The search for leptophilic WIMP at colliders

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based on [arXiv: 2102.08645]

Contents

- Introduction of WIMP
- Our model and motivation
- Some constraints
- Result
- Summary

About WIMP

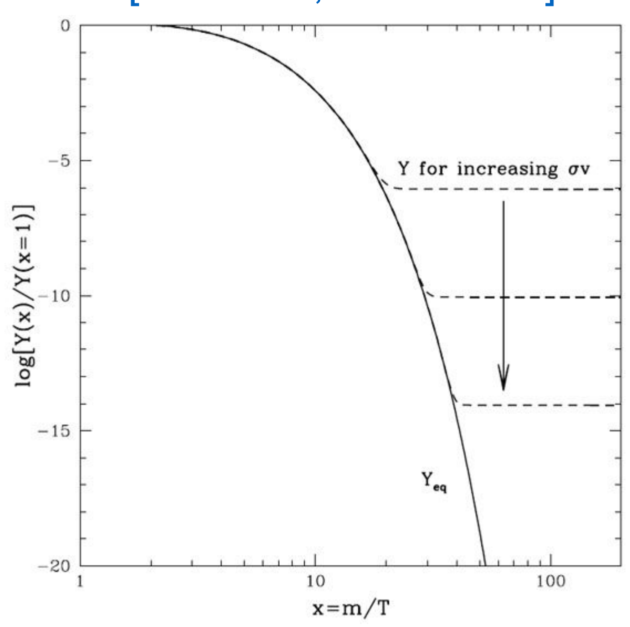
- Weakly Interacting Massive Particle (WIMP)
- Well motivated DM candidate

  (by many BSM models like SUSY)

- Thermally created at the early universe
- The abundance is determined by Freeze-out
- Number density follows Boltzmann-eq

$$\frac{dn}{dt} + 3Hn = \langle \sigma v \rangle (n_{\rm eq}^2 - n^2)$$

[E.W.Kolb, M.S.Turner]



WIMP model

- Classifying WIMP by the representation of gauge group

WIMP model

- Classifying WIMP by the representation of gauge group

Lorentz	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
scalar		$\mathbf{1}$	0
or		$\mathbf{2}$	$-1/2, +1/2$
fermion	$\mathbf{1}$	$\mathbf{3}$	$-1, 0, +1$
or		$\mathbf{4}$	$-3/2, -1/2, +1/2, +3/2$
vector		$\mathbf{5}$	$-2, -1, 0, +1, +2$
		$\vdots$	$\vdots$

- U(1) is quantized because WIMP must be neutral

WIMP model

- Classifying WIMP by the representation of gauge group

Lorentz	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
scalar or fermion or vector	$\mathbf{1}$	$\mathbf{1}$	0
		$\mathbf{2}$	$-1/2, +1/2$
		$\mathbf{3}$	$-1, 0, +1$
		$\mathbf{4}$	$-3/2, -1/2, +1/2, +3/2$
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Interaction is determined by gauge theory

WIMP model

- Classifying WIMP by the representation of gauge group

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		$\vdots$	$\vdots$

What about here?

Many possibilities for interaction

We have to study case-by-case

WIMP model

- Classifying WIMP by the representation of gauge group

Lorentz	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
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		$\vdots$	$\vdots$

What about here?

We focus on fermionic gauge singlet WIMP

WIMP model

- We impose Z_2 symmetry to make WIMP stable

  χ : odd   SM particles : even

- Fermionic gauge singlet WIMP cannot have renormalizable interaction with SM particles by itself

- We need mediator particles to connect WIMP and SM

- There are many choices of mediators!

