Searching for Heavy Neutrinos in Same-Sign Dilepton Events at $\sqrt{s}$ = 13 TeV Using the CMS detector

[CMS-EXO-17-028]

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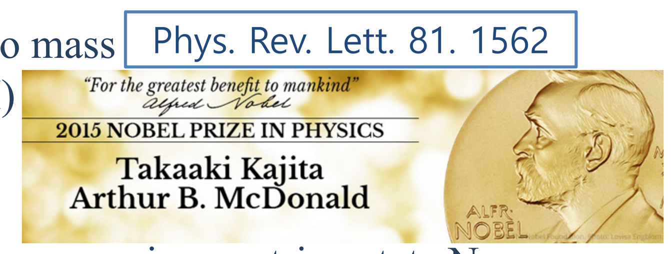
Ⅰ. Overview

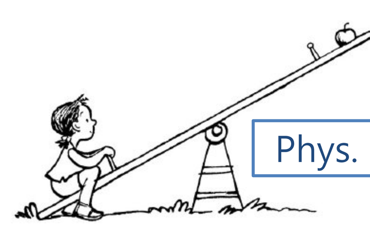
- The CMS experiment has performed searches for heavy neutrinos at the LHC. We present the studies of heavy neutrino searches (Majorana type) in the same-sign dilepton plus jets channel using 2016 proton-proton collision data at $\sqrt{s}$ = 13 TeV with integrated luminosity 35.9 fb^{-1}.

Ⅱ. Introduction

- Non-zero masses of ν
  - The discovery of neutrino oscillations ➡ Non-zero mass Phys. Rev. Lett. 81. 1562
  - Clear evidence for physics beyond the Standard Model (SM)



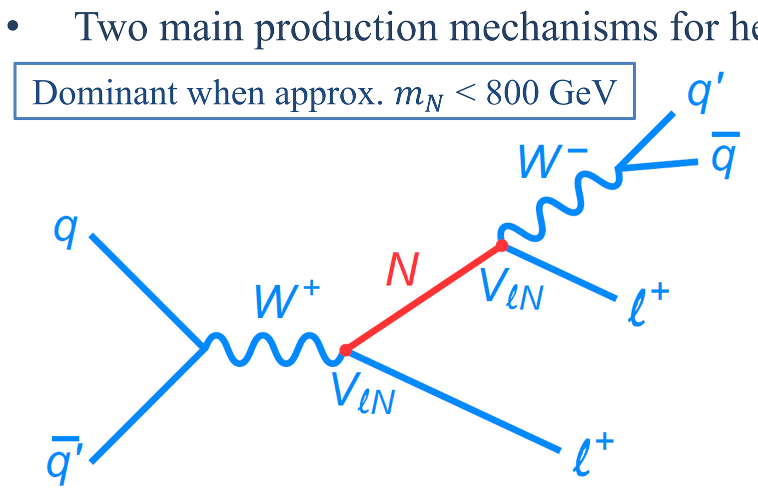
- See-saw mechanism
  - The smallness of the SM neutrinos (m_ν) is explained by a new massive neutrino state N, $m_\nu \approx \frac{y_\nu^2 v^2}{m_N}$
  - In this model, both ν and N are Majorana type

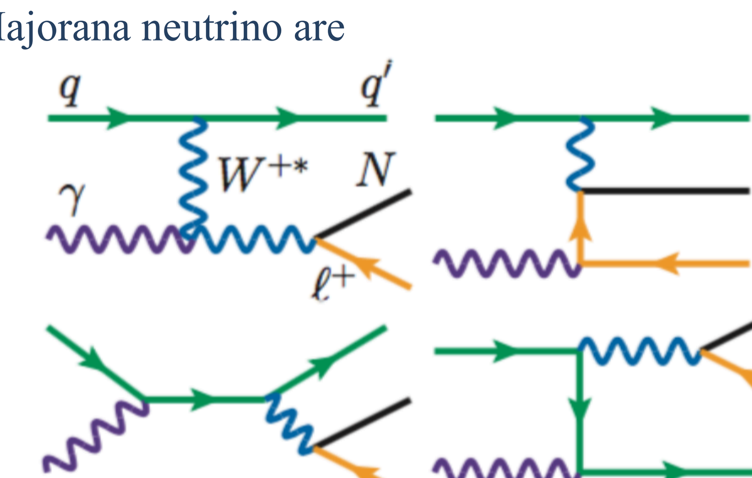


Phys. Rev. Lett. 44. 912

- Search for Majorana neutrino at the LHC
  - Some see-saw models predict heavy neutrinos at 100-1000 GeV, if m(ν_e) ~ 0.1 eV
  - Two main production mechanisms for heavy Majorana neutrino are

Dominant when approx. m_N < 800 GeV





NEW!!

