

# Constraining a top-philic dark matter model featuring contact terms

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Based on recent work

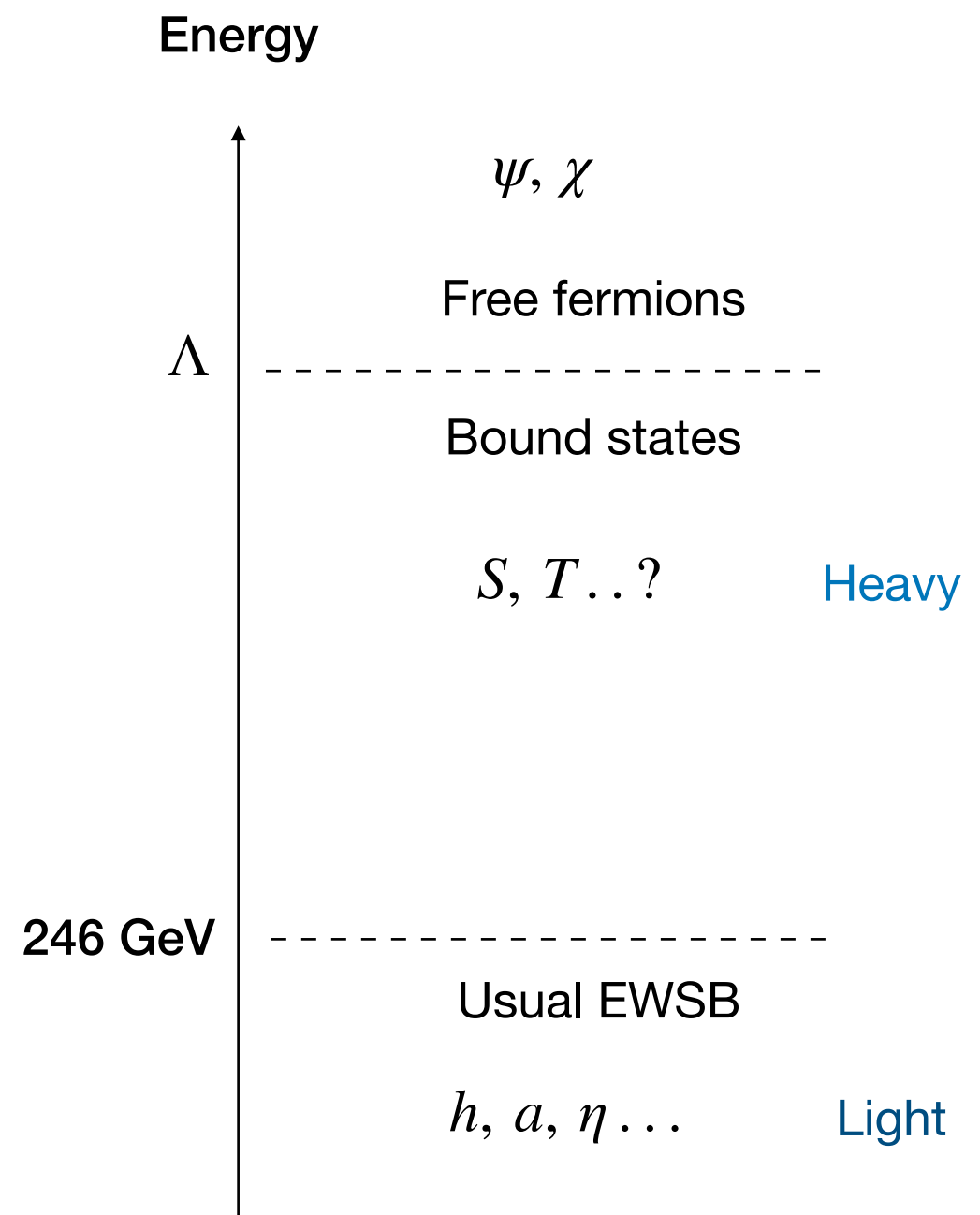
in collaboration with Alan Cornell, Aldo Deandrea, Benjamin Fuks, Thomas Flacke

SUSY21

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# Dark matter and composite Higgs models

- Composite Higgs models: new strong sector confining at low energies
- Higgs is a **bound state of fermions**
- Will be accompanied by bound states
- Dark matter appears often in composite Higgs models as a pNGB
- Instead, imagine it as a **heavy bound state**



# In this talk

*“Contact interactions and top-philic scalar dark matter”*

Journal of High Energy Physics (2021), no. 7, 026, [arXiv:2104.12795](https://arxiv.org/abs/2104.12795)

## Relic density: theory and fit

- DM may emerge from a composite Higgs model (usually light)
- Extension of previous heavy top-philic DM model + **contact term**
- Semi-analytic fit of the relic density

## Visibility at experiment

- Astrophysical constraints: direct detection, indirect detection
- Collider constraints

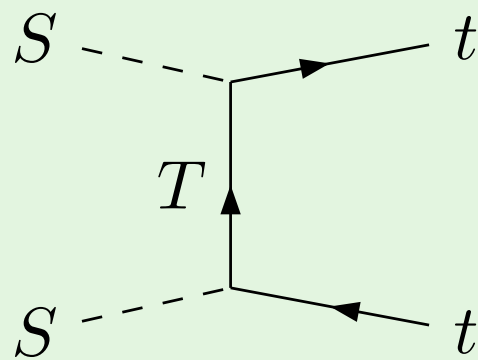
A. A theoretical motivation

B. Detection

- Astrophysical
- Collider

# Our setup

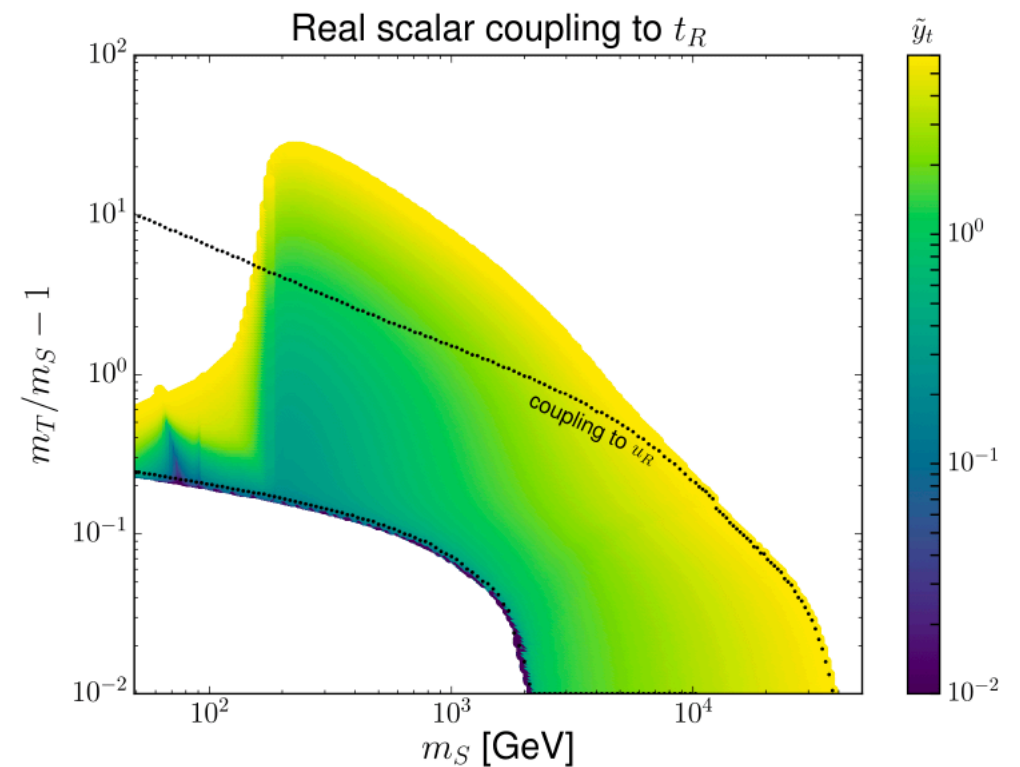
- $SS \rightarrow t\bar{t}$  annihilation dominates
- Heavy fermionic mediator,  $m_S < m_T$



- Could  $S, T$  emerge as heavy resonances in a CH model?
- $200 \text{ GeV} \lesssim m_S \lesssim 3 \text{ TeV}$

Extension of 1804.05068 (Colucci, Fuks, Giacchino, Lopez Honorez, Tytgat, Vandecasteele)

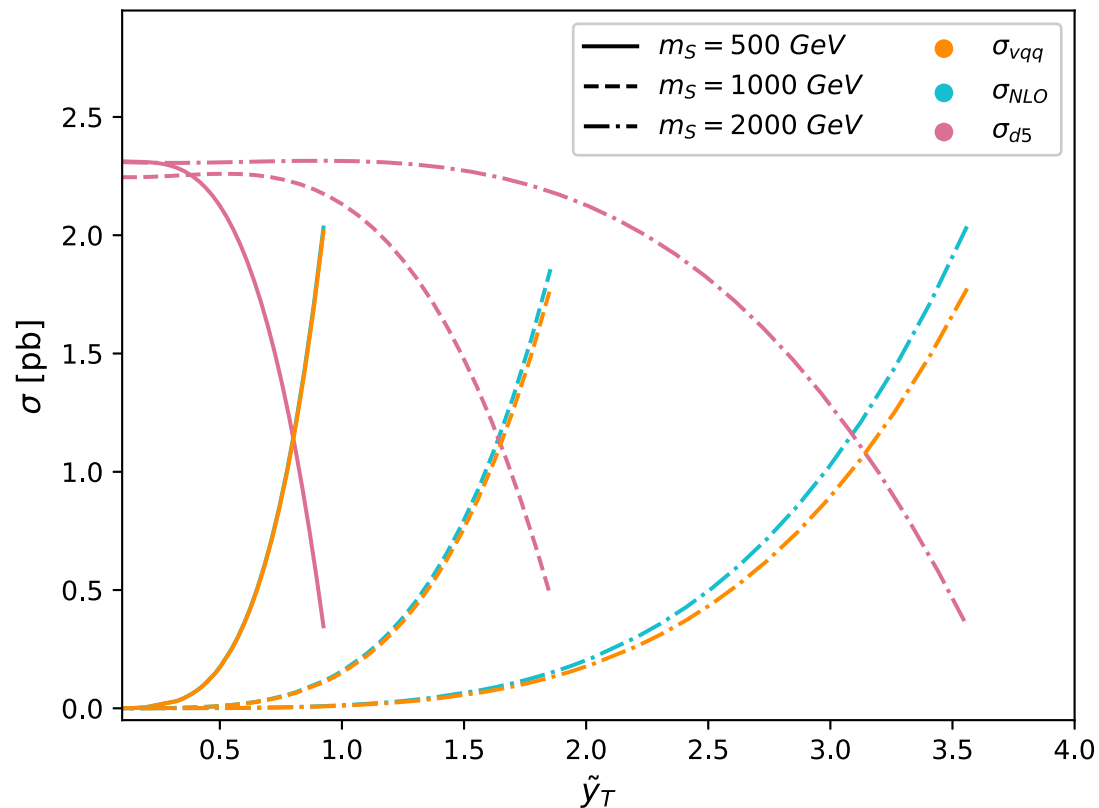
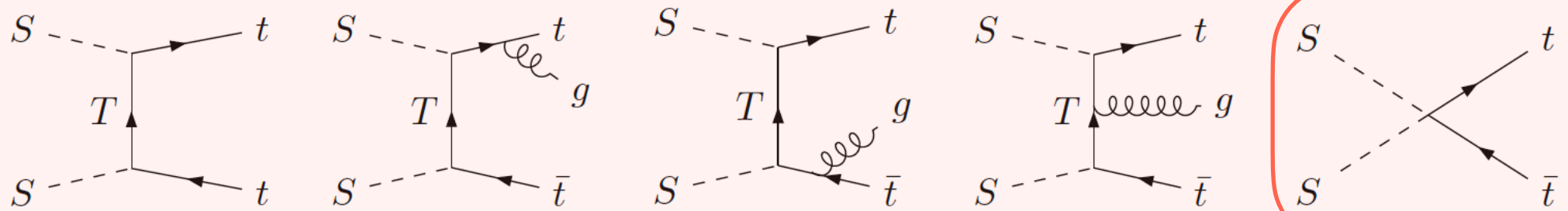
- Featuring  $S, T$  both heavy, NLO is NB



