Higgs boson pair production interfaced to a parton shower

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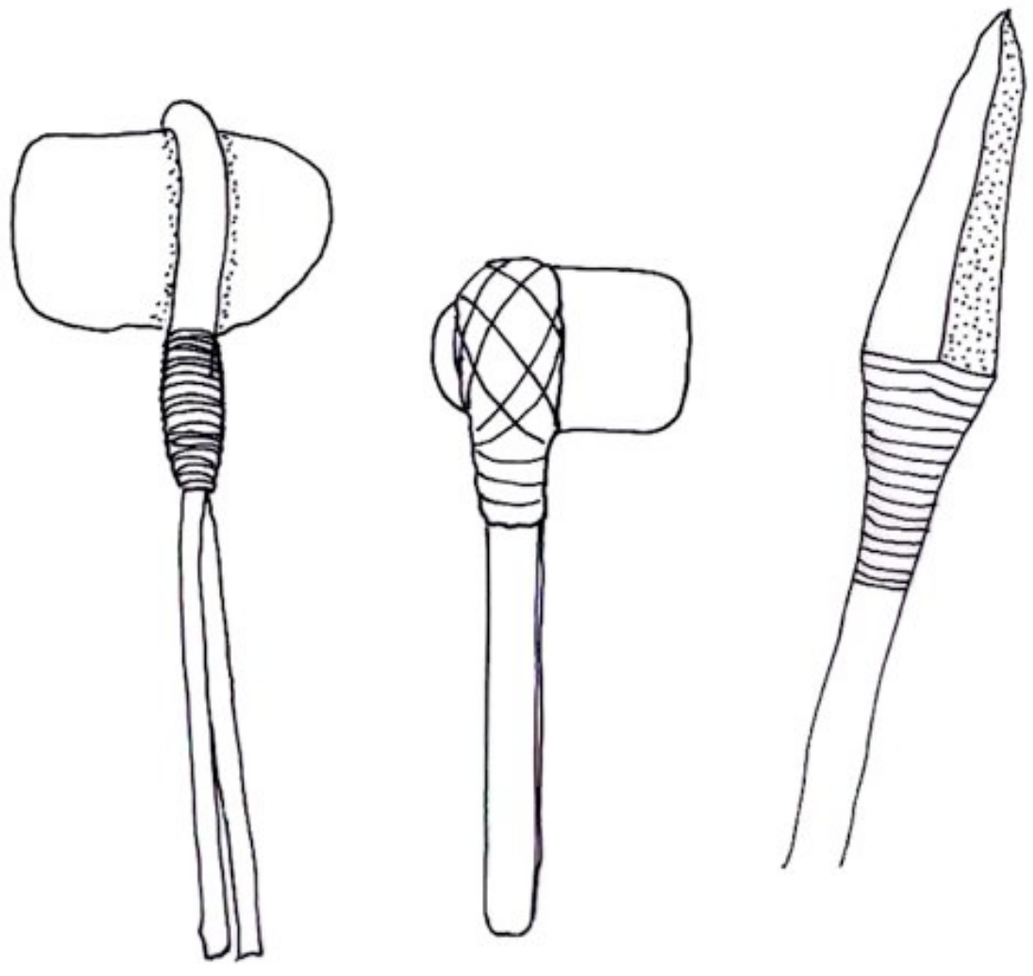
7th October 2016.

leading order + parton shower



leading order HH + PS

- LO events with full top-mass dependence can be showered with either **HERWIG** or **Pythia**.

- **MG5_aMC@NLO** can generate loop-induced processes “out-of-the-box”: get LO HH events with full top mass dependence. [Hirschi, Mattelaer, 1507.00020]

- + BSM models implemented: top-anti-top-HH coupling, complete two-Higgs doublet model HH production. [see: https://cp3.irmp.ucl.ac.be/projects/madgraph/wiki/HiggsPairProduction, Hespel, Vryonidou, e.g.1407.0281]

leading order HH + PS

- **HERWIG 7** contains hard-coded MEs (based on M. Spira's HPAIR), for **D=6 EFT** or intermediate heavy Higgs resonance.

  [e.g. Goertz, **AP**, Yang, Zurita, 1410.3471 + Herwig 7 release: 1512.01178]

- **LO+PS should be fine for most initial phenomenological studies, but ultimately, we would like to improve on it.**

going beyond LO + PS

merging & matching recap

- we would like higher-order matrix elements+PS.

- this introduces double-counting, since additional radiation is simulated by both MEs and PS.

- remove double-counting by:

  - **merging** the PS with "tree-level" MEs: via a veto algorithm, e.g. MLM, CKKW.

  - **matching** the PS with full higher-order calculations by subtracting the PS contributions, e.g. MC@NLO, POWHEG.

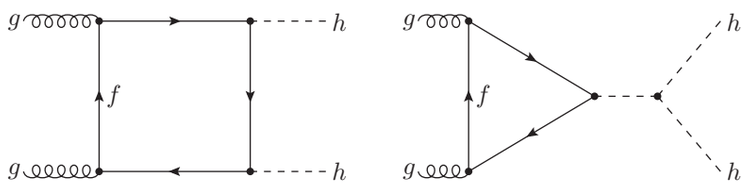
HH: beyond LO+PS

- **HERWIG 7 (+OpenLoops): merging via MLM.**

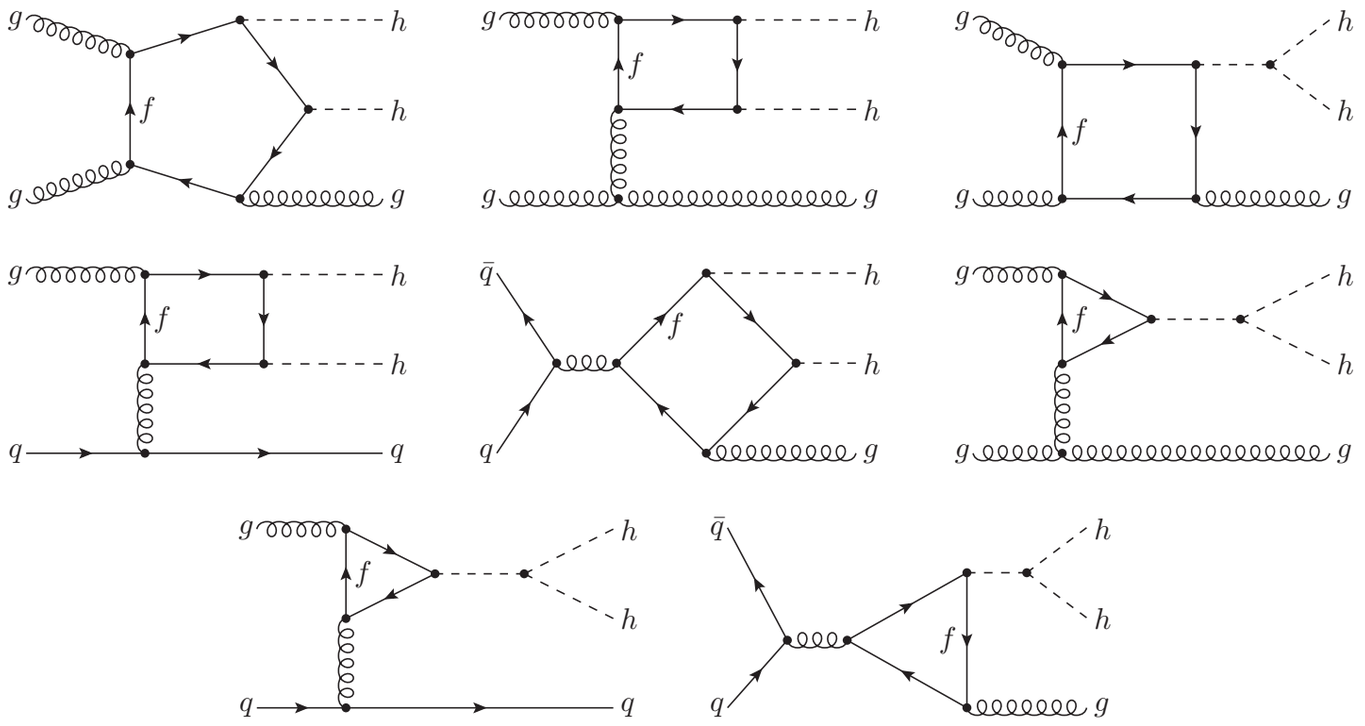
- **HH+0 partons** and **HH+1 parton** merged to the parton shower via the **MLM** method. [Maierhöfer, **AP**, 1401.0007]

