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Search for excited leptons in *pp* collisions at $\sqrt{s} = 7$ TeV

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Abstract. A search for excited leptons, carried out with the CMS detector in *pp* collision at the LHC with $\sqrt{s} = 7$ TeV, is presented. The search has been performed for an associated production of a lepton and an oppositely charged excited lepton $pp \rightarrow ll^*$, followed by the decay $l^* \rightarrow l\gamma$, resulting in $ll\gamma$ final state, where $l = e, \mu$. No excess above the Standard Model expectation is observed in the data. Interpreting the findings in the context of l^* production through four-fermion contact interactions and l^* decay via electroweak processes, upper limits are reported for l^* production at this collision energy and the exclusion region in the $\Lambda - M(l^*)$ parameter space is extended beyond the previously established limits.

Keywords. Large Hadron Collider; compact muon solenoid; compositeness; excited leptons; contact interaction.

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1. Introduction

One of the unanswered questions in the Standard Model (SM) of particle physics is the mass hierarchy of the quarks and leptons. A commonly proposed explanation for the three generations is a compositeness model in which the known leptons and quarks are bound states of either three fermions, or a fermion–boson pair [1]. The underlying substructure of these new bound states implies a large spectrum of excited states. The contact interactions (CI) can be described using the effective Lagrangian [2]:

$$\mathcal{L}_{\rm CI} = \frac{g^2}{2\Lambda^2}\, j^\mu\, j_\mu,$$

where Λ is the compositeness scale, g^2 is chosen to be 4π and j_μ is the fermion current where

$$j_\mu = \eta_{\rm L}\bar{\ell}_{\rm L}\gamma_\mu\ell_{\rm L} + \eta'_{\rm L}\,\bar{\ell}^*_{\rm L}\gamma_\mu\ell^*_{\rm L} + \eta''_{\rm L}\,\bar{\ell}^*_{\rm L}\gamma_\mu\ell_{\rm L} + \text{h.c.} + (L \rightarrow R).$$

The SM and excited fermions are denoted by ℓ and ℓ^*, respectively. The η factors for left-handed currents are conventionally set to one, and right-handed currents are set to zero.

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Gauge-mediated transitions between ordinary and excited fermions are described by the effective Lagrangian [2]

$$\mathcal{L} = \frac{1}{2\Lambda}\bar{\ell}^{*}_{\mathrm{R}}\,\sigma^{\mu\nu}\left[g_{\mathrm{s}} f_{\mathrm{s}}\frac{\lambda^{a}}{2}G^{a}_{\mu\nu} + g f\frac{\tau}{2}W_{\mu\nu} + g' f'\frac{Y}{2}B_{\mu\nu}\right]\ell_{\mathrm{L}} + \mathrm{h.c.},$$

where $G^{a}_{\mu\nu}$, $W_{\mu\nu}$ and $B_{\mu\nu}$ are the field strength tensors of the gluon, the $SU(2)$ and $U(1)$ gauge fields, respectively.

The scaling parameters, f_{s}, f and f', are assumed to be equal to 1. This paper considers the production of an excited lepton (μ^* or e^*) in association with an opposite charge lepton via four-fermion contact interactions, followed by the decay $\ell^* \to \ell\gamma$. The resulting final state, $\ell^+\ell^-\gamma$, is fully reconstructed. The dominant SM background for our search is the Drell–Yan production of $\ell^+\ell^-\gamma$. Other potential contributions are from *WW*, *WZ*, *ZZ*, $t\bar{t}$, and, for the electron channel, $\gamma\gamma$ production.

2. Experimental set-up

Compact muon solenoid (CMS) [3] consists of the silicon pixel and strip trackers, the crystal electromagnetic calorimeter (ECAL) and the brass/scintillator hadron calorimeter (HCAL). All the subdetector components are within a magnetic field of 3.8 T provided by the superconducting solenoid.

It provides an impact parameter resolution of approximately 15 μm and a transverse momentum (p_{T}) resolution of 4% for 500 GeV/c charged particles. The ECAL has an energy resolution of better than 0.5% above 100 GeV.

Muons are measured in gas-ionization detectors embedded in the steel return yoke. These subdetectors are of three types: drift tubes in the barrel region, cathode strip chambers in the end-caps and resistive plate chambers in the barrel and end-caps. Matching the muons to the tracks measured in the silicon tracker results in a transverse momentum resolution between 1 and 5% for p_{T} values up to 1 TeV/c.

3. Event selection

In this analysis, all the events are collected with single-muon and double-photon triggers. The trigger efficiency is close to 100% for $\ell^+\ell^-\gamma$ events passing our final selection criteria. Our analysis accepts events with one isolated photon, two isolated leptons of high p_{T} and at least one reconstructed primary vertex.

For the muon analysis, two high-quality muons with $p_{\mathrm{T}} > 20$ GeV/c and $|\eta| < 2.4$ are required [4]. The muons are further required to be isolated within a cone (ΔR) of 0.3.

For the electron analysis, two high-quality electrons with with $p_{\mathrm{T}} > 25$ GeV/c and $|\eta| < 2.5$ are required. Electrons lying within $1.4442 < |\eta| < 1.56$ are not selected. Photon is required to be in the central region of the ECAL (barrel), with $|\eta| < 1.4442$ and $p_{\mathrm{T}} >$ 20 GeV/c [5,6].

The angular separation of the photon and the selected leptons in the η–ϕ plane must be greater than 0.5.

Table 1. Predicted and observed event counts passing all selection criteria.

