INTEGRATING IN THE HIGGS PORTAL TO FERMION DARK MATTER

based on JHEP 1509 (2015) 015 with Ayres Freitas and Jure Zupan

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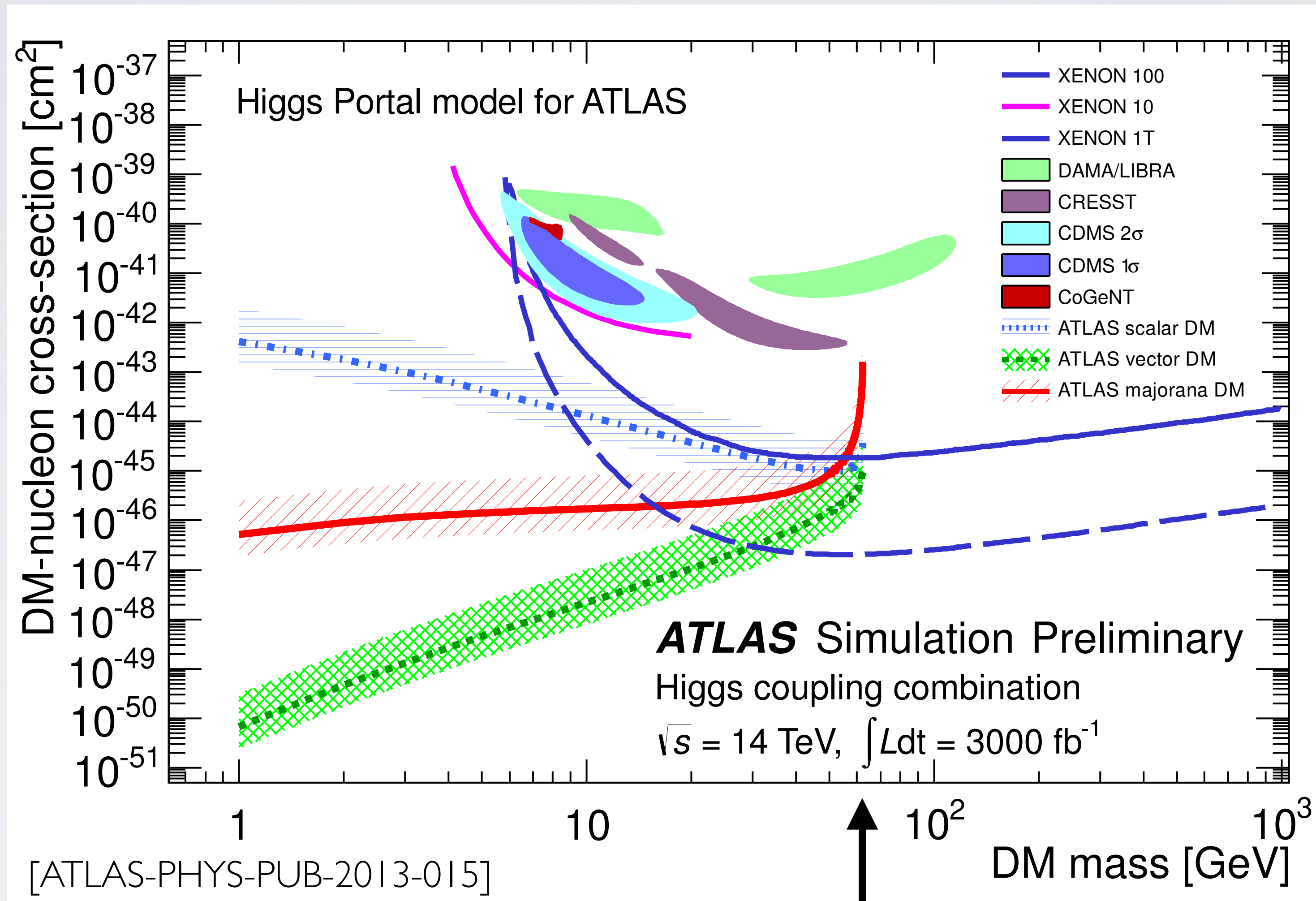
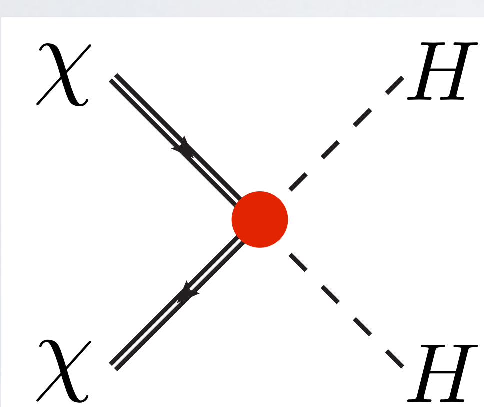
Workshop „Physics at the LHC and beyond“ — Sep 29 - Oct 2, 2015 — DESY Hamburg

