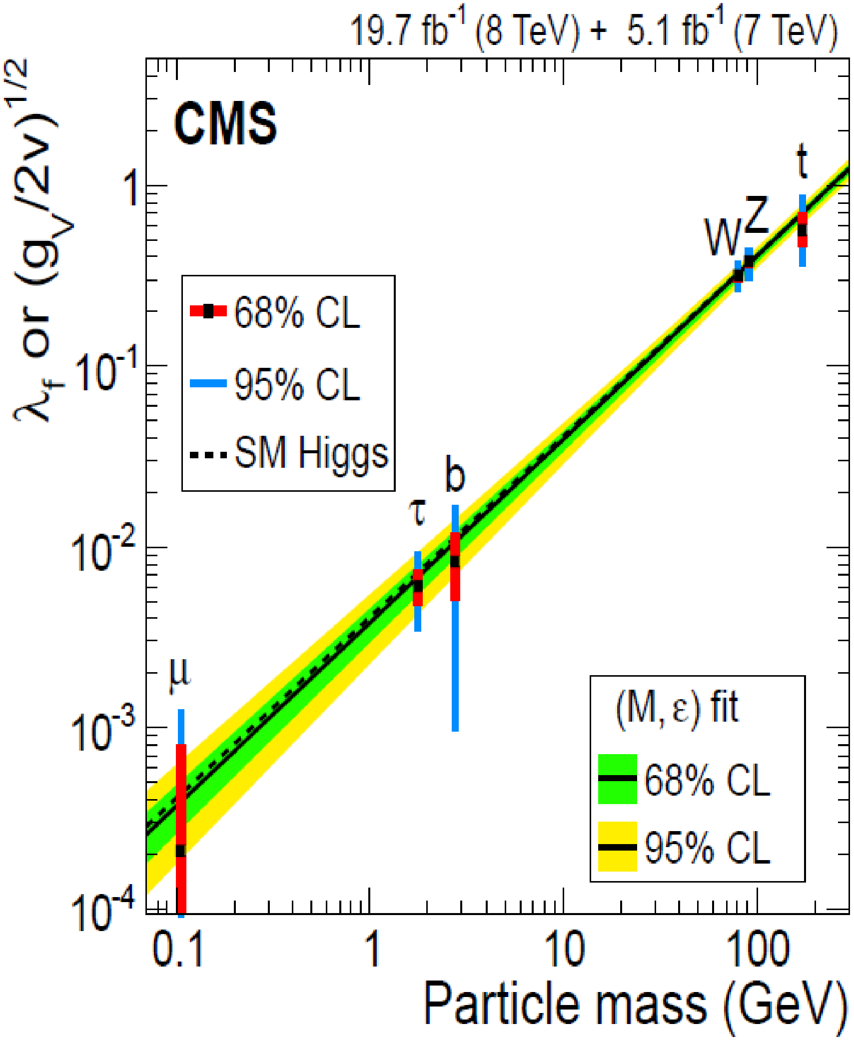
— See talk of S. F. Ge

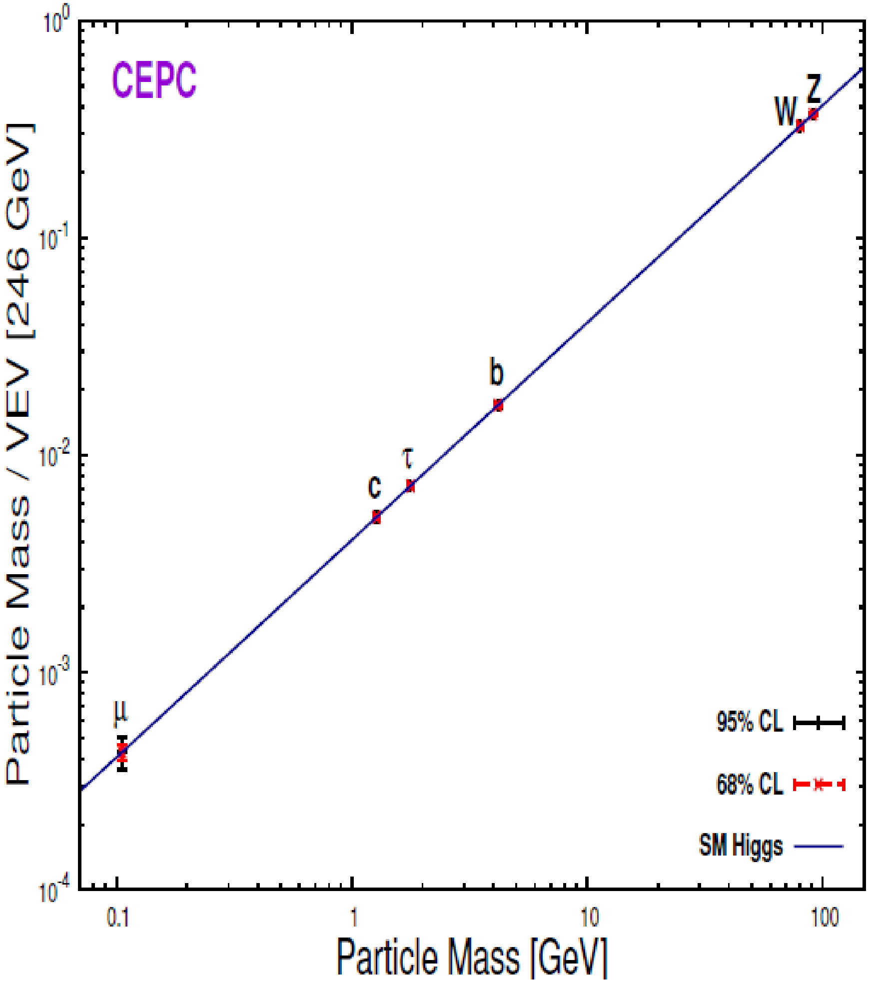
Combined Higgs Coupling Precision

Ge, He, Xiao, 1603.03385; preCDR



Precision on Higgs Couplings





— See talk of S. F. Ge

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Combined Higgs Coupling Precision

Ge, He, Xiao, 1603.03385; preCDR

Table: Precisions on measuring Higgs couplings at **CEPC (250GeV, 5ab^{-1})**, in comparison with **LHC (14TeV, 300fb^{-1})**, **HL-LHC (14TeV, 3ab^{-1})** and **ILC (250GeV, 250fb^{-1})+(500GeV, 500fb^{-1})**.

Software WS, March 26

Precision (%)	CEPC		LHC	HL-LHC	ILC-250+500
κ_Z	0.249	0.249	8.5	6.3	0.50
κ_W	1.21	1.21	5.4	3.3	0.46
κ_γ	4.67	4.67	9.0	6.5	8.6
κ_g	1.55	1.55	6.9	4.8	2.0
κ_b	1.28	1.28	14.9	8.5	0.97
κ_c	1.76	1.76	–	–	2.6
κ_τ	1.39	1.39	9.5	6.5	2.0
κ_μ	–	8.59	–	–	–
$\mathrm{Br}_{\mathrm{inv}}$	0.135	0.135	8.0	4.0	0.52
Γ_h	2.8	2.8	–	–	–

Indirect Probe of Higgs related New Physics

All can be formulated by:

Model-Independent Effective Operators

@ Dimension-6

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{M^2}\mathcal{O}_{6,i}$$

Higgs	EW Gauge Bosons	Fermions
$\mathcal{O}_H = \frac{1}{2}(\partial_\mu \lvert H \rvert^2)^2$	$\mathcal{O}_{WW} = g^2 \lvert H \rvert^2 W^a_{\mu\nu} W^{a\mu\nu}$	$\mathcal{O}_L^{(3)} = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\overline{\Psi}_L \gamma^\mu \sigma^a \Psi_L)$
$\mathcal{O}_T = \frac{1}{2}(H^\dagger \overleftrightarrow{D}_\mu H)^2$	$\mathcal{O}_{BB} = g'^2 \lvert H \rvert^2 B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{LL}^{(3)} = (\overline{\Psi}_L \gamma_\mu \sigma^a \Psi_L)(\overline{\Psi}_L \gamma^\mu \sigma^a \Psi_L)$
	$\mathcal{O}_{WB} = gg' H^\dagger \sigma^a H W^a_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_L = (iH^\dagger \overleftrightarrow{D}_\mu H)(\overline{\Psi}_L \gamma^\mu \Psi_L)$
Gluon	$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W^a_{\mu\nu}$	$\mathcal{O}_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\overline{\psi}_R \gamma^\mu \psi_R)$
$\mathcal{O}_g = g_s^2 \lvert H \rvert^2 G^a_{\mu\nu} G^{a\mu\nu}$	$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$	

