Novel Collider and Dark Matter Phenomenology of a Top-philic Z'

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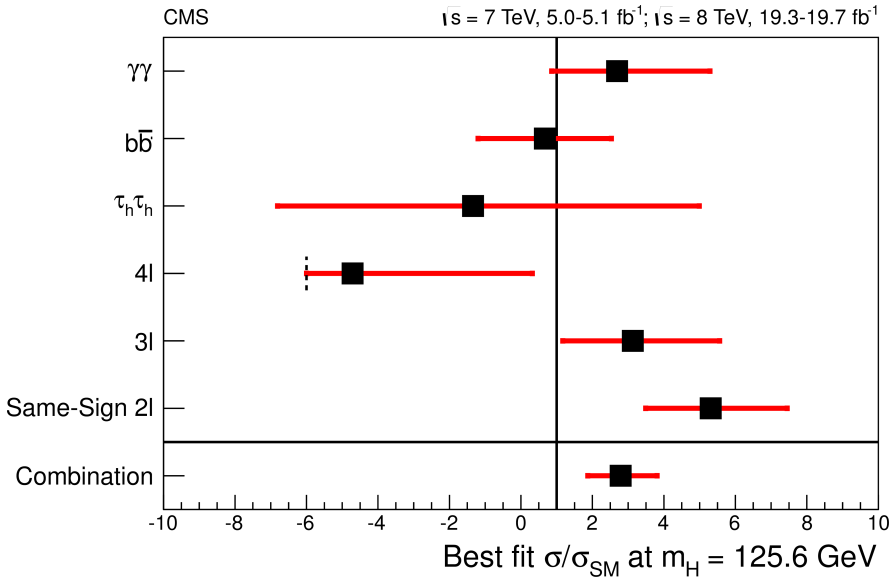
$t\bar{t}H$ anomaly

- Mild 2.3 σ excess in the $t\bar{t}H$ production
- Dominant contribution from CMS same-sign dilepton (dimuon) channel



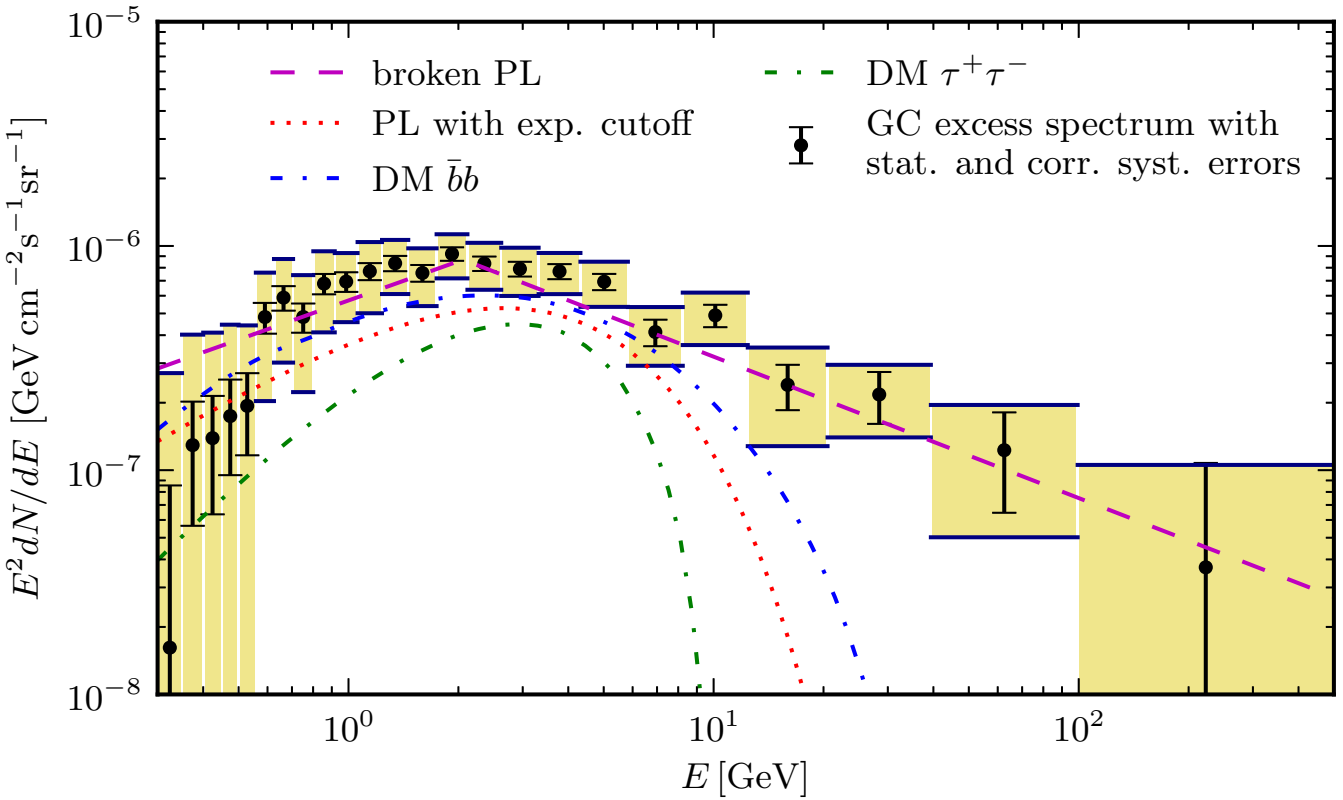
- Combined measurements of Higgs properties using complete Run I dataset
- Precise measurement of $t\bar{t}H$ key objective of Run II

	ATLAS	CMS	Combined
$\gamma\gamma$	$1.4^{+2.6}_{-1.7}$	$2.7^{+2.6}_{-1.8}$	2.1 ± 1.5
$b\bar{b}$	$1.5^{+1.1}_{-1.1}$	$1.2^{+1.6}_{-1.5}$	1.4 ± 0.9
$\tau_{\rm had}\tau_{\rm had}$	$-9.6^{+9.6}_{-9.7}$	$-1.3^{+6.3}_{-5.5}$	-3.5 ± 4.9
SS dilepton	$2.8^{+2.1}_{-1.9}$	$5.3^{+2.1}_{-1.8}$	4.2 ± 1.4
3 lepton	$2.8^{+2.2}_{-1.8}$	$3.1^{+2.4}_{-2.0}$	2.4 ± 1.5
4 lepton	$1.8^{+6.9}_{-2.0}$	$-4.7^{+5.0}_{-1.3}$	-2.5 ± 4.1

Fermi GeV Excess and Dark Matter

$$\text{DM} \quad \frac{dN}{dE} = \sum_f \frac{\langle \sigma v \rangle_f}{8\pi m_\chi^2} \frac{dN_\gamma^f}{dE} \int_{l.o.s.} ds\, \rho^2(r(s,\psi))$$

$$\text{Generalized NFW profile} \quad \rho(r) = \rho_\odot \left(\frac{r}{r_\odot}\right)^{-\gamma} \left(\frac{1+r_\odot/r_s}{1+r/r_s}\right)^{3-\gamma}$$



