DARK MATTER @ FCC

FUTURE CIRCULAR COLLIDER

DESY.

BIBHUSHAN SHAKYA

SEPTEMBER 16, 2022
FCC BSM PHYSICS PROGRAMME WORKSHOP

THIS TALK:

I will talk very broadly about prospects of exploring dark matter at FCC

See others talks at the workshop for more specific dark matter/dark sector discussions:

Yesterday

11:30 → 12:00 **Wino/Higgsino DM at FCC**

Speaker: Natsumi Nagata

Later in this session

14:00 → 14:30 **Exploring dark matter at FCC**

Speaker: Bibhushan Shakya

14:30 → 15:00 **Exploring dark sectors at FCC**

Speaker: Dr Emidio Gabrielli (Nat. Inst. of Chem.Phys. & Biophys. (EE))

15:00 → 15:30 **Signatures of complex hidden sectors at FCC**

Speaker: Matthew Strassler (Harvard University)

THIS TALK:

I will talk very broadly about prospects of exploring dark matter at FCC

RECOMMENDED READING:

European Strategy Update Physics Briefing Book (Sections 8.5, 9)

FCC sensitivities for various benchmark dark matter models

Physics Beyond the Standard Model at Energy Frontier (Sections XI)

Snowmass Energy Frontier BSM report combining the Topical Group reports of EF08 (Model-specific explorations), EF09 (More general explorations) and EF10 (Dark Matter at Colliders)

Includes updates and work from Snowmass whitepapers post-Physics Briefing Book

Snowmass Dark Matter Complementarity Report (arXiv:2210.xxxxx)

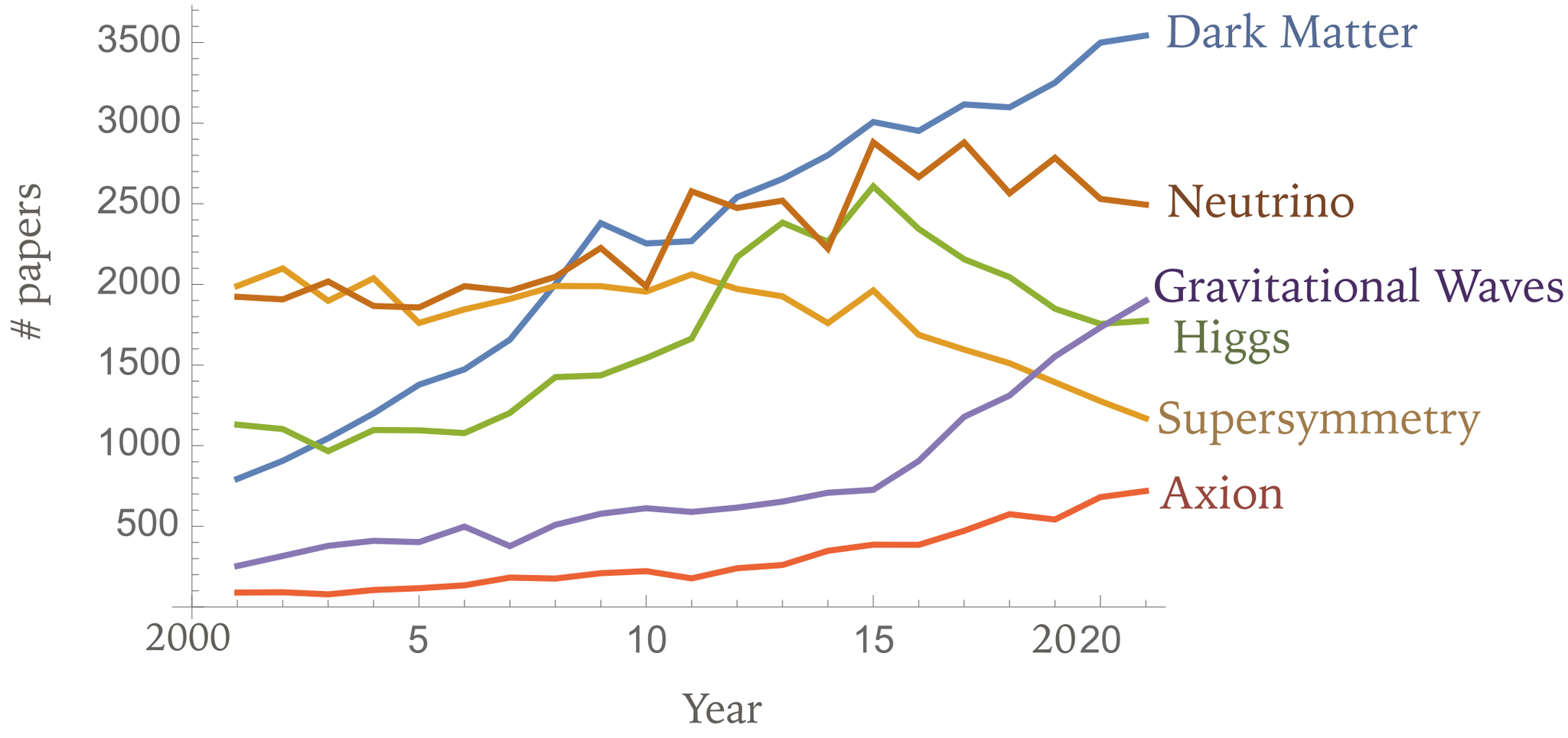
[also see hep-ph 2206.03456]

Discussion of complementary roles of future colliders in the greater dark matter program

MOTIVATION: WHY DARK MATTER AT FCC?

Dark matter: one of the most compelling evidences we have for BSM physics

A primary driver of contemporary research in high energy physics



Any theory of BSM physics contains (or can be expanded to include) dark matter

Dark matter will be a central target for any experimental program searching for new physics; FCC is no exception!

MOTIVATION: WHY DARK MATTER AT FCC?

Dark matter: one of the most compelling evidences we have for BSM physics

A primary driver of contemporary research in high energy physics

However, not a clearly defined target.