Effective Operators & Sizes of New Physics

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{M^2} \mathcal{O}_{6,i}$$

Model	$\Delta\kappa_V$	$\Delta\kappa_t$	$\Delta\kappa_b(\Delta\kappa_\tau)$
MSSM	$\sim -0.5\% \left(\frac{400\ \text{GeV}}{M_A}\right)^4 \cot^2\beta$	$-\mathcal{O}(10\%)\left(\frac{400\ \text{GeV}}{M_A}\right)^2 \cot^2\beta$	$\sim \mathcal{O}(10\%)\left(\frac{400\ \text{GeV}}{M_A}\right)^2$
Composite	$-3\% \left(\frac{1\ \text{TeV}}{f}\right)^2$	$-(3-9)\% \left(\frac{1\ \text{TeV}}{f}\right)^2$	$-(3-9)\% \left(\frac{1\ \text{TeV}}{f}\right)^2$

-- Higgs WG Report

Existing EWPO & Future HO

Observables: EWPO (PDG14) + HO (preCDR)

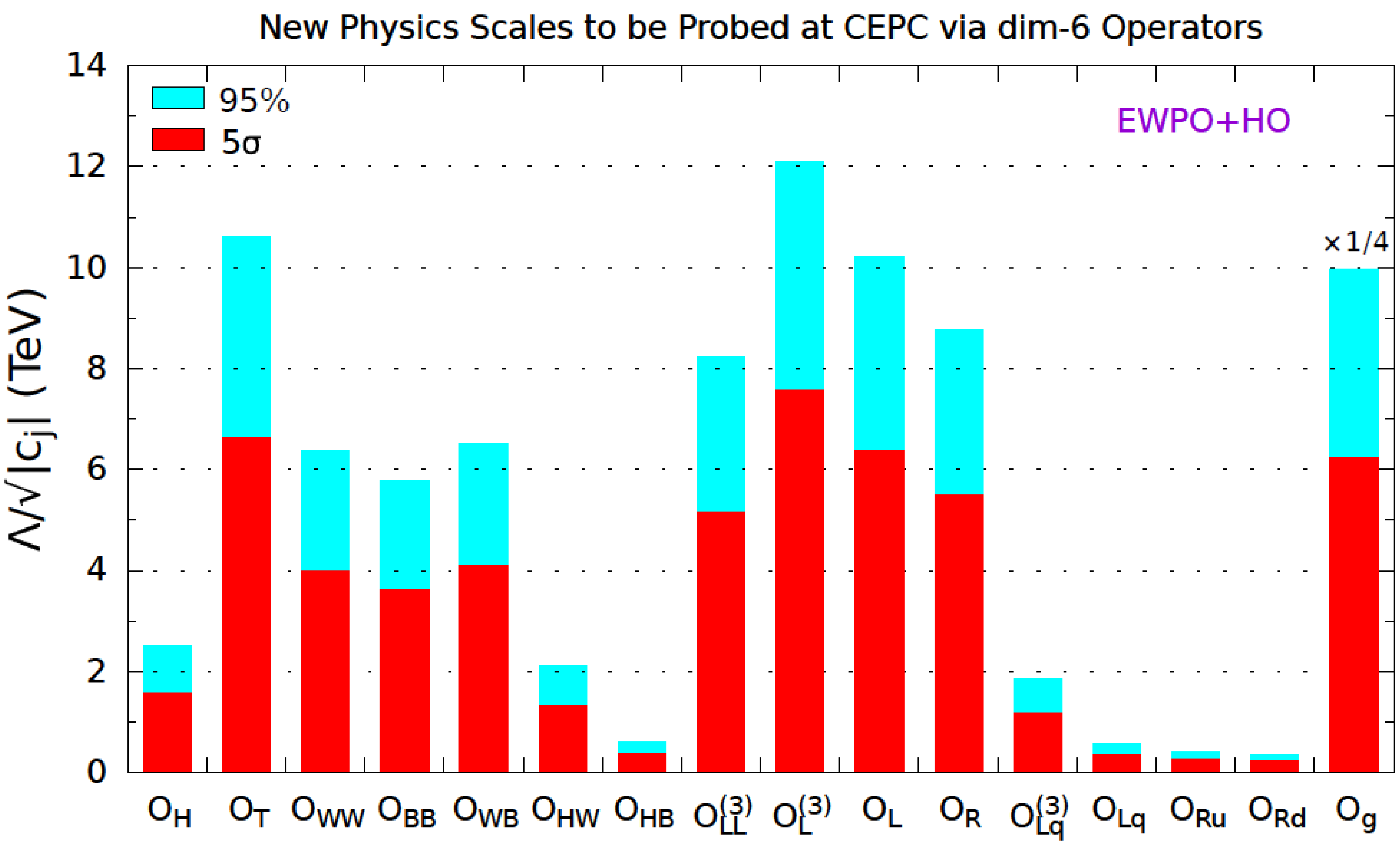
Observables	Central Value	Relative Error	SM Prediction
α	$7.2973525698 \times 10^{-3}$	3.29×10^{-10}	–
G_F	$1.1663787 \times 10^{-5} \mathrm{GeV}^{-2}$	5.14×10^{-7}	–
M_Z	91.1876GeV	2.3×10^{-5}	–
M_W	80.385GeV	1.87×10^{-4}	–
$\sigma[Zh]$	–	0.51%	–
$\sigma[\nu\bar{\nu}h]$	–	2.86%	–
$\sigma[\nu\bar{\nu}h]_{350\mathrm{GeV}}$	–	0.75%	–
$\mathrm{Br}[WW]$	–	1.6%	22.5%
$\mathrm{Br}[ZZ]$	–	4.3%	2.77%
$\mathrm{Br}[bb]$	–	0.57%	58.1%
$\mathrm{Br}[cc]$	–	2.3%	2.10%
$\mathrm{Br}[gg]$	–	1.7%	7.40%
$\mathrm{Br}[\tau\tau]$	–	1.3%	6.64%
$\mathrm{Br}[\gamma\gamma]$	–	9.0%	0.243%
$\mathrm{Br}[\mu\mu]$	–	17%	0.023%

Exclusion (95%) & Discovery (5σ) Reach

Ge, He, Xiao, 1603.03385

	$\mathcal{O}_H$	$\mathcal{O}_T$	$\mathcal{O}_{WW}$	$\mathcal{O}_{BB}$	$\mathcal{O}_{WB}$	$\mathcal{O}_{HW}$	$\mathcal{O}_{HB}$	$\mathcal{O}^{(3)}_{LL}$	$\mathcal{O}^{(3)}_{L}$	$\mathcal{O}_L$	$\mathcal{O}_R$	$\mathcal{O}^{(3)}_{L,q}$	$\mathcal{O}_{L,q}$	$\mathcal{O}_{R,u}$	$\mathcal{O}_{R,d}$	$\mathcal{O}_g$
95%	2.50	10.6	6.38	5.78	6.52	2.11	0.603	8.21	12.1	10.2	8.78	1.85	0.565	0.391	0.337	39.8
5σ	1.57	6.64	3.99	3.62	4.08	1.32	0.378	5.14	7.57	6.39	5.49	1.16	0.354	0.245	0.211	24.9

Sensitivities from Existing EWPO & Future HO



Ge, He, Xiao, 1603.03385

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	2.15	0.603	8.57	12.1	10.2	8.78	1.85	0.565	0.391	0.337	39.8
$+M_Z$	2.74	**10.7**	6.38	5.78	**6.54**	2.15	0.603	**8.61**	12.1	10.2	8.78	1.85	0.565	0.391	0.337	39.8
$+M_W$	2.74	**21.0**	6.38	5.78	**10.4**	2.15	0.603	**15.5**	**16.4**	10.2	8.78	1.85	0.565	0.391	0.337	39.8
$+M_{Z,W}$	2.74	**23.7**	6.38	5.78	**11.6**	2.15	0.603	**17.4**	**18.1**	10.2	8.78	1.85	0.565	0.391	0.337	39.8

Ge, He, Xiao, arXiv:1603.03385

- **Note: The CEPC Z-pole simulation is preliminary.**
  BUT, this does not really matter for above analysis —
  here the Key of our analysis is to demonstrate the matter of principle for probing New Physics: including vs excluding CEPC Z-pole observables

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].

