STATUS OF

PREDICTIONS FOR

DIFFERENTIAL CROSS SECTIONS

FOR HIGGS SEARCHES AT THE LHC

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ACCURATE PREDICTIONS: MOTIVATION

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- Predictions for both SM and BSM on the same ground.

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  - BSM : GluonFusion, bbH, tH+

Master QCD formula

$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2 \, f_a(x_1, \mu_F^2) f_b(x_2, \mu_F^2) \times \hat{\sigma}_{ab\to X}(x_1, x_2, \alpha_S(\mu_R^2), \frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2})$$

Two ingredients necessary:

1. Parton Distribution functions (from exp, but evolution from th).

2. Short distance coefficients as an expansion in α_S (from th).

HOW CAN WE MAKE ACCURATE PREDICTIONS?

First way:

- For low multiplicity include higher order terms in our fixed-order calculations (LO → NLO → NNLO...) (also in EW).

$$\Rightarrow \hat{\sigma}_{ab\to X} = \sigma_0 + \alpha_S \sigma_1 + \alpha_S^2 \sigma_2 + \ldots$$

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Comments:

1. The theoretical errors systematically decrease.
2. A lot of new techniques and universal algorithms have been developed for NLO computations (automation).
3. The frontier is now NNLO in QCD and NLO in EW : several results available by now!
4. Final description only in terms of partons and calculation of IR safe observables (histograms not events)⇒ not directly useful for exp simulations

NEW LOOP TECHNIQUES

For the calculation of one-loop matrix elements, several methods are now established :

- Generalized Unitarity (ex. BlackHat, Rocket,...)

[Bern, Dixon, Dunbar, Kosower, hep-ph/9403226 + ...; Ellis, Giele, Kunszt 0708.2398, +Melnikov 0806.3467]

- Integrand Reduction (ex. CutTools, Samurai)

[Ossola, Papadopolulos, Pittau, hep-ph/0609007; del Aguila, Pittau, hep-ph/0404120; Mastrolia, Ossola, Reiter, Tramontano, 1006.0710]

- Tensor Reduction (ex. Golem)

[Passarino, Veltman, 1979; Denner, Dittmaier, hep-ph/0509141, Binoth, Guillet, Heinrivh, Pilon, Reiter 0810.0092]

Which also has lead to stunning progress in the possibility of making NLO computations automatically:

- HELAC-NLO
- Golem
- MadLoop + MadFKS

From Grazzini's talk at Higgs Hunting 2011

The NNLO revolution

The method successfully applied to gg→H and the Drell-Yan process can be used to perform NNLO computations for other important processes

$$c\bar{c} \longrightarrow F + X \qquad c = q, g$$

S.Catani, L Cieri, G.Ferrera, D. de Florian, MG (to appear)

Examples:

Arbitrary colourless final state

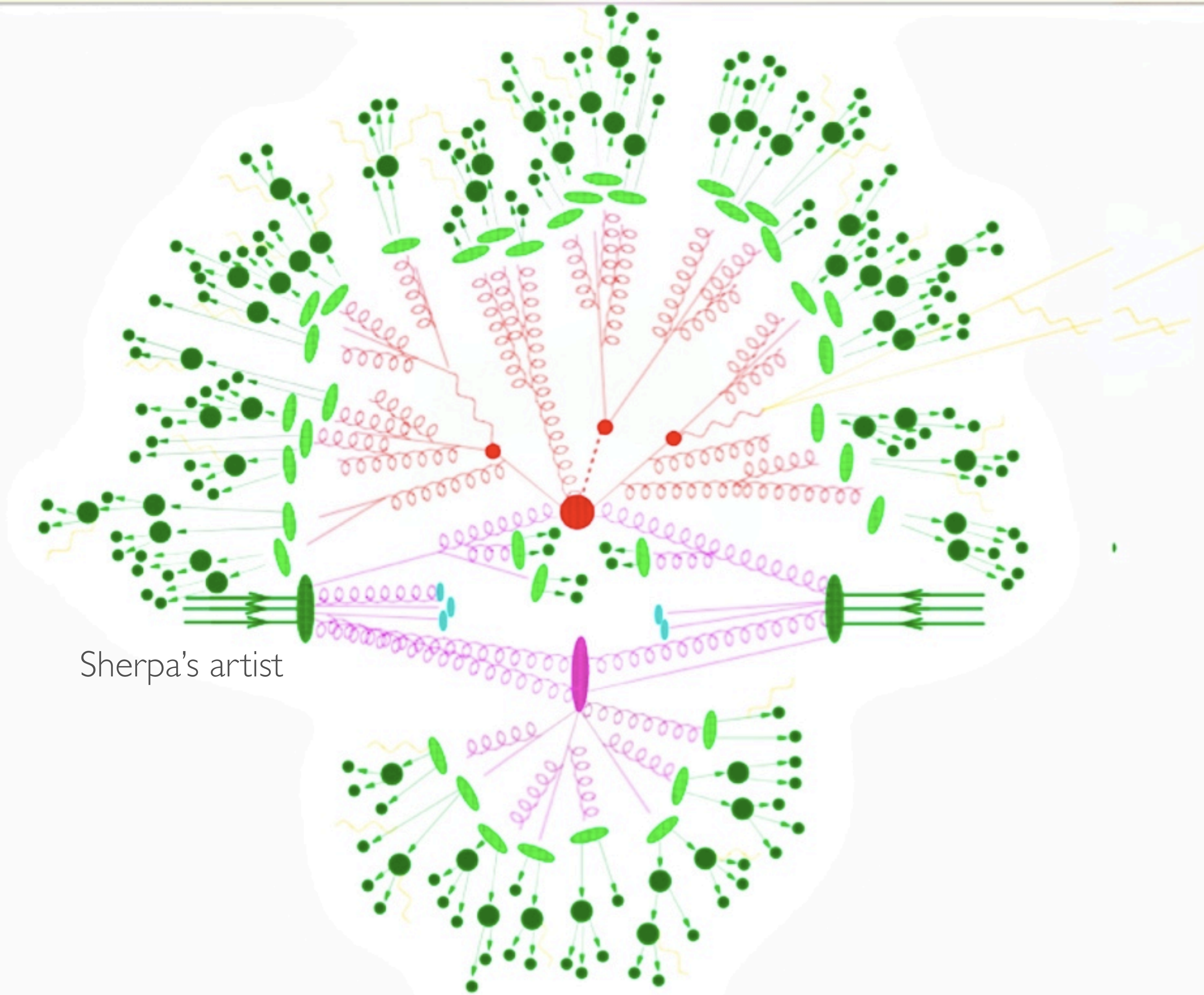
- Higgs-strahlung: F=WH, ZH
- $b\bar{b} \longrightarrow H$ R.Harlander, K.Ozeren, Wiesemann (2010)
- Vector boson pair production: F= γγ,WW, ZZ, WZ........

Important backgrounds for new physics searches

For each of these processes the ingredients that we need are:

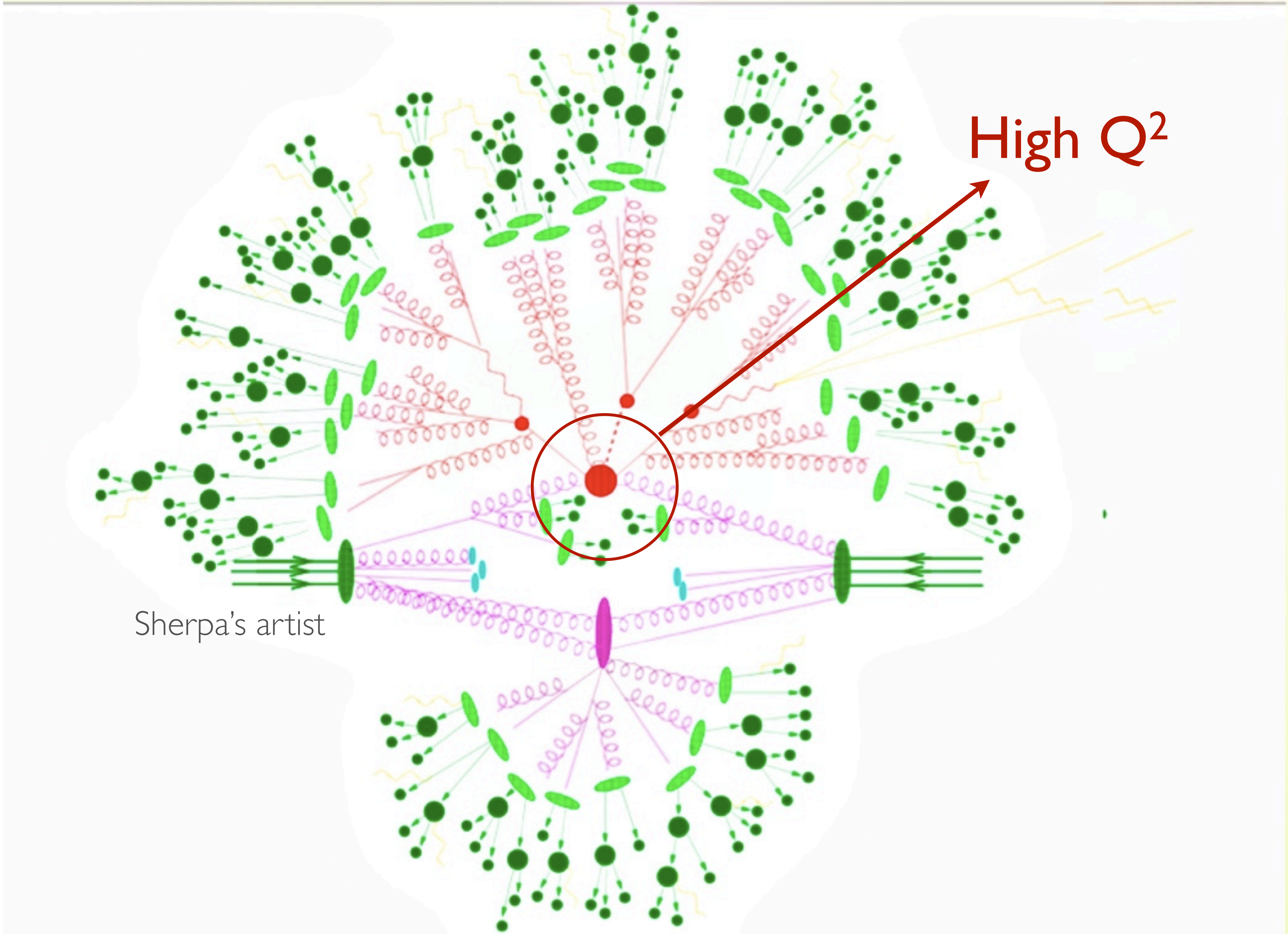
- Two loop amplitude for $c\bar{c} \longrightarrow F$
- NLO cross section for F+jet(s)

Events at hadron colliders



Sherpa's artist

Events at hadron colliders



HOW CAN WE MAKE USEFUL PREDICTIONS?

Second way:

- Describe final states with high multiplicities starting from 2 →1 or 2 →2 procs, using parton showers,

$$d\sigma^{\rm PS} = d\Phi_B B(\Phi_B)\left[\Delta(p_\perp^{\rm min}) + d\Phi_{R|B}\Delta(p_T(\Phi_{R|B}))\frac{R^{\rm PS}(\Phi_R)}{B(\Phi_B)}\right]$$

$$\Delta(p_T) = \exp\left[-\int d\Phi_{R|B}\frac{R^{\rm PS}(\Phi_R)}{B(\Phi_B)}\Theta(p_T(\Phi_R)-p_T)\right] \cdot \quad R^{\rm PS}(\Phi) = P(\Phi_{R|B})\,B(\Phi_B).$$

and hadronization model.

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and hadronization model.

Comments:

1. Fully exclusive final state description for experimental analyses
2. Normalization is very uncertain
3. Very crude kinematic distributions for multi-parton final states

Merging with PS

[Mangano]
[Catani, Krauss, Kuhn, Webber]
[Frixione, Nason, Webber]

Matrix Element	Shower MC
1. parton-level description	1. hadron-level description
2. fixed order calculation	2. resums large logs
3. quantum interference exact	3. quantum interference through angular ordering
4. valid when partons are hard and well separated	4. valid when partons are collinear and/or soft
5. needed for multi-jet description	5. nedeed for realistic studies

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Approaches are complementary: merge them!

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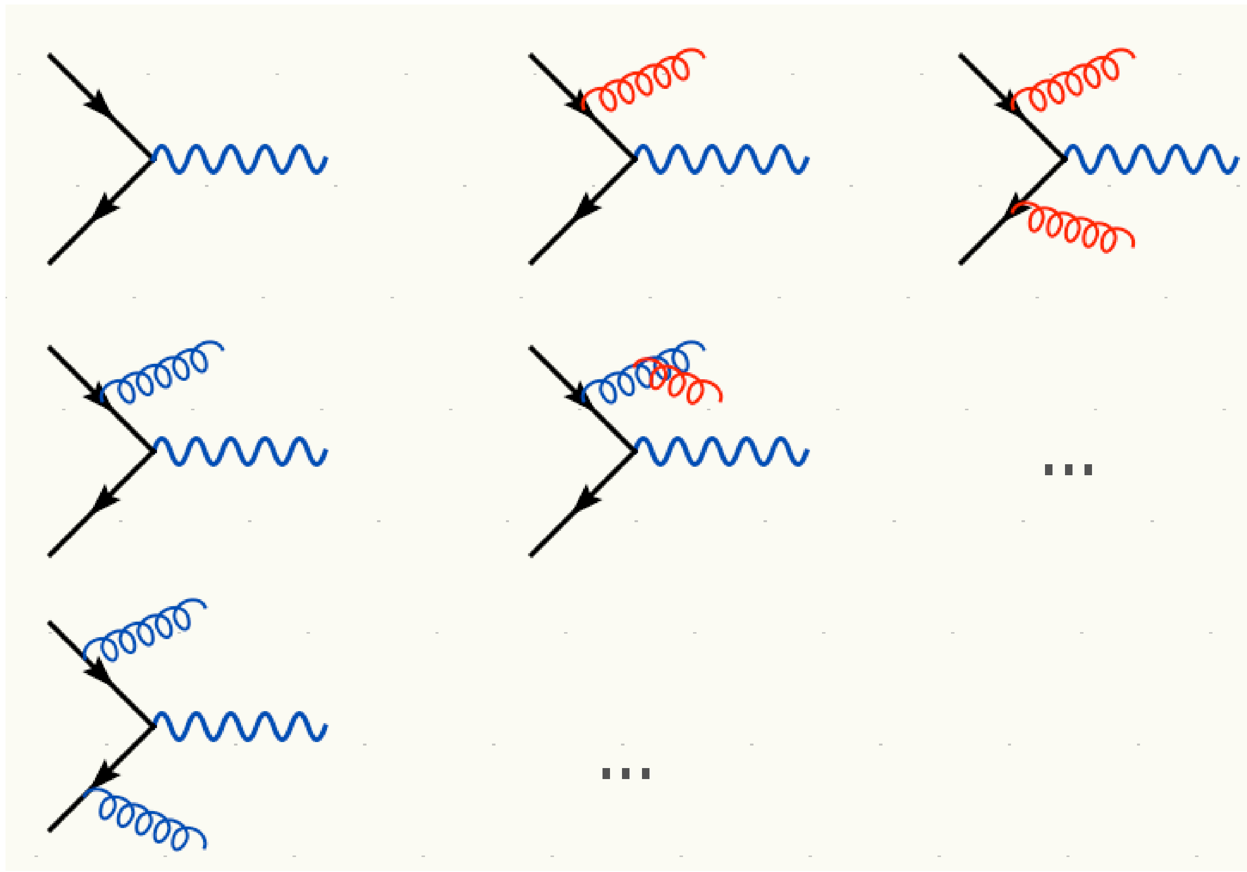
Difficulty: avoid double counting

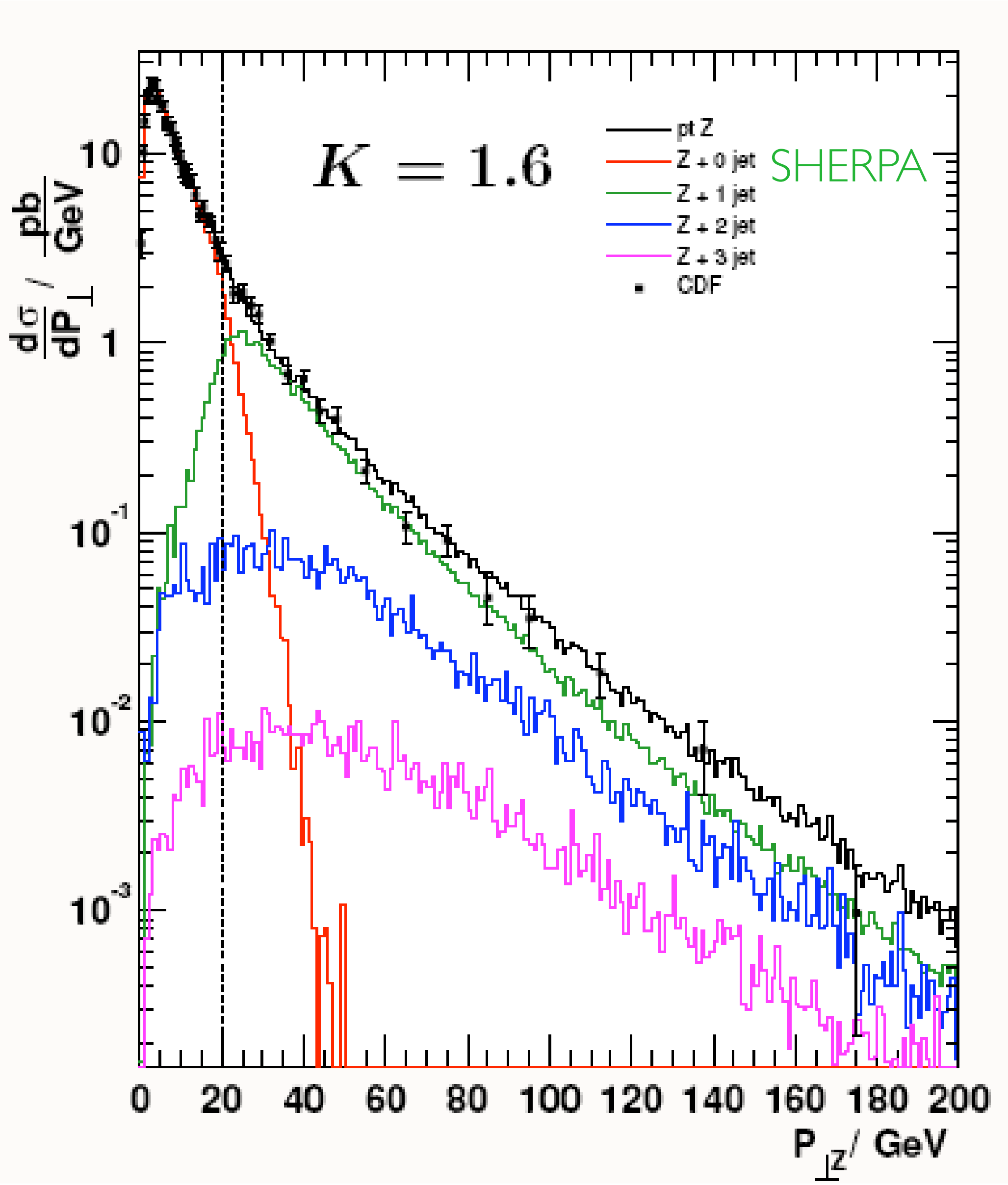
Merging ME with PS (LO)

[Mangano]
[Catani, Krauss, Kuhn, Webber]

PS →

ME ↓





Double counting of configurations that can be obtained in different ways (histories). All the matching algorithms (CKKW, MLM,...) apply criteria to select only one possibility based on the hardness of the partons. As the result events are exclusive and can be added together into an inclusive sample. Distributions are accurate but overall normalization still "arbitrary".

NLOwPS in a nutshell

$$d\sigma^{\mathrm{NLO+PS}} = d\Phi_B \bar{B}^s(\Phi_B)\left[\Delta^s(p_\perp^{\min}) + d\Phi_{R|B}\frac{R^s(\Phi_R)}{B(\Phi_B)}\Delta^s(p_T(\Phi))\right] + d\Phi_R R^f(\Phi_R)$$

integrates to 1 (unitarity)

with

$$\bar{B}^s = B(\Phi_B) + \left[V(\Phi_B) + \int d\Phi_{R|B} R^s(\Phi_{R|B})\right]$$

Full cross section (if F=1) at fixed Born kinematics

$$R(\Phi_R) = R^s(\Phi_R) + R^f(\Phi_R)$$

This formula is valid both for both MC@NLO and POWHEG

MC@NLO: $R^{\mathrm{s}}(\Phi) = P(\Phi_{R|B})\, B(\Phi_B)$

Needs exact mapping $(\Phi_B, \Phi_R) \to \Phi$

POWHEG: $R^{\mathrm{s}}(\Phi) = F R(\Phi)\,, R^{\mathrm{f}}(\Phi) = (1-F) R(\Phi)$

F=1 = Exponentiates the Real.
It can be damped by hand.

MC@NLO AND POWHEG

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MC@NLO

[Frixione, Webber, 2003;
Frixione, Nason, Webber, 2003]

- Matches NLO to HERWIG and HERWIG++ angular-ordered PS.
- Some events have negative weights.
- Large and well tested library of processes.

- Now available also for Pythia (Q^2) [Torrielli, Frixione, 1002.4293]
- Now automatized [Frederix, Frixione, Torrielli]
- Now available in aMC@NLO (see later)

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POWHEG

[Nason 2004;
Frixione, Nason, Oleari, 2007]

- Is independent* of the PS. It can be interfaced to PYTHIA, HERWIG or SHERPA.
- Generates only* positive unit weights.

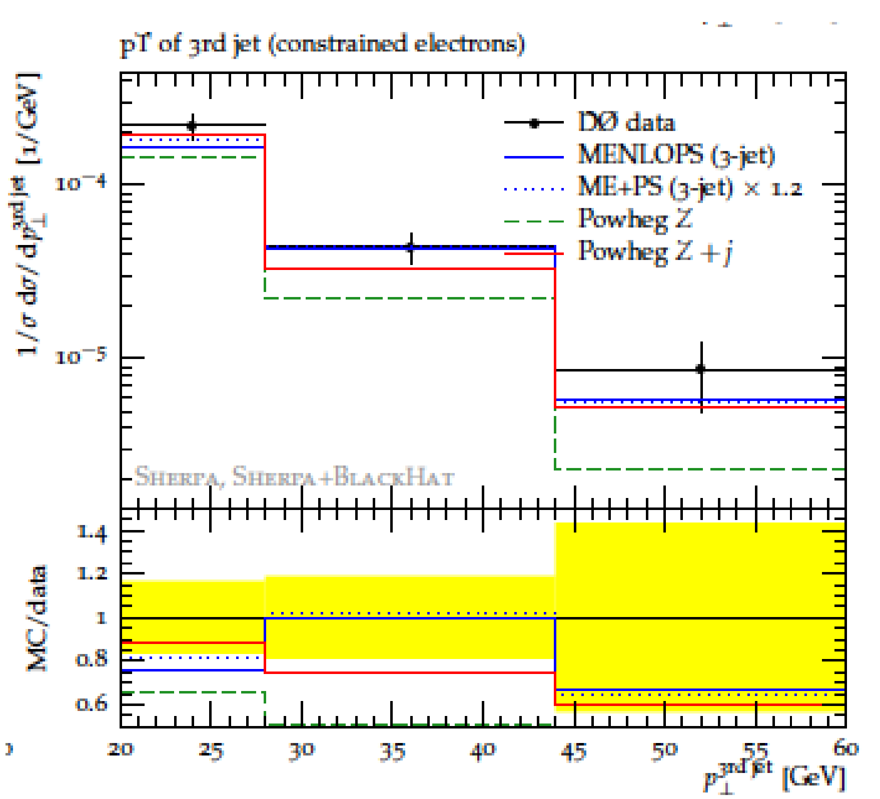
- Can use existing NLO results via the POWHEG-Box [Aioli, Nason, Oleari, Re et al. 2009]
- Method used by HELAC, HERWIG++ and SHERPA [Kardos, Papadopoulos, Trocsanyi 1101.2672], [Hoeche,Krauss, Schooenner, Siegert, 1008.5399]

GOING BEYOND: MENLOPS

[Hamilton, Nason,1004.1764]
[Hoche et al , 1009.1127]
[Aioli, Hamilton Re, 1108.0909]

A fully consistent and working CKKW at NLO missing, one can still aim at having matched samples with a built in NLO normalization. This is the aim of the MENLOPS which is currently implemented in the POWHEG framework:

$$\langle O \rangle = \int d\Phi_B \, \bar{B}(\Phi_B) \Bigg[\Delta^{(\mathrm{ME})}(t_0) \, O(\Phi_B) + \overbrace{\int d\Phi_{R|B} \frac{R(\Phi_R)}{B(\Phi_B)} \Delta^{(\mathrm{ME})}(t) \, \Theta(Q_{\mathrm{cut}} - Q) \, O(\Phi_R)}^{\text{POWHEG domain}} + \underbrace{\int d\Phi_{R|B} \frac{R(\Phi_R)}{B(\Phi_B)} \Delta^{(\mathrm{PS})}(t) \, \Theta(Q - Q_{\mathrm{cut}}) \, O(\Phi_R)}_{\text{ME domain}} \Bigg]$$



Still in exploration. Not many applications available so far, but promising.

