Warped-space Electroweak Gauge Bosons at the LHC

(arXiv:0709.0007 + 0810.1497)

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with

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Motivation

- SM Hierarchy Problem: $M_{Pl} \leftrightarrow M_{EW}$
- New dynamics?
  - Extra dimensions (Warped, Flat)
  - Supersymmetry
  - Strong dynamics
  - Little Higgs
- AdS/CFT correspondence

Talk Outline

- Focus on heavy EW spin-1 resonances
- Warped (RS) model
  - $SU(3)_{QCD} \times SU(2)_L \times SU(2)_R \times U(1)_X$ bulk gauge group
  - Heavy EW gauge bosons : 3 neutral (Z') & 2 charged $(W'^{\pm})$
  - Precision electroweak observables require $M_{Z'}$, $M_{W_1^{\pm}} \gtrsim 2$ TeV
    - Makes discovery challenging at the LHC
- What are general issues at the LHC?

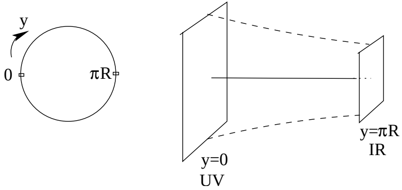
Warped Model

5D Warped Space [Randall, Sundrum 99]

$ds^2 = e^{-2k|y|}(\eta_{\mu\nu}dx^\mu dx^\nu) + dy^2$

Z_2 Orbifold -

- Planck (UV) Brane
- TeV (IR) Brane



R : radius of Ex. Dim.

k : curvature

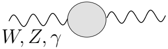
Hierarchy prob soln:

- TeV Brane Higgs : $M_{EW} \sim ke^{-k\pi R}$: Choose $k\pi R \sim 34$

Bulk fields →AdS/CFT

- Bulk Fermions explain flavor (FCNC's safe)
- Dual is a composite Higgs model

Constraints



Precision Electroweak Constraints (S, T, $Zb\bar{b}$)

- Bulk gauge symm - $SU(2)_L \times U(1)$ (SM ψ, H on TeV Brane)
  - T parameter $\sim (\frac{v}{M_{KK}})^2 log \frac{M_{Pl}}{M_{EW}}$ log enhanced [Csaki, Erlich, Terning 02]
  - S parameter also log enhanced
- Bulk gauge symm - $SU(2)_R$ $\Leftrightarrow$ Custodial Symm (AdS/CFT)

  [Agashe, Delgado, May, Sundrum 03]
  - T parameter - Protected
  - S parameter - log enhanced (with additional $\frac{1}{k\pi R}$ for bulk fermions)
  - $Zb\bar{b}$ shifted
- 3rd gen quarks (2,2) [Agashe, Contino, DaRold, Pomarol 06]
  - $Zb\bar{b}$ coupling - Protected
  - Precision EW constraints $\Rightarrow M_{Z'} \gtrsim 2 - 3$ TeV

[Carena, Ponton, Santiago, Wagner 06,07] [Bouchart, Moreau-08] [Djouadi, Moreau, Richard 06]

Fermion representations (Custodial protection for $Zb_L\overline{b_L}$)

[Agashe, Contino, DaRold, Pomarol 06]

Demand $SU(2)_V \otimes P_{LR}$ invariance

Fermions

- $Q_L = (2,2) = \begin{pmatrix} t_L & \zeta_L \\ b_L & T_L \end{pmatrix}$
- t_R : $(1,1)$ OR $(1,3)$
- b_R : $(1,1)$ OR $(1,3)$

Higgs

- $\Sigma = (2,2)$

Note: $Wt_L b_L$, $Zt_L t_L$ not protected, so expect shifts

Studies of KK states at the LHC

Our study on Electroweak KK

Agashe, Davoudiasl, SG, Han, Huang, Perez, Si, Soni.

arXiv:0709.0007 & 0810.1497

For KK Glue and Graviton see:

- KK Gluon at the LHC

  $L = 100\, fb^{-1}$ LHC reach is 4 TeV

  [Agashe, Belyaev, Krupovnickas,Perez,Virzi 06] [Lillie, Randall, Wang, 07] [Lillie, Shu, Tait 07]

- KK Graviton at LHC

  $L = 300\, fb^{-1}$ LHC reach is about 2 TeV

  [Agashe, Davoudiasl, Perez, Soni 07] [Fitzpatrick, Kaplan, Randall, Wang 07]

- Associated Prod.

  [Guchait, Mahmoudi, Sridhar 08]

[More Refs. to follow...]