Cannot come up with a full-proof strategy to detect dark matter at any experiment

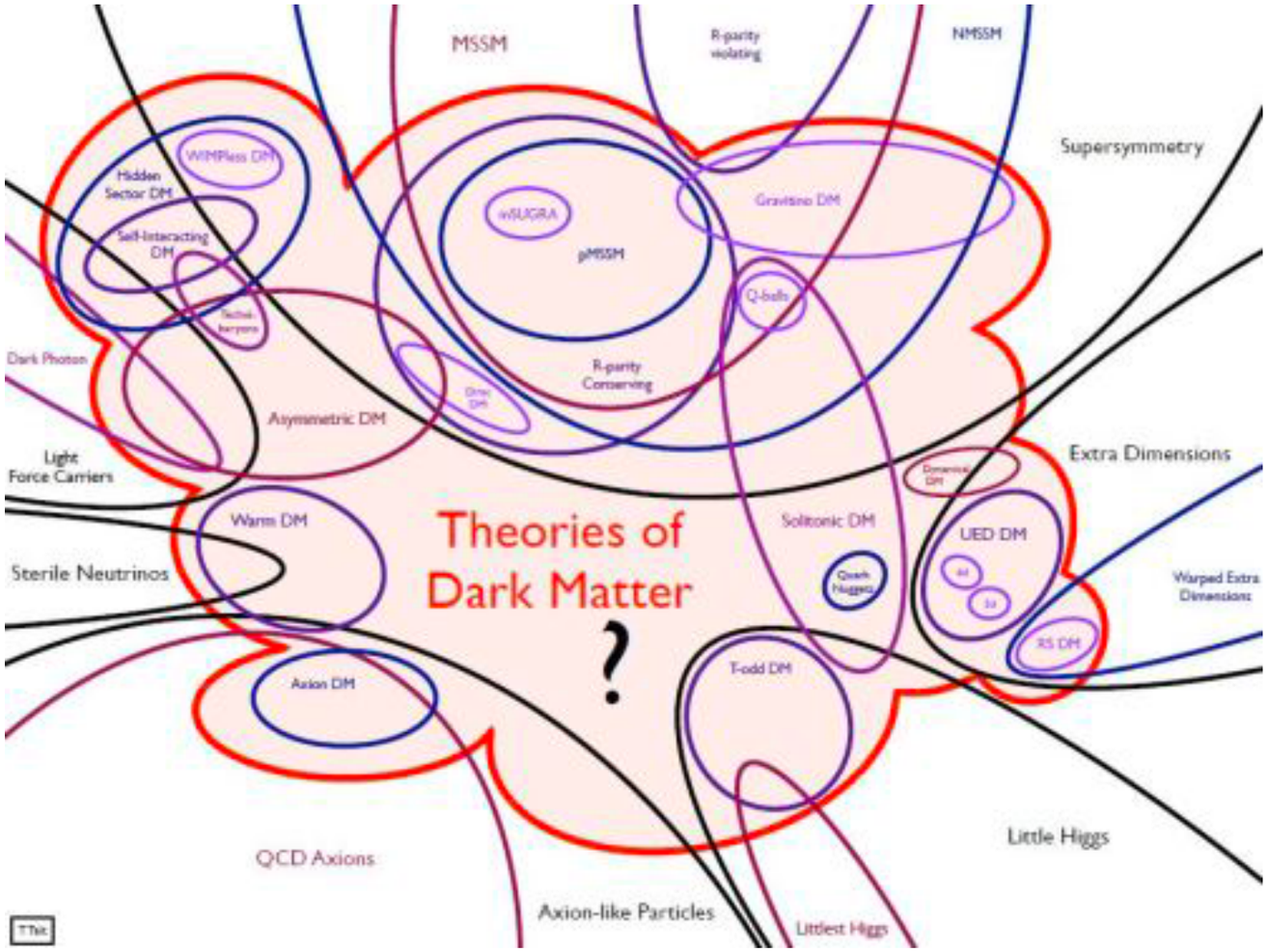
The allowed parameter space of dark matter is too vast to even comprehend in any meaningful manner

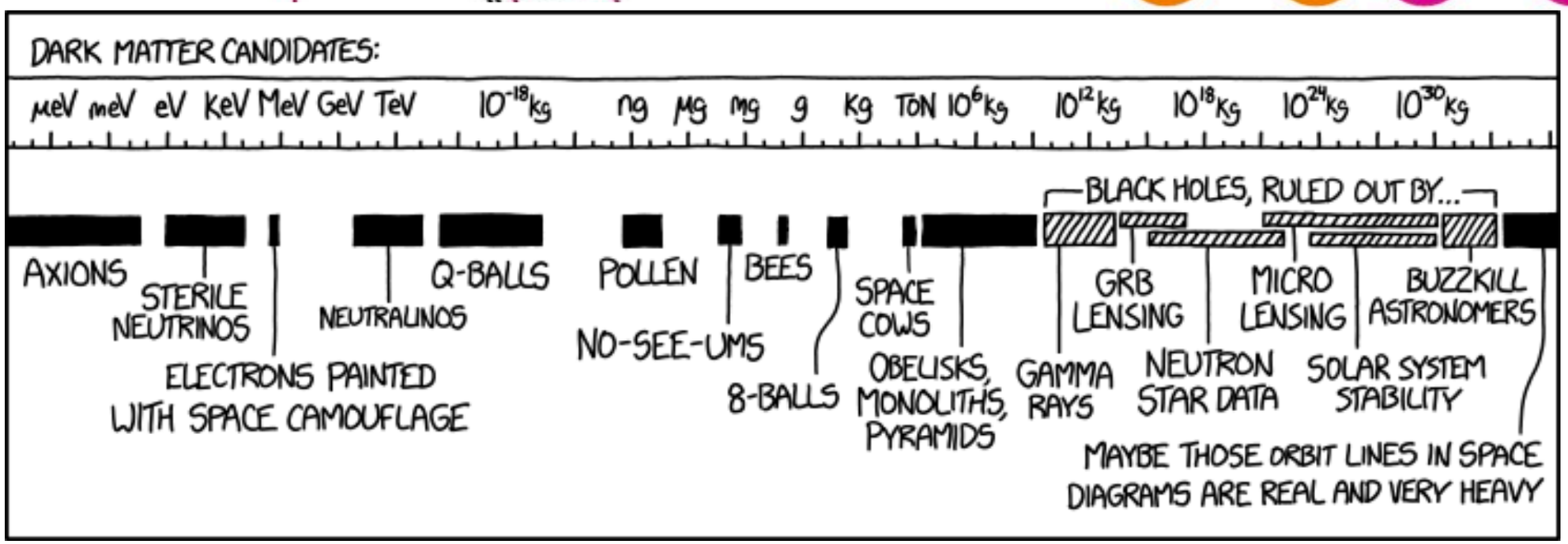
Year

Any theory of BSM physics contains (or can be expanded to include) dark matter

Dark matter will be a central target for any experimental program searching for new physics; FCC is no exception!