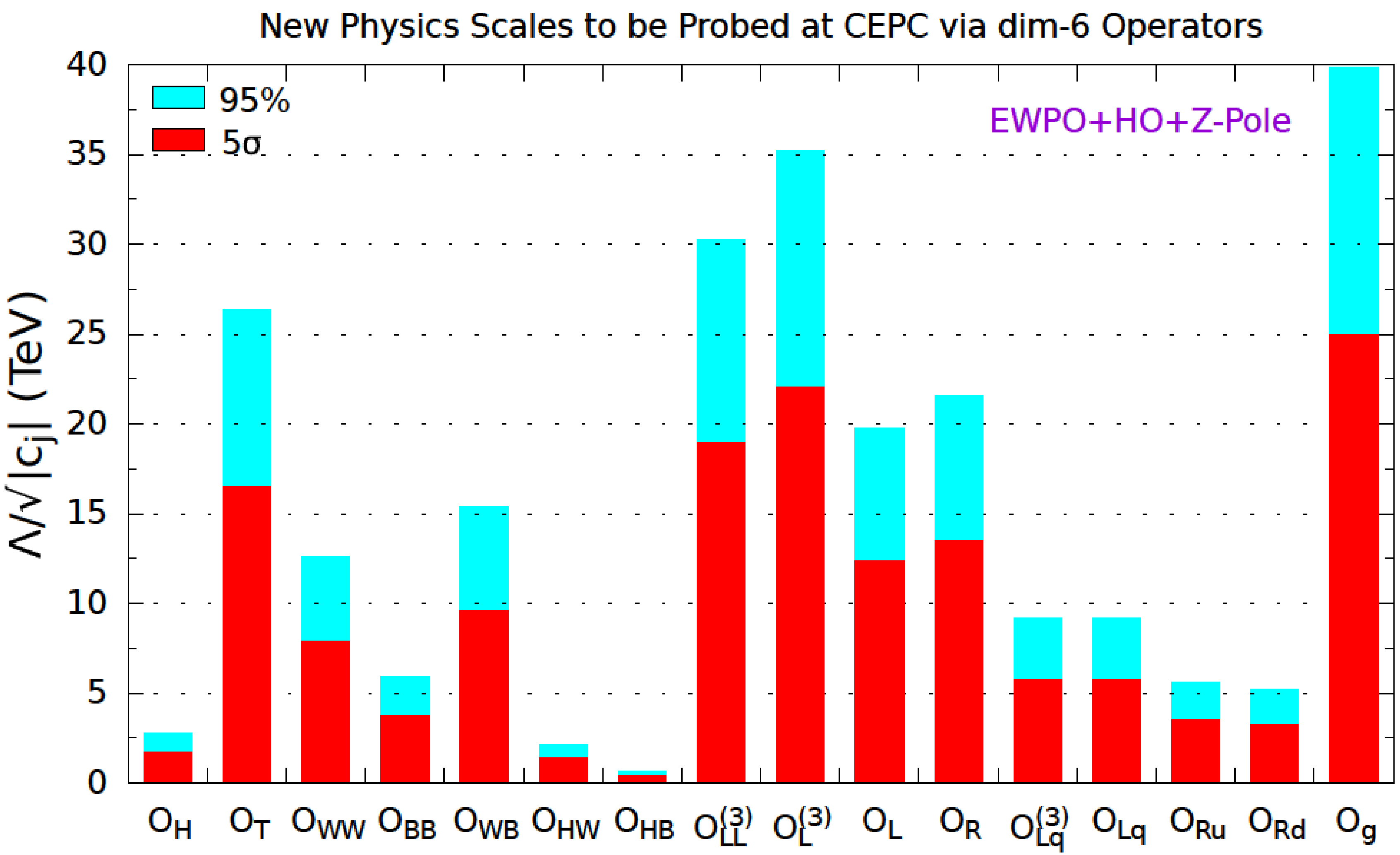
Ge, He, Xiao, 1603.03385

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

$\mathcal{O}_H$	$\mathcal{O}_T$	$\mathcal{O}_{WW}$	$\mathcal{O}_{BB}$	$\mathcal{O}_{WB}$	$\mathcal{O}_{HW}$	$\mathcal{O}_{HB}$	$\mathcal{O}^{(3)}_{LL}$	$\mathcal{O}^{(3)}_{L}$	$\mathcal{O}_L$	$\mathcal{O}_R$	$\mathcal{O}^{(3)}_{L,q}$	$\mathcal{O}_{L,q}$	$\mathcal{O}_{R,u}$	$\mathcal{O}_{R,d}$	$\mathcal{O}_g$
2.74	23.7	6.38	5.78	11.6	2.15	0.603	17.4	18.1	10.2	8.78	1.85	0.565	0.391	0.337	39.8
2.74	23.7	6.38	5.78	11.6	2.15	0.603	**17.5**	**18.3**	**10.5**	8.78	1.85	0.565	0.391	0.337	39.8
2.74	24.0	**8.32**	5.80	**12.2**	2.15	0.603	**20.7**	**23.0**	**12.5**	**13.0**	2.08	**1.62**	0.391	**3.97**	39.8
2.74	24.0	8.33	5.80	12.2	2.15	0.603	20.7	23.0	12.5	13.0	**7.90**	**7.89**	**3.55**	4.05	39.8
2.74	24.0	8.54	5.80	12.2	2.15	0.603	20.7	23.4	**14.4**	**14.0**	8.63	8.62	4.88	**4.71**	39.8
2.74	24.0	8.75	5.80	12.3	2.15	0.603	20.7	23.7	15.8	14.9	**9.21**	**9.21**	5.59	5.17	39.8
2.74	**26.3**	**12.6**	**5.93**	**15.3**	2.15	0.603	**30.2**	**35.2**	**19.8**	**21.6**	9.21	9.21	5.59	5.17	39.8

➢ **Extra Factor-2 Improvements from more Z-pole observales!**

Sensitivity from EWPO+HO+Z-Pole



Ge, He, Xiao, 1603.03385

Summary of CEPC Precision Tests:

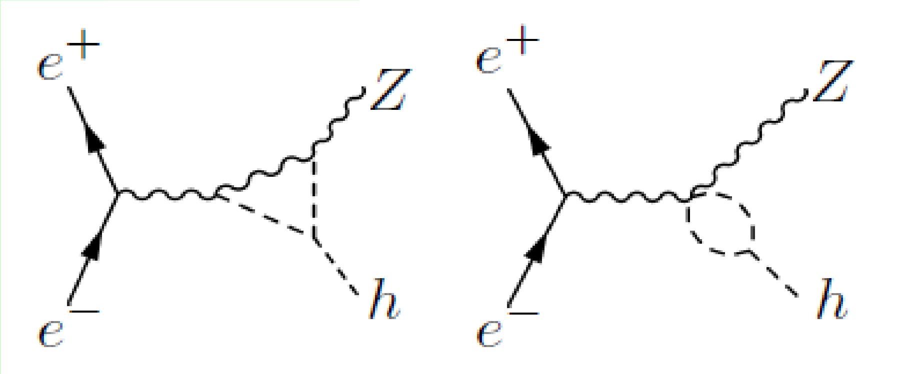
- CEPC produces 10^6 Higgs Bosons at 250GeV (5/ab).
  Higgs Gauge & Yukawa Couplings ~ O(1%)
  Higgs Self-coupling ~ 30%

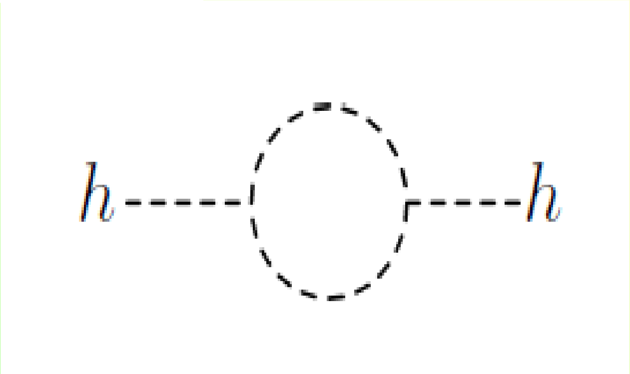
- CEPC Indirect Probe of New Physics Scales:
  up to 10TeV (40TeV for O_g) from EWPO + HO.
  up to 35TeV after including Z-pole(CEPC).

