Non-minimal Universal Extra Dimension: the QCD interacting sector at the LHC

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In collaboration with

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Based on arXiv:1206.3987

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minimal Universal Extra Dimension (mUED)

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We consider the SM in 5D.

a SM particle

minimal Universal Extra Dimension (mUED)

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Zooming up our world...

minimal Universal Extra Dimension (mUED)

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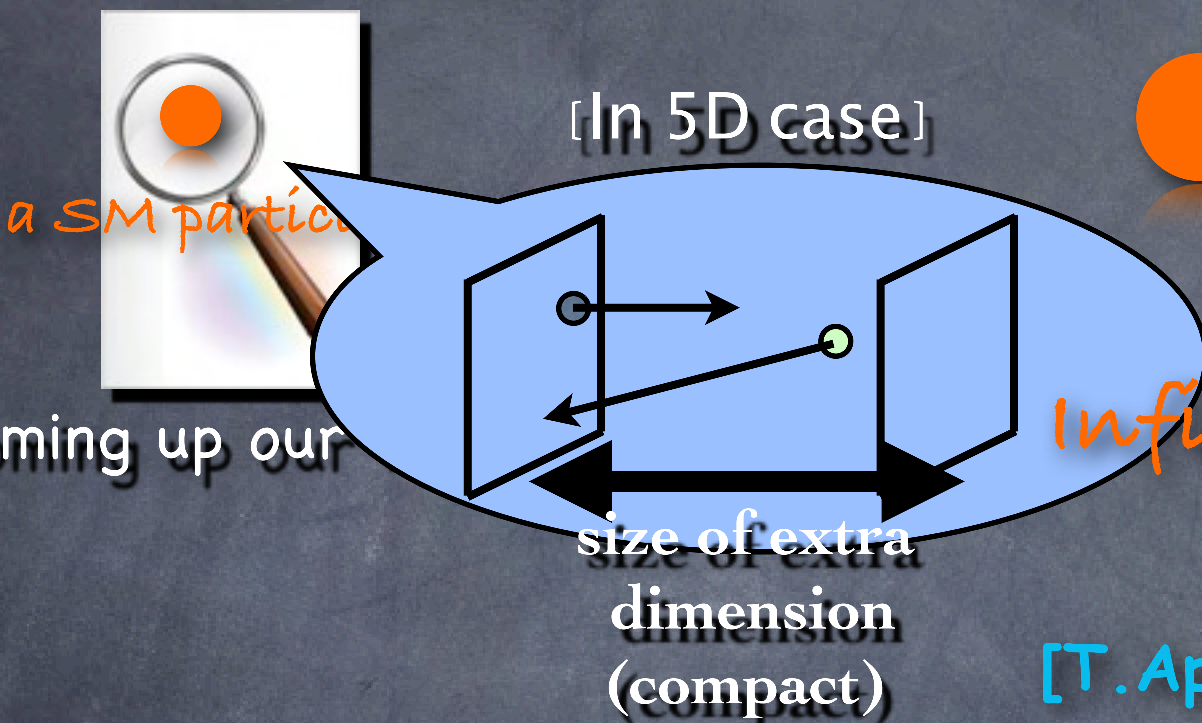


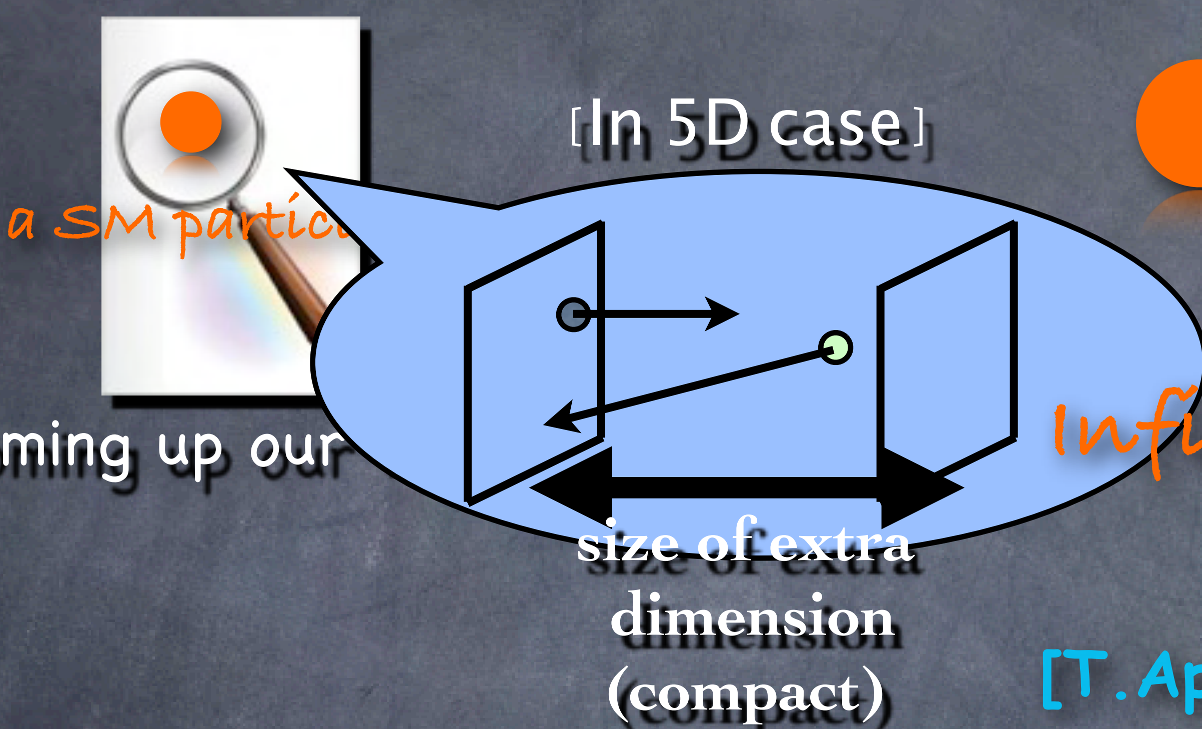
Zooming up our

Infinite # of massive copies appear.
(Kaluza-Klein Particles)

[T.Appelquist,H.C.Cheng,B.A.Dobrescu] (2001)

minimal Universal Extra Dimension (mUED)

We consider the SM in 5D.



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(Kaluza-Klein Particles)

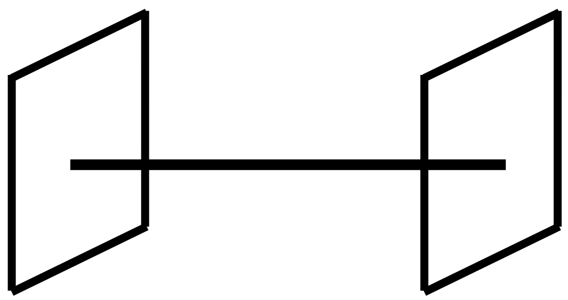
[T.Appelquist,H.C.Cheng,B.A.Dobrescu] (2001)

Interesting points

- Dark matter candidate = Lightest KK particle
- 125GeV Higgs is possible [Kakuda-san's talk]
- Loose constraint on m_{KK} ←Possibly detectable at the LHC

Way of extensions

mUED (in 5D) on S^1/Z_2

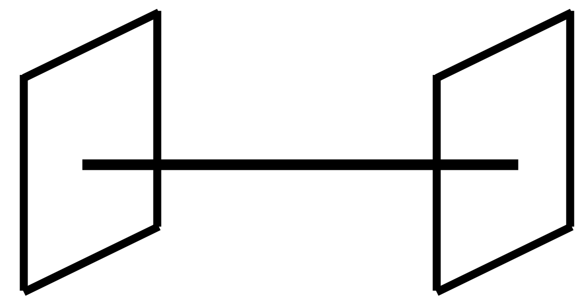


- SM matter & gauge group
- No tree-level brane-localized term
- Simplest background

Way of extensions

Go to 6D

mUED (in 5D) on S^1/Z_2



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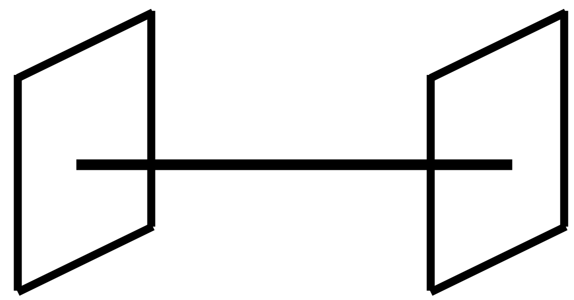

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Point interaction [Fujimoto-san's talk]

Way of extensions

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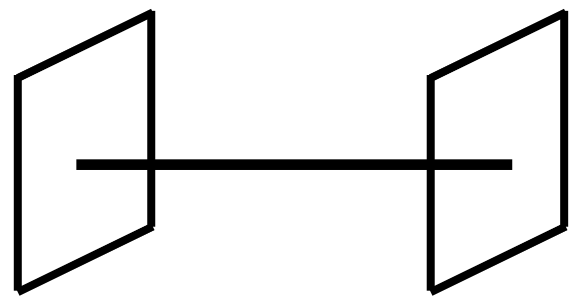

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Bulk terms (e.g., split UED)

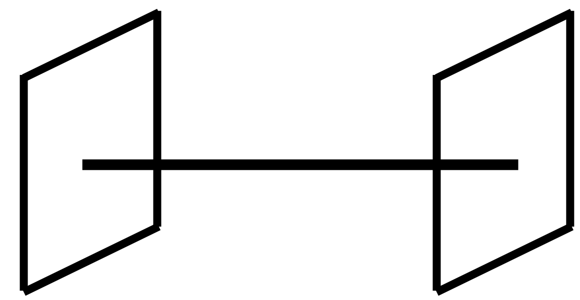
Point interaction [Fujimoto-san's talk]

Way of extensions

Brane-localized terms (tree-level)

Go to 6D

mUED (in 5D) on S^1/Z_2



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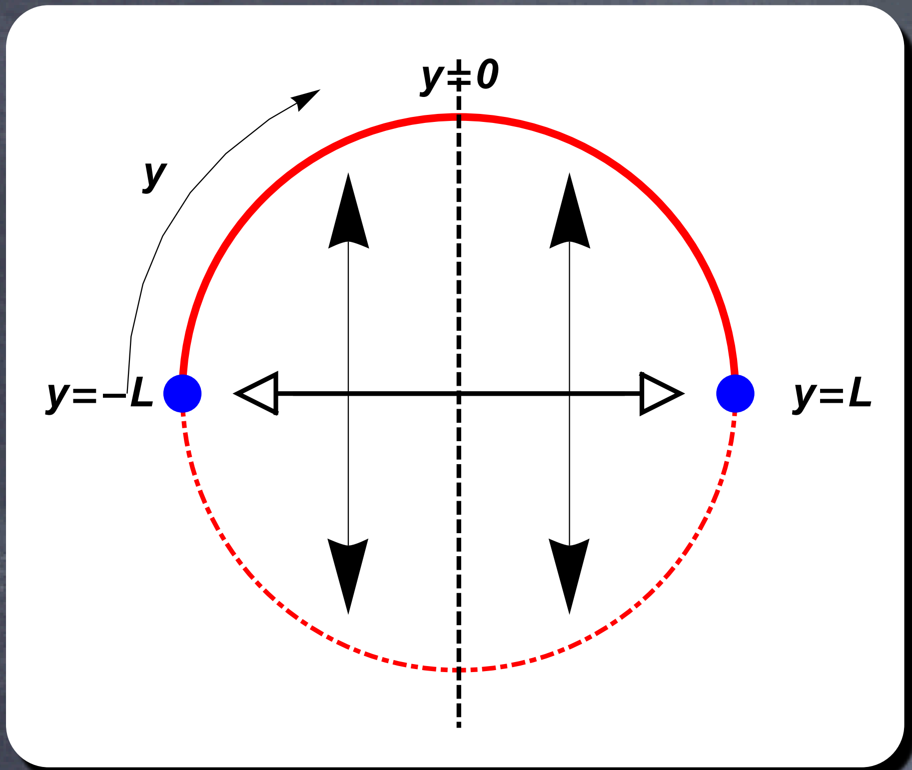
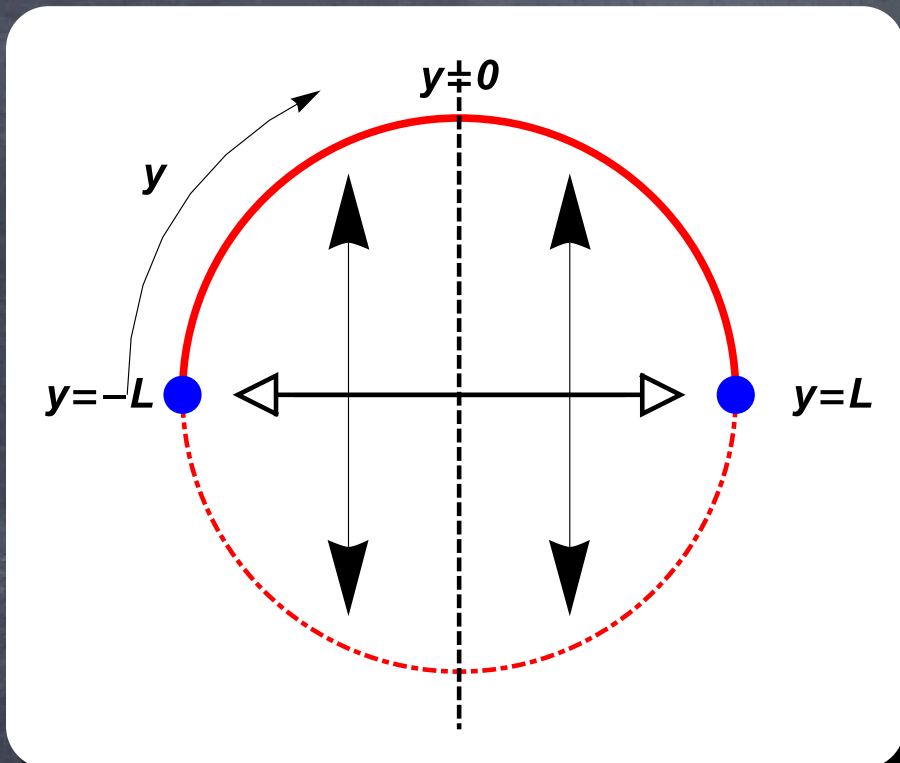
S^1/Z_2 geometry



✓ Two fixed points (branes) emerge.

- Chiral fermions appear (at zero modes).
- At these points, some terms can be localized.

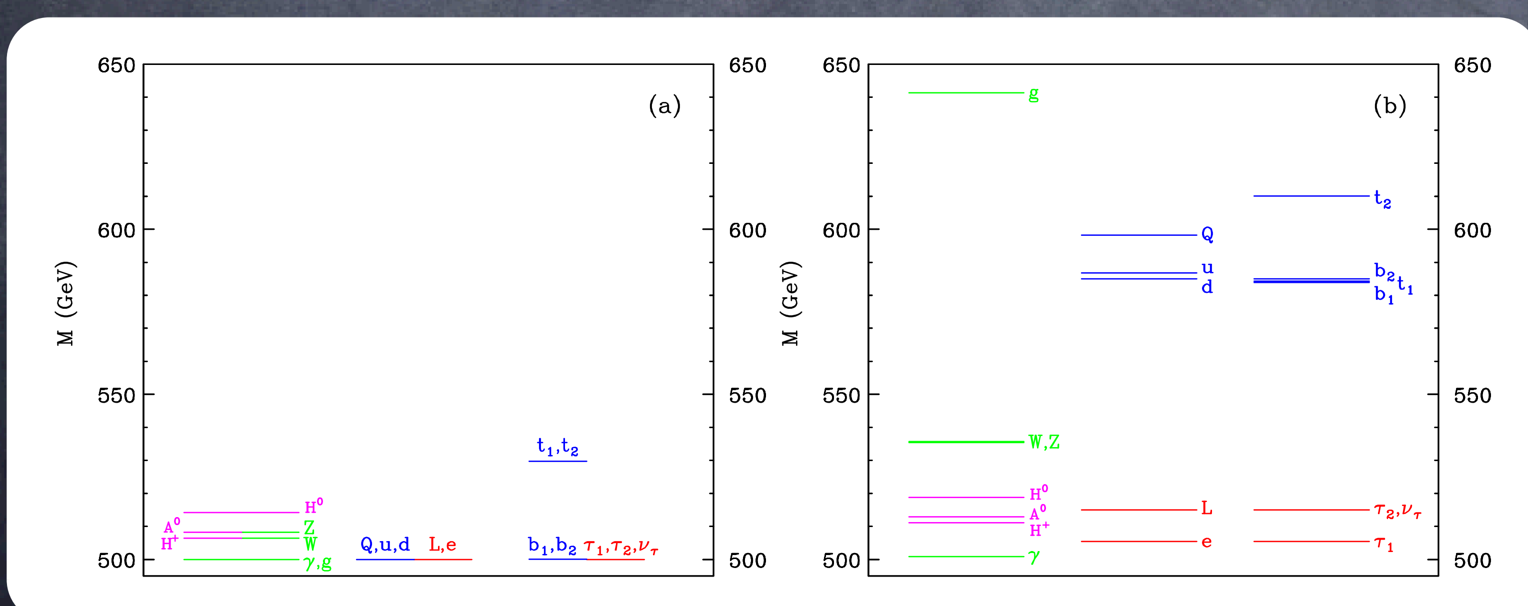
S^1/Z_2 geometry



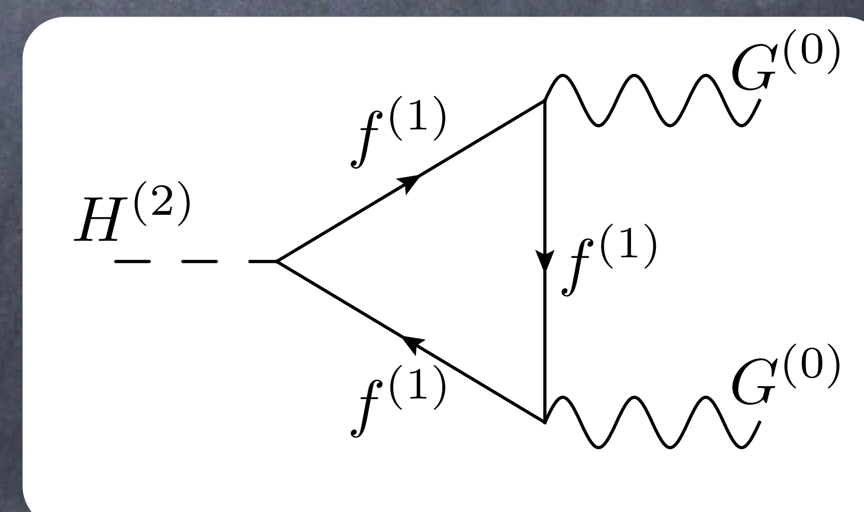
- ✓ Two fixed points (branes) emerge.
  - ☐ Chiral fermions appear (at zero modes).
  - ☐ At these points, some terms can be localized.

[H.C.Cheng,K.T.Matchev,M.Schmaltz] (2002)

- ✓ mUED: No tree-level brane-localized terms, but they are induced at the 1-loop level.



KK mass shift



KK momentum violating interaction

- ✓ When we introduce (tree-level) brane-localized terms, these interesting points possibly appear at the tree-level.
- ✓ We can find few study on LHC signature of this type "non-minimal" UED model.
- ✓ In this work, the properties of production processes of 1st KK particles via QCD interactions have been analyzed. (ignoring EW interactions.)

Contents

1. System with brane-localized terms

2. deviations in mass & couplings

3. Anomalous properties in cross section with low R^{-1}

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Gluon part

[F.del Aguila,M.Perez-Victoria,J.Santiago] (2003,2004)
[T.Flacke,A.Menon.D.J.Phalen] (2009)

$$S_{\text{gluon}} = \int d^4x \int_{-L}^{L} dy \left\{ -\frac{1}{4} G^a_{MN} G^{aMN} + \Big(\delta(y-L) + \delta(y+L)\Big) \left[-\frac{r_G}{4} G^a_{\mu\nu} G^{a\mu\nu} \right] \right\}$$

$$S_{\text{gluon,gf}} = \int d^4x \int_{-L}^{L} dy \left\{ -\frac{1}{2\xi_G} \left(\partial_\mu G^{a\mu} - \xi_G \partial_y G^a_y\right)^2 - \frac{1}{2\xi_{G,b}} \left[\left(\partial_\mu G^{a\mu} + \xi_{G,b} G^a_y\right)^2 \delta(y-L) + \left(\partial_\mu G^{a\mu} - \xi_{G,b} G^a_y\right)^2 \delta(y+L) \right] \right\}$$

- ✓ Bulk terms
  - ☐ These are the same with the mUED.
- ✓ Brane-localized terms
  - ☐ 4D gauge invariant term is introduced. (with coefficient r_G)
  - ☐ The system is invariant under y -> -y. (KK-parity is conserved.)
- ✓ G_y is unphysical d.o.f. (removed in the unitary gauge: ξ_G, $\xi_{G,b}$->∞)

✓ Bulk EOM of n-th mode is the same with the mUED.

$$\frac{\partial^2 f_{G_{(n)}}(y)}{\partial y^2} = -m^2_{G_{(n)}} f_{G_{(n)}}(y)$$

$$f_{G_{(n)}}(y) = N_{G_{(n)}} \times \begin{cases} \dfrac{\cos(m_{G_{(n)}} y)}{C_{G_{(n)}}} & \text{for } n \text{ even (even KK-parity)} \\ \dfrac{-\sin(m_{G_{(n)}} y)}{S_{G_{(n)}}} & \text{for } n \text{ odd (odd KK-parity)} \end{cases}$$

$$C_{G_{(n)}} = \cos\left(\frac{m_{G_{(n)}}\pi R}{2}\right), \quad S_{G_{(n)}} = \sin\left(\frac{m_{G_{(n)}}\pi R}{2}\right), \quad T_{G_{(n)}} = \tan\left(\frac{m_{G_{(n)}}\pi R}{2}\right)$$

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- But KK mass's dispersion relation is changed due to brane-localized terms.

$$r_G m_{G_{(n)}} = \begin{cases} -T_{G_{(n)}} & \text{for } n \text{ even} \\ 1/T_{G_{(n)}} & \text{for } n \text{ odd} \end{cases}$$

