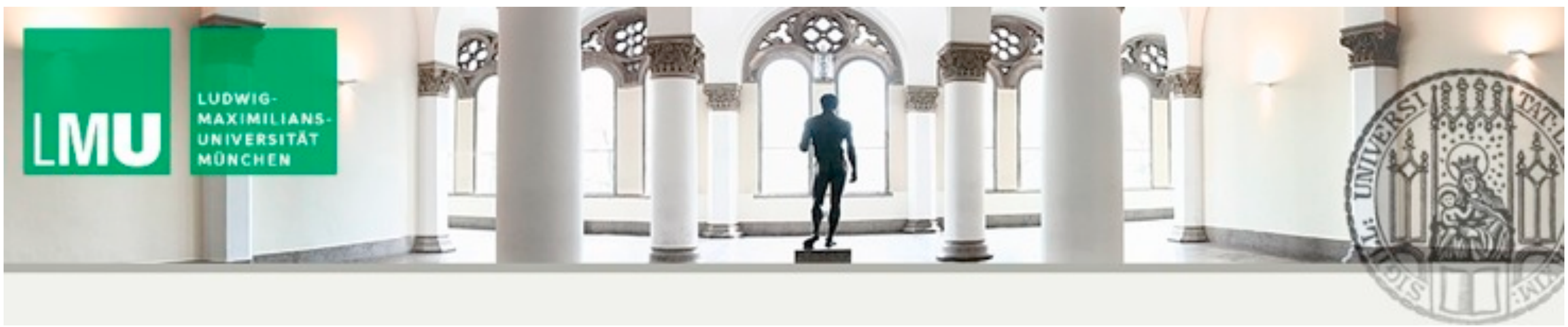
Stringy signatures at colliders

Dieter Lüst, LMU (Arnold Sommerfeld Center)
and MPI München



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Outline

- Direct tests of D-brane models at the LHC

  (The LHC string hunter's companion)

  (D. Lüst, S. Stieberger, T. Taylor, arXiv:0807.3333;
  L. Anchordoqui, H. Goldberg, D. Lüst, S. Nawata, S. Stieberger, T. Taylor, arXiv:0808.0497 [hep-ph]; arXiv:0904.3547 [hep-ph];
  D. Lüst, O. Schlotterer, S. Stieberger, T. Taylor, arXiv:0908.0409;
  L. Anchordoqui, H. Goldberg, D. Lüst, S. Stieberger, T. Taylor, arXiv:0909.2216;
  W. Feng, D. Lüst, O. Schlotterer, S. Stieberger, T. Taylor, arXiv:1007.5254)

- Leptophobic Z'-gauge bosons at colliders

  (L. Anchordoqui, H. Goldberg, X. Huang, D. Lüst, T. Taylor, PHLTA,B701(2011),224, arXiv:1104.2302 [hep-ph]
  L. Anchordoqui, I. Antoniadis, H. Goldberg, X. Huang, D. Lüst, T. Taylor, arXiv:1107.4309 [hep-ph])

II) Direct tests of D-brane models at LHC

Suppose that the fundamental scale of gravity is around 1 TeV.

At least two ways to realize:

RS: Warped compactifications.

(Randall, Sundrum (1999))

AADD: D-brane compactifications

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Collision of quarks and gluons at colliders:

- QCD is valid at low energies

  $\Rightarrow$ Background processes at LHC.

- New stringy physics at the collider in case $M_s = \mathcal{O}(\mathrm{TeV})$

  Discovery of universal heavy colored string excitations:

  Stringy Regge excitations of SM particles!