- CEPC can sensitively probe Exotic Higgs Decays
  (see Zhang Hao's talk)

CEPC Probe of h^3 Coupling

$$\Delta\mathcal{L} = -\frac{1}{3!}\,\delta\kappa_{h3}\,\lambda^{\rm sm}_{hhh}\,h^3$$





$$\delta_\sigma = \frac{\delta\sigma}{\sigma} = \frac{\sigma_{\delta_{h3}\neq 0}(e^+e^-\to hZ)}{\sigma_{\rm sm}(e^+e^-\to hZ)} - 1 = 2\,\delta\kappa_Z + 0.014\,\delta\kappa_{h3}$$

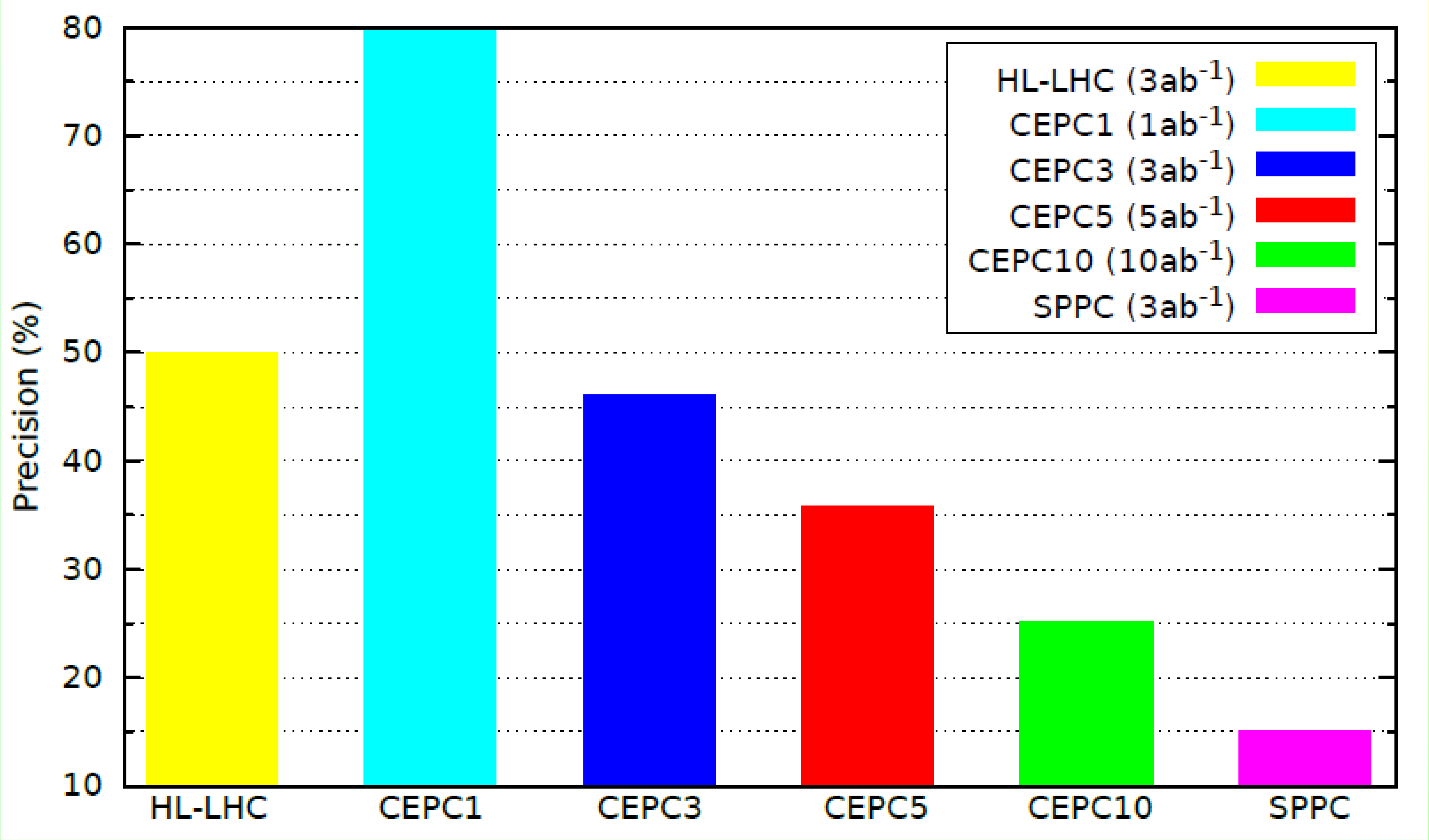
M. McCullough, arXiv:1312.3322

- **Recall: HL-LHC probes h^3 to 50%. ILC500 probes h^3 to 83%.**

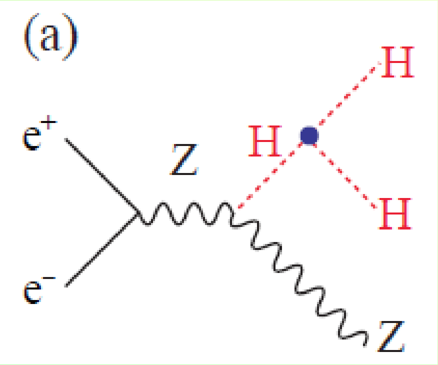
Sensitivity to Higgs Self-Coupling h^3

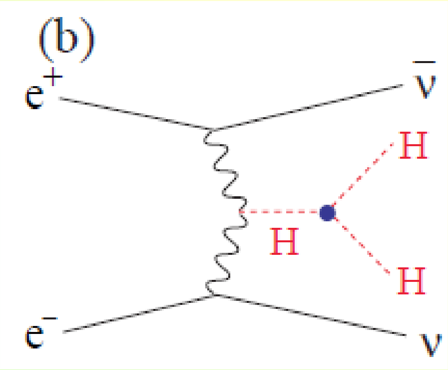
-- Higgs WG

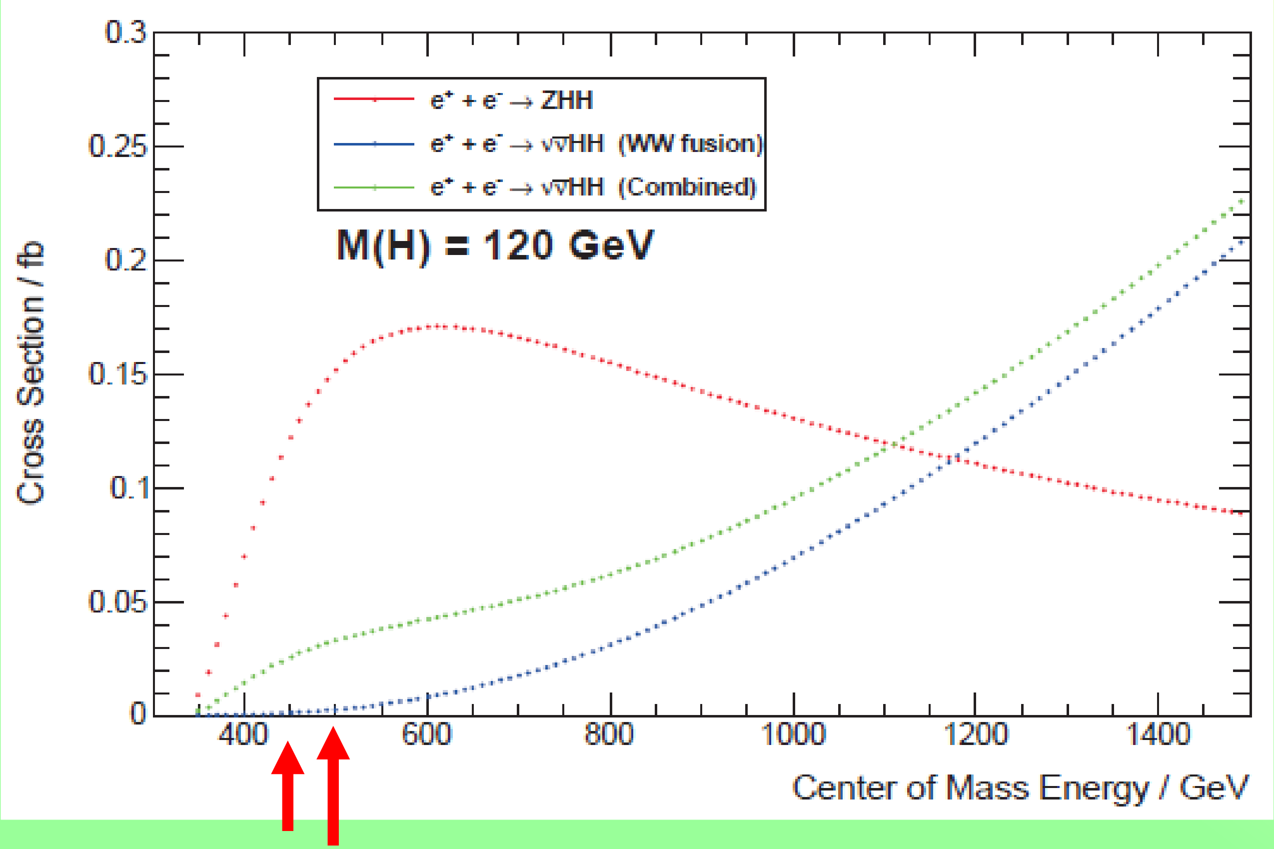
- **Comparison: h^3 at CEPC(1, 3, 5/ab) and SPPC(3/ab), vs HL-LHC (3/ab):** $|\lambda_{hhh}/\lambda_{hhh}^{\rm sm} - 1|$



