Validation of the HeavyN model in MadGraph below M_Z

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8th LLP Workshop, roundtable about Monte-Carlo generators for HNLs

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Context

- We were looking for a production-quality Monte-Carlo generator for HNLs.
- We were interested in possibly long-lived HNLs with masses *below* the Z pole.
- We needed:
  1. Full spin correlations (mediated by both the W/Z and the HNL).
  2. Effects from the finite W/Z mass (i.e. no Fermi theory).
  3. Automated cross-section computation.
  4. Narrow-width treatment (for long-lived HNLs).
  5. Finite lepton masses (for leptonic decays of light HNLs).
  6. Exclusive HNL semileptonic decays involving mesons.
- We had heard of the HeavyN model by Richard Ruiz, for heavy HNLs ($M_N \gtrsim M_Z$).
- Before using it, we wanted to validate it below M_Z ("trust but verify").
- To this end, we have performed a number of tests relevant to our use case.

  (The tests were performed at parton level, but the hadron-level results look good too.)

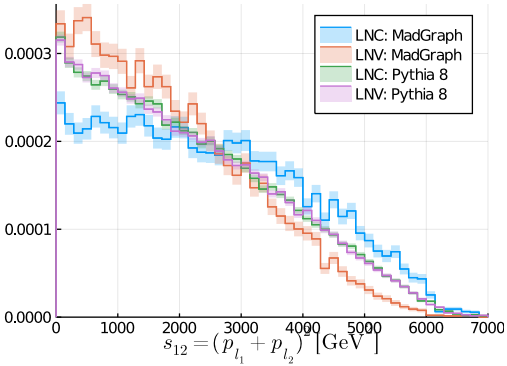
Results

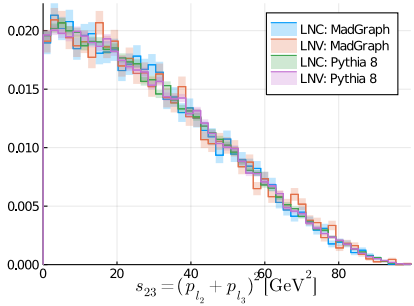
1. Spin correlations? **Yes**, both for the vector boson and the HNL.
   We compared the sampled distribution with analytical matrix elements obtained within the narrow-width approximation, for both LNC and LNV processes, and maximally polarized vector bosons produced in Drell-Yan.
2. Finite W/Z mass? **Yes**, since HeavyN extends the SM, not just the Fermi theory.
   We numerically checked the shape of the W/Z pole.
3. Automated cross-section computation? **Yes** and **No**: the total HNL width must be passed.
   However, the total width can be easily obtained by summing all partial widths computed with MadGraph, and the cross-section can even be rescaled a posteriori by $\Gamma_{\text{input}}/\Gamma_{\text{real}}$.
   We have successfully checked the values of the cross-sections against analytical estimates.
   (Minor issue: $G_{\text{F}}(\mu^2)$ is evaluated at $\mu = M_Z$ in HeavyN, instead of $\mu = 0$.)
4. Narrow-width treatment? **Yes** and **No**: the narrow-width treatment built into MadGraph does not always work, but it is possible to pass a tiny width $\Gamma_N \sim 10^{-5} \times M_N$ and obtain the same results in practice, with no noticeable slowdown.
5. Finite lepton masses? **No**, but adding them to the FeynRules model is easy.
6. Interactions with mesons? **No**, but a new model [2007.03701] covers this use case.
   (For GeV-scale HNLs, HeavyN can still be used for fully leptonic processes, if Γ_N is computed externally.)

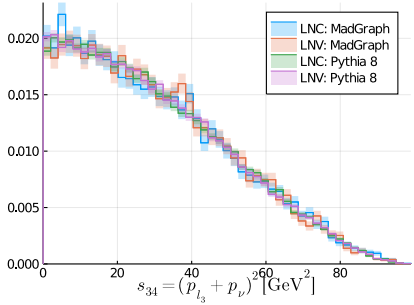
To conclude, we have successfully validated HeavyN *for* $\Lambda_{QCD} \ll M_N < M_Z$.

Backup slides

HNL spin correlations

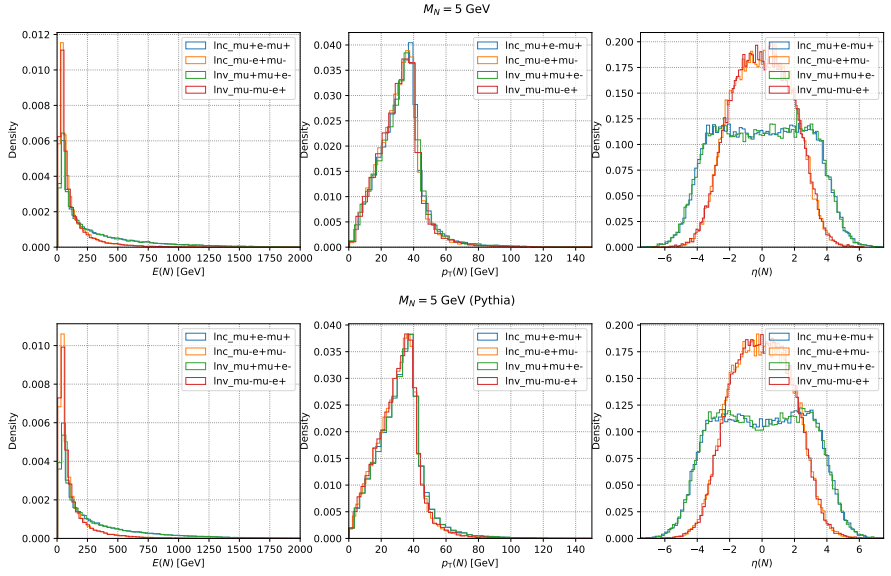






- s_{12} is sensitive to spin correlations mediated by N, but not s_{23} and s_{34}.
- No HNL spin correlations in PYTHIA.

W spin correlations



Top: MadGraph / bottom: Pythia. η is sensitive to the W charge, as expected.