

Heavy quark-philic scalar dark matter

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1606.00072 [JHEP10(2016)117]

1709.00697 [JCAP07(2018)008]

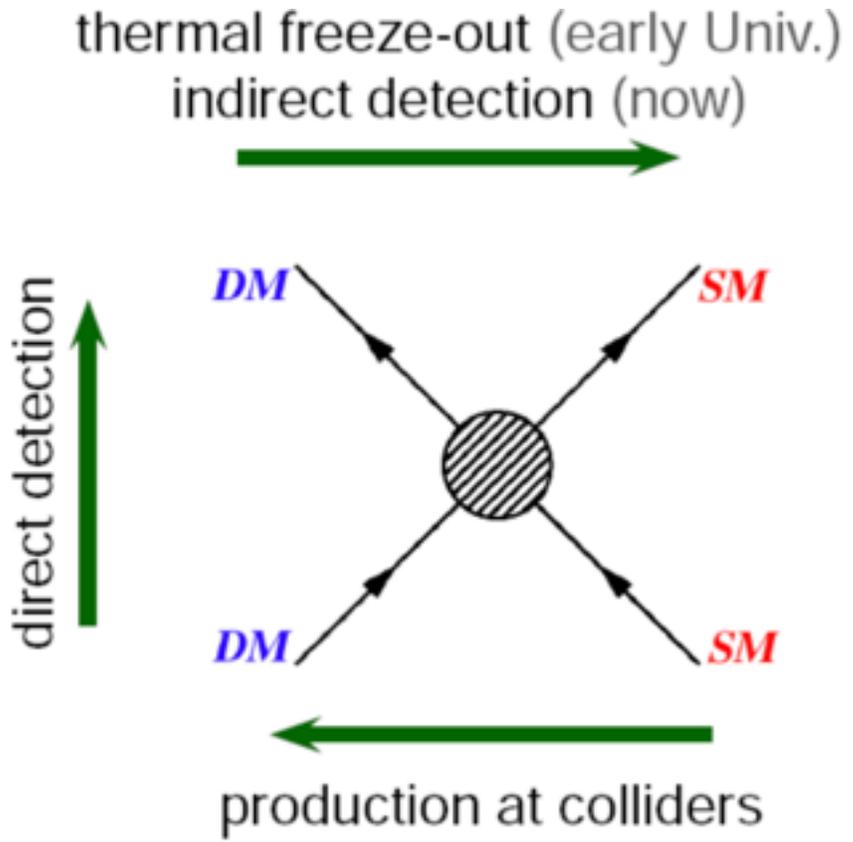
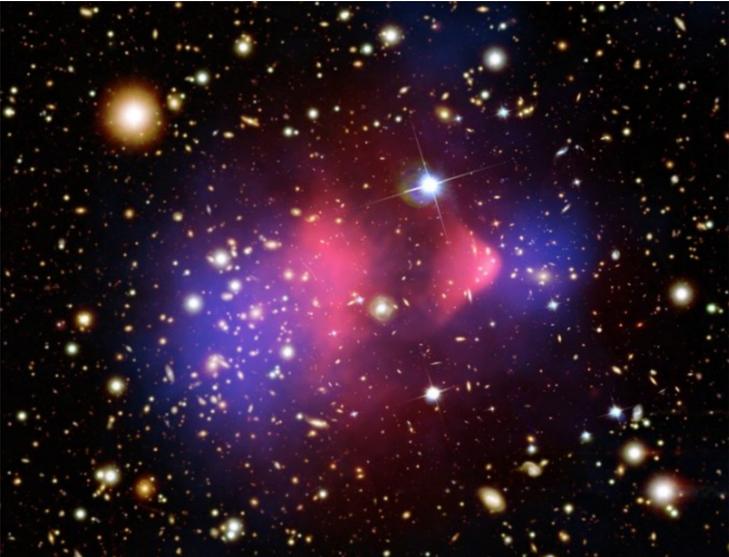
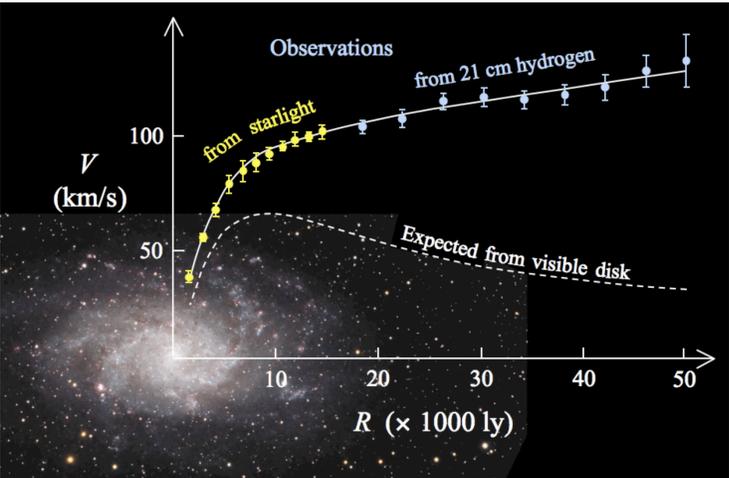
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Outline

- DM hints and detections
- Vector-like portal for DM-SM interaction
 - SM sector: $\{u_R, c_R, t_R\}$ as our choice
- Phenomenology
- Summary

DM hints and detections



https://www.mpi-hd.mpg.de/lin/research_DM.en.html

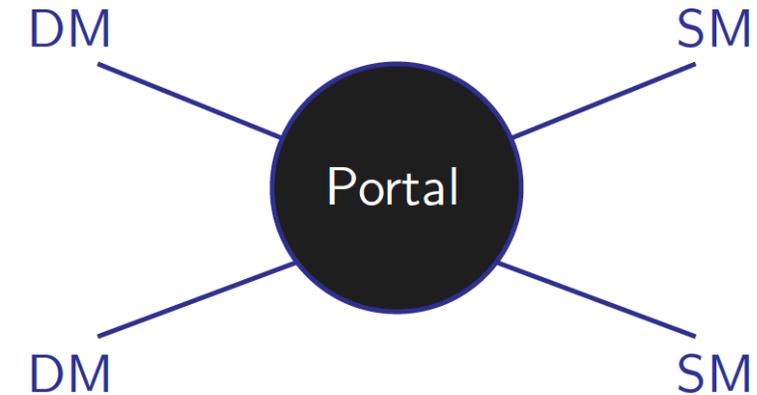
<https://en.wikipedia.org>

Portals of DM-SM interaction

- s -channel (e.g. scalar DM χ)

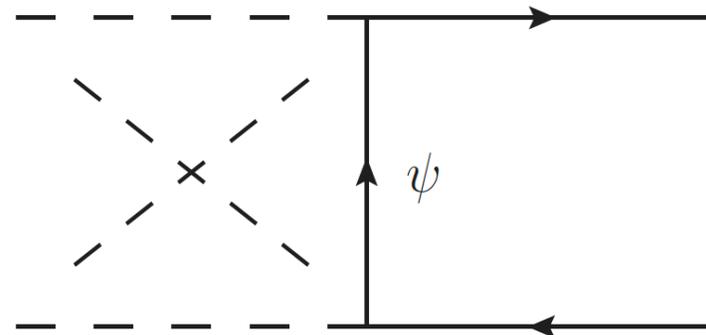
- Higgs : $\chi^* \chi H^+ H$

- Z boson: $\chi^* \overleftrightarrow{\partial}_\mu \chi \frac{H^+ \overleftrightarrow{D}_\mu H}{\Lambda^2}$ (after EWSB)



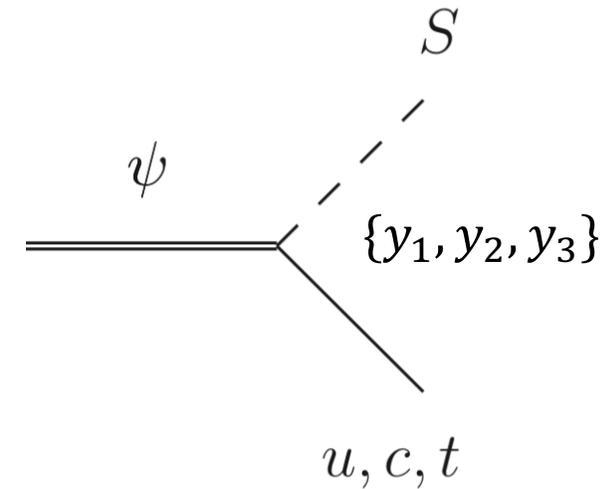
[Arcadi et al, 1703.07364]

