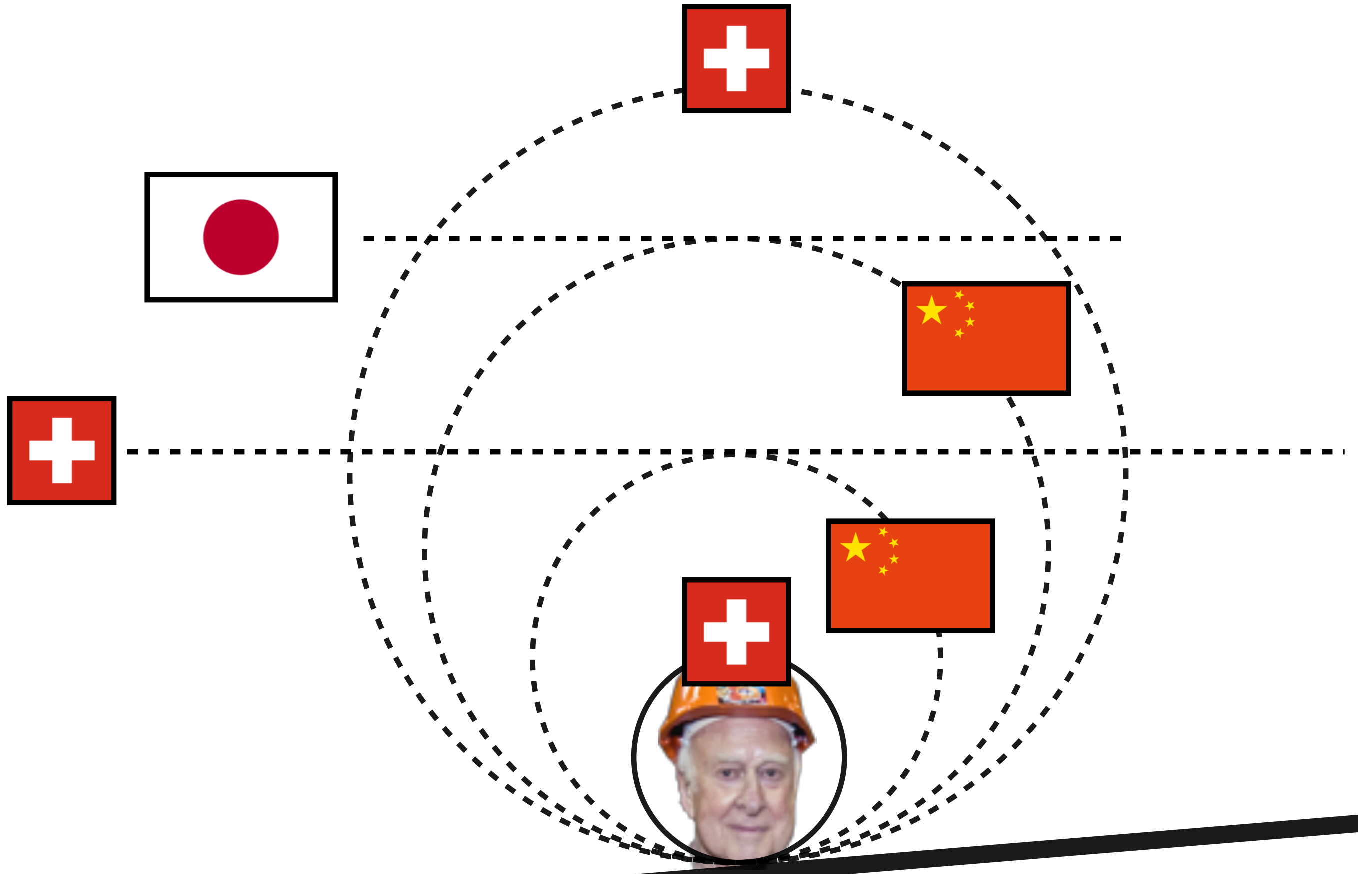
- Higgs self-coupling -

QU kickoff meeting, DESY, March 20, 2019



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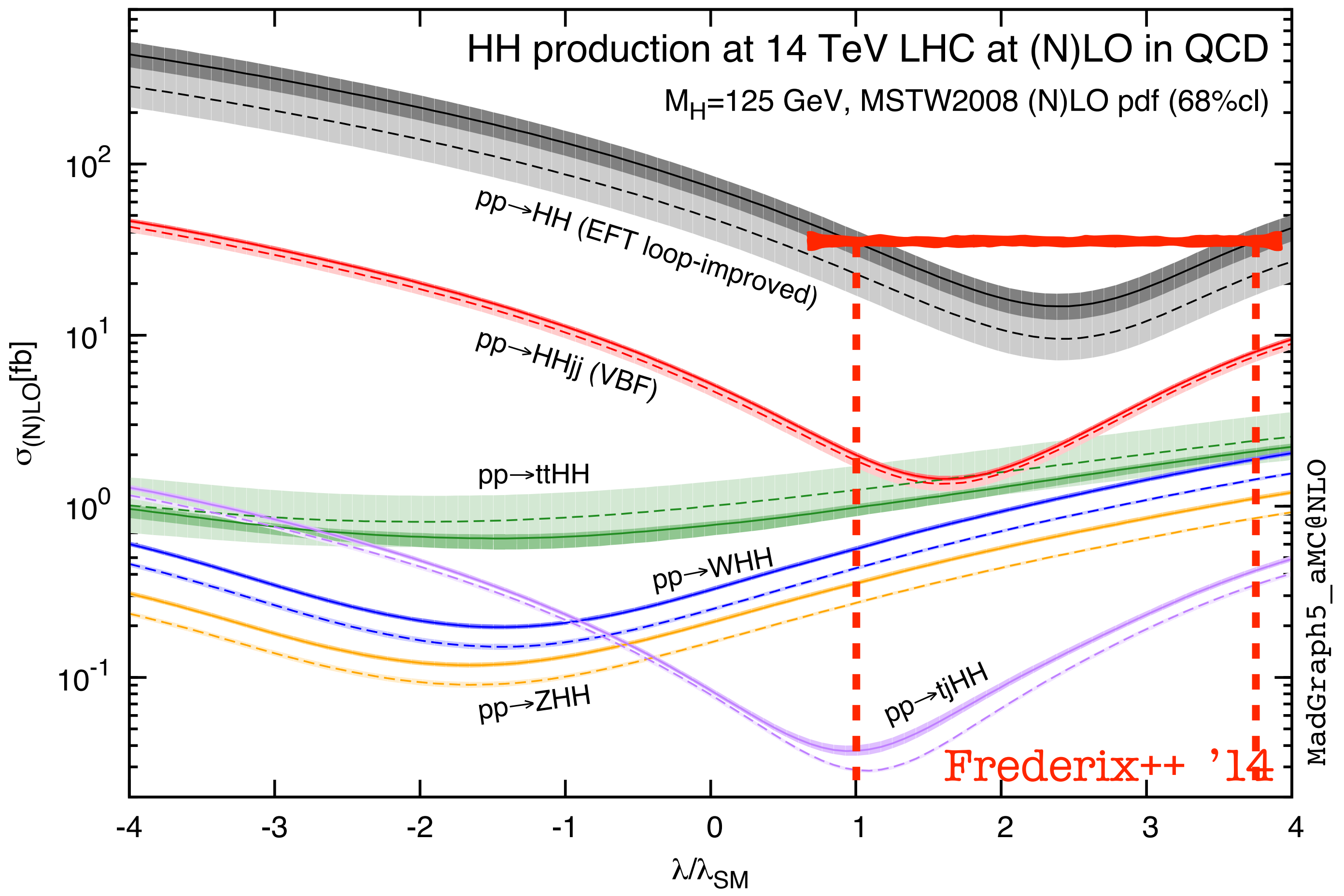
