Overview of CEPC Physics CDR

LianTao Wang
U. Chicago

IHEP. Nov 6, 2017

Studies of CEPC Physics

- Started in 2013.
- PreCDR produced in 2015. Outlined main physics case.
- Since then, many new developments, both internationally and within China.
  - Results updated based on more detailed studies.
  - New topics covered.
- This talk:
  - Summary of physics case to be presented in the CDR.
  - Brief highlights of a few new results.
  - Much more details in the parallel sessions.

CEPC at precision frontier

- Precision measurement of the Higgs coupling.
  - LHC precision: 5-10%
  - To go beyond the LHC, need 1% or less precision.
- For example, consider deviation of the form

$$\delta \simeq c\frac{v^2}{M_{\rm NP}^2}$$

M_{NP} : mass of new physics
c: $O(1)$ coefficient (weakly coupled)

  - LHC precision: 5-10% ⇒ sensitive to M_{NP} < TeV
  - Sub-percent accuracy can push $M_{NP} \approx$ 4-5 TeV, beyond LHC reach.

Measurement of Higgs properties

Results for individual channels

CEPC

	Tot	Z->ee	Z->mm	Z->qq	Z->vv
Inclusive $\sigma(ZH)$	0.50%	2.1%	0.9%	0.65%	\
$\sigma(ZH) * Br(H \to \mathrm{bb})$	$\{^{+0.27\%}_{-0.27\%}$	$\{^{+1.26\%}_{-1.26\%}$	$\{^{+1.02\%}_{-1.01\%}$	$\{^{+0.46\%}_{-0.46\%}$	$\{^{+0.40\%}_{-0.40\%}$
$\sigma(ZH) * Br(H \to cc)$	$\{^{+3.49\%}_{-3.47\%}$	$\{^{+15.2\%}_{-15.0\%}$	$\{^{+10.8\%}_{-10.6\%}$	$\{^{+16.6\%}_{-16.6\%}$	$\{^{+3.93\%}_{-3.89\%}$
$\sigma(ZH) * Br(H \to gg)$	$\{^{+1.44\%}_{-1.44\%}$	$\{^{+8.28\%}_{-8.21\%}$	$\{^{+5.48\%}_{-5.43\%}$	$\{^{+7.16\%}_{-7.16\%}$	$\{^{+1.56\%}_{-1.55\%}$
$\sigma(ZH) * Br(\mathrm{H} \to WW)$	$\{^{+1.21\%}_{-1.20\%}$	$\{^{+2.87\%}_{-2.82\%}$	$\{^{+2.65\%}_{-2.61\%}$	\	$\{^{+1.34\%}_{-1.34\%}$
$\sigma(ZH) * Br(H \to ZZ)$	$\{^{+5.29\%}_{-5.15\%}$	$\{^{+40.9\%}_{-39.6\%}$ eeqq; $\{^{+23.4\%}_{-22.4\%}$ mmqq	$\{^{+7.61\%}_{-7.28\%}$	\	$\{^{+35.5\%}_{-34.3\%}$ eeqq; $\{^{+8.53\%}_{-8.14\%}$ mmqq
$\sigma(ZH) * Br(H \to \tau\tau)$	$\{^{+0.68\%}_{-0.67\%}$	\	$\{^{+2.76\%}_{-2.73\%}$	0.76%	$\{^{+1.79\%}_{-1.78\%}$
$\sigma(ZH) * Br(H \to \gamma\gamma)$	$\{^{+8.28\%}_{-8.19\%}$	$\{^{+27.4\%}_{-26.5\%}$		$\{^{+13.0\%}_{-12.9\%}$	$\{^{+11.8\%}_{-11.6\%}$

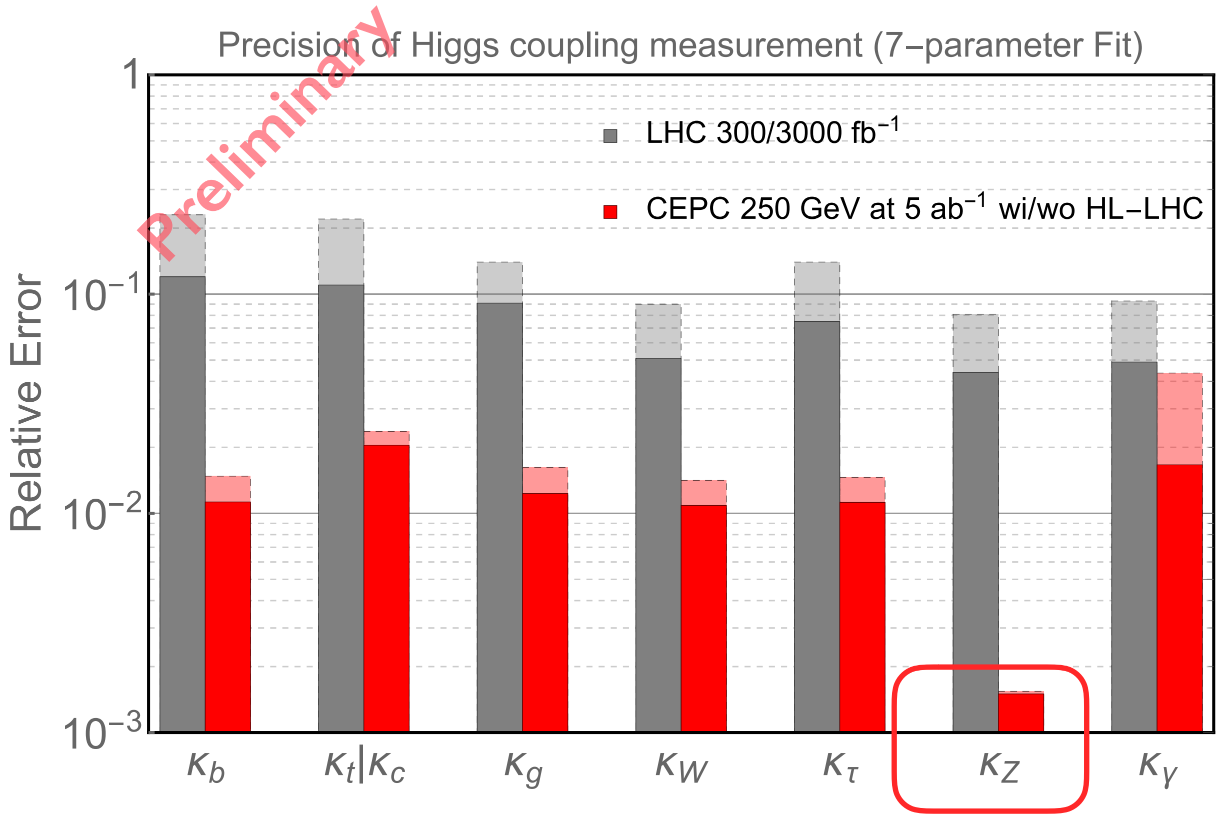
Preliminary

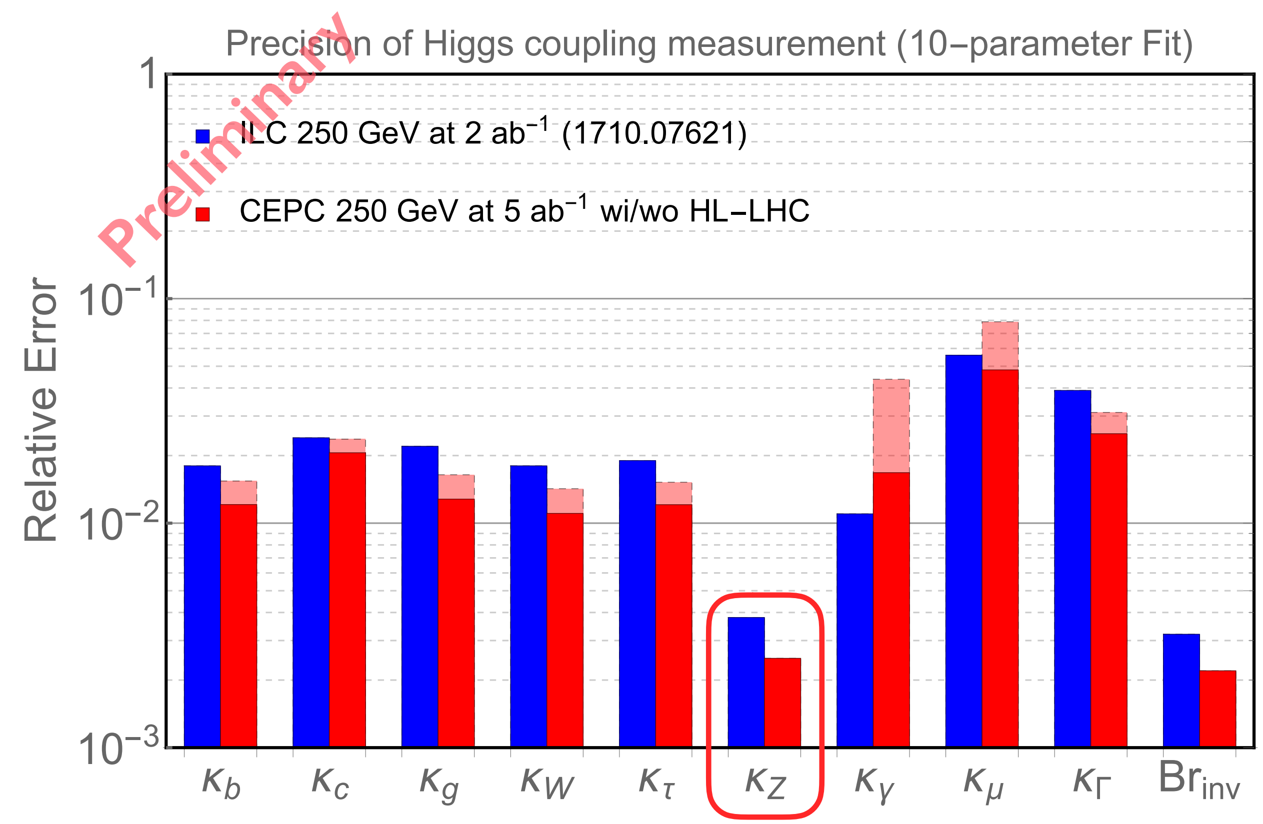
White paper forthcoming

Convener: Yaquan Fang (IHEP), Jianming Qian (Michigan)
Studies: Kaili Zhang, Jin Wang, Zhen Liu, + many others

Higgs coupling measurement

Zhen Liu, Jin Wang, Kaili Zhang





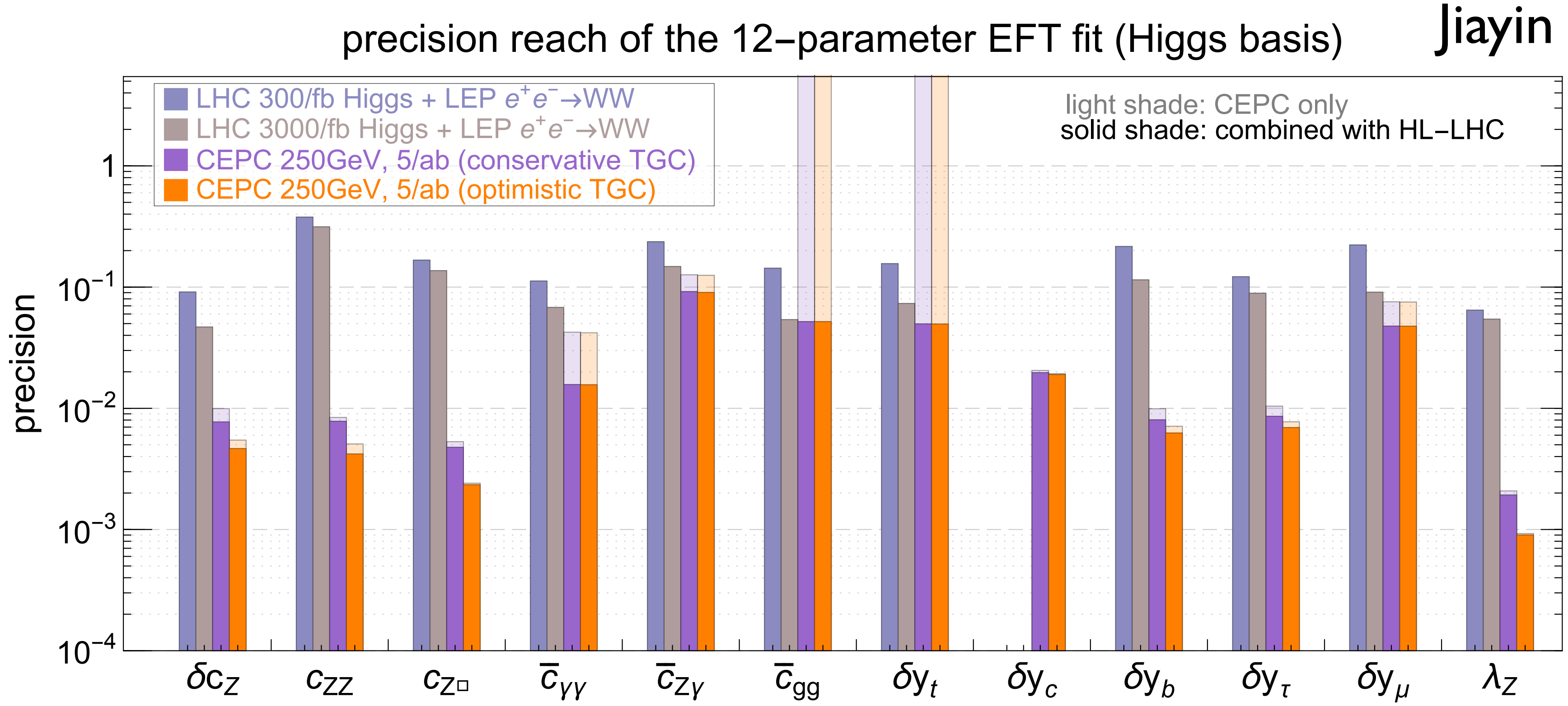
$$\kappa_i = \frac{g^{\rm exp}}{g^{\rm SM}}(\text{Higgs} - \text{SM particle i})$$

sub-percent measurement of Higgs coupling!

