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Higher level string resonances in four dimensions

Wan-Zhe Feng *, Tomasz R. Taylor

Department of Physics, Northeastern University, Boston, MA 02115, USA

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Abstract

We study higher level Regge resonances of open superstrings, focusing on the universal part of the Neveu–Schwarz sector common to all D-brane realizations of the standard model. For Regge states with masses far above the fundamental string scale, we discuss the spin-dependence of their decay rates into massless gauge bosons. Extending our previous work on lowest level string excitations, we study the second mass level at which spins range from 0 to 3. We construct the respective vertex operators and compute the amplitudes involving one massive particle and two or three gauge bosons. To illustrate the use of Britto–Cachazo–Feng–Witten (BCFW) recursion relations in superstring theory, we build the four-gluon amplitude from on-shell amplitudes involving string resonances and gauge bosons.

Keywords: String resonance; Higher spin; Massive state; Scattering amplitude

1. Introduction and summary

Over the past quarter of century, research in superstring theory has been largely focused on massless string excitations and their effective field theory description. Massless particles are the quantized string zero modes. There is a huge number of distinct massless spectra allowed by various compactifications. This arbitrariness limits the predictive power of the theory: it is referred to as the landscape problem. The quantization of first harmonic and higher level vibration modes yields massive particles — Regge resonances with masses quantized in units of the fundamental

* Corresponding author.
E-mail address: VicFengHunt@gmail.com (W.-Z. Feng).

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mass scale M as $\sqrt{n}M$ for nth harmonics. At the nth level, their spins range from 0 to $n+1$. The massive spectrum is also model-dependent, however it replicates massless states, therefore for any string compactification that reproduces the standard model, there is a sharp prediction that excited quarks, gluons, etc. will also appear among many excited states. The reason why there has not been much discussion of the properties of Regge resonances was the belief that the fundamental string scale must be of order of the Planck mass to explain the weakness of gravitational forces. This, however, has changed with the advent of D-brane constructions that allow arbitrary string scales because gravity can "leak" into large extra dimensions [1–3]. If the string scale is sufficiently low, excited gluons and other Regge resonances will be observed at the Large Hadron Collider (LHC) [4–21].

In a recent paper [18], we presented a detailed discussion of the "universal" part of the first massive level, common to all D-brane embeddings of the standard model. Here, we extend it to the second level, and discuss some general properties of higher levels. We are particularly interested in massive particles that couple to massless gauge bosons according to "(anti)self-dual" selection rules. These particles decay into two gauge bosons with the same (say $++$) helicities only and to more gluons in "mostly plus" helicity configurations.

We rely on the factorization techniques. They allow identifying not only the spins of Regge resonances propagating in a given channel, but also their couplings and decay rates. The paper is organized as follows. In Section 2 we perform the spin decomposition of the well-known four-gluon maximally helicity violating (MHV) amplitude in the s-channels of $(--)$ and $(-+)$ gluons. We examine decay rates of heavy states into two gluons, for masses much larger than M, i.e. in the large n limit. We find that for any particle with spin $j \leqslant n+1$, the maximum partial decay width into two gluons is n-independent — it never exceeds M. Particles with $j \sim \sqrt{n} = M_n/M$ have largest widths. We also find that for $j \sim n$, the decay rate into two gluons is exponentially suppressed. In Section 3, we study the second massive level. We construct the vertex operators for all "universal" bosons of the Neveu–Schwarz (NS) sector. We compute the amplitudes involving one such state and two or three gluons, focusing on the decays of the (anti)self-dual massive (complex) vector fields.

The amplitudes describing decays of heavy states into gauge bosons are also important for the superstring generalization of Britto–Cachazo–Feng–Witten (BCFW) recursion relations [22–25] to disk amplitudes with arbitrary number of external gauge bosons. Recently, it has been argued that the BCFW-deformed full-fledged string amplitudes have no singularities at the infinite value of the deformation parameter, therefore BCFW recursion relations should be valid also in string theory [26–30]. This approach to constructing the scattering amplitudes is however highly impractical because in order to increase the number of external massless particles from N to $N+1$, one needs to compute an infinite number of amplitudes involving one massive state and $N-1$ massless ones, for all mass levels. It may be useful, however, for revealing some general properties of the amplitudes. In Section 4, we show that at least the four-gluon amplitude can be obtained by a BCFW deformation of a factorized sum involving on-shell amplitudes of one massive Regge state and two gauge bosons.

Although the main motivation for the present study is the exciting possibility of observing massive string states at the LHC, we should emphasize that elementary higher spin states can also exist outside the string context. Higher spin theory has been developed for quite a long time [31–38]. More recently, there is also a growing interest in the dynamics of higher spin states in string theory [39–53]. We hope that our study offers some new insights into the nature of higher spin interactions.