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Searches for heavy neutrinos and high-mass ditau resonances with CMS

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On behalf of IHEP CMS group

Outline

- A new model with heavy composite Majorana neutrino and its search
- Search for heavy neutrinos, from the left-right model, with taus
- Search for high-mass ditau resonances

People involved in the measurements

Hunting for heavy composite Majorana neutrinos at the LHC

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Search for Heavy Composite Majorana Neutrinos produced in association with a lepton and decaying into a same-flavour lepton plus two quarks at $\sqrt{s} = 13$ TeV with the CMS detector

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Search for Heavy Neutrinos in Tau Final States at $\sqrt{s} = 13$ TeV

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Search for High Mass Resonances and New Physics with a DiTau Pair at $\sqrt{s} = 13$ TeV

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Introduction

Standard model (SM) of elementary particle physics

Theory that can explain many experimental observations, but with un-resolved issues:

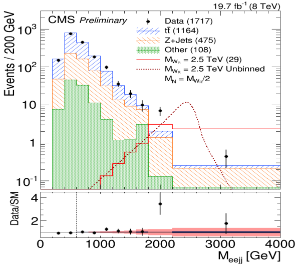
- experimental:
  neutrino masses, dark-matter/energy, gravity, baryogenesis
- theoretical:
  why SU_{SM}: SU(3)xSU(2)xU(1), hierarchy problem

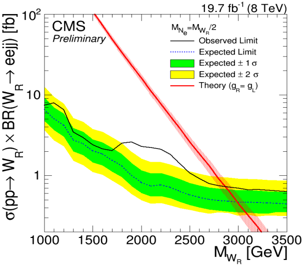
Use the large hadron collider (LHC) to test the SM

- LHC results have shown a good agreement between data and expectations
- Few measurements has reported a mild excess during Run I

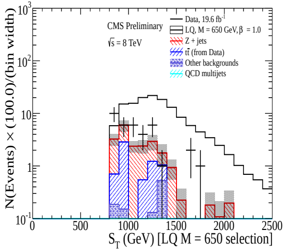
Run I CMS anomalies in the *eejj* final state with 19.7 fb^{-1}

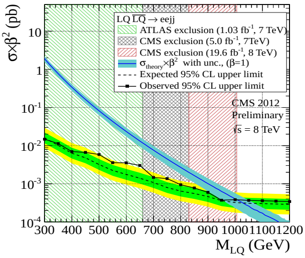
Heavy neutrino search from the Left-Right model





1st generation Lepto-Quark search





- 2.5 σ effect in the eejj channel
- Independent excesses in the 2 analyses
- We studied a new model to interpret these results

- No excess in the $\mu\mu$jj channels
- No searches in the $\tau\tau$jj channels
- We performed a measurement in this final state
- Excess also in search for LeptoQuark of 1st Gen in eνjj

Composite models for quarks and leptons (Ref: arXiv:1510.07988)

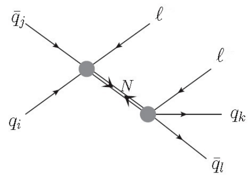
- Compositness of leptons and quarks is one possible scenario beyond the Standard Model
- If quarks and leptons are composite we expect
  - Contact interaction: a residual interaction of the internal dynamics which should become manifest at some sufficiently high-energy scale, Λ
  - Excited states of quarks and leptons

Among the composite models we consider the weak isospin model

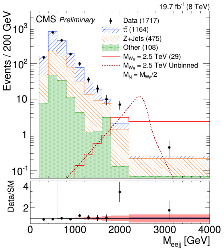
- It doesn't rely to the internal dynamics
- Fermion compositness trough weak isospin symmetry
- analogy with strong isospin $\rightarrow$ prediction of hadronic states before the discovery of quarks and gluons

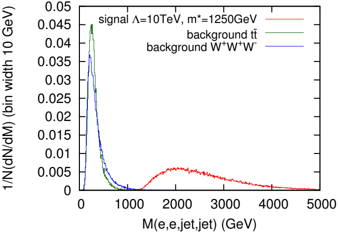
Excess in *eejj* channel in our model

The composite model scenario can take into account the HN eejj Run I excess via the production of a heavy composite (excited) neutrino.



