Baryonic Z' Solution for the Wjj Anomaly

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Baryonic Z' connection of LEP $R_{b,c}$ data with Tevatron $(W, Z, \gamma)b\bar{b}$ events

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Abstract

The mixing of a new Z' boson with the Z significantly improves the fit to the LEP precision electroweak data, provided that the Z' couples mainly to quarks. If $M_{Z_2} < 200$ GeV, the s-channel Z_2 production and $(W, Z, \gamma)Z_2$ pair production cross sections at the Tevatron give an excess above QCD of $b\bar{b}$ and $(W, Z, \gamma)b\bar{b}$ events, respectively, with invariant mass $m(b\bar{b}) \approx M_{Z_2}$, which provide viable signals for detection of the Z_2. The interference of the Z_2 with γ, Z_1 in $e^+e^- \to \bar{b}b$ $(\bar{c}c)$ at LEP 1.5 energies is correlated with R_b (R_c) and may be observable.

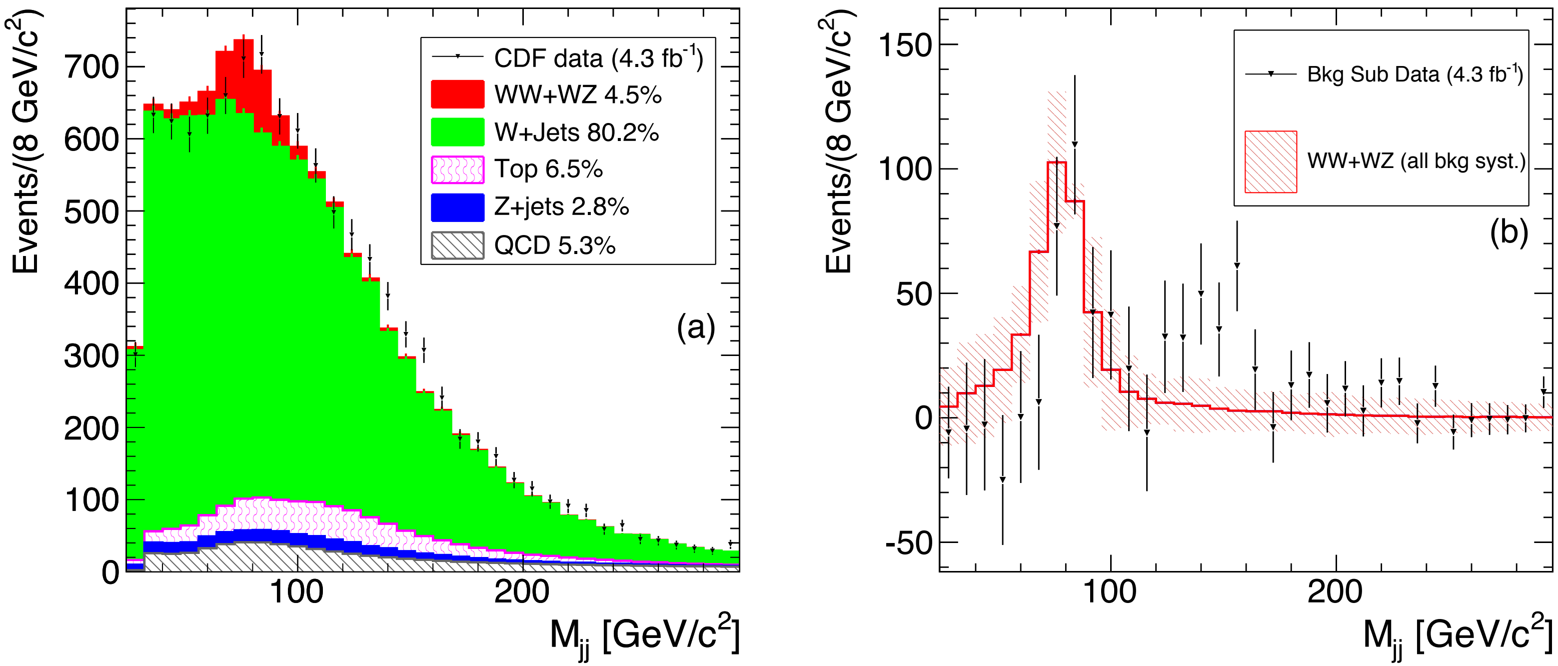
Outline

- Experimental measurements
- Baryonic Z' model
- Implications at the Tevatron

CDF Experimental Data

(1104.0699)

