New Physics virtual corrections to top-pair production

Mainly Based on:
[Blasi, Maltoni, Mariotti, Mimasu, Pagani, ST 2311.16048]
[Maltoni, Pagani, ST 2406.06694]

Simone Tentori

ICHEP, Prague, 18/07/2024

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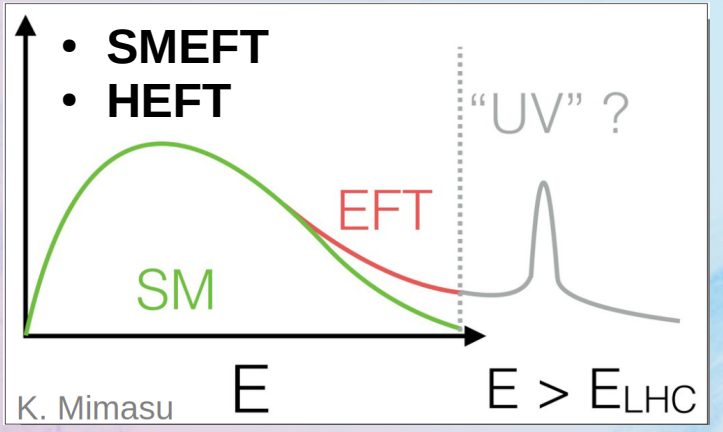
New Physics, which one?

Direct Searches

Indirect Searches



m_{NP}

Light Physics Searches:
- Specific approaches
- Cover part of UV models
- Small number of parameters

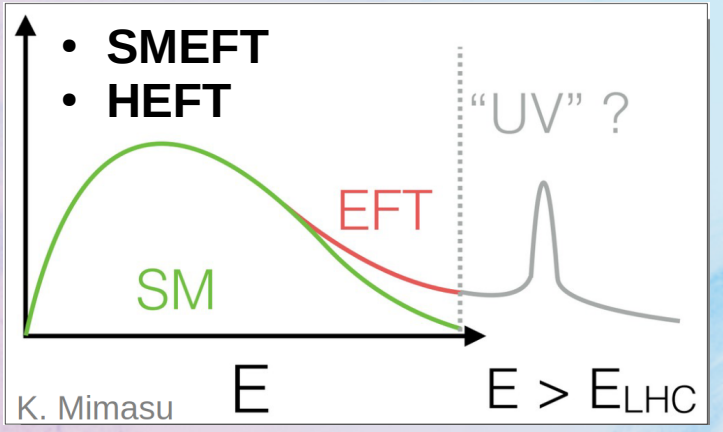
EFT approaches:
- Systematic approaches
- Cover large class of UV models
- Many parameters

New Physics, which one?

Direct Searches

THIS TALK!

Indirect Searches



m_{NP}

Light Physics Searches:
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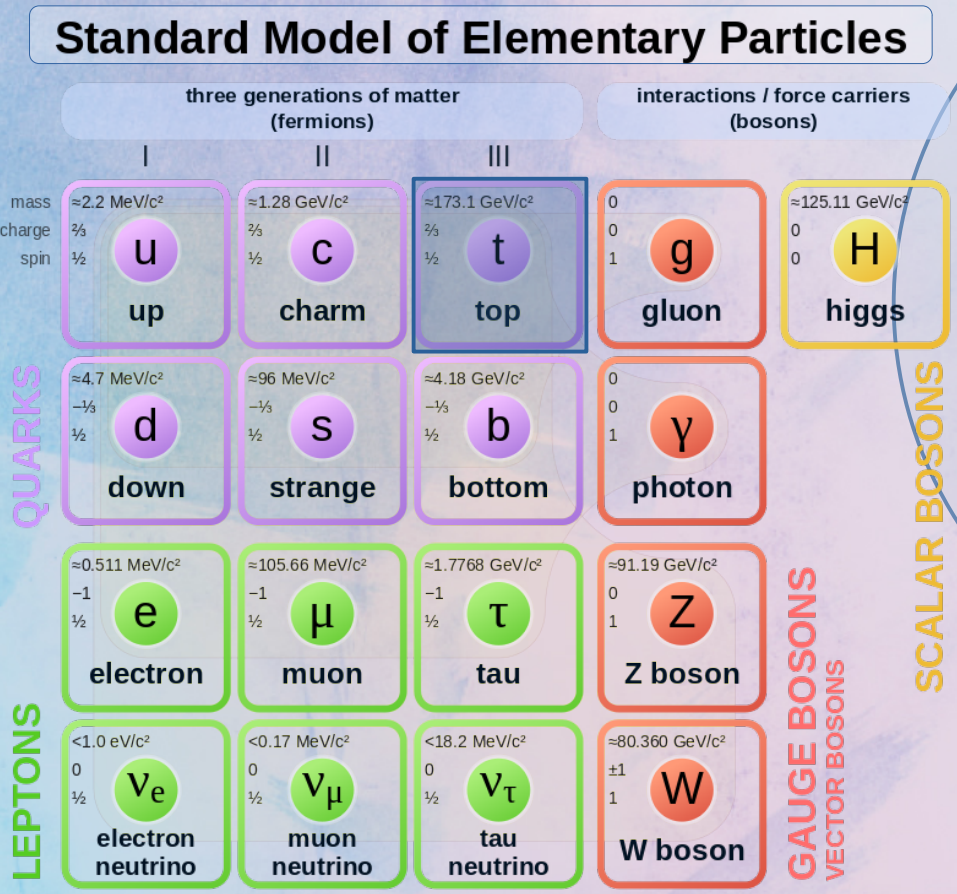
Top quark

NP Portal:

- Heaviest quark
- Model with mass hierarchical couplings



Accessible Differential Kinematical Distributions

- Invariant mass
- Top trasverse momentum
- Rapidity difference

Lot of statistics

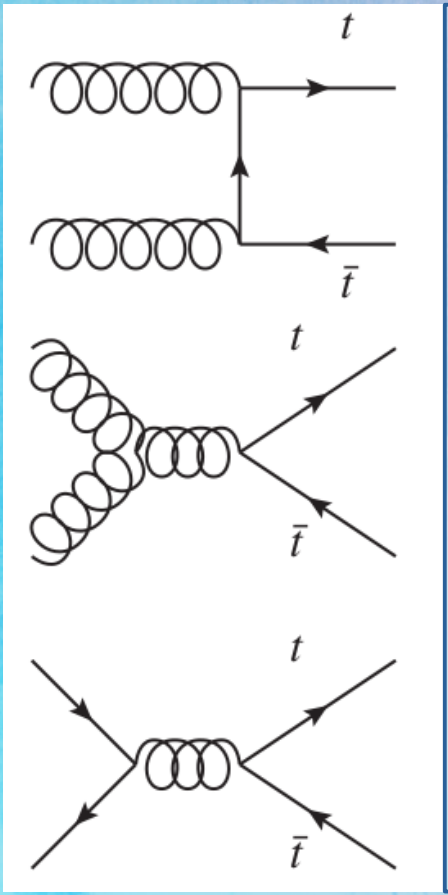
$t\bar{t}$ number of events:

- Run1: $2.7^{1}+3.8^{2}$ mln
- Run2: 152^{3} mln
- Run3: 251^{4} mln
- HL-LHC[5]: 3.1 bln

$\sigma_{t\bar{t}}$= 1:179.6 pb 2:256pb 3:833.9pb 4,5:926pb
NNLO-NNLL Top++v2.0

Simone Tentori

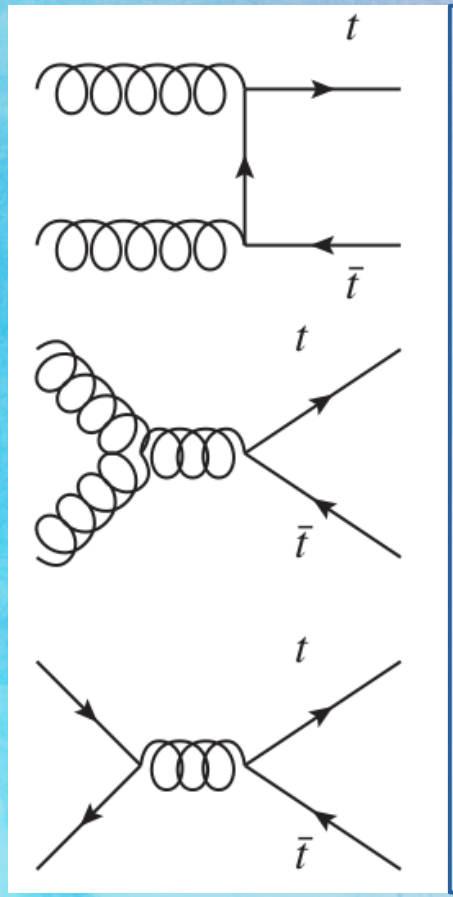
Which processes?



