CATERINA DOGLIONI - LUND UNIVERSITY

BASED ON MATERIAL PRESENTED AT 6TH LLP COMMUNITY WORKSHOP, GHENT 2019

Dark matter in dark sectors

Input and feedback by: Antonio Boveia, Oleg Brandt, Eva Brottman Hansen, Deepak Kar, Suchita Kulkarni, Jannik Geisen, Christian Ohm, Sukanya Sinha, the Lund University Theory division
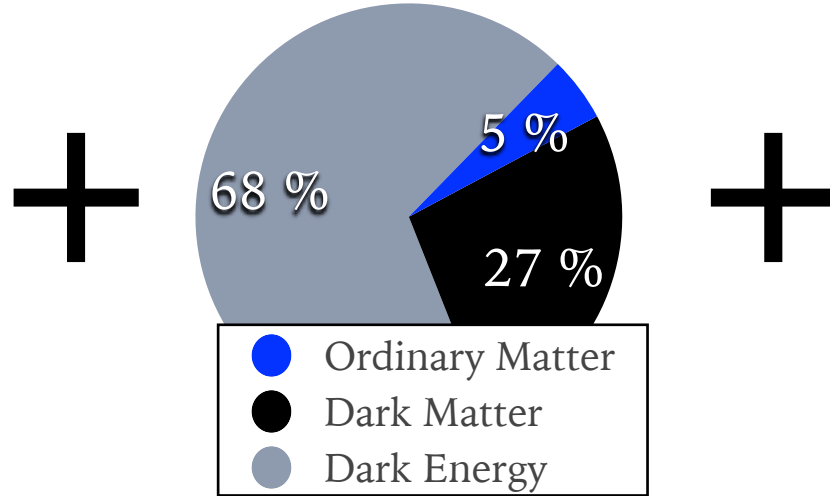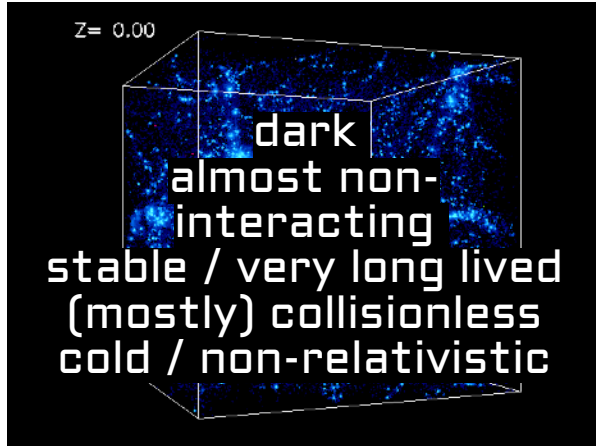
@CatDogLund
http://www.hep.lu.se/staff/doglioni/

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How does (particle) dark matter @ LHC look like?

dark
almost non-interacting
stable / very long lived
(mostly) collisionless
cold / non-relativistic

+

68 %

5 %

27 %

- Ordinary Matter
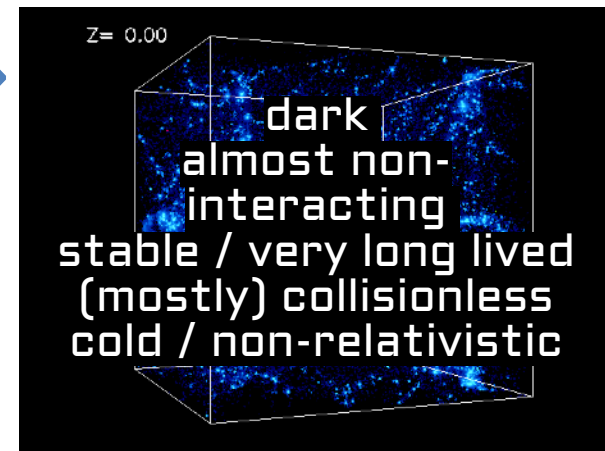- Dark Matter
- Dark Energy

+

=

interesting for **LHC DMWG** ?

Dark matter and dark sectors: naive view

Do we need a DM particle like this in our LLP models?

- It would be nice...
- ...but remember that is not needed to justify searching for the model, especially in broad-range searches
  - T. Sjöstrand: "[Hidden Valley] models don't have a direct connection to cosmology, they just "could happen" @ *Lund Dark Sector mini-workshop, Nov 2020*
- See LLP WG contribution today

dark
almost non-interacting
stable / very long lived
(mostly) collisionless
cold / non-relativistic

Do we need to make up *all* the DM relic density with this new particle?

- Some like Occam's razors...
- This has never been a strict requirement in WIMP models
  - Some reasons: see this talk
- Also: different ways to get at the relic (freeze in/out/...) lead to different (interesting) properties
  - see e.g. asymmetric DM arXiv: 1308.0338

5 %
68 %
27 %

- Ordinary Matter
- Dark Matter
- Dark Energy
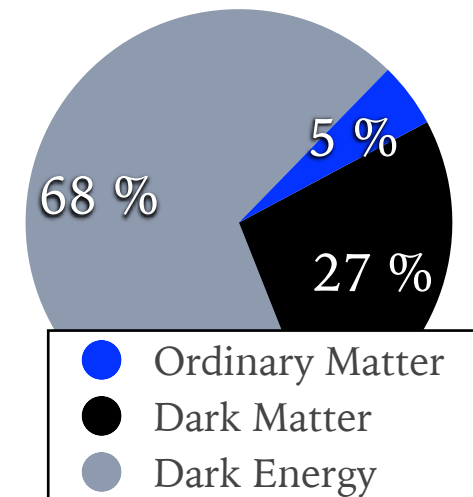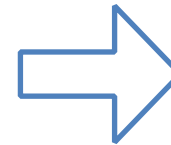
Is there any interest to connect dark sectors to dark matter as a future DMWG topic?