Dominant when approx. m_N > 800 GeV

  - The same-sign dilepton and jets final state with no MET
  - Violates the lepton-number conservation
- Previous results in CMS at $\sqrt{s} = 8$ TeV and trilepton channel $\sqrt{s} = 13$ TeV

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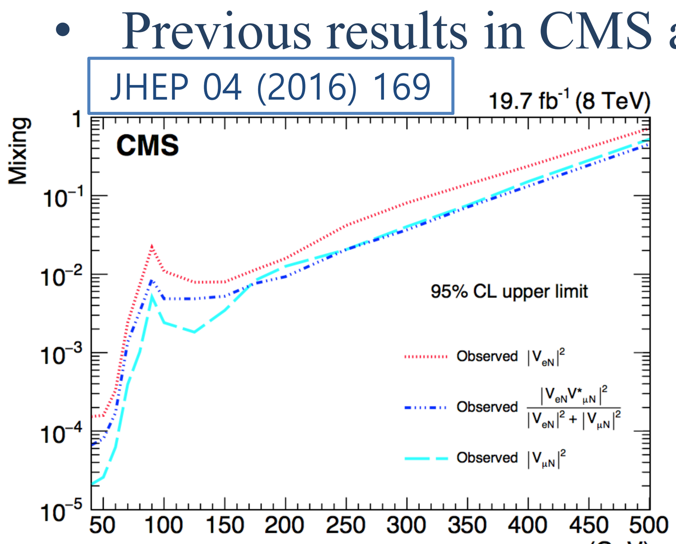
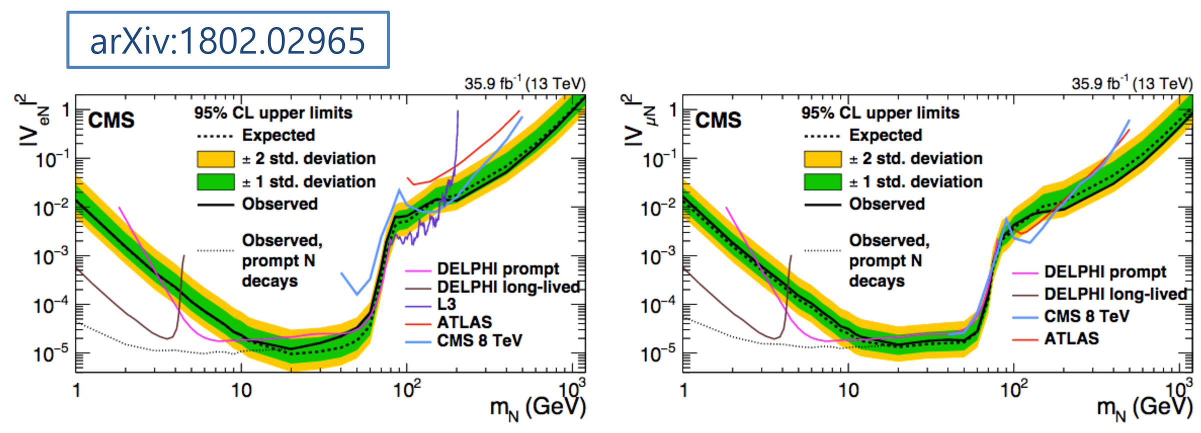