and can qualitatively reproduce the shape of the CMS excess in the M(eejj) distribution





It can reproduce also the absence of the excess in the $\mu\mu jj$ channel and the predominance of opposite sign on same sign di-leptons events (see backup)

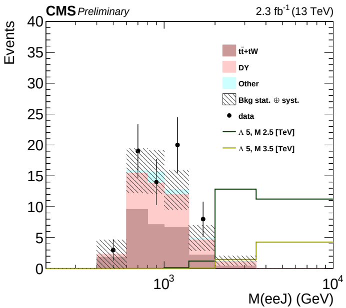
Heavy composite Majorana neutrino search with 2 leptons and 2 jets (Ref: CMS-EXO-16-026)

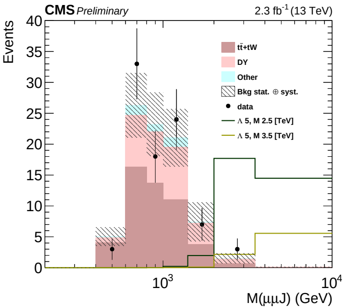
Consider ee+jj, $\mu\mu$+jj channels

- $\ell\ell$: pT>110,35(50,30) GeV for ee($\mu\mu$), $|\eta| < 2.4$
- $\geq$1 fat jet: pT>190 GeV, $|\eta| < 2.4$

Bkg estimation done consistently among channels

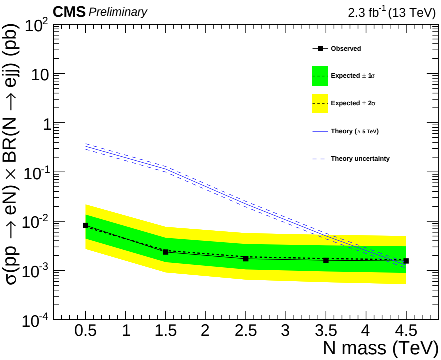
- Drell-Yan From simulation after data/MC correction taken from Z-peak
- Multijet From loose leptons weighted by probability of jet to be misidentified as leptons
- $t\bar{t}$ From eμ data scaled to the 2lep same-flavor region

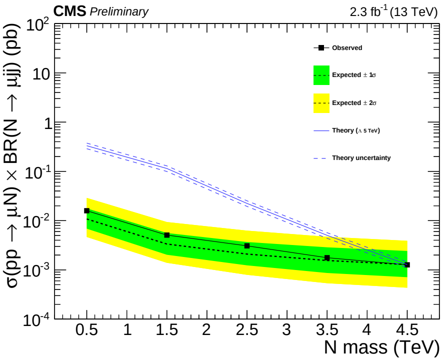




No excesses compared to the SM expectations

Heavy composite Majorna neutrino limits with 2 leptons and 2 jets





Exclusions for a heavy composite Majorana neutrinos for masses up to 4.35 (4.5) TeV in the *eejj* ($\mu\mu jj$) channel

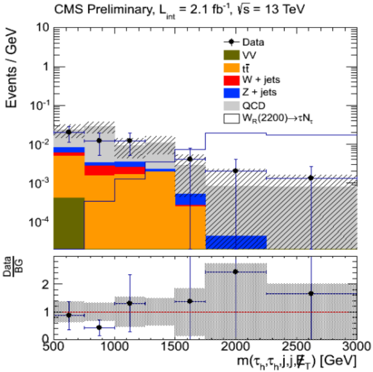
Heavy neutrino search, from left-right model, with 2 taus and 2 jets (Ref: CMS-EXO-16-016)

No searches with 3rd generation lepton in Run I looking for heavy neutrinos from the left-right model $\rightarrow$ we performed a new search to investigate this case