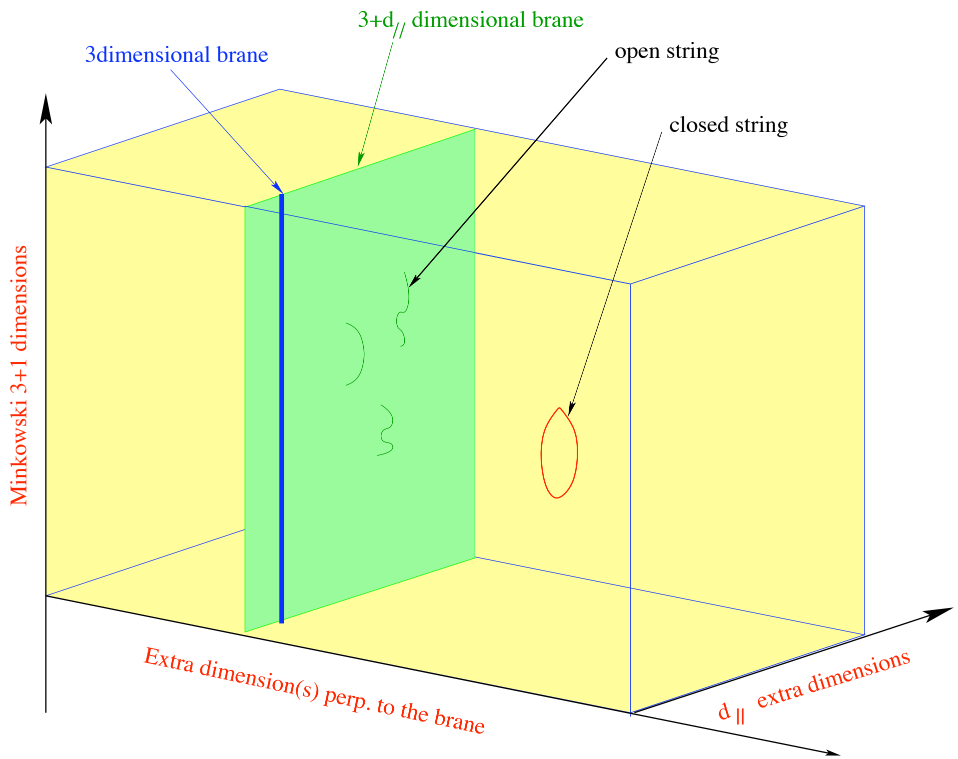
  g^* spin 0,1,2 & q^* spin 1/2, 3/2

Recall basic set-up of D-brane models:

- Gravitons live as closed strings in 10-dimensional bulk.

- Non-Abelian gauge bosons live as open strings on lower dimensional D-branes.

- Chiral fermions are open strings on the intersection locus of two D-branes:



(Picture thanks to I. Antoniadis)

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$$M_{\mathrm{Planck}}^2 \simeq M_s^8 \, V_6 \simeq 10^{19} \ \mathrm{GeV}$$

M_s is a free parameter in D-brane compactifications !

Test of D-brane models at the LHC:

$$gg\,,\;qq\,,\;q\bar{q}\,,\;qg\;\longrightarrow X\longrightarrow g,\gamma,Z,W,q,l$$

In string perturbation theory production of:

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In string perturbation theory production of:

model independent !

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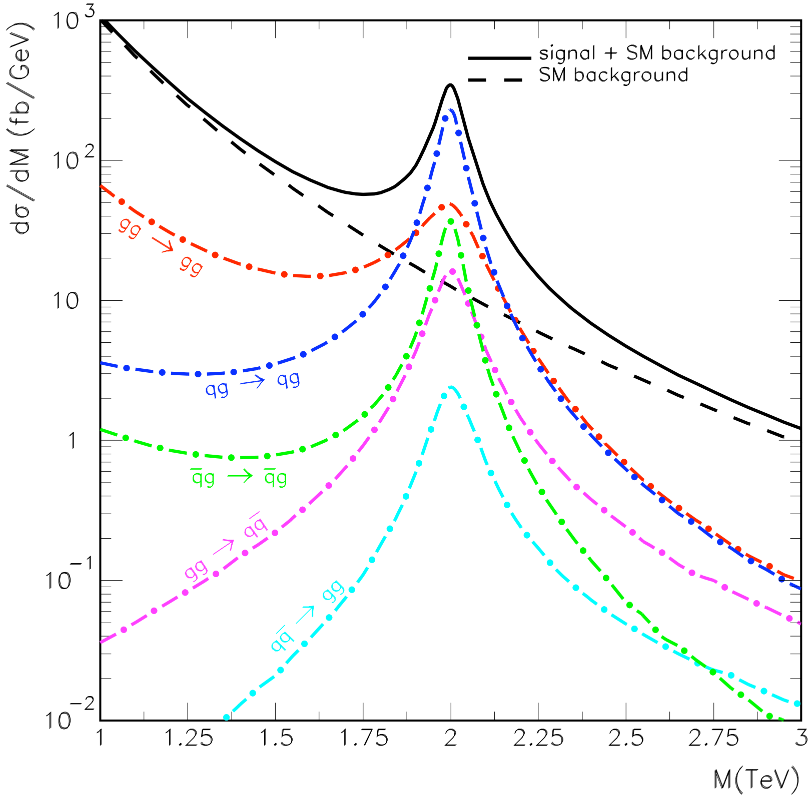
These stringy corrections can be seen in dijet events at LHC:



(Anchordoqui, Goldberg, Lüst, Nawata, Stieberger, Taylor, arXiv:0808.0497[hep-ph])

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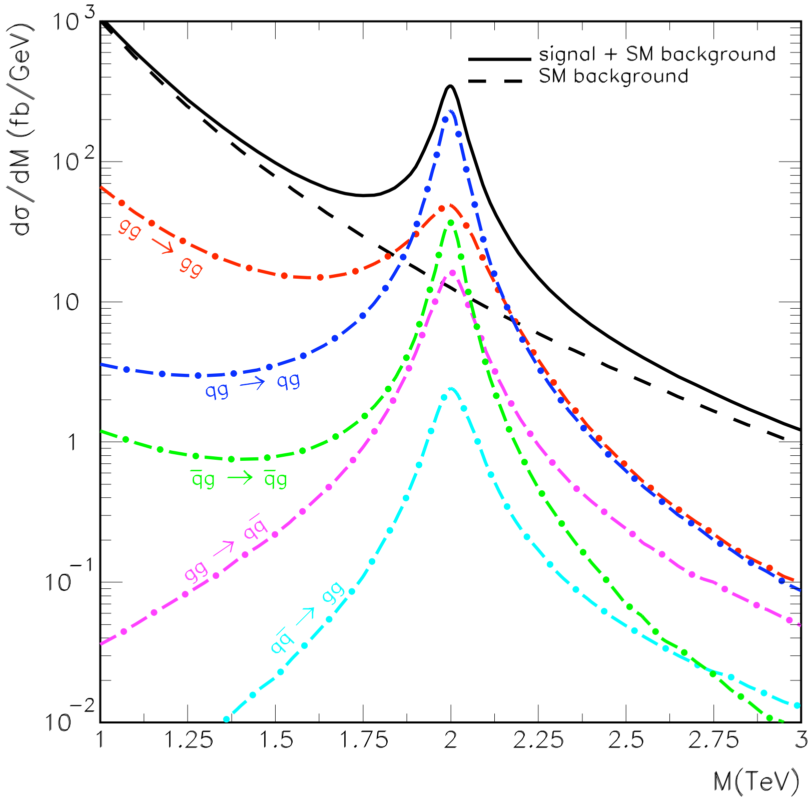

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Present limits from LHC (CMS & ATLAS):

2010 data from dijet mass distribution with 2.9 pb^{-1}

$$M_s \geq 2.5 \text{ TeV}$$

III) Leptophobic Z‘ gauge bosons at colliders

In string theory extra massive U(1) gauge bosons are generic.

Stack of N D-branes: $U(N)_a \to SU(N)_a \times U(1)_a$

The U(1)‘s generically get Stückelberg masses via mixing with axions:

$$\mathcal{L}_{\rm mass} = (M_{Z'})^2 (A'_{\mu a} - \partial_\mu \phi)^2$$

Two kinds of massive U(1)‘s:

(i) 4D anomalous U(1)‘s: $M_{Z'} \simeq g_a M_s$

(ii) 4D non-anomalous U(1)‘s: (they are related to 6D anomalies.)

$$M_{Z'} \simeq g_a M_s V_2$$

Light Z‘ gauge bosons should give a clear signal at colliders and can be viewed as string harbingers!

