FOUR TOPS FOR THE PRESENT AND THE FUTURE

TOBIAS THEIL

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THE 13TH INTERNATIONAL WORKSHOP ON TOP QUARK PHYSICS (TOP 2020)

Technische Universität München

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OUTLINE

- Current bounds and relation to BSM models
- Outlook for future colliders
- Slight tension in $t\bar{t}W$ $(t\bar{t}Z)$ and its connection to new physics

WHY CARE FOR FOUR-TOP PRODUCTION NOW…

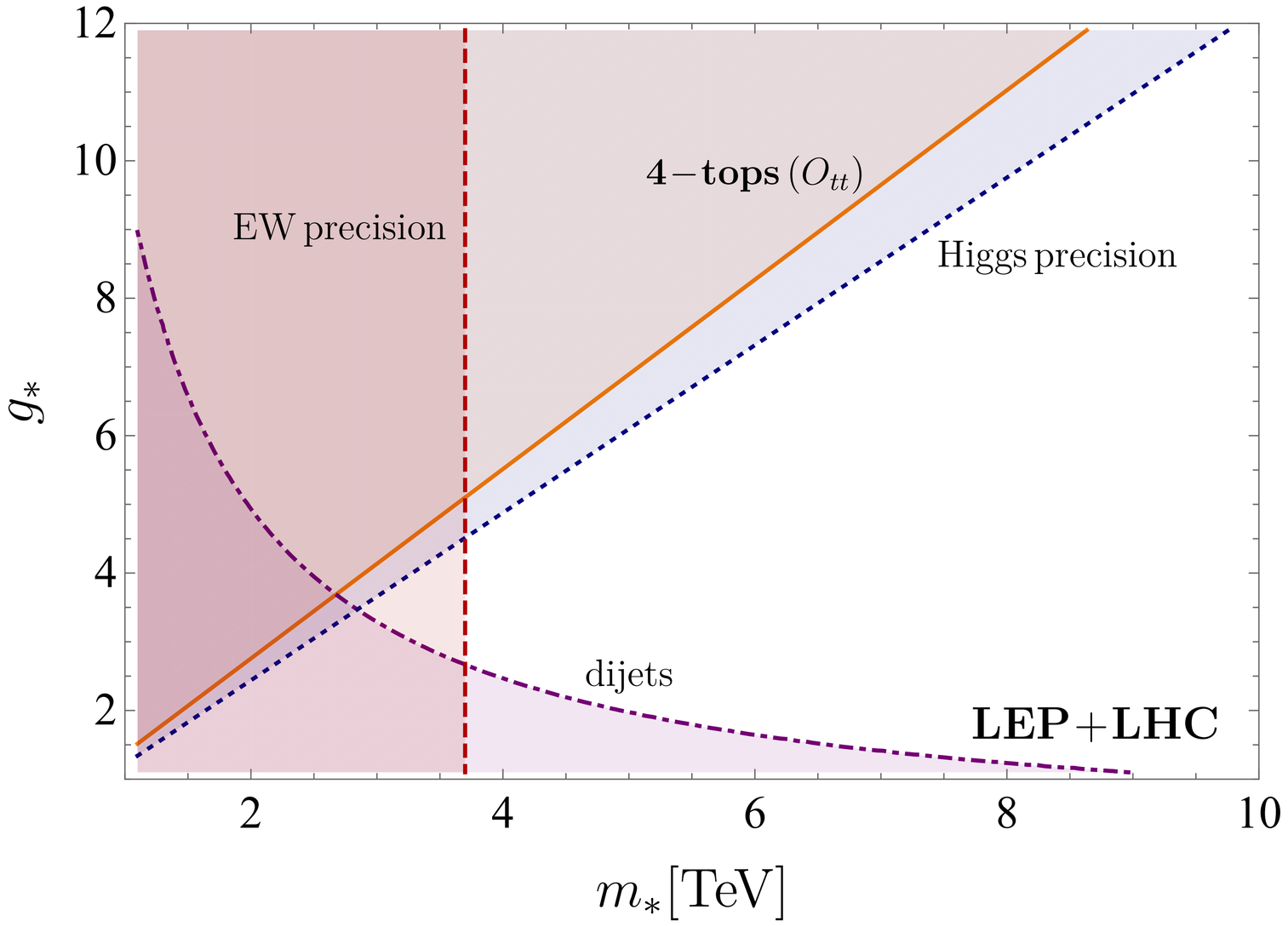
- Parametrize new physics with strong coupling g_* and heavy resonance mass m_*
- Models with composite Higgs and (right handed) top

  → Contact interaction $c_{tt}\,(\bar{t}_R\gamma_\mu t_R)\,(\bar{t}_R\gamma^\mu t_R)$ generated with $c_{tt} \sim \frac{g_*^2}{m_*^2}$

- For global analyses see, e.g.:
  - Degrande et al. 1010.6304, Durieux et al. 1807.02121, Farina et al. 1706.03068, de Blas et al. 1905.03764, Maltoni et al. 1910.03606 → Susanne Westhoff's talk on Thursday

  → See also Matthew McCullough's talk on Monday

WHY CARE FOR FOUR-TOP PRODUCTION NOW…



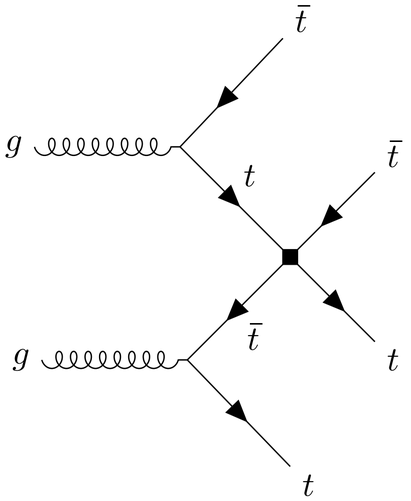
- Not a global fit
- Chose operators that dominate different parts of parameter space
- O_{tt} comparable to constraints from Higgs observables

LHC : $\sqrt{s} = 7,\ 8,\ 13\,\text{TeV},\ \mathcal{L} = 5,\ 20,\ 35.9\,\text{fb}^{-1}$

. . . AND IN THE FUTURE?

- FCC – hh
  - Much larger SM rate of four top events, $\frac{\sigma_{4t,FCC}}{\sigma_{4t,LHC}} \sim 350$ [Frederix, Pagani, Zaro 1711.02116]
  - O_{tt} contribution grows with energy
- CLIC/ILC /FCC-ee
  - Indirect probes exploiting high precision
  - One-loop sensitivity to $\mathcal{O}_{tt}$ through $e^+e^- \to t\bar{t}$

