Recent exotic results from CMS

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on behalf of the CMS collaboration

Implications of LHC results for TeV-scale physics
Introduction

• Very exciting news on new boson with ~125 GeV mass!
  • Whether it is the Higgs boson or a Higgs boson, or something entirely different – we cannot say yet…

• Even if it is SM Higgs, there must be New Physics beyond the SM
  • Mass of a Higgs candidate is a bit too low from comfortable 130-170 GeV range of the stability chimney.
  • Other puzzles: no dark matter candidate, neutrino masses, matter-antimatter asymmetry, number of generations, etc.

• Keep digging: study new boson + search for new physics!

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Strategy for BSM searches

• Unlike Higgs/SUSY searches no well defined guide on the parameter space/signatures
  • Look for an interesting features in data
    • Resonant structure
    • Anomalous couplings
  • Look at all possible signatures for disagreement with expectations
    • Utilize the very efficient identification of physics objects
  • Probe interesting new BSM models
BSM searches at CMS

- New resonances
  - $Z'$, $W'$, dijet resonances

- Extra dimensions
  - Black holes, ADD/RS Gravitons

- New symmetries/interactions
  - Leptoquarks, heavy neutrinos

- Fourth generations
  - Heavy bottom/top – like quarks

- The latest public results from CMS can be found at https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Covering only new results after Moriond 2012
New heavy gauge bosons

• The SM gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$ can be extended to solve some of the puzzles not explained by the SM
  • Additional $U(1)$ group gives rise to new heavy neutral boson $Z'$
  • Additional $SU(2)$ group gives rise to new heavy charge boson $W'$

• Various models predicting such new resonances
  • Sequential standard model – couplings to $W$ and $Z$ similar as in the SM
  • Superstring-inspired $E_6$ model
  • Left-right symmetric model $SU(2)_L \times SU(2)_R$
  • More complicated models, such as technicolor or ED, predict a chain of new bosons
**Z'→ee/μμ**

- **Signature with two energetic, isolated leptons**
  - Electrons and muons
- **Backgrounds**
  - Drell-Yan, top, diboson, multijets
  - Estimated from data

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**EXO-12-015**

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Z' → ee/μμ

- Limits from combined 2011-2012 data

\[ M(Z'_{\text{ssm}}) > 2590 \text{ GeV} \]
\[ M(Z'_{\psi}) > 2260 \text{ GeV} \]

8 TeV: ee (3.6 fb\(^{-1}\)) + μ⁺μ⁻ (4.1 fb\(^{-1}\))
7 TeV: ee (5.0 fb\(^{-1}\)) + μ⁺μ⁻ (5.3 fb\(^{-1}\))

\[ R_\sigma = \frac{\sigma(pp \rightarrow Z' + X \rightarrow \ell\ell + X)}{\sigma(pp \rightarrow Z + X \rightarrow \ell\ell + X)} \]

Reduces dependence on uncertainty in luminosity, acceptance and efficiency
• There are models in which $Z'$ preferentially couple to the 3$^{\text{rd}}$ generation fermions
  • Signature with $e\mu$, $e\tau$, $\mu\tau$, $\tau\tau$
  • Backgrounds from Drell-Yan $Z\rightarrow\tau\tau$, W+jets, Diboson, mujltijet -- estimated from data when possible

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

- New physics at high $M_{tt}$ scale would explain the observed FB asymmetry in ttbar events – focusing on $M_{tt} > 1$ TeV
- Z’ with 1% and 10% widths and RS KK gluon wide resonance
- Signature with fully hadronic decays of ttbar events – two or three jets

Using jet substructure to identify boosted tops

Limits are set on any generic process that would interfere SM tt production

EXO-11-006
W’ → lν

- New gauge boson decaying to a lepton and a neutrino
  - Signature of isolated, energetic lepton and large missing $E_T$
  - Backgrounds from W+jets, top, diboson, Drell-Yan
  - Data are found in agreement with the SM background prediction

$$M_T = \sqrt{2p_T^l E_T^{miss} (1 - \cos \Delta \varphi_{l,\nu})}$$
$W' \rightarrow l \nu$

- Combined limits

$$M(W'_{SSM}) > 2.85 \text{ TeV}$$

Electron and muon channel

7 TeV and 8 TeV data
W’→td

- Light W’ production with an additional top – ttbar + jet
  - signature with lepton, jets, and missing transverse energy
- At least 5 jets and at least 1 b-tagged jet

M(W’) > 840 GeV

EXO-11-056
Hadronic resonances

- Many extensions of the SM predict new massive objects that couple to quarks and gluons
  - String resonances which decay to \( qg \)
  - Excited quarks decaying to \( qg, qW, qZ \)
  - Diquarks predicted by GUT decaying to quark-anti-quark
  - New gauge bosons predicted by new symmetries decaying to quark-anti-quark
  - Randall-Sundrum Graviton decaying to quark-anti-quark or \( gg \)
  - Color octet scalar decaying to \( gg \) or \( bb \)
  - Axigluon or coloron decaying to \( qq \)
Dijet resonances

- Search for resonance in smoothly falling mass spectrum
- Background is estimated by fitting data

EXO-12-016
Dijet low mass

- Novel techniques for trigger, DAQ, analysis to search for dijet resonance with mass < 1 TeV
- Store reduced data format → bandwidth under control