- cross section is LO and merging scale introduced.

LO diagrams:



+



real radiation diagram classes

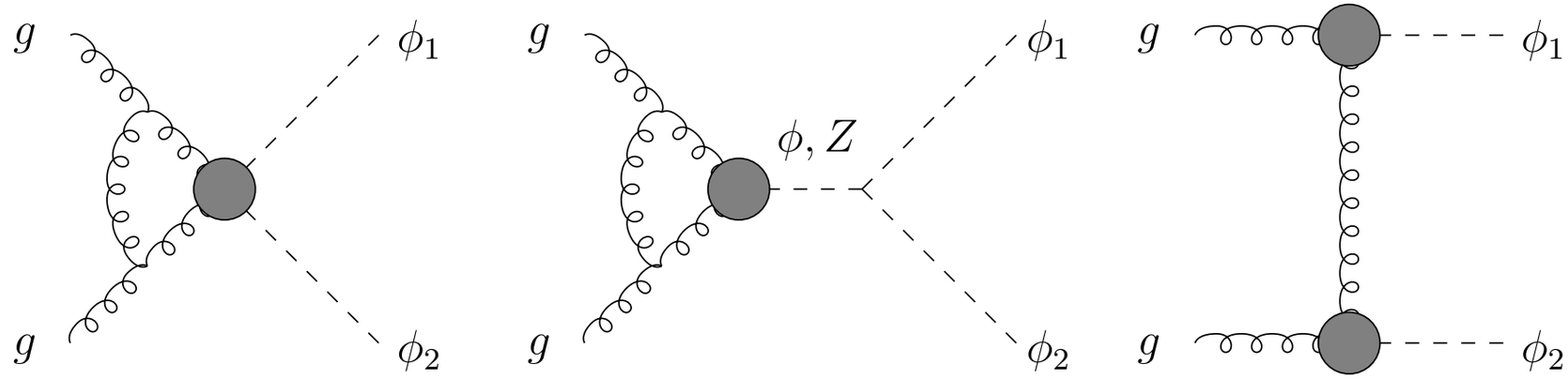
HH: beyond LO+PS

- using the **MC@NLO** method in **MG5_aMC@NLO**.

[Frederix, Frixione, Hirschi, Maltoni, Mattelaer, Torrielli, Vryonidou, Zaro,1401.7340, Maltoni, Vryonidou, Zaro, 1408.6542]

- LO + real emission with full top mass dependence + **Higgs Effective Theory (HEFT) virtual corrections.**

(as previous slide) +



- also gives an estimate of the NLO cross section.

- PS through HERWIG or Pythia.