- Use an integrated luminosity of 4.3 fb^{-1}, CDF found an excess in the $120-160$ GeV window in the M_{jj} distribution in Wjj production.
- Require isolated electron or muon with $p_T > 20$ GeV and $|\eta| < 1.0$. The transverse mass M_T consistent with the W boson.
- Require two jets with $E_T > 30$ GeV, $|\eta| < 2.4$, and $p_{Tjj} > 40$ GeV.
- The resulting sample is dominated by a W boson decaying leptonically and 2 jets. Minor contributions come from $WW + WZ$, $t\bar{t}$, $Z +$ jets, single top, and QCD multijets.
- The fit using the SM in the M_{jj} distribution in the range $28-300$ GeV is $\chi^2/\text{ndf} = 77.1/84$. But for the range $120-160$ GeV $\chi^2/\text{ndf} = 26.1/20$ – indicating local excess.

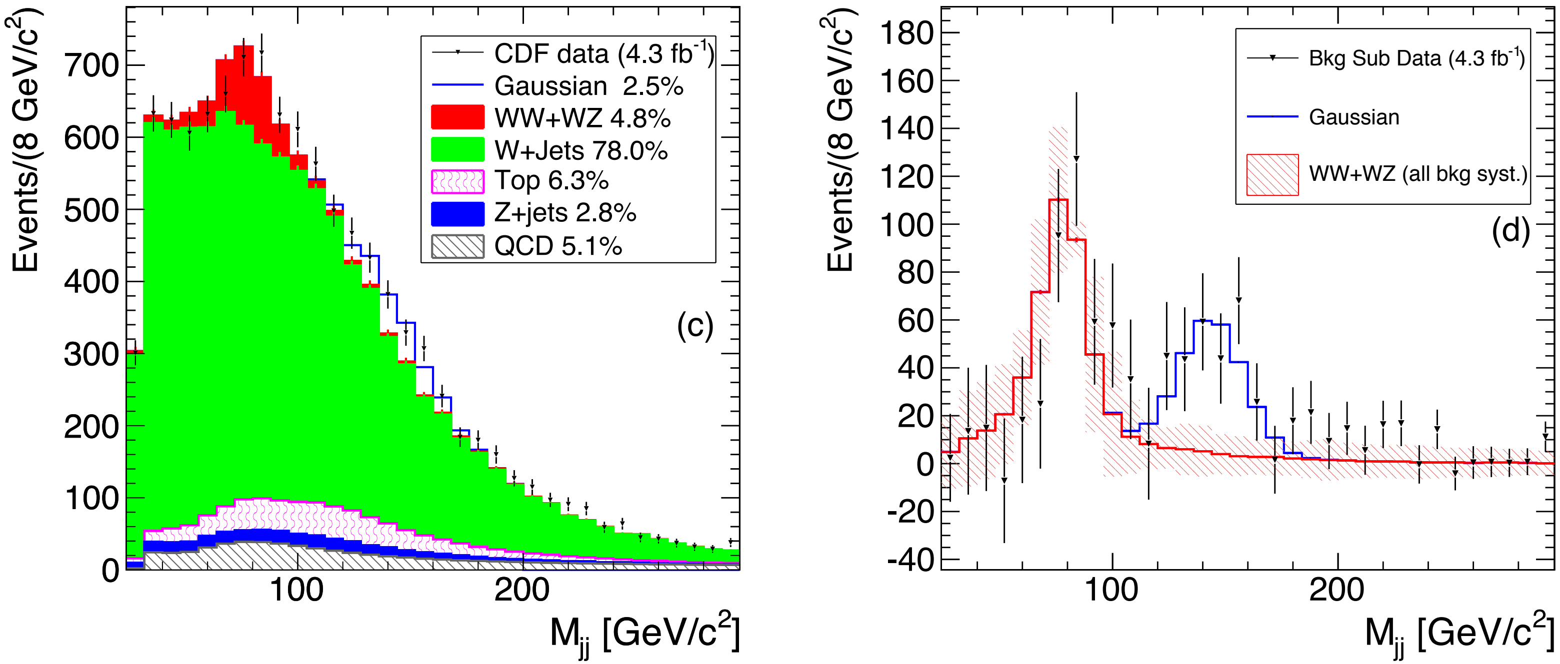

Events/(8 GeV/c^2)
CDF data (4.3 fb^-1)
WW+WZ 4.5%
W+Jets 80.2%
Top 6.5%
Z+jets 2.8%
QCD 5.3%
(a)
M_jj [GeV/c^2]
Bkg Sub Data (4.3 fb^-1)
WW+WZ (all bkg syst.)
(b)

- Fit with an additional Gaussian peak with resolution obtained by scaling

$$\sigma_{\rm resolution} = \sigma_{W\ \rm peak}\sqrt{\frac{M_{jj}}{M_W}} = 14.3\ \rm GeV$$

  The $\chi^2/\rm ndf = 10.9/20$ in the range 120 – 160 GeV.

- Assuming only background contributions and systematic errors, the probability of observing such an excess is 7.6×10^{-4} – 3.2 σ deviation for a Gaussian distribution.


Events/(8 GeV/c^2)
CDF data (4.3 fb^{-1})
Gaussian 2.5%
WW+WZ 4.8%
W+Jets 78.0%
Top 6.3%
Z+jets 2.8%
QCD 5.1%
(c)
M$_{jj}$ [GeV/c^2]
Events/(8 GeV/c^2)
Bkg Sub Data (4.3 fb^{-1})
Gaussian