DARK MATTER LANDSCAPE (BY CANDIDATES)





DARK MATTER LANDSCAPE (BY MASS)

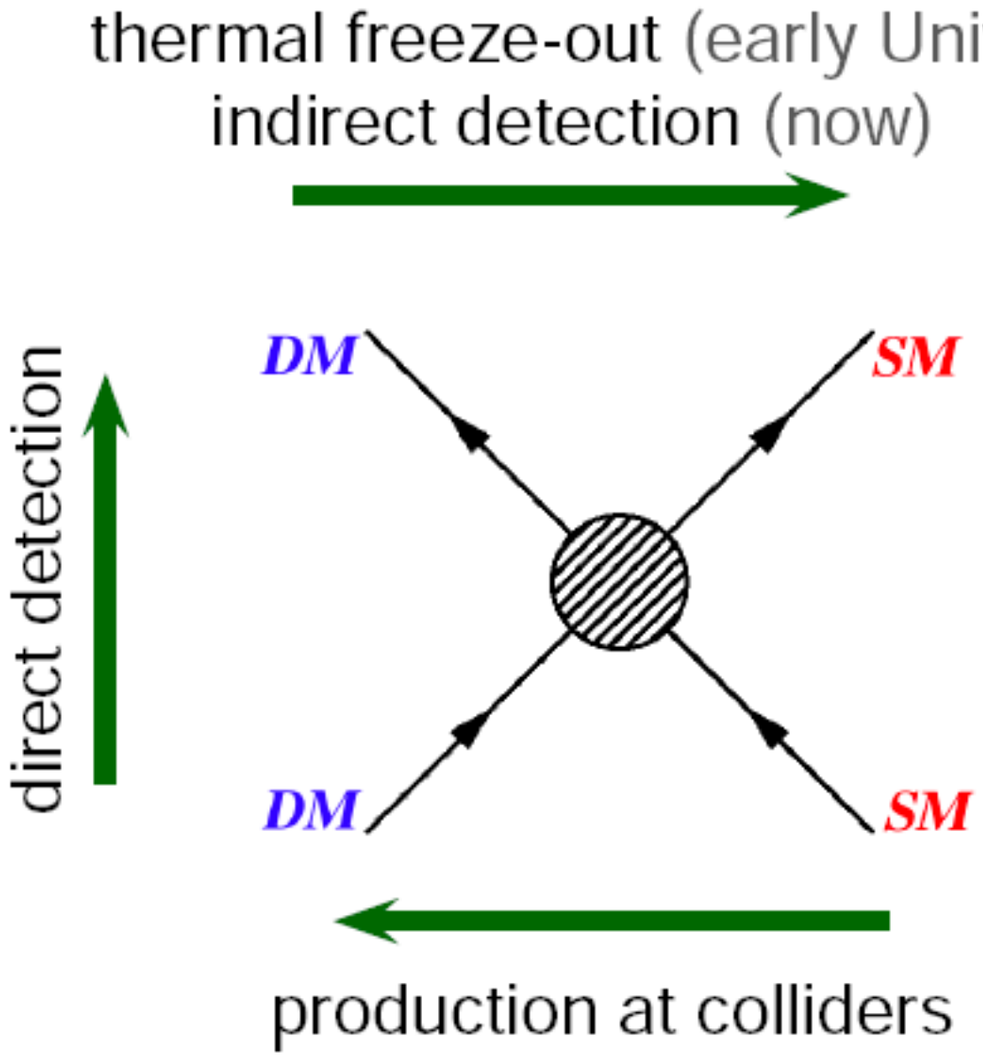
Not all the same - some regions are better motivated than others!

Particle dark matter that has large interactions with normal matter is in **thermal equilibrium** in the early Universe, and can obtain the correct relic abundance (after **freezeout**) in a **relatively narrow window**

This is precisely the energy range of high energy colliders:
FCC offers sensitivity to one of the most well motivated regions of dark matter parameter space!

FCC NOT THE ONLY EXPERIMENT LOOKING FOR DARK MATTER

KEY QUESTION: WHAT ADVANTAGES DOES FCC OFFER OVER OTHER EXPERIMENTS?



[advantages over LHC are obvious: **FCC-ee provides a cleaner environment** and better sensitivity to **BSM coupling preferentially to leptons**; **FCC-hh** provides **higher energies** that can probe **heavier BSM setups**]

KEY ADVANTAGE:

Does not rely on dark matter “out there”, but makes it!

Independent of **uncertainties** related to **dark matter abundance/ velocity distribution** locally/at targets (galactic centre, dwarf galaxies) that plague indirect/direct detection

Measurements of dark matter couplings can be much cleaner, and we will get a better idea of what SM particles DM couples to

KEY DISADVANTAGE:

Cannot discover dark matter per se, only some invisible particle that is stable on collider scales

will require further verification from indirect/direct detection to identify it as dark matter

COMPLEMENTARITY

FCC will be complementary to indirect/direct detection searches; need multiple observations to piece together the complete picture

Measurements in one experiment (hints/discover/exclusion) will **sharpen the picture for subsequent experiments**

Significant progress expected in other experimental directions before FCC. FCC should be prepared to take their input and focus their searches accordingly!