p-values

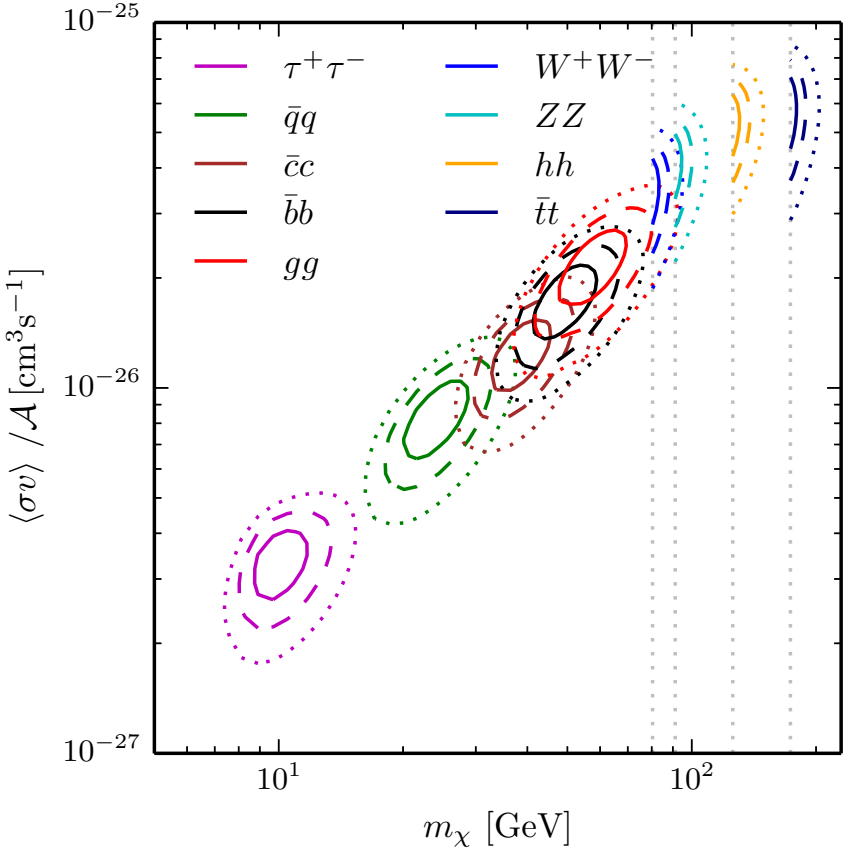
broken PL
$p = 0.47$

exp cutoff
$p = 0.16$

DM $b\bar{b}$
$p = 0.43$

DM $\tau^+\tau^-$
$p = 0.065$

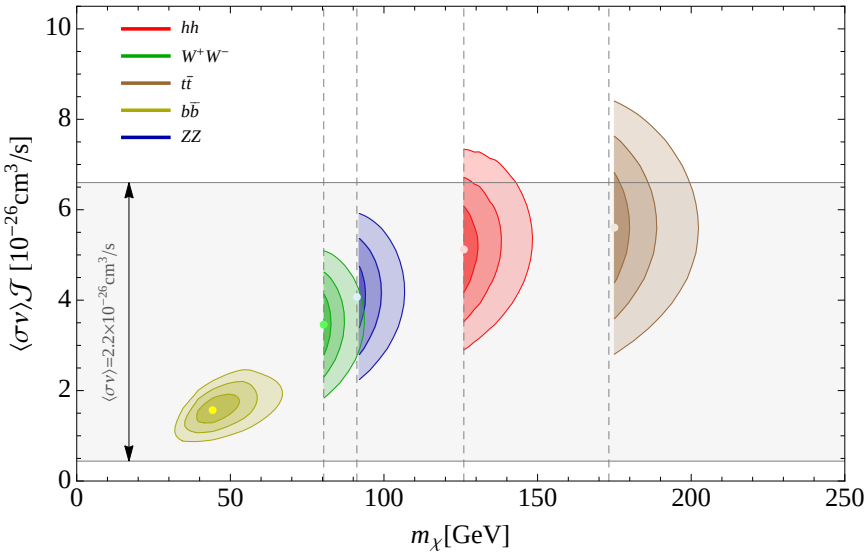
DM Fits: 3σ Regions



Calore, Cholis, McCabe, Weniger [1411.4647]

	$\langle\sigma v\rangle$	m_χ	$\chi^2_{\rm min}$	p-value
$\bar{b}b$	$1.75^{+0.28}_{-0.26}$	$48.7^{+6.4}_{-5.2}$	23.9	0.35
$\bar{t}t$	$5.8^{+0.8}_{-0.8}$	$173.3^{+2.8}_{-0}$	43.9	0.003
hh	$5.33^{+0.68}_{-0.68}$	$125.7^{+3.1}_{-0}$	29.5	0.13
W^+W^-	$3.52^{+0.48}_{-0.48}$	$80.4^{+1.3}_{-0}$	36.7	0.026
ZZ	$4.12^{+0.55}_{-0.55}$	$91.2^{+1.53}_{-0}$	35.3	0.036

Calore,Cholis,McCabe,Weniger [1411.4647]



Agrawal, Batell, Fox, Harnik [1411.2592]

Uncertainties in DM halo

$\mathcal{A} = [0.17, 5.3]$ $(\mathcal{J} = [0.19, 3])$

Effective theory for Top-philic Z'

- Extend the SM by an additional $U(1)'$ where t_R is the only SM particle charged.
- $U(1)'$ anomalous, assume spectators fermions at $\Lambda_{UV} \approx 1$ TeV.
- Assume that $U(1)'$ spontaneously broken by a Higgs sector leaving behind a Z_2 symmetry $\rightarrow$ associated Z' which is top-philic and a possible DM candidate in the "hidden" sector Jackson, Servant, Shaughnessy, Tait, Taoso.
- Low-energy effective Lagrangian for the top-philic Z' and a Dirac fermion χ, neutral under all SM gauge symmetries but charged under $U(1)'$

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4} Z'_{\mu\nu} Z'^{\mu\nu} - \frac{1}{2}\,\epsilon\, Z'_{\mu\nu} B^{\mu\nu} + \frac{1}{2}\, m^2_{Z'}\, Z'_\mu Z'^\mu + g_t\, Z'_\mu\, \bar{t}\gamma^\mu P_R t + \bar{\chi}\gamma^\mu \Big(i\partial_\mu + g_\chi Z'_\mu\Big)\chi - m_\chi\, \bar{\chi}\chi\,.$$

- ϵ depends on UV details, EWPT and dilepton searches $\rightarrow$ $\epsilon \ll 10^{-3}$.