Electroweak Gauge Sector

Bulk Gauge group : $SU(2)_L \times SU(2)_R \times U(1)_X$

- Three neutral gauge bosons: (W_L^3, W_R^3, X)
- Two charged gauge bosons: $(W_L^{\pm}, W_R^{\pm})$

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- $SU(2)_R \times U(1)_X \to U(1)_Y$: $(W_L^3, W_R^3, X) \to (W_L^3, B, Z_X)$
  - $Z_X \equiv \frac{1}{\sqrt{g_x^2+g_R^2}}(g_R W_R^3 - g_X X) \to (-,+)$; $W_R^\pm \to (-,+)$
  - $B \equiv \frac{1}{\sqrt{g_x^2+g_R^2}}(g_X W_R^3 + g_R X) \to (+,+)$; $W_L^\pm \to (+,+)$

Symm breaking by BC: $Z_X(-,+)$ means $Z_X|_{y=0} = 0$; $\partial_y Z_X|_{y=\pi R} = 0$

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Symm breaking by BC: $Z_X(-,+)$ means $Z_X|_{y=0} = 0$; $\partial_y Z_X\,|_{y=\pi R} = 0$

- $SU(2)_L \times U(1)_Y \rightarrow U(1)_{EM}$: $(W_L^3, B, Z_X) \rightarrow (A, Z, Z_X)$
  - By TeV brane Higgs

KK States

Kaluza-Klein (KK) expansion: $A(x,y) = \sum_0^\infty f_n(y)\, A^{(n)}(x)$

$A^{(n)}$ →KK tower with mass m_n. Equivalent 4D theory

Gauge Boson

- "Zero" modes: $A^{(0)}, Z^{(0)} \;\; ; \;\; W_L^{(0)}$
- First KK modes: $A^{(1)}, Z^{(1)}, Z_X^{(1)} \;\; \rightarrow \; Z' \;\; ; \;\; W_L^{(1)},\, W_R^{(1)}$

EWSB mixes : $Z^{(0)} \leftrightarrow Z^{(1)} \;\; ; \;\; Z^{(0)} \leftrightarrow Z_X^{(1)} \;\; ; \;\; Z^{(1)} \leftrightarrow Z_X^{(1)}$

$W_L^{(0)} \leftrightarrow W_L^{(1)} \;\; ; \;\; W_L^{(0)} \leftrightarrow W_R^{(1)} \;\; ; \;\; W_L^{(1)} \leftrightarrow W_R^{(1)}$

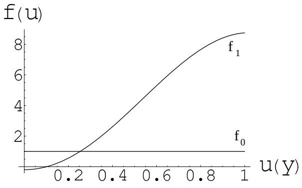
Mass eigenstates :

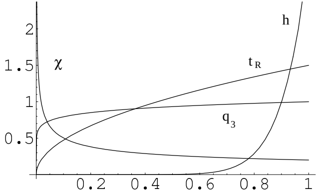
- "Zero" modes: $A, Z \;\; ; \;\; W^{\pm}$
- First KK modes: $A_1, \tilde{Z}_1, \tilde{Z}_{X_1} \;\; \rightarrow Z' \;\; ; \;\; \tilde{W}_{L_1}, \tilde{W}_{R_1} \;\; \rightarrow W'^{\pm}$

Wave functions

Bulk field EOM gives profiles in extra-dimension

Fermion bulk mass (c parameter) controls localization





Compute overlap integral of $f(y) \cdot g(y)$ to get 4D couplings

$$\mathcal{I}^{+,-} = \int [dy] g_\psi^2 f^{(++),(-+)}$$

- $A \to (+,+)$; $Z \to (+,+)$; $Z_X \to (-,+)$

Z' ANALYSIS

Z' couplings

$$\text{Define: } \xi \equiv \sqrt{k\pi R} \approx 5$$

Z' overlap with Higgs $\rightarrow \xi$
Z' overlap with fermions:

	Q_L^3	t_R	other fermions
$\mathcal{I}^+$	1	ξ	$-\frac{1}{\xi}$
$\mathcal{I}^-$	1	ξ	0

Compared to SM

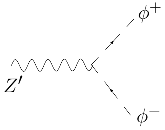
- Z' couplings to h enhanced (also V_L - Equivalence Theorem!)
- Z' couplings to t_R enhanced
- Z'couplings to χ suppressed

$$\bar{\psi}_{L,R}\gamma^\mu \Big[eQ\mathcal{I}A_{1\,\mu} + g_Z \left(T_L^3 - s_W^2 T_Q\right)\mathcal{I}Z_{1\,\mu} + g_{Z'}\left(T_R^3 - s'^2 T_Y\right)\mathcal{I}Z_{X1\,\mu}\Big]\psi_{L,R}$$

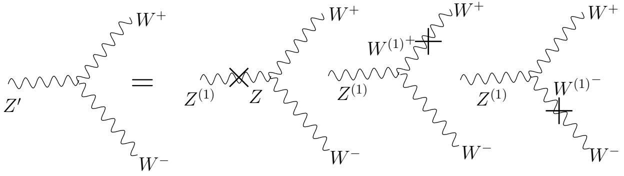
EWSB induced $Z'W^+W^-$ coupling

$Z^{(1)}V^{(0)}V^{(0)}$ is zero by orthogonality ...
... but induced after EWSB

Using Goldstone equivalence:



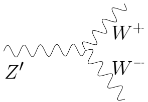
In Unitary Gauge:

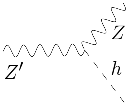


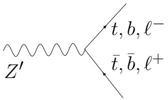
Even though $\xi \cdot (\frac{v}{M_{KK}})^2$ suppressed ...
... can be overcome by $(\frac{M_{KK}}{m_Z})^2$ (from long. pol. vectors)

Z'decays

[Agashe, Davoudiasl, SG, Han, Huang, Perez, Si, Soni - arXiv:0709.0007 [hep-ph]]

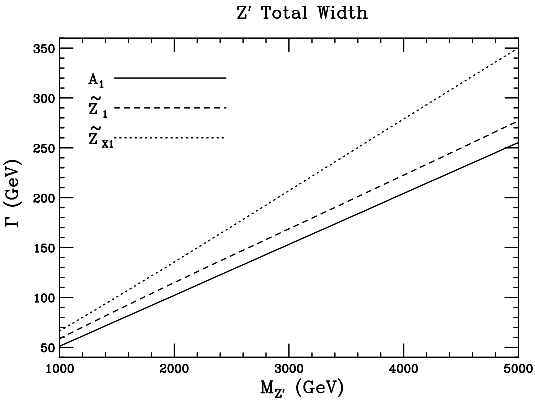






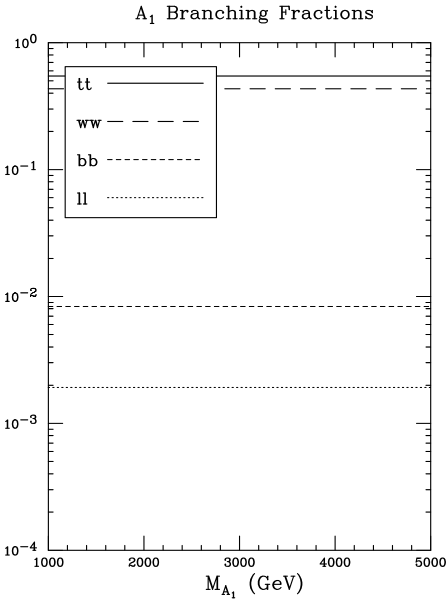
$$
\begin{aligned}
\Gamma(A_1 \to W_L W_L) &= \frac{e^2\kappa^2}{192\pi}\frac{M_{Z'}^5}{m_W^4} \; ; \quad \kappa \propto \sqrt{k\pi r_c}\left(\frac{m_W}{M_{W_1^\pm}}\right)^2 \; , \\
\Gamma(\tilde{Z}_1, \tilde{Z}_{X1} \to W_L W_L) &= \frac{g_L^2 c_W^2 \kappa^2}{192\pi}\frac{M_{Z'}^5}{m_W^4} \; ; \quad \kappa \propto \sqrt{k\pi r_c}\left(\frac{m_Z}{(M_{Z_1}, M_{Z_{X1}})}\right)^2 \; , \\
\Gamma(\tilde{Z}_1, \tilde{Z}_{X1} \to Z_L h) &= \frac{g_Z^2\kappa^2}{192\pi} M_{Z'} \; ; \quad \kappa \propto \sqrt{k\pi r_c} \; , \\
\Gamma(Z' \to f\bar{f}) &= \frac{(e^2, g_Z^2)}{12\pi}\left(\kappa_V^2 + \kappa_A^2\right) M_{Z'} \; .
\end{aligned}
$$

