

Search for Dark Matter at Colliders [1]

Hongyin Liu

October 12, 2021

1 Proposal: WIMP

DM consists of weakly interacting massive particles (WIMP) $\sim 100\text{GeV}$

2 Types of Searches for DM

2.A Indirect Detection (ID)

Detect SM fluxes of annihilation/decay of DM particles.

2.B Direct Detection (DD)

Scattering of DM particles off atomic nuclei: measure nuclear recoil energy.

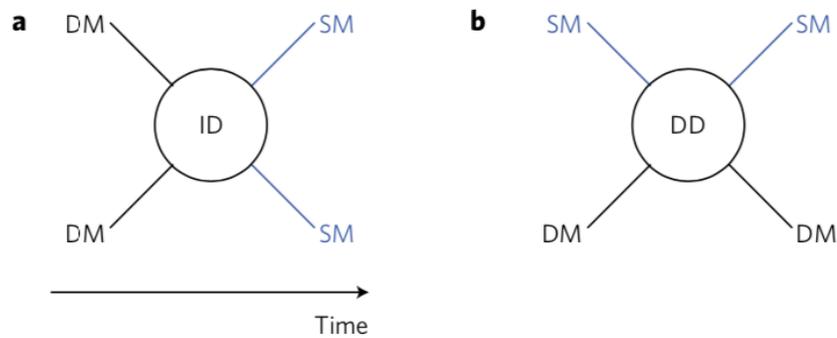


Figure 1: Left: DM annihilation; right: DM \rightarrow SM scattering

2.C Collider Searches

Detect signals from DM particles produced when colliding SM particles.

- Advantages: Can search for invisible DM particles; probe interaction b/w SM and DM particles by searching for mediators
- Limitations: Cannot probe whether or not DM particles have long life times.

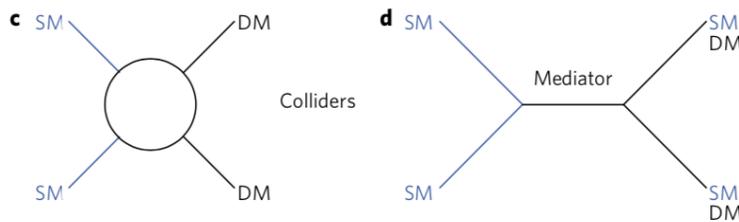


Figure 2: Left: Search Invisible DM particles; right: Probe mediator particles

3 Collider Searches for WIMP

- General method: Signals-Missing transverse momentum or energy E_T^{miss}
Explanation: $\rightarrow | \leftarrow$, Initial momentum = 0 at plane,
final vector sum of momenta $< 0 \Rightarrow$ DM signal.
- Goal: model-independent searches

Two types of searches are discussed:

3.A Based on a specific models: supersymmetry

- Models: Composite Higgs¹⁹, new spatial dimensions^{20–24}, SUSY²⁵, etc.
- SUSY:
 - (a) DM candidate- lightest SUSY particle (LSP, superpartner), a result of the R-parity symmetry.
 - (b) Signals: jets (quarks, gluons, etc), and significant E_T^{miss} .
 - (c) Majority employ simplified SUSY models.

3.B General Searches

- Effective field theories and simplified methods (approaches are not model specific)
- Design and interpretation of DM searches:
 - (a) Effective field theory (EFT) approach: May breakdown at energy scales of mediating particles of the SM-DM interaction.
 - (b) Simplified models:
 - Particles mediate SM-WIMP DM interactions
 - Consistent at all energy scales
 - Two types of mediators described by simplified models:
 - (1) Mediator is a SM particle/ has same couplings as SM particle:
 - * DM part of a weak $SU(2)_L$ multiplet; mediators of weak interaction: W and Z bosons
 - * Winos and higgsinos are weak triplet and doublet.
 - * Mediator of DM-SM interactions: Higgs boson
 - (2) Mediator is not yet included in the SM (new mediator) :
 - * ATLAS and CMS constrain mediator masses $\leq 2\text{TeV}$, DM masses $\leq 500\text{ GeV}$
 - * Mediators: Z-boson-like particle, or
 - * Mediators: New Higgs-like scalar/ pseudoscalar particle.
- Search Strategies:
 - (a) Mono-X searches:
 - Pair production of DM particles.
 - Signals: contains high-momentum object (jet, photon, vector boson), AND significant E_T^{miss} .

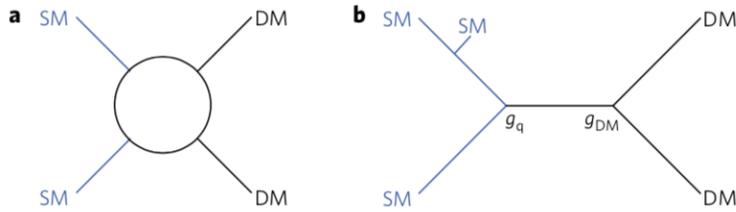


Figure 3: Left: DM-SM interaction in EFT; right: same except a new mediator particle

(b) Dijet Searches:

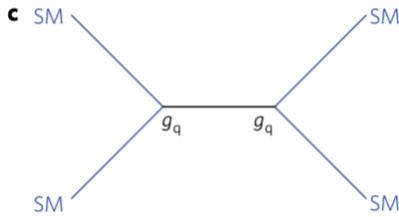


Figure 4: Left: Mediator decays into SM quarks

- Mediator decays into SM particles (a pair of quarks/gluons).
 - Signals: excess in mass of the two most energetic jets/dijets.
 - Use: investigate the decay of mediator particles.
 - More sensitive at higher mediator and DM masses.
- Note: parameter space covered by Mono-X and Dijet is highly dependent on the choice of quark couplings.

3.C To Conclude..

- Both collider and non-collider results use theoretical models: require assumptions
 - Non-collider: knowledge of relic density and DM density
 - Collider: specify the production and decay mechanisms in particle collisions

- Constraints on WIMP DM: linked to parameter space of new physics models (e.g. SUSY)
- Another direction for collider searches:
 - DM is part of a larger dark sector: more than one species of DM, can couple with DM— dark matter self interactions.
 - Signal: Produce signatures complementing E_T^{miss} .
 - E.g. the LHC searches for dark photons and long-lived particles

References

- [1] O. Buchmüller, C. Doglioni, and L.-T. Wang, “Search for dark matter at colliders,” *Nature Physics*, vol. 13, no. 3, p. 217–223, 2017.