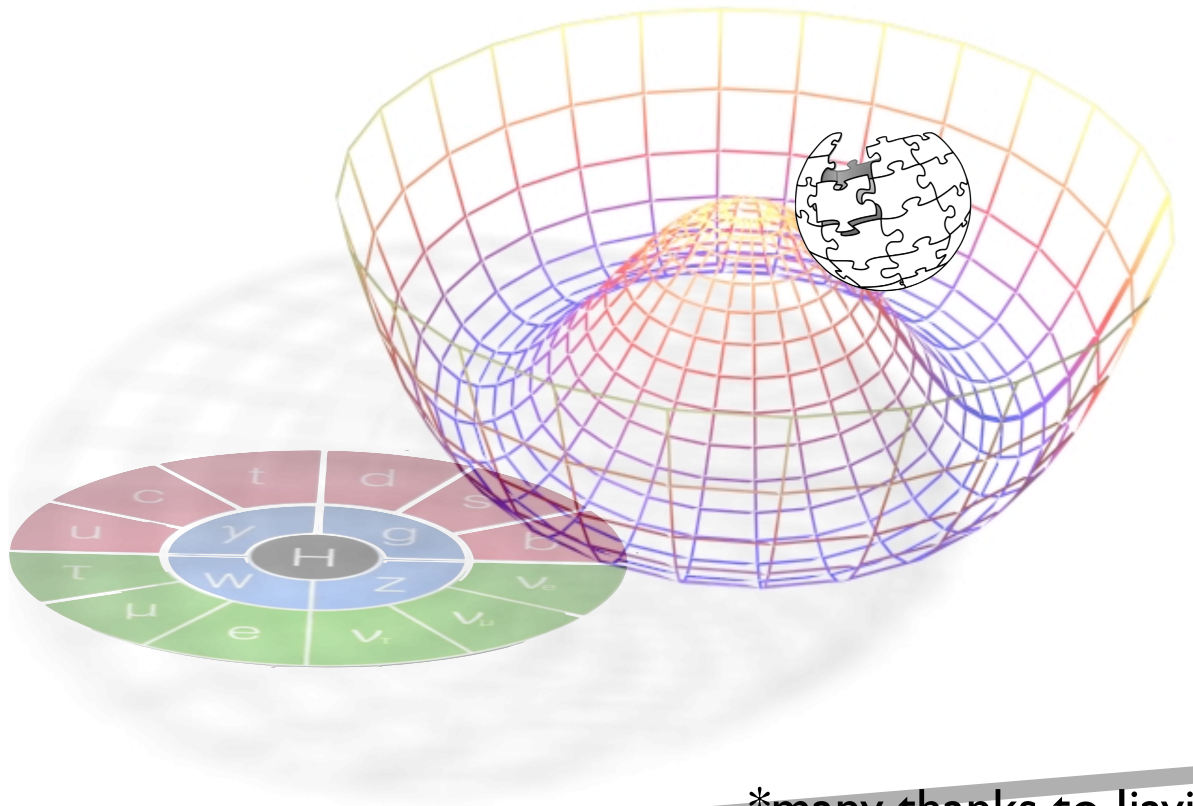
Higgs Synergies/ Complementarities

Berlin, May 30, 2017
" FCC week"



Christophe Grojean*
DESY (Hamburg)
Humboldt University (Berlin)

(christophe.grojean@desy.de)

*many thanks to Jiayin Gu for his help in producing several plots

The Higgs in the (B)SM landscape

The fundamental principles governing the structure of **Higgs sector** are yet unknown
(many arbitrary parameters taking seemingly un-natural values)
The Higgs plays a vital role in our life
(masses, stability of vacuum, DM?, inflation?)
It has an intimate link with the high energy completion of the SM

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The Higgs discovery has been an important milestone for HEP
but it hasn't taught us much about **BSM** yet

typical Higgs coupling deformation: $\frac{\delta g_h}{g_h} \sim \frac{g^2\, v^2}{\Lambda_{\rm BSM}^2}$

current (and future) LHC sensitivity O(10-20)% ⇔ $\Lambda_{\rm BSM}$ > 500-700 GeV

not doing better than direct searches
(except maybe for flavor violating processes, e.g. h→$\mu\tau$)

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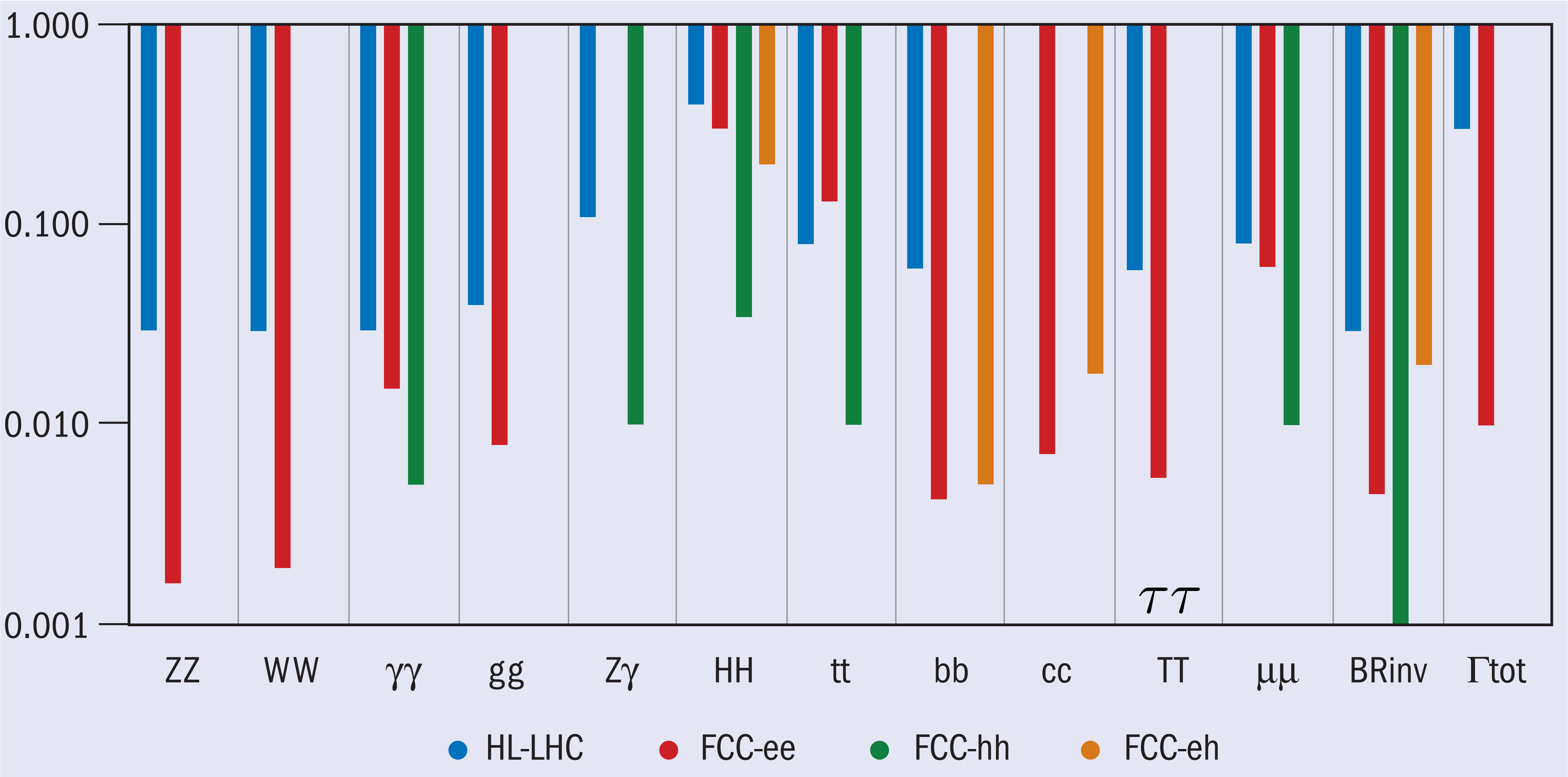
Higgs precision programme is very much wanted
complementary and synergetic measurements are essential to achieve this goal

Higgs precision: from κ to EFT

LHCHXSWG '12



oversimplified PR plot

1) not a unique coupling to each particle

2) powerful complementarity/synergy with non-Higgs measurements (e.g. EW, diboson, top)

Higgs precision: from κ to EFT

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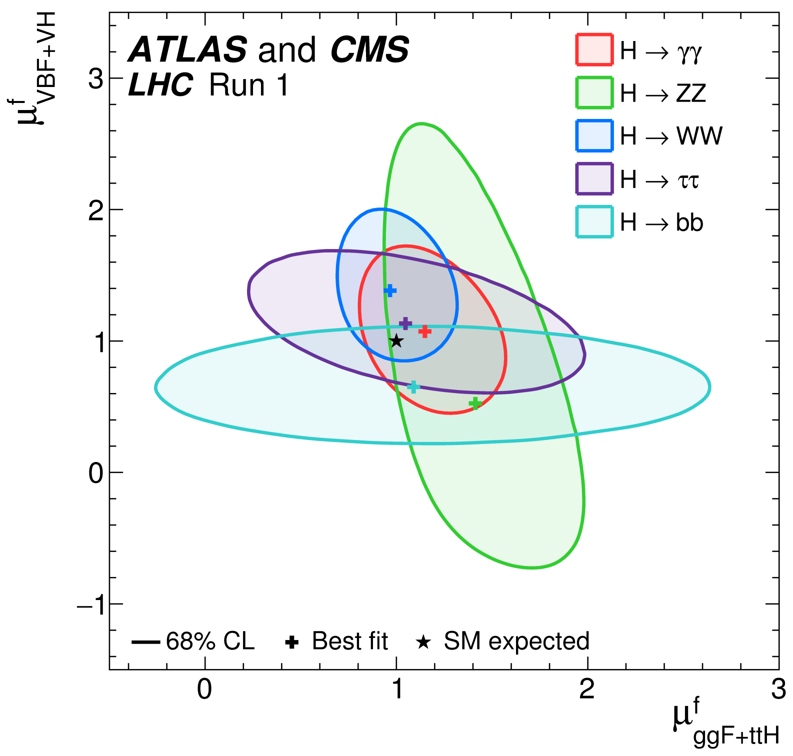

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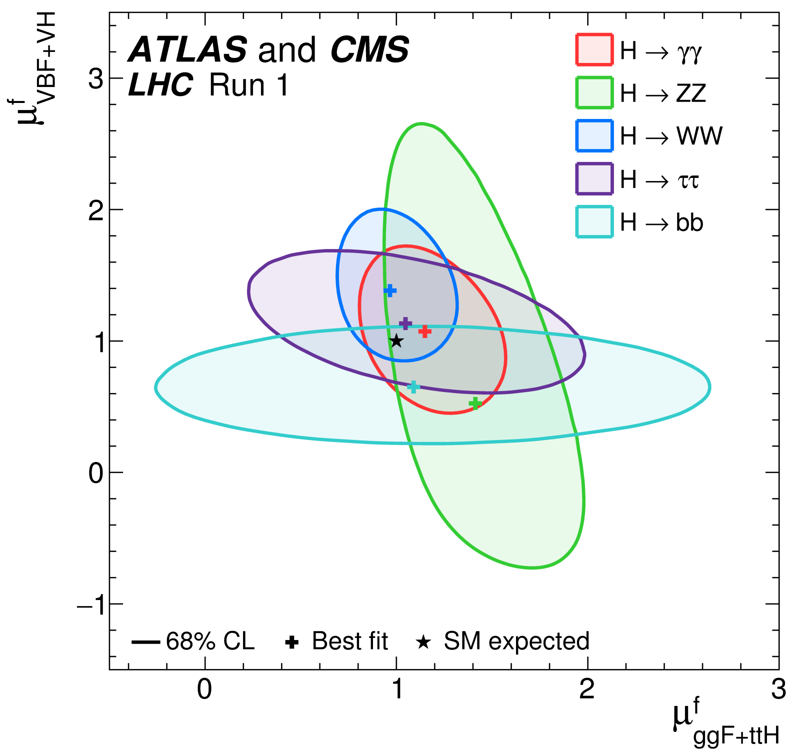