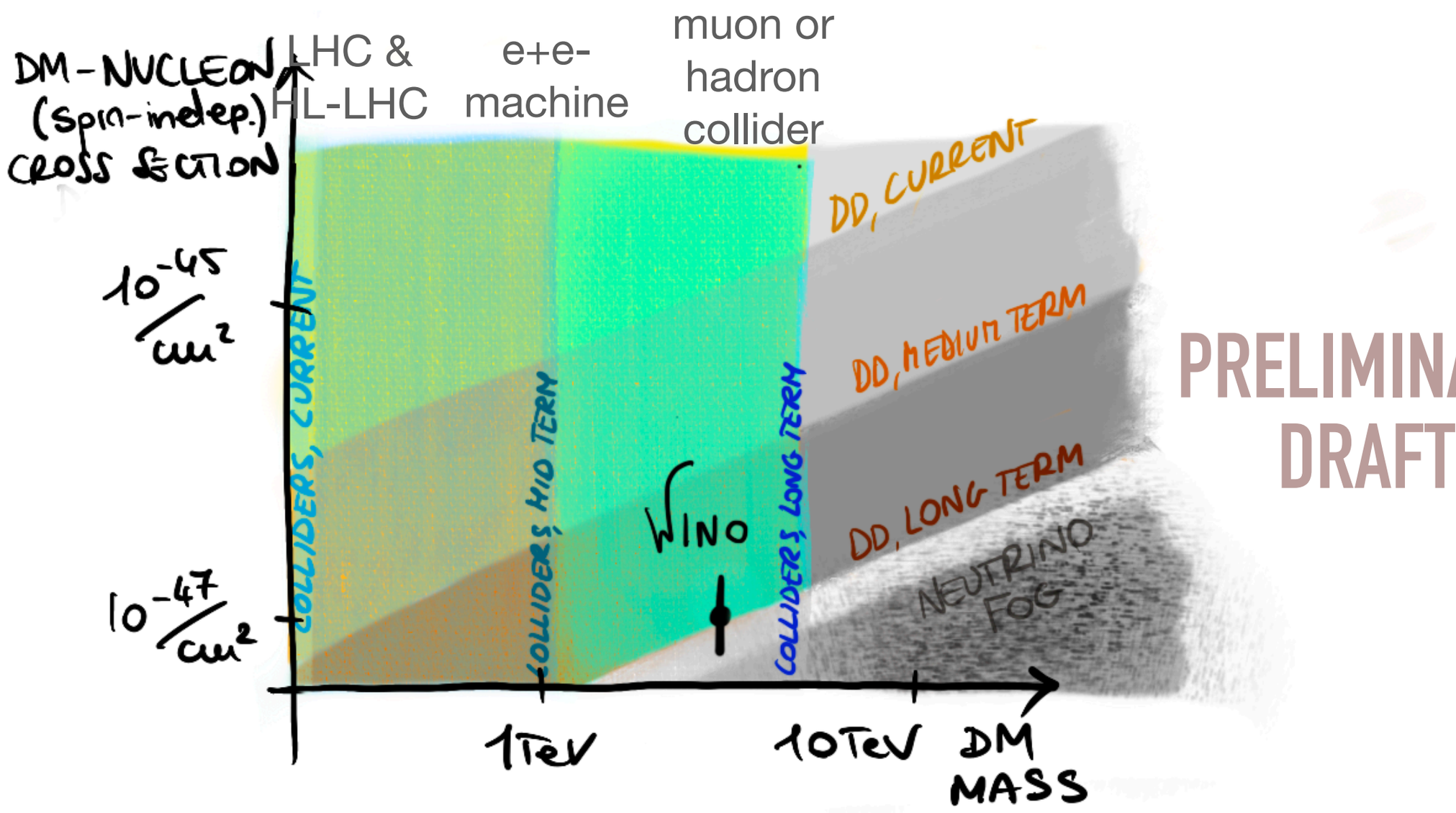
CASE IN POINT: HIGGSINO DARK MATTER

The Cherenkov Telescope Array (CTA) is expected to be sensitive to Higgsino dark matter (mild hints possibly already uncovered in Fermi data, perhaps also in HESS data)

Indirect detection, however, will not be able to “identify” the Higgsino; the dark matter mass can be reconstructed from the signal, but not the interaction cross section (due to large uncertainties regarding dark matter distribution in the galaxy)

Such observations would come before FCC, and would provide a very well defined target. FCC will be able to determine the interaction strengths. As well as determine the mass splitting with the chargino. FCC contribution will therefore be crucial in claiming the “discovery” of Higgsino dark matter!

COMPLEMENTARITY WITH DIRECT DETECTION EXPERIMENTS



PRELIMINARY DRAFT

Snowmass Dark Matter Complementarity Report (arXiv:2210.xxxxx)

FCC SENSITIVITY TO VARIOUS DARK MATTER MODELS

Many papers in the literature exploring various dark matter possibilities; see European Strategy Update Briefing Book or Snowmass whitepapers for details

In summary, FCC has excellent coverage for numerous classes of dark matter models, up to TeV scale dark matter masses

- SU(2) multiplets (including wino, higgsino)
- Simplified models with scalar, pseudoscalar, vector, axial couplings to SM states
- Higgs portal, vector portal models
- etc…

THREE CATEGORIES OF DARK MATTER MODELS FOR FCC:

1. DARK MATTER ONLY (SIMPLIFIED MODELS)

Some effective coupling between dark matter and SM particles. FCC has complementary reach with indirect and/or direct detection experiments

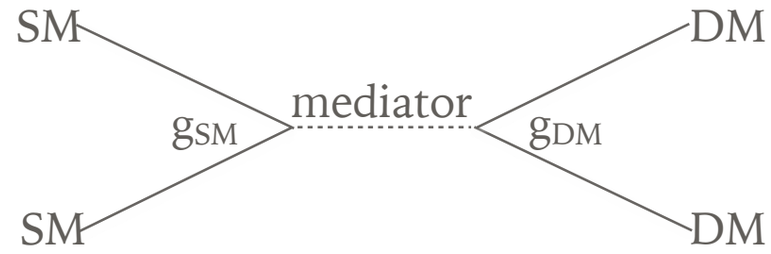
2. DARK MATTER+ MEDIATOR

3. DARK MATTER+ADDITIONAL PARTICLES DIRECTLY INVOLVED IN DARK MATTER FREEZEOUT/PRODUCTION

2. DARK MATTER+ MEDIATOR

More realistic, provides a full picture

Occurs in “portal” models (Higgs portal, kinetic mixing, neutrino portal)

