Executice Summary of the MITP Topical Scientific Program: "Dark Matter Identification: Connecting Theory and Signature Space" (DMI-2019)

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The goals of DMI-2019

The nature and the origin of Dark Matter (DM) is a fundamental problem of particle physics and cosmology, which requires physics Beyond the Standard Model (BSM). The existence of DM, contributing 80% of the matter in the Universe, has been established beyond any reasonable doubt thus providing undeniable experimental confirmation of BSM physics.

If DM is light enough and interacts with Standard Model particles directly or via some mediators with a strength beyond the gravitational one, it can be probed at particle accelerators with missing transverse energy signature (MET) originating from DM particles escaping detector. At the same time direct and indirect DM searches strongly complement collider searches for DM with large masses and pointing that collider and non-collider DM searches have unique power to probe the nature of Dark Matter. In the absence of such signals at present we can prepare ourselves for its discovery and identification: we can work out the systematic way of classification of DM models, search for new signatures (e.g. disappearing charged tacks) and new strategies (e.g. combined analysis of different experiments). The goals of DMI-2019 program was to bring experts together, discuss and make these further new steps towards DM exploration and identification, making progress on the following objectives in particular:

- discuss and work on the classification and building of sets of Minimal Consistent DM (MCDM) models for a consistent characterisation of DM searches
- start the implementation of missing models into DM tools such as micrOMEGAs and/or MadDM

- adapt and improve the tools designed for comprehensive scans of parameter space to MCDM
- assess the potential of all collider signatures, including the less explored signatures from mono-Z,W,H production, vector-boson fusion with missing transverse momentum, soft-lepton , displaced vertices and disappearing tracks, the latter also characterise non-WIMP scenarios
- develop strategies for comparing/mapping the multidimensional MCDM parameter space for collider and DD/ID searches
- as a result of the discussions and development above – develop mapping between models (theory space) and various DM signals at collider and non-collider experiments (signature space); this development would be a great step towards decoding the nature of DM in case some signals are observed.

Scientific Highlights of DMI-2019

In the first week general aspects of DM theory – WIMP models and beyond WIMP paradigm were discussed, together with experimental aspects of DM searches at the LHC, including new signatures, long-lived particles and new ideas for optimisation of signal significance. In particular, we have the following talks and discussions in the first week:

- "Dark Matter Theory (WIMP models)"[topical talk], Giacomo Cacciapaglia (Lyon)
- "DM searches at the LHC - challenges and innovations"[topical talk], Rachel Rosten (Universitat Autònoma de Barcelona, Atlas)
- "The Inert Doublet Model at current and future colliders" Tania Robens, (Institute Ruder Boskovic)
- "Dark Matter Phenomenology"[topical talk], Dr Martin Bauer (Durham University)
- "Prospects for discovery and spin discrimination of Higgs portal DM at future colliders", Pyungwon Ko (Korea Institute for Advanced Study)
- "DM Theory (beyond WIMP models)"[topical talk], Laura Covi (Universität Göttingen)
- "Boosted Dark Matter and the signal probes in Neutrino and Direct Detection Experiments" , Seodong Shin (University of Chicago / Yonsei University)
- "Simulating Structure Formation beyond CDM"[topical talk], Mark Vogelsberger (MIT)
- "Searching in 2-D mass space for final states with 2 invisible particles", Georgios Anagnostou (NCSR Demokritos, CMS)

During the second week participants have discussed various aspects of Indirect DM detection, DM signatures from composite Higgs models, problems of sub-GeV DM detection, reinterpretation of the LHC results, various DM tools and DM freeze-out scenarios:

- "Indirect DM detection"[topical talk], Martin Winkler[topical talk] (Stockholm University)
- "Scalar composite dark matter in non-minimal models" Maria Ramos (University of Porto)
- "Detection of sub-GeV Dark Matter" Rouven Essig[topical talk] (Stony Brook University)
- "Axions", Laura Covi (Universität Göttingen)
- "DM Tools", Pat Scott[topical talk] (Imperial College)
- "WIMPyDD: code for dark matter direct detection", Gaurav Tomar (Sogang University)
- "Black Holes as a Dark Matter", Pedro Schwaller (Mainz University)
- "Conversion-driven freeze-out: Dark matter genesis beyond the WIMP paradigm"[topical talk] , Jan Heisig (Université catholique de Louvain)
- "DM (re)interpretation of LHC searches", Sabine Kraml (LPSC Grenoble)
- Jose Zurita, Andreas Goudelis, KC Kong discussed gave summary talks on various aspects of DM discussed at DMI-2019.

