WH/ZH subgroup report

Alexander Mück

RWTH Aachen University

for the WH/ZH subgroup

S. Dittmaier, R.V. Harlander, J. Olsen, G. Piacquadio (eds.);

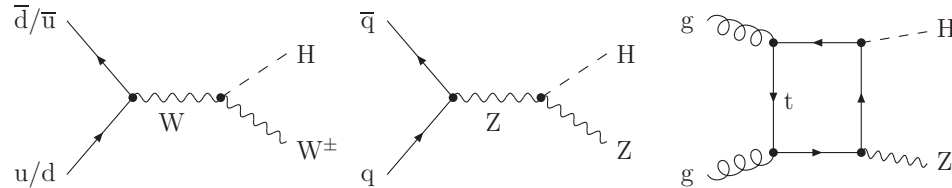A. Denner, G. Ferrera, M. Grazzini, S. Kallweit,

A. Mück, F. Tramontano

LHC Higgs Cross Sections Workshop

LAL Orsay, November 21, 2011

Outline

- tiny introduction to WH/ZH

- Status in YR1

- New developments

  additional NNLO contributions (inclusive)

  differential NNLO QCD predictions

  differential EW predictions

- Setup for YR2

- Results for YR2

Higgs strahlung

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

- only small fraction of total Higgs cross section
- for small Higgs masses $H \rightarrow b\bar{b}$ may be accessible
- small signal to background ratio
  $\Rightarrow$ boosted Higgs: use high p_{T} Higgs bosons only

  $\Leftrightarrow$ inclusive predictions?

- QCD corrections
  - similar to Drell-Yan ($\rightarrow$ relatively simple)
  - additional gluon-fusion contribution at NNLO (5% level)
  - even more top-mediated contributions at NNLO

- EW corrections large

Predictions in YR1

- NNLO QCD corrections
  - VH@NNLO — Brein, Djouadi, Harlander [hep-ph/0307206] based on Hamberg, van Nerveen, Matsuura ['91]
  - for total cross section only
  - including gluon-fusion contribution for ZH

- NLO EW corrections
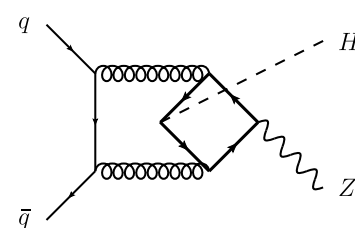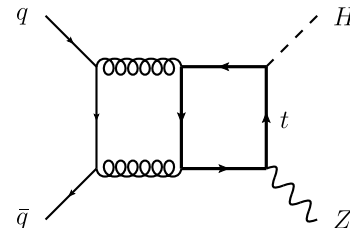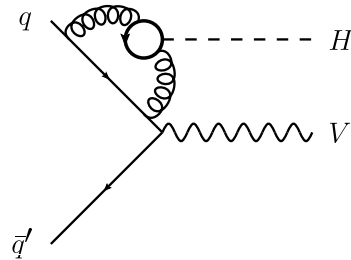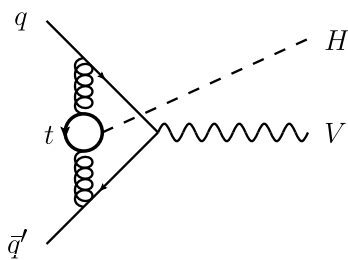 - private code only — Ciccolini, Dittmaier, Krämer [hep-ph/0306234]
  - for total cross section only
  - for stable W bosons
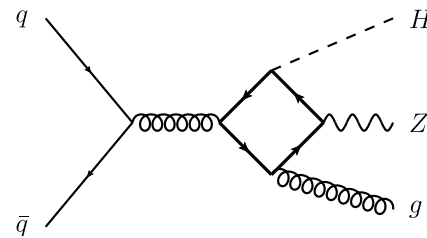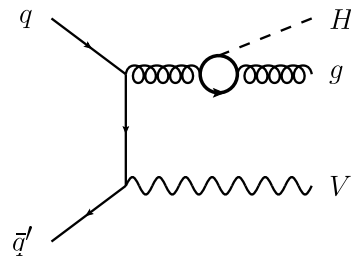 - problems at thresholds ($M_{\mathrm{H}} = 2M_{\mathrm{W}}$, $M_{\mathrm{H}} = 2M_{\mathrm{Z}}$)

more top loops

More diagrams at NNLO beyond Drell-Yan:

virtual two-loop (interfered with born)