Z' production

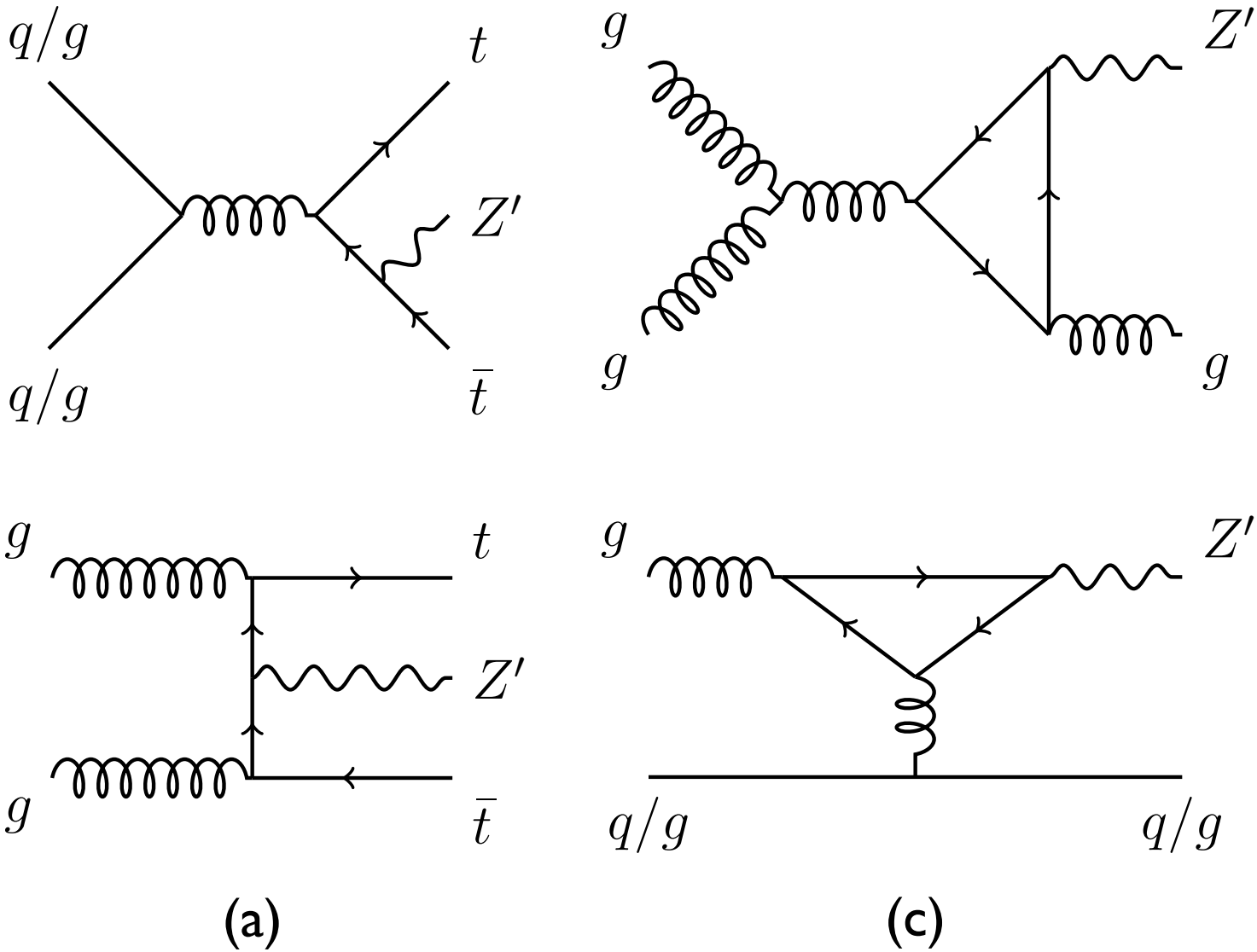
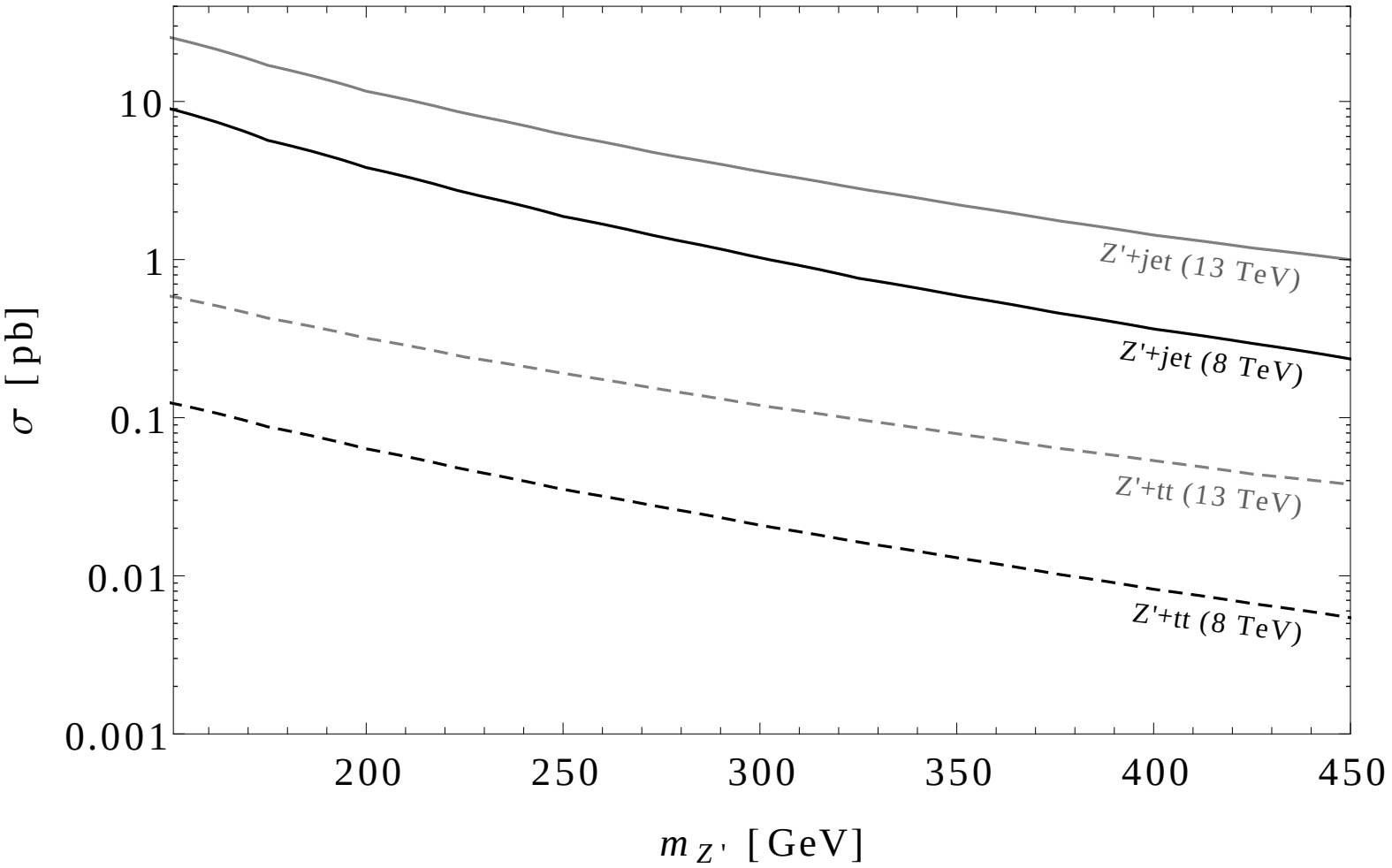


Figure: (a) Leading contributions to ttZ' (c) Loop production of $Z'j$.

