

# Beyond WIMP DM models

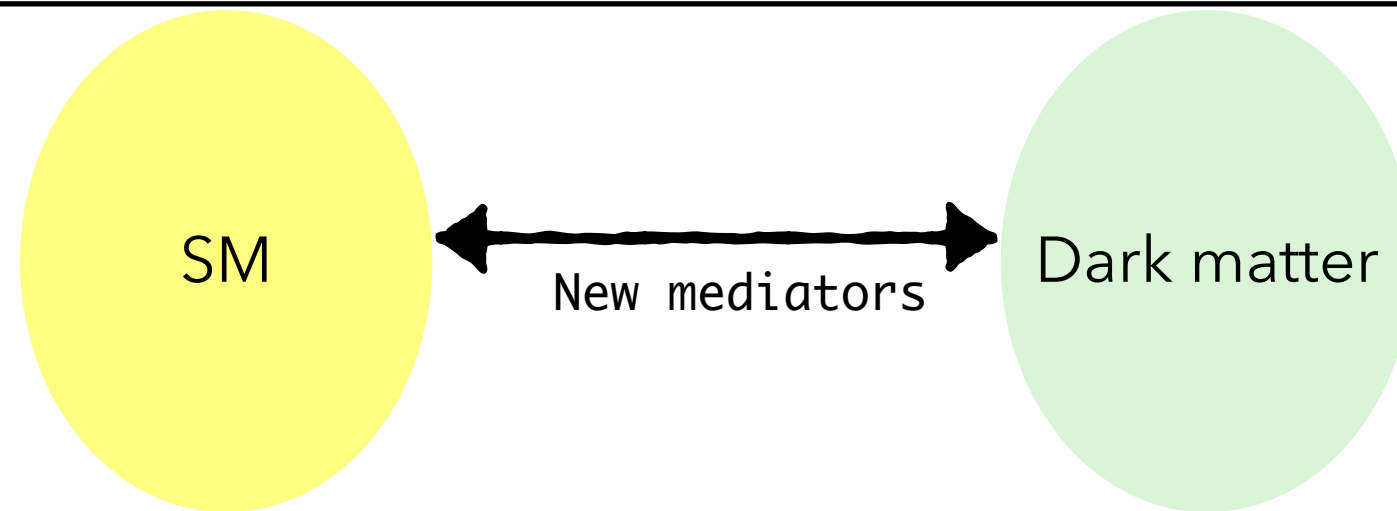
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 [@suchi\\_kulkarni](https://twitter.com/suchi_kulkarni)

# Setting the stage

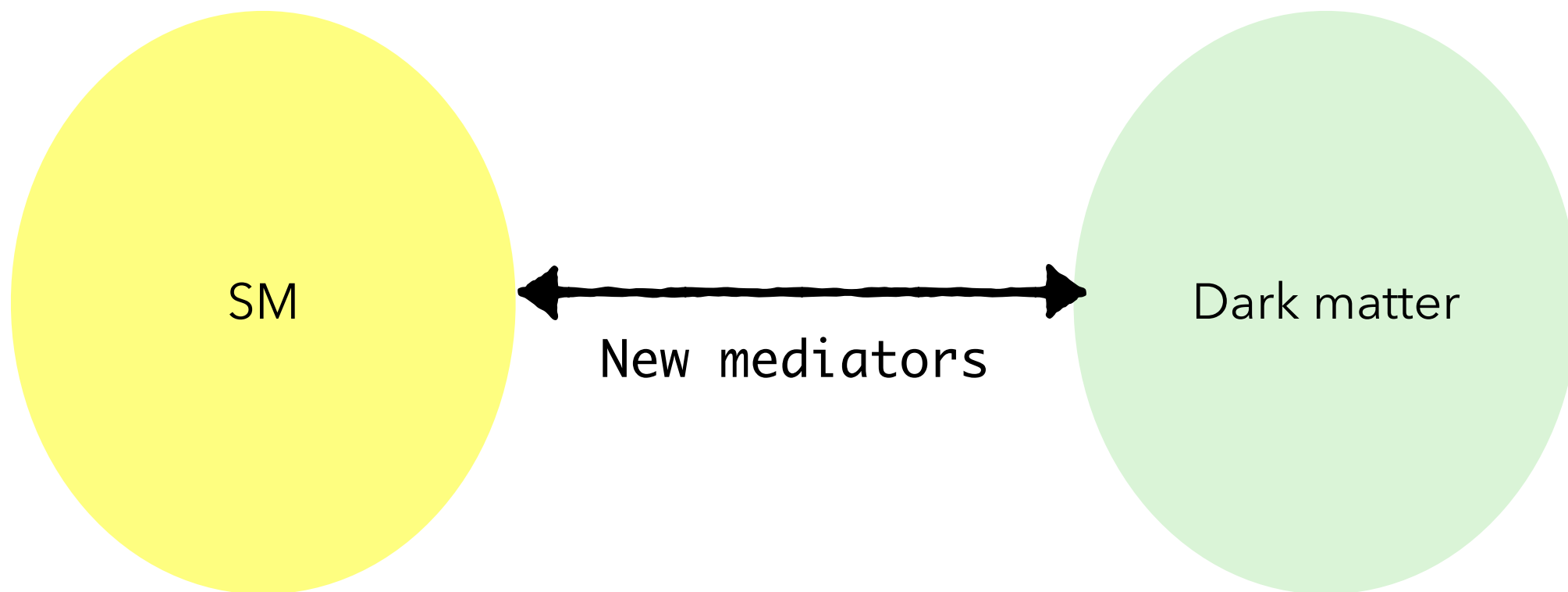


- This setup allows mediators (and correspondingly the DM) to be light

$$\langle \sigma v \rangle \sim 10^{-25} \text{ cm}^3 \text{ s}^{-1} g_{\text{DM}} g_{\text{SM}} \left( \frac{m_{\text{DM}}}{100 \text{ GeV}} \right) \left( \frac{1 \text{ TeV}}{m_{\text{med}}} \right)^4$$

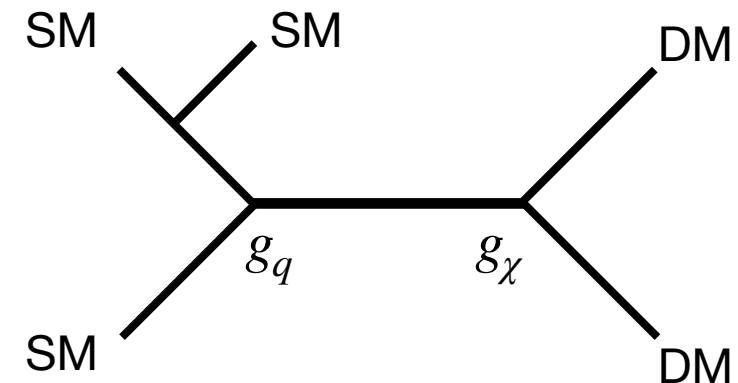
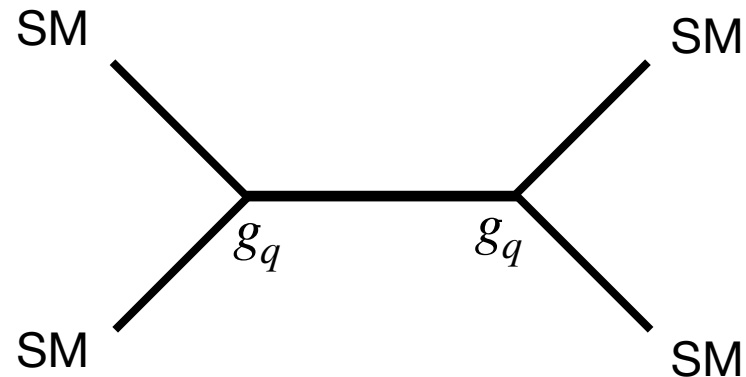
- Relic can still be satisfied by considering very feeble SM - DM interaction strengths
- Motivation for theory and experiments to extend WIMP paradigm to lower DM masses and smaller couplings
  - (Collider) signatures often include long lived particles
  - Optimal parameter space coverage requires dedicated experimental toolkit and dedicated experiments

