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Falsifying Leptogenesis at the LHC

FFD, Julia Harz, Martin Hirsch, arXiv:1312.4447 (tbp in Phys. Rev. Lett.)

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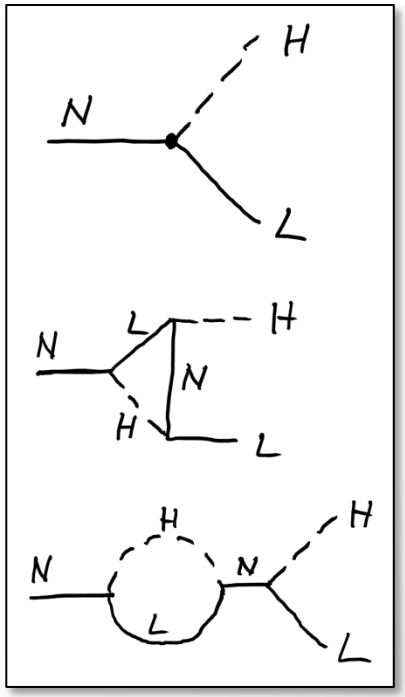
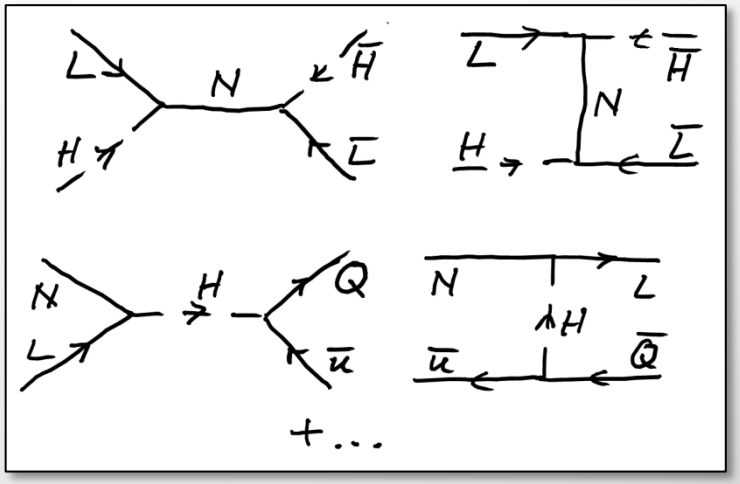
Leptogenesis

- Classic Scenario
  - Heavy Majorana Neutrino Decays
    - Out-of-equilibrium
    - CP and lepton number violation
  - Competition with LNV washout processes
  - Net lepton number asymmetry
  - Conversion to baryon asymmetry
    - EW Sphaleron Processes at $T \approx 100\ \mathrm{GeV}$
    - Observed Asymmetry

$$\eta_B \equiv \frac{n_B - n_{\bar{B}}}{n_\gamma} = (6.20 \pm 0.15) \times 10^{-10}$$



- Other possible scenarios
  - For us only important: Lepton number asymmetry generated above LHC scale