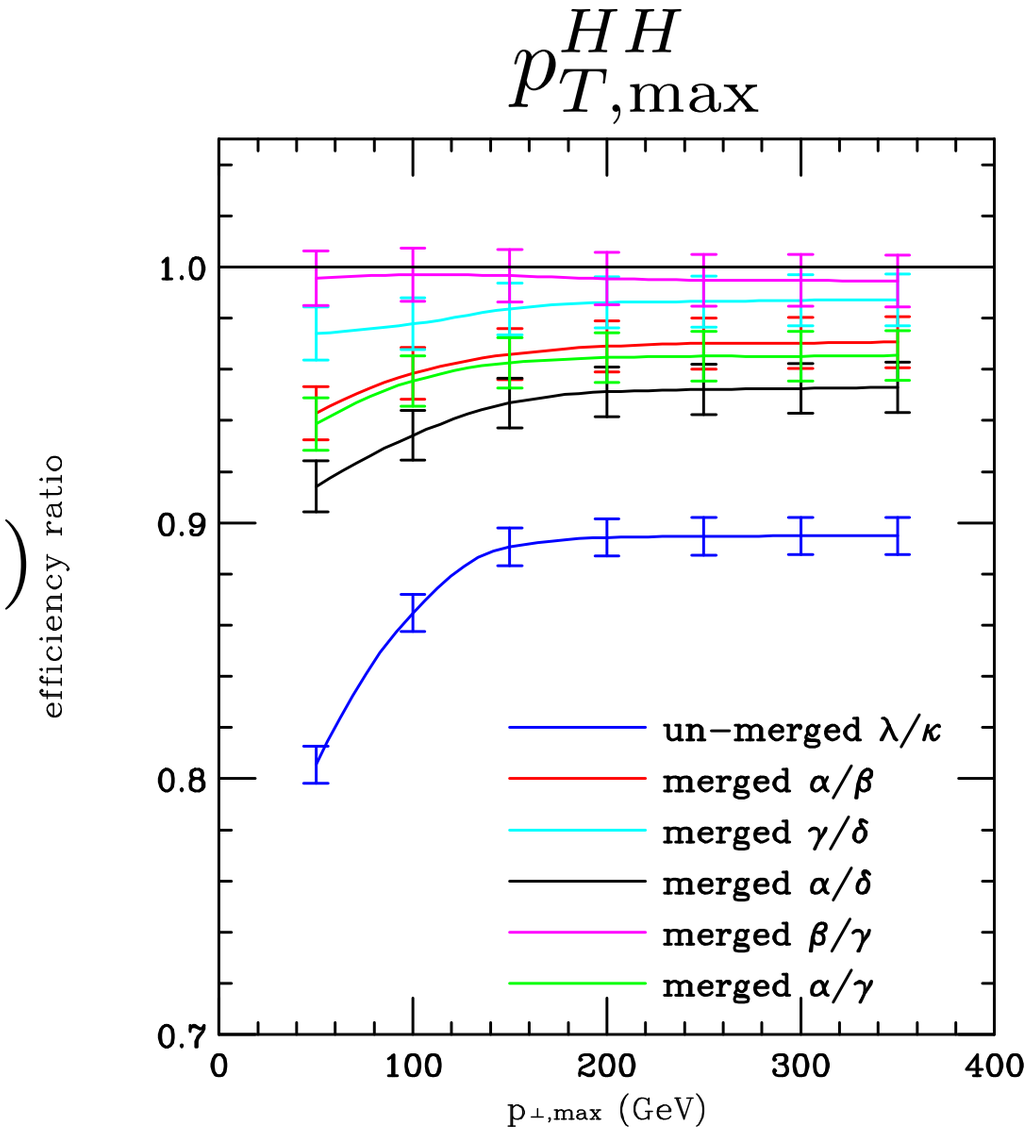
importance of exact real corrections

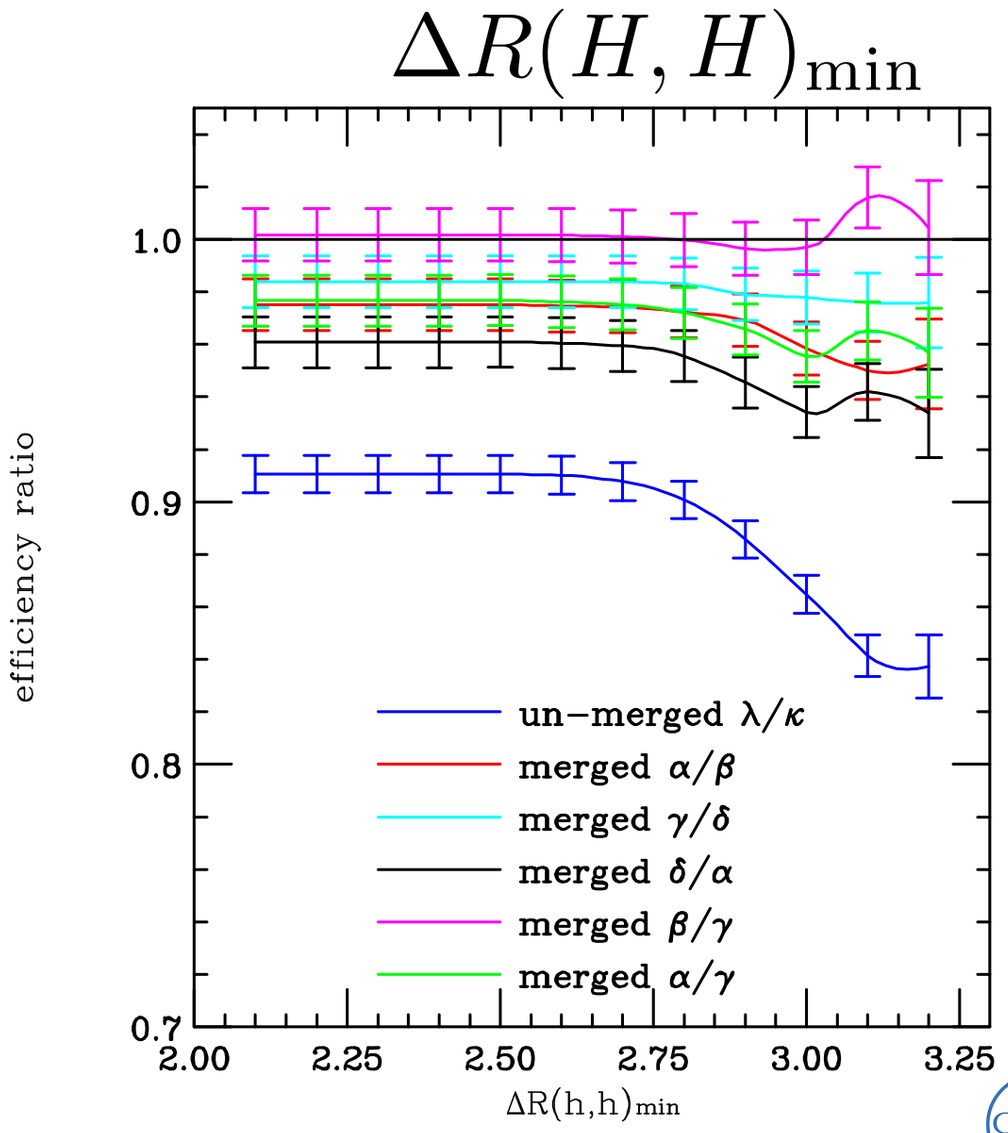
[Maierhöfer, **AP**, 1401.0007]

- define Monte Carlo samples **α**, **β**, **γ**, **δ** (merged), **κ**, **λ** (LO+PS), with different scale choices.

