Search for the Level-2 Gauge Bosons of Universal Extra Dimensions at the LHC

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- New physics at TeV scale
  - SUSY, ED, Little Higgs, Higgsless $\cdots$?
- Is new physics SUSY ? - Spin measurement
  - linear collider : easy
  - hadron collider : difficult
- Alternative $\rightarrow$ look for resonances
  - Z', ED, SUSY with Z' $\cdots$
  - Degenerate double resonances in MUED
- Finding resonances could be discrimination between different models

Plan

- Minimal Universal Extra Dimensions (MUEDs)
- Collider phenomenology of MUEDs
- Discovery reach for MUEDs : level 1
  - $4l + \not{E}_T$ with Level 1 KK
- Discovery reach for MUEDs : level 2
  - cross sections
  - branching fractions
  - LHC reach for level 2 gauge bosons
- Summary

Minimal Universal Extra Dimensions

- UEDs : All SM particles in the bulk!

  Appelquist, Cheng, Dobrescu hep-ph/0012100

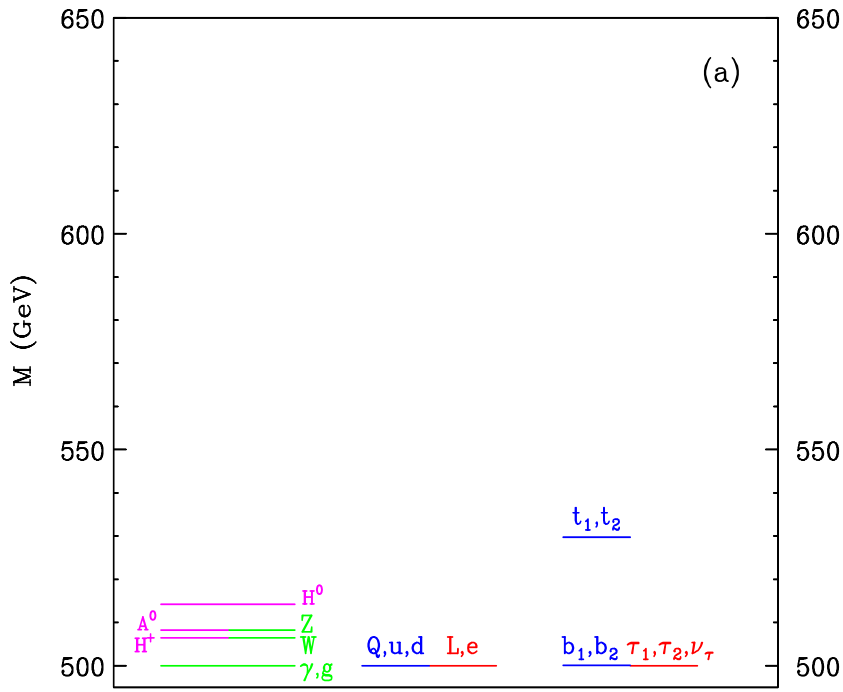
- Minimal model : d=4+1, ED compactified on S^1/Z_2
- Symmetries
  - Z_2 : project out unwanted zero modes and introduce chiral fermions in 5D
  - KK number : broken down to KK parity

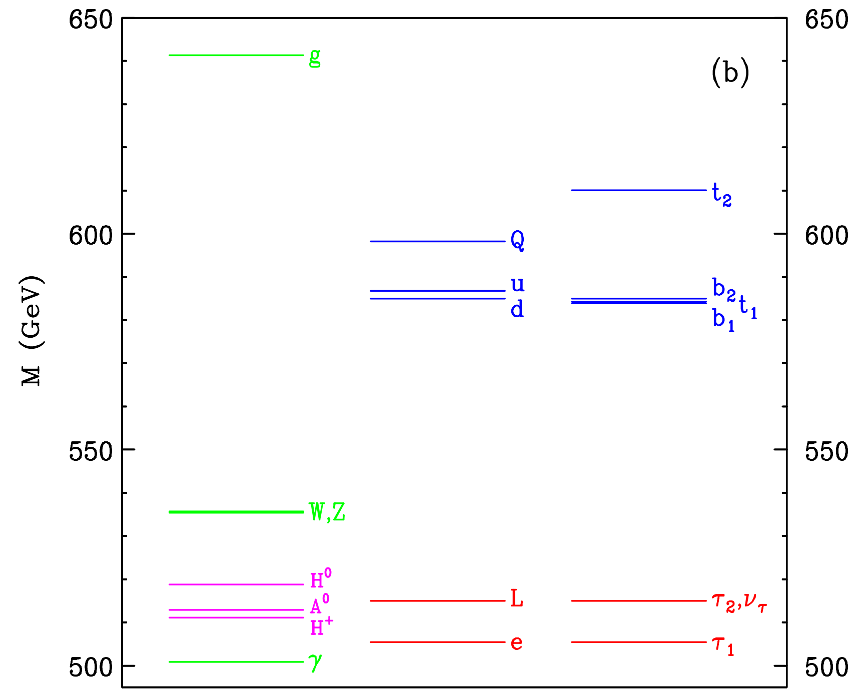
    $(-1)^n \Rightarrow$ Lightest KK particle is stable
- KK towers for each SM particle
  - identical spins/couplings as the SM particles
  - unknown masses of order of n/R
- The model is very predictive : $\{R, \Lambda, m_h\}$
- EW constraints   Appelquist, Cheng, Dobrescu hep-ph/0012100

  Appelquist, Yee hep-ph/0211023
  - no effect at tree level due to KK parity
  - $R^{-1} \geq 250 GeV$
- Cosmological bound   Servant, Tait hep-ph/0206071
  - $\Omega h^2 < 0.129$
  - $R^{-1} \leq \mathcal{O}(1) TeV$

Mass Spectrum : Tree level and radiative corrections

(Cheng, Matchev, Schmaltz, hep-ph/0204342, hep-ph/0205314)

