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Higgs Production via VBF, WH/ZH, and ttH Channels

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Higgs Cross Sections for the LHC

BNL, May 5, 2011

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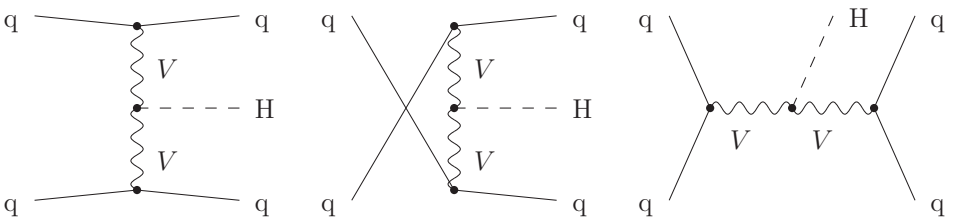
Outline

- Production channels:
  - Vector-boson fusion (VBF)
  - Higgsstrahlung (WH/ZH)
  - top-quark associated production (ttH)
- Status and new developments
  - Available tools
  - EW corrections for WH/ZH in HAWK
- Distributions
  - What is available/needed?
- Summary and discussion

Vector-Boson Fusion

$$q\bar{q} \to \mathrm{H}jj$$



- sizeable fraction of inclusive Higgs production
- special kinematics: forward and backward jet $\Rightarrow$ VBF signal
- VBF cuts on jets (p_{T}, y, rapidity gap, central jet veto)
  - to reduce background
  - to separate from $gg \to \mathrm{H}jj$ in gluon fusion (5% after cuts)
  - s-channel and interferences negligible (DIS^2 like process)
- measure HWW and HZZ couplings
- investigate non-standard couplings

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Status

NLO QCD+EW corrections available in public codes

- VBFNLO: Fully flexible parton level code
  - s-channel and interferences neglected
  - various Higgs-decay modes available
  - other VBF processes included
  - H+3 jets included
- HAWK: Fully flexible parton level code
  - no kinematic limitations (s-channel and interferences included)
  - isotropic 2-body Higgs decay available
  - off-shell Higgs production included
- VV2H: QCD only, σ_{tot} only

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Status

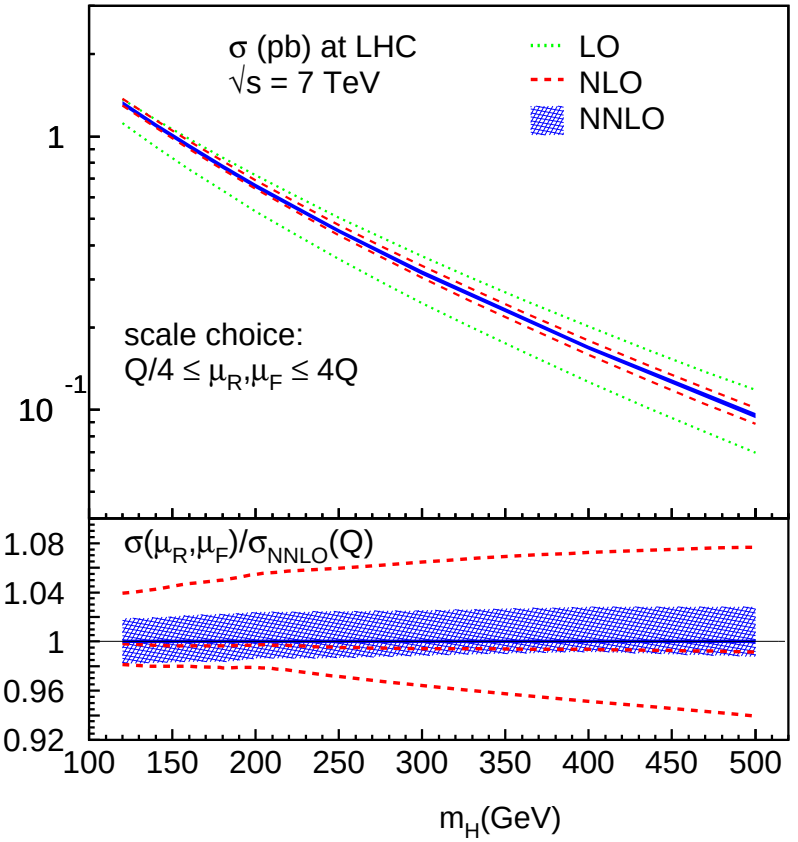
NNLO QCD corrections

- VBF@NNLO: $\sigma_{\rm tot}$ only

  structure function approach ($\rightarrow$ DIS^2)

  QCD under good theoretical control

  tough to extend to distributions



Bolzoni,Maltoni,Moch,Zaro [arXiv:1003.4451]

Beyond fixed order

- Powheg: merging NLO with PS ($\rightarrow$ later)

Inclusive Prediction

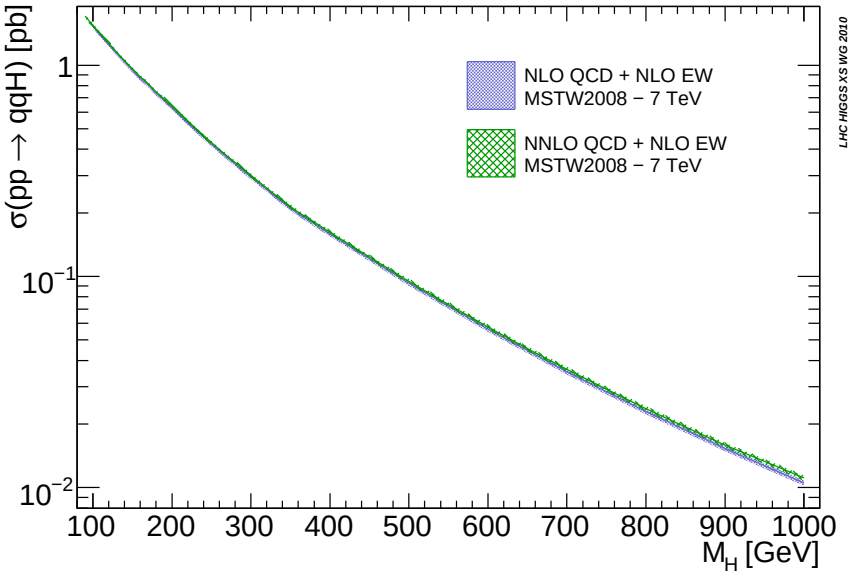
Total cross section: $\sigma = \sigma_{\mathrm{NNLO}}(1 + \delta_{\mathrm{EW}})$