- t -channel, e.g. vector-like fermion as mediator



Model set-up

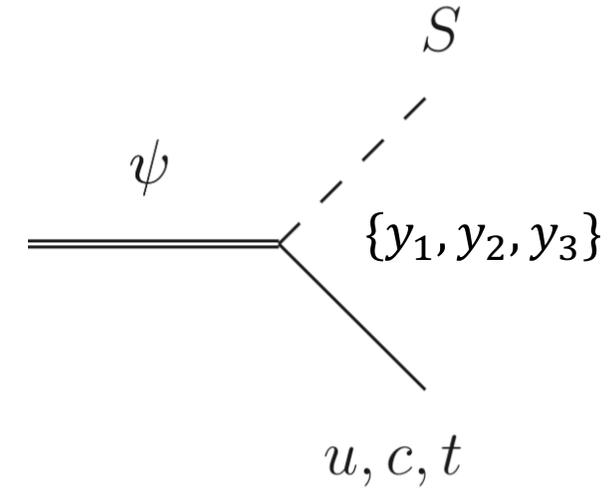
- DM: real scalar S
- Vector-like (VL) fermion ψ , $m_\psi > m_S$
 - (ψ, U_i) same quantum number
 - no chiral anomaly



$$\begin{aligned}\mathcal{L}_{\text{new}} &= \mathcal{L}_{\text{fermion}} + \mathcal{L}_{\text{scalar}} + \mathcal{L}_{\text{Yukawa}}, \\ \mathcal{L}_{\text{fermion}} &= \bar{\psi}(i\not{D} - m_\psi)\psi, \\ \mathcal{L}_{\text{scalar}} &= \frac{1}{2}\partial^\mu S\partial_\mu S - \frac{1}{2}m_S^2 S^2 - \frac{1}{4!}\lambda_S S^4 - \frac{1}{2}\lambda_{SH} S^2 H^2, \\ \mathcal{L}_{\text{Yukawa}} &= -y_1 S \bar{\psi}_L u_R - y_2 S \bar{\psi}_L c_R - y_3 S \bar{\psi}_L t_R + h.c.,\end{aligned}$$

Model set-up

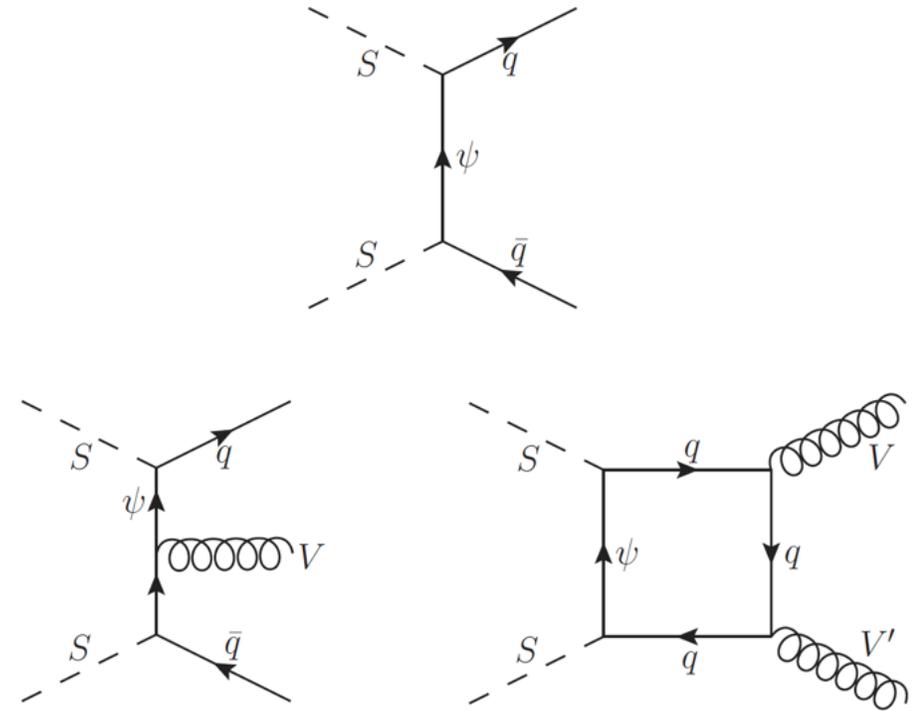
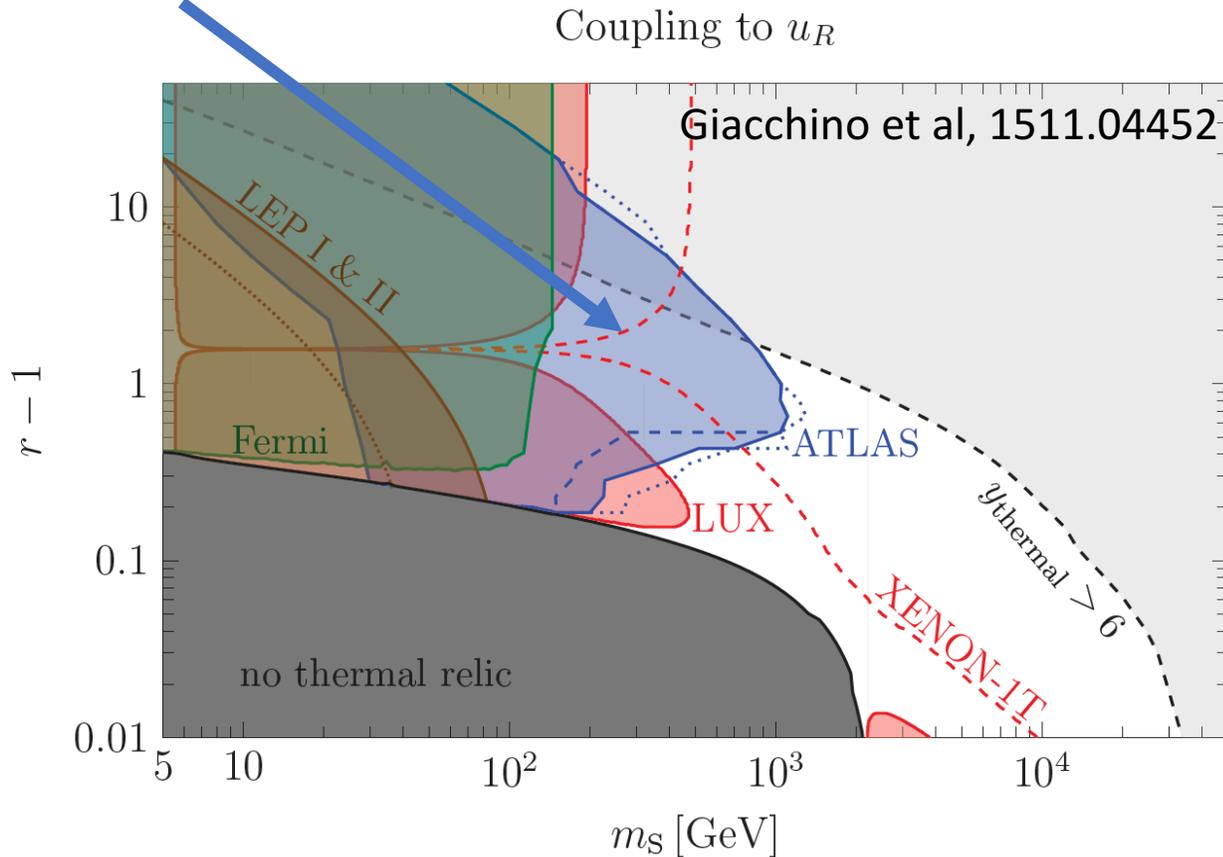
- Z_2 parity to stabilize DM: S, ψ are odd
 - no mass mixing $(S, H), (\psi, U_i)$
 - $Br(\psi \rightarrow SU_i^{(*)}) = 100\%$
 - LHC searches for VL (T, B) do not apply



$$\begin{aligned} \mathcal{L}_{\text{new}} &= \mathcal{L}_{\text{fermion}} + \mathcal{L}_{\text{scalar}} + \mathcal{L}_{\text{Yukawa}}, \\ \mathcal{L}_{\text{fermion}} &= \bar{\psi}(i\not{D} - m_\psi)\psi, \\ \mathcal{L}_{\text{scalar}} &= \frac{1}{2}\partial^\mu S\partial_\mu S - \frac{1}{2}m_S^2 S^2 - \frac{1}{4!}\lambda_S S^4 - \frac{1}{2}\lambda_{SH} S^2 H^2, \\ \mathcal{L}_{\text{Yukawa}} &= -y_1 S \bar{\psi}_L u_R - y_2 S \bar{\psi}_L c_R - y_3 S \bar{\psi}_L t_R + h.c., \end{aligned}$$

