Parameter Space of ‘fat-brane’ UED models after ATLAS di-photon and multi-jet plus missing transverse energy searches

Durmus Karabacak
Mugla Sitki Kocman University, Turkey
[work in progress with Satya Nandi and Kirtiman Ghosh]
SUSY17, TIFR, Mumbai, Dec. 14th, 2017

Outline

- The Minimal Universal Extra Dimension (mUED) model
- The fat-brane scenario with the mUED
- Decays of level-1 Kaluza-Klein (KK) particles in ‘fat-brane’ scenario
- ATLAS multi-jet and di-photon searches
- Parameter space of ‘fat-brane’ model with ATLAS results
- Conclusions

The minimal Universal Extra Dimension (mUED) model

The mUED model is constructed on $M_4 \times S_1$ with orbifolding $M_4 \times S_1/Z_2$

$\Longrightarrow$ An infinite number of KK excitations with mass nR^{-1} for each SM particle.
Quasi-degenerate mass spectra at each KK level.

The mUED has two free parameters:

- R^{-1} the size of small extra dim.
- Λ the cut-off scale of the model

With this setup the mUED expects:

1) The KK-parity $\equiv (-1)^n$ conservation at the vertices.
2) Lightest KK (LKP) is stable.

} The level-1 KK quarks and gluons can only be pair produced at the collider experiments.

The collider signal of level-1 KK quarks and gluons are then multi-jet/lepton plus missing transverse energy.

The ‘fat-brane’ scenario with the mUED

In its simplest realization, ‘fat-brane’ = mUED + ADD

- In general, (3+m+1)D manifold ((3+m)-brane) of UED can be embedded in (4+N)D bulk.
- The SM fields live in the 4-brane and only the gravity is allowed to access the full bulk.
- Small spatial dimension, accessible for both matter and gravity, can be viewed as the thickness of the SM 3-brane in (4+N)D bulk.
- The sizes of large and small extra dimensions are $r \sim \ \mathrm{eV}^{-1} \ \mathrm{to} \ \ \mathrm{keV}^{-1} \gg R \sim \mathrm{TeV}^{-1}$
- Both SM particles and the graviton get KK excitations with different masses resulting from different compactification scales.
- The gravity induced interactions respect neither KK number nor KK parity.

The 'fat-brane' scenario with the mUED

After fixing Λ there are three free parameters of the model
- R size of small extra dim.
- r size of large extra dim.
- N number of large extra dim.

$$M_{\rm Pl.} = M_D^{N+2}\left(\frac{r}{2\pi}\right)^N$$ [ADD Relation]

The gravitational coupling of the matter fields is given by:

$$\mathcal{S}_{\rm int} = \int d^{4+N}x\ \delta(x^5)...\delta(x^{4+N})\sqrt{-\hat{g}}\mathcal{L}_{\rm matter}$$

$$\kappa^2 \equiv 16\pi G^{(4)} = V_n^{-1}\hat{\kappa}^2$$

The $\mathcal{O}(\hat{K})$ term is

$$\mathcal{S}_{int} \supset -\frac{\hat{K}}{2}\int d^{4+N}x\delta(x^5)...\delta(x^{4+N})\hat{h}^{\hat{\mu}\hat{\nu}}T_{\hat{\mu}\hat{\nu}}$$

$$m_{\vec{n}} = 2\pi\frac{|\vec{n}|}{r}$$

$$\vec{n} = \{n_1, n_2, ..., n_N\}$$

The interaction Lagrangian then becomes:

Han, T., et.al. PRD 59, 105006
Macesanu, C. et.al. PRD 68, 084008

$$\mathcal{S}_{\rm int} - \frac{K}{2} \supset \int d^4x \int_0^{\pi R} dy \sum_{\vec{n}} \left[(h^{\vec{n}}_{\mu\nu} + \eta_{\mu\nu}\phi^{\vec{n}})T^{\mu\nu} - 2A^{\vec{n}}_{\mu 4}T^{\mu}_{4} + 2\phi^{\vec{n}}_{44}T_{44}\right]e^{2\pi i\frac{n_4 y}{r}}.$$

Level $\vec{n}$ Graviton Gravi-photon Gravi-scalar

Decays of level-1 KK particles in ‘fat-brane’ scenario

Two types of decays are possible:

Gravity Mediated Decays (GMD):

- Strong dependence on the number of large extra dimensions, N.
- pronounced when N = 2.
- GMD comes to play at the beginning of the decay:

$$q^1, g^1 \to q/g + G^{\vec{n}}$$

- Pair-produced particle’s final state is then multi-jet + MET.

KK-number Conserving Decays (KKDC):

- Independent of the number of large extra dimensions, N.
- pronounced when N = 6.
- GMD plays part in the final stage of decay:

$$q^1, g^1 \to \text{soft-jets/leptons } ,\gamma^1$$

$$\gamma^1 \to \gamma + G^{\vec{n}}$$

- Pair-produced particle’s final state is then di-photon + MET.

