Towards parton distributions with fitted charm

P. Groth-Merrild[a,1,*], L. Rottoli[b,*]

[a]*The Higgs Centre for Theoretical Physics, University of Edinburgh, JCMB, KB, Mayfield Rd, Edinburgh, EH9 3JZ, Scotland*
[b]*Rudolf Peierls Centre for Theoretical Physics, University of Oxford, 1 Keble Road, Oxford OX1 3NP, United Kingdom*

Abstract

Modern parton distribution function fits require an accurate treatment of heavy quark mass effects. In this contribution, we discuss how the FONLL general-mass variable flavour number scheme can be extended to allow for the possibility of a fitted charm PDF. We present a first estimate of the impact of a fitted charm contribution in the FONLL structure functions, and we discuss the development towards including a fitted charm PDF in the NNPDF framework.

Keywords: QCD, NNPDF, NNPDF3.0, Parton Distribution Functions, Intrinsic Charm, Fitted Charm, DIS

1. Introduction

One of the main sources of systematic errors in hadron colliders such as LHC is the uncertainty that affects the parton distribution functions (PDFs), which limit the accuracy of our knowledge of proton structure. Given the increasing precision of experimental data, it is necessary to have a reliable estimate of the PDF uncertainties.

Currently, three major collaborations provide global PDF sets. Their most recent releases are NNPDF3.0 [1], MMHT14 [2] and CT14 [3]. A detailed comparison was performed in [4, 5] and shows a reduced discrepancy between these sets with respect to previous releases.

A potential source for the differences in current PDF fits is the treatment of heavy quarks. Modern PDF sets include heavy quark effects by resorting to general-mass variable flavour numbers (GM-VFN) schemes. In current PDF fits the GM-VFN schemes are used under the assumption that the heavy quark is generated perturbatively above the threshold. Whereas this can be a reasonable assumption for top and bottom, one might question whether it is possible to rule out the existence of

non-vanishing charm PDF below threshold, sometimes called intrinsic charm (IC). Moreover, even if the charm PDF is entirely perturbative, and therefore vanishes below the threshold, the computation of the massive corrections in any GM-VFN scheme shows a substantial dependence on the charm mass m_c due to the large value of $\alpha_s(m_c)$. The inclusion of a fitted charm PDF provides a solution for both these problems. In this contribution, we will present some preliminary results showing the structure functions for neutral current deep inelastic scattering (DIS) obtained using an extension of the FONLL GM-VFN scheme [6, 7] which includes a fitted charm contribution.

2. NNPDF3.0

NNPDF3.0 is the latest PDF set released by the NNPDF collaboration. The PDF set features new data, improved methodology, and a new analysis code.

Besides the data included in previous releases, several new data are added to the dataset. These include HERA-II deep-inelastic inclusive cross-sections from ZEUS and H1, and the HERA combined charmed production cross-section data. NNPDF3.0 moreover includes a large amount of new data from LHC such as jet production from CMS and LHCb, top quark pair production total cross section from ATLAS and CMS, and

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*On behalf of the NNPDF collaboration: R. D. Ball, V. Bertone, S. Carrazza, L. Del Debbio, S. Forte, P. Groth-Merrild, A. Guffanti, N. P. Hartland, Z. Kassabov, J. I. Latorre, J. Rojo, L. Rottoli, M. Ubiali.

[1]Speaker.

$W + c$ data from CMS, which provide important information about strange PDFs.

NNPDF3.0 features many improvements in the fitting methodology. In order to include and process the new data, the fitting code has been completely rewritten in C++ optimising the computational intensive hadronic calculations used in the fitting methodology. Additionally, the minimisation of the genetic algorithm uses a new mutation approach, both improving the fitting speed and the fitted results. NNPDF3.0 also presents an extended kinematic range for positivity observables, thus obtaining better constraints. Finally, NNPDF3.0 introduces an improved form of cross-validation, which prevents over-learning in the neural networks while also reducing the chance of under-learning due to a premature stopping of the fit.

The benchmarking of fitting methodology becomes particularly important due to the increase in the experimental data included in NNPDF3.0 and the increased precision the resulting PDFs achieve. As data becomes more abundant, covering a wider kinematic range with higher precision, it becomes essential to eliminate any uncertainties due to the methodology, such that the PDFs reflect theoretical and experimental uncertainties exclusively.

NNPDF3.0 uses closure testing for methodological validation. The idea behind closure tests is rather simple: take an assumed form of the PDFs, a given theoretical model (pQCD), and then generate a set of global pseudo-data with realistic statistical properties. If the fitting methodology is performed using the pseudo-data, this should reproduce the assumed form of the underlying PDF, within the correct uncertainties. Closure testing allows one to assess directly the methodology; once validated, the methodology can be used in real fits.

All the NNPDF3.0 fits are available on LHAPDF, with results based on LO, NLO and NNLO QCD theory for various values of α_s.

3. Fitted charm

There are two main motivations for a fitted charm PDF. The first is related to the current treatment of the heavy quark PDFs in global fits. In existing published parton fits the heavy quark PDF is generated dynamically above the threshold. Whereas the bottom and top quarks are sufficiently heavy and thus can be treated entirely perturbatively, the charm sits at the border between perturbative and non-perturbative behaviour and in principle one should account for a non-perturbative contribution to the charm PDF close to the threshold. The second motivation is that even if most of the charm

PDF is of perturbative origin, it is sensitively dependent on the choice of the scale at which PDFs are parameterised. The inclusion of a fitted charm PDF would therefore ensure unbiased results since the ignorance about the vanishing scale would be absorbed by the PDF.

Over the years, several non-perturbative models of intrinsic charm have been proposed [8–10] (see e.g. [11] for a recent review). Currently, the general belief is that the intrinsic contribution is of the order of 1% or less and thus can be ignored in the majority of collider applications.. Charm present at the initial scale may have however some very distinct signatures in LHC processes, such as direct photon in association with charm jets [12] or open charm production [13, 14].

In a recent study [15] the CTEQ collaboration performed a global fit that incorporates different IC models into the charm PDF. In future releases, NNPDF will include a fitted charm distribution that will however not depend on any IC model, thus ensuring an unbiased result.

In the NNPDF framework, heavy quark effects are taken into account using the FONLL GM-VFN scheme. The scheme provides a consistent matching between the fixed order (or massive) calculation, in which the heavy quark is treated as massive, and the resummed (or massless) calculation, where the heavy quark is treated as massless and the collinear divergences are factorised in the PDFs. In [7] three variants of the FONLL scheme were proposed. Each variant is defined by the order of the resummed calculation and the number of terms in its expansion replaced by their massive counterparts. In the FONLL-A scheme one considers the resummed calculation at NLO with one term replaced; in the FONLL-B scheme the resummed calculation at NLO and two terms replaced; in the FONLL-C the resummed calculation at NNLO and two terms replaced.

In order to include a fitted charm, the formulation of FONLL as formulated in [7] must be modified by extra contributions, which are formally subleading in the case the charm PDF vanishes below the threshold. While the old implementation was equivalent to S-ACOT [16, 17], the new one is equivalent to ACOT [18]. In particular, it is necessary to include LO and NLO diagrams with a massive quark in the initial state to take into account the possibility of an initial state charm. Such diagrams incorporate the mass effects with incoming heavy quark lines. These corrections were first computed in [19] and then extended to general masses and couplings in [20], which also corrected some errors present in [19]. We have confirmed that the results of [20] properly correct the original calculation of [19].