HIGGS-PORTAL DARK MATTER AT THE LHC



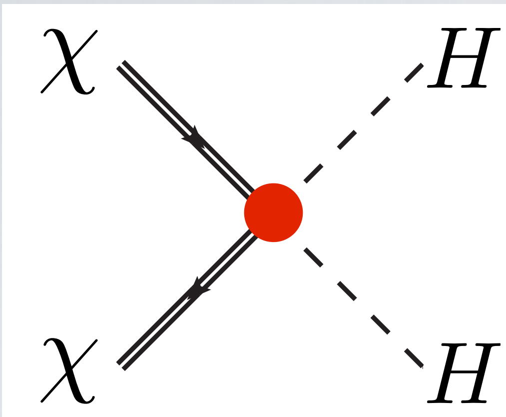
[ATLAS-PHYS-PUB-2013-015]



$m_h/2$

invisible Higgs decay	off-shell Higgs processes
[e.g. Djouadi et al., arXiv:1310.8214]	[e.g. Craig et al., arXiv:1412.0258]

FERMION DARK MATTER



$$\mathcal{L}_{\text{eff}} = \frac{g_S}{\Lambda}(\bar{\chi}\chi)(H^\dagger H) + i\frac{g_P}{\Lambda}(\bar{\chi}\gamma_5\chi)(H^\dagger H)$$

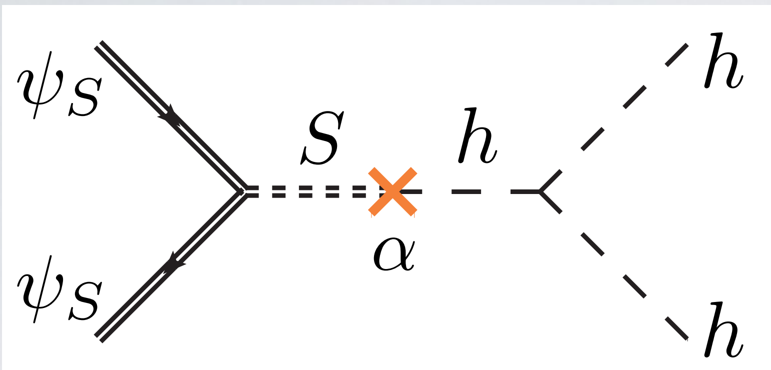
Higgs portal interaction is not renormalizable.
$\longrightarrow$ UV completion includes **mediator**.

Can we see Higgs-portal mediators at colliders?

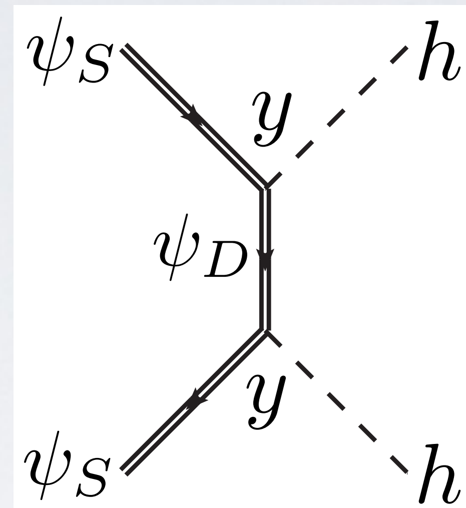
[image credit: CERN]

