High-Energy Resummation at the LHC

Giacomo Ruisi

Deutsches Elektronen-Synchrotron (DESY)

The High Luminosity-Large Hadron Collider (HL-LHC) project aims to investigate the Standard Model sector through precision measurements. The amount of data collected allows physicists to observe rare processes and study already known mechanisms in more detail, such as the Higgs one.

The most common modes of Higgs boson production are via the fusion of a pair of gluons (ggF-channel accounting for $\sim 87\%$ of Higgs boson decays) followed by the rarer fusion of W or Z bosons (VBF-channel $\sim 7\%$ of decays). The latter channel is fundamental for directly measuring the Higgs coupling to W and Z bosons. In addition, the VBF mode can be well identified by looking at the spatial separation and mass of the produced jets together with the Higgs. Specifically, the vector bosons are emitted by two quarks forming energetic jets in the detector along the beam direction and in opposite hemispheres. However, the gluons in the ggF production also emit additional jets, mimicking VBF jet pairs. Therefore, there is the need to implement kinematic cuts on the weak boson fusion, i.e. a large invariant mass and rapidity separation between the two hardest jets, to suppress the ggF contribution. These kinematic requirements of the VBF mode suggest that the ggF production of the Higgs boson plus jets is studied in the high-energy limit.

A fundamental challenge for the HL-LHC is to measure the strength of the Higgs boson self-coupling – one of the Standard Model parameters still largely unconstrained – through the rarer di-Higgs production. A better description of this process will provide new insights into the non-trivial structure of the Higgs potential and, the results could also shed light on the existence of phenomena beyond the Standard Model. Observing and measuring this process is crucial for the Higgs research programme. To achieve this goal, deepening our understanding of single Higgs production plus jets at high energies is essential to reduce the background for di-Higgs searches. On the other hand, the cross-section in this phase-space region depends strongly on large logarithms in invariant masses over transverse momenta. Therefore, a suitable framework to deal with these emerging divergences is auspicable.

The *High Energy Jets* (HEJ) formalism is introduced to handle the all-order resummation of high-energy logarithms of the form $(\alpha_s \ln \frac{s_{ij}}{p_\perp})^n$. For Higgs plus jets production, the leading logarithmic (LL) resummation has already been implemented for all dominant configurations. Here, two selected kinematic configurations are presented, i.e. *extremal quark-antiquark pair* and *central quark-antiquark pair*, relevant at next-to-leading logarithmic (NLL) order. In addition, the simple factorisation of the HEJ matrix element and the absence of approximations for the phase space (apart from the restriction to leading and selected subleading kinematic configurations) make this framework particularly suitable for a Monte Carlo event generator employing realistic cuts.

The impact of every configuration can be inferred by studying the behaviour of the corresponding amplitudes in the high-energy limit, as the dependence of a given amplitude is determined by Regge scaling in this regime. The latter states that any matrix element is dominated by those configurations that maximise the number of exchanged t-channel particles with the highest spin. For example in QCD, those configurations allowing the maximum number of t-channel gluons are included first. Studying $q\bar{q}$ processes along with the Higgs is relevant for the bottom-antibottom pair production. This mechanism is the most common fermionic decay of the Higgs boson ($\mathrm{BR}(H \to b\bar{b}) \sim 58\%$) and thus a key background process for di-Higgs searches.

To conclude, a more rigorous description of Higgs plus jets production is needed to explore the Standard Model of particle physics in depth. A significant deviation from its predictions would imply the existence of new phenomena, hence the need to extend current models. The HEJ formalism is one of the methods to provide reliable predictions and experimental physicists with a Monte Carlo event generator that implements realistic cuts.