Going Beyond Top EFT

12th LHCP

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UFABC, Sao Paulo, Brazil

Based on 2312.00670 , with Veronica Sanz

Top-Philic BSM@LHC

Top-BSM @ LHC

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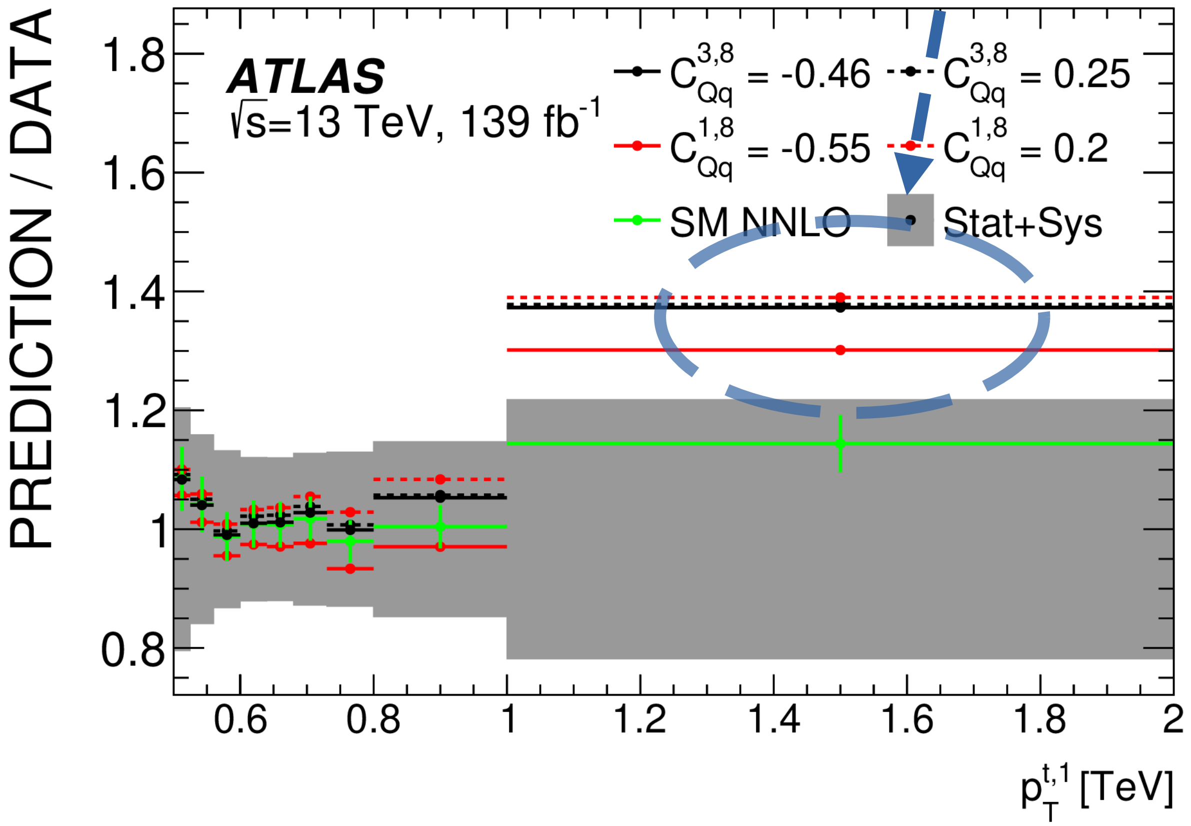

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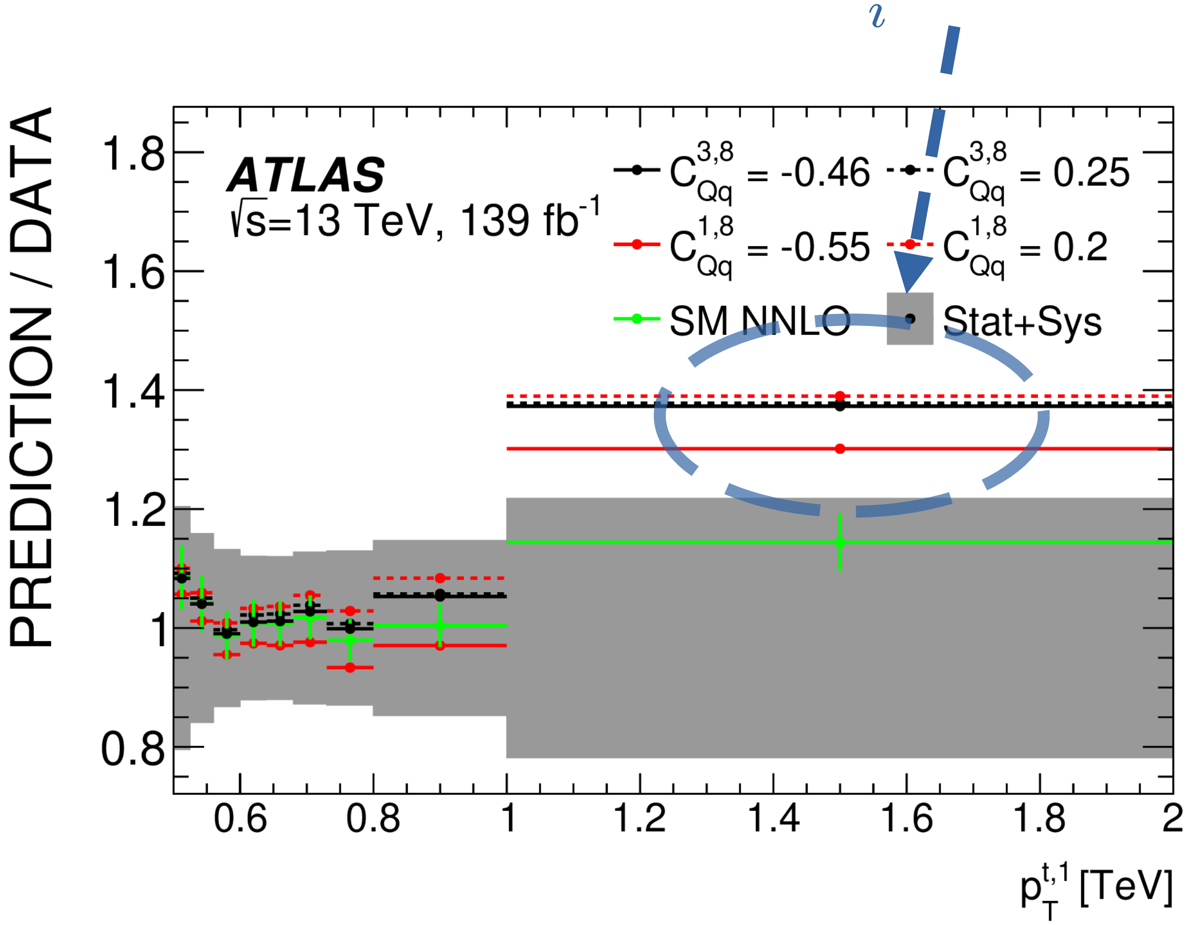

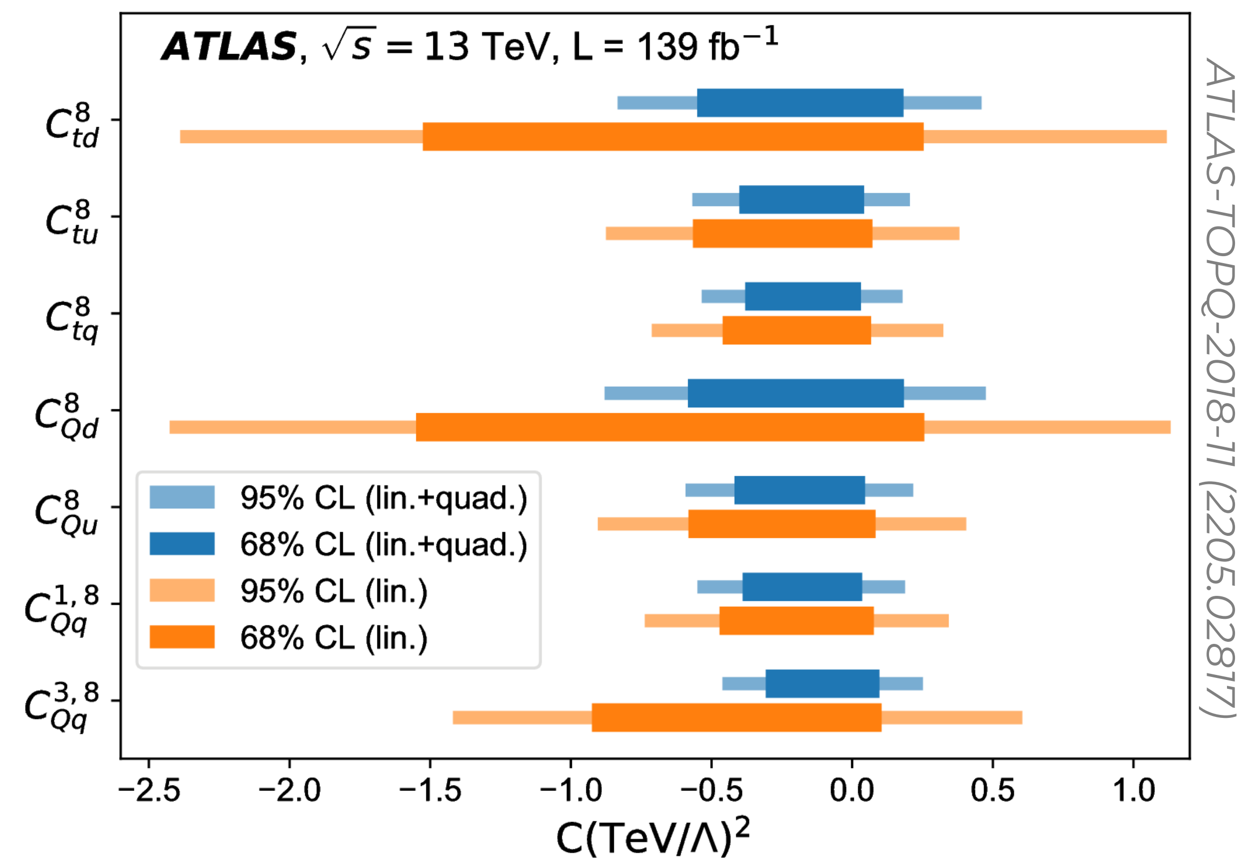

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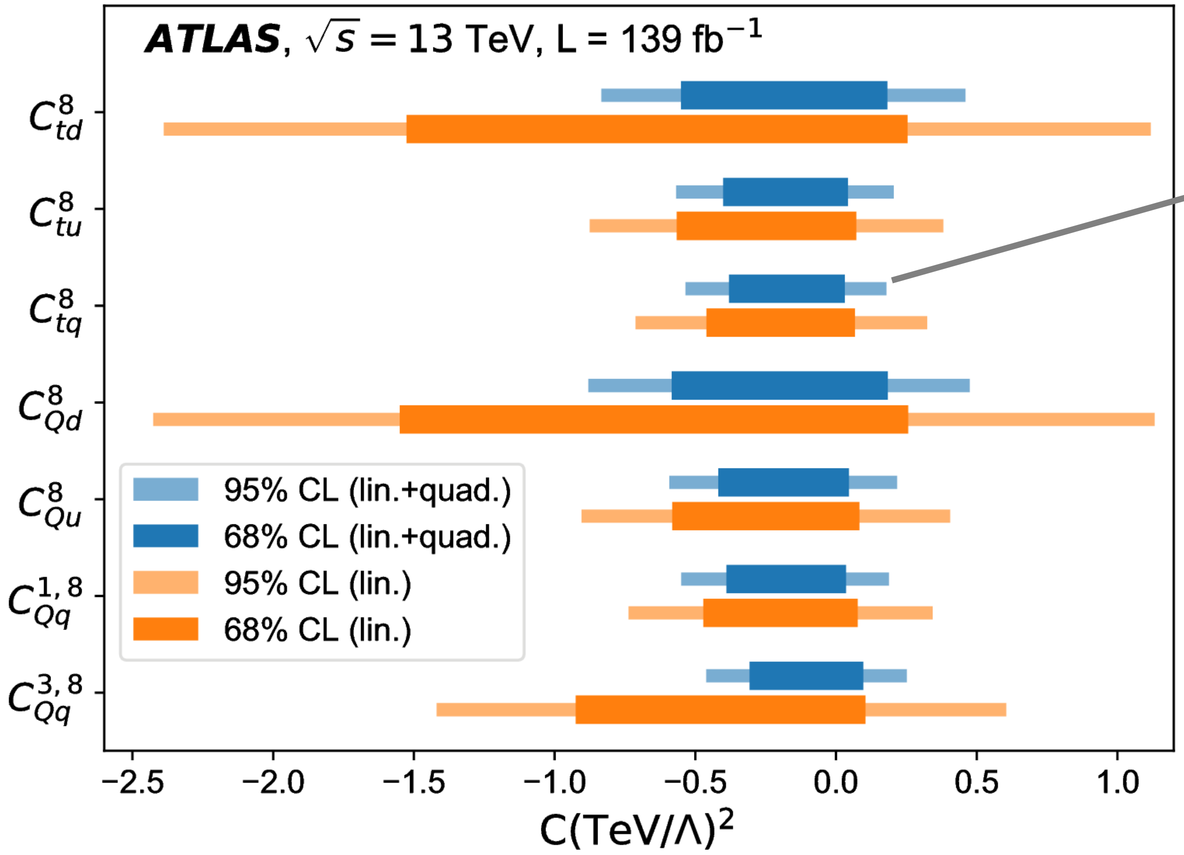

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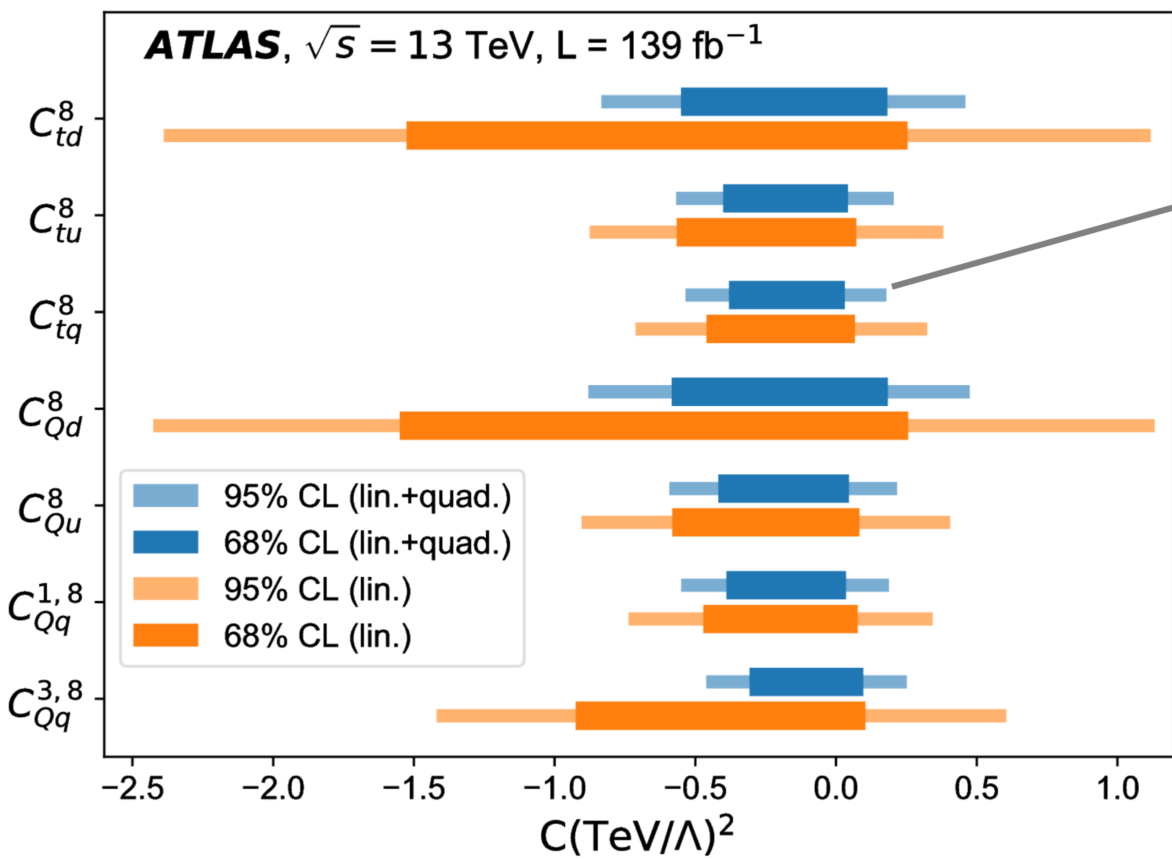


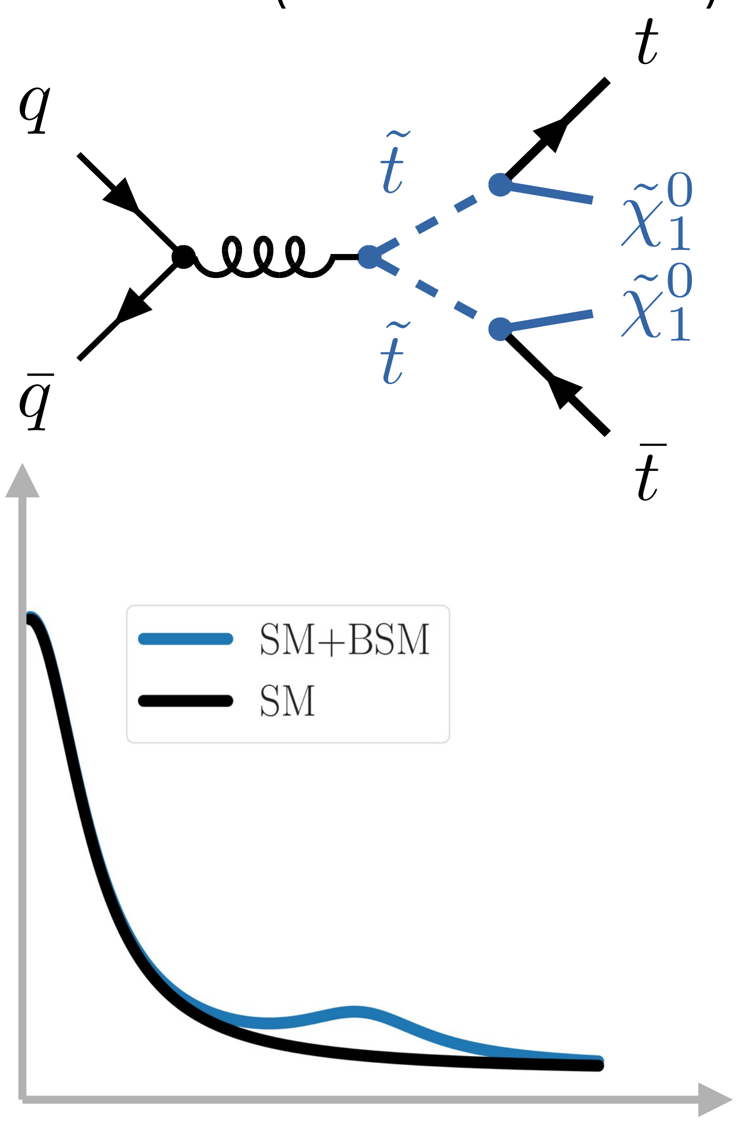
$$2.3\sqrt{C^{(8)}_{tq}} \lesssim \left(\frac{\Lambda}{\text{TeV}}\right)$$

→ The data is often only sensitive to scales at the edge of the EFT validity!

