A novel LHC dark matter search to test the Galactic Centre Excess arXiv:1705.09670

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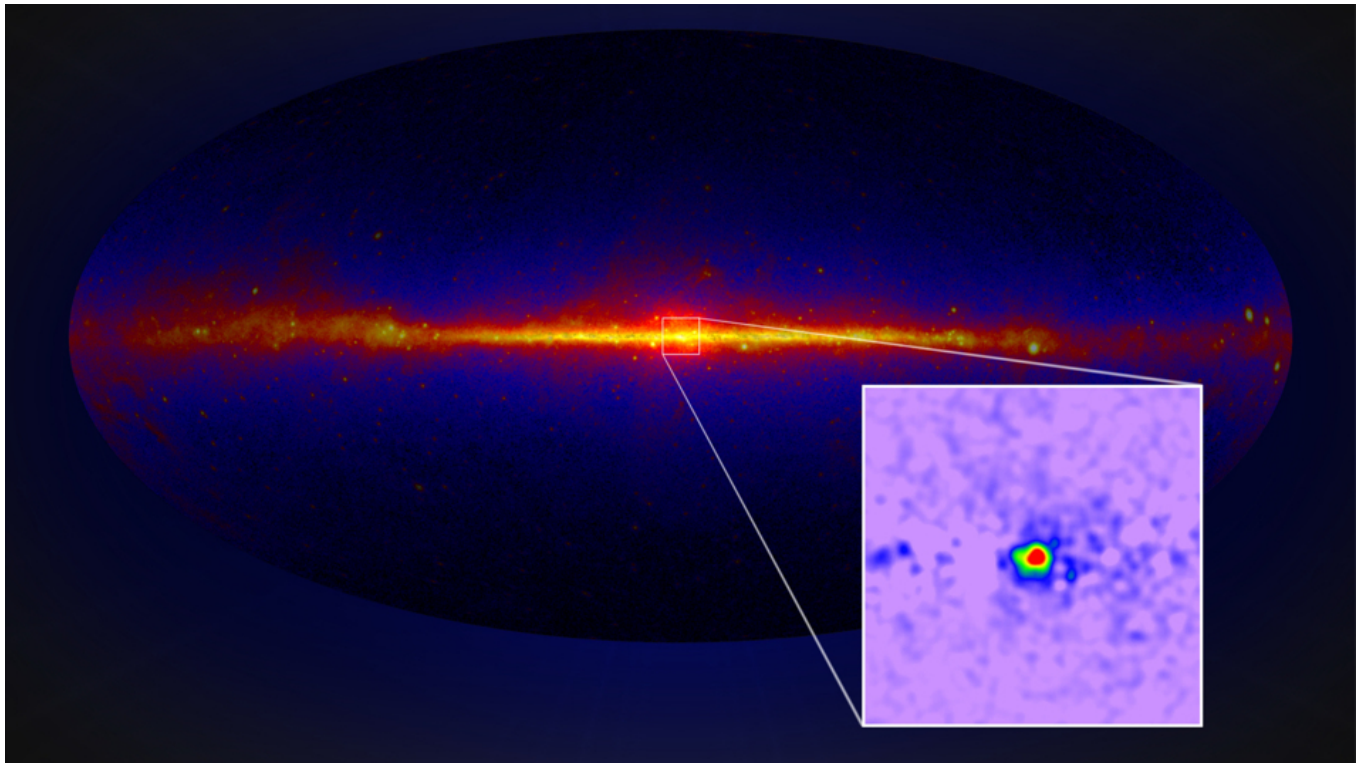
SLAP meeting

Overview

- Simplified models of Dark Matter (DM).
- Gauge-invariant extension of pseudoscalar mediated models, featuring a Two Higgs Doublet Model (2HDM).
- A new LHC search to test parameter space that explains the Galactic Centre Excess (GCE).



Pseudoscalar Simplified Model

$$\mathcal{L} = \frac{m_{a_0}^2}{2} a_0^2 + m_\chi \bar{\chi}\chi + y_\chi a_0 \bar{\chi} i\gamma^5 \chi + \sum_q y_q a_0 \bar{q} i\gamma^5 q$$

χ is DM, a_0 the pseudoscalar and y_q are the standard model yukawa couplings.