Comment: Probing h^3 Coupling via Zhh Channel







K. Fujii, arXiv:1305.1692

Comments on Shu Jing's Talk regarding ee(400): This does not really gain much, given also the difficulty of ee(400GeV) in circular tunnel.

Probing h^3 Coupling @ SPPC(100TeV)

$$\mathcal{L}_{\rm eff} = \sum_n \frac{f_n}{\Lambda^2}\mathcal{O}_n,$$

$$\mathcal{O}_{\Phi,2} = \frac{1}{2}\partial^\mu(H^\dagger H)\partial_\mu(H^\dagger H),$$
$$\mathcal{O}_{\Phi,3} = \frac{1}{3}(H^\dagger H)^3.$$

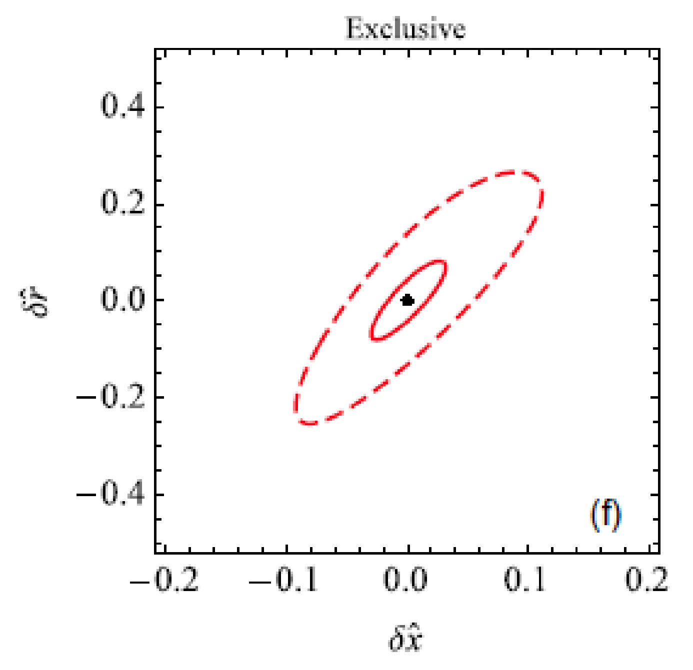
$$gg \to hh \to b\bar{b}\gamma\gamma$$

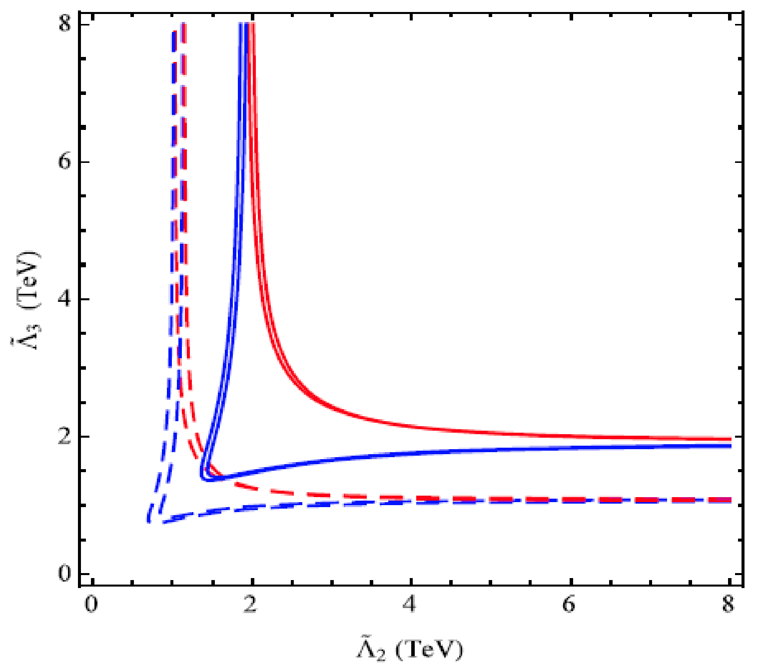
Sensitivity to (r, x):

3/ab: (13%, 5%)

30/ab: (4.2%, 1.6%)

$$x_j \equiv \frac{f_{\Phi,j}v^2}{\Lambda^2} \qquad \hat{r} \equiv -x_3\zeta^2\frac{2v^2}{3M_h^2}, \qquad \hat{x} \equiv x_2\zeta^2. \qquad \tilde{\Lambda}_j \equiv \frac{\Lambda}{\sqrt{|f_{\Phi,j}|}}$$

