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Search for heavy composite Majorana neutrinos at the CMS experiment at LHC

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Summary. — A search for physics beyond the standard model in the final state with two same-flavour leptons (electrons or muons) and two quarks produced in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$ is presented. The data were recorded by the CMS experiment at the CERN LHC and correspond to an integrated luminosity of $2.3\,\text{fb}^{-1}$. The observations are in good agreement with the standard model background prediction. The results of the measurement are interpreted in the framework of a recently proposed model in which a heavy Majorana neutrino, N_ℓ, stems from a composite-fermion scenario. Exclusion limits are set on the mass of the heavy composite Majorana neutrino, m_{N_ℓ}, and the compositness scale Λ. For the case $m_{N_\ell} = \Lambda$, the existence of N_e is excluded for masses up to 4.60 TeV and the existence of N_μ is excluded for masses up to 4.70 TeV at 95% confidence level.

1. – The heavy Majorana neutrino in composite models

Compositness of leptons and quarks can be one possible scenario beyond the standard model. In this approach quarks and leptons are assumed to have an internal substructure which should become manifest at some sufficiently high-energy scale, the compositness scale Λ. Two model-independent properties of this picture are experimentally relevant [1-5]: the existence of excited states of quarks and leptons with masses $m^* \le \Lambda$ and the contact interaction that is an effective approach to describe the effects of the unknown internal dinamics. The gauge interaction between excited and standard fermions is described by a magnetic-type coupling:

$$\mathcal{L} = \frac{1}{2\Lambda}\bar{L}^*_R \sigma^{\mu\nu}\left(gf\frac{\tau}{2}\mathbf{W}_{\mu\nu} + g'f'YB_{\mu\nu}\right)L_L + \text{h.c.} \quad (1)$$

The contact interaction is

$$\mathcal{L}_C = \frac{g_*^2}{\Lambda^2}\frac{1}{2}j^\mu j_\mu, \tag{2a}$$

$$j_\mu = \eta_L \bar{f}_L \gamma_\mu f_L + \eta'_L \bar{f}^*_L \gamma_\mu f^*_L + \eta''_L \bar{f}^*_L \gamma_\mu f_L + \text{h.c.} + (L \leftrightarrow R). \tag{2b}$$

The heavy composite Majorana neutrino can be produced in association with a lepton in pp collisions, via both gauge and contact interactions. The contact interaction dominates the production. The heavy composite Majorana neutrino can also decay via both gauge and contact interactions, the possible decays are

$$N_\ell \to \ell q \bar{q}', \qquad N_\ell \to \ell^+\ell^-\nu(\bar{\nu}), \qquad N_\ell \to \nu(\bar{\nu}) q \bar{q}'. \tag{3}$$

We implemented this model, described in detail in ref. [6], in the events generator CalcHEP [7], to produce the events to be used for the CMS simulations, needed for the analysis.

2. – The analysis

Our analysis takes into consideration the decay $N_\ell \to \ell q \bar{q}'$, producing the final states $eeq\bar{q}'$ and $\mu\mu q\bar{q}'$. When the decay happens via gauge interaction, the two quarks tend to overlap each other and they are reconstructed as an only large-radius jet. When the decay happens via contact interaction, the two quarks are not spatially constrained and they are reconstructed as two separated jets, for which the requirement of a large-radius jet guarantees again high signal efficiency, because of the overlapping with the final-state radiation of the quarks. Therefore, we require two same-flavour leptons and at least one large-radius jet.

The signal regions in the electron channel and in the muon channel are defined as

electron channel

– Single electron trigger requiring $p_T > 105\,\text{GeV}$ and $|\eta| < 2.4$;

– 2 electrons $pT(e1) > 110$, $pT(e2) > 35\,\text{GeV}$, $|\eta(e)| < 2.4$;

– $M(e,e) > 300\,\text{GeV}$;

– ≥ 1 large-radius Jet (J)

$pT > 190\,\text{GeV}$, $|\eta| < 2.4$, $DR(\ell, J) > 0.8$;

muon channel

– Single muon trigger requiring $p_T > 50\,\text{GeV}$ and $|\eta| < 2.4$;

– 2 muons $pT(\mu1) > 53$, $pT(\mu2) > 30\,\text{GeV}$, $|\eta(\mu)| < 2.4$;

– $M(\mu,\mu) > 300\,\text{GeV}$;

–≥ 1 large-radius Jet (J)

$pT > 190\,\text{GeV}$, $|\eta| < 2.4$, $DR(\ell, J) > 0.8$.

