Loop Matrix Element Matching with Parton Shower - Higgs Gluon fusion

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Outline

- Higgs productions at Hadron Colliders
  - Gluon fusion: HEFT and Exact Calculations (LOOP)
  - Higgs 0,1,2-jet rates: exclusive information

- Parton Shower Matching with Matrix Elements
  - MadGraph Implementation: MLM scheme
  - One Loop matrix element matching for Higgs GF

- Numerical Results

- Summary and Prospect

Higgs productions at Hadron Colliders

Higgs production at the LHC

- At the LHC, Higgs boson production via gluon fusion (GF) is the dominant channel, induced by heavy quark loop.

- Lots of studies on $pp \to H$ at NLO (in both HEFT and Loop):

  S. Dawson, NPB359, 283 (1991); A. Djouadi, M. Spira and P. M. Zerwas, PLB264, 440 (1991).

  D. Graudenz, M. Spira and P. Zerwas, PRL70, 1372 (1993); M. Spira, A. Djouadi, D. Graudenz and P.

  Zerwas, NPB453, 17 (1995).

  and at NNLO (with HEFT):

  Harlander, Kilgoren PRL 88 (2002) 201801; Anastasiou, Melnikov, NPB646 (2002) 220; Ravindran, Smith

  van Neerven, NPB665 (2003) 325.

  and resummation effects:

  S. Catani, D. de Florian, M. Grazzini and P. Nason, JHEP 0307 (2003) 028 .....

Higgs effective theory (HEFT)

- Heavy-top effective Lagrangian :

$$\mathcal{L}_{eff} = -n_h \frac{\alpha_s}{12\pi v} H G^a_{\mu\nu} G^{a\mu\nu}.$$

- HEFT has been implemented into MadGraph.

- Note A: HEFT is only a good approximation for light Higgs ($m_h \leq m_t$) and in appropriate kinematic region ($P_{T_j} \leq m_t$).

- Note B: The bottom contribution (and the top-bottom interference) for Higgs GF production at LO can be as large as 5-10 percent (negative), where HEFT is not applicable.

- For relatively light Higgs ($\sim$ 300 GeV), the HEFT at NNLO works extremely well, to better than 1%. (With the exact NLO cross section for normalization) [arxiv:1101.0593]

Higgs jets associated production: Parton level results

- Higgs associated productions with one or two hard jets can be used to refine the experimental cuts to increase the signal background ratio. see for example

  B. Mellado, W. Quayle and S. L. Wu, PRD76, 093007 (2007).

- $pp \to Hj$: NLO QCD in HEFT

  D. de Florian, M. Grazzini and Z. Kunszt, PRL82, 5209 (1999).

- $pp \to Hjj$:

  The 2jets correlation for probing Higgs CP properties

  T. Plehn, D. L. Rainwater and D. Zeppenfeld, PRL88, 051801 (2002);

  K. Hagiwara, Q. Li and K. Mawatari, JHEP0907 (2009) 101. ...

  Analytical calculation vs. HEFT at LO:

  V. Del Duca, W. Kilgore, C. Oleari, C. Schmidt and D. Zeppenfeld, NPB616, 367 (2001).

  NLO with HEFT:

  John M. Campbell, R. Keith Ellis, Giulia Zanderighi, JHEP0610 (2006) 028.
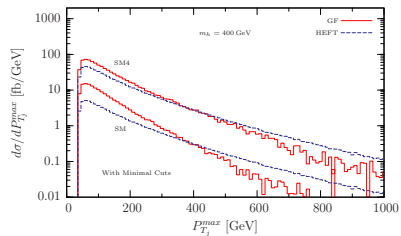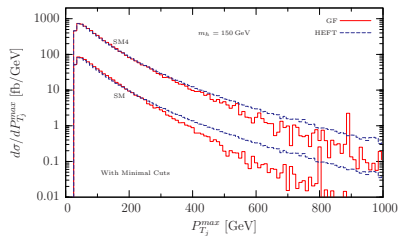
Higgs Production Cross section at the 14TeV LHC

