Search for heavy neutrinos in CMS

M. Kirsanov
INR RAS

20th annual RDMS CMS collaboration conference

September 2018 Tashkent

Heavy neutrino and SM

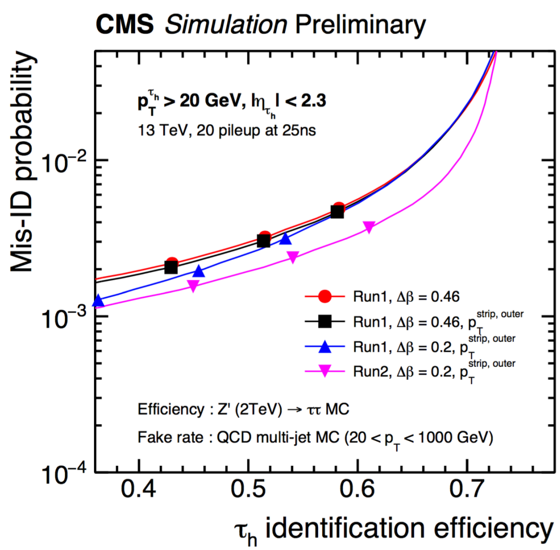
- Neutrino oscillations mean that neutrinos have masses, which is one of the most known manifestations of physics beyond SM
- There are several models that explain the neutrino masses and the smallness of them for ordinary neutrinos
- In most such models there are heavy neutrinos so that the very small masses of ordinary neutrinos are given by the See-Saw mechanism.
- Examples of such models are Left-Right symmetric model, Heavy Majorana neutrinos.

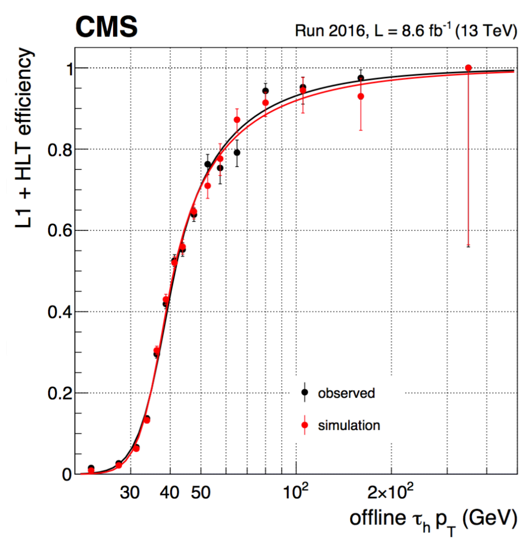
Heavy neutrino and SM

- If the See-Saw mechanism is realised, then naturally the lightest heavy neutrino will correspond to the lightest ordinary neutrino
- In the normal hierarchy of the light neutrinos (1, 2, 3) it is mostly electron neutrino
- However, the inverse hierarchy (3, 1, 2) is also possible. The measurement of the hierarchy is very difficult, will probably take many years.
- In the inverse hierarchy the lightest is tau neutrino. For this reason the searches of heavy neutrino corresponding to tau neutrino is important -> requires reconstruction of τ

Tau lepton reconstruction

- At the energies of LHC τ is a well-defined object, including also hadronic decay modes τ_h that have larger branching than semileptonic modes
- The reconstruction algorithm improved in Run II. The HPS (hadrons plus strips) algorithm with MVA technique is used. It reconstructs separately charged hadrons from the decay and π^0 with strips technique
- The reconstruction efficiency is of the order of 55%





LRSM: What and Why

	Standard Model	Left-Right-Symmetric Extension
Gauge group	$SU(2)_L \times U(1)_Y$	$SU(2)_L$ **X SU(2)$_R$** $\times U(1)_{B-L}$
Fermions	LH doublets: $Q_L = (u^i, d^i)_L$; $L_L = (l^i, \nu^i)_L$ RH singlets: $Q_R = u^i_R,\ d^i_R$; $L_R = l^i_R$	LH doublets: $Q_L = (u^i, d^i)_L,\ L_L = (l^i, \nu^i)_L$ RH doublets: $Q_R = (u^i, d^i)_R,\ L_R = (l^i, N^i)_R$
Neutrinos	ν^i_R do not exist ν^i_L are massless & pure chiral	N^i_R are heavy partners to the ν^i_L N^i_R Majorana in the Minimal LRSM
Gauge bosons	$W^{\pm}_L,\ Z^0,\ \gamma$	$W^{\pm}_L$, **$W^{\pm}_R$** Z^0, **Z'**, γ

Parity Violation, in SM is not explained

LRSM explains by symmetry breaking at an intermediate mass scale

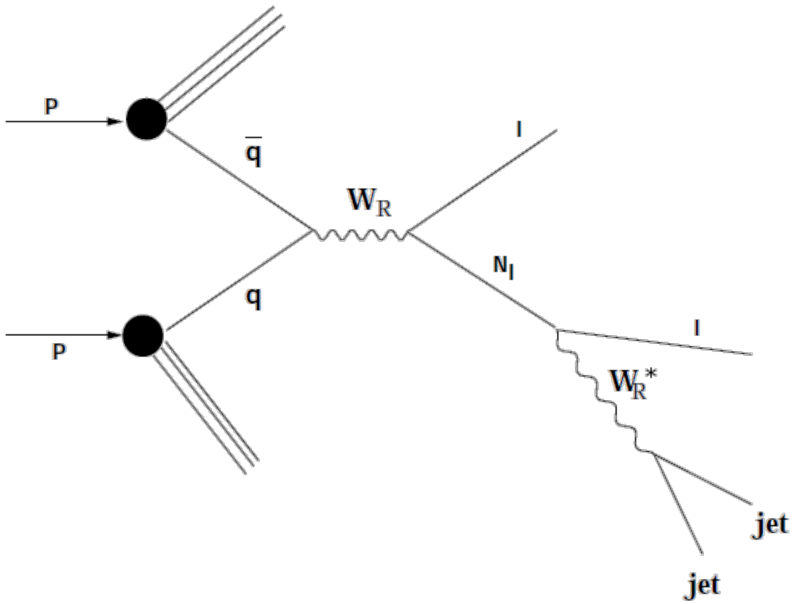
Neutrino Oscillations $\Rightarrow$ Mass, turns out to be very small

