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

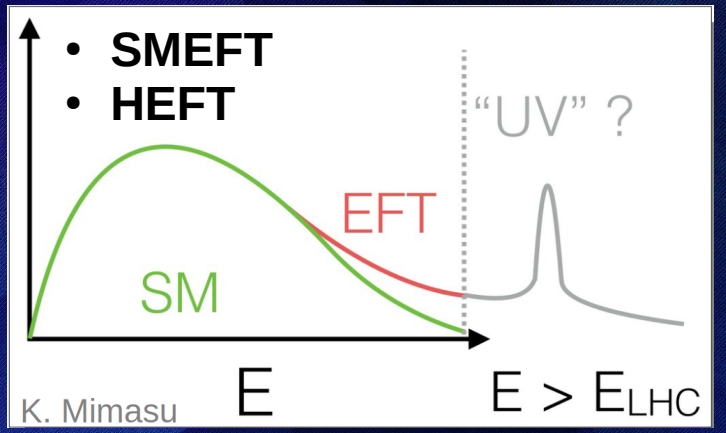
HEFT, Bologna
12/05/2024

fnrs
LA LIBERTÉ DE CHERCHER
UCLouvain

New Physics, which one?

Direct Searches

Indirect Searches



m_{NP}

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

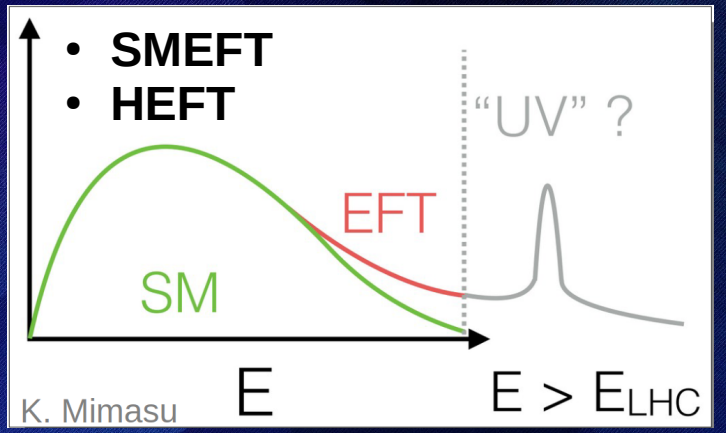
EFT approaches:
- Systematic approaches
- Cover large class of UV models
- Many parameters

New Physics, which one?

Direct Searches

THIS TALK!

Indirect Searches

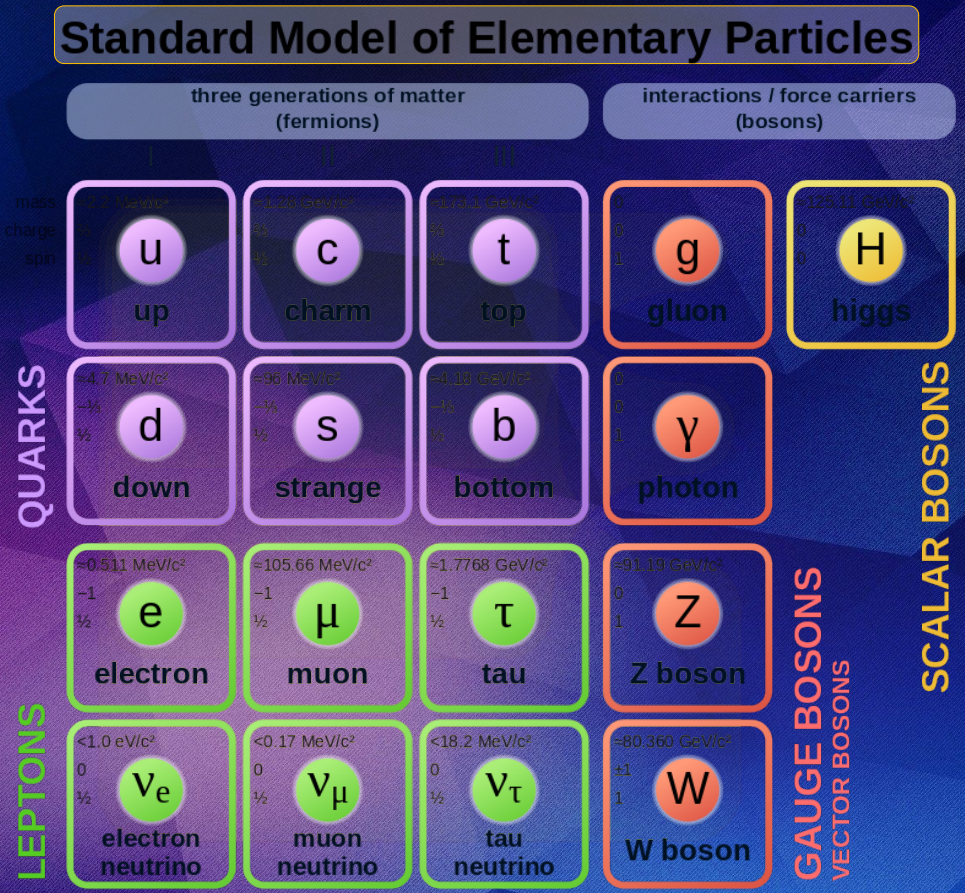


m_{NP}

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

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

Which SM?



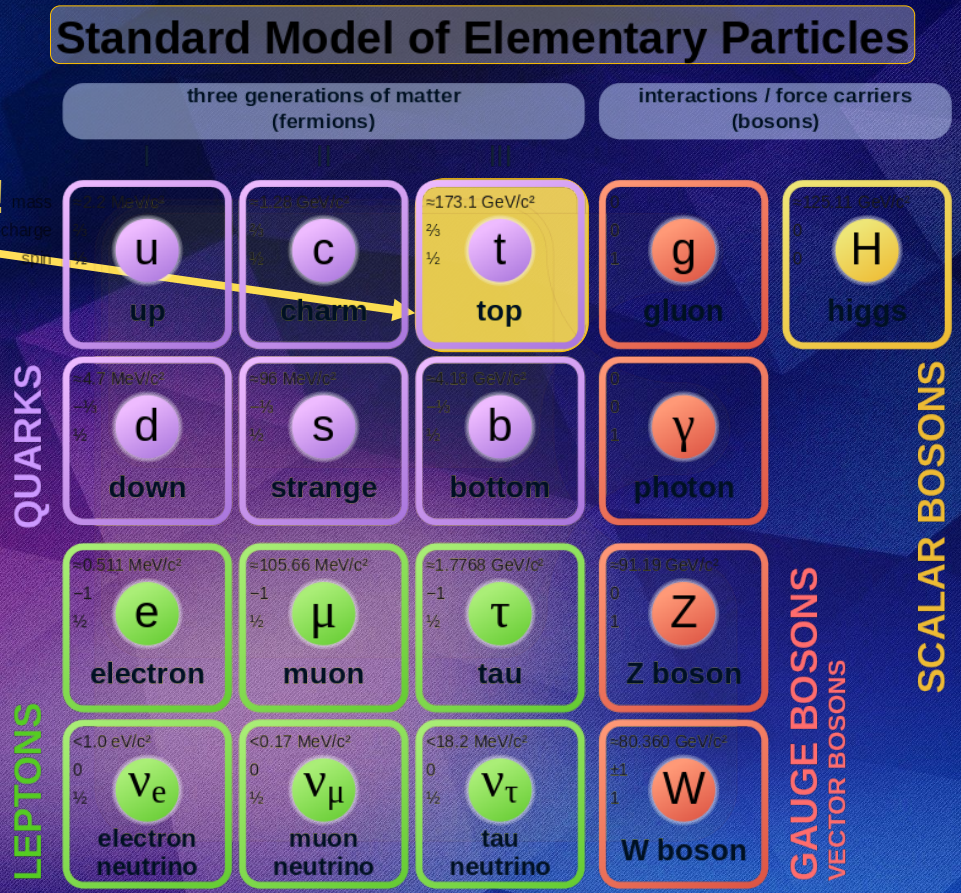
Simone Tentori

HEFT, Bologna
12/05/2024

fnrs LA LIBERTÉ DE CHERCHER

UCLouvain

Which SM?