Consider $\tau_h \tau_h$ jj channel

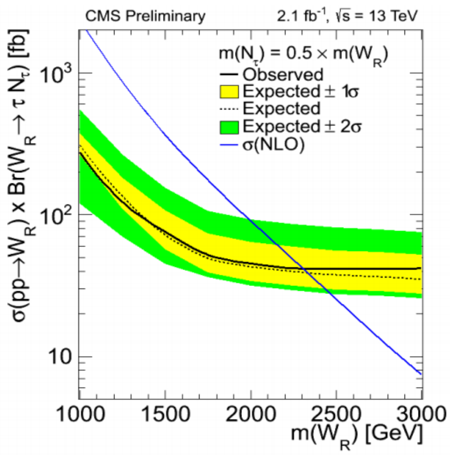
- τ_h: pT$>$70 GeV, $|\eta| < 2.1$
- j: pT$>$50 GeV, $|\eta| < 2.4$
- $\not{E}_T > 50$ GeV, no b-jet
- $M(\tau_h, \tau_h) >$100 GeV

- Drell-Yan ditau part well modelled, for dijet side take data/MC correction from $Z \rightarrow \mu\mu$+jets
- Multijet data events with loose τ_h isolation weighted by tight-to-loose τ_h efficiencies measured with $\not{E}_T <$30
- $t\bar{t}$ From simulation, after validation in high-multiplicity b-jet region



No excess compared to the SM expectations

Heavy neutrino limits, from left-right model, with 2 taus and 2 jets



W_R masses below 2.35 (1.63) TeV are excluded at a 95% confidence level, assuming the HN_τ mass is 0.8 (0.2) times the mass of W_R boson

High-mass ditau search Ref: CMS-EXO-16-008

We further performed a search for new physics with two taus, which is an important signature due to the increase in $\sqrt{s}$ at LHC

Consider $\tau_h\tau_h, \mu\tau_h, e\tau_h, e\mu$ channels

- ℓ: pT$>$20,30,35,60 (τ_h, μ, e, τ_h in $\tau_h\tau_h$) GeV, $|\eta| < 2.1$
- $\not{E}_T > 30$ GeV
- Opposite charge, no b-jets, τ pair consistent with ditau topology

Event for $M(\tau_1, \tau_2, \not{E}_T) > 300$ GeV

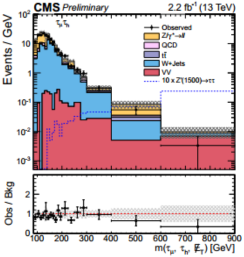
Bkg estimation done consistently among channels

- Drell-Yan taken from Monte-Carlo (MC) after correction/validation w.r.t. data
- W+jets using data control region weighted by the efficiencies to derive signal region contribution
- Multijet using data considering like-sign events

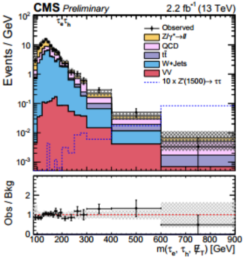
Process	$\tau_h\tau_h$	$\tau_\mu\tau_h$	$\tau_e\tau_h$	$\tau_e\tau_\mu$
Drell-Yan	5 ± 2	16 ± 4	9 ± 4	4 ± 3
W+jets	0.004 ± 0.004	23 ± 9	7 ± 5	0.2 ± 0.5
Diboson	0.02 ± 0.02	6 ± 3	3 ± 2	23 ± 5
$t\bar{t}$	–	4 ± 2	5 ± 3	65 ± 12
Multijet	18 ± 6	4 ± 3	9 ± 3	0.8 ± 1.0
Total	23 ± 6	51 ± 11	33 ± 8	93 ± 13
Observed	20	42	40	96
Z'_{SSM} (1.0 TeV)	44 ± 3	49 ± 4	18.1 ± 1.3	21.1 ± 1.6
Z'_{SSM} (1.5 TeV)	8.5 ± 0.4	9.0 ± 0.4	2.9 ± 0.1	4.4 ± 0.3
Z'_{SSM} (2.0 TeV)	2.1 ± 0.1	2.3 ± 0.1	0.77 ± 0.04	1.2 ± 0.05

