A WIMP Status Report: Constraints and Discovery Prospects for Singlet-Doublet Dark Matter

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Work in progress with
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Outline

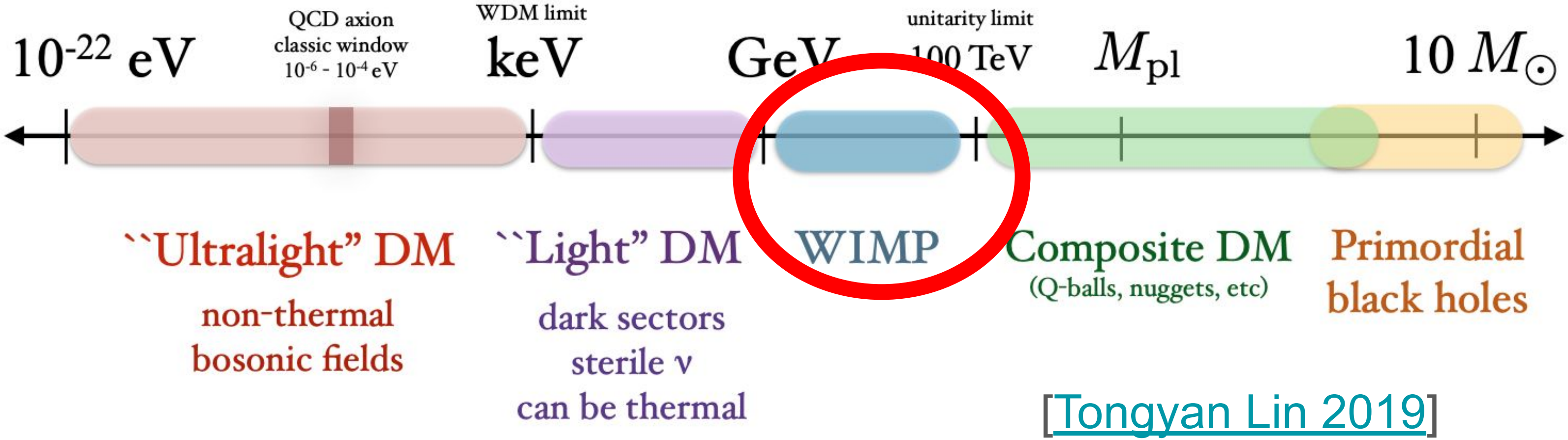
- Dark Matter and the WIMP Paradigm
- Singlet-Doublet Model
  - Blind spots
- Viable Parameter Space Points

Observations Require Cold Dark Matter

“We find that the **base-ΛCDM model provides a remarkably good fit to the *Planck* power spectra and lensing measurements**, with no compelling evidence to favour any of the extended models considered in this paper”

[Planck Collaboration 2018]

But what is Dark Matter? Many possibilities…



[Tongyan Lin 2019]

- This Talk: Weakly Interacting Massive Particles (WIMPs)