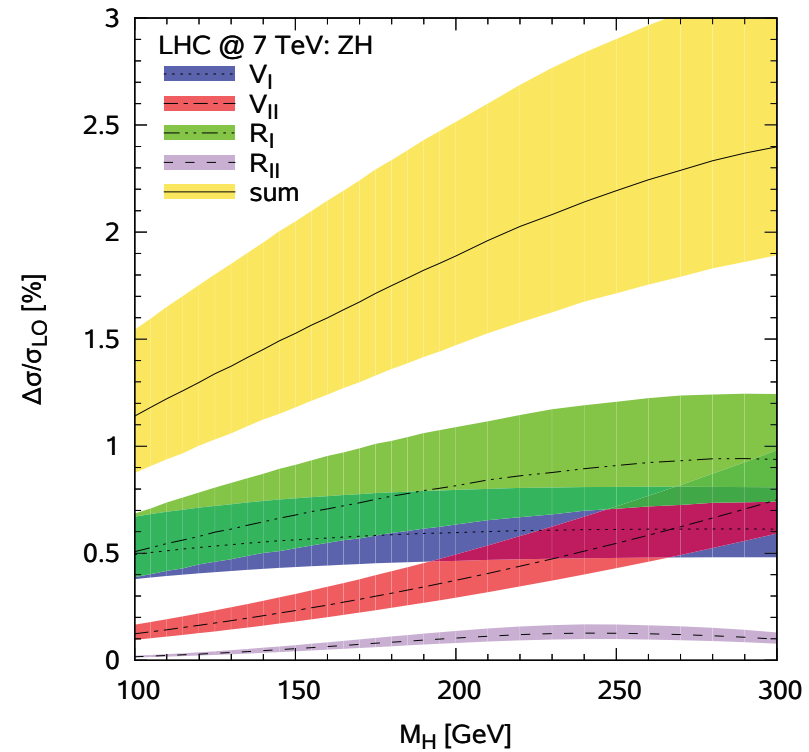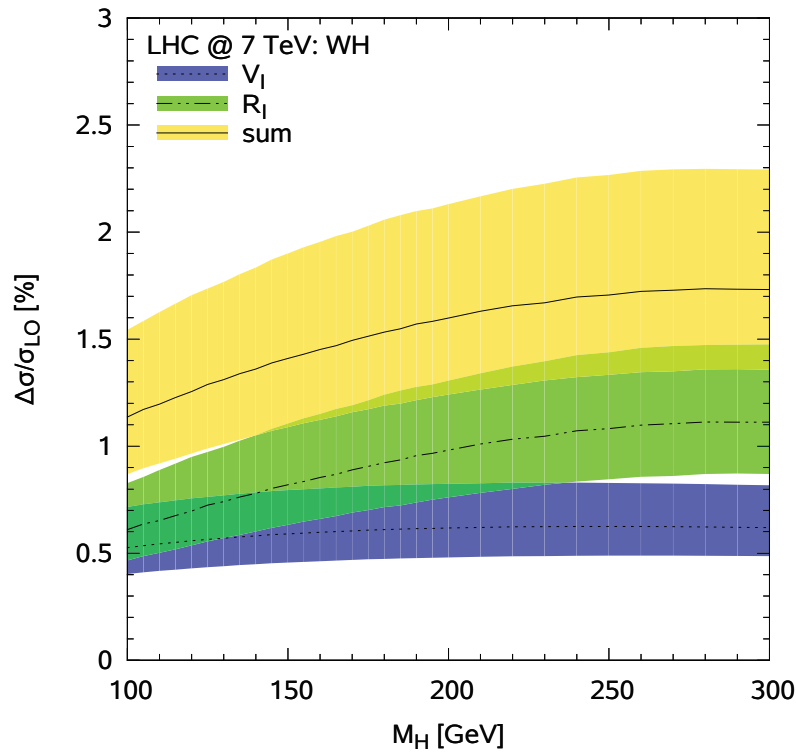one-loop + gluon (interfered with born + gluon)

- calculation recently completed

  Brein, Harlander, Wiesemann, Zirke [arXiv:1111.0761]

  - two-loop contribution in heavy-top limit
  - inclusive prediction only

updated predictions
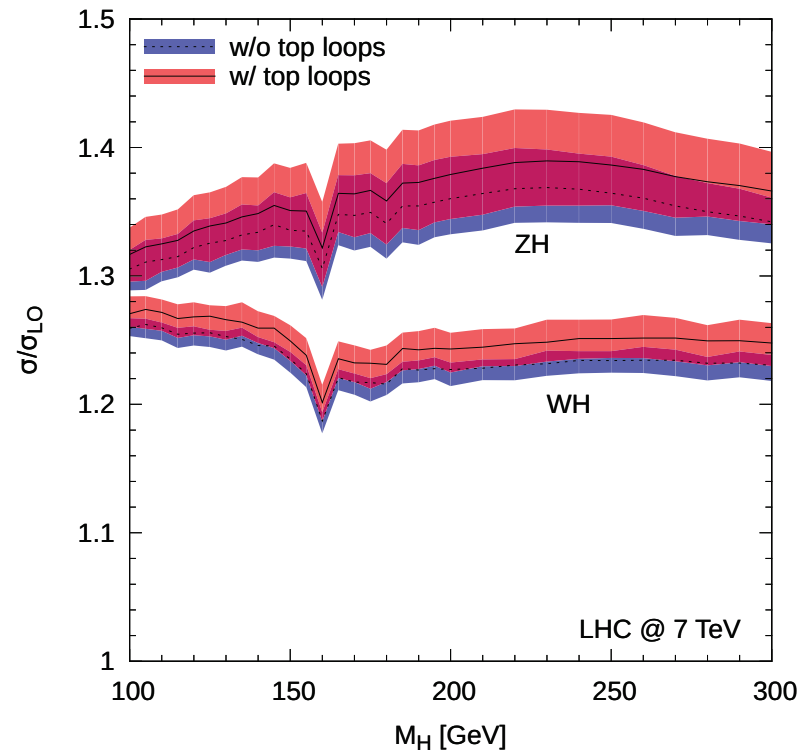
Brein, Harlander, Wiesemann, Zirke [arXiv:1111.0761]