SM:

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

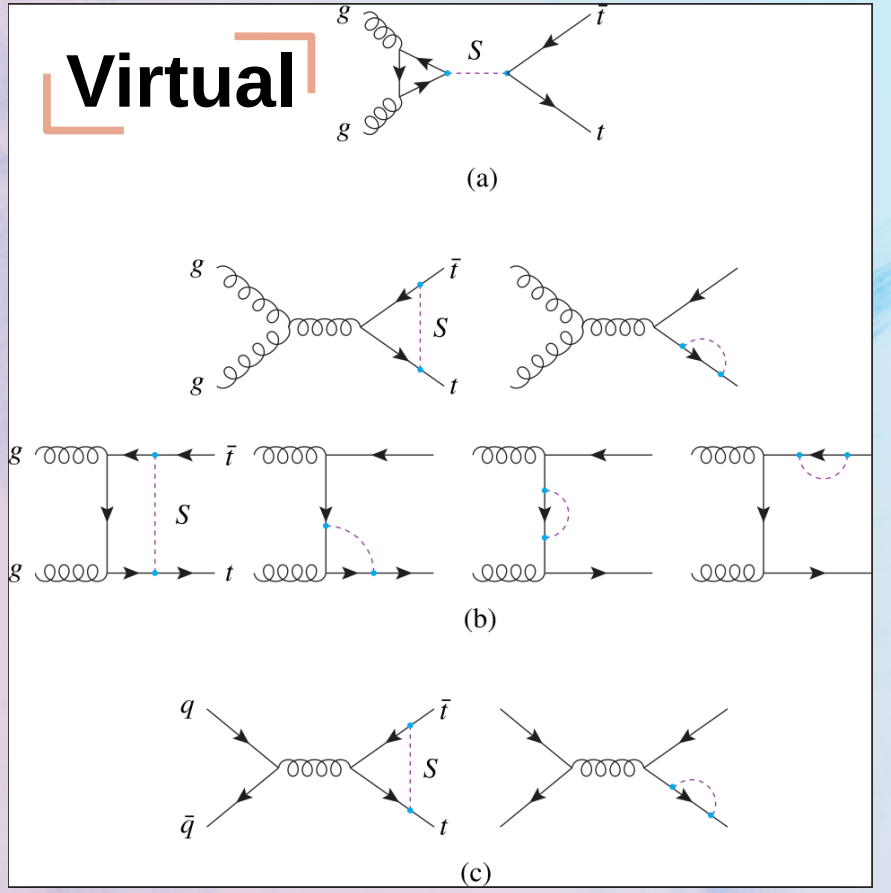
Which processes?



SM:

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

Virtual



The Model

$$\mathcal{L}_{NP} = -\bar{t}(c_t + i\tilde{c}_t\gamma_5)tS$$

CP-EVEN

CP-ODD

Generic Scalar State

Induced corrections to top-pair production

$$\sigma_{NP} = \bar{\sigma}_{c_t} c_t^2 + \bar{\sigma}_{\tilde{c}_t} \tilde{c}_t^2 + \bar{\sigma}_{c_t \tilde{c}_t} c_t \tilde{c}_t$$

The Model

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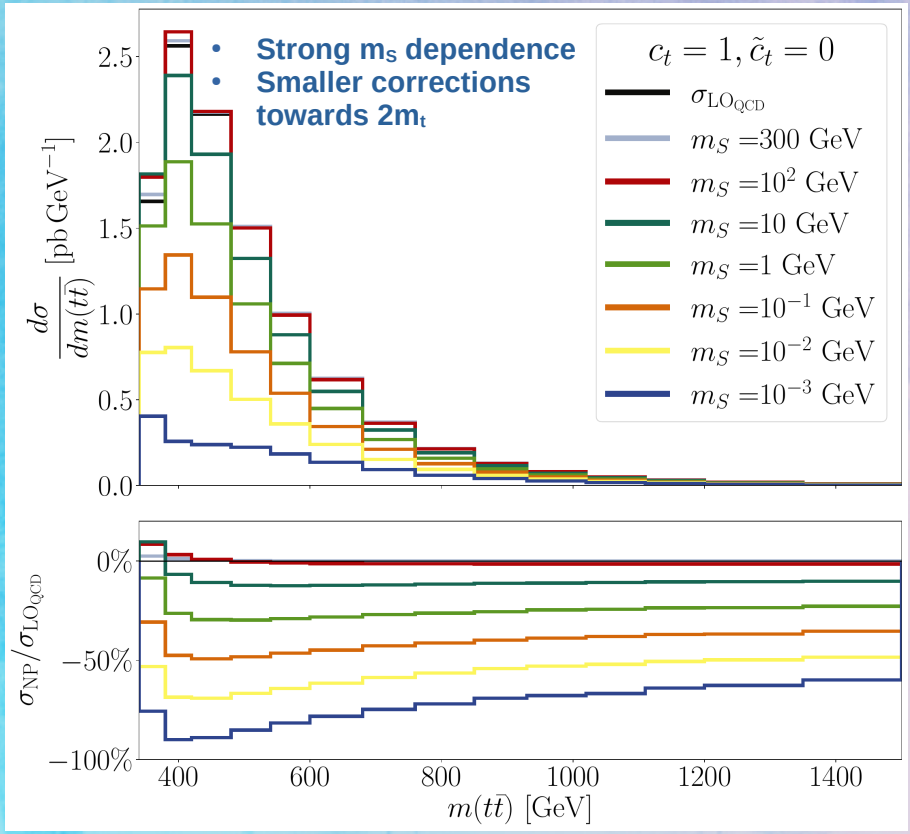
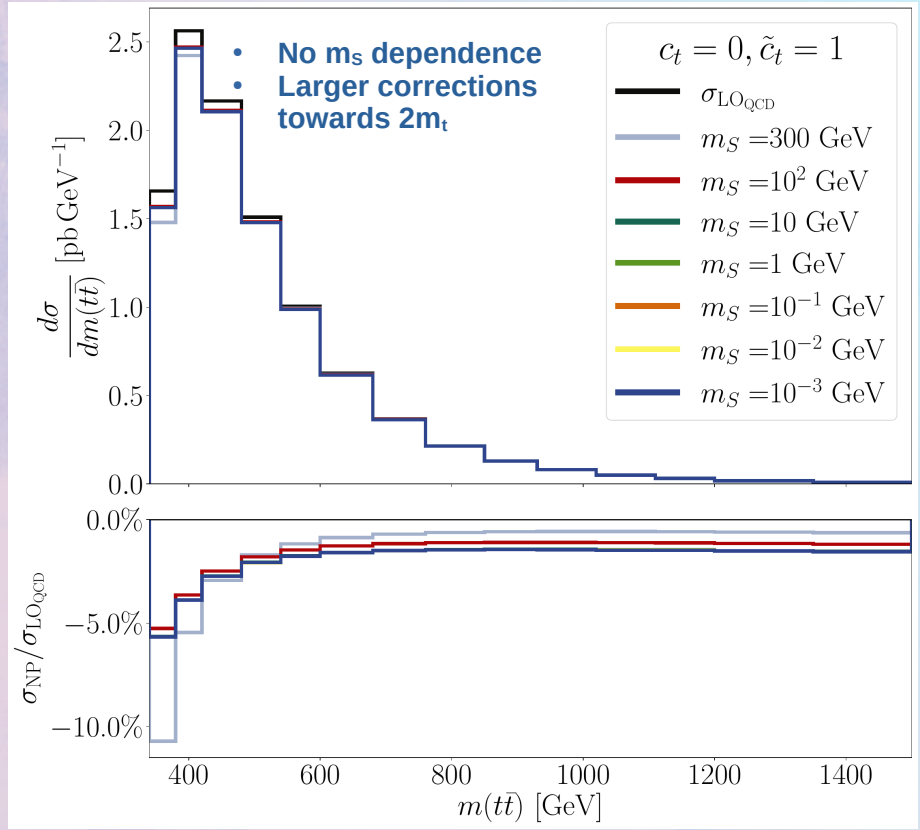
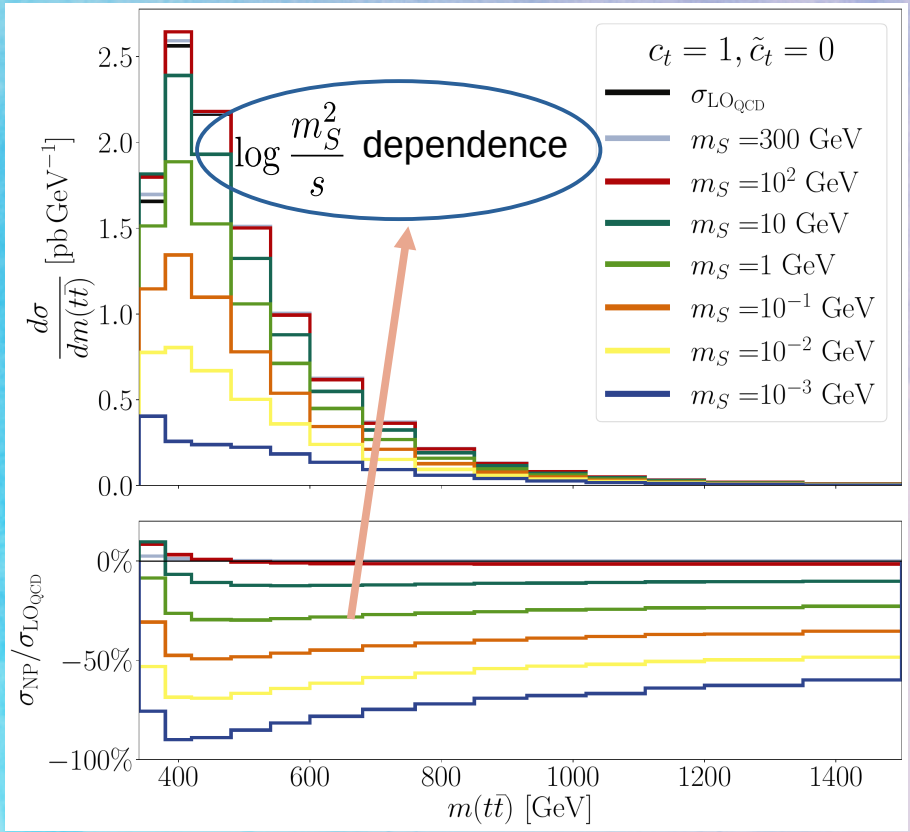
ZERO