h^3 from HH @ hadron and electron colliders

pp colliders

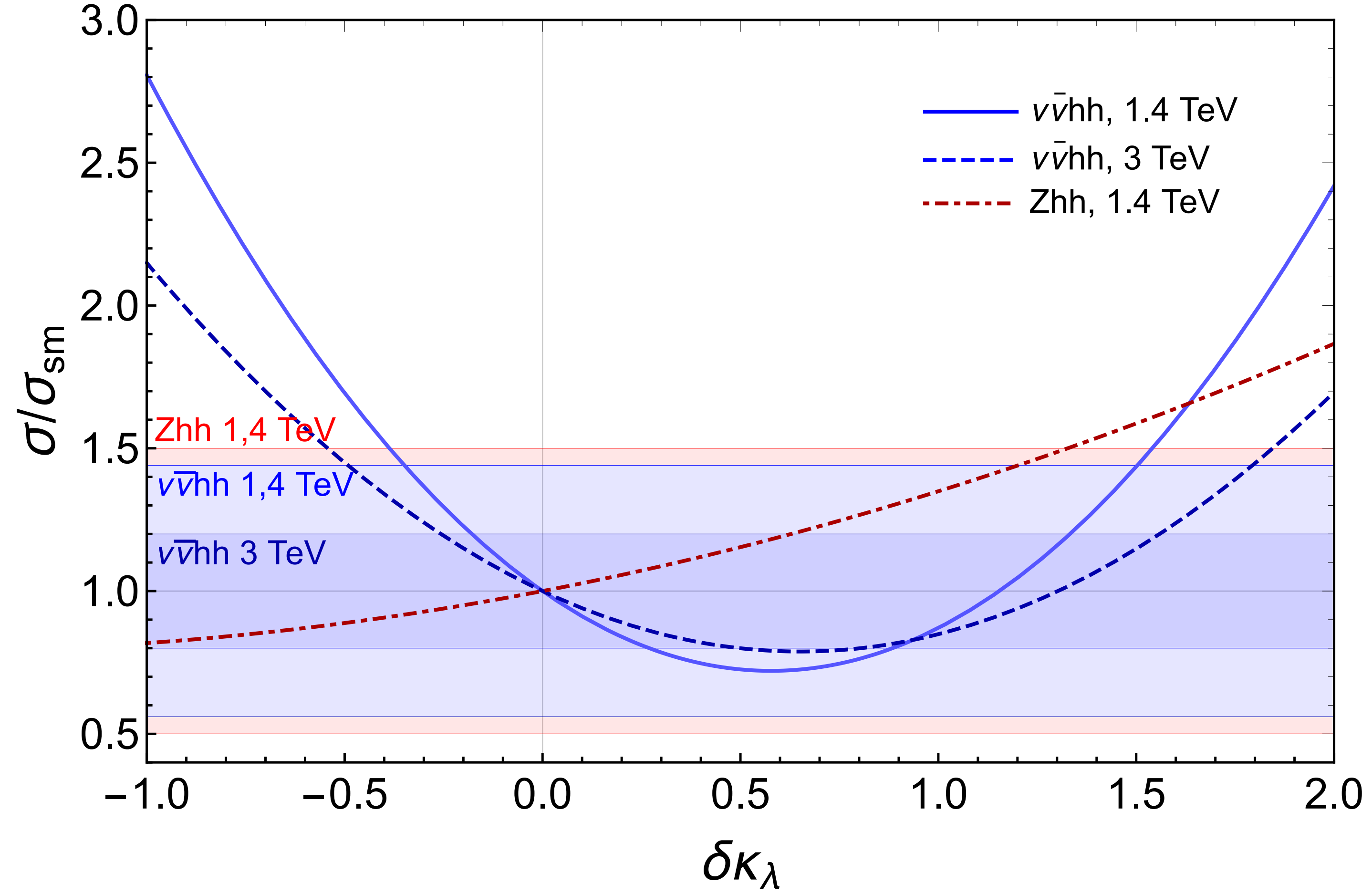


m_{hh} distribution will help separate the two degenerate points

(larger h^3, m_{hh} more picked close to threshold)

