Christoph Englert

Higgs portals at ee Higgs factories

CEPC Workshop

26/10/20

singlets above threshold

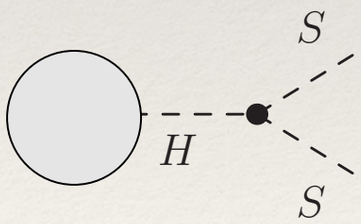
- $\mathbb{Z}_2$-symmetric Higgs portal

[Craig , Lou. et al.` 14]
[Curtin, Meade, Yu ` 14]
...

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial_\mu S)^2 - \frac{m_S^2}{2} S^2 - \lambda S^2 (\Phi^\dagger \Phi - v^2/2)$$

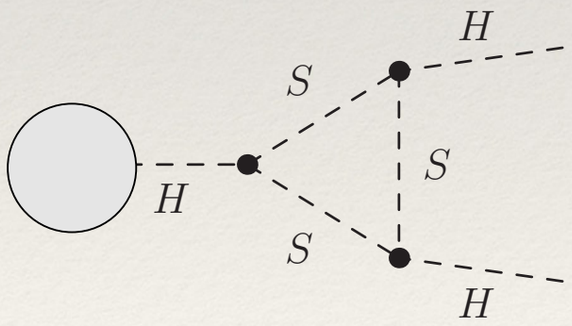
- for $m_S > m_H/2$ no direct SM Higgs decays
- BSM Higgs physics via momentum- or loop-suppressed effects

off-shell production



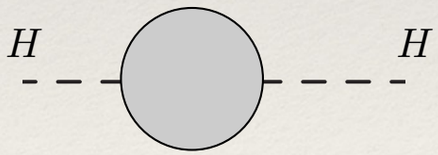
[Craig , Lou. et al.` 14]
[Ruhdorfer, Salvioni, Weiler ` 19]

di-Higgs physics



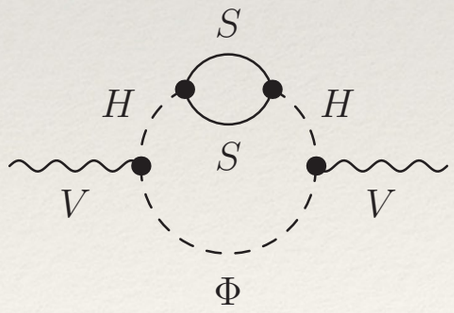
[Curtin, Meade, Yu ` 14]
[He, Zhu ` 16]
[Voigt, Westhoff ` 17]

Higgs couplings



[CE, McCullough ` 13]
[Craig, CE, McCullough ` 13]
[Goncalves, Han, Mukhopadhyay ` 18]

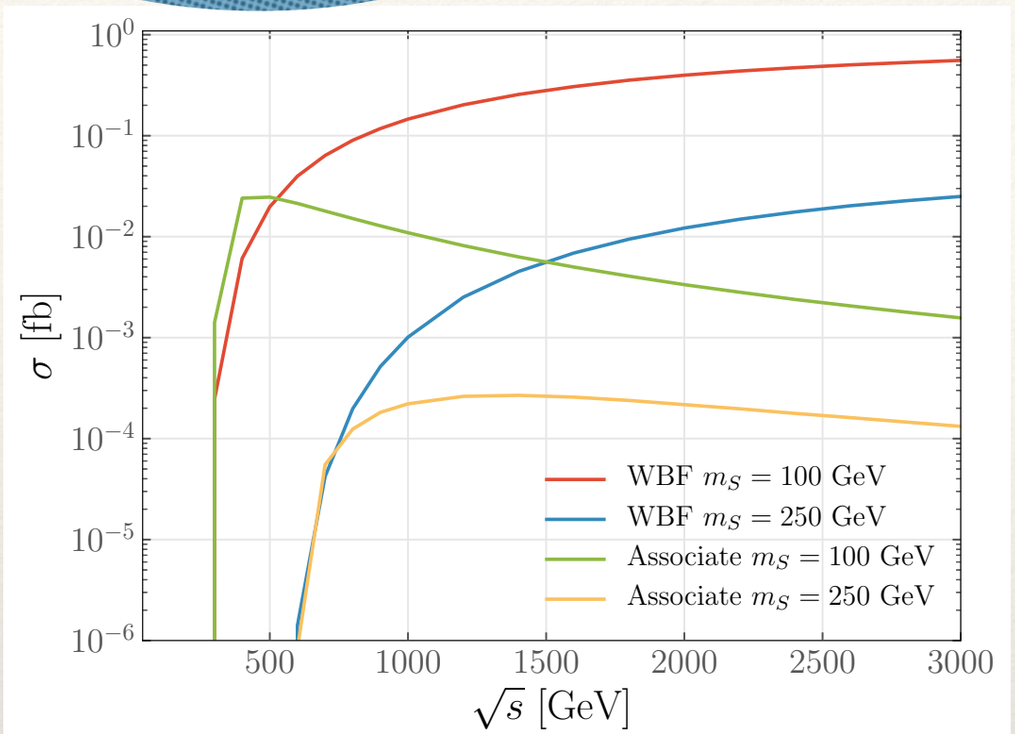
Oblique corrections

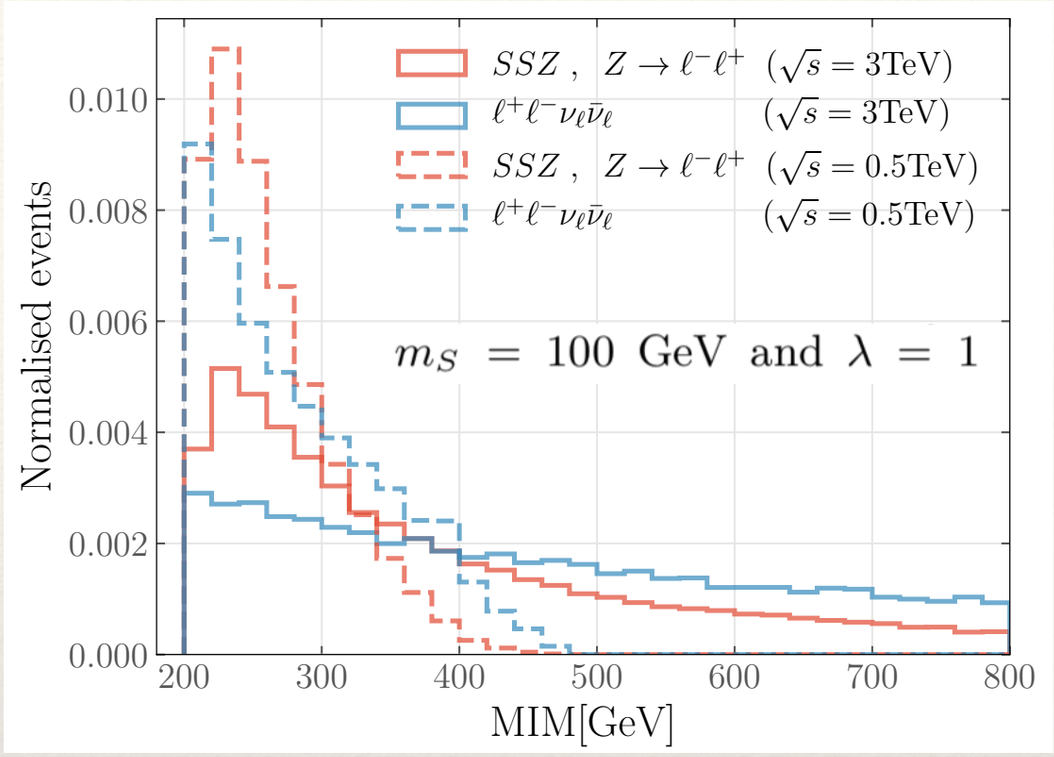


[CE, Jaeckel, Spannowsky, Stylianou ` 20]