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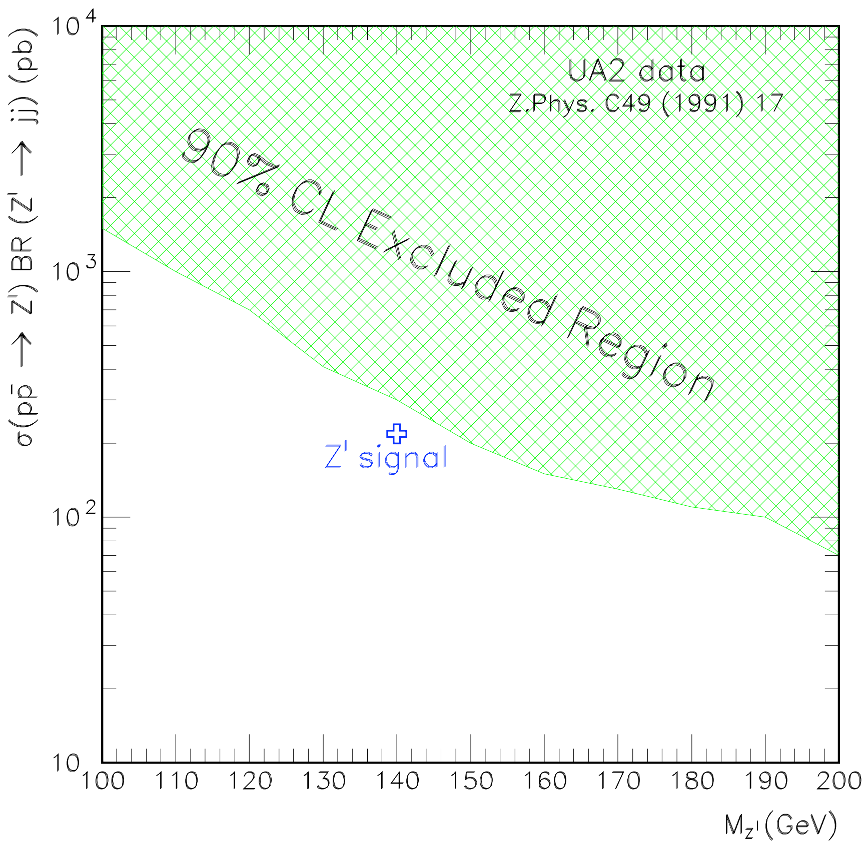
Bounds from direct production at UA2:

$$p\bar{p} \to Z' \to jj \quad \text{at} \quad \sqrt{s} = 640 \text{ GeV}$$



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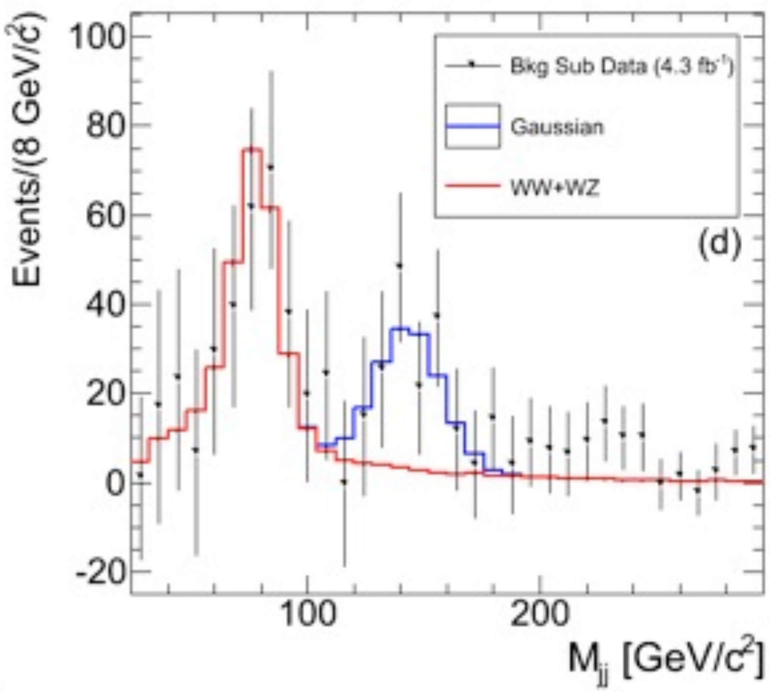