Final term does not respect $SU(2)_L \times U(1)_Y$ gauge invariance.

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2HDM portal

Introduce 2 Higgs Doublets $H_i = \left(\phi_i^+, (v_i + h_i + \eta_i)/\sqrt{2}\right)^T$

The vevs are related as $v_2/v_1 \equiv \tan\beta$

The spectrum contains a pseudoscalar $A_0 = \cos\beta\,\eta_2 - \sin\beta\,\eta_1$, a charged scalar $H^\pm = \cos\beta\,\phi_2^\pm - \sin\beta\,\phi_1^\pm$ and two neutral CP-even scalars $h = \cos\alpha\,h_2 - \sin\alpha\,h_1$, $H_0 = -\sin\alpha\,h_2 - \cos\alpha\,h_1$

h is the 125 GeV SM Higgs state in the limit $\beta - \alpha = \pi/2$.

The pseudoscalar A_0 mixes with a_0 via

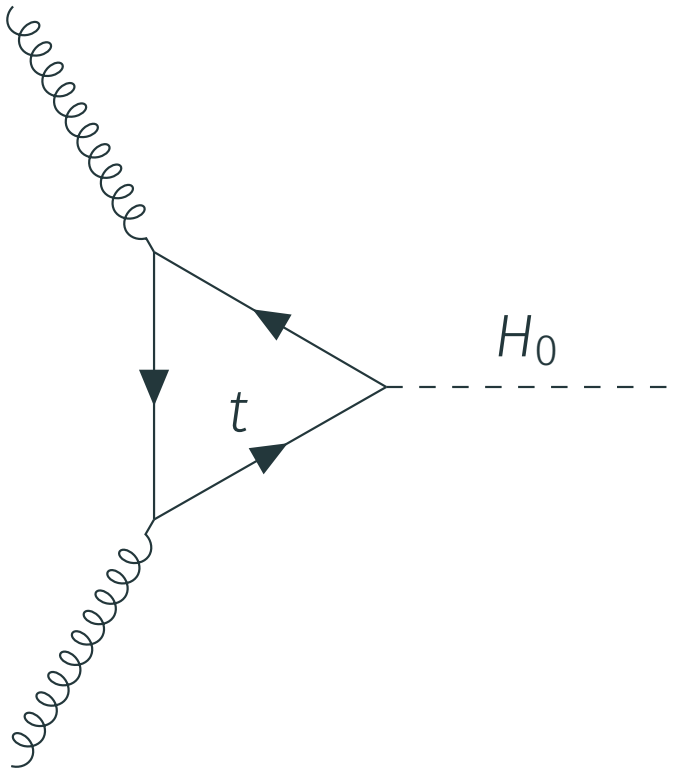
$$V_{\text{portal}} = i\,\kappa\,a_0\,H_1^\dagger H_2 + \text{h.c.} \tag{1}$$

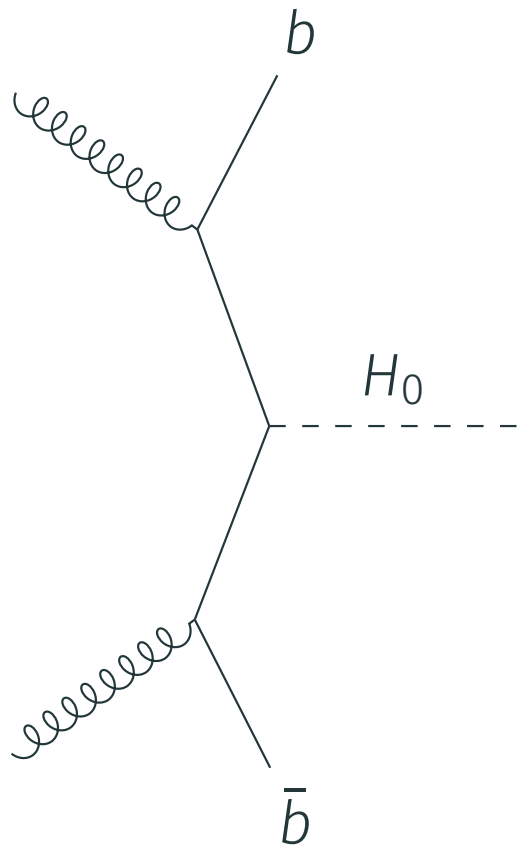
to give two mass eigenstates $a = c_\theta\,a_0 - s_\theta\,A_0$, $A = c_\theta\,A_0 + s_\theta\,a_0$, with $c_\theta \equiv \cos\theta$ and $s_\theta \equiv \sin\theta$.