Z' production cross-sections



Z' decays

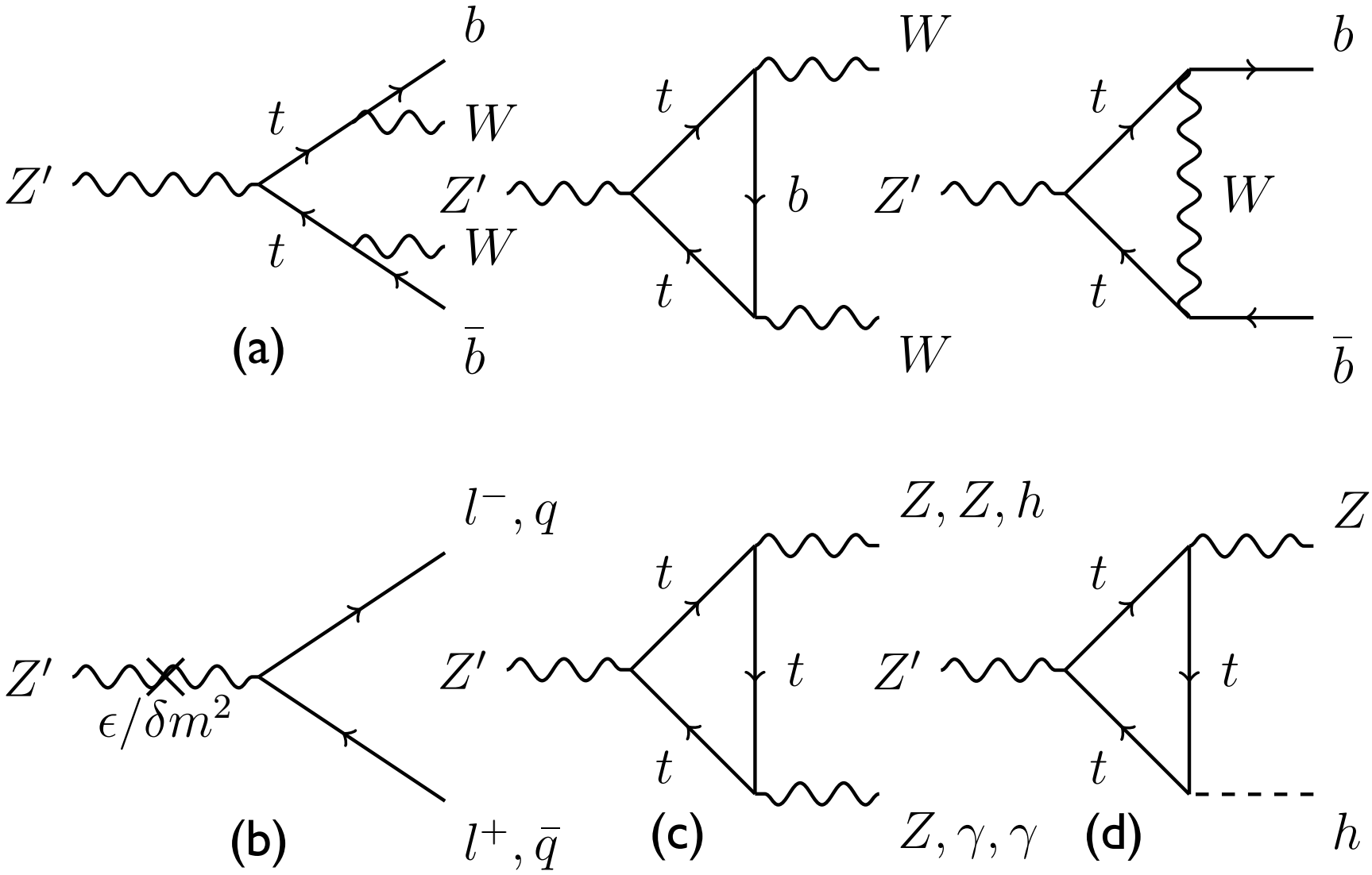
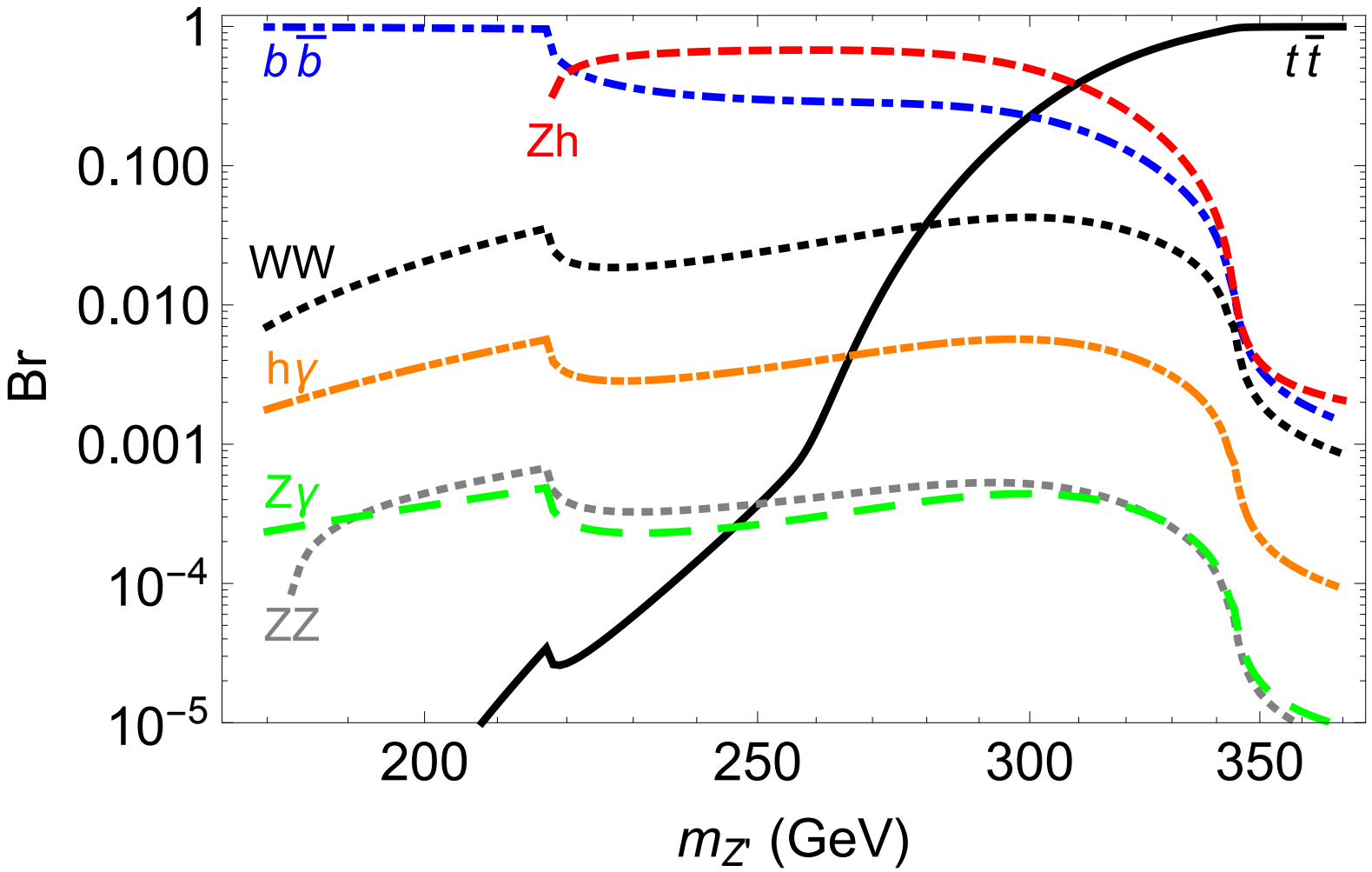
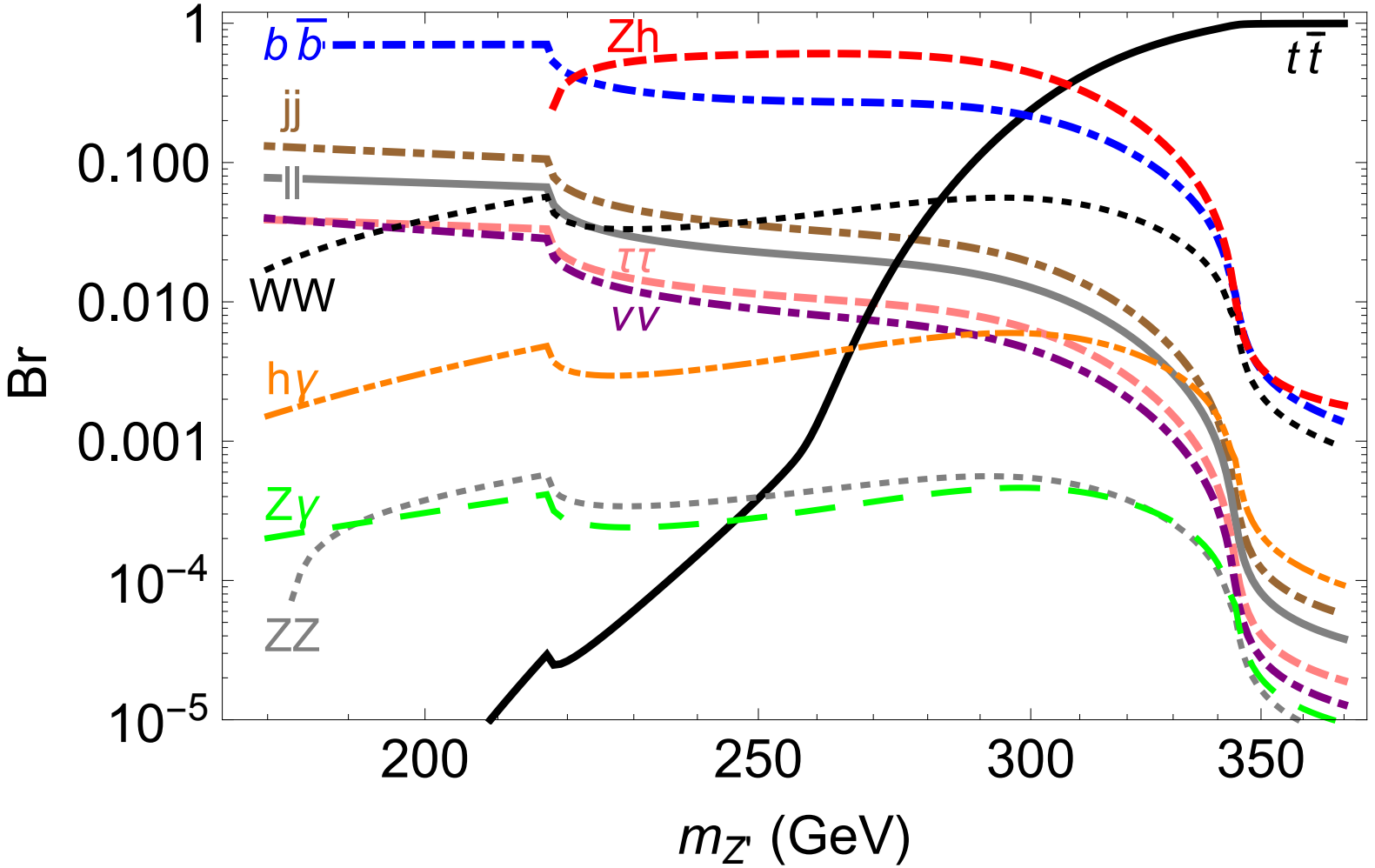


