CPM #136: Heavier Particle Dark Matter >~ 10 GeV

Coordinates: Tuesday 6/10 @ 11:30AM - 12:30PM CDT
Indico Agenda: link
Zoom Connection: Room 13, https://fnal.zoom.us/j/99209558629
Slack Channel: #cpm_topic_136
Organizers: Tulika Bose, Caterina Doglioni, Hugh Lippincott, Tracy Slatyer, Liantao Wang

Goals:

The Snowmass CPM seeks to:

- Focus on inter-frontier discussions and establish cross-working-group connections
- Provide space for members across the field to talk to each other and to discuss, promote, and develop new ideas
- Identify gaps and further input needed to achieve Snowmass goals

This session in particular seeks to discuss experimental searches for dark matter at the 10 GeV mass scale and higher, spanning direct detection, indirect detection, and collider searches. As such, this session lies at the intersection of the Cosmic and Energy Frontiers, and we are seeking input on how to ensure proper coverage of overlap and complementarity between these different approaches.

The first half of the session will consist of a short talk on theory background and motivations for heavy particle dark matter, followed by summaries from the CF and EF organizers of relevant LOIs and activities in their topical groups. A list of LOIs, roughly clustered by topic, is provided below.

In the second half of the session, since useful and inclusive discussions are challenging in large groups, we will split participants into a set of smaller, randomly assigned breakout rooms, to discuss objectives and priorities for the Snowmass process going forward. The results of these breakout discussions should be recorded in google docs and will be shared after the session.

Comments, questions, and suggestions on the organization of this session are welcome and should be posted on the Slack channel linked above (#cpm_topic_136).

Rough Agenda:

- General motivation/theory talk (Nausheen Shah) - 15min
- Summary by EF organizers - 10min
- Summary by CF organizers - 10min
- Breakout Sessions for Discussion/Brainstorming (25 min)

- Breakout Template Located [here]

Letters of Interest:

Below is a list of LOIs that we have associated with this session. These LOIs have been roughly organized by topic, for ease of access.

Direct detection for heavy DM

Noble liquids:
SNOWMASS21-CF1_CF0_Giovanetti-172.pdf (Searching for Dark Matter with Liquid Argon)
SNOWMASS21-NF10_NF4-CF1_CF0-IF8_IF0-UF1_UF3-137.pdf (Low Background kTon-Scale Liquid Argon Time Projection Chambers)
SNOWMASS21-CF1_CF0_Matthew_Szydagis-174.pdf (Particle dark matter searches with a G3 liquid-xenon detector)
SNOWMASS21-CF1_CF0_Hugh_Lippincott-106.pdf (HydroX- Using Hydrogen Doped in Liquid Xenon to Search for Dark Matter)
SNOWMASS21-CF1_CF7-NF5_NF3_PandaX-073.pdf (The PandaX Experiment)
SNOWMASS21-CF1_CF2_Baudis-114.pdf (Dark Matter Physics with the DARWIN Observatory)
SNOWMASS21-CF1_CF2-NF5_NF4-IF8_IF0-CompF0_CompF0-UF2_UF3_Matthew_Szydagis-236.pdf (The Exploitation of Xe Large Scale Detector Technology for a Range of Future Rare Event Physics Searches)
SNOWMASS21-IF8_IF0-CF1_CF0_sorensen-053.pdf (A crystalline future for dual phase xenon direct detection instruments)

Bubble/snowball chambers:
SNOWMASS21-CF1_CF0-NF10_NF6-IF8_IF6_Matthew_Szydagis-012.pdf (Metastable Water: Breakthrough Technology for Dark Matter and Neutrinos)
SNOWMASS21-CF1_CF0-079.pdf (Multi-ton Scale Bubble Chambers)
SNOWMASS21-CF1_CF0_Eric_Dahl-099.pdf (Reaching the Solar CEvNS Floor with Noble Liquid Bubble Chambers)

Sodium iodide / modulation:
SNOWMASS21-CF1_CF0_Jay_Hyun_Jo-263.pdf (DM-Ice200: Search for a Dark Matter Modulation Signal with NaI(Tl) in the Southern Hemisphere)
SNOWMASS21-CF1_CF0_William_Thompson-264.pdf (COSINE-200: A Next-Generation NaI(Tl) Experiment)