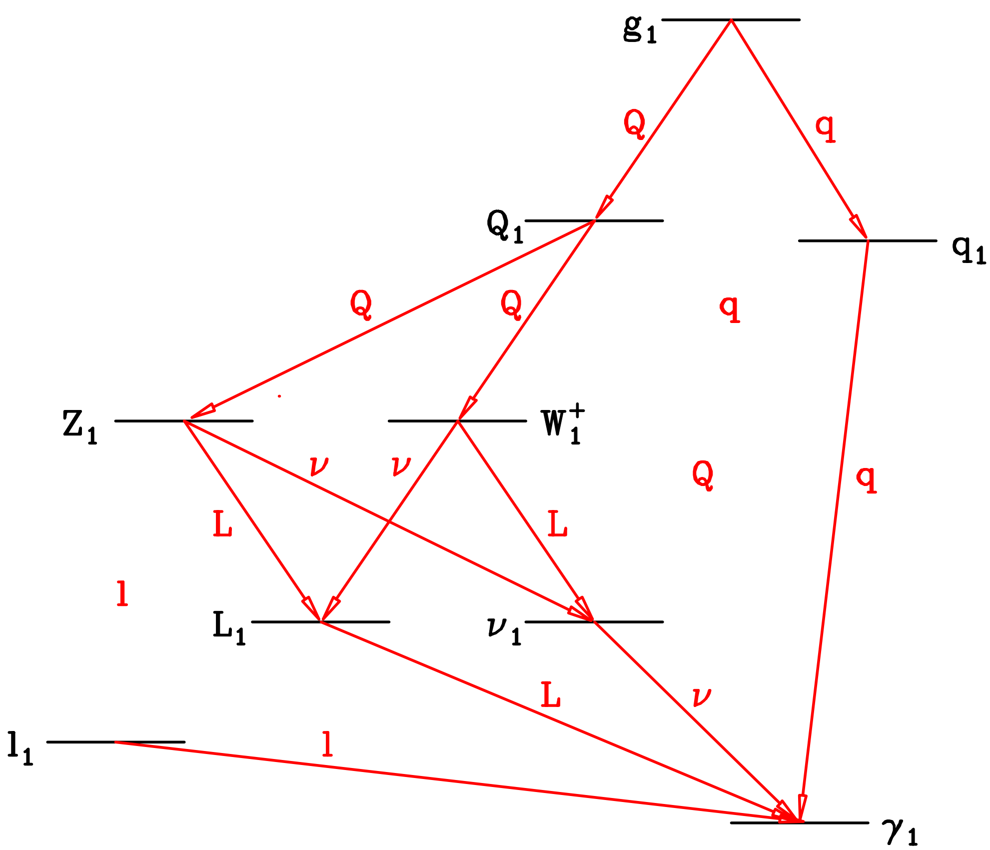




- Tree level mass $m_n = \sqrt{\left(\frac{n}{R}\right)^2 + m^2}$, e_1 is stable $\cdots$
- Radiative corrections are important ! (Cheng, Matchev, Schmaltz)

Collider phenomenology of MUEDs

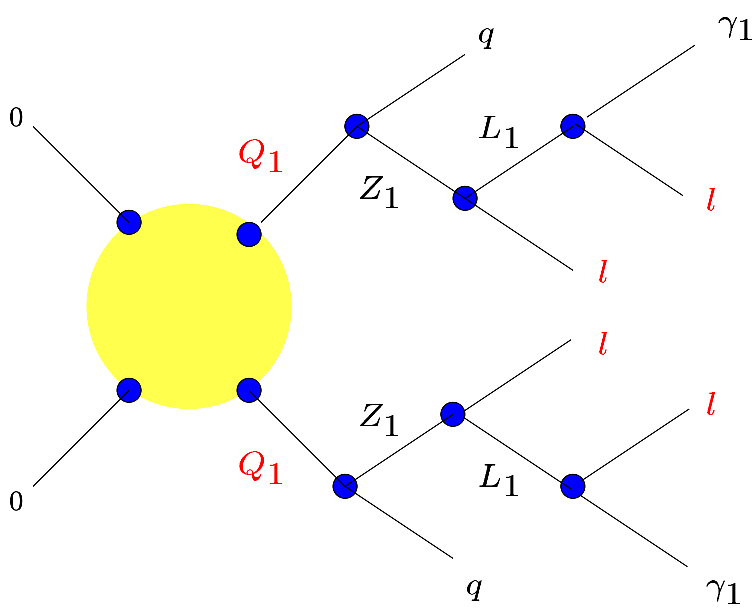
(Cheng, Matchev, Schmaltz, hep-ph/0205314)

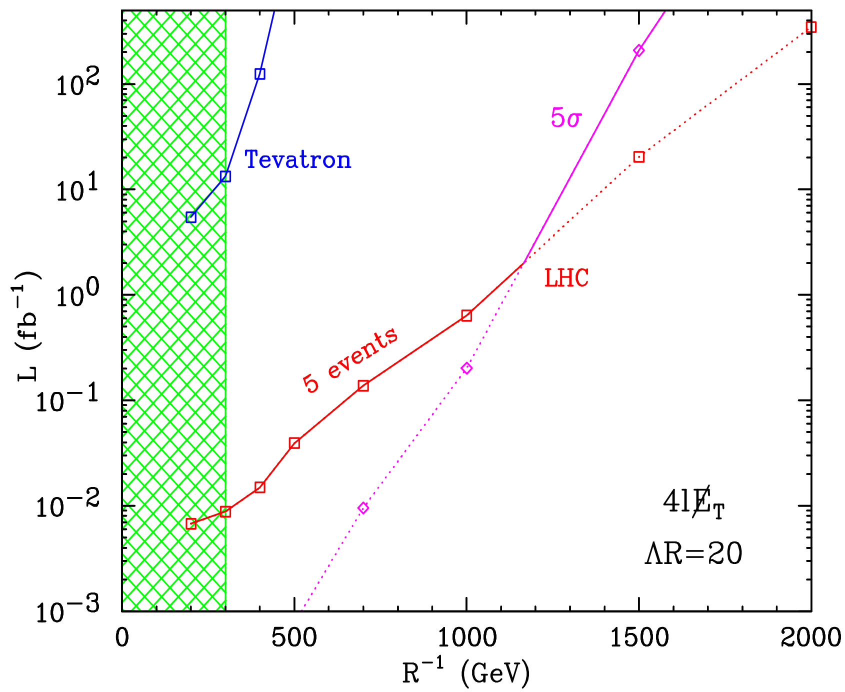


- 1st Level looks like SUSY
- KK gluon : BR($g_1 \to Q_1 Q_0$) $\approx$ BR($g_1 \to q_1 q_0$) $\sim$ 0.5
- SU(2) singlet KK quarks : $q_1 \to \gamma_1 q_0$
- SU(2) doublet KK quarks : $Q_1 \to W_1 Q_0'$ or $Z_1 Q_0$
- KK W and Z bosons : only leptonic decays
- KK leptons : 100 % directly to LKP
- At hadron collider we want : strong production and weak decays
- Weinberg angles for KK small : $Z_1 \sim W_1^3$ and $\gamma_1 \sim B_1$

