COLLEGE OF
COMPUTER, MATHEMATICAL,
& NATURAL SCIENCES
DEPARTMENT OF PHYSICS

Signals of KK Graviton from Extended Warped Extra Dimensions at the LHC (II)

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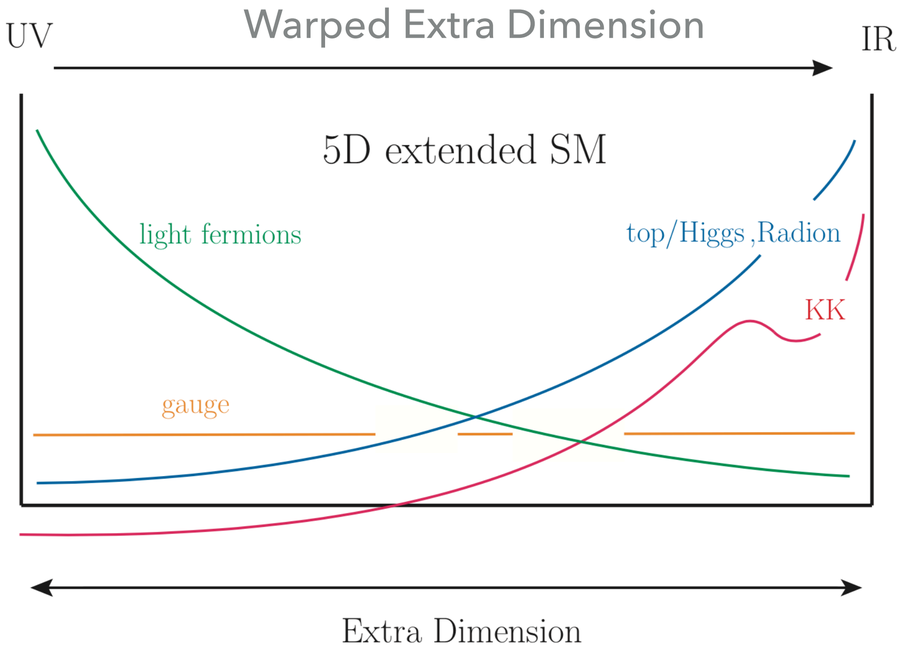
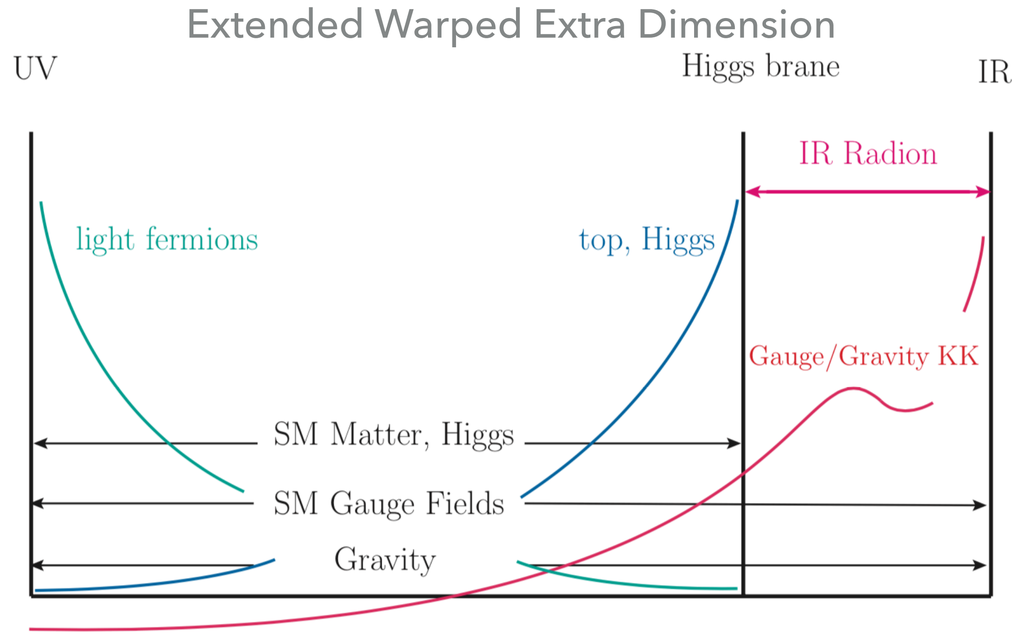
(Based on work by K. Agashe, D. Kim, M. Ekhterachian, D. Sathyan)

Outline

- Extended warped extra dimension model
- Overview of two 4-jet signals predicted by model
    1. Radion channel: $pp \rightarrow Gr_{KK} \rightarrow \phi\phi \rightarrow jjjj$
    2. KK gluon channel: $pp \rightarrow Gr_{KK} \rightarrow g_{KK}j \rightarrow \phi jj \rightarrow jjjj$
- CMS dijet bounds on BSM particles
- Event generation
- Analysis Part 1: Heavy KK gluon (radion channel dominates)
- Analysis Part 2: Light KK gluon (both channels contribute)
- Conclusions and Outlook

Extended warped extra dimension model





- Warped extra dimension contains KK graviton couplings to top, Higgs, Radion, SM gauge bosons
- Extended model suppresses KK graviton couplings to top and Higgs, leaving couplings to IR radion, KK gauge bosons, and SM gauge bosons