Our model

- We consider leptophilic mediator (Z_2 odd)
- Correspond to bino (WIMP) and slepton (mediator) in SUSY
- Such model can explain muon g-2 anomaly
- Difficult to search by direct detection experiment
- Collider search becomes important
- Two minimal cases
  (left-handed slepton, right-handed slepton)

Lagrangian
(left-handed slepton)

$$\mathcal{L}_L = \mathcal{L}_{\rm SM} + \frac{1}{2}\bar{\chi}\left(i\partial\!\!\!/ - m_\chi\right)\chi + (D_L^\mu \tilde{L}_i)^\dagger (D_{L\,\mu}\tilde{L}_i) + \mathcal{L}_{{\rm DM}\,L} - V_L(H, \tilde{L}_i),$$

$$\mathcal{L}_{{\rm DM}\,L} = -y_L \bar{L}_i \tilde{L}_i \chi + h.c,$$

interaction term

$$V_L = m_{\tilde{L}}^2\,|\tilde{L}_i|^2 + \frac{\lambda_L}{4}\,|\tilde{L}_i|^4 + \lambda_{LH}\,|\tilde{L}_i|^2|H|^2$$
$$+ \lambda'_{LH}\,(\tilde{L}_i^\dagger \tau^a \tilde{L}_i)(H^\dagger \tau^a H) + [\frac{\lambda''_{LH}}{4}(\tilde{L}_i^\dagger H^c)^2 + h.c.].$$

potential term

- Most important parameters are $m_\chi, m_{\tilde{L}}, y_L$

- Assuming flavor blindness
  (slepton mass and interaction are same for each flavor)

Lagrangian (right-handed slepton)

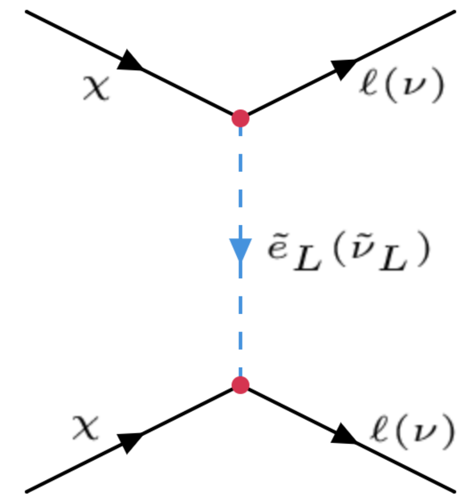
$$\mathcal{L}_R = \mathcal{L}_{\rm SM} + \frac{1}{2}\bar{\chi}\left(i\partial\!\!\!/ - m_\chi\right)\chi + (D^\mu_R \tilde{R}_i)^\dagger (D_{R\mu}\tilde{R}_i) + \mathcal{L}_{{\rm DM}\,R} - V_L(H, \tilde{R}_i),$$

$$\mathcal{L}_{{\rm DM}\,R} = -y_R \bar{E}_i \tilde{R}_i \chi + h.c,$$ interaction term

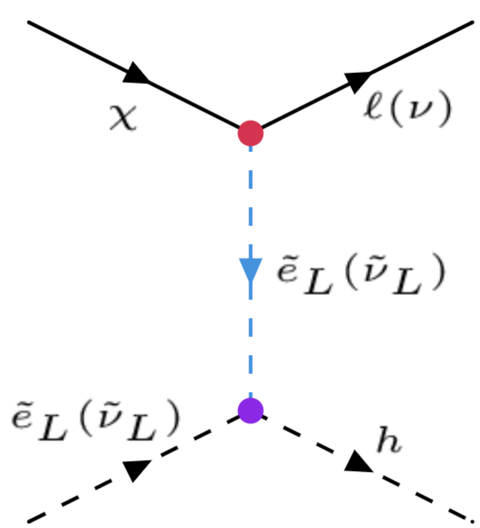
$$V_R = m^2_{\tilde{R}}\,|\tilde{R}_i|^2 + \frac{\lambda_R}{4}\,|\tilde{R}_i|^4 + \lambda_{RH}\,|\tilde{R}_i|^2|H|^2,$$ potential term

