Christoph Englert

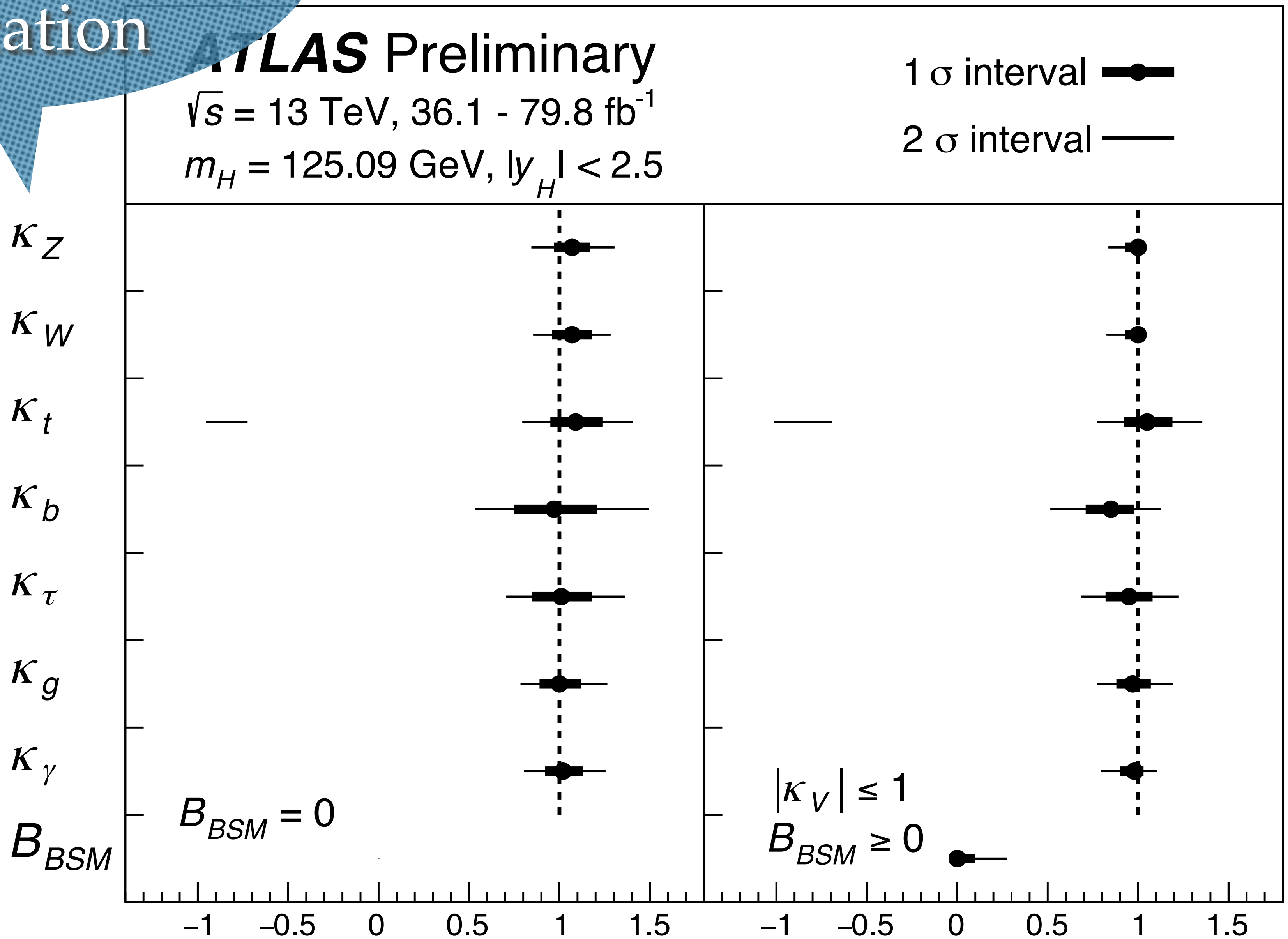
Higgs phenomenology for new physics

XXVI Cracow Epiphany Conference

09/01/2020

Status of LHC measurements

Higgs coupling/SM expectation



[ATLAS `18]

- lack of CP violation, hierarchy,…. Where's the new physics?

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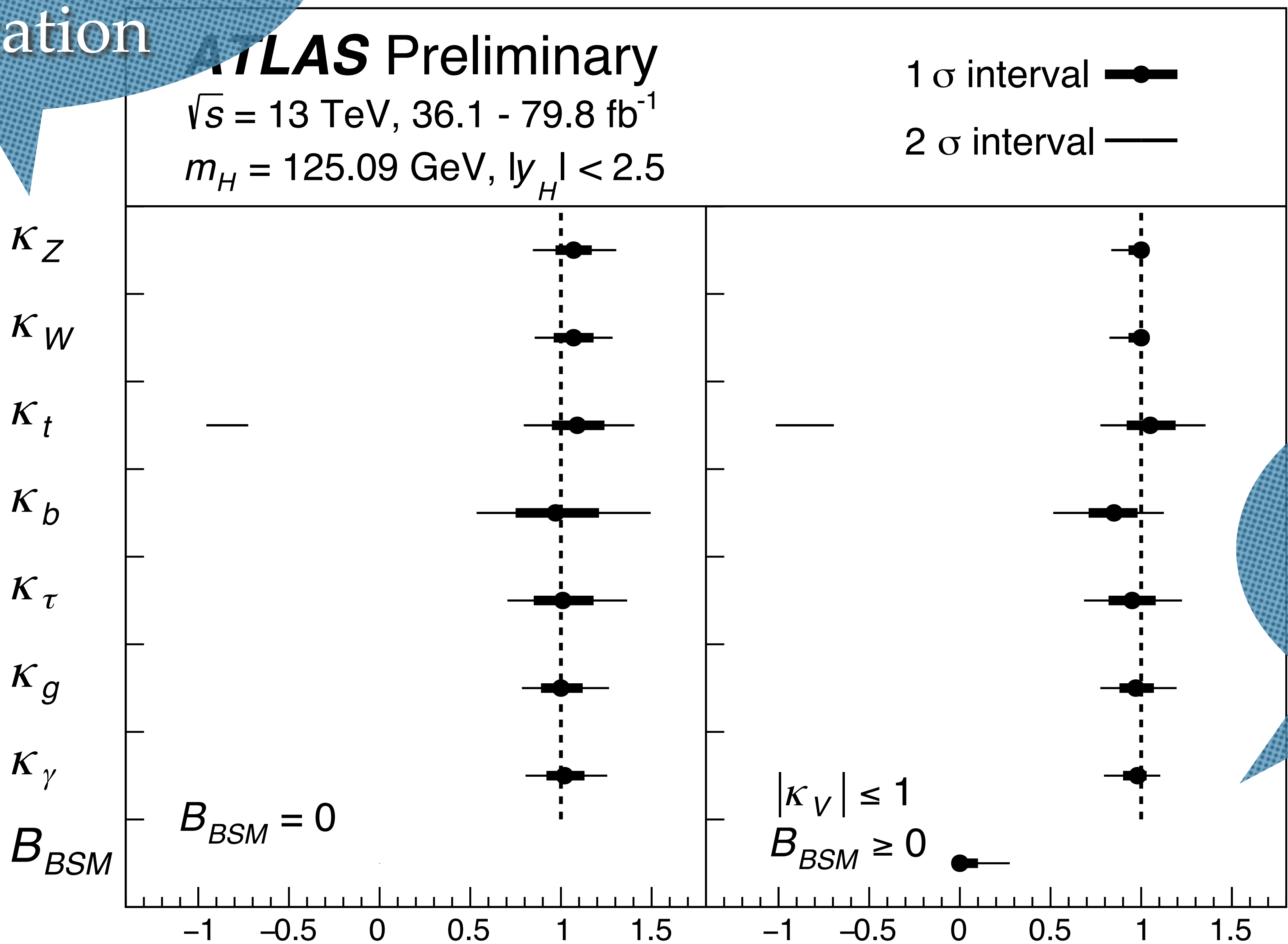

[ATLAS `18]

Higgs coupling/SM expectation

Higgs self-coupling missing…

☛ lack of CP violation, hierarchy,…. Where's the new physics?

- Can Higgs phenomenology pinpoint BSM solutions?

Why have we not seen them yet?

What can be learned at 3/ab?

What about beyond the LHC?

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LHC can investigate this in three directions

1. precision of Higgs coupling extraction
2. sensitivity of rare final states (e.g. di-Higgs) and exotics
3. sensitivity to weakly-coupled BSM

Higgs physics as a probe of (B)SM physics

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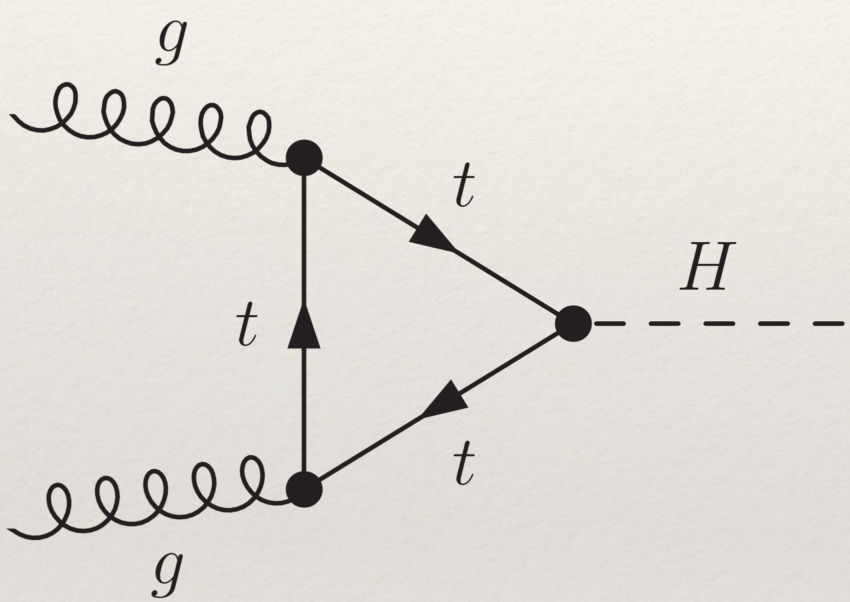
SM couplings

- Higgs coupling extraction is made difficult by “blind directions”
- one of the most prominent an relevant for Higgs physics

[Vainstein et al. ` 70]
[Ellis et al. ` 76]
....



$$\xrightarrow{m_t \to \infty} \quad \supset \frac{\alpha_s}{12\pi} G^{a\mu\nu} G^a_{\mu\nu} \frac{H}{v}$$