A shape-based analysis is performed, by considering the distribution of the mass of the two leptons and the leading large-radius jet, $m_{\ell\ell J}$. This variable provides good discrimination between the signal and the standard model background contributions.

The DY contribution is estimated from the Monte Carlo simulation normalised to data in the signal-free region around the Z boson mass peak, given by $80 < m_{\ell\ell} < 100\,\text{GeV}$. The multijet contamination is estimated from a control region defined like the signal

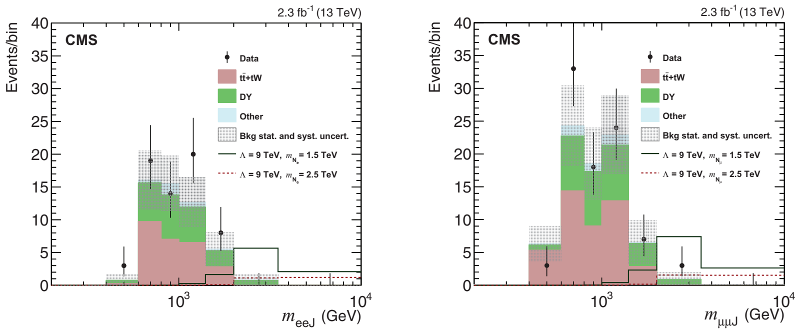

Fig. 1. – Distribution of the variable $m_{\ell\ell J}$ for the data (black points), the estimated standard model backgrounds (stacked filled histograms), and the signal (lines) with $\Lambda = 9$ TeV and masses of N_ℓ equal to 1.5 and 2.5 TeV, for the electron (left) and muon (right) channels.

region, but with nonisolated and poorly identified lepton candidates and normalizing it to the signal region by a factor related to the probability of misidentifing a jet as a lepton. This contribution is found to be negligible. The $t\bar{t} + tW$ background is estimated from a control region defined like the control region, but with two leptons of different flavours and normalizing it to the signal region by a factor evaluated from the Monte Carlo. The $W +$ jets, WW, WZ and ZZ backgorunds are very small and they are taken directly from the Monte Carlo.

Comparison between data and expectations is shown in fig. 1. The observation are in agreement with the background expectations from the standard model. We set exclusion curves in the parameter space (m^*, Λ) at 95% confidence level (see fig. 2). For the representative case $\Lambda = m^*$, N_e masses up to 4.60 TeV and N_μ masses up to 4.70 TeV are excluded. This measurement is the first that uses the model described in ref. [6] as benchmark.

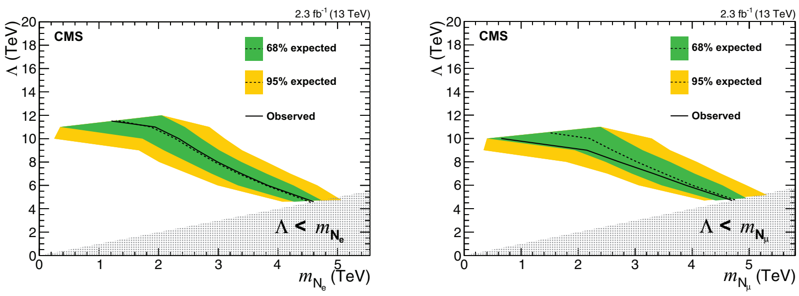

Fig. 2. – The observed 95% confidence level limits (solid black lines) on the compositness scale Λ, obtained in the analysis of the electron (left) and muon (right) channels, as a function of the heavy composite Majorana neutrino. The dotted lines represent the corresponding expected limits and the bands, the expected variation to one and two standard deviation(s). The grey zone represents the phase space $\Lambda < M_{N_\ell}$, which is not allowed by the model.

REFERENCES

[1] Terazawa H., Akama K. and Chikashige Y., *Phys. Rev. D*, **15** (1977) 480.
[2] Terazawa H., *Phys. Rev. D*, **22** (1980) 184.
[3] Eichten E., Lane K. D. and Peskin M. E., *Phys. Rev. Lett.*, **50** (1983) 811.
[4] Cabibbo N., Maiani L. and Srivastava Y., *Phys. Lett. B*, **139** (1984) 459.
[5] Baur U., Spira M. and Zerwas P., *Phys. Rev. D*, **42** (1990) 815.
[6] Leonardi R., Alunni A., Romeo F., Fanò L. and Panella O., *Eur. Phys. J. C*, **76** (2016) 593.
[7] Belyaev A., Christensen N. D. and Pukhov A., *Phys. Commun.*, **184** (2013) 1729.