No excesses compared to the SM expectations

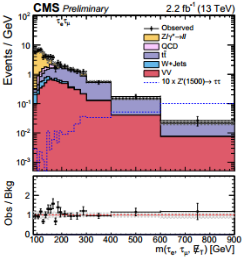
High-mass ditau mass distributions



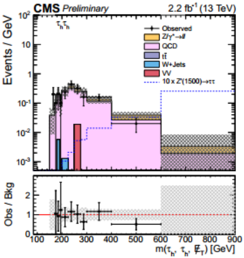
$\tau_\mu\tau_h$



$\tau_e\tau_h$



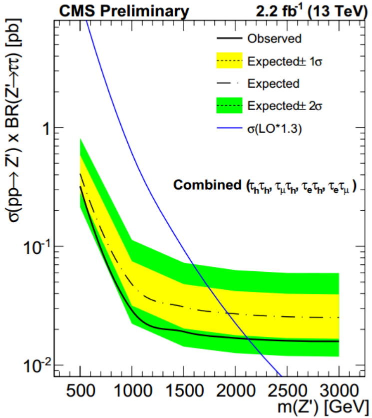
$\tau_e\tau_\mu$



$\tau_h\tau_h$

High-mass ditau limits

Results w.r.t. Z' Sequential Standard Model



$Z' < 2.1$ TeV, world best limit

Conclusions

- LHC results have not shown any clear sign of new physics so far
- Some Run I results have modest excesses
  → we have focused on them at the beginning of Run II:
  • we have studied a **new model** to interpret them,
  based on **heavy composite Majorana neutrinos**
  • we have looked for **heavy composite Majorana neutrinos**
  • we have also **looked for heavy neutrinos (left-right model)** in the **tau channel**
- We have further **search**ed for new physics with two **high-mass ditau**, which is an important signature due to the increase in $\sqrt{s}$ at LHC
- Again we have not found relevant discrepancies between data and expectations → much more data are coming in order to set more stringent conclusions on these searches

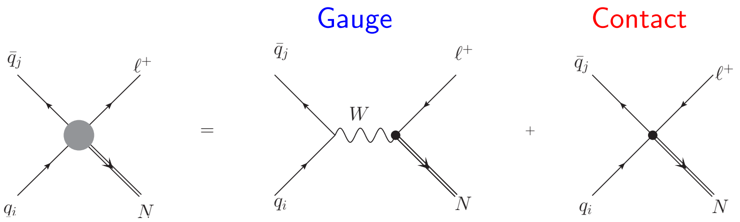
Thanks for the attention!

Extended weak isospin model

I_W	Multiplet
0	E^-
1/2	$\epsilon \equiv \begin{pmatrix} E^0 \\ E^- \end{pmatrix}$
1	$\epsilon \equiv \begin{pmatrix} E^0 \\ E^- \\ E^{--} \end{pmatrix}$
3/2	$\epsilon_M \equiv \begin{pmatrix} E^+ \\ E^0 \\ E^- \\ E^{--} \end{pmatrix}$

I_W	Multiplet
0	$U,\ D$
1/2	$\Psi \equiv \begin{pmatrix} U \\ D \end{pmatrix}$
1	$\mathbf{U} \equiv \begin{pmatrix} U^+_{(5/3)} \\ U \\ D \end{pmatrix},\ \mathbf{D} \equiv \begin{pmatrix} U \\ D \\ D^-_{(4/3)} \end{pmatrix}$
3/2	$\mathbf{\Psi}_M \equiv \begin{pmatrix} U^+_{(5/3)} \\ U \\ D \\ D^-_{(4/3)} \end{pmatrix}$

Gauge and Contact interactions



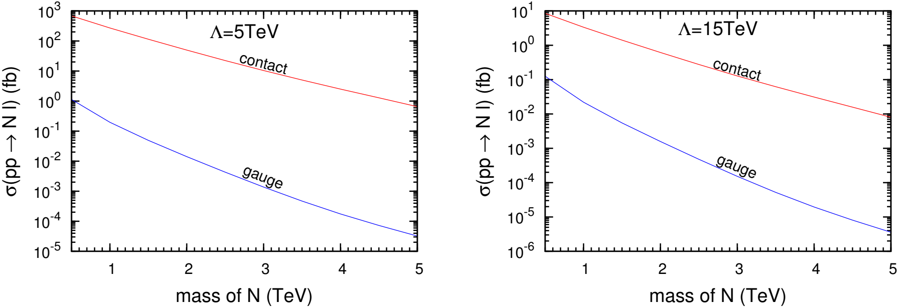
$$\mathcal{L}_G = \frac{1}{2\Lambda}\,\bar{\phi}\sigma^{\mu\nu}\left(gf\,\frac{\vec{\tau}}{2}\cdot\overrightarrow{W}_{\mu\nu} + g'f'YB_{\mu\nu}\right)\phi_L + h.c.$$