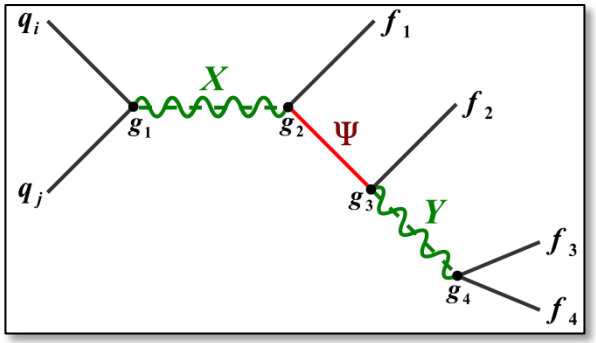


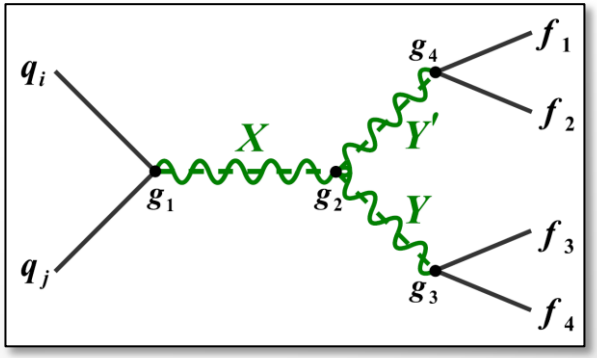
LNV @ LHC

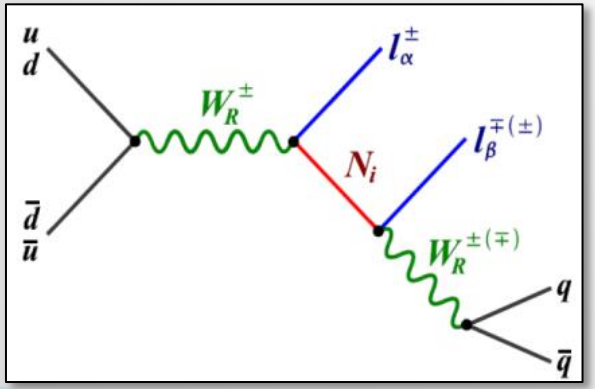
- General resonant process with signature

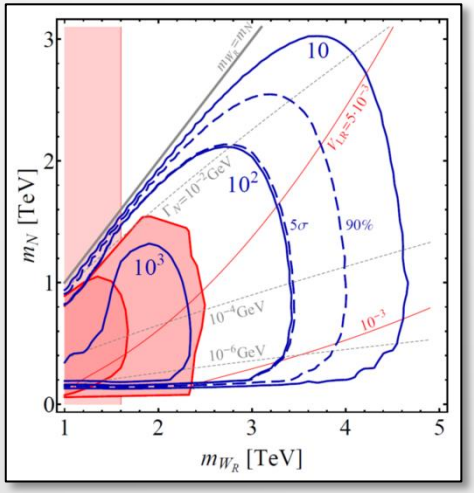
$$pp \to l^{\pm} l^{\pm} + 2\text{jets}$$

  - Lepton number violating with $\Delta L = \pm 2$
- Model-independence
  - Unspecified heavy states and couplings
- Example
  - Heavy W_R and N production









Das, FFD, Kittel, Valle '12

Induced Washout

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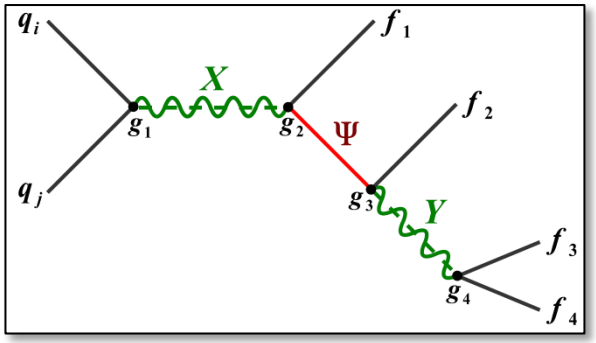
- Compare LHC cross section with lepton number asymmetry washout

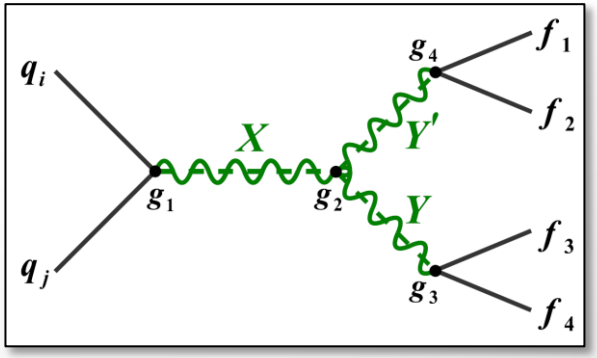
$$\frac{\Gamma_W}{H} > 3 \times 10^{-3} \frac{M_P M_X^3}{T^4} \frac{K_1(M_X/T)}{f_{q_1 q_2}(M_X/\sqrt{s})} \times (s\,\sigma_{\mathrm{LHC}})$$

  - Lower limit on total washout rate
    - Neglecting other washout processes

$$\log_{10}\frac{\Gamma_W}{H} > 7 + 0.6\left(\frac{M_X}{\mathrm{TeV}} - 1\right) + \log_{10}\frac{\sigma_{\mathrm{LHC}}}{\mathrm{fb}}$$