Remark: ggF xs grows rapidly with energy but h^3 is mostly affecting m_{hh} distribution near threshold

ee colliders



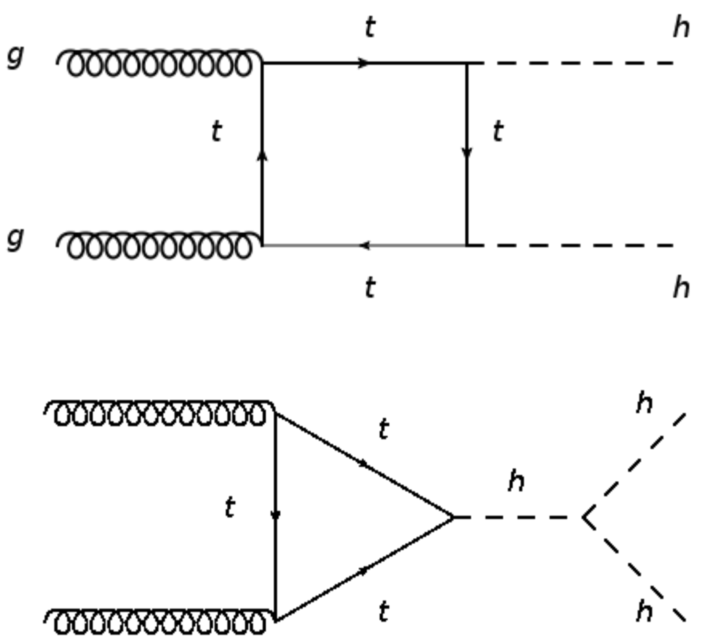
ZHH gives stronger constraints on $\delta\kappa_\lambda > 0$

$\nu\bar{\nu}HH$ gives stronger constraints on $\delta\kappa_\lambda < 0$

Remark: VBF xs grows with energy but becomes less sensitive to h^3

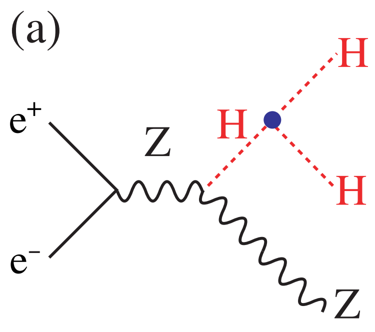
h^3 from HH @ hadron and electron colliders