Top-BSM @ LHC

$\Lambda < \sqrt{\hat{s}}$

On-Shell (BSM Searches)



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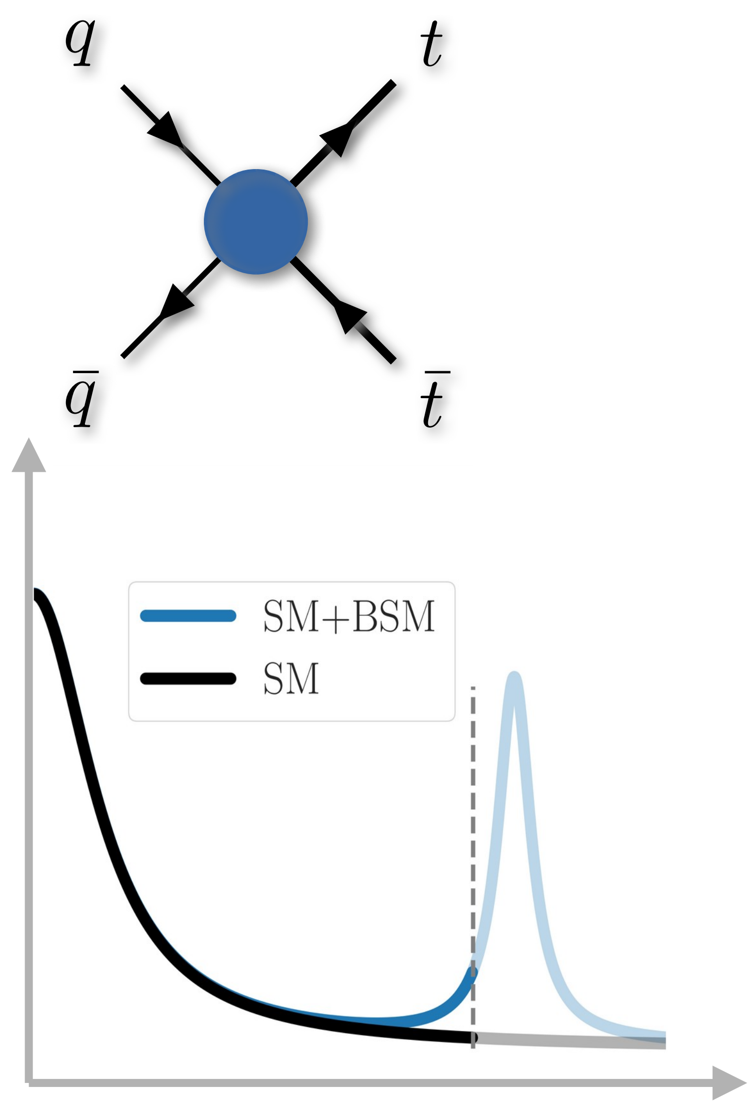
EFT (SM Measurements)



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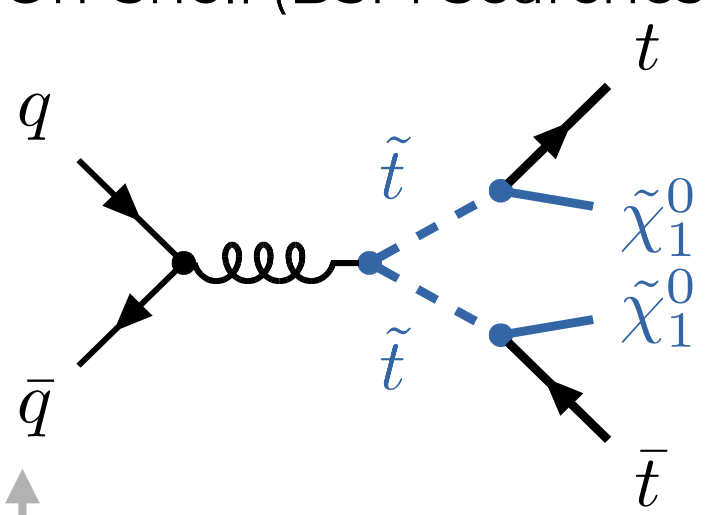

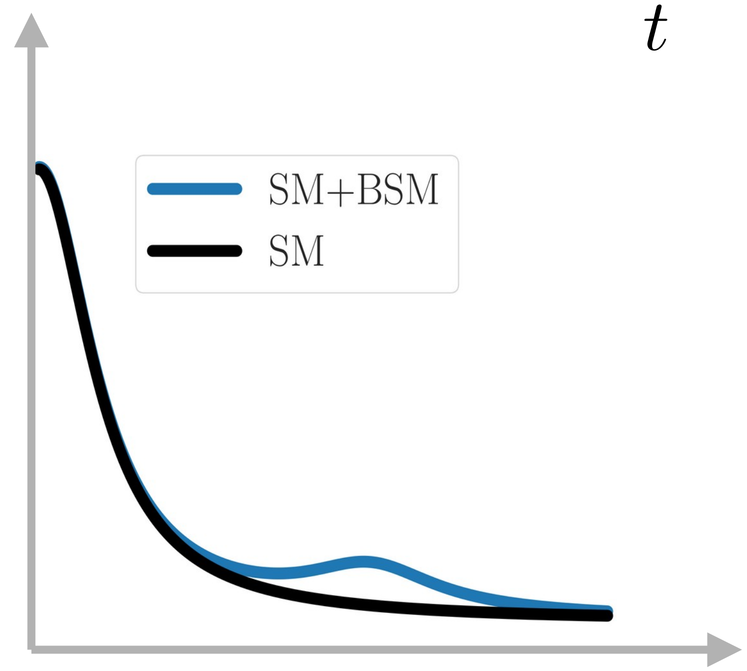

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"Beyond EFT" regime

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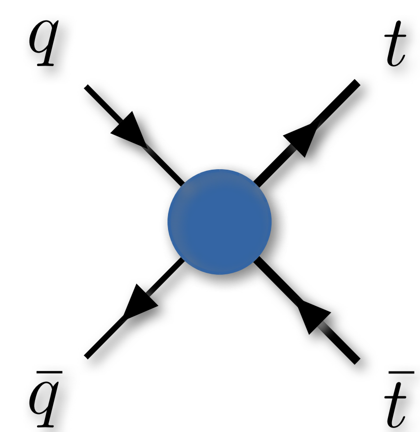

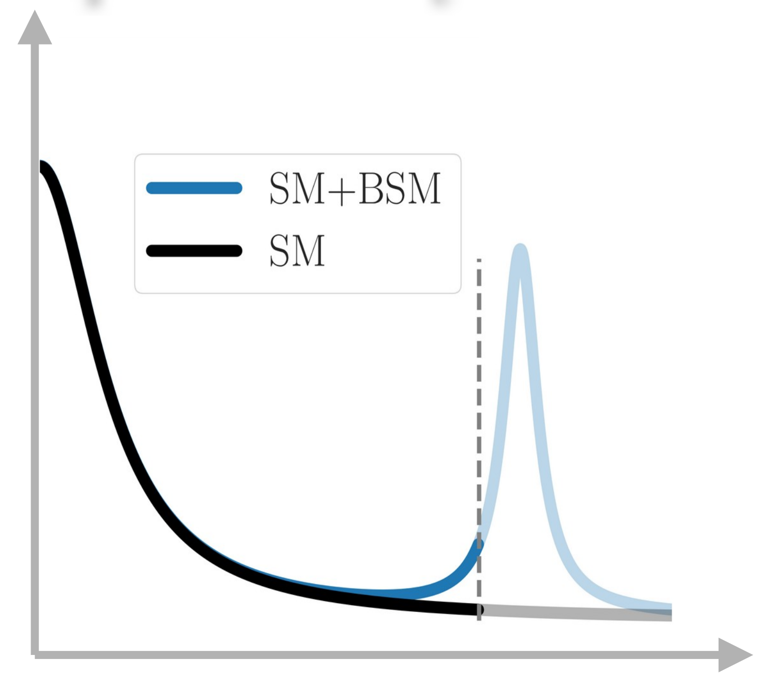

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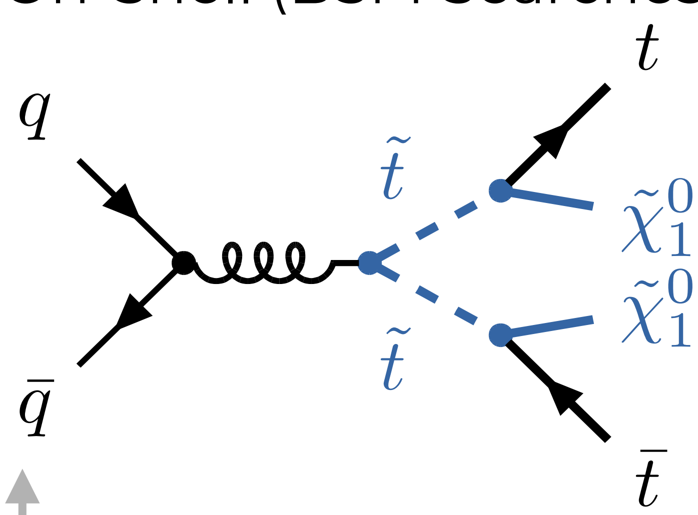

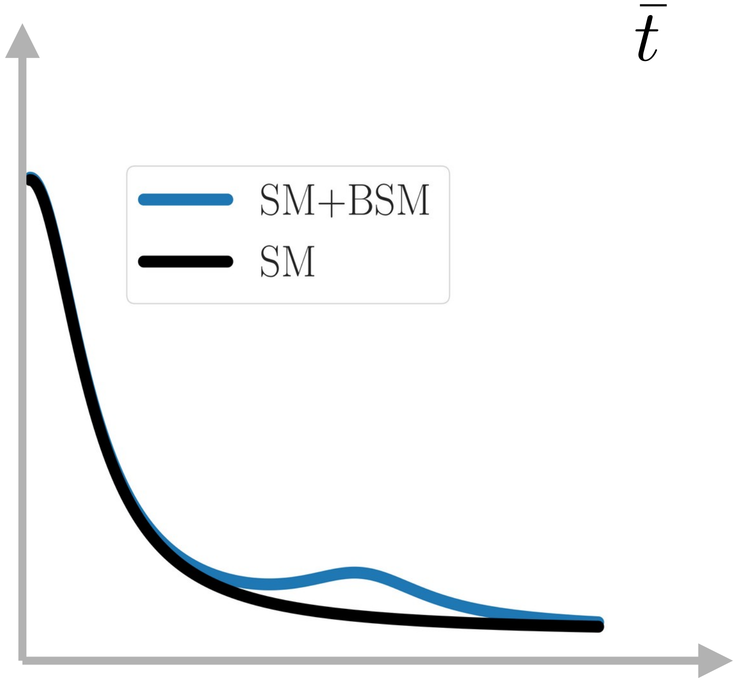

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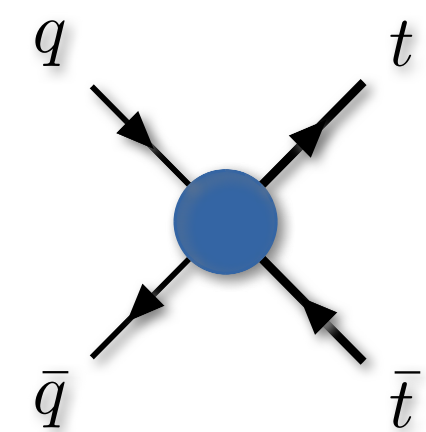

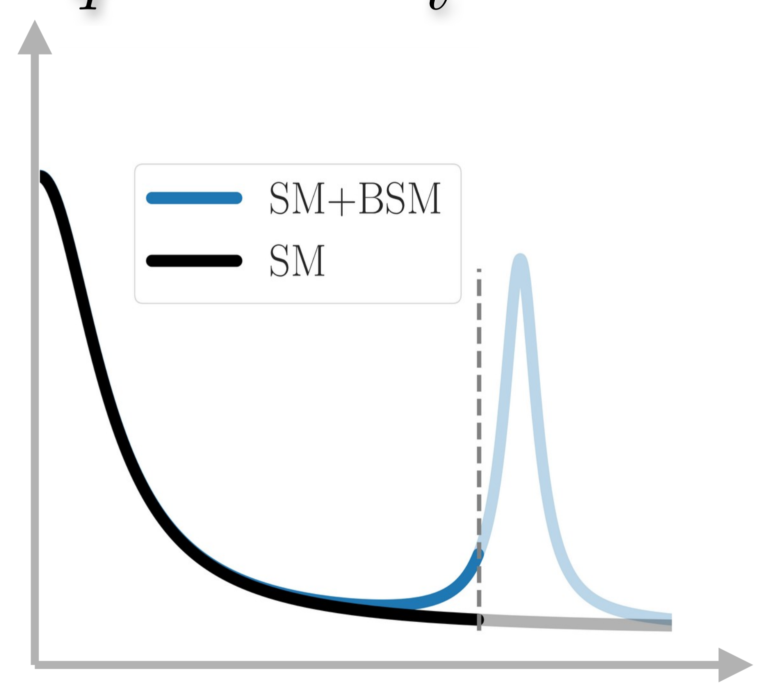

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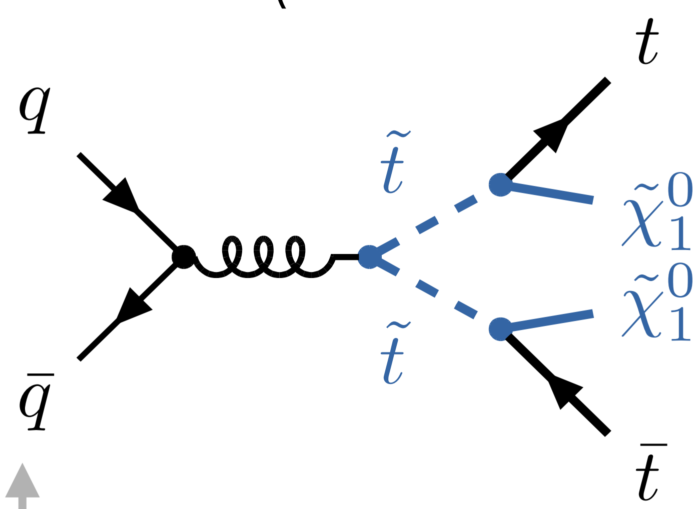

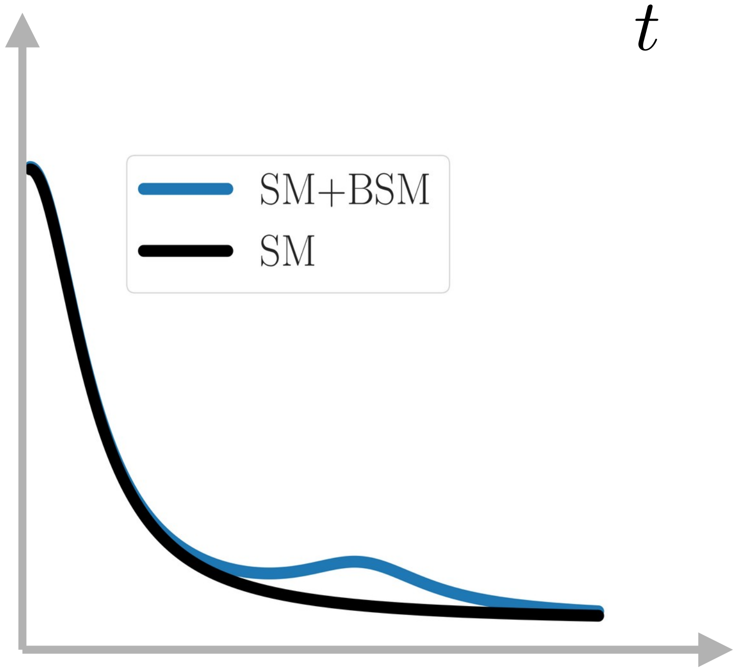

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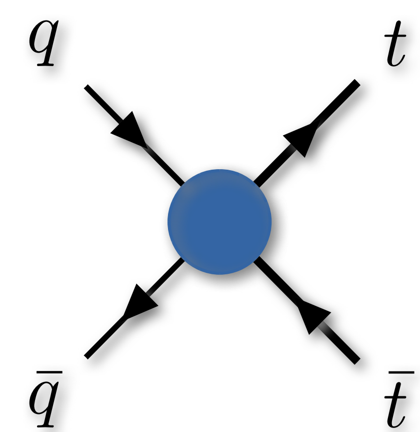

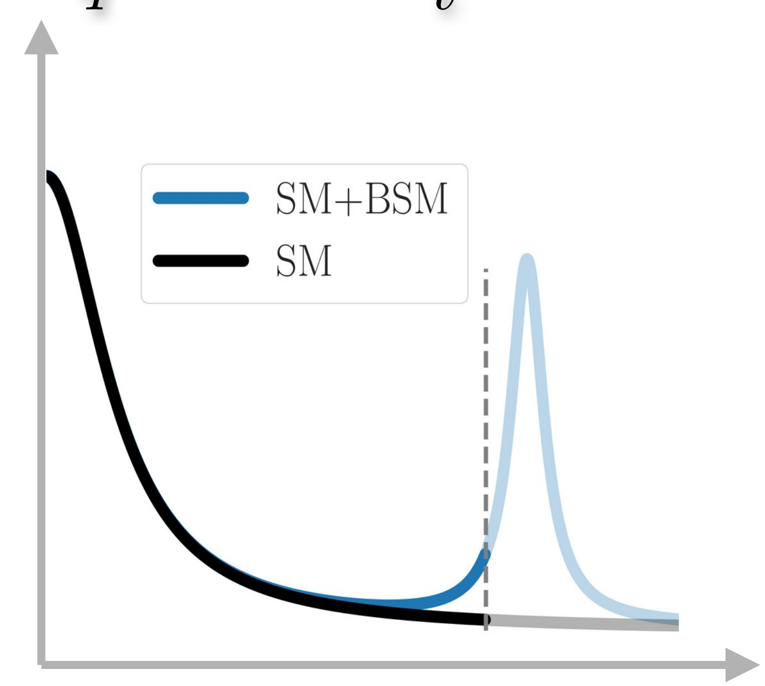

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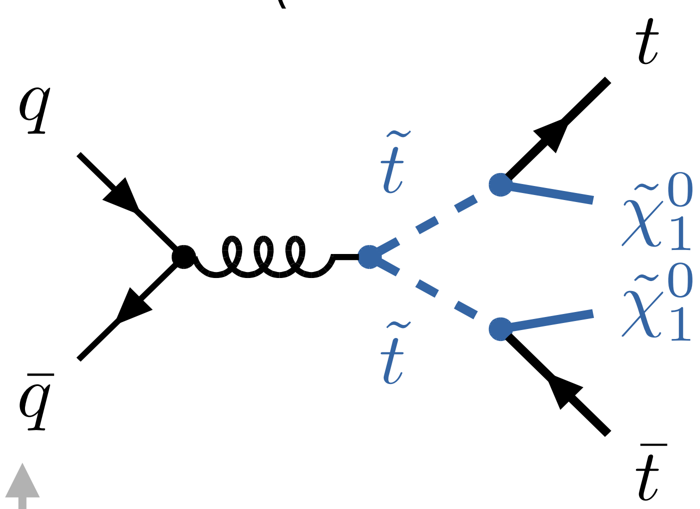