During workshop several of these talks were presented by junior participants which do not hold a permanent position. For the presentations we asked the audience not to bring their laptops. We have also encouraged speakers to give preferably black board talks. This worked very well and had a positive effect on fostering discussions during and after the talks.

The discussions during the workshop centred around important questions on exploration and decoding of DM, for example:

- How the generic classification of DM models should be done?
- What are new DM signatures which are missed so far?
- What are new features from DM tools are required?
- What are new strategies for detection of sub-GeV DM?
- Is there any room for DM from black holes?
- How important the approach with consistent minimal DM models versus just minimal DM models?

This workshop was a great example of the real workshop, where participants start new and to reinforce existing collaborations. That is why participants liked is so much, as one can see from the workshop evaluation score. MITP has a perfect environment to start new projects, to propel existing ones, and to finish publications. We provide here the list of only few examples of such projects:

- classification of minimal consistent DM models (see Fig.1)
- new signatures and new LHC production processes for inert two Higgs doublet models(Fig.2)
- exploration of long lived particles (LLP) and disappearing charged tracks at Hi luminosity LHC and future colliders (Fig.3)
- phenomenology of DM from composite Higgs models
- neural net application for missing transverse momentum plus top quarks in final state from composute Higgs models
- exploration of DM models with vector-like leptons
- ruling out the Minimal model with Universal Extra Dimensions (MUED) from collider and non-collider search combination (Fig.4)

The great setup of the centre and the smooth organization of the local staff provided a very nice and productive atmosphere. The workshop will certainly influence the further development of the field. We are confident that many publications will emerge from the discussions and initiated collaborations. Many participants wanted to continue this workshop in the future. Therefore we are planning to apply for DMI-2021 Program.

Acknowledgements

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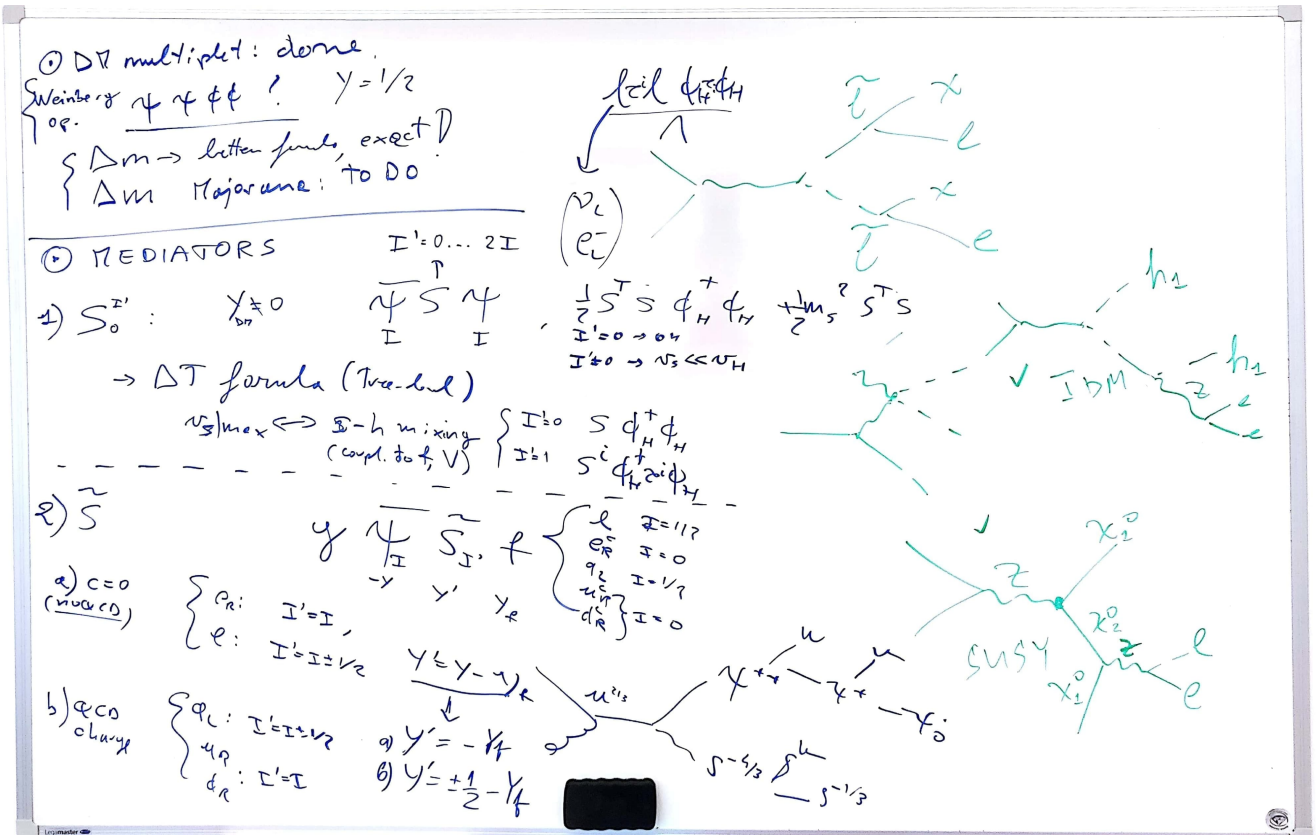