$$\sigma_{v_{t\bar{t}}}|_{\text{NLO}} \approx \begin{cases} \sigma_{v_{t\bar{t}}} & m_S < 300 \text{ GeV}, \\ \sigma_{v_{t\bar{t}g}}|_{m_t=0} + \sigma_{v_{t\bar{t}}} & m_S > 300 \text{ GeV}. \end{cases}$$

# Our setup

$$\mathcal{L} = i\bar{T}\not{D}T - m_T\bar{T}T + \frac{1}{2}\partial_\mu S\partial^\mu S - \frac{1}{2}m_S^2 S^2 + [\tilde{y}_t S\bar{T}P_R t + h.c.] + \frac{1}{2}\lambda S^2\phi^\dagger\phi + \frac{C}{\Lambda}SSt\bar{t}$$



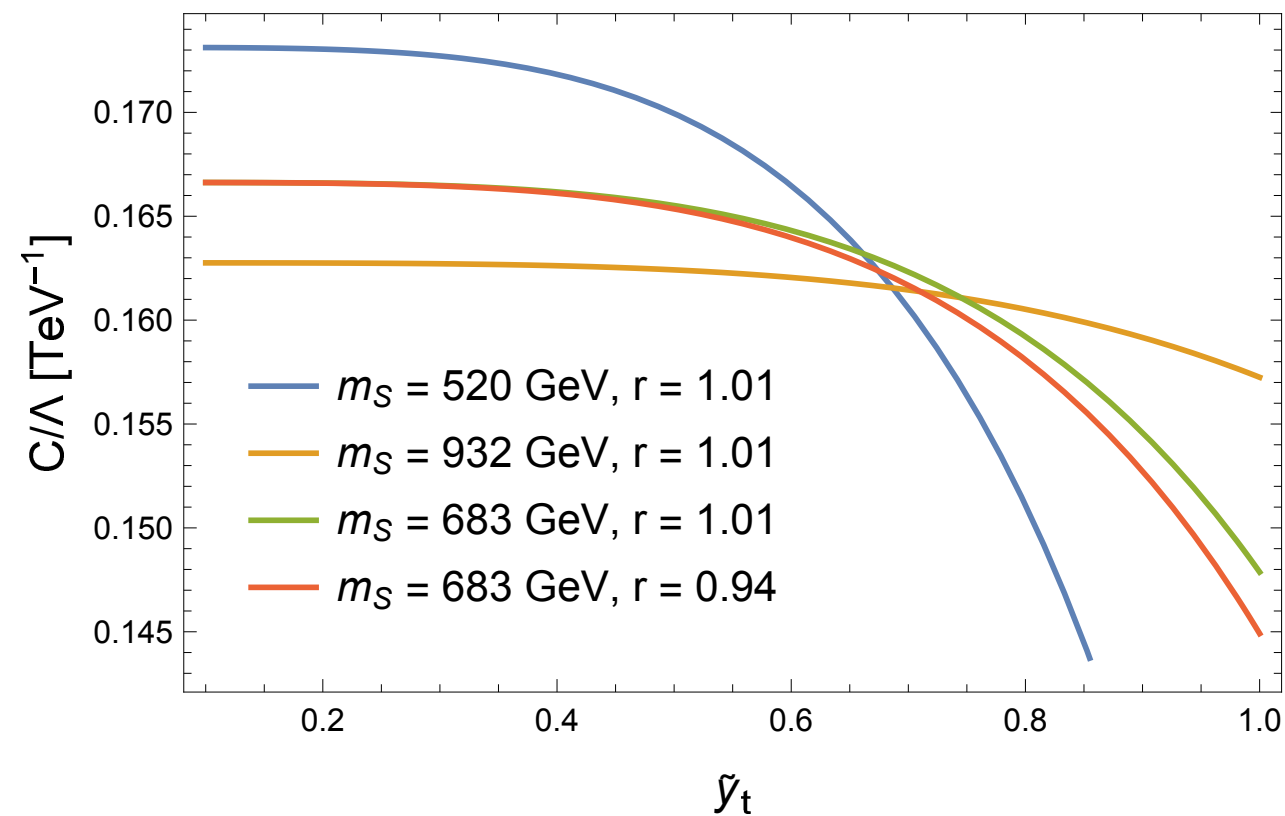
- Addition of generic dim-5 operator with  $\mathcal{O}(1)$  Wilson coefficient
- Contact term competes with Yukawa term in annihilation
- Modification of the relic density

# Parameter interplay

$$\langle\sigma v\rangle = \langle\sigma v\rangle_{NLO} + \langle\sigma v\rangle_{SStt}$$

$$\frac{C}{\Lambda} \approx f(m_S, m_T, \tilde{y}_t) = \frac{1}{\sqrt{A(m_S)}} \sqrt{b' - B(m_S, m_T) \left( \tilde{y}_t - \alpha \left[ \beta \gamma \frac{m_S}{\Lambda} \right]^r \right)^4}$$

See 2104.12795 for more on fit



A. A theoretical motivation

- Relic density fit

B. Detection

- Astrophysical

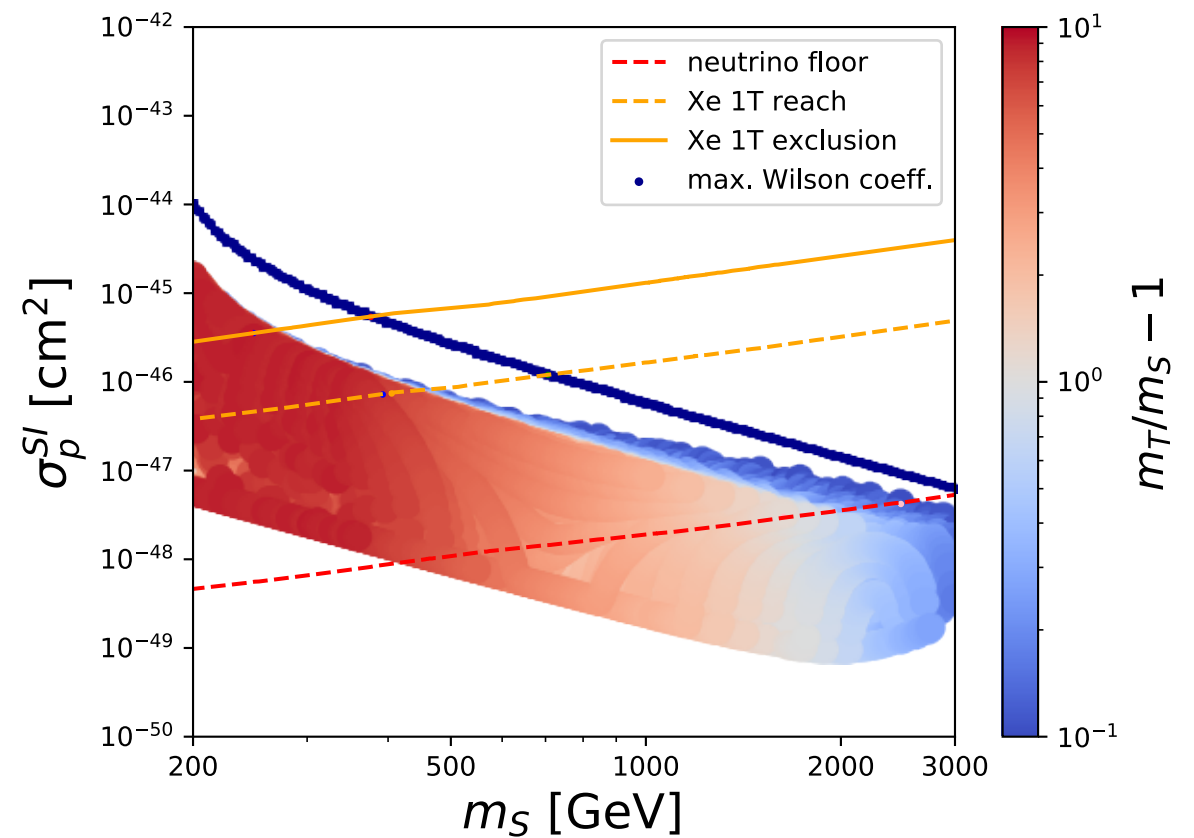
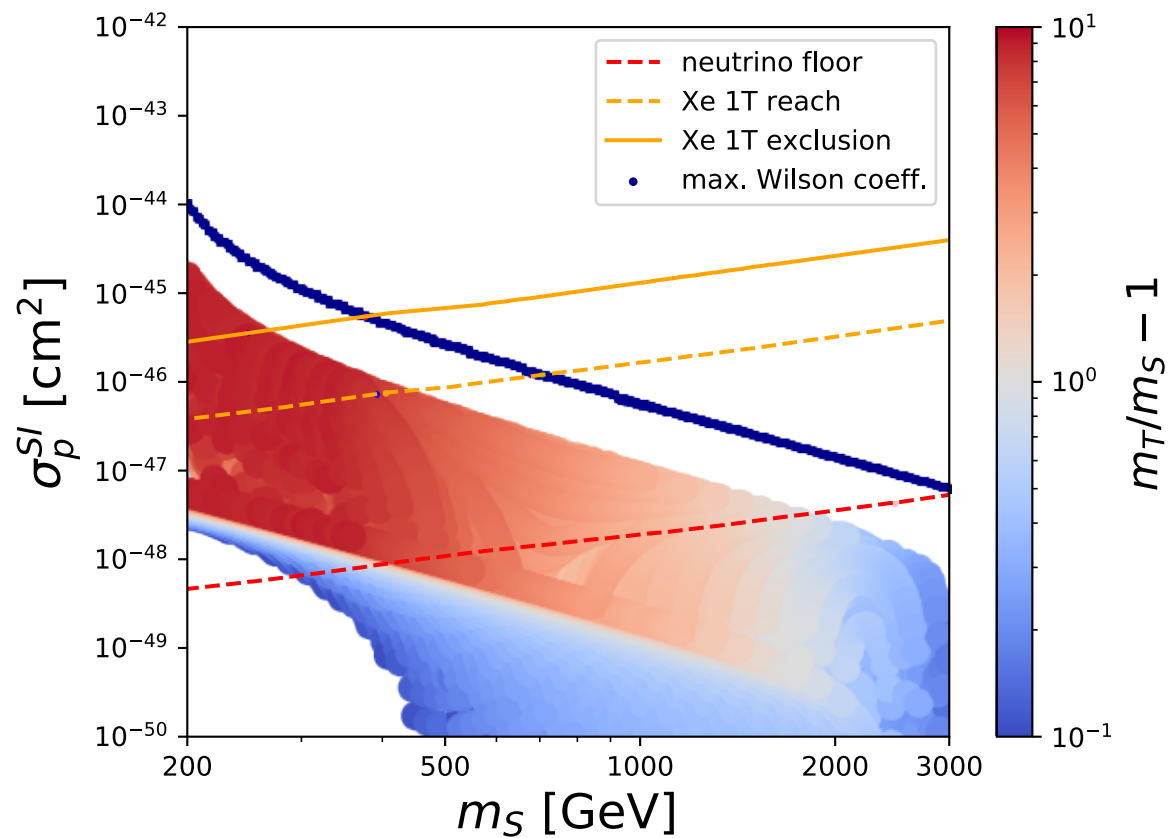
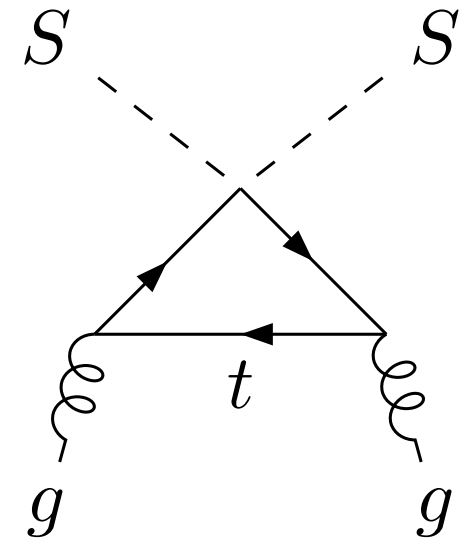
- Collider



