Exotica at CMS

Anastasia Karavdina on behalf of CMS collaboration

6th International Conference on New Frontiers in Physics

August 23, 2017
Compact Muon Solenoid (CMS)

CMS DETECTOR
- Total weight: 14,000 tonnes
- Overall diameter: 15.0 m
- Overall length: 28.7 m
- Magnetic field: 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
- Pixel (100x150 μm) ~16m² ~66M channels
- Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
- Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
- Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
- Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
- Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
- ~76,000 scintillating PbWO₄ crystals

HADRON CALORIMETER (HCAL)
- Brass + Plastic scintillator ~7,000 channels
LHC Run2 @ 13 TeV

- RunII dataset: ~3 fb\(^{-1}\) (2015), ~38 fb\(^{-1}\) (2016)
- Excellent detector performance
- High data-taking efficiency
- High Energy → many searches with boosted topologies
  ⇒ dedicated algorithms, e.g. jet sub-structure

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Exotica at CMS, ICNFP 2017
Beyond the Standart Model searches community at CMS

Exotica group

Generic searches for physics beyond the Standard Model

- Resonances
- Randall–Sundrum Gravitons
- Heavy Gauge Bosons
- Leptoquarks
- Excited Fermions
- Colorons, Axigluons, Diquarks
- ... 

Final states:
- Non-hadronic, Jet+X, MET+X, Long-Lived Particles

Beyond-Two-Generations group

New physics featuring the decay to heavy SM objects such as top, W, Z, or Higgs

- Exotic diboson resonances
- Partners of the top quark with vector-like properties (VLQ)
- Heavy resonances, e.g. $W'$ and $Z'$, decaying to final states with top quarks

Typical final states signatures involve
- top quarks, Higgs bosons, vector bosons and/or $b$ quarks
Low mass Di-Jet resonances search

- Search for leptophobic vector resonances, the mass region 50-300 GeV
- ISR jet with high $p_T$ required to trigger the event
- Resonance reconstructed within single jet:
  - 2-prong substructure ($N_2$)
  - Groomed (soft drop) mass → discriminating variable
  - Transformation employed to decorrelate the soft drop mass from $N_2$
- Multijet QCD background estimated from data

Maximum local p-value (2.9 $\sigma$) corresponds to $M_{Z'} = 115$ GeV, global p-value 2.2 $\sigma$
High-mass resonances in the \(Z^+\gamma\) final state

- Search for spin-0 \(Z^+\gamma\) in the leptonic and hadronic decay channels of Z boson
- \(Z\rightarrow ll^+\gamma\) sensitive for \(M<\sim 1\) TeV
- \(Z\rightarrow qq\) dominates the sensitivity for \(M>2\) TeV
  - Merged jet topology → cone size \(R=0.8\)
  - Pruned with Cambridge-Aachen algorithm jets, sub-jet CSV b-tagging
- Background from direct fit to data

Small (~2σ) deviation around 2 TeV in jet+\(\gamma\)
Excited states of light and heavy flavor quarks in the $\gamma$+jets final state

- Number of models predict existence of excited states of quarks
- Search for $qg \rightarrow q^* \rightarrow q\gamma$, $bg \rightarrow b^* \rightarrow b\gamma$ by looking for resonances in $\gamma$+jets
- High $p_T (>200 \text{ GeV})$ isolated photon, $\Delta R(\text{jet},\gamma)>0.5$, $\Delta \eta(\text{jet},\gamma)<1.5$
- Background:
  - QCD multijet
  - The quark-gluon Compton scattering ($qg \rightarrow q\gamma$)
  - The quark-antiquark annihilation ($qq \rightarrow q\gamma$)

Observed lower bounds for coupling=1
5.5 TeV ($q^*$), 1.8 TeV ($b^*$)

The first result on the search of $b^*$ @13 TeV
Excited top quarks in the lepton+jets final state

- Top quark = composite, spin-3/2 particle; dominant decay $t^* \rightarrow tg$
- Search for pair produced $t^*$:
  $t^*\bar{t}^* \rightarrow (tg)(\bar{tg}) \rightarrow (W^+bg)(W^-\bar{bg}) \rightarrow (q_1q_2bg)(l\bar{l}bg)$
- Final state: isolated lepton, $E_T^l$, at least six jets, two of which must be b-tagged
- Background (mainly SM $t\bar{t}$) estimated with data-driven approach
- Event by event $t^*$ reconstruction:
  $S = \left( \frac{m_{qq} - M_W}{\sigma_W} \right)^2 + \left( \frac{m_{qqb} - M_t}{\sigma_{t,\text{had}}} \right)^2 + \left( \frac{m_{l\nu b} - M_t}{\sigma_{t,\text{lep}}} \right)^2 + \left( \frac{m_{l\nu bg} - m_{qqbg}}{\sigma_{t^*}} \right)^2$
Heavy resonances in the $\nu\nu q\bar{q}$ final state

- Search for heavy resonances decaying into a pair of vector bosons: $ZZ$ or $ZW \rightarrow (\nu\nu)(qq)$
- The vector bosons produced back-to-back with large Lorentz boost
- Selection: $E_T > 200$ GeV + AK8 jet ($p_T > 200$ GeV, $|\eta| < 2.4$)
- Jet mass expected to lie within a window around $W$ and $Z$ mass
- $\tau_{21}$ n-subjettiness ratio to distinguish jets with two substructure components
- AK4 jets outside the cone of AK8 jets used for background rejection
  - Top jets with b-tagging
  - Multijet QCD with $\Delta \phi$(AK4 jet,$E_T$) $> 0.5$ rad
- Data-driven background estimate with $\alpha$-method
Heavy resonances in the $\text{ZZ} \rightarrow (\nu\nu)(ll)$ final state

- Selection: $E_T$ and 2 opposite sign leptons with $70 \text{ GeV} < M_{ll} < 110 \text{ GeV}$
- The ZZ produced back-to-back $\rightarrow |\Delta \phi (Z, E_T)| > 0.5$
- Data-driven background estimate
  - $\gamma + \text{jets}$ to estimate Drell-Yan $Z + \text{jets}$ with instrumental $E_T$
  - Dilepton $e\mu$ to describe non-resonant background

Higher sensitivity in the low mass region ($<1.5 \text{ TeV}$) compare to all hadronic channel.
Conclusion

- CMS keep exploring the new energy scale (13 TeV) using $\sim 40 \text{ fb}^{-1}$ dataset
- Large number of physics analyses with multiple number of final states
- Data-driven background is useful tool complementary to MC simulation
- No evidence for new physics so far
- LHC continues data taking until the end of 2018
- Expecting $\sim 3$ times more data than used in the presented analyses

Stay Tuned!
Back up
Heavy resonances in the $ZZ \rightarrow (\nu\nu)(ll)$ final state. Systematic uncertainties:

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