UV COMPLETIONS OF THE HIGGS PORTAL

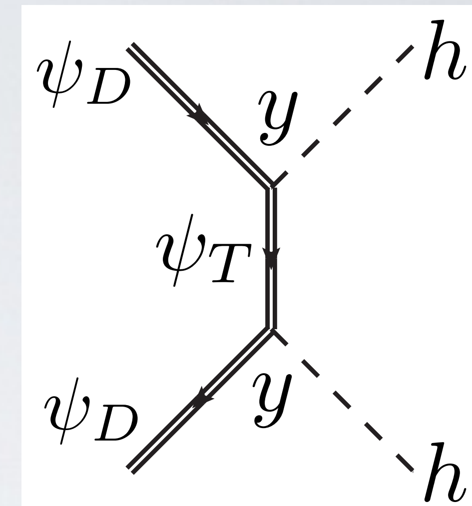
singlet-singlet



singlet-doublet

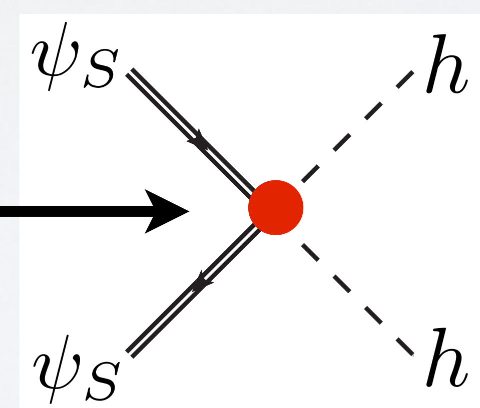


doublet-triplet



$m_D \gg m_S$

$$g_S = \frac{y^2}{2m_D}$$



Mediators with mass up to a few 100 GeV:
Higgs portal is „open" at the LHC.

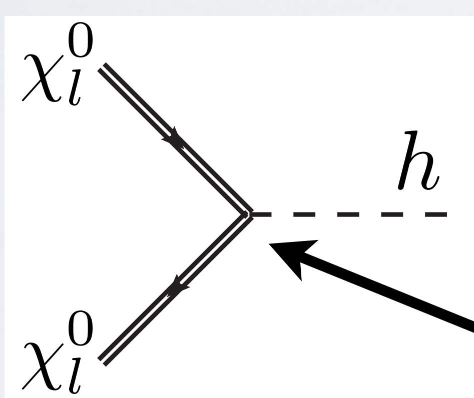
EXAMPLE: SINGLET-DOUBLET MODEL

Dark fermions mix through Yukawa interaction:

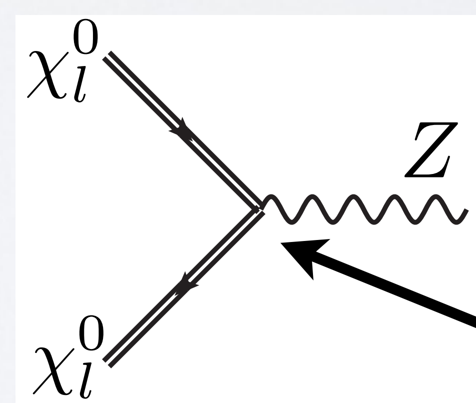
$$\mathcal{L} = -m_D \overline{\psi}_D \psi_D - m_S \overline{\psi}_S \psi_S - (y \overline{\psi}_D H \psi_S + \text{ h.c.})$$

$$\xrightarrow{\langle H \rangle = v/\sqrt{2}} \quad \boxed{\begin{aligned} \chi_l^0 &= \cos\theta \psi_D^0 - \sin\theta \psi_S \\ \chi_h^0 &= \sin\theta \psi_D^0 + \cos\theta \psi_S \end{aligned}}$$