# Direct detection

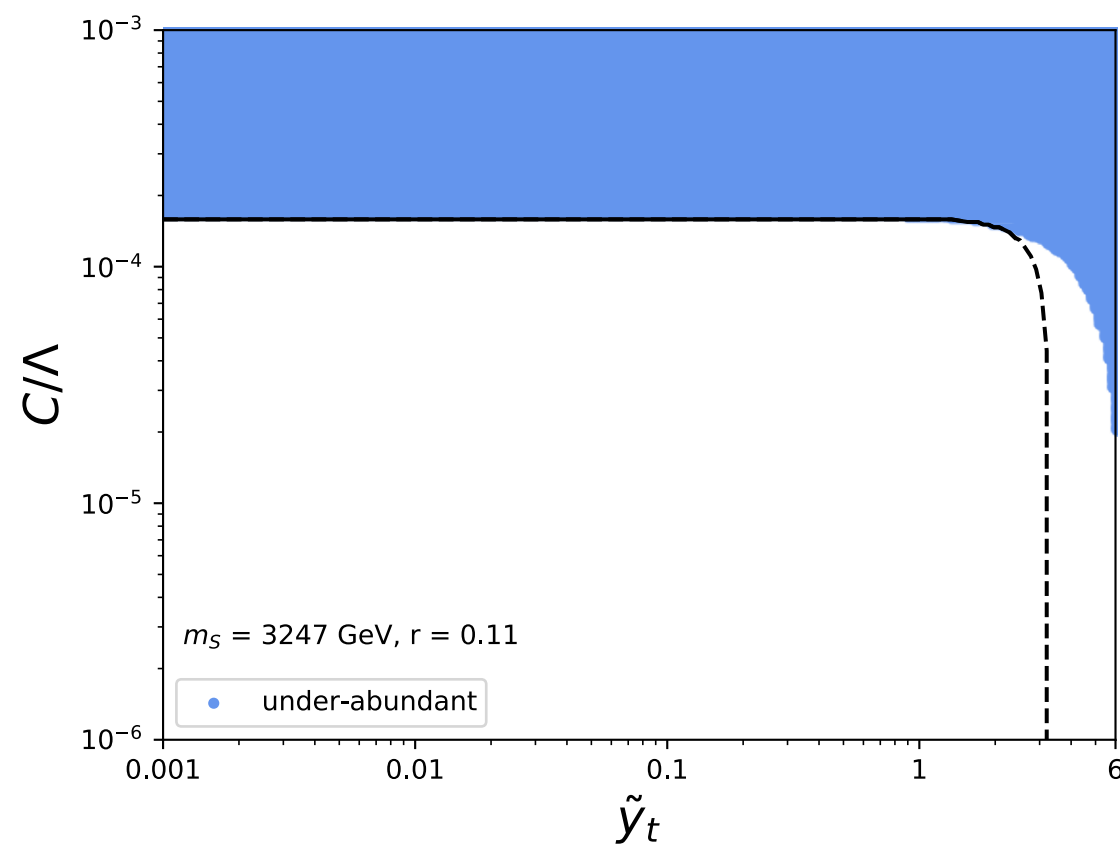
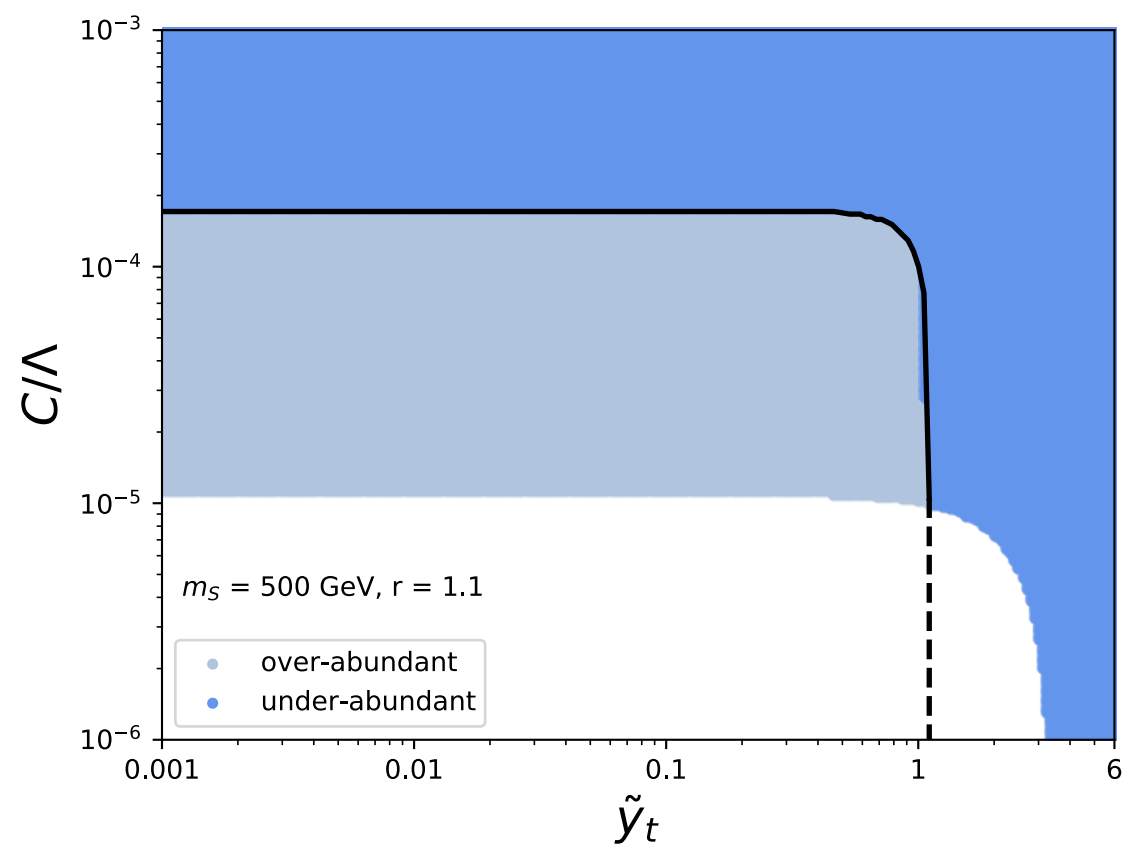
- Scattering off atomic nuclei: DM gluon interactions
- (top quark absent from nucleus!)

$$\mathcal{L} = C_S^g \mathcal{O}_S^g = C_S^g \frac{\alpha_s}{\pi} S^2 G^{\mu\nu} G_{\mu\nu}$$



