Dark Matter & Long-Lived Particles Working Group and Community

José Francisco Zurita

Based on:

J. Alimena et al, arXiv 1903.04497 [LLP@LHC White Paper, *J.Phys.G* 47 (2020) 9, 090501].

Ongoing activities within LLP WG and LLP Community.

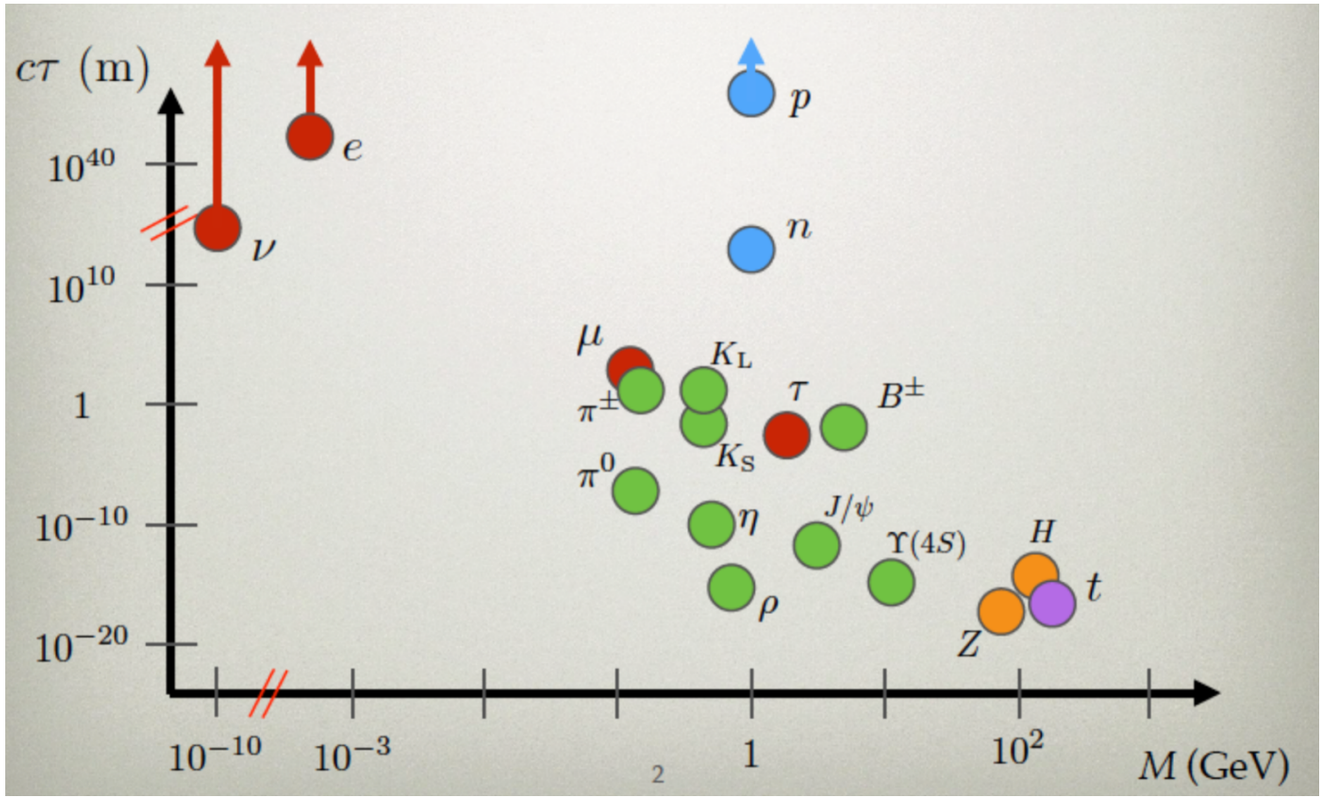
On behalf of the Long-Lived Particle Working Group and Long-Lived Particle Community

Initiative for Dark Matter in Europe and beyond (iDMEu) kickoff meeting, Zoom, 10.05.2021

