LHC Results on Heavy Neutrino Searches

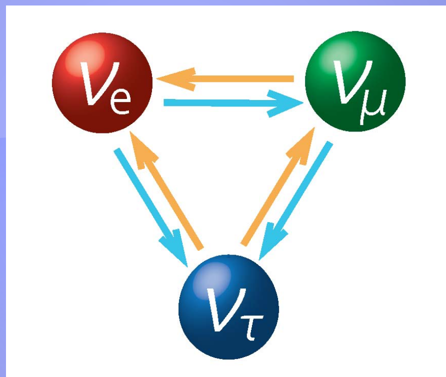
Un-ki Yang

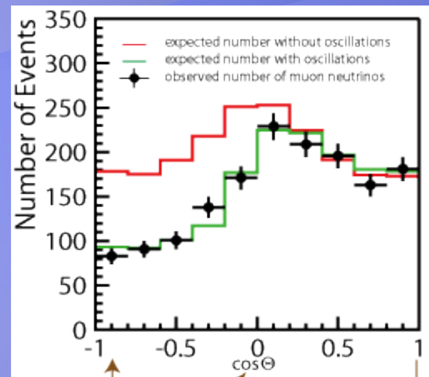
Seoul National University

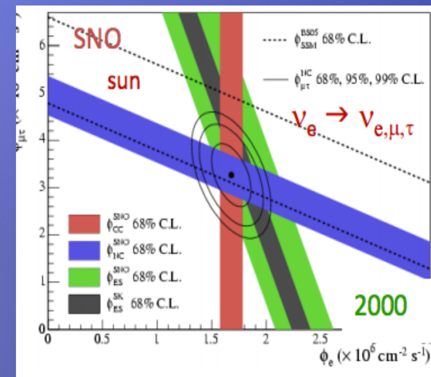
On behalf of the ATLAS & CMS collaborations

NuFact 2018, Aug. 13 – 18, 2018, Virginia Tech

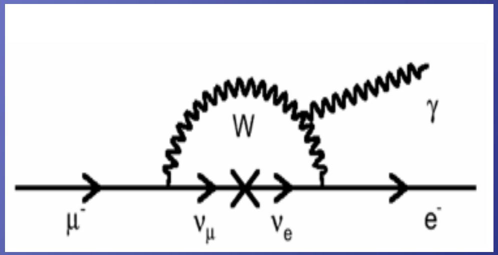
Neutrino Oscillation

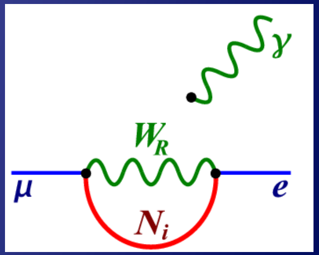






- Neutrino oscillations
- Small neutrino mass





- Lepton Number Violation (LNV)
- Neutrino Mass Generation

See WG4 LNV talks this afternoon (ATLAS, CMS, LHCb)

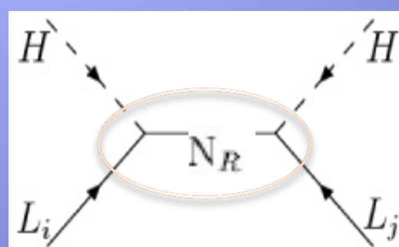
- Beyond the Standard Model

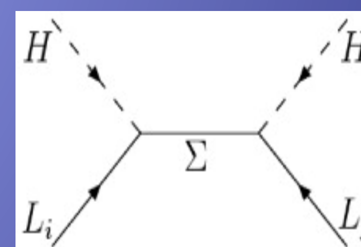
Neutrino: Physics Beyond SM

- A natural way to generate LNV and neutrino mass
  - Introduce an effective operators to the SM

$$\frac{Y_L}{\Lambda_L} LLH^2 + \frac{Y_B}{\Lambda_B^2} qqqL + \ldots$$

  - Seesaw Mechanism (type I, II, III)





Type I: weak-singlet

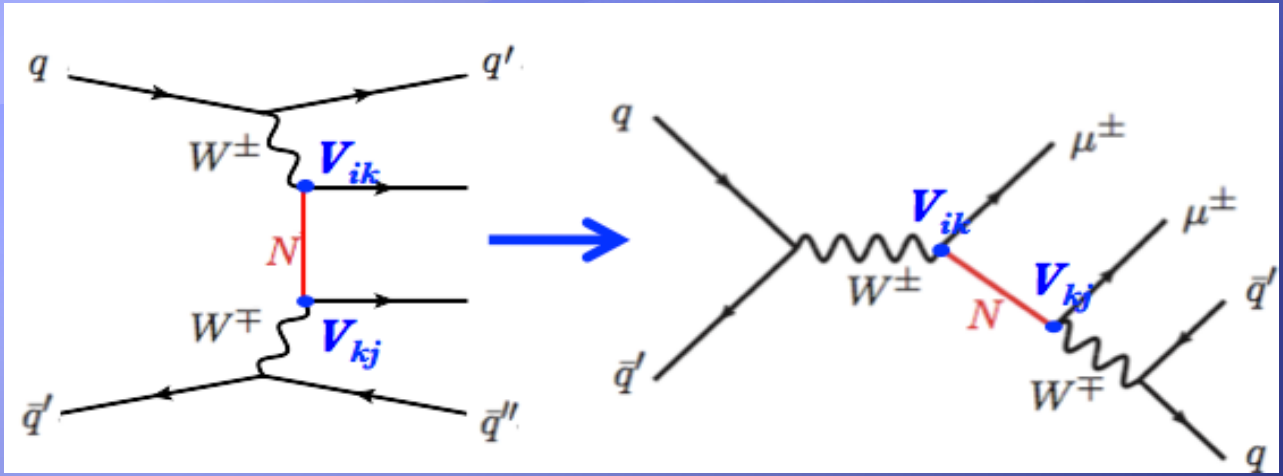
Type III: weak-triplet

- Physics behind the Seesaw? Left-Right Symmetry model offers the Seesaw scale and heavy neutrinos