arXiv:1011.4484
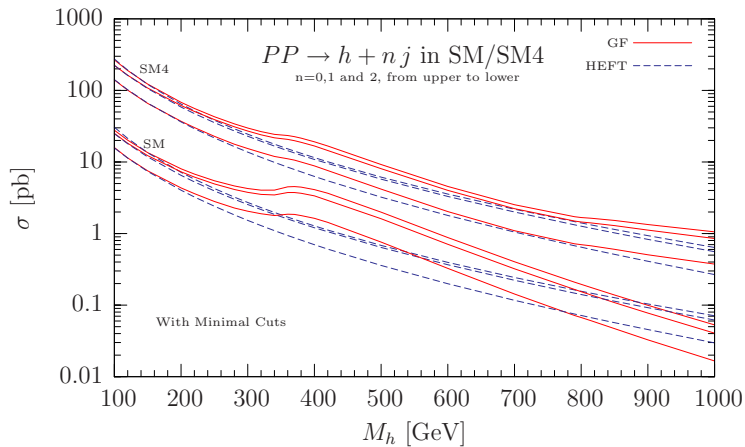
$P_{T_j}^{max}$ distributions

arXiv:1011.4484

Can we have a fully exclusvie while reliable ($\sim$ NLL) description, for light and heavy Higgs, at small and large PT, at Parton or Hadron level?
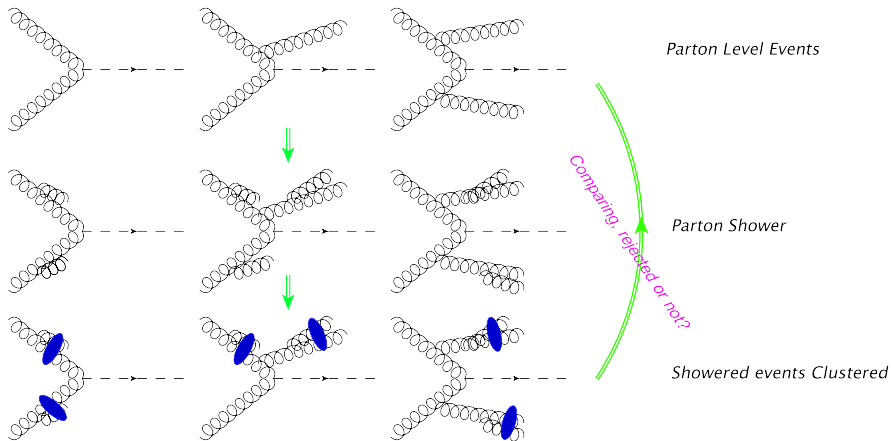
Parton shower matching with Matrix elements
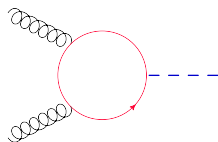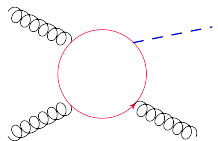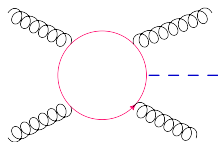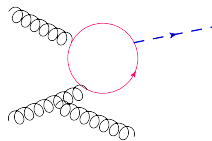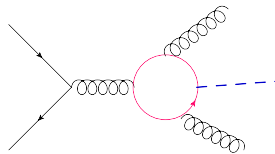
CKKW/MLM matching

- Yes, combining PS and ME consistently without double counting, by reweighting and veto

  - the CKKW method, based on shower veto and therefore on event re-weightning.
    S. Catani, F. Krauss, R. Kuhn and B. R. Webber,JHEP **0111**, 063 (2001); F. Krauss, JHEP **0208**, 015 (2002)

  - the MLM-based scheme, based on event rejection.
    S. Hoche, F. Krauss, N. Lavesson, L. Lonnblad, M. Mangano, A. Schalicke and S. Schumann, arXiv:hep-ph/0602031.

- Various implementations verified within ALPGEN, ARIADNE, HELAC, MG/ME, SHERPA on W+njets studies:
  Eur.Phys.J.C53:473,2008 [arXiv:0706.2569]
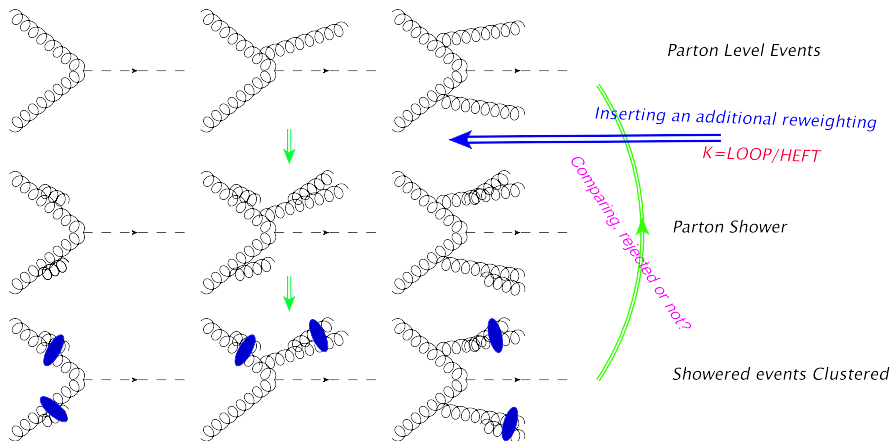
MLM matching implemented into MG/ME

