A. Notes on unitarity and the Higgs field

As any gauge theory in 5 space-time dimensions, the 5D-DBESS model has couplings with negative mass dimension and is therefore not renormalizable. In the KK expanded 4D theory emerging from the compactification of the extra dimension, the nonrenormalizability manifests as a partial wave unitarity violation at tree level at an energy scale proportional to the inverse square of the gauge coupling [75]. A detailed study of the unitarity properties of the model was beyond the scope of the present work, but it is still possible to give an estimate based on naive dimensional analysis. In flat space, the naive estimate for a gauge theory with dimensional coupling constant g_5 gives a cut-off $\Lambda = (16\pi^2)/g_5^2$ [45].

In a warped space, the cut-off is dependent on the location along the fifth dimension: starting from Λ at the $y = 0$ brane, it is redshifted along the interval (as any other energy scale in the theory), getting down to $\Lambda' = \Lambda\sqrt{b(\pi R)}$ upon reaching the $y = \pi R$ brane. To get an estimate for the Kaluza-Klein 4D effective theory, we will use the most restrictive cut-off:

$$\Lambda' = \frac{16\pi^2}{g_5^2}\sqrt{b(\pi R)}. \tag{81}$$

In addition to the one coming from the negative mass dimension bulk coupling g_5 (or equivalently from the infinite tower of KK excitations), the 5D-DBESS has another, more stringent unitarity bound: the one coming from the WW scattering. In this model, in fact, the longitudinal components of the electroweak gauge bosons are only coupled to the U field and, as a consequence, the corresponding scattering amplitudes violate partial wave unitarity at the same energy scale as in the Higgsless SM [61], that is $\Lambda_{cut-off} \simeq 1.7$ TeV. The violation of unitarity is not postponed to higher scales as in the 5D Higgsless model [8, 10]. This situation exactly mirrors the one of the GD-BESS model [39, 60].

However, this problem can be easily cured by generalizing the U field to a matrix containing an additional real scalar excitation ρ, mimicking the standard Higgs sector in the matrix formulation:

$$U \to M \equiv \frac{\rho}{\sqrt{2}}U. \tag{82}$$

Just as in the case of the SM, the exchange of the new scalar degree of freedom ρ cancels the growing with energy terms in the scattering of the longitudinal EW gauge bosons, delaying unitarity violation. A similar process of unitarization via the addition of scalar fields was also studied in the context of the D-BESS model in ref. [76].