- consider **ratio** of obtained efficiencies: **ε(i)/ε(j)**, at LHC 14 TeV**.**

$\epsilon(i)/\epsilon(j)$





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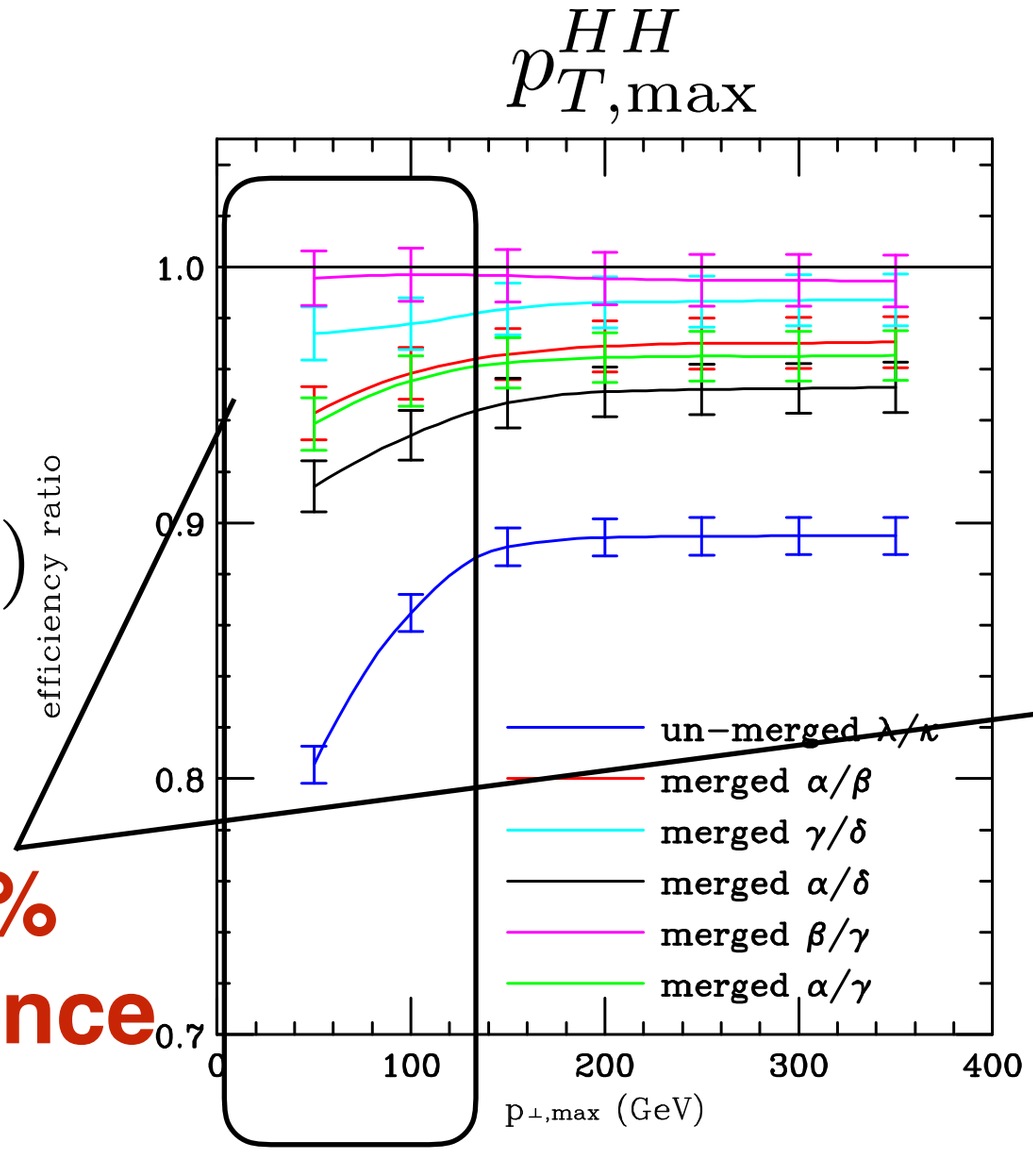
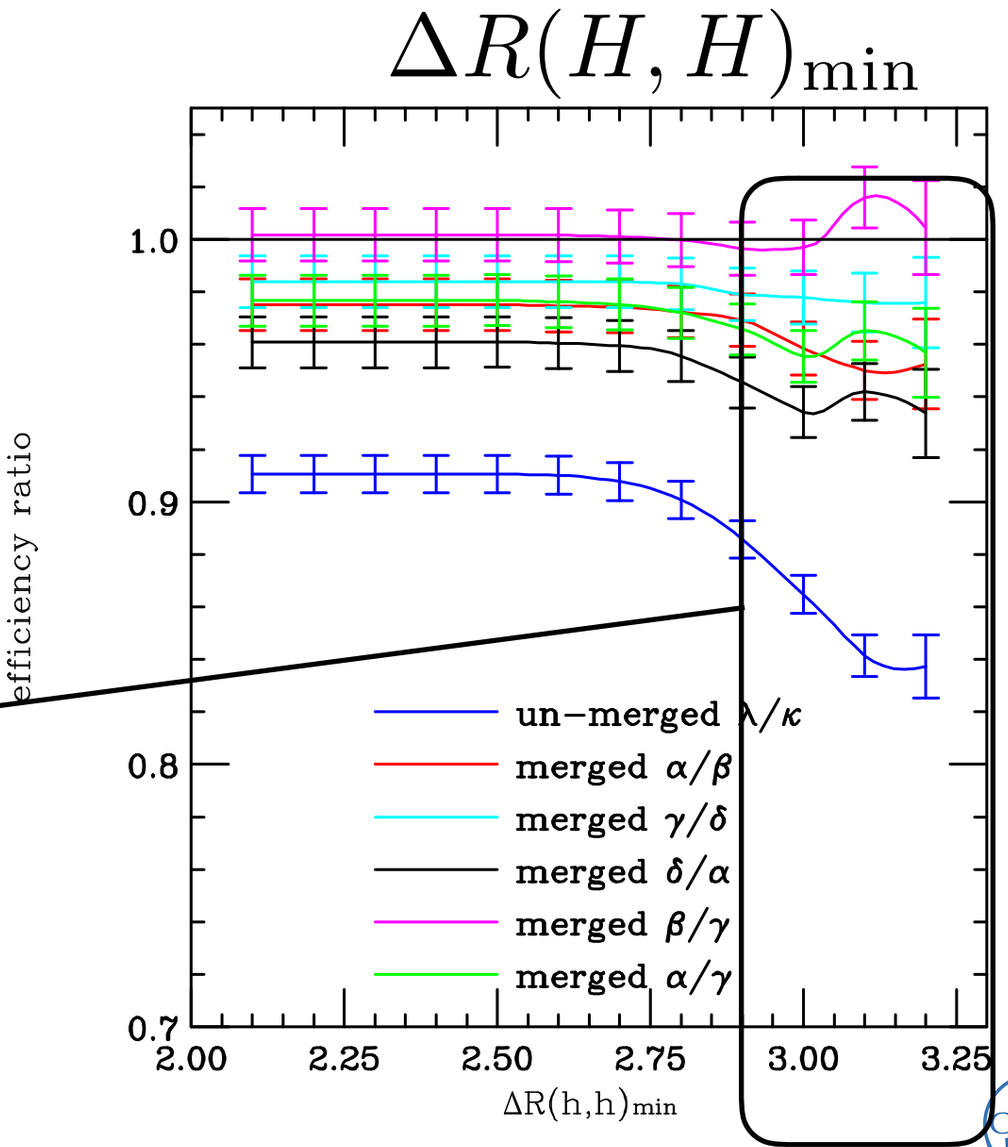