$$SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$$

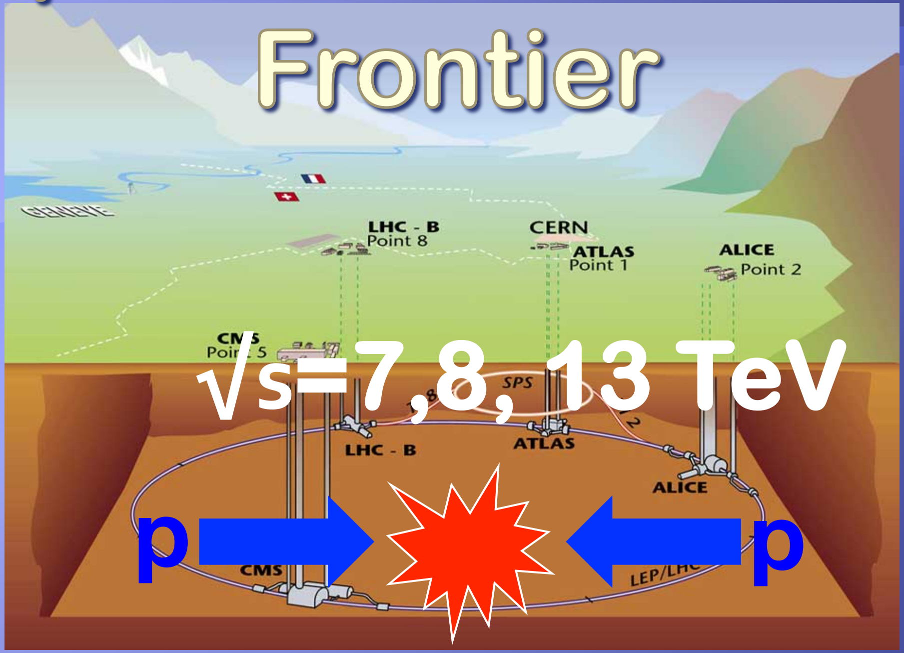
$$M_{W_R} \gg M_{W_L}$$

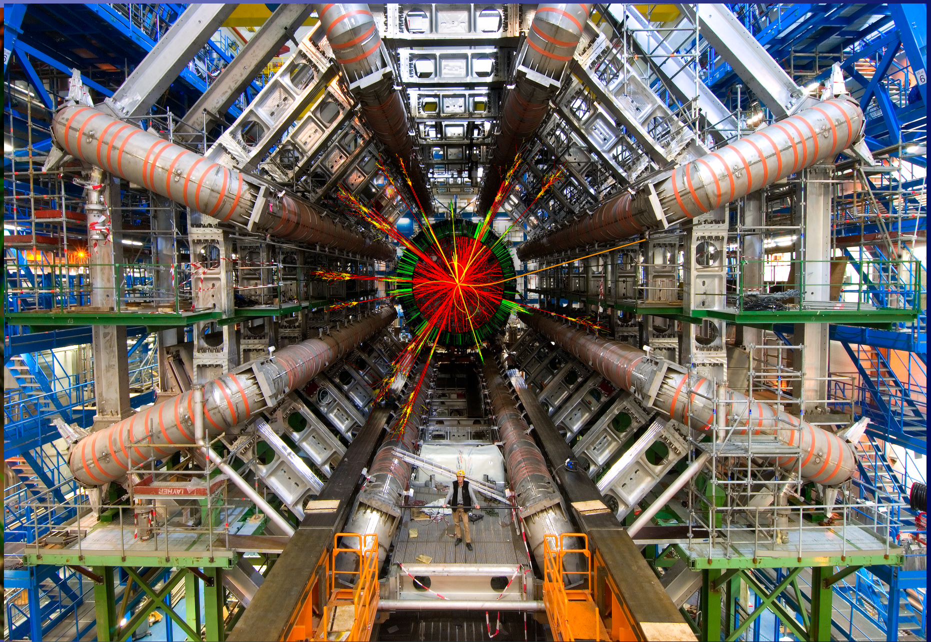
Heavy Neutrino (N) at the LHC



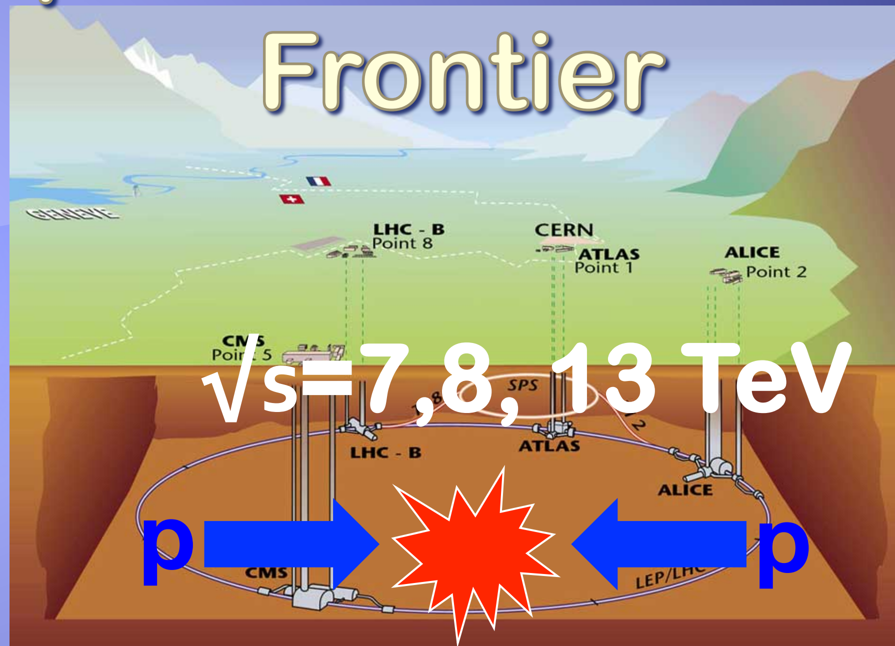
- LHC: direct production of heavy N (→lqq, llν)
  - Same-sign two leptons + 2 jets (3 leptons)
  - Type I: probe light-heavy mixing & m_N
  - LRSM: a resonance W_R production & m_N
  - Complementary to the $0\nu\beta\beta$

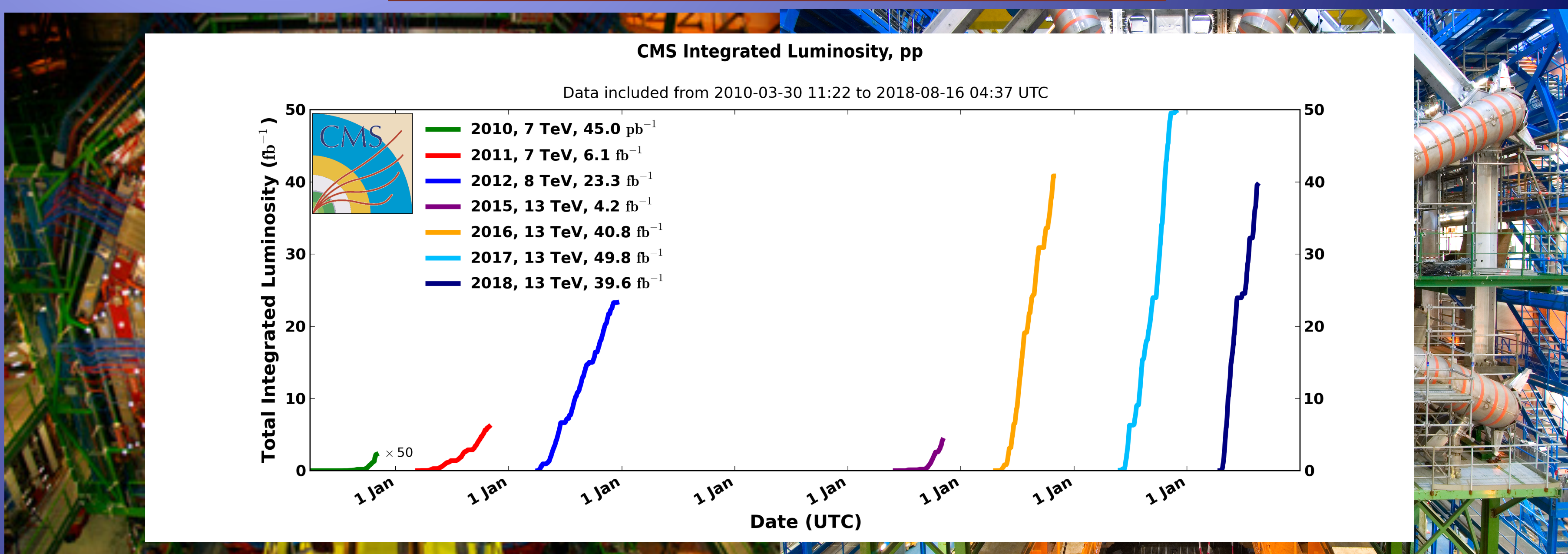
LHC Experiments at the Energy Frontier



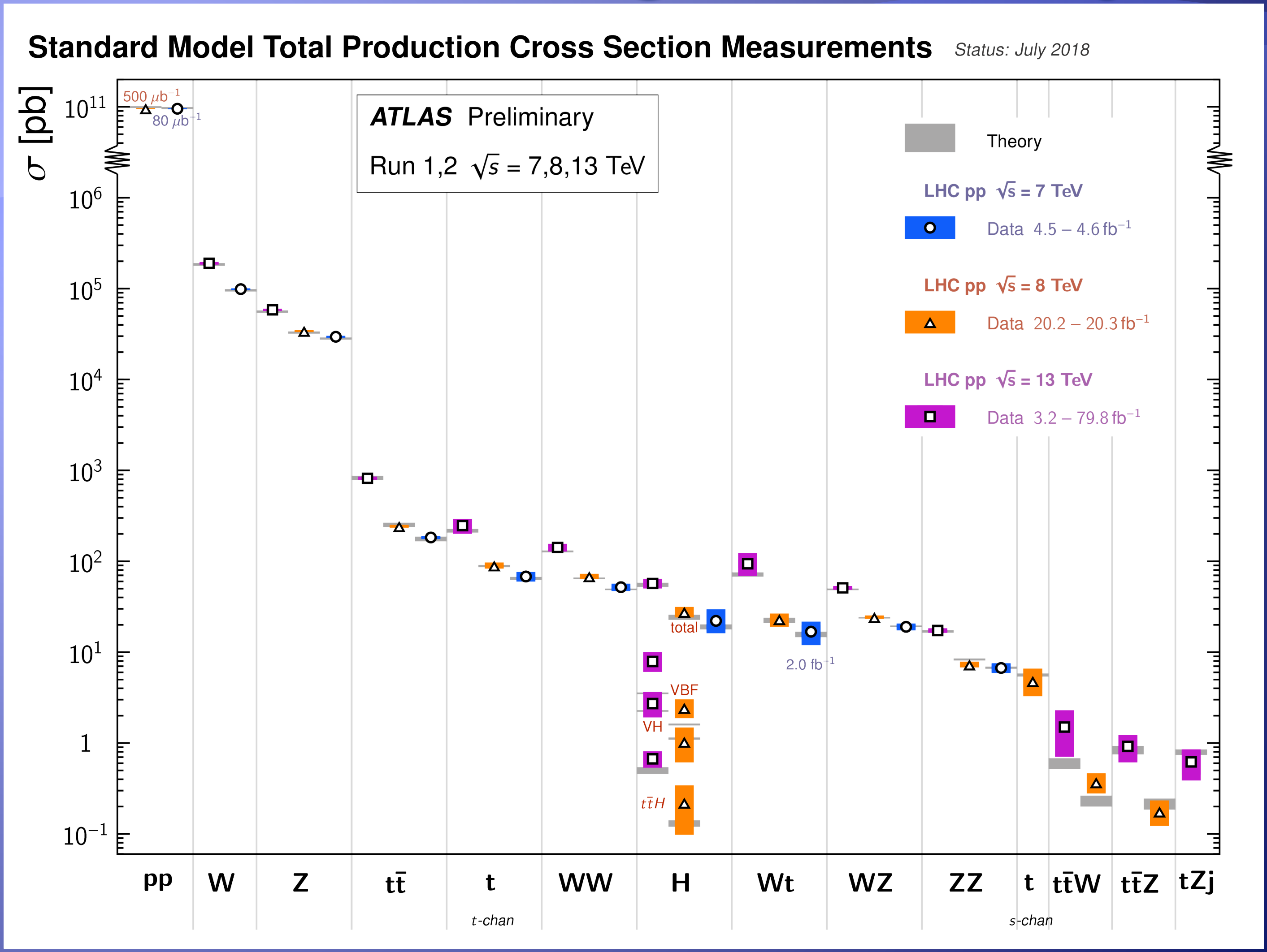


LHC Experiments at the Energy Frontier





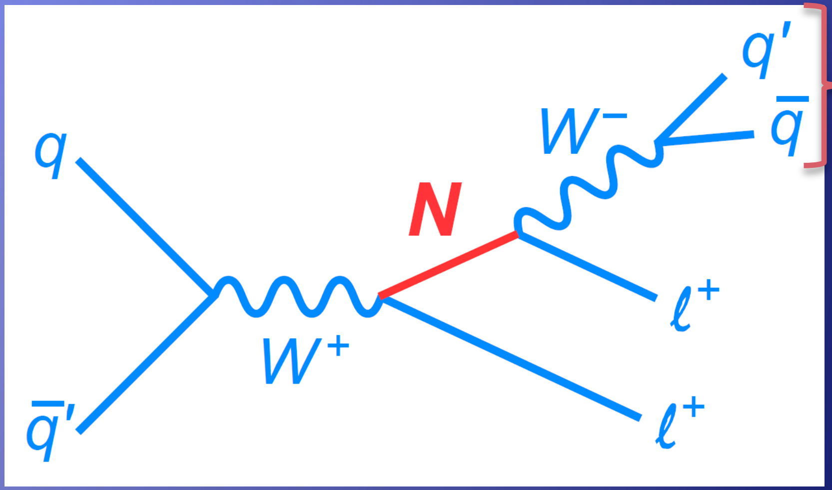
Before Searching for New Physics



- Impressive agreements with the SM

Search for Type I (dilepton)

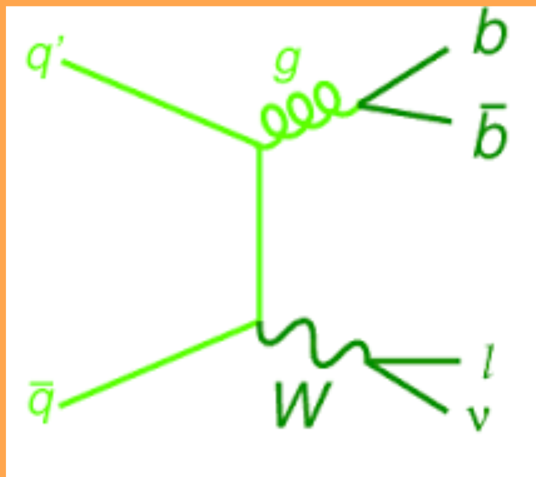
- s-channel production
- Events Selection
  - 2 same sign leptons (50%)
  - Njets: W jets (2 jets or 1 jet)