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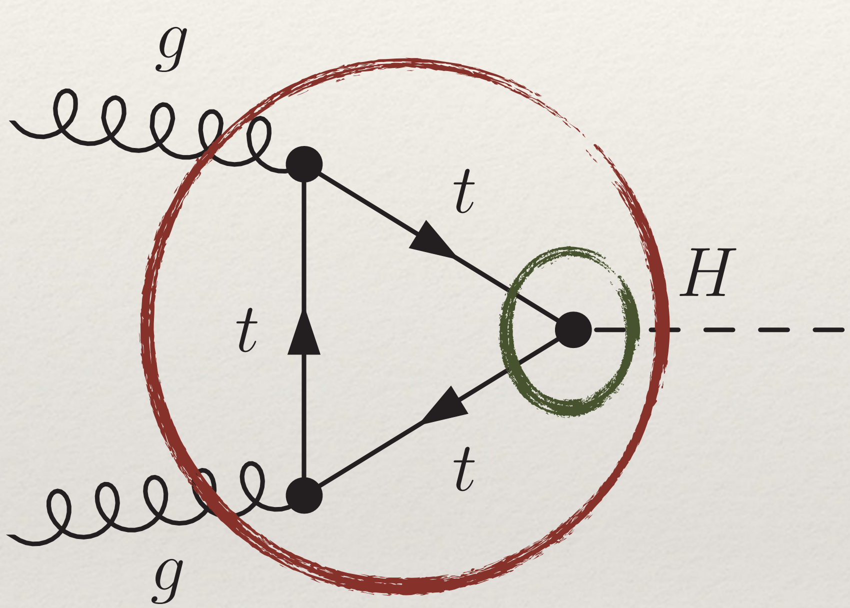


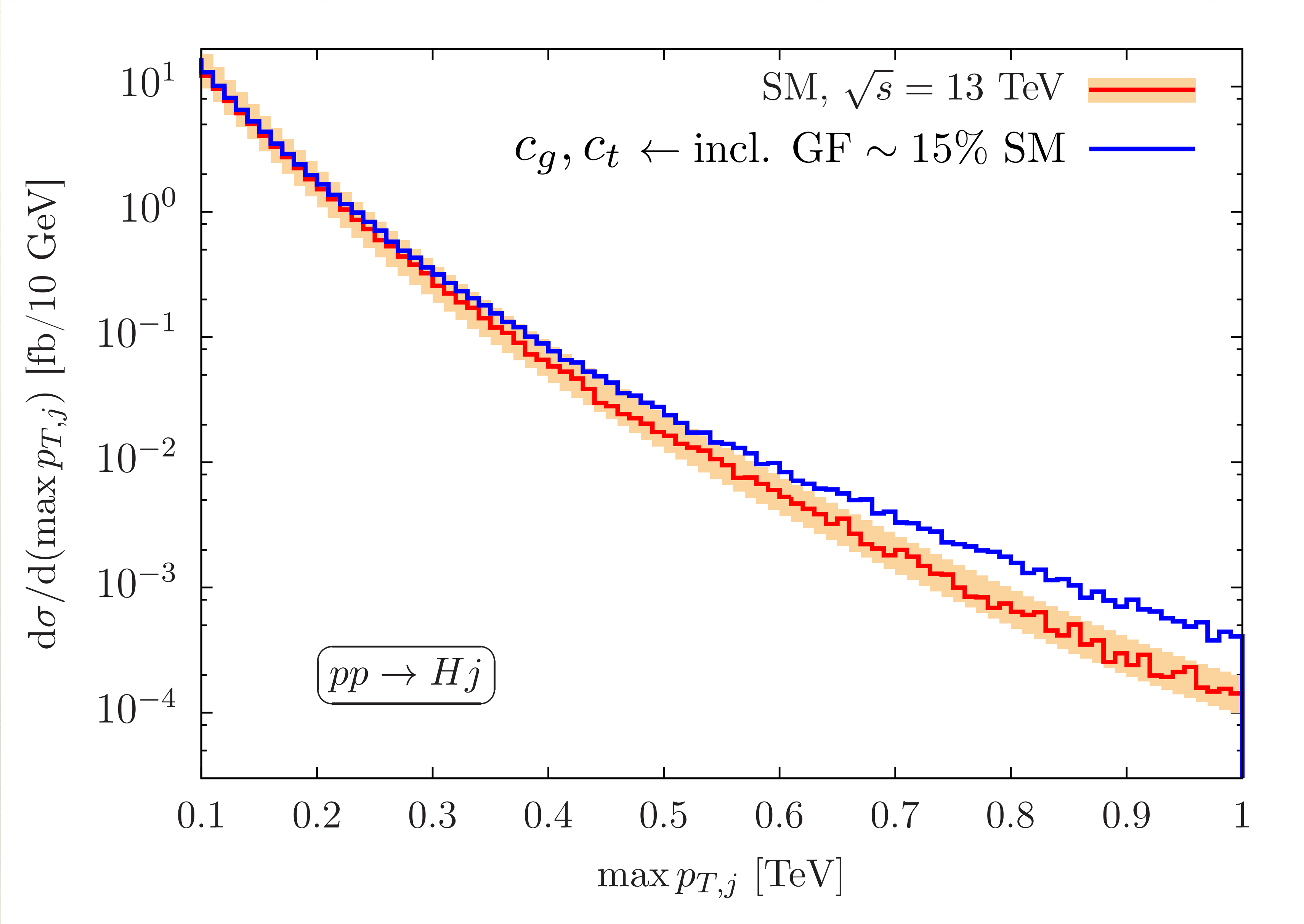
$$\xrightarrow{m_t \to \infty} \quad \subset \frac{\alpha_s}{12\pi} G^{a\mu\nu} G^a_{\mu\nu} \frac{H}{v}$$

contact ggH interactions mask top Yukawa measurements

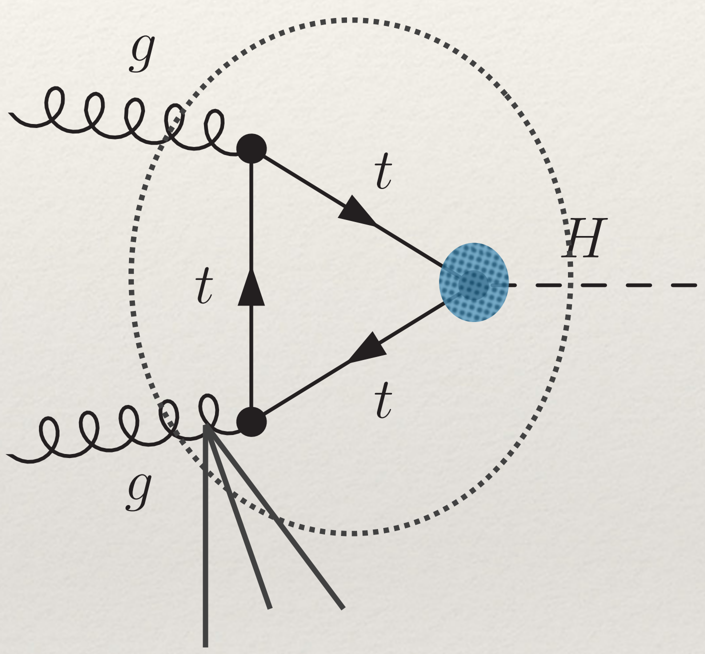
- way out: resolve loop for $p_T(H) \gtrsim m_t$ with one or more jets

[Banfi, Martin, Sanz ` 13] [Grojean, Salvioni, Schlaffer, Weiler ` 13]
[Schlaffer et al` 14] [Buschmann et al. ` 14] [Buschmann et al. ` 14]...

Hadron collider systematics



→ J. Lindert's talk



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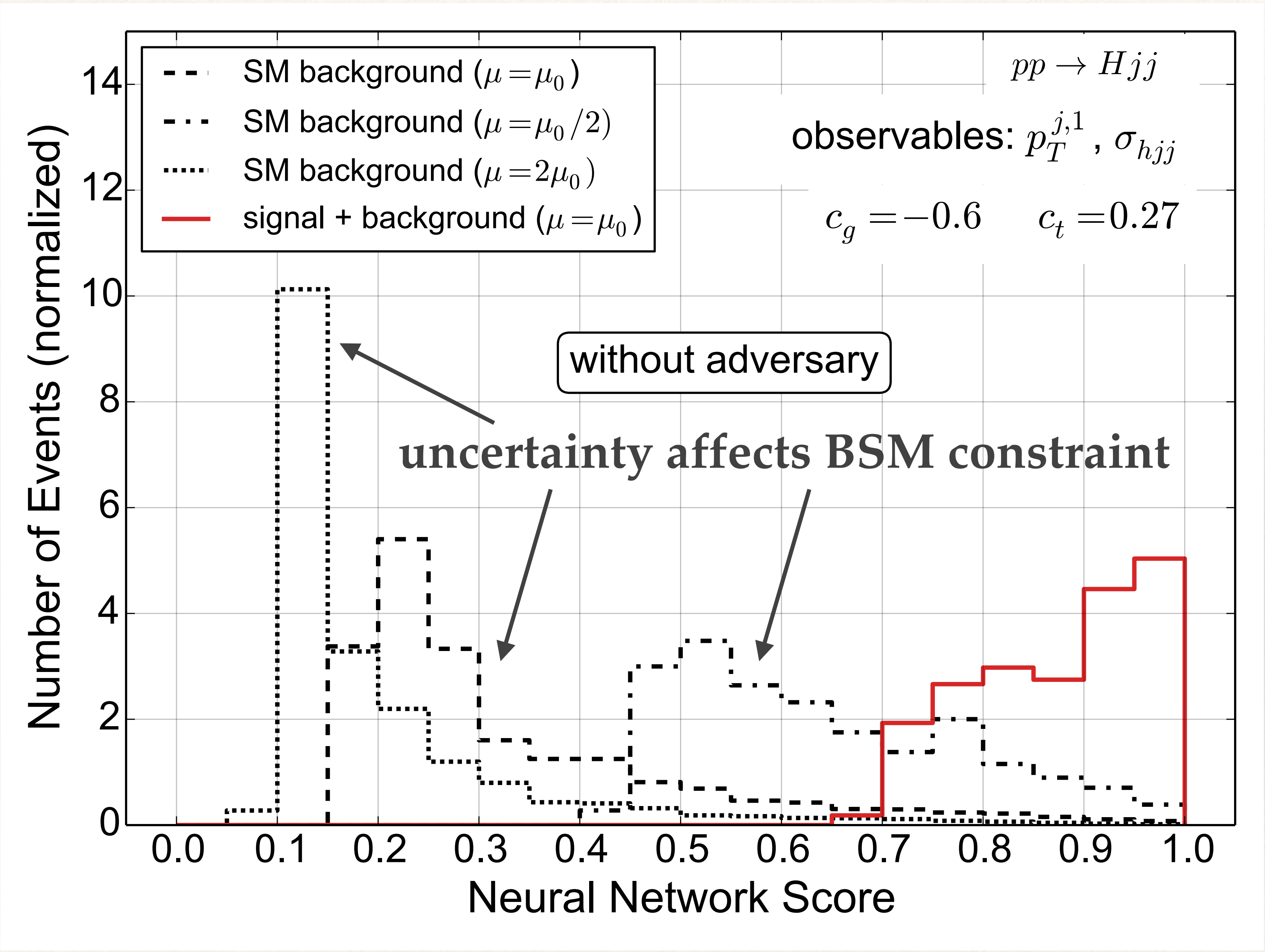
SM couplings

- more kinematic information for H+2j, which is particularly promising, unfortunately $m_t=\infty$ SM limit accidentally good [Del Duca et al. `01]...



→ S. Forte's talk

[CE, Galler, Harris, Spannowsky `18]

neural net learns regions that are sensitive to uncertainty....