Mixing controls coupling to Higgs and gauge bosons:



$$\frac{y}{\sqrt{2}} \sin(2\theta)$$



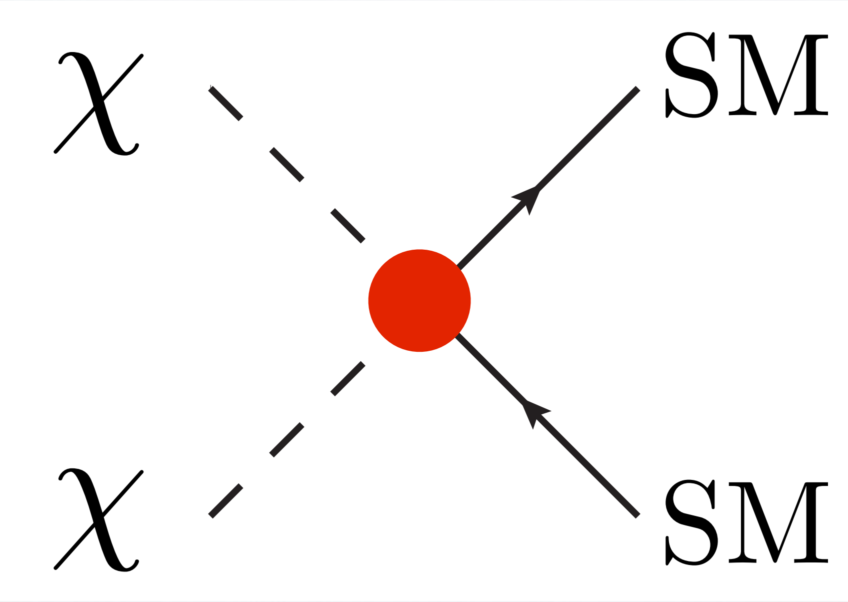
$$-\frac{g}{2c_W} \cos^2\theta$$

Z_2 symmetry ensures DM stability.

OBSERVING PARTICLE DARK MATTER

annihilation
relic density and indirect detection

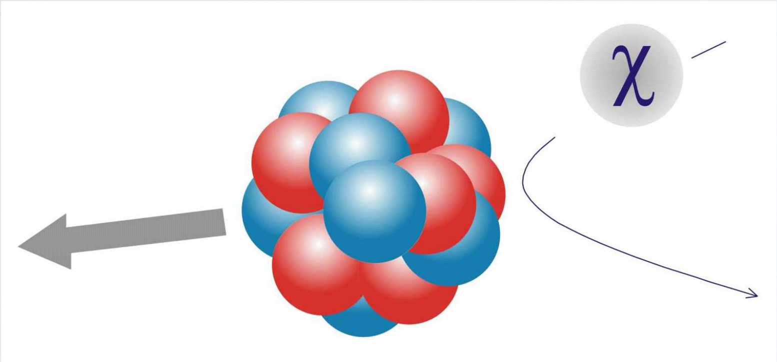
scattering
direct detection



production
colliders

DIRECT DETECTION

Spin-independent DM-nucleus scattering:



$$\sigma_0 = \frac{\mu_A^2}{\pi} |Z f_p + (A-Z) f_n|^2$$

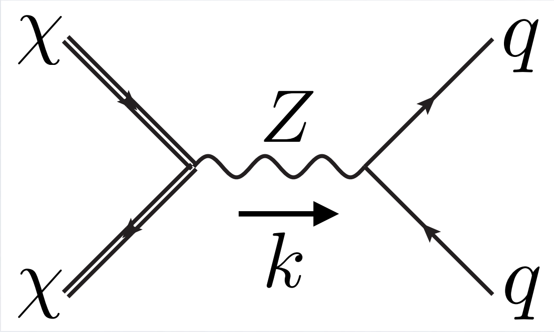
$\sqrt{k^2} \simeq 10 - 50\,\mathrm{MeV} \ll M_{\mathrm{EW}}$

Currently strongest bound on weak-scale DM scattering:

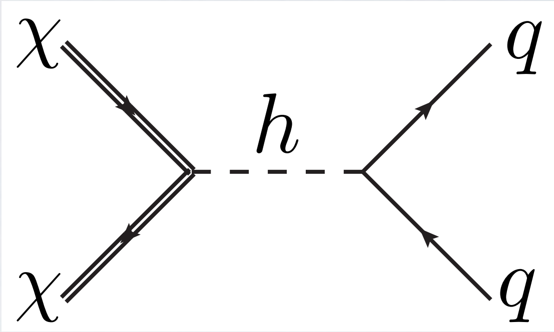
LUX experiment: $\sigma_0(m_\chi \approx 100\,\mathrm{GeV}) \lesssim 10^{-45}\mathrm{cm}^2$ [LUX coll., arXiv:1310.8214]

[picture: lux.brown.edu]

DARK FERMION-NUCLEON SCATTERING



$$\mathcal{O}_V = (\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)$$



$$\mathcal{O}_S = (\bar{\chi}\chi)(\bar{q}q)$$

Effective interactions:

$$f_{p,n} \sim \frac{g_\chi^Z g_q^Z}{M_Z^2} \qquad\qquad f_{p,n} \sim \frac{g_\chi^h}{M_h^2}\frac{m_q}{v}$$

Dirac singlet:

$$g_\chi^Z = -\frac{g}{2c_W}\cos^2\theta \qquad\qquad g_\chi^h = \frac{y}{\sqrt{2}}\sin(2\theta)$$

Majorana singlet:

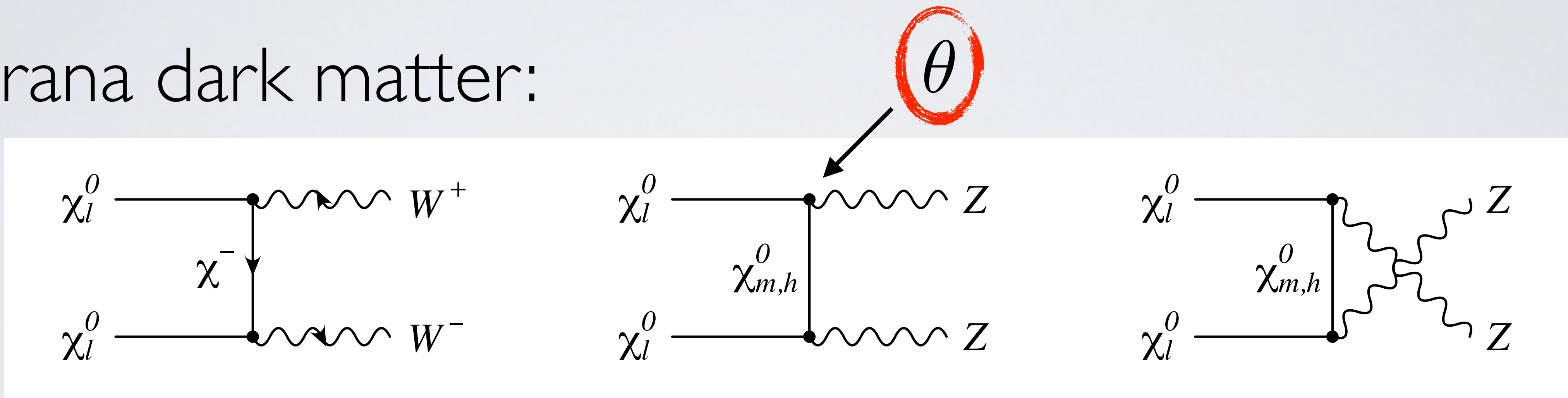
$$g_\chi^Z = 0 \qquad\qquad g_\chi^h = \frac{y}{2}\sin(2\theta')$$

$\boxed{\text{LUX bound} \longrightarrow \text{DM must be singlet-like, } \theta \approx \pi/2.}$

RELIC DENSITY

Dirac dark matter annihilation: $\chi\bar{\chi} \to Z \to q\bar{q}, \ell^+\ell^-$

Majorana dark matter:



Observed relic density: $\Omega_\chi h^2 = 0.1199 \pm 0.0022$ [Planck coll., arXiv:1502.01589]

LUX bound strongly constrains annihilation rate.

