Top-quark pair production and anomalous Higgs interactions

Mainly Based on:
[Maltoni, Pagani, ST 2406.06694]

Simone Tentori

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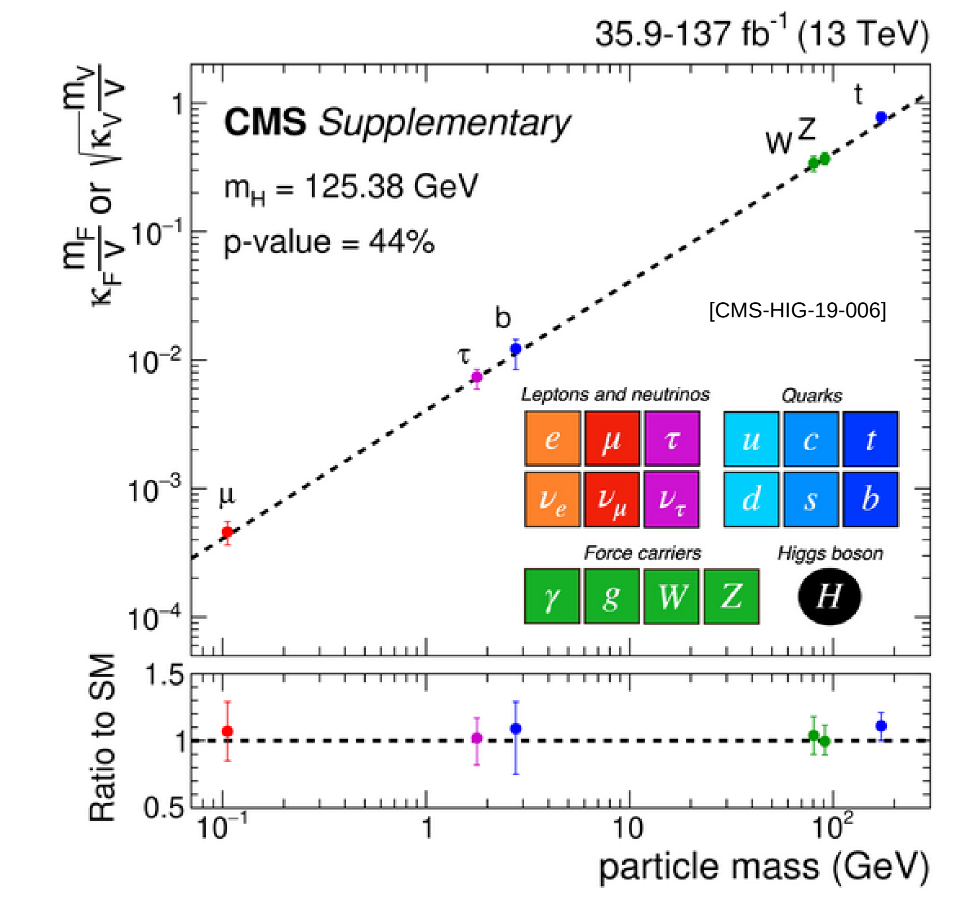
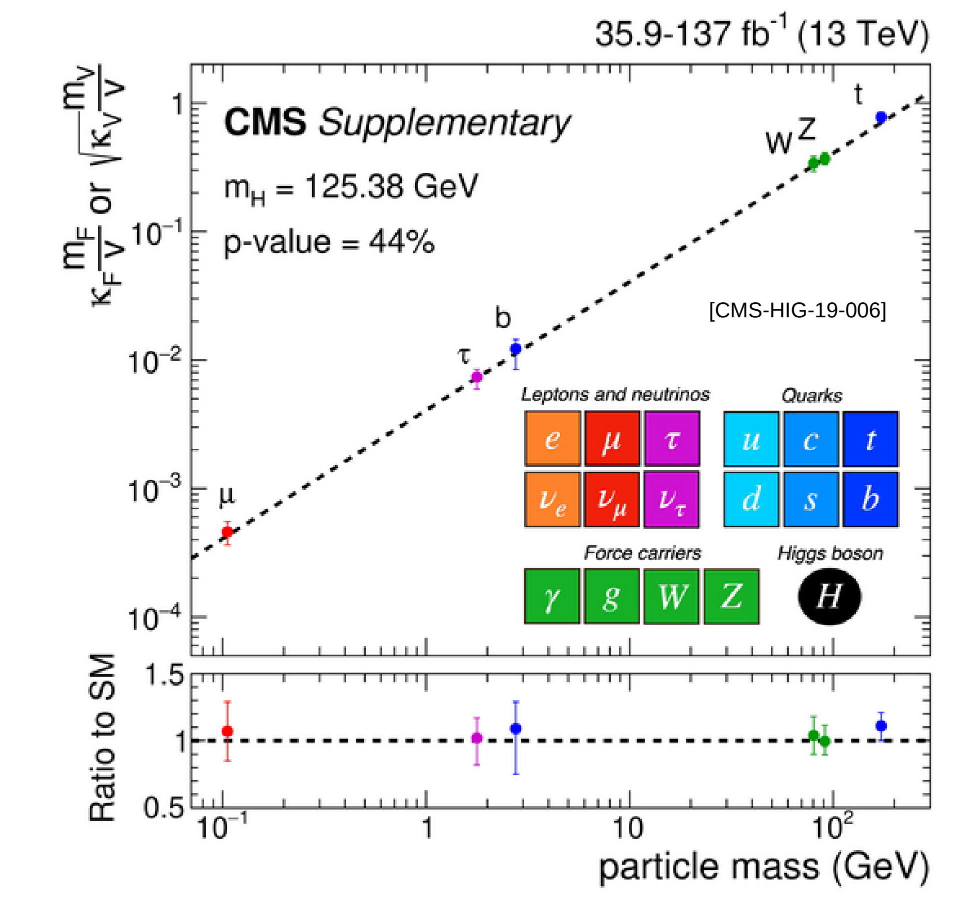
The SM Higgs



- Higgs-fermion couplings in SM uniquely depend on:
  - m_f
  - Higgs vev (v)

$$y_f = \frac{\sqrt{2} m_f}{v}$$

The SM Higgs



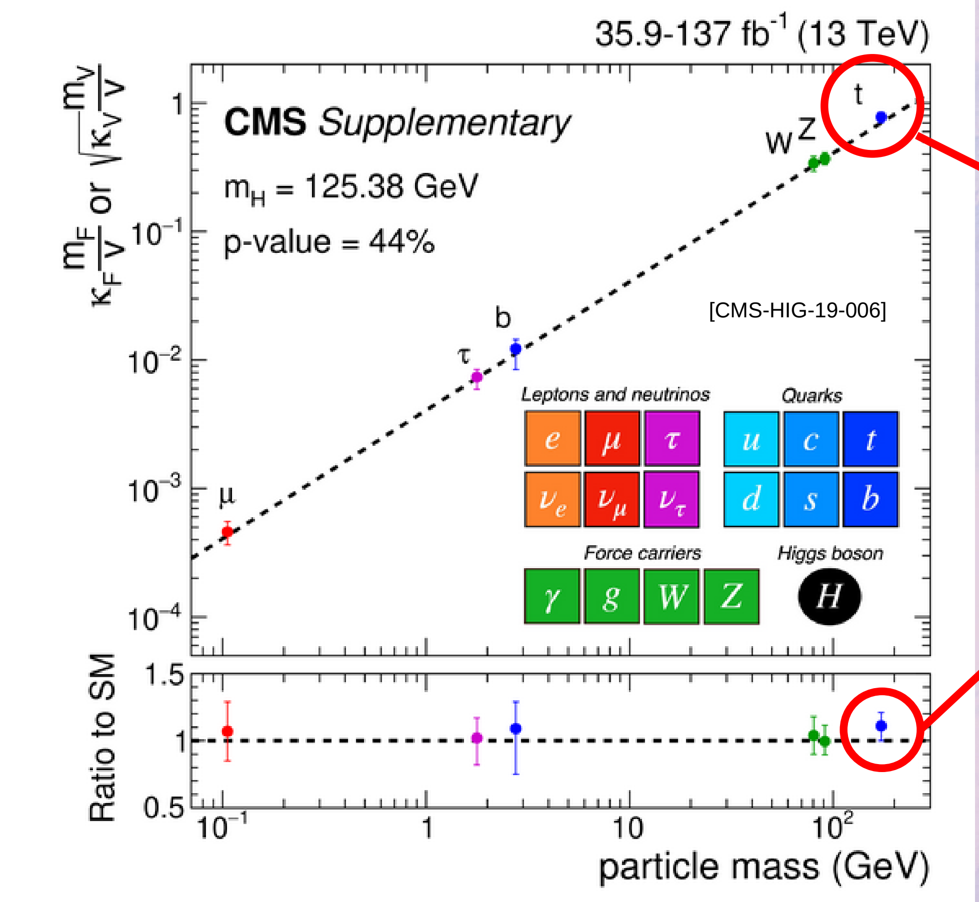
- Higgs-fermion couplings in SM uniquely depend on:
  - m_f
  - Higgs vev (v)