2HDM portal

- Take $\cos(\beta - \alpha) = c_{\beta-\alpha} = 0$ to make h SM like
- Type-II 2HDM gives couplings to b quarks and τ leptons $\propto \tan\beta = t_\beta$. Coupling to t quark $\propto 1/t_\beta$
- Flavour constraints from $\bar{B} \to X_s\gamma$ and electroweak precision observables require m_A, m_{H_0}, $m_{H^\pm} \gtrsim 500$ GeV.
- Unitarity requires $m_A \leq 1.4$ TeV, $m_{H_0} \leq 1$ TeV.
- $\langle \sigma \mathrm{v} \rangle \simeq 3 \times 10^{-26} \mathrm{cm}^3/\mathrm{s}$ gives the right relic density and fits the Galactic Centre Excess.
- Fix $m_\chi = 30$ GeV to be compatible with the GCE

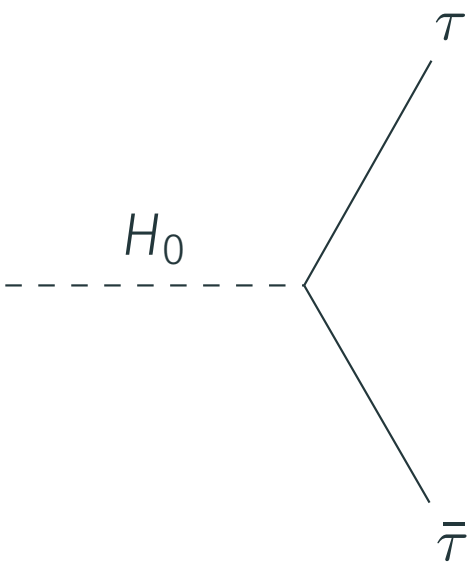
Production mechanisms

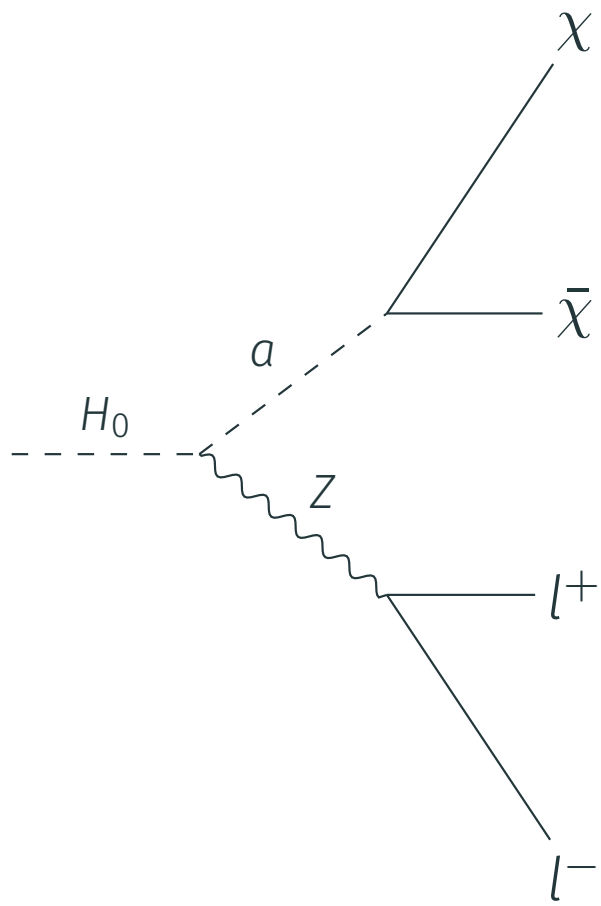




Production via gluon fusion (suppressed at high t_β) or $b\,\bar{b}$ associated (enhanced at high t_β)