# Direct detection

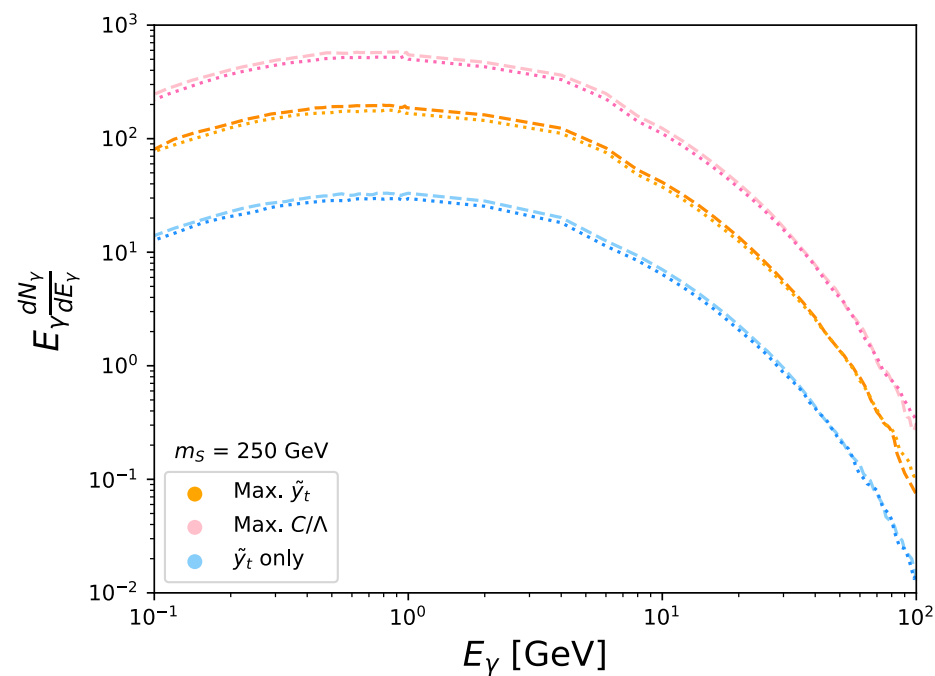
- Identify over/under-abundant areas of parameter space



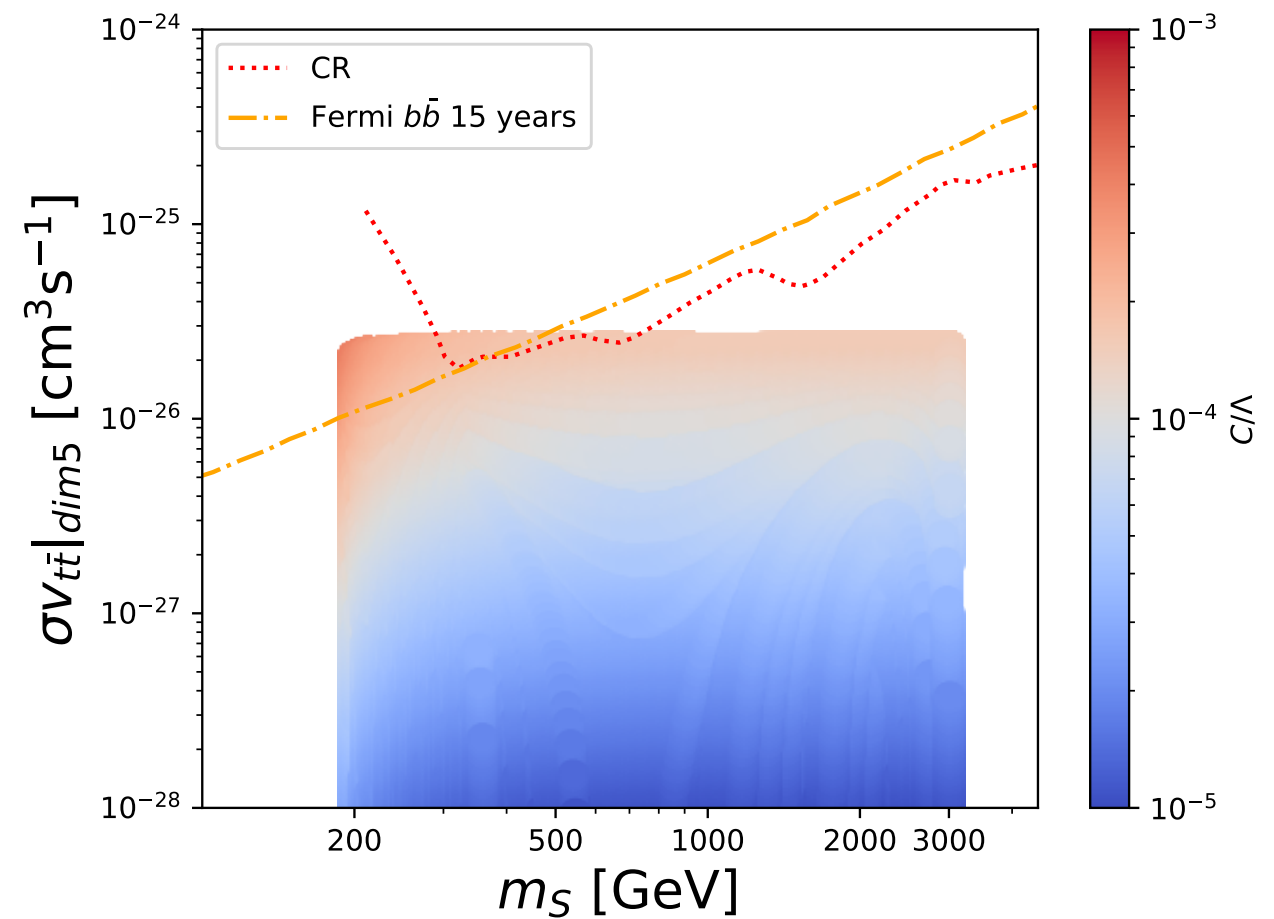
# Indirect detection

In indirect detection of DM, experiments aim to measure the annihilation or decays of the WIMPS via the SM particles produced during these processes

Check behaviour and for rescaling of bounds:



$$\sigma v_{t\bar{t}} = \sigma v_{b\bar{b}} \frac{N_\gamma^{b\bar{b}}}{N_\gamma^{t\bar{t}}}$$