LRSM deploys a "see-saw mechanism" to explain smallness of mass

$$\nu_{heavy}\nu_{light} \sim |<H>|^2$$

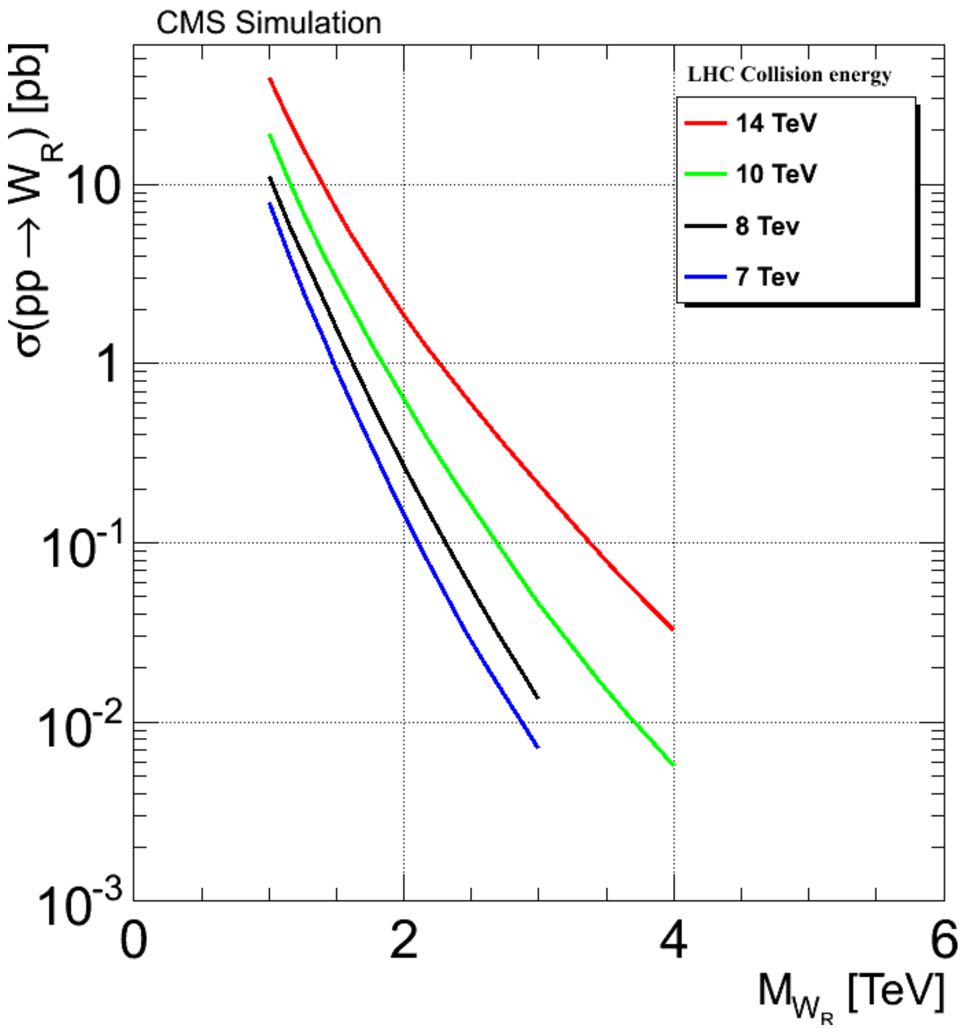
LRSM: 6 new particles: **$W^{\pm}_R$, Z', N_l** (3 heavy neutrinos)