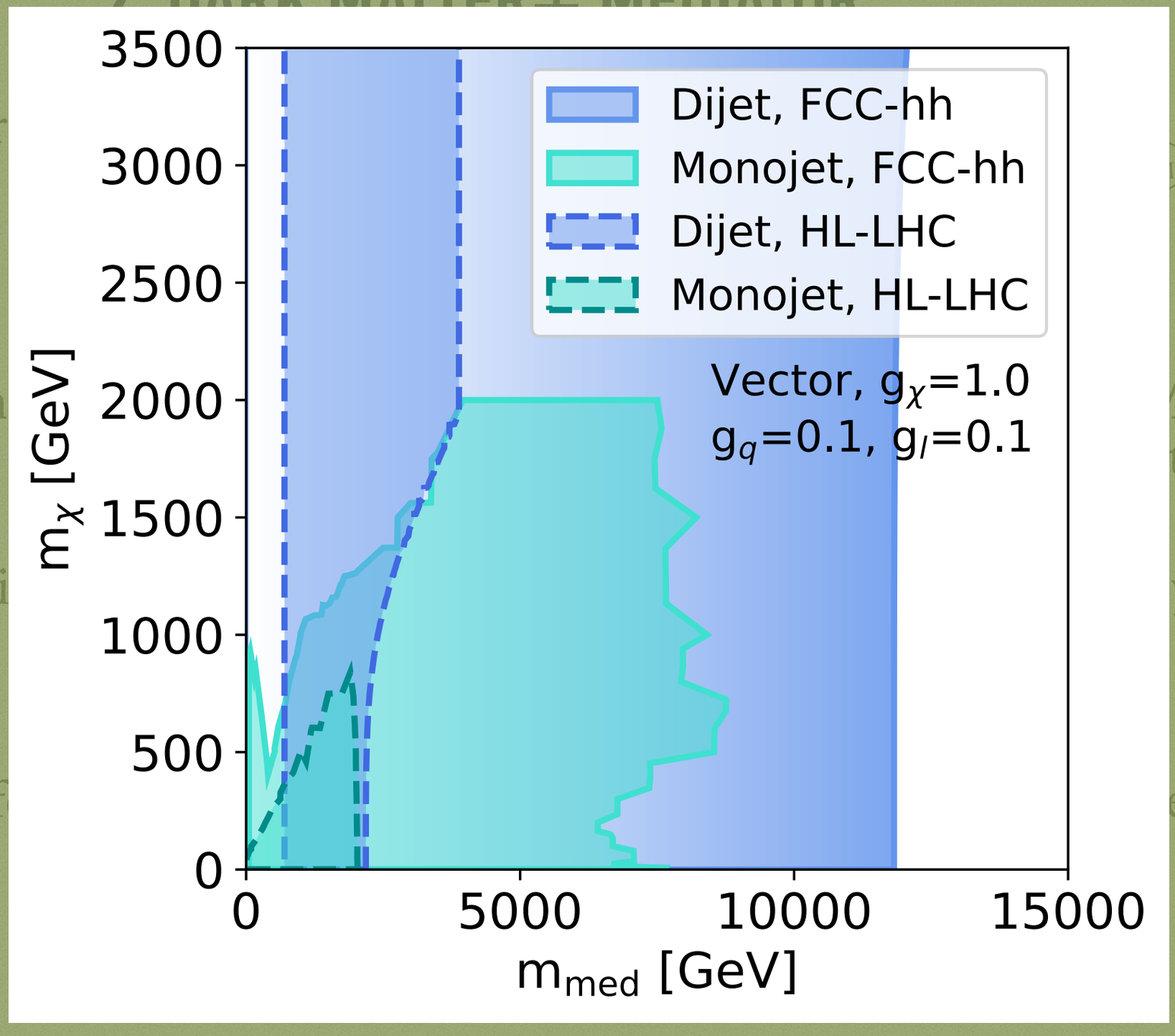


Indirect/direct detection can probe the effective SM-DM interaction, but cannot directly access the mediator

Colliders (LHC, FCC) could produce the mediator directly and detect it, enhancing the reach for such models!

Differing search strategies (monojet vs dijet/dilepton), depending on the relative sizes of g_{SM}, g_{DM}