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

$$j_\mu = \eta_L\bar{\phi}_L\gamma_\mu\phi_L + \eta\prime_L\bar{\phi}_L^*\gamma_\mu\phi_L^* + \eta\prime\prime_L\bar{\phi}_L^*\gamma_\mu\phi_L + h.c. + (L\to R)$$

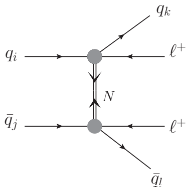
where $g_* = 4\pi$, $\eta = 1$ and $f, f' = 1$

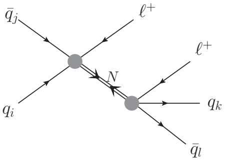
Production cross section



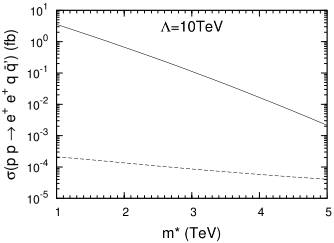
Excess in *eejj* channel in our model

The composite model scenario can explain this excess via the production of a heavy composite (excited) neutrino. Two processes are possible





Exchange of virtual heavy Majorana neutrino (left)
HEP equivalent of neutrinoless double β-decay
Resonant production of heavy Majorana neutrino (right)



The resonant production is the dominant process

Excess in *eejj* channel in our model

- In our model is possible to have the excess in the *eejj* channel and not in the $\mu\mu jj$ channel assuming excited μ state heavier than excited e state
- It is also possible to take into account the predominance of opposite sign on same sign di-leptons. Two possible explanations:
  - processes giving only opposite sign: $pp \to e^+ L^{--} \to e^+ e^- jj$, $pp \to e^- L^{++} \to e^- e^+ jj$
  - existence of an additional neutrino with a slightly different mass, the interference between the two states can depress same sign. (arXiv:1508.02277 [hep-ph]. , arXiv:1509.05387 [hep-ph])

Excess in $e\not{p}_T jj$ channel

CMS reported an excess in a search of lepto-quarks in the channel $e\not{p}_T jj$ for $\sqrt{s} = 8$ TeV (http://arxiv.org/abs/1509.03744)

This can be explained by our model with processes like
$pp \to \ell N \to \ell \nu Z \to \ell \nu jj$

The absence of the excess in $\mu\not{p}_T jj$ channel can be explained assuming that the excited muon state is heavier than excited electron state

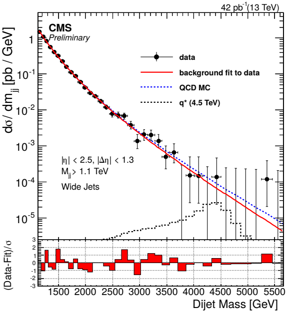
Excess in di-boson search

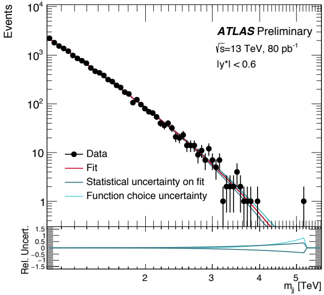
Recently ATLAS observed an excess around 2 TeV in a search for high-mass diboson resonances with boson-tagged jets at $\sqrt{s} = 8$ TeV (http://arxiv.org/abs/1506.00962)

We can produce a pair of charged excited fermions that could form a 1S bound state wich could decay in a pair of gauge bosons
Example: $pp \to L^+L^- \to 1SBoundstate \to W^+W^-$

Events at di-jet mass 5 TeV

CMS and ATLAS observed few events at 5 TeV in the di-jet mass at Run II of the LHC (CMS-PAS-EXO-15-001, ATLAS-CONF-2015-042)





If they are confirmed by higer statistics and result in an excess, this could be interpreted as the first hadronic resonance in a composite scenario