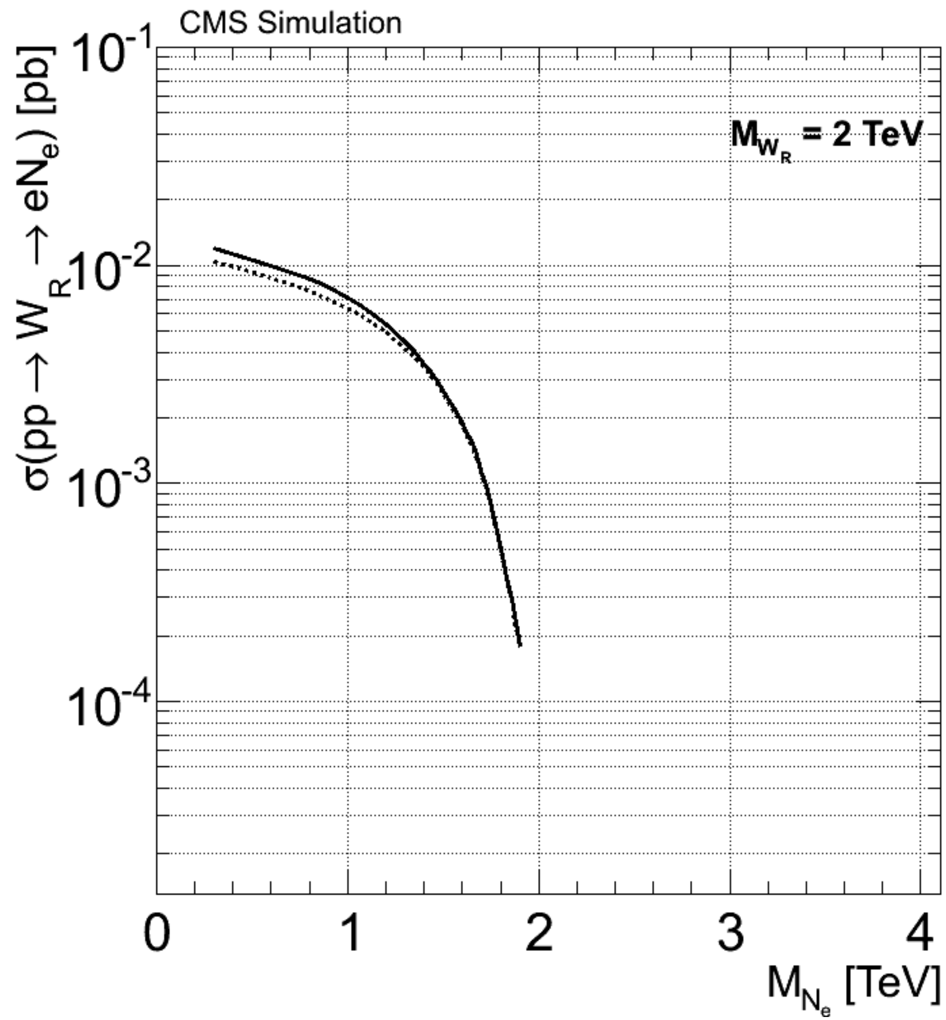
Signature and channels



- Main production diagram: s-channel from 2 quarks
- No L-R mixing means N_l → off-shell W_R+ l → $j\,j\,l$
- Two-dimensional resonant structure
- Cross sections depend on $M(W_R)$ and M(N), ~ 1 pb at 1 TeV
- Final signature is 2 leptons + 2 jets, $l = e\,,\,\mu\,,\,\tau$

Cross sections





Search status in CMS

- W' in jj, full 2016 dataset, limit up to M_{WR} = 3.6 TeV, full 2016+2017 datasets limit up to 3.8 TeV (EXO-17-026). This covers all LR-symmetric models with g_R=g_L
- Existing heavy neutrino analyses (LR symmetric):
  - at 8 TeV on the full 2012 dataset, limits in the 2D M_{WR} – M_N space reaching M_{WR} = 3080 GeV, electron and muon channel
  - At 13 TeV, 2016 dataset, τ channel, EXO-17-016
  - on the full 2016 dataset, EXO-17-011, electron and muon channel

EXO-17-016 data and MC samples

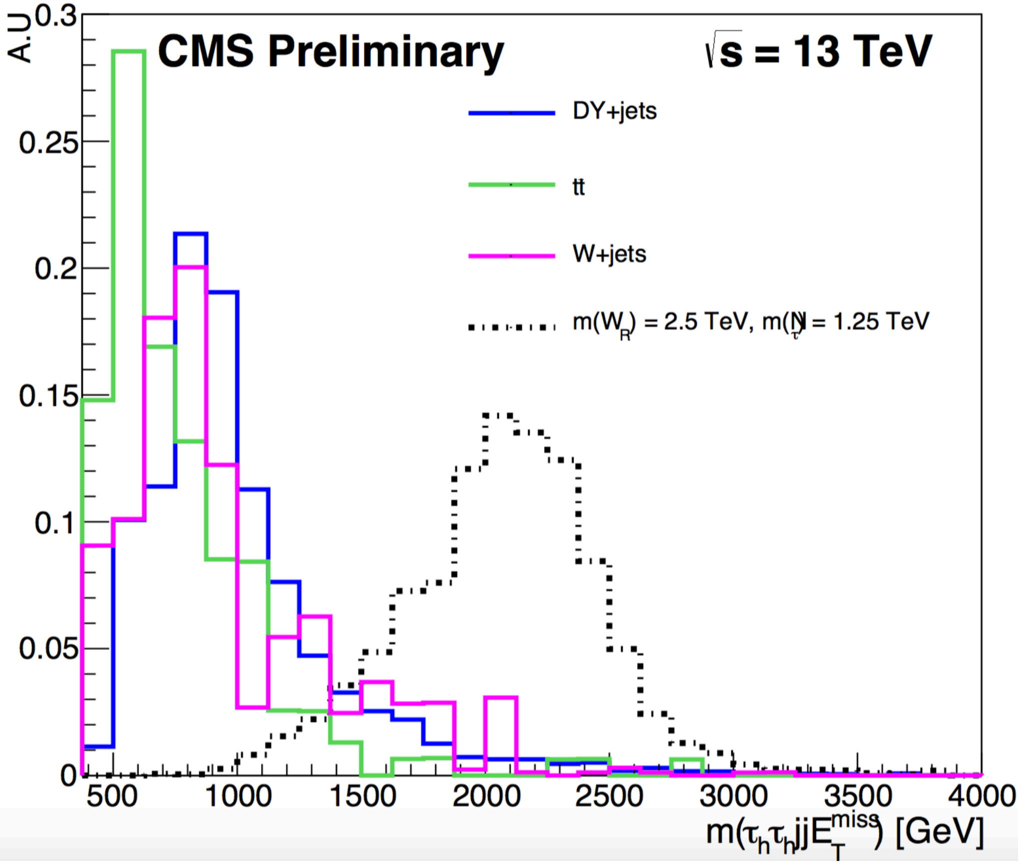
- Data 2016 35.9 fb^{-1}
- Double τ_h trigger (threshold 32 GeV) datasets
- For the backgrounds: AMC@NLO DY+jets and tt +jets, madgraph W+jets, pythia8 WW, WZ, ZZ, powheg tW
- For the signal: pythia8 LRSM. It was assumed that only one N_l is reachable. NLO k-factors for the cross section

Objects used and event selection

- At least two HPS τ_h objects, p_T cut 70 GeV, $|\eta| < 2.1$ to ensure that all object is within the tracker range (2.4)
- At least two PF jets (tracker region only, p_T cut 50 GeV)
- $\Delta R > 0.4$ between any 2 objects
- Missing $p_T > 50$ GeV
- $m(\tau_{h1}, \tau_{h2}) > 100$ GeV to avoid BG from Z
- Signal efficiency with these cuts at M_{WR}=4 TeV is 15.7% (4.76% at 1 TeV)
- Reminder: Br(τ, τ) -> (τ_{h1}, τ_{h2}) is 42%

