"Tell me that you have found no sign of
New Physics again, I dare you.
I double dare you. Tell me
one more goddamn time!"

Tracing 2HDM/MSSM Higgs sectors at the HL-LHC and ILC

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virtual only, 06/2020

In collaboration with: [*arXiv:2005.14536*]

H. Bahl, P. Bechtle, S. Liebler, T. Stefaniak, G. Weiglein

Models with extended Higgs sectors:

1. SM with addional Higgs singlet
2. Two Higgs Doublet Model (THDM): type I, II, III, IV
3. N2HDM: 2HDM with one extra singlet: type I, II, III, IV
4. Minimal Supersymmetric Standard Model (MSSM)
5. MSSM with one extra singlet (NMSSM)
6. MSSM with more extra singlets (e.g. $\mu\nu$SSM)
7. SM/MSSM with Higgs triplets
8. ...

$\Rightarrow$ BSM models without extended Higgs sectors still have changed Higgs properties (quantum corrections!)

$\Rightarrow$ SM + vector-like fermions, Higgs portal, Higgs-radion mixing, ...

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Current at future collider experiments:

LHC (Large Hadron Collider): running
pp collisions at 13(14) TeV
HL-LHC final high-luminosity phase: approved
HE-LHC new magnets $\Rightarrow$ 27 TeV (possible?)

ILC (International Linear Collider) decision 2020/21 in Japan
e^+e^- collisions at 250 GeV (final stage 1000 GeV)

CLIC (Compact LInear Collider)
e^+e^- collisions at 380 GeV (final stage 3000 GeV)

FCC-ee (Future Circular Collider e^+e^-)
e^+e^- collisions up to 350 GeV

CEPC (Chinese e^-e^+ Collider)
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FCC-hh (Future Circular Collider had-had)
pp collisions at 100 TeV (possible?)

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What to expect from future colliders

$\Rightarrow$ focus on Higgs searches and measurements

HL-LHC:

- will improve direct search limits
- will improve rate measurements (production $\times$ decay)
  systematic/theory uncertainties: S2 scenario

[*M. Cepeda et al. '19 – YR18*]

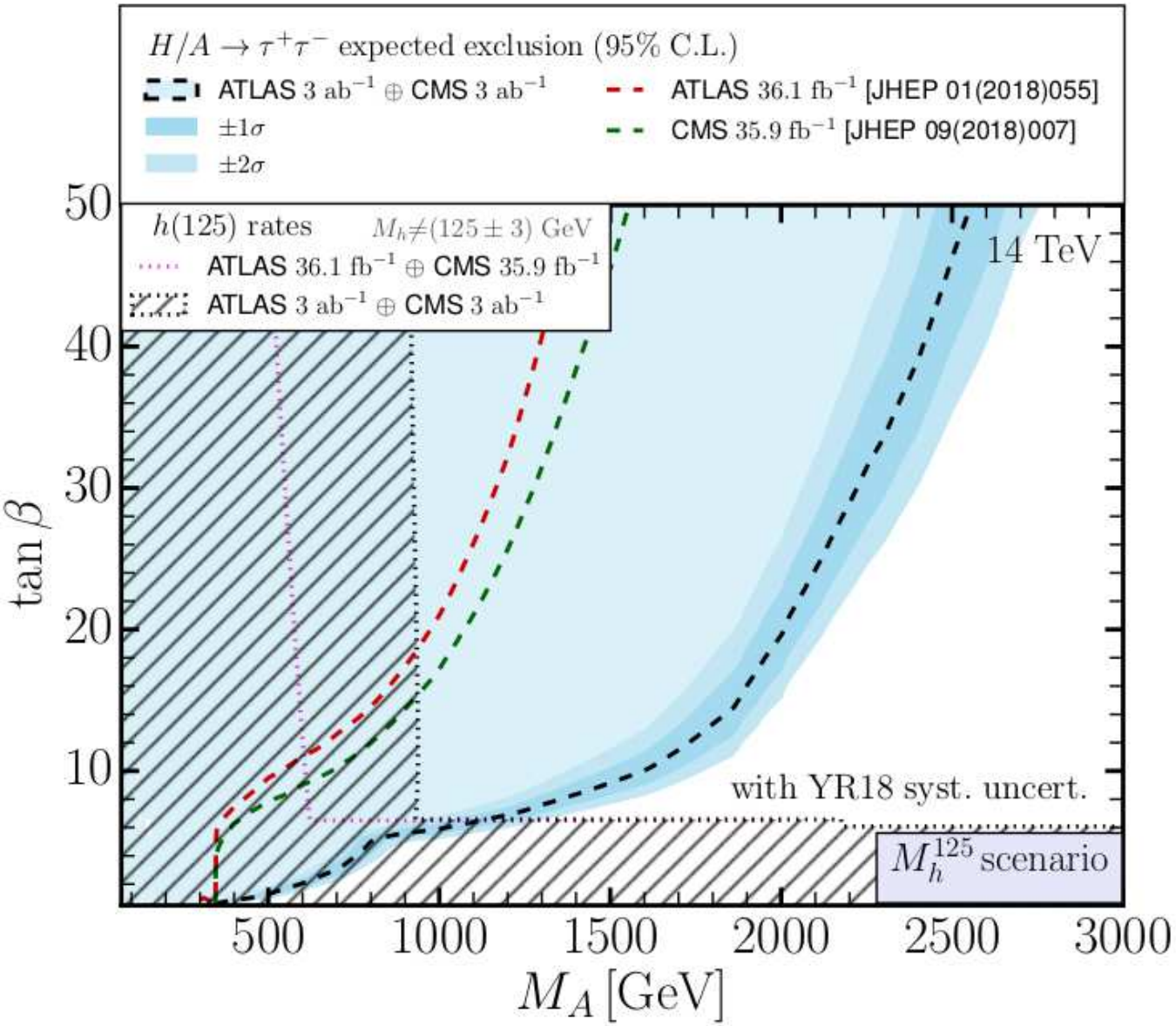
ILC:

- will improve rate measurements (no theory assumptions!)
  - $250\,\text{fb}^{-1}$ at ILC250 $\oplus$ $500\,\text{fb}^{-1}$ at ILC500
  - polarization: $P(e^-, e^+) = (-80\%, +30\%)$

[*T. Barklow et al. '17, '19*]