off-shell production

singlets above threshold

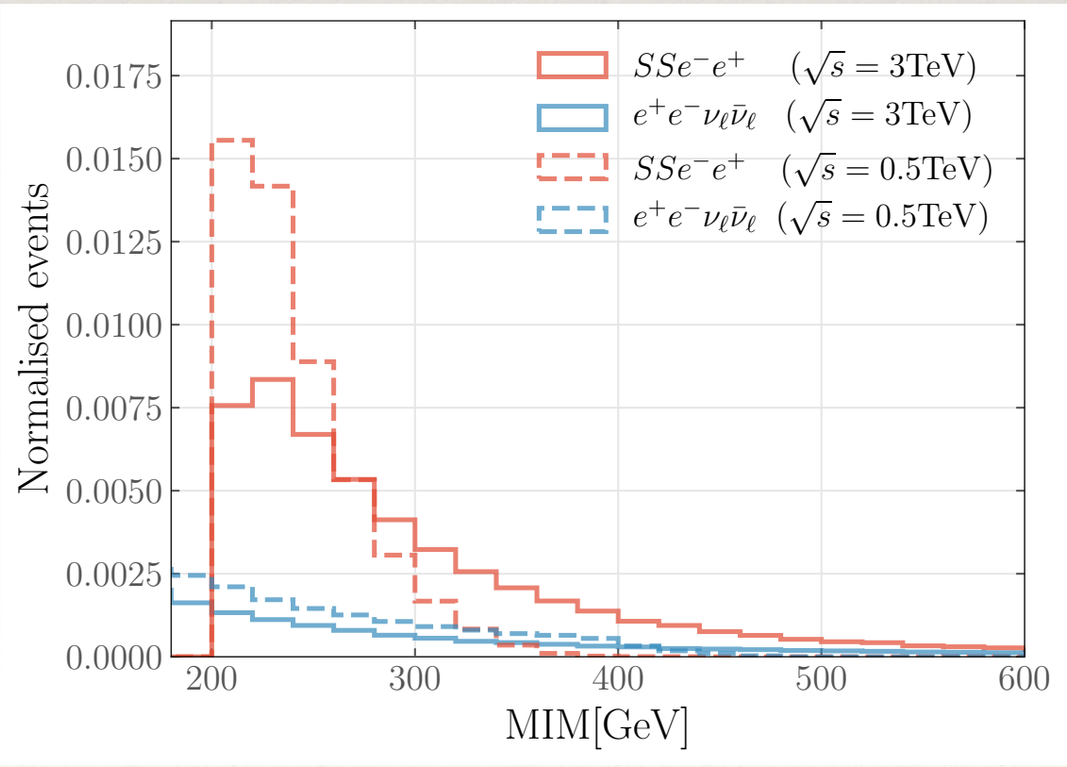




Cuts	SSe^-e^+ [fb]	$e^+e^-\nu_\ell\bar{\nu}_\ell$ [fb]
Generation	0.5364	43.86
MIM > 200 GeV	0.5364	9.257
$\Delta\eta_{ee} > 6$	0.4144	1.687
$\not{E}_T > 80$ GeV	0.2811	1.446
$M_{ee} > 2200$ GeV	0.2346	0.468

@3 TeV

High energy WBF most sensitive channel



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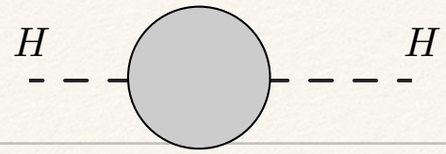


singlets above threshold

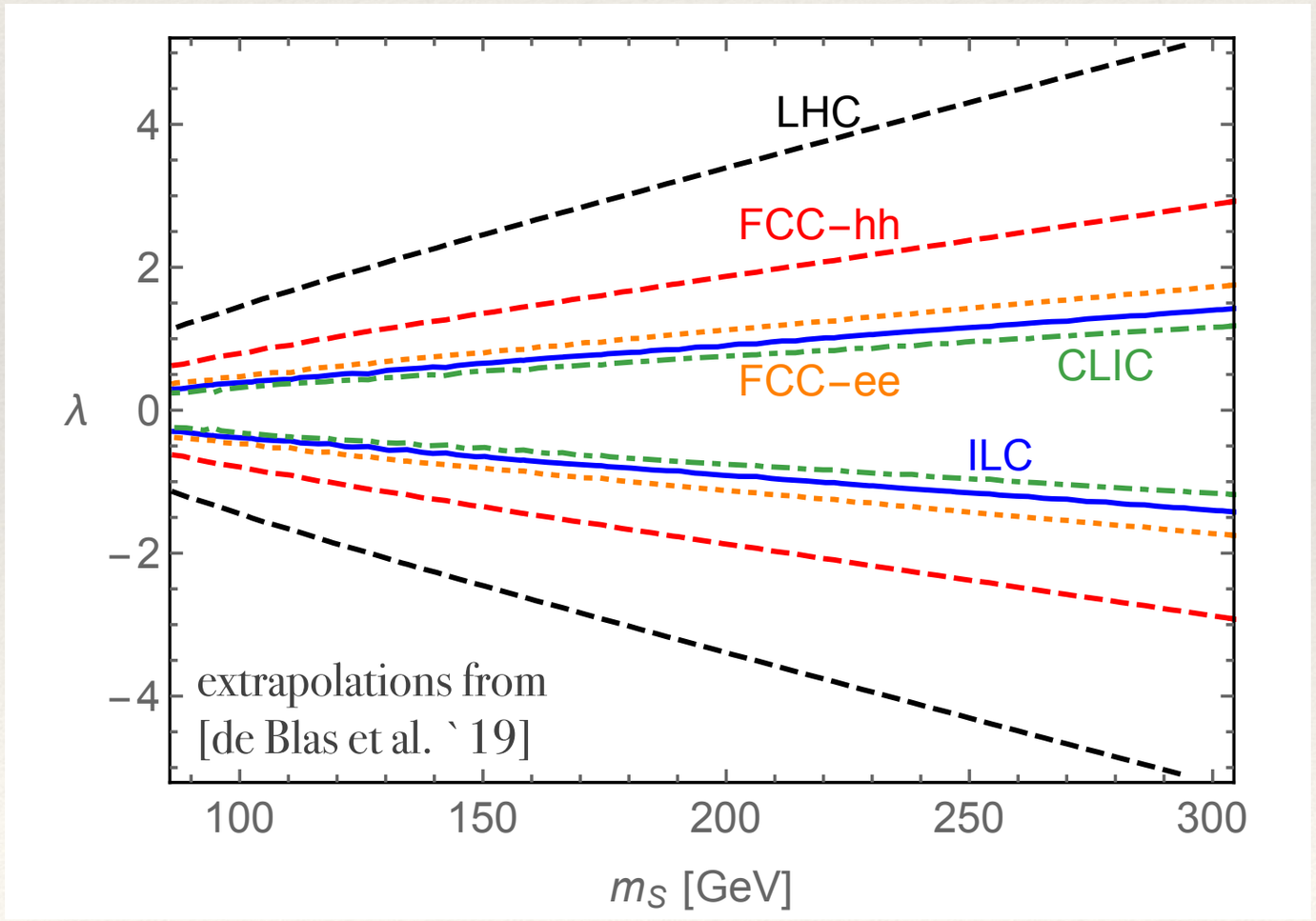
- Higgs couplings receive uniform radiative corrections, accessible through signal strength measurements

$$\mu = \frac{\sigma(H) \times \mathrm{BR}}{[\sigma(H) \times \mathrm{BR}]_{\mathrm{SM}}} = 1 + \delta Z_H \,.$$