Calibration and backgrounds:
SNOWMASS21-IF6_IF8-NF4_NF9-CF1_CF2_Rick_Gaitskell-172.pdf (Nuclear Recoil Calibration Techniques for Dark Matter and Neutrino Experiments)

SNOWMASS21-NF4_NF3-CF1_CF7-TF9_TF11-039.pdf (Astrophysical neutrinos and dark matter experiments)
SNOWMASS21-IF8_IF0-CF1_CF0_Dongqing_Huang-152.pdf (Charcoal-based Radon Reduction Systems for Ultra-clean Rare-event Detectors)
SNOWMASS21-CF1_CF0-NF5_NF0-RF4_RF0-AF5_AF0-IF9_IF0_Shawn_Westerdale-052.pdf (Neutron Yield in (α-n)-reactions in Rare Event Searches)

Directional detection:
SNOWMASS21-CF1_CF0-NF10_NF4-IF5_IF4_Vahsen-189.pdf (CYGNUS: A nuclear recoil observatory with directional sensitivity to dark matter and neutrinos)
SNOWMASS21-IF1_IF0-CF1_CF0_Marshall-110.pdf (Solid-state directional detection of massive dark matter particles via spectroscopy of quantum defects)
SNOWMASS21-IF9_IF8-NF3_NF10-CF1_CF0-145.pdf (Dual-Readout Time Projection Chamber: exploring sub-millimeter pitch for directional dark matter and tau identification in ντC C interactions.)

Other techniques:
SNOWMASS21-CF1_CF0-NF10_NF4-IF3_IF0_Ethan_Brown-034.pdf (Snowmass 2021 LOI: Paleo Detectors)
SNOWMASS21-CF7_CF1-NF4_NF0-216.pdf (Observing the High-Energy Sun)
SNOWMASS21-IF2_IF0-CF0_CF1_JUIJEN_WANG-132.pdf (Transparent Thermoplastic Acrylic Scintillator)

Indirect detection for heavy DM

Gamma rays:
SNOWMASS21-CF1_CF7_David_Williams-185.pdf (The Cherenkov Telescope Array (CTA): A Transformational Instrument for Fundamental Physics and Cosmology with Very High-Energy Gamma Rays and Cosmic Rays)
SNOWMASS21-CF1_CF7_Andrea_Albert-187.pdf (Searching for TeV Gamma-Ray Dark Matter Signals from Galactic Substructure with the Southern Wide-field Gamma-ray Observatory (SWGO)∗)
SNOWMASS21-CF1_CF7_Andrea_Albert-190.pdf (Searching for Dark Matter Signals in the Galactic Center with the Southern Wide-field Gamma-ray Observatory (SWGO)∗)
SNOWMASS21-CF1_CF7_Andrea_Albert-191.pdf (Constraining the Local Positron Contribution from TeV Halos with the Southern Wide-field Gamma-ray Observatory (SWGO)∗)
SNOWMASS21-CF1_CF3-TF9_TF0_Steven_Clark-197.pdf (Probing Dark Matter Dynamics with An Ensemble of Gamma-Ray Signals from Different Galaxies)
SNOWMASS21-CF1_CF0-TF9_TF0_Rebecca_Leane-182.pdf (Understanding the Galactic Center Gamma-Ray Excess: Observational Prospects)
SNOWMASS21-CF1_CF0-TF9_TF0_Rebecca_Leane-183.pdf (Understanding GCE: improving diffuse models, fitting methods and templates; complementary signals)

Charged cosmic rays:

SNOWMASS21-CF7_CF1_Homola-074.pdf (Cosmic Ray Ensembles as a Potentially New Probe of Fundamental Physics)
SNOWMASS21-CF1_CF3_Perez-137.pdf (The GAPS Experiment: Cosmic Antinuclei as Messengers for Dark Matter)