$\mathcal{O}$(5-10%) QCD corrections

EW corrections of similar size

scale uncertainty: < 1% (3%)
for $M_{\mathrm{H}} < 250$ GeV ($M_{\mathrm{H}} < 1000$ GeV)

PDF+α_{s} uncertainty: < 4% (10%)
for $M_{\mathrm{H}} < 300$ GeV ($M_{\mathrm{H}} < 1000$ GeV)



so far:

no VBF cuts, but no s-channel contribution

$\Rightarrow$ need for differential predictions (including cuts)

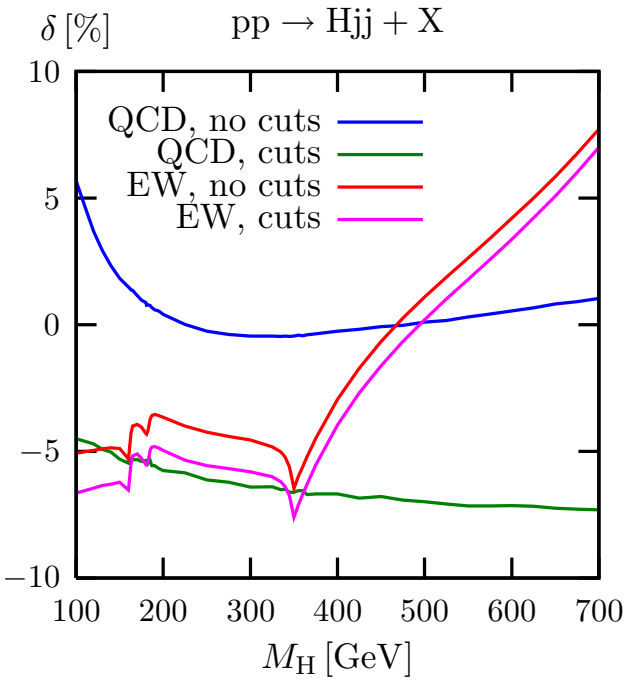
The tools are available at NLO!

(though usually only LO H decays in production codes)

inclusive $\Leftrightarrow$ VBF cuts

relative NLO corrections for VBF:

Ciccolini,Denner,Dittmaier [arXiv:0710.4749]



cuts $\Leftrightarrow$ no cuts:
large difference for NLO QCD

however in this plot:
- s-channel included (large, positive correction)
- MRSTQED2004 PDF at LO/NLO

Tuned comparison in 2007:

LH Higgs working group [arXiv:0803.1154]

without cuts ($M_H = 120$ GeV)

$\sigma_{\mathrm{LO}}^{\mathrm{VBFNLO}} = 4227.1(1)$ fb

$\sigma_{\mathrm{NLO}}^{\mathrm{VBFNLO}} = 4414.8(2)$ fb

$\to$ NLO QCD corrections: 4.4%

with cuts ($M_H = 120$ GeV)

$\sigma_{\mathrm{LO}}^{\mathrm{VBFNLO}} = 1686.90(5)$ fb

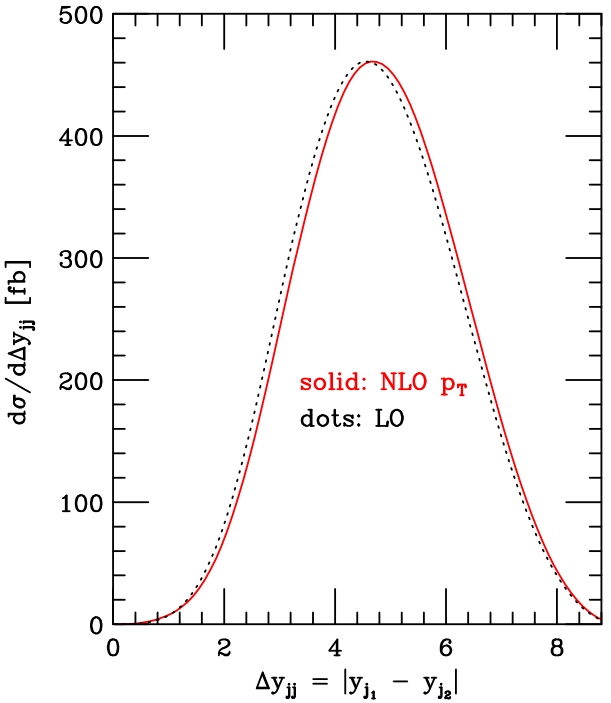
$\sigma_{\mathrm{NLO}}^{\mathrm{VBFNLO}} = 1728.8(2)$ fb

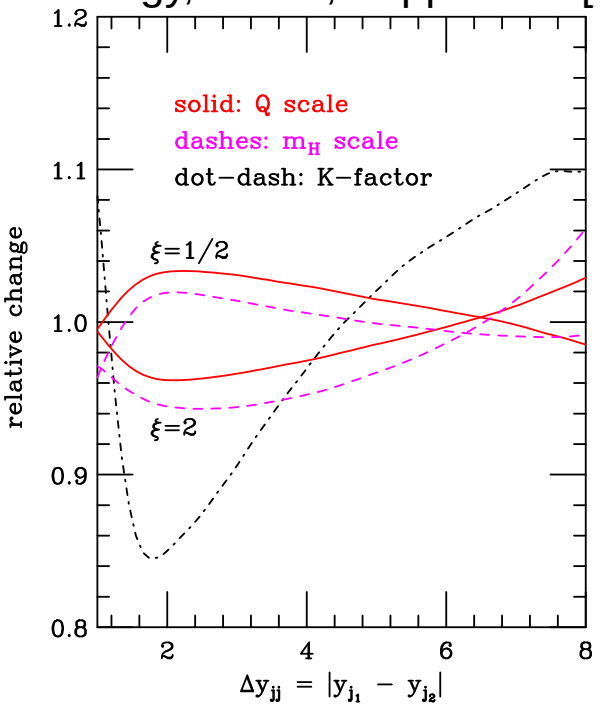
$\to$ NLO QCD corrections: 2.5%

Distributions

example 1: rapidity separation (leading p_{T} jets)

Figy, Oleari, Zeppenfeld [hep-ph/0306109]