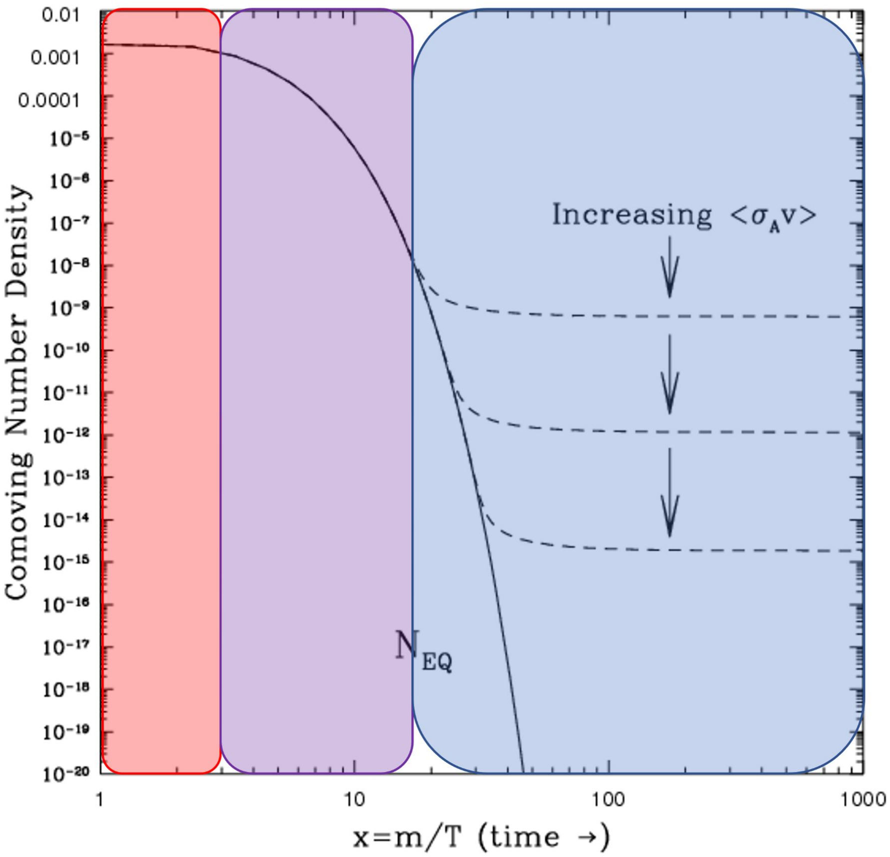
WIMPs

- Thermal freeze-out requires:

$$\langle \sigma v \rangle \sim 10^{-26}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$$

- Weak-scale couplings and masses naturally yield an appropriate cross section

[Adam Green, 2020 ParticleBites]



Singlet-Doublet Dark Matter (1)

- Paradigmatic WIMP model
- No new mediators
  - Annihilation controlled by SM higgs, W and Z bosons
- Dark matter is a majorana fermion
- Generalization of Bino-Higgsino dark matter in SUSY

Singlet-Doublet Dark Matter (2)

- New Particle Content
    - Singlet: **S** in representation (1, 1, 0) of SM gauge group
    - Doublets: **D** and **D̄** in (1, 2, -½) and (1, 2, ½)
- Lagrangian

SM Higgs

$$\Delta\mathcal{L} = -\frac{1}{2}M_S S^2 - M_D D\overline{D} - y_1 DHS - y_2 H^\dagger \overline{D} S + \text{h.c.}$$

- In this talk, I focus on the case when $M_S < M_D$ (and away from resonances)

Singlet-Doublet Dark Matter (3)

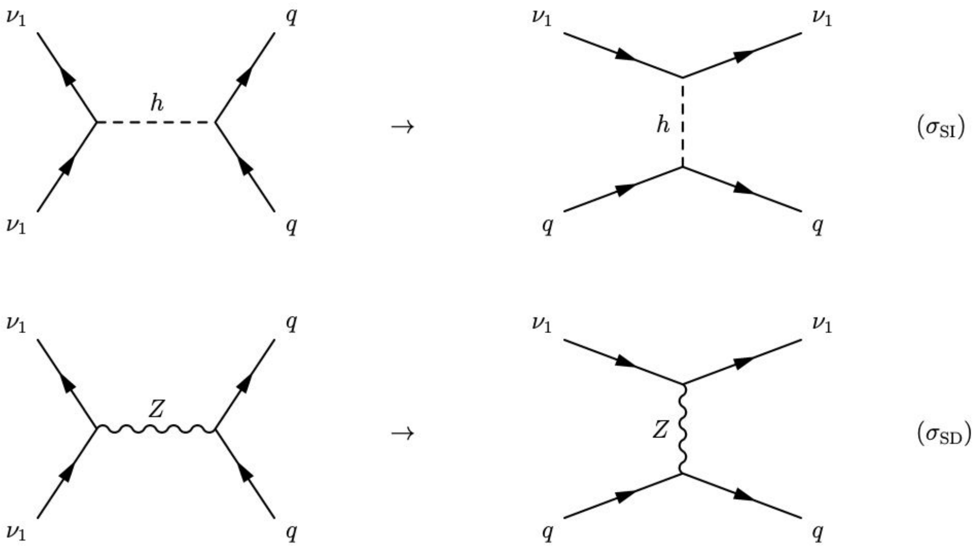
- After EWSB we get
  - 1 charged Dirac Fermion: E
  - 3 neutral majorana fermions: ν_i
- For this model, direct detection bounds are the most constraining
- Blind Spots can help evade constraints:

$$y_2 = -y_1 \frac{M_S}{M_D} \left(1 \pm \sqrt{1 - \left(\frac{M_S}{M_D} \right)^2} \right)^{-1} \implies g_{Z\nu_1\nu_1} = 0$$

$$y_1 = \pm y_2 \implies g_{h\nu_1\nu_1} = 0$$

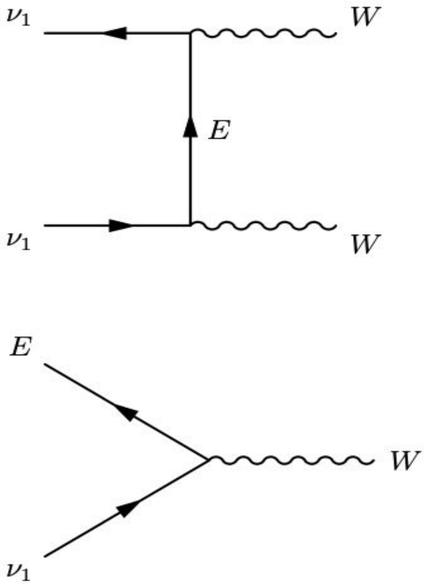
Annihilation and Direct Detection (DD)

Diagrams with DD analogs



[Cohen, Kearney, Pierce, Tucker-Smith 2011]

