

PROBING
DARK MATTER AT THE LHC
THROUGH WEAKLY INTERACTING MEDIATORS

Susanne Westhoff

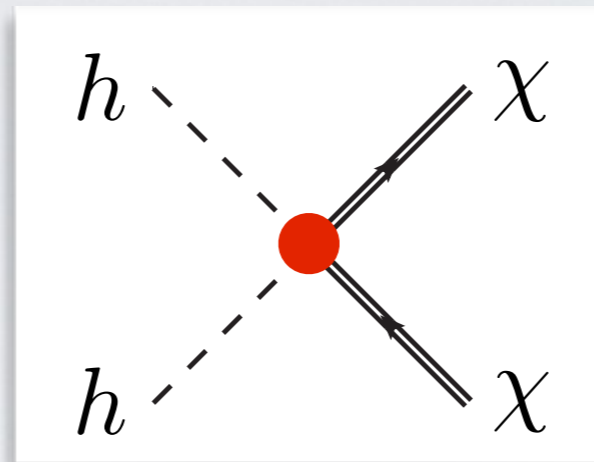


Universität Heidelberg

Rencontres de Moriond EW — March 18, 2016 — La Thuile, Italy

HIGGS-PORTAL DARK MATTER

Collider signals?



Renormalizable interaction: [Patt, Wilczek, hep-ph/0605188]

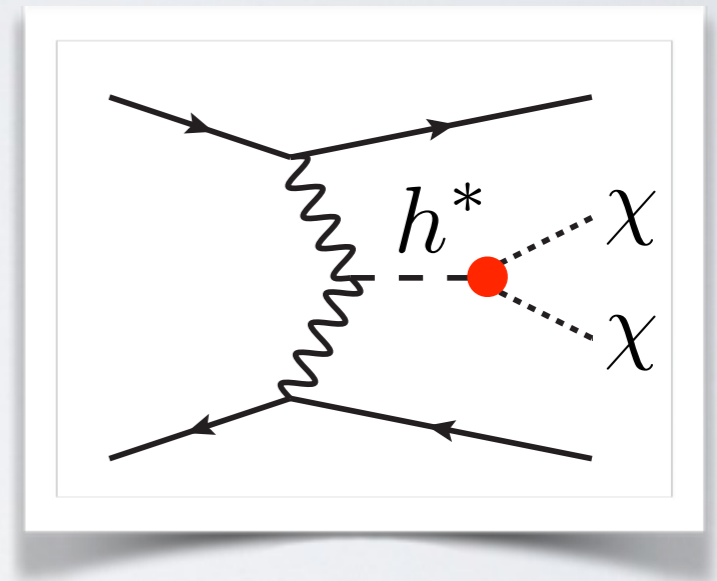
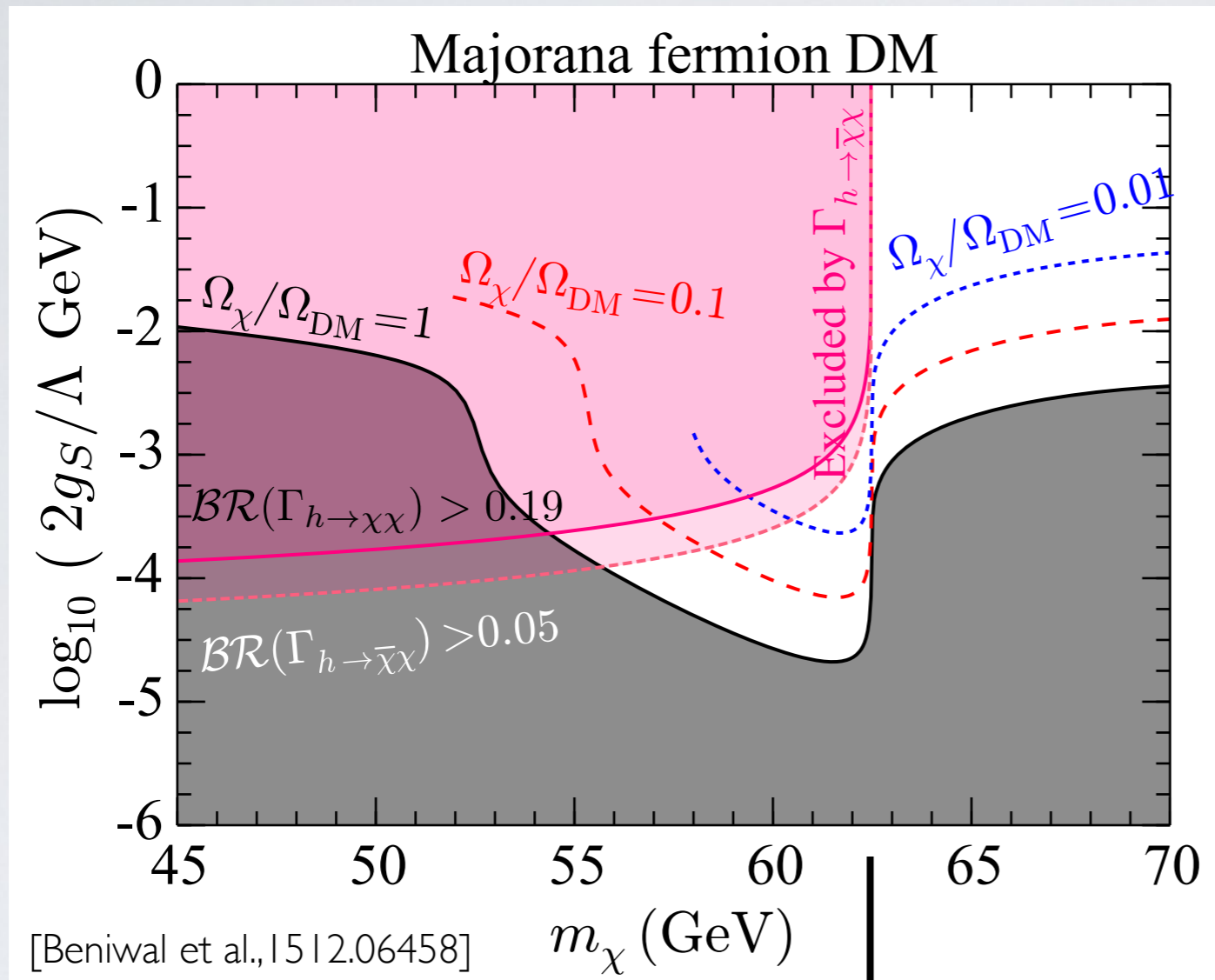
Scalar $\mathcal{L} \supset \lambda_S S^2 H^\dagger H$ [e.g., O'Connell et al., hep-ph/0611014]