SM couplings

[CE, Galler, Harris, Spannowsky ` 18]

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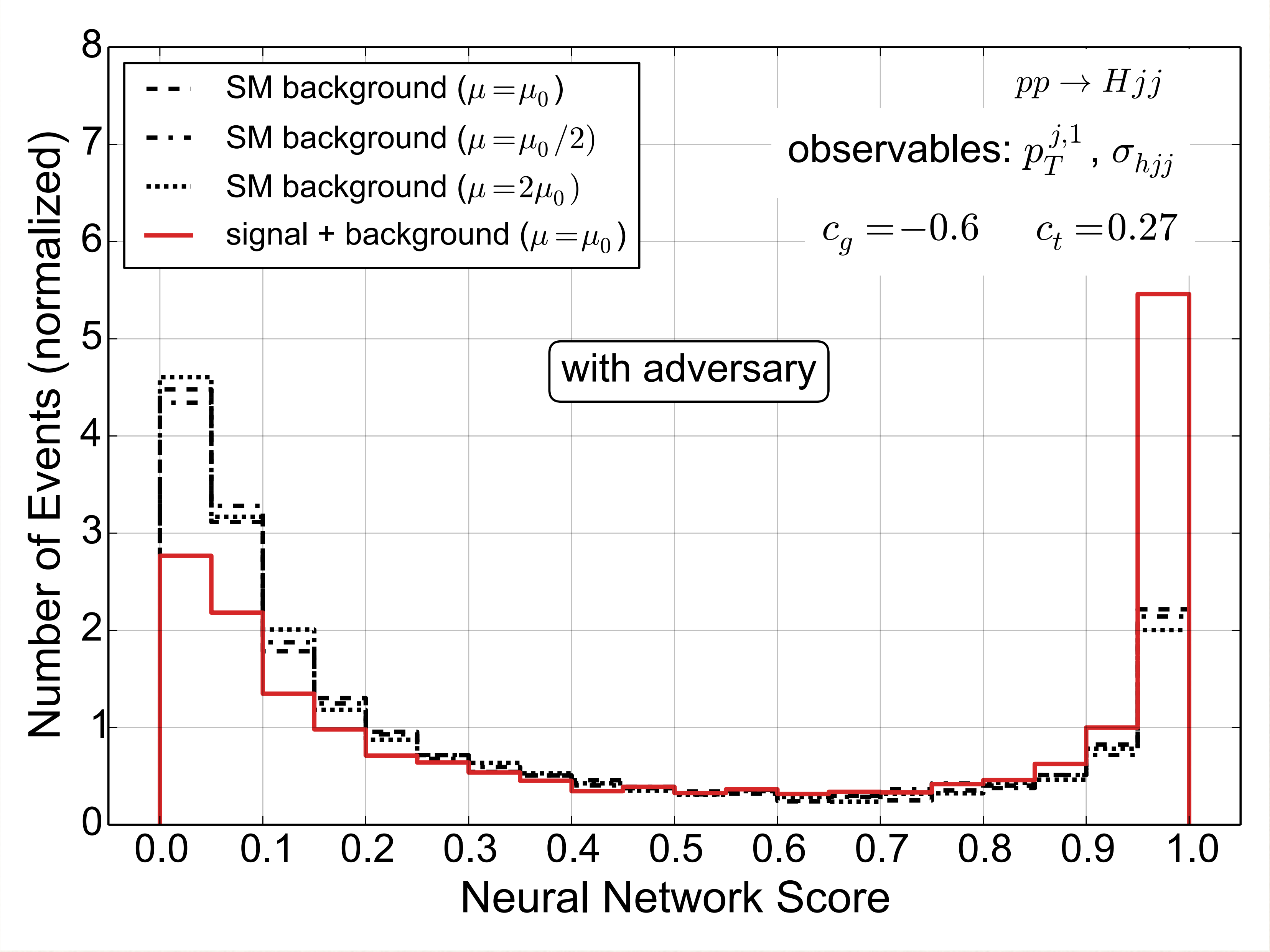

[CE, Galler, Harris, Spannowsky ` 18]

… and can learn to avoid them → **robustness at highest sensitivity**

see also [Goodfellow et al. ` 14] [Louppe, Kagan, Cranmer ` 16] …

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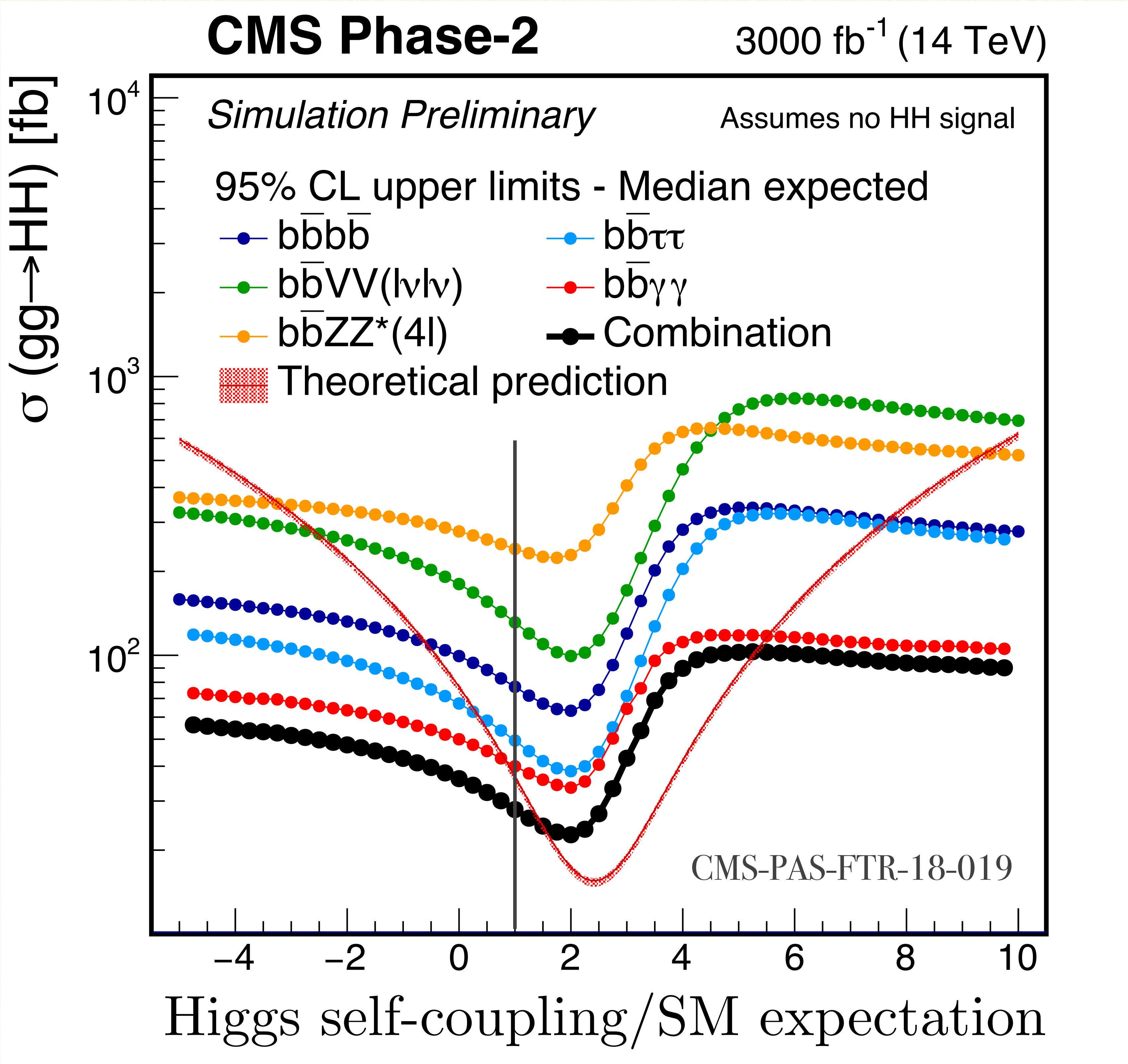
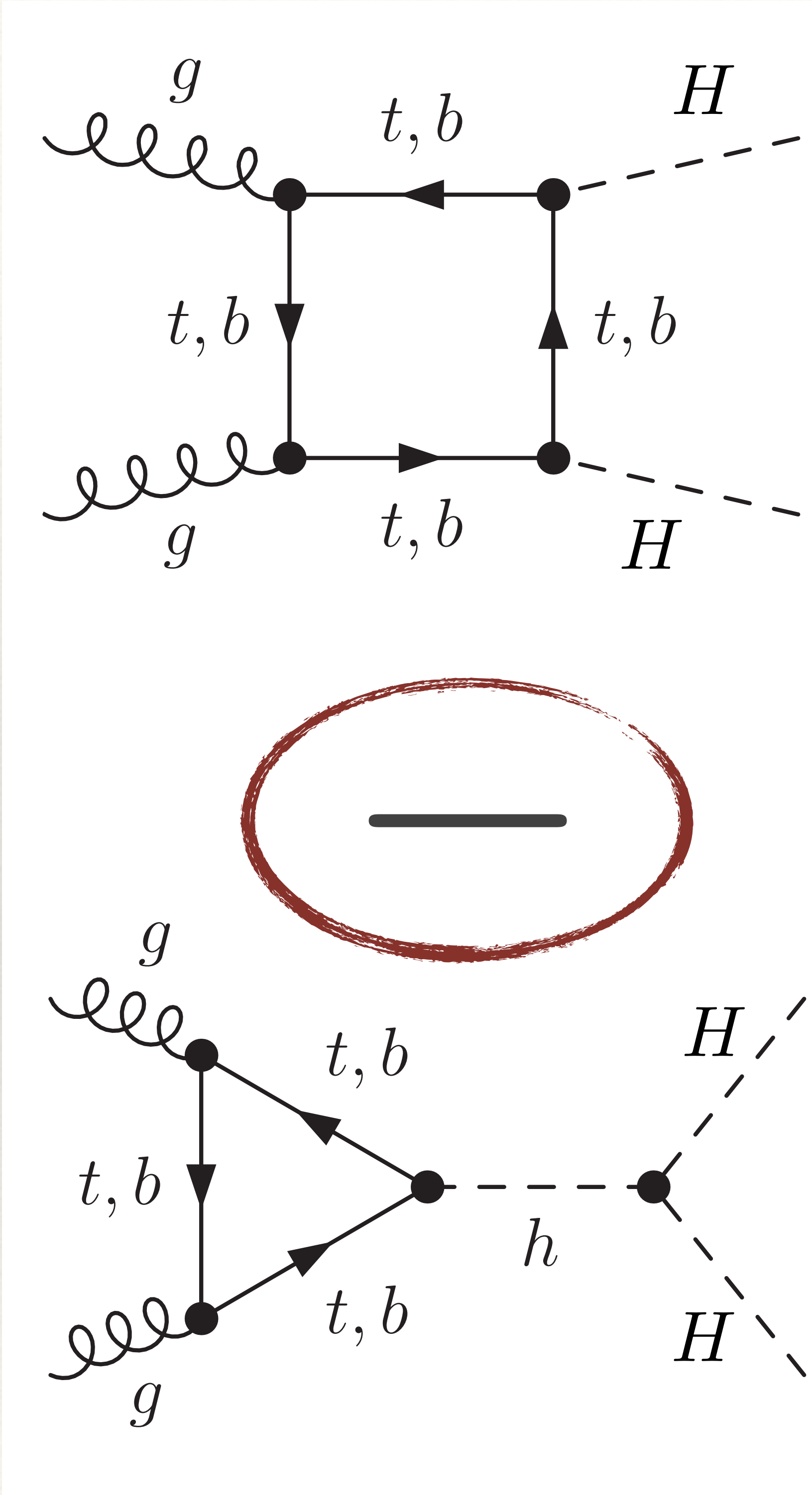
di-Higgs final states

