LHC Signals from Cascade Decays of Warped Vector Resonances

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K. Agashe, PD, S. Hong, R. Sundrum, arXiv:1608.00526

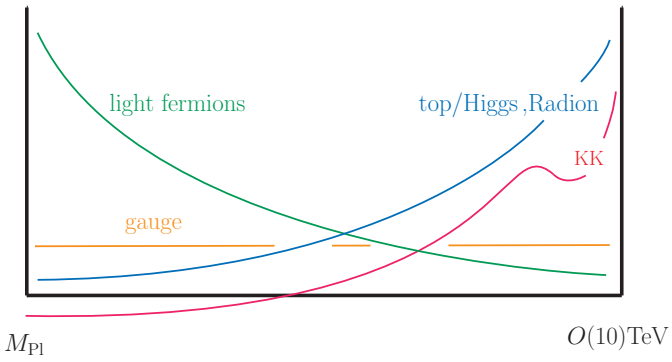
K. Agashe, J.Collins, PD, S. Hong, D. Kim, R. Mishra, arXiv:1612.00047

Outline

Motivation

Standard RS

[Randall, Sundrum,99]



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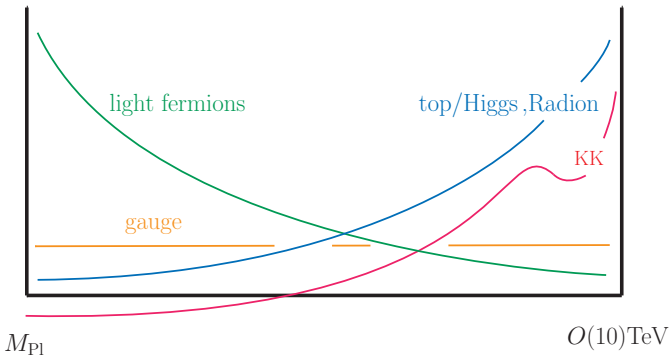

- Flavor constraints push KK scale to be $\gtrsim O(10)$ TeV.
- KK modes lie out of LHC reach?

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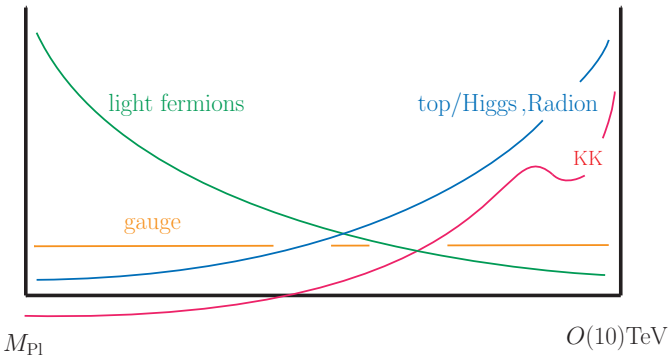

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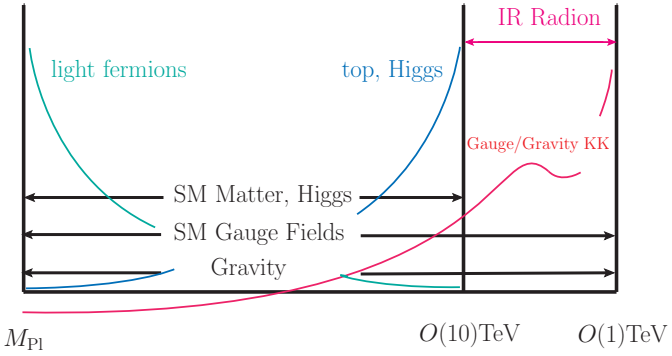
Extended RS

[Agashe,PD,Hong, Sundrum,16]