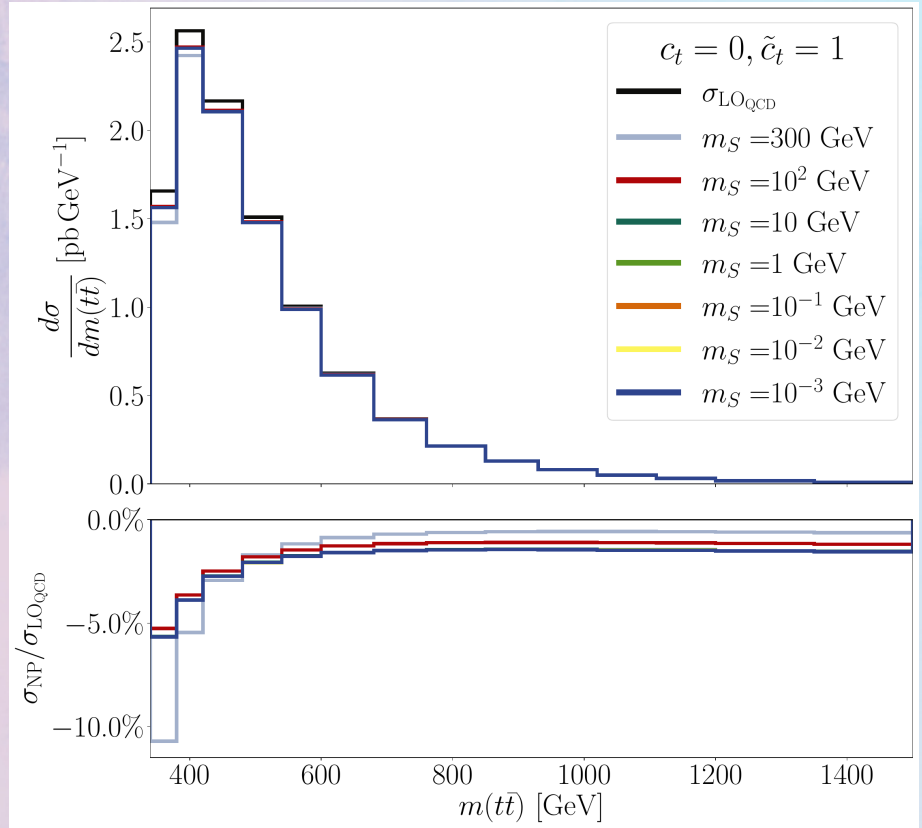
Purely Virtual Corrections



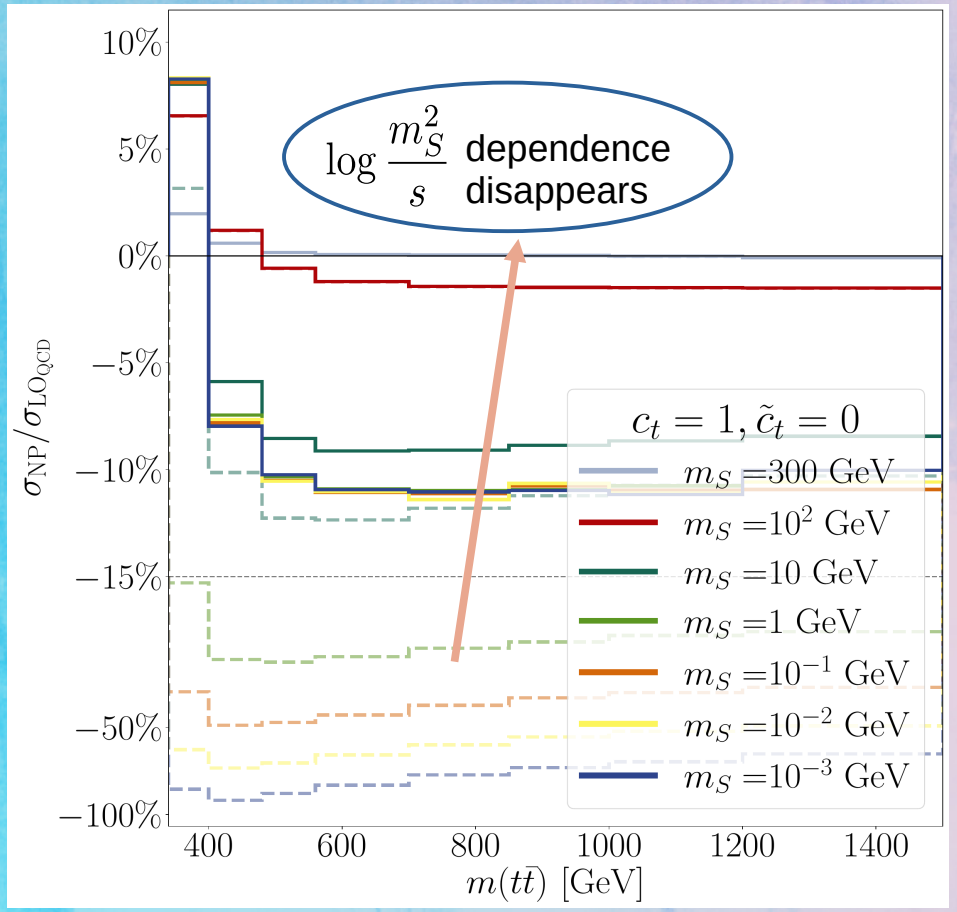


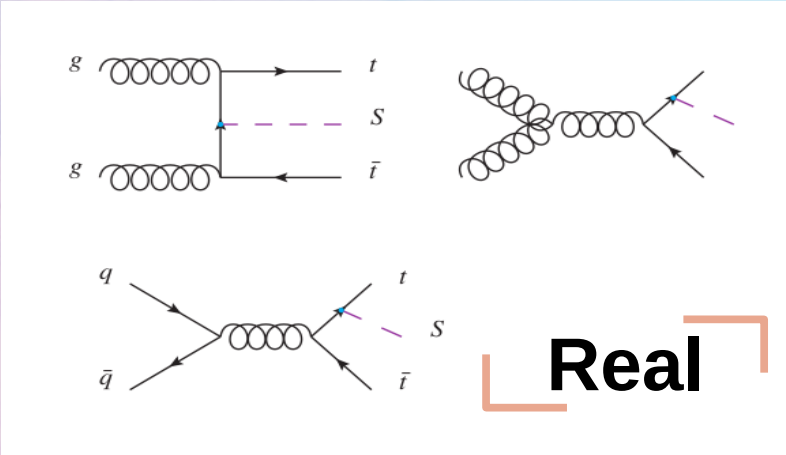
Purely Virtual Corrections



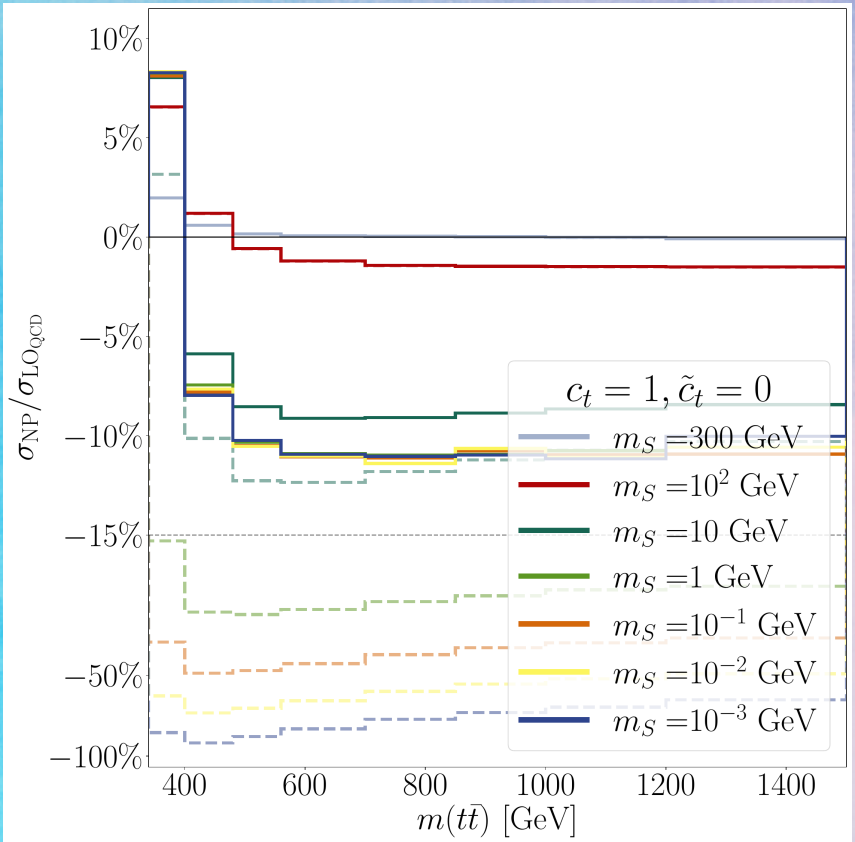


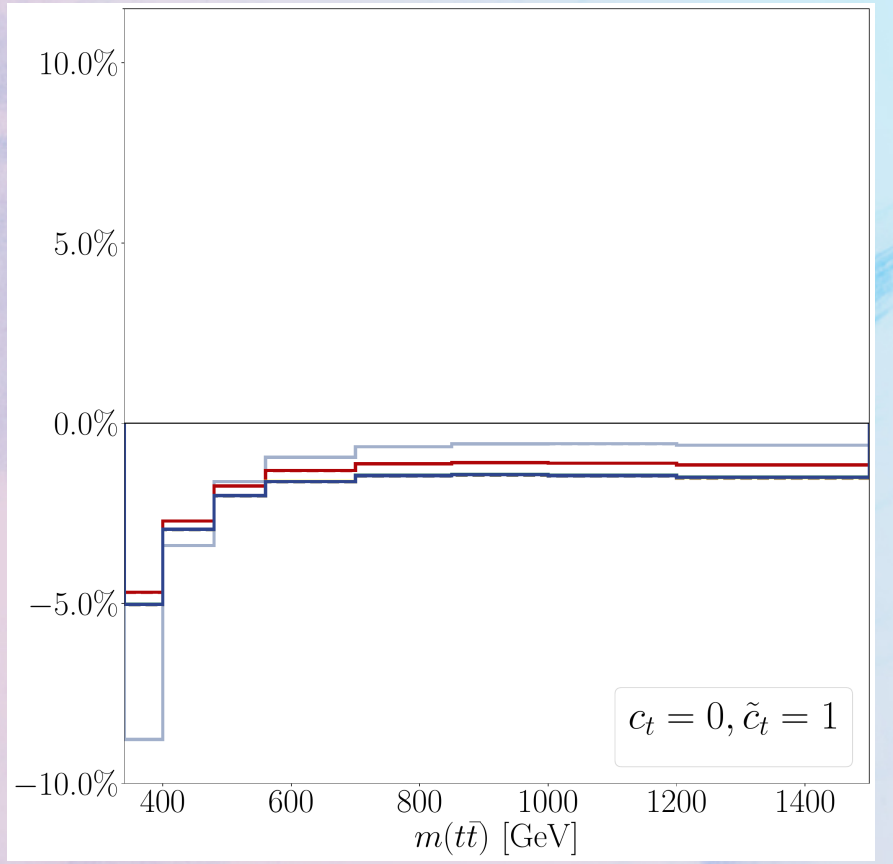
Adding the real



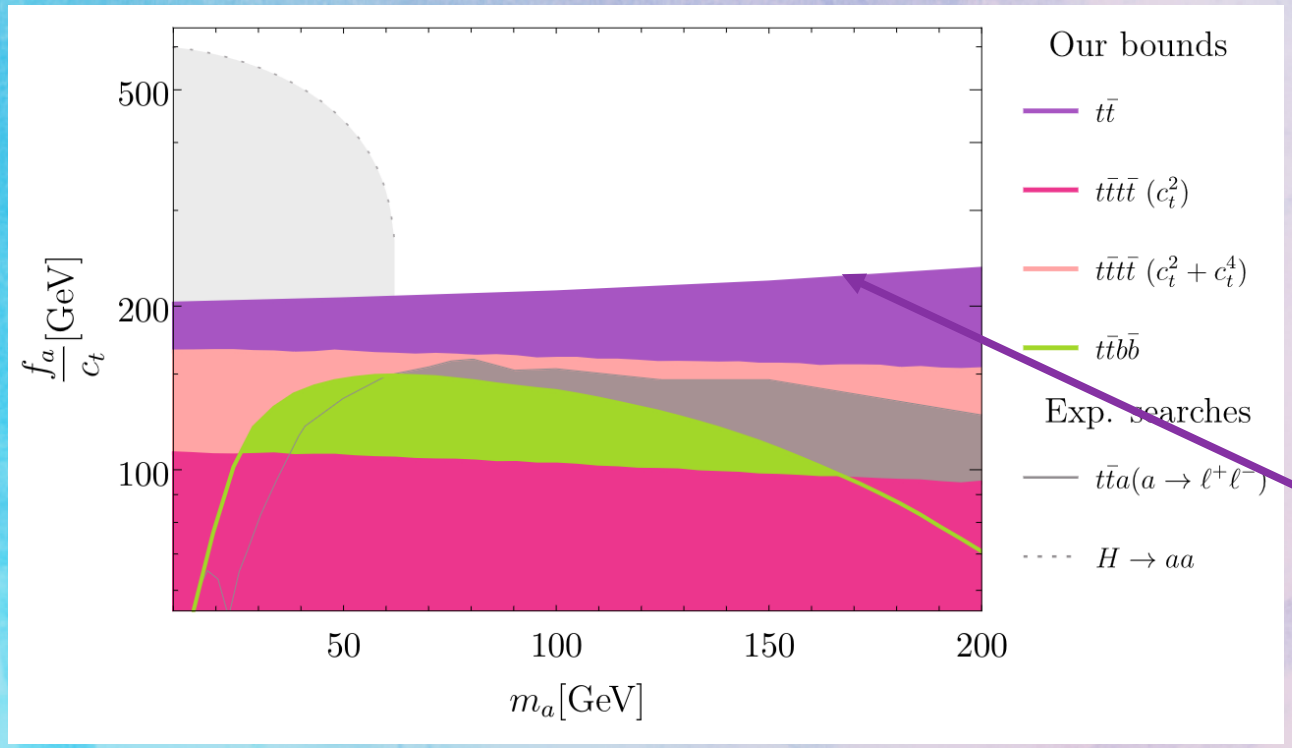


Adding the real

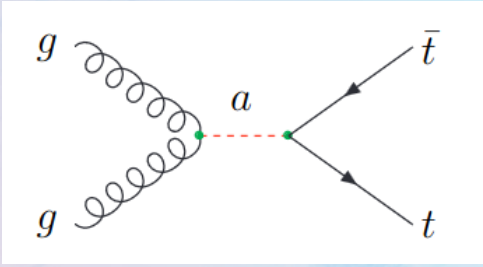