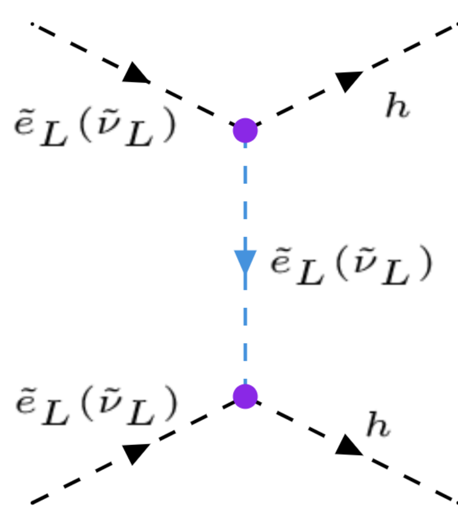
- Most important parameters are $m_\chi, m_{\tilde{R}}, y_R$
- Assuming flavor blindness
  (slepton mass and interaction are same for each flavor)

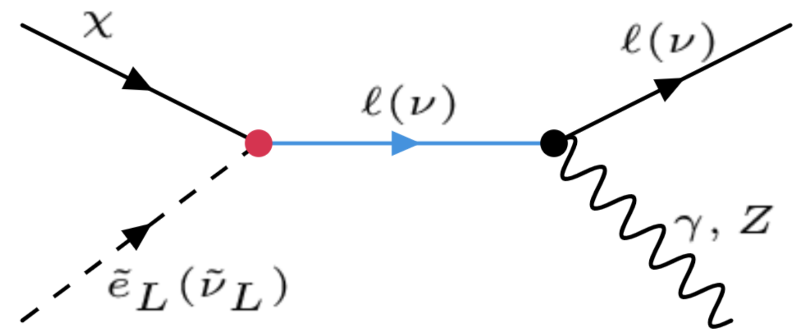
Relic abundance condition
(e.g. left-handed case)



- $\chi\chi \to \bar{l}l$ is dominant annihilation mode
- The abundance is determined by $m_\chi, m_{\tilde{L}}, y_L$
- If WIMP and mediator mass are degenerate, other processes also become important (co-annihilation)