UED discovery reach at the Tevatron and LHC

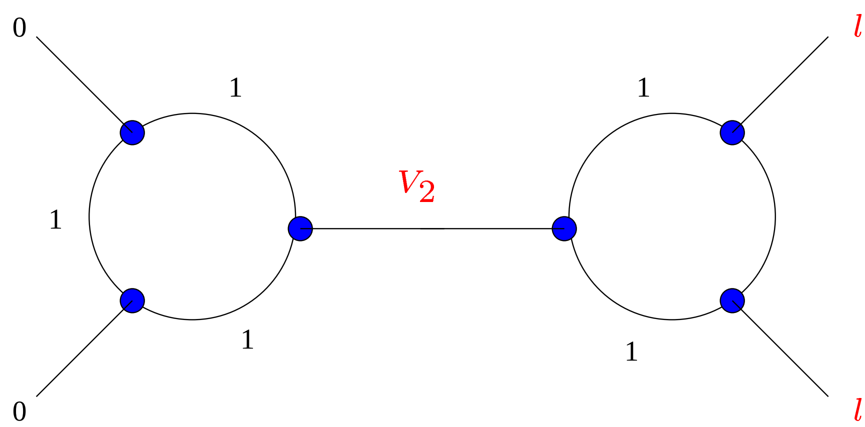
(Cheng, Matchev, Schmaltz, hep-ph/0205314)





- Discovery reach in the $Q_1 Q_1 \to Z_1 Z_1 \to 4l + \not{E}_T$ channel

Production of level 2 bosons

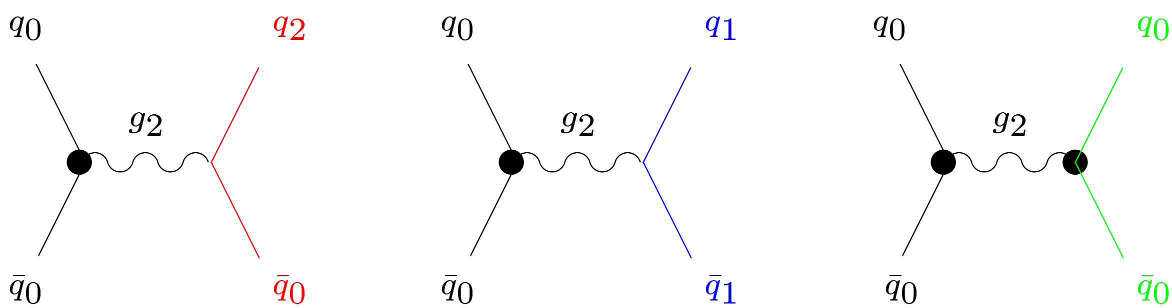


- Pair produce two level 1 KK or produce one level 2 KK
- 200 coupling is loop-suppressed

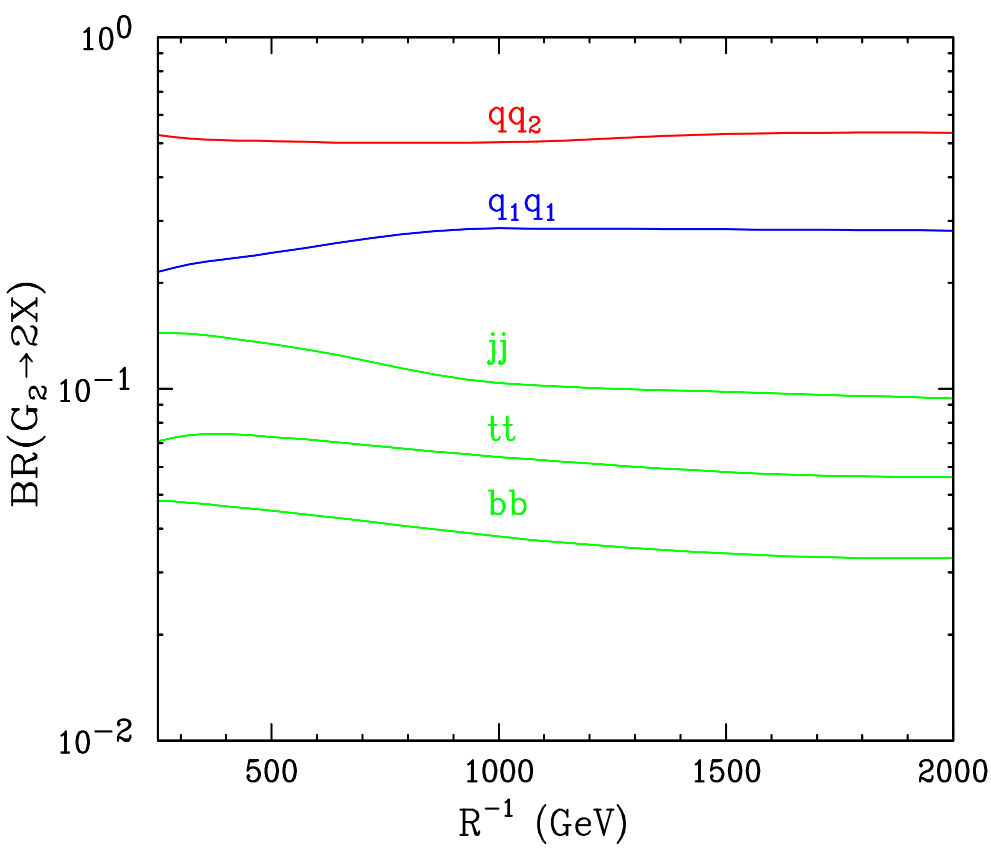
  (Cheng, Matchev, Schmaltz, hep-ph/0204342, hep-ph/0205314)
- Each dot satisfies KK number conservation

Level 2 gauge bosons : g_2

- Look for the higher KK levels : e.g. g_2 resonance



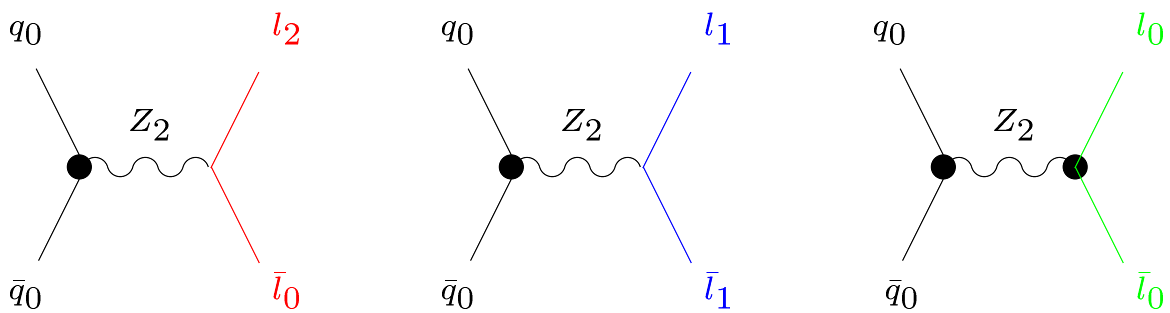
(Datta, Kong, Matchev, Preliminary)



- high mass dijet resonance. Z'