pp colliders

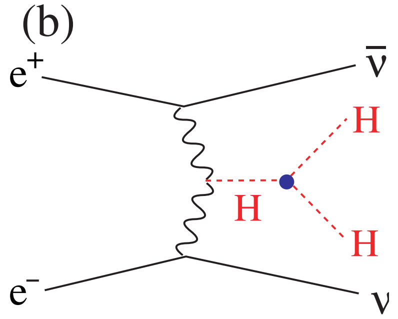


Only one kinematic observable to separate the two contributions: m_{hh}

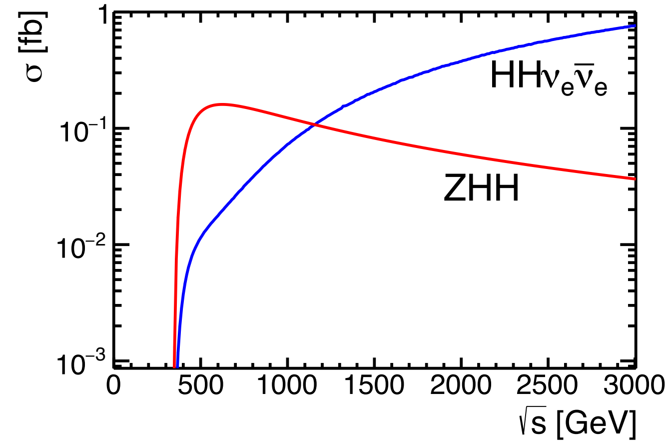
ee colliders



Signal diagram



Signal diagram

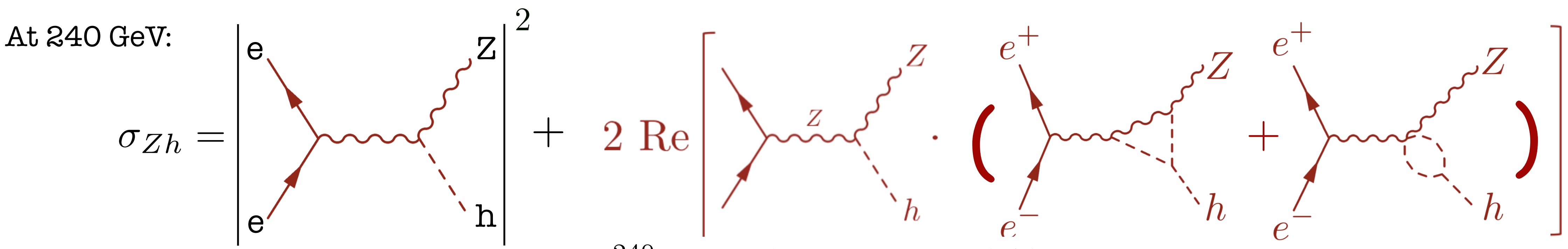


Exploit angular dependence to increase sensitivity to h^3

Future project

h^3 from h@NLO

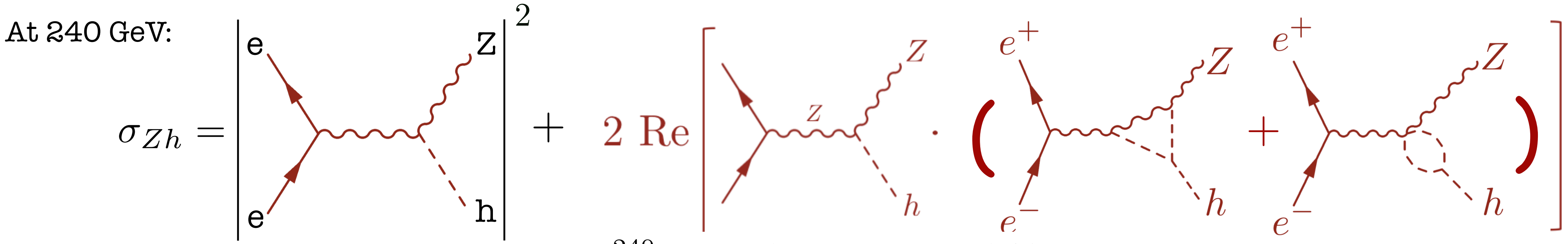
M. McCullough '14



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

h^3 from h@NLO

M. McCullough '14

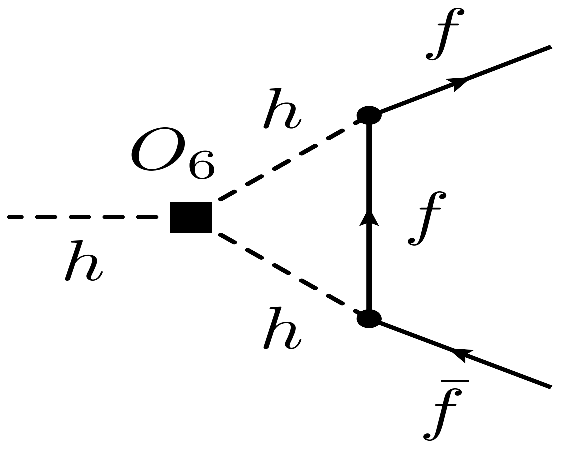


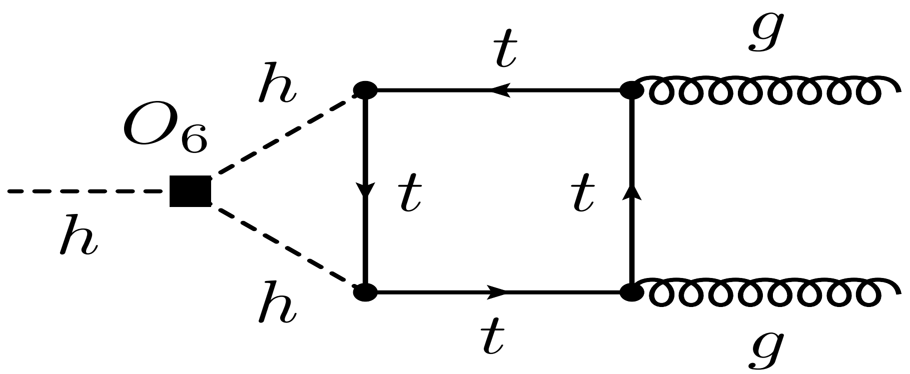
$$\delta_\sigma^{240} = 100\,(2\delta_Z + 0.014\delta_h)\,\%$$