- ATLAS
  - 25/20 GeV lepton pt cuts
  - Single lepton trigger
  - Search for m(N)>100 GeV
  - Use m(W(jj)) for signals

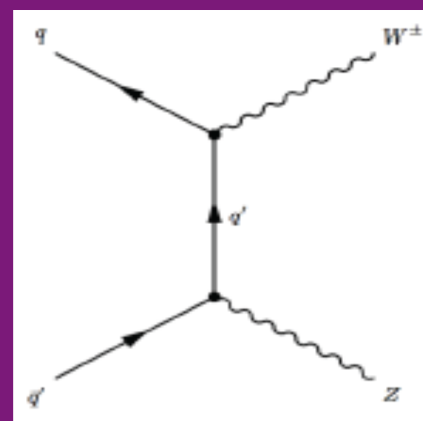
- CMS
  - 25/10 GeV lepton pt cuts
  - Di-lepton triggers
  - Search for m(N)>20 GeV
  - Use m(lW),m(llW) for signals
  - Include t-channel

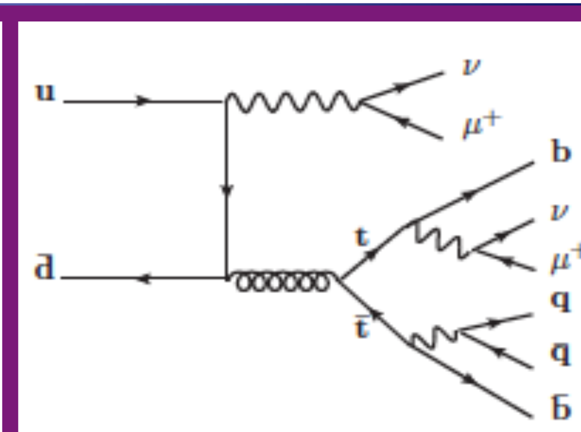
Backgrounds: ee/μμ/eμ+2 jets

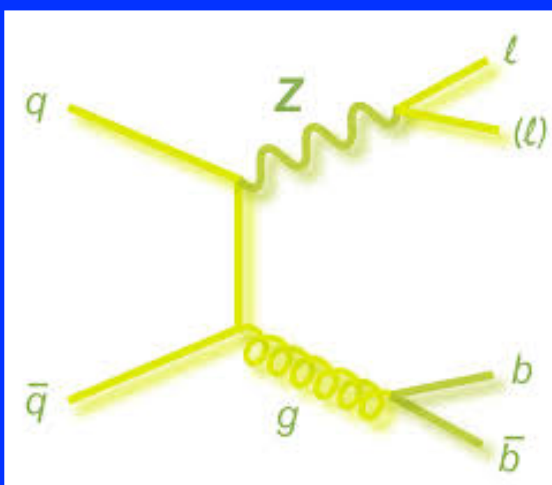


Fake leptons: "data"
W(e,μ)+jets:
dominant bkgd

SM prompt lepton; MC
dibosons(VV), tt+V



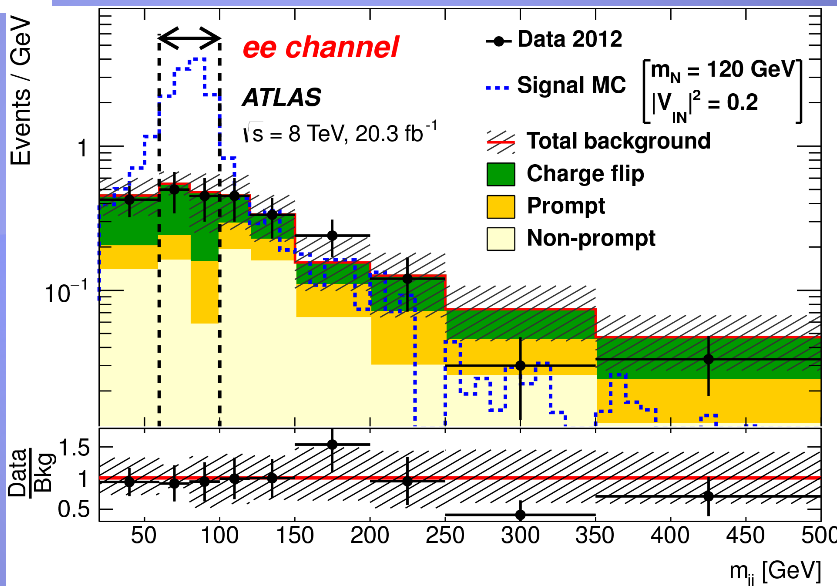