- error band from scale variation (by factor 3, $\mu = \sqrt{(p_{\mathrm{H}} + p_V)^2}$)
- additional 30% error assigned to heavy-top limit

updated predictions

adding new contribution to YR1 results:

Brein, Harlander, Wiesemann, Zirke [arXiv:1111.0761]

no distributions for YR2 available

Differential NNLO QCD

recently completed calculation for WH:
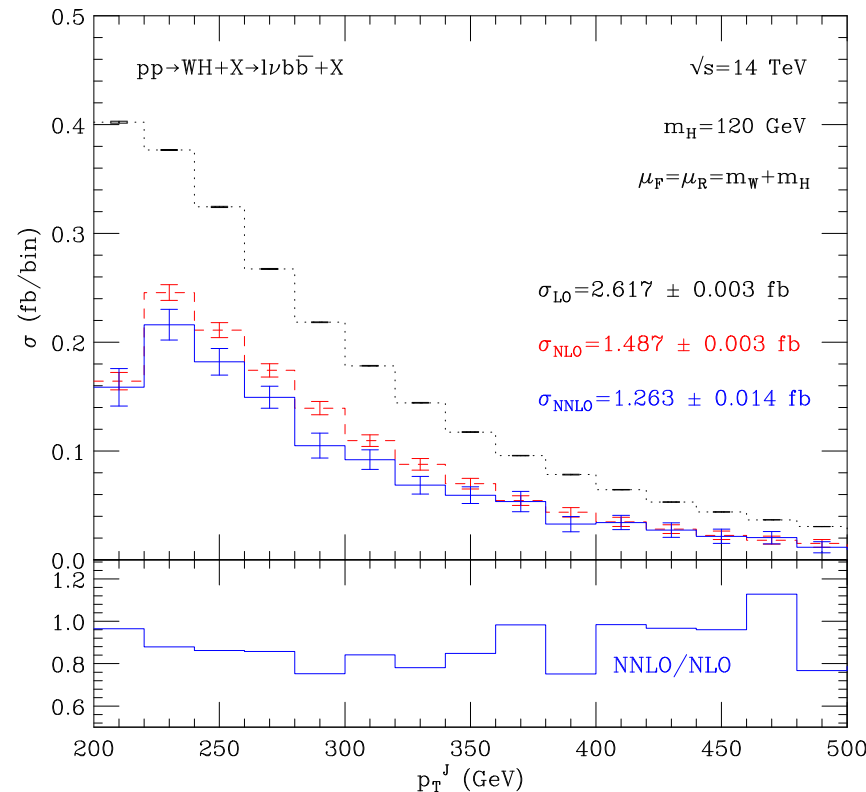
Ferrera, Grazzini, Tramontano [arXiv:1107.1164]

- fully differential Drell-Yan like NNLO QCD contributions

- including Higgs and vector-boson decays

- $H \rightarrow b\bar{b}$ analysis possible (b-tagging, jet veto, etc...)

Differential NNLO QCD

recently completed calculation for WH:

Ferrera, Grazzini, Tramontano [arXiv:1107.1164]

large negative correction due to strict jet veto

(jet veto not used in the following for YR2)

Differential NLO EW

WH/ZH implemented in HAWK:

- HAWK for VBF includes s-channel contribution
  $\Rightarrow$ replace hadronic by leptonic boson decay

- independent second calculation

- EW corrections for the processes
  $$pp \to H l^+ l^-, \quad pp \to H l \nu_l, \quad pp \to H \bar{\nu}_l \nu_l$$

- vector-boson resonance
  $\Rightarrow$ use the complex mass scheme
  (will also regularize threshold spikes in EW corrections)

- HAWK for WH/ZH will also be public

Setup for YR2

- WH results: NNLO QCD from the authors of 1107.1164
  NLO EW from HAWK

  ZH results: NLO QCD and EW from HAWK

  QCD and EW corrections combined in factorized form:

$$\sigma = \sigma^{\mathrm{QCD}} \times (1 + \delta^{\mathrm{rec}}_{\mathrm{EW}}) + \delta_\gamma$$