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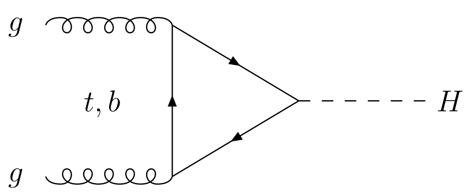
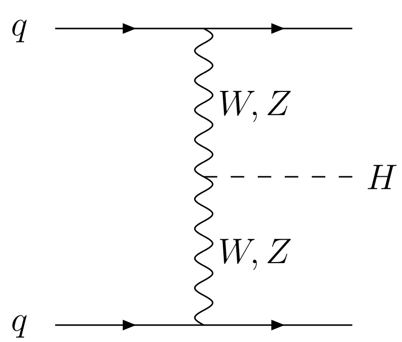
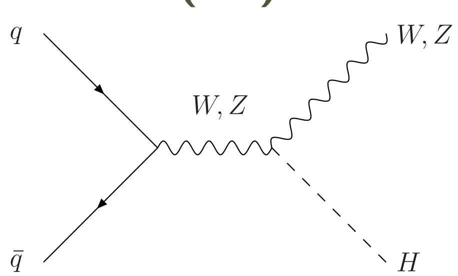
Higgs production at LHC7



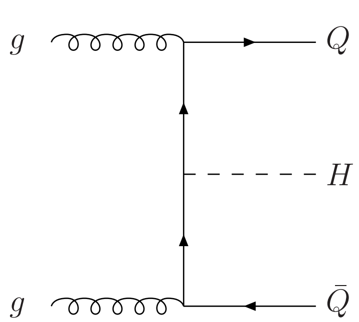
GluonFusion



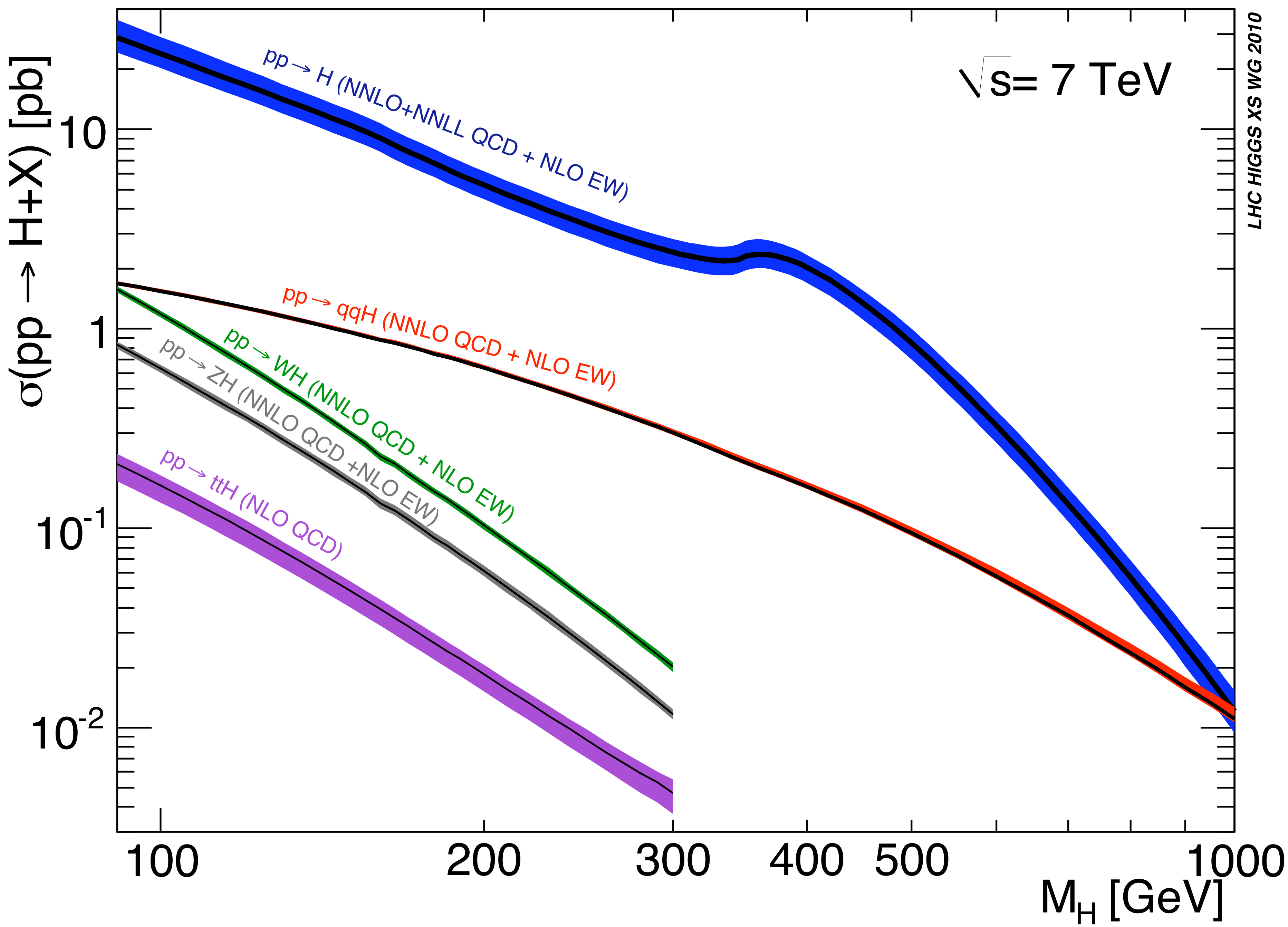
vector boson fusion (VBF)



associated production with vector bosons



associated production with heavy quarks



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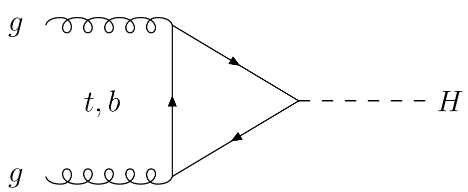

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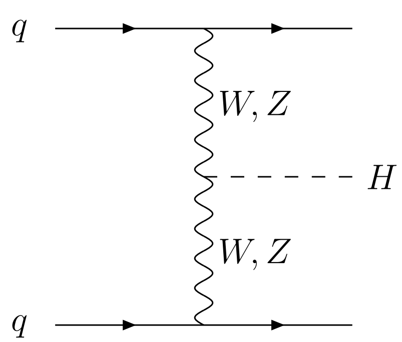
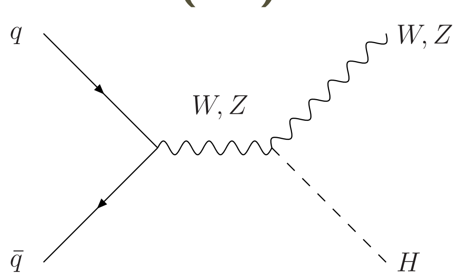
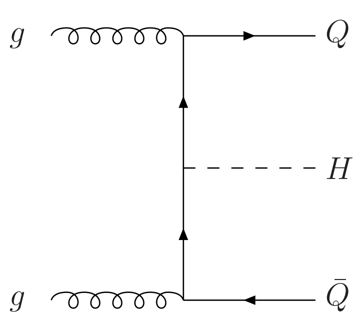


vector boson fusion (VBF)



associated production with vector bosons



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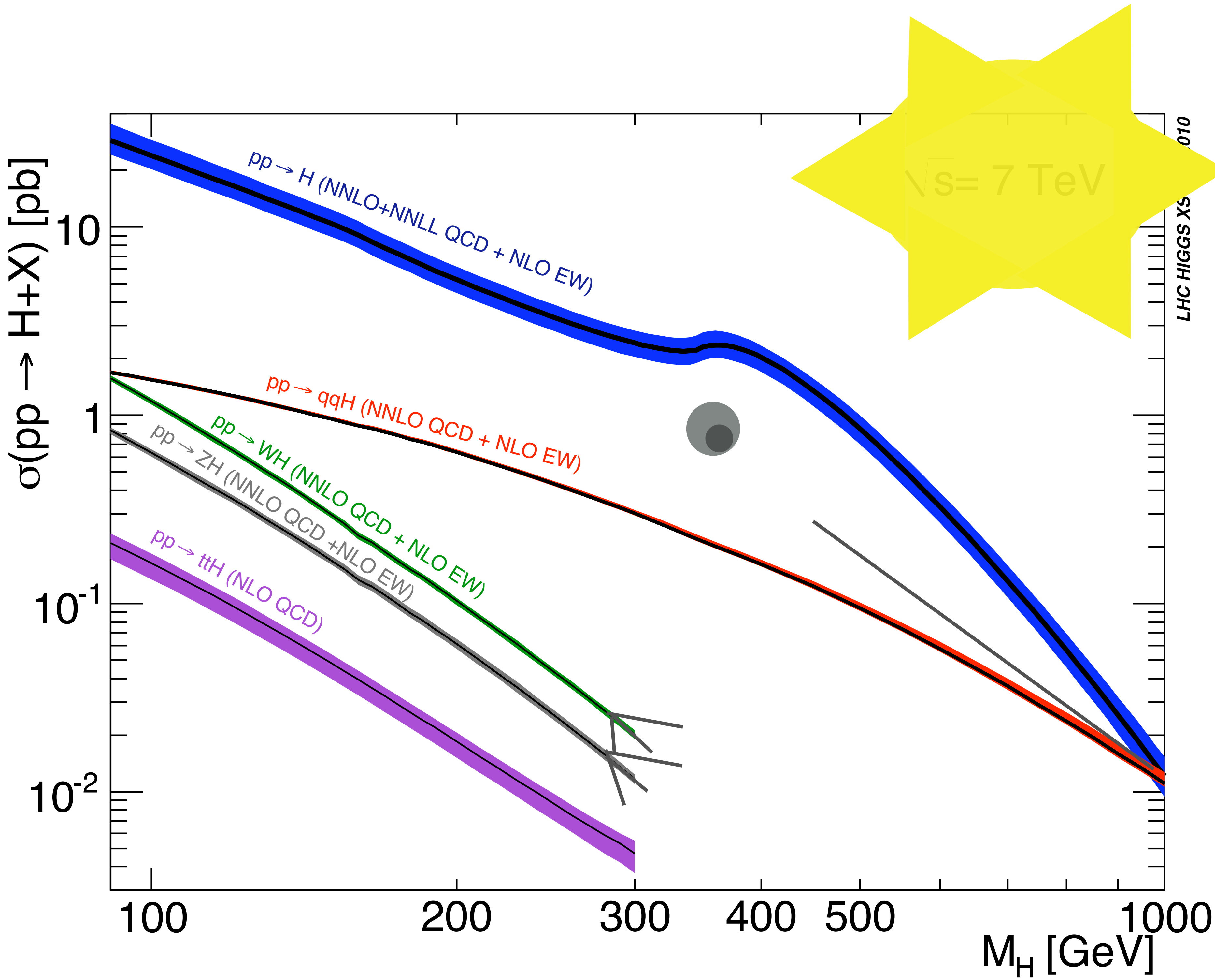
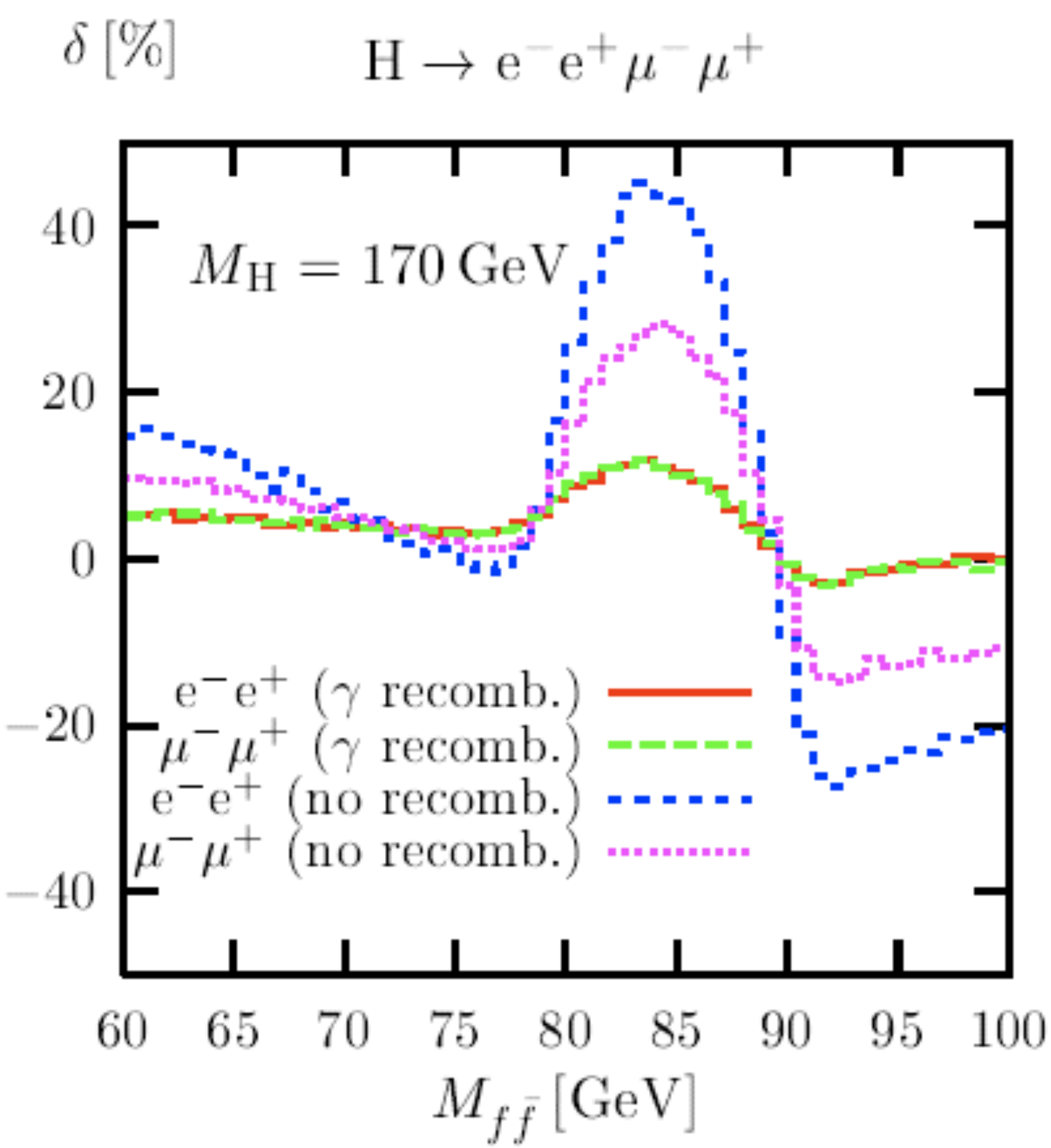


Higgs decays

Precise predictions for Higgs production must be followed by comparable precision in the rates and distributions in Higgs decay.



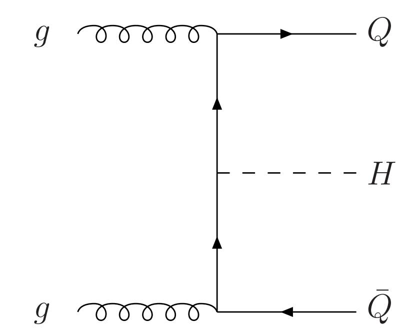
One-loop EW and QCD effects for the H→WW(ZZ)→4fermions decay channels are known

[A.Bredenstein, A.Denner, S.Dittmaier, M.Weber, hep-ph/0604011/0611234]

Important effects in the peak region but not taken into account at present

Implemented in PROPHECY4F.
No NLOwPS version available yet.

PP→TTH/TTA

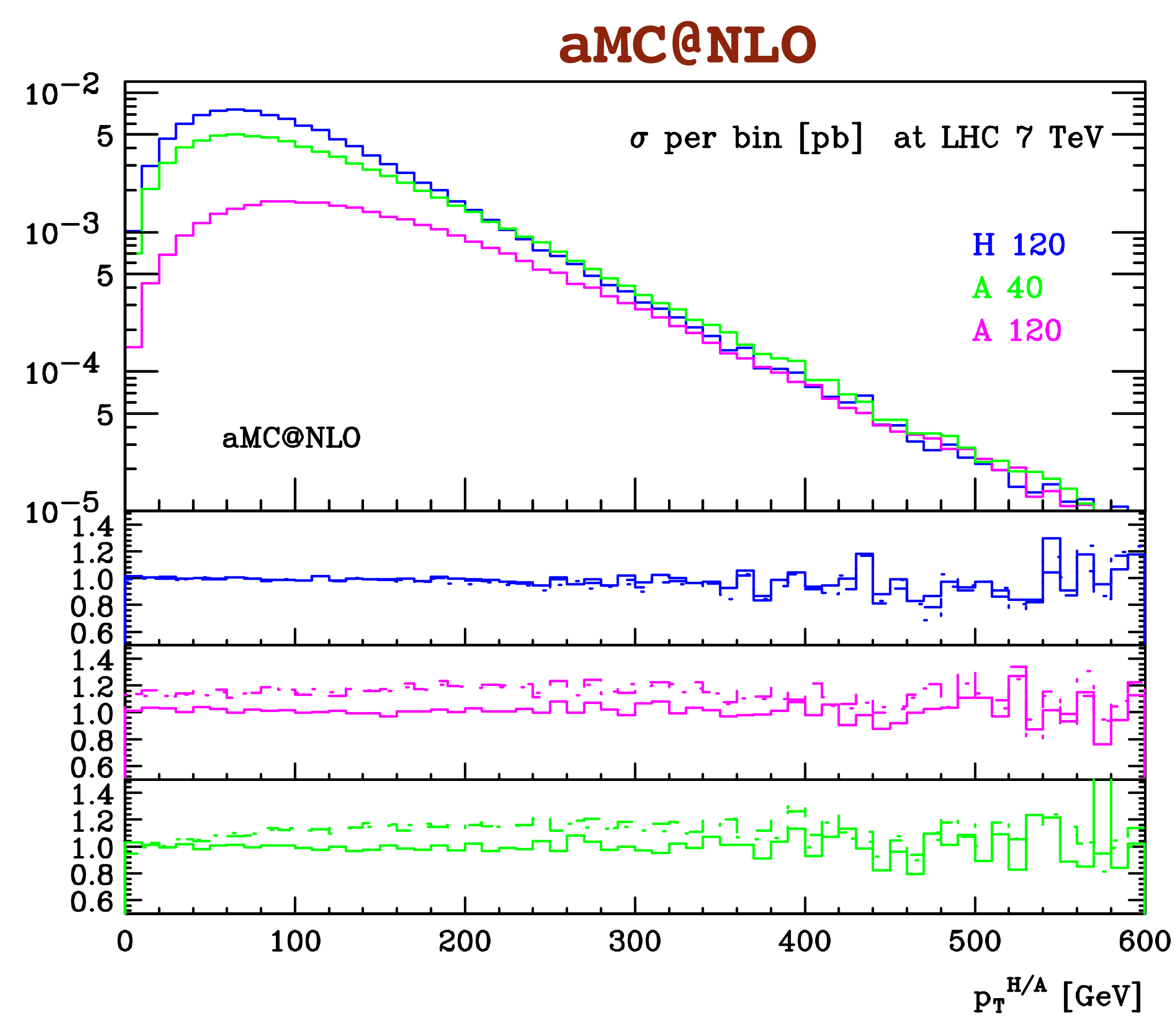


SIGNAL:

NLO known since 10 years
[Beenakker, 2001; Reina, 2001]

Available now in aMC@NLO for both Scalar and Pseudoscalar [Frederix, et al. 1104.5613] and SM available in POWHEG [Garzelli, et al. 1108.0387]

Upshot: modest corrections to shapes.



BACKGROUNDS:

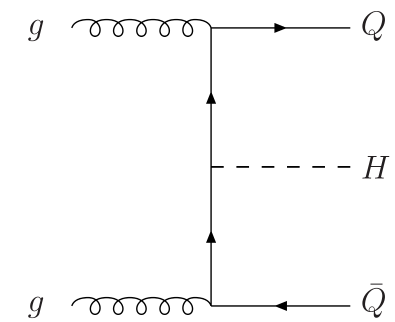
ttbb: [mb=0: Bredenstein, 0905.0110,
Bevilacqua, 0907.4723]
ttjj : [Bevilacqua, 1002.4009,1108.2851]
ttZ:[Lazopolous, 0804.2220 ; Hirshi, 1103.0621]

NONE available at NLOwPS yet.

	$K_{NNLO/NLO}$ ($K_{NLO/LO}$)	Scale	PDF+α_s	Scale+PDF
ttH	- (+5-20%)	+4 -10%	±8%	**+12 -18%**

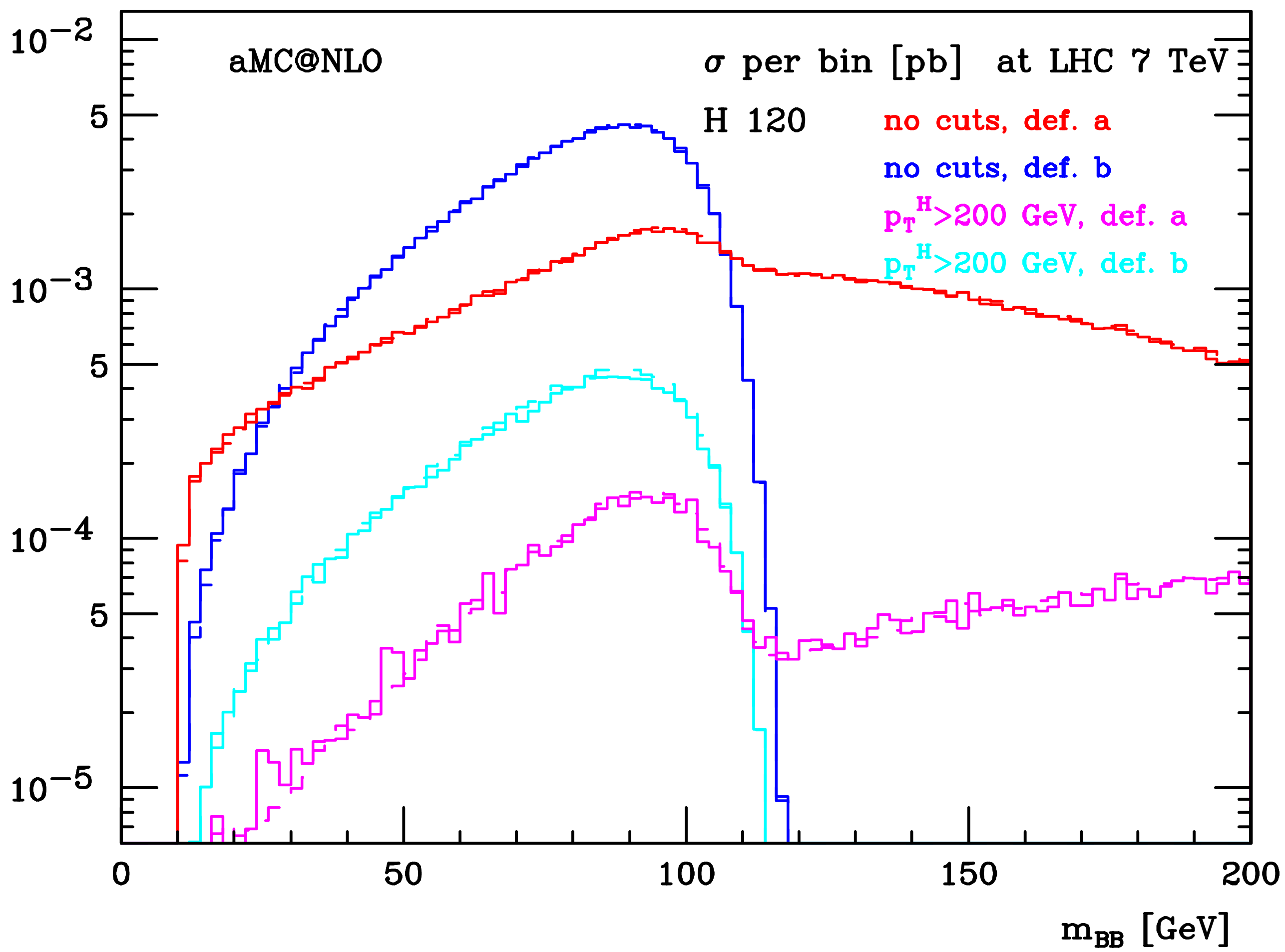
COMMENTS:

ttZ straightforward in the aMC@NLO framework.

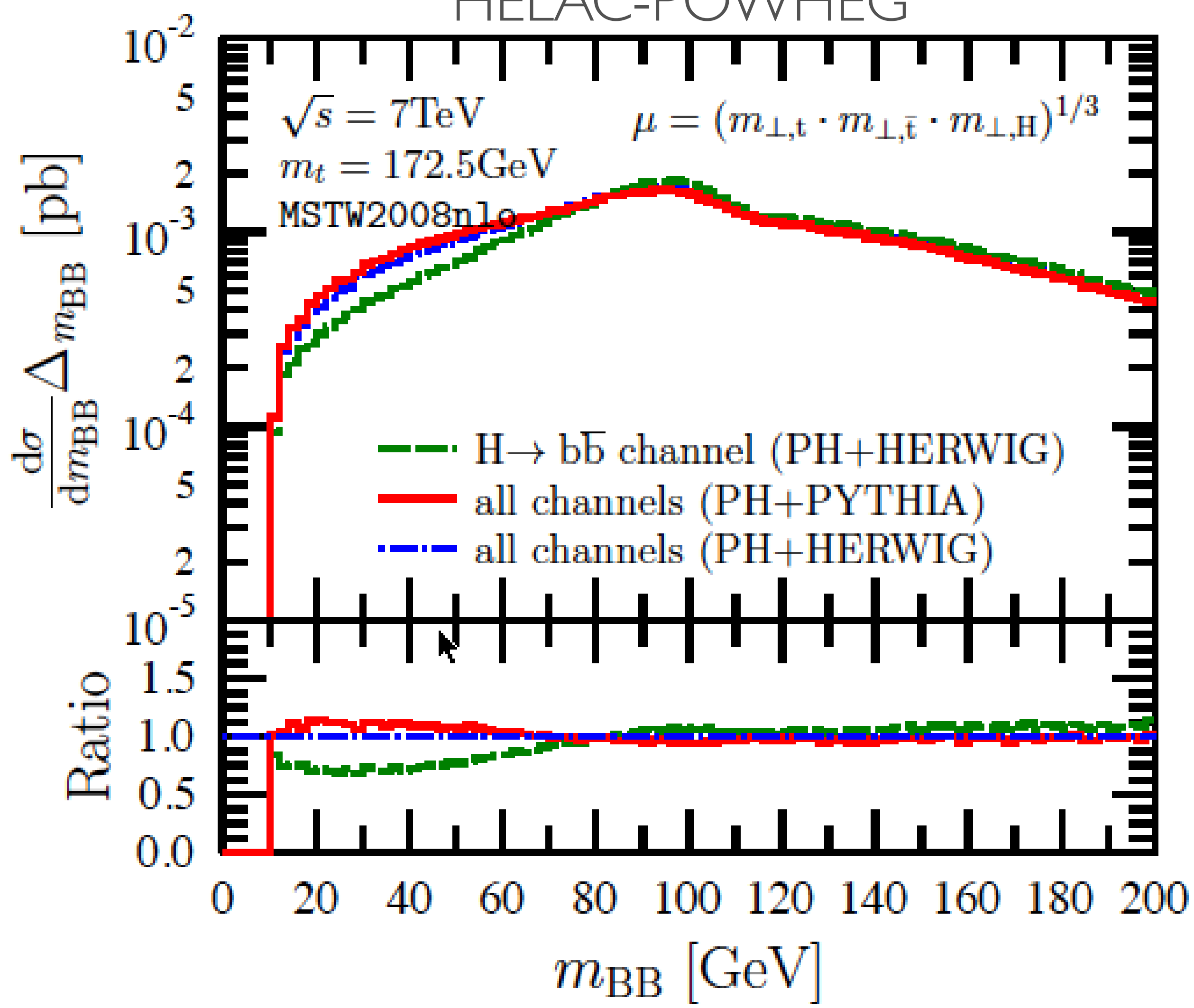


PP→TTH/TTA

aMC@NLO

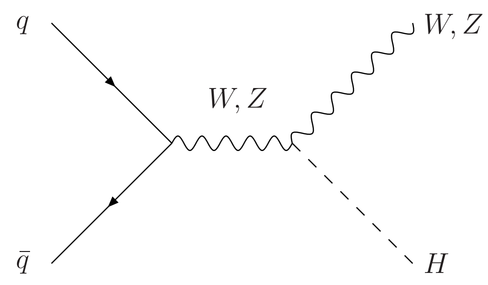


HELAC-POWHEG



MC gives the possibility to study fully exclusive (and/or hadronic) kind of variables for this process for the first time at the NLO.