EXO-11-094

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Dijet resonances with btag

- Search for resonance in b-enriched sample
  - Signature with 0, 1, 2-tag
  - Multijet background is reduced by factor 50
  - Set model-independent limit as a function of the signal branching ratio fraction

\[
f_{bb} = \frac{BR(X \rightarrow b \bar{b})}{BR(X \rightarrow jj)}
\]

\[
\frac{BR(X \rightarrow bb)}{BR(X \rightarrow jj)} = \frac{BR(X \rightarrow b \bar{b})}{BR(X \rightarrow jj)}
\]

EXO-11-008

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Extra dimension

- Attractive extension of the SM
  - Explains hierarchy and several other problems
- Can be searched in both resonant and non-resonant states
Graviton

- Search for $G \rightarrow ZZ \rightarrow 2\ell 2j$
  - High branching fraction and high purity
  - Likelihood discriminant built from 5 helicity angles
  - Backgrounds estimated from sidebands in $M_{ZZ}$
• Limit on RS1 and ADPS models

RS1:
M > 945 GeV for k= 0.05
720 < M < 760 GeV, M > 850 GeV for k=0.10

ADPS
M > 720 GeV for k= 0.05
M > 610 GeV for k=0.10
G→ZV

- V is highly boosted for heavy G resulting in signature with 2l+1 jet
  - V is identified from highest pT jet 60<M_J<100 GeV
  - M_J efficiency is determined in ttbar control sample
  - Limits set on RS1 G and W’

M(G) > 933 GeV for k/M_{pl} = 0.05

EXO-12-014
Black holes

- Signature of high multiplicity of high pT objects
- Background from multijet process is estimated from the fit
  - For each multiplicity bin separately at ST = 1.8-2.2 TeV

EXO-12-009
Black holes

- Model independent limit vs ST and multiplicity
- Setting limit on specific BH models

\[ n=2, \ M_{BH} > \sim 4.8 \ -- \ 5.8 \ TeV \]
\[ n=6, \ M_{BH} > \sim 5.2 \ -- \ 6.1 \ TeV \]
Heavy neutrino & $W_R$

- Predicted from left-right symmetric model
  - Signature of $\mu\mu jj$ and $ee jj$, with high $p_T$ isolated leptons
  - Backgrounds from Drell-Yan, top, multijet estimated from data
Heavy neutrino & $W_R$

- Combining 2011-2012 data for dimuon channel
  - Assuming small $W_R$-$W_L$ and $N_1$-$N_1'$ mixing

$M(W_R) > 2800 \text{ GeV}$ for $M(N_\mu) = 1/2M(W_R)$
Leptoquarks

- Predicted by composite models, GUT, Technicolor
  - Two energetic leptons and two jets
  - Lepton, missing transverse energy and two jets
  - Backgrounds from DY+jets, ttbar, W+jets
  - Using M(lj), MET, ST to reject
  - Remaining background estimated from data

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EXO-11-028
1st/2nd generation scalar LQ

- Limits on LQ mass and decay branching fraction
  - $\beta = \text{BR}(\text{LQ} \rightarrow \text{lq})$

- $M_{\text{LQ1}} > 830 (640) \text{ GeV}$ for $\beta=1 (0.5)$
- $M_{\text{LQ2}} > 840 (650) \text{ GeV}$ for $\beta=1 (0.5)$
3rd generation LQ

- LQ decaying to tau and b quark
  - Signature with $e\tau bb$ and $\mu\tau bb$
  - Major backgrounds from ttbar and V+jets
  - Rejected by $M(\tau,b)$
  - Using ST distribution to extract limits

EXO-12-002

CMS Preliminary | $\sqrt{s} = 7$ TeV, 4.8 fb$^{-1}$

- Data
- ttbar
- W/Z + jets
- Other
- Signal $M_{LQ} = 450$ GeV

Events vs $M_{\tau,b}$ (GeV)

Events vs $S_T$ (GeV)
3rd generation LQ

- Limits set on both scalar and vector LQ
  - The difference in kinematics of vector and scalar LQ decay products have effect of a few percents on the selection efficiency

\[ M_{SLQ3} > 525 \text{ GeV for } \beta=1 \]
\[ M_{VLQ3} > 763 \text{ GeV for } \beta=1 \]

Limits are also interpreted for RPV stop
4th generation

- Inclusive t' and b' search, assume $V_{tb}^2 = V_{tb'}^2 = A$
  - Final topology with 1-4 W and 2 bjets
  - Signature with single, same-sign double, or triple leptons, jets, missing ET
  - Discriminator against backgrounds ST

Assuming $m_{t'} = m_{b'}$, $m_q > 685$ GeV
Assuming $A=1$, $\Delta m = 25$ GeV
mass of up-type 4th gen quarks $> 640$ GeV
B’ → Zb

- Signature with dileptons and b jet
- Search for resonant peak in Zb mass spectrum
  - B candidate is reconstructed using leading Z and b jet

EXO-11-066

M(B’) > 550 GeV assuming 100% Br.
Summary of CMS searches

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A lot of results made public since Moriond 2012
- Unfortunately no BSM discoveries (yet)
- Note that a lot of updates with full statistics will follow shortly
Where we go from here

• These first results from CMS (LHC) is an “ouverture”
  • Excellent performance of detector, trigger, computing, object identification

• Is new physics too rare and too heavy for 7/8 TeV?
  • Higher statistics and higher center of mass energy is the way to go

• We should also think outside the box
  • Adequate coverage of “unusual” topologies is crucial
  • Important to have close collaboration with phenomenologists and theorists to test new models/ideas

• My hope that the discovery of a new boson is the first drop in the end of a long dry season!
BACKUP