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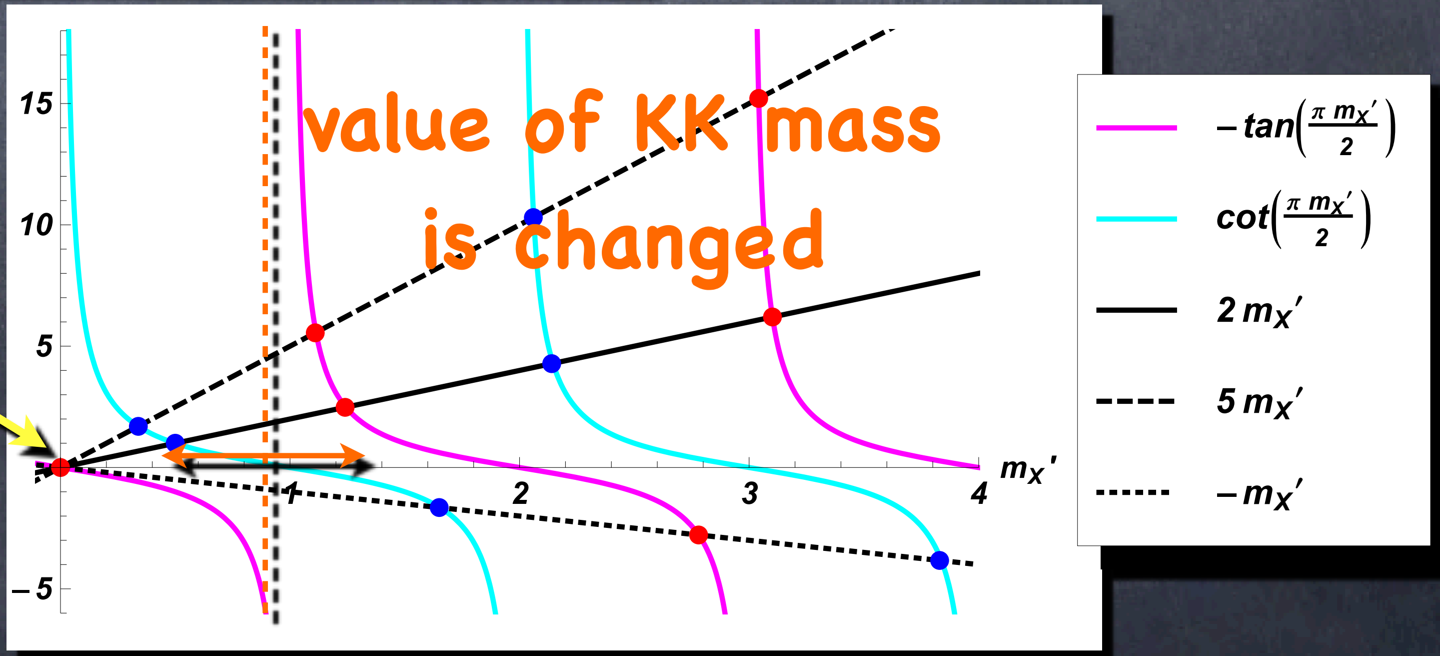
massless mode exists irrespective of r_G



✓ A theoretical bound on r_G:

$$N_{G_{(0)}} = \frac{1}{\sqrt{2r_G + \pi R}}$$

No tachyonic zero mode →

$$r_G > -\frac{\pi R}{2}$$

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✓ KK mode functions obey the relation:

$$\int_{-L}^{L} dy \left[1 + r_G\left(\delta(y-L) + \delta(y+L)\right)\right] f_{G_{(m)}} f_{G_{(n)}} = \delta_{m,n}$$

$$g_{4s} \equiv N_{G_{(0)}} g_{5s} = \frac{g_{5s}}{\sqrt{2r_G + \pi R}}$$

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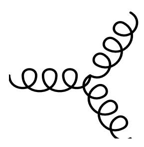
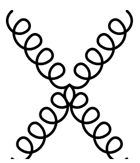
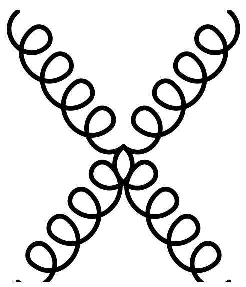


$$= g_{4s} f^{abc}\Big[\eta^{\mu\nu}(k-p)^\rho + \eta^{\nu\rho}(p-q)^\mu + \eta^{\rho\mu}(q-k)^\nu\Big]$$



$$= -ig_{4s}^2\Big[f^{abe}f^{cde}\left(\eta^{\mu\rho}\eta^{\nu\sigma} - \eta^{\mu\sigma}\eta^{\nu\rho}\right) + f^{ace}f^{bde}\left(\eta^{\mu\nu}\eta^{\rho\sigma} - \eta^{\mu\sigma}\eta^{\nu\rho}\right) + f^{ade}f^{bce}\left(\eta^{\mu\nu}\eta^{\rho\sigma} - \eta^{\mu\rho}\eta^{\nu\sigma}\right)\Big]$$

No difference



Nontrivial factor occurs in $G^{(1)}\times 4$ vertex

(Not so interesting in KK particle production)

$$= -ig_{4s}^2\left(\underline{g'_{G_1G_1G_1G_1}}\right)\Big[f^{abe}f^{cde}\left(\eta^{\mu\rho}\eta^{\nu\sigma} - \eta^{\mu\sigma}\eta^{\nu\rho}\right) + f^{ace}f^{bde}\left(\eta^{\mu\nu}\eta^{\rho\sigma} - \eta^{\mu\sigma}\eta^{\nu\rho}\right) + f^{ade}f^{bce}\left(\eta^{\mu\nu}\eta^{\rho\sigma} - \eta^{\mu\rho}\eta^{\nu\sigma}\right)\Big]$$

Fermion part

[F.del Aguila,M.Perez-Victoria,J.Santiago] (2003,2004)
[T.Flacke,A.Menon.D.J.Phalen] (2009)

$$
\begin{aligned}
S_{\text{quark}} = \int d^4x \int_{-L}^{L} dy \sum_{i=1}^{3} \Big\{ & i\overline{U}_i \Gamma^M \mathcal{D}_M U_i + r_Q \Big(\delta(y-L) + \delta(y+L) \Big) \left[i\overline{U}_i \gamma^\mu \mathcal{D}_\mu P_L U_i \right] \\
& + i\overline{D}_i \Gamma^M \mathcal{D}_M D_i + r_Q \Big(\delta(y-L) + \delta(y+L) \Big) \left[i\overline{D}_i \gamma^\mu \mathcal{D}_\mu P_L D_i \right] \\
& + i\overline{u}_i \Gamma^M \mathcal{D}_M u_i + r_Q \Big(\delta(y-L) + \delta(y+L) \Big) \left[i\overline{u}_i \gamma^\mu \mathcal{D}_\mu P_R u_i \right] \\
& + i\overline{d}_i \Gamma^M \mathcal{D}_M d_i + r_Q \Big(\delta(y-L) + \delta(y+L) \Big) \left[i\overline{d}_i \gamma^\mu \mathcal{D}_\mu P_R d_i \right] \Big\},
\end{aligned}
$$

- ✓ Bulk terms are also the same with the mUED.
  - ☐ U_i, D_i: $SU(2)_W$ doublet (with left-handed zero mode)
  - ☐ u_i, d_i: $SU(2)_W$ singlet (with right-handed zero mode)
- ✓ We assume the coefficients take the same value r_Q.
  - ☐ The system is invariant under y -> -y.
    (KK-parity is conserved.)

✓ The situation is similar to the gluon case.

- For orbifold Z_2 even modes:

$$f_{Q_{(n)}} \equiv f_{U_{i(n)L}} = f_{D_{i(n)L}} = f_{u_{i(n)R}} = f_{d_{i(n)R}} = N_{Q_{(n)}} \times \begin{cases} \dfrac{\cos(M_{Q_{(n)}} y)}{C_{Q_{(n)}}} & \text{for } n \text{ even} \\ \dfrac{-\sin(M_{Q_{(n)}} y)}{S_{Q_{(n)}}} & \text{for } n \text{ odd} \end{cases}$$

$$\int_{-L}^{L} dy \Big[1 + r_Q(\delta(y-L) + \delta(y+L))\Big] f_{Q_{(m)}} f_{Q_{(n)}} = \delta_{m,n}$$

- For orbifold Z_2 odd modes:

$$g_{Q(n)} \equiv f_{U_{i(n)R}} = f_{D_{i(n)R}} = -f_{u_{i(n)L}} = -f_{d_{i(n)L}} = N_{Q_{(n)}} \times \begin{cases} \dfrac{\sin(M_{Q_{(n)}} y)}{C_{Q_{(n)}}} & \text{for } n \text{ even} \\ \dfrac{\cos(M_{Q_{(n)}} y)}{S_{Q_{(n)}}} & \text{for } n \text{ odd} \end{cases}$$

$$\int_{-L}^{L} dy g_{Q_{(m)}} g_{Q_{(n)}} = \delta_{m,n}$$

- KK mass condition:

$$r_Q M_{Q_{(n)}} = \begin{cases} -T_{Q_{(n)}} & \text{for } n \text{ even} \\ 1/T_{Q_{(n)}} & \text{for } n \text{ odd} \end{cases}.$$

Yukawa part

$$S_{\text{Yukawa}} = \int d^4x \int_{-L}^{L} dy \sum_{i,j=1}^{3} \left\{ -\left(1 + r_Y(\delta(y-L) + \delta(y+L))\right) \times \left[Y_{ij}^u \overline{Q}_i u_j \tilde{\Phi} + Y_{ij}^d \overline{Q}_i d_j \Phi + \text{h.c.} \right] \right\}$$

- ✓ Bulk terms are also the same with the mUED.
  - Here we assumed the ordinary Higgs mechanism.
- ✓ We assume the universal coefficient r_Y for avoiding tree-level FCNC.
  - The system is invariant under y -> -y. (KK-parity is conserved.)

$$-\left(\mathcal{Y}^q_{ii}\frac{v}{\sqrt{2}}\right)\int d^4x\left\{R_{Q00}\overline{q}^{(0)}_{iL}q^{(0)}_{iR}+r_{Q11}\overline{Q}^{(1)}_{iL}q^{(1)}_{iR}-R_{Q11}\overline{q}^{(1)}_{iL}Q^{(1)}_{iR}+\text{h.c.}\right\}$$

Diagonalized

(Q_i: $SU(2)_W$ doublet, q_i: $SU(2)_W$ singlet)

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away from 1 (mUED value)

(f_Q and g_Q are not orthonormal each other.)

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away from 1 (mUED value)

(f_Q and g_Q are not orthonormal each other.)

✓ Zero mode Yukawa mass is identified as

$$m_{q_i}=\left(\mathcal{Y}^q_{ii}\frac{v}{\sqrt{2}}\right)R_{Q00}$$

$$R_{Q00}=\frac{2r_Y+\pi R}{2r_Q+\pi R}$$

- ☐ $r_Y = -\pi R/2$ is meaningless.

$$-\left(\mathcal{Y}^q_{ii}\frac{v}{\sqrt{2}}\right)\int d^4x\left\{R_{Q00}\overline{q}^{(0)}_{iL}q^{(0)}_{iR}+r_{Q11}\overline{Q}^{(1)}_{iL}q^{(1)}_{iR}-R_{Q11}\overline{q}^{(1)}_{iL}Q^{(1)}_{iR}+\text{h.c.}\right\}$$

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☐ $r_Y = -\pi R/2$ is meaningless.

✓ The mass matrix for 1st KK quarks:

$$-\int d^4x\left\{\left[\overline{Q}^{(1)}_i,\ \overline{q}^{(1)}_i\right]_L\underbrace{\begin{bmatrix}M_{Q_{(1)}} & r'_{Q11}m_{q_i}\\ -R'_{Q11}m_{q_i} & M_{Q_{(1)}}\end{bmatrix}}_{\equiv\mathcal{M}^{(1)}_{q_i}}\begin{bmatrix}Q^{(1)}_i\\ q^{(1)}_i\end{bmatrix}_R+\text{h.c.}\right\}$$

$$r'_{Q11}=\frac{r_{Q11}}{R_{Q00}},\qquad R'_{Q11}=\frac{R_{Q11}}{R_{Q00}}$$

☐ Two mass eigenstates are not degenerated.

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2. deviations in mass & couplings

3. Anomalous properties in cross section with low R^{-1}

Values of 1st KK mass (= 1st KK gluon mass)

$$r_X m_{X_{(1)}} = 1/T_{X_{(1)}} = r'_X m'_{X_{(1)}}$$

$$(r_X \equiv r'_X R, \ m_{X_{(1)}} \equiv m'_{X_{(1)}}/R)$$

scaled values

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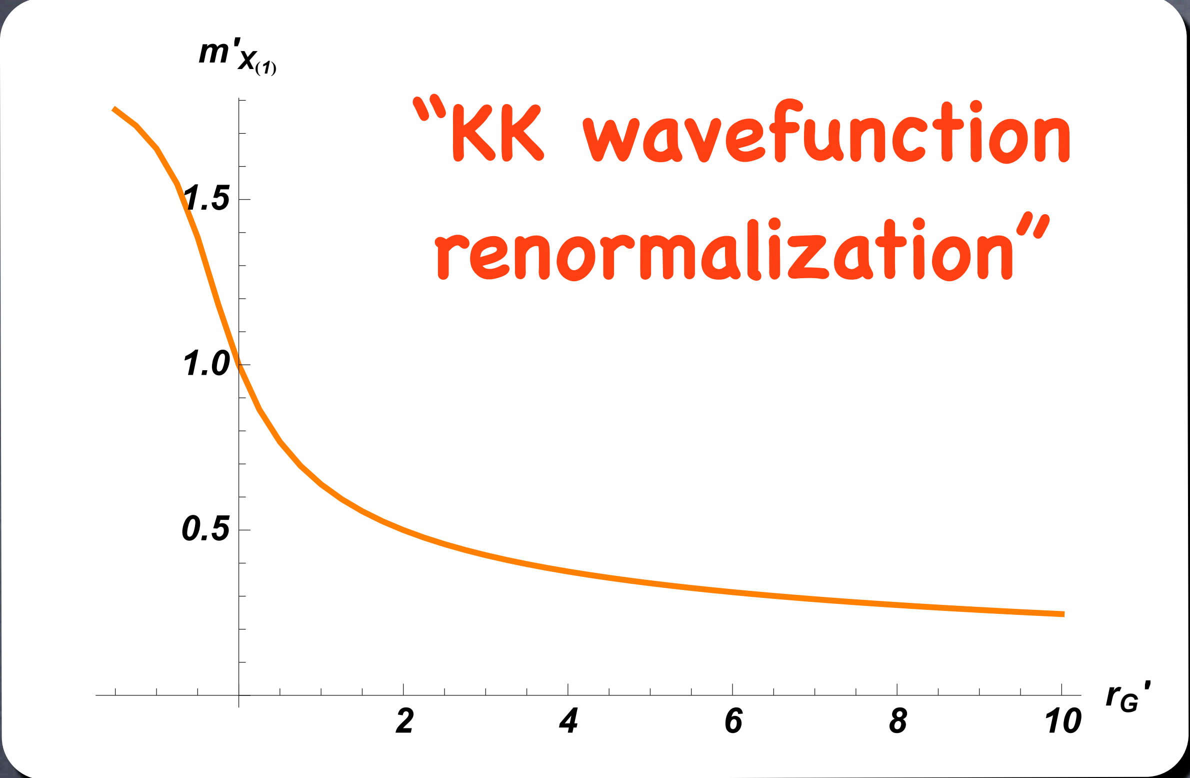

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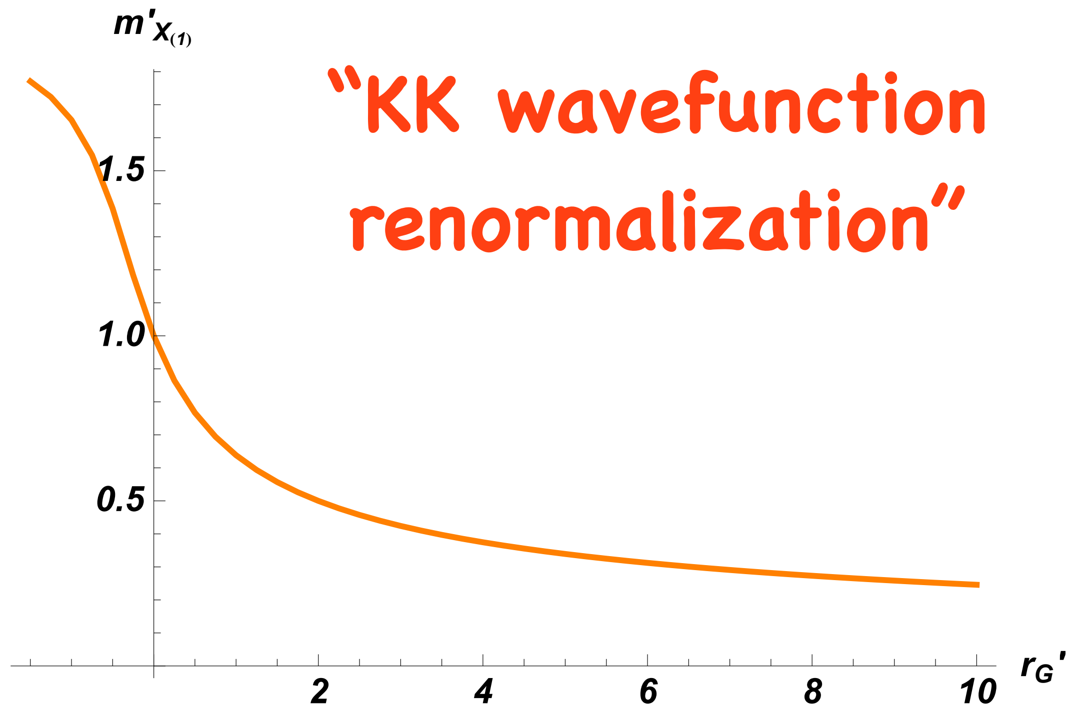
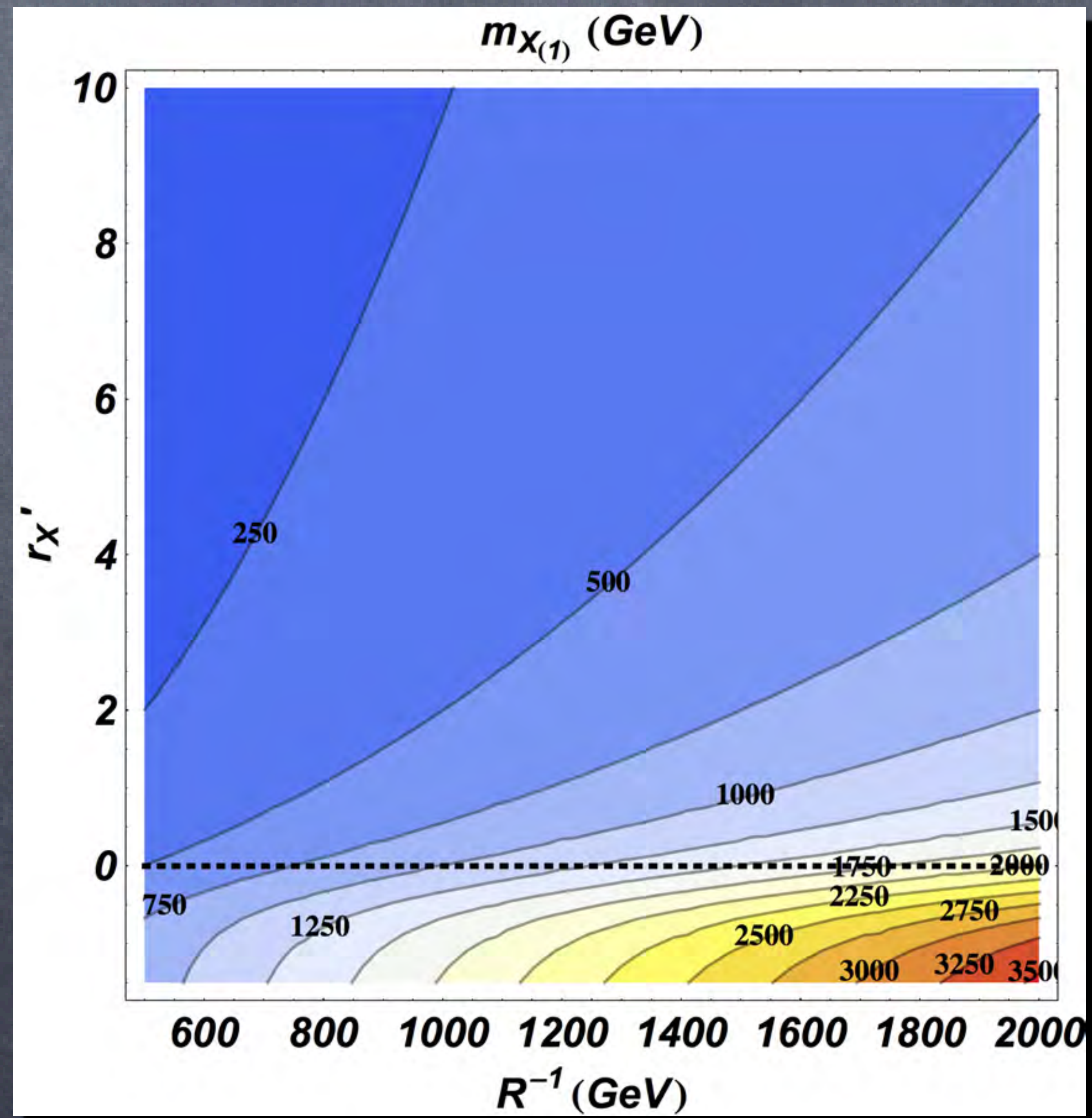


"KK wavefunction renormalization"

$$r_X m_{X_{(1)}} = 1/T_{X_{(1)}} = r'_X m'_{X_{(1)}}$$

$$(r_X \equiv r'_X R,\ m_{X_{(1)}} \equiv m'_{X_{(1)}}/R)$$

scaled values



Values of 1st quark masses

$$-\int d^4x \left\{ \left[\overline{Q}_i^{(1)},\ \overline{q}_i^{(1)}\right]_L \underbrace{\begin{bmatrix} M_{Q_{(1)}} & r'_{Q11} m_{q_i} \\ -R'_{Q11} m_{q_i} & M_{Q_{(1)}} \end{bmatrix}}_{\equiv \mathcal{M}_{q_i}^{(1)}} \begin{bmatrix} Q_i^{(1)} \\ q_i^{(1)} \end{bmatrix}_R + \text{h.c.} \right\}$$

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- In general, $M_{Q(1)}$ (KK mass) > m_{qi} (SM quark mass).