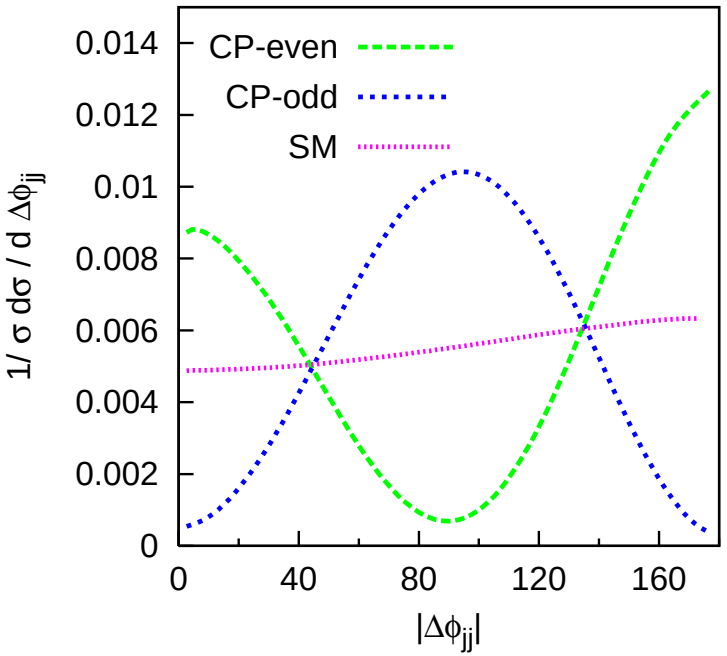


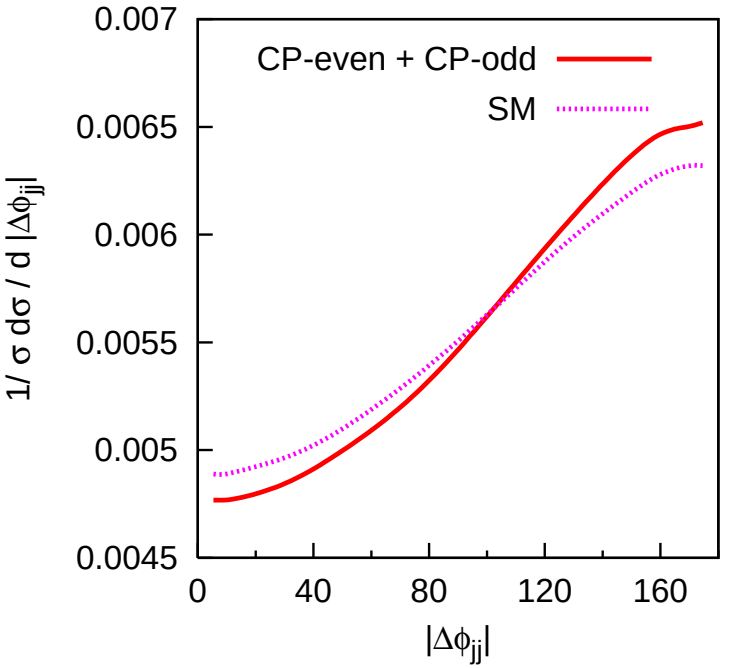
$\Rightarrow$ no uniform K-Factor

Distributions

example 2: azimuthal angle between tagging jets

Hankele, Klämke, Zeppenfeld [hep-ph/0609075]



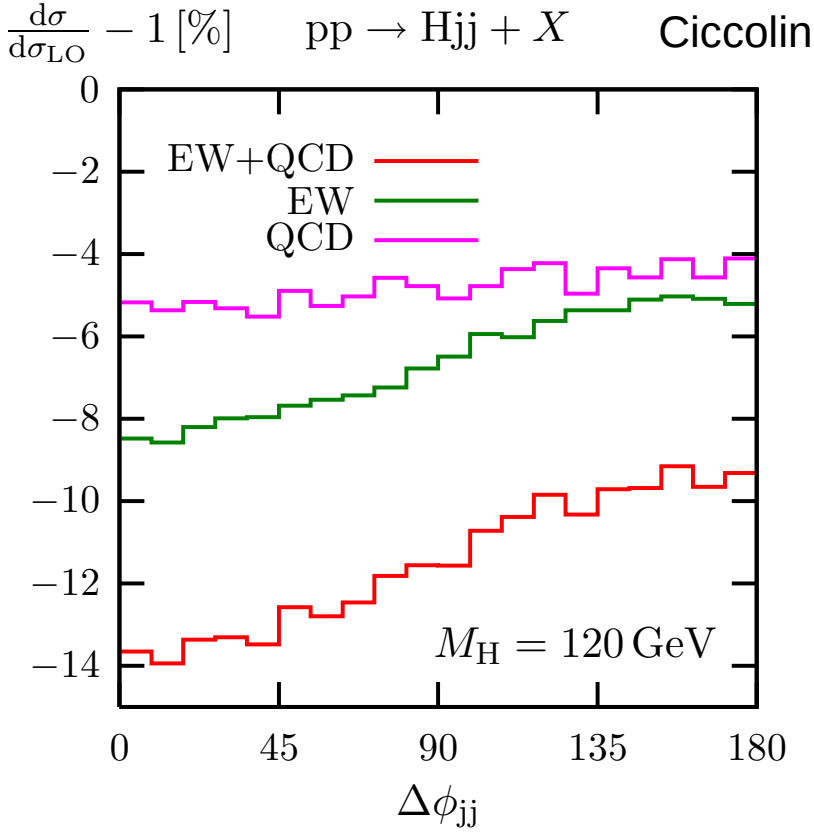


$\Rightarrow$ shape difference as signal for new physics

What about higher order corrections in distribution?