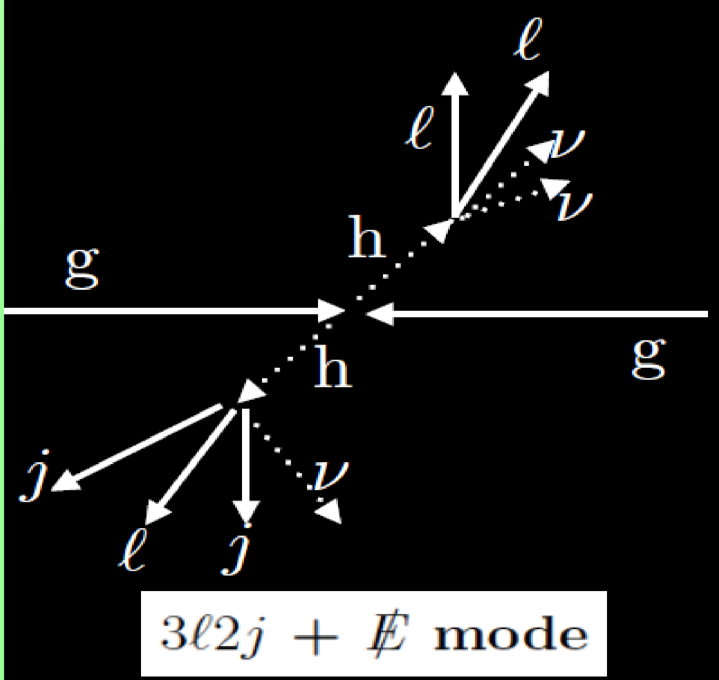


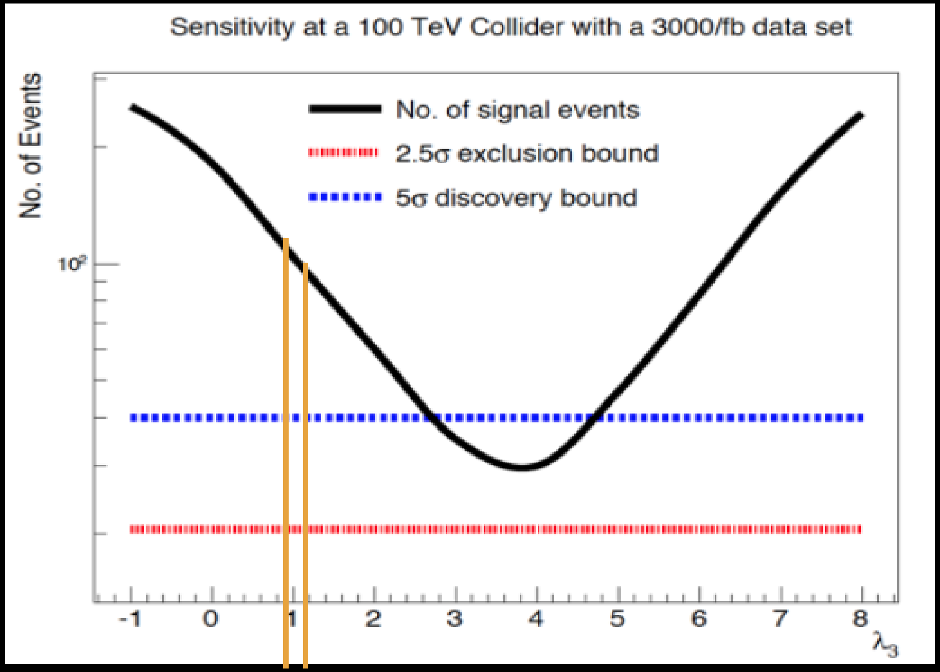


He, Ren, Yao,
arXiv:1506.03302
PRD.93(2016)015003

Probing h^3 Coupling via $gg \to hh \to WW^*WW^*$

Q. S. Yan's talk





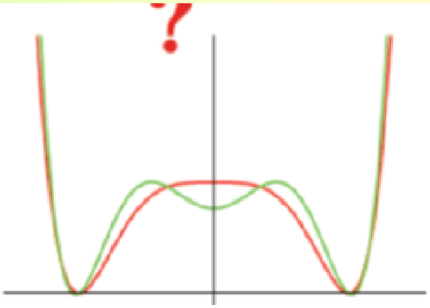
To overcome the b mistag and photo mistag issues, $gg \to hh \to WW^*WW^* \to 3\ell + 2j + MET$ is proposed. By using this mode, SPPC can determine λ_3 to the window [0.9,1.2]

Q. Li, Z. Li, QY, X.R. Zhao, PRD92(2015)1,014015, arXiv:1503.07611

Electroweak Phase Transition

See F. P. Huang's talk

For the Higgs potential and the type of the EW phase transition, we know nothing but the quadratic oscillation around the vev v with the mass 125 GeV from the current LHC data.



$$V(h) = \frac{1}{2}\mu^2 h^2 + \frac{\lambda}{4} h^4$$

or

$$V(h) = \frac{1}{2}\mu^2 h^2 - \frac{\lambda}{4} h^4 + \frac{1}{\Lambda^2} h^6$$

First order EW phase transition ⟺

- The true shape of Higgs potential
- Baryon asymmetry of the universe
- Gravitational wave : Higgs bubble collision, turbulence with plasma……

Pre CDR of CEPC

Electroweak Phase Transition

See F. P. Huang's talk

potential

$$\delta\mathcal{L} = -x_u^{ij}\frac{\phi^\dagger\phi}{\Lambda^2}\bar{q}_{Li}\tilde{\phi}u_{Rj} + \mathrm{H.c.} - \frac{\kappa}{\Lambda^2}(\phi^\dagger\phi)^3$$

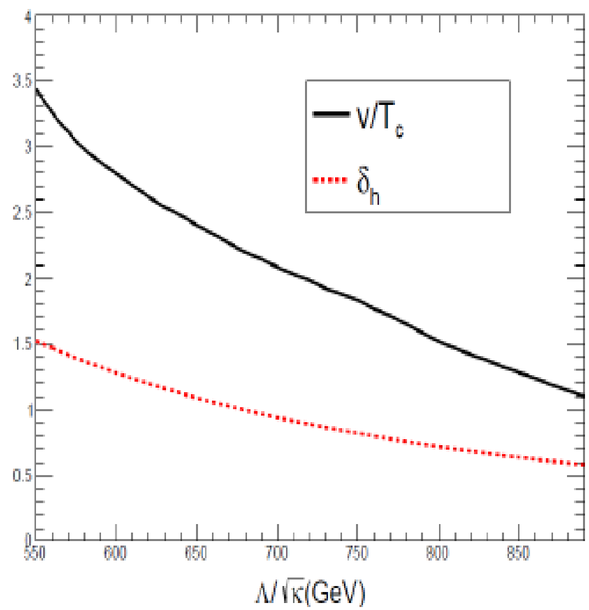
provide sizable CP violation source

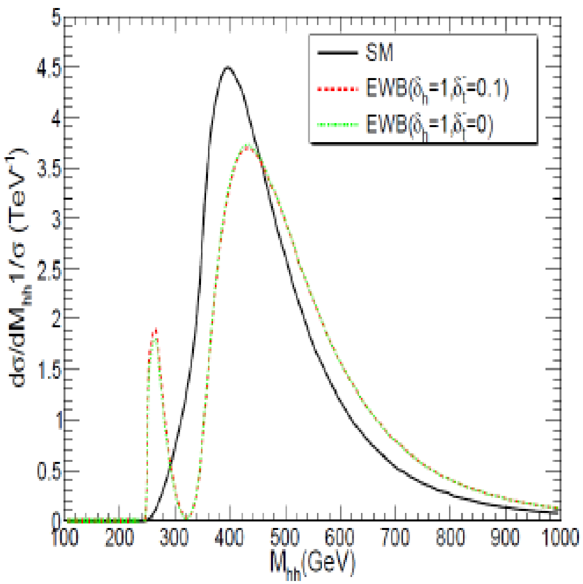
provide another possible Higgs potential; allow strong first order phase transition(SFOPT)