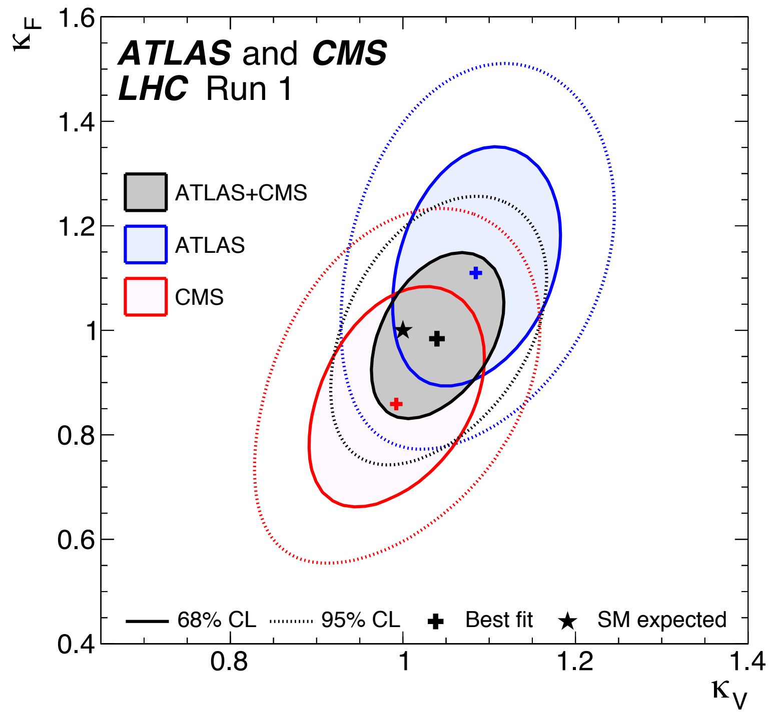

$$(\sigma \cdot {\rm BR})\,(gg \to H \to \gamma\gamma) \;=\; \sigma_{\rm SM}(gg \to H) \cdot {\rm BR}_{\rm SM}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

individual coupling rescaling factors

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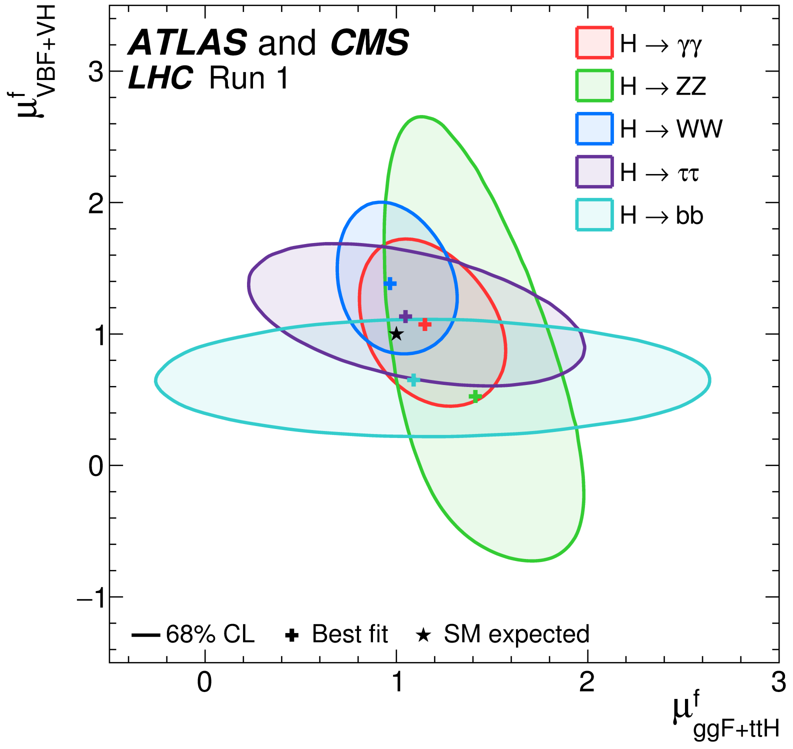

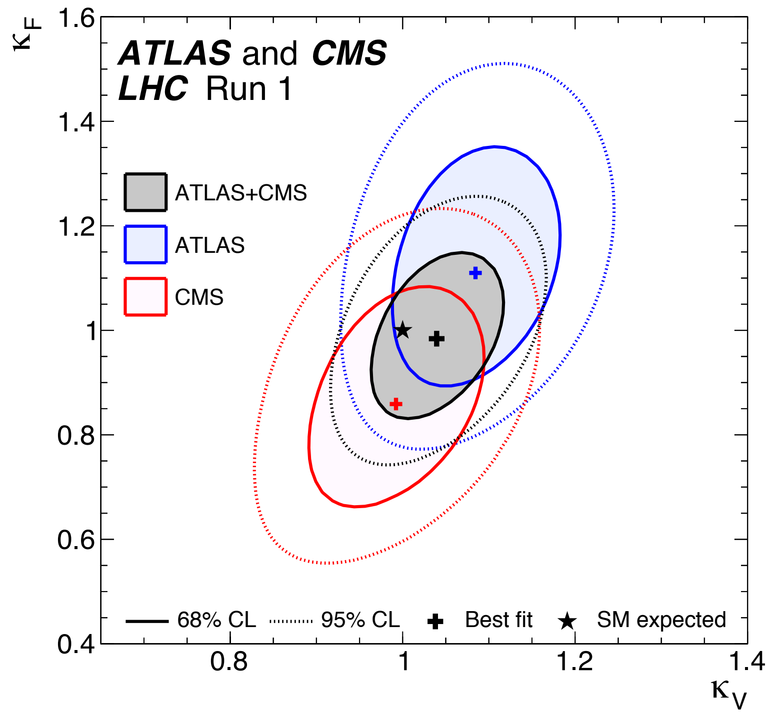

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Well suited parametrization for inclusive measurements

But doesn't do justice to wealth of information available (in particular at e^+e^- colliders)

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Pros of EFT

- correlations between different channels/observables
- combination of measurements at different energies
  e.g. EW precision data and Higgs measurements
- test of self-consistency

unique to EFT

allow to focus on channels yet unconstrained and more likely to offer new discovery opportunities

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Higgs synergy/complementarity

"(A∪B) > A+B"

1. (SM input parameter determination to control parametric uncertainties)

obvious examples: m_Z, m_W, α_{em}, α_s, m_t ...

but also $\frac{\Delta\Gamma_{H\to b\bar{b}}}{\Gamma_{H\to b\bar{b}}} \simeq \frac{\Delta m_b(m_b)}{10\ \text{MeV}} \times 0.56\%$

sub-% precision requires reducing current uncertainties by a factor 3-5.

2. (Higgs ratios @ hh + absolute normalization @ ee)

3. EW + Higgs synergy

4. Diboson + Higgs synergy

5. LHC and FCC-ee synergy for top Yukawa measurement

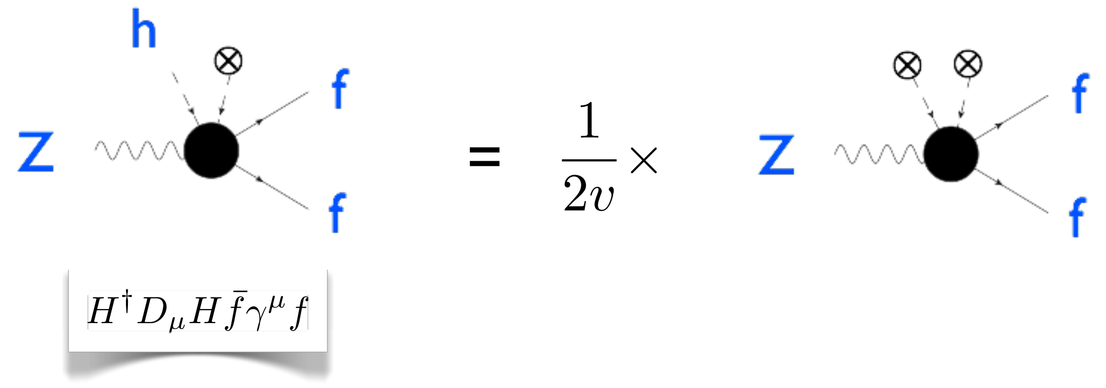
6. Inclusive rate + distributions complementarity

7. 240GeV + 350GeV complementarity

8. ee/ep/pp (...PDF measurements to control PDF uncertainties in Higgs data)

EW + Higgs

I Reducing numbers of parameters



Modifications in h→Zff related to Z→ff

EW + Higgs

1. **Reducing numbers of parameters**
2. **Exploring different regions of parameter space** (in specific models)

Assuming **composite** Higgs, **elementary** gauge bos.:

$$\mathcal{L}^{d=6}_{\rm BSM} = \frac{1}{m_*^2}\frac{1}{g_*^2}\,\widehat{\mathcal{L}}[g_* H, g_w V_\mu, \partial_\mu]$$

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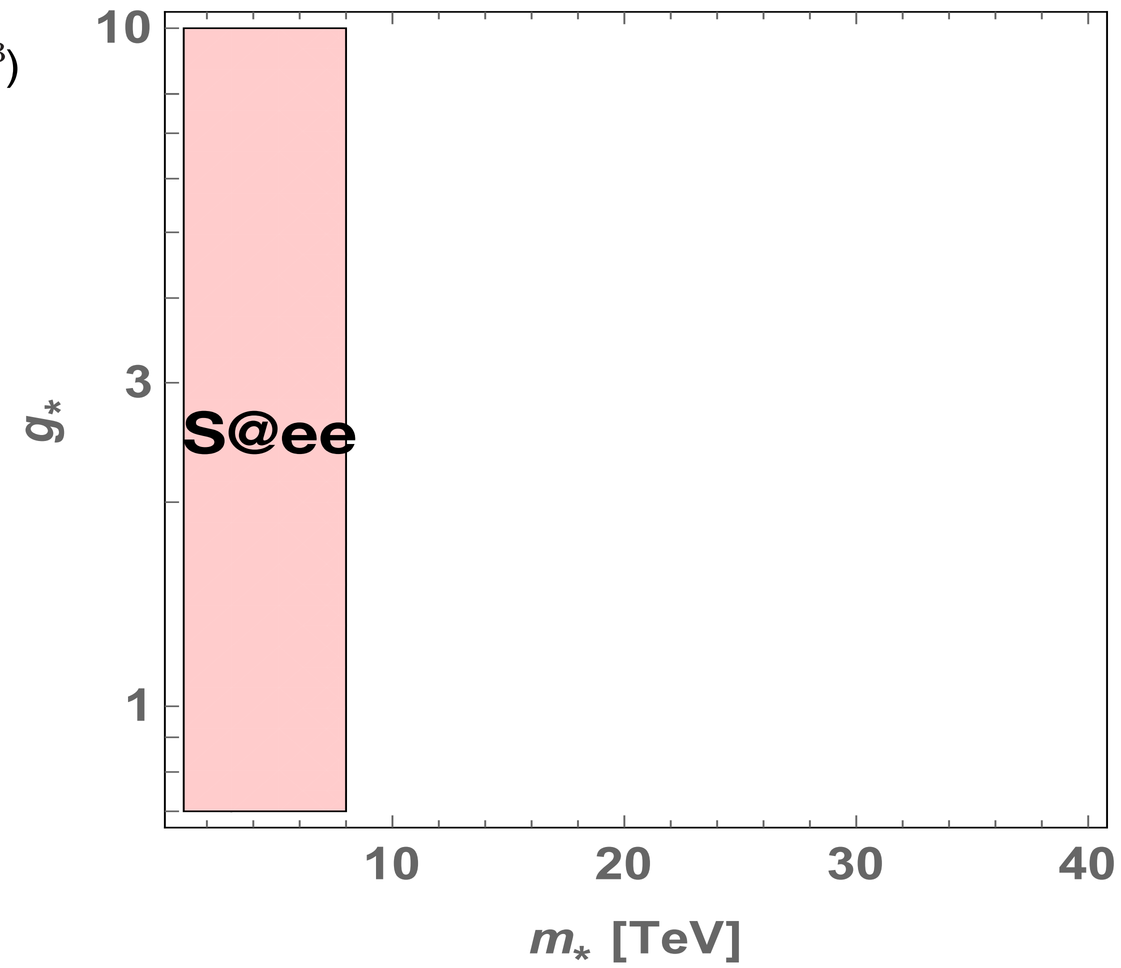
S-parameter @ee: [De Blas et. al.] (LEP: 10^{-3})

$$\frac{g_w g'}{m_*^2} H^\dagger \sigma_a H W^a_{\mu\nu} B^{\mu\nu} \Rightarrow \hat{S} = \frac{m_w^2}{m_*^2} < 10^{-4}$$



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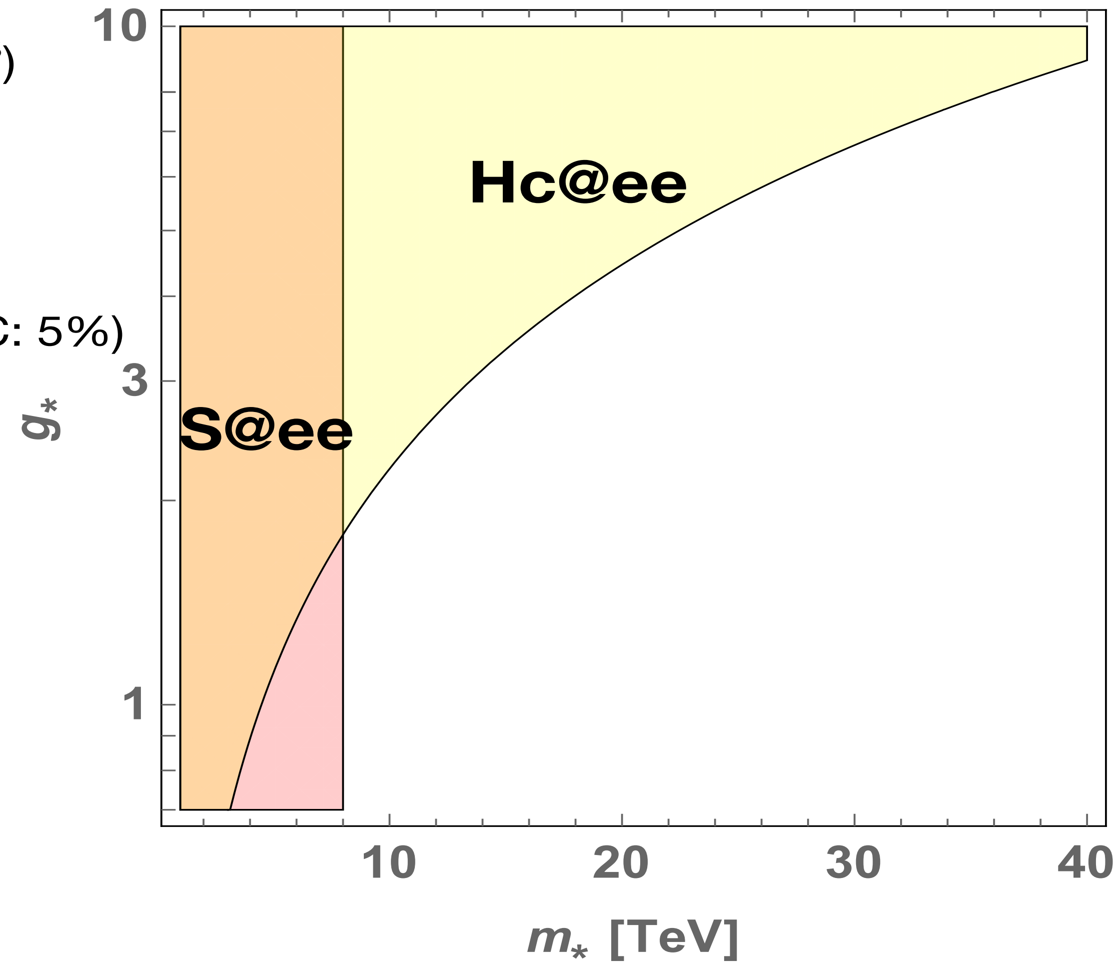