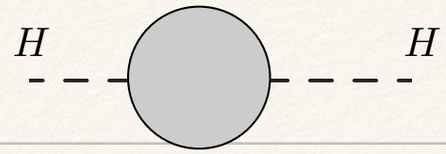
$\sim 0.4\% \times \mathrm{SM}$

[de Blas et al. `19]

[Craig, CE, McCullough `13]



Higgs couplings



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[de Blas et al. `19]

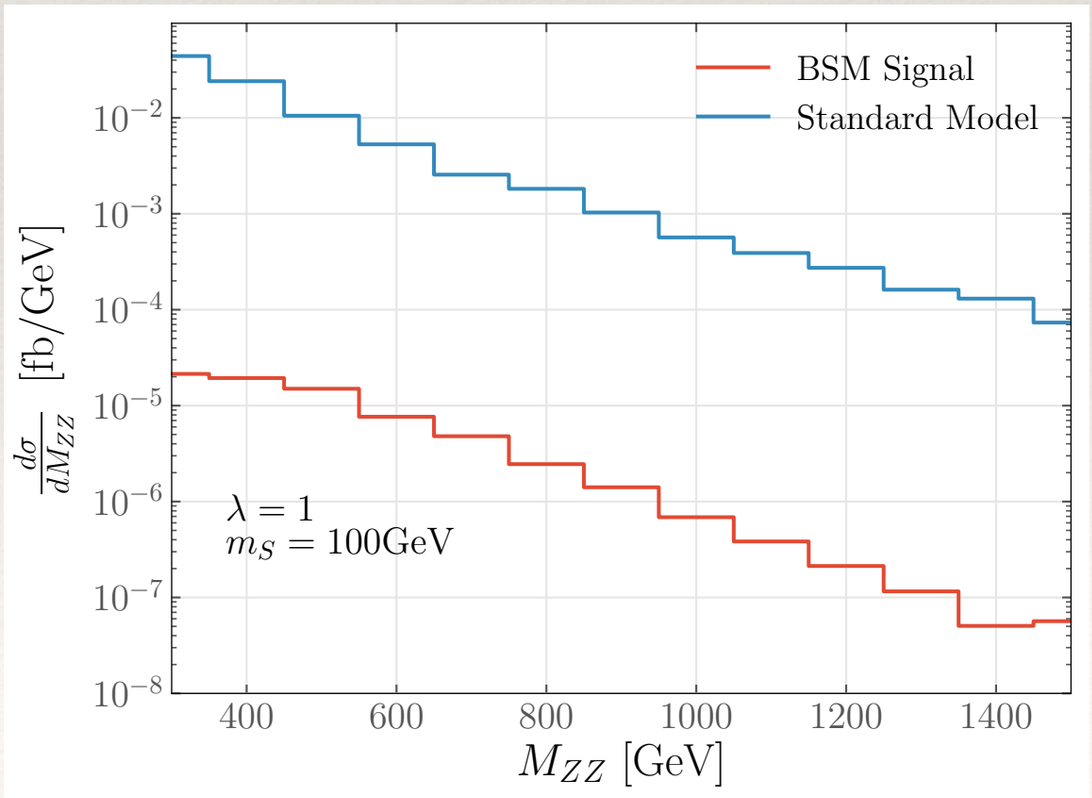
[Craig, CE, McCullough `13]

- Higgs propagation accesses absorptive parts when probed off-shell and unitarity restoration guarantees non-decoupling (e.g. $gg \to ZZ$)

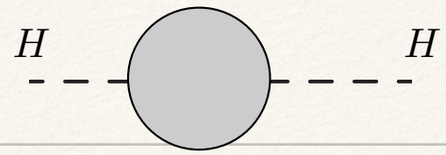
[Kauer, Passarino `12]

Cancellation between gauge couplings and Higgs propagation

[CE, Giudice, Greljo, McCullough `19]

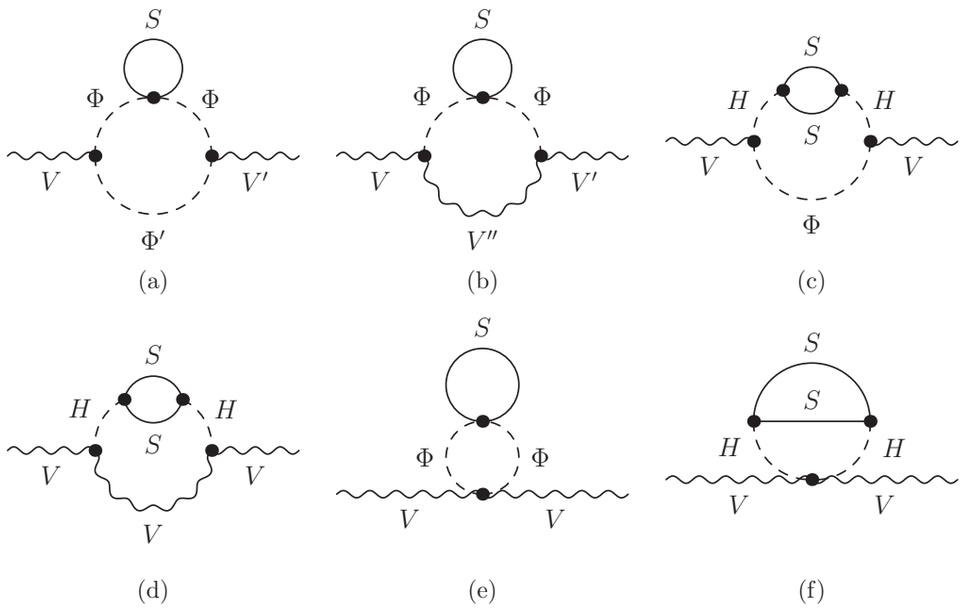


Oblique corrections



singlets above threshold

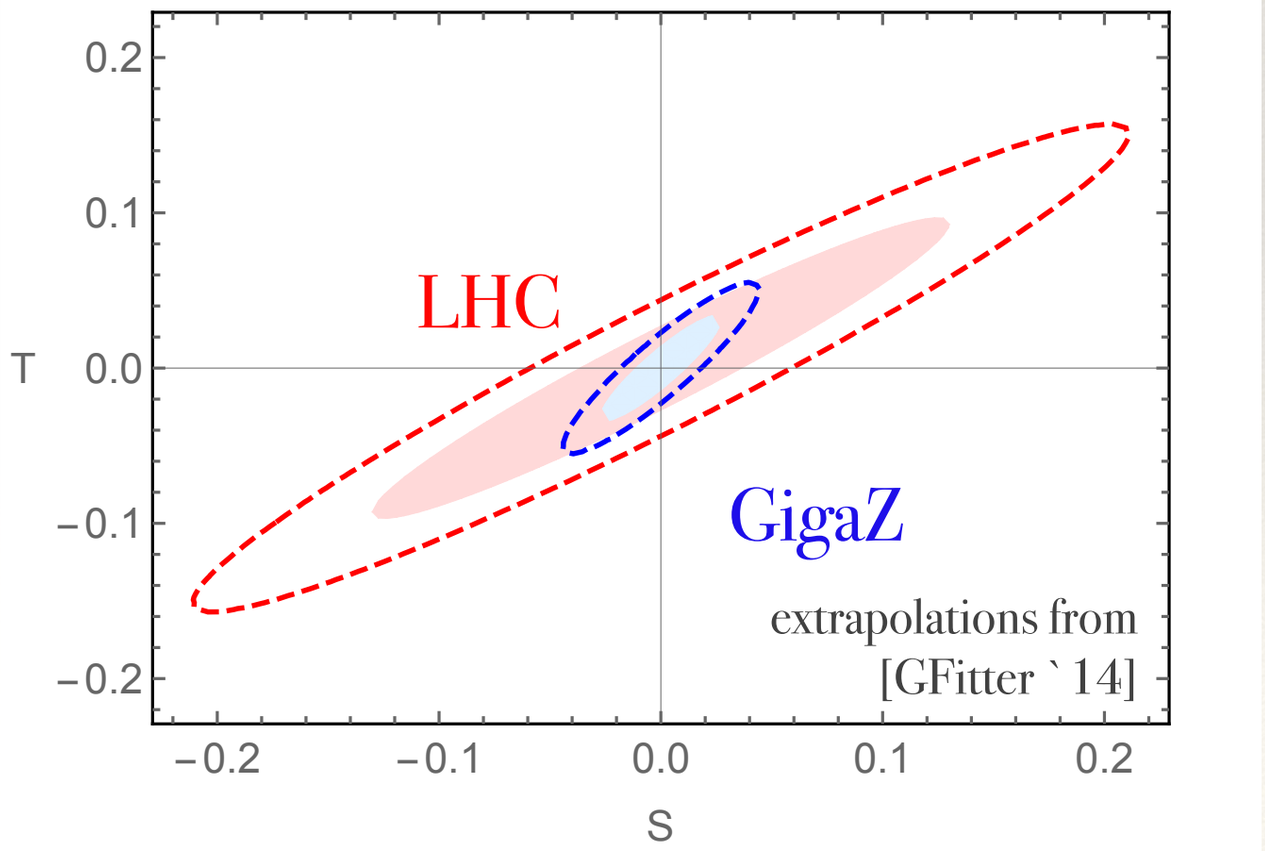
- Precision analysis of Z-pole measurements ($e^+ e^- \to ff'$) [Peskin, Takeuchi `90]



