

Letter of Interest: EW effects in very high-energy phenomena

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1 Introduction

Phenomena that take place at multi-TeV scales — high-energy elementary particle scattering or the annihilation/decay of ultra heavy states such as dark matter particles — can give rise to relativistic, final states that are naturally accompanied by additional radiation, that in turn leads to particle showers and final states with large particle multiplicities. In the the Standard Model, the effects of QCD and QED radiation are well understood and treated at various level of sophistication. These range from fixed-order computations at an increasing accuracy to resummed computations via parton showering algorithms and semi-analytic approaches. Even matching/merging between the two while keeping their respective accuracies is available.

In such multi-TeV scales processes typical momentum transfers Q are much larger than the electroweak (EW) scale $m \sim m_Z$, and initial- and final-state EW radiation becomes important. In particular, EW boson emission gives rise to transition rates that grow with logarithms of the type $\log Q/m$. For sufficiently large Q , these logarithms must be resummed in order to recover physically meaningful results. Despite recent progress, a fully exclusive approach that can take care of fixed-order EW corrections, resum large EW logarithms in both initial and final states, systematically account for power corrections, and is implemented in ready-to-use Monte Carlo simulation software is not yet available.

The purpose of this LoI is to undertake a critical assessment of recent progress towards studying EW effects in multi-TeV processes and to set goals for the coming years by identifying the hurdles and open questions. In this quest, it is important to stress the broad scope of this task, which ranges from the need for field-theoretic constructions such as factorization theorems to efficient Monte Carlo techniques. Such a broad-based approach is necessary for a precise description of EW interactions at high energies.

2 Theoretical approaches - State of the art

- Fixed Order
 - Universal Leading terms for arbitrary processes are known since many years [1,2] and also implemented in Sherpa [3].
 - Currently, exact EW corrections at NLO are available in an automatic form for arbitrary processes in the SM, for example in MADGRAPH5_MC@NLO [4], SHERPA+RECOLA [5].
- Resummation
 - General
In Ref. [6–8], resummed EW corrections were computed to NLL order, and a universal factorization formalism for the amplitude in terms of soft and collinear functions was developed.
In Ref. [9] electroweak collinear splitting functions for the Standard Model, including the massive fermions, gauge bosons and the Higgs boson are derived, identifying the leading contributions at a splitting scale k_T far above the EW scale v . A practical EW showering scheme based on these splitting functions using a Sudakov evolution formalism is also proposed.

Ref. [10] discusses a formalism, applicable to any covariant gauge, in which the transition between the broken and unbroken phases of gauge theories is manifestly smooth. Very recently, in Ref. [11], a PS formalism to resum EW logs is introduced based on the VINCIA antenna shower.

– Initial State Radiation (ISR)

Generic PDF in the SM respecting $SU(3) \times SU(2) \times U(1)$ symmetries have been introduced [12].

In Ref. [13] a framework to perform all-orders resummation of electroweak logarithms for inclusive scattering processes at energies Q much above the electroweak scale M is presented. A factorization theorem for inclusive cross sections was derived in terms of PDFs, fragmentation functions and soft functions. In Ref. [14] transverse and longitudinal electroweak gauge boson parton distribution functions (PDFs) are computed in terms of deep-inelastic scattering structure functions. The EW analog of DGLAP evolution equations were derived, which allow for the resummation of Sudakov double-logarithms.

Ref. [15] argues that electroweak parton distribution functions (EW PDFs) should be adopted as the proper description for partonic collisions of the initial states. The leptons and electroweak gauge bosons are the EW partons, that evolve according to the unbroken Standard Model (SM) gauge group and that effectively resum potentially large collinear logarithms.

– Final State Radiation (FSR)

In Refs. [16, 17] efforts have been made to extend Pythia FSR to include the radiation of weak bosons from fermionic lines.

3 Phenomenological applications

- ISR and FSR in multi-TeV lepton (electron and muon) collider and at 100+ TeV pp collider;
- Very-high energy cosmic neutrino interactions;
- The energy spectra including EW corrections of stable particles coming from DM annihilation or decay are available from PPPC4DM, outlined in [18] and based on approximate formulæ implemented in Pythia. A new approach has recently appeared, Ref. [19]. EW corrections mainly affect the photon, positron and neutrinos energy spectra, and the two approaches described above show significant discrepancies in the predicted spectra. In the next decade space and ground based experiments will focus on high energy photons, neutrinos and cosmic rays observatories, see for instance HAWC [20], LHAASO [21], CTA [22], Antares/IceCube [23], KM3NeT [24]. Improving the precision of energy spectra is relevant for achieving better theoretical predictions for DM models and searches.

4 Open questions and Long-term goals

- Understanding of the transition between EW broken to symmetric phase and the role of formally subleading terms;
- Fully fledged EW PS with control of power corrections applicable to any high-energy event;
- NLL resummation and two-loop universal dominant effects;
- Matching/merging resummation/fixed-order computations.

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