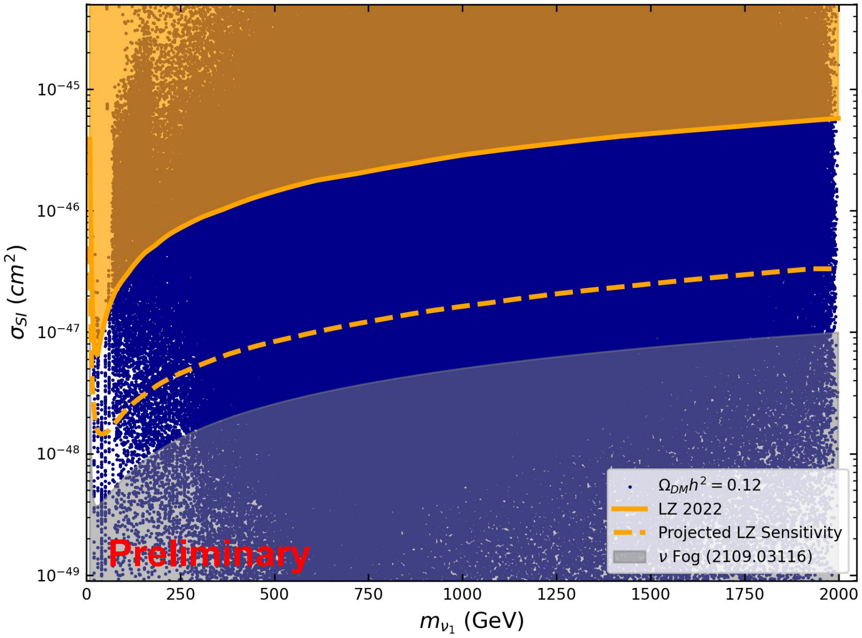
No tree-level DD analogs

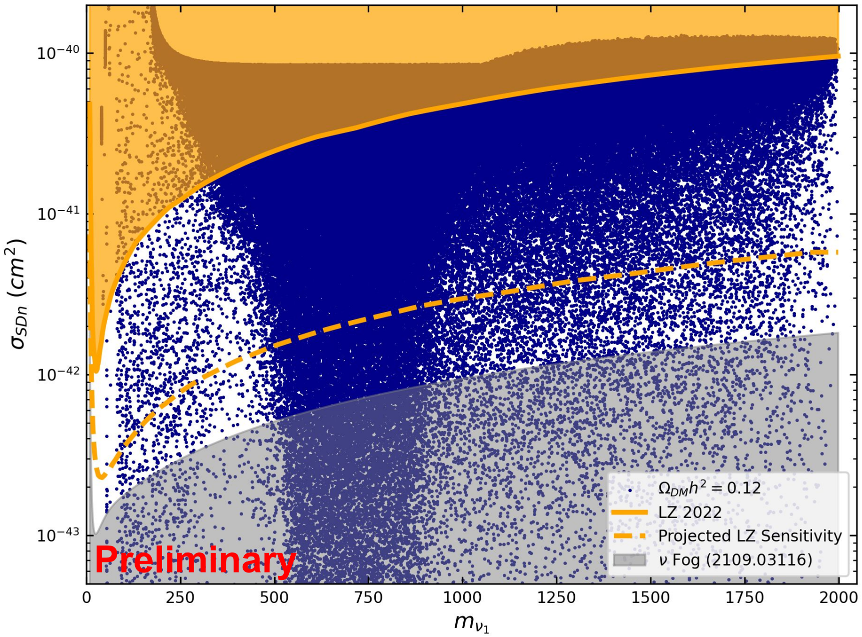


Probing the Singlet-Doublet Parameter Space

- Key Questions; In what areas of parameter space (M_S, M_D, y_1, y_2) is it possible to evade direct detection constraints and still produce the correct relic density?
- We perform a targeted parameter scan of (M_S, M_D, y_1, y_2)
- We implement our model using SARAH and calculate relic densities using micrOMEGAs

Results


10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
σ_{SI} (cm^2)
0
250
500
750
1000
1250
1500
1750
2000
m_{ν_1} (GeV)
$\Omega_{DM}h^2 = 0.12$
LZ 2022
Projected LZ Sensitivity
ν Fog (2109.03116)
Preliminary