Decays of level-1 KK particles in ‘fat-brane’ scenario

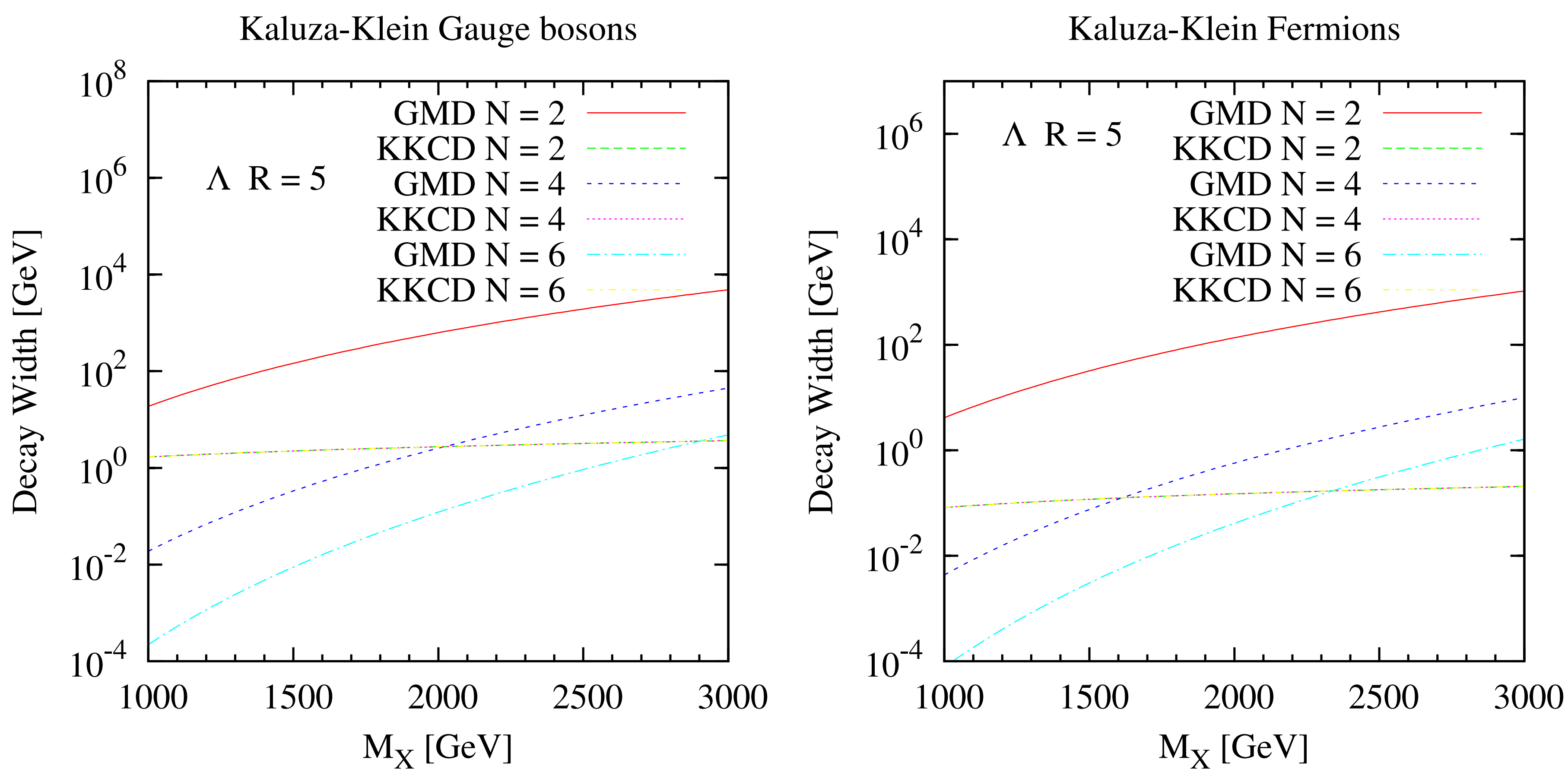


Figure: The decay widths of level-1 KK gauge boson (left) and fermion (right)

Decays of level-1 KK particles in ‘fat-brane’ scenario

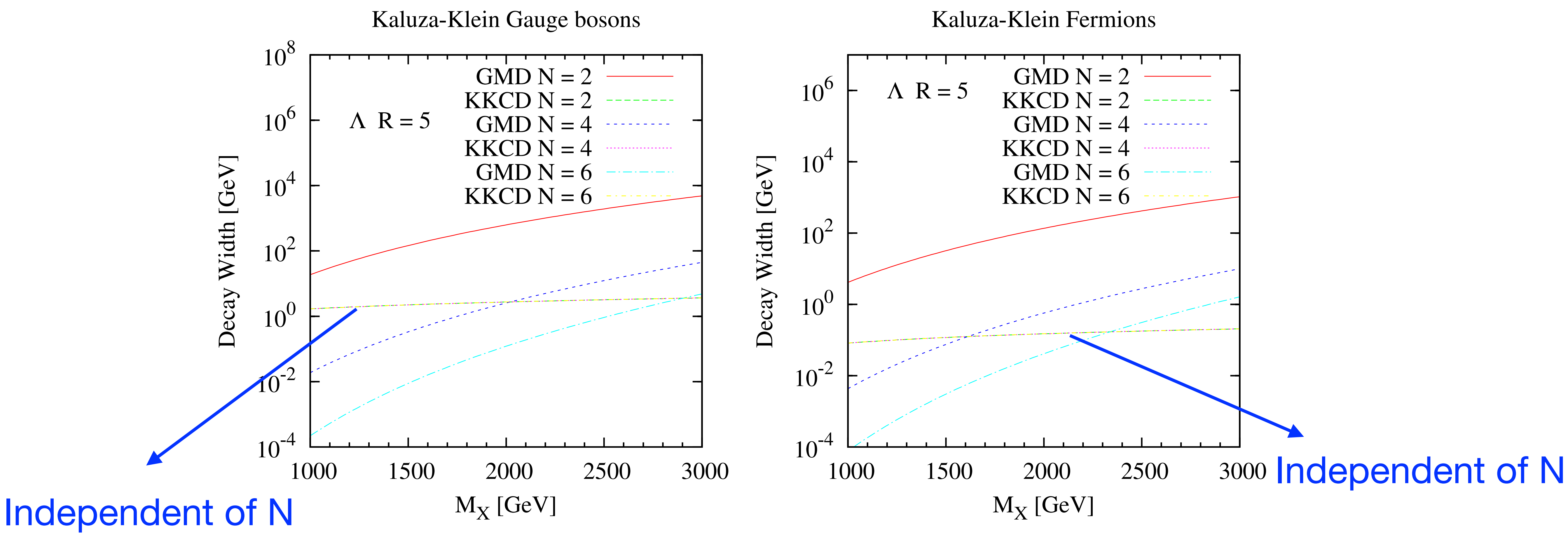


Figure: The decay widths of level-1 KK gauge boson (left) and fermion (right)