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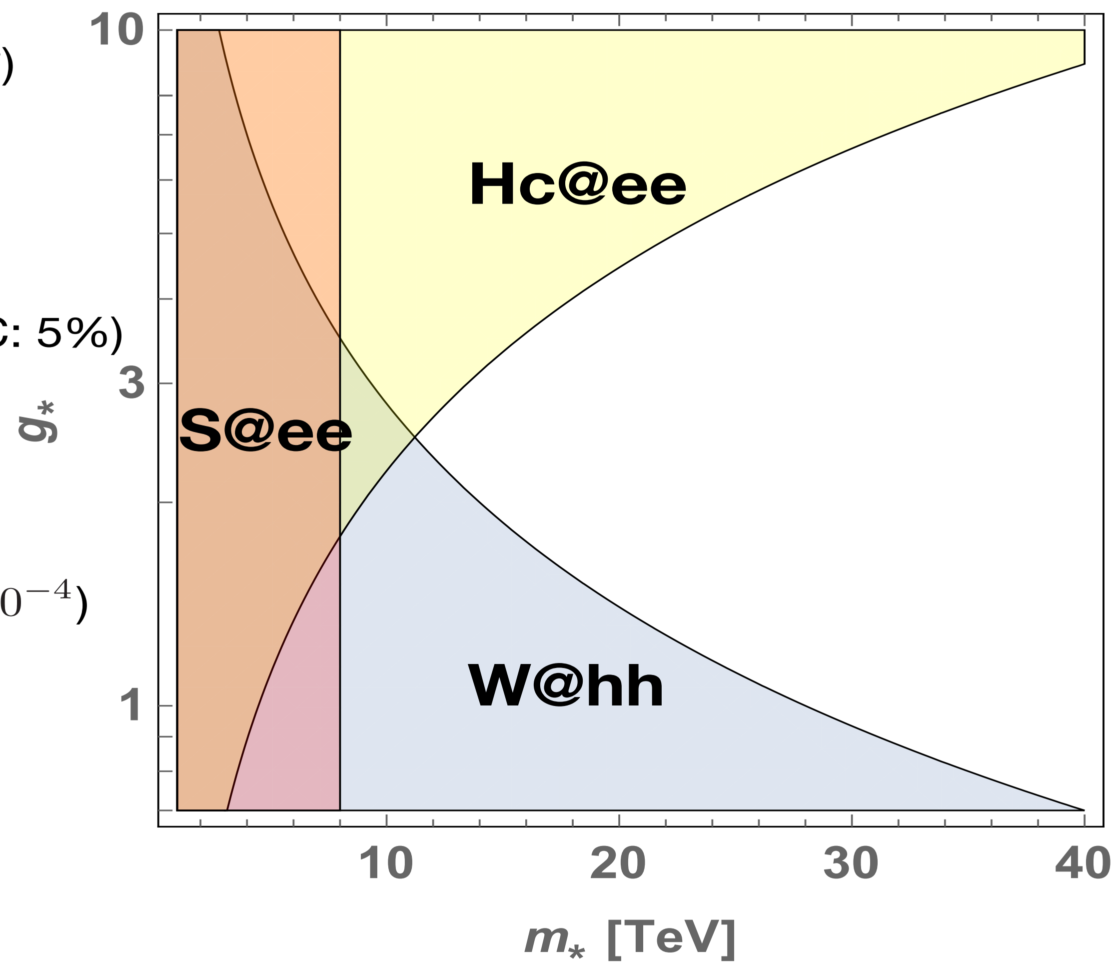
W @hh: (energy + accuracy) (HL-LHC< 10^{-4})

$$\frac{g_w^2}{g_*^2 m_*^2}(D_\mu W_{\nu\rho})^2 \Rightarrow W = \frac{g_w^2 m_w^2}{g_*^2 m_*^2} < 4\,10^{-6}$$



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Gauge bosons + Higgs

In $EFT_{(dim-6)}$

8 deformations affecting Higgs physics alone

2 deformations affecting Higgs and diboson data

TGC (1%) are a priori more constraining than

Higgs (10%)

Is there any value in doing a global fit?

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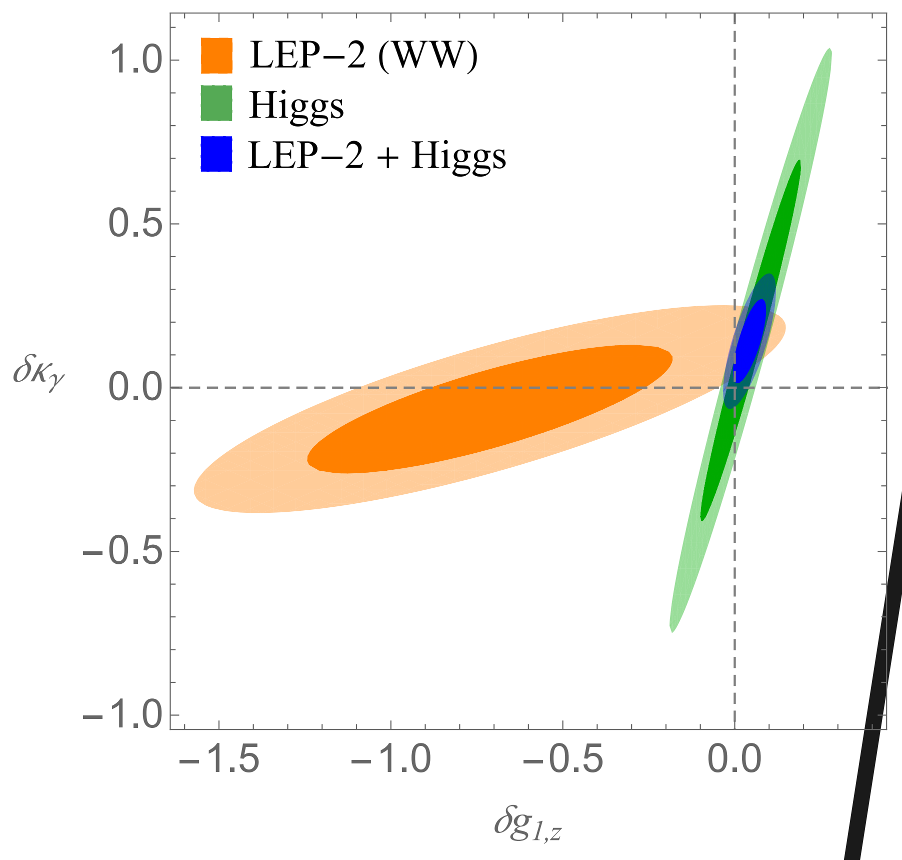
Falkowski et al '15



(TGC ∪ Higgs) > (TGC) + (Higgs)

Strong correlations between 2 data sets

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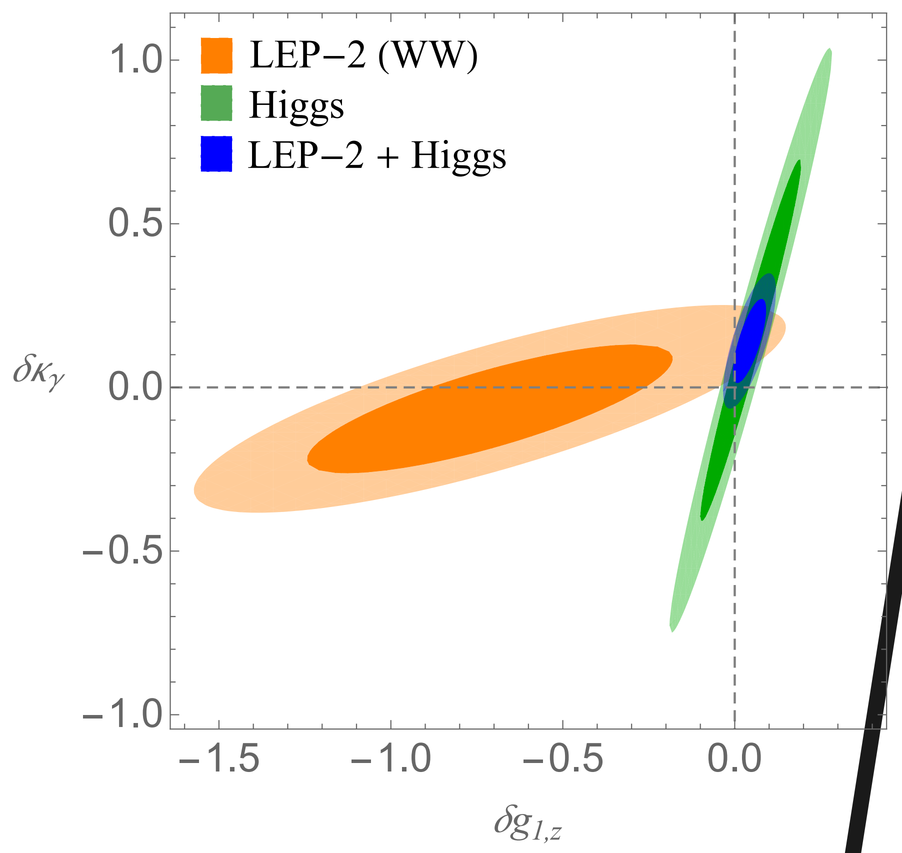

Impact of LHC WW data?

Impact of FCC-ee$_{350\text{GeV}}$ WW data?

Impact of FCC-hh WW data?

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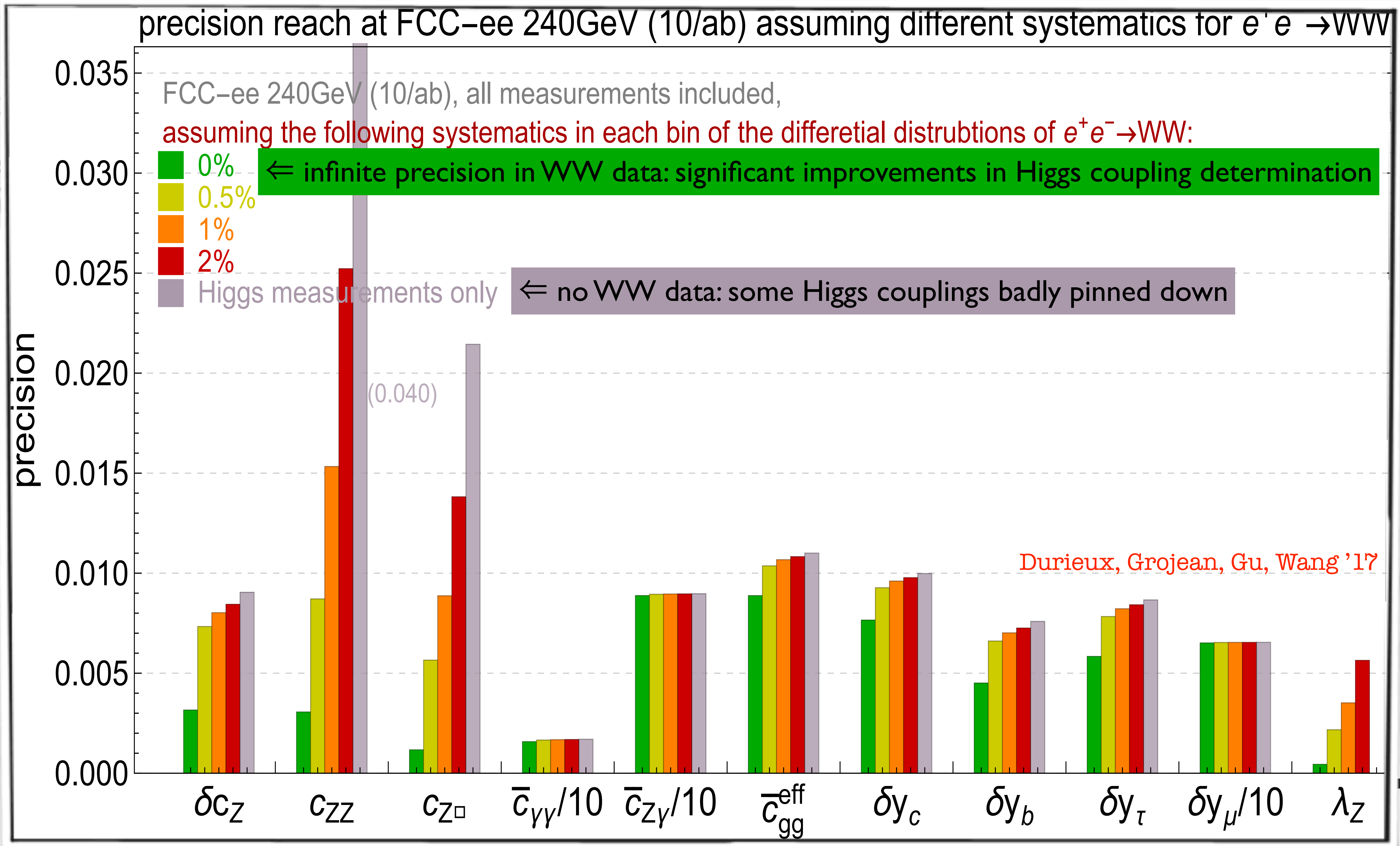
Gauge bosons + Higgs