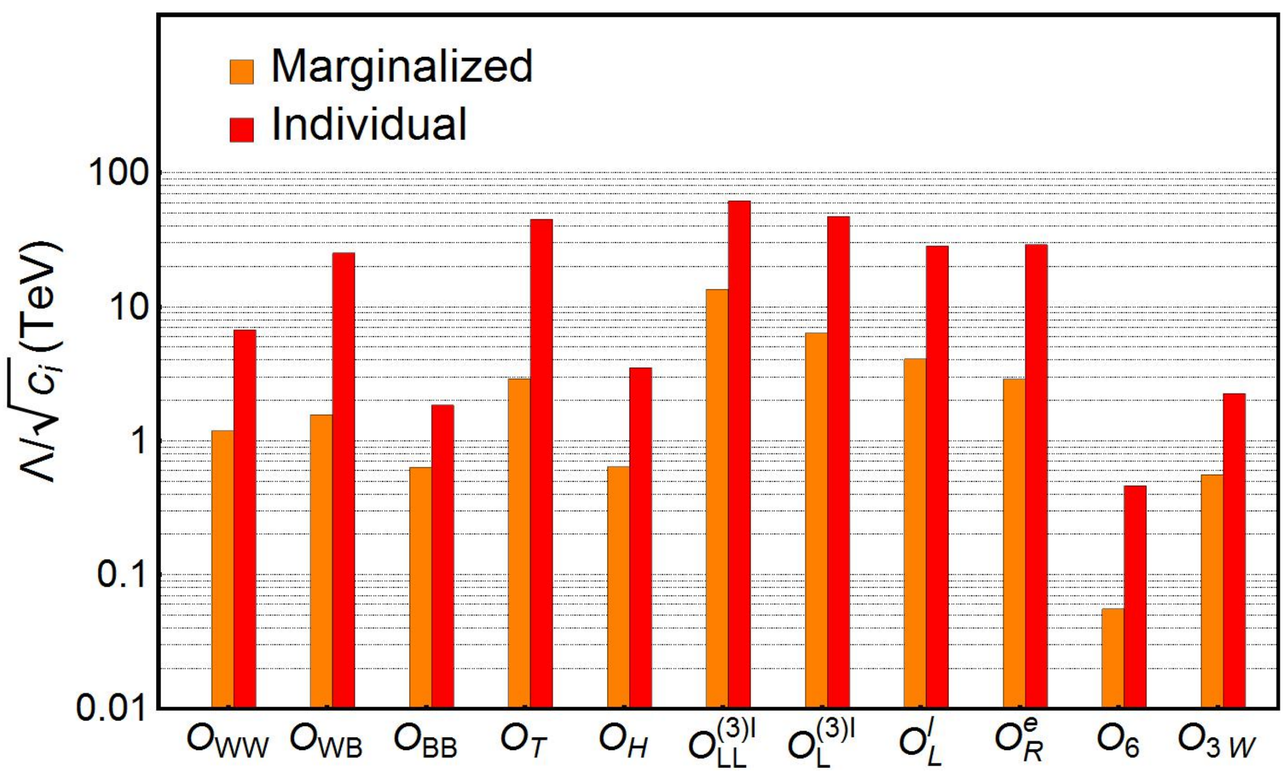
Best sensitivity to Higgs Z coupling.
Model independent determination of width.
Many more…

Reach for new physics, EFT approach

Jiayin Gu

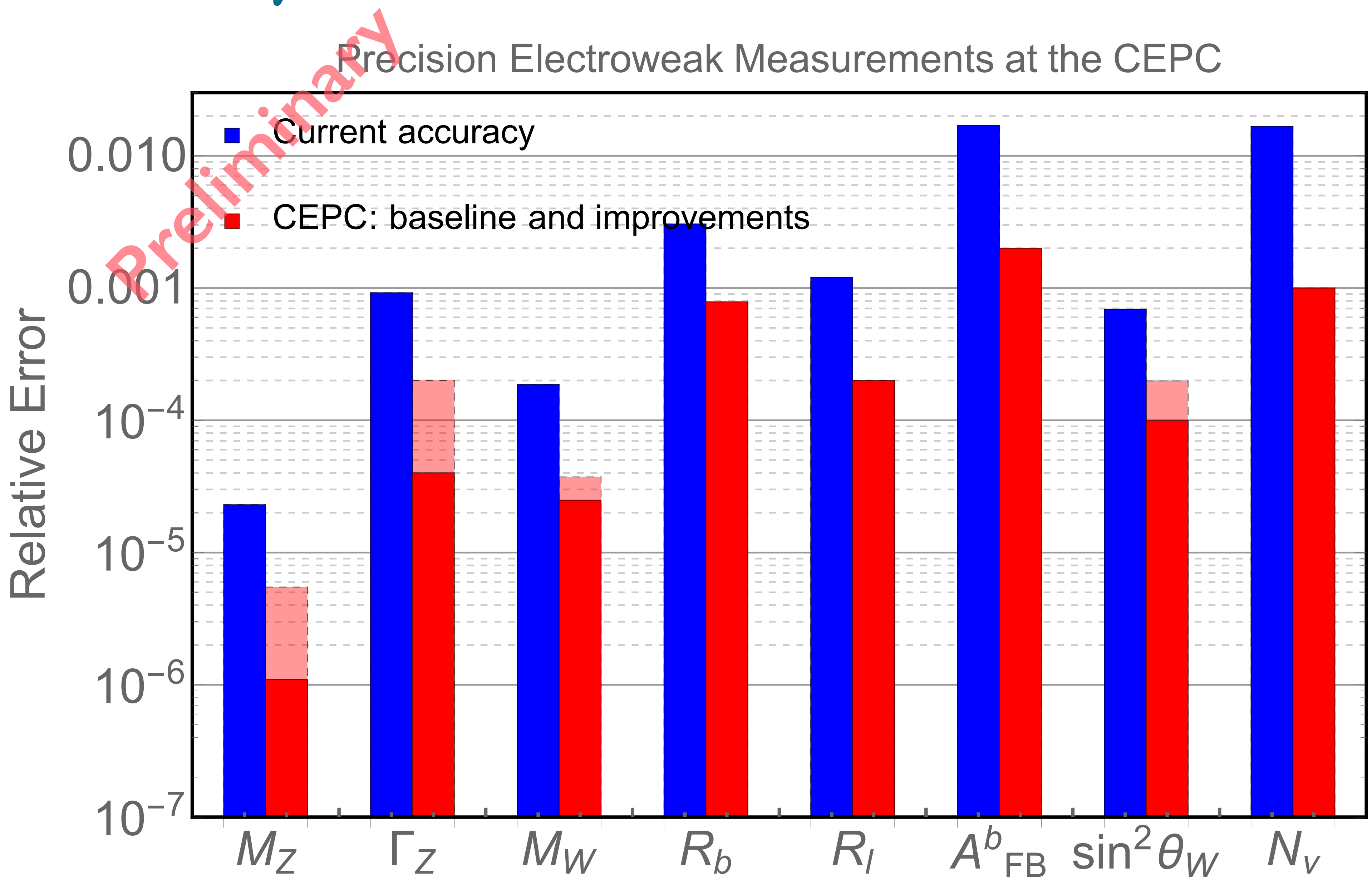


Reach up to multiple TeVs!



W. Chiu, I. Leung, T. Liu, K. Lv, LTW

Z-factory

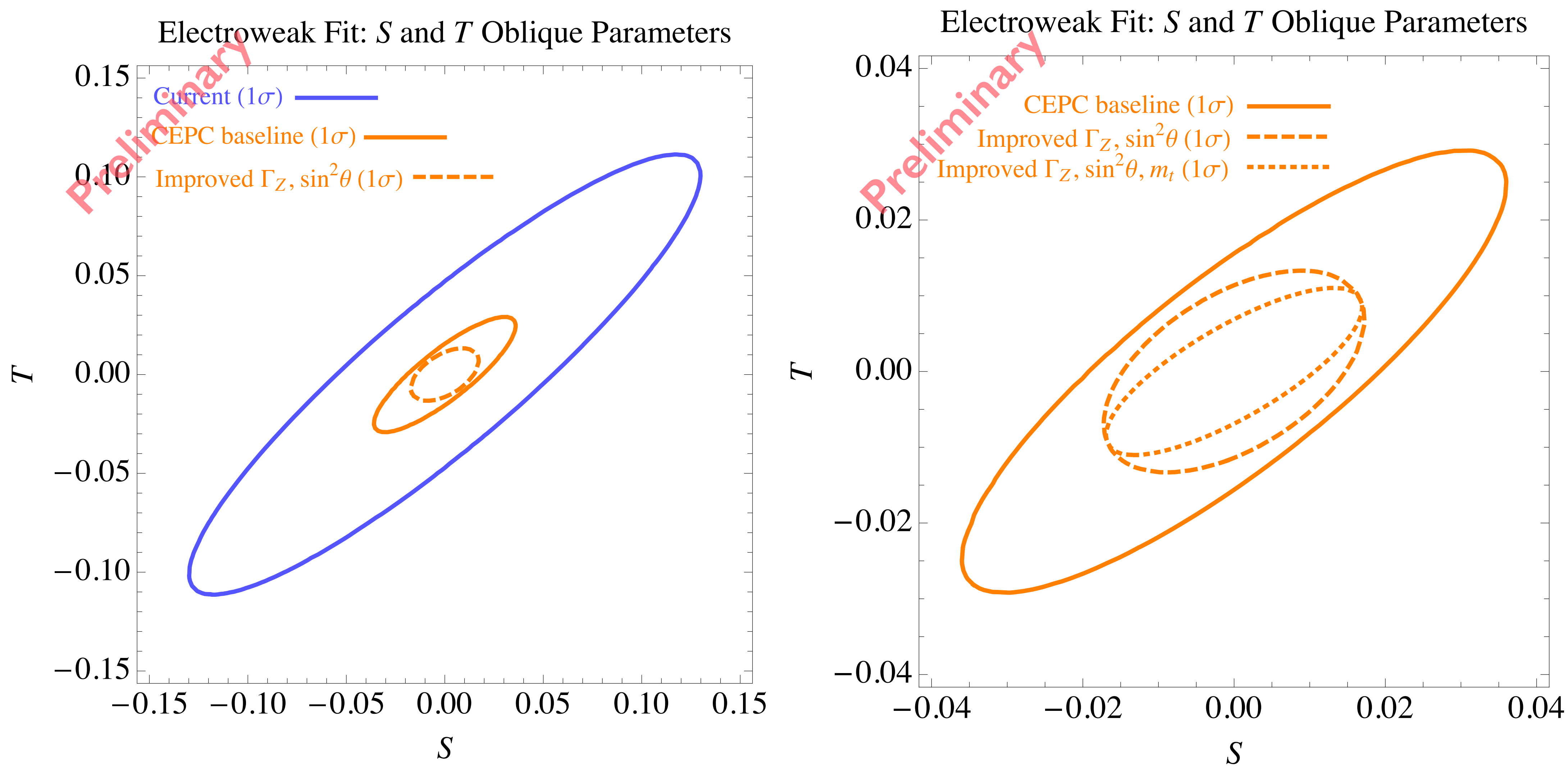


Based on Giga-Z. Large improvement.
Systematic dominated

projection: Zhijun Liang

Constraints on Oblique Parameters

J. Fan, M. Reece, LTW



Based on a Giga-Z, a factor of 10 improvement on LEP-1. Complementary to Higgs coupling measurements.