FIG. 1: Development of the classification of minimal consistent DM models with Giacomo Cacciapaglia

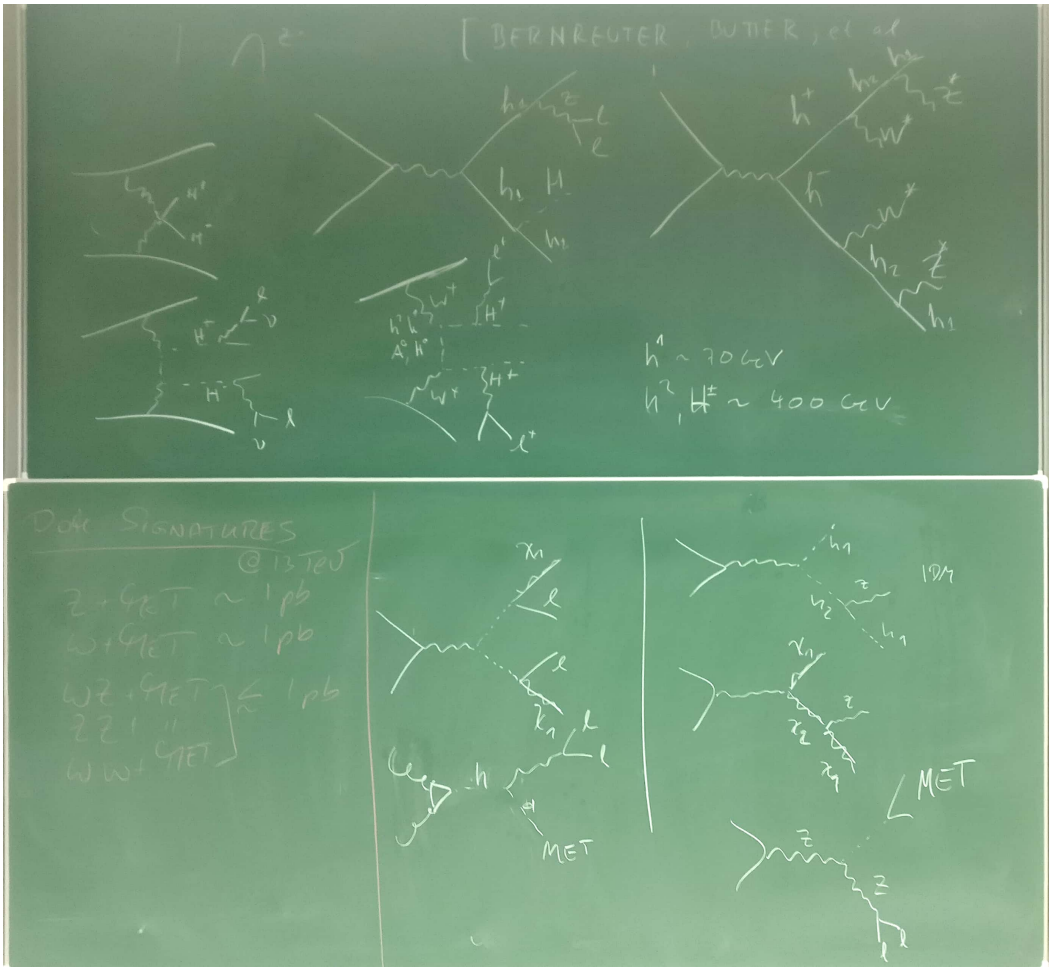