Variables

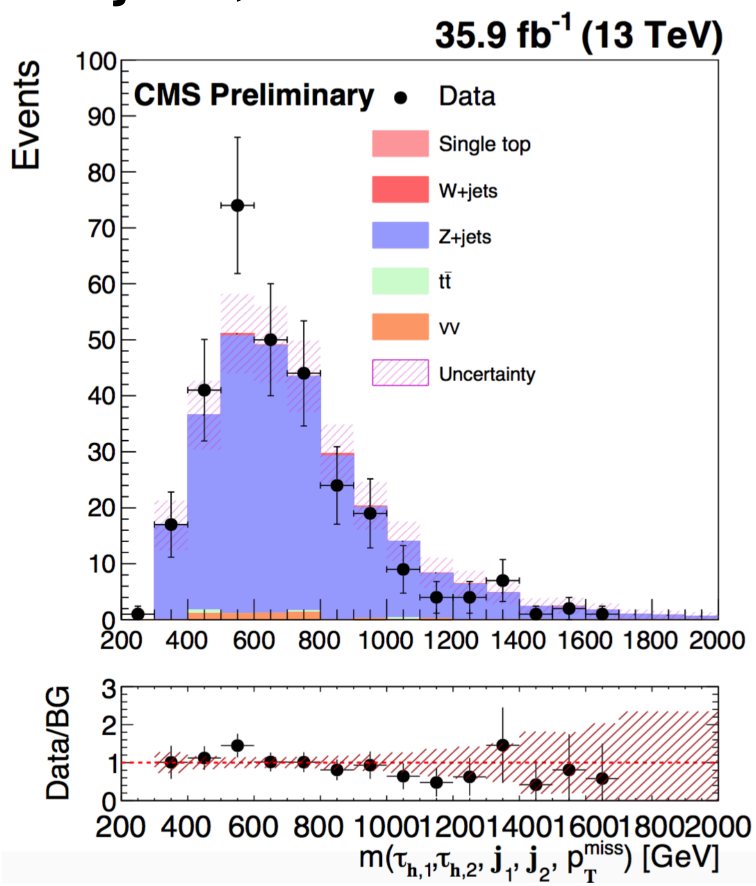
$$m(\tau_{h,1}, \tau_{h,2}, j_1, j_2, p_T^{miss}) = \sqrt{(E_{\tau_{h,1}} + E_{\tau_{h,2}} + E_{j_1} + E_{j_2} + p_T^{miss})^2 - (\vec{p}_{\tau_{h,1}} + \vec{p}_{\tau_{h,2}} + \vec{p}_{j_1} + \vec{p}_{j_2} + \vec{p}_T^{miss})^2}.$$

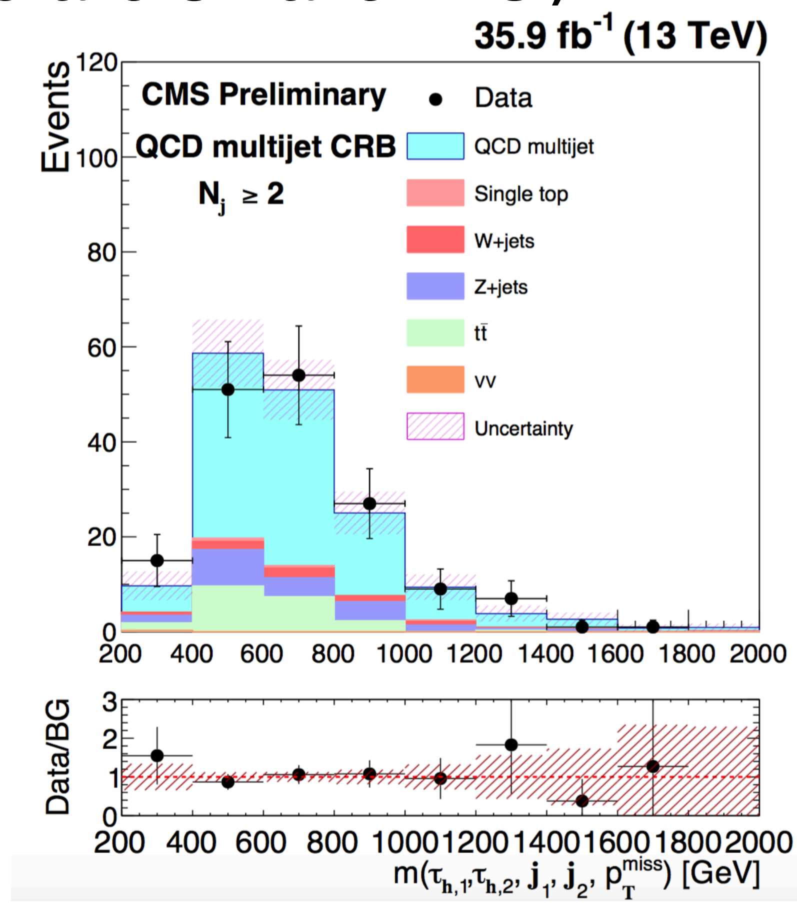


- Full reconstruction of invariant mass is impossible due to escaping neutrinos
- Partial mass is used