SFOPT leads to obvious deviation of the tri-linear Higgs Coupling (modify Higgs pair production at the LHC and Zh production at CEPC)

$$\mathcal{L}_{hhh} = -\frac{1}{3!}(1+\delta_h)A_h h^3$$

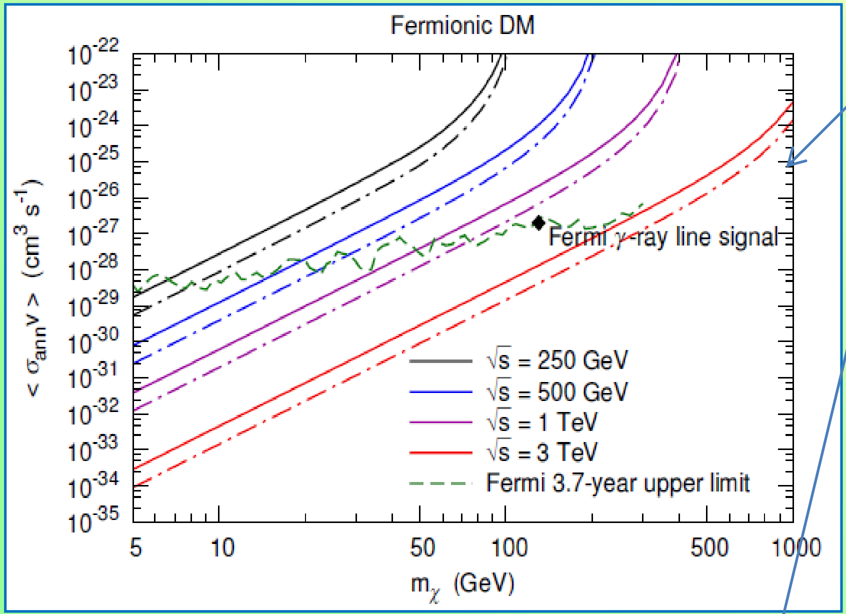
$\delta_h = (\Lambda_{min}/\Lambda)^2 \in (0.6, 1.5)$



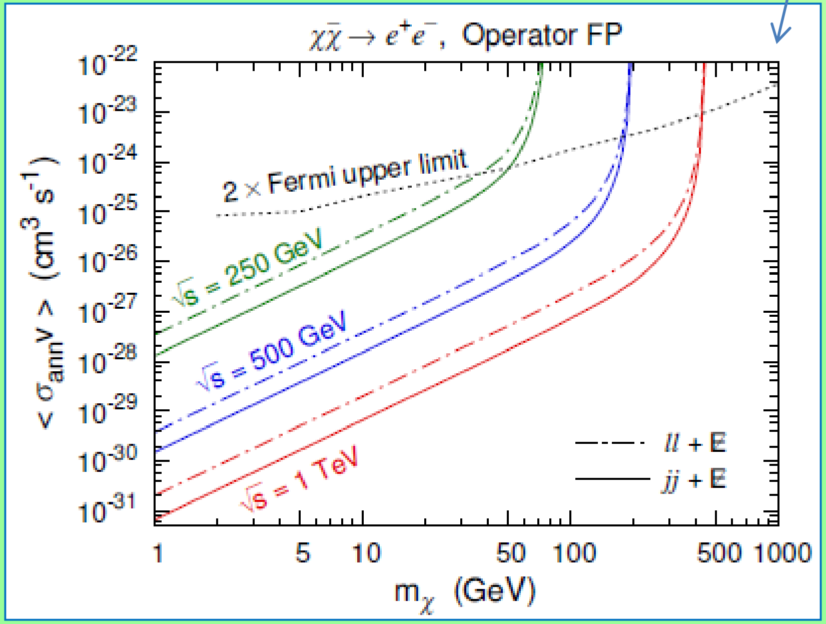


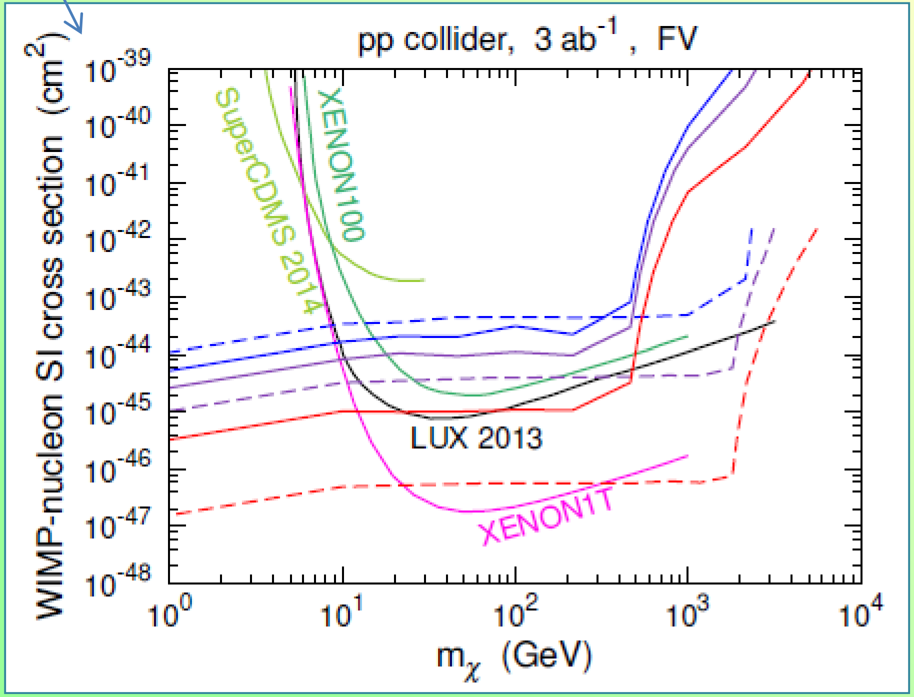
Sensitivities of future colliders

See P. F. Yi's talk



- Investigation of DM-gamma interactions through mono-photon searches at e^+e^- colliders
- Investigation of DM-Z interactions through mono-Z searches at e^+e^- colliders
- Investigation of DM-Z' interactions through mono-jet searches at hadron colliders

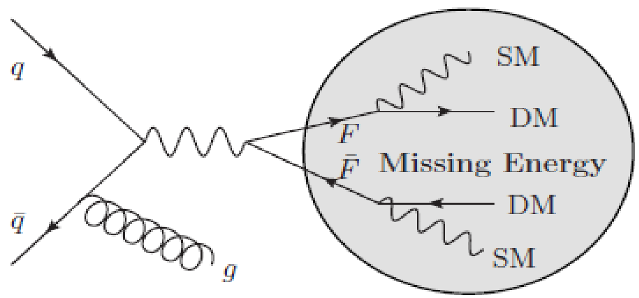




Probing New Physics Through Loops at the CEPC

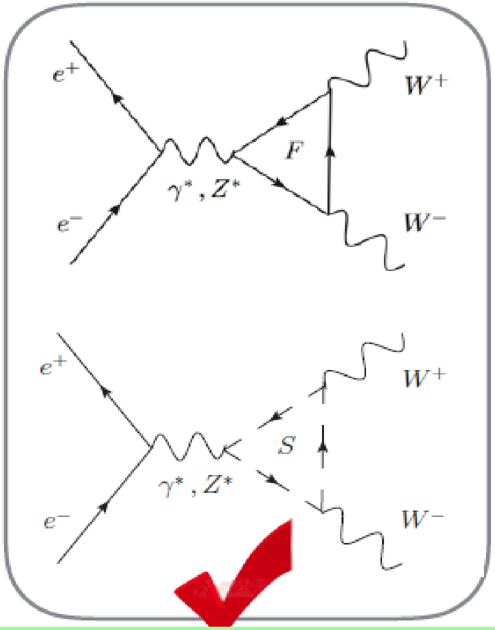
see Q.H. Cao's talk

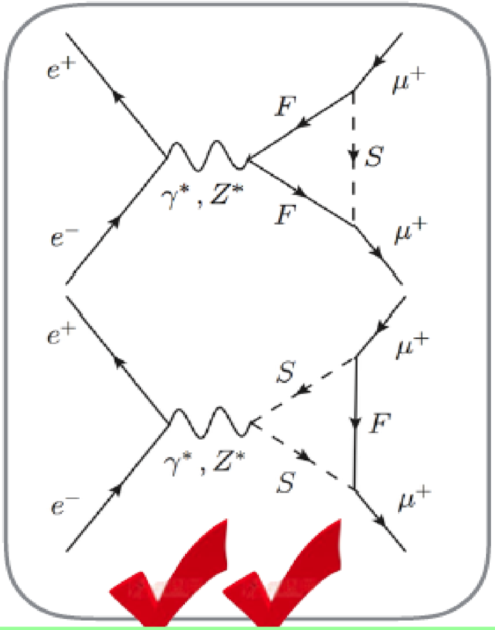
It is hard to probe DM models with nearly degenerate mass spectrum

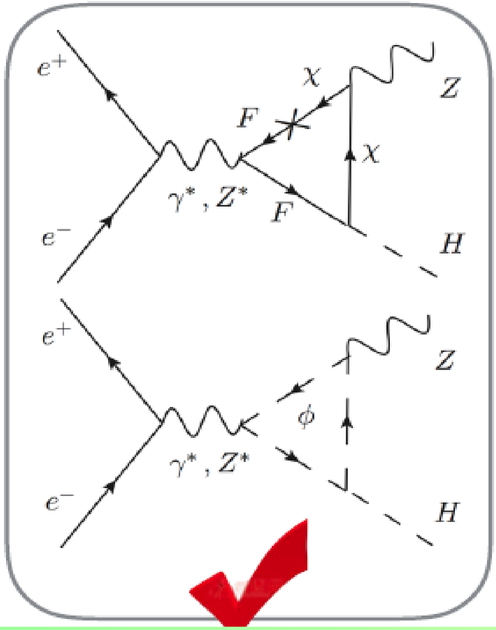


Mono-jet (photon) + MET

One could probe the loop effects of light NP particles, e.g.