[CE, Jaeckel, Spannowsky, Stylianou `20]

GigaZ gives non-trivial constraint

- Oblique corrections are two-loop suppressed, but large statistics and particularly clean measurement at Higgs factories



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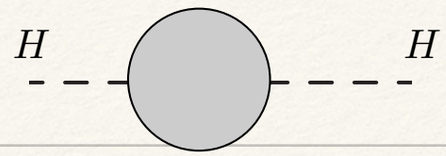

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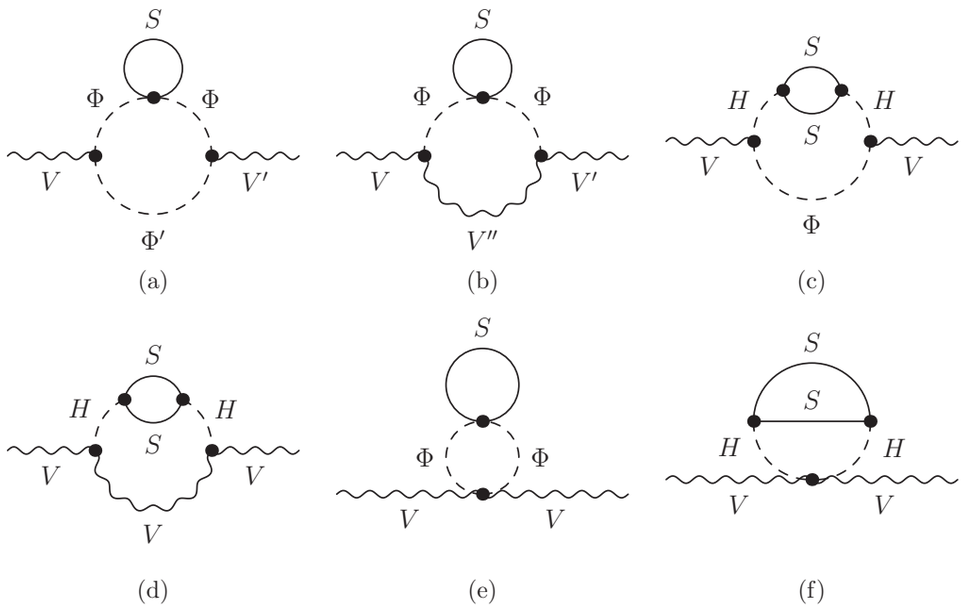

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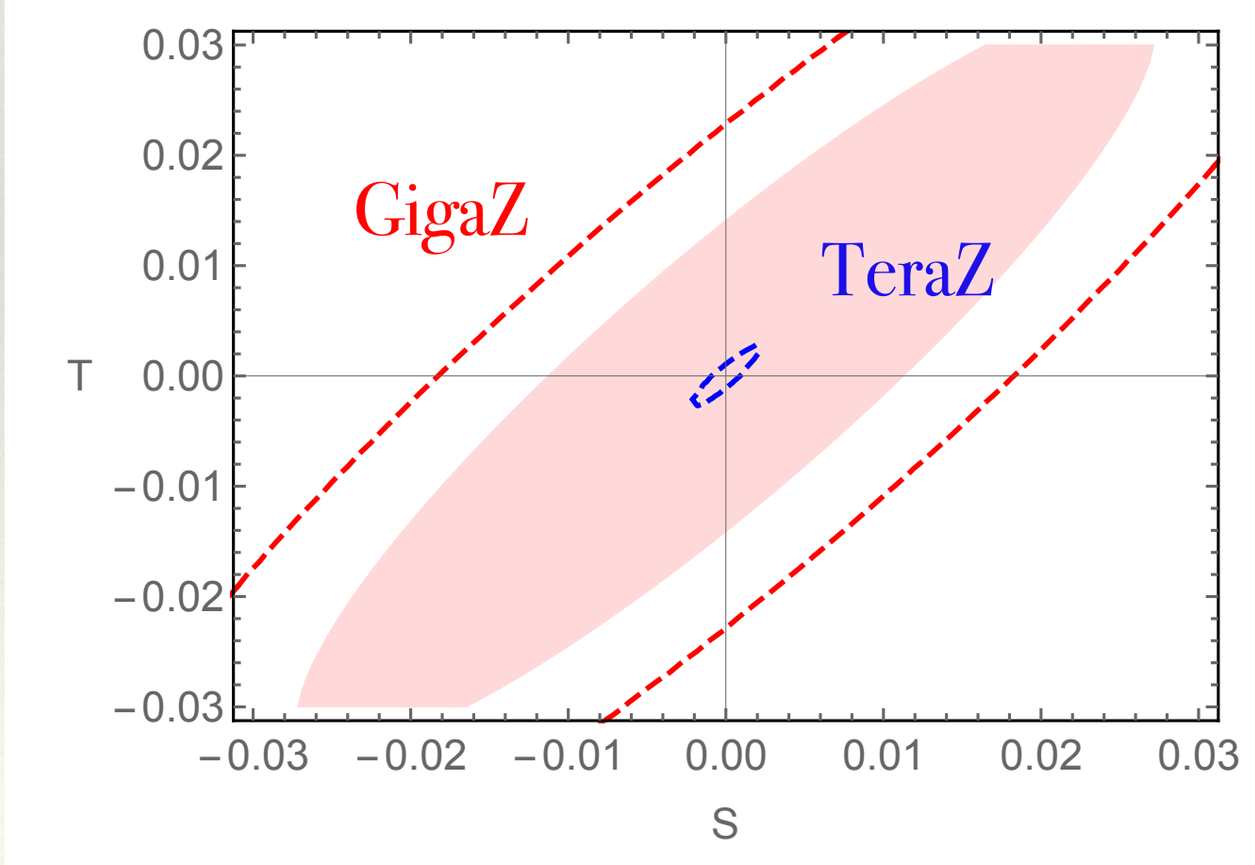
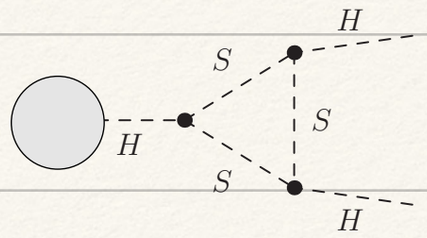