# Portal phenomenology



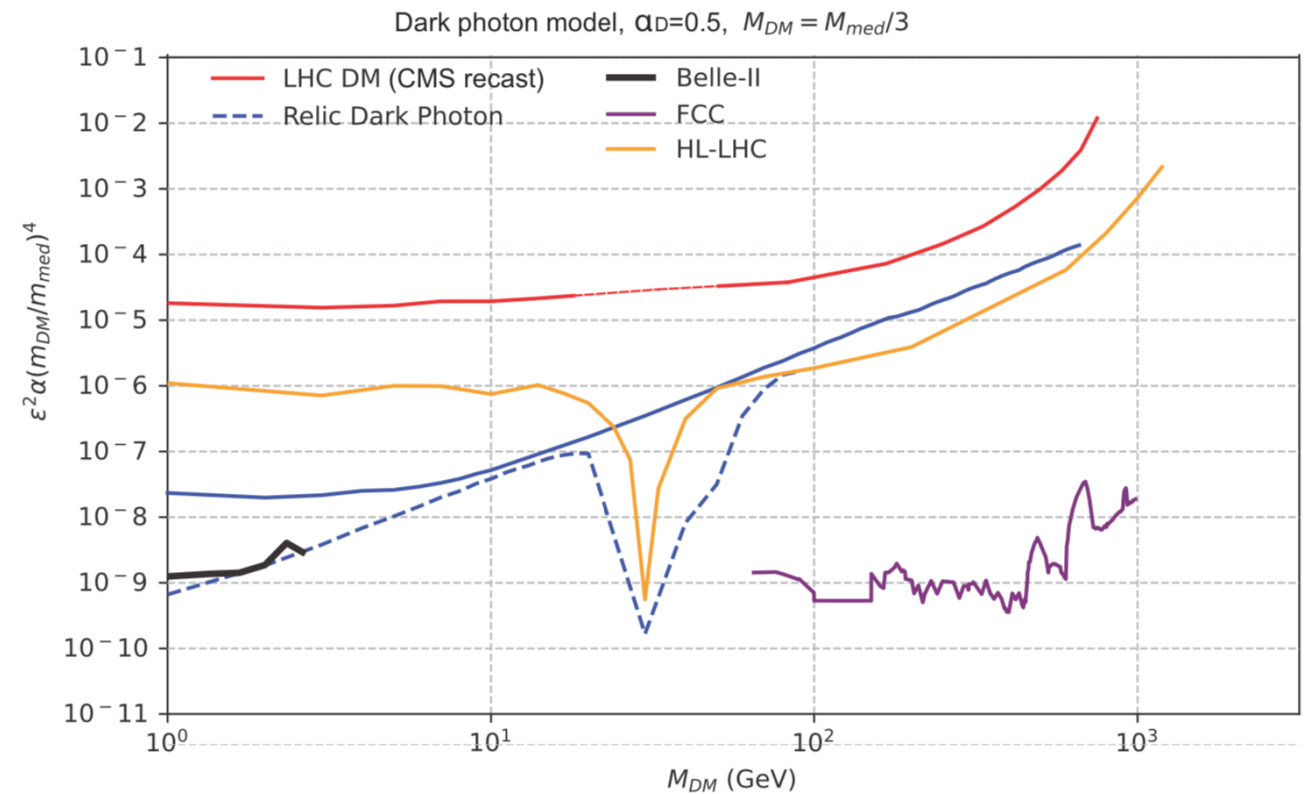
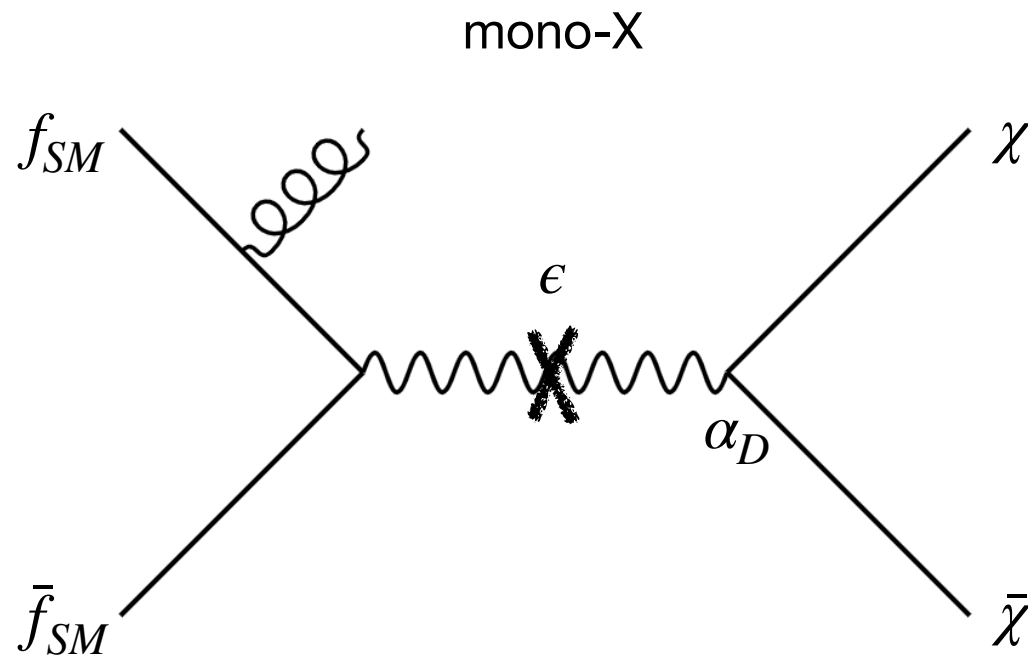
- SM extension with one DM particle and one mediator a la simplified models approach
- New mediators (portals) can be vector, scalar or pseudo-scalar
  - Well motivated model parameter space
  - Concentrate on lowest dimensional operators to begin with

# Complementarity between final states



- We want to completely characterise the particle nature of dark matter
- Utilise complementarity between visible and invisible final states to obtain information on the nature of portal and DM
- E.g. for dark photon, which decays to all available SM fermions, a complete set of measurements/searches in all final states will nail down dark photon properties or allow us to confirm that it is indeed a dark photon
- Such exercises may require a number of different experiments e.g. Forward Physics Facilities can play an important role here as high energy beam collisions create large flux of (new) particles in forward region (see RF06 report for detailed case studies)