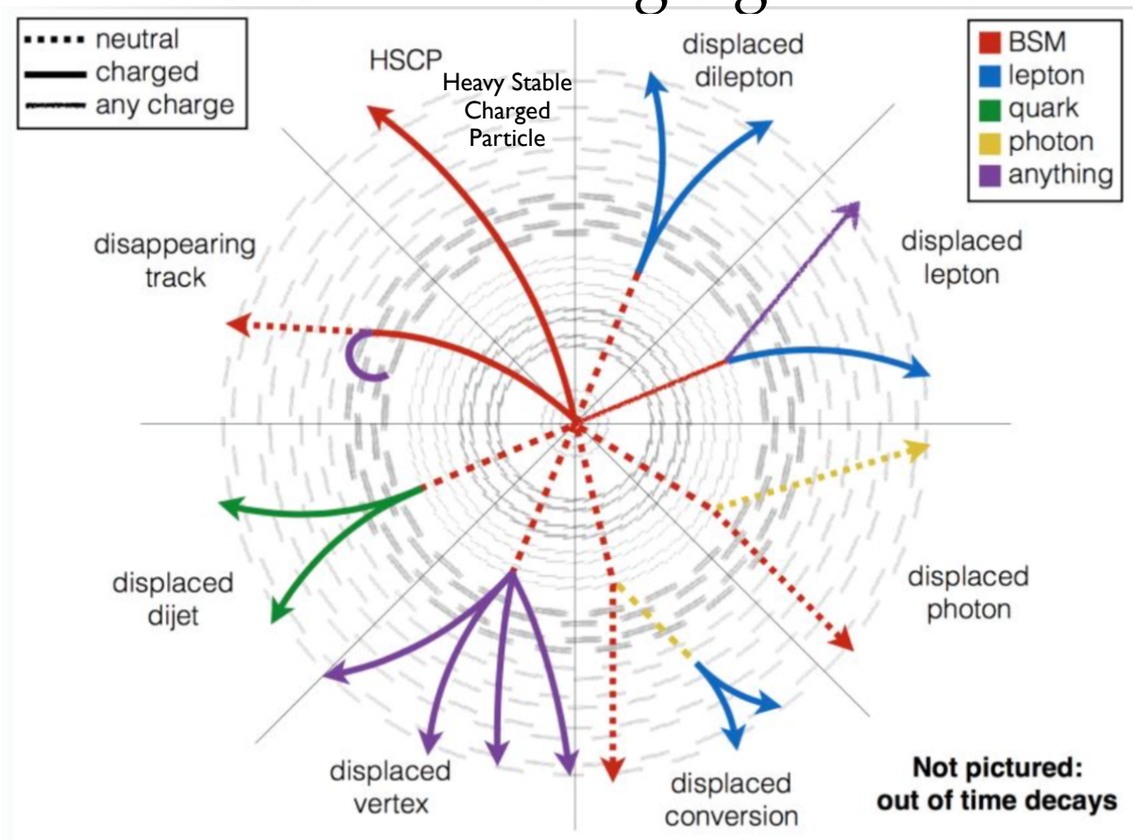
Long-Lived Particles

- LLPs: New Particles with macroscopic lifetimes (τ~ns, cτ~cm), theoretically well motivated.

Exist in the SM!



A lot of interesting signatures!



large cτ, small Γ

- Large mass hierarchies
- Compressed spectra
- Small couplings

EW Baryogenesis
Dark Matter
Hierarchy Problem
Neutrino Masses

BSM Models: Supersymmetry, dark QCD, RH neutrinos , Neutral Naturalness, Higgs Portal, Z' Portal, Hidden Valleys, …

LLP signatures->arXiv:1903.04497 ; LLP theory motivations-> arXiv 1806.07396

Dark Matter is an important pillar for the LLP@LHC programme

LLP-Genesis (Lessons from the [B]SM)

3 mechanisms to get large cτ / small Γ

$$\left(\frac{c\tau}{\text{mm}}\right) = 1.98 \times 10^{-16} \left(\frac{\text{GeV}}{\Gamma}\right)$$

1) Large mass hierarchies / off-shell mediator: heavy E scale — muon

$$c\tau(\mu \to e\nu) = \frac{1.2 \text{ fm}}{g_X^4} \left(\frac{m_e}{m_\mu}\right)^4 \left(\frac{1 \text{ TeV}}{m_\mu}\right) \sim 1 \text{ cm}$$

$m_e = 10\text{GeV}, \text{m}_\mu = 100 \text{ GeV}, \text{g}_\text{X}^4 = 10^{-7}$ RH neutrinos

$m_e = 10 \text{ GeV}, \text{m}_\mu = 1 \text{ TeV}, \text{g}_\text{X}^4 = 10^{-3}$ Hidden Valleys

2) Compressed spectra: Object reconstruction, thresholds — neutron

$$c\tau(n \to pe\nu) \sim \frac{1.2 \text{ fm}}{g_X^4} \left(\frac{m_p}{m_n - m_p}\right)^4 \left(\frac{1 \text{ TeV}}{m_n - m_p}\right) \sim 1 \text{ cm}$$

SUSY

$m_n = 101 \text{ GeV}, \text{m}_\text{p} = 100 \text{ GeV}, \text{g}_\text{X}^4 = 10^{-2}$

3) Tiny coupling: Low rates — Z' / dark photon

$$c\tau(Z \to \nu\nu) \sim \frac{0.02 \text{ fm}}{g_Z^4} \left(\frac{1 \text{ TeV}}{m_Z}\right) \sim 1 \text{ cm}$$

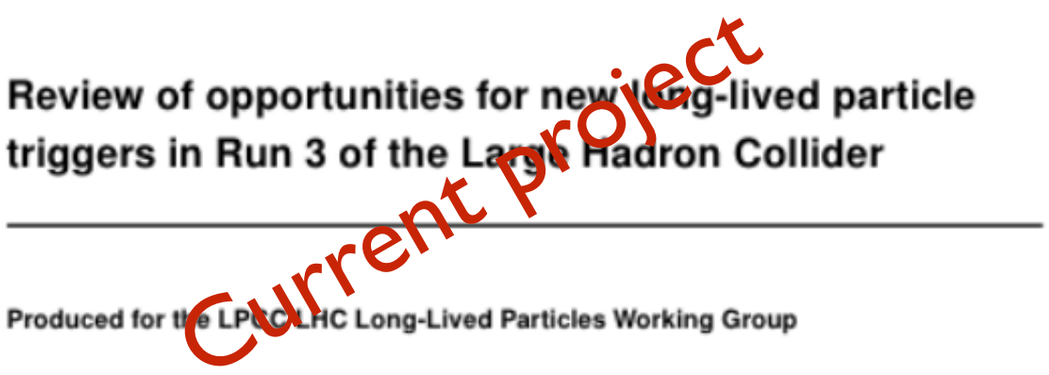
$m_Z = 1 \text{ GeV}, \text{g}_\text{Z}^2 = 10^{-12}$ Z_D models

LLP WG & Community

The ***LLP Working Group*** (within LHC Physics Centre, kicked-off May 2020) aims at facilitating communication between the LHC experiments and TH, providing recommendations for benchmark models and result presentations, development/validation of tools, discussing new search directions based on TH/EXP input.

Convenors: James Beacham, Sascha Mehlhase (ATLAS), Juliette Alimena, Albert de Roeck (CMS), Federico Leo Redi, Carlos Vázquez Sierra (LHCb), James Pinfold (MoEDAL), Dave Casper (FASER), Nishita Desai, José Zurita (Theory)