choices here are limited to what I'm familiar with, there's a lot more literature out there

> **Bryan Gaensler** 📡 🧲 ✓
> @SciBry
>
> Research is spending 6 hours reading 35 papers, so you can write one sentence containing 2 references.
>
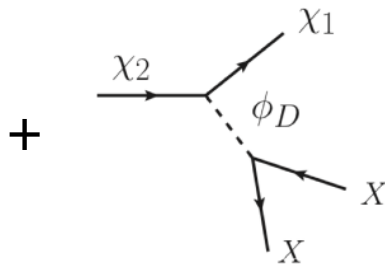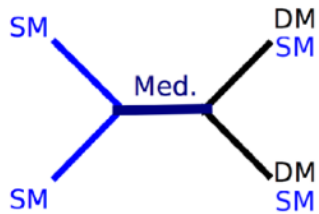> 11:51 PM · Apr 26, 2018 · Twitter for iPhone
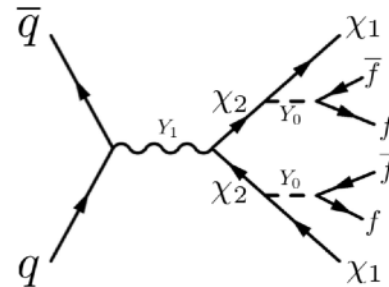
An approach we saw a few DMWGs ago

~~Take a 2HDM, add a pseudoscalar particle mediating DM~~

Take WIMP simplified models for production, add LLP in decay
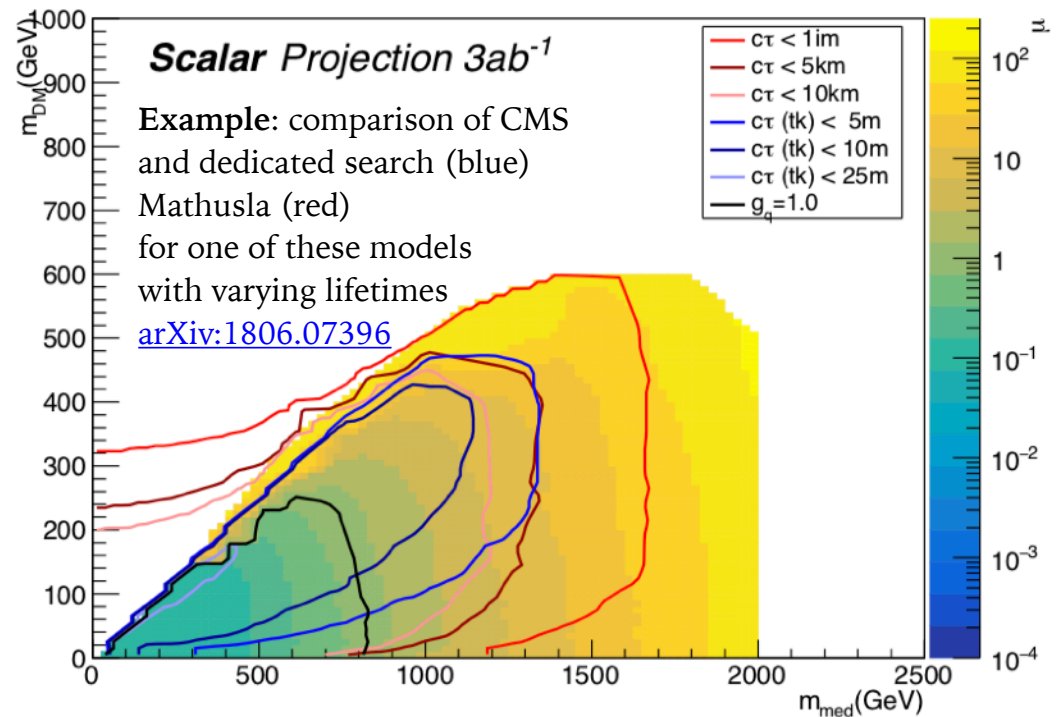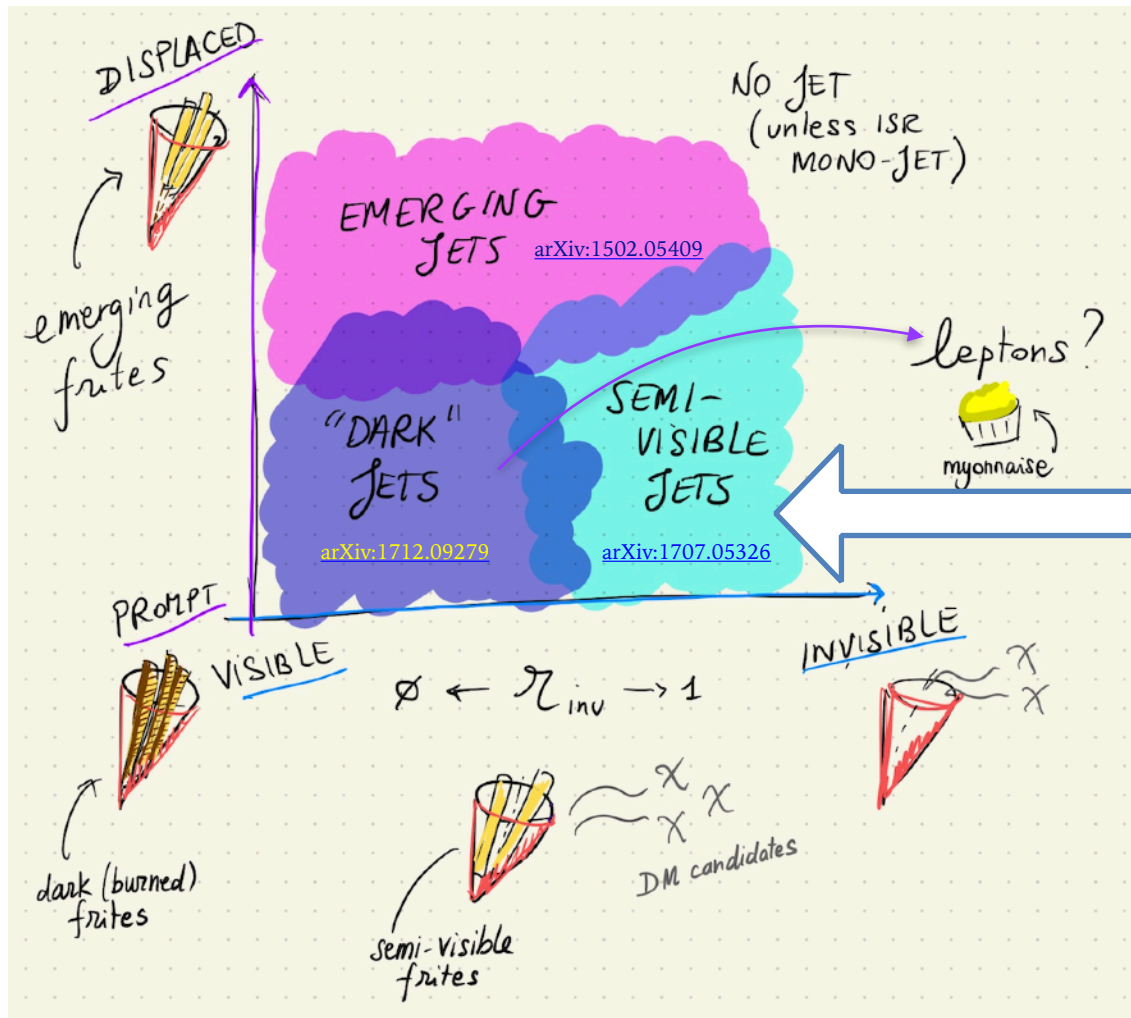
simplified examples from paper