$$y_f = \frac{\sqrt{2} m_f}{v}$$

- NP can modifies SM couplings in many ways

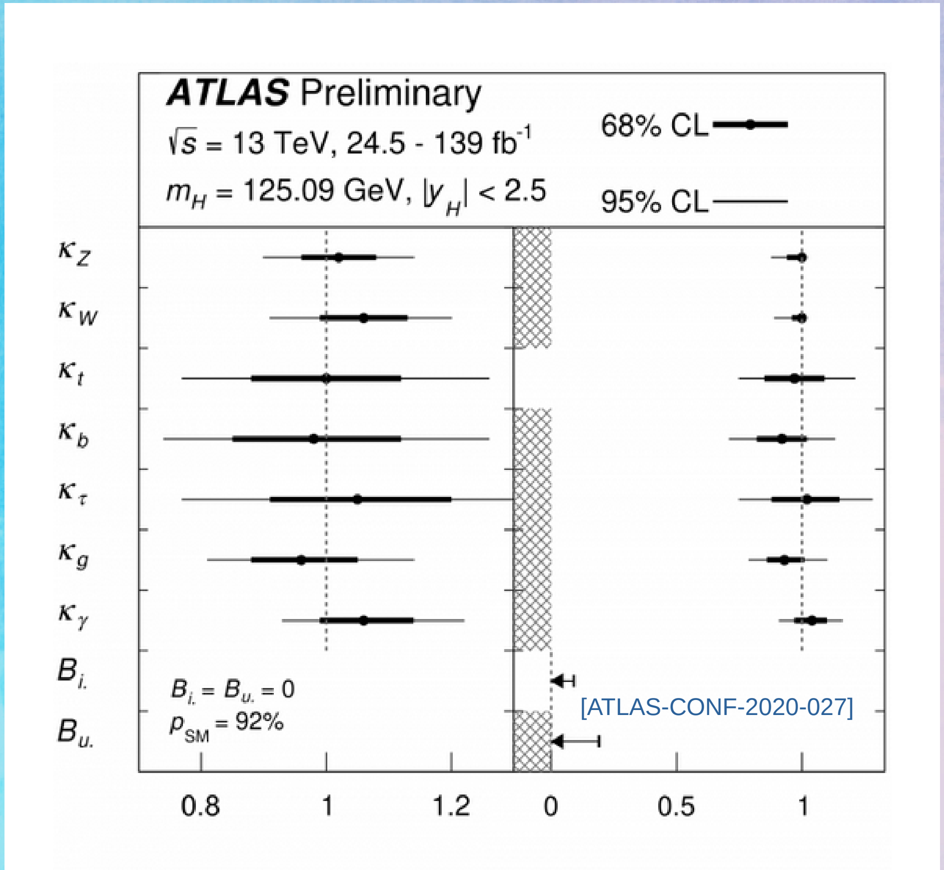
Anomalous Higgs coupling

The SM Higgs



THIS TALK!

The Kappa Framework

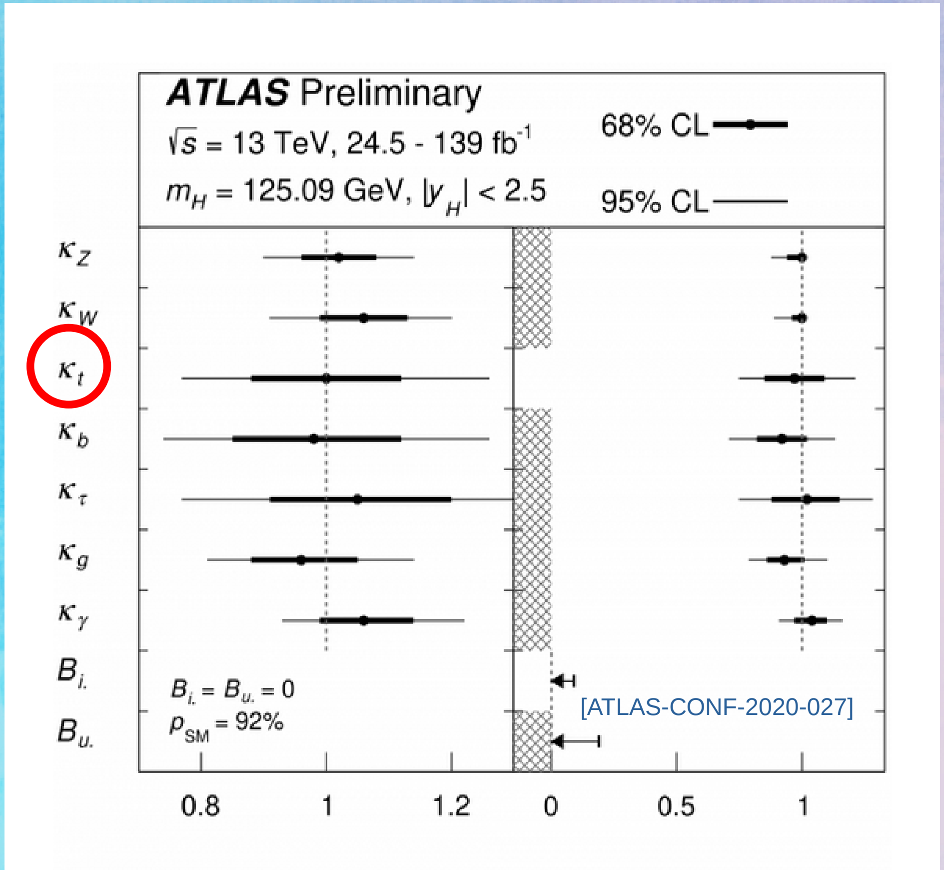


[ATLAS-CONF-2020-027]

- Dress SM cross-section and partial decay width with scale factor κ

$$\sigma(i \to H \to f) = \sigma^i_{\rm SM} {\rm Br}_{\rm SM} \cdot \left(\frac{\kappa_i^2 \kappa_f^2}{k_H^2} \right)$$

The Kappa Framework



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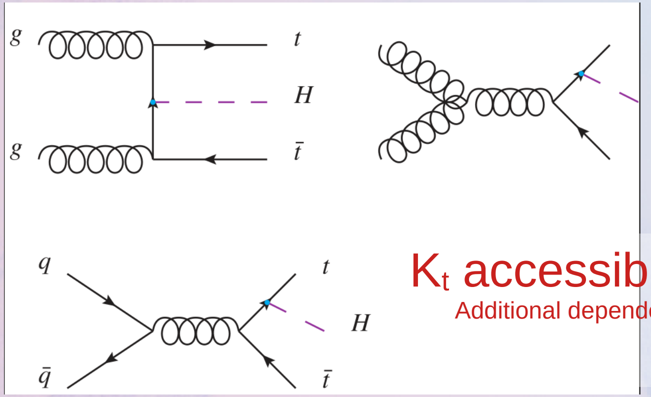
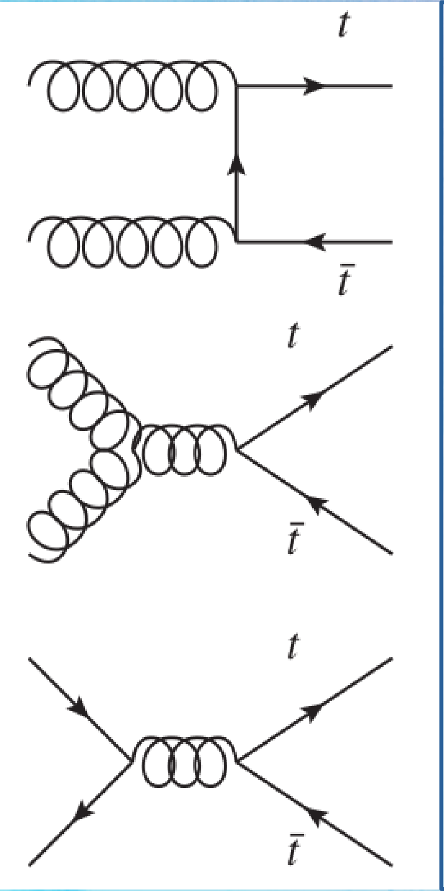


K_t accessible in ttH

Additional dependencies in H decay

Off-shell strategy: going virtual

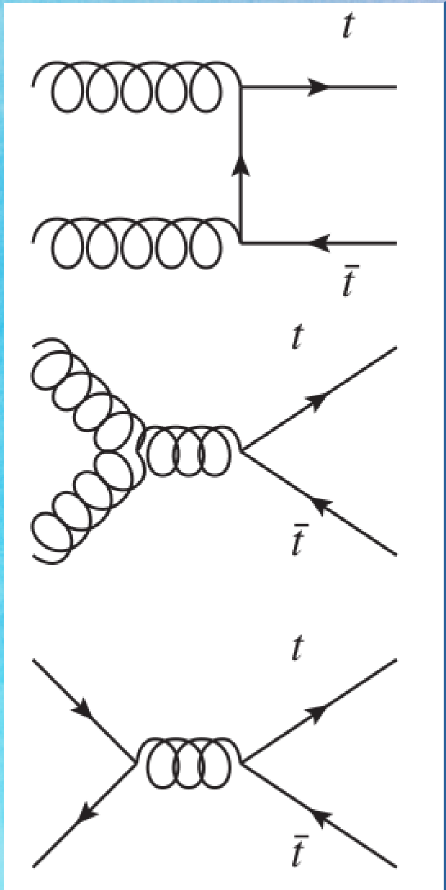


SM:

- **NNLOQCD**
- **NLOEW**

- 250 mln of top-pair at end of Run3
- Accessible differential distribution
- Theory prediction known at NNLOQCD+NLOEW