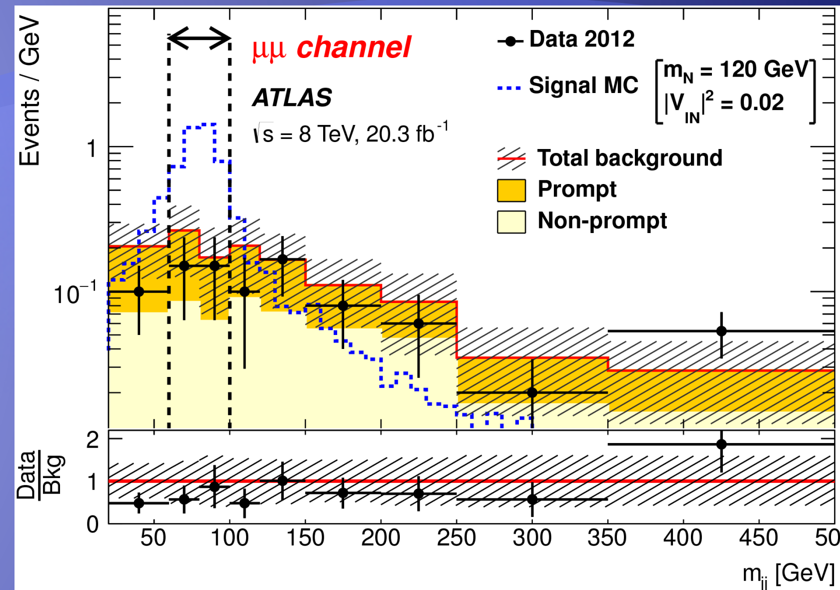


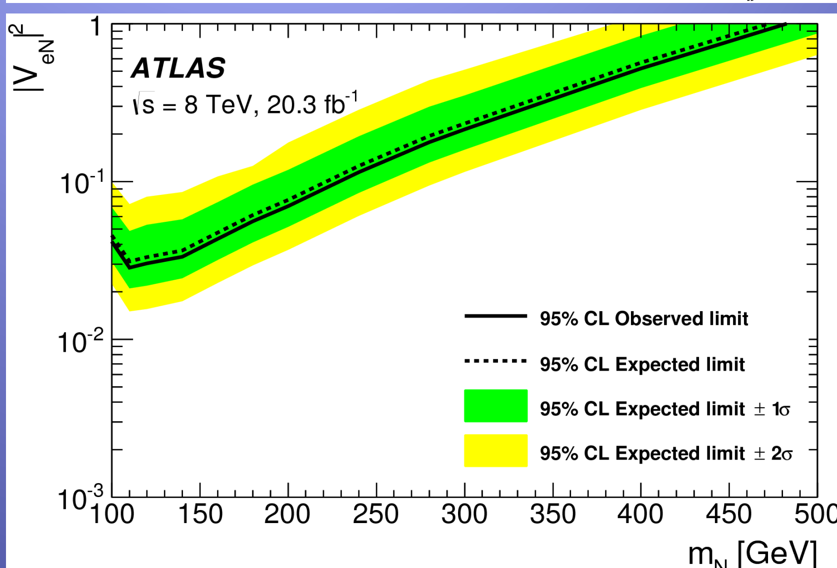
Charge-flip: "data+MC"
Z(ll)+2jets

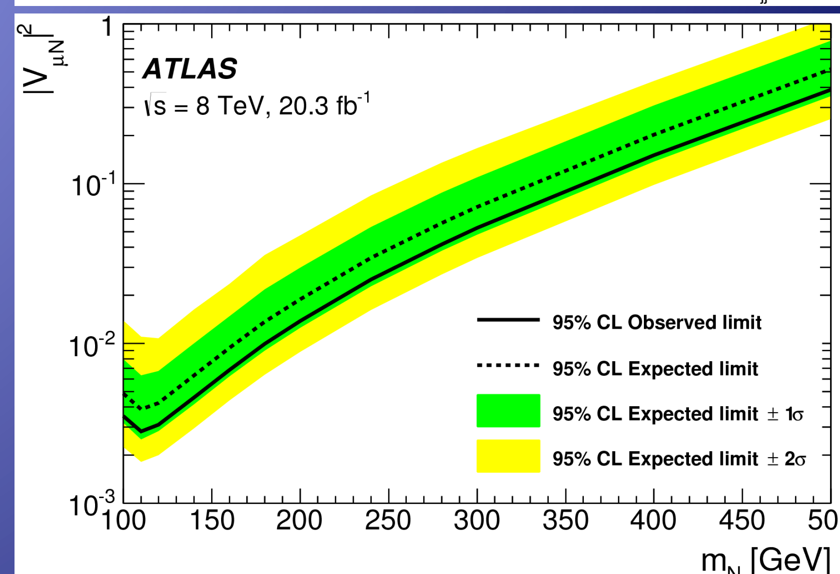
ATLAS Results @ 8 TeV

JHEP 1507 (2015) 162





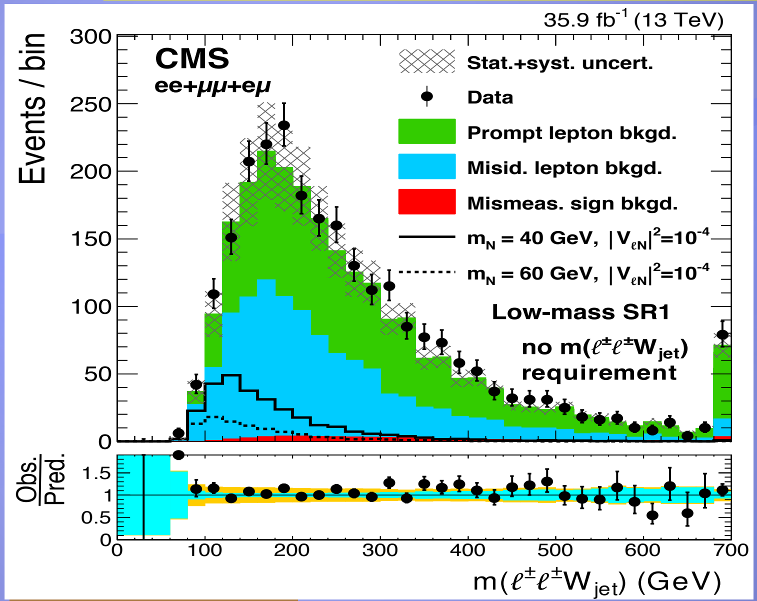


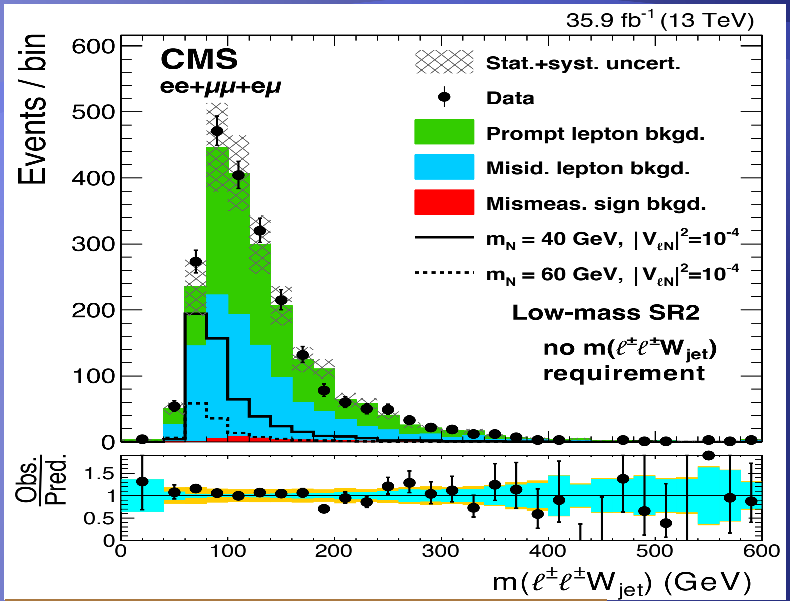


- No excess, upper limits on $|V_{eN}|^2$ and $|V_{\mu N}|^2$

CMS Results@13 TeV

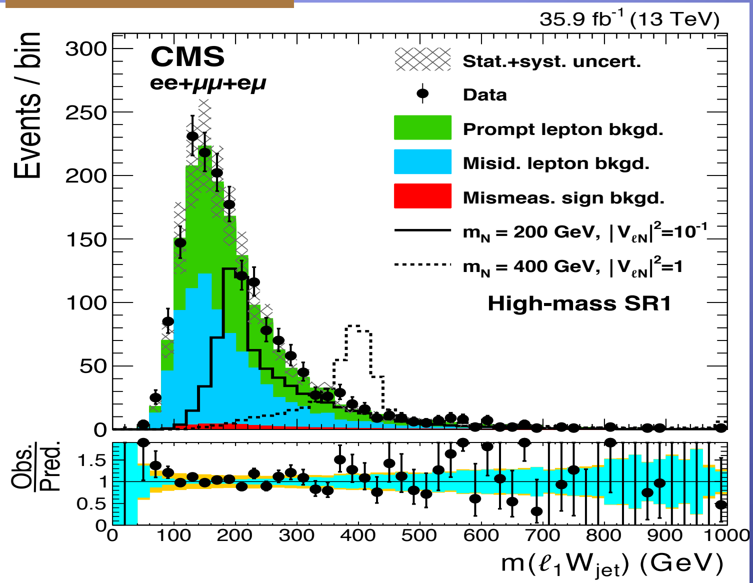
arXiv:1806.10905
CMS:EXO-17-028

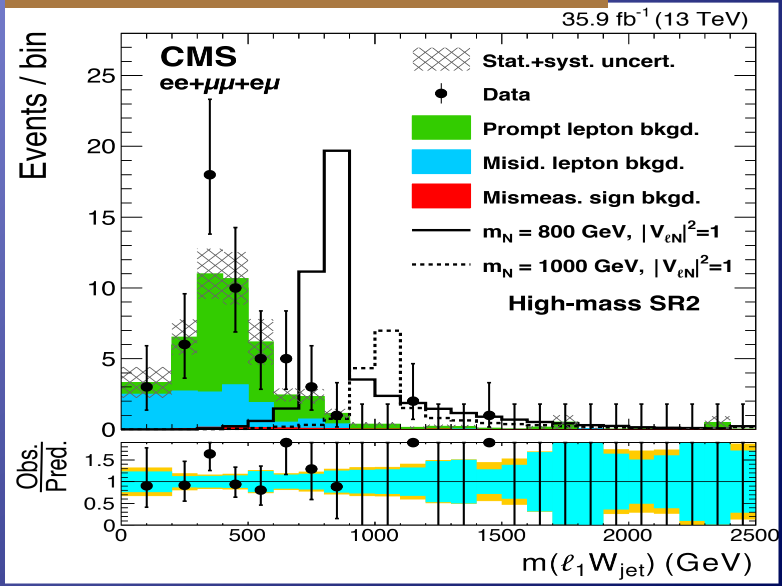




SR1: W: 2 jet

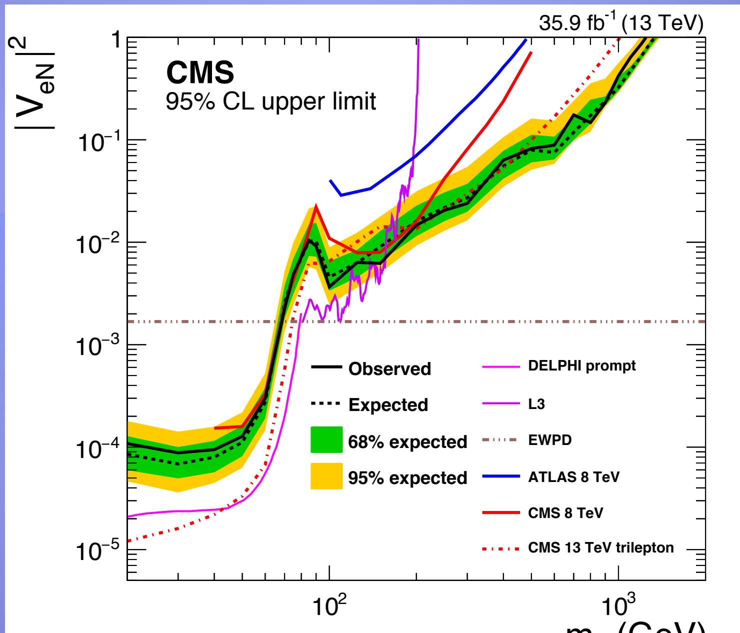
SR1 W: 1 jet (lost or merged)