$t\bar{t}$ 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

HEFT, Bologna
12/05/2024

fnrs LA LIBERTÉ DE CHERCHER

UCLouvain

The Model

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

CP-EVEN

CP-ODD

NEW BSM STATE

Induced corrections to top-pair production

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

Simone Tentori

HEFT, Bologna
12/05/2024

The Model

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

CP-EVEN

CP-ODD

NEW BSM STATE

Induced corrections to top-pair production

ZERO

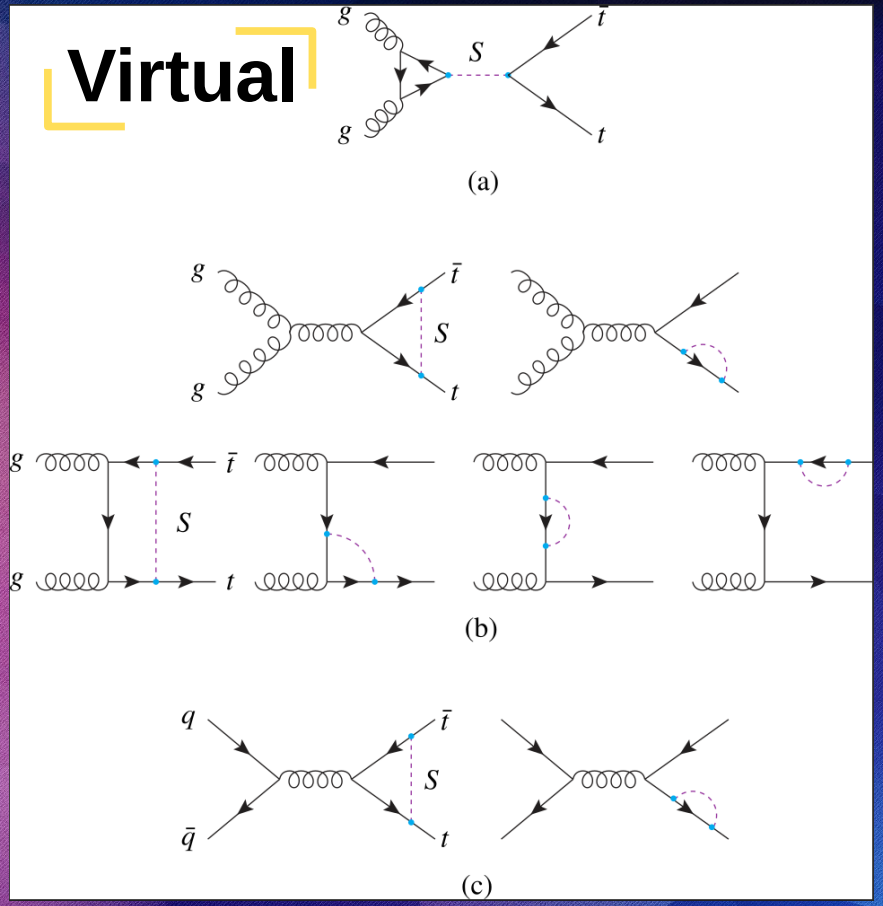
$$\sigma_{NP} = \bar{\sigma}_{c_t} c_t^2 + \bar{\sigma}_{\tilde{c}_t} \tilde{c}_t^2 + \bar{\sigma}_{c_t \tilde{c}_t} c_t \tilde{c}_t$$

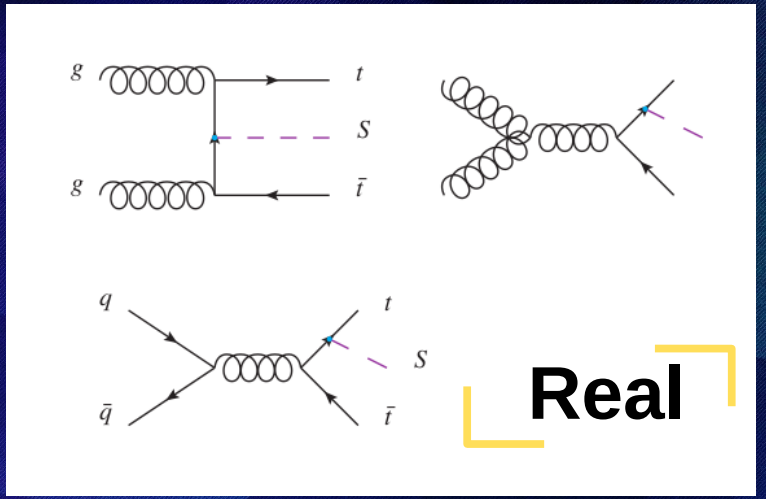
Simone Tentori

HEFT, Bologna
12/05/2024

Which processes?