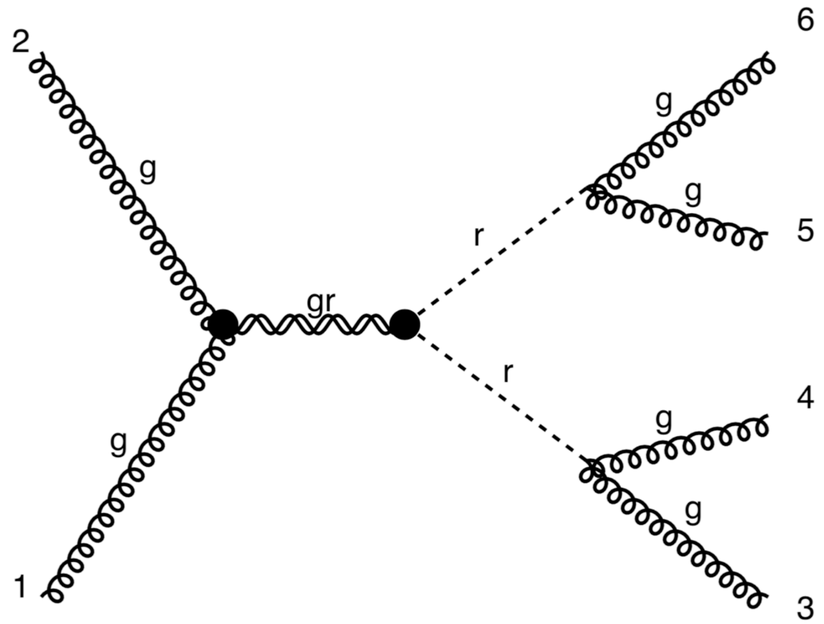
Radion Channel

- "Antler topology": large KK graviton resonance with two smaller, identical radion resonances Han, Kim, Song 2013
- Coupling of gluon-gluon-KK graviton:

$$g_{g-g-Gr_{KK}} \propto g_{grav}\left(\frac{g_s}{g_{g_{KK}}}\right)^2$$

- Coupling of KK graviton to 2 radions:

$$g_{Gr_{KK}-R-R} \propto g_{grav}$$



KK Gluon Channel

- "Sequential Cascade" topology: Three hierarchical resonances: KK graviton, lighter KK gluon, and lightest radion
- Coupling of KK graviton to KK gluon and SM gluon:

$$g_{Gr_{KK}-g_{KK}-g} \propto g_{grav}\frac{g_s}{g_{g_{KK}}}$$

- Coupling of KK gluon to radion and SM gluon:

$$g_{g_{KK}-R-g} \propto \epsilon g_{grav}\frac{g_s}{g_{g_{KK}}}$$

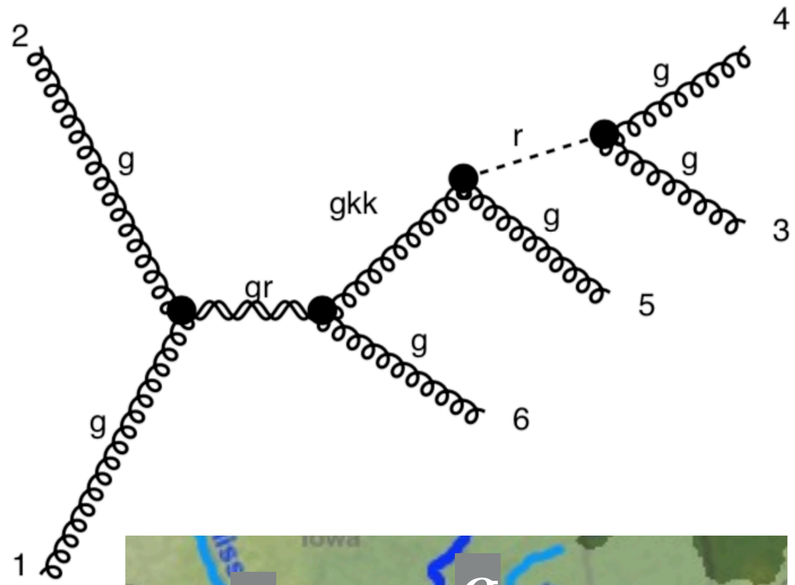


Image taken from Wikipedia: https://en.wikipedia.org/wiki/Mississippi_River_System

KK graviton dijet bounds by CMS

- KK graviton produces gg dijet

- All KK graviton benchmarks are safely within current CMS dijet bounds

	M_{Gr}	$M_{g_{KK}}$	g_{grav}	$\sigma_{pp\to Gr_{KK}}$	$\frac{\Gamma_{Gr_{KK}\to gg}}{\Gamma_{Gr_{KK}}}$	σB	CMS σBA
1	3.5	3	5	11.1	0.52	5.8	23.3
2	3.5	3	6	16.0	0.52	8.4	23.3
3	3.5	3.25	5	11.1	0.66	7.4	23.3
4	3.5	3.25	6	16.0	0.66	10.6	23.3
5	4	3	5	2.9	0.58	1.7	13.7
6	4	3	6	4.1	0.58	2.4	13.7
7	4	3.75	5	2.9	0.62	1.8	13.7
8	4	3.75	6	4.1	0.62	2.6	13.7

Table 12: KK graviton dijets at LHC13 with varying parameters. Parameter $g_{g_{KK}} = 3$ for all points to maximize dijet cross section. KK graviton dijet production is independent of ϵ. All parameter sets satisfy the CMS dijet bound. See Table 29 for CMS bounds on KK gluon.

Masses in TeV Cross sections in fb

arXiv:1806.00843v2, CMS collaboration

Radion dijet bounds by CMS

- Radion produces gg dijet

- All benchmarks used satisfy current CMS dijet bounds.