Bounds on Axion Like Particles (ALP) couplings



One additional diagram:



Purple Line:
-Virtual corrections to $t\bar{t}$ production

BEST BOUND!!

[Blasi, Maltoni, Mariotti, Mimasu, Pagani, **ST** 2311.16048]

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The Model: Higgs case

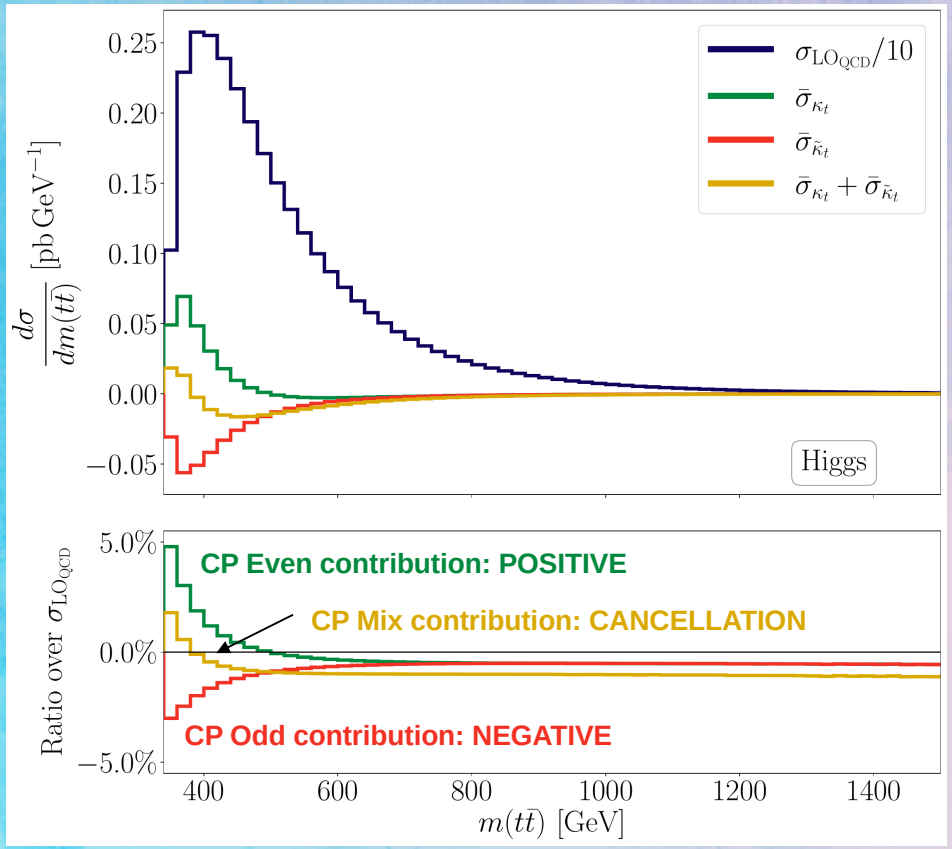
$$\mathcal{L}_H = -\frac{1}{\sqrt{2}}\bar{t}\left[y_t + i\tilde{y}_t\gamma_5\right]tH$$

