Snowmass 2021: Dark matter at colliders

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2020/05/21 - EF Kick-off meeting

Goal of the topical group "EF10 Dark Matter at Colliders"

This topical group focuses on **Dark Matter and Dark Sector searches at high energy colliders**. We will also address the **complementarity** between the collider searches and other probes of dark matter.

The landscape of high-energy colliders for DM

Hadron Colliders: HL-LHC, HE-LHC, 100 TeV colliders (FCC-hh, SppC) ...

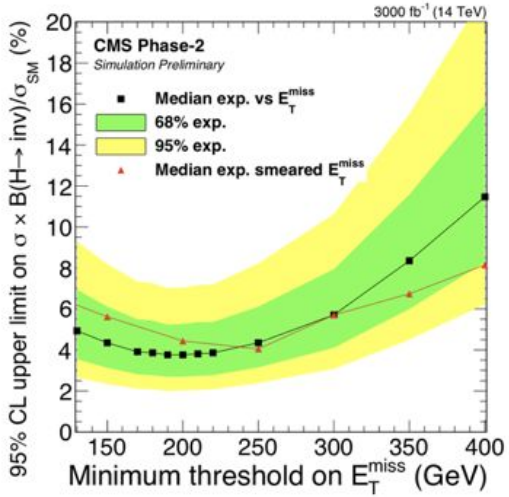
Perhaps the most promising way of getting to higher energy.
Reach of DM mass scale (roughly) linearly with machine energy.

Noisy environment, typically dominated by systematic uncertainties

Hadron colliders for DM at the energy frontier

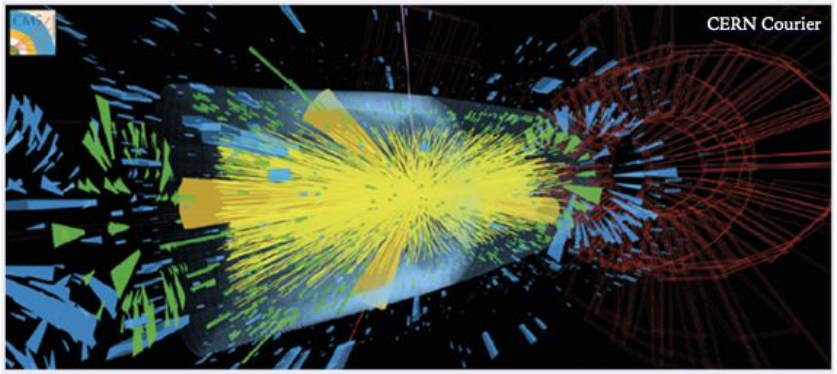
- Generally best reach to discovery of high-mass DM/mediators (MET searches)
- Challenges: online data taking thresholds, simultaneous collisions (pile-up)

arXiv:1902.10229 and CMS-PAS-FTR-18-016



MET threshold influences search sensitivity
(trade-off between higher backgrounds and acceptance)

Higgs to invisible (VBF) + 200 pile-up collisions



HL-LHC uncertainty on Higgs to invisible BR (VBF)
depends on pile-up rejection method

arXiv:1902.10229 and ATL-PHYS-PUB-2018-038

- Main experimental uncertainties: energy scales, simulation modeling, luminosity

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Lepton Colliders: FCC-ee, ILC, CLIC, CEPC, muon collider...

Clean, can carry out very sensitive DM searches
Competitive with reach of hadron colliders for certain models