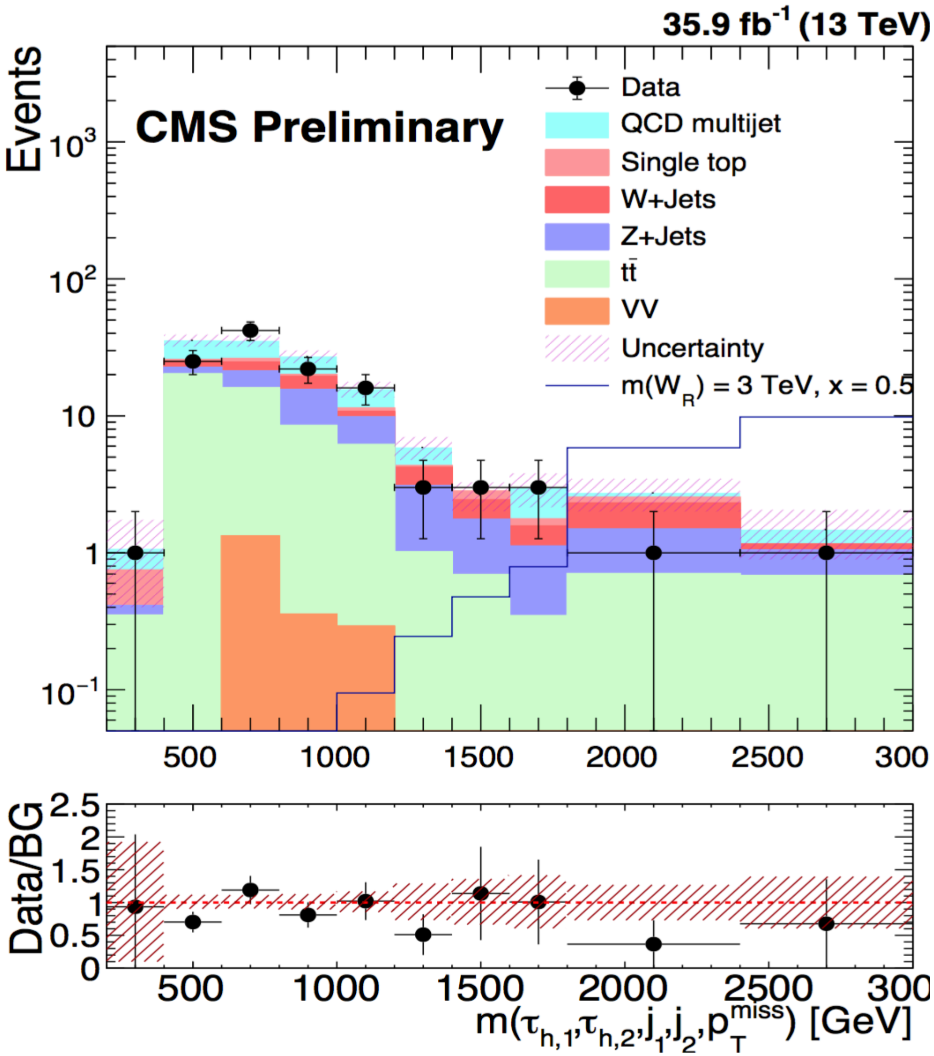
Backgrounds

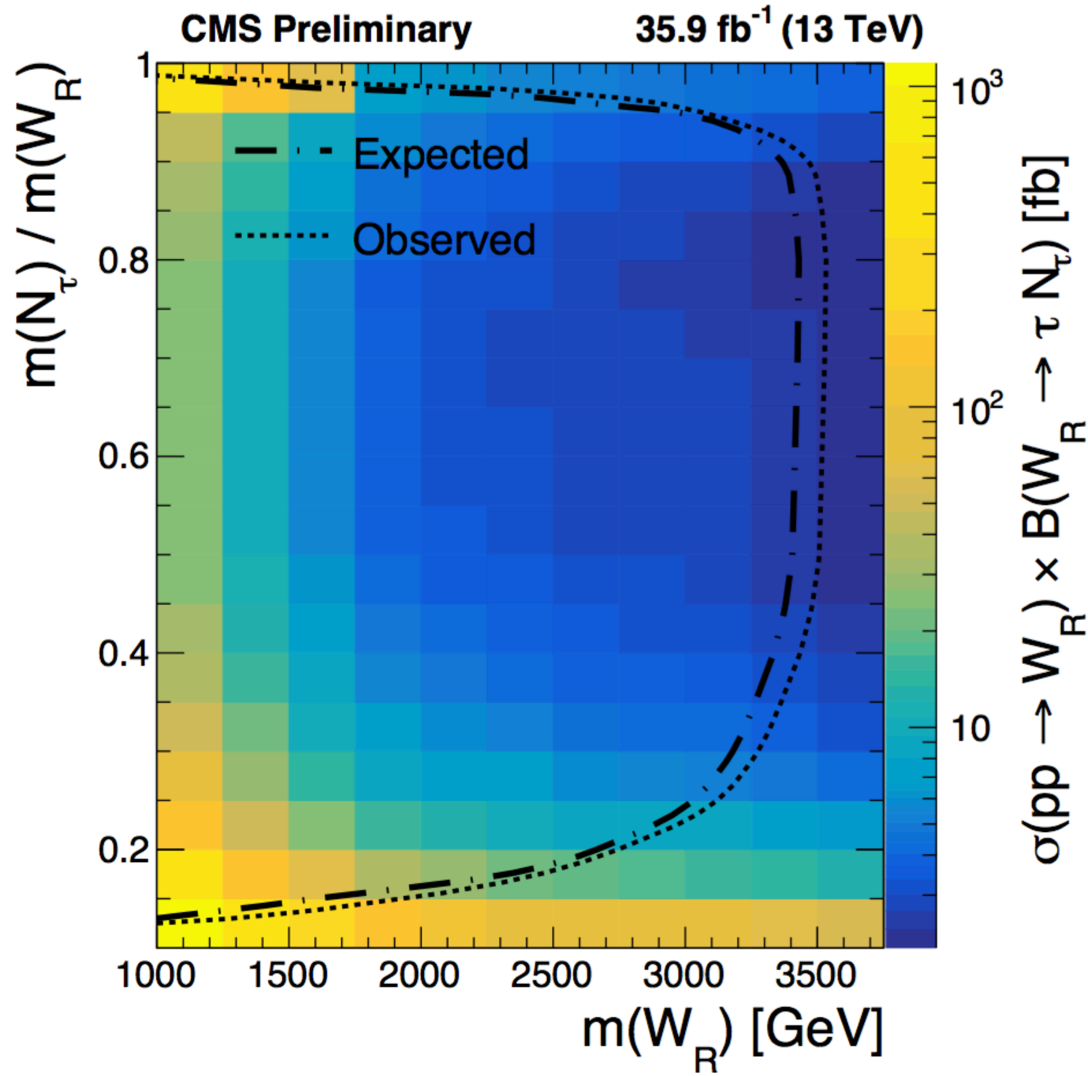
- tt, Z+jets – from data CR with τ->μ
- QCD dijets – ABCD method using loose and tight τ_h
- W+jets, VV – from MC (these are smaller BG)