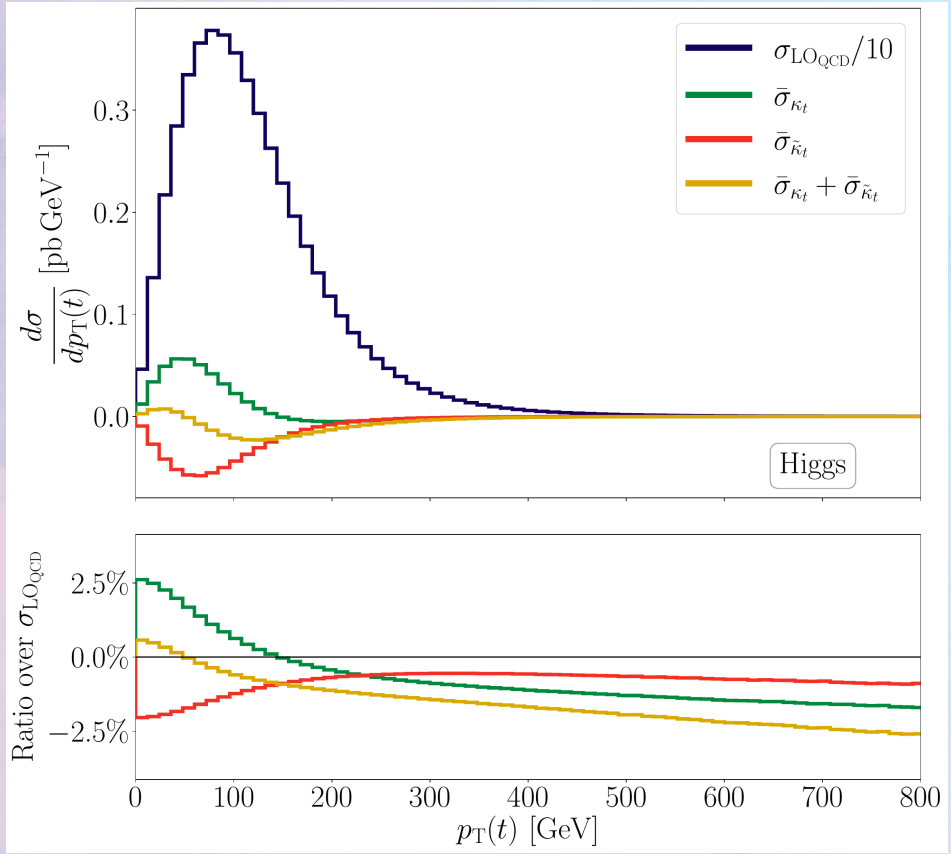
$$\begin{cases} \kappa_t = \dfrac{y_t}{y_t^{\mathrm{SM}}}, \\ \tilde{\kappa}_t = \dfrac{\tilde{y}_t}{y_t^{\mathrm{SM}}} \end{cases}$$

SM:

- K_t=1 (y_t=m_t/v)
- $\widetilde{K_t}$=0.

Distributions





Fit: 1 parameter CP Even

FIT INFO:
- Data: SM
- Errors and Bins: [CMS: 1803.08856]

Doable and done! Look at:
- [CMS: 1907.01590]
- [CMS: 2009.07123]

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

	κ_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)
- Errors and Bins: [CMS: 1803.08856]

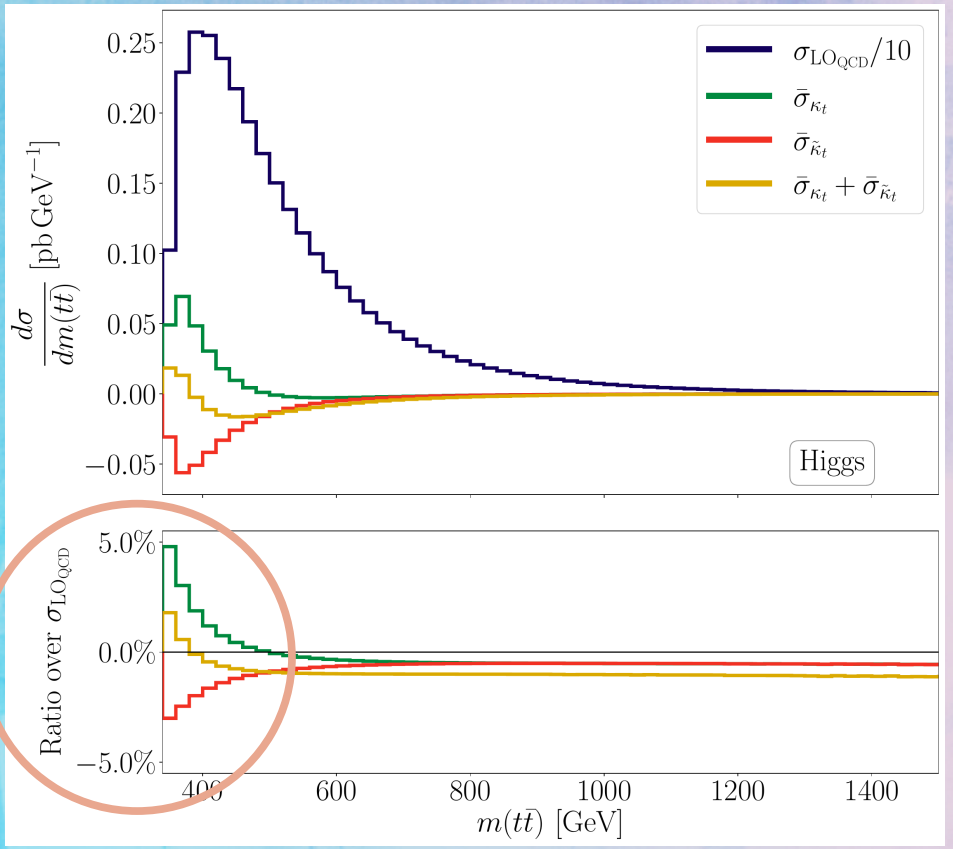
$$\mathcal{L} = \mathcal{L}_{\text{SM, no Higgs}} - \frac{y_t}{\sqrt{2}} \bar{t} \gamma_5 t H$$

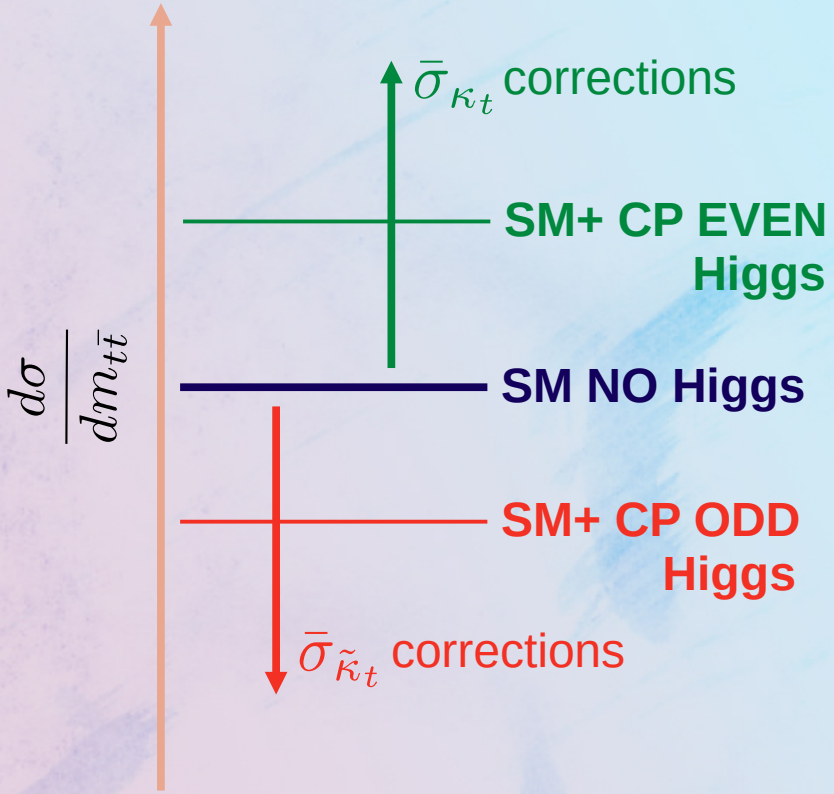
	$\kappa_t {}^{+1\sigma, 2\sigma, 3\sigma}_{-1\sigma, 2\sigma, 3\sigma}$	$\tilde{\kappa}_t {}^{+1\sigma, 2\sigma, 3\sigma}_{-1\sigma, 2\sigma, 3\sigma}$
SM_{mult} LHC	$0.00^{+0.55, 0.93, 1.22}_{-0.55, 0.93, 1.22}$	$1.0^{+0.44, 0.78, 1.06}_{-1.00, 1.00, 1.00}$

By "Magic"