White paper forthcoming

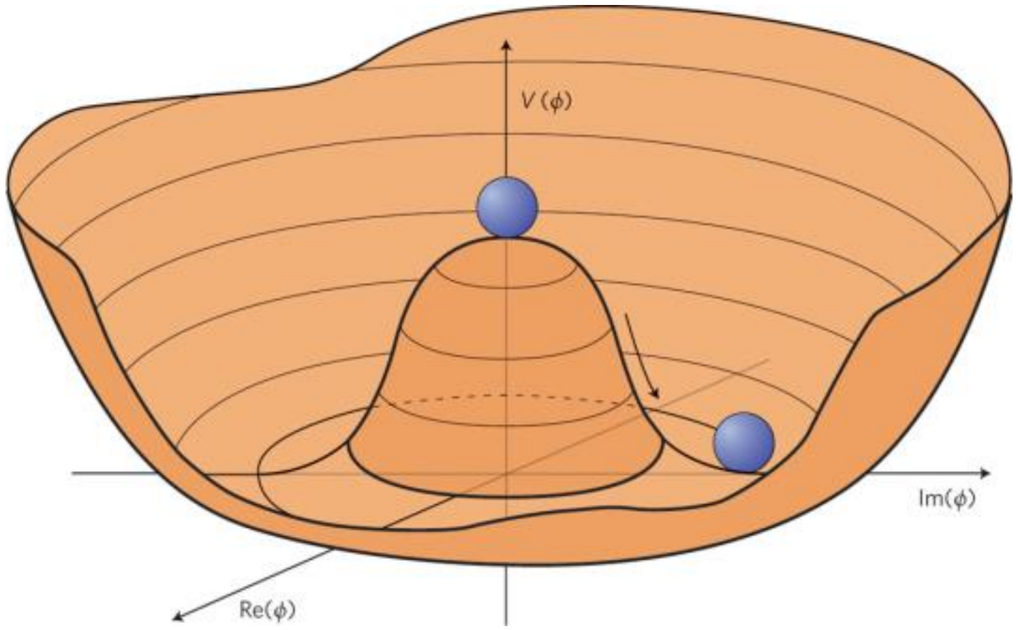
C. Carloni, J. Erler, J. Fan, A. Freytas, S. Heinemeyer, Z. Liang, F. Piccinini, M. Reece, LTW

Addressing important physics questions at CEPC

Addressing important physics questions at CEPC

Primary Physics goal:
Electroweak symmetry breaking

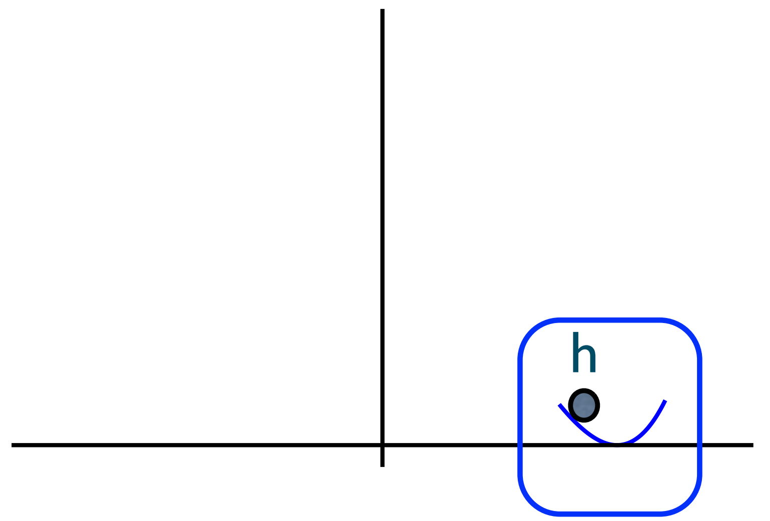
Mysteries of the electroweak scale.



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

$$\langle h \rangle \equiv v \neq 0 \;\rightarrow\; m_W = g_W \frac{v}{2}$$

Mysteries of the electroweak scale.

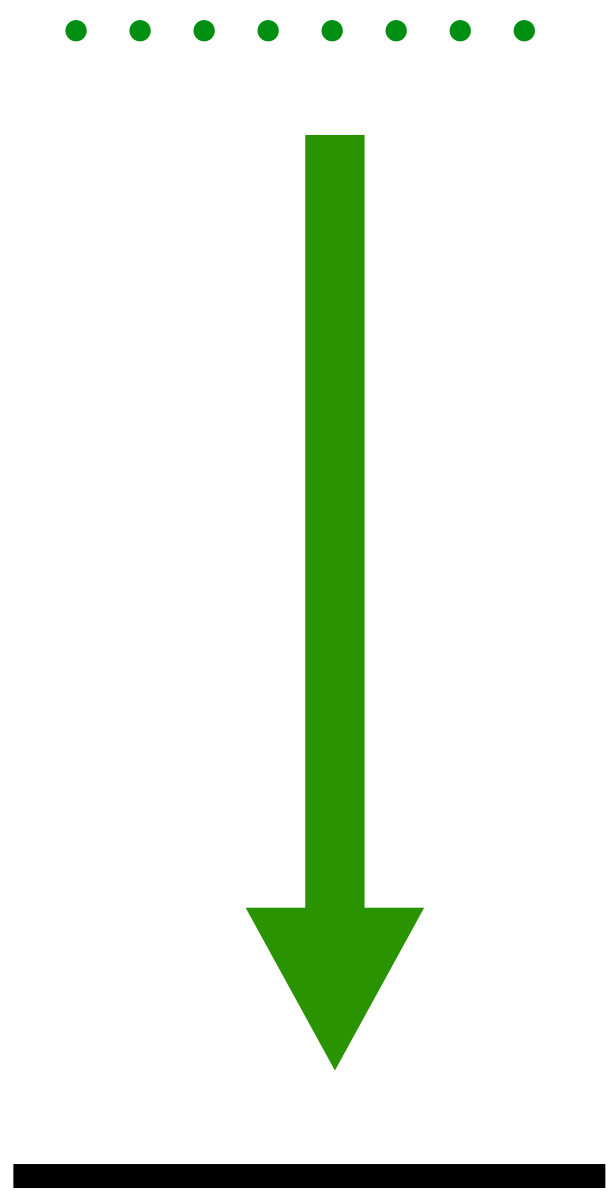


What we know now

- How to predict/calculate Higgs mass?

- Higgs potential beyond this? Nature of electroweak phase transition?

How to predict Higgs mass?



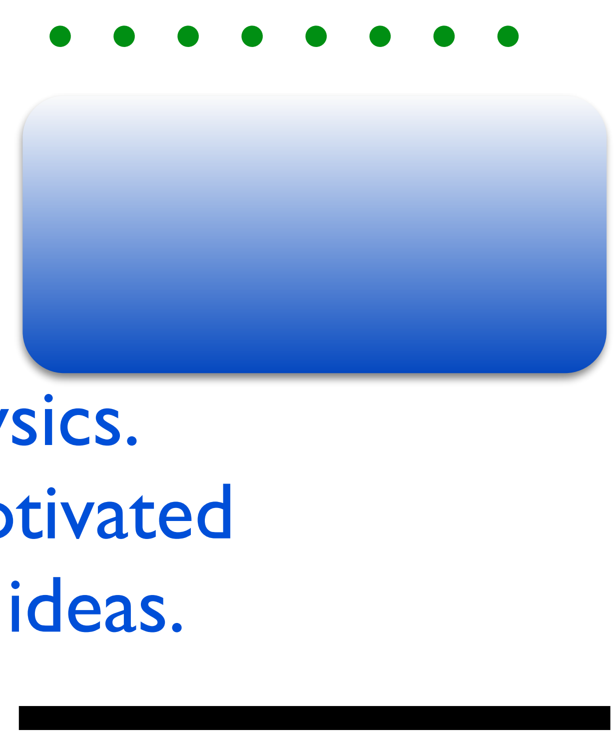
The energy scale of new physics
responsible for EWSB

What is this energy scale?
$M_{Planck} = 10^{19}$ GeV, …?

If so, why is so different from 100 GeV?
The so called naturalness problem

Electroweak scale, 100 GeV.
m_h , m_W …

Naturalness of electroweak symmetry breaking



The energy scale of new physics
responsible for EWSB

TeV new physics.
Naturalness motivated
Many models, ideas.

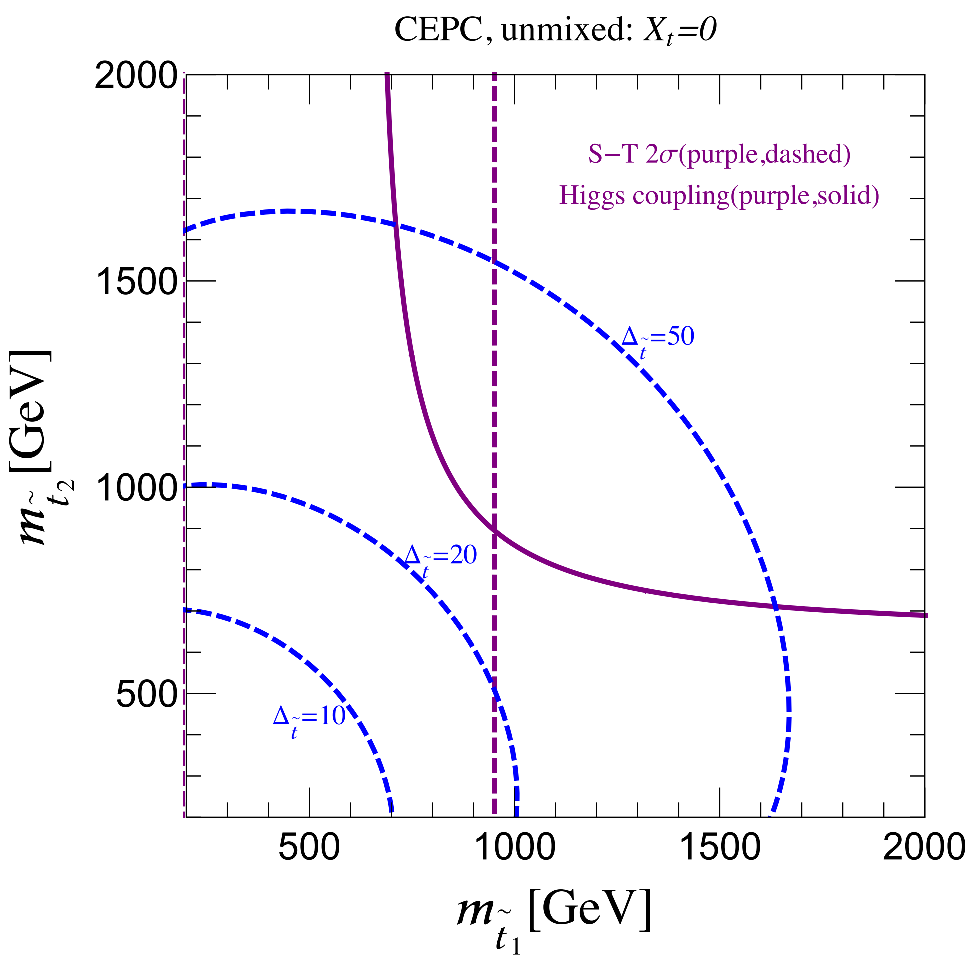
Electroweak scale, 100 GeV.
m_h , m_W …

No lose on naturalness

- It is the most pressing question of EWSB.
  - How should we predict the Higgs mass?
- We may not have the right idea. No confirmation of any of the proposed models. Need experiment!
- Fortunately, with Higgs, we know where to look.
  - Clue to any possible way to address naturalness problem must show up in Higgs coupling measurement.
  - Almost a "no-lose" theorem for making progress.