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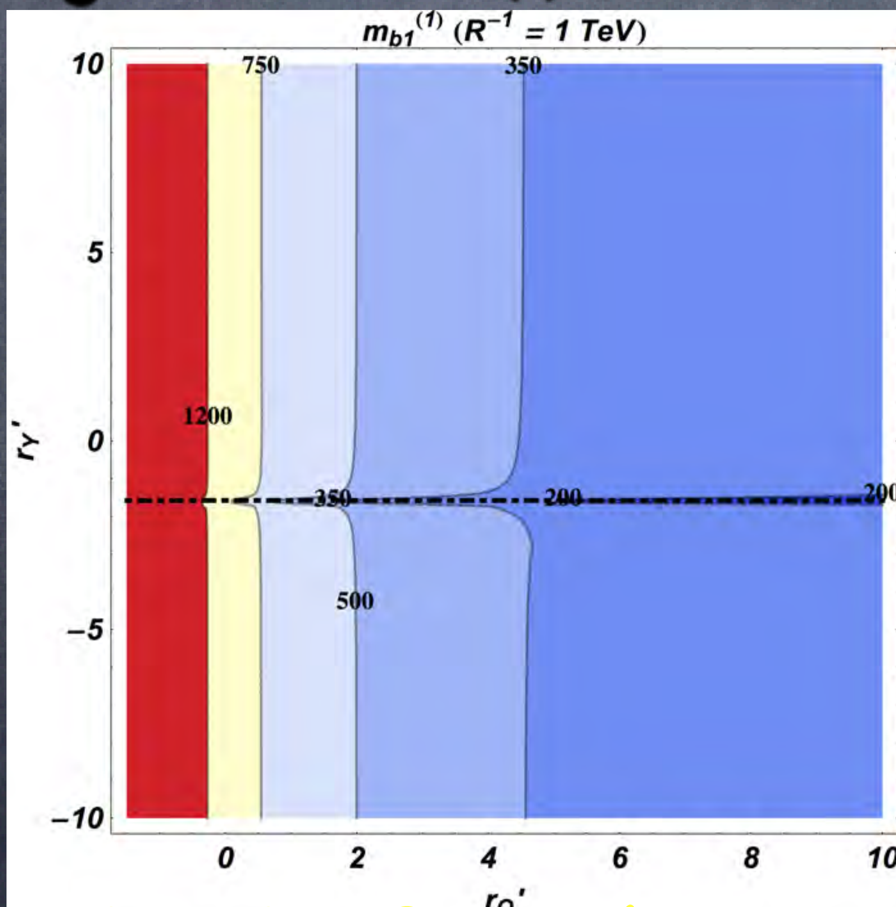
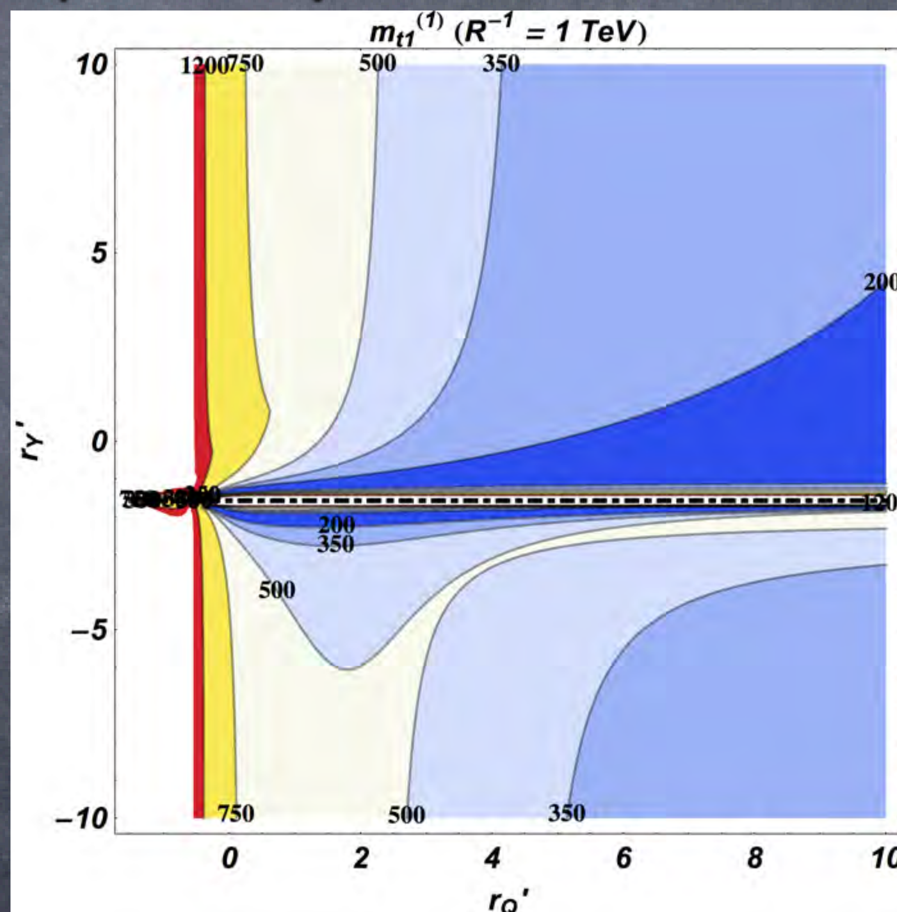
- ☐ In general, $M_{Q(1)}$ (KK mass) > m_{qi} (SM quark mass).





for the first five flavors (e.g. bottom):
r'$_Q$ dominant (two mass eigenstates are almost degenerated.)

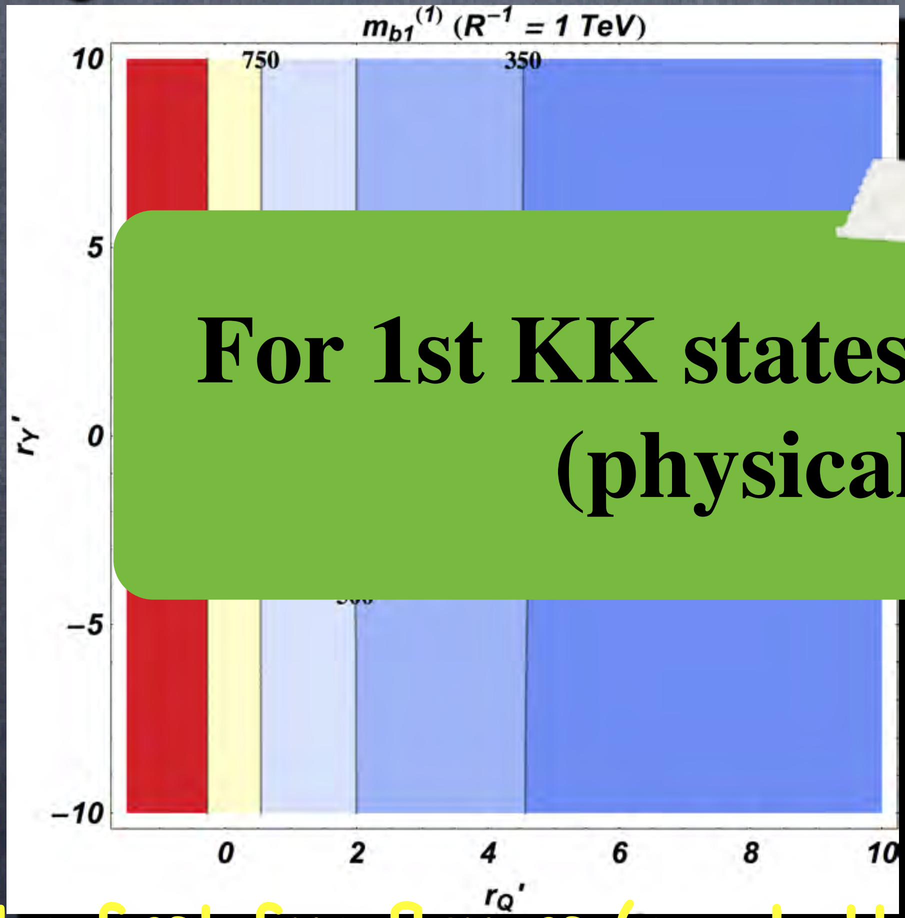
for the top flavor:
r'$_Y$ is also effective

Values of 1st quark masses

$$-\int d^4x \left\{ \left[\overline{Q}_i^{(1)},\ \overline{q}_i^{(1)}\right]_L \underbrace{\begin{bmatrix} M_{Q^{(1)}} & r'_{Q11} m_{q_i} \\ -R'_{Q11} m_{q_i} & M_{Q^{(1)}} \end{bmatrix}}_{\equiv \mathcal{M}_{q_i}^{(1)}} \begin{bmatrix} Q_i^{(1)} \\ q_i^{(1)} \end{bmatrix}_R + \text{h.c.} \right\}$$

✓ The mass matrix for 1st KK quarks:

- In general, $M_{Q(1)}$ (KK mass) > m_{qi} (SM quark mass).



For 1st KK states of the first five flavors, (physical mass) ~ $M_{Q(1)}$

for the first five flavors (e.g. bottom): r'_Q dominant (two mass eigenstates are almost degenerated.)

for the top flavor: r'_Y is also effective

Quark-gluon interactions

$$S_{\text{quark}}|_{\text{int}} = \int d^4x \sum_i \Big\{ g_{4s} T^a \Big[G_\mu^{a(0)} \left(\overline{q}_i^{(0)} \gamma^\mu q_i^{(0)} + \overline{\mathcal{Q}}_{i1}^{(1)} \gamma^\mu \mathcal{Q}_{i1}^{(1)} + \overline{\mathcal{Q}}_{i2}^{(1)} \gamma^\mu \mathcal{Q}_{i2}^{(1)} \right)$$

$$+ G_\mu^{a(1)} (g'_{G_1 Q_1 Q_0}) \Big(\overline{q}_i^{(0)} \gamma^\mu \left(v^{(1)}_{q_i R(21)} P_R + v^{(1)}_{q_i L(11)} P_L \right) \mathcal{Q}_{i2}^{(1)} + \overline{q}_i^{(0)} \gamma^\mu \left(v^{(1)}_{q_i R(22)} P_R + v^{(1)}_{q_i L(12)} P_L \right) \mathcal{Q}_{i1}^{(1)}$$

Nontrivial factor

$$+ \overline{\mathcal{Q}}_{i2}^{(1)} \gamma^\mu \left(v^{(1)}_{q_i R(21)} P_R + v^{(1)}_{q_i L(11)} P_L \right) q_i^{(0)} + \overline{\mathcal{Q}}_{i1}^{(1)} \gamma^\mu \left(v^{(1)}_{q_i R(22)} P_R + v^{(1)}_{q_i L(12)} P_L \right) q_i^{(0)} \Big) \Big] \Big\},$$

bi-unitary transformations: $\begin{bmatrix} Q_i^{(1)} \\ q_i^{(1)} \end{bmatrix}_L = V^{(1)}_{q_i L} \begin{bmatrix} \mathcal{Q}_{i2}^{(1)} \\ \mathcal{Q}_{i1}^{(1)} \end{bmatrix}_L , \quad \begin{bmatrix} Q_i^{(1)} \\ q_i^{(1)} \end{bmatrix}_R = V^{(1)}_{q_i R} \begin{bmatrix} \mathcal{Q}_{i2}^{(1)} \\ \mathcal{Q}_{i1}^{(1)} \end{bmatrix}_R$

$$V^{(1)}_{q_i L} = \begin{bmatrix} v^{(1)}_{q_i L(11)} & v^{(1)}_{q_i L(12)} \\ v^{(1)}_{q_i L(21)} & v^{(1)}_{q_i L(22)} \end{bmatrix} , \quad V^{(1)}_{q_i R} = \begin{bmatrix} v^{(1)}_{q_i R(11)} & v^{(1)}_{q_i R(12)} \\ v^{(1)}_{q_i R(21)} & v^{(1)}_{q_i R(22)} \end{bmatrix}$$

Quark-gluon interactions

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$$+ G_\mu^{a(1)} (g'_{G_1 Q_1 Q_0}) \Big(\overline{q}_i^{(0)} \gamma^\mu \left(v_{q_i R(21)}^{(1)} P_R + v_{q_i L(11)}^{(1)} P_L \right) \mathcal{Q}_{i2}^{(1)} + \overline{q}_i^{(0)} \gamma^\mu \left(v_{q_i R(22)}^{(1)} P_R + v_{q_i L(12)}^{(1)} P_L \right) \mathcal{Q}_{i1}^{(1)}$$

Nontrivial factor

$$+ \overline{\mathcal{Q}}_{i2}^{(1)} \gamma^\mu \left(v_{q_i R(21)}^{(1)} P_R + v_{q_i L(11)}^{(1)} P_L \right) q_i^{(0)} + \overline{\mathcal{Q}}_{i1}^{(1)} \gamma^\mu \left(v_{q_i R(22)}^{(1)} P_R + v_{q_i L(12)}^{(1)} P_L \right) q_i^{(0)} \Big) \Big] \Big\},$$

bi-unitary transformations: $\begin{bmatrix} Q_i^{(1)} \\ q_i^{(1)} \end{bmatrix}_L = V_{q_i L}^{(1)} \begin{bmatrix} \mathcal{Q}_{i2}^{(1)} \\ \mathcal{Q}_{i1}^{(1)} \end{bmatrix}_L, \quad \begin{bmatrix} Q_i^{(1)} \\ q_i^{(1)} \end{bmatrix}_R = V_{q_i R}^{(1)} \begin{bmatrix} \mathcal{Q}_{i2}^{(1)} \\ \mathcal{Q}_{i1}^{(1)} \end{bmatrix}_R$

$$V_{q_i L}^{(1)} = \begin{bmatrix} v_{q_i L(11)}^{(1)} & v_{q_i L(12)}^{(1)} \\ v_{q_i L(21)}^{(1)} & v_{q_i L(22)}^{(1)} \end{bmatrix}, \quad V_{q_i R}^{(1)} = \begin{bmatrix} v_{q_i R(11)}^{(1)} & v_{q_i R(12)}^{(1)} \\ v_{q_i R(21)}^{(1)} & v_{q_i R(22)}^{(1)} \end{bmatrix}$$

✓ For the first five flavors:

$$V_{q_i L}^{(1)} = V_{q_i R}^{(1)} \approx \begin{bmatrix} -\text{sgn}(r'_Q) \cos\left(\frac{\pi}{4}\right) & \sin\left(\frac{\pi}{4}\right) \\ -\text{sgn}(r'_Q) \sin\left(\frac{\pi}{4}\right) & -\cos\left(\frac{\pi}{4}\right) \end{bmatrix} \neq V_{q_i L}^{(1)}|_{\text{mUED}} = V_{q_i R}^{(1)}|_{\text{mUED}} \simeq \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

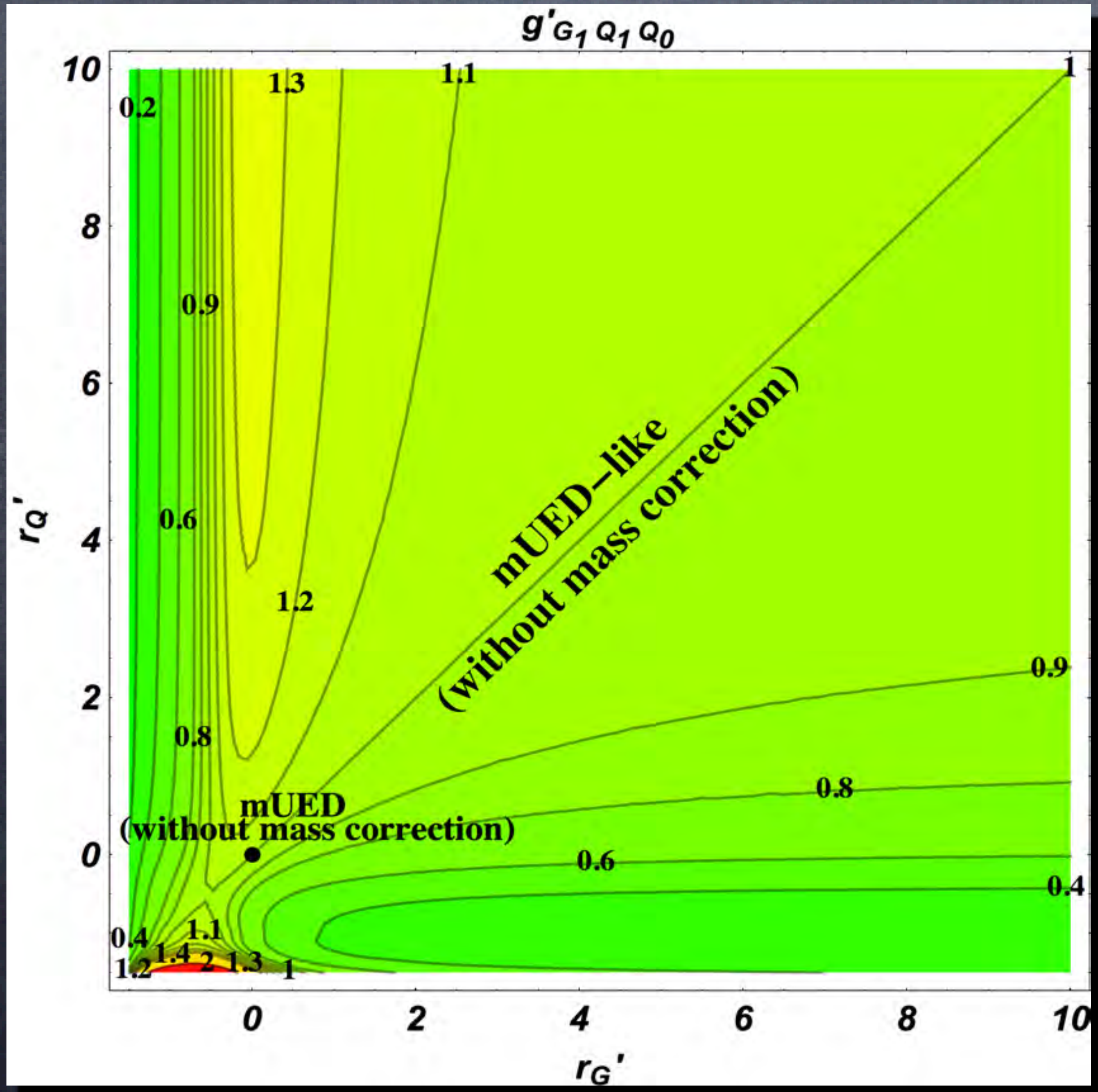
discrepancy between degenerated and almost degenerated cases

✓ The form of the nontrivial factor is as follows:

$$g'_{G_1 Q_1 Q_0} \equiv \frac{1}{N_{G(0)}} \int_{-L}^{L} dy \Big(1 + r_Q \left(\delta(y-L) + \delta(y+L)\right)\Big) f_{G_{(1)}} f_{Q_{(1)}} f_{Q_{(0)}}$$

$$= \frac{N_{Q_{(0)}}}{N_{G_{(0)}}} \frac{N_{G_{(1)}} N_{Q_{(1)}}}{S_{G_{(1)}} S_{Q_{(1)}}} \left[2 r_Q S_{G_{(1)}} S_{Q_{(1)}} - \frac{\sin((M_{Q_{(1)}} + m_{G_{(1)}})\frac{\pi R}{2})}{M_{Q_{(1)}} + m_{G_{(1)}}} + \frac{\sin((M_{Q_{(1)}} - m_{G_{(1)}})\frac{\pi R}{2})}{M_{Q_{(1)}} - m_{G_{(1)}}} \right]$$

This factor is possibly important in production of 1st KK particle.



