Search for high-mass resonances @ CMS

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Motivation

• The Standard Model (SM) is a successful theory supported by many experimental evidences
• Recent discovery of the SM Higgs boson by ATLAS and CMS experiment is one of them

• **SM omissions:** hierarchy problem, absence of gravity, lack of dark matter...

• Many theories beyond the SM address these omissions:
  • Models with extended Higgs sectors
    • e.g. Two-Higgs-Doublet model (2HDM) predicts heavy spin-0 resonance
  • Extra dimensional models
    • e.g. Arkani-Hamed, Dimopoulos and Dvali (ADD) and Randall-Sundrum (RS) models predict heavy spin-2 resonance
  • **Superstring-inspired** models and Sequential Standard Model (SSM) predict heavy spin-1 gauge bosons, $Z'$
  • 100s of phenomenological papers in arXiv 😊
Outline

• Diphoton search:
  • 13 TeV: 2.7 /fb (B = 3.8 T) + 0.6 /fb (B = 0 T)
  • 8 TeV: 19.7 /fb

• Dijet search:
  • 13 TeV: 2.4 /fb

• Dijet search @ low mass:
  • 8 TeV: 18.8 /fb

• Dilepton search:
  • 13 TeV: 2.8(2.6) /fb for muons(electrons)
Diphoton search

- **Signal:** two well isolated high-\(p_T\) photons reconstructed as high energy deposits in EM calorimeter
- **Backgrounds:** irreducible \(\gamma\gamma\) and reducible \(\gamma\) +jets and dijet

- **Strategy:** search for localised excess of events in the \(m_{\gamma\gamma}\) spectrum in data, from 500 GeV to 4.5 TeV
- **Four categories:** barrel-barrel (EBEB) and barrel-endcap (EBEE) for \(B = 3.8\) and \(0\) T
- **Three width scenarios:**
  - \(\Gamma/m_{\gamma\gamma} = 1.4\times10^{-4}\) (narrow), \(1.4\times10^{-2}\) (wide) and \(5.6\times10^{-2}\) (wider)
Diphoton event

$m_{\gamma\gamma} = 745 \text{ GeV} @ 13 \text{ TeV} (3.8 \text{ T})$
$m_{\gamma\gamma}$ spectrum ($B = 3.8$ T)
$m_{\gamma\gamma}$ spectrum ($B = 0 \, T$)

![Graphs showing $m_{\gamma\gamma}$ spectrum](image-url)
Upper limits ($B = 3.8 \, T + 0 \, T$)
p-values

13 TeV:
- @ m_\chi = 760 GeV for wide width scenario
- Local significance: 2.9\sigma
- Global significance (LEE from 0.5 to 3.5 TeV) < 1\sigma

13 + 8 TeV:
- @ m_\chi = 750 GeV for wider width scenario
- Local significance: 3.4\sigma
- Global significance (LEE from 0.5 to 3.5 TeV) = 1.6\sigma
Dijet search

- Signature of two high-\(p_T\) (leading) jets with very low background at high-mass: \(\Sigma_{\text{jet}} p_T(\text{jet}) > 800\ \text{GeV}\) (or a jet with \(p_T > 500\ \text{GeV}\))
- Backgrounds: irreducible dijet, reducible lepton+jets
- Strategy: search for localised excess in \(m_{jj}\) spectrum, from 1.5 to 7 TeV
- Highest mass events: 6.14 TeV
Dijet event

highest $m_{jj} = 6.14$ TeV @ 13 TeV
Dijet search @ low mass

- **Data Scouting**: a dedicated algorithm with trigger which filters the events if $\Sigma_{\text{jet}} E_T(jet) > 250 \text{ GeV}$
  - Only kinematics of trigger level reco. jets are stored then
  - Fits to the CMS data storage capabilities: 1kHz
  - Allows to perform the dijet resonance search at low masses

- No evidence for signal has been found
- Search is being performed @ 13 TeV
Search for $Z' \rightarrow \mu^+\mu^-$ or $e^+e^-$

- Signal: clean signature of two same flavour high-$p_T$ leptons with very low background at high-mass
- Backgrounds: irreducible $Z/\gamma^*$ and reducible ttbar, tW and diboson
- Strategy: search for localised excess in $m_{ll}$ spectrum, up to 5 TeV
- Three width scenarios: 0%, 0.6% ($Z'_{\psi}$) and 3% ($Z'_{SSM}$)
- Highest mass events:
  - Muon - 2.4 TeV
  - Electron - 2.9 TeV
- Probability to observe at least one dielectron event with mass > 2.8 TeV is 3.6%
Dimuon event

highest $m_{\mu\mu} = 2.4\text{ TeV} @ 13\text{ TeV}$
Upper limits

- **13 TeV**: \( Z'_{\text{SSM}} < 3.15 \text{ TeV} \) and \( Z'_{\psi} < 2.6 \text{ TeV} \) are excluded
- **8 TeV**: \( Z'_{\text{SSM}} < 2.9 \text{ TeV} \) and \( Z'_{\psi} < 2.57 \text{ TeV} \) are surpassed
Summary

- Search for high-mass resonances have been performed by CMS using 13 and 8 TeV datasets, and results have been presented today.

- An excess of events has been observed in \( m_{\gamma\gamma} \) spectrum over the SM backgrounds continuum, around 750-760 GeV.
  - Local significance @ 13 TeV + 8 TeV: \( 3.4\sigma \)
  - Global significance @ 13 TeV + 8 TeV = \( 1.6\sigma \)

- Same excess has been investigated in dijet channel using the data collected @ 8 TeV by so-called “data-scouting” algorithm.
  - No any excess has been observed.