## A. A theoretical motivation

- Relic density fit

## B. Detection

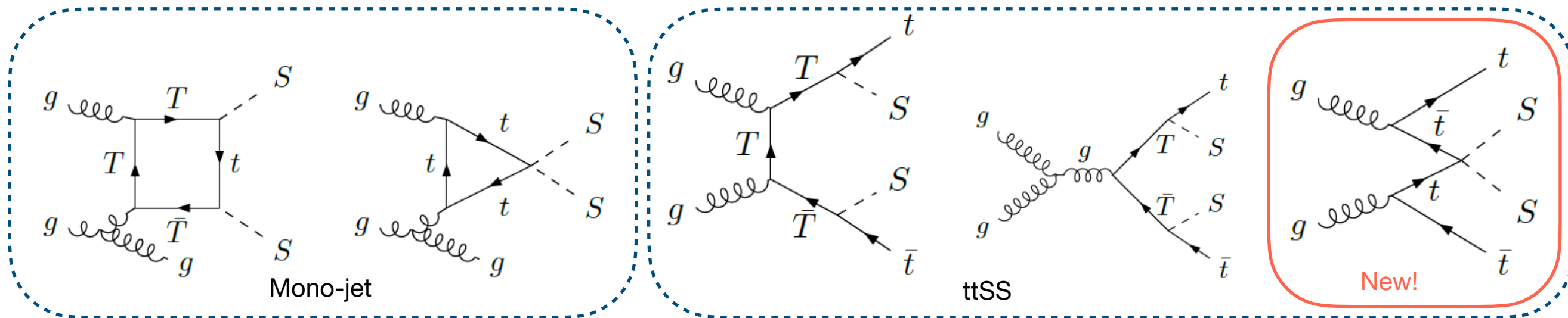
- Astrophysical

- Collider

# Collider: $pp \rightarrow t\bar{t}SS$

Recasting previous ATLAS and CMS analyses using MadAnalysis5

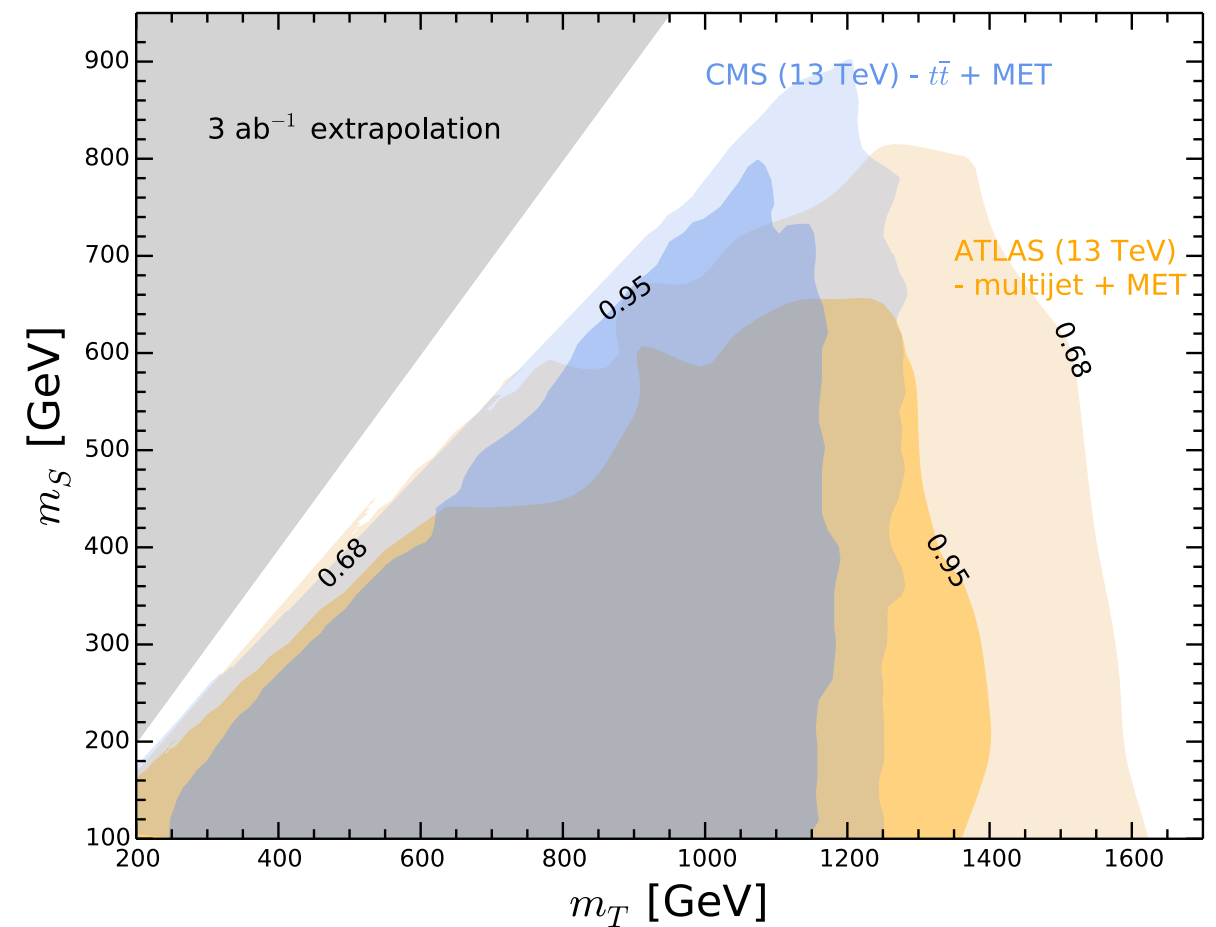
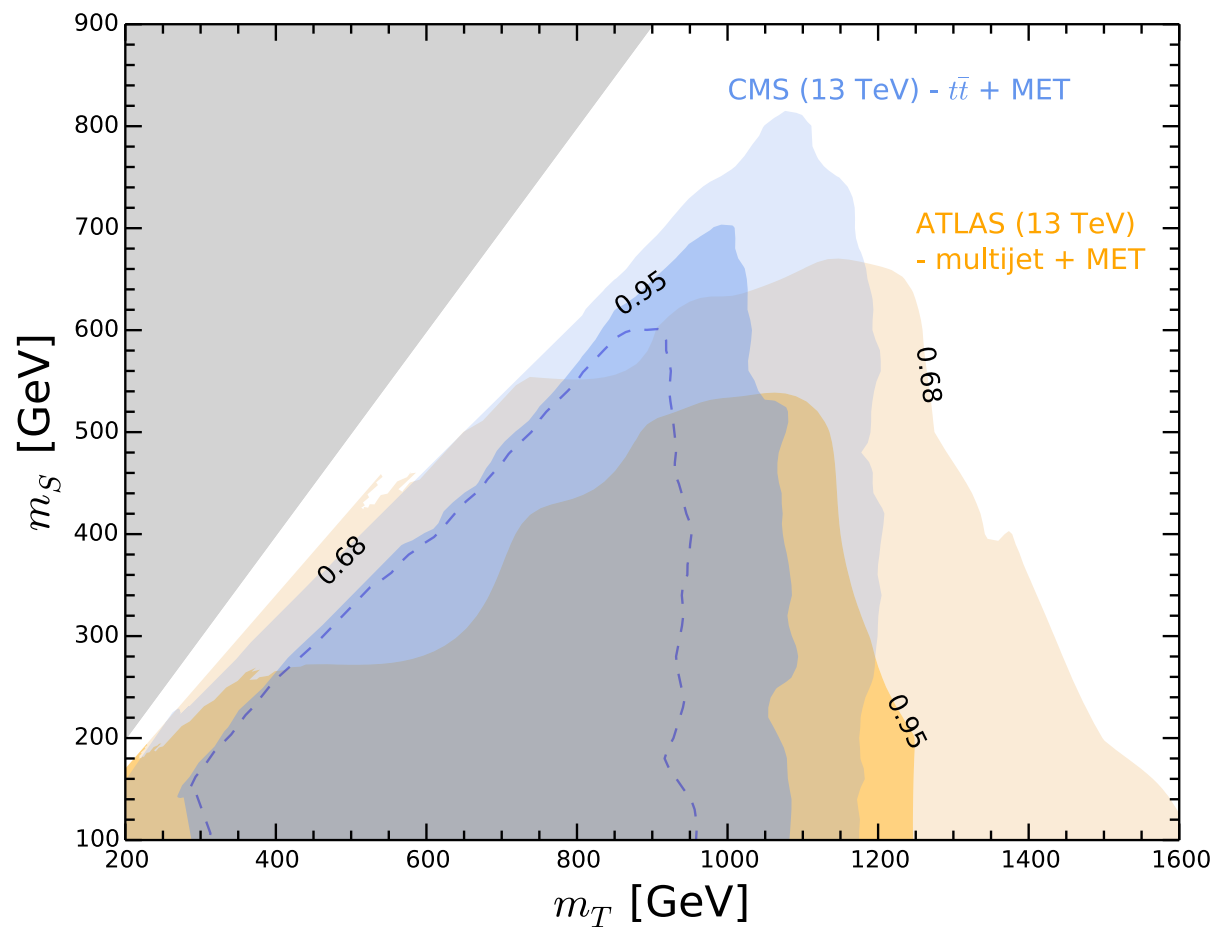
Collider signatures ( $pp \rightarrow t\bar{t} + \cancel{E}_T$ ) can be probed using existing DM searches focusing on the mono-jet / multi-jet / ttbar + MET signatures



$$\sigma_{t\bar{t}SS}(M_T, M_S) = \sigma_{t\bar{t}SS}^0(M_T, M_S) + \frac{C}{\Lambda} \hat{\sigma}_{t\bar{t}SS}^{\text{int}}(M_T, M_S) + \frac{C^2}{\Lambda^2} \hat{\sigma}_{t\bar{t}SS}^{\text{dim5}}(M_S)$$

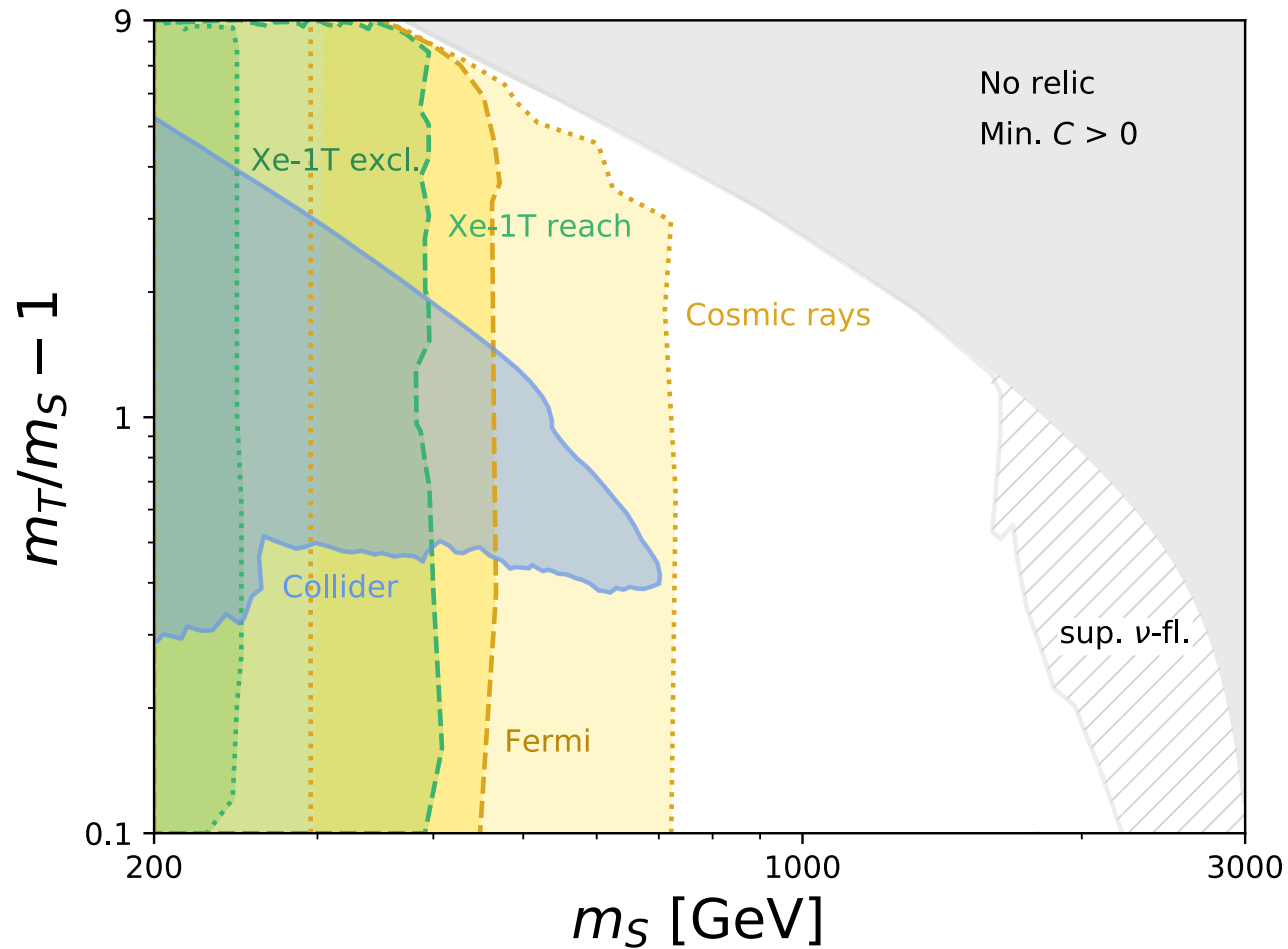
# Collider: Madanalysis5 recasting

- Multi-jet: ATLAS\_CONF\_2019\_040 ( $\geq 2$  hard jets +  $\vec{p}_T^{\text{miss}}$ ,  $139 \text{ fb}^{-1}$ )
- ttbar + MET: CMS\_SUS\_17\_001 ( $\ell^+ \ell^- + \vec{p}_T^{\text{miss}}$ ,  $35.9 \text{ fb}^{-1}$ )
- Additional operator yields no significant modification