Virtual

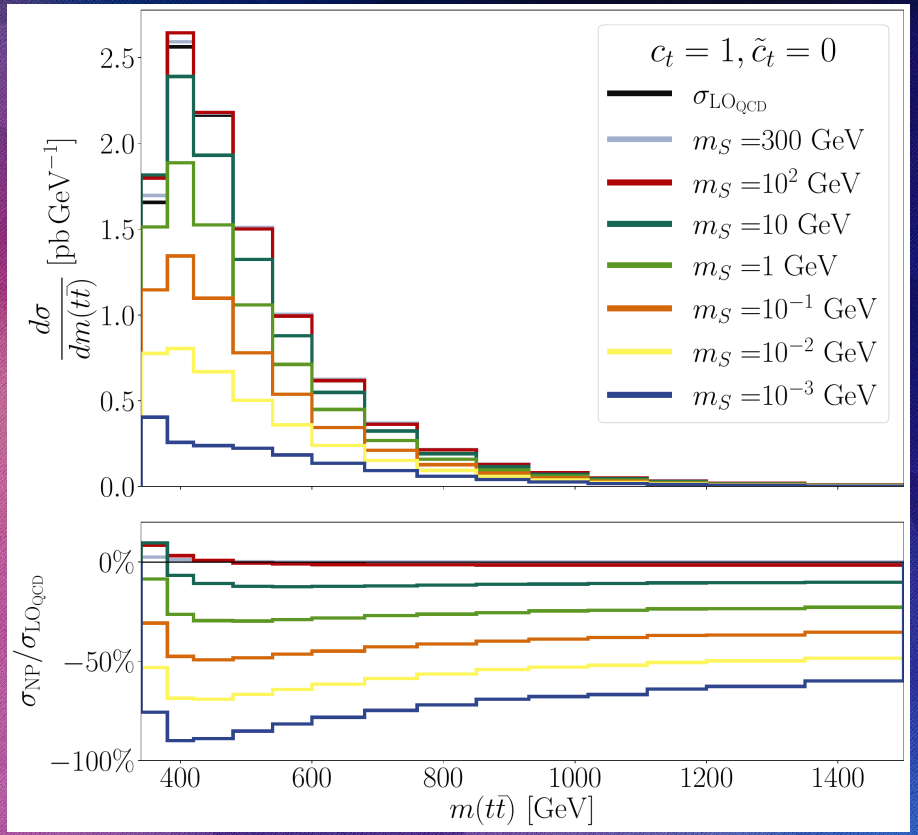


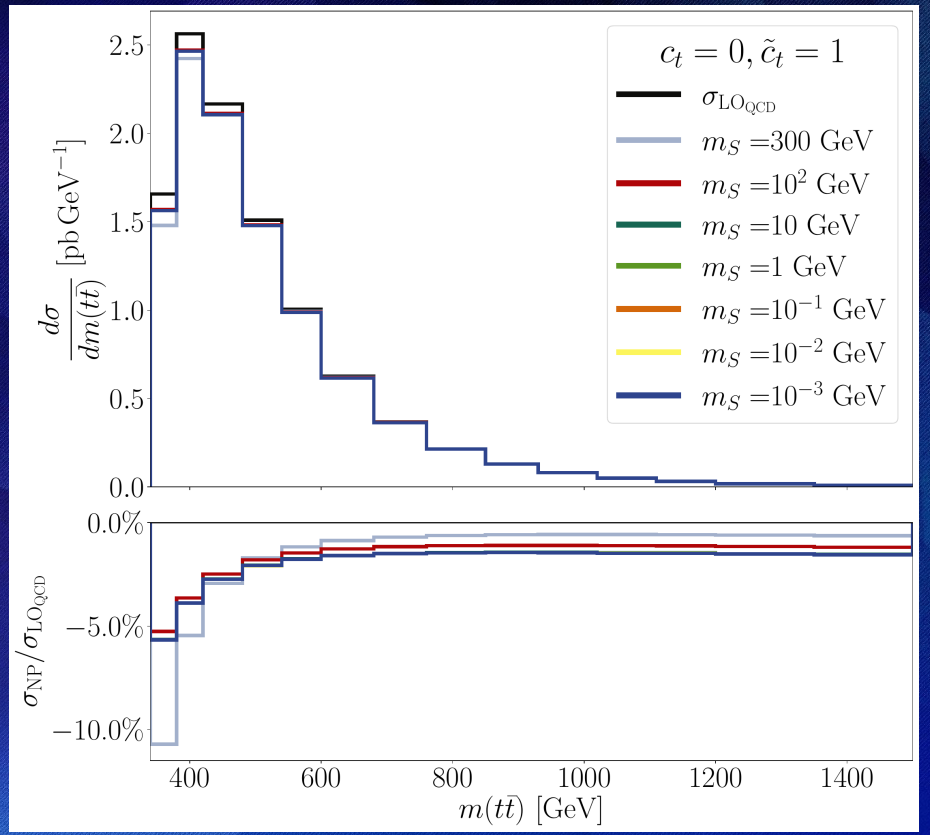


Real

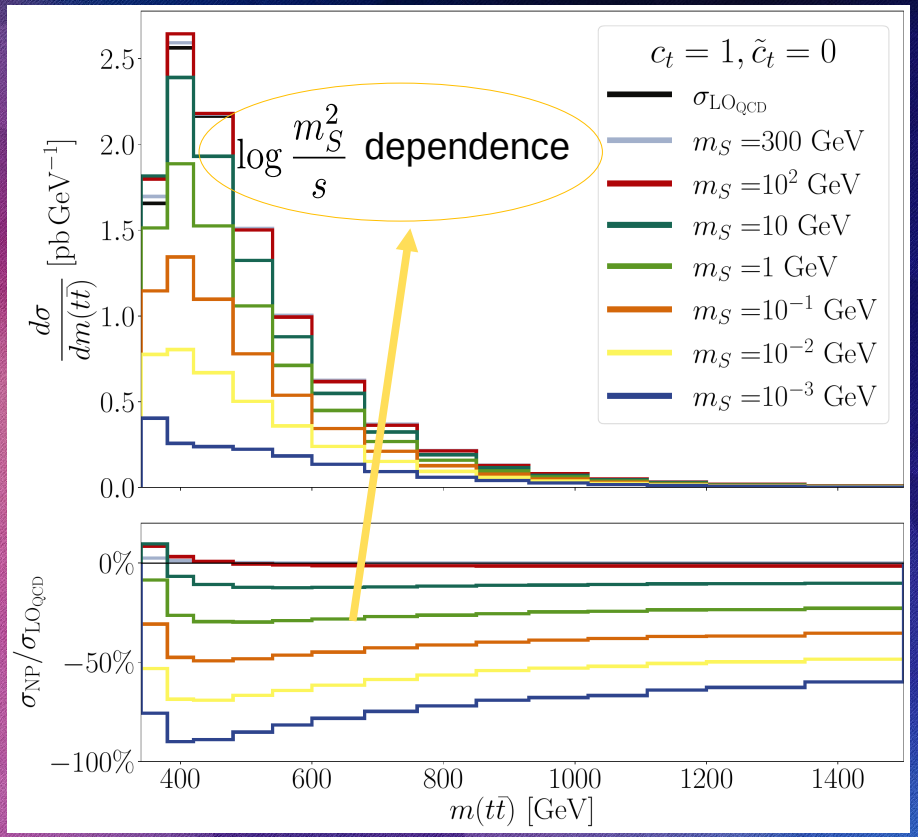
IMPLEMENTATION:
MG5 + Dedicated UFO model