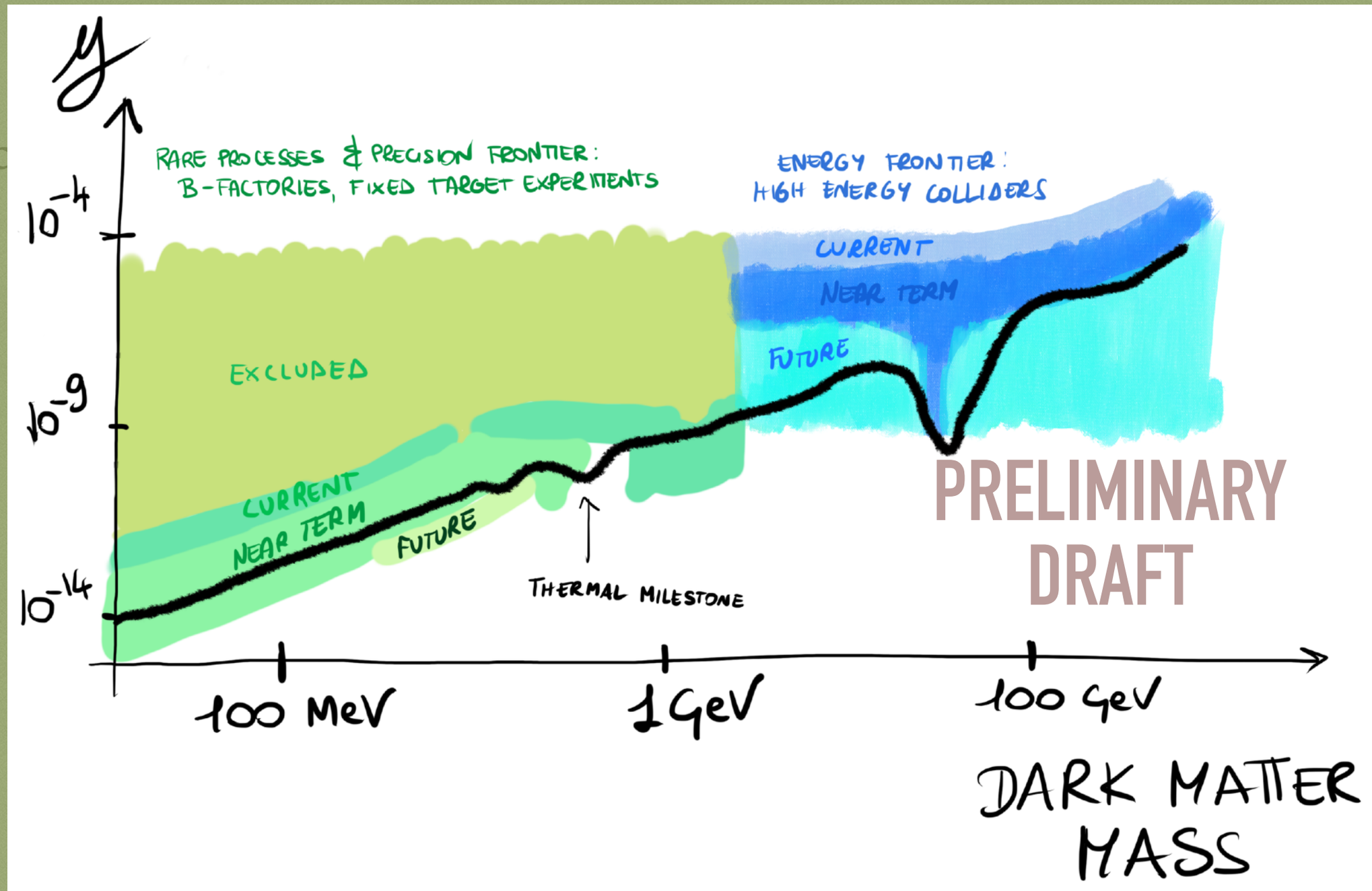
Discover mediator first, infer DM connection afterwards!



LHC, FCC reach for a vector mediator

Snowmass Energy Frontier
BSM report

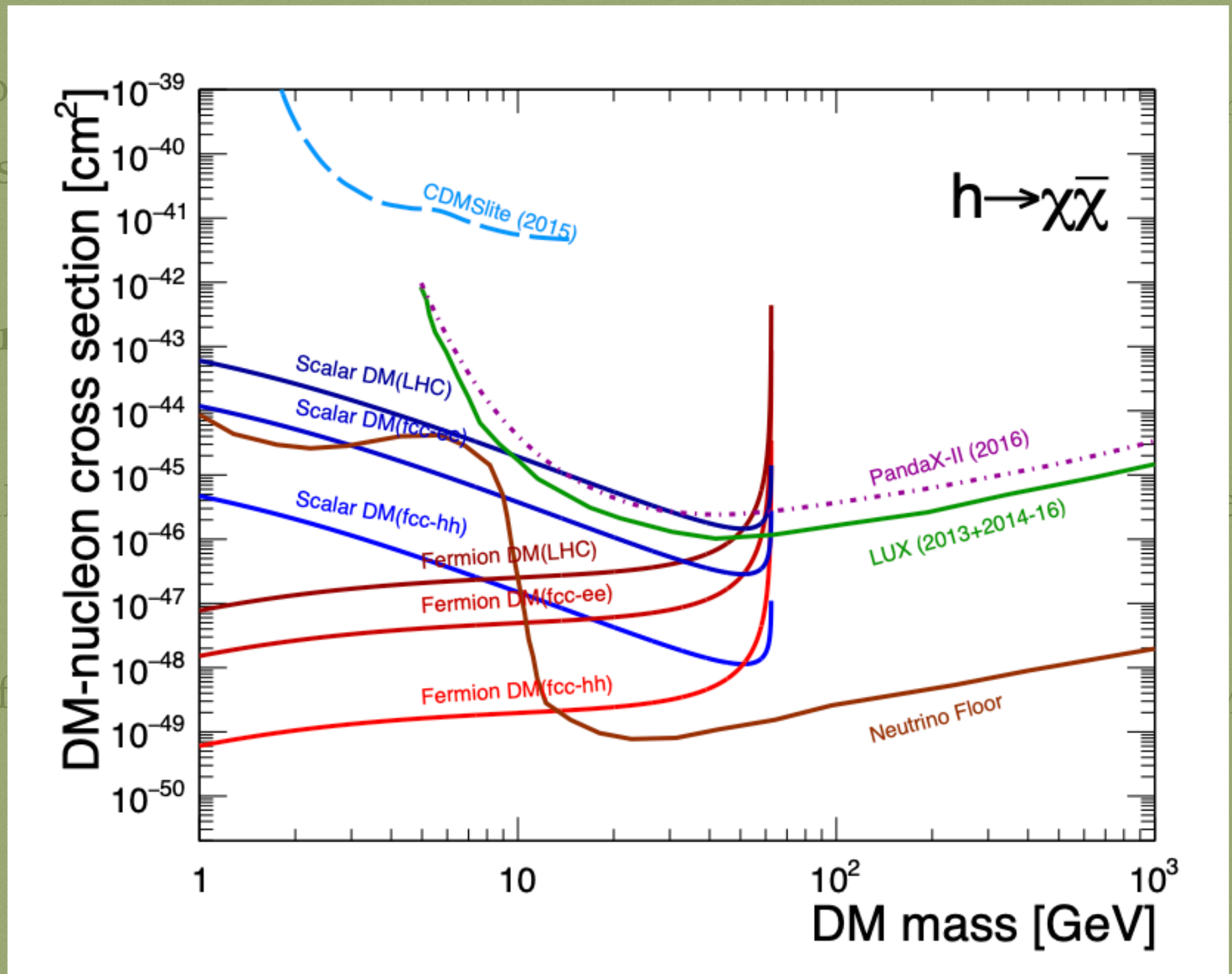
2. DARK MATTER+ MEDIATOR



Snowmass Dark Matter Complementarity Report (arXiv:2210.xxxxx)