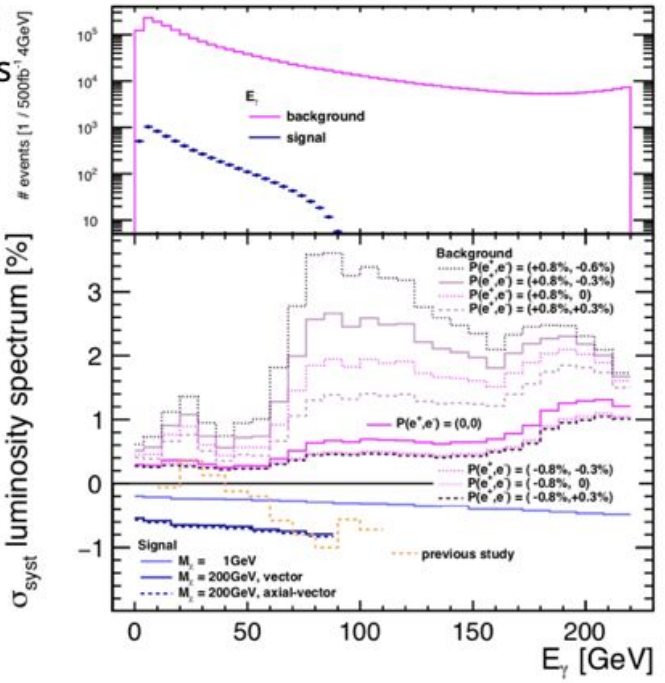
Generally limited by machine energy. Higher energy preferred.

Lepton colliders for DM at the energy frontier

- Limited by CoM energy but clean environment
  → good reach in mediator masses or new energy scales
- Lower backgrounds
  → ILC/CLIC could run *untriggered*
  - Can probe lower masses, search for other theory benchmarks at a later stage

- Specific strengths of lepton colliders:
  - clear tagging for Higgs recoiling against Z
  - beam polarization can enhance/help identify signal

- Main experimental uncertainties: luminosity, electron identification (theory also similar magnitude)



M. Habermehl's PhD thesis

The landscape of high-energy colliders for DM

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Electron-ion / electron-proton colliders: EIC, LHeC ...will also be considered

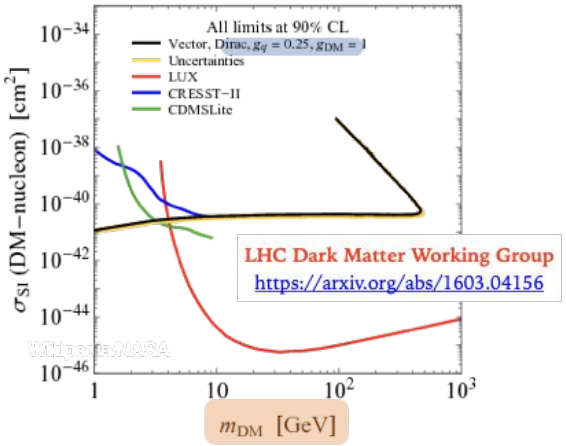
List of topics to be covered and synergies

An evolving list, based on the input from the community
(= you!)

See summary at kick-off meeting - Notes can be found [at this link]

Status of DM@collider from the European Strategy

- European Strategy Update prompted conceptual design studies for HL-LHC and future collider proposals including DM/invisible particle signatures
- DM@colliders **focused on WIMP scenarios**
  - Full list of inputs to European Strategy is here: https://indico.cern.ch/event/765096/contributions/
  - Benchmark scenarios covered:
    - **SUSY Wino/Higgsino**
    - **Vector/scalar mediators with o(1) couplings** (DM Forum / WG, Phys. Dark Univ. 26 (2019) 100371)
    - **Higgs portal**
  - List of *European Strategy Big Questions* in backup slides
- Emphasis on **Synergies** within the Dark Matter community



Snowmass EF10: building, expanding and innovating upon this work

Snowmass topics #1: Testing (simple) WIMP Models

1. **Electroweak multiplet.**
   a. Electroweak multiplet: higgsino/wino(minimal DM). Mediator W/Z/h.
   b. Target: TeV-scale DM masses, motivated by relic density