rare final states = large statistics





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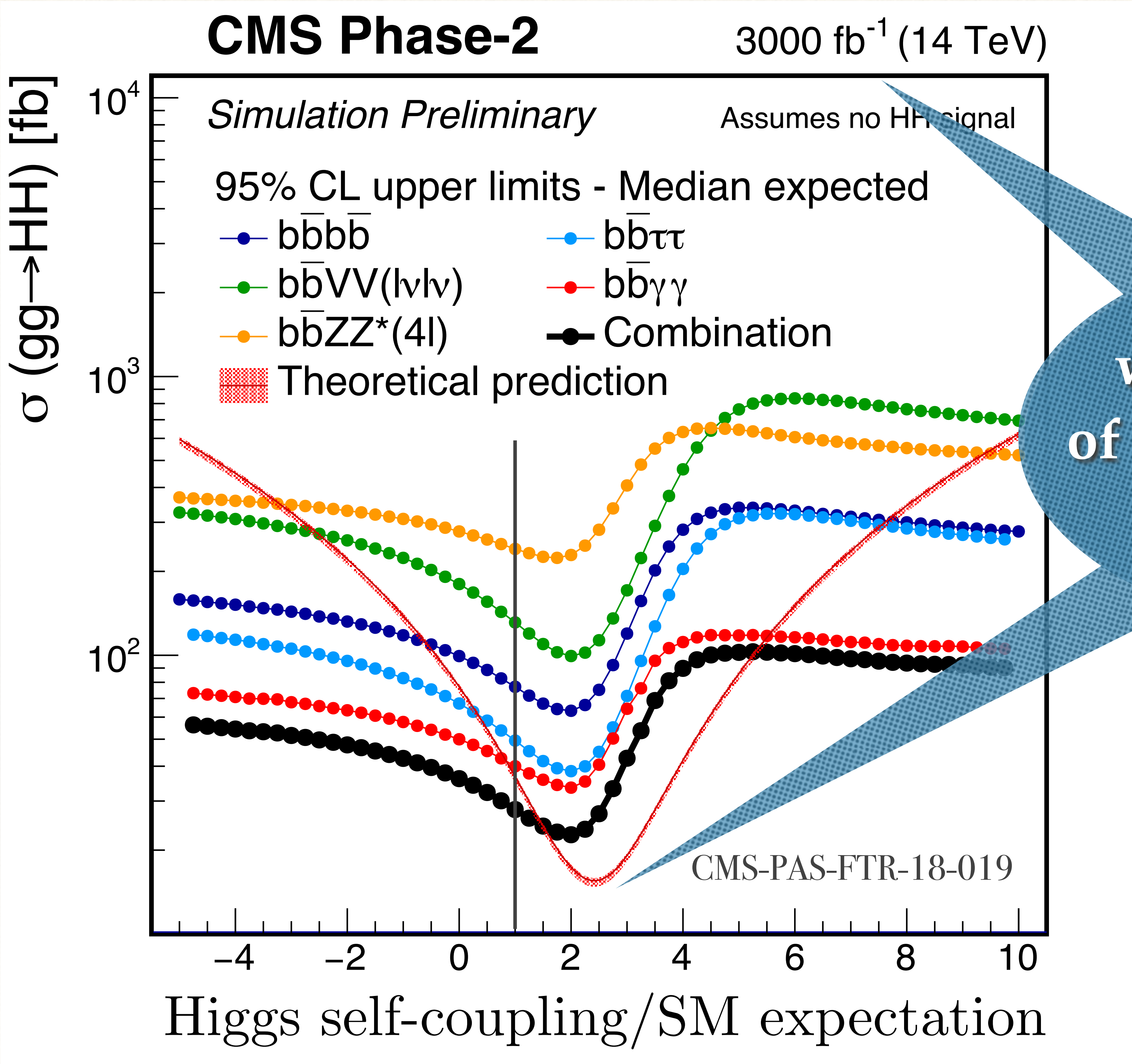