Neutrinos:
SNOWMASS21-CF7_CF1-NF4_NF3-TF11_TF0_Mauricio_Bustamante-048.pdf (High energy cosmic neutrinos as probes of new physics)
SNOWMASS21-NF8_NF4-CF1_CF7_Evan_Grohs-174.pdf (Cosmological Neutrinos)
SNOWMASS21-NF3_NF2-CF7_CF1-TF9_TF8_Katori-073.pdf (New physics with astrophysical neutrino flavor)
SNOWMASS21-NF0_NF0-CF1_CF2_Rott-190.pdf (Letter of Interest on Dark Matter Physics with the IceCube Neutrino Observatory)
SNOWMASS21-NF10_NF4-CF7_CF1-TF11_TF0_Darren_Grant-105.pdf (The IceCube Neutrino Observatory)
SNOWMASS21-NF0_NF0-RF4_RF0-CF1_CF0_HyperK-187.pdf (The Hyper-Kamiokande Experiment)
SNOWMASS21-NF4_NF10-CF1_CF7-020.pdf (The Pacific Ocean Neutrino Experiment: a new cabled observatory within Ocean Networks Canada)

Ultraheavy DM

SNOWMASS21-CF7_CF1_Romero-Wolf-024.pdf (Radio Detection of Ultra-high Energy Cosmic Rays with Low Lunar Orbiting Small Stats)
SNOWMASS21-NF3_NF10-EF8_EF0-CF1_CF7_Anna_Pollmann-065.pdf (Searches for exotic particles with the IceCube Neutrino Observatory)
SNOWMASS21-CF1_CF0-NF3_NF0-TF8_TF9_Joshua_Berger-148.pdf (Multi-scattering Dark Matter at Neutrino Experiments)
SNOWMASS21-CF1_CF7-203.pdf (Hunting super-heavy dark matter with ultra-high energy photons)
SNOWMASS21-IF1_IF0-CF1_CF2-TF10_TF0-013.pdf (Mechanical Sensors as particle detectors)

Complementarity and comparisons

SNOWMASS21-CF1_CF3-TF9_TF0-056.pdf (Snowmass LOI: Defining the WIMP)
SNOWMASS21-CF1_CF0_Hugh_Lippincott-105.pdf (Phystat-DM - Statistical Methods for Dark Matter Direct Detection)
SNOWMASS21-EF9_EF10-RF6_RF0-CF1_CF3_Boyu_Gao-160.pdf (Summarizing experimental sensitivities of collider experiments to Dark Matter models and comparison to other experiments)
https://www.snowmass21.org/docs/files/summaries/CF/SNOWMASS21-CF2_CF7-EF10_EF0-RF6_RF0-TF9_TF0-150.pdf (Dark Matter Complementarity)

Theory, analysis, and computing

SNOWMASS21-CF1_CF0-TF5_TF8-CompF2_CompF0_Pavlos_M._Vranas-166.pdf (Composite Dark Matter from Strong Dynamics on the Lattice)
SNOWMASS21-TF8_TF5-EF3_EF5-NF3_NF0-RF4_RF0-CF1_CF3-012.pdf (Probing High Scale Physics via Standard Model Parameters)
SNOWMASS21-NF2_NF3-EF9_EF0-RF4_RF6-CF1_CF0-TF8_TF11_Matheus_Hostert-041.pdf (Opportunities and signatures of non-minimal Heavy Neutral Leptons)
SNOWMASS21-EF10_EF0-CF1_CF0-TF7_TF9_Mariotti-070.pdf (Feebly interacting dark matter at colliders and early universe cosmology)
SNOWMASS21-CF1_CF0-CompF6_CompF0_A.B._Balantekin-107.pdf (Insights from Quantum Information Science into Dark Matter Direct Detection Experiments)
SNOWMASS21-CF1_CF0-TF2_TF0-171.pdf (Effective Field Theory for Dark Matter Direct Detection)
SNOWMASS21-IF8_IF0-NF5_NF10-CF1_CF0-CompF5_CompF7_Matthew_Szydagis-104.pdf (NEST, the noble element simulation technique: a multi-disciplinary Monte Carlo Tool and Framework for Noble Elements)
SNOWMASS21-CompF3_CompF2-NF1_NF5-CF1_CF2-IF8_IF3_Monzani-084.pdf (The Future of Machine Learning in Rare Event Searches)
SNOWMASS21-CompF2_CompF1-NF1_NF5-CF1_CF2-IF8_IF2_Monzani-085.pdf (Fast Simulations for Noble Liquid Experiments)