$y_1 \gg y_2, y_3$: light quark-philic scalar DM

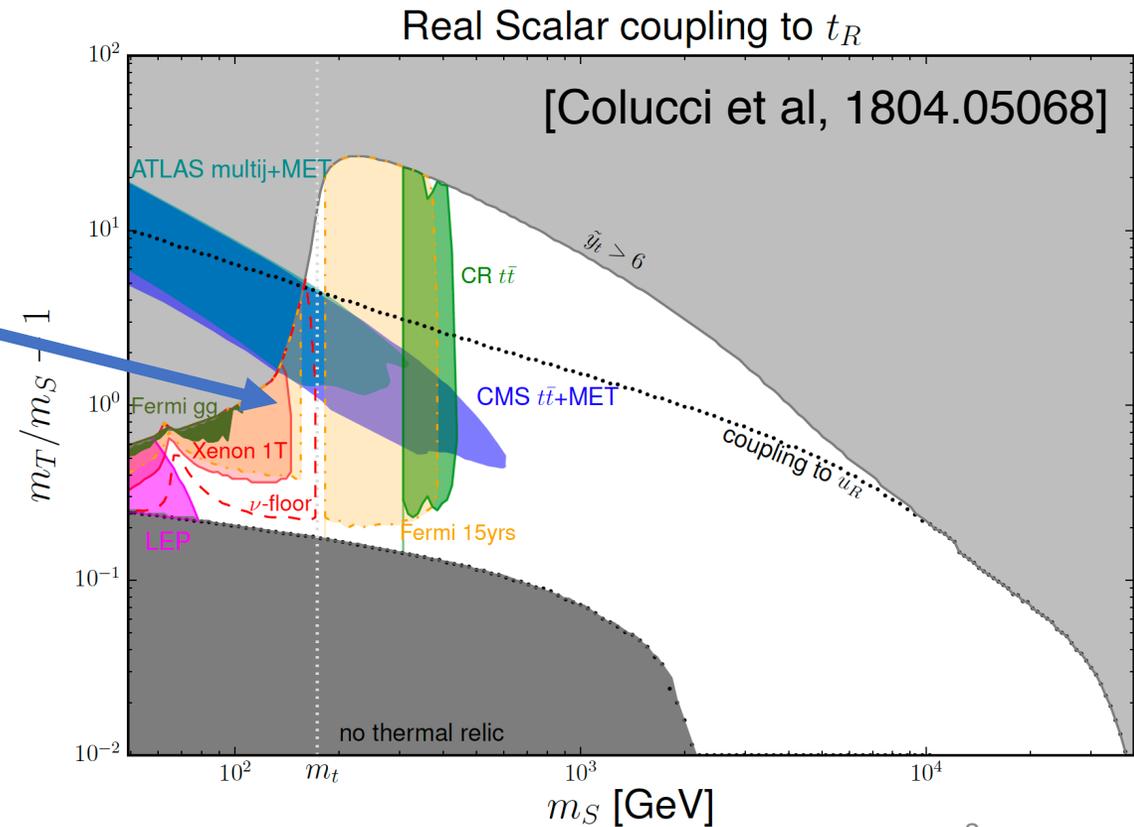
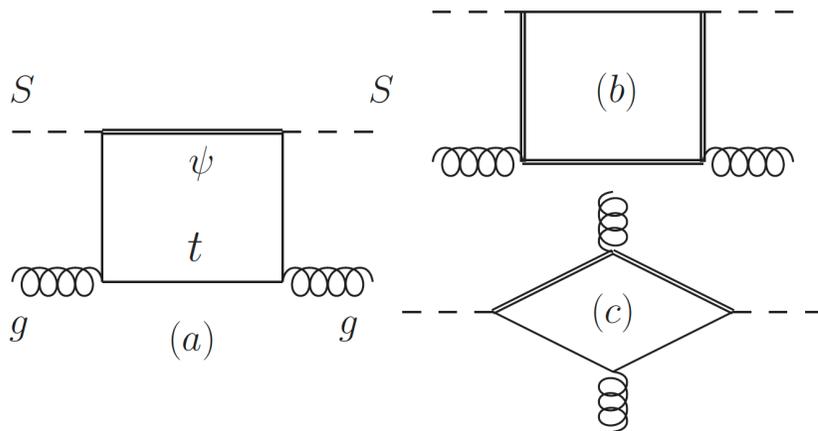
- **Real scalar** $SS \rightarrow f\bar{f}$ is **d -wave** dominated
 - $\langle\sigma v\rangle \simeq a + bv^2 + \mathbf{d}v^4$, NLO effects are significant
- strong constraints from LUX/XENON-1T



$y_3 \gg y_1, y_2$: top-philic scalar DM

- $SS \rightarrow t\bar{t}$ is closed for $m_S < m_t$, one needs
 - co-annihilations: $S\psi \rightarrow tg, t\gamma$
 - loop-annihilations: $SS \rightarrow VV^{(\prime)}$, $V^{(\prime)} = g, \gamma, Z$ \rightarrow γ -ray line signals

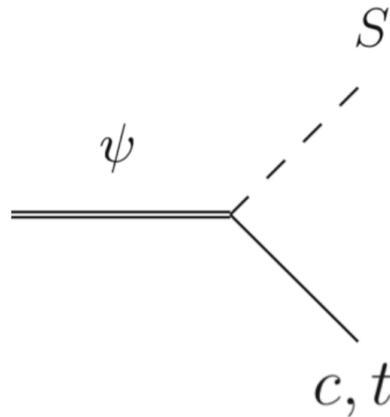
- DM-gluon scattering via loops
- weak constraints from XENON-1T



In this work

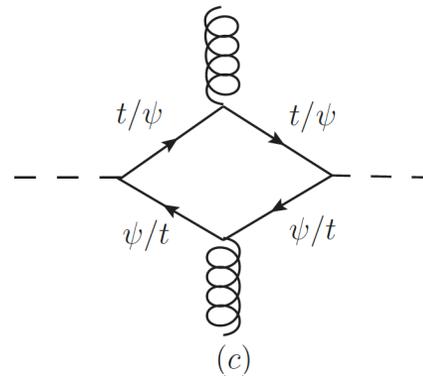
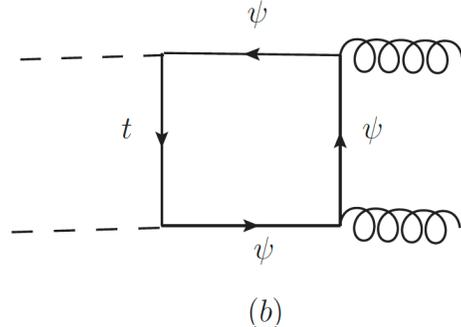
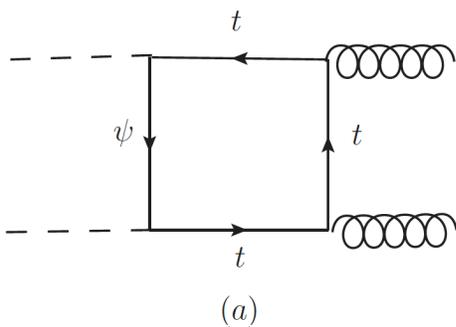
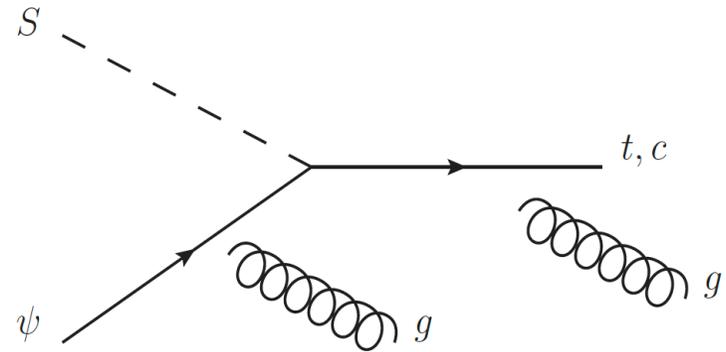
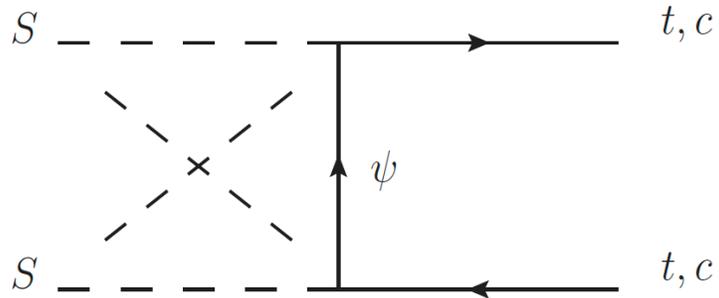
- We consider $y_2, y_3 \gg y_1$, Heavy quark-philic scalar DM

$$\mathcal{L} \supset -y_2 S \overline{\psi}_L c_R - y_3 S \overline{\psi}_L t_R + \text{h.c.}$$