Simplified DM Models		
Variables	DM candidate	Interaction
m_ϕ	Dirac	Vector
m_1	Majorana	Axial-Vector
g_χ	Scalar-real	Scalar
g_ϕ	Scalar-complex	Pseudoscalar
Displaced Signature Extension		
τ , m_2	Decay of $\chi_2 \to \chi_1 X$	

- Start with WIMP simplified models (including DM candidate), add LLP in final state
  - Adds displaced vertex signature
  - Need to keep limitations in mind!

- Pros behind this approach:
  - Can be used systematically
  - Can map to more complete/ realistic models
- Cons: not very representative/ realistic

Scalar Projection 3ab^{-1}

Example: comparison of CMS and dedicated search (blue) Mathusla (red) for one of these models with varying lifetimes
arXiv:1806.07396

Legend:
- $c\tau < 1im$
- $c\tau < 5km$
- $c\tau < 10km$
- $c\tau$ (tk) < 5m
- $c\tau$ (tk) < 10m
- $c\tau$ (tk) < 25m
- $g_q = 1.0$

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A different approach to dark sectors

arXiv:1907.04346,
see also: E. Bernreuther's talk @ DMLHC2019

~~Take WIMP simplified models, add a LLP~~
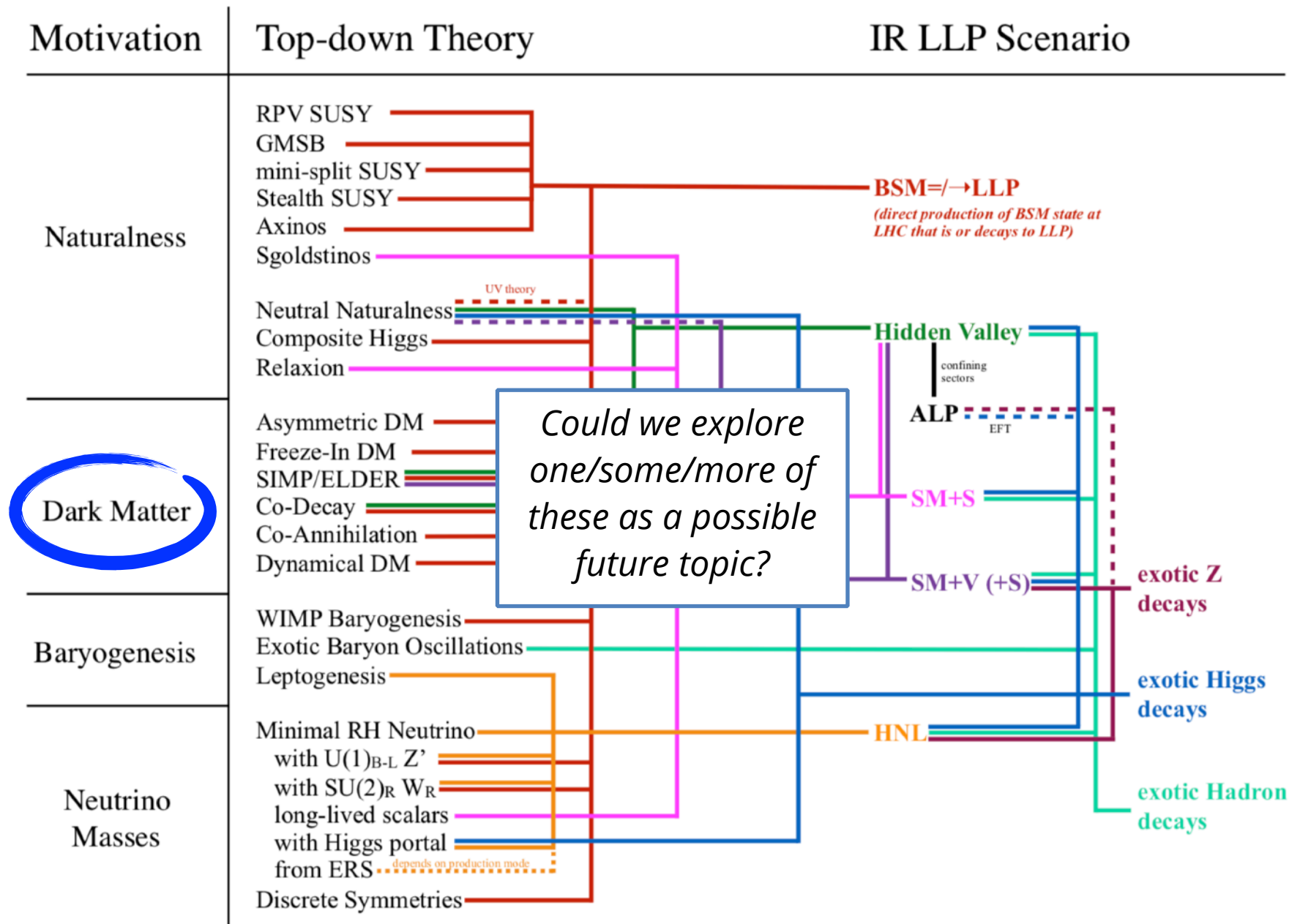Take WIMP simplified models, add a dark sector (with a thermal relic)