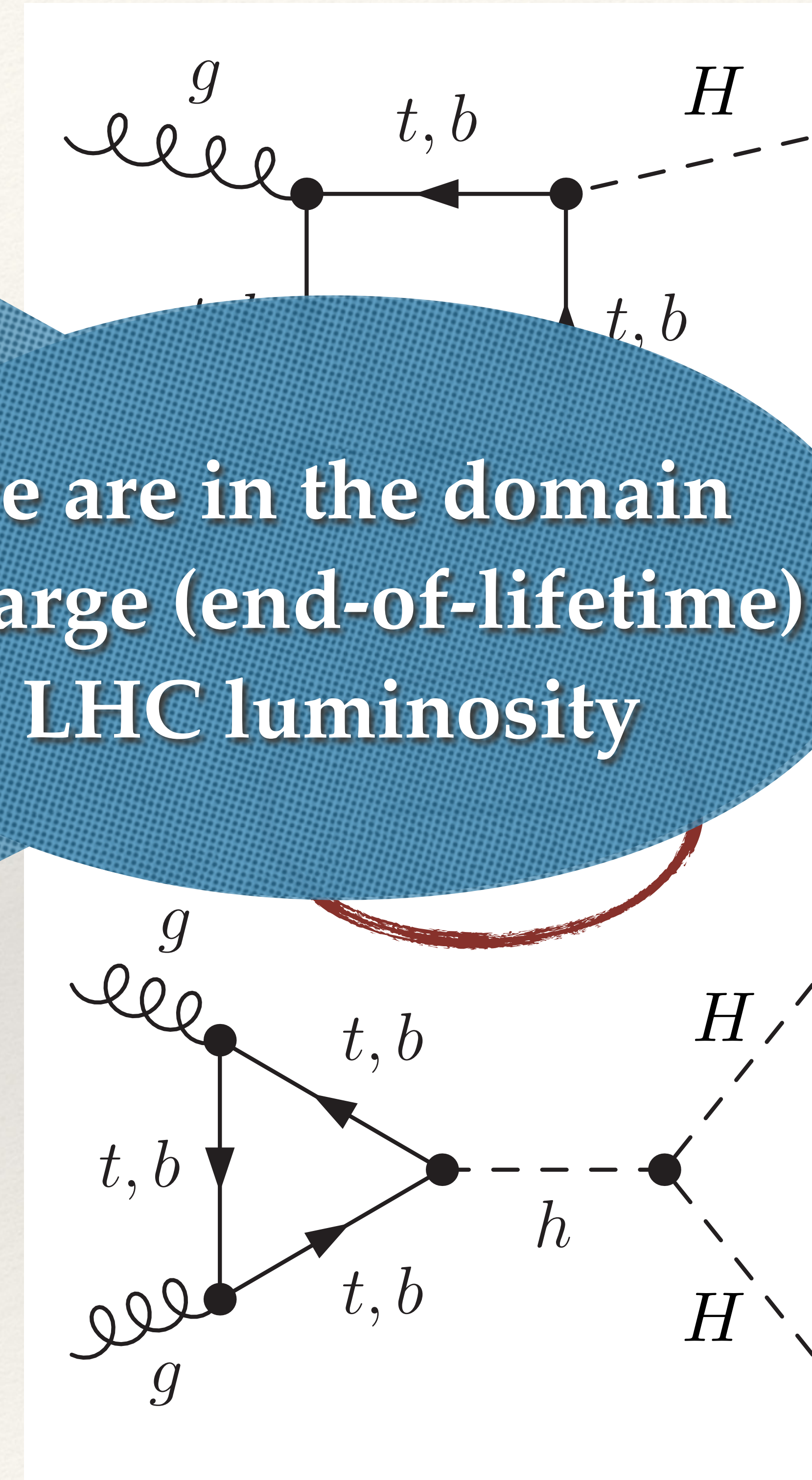

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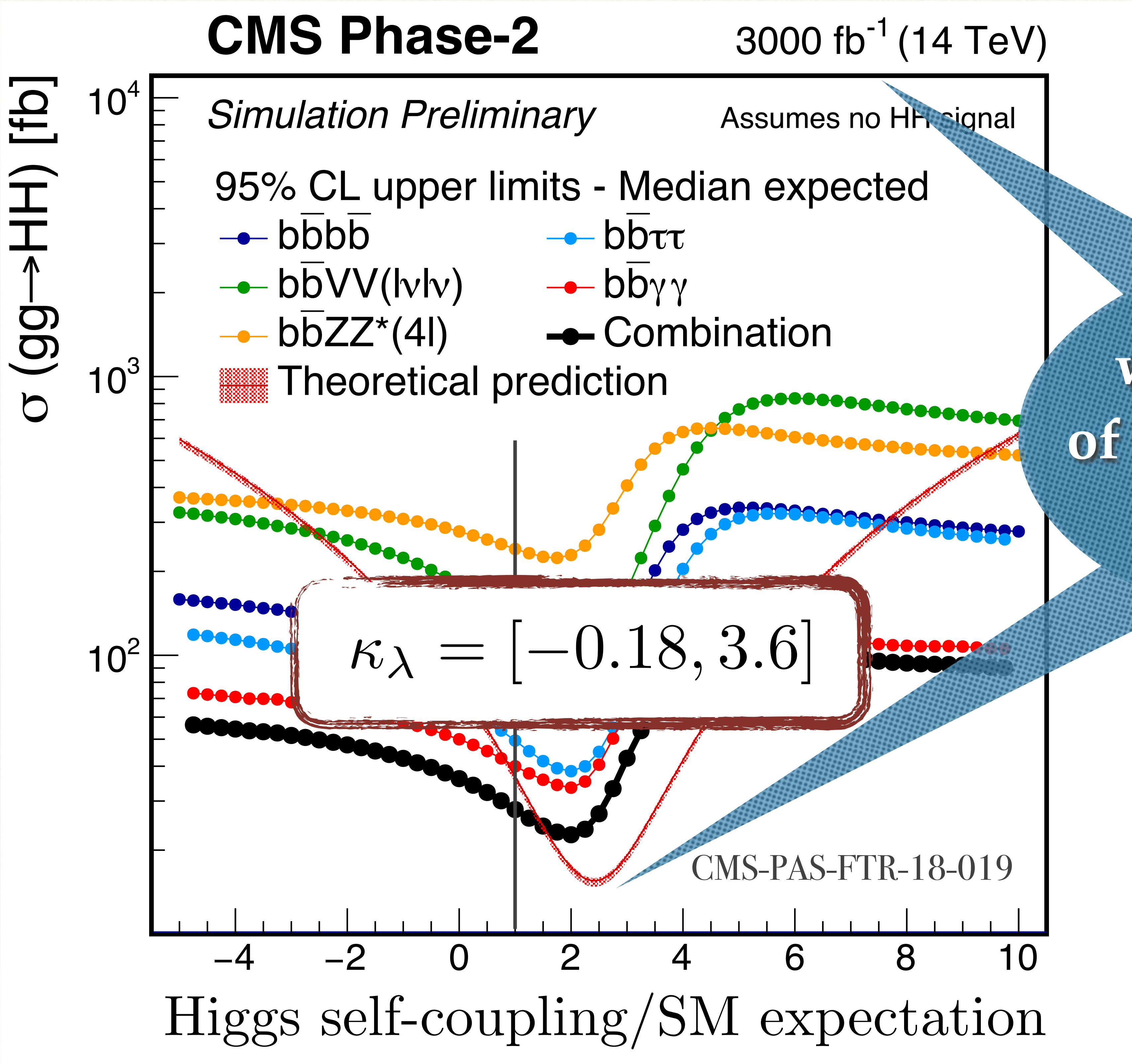
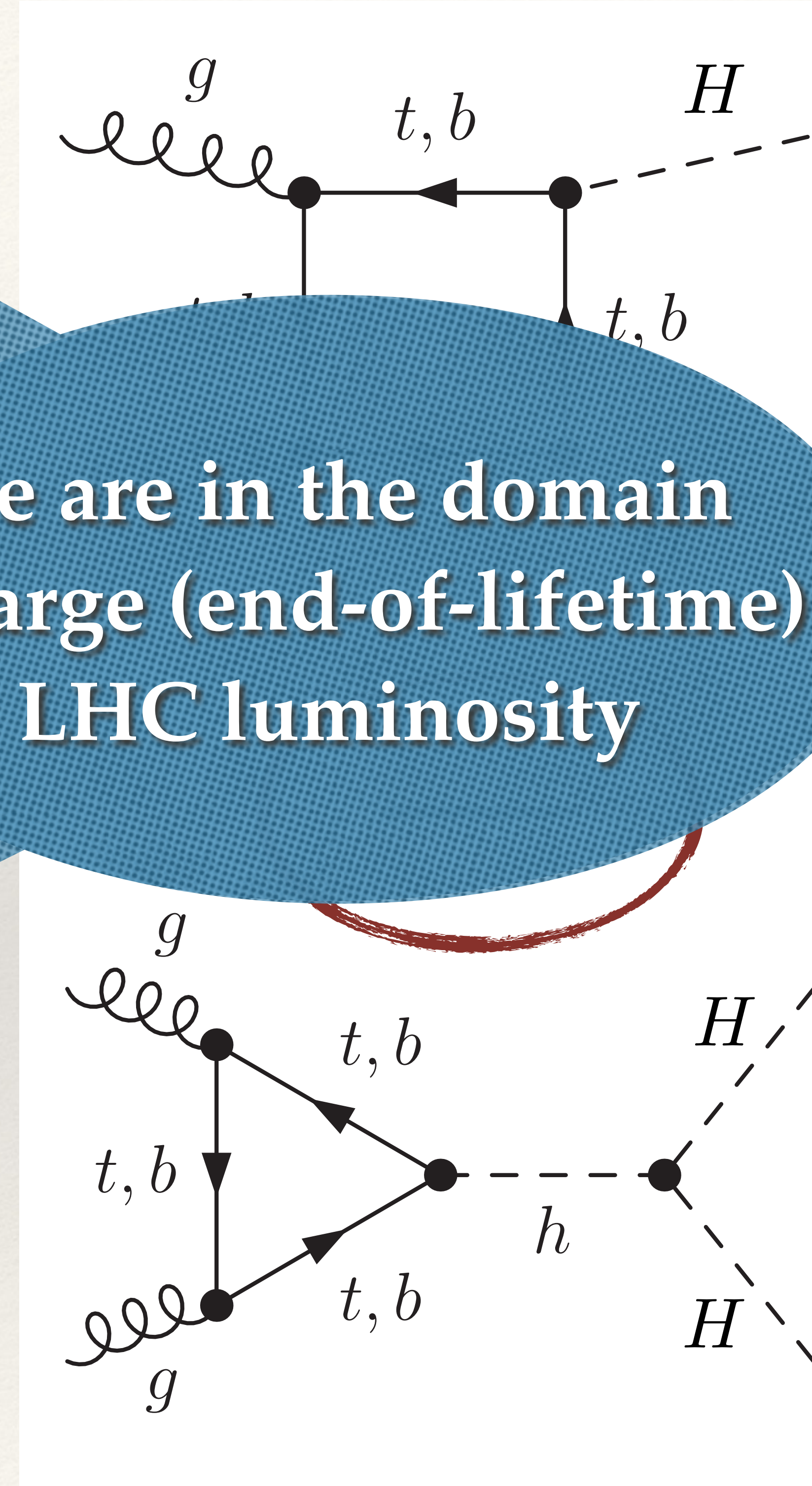
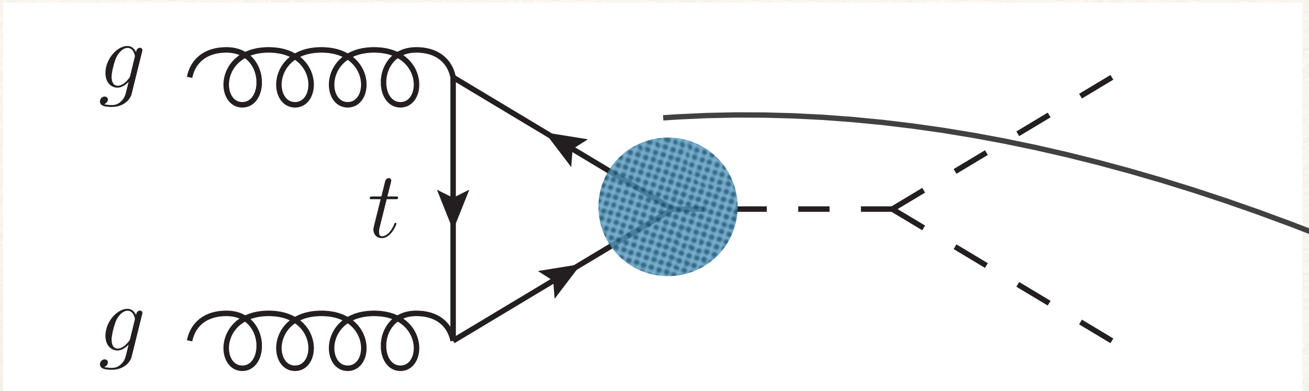
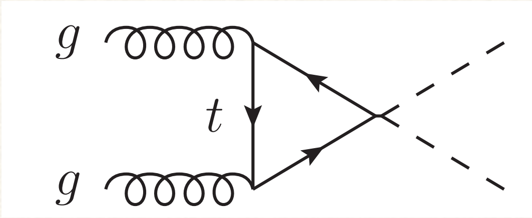




we are in the domain of large (end-of-lifetime) LHC luminosity

di-Higgs anatomy at 3/ab





e.g. [Gröber, Mühlleitner `10]

correlated with on-shell Higgs phenomenology
broken by $\sim \bar{t}th^2/\Lambda$....

- easy to arrange ad-hoc EFT in a way to get spectacular rates, but can doubt physical relevance of such limits ($\longrightarrow$ matching)

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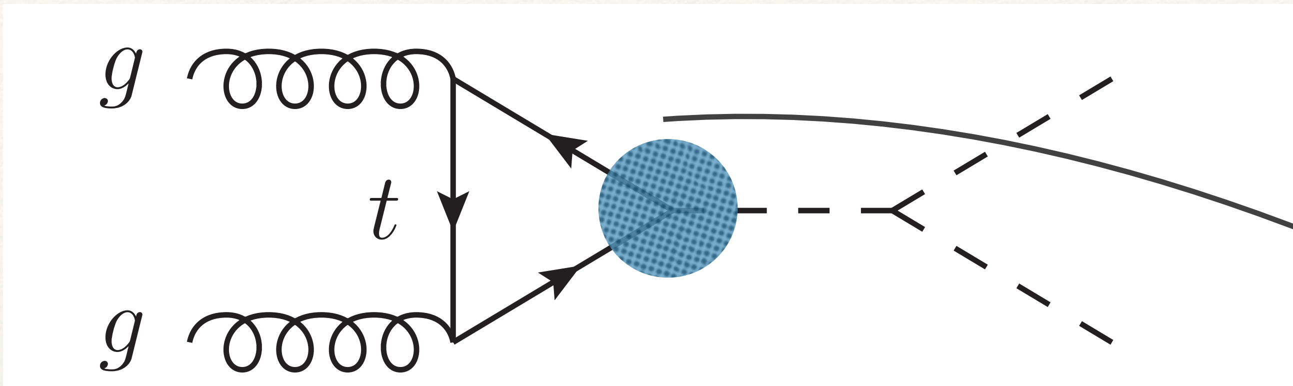

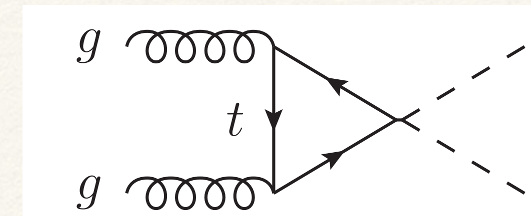

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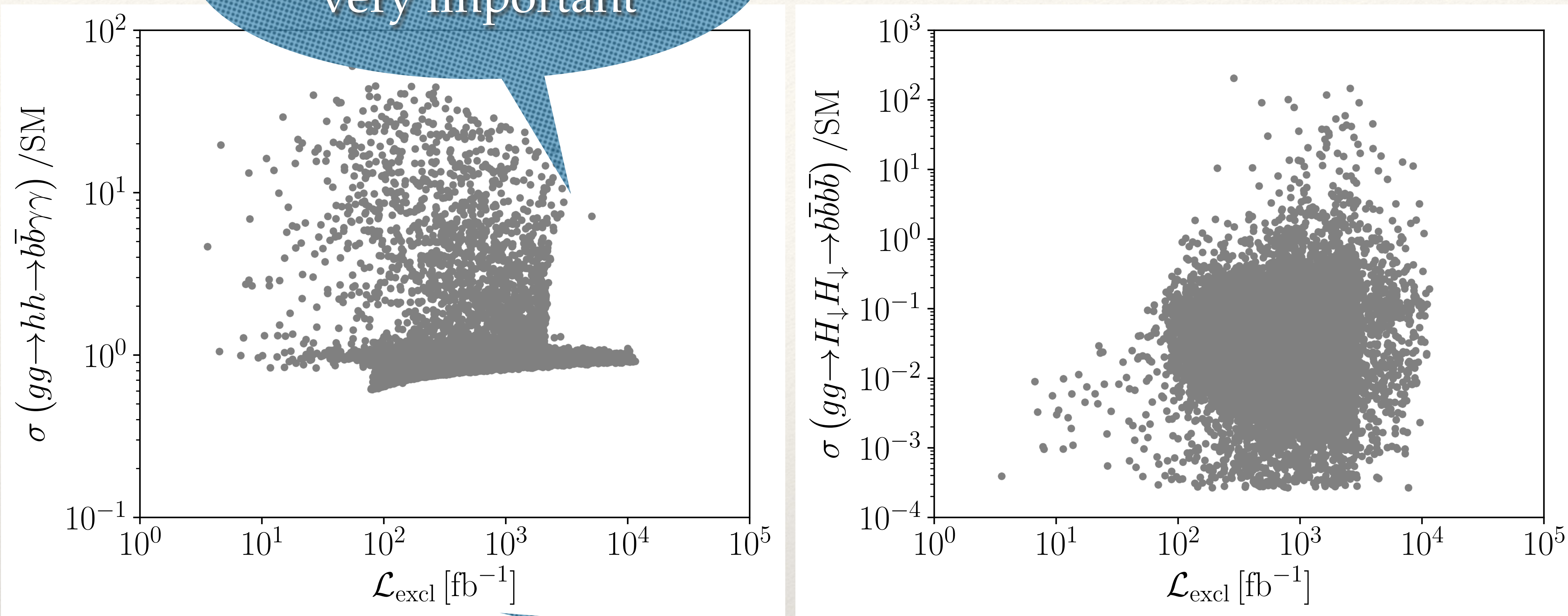
[Basler, Dawson, CE, Mühlleitner `18]