HL-LHC reach in M_h^{125} scenario $\sim$ 2HDM reach

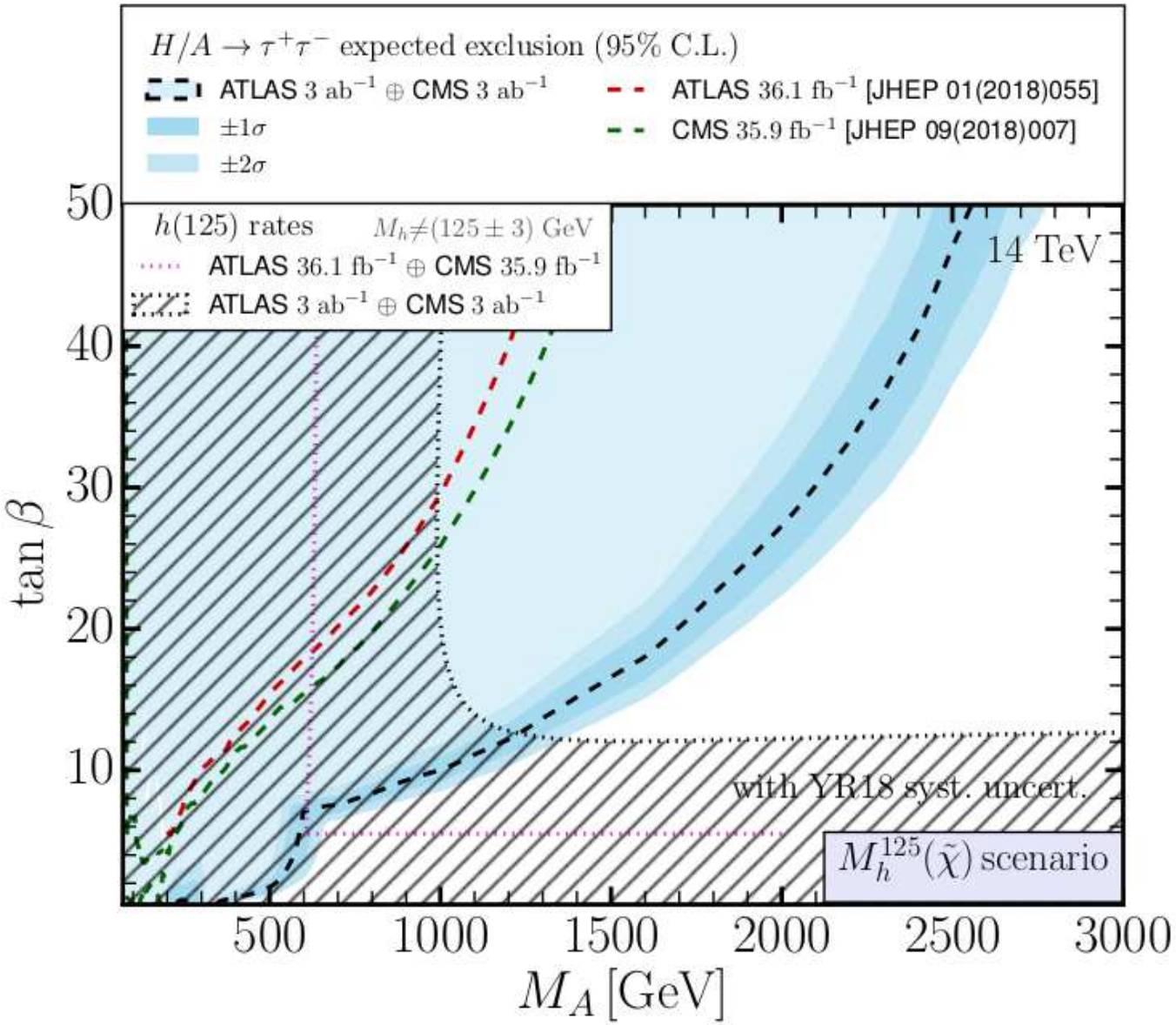
[*H. Bahl et al., '20*]



$\Rightarrow$ direct and indirect measurements: $M_A \gtrsim 1200$ GeV

HL-LHC reach in $M_h^{125}(\tilde{\chi})$ scenario

[*H. Bahl et al., '20*]