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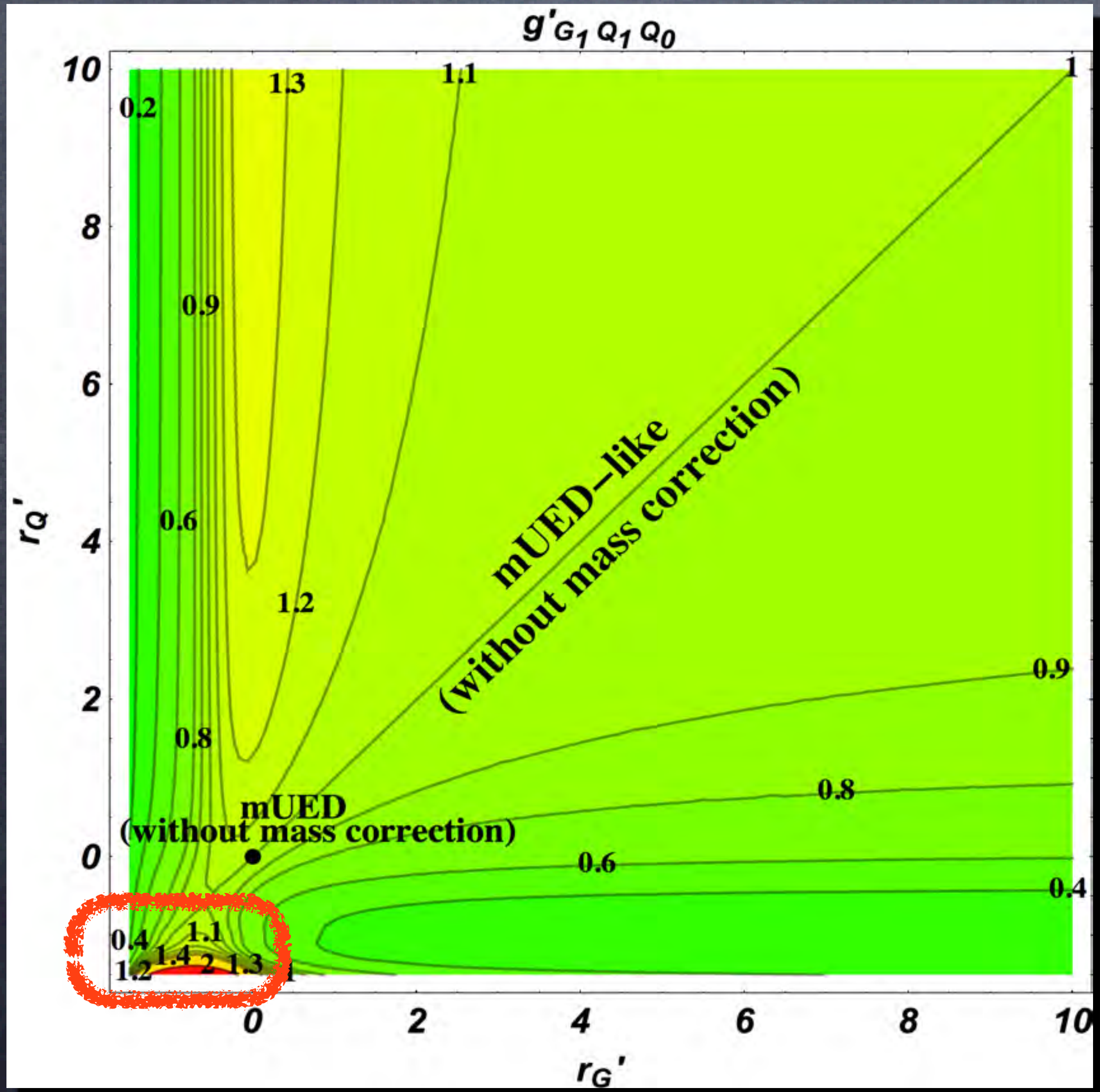
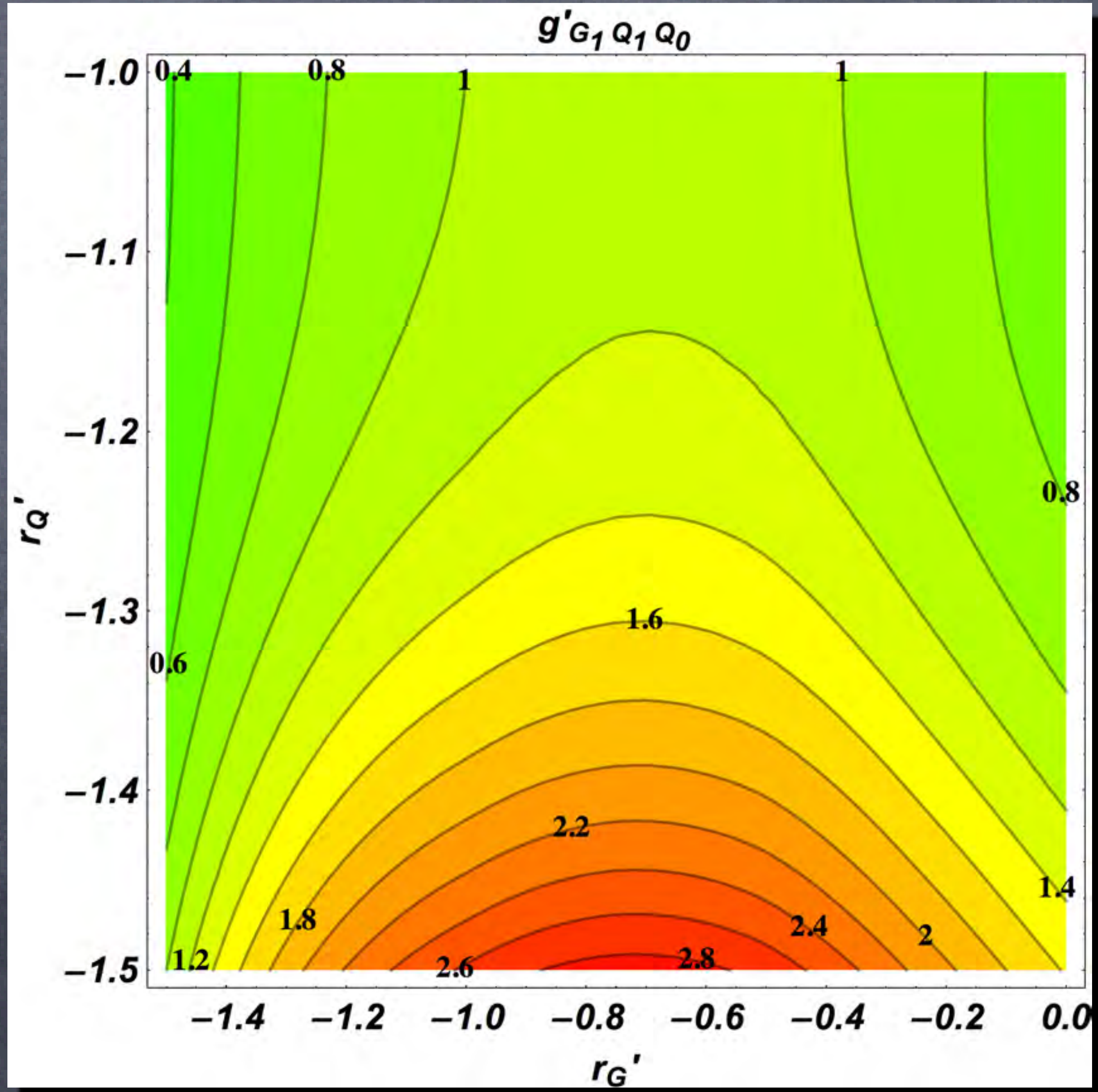
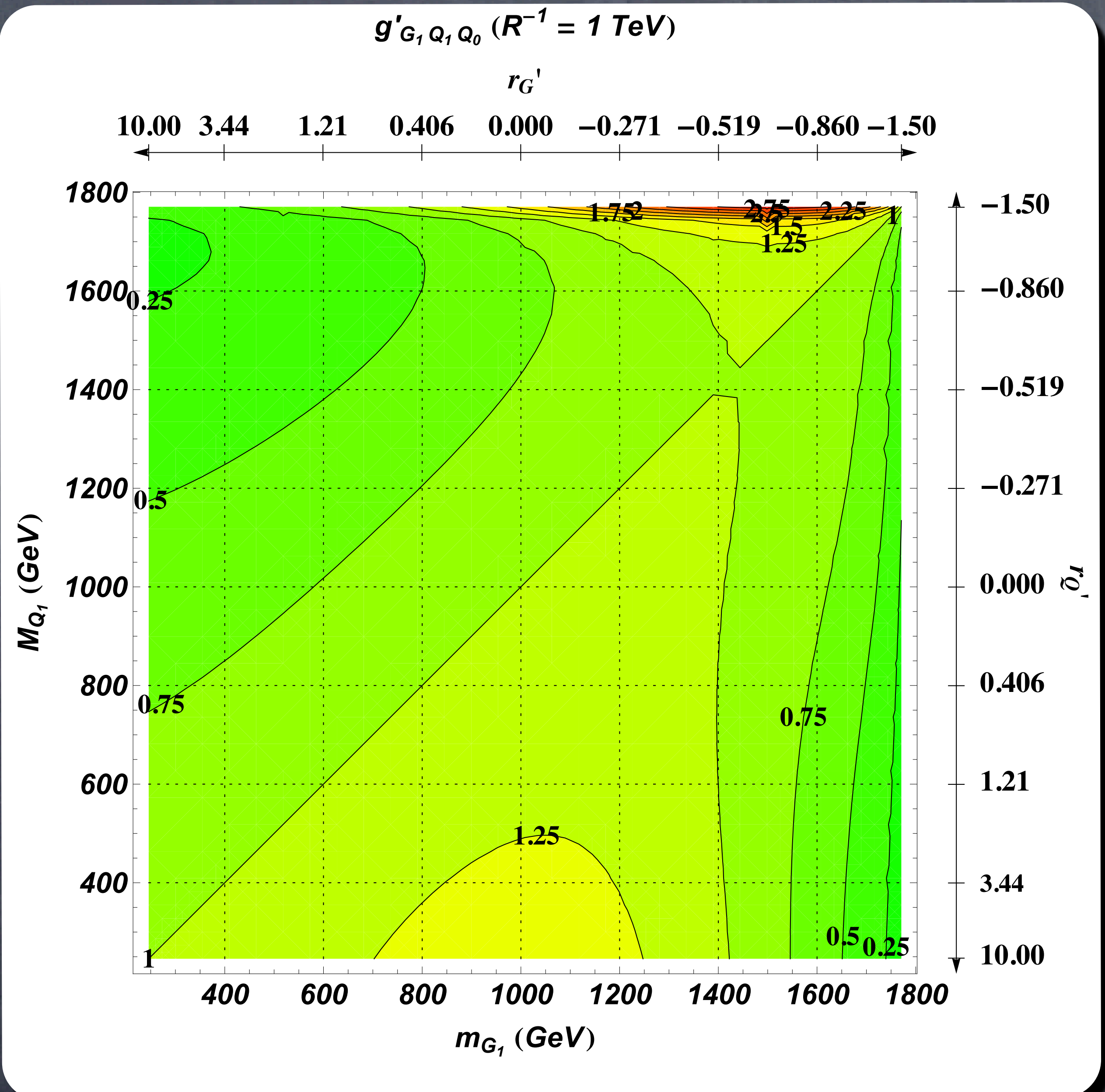
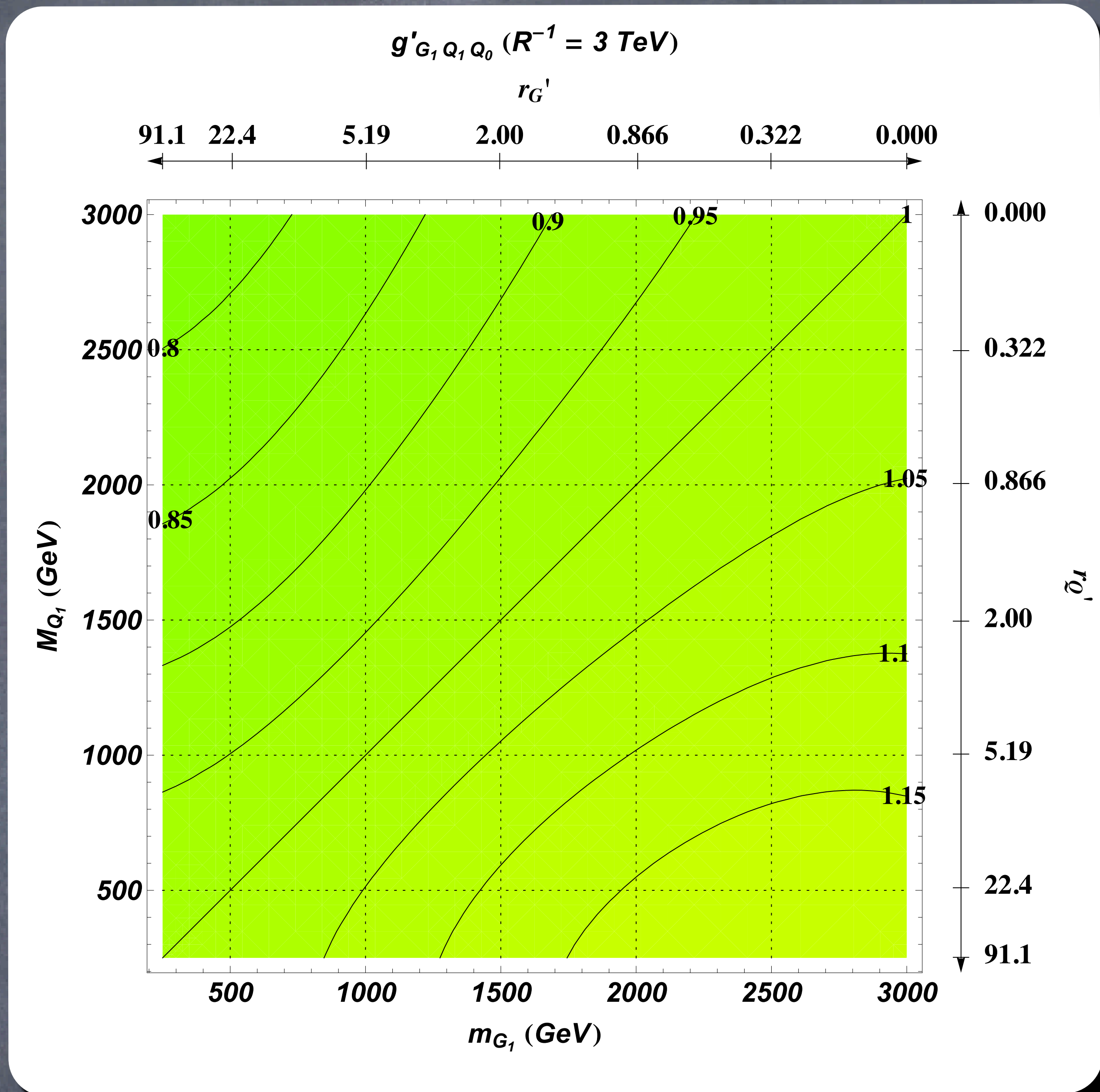
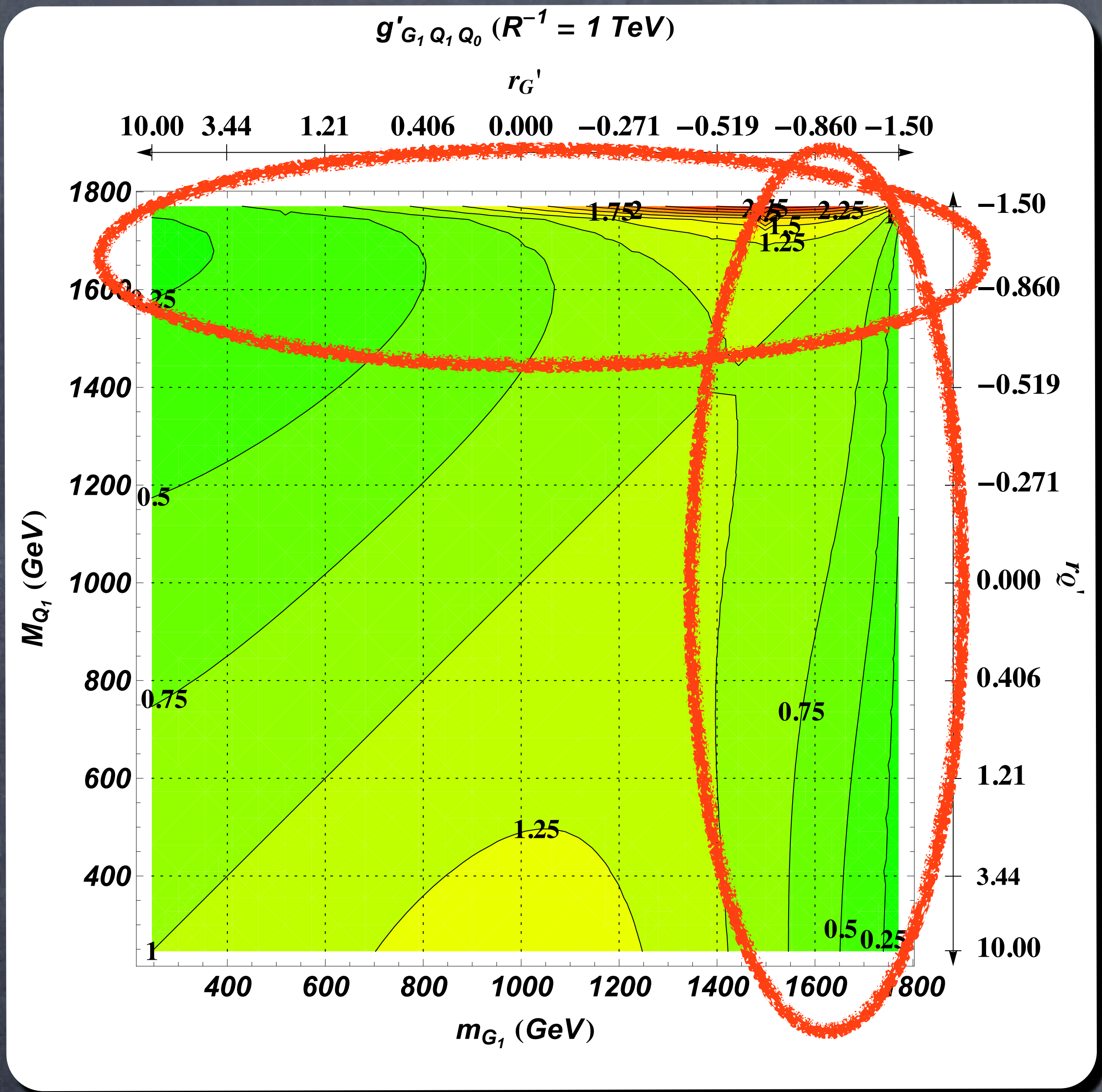
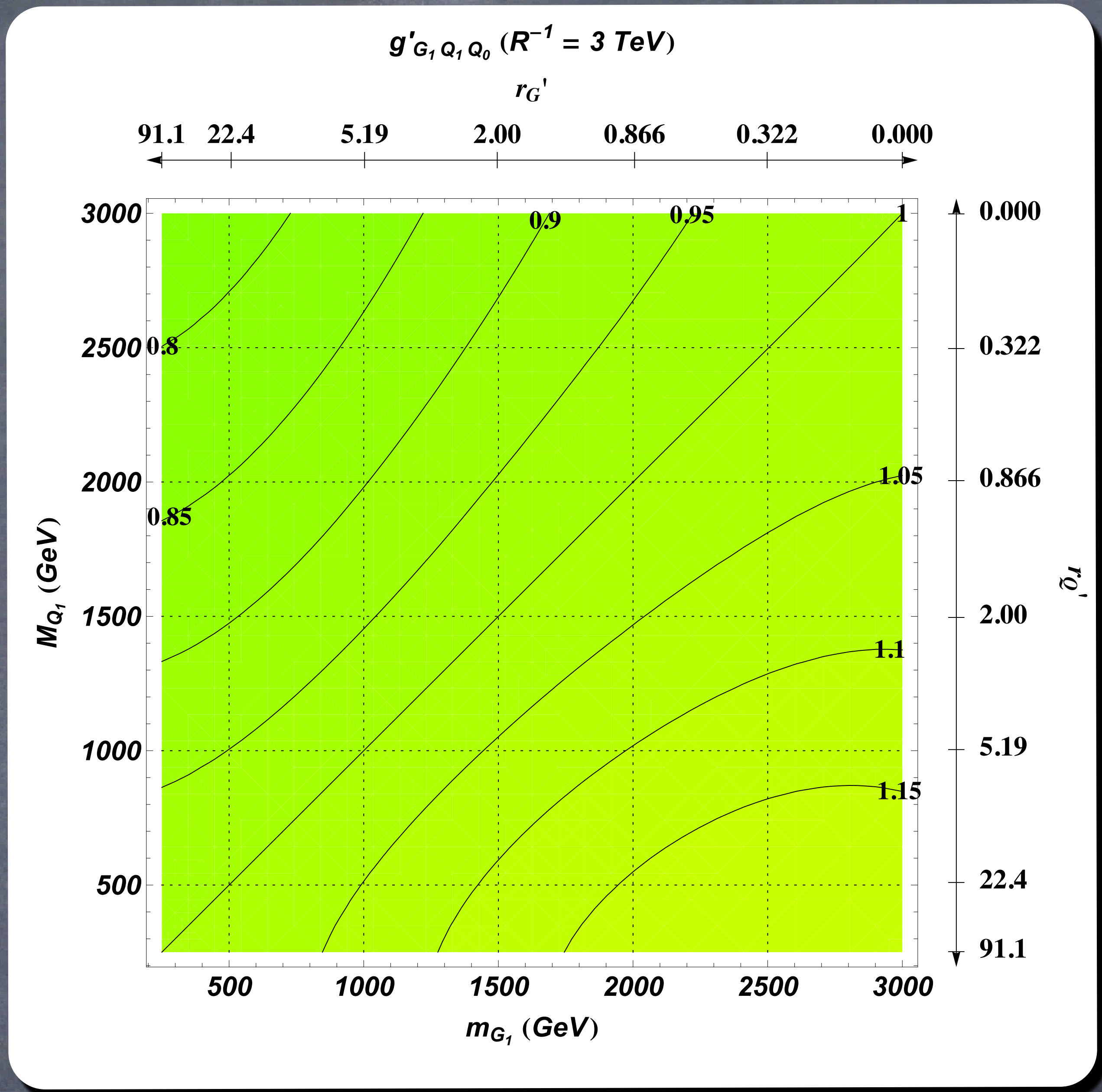





$g'_{G_1 Q_1 Q_0}$ (R^{-1} = 1 TeV)
r_G'
10.00 3.44 1.21 0.406 0.000 −0.271 −0.519 −0.860 −1.50
r_Q'
−1.50 −0.860 −0.519 −0.271 0.000 0.406 1.21 3.44 10.00
M_{Q_1} (GeV)
m_{G_1} (GeV)
400 600 800 1000 1200 1400 1600 1800


$g'_{G_1 Q_1 Q_0}$ (R^{-1} = 3 TeV)
r_G'
91.1 22.4 5.19 2.00 0.866 0.322 0.000
r_Q'
0.000 0.322 0.866 2.00 5.19 22.4 91.1
M_{Q_1} (GeV)
m_{G_1} (GeV)
500 1000 1500 2000 2500 3000





Anomalous region can be found.

Contents

1. System with brane-localized terms

2. deviations in mass & couplings

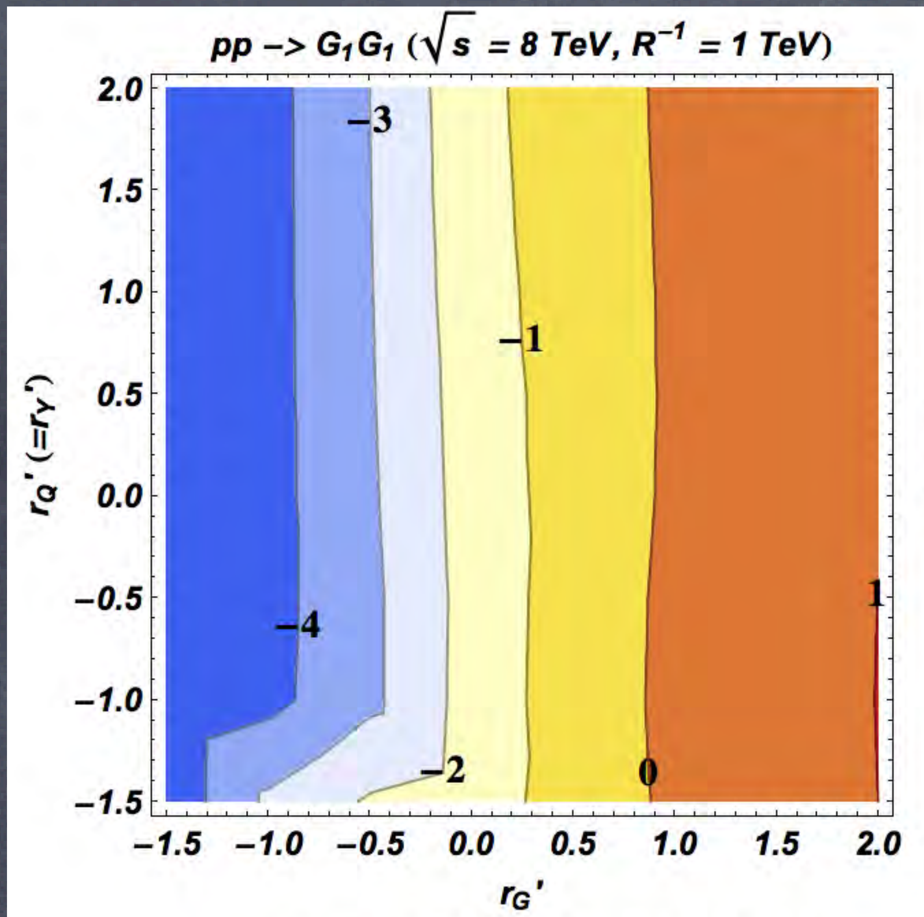
3. Anomalous properties in cross section with low R^{-1}

