Extra Dimensions Working Group Report

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Outline

Introduction

- An area that has been actively researched into in this working group has been Bulk Randall-Sundrum Models.
- It is important to go through the basics of the model before discussing the projects completed.

Bulk RS Model basics

- Start with the action for a 5-d scalar field ϕ with a bulk mass ak, boundary mass term bk, k: bulk curvature.
- Separation of variables in the KK decomposition gives

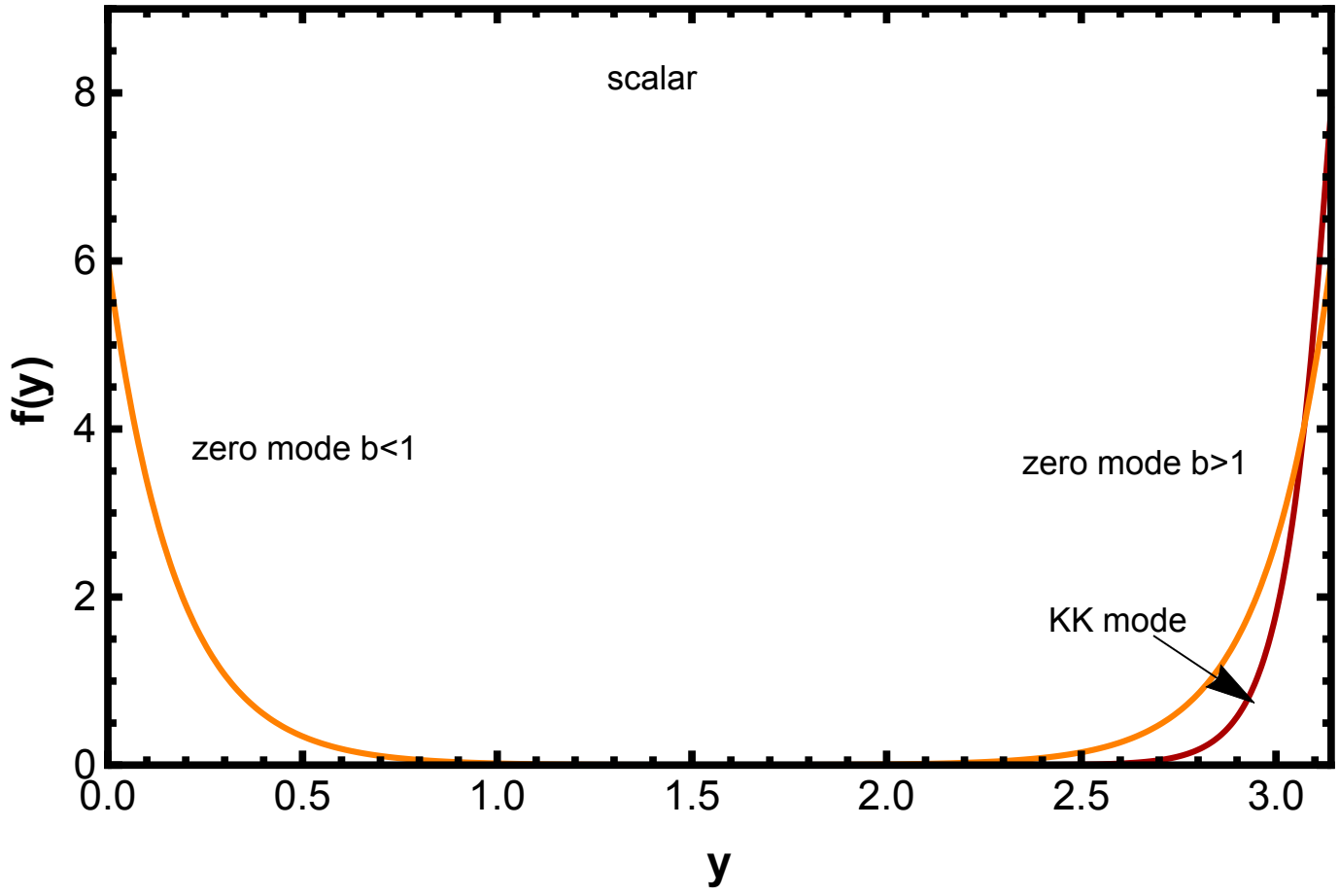
$$\phi(x^\mu, y) = \sum_{n=0}^{\infty} \phi^{(n)}(x^\mu) f_\phi^{(n)}(y) \tag{1}$$

- We can solve for the profiles $f_\phi^{(n)}(y)$.

