Search for Heavy Majorana Neutrinos in Events with Same-Sign Leptons and Jets at $\sqrt{s}$ = 13 TeV with the CMS Detector

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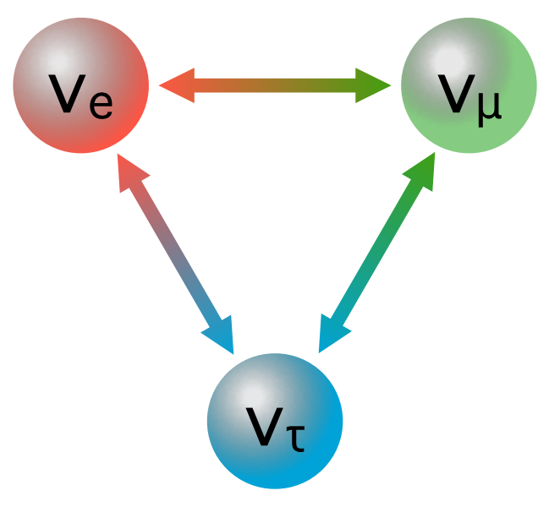
on behalf of CMS Collaboration

1. Motivation



The Mass of Neutrino (ν)

- In the Standard Model (SM), neutrinos are massless
- HOWEVER, neutrinos oscillate! Phys. Rev. Lett. 81 1562 : Nobel Prize 2015
  → Neutrinos have mass! (BUT, Σm_ν < 0.2 eV.. WHY SO SMALL?)
- Clear evidence of physics beyond the SM (BSM)

Seesaw Mechanism

Phys. Rev. Lett. 44 912

- Introduce a right-handed neutrino (N) which mixes with SM ν's
- Neutrino mass term :

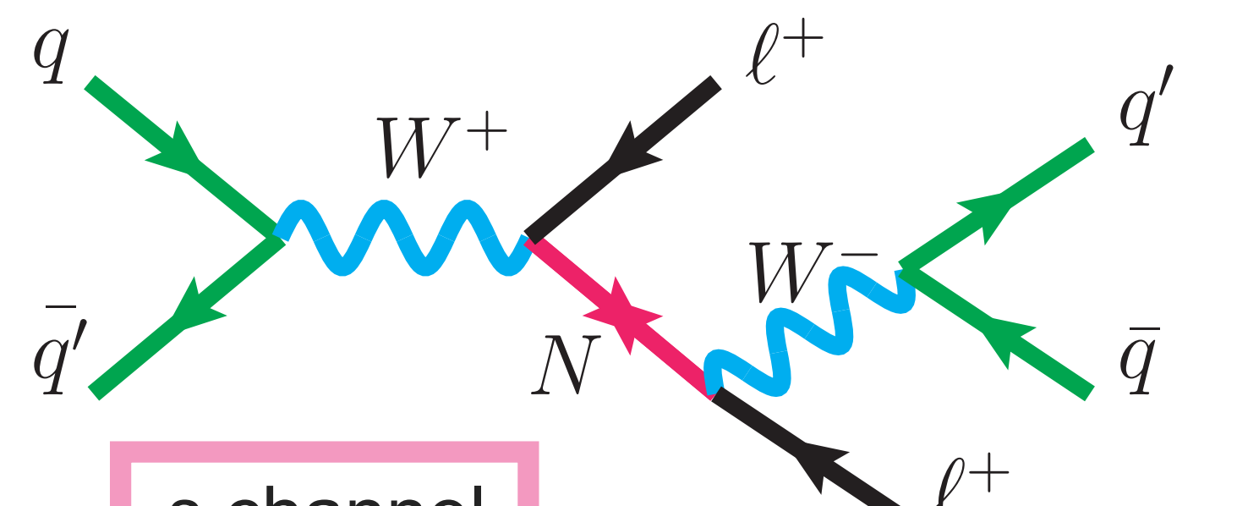
$$\begin{pmatrix}\overline{\nu_L} & \overline{N_R{}^C}\end{pmatrix}\begin{pmatrix}0 & M_D\\ M_D{}^T & M_M\end{pmatrix}\begin{pmatrix}\nu_L{}^C\\ N_R\end{pmatrix}$$

