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Research Statement

Starting with my Master thesis and then during my Ph.D., my research focused on phenomenological aspects of high energy physics (HEP) and in particular on Quantum Chromodynamics (QCD). I am involved in developing methods and computational tools to provide high precision theoretical predictions in HEP.
My research covered mainly the topics of PDF fits and theory predictions in deep-inelastic-scattering (DIS): on one hand I worked as a member of the NNPDF collaboration and as a developer of the NNPDF code to include Quantum Electrodynamics (QED) effects in PDF fits. On the other hand, I worked to develope a new scheme designed to increase the precision of DIS predictions.
I'm interested also in computational problems like machine learning but also in more theoretical ones related to phenomenology in HEP like resummation or fixed order calculations.

Construction of an N^{3}LO DIS scheme

During my Master Thesis I worked on the development of a so-called variable flavor number scheme (VFNS) for DIS predictions. This construction, unlike the ones that are available in the literature, takes into account the fact that the heavy quark PDF is generated perturbatively and therefore must be accounted as $\mathcal{O}(\alpha_s)$. We developed it up to next-to-next-to-leading order (NNLO) in perturbation theory, where all the needed ingredients are known. Moreover, we extended it to N^{3}LO using approximate results for the unknown terms. Even though I was also involved in the construction of the scheme, the bulk of the work I did was to construct an approximation of the unknown terms of the N^{3}LO partonic cross section for DIS (the so-called coefficient functions) by combining some known limits.
As a result of this work two codes were written to produce the results. Both of them are now public. The first one, `Adani`, is a `C++` code which computes both the approximation of the unknown terms and the exact value of the known ones for the massive coefficient functions at N^{3}LO. The second one, `DIS_TP`, is a `Python` code whose aim is to combine the different ingredients (like the output of the first code) to actually compute the theory predictions with our scheme. Regarding this work, a publication is in preparation.

PDF fit

During my Ph.D. my main project has been the inclusion of QED effects in PDF fits. The goal of the work was to produce the QED fit of the NNPDF4.0 series that had to replace the previous QED fit from NNPDF, i.e. the NNPDF3.1QED PDF set. In order to achieve it, different things had to be implemented in different codes.
The first step is the implementation of QED corrections to the PDFs evolution equations, i.e. the DGLAP equations. They have been implemented in the public code `EKO`. Before I joined the NNPDF collaboration, `EKO` could handle only the pure QCD evolution, but I extended it to consider also QED corrections. The second step has been the extension of the NNPDF fitting code to consider also a photon PDF. This is obtained through the LuxQED method [1, 2]: with this approach the

photon PDF is linked through a perturbative calculation to the quark and gluon PDFs. In order to implement this method in the fitting framework, I interfaced the `FiatLux` code, a public code written in `C++` that implements the LuxQED formula, with the NNPDF code. A publication for this work is in preparation and preliminary results were presented in Ref. [3].
I was also involved in the approximate N^{3}LO PDFs determination by NNPDF. The aim of this project is to include the N^{3}LO corrections in DIS predictions and in PDFs evolution, using the exact results when available and approximate ones for the missing terms. I was mainly involved in the implementation of the approximation for the N^{3}LO massive DIS coefficient functions, that I developed during my Master thesis, in the NNPDF code. Also for this work a pubblication is in preparation.

Side projects

During my Ph.D. I also had the opportunity to work on different side projects.
One of these was the use of resummation results to approximate the missing higher orders for processes with colorless final states, like Higgs production and Drell-Yan: given that the resummed expressions contains to all-orders the informations on the various kinematic limits that appear in the fixed order calculations, it is possible to combine such limits to approximate the unknown higher order terms. This has been done for Higgs production, yelding resonable predictions, while for Drell-Yan it is still a work in progress. This work was presented in Ref. [4]. In this context I had the chance to deepen my understanding of resummation, and in particular threshold and small-p_T resummations.

Other interests

As a member of the NNPDF collaboration, I have great interest in computational problems like machine learning and neural networks. Even though I didn't write directly the neural network fitting code (as mentioned before, I extended it to consider also the photon PDF) I have interest in this field, that is of great importance for the power of such tool and for spread that it had in the recent years also in accademia.
Despite I spent the most of my Ph.D. on the PDF fits, I have also great interests in more theoretical topics of phenomenology in HEP, like resummation or fixed order calculation, that are needed in order to reach the percent accuracy in theoretical predictions.

References

[1] Aneesh Manohar, Paolo Nason, Gavin P. Salam, and Giulia Zanderighi. How bright is the proton? A precise determination of the photon parton distribution function. *Phys. Rev. Lett.*, 117(24):242002, 2016.

[2] Aneesh V. Manohar, Paolo Nason, Gavin P. Salam, and Giulia Zanderighi. The Photon Content of the Proton. *JHEP*, 12:046, 2017.

[3] Niccolò Laurenti. Inclusion of QED corrections in PDFs fits. *Nuclear and Particle Physics Proceedings*, 2023.

[4] Niccolò Laurenti, Tanjona R. Rabemananjara, and Roy Stegeman. Approximating missing higher-orders in transverse momentum distributions using resummations, 2022.