Inspired by C. Fallon's talk @ DMLHC2019 and by this twitter thread

A family of signatures, with DM particles (& more) in the dark shower
Generate using Madgraph WIMP simplified models + Pythia Hidden Valley
Can be searched for in ATLAS and CMS [arXiv:1810.10069]

Many other theory possibilities...

Putting non-WIMP benchmarks on the same plot

…it is possible, but there may be disagreements

Practice and research

Comparing apples and oranges: a randomised prospective study

James E Barone

For many years the comparison of apples and oranges was thought to be impossible. Many authors use the analogy of the putative inability to compare apples and oranges as a means of scornfully reviewing the work of others. The titles of some recent publications[1][2] suggest an actual comparison of apples and oranges, but the authors do not, in fact, compare these two fruits. Our laboratory has been interested in this problem for many years. We attempted numerous pilot studies (unpublished data) but had not accomplished a true comparison until now. At last, successful comparison of apples and oranges has been achieved and is the subject of this report.

Table 1 Non-parametric background fructological information

	Apples	Oranges
Grown in orchards	Yes	Yes
Flowering trees	Yes	Yes
Considered a fruit	Yes	Yes
May be eaten	Yes	Yes
May be made into juice	Yes	Yes
Subject to damage by disease	Yes	Yes
Subject to damage by insects	Yes	Yes
Involvement of Johnny Appleseed*	Yes	No

*$P<0.01$.

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James E Barone
*surgeon in chief*

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BMJ 2000;321:1569–70

https://www.bmj.com/content/bmj/321/7276/1569.full.pdf

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C. Doglioni - 27/11/2019 - 6th LLP Community Workshop

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# "LLP complementarity could be behind the corner!"

- Physics Beyond Colliders (&& LLP community): non-WIMP benchmark models for **dark sector** searches with dark matter interpretation:
  - e.g. Dark photon ([DMWG meeting June 2018](#)), Axion(-like particles)

- Benchmark with thermal dark matter interpretation: dark photon → **complementarity of collider, non-collider and astrophysics**
  - note that colliders will most likely occupy top right corner in these comparisons!

- Axions/Axion-Like Particles (ALPs): inter-field connections, solve more than the DM problem
  - note that colliders will most likely not play a role in the mass range of this plot, and end up in the very top very right corner