Vector $\mathcal{L} \supset \lambda_V V_\mu V^\mu H^\dagger H$ [e.g. Hambye et al., arXiv:0811.0172]

Effective interaction through **mediators**:

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

HIGGS PORTAL AT THE LHC



invisible Higgs decay
very strong bounds

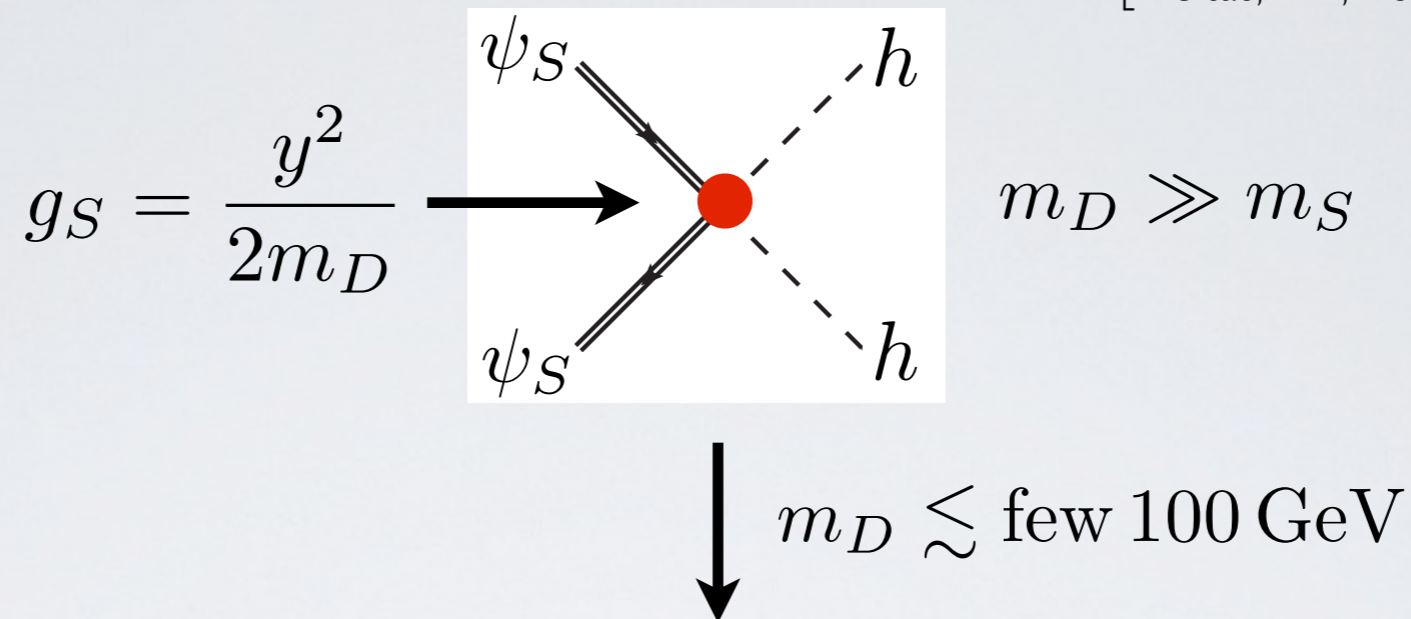
off-shell Higgs processes
very weak bounds