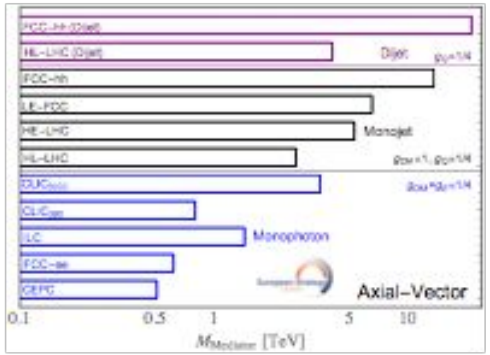
2. **Simplified mediator models.**
   a. S-channel and t-channel mediators. Well established benchmarks for LHC.
   b. Target: > GeV-scale DM masses, simple benchmarks for comparisons

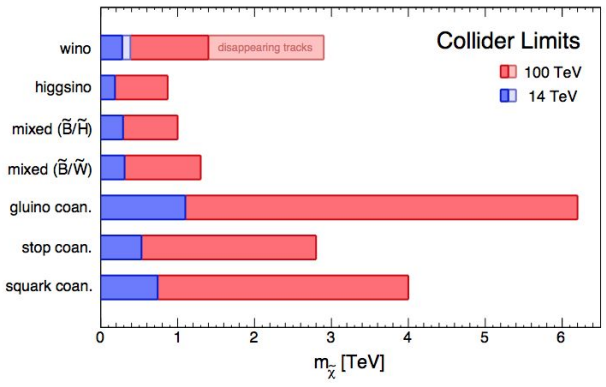
3. **Higgs portal**
   a. Well motivated coupling between SM to the dark world.
   b. Target: > GeV-scale DM masses

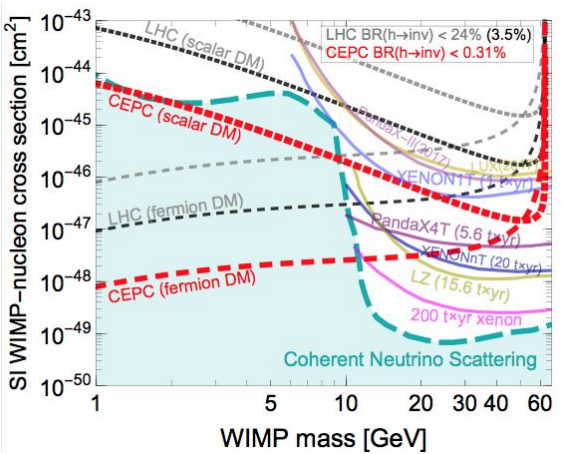
Testing Simple WIMP Models: Results

A number of results are available for simple WIMP-like models

https://arxiv.org/abs/1910.11775







Questions:

- Any obvious case missing?
- What kind of refinement of analysis/projections are needed?
- What are the challenges for controlling systematic uncertainties, trigger/detector/machine design?

Snowmass topics #2: going beyond WIMP

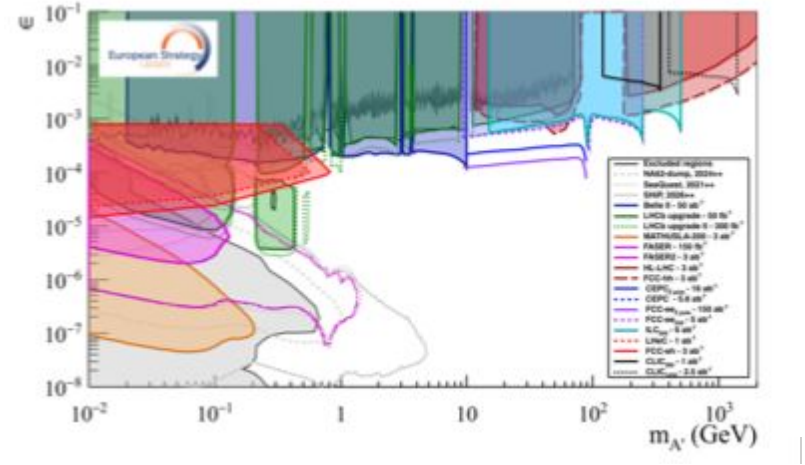
1. **Different DM masses and couplings** with respect to the WIMP
   a. E.g. strongly interacting DM; light DM (< GeV)