Physics Beyond Colliders Working Group
arXiv:1901.09966

https://arxiv.org/abs/1905.06952
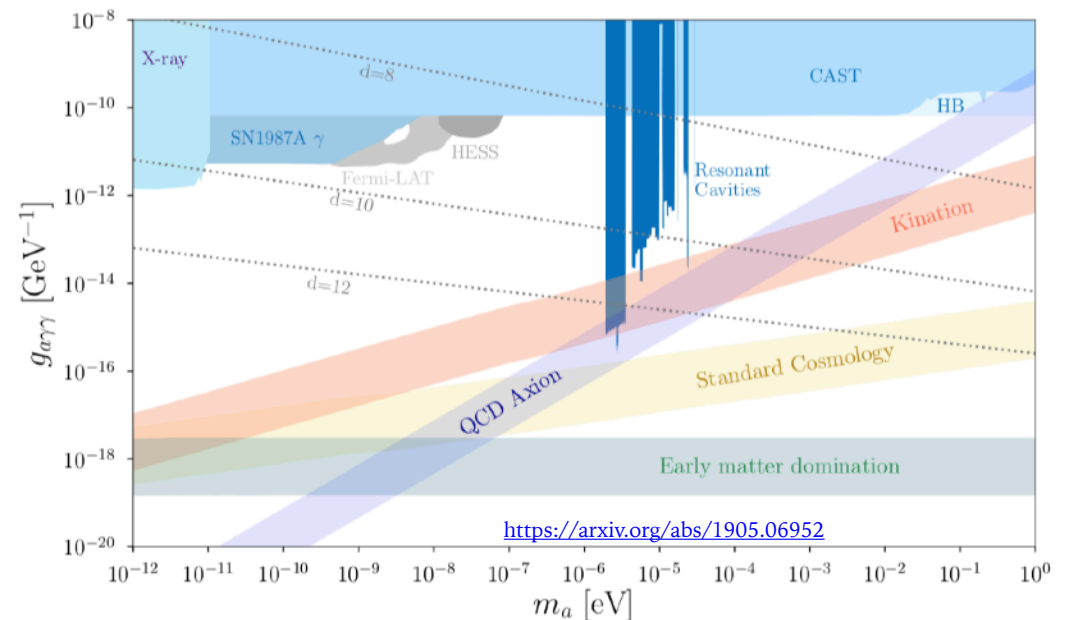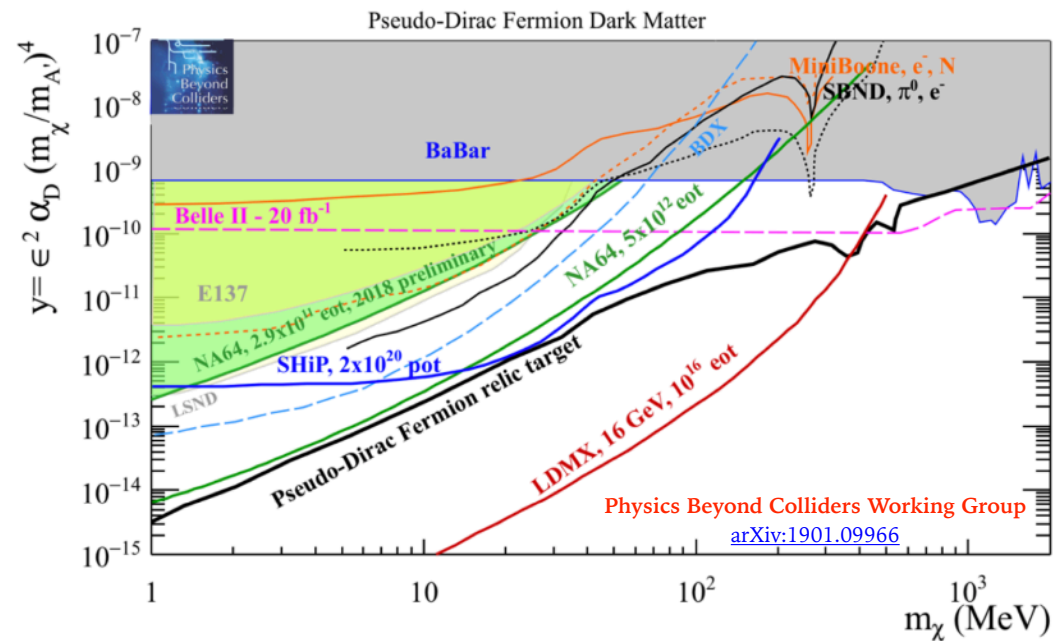
Complementarity for strongly interacting particles

"Looking at stronger-interacting particles"
also as a consequence of "looking at lower masses"

change of paradigm from "DM == invisible particles"
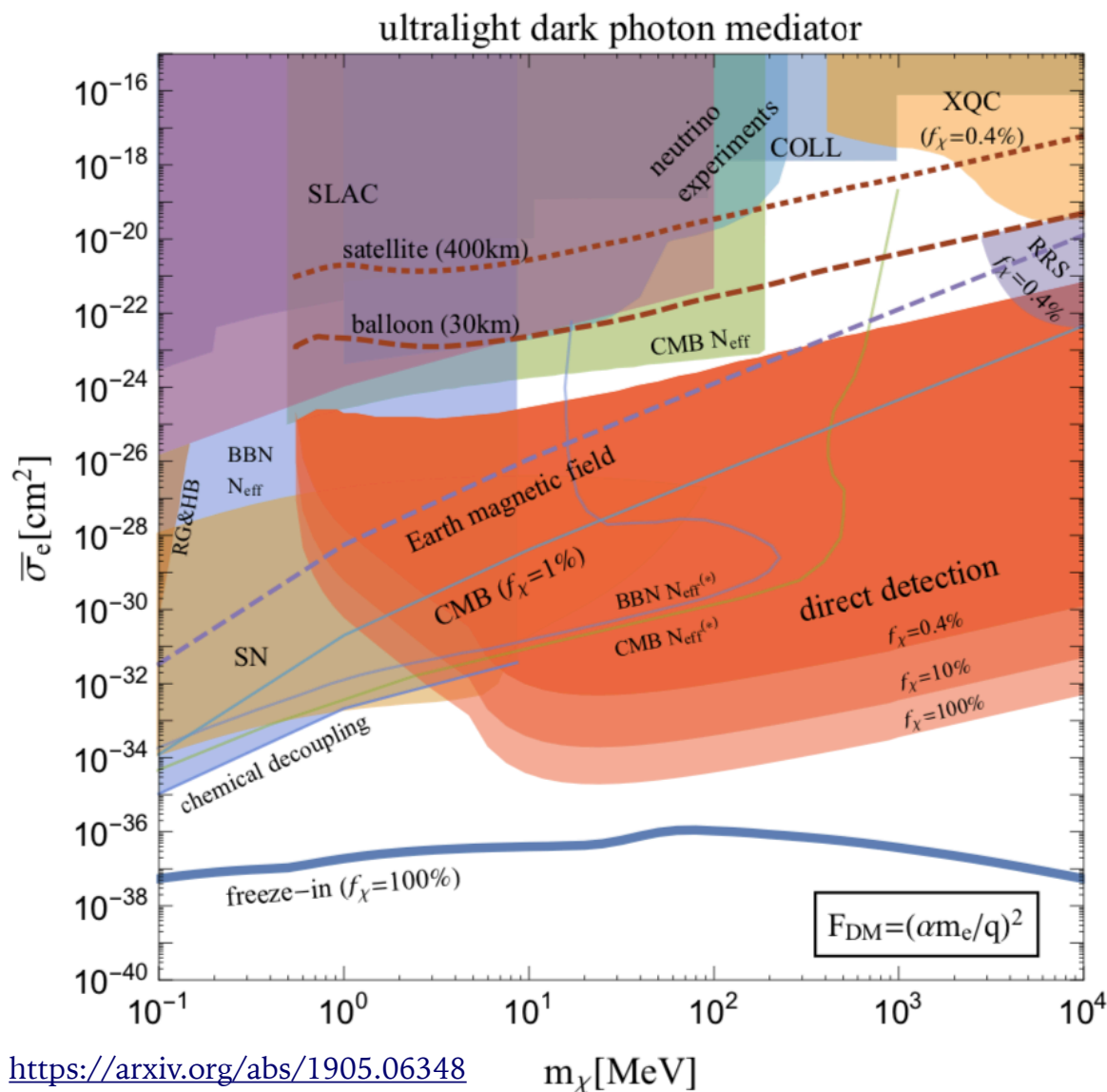
very low-mass but "strongly interacting" DM particles will