[e.g. Djouadi et al., arXiv:1310.8214]

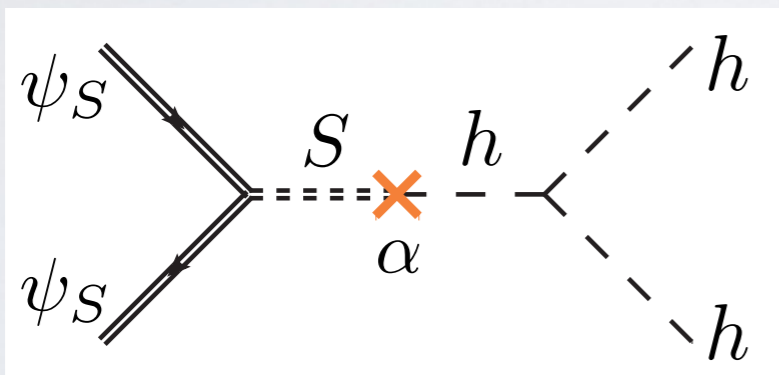
[e.g. Craig et al., arXiv:1412.0258]

UV-COMPLETE FERMION HIGGGS PORTALS

[Freitas, SW, Zupan, arXiv:1506.04149]

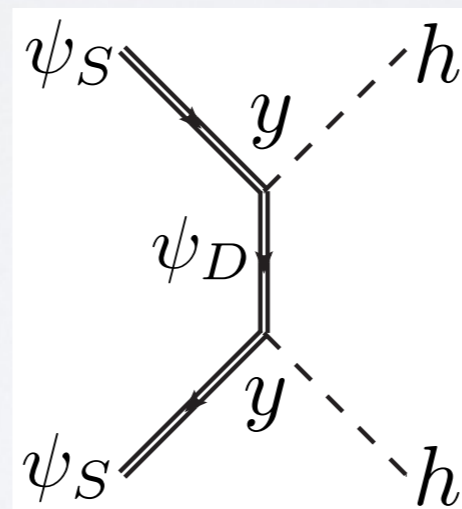


singlet-singlet



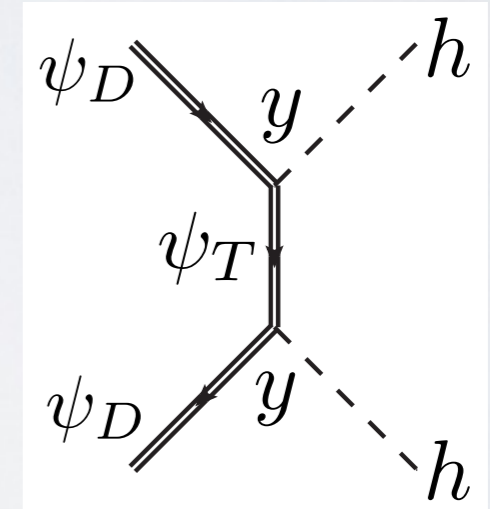
[Lee et al., arXiv:0803.2932, ...]

singlet-doublet



[e.g. Mahbubani, Senatore, 2005]

doublet-triplet



[Dedes, Karamitros, 2014]
[triplet-quadruplet: Tait, Yu, 2016]

Higgs portal at the LHC is “open” for mediator searches.

SINGLET-DOUBLET MODEL

Dark fermions mix through Yukawa interaction:

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

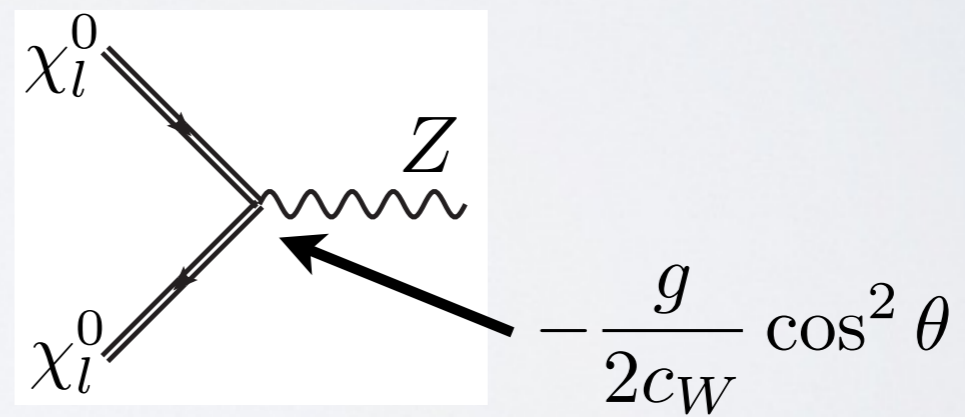
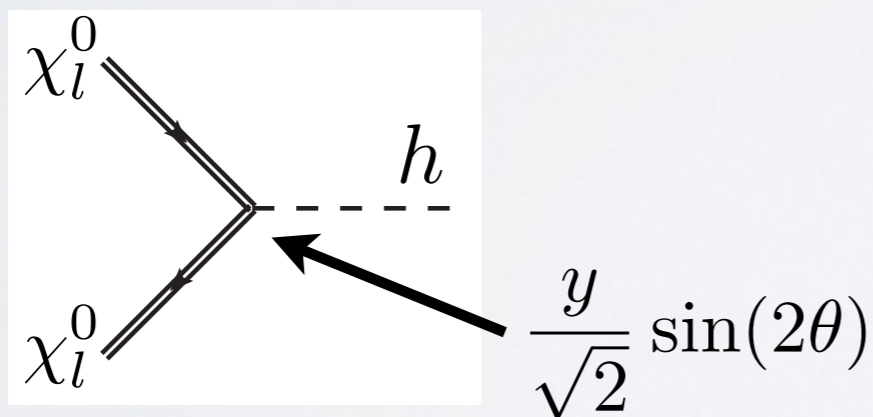
$$\psi_D = \begin{pmatrix} \psi_D^+ \\ \psi_D^0 \end{pmatrix}$$