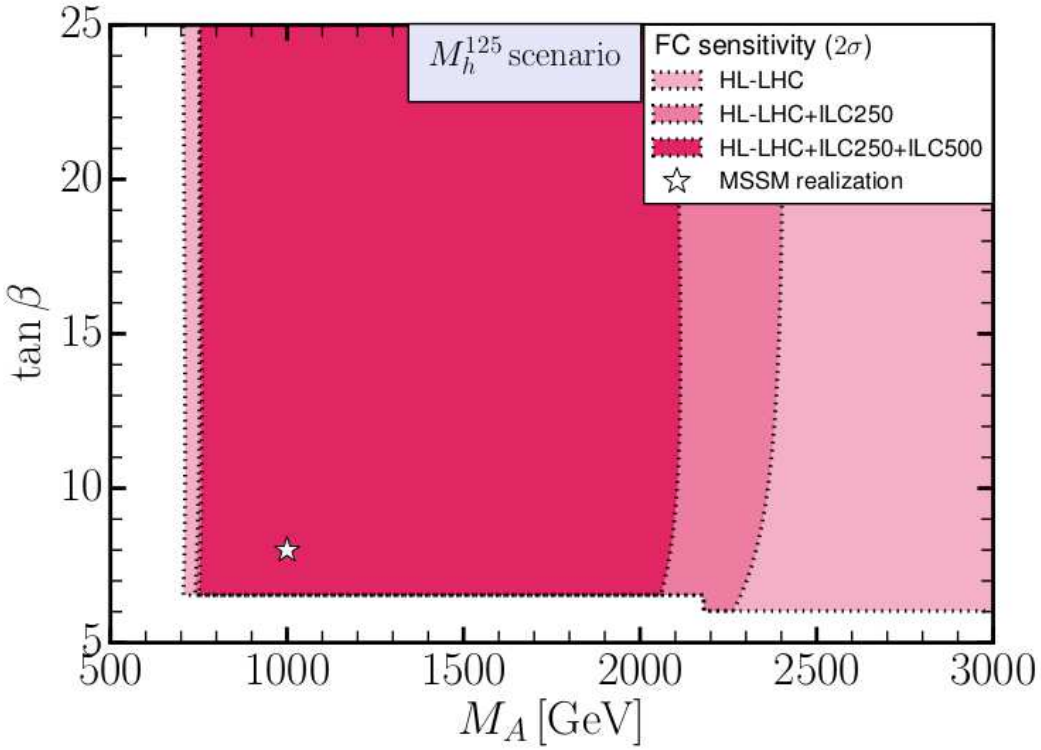


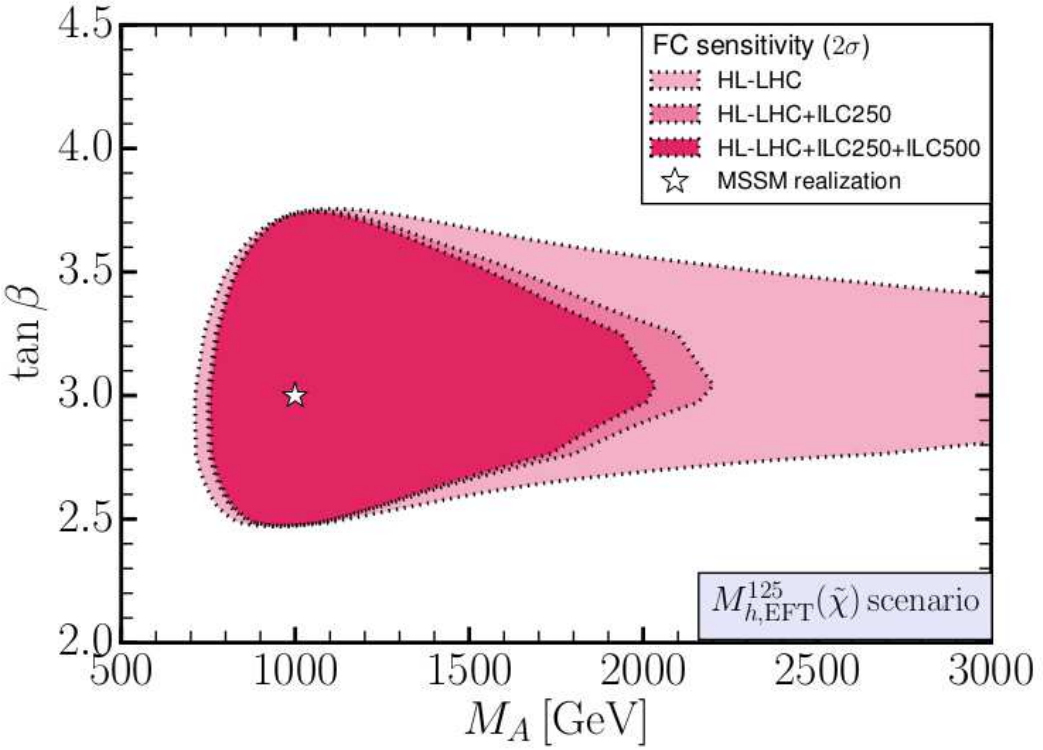
⇒ clear effect of enlarged MSSM particle content

Relevance of ILC improvement:

[H. Bahl et al., '20]

– Assume a realization of an MSSM point: $M_A = 1$ TeV, $\tan\beta = 7/3$
– What limits can be set from rate/coupling measurements?





⇒ only ILC measurements give upper limit on M_A

⇒ limits on $\tan\beta$ only for small(er) $\tan\beta$

Let us assume that we do see a deviation

What do we learn from that?
How do we learn something from that?

⇒ We have to compare the observed deviation with
predicted deviations

⇒ Preferrably with the predicted deviations in a concrete models
(A comparison with an EFT result subsequently requires the mapping
to concrete models anyway . . .)

⇒ Needed: sufficiently precise predictions in BSM model
close to ready: MSSM, NMSSM
(I am not aware of uncertainty estimates in other models)

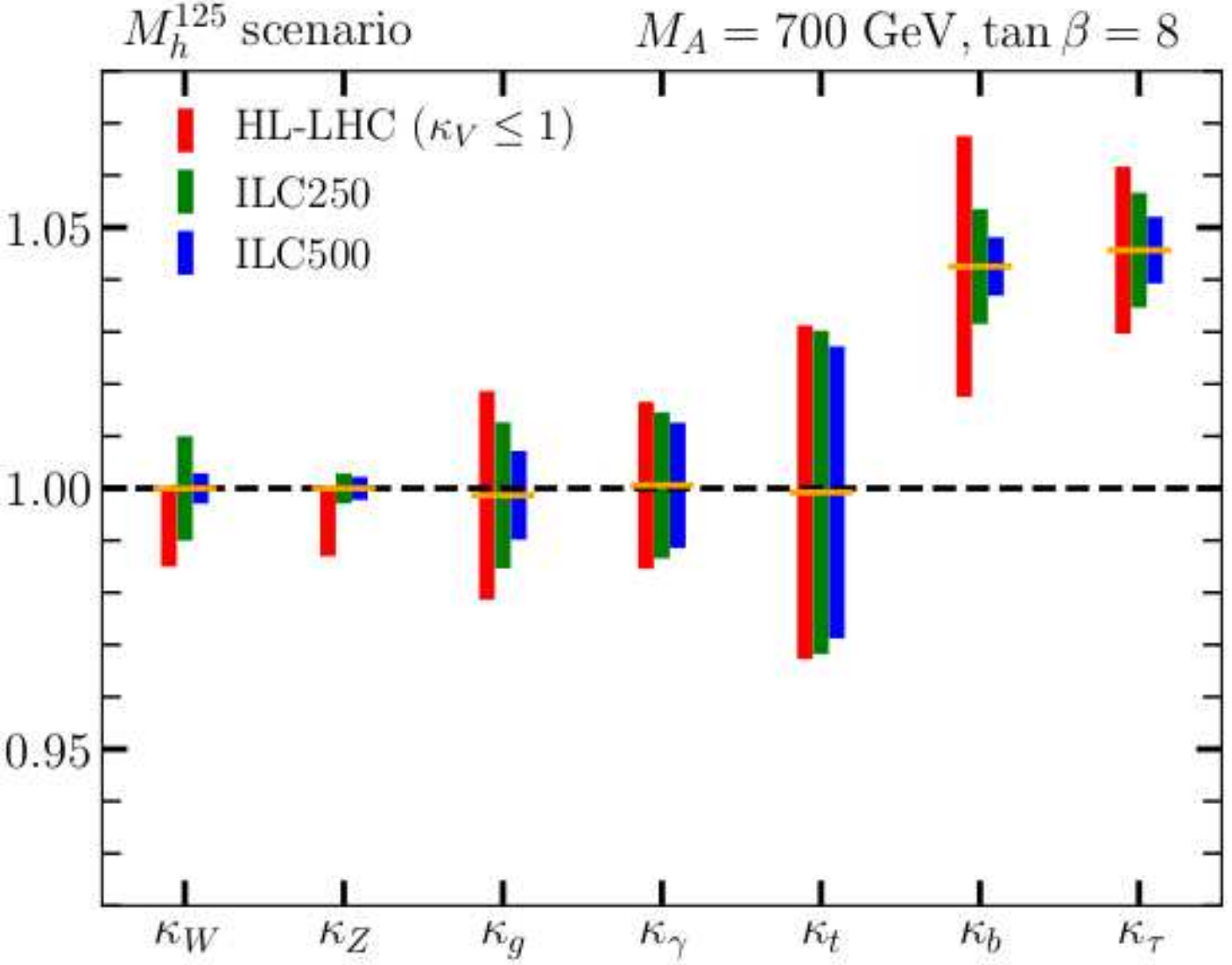
⇒ in the following:

model prediction (w/o TH unc.) $\Leftrightarrow$ e^+e^- precision

⇒ "Wäscheleinen-Plots"