PP→ZH/WH



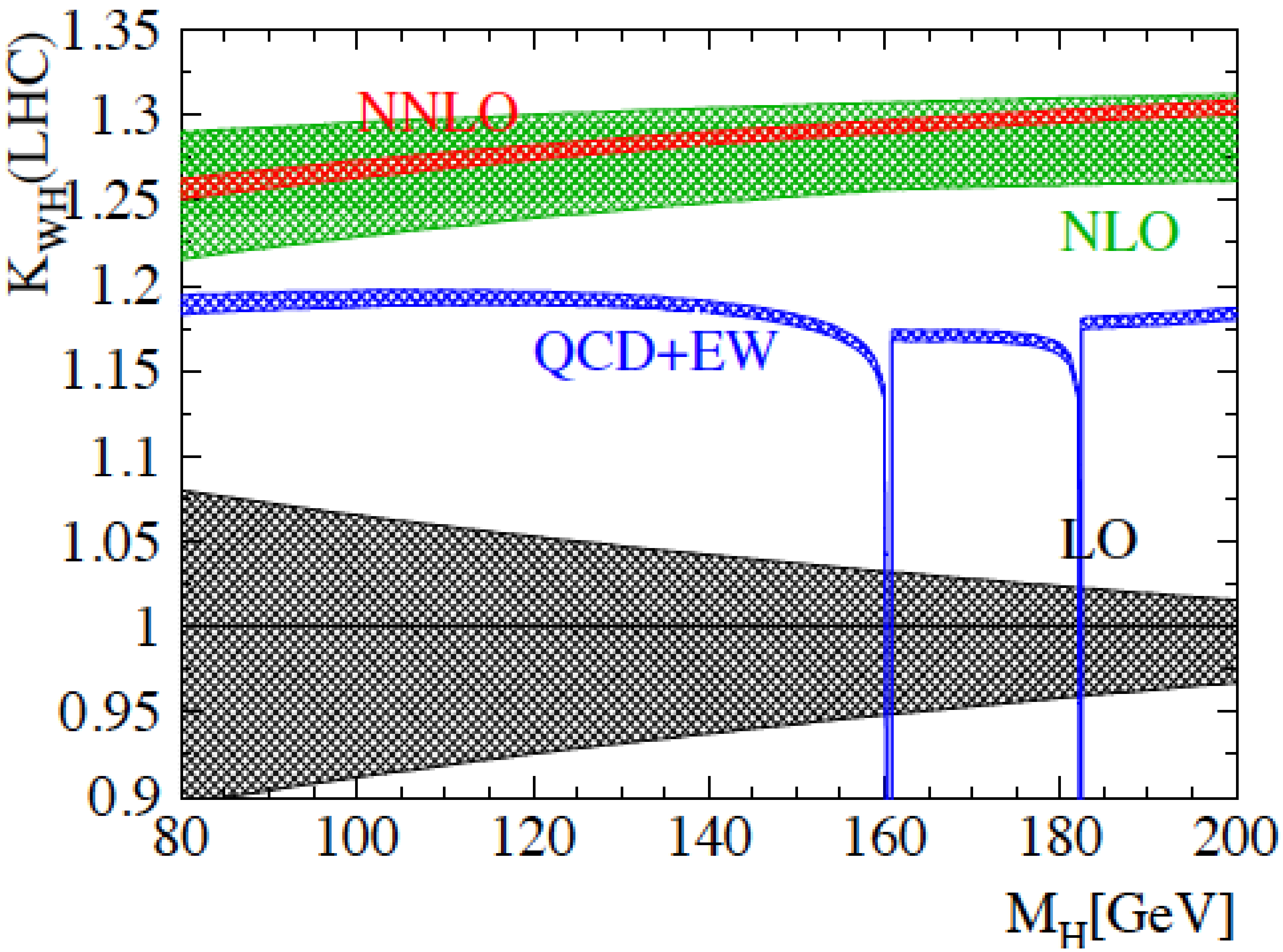
SIGNAL:

Very similar to Drell-Yan,

NLO known since a long time.
[Han, Willenbrock '90]

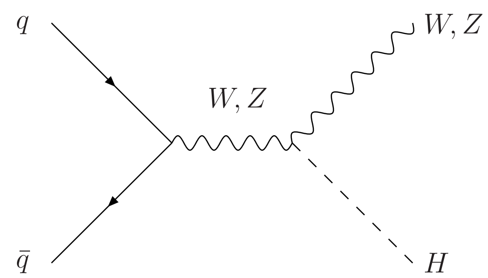
NNLO

[Brein, Djouadi, Harlander '03]
[Ciccolini, Dittmaier, Krämer '03]
[Brein, Harlander, Wiesemann, Zirke '11]



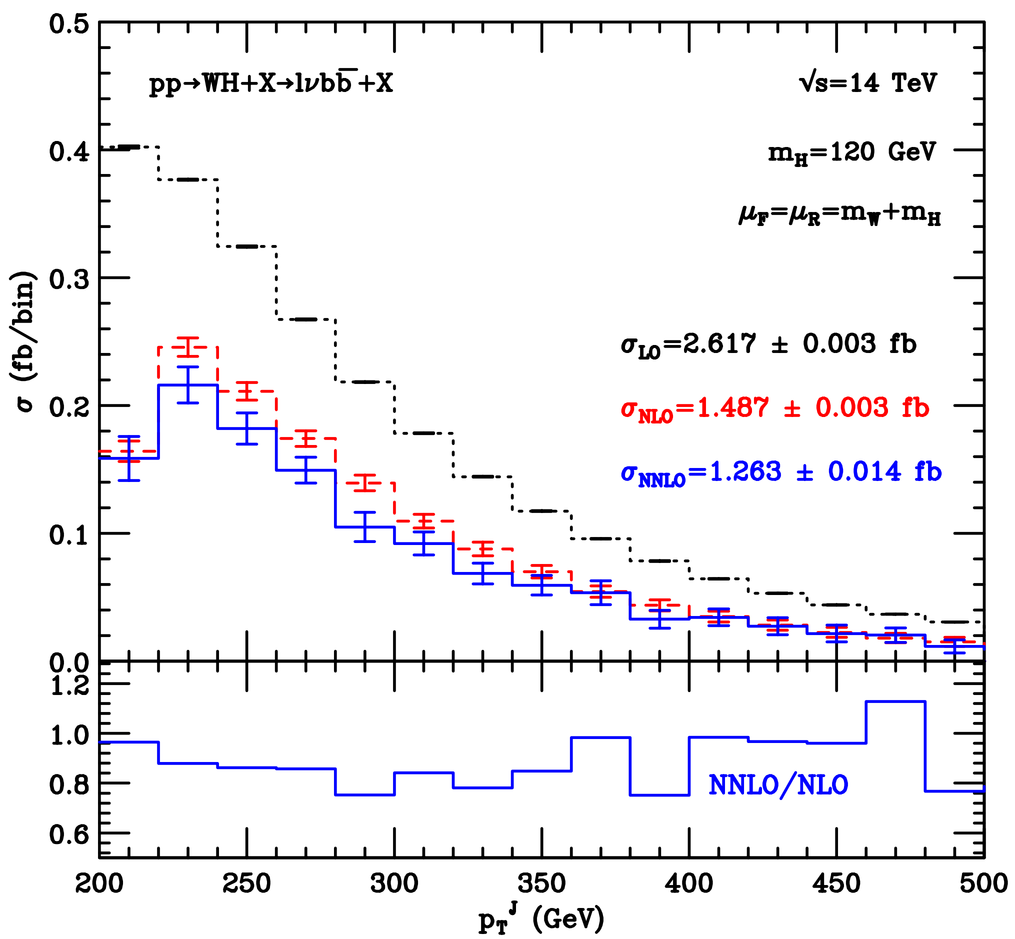
	$K_{NNLO/NLO}$ ($K_{NLO/LO}$)	Scale	PDF+α_s	Scale+PDF
WH/ZH	+2-6% (+30%)	±1%	±4%	**±5%**

PP→WH



Results at the LHC (√s=14 TeV) for boosted Higgs

First differential (parton level) NNLO calculation now available [G.Ferrera, F.Tramontano, M. Grazzini, 1107.1164]



Cuts: lepton: p_T > 30 GeV and |η|<2.5, p_T^{miss} > 30 GeV

Jets: CA algorithm with R=1.2

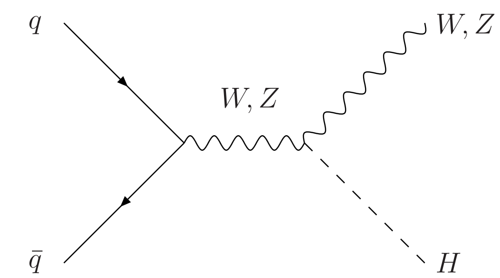
One of the jets (fat jet) must have p_T^J>200 GeV and $|\eta_J|$<2.5 and must contain the bb pair; no other jet with p_T > 20 GeV and |η|<5

σ (fb)	LO	NLO	NNLO
$\mu_F = \mu_R = (m_W + m_H)/2$	2.640 ± 0.002	1.275 ± 0.003	1.193 ± 0.017
$\mu_F = \mu_R = m_W + m_H$	2.617 ± 0.003	1.487 ± 0.003	1.263 ± 0.014
$\mu_F = \mu_R = 2(m_W + m_H)$	2.584 ± 0.003	1.663 ± 0.002	1.346 ± 0.013

Impact of radiative corrections strongly reduced by the jet veto ⇨

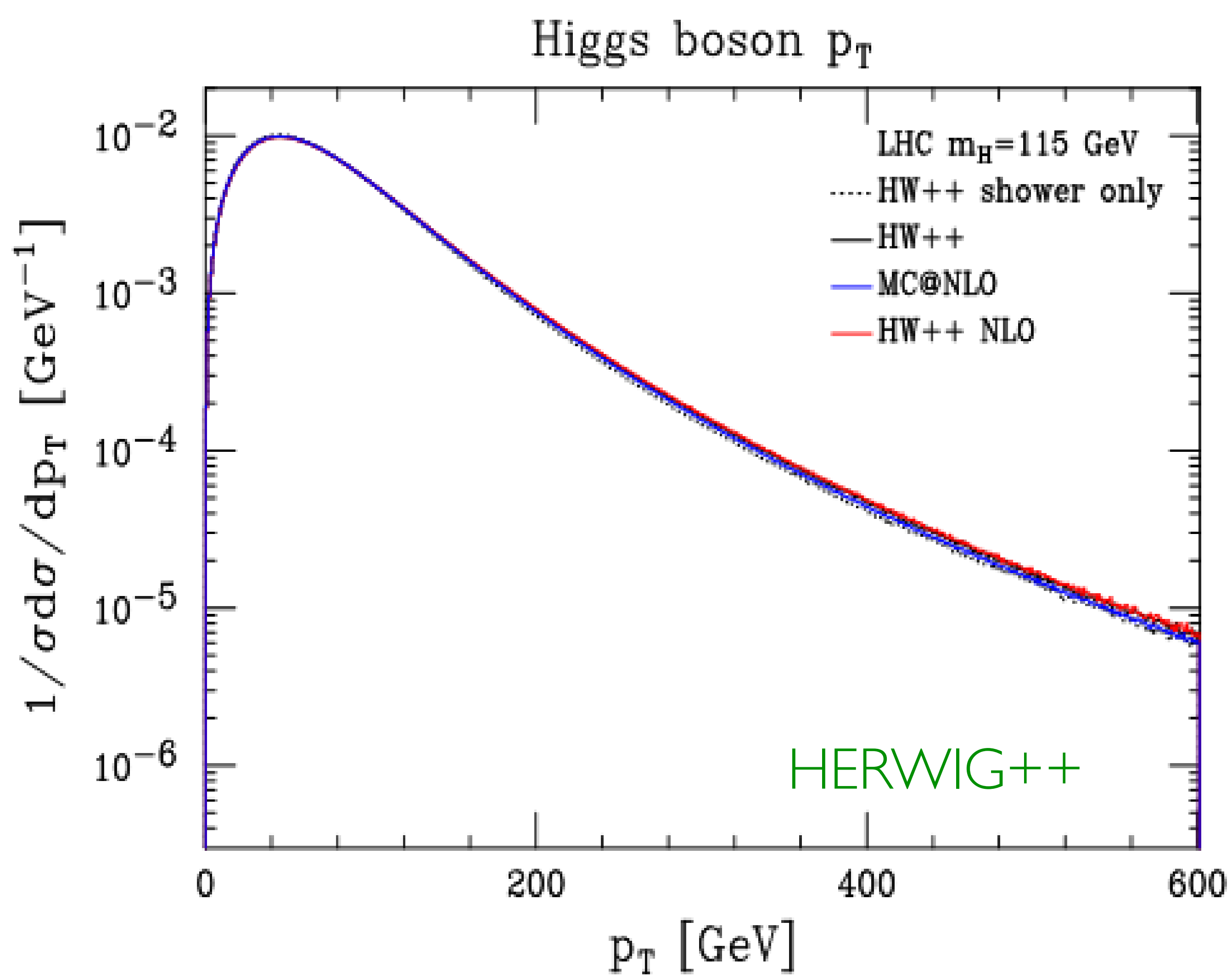
Stability of fixed-order expansion is challenged

$pp \to ZH/WH$



SIGNAL:

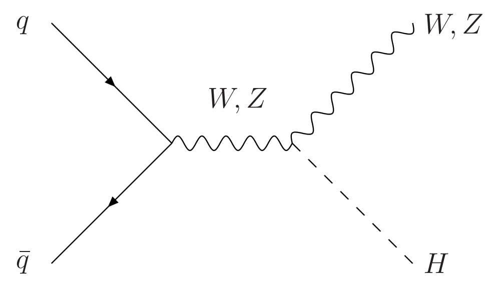
HERWIG++ (POWHEG) [Hamilton, Richardson]
MC@NLO (and aMC@NLO)



COMMENTS:

It could be implemented in the POWHEG-Box for Pythia interfacing.

PP→ZH/WH



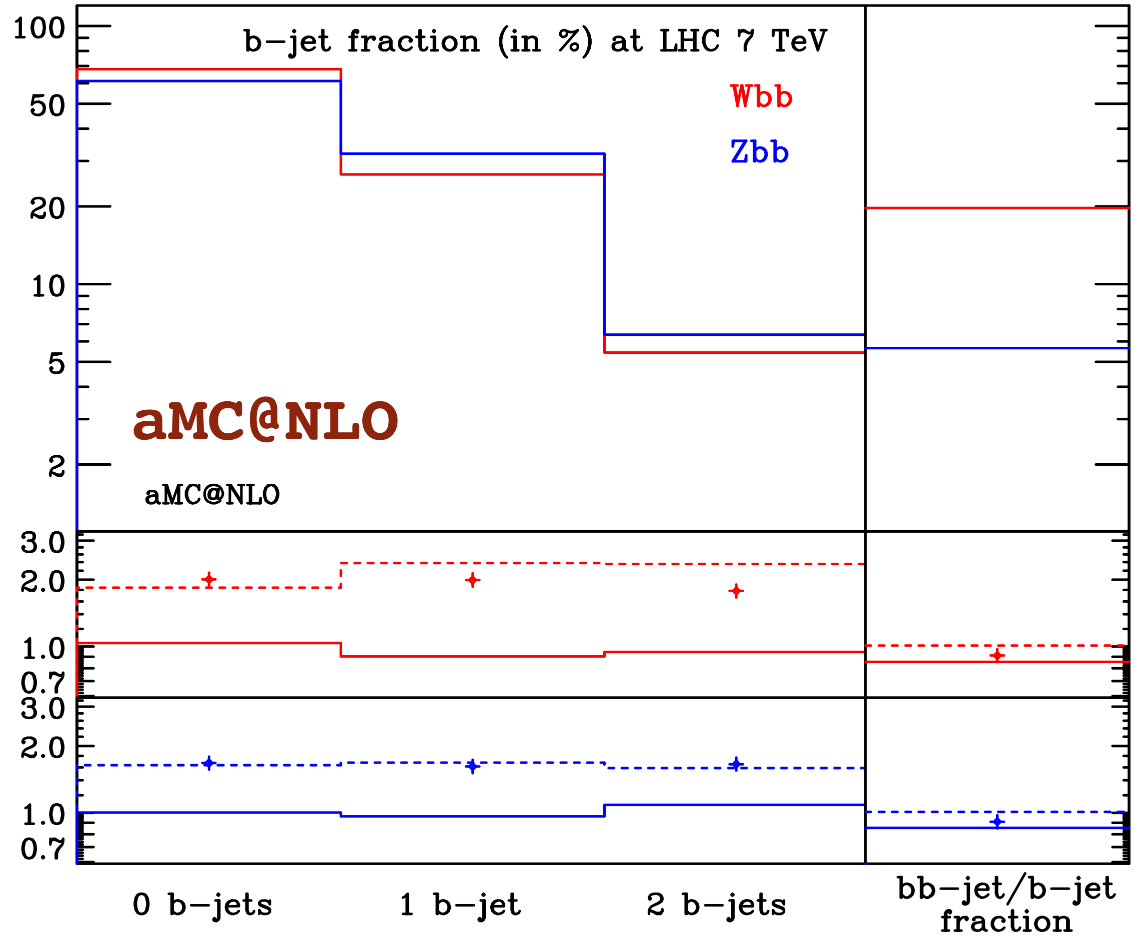
BACKGROUNDS:

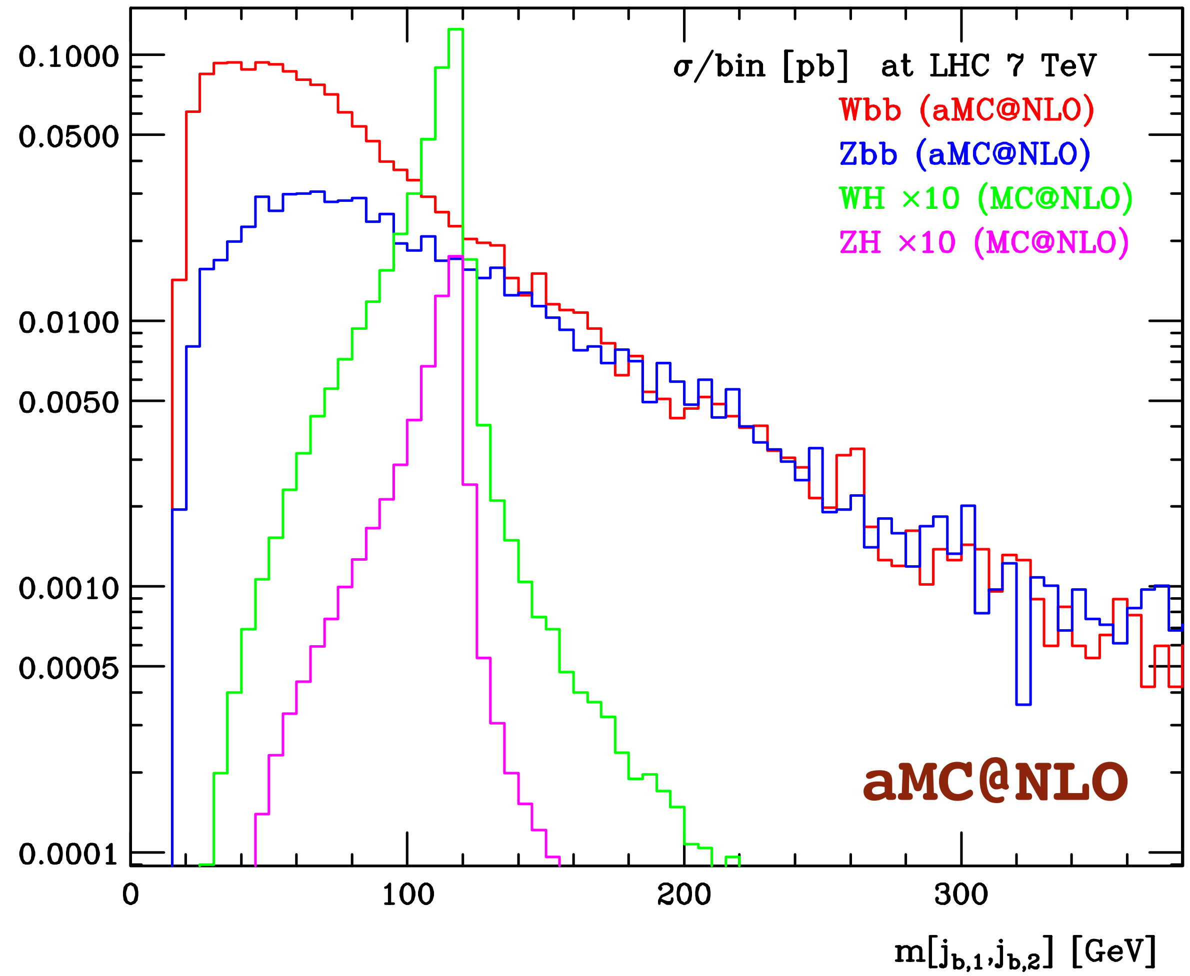
pp→Wbb : POWHEG [Oleari, Reina, 1105.4488] and aMC@NLO [Frederix et al, 1106.6019]

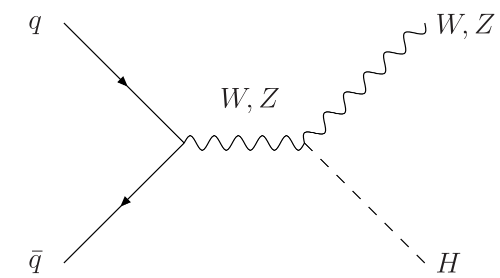
pp→Zbb : available in aMC@NLO [Frederix et al. 1106.6019]

pp→Wjj : done in aMC@NLO [Frederix et al. to appear]

pp→Zjj : not yet available at NLOwPS.







pp→ZH/WH

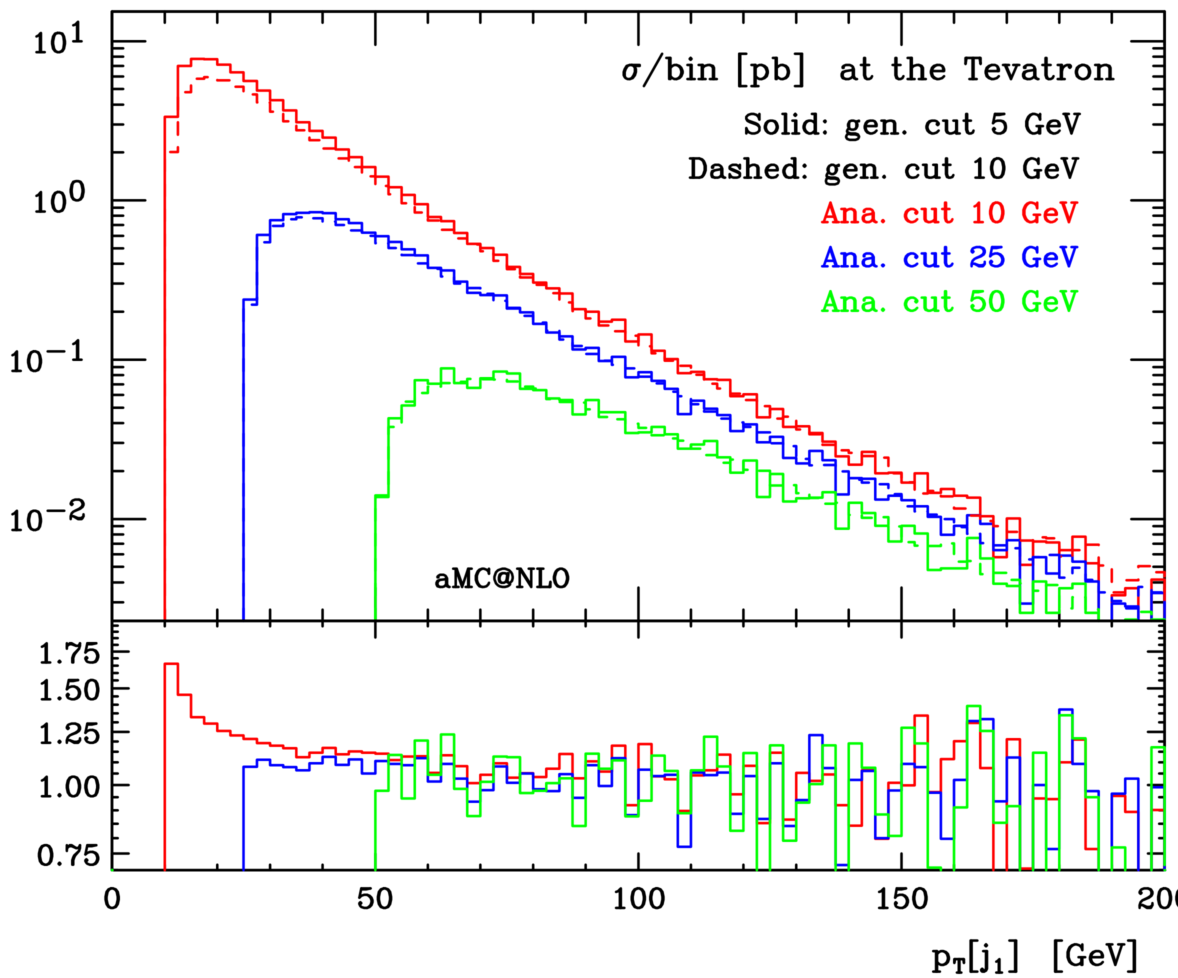
BACKGROUNDS:

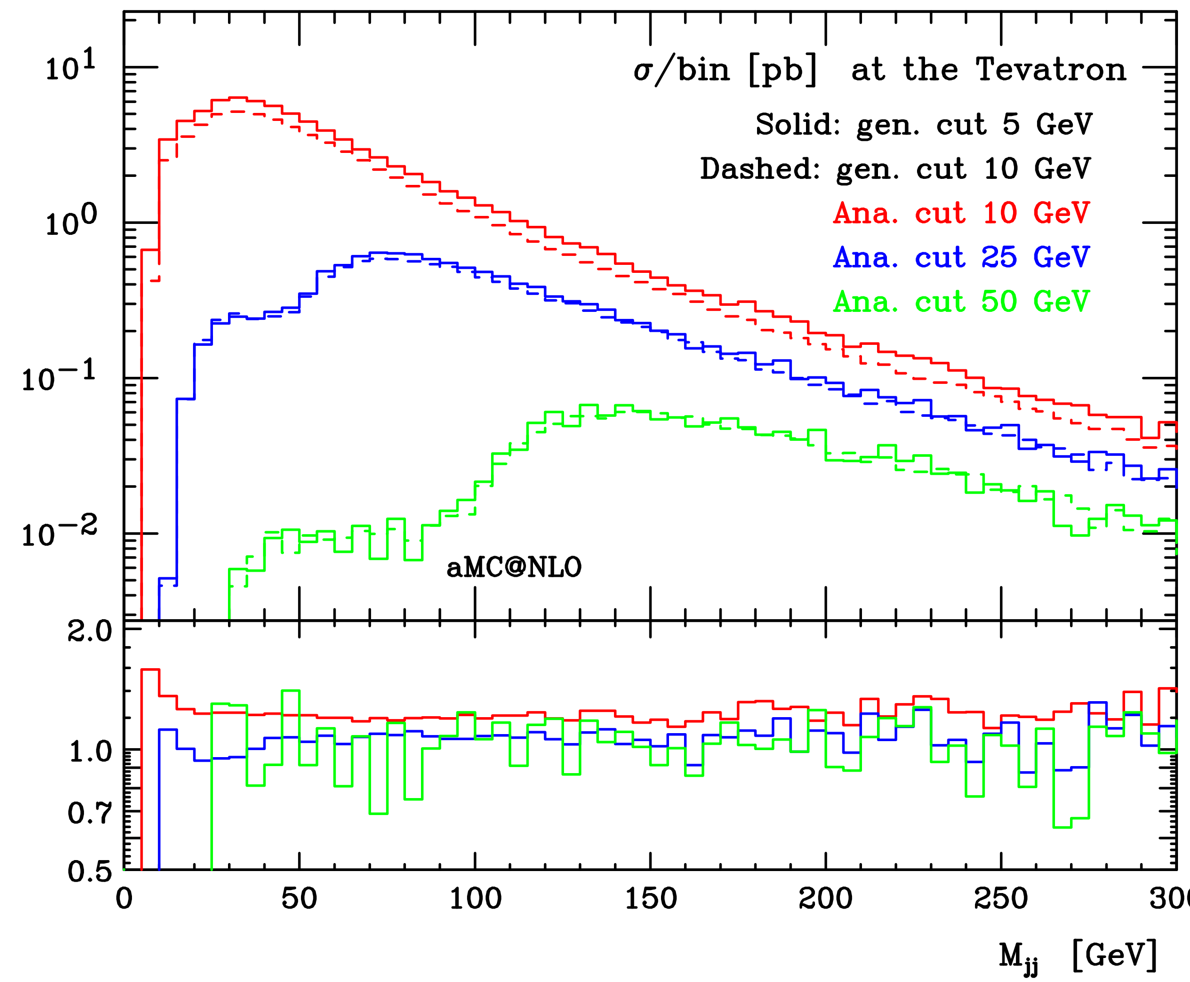
pp→Wbb : POWHEG [Oleari, Reina, 1105.4488] and aMC@NLO [Frederix et al, 1106.6019]

pp→Zbb : available in aMC@NLO [Frederix et al. 1106.6019]

pp→Wjj : done in aMC@NLO [Frederix et al. , to appear]

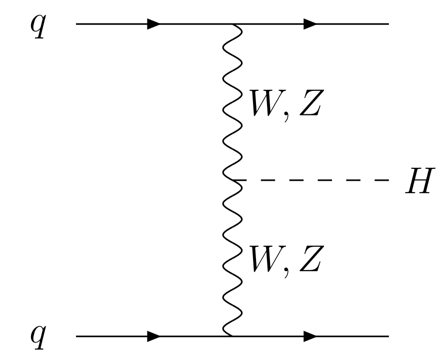
pp→Zjj : not yet available at NLOwPS.