$$\langle H \rangle = v/\sqrt{2}$$

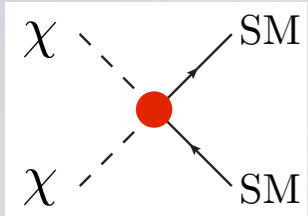
→

$$\begin{aligned} \chi_l^0 &= \cos \theta \psi_D^0 - \sin \theta \psi_S \\ \chi_h^0 &= \sin \theta \psi_D^0 + \cos \theta \psi_S \end{aligned}$$

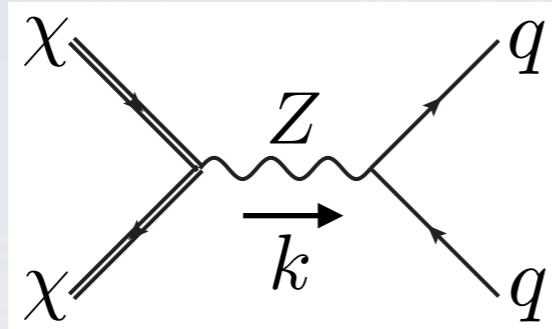
Mixing controls coupling to Higgs and gauge bosons:



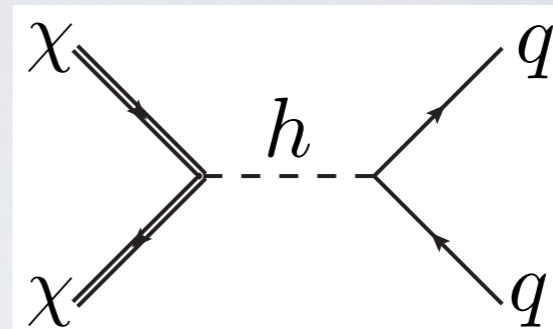
Three parameters: $m_{\chi_l^0}$, $m_{\chi_h^0}$, y



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:

$$f_{p,n} \sim \frac{g_\chi^Z g_q^Z}{M_Z^2}$$

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

Dirac singlet:

$$g_\chi^Z = -\frac{g}{2c_W} \cos^2 \theta$$

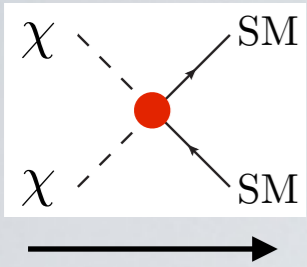
$$g_\chi^h = \frac{y}{\sqrt{2}} \sin(2\theta)$$

Majorana singlet:

$$g_\chi^Z = 0$$

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

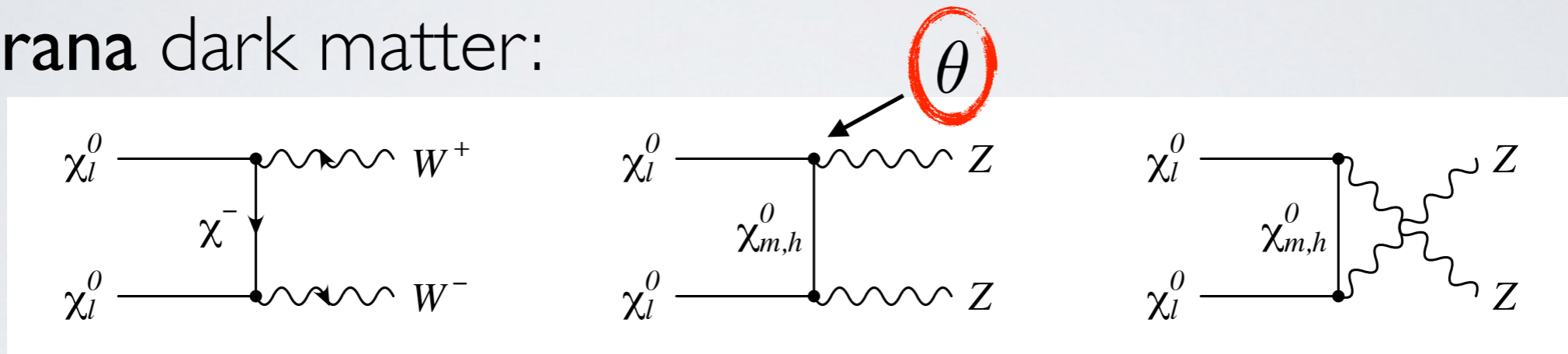
direct detection bounds \rightarrow DM must be singlet-like, $\theta \approx \pi/2$.