~20% difference

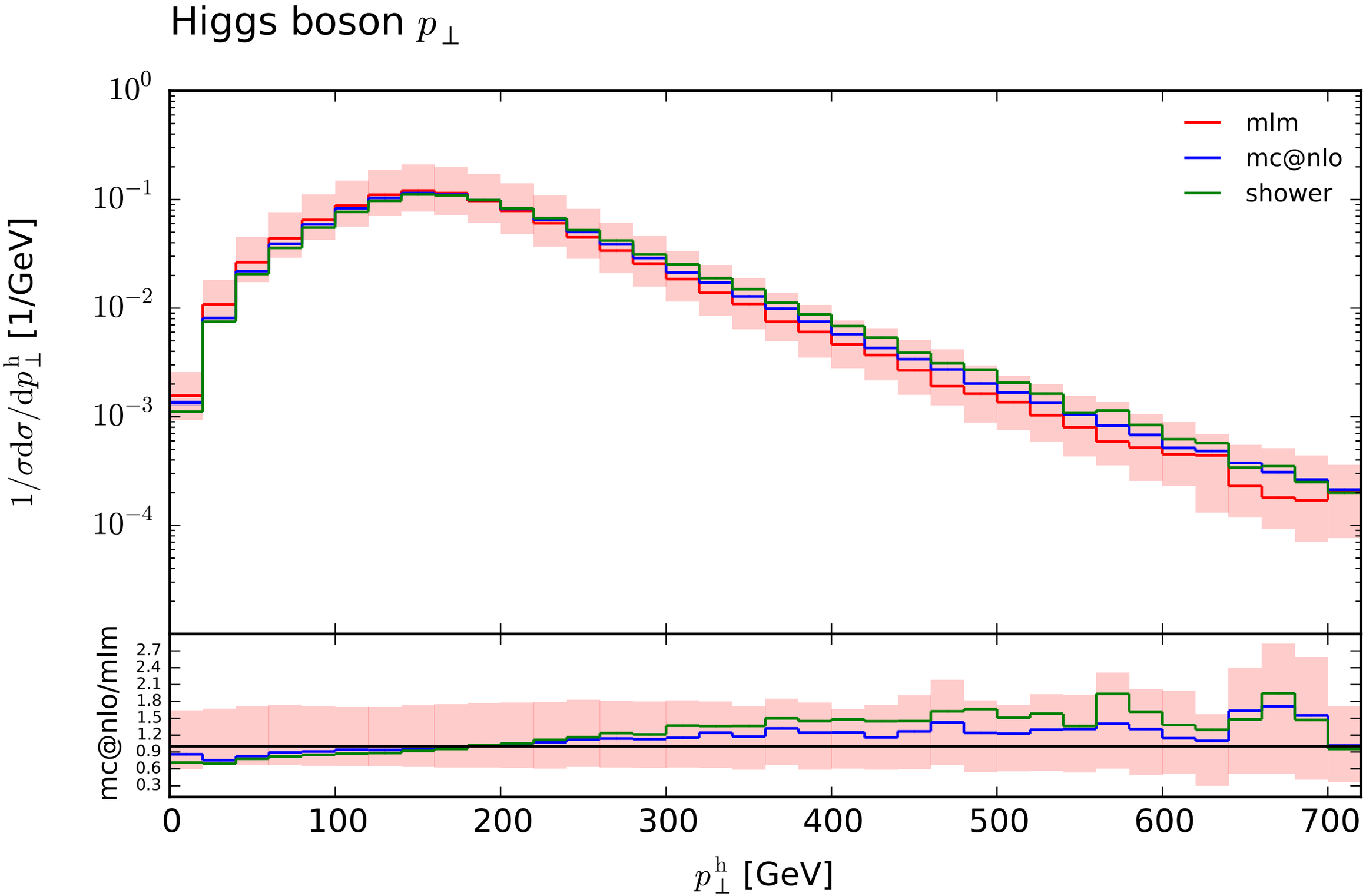
merging vs matching in HH

[**AP**, Vryonidou, see upcoming YR4]

- set central renorm./fact. scale in both $\mu_0 = M_{HH}/2$.
- in merging calculation: vary between 2 x μ_0 and $\mu_0/2$.
- also vary MLM merging scale in [40, 90] GeV and “smoothing” function between [10, 30] GeV.
- run through a Rivet analysis, normalize all distributions to unity.

- PS for all samples HERWIG angular-ordered (“q-tilde” shower).
- in what follows (and in YR4), for a 14 TeV LHC:
  - “mc@nlo” (blue): MG5_aMC@NLO samples,
  - “mlm” (red): MLM-merged HERWIG samples,
  - “shower” (green): LO+HERWIG parton shower samples.

merging vs matching in HH



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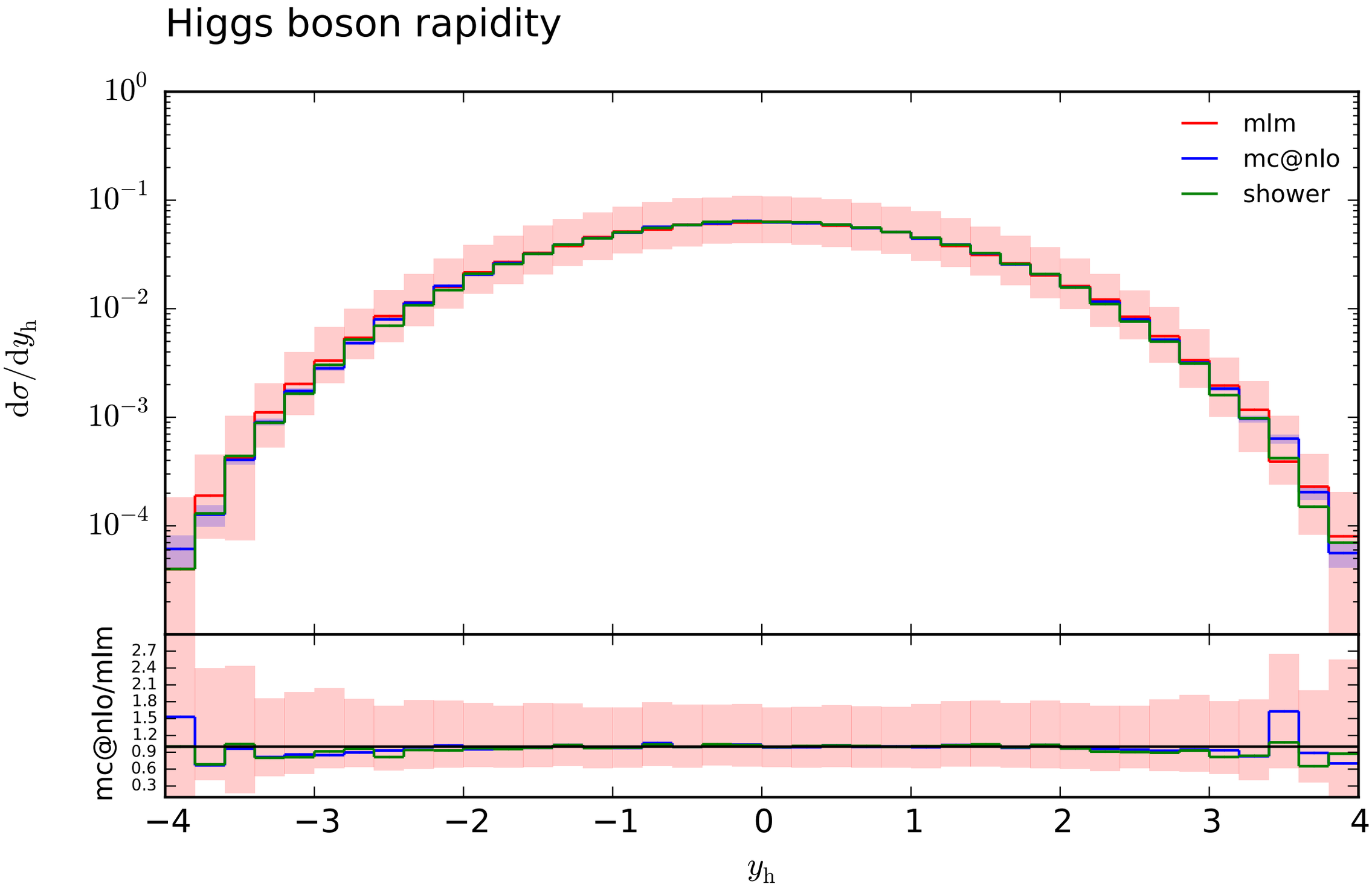