2. **Different portals** with respect to LHC simplified models:
   a. dark photon and generic dark scalar/pseudoscalar (including rare decays)

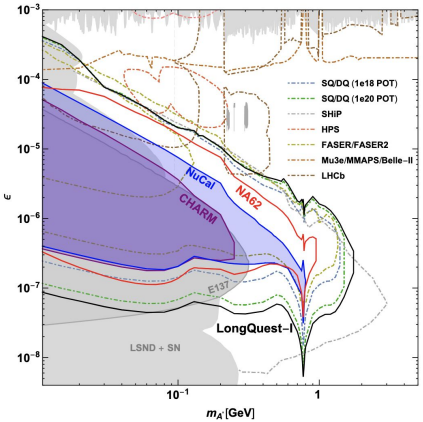
Questions:

- what are the most relevant benchmarks? To be decided together with EF09/RP06
- are we missing any new ideas?

https://arxiv.org/abs/1910.11775



https://arxiv.org/abs/1908.07525



Synergies with other EF groups/frontiers

1. Astro/Cosmology (CF, liaison Caterina Doglioni).
2. DM models (TF)
3. Future colliders (AF)
4. Direct detection (Underground Facilities)
5. Small exp, Dark sector at Low energies (RF, in particular RF06)
6. Triggering, systematics… Instrumentation and computation frontiers
7. Within EF:
    a. EF01/02: Higgs portal
    b. EF08: SUSY models
    c. EF09: dark sector, LLP.
    d. MC task force

Our focus: MET+X searches, dark matter interpretation of models/searches, placing collider limits in context w/other experiments

Will coordinate and liaise with other frontiers and groups (see later for meeting on LLP with EF09/RF06).

Meetings and contributions received so far, and future plans

Summary of kick-off meeting

- Held on May 14th, https://indico.fnal.gov/event/43149/
  a. Attended by ~100 participants (~ # of subscribers on the mailing list)
  b. Notes can be found at this link

- Summary of European Strategy DM projections
  a. What can we learn / improve upon? Some ideas:
  b. MET searches
     i. Encourage studies on similar experimental footing (systematics…) for easier comparison
  c. Beyond MET searches
     i. Cooperate with other groups to add DM signal regions/interpretations
  d. DM Interpretation
     i. Arrange for discussions on “summary plots” (colliders + other experiments) with:
        1. Cosmic Frontier + Underground Frontier
        2. Accelerator (for lepton/hadron colliders) + Rare precision frontier

Summary of kick-off meeting discussion

Discussion notes and transcript can be found at this link

- Wish to expand on models:
  a. Higgsino/Wino benchmarks → add minimal multiplet, different spins (also for interplay with direct/indirect detection)
  b. Higgs portal → add DM production via heavy Higgs
  c. Coannihilation beyond SUSY models
  d. Models motivating the SM-DM interaction via shared anomalies or loop interactions

- Wish to update summary plots of WIMP/non-WIMP with more recent results
  a. Joint work with EF09 / RP6
  b. Will cooperate with LHC Dark Matter and Long Lived Particles Working Group

Note: we don't aim to have an exhaustive set of results in terms of benchmarks, but rather a representative *big picture* set where we can highlight different aspects

Nevertheless, work / new ideas on any DM benchmarks are welcome and will be considered!

Summary of kick-off meeting discussion

Discussion notes and transcript can be found at this link

- Long-lived particle signatures: where are they studied?
  a. Signatures in EF09, interpretation in EF10 (and EF08)
  b. Discussion among conveners of EF10/EF09/RP06:
     i. Joint meetings when talking about the topic, to optimize attendance
     ii. First meeting on two afternoons of July 23-24 (TBC)