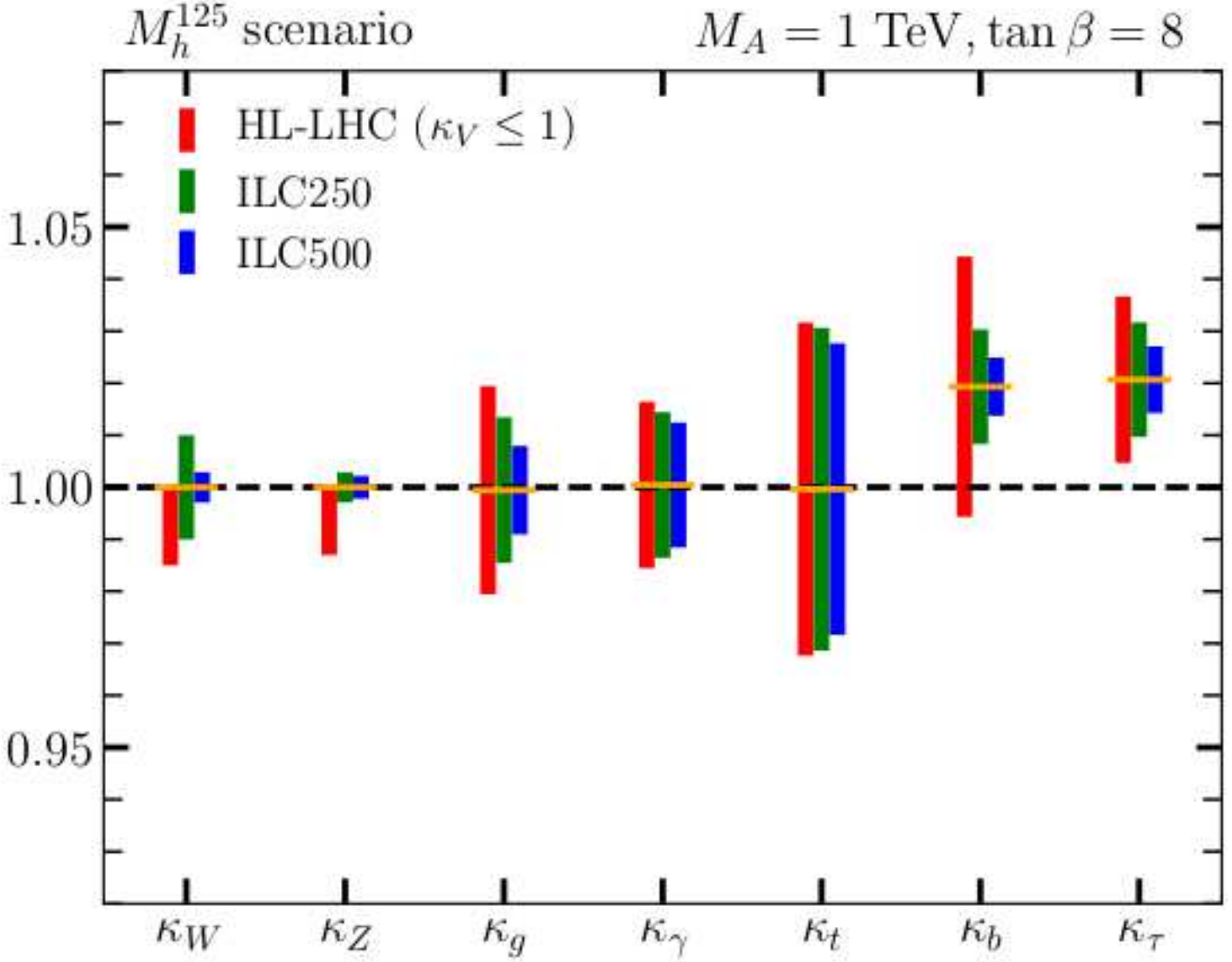
MSSM Wäscheleine I: e^+e^- precision vs. M_h^{125} ($M_A = 700$ GeV, $\tan\beta = 8$)

[*H. Bahl et al – '20*]



MSSM Wäscheleine II: e^+e^- precision vs. M_h^{125} ($M_A = 1000$ GeV, $\tan\beta = 8$)

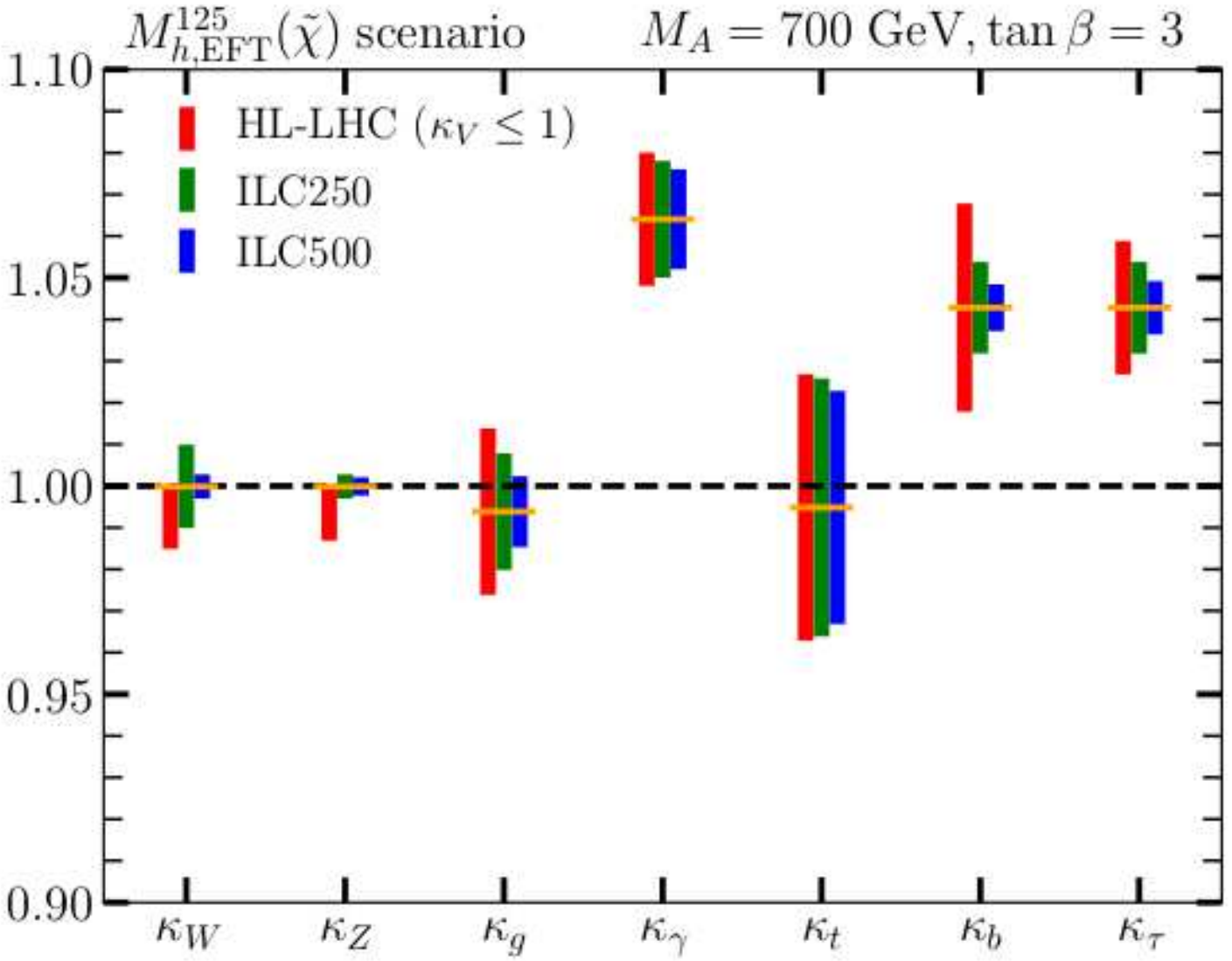
[*H. Bahl et al – '20*]



