Search for BSM physics in dilepton, multilepton and lepton + MET final states at CMS

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On behalf of the CMS collaboration
Search for new physics with leptons

- Final states of leptons are clean probes of new physics in both SUSY and non-SUSY searches
- non-SUSY searches involving leptonic final states:
  - Search for $Z'$ in dilepton events (EXO-15-005)
  - Search for $W'$ in lepton+MET events (EXO-15-006)
  - Search for high-mass resonances and quantum black holes in the $e\mu$ final state (EXO-16-001)
  - Search for type-III seesaw mechanism in multilepton events (EXO-16-002)
  - Search for resonances in $Z(\mu\mu)\gamma$ events (EXO-16-019)
  - Search for pair production of second-generation scalar leptquarks (EXO-16-007)
  - Search for heavy stable charged particles (EXO-15-010)

All the analyses shown are with 2015 data

covered in today’s talk
Narrow resonance $\rightarrow$ $ee, \mu\mu$

**Models:**
- massive neutral spin 1:
  - $Z'_{\psi}$: width 0.6%
  - $Z'_{SSM}$: width 3%

**Experimental signature:** 2 high pT leptons:
- $pT > 35$ GeV (53 GeV) for e ($\mu$)

**Backgrounds:**
- Major background: SM DY - estimated using MC
- **non-prompt leptons** - estimated using data-driven estimate by measuring the probability for a misidentified lepton passing a loose selection and then full selection
  - $\sim 3\%$ for electron channel and $< 1\%$ for muon channel
Significance at 2.9 TeV

- Highest mass event observed in the electron channel at 2.9 TeV
- Local p-value for the null hypothesis to observe at least one event above 2.8 TeV is 0.036 - could be just a statistical fluctuation
Results

- Observed spectrum agrees well with the SM background

- Excludes:
  
  - $Z'_{SSM} < 3.15$ TeV and $Z'_{\psi} < 2.6$ TeV

- Compared to Run I:
  
  - $Z'_{SSM} < 2.9$ TeV and $Z'_{\psi} < 2.57$ TeV
$W'_{\text{SSM}} \rightarrow \text{lepton} + \text{MET}$

Model:

- TeV object $W' \rightarrow \ell + \nu$
- Experimental signature: high energy charged lepton + MET
- Dominant background: $W \rightarrow \ell + \nu$ - estimated from MC
  - QCD mulitjet - data-driven
- Event selection includes:
  - $M_T > 120$ GeV
  - second lepton veto
- To ensure back to back pattern, apply:
  - $|\Delta \phi(\ell, \text{MET})| > 2.5$
  - $0.4 < p_T/\text{MET} < 1.5$

Main discriminant: $M_T$

Signal has high $M_T$, whereas, background appears as a tail
How well are the leptons understood?

- **Challenge:**
  - Single high pT lepton signal
  - Understanding leptons in high pT regions is important

- **Electrons:**
  - Constant resolution at high energy: $O(2\%)$
  - Saturation of ECAL crystals do not play a role yet at that energy

- **Muons:**
  - Resolution decreases with pT
    - Look at cosmic to study resolution and scale: $O(10\%)$ at 1 TeV
  - Alignment is also looked at using cosmics

Using the lower and upper "legs", resolution and scale is studied in the TeV region.
Results

- MT > 1 TeV, Run II is expected to be more sensitive to new physics than Run I
  - signal cross-section depends on $W'$ mass
- No significant deviation seen - limits are set
- Combining both channels, $W'$ mass < 4.4 TeV is excluded
  - compared to Run I: $W'$ mass < 3.24 was excluded
**e-\(\mu\) resonance**

- Model: RPV SUSY with \(\tau\) sneutrino as LSP and Quantum black holes (QBH)

- Event selection:
  - \(p_T > 35\) GeV (53 GeV) for e (\(\mu\))
  - High energetic muons can produce bremsstrahlung and can thus be mis-identified as electrons
    - Reject electron candidate if \(dR_{e-\mu} < 0.1\) and \(p_T\) of \(\mu\) > 5 GeV
  - e\(\mu\) pair with highest invariant mass is selected

- Backgrounds:
  - Prompt leptons: \(tt\), diboson - estimated from MC
  - \(W\) + jets and QCD: data-driven

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**Parameters of the theory:**
- SUSY: \(\lambda_{132}, \lambda_{231}, \lambda'_{311}\)
- QBH: \(M_{th}\) (threshold mass for QBH production) and \(n\) (number of extra dimensions)

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PAS-EXO-16-001
Results

- **Shape based limits:**
  - **RPV SUSY:** narrow signal - shapes obtained by fitting MC sample with Gaussian
  - **QBH:** shapes directly from MC sample

- **Background:** all shapes from MC except for jet->electron which is taken from data