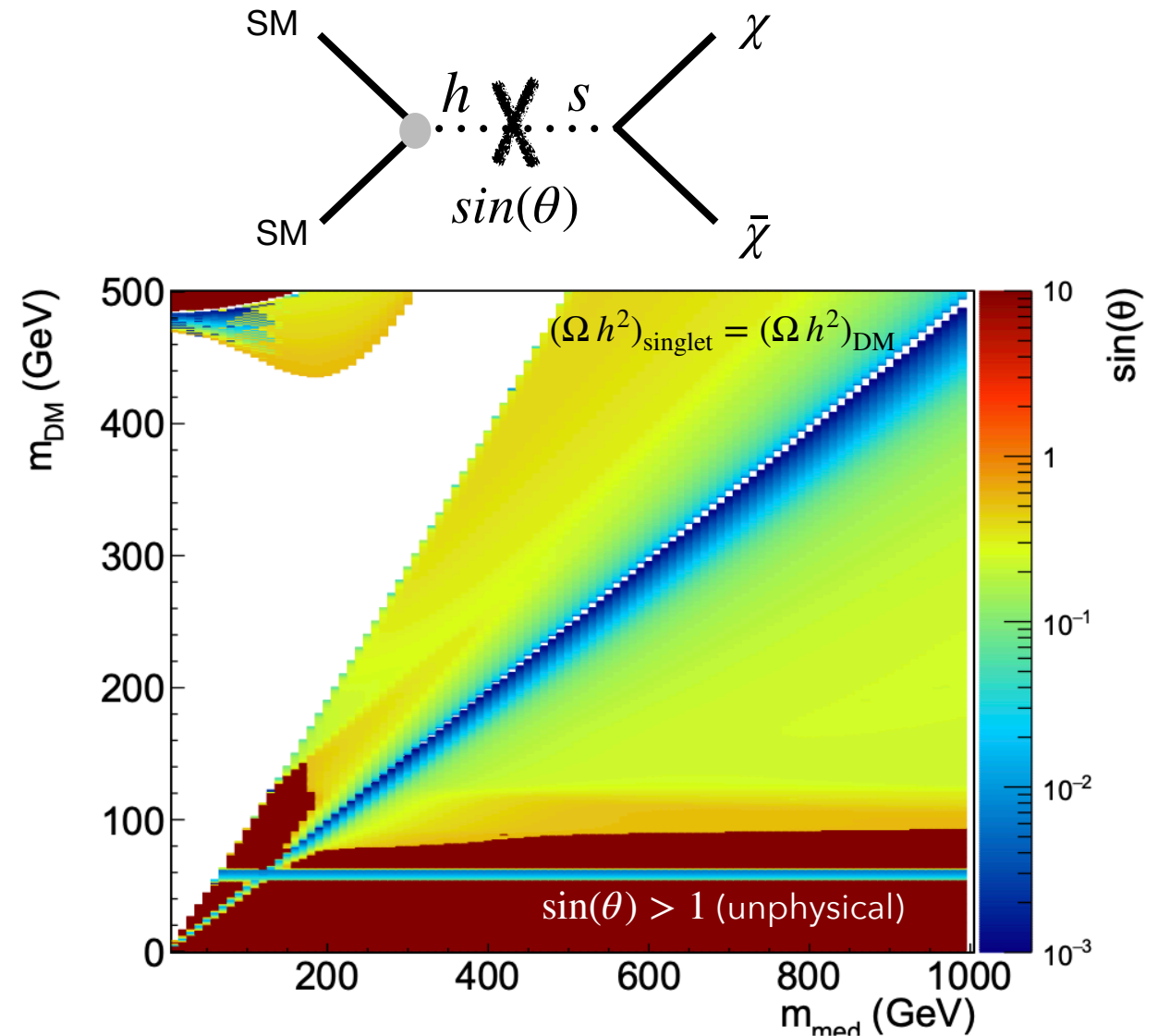
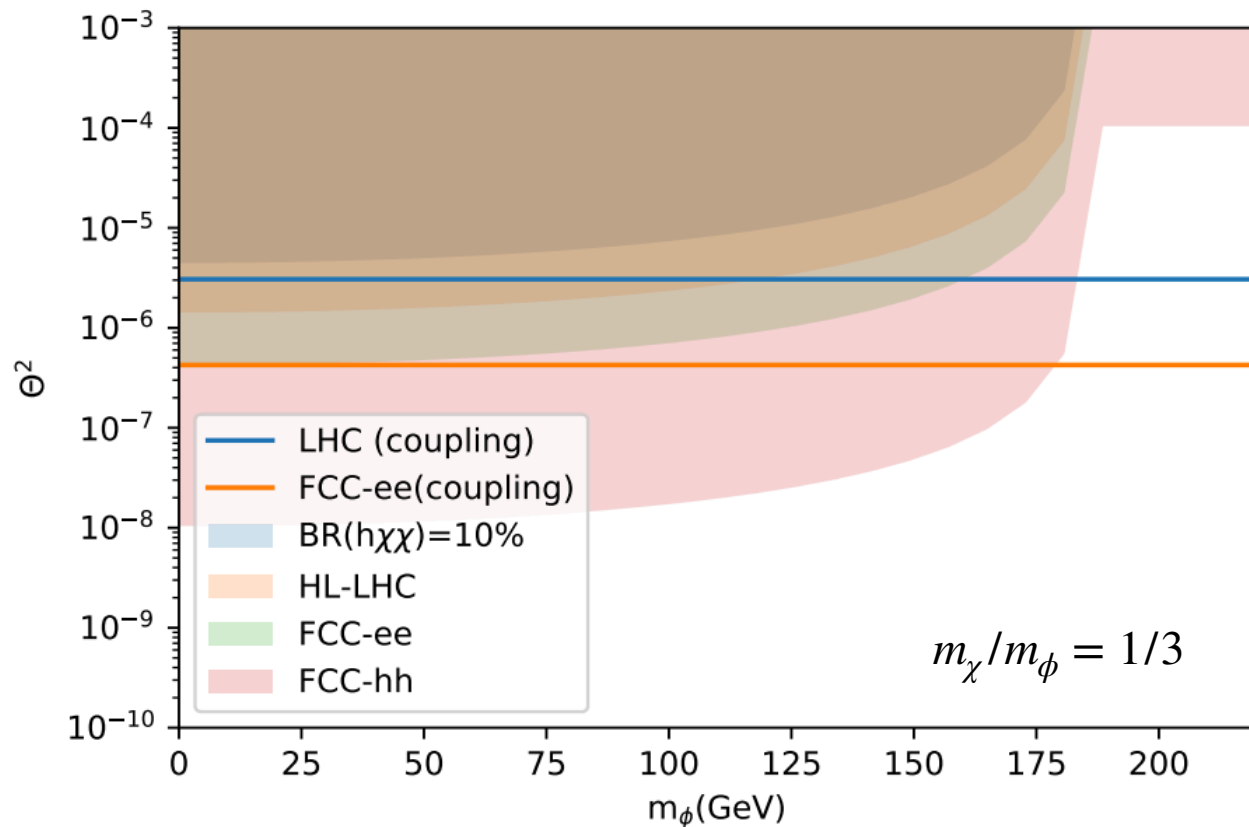
# Dark photon portal



- Simple, predictive model that consistently captures phenomenology and experimental observables
- Colliders have a good reach for dark photon masses  $> 3$  GeV
- Complimentary to low energy experiments (see RF06 report for low mass version of this plot)