RELIC ABUNDANCE

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

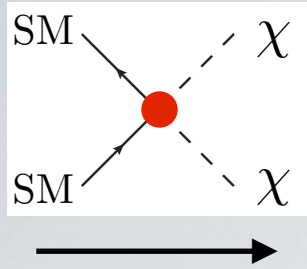
Majorana dark matter:



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

Direct detection strongly constrains DM annihilation rate.

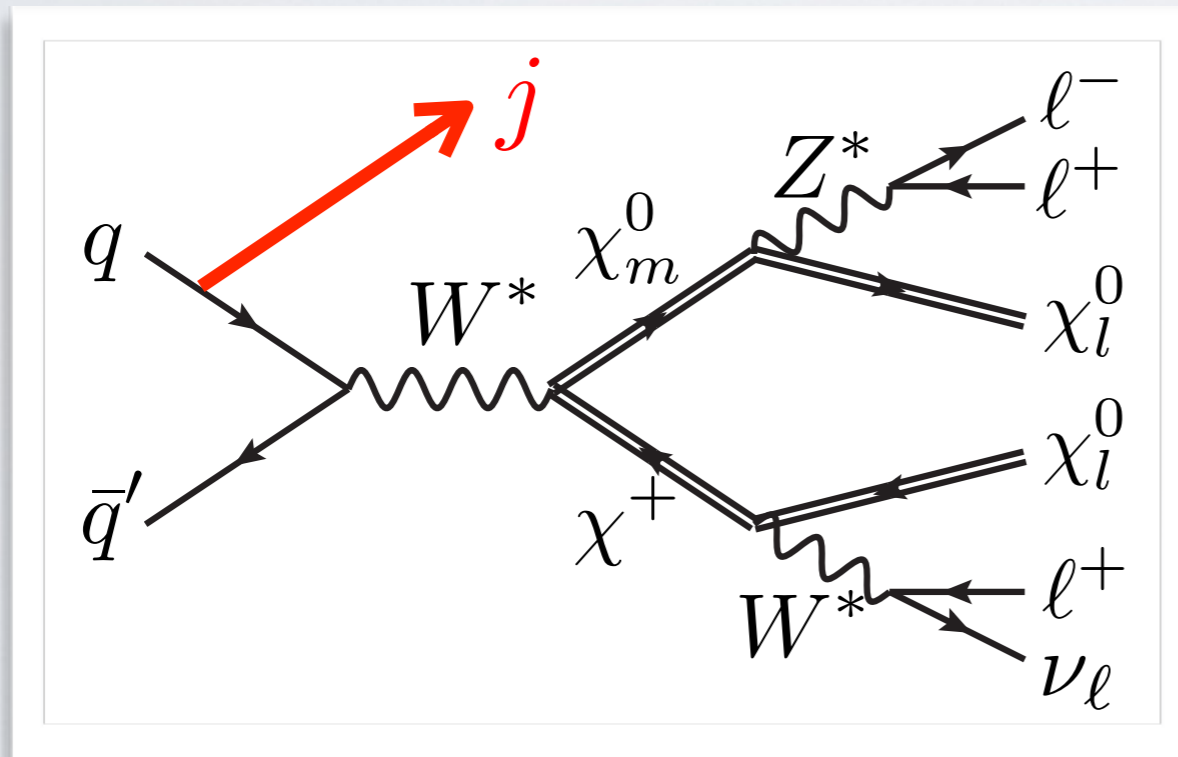
Co-annihilation prevents over-abundance:
small DM-mediator mass splitting



DARK FERMION SEARCHES AT COLLIDERS

Soft leptons: $m_m^0 - m_l^0, m^+ - m_l^0 \lesssim 30 \text{ GeV}$

Similar to SUSY electroweakino searches: [Giudice, Han, Wang, Wang, arXiv:1004.4902]
 [Gori, Jung, Wang, arXiv:1307.5952]
 [Schwaller, Zurita, arXiv:1312.7350]