- No analytic Sudakov reweighting; instead showered events are rejected if the jets inside are not matched to the matrix element-level partons.

- Producing matrix element $(H + 0, 1, 2j)$ events with a minimum separation $k_\perp$ cutoff of $Q_{\min}^{\mathrm{ME}}$.

- Passing the events to the parton shower. Before hadronizing/decaying, the final partons are clustered into jets using the $k_\perp$ algorithm with a jet cutoff of $Q_{\min}^{\mathrm{jet}}$ (like $50\,\mathrm{GeV}$) $> Q_{\min}^{\mathrm{ME}}$ (like $40\,\mathrm{GeV}$)

- The jets are then compared to the partons : Matched if $k_\perp(\mathrm{parton}, \mathrm{jet})$ is smaller than the cutoff $Q_{\min}^{\mathrm{jet}}$.

- The event is rejected unless each jet is matched to a parton. Except for the highest multiplicity sample, extra jets are not allowed.

Parton Level Events

Parton Shower

Showered events Clustered

Comparing, rejected or not?

One loop Matrix Elements at LO

H+0j

H+1j

H+2j

Modified Flow Chart

Parton Level Events

Inserting an additional reweighting

K=LOOP/HEFT

Comparing, rejected or not?

Parton Shower

Showered events Clustered

With LOOP/HEFT ratio got from MG and FeynArts/FormCalc/LoopTools.

Numerical Results

$PP \rightarrow h + X$ at the 7 TeV LHC

- CTEQ6L1 PDF, $\mu_r = \mu_f = M_h^T$.

- $m_t = 173.0\,\text{GeV}$, $m_b = 4.6\,\text{GeV}$.

- Generating $H + 0, 1, 2j$ sample for matching within MadGraph/MadEvent, with benchmark points: $m_H = 160, 300\,\text{GeV}$

- Unless specified, $Q_{\min}^{\text{ME}} = 40\,\text{GeV}$, $Q_{\min}^{\text{jet}} = 60\,\text{GeV}$.