- Diagonalization gives $M_{1,2} = \dfrac{M_M \pm \sqrt{M_M^2 + 4M_D^2}}{2}$

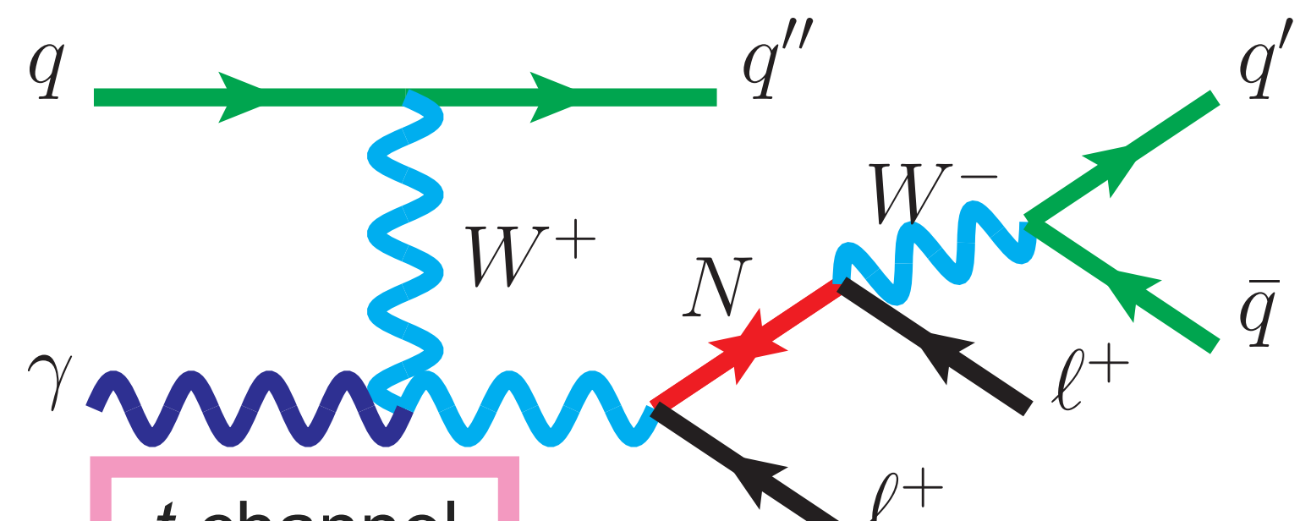
For $M_D \ll M_M$, $\begin{cases} M_1 \approx M_M & \text{: Heavy N (\sim TeV)} \\ M_2 \approx -\dfrac{M_D^2}{M_M} & \text{: small } \nu \text{ mass!} \end{cases}$

Search for Majorana Neutrinos at the LHC

- m_ν ~ 0.1 eV predicts m_N 100-1000 GeV
- Two main production mechanisms are s- and t-channel :



s-channel



t-channel

2. Event Selections

High-Level Trigger

- Unprescaled dilepton (e or μ) triggers

Offline Selection

- Preselection
  - Two same-sign (SS) leptons (ℓ)
  - At least one jet (j, AK4) or wide jet (J, AK8)
- Two mass categories with two signal regions
  - Low-mass ($m_N < m_W$)
    - No b-tagged jet, $m(\ell\ell W_{jet})$ < 300 GeV, p_T^{miss} < 80 GeV
    - SR1 : **N(j) ≥ 2**; W_{jet} = dijet with $m(\ell\ell jj)$ closest to m_W
    - SR2 : **N(j) = 1**; W_{jet} is the jet
  - High-mass ($m_N > m_W$)
    - No b-tagged jet, $m(W_{jet})$ < 150 GeV, $(p_T^{miss})^2/S_T$ < 15 GeV, where S_T is scalar p_T sum of lepton, jet and p_T^{miss}
    - SR1 : N(J) = 0 and **N(j) ≥ 2**; W_{jet} = dijet with m(jj) closest to m_W
    - SR2 : **N(J) ≥ 1**; W_{jet} is the wide jet with m(J) closest to m_W
- Additional optimized selections for each m_N hypothesis