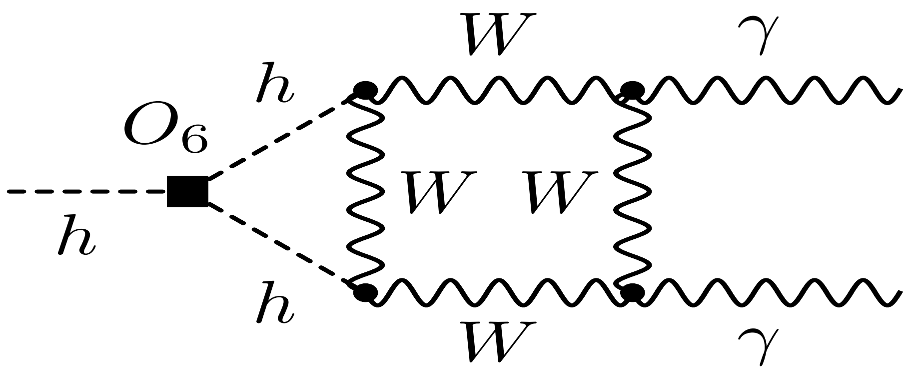
Gorbahn et al '16

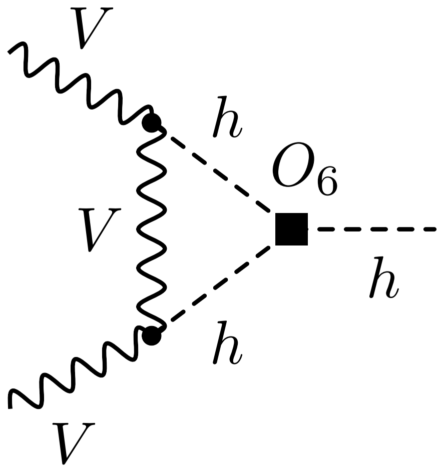
Degrassi et al '16

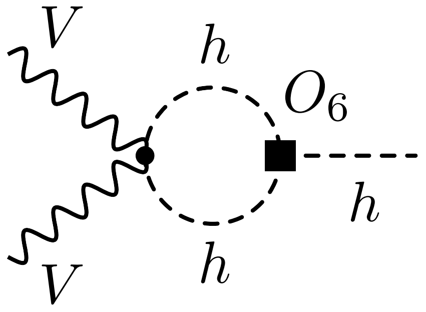
Bizon et al '16

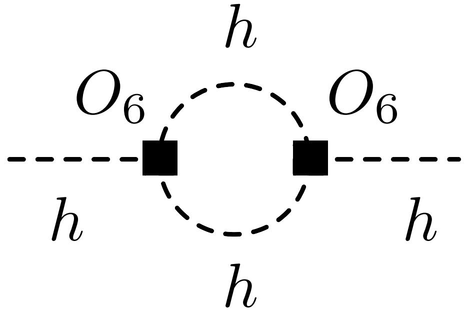




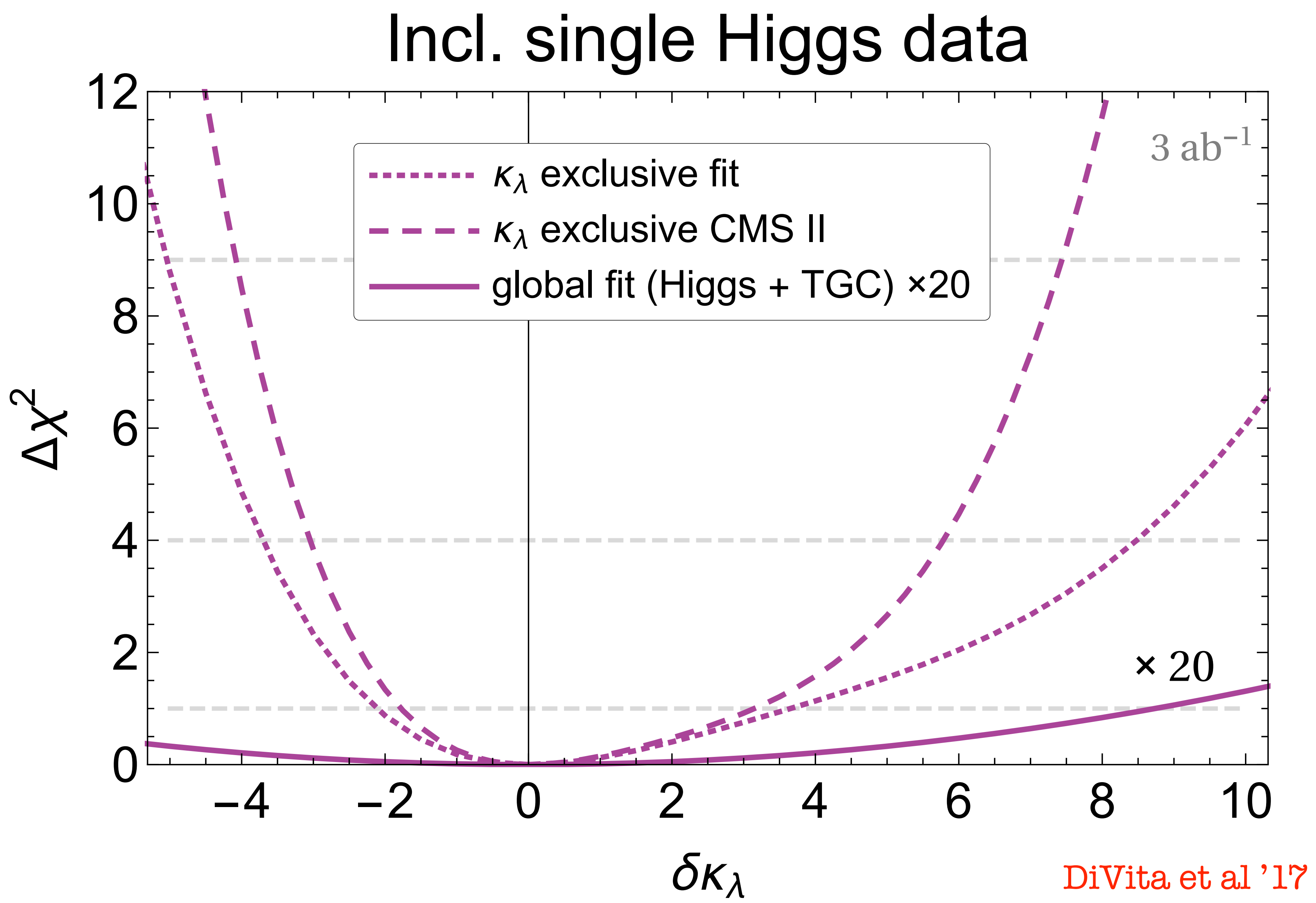