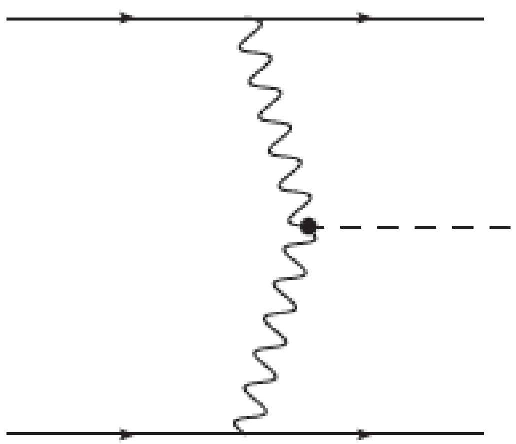


First non-trivial multi-jet process consistently interfaced to a parton-shower

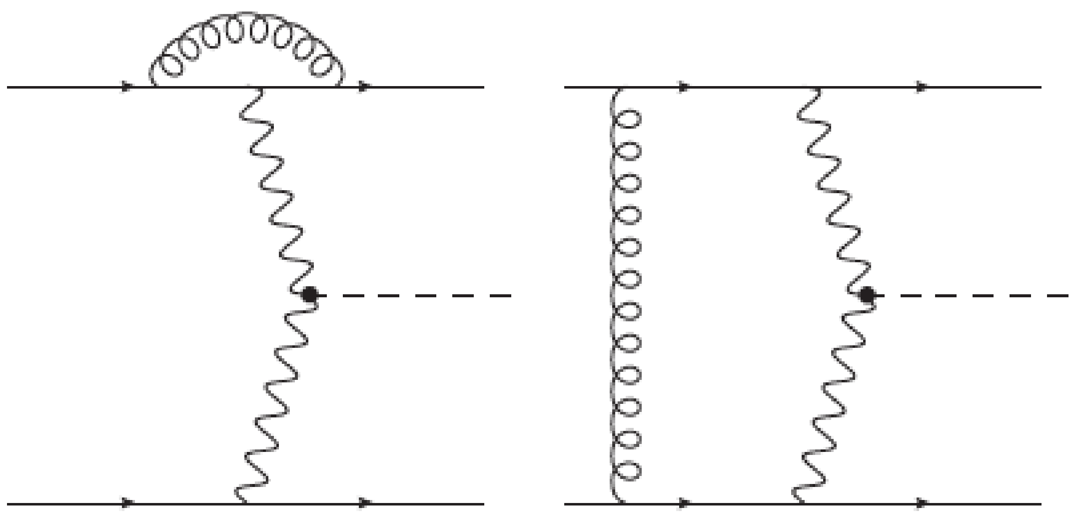
PP→HJJ (VBF)



SIGNAL:



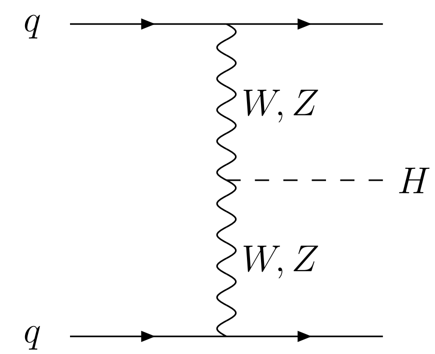
LO



NLO

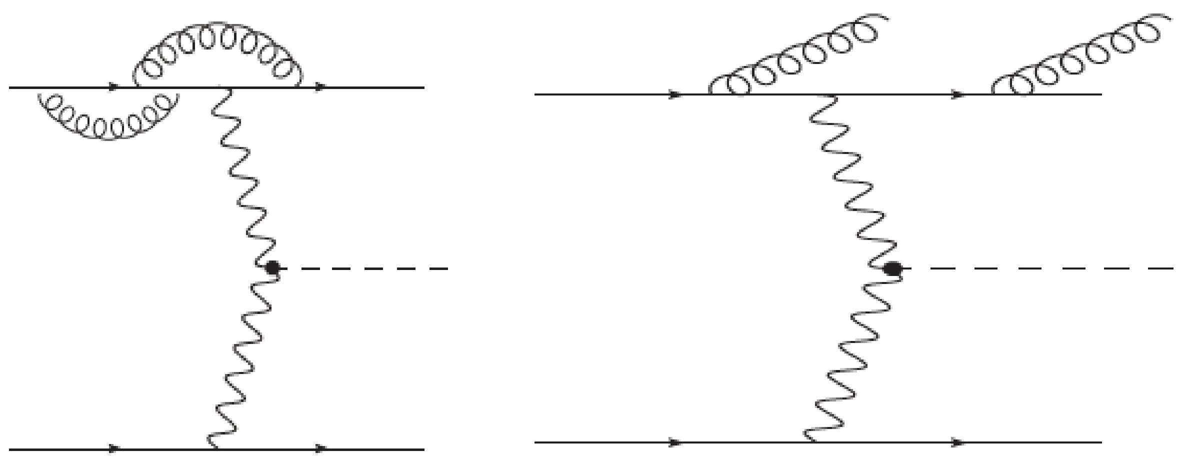
It interferes with VH already at LO. Interference is, however, small.

Total cross section known since a long time [Han and Willenbrock, '90]. Differential NLO available [Figy, Oleari, Zeppenfeld, hep-ph/0306109] and also for the (large) EW corrections [Ciccolini, et al, 0707.0381].



PP→HJJ (VBF)

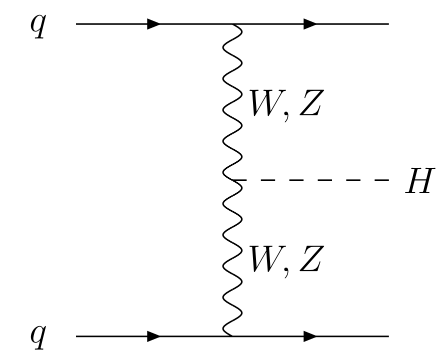
SIGNAL: NNLO



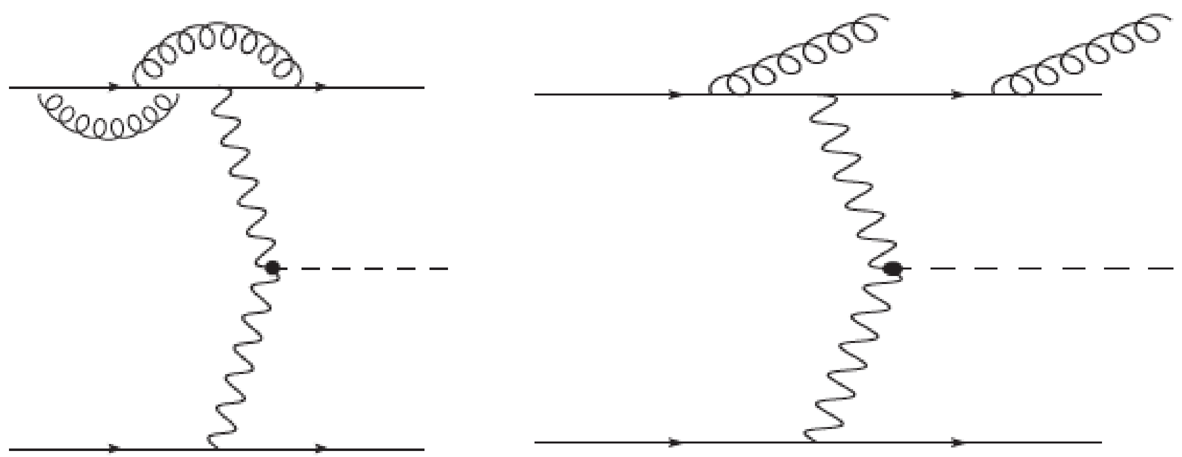
Factorizable contributions. Dominant correction.

[Bolzoni et al, 1003.4451]

PP→HJJ (VBF)

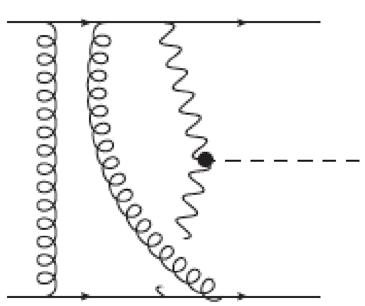


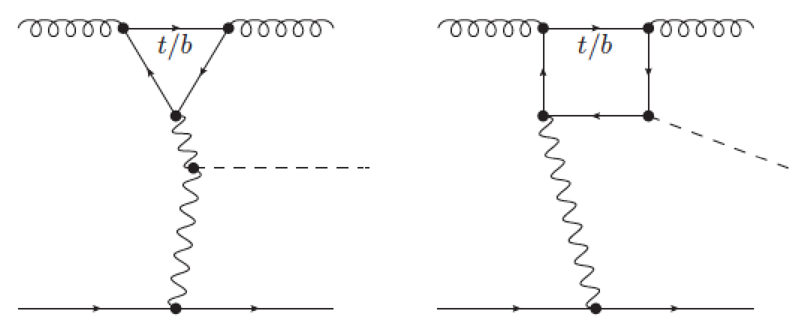
SIGNAL: NNLO

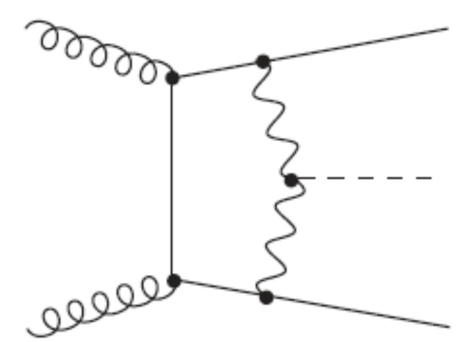


Factorizable contributions.
Dominant correction.

[Bolzoni et al, 1003.4451]







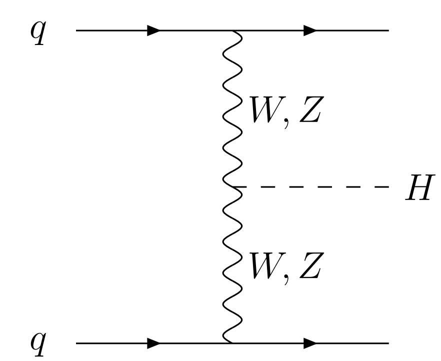
Estimated <1%
[Bolzoni et al, to appear]

Calculated <1%
[Bolzoni et al, to appear]

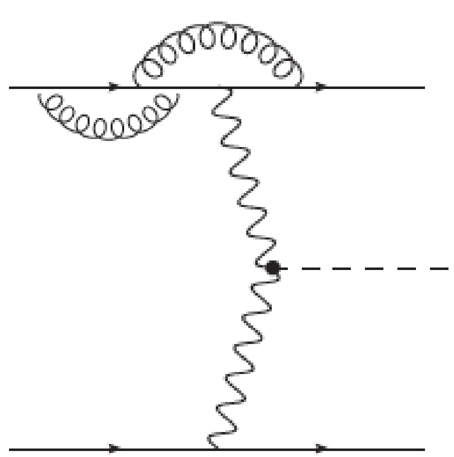
<1%
[Harlander et al,0801.3355]

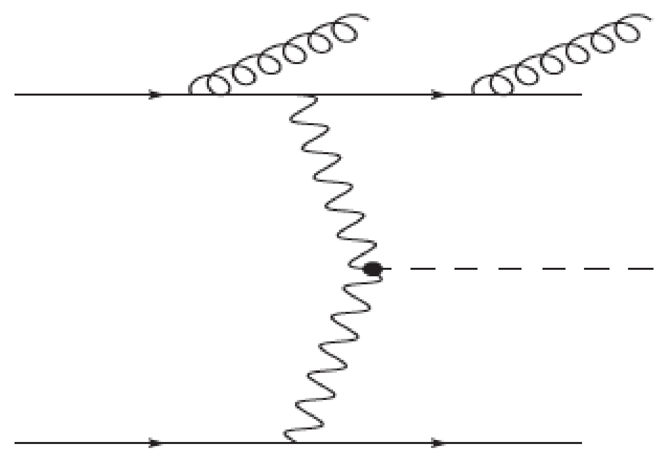
Other contributions have been calculated, such as the interferences with GluonFusion [Andersen, Binoth, Heinrich, Smillie (2007) Andersen, Smillie (2008), Bredenstein, Hagiwara, Jäger (2008)] and found small.

PP→HJJ (VBF)

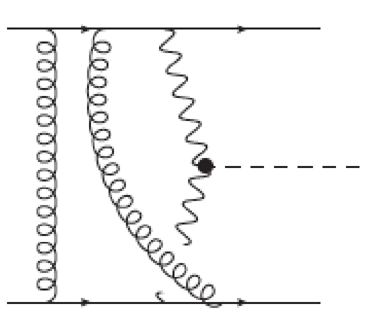


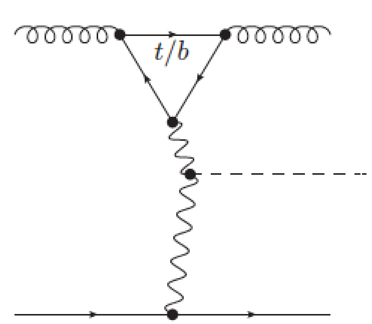
SIGNAL: NNLO

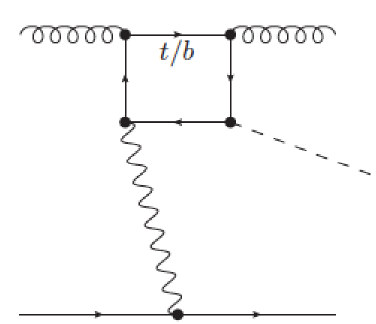


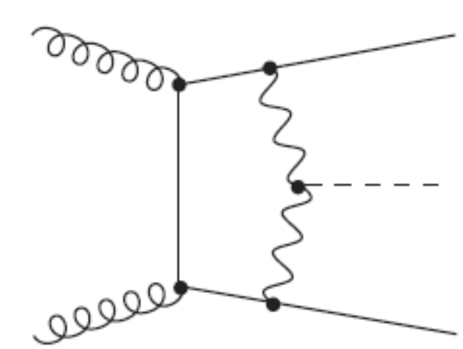


	$K_{NNLO/NLO}$ ($K_{NLO/LO}$)	Scale	PDF+α_s	Scale+PDF
VBF	<1% (+5-10%)	±1%	±4%	**±5%**









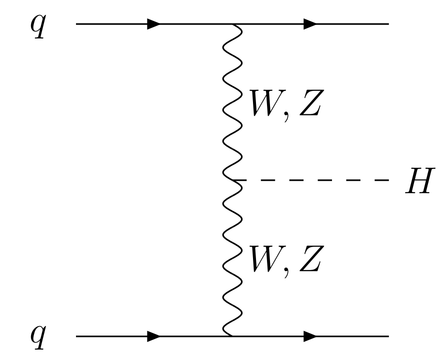
Estimated <1%
[Bolzoni et al, to appear]

Calculated <1%
[Bolzoni et al, to appear]

<1%
[Harlander et al,0801.3355]

Other contributions have been calculated, such as the interferences with GluonFusion [Andersen, Binoth, Heinrich, Smillie (2007) Andersen, Smillie (2008), Bredenstein, Hagiwara, Jäger (2008)] and found small.

pp→Hjj (VBF)

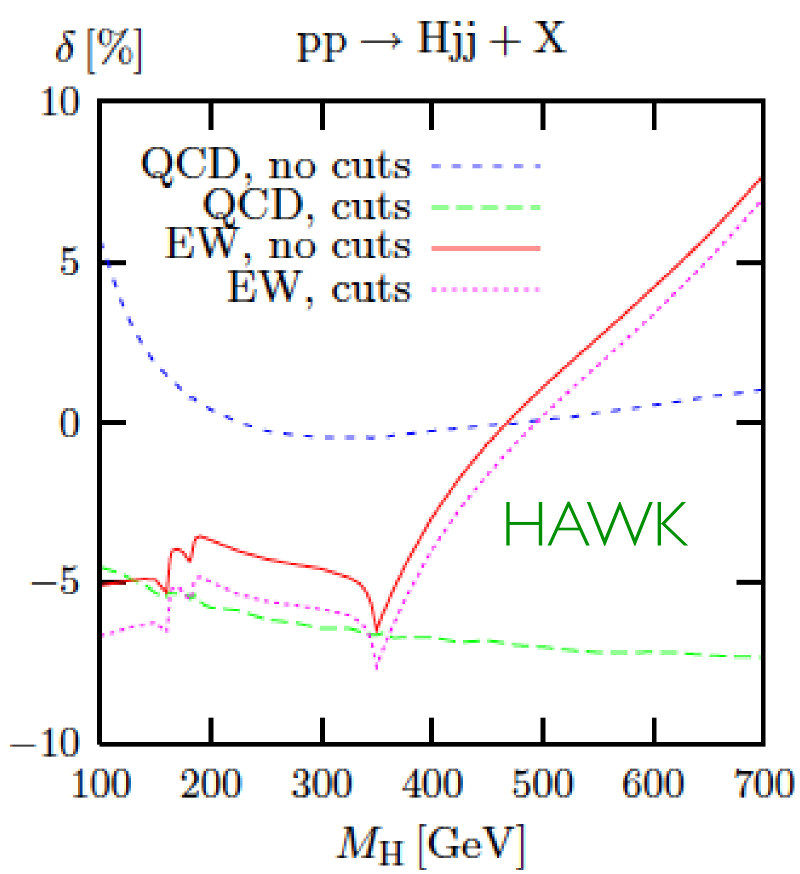


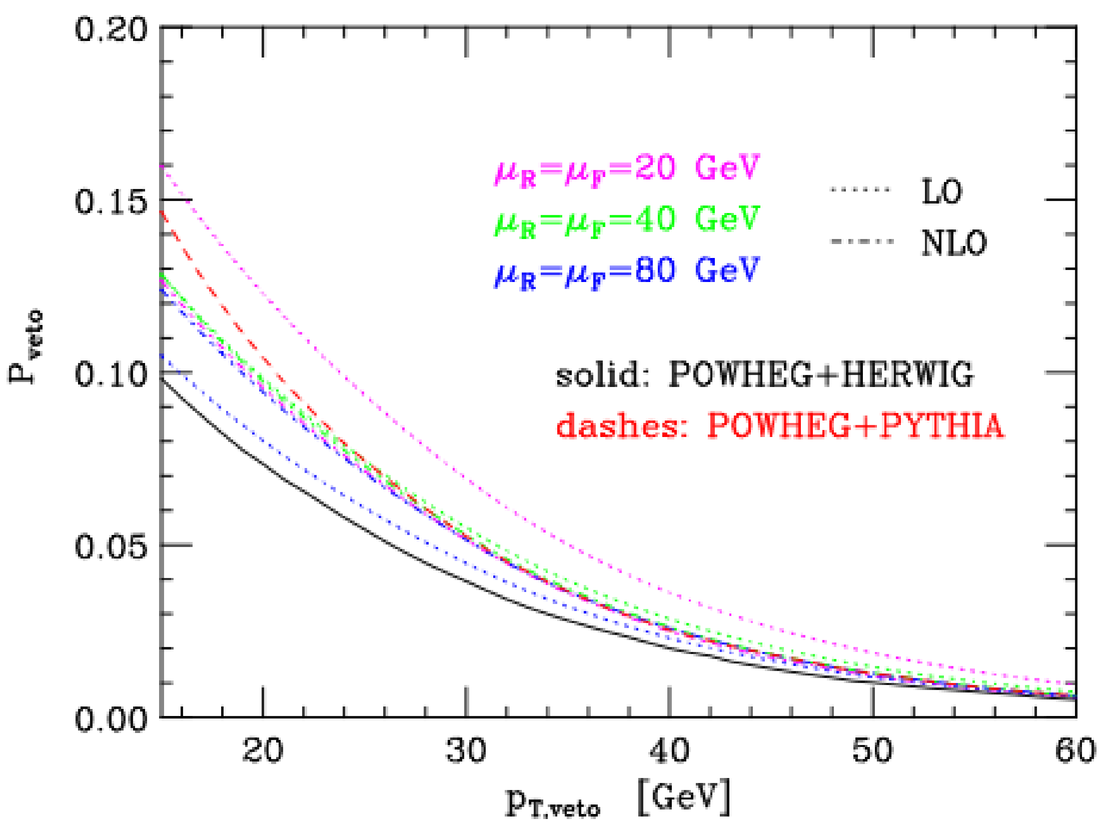
SIGNAL:

Parton level NLO available in VBFNLO [Zeppenfeld et al.] and in HAWK [Ciccolini, et al] which includes both QCD and EW corrections.

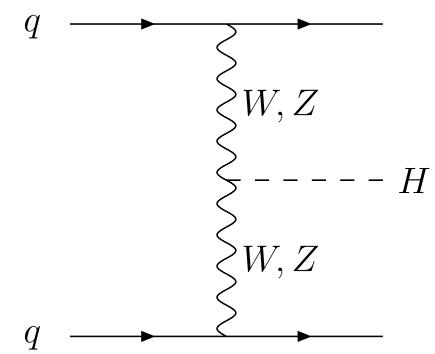
Full 6f final state in PHANTOM [Ballestrero, 0801.3359] or by automatic tree-level ME generators (Whizard, Madgraph or Sherpa).

Available in the POWHEG-BOX [Nason, Oleari, 0911.5299].





pp→HJJ (VBF)



Backgrounds:

NLO : pp→W+W- jj (QCD) [Melia et al. 1104.2327]

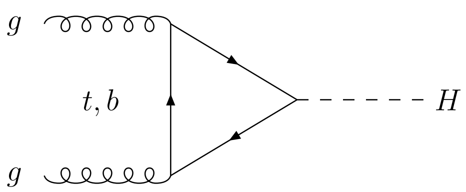
NONE of the EW backgrounds are available at NLOwPS yet.

NLO for several EW background processes known in VBFNLO could be interfaced to a PS (via POWHEG, for example). QCD backgrounds not available either.

pp→Hjjj might be important. NLO EW corrections are known and could be included.

For measurements also pp→Hjj via gluon-fusion is relevant.

GG→H+X



SIGNAL TOTAL:

NLO QCD corrections found large 20 years motivated NNLO computation.
[A. Djouadi, D. Graudenz, M. Spira, P. Zerwas (1991)] [R.Harlander (2000)] [S. Catani, D. De Florian, MG (2001)][R.Harlander, W.B. Kilgore (2001,2002)] [C. Anastasiou, K. Melnikov (2002) V. Ravindran, J. Smith, W.L.Van Neerven (2003)]

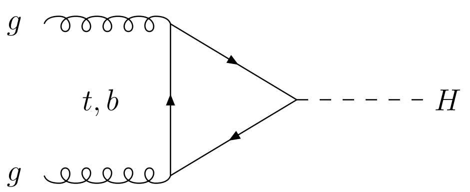
HEFT approximation works extremely well
[R.Harlander et al. (2009,2010 M.Steinhauser et al. (2009)]

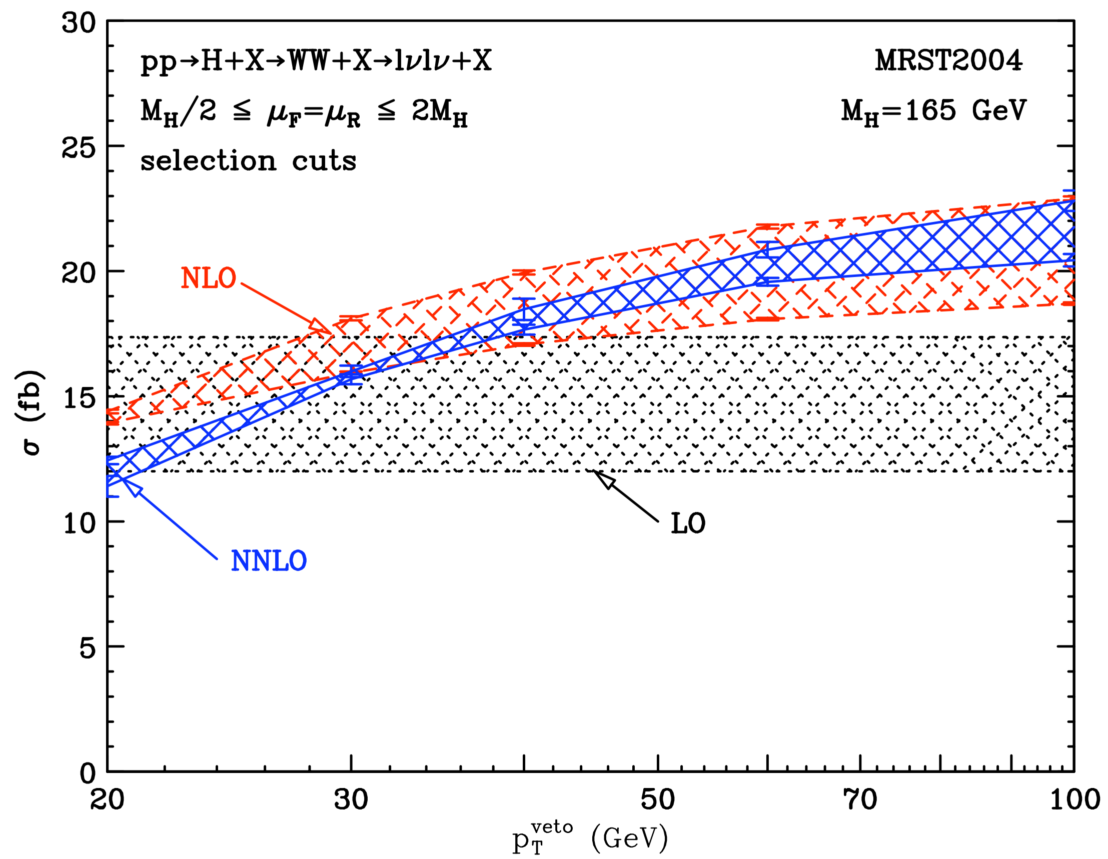
Resummation of soft enhanced terms known ap NNLL and more (about 10%)
[S. Catani, D. De Florian, P. Nason, MG (2003) S. Moch, A. Vogt (2005), E. Laenen, L. Magnea (2005)]

Two-loop EW effects calculated (about 5%)
[U. Aglietti et al. (2004) G. Degrassi, F. Maltoni (2004) G. Passarino et al. (2008)]

Mixed QCD-EW effects evaluated in EFT approach (effect O(1%))
[Anastasiou et al. (2008)]

GG→H+X





SIGNAL (parton level):

NNLO QCD corrections

HNNLO S. Catani, M. Grazzini, hep-ph/0703012;
FEHIP C.Anastasiou, K.Melnikov, F.Petrello, 2005

SIGNAL (pt higgs):

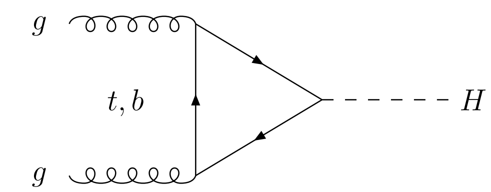
HQT G. Bozzi, S. Catani, D. de Florian, M. Grazzini, hep-ph/0302104

SIGNAL (parton level):

NLO QCD corrections

H + 1 jet MCFM [Campbell, Ellis]
H + 2 jets MCFM [Campbell, Ellis, Zanderighi, hep-ph/0608194]

GG→H+X



SIGNAL (MC)

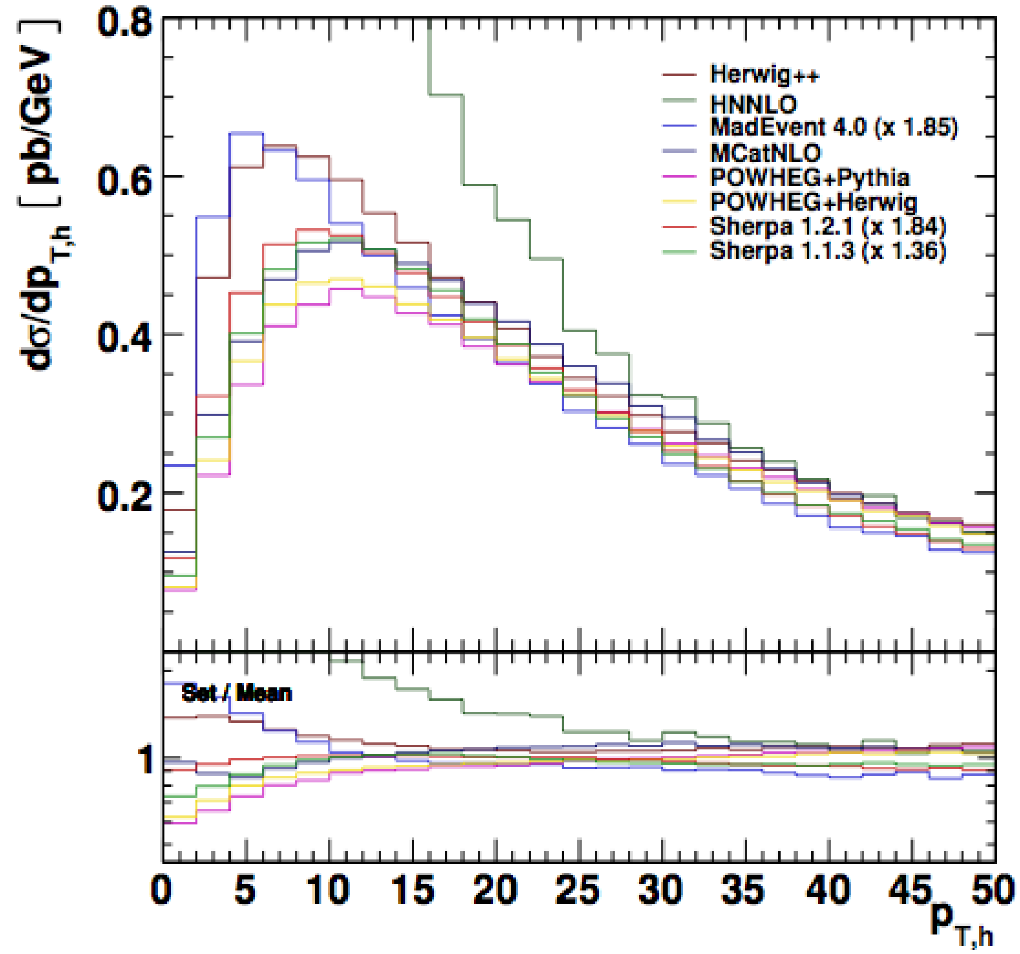
Available in NLOwPS implementations in the EFT:

- (a)MC@NLO [Frixione et al. 0805.4802]
- POWHEG Box [Aioli et al, 0805.4802]
- HERWIG++ (POWHEG)[Hamilton et al. 0903.4345]
- SHERPA (POWHEG)[Hoeche et al, 1008.5399]

Available also in the EFT MEwPS [MadGraph, SHERPA]

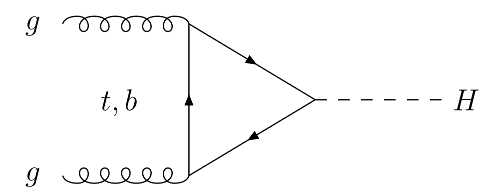
COMMENTS ON THE SIGNAL:

-pp → H + 1,2 jets not available jet in NLOwPS!!!
-Heavy-quark loop effects
-BSM production not available yet.
-Missing: interference between signal and backgrounds in MC's.