$\Rightarrow$ only e^+e^- measurements allows to set upper limit on M_A

MSSM Wäscheleine III: e^+e^- vs. $M_h^{125,\mathrm{EFT}}(\tilde{\chi})$ ($M_A = 700$ GeV, $\tan\beta = 3$)

[*H. Bahl et al – '20*]



MSSM Wäscheleine IV: e^+e^- vs. $M_h^{125,\mathrm{EFT}}(\tilde{\chi})$ ($M_A = 1000$ GeV, $\tan\beta = 3$)

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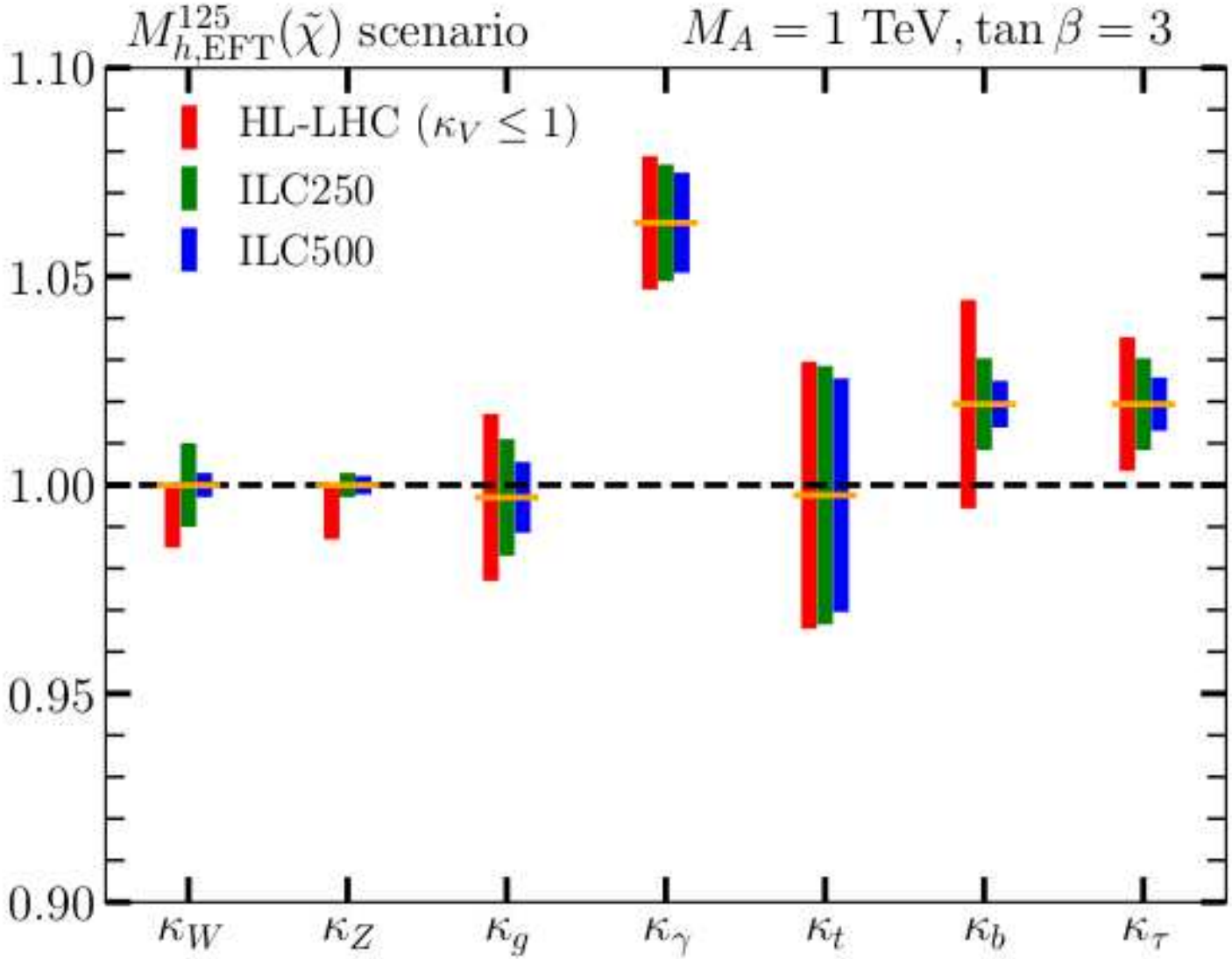

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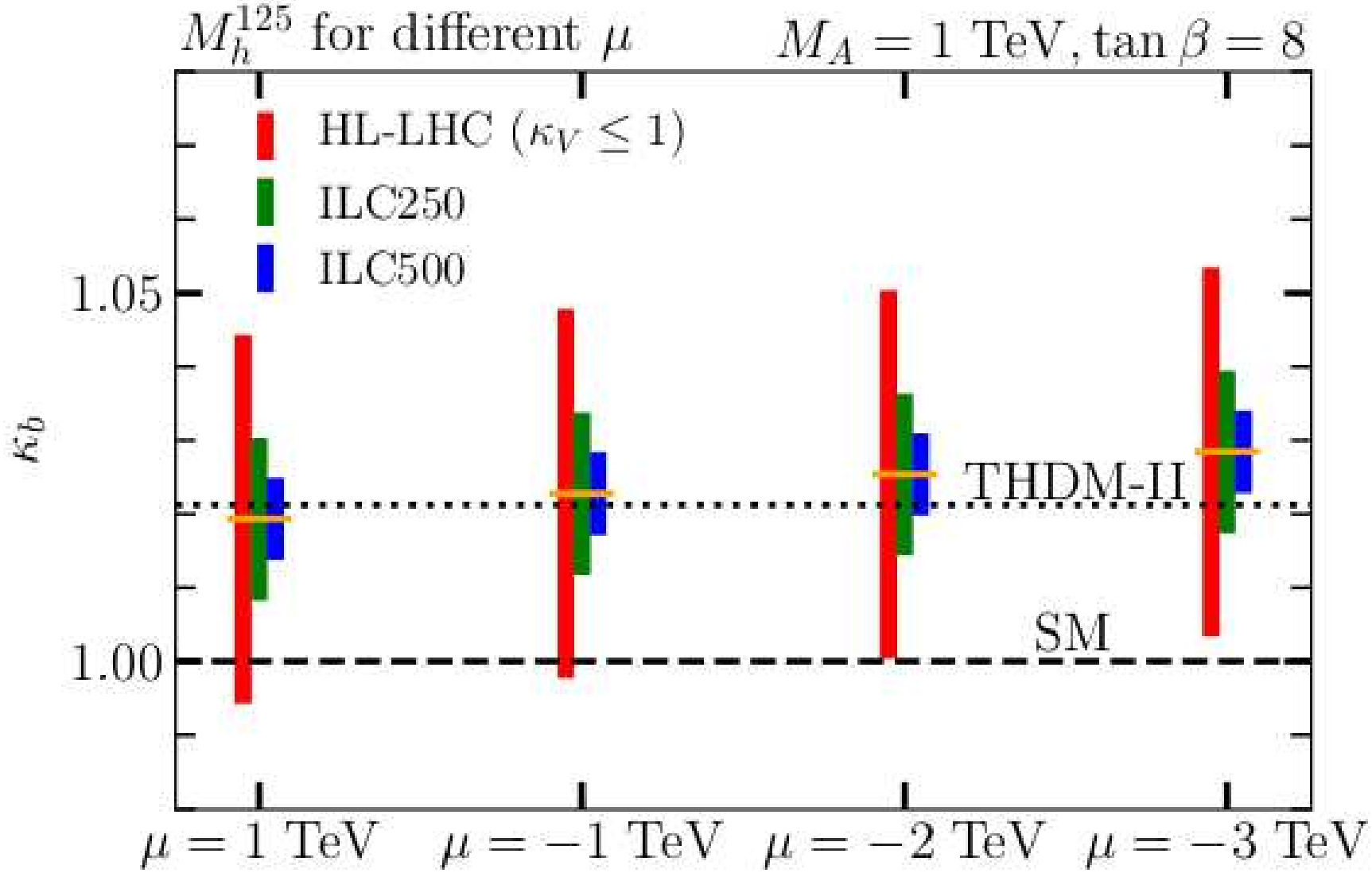
MSSM Wäscheleine V: e^+e^- vs. M_h^{125} ($M_A = 1000$ GeV, $\tan\beta = 8$)

