

Snowmass 2021: Dark matter at colliders

Caterina Doglioni (Lund University)
Liantao Wang (University of Chicago)
Energy Frontier Topical Group convenors (EF10)

2020/05/14 - Kick-off meeting

The Snowmass process - <https://snowmass21.org>

Goal:

*The Snowmass Process is organized by the Division of Particles and Fields (DPF) of the American Physical Society. Snowmass is an opportunity for the entire HEP community to come together to **identify and document a vision for the future of particle physics in the U.S. and its international partners.***

Organization:

Snowmass 21 \supset Energy Frontier (EF) \supset topical group EF10 = Dark Matter at Colliders

Current call for Letters of Interest and Papers:

- <https://snowmass21.org/loi>, deadline Aug 31, 2020

- <https://snowmass21.org/submissions/start>, deadline July 31 2021

Join us, 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 discussion (same link will work for every meeting):

<https://docs.google.com/document/d/1MWH4W1PAs4xKzWBJVzP3fBU8Z06aEsVvorGa2Frlijw/edit#>

Expression of Interest form:

<https://docs.google.com/forms/d/1pP-iSK2YbiSEg5kyQyEitwu8EKUIGljYG8QXLuSCDYU/edit>

Goal of this 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.

Colliders at the energy frontier

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 systematics dominated.

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

Clean, can carry out very sensitive DM search.

Limited by machine energy. Higher energy preferred.

List of topics

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

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.

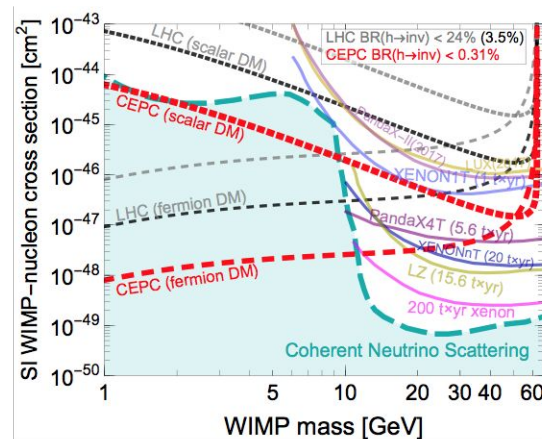
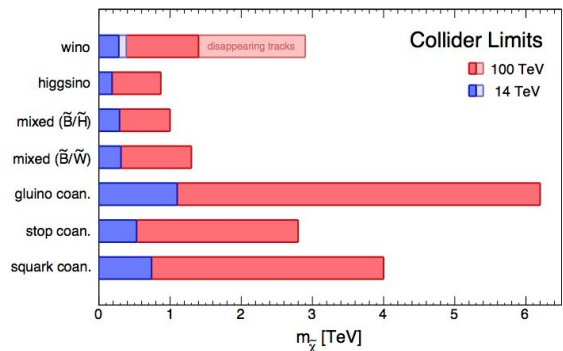
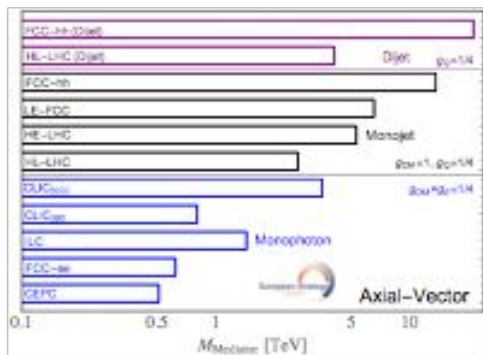
- a. S-channel and t-channel mediators. Well established benchmarks for LHC.
- b. Target: $>$ GeV-scale DM masses, simple benchmarks for comparisons

3. Higgs portal

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

Testing Simple WIMP Models

1. *A lot of results available for simple WIMP-like models (see Caterina's talk)*



Questions: any obvious case missing? What kind of refinement of analysis/projections are needed?