- use concrete Higgs sector extensions (C2HDM/CxSM/…)
  - extrapolate 125 GeV signal strengths
  - extrapolate exotic Higgs searches
  - more constraints (*electron EDMs, flavor, perturbativity, strong PS, CP viol.*)

What's left for di-Higgs?

e.g. C2HDM

tt resonance searches very important



[Basler,Dawson, CE, Mühlleitner ` 18]

luminosity at which non-HH searches become sensitive

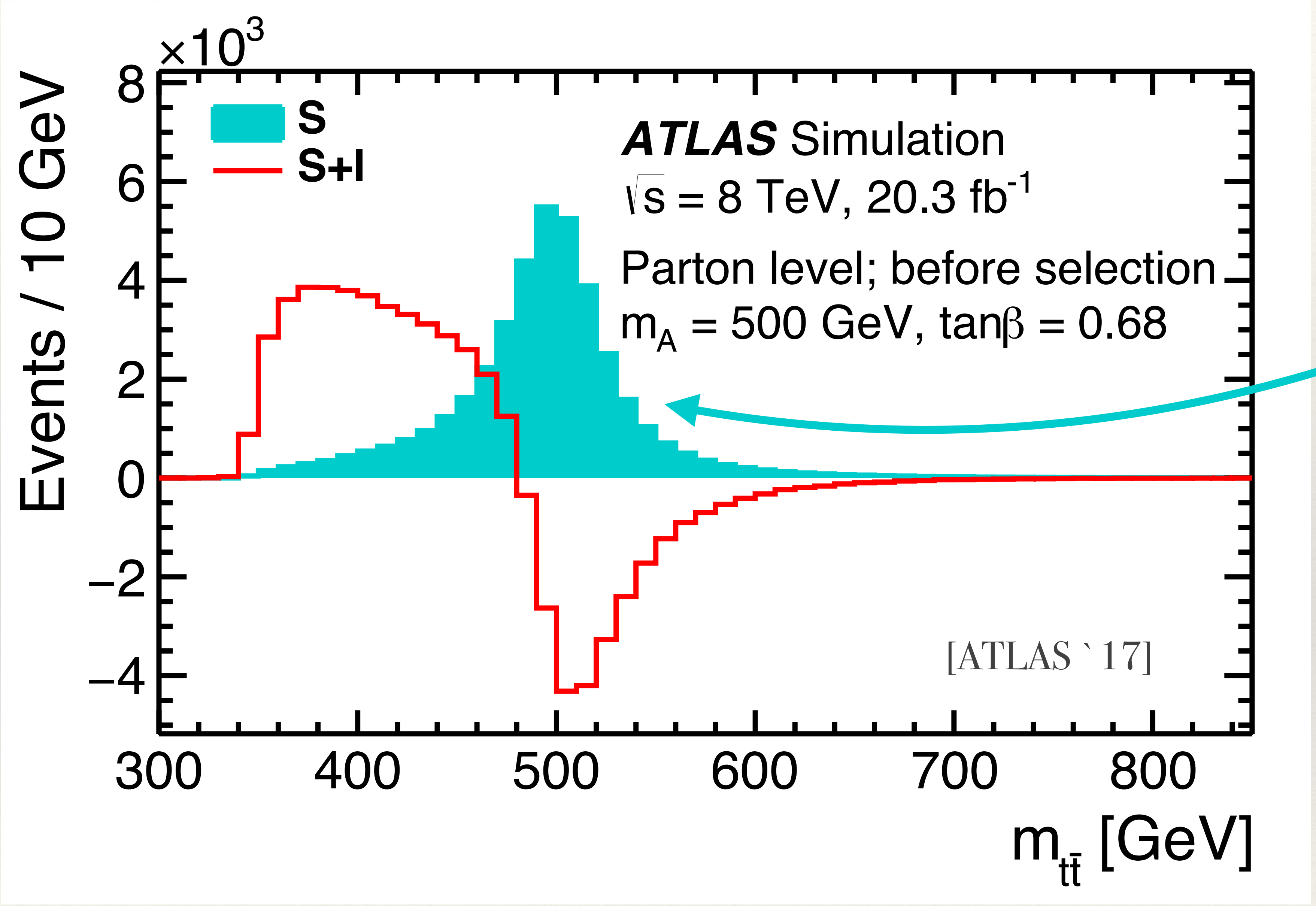
SM-like measurements can show a plethora resonant anomalies
diHiggs final states important for BSM discovery

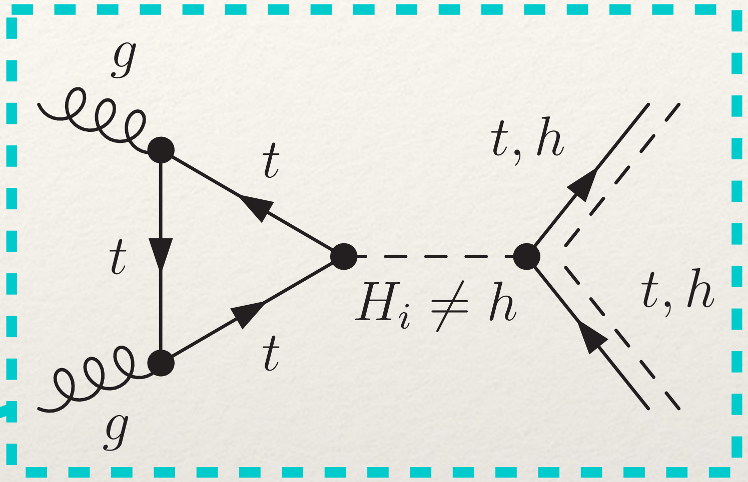
…di Higgs final states quickly lose relevance when approaching EFT limit

special role of tops

- large interference effects of Higgs "signal" with QCD background

[Gaemers, Hoogeveen `84] [Dicus et al. `94]....





