LABORATOIRE DE PHYSIQUE THEORIQUE ET HAUTES ENERGIES

Precision predictions for present and future colliders

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Context and objectives

The Standard Model of particle physics stands as a highly successful theory, accurately predicting experimental outcomes. However, despite its achievements, the current experimental status exposes certain conceptual and practical limitations, including the absence of a candidate for dark matter, the hierarchy problem, and an incomplete description of neutrino masses and mixings. Therefore, acknowledged as an effective theory, the Standard Model is believed to derive from a more fundamental theory yet to be discovered, with the anticipation of encountering new phenomena at scales currently being explored experimentally. A promising avenue in the search for these new physics phenomena involves probes that compare precision theoretical predictions to experimental measurements of the highest accuracy. Currently, this entails utilising matrix elements computed to at least the next-to-leading-order accuracy in perturbative quantum chromodynamics (QCD), possibly incorporating parton showers as achieved by state-of-the-art Monte Carlo simulations [1–3]. **This thesis proposal aims to leverage these tools to extract key components for predictions computed at unprecedented level of precision, and this in the context of any particle physics theory and for any scattering process relevant to present and future colliders**.

Project details and work plan

Precision predictions at colliders should encompass, among other aspects, the resummation of logarithms that become prominent near the production threshold. However, although these logarithms manifest in the partonic cross-section, they generally do not result in divergences in physical cross sections due to convolution with steeply falling parton distribution functions. Their proper treatment, referred to as threshold resummation [4, 5], can thus be seen as an attempt to quantify the effects of a well-defined set of quantum corrections to all orders. These effects can be substantial, even far from the hadronic threshold, and they lead to a reduction of theoretical uncertainties in predictions (see, e.g., [6]). Therefore, the threshold resummation procedure offers a systematic approach to improve predictions.

In recent years, we have developed at the LPTHE a numerical code to provide resummed predictions for four-top production at hadron colliders. The choice to focus on this process stems from the fact that, among all the measurements in progress during LHC Run 3, those related to four-top production will, for the first time, be performed with sufficient precision for comparison with theoretical predictions. Hence, it is crucial to refine the latter. However, the existing code needs improvement, particularly concerning its numerical convergence, which currently lacks scalability and, as a result, impedes the performance of several important checks.

Undertaking this task will provide the doctoral candidate with an opportunity to familiarise themselves with perturbative QCD, comprehend the concepts underlying threshold resummation, and become proficient in numerical techniques. Subsequently, they will acquire the skills necessary to design an innovative and versatile plugin for the event generator MG5aMC [1–3], enabling the generation of resummed predictions for arbitrary processes in any model. This expansion will broaden the scope of the Resummino code developed within our institute over several years [7, 8], paving the way for new phenomenological explorations both within the Standard Model and beyond. Our focus will centre on well-motivated and extensively studied models, including those featuring strong dynamics at a high-energy scale, such as QCD, supersymmetry, or dark matter. These calculations will facilitate a re-assessment of existing limits, updating them in light of more precise theoretical predictions.

Expertise and skills to be developed

In the course of this thesis project, the candidate is anticipated to build a comprehensive understanding of high-energy physics, from both theoretical and phenomenological aspects, while developing proficient analytical and computing skills. Achieving the thesis objectives will provide the doctoral candidate with expertise valued by research groups worldwide, offering potential opportunities for a career in academia. Additionally, the technical competencies in programming and computing, coupled with a problem-solving mindset inherent in high-energy particle physics, are versatile skills applicable across various scientific domains, including the private sector. This diverse skill set will enable the candidate to explore various career paths upon completion of the thesis.

Application

Candidates should send by email to fuks@lpthe.jussieu.fr and huasheng.shao@lpthe.jussieu.fr their CV, a transcript of their academic records (from bachelor 3 to master) and a motivation letter. They should also arrange for one or two letters of recommendation to be sent to the same addresses, by scientists familiar with their studies and academic records.

References

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