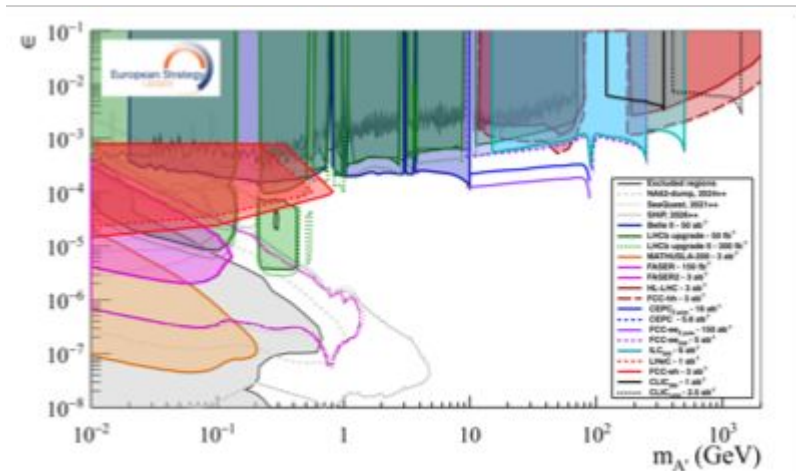
Questions: what are the challenges for controlling systematic uncertainties, trigger/detector/machine design?

Topics 2: beyond WIMP

1. Different DM masses and couplings with respect to the WIMP
 - a. Strongly interacting DM; light DM ($< \text{GeV}$)
2. Different portals with respect to LHC simplified models:
 - a. dark photon and generic dark scalar/pseudoscalar (including rare decays)

Question: what are the most relevant benchmarks?

Question: are we missing any new ideas?



A lot of synergies with the rest of the Snowmass

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 E (RF)
6. Triggering, systematics... Instrumentation and computation frontiers
7. Within EF:
 - a. EF02: Higgs portal
 - b. EF08: SUSY
 - c. EF09: dark sector, LLP.
 - d. MC task force

**Our focus: dark matter interpretation
of models/searches, MET searches**

Will coordinate and liaise with other frontiers and groups.

Coming up next

EF 10 Bi-weekly meeting with the community. Focusing on more specific topics.

Every other Thursday, 12:00 -1 pm (US Eastern time). Next meeting: June 4th.

For most up to date info, see our [webpage](#) and slack channel

Energy frontier Kick off workshop, May 21. <https://indico.fnal.gov/event/24264/>

Energy frontier workshop: July 9-10, 2020

Again, please let us know your thoughts!

Give your input for discussion:

<https://docs.google.com/document/d/1MWH4W1PAs4xKzWBJVzP3fBU8Z06aEsVvorGa2Friljw/edit#>

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Current status of physics cases

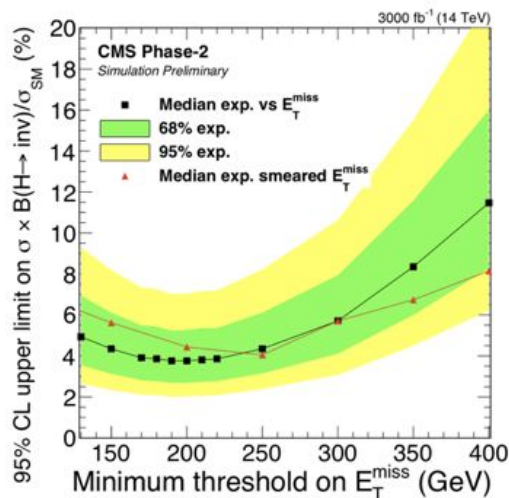
Large body of work available:

- European Strategy studies asked for conceptual design studies for HL-LHC and future collider proposals, focusing on WIMP scenarios
 - Full list of proposals is here: <https://indico.cern.ch/event/765096/contributions/>
 - Benchmark scenarios covered: **SUSY Wino/Higgsino, Vector/scalar mediators with $o(1)$ couplings** (Dark Matter Forum / WG, [Phys. Dark Univ. 26 \(2019\) 100371](#)), **Higgs portal**
 - List of *European Strategy Big Questions* in backup slides
 - CD had an equivalent role as Snowmass subconvener for BSM subgroup DM @ colliders and as “liaison” to Dark Matter and Dark Sector WG
 - Work spanned a few months, can still contact groups for updates of studies if needed
- Emphasis on **Synergies** within the Dark Matter community
 - liaising with other WGs and frontiers, also backup slides

Hadron colliders at the energy frontier

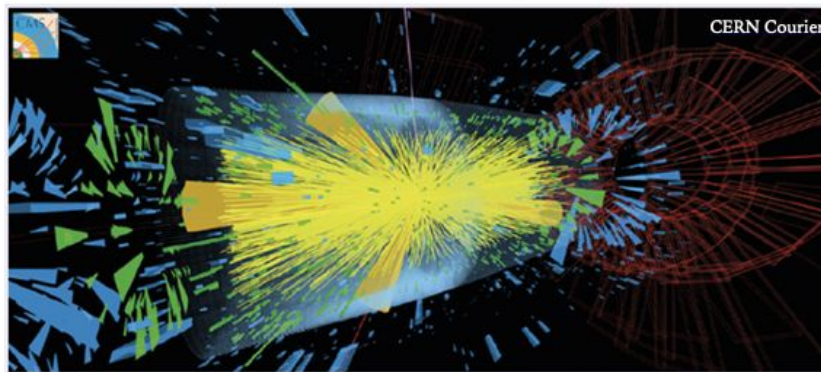
- Generally best reach to discovery of high-mass DM/mediators (MET searches)
- Challenges: online data taking thresholds, simultaneous collisions (pile-up)

[arXiv:1902.10229](https://arxiv.org/abs/1902.10229) and [CMS-PAS-FTR-18-016](https://arxiv.org/abs/1808.016)



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

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



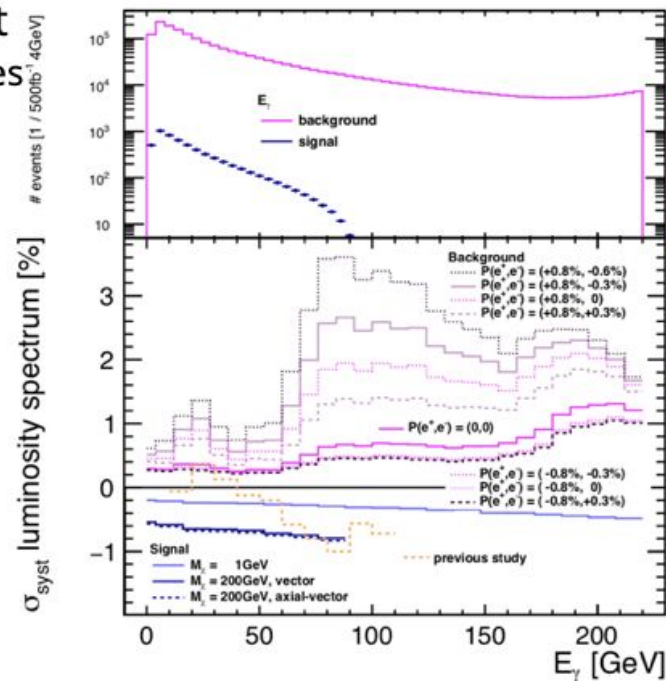
HL-LHC uncertainty on Higgs to invisible BR (VBF)
depends on pile-up rejection method

[arXiv:1902.10229](https://arxiv.org/abs/1902.10229) and [ATL-PHYS-PUB-2018-038](https://arxiv.org/abs/1808.038)

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

Lepton colliders 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](#)