  - Observation of LNV @ LHC corresponds to highly effective washout $\Gamma_W/H \gg 1$
    - Excludes Leptogenesis models that generate asymmetry above M_X





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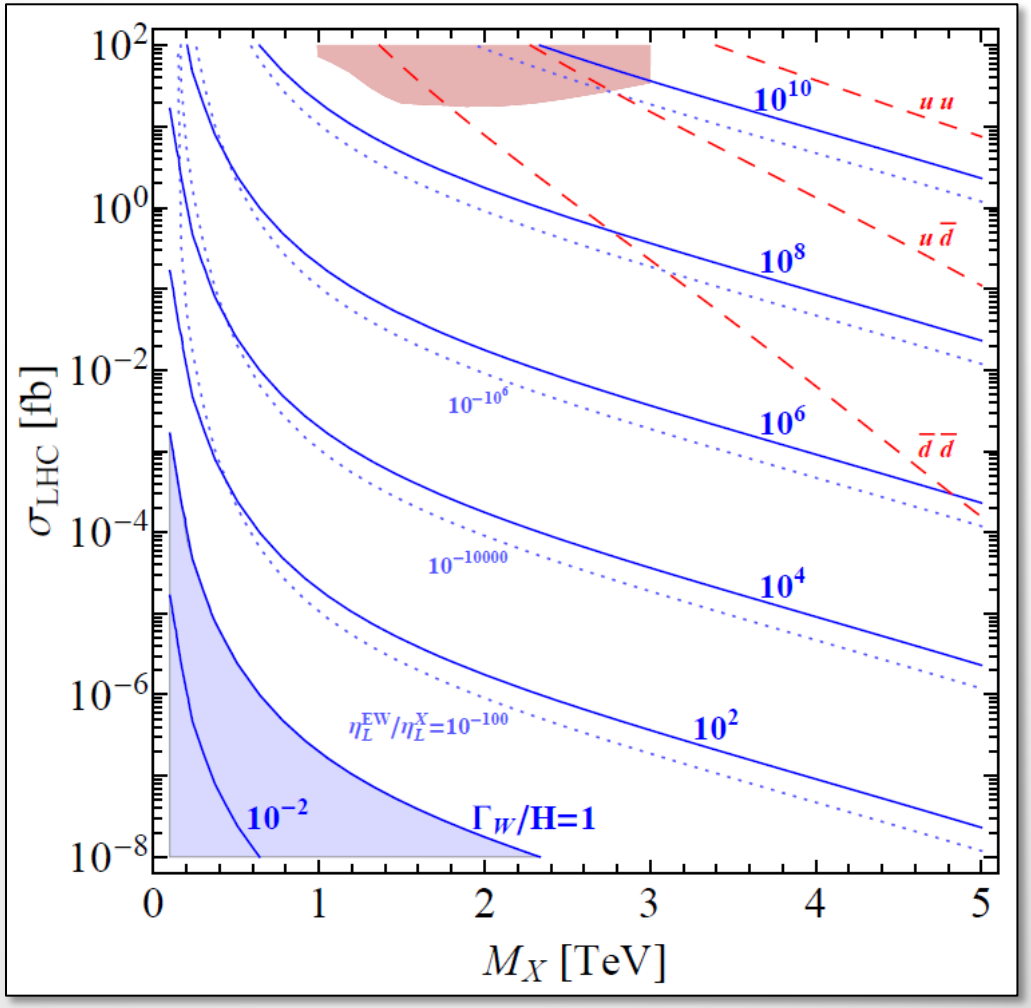