10^{-40}
10^{-41}
10^{-42}
10^{-43}
σ_{SDn} (cm^2)
0
250
500
750
1000
1250
1500
1750
2000
m_{ν_1}
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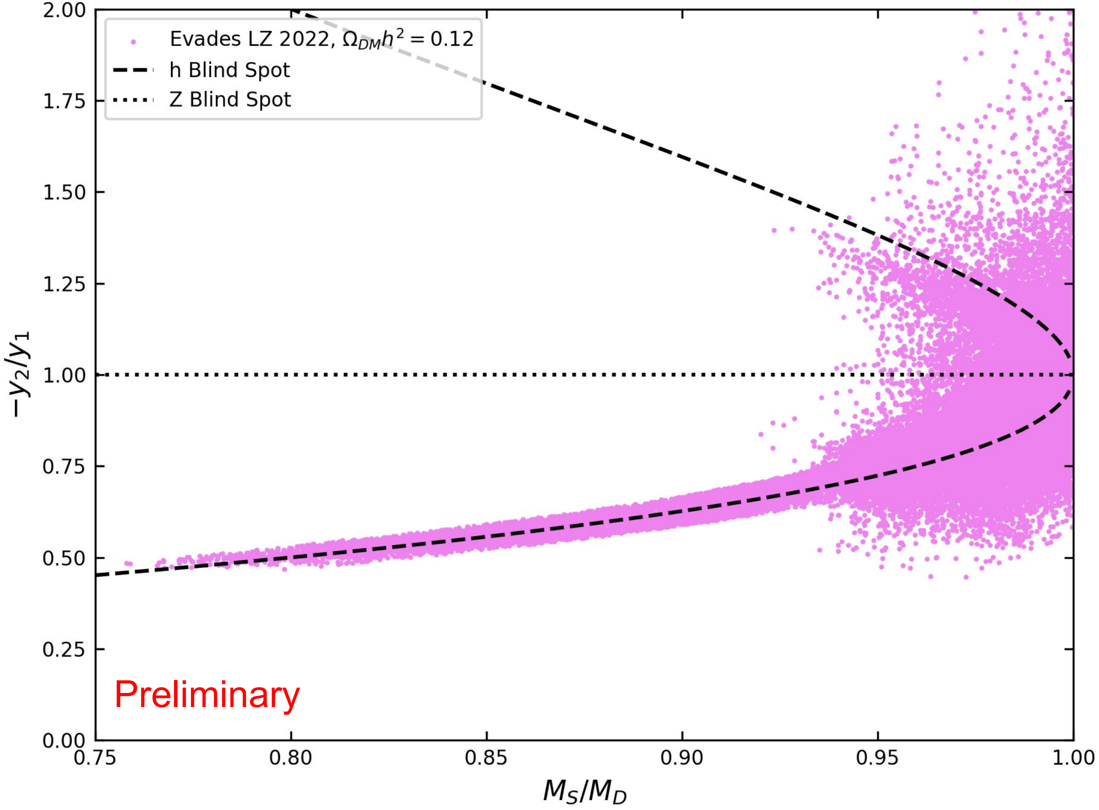
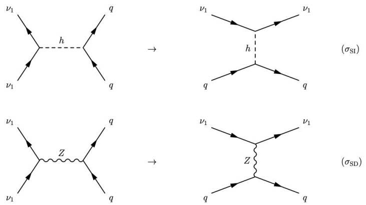
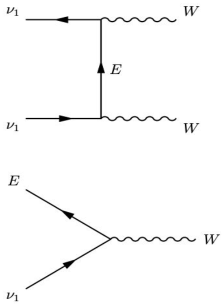
Blind Spots and Coannihilation