- interact with **detectors**
  - need to take this into account for WIMPs@colliders

- interact with **atmosphere & earth**
  - use/send detectors higher up!

- be detectable using **astrophysical signals**
  - SN (supernova), BBN, CMB…

https://arxiv.org/abs/1905.06348

(Yet) another discussion forum

- Discussions, from **European Strategy** to the **APPEC-ECFA-NuPECC** JENAS meeting encourage **synergies between different communities**

- Iinitiative centered around **dark matter**, prompted by JENAS
  - https://indico.cern.ch/e/iDMEu

- **Summary of the aims** in N bullet points (for full list: see link above):
  - offer a _permanent platform_ where different communities discuss
    - make new connections e.g. with nuclear physics/gravitational waves
  - _build on the work of existing working groups_ in terms of e.g. benchmarks
    - WIMP and beyond, "how to put different experiments on the same plot"
    - **Important**: this does not decide/suggest what DMWG does!
      The DMWG community decides where to go via brainstormings like today
  - connect _repositories for sharing of results_ with software experts
  - gather _list of experiments/tools/conferences/outreach material_

- **Kick-off meeting in the Fall**, connected to kick-off of EuCAPT (Theory-astroparticle institute headed by CERN)

Summary

- **Why do I suggest to connect DM and LLP?**
  - good to look everywhere and leave no stone unturned…
  - …but models & big picture (e.g. complementarity) inevitably influence motivation to work on a search
    - → use model/relic dependence (in moderation) to our advantage
- **Work could be done, in synergy with other communities**
  - one possible approach (not necessarily the only one to advocate): build from current simplified models
    - …if we do so, we must not forget their limitations!
  - another approach: look into connections with PBC benchmarks
    - this would clarify some misunderstandings that come from lack of communication
  - work with theory community and LLP to pick one/more models
    - difficult to pick and prioritize given the wide variety…
- **Complementarity**: many upcoming *beyond colliders* experiments
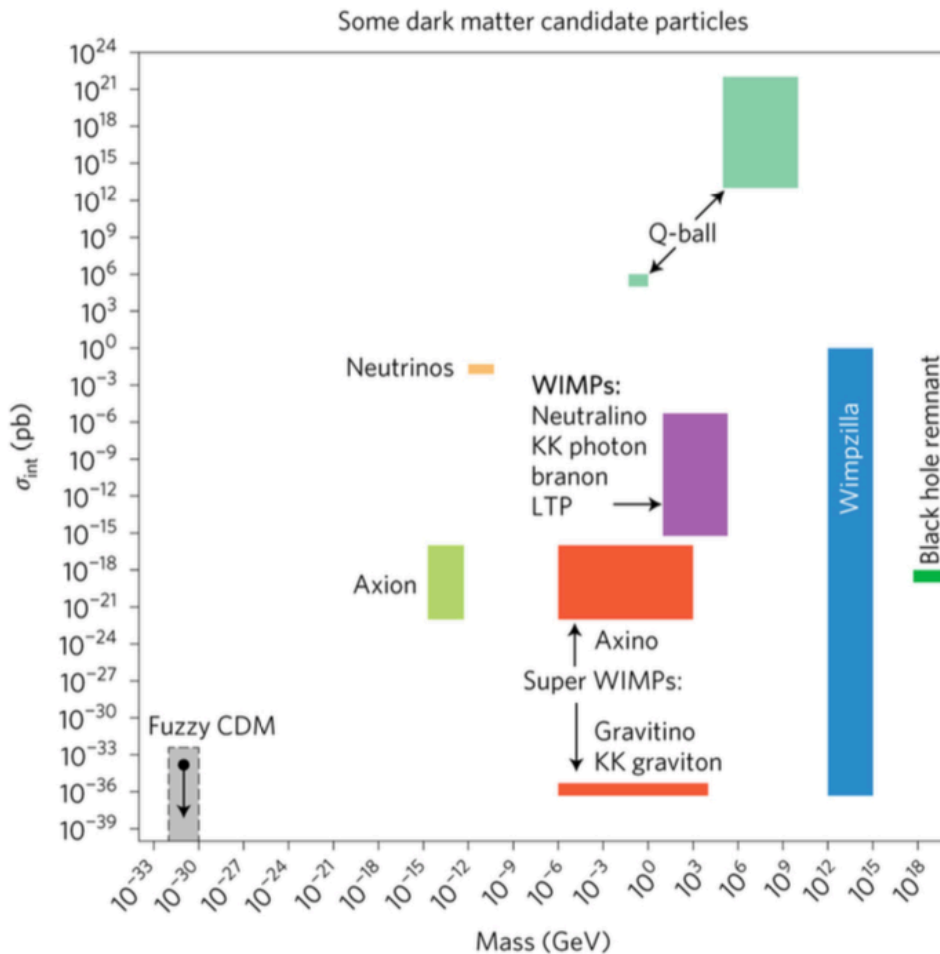 - upcoming discussion platform(s) where DMWG will be invited!