GigaZ gives non-trivial constraint

massive improvement for TeraZ (if attainable)

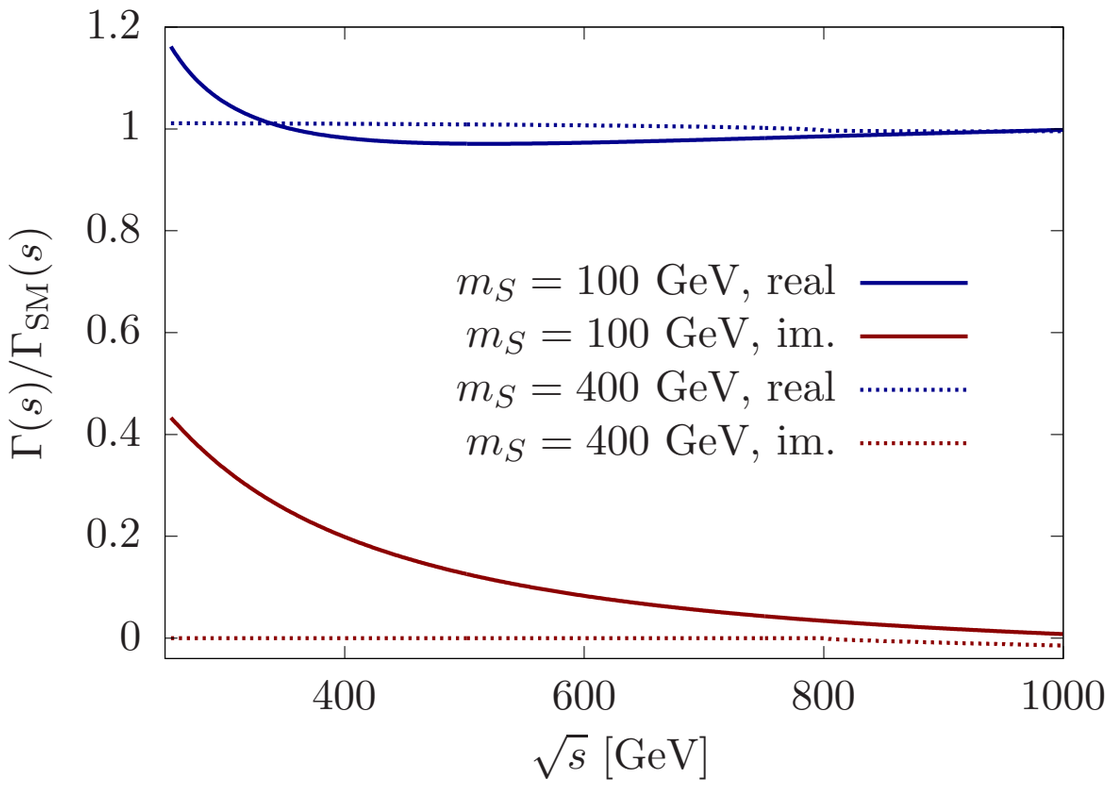
Higgs pairs

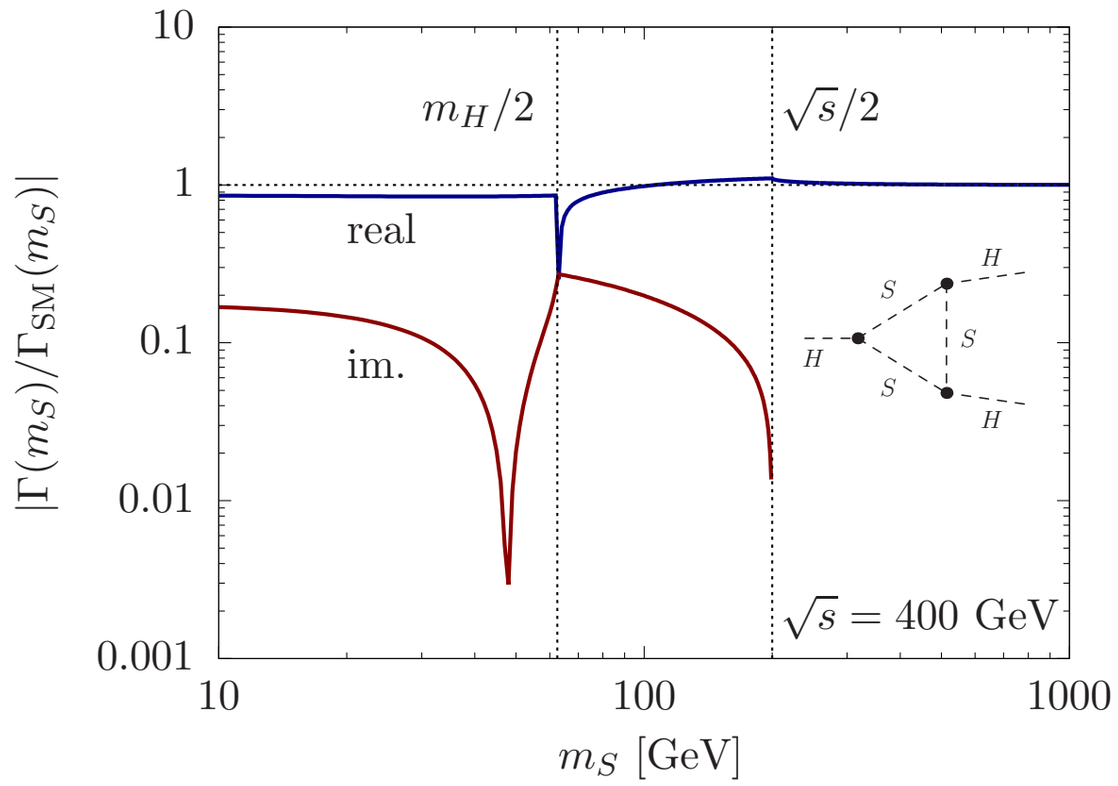


singlets above threshold

- virtual *S* exchange impacts the trilinear coupling - absorptive parts and SM coupling correlation modification

[He, Zhu `16]
[Voigt, Westhoff `17]





[CE, Jaeckel `19]

- deviation from expected SM results, with characteristic shape in invariant m_{HH} distribution

[CE, Jaeckel, Spannowsky, Stylianou `20]