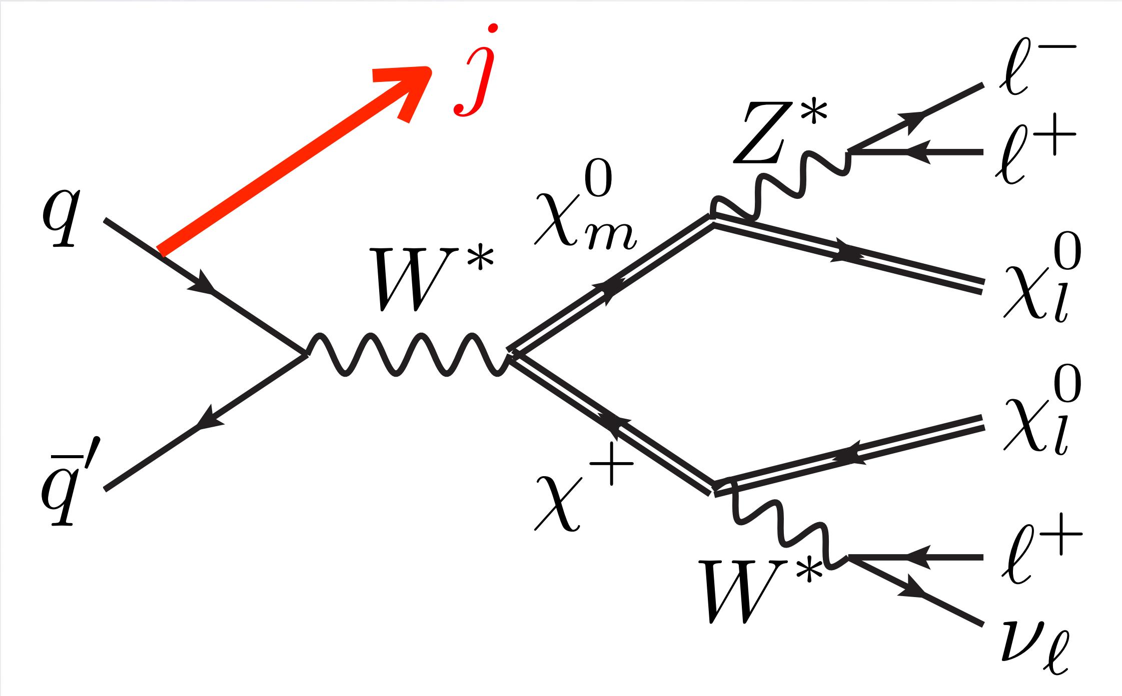
$\boxed{\text{Co-annihilation } \chi_l^0\chi^+, \chi_l^0\chi_m^0 \text{ prevents over-abundance.}}$

Exception: Higgs-resonance region for Majorana DM.

DARK FERMION SEARCHES AT COLLIDERS

Relic density and direct detection:
Small mass splittings $m_m^0 - m_l^0, m^+ - m_l^0 \longrightarrow$ soft decay products.

Hard jet helps to trigger on soft-lepton events:



<u>LHC run II</u>

$\not{E}_T > 300\,\mathrm{GeV}$

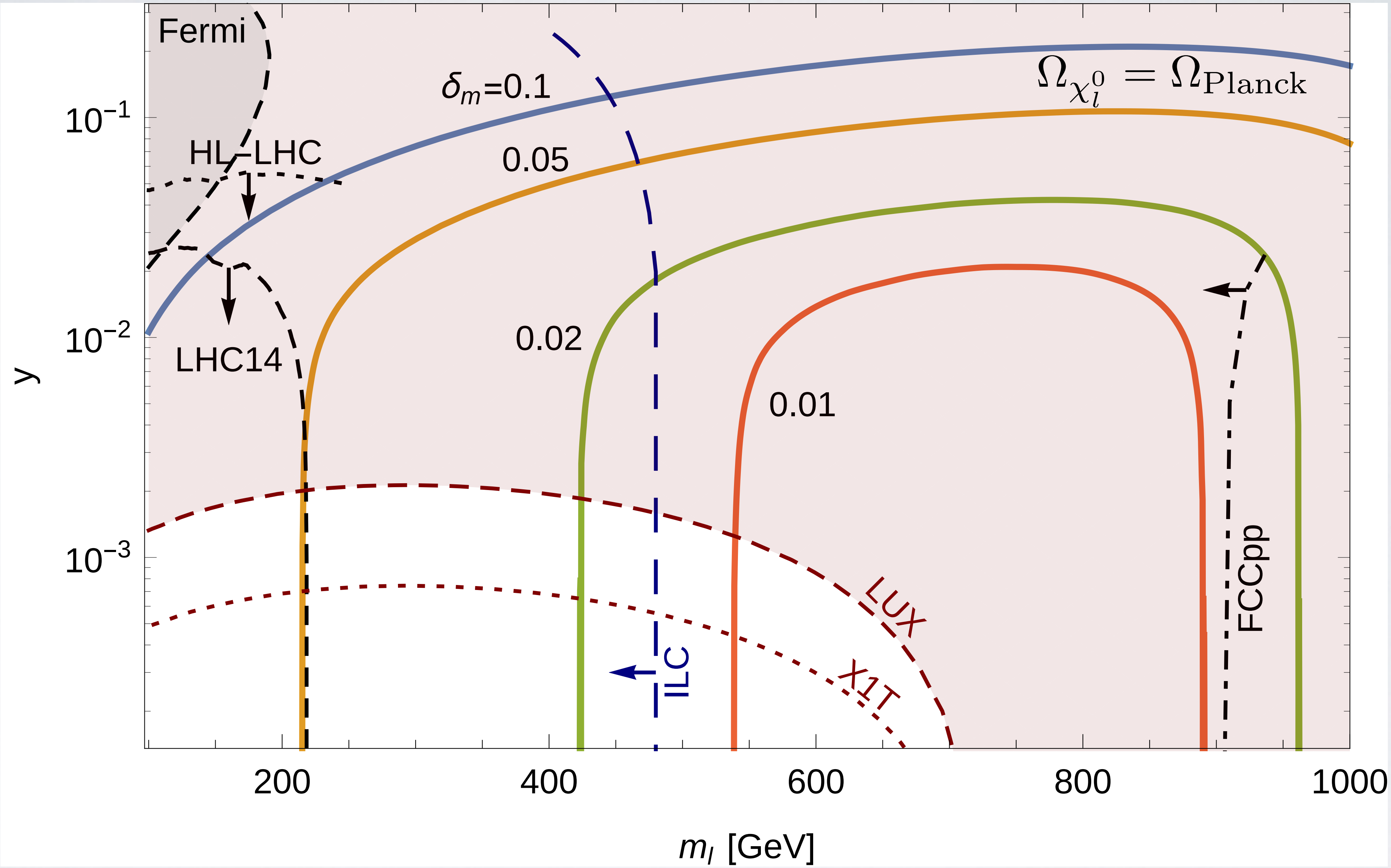
$p_T(j_1) > 300\,\mathrm{GeV}$

$p_T(\ell) < 20\,\mathrm{GeV}$

[Schwaller, Zurita, arXiv:1312.7350, et al.]