Masses in TeV Cross sections in pb

	$M_{g_{KK}}$	$g_{g_{KK}}$	g_{grav}	$\sigma_{pp\to R\to gg}$
1	3	3	5	2.00
2	3	3	6	**2.88**
3	3	3.25	5	1.45
4	3	3.25	6	2.09
5	3.25	3	5	1.70
6	3.25	3	6	2.45
7	3.25	3.25	5	1.23
8	3.25	3.25	6	1.78
9	3.75	3	5	1.28
10	3.75	3	6	1.84
11	3.75	3.25	5	0.93
12	3.75	3.25	6	1.34

Table 12: This table contains radion dijets at LHC13 with varying parameters. Radion mass is 1 TeV for all points. Branching ratio of radion to two SM gluons is 100%. Radion production cross section is independent of M_{Gr} and ϵ. CMS observed dijet bound is $\sigma BA = 2.60$ pb. All runs except run 2 pass the cut before imposing any estimated acceptance. Imposing acceptance of 97.4% still does not put run 2 below the CMS dijet bound, but we don't use that point for any of our benchmarks, since that point also fails the KK gluon dijet bound. See Table 28 for CMS bounds on KK gluon.

arXiv:1806.00843v2, CMS collaboration

KK gluon dijet bounds by CMS

- KK gluon produces $q\bar{q}$ dijet
- KK gluon dijet bound is harder to satisfy at lower masses, but there are multiple parameter sets
- Nearly all parameter sets pass with 3.75 TeV KK gluon

	$M_{g_{KK}}$	$g_{g_{KK}}$	g_{grav}	ϵ	$\sigma_{pp\to g_{KK}}$	$\frac{\Gamma_{g_{KK}\to q\bar{q}}}{\Gamma_{g_{KK}}}$	σB	CMS σBA
1	3	3.25	5	0.75	129	0.372	48.0	26.8
2	3	3.25	6	0.75	129	0.292	37.7	26.8
3	3	3.25	5	1	129	0.25	32	26.8
4	3	3.25	5.5	1	129	0.216	27.8	26.8
5	3	3.25	6	1	129	0.19	**24.3**	26.8
6	3	3.5	6	0.75	111	0.292	32	26.8
7	3	3.5	5	1	111	0.25	28	26.8
8	3	3.5	5.5	1	111	0.216	**24.0**	26.8
9	3	3.5	6	1	111	0.19	**21**	26.8
10	3.25	3	5	0.75	85.9	0.358	30.8	17.8
11	3.25	3	6	0.75	85.9	0.279	24.0	17.8
12	3.25	3	5	1	85.9	0.239	20.5	17.8
13	3.25	3	6	1	85.9	0.179	**15.4**	17.8
14	3.25	3.25	5	0.75	73.2	0.358	26.2	17.8
15	3.25	3.25	6	0.75	73.2	0.279	20.4	17.8
16	3.25	3.25	5	1	73.2	0.239	**17.5**	17.8
17	3.25	3.25	6	1	73.2	0.179	**13.1**	17.8
18	3.25	3.5	6	0.75	31.7	0.261	**8.3**	17.8

Masses in TeV Cross sections in fb

arXiv:1806.00843v2, CMS collaboration

KK gluon dijet bounds by CMS

- KK gluon produces $q\bar{q}$ dijet
- KK gluon dijet bound is harder to satisfy at lower masses, but there are multiple parameter sets
- Nearly all parameter sets pass with 3.75 TeV KK gluon

	$M_{g_{KK}}$	$g_{g_{KK}}$	g_{grav}	ϵ	$\sigma_{pp\to g_{KK}}$	$\frac{\Gamma_{g_{KK}\to q\bar{q}}}{\Gamma_{g_{KK}}}$	σB	CMS σBA
19	3.75	3	5	0.75	28.7	0.337	9.67	9.02
20	3.75	3	6	0.75	28.7	0.261	**7.49**	9.02
21	3.75	3	5	1	28.7	0.222	**6.37**	9.02
22	3.75	3	6	1	28.7	0.166	**4.76**	9.02
23	3.75	3.25	6	0.5	24.4	0.443	10.8	9.02
24	3.75	3.25	5	0.75	24.4	0.337	**8.22**	9.02
25	3.75	3.25	6	0.75	24.4	0.261	**6.37**	9.02
26	3.75	3.25	5	1	24.4	0.225	**5.5**	9.02
27	3.75	3.25	6	1	24.4	0.166	**4.1**	9.02

Table 30: This table contains KK gluon dijets at LHC13 with varying parameters. KK graviton mass is 4 TeV and radion mass is 1 TeV for all points. Masses are in TeV and cross sections are in fb. Refer to Table 13 for CMS bounds on 1 TeV radion.