# Dark Higgs portal

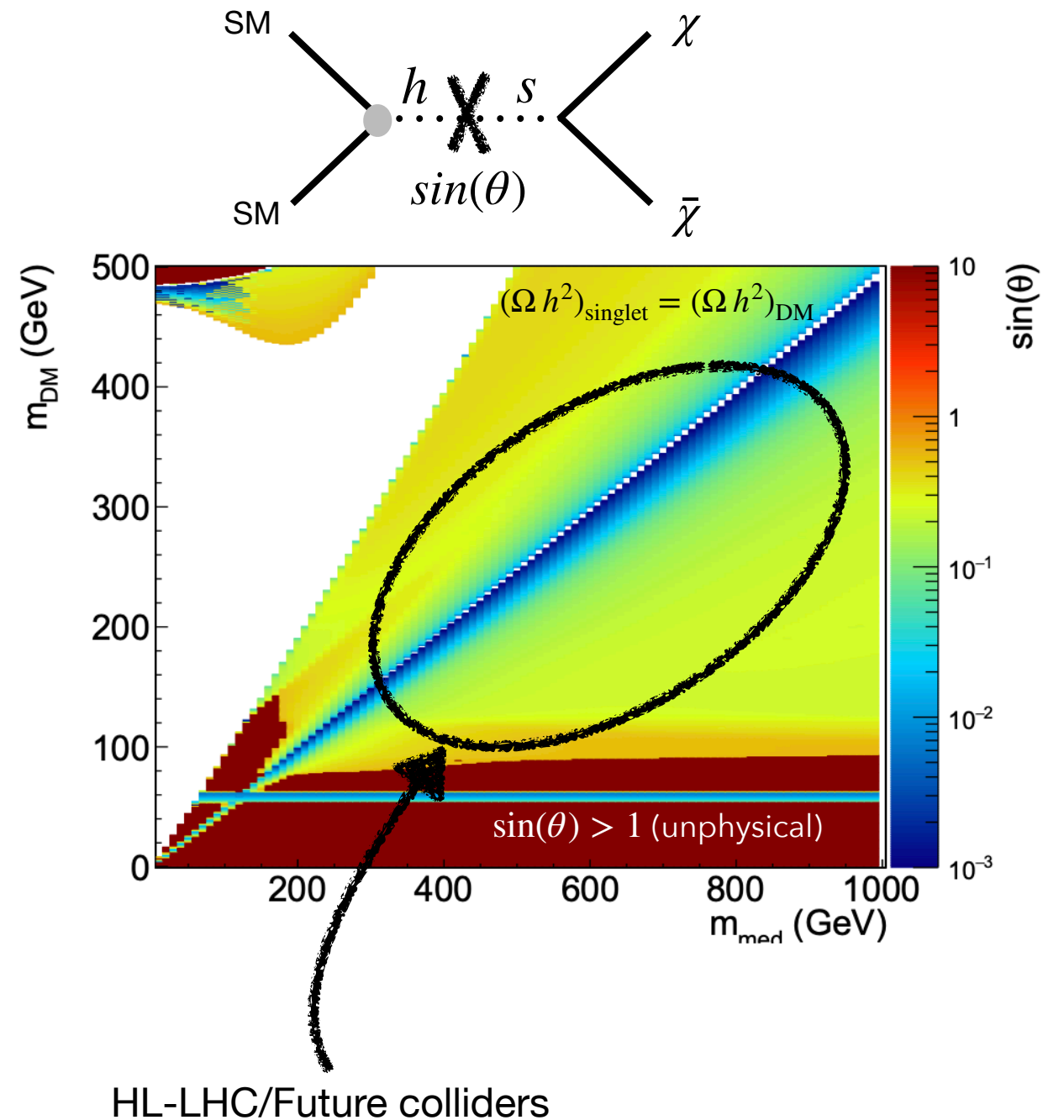
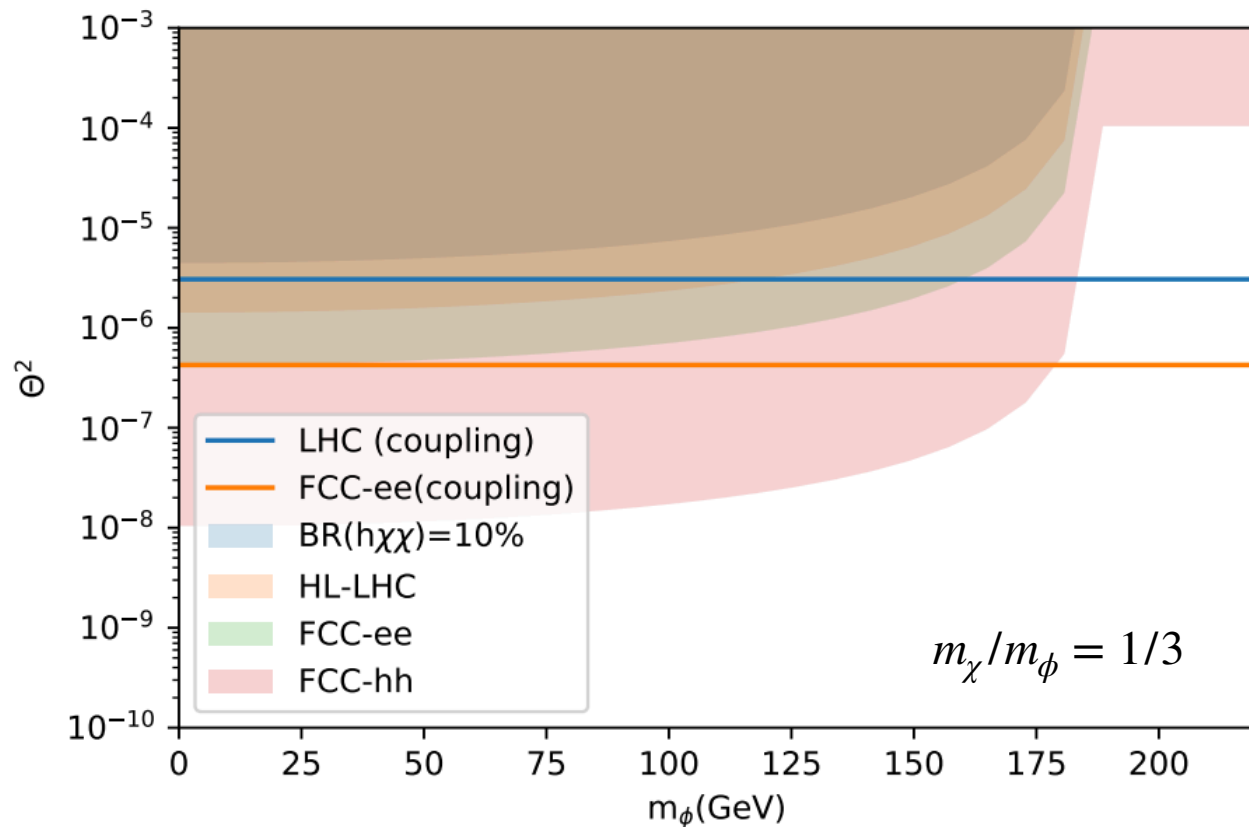
$$\mathcal{L} \subseteq -y_{DM} S \bar{\chi} \chi + (\mu S + \lambda S^2) H^\dagger H$$



- Low DM and singlet masses do not provide good relic density, always overproduced
- High mass DM and singlet masses may still be within reach for future colliders