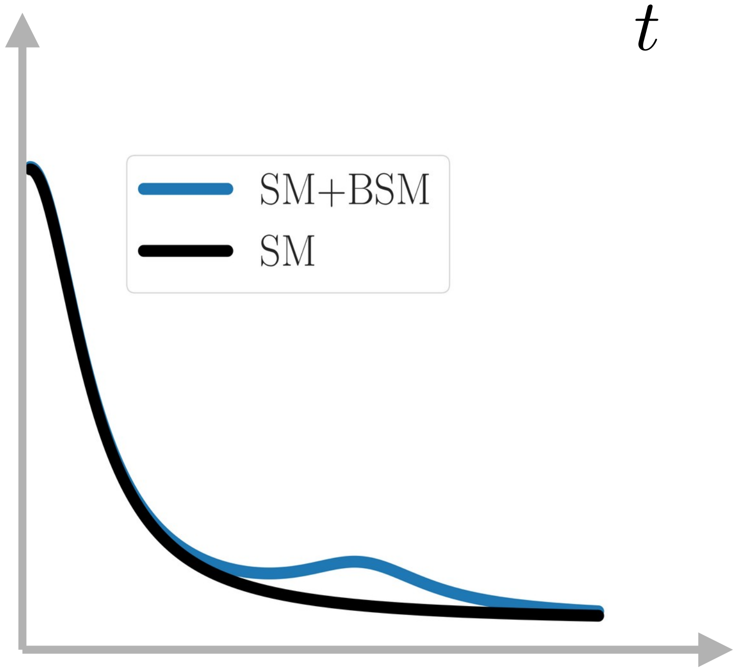

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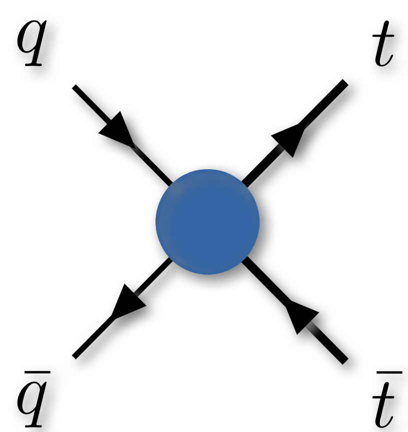

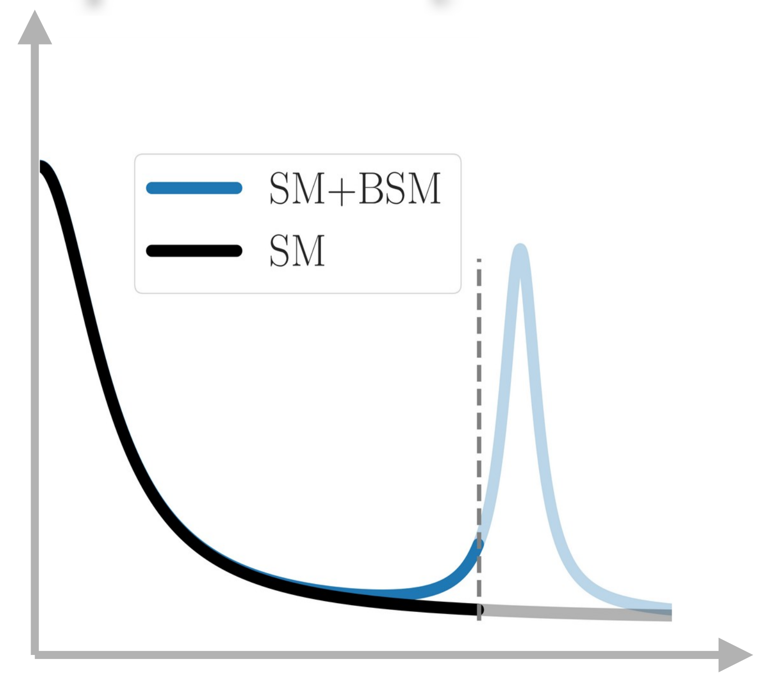

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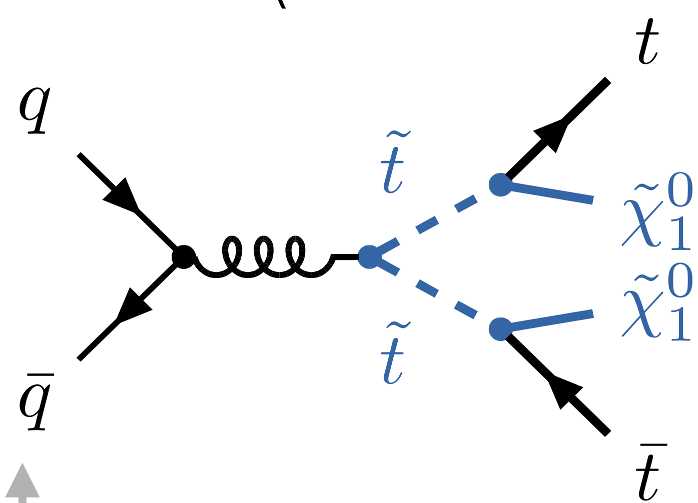

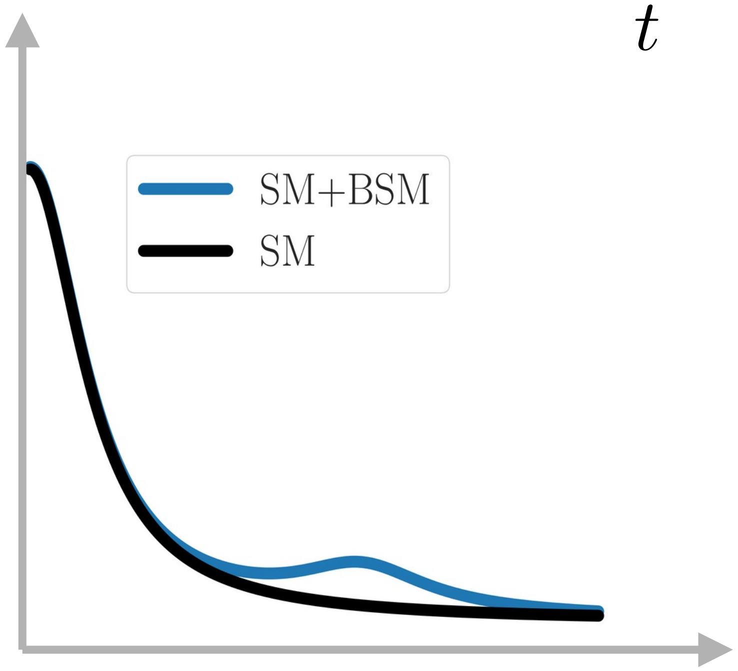

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"Beyond EFT" regime

- What happens at the EFT → on-shell transition?
- Are the EFT constraints valid even if the EFT assumption is violated?
- If not, are they too conservative/too aggressive?
- What do we learn going beyond EFT?

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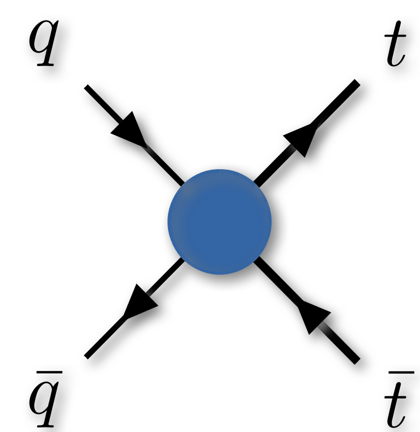

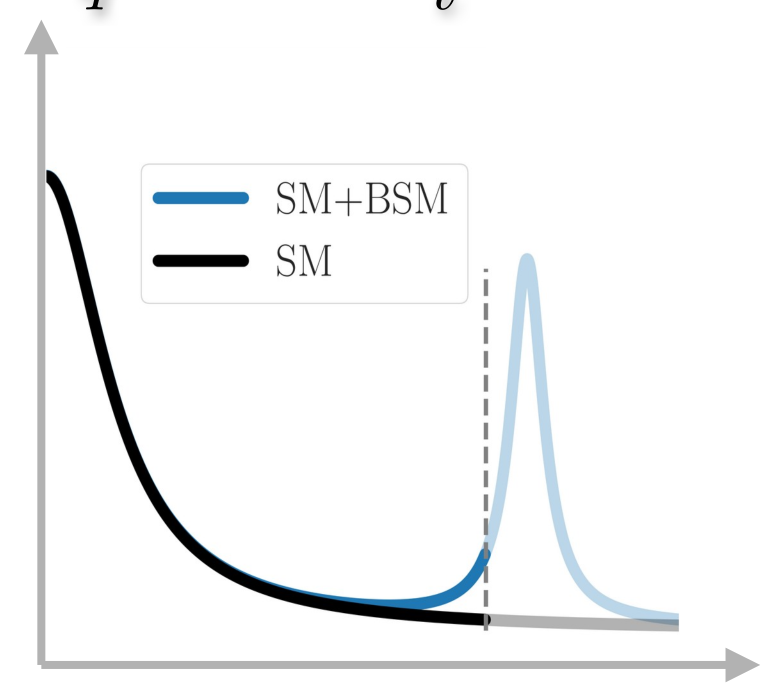

Going Beyond Top EFT

Beyond (Top)EFT

- Toy Model (*DM inspired*):

$$\phi_T \rightarrow \text{ scalar top partner} \quad \chi \rightarrow \text{ Majorana singlet}$$

$$\mathcal{L}_{BSM} = \bar{\chi}\left(i\partial - \frac{1}{2}m_\chi\right)\chi + |D_\mu \phi_T|^2 - m_T^2|\phi_T|^2 - \left(y_{\rm DM}\phi_T^\dagger \bar{\chi} t_R + h.c.\right)$$

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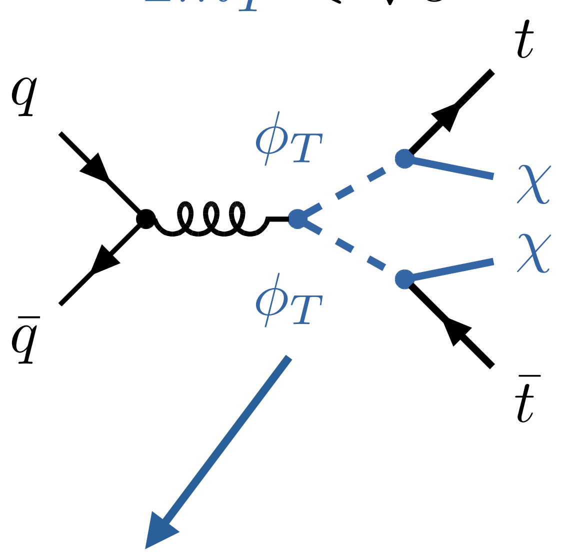

Direct Searches

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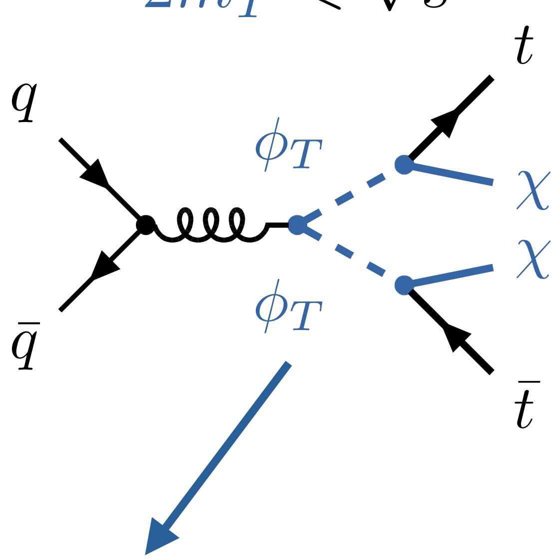

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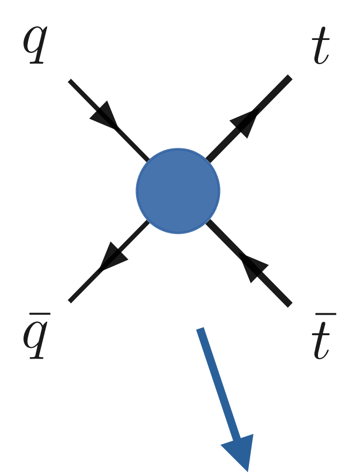

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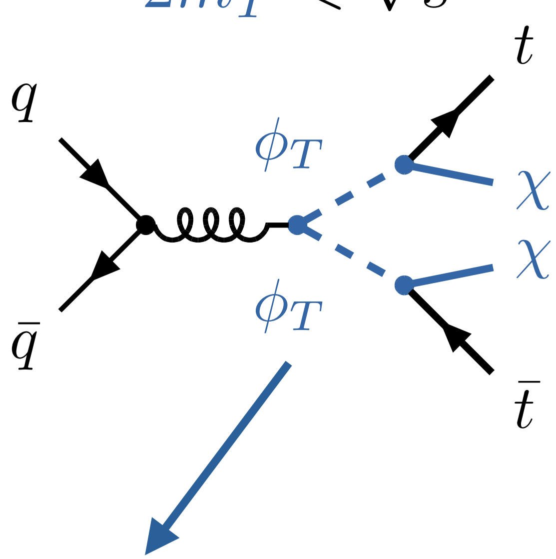

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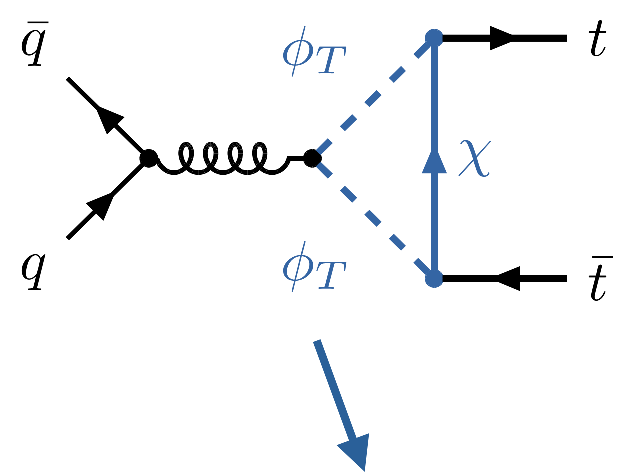

Indirect Searches
(1-loop)

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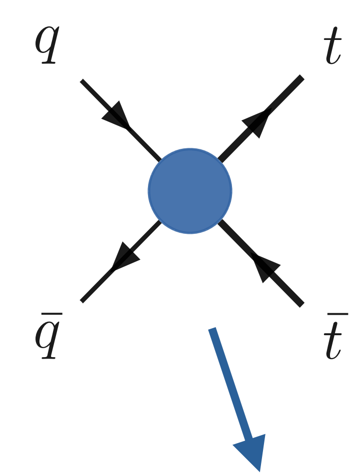

Indirect Searches
(EFT)

Beyond (Top)EFT

- EFT lagrangian:

$$\mathcal{L}_{EFT} = C_q\,(\bar{t}_R T^A \gamma^\mu t_R)\,(\bar{Q}_L T^A \gamma^\mu Q_L + \bar{u}_R T^A \gamma^\mu u_R + \bar{d}_R T^A \gamma^\mu d_R)$$
$$+ C_q\,(\bar{t}_R T^A \gamma^\mu t_R)\,(\bar{Q}_{3,L} T^A \gamma^\mu Q_{3,L})$$
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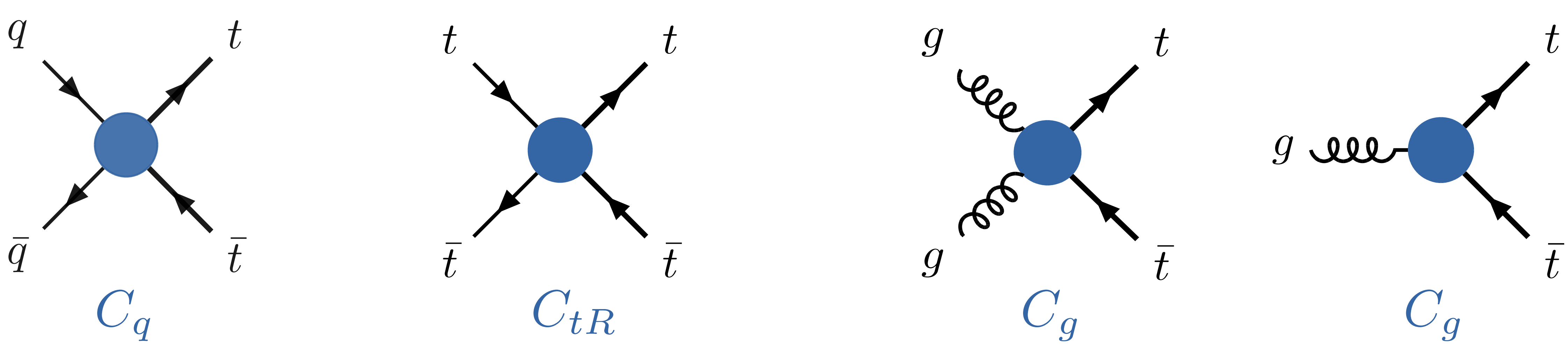
$$+ m_t C_g\, G^A_{\mu\nu}\,(\bar{t} T^A \sigma^{\mu\nu} t)$$

$$\left(C_g \to C_{tG},\; C_q \to C^{(8)}_{t(q,u,d)},\; C_{tR} \to C^{(8)}_{tt}\right)$$



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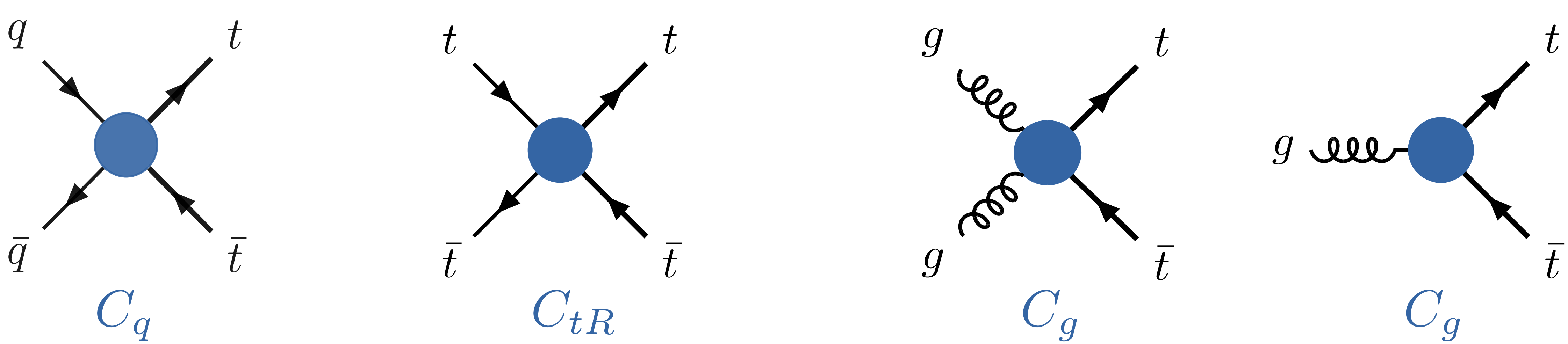

$$C_g \simeq -\frac{1}{2}\frac{g_s y^2_{DM}}{384\pi^2}\frac{1}{m_T^2},\quad C_q = -2 g_s C_g,\quad C_{tR} \simeq -\frac{1}{3}\frac{y^4_{DM}}{128\pi^2}\frac{1}{m_T^2} \quad (m_T \simeq m_\chi)$$

Beyond (Top)EFT

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$$\mathcal{L}_{FF} = \pi^2 g_s y_{DM}^2 \left[\mathcal{F}^{\mu}\left(p_t, p_{\bar{t}}\right)\right] G_{\mu}\bar{t}t + \pi^2 g_s^2 y_{DM}^2 \left[\mathcal{F}^{\mu\nu}\left(p_g, p_t, p_{\bar{t}}\right)\right] G_{\mu}G_{\nu}\bar{t}t$$