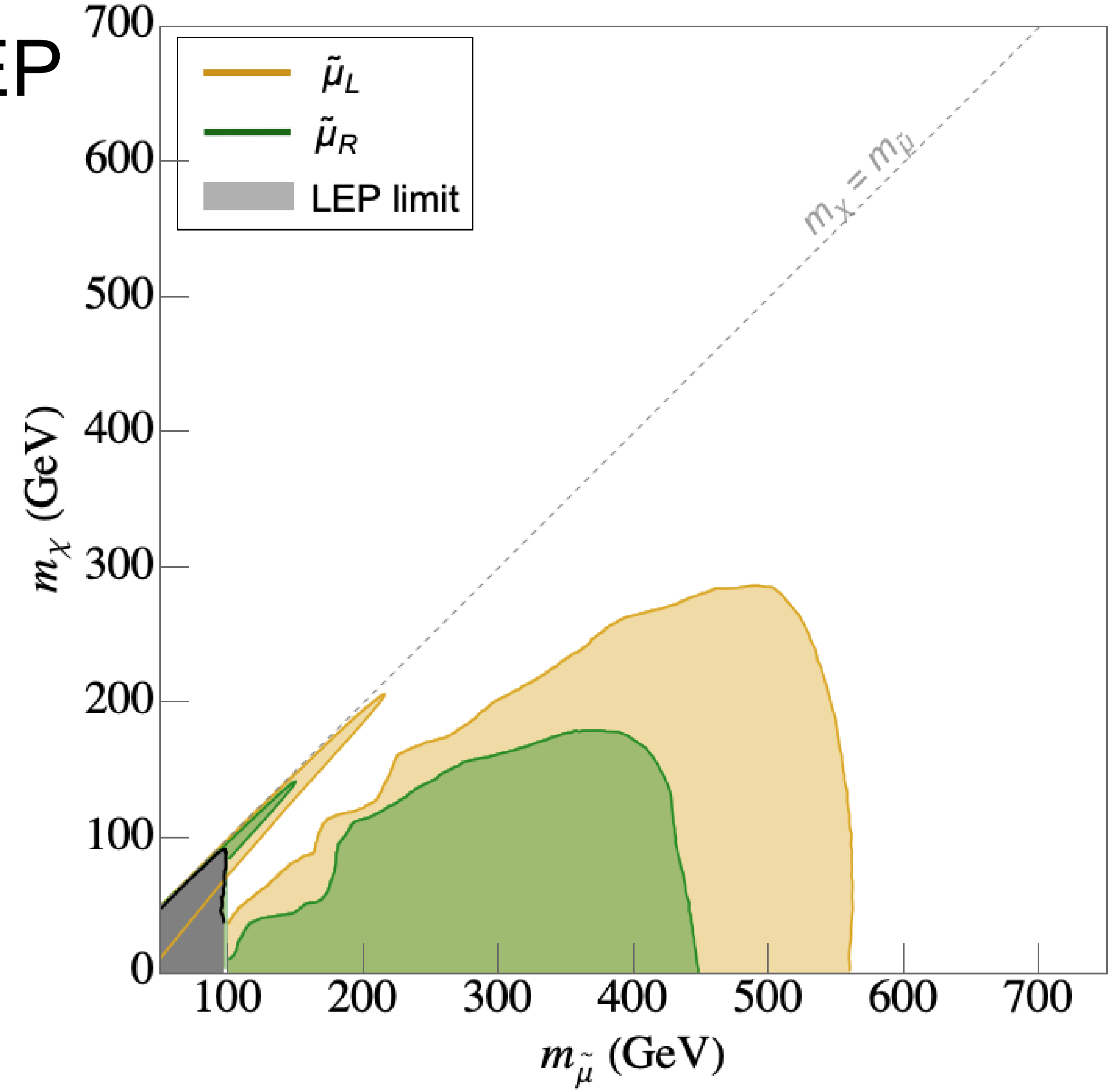




and so on

Collider constraint

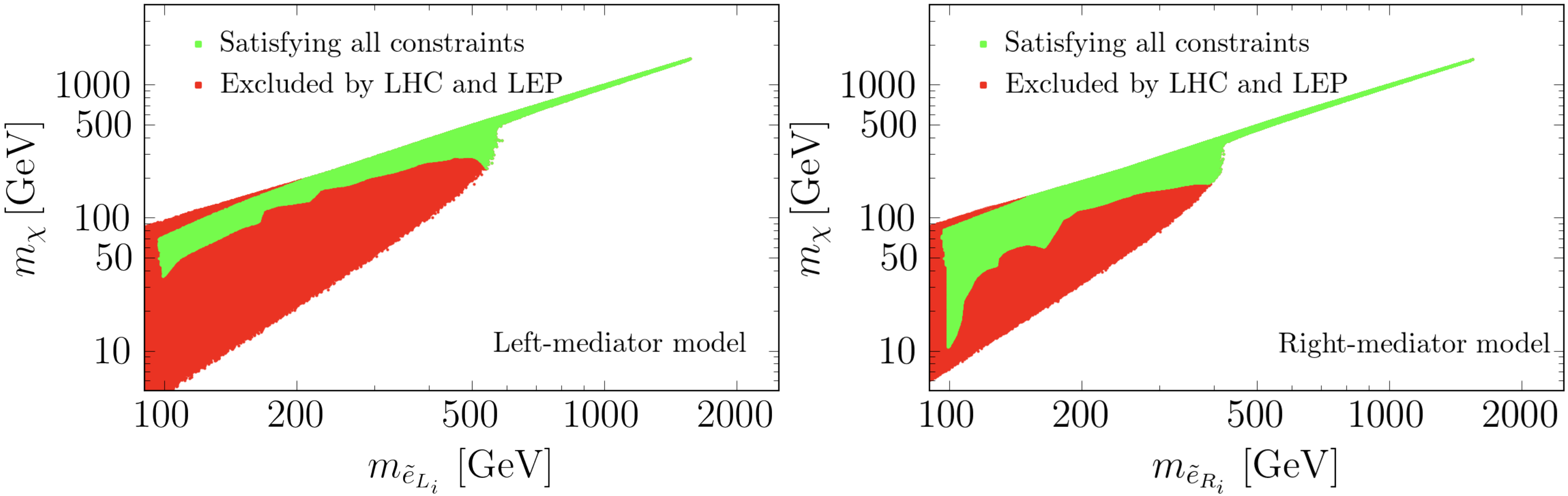
- Slepton pair can be created via Drell-Yan process at LHC or LEP
- Slepton decays into WIMP and lepton
- Constraint on slepton mass and WIMP mass
- LEP constrain slepton below 94 GeV
  (under flavor blindness)