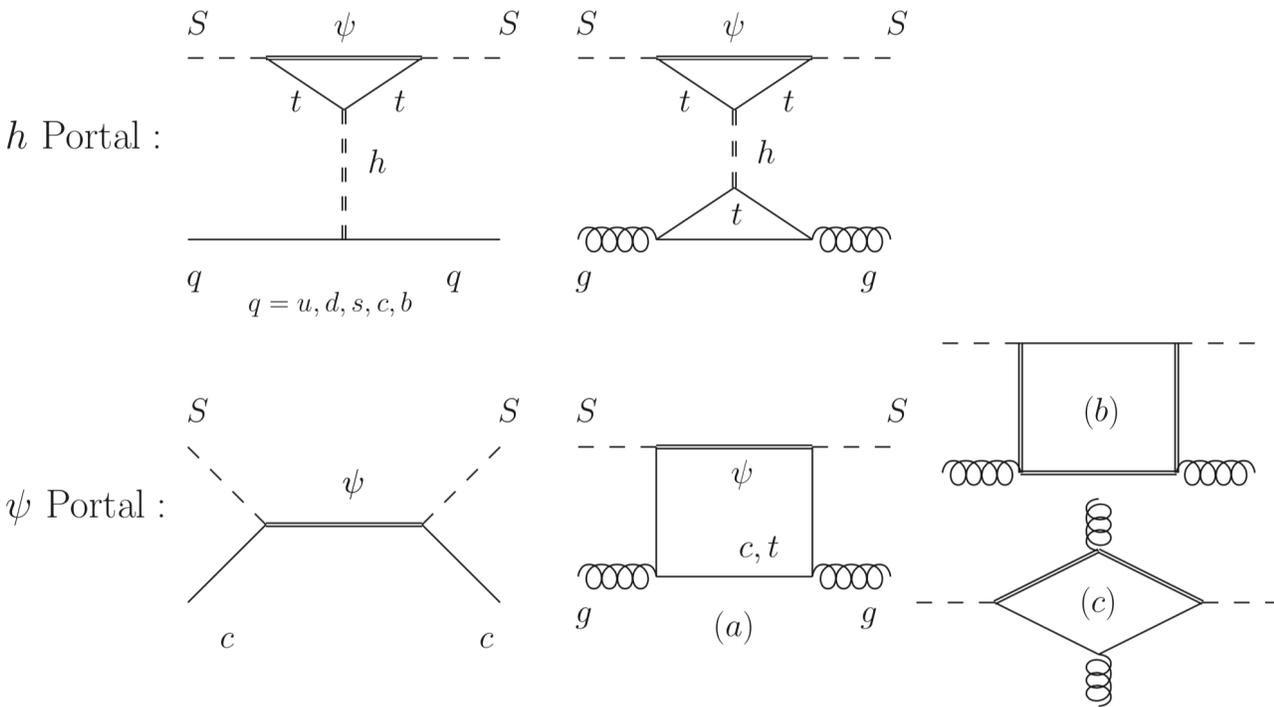
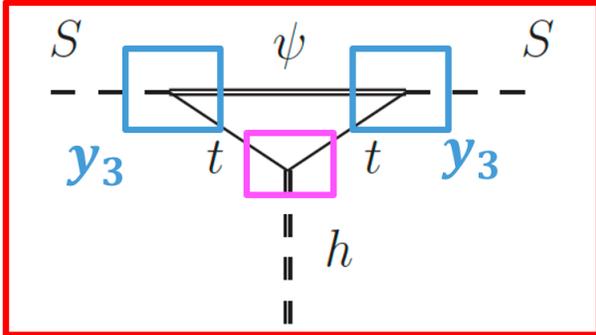
Thermal Relic & Indirect Detection

- $m_S < m_t$, more channels available, e.g. $SS \rightarrow f\bar{f}^{(\prime)}$, $f^{(\prime)} = c, t$



DM-nucleon scattering

- We focus on vector-like portal (VLP)
 - by tuning VLP (y_3) to cancel HP (λ_{SH}) at 1-loop
- heavy *d.o.f.* $\{\psi, t, h\}$ are integrated out at $\mu_{EFT} = m_Z$
- RGE and $\{c,b\}$ threshold effects are included



Indirect Detection: Fermi dwarf γ -spectrum

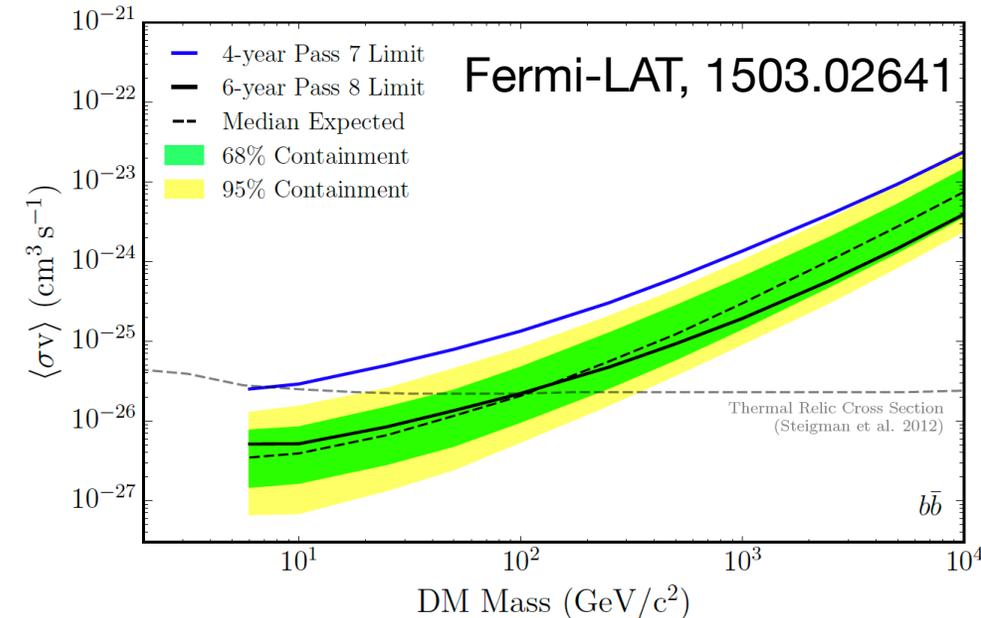
- We compare number of photons produced in a single DM annihilation:

$$N_{\gamma}^{th} = 2N_{\gamma,t}(m_S) \times \sigma v(SS \rightarrow t\bar{t})_s + 2N_{\gamma,c}(m_S) \times \sigma v(SS \rightarrow c\bar{c})_s \quad (5.1)$$

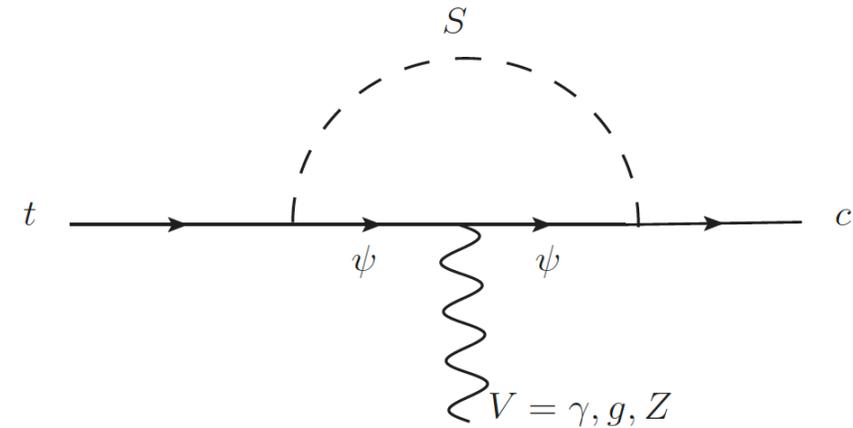
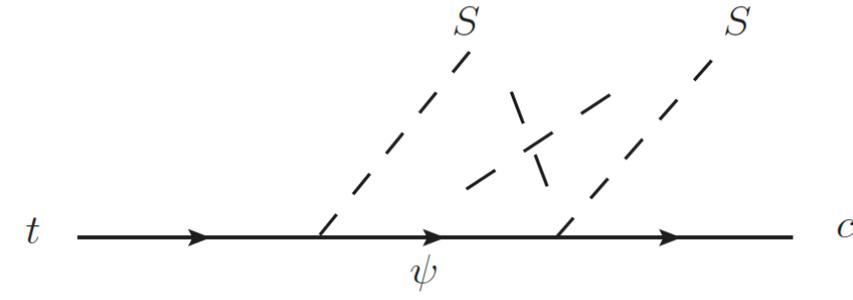
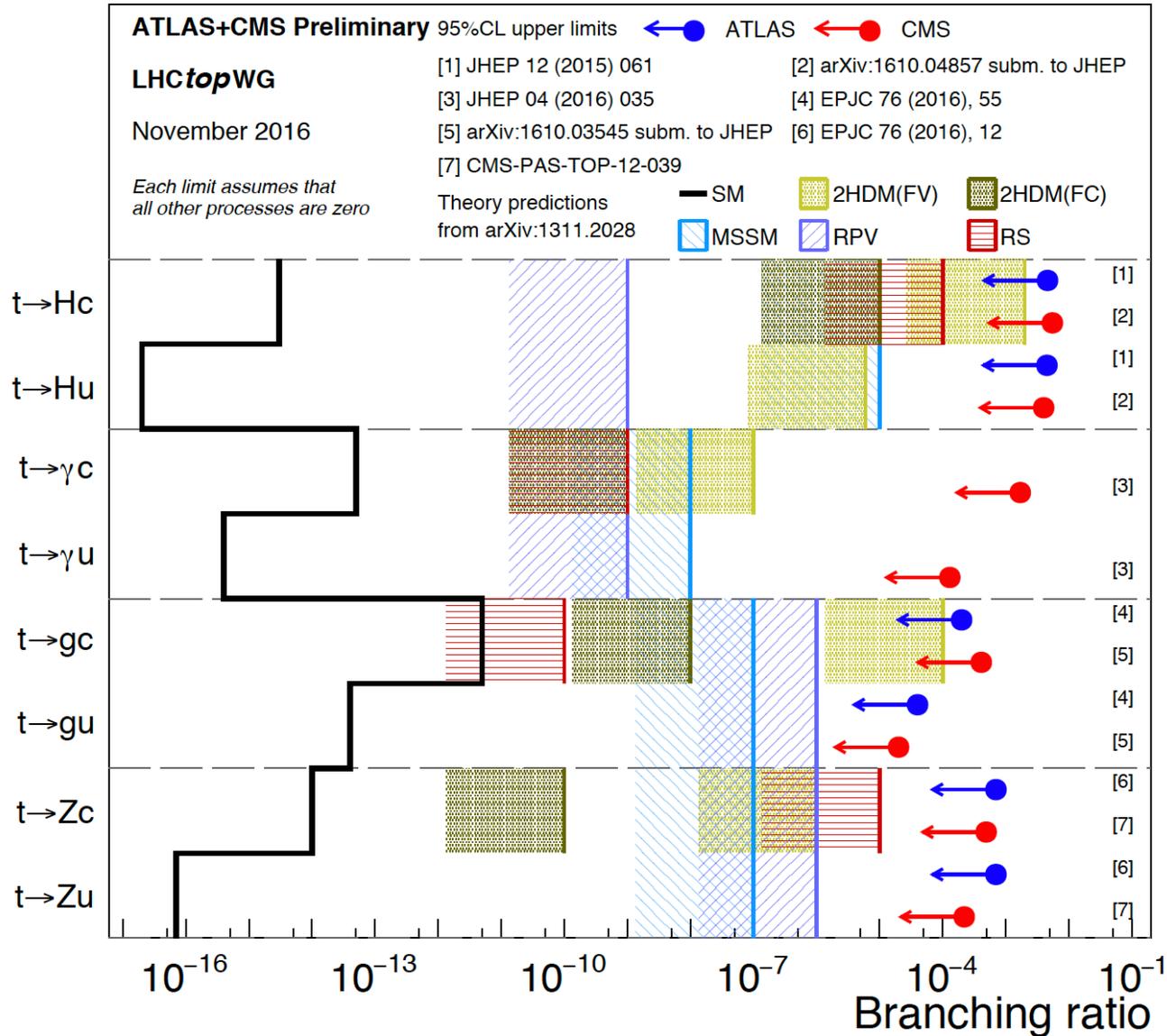
$$+ \left(N_{\gamma,t}(E_t) + N_{\gamma,c}(E_c) \right) \times \sigma v(SS \rightarrow t\bar{c} + c\bar{t})_s + 2N_{\gamma,g}(m_S) \times \sigma v(SS \rightarrow gg)_s ,$$