Setup for YR2

- WH results: NNLO QCD from the authors of 1107.1164
  NLO EW from HAWK

  ZH results: NLO QCD and EW from HAWK

- all results for 7 TeV LHC

- all results for $M_{\mathrm{H}} = 120$ GeV

  - on-shell Higgs without decay

Setup for YR2

- **WH** results: **NNLO QCD** from the authors of 1107.1164
  NLO EW from HAWK
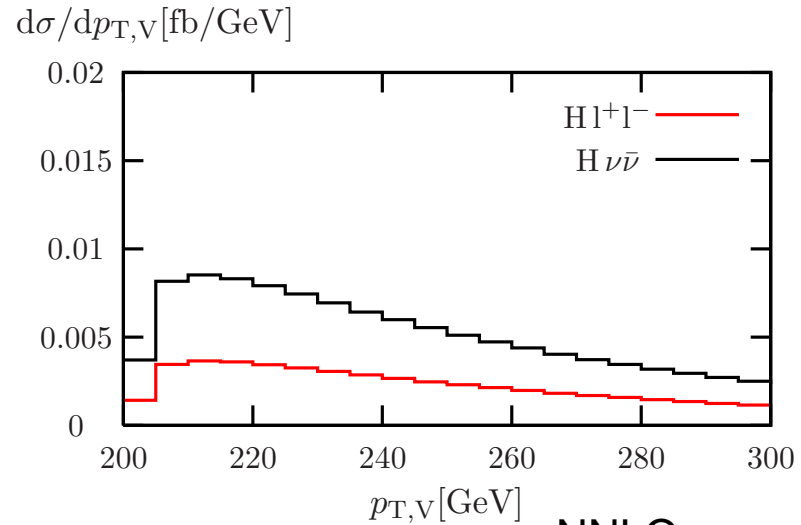
  ZH results: **NLO QCD and EW** from HAWK

- all results for **7 TeV LHC**

- all results for $M_{\mathrm{H}} = 120$ GeV

- off-shell vector bosons with **leptonic decay**

  - all results for **specific** leptonic **channel**
  - different **lepton–photon recombination** for μ and e
  - corrections for partial width included in EW corrections
  - results proportional to $1/\Gamma_{\mathrm{tot}}$ where Γ_{tot} **is input**

Setup for YR2

- WH results: NNLO QCD from the authors of 1107.1164
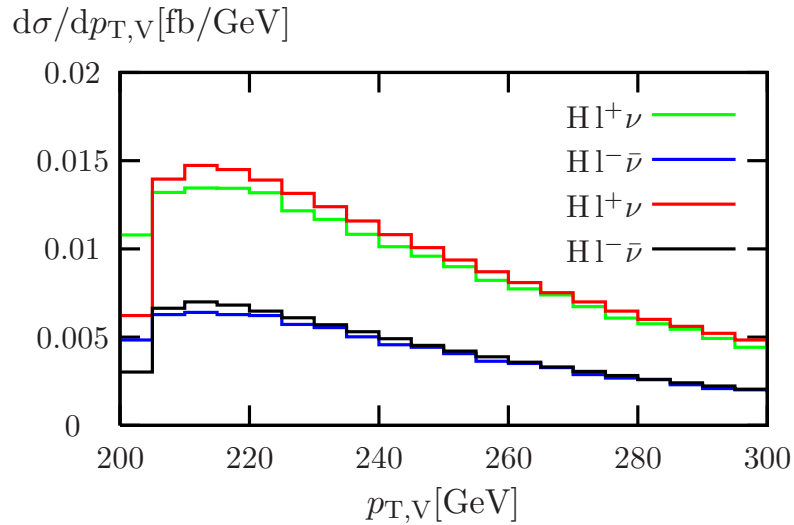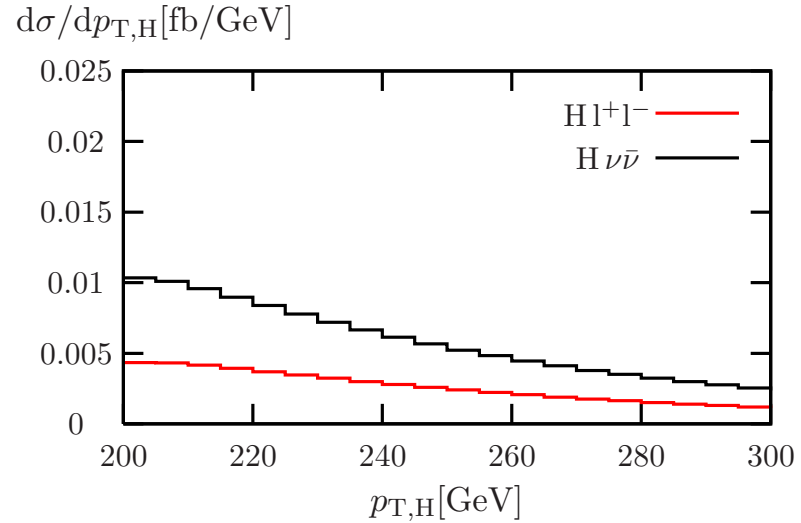 NLO EW from HAWK