LHC Run II

$$\cancel{E}_T > 300 \text{ GeV}$$

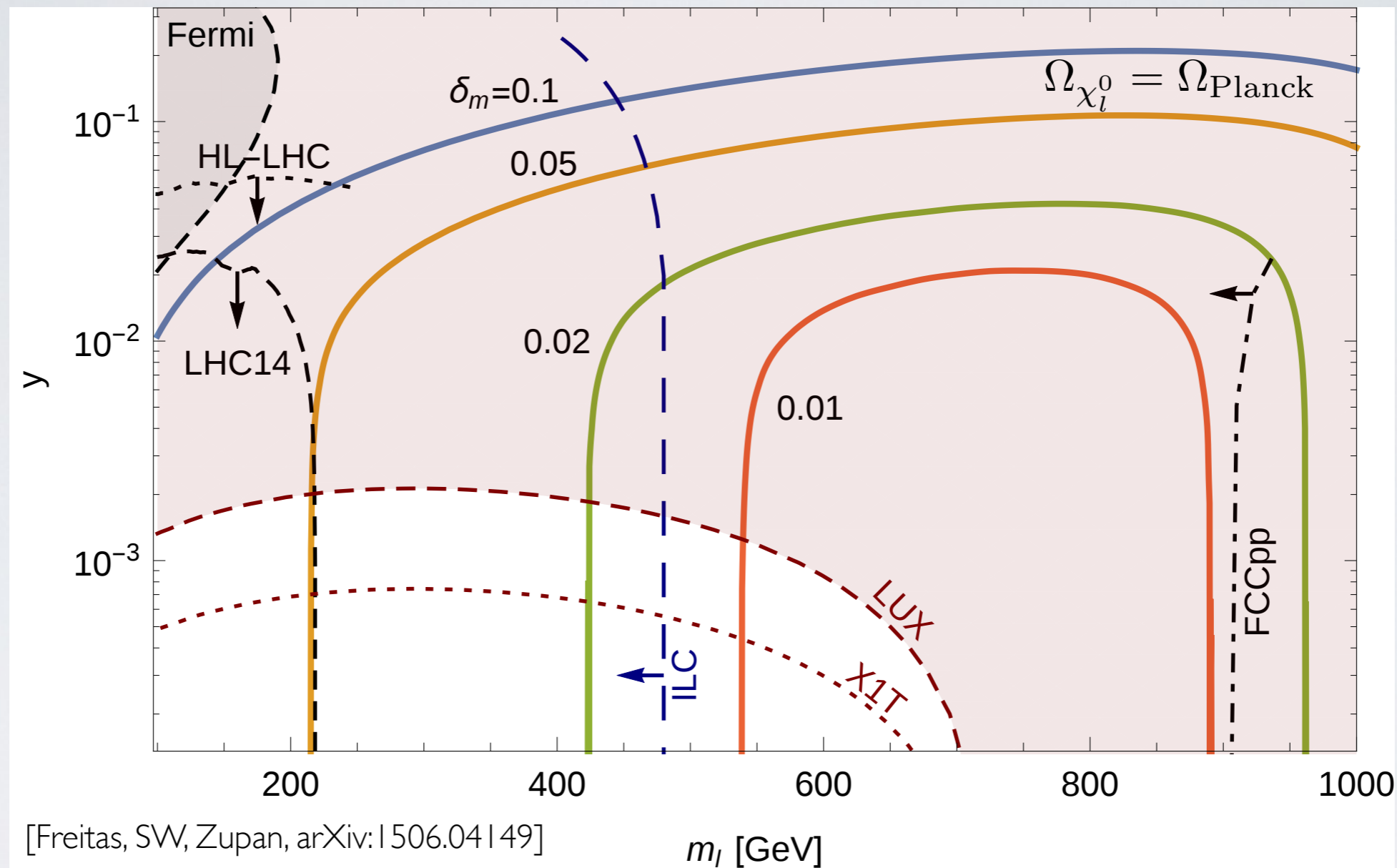
$$p_T(j_1) > 300 \text{ GeV}$$

$$p_T(\ell) < 20 \text{ GeV}$$

Vector boson fusion might be complementary. [Dutta et al., arXiv:1411.6043]
 [Berlin et al., arXiv:1502.05044]

Mono-jet signal is too small at LHC energies.