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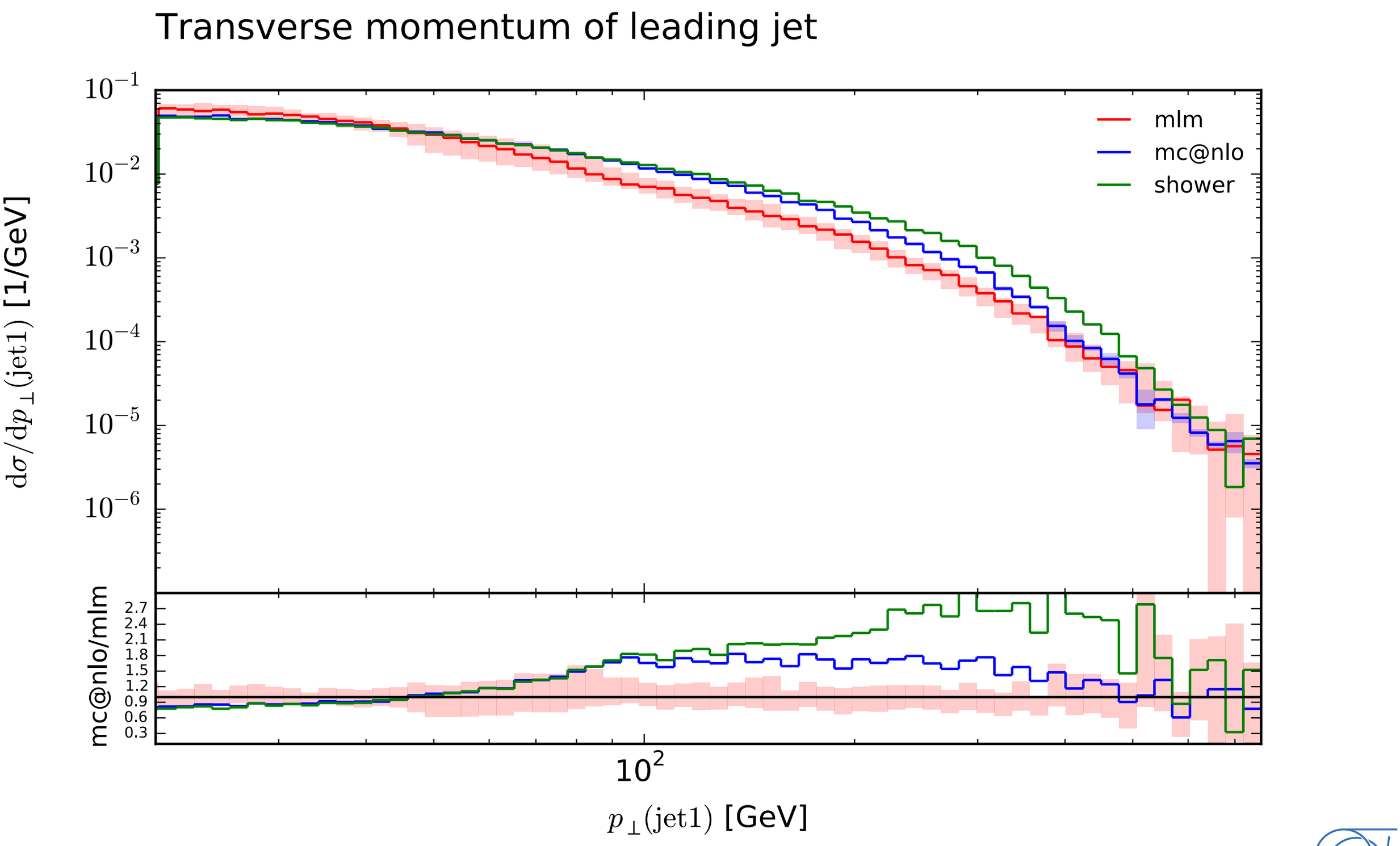

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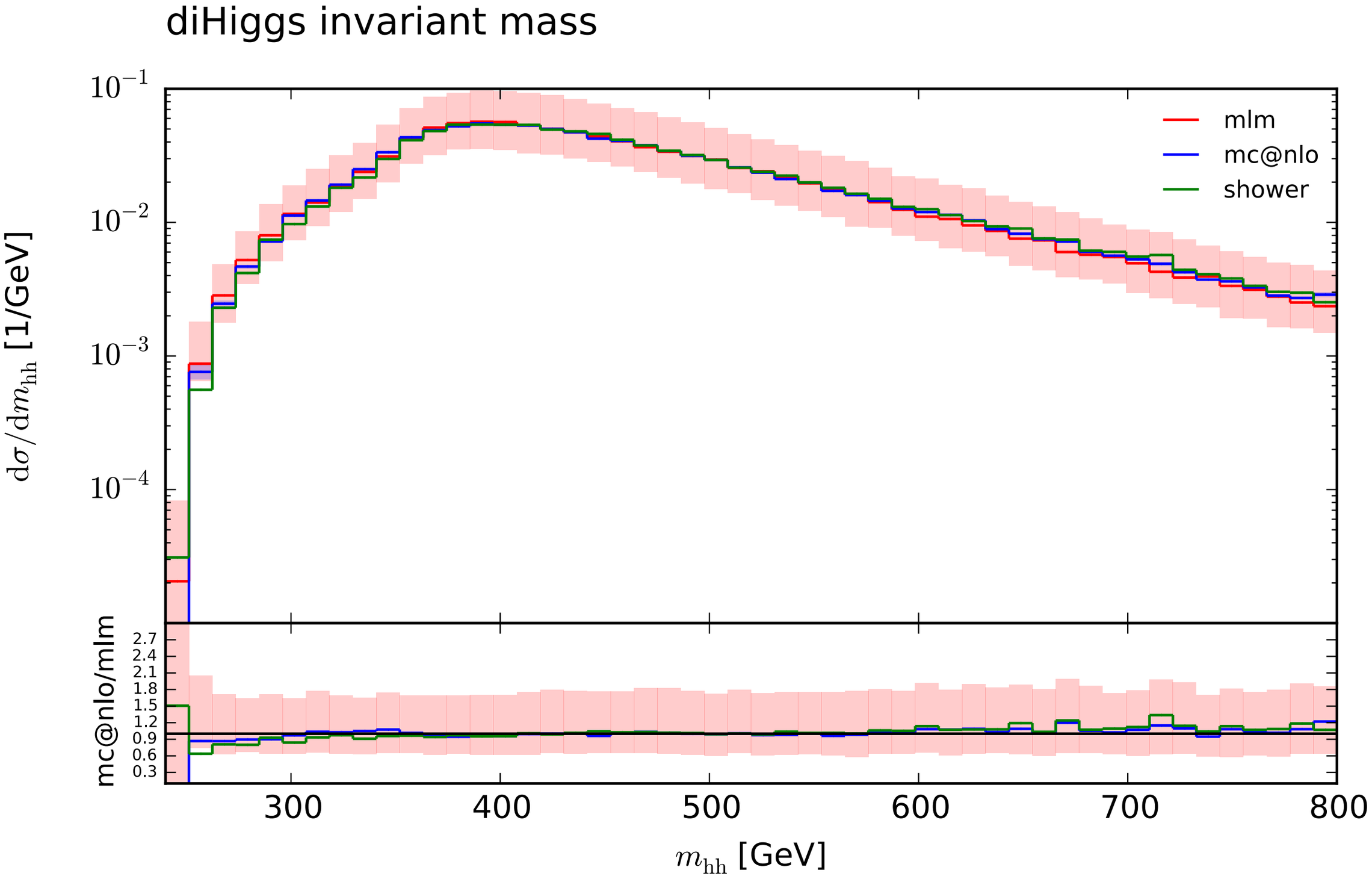