[*H. Bahl et al – '20*]

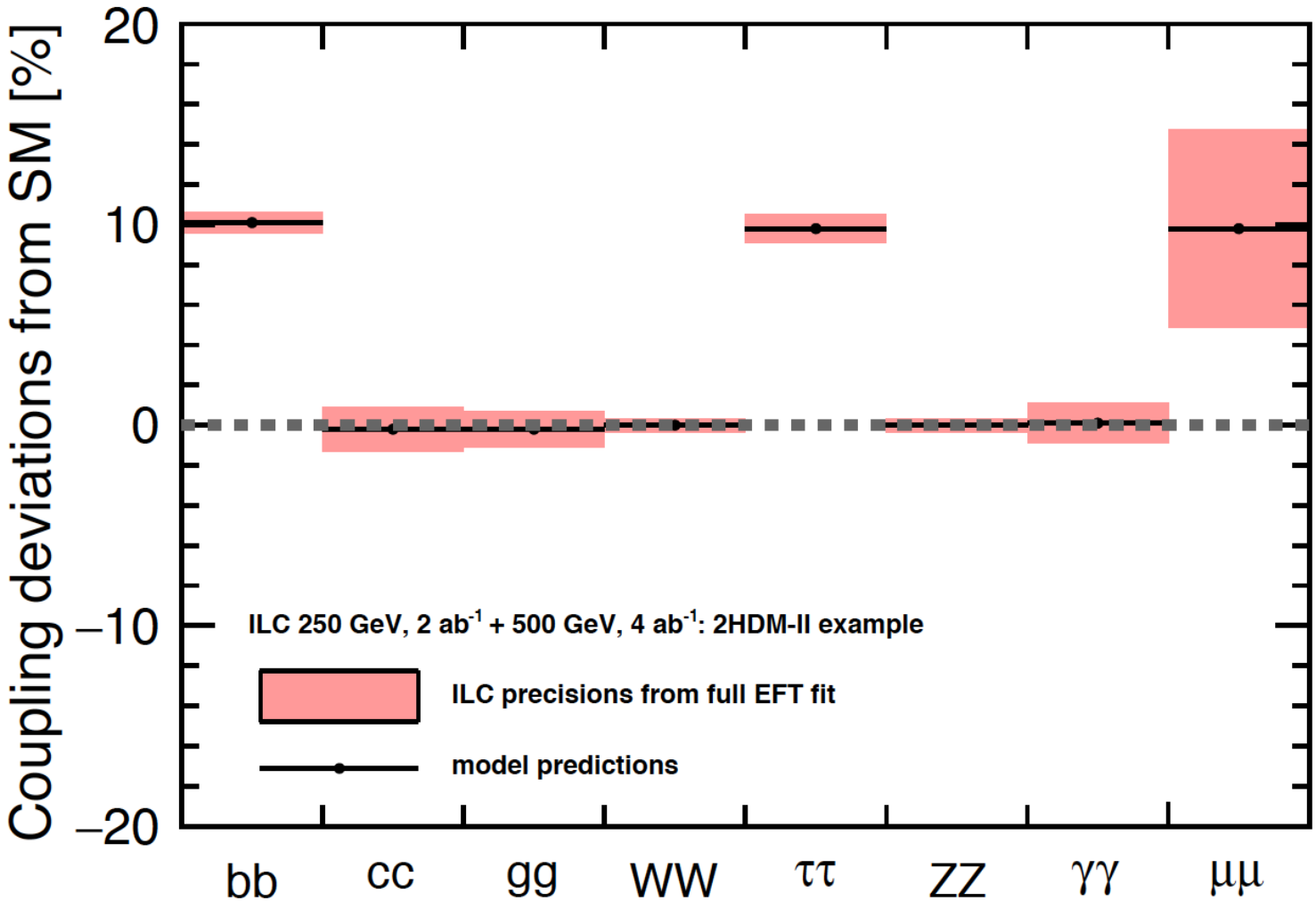


⇒ MSSM vs. 2HDM: very challenging!


Further Questions?