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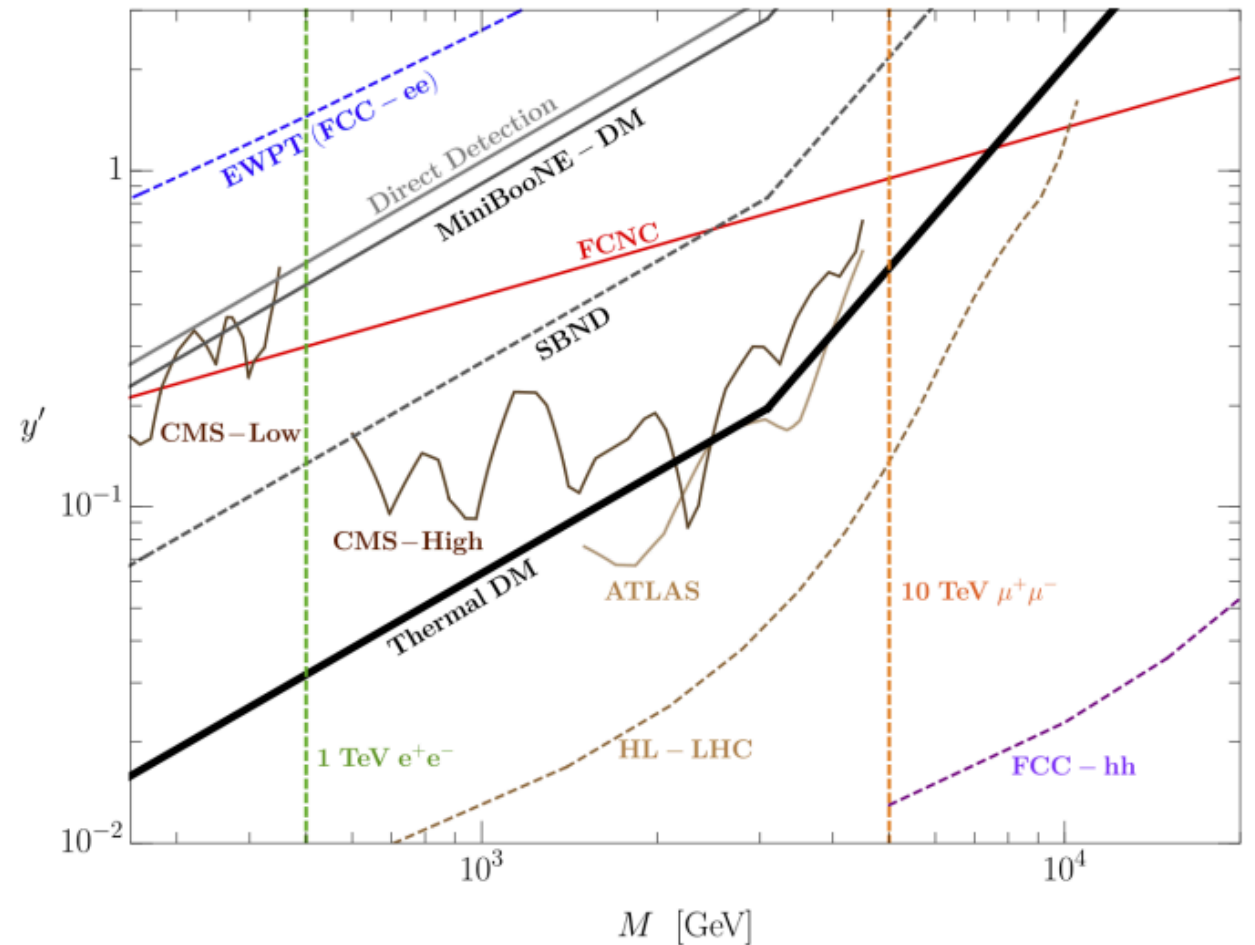
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# Towards full models

..... New particles

———— Mediator

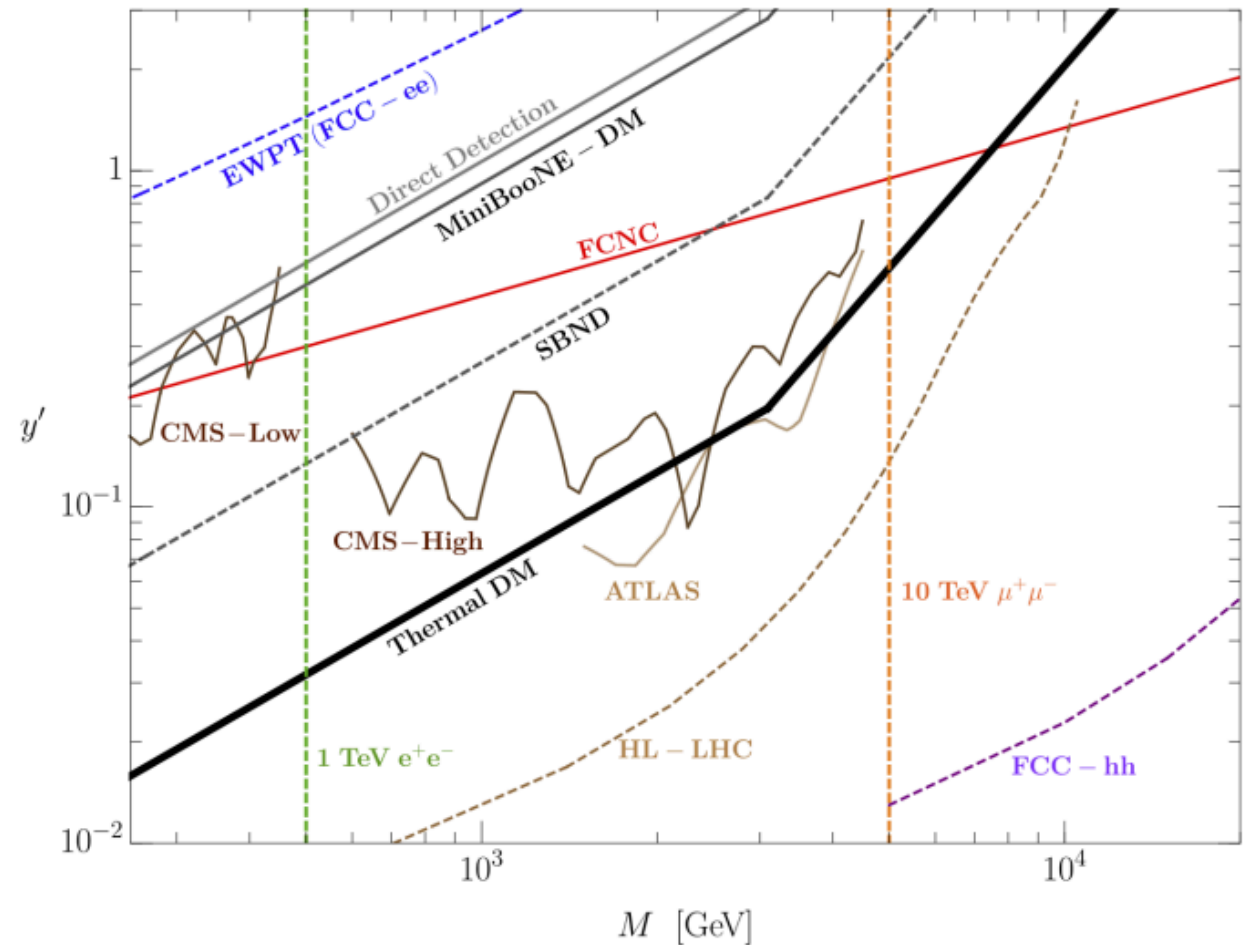
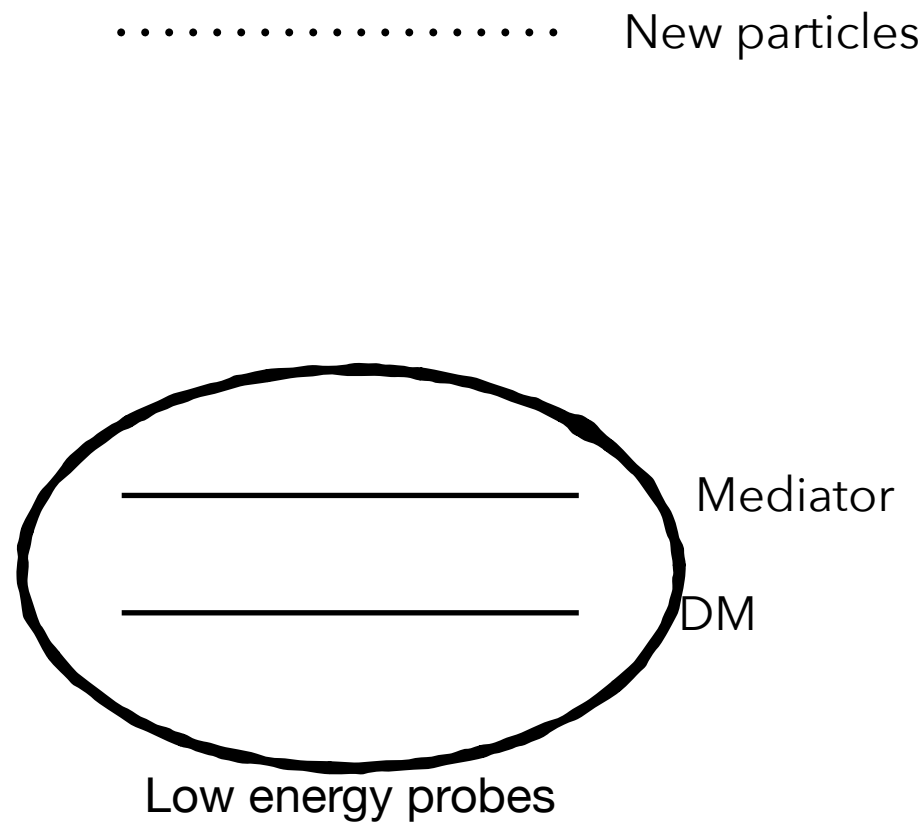
———— DM