FIG. 2: Study of new signatures from I2HDM model

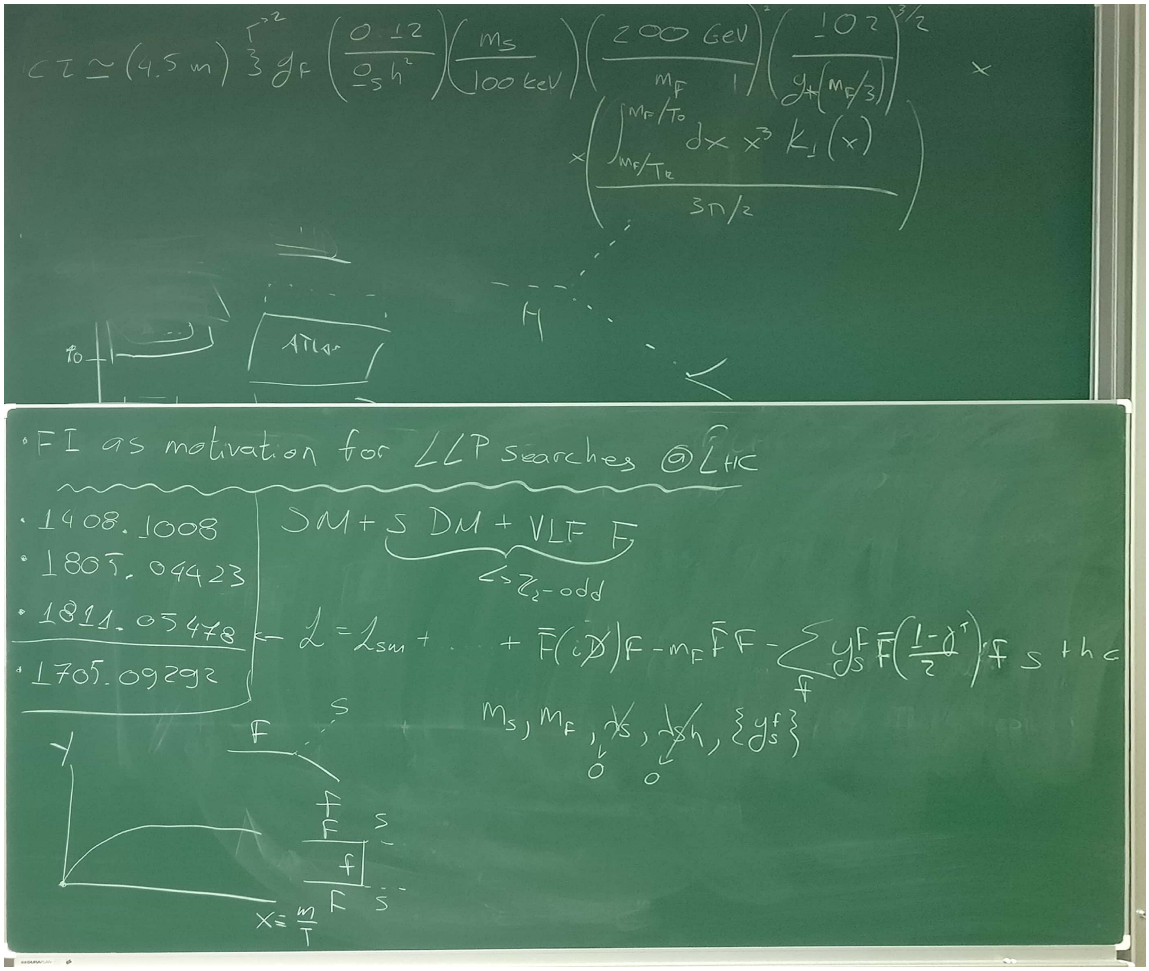

FIG. 3: Study of LLP