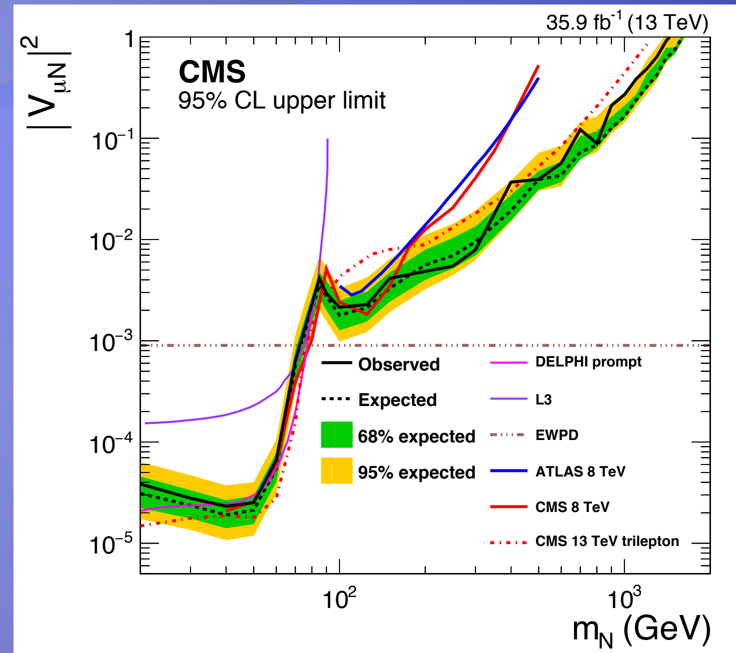


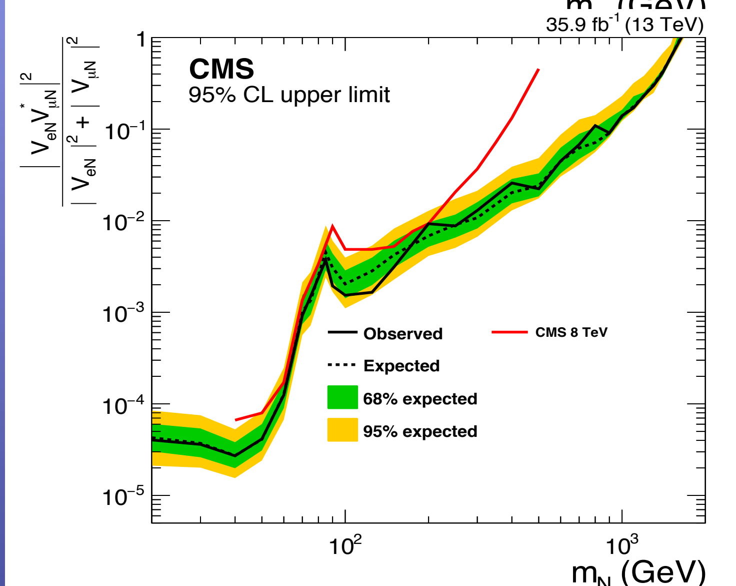


Results on Mixing

arXiv:1806.10905
CMS:EXO-17-028



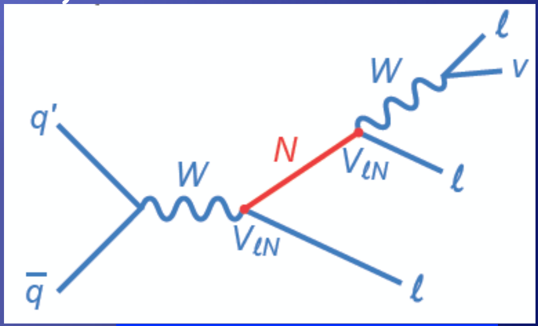




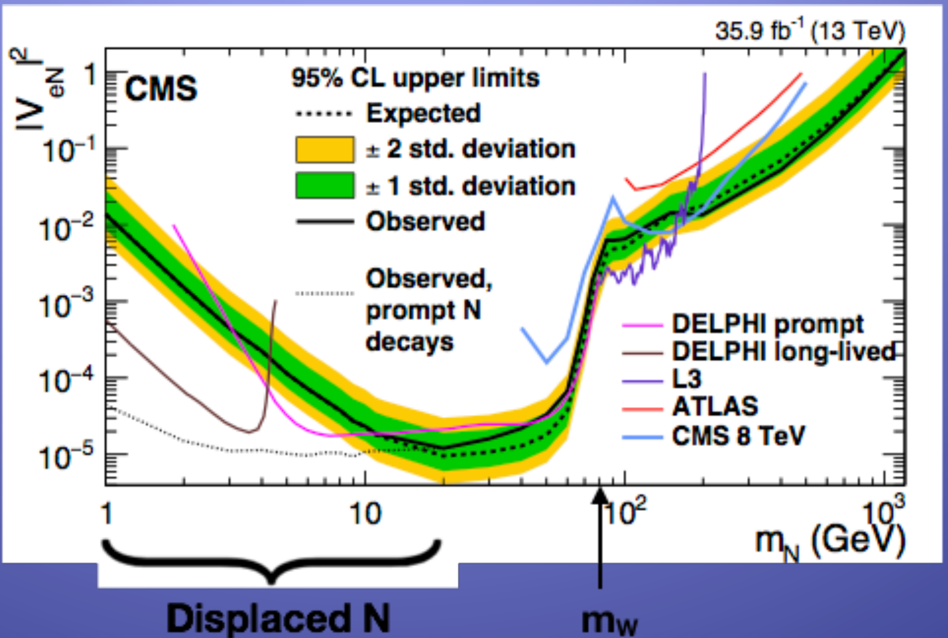
- **LHC provides the best direct limits on $|V_{eN}|^2$, $|V_{\mu N}|^2$, and $|V_{eN}{}^*V_{\mu N}|$ for high mass region**
- **Significant improvement to past searches**
  - **CMS limits down to 20 GeV, and up to 1.2 TeV**
  - **Lepton flavor change case by CMS**

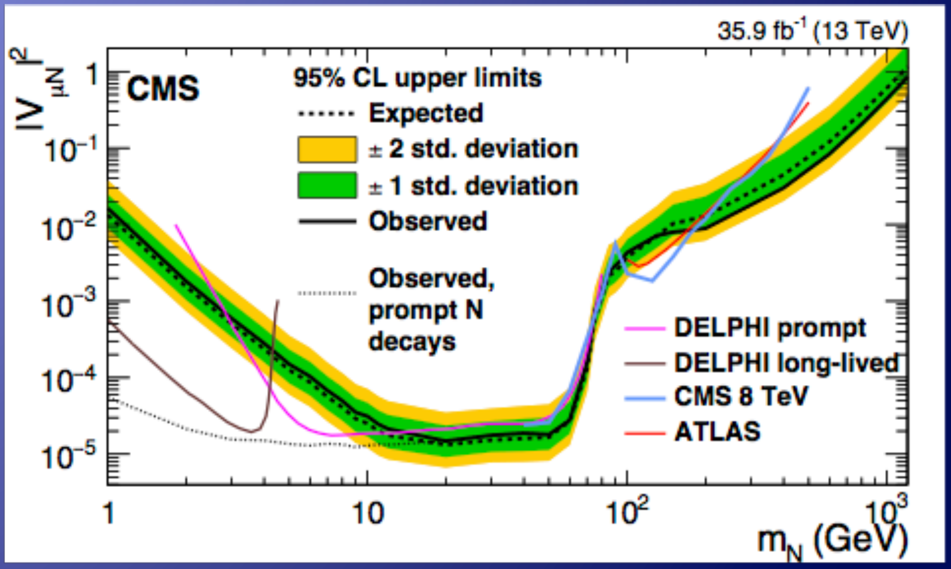
Searches in tri-lepton @ 13 TeV

- In di-lepton+2 jets: difficulty to explore small m_N region due to jet pt cut (hard to select jets below 20 GeV, but lepton is easier)
- Tri-lepton channel: smaller BR, but no jet
  - Promising with high-statistics
- No evidence for heavy N
  - Significant improvement below 40 GeV



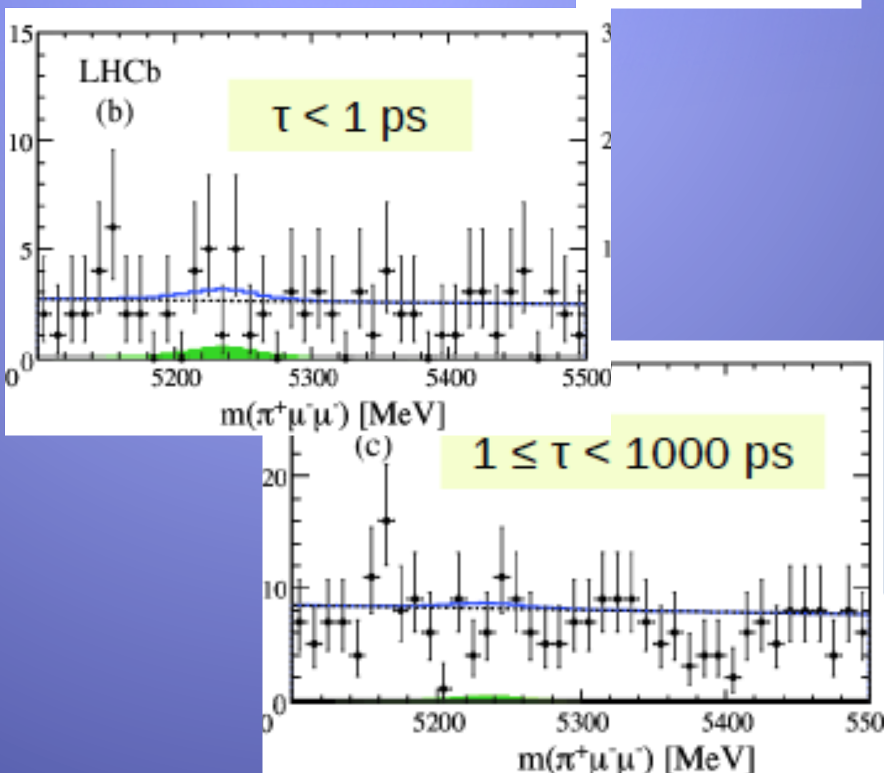
PRL 120.221801

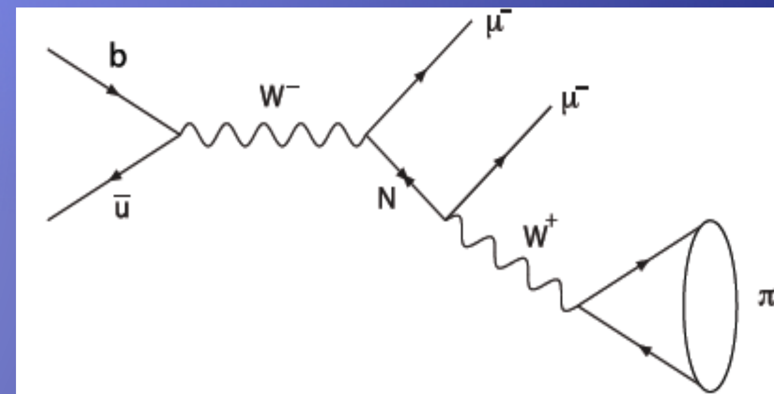




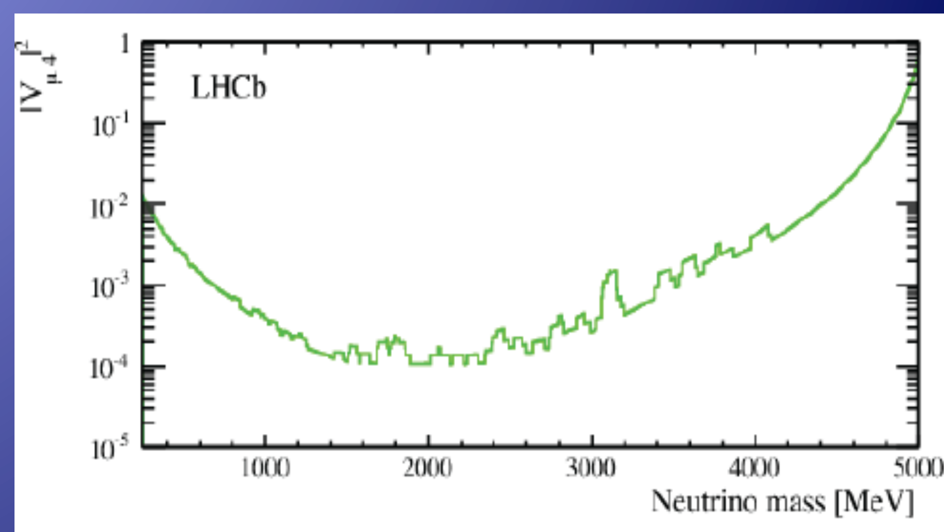
Search for Type I at LHCb

- For $0.25 < m_N < 5$ GeV
- Searches in $B^- \to \pi^+ \mu^- \mu^-$
  - Normalize to $B^- \to J/\psi K^-$