[Georges Aad et al. Phys. Rev. D, 101(5):052005,2020]

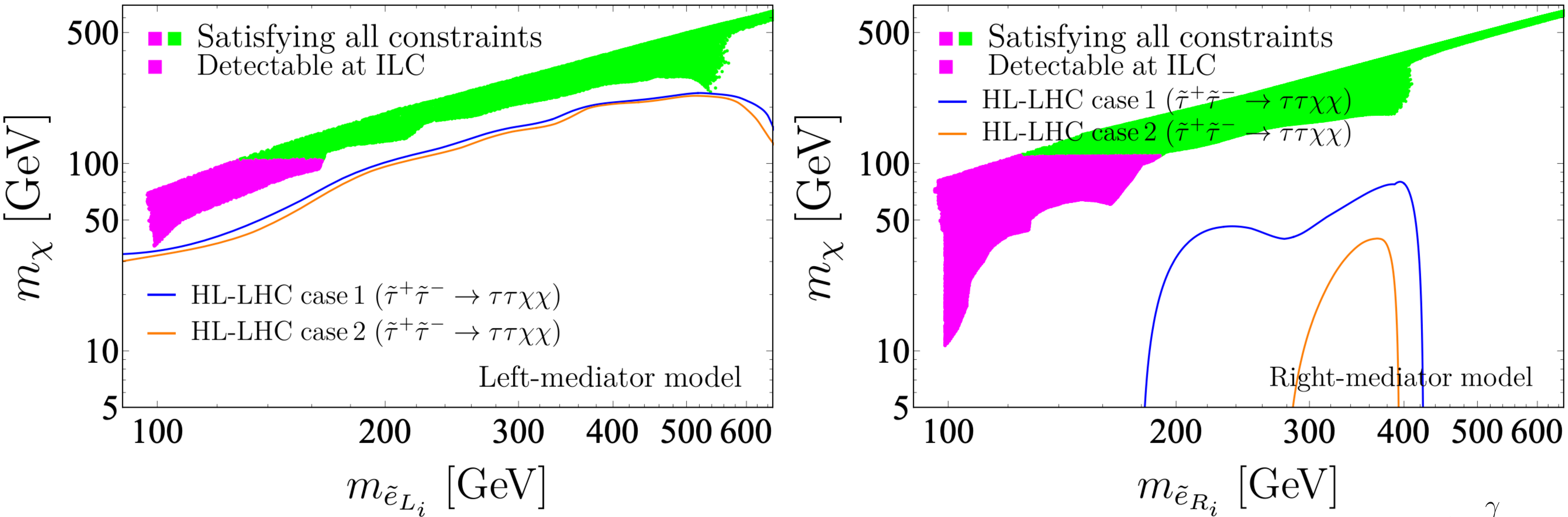
[Georges Aad et al. Phys. J. C, 80(2):123,2020]