  ZH results: NLO QCD and EW from HAWK
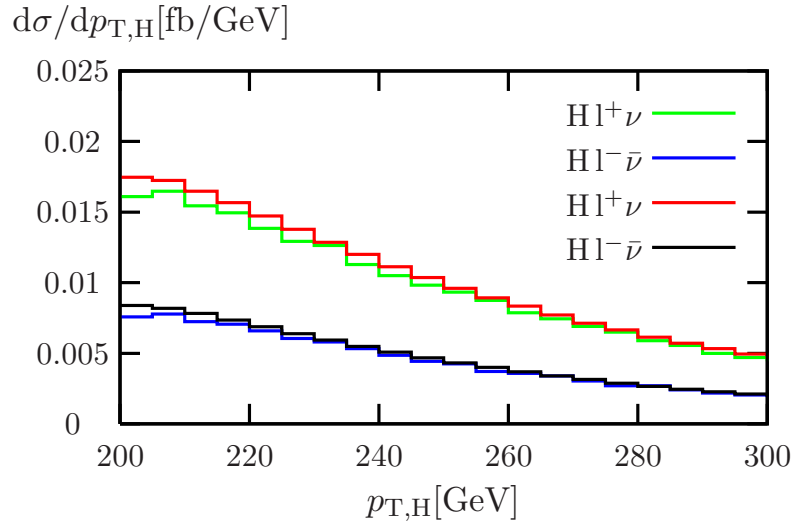
- all results for 7 TeV LHC

- all results for $M_{\mathrm{H}} = 120$ GeV

- off-shell vector bosons with leptonic decay

- cuts for boosted Higgs bosons:

$$p_{\mathrm{T,l}} > 20\,\mathrm{GeV}, \quad |y_{\mathrm{l}}| < 2.5, \quad p_{\mathrm{T,miss}} > 25\,\mathrm{GeV}$$

$$p_{\mathrm{T,H}} > 200\,\mathrm{GeV}, \quad p_{\mathrm{T,W/Z}} > 190\,\mathrm{GeV}$$

(symmetric cuts problematic)

Setup for YR2

- WH results: NNLO QCD from the authors of 1107.1164
  NLO EW from HAWK

  ZH results: NLO QCD and EW from HAWK

- all results for 7 TeV LHC

- all results for $M_{\mathrm{H}} = 120$ GeV

- off-shell vector bosons with leptonic decay

- cuts for boosted Higgs bosons:

$$p_{\mathrm{T,l}} > 20\,\mathrm{GeV}, \quad |y_{\mathrm{l}}| < 2.5, \quad p_{\mathrm{T,miss}} > 25\,\mathrm{GeV}$$

$$p_{\mathrm{T,H}} > 200\,\mathrm{GeV}, \quad p_{\mathrm{T,W/Z}} > 190\,\mathrm{GeV}$$

(symmetric cuts problematic)

- central scale choice: $\mu_{\mathrm{F}} = \mu_{\mathrm{R}} = M_{\mathrm{H}} + M_V$