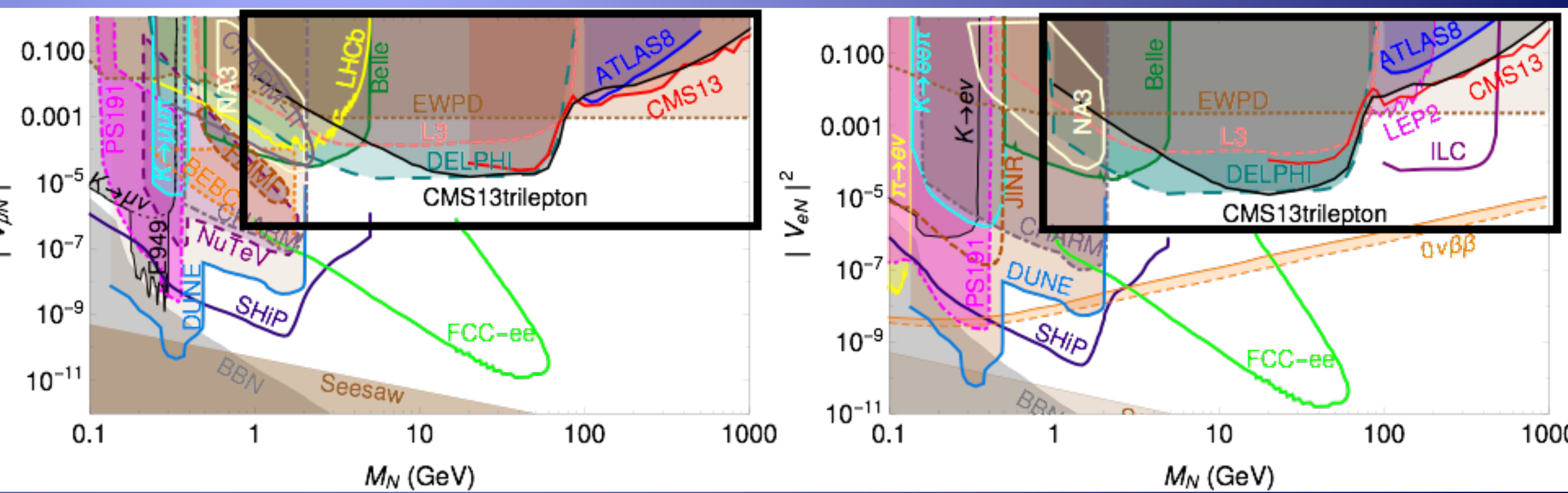
PRL 112, 131802



- Set limits on $|V_{\mu N}|^2$ for m_N<5 GeV

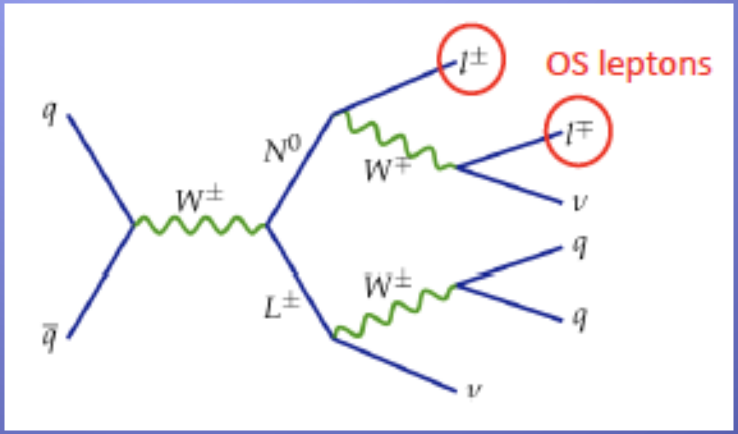
Summary on the type I

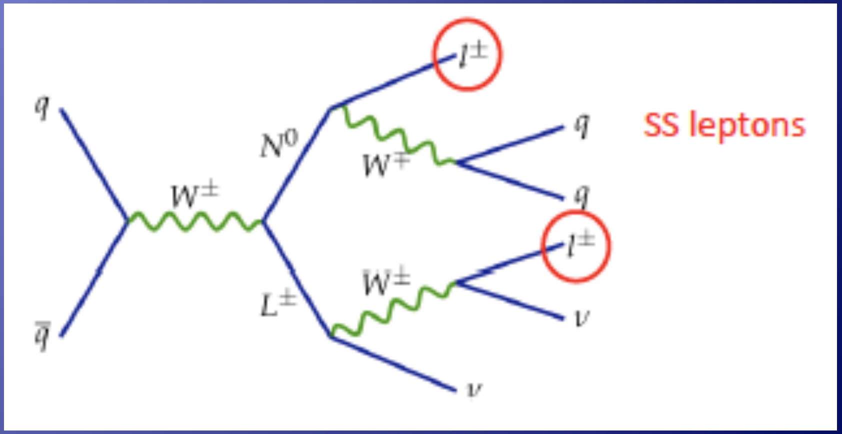
- LHC experiments probed heavy N in mass range: 1~1.6TeV with $10^{-5}<|V_{lN}|^2<1$



Search for Type III Seesaw

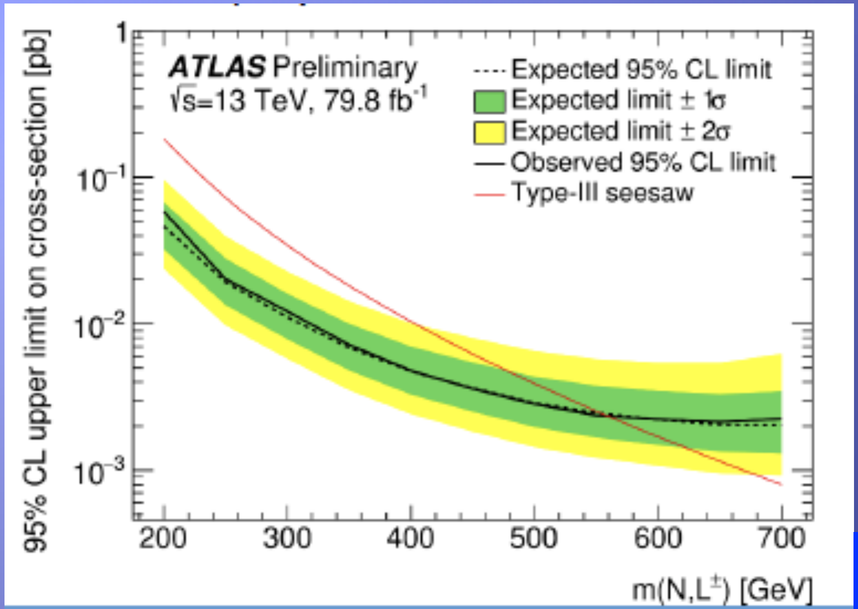
- Look for decay of new heavy fermions (N^0, N^+, N^-)
- ATLAS: OS or SS leptons + 2 jets
- CMS: 3 or 4 leptons with MET
- Both used MET + H_T(scalar sum) as search variable