Level 2 gauge bosons : Z_2

- Z_2 has no hadronic decays to level 2 or 1



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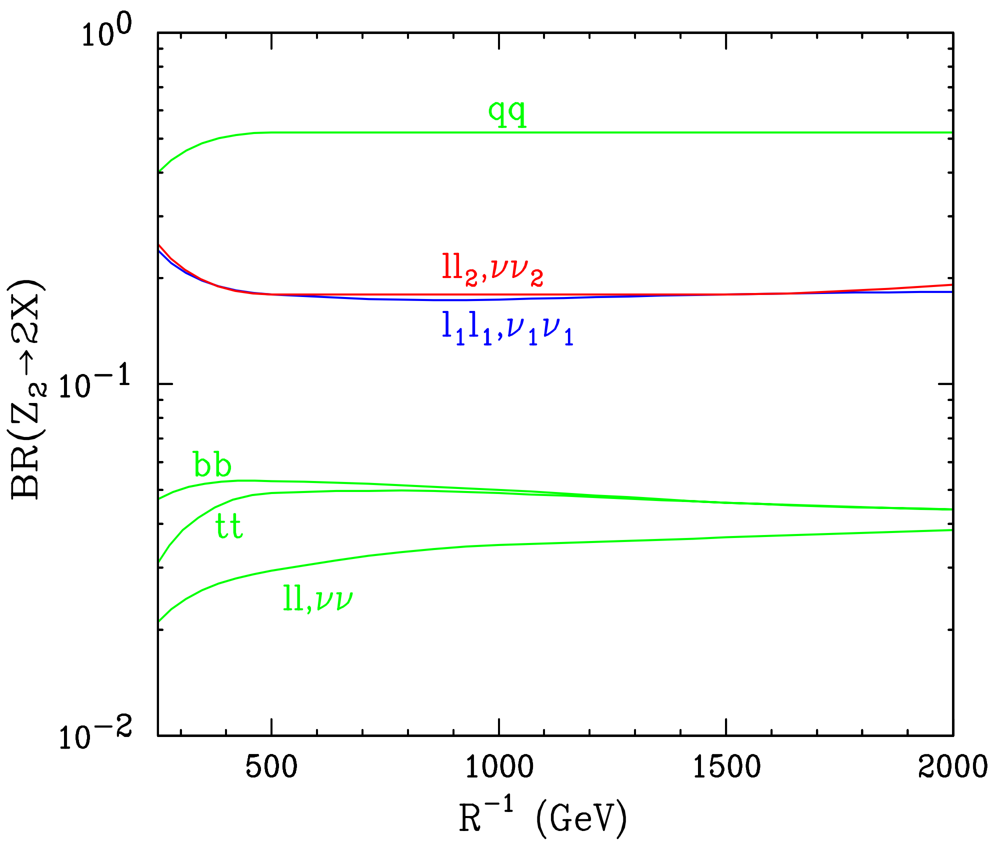
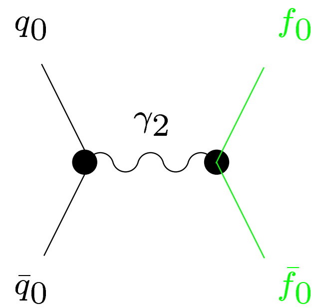


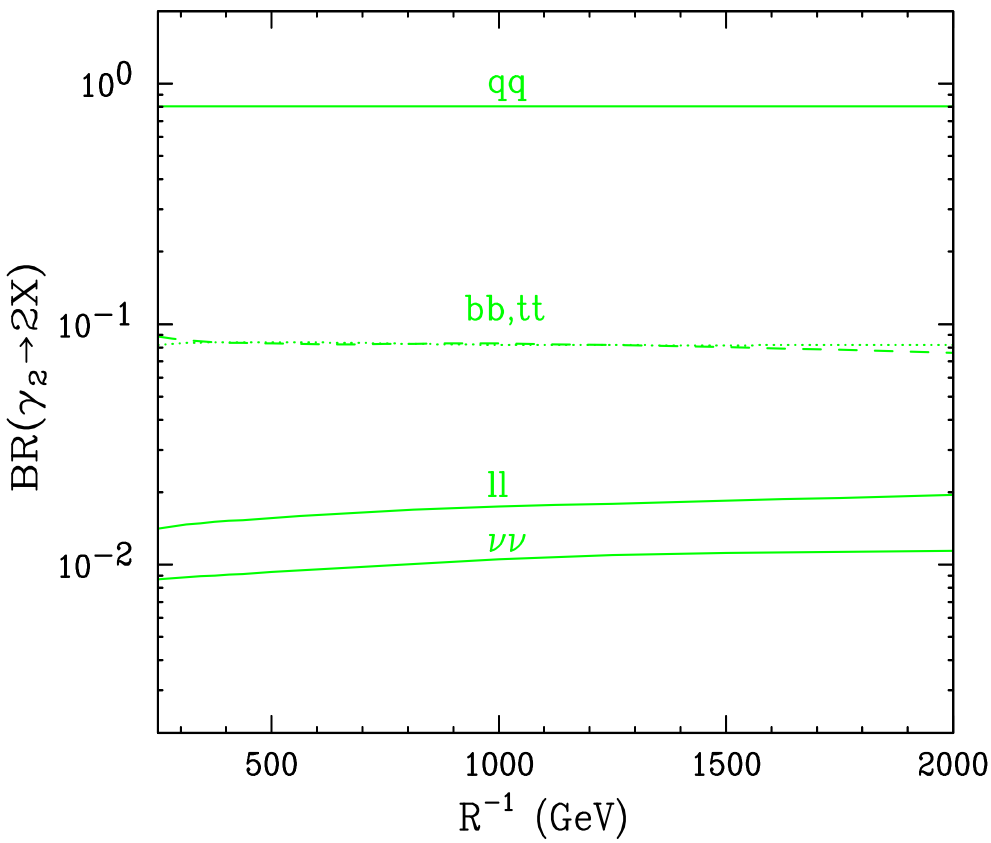
- Z_2 also a dijet resonance. $Z_2 \to l^+l^-$ rare but allowed

Level 2 gauge bosons : γ_2

- γ_2 cannot decay to level 2 or 1. The only possibility :