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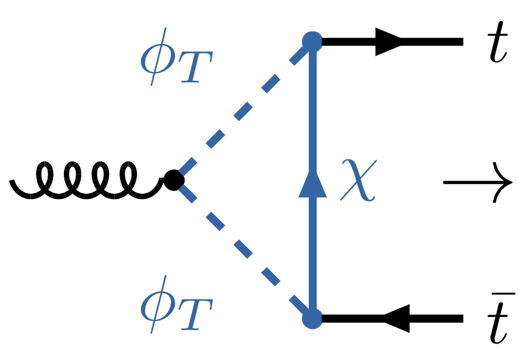

$$\to \mathcal{F}^{\mu}\left(p_t, p_{\bar{t}}\right)$$

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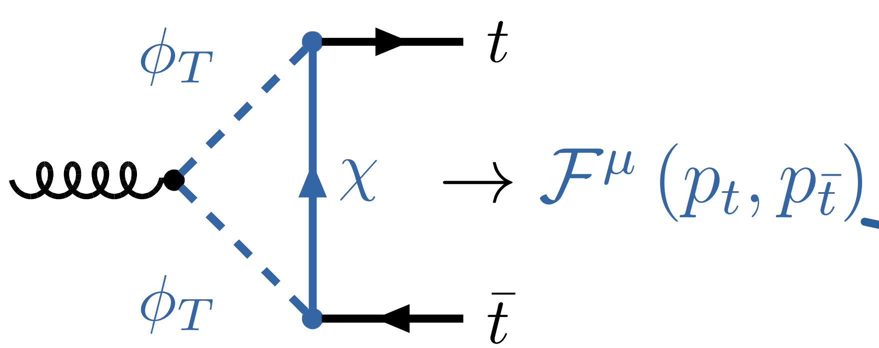

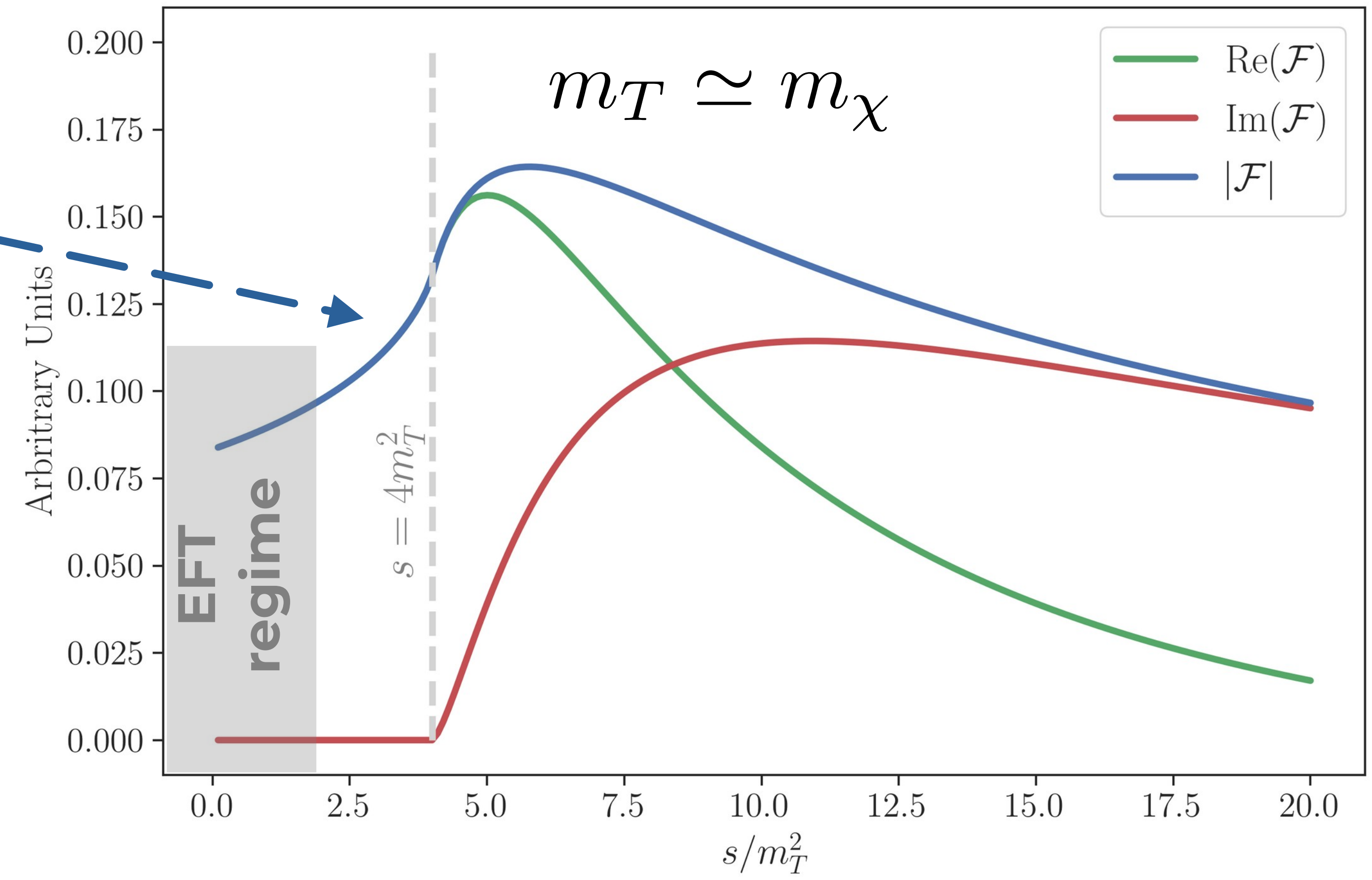

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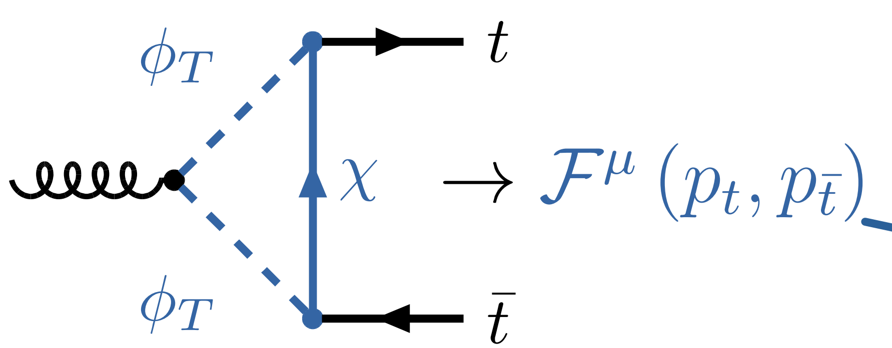
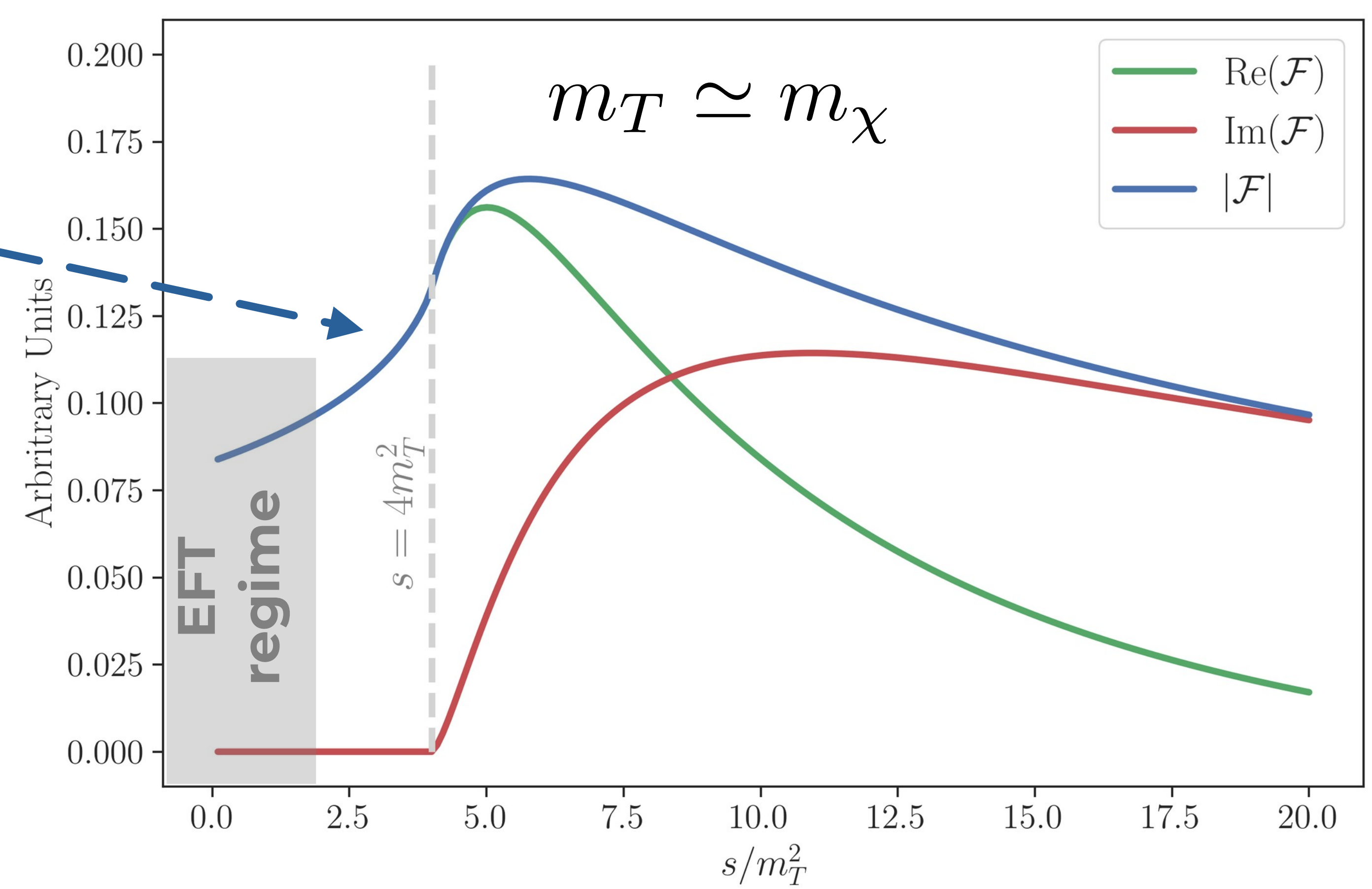


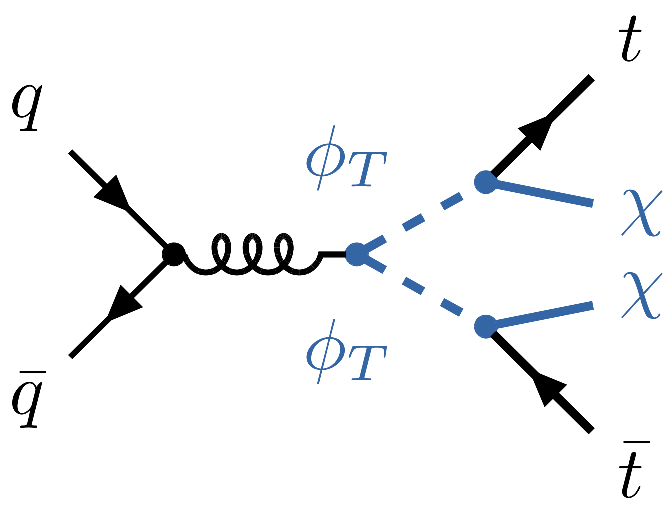


- *Broad bump* behavior
- Form factor is real in the EFT region
- Imaginary part becomes dominant at large energies

LHC Constraints

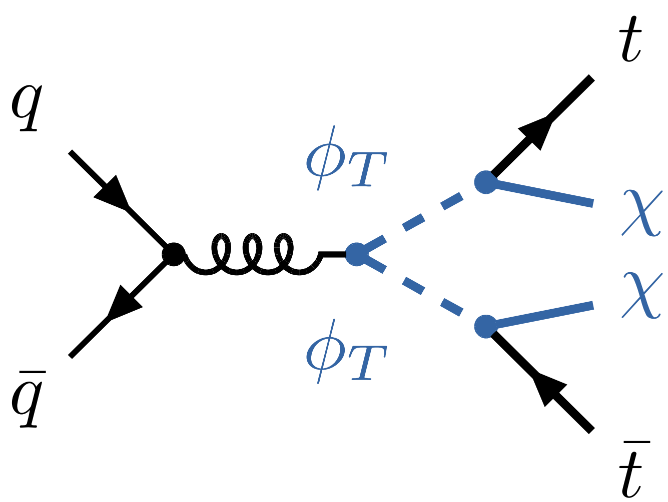
Direct and Indirect Searches

Direct Searches



- Constraints computed using:
  - SModelS (7 top+MET searches)
  - CMS mono-jet search (compressed region)

Direct Searches



- Constraints computed using:
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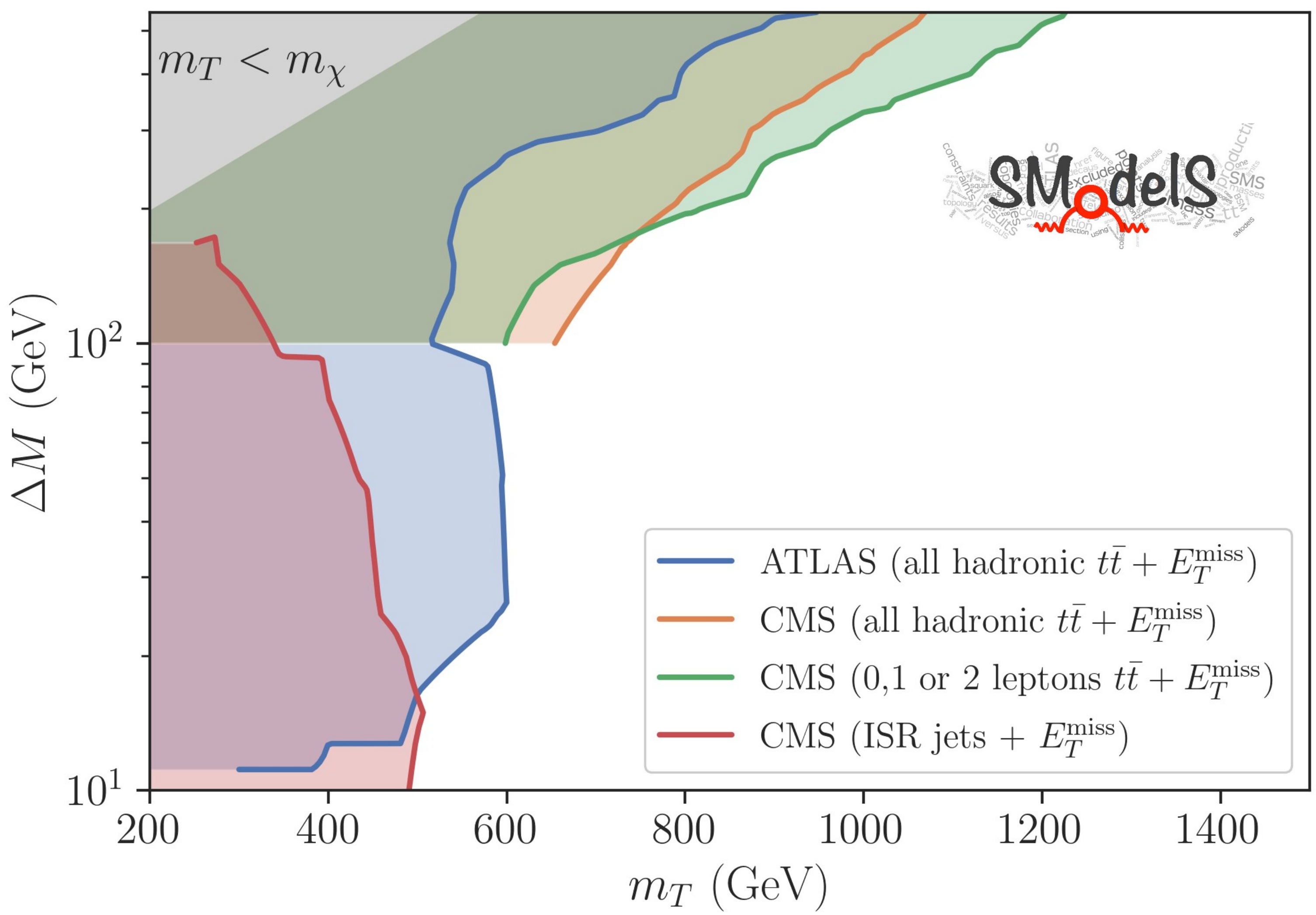

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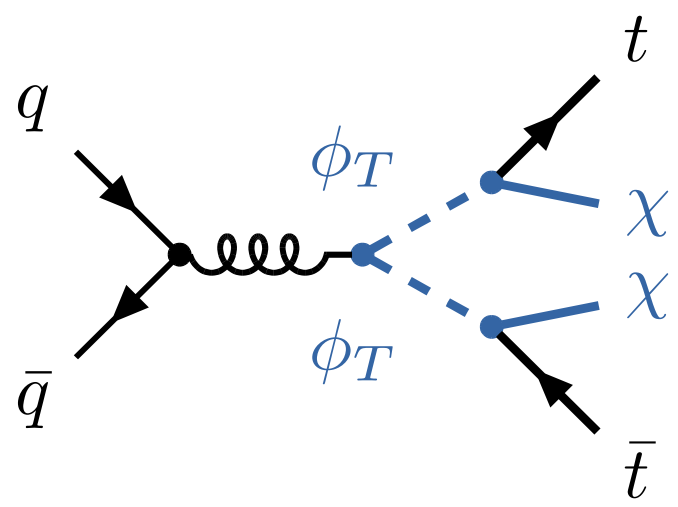

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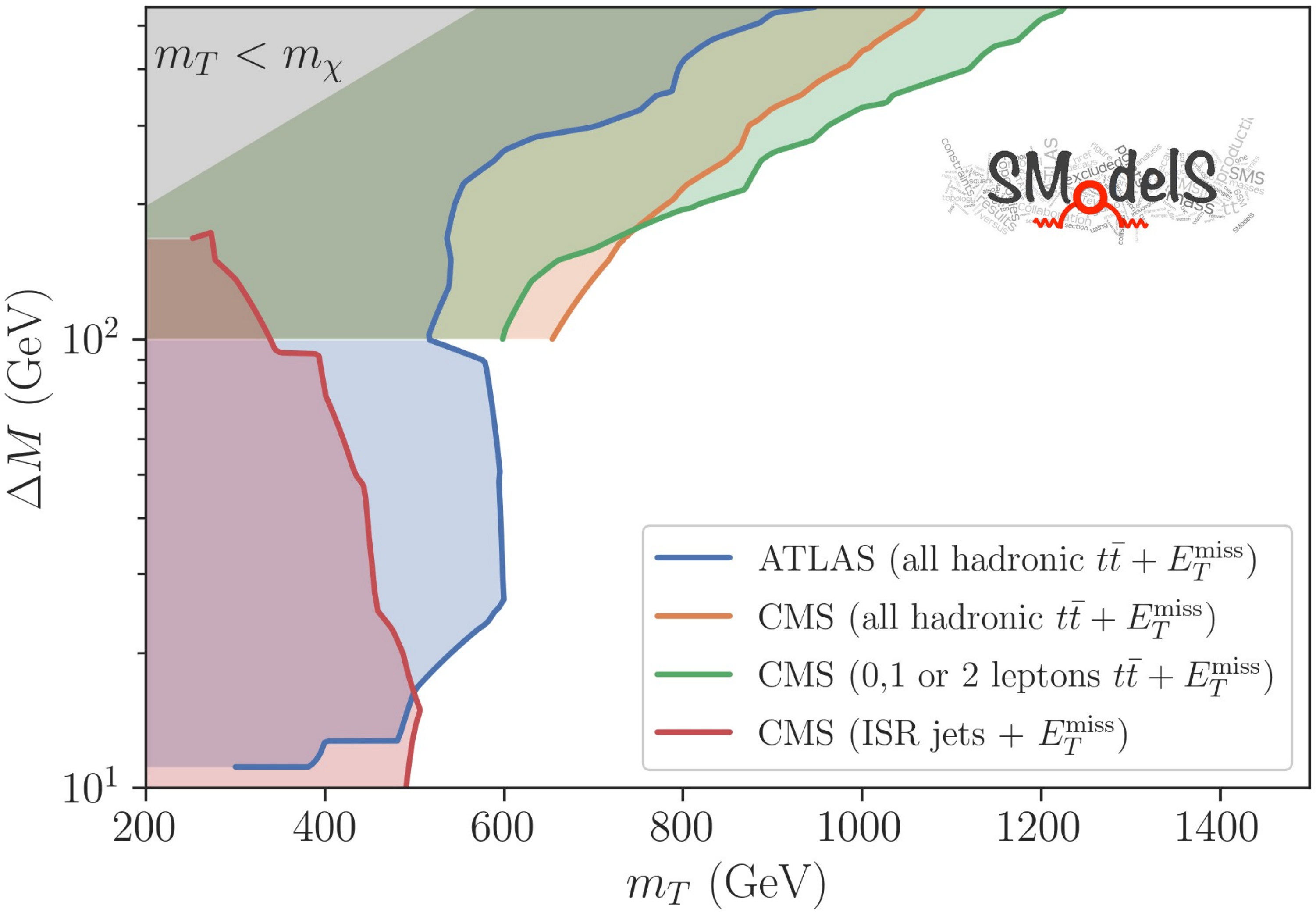

- Loss of sensitivity in the compressed region.
- ~500 GeV top-partners are still allowed
- Does not depend on y_{DM}!