Decays of level-1 KK particles in ‘fat-brane’ scenario

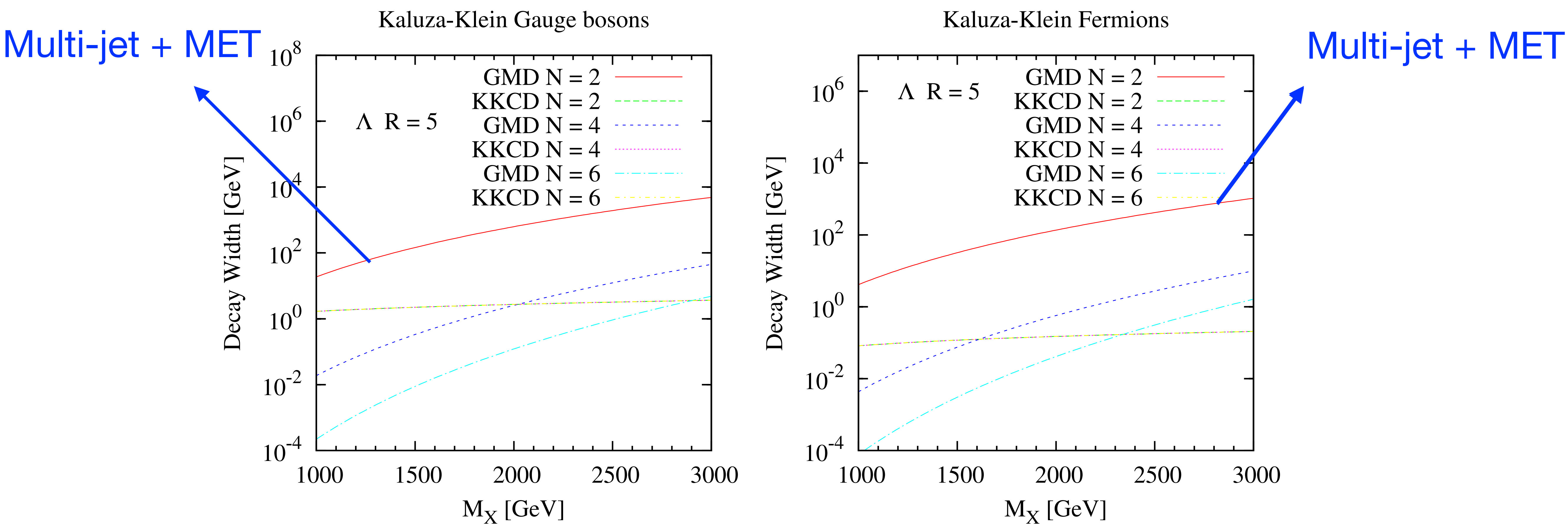


Figure: The decay widths of level-1 KK gauge boson (left) and fermion (right)

Decays of level-1 KK particles in ‘fat-brane’ scenario

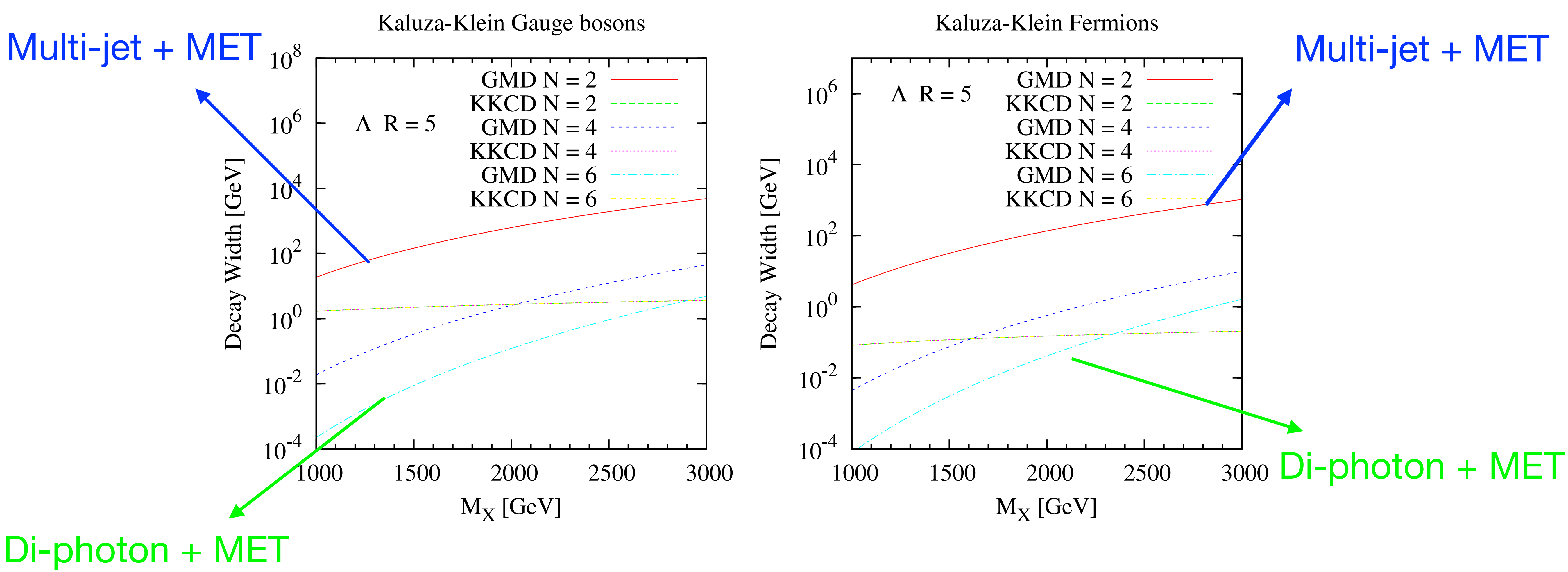


Figure: The decay widths of level-1 KK gauge boson (left) and fermion (right)