Figure: (a): Tree-level decay to $t^{(*)}\bar{t}^{(*)}$. (b): Tree-level decay from mixing. (c): UV-finite loop decays. (d): UV-divergent loop decays.

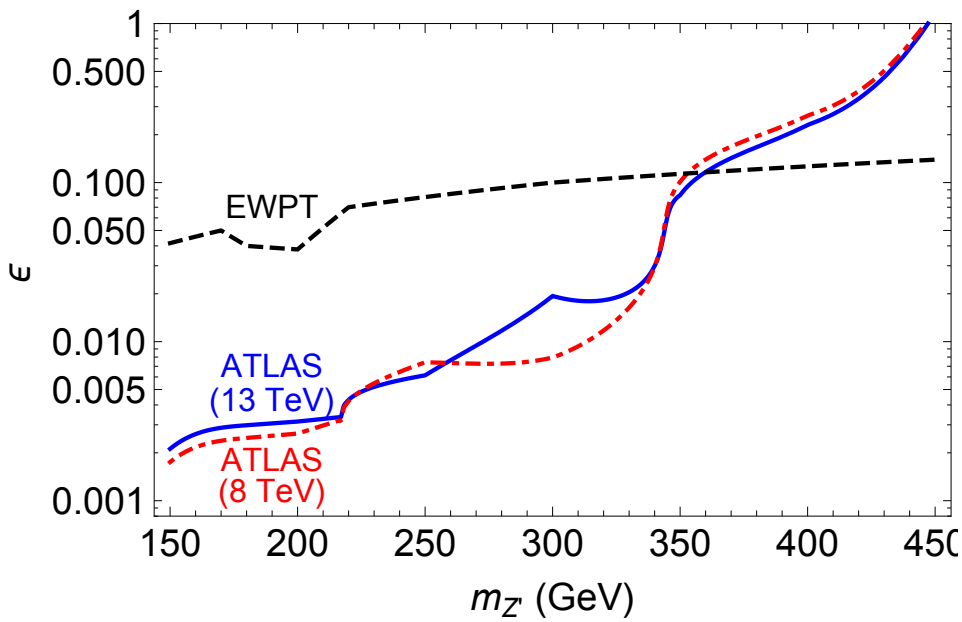
Z' decays for zero mixing

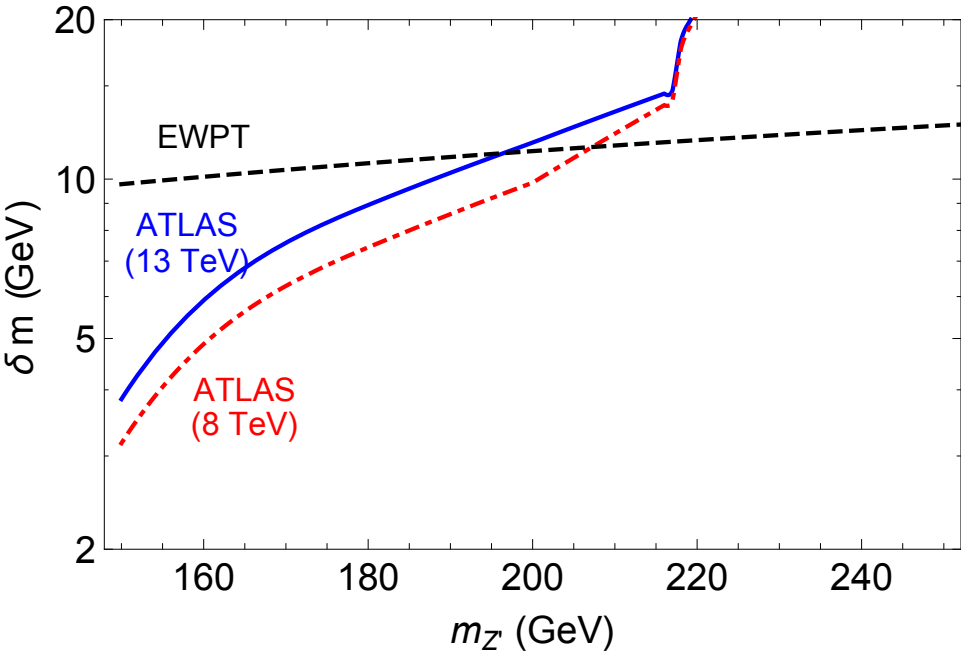


Z' decays with kinetic mixing