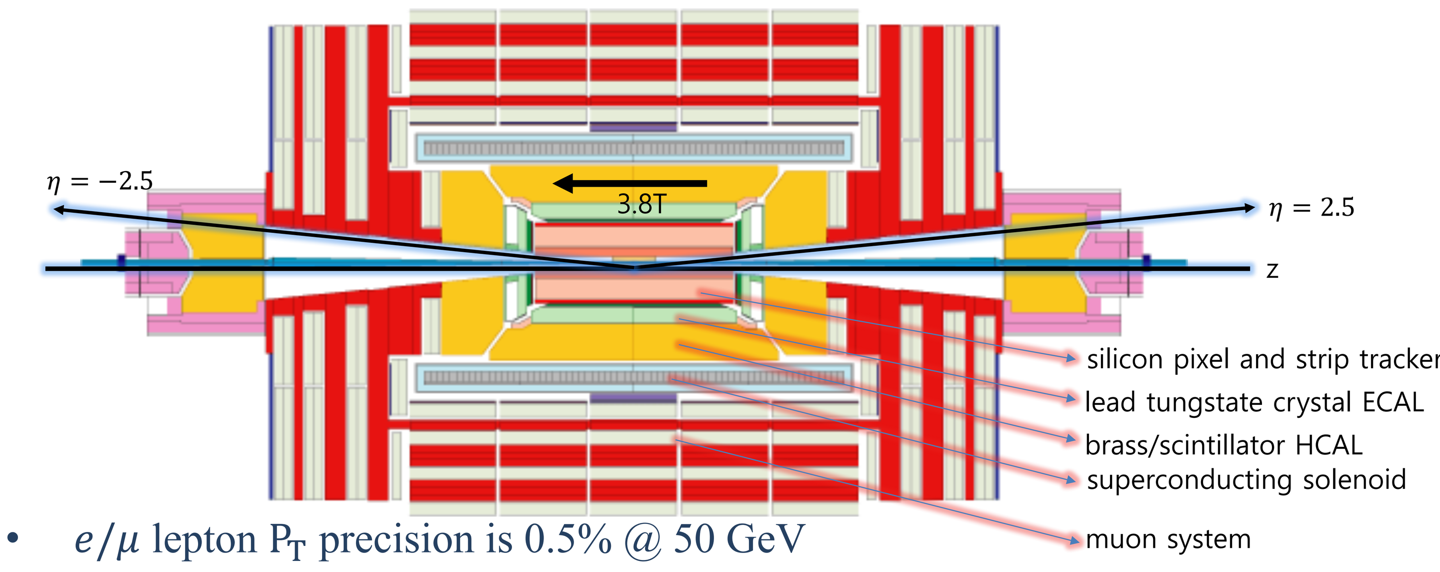
arXiv:1802.02965



  - No significant excess of events beyond the standard model background prediction is found

Ⅲ. CMS detector and data selection

- The CMS detector



  - e/μ lepton P_T precision is 0.5% @ 50 GeV
  - Jet P_T precision is 10% @ 100 GeV
  - 40 MHz event rate → ~ 100 kHz after level 1 triggers → ~ 1 kHz after high level triggers (HLT)
- Event selection
  - HLT : un-prescaled triggers with two isolated leptons (e/μ)
  - Two same-sign leptons (e/μ) with CMS standard jets (j, AK4) and wide cone jets (J, AK8)
  - Two signal regions (SR) divided by m_N
    - Low mass region ($m_N < m_W$) : ~ 0.2 to 3 % signal efficiency
      - SR1 : N(j) ≧ 2. W_{jet} is defined as two jets where m(jj) closest to m_W
      - SR2 : N(j) = 1. W_{jet} is defined as the jet NEW!!
      - No b-tagged jet, m(ll W_{jet}) < 300 GeV, and E_T^{miss} < 80 GeV
    - High mass region ($m_N > m_W$) : ~ 0.5 (m_N = 85 GeV) to 40 (m_N = 1 TeV) % signal efficiency
      - SR1 : N(J) = 0 and N(j) ≧ 2. W_{jet} is defined as two jets where m(jj) closest to m_W
      - SR2 : N(J) ≧ 1. W_{jet} is defined as a fat jet where m(J) closest to m_W NEW!!
      - No b-tagged jet, m(W_{jet}) < 150 GeV, and $\frac{(E_T^{miss})^2}{S_T}$ < 15 GeV where S_T is scalar sum of leptons P_T, jets' P_T and E_T^{miss}
  - Additional optimized event cuts are applied for each heavy neutrino mass point