- Even if dark matter and mediator are very light, UV completion can predict additional particles
- Search for these particles at colliders leading to new complementarity between low and high energy probes

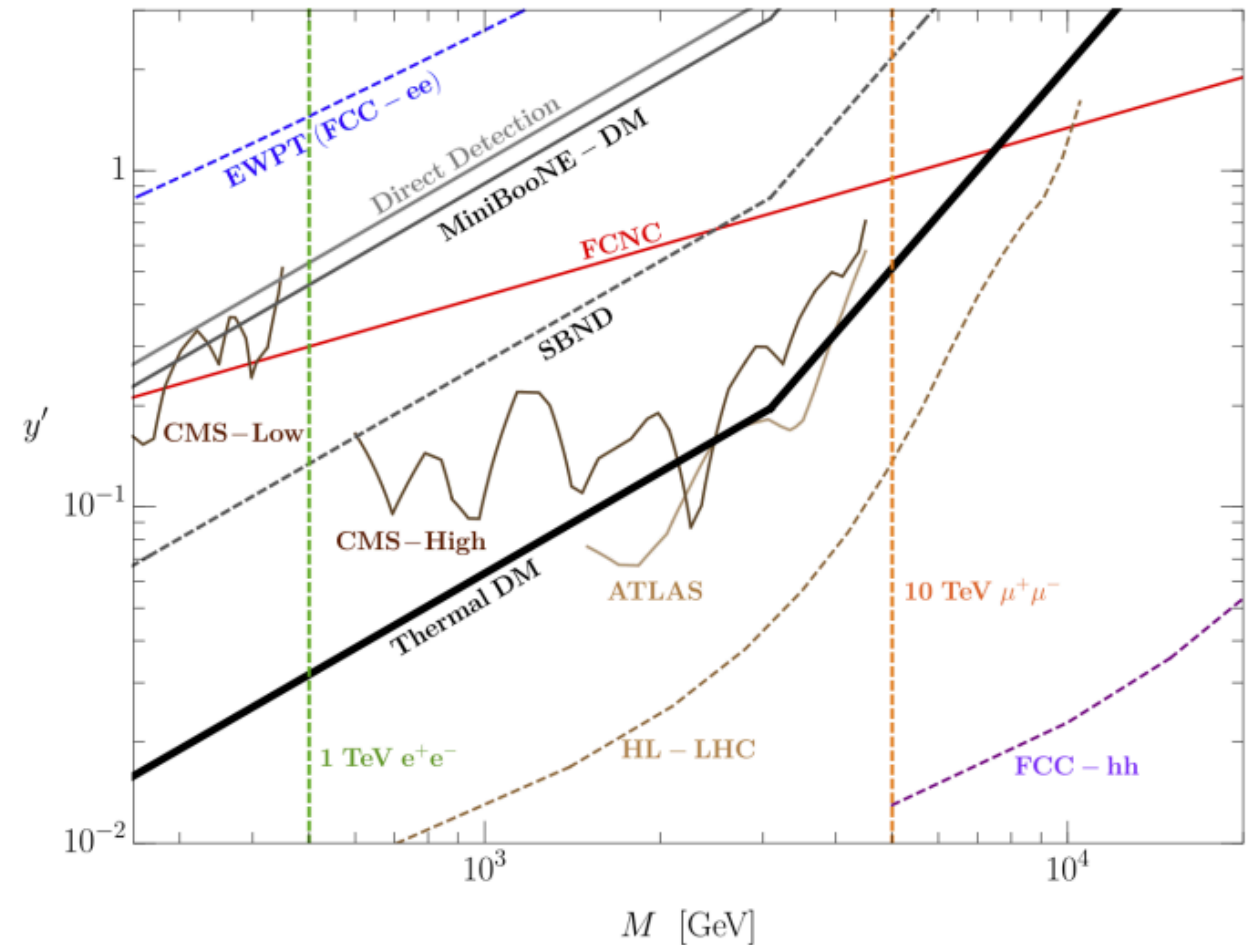
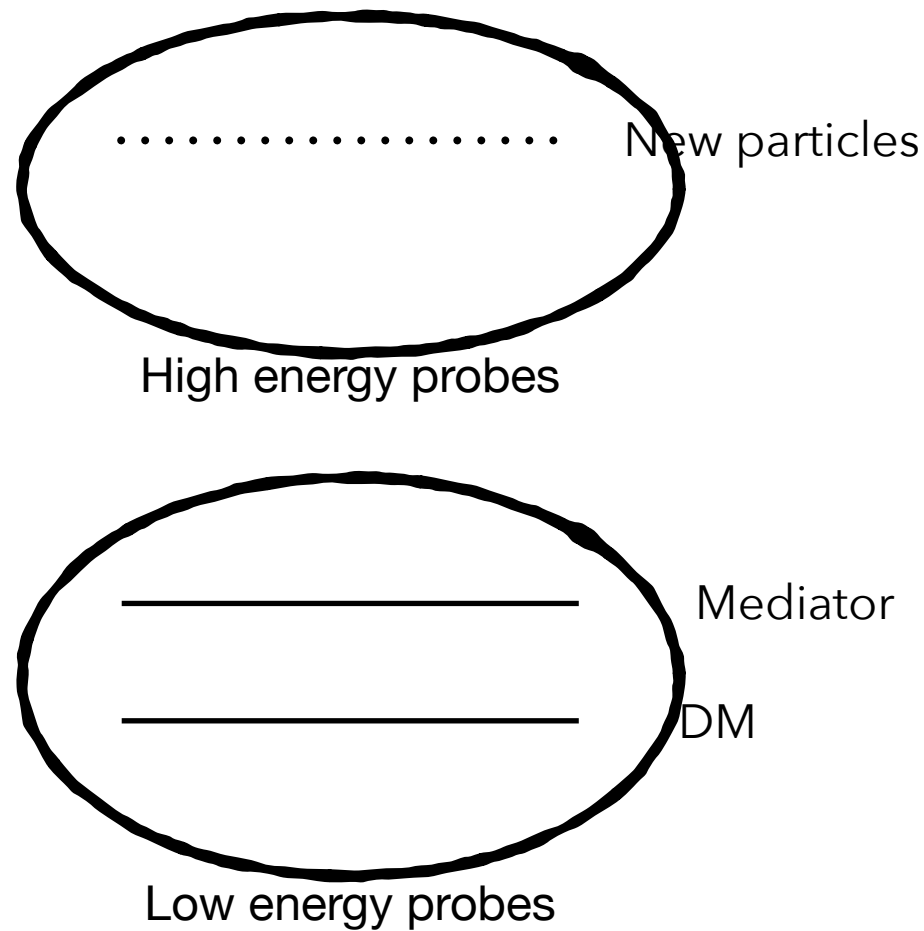