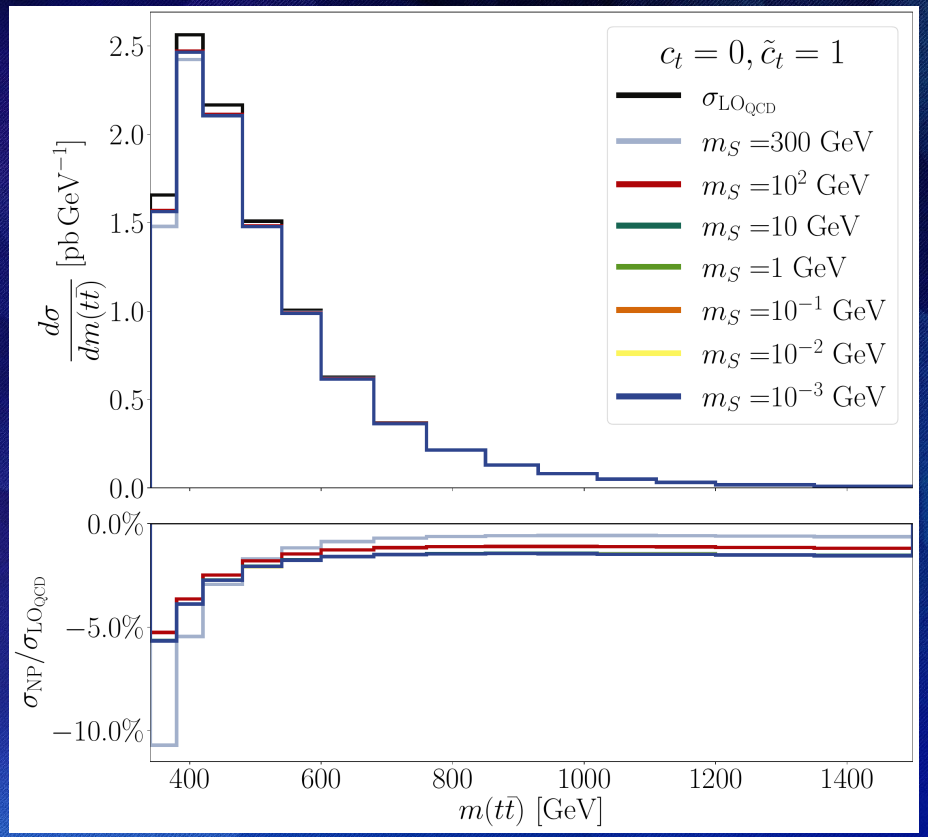
Purely Virtual Corrections



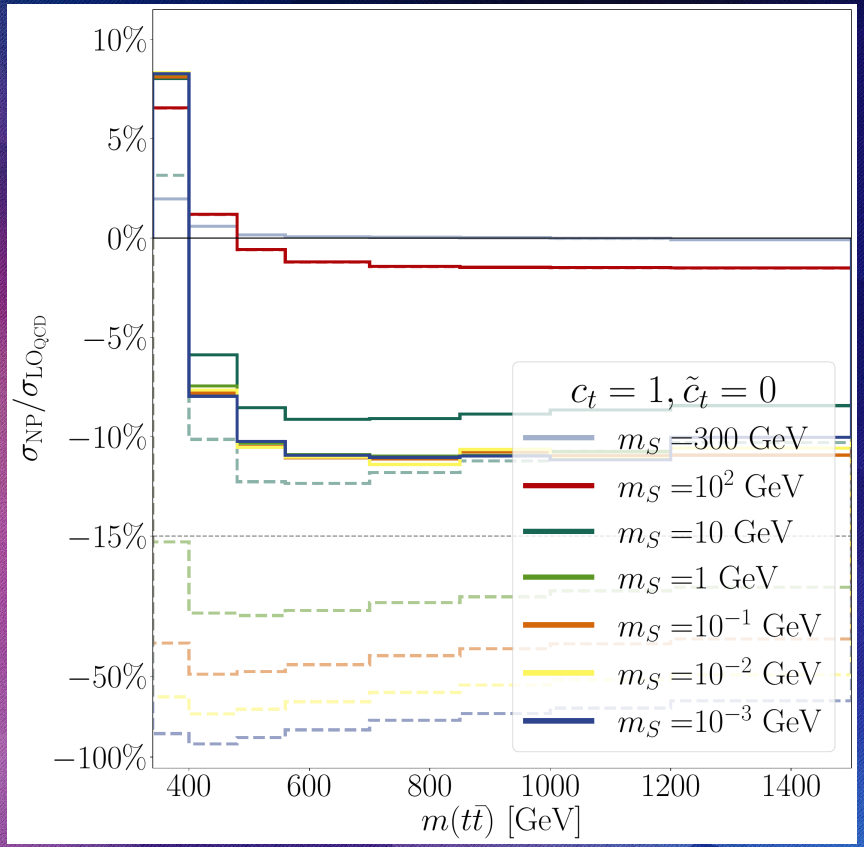


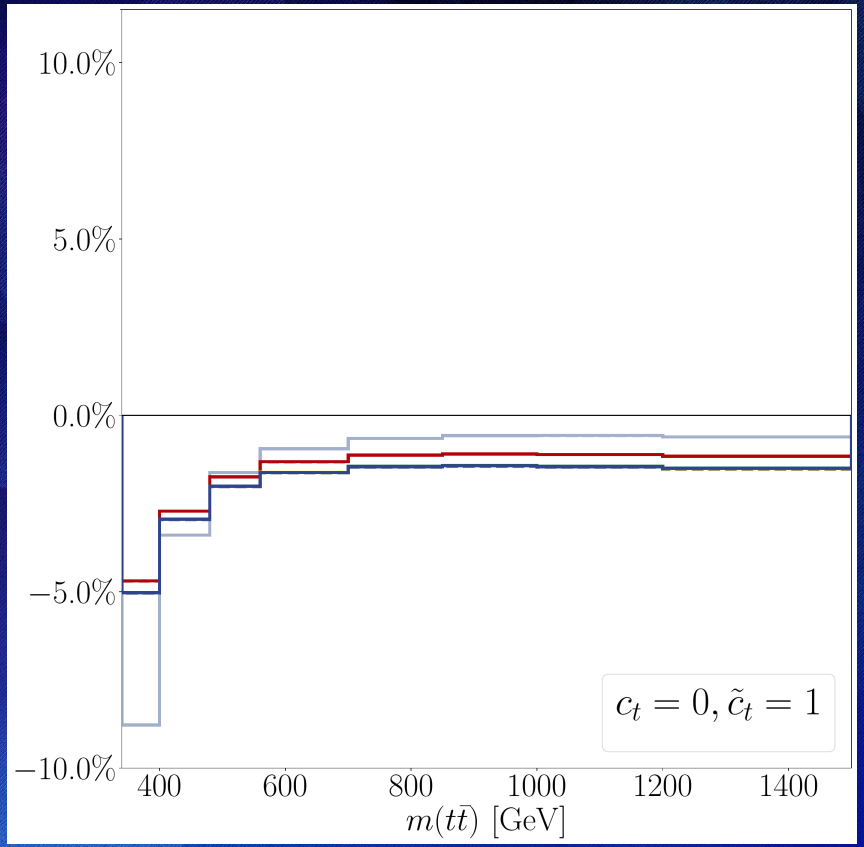
Purely Virtual Corrections



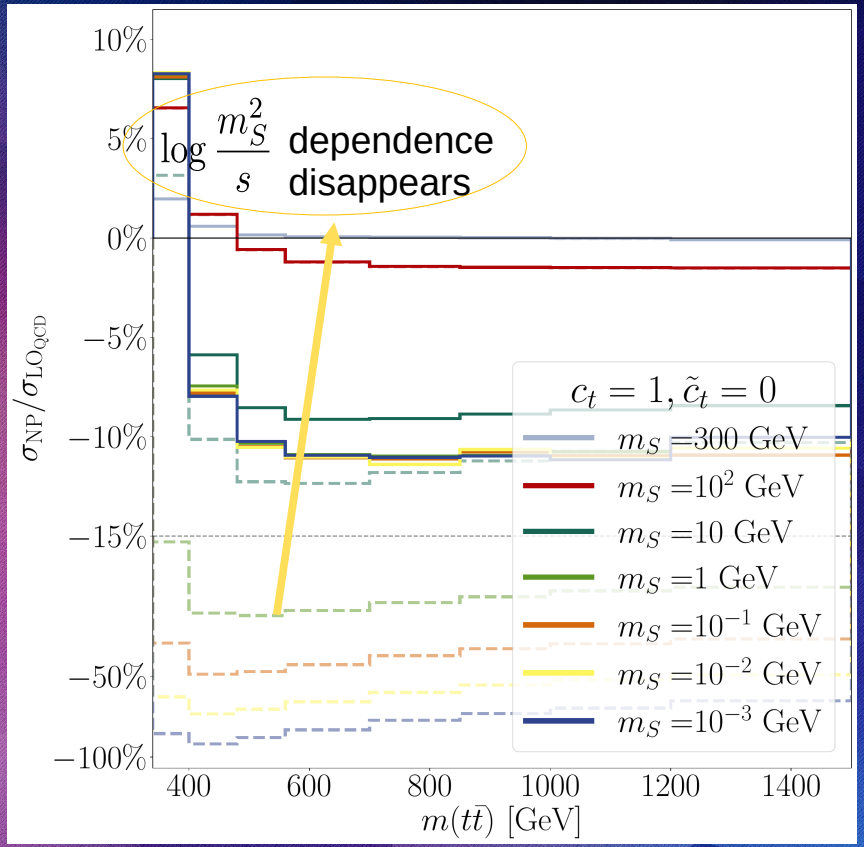


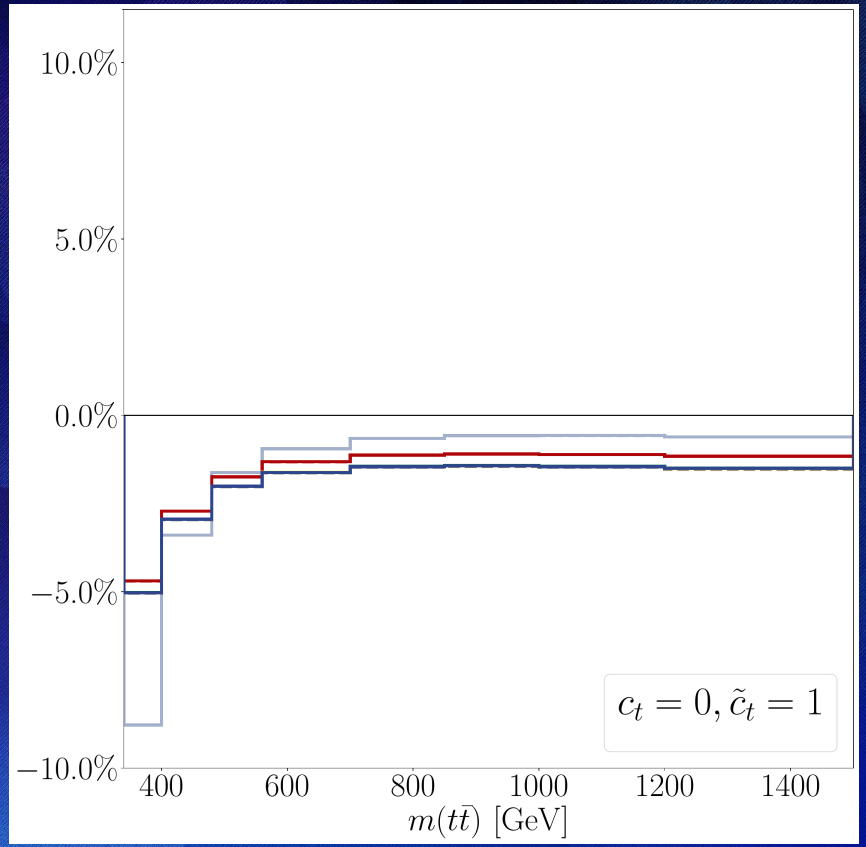
Adding the real





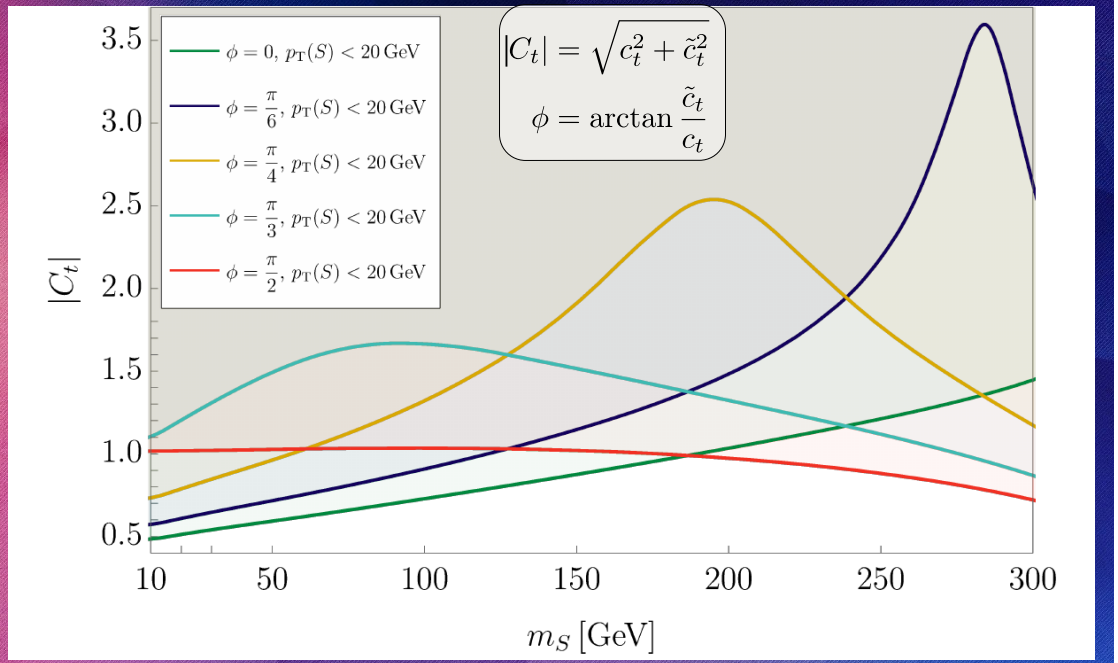
Adding the real

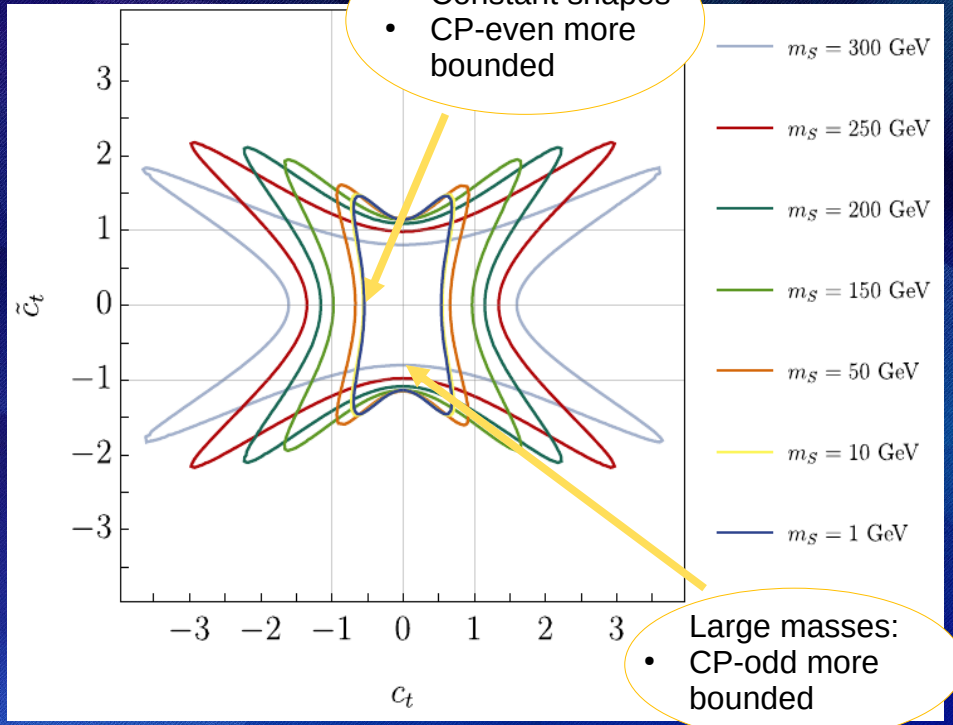




FIT INFO:
- Data: SM
- Theory: SM+S(NP)
- Errors and Bins: [CMS: 1803.08856]

Mixing the couplings





The Model

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

Recycling is an environmentally friendly practice

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

Naturally Arising in SMEFT

Higgs Boson

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

Simone Tentori