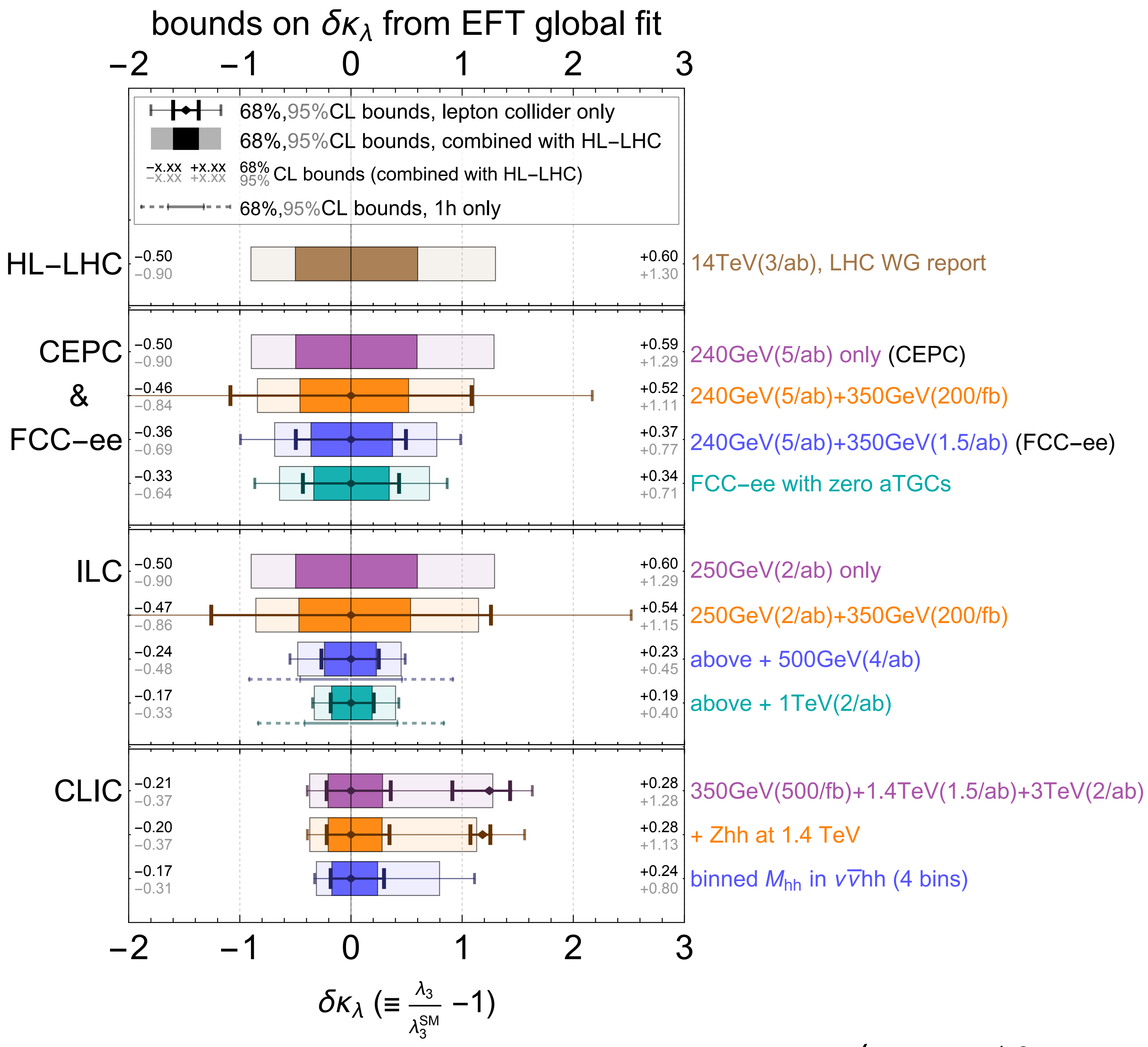
h^3 from h@NLO



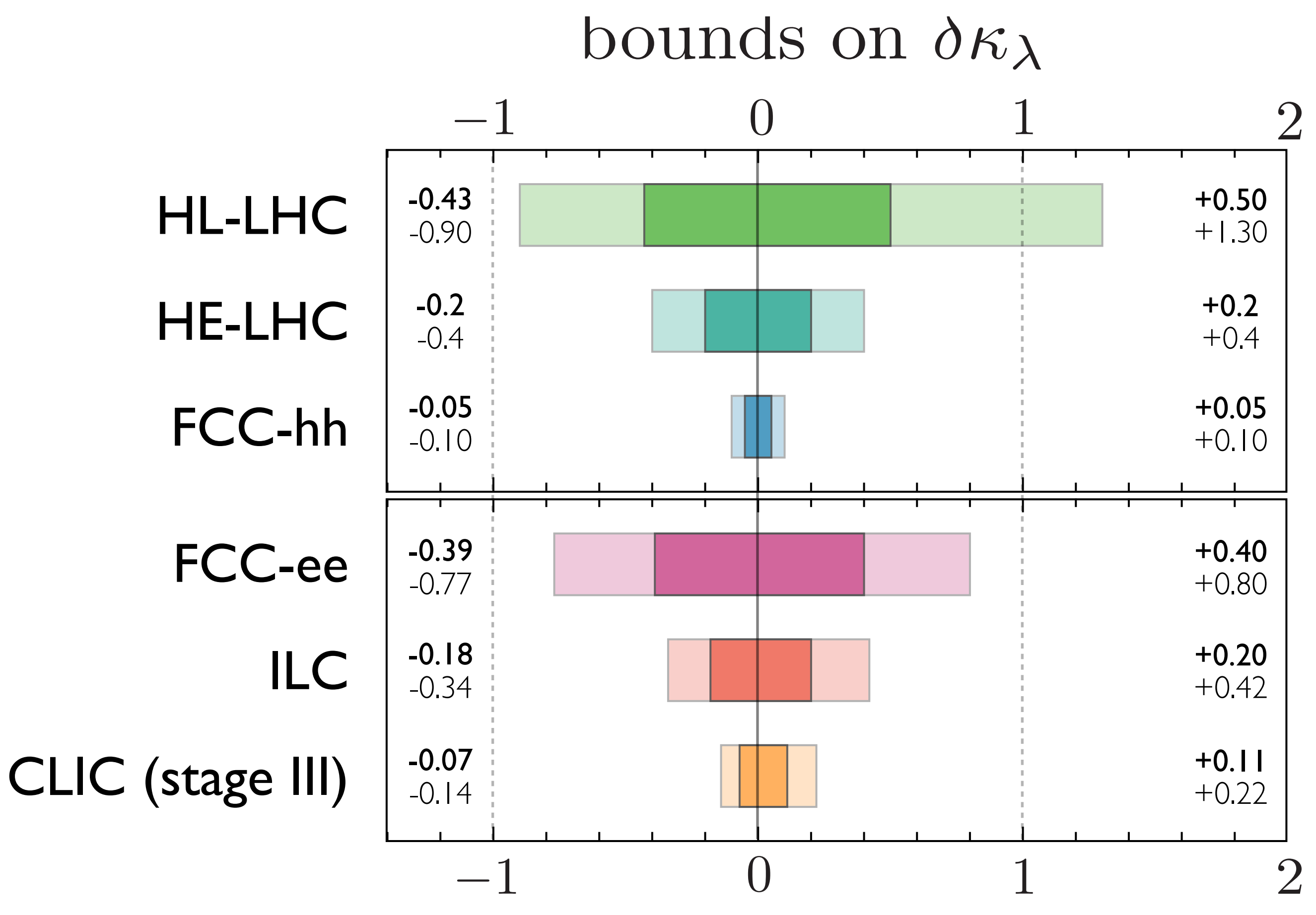
Flat likelihood (at hadron colliders) when using inclusive measurements only
Need differential information with careful estimate of corresponding uncertainty