WW+WZ (all bkg syst.)
(d)
M$_{jj}$ [GeV/c^2]

Further information about the data

(1104.0699)

- The excess around 145 GeV implies a production cross section of

$$\sigma(Z') \times B(Z' \to jj) \approx 4 \text{ pb}$$

- Imcompatible with the SM Higgs boson, because

$$\sigma(WH) \times B(H \to b\bar{b}) \simeq 12 \text{ fb}$$

  for $m_H = 150$ GeV.

- Flavor content of the dijet: compatible with side bands, which are not particular in any flavors.

- Coming from a parent resonance – negative. The invariant mass $M_{\ell\nu jj}$ and $M_{\ell\nu jj} - M_{jj}$ distributions did not show any structure.

Baryonic Z' Solution

(KC, Song 1104.1375)

Z_1^0, Z_2^0 interactions

$$-\mathcal{L}_{Z_1^0 Z_2^0} = g_1 Z_{1\mu}^0 \left[\frac{1}{2} \sum_i \bar{\psi}_i \gamma^\mu (g_v^{i(1)} - g_a^{i(1)} \gamma^5) \psi_i \right] + g_2 Z_{2\mu}^0 \left[\frac{1}{2} \sum_i \bar{\psi}_i \gamma^\mu (g_v^{i(2)} - g_a^{i(2)} \gamma^5) \psi_i \right]$$

where in GUT

$$\frac{g_2}{g_1} = \left(\frac{5}{3} x_{\mathrm{w}} \lambda \right)^{1/2} \simeq 0.62 \lambda^{1/2} \,,$$

- Consider Z_2^0 only couples to quarks

$$g_v^{q(2)} = \epsilon_V = \sin\gamma \,, \quad g_a^{q(2)} = \epsilon_A = \cos\gamma \,; \qquad g_v^{\ell(2)} = g_a^{\ell(2)} = 0$$

  with $\epsilon_V^2 + \epsilon_A^2 = 1$.

- The weak eigenstates Z_1^0 and Z_2^0 are mixed to form mass eigenstates

Z and Z'

$$\begin{pmatrix} Z \\ Z' \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} Z_1^0 \\ Z_2^0 \end{pmatrix} \quad (1)$$

The mass of Z is $M_Z = 91.19$ GeV.