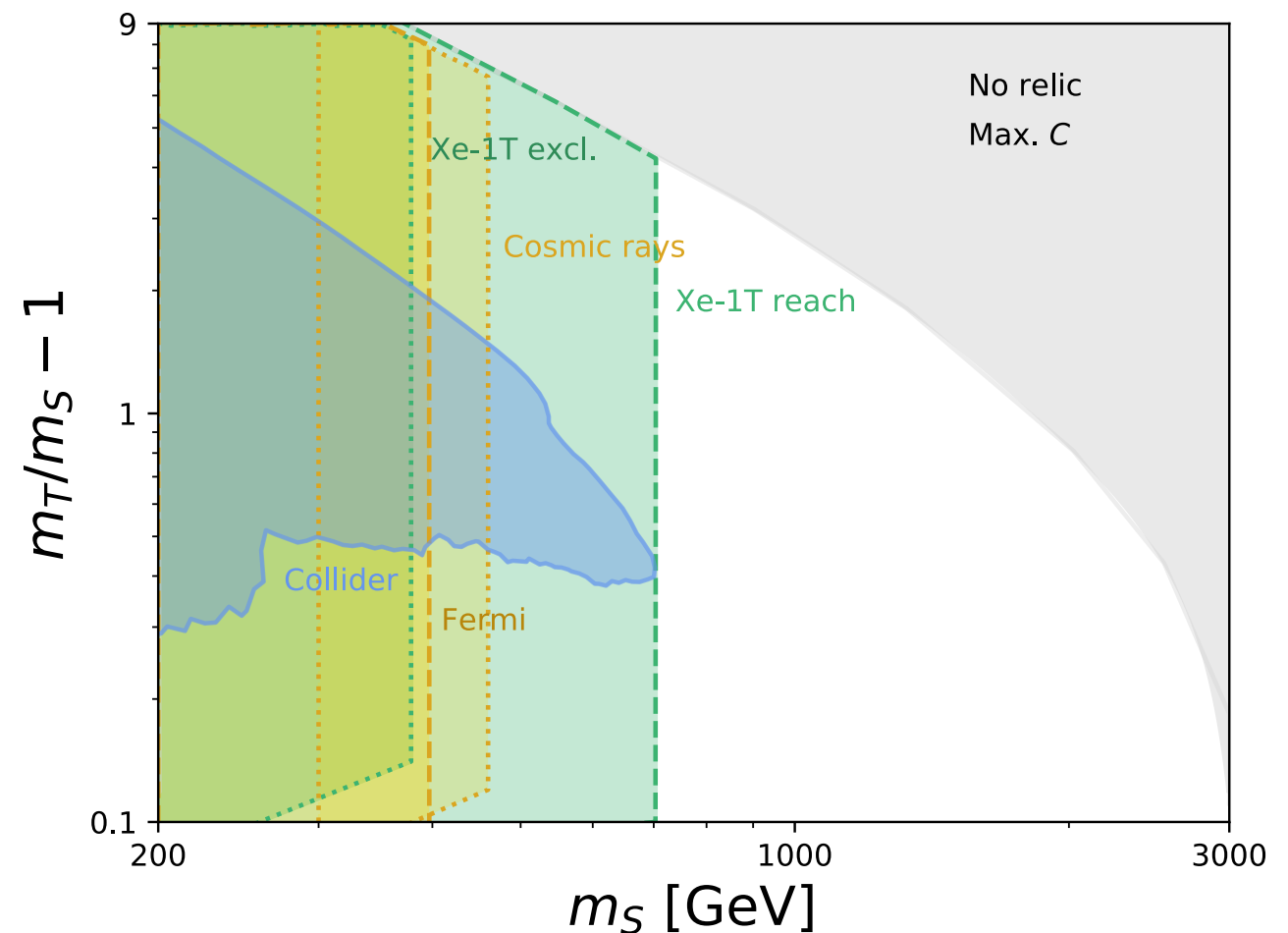
Re scaling: see 1910.11418 (Araz, Frank, Fuks)

# Exclusions



- LHC bounds due to **extrapolation to full Run-2**
- Larger luminosities hold even more potential
- Wilson coefficient dep. on underlying theory, but collider immune

- **Complementarity** of collider constraints with astrophysical ones (more affected by the contact term)



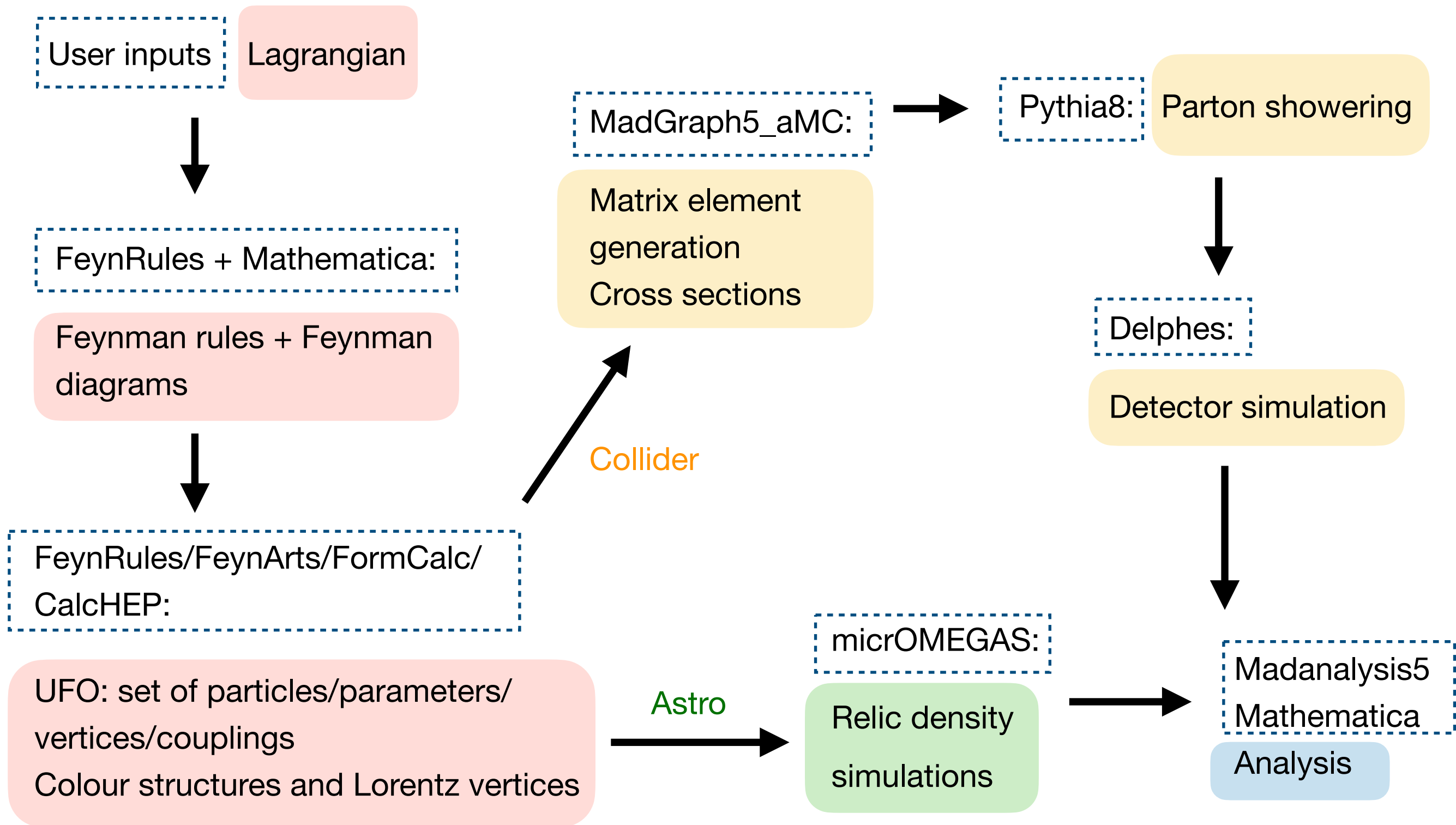
- Semi-analytic fit to the relic density shows **interplay** of new term
- Opening up of parameter space
- Astrophysical constraints strengthened
- No impact on collider - **complementarity!**
- Could we include a (Z2- even) top partner in the theory?