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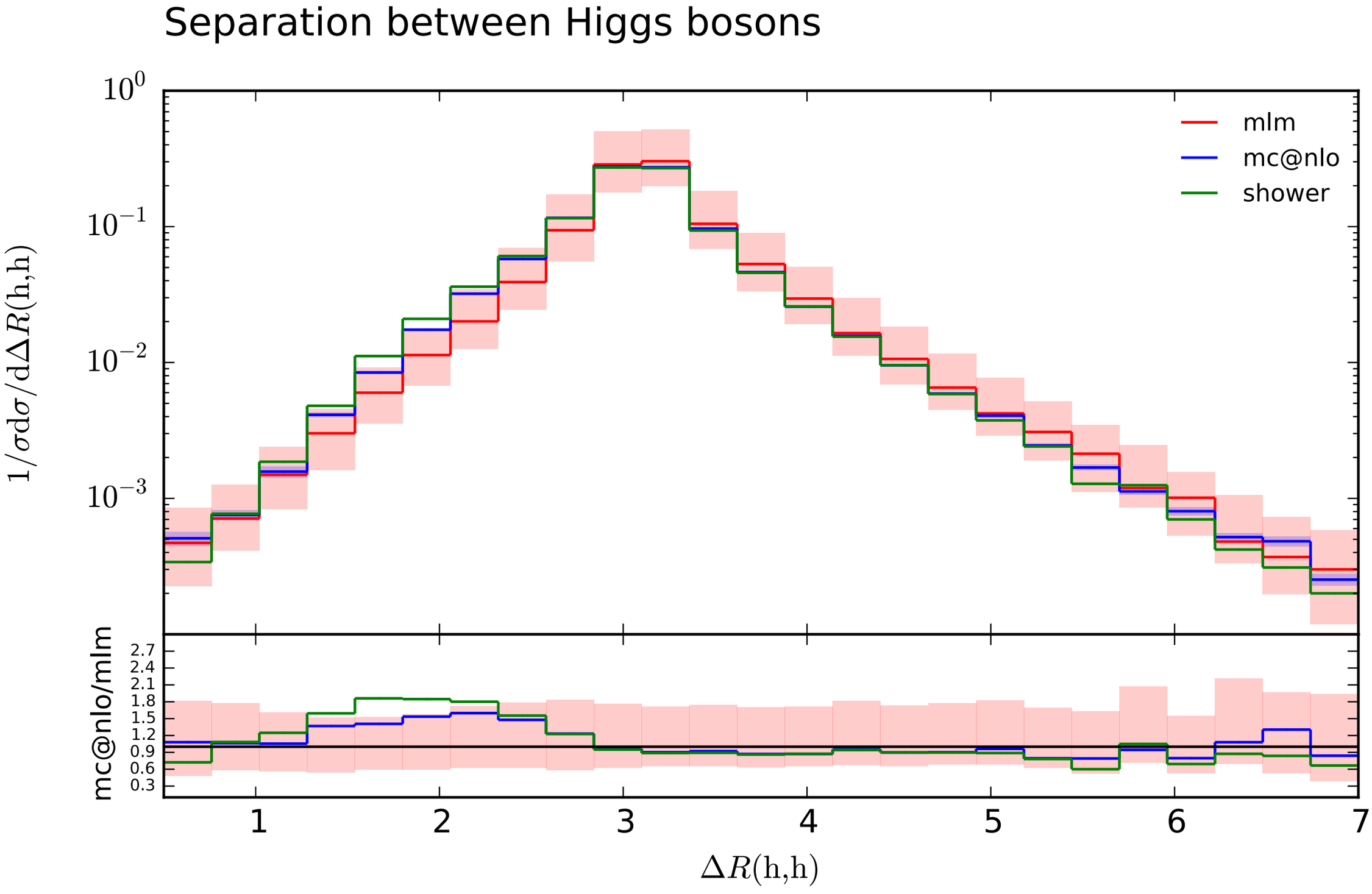