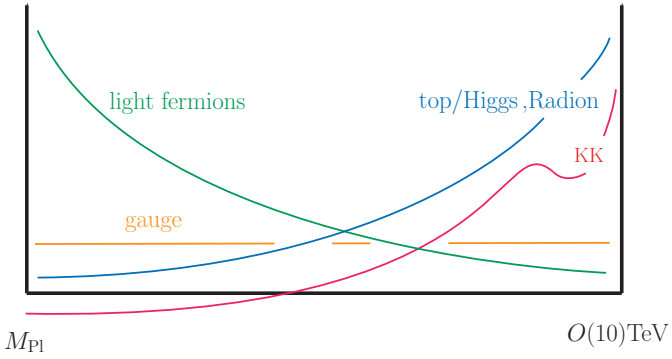


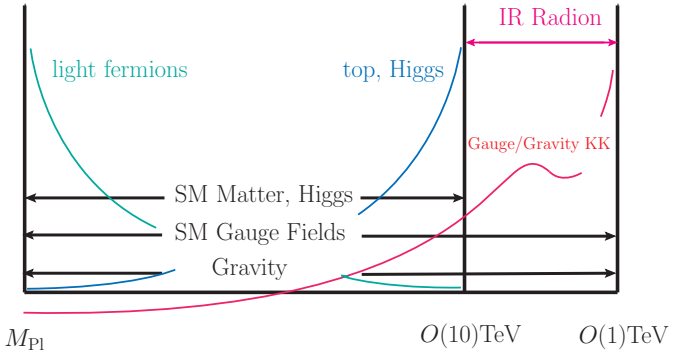
- Robust generalization of standard RS models.
- Extended RS framework can address flavor problem and also give interesting signals at LHC.

Extended RS framework

[Randall, Sundrum,99]

[Agashe, PD, Hong, Sundrum,16]



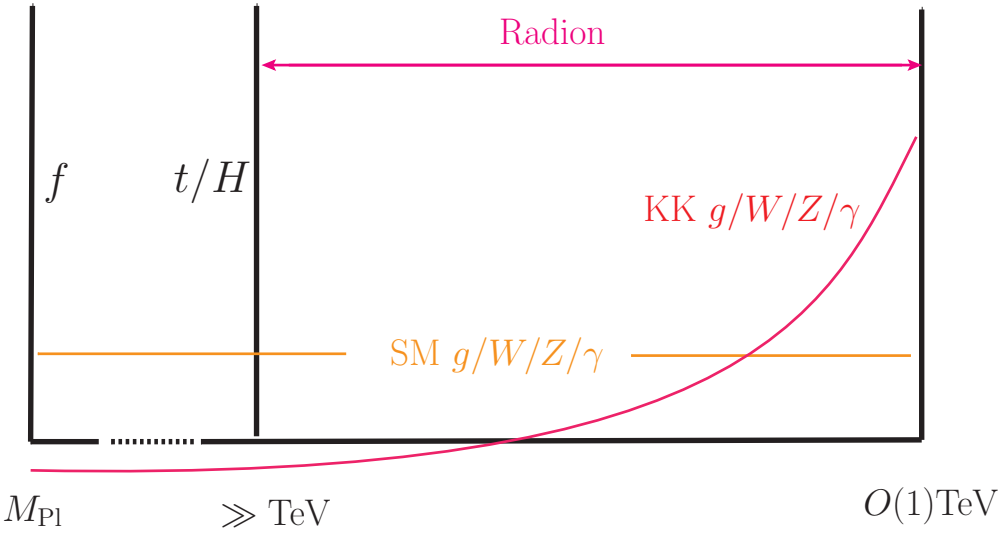


		Standard	Extended
KK gauge	Mass	$\gtrsim \mathcal{O}(10)$ TeV	a few TeV
	Decay	$t\bar{t}$, HH	$f\bar{f}$ (universally), radion $+\gamma/W/Z/g$
Radion	Mass	$\gtrsim \mathcal{O}(10)$ TeV/(a few)	$\mathcal{O}(1)$ TeV
	Decay	$t\bar{t}$, HH	$gg/WW/ZZ/\gamma\gamma$

- KK gauge bosons/ radions decay flavor universally to SM particles.
- KK gauge bosons could have significant coupling with radion and SM gauge boson .

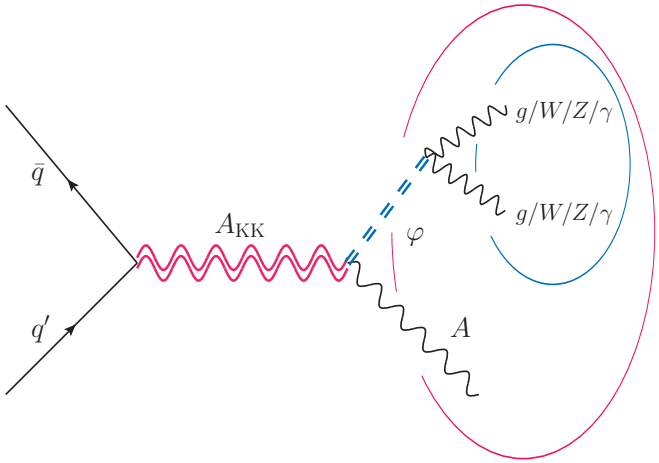
Simplified model

[Agashe, Collins, PD, Hong, Kim, Mishra,16]



- Keep only first KK gauge modes and radion.
- Couplings are mostly free parameters, which can cover a general class of theories.
- Middle brane is taken to be $\gg$ TeV. Flavor non-universal couplings to Higgs and tops are suppressed.