Future prospects for h^3 measurements

DiVita et al, arXiv: 1711.03978, Fig. 12, p.23
(updated with latest HL-LHC) projections



Summary of final sensitivity on h^3 at various colliders



Dark: 68%CL, Light: 95%CL

Connections with Platform for Future Facilities

Theoretical bounds on h^3 deviations?

Question

How large can λ_{h3} be without visible deviations in other single Higgs couplings?
Or without direct discovery of new particles?
i.e. how likely it is to discover new physics in measurements of Higgs trilinear?
The answer is necessarily model depend.
In principle $|H|^6$ in EFT is independent of other operators but UV dynamics dictates power counting

Stability argument:

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

Unstable potential and/or no EWSB minimum, when κ_λ is outside [1,3]
However, the instability scale is beyond Λ, so conclusion is not EFT robust.
And consistent EFT can certainly lead to larger Higgs self-coupling deviations

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Stability argument:

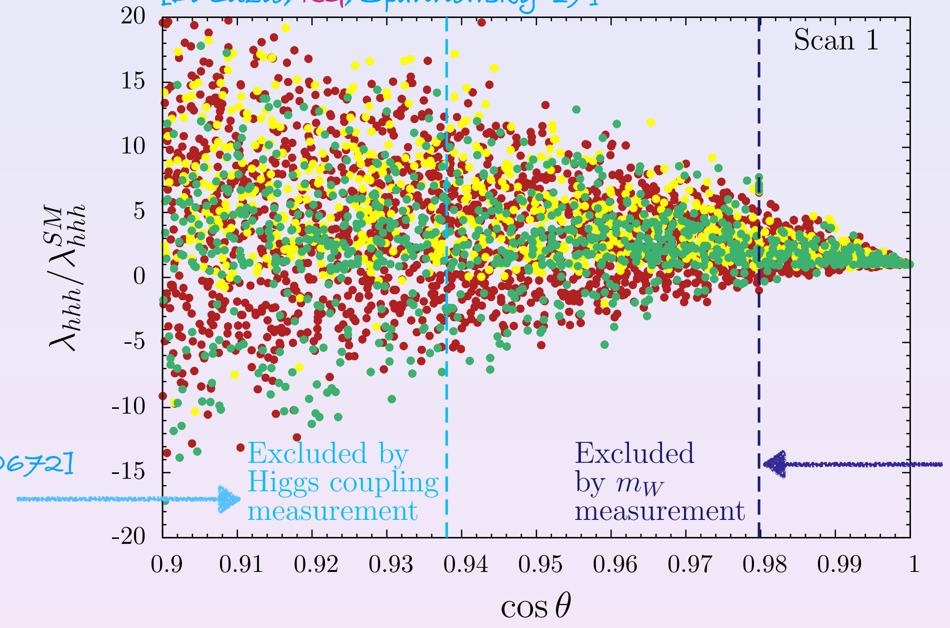
DiLuzio, Grober, Spanowsky
arXiv: 1704.02311

Example of of a model with large deviation of h^3

Singlet model

$$V(H,\Phi) = \mu_1^2|H|^2 + \lambda_1|H|^4 + \frac{1}{2}\mu_2^2\Phi^2 + \mu_4|H|^2\Phi + \frac{1}{2}\lambda_3|H|^2\Phi^2 + \frac{1}{3}\mu_3\Phi^3 + \frac{1}{4}\lambda_2\Phi^4$$

[Di Luzio, RG, Spannowsky '17]



[ATLAS 1509.00672]

[Lopez-Val, Robens '14]

Color code: electroweak vacuum is stable, metastable, unstable

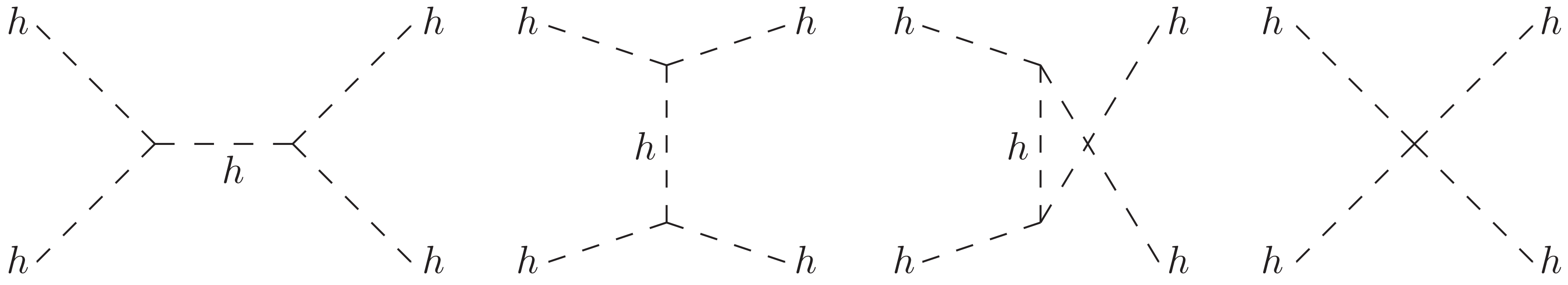
Singlet model allows for deviations of

$$-1.5 < \lambda_{hhh}/\lambda_{hhh}^{SM} < 8.7$$

Theoretical bounds on h³ deviations?

