Master 2: *International Centre for Fundamental Physics*

INTERNSHIP PROPOSAL

Laboratory name: Laboratoire de Physique des 2 infinis Irène Joliot-Curie – IJCLab
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Internship location: IJCLab, Orsay

Thesis possibility after internship: YES
Funding: NO If YES, which type of funding:

Perturbative QCD & Quarkonia: radiative corrections

With the advent of the high-luminosity program at the LHC and future experiments, the FCC (Future Circular Collider) at CERN and the EIC (Electron-Ion Collider) at Brookhaven, it will be essential to provide precise and reliable theory predictions for various number of processes. These experiments will allow us to measure the fundamental interactions at an unprecedented level of precision.

Charmonium and bottomonium production, bound states consisting of a heavy quark and its anti-quark, cc and bb pairs respectively, provide interesting opportunities to study the interplay between the perturbative and non-perturbative regimes of Quantum Chromodynamics (QCD) which is at the heart of formation of hadrons such as the proton.

In order to provide reliable cross-section predictions for collider processes, it is essential to compute perturbative QCD corrections as an expansion of the strong coupling constant. These perturbative corrections can be computed via means of Feynman diagrams. The Born cross-section is represented by Leading Order (LO) Feynman diagrams, while at Next-To-Leading Order (NLO), one has both virtual (loop integrals) and real emission corrections (phase-space integrals). For many collider processes, NLO calculation is currently routinely used for cross-section predictions, in some cases, Next-To-Next-To-Leading Order (NNLO) and even N3LO calculations are available.

In the case of quarkonium production, the strong coupling constant is not so small, hence, radiative corrections turn out to be crucial. In some cases NLO corrections are quite large and exceed the Leading Order (LO) contribution. This can result into unphysical negative cross-sections. This has been a long-standing issue in the community, which has only been recently understood and resolved for pseudo-scalar quarkonium production [1] and vector quarkonium production [2]. For phenomenology, it will be essential to move to NNLO accuracy. This presents a tough challenge primarily due to the calculation of the double-virtual two-loop master integrals [3, 4].

The goal of the internship will be to understand concepts of NLO calculational techniques, renormalisation and factorisation in the framework of quarkonium production. The internship might be followed, subject to funding, by a PhD starting in fall 2024.

References:

[1] Curing the unphysical behaviour of NLO quarkonium production at the LHC and its relevance to constrain the gluon PDF at low scales
J.P. Lansberg, M.A. Ozcelik
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[2] Revisiting NLO QCD corrections to total inclusive J/ψ and ϒ photoproduction cross sections in lepton-proton collisions
A. Colpani-Serri, Y. Feng, C. Flore, J.P. Lansberg, M.A. Ozcelik, H.S. Shao, Y. Yedelkina
Phys.Lett.B 835 (2022) 137556

[3] Two-loop master integrals for pseudo-scalar quarkonium and leptonium production and decay
S. Abreu, M. Becchetti, C. Duhr, M.A. Ozcelik
JHEP 09 (2022) 194

[4] Two-loop form factors for pseudo-scalar quarkonium production and decay
S. Abreu, M. Becchetti, C. Duhr, M.A. Ozcelik
JHEP 02 (2023) 250

Keywords: pQCD, radiative corrections, quarkonium

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics:	NO	**Soft Matter and Biological Physics:**	NO
Quantum Physics:	NO	**Theoretical Physics:**	YES