HEFT, Bologna
12/05/2024

fnrs LA LIBERTÉ DE CHERCHER

UCLouvain

The Model

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

Recycling is an environmentally friendly practice

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

Naturally Arising in SMEFT

Higgs Boson

$$\sigma_{H,NP} = (\kappa_t^2$$

$$\bar{\sigma}_{\kappa_t} = \frac{y_t^{SM}}{\sqrt{2}}\bar{\sigma}_{c_t}\Big|_{m_S=m_H}$$

$$\bar{\sigma}_{\tilde{\kappa}_t} = \frac{y_t^{SM}}{\sqrt{2}}\bar{\sigma}_{\tilde{c}_t}\Big|_{m_S=m_H}$$

Simone Tentori

HEFT, Bologna
12/05/2024

Fit: 1 parameter

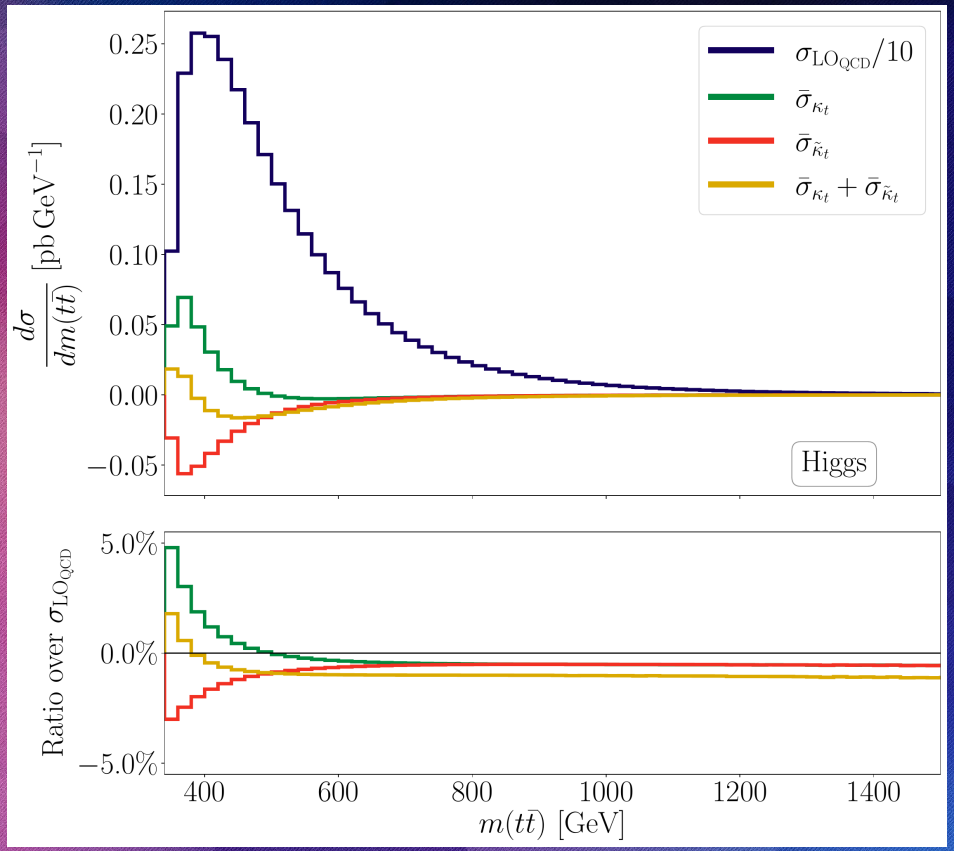
FIT INFO:
- Data: SM
- Theory: SM+H(NP)
- Errors and Bins: [CMS: 1803.08856]

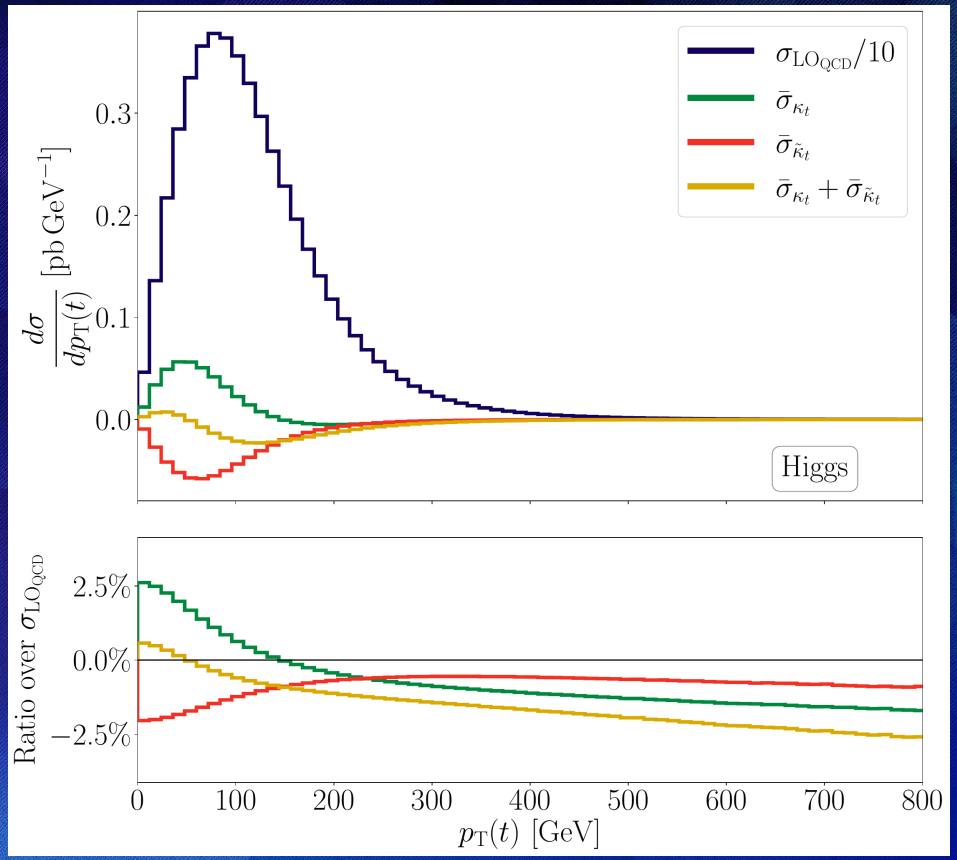
Doable and done! Look at:
- [CMS: 1907.01590]
- [CMS: 2009.07123]