Signal channels



SM gauge bosons: $A = \{g, W, Z, \gamma\}$
KK gauge bosons : $A_{\rm KK}$
Radion : φ
Couplings : $g_{A_{\rm KK}}$,$g_{\rm grav}$

- Production/decays of KK gauge bosons

$$Q_A \frac{g_A^2}{g_{A_{\rm KK}}} A^\mu_{\rm KK} \bar{\psi}\gamma_\mu\psi$$

- Dominant decay channel of KK gauge bosons

$$\epsilon g_{\rm grav} \frac{g_A}{g_{A_{\rm KK}}} \frac{\varphi}{m_{\rm KK}} A_{\mu\nu} A^{\mu\nu}_{\rm KK}$$

- Radion decay channels

$$-\frac{1}{4}\left(\frac{g_A}{g_{A_{\rm KK}}}\right)^2 \frac{g_{\rm grav}}{m_{\rm KK}} \varphi A_{\mu\nu} A^{\mu\nu}$$

Signal channel

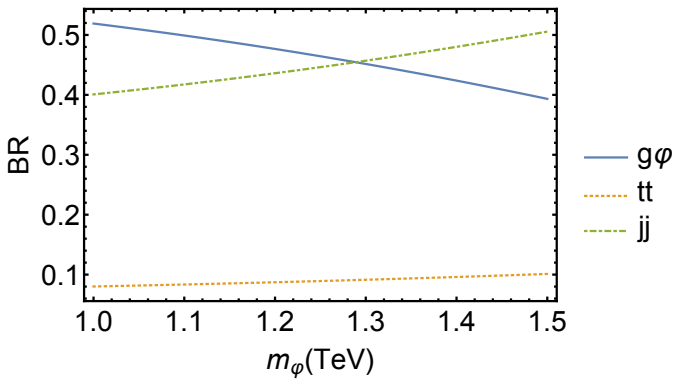
Three SM gauge boson final states with **two** invariant mass peaks corresponding to $A_{\rm KK}$ and φ

KK gluon&Radion

KK gluon

- Production: $q\ q$
- BR:

$$\frac{\mathrm{BR}(g_{\mathrm{KK}} \to qq)}{\mathrm{BR}(g_{\mathrm{KK}} \to \varphi g)} = \frac{g_g^2}{(\epsilon g_{\mathrm{grav}})^2 \left(1 - \left(\frac{m_\varphi}{m_{\mathrm{KK}}}\right)^2\right)^3}$$

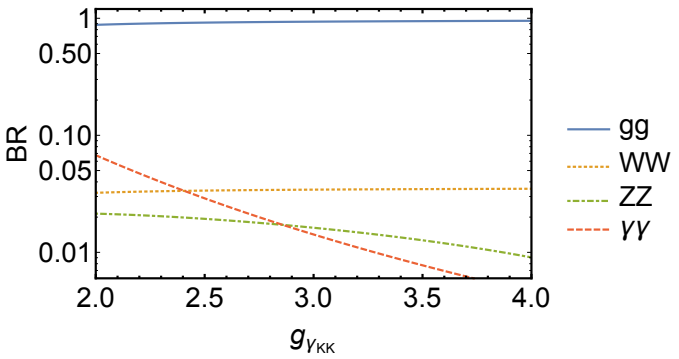


$g_{\mathrm{grav}} = 6,\ \epsilon = 0.5,\ m_{\mathrm{KK}} = 3\mathrm{TeV}$

Radion

- Production: $g\ g$
- BR:

$$\frac{\mathrm{BR}(\varphi \to gg)}{\mathrm{BR}(\varphi \to \gamma\gamma)} = \frac{8\frac{g_g^4}{g_{g_{\mathrm{KK}}}^4}}{\frac{g_\gamma^4}{g_{\gamma_{\mathrm{KK}}}^4}}$$