Results

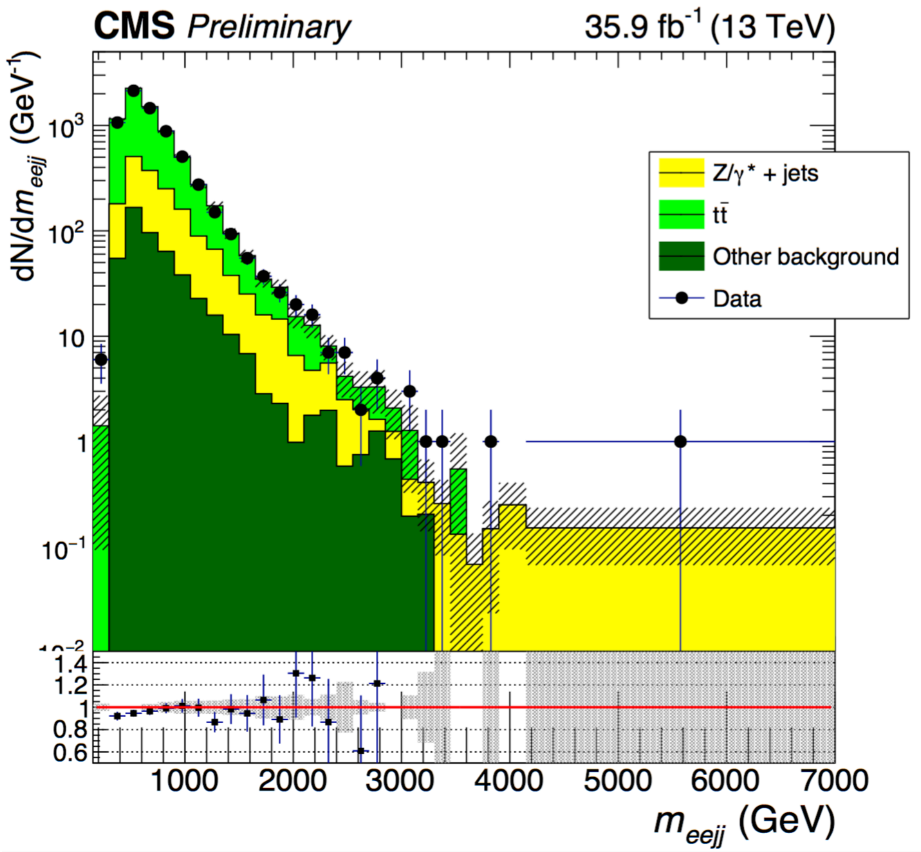

35.9 fb-1 (13 TeV)
CMS Preliminary
Events
Data
QCD multijet
Single top
W+Jets
Z+Jets
tt̄
VV
Uncertainty
m(W_R) = 3 TeV, x = 0.5
Data/BG
m(τh,1,τh,2,j1,j2,pTmiss) [GeV]


CMS Preliminary
35.9 fb-1 (13 TeV)
Expected
Observed
m(Nτ) / m(W_R)
m(W_R) [GeV]
σ(pp → W_R) × B(W_R → τ Nτ) [fb]

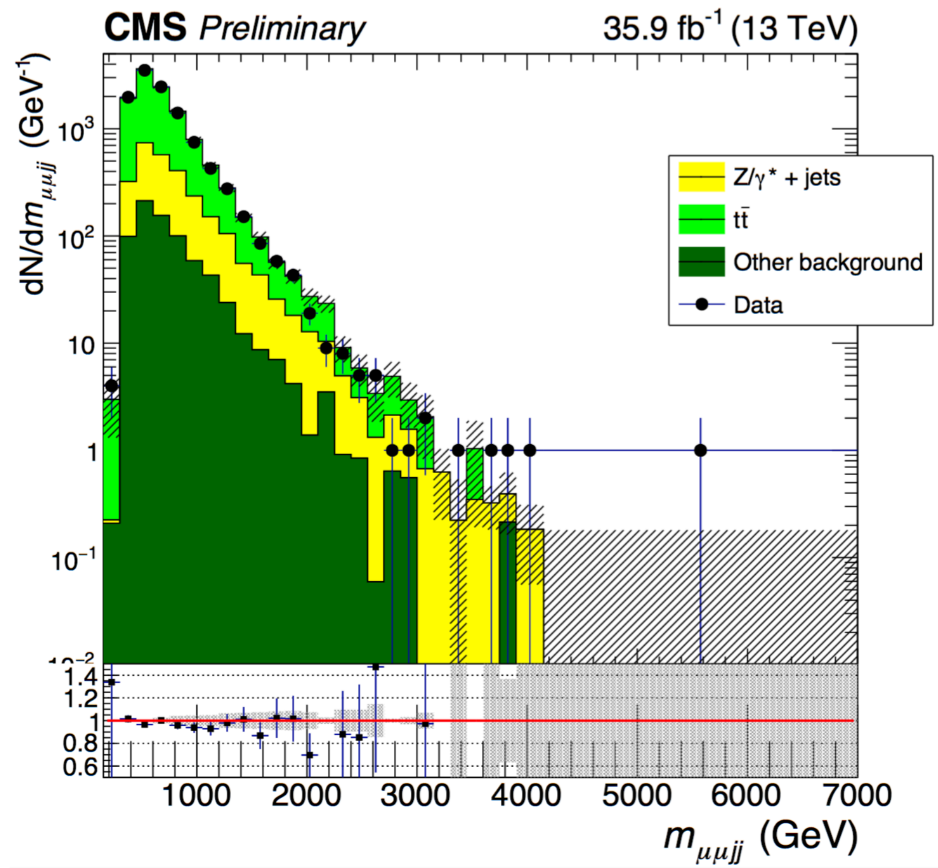
Results (2)