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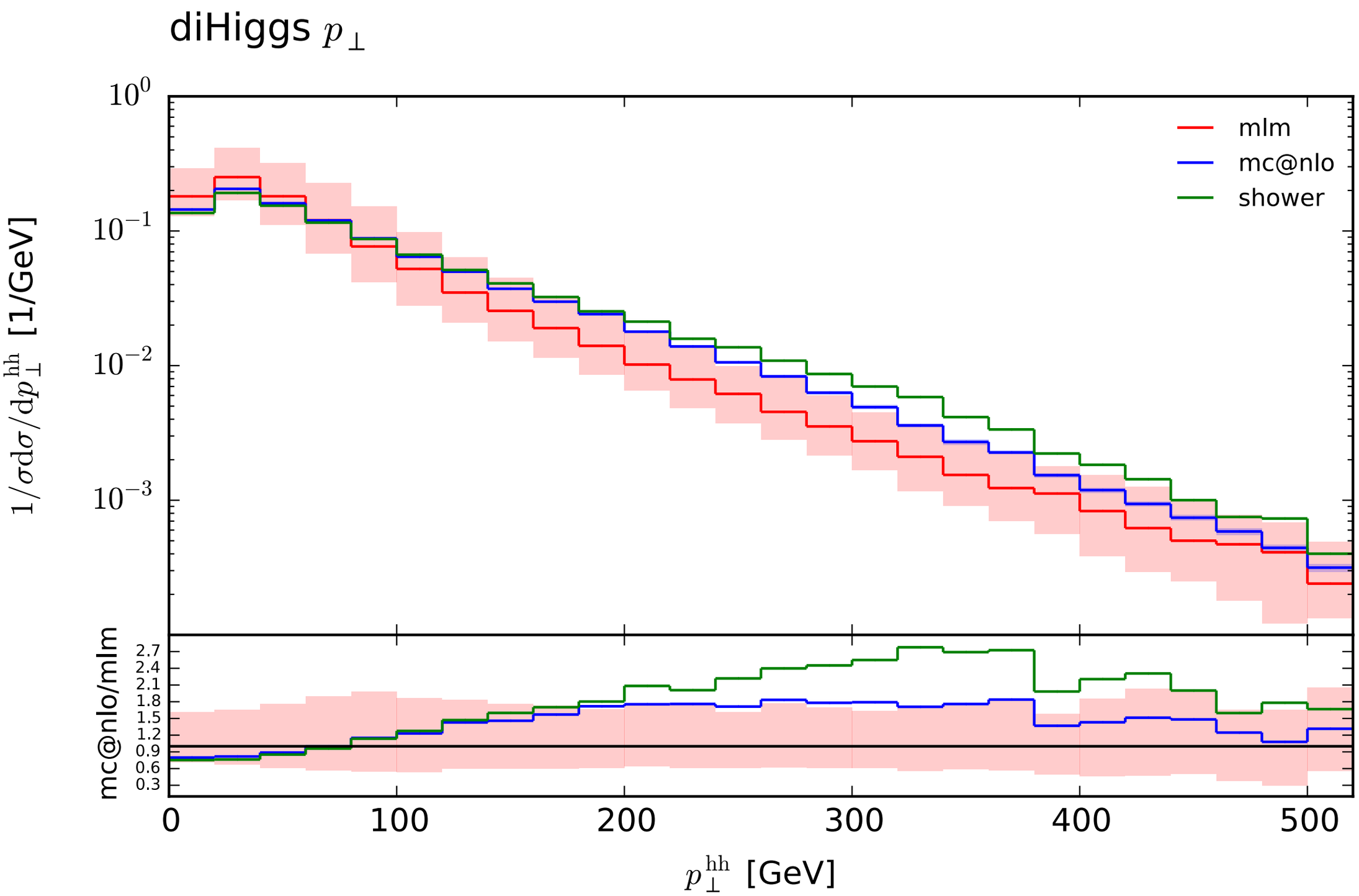
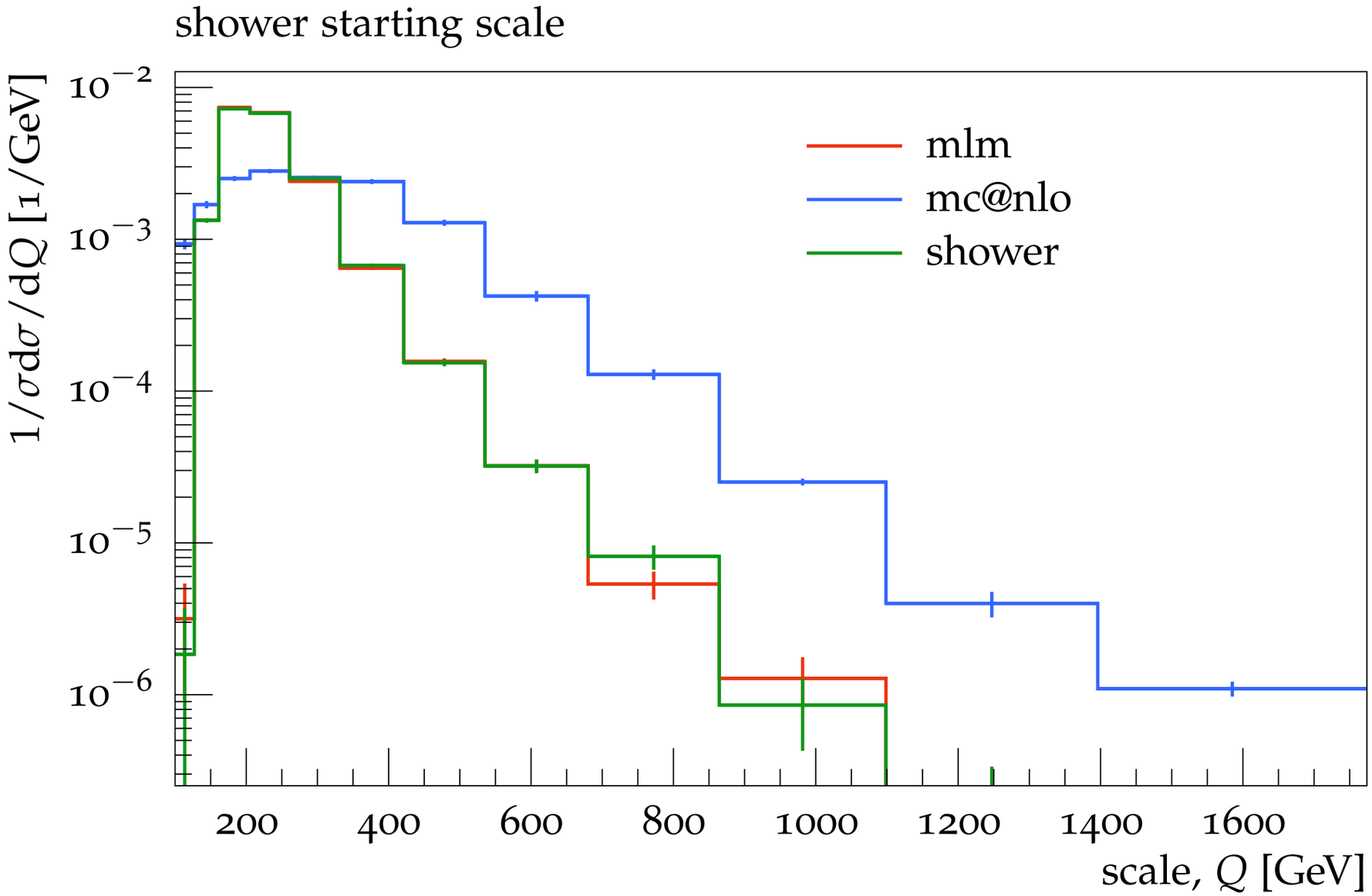


starting scale for the shower

- discrepancies can be attributed to the different starting scales for the shower (i.e. the so-called “SCALUP”):



conclusions

- current state-of-the art of HH Monte Carlo simulations relies on full LO + full hard radiation + virtual corrections from HEFT.

- LO+PS vs. PS+full real radiation efficiencies can vary up to 20% in an LHC analysis.

- merged vs. matched samples display some differences due to uncertainties related to the shower starting scale.

outlook

- full fixed-order NLO calculation now available, i.e. with top mass dependence fully included @ two loops.

  [Borowka, Greiner, Heinrich, Jones, Kerner, Schlenk, Zirke, Schubert, 1604.06447]

- can it be exploited in an MC@NLO calculation? (i.e. instead of using the HEFT virtuals).

- e.g. by tabulation/parametrization of the virtuals?

- + can we include QCD corrections to D=6 EFT operator effects?

Thanks for your attention!