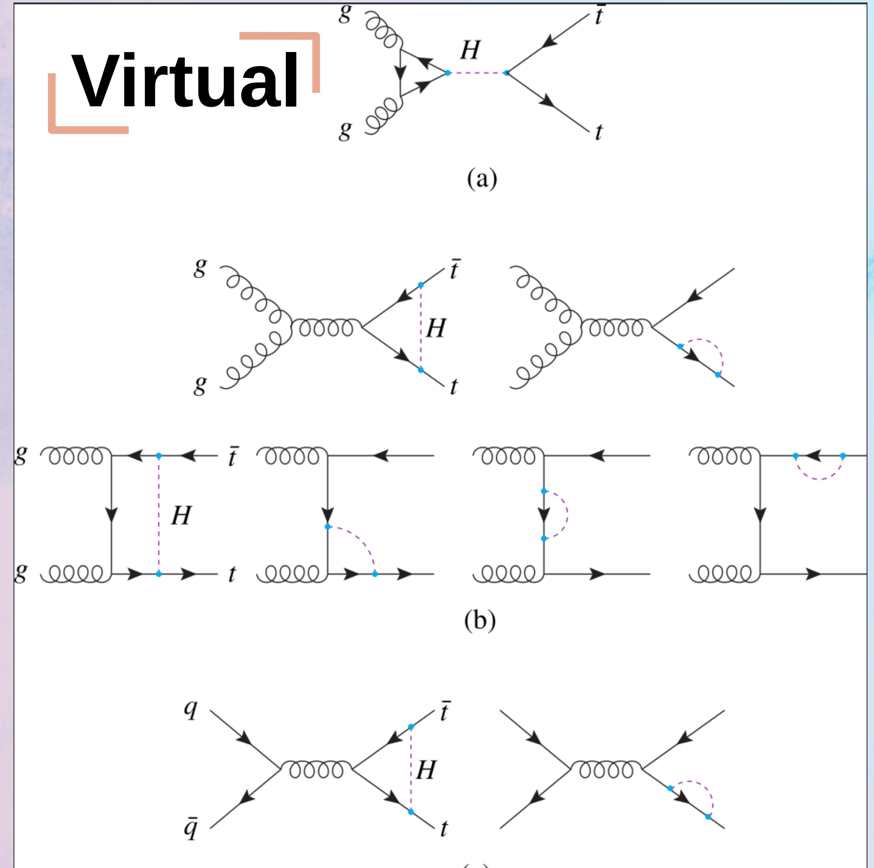
Off-shell strategy: going virtual



SM:

- **NNLOQCD**
- **NLOEW**

Virtual



(a)

(b)

(c)

Higgs–Top modified couplings

$$\mathcal{L}_H = -\frac{1}{\sqrt{2}}\bar{t}\left[y_t + i\tilde{y}_t\gamma_5\right]tH$$

CP-EVEN CP-ODD

$$\begin{cases} \kappa_t = \dfrac{y_t}{y_t^{\mathrm{SM}}}, \\ \tilde{\kappa}_t = \dfrac{\tilde{y}_t}{y_t^{\mathrm{SM}}} \end{cases}$$

SM:

- **K_t=1 ($y_t=m_t/v$)**
- **$\tilde{K}_t$=0.**

$$\sigma_{H,NP} = (\kappa_t^2 - 1)\bar{\sigma}_{\kappa_t} + \tilde{\kappa}_t^2\bar{\sigma}_{\tilde{\kappa}_t}$$

y_t from $t\bar{t}$: Experiments

Measurement of the top quark Yukawa coupling from $t\bar{t}$ kinematic distributions in the lepton+jets final state in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration*

Measurement of the top quark Yukawa coupling from $t\bar{t}$ kinematic distributions in the dilepton final state in proton-proton collisions at $\sqrt{s} = 13$ TeV

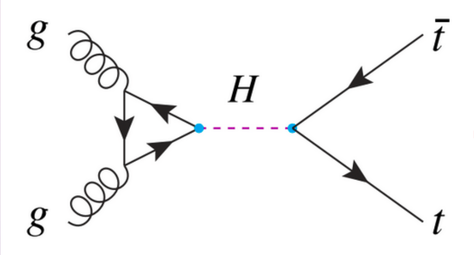
The CMS Collaboration*

total of 55 bins in $M_{t\bar{t}}$, $|\Delta y_{t\bar{t}}|$, and the number of reconstructed jets. The measured value of Y_t is $1.07^{+0.34}_{-0.43}$, compared to an expected value of $1.00^{+0.35}_{-0.48}$. The observed upper limit on Y_t is 1.67 at 95% confidence level (CL), with an expected value of 1.62.

antiquark are sensitive to the value of Y_t. The measurement yields a best fit value of $Y_t = 1.16^{+0.24}_{-0.35}$, bounding $Y_t < 1.54$ at a 95% confidence level.

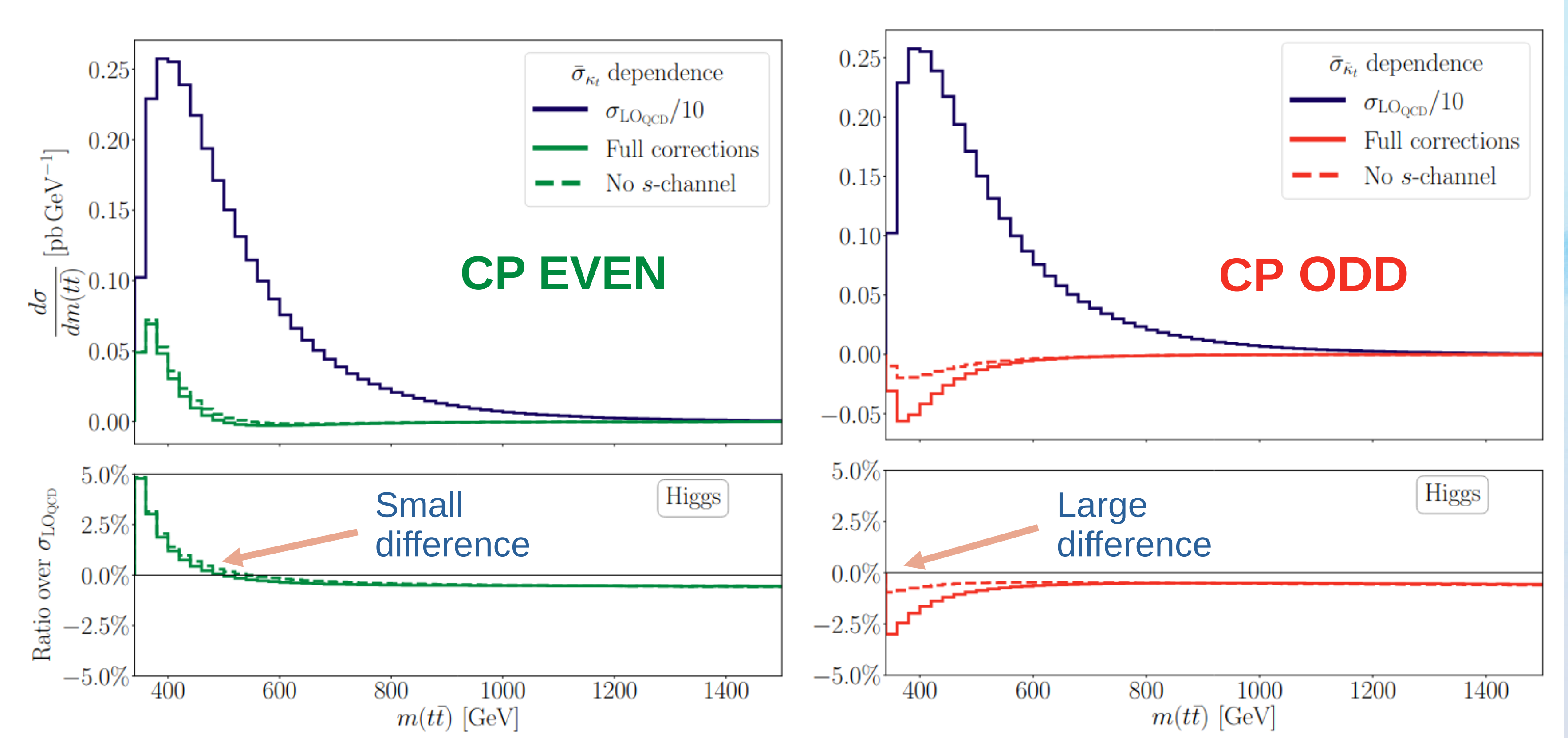
Theory prediction:

- HATHOR (Aliev et al. ‘10)
- Complemented with CP-odd Higgs interaction from [2104.04277]

