Search for $W'$ bosons at the CMS Experiment

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(on behalf of the CMS Collaboration)

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W’ searches

- New heavy gauge bosons (W’, Z’) predicted by many new physics theories
  - Little Higgs, Extra Dimensions, GUT, Technicolor, etc.

- W’ signatures
  - Leptonic: e + ν, μ + ν, τ + ν
  - Bosonic: WZ, Wγ
  - Hadronic: qq’, tb

- This talk focuses on the e + ν, μ + ν channels (∼ 1 fb⁻¹)

- Previous CMS W’ search (2010) with 36 pb⁻¹ of data
    - 1.36 TeV limit
    - 1.58 TeV combined limit
$W' \rightarrow l \nu$ model

- Concentrate on the Sequential Standard Model for now
  - “Reference model” (G. Altarelli et al.)

- $W'$ boson is a copy of the SM $W$ boson (same couplings to fermions)

- Neutrino is light & stable

- No mixing between $W'$ and other bosons ($W, Z, Z'$)

- $WZ$ channel is suppressed
Analysis Outline

• Spectacular signature:
  – One very energetic lepton in event (“straight track”)
  – Plus “nothing else”

• Very similar event selection & analysis cuts for e, \( \mu \) channels
  – Trigger:
    • Highest \( p_T/E_T \) unprescaled single lepton trigger
    • Plus \( M_T \) condition for electron channel
  – Only one (good quality) isolated high-\( p_T/E_T \) lepton
  – And “nothing else” in the event
    • Apply kinematic cuts (e.g. lepton \( p_T \) and MET are similar in magnitude and back-to-back in \( xy \) plane)
Muon channel: Event with $M_T = 783$ GeV

Spectacular signature
- One high-$p_T$ lepton in event ("straight track")
- Plus "nothing else"
Signature

Spectacular signature
- One high-\(p_T\) lepton in event ("straight track")
- Plus "nothing else"

- \(m_T = 922.0\) GeV
- one 19 GeV muon inside a jet in EE

Electron channel: Event with \(M_T = 922\) GeV
Signal simulation

- Signal samples generated with PYTHIA6 in LO

- Determination of NNLO k-factors for each $W'$ mass point using FEWZ 2.0
  - Calculated LO cross-section for CTEQ6L1 (used for generation) and NNLO cross-section for MSTW2008 PDF-sets for masses 600-2500 GeV in steps of 100 GeV

- Analysis uses NNLO = LO $\times$ $k$-factor
  
  $$K_{Factor}^{NNLO} = \frac{\sigma_{FEWZ}(NNLO;MSTW2008)}{\sigma_{FEWZ}(LO;CTEQ6L1)}$$

- NNLO $W'\rightarrow l\nu$ production cross sections range from 0.346 pb (for $m_{W'}=1.2$ TeV) to 0.0025 pb (for $m_{W'}=2.5$ TeV)

- Signal efficiencies $> 80\%$ for both electron and muon channels
  - Fairly independent of $W'$ mass
Transverse mass distributions

\[ M_T = \sqrt{2 \cdot (p_T^\mu \cdot c) \cdot E_{T}^{\text{miss}} \cdot (1 - \cos \Delta \phi_{\mu,\nu})} \]
Transverse mass (electron channel)

1.03 fb⁻¹

Figure 2: Transverse mass distribution (left) and cumulative distribution (right) for the electron channel.

No excess observed in data when compared to SM background expectation.
Transverse mass (muon channel)

1.13 fb$^{-1}$

Figure 3: Transverse mass distribution (left) and cumulative distribution (right) for the muon channel.

No excess observed in data when compared to SM background expectation.
Analysis Strategy

• No excess found => calculate exclusion limit

• Look at tail of $M_T$ distribution and obtain:
  – Total number of expected signal events
    • Cross sections, k-factors, efficiencies
  – Total number of expected background events
    • How confident are we that we understand the composition of the background in the $M_T$ spectrum?
    • What is the expected background in the signal region?
  – Total number of observed events in the data

• Event-counting for setting exclusion limit
  – Bayesian method with flat prior for signal cross section
  – Use “Sliding search” window optimized for best expected limit
Background Determination
Background Determination

- Data-driven method for combined (beam-induced) bgd
  - Find “signal-free” region of $M_T$ spectrum [signal contamination $< 1\%$]
    - $(170-210 < M_T < 550-650 \text{ GeV})$
  - Fit sideband & use parameters to model background shape
  - Extrapolate bgd to “region of interest” (e.g. $M_T > 1 \text{ TeV}$)
  - Estimate # of bgd events in signal region (w/o relying on MC)

Method proven to work in MC
- Background in MC is sum of all SM contributions (but mainly off-peak $W \to \mu/e \nu$)
Background determination: Fit functions

Tested several fitting functions

Function 1:
\[ \frac{a}{(M_T + b)^c} \]

Function 2:
\[ \frac{a}{(M_T)^2 + b \cdot M_T + c)^d} \]

Function 3:
\[ \frac{a(1 + M_T)^b}{(M_T^{e+d\cdot\log M_T})} \]

Tested varying sideband
Lower edge varied between 170 and 210 GeV.
Upper edge (rather insensitive) varied between 550 and 650 GeV.

Example: muon channel

Cross check with MC: functions describe simulation very well
## Systematic Uncertainties

### Signal

<table>
<thead>
<tr>
<th>Systematic uncertainty</th>
<th>Value</th>
<th>Impact on signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>6 %</td>
<td>6 %</td>
</tr>
<tr>
<td>Muon $p_T$ resolution and Momentum scale</td>
<td>0.14 TeV$^{-1}$ (pT)</td>
<td>10 %</td>
</tr>
<tr>
<td></td>
<td>0.4% (scale)</td>
<td></td>
</tr>
<tr>
<td>MET resolution, hadronic component</td>
<td>10 %</td>
<td>2 %</td>
</tr>
<tr>
<td>Muon trigger efficiency</td>
<td>3 %</td>
<td>3 %</td>
</tr>
<tr>
<td>Combined electron efficiency (trigger, ID and reconstruction)</td>
<td>2 %</td>
<td>2 %</td>
</tr>
<tr>
<td>Electron energy scale</td>
<td>1% EE, 3% EC</td>
<td>&lt;1%</td>
</tr>
</tbody>
</table>

### Background

Taking into account uncertainties due to fit parameter errors in extrapolation, sensitivity of fit on range of sideband, choice of fitting function and discrepancy between MC and sideband fit prediction.
Combined Exclusion Limit

- Fully correlated luminosity uncertainty
- Fully uncorrelated background uncertainty (correlated also tested, yields same result)

Combined limit (SSM):

Expected: $m(W') > 2.20$ TeV
Observed: $m(W') > 2.27$ TeV

Significant improvement over 2010 results (1.58 TeV)
Summary

• We have performed a search for $W'$ bosons decaying to the lepton + MET final state using $\sim 1 \text{ fb}^{-1}$ of data

• No significant excess above the SM background expectation is observed in the data

• We set a lower bound on the $W'$ mass, assuming SM-like couplings and no interference with other bosons:

\[ M(W') > 2.27 \text{ TeV} \]

• Significant improvement over the 2010 result.
Backup
A W' with SSM couplings is excluded for masses up to 2.15 TeV at the 95% CL.