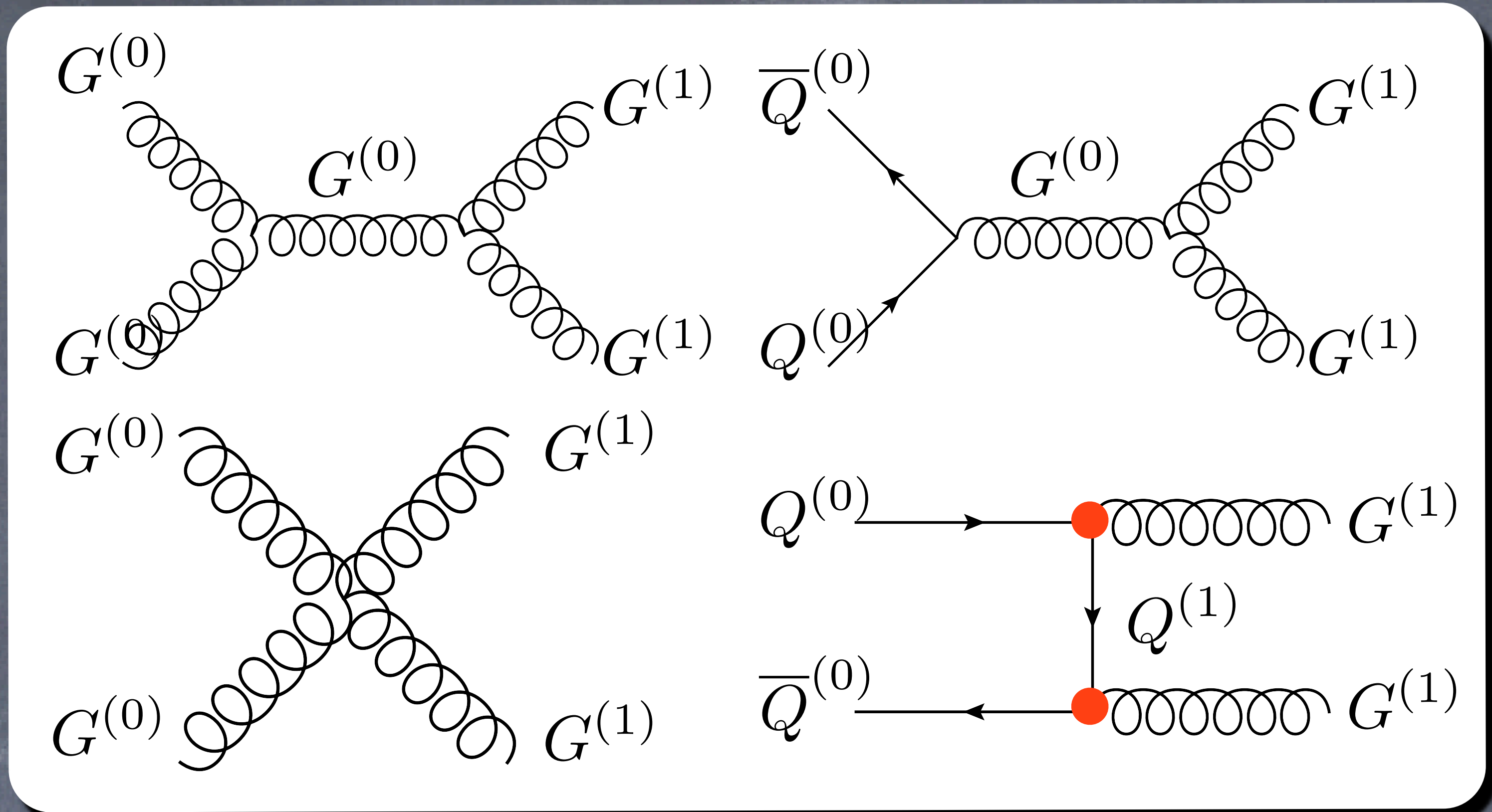
Numerical cross section calculation

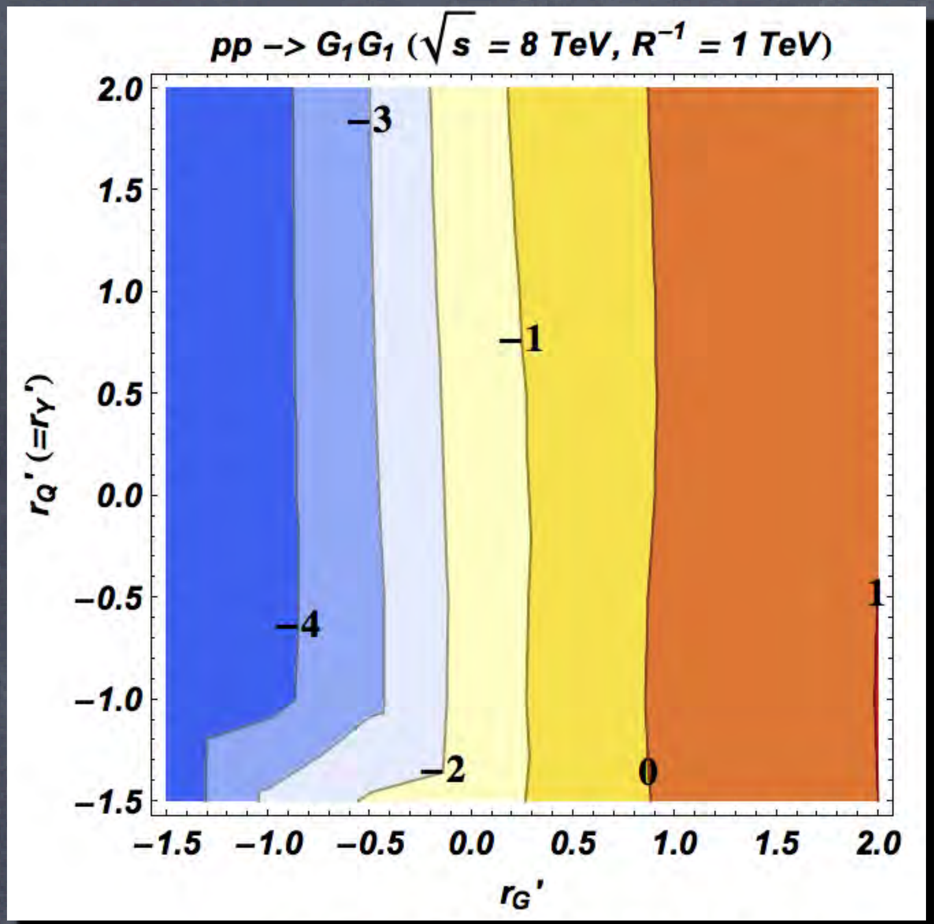
✓ We calculate the three processes:
$pp \to G^{(1)}G^{(1)}$, $pp \to G^{(1)}Q^{(1)}$, $pp \to Q^{(1)}Q^{(1)}$.

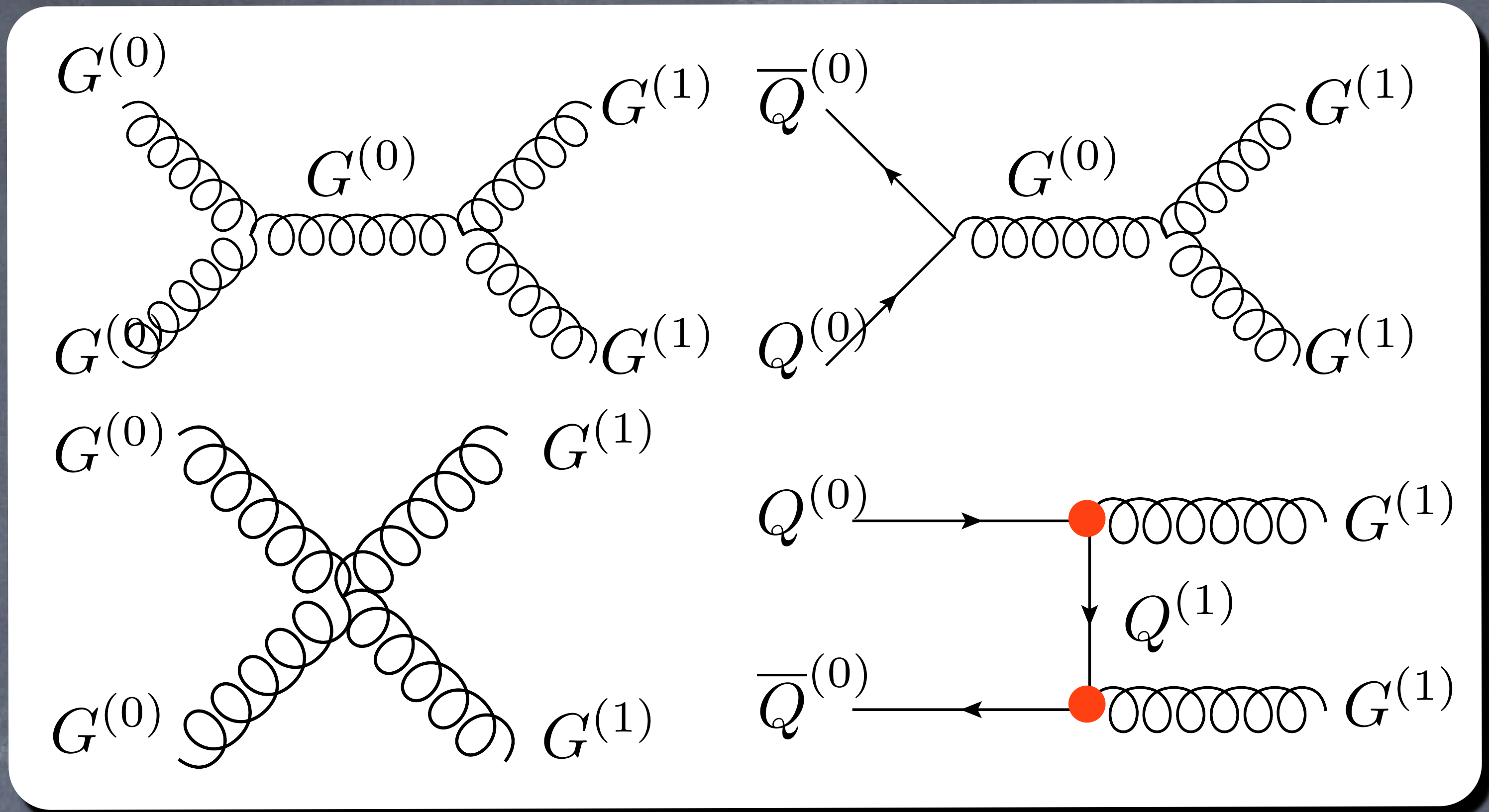
- We sum up the KK quarks' first five flavors & particle/antiparticle.
- We use Feynrules for launching our model, Madgraph5 for calculating the cross section.
- We use CTEQ6L parametrization for PDF.
- The QCD factorization/renormalization scale is fixed at sum of the masses of the final state particles.
- We search for the range: 500 GeV $< M_{KK} <$ 2 (3) TeV @ 8 (14) TeV run.

8TeV run with R^{-1} = 1TeV

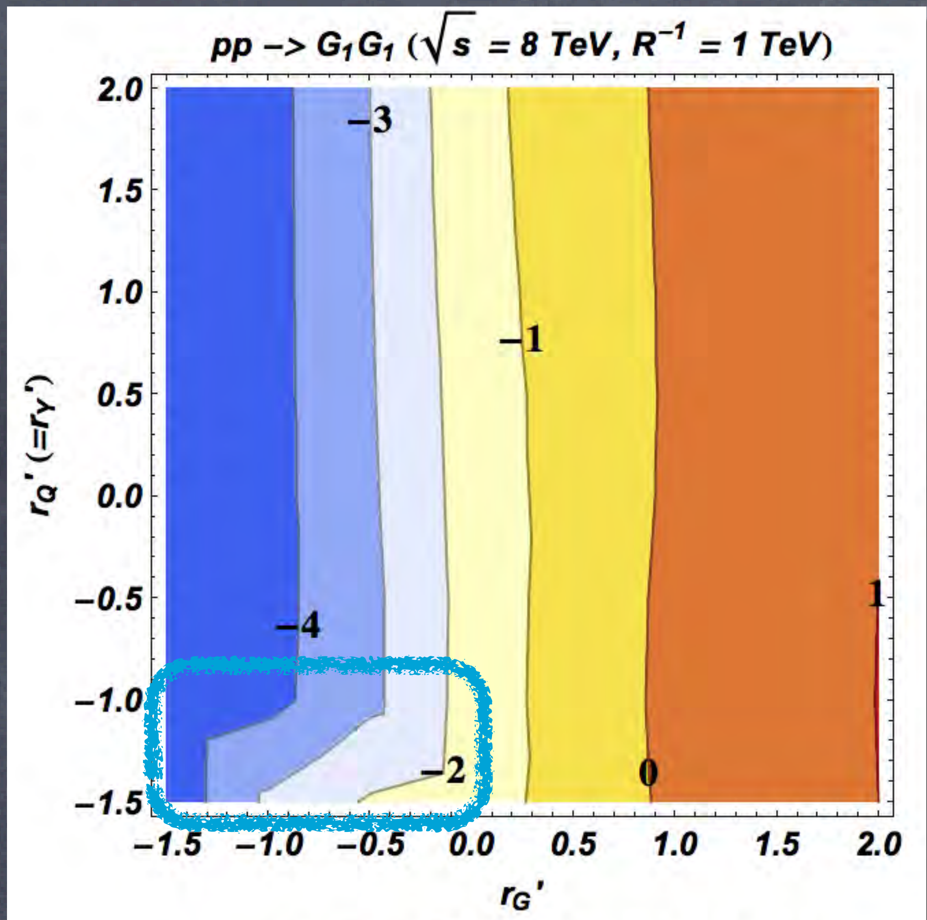

pp -> G1G1 (√s = 8 TeV, R^-1 = 1 TeV)
rQ' (=rY')
rG'
−4
−3
−2
−1
0
1
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0

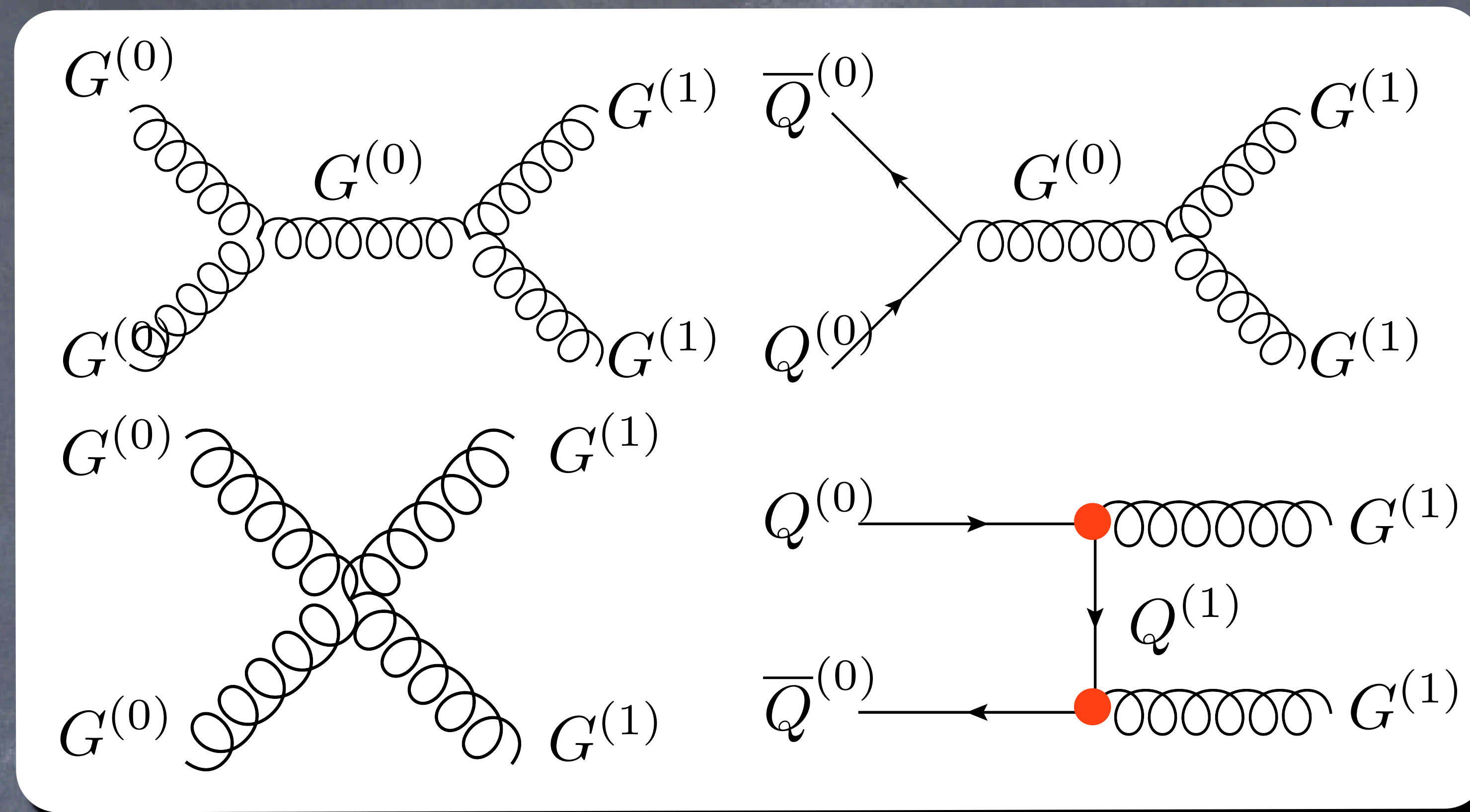

$G^{(0)}$
$G^{(0)}$
$G^{(0)}$
$G^{(1)}$
$G^{(1)}$
$\overline{Q}^{(0)}$
$Q^{(0)}$
$G^{(0)}$
$G^{(1)}$
$G^{(1)}$
$G^{(0)}$
$G^{(0)}$
$G^{(1)}$
$G^{(1)}$
$Q^{(0)}$
$\overline{Q}^{(0)}$
$Q^{(1)}$
$G^{(1)}$
$G^{(1)}$



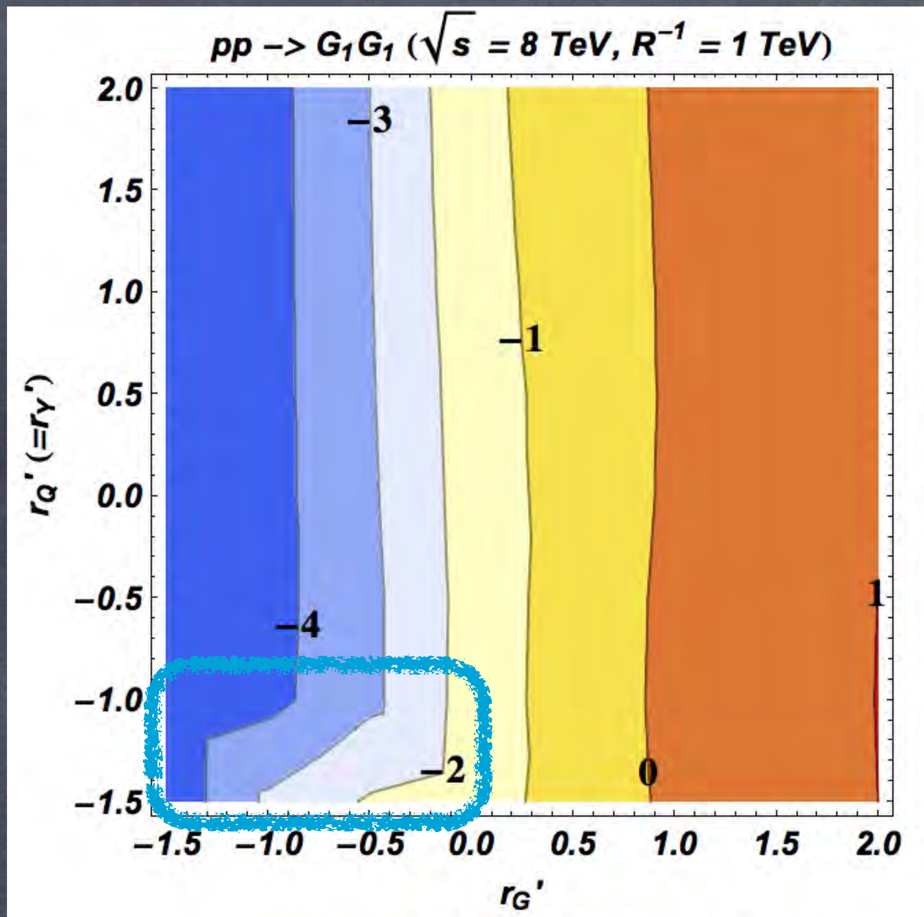


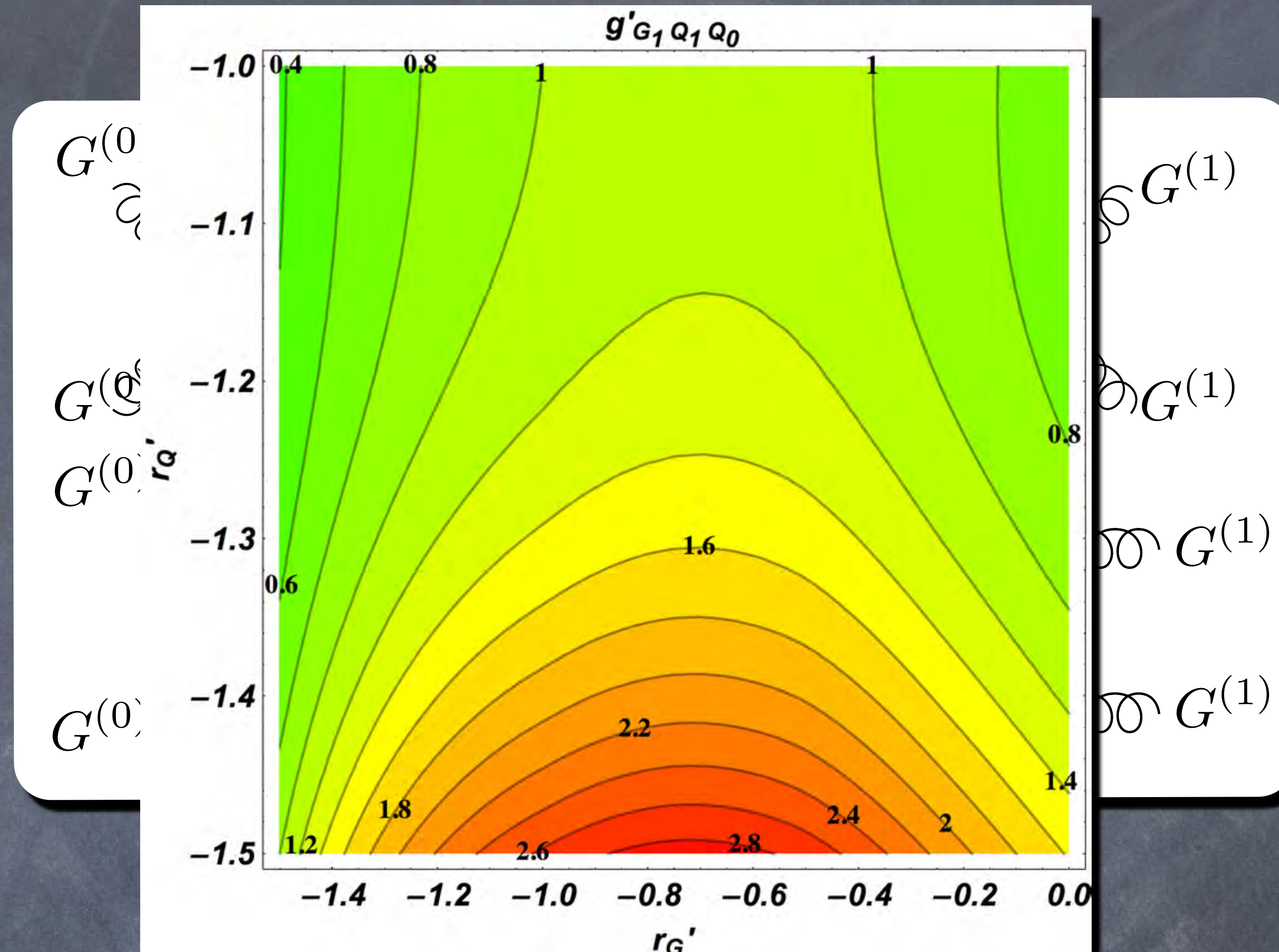
- ✓ In $r'_G > 0$ or $r'_Q > -1.0$, the cross section mostly depends on r'_G.
  - ☐ S-channel is dominant.





- ✓ In $r'_G > 0$ or $r'_Q > -1.0$, the cross section mostly depends on r'_G.
  - ☐ S-channel is dominant.
- ✓ In $r'_G < 0$ & $r'_Q < -1.0$, anomalous situation appears.
  - ☐ 1st KK gluon becomes heavy: lower gluon partonic flux,
  - ☐ Very large value of nontrivial factor.