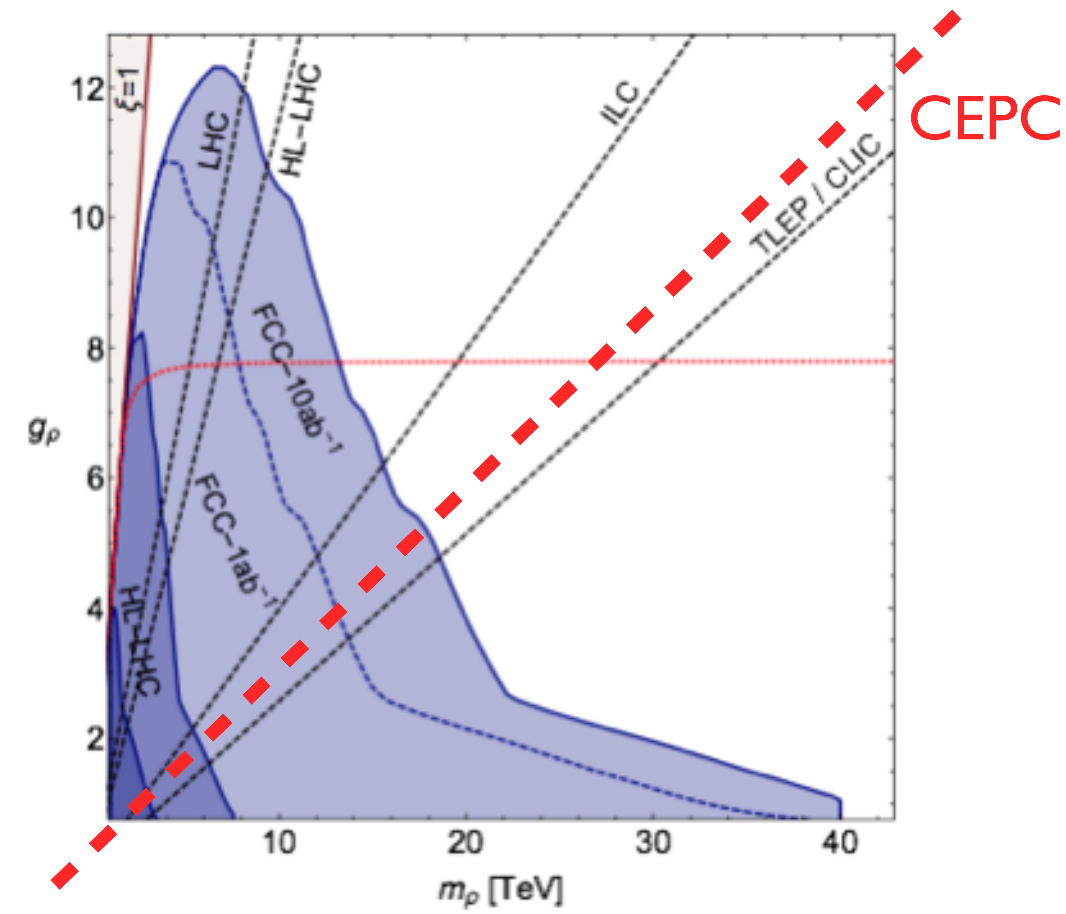
“Standard” new physics scenarios

J. Fan, M. Reece, LT W



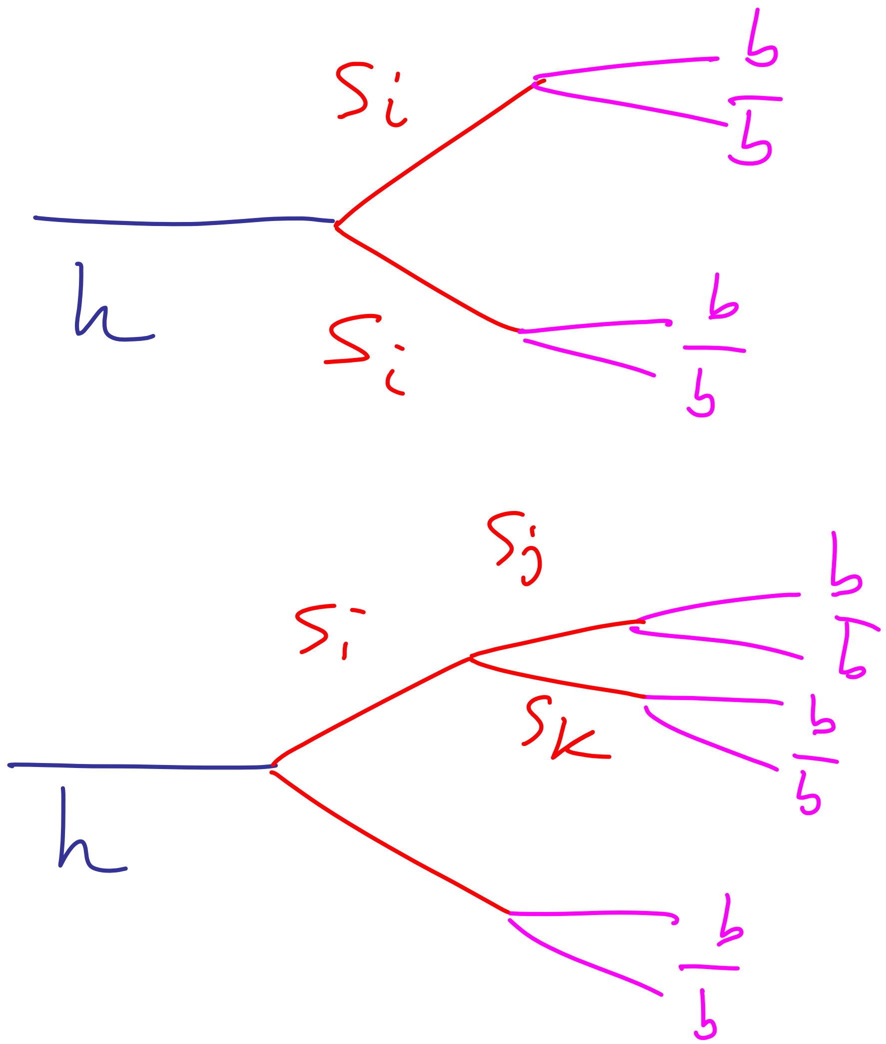
Supersymmetry

Papadopulo, Thamm, Torre, Wulzer



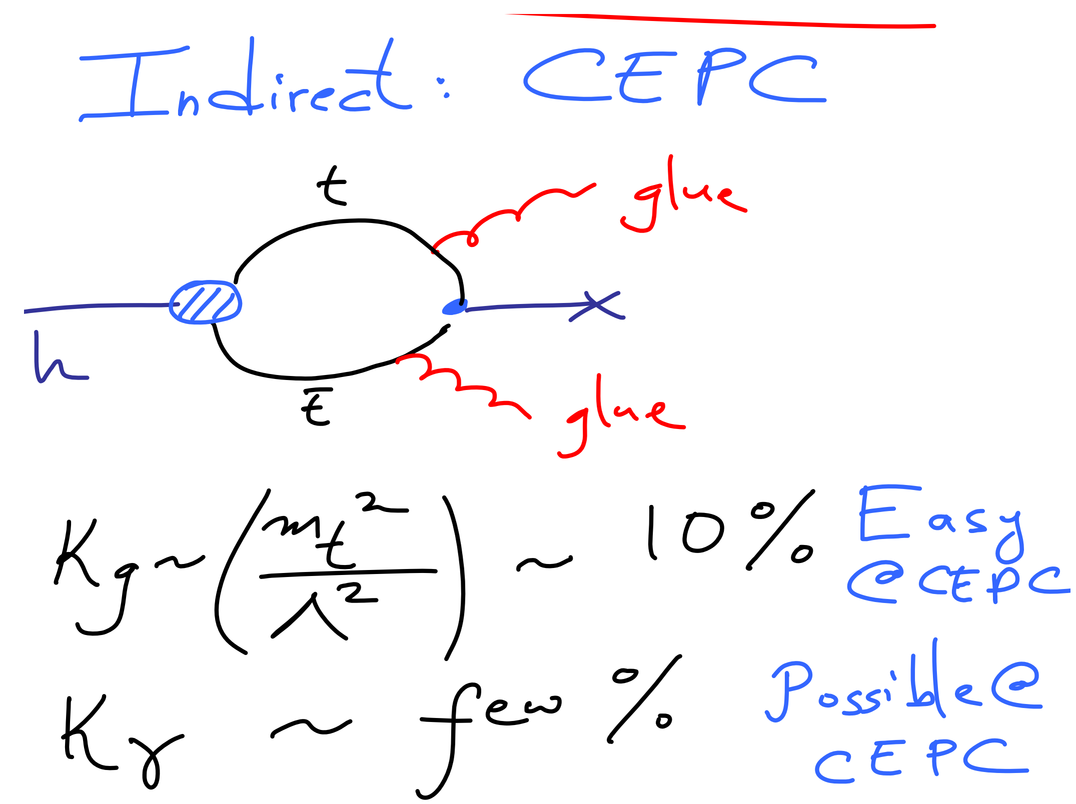
Composite Higgs

More exotic ideas



Low scale landscape

Higgs rare decay.



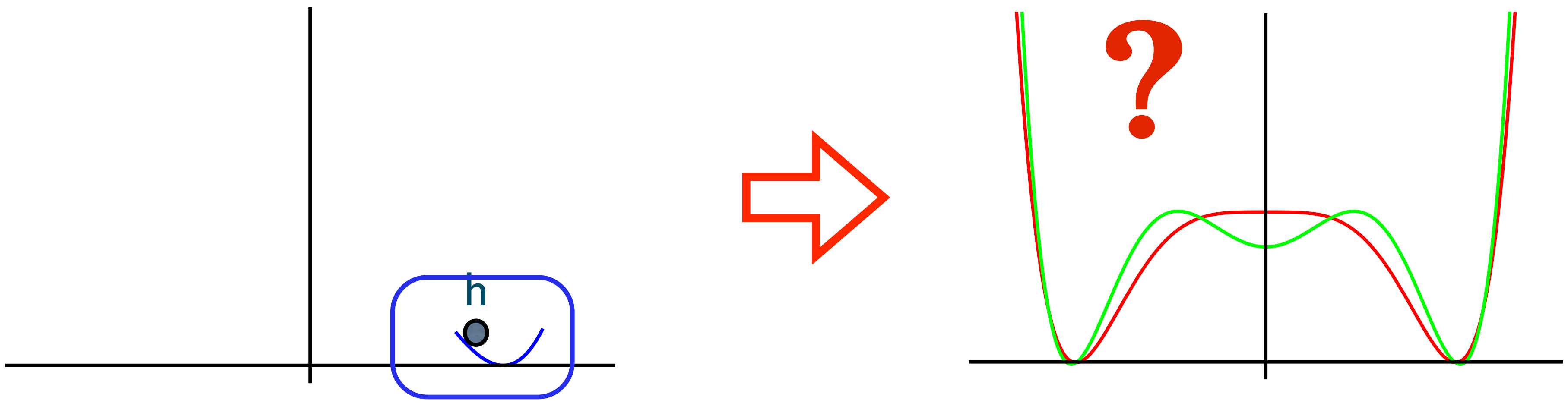
"fat" Higgs

Higgs coupling

Can't hide from the Higgs.