- default PDF set: MSTW2008

Results

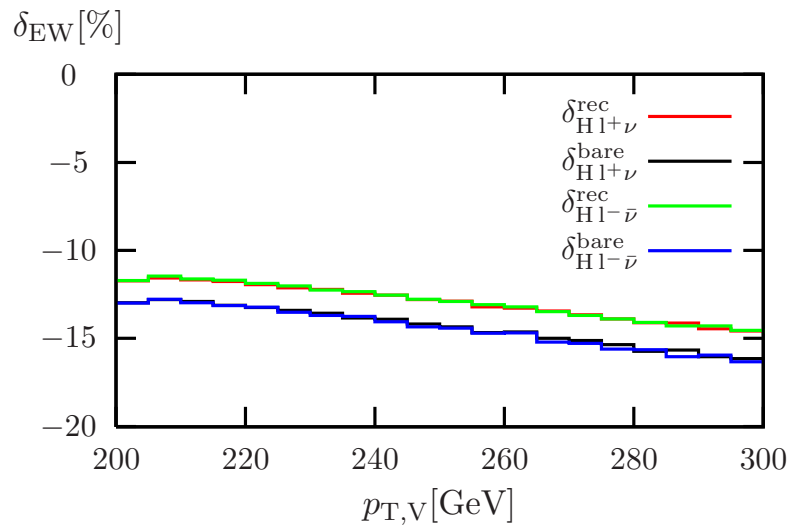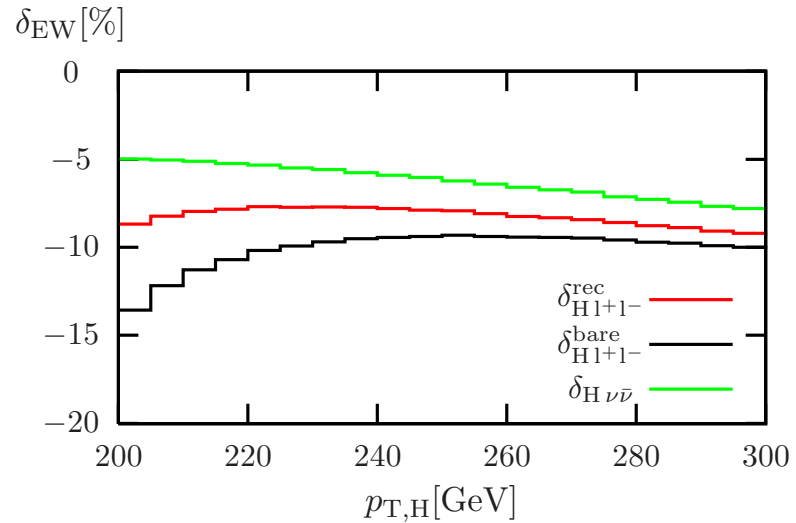

$$\sigma = \sigma^{\mathrm{QCD}} \times (1 + \delta_{\mathrm{EW}}^{\mathrm{rec}}) + \delta_\gamma$$
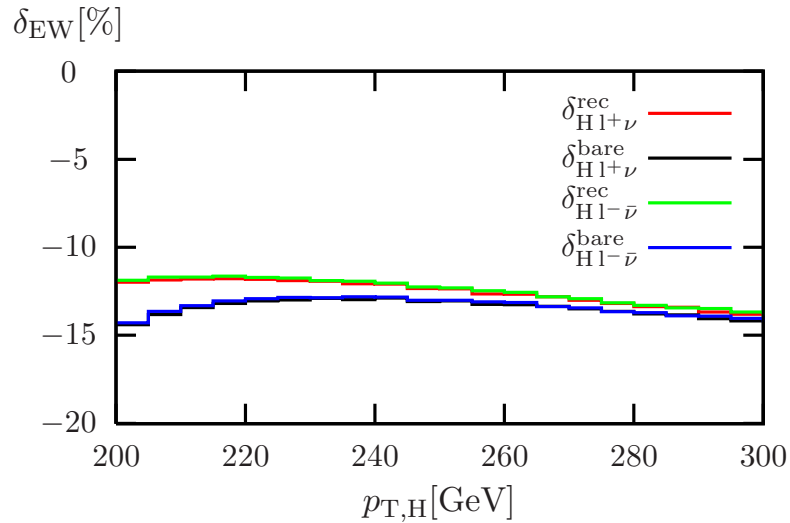
NNLO: green, blue
NLO: red, black