ATLAS multi-jet and di-photon searches

Both searches look for SUSY signal at 13 TeV with 36.1 (multi-jet) and 3.2 fb^{-1} (di-photon) searches:

Multi-jet search (ATLAS-CONF-2017-022):

- 44 inclusive Signal Regions (SR) in Meff search strategy.
- SRs are characterized by increasing number of jets (2j - 6j) and $m_{\text{eff}}(\text{incl.})$

$$m_{\text{eff}}(\text{incl.}) = \sum_{p_T > 50}^{N} p_T(j) + \text{MET}$$

- No excess of events above the SM background is observed.
- For each SR %95 C.L. upper limits are put on observable BSM cross-section.

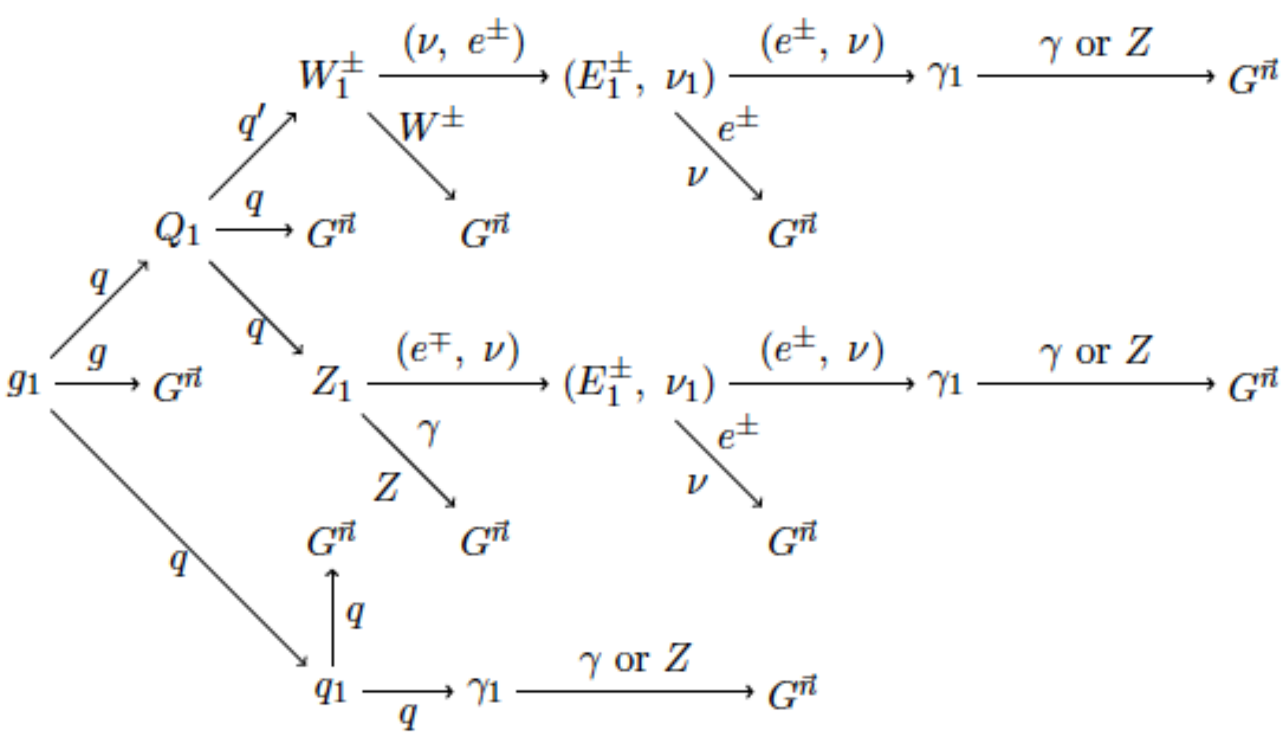
Di-photon search (arXiv:1606.09150):

- 2 tight photons with $p_T > 75$ GeV
- $\Delta\phi_{\text{min}}(\text{jet}, p_T^{\text{miss}}) > 0.5$,
- $E_T^{\text{miss}} > 175$ GeV,
- $m_{eff} > 1500$ GeV,
- No excess of events above the SM background is observed.
- %95 C.L. upper limit of 0.93 fb on visible BSM cross-section is put.

ATLAS multi-jet and di-photon searches

Both searches look for SUSY signal at 13 TeV with 36.1 (multi-jet) and 3.2 fb^{-1} (di-photon) searches:

Multi-jet search (ATLAS-CONF-2017-022):



1203.1551 [hep-ph]

Di-photon search (arXiv:1606.09150):

- 2 tight photons with $p_T > 75$ GeV
- $\Delta\phi_{\min}(\text{jet}, p_T^{\text{miss}}) > 0.5$,
- $E_T^{\text{miss}} > 175$ GeV,
- $m_{eff} > 1500$ GeV,
- No excess of events above the SM background is observed.
- %95 C.L. upper limit of 0.93 fb on visible BSM cross-section is put.