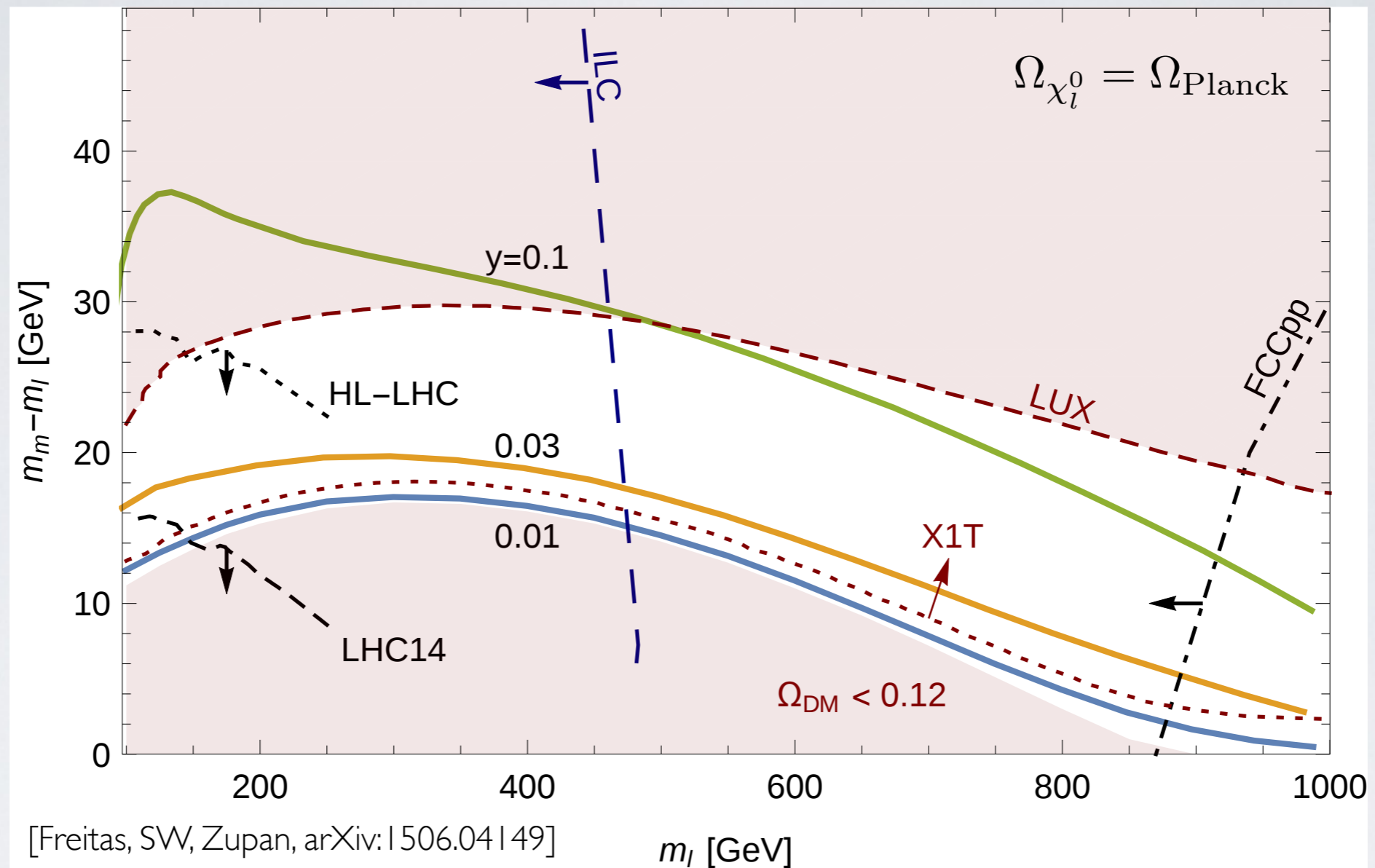
SUMMARY DARK DIRAC FERMIONS



A high-energy collider can test this model conclusively.

[Bramante et al., arXiv:1412.4789] [Low, Wang, arXiv:1404.0682]