Present status



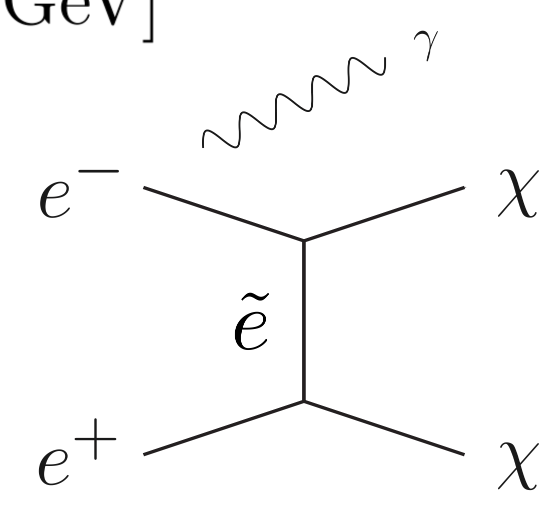
- Here we also consider other constraints (vacuum stability, electroweak precision, higgs decay, etc.)
- Green region is surviving region

Future prospect



- We consider mono-photon search at 250 GeV ILC

(For HL-LHC, only tau channel analysis is shown)

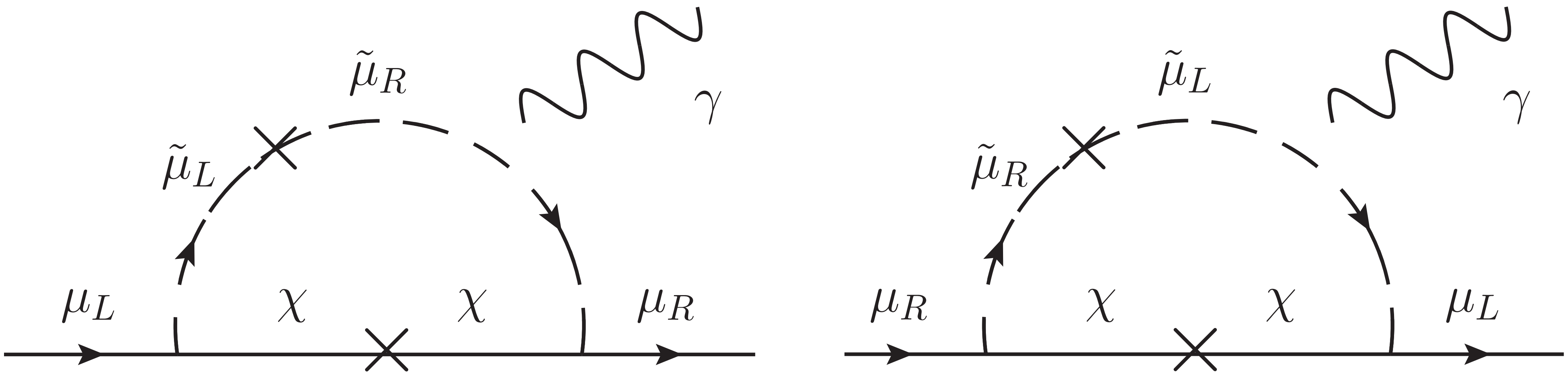


Muon g-2

- If we consider left and right model simultaneously, there emerge new terms

$$\lambda_{LR}(\tilde{L}_i^\dagger \tilde{L}_i)(\tilde{E}_i^\dagger \tilde{E}_i) \qquad\qquad A m_i \tilde{E}_i \tilde{L}_i^\dagger H + h.c.$$