Talk by Arkani-Hamed CEPC workshop Sept. 2016

Nature of EW phase transition

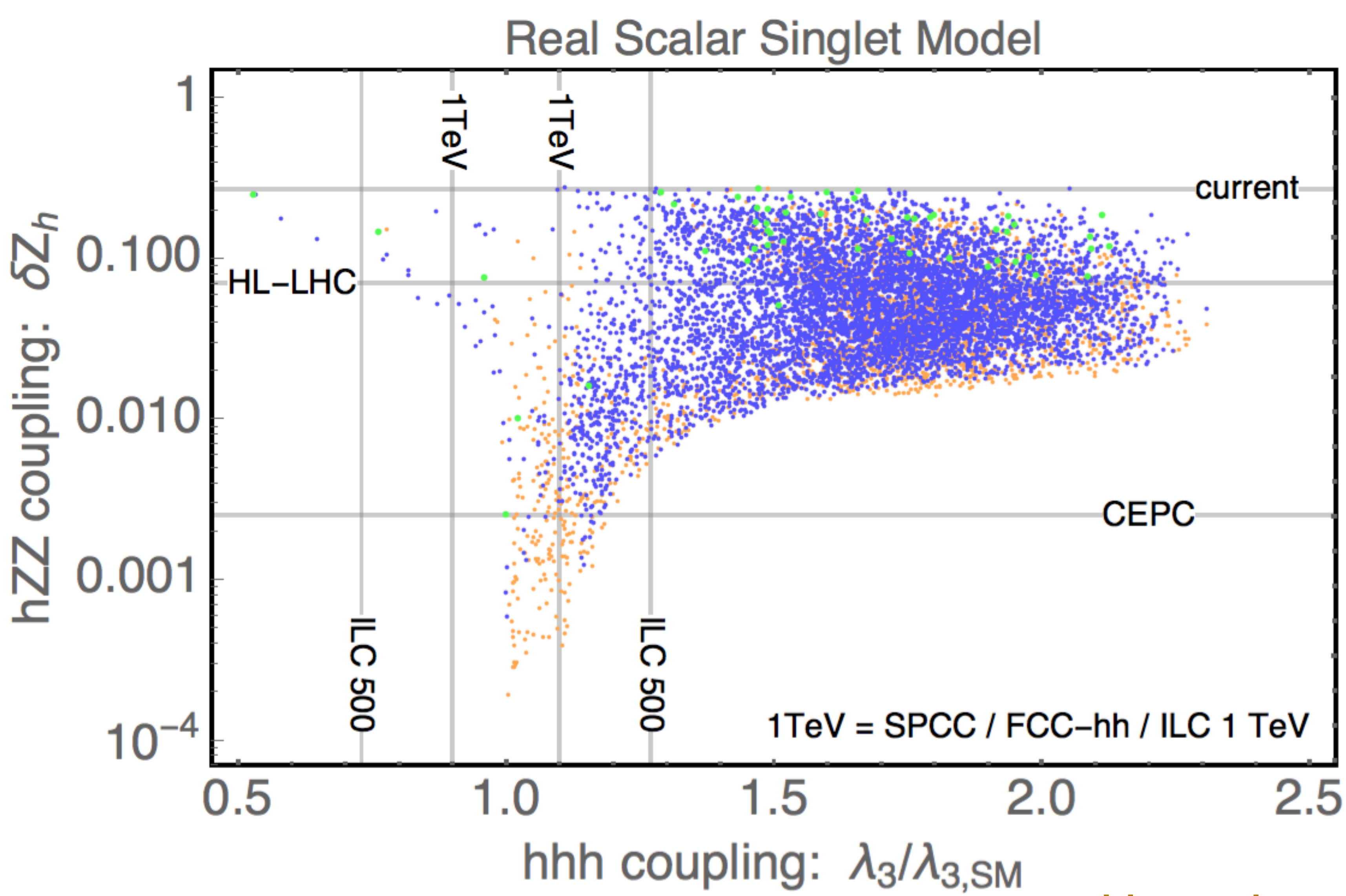


What we know from LHC
LHC upgrades won't go much further

"wiggles" in Higgs potential

Big difference in triple Higgs coupling
Will have deviation in other Higgs coupling as well

Probing EWSB at higgs factories



Huang, Long, LTW, 1608.06619

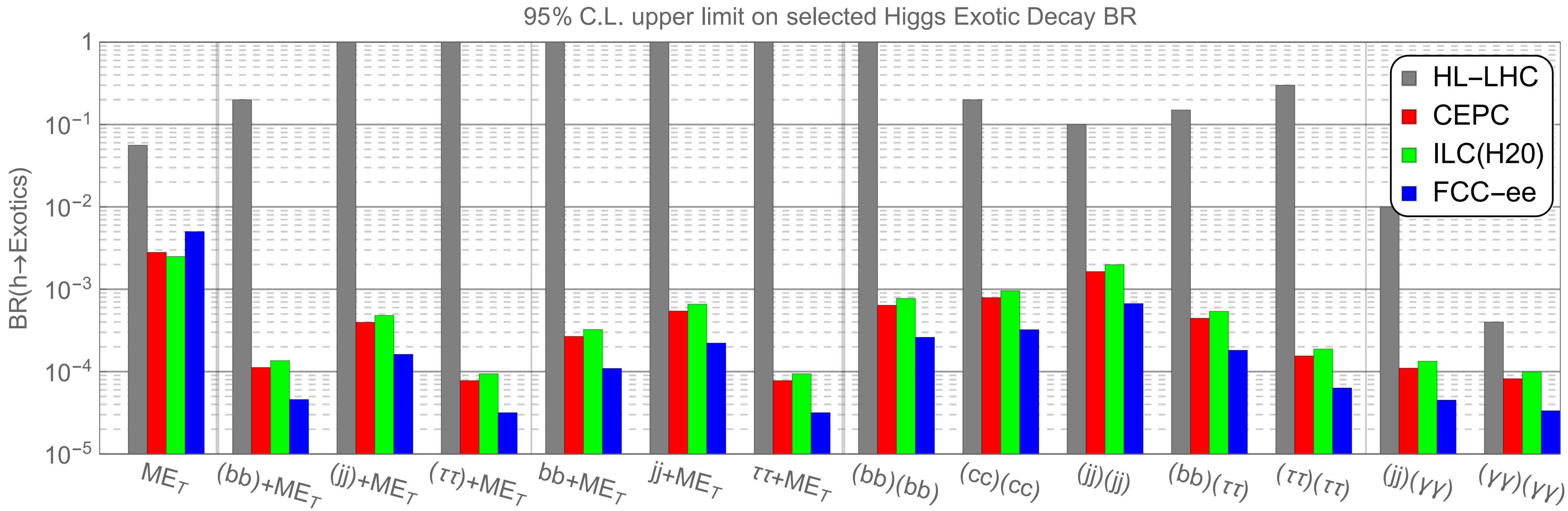
Orange = first order phase transition, $v(T_c)/T_c > 0$
Blue = "strongly" first order phase transition, $v(T_c)/T_c > 1.3$
Green = very strongly 1PT, could detect GWs at eLISA

Good coverage in model space

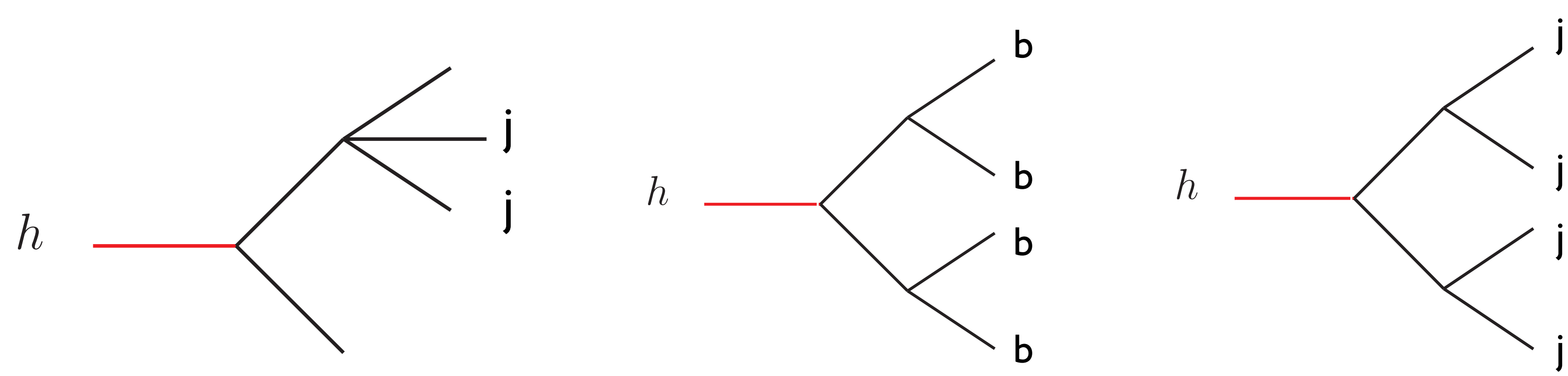
Exotica

Higgs exotic decay

Zhen Liu, LTW, Hao Zhang

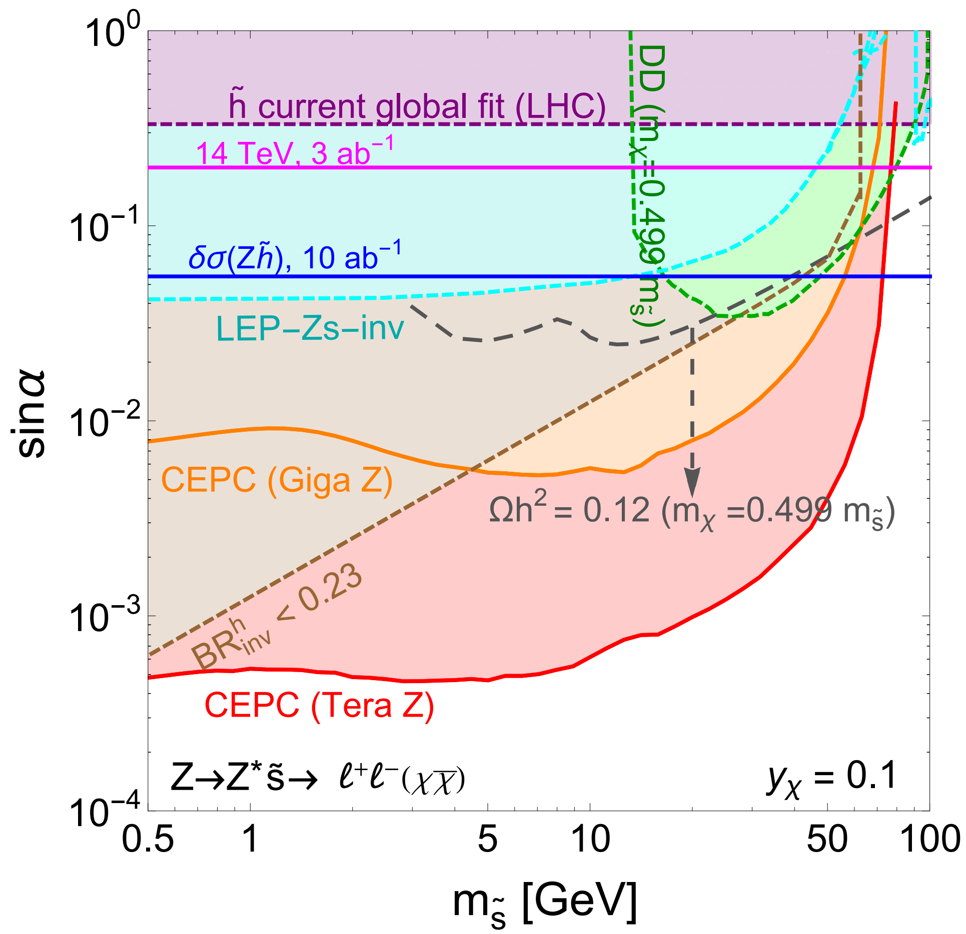


Examples:

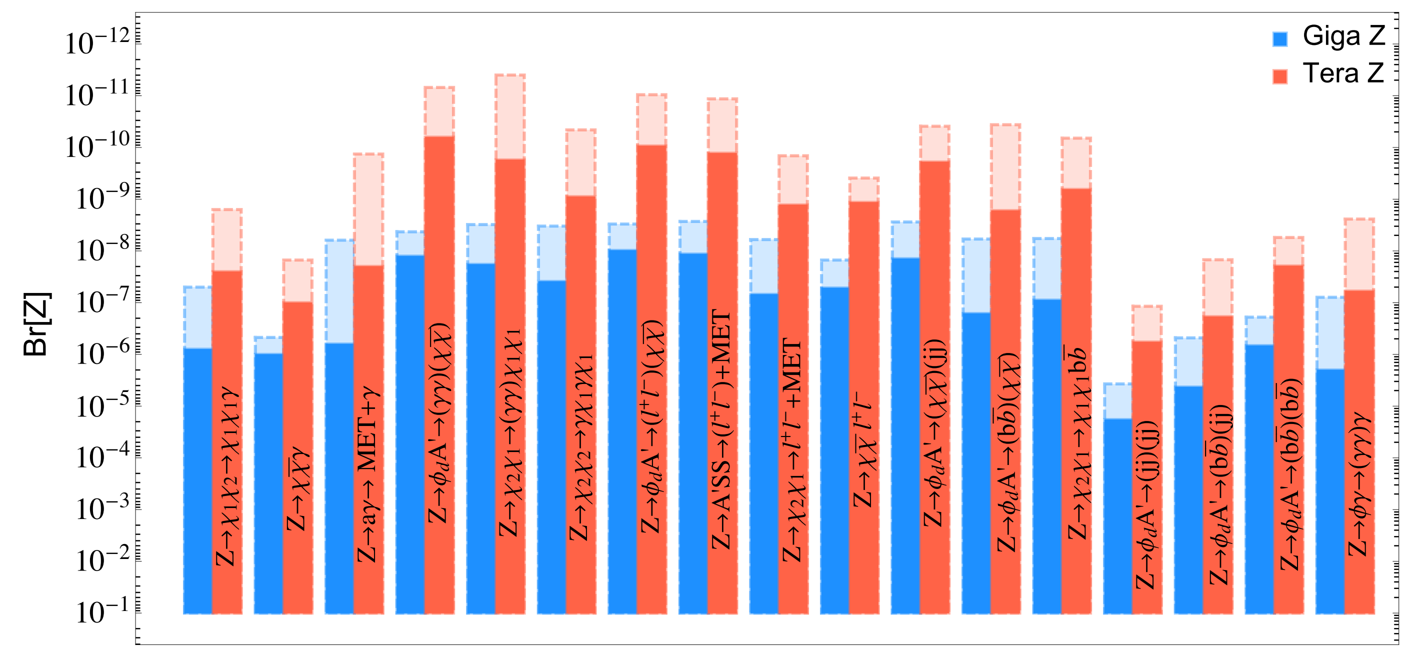


Covers difficult channels at the LHC

Z exotic decay



Jia Liu, Xiaoping Wang, LTW, Wei Xue



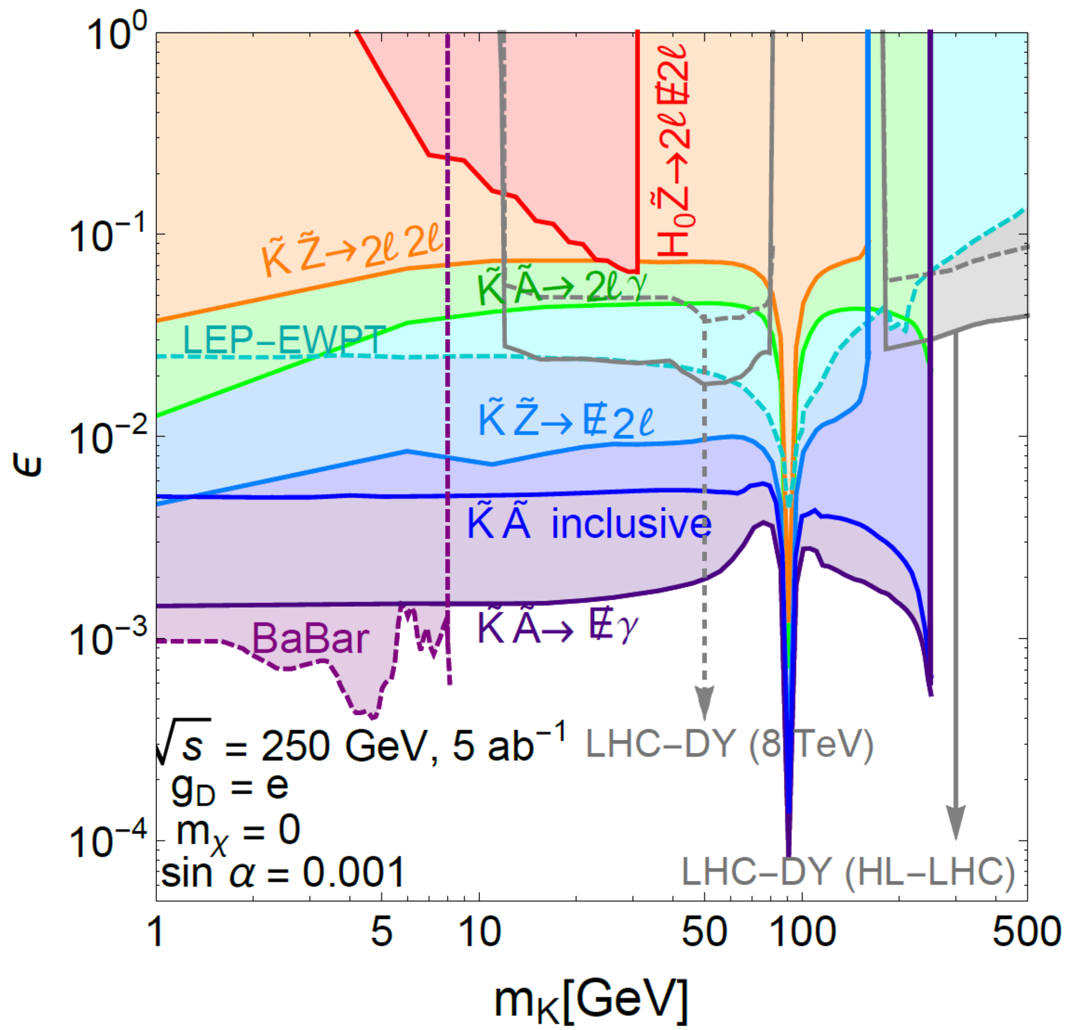
Sensitive to very rare Z decays, down to 10^{-9}

Powerful probe to dark sector models

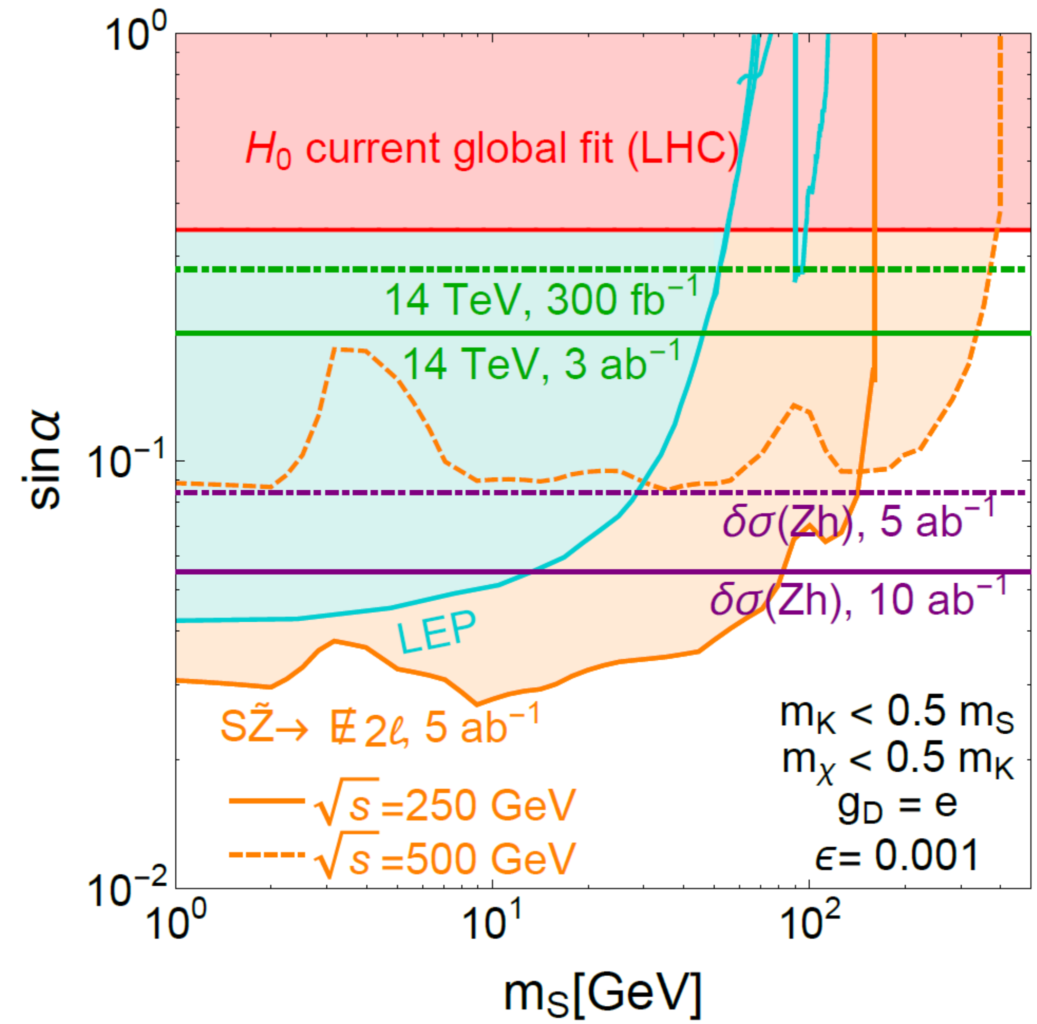
Dark sector searches

CEPC has leading discovery prospects for light, weakly-coupled dark sector vector and scalar particles

Kinetic mixing + dark vector



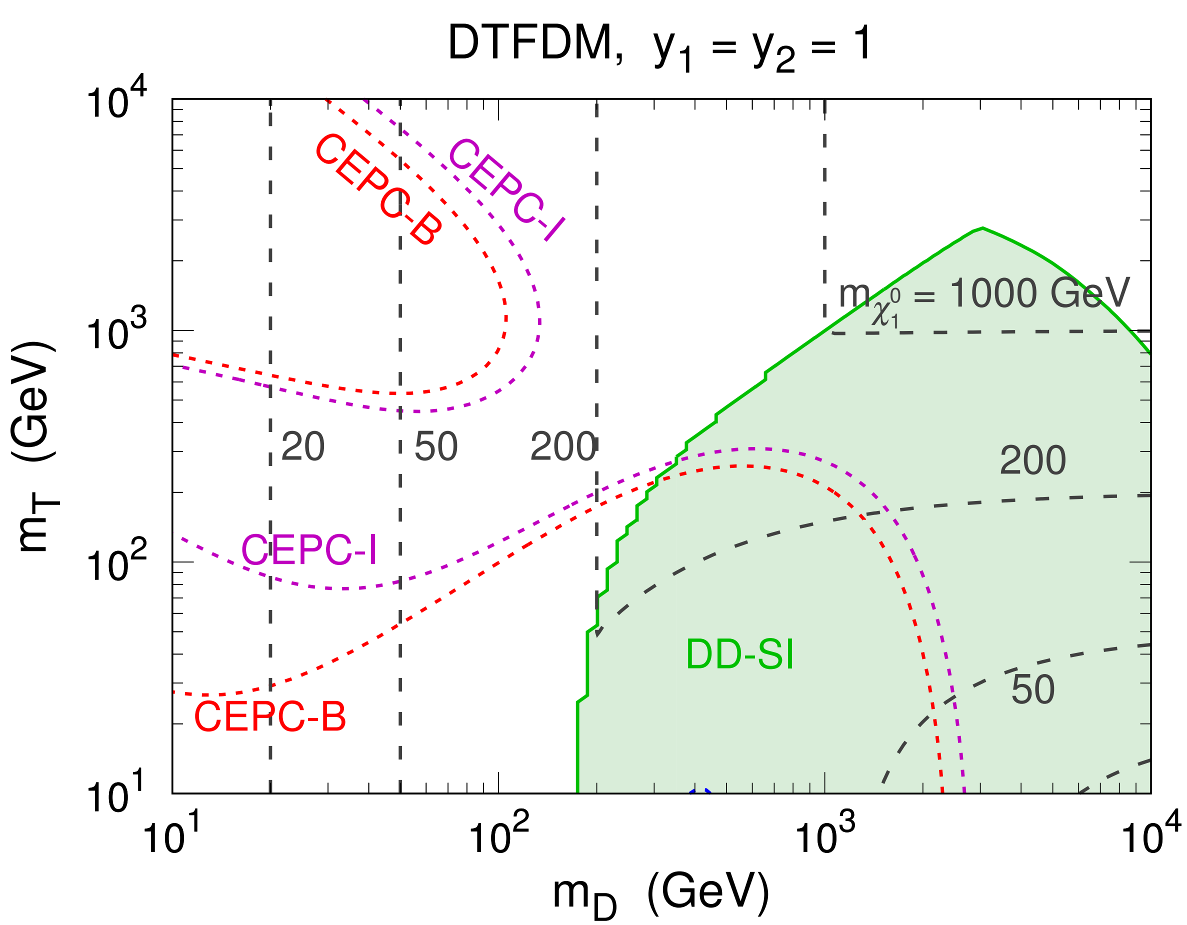
Higgs portal + dark scalar



Figures from Jia Liu, Xiao-Ping Wang, Felix Yu, JHEP **1706**, 077 (2017)