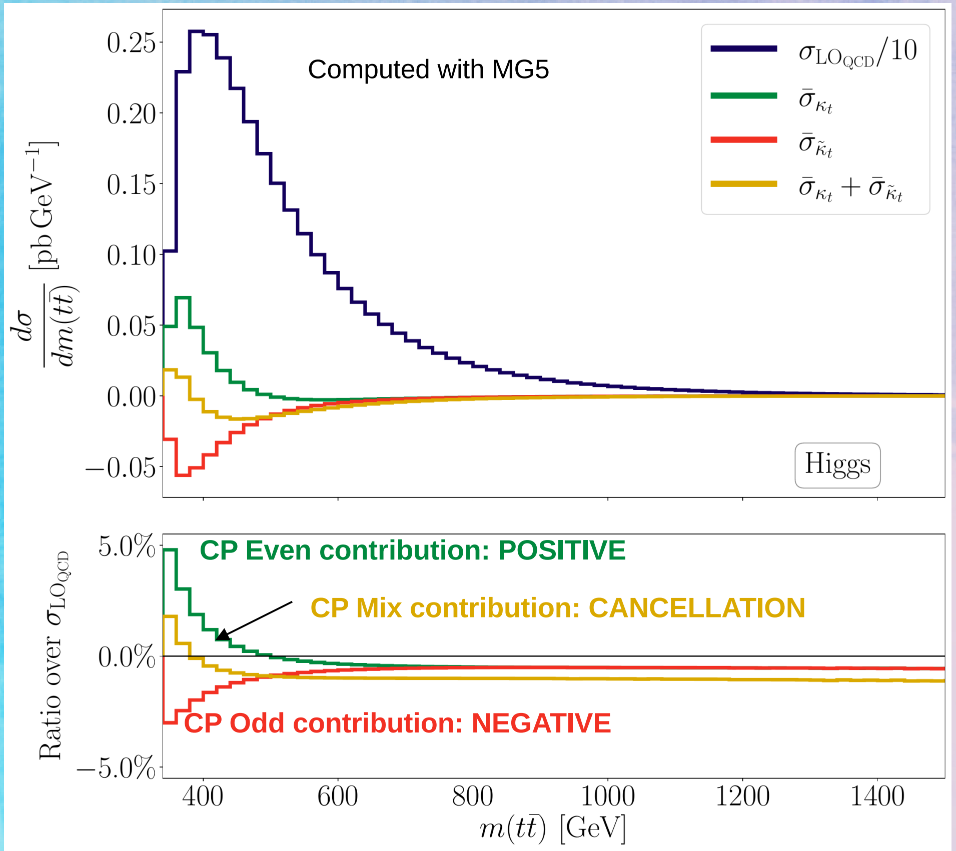


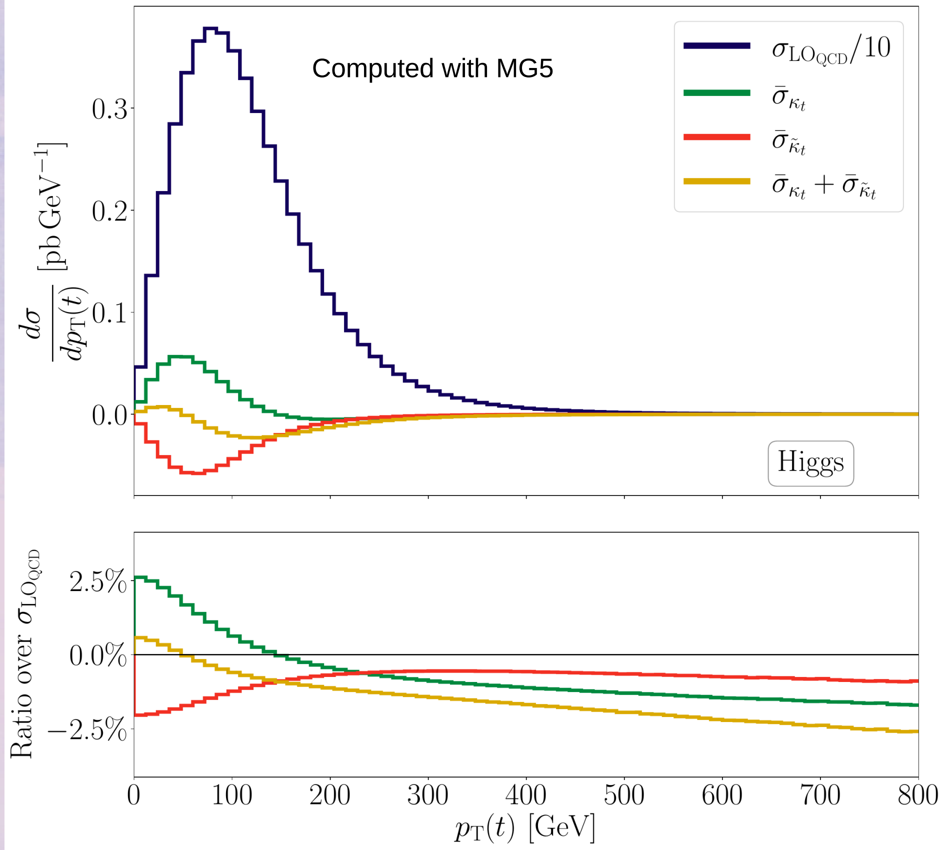
Omitted in the theoretical calculation

S-channel contribution



Distributions





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Fit: 1 parameter CP Even

FIT INFO:
- Data: SM
- Baseline: SM without Higgs
- Errors and Bins: [CMS: 1803.08856]

$$\mathcal{L} = \mathcal{L}_{\text{SM, no Higgs}} - \frac{y_t}{\sqrt{2}} \bar{t} t H$$

	$\kappa_t{}^{+1\sigma,2\sigma,3\sigma}_{-1\sigma,2\sigma,3\sigma}$	$\tilde{\kappa}_t{}^{+1\sigma,2\sigma,3\sigma}_{-1\sigma,2\sigma,3\sigma}$
SM_{mult} LHC	$1.00^{+0.28,0.52,0.72}_{-0.41,1.0,1.0}$	$0.0^{+0.59,1.05,1.43}_{-0.59,1.06,1.44}$

By Construction **By "Magic"**

Fit: 1 parameter CP Odd

FIT INFO:
- Data: SM (CP Odd Higgs)
- Baseline: SM without Higgs
- Errors and Bins: [CMS: 1803.08856]

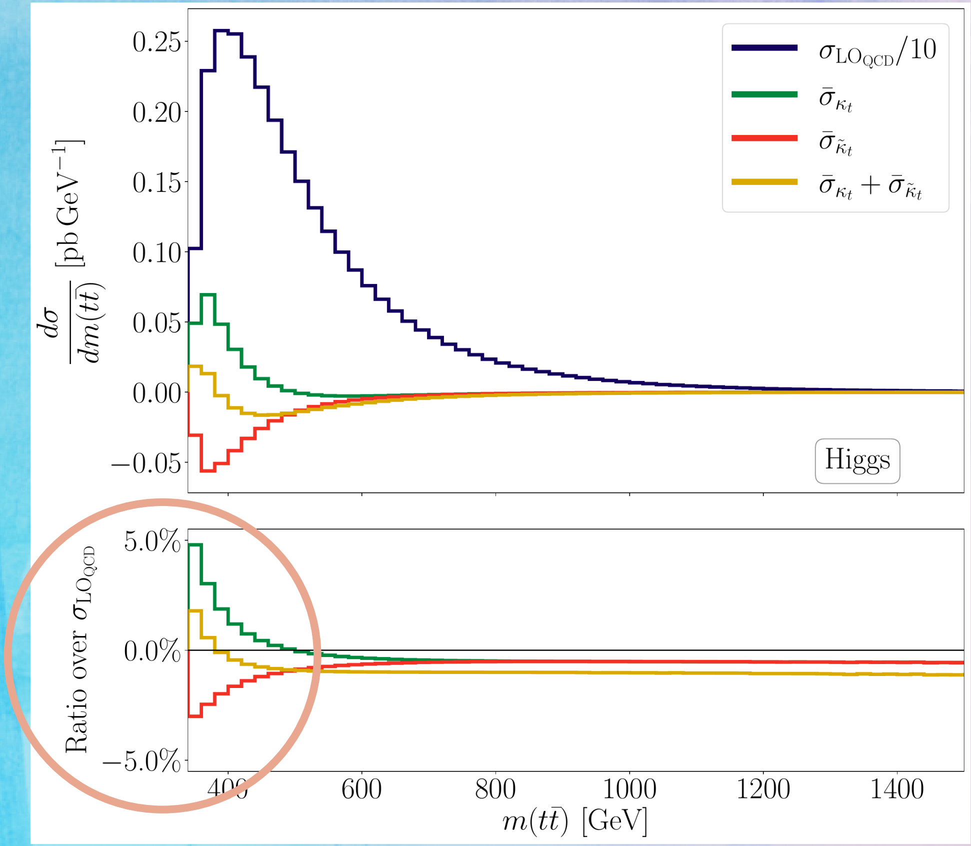
$$\mathcal{L} = \mathcal{L}_{\text{SM, no Higgs}} - \frac{y_t}{\sqrt{2}} \bar{t} \gamma_5 t H$$

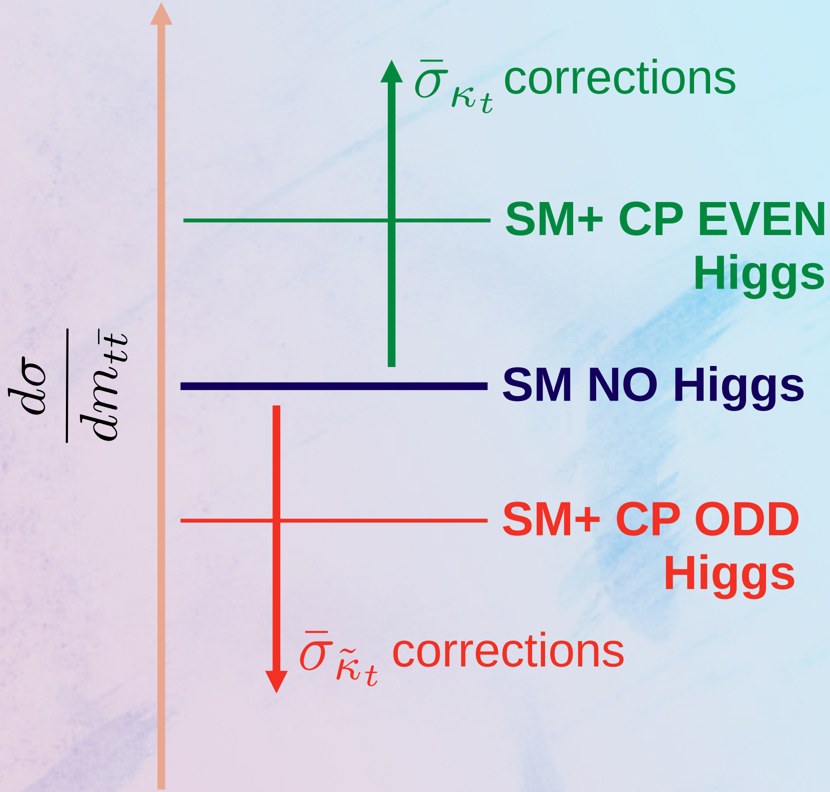
	$\kappa_t{}^{+1\sigma, 2\sigma, 3\sigma}_{-1\sigma, 2\sigma, 3\sigma}$	$\tilde{\kappa}_t{}^{+1\sigma, 2\sigma, 3\sigma}_{-1\sigma, 2\sigma, 3\sigma}$
SM_{mult} LHC	$0.00^{+0.55, 0.93, 1.22}_{-0.55, 0.93, 1.22}$	$1.0^{+0.44, 0.78, 1.06}_{-1.00, 1.00, 1.00}$