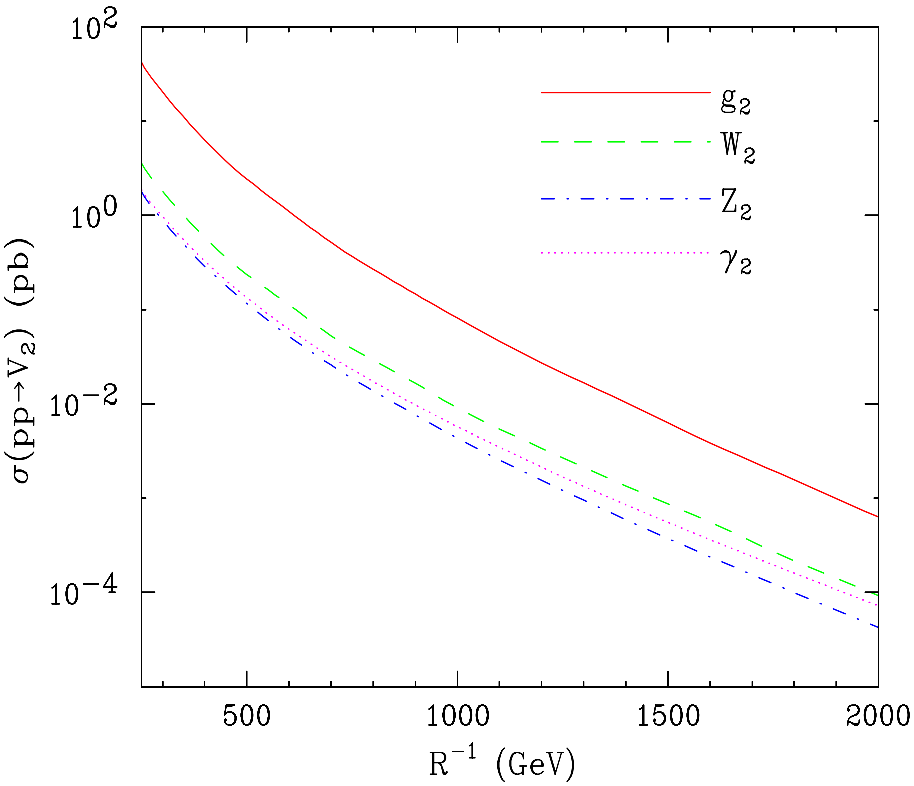
(Datta, Kong, Matchev, Preliminary)

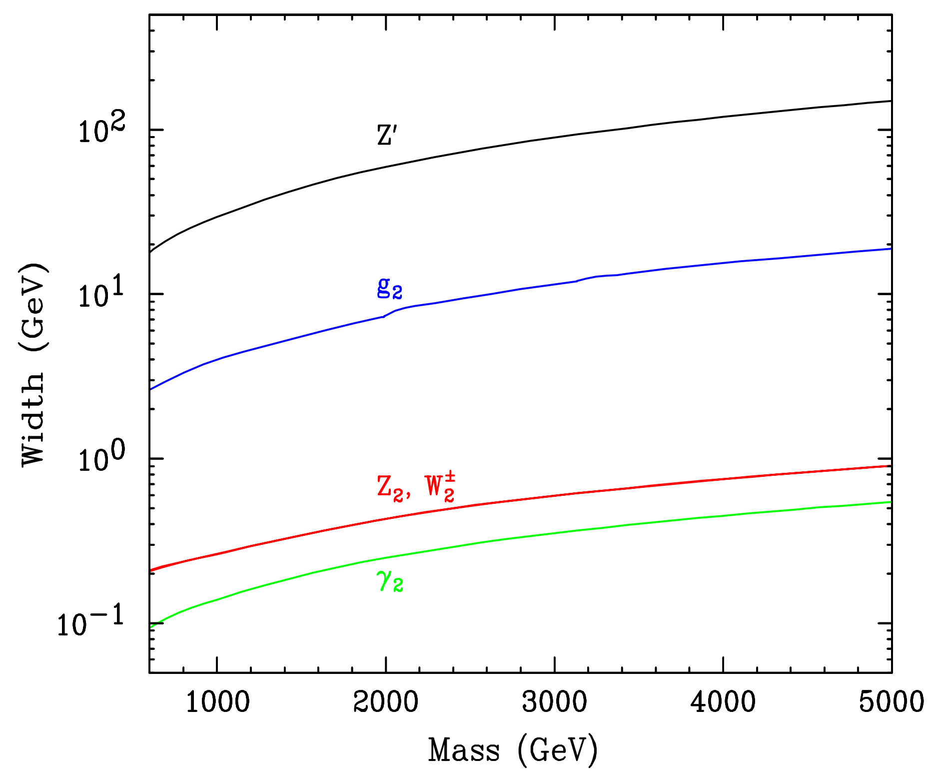


- Unfortunately, small leptonic branching fractions

Single production cross sections and widths of level 2 KKs

(Datta, Kong, Matchev, Preliminary)

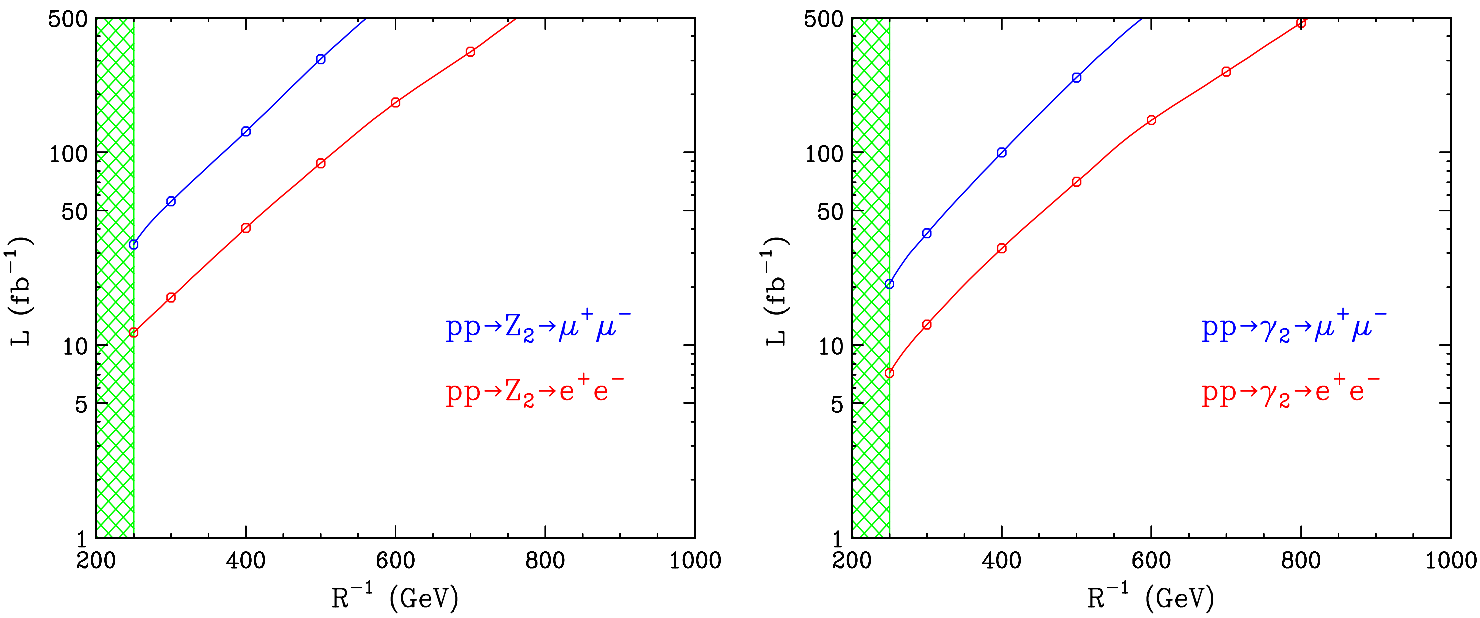




- Drell-Yan production of level 2 gauge bosons
- g_2 production cross section is lager by 1 order magnitude
- Small cross sections and decay widths due to KK number violating interactions