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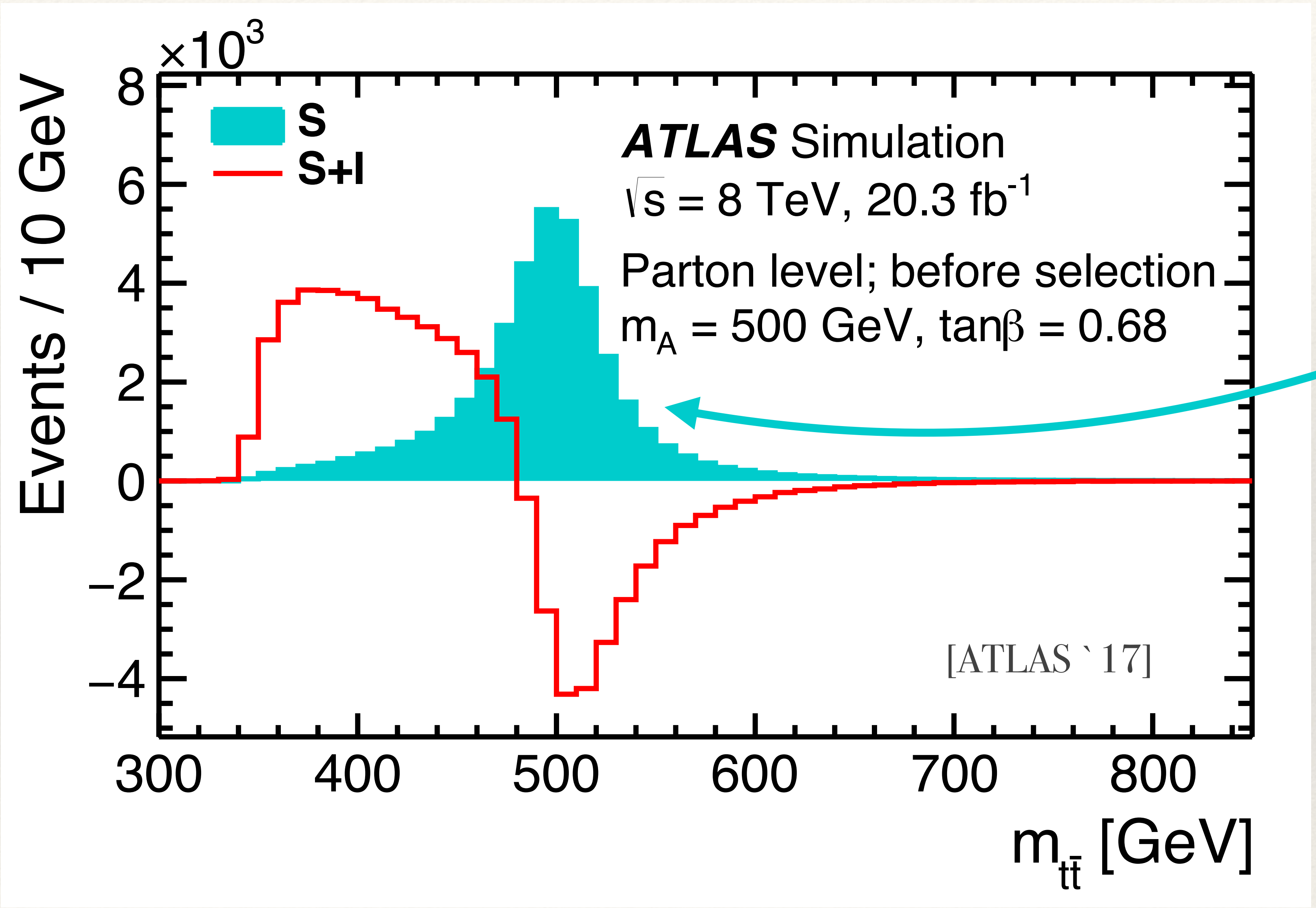
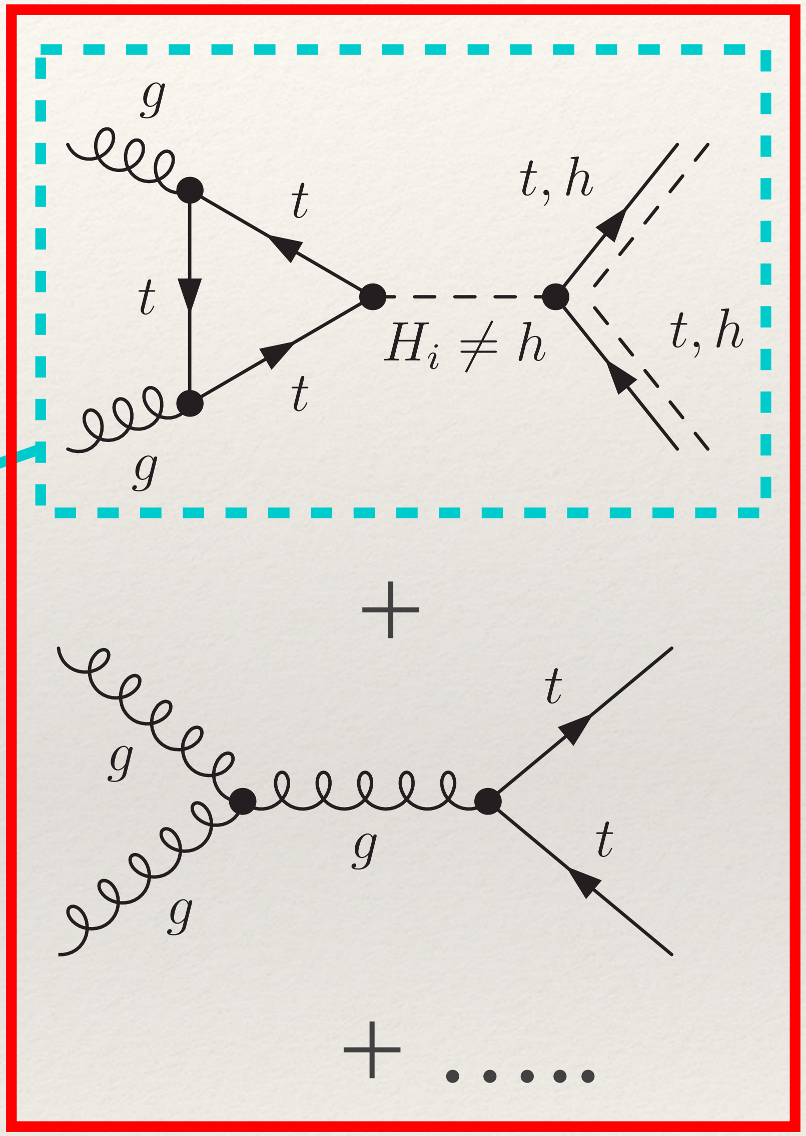
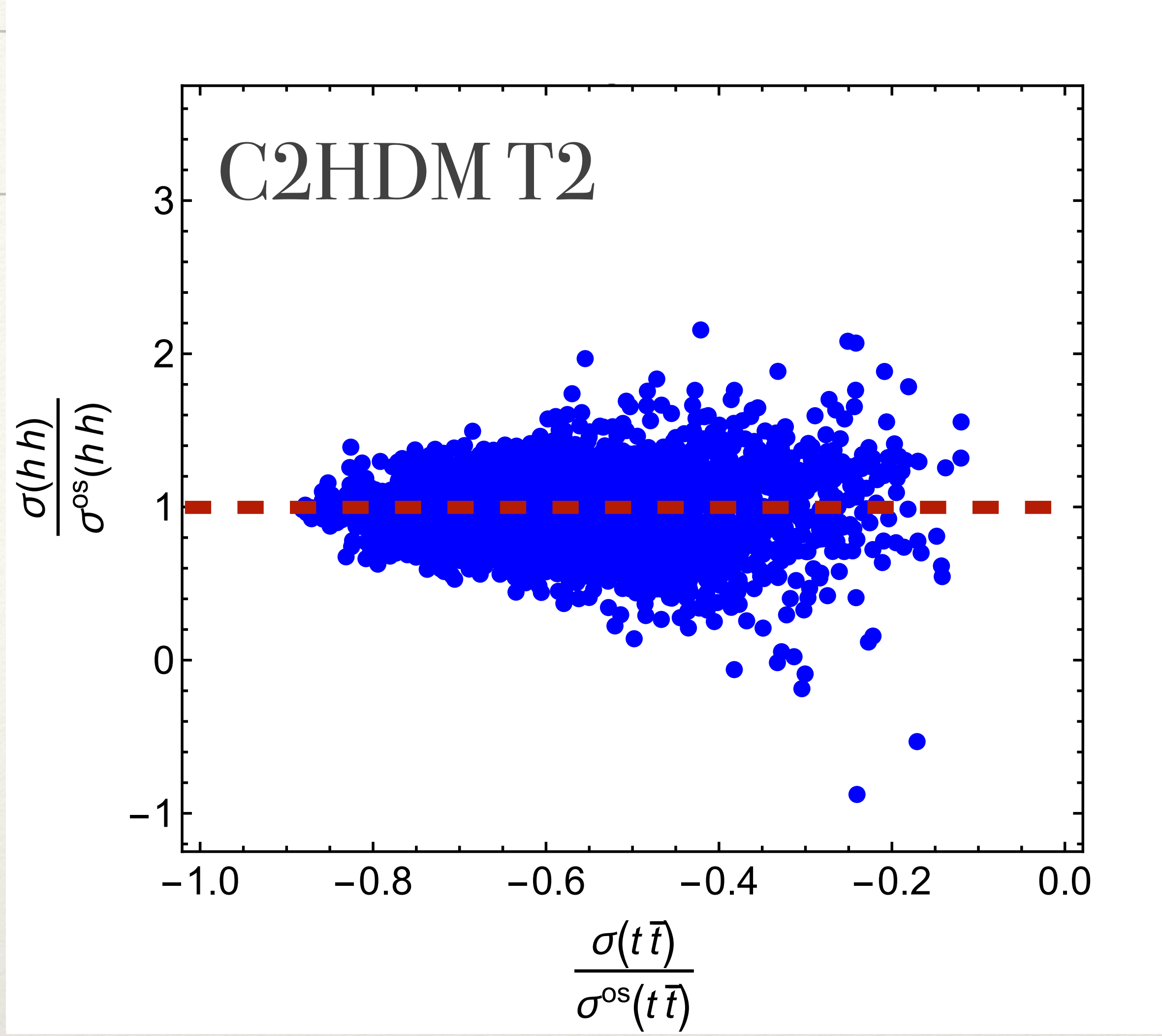




- top resonance searches in Higgs sector extensions with narrow width approximation is inadequate!

special role of tops

- destructive interference in top final states can be correlated with excess in HH - how ?



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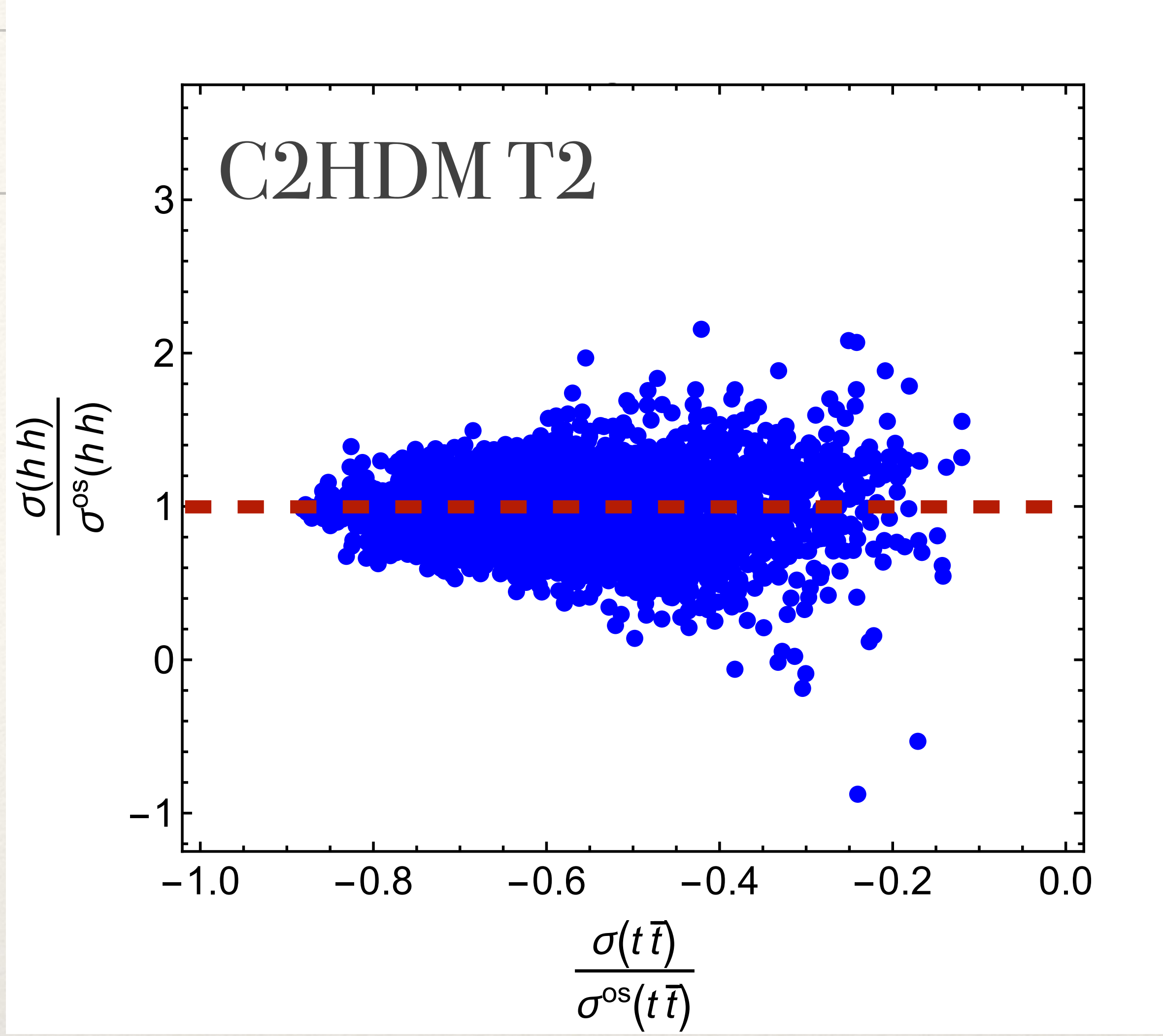
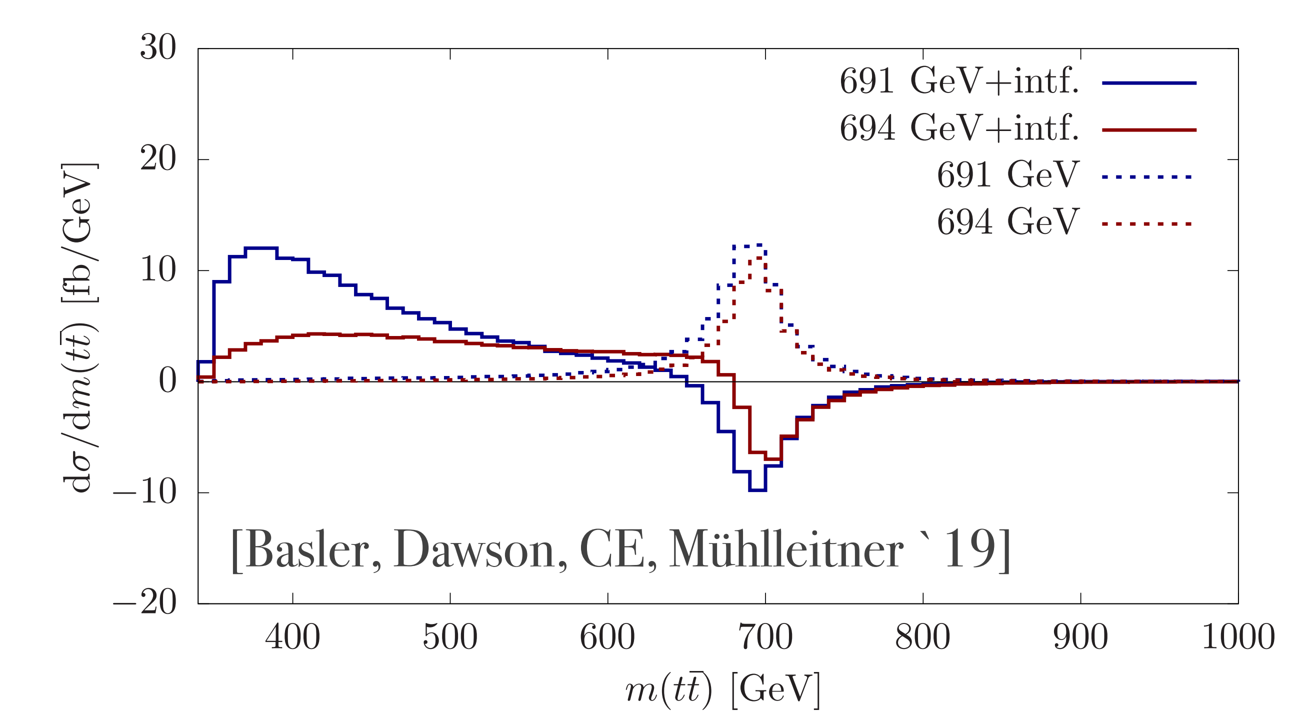
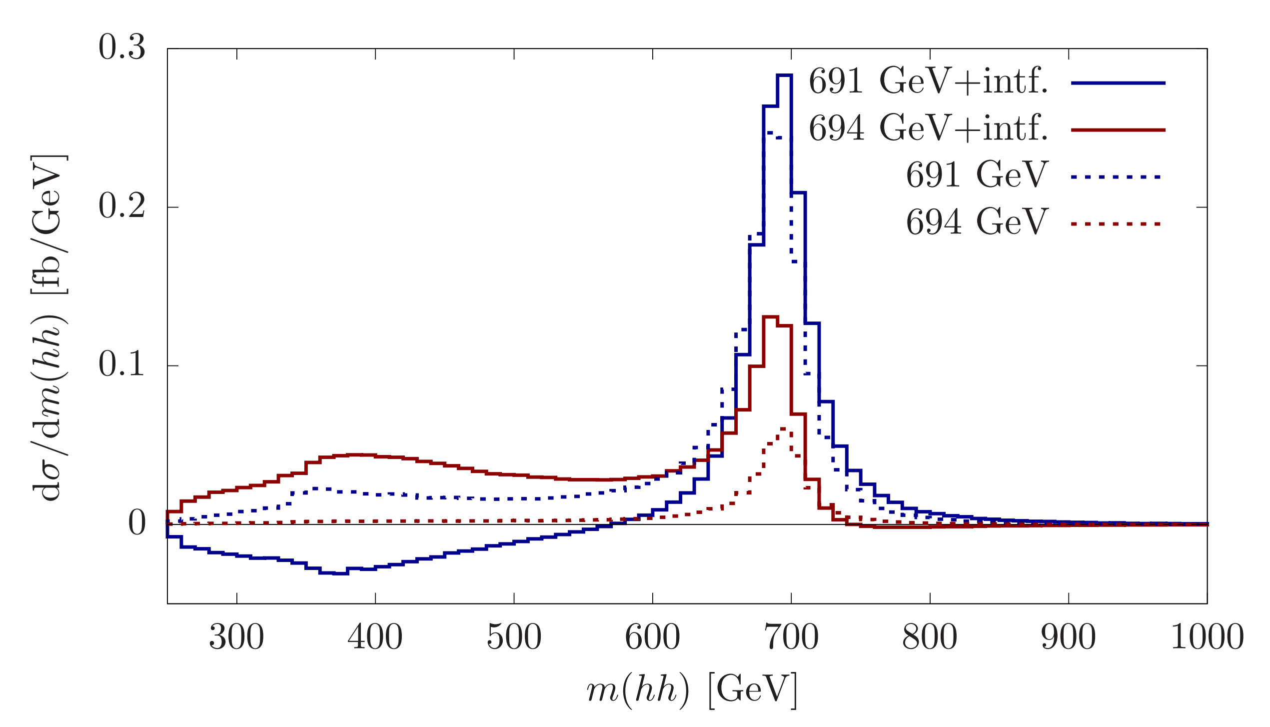
- phenomenologically viable regions exhibit compressed spectra: **signal-signal interference**