Total Widths

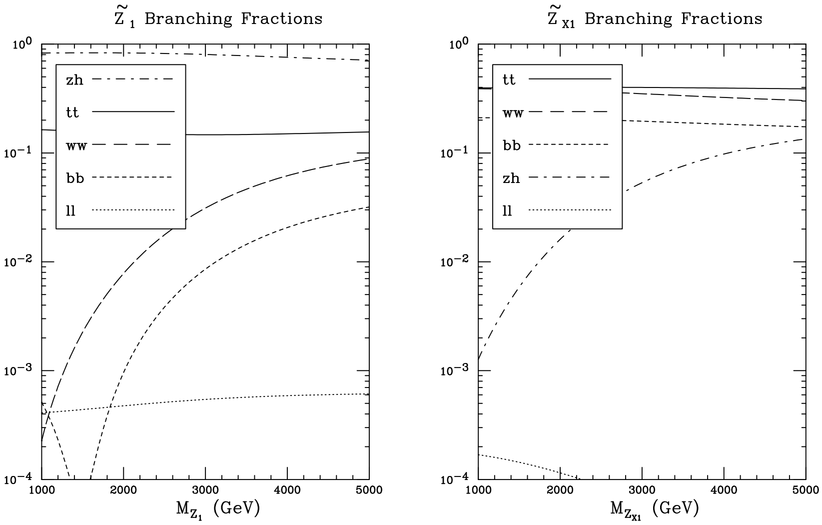


$M_{Z'} = 2$TeV	A_1	Z_1	Z_{X1}
Γ (GeV)	103.3	114.6	135.6

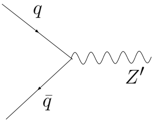
Z' Branching Ratios

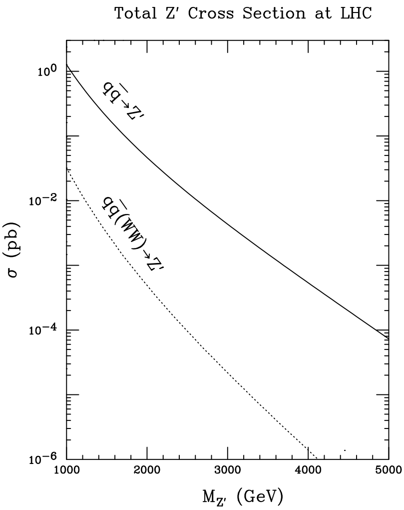


Z' Branching Ratios (Contd.)



Z'production at the LHC



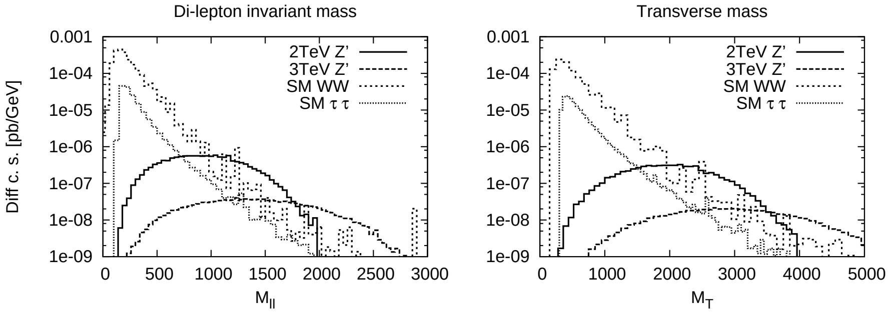


LHC Channels

- $pp \to Z' \to W^+ W^-$
  - Fully leptonic : $W \to \ell\nu$; $W \to \ell\nu$
  - Semi leptonic : $W \to \ell\nu$; $W \to (j\,j)$
- $pp \to Z' \to Z\,h$
  - $m_h = 120\text{GeV}$: $Z \to \ell^+\ell^-$; $h \to b\,\bar{b}$
  - $m_h = 150\text{GeV}$: $Z \to (j\,j)$; $h \to W^+\,W^- \to (j\,j)\ \ell\nu$
- $pp \to Z' \to \ell^+\ell^-$
  - Clean but needs high luminosity
- $pp \to Z' \to t\,\bar{t}$, $b\,\bar{b}$ [Djouadi, Moreau, Singh 07]
  - KK gluon "pollution"

$pp \to Z' \to W^+W^- \to \ell\,\nu\,\ell\,\nu$

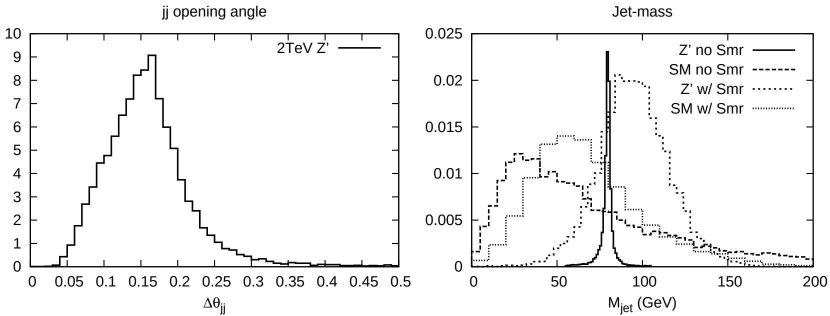
2 ν's $\Rightarrow$ cannot reconstruct event



$$M_{eff} \equiv p_{T_{\ell_1}} + p_{T_{\ell_2}} + \not{p}_T \qquad M_{T_{WW}} \equiv 2\sqrt{p_{T_{\ell\ell}}^2 + M_{\ell\ell}^2}$$

$\mathcal{L}$ needed: 100 fb^{-1} (2 TeV) ; 1000 fb^{-1} (3 TeV)

$pp \to Z' \to W^+W^- \to \ell\,\nu\,j\,j$



j j Collimation implies forming m_W nontrivial : use jet-mass

In our study: Jet-mass after Parton shower in Pythia

[Thanks to Frank Paige for discussions]