8 d

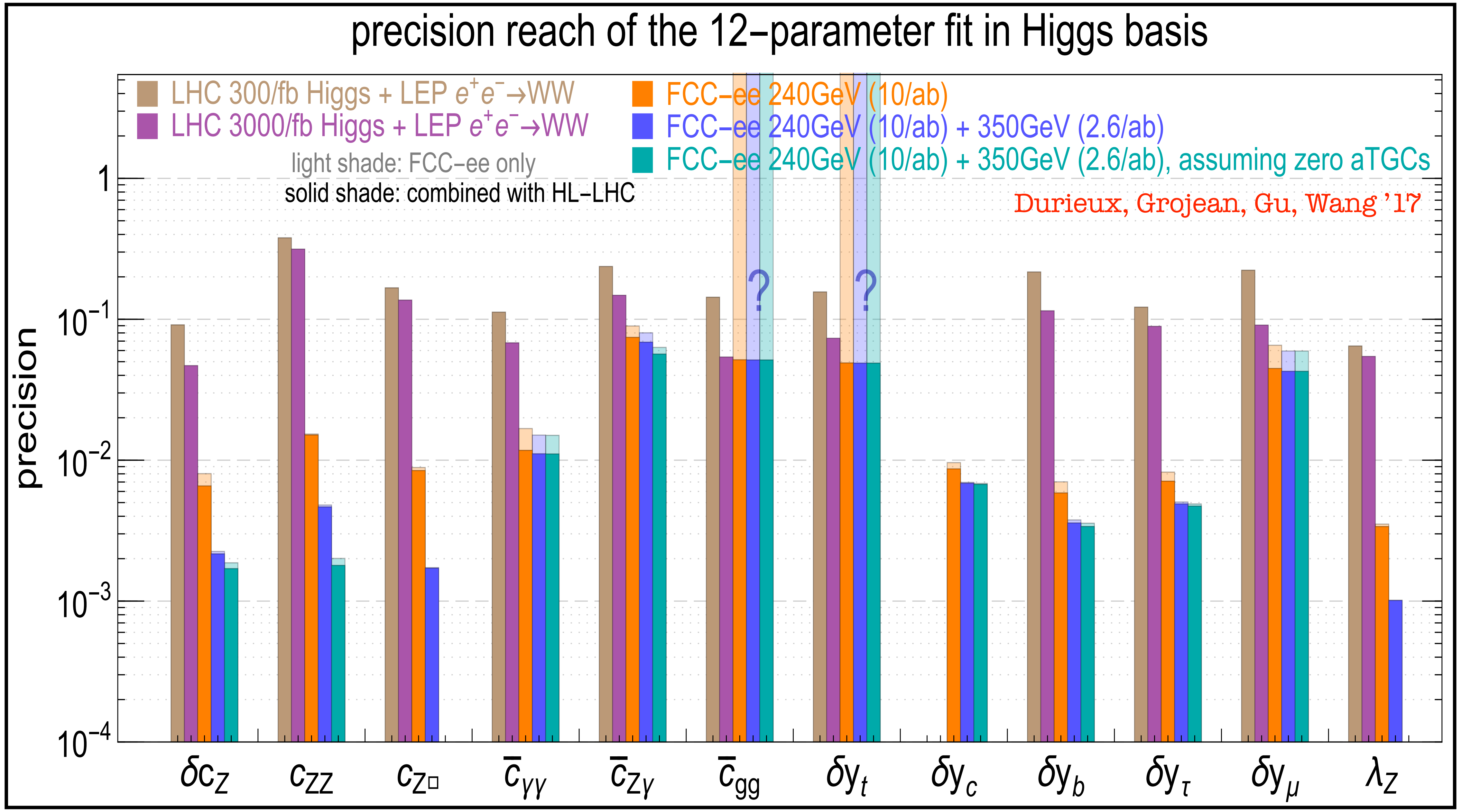
2 de

TG



Top + Higgs

I low energy ee collider doesn't have access to top Yukawa



1) HL-LHC compensates for the absence of tth measurement at FCC-ee

2) in principle tt near threshold could also help assessing y_t individually (not yet included in this plot)

Top + Higgs

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2. **Exploring different regions of parameter space** (in specific models)

Composite tR, comp. Higgs, **elementary tL** and gauge

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ttH coupling @hh/ee: [Reports] (HL-LHC:10%)

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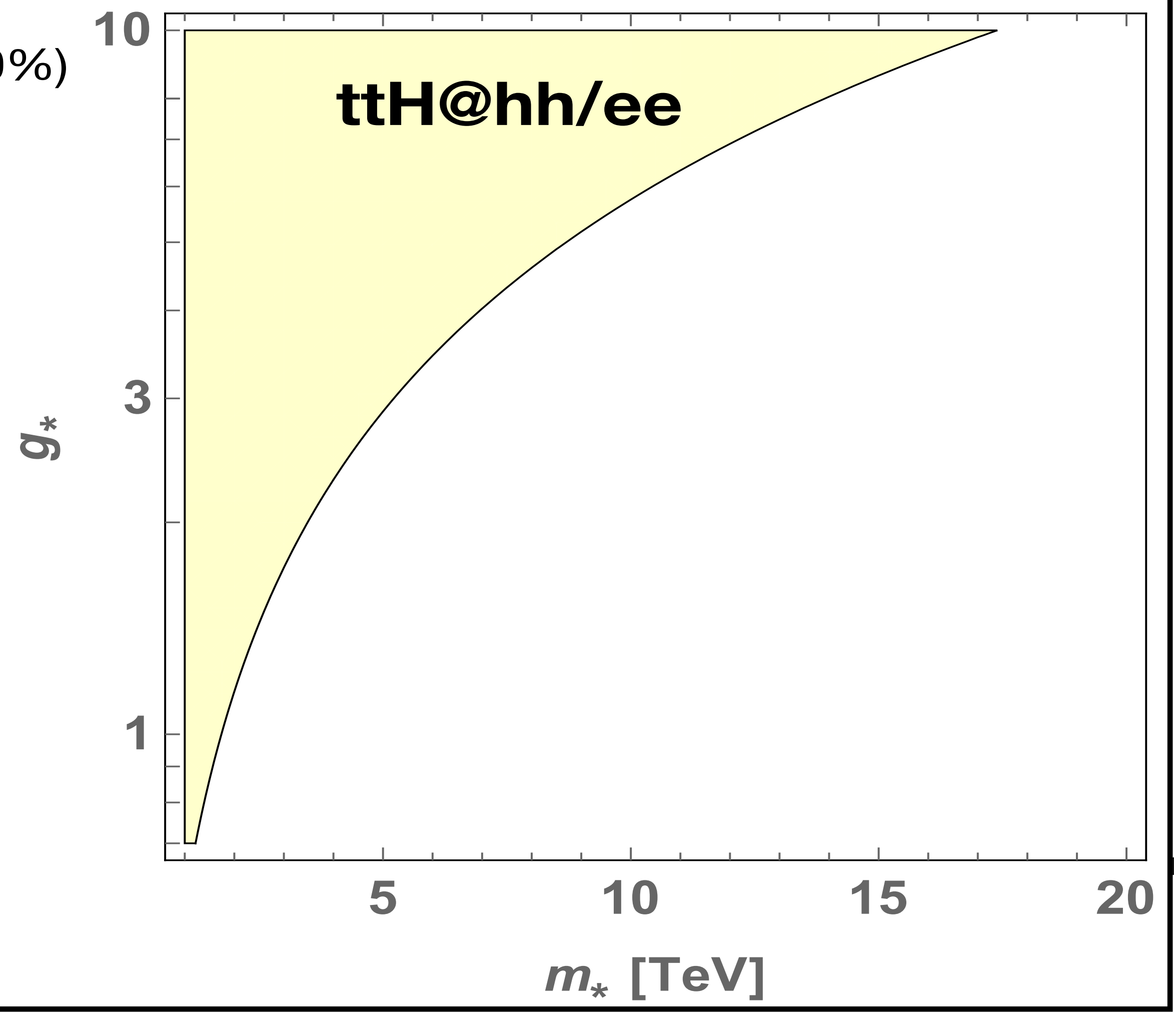
Diff. oper.s comb. in ee and hh!!



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ttV coupling @ee/hh: [Janot / Farina et.al.]

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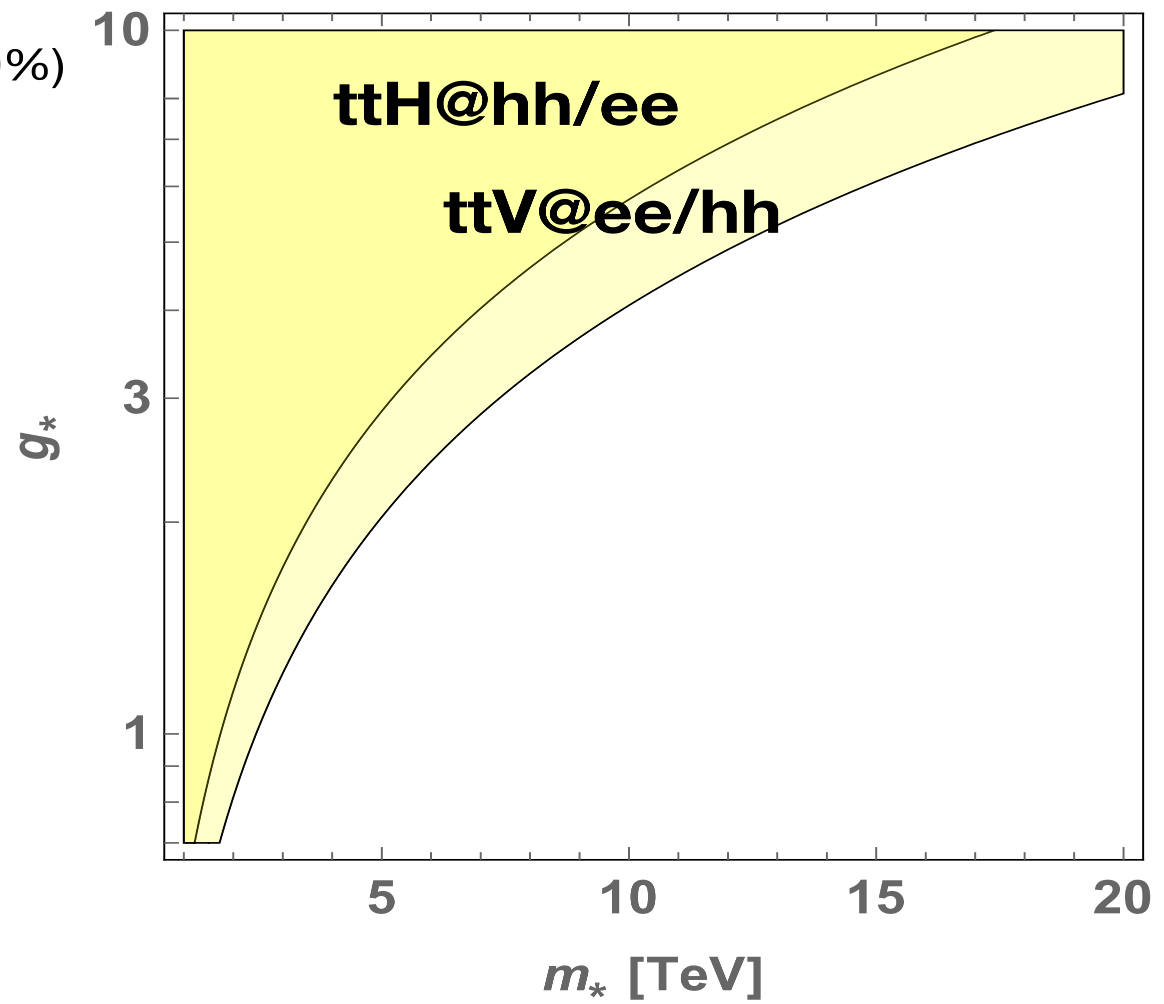
Same hh reach from en. + acc.?



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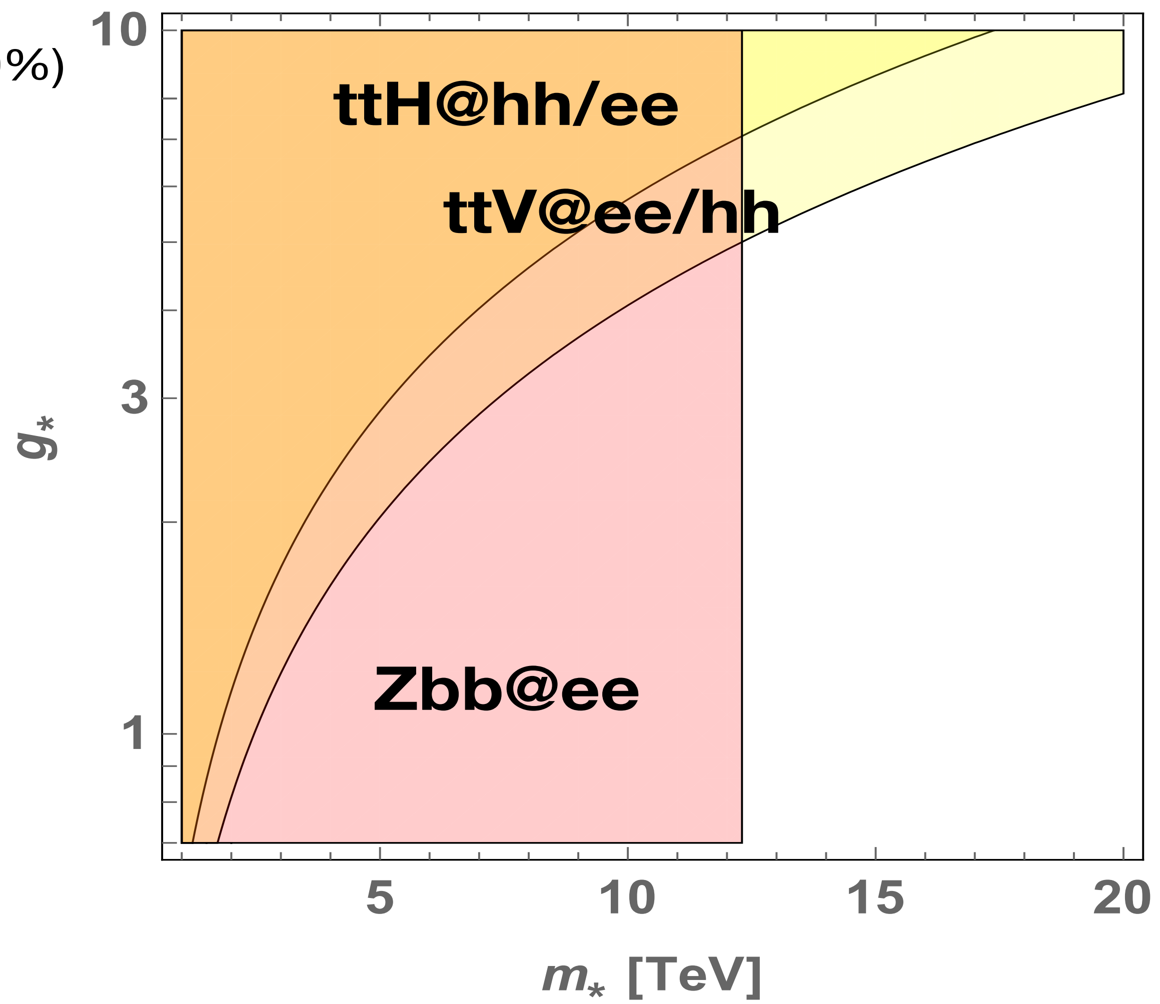
Zbb coupling @ee: [ee Report] (LEP: 10^{-3})

$$\frac{y_t^2}{m_*^2} H^\dagger \overleftrightarrow{D}_\mu H\, \bar{q}_L \gamma^\mu q_L + .. \;\Rightarrow\; \frac{\delta g_b}{g_b} = \frac{m_t^2}{m_*^2} < 2\,10^{-4}$$



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Diff. oper.s comb. in ee and hh!!