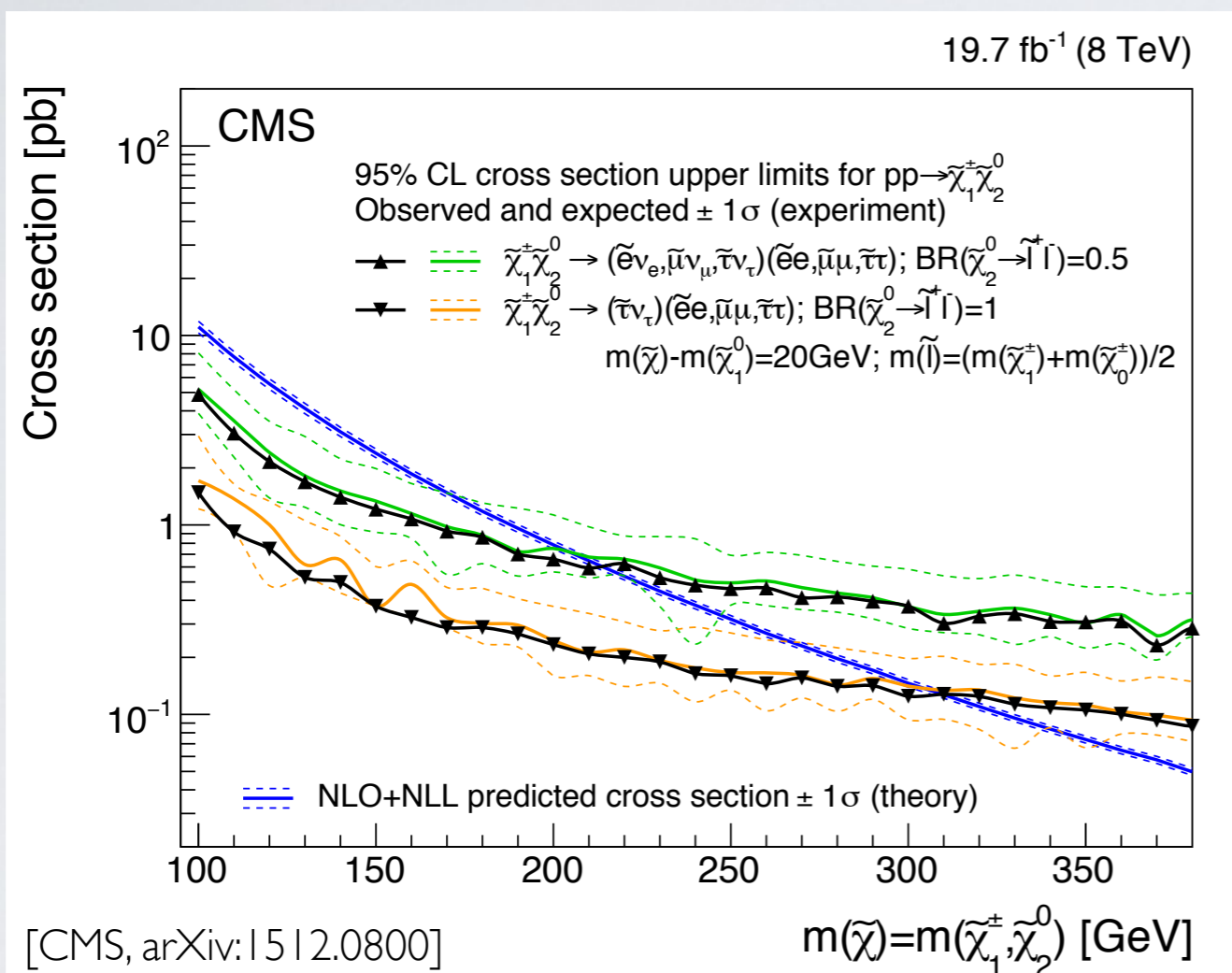
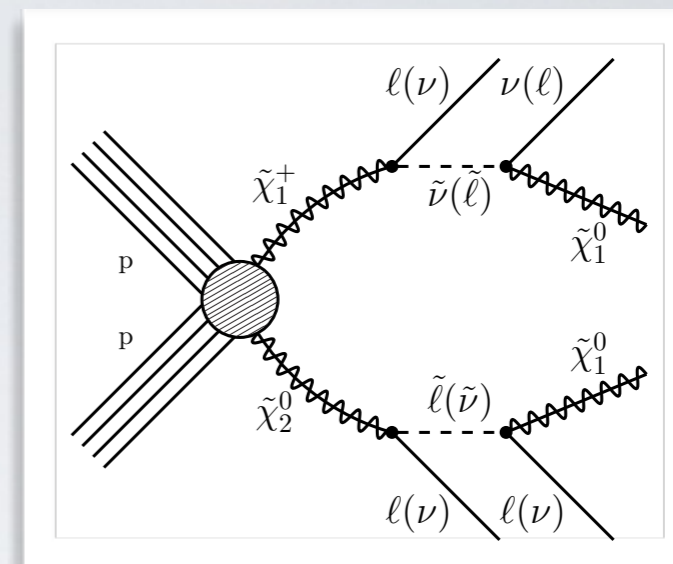
SUMMARY DARK MAJORANA FERMIONS



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

EWK-INO SEARCH WITH SOFT LEPTONS

Di-leptons + ISR jet + missing energy:



$$E_T^{\text{miss}} > 200 \text{ GeV}$$

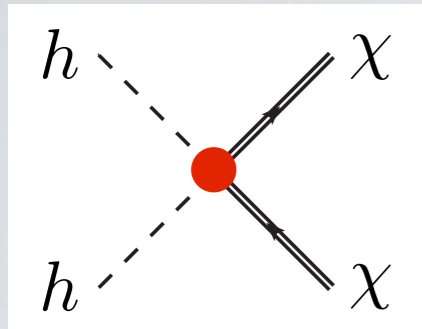
$$p_T^j > 150 \text{ GeV}$$

$$p_T^{\ell_1} : 5 - 15, 15 - 25 \text{ GeV}$$

$$p_T^{\ell_2} < 15 \text{ GeV}$$

Interpret these signatures in fermion Higgs portal context.

TAKE HOME



Higgs-portal fermion dark matter

- Opportunity at **LHC Run II**:

Search for **resonant production of mediators** with soft leptons and missing transverse energy.

- **Direct detection** experiments provide complementary information.
- **Future** lepton and high-energy hadron **colliders** are helpful to test such models conclusively.

BACKUP

MAJORANA SINGLET-DOUBLET MODEL

Higgs resonance region