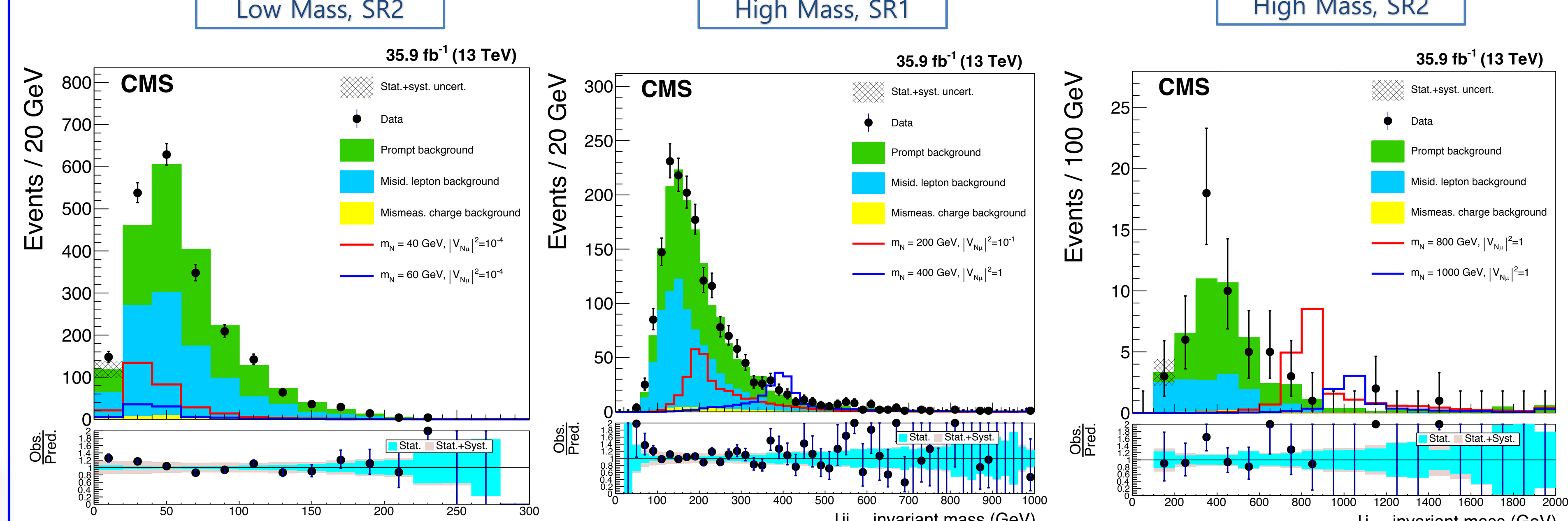
Ⅴ. Backgrounds

- Fake leptons: at least one lepton originated from B decay or generic jets
  - Examples of fake leptons from generic jets
    - Electron : $\pi^0 \longrightarrow \gamma\gamma$ decay with nearby track, photon conversion
    - Muon : $K^\pm$ decay into muon, punch through of charged hadrons to muon system
  - Estimation
    - Measure T/L, where T is number of leptons passing tight ID and L is number of leptons passing loose ID, after subtracting prompt lepton contribution by Monte-Carlo (MC) simulation
    - By using T/L, we can estimate fake background with TL and LL dilepton data events while L leptons failed tight criteria
  - Systematics ~ 30 %
    - Different loose lepton ID criteria, detector effects, and varying event selection cuts used to define T/L measuring region are included
    - Tested by MC closure test, comparison between data and expected background in fake lepton dominant control region
- Charge mis-measurement (CM) of leptons
  - The probability is very small for muons ➡ Ignore!
  - Estimation for electrons
    - CM probability is estimated from MC simulation of DY events as function of 1/P_T and |η|
    - Validated with observed $e^\pm e^\pm$ event yield and expected $e^\pm e^\pm$ yield by applying CM probability to $e^\pm e^\mp$ events, after requiring m(ee) to be |m(ee) – m_Z| < 15 GeV
      - Difference in number of observed and expected $e^\pm e^\pm$ events is corrected by scale factors (SF) for CM probability
  - Systematics < 4% uncertainty on total background
    - MC closure test, half sample test, and small statistic effect for high P_T electrons
    - Uncertainty on SF is measured by varying Z boson mass window, and P_T cut of electrons
- Irreducible background from SM production
  - VV, VVV, $t\bar{t}V$ (V : vector bosons), $W^\pm W^\pm$qq, and double-parton scattering by MC simulation
  - Three main prompt backgrounds (WZ, ZZ, and Zγ) are normalized in data from control regions
  - Systematics on cross sections and detector effects are estimated ~ 13 to 45 %