https://lpcc.web.cern.ch/lhc-llp-wg

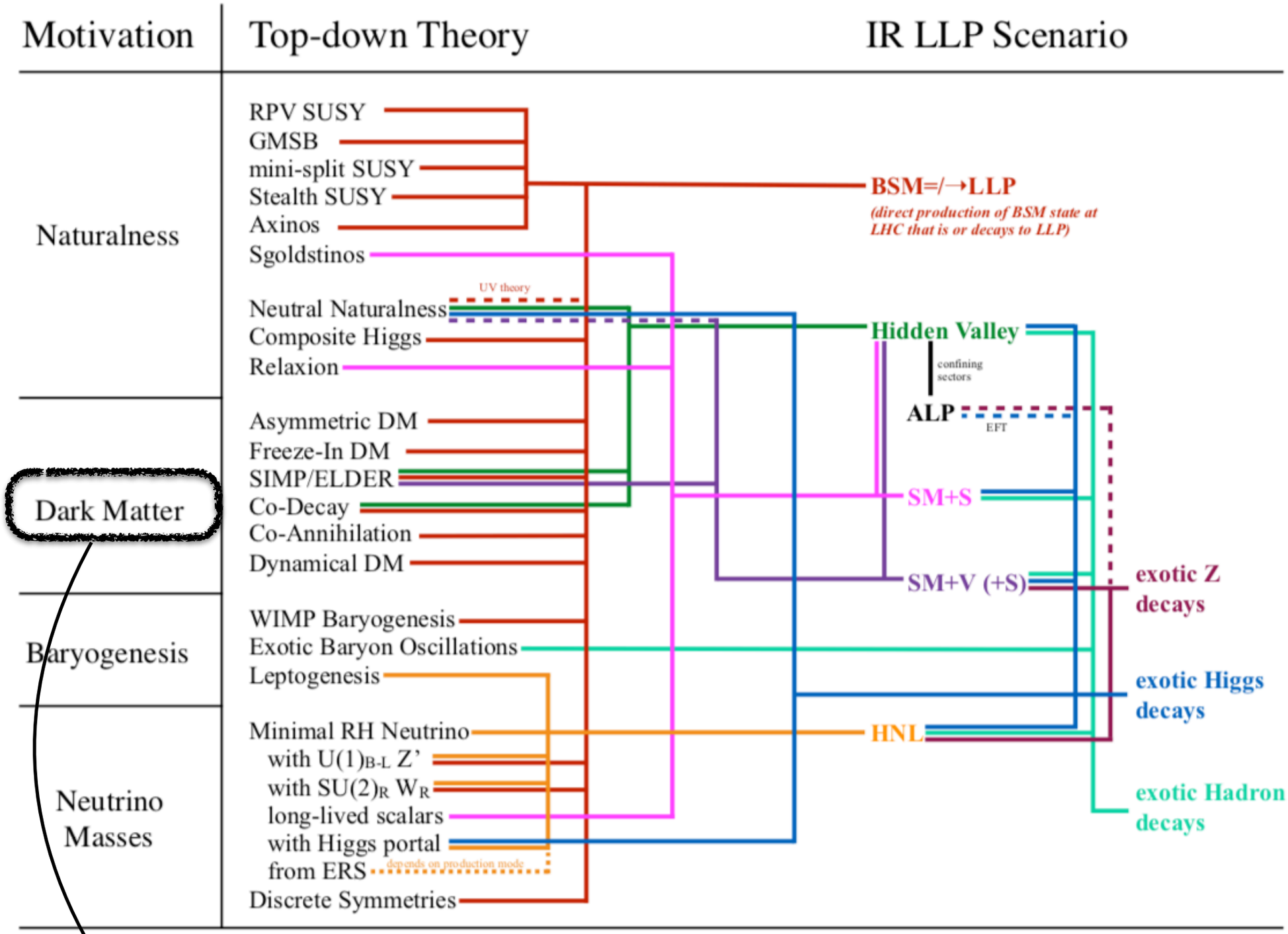


We also contacted other WGs (we met with DMWG!) and have other projects under consideration.

The ***LLP Community*** is a group of scientists interested in the exploration of long-lived signatures at colliders (not only LHC!) and beyond, operating since 2016. It organises two yearly workshops where new results are presented, and topics of relevance are discussed in an informal atmosphere.
Most of these discussions summarised in LLP@LHC White Paper, arXiv 1903.04497 *J.Phys.G* 47 (2020) 9, 090501.
Large community effort (21 editors, 201 signatories imply a broad range of topics).
Ongoing work on several topics (pushing forward the LLP frontiers!)

https://longlivedparticles.web.cern.ch

LLP Dark Matter



Curtin et al, arXiv 1806.07396, *Rept.Prog.Phys.* 82 (2019) 11, 116201

In these 6 model *classes* for LLP DM, the 3 LLP-genesis mechanisms are present.

Challenges in LLP-Realm

Problem: original LHC detectors not built with LLPs as main target (except LHCb)

a) *Triggers*: Existing menu not optimal for LLPs: LLP WG already into this!

b) *Analysis Strategies*: Within experiments, a lot of creativity is needed!

c) *Reinterpretation*: Use search based on model X to set constraints on model Y.
Particularly difficult since i) there is no standard definition of LLP objects, and
ii) LLP backgrounds are often not possible to simulate with Monte Carlo.

Reinterpretation Forum, 2003.07868 *SciPost Phys.* 9 (2020) 2, 022

d) *New signatures*: *dark showers* (emerging jets, semi-visible jets, dark jets, etc)
Important ongoing activities in LLP Community & Snowmass.

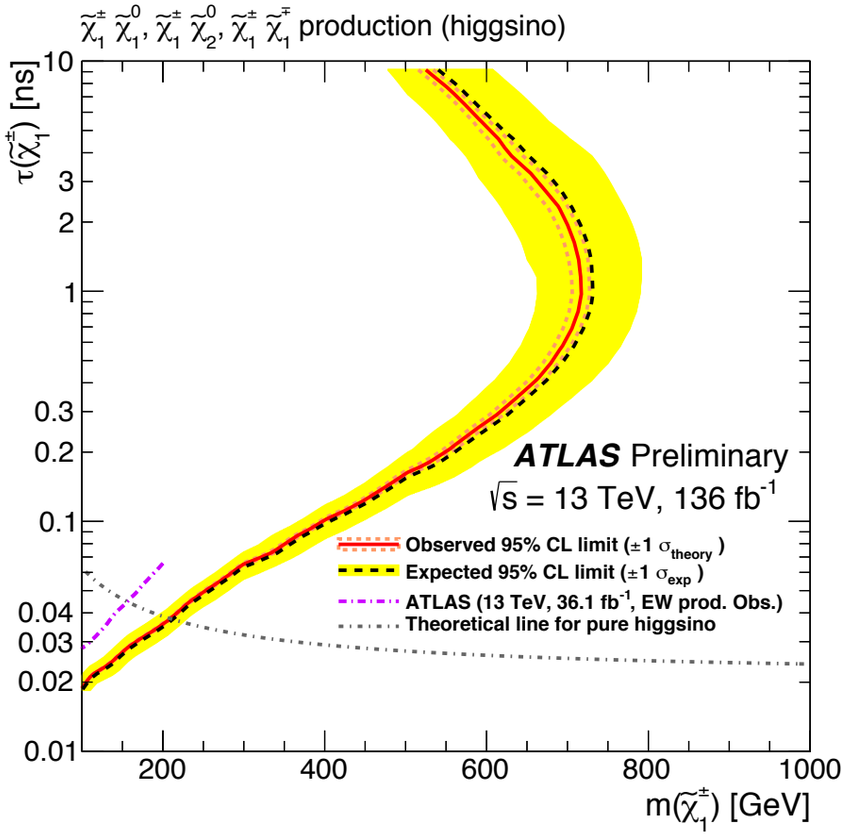
e) *New Experiments*: Place external detectors to catch all LLPs produced at LHC.