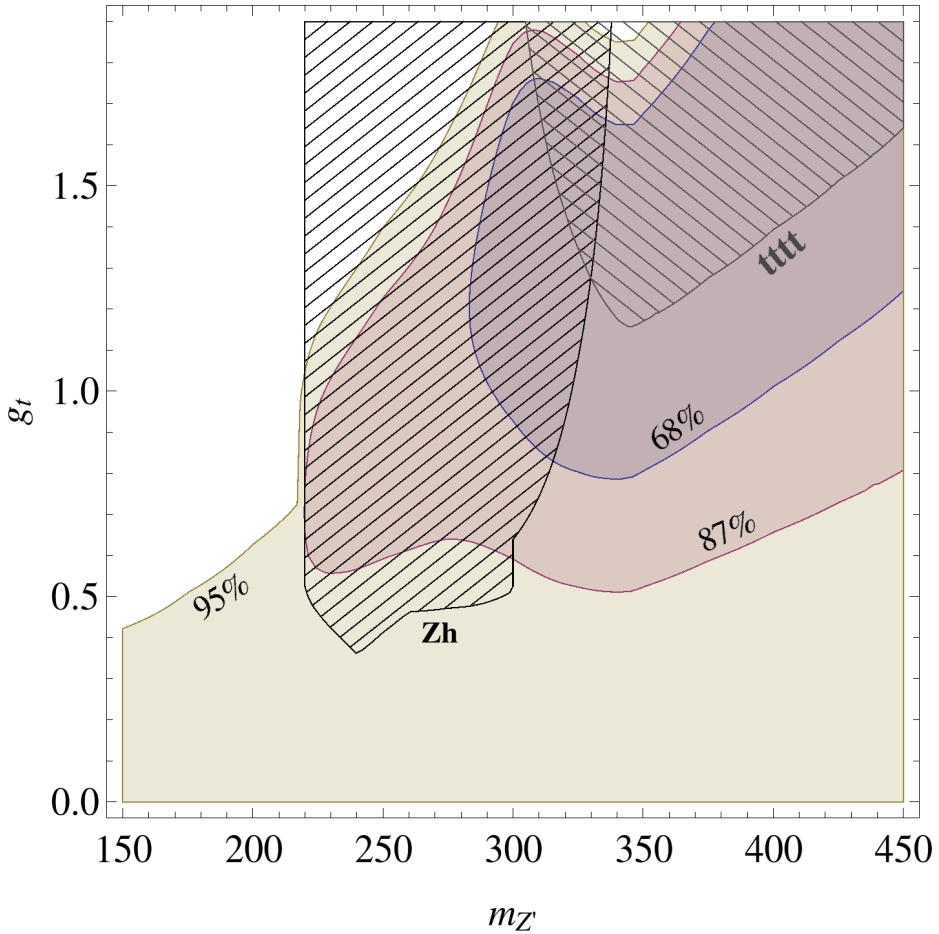


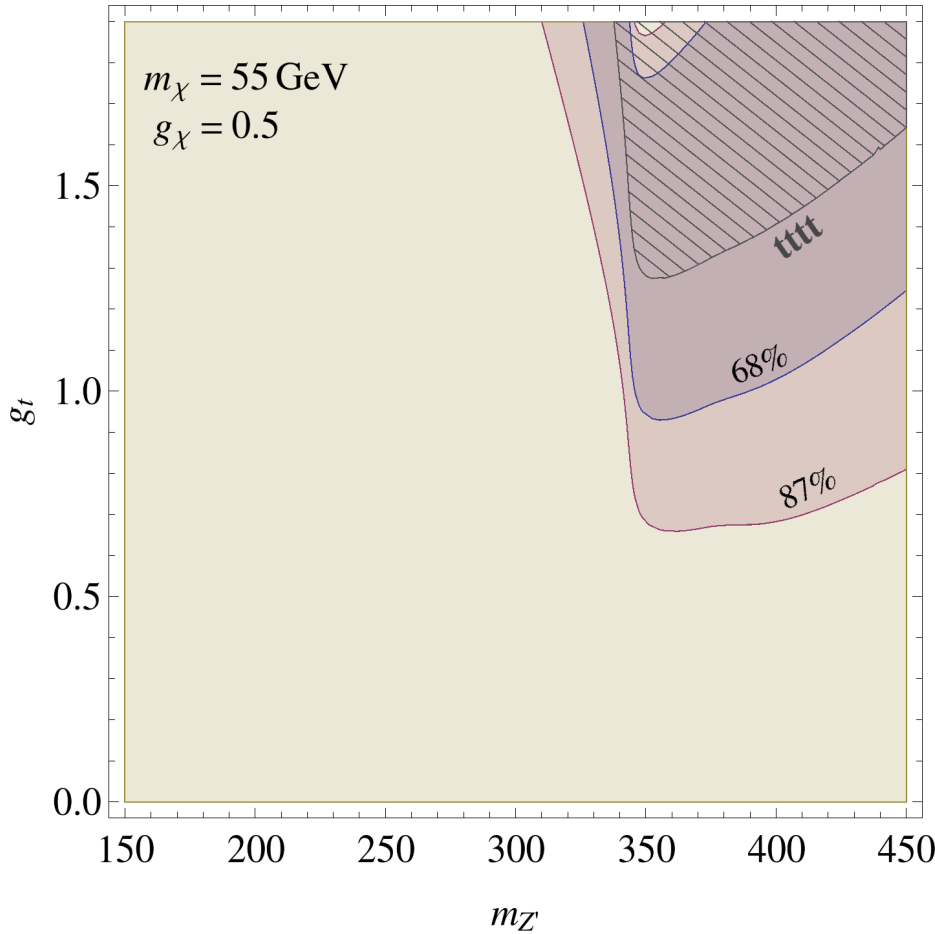
Limits on kinetic and mass mixing from dilepton searches



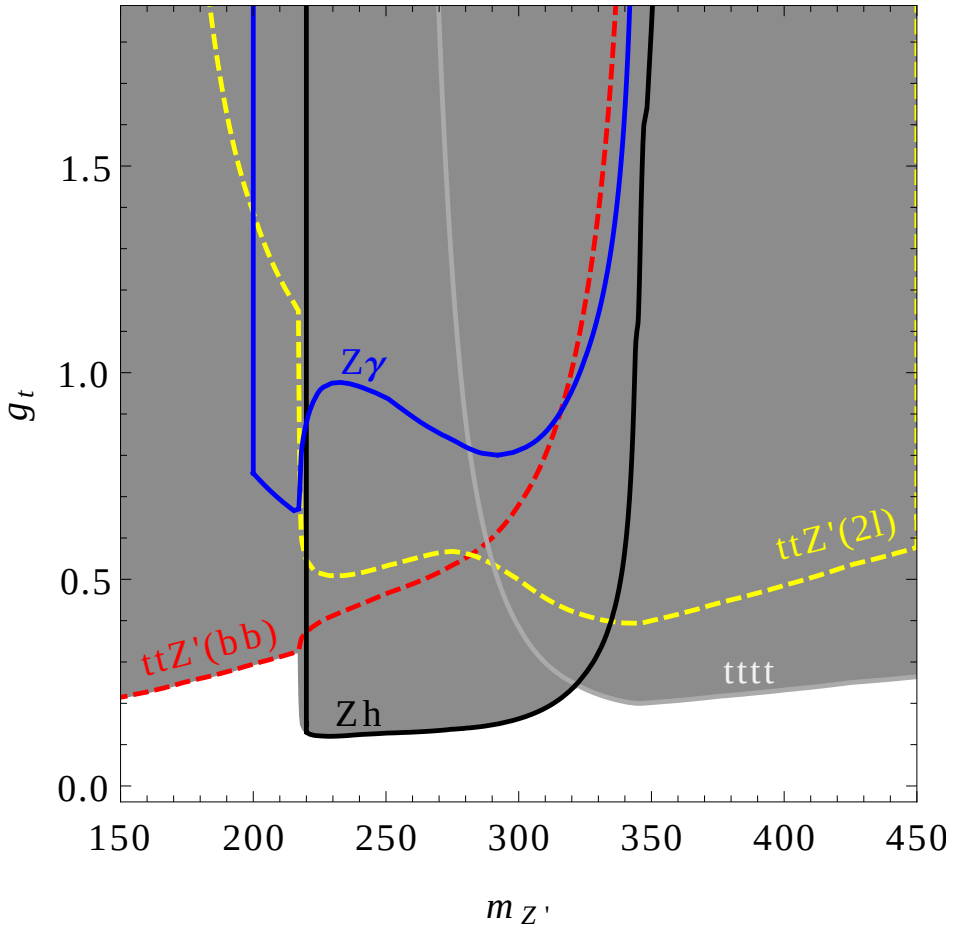


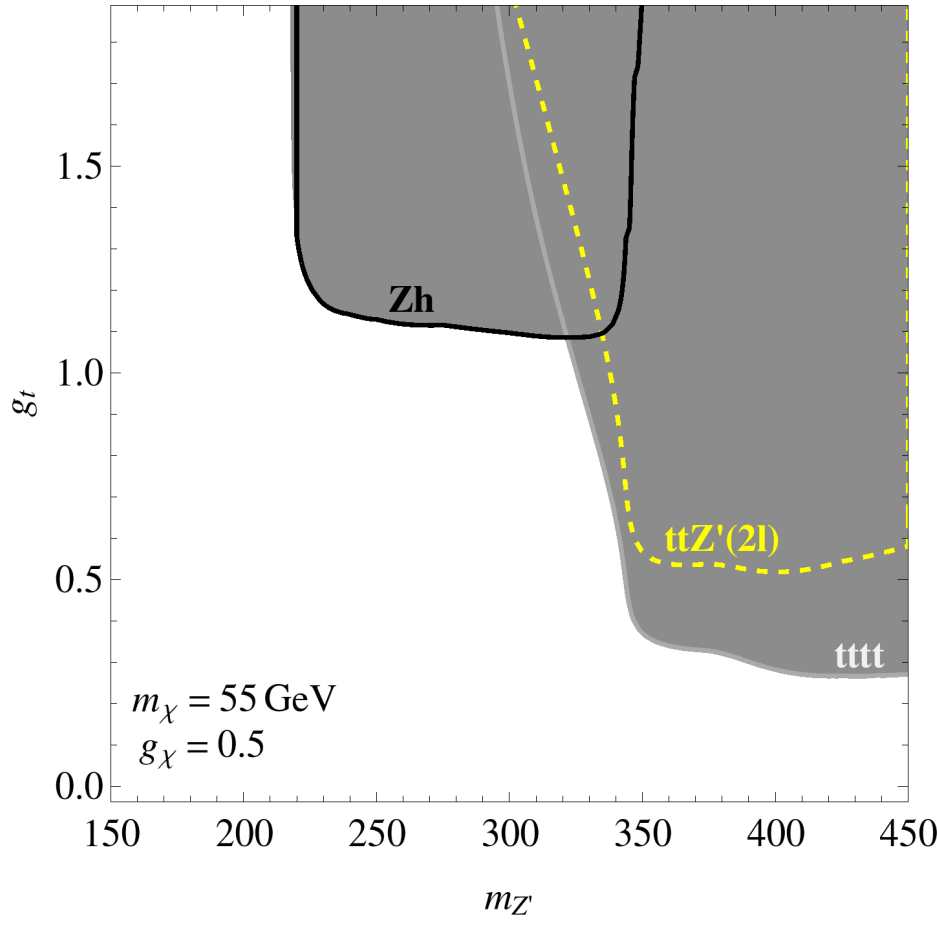
Best fit regions for $t\bar{t}H$ signal strengths