By "Magic"

By Construction

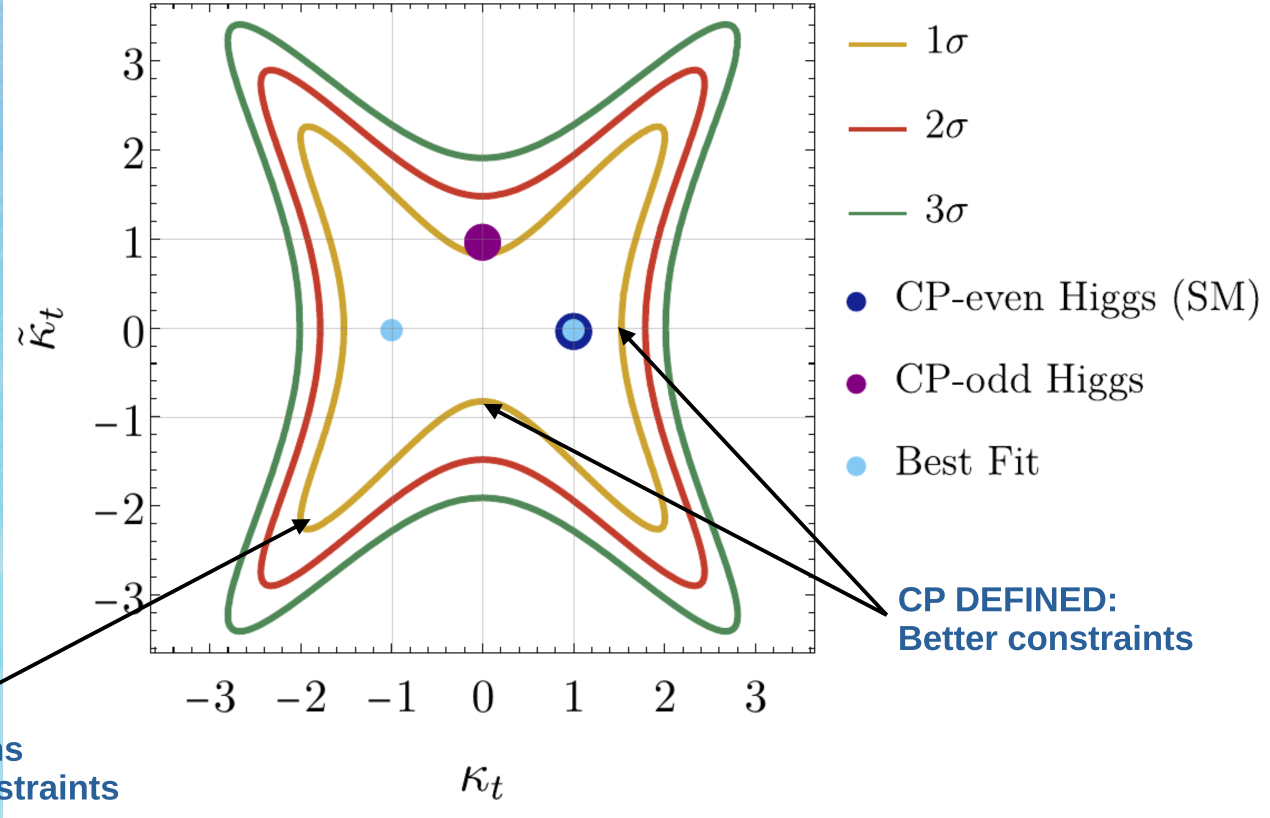
Fit: CP Even or CP Odd





Fit: 2 parameters

SEE ALSO:
[Martini, Pan, Schulze and Xiao, 2104.04277]



CP DEFINED:
Better constraints

CP MIX:
Cancellations weaken constraints

Conclusions

Thanks for the attention and stay tuned!

What has been done:

- y_t fitted in $t\bar{t}$ production considering virtual H

What we can do now:

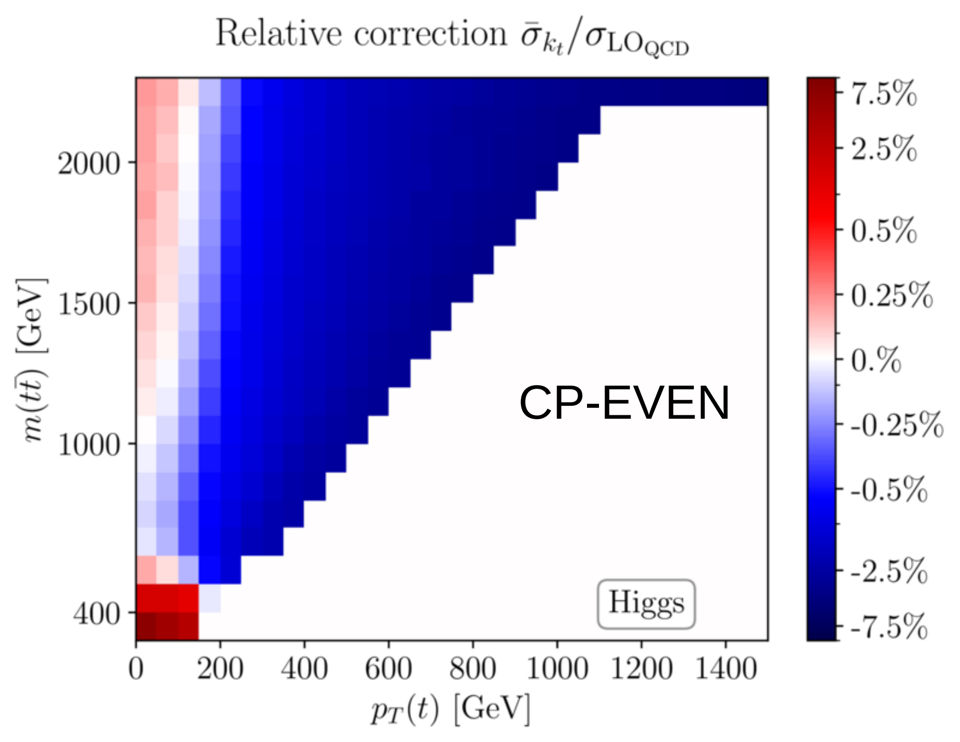
- Repeat the analysis with full virtual correction and finer binning in Run3 (or HL-LHC)
- Simultaneous fit of CP-Even and CP-Odd couplings

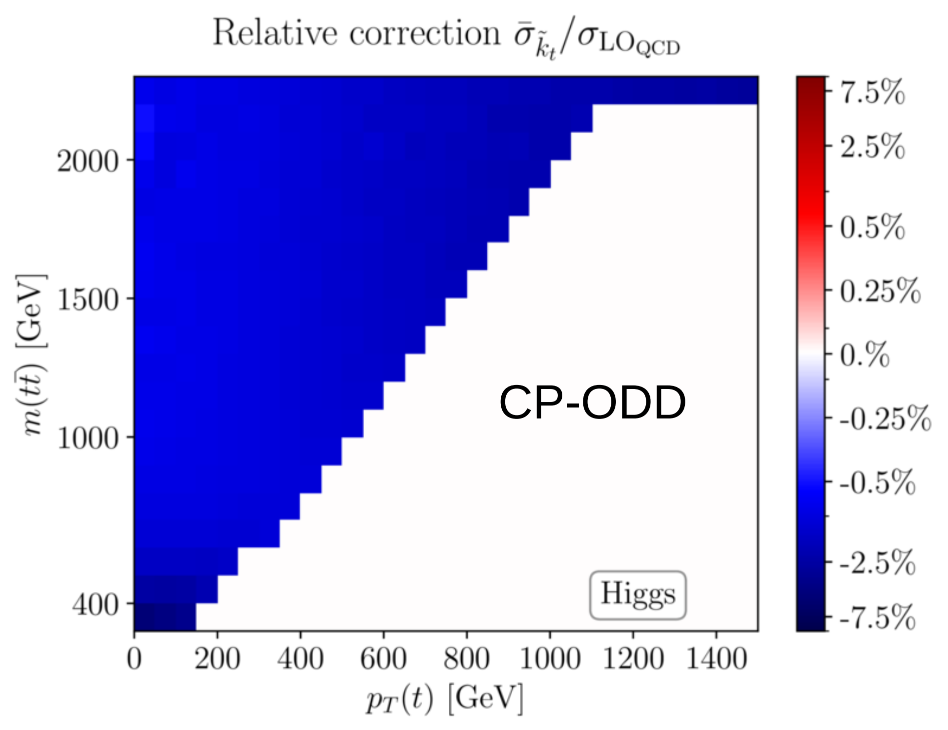
What can be interesting for the future:

- Let the top decays (avoid degeneracy)
- FCC-ee365 study (no enough energy for on-shell $t\bar{t}H$)