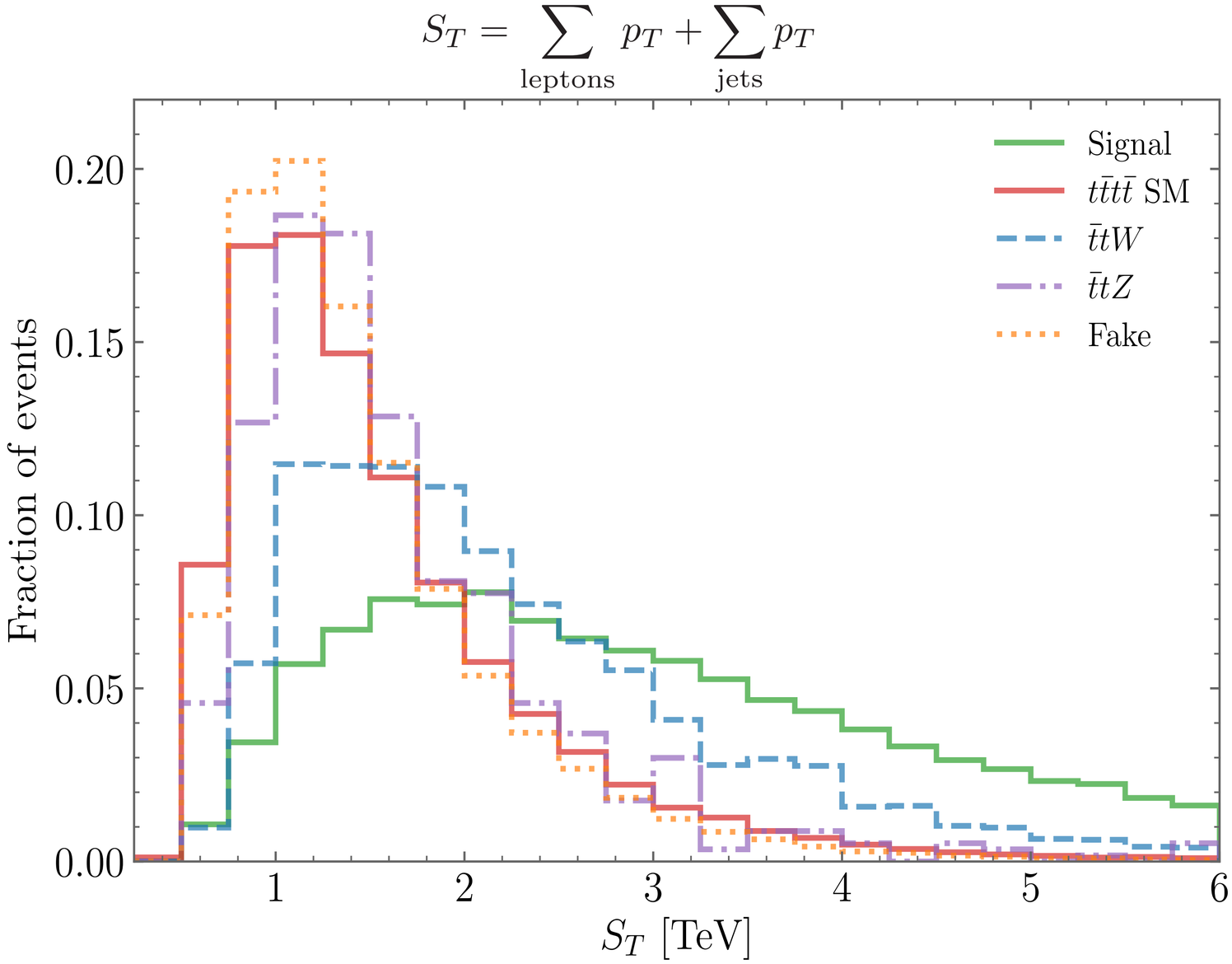
$\mathcal{O}_{tt}$ AT FUTURE HADRON COLLIDERS



- Setup:
  - Generation at LO, rescaled to highest order predictions
  - SS dilepton and three lepton decay channel

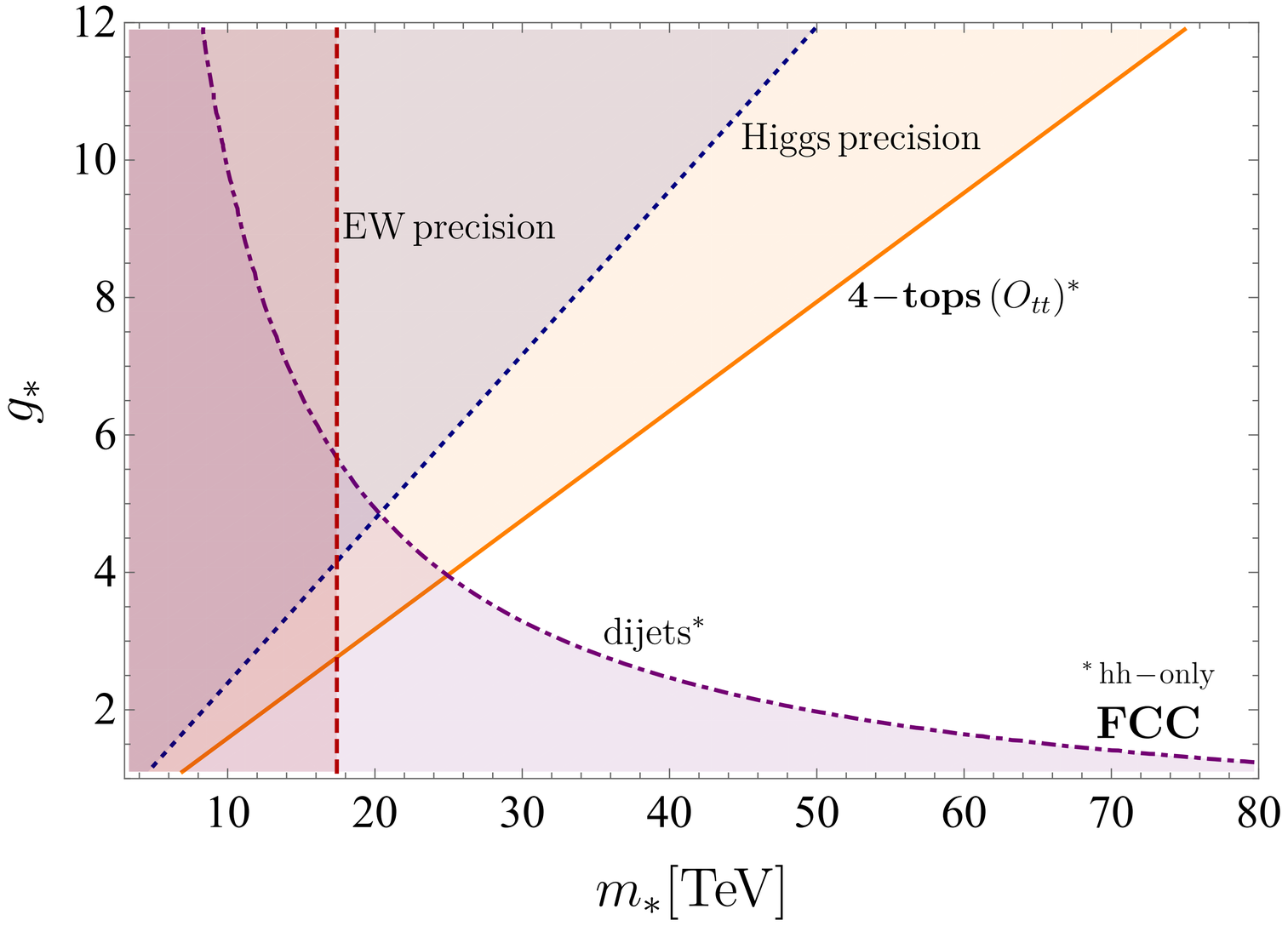
- Analysis:
  - Require $N_j \geq 5(4)$, $N_b \geq 3$ and $p_T^{\ell_1} \geq 275\,\mathrm{GeV}$
  - Perform binned fit over three bins in S_T in both decay channels

$\mathcal{O}_{tt}$ AT FUTURE HADRON COLLIDERS



- Four-fermion interaction
  → enhancement at high energies

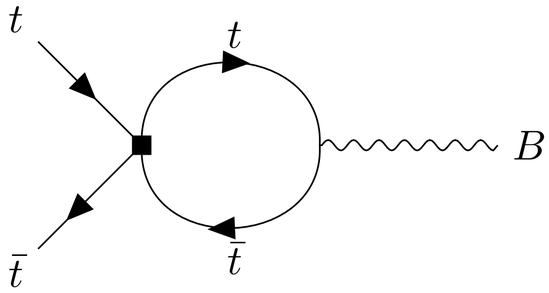
$\mathcal{O}_{tt}$ AT FUTURE HADRON COLLIDERS



- Projected bounds for the full FCC program
- O_{tt} overtakes Higgs measurement, despite precision from FCC-ee