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

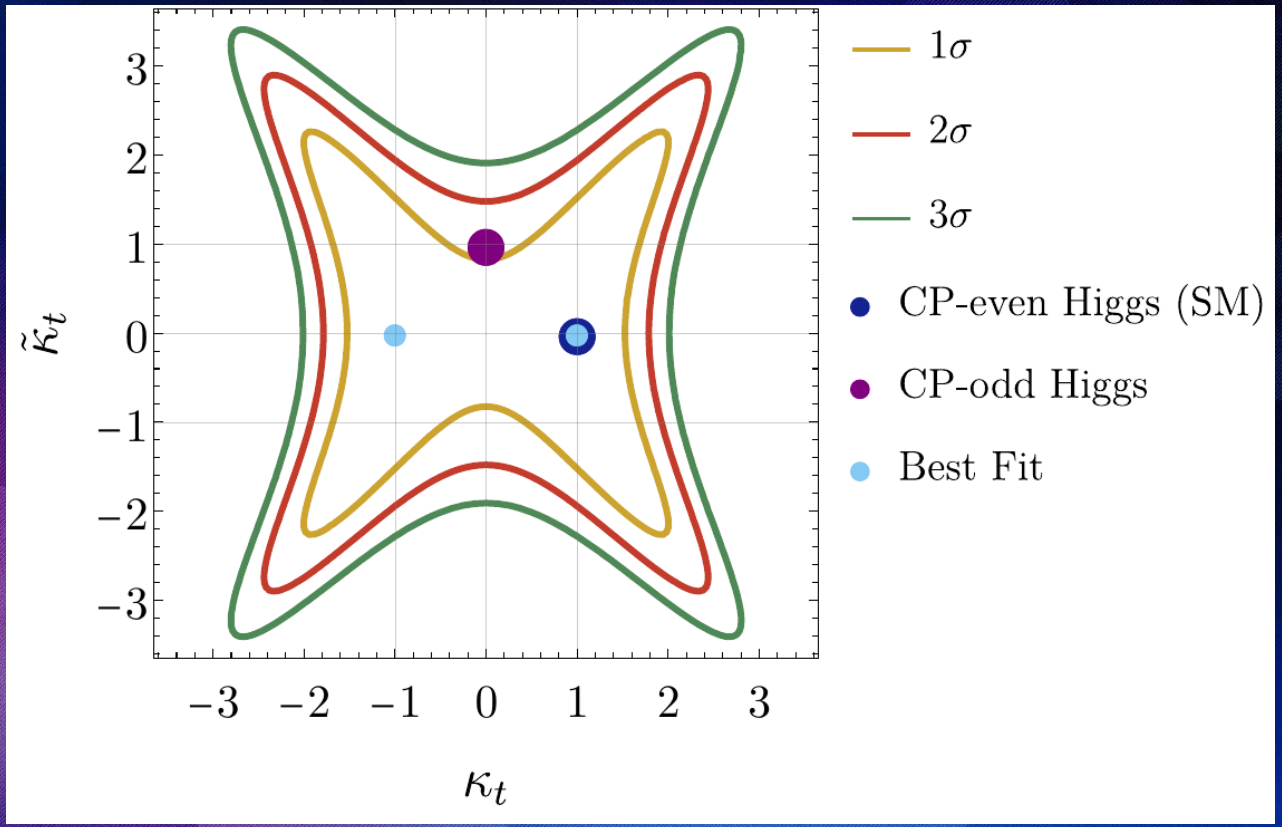
By Construction **By "Magic"**

Distributions





Fit: 2 parameters



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

The view from the ALPs

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

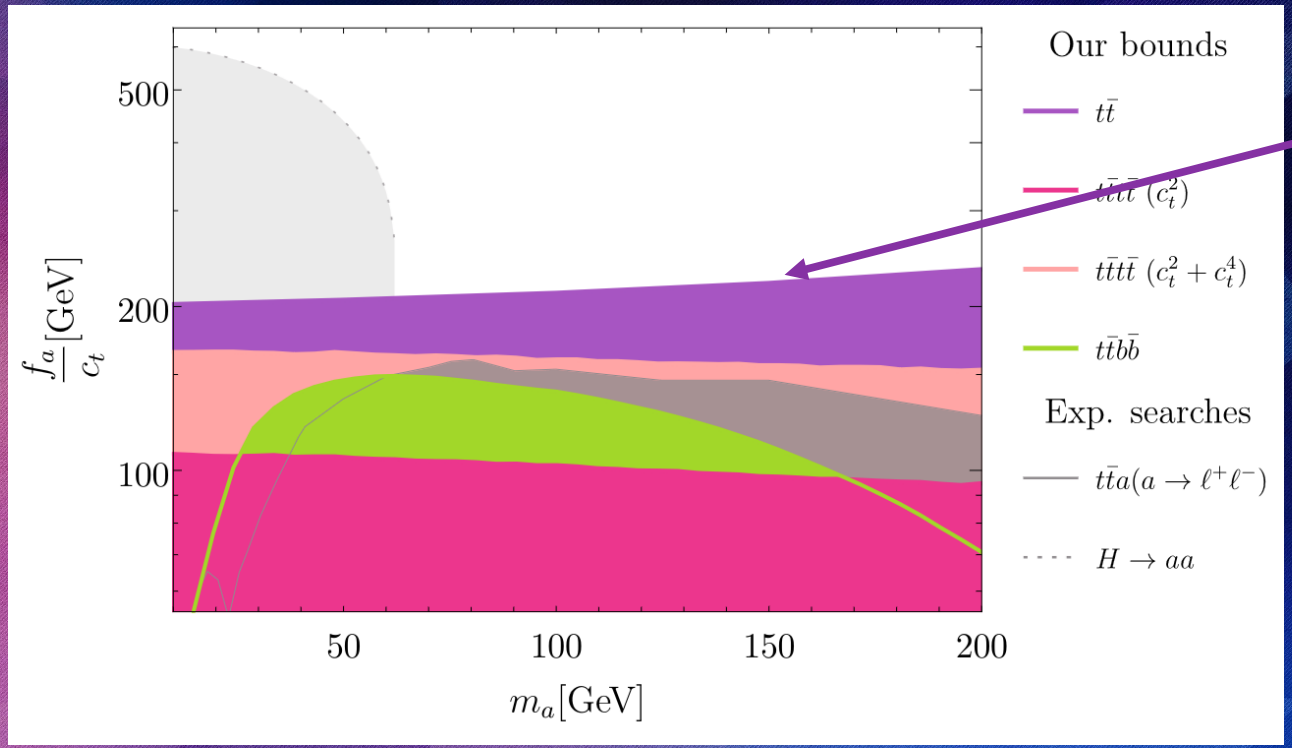
SEE ALSO:
[Esser. Madigan, Sanz, Ubiali, 2303.17634]
[Vu Phan, Westhoff, 2312.00872]
[Rygaard, Niedziela, Schäfer, Bruggisser, Alimena, Westhoff, Blekman, 2306.08686]
[Blasi, Maltoni, Mariotti, Mimasu, Pagani, **ST** 2311.16048]

Equations of motion

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

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

Bounds on ALP couplings



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

BEST BOUND!!