3. Backgrounds

Prompt Same-sign Lepton Backgrounds

- Multiboson, tt+boson, W±W±, double-parton scattering
- Systematics on the cross sections and detector effects ~ 13-45%
- Use **Monte-Carlo simulation** (WZ, ZZ and Zγ are normalized in data)

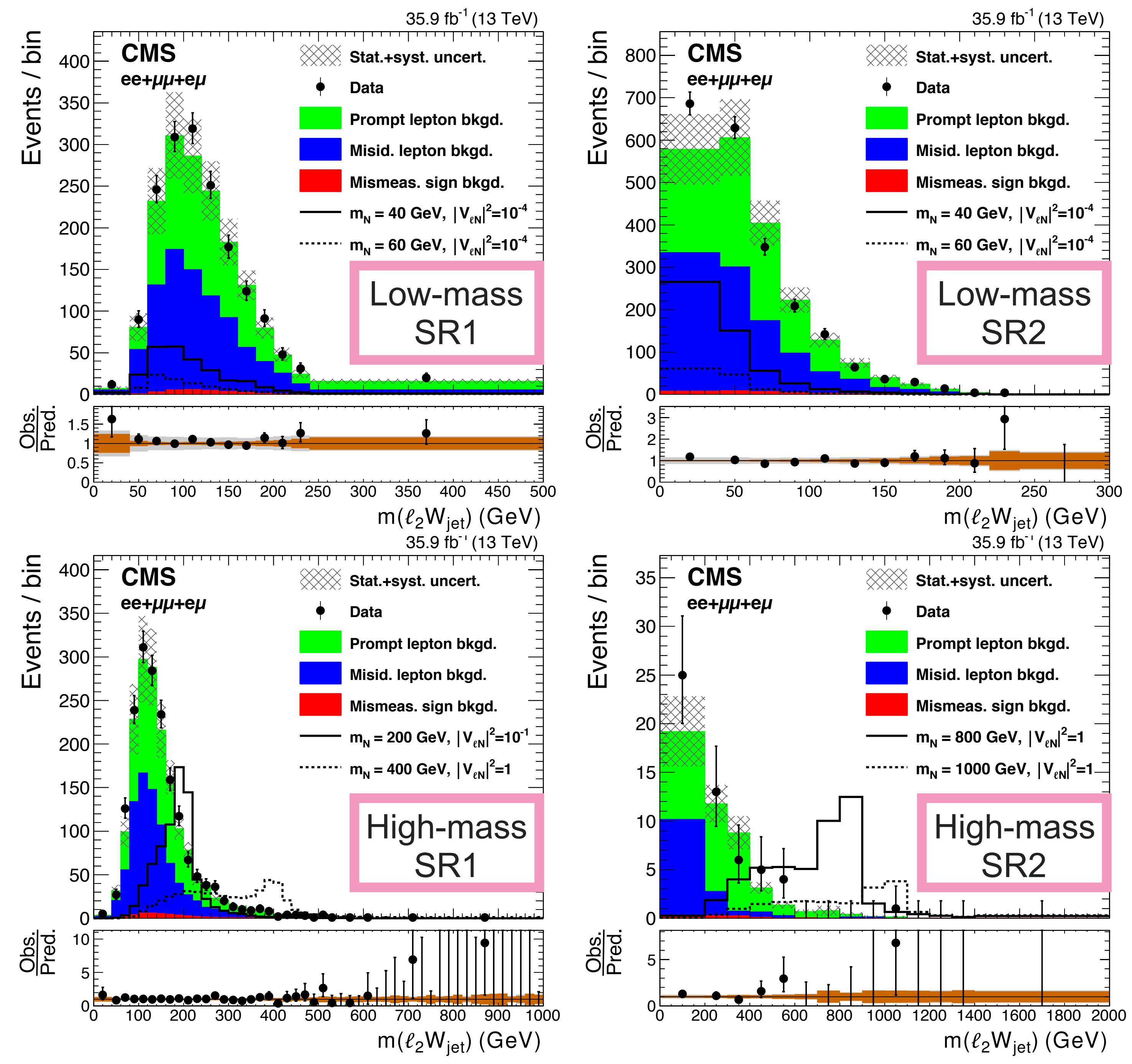
Misidentified-lepton Backgrounds

- Fake electron : π0→γγ + nearby track, photon conversion
- Fake muon : π/K decay into muons, punch through to muon system
- Measure T/L, where T is lepton passing tight selection, and L is lepton passing loose selection
- Apply T/L weights to data, which has "loose but NOT tight" leptons
  → **Data-driven estimation**
- Systematic ~ 30% from simulation closure test