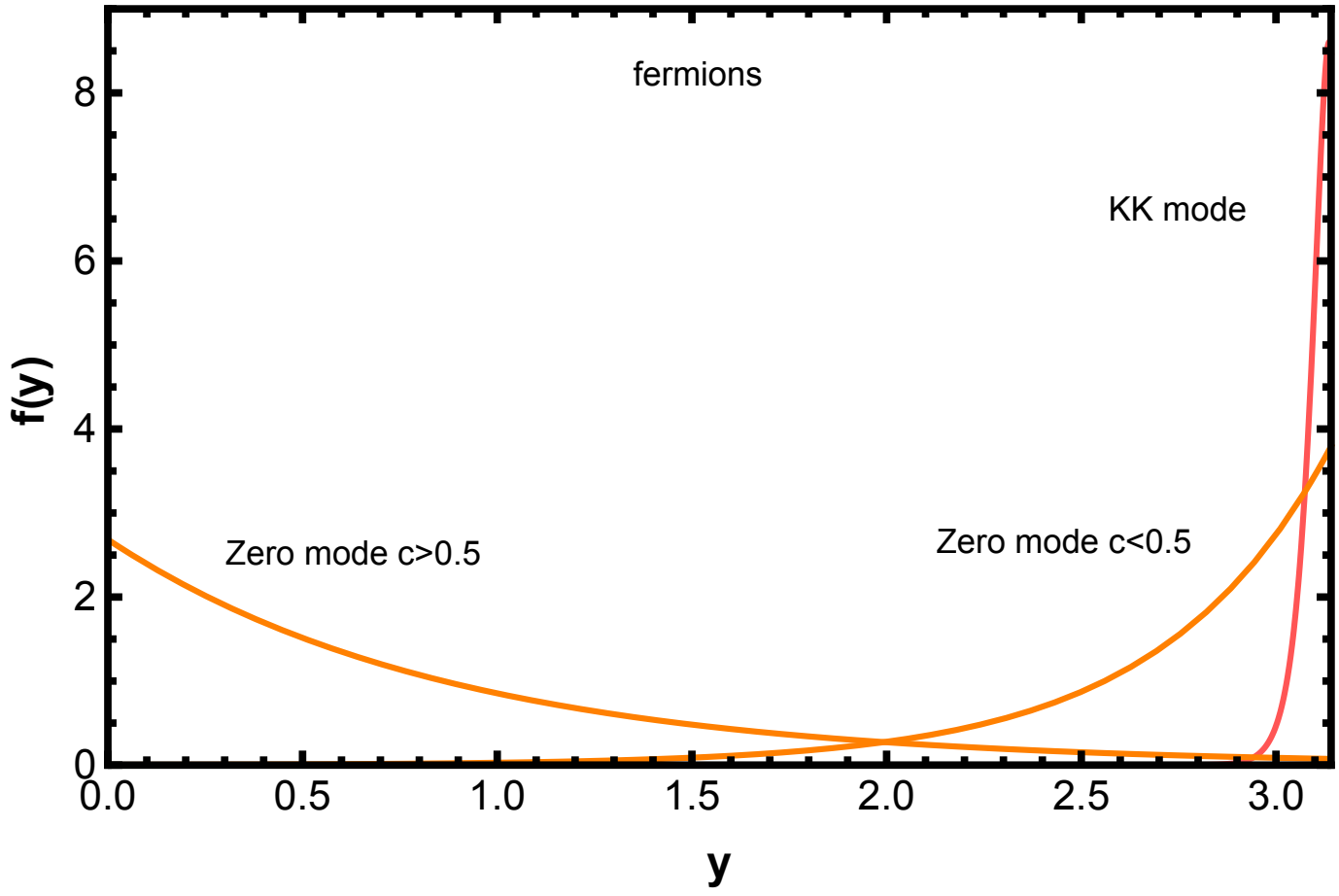
Bulk RS Model basics II

- By tuning b, scalar zero-mode can be localised anywhere in the bulk.
- KK modes are given by combinations of Bessel functions and are localised towards the IR brane and have masses of the order of the infrared scale $ke^{-\pi kR}$.
- Follows similarly for fermion, gauge and graviton fields.