$$N_{\gamma}^{exp} = 2N_{\gamma,b}(m_S) \times \sigma v_{b\bar{b}}(m_S),$$

$$N_{\gamma}^{th} \lesssim N_{\gamma}^{exp}$$



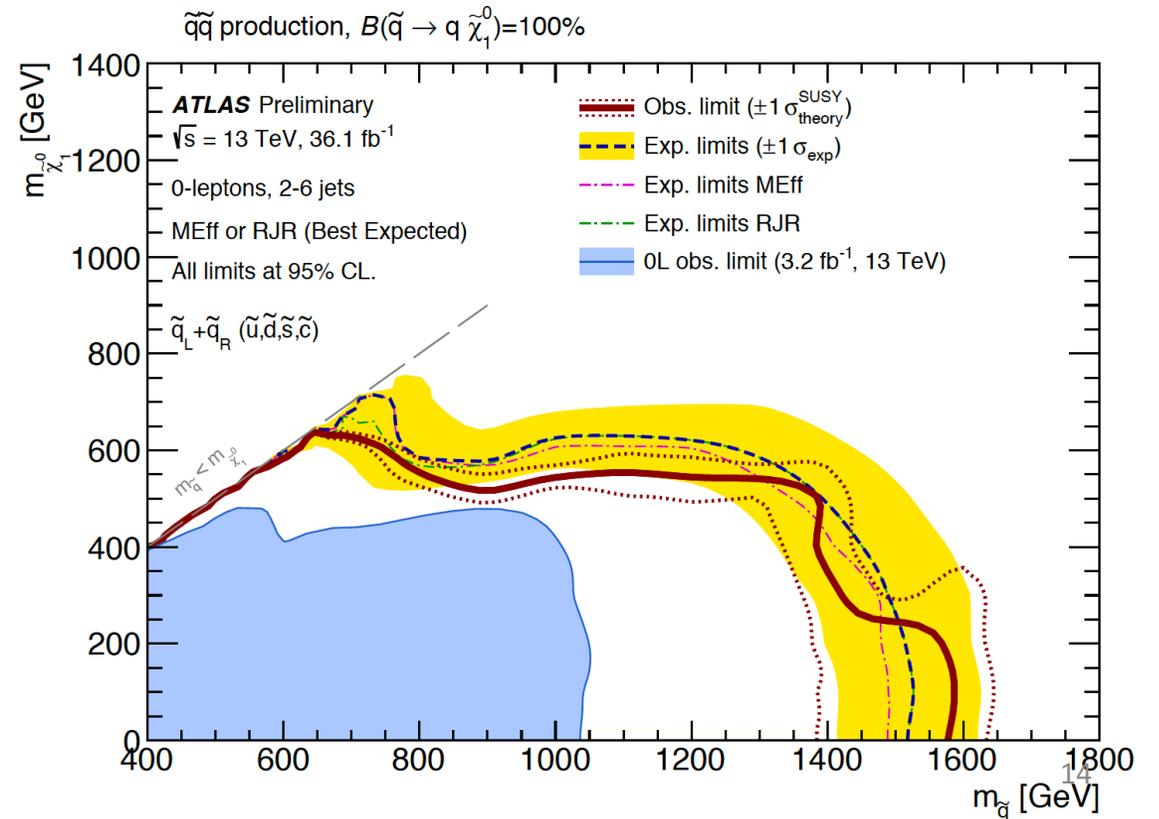
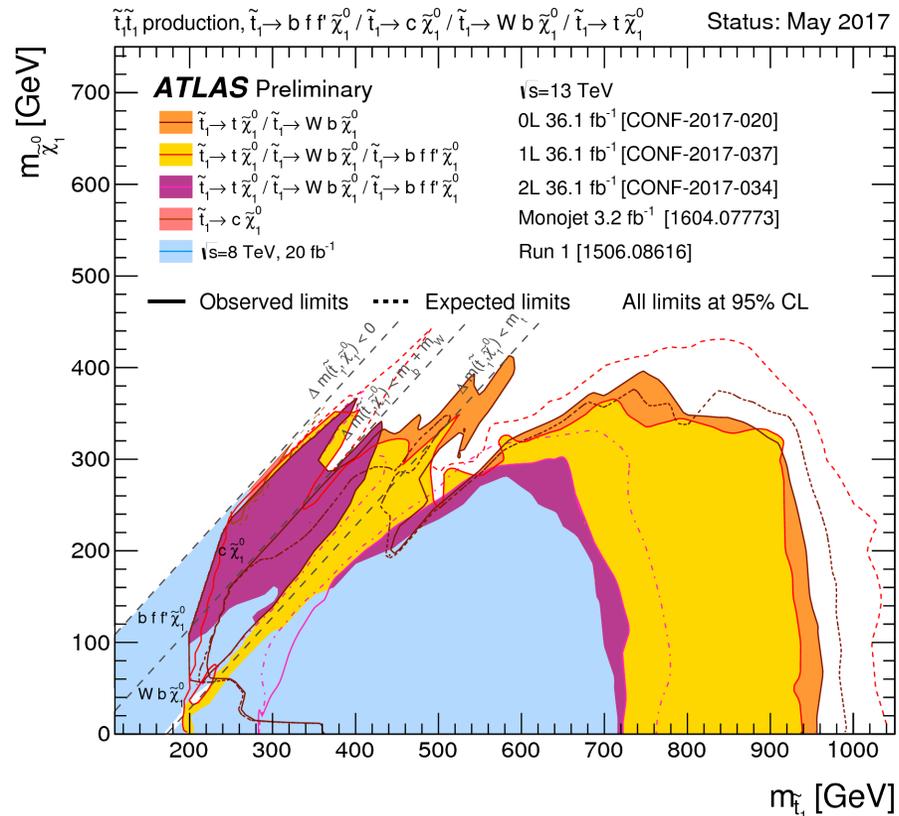
Top FCNC $< 10^{-4}$



Bhowmik, CKM2016

Collider signals (ATLAS 36 fb^{-1} @ 13 TeV)