Backup slides

The dark matter landscape

10^{-22} eV $\qquad\qquad$ 10^{-2} eV $\qquad$ 1 GeV 1 TeV $\qquad$ 10^{19} GeV $\qquad\qquad$ 10^{57} GeV
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ $(10^{-5}$ g) $\qquad\qquad$ $(10^{33}$ g)

Some dark matter candidate particles

- Identification strategies are necessarily (more or less) model dependent

- The **theoretical prejudice in dark matter searches** is also set by what we can probe with available data

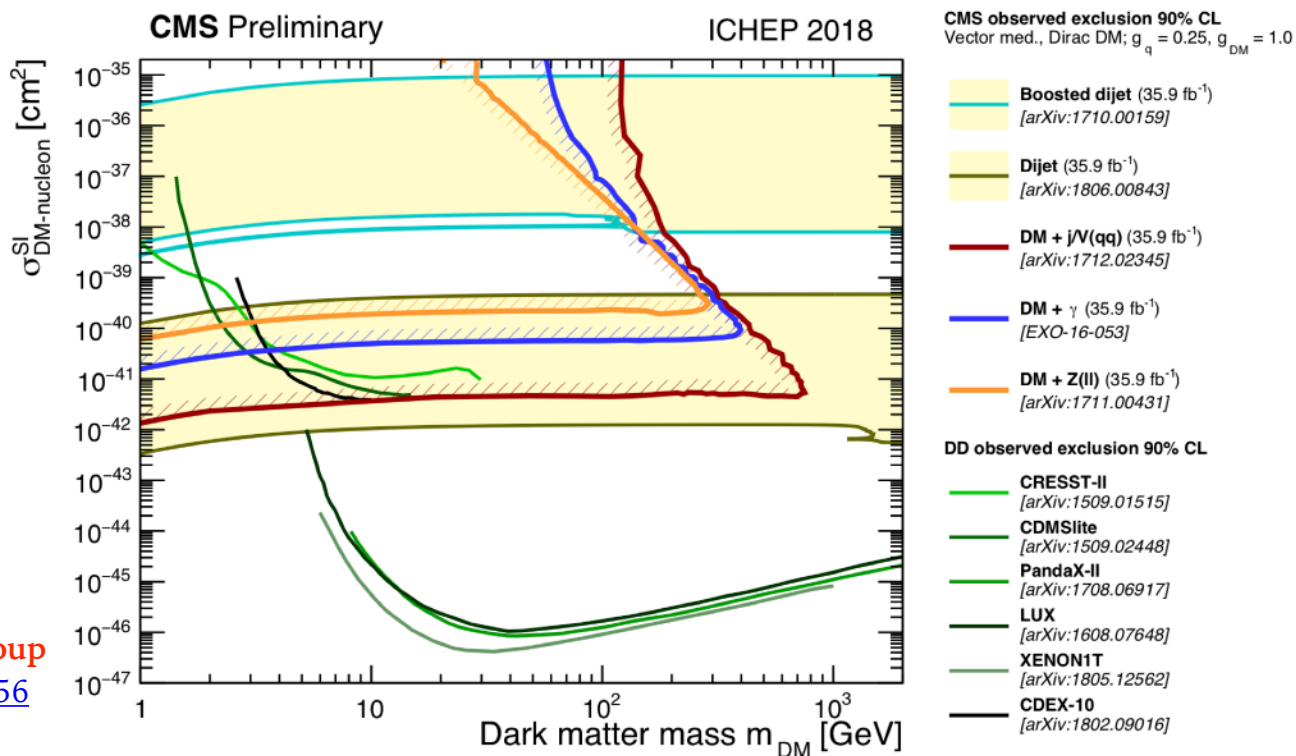- You always need some sort of signature of your model!