Measured production cross section: $\sigma \simeq 3.62\ \mathrm{pb}$

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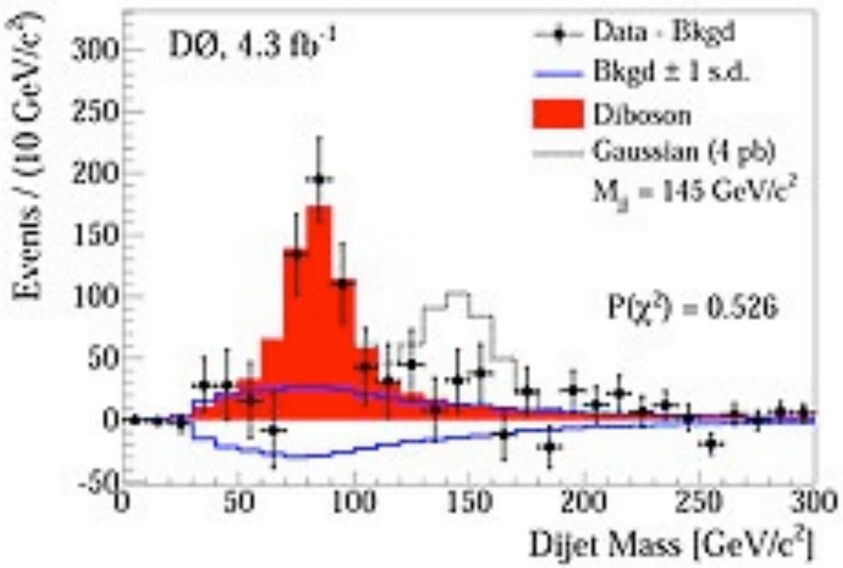
However more recently D0 dismissed the CDF result:



Limit on cross section: $\sigma \leq 1.9 \text{ pb}$

Many model dependent explanations:

Technicolor, supersymmetry, new forces (Z‘), color octets, SM, ...

A model independent analysis incorporating Tevatron and UA2 constraints has been presented by:

J. Hewett, T. Rizzo, arXiv:1106.0294 [hep-ph]

Our proposal: The would-be signal with $\sigma \sim 1 - 2 \text{ pb}$

is due to a stringy Z' gauge boson from D-brane models with mass around 140 GeV :

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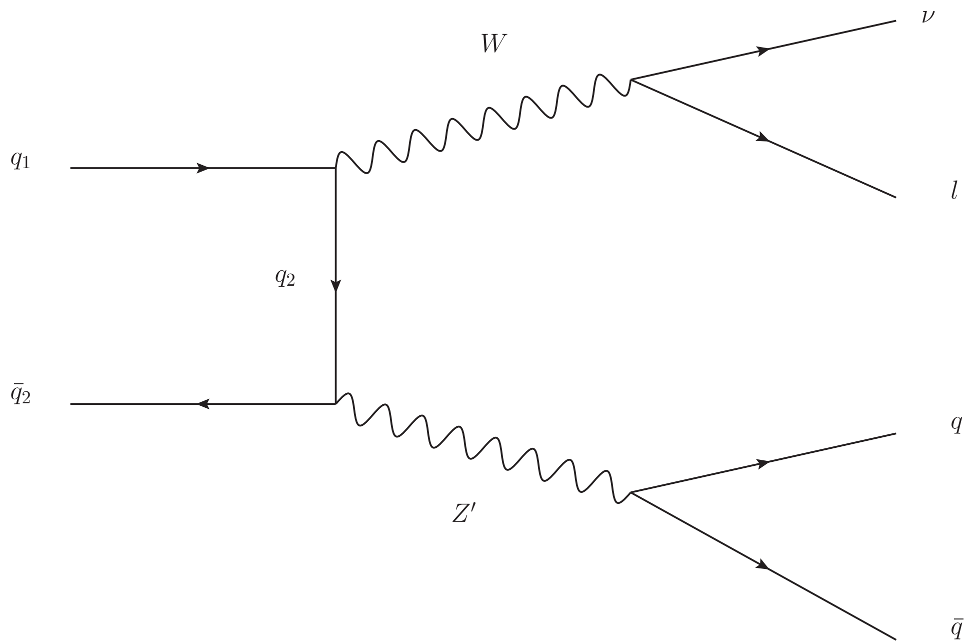