- **RPV SUSY:** For $\lambda_{132}$, $\lambda_{231}$, $\lambda_{311}' = 0.2$, mass below 3.3 TeV is excluded

- **QBH:** For $n = 6$, $M_{\text{th}} < 4.5$ TeV is excluded
Multileptons: Type III see-saw

- Predicts the existence of SU(2) triplet: $\Sigma^+, \Sigma^-$ to explain smallness of neutrino masses
- Channels: $\Sigma^+ \rightarrow W^+\nu$, $\Sigma^+ \rightarrow Z (H)\ell^+$, $\Sigma^0 \rightarrow W^-\ell^-$, $\Sigma^0 \rightarrow Z (H)\nu$
  - These give rise to 27 different final states with multi-leptons
- Final state: $\geq 3$ leptons (each lepton could be $e$ or $\mu$)
- Decay rate is proportional to:
  $$\mathcal{L}_N = \frac{V_{\ell\nu}}{\sqrt{|V_e|^2 + |V_\mu|^2 + |V_\tau|^2}}$$
- Sensitive variable: $L_T + E_T^{\text{miss}}$ ($L_T$ is scalar lepton pT sum)
  - maintains efficiency for signal topology like: $\Sigma^+ \rightarrow Z\ell^+$ (LT is high) and $\Sigma^0 \rightarrow H\nu \rightarrow WW\nu$ (high $E_T^{\text{miss}}$) at the same time
Search strategy and backgrounds

Event classification:

- based on maximum number of Opposite Sign Same Flavour (OSSF) leptons (4 categories)
  - further categorized in bins of $L_T + E_T^{\text{miss}}$ variable (5 bins)
  - in all 20 signal bins (4x5)

Backgrounds:

- $WZ$: 51%. Estimated using MC
- $tt\bar{t}$: 21%. Kinematics from MC and rate using data-driven
- $Z+\text{jets}$: 17%. Data-driven
- $ZZ$: 3%. Estimated using MC
- remaining: $tt\bar{t} W$, $tt\bar{t} Z$, $H\rightarrow 2l$: MC

Final selection:

$L_T + E_T^{\text{miss}} > 350 \text{ GeV}$
Results

- No significant excess
- Put limits assuming flavour-democratic scenario and \(M_{\Sigma^-} = M_{\Sigma^+} = M_{\Sigma^0}\)
- \(M_{\Sigma} < 440\) GeV excluded (expected 430 GeV)
- In Run I \(M_{\Sigma} < 278\) GeV (expected 250 GeV) was excluded
Summary

- Many new searches for BSM physics have been performed in leptonic final state
  - Most recent have been presented today
  - More can be found here:
- Improved limits on the dilepton, multilepton and lepton+MET final states compared to Run I
  - $Z'_{SSM} > 3.15$ TeV and $Z'_{\psi} > 2.6$ TeV
  - $W'$ mass $> 4.4$ TeV
  - RPV SUSY: $s\tau$ neutrino mass $> 3.3$ TeV; QBH: $M_{th} > 4.5$ GeV
  - $M_{\Sigma} > 440$ GeV
- Exciting times ahead for the search of new physics with the new energy frontier at the LHC
We continue to dig further LHC data in 2016 ... we may be just a few fb$^{-1}$ away from new physics. So stay tuned!
Backup
$Z'$
Categories in Type III see-saw

- 3 leptons without OSSF pair
- 3 leptons with one OSSF pair on-Z
- 3 leptons with one OSSF pair above-Z
- 4 leptons with at least one OSSF pair
- Distribution starts from 350 GeV and goes beyond 1150 in bins of 200 GeV
High mass $X \rightarrow \ell\ell\gamma$

- Model: scalar resonance ($X$) decaying to $Z(\rightarrow\ell\ell)\gamma$
- Experimental signature: 2 leptons ($e, \mu$) and a high $p_T\gamma$
- Selection:
  - $p_T$ of leptons > 25 (20 GeV)
  - $p_T\gamma$ > 40 GeV
  - $M_{\ell\ell}$ > 50 GeV
  - $p_T\gamma/M_{\ell\ell}\gamma$ > 40./150.
- Background estimation: Fit function to data
Results: High mass X → ℓℓγ

- Local significance around 370 GeV is 2.6σ and global is < 1σ
Search for long-lived charged particles

- Signature: Large energy deposition in silicon tracker and long-time-of-flight to muon detectors
- Exclude masses < 1590 GeV
Comparison with ATLAS

- **Z’**:  
  - SSM: $M > 3.4$ TeV excluded  
  - $Z'$ psi > 2.79 TeV  

- **W’**: $M > 4.04$ TeV

- **e-μ**:  
  - QBH > 4.54 TeV for ADD model (n=6)  
  - QBH > 2.54 TeV for RS (n=1)  

- no RPV