ATLAS multi-jet and di-photon searches

Both searches look for SUSY signal at 13 TeV with 36.1 (multi-jet) and 3.2 fb^{-1} (di-photon) searches:

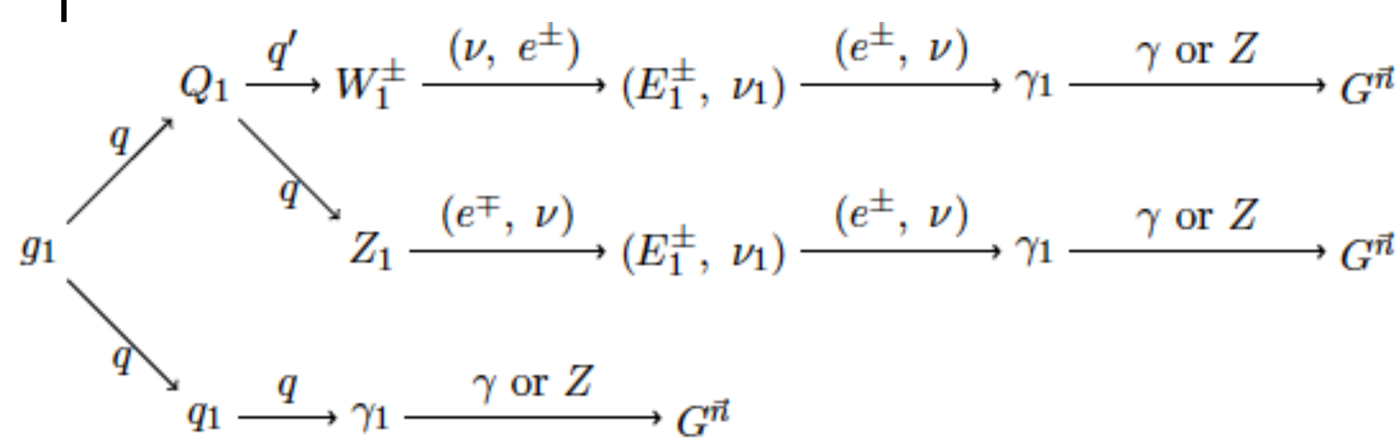
Multi-jet search (ATLAS-CONF-2017-022):

- 44 inclusive Signal Regions (SR) in Meff search strategy.
- SRs are characterized by increasing number of jets (2j - 6j) and $m_{\text{eff}}(\text{incl.})$

$$m_{\text{eff}}(\text{incl.}) = \sum_{p_T>50}^{N} p_T(j) + \text{MET}$$

- No excess of events above the SM background is observed.
- For each SR %95 C.L. upper limits are put on observable BSM cross-section.

Di-photon search (arXiv:1606.09150):



1203.1551 [hep-ph]

The parameter space of ‘fat-brane’ model after ATLAS searches

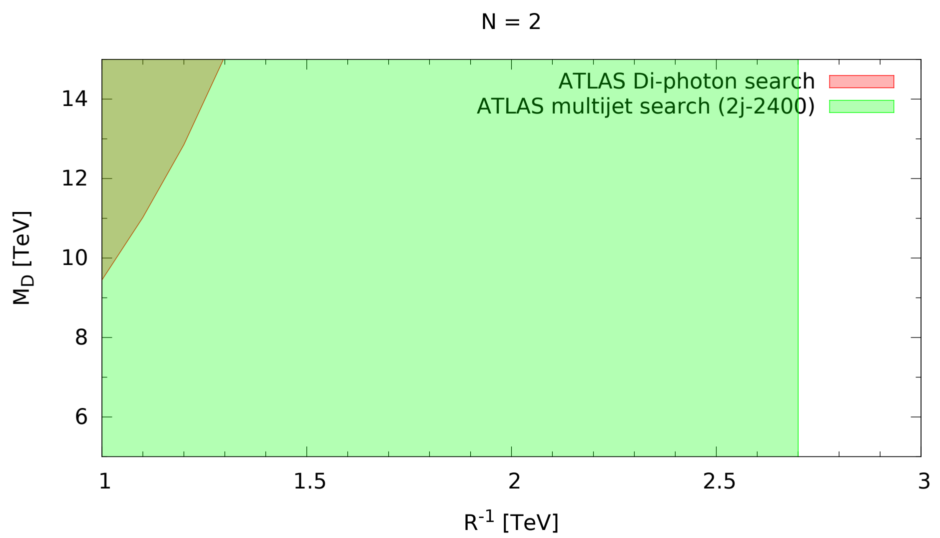
- The model is analyzed for N = 2, 4 and 6 and 1 small extra dimension.
- We assumed that $\Lambda R = 5$.
- $q^1 q^1, q^1 g^1 \text{ and } g^1 g^1$ are produced in PYTHIA along with ISR, FSR and fragmentation etc.
- GMD’s of level-1 KK particles are incorporated.
- In addition to $\gamma^1 \to \gamma + G^{\vec{n}}$ dominant decay (~72%), $\gamma^1 \to Z + G^{\vec{n}}$ (~28%)is also included.

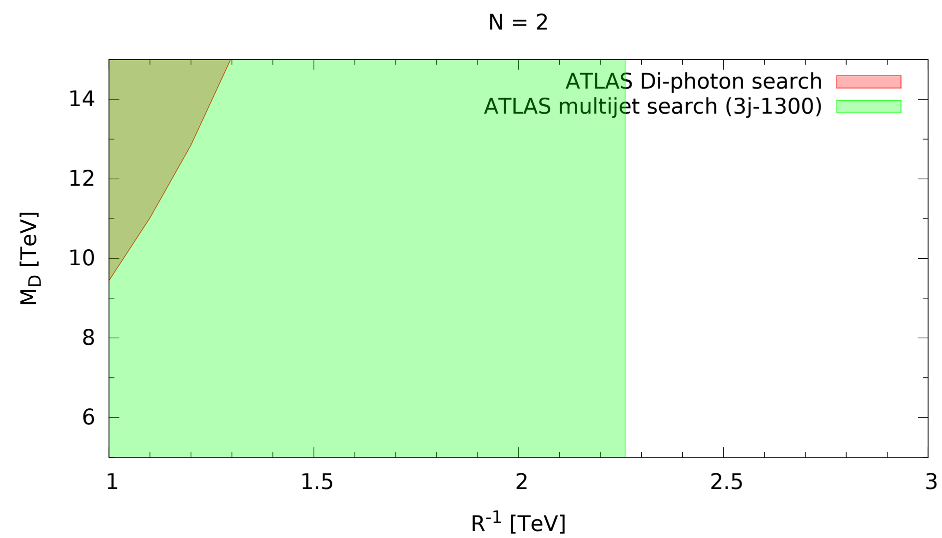
PRD 68, 084008 (2003)