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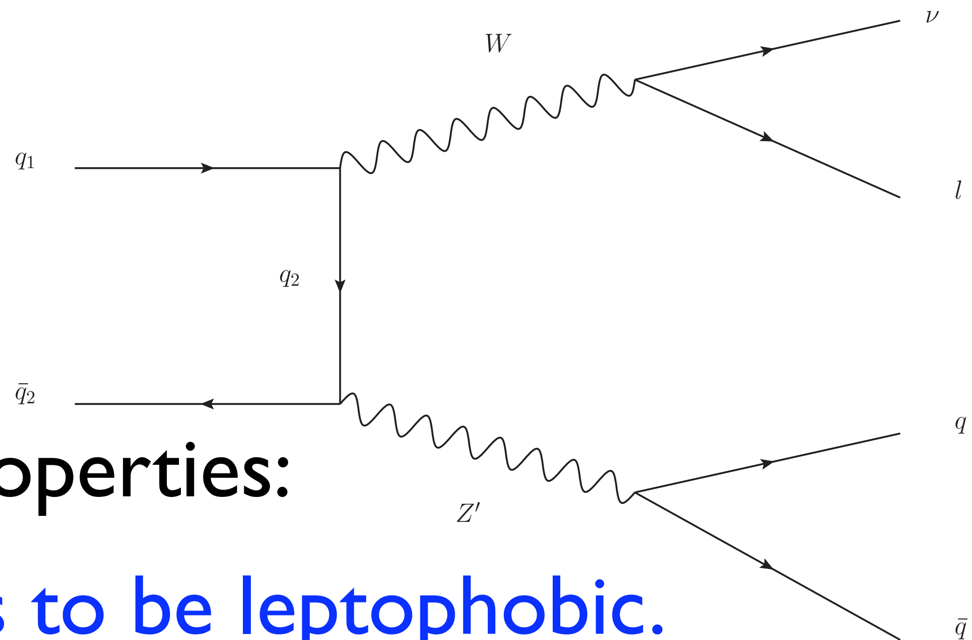

Required properties:

- Z' has to be leptophobic.
- No Mixing with Z after e.-w. symmetry breaking.
- $M_{Z'} < M_s$

Good candidate: Anomalous baryon number.

$U(1)_B$ (loop suppressed mass)

D-brane realizations of SM:

(Antoniadis, Kiritsis, Tomaras(2000); Ibanez, Marchesano, Rabadan (2001); Blumenhagen, Körs, D.L., Ott (2001); Cvetic, Shiu, Uranga (2001); Berenstein, Jejjala, Leigh (2001); Antoniadis, Kiritsis, Rizos (2002); Verlinde, Wijnholt (2005); Berenstein, Pinansky (2006); Blumenhagen, Gmeiner, Honecker, D.L., Weigand (2006); Anastosopoulos, Dijkstra, Kiritsis, Schellekens (2006))

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(i) 3 stack D-brane quivers:

(ia) Minimal realization: $G = U(3) \times Sp(1) \times U(1)$

Name	Representation	Q_3	Q_1	Q_Y
U_i	$(\bar{3}, 1)$	-1	1	$-\frac{2}{3}$
D_i	$(\bar{3}, 1)$	-1	-1	$\frac{1}{3}$
L_i	$(1, 2)$	0	1	$-\frac{1}{2}$
E_i	$(1, 1)$	0	-2	1
Q_i	$(3, 2)$	1	0	$\frac{1}{6}$
H	$(1, 2)$	0	-1	$-\frac{1}{2}$

(Antoniadas, Dimopoulos (2004); Berenstein, Pinansky (2006); Anastosopoulos, Dijkstra, Kiritsis, Schellekens (2006); Berenstein, Martinez, Ochoa, Pinansky (2009))

$$Q_Y \equiv \frac{1}{6} Q_{U(3)} - \frac{1}{2} Q_{U(1)} \,, \quad Q_{U(3)}$$: anomalous B-number

However this quiver has too few parameters to satisfy all bounds.