FCC can probe the thermal target for up to TeV scale DM

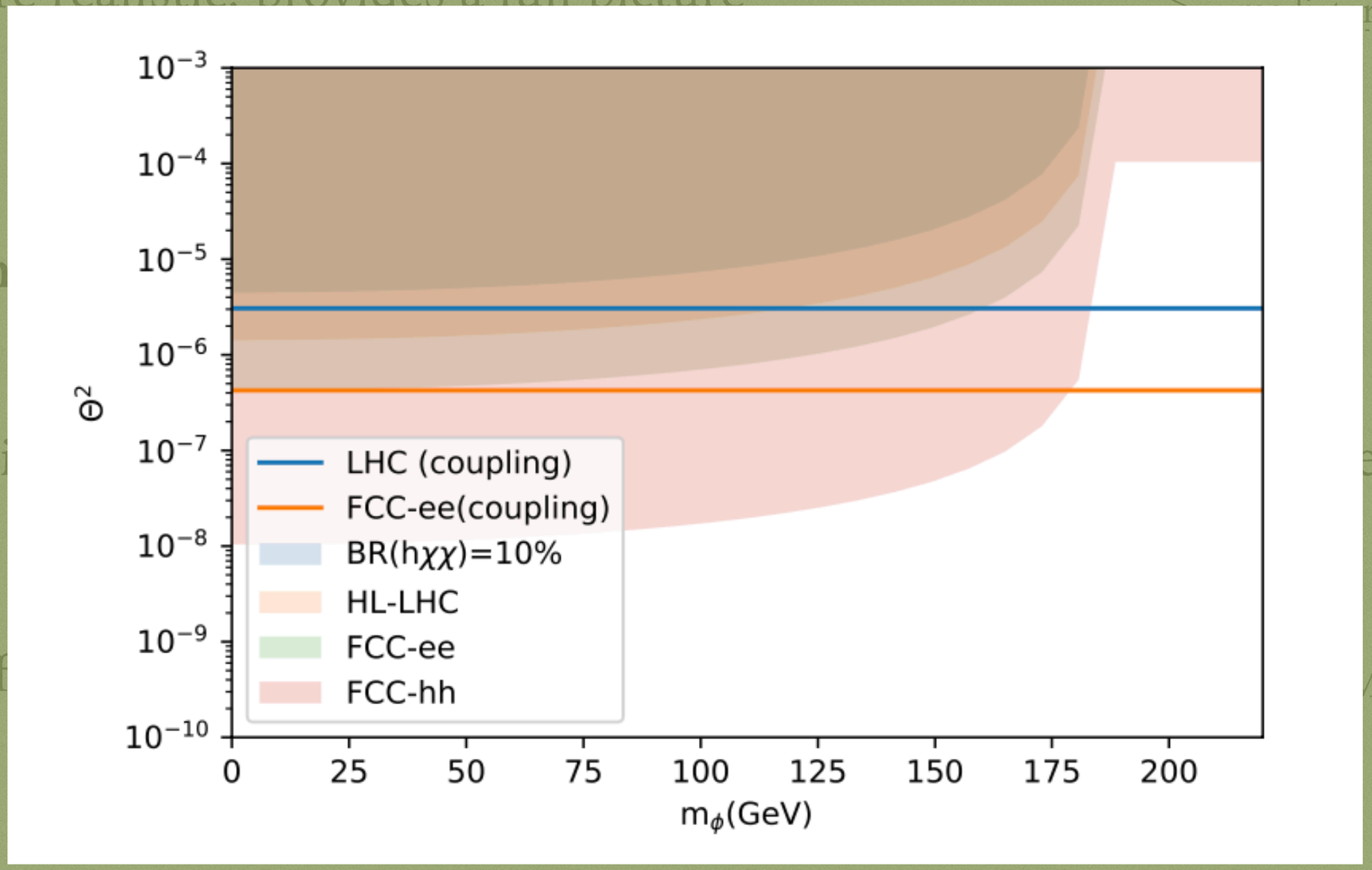
Higgs portal: complementary with direct searches



S. Borgonovi et al., Higgs measurements at fcc-hh, Oct, 2018

2. DARK MATTER+ MEDIATOR

Higgs portal: reach for mixing angle



[hep-ph 2206.03456]