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weakly-coupled BSM

- weakly coupled BSM: the $\mathbb{Z}_2$-symmetric Higgs portal

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

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

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Trilinear Higgs coupling modifications

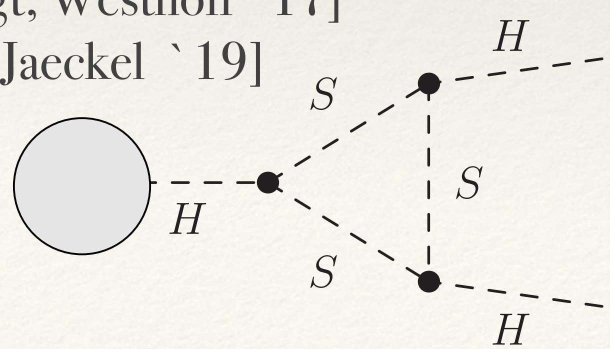
Higgs precision studies at colliders

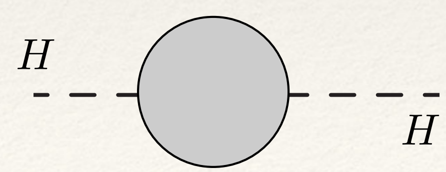
off-shell production

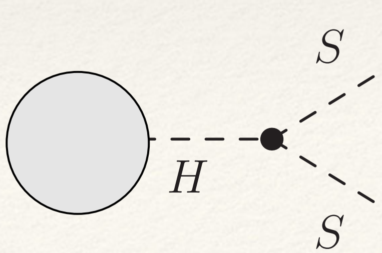
[Craig , Lou. et al.` 14]
[Ruhdorfer, Salvioni, Weiler ` 19]

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

[He, Zhu ` 16]
[Voigt, Westhoff ` 17]
[CE, Jaeckel ` 19]

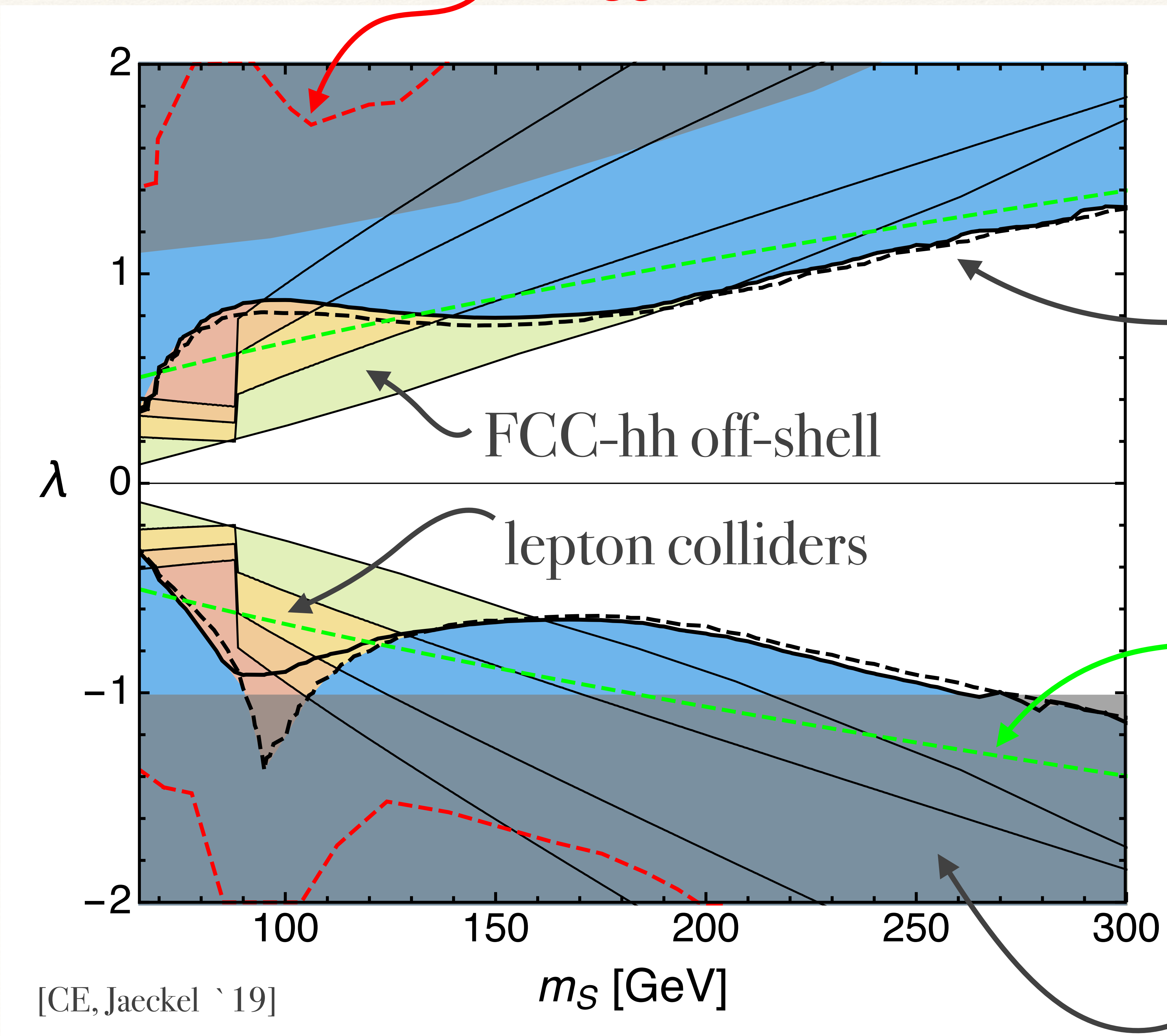






weakly-coupled BSM

diHiggs @ LHC



diHiggs @ FCC-hh

[Contino et al. `17]

Coleman-Weinberg approximation for diHiggs

electroweak potential unstable

[Curtin , Meade. Yu` 14]

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  - enhancing theoretical predictions
  - limit setting tailored to minimise systematics pollution

Summary

- *Higgs physics sits at the heart of our BSM efforts*
  - enhancing theoretical predictions
  - limit setting tailored to minimise systematics pollution

- *Opportunity to link the Higgs sector to new physics*
  - cure SM shortcomings (CP violation…)
  - multi-Higgs is a hard case for BSM sensitivity
  - new collider concepts can maximise precision vs energy reach in complementary ways