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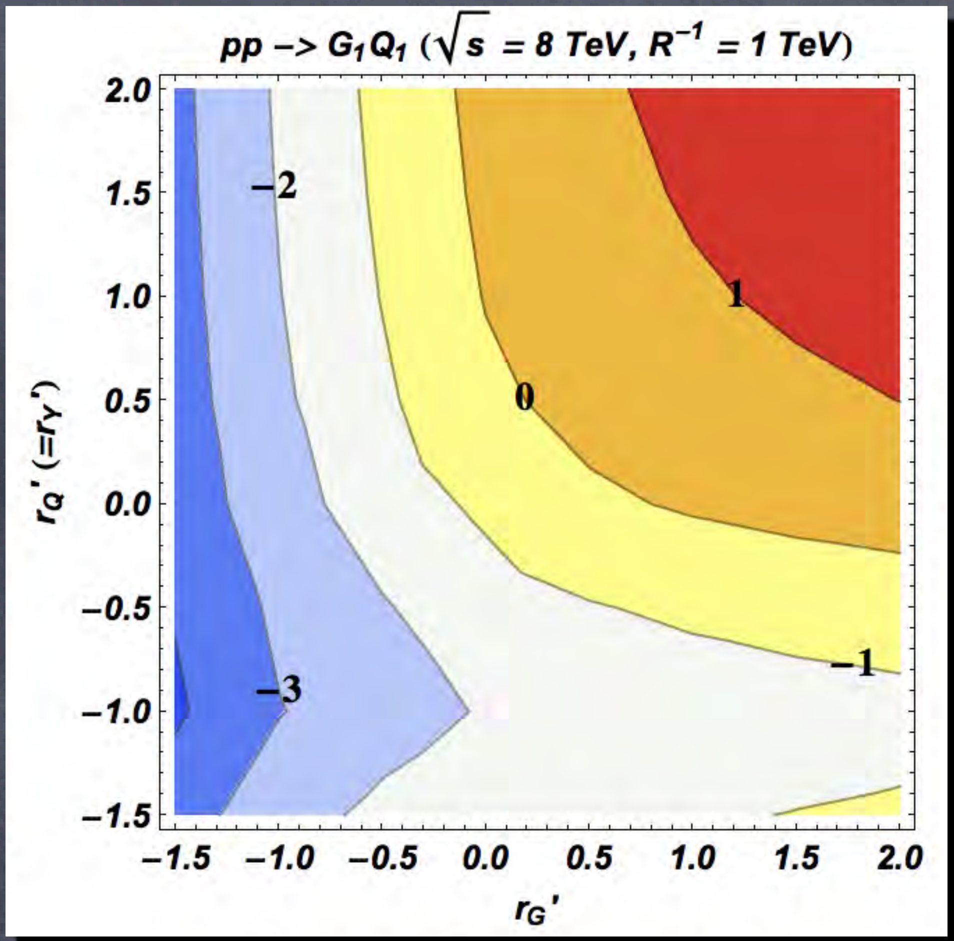
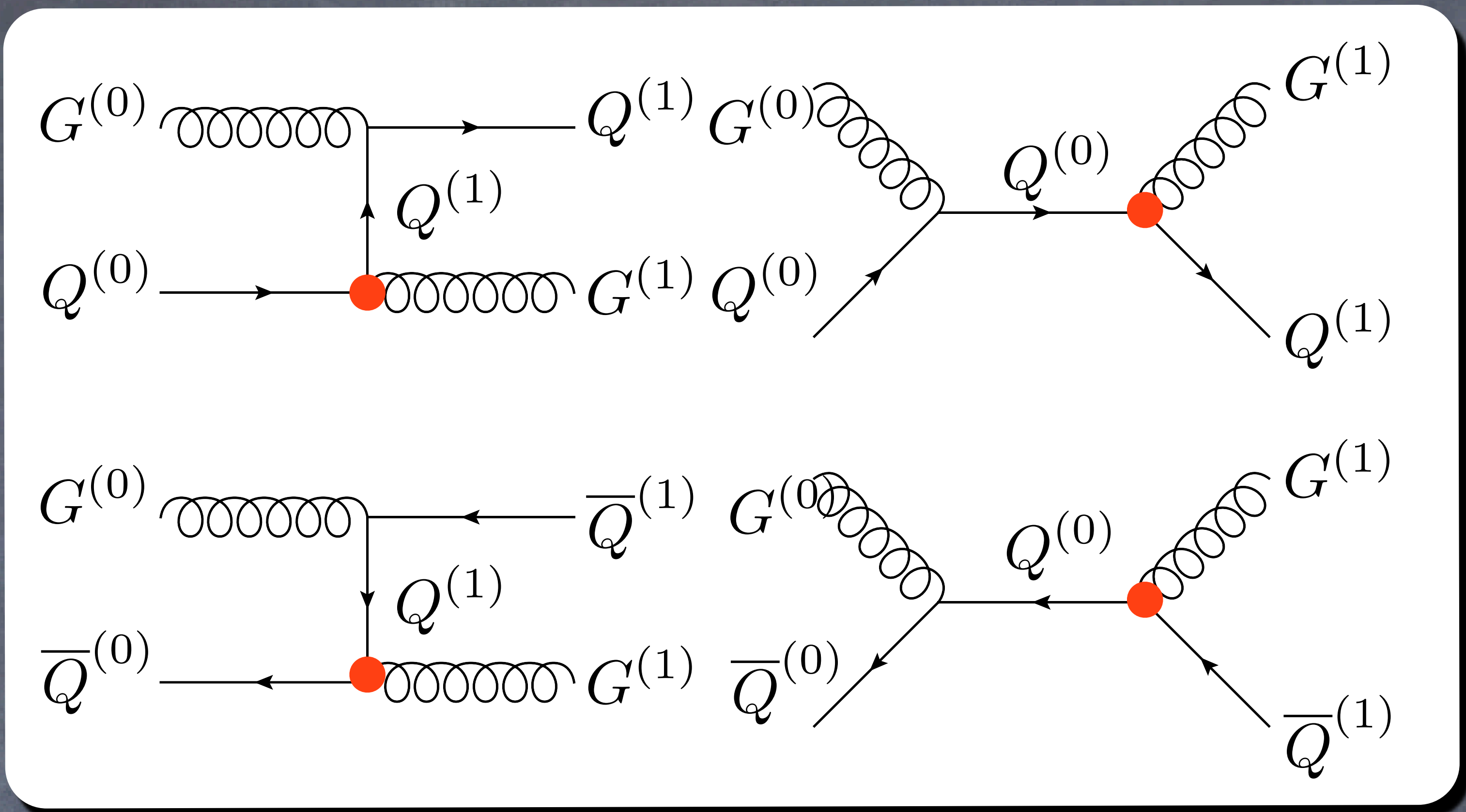
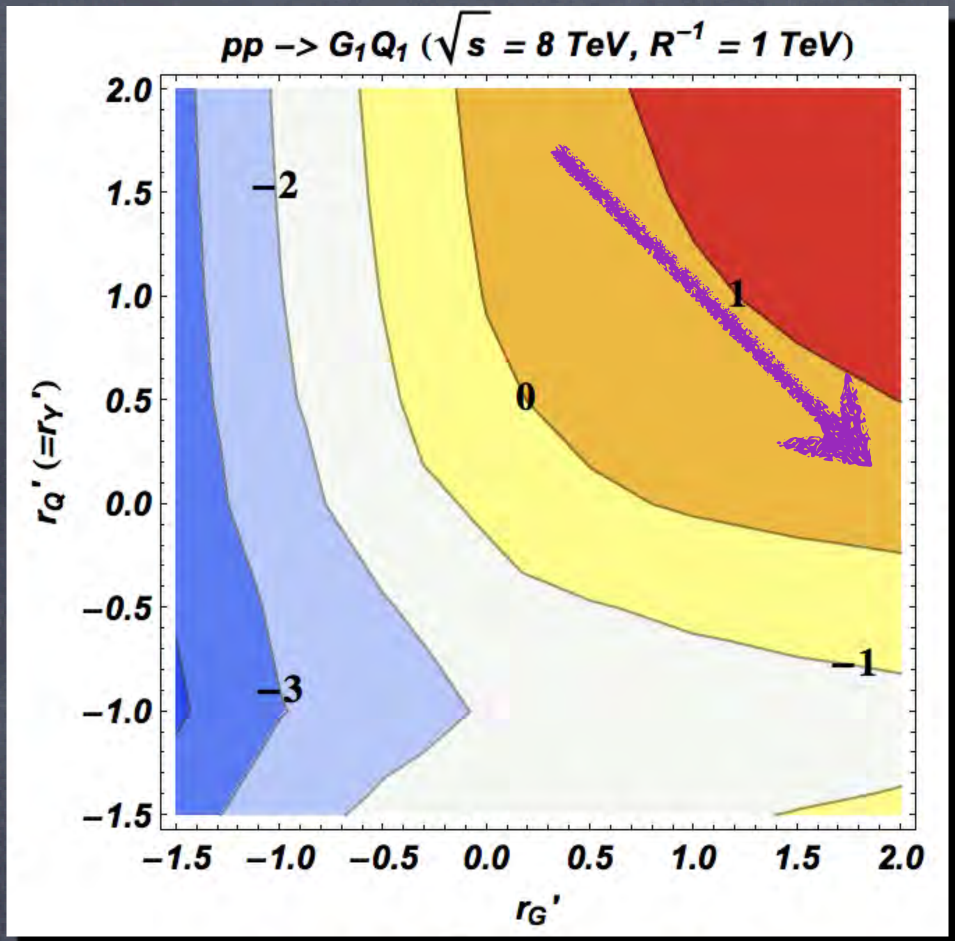
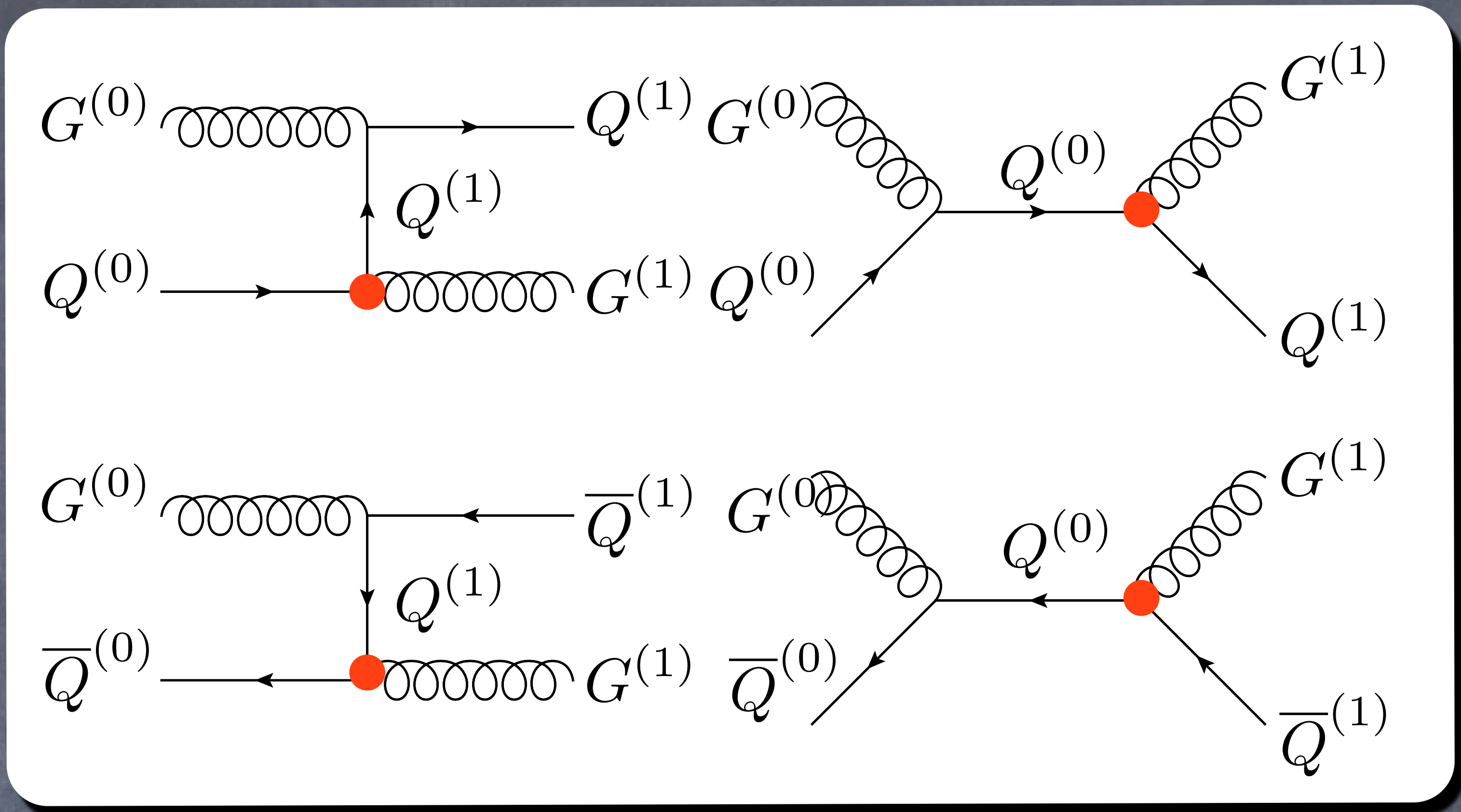


pp -> G1Q1 (√s = 8 TeV, R^-1 = 1 TeV)
rQ' (=rY')
rG'
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
−2
1
0
−1
−3



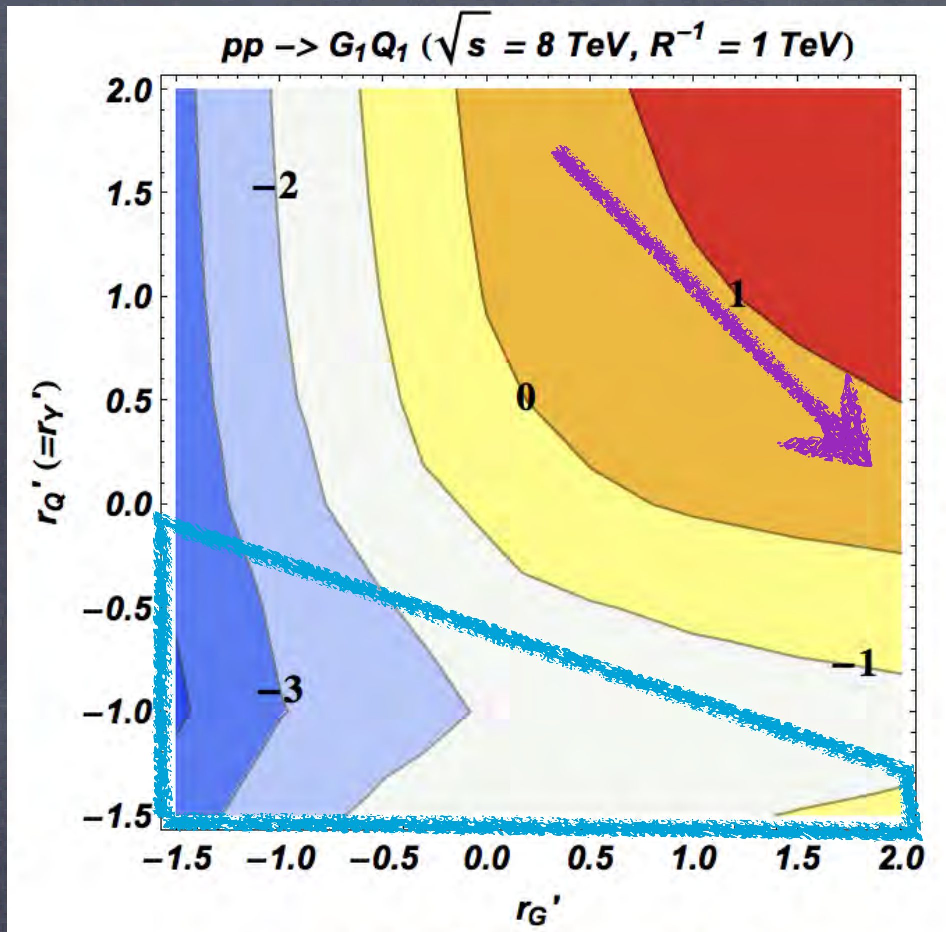
$G^{(0)}$
$Q^{(1)}$
$Q^{(1)}$
$Q^{(0)}$
$G^{(1)}$
$G^{(0)}$
$Q^{(0)}$
$G^{(1)}$
$Q^{(0)}$
$Q^{(1)}$
$G^{(0)}$
$\overline{Q}^{(1)}$
$Q^{(1)}$
$\overline{Q}^{(0)}$
$G^{(1)}$
$G^{(0)}$
$Q^{(0)}$
$G^{(1)}$
$\overline{Q}^{(0)}$
$\overline{Q}^{(1)}$

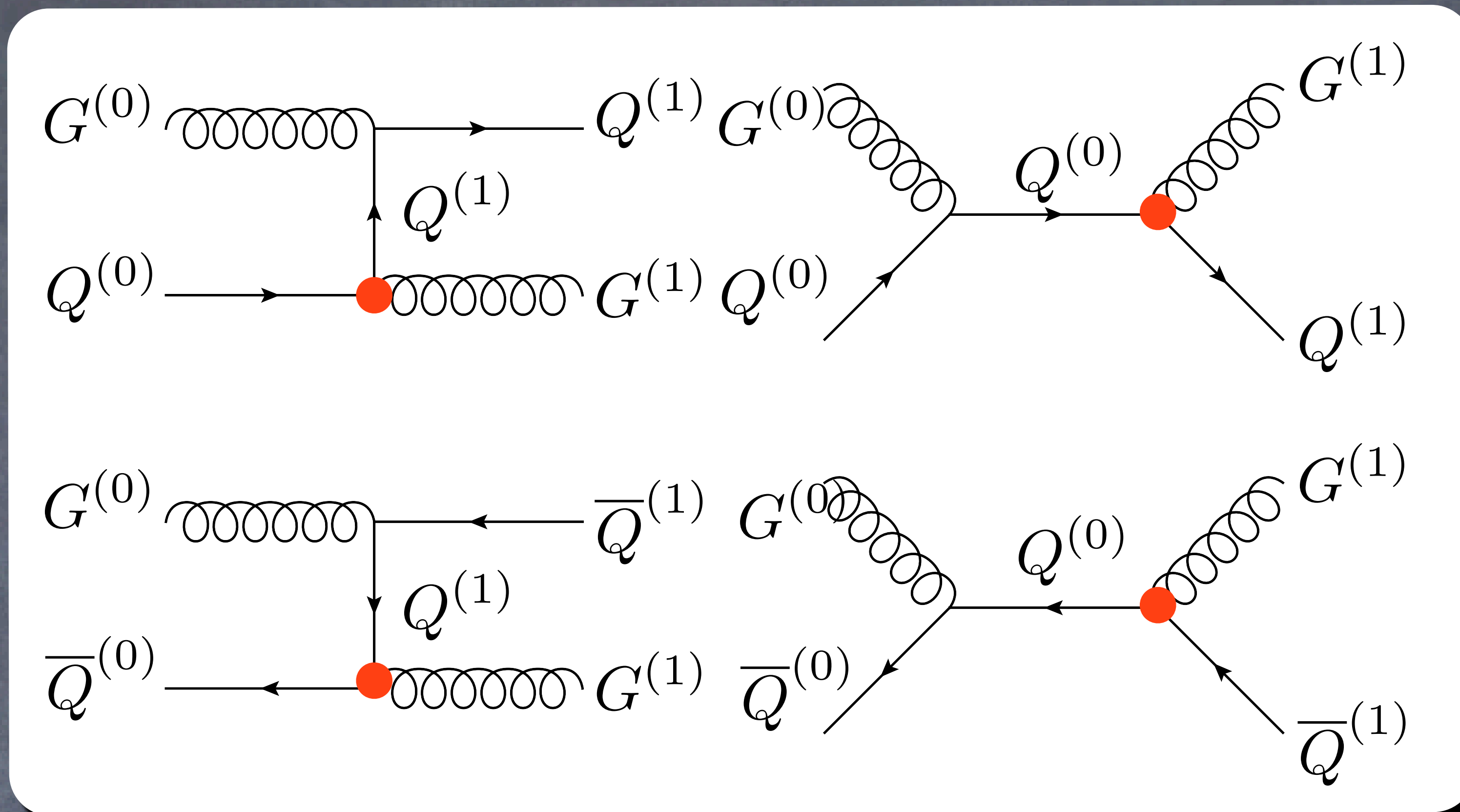




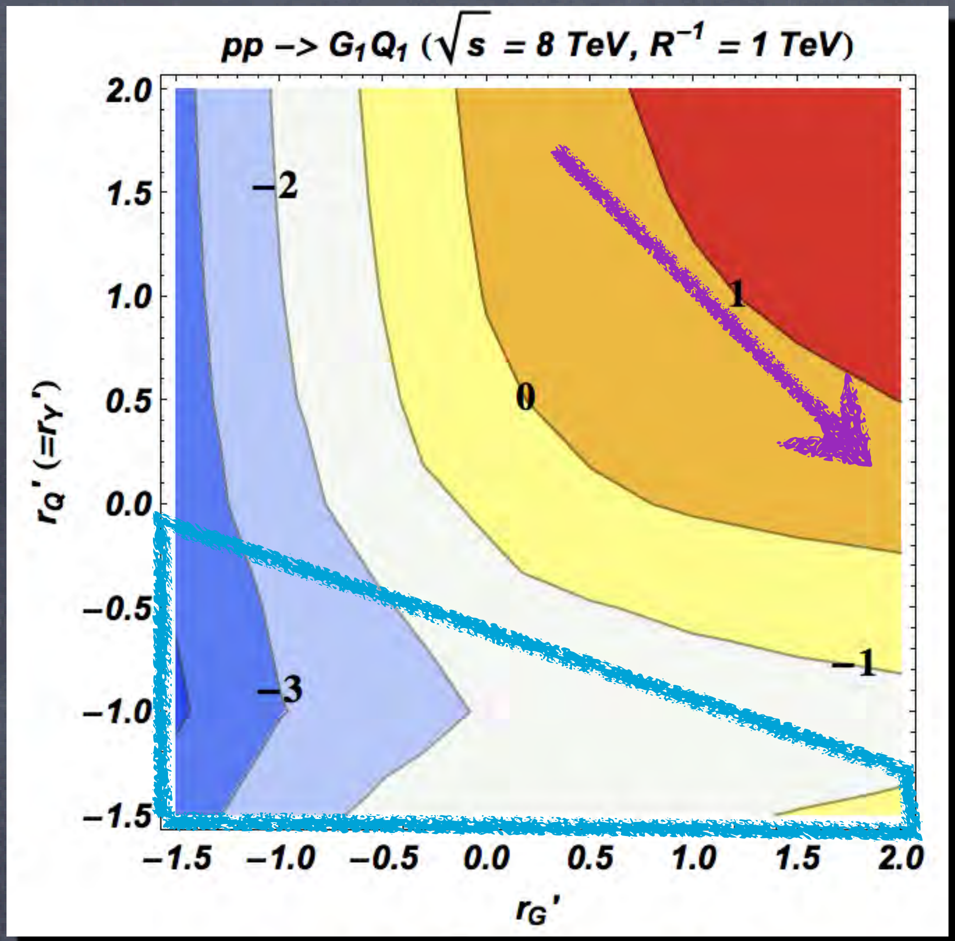
✓ The shape of contours is changed.