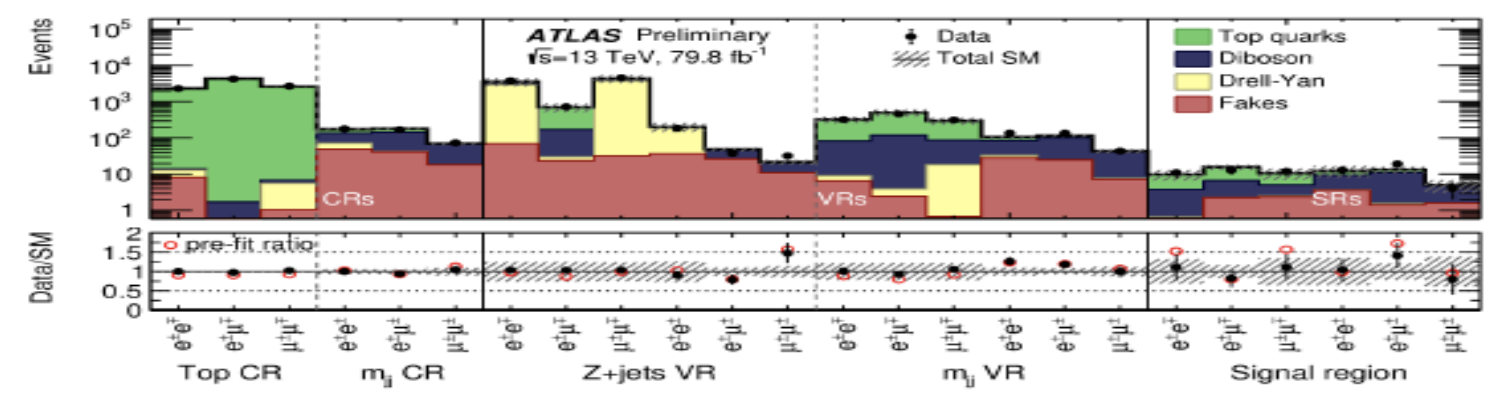


ATLAS Search for Type III

- Used MET + H_T(scalar sum) as search variable

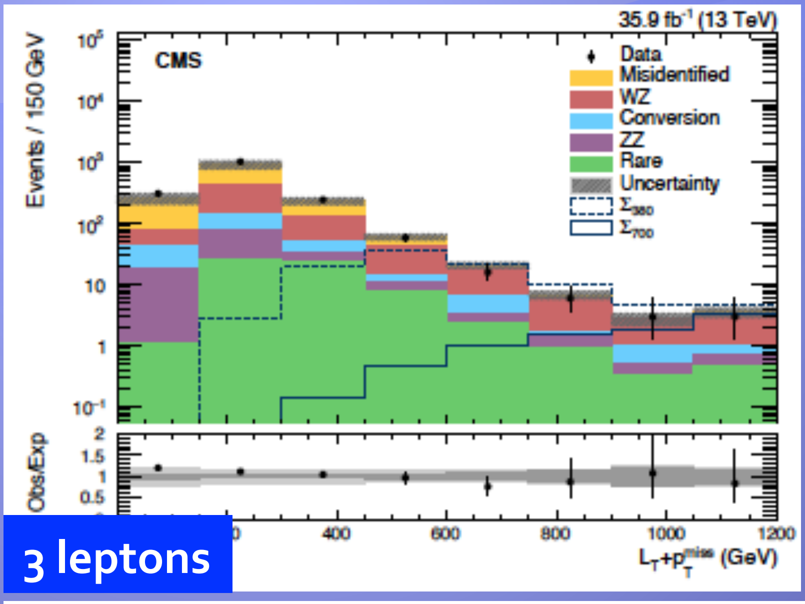


ATLAS-CONF-2018-020

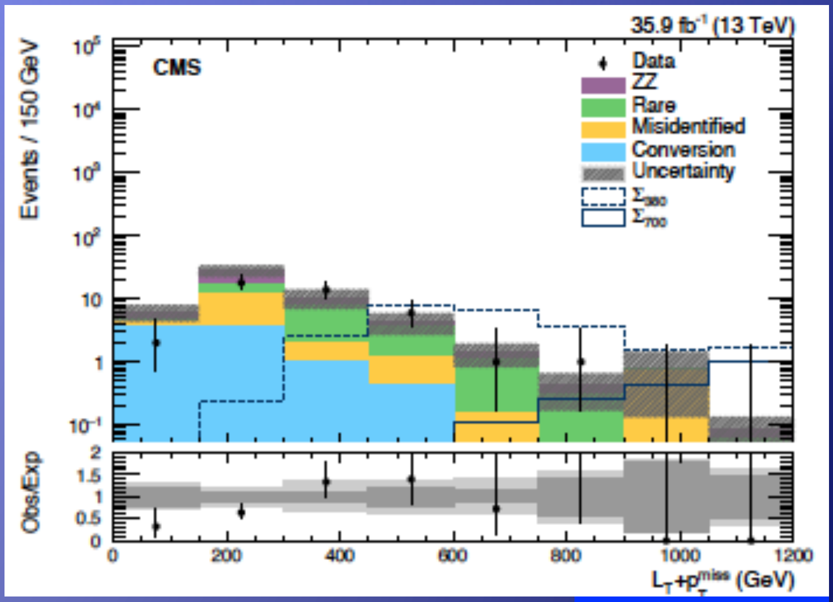


Search for Seesaw Type III

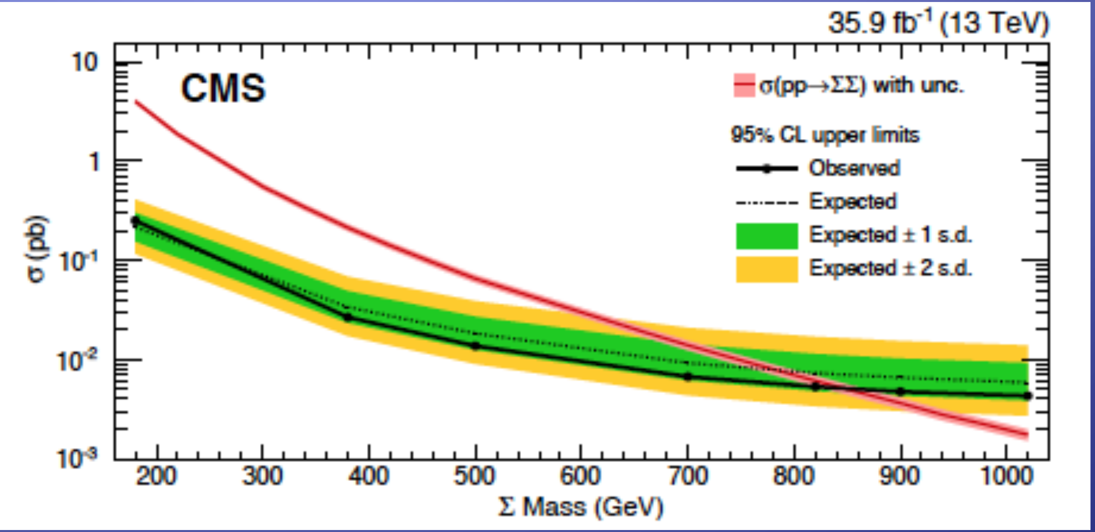
- Used MET + L_T(scalar sum over leptons)



3 leptons



>3 leptons



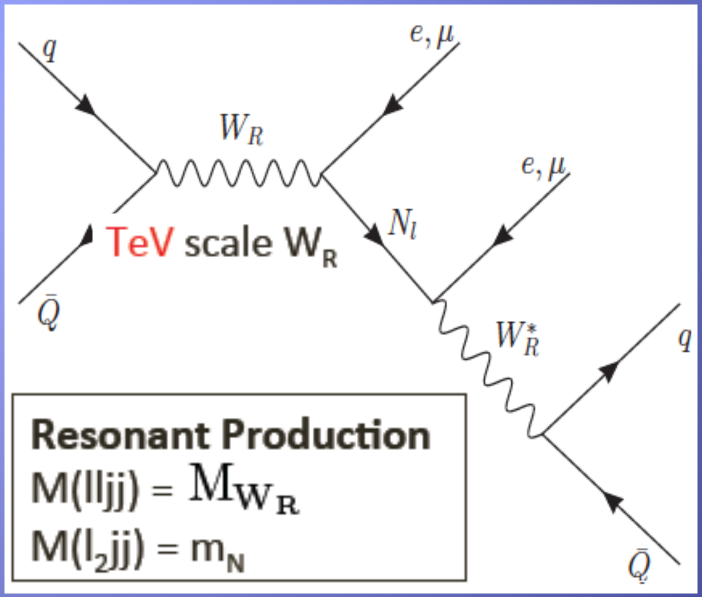
- **Exclude m(Σ) up to 840 GeV**

$V_{\mu N} = V_{eN} = V_{\tau N}$

PRL119.221802 (2017)

Searches in the LRSM

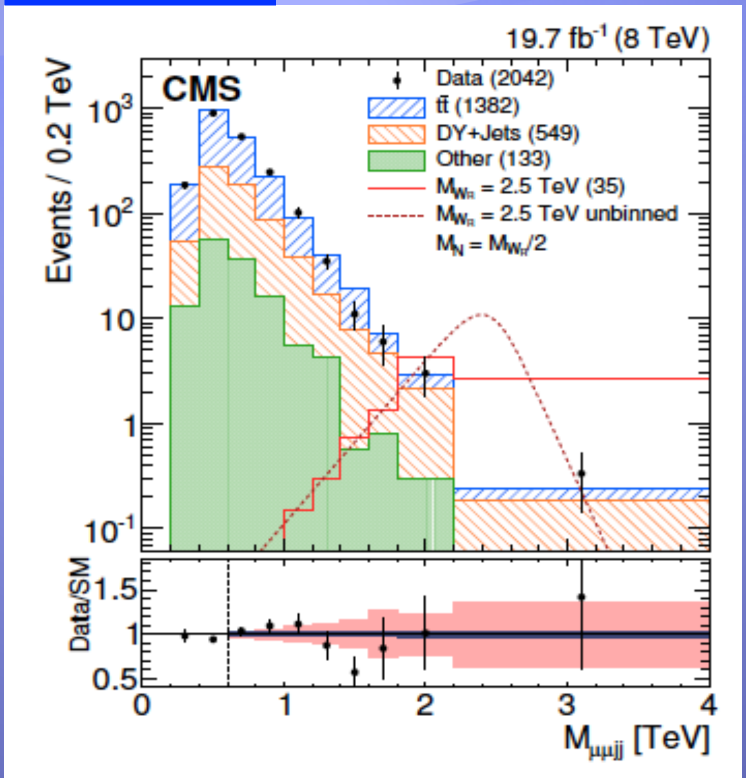
Same Final state as type I
but very different kinematics



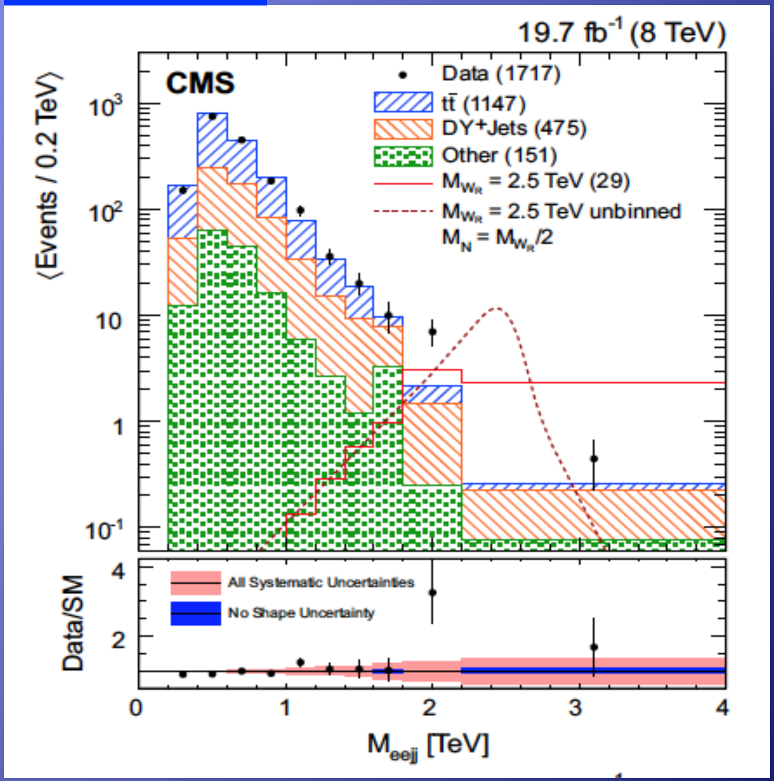
- **Challenges:**
  - **For $m_N \ll m_{WR}$, jets and lepton from N decays overlap → standard isolation will kill signals**
  - **Same challenges as Type I in terms of bkgds**

CMS Results @ 8 TeV

μμ channel



ee channel

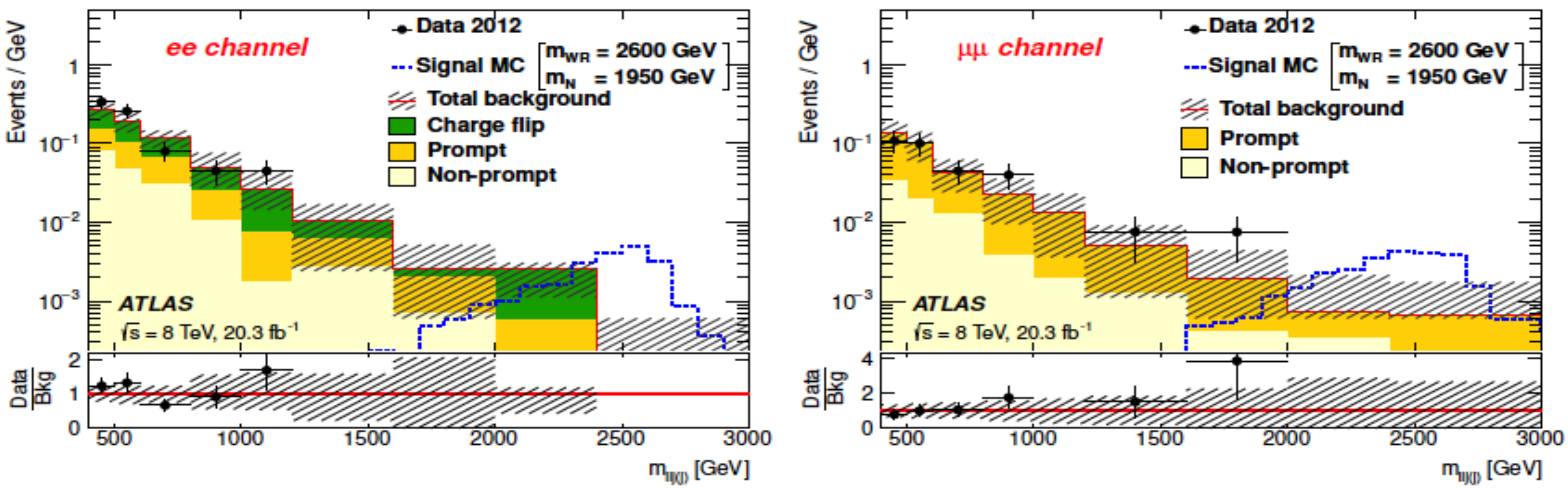


EPJ C74 (2014) 3149

- **A local significance, 2.8σ effect**
- **Consistency with the LRSM?**

Results @ ATLAS

JHEP 1507 (2015) 162



Invariant mass (lljj)

- No excess in ee channel (SS), exclude WR up to 3TeV
- OS channel?