(ib) Non-minimal realization: $G = U(3) \times U(2) \times U(1)$

(Antoniadis, Kiritsis, Tomaras (2000))

$$Q_Y = c_1 Q_{U(1)} + c_2 Q_{U(2)} + c_3 Q_{U(3)}$$

Name	Representation	$Q_{U(3)}$	$Q_{U(2)}$	$Q_{U(1)}$	Q_Y	$g_{Z'}Q_{Z'}$	$g_{Z''}Q_{Z''}$
U_i	$(\bar{3}, 1)$	2	0	0	$-\frac{4}{3}$	0.265	0.867
D_i	$(\bar{3}, 1)$	-1	0	1	$\frac{2}{3}$	-0.098	-0.444
L_i	$(1, 2)$	0	-1	1	-1	-0.004	-0.138
E_i	$(1, 1)$	0	2	0	2	0.078	0.255
Q_i	$(3, 2)$	1	1	0	$\frac{1}{3}$	0.172	0.561

Possible choice: $c_1 = 0, \quad c_2 = 1, \quad c_3 = -2/3$

(D.L., Stieberger, Taylor (2008))

What is the leptophobic linear combination of the three U(1)'s that satisfies the experimental bounds?

Most general 3 x 3 rotation matrix:

$$\mathcal{R} = \begin{pmatrix} C_\theta C_\psi & -C_\phi S_\psi + S_\phi S_\theta C_\psi & S_\phi S_\psi + C_\phi S_\theta C_\psi \\ C_\theta S_\psi & C_\phi C_\psi + S_\phi S_\theta S_\psi & -S_\phi C_\psi + C_\phi S_\theta S_\psi \\ -S_\theta & S_\phi C_\theta & C_\phi C_\theta \end{pmatrix}$$

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Actually we get:

$\sigma(p\bar{p} \to W Z') \times \mathrm{BR}(Z' \to jj) \approx 1.57 \text{ pb}$ ⇨ D0 ✔

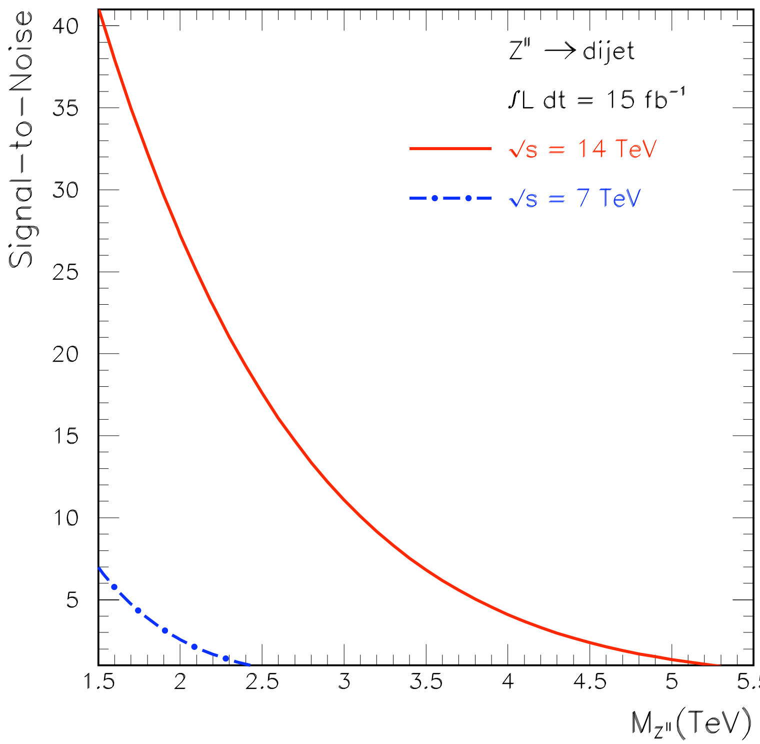
$\sigma(p\bar{p} \to Z') \times \mathrm{BR}(Z' \to jj) \approx 250 \text{ pb}$ ⇨ UA2 ✔

What about the third U(1) with gauge boson Z'' ?