FCC-hh : $\sqrt{s} = 100\text{TeV},\ \mathcal{L} = 30\,\text{ab}^{-1}$

$\mathcal{O}_{tt}$ AT FUTURE LEPTON COLLIDERS



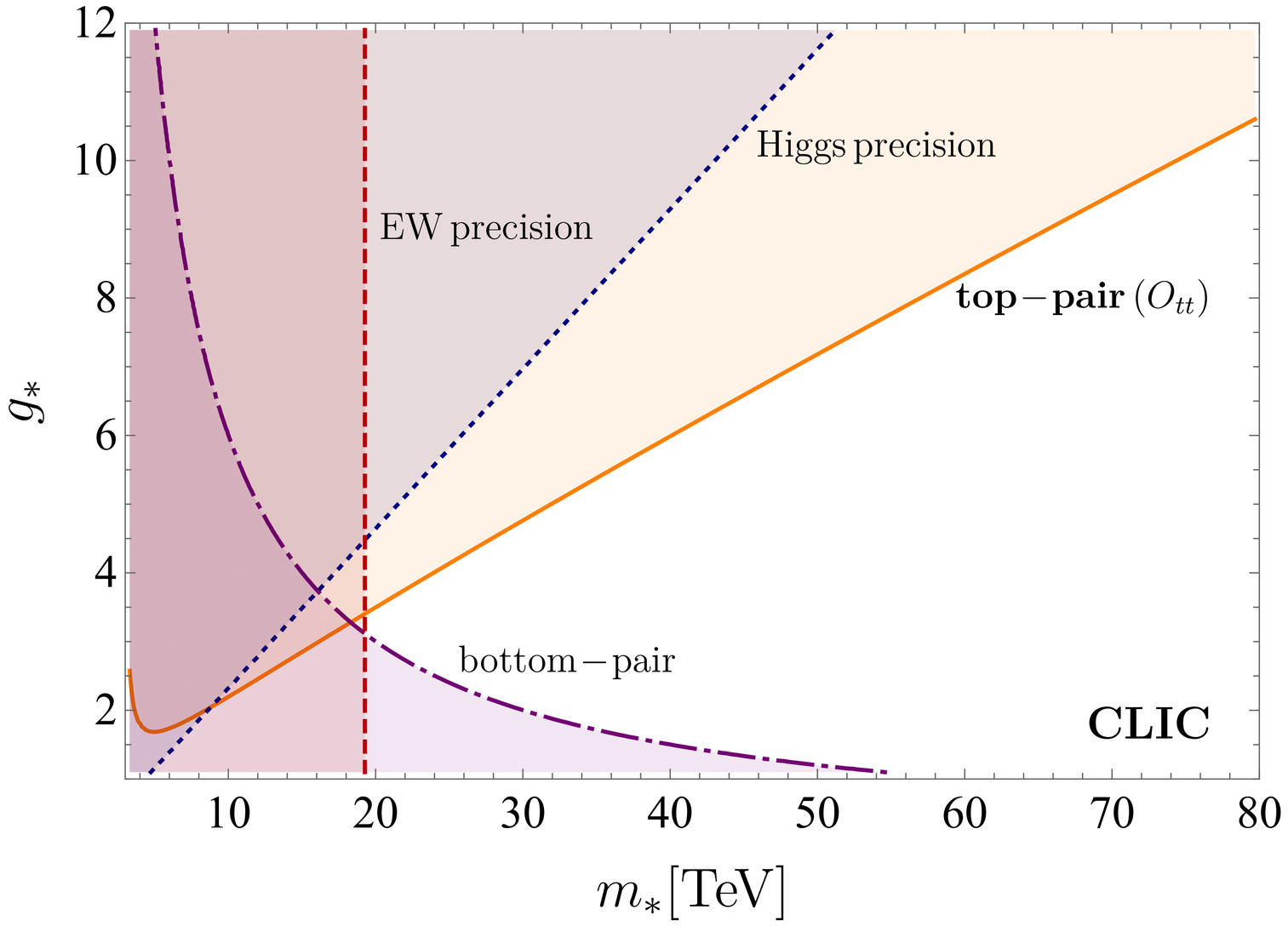
- Lower energies at lepton colliders ⟶ Cannot probe four-top production directly
- $\mathcal{O}_{tt}$ contributes at 1-loop to $t\bar{t}$ production:

$$(\bar{t}_R\gamma_\mu t_R)\,(\bar{t}_R\gamma^\mu t_R) \overset{\text{RGE}}{\Longrightarrow} (\partial^\mu B_{\mu\nu})\,(\bar{t}_R\gamma^\nu t_R) \overset{\text{EOM}}{\Longrightarrow} (e\gamma_\mu e)\,(\bar{t}_R\gamma^\mu t_R)$$

- Reinterpret existing results by adding loop contribution

[Durieux, Perello, Vos, Zhang 1807.02121] [de Blas et al. 1905.03764]

$\mathcal{O}_{tt}$ AT FUTURE LEPTON COLLIDERS



- Projected bounds from CLIC
- High energy + high precision

→ highest sensitivity to O_{tt}

CLIC : $\sqrt{s} = 0.38,\ 1.4,\ 3\,\text{TeV},\ \mathcal{L} = 0.5,\ 1.5,\ 3\,\text{ab}^{-1}$

FURTHER MOTIVATION: LHC MULTILEPTON + JETS “EXCESSES”

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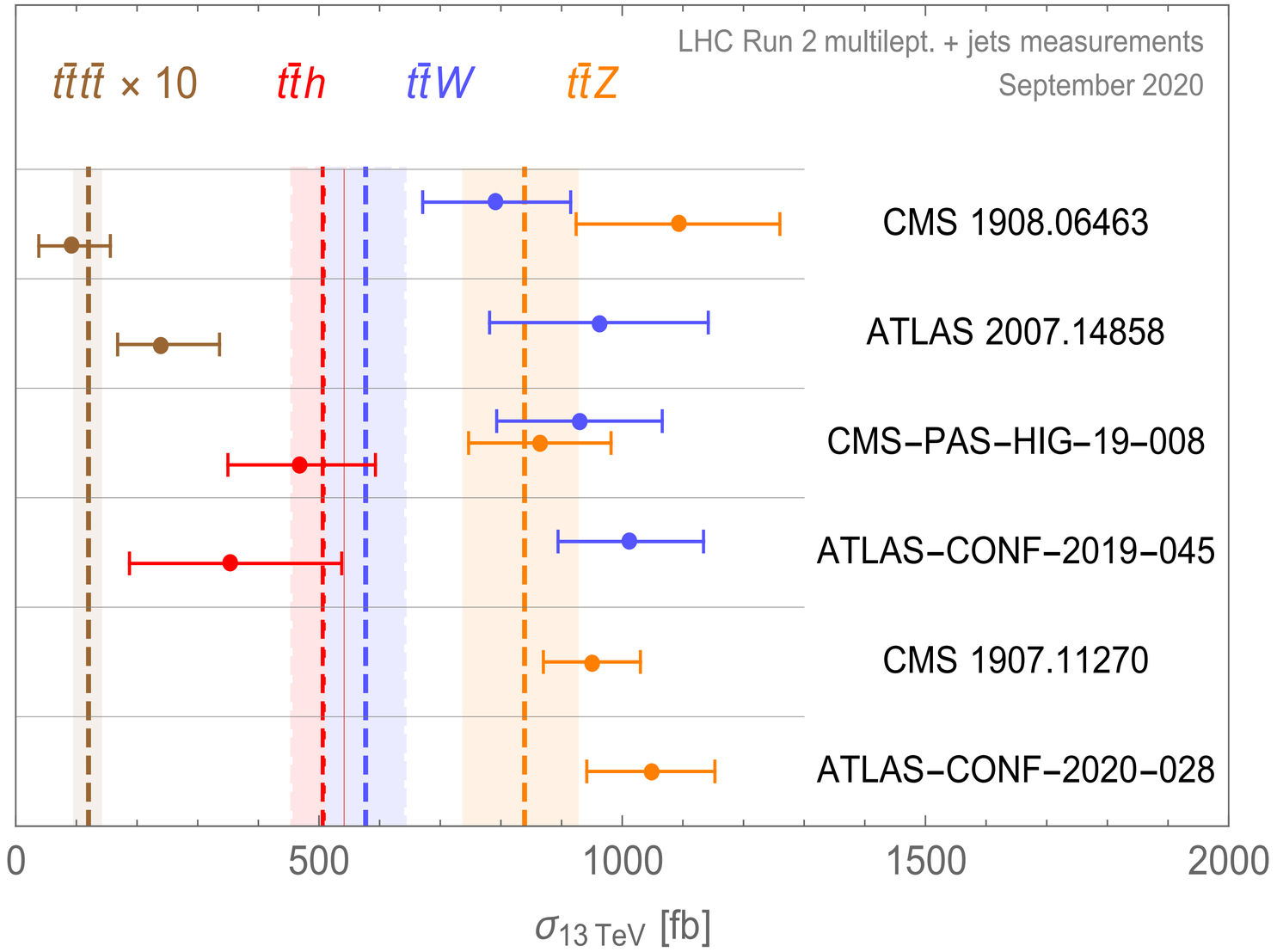