$g_{g_{\mathrm{KK}}} = g_{W_{\mathrm{KK}}} = 6$

Current bounds and parameter space: Jet+diphoton channel

$$g_{\mathrm{KK}} \to g\varphi \to g\gamma\gamma$$

Current constraints:

- For KK gluon:
  Dijet/Ditop: Suppressed by BR.
  Relevant channels: $qq \to g_{\mathrm{KK}} \to tt/jj$

- For Radion:
  Diphoton: Radion direct production.
  Relevant channel: $gg \to \varphi \to \gamma\gamma$
  Dijet: Weaker than diphoton

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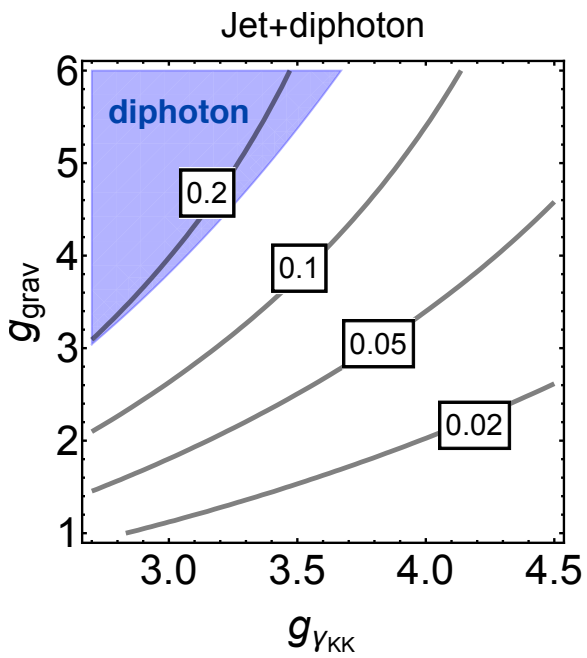
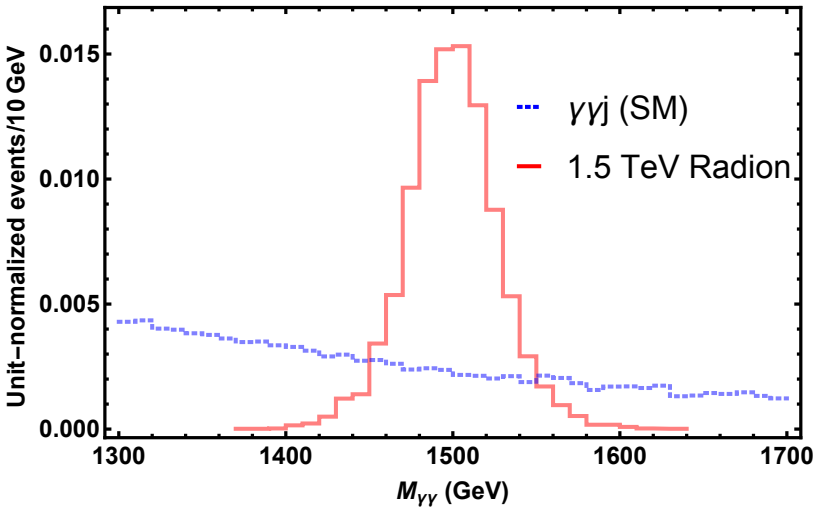
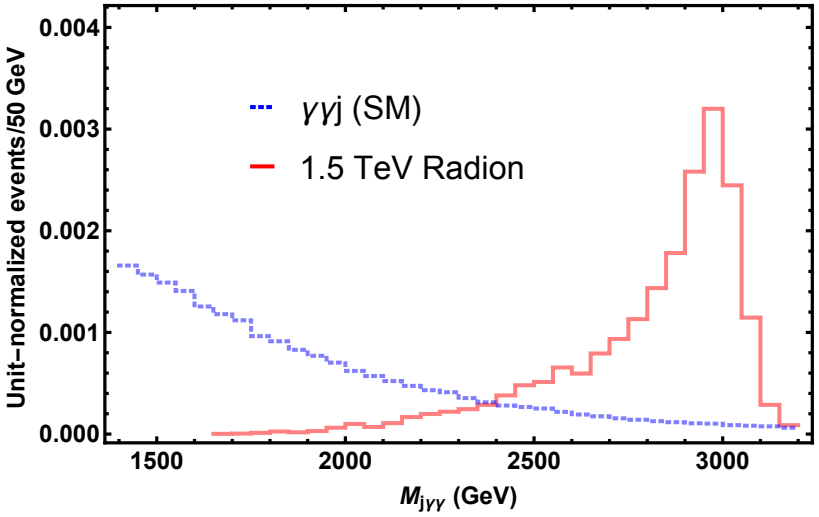