- New ‘A’ term induce muon g-2

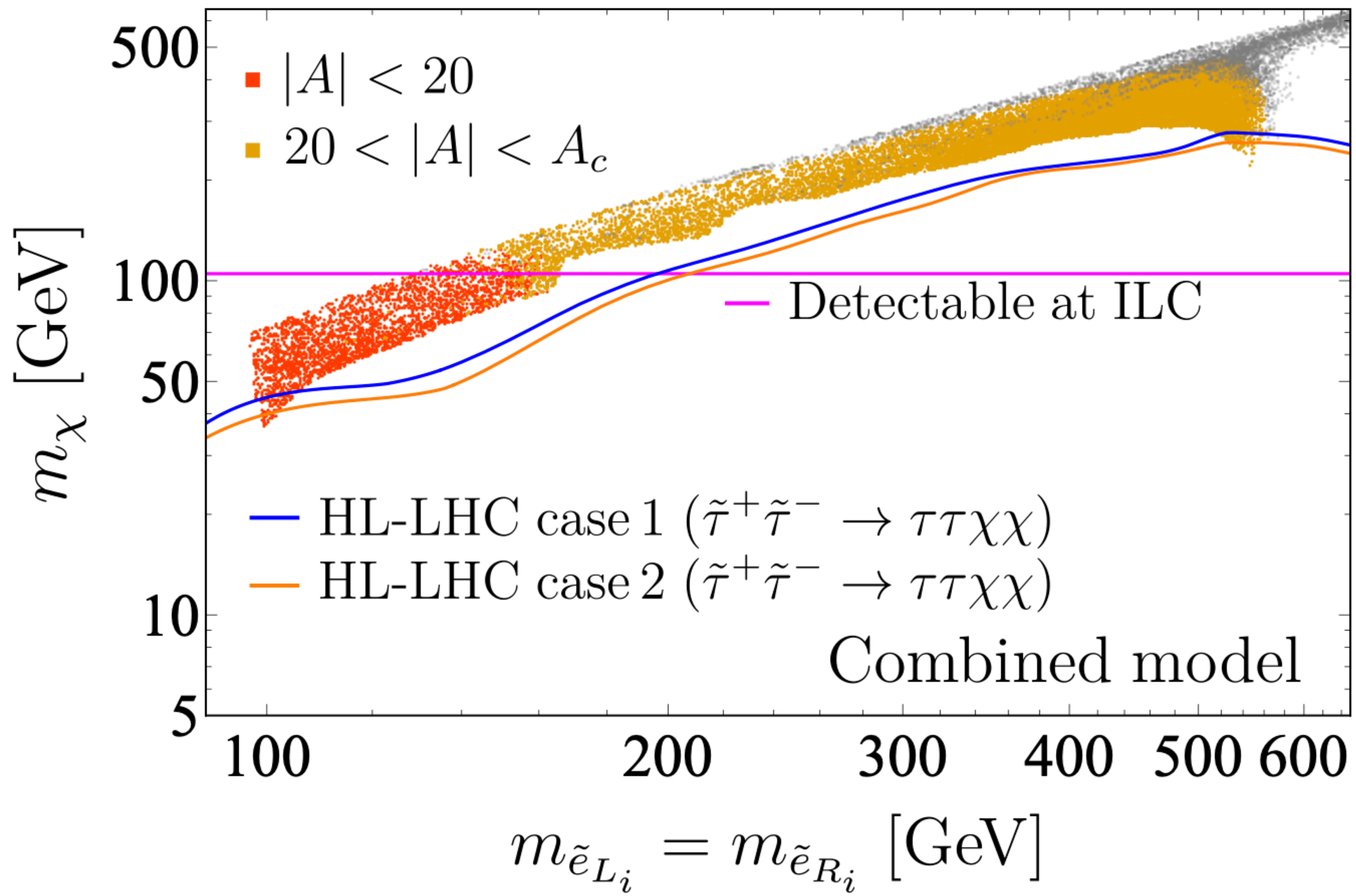


- Muon g-2 anomaly can be explained by combined model

Muon g-2

- This plot shows the value of ‘A’ to explain muon g-2 anomaly
- Yellow and red region have stable vacuum at least SUSY case

[G. H. Duan, C. Han, B. Peng, L. Wu and J. M. Yang, 2019]



Summary

- We studied the phenomenology of fermionic gauge singlet WIMP with leptophilic mediator
- Future collider experiments have important roles to search such models
- Left and right combined model can be the solution of muon g-2 anomaly
- There are some region which can explain muon g-2 anomaly and also detectable at ILC