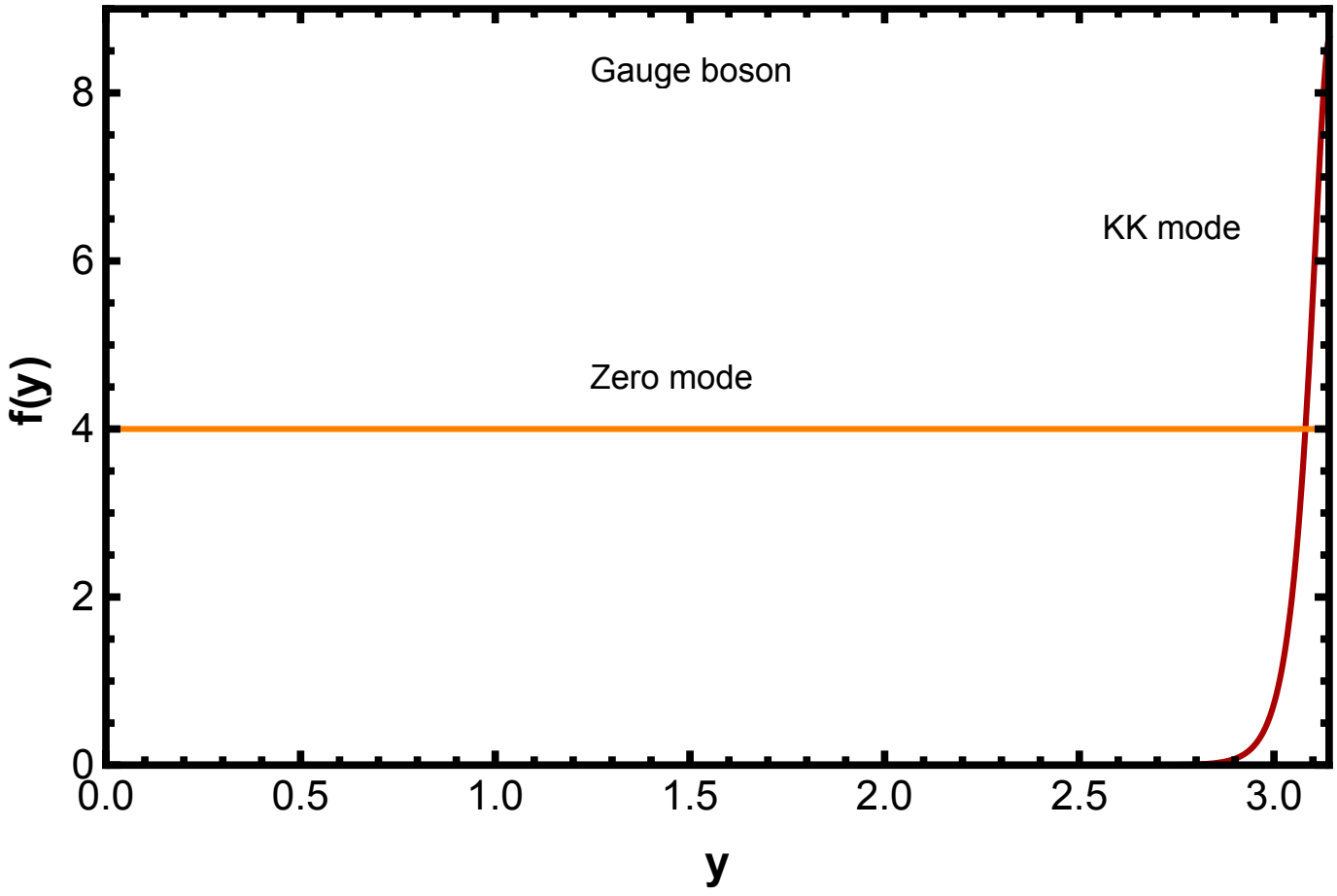
Scalar modes



Fermion modes



Gauge modes



AdS/CFT in a segment

- AdS/CFT works very differently in a segment of space-time i.e. between the UV and the IR branes.
- The UV brane in 5d shows up as a UV cut-off in the dual theory. Schwinger source field ϕ_0 becomes dynamical.
- The IR brane leads to a spontaneous breakdown of 4d-conformal symmetry, gives rise to CFT bound states.
- The mixing $\phi_0 \mathcal{O}$ between the source field (elementary) and the CFT bound states (composites) gives rise to the mass eigenstates which are from a 5-d perspective KK excitations of the bulk fields.