- FASER is an official LHC experiment (proposed Aug 2017, approved Mar 2019).
- SND@LHC (forward direction, approved March 12th 2021).
- Other proposals updating EoI, TDRs (MATHUSLA, Codex-B, ANUBIS, MilliQan, …).
- Proposal to build a Forward Physics Facility (FPF).

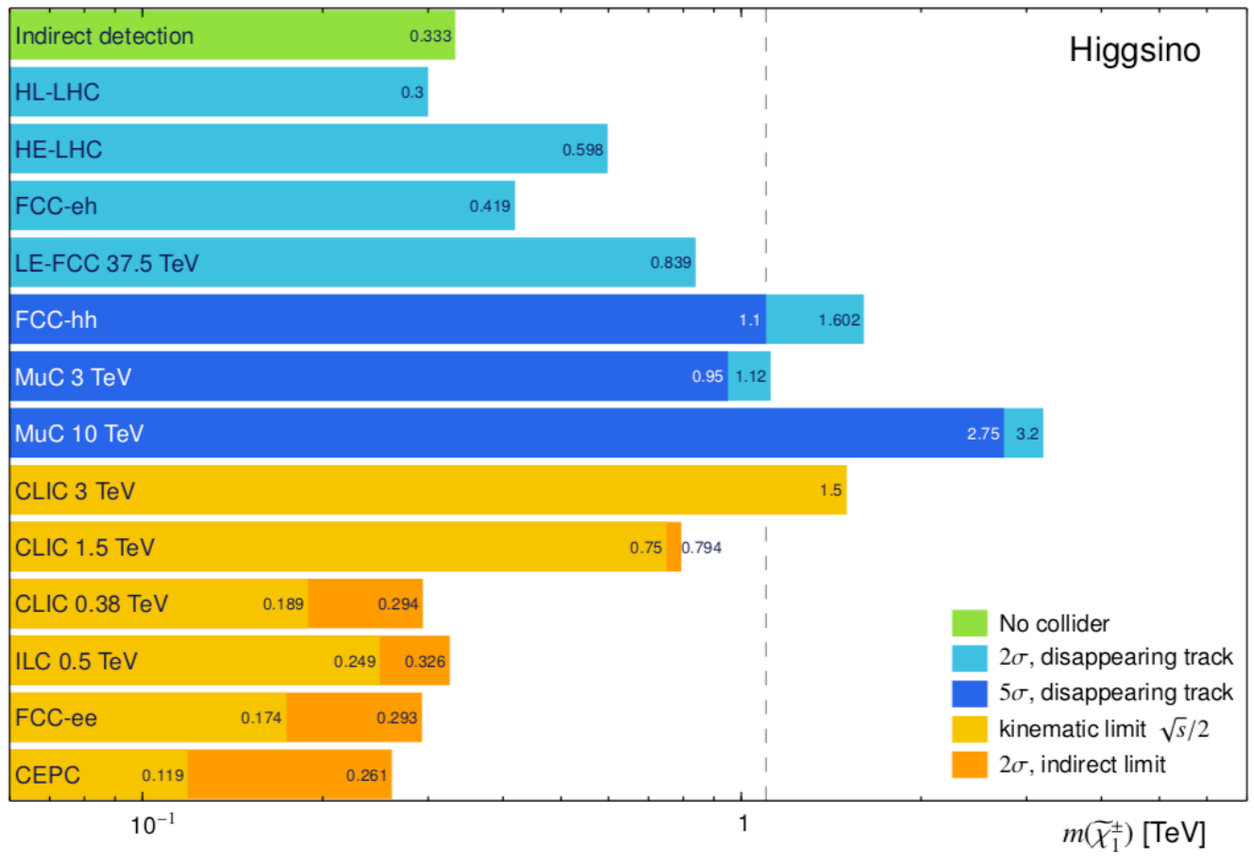
MSSM pure-Wino / Higgsino (golden model)

Large cτ due to $\Delta m = m_{\chi^+} - m_{\chi^0} \sim O(100\ \text{MeV})$ [1-loop EW, generic for WIMPs]

Wino / Higgsino have cτ ~ 6 cm / 6 mm (fermion triplet / fermion doublet)



ATLAS-CONF-2021-015 (31.03.2021)

