Interference effects from double gluon emissions

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1 Aims & Objectives

This project aims to determine probability amplitudes for processes involving double-gluon emission (Section 2.1), in doing so accounting for interference effects that occur due to interactions between different Feynman diagrams. The amplitudes are described in terms of antenna functions (Section 2.3), which are however too complicated to be integrated analytically. Therefore, a suitable overestimate is required which will be the target of Monte Carlo simulations exploring the phase space of this process. The following recounts a series of investigations into the underlying physics this process, leading up to a summary of current progress and future plans.

2 Investigations

2.1 Particle Decay Basics

We first investigated the various types of interactions leading to double gluon emission from $q\bar{q}$ pairs. These interactions are described using Feynman diagrams which depict incoming particles, called *initial state particles*, and outgoing particles, called *final state particles*, as external legs of the diagram, connected by internal lines, representing exchanged intermediate particles, which meet at internal vertices. Only certain combinations of exhanged particles and vertices are allowed, and these are prescribed by Quantum Electrodynamics (QED) for electromagnetic interactions, or Quantum Chromodynamics (QCD) for strong interactions. Figure 1 depicts a *quark* and an *antiquark* in the initial state, with each radiating a gluon that appears in the final state. This is just one possible Feynman diagram for this process, and physically all the possible Feynman diagrams of this process must be added together to get a complete picture of this interaction that properly accounts for interference effects between the diagrams.

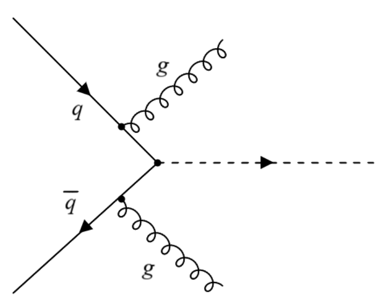

Figure 1: Feynman diagram with a $q\bar{q}$ pair in the inital state, each emitting a gluon which appears in the final state.

2.2 Parton Showers

High energy partons emit gluons in *bremsstrahlung showers*, and these gluons further radiate other partons and gluons in a chained process called a *parton shower*. We explored parton showers under the special but frequently occurring cases of *soft* radiation, where the radiated particle is of low energy, and the *collinear* limit, where the radiated particle has low transverse momentum. In these limits, the complicated functions describing one of these *bremsstrahlung* emissions, say the decay of $Q \to i + j + k$, can be simplified through a process of factorisation into a product of two contributing terms, the first describing a decay from $Q \to I + K$ and the second term describing emission of another particle j as $I + K \to i + j + k$. This second term is called the *splitting function*, and is closely related to the Antenna functions of Section 2.3. However, this model doesn't take into account the interference between higher-order processes, such as those of double-gluon emissions.

There exists well established software used in research to simulate and explore parton showers. PYTHIA [1] is an event generator for high-energy particle collisions developed in-part here at Monash, simulating parton showers given some specific initial configuration. The phase space of these events can be probed using the RAMBO [2] algorithm, which generates uniformly random points in an n-body phase space of massless particles, obeying the laws of energy and momentum conservation. In this way, RAMBO enables the uniform sampling of the double-gluon emission phase space.

2.3 Antenna Functions & Crossing Symmetry

Antenna functions describe the likelihood of radiation from particles which may be in the initial or final states. The antenna function for double gluon emission in which all particles are in the final state is known from the work of [3] (henceforth GGG), however we are interested in the antenna function describing two particles in the initial state. We use *crossing symmetry* to achieve this, which refers to an invariance in the amplitudes describing particle interactions, such that a particle X with four-momentum p^μ in the final state can be *crossed* into the initial state by replacing X with its antiparticle $\bar{X}$ and taking its negative momentum $-p^\mu$. For example, examining the four-momentum conservation equation of the interaction $A \to B + C$, we can cross B into the initial state as

$$p_A^\mu = p_B^\mu + p_C^\mu \qquad \to \qquad p_A^\mu + \left(-p_{\bar{B}}^\mu\right) = p_C^\mu$$

which describes the interaction $A + \bar{B} \to C$. Importantly, the same amplitude is used to describe both these interactions. By crossing the two final state particles from GGG into the initial state, we attain our desired antenna function.

3 Future Plans

The antenna function of GGG has been implemented in *Mathematica* software. From this, we use the substitutions described from crossing symmetry to determine the antenna function. To probe the phase space of this event, we require a well-chosen over-estimate of this function that can be integrated analytically. If this is not possible over the entire domain, then proper characterisation of problematic regions will be required.

References

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[2] Kleiss, R., Stirling, W. J., & Ellis, S. D. (1986). A new Monte Carlo treatment of multiparticle phase space at high energies. Computer Physics Communications, 40(2), 359–373.
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