Masses in TeV

Cross sections in fb

arXiv:1806.00843v2, CMS collaboration

Event generation

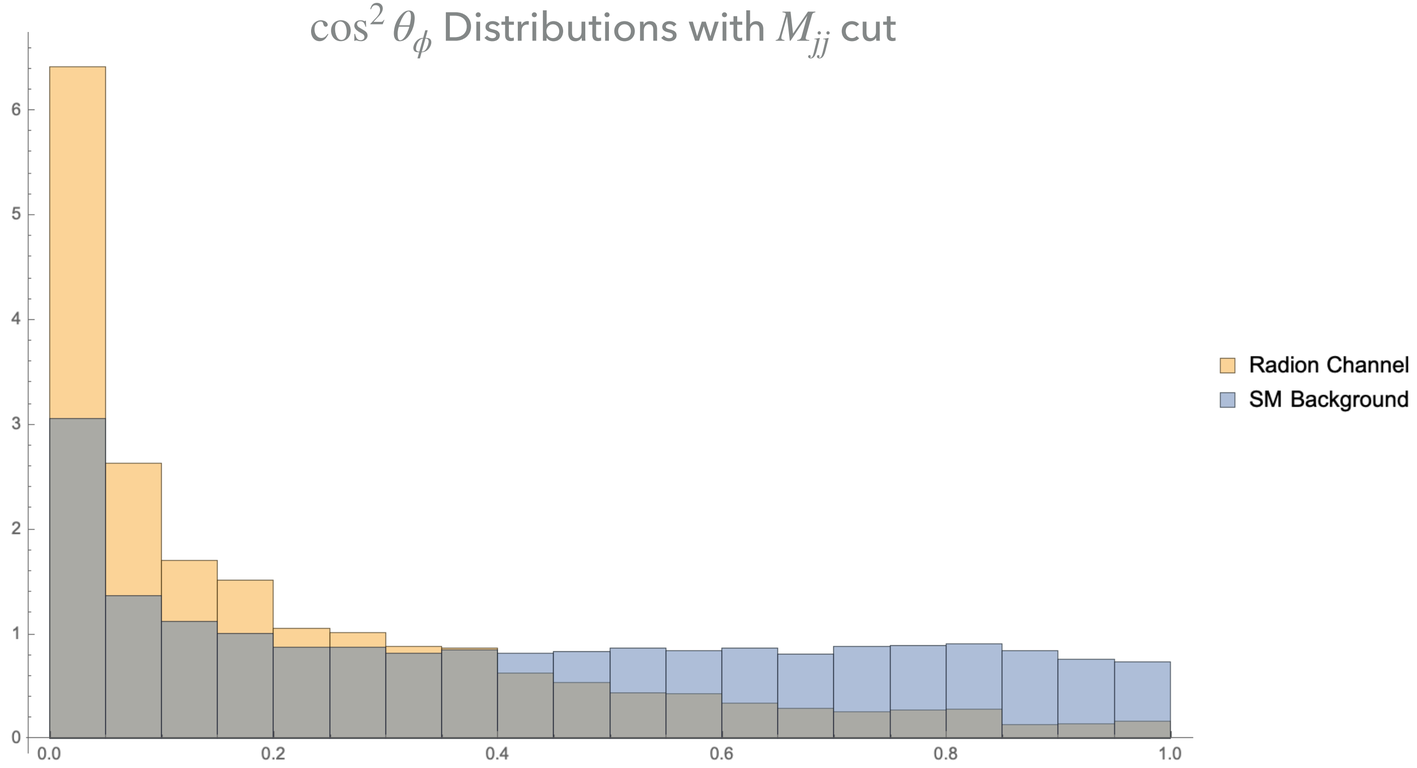
- Parton level events generated using MadGraph's mg5_aMC with PDF set NN23LO1 and $\sqrt{s} = 14$ TeV pp collider
  - Events sent to Pythia6 and Delphes for showering, hadronization, detector effects
- 500k background events generated, 10k signal events generated
- Keep 4 highest p_T jets in each event

Part 1: Heavy KK Gluon

- KK gluon mass is close to KK graviton: KK gluon channel now heavily suppressed (negligible)
- 4-jet signal is dominated by decay to two radions
- Focus on antler topology cuts:
  - M_{4j}: 4-jet invariant mass should match KK graviton mass
  - M_{jj}: two dijet invariant masses should match radion mass
  - $\cos^2\theta_\phi$: angle between one radion and KK graviton boost direction in KK graviton rest frame peaks at $\pi/2$ and $-\pi/2$

Signal and Background $\cos^2\theta_\phi$ Distributions

- Peaked signal distribution is a feature of spin-2 KK graviton
- SM background distribution is relatively flat
- Requiring events with $\cos^2\theta_\phi \leq 0.2$ improves significance



arXiv:hep-ph/0701186
Agashe, Davoudiasl, Perez, Soni

BP1: 4 TeV KK Graviton, 3.75 Tev KK Gluon, 1 TeV Radion

- Model parameter set:

  $g_{grav} = 6,\ g_{g_{KK}} = 3.0,\ \epsilon = 0.75$

- Imposing antler topology cuts, then impose harder p_T cuts on all jets
- Both channels considered signal
- 5σ at 3000 fb^{-1} obtained with multiple parameter sets

Cross sections in fb

Antler Cuts on Part I BP1	KK Gluon	Radion	pp-$jjjj$
No cuts	0.18	2.09	$1 * 10^{10}$
Pre-selection cuts (η, Δ_r)	0.16	1.99	–
p_T pre-selection cuts	–	–	54300
$N_j \geq 4$	0.16	1.99	53700
$M_{4j} \in [3500, 4100]$ GeV	0.06	0.94	3380
$M_{jj} \in [750, 1000]$ GeV	$6 * 10^{-3}$	0.34	147
$\cos^2\theta_{RR} \leq 0.2$	$3 * 10^{-3}$	0.22	13.1
$p_{T,[j1,j2,j3,j4]} \geq [800, 700, 500, 200]$ GeV	$1.2 * 10^{-3}$	0.13	1.19
S/B	$1 * 10^{-3}$	0.11	–
$S/\sqrt{B}$ $(\mathcal{L} = 300\ \text{fb}^{-1})$	0.02	2.1	–
$S/\sqrt{B}$ $(\mathcal{L} = 3000\ \text{fb}^{-1})$	0.06	6.7	–
Combined $S/\sqrt{B}$ $(\mathcal{L} = 3000\ \text{fb}^{-1})$	–	6.8	–

Table 20: Cut flows at LHC14 with 4 TeV KK graviton mass, 3.75 KK gluon mass, 1 TeV radion mass, with $g_{grav} = 6$, $\epsilon = 0.75$, $g_{gKK} = 3.0$. Graviton production cross section is 7.4 fb. This has been scaled by the branching ratios to get the cross section without pre-selection cuts. Our applied pre-selection cuts are the following: ptj1min $\geq$ 600 GeV, ptj2min $\geq$ 400 GeV, ptj3min $\geq$ 200 GeV, ptj4min $\geq$ 100 GeV, $|\eta|_j \leq 2.5$, with all other default MadGraph pre-selection cuts. The KK gluon signal with the same cuts has just 0.05σ significance with 3000 fb^{-1} luminosity.