Discovery reach for MUEDs at LHC in dilepton channel

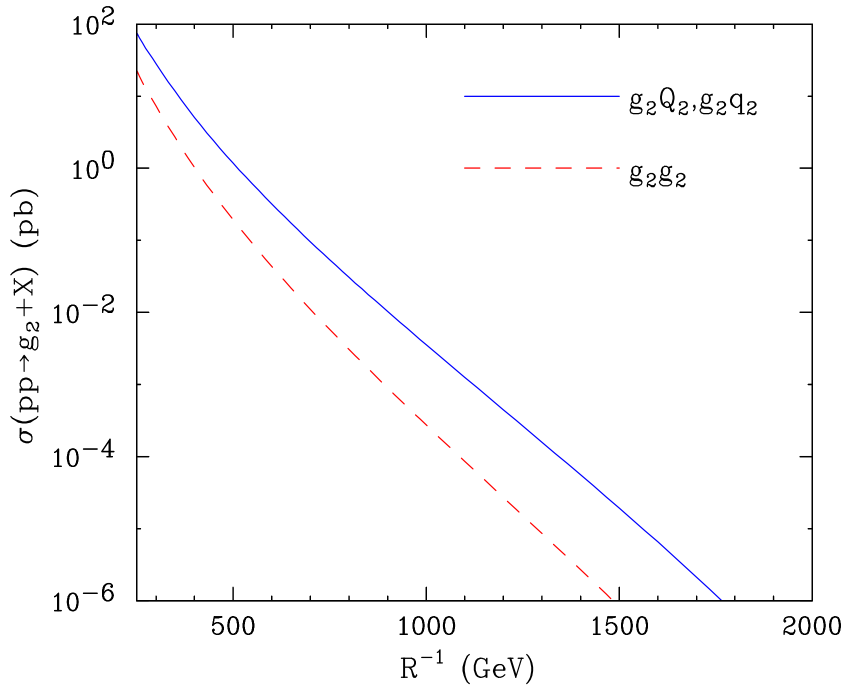
(Datta, Kong, Matchev, Preliminary)

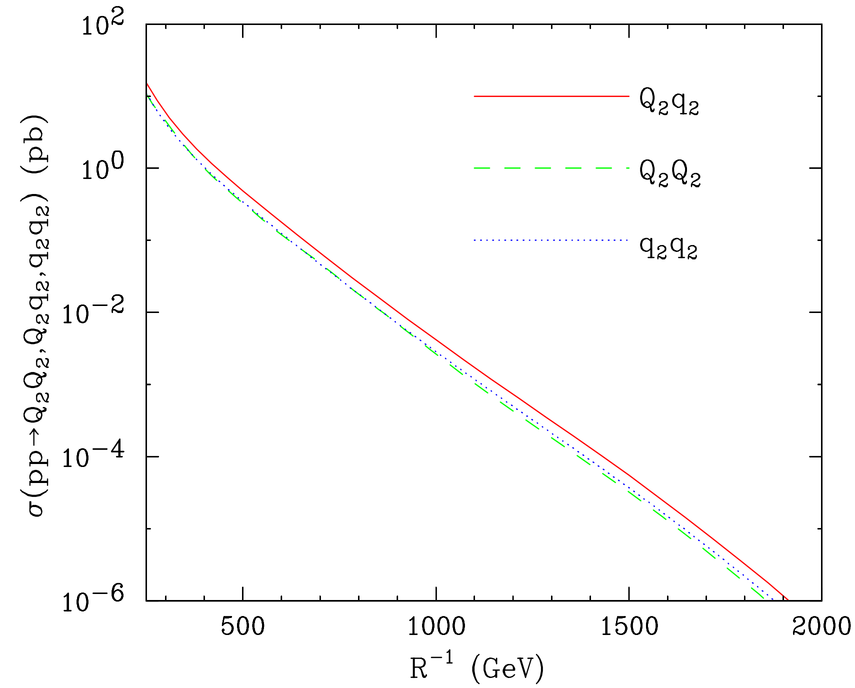


- $\frac{N_S}{\sqrt{N_B}} = 5 \longrightarrow \sqrt{\mathcal{L}} = \frac{5\sqrt{\sigma_B(pp\to\gamma^*/Z\to l^+l^-)\cdot\epsilon}}{\sigma_S(pp\to V_2)BR(V_2\to l^+l^-)\cdot\epsilon}$
- $|p_t| > 20$ GeV, $|\eta| < 2.4$
- $\Gamma_{l^+l^-} \approx$ mass resolution
  - $\Gamma_{V_2} < 1$ GeV $\ll$ mass resolution
- $|M_{l^+l^-} - M_{V_2}| < 2\Gamma_{l^+l^-}$

Inclusive productions

(Datta, Kong, Matchev, Preliminary)

