



HNL signal generation at LHCb, ATLAS, CMS

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Typical MC generators used in the LHC experiments

For BSM processes modeling, typically two generators are widely used:

① MADGRAPH5_aMC@NLO used for:

- pp collision and particle production simulation, e.g. $pp \rightarrow W + \text{jets}$
- full process: particle production and decay

② PYTHIA8 used for:

- particle decay modeling after particle production has already been simulated by the MG, e.g. $N \rightarrow ll\nu$
- full process: particle production and decay
- heavy flavor production simulation, e.g. $pp \rightarrow b\bar{b}$

Latest LHC publications on HNLs

The summary is based on the most recent LHC collaborations publications on HNLs:

- ATLAS: *JHEP* **10** (2019) 265
- CMS: *Phys. Rev. Lett.* **120** (2018) 22, 221801 and *JHEP* **01** (2019) 122
- LHCb: [arXiv:2011.05263](https://arxiv.org/abs/2011.05263)

HNL signal simulation: production cross section

Options used for HNL signal normalization in ATLAS, CMS, LHCb:

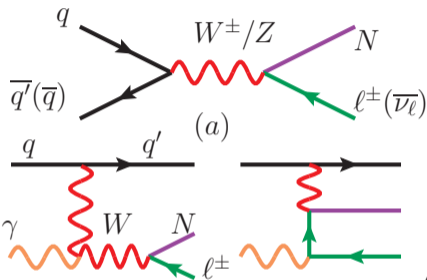
- use measured W production cross section and [M. Dittmar *et al*](#) (ATLAS);
- use theoretical W production cross section and [M. Dittmar *et al*](#) (LHCb);
- use signal production cross section from the full signal generation chain as computed by the generator from [R. Ruiz *et al*](#) (CMS)

Note: in the first two cases:

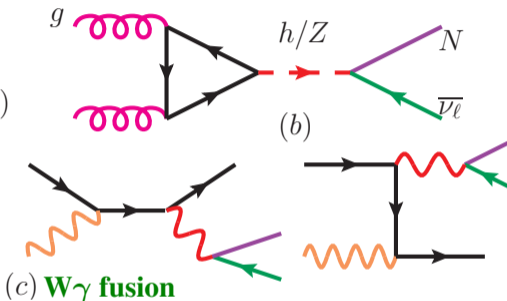
- need to add phase space suppression by hand (dependence on HNL mass) – bugprone, can be forgotten;
- does not take into account other production processes (like gluon fusion, relevant only for high HNL masses)

HNL signal simulation: production cross section

(a) **DY current**

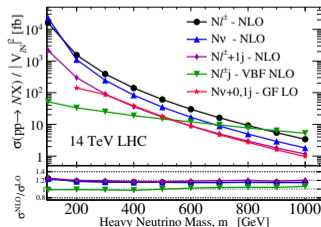


(b) **gluon fusion**



(c) **Wγ fusion**

- produced in decays of W or Z bosons
- for high N masses **VBF channel** (Wγ fusion) becomes important



HNL signal simulation: lifetime calculation

Options used for computing HNL lifetime in ATLAS, CMS, LHCb:

1 ATLAS:

- used [M. Gronau *et al*](#) for widths computation;
- provided interpretation for Majorana-like and Dirac-like HNL, taking into account width differences;

2 LHCb:

- used [Helo *et al*](#) for widths computation;
- provided interpretation for Majorana-like and Dirac-like HNL, taking into account width differences;

3 CMS:

- used generator output for widths and lifetimes (from [R. Ruiz *et al*](#));
- provided interpretation only for Majorana-like HNL

HNL signal simulation: signal kinematics

- 1 ATLAS used PYTHIA8;
- 2 CMS used model from [R. Ruiz *et al*](#) in MADGRAPH5_aMC@NLO;
- 3 LHCb used minimal mixing scenario model from [Shuve *et al*](#) implemented in MADGRAPH5_aMC@NLO

Summary

For the consistent comparison of various results, the recommendation on signal benchmarks should also contain recipes for:

- production cross section computation;
- widths and lifetime computation;
- special care of the HNLs produced in b/c-decays (PYTHIA)

Personal preferences based on the previous experience:

- 1 for me, as an analyzer, the most convenient would be to have an implementation of recommended signal benchmarks in MADGRAPH5_aMC@NLO, where all the items above can be directly extracted from the generator. As it has been done by [R. Ruiz *et al*](#), whose implementation we used in CMS.
- 2 a separate implementation in PYTHIA8 is required for HNLs produced in heavy flavor decays!