$\Leftarrow \mid \longleftrightarrow \mid \Rightarrow$

Results
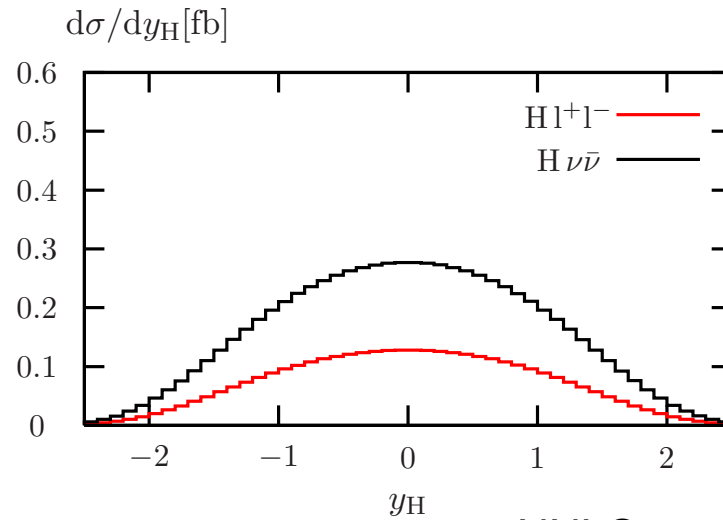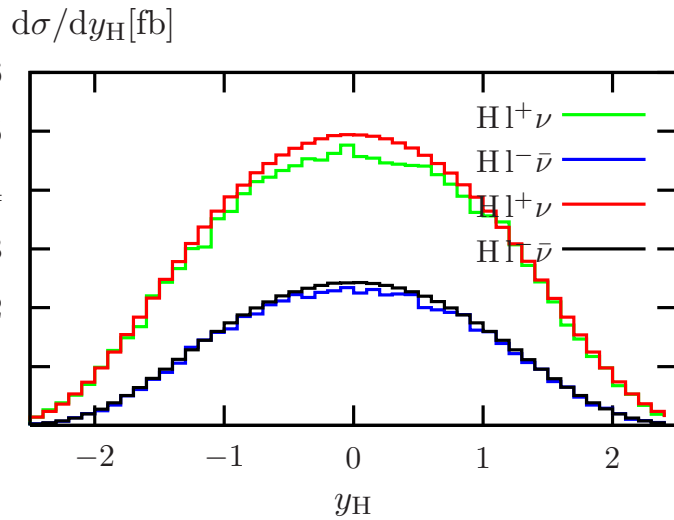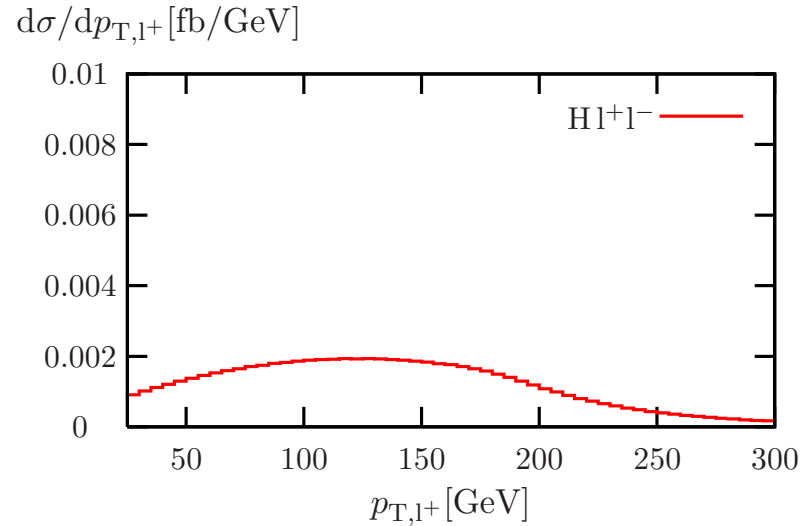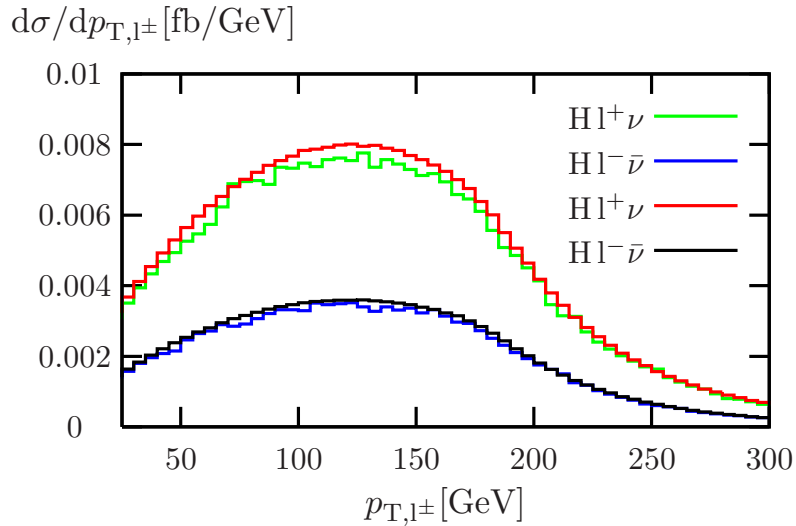
$$\sigma = \sigma^{\mathrm{QCD}} \times (1 + \delta_{\mathrm{EW}}^{\mathrm{rec}}) + \delta_\gamma$$
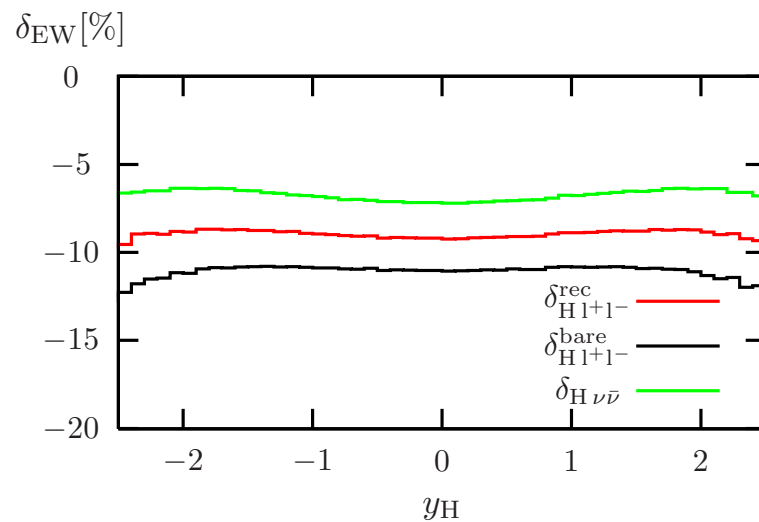
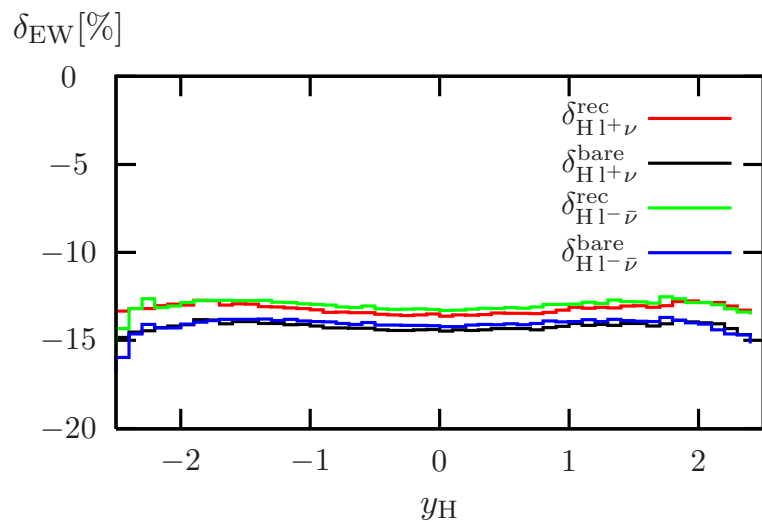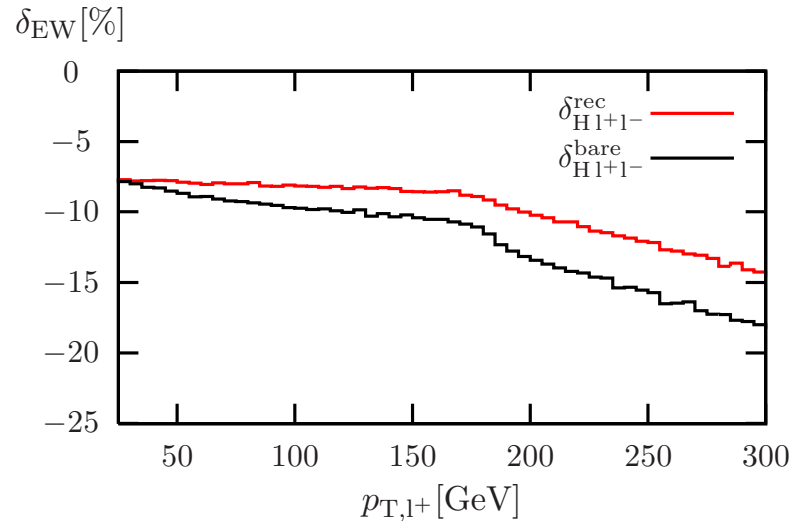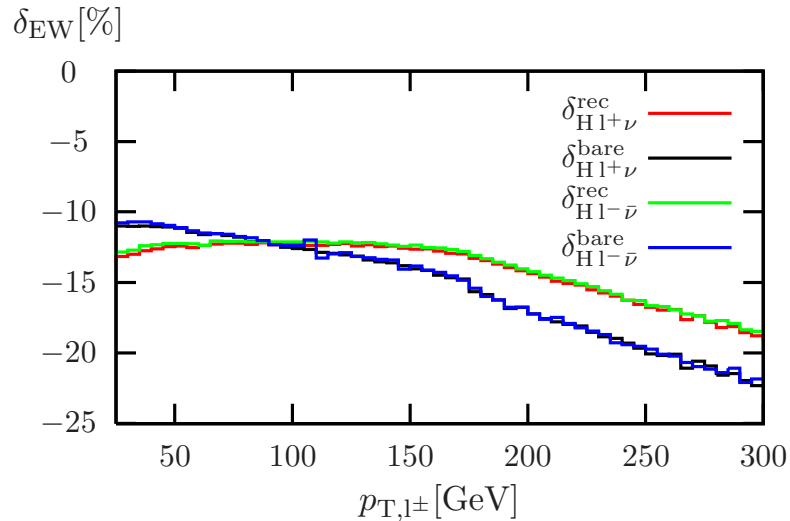NNLO: green, blue
NLO: red, black