Final State	$\ell^+\ell^-\gamma$	$\ell^+\ell^- +$jet(s)	$\ell\gamma +$jet(s)	Total	Observed
$\mu^+\mu^-\gamma$	16.3 ± 1.3	5.5 ± 2.1	0.7 ± 0.9	22.6 ± 2.6	25
$e^+e^-\gamma$	8.3 ± 0.9	1.4 ± 0.8	1.0 ± 0.4	10.7 ± 1.3	7

4. Background estimation

The contamination from SM processes with real leptons and photons final state is estimated using Monte Carlo simulation. Backgrounds from processes in which jets are mis-reconstructed as leptons or photons is measured in data samples containing jets [6].

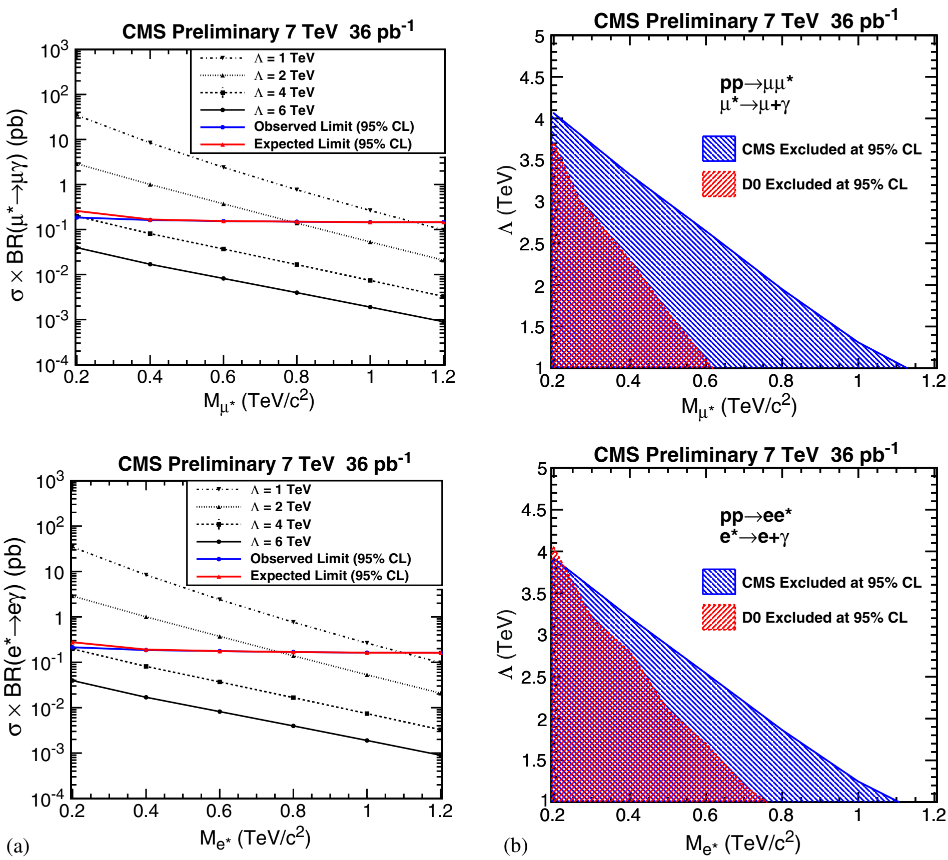

Figure 1. (**a**) Observed (blue) and predicted (red) limits on the excited muon (top) and electron (bottom) production cross-section times branching ratio at 95% CL, as functions of the excited lepton mass. (**b**) The region in the (Λ, M_{ℓ^*}) plane excluded at the 95% CL by the present search, both for muons (top) and electrons (bottom).

We define the 'fake rate' as the ratio of the number of objects passing all selection cuts (numerator) to the number of potential-fake objects (denominator) which fail some of the selection criteria. Numerator and denominator samples are defined so as to be orthogonal to each other. Table 1 compares the predicted and observed number of events passing all selection requirements.

5. Results and discussion

In order to enhance the sensitivity of the analysis, the search is restricted to the high invariant mass region by applying a cut on the maximum invariant mass of $\ell\gamma$ ($M_{\ell\gamma}^{\max}$) that depends on the excited lepton mass hypothesis. No excited lepton candidate is found in the search region, and the data are in agreement with the SM expectation.

Considering the production of excited leptons via four-fermion contact interaction as our alternative hypothesis to the SM, upper limits on the ℓ^* production cross-section times branching fraction for the $\ell^* \to \ell\gamma$ decay are set using Poisson distributed datasets and a Bayesian method with a flat prior [7]. A log-normal prior is used for the integration of the nuisance parameters. Cross-sections higher than 0.14–0.19 pb for μ^* production, and higher than 0.16–0.21 pb for e^* production, are excluded at the 95% confidence level for excited lepton masses ranging from 200 to 1500 GeV/c^2. At contact interaction scale of $\Lambda = M_{\ell^*}$, excited lepton masses are excluded below 1091 GeV/c^2 for muons and 1075 GeV/c^2 for electrons. Figure 1 displays the exclusion regions in the (Λ, M_{ℓ^*}) plane obtained from these limits.

References

[1] H Terazawa, M Yasue, K Akama and M Hayashi, *Phys. Lett.* **B112**, 387 (1982)
[2] U Baur, M Spira and P M Zerwas, *Phys. Rev.* **D42**, 815 (1990)
[3] The CMS Experiment at the CERN LHC, *J. Instr.* **3**, S08004 (2008)
[4] *Performance of CMS muon identification in pp collisions at* $\sqrt{s} = 7\ TeV$, MUO-10-002 (2010)
[5] *Photon reconstruction and identification at* $\sqrt{s} = 7\ TeV$, EGM-10-005 (2010)
[6] *Electron reconstruction and identification at* $\sqrt{s} = 7\ TeV$, EGM-10-004 (2010)
[7] J Heinrich *et al*, physics/0409129