KK Graviton and Vector boson associated production in ADD Model at the LHC via Gluon fusion

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Outline

- SM, hierarchy problem and TeV-scale physics.

- Models of Extra-Dimensions (in particular ADD model) attempt to solve the hierarchy problem by proposing fundamental scale of gravity in TeV range.

- In ADD model, SM particles live in 4-dim while gravity propagtes in full $4 + \delta$-dim. for simplicity we assume that these extra spatial dimensions are compactified on a torus with common scale R.

$$\Longrightarrow \quad M_P^2 = M_S^{\delta+2} R^\delta \tag{1}$$

- The $4+\delta$-dimensional Graviton corresponds to a tower of massive Kaluza-Klein (KK) modes in 4 dimensions with masses given by

$$m_n^2 = \frac{\vec{n}^2}{R^2}. \qquad (2)$$

- The interaction of spin-2 KK modes with the SM particles is given by an effective theory

$$L_{int} \approx \frac{1}{M_P} \sum_{\vec{n}} \int d^4x \;\; h_{\mu\nu}^{(\vec{n})}(x) \;\; T^{\mu\nu}(x). \qquad (3)$$

- For the production of single KK-Graviton, the cross-section is proportional to $\frac{1}{M_P^2}$.

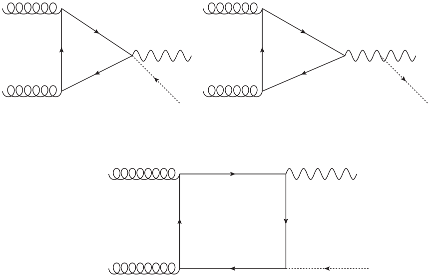
- The inclusive cross-section is obtained by summing over all accessible KK-modes. In the contunumm limit the cross-section is enhanced by a factor of $\frac{M_P^2}{M_S^{\delta+2}}$. Thus the overall suppression factor is only $\frac{1}{M_S^{\delta+2}}$.
- If M_S is near the TeV-scale, Graviton production can thus be probed at present and future high-energy colliders.
- Direct graviton production gives rise to missing energy signals.

- We are interested in gluonic contribution to

$$p + p \to \gamma/Z + G(KK) \tag{4}$$

at the LHC.

- At LO, this process proceeds via quark loop diagrams and these can be put into three classes (arXiv:hep-ph/9811350)



- We work with five massless flavours of quarks.
- Due to charge conjugation vector part of the amplitude does not contribute.

$$\Longrightarrow \qquad M(g + g \rightarrow \gamma + G(KK)) = 0.$$

- The amplitude being proportional to T_3, receives contribution from left-handed b-quarks only.

- Quark loop trace is calculated in FORM. The amplitude at this stage involves tensor integrals, 4-tensor Box integral being the most complicated one.

$$D_{\mu\nu\rho\sigma} = \int \frac{d^n l}{(2\pi)^n} \frac{l_\mu l_\nu l_\rho l_\sigma}{N_0 N_1 N_2 N_3} \tag{5}$$

- Reduction of tensor integrals is done using methods of Oldenborgh and Vermaseren (Z. Phys. C 46 (1990))
- Scalar Integrals are evaluated analytically (upto D_0 with two massive legs) following ‘t Hooft and Veltman (Nucl. Phys. B 153, 365 (1979)).

- We regularize UV sing. in dimensional regularization while IR sing. are regularized by giving small mass to quarks in the loop.

- The general structure of the amplitude is

$$M = A\,\frac{1}{\epsilon_{UV}} + B\;log^2(m^2) + C\;log(m^2) + F \tag{6}$$

- UV cancellation ($A = 0$) ✓
- IR^2 cancellation ($B = 0$) ✓
- IR cancellation ($C = 0$) ✓
- Gauge Invariance ??

- for $\delta = 2$ and $M_s = 5 TeV$ (with no cuts)

$$\sigma_{pp \to Z+G} \sim 342 fb \tag{7}$$

- Gluon initiated processes are important at the LHC.
- Models with large extra space dimensions can be probed at the colliders using an effective field theory approach.
- The real Graviton emission gives rise to missing energy signals.
- Searches for the process $pp \rightarrow Z + p_T^{miss}$ at the LHC will be able to extend the sensitivity to the fundamental scale M_S into the multi-TeV region.