Baryon Asymmetry Limit

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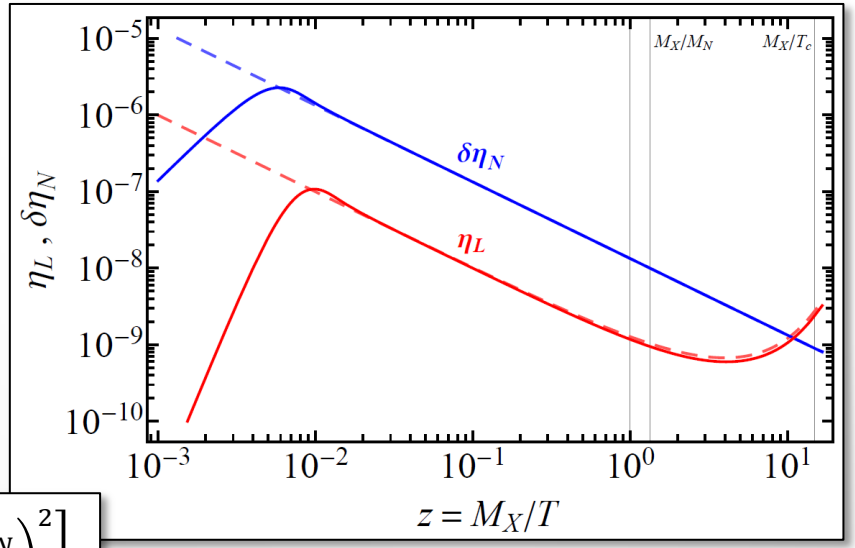
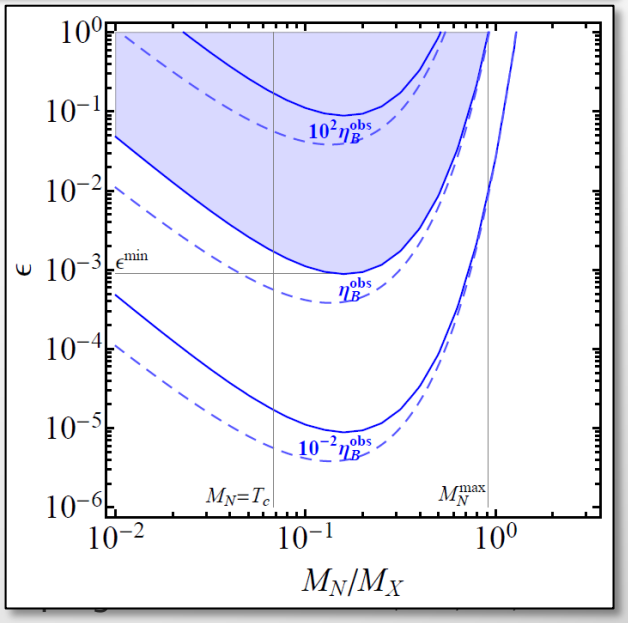
- Classic Leptogenesis with one heavy neutrino N, neglecting flavour
  - Solve Boltzmann equations for η_N and η_L with LHC process as only washout source
  - Upper limit on baryon asymmetry



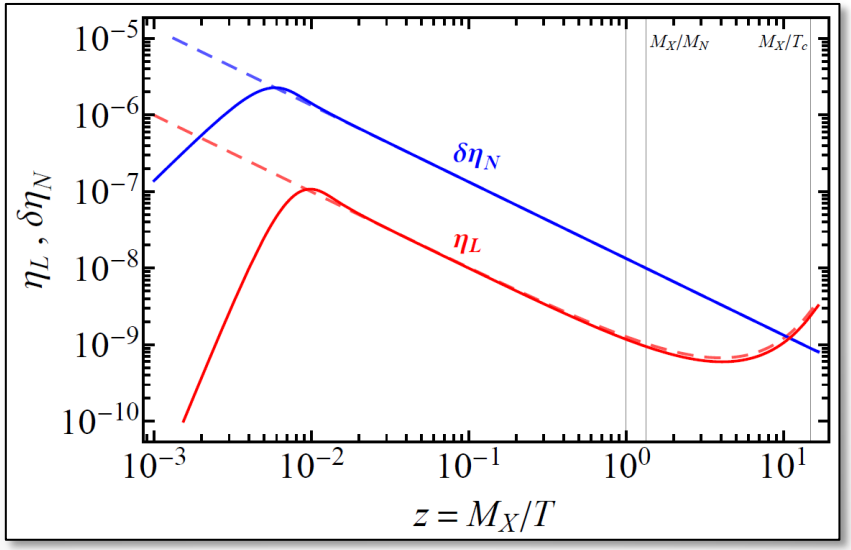
$$\log_{10}\left|\frac{\eta_B}{\eta_B^{\text{obs}}}\right| < 2.4\frac{M_X}{\text{TeV}}\left(1-\frac{4}{3}\frac{M_N}{M_X}\right) + \log_{10}\left[|\epsilon|\left(\frac{\sigma_{\text{LHC}}}{\text{fb}}\right)^{-1}\left(\frac{4}{3}\frac{M_N}{M_X}\right)^2\right]$$