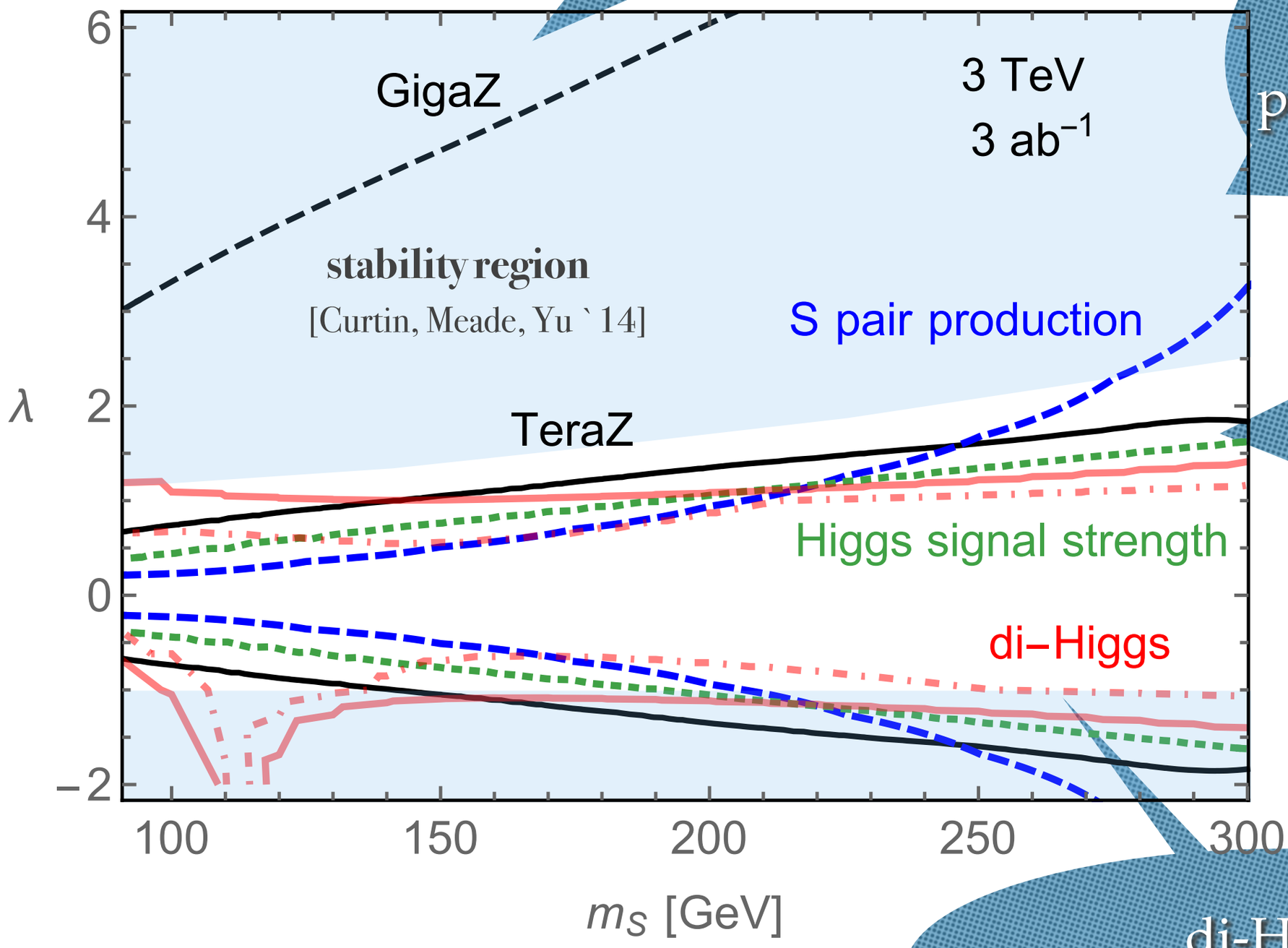
overview

Oblique corrections

off-shell production: WBF

Higgs couplings @0.4%

di-Higgs physics @ 5-10%



9

iso-singlet mixing

[Binoth, van der Bij `97]
[Schabinger, Wells `05]
[Patt, Wilczek `06]

$$V = \mu_s^2|\phi_s|^2 + \lambda_s|\phi_s|^4 \; + \; \mu_h^2|\phi_h|^2 + \lambda_h|\phi_h|^4 \; + \; \eta_\chi|\phi_s|^2|\phi_h|^2$$

- if singlet develops a vev, Higgs phenomenology is parametrised by single mixing angle

$$H_1 = \quad \cos\chi\, H_s + \sin\chi\, H_h$$
$$H_2 = -\sin\chi\, H_s + \cos\chi\, H_h$$

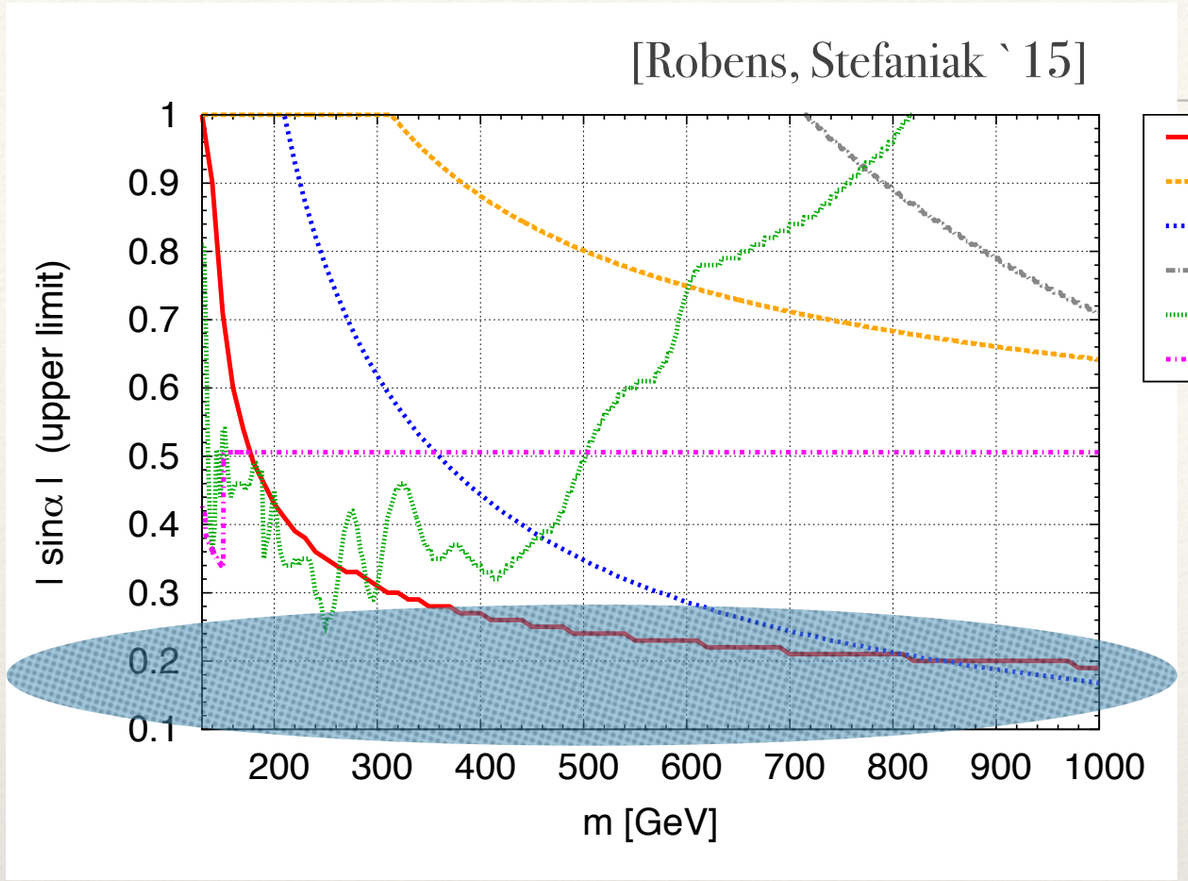
precision pheno studies:
[Bowen et al. `07]
[CE, Plehn, Zerwas `12]
[Bertoloni, McCullough `12]
[Chen, Dawson, Lewis `14]
[Lopez-Val, Robens `14]
[Chako, Cui, Hong `14]
...