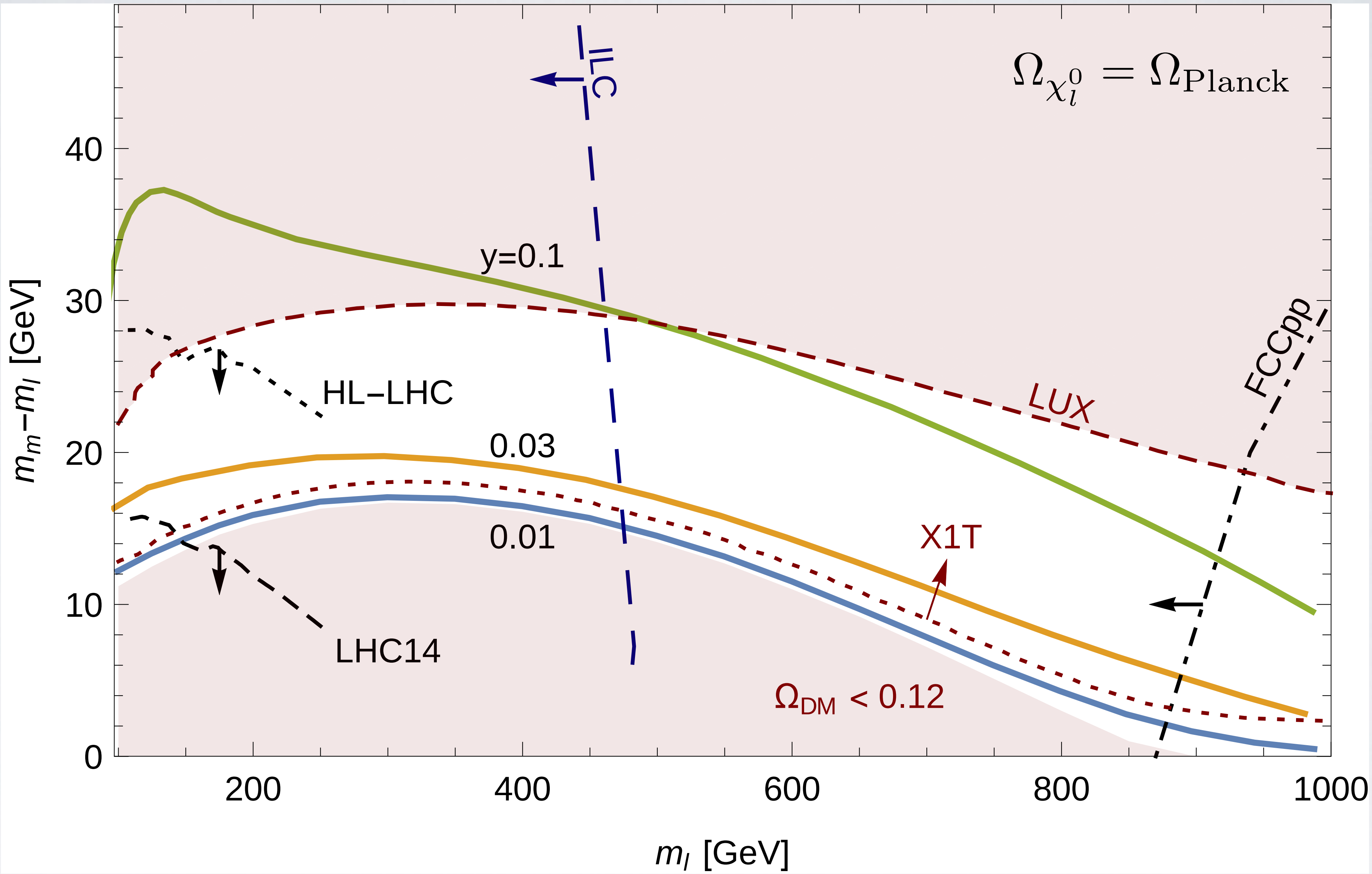
Cross section too small for mono-jet searches at the LHC.

SUMMARY DARK DIRAC FERMIONS

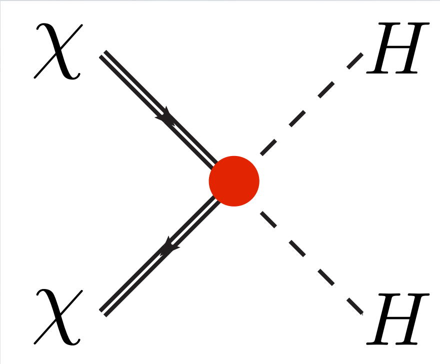


Need high-energy collider to test this model conclusively.

SUMMARY DARK MAJORANA FERMIONS



Future direct detection experiments and/or high-energy collider can test this model.



TAKE HOME

Higgs-portal fermion dark matter

- **Mediators** can be searched for in signatures with soft leptons at the LHC.

- **Future** lepton and high-energy hadron **colliders** are needed to test such models conclusively.

- **Direct detection** experiments provide complementary information.