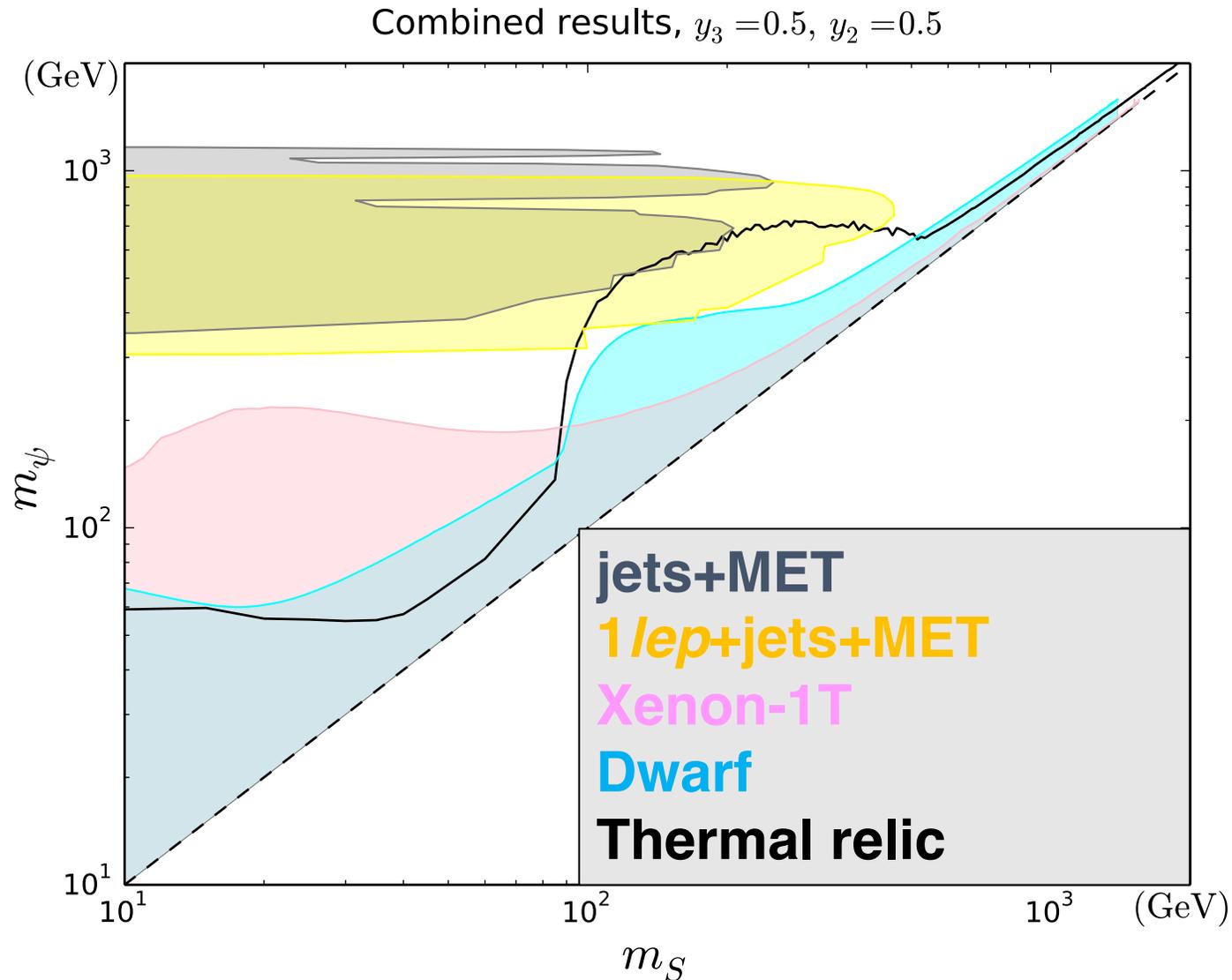
- $pp \rightarrow \psi\bar{\psi} \rightarrow SS + t/c + t/c$, i.e. $E_t^{miss} + t\bar{t}, jj, tj$
- similar to SUSY stop and first 2 gen. squarks



Combined results (color regions are excluded)