Projected limits from LHC at $\sqrt{s} = 13$ TeV and $\mathcal{L} = 300$ fb^{-1}





Dark matter annihilation channels

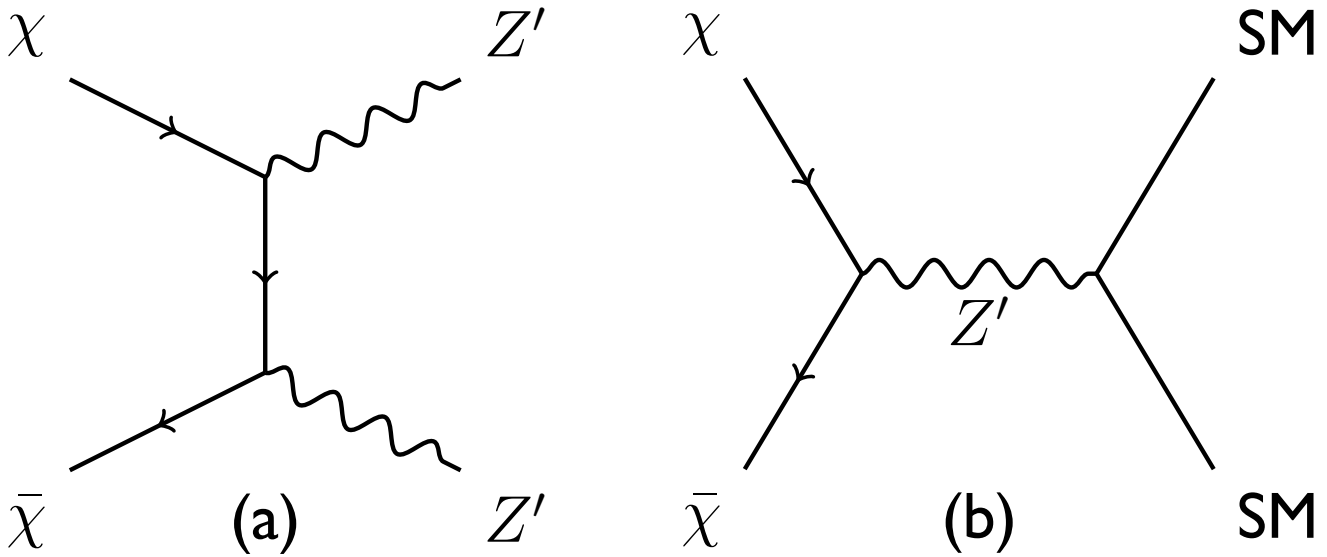
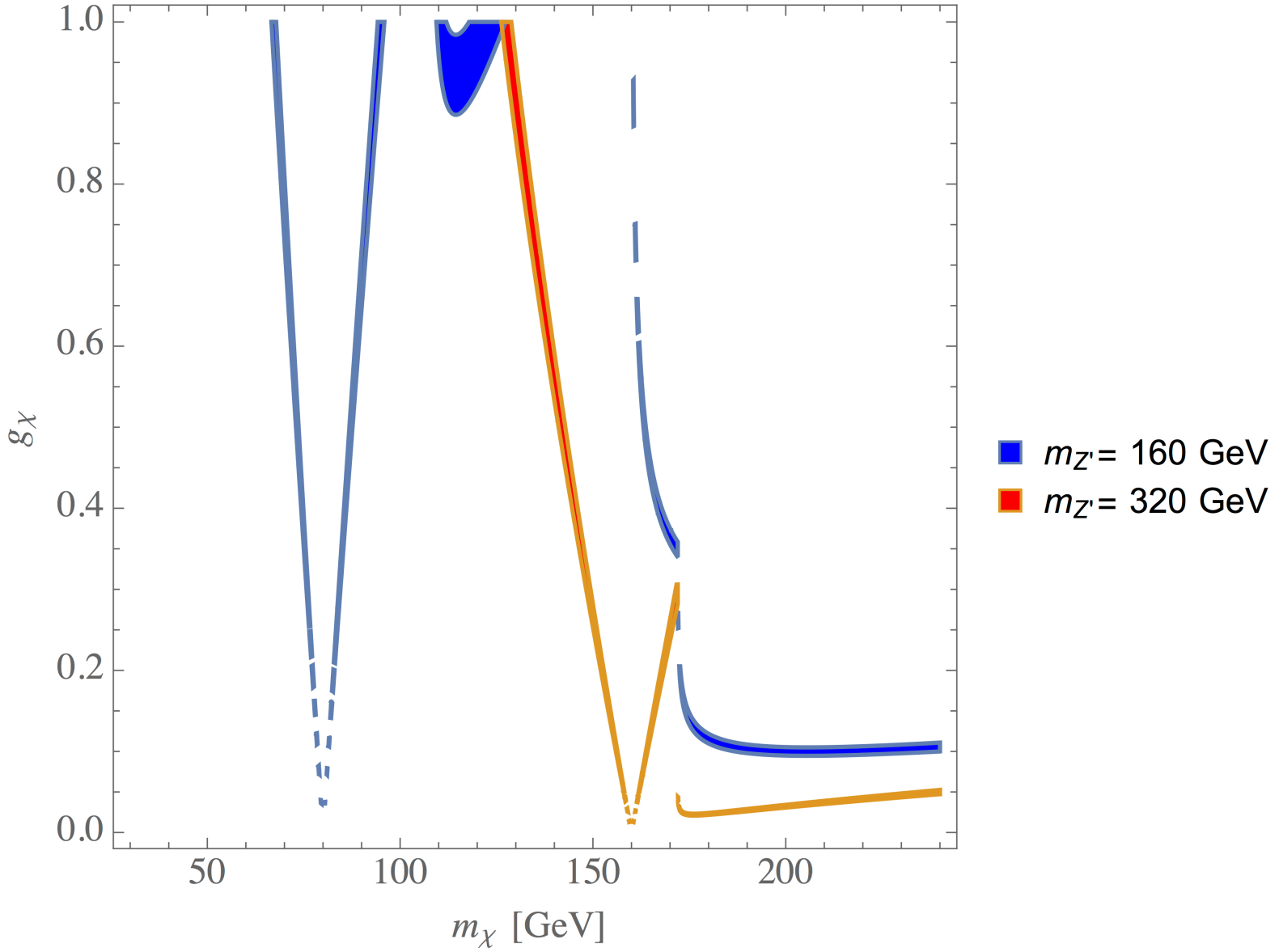


Figure: (a): t-channel annihilation to two Z', relevant when $m_\chi > m_{Z'}$ (there is also a u-channel diagram). (b): s-channel annihilation through on- or off-shell Z' to SM.