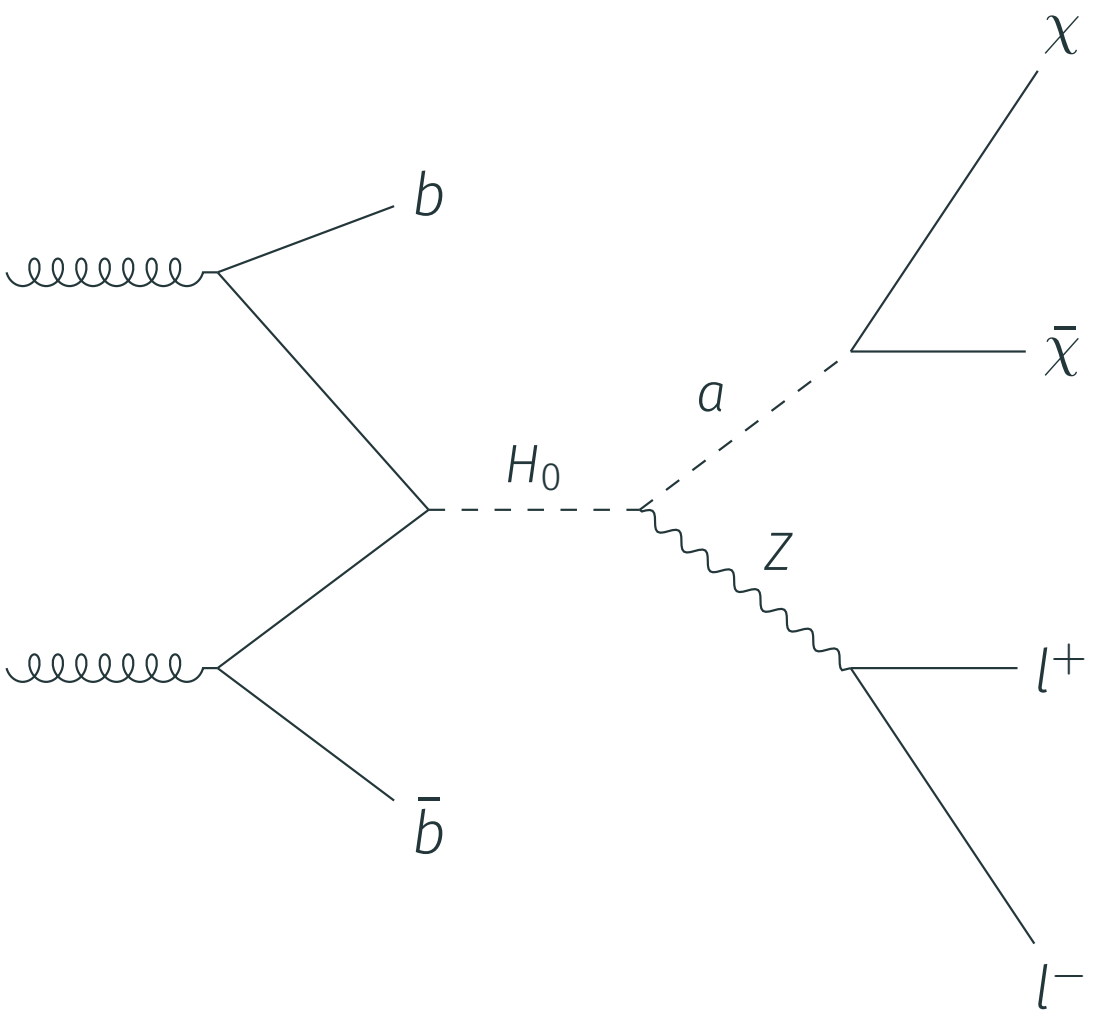
Decay mechanisms





Decay into τ pairs or into mono-Z + missing energy

Our new search



Our new search

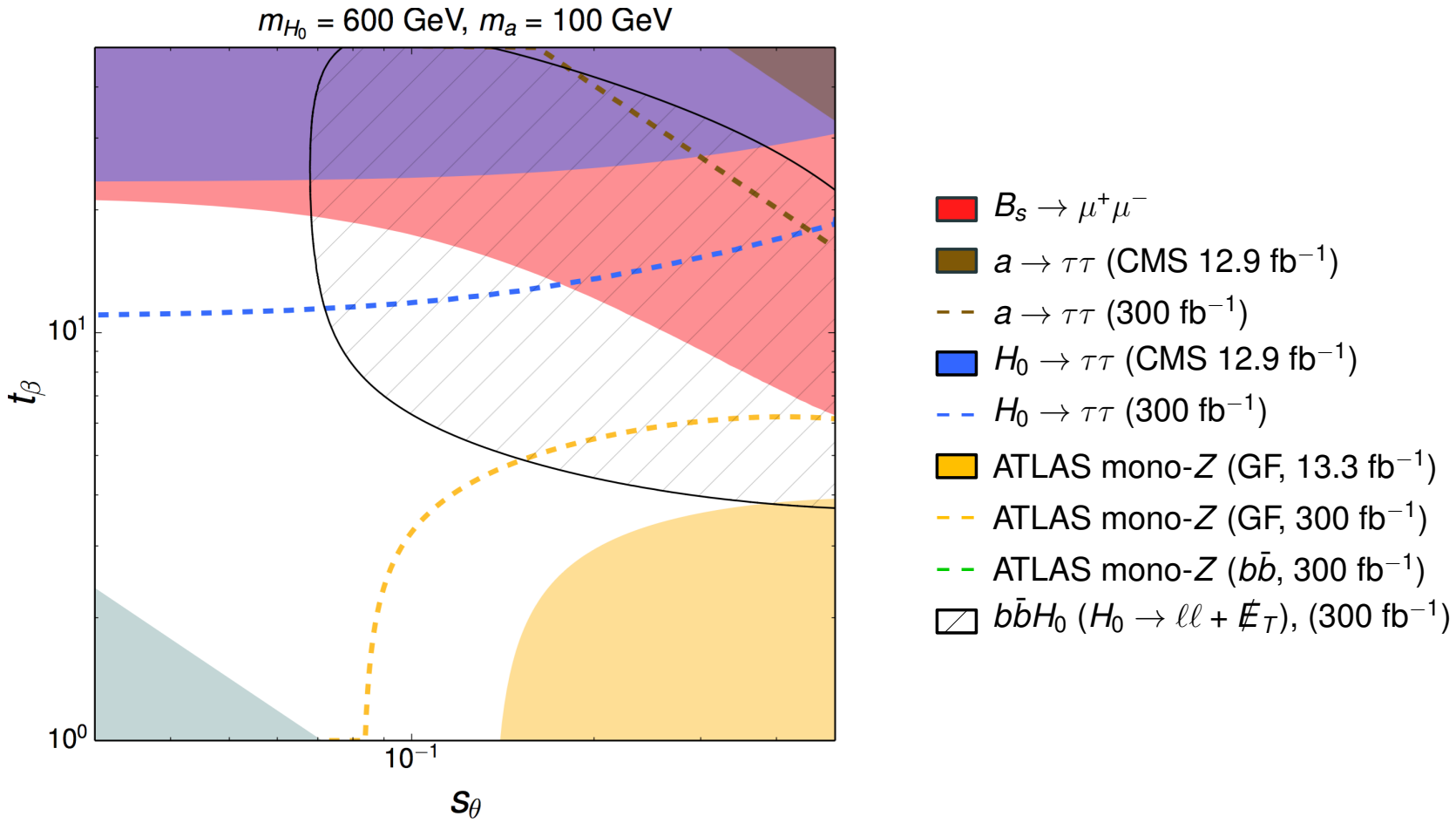
With a $b\,\bar{b}\,l^+\,l^- + \not{E}_T$ final state the dominant background is from $t\,\bar{t}$ decaying leptonically.

We can take advantage of the fact our leptons come from a Z and impose $m_{\ell\ell} \in [76, 106]$.