- Summary of $t\bar{t}t\bar{t}$, $t\bar{t}h$, $t\bar{t}W$, $t\bar{t}Z$ cross sections
- Mild, but coherent pattern of excesses in $t\bar{t}W$ and $t\bar{t}Z$
  - → SM corrections*?
  - → New physics?

*Giuseppe Bevilacqua's talk on Tuesday

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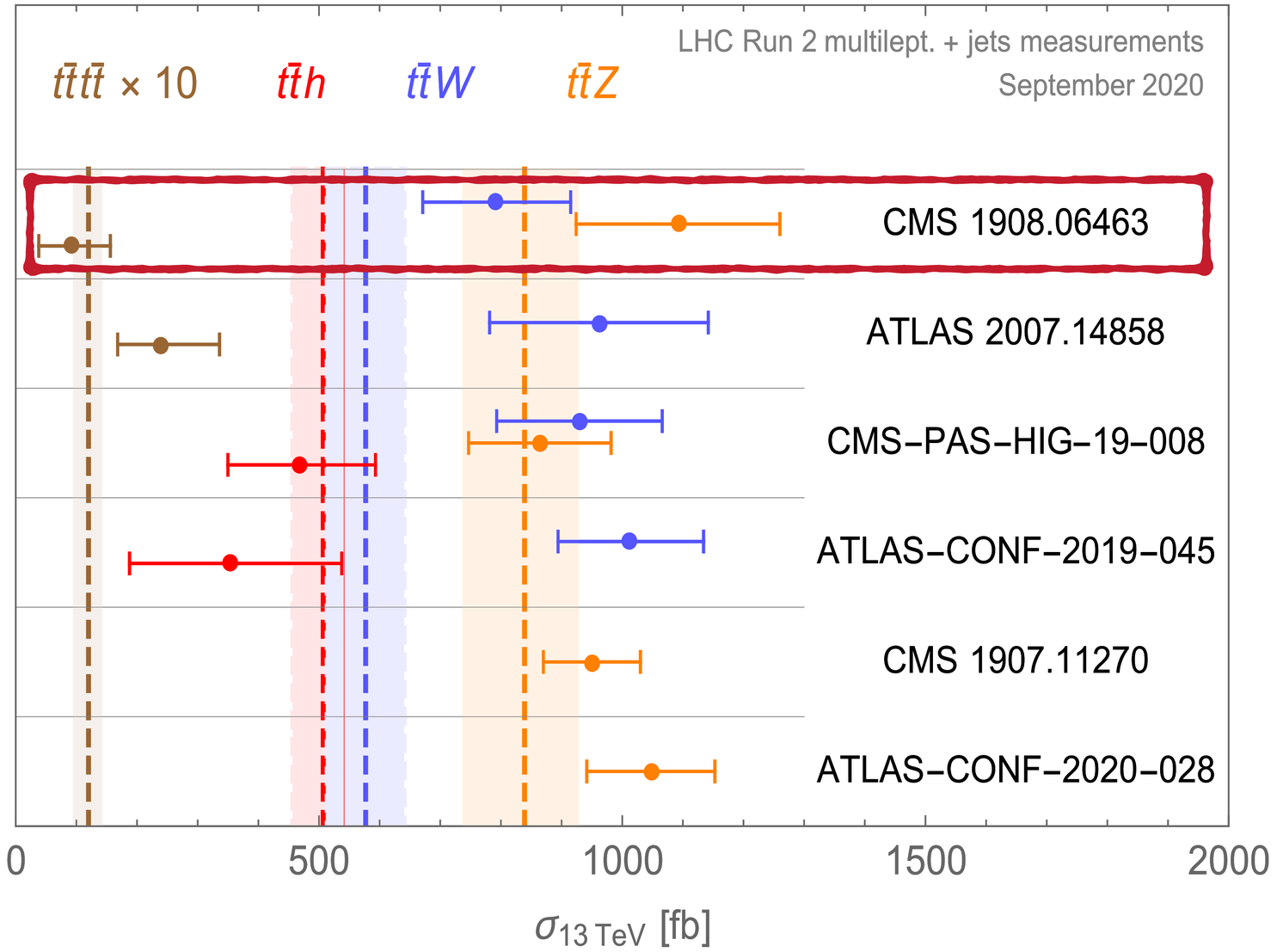

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FURTHER MOTIVATION: LHC MULTILEPTON + JETS "EXCESSES"

- Follow CMS four-top cut and count strategy [1908.06463]
  - Add missing $ttWj_{EW}$ contribution, large in the SM [Dror, Farina, Salvioni, Serra 1511.03674]