- Jet clustering algorithm: K_T with cutoff at 30 GeV. Moreover, jets are required to satisfy $P_T^j > 30\,\text{GeV}$ and $|\eta_j| < 4.5$.
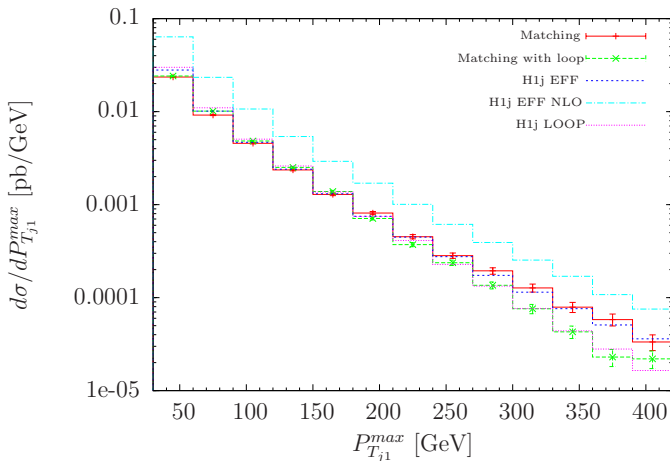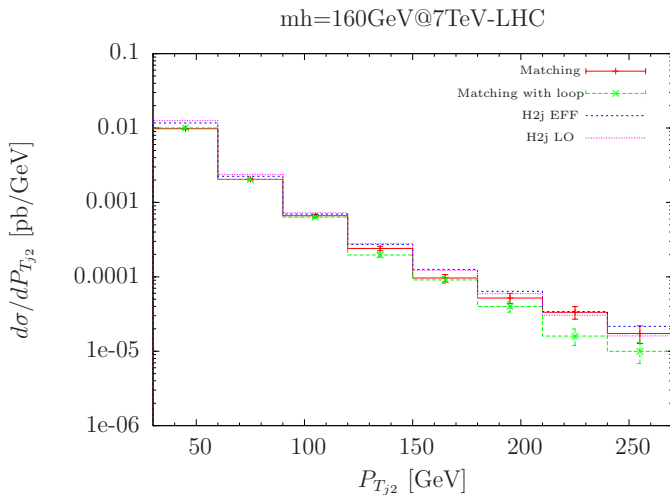
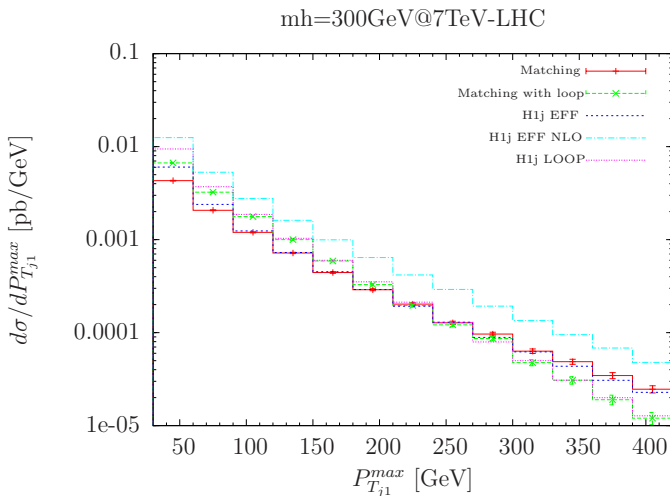# Differential Jet rate check

Higgs PT

mh=160GeV@7TeV-LHC
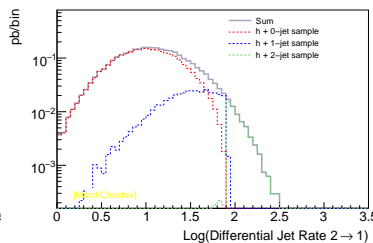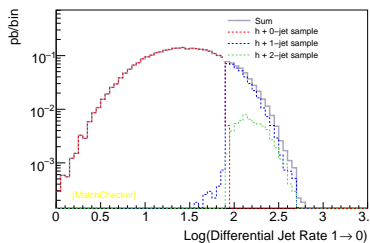
Leading jet PT
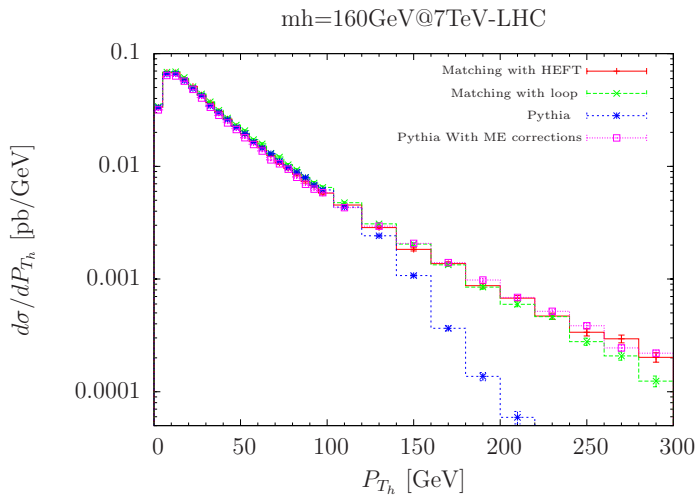
Second leading jet PT

mh=160GeV@7TeV-LHC

PTj1 for 300GeV Higgs

mh=300GeV@7TeV-LHC

Summary and Prospect

- We have performed the study of merging matrix element parton-level events with Pythia, for Higgs Gluon Fusion production at Hadron colliders, in the framework of MadGraph/MadEvent, in both HEFT and LOOP

- We compare and verify our results with pythia, parton level and MCFM ones.

- We give for the first time the results of ME/PS matching, out of the limit of HEFT approximation and thus appropriate for Heavy Higgs and hard jet kinematic region.

- Experimental use; Pseudoscalar Higgs; SM4...