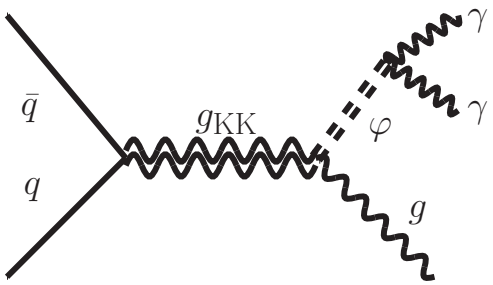
$$g_{W_{\rm KK}} = 6, g_{g_{\rm KK}} = 6, \epsilon = 0.5$$

$$m_{\rm KK} = 3{\rm TeV},\ {\rm m}_{\varphi} = 1.5{\rm TeV}$$

Jet+diphoton channel: Backgrounds and Signal







- Two invariant mass peaks are successfully reconstructed in this clean channel.
- Backgrounds: $j\gamma\gamma$, $jj\gamma$ (jet fakes photon).
- Significance : 5.4σ with 300fb^{-1}@ 14 TeV LHC

Current bounds and parameter space: Trijet channel

$$g_{\mathrm{KK}} \to g\varphi \to ggg$$

Current constraints:

- **Dijet/Ditop**: Suppressed by BR.
- **Diphoton**: Radion direct production
- **Trijet(Signal) channel**: Combinatorics weaken the dijet bounds.

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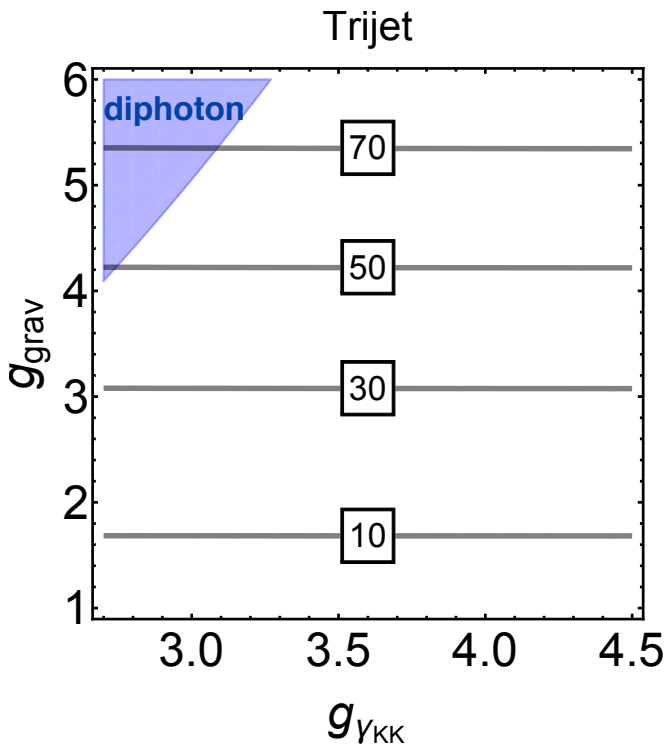