BP2: 3.5 TeV KK Graviton, 3.25 TeV KK Gluon, 1 TeV Radion

- Model parameters:

  $g_{grav} = 5,\ g_{g_{KK}} = 3.25,\ \epsilon = 0.75$

- Lower KK graviton mass gives bigger signal cross section

Antler Cuts on Part I BP2	KK Gluon	Radion	pp-$jjjj$
No cuts	0.45	3.68	$1 * 10^{10}$
Pre-selection cuts (η, Δ_r)	0.39	3.50	–
p_T pre-selection cuts	–	–	54300
$N_j \geq 4$	0.39	3.50	53700
$M_{4j} \in [3100, 3600]$ GeV	0.14	1.35	4970
$M_{jj} \in [750, 1000]$ GeV	$2.0 * 10^{-2}$	0.51	285
$\cos^2 \theta_{RR} \leq 0.2$	$8.2 * 10^{-3}$	0.35	35
$p_{T,[j1,j2,j3,j4]} \geq [800, 700, 400, 200]$ GeV	$2.6 * 10^{-3}$	0.20	4.7
S/B	$5.5 * 10^{-4}$	0.04	–
$S/\sqrt{B}$ $(\mathcal{L} = 300\ \text{fb}^{-1})$	0.02	1.6	–
$S/\sqrt{B}$ $(\mathcal{L} = 3000\ \text{fb}^{-1})$	0.07	5.1	–
Combined $S/\sqrt{B}$ $(\mathcal{L} = 3000\ \text{fb}^{-1})$	–	5.1	–

Table 25: All cross sections are in fb. Cut flows at LHC14 with 3.5 TeV KK graviton mass, 3.25 TeV KK gluon mass, 1 TeV radion mass, with $g_{grav} = 5$, $\epsilon = 0.75$, $g_{g_{KK}} = 3.25$. Graviton production cross section is 13.3 fb. Our applied pre-selection cuts are the following: ptj1min $\geq$ 600 GeV, ptj2min $\geq$ 400 GeV, ptj3min $\geq$ 200 GeV, ptj4min $\geq$ 100 GeV, $|\eta|_{j,b} \leq 2.5$, $\Delta r_{j,b} \geq 0.4$ with all other default MadGraph pre-selection cuts.

Part 2: Light KK Gluon (3 TeV)

- KK graviton to KK gluon mass gap is bigger
  - KK gluon branching ratio is largest –> Focus on sequential cascade topology

- Sequential cascade topology cuts:
  - M_{4j}: 4-jet invariant mass should match KK graviton mass
  - M_{3j}: 3-jet invariant mass should match KK gluon mass
  - M_{jj}: dijet invariant masses should match radion mass

BP1: 4 TeV KK Graviton, 3 TeV KK Gluon, 1 TeV Radion

- Model parameters:

  $g_{grav} = 6,\ g_{g_{KK}} = 3.25,\ \epsilon = 1$

- KK gluon channel has bigger cross section, but both channels contribute

- Background has higher acceptance with cascade cuts compared to antler cuts, reducing significance

Cross sections in fb

Cascade Cuts on Part II BP1	KK Gluon	Radion	pp-$4j$
No cuts	2.55	0.79	$1 * 10^{10}$
Pre-selection cuts (η, Δ_r)	2.22	0.75	–
p_T pre-selection cuts	–	–	54300
$N_j \geq 4$	2.22	0.75	53700
$M_{4j} \in [3100, 4800]$ GeV	1.63	0.62	9230
$M_{3j} \in [2500, 3400]$ GeV	1.57	0.57	8110
$M_{jj} \in [700, 1100]$ GeV	1.13	0.49	4960
$p_{T,[j1,j2,j3,j4]} \geq [850, 750, 550, 250]$ GeV	0.39	0.22	93.4
S/B	0.0038	0.0023	–
$S/\sqrt{B}$ $(\mathcal{L} = 300\ \text{fb}^{-1})$	0.63	0.38	–
$S/\sqrt{B}$ $(\mathcal{L} = 3000\ \text{fb}^{-1})$	2.0	1.2	–
Combined $S/\sqrt{B}$ $(\mathcal{L} = 3000\ \text{fb}^{-1})$	3.2	–	–

Table 34: Cut flows at LHC14 with 4 TeV KK graviton, 3 TeV KK gluon, 1 TeV radion, with $g_{grav} = 6$, $g_{g_{KK}} = 3.25$, $\epsilon = 1$. Our applied pre-selection cuts are the following: ptj1min $\geq$ 600 GeV, ptj2min $\geq$ 400 GeV, ptj3min $\geq$ 200 GeV, ptj4min $\geq$ 100 GeV, $|\eta|_j \leq 2.5$, $\Delta r_j \geq 0.4$ with all other default MadGraph pre-selection cuts. Branching ratio of radion to 2 SM gluons is 100%.

BP2: 3.5 TeV KK Graviton, 3 TeV KK Gluon, 1 TeV Radion

- Model parameters:

  $g_{grav} = 6,\ g_{g_{KK}} = 3.25,\ \epsilon = 1$

- At lower KK graviton mass, channels have similar cross sections

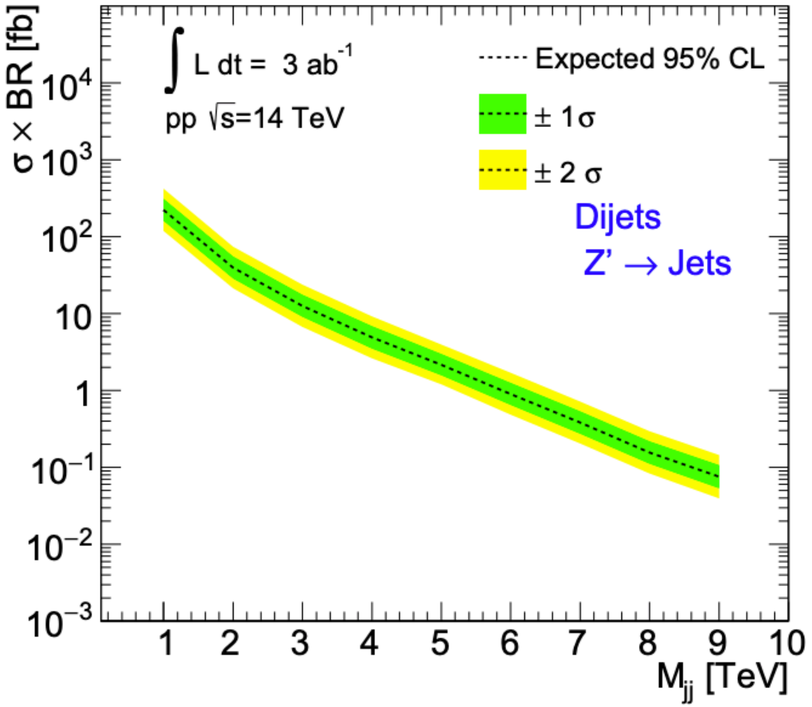
Cross sections in fb

Cascade Cuts on Part II BP2	KK Gluon	Radion	pp-$4j$
No cuts	4.23	4.08	$1 * 10^{10}$
Pre-selection cuts (η, Δ_r)	3.68	3.88	–
p_T pre-selection cuts	–	–	54300
$N_j \geq 4$	3.68	3.88	53700
$M_{4j} \in [2900, 4000]$ GeV	2.17	2.54	10150
$M_{3j} \in [2500, 3400]$ GeV	1.96	2.27	9300
$M_{jj} \in [700, 1100]$ GeV	1.51	1.98	5600
$p_{T,[j1,j2,j3,j4]} \geq [950, 650, 350, 250]$ GeV	0.49	0.84	195
S/B	0.0025	0.0043	–
$S/\sqrt{B}$ $(\mathcal{L} = 300\ \text{fb}^{-1})$	0.61	1.0	–
$S/\sqrt{B}$ $(\mathcal{L} = 3000\ \text{fb}^{-1})$	1.9	3.3	–
Combined $S/\sqrt{B}$ $(\mathcal{L} = 3000\ \text{fb}^{-1})$	5.2	–	–

Table 37: Cut flows at LHC14 with 3.5 TeV KK graviton, 3 TeV KK gluon, 1 TeV radion, with $g_{grav} = 6$, $g_{g_{KK}} = 3.25$, $\epsilon = 1$. Our applied pre-selection cuts are the following: ptj1min $\geq$ 600 GeV, ptj2min $\geq$ 400 GeV, ptj3min $\geq$ 200 GeV, ptj4min $\geq$ 100 GeV, $|\eta|_j \leq 2.5$, $\Delta r_j \geq 0.4$ with all other default MadGraph pre-selection cuts.

KK Graviton Discovery Mode

- CMS dijet searches require higher cross sections to reach 2σ significance (KK graviton BR to dijets $\sim 60\,\%$)
- At 4 TeV, $\sigma_{CMS} * BR \sim 8$ fb. Then $\sigma_{Gr_{KK}} \sim 13$ fb for 2σ significance (~ 20 fb for 3σ)
  - $\sigma_{Gr_{KK}} = 7.4$ fb for 5σ significance with antler cuts for heavy KK gluon
  - $\sigma_{Gr_{KK}} = 5.4$ fb for minimum 3σ significance with cascade cuts for lighter KK gluon
- At 3.5 TeV, $\sigma_{CMS} * BR \sim 10$ fb. Then $\sigma_{Gr_{KK}} \sim 16.7$ fb for 2σ significance (~ 42 fb for 5σ)
  - $\sigma_{Gr_{KK}} = 13.3$ fb for 5σ significance with antler cuts for heavy KK gluon
  - $\sigma_{Gr_{KK}} = 19.2$ fb for 5σ significance with cascade cuts for lighter KK gluon



$(\mathrm{b})3\ \mathrm{ab}^{-1}$

Precision searches in dijets at the HL-LHC and HE-LHC: https://arxiv.org/abs/1710.09484v3 (S. V. Chekanov, J. T. Childers, D. Frizzell, J. Proudfoot, R. Wang)

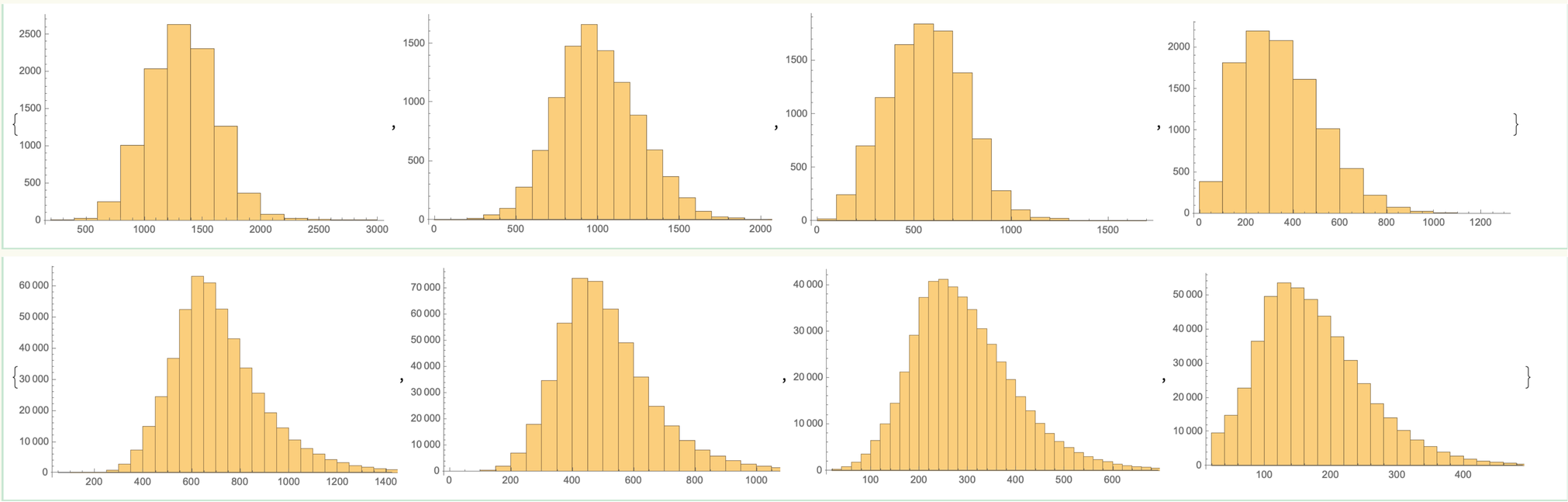
Conclusions and Outlook

- Cuts based on antler topology and sequential cascade topology efficiently probe model's parameter space
  - CMS is in process of starting antler topology search
- Multiple benchmark points and multiple parameter sets give $> 3\sigma$ significance
- 4-jet search is discovery channel of KK graviton with HL-LHC (dijet searches require higher signal cross sections to obtain 3σ significance)
- Analysis could be useful for other models that contain same topologies
- Model files can be obtained from Deepak Sathyan (dsathyan@umd.edu)

