New Heavy Gauge Bosons at CMS

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New heavy gauge bosons

To solve known shortcomings of the Standard Model, extensions have been proposed. The SM gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$ can be extended by:

- An extra $U(1)$ group, giving rise to a neutral heavy vector boson $Z'$
- An extra $SU(2)$ group, giving rise to a charged heavy vector boson $W'$

Model examples:
- Sequential Standard Model (SSM): new bosons have similar couplings as $W, Z$ in SM

- Left-right symmetric models: $SU(2)_L \times SU(2)_R$

- Superstring-inspired $E_6$ models: $E_6 \rightarrow SO(10) \times U(1)_\psi \rightarrow SU(5) \times U(1)_\chi \times U(1)_\psi$. Only one linear combination $G$ leads to particles at the TeV scale:
  $G = \cos \theta \ U(1)_\chi - \sin \theta \ U(1)_\psi$. $\theta = 0$: $\psi$-model

- More complicated scenarios predict a tower of new gauge bosons ($W^n, Z^n$, or gravitons $G^n$), such as technicolor or extra dimension models.
Many Z’ models predict narrow resonances decaying to dileptons.

**Event selection:**

\[ E_T(e_1,e_2) > 35 \text{ GeV}, \ p_T(\mu_1,\mu_2) > 45 \text{ GeV}, \]  

plus isolation criteria

**Backgrounds:**

- \( Z/\gamma^* , \ tt , \ tW , \ VV , \ Z \rightarrow \tau\tau , \) multijets with \( \geq 1 \) jet reconstructed as lepton
- estimated by fitting data with appropriate function

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**CMS PAS EXO-12-015, hep-ex 1206.1849, CMS PAS EXO-11-019**
There are non-universal scenarios in which the $Z'$ couples preferentially to third-generation fermions. Final states studied: $\tau_e \tau_\mu$, $\tau_e \tau_h$, $\tau_\mu \tau_h$, $\tau_h \tau_h$. $\nu$'s in final state do not allow to reconstruct mass of $\tau\tau$ system.

**Event selection:**
2 $\tau$ candidates with $p_T$ between 15 and 35 GeV, $\eta < 2.1$, isolation criteria, no $b$-jets

**Backgrounds:**
DY $Z \rightarrow \tau\tau$, $W$+jets, $t\bar{t}$, $VV$, QCD

Backgrounds are estimated from data where possible.

**Effective visible mass**

$M(\text{Z'_{SSM}}) > 1.4$ TeV
$M(\text{Z'_{\psi}}) > 1.1$ TeV

**hep-ex 1206.1725**
**submitted to PLB**
**CMS PAS EXO-11-031**
Models studied:
- $W'_\text{SSM}$ with SM-like couplings, with $W'_\text{SSM} \to t\bar{b}$ allowed
- Kaluza-Klein $W^2_{\text{KK}}$ in split UED framework

Event selection: ~back-to-back isolated $l+E_T^{\text{miss}}$, energy-balanced

Backgrounds: $W \to l\nu$, QCD, tt+single top, DY,VV from data

CMS PAS EXO-12-010

M($W'_\text{SSM}$) > 2.8 TeV
M($W^2_{\text{KK}}$) > 1.25 TeV ($\mu = 0.05$ TeV)
M($W^2_{\text{KK}}$) > 3.3 TeV ($\mu = 10$ TeV)

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A left-handed $W_L'$ can interfere with the $W$. Studies were performed with 7 TeV data. Limits for a $W_R'$ have also been derived.

Theoretical Cross Section SSM $W'$ with K-factor
Theoretical Cross Section SSM $W'$ without K-factor
Theoretical Cross Section for $W_R$ ($\sigma \times B$)

$\int L dt = 5.0 \, \text{fb}^{-1}$

CMS Simulation

CMS = 7 TeV

95% Observed Limit (Electron)
95% Observed Limit (Muon)
95% Expected (Combined)
95% Observed (Combined)

$M(W'_{SSM}) > 2.5 \, \text{TeV}$
$M(W_L'_{SSM}) > 2.63 \, \text{TeV}$ (constructive interference)
$M(W_L'_{SSM}) > 2.43 \, \text{TeV}$ (destructive interference)
$W' \rightarrow tb$

- $W'_R$ decays to leptons suppressed if $M(\nu_R) > M(W') \rightarrow$ search in hadronic final states important. Decay chain: $W' \rightarrow tb \rightarrow Wbb \rightarrow l\nu bb$.

Event selection: $\text{isol.e}(\mu)$ with $p_T > 35(32)$ GeV, $E_T^{\text{jet1(jet2)}} > 100(40)$ GeV, $\geq 1$ b-tag

Backgrounds: $t\bar{t}$+single top, $W(\rightarrow l\nu)+$jets, $Z/\gamma^* (\rightarrow ll)+$jets, QCD, VV

New BDT analysis for signal/background discrimination with $\sim 50$ variables (object and event kinematics, top reconstruction, angular correlations).

![Comparison of BDT and invariant mass analyses](image)
$W' \rightarrow tb$

Most general model-independent LO Lagrangian for a $W'$ coupling to SM fermions:

$$\mathcal{L} = \frac{V_{fi}V_{fj}}{2\sqrt{2}} g_w \bar{f}_i \gamma_\mu (a_{fi}^R (1 + \gamma^5) + a_{fi}^L (1 - \gamma^5)) W'^\mu f_j + h.c.$$  

$$a_{ud}^L = a_{cs}^L = a_{tb}^L = a^{L,R}$$

Mass limit and constraints of $W'$

gauge coupling for a set of left- and

right-handed coupling combinations

have been set:

$M(W'_R) > 1.85$ TeV

Contours of $W'$ mass at which the

observed 95% CL cross-section upper limit equals the predicted cross-section

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ICHEN, July 2012
$W' \rightarrow td$

- Tevtron measurement of forward-backward asymmetry at high $t\bar{t}$ inv. mass

\[ A_{FB}^t = \frac{N_t(\eta \geq 0) - N_t(\eta \leq 0)}{N_t(\eta \geq 0) + N_t(\eta \leq 0)} \]

- Possible explanation: light $W'$

- $N(W'^-) > N(W'^+)$ at LHC -> aids in reconstructing the $W'$

Decay chain:

$pp \rightarrow tW' \rightarrow ttd$, with semileptonic $t$-decays plus a jet in final state.

Difference of yields for $t^-d$ and $t^+d$ invariant mass distributions (charge assignment from leptonic top decay):

*hep-ex 1206.3921, CMS PAS EXO-11-056*
$W' \rightarrow td$

CMS 5.0 fb$^{-1}$ at $\sqrt{s} = 7$ TeV

- Combined $e^+\mu$ channels
- Theory cross section (arXiv:1111.5857)
- Observed limit
- Median expected limit
- $\pm 1\sigma$ expected limit band
- $\pm 2\sigma$ expected limit band

$M(W') > 839$ GeV
W', G_{RS} \rightarrow VZ \rightarrow wide jet + lepton pair

W'_{SSM} \rightarrow ZW \rightarrow lljj, G_{RS} \rightarrow ZZ \rightarrow lljj
• 2-fermion systems boosted for heavy resonance

Event selection:
based on high-p_T Z candidates from lepton pair and wide jet well separated from leptons

Backgrounds: from data
W+jets, tt, γV+jets, Z/γ*+jets, ZZ, VV+jets

CMS PAS EXO-11-081

95% CL exclusion limits
• CMS has studied scenarios for new heavy gauge bosons.

• Although no signals for new physics have been found yet, limits on masses and other quantities have been set.

• Details may be found here:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

We are looking forward to more LHC data!