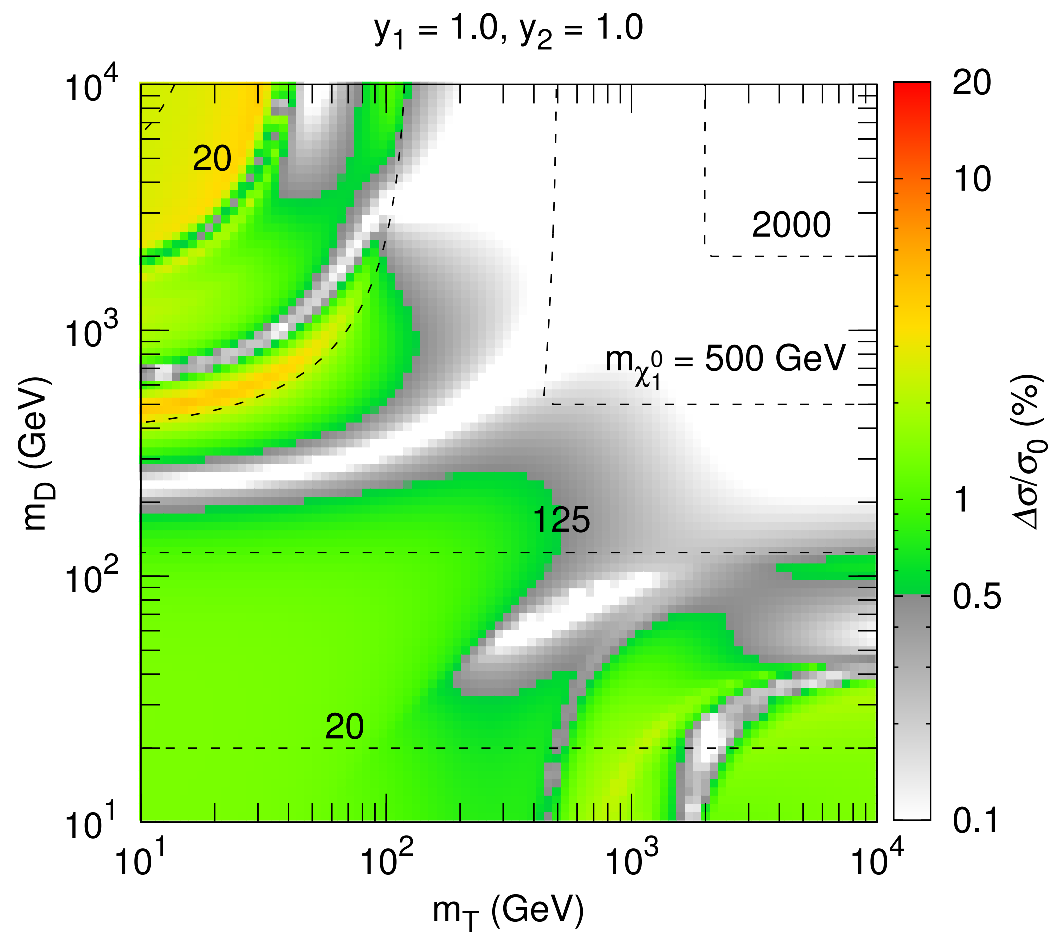
Dark matter

C. Cai, Z. H. Yu, H. H. Zhang



Precision Z-pole measurements

Q.F. Xiang, X. J. Bi, P. F. Yin, Z. H. Yu

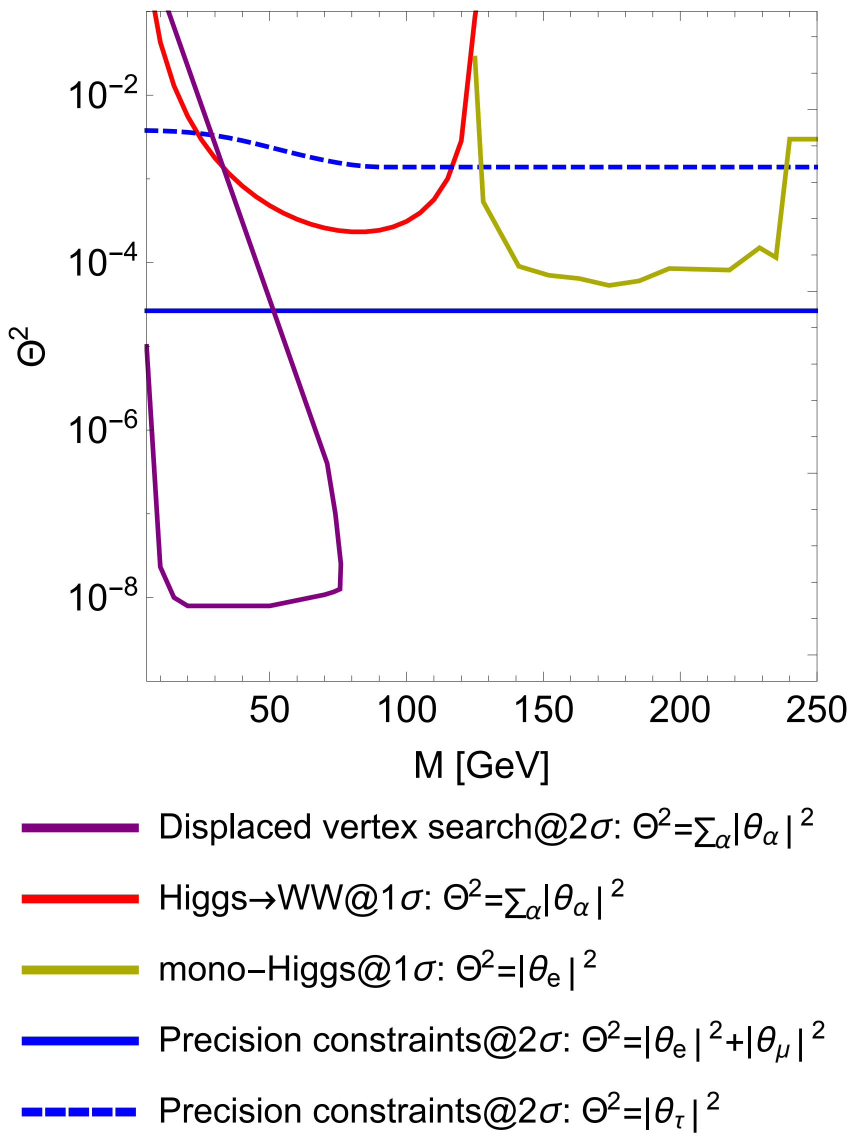


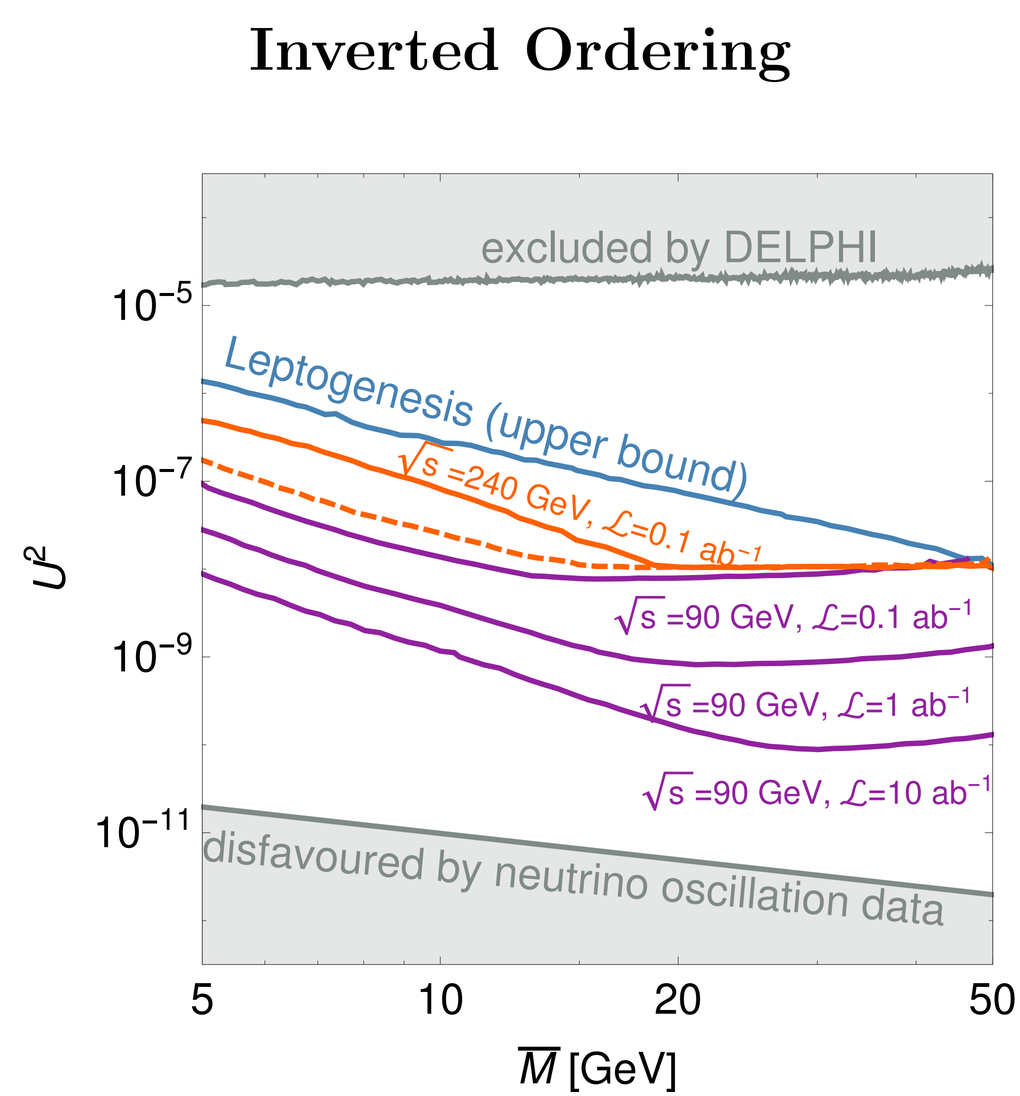
Precision Higgs production measurements

Precision measurement can probe weak scale dark matter

Neutrino mass and leptogenesis

S. Antusch, E. Cazzato, M. Drewes O. Fischer, B. Garbrecht, D. Gueter, J. Klaric





Probing light (10s GeV) sterile neutrino
Connection to neutrino mass and lepta-genesis

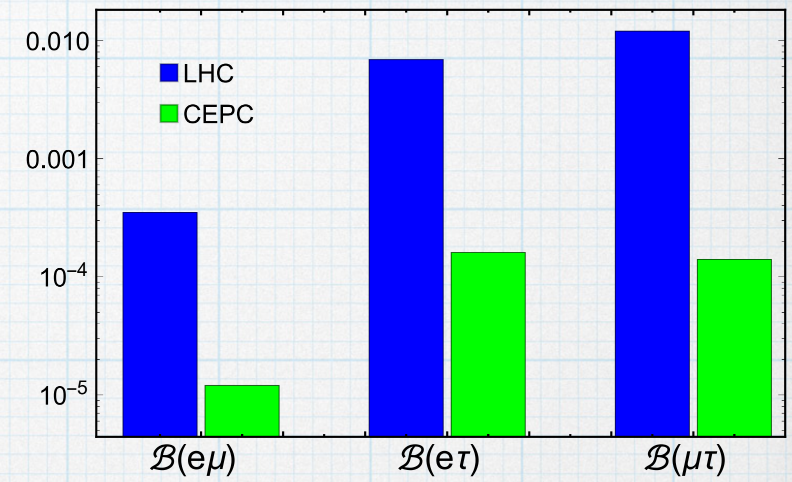
Flavor

CaiDian Lv, Qin Qin, Fusheng Yu

Lepton flavor violation (Higgs)

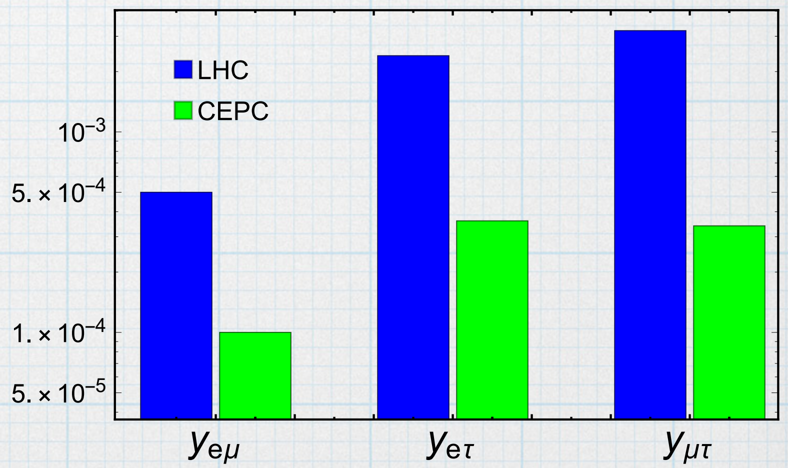
$$\mathcal{L}^{H\to\mu^\mp\tau^\pm} = -Y_{\mu\tau}\bar{\mu}_L H\tau_R - Y_{\tau\mu}\bar{\tau}_L H\mu_R + h.c.,$$

$$\Gamma(H\to\mu^\mp\tau^\pm)_{m_{\mu,\tau}\to 0} = \frac{m_H}{8\pi}(|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2)$$