Indirect Searches

- $t\bar{t}$ production

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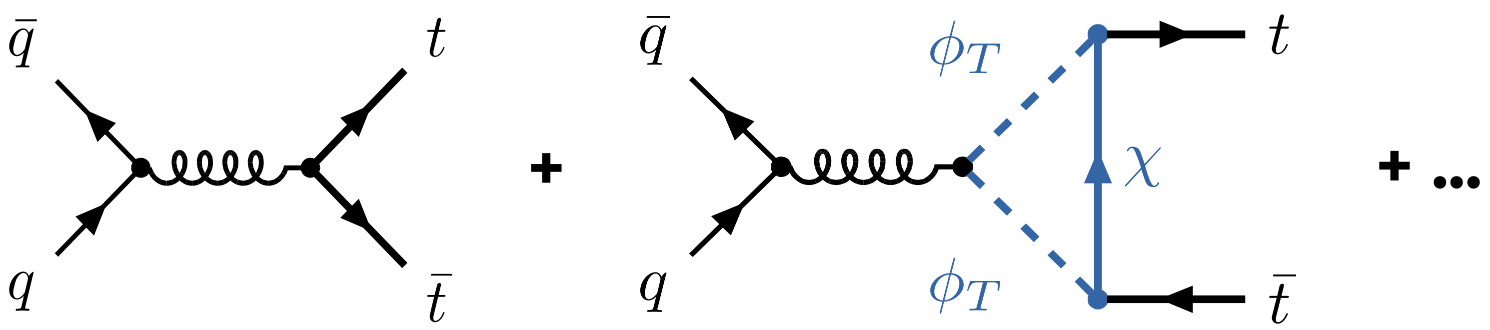
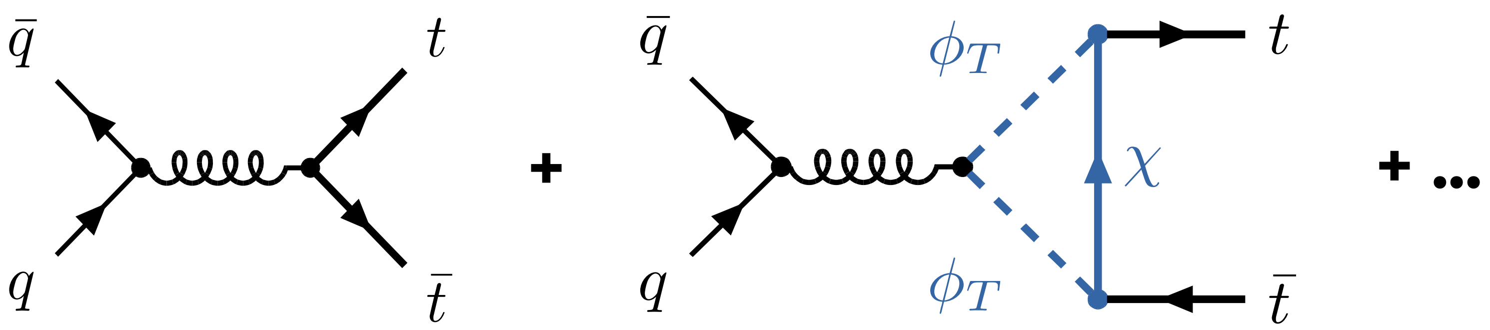


(1-loop)

Indirect Searches

- $t\bar{t}$ production

$$|\mathcal{M}_{\rm T}|^2 = |\mathcal{M}_{\rm SM}|^2 + 2\,{\rm Re}\,(\mathcal{M}_{\rm SM}\mathcal{M}^*_{\rm BSM}) + \mathcal{O}(y^4_{\rm DM})$$



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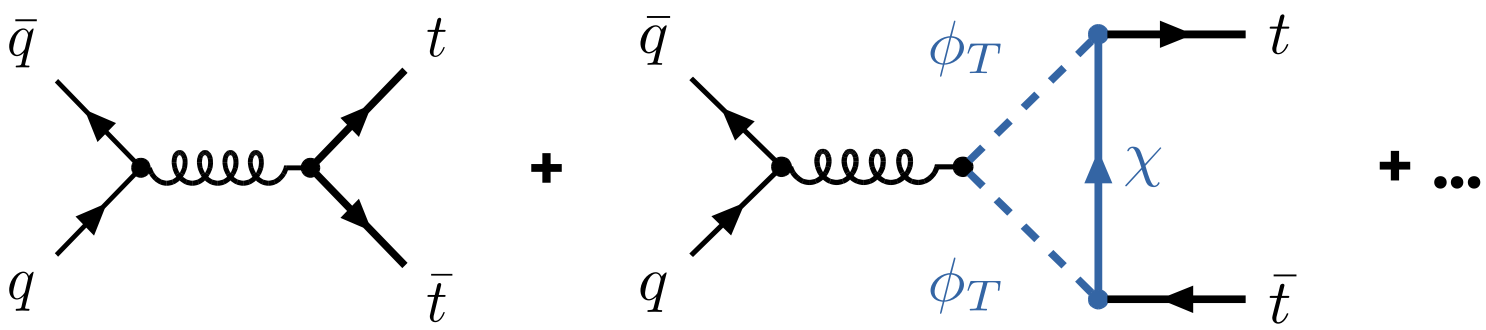

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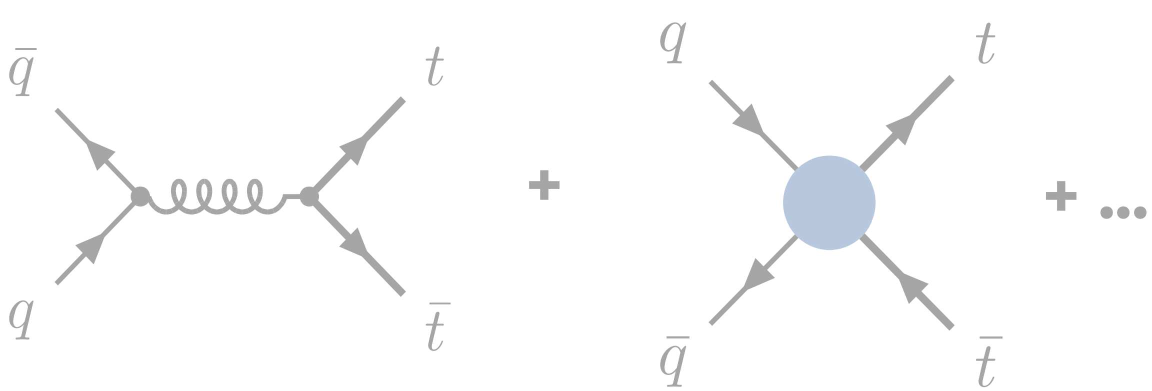

(EFT approximation)

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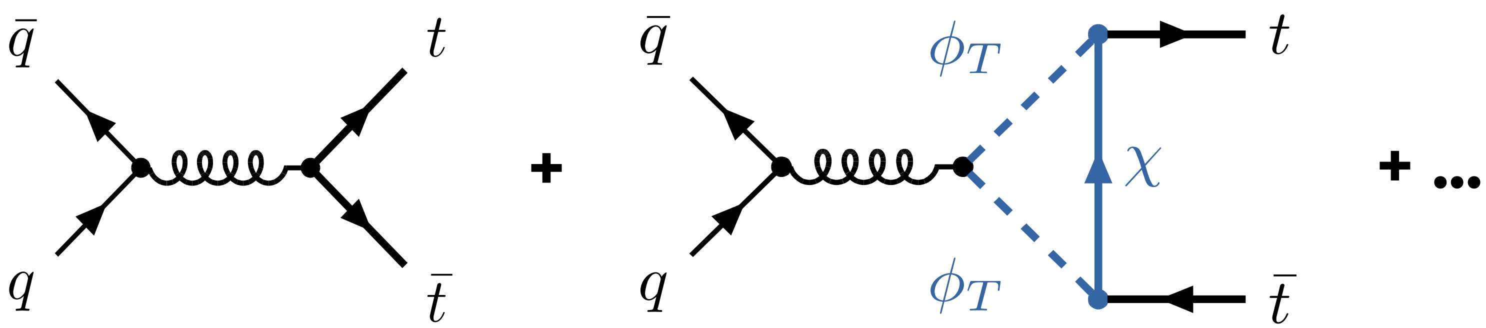

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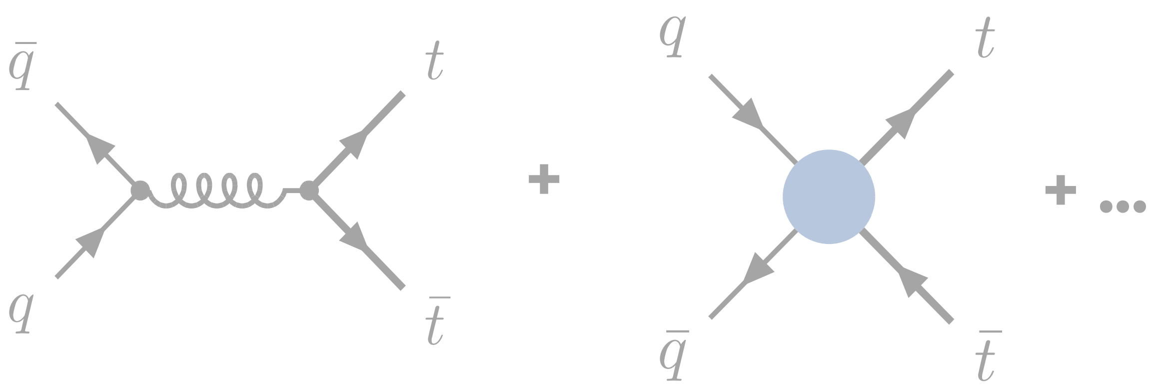
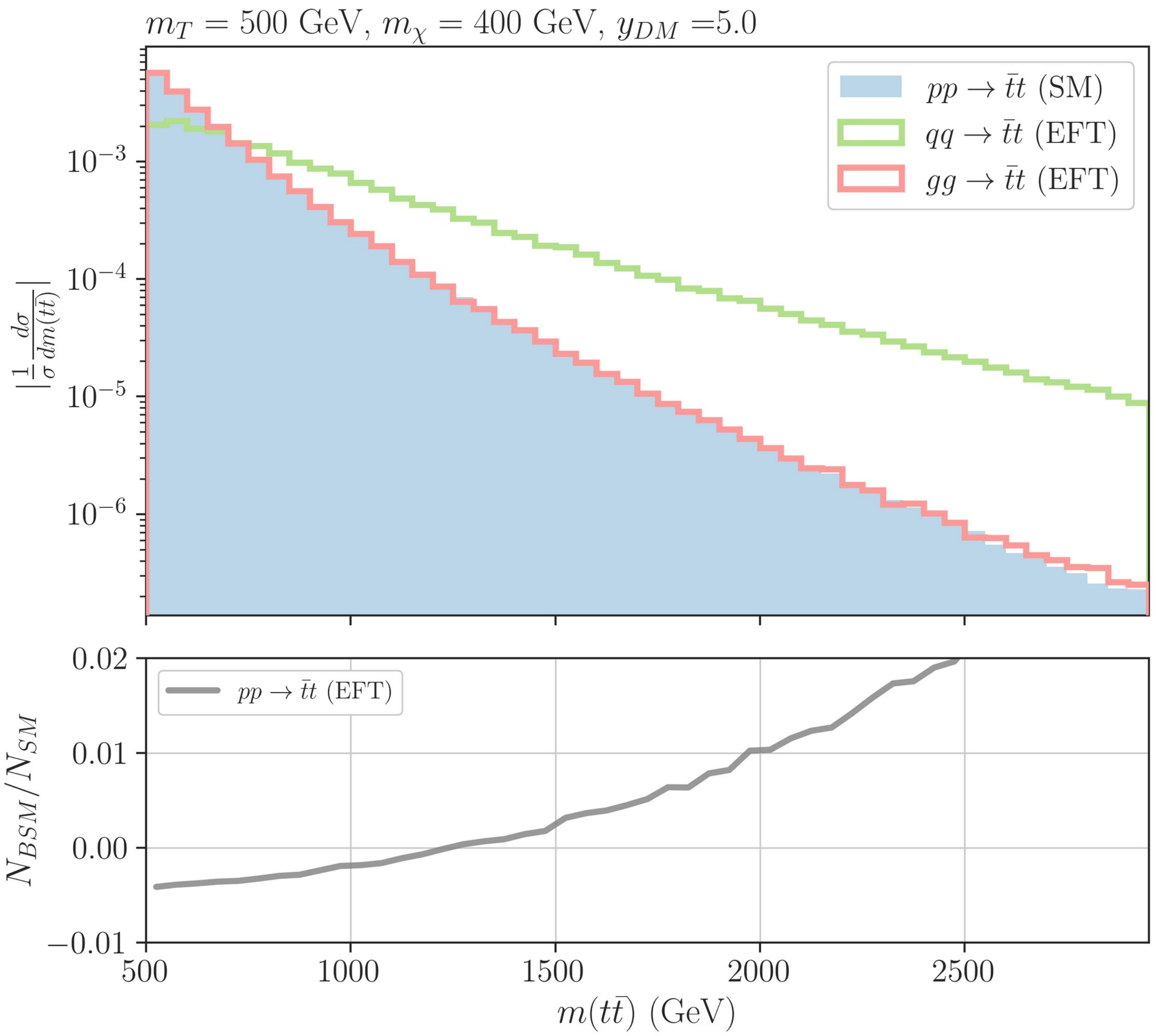


(EFT approximation)

- BSM contribution can be negative!
- Corrections scale as $(y_{DM})^2$!

Indirect Searches

- Distributions (LO):



- EFT:
  - grows with energy
  - always positive

Indirect Searches

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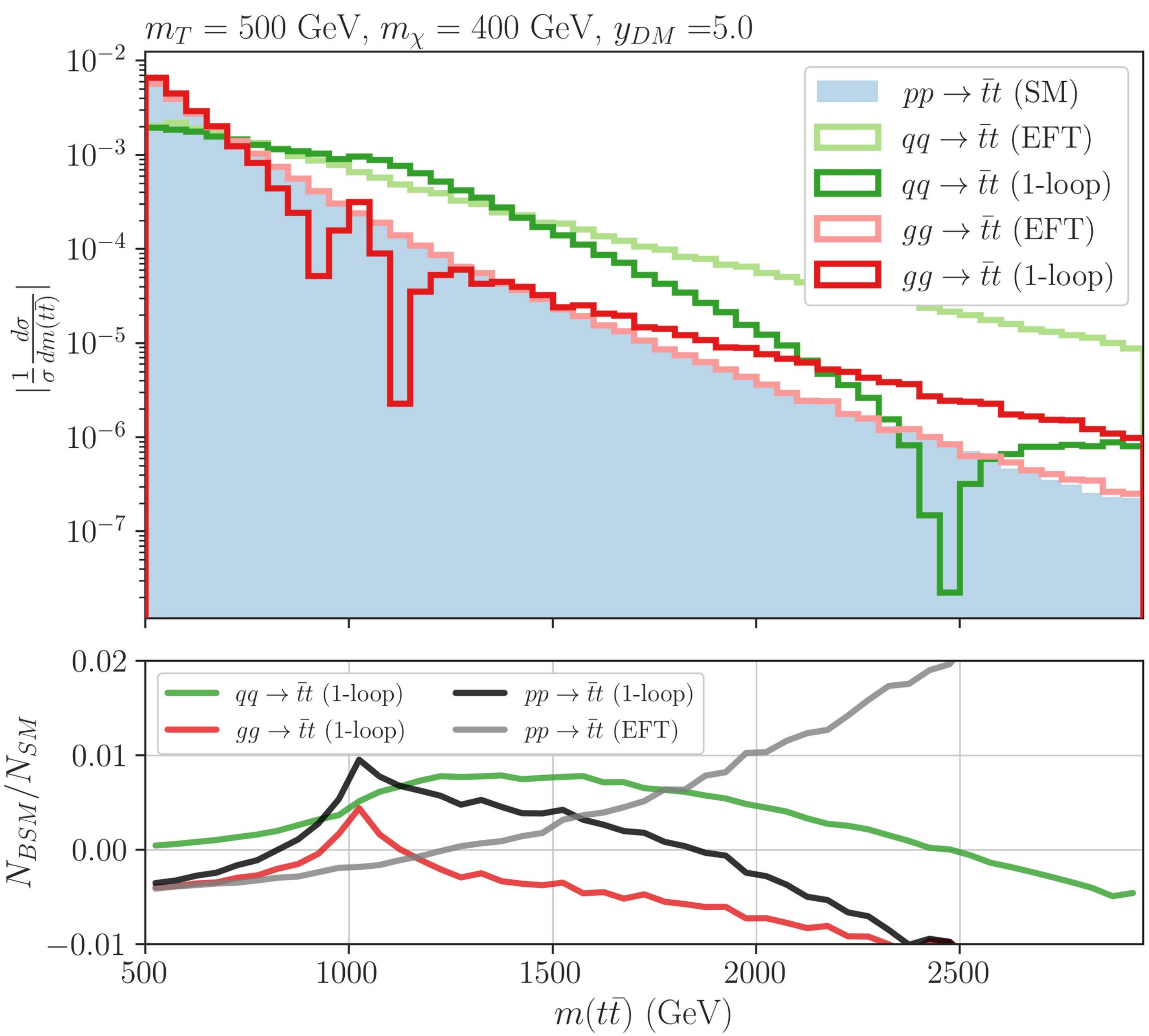

- EFT:
  - grows with energy
  - always positive
- 1-loop Form Factors:
  - "broad bump"
  - negative contributions at large m_{tt}
  - Larger than EFT at low m_{tt}, but lower at high m_{tt}

Indirect Searches

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  - ATLAS-TOPQ-2019-23 (semi-leptonic)