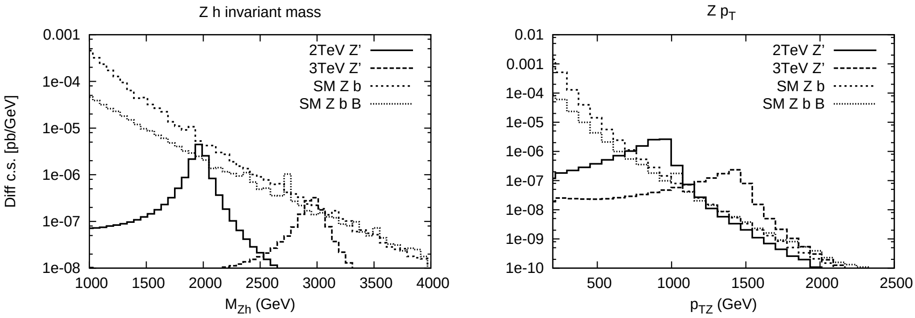
To account for (HCal) expt. uncert.

Smearing by $\delta E = 80\%/\sqrt{E}$; $\delta\eta, \delta\phi = 0.05$

Tracker + ECal (2 cores?) have better resolutions [F. Paige; M. Strassler]

$\mathcal{L}$ needed: $100\ fb^{-1}$ (2 TeV) ; $1000\ fb^{-1}$ (3 TeV)

$pp \rightarrow Z' \rightarrow Z\,h \rightarrow \ell^+\ell^-\;\; b\,\bar{b} \quad (m_h = 120\text{ GeV})$



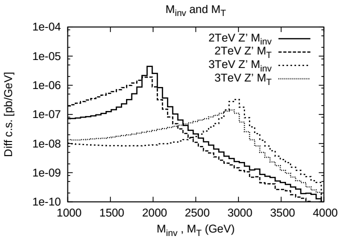
How well can we tag high p_T b's ?

For $\epsilon_b = 0.4$, expect $R_j \approx 20 - 50$; $R_c = 5$

Two b's close : $\Delta R_{bb} \sim 0.16$

$\mathcal{L}$ needed: $200\ fb^{-1}$ (2 TeV) ; $1000\ fb^{-1}$ (3 TeV)

$pp \rightarrow Z' \rightarrow Z\,h$: $Z \rightarrow jj$; $h \rightarrow W^+W^- \rightarrow jj\,\ell\,\nu$ ($m_h = 150$ GeV)



$$M_{T_{Zh}} \equiv \sqrt{p_{T_Z}^2 + m_Z^2} + \sqrt{p_{T_h}^2 + m_h^2}$$

$M_{Z'} = 2$ TeV $m_h = 150$ GeV	Basic	p_T, η	$\cos\theta$	M_T	M_{jet}	# Evts	S/B	$S/\sqrt{B}$
$Z' \rightarrow hZ \rightarrow \ell\,\not{E}_T\,(jj)\,(jj)$	2.4	1.6	0.88	0.7	0.54	54	2.5	11.5
SM $W\,j\,j$	3×10^4	35.5	12.7	0.62	0.19	19		
SM $W\,Z\,j$	184	0.45	0.15	0.02	0.02	2		
SM $W\,W\,j$	712	0.54	0.2	0.02	0.01	1		
$M_{Z'} = 3$ TeV $m_h = 150$ GeV								
$Z' \rightarrow hZ \rightarrow \ell\,\not{E}_T\,(jj)\,(jj)$	0.26	0.2	0.14	0.06	—	18	1.2	4.7
SM $W\,j\,j$	3×10^4		4.1	0.05	—	15		

events above is for

- 2 TeV : 100 fb^{-1}
- 3 TeV : 300 fb^{-1}

$pp \to Z' \to \ell^+\ell^-$

$M_{Z'} = 2$ TeV	Basic	$p_{T\ell}$	$M_{\ell\ell}$	# Evts	S/B	$S/\sqrt{B}$
Signal	0.1	0.09	0.06	60	0.3	4.2
SM $\ell\ell$	3×10^4	5.4	0.2	200		
SM WW	295	0.03	0.002	2		