Perturbativity bounds:

DiLuzio, Grober, Spanowsky arXiv: 1704.02311
Chang, Luty arXiv: 1902.05556
Falkowski, Rattazzi arXiv: 1902.05936



The $J = 0$ partial wave is found to be

$$a^0_{hh\to hh} = -\frac{1}{2}\frac{\sqrt{s(s-4m_h^2)}}{16\pi s}\left[\lambda^2_{hhh}\left(\frac{1}{s-m_h^2} - 2\frac{\log\frac{s-3m_h^2}{m_h^2}}{s-4m_h^2}\right) + \lambda_{hhhh}\right]$$

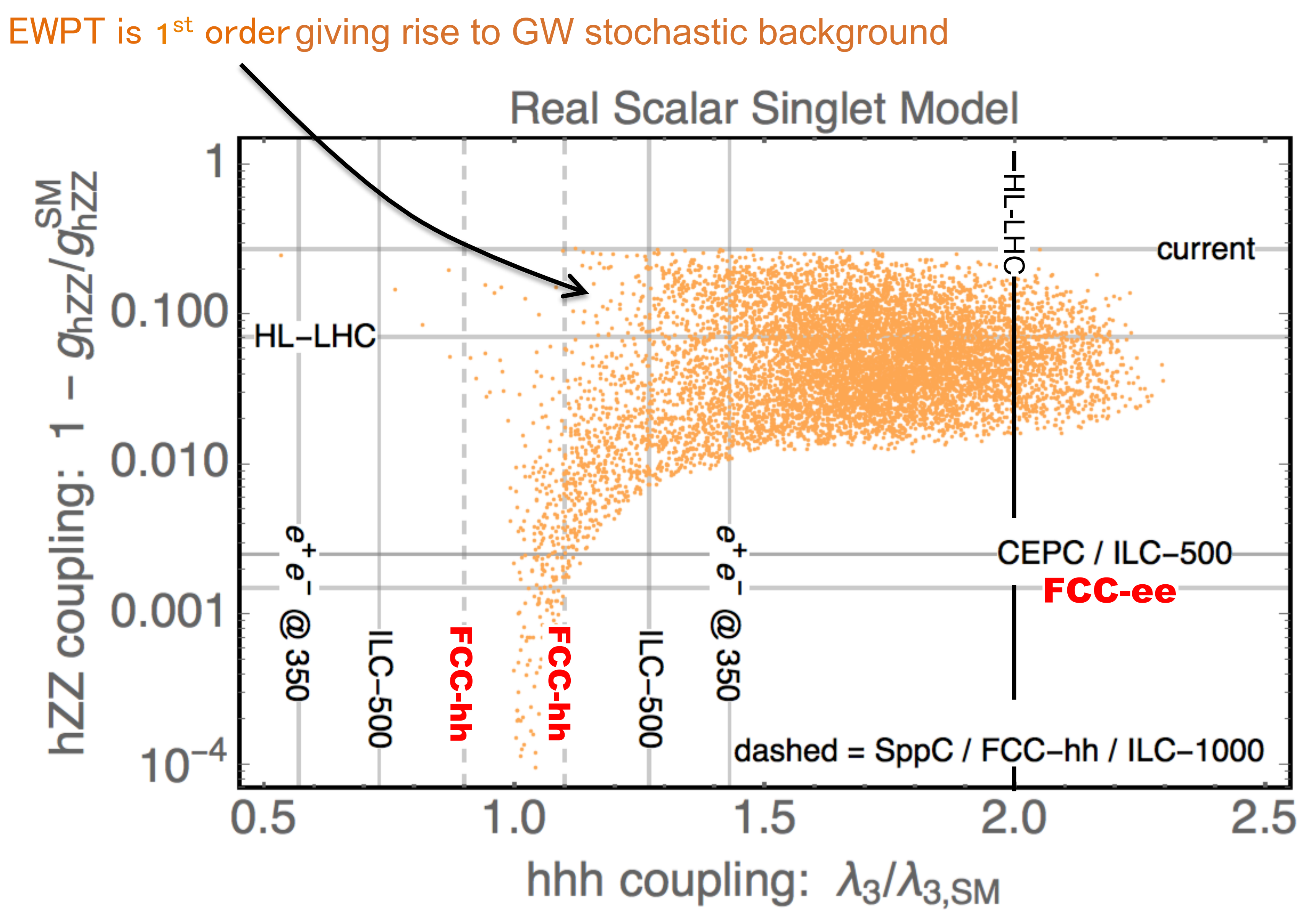
$\left|\mathrm{Re}\, a^0_{hh\to hh}\right| < 1/2$ ➡ $\left|\lambda_{hhh}/\lambda^{\rm SM}_{hhh}\right| \lesssim 6.5$ and $\left|\lambda_{hhhh}/\lambda^{\rm SM}_{hhhh}\right| \lesssim 65$

However new degrees of freedom can appear before perturbativity is lost and larger deviations on Higgs self-couplings can be theoretically consistent
New physics scale around 1TeV for O(1) modifications of h³

Connections with QT projects: perturbativity bounds with multi-particle final states?

Higgs couplings and EW phase transition

Huang, Long, Wang '16



Collider sensitivities not updated!

Connections with GW3/H1/H2 projects

Look at various BSM models
e.g. composite Higgs or extended Higgs sector

Future project