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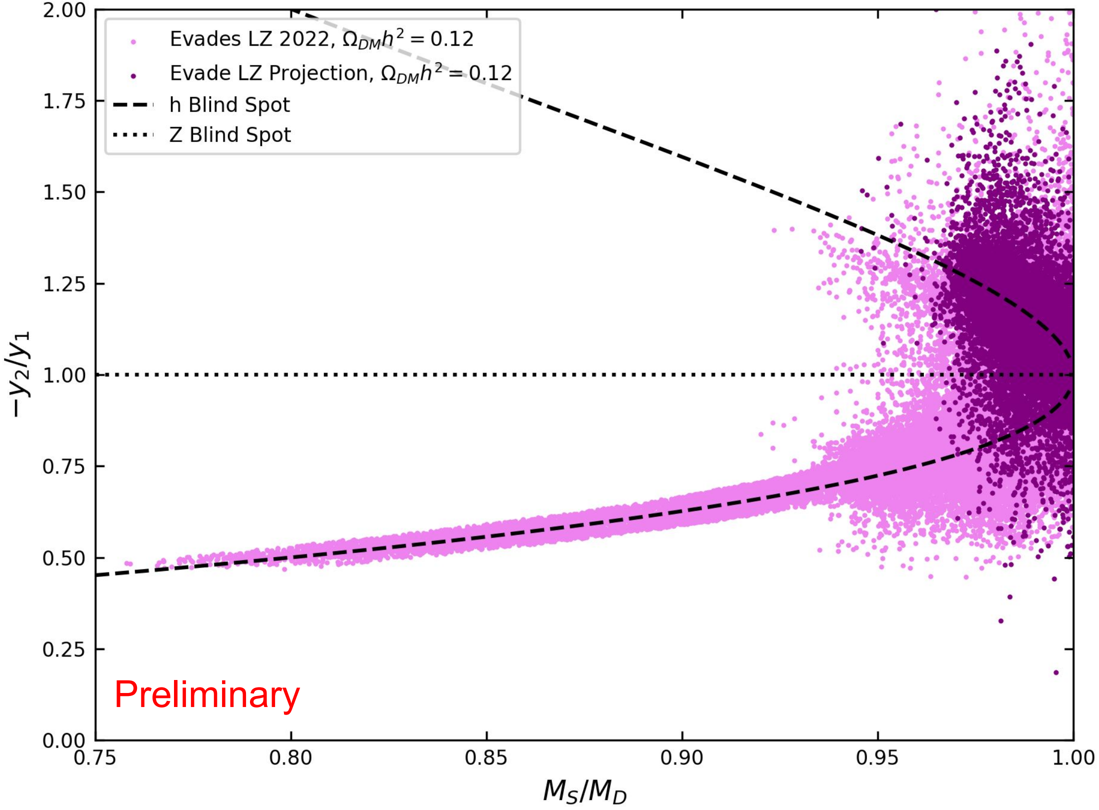
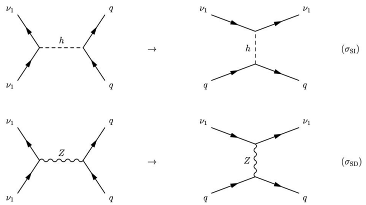
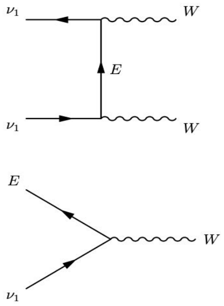
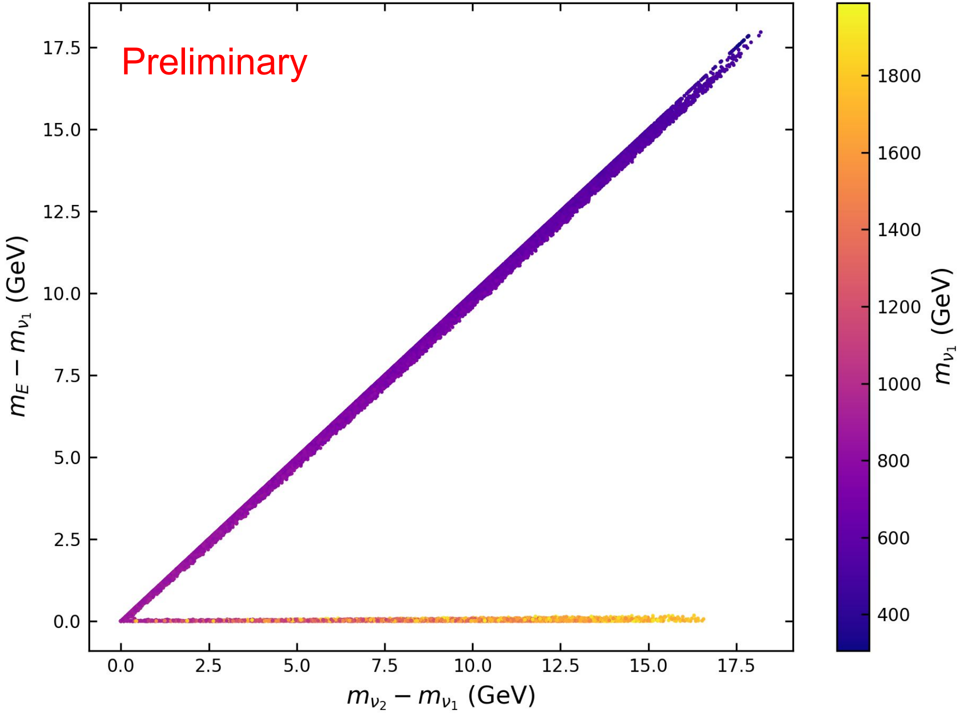






Where is Direct Detection Difficult?