Thank you

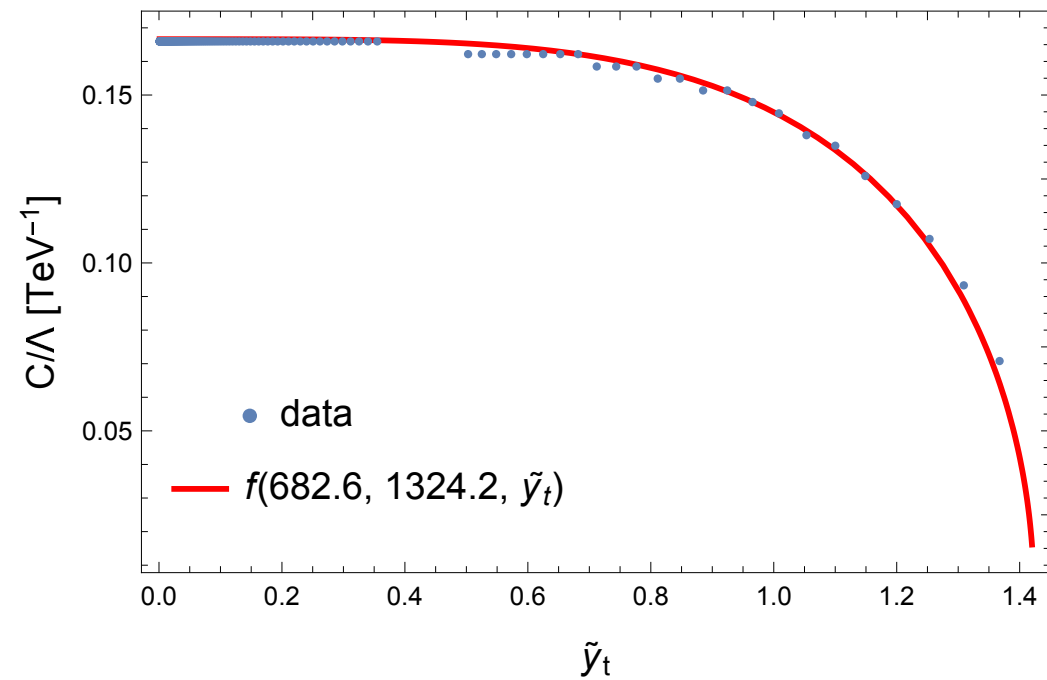


**BACKUP**

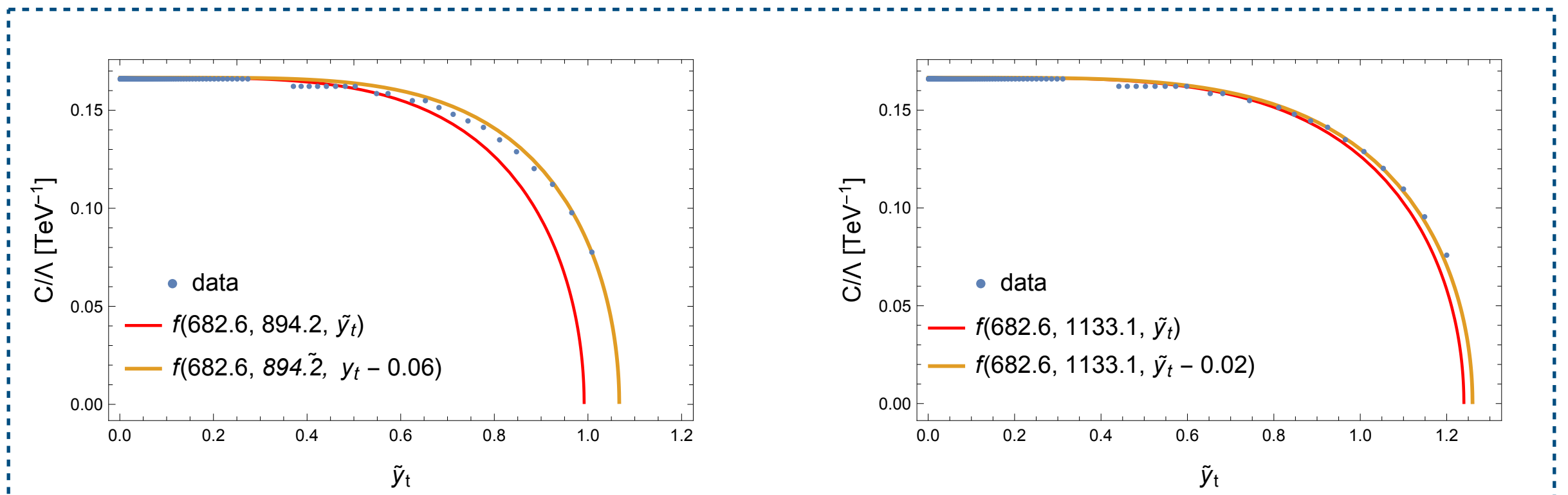
# Simulation ecosystem



# Coannihilations



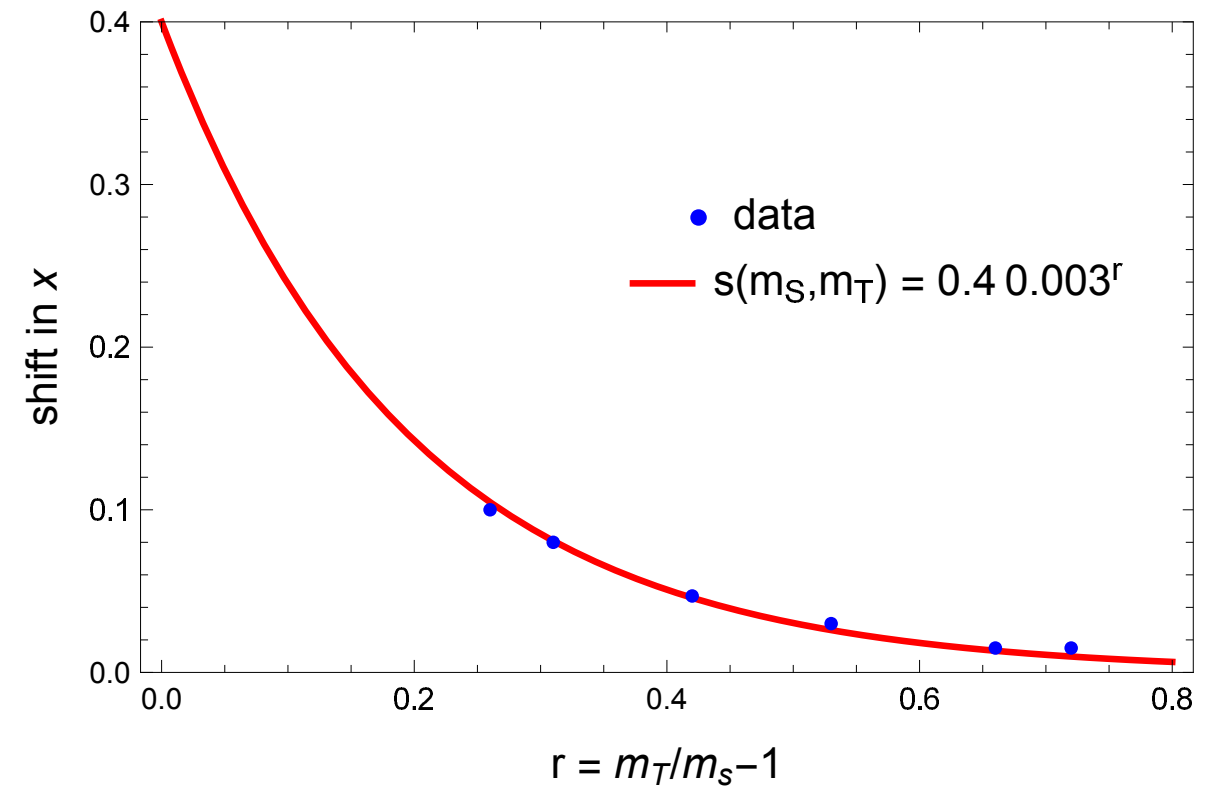
- Define  $r = m_T/m_S - 1$
- When  $S$  and  $T$  get close in mass, the coannihilations of  $T$  with  $S$  are **no longer negligible** ( $r \leq 0.8$ )



# Coannihilations

- The Boltzmann equation is generalised to a set of coupled equations

$$\sigma_{eff}(x) = \sigma_{SS} + \sigma_{ST} \frac{g_S g_T}{g_{eff}^2} \left( \frac{m_T}{m_S} \right)^{3/2} \exp[-x r]$$



$$\frac{C}{\Lambda} \approx f(m_S, m_T, \tilde{y}_t) = \frac{1}{\sqrt{A(m_S)}} \sqrt{b' - B(m_S, m_T) \left( \tilde{y}_t - \alpha \left[ \beta \gamma \frac{m_S}{\Lambda} \right]^r \right)^4}$$

# Just for completeness..

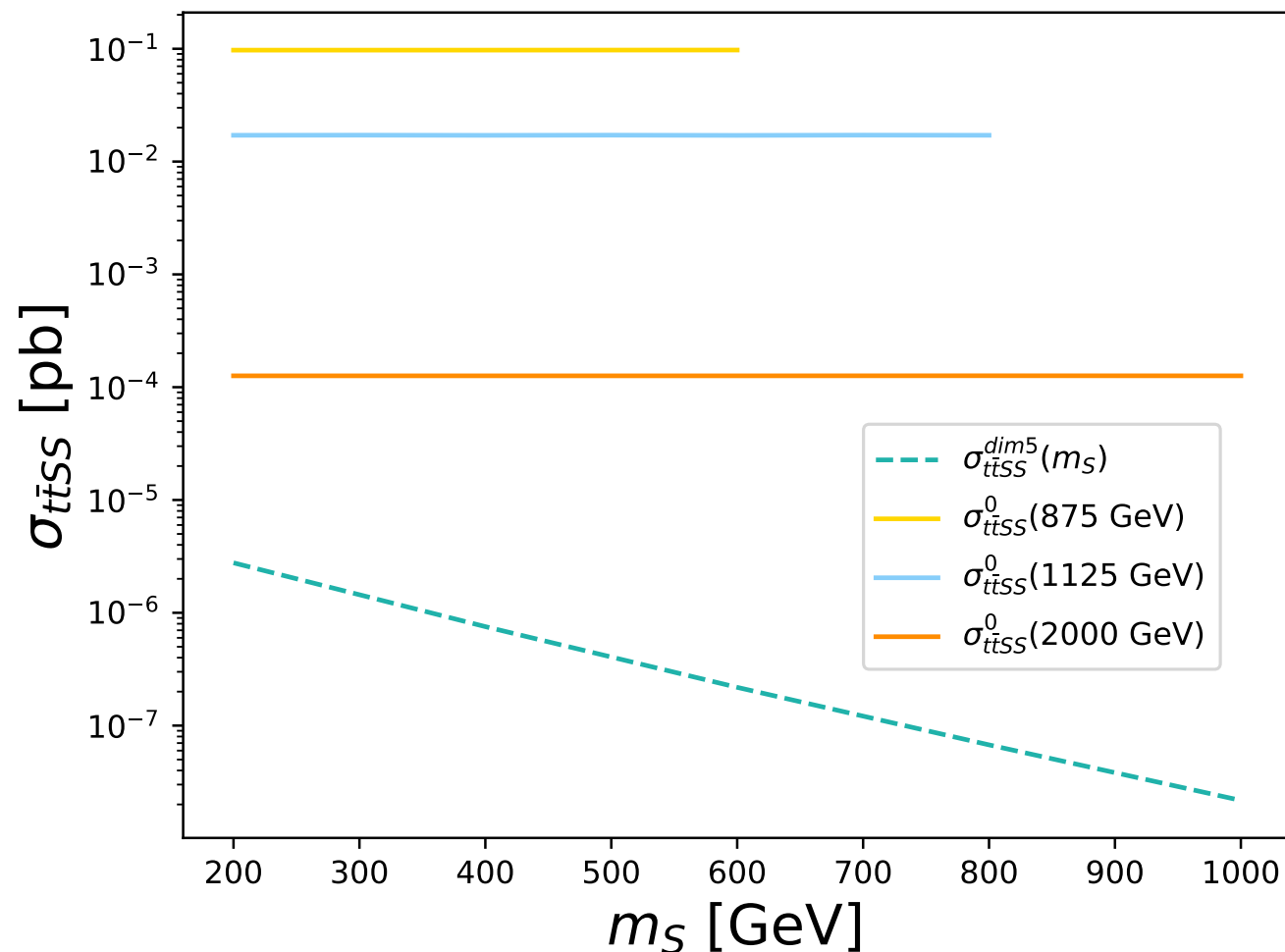
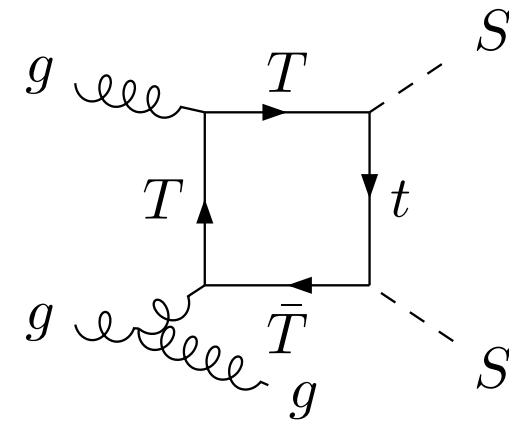
$$A(m_S) = \frac{\Lambda^2 \langle \sigma v \rangle_{SStt}}{C^2} = \frac{N_c}{4\pi} \left( 1 - \frac{m_t^2}{m_S^2} \right)^{3/2},$$

$$\begin{aligned} B(m_S, m_T) &= \frac{\sigma v_{q\bar{q}} + \sigma v_{VIB}^{(0)}}{\tilde{y}_t^4} \\ &= \frac{N_c}{4\pi m_S^2} \left( \frac{m_t^2 (m_S^2 - m_t^2)^{3/2}}{m_S (m_S^2 + m_T^2 - m_t^2)^2} \right. \\ &\quad \left. + \frac{\alpha_S C_F}{2\pi} \left[ ((r+1)^2 + 1) \left( \frac{\pi^2}{6} - \log^2 \frac{1 + (r+1)^2}{2(r+1)^2} - 2\text{Li}_2 \left( \frac{1 + (r+1)^2}{2(r+1)^2} \right) \right) \right. \right. \\ &\quad \left. \left. + \frac{4(r+1)^2 + 3}{(r+1)^2 + 1} + \frac{4(r+1)^2 - 3(r+1)^2 - 1}{2(r+1)^2} \log \frac{(r+1)^2 - 1}{(r+1)^2 + 1} \right] \right), \end{aligned}$$

$$b'(x_F, g_*(x_F)) = (7.19 \times 10^{-10} \text{ GeV}^{-2}) \frac{x_F}{\sqrt{g_*(x_F)}}.$$