Distributions

example 2: azimuthal angle between tagging jets



Ciccolini,Dittmaier, Krämer [hep-ph/0306234]

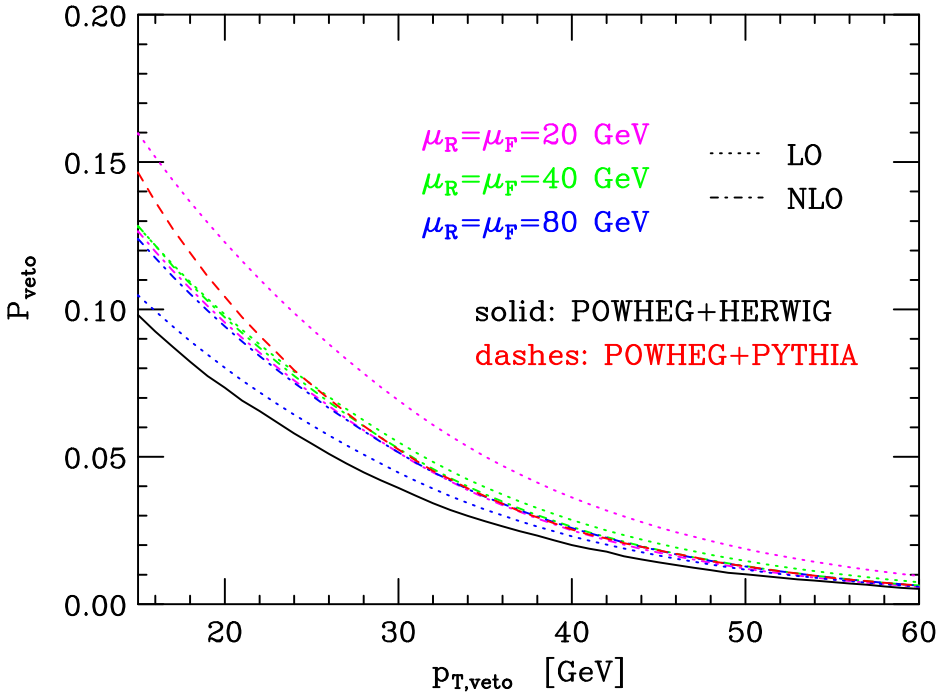
NLO QCD corrections rather flat

NLO EW corrections distort shape

Beyond fixed order

example: jet-veto using the POWHEG

Nason, Oleari [arXiv:0911.5299]



veto probability from:

POWHEG + PS

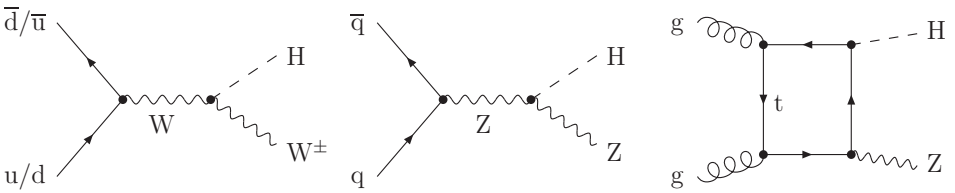
compared to

Hjjj at NLO QCD

Figy, Hankele, Zeppenfeld [arXiv:0710.4749]

Higgsstrahlung

$$pp \to W/Z + \mathrm{H}$$



- only small fraction of total Higgs cross section
- for small Higgs masses $H \to b\bar{b}$ may be accessible
- small signal to background ratio

  $\Rightarrow$ boosted Higgs: use high p_{T} Higgs bosons only
- QCD corrections
  - similar to Drell-Yan ($\to$ relatively simple)
  - additional gluon-fusion contribution (5% level)
- EW corrections more involved

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Status

For total cross section only:

- NNLO QCD corrections
  - VH@NNLO

Brein, Djouadi, Harlander [hep-ph/0307206]
based on Hamberg, van Nerveen, Matsuura ['91]

- NLO EW corrections
  - private code only

Ciccolini,Dittmaier, Krämer [hep-ph/0306234]

Differential predictions:

- MC@NLO and Powheg implementations available
- distributions at NNLO? (techniques available)
- new development:
  inclusion of WH/ZH NLO QCD+EW into HAWK

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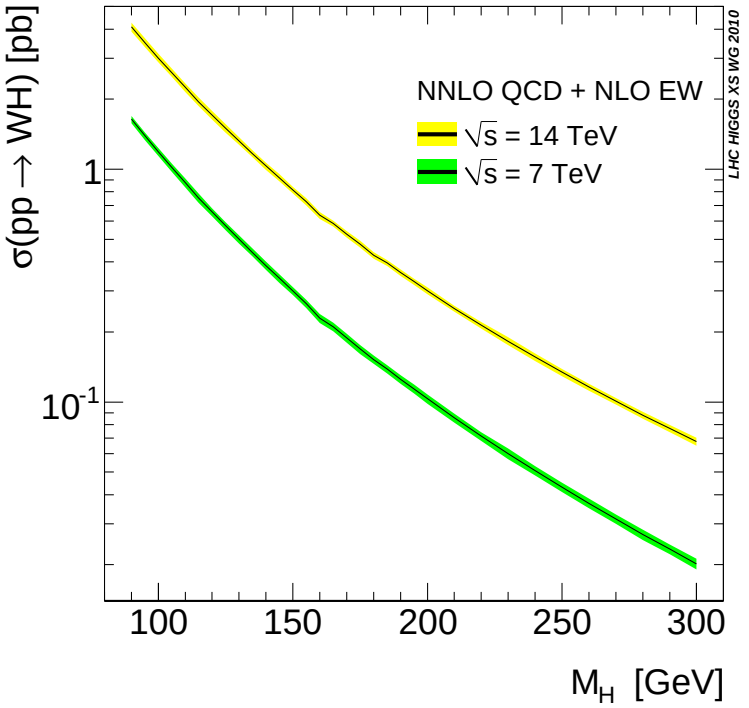
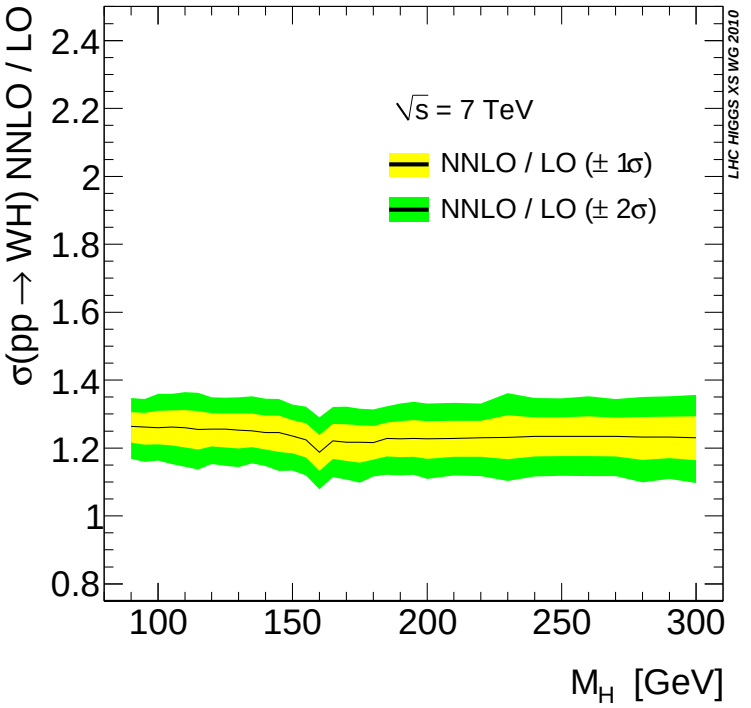
Inclusive Prediction