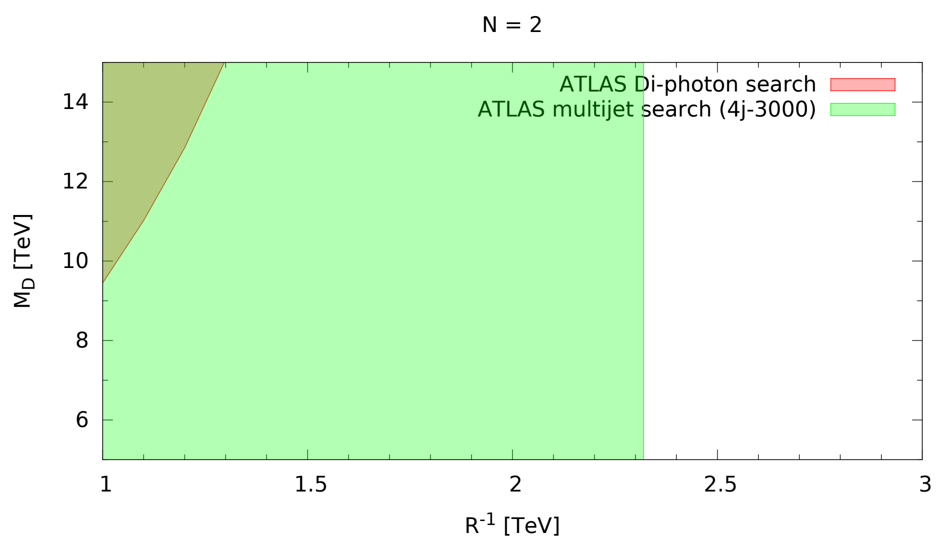
hep-ph/0510418

The parameter space of ‘fat-brane’ model after ATLAS searches [N = 2]

Exclusions from ATLAS Multi-jet and di-photon searches for N = 2 at 13 TeV in 2j, 3j and 4j Signal Regions.