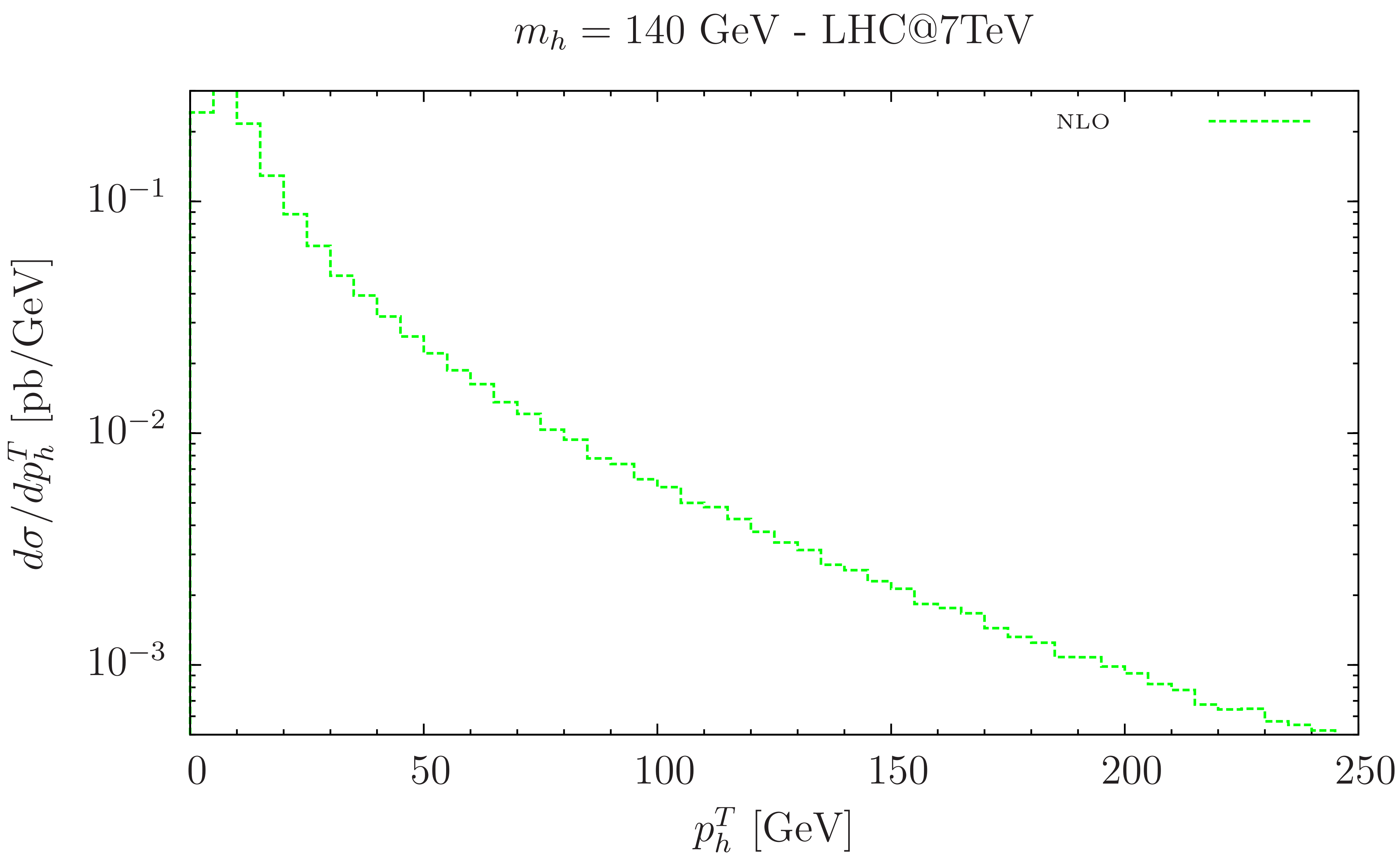


[Butterworth, Les Houches 2009]

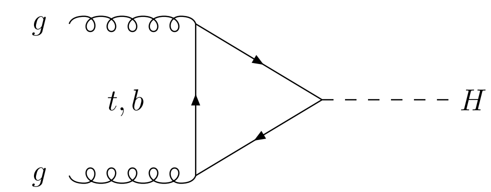
GG→H : COMPARISON

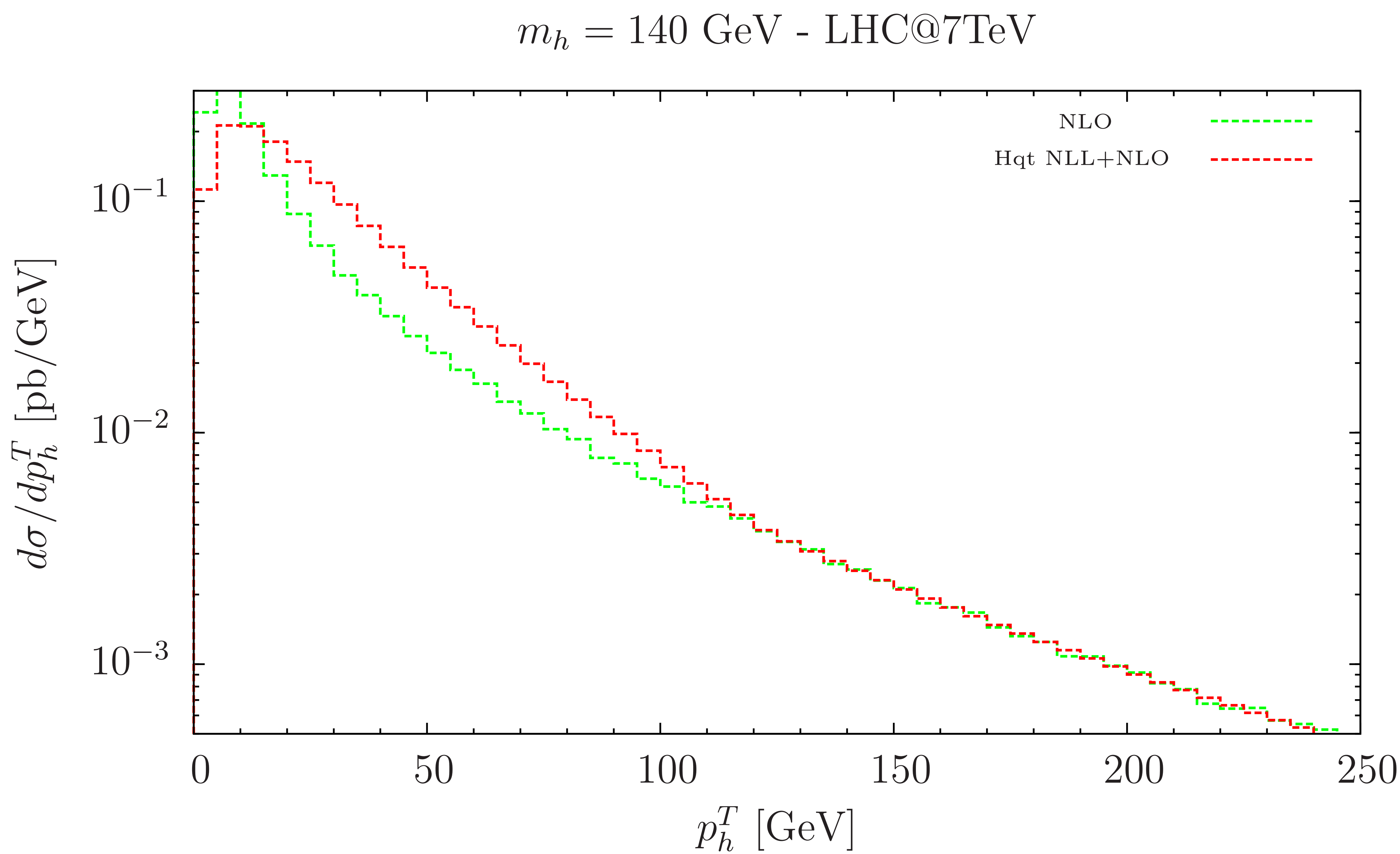


[thanks to J. Alwall, Q. Li, FM, P. Torrielli]

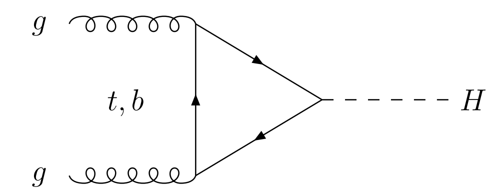


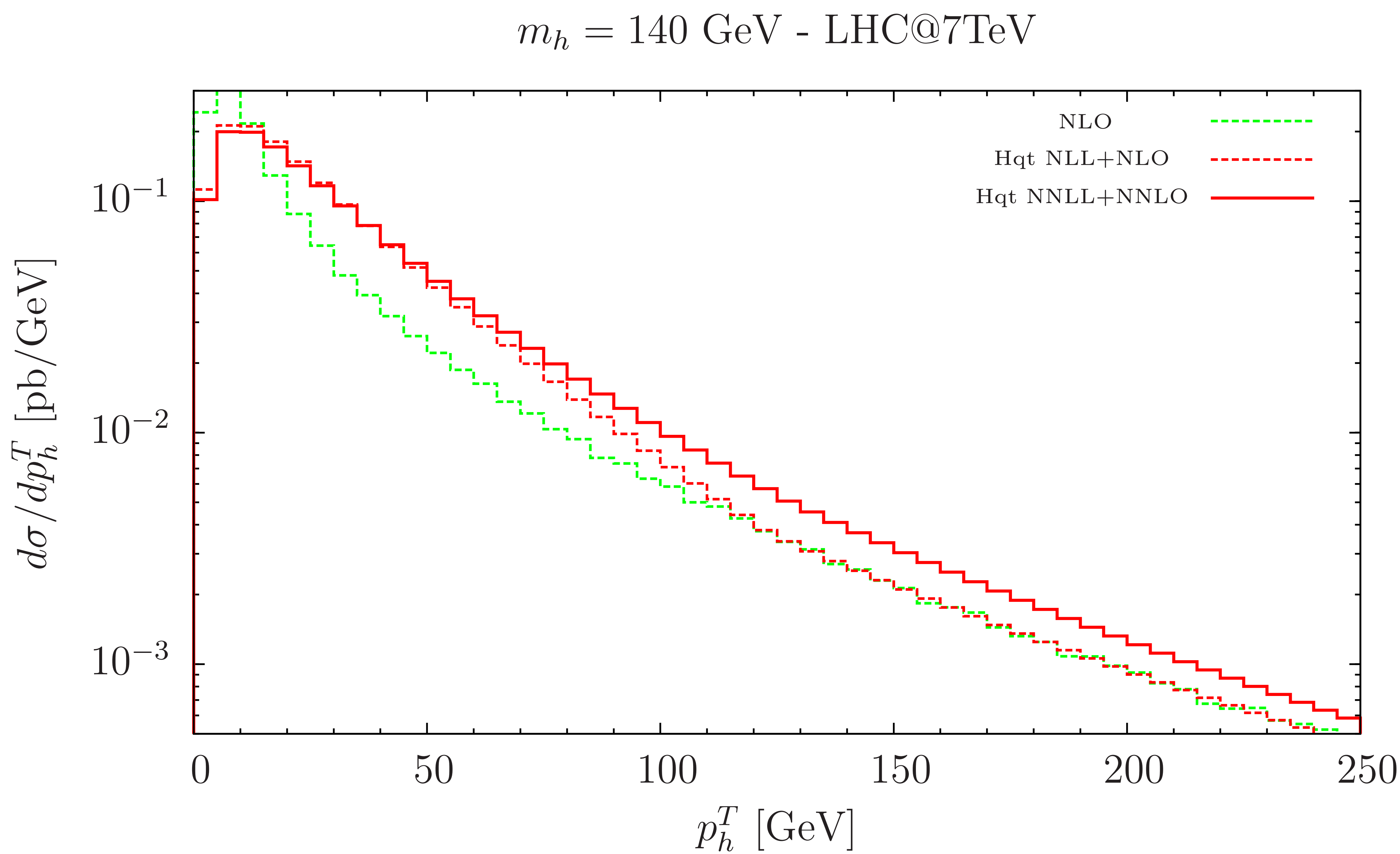
GG→H : COMPARISON



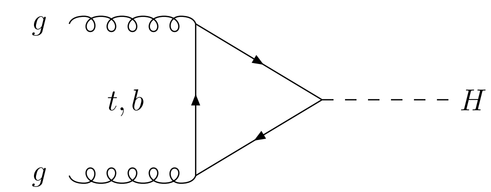


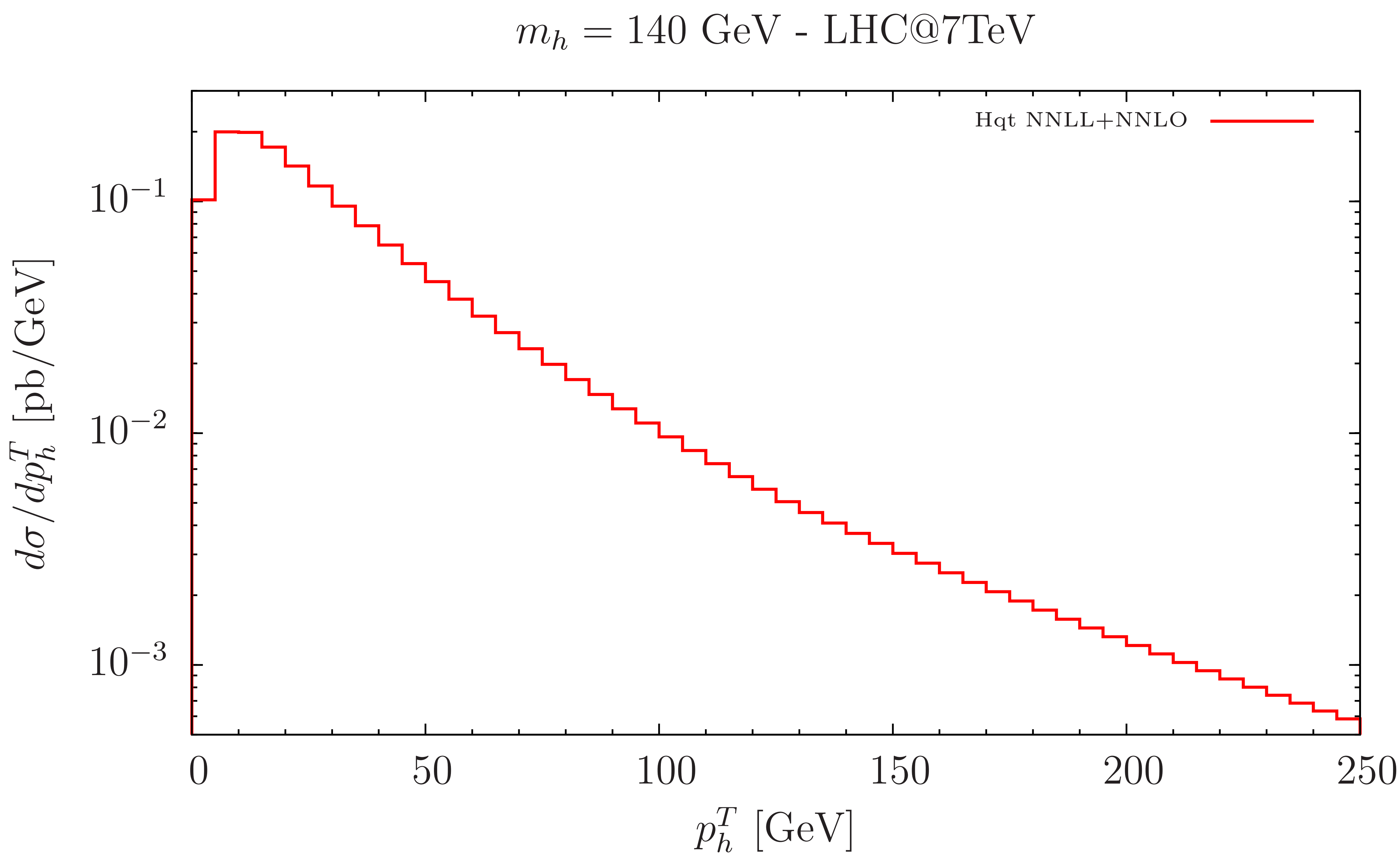
GG→H : COMPARISON





GG→H : COMPARISON





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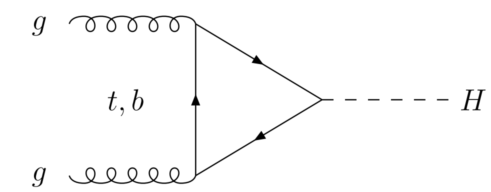
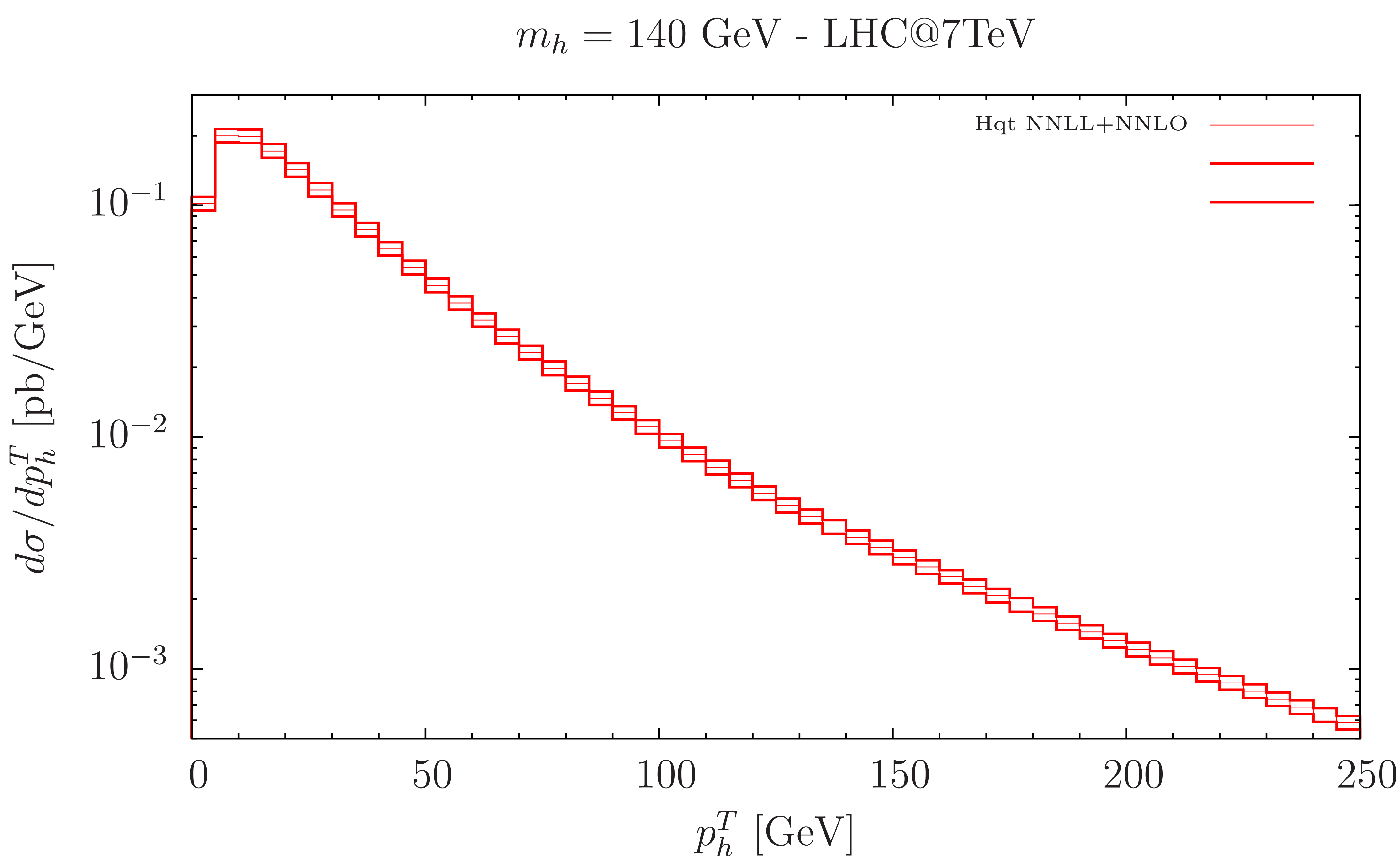
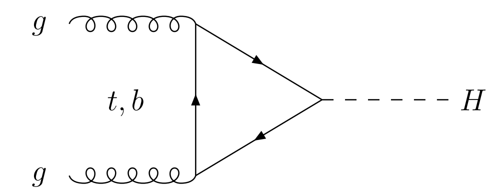
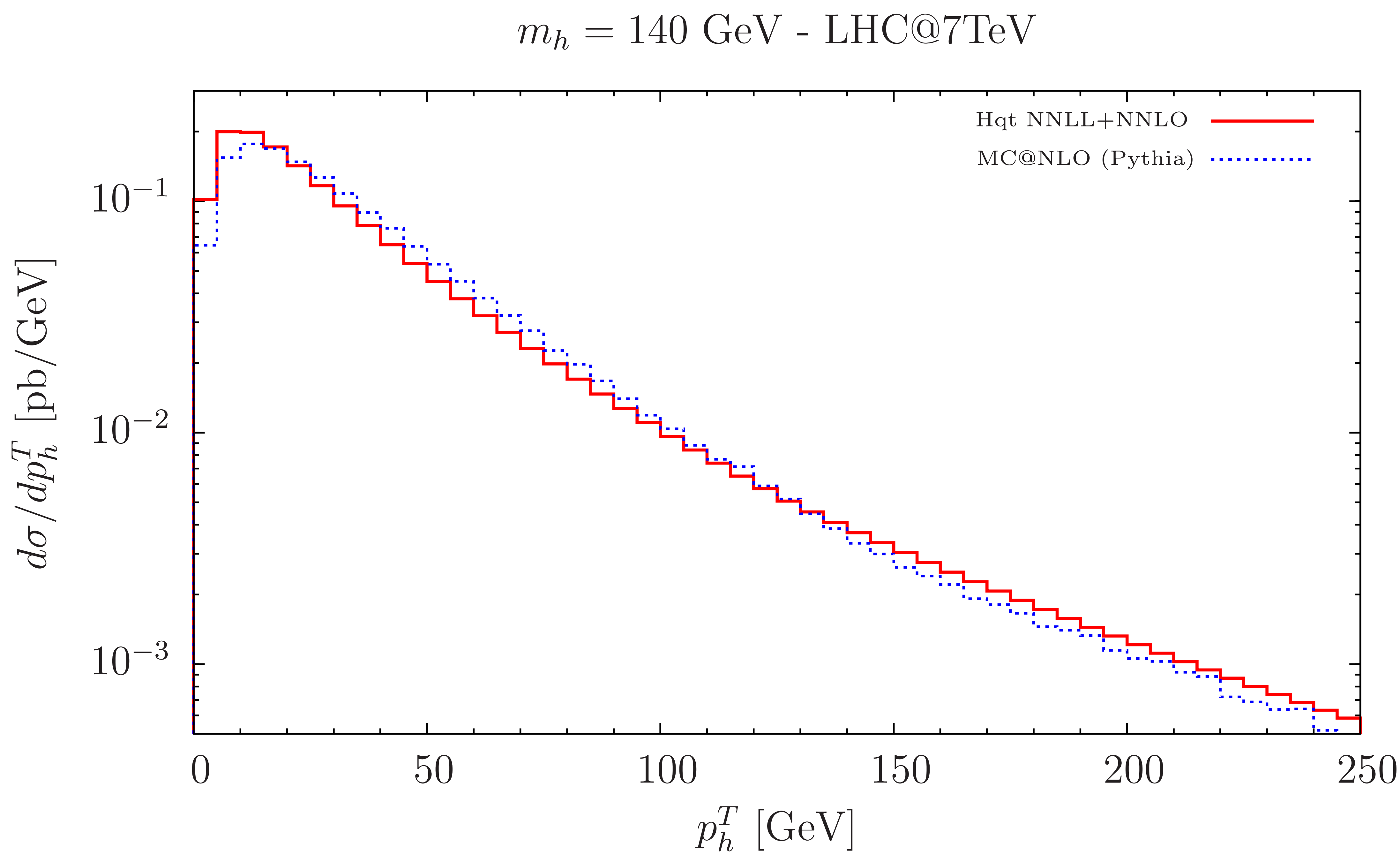