# Towards full models



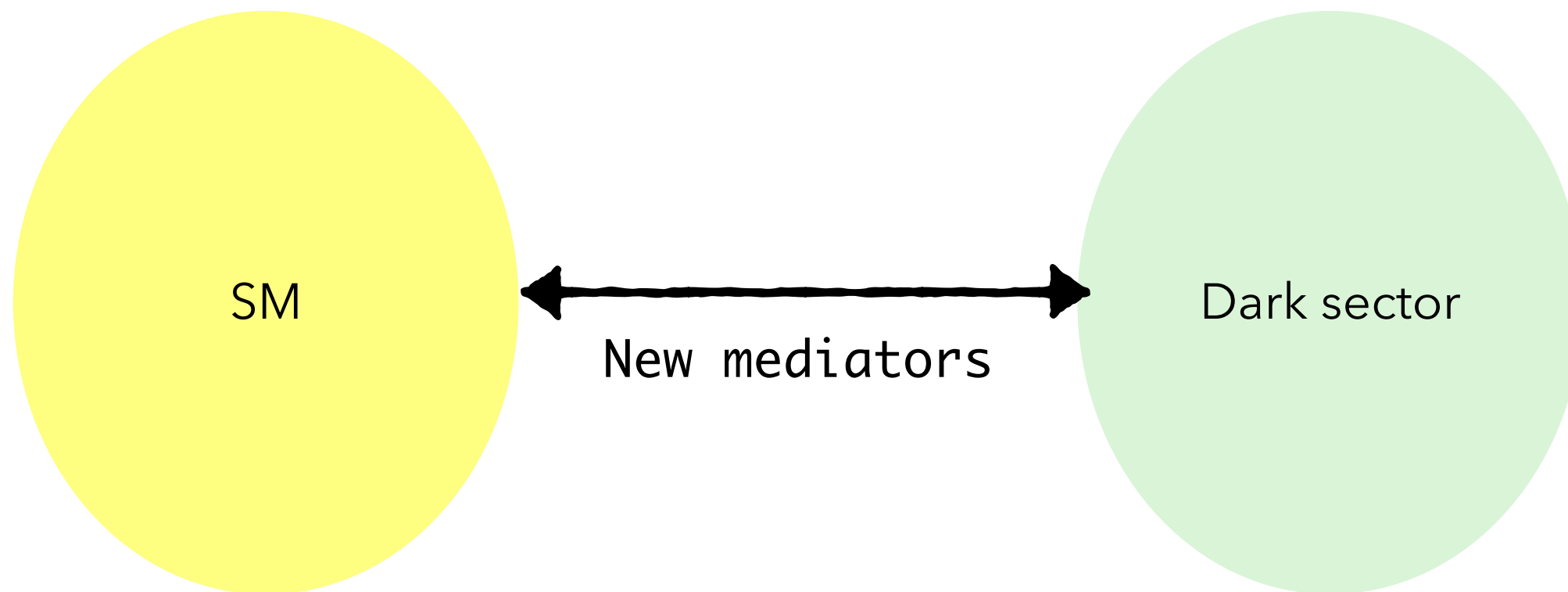
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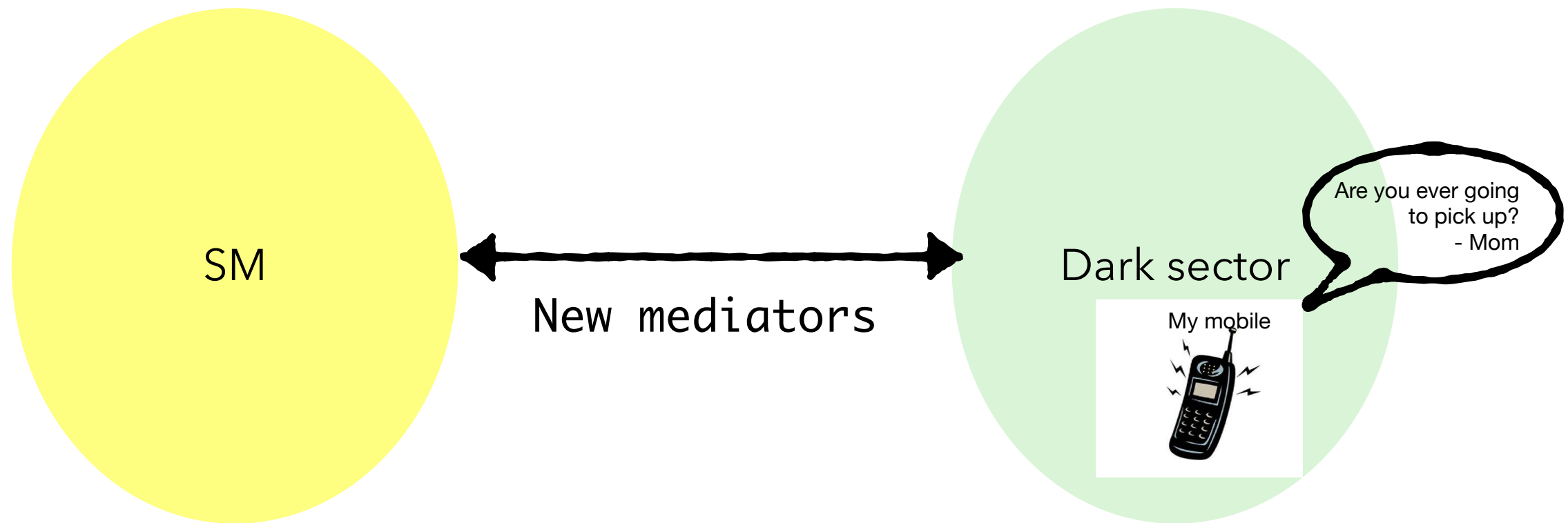
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# Dark sector phenomenology



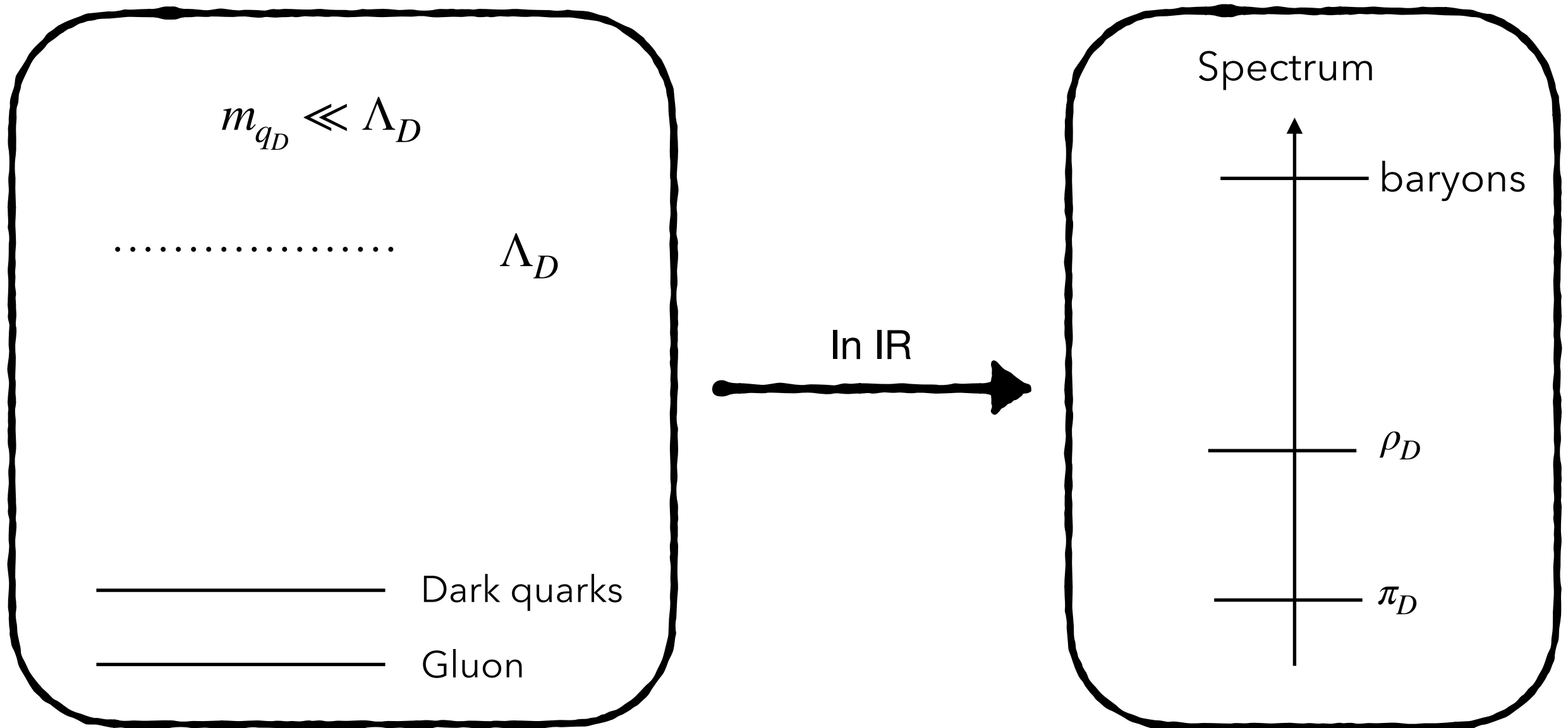
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  - Concentrate on composite dark matter scenarios a la Hidden Valleys formalism