signatures with Jose Zurita

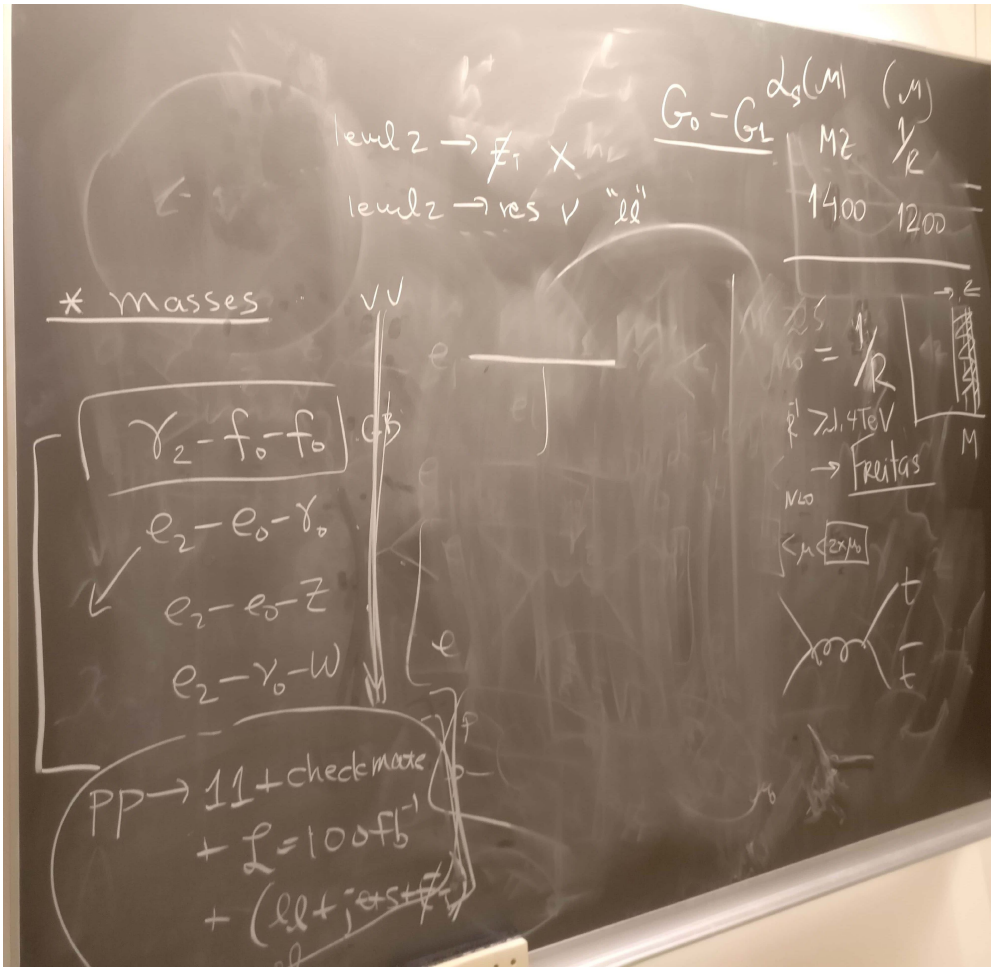

FIG. 4: Study of MUED with Kc Kong and Genevieve Belanger