- **Real Experimental Data**
- **Accurate SM predictions from experiments**
- **Everything already there**

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

Conclusions

Thanks for the attention

NP Virtual Corrections

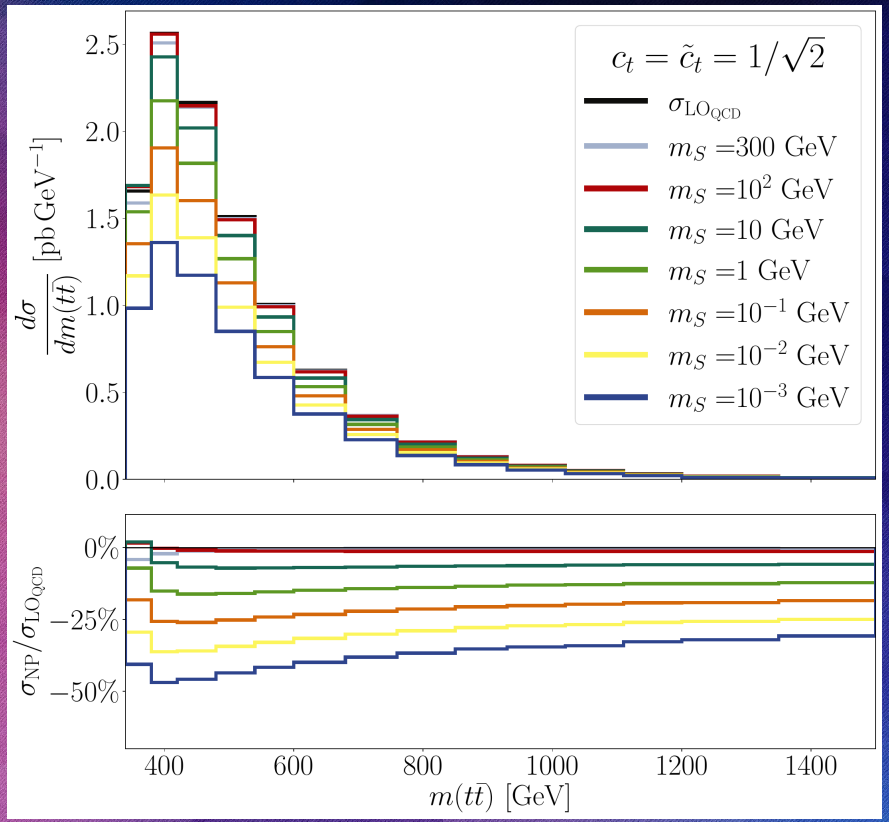
- **Powerful tool to constrain NP**
- **Can be use to fit SM parameters**
- **Can unveil elseways elusive particles**

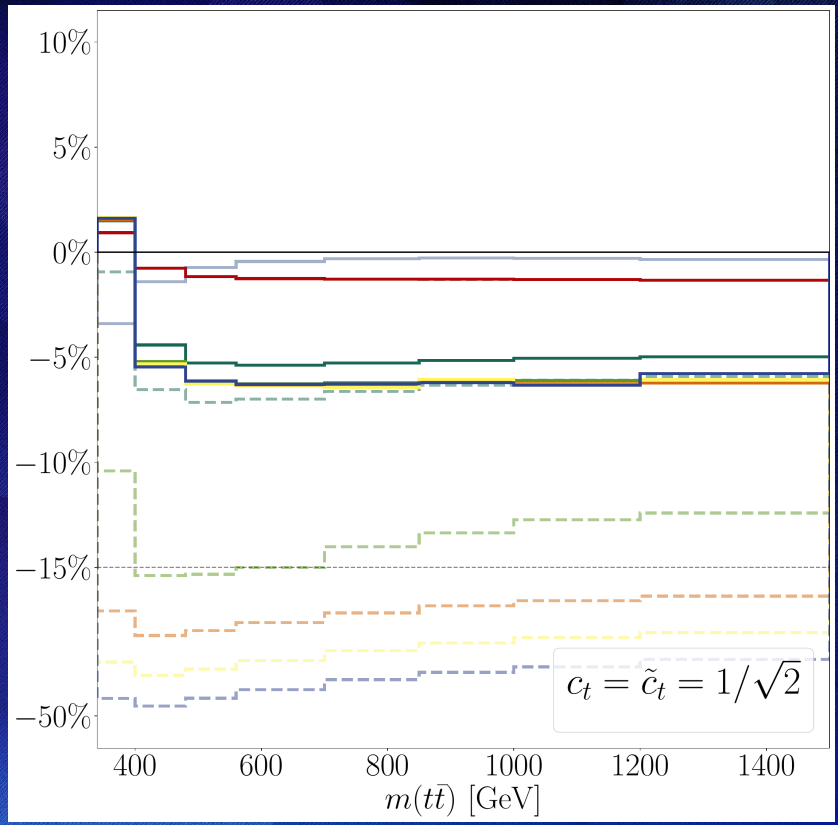
Backup

Simone Tentori

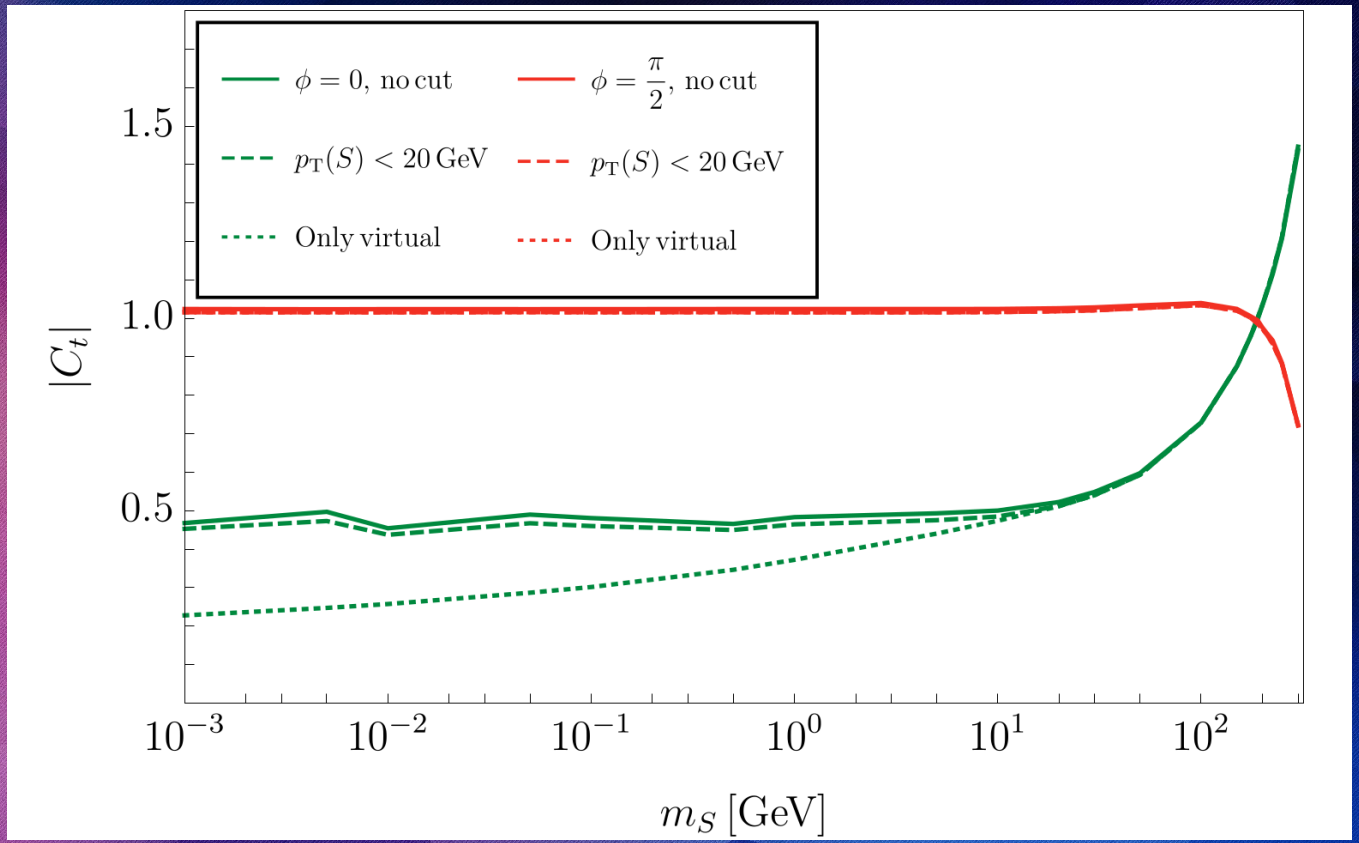
HEFT, Bologna
12/05/2024

Mixing the CP





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]