Searches in $\tau\tau$ channel

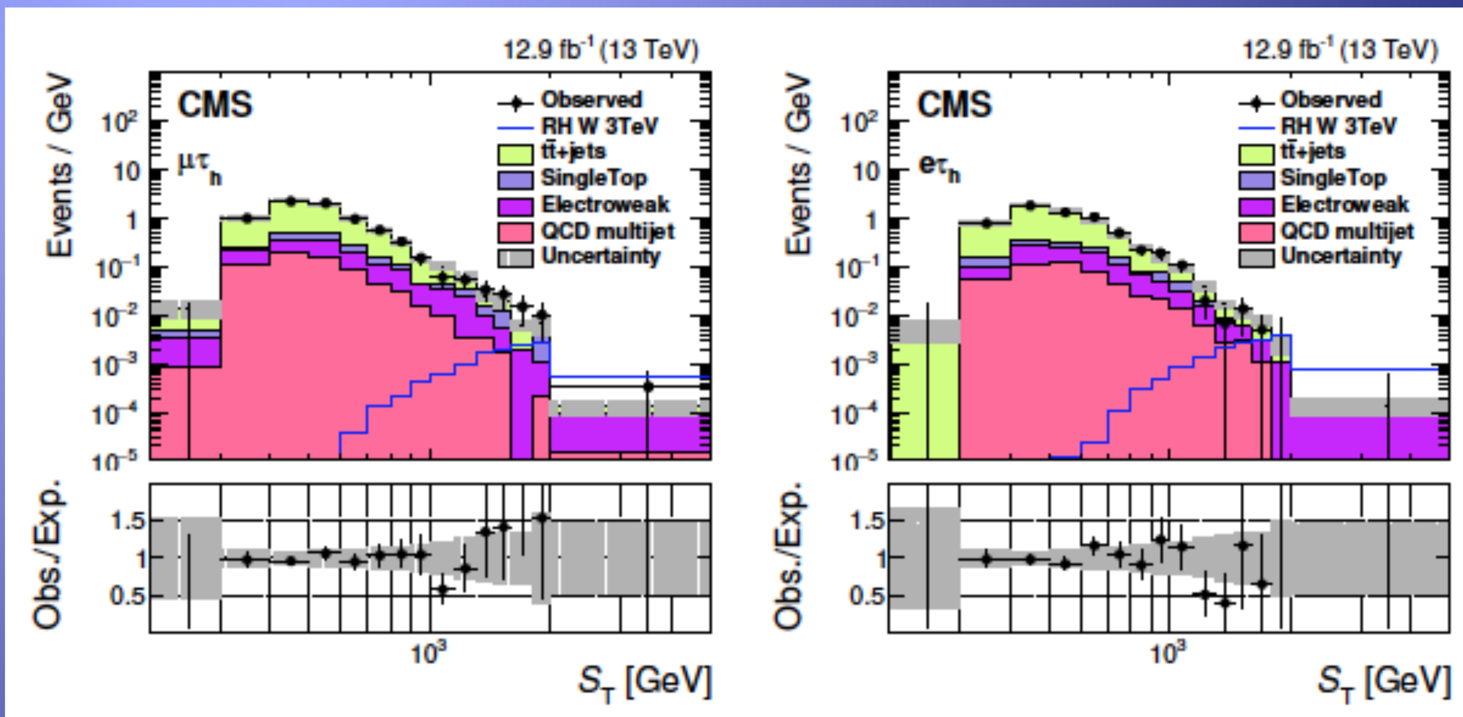
- A 2.8σ excess in eejj channel (8 TeV) but no excess in dimuon channel
  - Any broad excess in 3rd generation?

- Searches in $\tau\tau$:
  - All hadronic channel, $\tau(h)\tau(h)$ using 2.1 fb^{-1} at 13 TeV
    → Largest branching ratio, but a large QCD fake-tau
  - Lepton+hadronic channel: $\tau(e)\tau(h)$, $\tau(\mu)\tau(h)$
    → Relatively clean events, but a small branching ratio,
    → thus use 12.9 fb^{-1} at 13 TeV

Results in $\tau(l)\tau(h)$ channel

- 2016 data: 12.9 fb^{-1}
- p_T(e or μ) > 50 GeV, $p_T(\tau_h)$ > 60 GeV, MET> 50 GeV
- $m(e\tau_h$ or $\mu\tau_h)$ > 150 GeV, $m(j\tau_h)$ > 250 GeV,
- 2 jets with p_T>50 GeV

JHEP07(2017)121

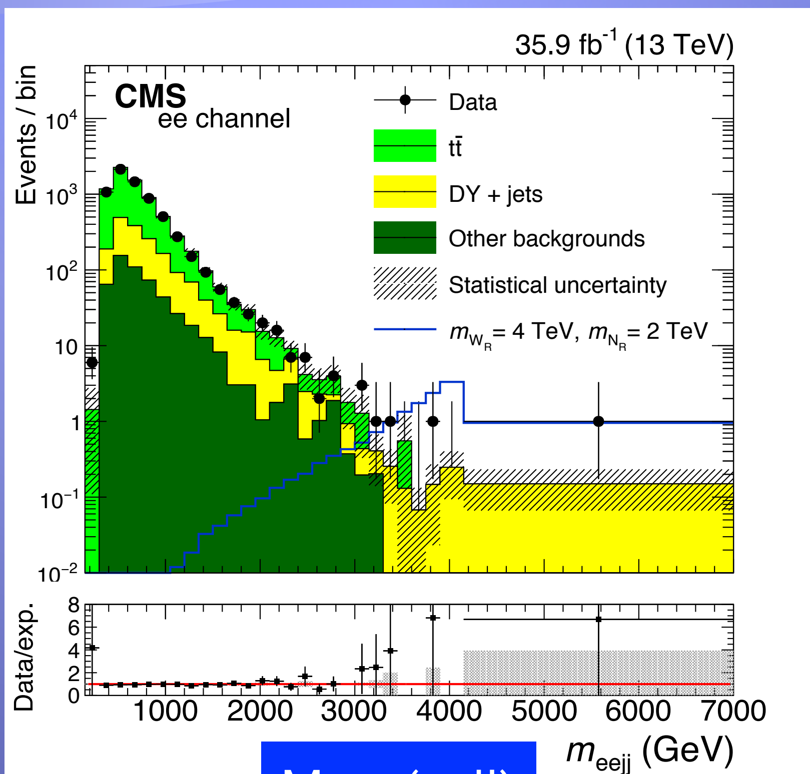


$$S_T = p_T(\ell) + p_T(\tau_h) + p_T(jet_1) + p_T(jet_2) + E_T^{miss}$$

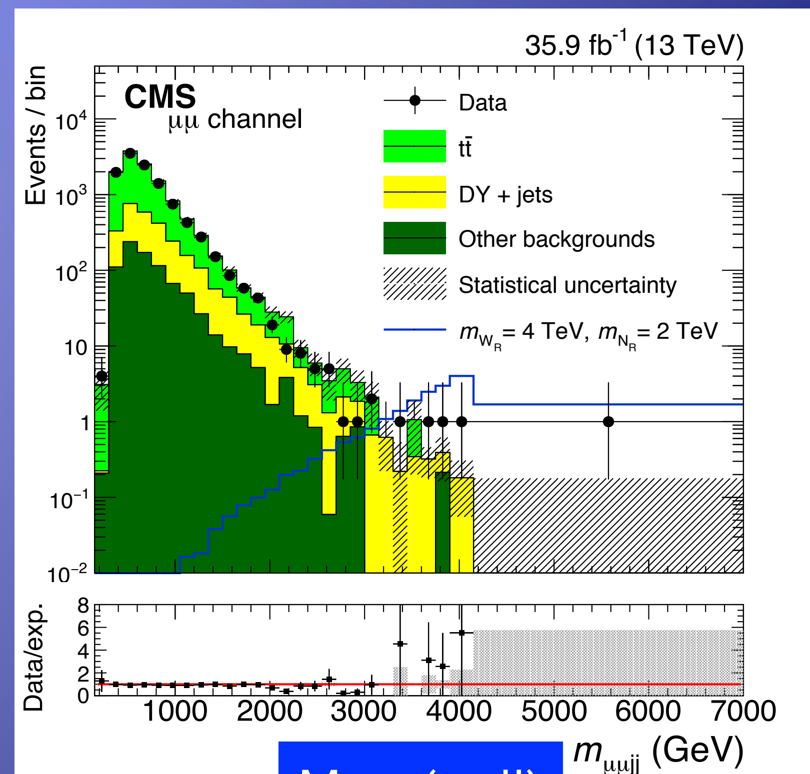
No excess in data, exclude W_R up to 3.2 TeV

Searches in the LRSM: 13 TeV

JHEP05(2018) 148



Mass (eejj)



Mass (μμjj)

- **The exclusion of W_R up to 4.4 TeV**

Summary

- Neutrino oscillations attract many interesting searches at the LHC
  - Nature of neutrino: Majorana or Dirac can be tested at high energy scale, LHC
  - Tests of Seesaw models to explain small ν mass: heavy N
    - ✓ Different Seesaw types
    - ✓ Left-Right Symmetry model

- Searches by ATLAS and CMS show no excess seen in data: set upper limits are set on $|V_{lN}|^2$, exclude W_R mass up to 4.4 TeV

- Searches will be explored using the full 13 TeV data, and will be extended to additional channels (t-channel, pair N production, and long-lived N)