Current and expected CEPC bounds on the branching ratios

Channels	$\mu^\mp\tau^\pm$	$e^\mp\tau^\pm$	$e^\mp\mu^\pm$
ATLAS bound	1.43%	1.04%	
CMS bound	1.2%	0.69%	3.5×10^{-4}
CEPC bound	1.4×10^{-4}	1.6×10^{-4}	1.2×10^{-5}



Current and expected CEPC bounds on the couplings

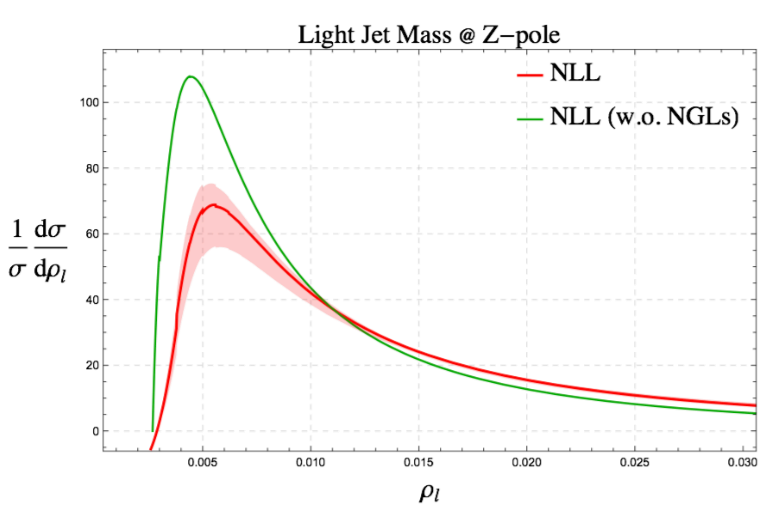
Channels	$\mu^\mp\tau^\pm$	$e^\mp\tau^\pm$	$e^\mp\mu^\pm$
ATLAS bound	3.5×10^{-3}	2.9×10^{-3}	
CMS bound	3.2×10^{-3}	2.4×10^{-3}	5.4×10^{-4}
CEPC bound	3.4×10^{-4}	3.6×10^{-4}	1.0×10^{-4}

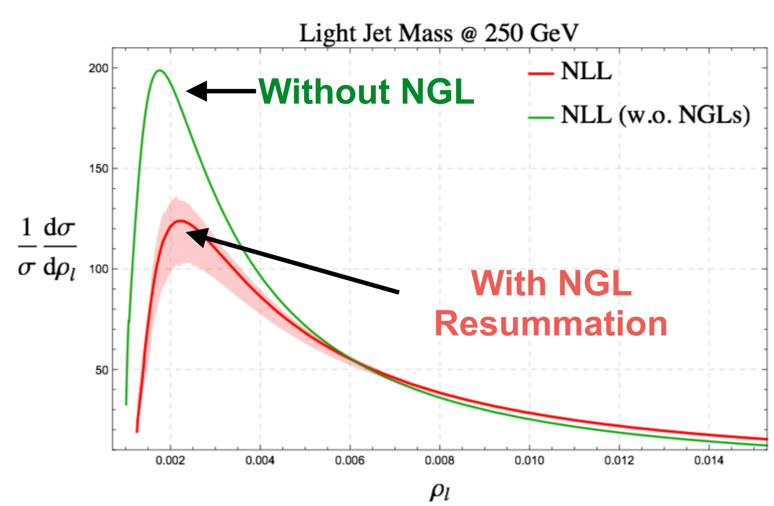
QCD precision measurement

Precision α_s extraction at CEPC

	Current relative precision (LEP+B fact.)	Future relative precision (CEPC)
Z decay EW fit	expt. $\sim 3\%$ (mostly statistics) theo. $\sim 0.6\%$ (pert. QCD/EW)	expt. $< 0.1\%$ (possible) theo. $\sim 0.3\%$ (N^4LO, almost there)
τ decay	expt. $\sim 0.5\%$ theo. $\sim 2-3\%$ (FOPT v.s. CIPT)	expt. $< 0.2\%$ (possible) theo. $\sim 1\%$ (feasible, N^4LO)
jet rates	expt. $\sim 2\%$ (exp.) theo. $\sim 2\%$ (pert. QCD scale)	expt. $< 1\%$ (possible) theo. $< 1\%$ (feasible, NNLO+NNLL)
event shapes	expt. $\sim 1\%$ theo. $\sim 1-3\%$ (analytic v.s. MC N.P.)	expt. $< 1\%$ (possible) theo. $< 1\%$ (feasible, Q^2, NLO+NLL MC)

Probing BFKL-like dynamics from jet production at CEPC





Evolution of non-global logarithms governed by BFKL-like equation. Effects Can be clearly observed at CEPC.

Becher, Pecjak, Shao, 2016

Conclusions

- Precision measurement at CEPC: a big step forward.
- Addressing the question of electroweak symmetry breaking.
- Will have a rich physics program, covers a broad range of physics.
- CDR writing in progress. Will keep updating with new results and studies.

“Drafter”s of theory part of CDR

XiaoJun Bi (IHEP)
Qing Hong Cao (Peking U.)
Nathanial Craig (U. California, Santa Barbara)
JiJi Fan (Brown U.)
Tao Liu (Hong Kong U. of Sci. Tech.)
Yan Qing Ma (Peking U.)
Matthew Reece (Harvard U.)
Shufang Su (U. Arizona)
Jing Shu (ITP)
LianTao Wang (U. Chicago)

Please let us know your suggestion, ideas, complaints.

Inputs for the further study

Baseline option

	Present data	CEPC fit
$\alpha_s(M_Z^2)$	0.1185 ± 0.0006 [17]	$\pm 1.0 \times 10^{-4}$ [18]
$\Delta\alpha_{\rm had}^{(5)}(M_Z^2)$	$(276.5 \pm 0.8) \times 10^{-4}$ [19]	$\pm 4.7 \times 10^{-5}$ [20]
m_Z [GeV]	91.1875 ± 0.0021 [21]	$\pm\mathbf{0.0005}$
m_t [GeV] (pole)	$173.34 \pm 0.76_{\rm exp}$ [22] $\pm 0.5_{\rm th}$ [20]	$\pm 0.6_{\rm exp} \pm 0.25_{\rm th}$ [20]
m_h [GeV]	125.14 ± 0.24 [20]	$< \pm 0.1$ [20]
m_W [GeV]	$80.385 \pm 0.015_{\rm exp}$ [17] $\pm 0.004_{\rm th}$ [23]	$(\pm\mathbf{3}_{\rm exp} \pm 1_{\rm th}) \times 10^{-3}$ [23]
$\sin^2\theta_{\rm eff}^{\ell}$	$(23153 \pm 16) \times 10^{-5}$ [21]	$(\pm\mathbf{4.6}_{\rm exp} \pm 1.5_{\rm th}) \times 10^{-5}$ [24]
Γ_Z [GeV]	2.4952 ± 0.0023 [21]	$(\pm\mathbf{5}_{\rm exp} \pm 0.8_{\rm th}) \times 10^{-4}$ [25]
$R_b \equiv \Gamma_b/\Gamma_{\rm had}$	0.21629 ± 0.00066 [21]	$\pm\mathbf{1.7} \times 10^{-4}$
$R_\ell \equiv \Gamma_{\rm had}/\Gamma_\ell$	20.767 ± 0.025 [21]	$\pm\mathbf{0.007}$

With possible improvements.

CEPC	$\sin^2\theta_{\rm eff}^{\ell}$	Γ_Z [GeV]	m_t [GeV]
Improved Error	$(\pm 2.3_{\rm exp} \pm 1.5_{\rm th}) \times 10^{-5}$	$(\pm 1_{\rm exp} \pm 0.8_{\rm th}) \times 10^{-4}$	$\pm 0.03_{\rm exp} \pm 0.1_{\rm th}$

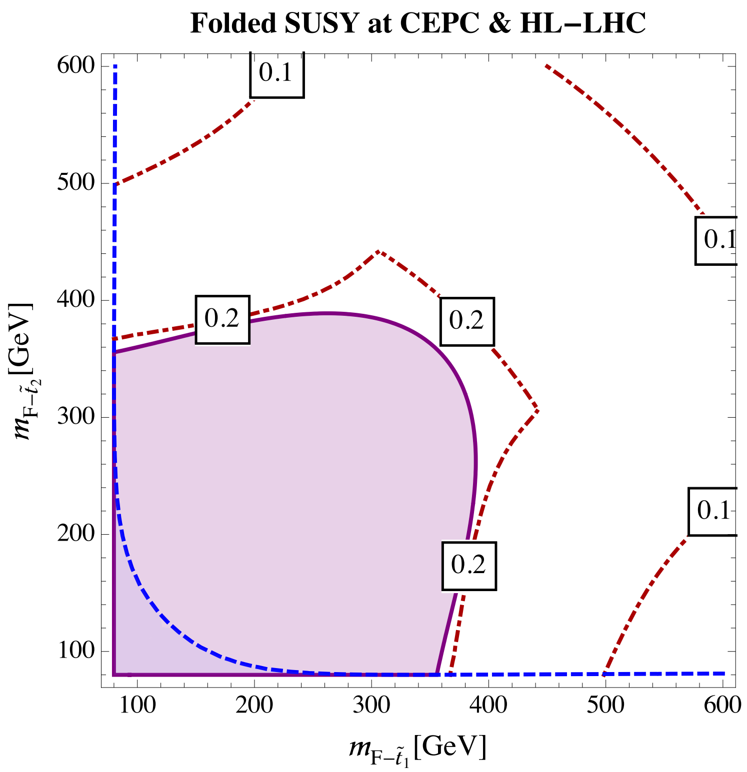
x4 statistics off Z-pole

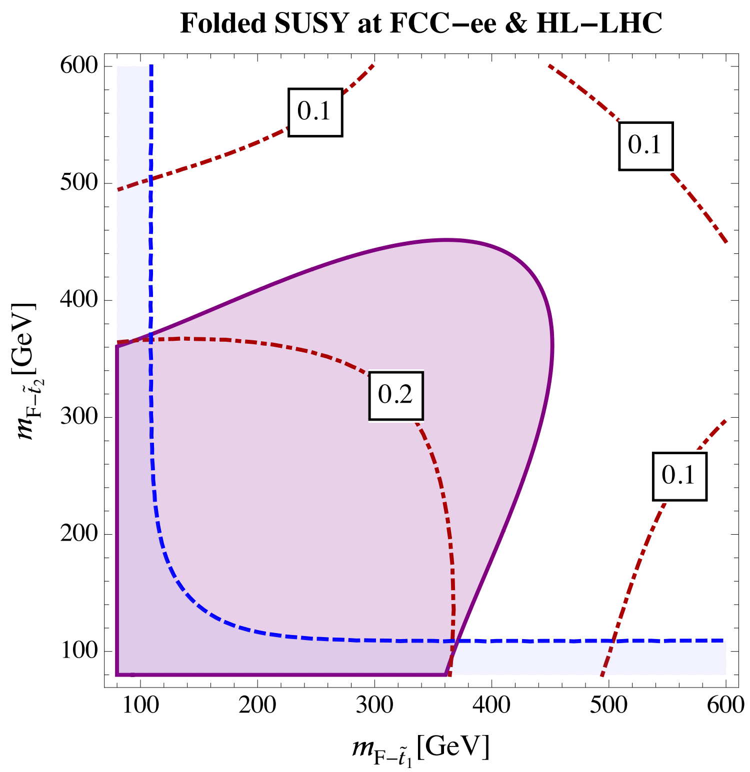
energy calibration

ILC?

More exotic ideas: Folded SUSY

- Top partner has SM electroweak couplings only.
- Deviations in $h \to \gamma\gamma$.





J. Fan, M. Reece, LTW, 1412.3107

Triple Higgs coupling measurement

- Very difficult at HL-LHC: “order 1”
- Not very good at 250 GeV Higgs factory.
- 100 TeV pp collider or 1 TeV ILC can reach about 10%.
- However, if new physics modifies electroweak phase transition, it will also generate corrections to other Higgs couplings.
    - e.g. Generating deviations in Higgs-Z coupling, which can be measured very well at 250 GeV Higgs factories.