- LRSM W_R decaying dominantly to quarks and N_τ is excluded in the two-dimensional region up to MWR = 3.5 TeV
- This region is also excluded in the W' -> jj analysis using the same data sample (full 2016)
- Requires improvements of technique to have a better sensitivity than the dijet analysis

LRSM in electron and muon channels (EXO-17-011)



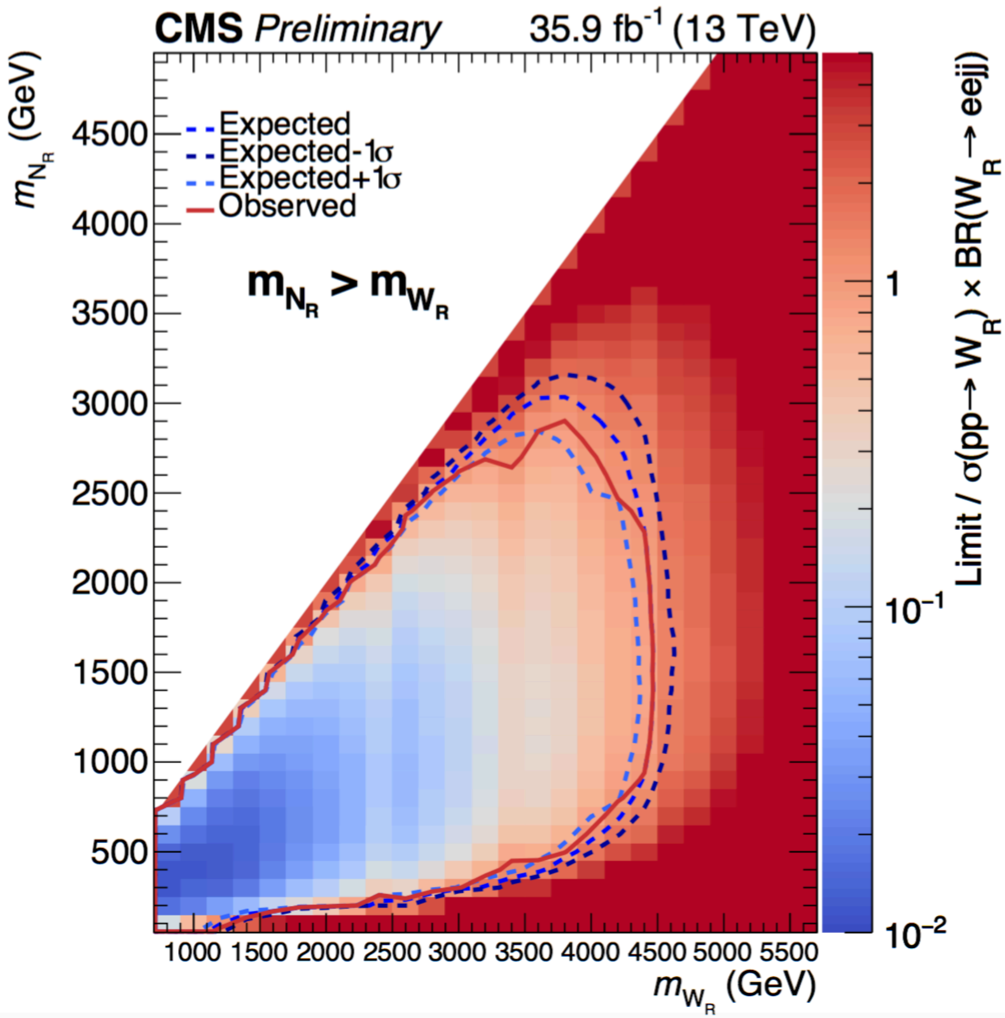
Electron channel



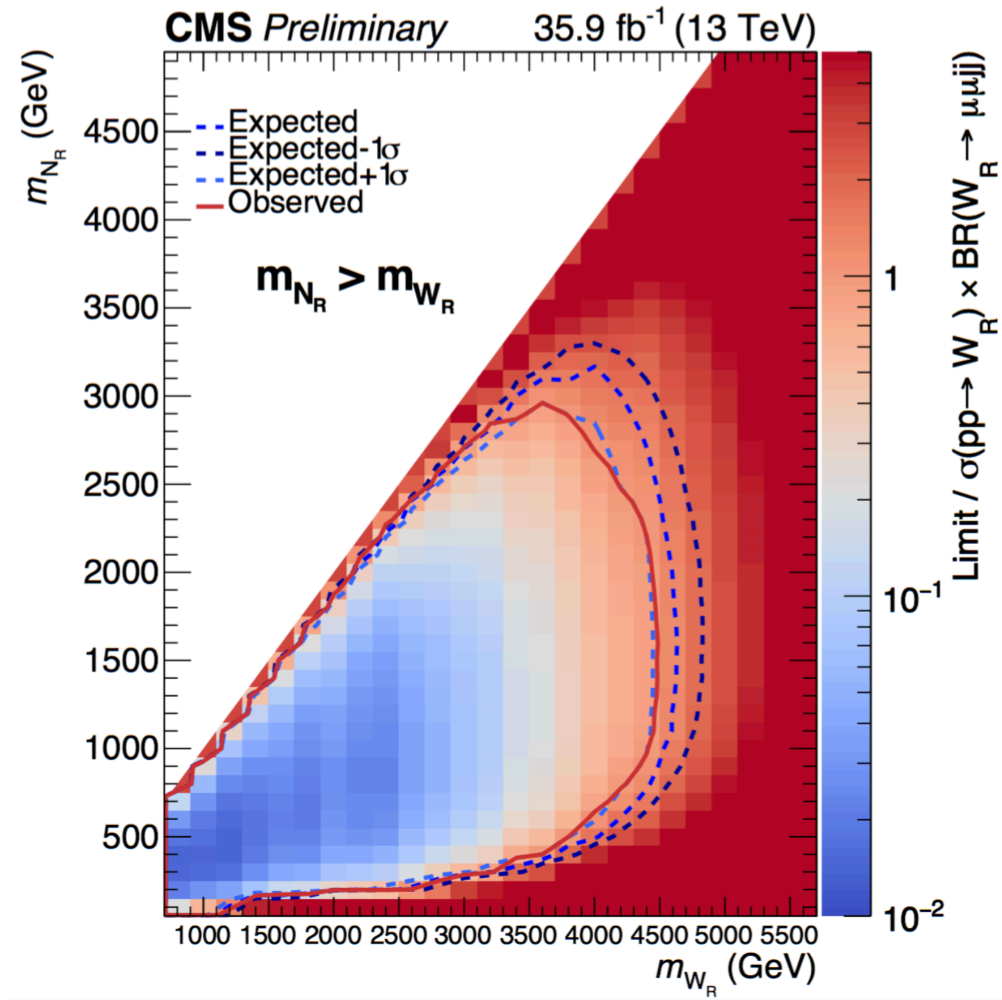
Muon channel

No significant excess observed

Results 2D



Electron channel



Muon channel

Summary on LRSM e and μ channels

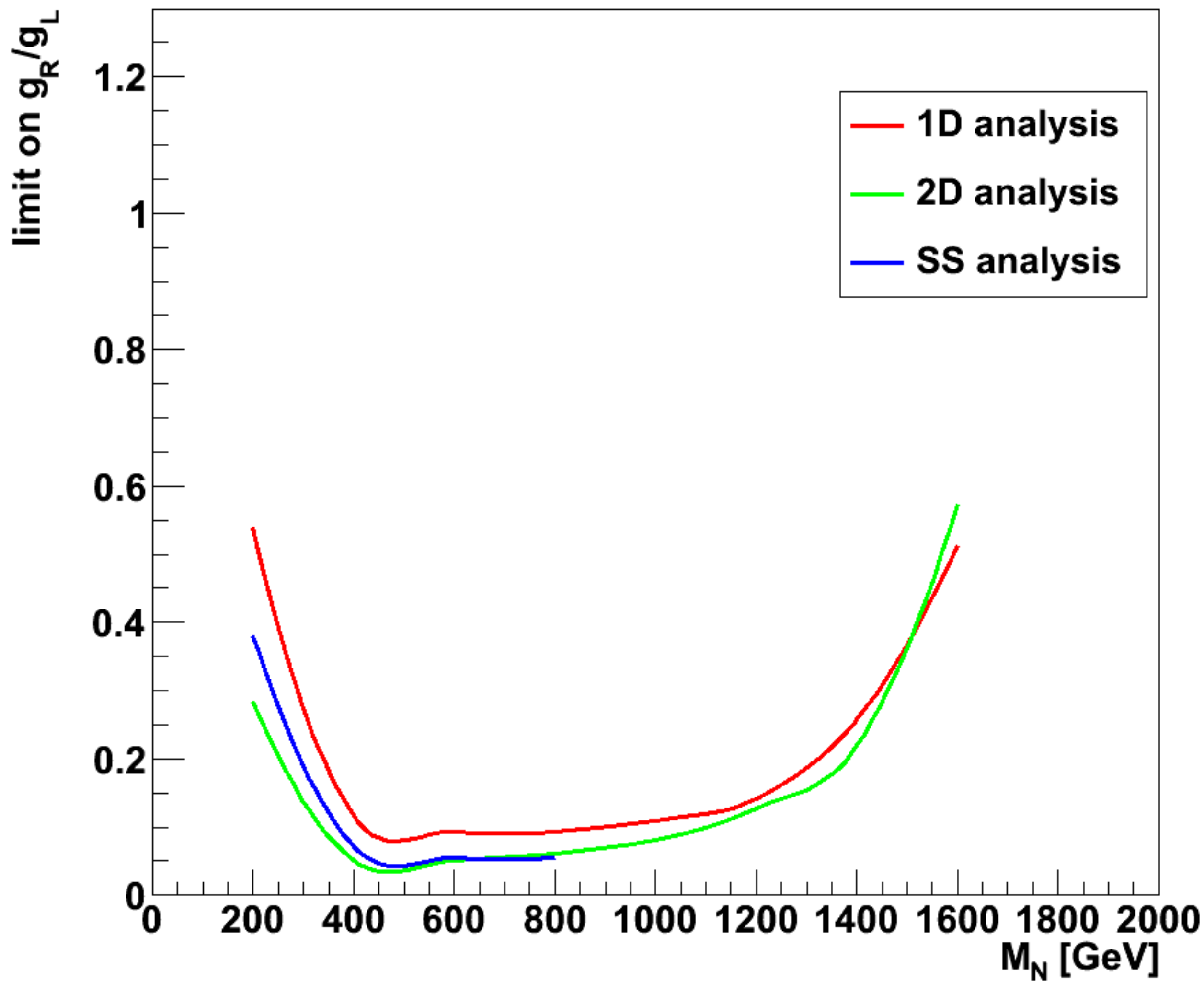
- LRSM new particle W_R decaying to N_l with $l = e, \mu$ is excluded in the wide region of the 2D mass space $M_{WR} - M_N$ reaching the value of $M_{WR} = 4.4$ TeV
- Expecting the full dataset 2016 – 2018, now the paper on the 2016 data is being published

Further searches

- For the classical LRSM model most important to improve the sensitivity in terms of the mass reach is the LHC collision energy as the cross sections are not small
- However, it is possible that $g_R < g_L$. There are models with concrete predictions, for example $g_R = 0.6g_L$. Then statistics and luminosity become more important.
- In the analysis presented here the tt background is taken from the data eμ sample. The statistics at high masses is small, which limits the sensitivity
- Some time ago we studied the possibility to perform the 2D analysis (analyse simultaneously m(ljj) and m(lljj)). This is also better to do with good statistics

Results

Expected 95% C.L. limits (median) for MWR = 2000 GeV



Summary

- **Heavy neutrinos of different models are extensively searched for in CMS**
- **These searches will certainly continue, new searches with new models can be initiated**
- **Some new interesting possibilities to improve the sensitivity of these searches appear with more statistics**