LHeC and FCC-he: Dark Matter (EF 10)

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I. INTRODUCTION

The LHC was originally envisioned as the ultimate machine to search for physics beyond the Standard Model at the TeV scale. Since electrons and quarks share only electroweak interactions, an electron-proton collider could allow to measure the same phenomena in a different environment with generally higher precision. It could add complementary search channels or lead to the discovery of a weak signal. The possibility of undiscovered New Physics (NP) below the TeV scale could thus be also addressed by the LHeC, to be operated when the LHC will be in its high luminosity phase, and its potential higher energy successor, the FCC-eh.

A most notable and distinctive feature of electron-proton collisions compared to pp collisions is the absence of color exchange between the electron and proton beams, which leads to a reduced level of background from SM processes and negligible pileup. The LHeC and FCC-eh colliders will thus provide new opportunities for tests of Beyond the Standard Model physics, with a clean collision environment allowing for detailed and precision studies of many scenarios. Furthermore, the vastly improved parton distribution functions obtained at these colliders will considerably reduce the theoretical uncertainties of BSM signals and SM backgrounds.

II. AIM: DARK MATTER

Despite the null results from the LHC, dark matter remains a strong case for BSM physics. Scenarii exist, where ep colliders provide complementary probes to the LHC and possible lepton colliders.

- **Supersymmetry:** SUSY in general provides a theoretical framework with natural dark matter candidates, for instance the neutralino. When the electroweakinos have a compressed mass spectrum, with mass differences of less than 50 GeV, LHC searches are not effective. The ep colliders provides this scenario can be tested for prompt [1, 2] and displaced decays [3] of the heavier electroweakinos.

- **Feebly interacting particles:** BSM extensions addressing the Dark Matter problem often introduce an entire dark sector that comprises new forces and several particle species. In this scenario DM may interact with the SM via the vector, scalar, pseudoscalar, or neutrino portal, which mediate a very feeble interaction strength between dark sector and SM particles. Examples are the right-handed singled neutrino [4–7], left-right symmetric models [8, 9], triplet neutrinos [10, 11], and axion-like particles [12].

- **Exotic Higgs decays:** The Higgs boson provides a natural portal for many DM models. Dark sectors with additional particles often feature exotic decays of the Higgs boson with small branching ratio. If these are QCD-like, or show up via missing energy at the LHC, their detection in ep is more feasible [13].

- **Dark photon:** Dark photons in the mass below one GeV can be studied at the LHeC and FCC-he via their displaced decays into SM fermions [14] and via precision measurements of standard observables [15]. Ref. [14] shows that the LHeC and FCC-he can test a domain that is complementary to other present and planned experiments. Further opportunities are studies of invisible dark photon decays, and their decays in the upstream hadron detectors.

III. TECHNICAL SUPPORT AND IMPLEMENTATION

Realistic predictions of the exploration by LHeC and FCC-eh of BSM phenomena require a good understanding of theoretical and experimental systematic uncertainties. For high-Q^2 processes, parton-level simulations must account for the proton remnants in the highly asymmetric beam configurations (60 GeV e x 7 TeV p or 60 GeV e x 50 TeV p). Also, the detector must allow for good reconstruction of particles, such as b-jets, in the forward region. Supporting documentation on software relevant for e-p analyses can be found in [16].

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