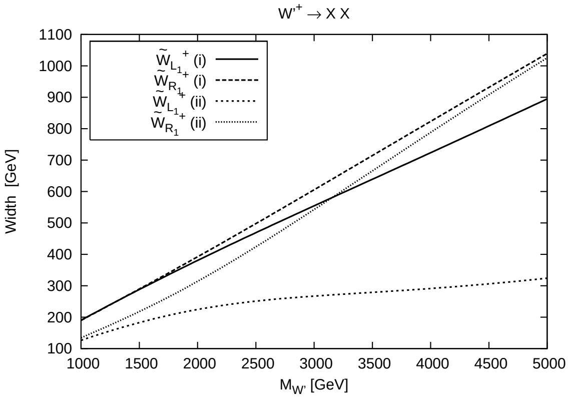
events above is for

- 2 TeV : 1000 fb^{-1}

Experimentally clean, but needs a LOT of luminosity

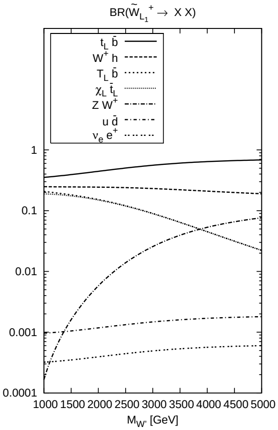
$W'^{\pm}$ ANALYSIS

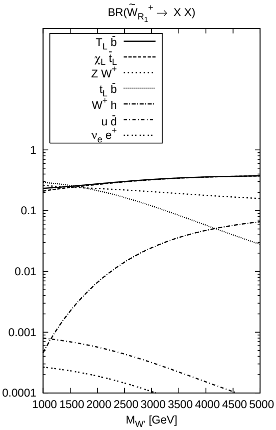
$W'^{\pm}$ width



W'+ → X X
W̃L1+ (i)
W̃R1+ (i)
W̃L1+ (ii)
W̃R1+ (ii)
Width [GeV]
MW' [GeV]
100
200
300
400
500
600
700
800
900
1000
1100
1000
1500
2000
2500
3000
3500
4000
4500
5000

$W'^{\pm} BR$


BR($\tilde{W}_{L_1}^{+} \to$ X X)
$t_L\ \bar{b}$
$W^+\ h$
$T_L\ \bar{b}$
$\chi_L\ \bar{t}_L$
$Z\ W^+$
$u\ \bar{d}$
$\nu_e\ e^+$
1
0.1
0.01
0.001
0.0001
1000 1500 2000 2500 3000 3500 4000 4500 5000
$M_{W'}$ [GeV]

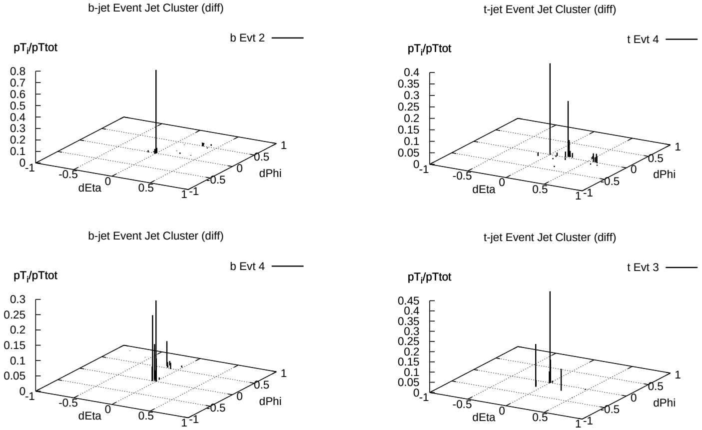

BR($\tilde{W}_{R_1}^{+} \to$ X X)
$T_L\ \bar{b}$
$\chi_L\ \bar{t}_L$
$Z\ W^+$
$t_L\ \bar{b}$
$W^+\ h$
$u\ \bar{d}$
$\nu_e\ e^+$
1
0.1
0.01
0.001
0.0001
1000 1500 2000 2500 3000 3500 4000 4500 5000
$M_{W'}$ [GeV]

$W'^{\pm} \to t\,b \to \ell\nu\,b\,b$

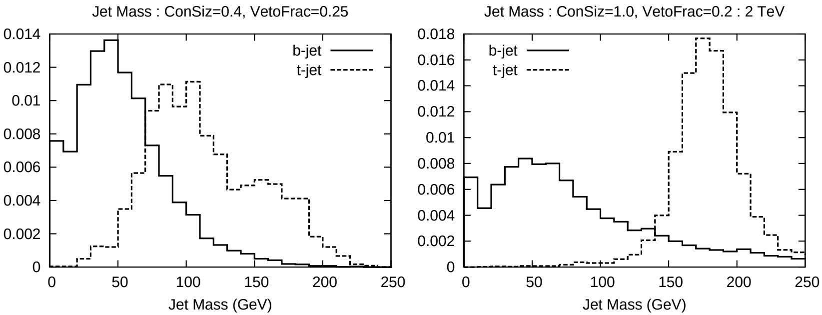
Signal c.s. $\sim 1fb$

Bkgnd is single top + QCD W b b .... AND ...