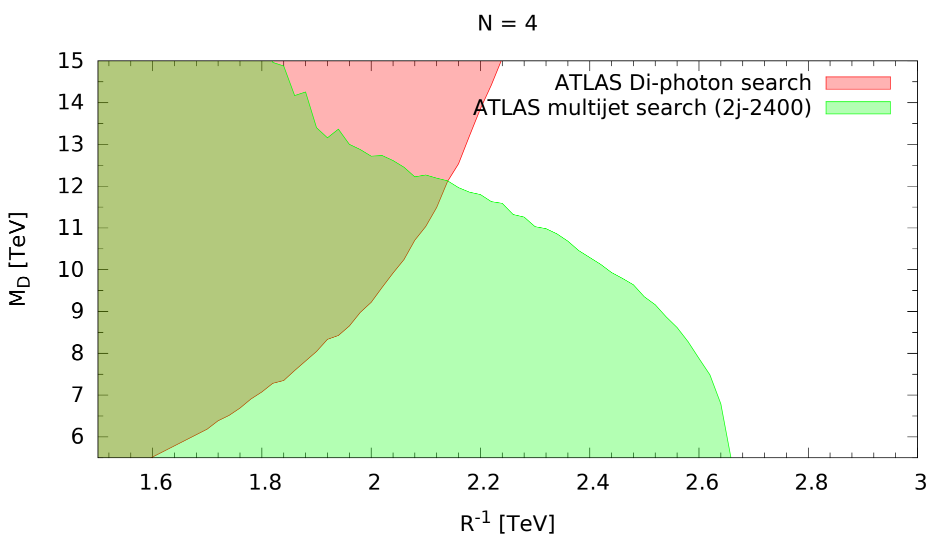


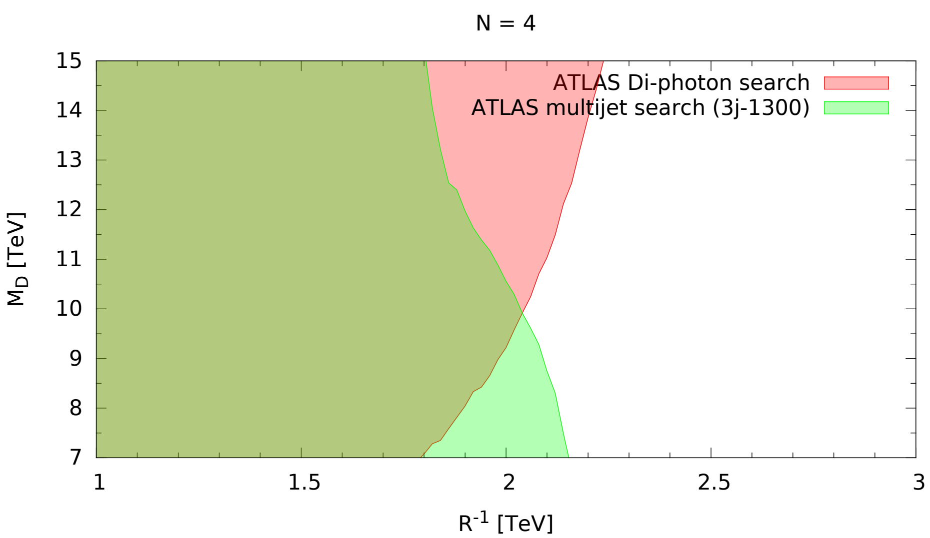


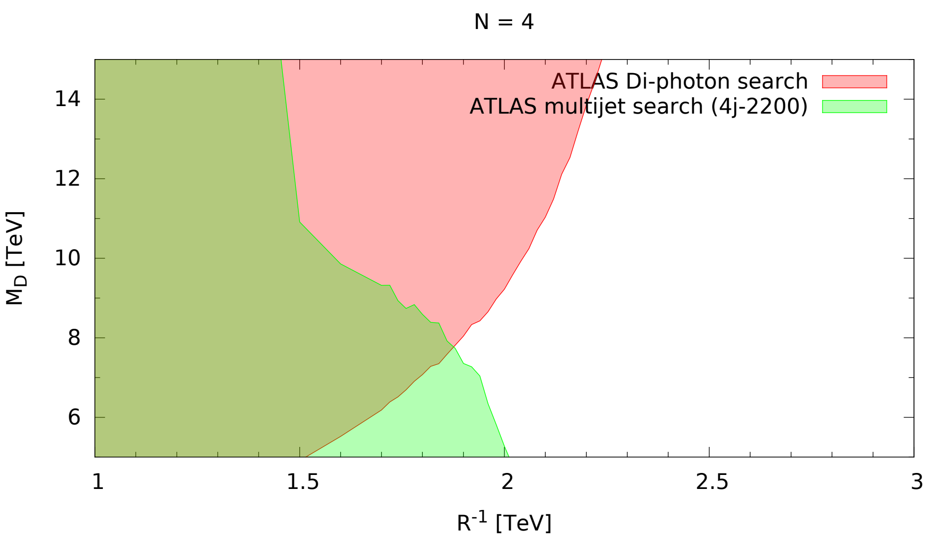


The parameter space of ‘fat-brane’ model after ATLAS searches [N = 4]

Exclusions from ATLAS Multi-jet and di-photon searches for N = 4 at 13 TeV in 2j, 3j and 4j Signal Regions.

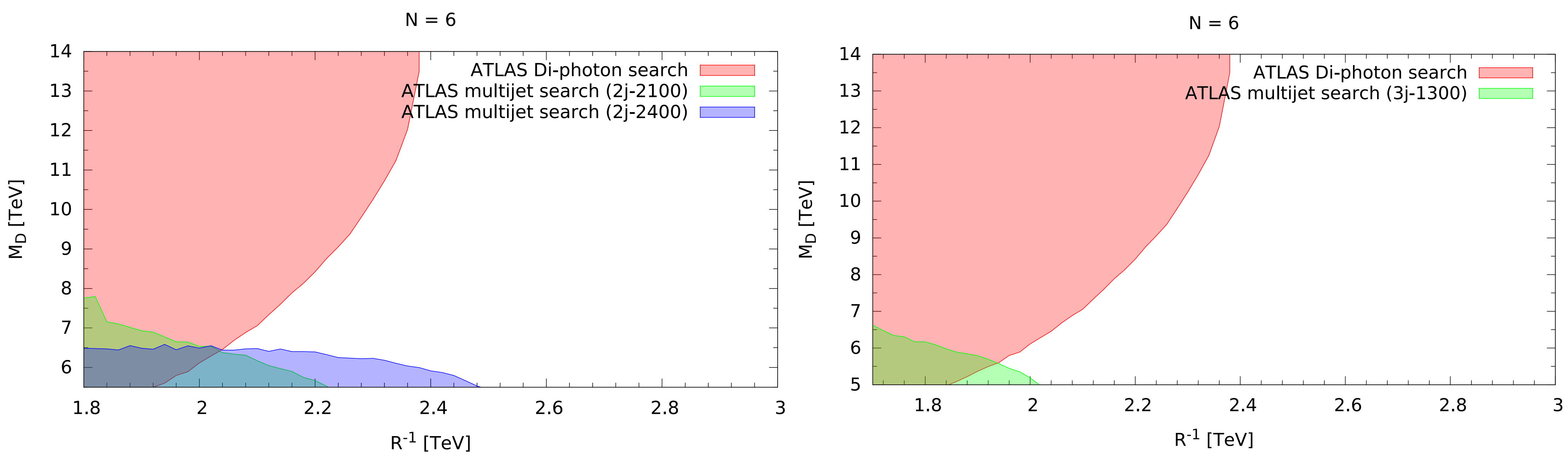






The parameter space of ‘fat-brane’ model after ATLAS searches [N = 6]

Exclusions from ATLAS Multi-jet and di-photon searches for N = 6 at 13 TeV in 2j, 3j Signal Regions.



Conclusions

- For N = 2 the multi-jet search is more pronounced than di-photon in excluding the ‘fat-brane’ model.
- Starting from N = 4 the di-photon analysis starts keeping up with the multi-jet results.
- For = 6 exclusion of the parameter space almost dominated by the di-photon analysis alone.
- Multi-jet and di-photon searches are complementary in excluding different parts of the model parameter space.
- For N = 2, 4 and 6 $(R^{-1}, M_D) = \Big\{(1.3, 15),\ (2.1,\ 12),\ (2.1, 6.5)\Big\}\ \mathrm{TeV}$ are excluded by both searches.