4-top contact interactions @hh:

$$\frac{g_*^2}{m_*^2}(\bar{t}_R\gamma_\mu t_R)^2 \;\rightarrow\; \frac{g_*^2}{m_*^2} < \frac{1}{\Lambda_{4t}^2}$$

$$\frac{y_t^2}{m_*^2}(\bar{q}_L\gamma_\mu q_L)(\bar{t}_R\gamma_\mu t_R) \;\rightarrow\; \frac{y_t^2}{m_*^2} < \frac{1}{\Lambda_{4t}^2}$$

$$\frac{y_t^4}{g_*^2 m_*^2}(\bar{q}_L\gamma_\mu q_L)^2 \;\rightarrow\; \frac{y_t^4}{g_*^2 m_*^2} < \frac{1}{\Lambda_{4t}^2}$$

No study available (?)

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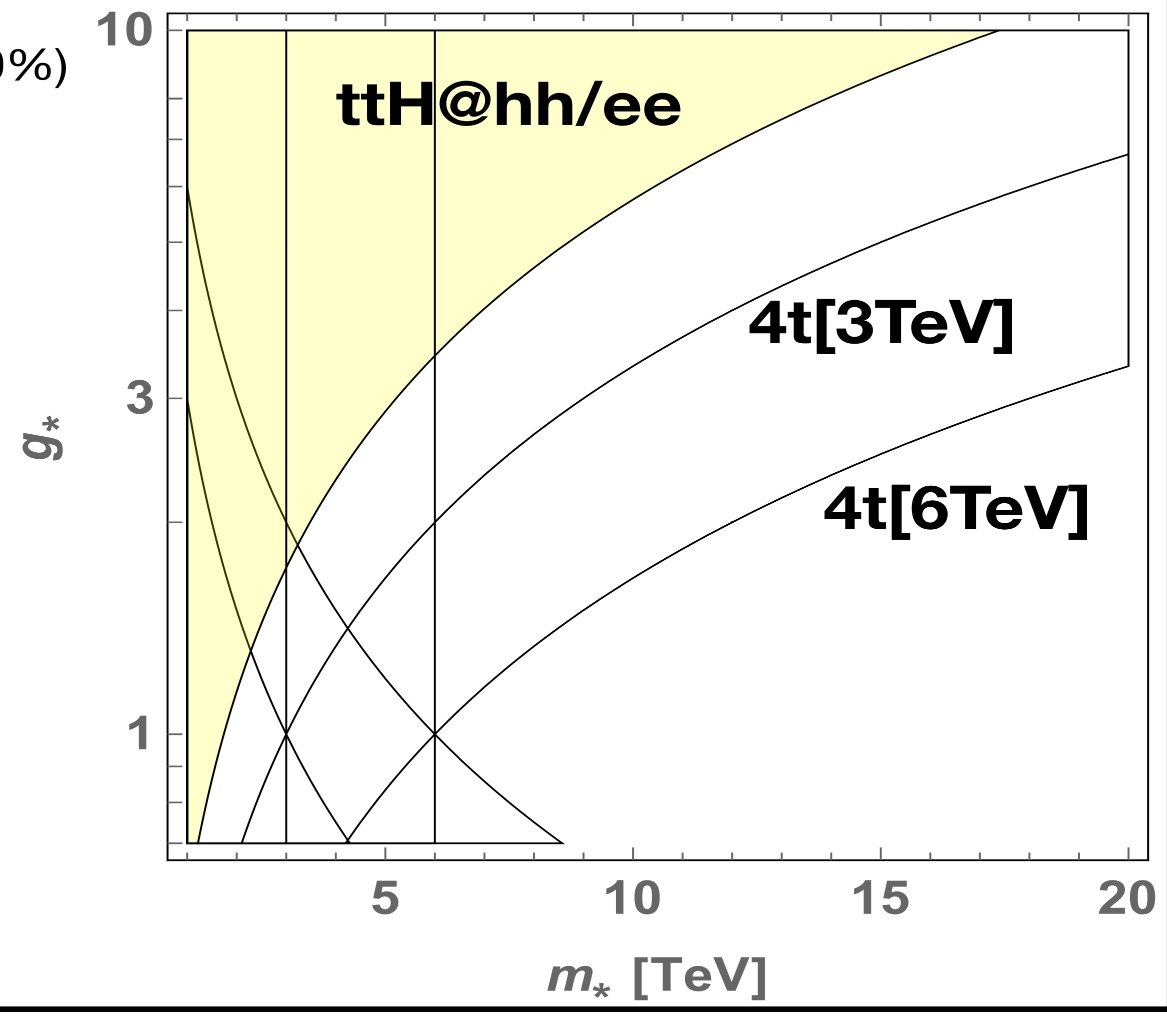
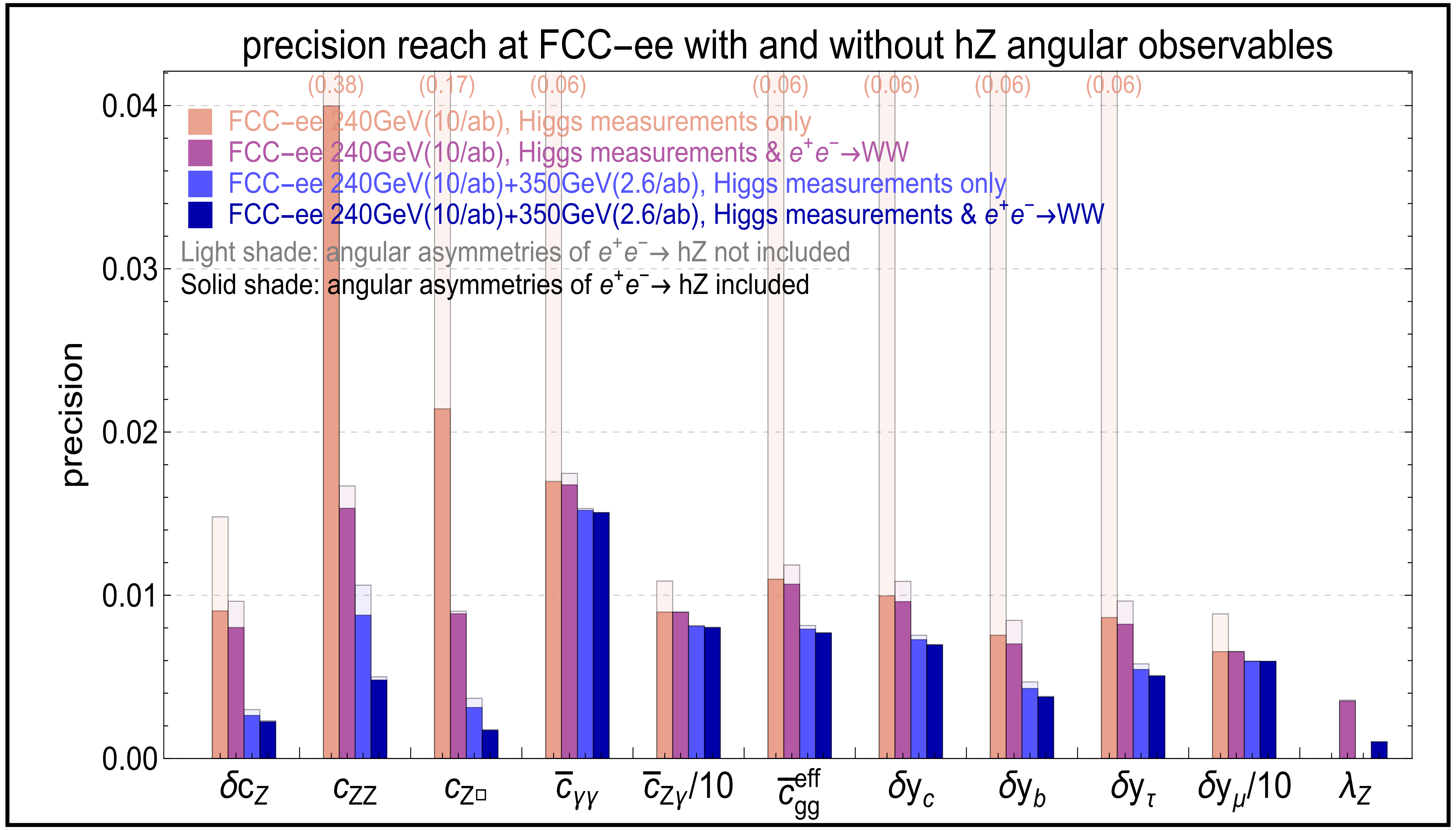


Inclusive rates + distributions

Durieux, Grojean, Gu, Wang '17

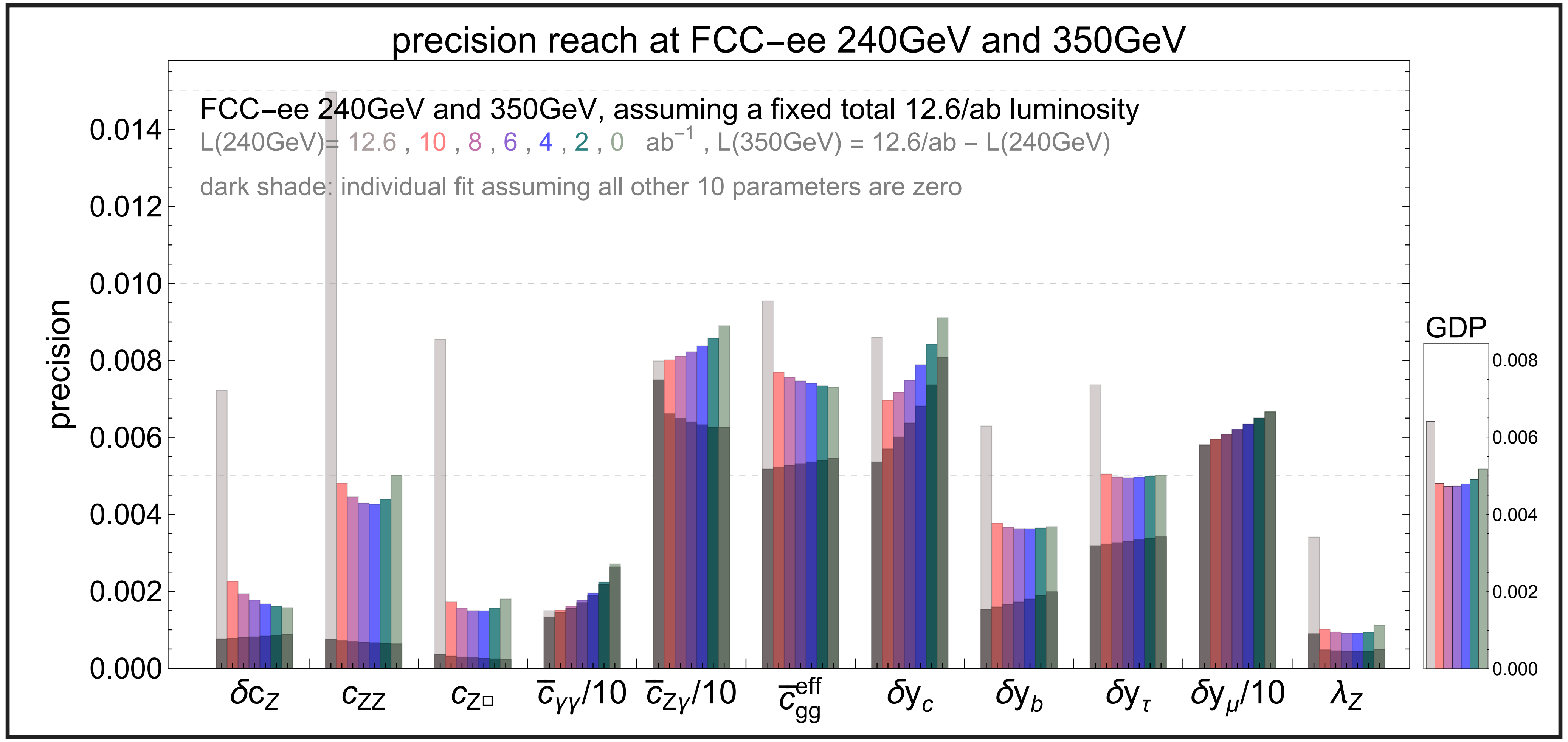


1) with a run at 240 GeV alone, crucial to have access to angular distributions to break degeneracies