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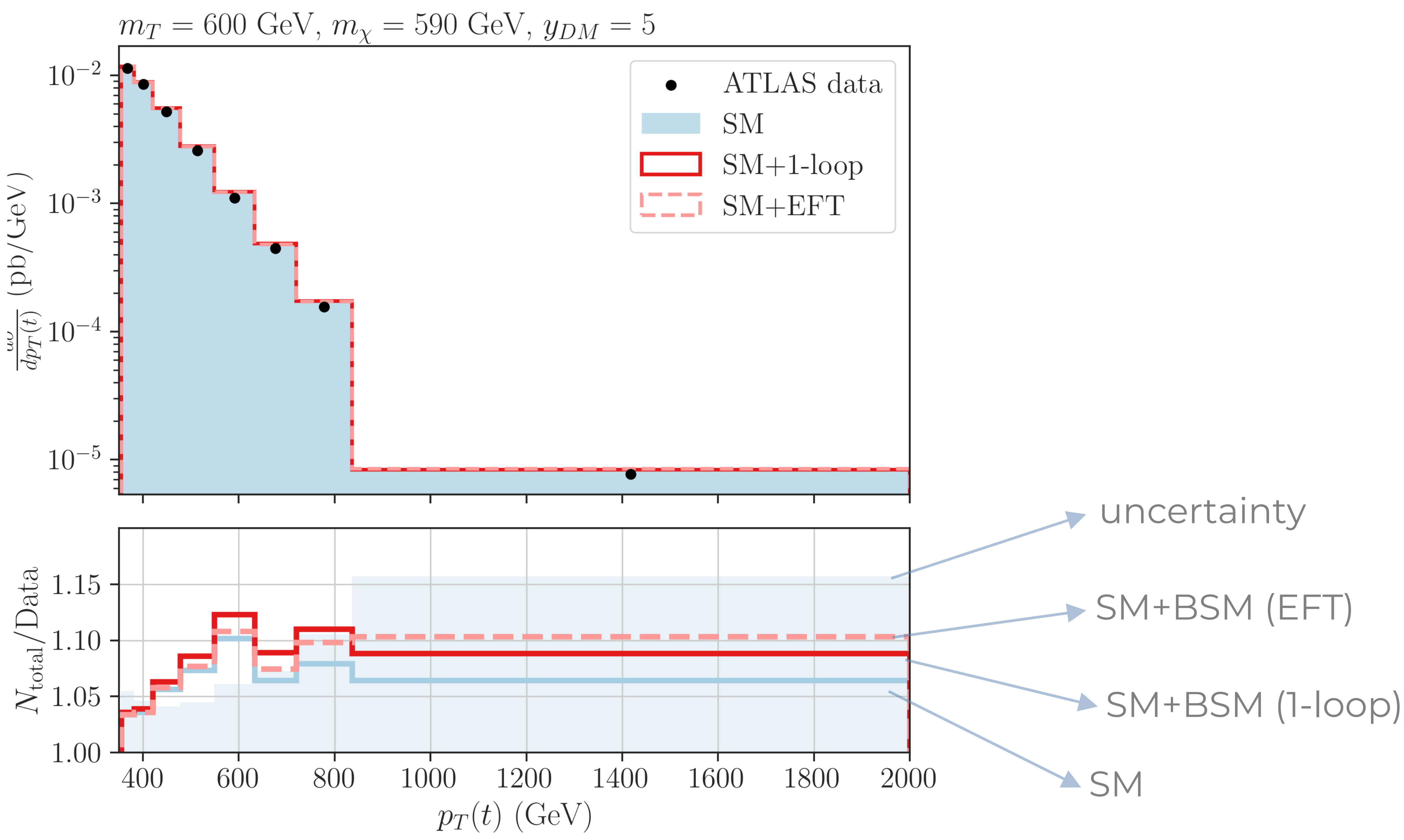

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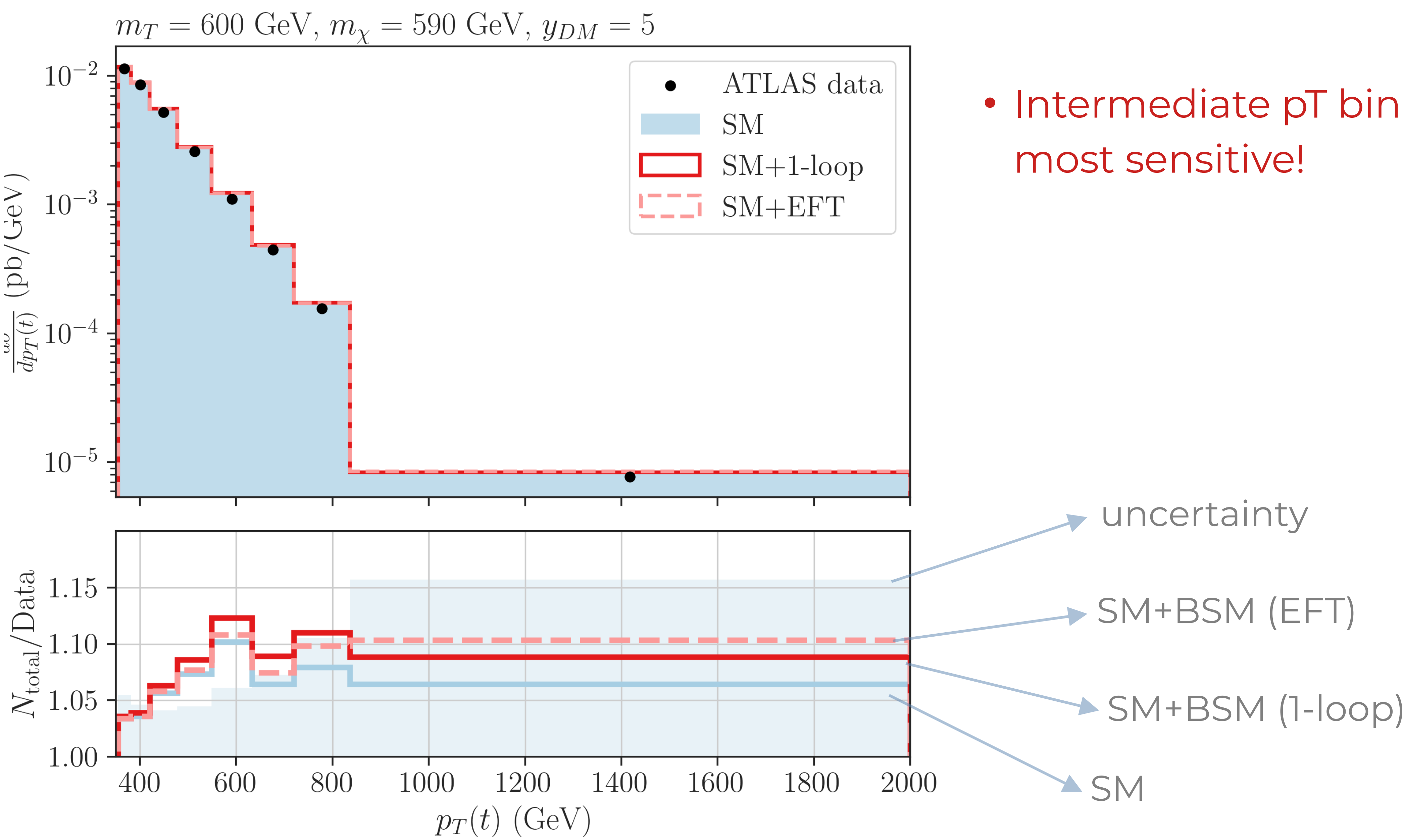

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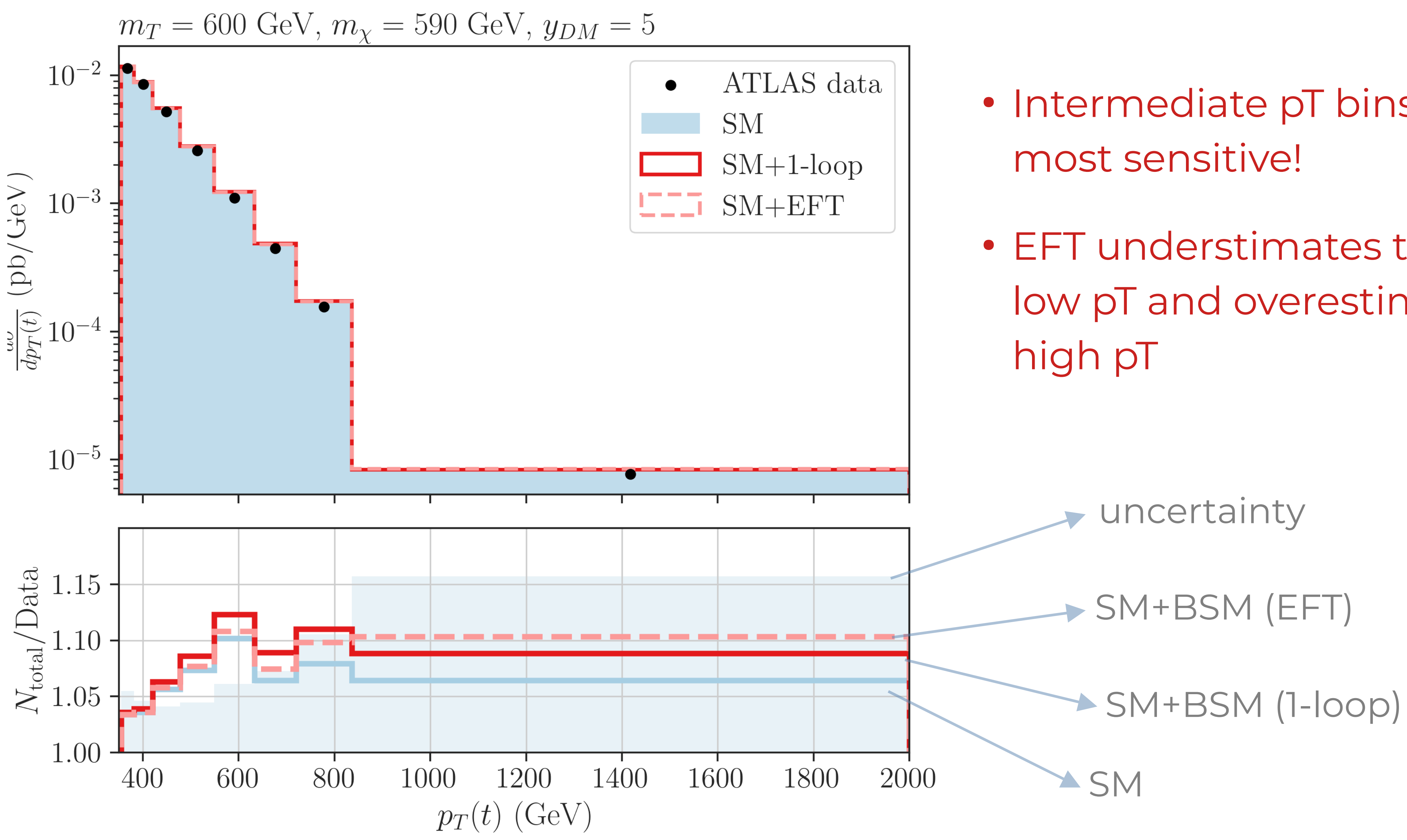

- Intermediate pT bins are the most sensitive!
- EFT understimates the signal at low pT and overestimates at high pT

Direct + Indirect

- Combined results:

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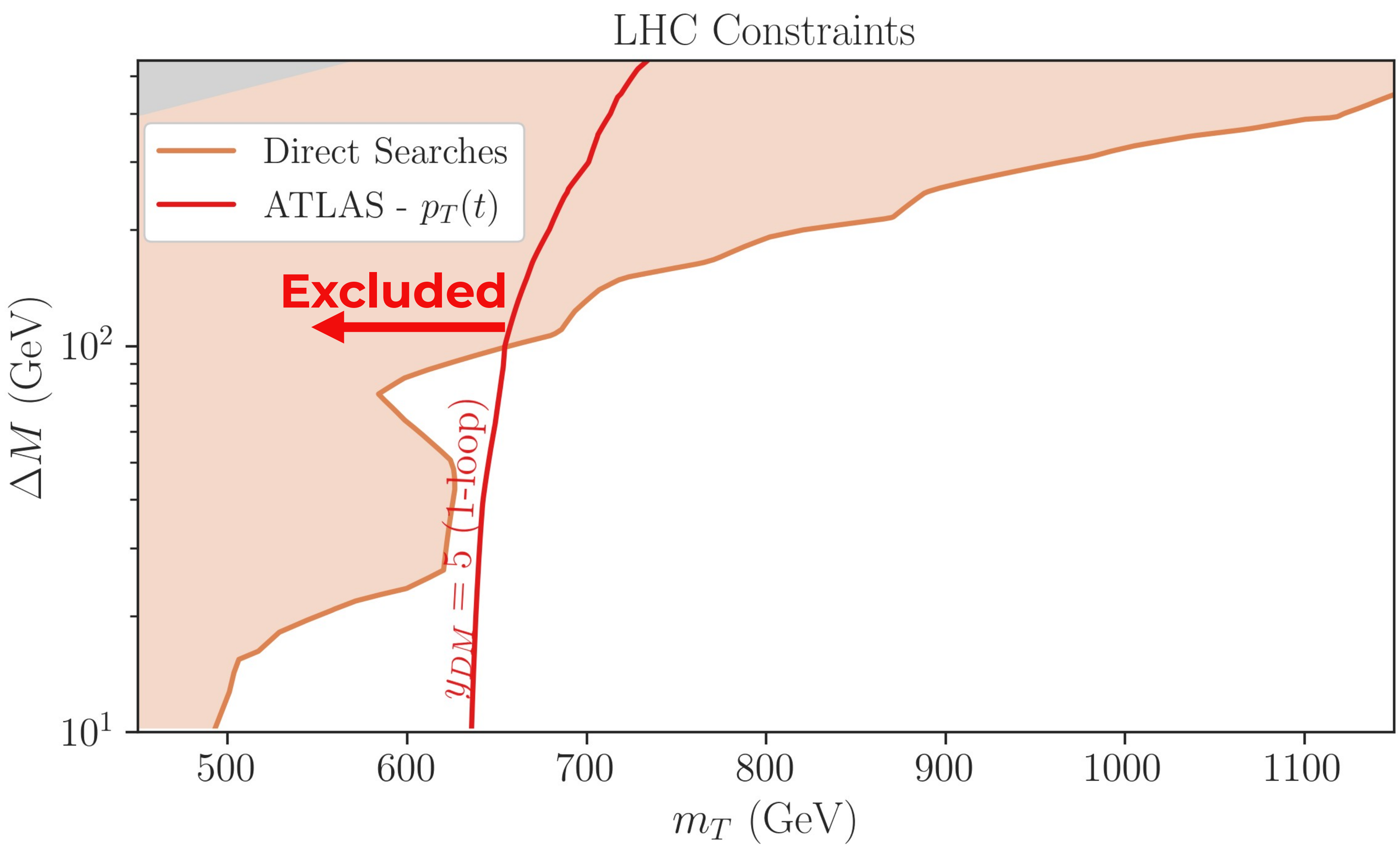

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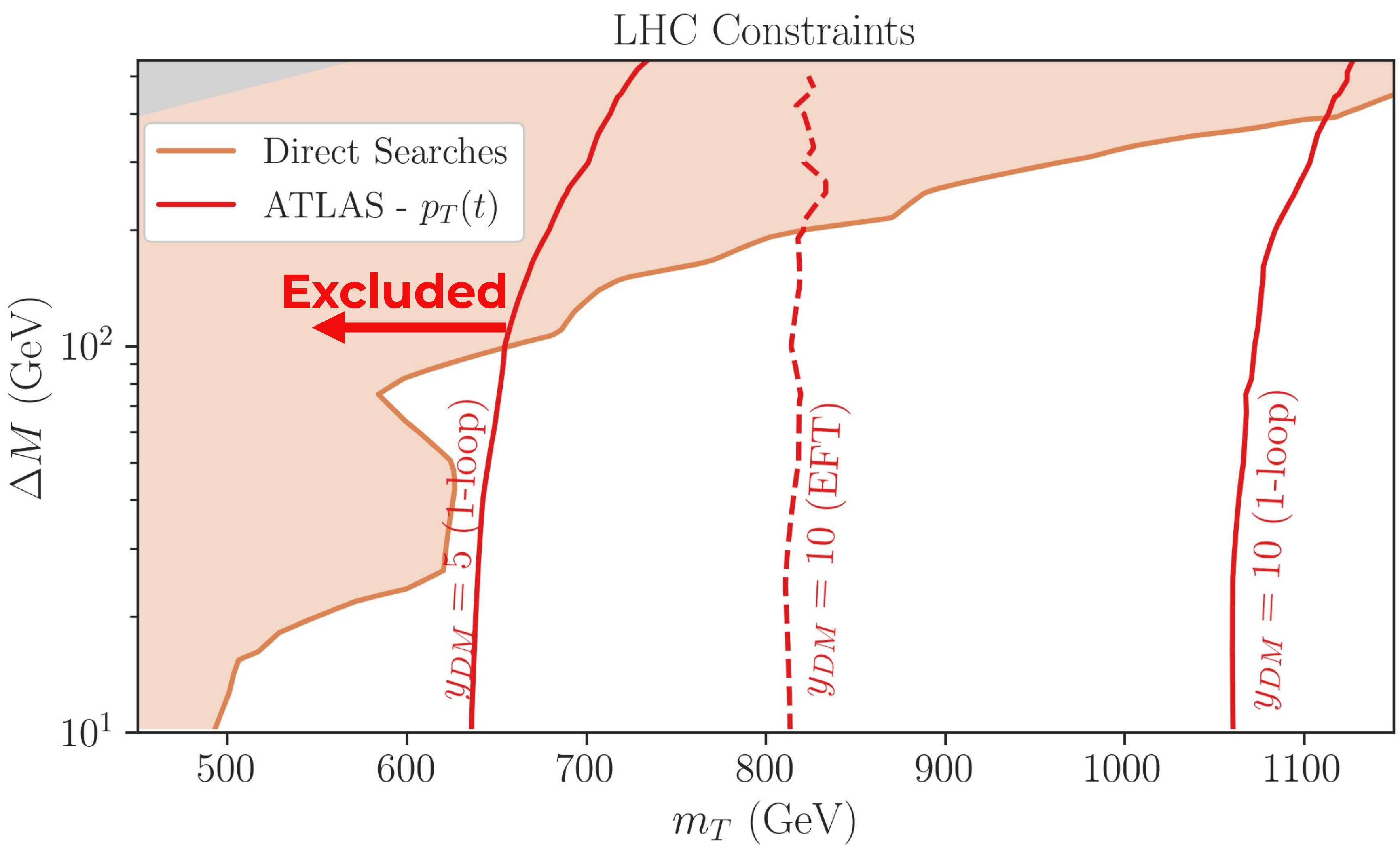

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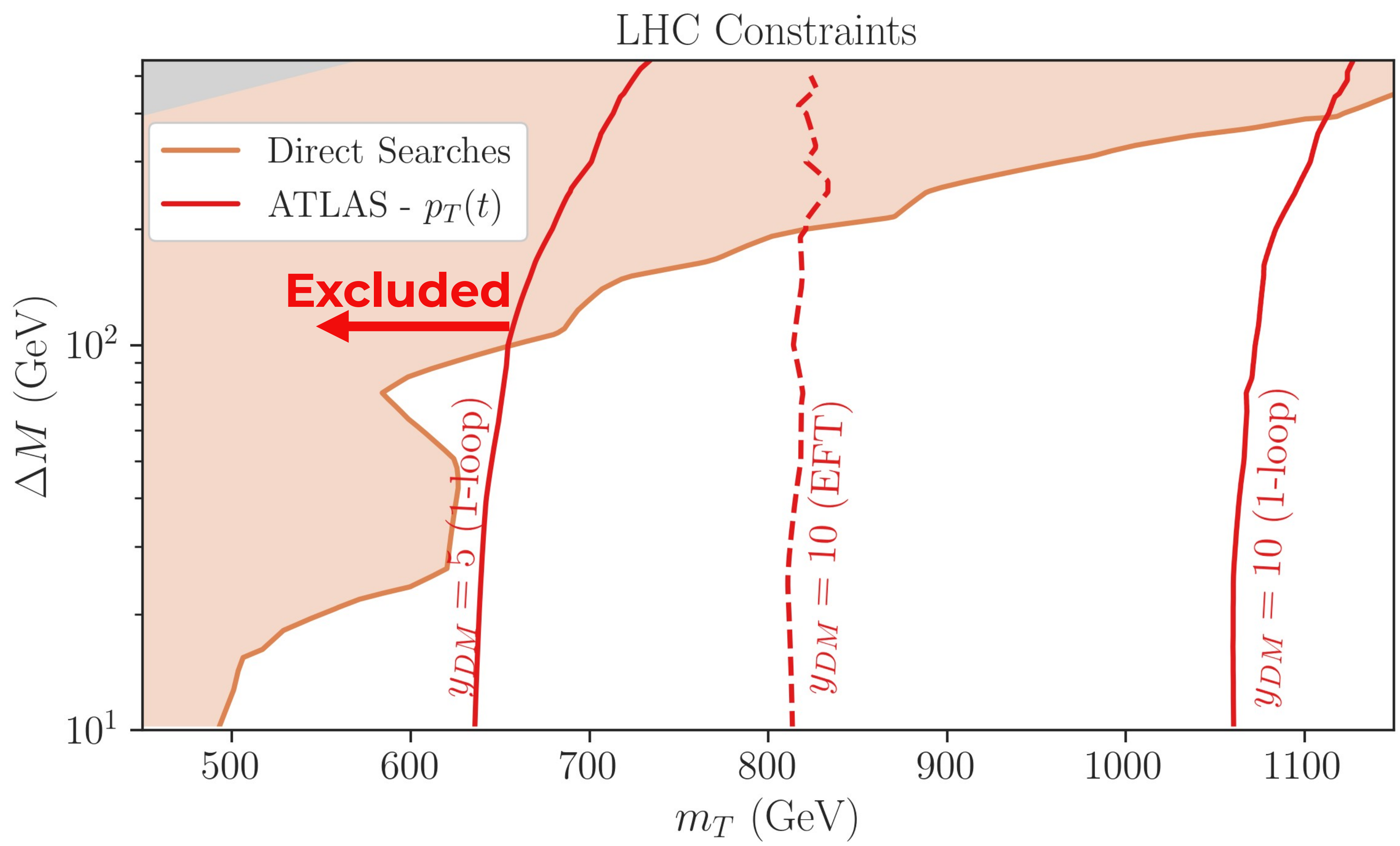

- EFT approximation understimates the signal!
- Constraints on the compressed region are competitive with direct searches!