Z and a are roughly back to back, so impose $|p_T^{\ell\ell} - \not{E}_T|/p_T^{\ell\ell} < 0.5$

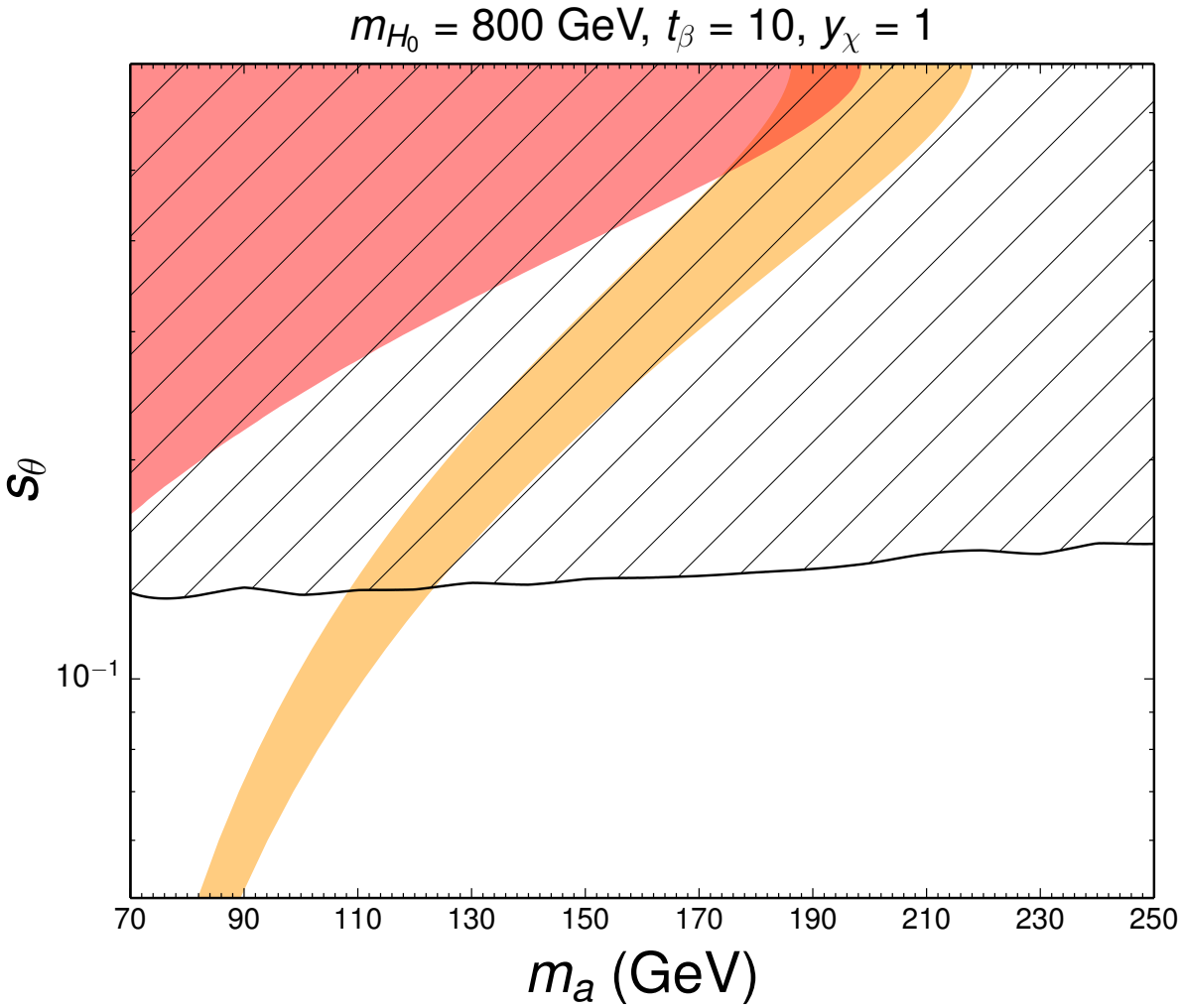
Harsh cuts of $\not{E}_T > 110$ GeV and $m_{T2} > 110$ GeV get the $t\,\bar{t}$ background to a controllable level.

Results



y_χ is fixed by the relic density. If $y_\chi > 4\pi$ the point is shaded grey. The DM mass is $m_\chi = 30$ GeV.

Results



Hatched region is our new search. Red: excluded by $B_s \to \mu^+\mu^-$, orange band: relic density. The DM mass is $m_\chi = 30$ GeV.