μ – perspective

Rescale the total $\bar{t}tW$, $\bar{t}tZ$ yields

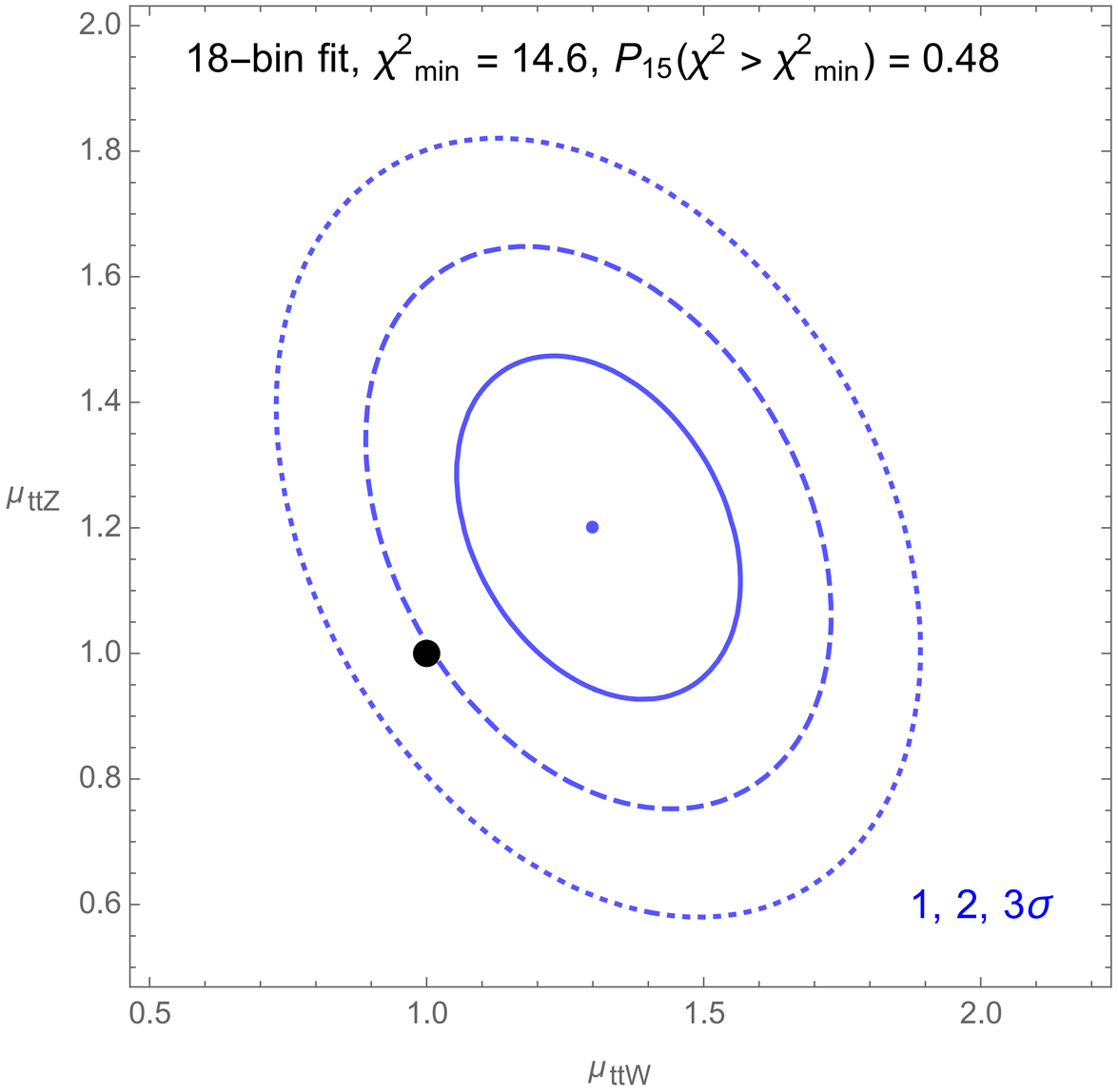
EFT – perspective

$$c_{tt}\,(\bar{t}_R\gamma_\mu t_R)\,(\bar{t}_R\gamma^\mu t_R)$$

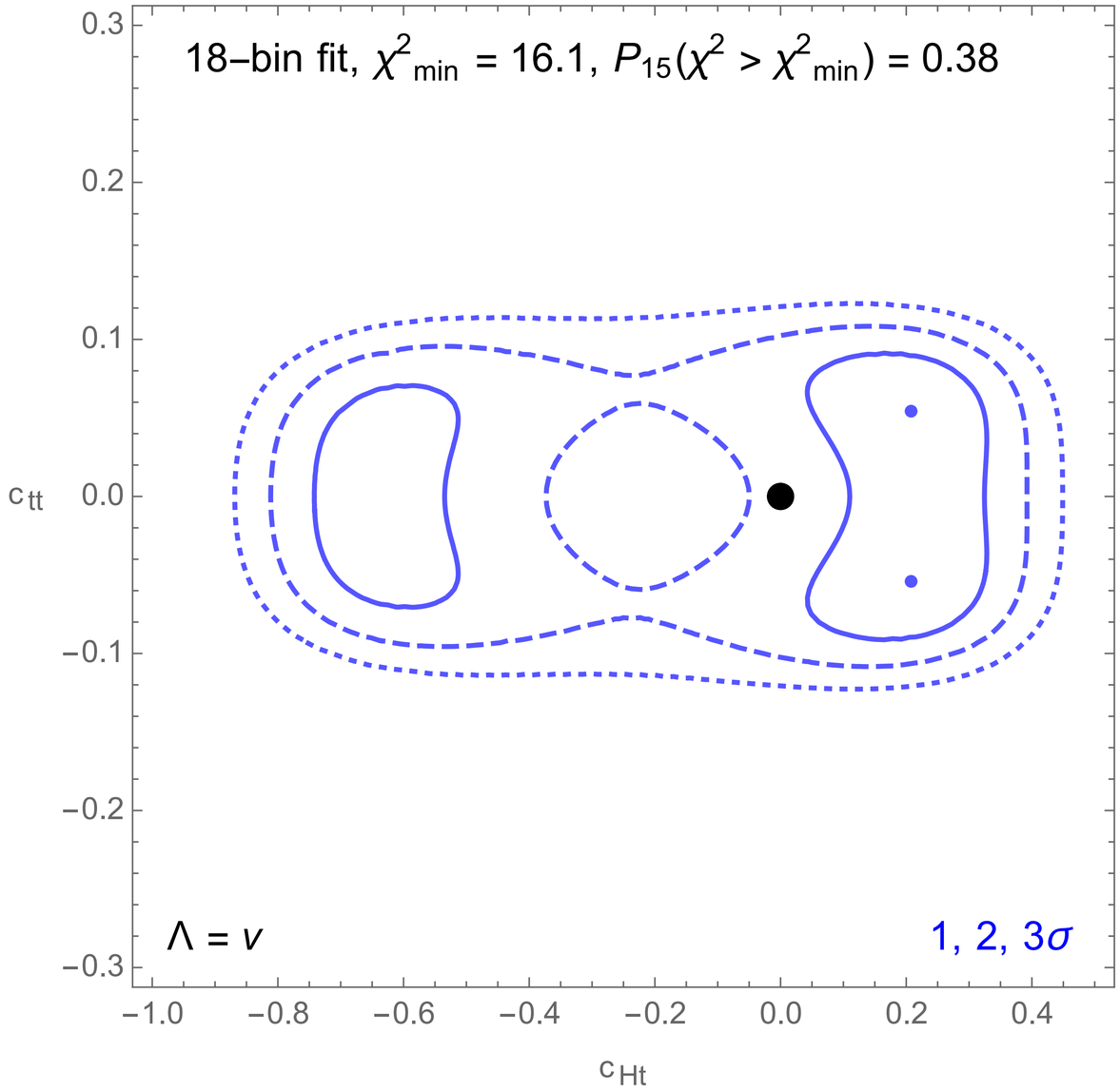
$$c_{Ht}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)(\bar{t}_R\gamma^\mu t_R)$$

FURTHER MOTIVATION: LHC MULTILEPTON + JETS "EXCESSES"

μ



EFT



SUMMARY

- Four top production provide a competitive or even supreme probe of composite Higgs models, e.g. compared to Higgs precision

$$\left(\frac{m_*}{g_*}\right)_{\mathrm{LHC}} > 725\,\mathrm{GeV}, \qquad \left(\frac{m_*}{g_*}\right)_{\mathrm{FCC}} > 6.3\,\mathrm{TeV}, \qquad \left(\frac{m_*}{g_*}\right)_{\mathrm{CLIC}} > 7.7\,\mathrm{TeV}$$

