LABORATOIRE DE PHYSIQUE THEORIQUE ET HAUTES ENERGIES

Prof. Benjamin Fuks
LPTHE - CNRS - UPMC
Box 126, T13-14 fourth floor
4 place Jussieu
F-75252 Paris Cedex 05
France

Tel: + 33 1 44 27 63 38
E-mail: fuks@lpthe.jussieu.fr

Proposal for a Ph.D. thesis to be started in October 2017 at the LPTHE
Dark matter at colliders - from phenomenology to the development of novel analysis techniques

Context - simplified dark matter models for dark matter LHC searches

Many models including a particle that is a viable candidate for dark matter also feature TeV scale states mediating the interactions of the visible sector of the Standard Model with dark matter. After imposing compatibility with cosmological and astrophysical constraints, the remaining part of these model parameter spaces can in general be complementarily constrained by a varied selection of searches for dark matter at the LHC. This includes, on the one hand, the so-called mono-X searches where one targets final state signatures related to an invisibly decaying mediator produced in association with a single hard Standard Model object X, and, on the other hand, dark-matter-independent probes where the mediator decays back into a pair of Standard Model particles.

The models that have gathered the most attention so far are simplified scenarios in which the Standard Model is minimally extended in terms of new particles and interactions. For instance, the so-called *s-channel dark matter models* feature a mediator that can be produced either by gluon fusion or by quark-antiquark annihilation in the s-channel, and that then decays into a pair of dark matter particles.

Most simplified models however generally violate key principles like electroweak gauge invariance, and are put into troubles when one tries to map them onto ultraviolet-complete new physics scenarios. This occurs for instance in a popular classes of s-channel dark matter models where the mediator is a pseudoscalar and where it couples to the Standard Model quarks and leptons via a non-renormalizable higher-dimensional coupling proportional to the corresponding fermion mass.

From minimal to next-to-minimal and ultraviolet complete models

In this Ph.D. thesis, we propose to generalize previous works based on simplified models. One of the first steps will be to construct simple ultraviolet-complete setups where the theoretical framework is kept as simple as possible, but where electroweak gauge-invariance is imposed as a first principle. The simplest example, that is a good starting point, is inspired by the Two-Higgs-Doublet-Model (2HDM) in which the Standard Model is supplemented by a second Higgs doublet, but in a context where a dark matter candidate is also added to the theory. Other scenarios, possibly featuring more than one option for a dark matter candidate and much more complicated in terms of parameters and particle content (like in non-minimal supersymmetric models with an extended gauge symmetry), will then be investigated. This will however require the design of efficient techniques for probing high-dimensional parameter space in accounting for various constraints, based, *e.g.* on multinest or similar techniques.

In order to understand which regions of the parameter space are viable and how to further probe them with the expected amount of data that will be collected in the next decades, we aim to perform a phenomenological analysis accounting for the current experimental status, *i.e.* when all existing experimental constraints originating from colliders, cosmology and astrophysics are included simultaneously. On the collider side, we will first reinterpret searches for dark matter in numerous modes targeting signatures with and without the missing transverse energy assumed to be connected to the production of one or more than one dark matter particles, and secondly combine the results to assess the viability of the different regions of the parameter space. On the cosmological side, we will focus on relic density measurement and direct and indirect dark matter search results at observatories both on Earth and in space. Our approach is expected to contrast with previous phenomenological analyses where only the dark matter side was cornered, although mediator particles can consist of very efficient handles to new phenomena.

This work will be embedded into an international effort that is about to start in the next few months within a Les Houches working group and the CERN Dark Matter Forum, and whose goal is to design new benchmark dark matter scenarios to be used in future LHC searches for dark matter.

Improving dark matter searches with big data techniques

We will investigate which regions of the parameter space remain viable today, what are the main features of these regions and how to get a better sensitivity to them in the future. Considering the collider prospects, we will rely both on improving the currently followed (cut-based and distribution-shape-based) analysis approaches and on the possible usage of novel techniques. The latter will be developed from the idea of combining theoretical particle physics calculations of matrix elements with methods that have been proved useful in the context of big data analyses.

The idea that will be investigated in the thesis originates from the matrix element method, a technique that was initially introduced to assign probabilities to competing hypotheses for a given sample of collider events. Inspired by classification methods from the big data community, we aim to make use of matrix elements to be able to tag, in a probabilistic manner and beyond the sole signal or background information, the physical origin behind an event sample.

The improvement of potential future searches in terms of sensitivity will be evaluated and if promising, the techniques will be applied to other new physics context like supersymmetric models or vector-like quark models, and implemented in computer programs widely-used by the high-energy physics community.

Skills and methods

With this project, the candidate is expected to develop a deep knowledge in dark matter models and how to probe dark matter both at colliders and in cosmology. This topic is today one of the cornerstone of the current experimental program and is gathering a lot of interests within our community. In addition, skills in learning from data techniques will be developed.

Achieving the predefined goals moreover requires to get a strong expertise in the usage of various tools that range from collider event simulators to dark matter observable calculators. State-of-the-art predictions include higher-order corrections in QCD, which is a topic that will also be addressed during the thesis. In particular, this leads to the problematics of the reliability of the theoretical predictions and the treatment of the errors when the reinterpretation of LHC results is at stake. A particular attention has to be paid to this issue that is currently overlooked in most LHC result reinterpretation studies. Solutions will be searched for and proposed, so that reliable estimates, or at least estimates with a theory error attached to them, could be derived within the context of the existing tools.