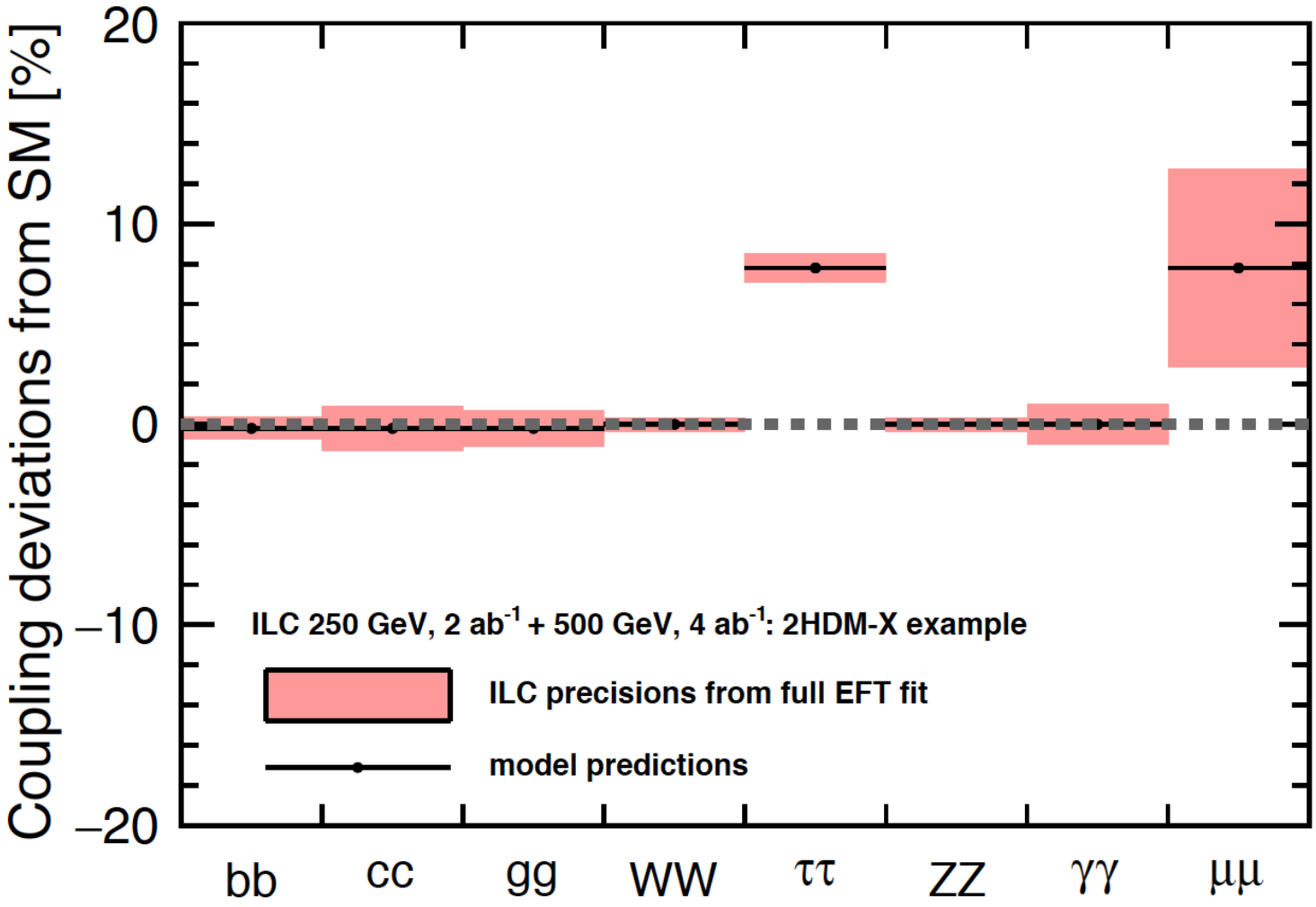
Wäscheleine I: e^+e^- precision vs. 2HDM type II prediction:

[*T. Barklow et al., '17*]



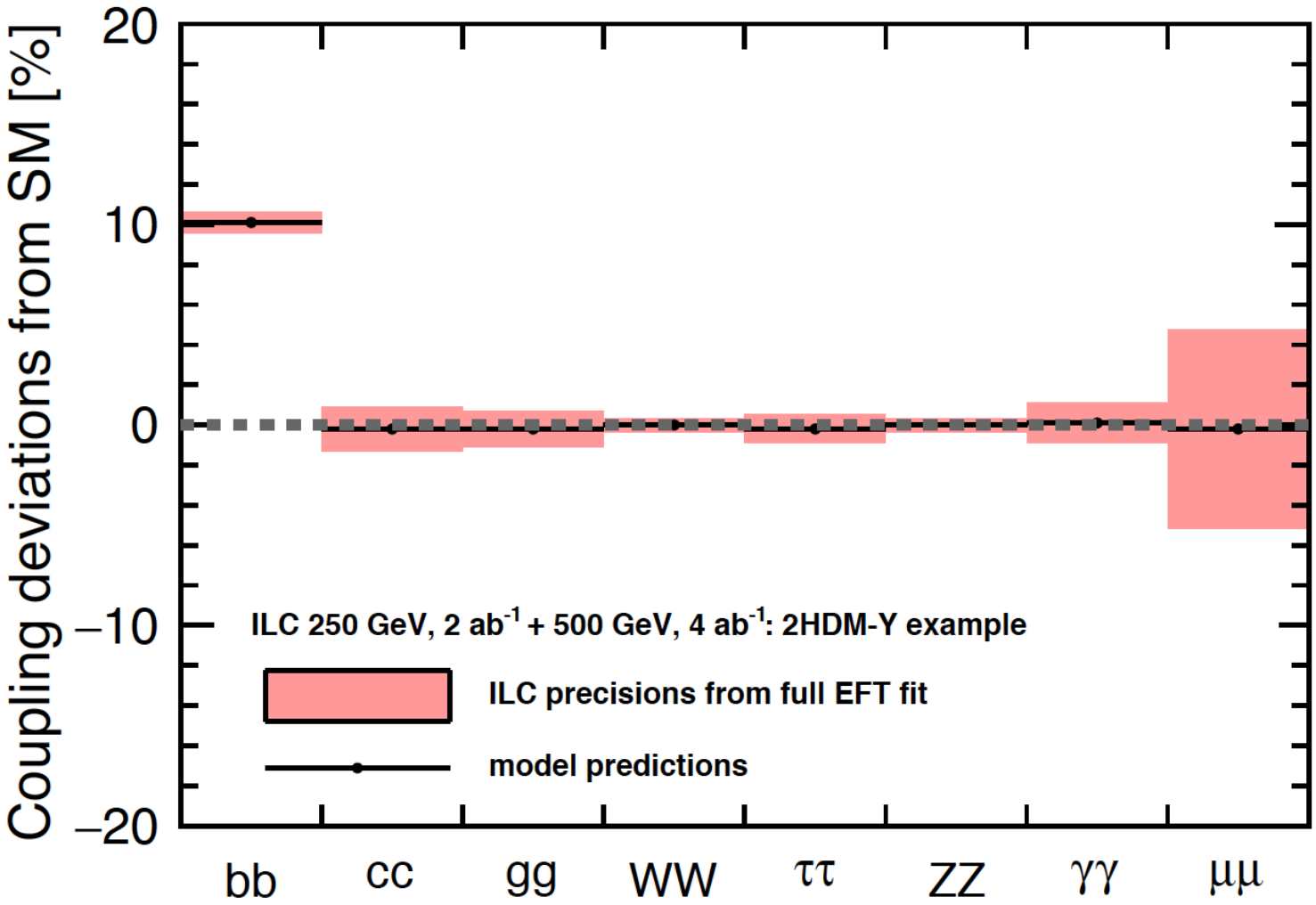
Wäscheleine II: e^+e^- precision vs. 2HDM type X prediction:

[*T. Barklow et al., '17*]