- Explored a BSM interpretation of the CMS four-top search

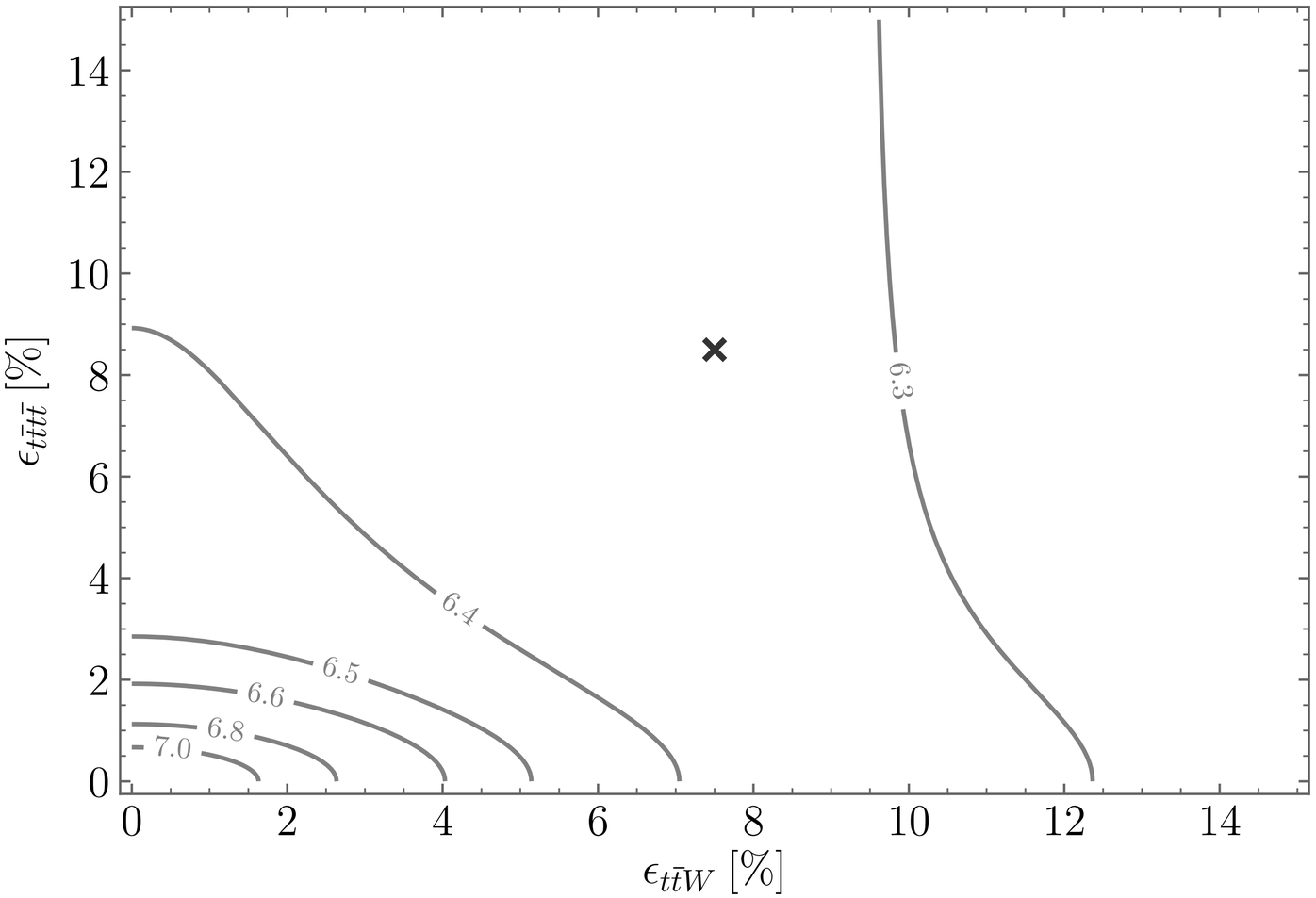
Banelli, Salvioni, Serra, Theil, Weiler: to appear

BACKUP

SYSTEMATIC UNCERTAINTIES

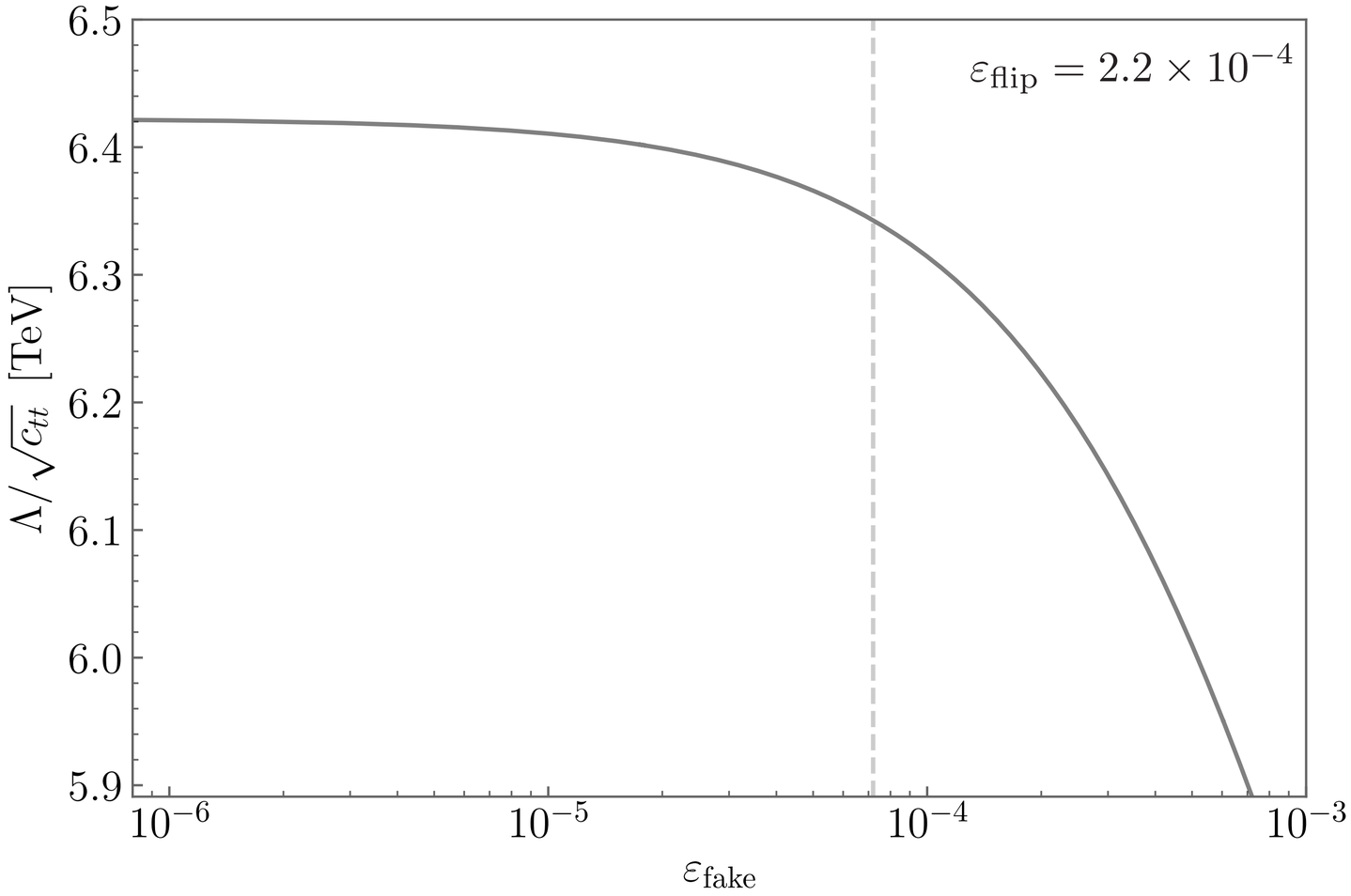
- Systematics: $(\epsilon_{t\bar{t}t\bar{t}}, \epsilon_{t\bar{t}W}) = (8.5\%, 7.5\%)$, half of current theoretical uncertainties

[Frederix, Pagani, Zaro 1711.02116]