- The interactions of Z and Z' are

$$-\mathcal{L}_{ZZ'} = \sum_i \frac{g_1}{2}\left[Z_\mu \bar{\psi}_i \gamma^\mu (v_s^i - a_s^i \gamma^5)\psi_i + Z'_\mu \bar{\psi}_i \gamma^\mu (v_n^i - a_n^i \gamma^5)\psi_i\right]$$

where

$$v_s^i = g_v^{i(1)} + \frac{g_2}{g_1}\,\theta\, g_v^{i(2)}\,, \qquad a_s^i = g_a^{i(1)} + \frac{g_2}{g_1}\,\theta\, g_a^{i(2)}\,,$$
$$v_n^i = \frac{g_2}{g_1}\, g_v^{i(2)} - \theta\, g_v^{i(1)}\,, \qquad a_n^i = \frac{g_2}{g_1}\, g_a^{i(2)} - \theta\, g_a^{i(1)}\,.$$

- EWPD constrains $\theta < 10^{-3}$. We choose $\theta = 0$.
- We take democratic choice of equal coupling to up- and down-type quarks.

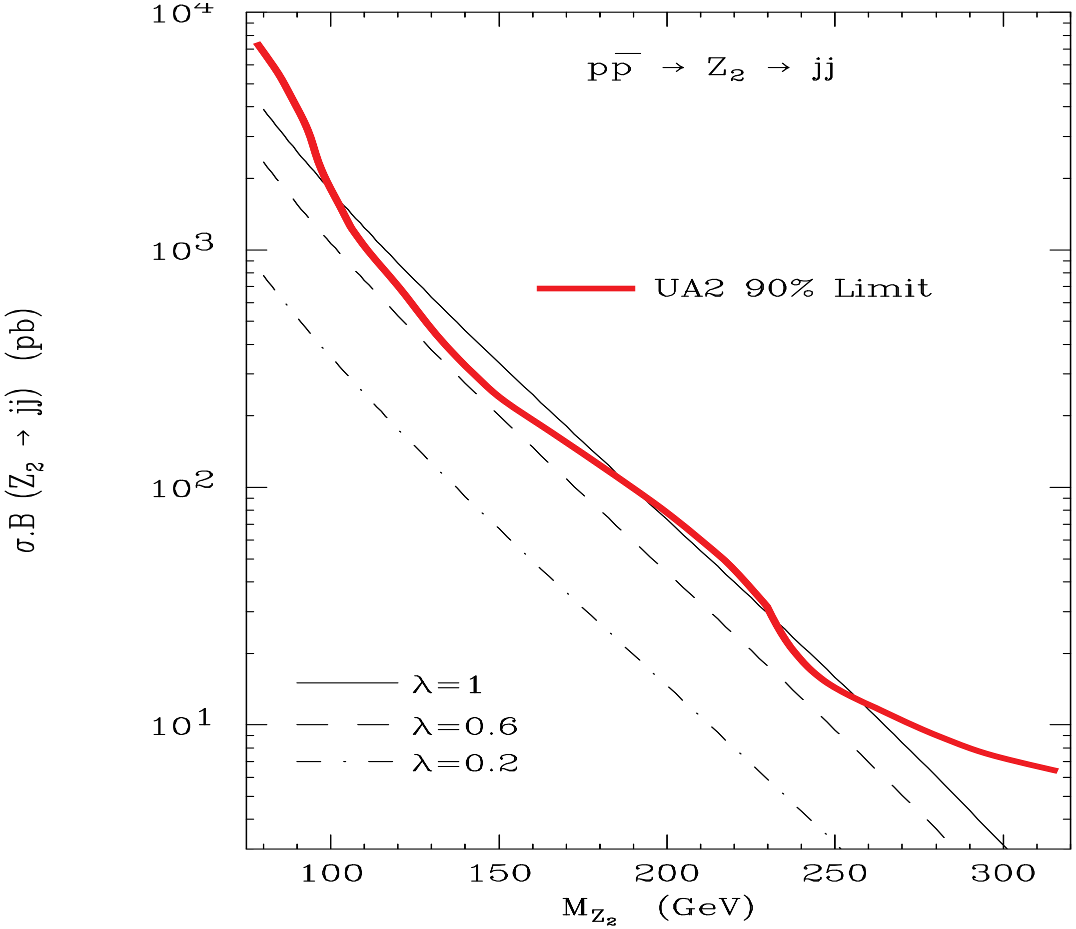
s-channel Z' Production

- The Z' is narrow, $\Gamma_{Z'}/M_{Z'} \simeq 0.022$.
- Production at hadronic collisions

$$\hat{\sigma}(q\bar{q} \to Z') = K \frac{2\pi}{3} \frac{G_F\, M_Z^2}{\sqrt{2}} \left[\left(v_n^q\right)^2 + \left(a_n^q\right)^2 \right] \delta\left(\hat{s} - M_{Z'}^2\right) \; .$$