Total cross section:

$$\sigma_{\mathrm{WH}} = \sigma_{\mathrm{WH}}^{\mathrm{VH@NNLO}} \times (1+\delta_{\mathrm{WH,EW}}) \,, \qquad \sigma_{\mathrm{ZH}} = \sigma_{\mathrm{ZH}}^{\mathrm{VH@NNLO}} \times (1+\delta_{\mathrm{ZH,EW}}) + \sigma_{\mathrm{gg\to ZH}} \,,$$





scale uncertainty: 1-2 % @ NNLO, PDF+α_{s} uncertainty: 3-5%

unphysical spikes: thresholds in EW corr. → will disappear in HAWK

EW corrections for boosted Higgs? → new HAWK version

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WH/ZH in HAWK

Denner, Dittmaier, Kallweit, Mück

- from s-channel in VBF discussion
  $\Rightarrow$ replace hadronic by leptonic boson decay
- independent second calculation
- full access to leptons in final state
  ($pp \to Hl^+l^-$ or $pp \to Hl\nu_l$)
- isotropic Higgs decay (only), off-shell Higgs (in the making)
- vector-boson resonance
  $\Rightarrow$ use the complex mass scheme
  (will also regularize threshold spikes in EW corrections)
- expect new release quite soon

Resonances

problem: $\frac{1}{p^2-M^2} \stackrel{?}{\rightarrow} \frac{1}{p^2-M^2+iM\Gamma}$

solution: complex mass scheme

Denner, Dittmaier, Roth, Wieders [hep-ph/0505042]

- use complex W and Z masses everywhere by means of complex renormalization:

  $M^2_{\mathrm{V},0} = \mu^2_{\mathrm{V}} + \delta\mu^2_V$

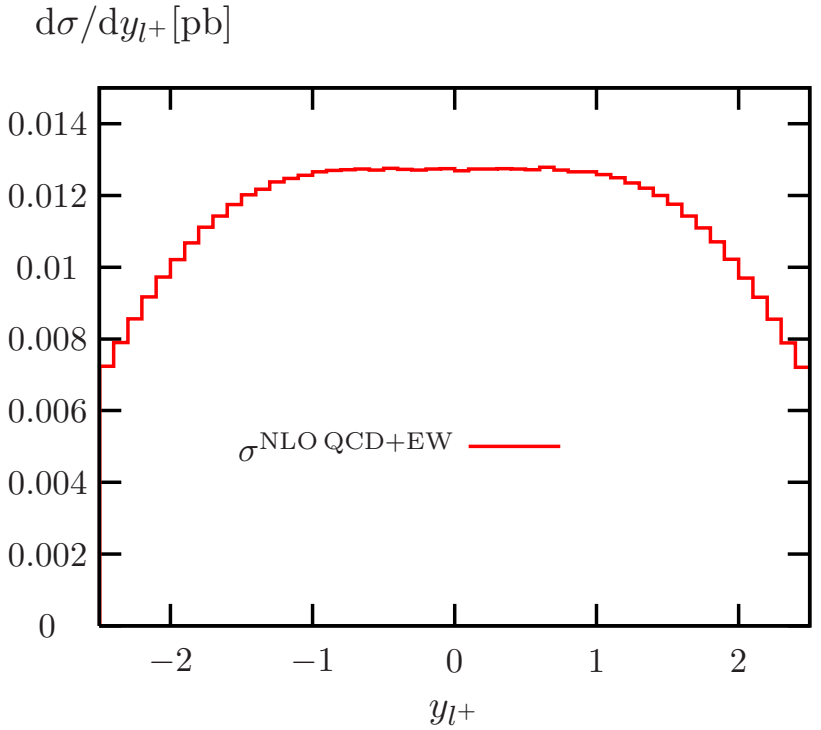
  with: $M^2_{\mathrm{V},0}$ = bare mass $(\mathrm{V} = \mathrm{W}, \mathrm{Z})$
  μ^2_{V} = ren. complex mass
  $\delta\mu^2_V$ = complex counterterm

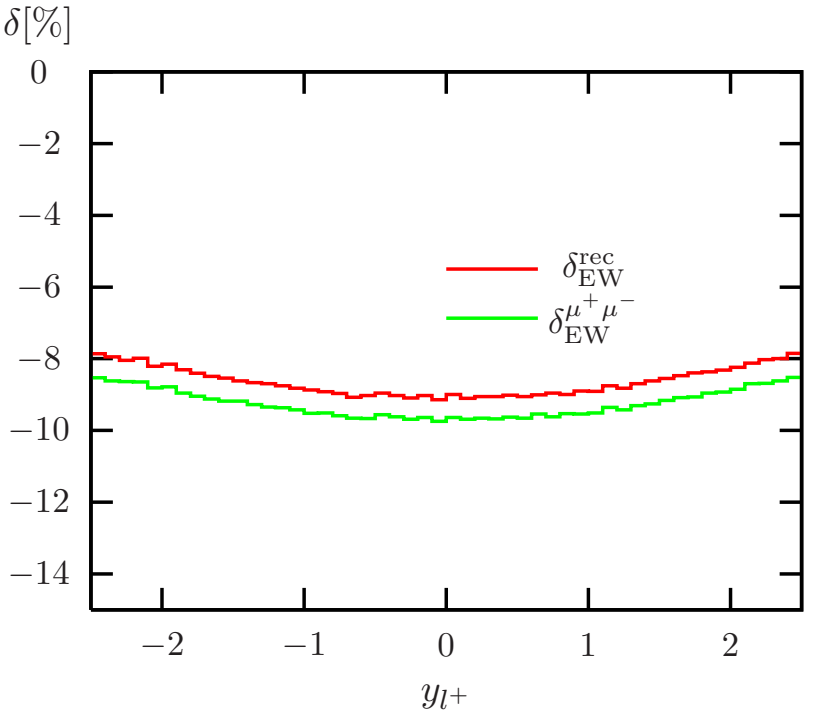
- $\Rightarrow$ complex $s^2_{\mathrm{W}} = 1 - \mu^2_{\mathrm{W}}/\mu^2_{\mathrm{Z}}$
- loop-integrals for complex masses needed
- unitarity-violating beyond NLO accuracy
- gauge invariant
- valid everywhere in phase space