Mismeasured-sign Backgrounds

- Opposite-sign (OS) backgrounds mismeasured as SS events
- Negligibly small probability for muon
- Electron chargeflip (CF) rate measured from simulation
- Obtained scale factor in Z→ee data events
- Multiplied to OS data events → **Data-driven estimation**
- Systematic ~ 29-88%
  - Yield of this background is small compared to others

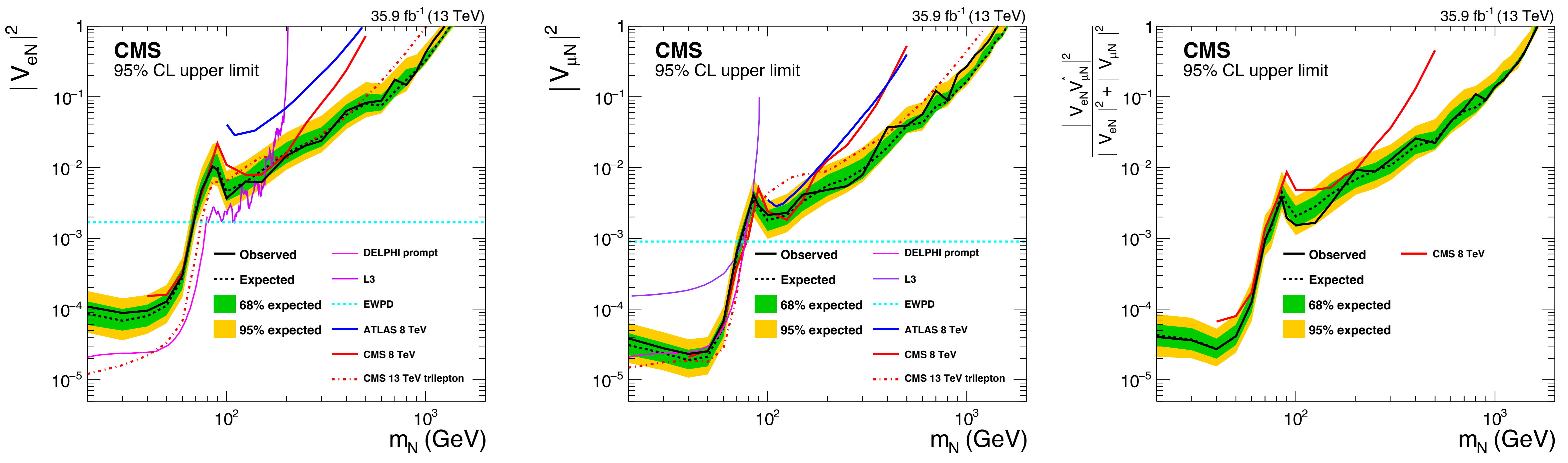
4. Search Results



No significant deviation from the SM

5. Result Interpretations

95% CL Upper Limits on the mixing matrix element, $|V_{\ell N}|^2$



6. Conclusion

- Heavy Majorana neutrino search in SS dilepton final states at 13 TeV has been performed
- m_N between 20 and 1600 GeV was searched, but no significant deviation from SM prediction observed
- Upper limits of the mixing matrix elements are set for electron, muon, and electron-muon.
- Most stringent direct limits for N masses above 430 GeV
- Publication : 10.1007/**JHEP**01(2019)122

Posters@LHCC: Students' Poster Session at the 2019 Winter LHCC meeting, 27 Feb 2019, CERN, Geneva (Switzerland)