2) with a second run at higher energy makes it less important to look at distributions

240GeV + 350GeV

Runs at different energies break degeneracies plaguing coupling fits at 240GeV alone



Durieux, Grojean, Gu, Wang '17

share the luminosity between different energies

(run at two different energies compensates for the lack of beam polarization)

240GeV + 350GeV

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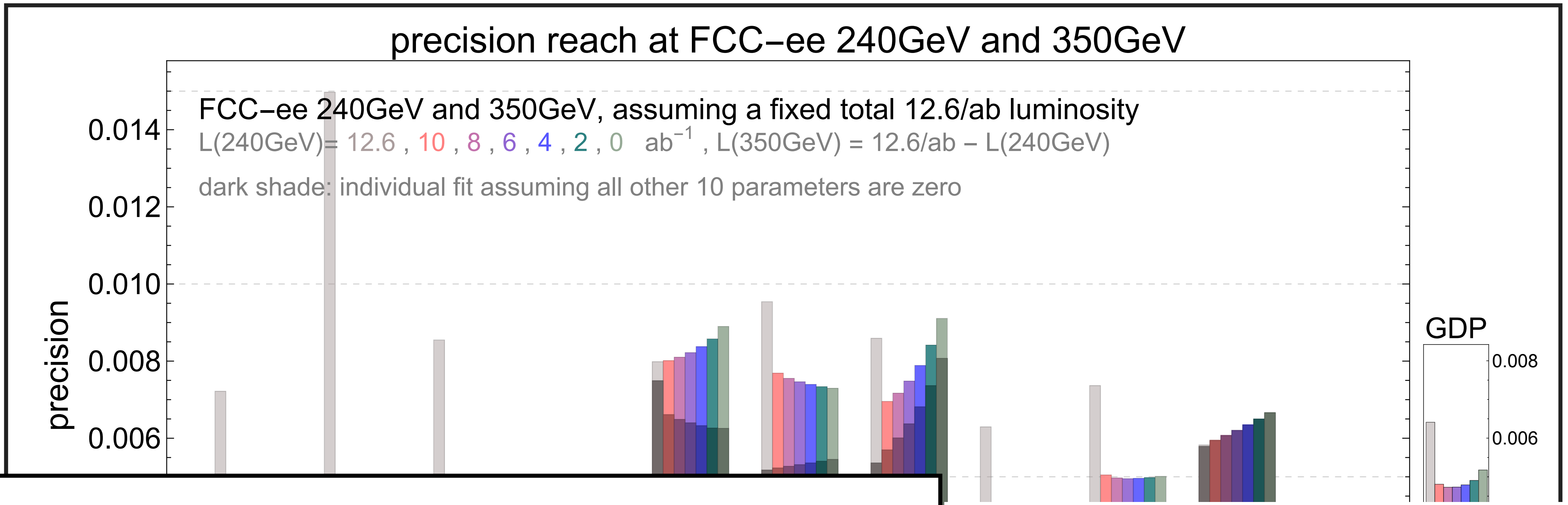
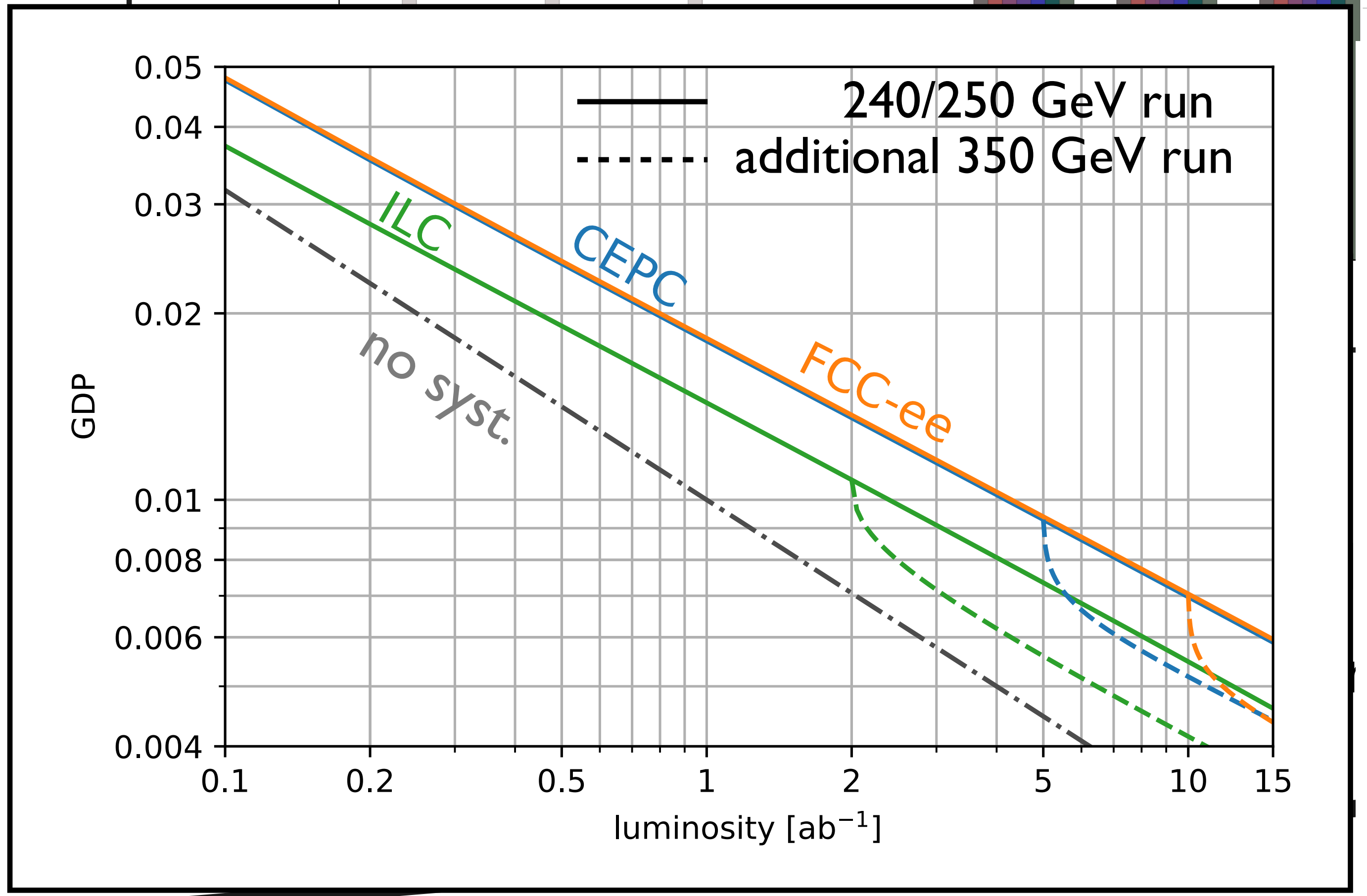




GDP quantifies the overall precision measurement (the smaller - the better)

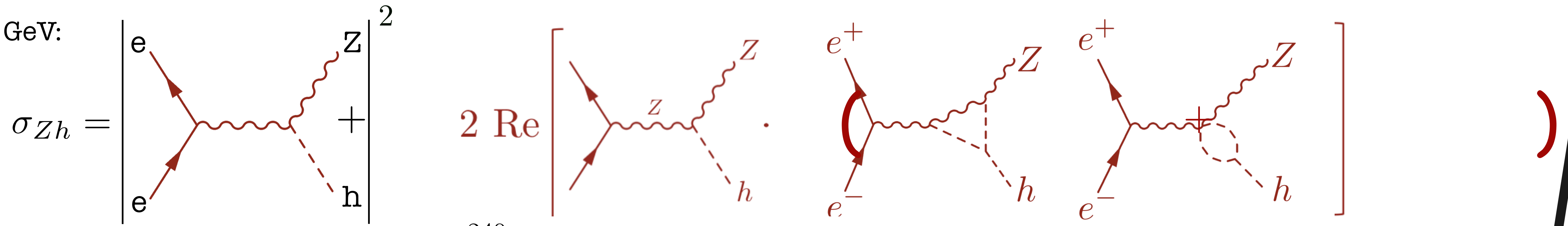
Sharing the luminosity between the energies reduces the GDP faster than accumulating luminosity at low energy

Durieux, Grojean, Gu, Wang '17

Higgs self-coupling(s)

M. McCullough '14

At 240 GeV:



$$\delta_\sigma^{240} = 100\left(2\delta_Z + 0.014\delta_h\right)\%$$

can we disentangle NLO effects from h^3 from LO effects from other Higgs couplings?

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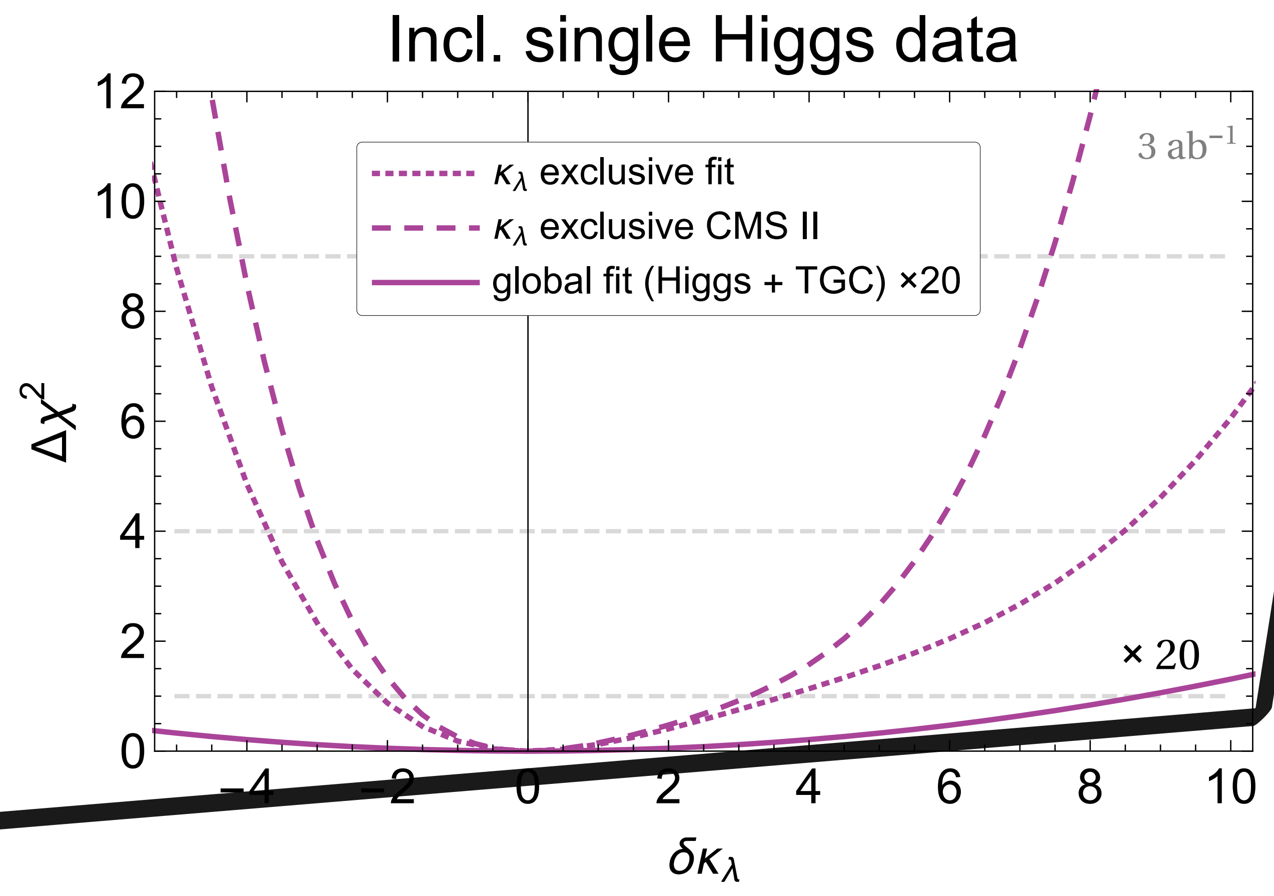
not at the LHC

10 parameters for 9 observables

one flat direction!