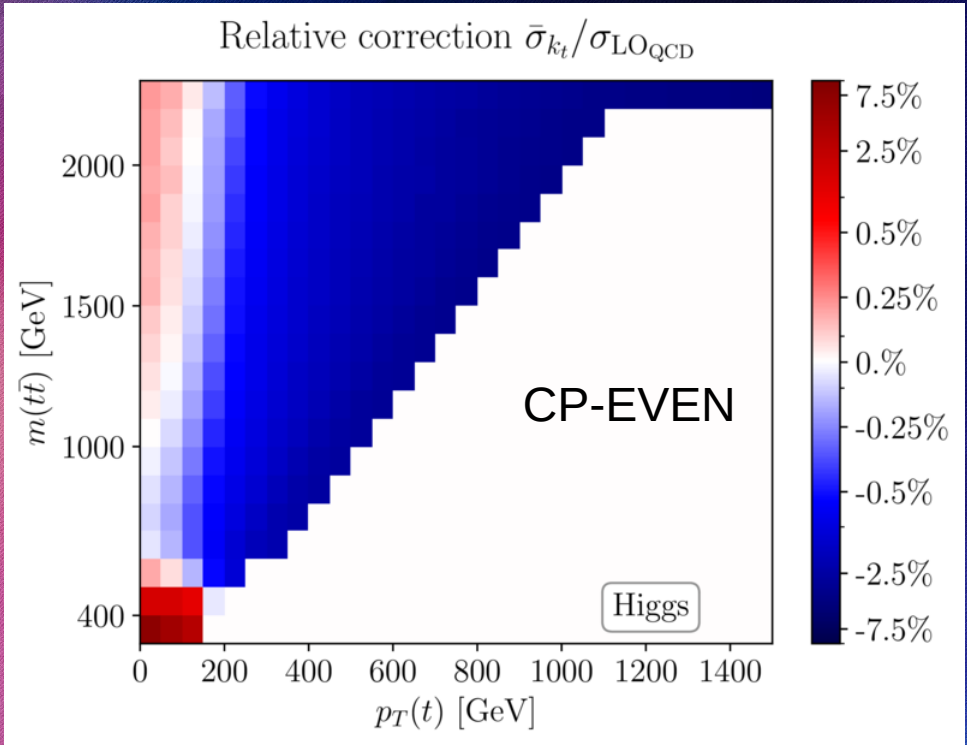
SMEFT relations

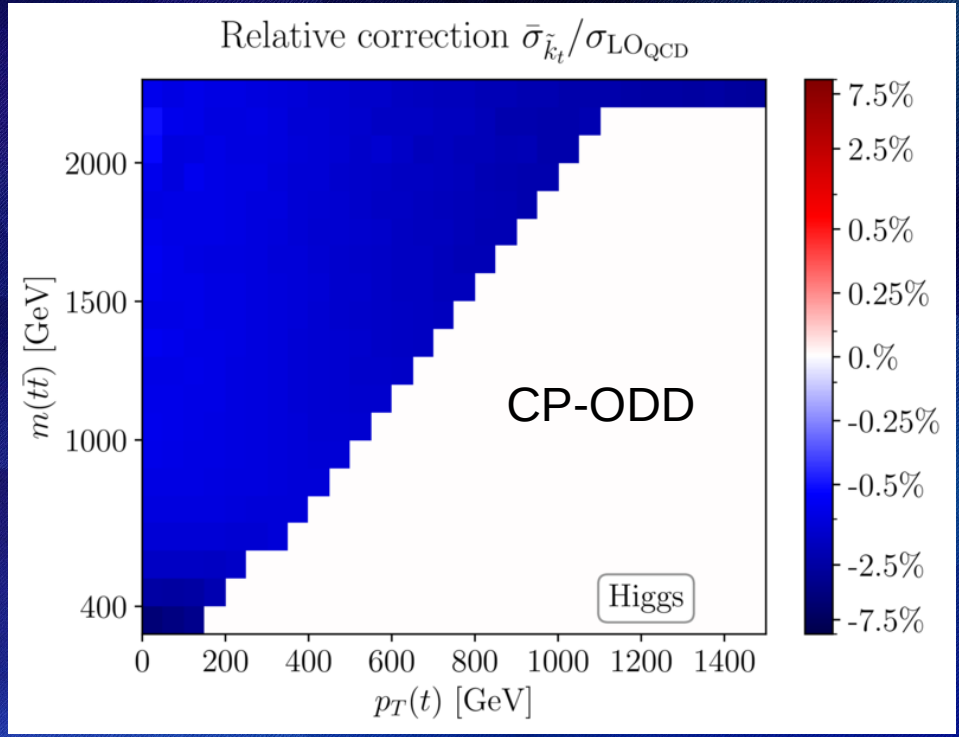
$$\mathcal{L}^{\text{dim}=6}_{\text{SMEFT, top}-\text{Higgs}} \equiv \mathcal{L}_{\text{SM}} + \frac{C^{u\Phi}_{tt}}{\Lambda^2}\left(\Phi^\dagger\Phi - \frac{v^2}{2}\right)\overline{\psi}_{Q_{3,L}}\tilde{\Phi}\psi_{t,R} + \text{h.c.}\,,$$

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

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

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

$2m_t > m_a$

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

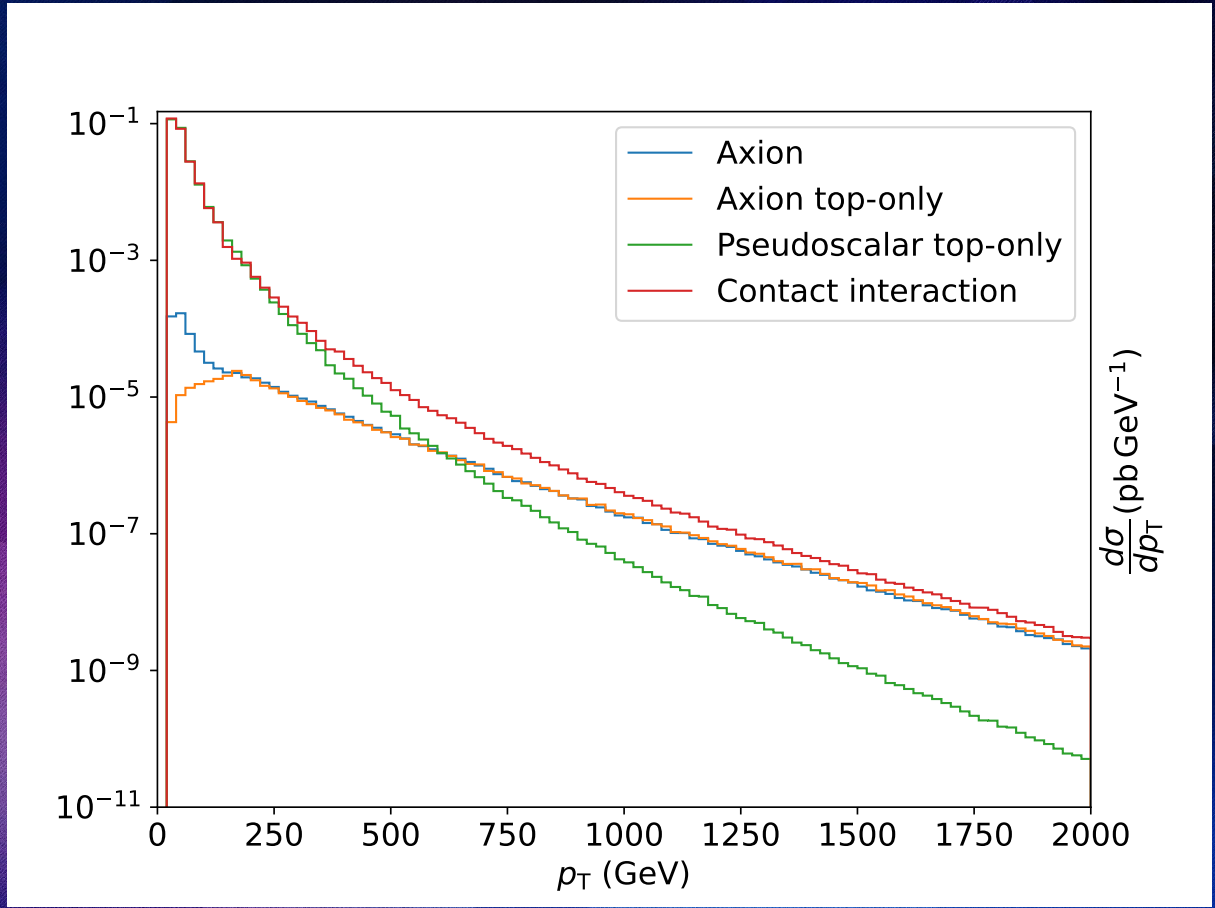
Cancellation between contact interaction and pseudoscalar!

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

Super-suppressed w.r.t. single terms

Simone Tentori

Top-only vs full couplings



Simone Tentori