  - LNV is observed at LHC
    → High scale Leptogenesis ($M_N > M_X$) is not viable
    → Strong limit on CP asymmetry ϵ for low scale Leptogenesis ($M_{EW} < M_N < M_X$)



Possible Caveats

- Cannot exclude scenarios that generate a lepton number asymmetry below observed scale M_X
  - But strong limits still apply
- Asymmetry can be present in one lepton generation only
  - Unambiguous falsification requires observation of LNV in all flavours (or observation of low energy LFV such as $\tau \to e\gamma$)
- Sphalerons only affect l.h. leptons… What if LNV is observed for r.h. leptons only?
  - Not an issue as all l.h. and r.h. charged fermions are in thermal equilibrium $\approx M_{EW}$



Other LNV Processes

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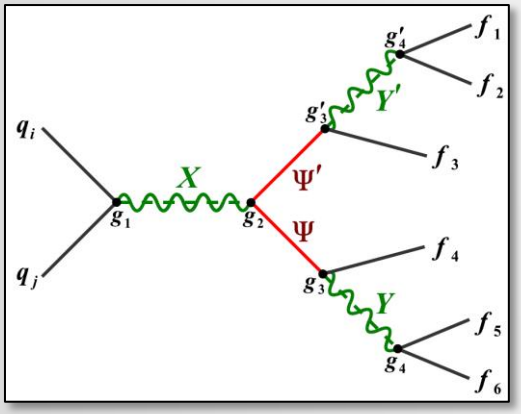
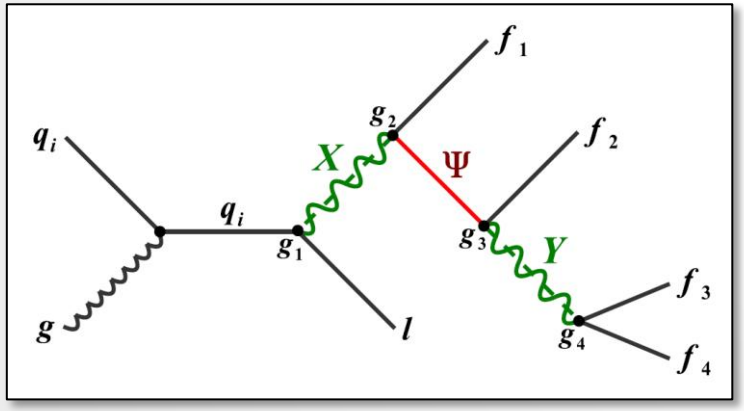
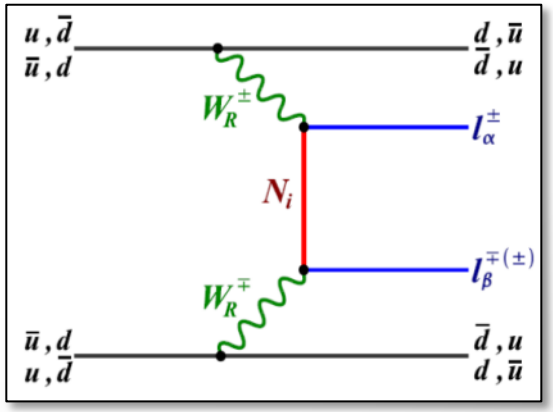
- The argument can be easily extended to
  - other resonant and non-resonant LNV processes at the LHC







  - LNV processes at other future colliders

Conclusion

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- Observation of LNV @ LHC corresponds to strong washout of lepton number asymmetry in early Universe
- This would rule out a large number of high scale Leptogenesis models
  - Observation of LNV/LFV in all flavours would rule out **all** high scale scenarios
- Strong motivation to search for LNV @ LHC in as many channels as possible
- Strong Synergy with $0\nu\beta\beta$ searches
  - Probing models of neutrino mass generation
    - Observation of $0\nu\beta\beta$
    - No observation of LNV @ LHC

    } Improved confidence in high scale Majorana models (Seesaw)

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    - "Compatible" observation of LNV @ LHC

    } LNV @ TeV Scale
    Disfavours high scale seesaw

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