Ordered p_T Jet Distributions

- 4 TeV Gr_{KK} Radion Channel:
- Background:

Jet 1 p_T | Jet 2 p_T | Jet 3 p_T | Jet 4 p_T



Horizontal axis is GeV

Why does radion channel survive cascade cuts better?

- Radion channel M_{4j} distribution peaks at higher value
- Radion channel has two dijet resonances –> higher M_{jj} acceptance
- Radion channel jet p_T distribution peaks at higher values

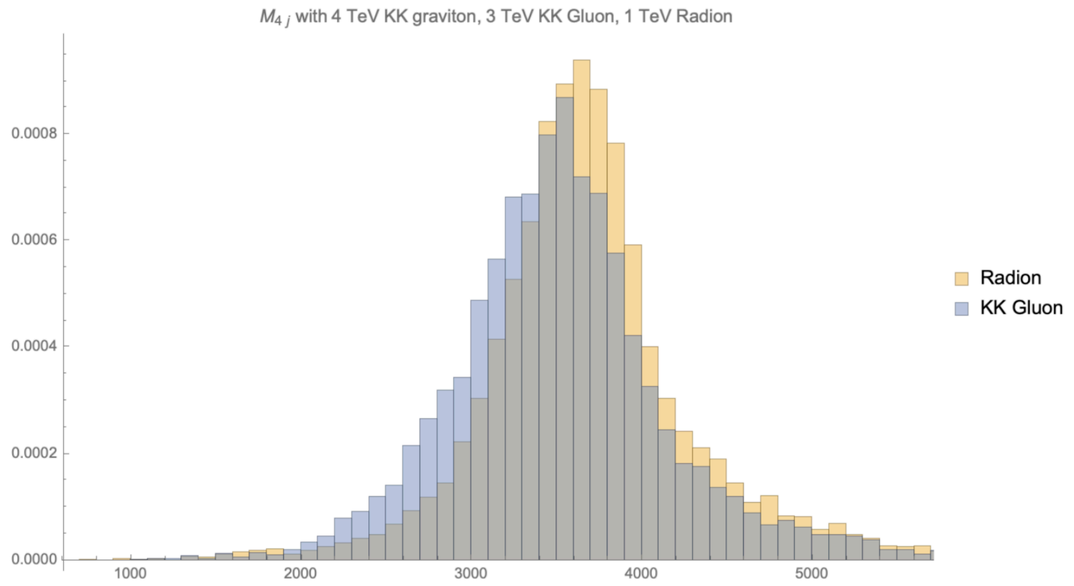


Figure 6: M_{4j} distributions of radion and KK gluon signal with Part 2 BP1 (4 TeV KK graviton, 3 TeV KK gluon, 1 TeV radion.) The KK gluon distribution is shifted slightly left, causing it to have lower acceptance when imposing a minimum M_{4j} cut.

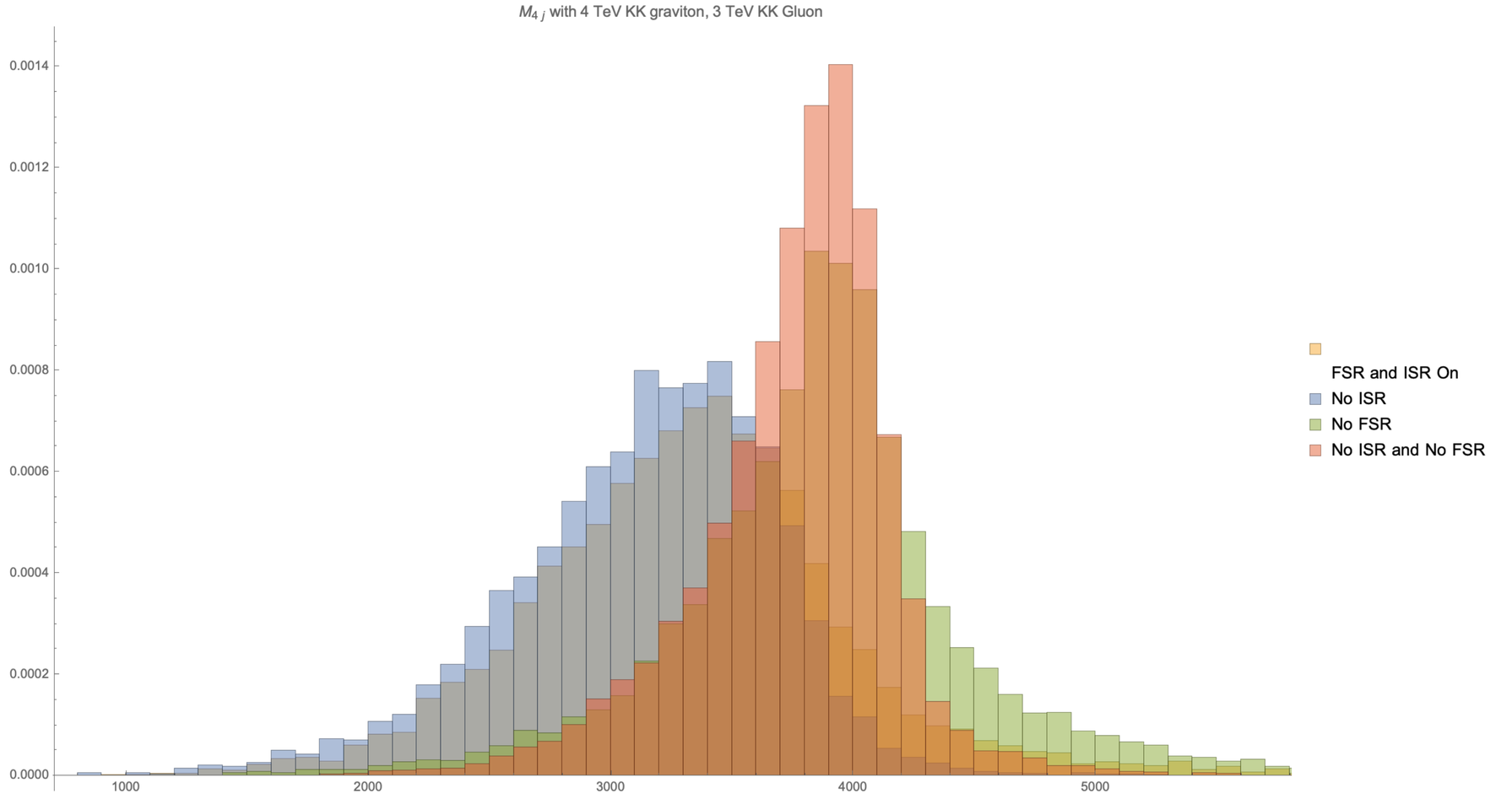
Background's higher acceptance to cascade cuts