# Dark sector phenomenology



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# What we have in mind



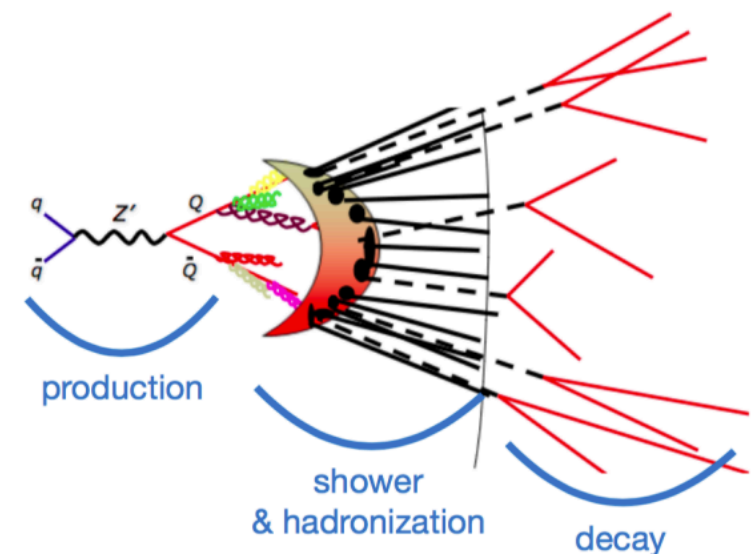
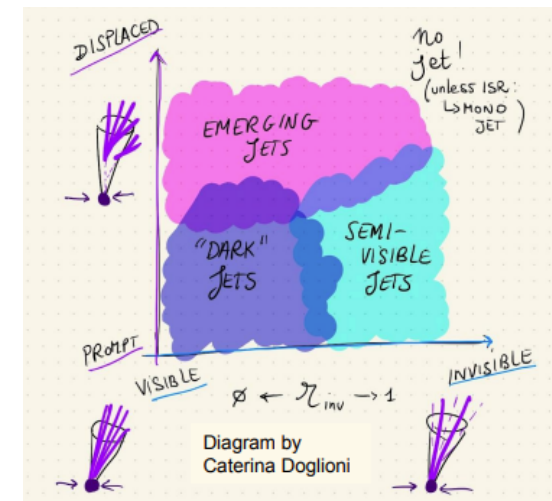
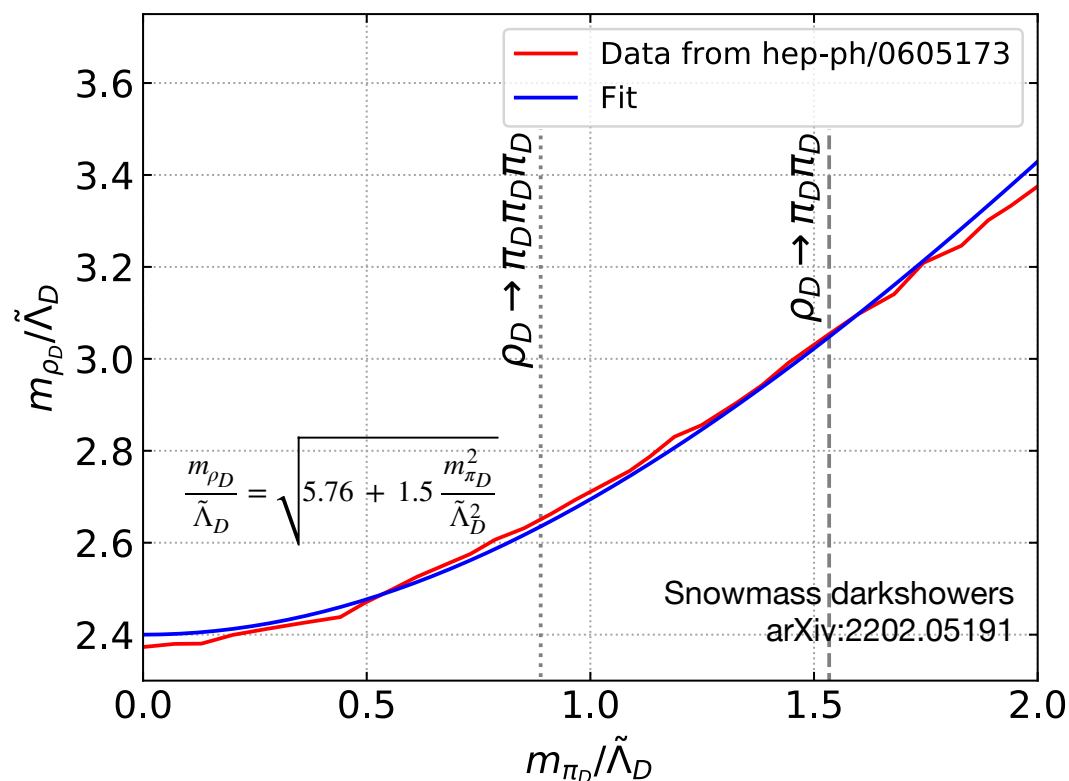
- If this is the reality of nature how do we look for it?



non-Standard jets!

# First steps towards an exciting journey

- Generically possible to get dark matter candidates, lead to new signatures
- Simulating such signatures correctly is challenging, need theory and experiments working together
- First steps towards theory understanding, first steps towards testing, improving simulation tools
- Contacts with lattice community
- Difficult but not impossible problem!



# Conclusions

- Beyond WIMP scenarios featuring light new BSM sectors present an interesting opportunity at the LHC and at future colliders
- Well motivated portals with viable parameter space for HL-LHC and future colliders exist
  - Colliders can probe dark photon models above 3 GeV
  - For Higgs portal models, large DM and mediator masses more promising
  - FPF can play an important role in investigating such light new physics scenarios
- New dark sectors with non-Abelian gauge groups presenting (light) composite dark matter candidates are challenging
  - First progress in snowmass towards a consistent formalism, connections with lattice community
  - First improvements to the pythia Hidden Valley simulation framework
  - Ongoing efforts to progress on the discussions started during snowmass
- It is necessary to think critically and explore all viable options to make most of the data and results coming out of the LHC and other experiments

# DM at FPF

- Facilities with smaller experiments built near / exploiting collider beams → spatial complementarity
  - example: the Forward Physics Facility for HL-LHC
  - Make the most of civil engineering at future colliders
  - Maximise the physics potential e.g. with “dark matter beams” in the forward region
    - Many different dark matter models within reach