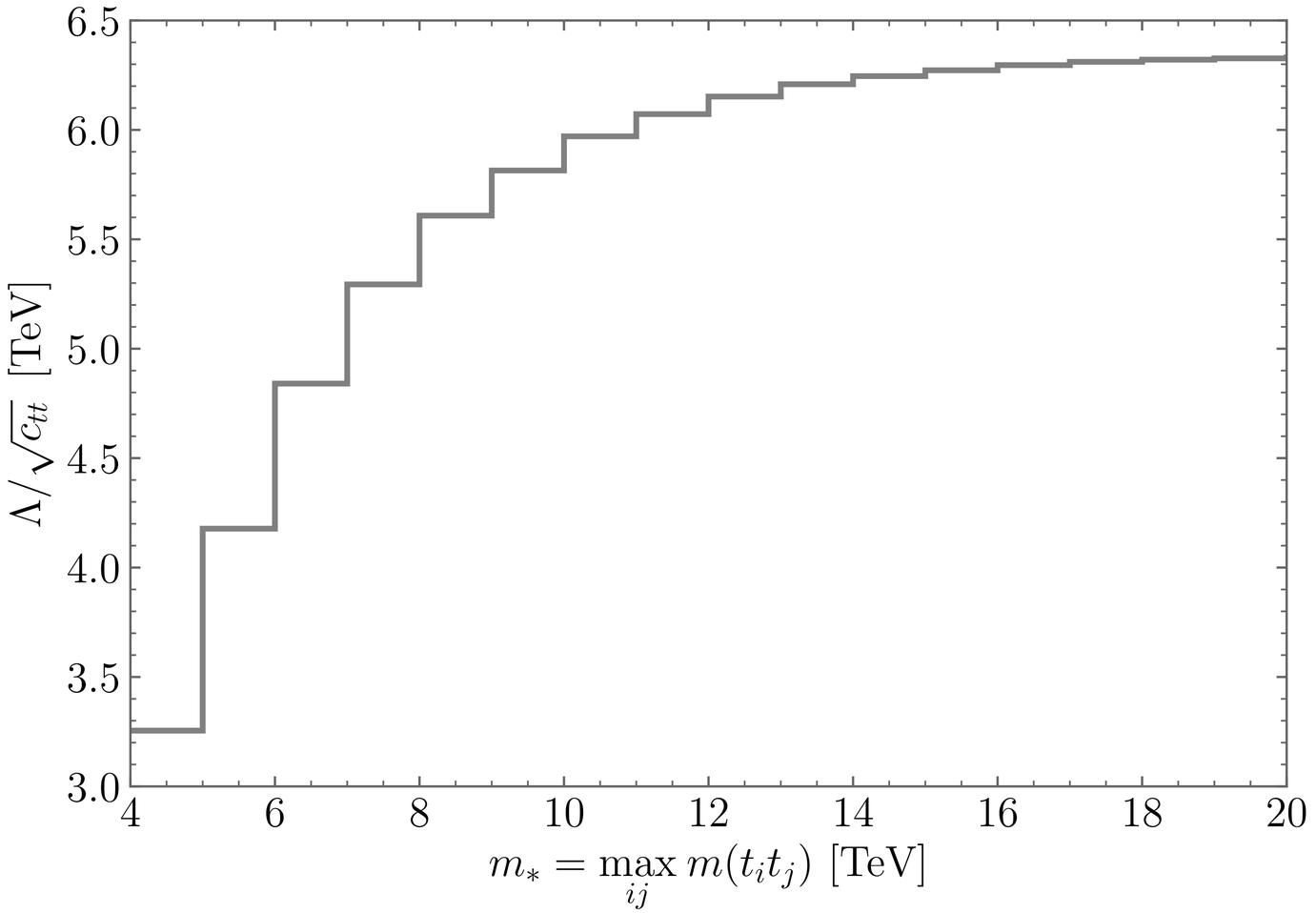
DETECTOR EFFCIENCIES

- In the main analysis $(\varepsilon_{\text{fake}}, \varepsilon_{\text{flip}}) = (0.72, 2.2) \times 10^{-4}$ were used [arXiv:1611.05032]