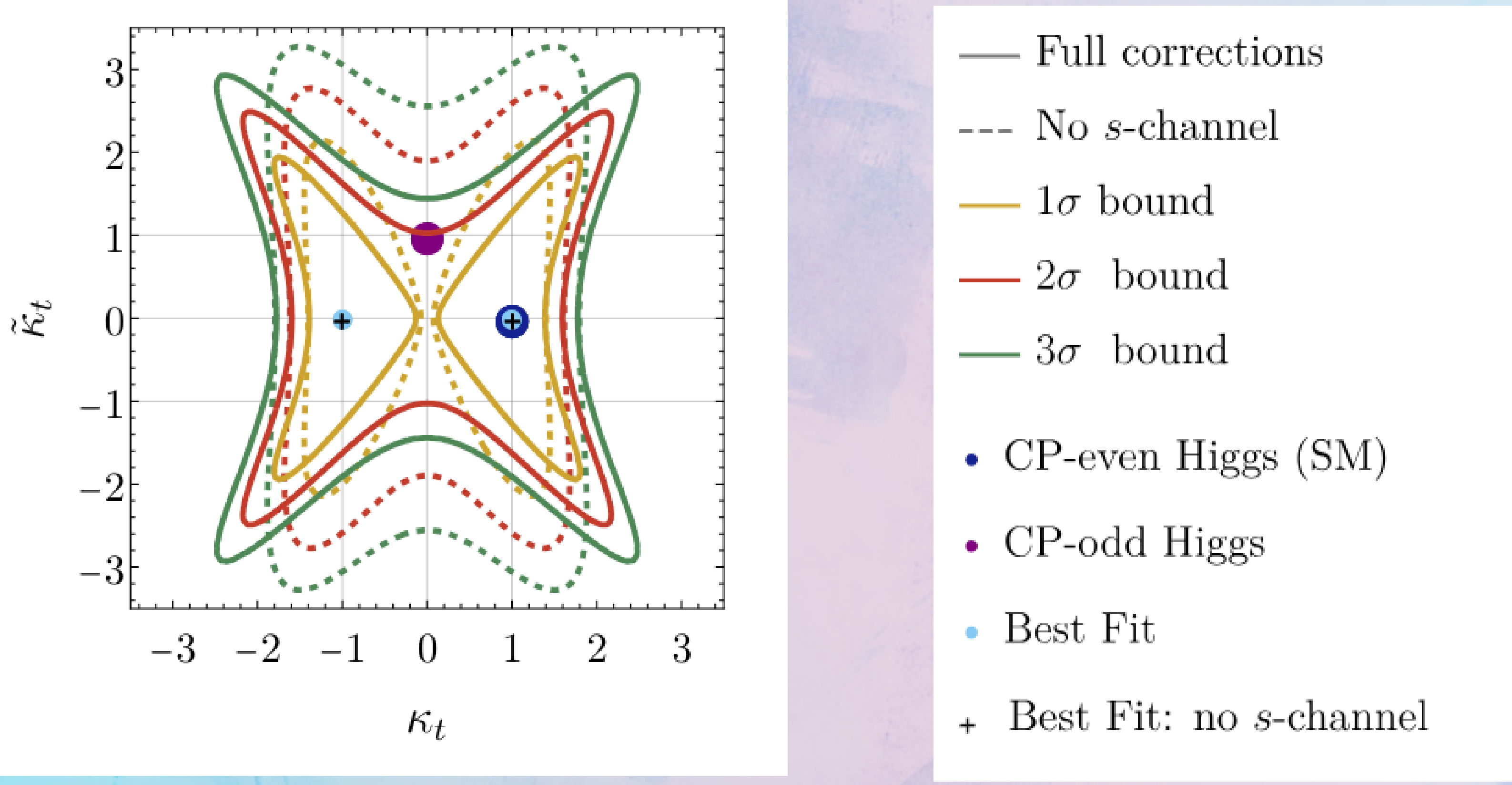
Backup

Double differential

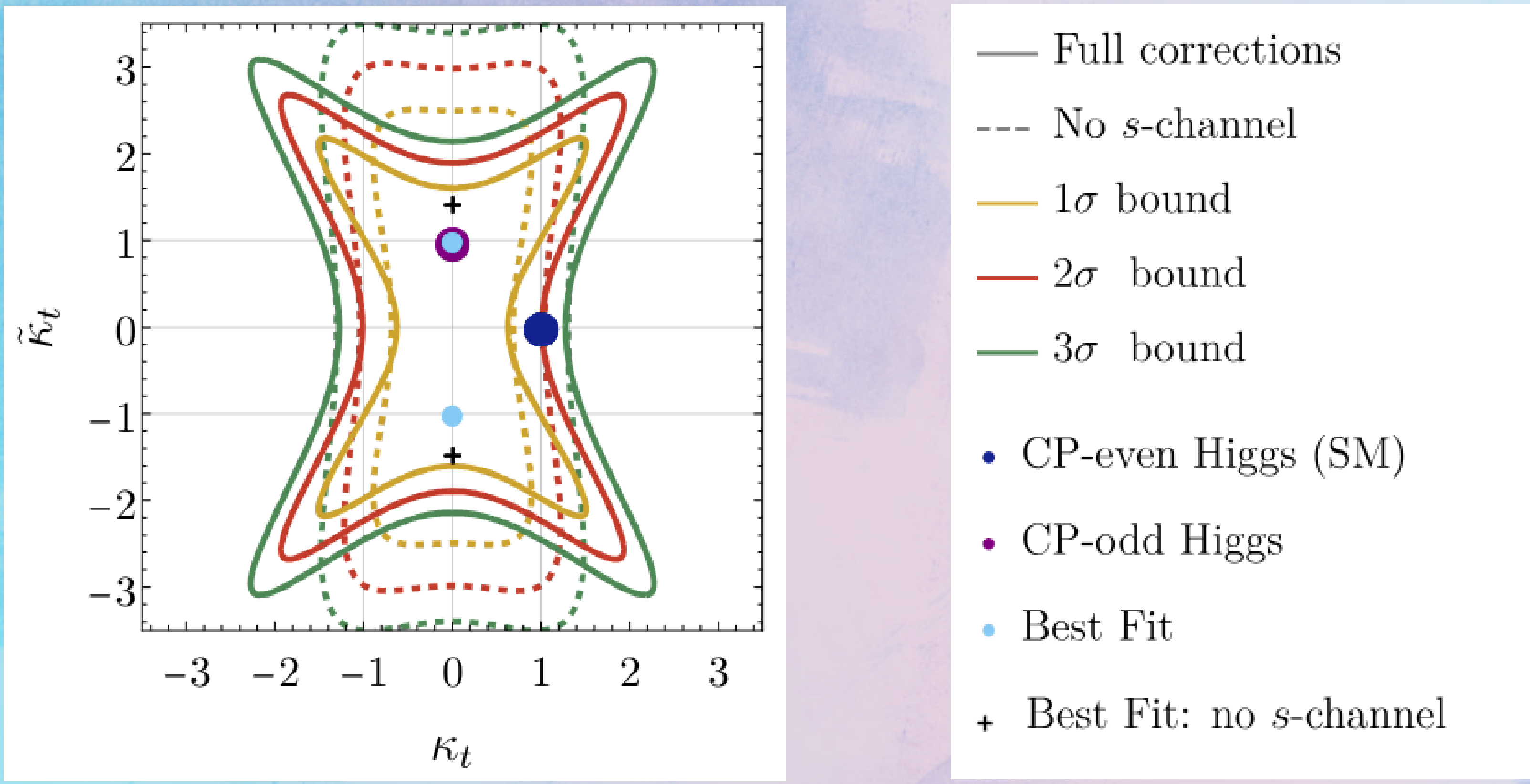




Fit comparison



CP-Odd Higgs fit comparison



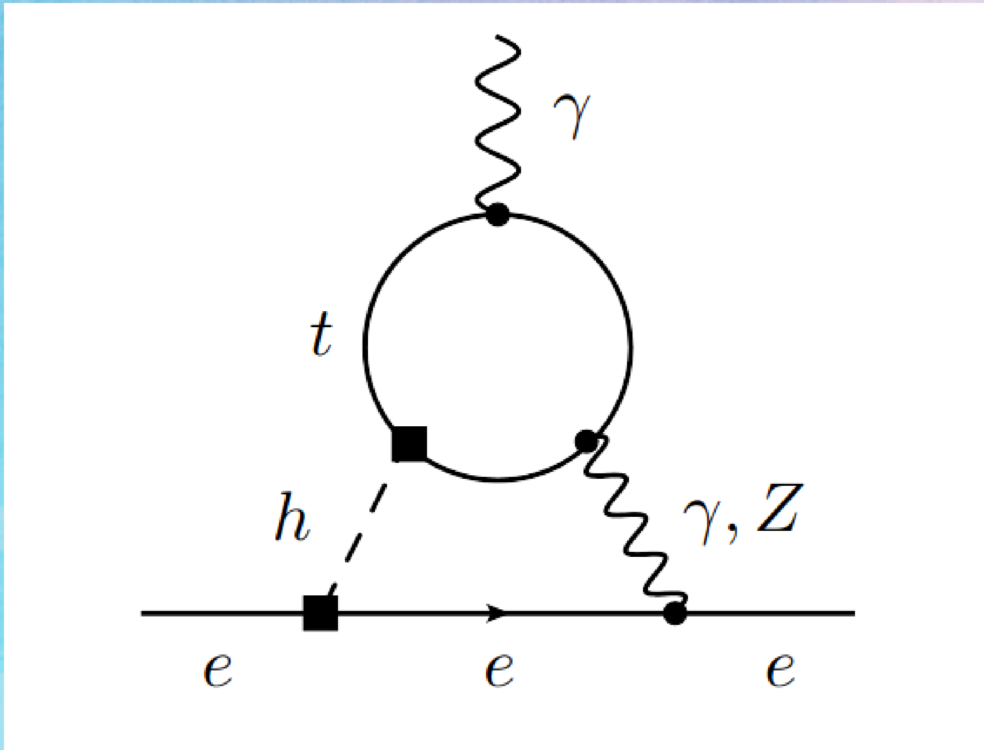
SMEFT Relations

$$\mathcal{L}^{\mathrm{dim}=6}_{\mathrm{SMEFT,\,top-Higgs}} \equiv \mathcal{L}_{\mathrm{SM}} + \frac{C^{u\Phi}_{tt}}{\Lambda^2}\left(\Phi^\dagger\Phi - \frac{v^2}{2}\right)\overline{\psi}_{Q_{3,L}}\tilde{\Phi}\psi_{t,R} + \mathrm{h.c.}\,,$$

$$\kappa_t = 1 - \frac{v^2}{\Lambda^2}\frac{\Re(C^{u\Phi}_{tt})}{y^{\mathrm{SM}}_t}\,,$$

$$\tilde{\kappa}_t = -\frac{v^2}{\Lambda^2}\frac{\Im(C^{u\Phi}_{tt})}{y^{\mathrm{SM}}_t}\,.$$