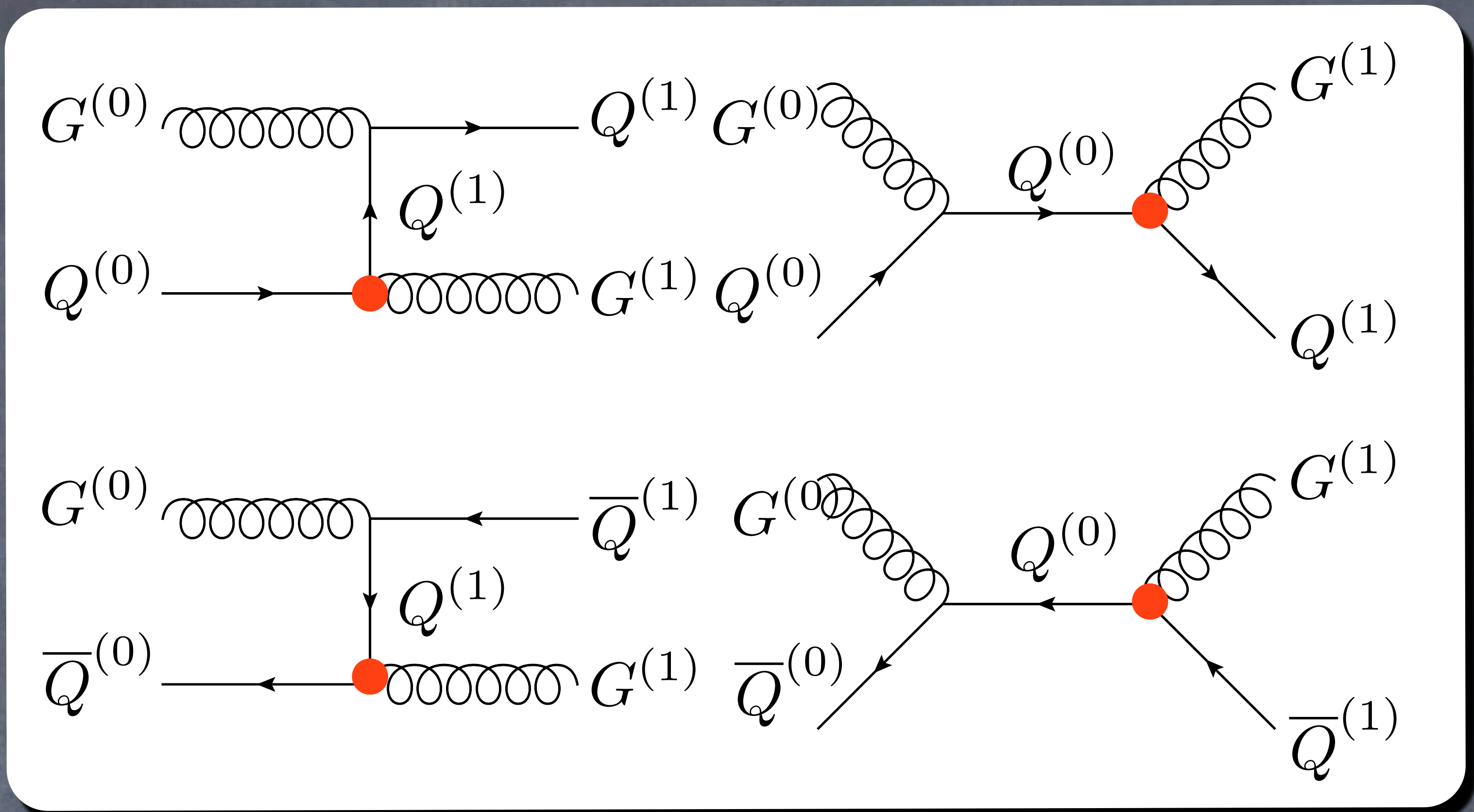
- Mass of $Q^{(1)}$ becomes important.





- ✓ The shape of contours is changed.
  - ☐ Mass of $Q^{(1)}$ becomes important.
- ✓ Anomalous range is enlarged.
  - ☐ Less s-channel effects compared to the $G^{(1)}G^{(1)}$ case.





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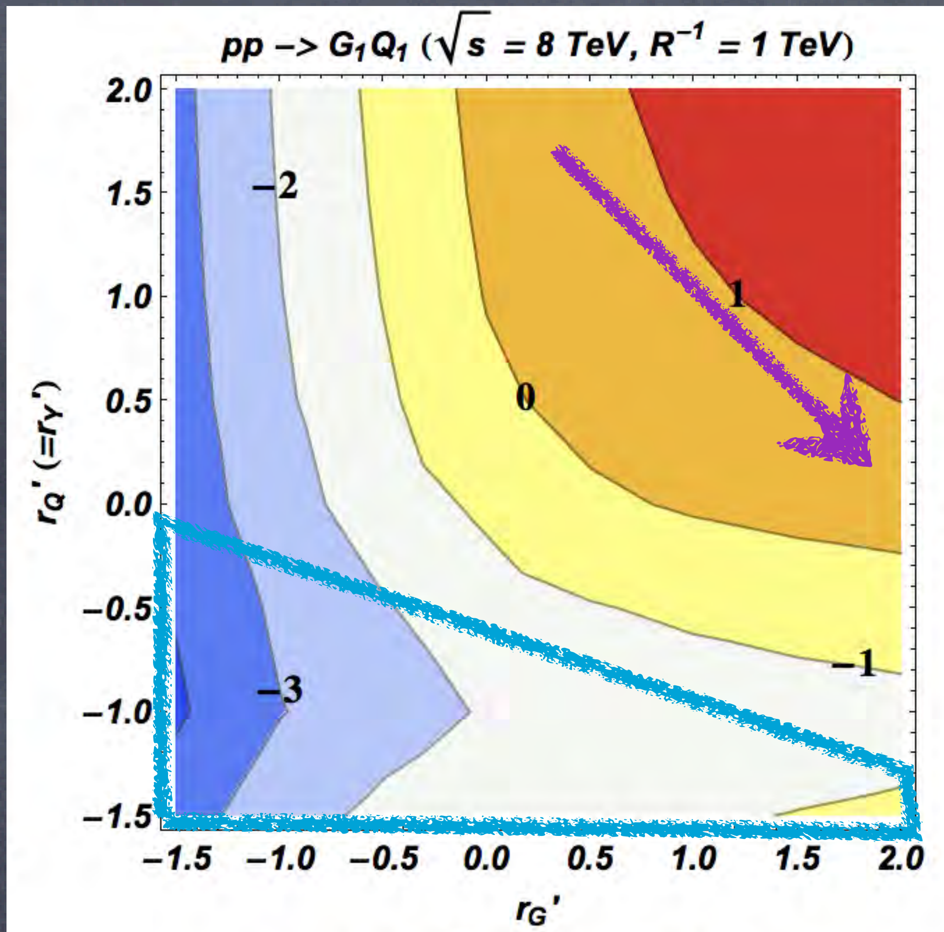
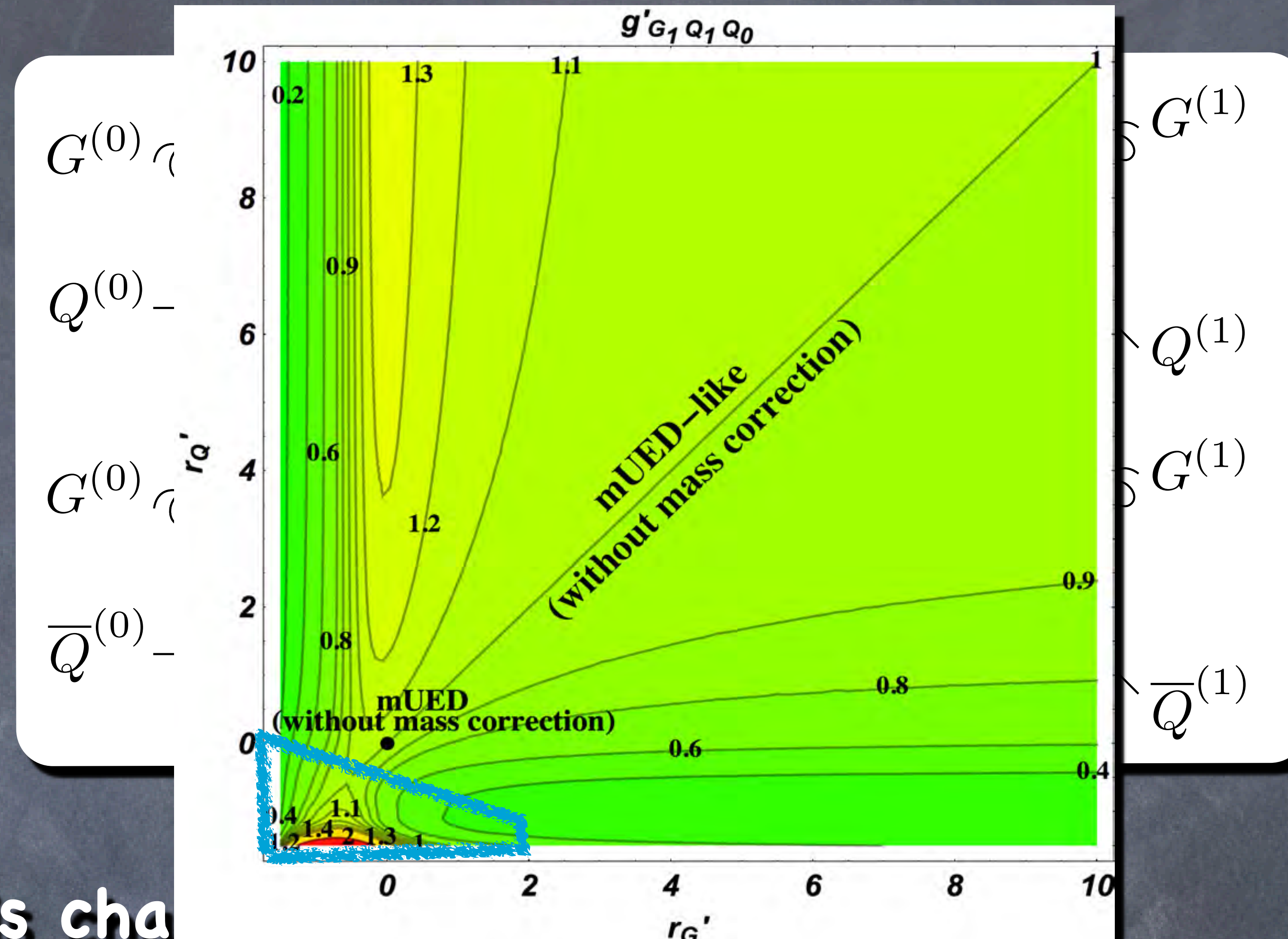
- ✓ Cross section differs more slowly in the Anomalous range.
  - ☐ Nontrivial factor appears only once per diagram.





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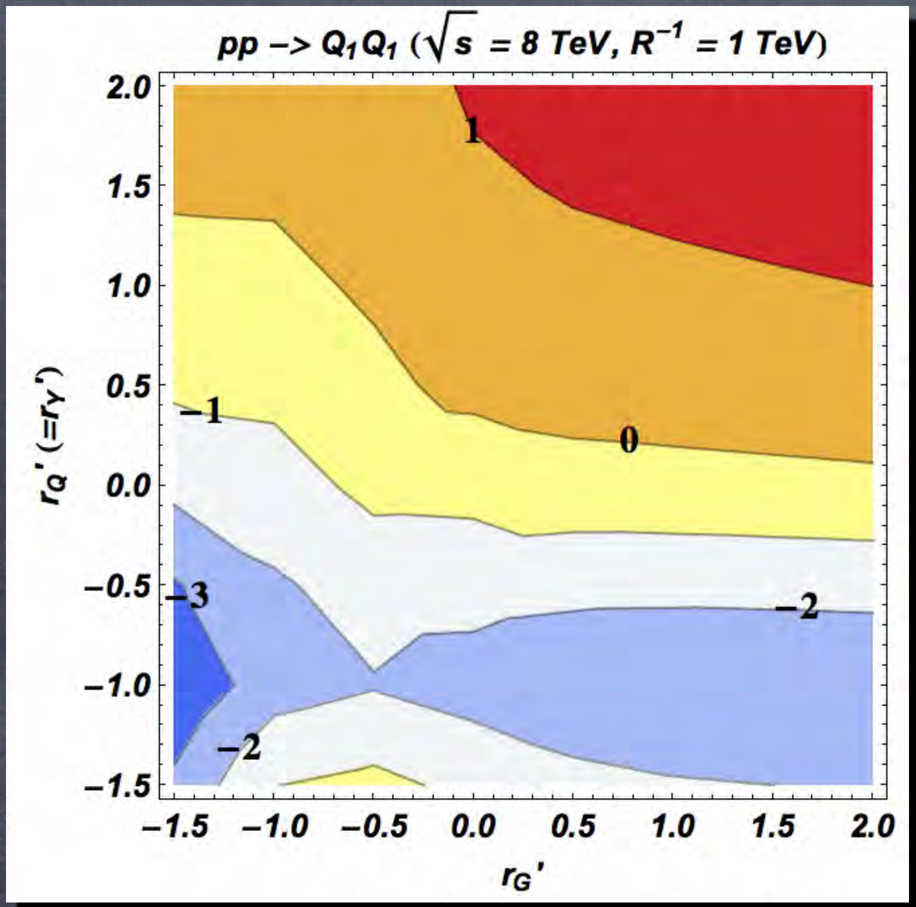
pp -> Q1Q1 (√s = 8 TeV, R^-1 = 1 TeV)
rQ' (=rY')
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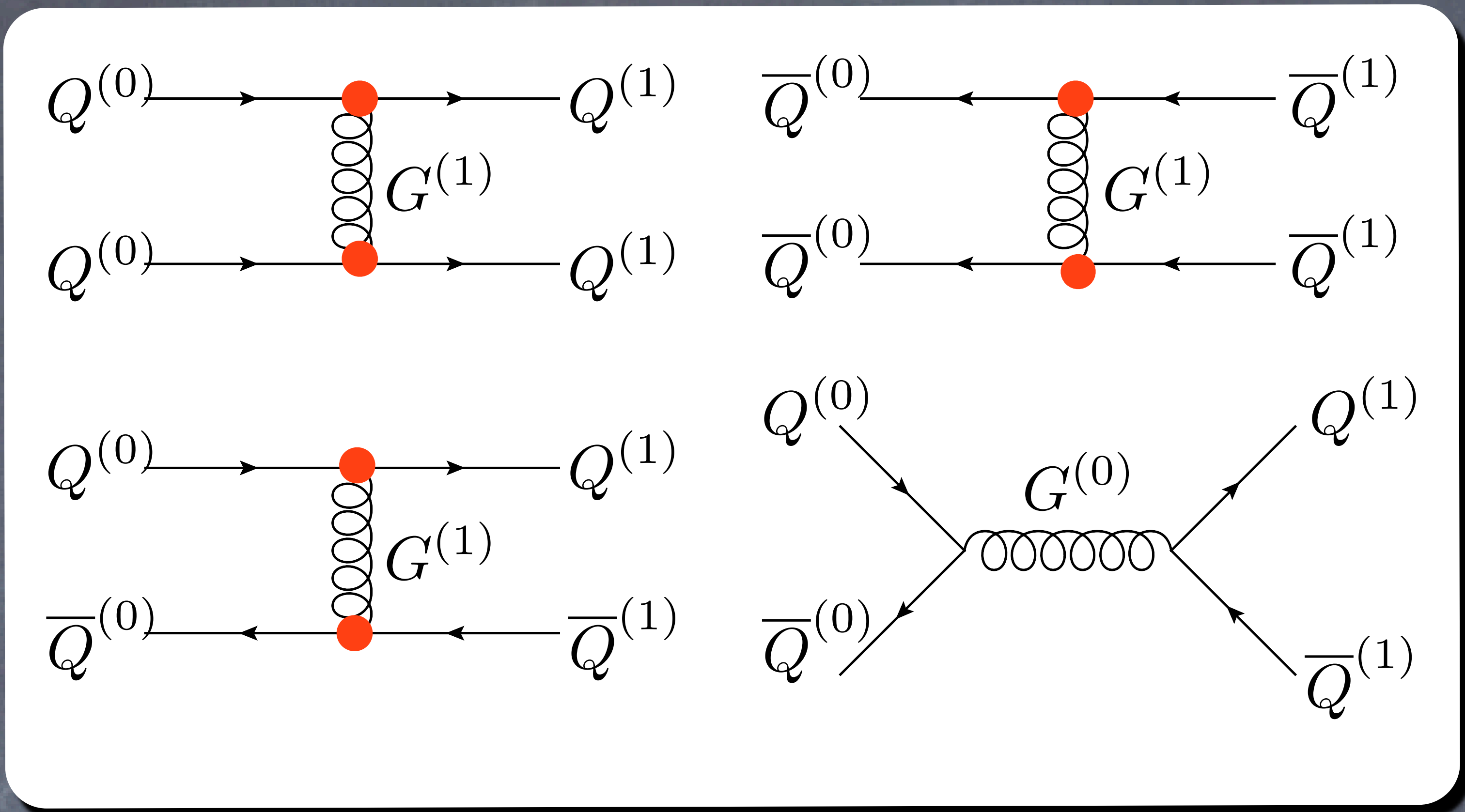
0.5
0.0
−0.5
−1.0
−1.5
−1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0
1
0
−1
−2
−3
−2