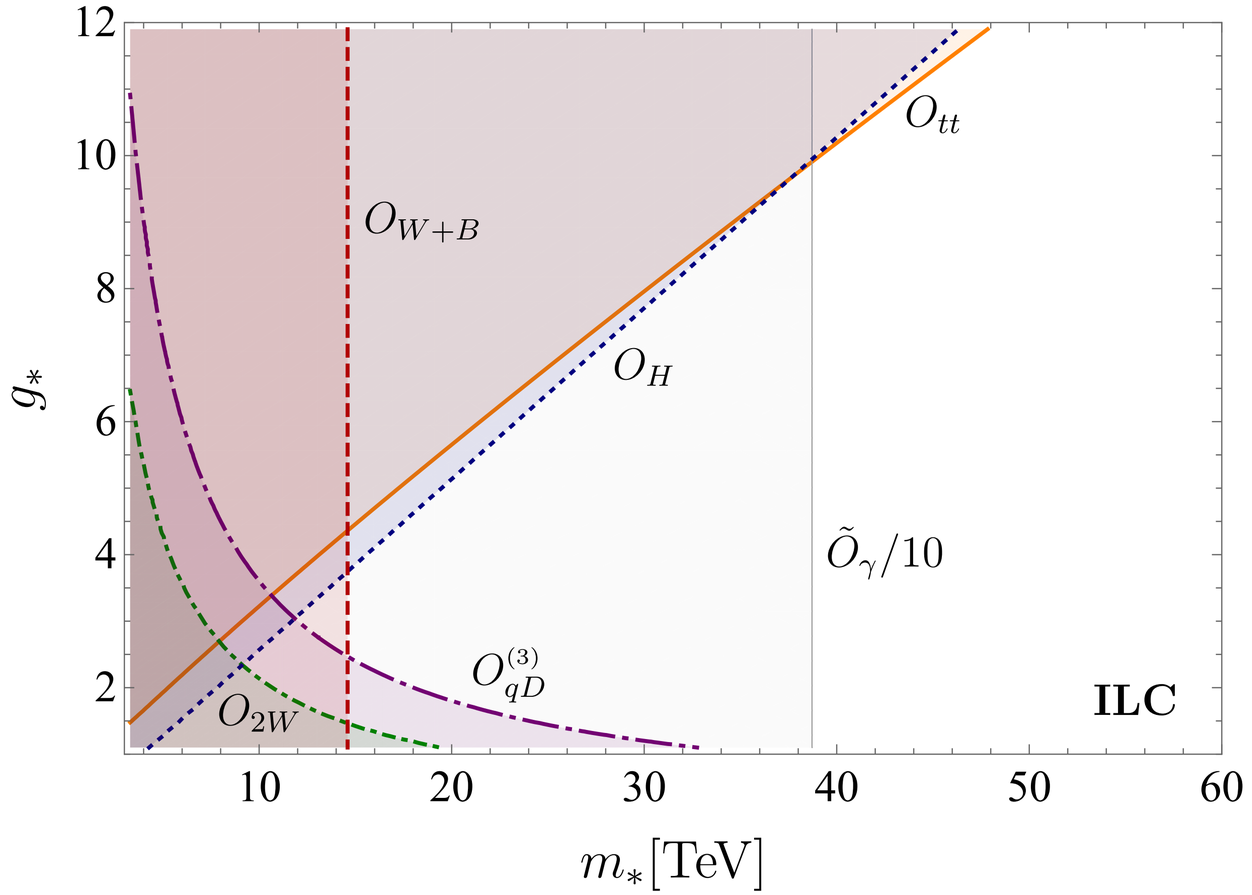


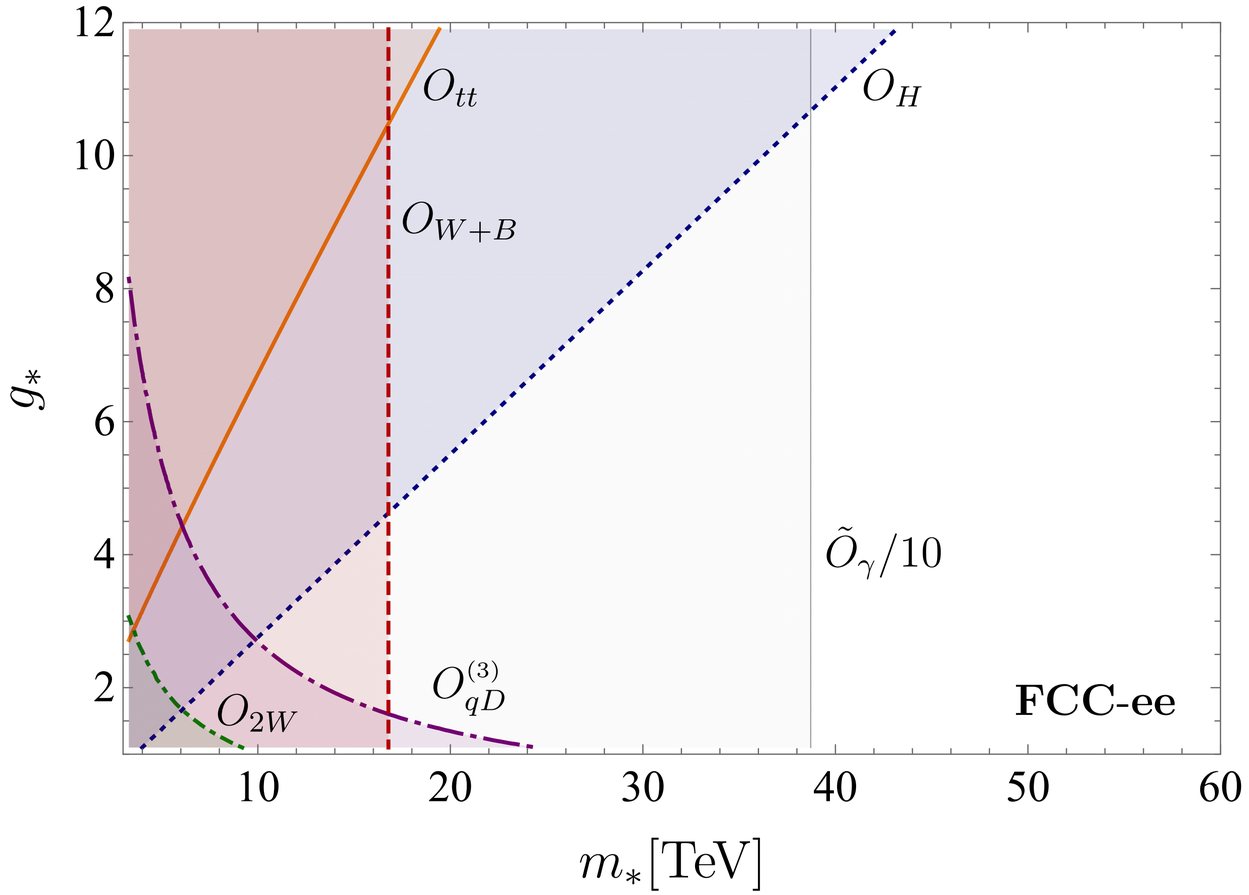
EFT VALIDITY

- Discard all events with with $\max_{ij} m(t_i t_j) > m_*$

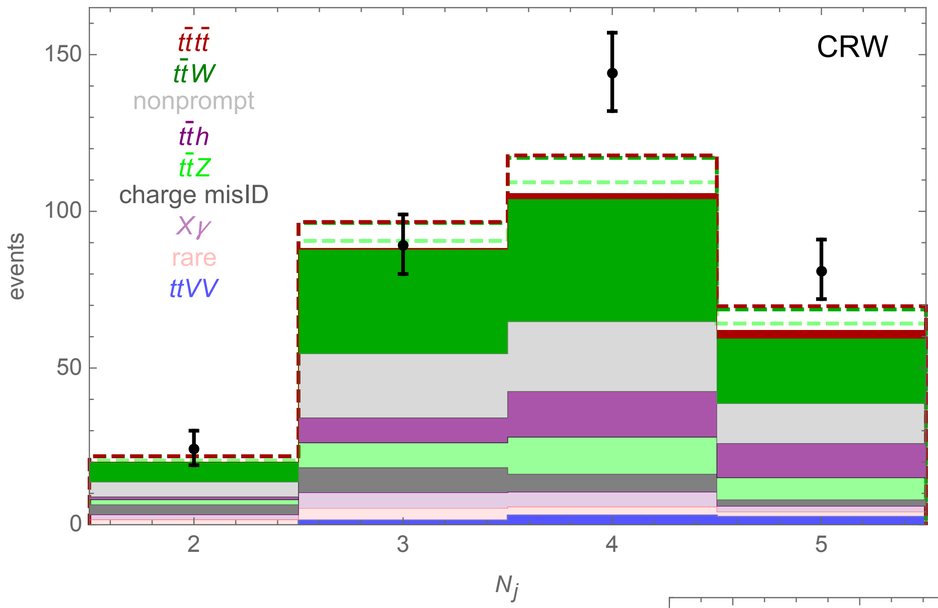


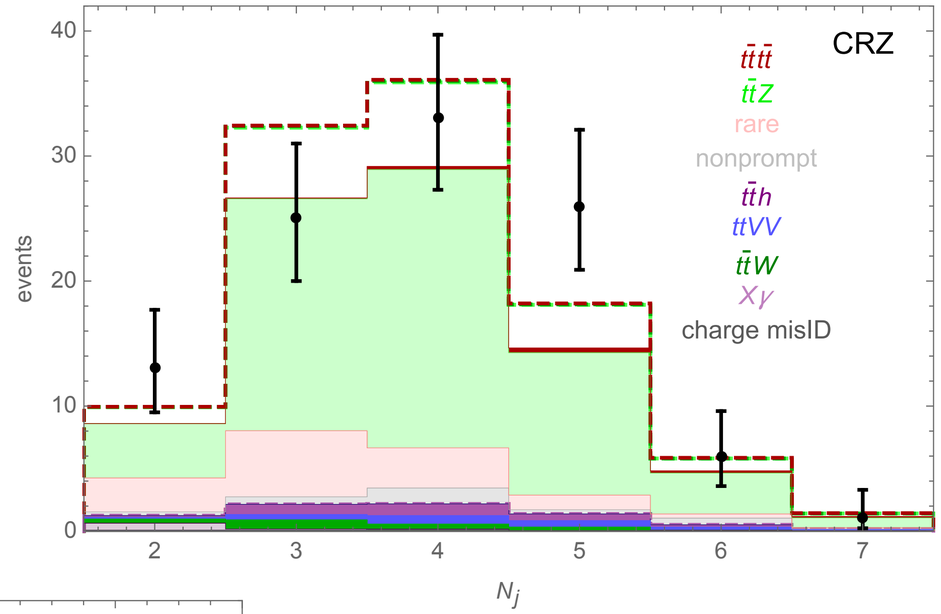
CONSTRAINTS FROM OTHER LEPTON COLLIDERS

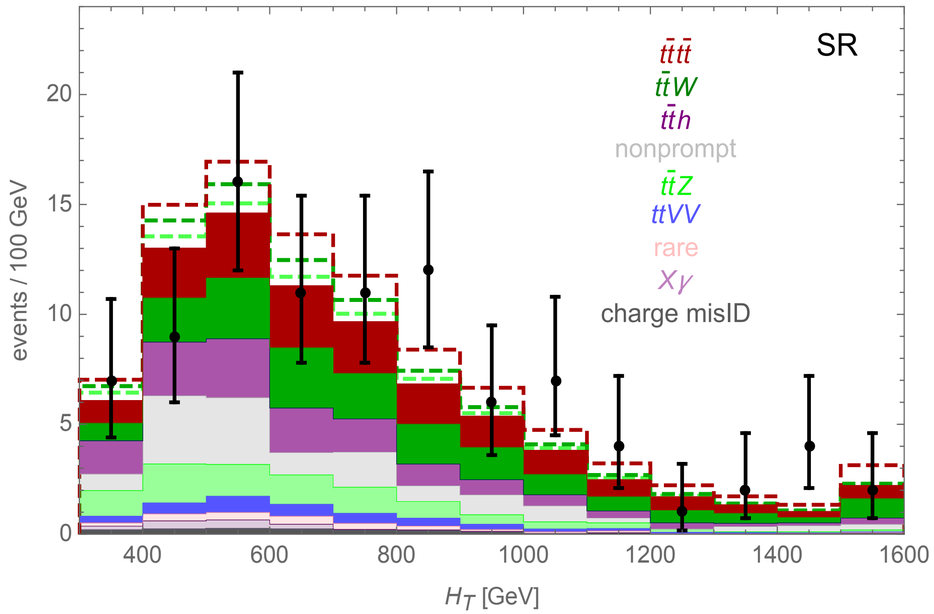




HISTOGRAMS USED FOR FIT TO CMS DATA







[1908.06463]