Conclusions

- Whether the GCE is dark matter or not, it is important to test its interpretation
- Consistent completions of simplified models are not so simple, and always offer richer phenomenology
- The implications of gauge invariance on the pseudoscalar model has opened up a new channel at the LHC

BACKUP:relic

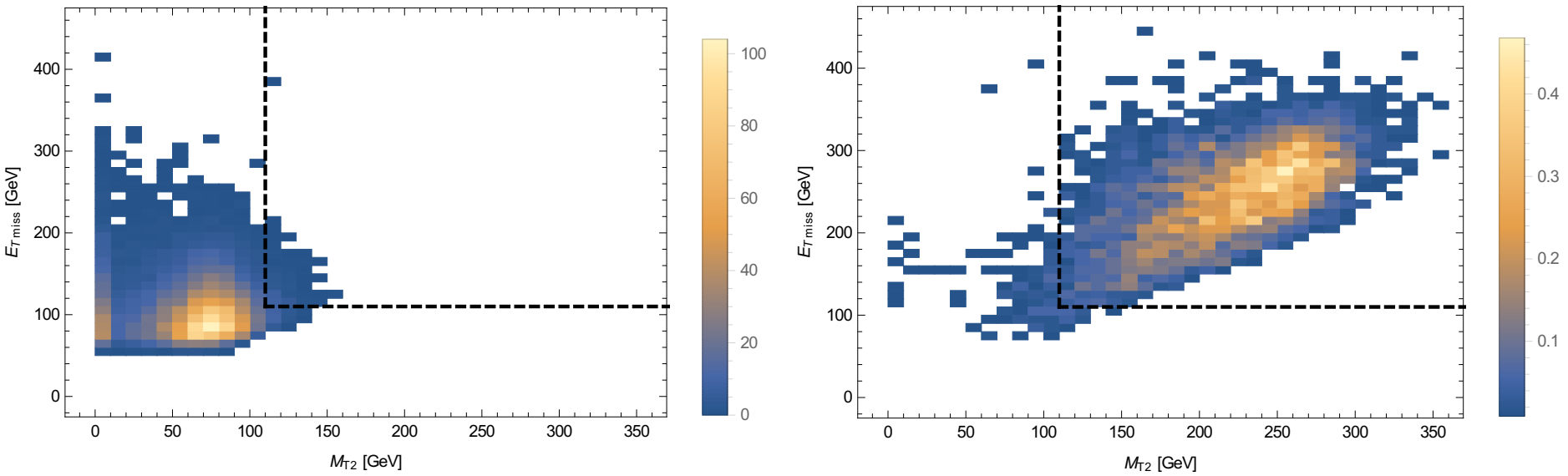
Dominated by s-channel a-exchange when $m_a << m_A$

$$\langle \sigma \mathrm{v} \rangle = \frac{y_\chi^2}{2\pi} \frac{m_\chi^2}{m_a^4} s_\theta^2 c_\theta^2 t_\beta^2 \left[\left(1 - \frac{4m_\chi^2}{m_a^2} \right)^2 + \frac{\Gamma_a^2}{m_a^2} \right]^{-1} \times \sum_f N_C \frac{m_f^2}{v^2} \sqrt{1 - \frac{m_f^2}{m_a^2}}. \quad (2)$$

$\langle \sigma \mathrm{v} \rangle \simeq 3 \times 10^{-26} \mathrm{cm}^3/\mathrm{s}$ gives the right relic density and fits the Galactic Centre Excess.

Fix $m_\chi = 30$ GeV to be compatible with the GCE

BACKUP:cuts



Requiring $\not{E}_T > 110$ GeV and $m_{T2} > 110$ GeV removes most of the background (left) while not affecting most of the signal (right)

BACKUP:MT2

We calculate m_{T2} as

$$m_{T2}^2 \equiv \min_{\vec{k_T}+\vec{q_T}=\vec{p_T}} \left\{ \max \left[m_T^2(p_T^{\vec{\ell}^+}, \vec{k_T}), m_T^2(p_T^{\vec{\ell}^-}, \vec{q_T}) \right] \right\} \tag{3}$$

where the minimisation is over all possible vectors $\vec{k_T}$ and $\vec{q_T}$ that satisfy $\vec{k_T} + \vec{q_T} = \vec{p_T}$

BACKUP