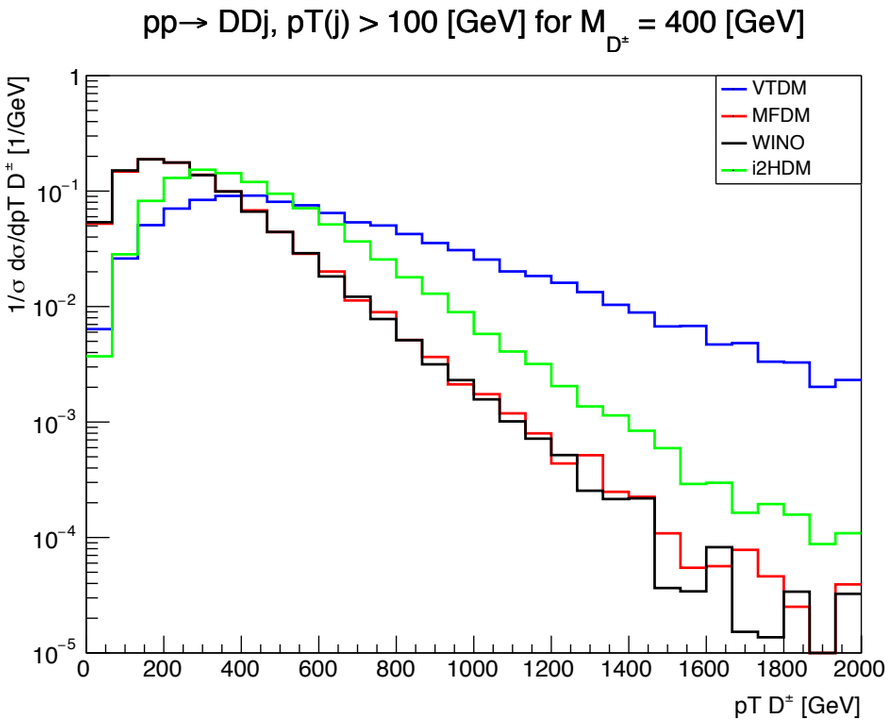


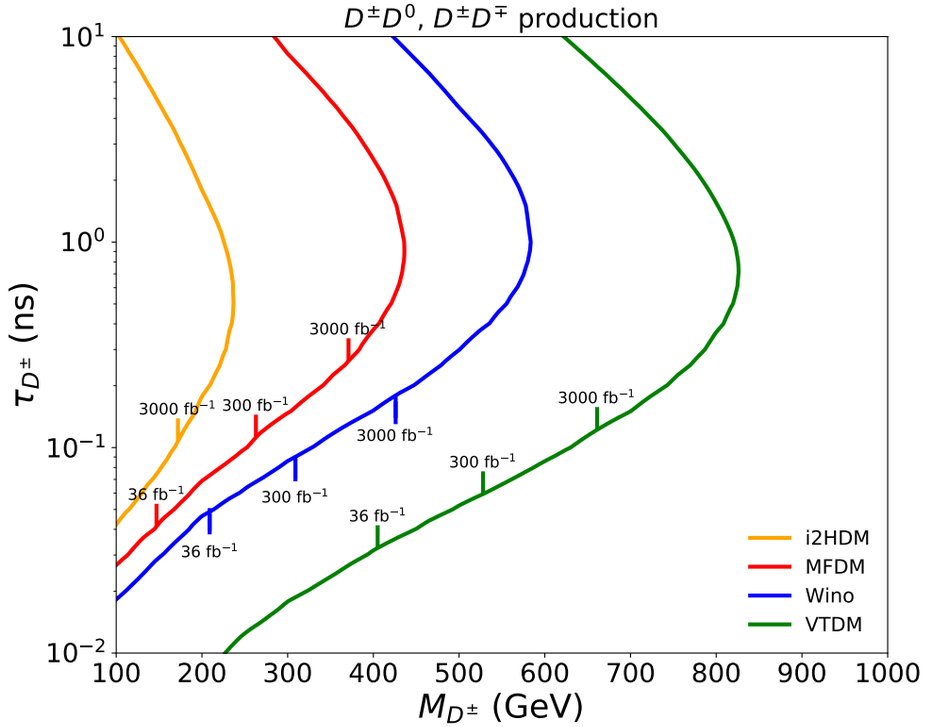
Capdevilla, Meloni, Simoniello, JZ, 2102.11292

Good to have a common benchmark to compare future experiments!

e.g: Muon Collider

Reinterpreting disappearing tracks





Minimal DM (Cirelli et al)

Belyaev, Cacciapaglia, McKay, Marin, Zerwekh, 1808.10464

Model	N	s
VTDM	3	1
MFDM	2	1/2
WINO	3	1/2
i2HDM	2	0

Belyaev, Cacciapaglia, Ivanov Rojas-Abbate, Thomas, 1612.00511

N=3, s=0, see Chiang, Cottin, Du, Fuyuto, Musolf,.2003.07867

- DT gives the strongest constraints on these models: great discovery prospects.
- Python code made public in the LLP Recasting Repository (Community initiative)

LLPrecasting

llp-recasting@googlegroups.com

LLP Recasting Repository

This repository holds example codes for recasting long-lived particle (LLP) searches. The code authors and repository maintainers are not responsible for how the code is used and the user should use discretion when applying it to new models.