$Q^{(0)}$ $Q^{(1)}$ $G^{(1)}$ $Q^{(0)}$ $Q^{(1)}$
$\overline{Q}^{(0)}$ $\overline{Q}^{(1)}$ $G^{(1)}$ $\overline{Q}^{(0)}$ $\overline{Q}^{(1)}$
$Q^{(0)}$ $Q^{(1)}$ $G^{(1)}$ $\overline{Q}^{(0)}$ $\overline{Q}^{(1)}$
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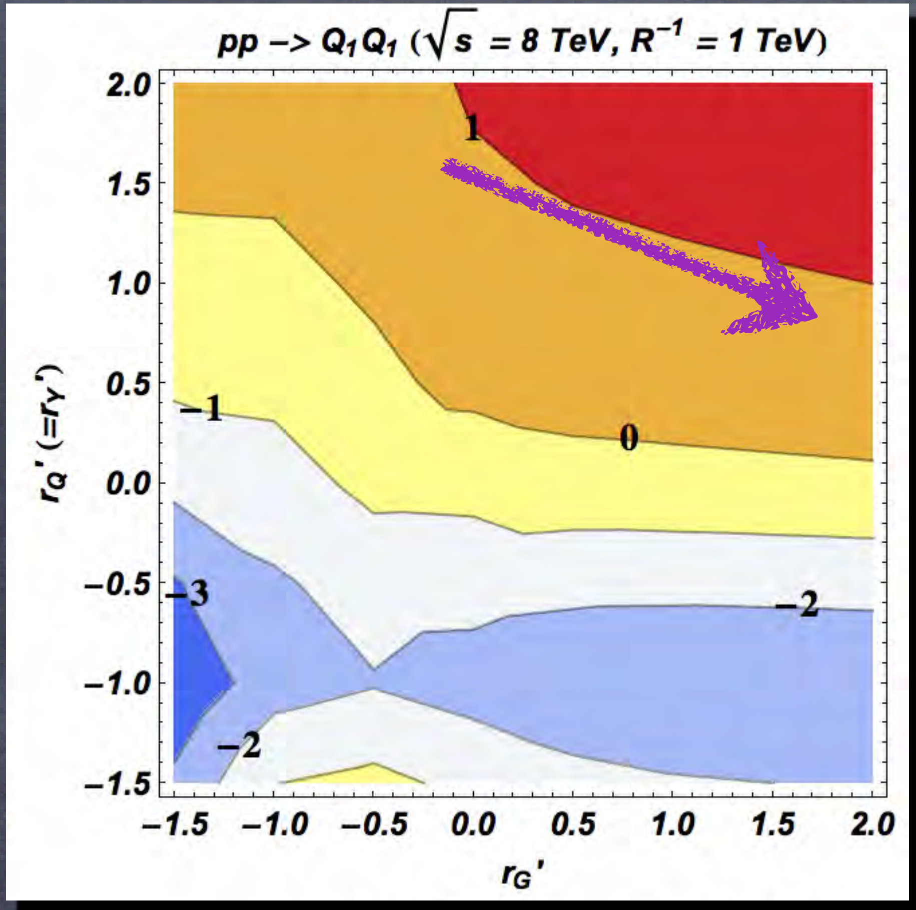
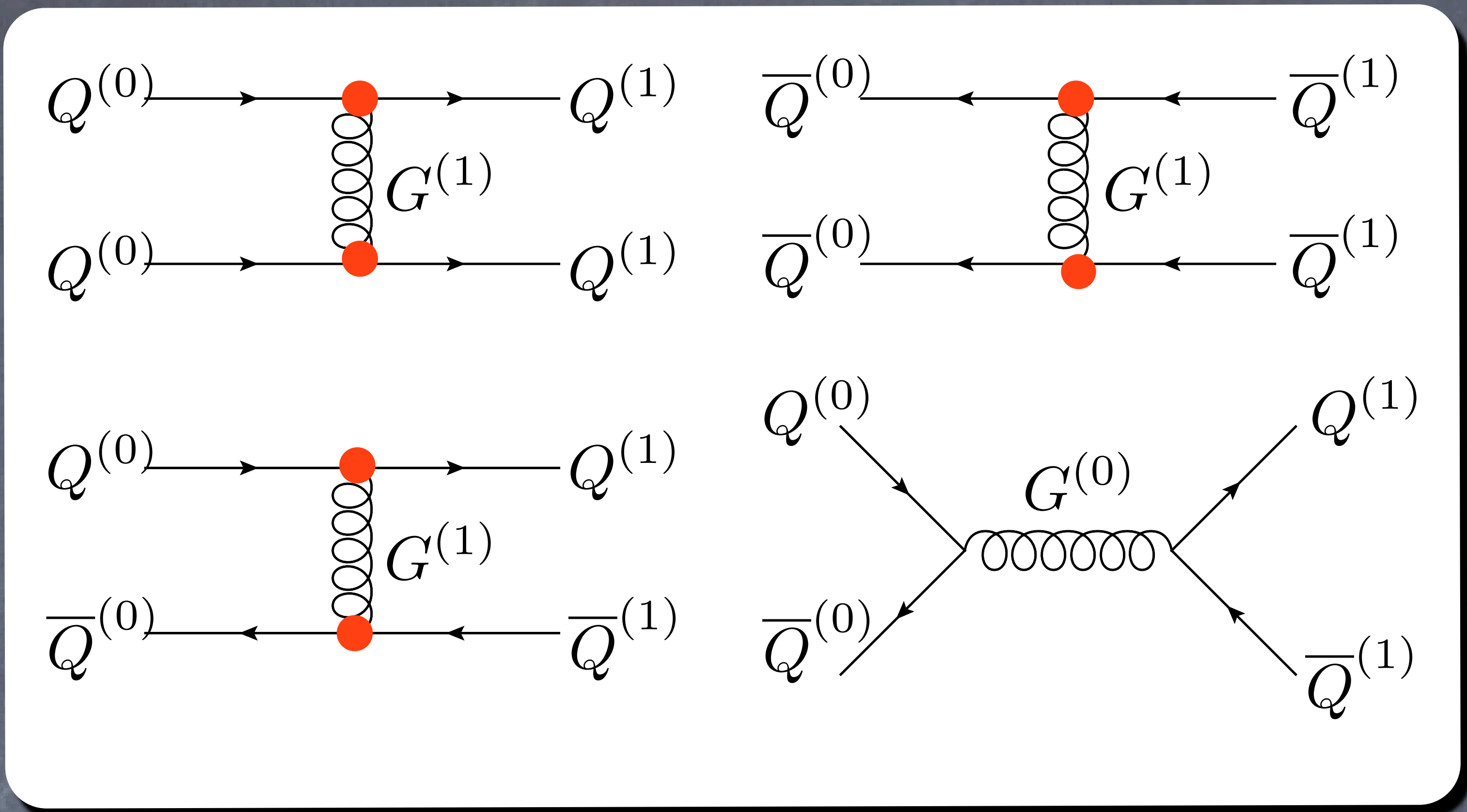
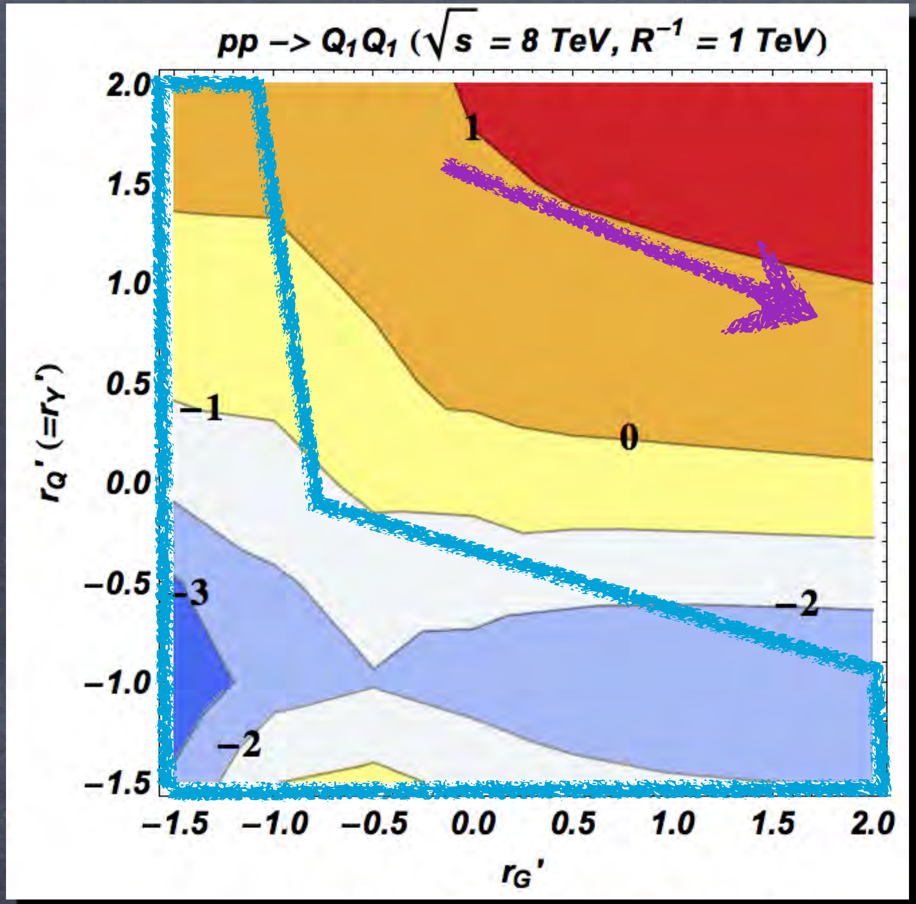
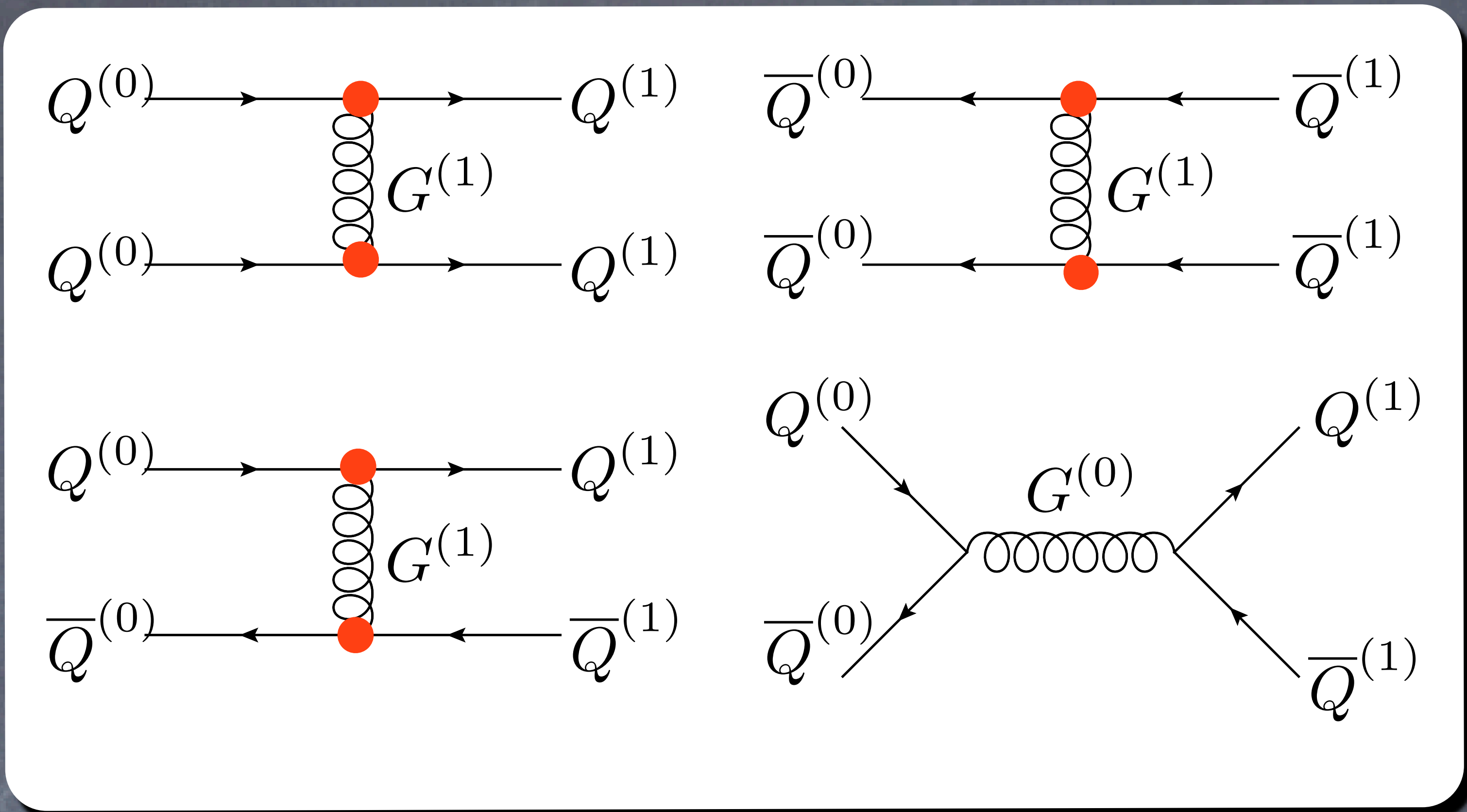




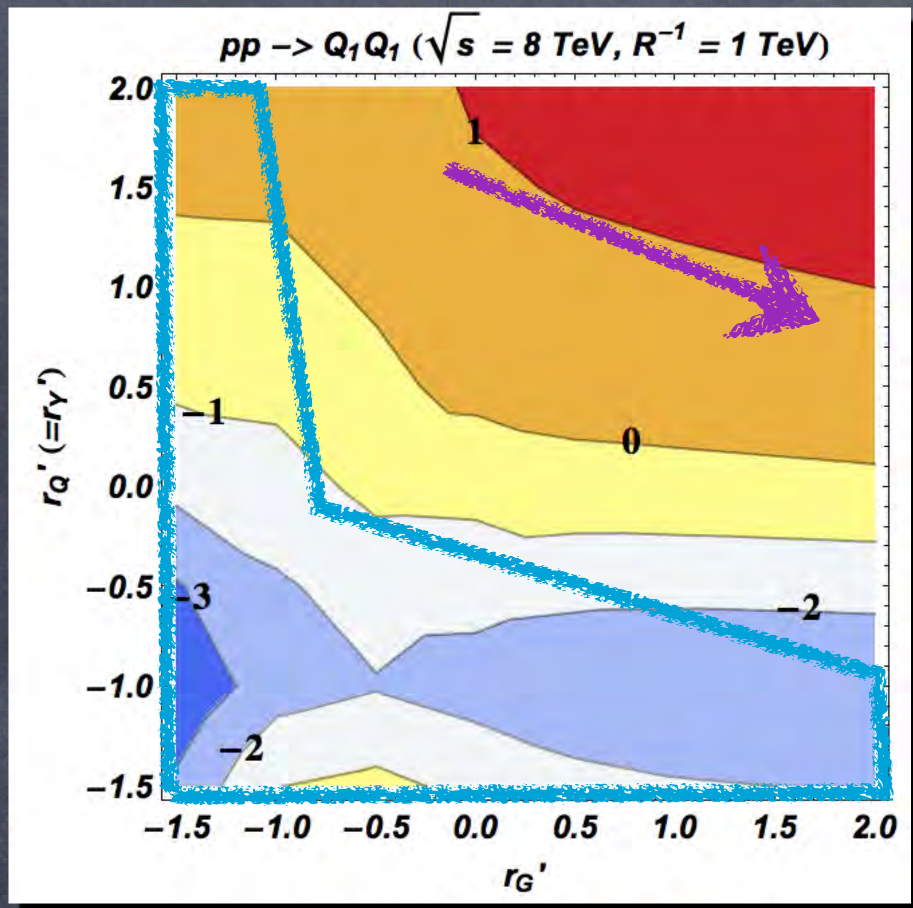
✓ The shape of contours is flatten.

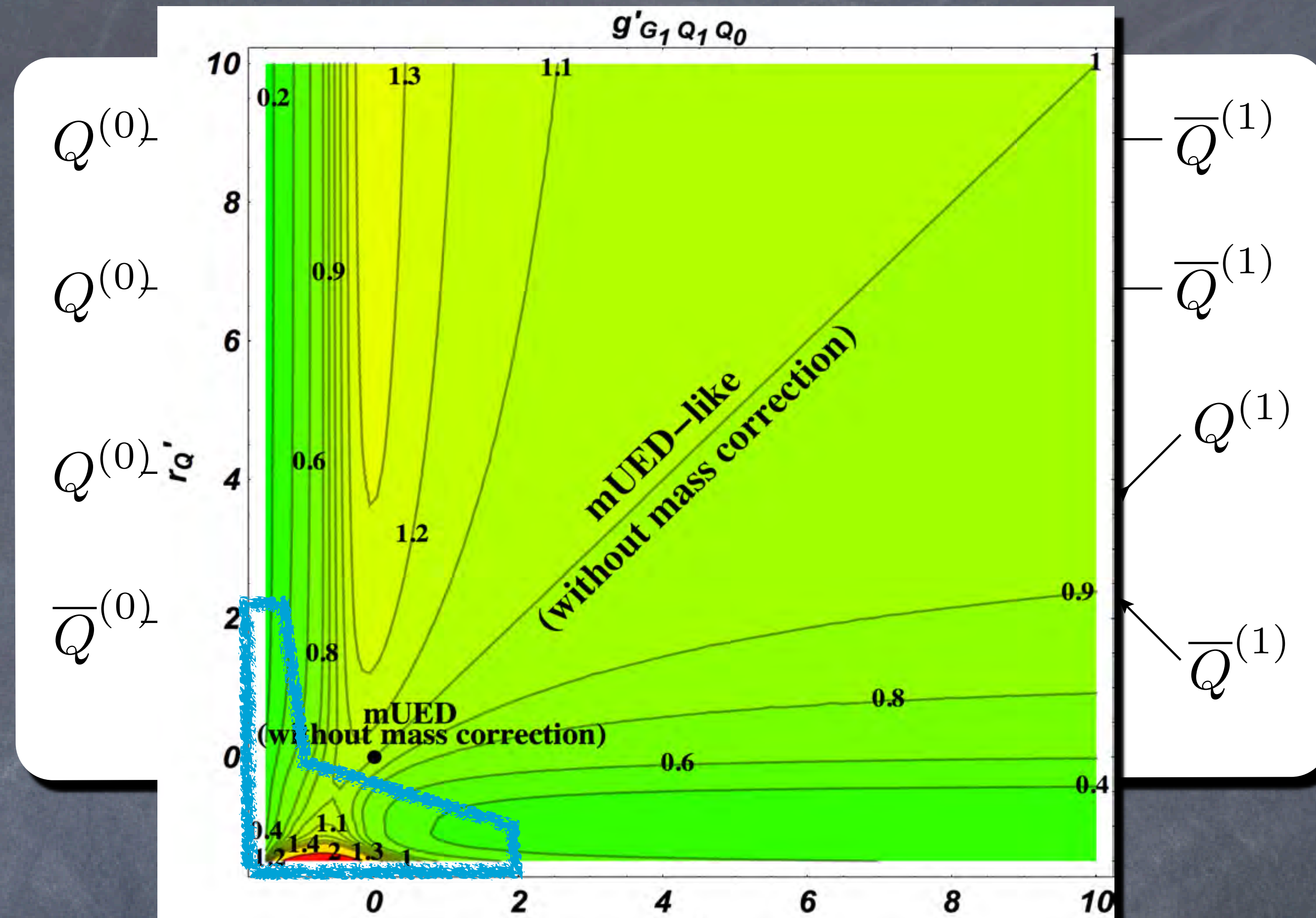
- Final states are only 1st KK quarks, but $G^{(1)}$ appears in the t-channels.





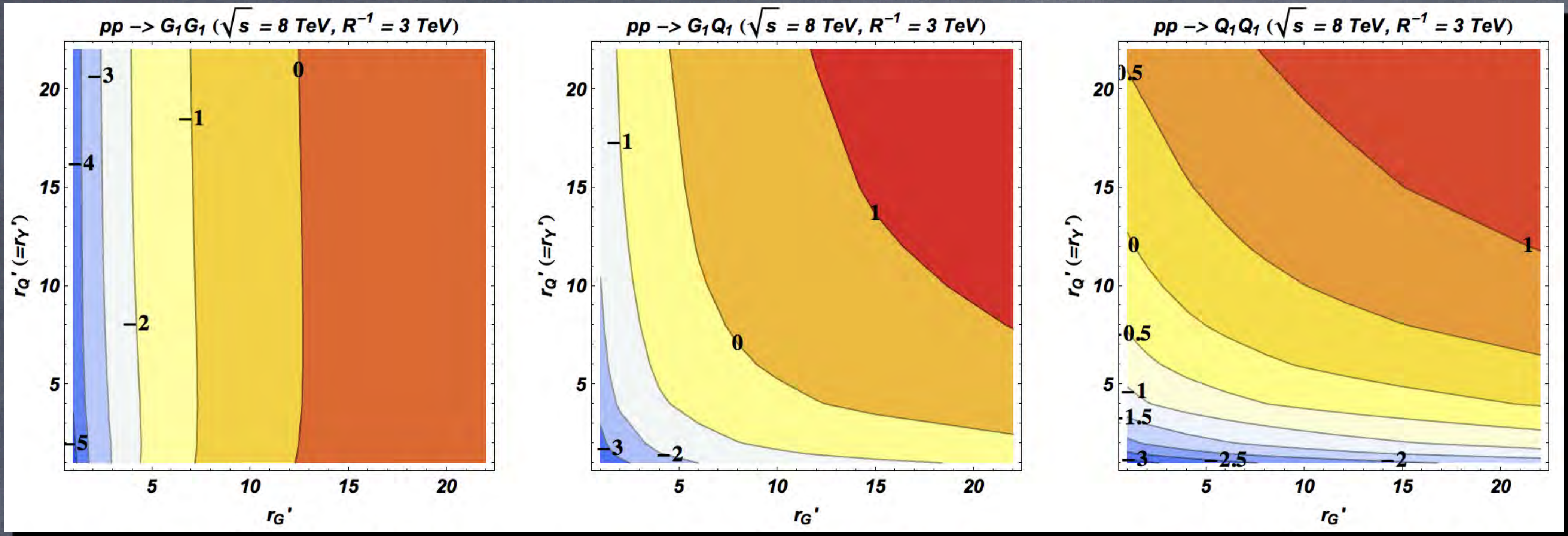
- ✓ The shape of contours is flatten.
  - ☐ Final states are only 1st KK quarks, but $G^{(1)}$ appears in the t-channels.
- ✓ Anomalous range is more enlarged.
  - ☐ Much less s-channel dominant,
  - ☐ Nontrivial factor appears twice per diagram.





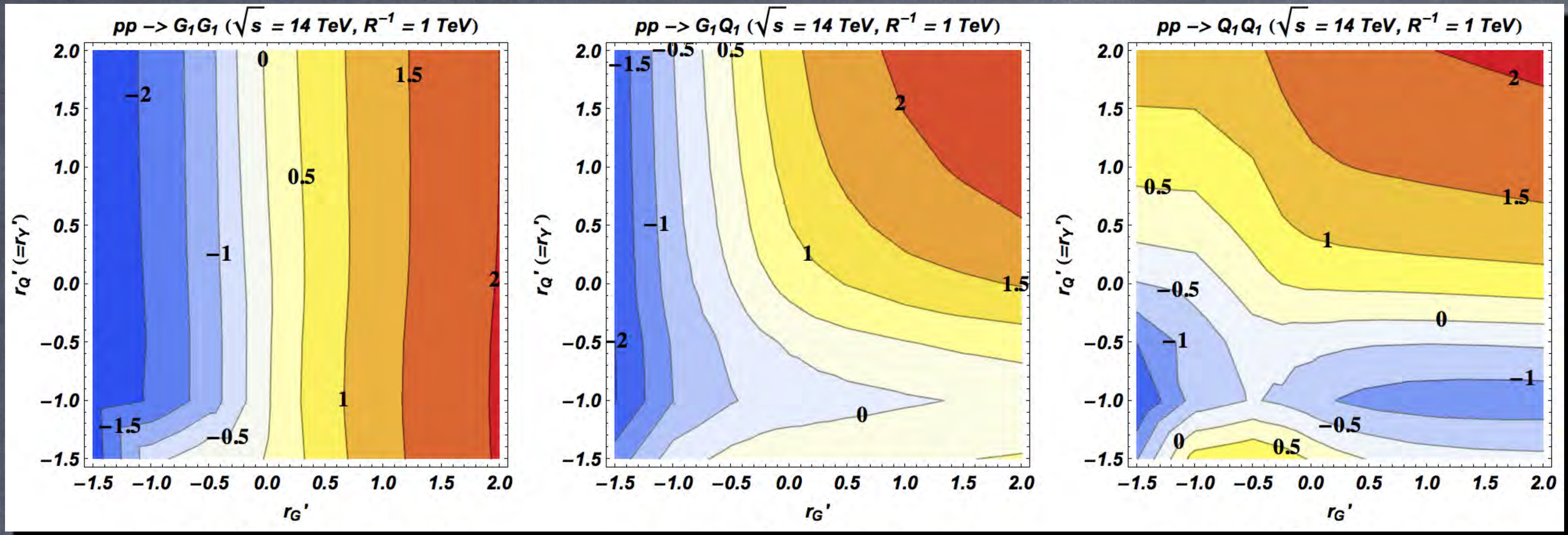
- ✓ The shape of contours is fla...
  - ☐ Final states are only 1st KK quarks, but $G^{(1)}$ appears in the t-channels.
- ✓ Anomalous range is more enlarged.
  - ☐ Much less s-channel dominant,
  - ☐ Nontrivial factor appears twice per diagram.

8TeV run with R^{-1} = 3 TeV



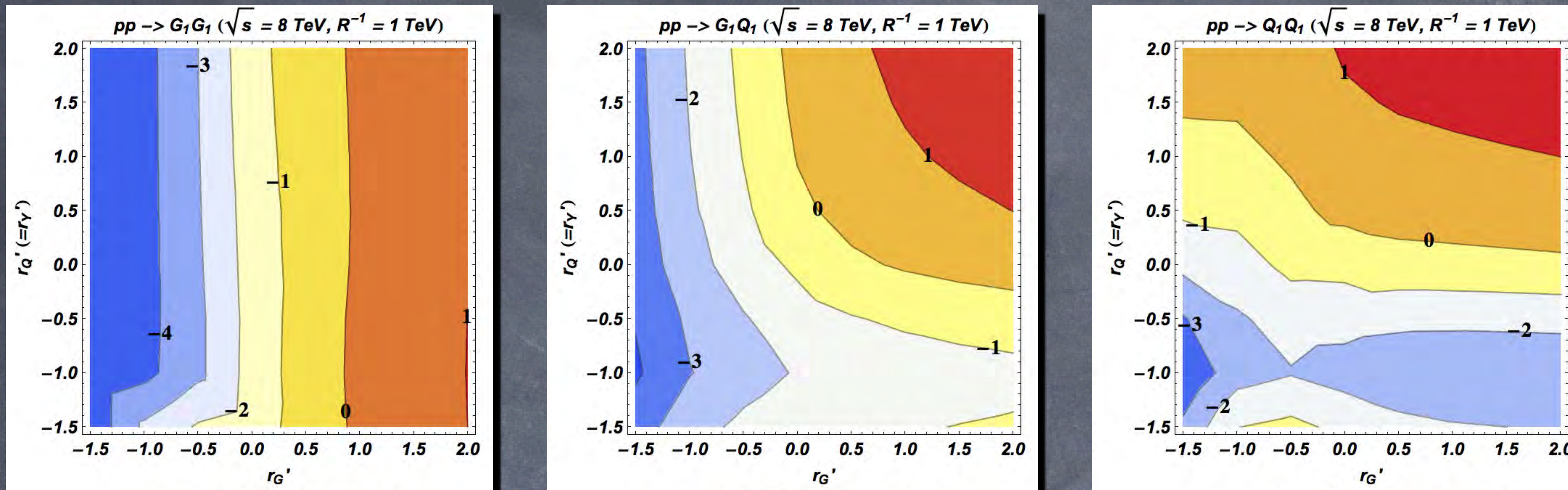
- There is no anomalous region.
- Values of cross section is almost the same in "normal" region.

14TeV run with R^{-1} = 1 TeV



- KK mass range is the same with 8 TeV run.
- The shapes are similar to those with 8 TeV run. (cross section is larger.)

Summary



- Cross section of 1st KK particles possibly anomalous in low R^{-1}.

Future works

- KK top analysis.
- Full simulation with EW sector.
- considering Direct/indirect constraints on model

Thank you for your attention