Thank you

Backup

The total decay width is obtained by summing over all possible gravity excitations with mass smaller than the decaying particle:

$$\Gamma = \sum_{\vec{n}} \Gamma_{\vec{n}} = \sum_{\vec{n}} \left[\Gamma_{h^{\vec{n}}} + \Gamma_{A^{\vec{n}}} + \Gamma_{\phi^{\vec{n}}} \right]$$

The gravity KK-states are nearly degenerate in mass is given by $\Delta m = 2\pi / r \sim \mathrm{eV}$ to keV

The mUED mass spectra:

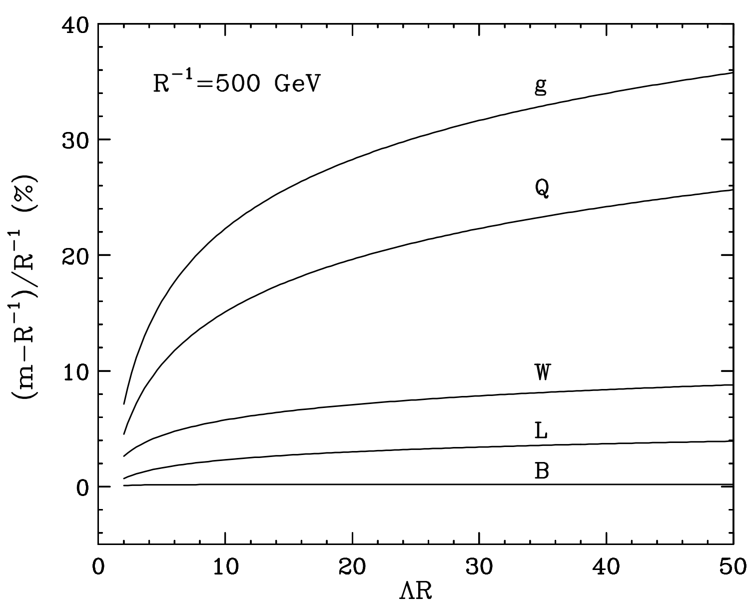


FIG. 2: *Radiative corrections (in %) to the spectrum of the first KK level for $R^{-1} = 500$ GeV, versus ΛR.*

hep-ph/020531

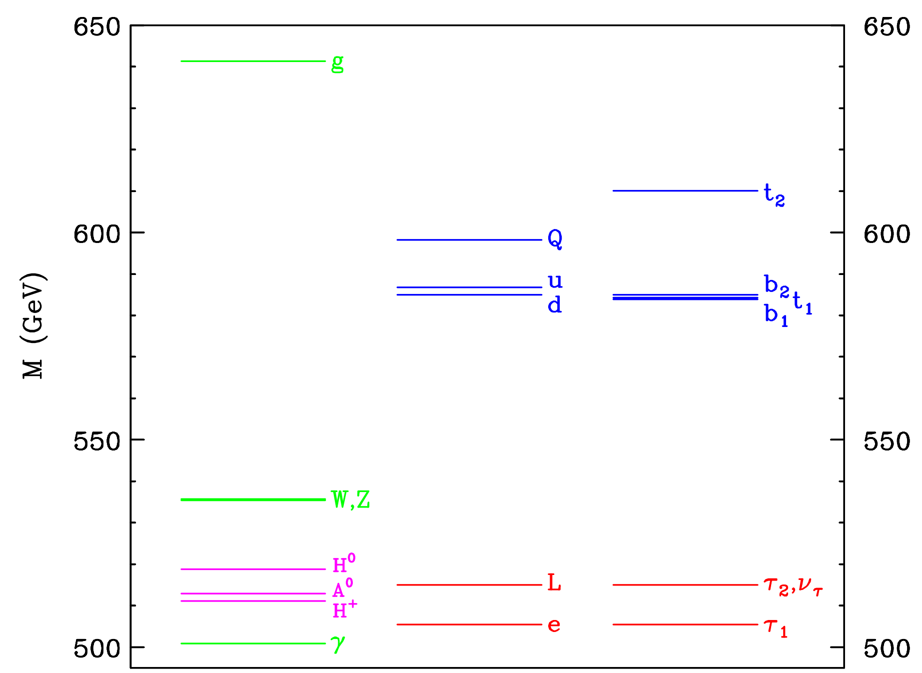


FIG. 1: *One-loop corrected mass spectrum of the first KK level in MUEDs for $R^{-1} = 500$ GeV, $\Lambda R = 20$ and $m_h = 120$ GeV.*

Backup

The (4+N)D metric, assumed to be approximately flat, is $\hat{g}_{\hat{\mu}\hat{\nu}} = \eta_{\hat{\mu}\hat{\nu}} + \hat{\kappa}\hat{h}_{\hat{\mu}\hat{\nu}}$ where

$$\hat{\kappa}^2 = 16\pi G^{(4+N)}$$

The higher dimensional (4+N) tensor consists of:

$$\hat{h}_{\hat{\mu}\hat{\nu}} = V_N^{-1/2} \begin{pmatrix} h_{\mu\nu} + \eta_{\mu\nu}\phi & A_{\mu i} \\ A_{\nu j} & 2\phi_{ij} \end{pmatrix}$$

The files can be KK expanded as:

$$h_{\mu\nu}(x,y) = \sum_{\vec{n}} h^{\vec{n}}_{\mu\nu}(x) \ \exp\left(i\frac{2\pi\vec{n}\cdot\vec{y}}{r}\right) ,$$

$$A_{\mu i}(x,y) = \sum_{\vec{n}} A^{\vec{n}}_{\mu i}(x) \ \exp\left(i\frac{2\pi\vec{n}\cdot\vec{y}}{r}\right) ,$$

$$\phi_{ij}(x,y) = \sum_{\vec{n}} \phi^{\vec{n}}_{ij}(x) \ \exp\left(i\frac{2\pi\vec{n}\cdot\vec{y}}{r}\right) , \qquad \vec{n} = \{n_1, n_2, \cdots, n_N\}$$