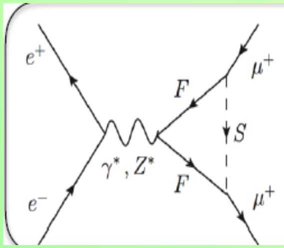






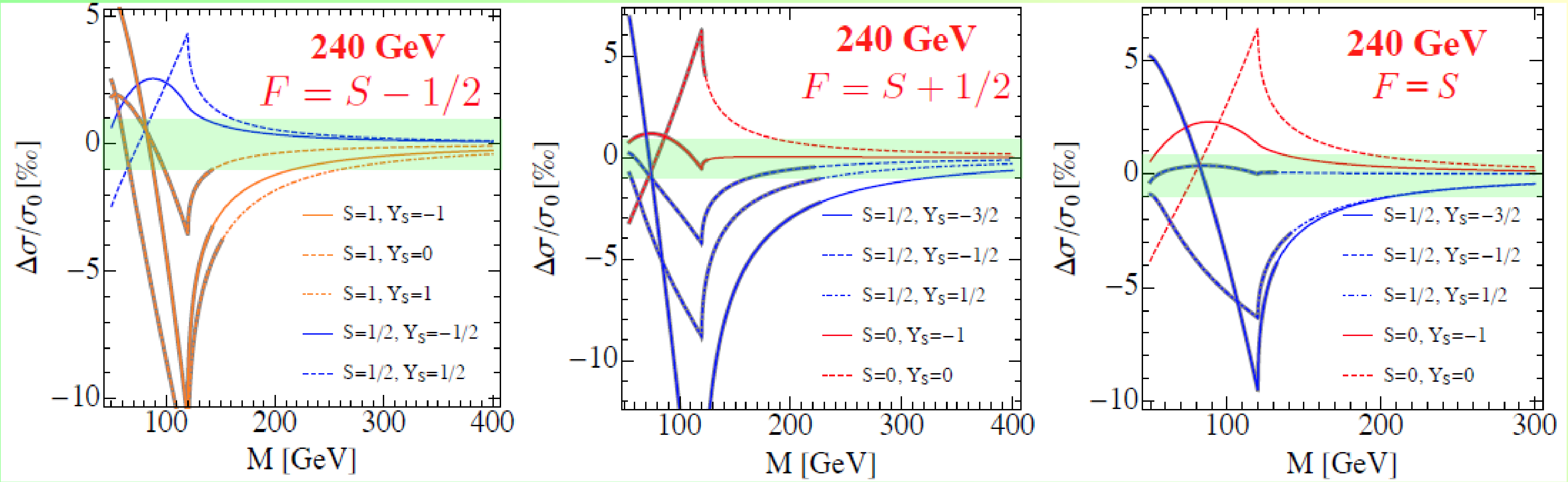
Probing New Physics Through Loops at the CEPC

see Q. H. Cao's talk



$F = S \pm 1/2 \qquad y C_{ijk} S^i \bar{\mu}_L^k F^j + h.c.$

$F = S \qquad y C_{ij} S^i \bar{\mu}_R F^j + h.c.$



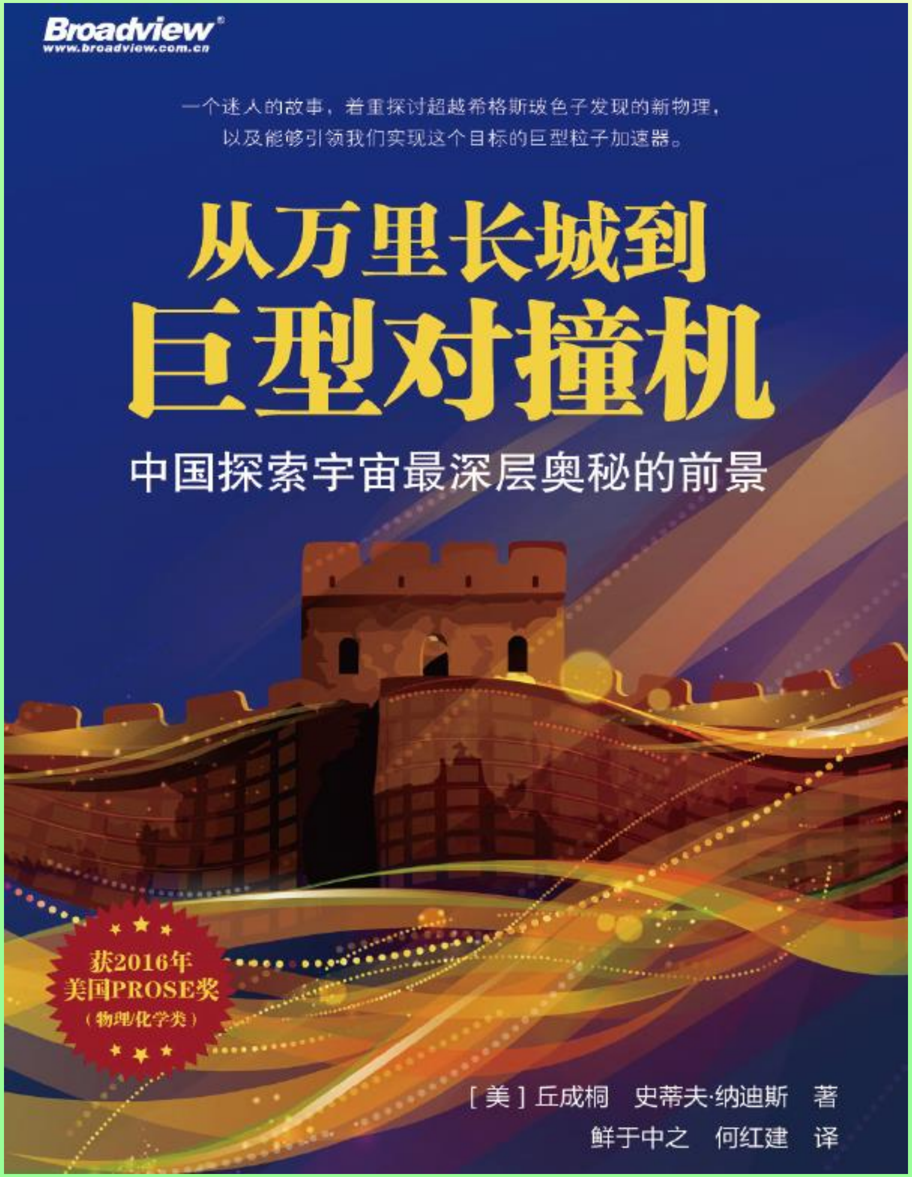
The e+e- collider with 10^{-3} Precision can probe certain parameter spaces of NP models

From Great Wall to Great Collider

see book of Nadis and Yau

➢ 巨型对撞机（Great Collider）与万里长城（Great Wall）相呼应。

巧合的是，这座巨型对撞机很可能就将修建在山海关长城附近。



More Excitments Ahead ！

Let us continue to work together and do good works !


Thank You !