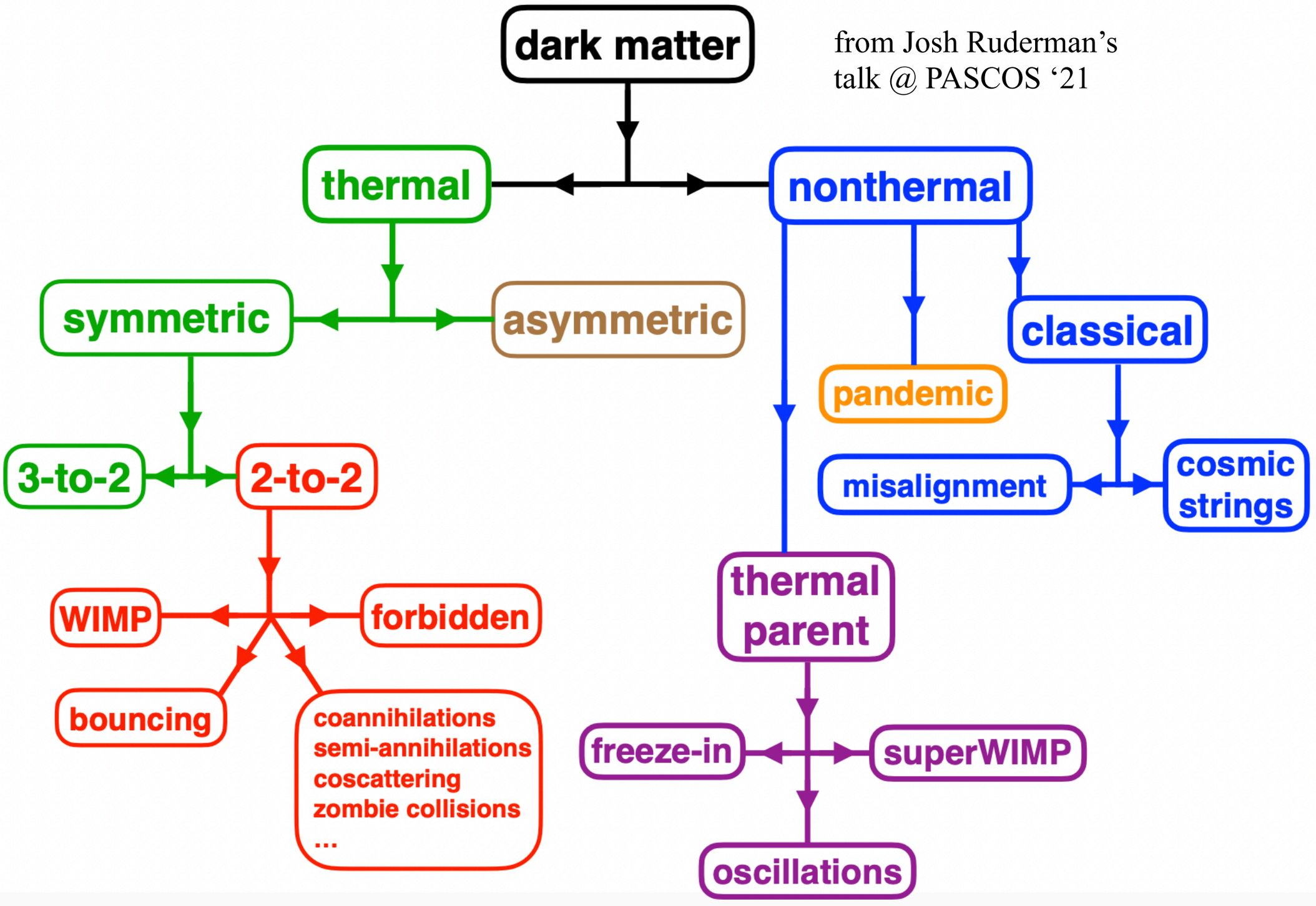
3. DARK MATTER+ADDITIONAL PARTICLES DIRECTLY INVOLVED IN DARK MATTER FREEZEOUT/PRODUCTION

Dark matter production (even for thermal processes) can be complicated, and **directly involve other BSM particles present in the early Universe**

Indirect/direct detection processes **might not occur** in the absence of these particles, **leaving FCC as the only experiment that can probe such frameworks!**

DARK MATTER LANDSCAPE (BY PRODUCTION MECHANISM)

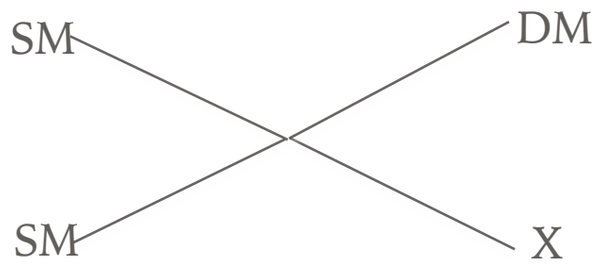
from Josh Ruderman's talk @ PASCOS '21



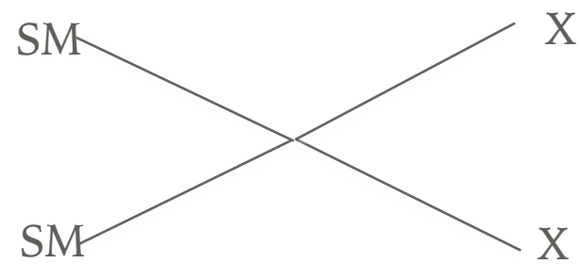
"Thermal" production can involve several variations, **with new particles involved**!

3. DARK MATTER+ADDITIONAL PARTICLES DIRECTLY INVOLVED IN DARK MATTER FREEZEOUT/PRODUCTION

Coannihilation



SuperWIMP (~freeze-in)

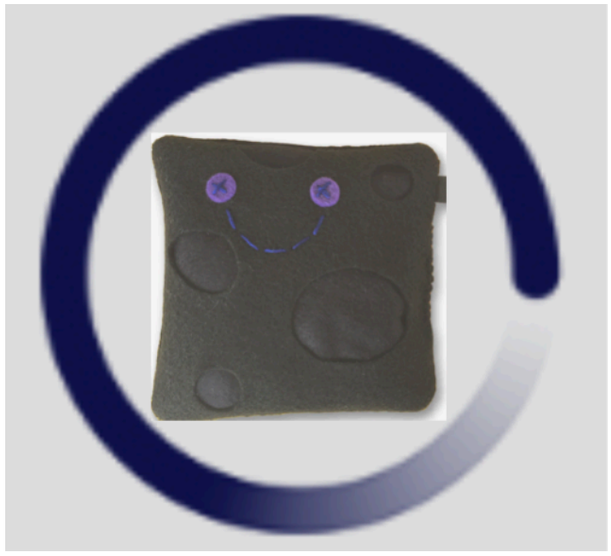


X decays to DM afterwards

Indirect/direct detection suppressed in the absence of X

X could be produced and detected at FCC

SUMMARY



- FCC will explore an extremely well motivated region of dark matter parameter space: thermal dark matter in the 100 GeV- TeV range

- FCC will be **complementary with direct/indirect dark matter searches**: piece together separate dark matter properties. Discovery/ hints/exclusion in one should sharpen the physics case for the others. **Extremely likely that current/near future indirect/direct searches will sharpen the dark matter landscape for FCC.**

- There are dark matter scenarios where **FCC can do better than indirect/direct detection** (e.g. where mediators are involved), or be the only probe because indirect/direct detection are not sensitive (coannihilation, superWIMPs etc)