Indirect Searches: electron EDM



Brod, Haisch, Zupan: [1310.1385]

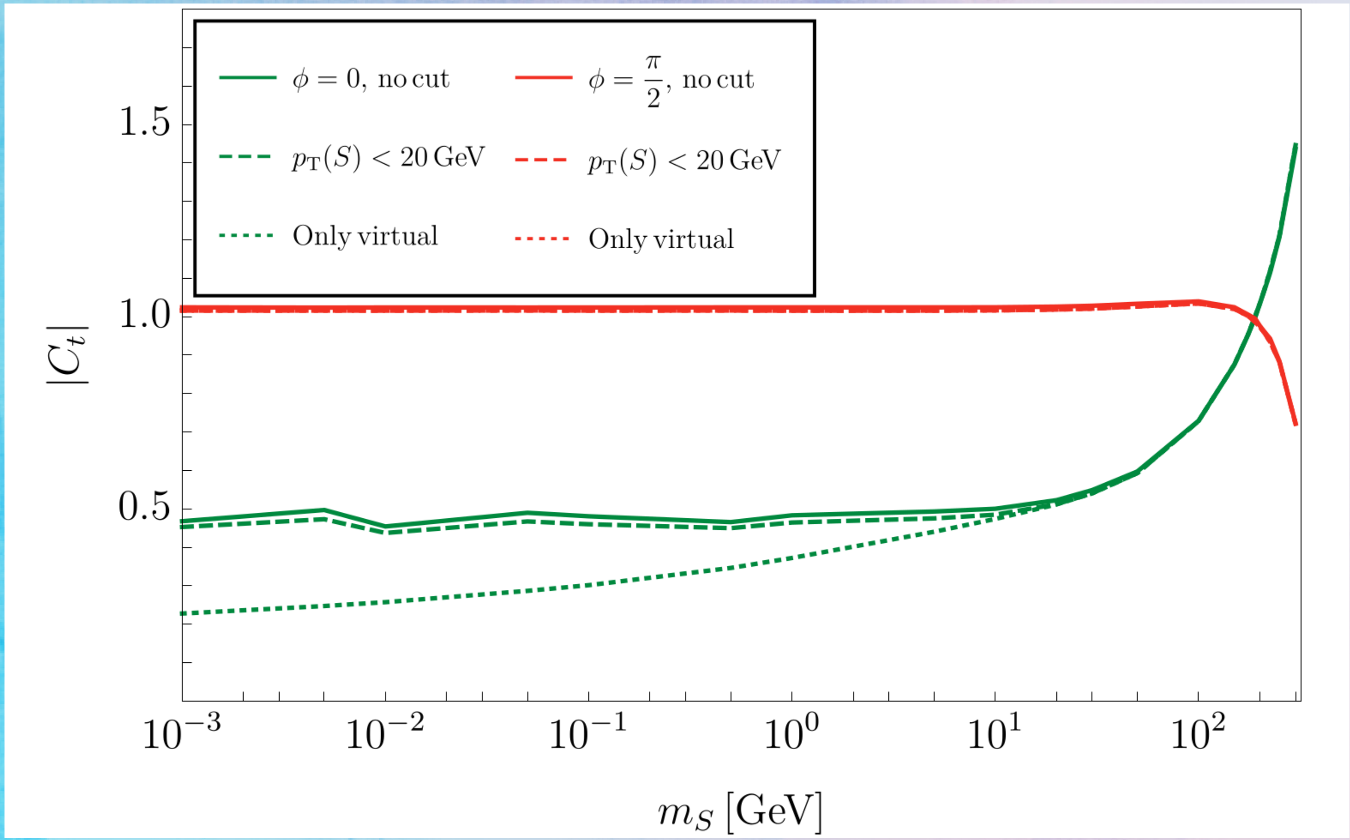
Extremely precise measurement:

- **$|\tilde{k}_t|<0.01$**

Additional assumption:

- **Higgs couples to SM electron**
- **$|\tilde{k}_e|=0$, $|k_e|=1$**
- **Possible One Loop NP effects**

Transverse momentum sensitivity

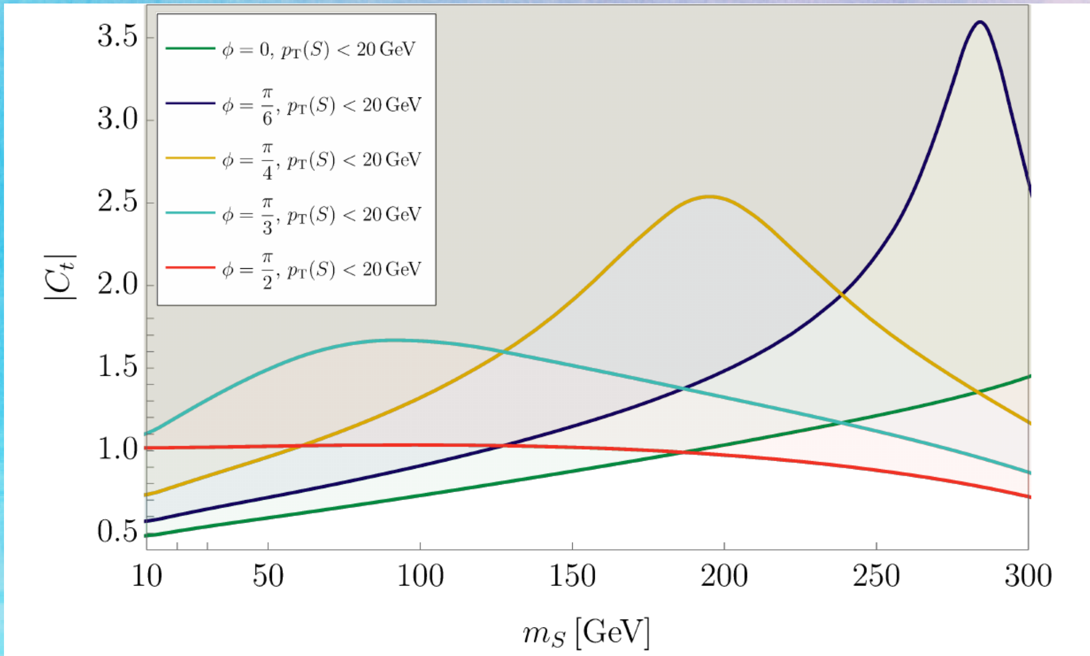


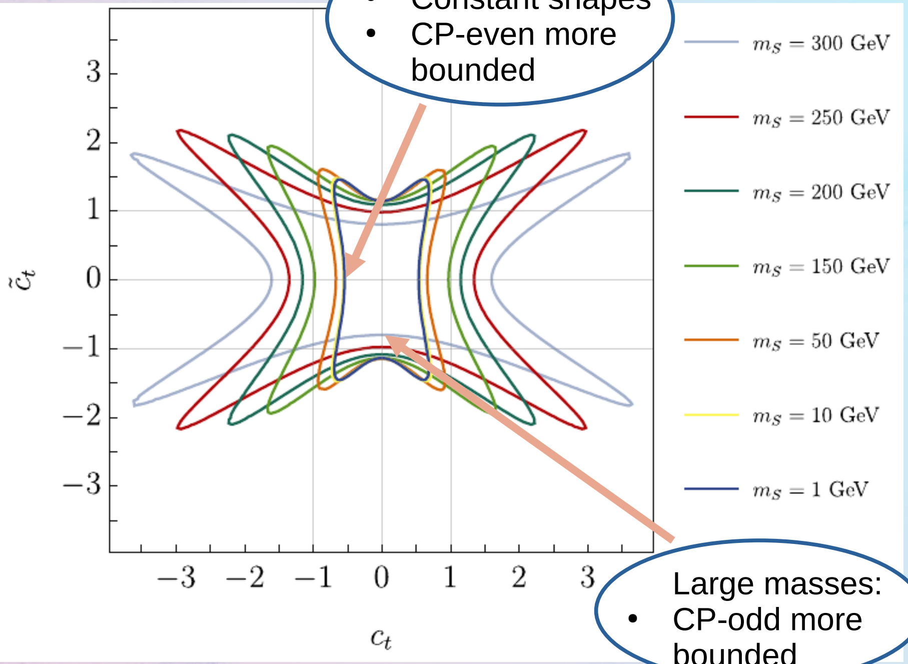
$$C_t| = \sqrt{c_t^2 + \tilde{c}_t^2}$$

$$\phi = \arctan \frac{\tilde{c}_t}{c_t}$$

FIT INFO:
- Data: SM
- Theory: SM+S(NP)
- Errors and Bins: [CMS: 1803.08856]