Conclusions

- Lessons learned:
  - SMEFT is not always a good parametrization of NP!
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    - Broad bump
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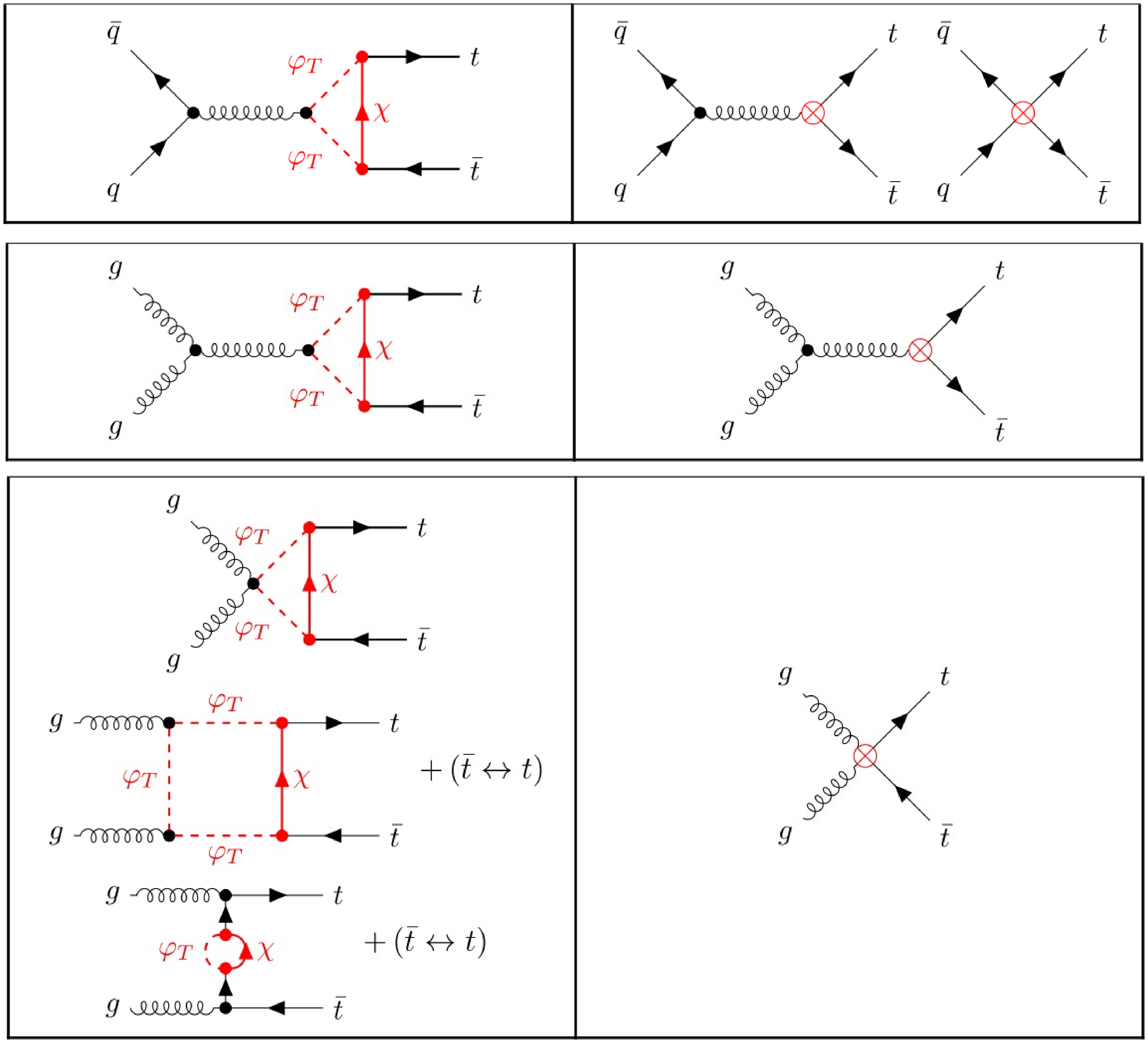
Thanks!

Backup

Diagrams - Matching



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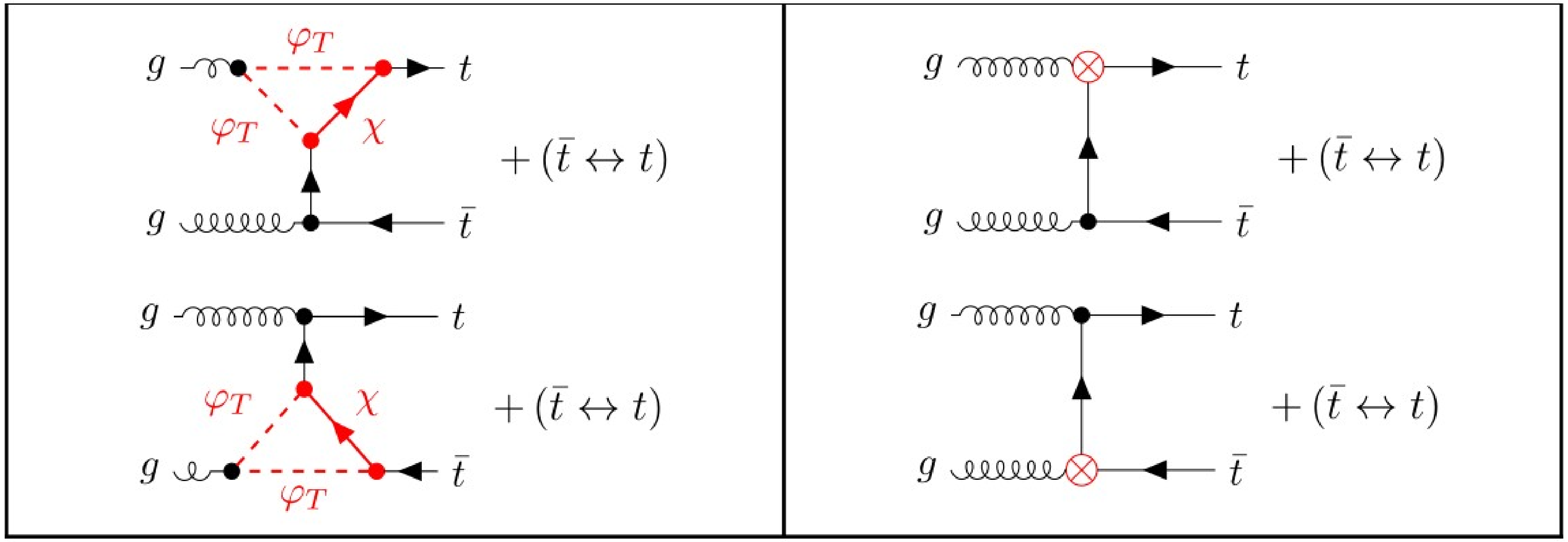
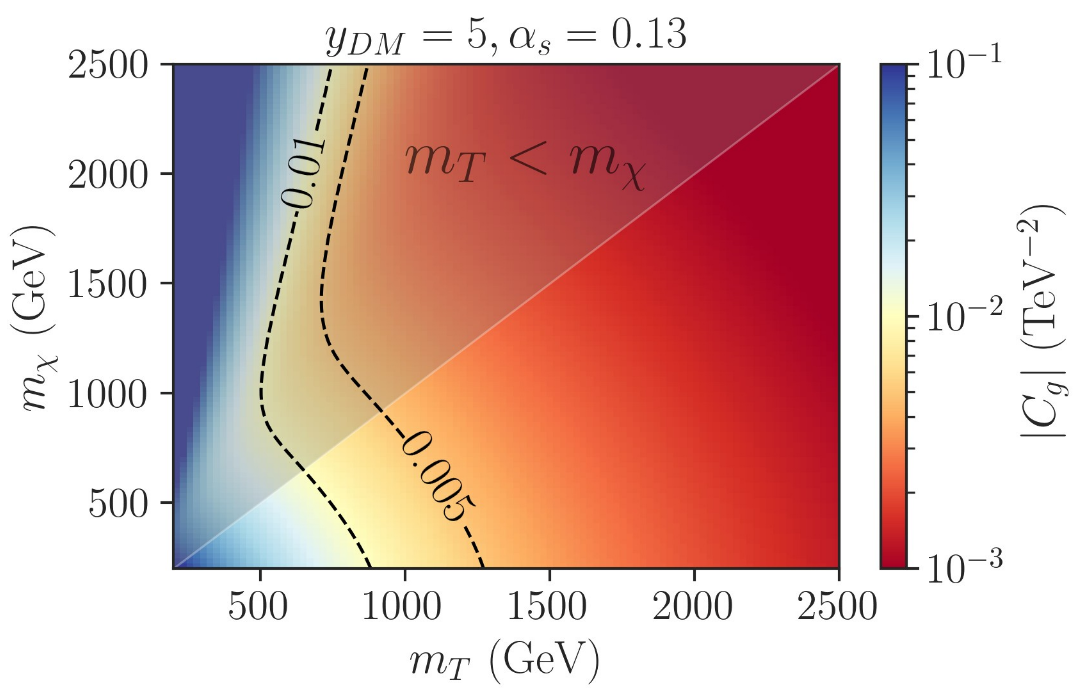
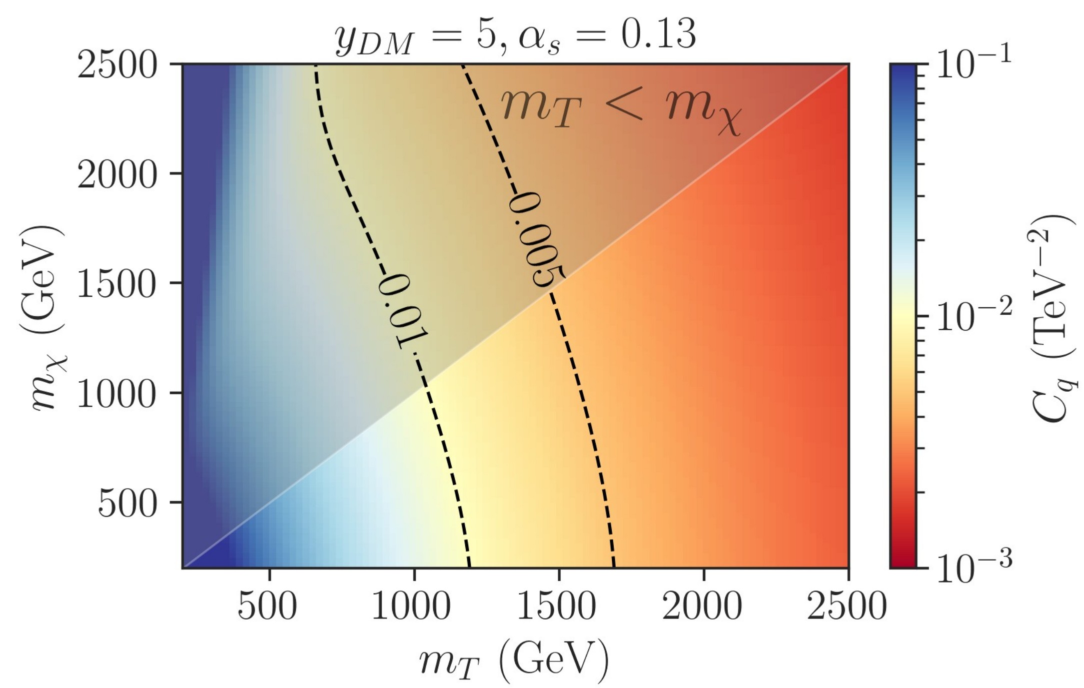


EFT Coefficients

- Toy Model:





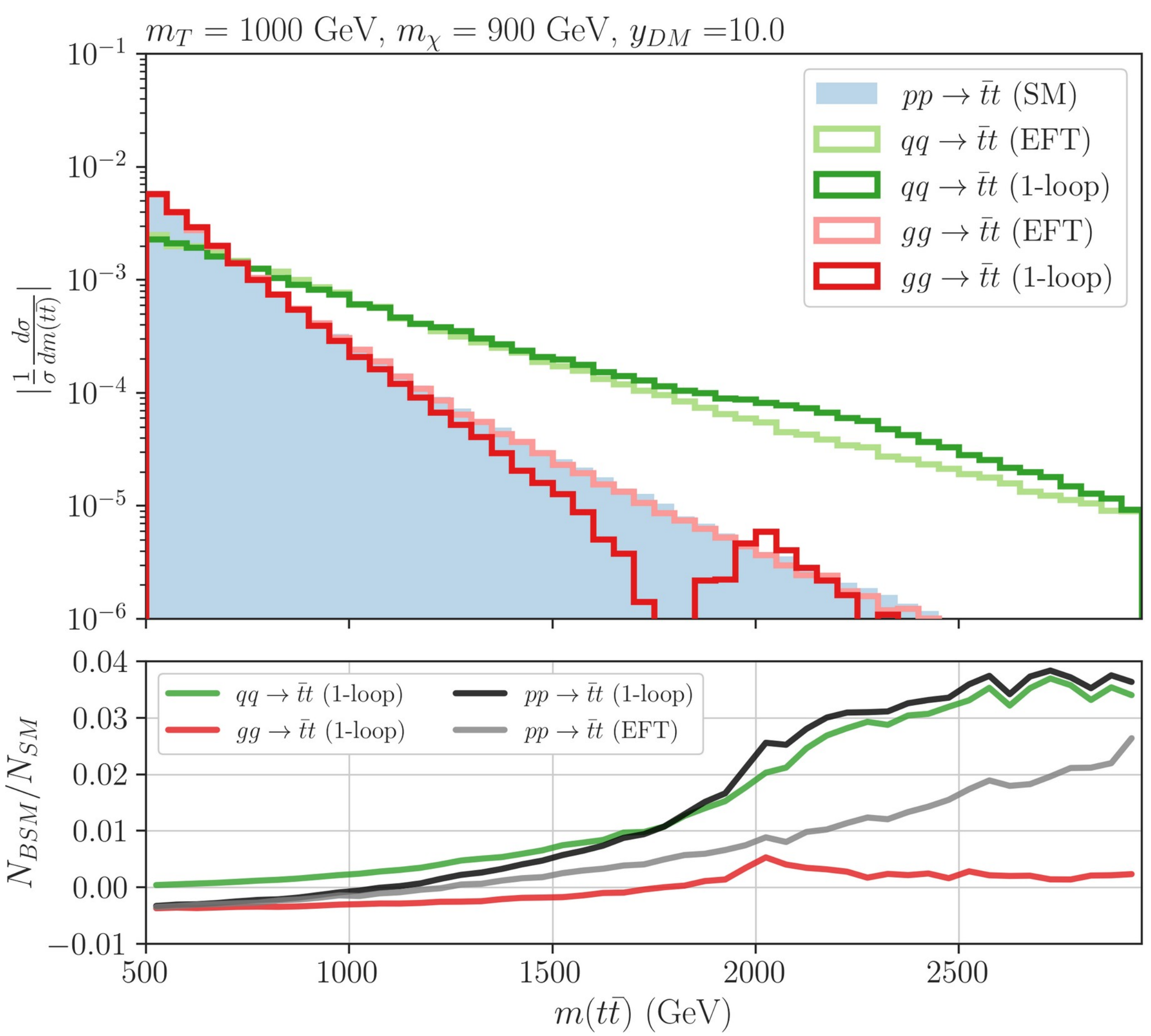
- Constraints:

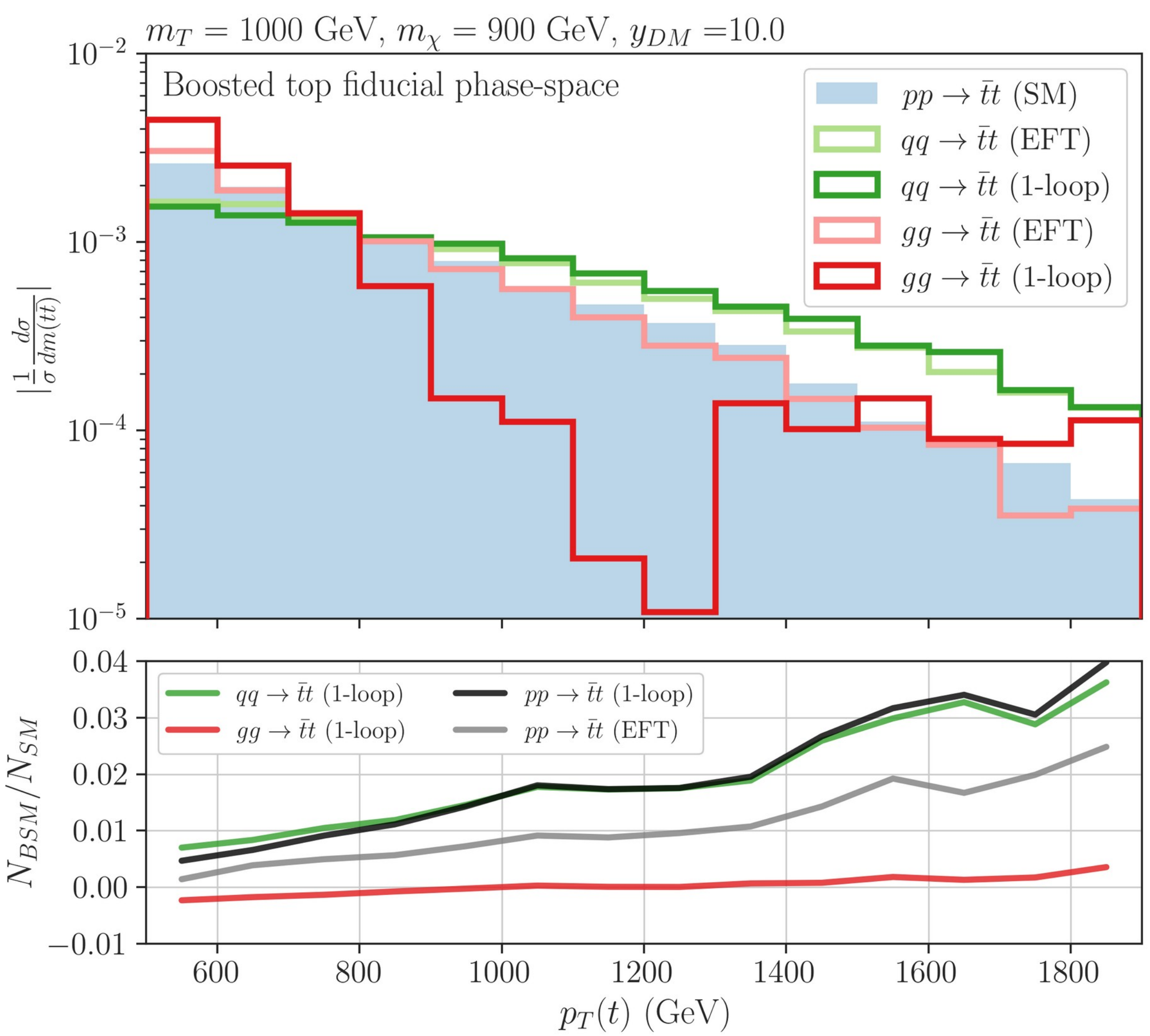
Operator	Individual fit (TeV^{-2})	Marginalised fit (TeV^{-2})
$\mathcal{O}_{tG}$	$-0.01^{+0.086}_{-0.1}$	$0.36^{+0.12}_{-0.6}$
$\mathcal{O}^{(8)}_{tq}$	$-0.4^{+0.06}_{-0.85}$	$5.^{+2.2}_{-13}$
$\mathcal{O}^{(8)}_{tu}$	$-0.45^{+0.23}_{-1.1}$	$4.0\ ^{+19}_{-11}$
$\mathcal{O}^{(8)}_{td}$	$-1.0^{+0.38}_{-2.5}$	-0.42^{+11}_{-12}

J. Ellis, M. Madigan, K. Mimasu, V. Sanz and T. You (2012.02779)

More Results

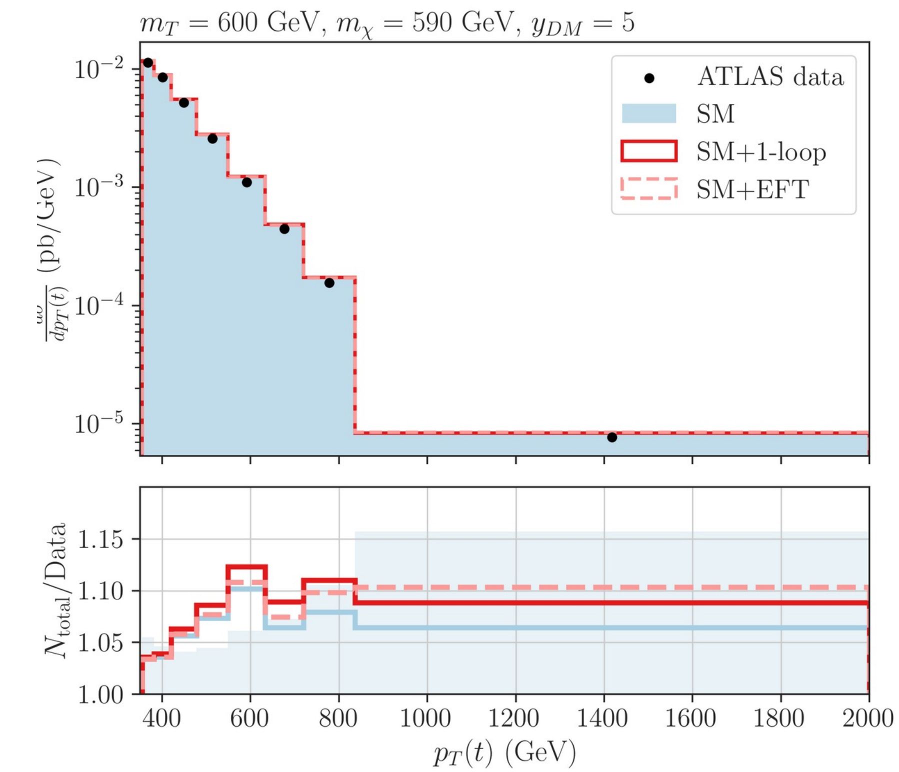
- Distributions for heavy masses:

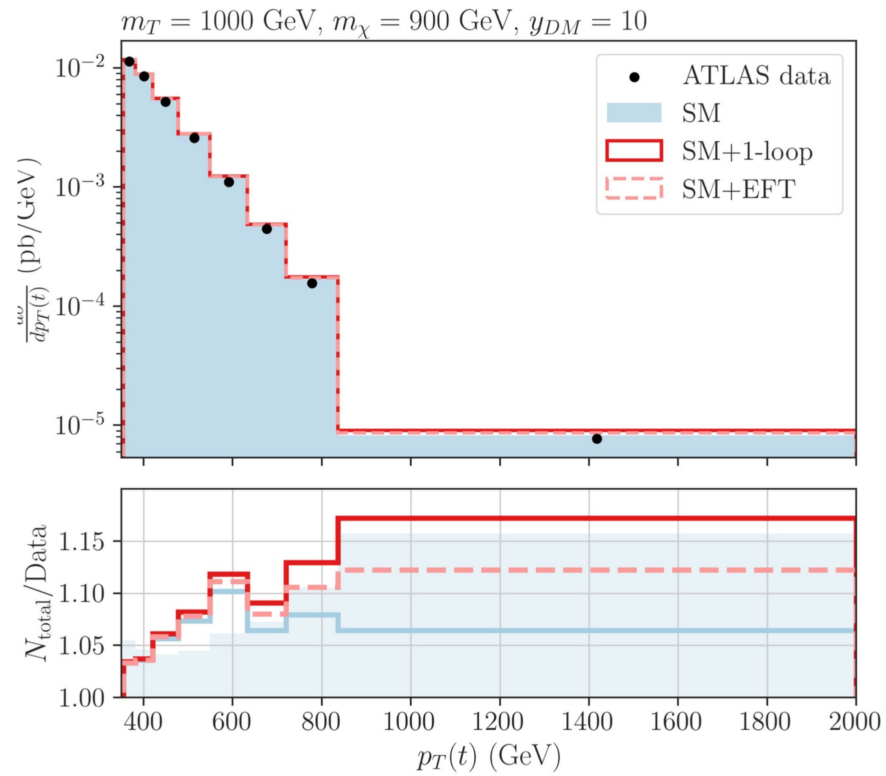




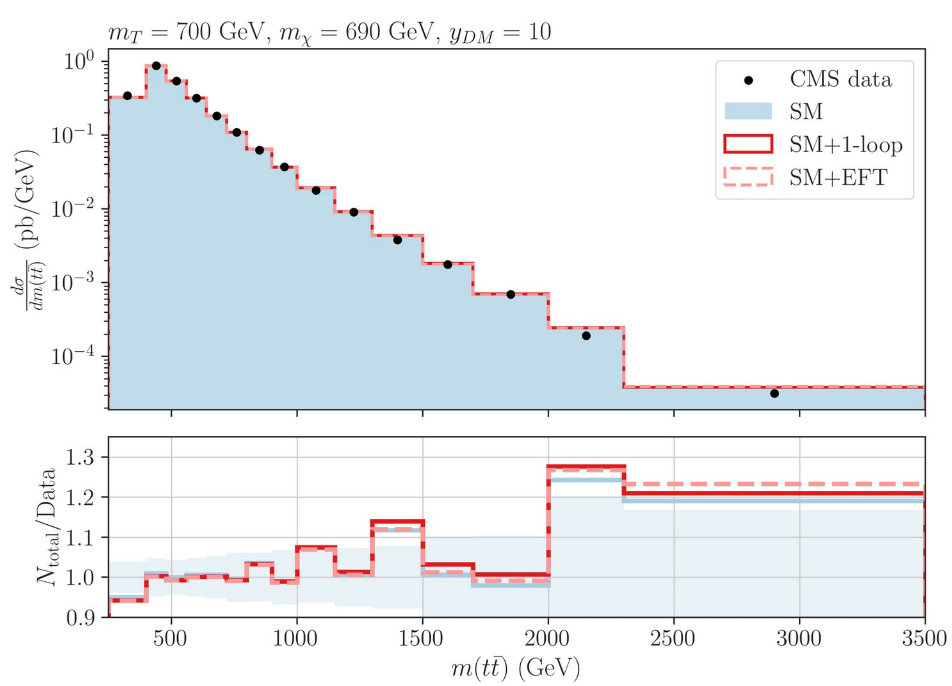
More Results

- ATLAS-TOPQ-2019-23





- CMS-TOP-20-001

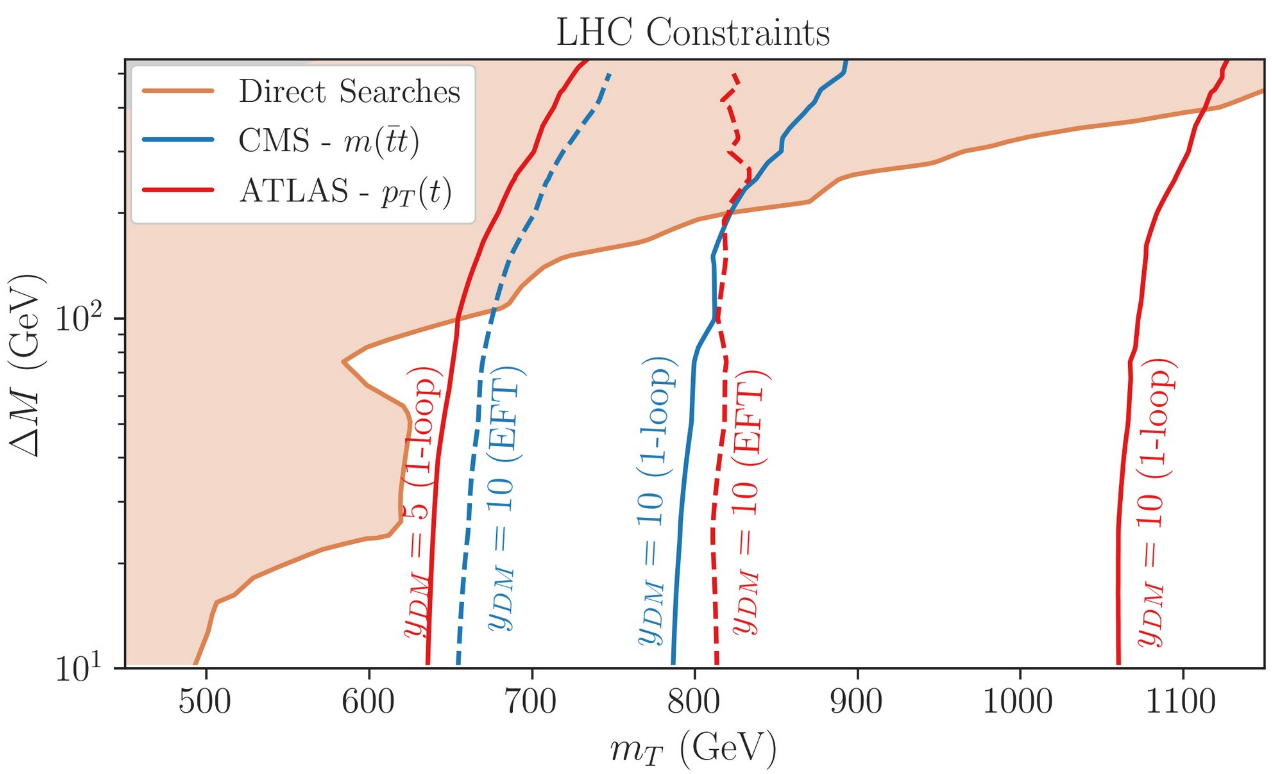


Bin-dependent k-factor:

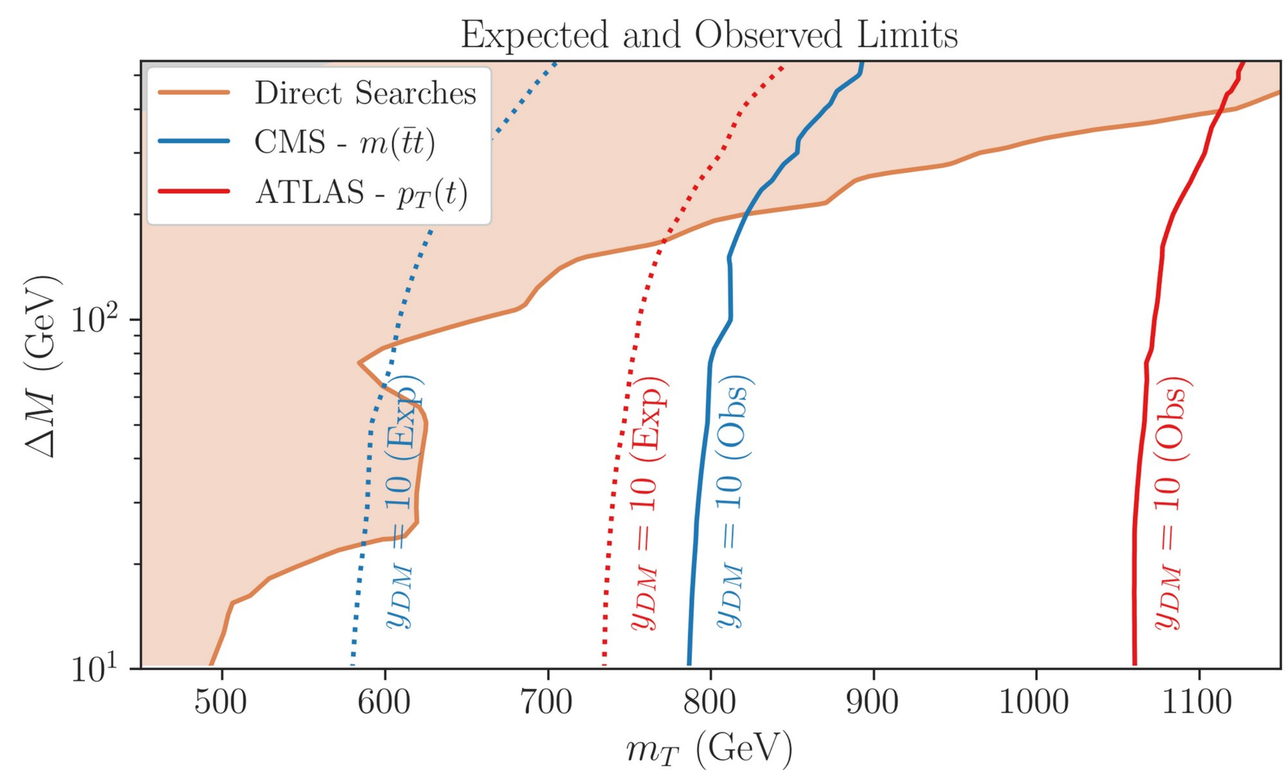
$$k_i = \frac{N^i_{\rm SM}(\rm NNLO)}{N^i_{\rm SM}(\rm LO)} \Rightarrow N^i_{\rm BSM}(\rm NNLO) \simeq k_i N^i_{\rm BSM}(\rm LO)$$

More Results

Observed Limits:

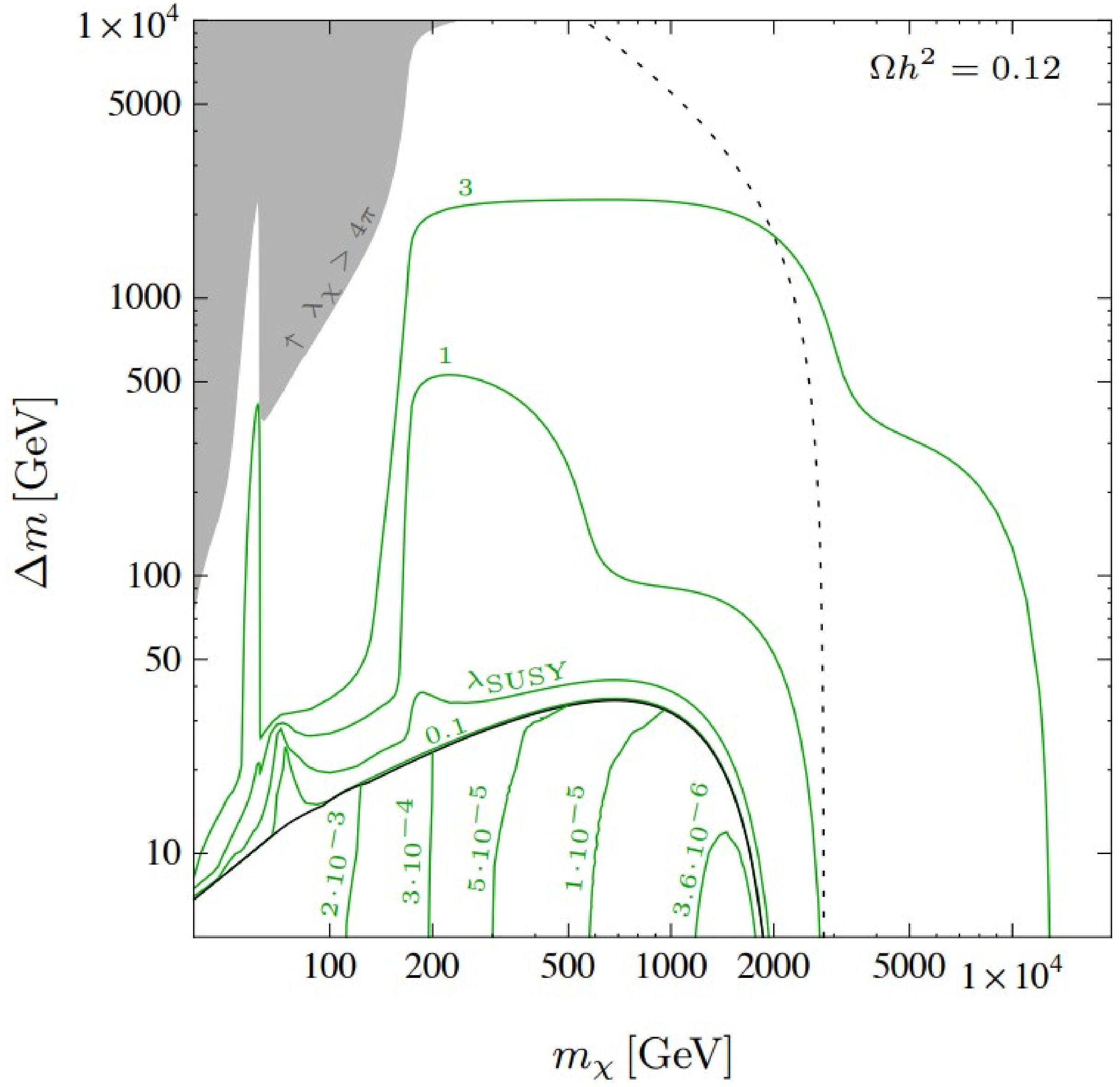


Expected Limits:



Relic Density

- Parameter space:



M. Garny, J. Heisig, M. Hufnagel and B. Lulf (1802.00814)