- As seen from cut flows in Analysis Part 2, M_{3j} is not very effective in cutting background. Why is this?
- If we require M_{4j} = 4 TeV, then $M_{4j}^2 = 16\ \text{TeV}^2 = (p_1 + p_2 + p_3 + p_4)^2$
- $M_{4j}^2 = 2p_1 \cdot p_2 + 2p_1 \cdot p_3 + 2p_1 \cdot p_4 + 2p_2 \cdot p_3 + 2p_2 \cdot p_4 + 2p_3 \cdot p_4 = 6 * 2 < p_a \cdot p_b >$
- $< M_{abc}^2 > = (p_a + p_b + p_c)^2 = 2p_a \cdot p_b + 2p_a \cdot p_c + 2p_b \cdot p_c = 6 < p_a \cdot p_b >$
- Solve for the average trijet invariant mass: $\sqrt{< M_{abc}^2 >} = \sqrt{16\ \text{TeV}^2/2} = 2.8\ \text{TeV}$
- Background events have an average trijet invariant mass of 2.8 TeV, which is close to the KK gluon resonance of 3 TeV.

- Similarly, one can solve for the average dijet invariant mass given M_{4j} = 4 TeV: $\sqrt{< M_{ab}^2 >} = \sqrt{16\ \text{TeV}^2/6} = 1.6\ \text{TeV}$
  - Raising radion mass to 1.5 TeV would make the dijet invariant mass cut ineffective with 4 TeV KK graviton

Effects of ISR and FSR in Pythia

- FSR shifts M_{4j} left
- ISR extends tail on the right



Antler Cuts vs. Cascade Cuts for Part 2

- Depending on BSM particle masses and model parameters, antler cuts and cascade cuts are comparable
- Both can be used to determine if a signal is from KK graviton or any model with both topologies

Cascade Cuts on Part II BP1	KK Gluon	Radion	pp-$4j$
No cuts	2.55	0.79	$1 * 10^{10}$
Pre-selection cuts (η, Δ_r)	2.22	0.75	–
p_T pre-selection cuts	–	–	54300
$N_j \geq 4$	2.22	0.75	53700
$M_{4j} \in [3100, 4800]$ GeV	1.63	0.62	9230
$M_{3j} \in [2500, 3400]$ GeV	1.57	0.57	8110
$M_{jj} \in [700, 1100]$ GeV	1.13	0.49	4960
$p_{T,[j1,j2,j3,j4]} \geq [900, 600, 500, 200]$ GeV	0.53	0.28	224
S/B	0.0024	0.0013	–
$S/\sqrt{B}$ $(\mathcal{L} = 300$ fb$^{-1})$	0.61	0.33	–
$S/\sqrt{B}$ $(\mathcal{L} = 3000$ fb$^{-1})$	1.9	1.0	–
Combined $S/\sqrt{B}$ $(\mathcal{L} = 3000$ fb$^{-1})$	3.0	–	–
Antler Cuts on Part II BP1	**KK Gluon**	**Radion**	pp-$4j$
$M_{4j} \in [3500, 4100]$ GeV	0.80	0.34	3380
$M_{jj} \in [750, 1000]$ GeV	0.046	0.12	285
$\cos^2 \theta_{RR} \leq 0.2$	0.018	0.08	13
$p_{T,[j1,j2,j3,j4]} \geq [900, 600, 500, 200]$ GeV	0.012	0.047	1.2
S/B	0.01	0.04	–
$S/\sqrt{B}$ $(\mathcal{L} = 300$ fb$^{-1})$	0.19	0.77	–
$S/\sqrt{B}$ $(\mathcal{L} = 3000$ fb$^{-1})$	0.60	2.4	–
Combined $S/\sqrt{B}$ $(\mathcal{L} = 3000$ fb$^{-1})$	–	3.0	–

Table 42: Cut flows at LHC14 with the following parameters: $g_{grav} = 6$, $g_{g_{KK}} = 3.25$, $\epsilon = 1$. Both channels use the branching ratios for the following mass parameters: 4 TeV KK graviton, 3 TeV KK gluon, and 1 TeV radion. Our applied pre-selection cuts are the following: ptj1min $\geq$ 600 GeV, ptj2min $\geq$ 400 GeV, ptj3min $\geq$ 200 GeV, ptj4min $\geq$ 100 GeV, $|\eta|_j \leq 2.5$, $\Delta r_j \geq 0.4$ with all other default MadGraph pre-selection cuts.