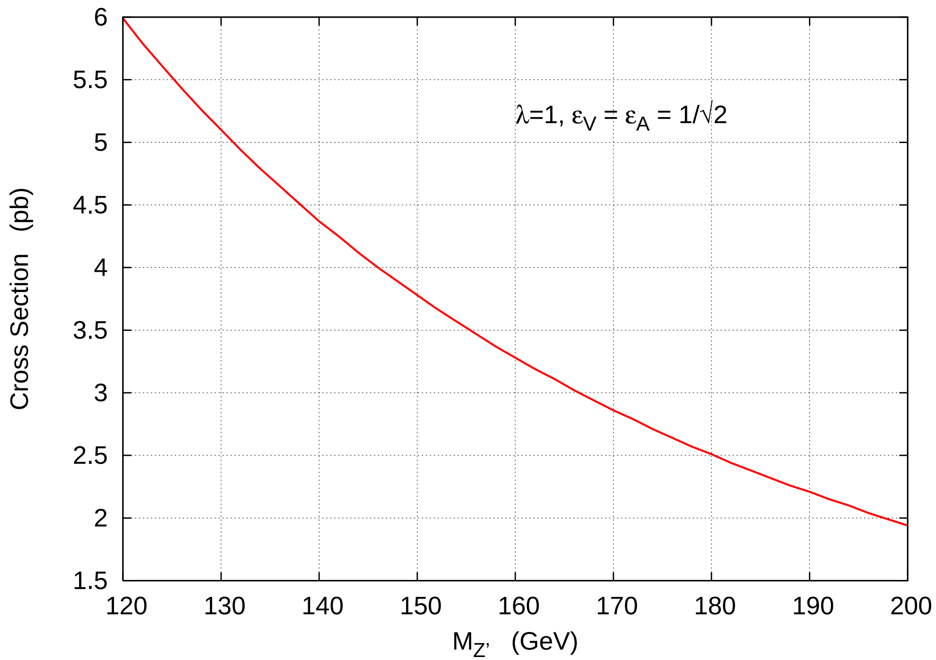
where $K \simeq 1.3$ and $\left(v_n^q\right)^2 + \left(a_n^q\right)^2 = (0.62)^2 \lambda$ if no mixing.

- Nearly all dijet search at the Tevatron started from 200 GeV.
- The relevant dijet data was from UA2. UA2 placed upper bounds on $\sigma \cdot B(Z' \to jj)$ over the range $80 < M_{jj} < 320$ GeV.
- The allowed values are $\lambda \lesssim 1$ for $M_{Z'} = 100 - 180$ GeV, given all the uncertainty in theoretical calculation and experimental subtraction of a smooth background.


$p\bar{p} \rightarrow Z_2 \rightarrow jj$
UA2 90% Limit
λ=1
λ=0.6
λ=0.2
$\sigma.B\ (Z_2 \rightarrow jj)\ \ (pb)$
M_{Z_2} (GeV)
10^4
10^3
10^2
10^1
100
150
200
250
300

WZ' Production

- WZ' goes through the t and u channels but not the s-channel boson exchange, such that there is no destructive interference. So we expect for the same mass $\sigma(WZ') > \sigma(WZ)$.
- Here $K \simeq 1.3$, and $\lambda = 1$. At around $140 - 150$ GeV, $\sigma(WZ') \simeq 4$ pb.



- The total width of the Z' is a mere 3 GeV. The width of the bump is mainly due to resolution.

- We have assumed democratic couplings so that $Z' \to u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$, $b\bar{b}$ equally. $B(Z' \to b\bar{b}) \simeq 0.2$.