Preliminary results

example: charged lepton rapidity for $pp \to l^+ \nu_l H$

EW corrections:



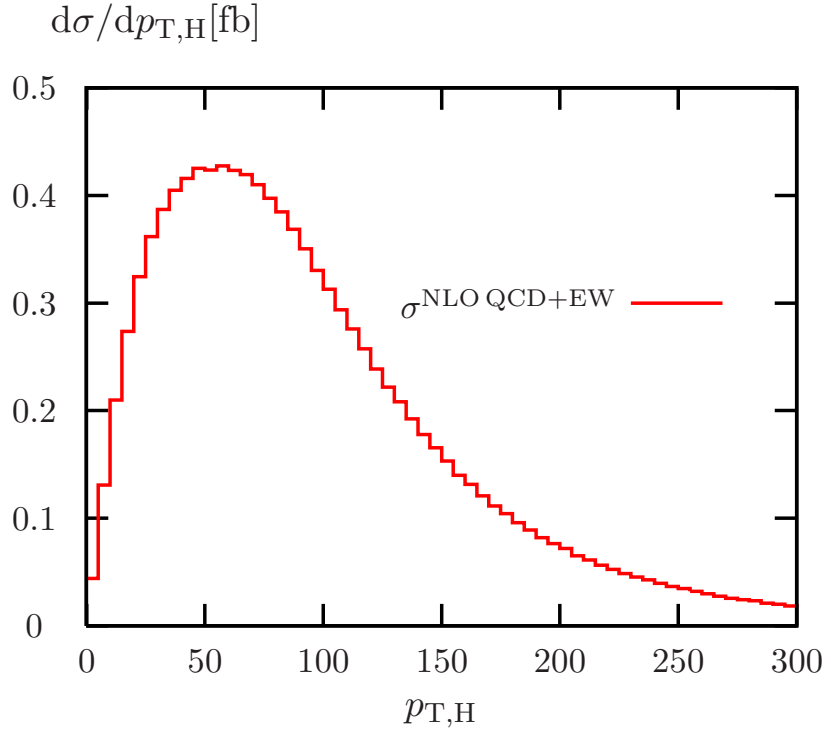


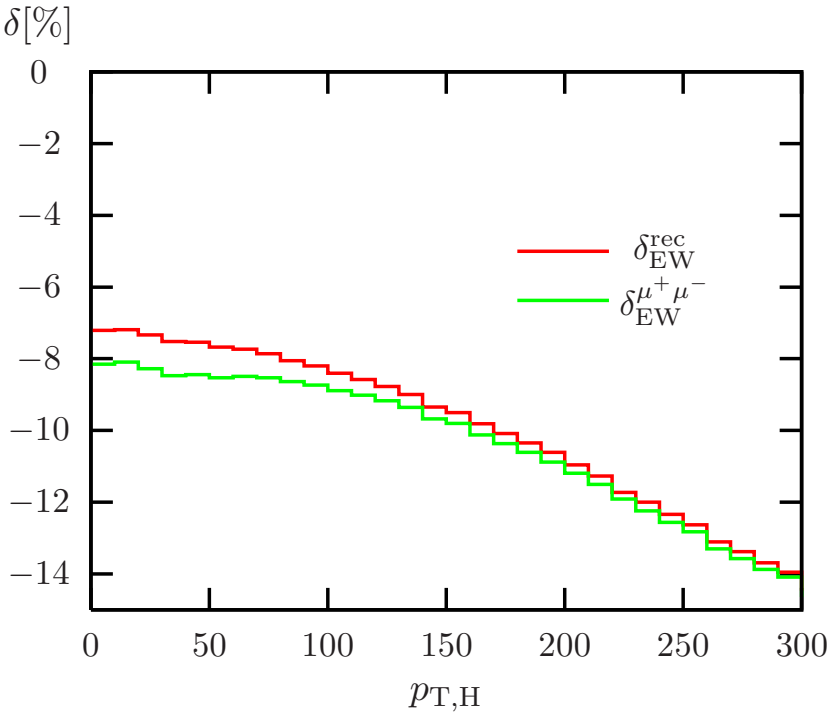
quite large negative corrections in G_μ scheme
(similar to the inclusive calculation)

Preliminary results

example: Higgs p_{T} for $pp \to l^+\nu_l\, H$

EW corrections:

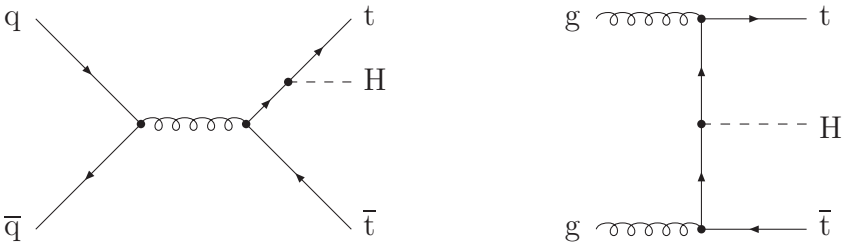




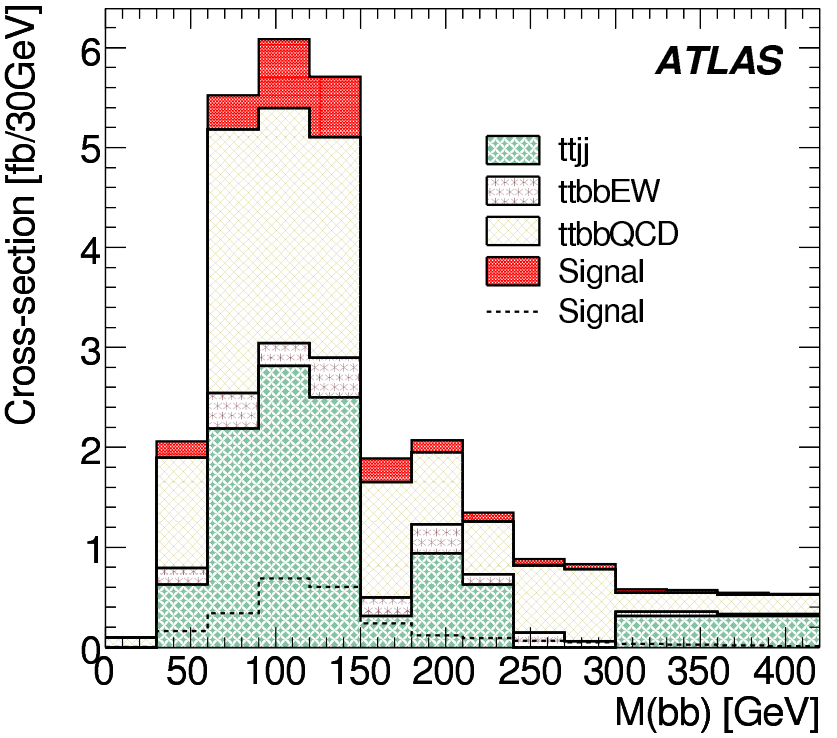
size increases with $p_{\mathrm{T,H}}$
(generic feature of EW corrections)