Adding your recasting code

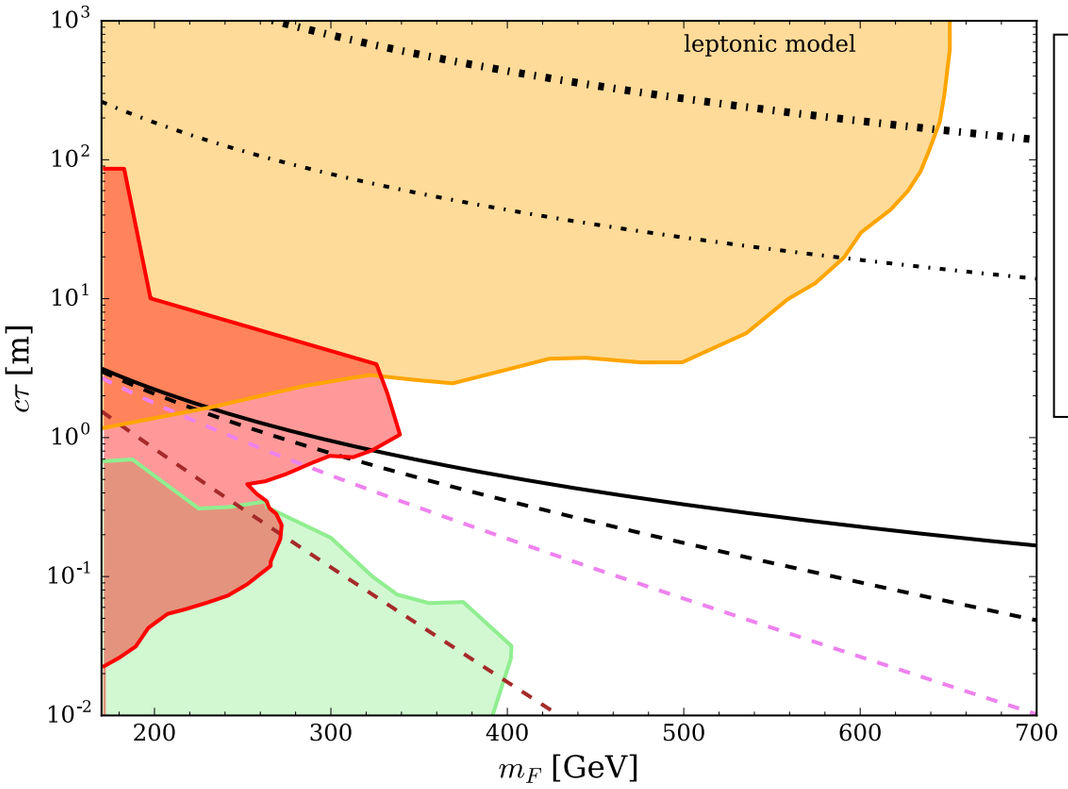
This is an open repository and if you have developed a code for recasting a LLP analysis, we encourage you to include it here. Please contact llp-recasting@googlegroups.com and we will provide you with the necessary information for including your code.

Repository Structure

The repository folder structure is organized according to the type of LLP signature and the corresponding analysis and authors:

- Displaced Vertices
  - 13 TeV ATLAS Displaced Vertex plus MET by ALessa
  - 13 TeV ATLAS Displaced Vertex plus MET by GCottin
  - 8 TeV ATLAS Displaced Vertex plus jets by GCottin
- Heavy Stable Charged Particles
  - 8 TeV CMS HSCP
  - 13 TeV ATLAS HSCP
- Disappearing Tracks
- Displaced Jets

DM beyond WIMPS: freeze-in

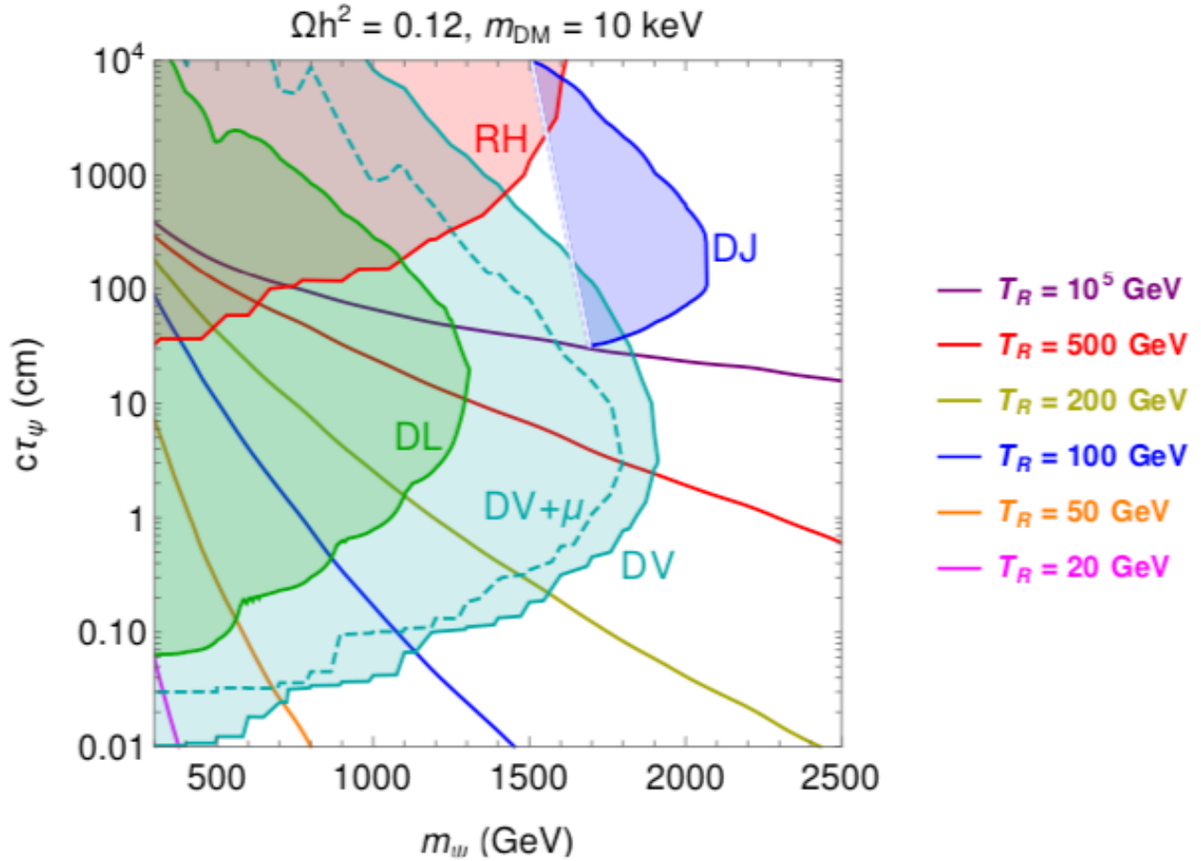


Freeze-in has *tiny coupling* built-in (prevent equilibrium). LLPs are naturally present!