Further constraints from mixing with Z-boson:

$$M_{Z''} \geq 3 \text{ TeV}$$

Prospects for searches at LHC:



But can we explain why $M_{Z''} >> M_{Z'}$?

Refined analysis for

(L. Anchordoqui, I. Antoniadis, H. Goldberg, X. Huang, D. Lüst, T. Taylor, arXiv:1107.4309))

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D_i	$(\bar{3},1)$	-1	0	1	$\frac{1}{3}$	-0.386	-0.251
L_i	$(1,2)$	0	1	0	$-\frac{1}{2}$	-0.125	-0.125
E_i	$(1,1)$	0	-1	1	1	-0.061	-0.027
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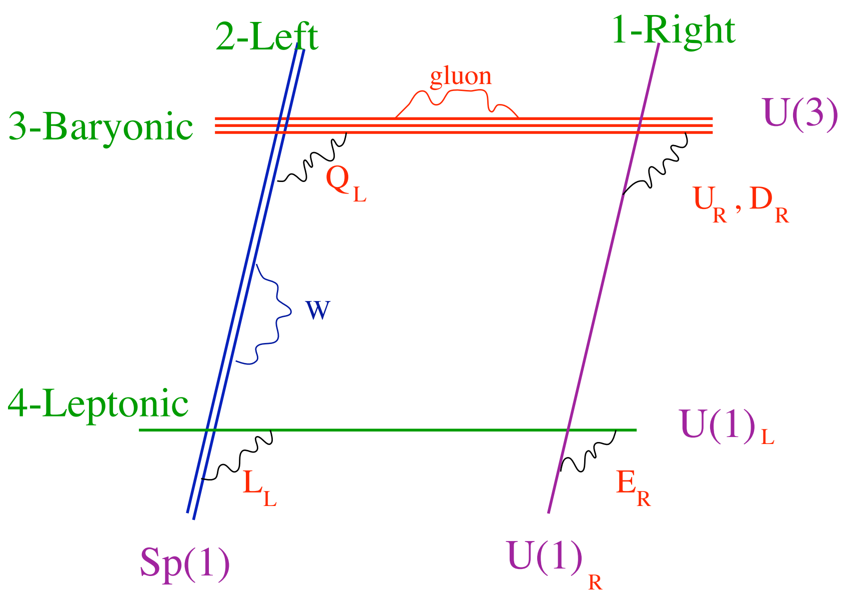

Again three U(1)'s: $Y\,,\,Z'\,,\,Z''$ $\quad (Q_Y = \frac{1}{6}Q_3 - \frac{1}{2}Q_{1L} + \frac{1}{2}Q_{1R})$

New aspects in the detailed analysis of this model:

- RG analysis for gauge couplings

  (different running for $U(1)_a$ and $SU(N)_a$)

- smaller cross section for $p\bar{p} \rightarrow W\ Z' \rightarrow W\ jj$

- Three natural U(1)‘s : Y, B, B-L

  B-L can be anomaly free (depending on the right handed neutrino) $\Rightarrow$ more natural hierarchy:

  Z‘ corresponds to B and Z“ corresponds to B-L.

$$M_{B-L} >> M_B$$

- Discussion about the discovery potential of leptophobic Z‘ at the LHC.

For a leptophobic Z' with $M_{Z'} \simeq 1 \text{ TeV}$

we obtain

$$\sigma(pp) \times BR(Z' \to jj) \simeq 40 \text{ pb}$$

This is within reach of LHC7.

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Thank you for your attention!