- Parameter regions outside the reach of LZ have compressed mass spectra
- Possibility of reaching some of these points with the LHC



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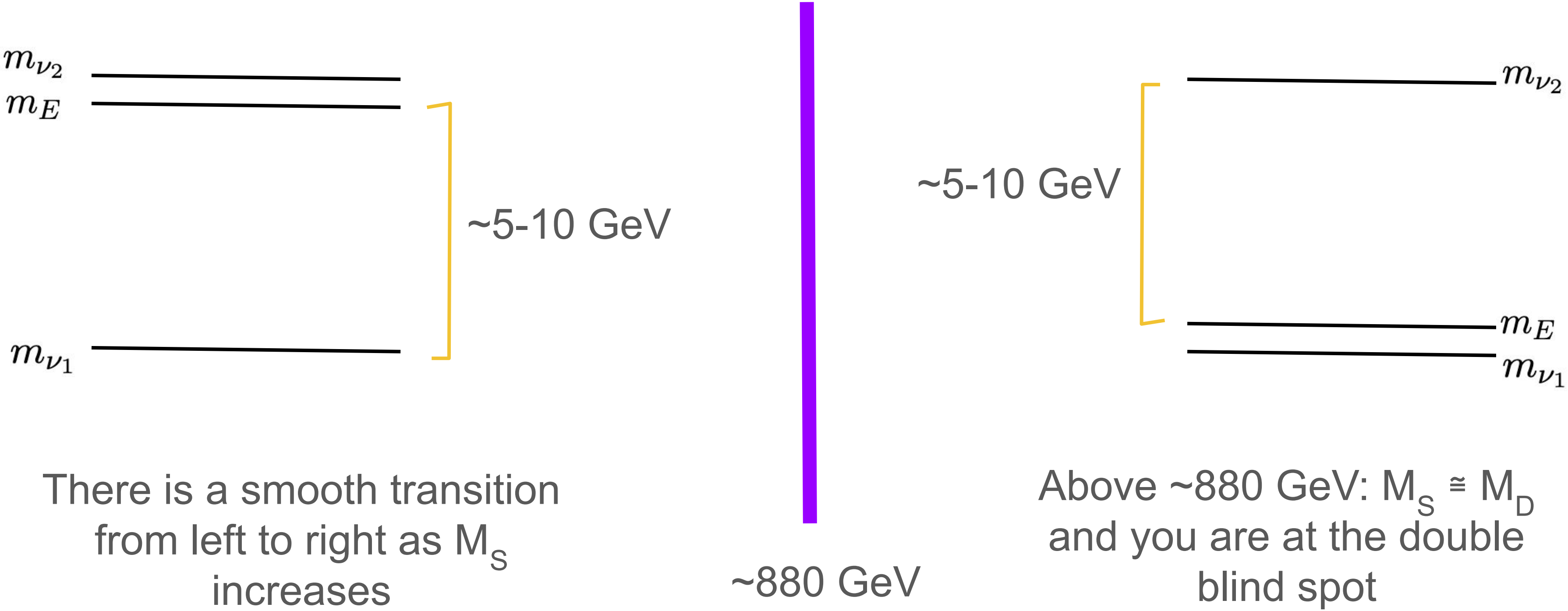

There is a smooth transition from left to right as M_S increases

Above ~880 GeV: $M_S \cong M_D$ and you are at the double blind spot

Summary

- Singlet-Doublet Dark Matter is a well-motivated and economical model that captures the essential features of the WIMP paradigm
- To get the correct relic density and evade LZ constraints:
    - The couplings must satisfy blind spot conditions
    - Need some coannihilation in early universe
- Areas of parameter space beyond the reach of LZ have $M_S \cong M_D$ and may be detectable at the LHC (work in progress)

Thank You!