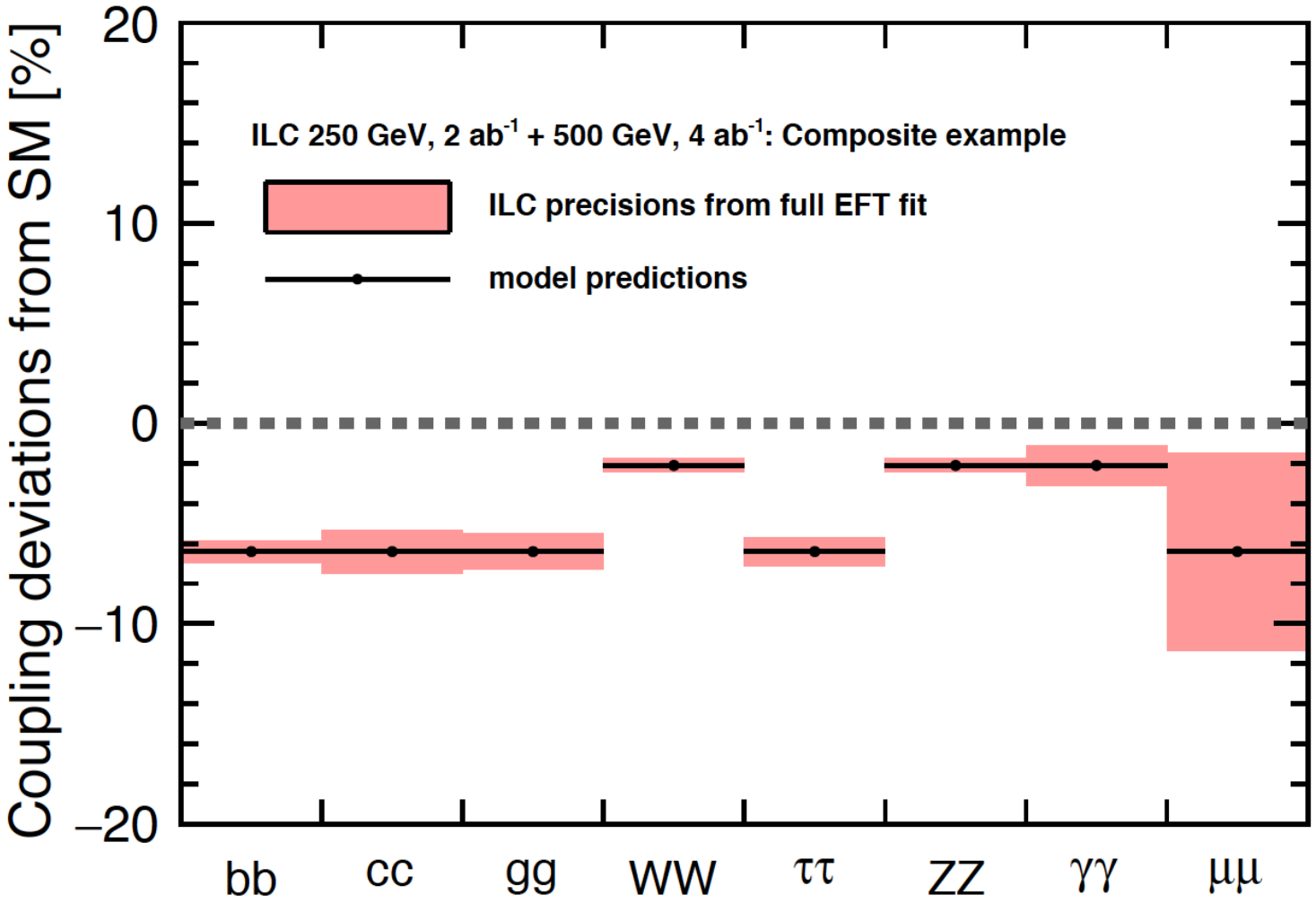
Wäscheleine III: e^+e^- precision vs. 2HDM type Y prediction:

[*T. Barklow et al., '17*]



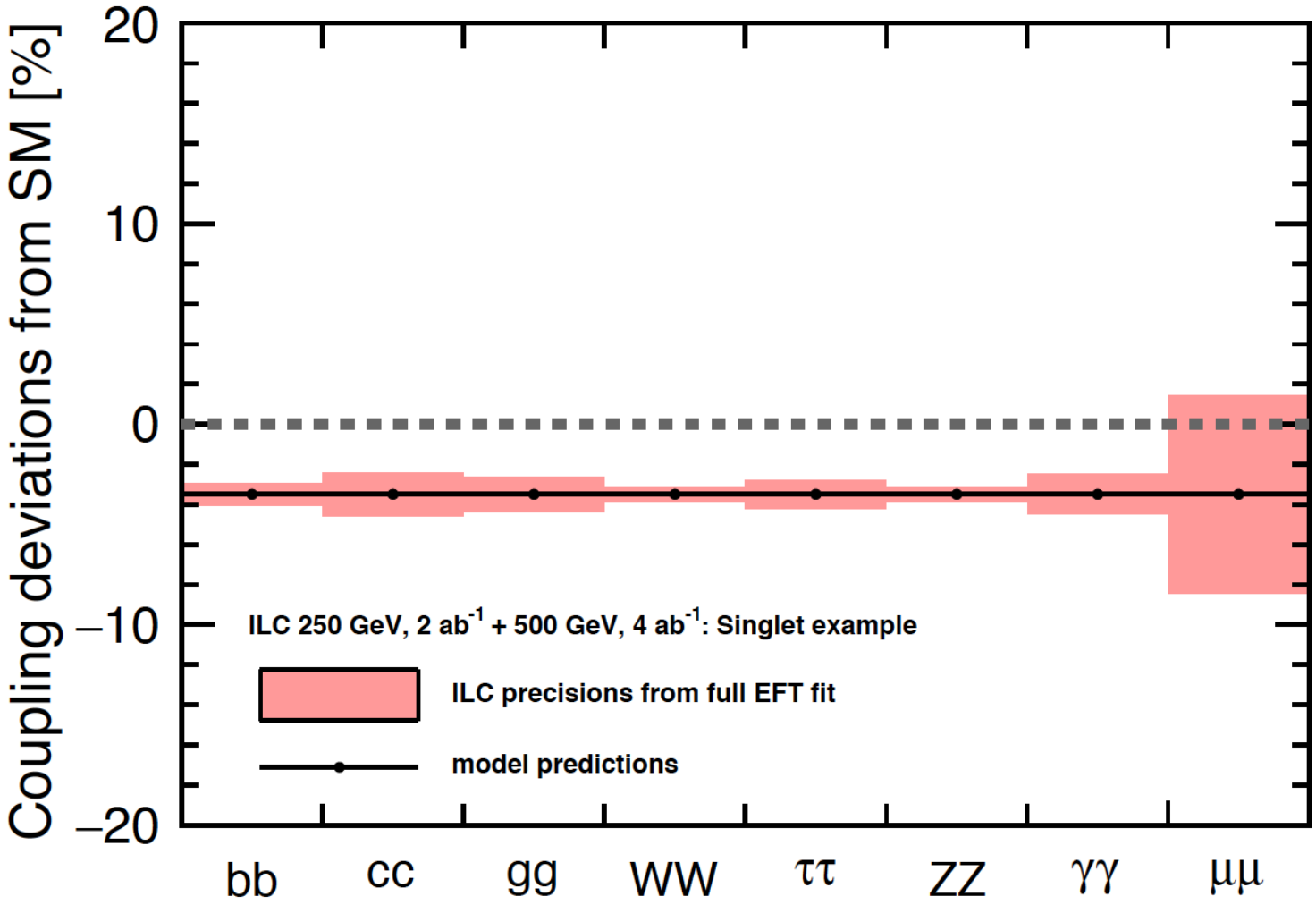
Wäscheleine IV: e^+e^- precision vs. Composite Higgs prediction:

[*T. Barklow et al., '17*]



Wäscheleine V: e^+e^- precision vs. HxSM prediction:

[*T. Barklow et al., '17*]



Wäscheleine VI: e^+e^- precision vs. Higgs-Radion prediction:

[*T. Barklow et al., '17*]