$$y_3 = 0.5$$

$$y_2 = 0.5$$



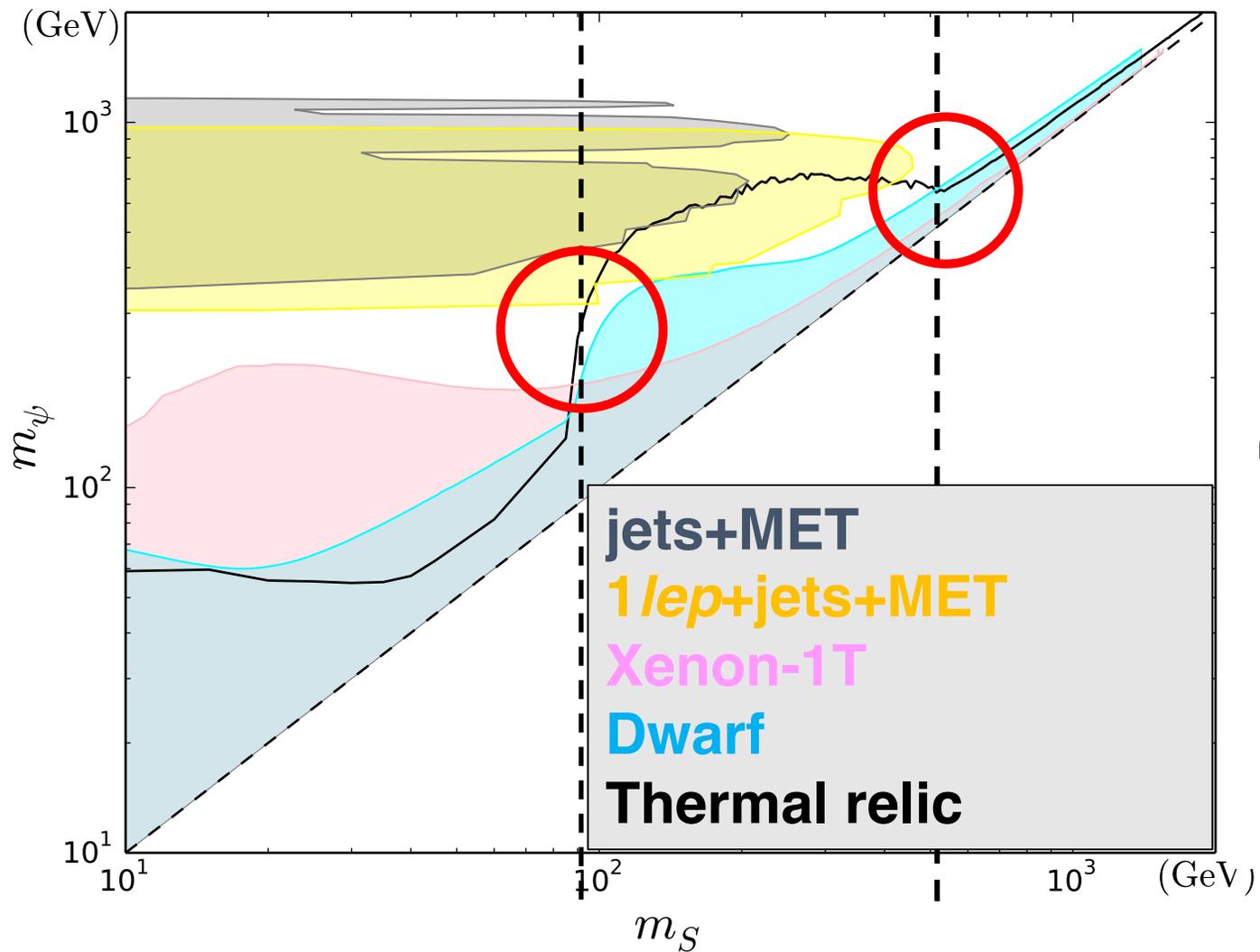
$$y_3 = 0.5$$

$$y_2 = 0.5$$

$$m_S \sim \frac{m_t}{2}$$

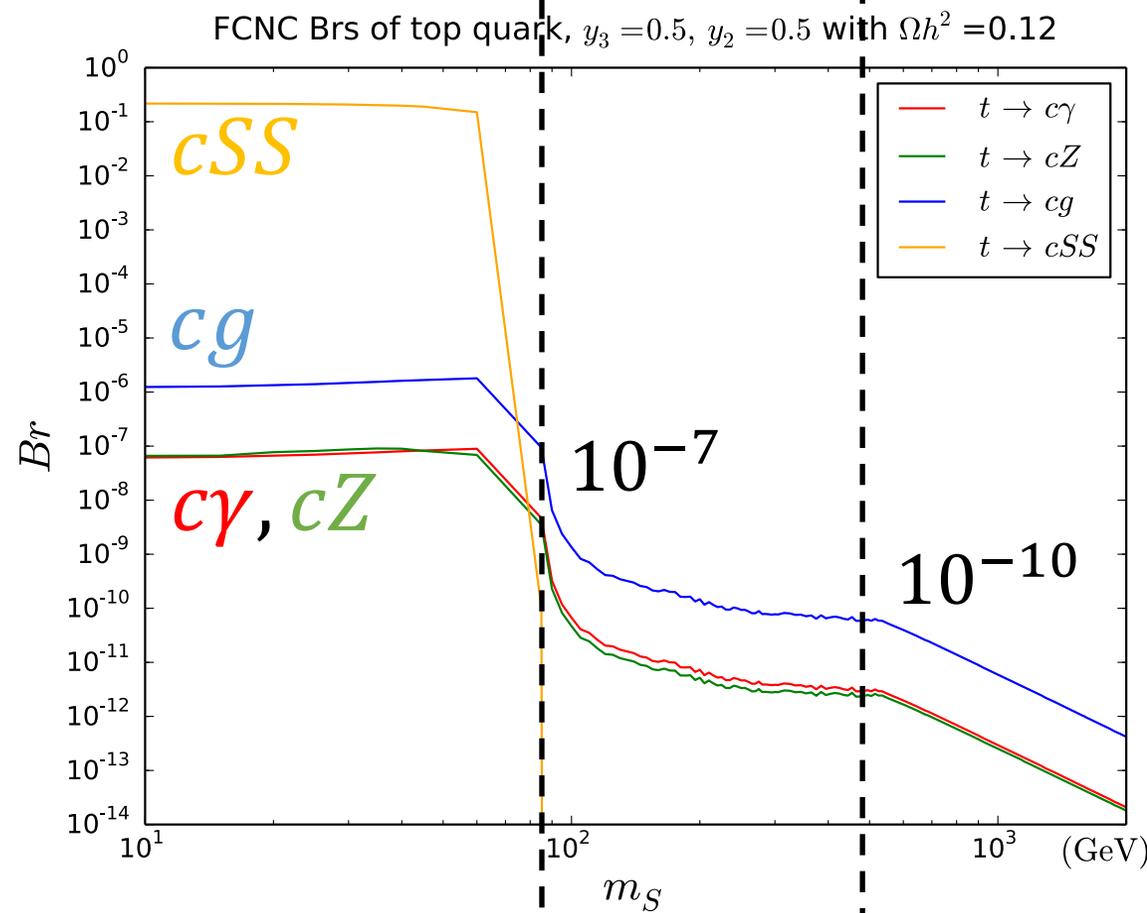
$$m_S \sim 500 \text{ GeV}$$

Combined results, $y_3 = 0.5, y_2 = 0.5$



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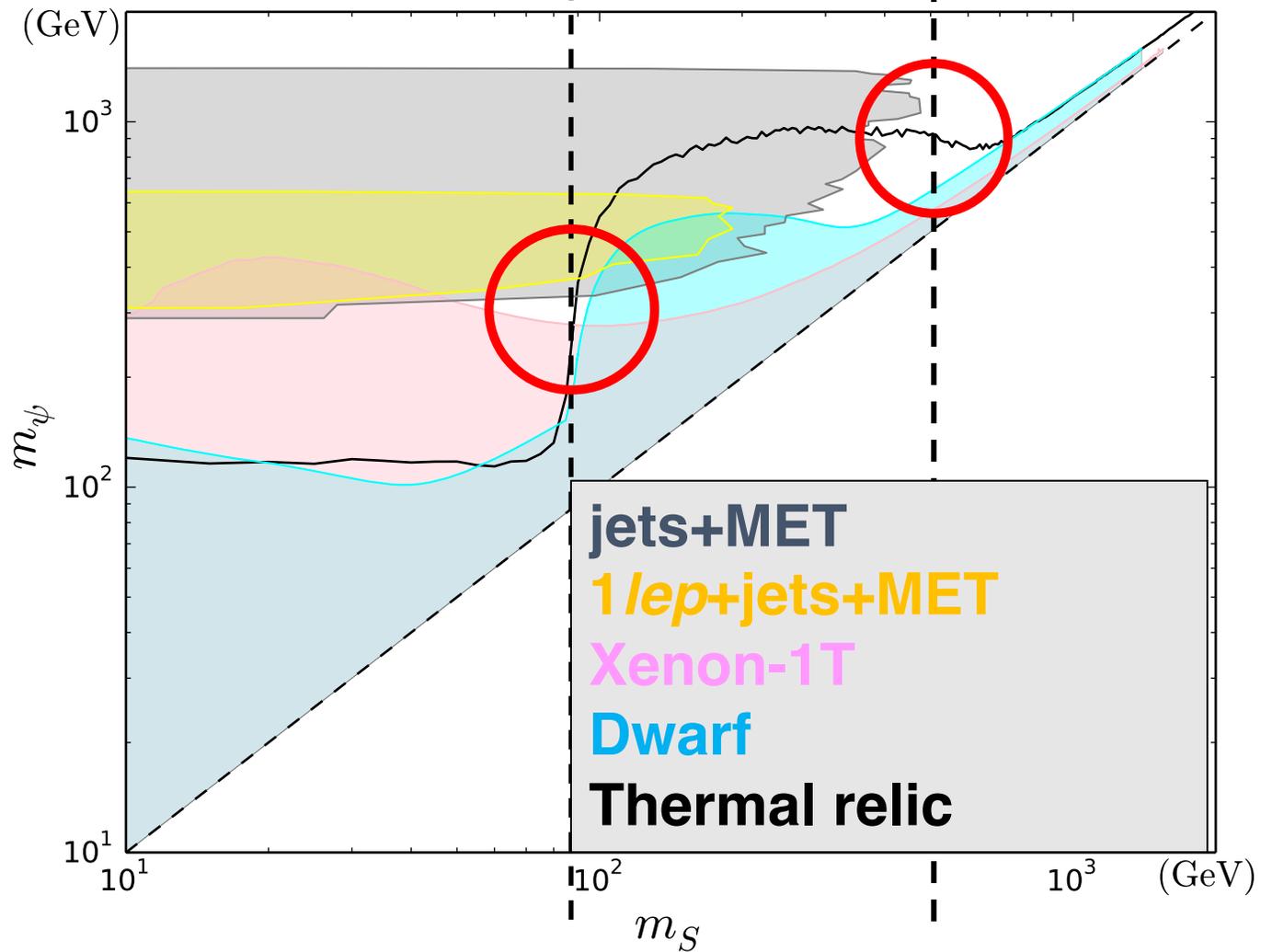
$$y_3 = 0.5$$

$$y_2 = 1.0$$

$$m_S \sim \frac{m_t}{2}$$

$$m_S \sim 500 \text{ GeV}$$

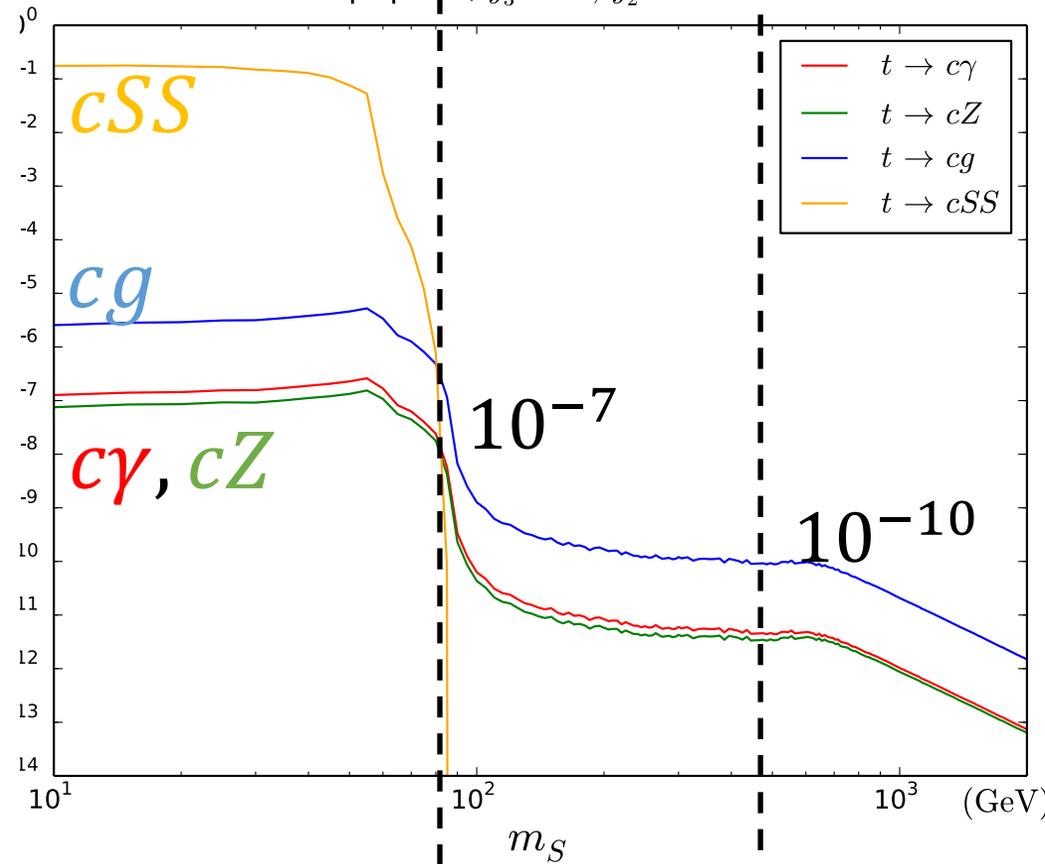
Combined results, $y_3 = 0.5, y_2 = 1.0$