DM relic density regions consistent with Planck



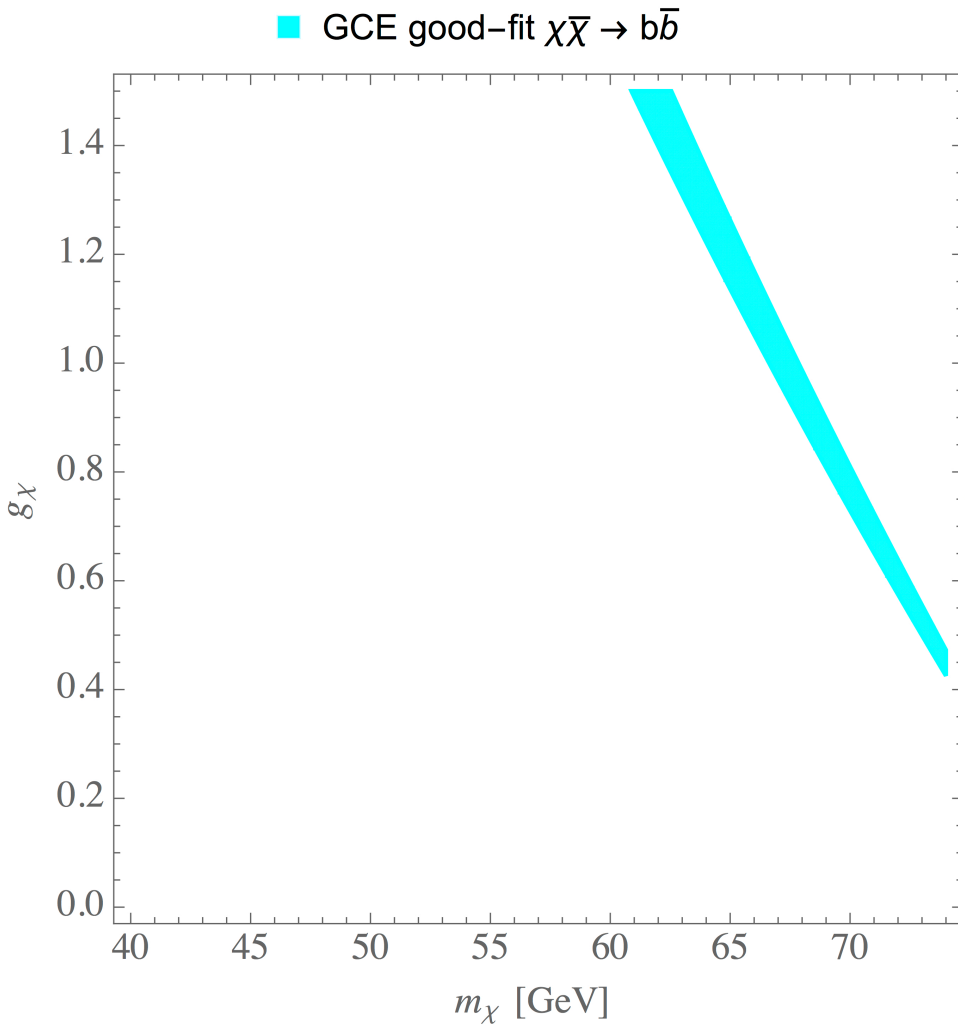
Direct detection constraints

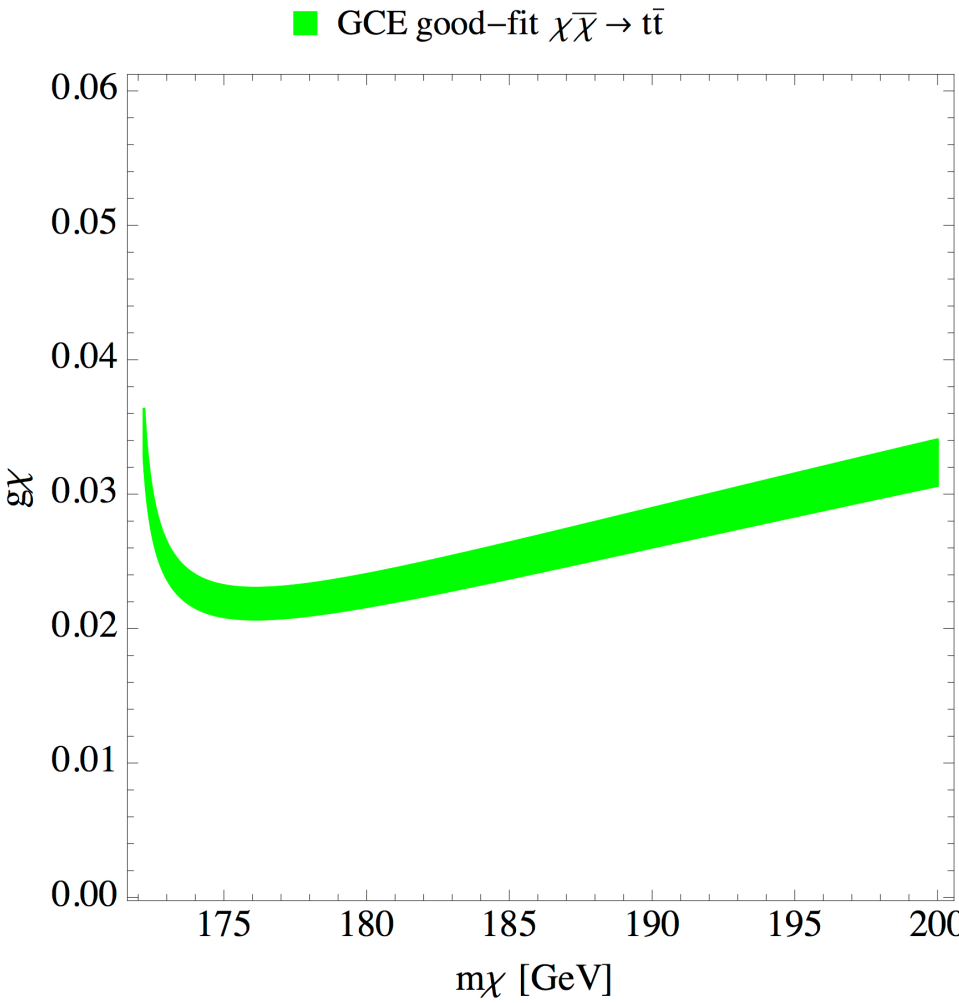
- Mostly insensitive due to small $Z - Z'$ mixing.
- Current LUX constraints bound the DM-nucleon scattering to $\sigma_n \lesssim 10^{-45}$ cm^2 for $m_\chi = 100$ GeV.
- For kinetic mixing: $g_\chi \, \epsilon \lesssim 4 \times 10^{-4}$, which requires at most a tuning of $\mathcal{O}(20\%)$.
- Scattering induced by the Z' coupling to gluons:

$$\sigma \sim \frac{g_t^2 g_\chi^2 \alpha_s^2}{36\pi^3} \frac{m_n^4}{m_t^4} \frac{\mu_\chi^2}{m_{Z'}^4} \sim 10^{-47}\text{cm}^2 \, g_t^2 g_\chi^2 \left(\frac{100 \text{ GeV}}{m_{Z'}} \right)^4 .$$

well below current experimental limits.

Regions consistent with the GCE fits for $b\bar{b}$ and $t\bar{t}$





Conclusions

- Considered a $U(1)'$ under which only the t_R is charged and a possibly light "hidden" Dirac fermion which plays the role of DM.

- Dominant production mechanisms are $t\bar{t}Z'$ and loop-induced Z'+jets.

- Z' phenomenology divided in 3 distinct regions:
  $150 \lesssim m_{Z'} \lesssim 220$ GeV with dominant annihilation into $b\bar{b}$,
  $220 \lesssim m_{Z'} \lesssim 300$ GeV with dominant annihilation into ZH
  and $m_{Z'} \gtrsim 300$ GeV with Z' decays dominantly into $t\bar{t}^{(*)}$.

- Including the contribution of $t\bar{t}Z'$ improves the fit from the combined ATLAS and CMS 2.3-σ excess in $t\bar{t}H$ production for $m_{Z'} \gtrsim 300$ GeV and $g_t \gtrsim 0.8$.

- DM χ explains the GCE via annihilation into $b\bar{b}$ and $t\bar{t}$