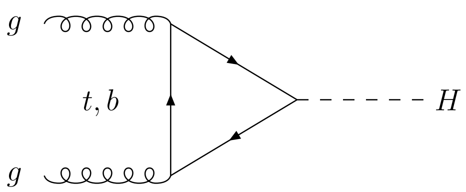


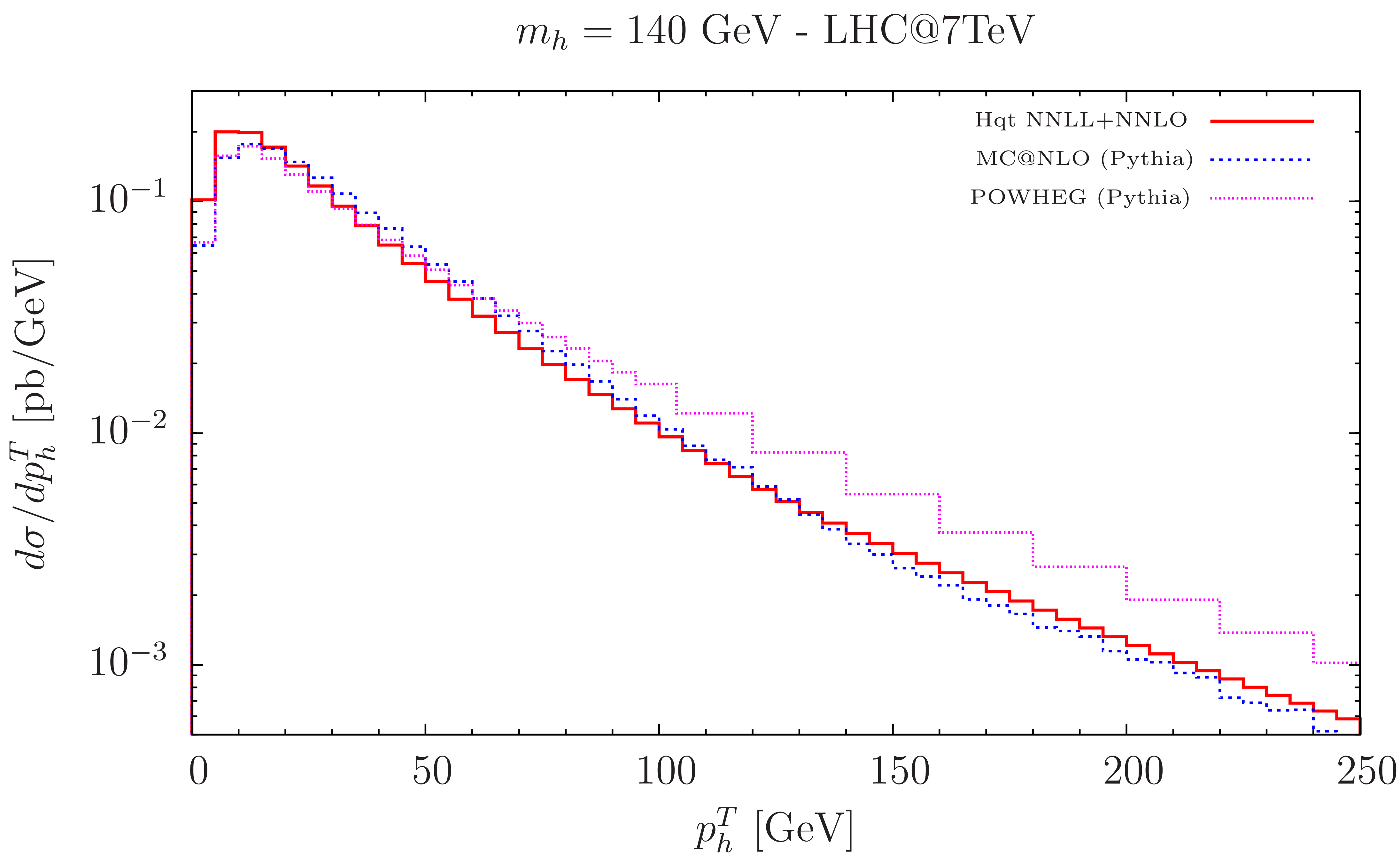
GG→H : COMPARISON



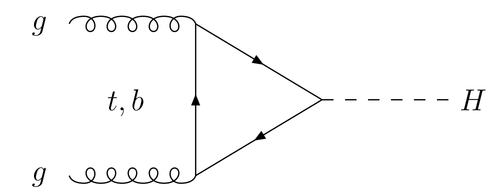


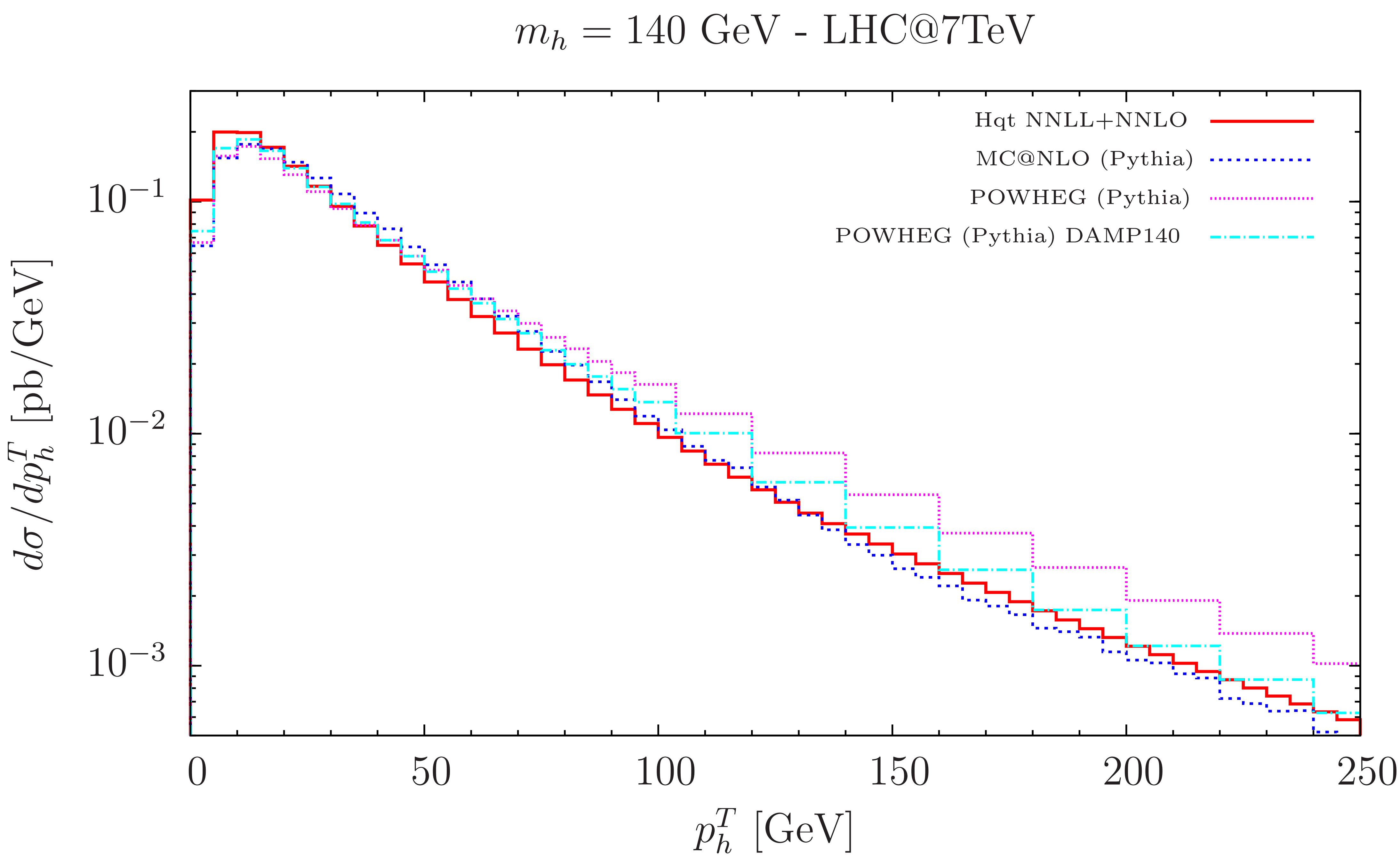
GG→H : COMPARISON



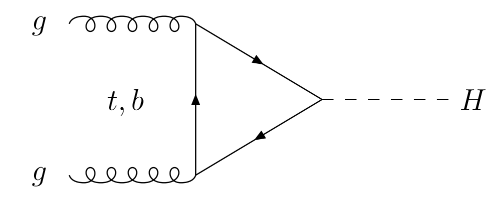


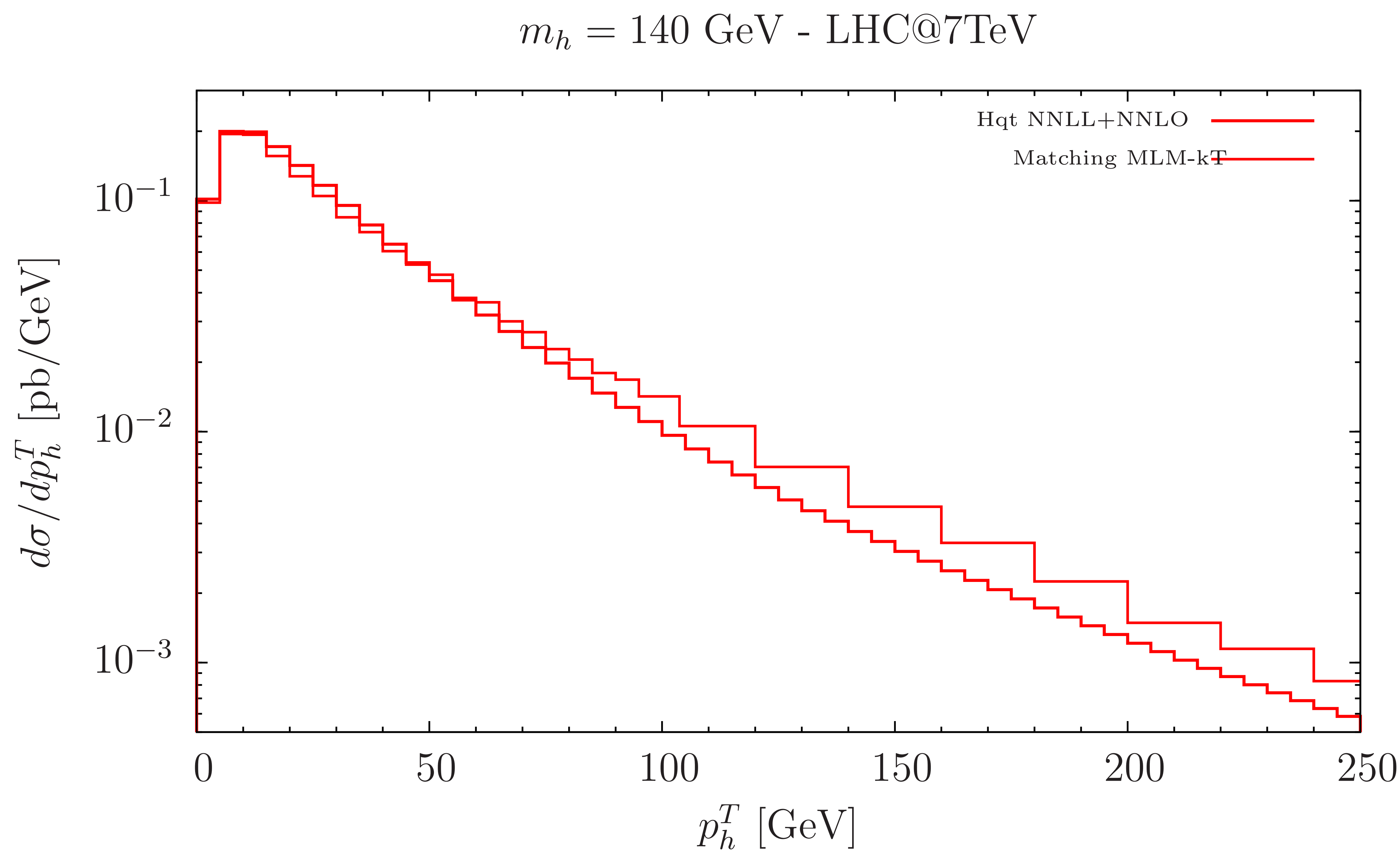
GG→H : COMPARISON



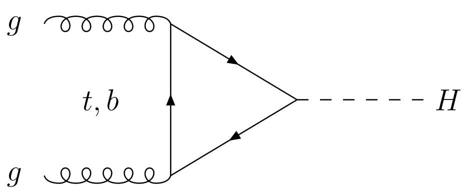


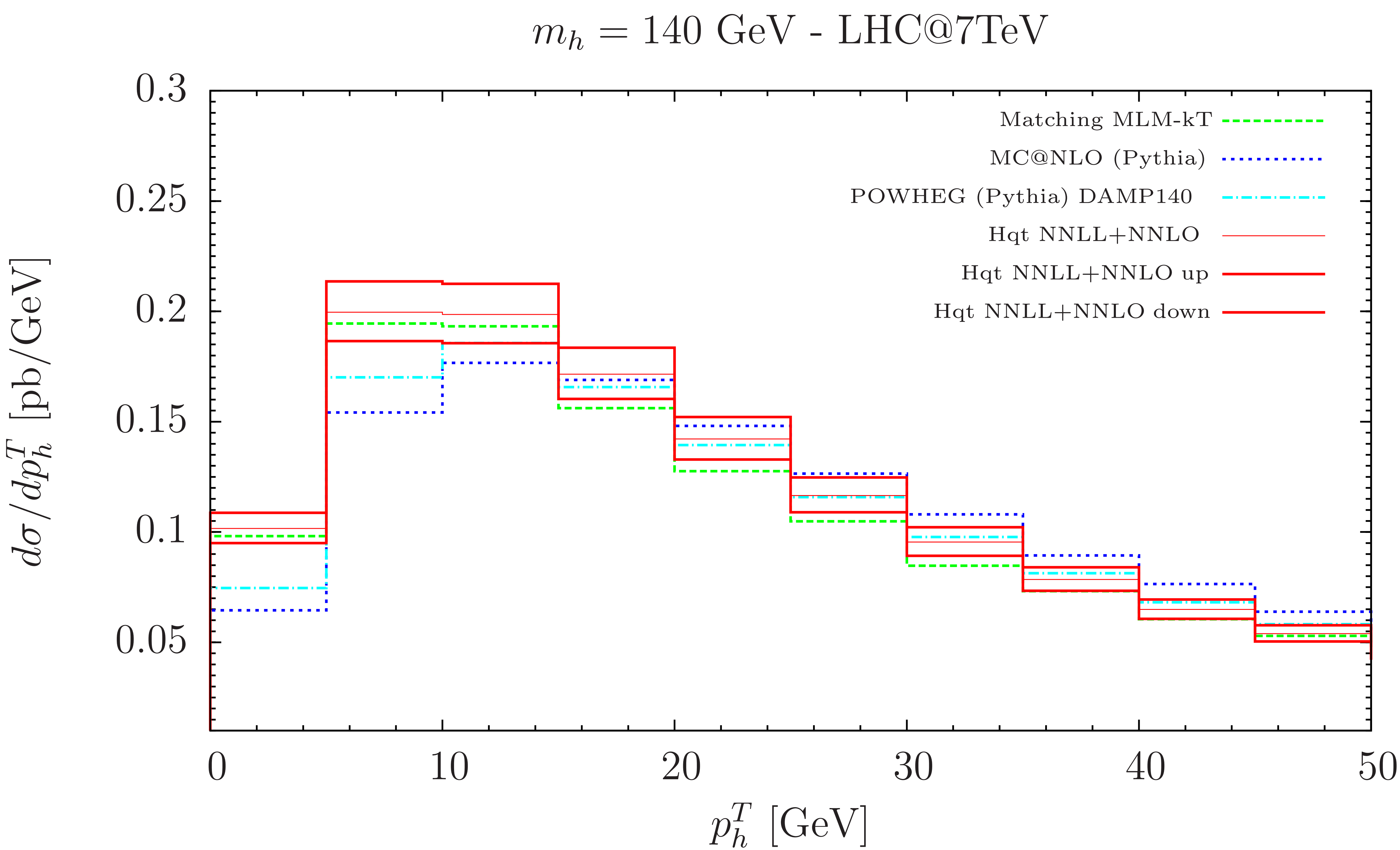
GG→H : COMPARISON



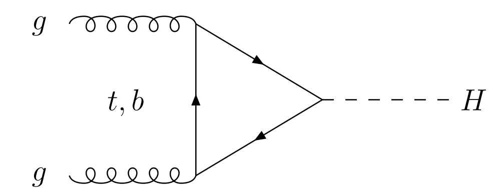


GG→H : COMPARISON



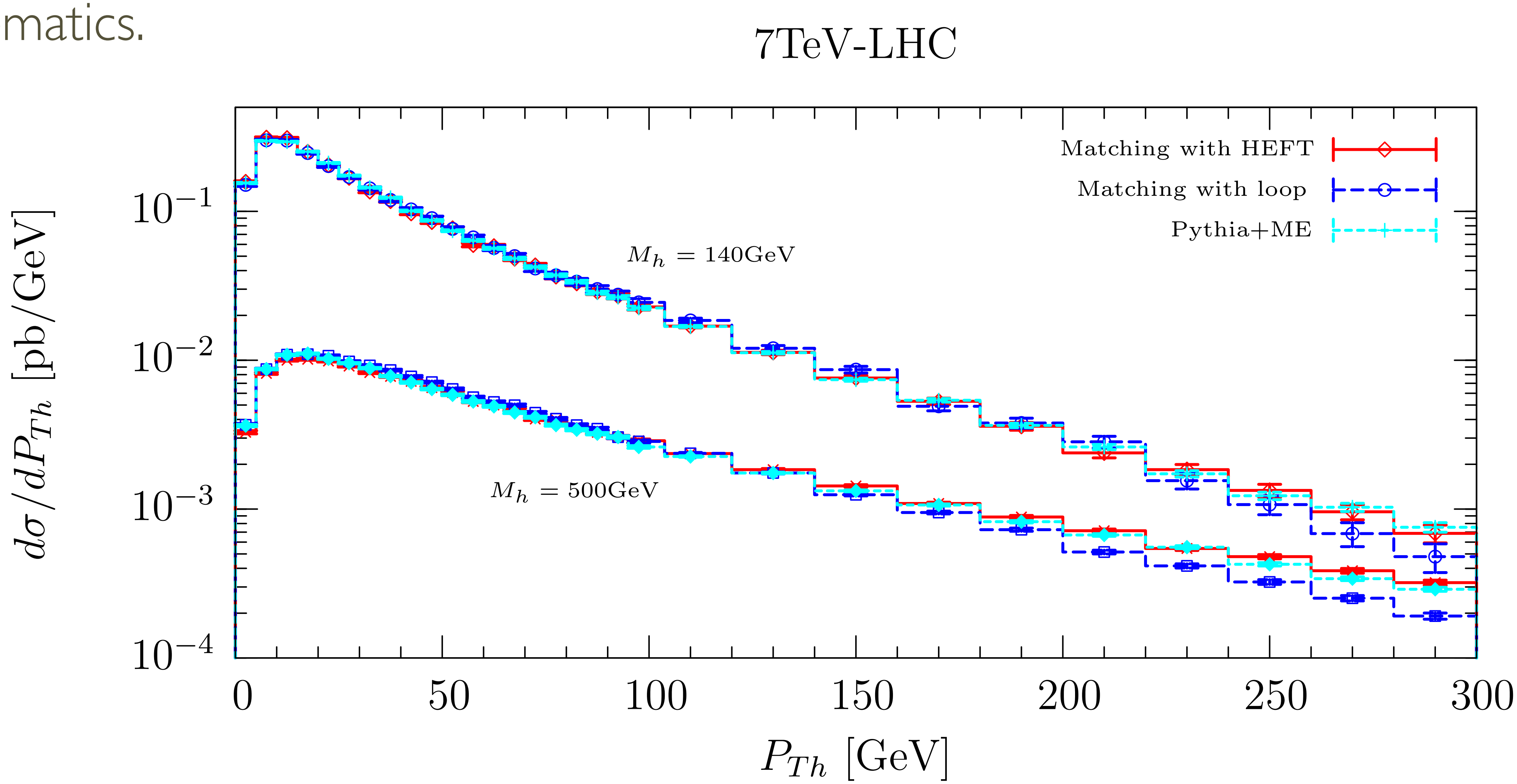


GG→H+0,1,2 JETS WITH MLM-KT

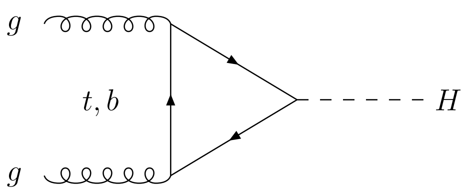


[J. Alwall, Q. Li, FM, to appear]

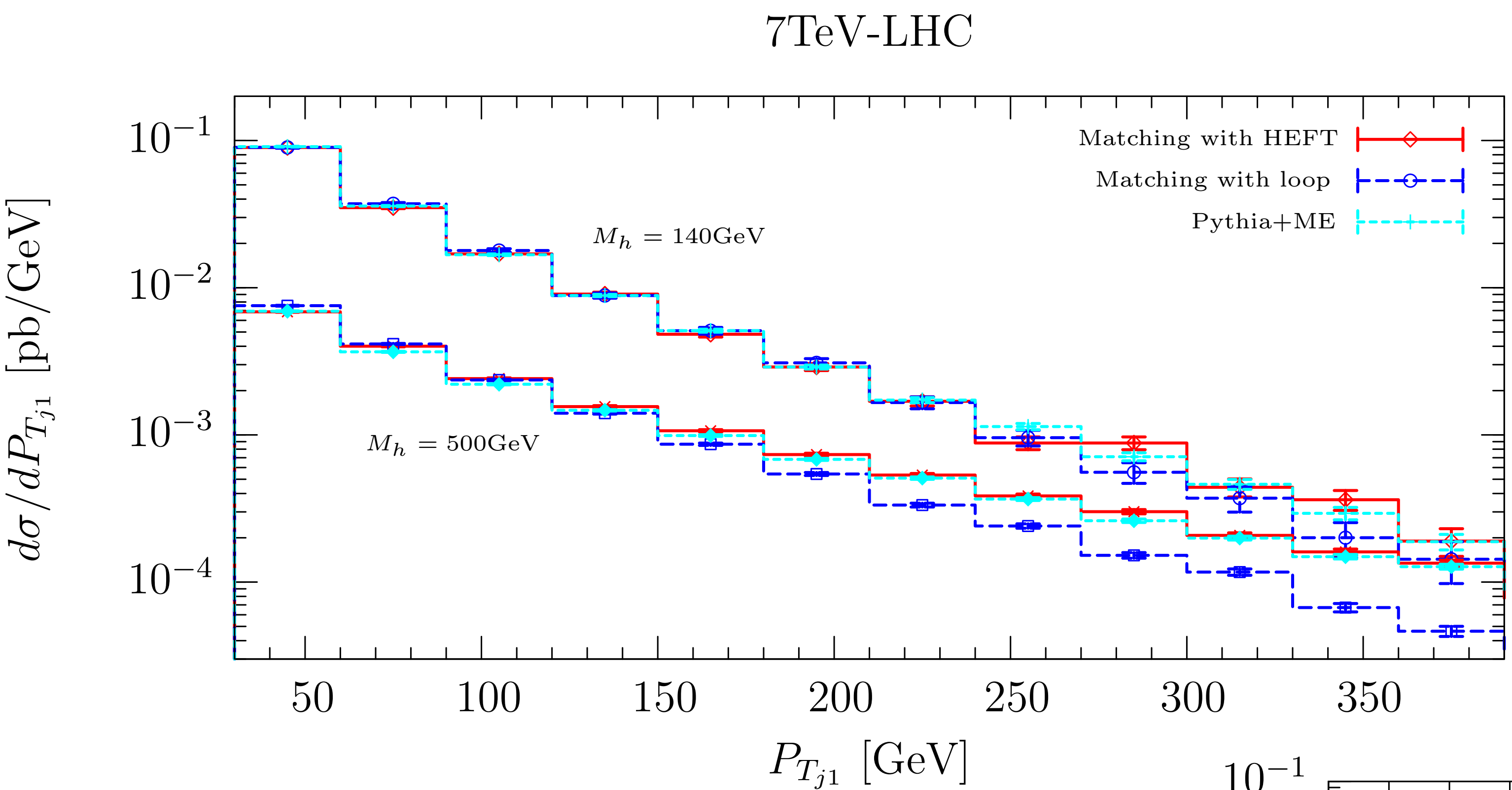
In total rates we know that large-m_{top} approximation works extremely well up (differences of the order of 0.5 % for mh<300 GeV !) [Harlander et al. (2009,2010), Steinhauser et al. (2009)]. In differential rates corrections show up only for very hard kinematics.

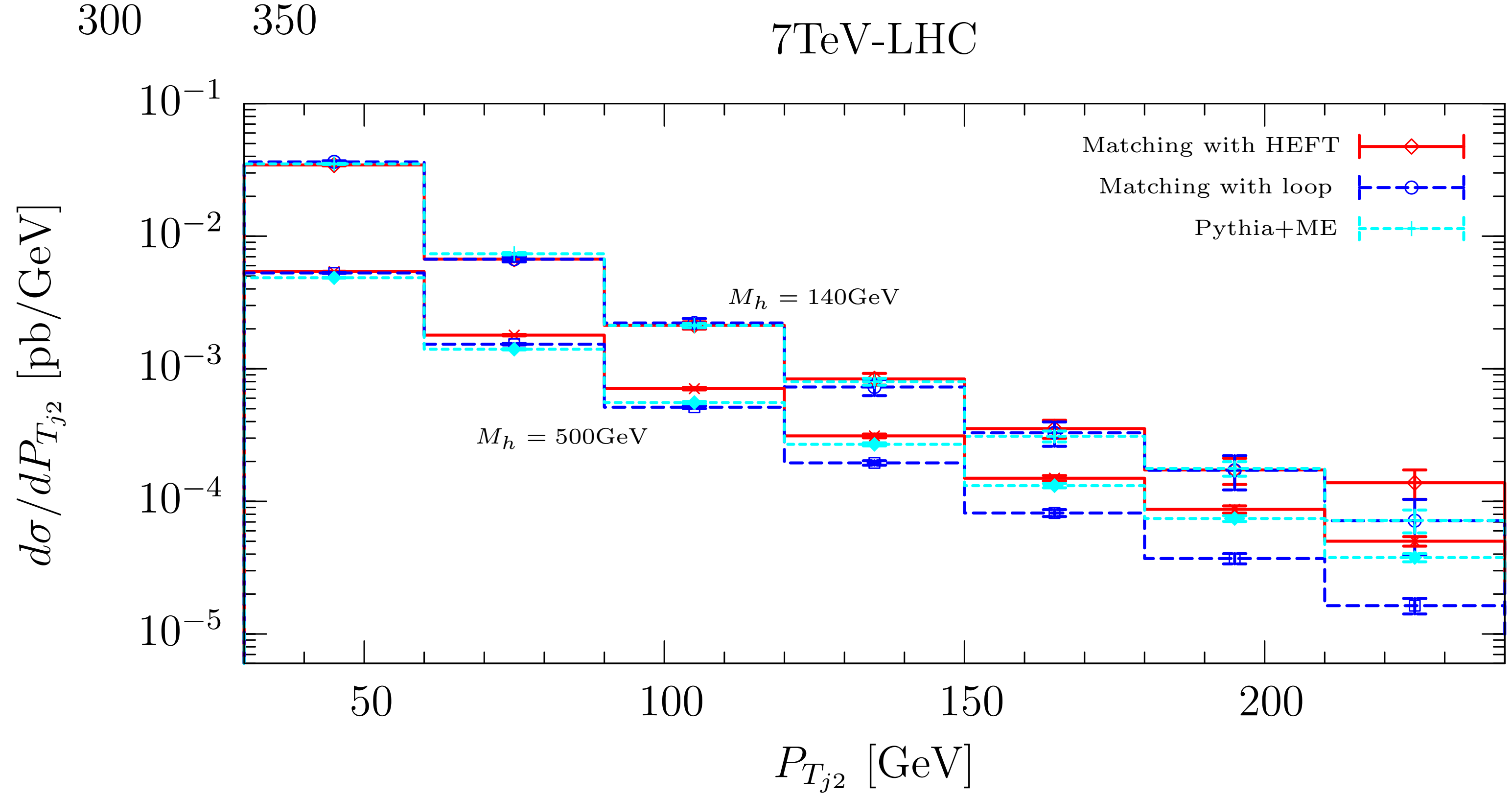


GG→H+0,1,2 JETS WITH MLM-KT

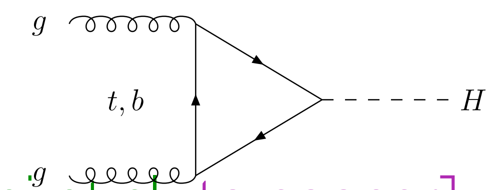


[J. Alwall, Q. Li, FM, to appear]





BACKGROUND: PP→γγ AT NNLO



[Catani et al., to appear]

The NNLO calculation can be done by using hard coefficients obtained for Drell-Yan