Bélanger, Desai, Goudelis, Harz, Lessa, No, Pukhov, Sekmen, Sengupta, Zaldivar, JZ, [arXiv: 1811.05478, JHEP 1902 (2019) 186]

No favourite cτ: we must target the broadest range possible *comprehensive program*

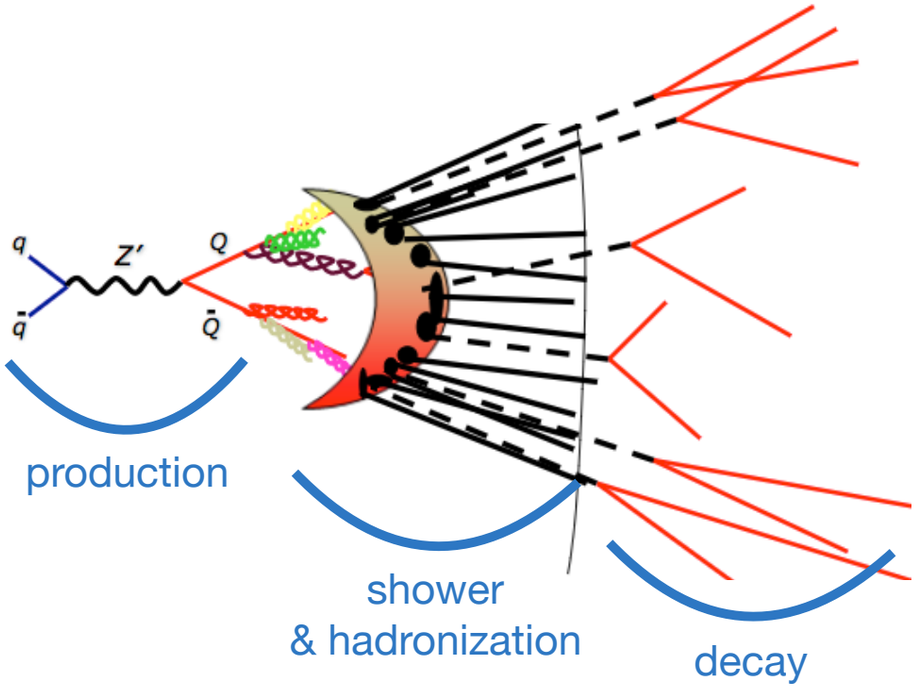
LLP searches can teach us about Early Universe physics!

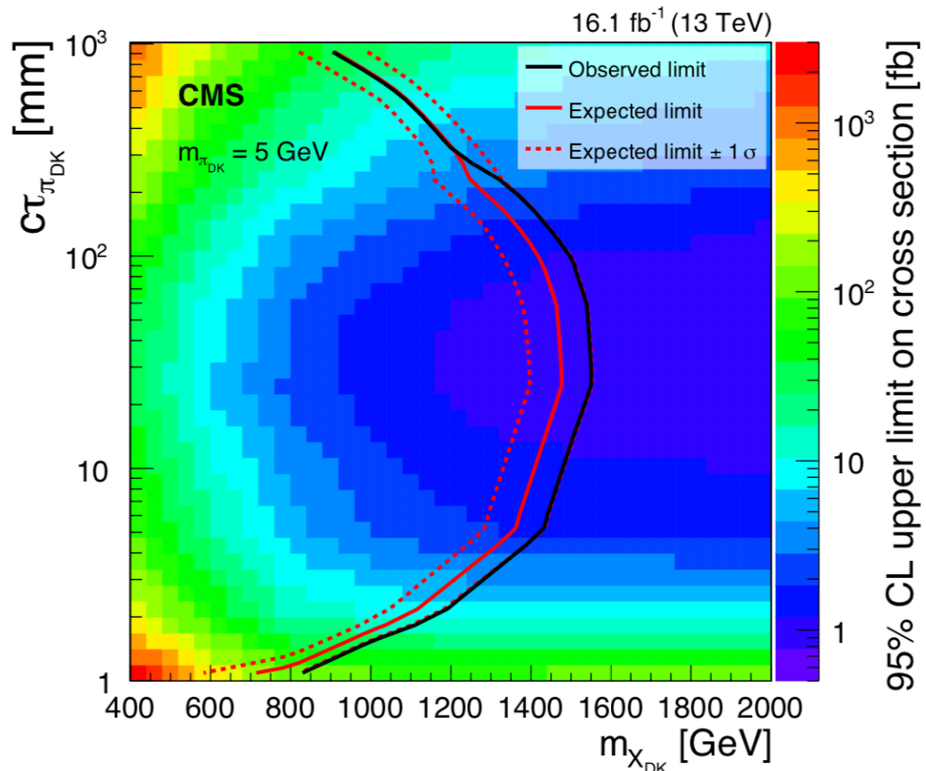


Calibbi, D'Eramo, Junius, Lopez-Honorez, Mariotti [arXiv:2102.06221]

LLP Frontiers: Dark Showers

A *confining dark sector*: Hidden Valley models, Asymmetric Dark Matter (ADM).
New *dark* quarks Q shower & hadronize in the dark sector, and decay to SM later.