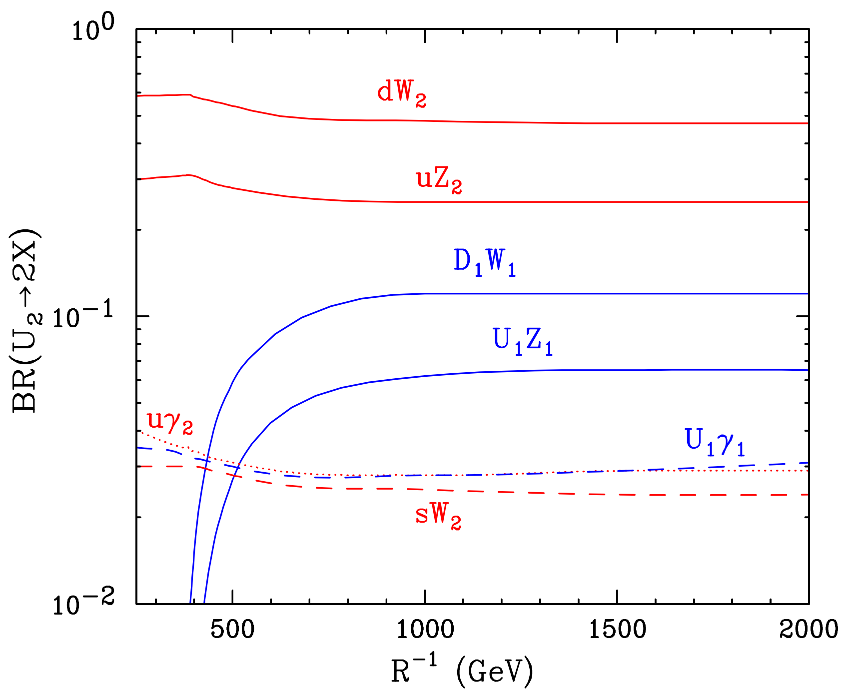


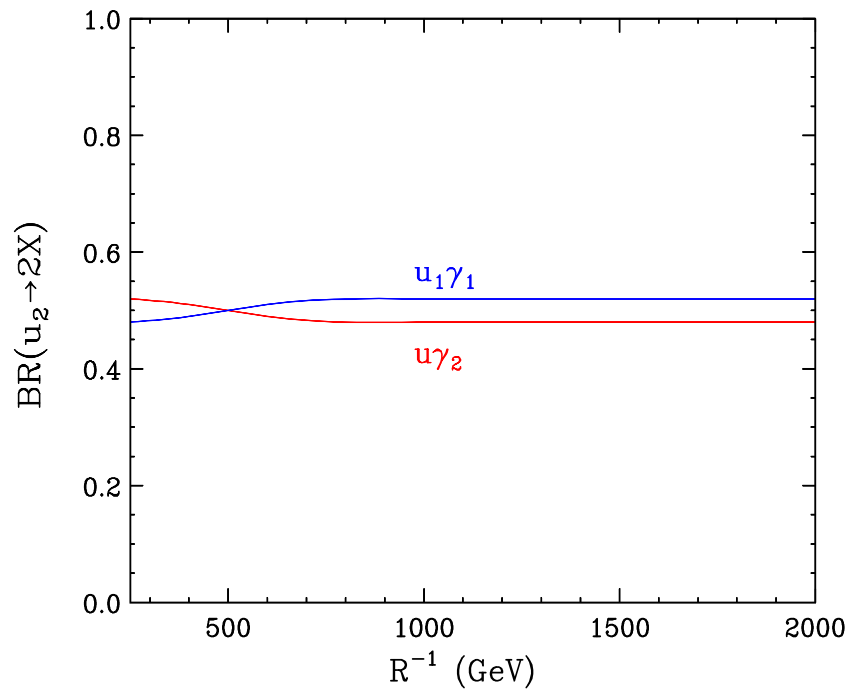


- QCD cross section is large
- Phase space suppressed
- Larger cross sections due to strong interaction
- KK number preserving interaction : $V_2 f_2 f_0$ vs. $V_2 f_0 f_0$
- 12 KK quarks + 12 anti KK quarks : Q_2 and q_2, (multiplicity)
- Branching ratios of level 2 QCD particles into level 2 KK bosons ?

Branching Ratios of level 2 KK quarks

(Datta, Kong, Matchev, Preliminary)

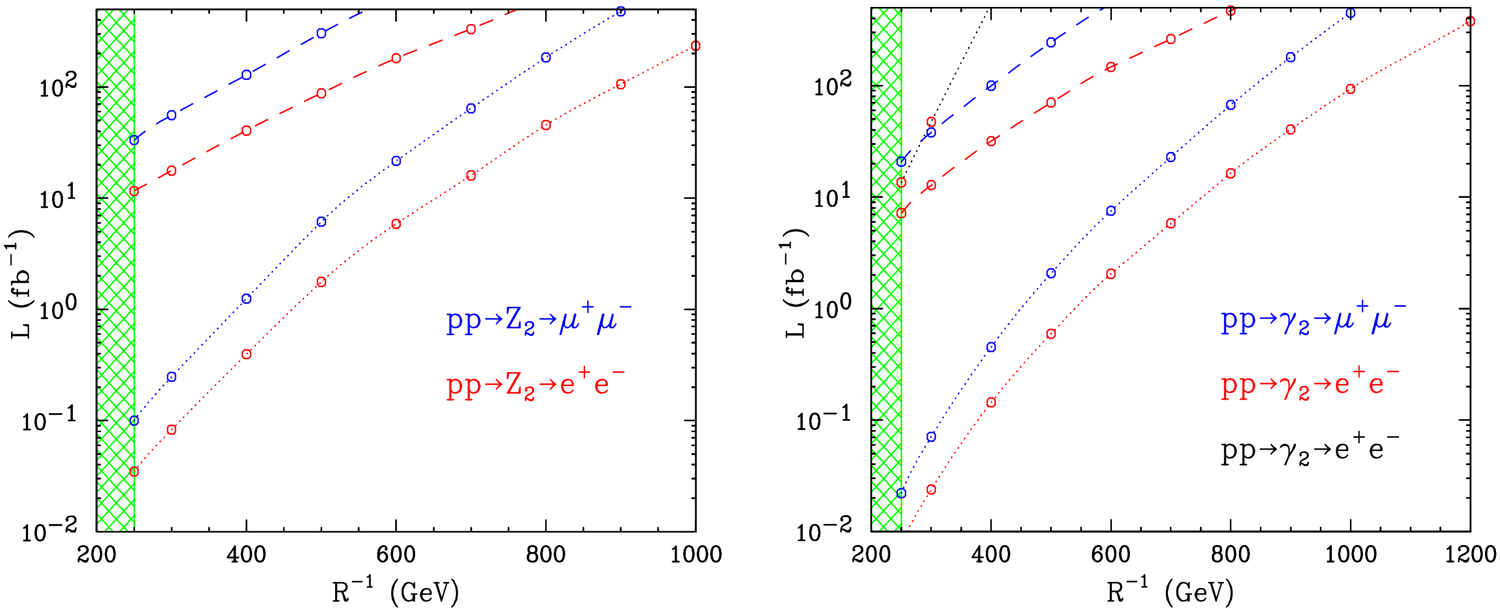




- Large Branching ratios
  - $BR(Q_2 \to Z_2 Q_0) \geq 25\%$
  - $BR(Q_2 \to \gamma_2 Q_0) \geq 3\%$
  - $BR(q_2 \to \gamma_2 Q_0) \approx 50\%$
  - $BR(g_2 \to Q_2 Q_0 + q_2 q_0) \approx 50\%$