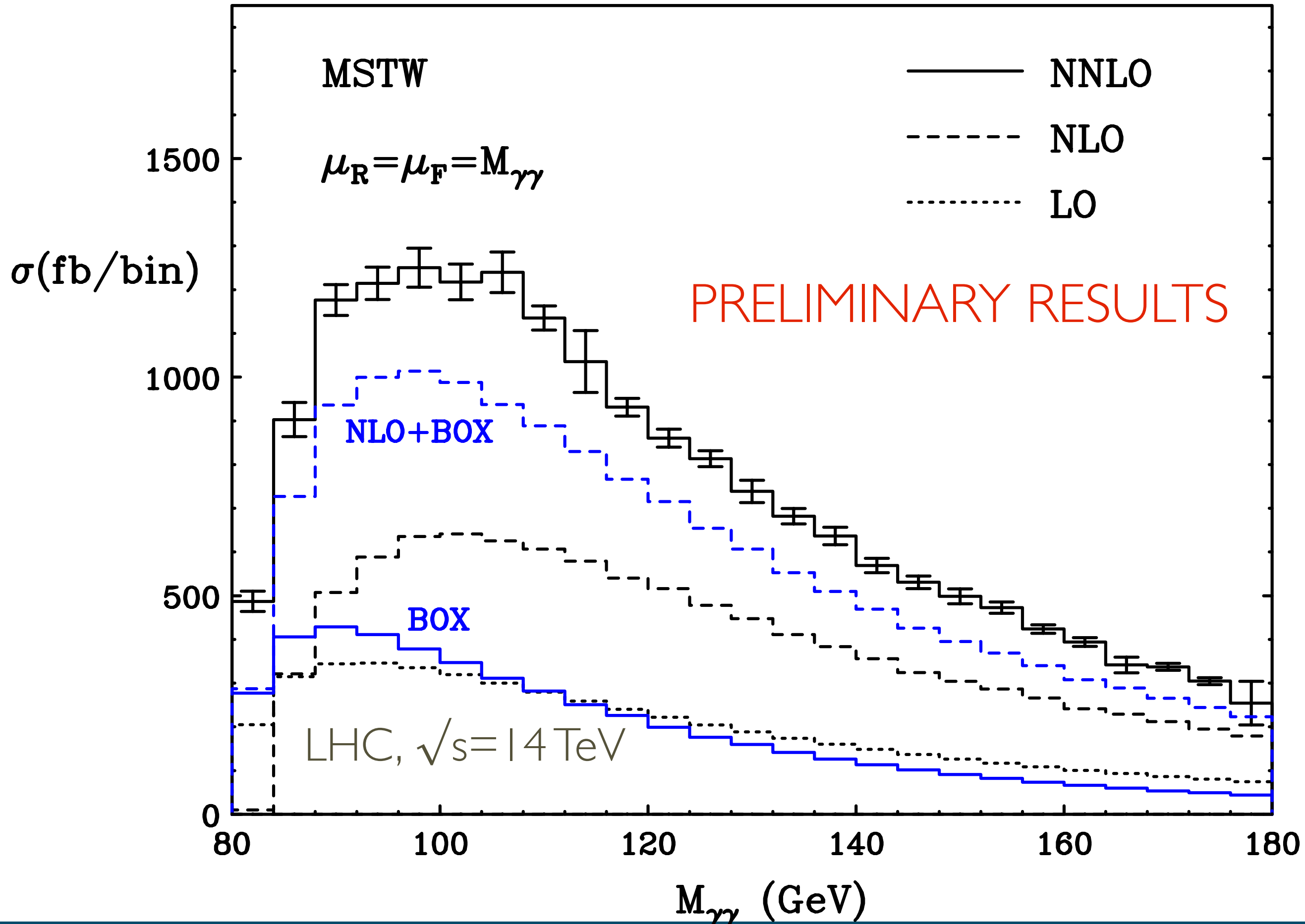
- gg→ γγ 1-loop known since a long time.
- qq→ γγ 2 loop [C.Anastasiou, E.W.N.Glover, M.E.Tejeda-Yeomans, hep-ph/0101304]
- γγ +1 jet [Z.Nagy et al., hep-ph/0303012]

$p^{\gamma}_T \geq 40$ GeV $|\eta^{\gamma}| \leq 2.5$

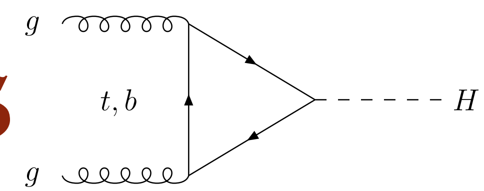
60 GeV $\leq M_{\gamma\gamma} \leq$ 180 GeV

$$\chi(\delta) = \epsilon_\gamma E_T^\gamma \left(\frac{1-\cos(\delta)}{1-\cos(R_0)} \right)^n \qquad n = 1, \quad \epsilon_\gamma = 0.5, \quad R_0 = 0.4$$

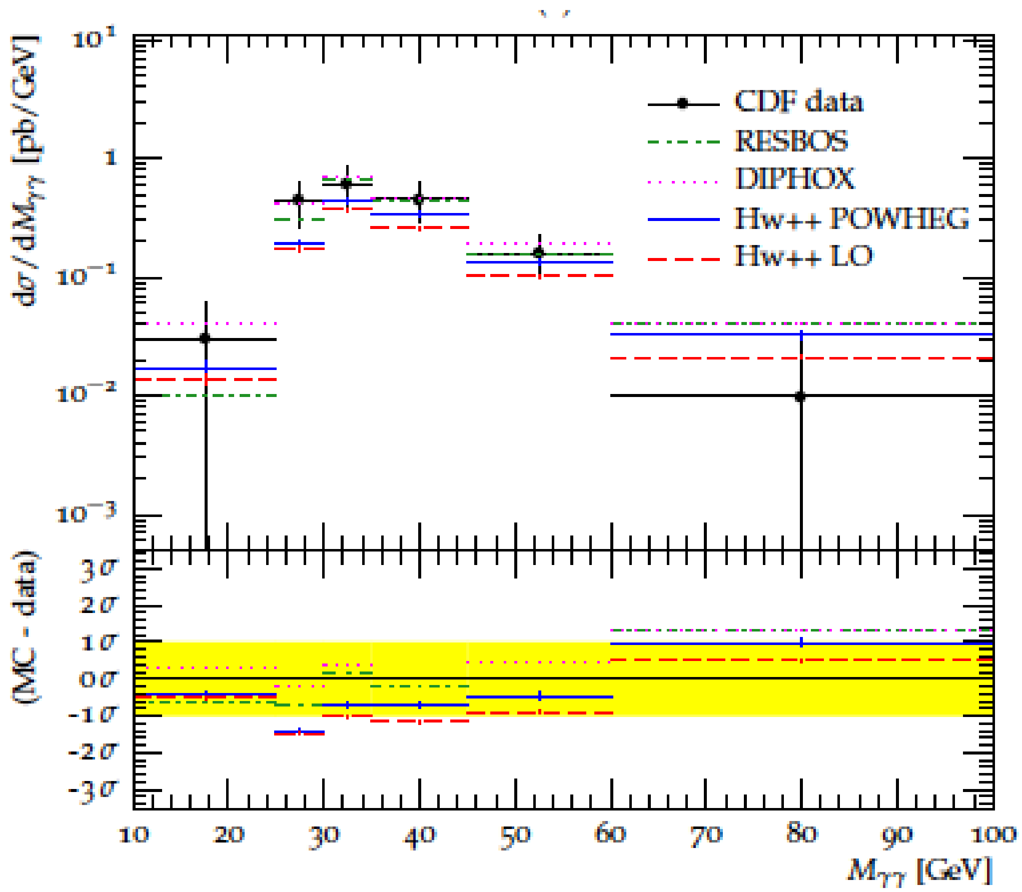
$$E_T^{had}(\delta) \leq \chi(\delta)$$

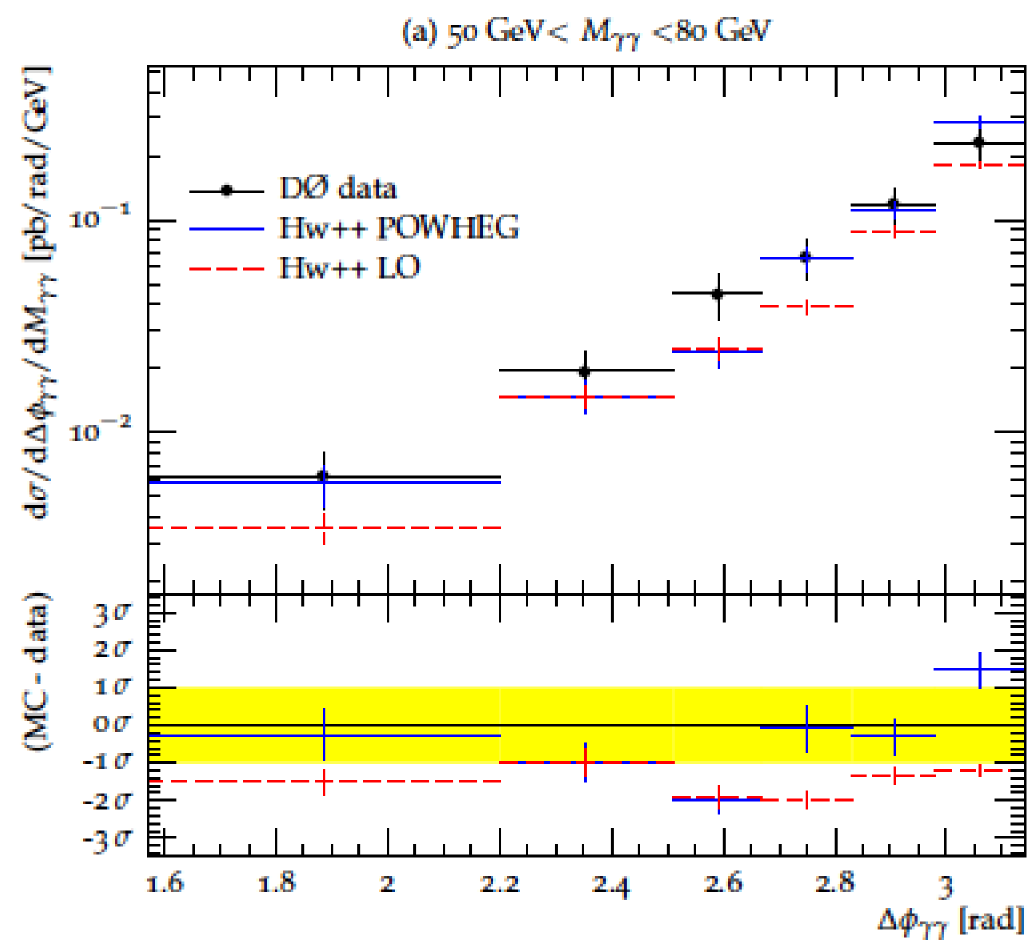


BACKGROUND: PP→γγ AT NLOwPS



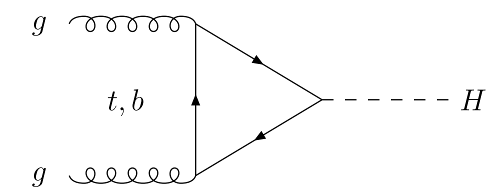
[D'Errico and Richardson, 1106.3939]



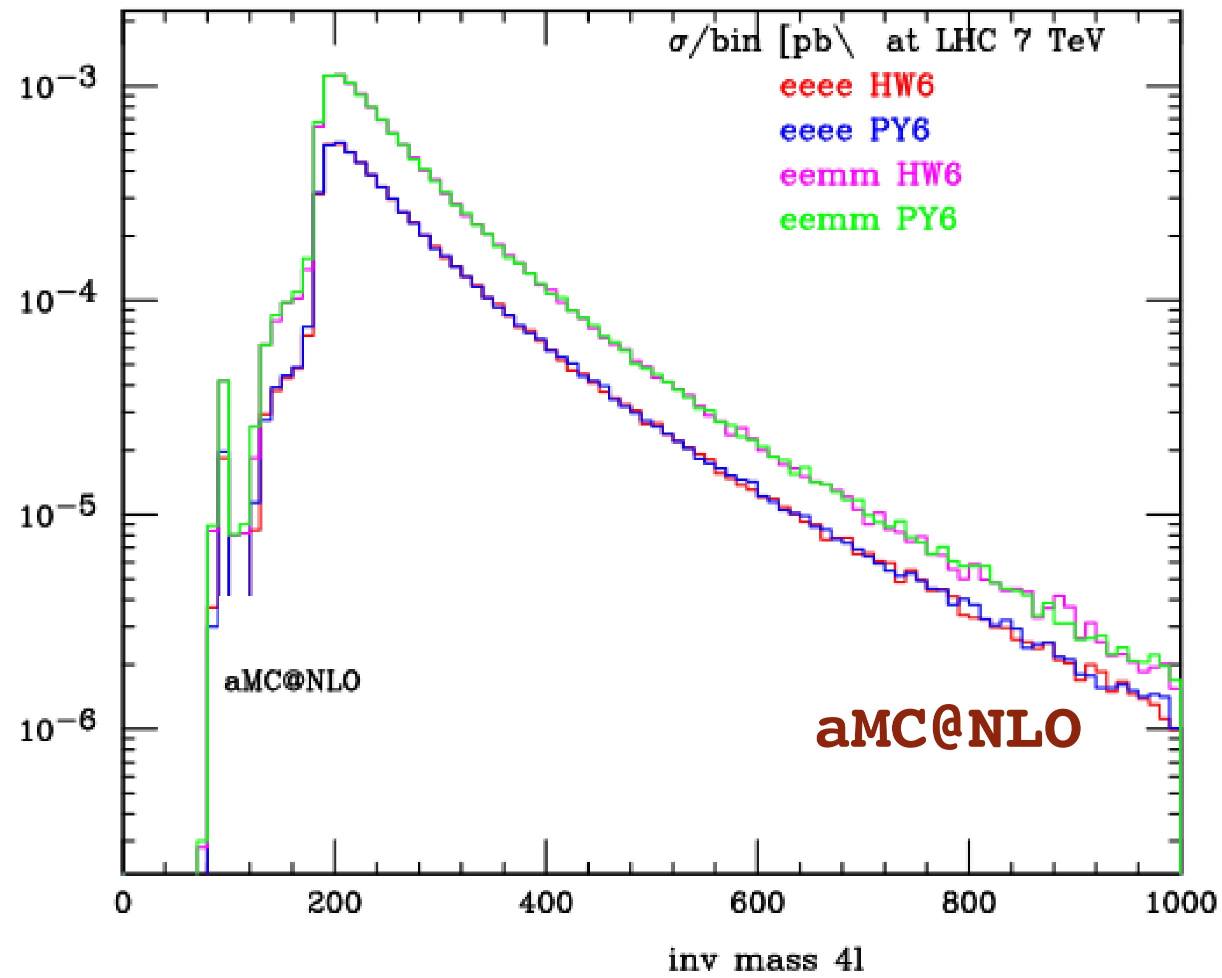


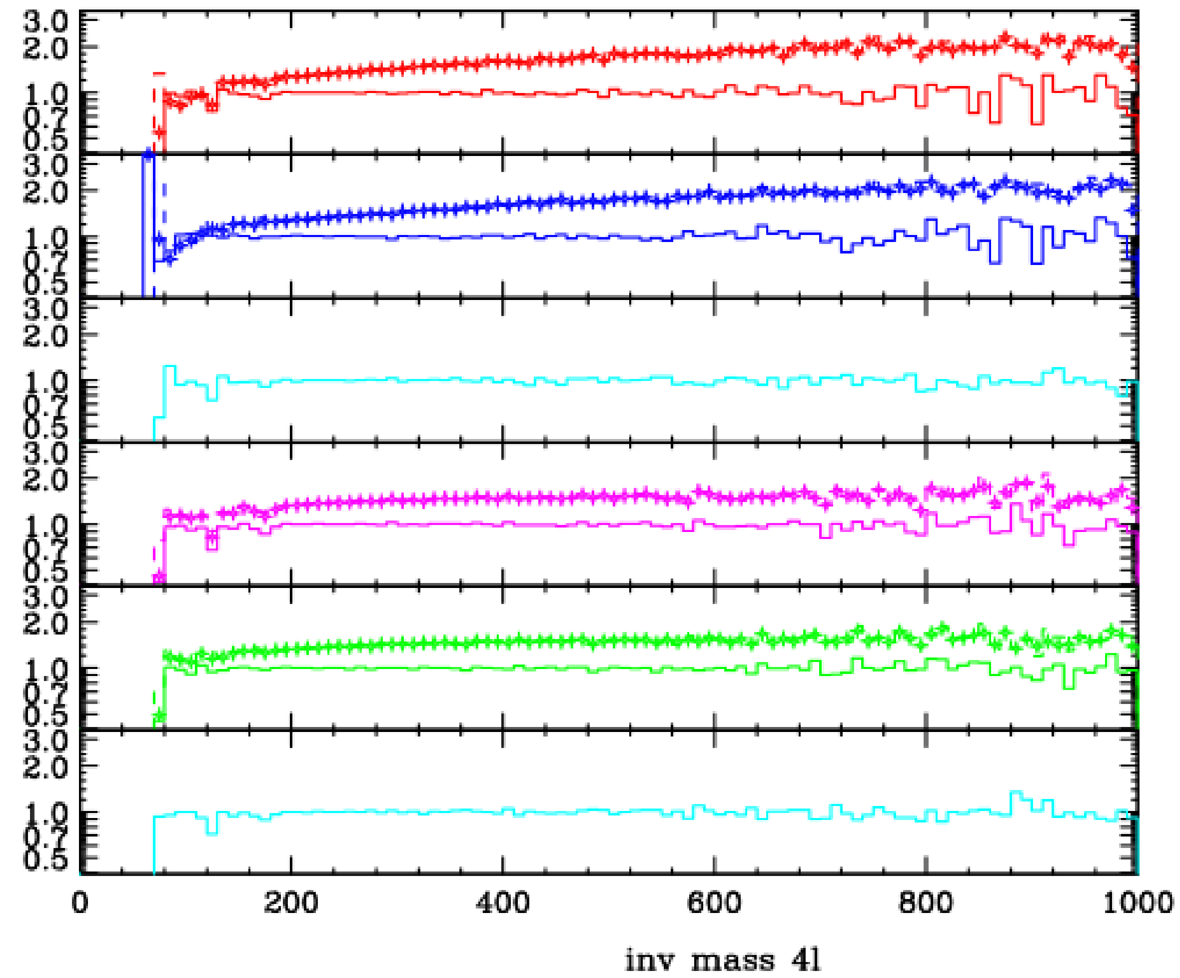
HERWIG++ with POWHEG method, includes fragmentation contributions!
Very complete NLOwPS implementation!

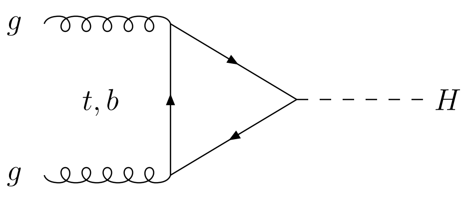
Background : pp→ZZ→4l



ZZ in aMC@NLO [Frederix et al., to appear] NLO calculation includes γ^{*}/Z interference, full spin correlations and interferences and single resonant diagrams and gg channel. Interfaced to Pythia and HERWIG. Automatic scale and PDF uncertainties evaluation.

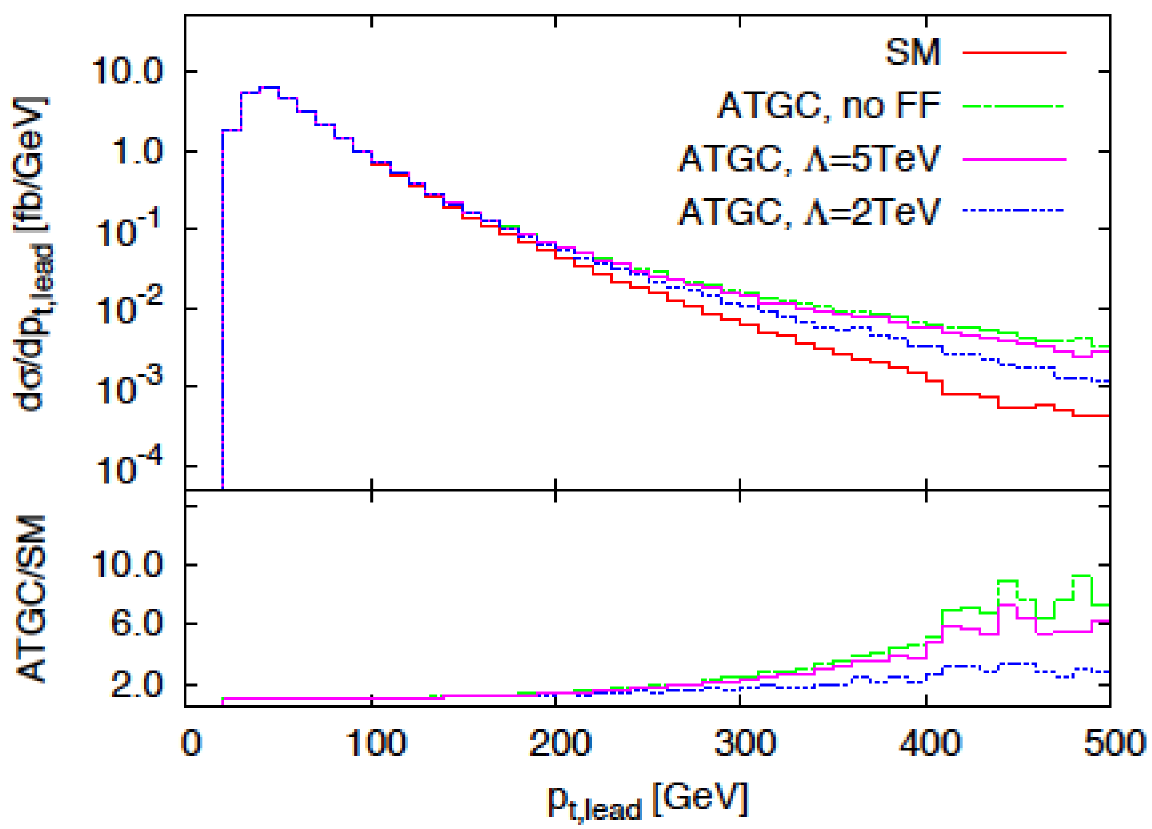


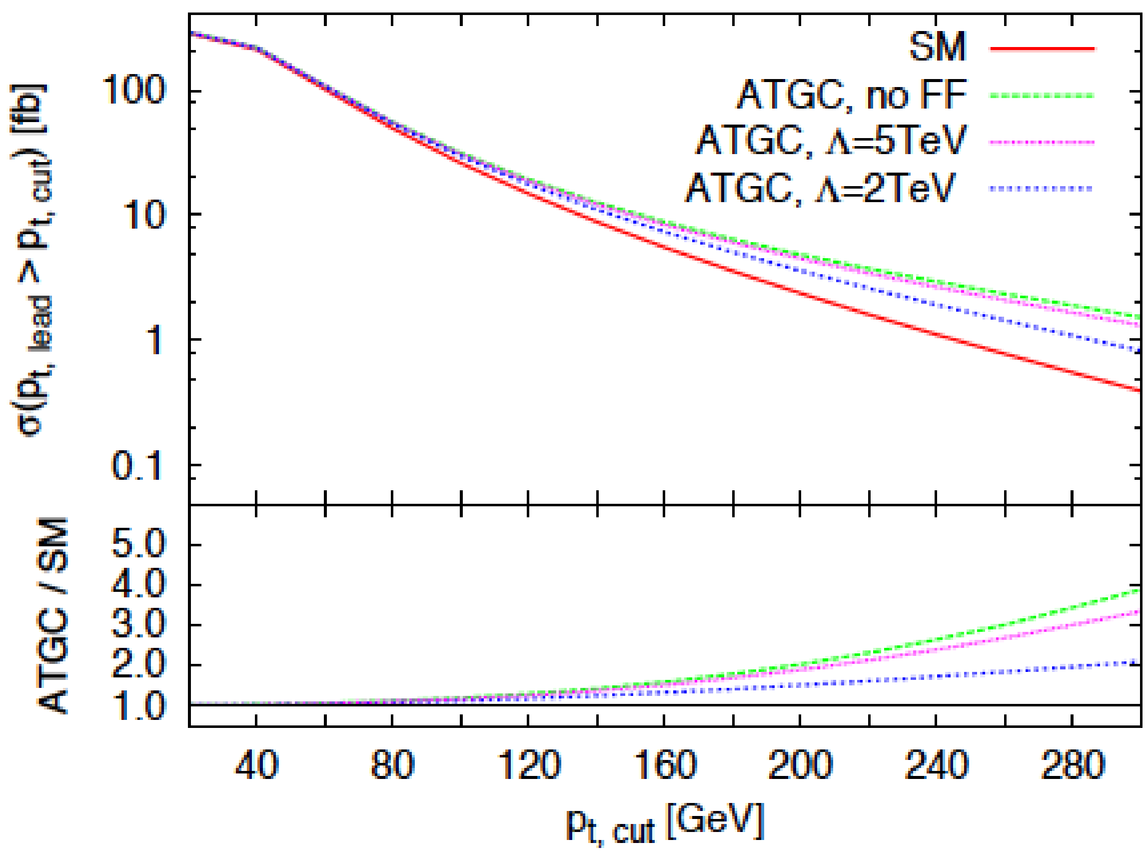




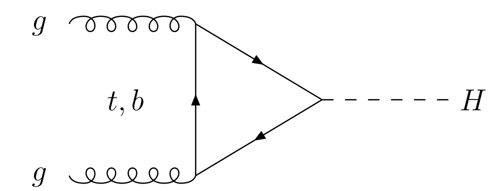
Background : pp→VV→4l

ZZ POWHEG-box implementation now together with ZW, WW with spin correlations and single-resonant diagrams. No gg channel. [Melia et al, 1107.5051] .
Anomalous couplings included.