Holographic Expansion

- Instead of a KK expansion of the bulk field, expand it in terms of the source field and CFT composites $\rightarrow$ Holographic Expansion
- In general, there will be mixing but after diagonalisation and matching with the KK decomposition, one can identify the degree of compositeness of any bulk field.

Elementary or composite?

- Graviton zero mode is UV localised and is pure elementary (tiny mixing with composites). KK modes are purely composite.
- Gauge field zero mode has a flat profile. So mixing is expected to be large. But coupling is marginal and the zero-modes are elementary. KK modes are purely composite.

Elementary or composite? -II

- Light fermions like electrons ($c > 1/2$) are UV localised and so elementary. For $(t,\ b)_L$, c is $0.3 - 0.4$. Zero modes contain significant fraction of the composite CFT states though it is largely elementary. Massive modes are elementary
- Right handed top ($c < -1/2$) has a large composite component.
- Higgs is localised on or close to the brane so fully composite or very nearly so.

Custodial model

- Bulk RS models have large custodial symmetry violations because of interactions between Higgs and KK excitations of gauge bosons.
- Leads to large effects in EW parameters.
- Gauge KK modes mass $\rightarrow$ 15 -20 TeV.
- Custodial models extend the gauge group to $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$. Reduces bound to 3 TeV on gauge boson masses.

Deformed Metric

- A metric singular at $y = y_s = L + \Delta$:

$$A(y) = ky - \frac{1}{\nu^2}\log\left(1 - \frac{y}{y_s}\right) \tag{2}$$

- Becomes the usual R-S metric for $\nu \to \infty$.
- The singularity at $y = y_s$ deforms the metric near the TeV brane.
- The Higgs is also moved into the bulk and alongwith the deformed metric keeps T under control.

KK gluons

- Interesting signal – KK gluon production.
- The KK gluon coupling to t_R is enhanced by a factor ξ compared to α_s where $\xi \equiv \sqrt{\log(M_{pl}/\mathrm{TeV})} \sim 5$.
- Consequently, it decays predominantly to tops if produced.
- To the $(t, b)_L$ doublet its coupling is α_s and to the light quarks its couplings are suppressed.

KK Gluon Production

- However, the ggg_{KK} vanishes because of the the orthogonality of the profiles of these particles.
- So gg initial state does not contribute, only $q\bar{q}$ does.
- At the LHC, KK gluon masses of the order of 2 TeV can be probed with this process.

Associated Jets Production

- It is useful to consider other production mechanisms: g_{KK}+jets is interesting because qg and gg-initial states contribute.
- Hadron-level simulation of the signal and background shows that the jet-shape variable N-subjettiness can very effective in suppressing the QCD background.
- The irreducible $t\bar{t}$ background can be suppressed using transverse momentum cuts.
  A.M. Iyer, F. Mahmoudi, N. Manglani, K. Sridhar, Phys.Lett. B759 (2016) 342-348.