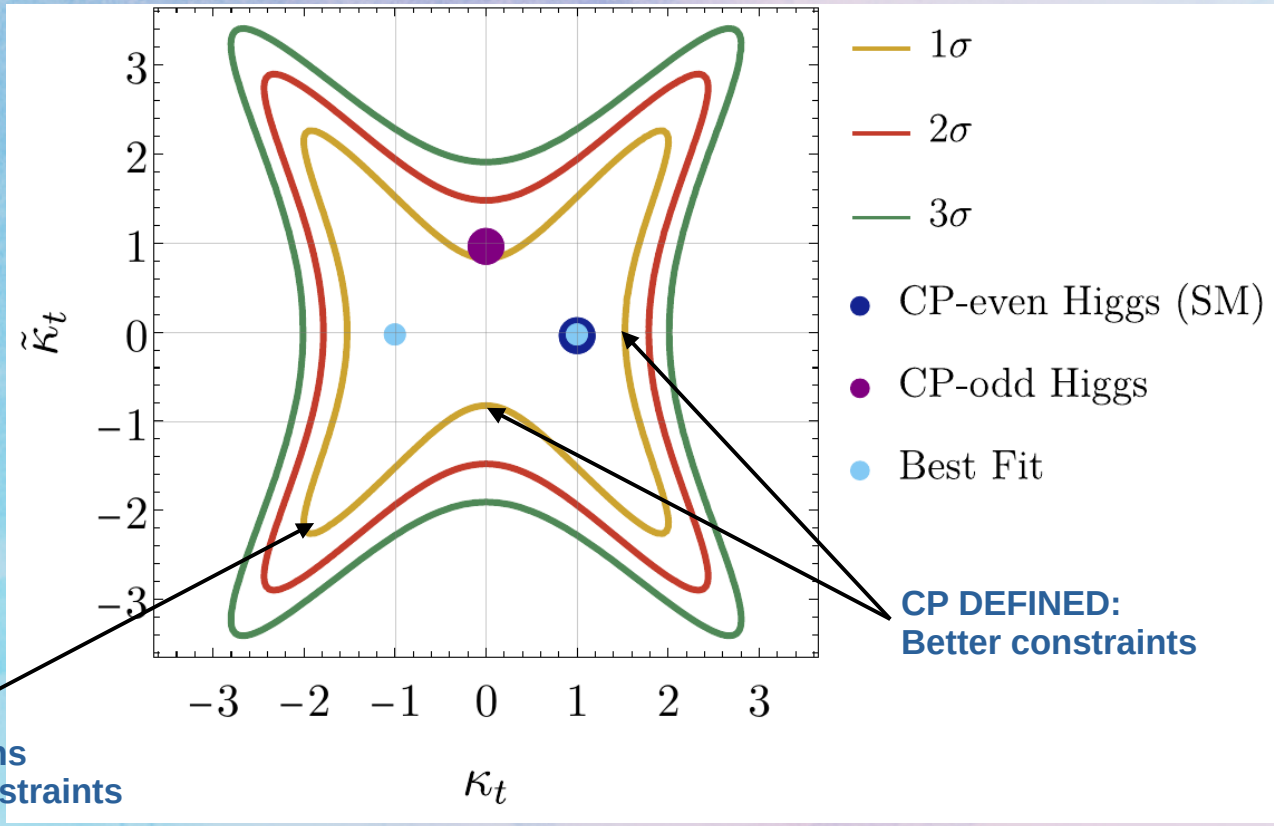
By Construction

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

NP Virtual Corrections to top-pair production

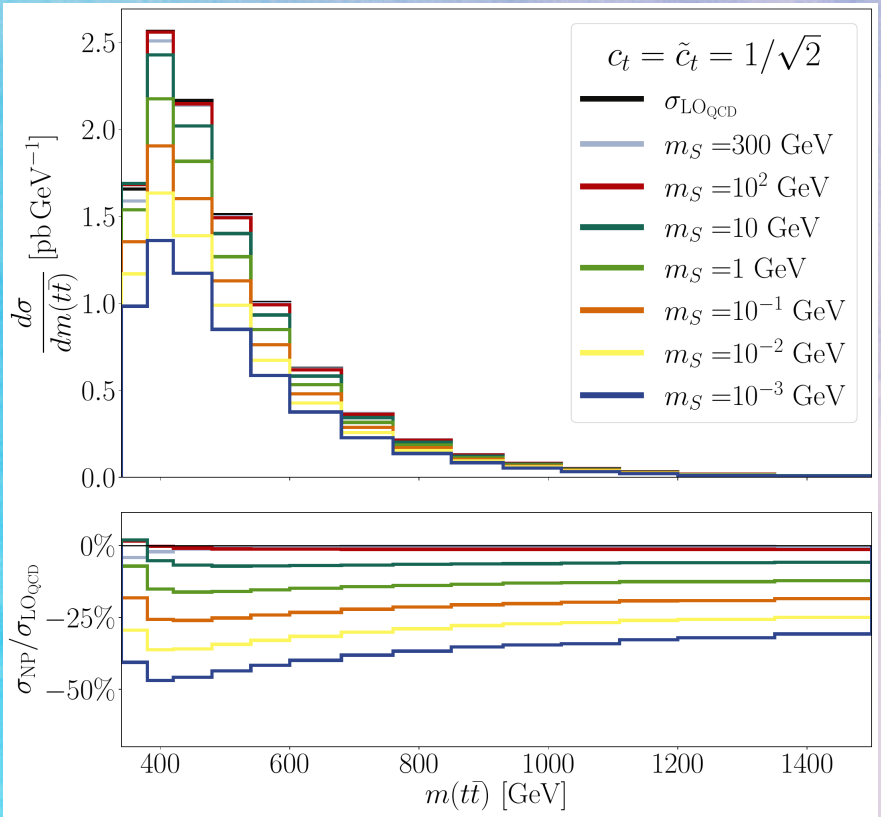
Powerful tool to constrain NP
No specific decay assumptions

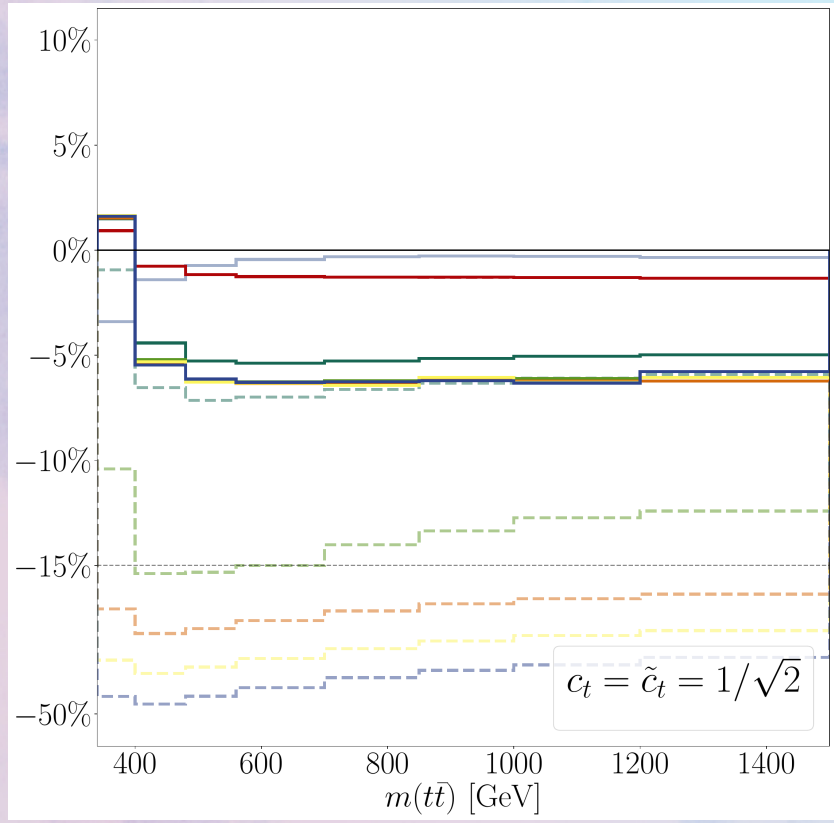
Can unveil elseway elusive particles
ALP
Additional Scalars

