Electroweak parton distributions and fragmentations at ultrahigh energies

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(Dated: August 30, 2020)

At energy scales well above the electroweak (EW) scale ($M_{W,Z}$), all Standard Model (SM) particles are essentially massless and should be viewed as EW partons, collinearly radiated off the high-energy leptonic beams. In a recent publication [1], we studied the physics cases at a future high energy muon collider and argued that it is appropriate to adopt the EW partonic picture for inclusive processes, a notion thus far only reserved for hadron colliders. We set up the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) formalism and calculated the EW parton luminosities. We presented cross sections for some important SM processes for a proposed muon collider. Yet, there are theoretical and practical issues that we must continue to tackle.

Matching. When the collision energy is far above the threshold ($\hat{s} \gg 4m^2$), the EW parton distribution functions (PDF) formalism is appropriate to predict the (semi-)inclusive cross sections. However, when the energy is right above threshold ($\hat{s} \geq 4m^2$), the factorization picture suffers from large corrections due to the threshold constraint of massive particles. Instead, we expect the diagrammatic calculations at a fixed order (FO) is valid in this regime, analogous to the fixed-flavor-number (FFN) scheme to treat the heavy-flavor production. The transition from the low- to high-energy regimes requires a systematical matching between the FO diagrammatic calculation and the PDF resummation.

Fragmentation. We have not taken into account the effects of the final-state radiation (FSR) in Ref. [1]. At very high energy, the dominant FSR features can be described by the "fragmentation functions" [2, 3], which effectively resums the large logarithms due to FSR collinear enhancement. This FSR resummation can be performed in terms of parton showering algorithms [2], which evolves according to the Sudakov form factor. Around the threshold region, a similar matching to the FO calculation is also needed to capture the massive particle effects.

Hadronic colliders. In Ref. [1], we took $\mu^+\mu^-$ as an example of the leptonic collisions to demonstrate the EW PDF formalism. It is straightforward to apply this formalism to the high-energy hadronic colliders. The complication lies that we need to run the QCD as well as the EW gauge groups simultaneously, which involves 60 PDFs in the isospin ($\mathbf{T}$) and charge-parity (CP) basis [4]. The photon PDF of a proton at a low scale is more subtle [5]. Furthermore, different from the leptonic case, we can have a significant contribution to the EW PDFs from the proton structure functions even at the starting scale of the evolution ($\mu \sim M_{W,Z}$) [6]. We would like to see the implications of the EW PDFs to phenomenological

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predictions at the FCC-hh collider.

[1] T. Han, Y. Ma, and K. Xie, High Energy Leptonic Collisions and Electroweak Parton Distribution Functions, (2020), arXiv:2007.14300 [hep-ph].

[2] J. Chen, T. Han, and B. Tweedie, Electroweak Splitting Functions and High Energy Showering, JHEP **11**, 093, arXiv:1611.00788 [hep-ph].

[3] C. W. Bauer, D. Provasoli, and B. R. Webber, Standard Model Fragmentation Functions at Very High Energies, JHEP **11**, 030, arXiv:1806.10157 [hep-ph].

[4] C. W. Bauer and B. R. Webber, Polarization Effects in Standard Model Parton Distributions at Very High Energies, JHEP **03**, 013, arXiv:1808.08831 [hep-ph].

[5] A. Manohar, P. Nason, G. P. Salam, and G. Zanderighi, How bright is the proton? A precise determination of the photon parton distribution function, Phys. Rev. Lett. **117**, 242002 (2016), arXiv:1607.04266 [hep-ph].

[6] B. Fornal, A. V. Manohar, and W. J. Waalewijn, Electroweak Gauge Boson Parton Distribution Functions, JHEP **05**, 106, arXiv:1803.06347 [hep-ph].