$$m_S \sim \frac{m_t}{2}$$

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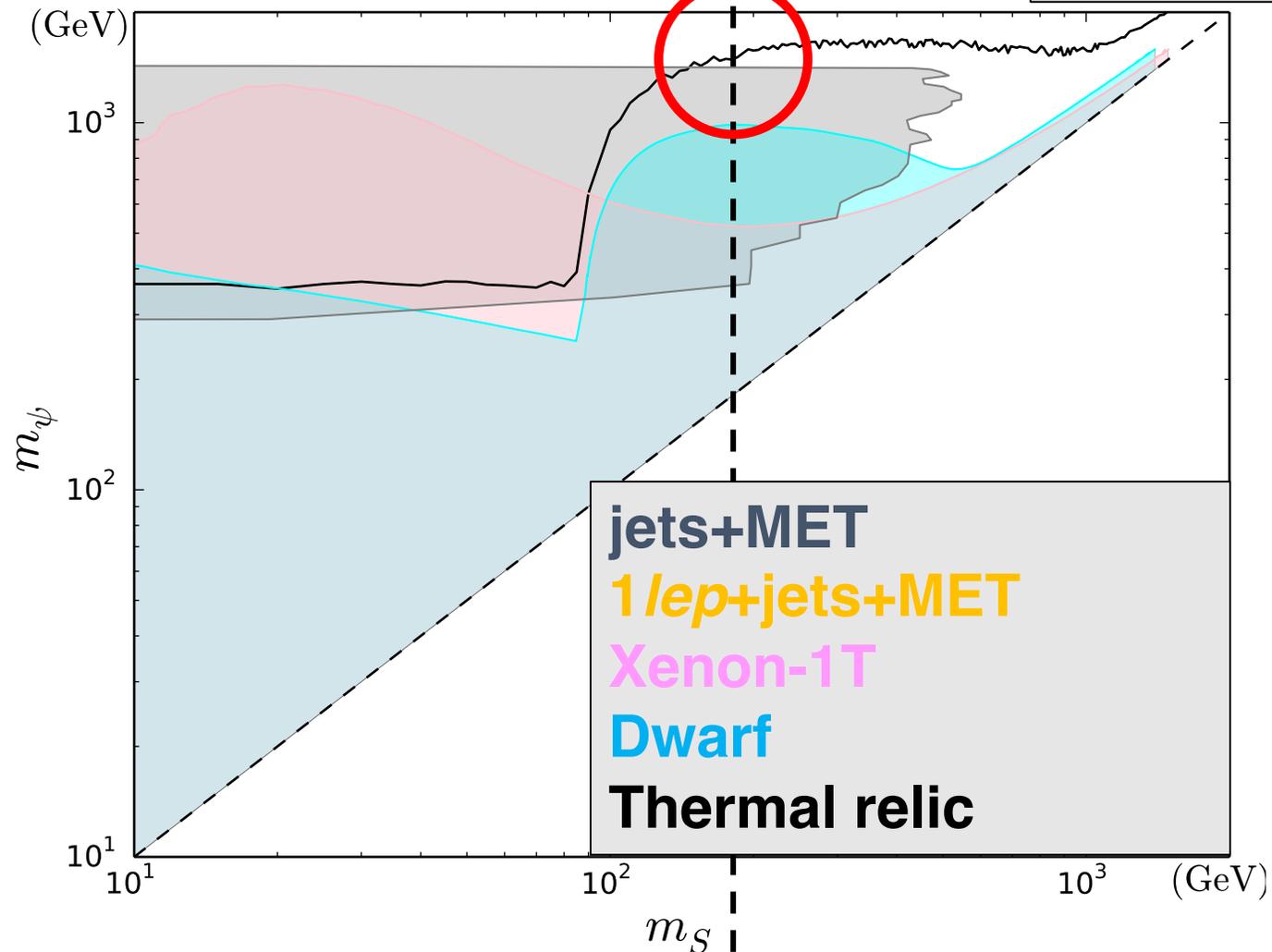
FCNC Brs of top quark, $y_3 = 0.5, y_2 = 1.0$ with $\Omega h^2 = 0.12$



$$y_3 = 0.5$$

$$y_2 = 3.0$$

Combined results, $y_3 = 0.5, y_2 = 3.0$

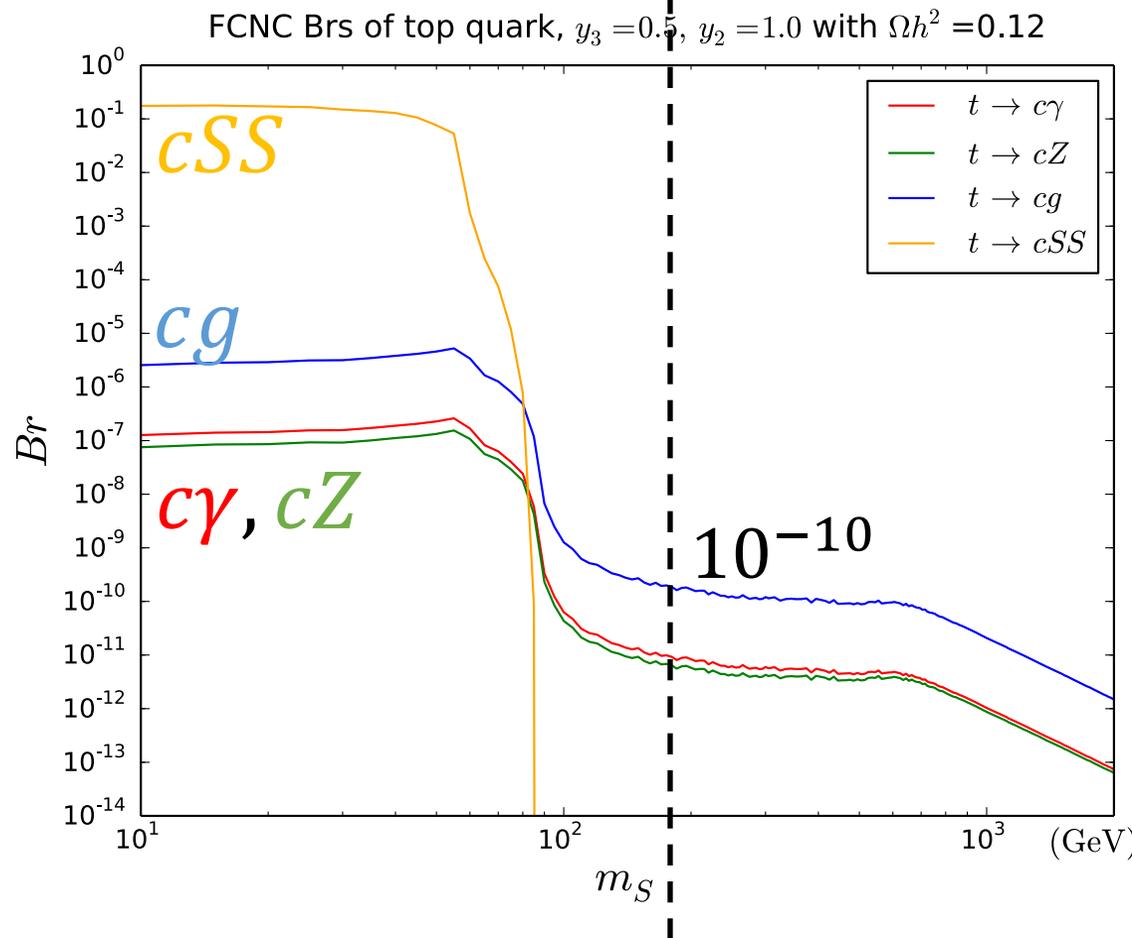


Thermal relic DM

with $m_S < m_t$

are almost **excluded**

$$m_S \sim m_t$$



Summary

- We considered a real scalar DM S , coupling to $\{c_R, t_R\}$ via a vector-like fermion ψ .
- XENON1T constraints can be strong through S - c_R coupling y_2
 - for $m_S < m_t/2$, $y_2 = 1$ (3) excludes $m_\psi < 400$ (1000) GeV
- loop correction to λ_{SH} can be sizable through S - t_R coupling y_3
 - one can tune y_3 to suppress Higgs portal-induced constraints
- For $y_2, y_3 \sim O(1)$, thermal relic $m_S < m_t$ are almost excluded
 - top FCNC Brs $\sim 10^{-7}$, below current bounds $\sim 10^{-4}$

Thank you for your attention