Can be use to fit SM parameters
Higgs anomalous couplings
Higgs top Yukawa

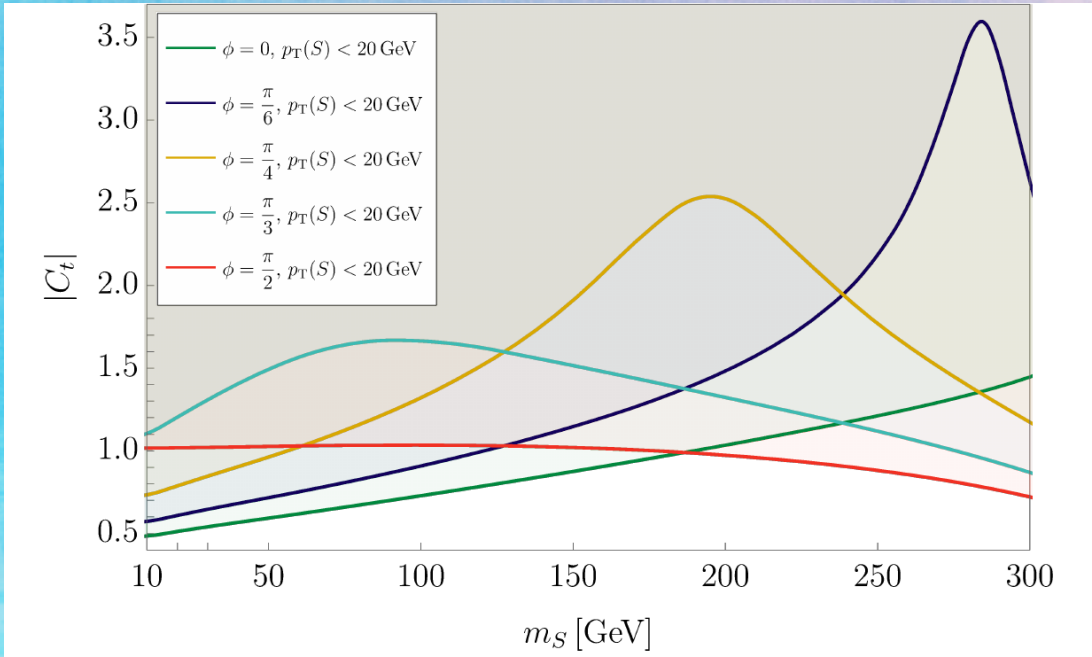
Backup

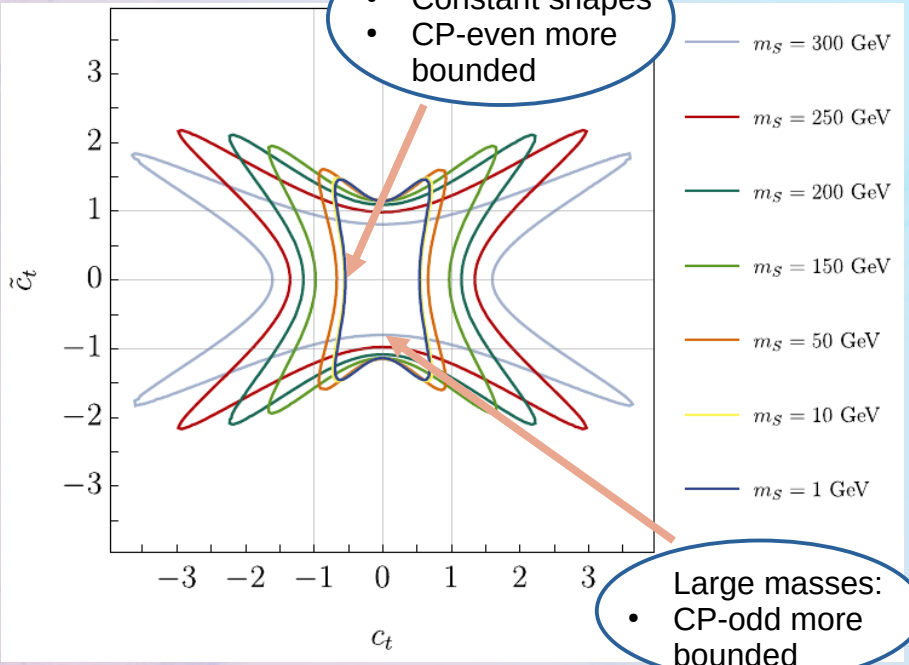
Mixing the CP



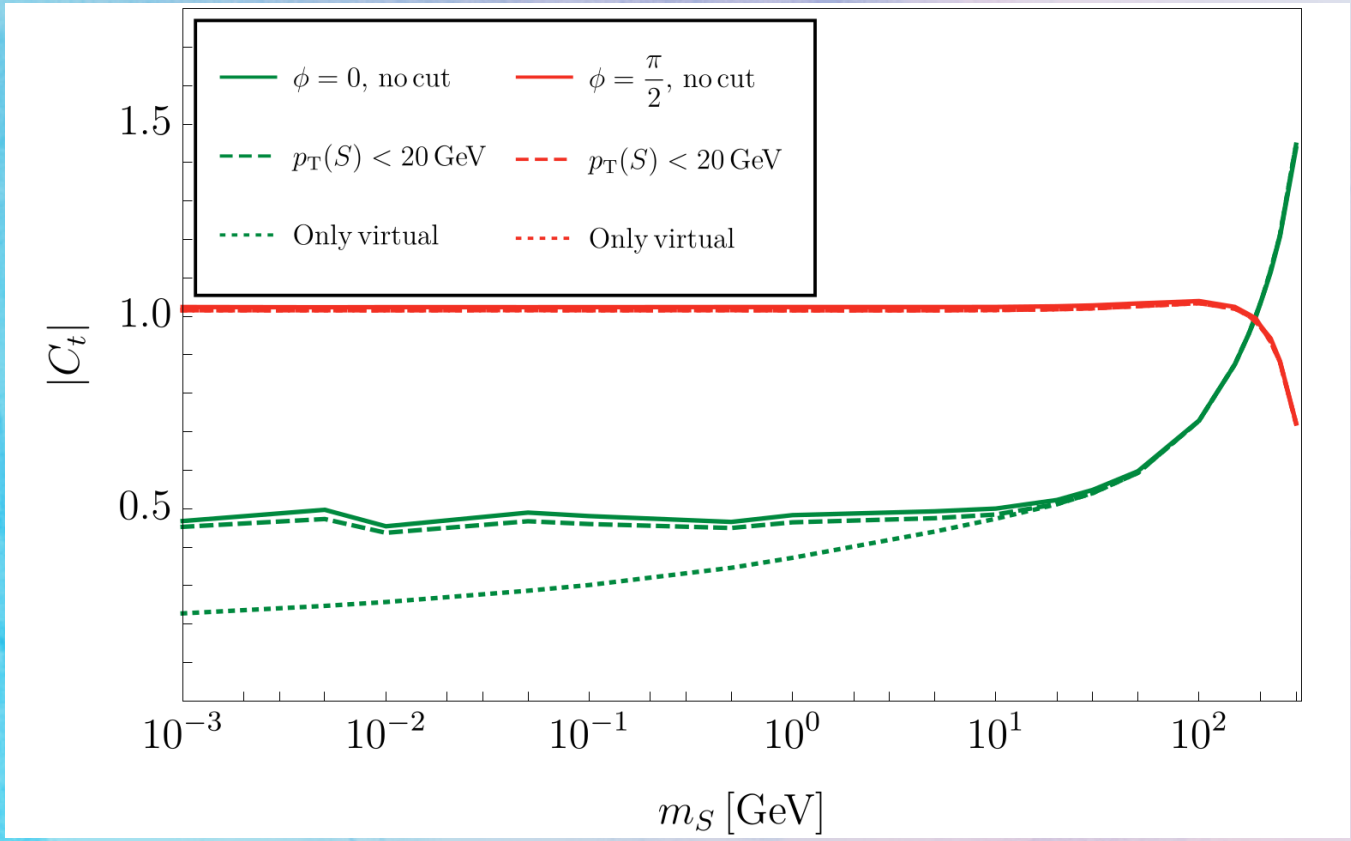


Mixing the couplings





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]

The view from the ALPs

$$\mathcal{L} = \frac{c_t}{2}\frac{\partial_\mu a}{f_a}\bar{t}\gamma^\mu\gamma^5 t$$

Equations of motion

SEE ALSO:
[Esser. Madigan, Sanz, Ubiali, 2303.17634]
[Vu Phan, Westhoff, 2312.00872]
[Rygaard, Niedziela, Schäfer, Bruggisser, Alimena, Westhoff, Blekman, 2306.08686]
[Blasi, Maltoni, Mariotti, Mimasu, Pagani, **ST** 2311.16048]

ALP = Pseudoscalar term + Contact term → **Naturally supressed diphoton decay**

$$\mathcal{L}_{\text{equiv.}} = -ic_t\frac{m_t}{f_a}a\bar{t}\gamma_5 t + c_t\frac{\alpha_S}{8\pi}\frac{a}{f_a}G\tilde{G} + \text{E.W.terms}$$

The Model: Higgs case

$$\mathcal{L}_{H,NP} = -\frac{y_t^{SM}}{\sqrt{2}}\bar{t}\left[(\kappa_t - 1) + i\tilde{\kappa}_t\gamma_5\right]tH$$

Naturally Arising in SMEFT

Higgs Boson

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

The Model: Higgs case

$$\mathcal{L}_{H,NP} = -\frac{y_t^{SM}}{\sqrt{2}}\bar{t}\left[(\kappa_t - 1) + i\tilde{\kappa}_t\gamma_5\right]tH$$