- Both CDF and DØ have dedicated $\ell\nu b\bar{b}$ search. With 5.7 fb^{-1} CDF put 95% C.L. upper limits on

$$\frac{\sigma(WX) \times B(X \to b\bar{b})}{\sigma(WH) \times B(H \to b\bar{b})} = \begin{cases} 15.8 & m_H = 140 \text{ GeV} \\ 25.3 & m_H = 145 \text{ GeV} \\ 44.3 & m_H = 150 \text{ GeV} \end{cases}$$

With $\sigma(WH) \times B(H \to b\bar{b}) \simeq 21$ fb at $m_H = 145$ GeV, the largest allowed cross section for

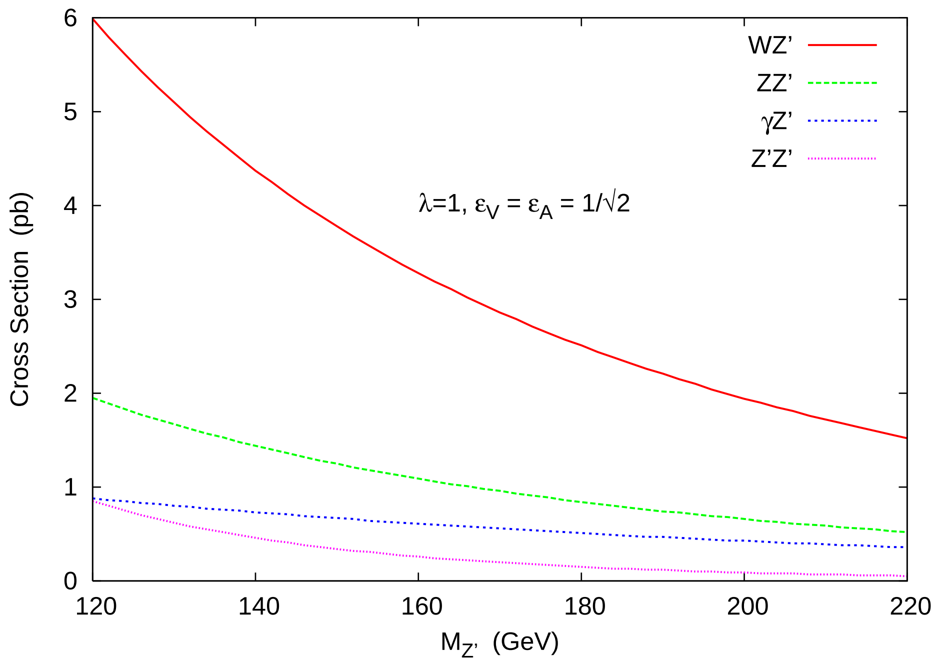
$$\sigma(WZ') \times B(Z' \to b\bar{b}) \simeq 0.53 \text{ pb}$$

Right now we have $\sigma(WZ') \times B(Z' \to b\bar{b}) = 4 \text{ pb} \times 0.2 \simeq 0.8$ pb.

- We can easily give up the democratic choice of couplings to make it consistent.

Implications at the Tevatron

- $\gamma Z'$, ZZ' and possibly $Z'Z'$ can be produced at the Tevatron.



- The γjj could be promising. We did an estimate of SM background and $\gamma Z'$ signal, with cuts

$$E_{T\gamma} > 50 \text{ GeV}, \quad |\eta_\gamma| < 1.1$$

$$E_{Tj} > 30 \text{ GeV}, \quad |\eta_j| < 2.4, \quad p_{Tjj} > 40 \text{ GeV}, \quad 120 \text{ GeV} < M_{jj} < 160 \text{ GeV}$$

- The $\sigma_{\text{signal}} : \sigma_{\text{bkgd}} = 0.5$ pb : 10 pb, which gives a significance of 10 for 4.3 fb^{-1}.
- The other channel ZZ' will be weaker because of small leptonic branching ratio of Z.

Conclusions

1. It is beginning of collider era – one rumor per two weeks.
2. This bump at $140 - 150$ GeV has been hidden in all previous dijet searches. But showing up together with a W boson.
3. It has to be baryonic to prevent strong constraint of dilepton.
4. The size of cross section needed to explain the excess is consistent with a baryonic Z' model with a weak-scale coupling.
5. It can be made consistent with all previous dijet search and $\ell\nu b\bar{b}$ search.
6. Interesting implication for γjj production at the Tevatron.