Heavy WIMP and WIMP-like models at colliders

Electroweak multiplets at the Muon Collider
Doublet Singlet Dark Matter
A final word on minimal dark matter at future lepton colliders
Letter of Interest Long-lived charginos in the MSSM and beyond
Letter of Interest Searching for the Stop-Bino Coannihilation Using CMS Open Data
Snowmass21: Letter of interest Future collider reach for light DM in the NMSSM via light Higgs searches and direct electroweakin

Higgs portal searches at colliders

Snowmass 2021 LOI on H —> invisible
Letter of Interest Dark Matter via Higgs portal at CEPC
Invisible Higgs at FCC-ee

DM Simplified models at colliders

Letter of Interest Search for t + j + MET signals from dark matter models at future ee collider
New approach to DM searches with mono-photon signature
Displaying dark matter constraints from colliders with varying simplified model parameters

Future collider and experiment (they group more than one search)
HL-LHC ATLAS: EF/SNOWMASS21-EF0_EF0-RF0_RF0_ATLASCollaboration-195.pdf
HL-LHC CMS: EF/SNOWMASS21-EF1_EF10-RF5_RF7_CMSCollaboration-109.pdf
Muon collider: EF/SNOWMASS21-EF10_EF0_Jayatilaka-225.pdf
LHeC: EF/SNOWMASS21-EF10_EF0_Armesto_LHeC_BSM10-180.pdf
CLIC: EF/SNOWMASS21-EF0_EF0_CLICphysics-170.pdf
Lepton colliders: EF/SNOWMASS21-EF0_EF0-TF0_TF0-AF0_AF0-244.pdf

Theory (general BSM overviews)

https://www.snowmass21.org/docs/files/summaries/EF/SNOWMASS21-EF0_EF0-TF0_TF0-AF0_AF0-235.pdf

Breakout room summaries (prior to summary in #150):
https://docs.google.com/document/d/1DeEPiULNWLTeOvGQpWegyIaCl6B-HbshDi2xG25fGx0/edit?usp=sharing

Breakout Room Notes:

1. Breakout 01 [facilitator(s): Hugh Lippincott]
   https://docs.google.com/document/d/19DBTBk56EY2H8su35g0EiDDNBFpC4G8U7-L-XjrIgVo/edit#
2. Breakout 02 [facilitator(s): Tracy Slatyer]
   https://docs.google.com/document/d/1LCS3NHkR6FpnkGrpq0fV2azFIR2r_C9i--zgXnYLLtA/
3. Breakout 03 [facilitator(s): Caterina Doglioni]
   https://docs.google.com/document/d/1bDFdphugd2Tp4h79UeRQrKTItw4LUrb9gS0amsmeank/edit#
4. Breakout 04 [facilitator(s): Simone Pagan Griso]
   https://docs.google.com/document/d/1LY7FIy9gArIHBe9n6cGhuh8Sozzruga3DnZ6UnnI9MI
5. Breakout 05 [facilitator(s): Nausheen Shah]
   https://docs.google.com/document/d/1-rsCYK16aKY1La0cTnXyoUnAtyG2b2DHgjtSP66bZNw/edit
6. Breakout 06 [facilitator(s): Tim Tait]
   https://drive.google.com/file/d/1pLP28u0YhOquh0XKjs7Ezj58zkpIOQwE/
7. Breakout 07 [facilitator(s): Vetri Velan]
   https://docs.google.com/document/d/1WKaIAjNdC6pMs0cjXMAnhgu2OJyx6UIj3Y1doY-pnrs/edit
8. Breakout Template (copy if needed)
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CPM #136: Main session (live) notes

Inspirational theory talk: Nausheen Shah

Relic density motivation: annihilation xsec required for relic density is the right order given weak scale && masses.
But ALSO: something sets the weak scale at around 100 GeV.

Another reason why we have been focusing on WIMP DM: complementarity of the same process (that gives the correct relic density) leading to signals in different experiments (DD, ID, colliders).

Potential problem with comparisons: EFT not valid if mediator masses ~o(DM mass) → move on from "EFT WIMP" via boosting annihilating xsec / suppressing DD xsec, and as a consequence obtain extended BSM sectors.