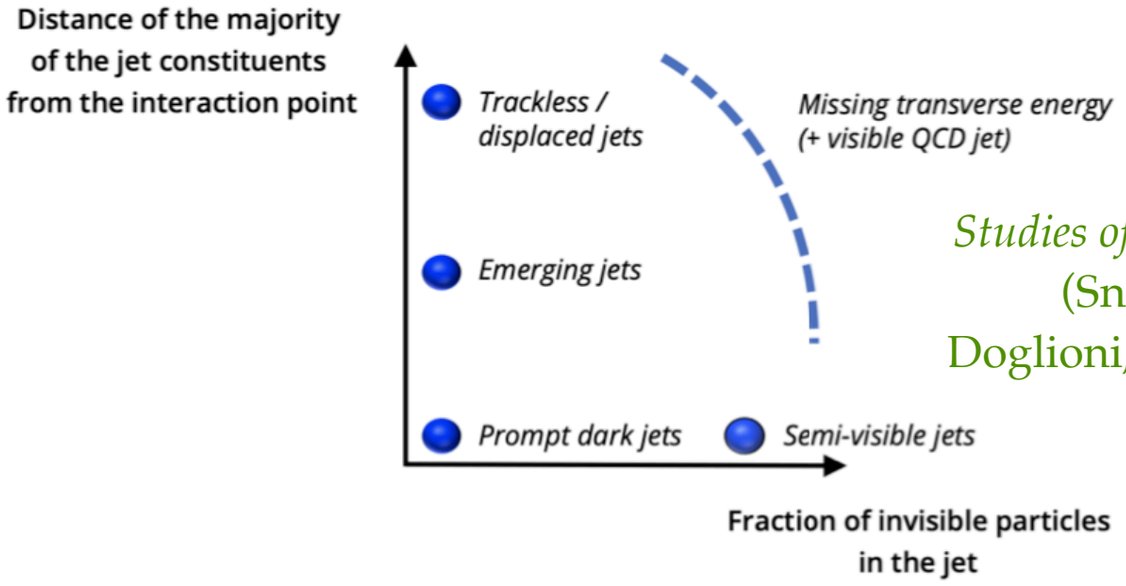




LLP@LHC White Paper, *J.Phys.G* 47 (2020) 9, 090501

CMS collaboration, 1810.10069, *JHEP* 02 (2019) 179

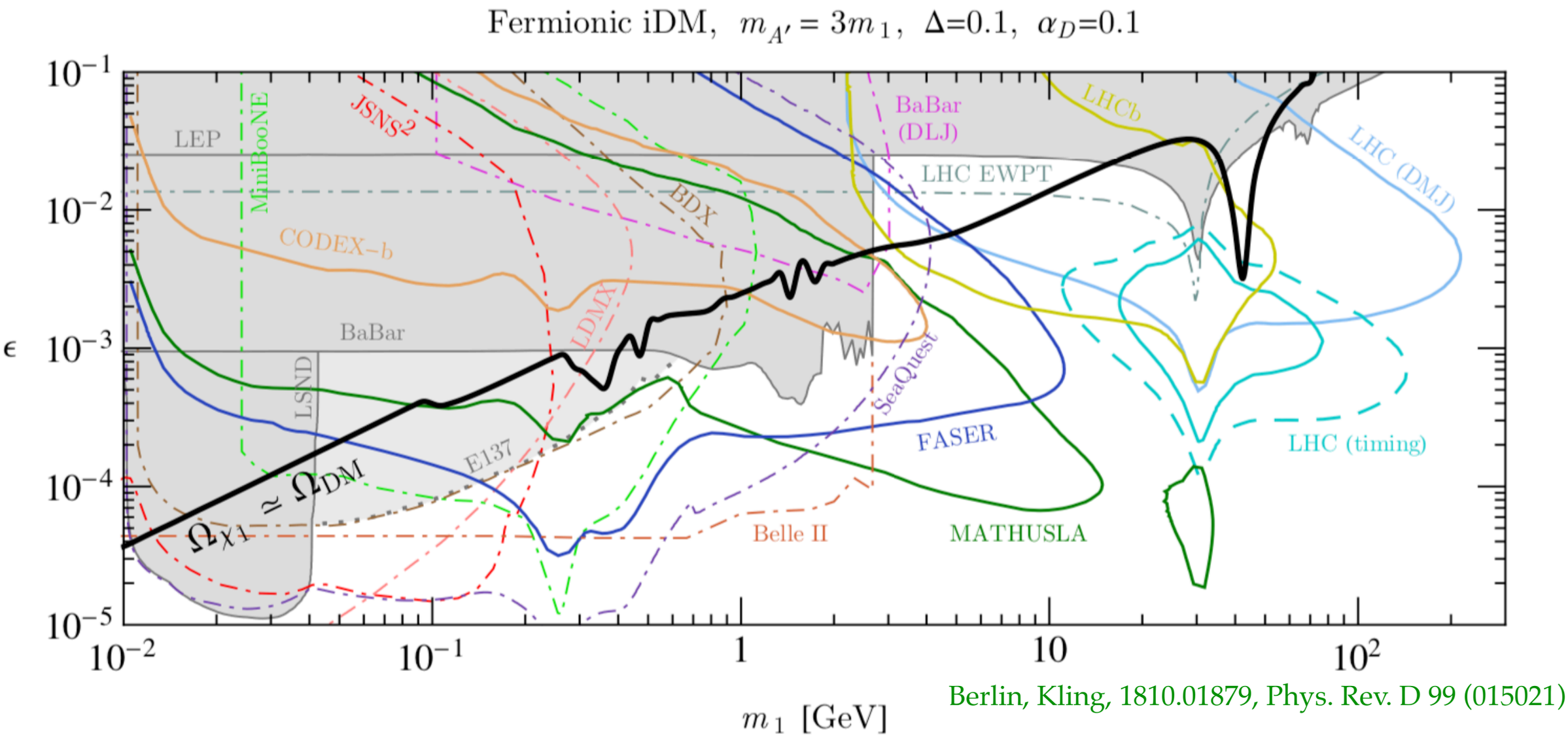
Many possible signatures.
Currently only one public analysis on emerging jets.
Ongoing effort under the Snowmass umbrella



Studies of dark shower benchmarks
(Snowmass 2021 LoI,
Doglioni, Genest, Kulkarni et al)

Light (≤ few GeV) dark matter

GeV scale DM requires light (neutral) mediators with small couplings to SM.
New experiments can target visible decays (in the 10-1000 MeV range).
Example iDM χ_1 with A′ mediator, long-lived χ_2: A′-> $\chi_2\,\chi_1$, χ_2 -> $f_{SM}\,f_{SM}\,\chi_1$



Berlin, Kling, 1810.01879, Phys. Rev. D 99 (015021)

Many more models and plots in :
Physics Beyond Colliders (PBC) report, Beacham et al, 1901.09966, *J.Phys.G* 47 (2020) 1, 010501
Feebly-Interacting Particles (FIPS) 2020 report: Agrawal et al, 2102.12143

Outlook

- Dark matter is an important motivation for Long-Lived Particles, and a key motivation of the LLP WG and LLP Community activities.
- Ongoing dialogue between theoreticians and experimentalists thanks to the LLP WG and the LLP Community.
- LLP WG and Community can contribute to external communities with a broad palette of LLP searches, and the corresponding reinterpretation to arbitrary models.
- LLP WG and Community are also open to explore particle physics models with new motivations.
- Being concrete: models of self-interacting DM solving the cusp-core problem have LLPs as a generic prediction? Known example: Strongly Interacting Massive Particles (SIMPs) [Hochberg, Kuflik, Murayama, Volansky, Wacker 1411.3727] do!