# Collider: Madanalysis5 recasting

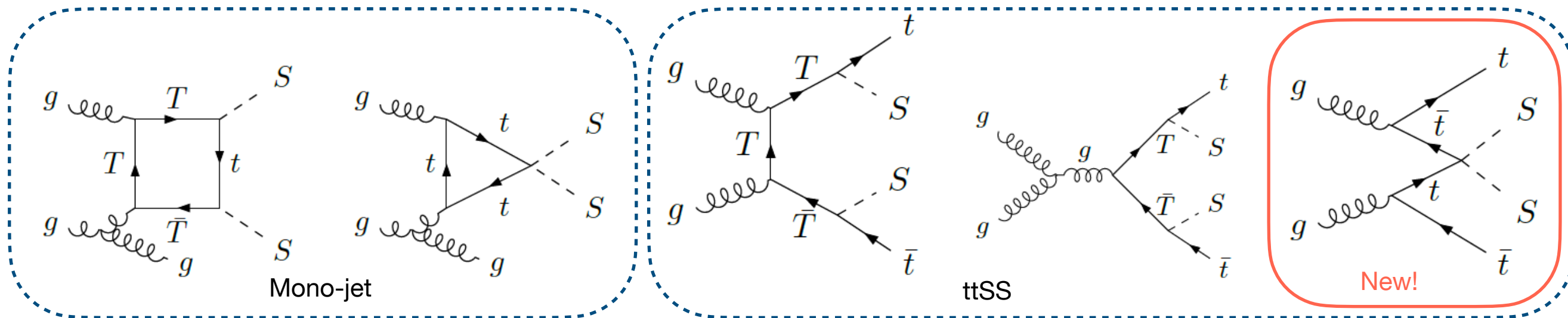
- Mono-jet: ATLAS\_EXOT\_2016\_27 (energetic jet and large missing momentum,  $36.1 \text{ fb}^{-1}$ )
- Shown previously to have minimal contribution.



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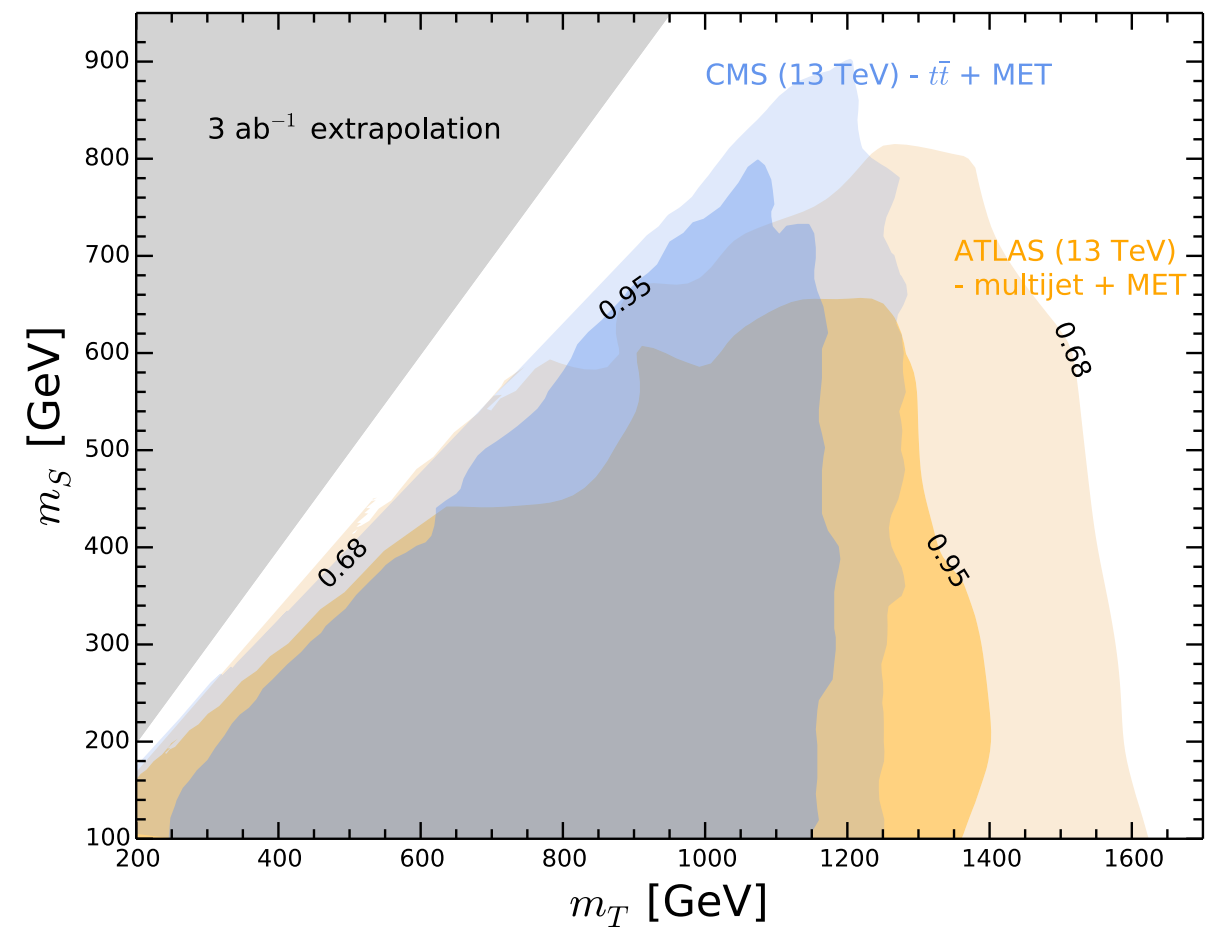
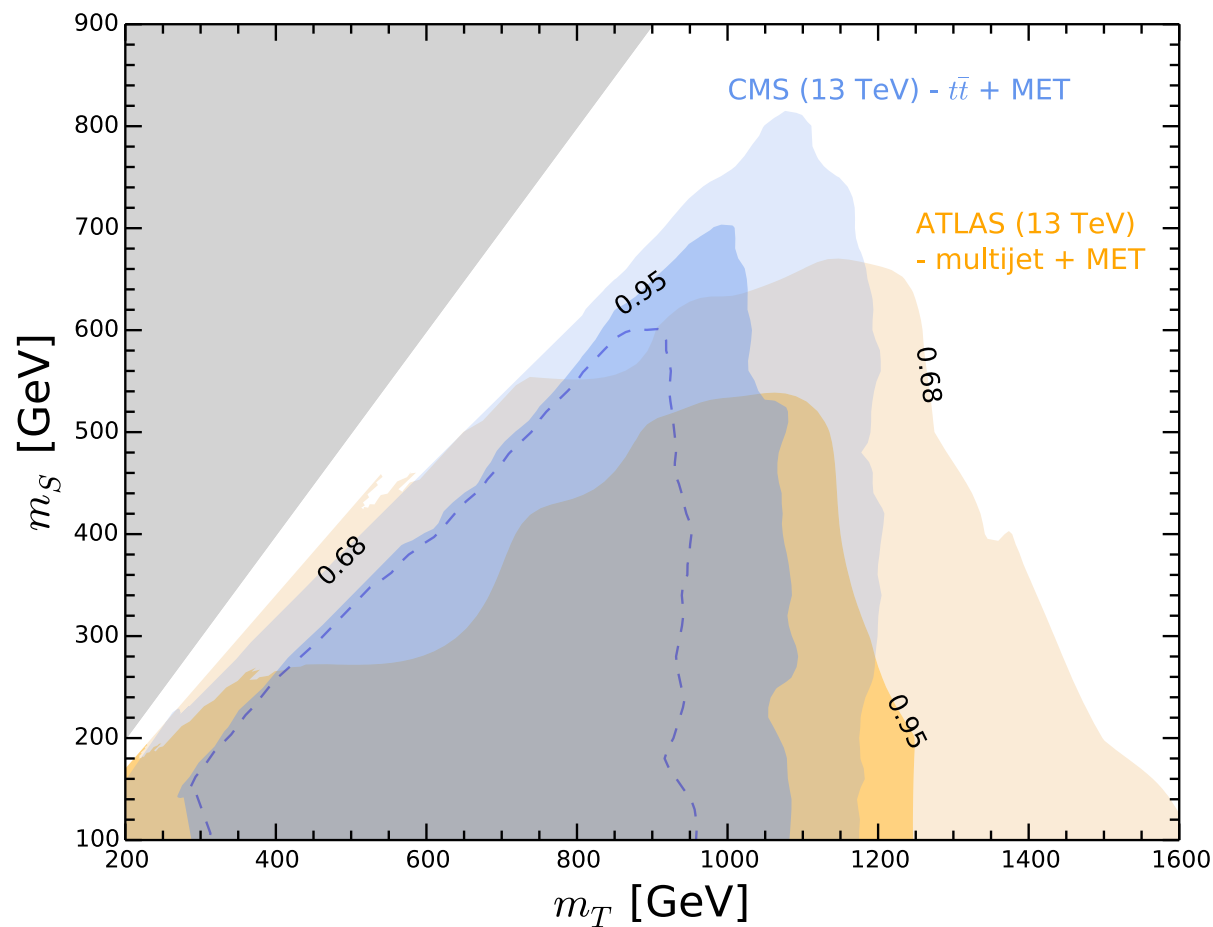
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