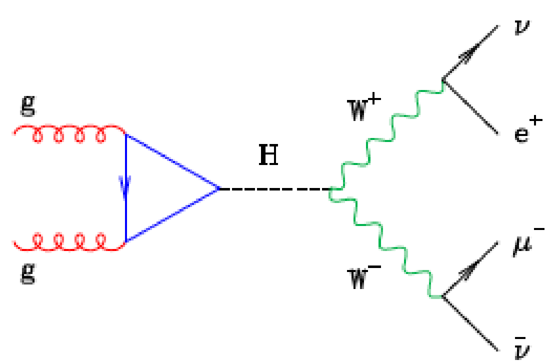


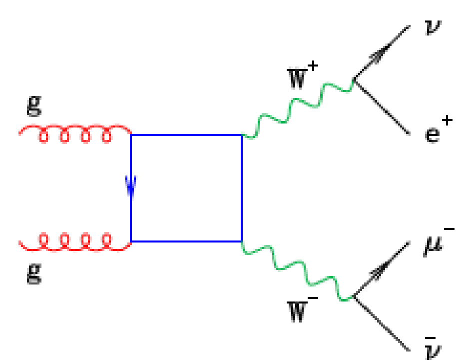


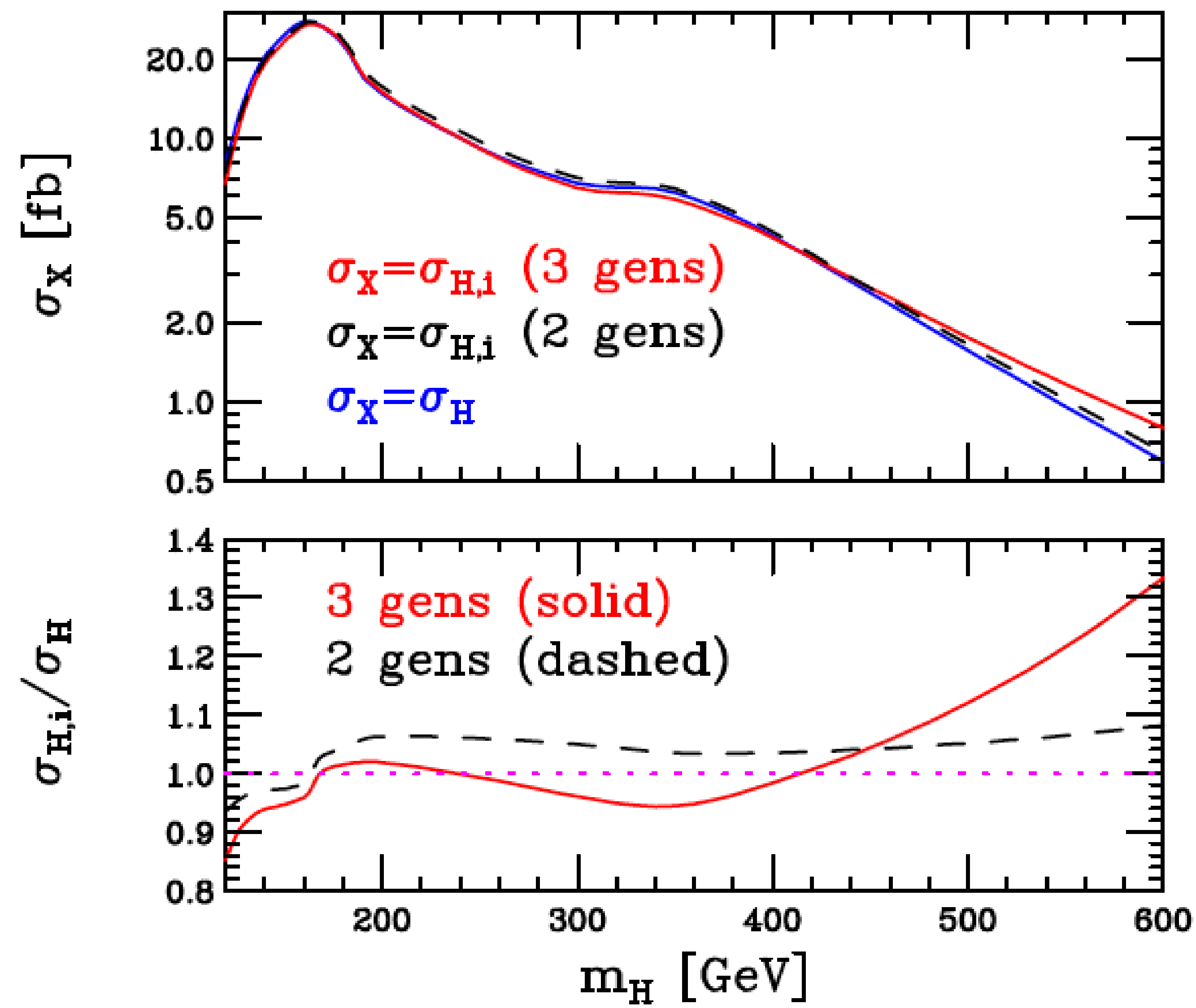
GG→H→WW→4L : BACKGROUND



[Binoth et al. hep-ph/0503094/0611170]
[Campbell, Ellis, Williams, 1107.5569]







$$\sigma_B \longrightarrow |\mathcal{A}_{\text{box}}|^2 \,, \qquad \mathcal{A}_{\text{box}} = 2\mathcal{A}_{\text{massless}} + \mathcal{A}_{\text{massive}} \,,$$

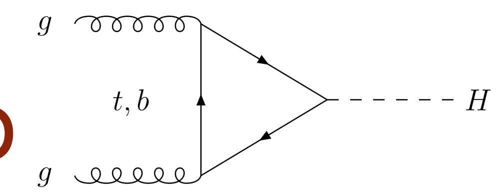
$$\sigma_H \longrightarrow |\mathcal{A}_{\text{Higgs}}|^2 \,,$$

$$\sigma_i \longrightarrow 2\text{Re}\left(\mathcal{A}_{\text{Higgs}}\mathcal{A}^*_{\text{box}}\right) \,,$$

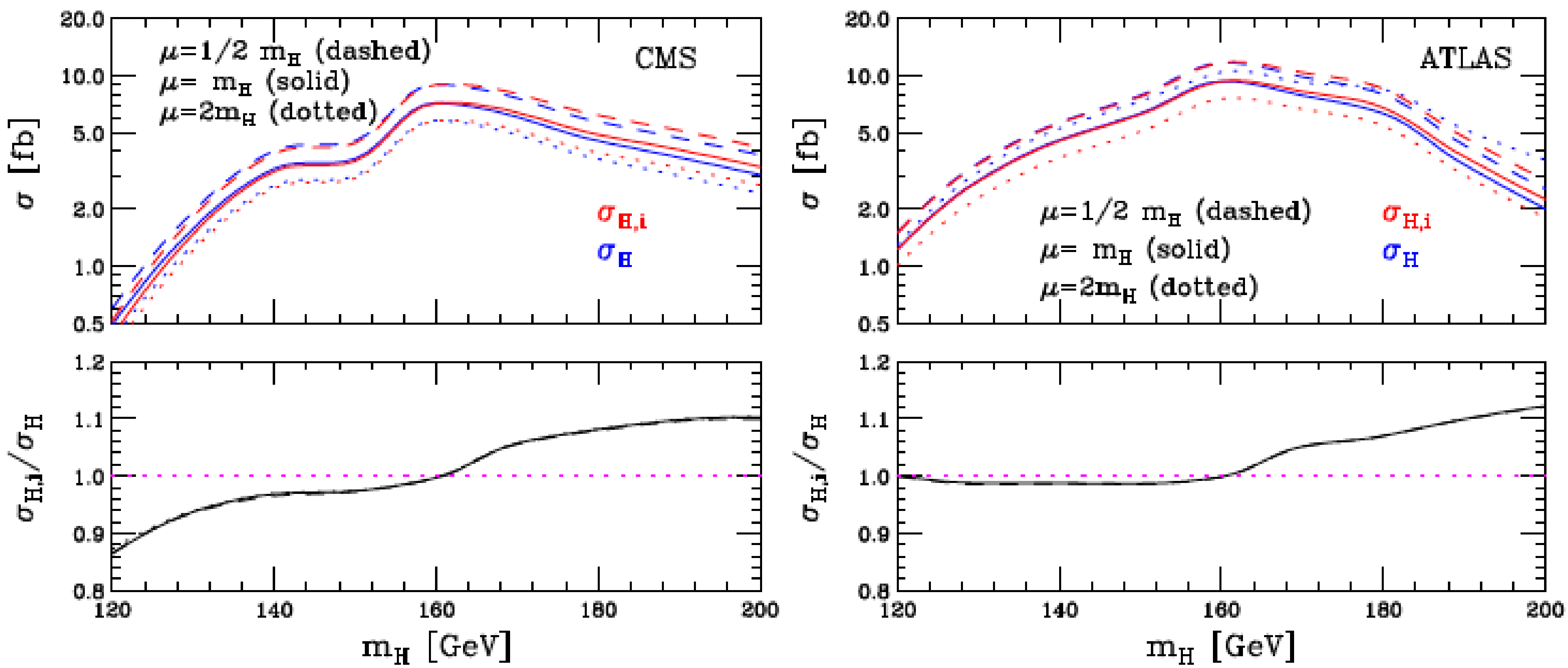
$$\sigma_{H,i} = \sigma_H + \sigma_i \,.$$

$$\delta\sigma_i = \frac{(\hat{s}-m_H^2)}{(\hat{s}-m_H^2)^2 + m_H^2\Gamma_H^2}\,\Re\mathfrak{e}\left\{2\widetilde{\mathcal{A}}_{\text{Higgs}}\mathcal{A}^*_{\text{box}}\right\} + \frac{m_H\Gamma_H}{(\hat{s}-m_H^2)^2 + m_H^2\Gamma_H^2}\,\Im\mathfrak{m}\left\{2\widetilde{\mathcal{A}}_{\text{Higgs}}\mathcal{A}^*_{\text{box}}\right\}$$

GG→H→WW→4L : BACKGROUND



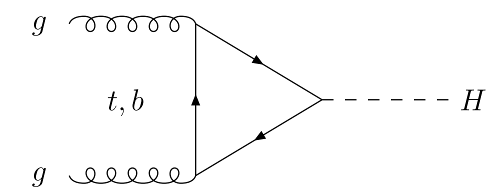
[Campbell, Ellis, Williams, 1107.5569]



Further improvement in an accurate simulation could be obtained by merging it to a NNLO computation (+ or *) or to a NLOwPS (+).

$$\sigma_{H,i}^{NNLO} = \sigma_H^{NNLO} + (\sigma_{H,i}^{LO} - \sigma_H^{LO})$$

$$\sigma_{H,i}^{NNLO} = \sigma_H^{NNLO} \left(\frac{\sigma_{H,i}^{LO}}{\sigma_H^{LO}} \right)$$



GG→H :
Backgrounds NLOwPS Summary

- pp→ γγ : available at NNLO and at NLOwPS
- pp→ VV : available at NLOwPS, including gg channels soon.
- pp→ tt : available at NLOwPS.
- pp →VV+1jet, ZZ+1jet possible in NLOwPS but not available yet.
- Signal-Background interferences possible in NLOwPS but need to be done.

OUTLINE

- Introduction : the main classes of available predictions
- Signal and backgrounds at 7 TeV channel-by-channel
  - SM : tth, WH/ZH, VBF, GluonFusion
  - BSM : GluonFusion, BBH, tH+

BSM : GluonFusion, BBH, tH+

- Gluon Fusion in BSM

4th generation:
NNLO QCD [Anastasiou, Buehler, Furlan, Herzog, Lazopoulos '11] (~9 effect as expected).
NLO EW production and decay [Passarino et al.] (large corrections)

However, NLOwPS not really affected

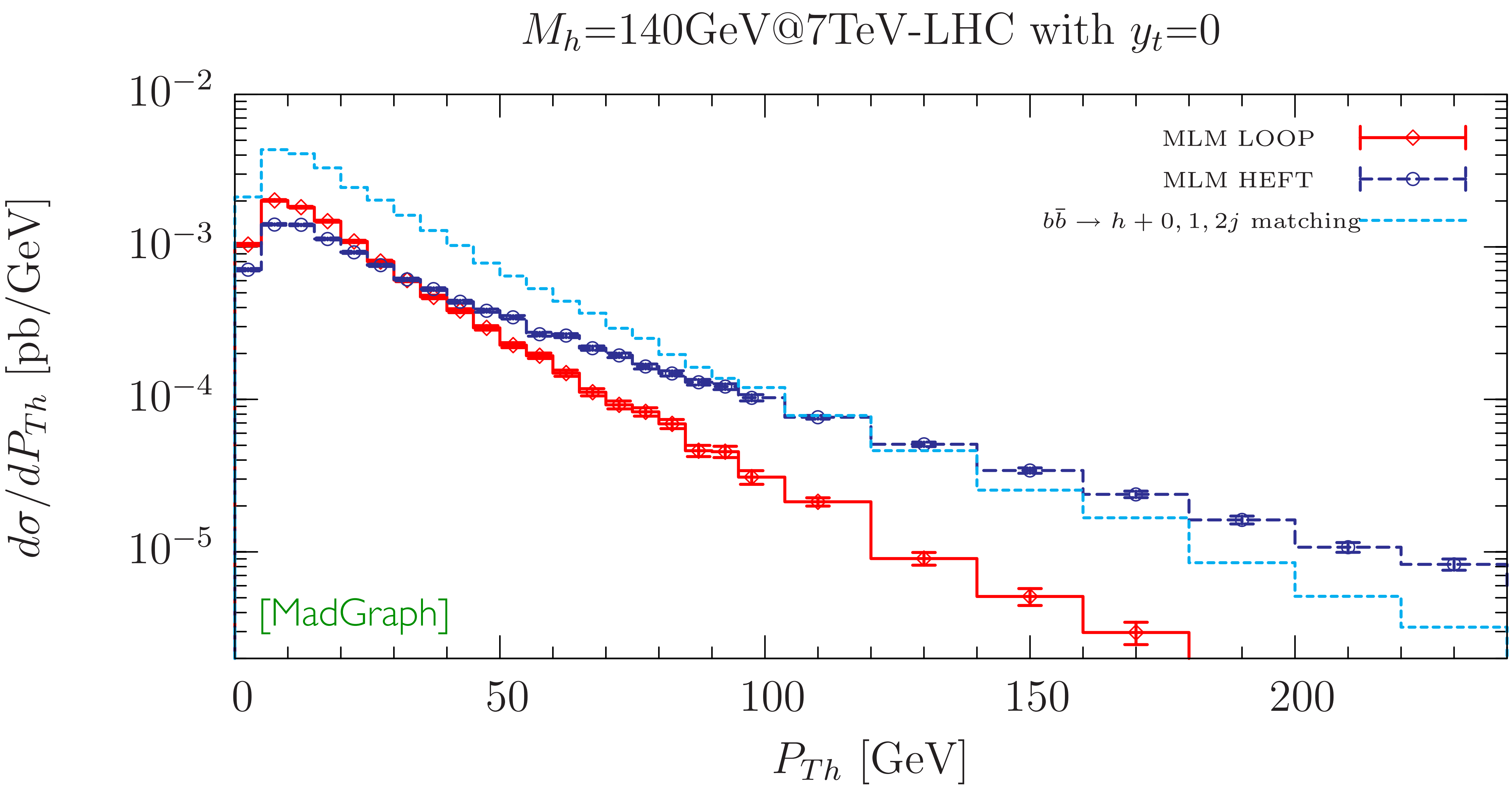
SUSY:
corrections can be large [Djouadi 98], [Carena et al. 99] [R.H., Steinhauser '04] [Anastasiou et al. '06/'08][Mühlleitner, Rzehak, Spira '07/'08] [Aglietti, Bonciani, Degrassi, Vicini '06] [Degrassi, Slavich '08], however for distributions not very important (SUSY partners heavy).

Only important corrections for distributions are those coming from the bottom loops! [Spira, Djouadi, Graudenz, Zerwas '95] [Harlander, Kant '05] . NLO (two-loops) corrections are included in HIGLU which also provides histogram for the pt of the Higgs.

NLOwPS NEEDED and not available yet!!

GG→H+0,1,2 PARTONS MATCHED

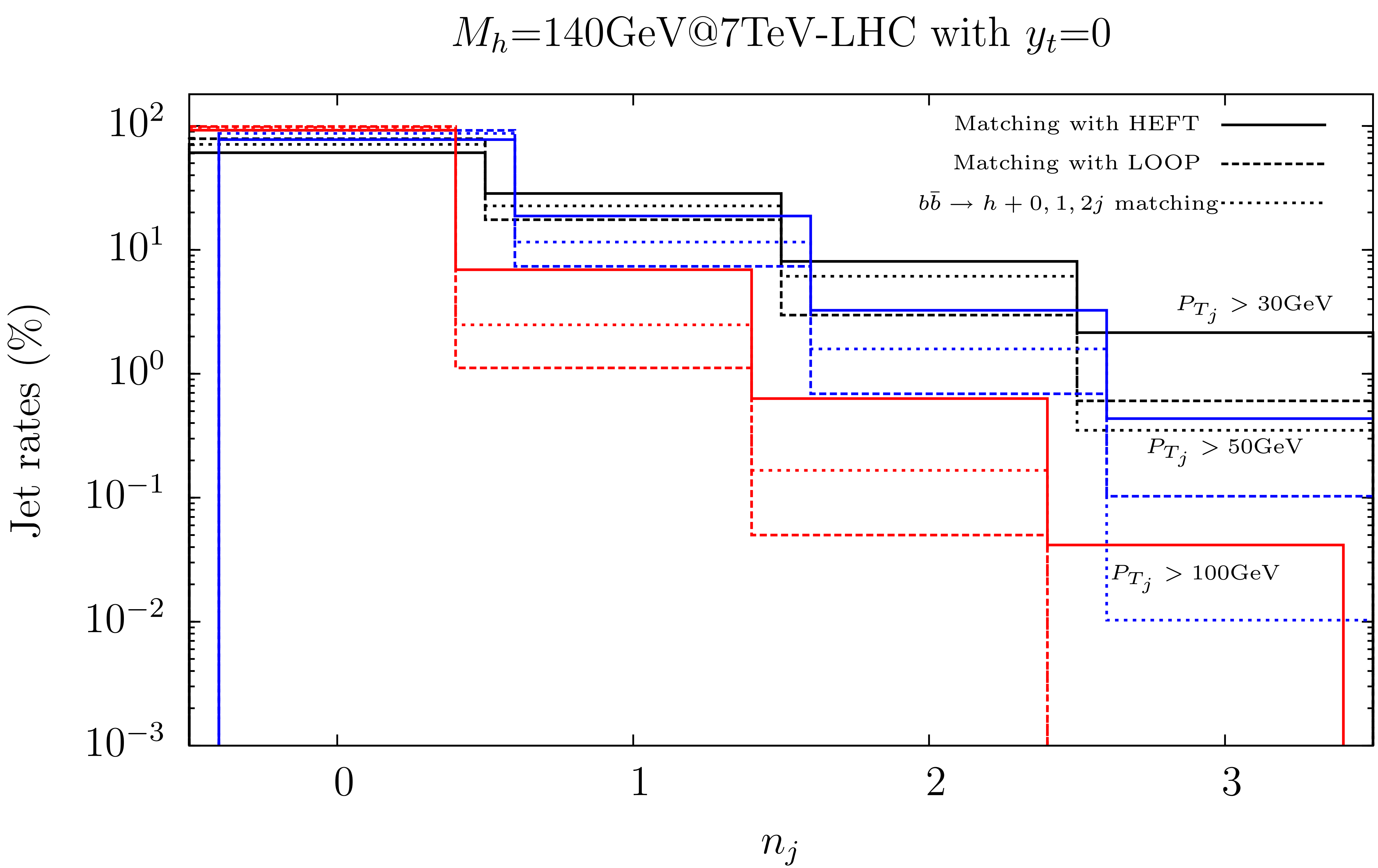
[J. Alwall, Q. Li, FM, to appear]



GG→H via bottom loops at NLO, including pt distribution done in [Langenegger et al, hep/0604156v2].
Fully exclusive description of Higgs + jets via MLM-kt matching, including exact loop effects.

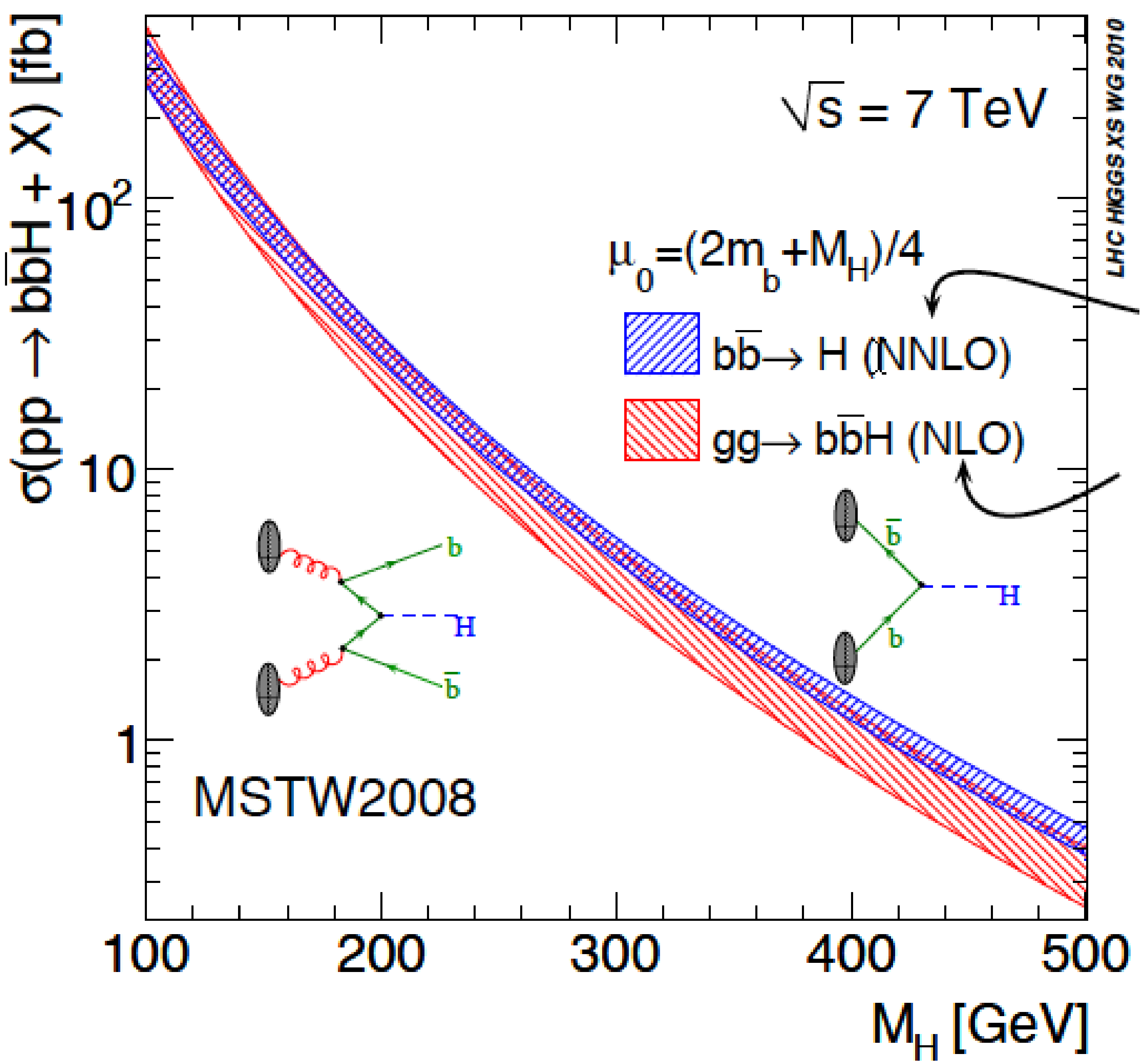
GG→H+0,1,2 PARTONS MATCHED

[J. Alwall, Q. Li, FM, to appear]



BSM : GluonFusion, BBH, tH+

- BBH



4F and 5F calculations available.

[Harlander and Kilgore, 2003]

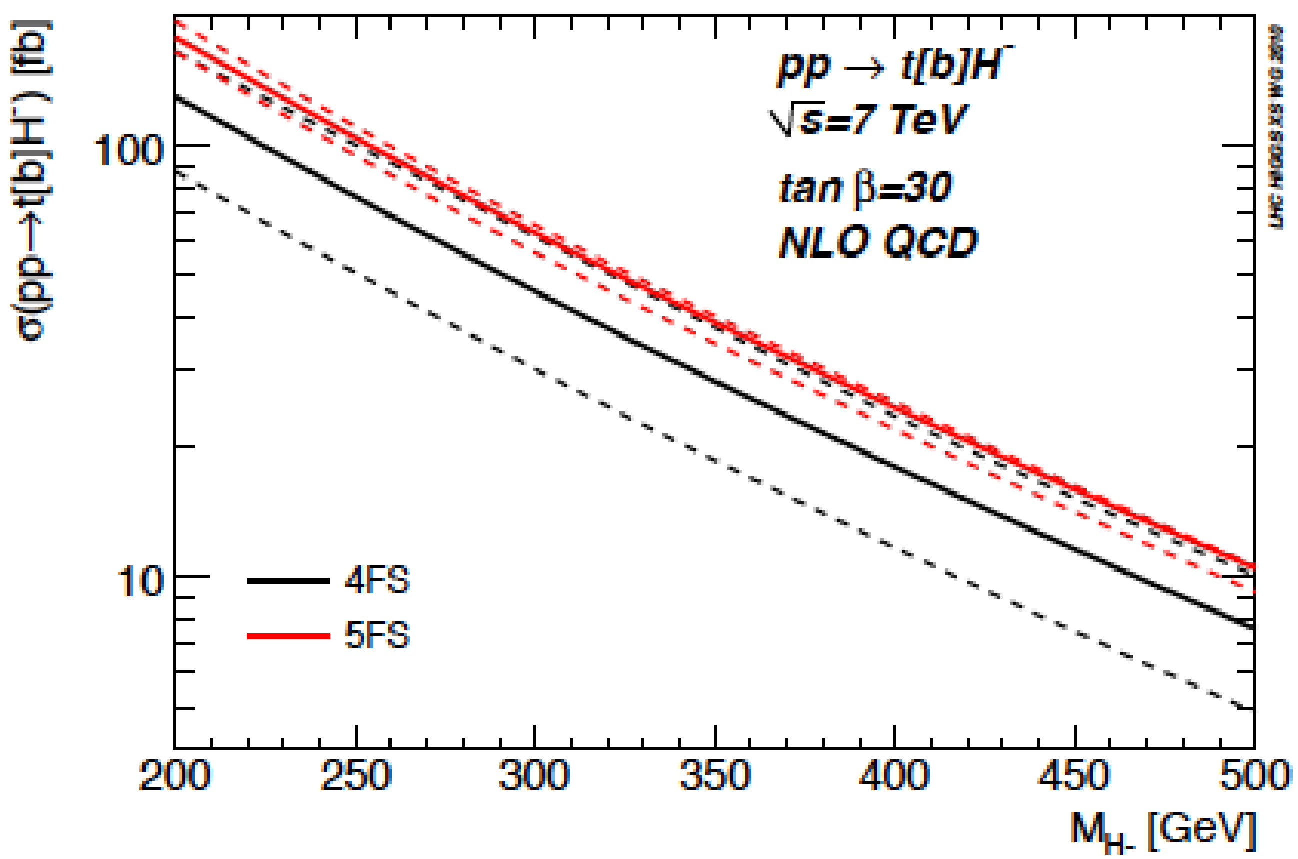
[Dittmaier, Krämer, Spira '04]
[Dawson, Jackson, Reina, Wackeroth '04]
[Hirschi et al. 1103.0621]

Recently available "Santander Matching" for total cross sections [Harlander, Kramer, Schumacher, 2003]

2→3 Only available at parton-level.
NLOwPS possible in aMC@NLO and to interface in POWHEG-BOX.
MEwPS available (see plot before).

BSM : GluonFusion, BBH, tH+

- tH+ (heavy)



4F and 5F calculations available:

5F : [Weydert et al. , 0912.3430]

4F: [Dittmaier et al. 0906.2648]

5F calculation available in MC@NLO and POWHEG [Weydert at al.]

4F calculation can be implemented via the POWHEG box or aMC@NLO.

SUMMARY : WHAT WE HAVE

channel	δ_{QCD}	δ_{EW}	$d\sigma/dX$ QCD/EW	NLOwPS mc@NLO/POWHEG	Interferences: signal-signal/ signal-back
GluonFusion	NNLO/NNLL	NLO	NNLO/LO	✓/✓	*/***
VBF	NNLO	NLO	NLO/NLO	x/✓	*/*
VH	NNLO/NNLL	NLO	NNLO/NLO	✓/x	*/*
TTH	NLO	LO	NLO/LO	✓/✓	*/x

SUSY					
GluonFusion	NNLO	NLO	NLO/LO	x/x	-
BBH	NLO	LO	NLO/LO	x/x	-
tH+	NLO	LO	NLO/LO	✓/✓	-

SUMMARY : WHAT WE'D LIKE TO HAVE

- SM
  - MC@NLO and POWHEG implementations for all signal and background processes to study systematic effects HERWIG/Pythia/SHERPA differences. A corresponding study process by process and comparison with NNLO.
  - H+1jet and H+2jets in NLOwPS
  - W+W- +1,2jets in NLOwPS
  - Interference effects for heavy Higgs in NLOwPS.
  - Always public codes or at least events.
- BSM
  - GluonFusion (b loop effects) in NLOwPS
  - bbh (4F and 5F) in NLOwPS
  - 4F tH + in NLOwPS
  - Always publics codes or at least events.

CONCLUSIONS

- LHC running has given an enormous motivation to the QCD/EW/MC TH community and many new results for Higgs signal and backgrounds have become available in the last 6 months and others on the way...
- State of the art for the signal is:
  - Parton level (histograms) : NNLO (QCD) and NLO (EW)
  - Event generators : MC@NLO and POWHEG methods
- Systematic comparisons between different approaches for differential rates still to be done.
- Higgs backgrounds quickly approaching the NLOwPS level.
- Signal-Background and Signal-Signal interferences start to be addressed.

CREDITS

For this seminar I have happily and largely used material from:

Massimiliano Grazzini's excellent review at the Higgs Hunting Workshop 2011 (Paris, July)

Robert Harlander's excellent review at "Standard Model Processes at the LHC", DESY-Zeuthen, June 201.