Conrad & Reimer, Nature Physics 13 (2017) 224-231

Complementarity of DM experiments

Comparisons are possible only in the context of a model
Essential to **fully specify model/parameters**
and **be aware of limitations**
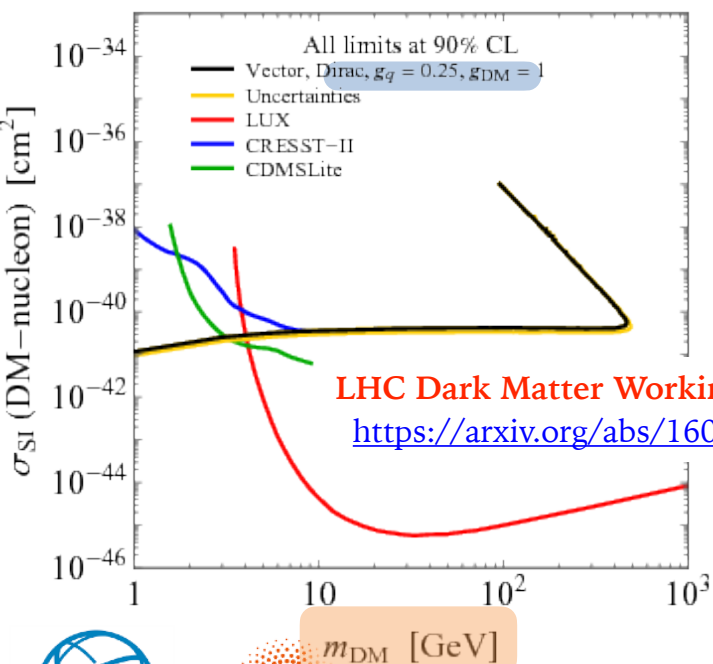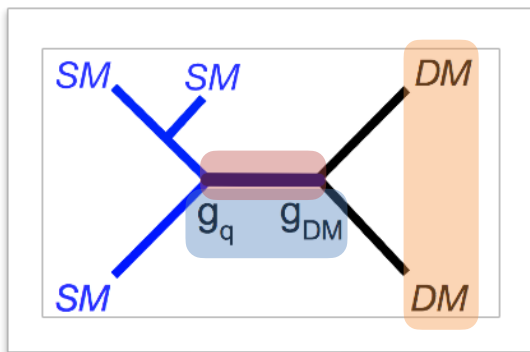

LHC Dark Matter Working Group
https://arxiv.org/abs/1603.04156

CMS Dark Matter Summary Plots for ICHEP 2018

For more thought on upper bounds to collider sensitivity:
G. Landsberg's contribution, DMWG meeting June 2017
https://arxiv.org/abs/1810.07705

See S. Sevova's talk

What about complementarity with astrophysics?

Dark Matter in the Coming Decade: Complementary Paths to Discovery and Beyond + many more
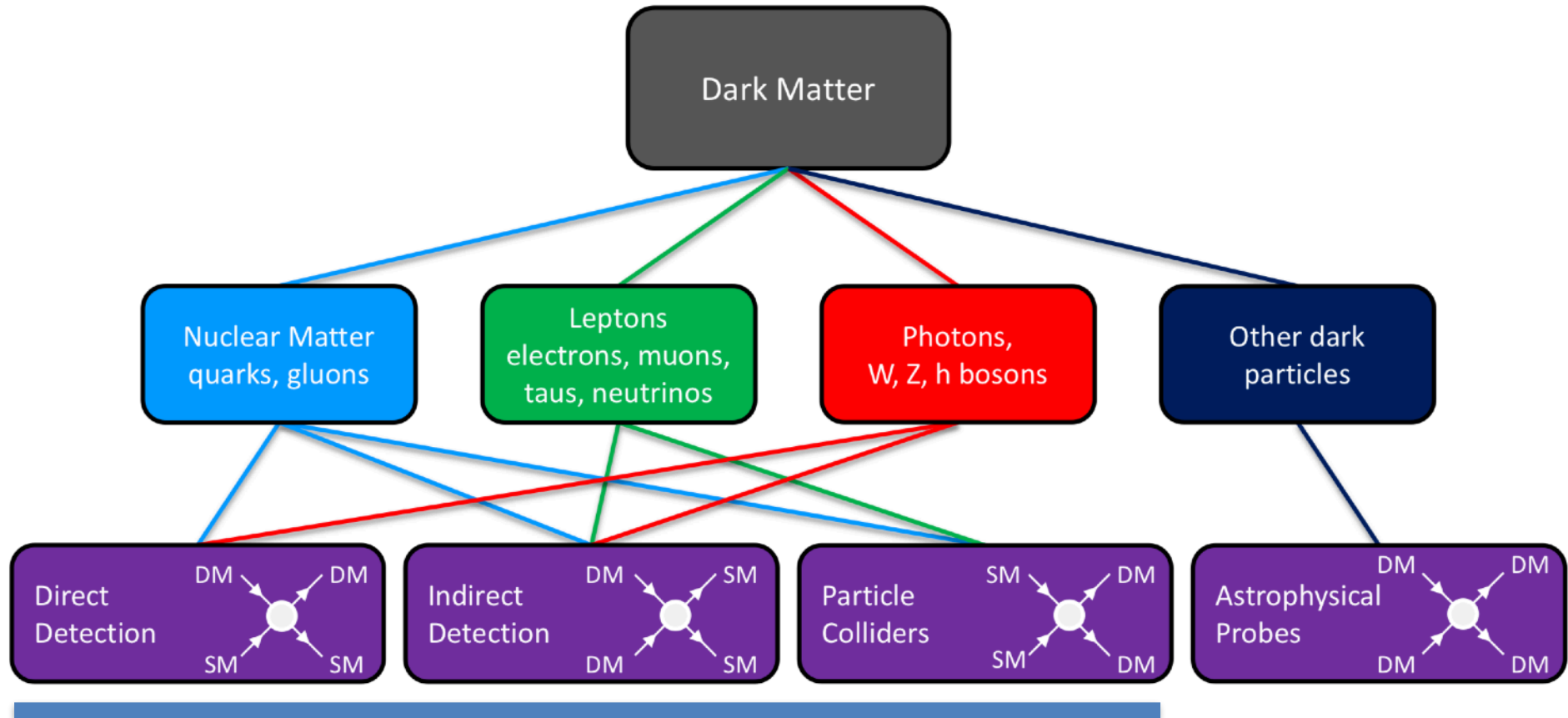
Complementarity focus so far

Possible inputs to LHC DM searches: constraints on DM particle candidates from impact on **astrophysical observables**