KK gluon + jet: PT distributions

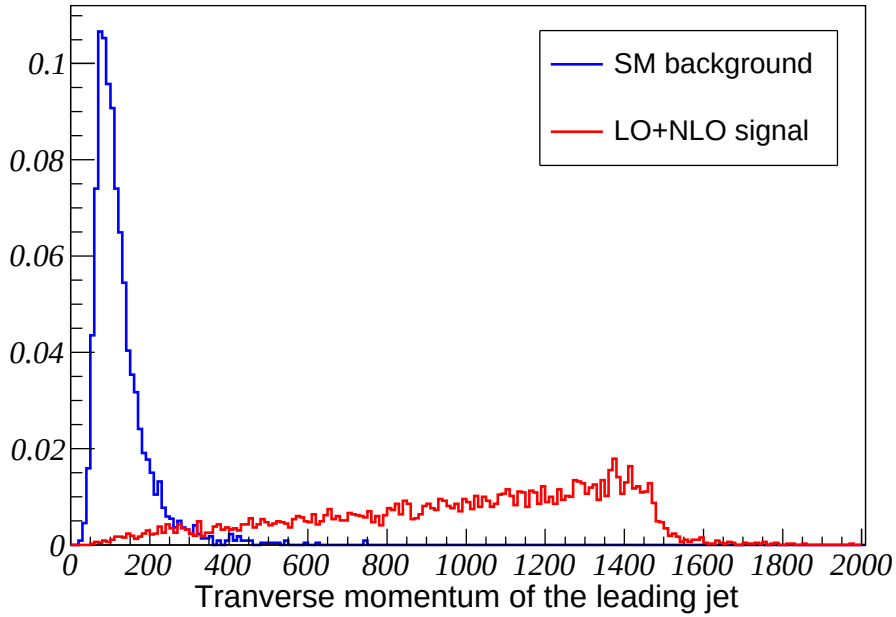


Figure: p_T *of the leading jet*

KK gluon + jet: Cross-section

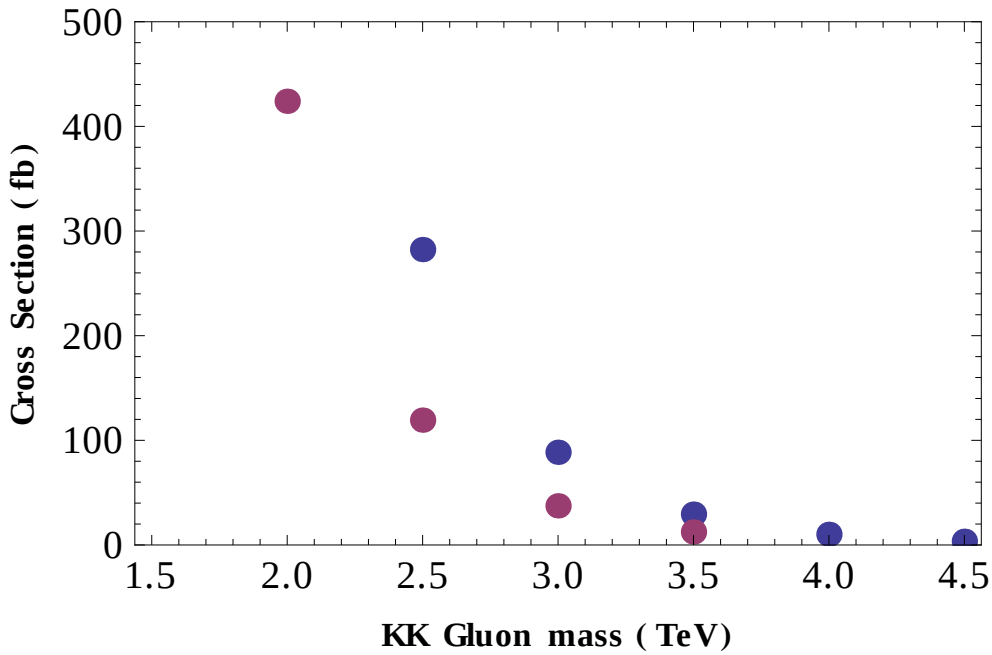


Figure: *Cross-section as a function of* g_{KK} *mass*

Higgs KK mode: Custodial

- We have shown that in Bulk Higgs models, the Higgs KK modes can be light consistent with naturalness, electroweak precision and Higgs mass constraint.
- The first KK mode of the Higgs (h_1) could lie in the 1-2 TeV range in the custodial model.
- h_1 decays dominantly into a boosted $t\bar{t}$ pair.
- HEPTopTagger is efficient in taming the large QCD background.
- The irreducible $t\bar{t}$ background can be controlled by using a cut on $\Delta\eta$ and p_T.
  F. Mahmoudi, U. Maitra, N. Manglani, K. Sridhar, JHEP 1611 (2016) 075.

Higgs KK mode: Deformed

- The first KK mode in the deformed model is even lighter (800 GeV - 1.2 TeV) but the cross-sections are small.
- To handle the QCD background, the HEPToptagger needs to be supplemented with b-tagging inside the top jet.
- We need to go to the high-luminosity option of the LHC to be able to fully study the h_1-mass range.
  F. Mahmoudi, N. Manglani, K. Sridhar. arXiv:1712.04966

Vector-Like Quarks

- One novel way of searching for exotic vector-like quarks is to look for their effects in electroweak loops.
- We have begun the study of $gg \to ZZ/\gamma\gamma$ through a box involving a vector-like quark.
  G. Cacciapaglia, D. Choudhury, N. Gaur, K. Sridhar – Work in progress