Naturally Arising in SMEFT

Higgs Boson

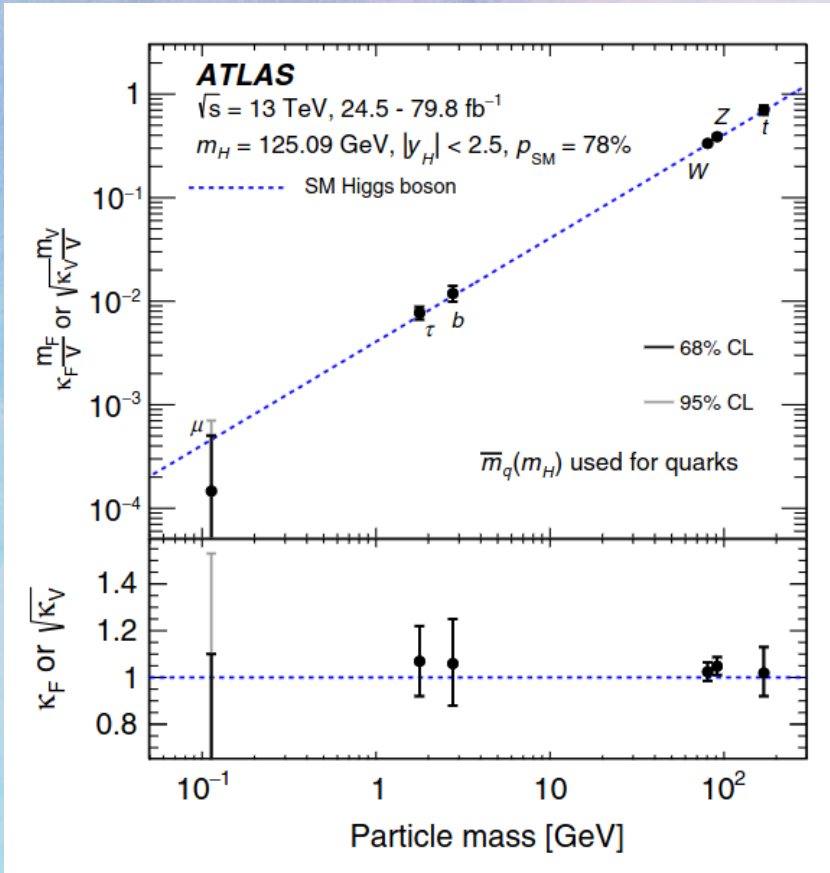
SMEFT Relations

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

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

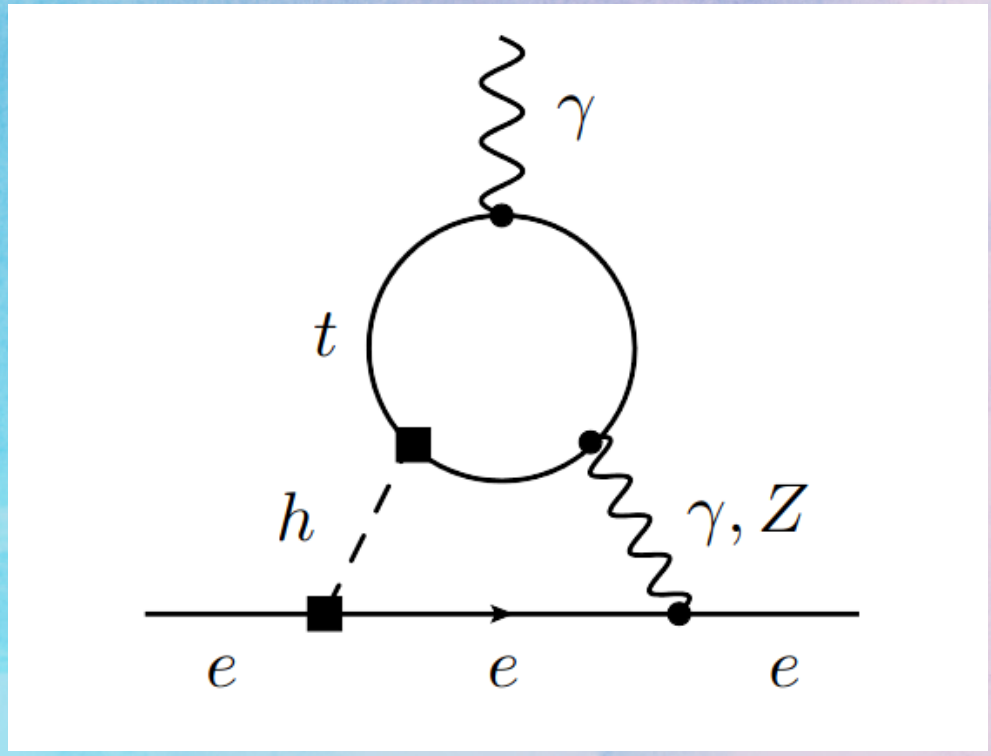
$$\tilde{\kappa}_t = -\frac{v^2}{\Lambda^2}\frac{\Im(C^{u\Phi}_{tt})}{y_t^{\text{SM}}}\,.$$

Higgs couplings state



[ATLAS: 1909.02845]

Indirect Searches: electron EDM



Brod, Haisch, Zupan: [1310.1385]

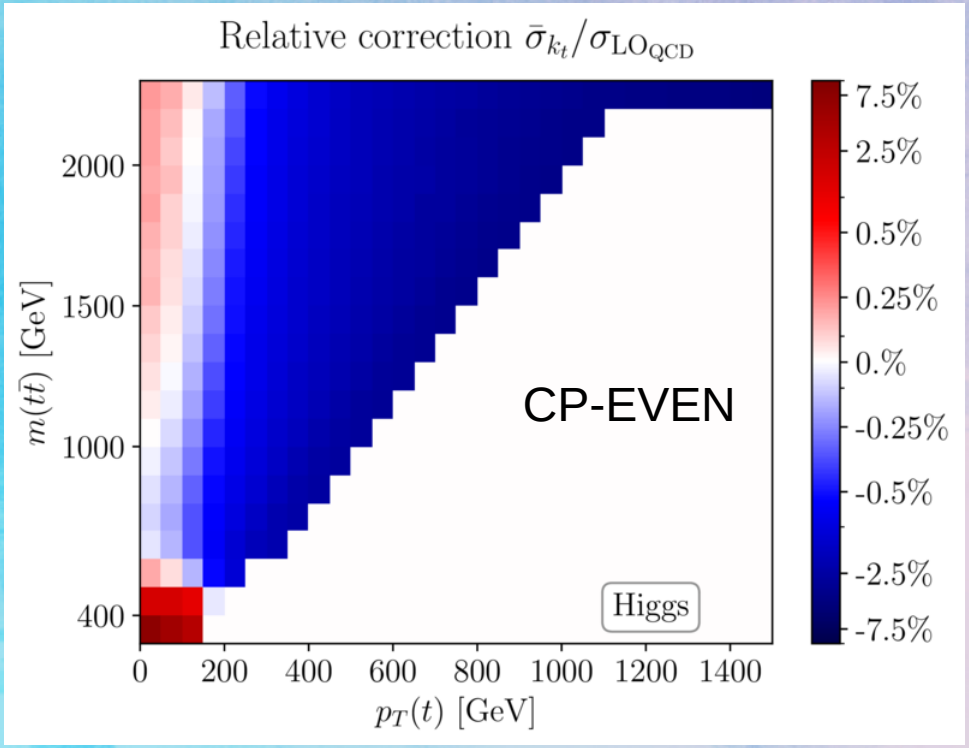
Extremely precise measurement:

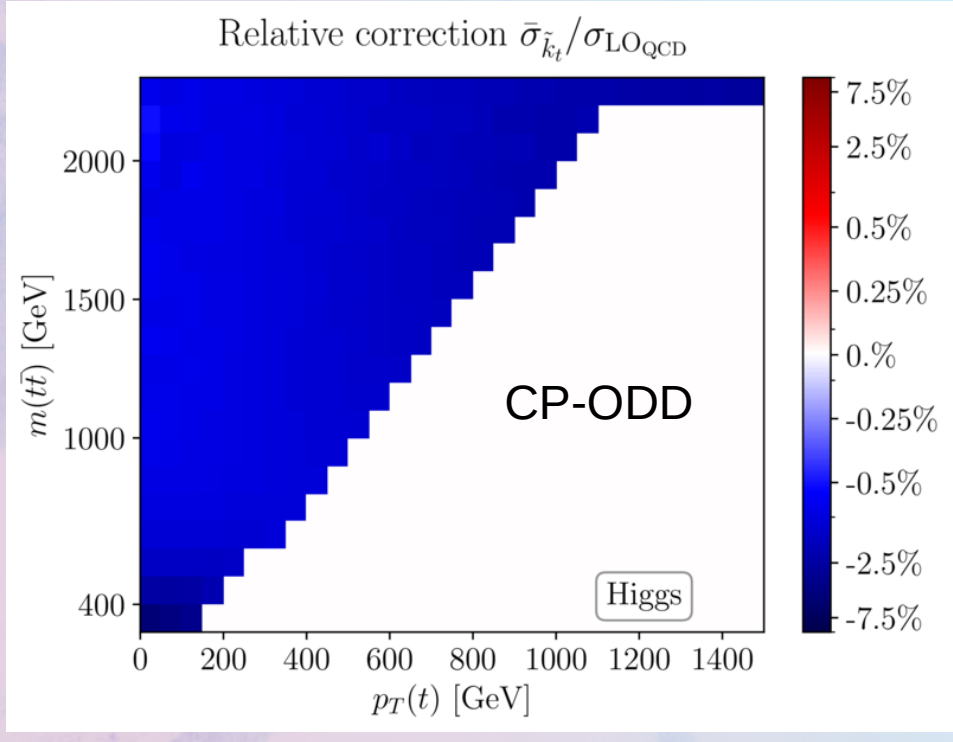
- $|\widetilde{k}_t|<0.01$

Additional assumption:

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

Double differential





TOP-ALP vs Pseudoscalar

$$a \to gg(\gamma\gamma)$$

Blasi, Maltoni, Mariotti, Mimasu, Pagani, **ST** [23XX.XXXX]
Bauer, Neubert, Thamm [1708.00443]

$$\Gamma \propto \left[1 + 2m_t^2 C(p,q,m_t)\right]^2$$

Only contact interaction

Only Pseudoscalar

$2m_t > m_a$

$$\Gamma \propto \left[1 + 2m_t^2\left(-\frac{1}{2m_t^2} - \frac{m_a^2}{24m_t^4}\right)\right]^2$$

Cancellation between contact interaction and pseudoscalar!

$$\Gamma \propto \frac{m_a^4}{144 m_t^4}$$

Super-suppressed w.r.t. single terms

ALP: PT Comparison