Discovery reach for MUEDS at LHC in dilepton channel

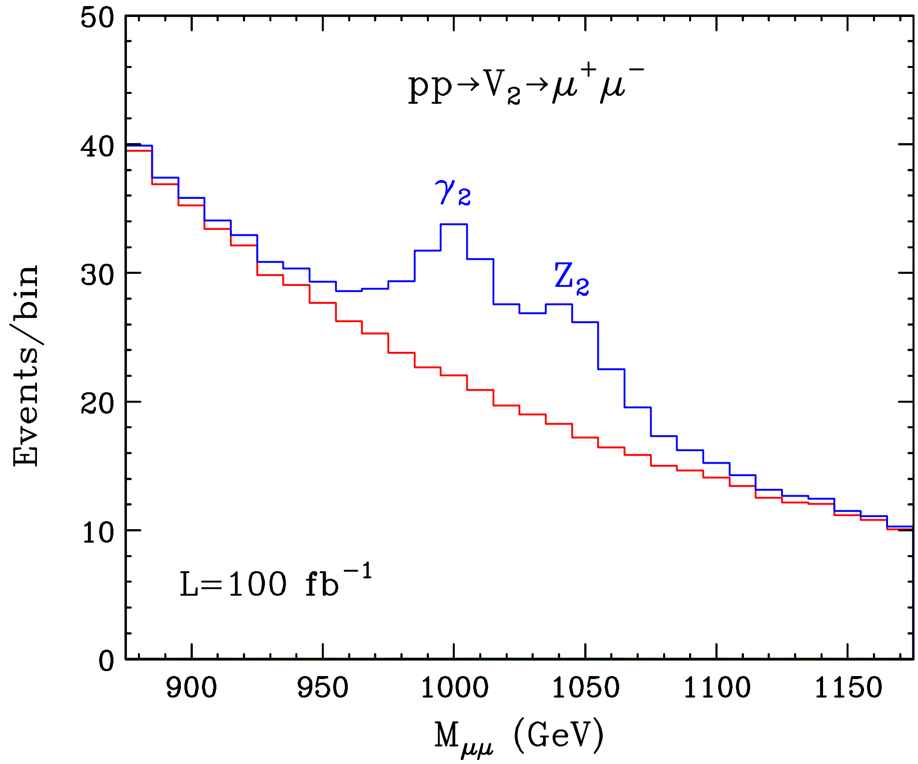
(Datta, Kong, Matchev, Preliminary)



- $\sqrt{\mathcal{L}} = \frac{5\sqrt{\sigma_B(pp\to\gamma^*/Z\to l^+l^-)\cdot\epsilon}}{\sigma_s(pp\to V_2+X)x\cdot\epsilon+\sigma_s(pp\to V_2V_2+X)[x^2(1-(1-\epsilon)^2)+2x(1-x)\epsilon]}$
- $x = BR(V_2 \to l^+l^-)$
- $|p_t| > 20$ GeV, $|\eta| < 2.4$
- $|M_{l^+l^-} - M_{V_2}| < 2\Gamma_{l^+l^-}$
- $\Gamma_{\mu^+\mu^-} \approx$ Mass resolution ($\Gamma_{V_2} \ll 1GeV$)
- For Tevatron, 4 leptons + missing E_T channel is better

Can we distinguish γ_2 and Z_2 ?

(Datta, Kong, Matchev, Preliminary)



(Cheng, Matchev, Schmaltz, hep-ph/0204342)

$$\begin{pmatrix} \frac{n^2}{R^2} + \hat{\delta} m^2_{B_n} + \frac{1}{4} g_1^2 v^2 & \frac{1}{4} g_1 g_2 v^2 \\ \frac{1}{4} g_1 g_2 v^2 & \frac{n^2}{R^2} + \hat{\delta} m^2_{W_n} + \frac{1}{4} g_2^2 v^2 \end{pmatrix}$$

- 3.6 % mass resolution in dimuon channel for 1 TeV mass
- For $R^{-1} = 500 GeV$
  - $\Gamma_{eff} = 36$ GeV for $M_{\gamma_2} = 1000.4$ GeV
  - $\Gamma_{eff} = 37.6$ GeV for $M_{Z_2} = 1045.7$ GeV
- Narrow peaks are smeared due to the mass resolution

Can we distinguish γ_2 and Z_2 ?

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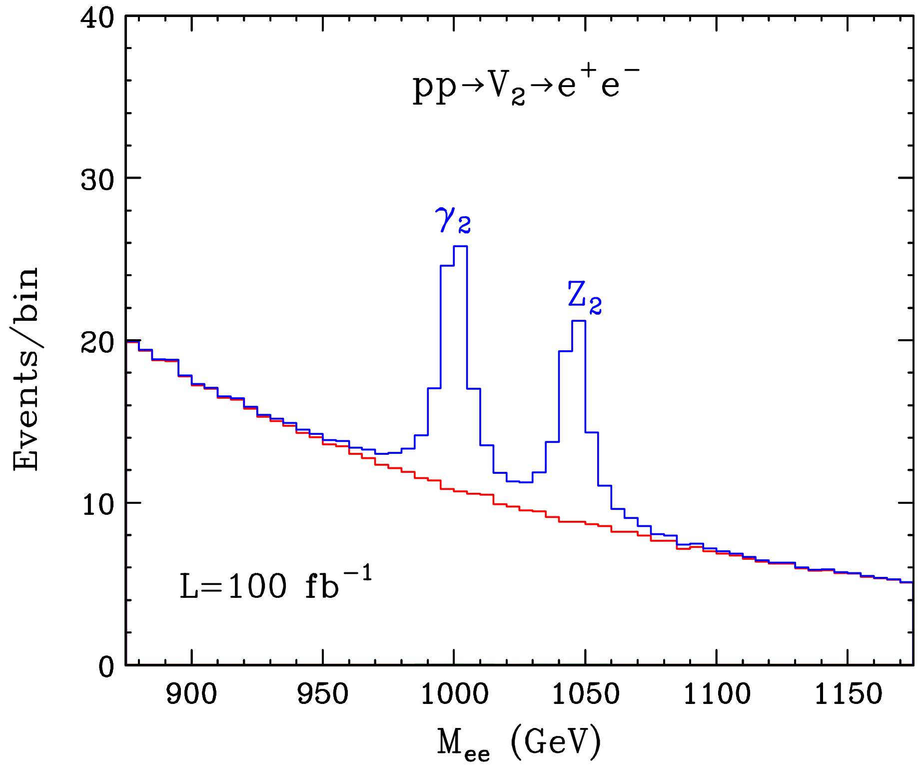

- 1 % mass resolution in dielectron channel for 1 TeV mass
- For $R^{-1} = 500GeV$
  - $\Gamma_{eff} = 10$ GeV for $M_{\gamma_2} = 1000.4$ GeV
  - $\Gamma_{eff} = 10.5$ GeV for $M_{Z_2} = 1045.7$ GeV
- Two resonances can be resolved in e^+e^- channel

Summary

- Reach for R^{-1} in $4l + \not{E}_T$
  - $\sim 250 - 300$ GeV at Run II ?
  - ~ 1.5 TeV at LHC (100 fb^{-1})
- Reach for R^{-1} in dilepton channel
  - ~ 1 TeV in e^+e^- $(100 fb^{-1})$
  - including indirect channels
- LHC can cover most of cosmologically allowed parameter space
- Difference between SUSY and MUED
- Degenerate double resonances
  - Z' ? : accidental
  - clear indication of MUED : two degenerate resonances
  - e^+e^- channel can resolve two gaussian peaks with 1% mass resolution