$t\bar{t}$: hadronically decaying top can fake a b



$W'^{\pm} \to t\,b \to \ell\nu b\,b$



Jet-mass cut: cone size 1.0 and $0 < j_M < 75 \Rightarrow$0.4% of *top* fakes *b*

$\mathcal{L}$ needed: 100 fb^{-1} (2 TeV)

$W'^{\pm} \to Z\,W$ and $W\,h$

$W'^{\pm} \to Z\,W$:

- Fully leptonic $\to \mathcal{L}$: 100 fb^{-1} (2 TeV) ; 1000 fb^{-1} (3 TeV)
- Semi leptonic $\to \mathcal{L}$: 300 fb^{-1} (2 TeV) (SM $W/Z + 1j$ large)

$W'^{\pm} \to Z\,W$ and $W\,h$

$W'^{\pm} \to Z\,W$:

- Fully leptonic $\to \mathcal{L}$: 100 fb^{-1} (2 TeV) ; 1000 fb^{-1} (3 TeV)
- Semi leptonic $\to \mathcal{L}$: 300 fb^{-1} (2 TeV) (SM $W/Z + 1j$ large)

$W'^{\pm} \to W\,h$:

- $m_h \approx 120$: $h \to b\,b$
  - What is b-tagging eff?
- $m_h \approx 150$: $h \to W\,W$
  - Use W jet-mass to reject light jet

$\mathcal{L}$ needed: 100 fb^{-1}(2TeV) ; 300 fb^{-1} (3TeV)

Conclusions

- LHC : $pp \to Z' \to W^+W^-,\ Z\,h,\ \ell^+\ell^-,\ (t\,\bar{t},\ b\,\bar{b})$
  $pp \to W'^{\pm} \to t\,b,\ Z\,W,\ Z\,h,\ \ell\nu$ (ongoing work)
  $t\bar{t}$ bkgnd sneaks in
  - Probing electroweak KK sector challenging, but possible
- Warped model with $SU(2)_L \times SU(2)_R \times U(1)_X$
  $Z' :\ A_1,\ Z_1,\ Z_{X1} \quad W'^{\pm} :\ W_L,\ W_R$
- Thanks to:
  - Colleagues at BNL : Bill Kilgore, Frank Paige
  - CalcHEP (help from Alaxender Belyaev)
  - Pythia (help from Steve Mrenna, Peter Skands)
  - MadGraph (help from Rikkert Frederix)
  - Bridge (help from Matt Reece)

BACKUP SLIDES

Z' Overlap Integrals

Define: $\xi \equiv \sqrt{k\pi R} = 5.83$

Z' overlap with Higgs $\rightarrow \xi$

Z' overlap with fermions:

	Q_L^3	t_R	other fermions
$\mathcal{I}^+$	$-\frac{1.13}{\xi} + 0.2\xi \approx 1$	$-\frac{1.13}{\xi} + 0.7\xi \approx 3.9$	$-\frac{1.13}{\xi} \approx -0.2$
$\mathcal{I}^-$	$0.2\xi \approx 1.2$	$0.7\xi \approx 4.1$	0

Compared to SM

- Z' couplings to h enhanced (also V_L - Equivalence Theorem!)
- Z' couplings to t_R enhanced
- Z'couplings to χ suppressed

$$\bar{\psi}_{L,R}\gamma^\mu \Big[eQ\mathcal{I}A_{1\,\mu} + g_Z\left(T_L^3 - s_W^2 T_Q\right)\mathcal{I}Z_{1\,\mu} + g_{Z'}\left(T_R^3 - s'^2 T_Y\right)\mathcal{I}Z_{X1\,\mu}\Big]\psi_{L,R}$$

Widths & BR's (For $M_{Z'} = 2$TeV)

	A_1		$\tilde{Z}_1$		$\tilde{Z}_{X1}$	
	Γ(GeV)	BR	Γ(GeV)	BR	Γ(GeV)	BR
$\bar{t}t$	55.8	0.54	18.3	0.16	55.6	0.41
$\bar{b}b$	0.9	8.7×10^{-3}	0.12	10^{-3}	28.5	0.21
$\bar{u}u$	0.28	2.7×10^{-3}	0.2	1.7×10^{-3}	0.05	4×10^{-4}
$\bar{d}d$	0.07	6.7×10^{-4}	0.25	2.2×10^{-3}	0.07	5.2×10^{-4}
$\ell^+\ell^-$	0.21	2×10^{-3}	0.06	5×10^{-4}	0.02	1.2×10^{-4}
$W_L^+ W_L^-$	45.5	0.44	0.88	7.7×10^{-3}	50.2	0.37
$Z_L h$	-	-	94	0.82	2.7	0.02
Total	103.3		114.6		135.6	

$pp \to Z' \to W^+W^- \to \ell\,\nu\,\ell\,\nu$

Cross-section (in fb) after cuts:

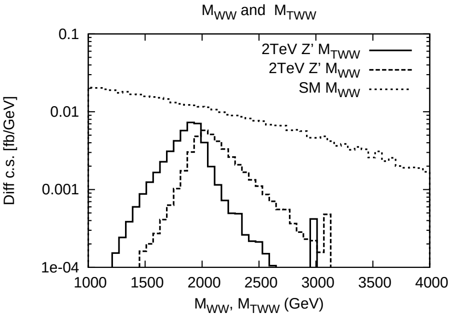
2 TeV	Basic cuts	$\lvert\eta_\ell\rvert < 2$	$M_{eff} > 1$ TeV	M_T >1.75 TeV	# Evts	S/B	$S/\sqrt{B}$
Signal	0.48	0.44	0.31	0.26	26	0.9	4.9
WW	82	52	0.4	0.26	26		
$\tau\tau$	7.7	5.6	0.045	0.026	2.6		
3 TeV	Basic cuts	$\lvert\eta_\ell\rvert < 2$	$1.5 < M_{eff} < 2.75$	$2.5 < M_T < 5$	# Evts	S/B	$S/\sqrt{B}$
Signal	0.05	0.05	0.03	0.025	25		
WW	82	52	0.08	0.04	40	0.6	3.8
$\tau\tau$	7.7	5.6	0.015	0.003	3		

events above is for

- 2 TeV : 100 fb^{-1}
- 3 TeV : 1000 fb^{-1}

$pp \to Z' \to W^+W^- \to \ell\,\nu\; j\, j$

$$M_{eff} \equiv p_{T_{jj}} + p_{T_\ell} + \not{p}_T \qquad M_{T_{WW}} \equiv 2\sqrt{p_{T_{jj}}^2 + m_W^2}$$



Cross-section (in fb) after cuts:

$M_{Z'} = 2$ TeV	p_T	$\eta_{\ell,j}$	M_{eff}	$M_{T_{WW}}$	M_{jet}	# Evts	S/B	$S/\sqrt{B}$
Signal	4.5	2.40	2.37	1.6	1.25	125	0.39	6.9
W+1j	1.5×10^5	3.1×10^4	223.6	10.5	3.15	315		
WW	1.2×10^3	226	2.9	0.13	0.1	10		
$M_{Z'} = 3$ TeV								
Signal	0.37	0.24	0.24	0.12	-	120	0.17	4.6
W+1j	1.5×10^5	3.1×10^4	88.5	0.68	-	680		
WW	1.2×10^3	226	1.3	0.01	-	10		

events above is for

- 2 TeV : 100 fb^{-1}
- 3 TeV : 1000 fb^{-1}

$pp \to Z' \to Z\,h \to \ell^+\ell^-\ \ b\,\bar{b} \quad (m_h = 120\text{ GeV})$

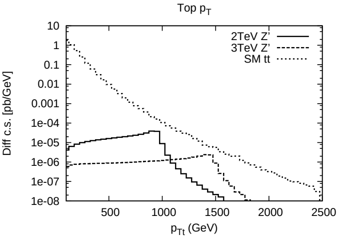
Cross-section (in fb) after cuts:

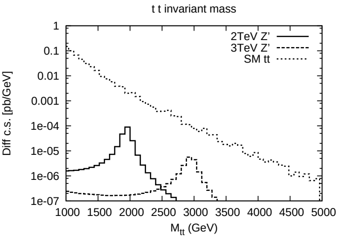
$M_{Z'} = 2$ TeV	Basic	p_T, η	$\cos\theta_{Zh}$	M_{inv}	b-tag	# Evts	S/B	$S/\sqrt{B}$
$Z' \to hZ \to b\bar{b}\,\ell\ell$	0.81	0.73	0.43	0.34	0.14	27	1.1	5.3
SM $Z + b$	157	1.6	0.9	0.04	0.016	3		
SM $Z + b\bar{b}$	13.5	0.15	0.05	0.01	0.004	0.8		
SM $Z + q_l$	2720	48	22.4	1.5	0.08	15		
SM $Z + g$	505.4	11.2	5.8	0.5	0.025	5		
SM $Z + c$	184	1.9	1.1	0.05	0.01	2		
$M_{Z'} = 3$ TeV								
$Z' \to hZ \to b\bar{b}\,\ell\ell$	0.81	0.12	0.05	0.04	0.016	16	2	5.7
SM $Z + b$	157	0.002	0.001	3×10^{-4}	1.2×10^{-4}	0.12		
SM $Z + b\bar{b}$	13.5	0.018	0.014	0.002	0.001	1		
SM $Z + q_l$	2720	1.1	0.7	0.1	0.005	5		
SM $Z + g$	505.4	0.3	0.2	0.03	0.0015	1.5		
SM $Z + c$	183.5	0.03	0.02	0.002	4×10^{-4}	0.4		

events above is for

- 2 TeV : 200 fb^{-1}
- 3 TeV : 1000 fb^{-1}

$pp \longrightarrow Z' \longrightarrow t\bar{t}$





$M_{Z'} = 2$ TeV	Basic	$p_T > 800$	$1900 < M_{tt} < 2100$
Signal	17	7.2	5.6
SM $t\bar{t}$	1.9×10^5	31.1	19.1
$M_{Z'} = 3$ TeV	Basic	$p_T > 1250$	$2850 < M_{tt} < 310$
Signal	1.7	0.56	0.45
SM $t\bar{t}$	1.9×10^5	4.1	1.1