Falsifying Leptogenesis at the LHC


Frank Deppisch
f.deppisch@ucl.ac.uk

University College London
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 $T \approx 100$ GeV
    - Observed Asymmetry
      \[ \eta_B \equiv \frac{n_B - n\overline{B}}{n_\gamma} = (6.20 \pm 0.15) \times 10^{-10} \]

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

- General resonant process with signature
  \[ pp \rightarrow l^\pm l^\pm + 2\text{jets} \]
  - 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

- Compare LHC cross section with lepton number asymmetry washout

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

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

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

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

- Compare LHC cross section with lepton number asymmetry washout
  - Lower limit on total washout rate
  - Observation of LNV @ LHC corresponds to highly effective washout $\Gamma_W/H \gg 1$
    - Excludes Leptogenesis models that generate asymmetry above $M_X$
Baryon Asymmetry Limit

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

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

- LNV is observed at LHC
  - High scale Leptogenesis ($M_N > M_X$) is not viable
  - Strong limit on CP asymmetry $\epsilon$ 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 $\tau \rightarrow e\gamma$)

- 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

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

- 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)
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 $0\nu\beta\beta$
  - “Compatible” observation of LNV @ LHC
  - LNV @ TeV Scale
  - Disfavours high scale seesaw
Conclusion

- 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
    - No observation of $0\nu\beta\beta$
    - No observation of LNV @ LHC