Fine-tuning/naturalness can also be one guiding principle for WIMP. But rather than thinking of "unnaturalness", look for patterns in UV theory and look for mediators of the interaction. As a consequence:

- Higgs could also be one of those mediators
- Colliders can look for mediators themselves, and EW-scale limits on that are quite weak so far…

Example: SUSY DM, Higgsino/Bino for DM candidate at ~60 GeV. There are many interesting excesses to explore (AMS, galactic center excess) that could be explained by it.

To sum up:

- We know that DM is there
- A weak scale and the Higgs sector point to an EW-scale particle
- What about naturally unnatural, pointing to resonances, degeneracies and cancellations

Where to look next? Data+theory, next generation collider and astrophysical probes

Q&A

Tim Tait: how to correlate relic and new physics? Another example is to change the assumptions of the cosmological history.
A: Not the simplest picture only, "look at the SM"

Andrea Albert: 100 TeV / 20 TeV masses above is just Indirect Detection.
A: much broader range, the number is much higher than the EW scale

Caterina Doglioni: EF summary

What are we aiming to do? Think not just about DM at colliders but about the broader Snowmass context
Direct and indirect detection can find DM with cosmological origin, which colliders may not be able to do
Colliders and accelerators can probe interactions
Need theory to put everything in context
Energy scales from MeV to TeV at colliders
Motivated by many different DM models (WIMP models, SUSY, dark sectors)
Slide 3: summary of DM@colliders in the Snowmass context
Nearly all the physics we do in EF10 overlaps with other frontiers
Hope this meeting is the start of a conversation

We care more about models at colliders because different benchmark models give rise to very different signatures and searches
Need to design searches differently depending on what benchmark model we're after
This is why we use benchmark models as guiding principles, in order to put work in a broader context
Have categorized work into two categories:

1) Testing the WIMP paradigm
2) Exploring signatures of DM beyond the WIMP - sessions 108, 127

Need broad and comprehensive search strategies to counter small probability that any individual scenario is correct
One consideration you can be guided by is naturalness - our prior affects what we think is plausible
DM@Colliders community is quite broad - want to be inclusive as possible with what people are studying but still keep an eye on the big picture
Want to study common benchmarks, agree on them with other frontiers/experiments
Similar to what was done for the European Strategy briefing book
Aim to have a set of benchmarks and provide technical help to collaborations and interested parties so they can show results on common plots without too much effort
Non-comprehensive studies to highlight complementarity of different signatures, differences with respect to standard benchmarks
Studies that point out novel/less-explored DM models, highlighting uncovered phase space

List of focused questions from EF10:
-How can we best test the WIMP paradigm?
Benchmarks: simplest/minimal WIMP models and their extensions, simple mediator models, through the Higgs portal - simplest portal between SM and others, connection to precision measurements

-How to best exploit synergies between DM@Colliders and others, in terms of experiments/observations answering the same physics questions on the nature of DM

Testing the WIMP paradigm:
-Electroweak multiplets (higgsino, wino, minimal DM) - TeV-scale masses. Benchmarks: minimal higgsino and wino, discuss among EF.
-Simplified mediator models - s-channel and t-channel mediators

Ongoing work on complementarity: want feedback from Cosmic Frontier
Questions to be discussed in breakout sessions are listed on slides
Looking to update 2013 complementarity white paper

Hugh Lippincott: CF summary

Looking for DM as individual quanta rather than as a wave phenomenon (roughly \gtrsim 1 eV)
Nine CF1 meetings, 50+ participants/meeting, ~150 LOIs cross-listed with CF1
Want to convey: DM as top priority of field, crossing all frontiers
Update complementarity discussion since last Snowmass
Consolidate from O(150) LOIs down to 10 or so summary white papers capturing physics of particle dark matter

Summary of LOIs (broad categories):
- Direct detection
- Indirect detection
- Ultra-heavy DM
- theory/analysis/computing

What are we thinking about as open community questions:
- DD in this mass range is in transition:
    - G2 experiments have ended/are ending → new data is coming soon
    - G3 DM was a priority from the last Snowmass, but hasn't started yet (has to wait until this process is done)
    - Much interest in low-mass DD → how do we keep doing the (still well motivated) high mass range?
- ID - where next?
    - What do we need to increase sensitivity? E.g. after Fermi
    - Are our analysis techniques sufficient / can we improve?
    - What are the targets?

- Common: complementarity arguments