- No excess has been observed in dilepton resonance searches.
  - Exclusion @ 13 TeV: \( Z'_{\text{SSM}} \) of mass below 3.15 TeV and \( Z'_{\psi} \) of mass below 2.6 TeV are excluded.
Summary

- Search for high-mass resonances in the dijet channel performed by CMS using 13 and 8 TeV datasets, and results have been presented today.

- An excess of events has been observed in the $m_{\gamma\gamma}$ spectrum over the SM backgrounds continuum, around 750-760 GeV.
  - Local significance @ 13 TeV: 3.4 $\sigma$
  - Global significance @ 13 TeV + 8 TeV: 1.6 $\sigma$

- Same excess has been investigated in the dijet channel using the data collected @ 8 TeV by so-called “data-scouting” algorithm.
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- No excess has been observed in dilepton resonance searches.
  - Exclusion @ 13 TeV: $Z'$ SSM of mass below 3.15 TeV and $Z'$ of mass below 2.6 TeV are excluded.
Bibliography

- **CMS PAS EXO-16-018**: “Search for new physics in high mass diphoton events in 3.3 /fb of proton-proton collisions at \( \sqrt{s} = 13 \) TeV and combined interpretation of searches at 8 TeV and 13 TeV”

- **CMS PAS EXO-15-001**: “Search for narrow resonances decaying to dijets in proton-proton collisions at \( \sqrt{s} = 13 \) TeV”

- **CMS PAS EXO-14-005**: “Search for resonance decaying to dijet final states at \( \sqrt{s} = 8 \) TeV with scouting data”

- **CMS PAS EXO-15-005**: “Search for a narrow resonance produced in 13 TeV pp collisions decaying to electron pair or muon pair final states”

- [https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO)
Particles’ signature in CMS
Increased reach @ 13 TeV
Energy scale and resolution calibration

- Obtained by using $Z \rightarrow ee$ events: adjusting simultaneously the energy and resolution as a function of pseudo-rapidity and shape of the energy cluster in EM calorimeter
  - Energy scale corrections: 0.5(1.5)% for $B = 3.8(0)$ T
  - Gaussian smearing for energy resolution: 0.8-1.5% and 2-2.5% for barrel and endcaps respectively, for both $B = 3.8$ and 0 T
Vertex and photon identification

- **Vertex identification:**
  - For $B = 3.8$ T: based on BDT (using recoil and track $p_T$) trained for $H\rightarrow\gamma\gamma$
  - For $B = 0$ T: based on track-counting
  - 90(60)% correct assignment for $B = 3.8(0)$ T

- **Photon identification:**
  - Obtained by using $Z\rightarrow ee$ events
  - Efficiency: $\sim 90\%$ per photon in both barrel and endcaps
Upper limits for diphoton search @ 8TeV

spin-2

spin-2
Diphoton upper limits for different widths ($B = 3.8T + 0T$)
Diphoton upper limits ($B = 3.8T$)

- RS graviton of mass below 1.3, 3.1 and 3.8 TeV are excluded for $\Gamma/m_{\gamma\gamma} = 1.4\times10^{-4}$, $1.4\times10^{-2}$ and $5.6\times10^{-2}$ respectively
Zγ invariant mass spectrum
Upper limits for $Z\gamma$

CMS Preliminary

2.7 fb$^{-1}$ (13 TeV)

$W = 0.014\%$

- Observed
- Expected ± 1σ
- Expected ± 2σ

95% CL UL on $\sigma \times$ BR($A \rightarrow Z\gamma \rightarrow e^+e^\gamma$) [fb]

Resonance Mass [GeV]

CMS Preliminary

2.7 fb$^{-1}$ (13 TeV)

$W = 0.014\%$

- Observed
- Expected ± 1σ
- Expected ± 2σ

95% CL UL on $\sigma \times$ BR($A \rightarrow Z\gamma \rightarrow \mu^+\mu^\gamma$) [fb]

Resonance Mass [GeV]
Statistical analysis

Upper limits

\[ q_\mu = -2 \ln \frac{\mathcal{L}(\text{obs} \mid \mu \cdot s + b, \hat{\theta}_\mu)}{\mathcal{L}(\text{obs} \mid \hat{\mu} \cdot s + b, \hat{\theta})} \]

\[ \text{CL}_s = \frac{\mathbb{P}(q_\mu \geq q^{\text{obs}}_\mu \mid \mu \cdot s + b)}{\mathbb{P}(q_\mu \geq q^{\text{obs}}_\mu \mid b)} \leq \alpha \]

p-value

\[ q_0 = -2 \ln \frac{\mathcal{L}(\text{data} \mid b, \hat{\theta}_0)}{\mathcal{L}(\text{data} \mid \hat{\mu} \cdot s + b, \hat{\theta})}, \text{ with } \hat{\mu} > 0 \]

\[ p_0 = \mathbb{P}(q_0 \geq q^{\text{obs}}_0 \mid b) \]

signal parameters

\[ q(a) = -2 \Delta \ln \mathcal{L} = -2 \ln \frac{\mathcal{L}(\text{data} \mid s(a) + b, \hat{\theta}_a)}{\mathcal{L}(\text{data} \mid s(\hat{a}) + b, \hat{\theta})} \]