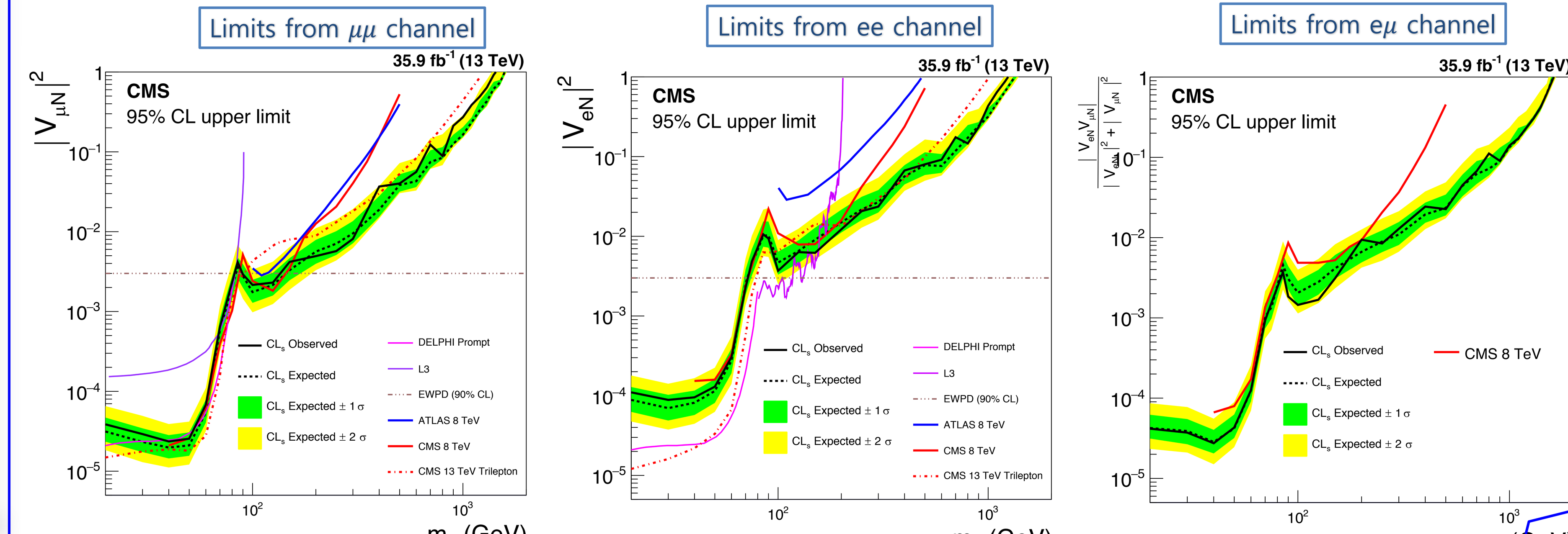
Ⅵ. Result

- Results for ee, eμ, and $\mu\mu$ channels
- 95% CL limits are obtained using cut and count method

Low Mass, SR2 — High Mass, SR1 — High Mass, SR2



Limits from $\mu\mu$ channel — Limits from ee channel — Limits from eμ channel



Ⅶ. Conclusion

- Analysis in same-sign dilepton with jets channel @ 13 TeV data has been performed
- World best direct limit on $|V_{\mu N}|^2$ for m_N > 100 GeV and on $|V_{eN}|^2$ for m_N > 150 GeV
- Unique searching for heavy neutrino at same-sign electron-muon channel with 13 TeV data