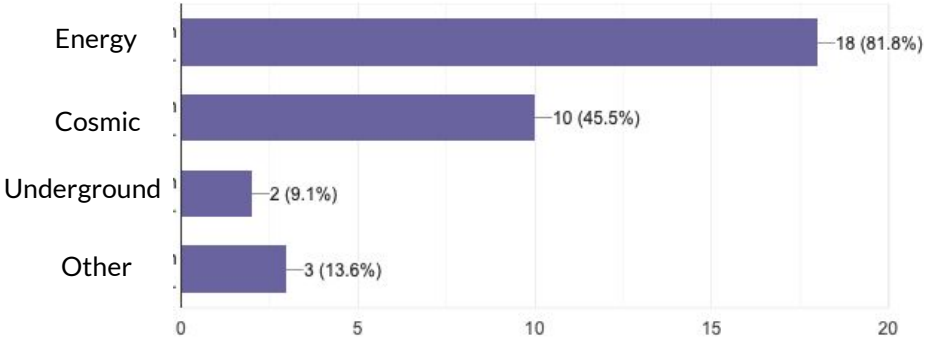
- Can we add upcoming LHC SUSY scans with DM constraints to inform future collider benchmarks?
  a. Snowmass process can facilitate this kind of requests
  b. Discussion has started in ATLAS, will probably have a topical meeting soon

- Can we discuss CP violation in interactions between DM and SM?
  a. Will have a topical meeting about this

Short overview of responses to form so far

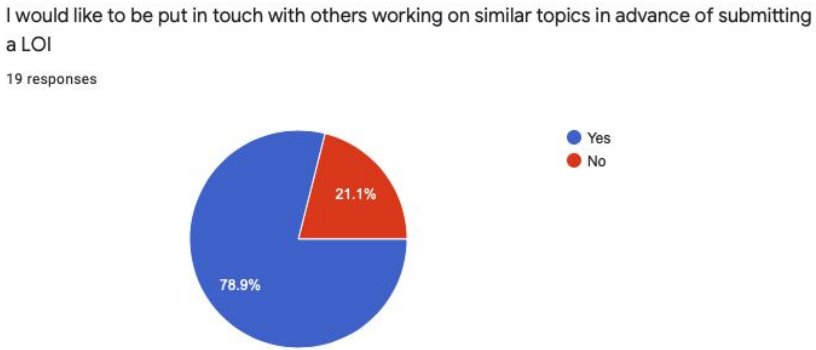
- 23 answers so far, slightly more theorists than experimentalists

Main interests (can fill multiple values)
→ cross-frontier participation



Collaborative environment:

we will help connecting people working on the same topic if they wish to



- We will go through the answers and contact people who answered by our next meeting

Coming up next

Initial focus: broadly agree on benchmarks to study and why → focused questions
- need input from theory/experiments/other Topical Groups & frontiers

Ongoing goal: offer a discussion platform for ongoing studies
Overall goal: propose and answer focused questions with studies on DM benchmarks

EF 10 **Bi-weekly meetings** with the community will be focusing on **more specific topics.**

Every other Thursday, 12:00 -1 pm (US Eastern time).

Next meeting: June 4th.
Topics: Review of questionnaire so far → building up to **focused questions (TBC)**

For most up to date info, see our webpage and slack channel

Energy frontier workshop: July 9-10, 2020
Joint meeting on LLP and DM interpretations: tentatively July 23-24

Join us and give input!

Webpage of EF 10: https://snowmass21.org/energy/dark_matter

Slack channel: #ef10-dark_matter under https://snowmass2021.slack.com

Email list: SNOWMASS-EF-10-DARK_MATTER@FNAL.GOV

Instructions on how to join: https://snowmass21.org/energy/start#communications

Give your input for our next discussion (same link will work for every meeting):

https://docs.google.com/document/d/1MWH4W1PAs4xKzWBJVzP3fBU8Z06aEsVvorGa2Frjljw/edit#

Expression of Interest form:

https://docs.google.com/forms/d/e/1FAIpQLSeFRaT5iUx4GYrypEiM-T6VId1b8y8Isqaruk714Yomw-9mOQ/viewform?usp=sf_link

Backup slides