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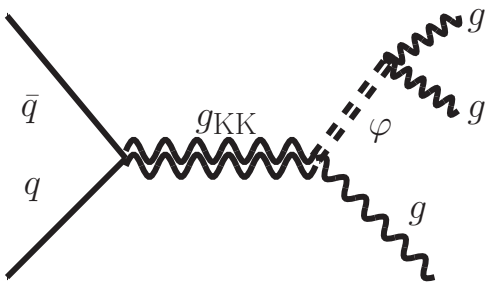
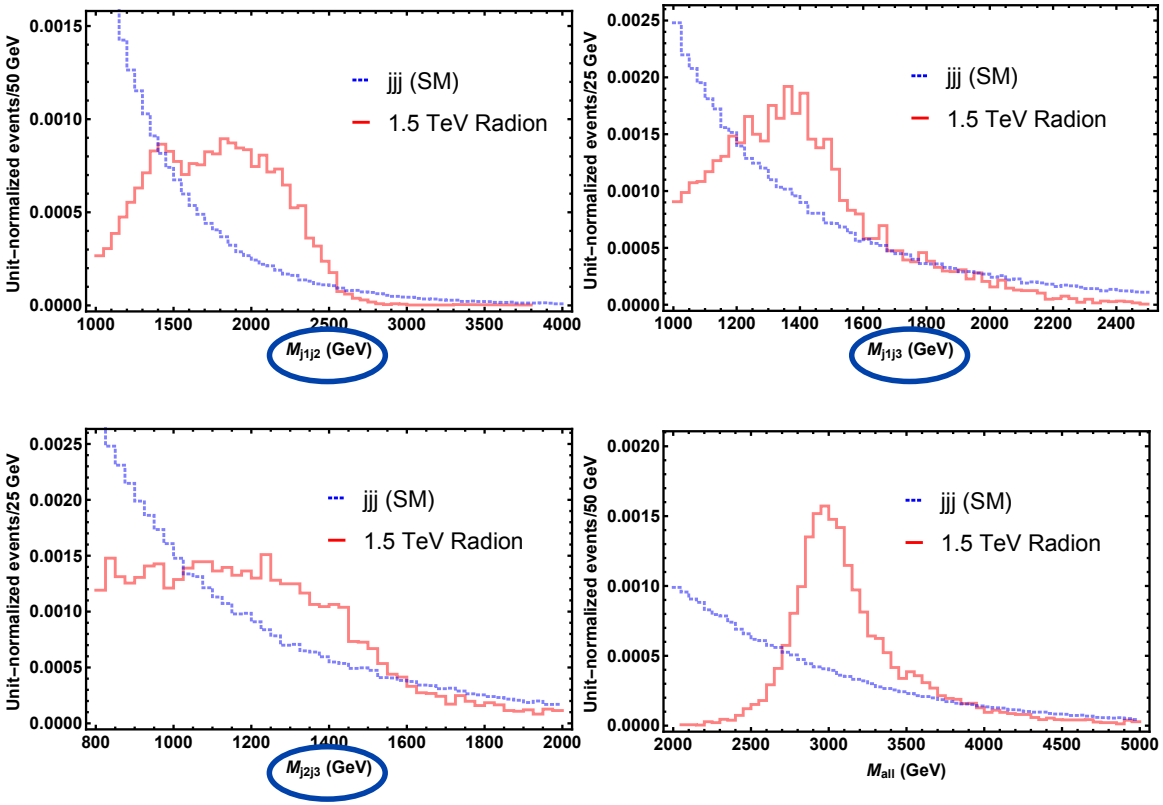
Trijet channel: Backgrounds and Signal





- Combinatorics makes the two-jet invariant mass distribution broad.
- Various combinations of dijet and trijet invariant mass cuts are all important.
- Backgrounds: jjj
- Significance : 5.3σ with 300fb^{-1}@ 14 TeV LHC

Conclusion

- The extended RS framework can address flavor problem and also provide new signals accessible at LHC.
- New signals with **three** gauge boson final states arise from cascade decays of KK gauge boson and radion (**two** intermediate on-shell particles).
- 5σ significance can be achieved in both jet+diphoton and trijet channel of KK gluon.
- More possibilities in other channels: photon+dijet (KK photon), W+dijet (KK W), jet+diboson (KK gluon) etc.

Thank you !

Backup: Allowed parameter space

- $g_{A_{\rm KK}}$

$$g_{\gamma_{\rm KK}} = \frac{g_{W_{\rm KK}} g_{B_{\rm KK}}}{\sqrt{g^2_{W_{\rm KK}} + g^2_{B_{\rm KK}}}}\,, \quad g_{Z_{\rm KK}} = \sqrt{g^2_{W_{\rm KK}} + g^2_{B_{\rm KK}}}$$

$$3 \lesssim g_{g_{\rm KK}}\,, g_{W_{\rm KK}}\,, g_{B_{\rm KK}} \lesssim 6$$

- $g_{\rm grav}$

$$1 \lesssim g_{\rm grav} \lesssim 6$$

- Parameter ϵ

$$\frac{1}{4} \lesssim \epsilon \lesssim \frac{1}{2}$$