Higgs production in ttH

$$pp \to t\bar{t} + H$$



- for small Higgs masses $M_{\mathrm{H}} < 150$ GeV
- relevant information on the top Yukawa coupling
- plagued by large backgrounds
- backgrounds hard to predict/measure



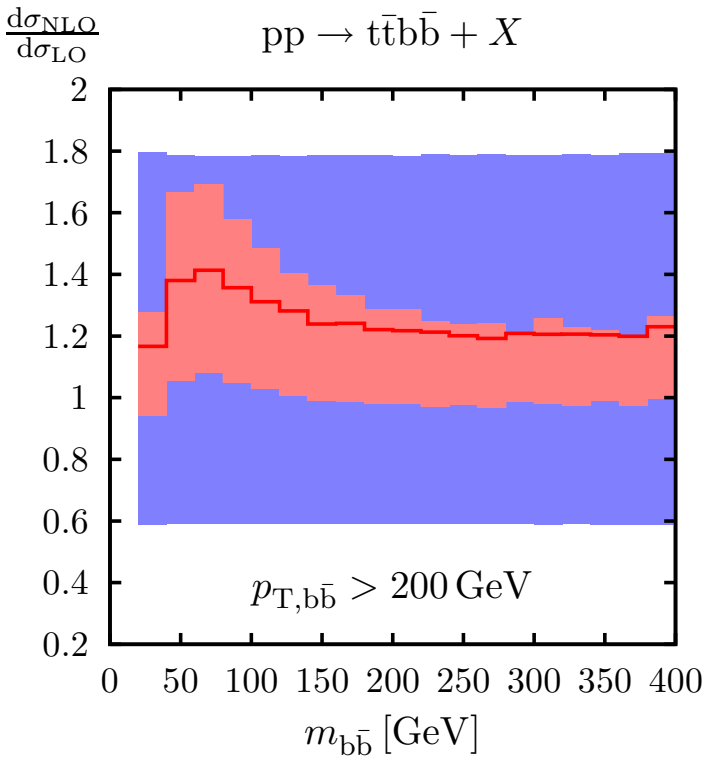
ATLAS [CERN-OPEN-20008-020]

Status

- QCD corrections
  - NLO corrections available in private codes
  - new: ttH in the aMC@NLO framework (→ later)
  - NLO predictions for backgrounds available

    (shape distributions in signal region)

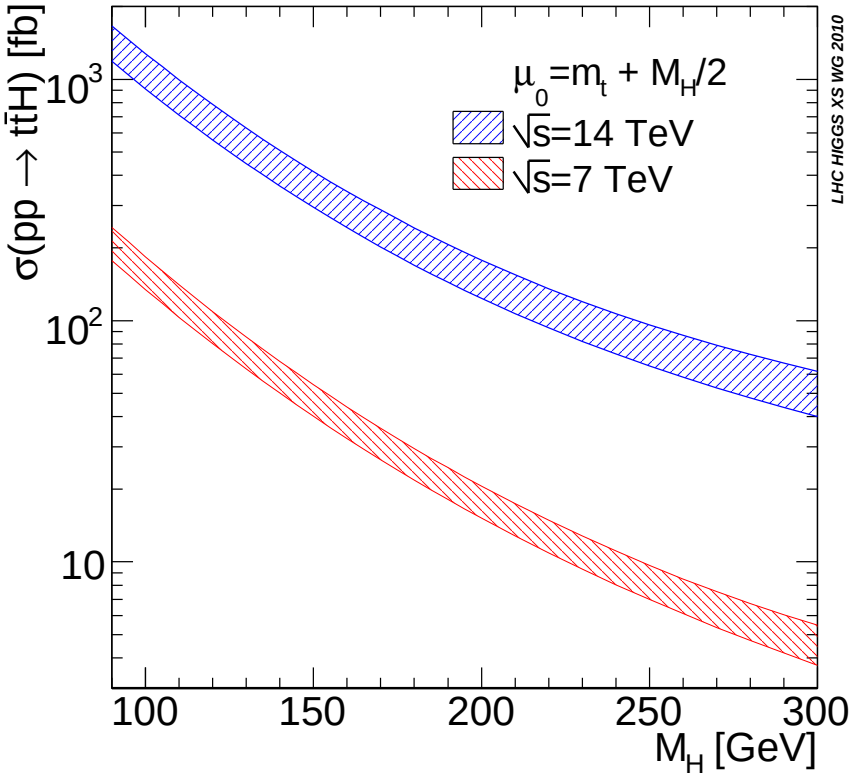
    Bredenstein et al. [1001.4006]



- no EW corrections available

Inclusive Results

Total cross section at NLO QCD:

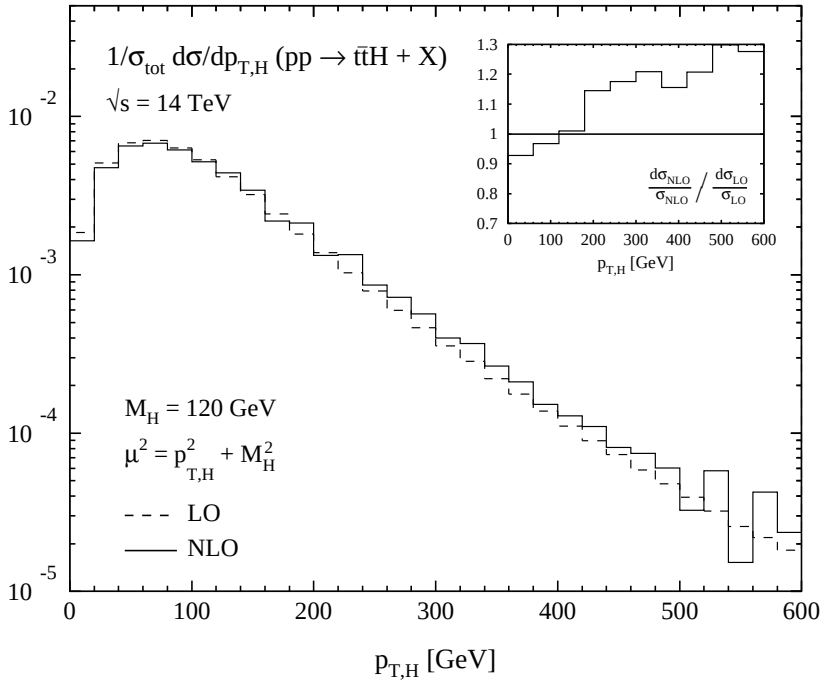


scale uncertainty: $\sim$ 10%
PDF+α_s uncertainty: 8-10%

Distributions

differential NLO QCD results available from private codes:

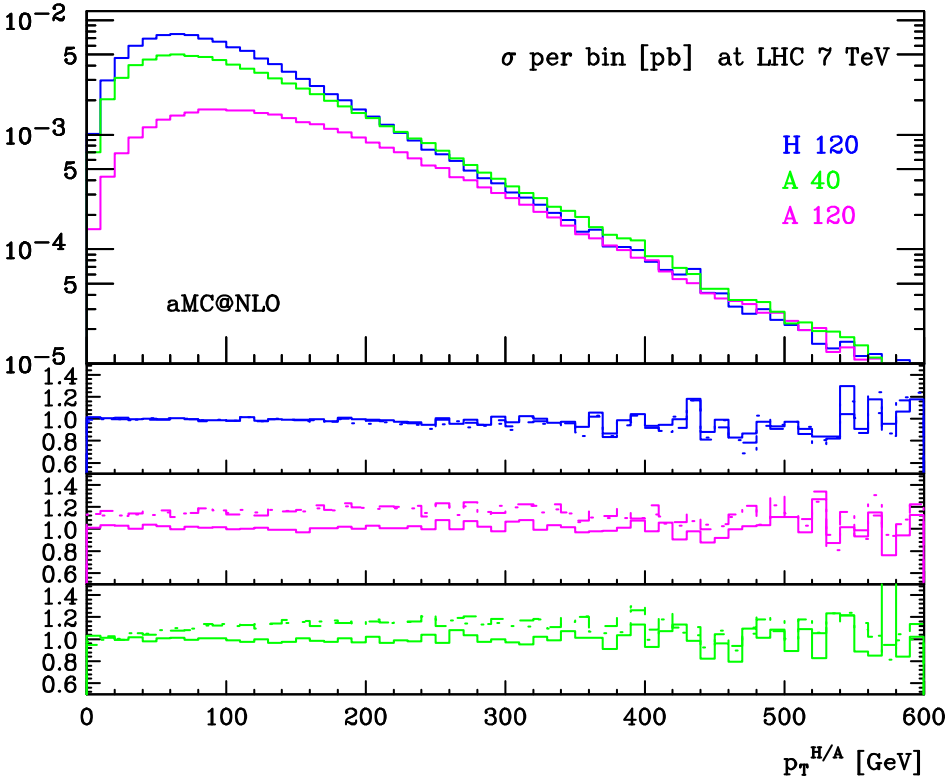
Beenakker et al. [hep-ph/0211352]



Distributions

new result from aMC@NLO:

Frederix et al. [arXiv:1104.5613]



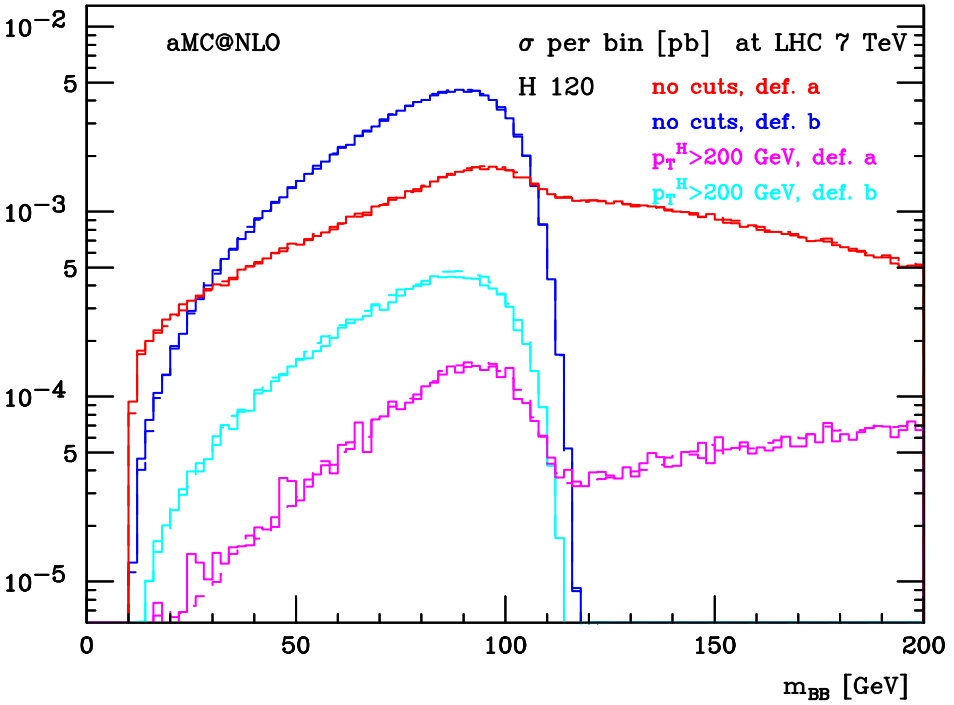
blue:
standard Higgs
$M_{\mathrm{H}} = 120$ GeV

solid: aMC@NLO/NLO
dashed: aMC@NLO/LO
dotted: aMC@NLO/aMC@LO

Distributions

new result from aMC@NLO: b's at the hadron level

Frederix et al. [arXiv:1104.5613]



blue:
b hadrons
from Higgs decay only

red:
all b hadrons

no NLO QCD information in $\mathrm{H} \to b\bar{b}$

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Summary

- Inclusive cross sections and error estimates established
- Many tools available for differential analysis
- New calculation for differential EW corrections in WH/ZH $\Rightarrow$ HAWK

- Missing/needed tools?
- Strategy for differential distributions?
- How to estimate errors in differential distributions?
- How to combine tools for production and decay?