SM-like cross sections & BRs

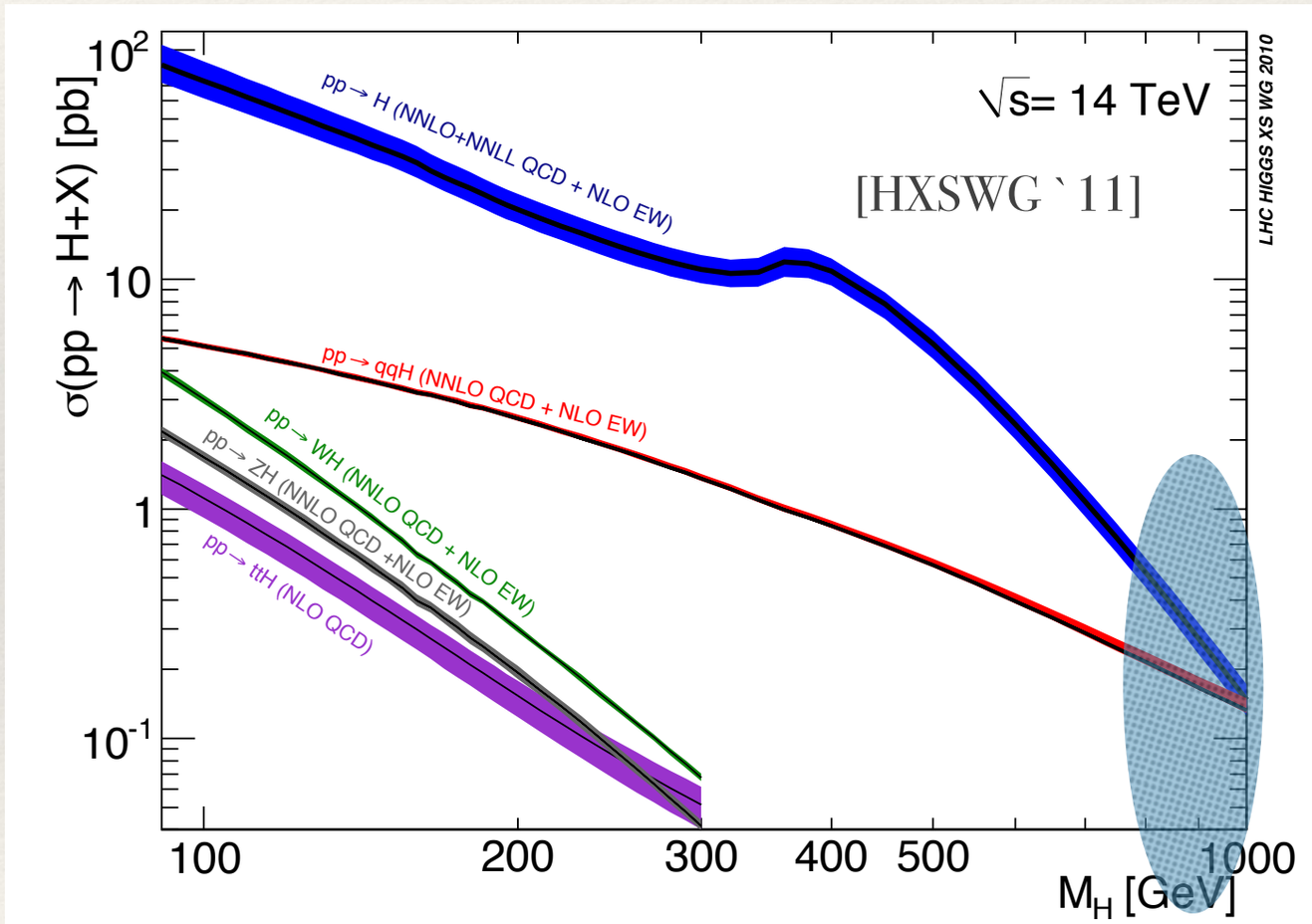
Cascade decays & modifications of SM trilinear couplings

$$\Lambda_{211} = 3\sin 2\chi \left[\cos\chi\,\frac{\lambda_s v_s^2}{v_s} - \sin\chi\,\frac{\lambda_h v_h^2}{v_h}\right]$$
$$- \tan 2\chi\,[\lambda_s v_s^2 - \lambda_h v_h^2]\left[(1-3\cos^2\chi)\,\frac{\sin\chi}{v_h} - (1-3\sin^2\chi)\,\frac{\cos\chi}{v_s}\right]$$

iso-singlet mixing



- W mass measurement crucial!