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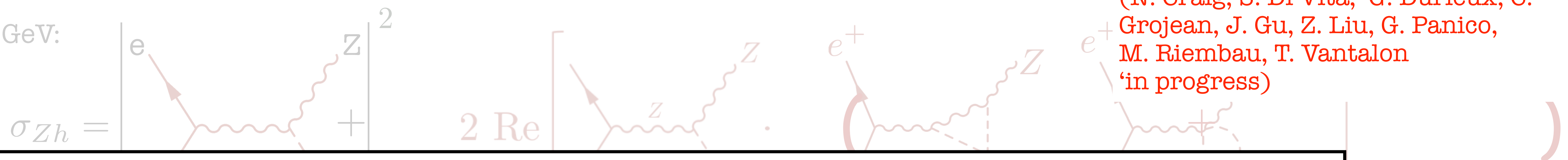


(N. Craig, S. Di Vita, G. Durieux, C. Grojean, J. Gu, Z. Liu, G. Panico, M. Riembau, T. Vantalon 'in progress)

1) if you run at 240 GeV, bound starts to become meaningful only if perfect control of di-boson

2) combining 240+350 improves significantly the bounds on h^3

not at the LHC

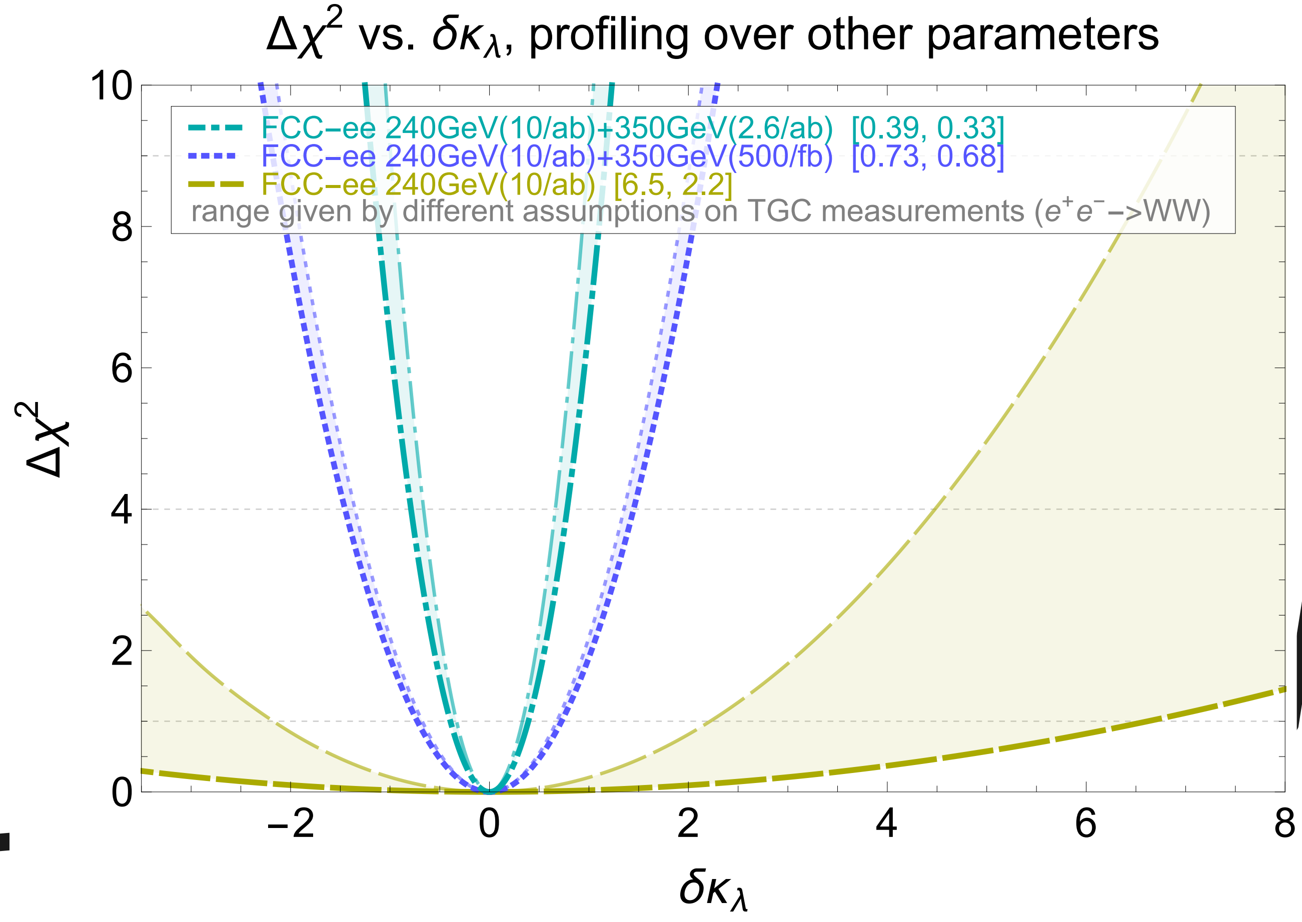
10 parameters for 9 observables

one flat direction!

better hope at ee

10 parameters for more than 10 observables

1 main production mode: ZH & 1 subdominant production: VBF
+ access to full angular distributions (4) and/or beam polarizations (2)
7 (+2) accessible decay modes: ZZ, WW, γγ, Zγ, ττ, bb, gg, (cc, μμ)



Higgs self-coupling(s)

M. McCullough '14

(N. Craig, S. Di Vita, G. Durieux, C. Grojean, J. Gu, Z. Liu, G. Panico, M. Riembau, T. Vantalon 'in progress)

1) if you run at 240 GeV, bound starts to become meaningful only if perfect control of di-boson

2) combining 240+350 improves significantly the bounds on h^3

3) combination FCC-ee and HL-LHC is very powerful (especially if you cannot afford FCC-ee @ 350GeV)

not at the LHC

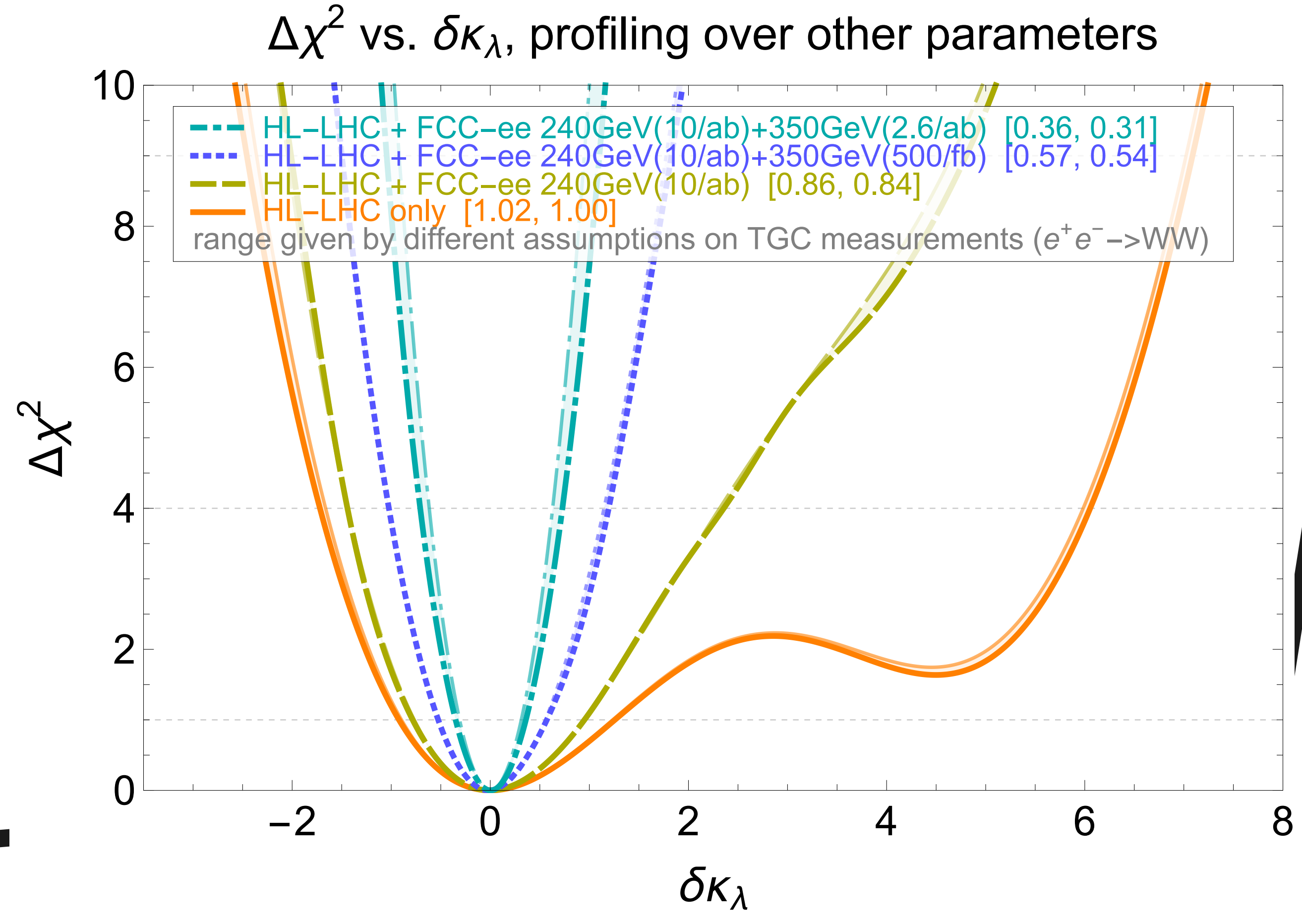
10 parameters for 9 observables

one flat direction!

better hope at ee

10 parameters for more than 10 observables

1 main production mode: ZH & 1 subdominant production: VBF
+ access to full angular distributions (4) and/or beam polarizations (2)
7 (+2) accessible decay modes: ZZ, WW, γγ, Zγ, ττ, bb, gg, (cc, μμ)



Conclusions

Higgs discovery = profound change in paradigm:

missing SM particle ➪ tool to explore SM and venture into physics landscape beyond

we should exploit the full power of this new tool
rich opportunities for **synergy/complementarity**
the case is growing with several new examples beyond trivial ones
it is up to us to make the best use of them

it takes **two** to "synergy"
FCC-ee has a lot to offer to partners and a lot to gain too
it is time to join forces

Backup

e^+e^- Colliders

CepC

5/ab @ 240GeV
(200/fb @ 350GeV)

FCC-ee

10/ab @ 240GeV
(2.6/ab @ 350GeV)

ILC

2/ab @ 250GeV
P(e⁻,e⁺)=(±80%,±30%)
(200/fb @ 350GeV)
(4/ab @ 500GeV)

CLIC

0.5/ab @ 350GeV
(1.5/ab @ 1.4TeV)
(3/ab @ 3TeV)

	CEPC				FCC-ee			
	[240 GeV, 5 ab^{-1}]		[350 GeV, 200 fb^{-1}]		[240 GeV, 10 ab^{-1}]		[350 GeV, 2.6 ab^{-1}]	
production	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$
σ	0.50%	-	2.4%	-	0.40%	-	0.67%	-
	$\sigma \times$ BR				$\sigma \times$ BR			
$h \to b\bar{b}$	0.21%*	0.39%$^\diamond$	2.0%	2.6%	0.20%	0.28%$^\diamond$	0.54%	0.71%
$h \to c\bar{c}$	2.5%	-	15%	26%	1.2%	-	4.1%	7.1%
$h \to gg$	1.2%	-	11%	17%	1.4%	-	3.1%	4.7%
$h \to \tau\tau$	1.0%	-	5.3%	37%	0.7%	-	1.5%	10%
$h \to WW^*$	1.0%	-	10%	9.8%	0.9%	-	2.8%	2.7%
$h \to ZZ^*$	4.3%	-	33%	33%	3.1%	-	9.2%	9.3%
$h \to \gamma\gamma$	9.0%	-	51%	77%	3.0%	-	14%	21%
$h \to \mu\mu$	12%	-	115%	275%	13%	-	32%	76%
$h \to Z\gamma$	25%	-	144%	-	18%	-	40%	-

ILC

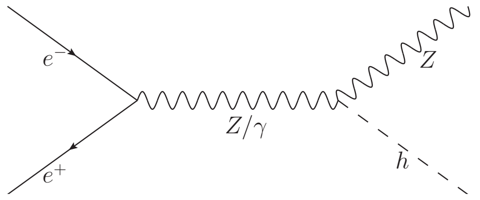
	[250 GeV, 2 ab^{-1}]		[350 GeV, 200 fb^{-1}]		[500 GeV, 4 ab^{-1}]			[1 TeV, 1 ab^{-1}]		[1 TeV, 2.5 ab^{-1}]	
production	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	$t\bar{t}h$	$\nu\bar{\nu}h$	$t\bar{t}h$	$\nu\bar{\nu}h$	$t\bar{t}h$
σ	0.71%	-	2.1%	-	1.1%	-	-	-	-	-	-
	$\sigma \times$ BR										
$h \to b\bar{b}$	0.42%	3.7%	1.7%	1.7%	0.64%	0.25%	9.9%	0.5%	6.0%	0.3%	3.8%
$h \to c\bar{c}$	2.9%	-	13%	17%	4.6%	2.2%	-	3.1%	-	2.0%	-
$h \to gg$	2.5%	-	9.4%	11%	3.9%	1.4%	-	2.3%	-	1.4%	-
$h \to \tau\tau$	1.1%	-	4.5%	24%	1.9%	3.2%	-	1.6%	-	1.0%	-
$h \to WW^*$	2.3%	-	8.7%	6.4%	3.3%	0.85%	-	3.1%	-	2.0%	-
$h \to ZZ^*$	6.7%	-	28%	22%	8.8%	2.9%	-	4.1%	-	2.6%	-
$h \to \gamma\gamma$	12%	-	44%	50%	12%	6.7%	-	8.5%	-	5.4%	-
$h \to \mu\mu$	25%	-	98%	180%	31%	25%	-	31%	-	20%	-
$h \to Z\gamma$	34%	-	145%	-	49%	-	-	-	-	-	-

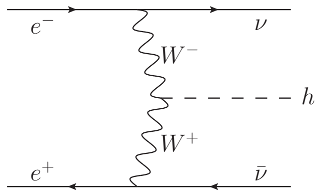
CLIC

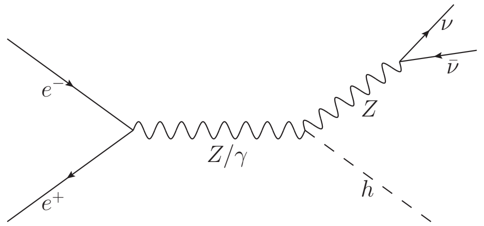
	[350 GeV, 500 fb^{-1}]		[1.4 TeV, 1.5 ab^{-1}]		[3 TeV, 2 ab^{-1}]
production	Zh	$\nu\bar{\nu}h$	$\nu\bar{\nu}h$	$t\bar{t}h$	$\nu\bar{\nu}h$
σ	1.6%	-	-	-	-
	$\sigma \times$ BR				
$h \to b\bar{b}$	0.84%	1.9%	0.4%	8.4%	0.3%
$h \to c\bar{c}$	10.3%	14.3%	6.1%	-	6.9%
$h \to gg$	4.5%	5.7%	5.0%	-	4.3%
$h \to \tau\tau$	6.2%	-	4.2%	-	4.4%
$h \to WW^*$	5.1%	-	1.0%	-	0.7%
$h \to ZZ^*$	-	-	5.6%	-	3.9%
$h \to \gamma\gamma$	-	-	15%	-	10%
$h \to \mu\mu$	-	-	38%	-	25%
$h \to Z\gamma$	-	-	42%	-	30%