Arbitrary mass: Mixing the couplings

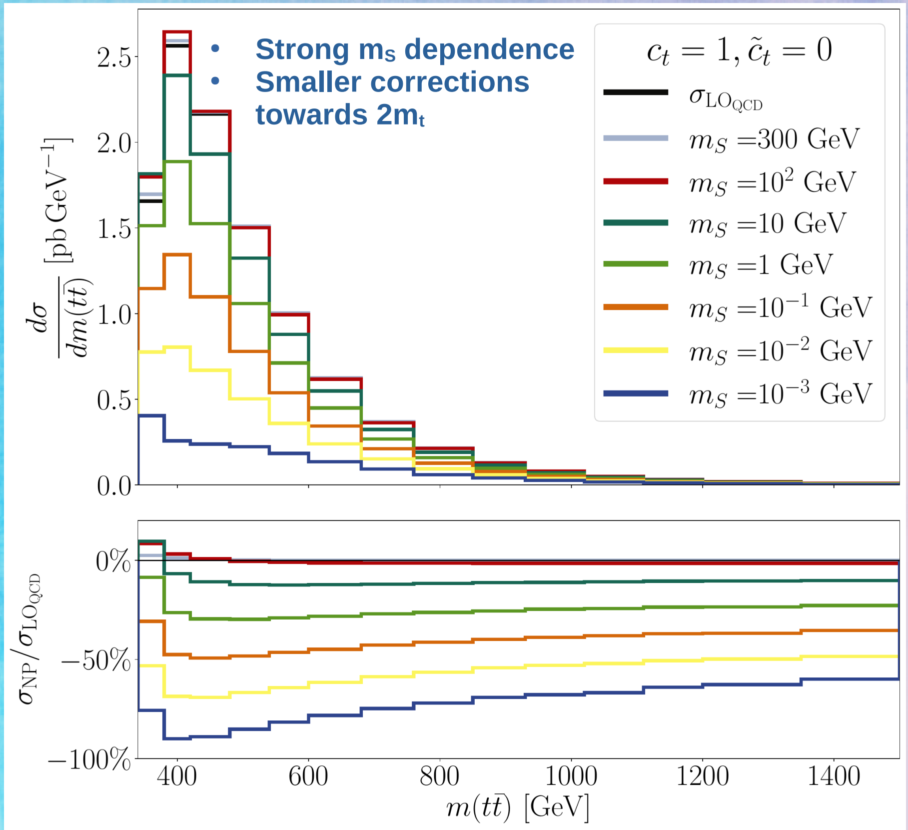


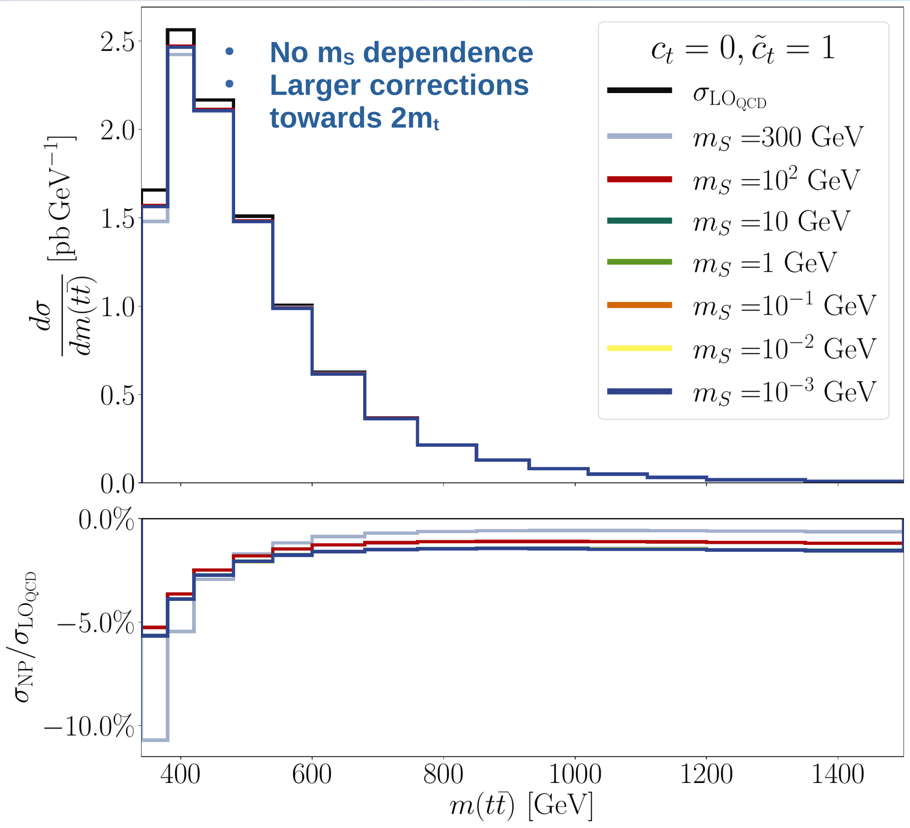


Small masses:
- Constant shapes
- CP-even more bounded

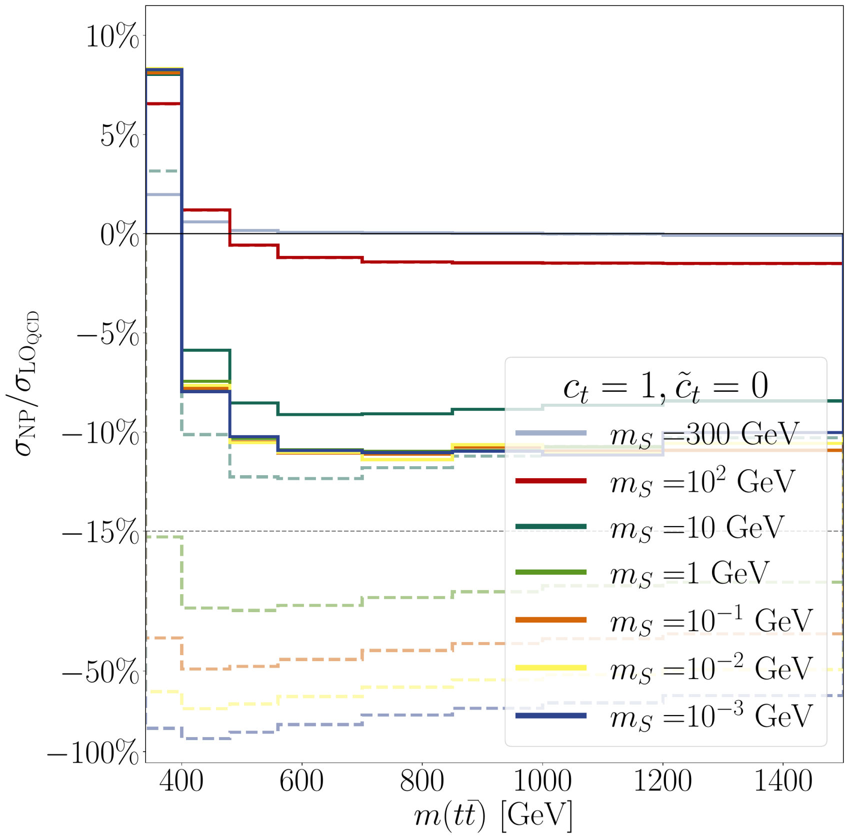
Large masses:
- CP-odd more bounded

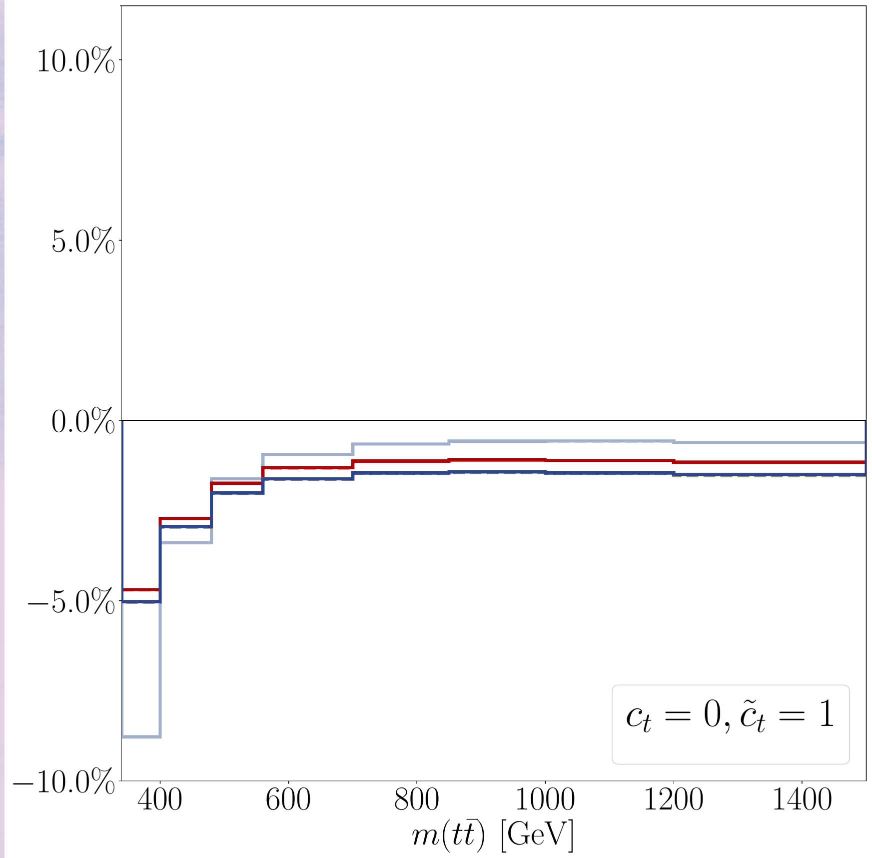
Purely Virtual Corrections: variable mass





Adding the real





Higgs-Top modified couplings

$$\mathcal{L}_H = -\frac{1}{\sqrt{2}}\bar{t}\left[y_t + i\tilde{y}_t\gamma_5\right]tH$$

CP-EVEN (y_t) **CP-ODD** ($i\tilde{y}_t\gamma_5$)

$$\begin{cases} \kappa_t = \dfrac{y_t}{y_t^{\mathrm{SM}}}, \\ \tilde{\kappa}_t = \dfrac{\tilde{y}_t}{y_t^{\mathrm{SM}}} \end{cases}$$

Very different distributions in angular observables with on-shell H

[e.g. 1407.5089]