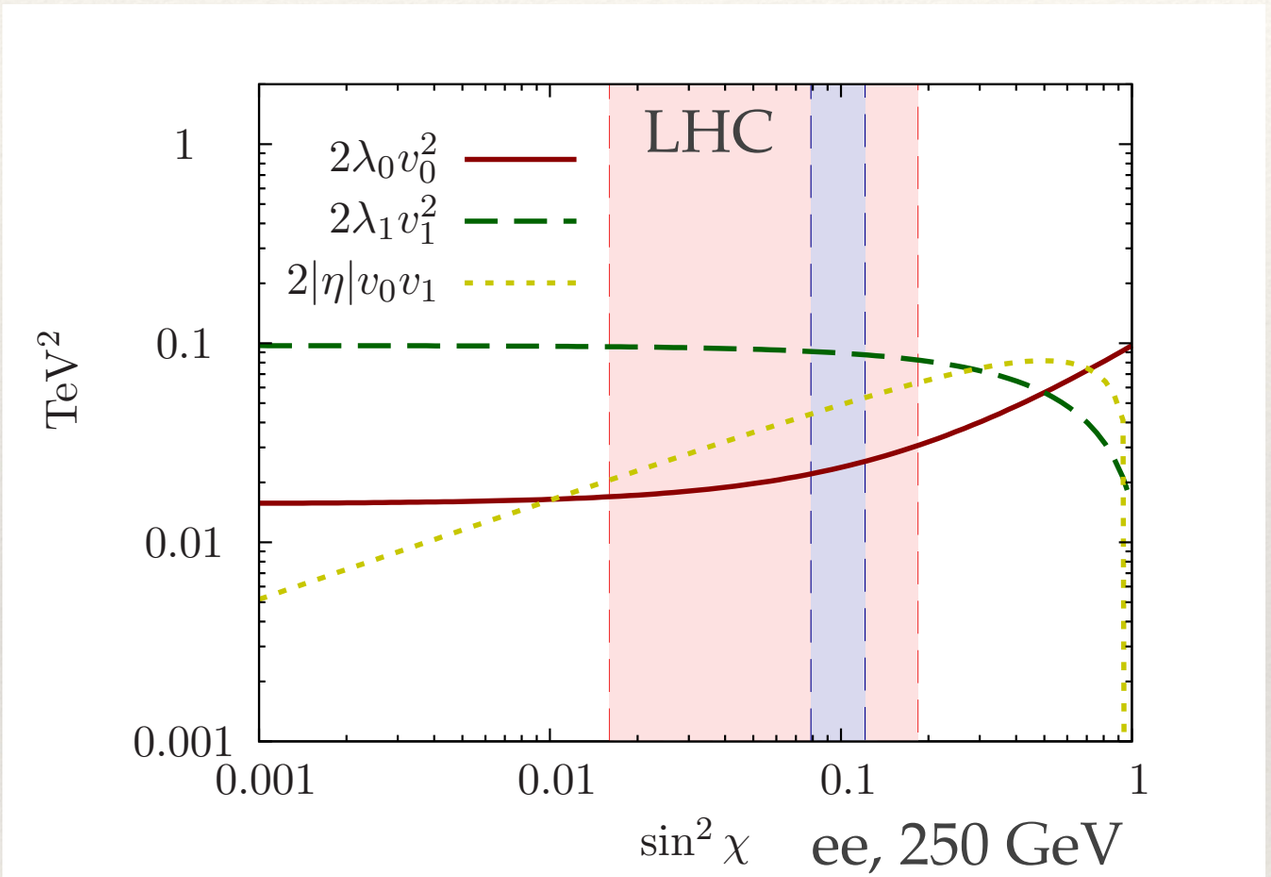


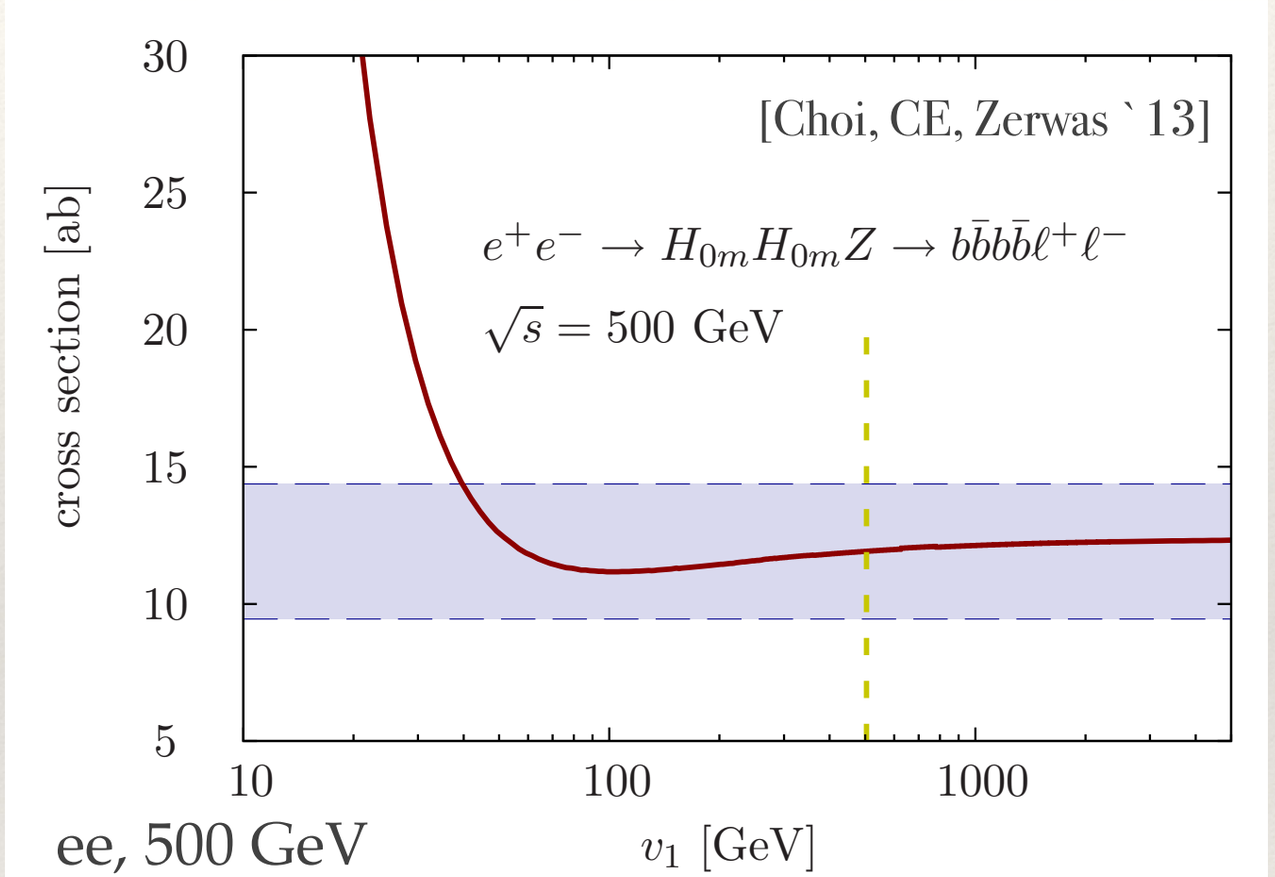
- SM-likeness of 125 GeV selects small mixing angles
- cross sections decouple for large masses

…heavy states with small mixing angles could be missed……

iso-singlet mixing

- precision measurement of diHiggs production at lepton colliders enables the parameter determination of



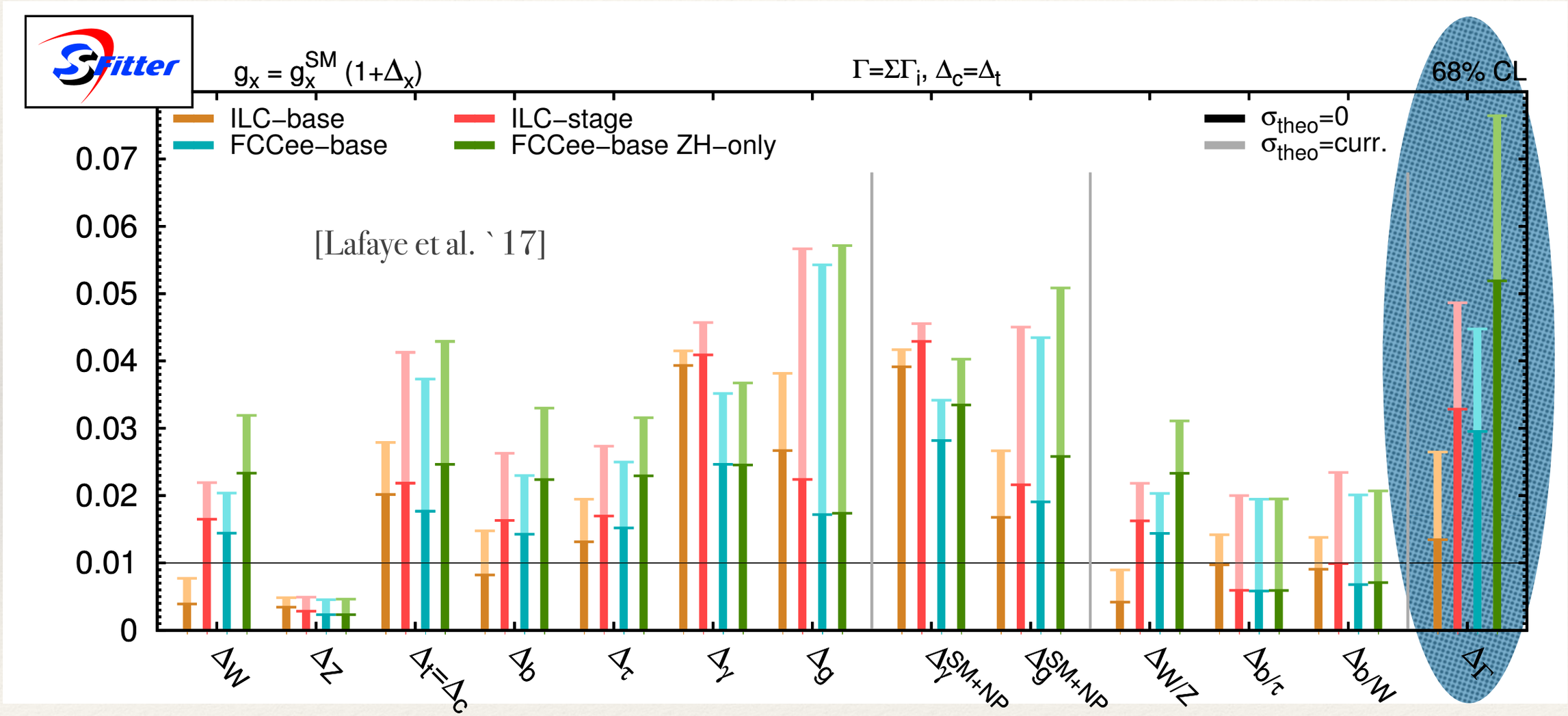


- combination of precision lepton colliders studies + possible ee/ LHC discovery → full reconstruction of extended Higgs potential

iso-singlet mixing

- Higgs width measurement possible as kappa framework is appropriate

$$\Gamma_h \sim \frac{\sigma_{\nu\nu bb}/\sigma_{Zbb}}{\sigma_{ZWW}/\sigma_{Zh}} \times \sigma_{Zh}$$



→ spectroscopy of hidden sector dynamics possible!

Summary

- Higgs portals are motivated extensions of the SM
- Portal phenomenology is a great playground to estimate collider sensitivity reach
- Clean lepton collider environment, possibly directed by LHC measurements/discoveries will yield a fine-grained picture of extended Higgs potential

Electroweak precision observables

Higgs signal strengths

Higgs pair production