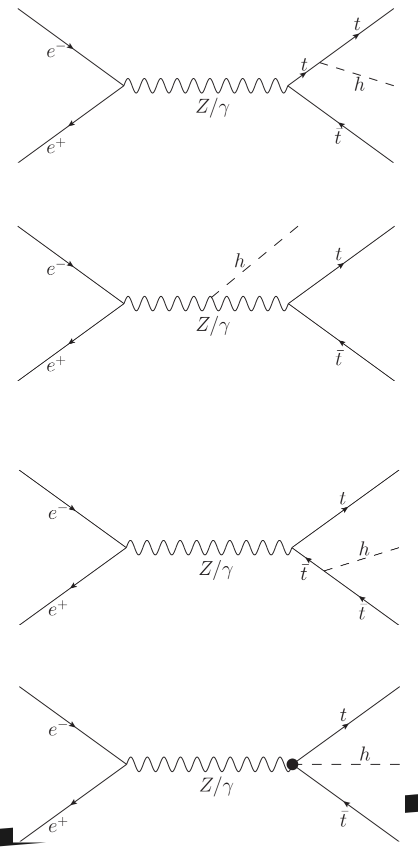
Future measurements used in the fit

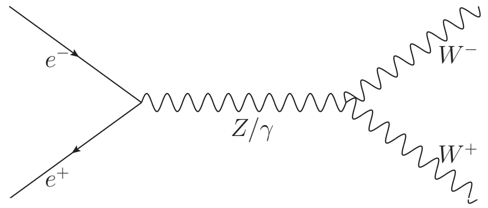
- Higgsstrahlung production: $e^+e^- \to hZ$ (rates and distributions), followed by Higgs decays in various channels,
- Higgs production through weak-boson-fusion: $e^+e^- \to \nu\bar{\nu}h$,
- Higgs production in association with top quarks: $e^+e^- \to t\bar{t}h$,
- weak boson pair production: $e^+e^- \to WW$ (rate and distributions).

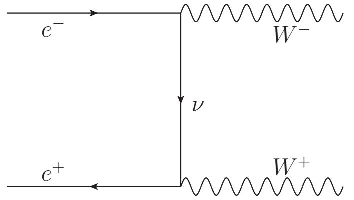












5/ab @ 240GeV
1.06x10^6 Higgses

2/ab @ 250GeV
$P(e^-,e^+)$=(-80%,+30%)
6.4x10^5 Higgses

Higgs Basis

A. Falkowski '15

LHCHXSWG YR4 '16

$$
\begin{aligned}
\mathcal{L} \supset \frac{h}{v}\Big[& \delta c_w \frac{g^2 v^2}{2} W_\mu^+ W^{-\mu} + \delta c_z \frac{(g^2+g'^2)v^2}{4} Z_\mu Z^\mu \\
& + c_{ww} \frac{g^2}{2} W_{\mu\nu}^+ W^{-\mu\nu} + c_{w\Box} g^2 \left(W_\mu^- \partial_\nu W^{+\mu\nu} + \text{h.c.}\right) + \hat{c}_{\gamma\gamma} \frac{e^2}{4\pi^2} A_{\mu\nu} A^{\mu\nu} \\
& + c_{zz} \frac{g^2+g'^2}{4} Z_{\mu\nu} Z^{\mu\nu} + \hat{c}_{z\gamma} \frac{e\sqrt{g^2+g'^2}}{2\pi^2} Z_{\mu\nu} A^{\mu\nu} + c_{z\Box} g^2 Z_\mu \partial_\nu Z^{\mu\nu} + c_{\gamma\Box} g g' Z_\mu \partial_\nu A^{\mu\nu} \Big] \\
& + \frac{g_s^2}{48\pi^2} \left(\hat{c}_{gg} \frac{h}{v} + \hat{c}_{gg}^{(2)} \frac{h^2}{2v^2} \right) G_{\mu\nu} G^{\mu\nu} - \sum_f \left[m_f \left(\delta y_f \frac{h}{v} + \delta y_f^{(2)} \frac{h^2}{2v^2} \right) \bar{f}_R f_L + \text{h.c.} \right] \\
& - (\kappa_\lambda - 1) \lambda_3^{SM} v h^3 \, ,
\end{aligned}
$$

with

$$
\begin{aligned}
\delta c_w &= \delta c_z \, , \\
c_{ww} &= c_{zz} + 2 \frac{g'^2}{\pi^2 (g^2+g'^2)} \hat{c}_{z\gamma} + \frac{g'^4}{\pi^2 (g^2+g'^2)^2} \hat{c}_{\gamma\gamma} \, , \\
c_{w\Box} &= \frac{1}{g^2-g'^2} \left[g^2 c_{z\Box} + g'^2 c_{zz} - e^2 \frac{g'^2}{\pi^2(g^2+g'^2)} \hat{c}_{\gamma\gamma} - (g^2-g'^2) \frac{g'^2}{\pi^2(g^2+g'^2)} \hat{c}_{z\gamma} \right] , \\
c_{\gamma\Box} &= \frac{1}{g^2-g'^2} \left[2 g^2 c_{z\Box} + \left(g^2+g'^2\right) c_{zz} - \frac{e^2}{\pi^2} \hat{c}_{\gamma\gamma} - \frac{g^2-g'^2}{\pi^2} \hat{c}_{z\gamma} \right] , \\
\hat{c}_{gg}^{(2)} &= \hat{c}_{gg} \, , \\
\delta y_f^{(2)} &= 3 \delta y_f - \delta c_z \, .
\end{aligned}
$$

10 parameters

6 deformations of Higgs couplings to gauge bosons

$\delta c_z \, , \; c_{zz} \, , \; c_{z\Box} \, , \; \hat{c}_{z\gamma} \, , \; \hat{c}_{\gamma\gamma} \, , \; \hat{c}_{gg}$

3 deformations of Higgs couplings to fermions

$\delta y_t \, , \; \delta y_b \, , \; \delta y_\tau \, ,$

1 deformations of Higgs self-couplings

κ_λ

Higgs Basis

A. Falkowski '15

LHCHXSWG YR4 '16

$$\mathcal{L} \supset \frac{h}{v}\Big[\delta c_w \frac{g^2 v^2}{2} W^+_\mu W^{-\mu} + \delta c_z \frac{(g^2+g'^2)v^2}{4} Z_\mu Z^\mu$$
$$+ c_{ww}\frac{g^2}{2} W^+_{\mu\nu}W^{-\mu\nu} + c_{w\Box} g^2 \left(W^-_\mu \partial_\nu W^{+\mu\nu} + \text{h.c.}\right) + \hat{c}_{\gamma\gamma}\frac{e^2}{4\pi^2} A_{\mu\nu}A^{\mu\nu}$$
$$+ c_{zz}\frac{g^2+g'^2}{4} Z_{\mu\nu}Z^{\mu\nu} + \hat{c}_{z\gamma}\frac{e\sqrt{g^2+g'^2}}{2\pi^2} Z_{\mu\nu}A^{\mu\nu} + c_{z\Box} g^2 Z_\mu \partial_\nu Z^{\mu\nu} + c_{\gamma\Box} g g' Z_\mu \partial_\nu A^{\mu\nu}\Big]$$
$$+ \frac{g_s^2}{48\pi^2}\left(\hat{c}_{gg}\frac{h}{v} + \hat{c}^{(2)}_{gg}\frac{h^2}{2v^2}\right) G_{\mu\nu}G^{\mu\nu} - \sum_f \left[m_f\left(\delta y_f \frac{h}{v} + \delta y_f^{(2)}\frac{h^2}{2v^2}\right)\bar{f}_R f_L + \text{h.c.}\right]$$
$$- (\kappa_\lambda - 1)\lambda_3^{SM} v h^3 ,$$

with

$$\delta c_w = \delta c_z ,$$
$$c_{ww} = c_{zz} + 2\frac{g'^2}{\pi^2(g^2+g'^2)}\hat{c}_{z\gamma} + \frac{g'^4}{\pi^2(g^2+g'^2)^2}\hat{c}_{\gamma\gamma} ,$$
$$c_{w\Box} = \frac{1}{g^2-g'^2}\left[g^2 c_{z\Box} + g'^2 c_{zz} - e^2\frac{g'^2}{\pi^2(g^2+g'^2)}\hat{c}_{\gamma\gamma} - (g^2-g'^2)\frac{g'^2}{\pi^2(g^2+g'^2)}\hat{c}_{z\gamma}\right],$$
$$c_{\gamma\Box} = \frac{1}{g^2-g'^2}\left[2g^2 c_{z\Box} + \left(g^2+g'^2\right)c_{zz} - \frac{e^2}{\pi^2}\hat{c}_{\gamma\gamma} - \frac{g^2-g'^2}{\pi^2}\hat{c}_{z\gamma}\right],$$
$$\hat{c}^{(2)}_{gg} = \hat{c}_{gg} ,$$
$$\delta y_f^{(2)} = 3\delta y_f - \delta c_z .$$

12 parameters

6 deformations of Higgs couplings to gauge bosons

$\delta c_z ,\ c_{zz} ,\ c_{z\Box} ,\ \hat{c}_{z\gamma} ,\ \hat{c}_{\gamma\gamma} ,\ \hat{c}_{gg}$

5 deformations of Higgs couplings to fermions

$\delta y_t ,\ \delta y_c ,\ \delta y_b ,\ \delta y_\tau ,\ \delta y_\mu$

1 deformations of gauge boson self-couplings

λ_Z

Running at different energies

$$\left.\frac{\sigma_{hZ}}{\sigma_{hZ}^{\rm SM}}\right|\begin{pmatrix}240\,\text{GeV unpolarized}\\ 250\,\text{GeV }(-0.8,+0.3)\\ 250\,\text{GeV }(+0.8,-0.3)\\ 350\,\text{GeV unpolarized}\\ 350\,\text{GeV }(-0.8,+0.3)\\ 500\,\text{GeV }(-0.8,+0.3)\\ 1.4\,\text{TeV unpolarized}\\ 3\,\text{TeV unpolarized}\end{pmatrix} \simeq 1+2\,\delta c_Z+\begin{pmatrix}1.8\\5.6\\-2.9\\2.8\\11\\21\\14\\52\end{pmatrix}c_{ZZ}+\begin{pmatrix}3.7\\9.8\\-3.2\\7.5\\20\\41\\115\\526\end{pmatrix}c_{Z\Box}+\begin{pmatrix}-0.048\\-0.73\\0.79\\-0.11\\-1.5\\-3.3\\-1.9\\-8.8\end{pmatrix}c_{\gamma\gamma}+\begin{pmatrix}-0.087\\-1.3\\1.5\\-0.24\\-3.3\\-8.1\\-5.5\\-26\end{pmatrix}c_{Z\gamma}$$

interferences between s-channel Z and γ amplitudes are accidentally suppressed in the unpolarized total cross section

large interference for polarized beam

$$\left.\frac{\sigma_{WW\to h}}{\sigma_{WW\to h}^{\rm SM}}\right|\begin{pmatrix}240\,\text{GeV}\\250\,\text{GeV}\\350\,\text{GeV}\\500\,\text{GeV}\\1\,\text{TeV}\\1.4\,\text{TeV}\\3\,\text{TeV}\end{pmatrix}\simeq 1+2\,\delta c_Z+\begin{pmatrix}-0.25\\-0.27\\-0.40\\-0.53\\-0.76\\-0.86\\-1.1\end{pmatrix}c_{ZZ}+\begin{pmatrix}-0.68\\-0.72\\-1.1\\-1.5\\-2.2\\-2.5\\-3.4\end{pmatrix}c_{Z\Box}+\begin{pmatrix}0.035\\0.037\\0.056\\0.075\\0.12\\0.14\\0.18\end{pmatrix}c_{\gamma\gamma}+\begin{pmatrix}0.090\\0.097\\0.14\\0.20\\0.32\\0.37\\0.52\end{pmatrix}c_{Z\gamma}$$

Introducing the Global Determinant Parameter

Durieux, Grojean, Gu, Wang '17

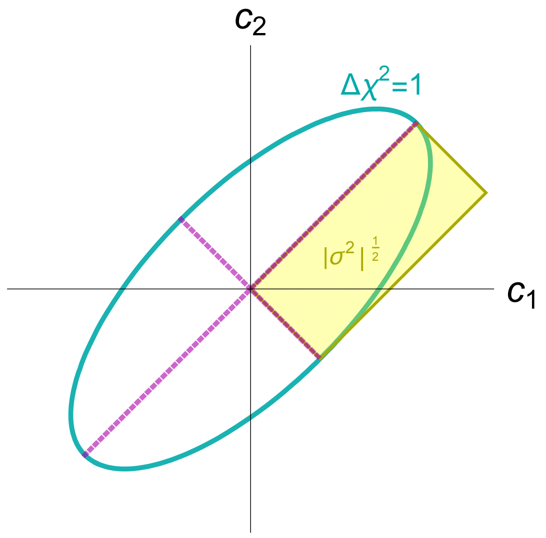


Figure 6: In a two-dimensional parameter space, the area of the Gaussian one-sigma ellipse is proportional to the square root of the determinant of the covariance matrix, $\sqrt{\det\sigma^2}$. In n dimensions, the nth root of this quantity or *global determinant parameter* (GDP) provides an average of constraints strengths. GDP $\equiv \sqrt[2n]{\det\sigma^2}$ ratios measure improvement in global constraint strengths independently of effective-field-theory operator basis.

ratios of GDP are independent of parameters normalization
ratios of GDP are independent of EFT operator basis

smaller GDP = better precision