⇐ | ⟷ | ⇒

EW corrections
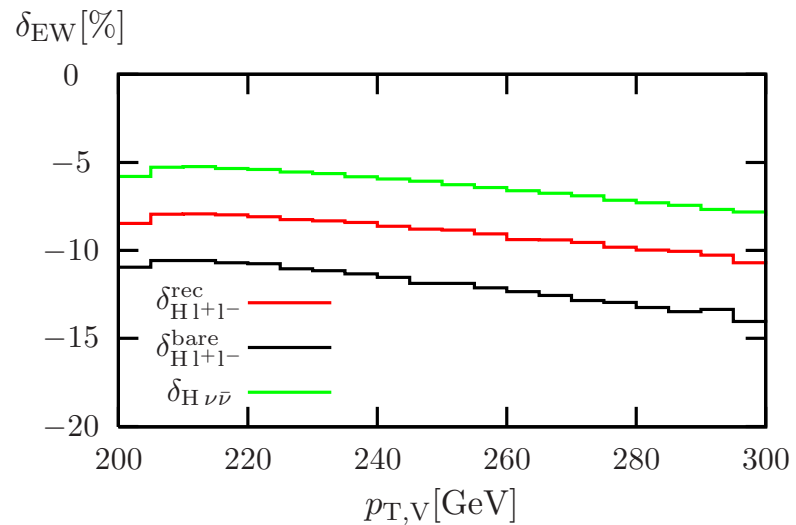
different lepton–photon recombination: rec for electrons
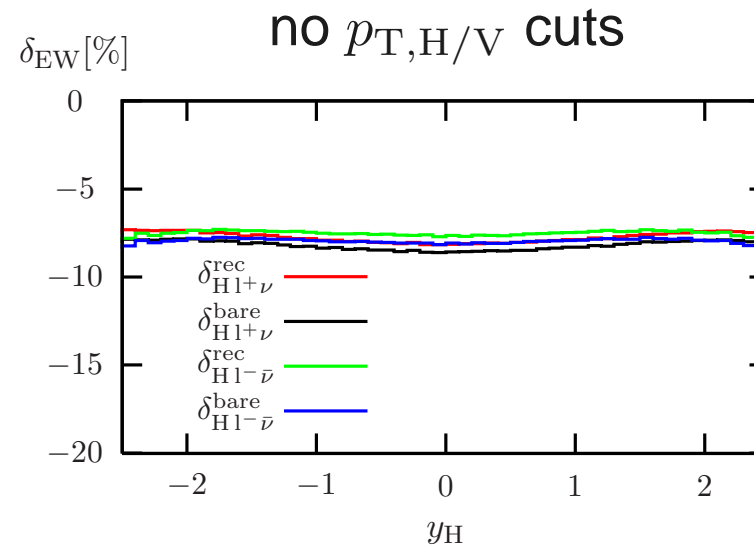bare for muons

EW corrections
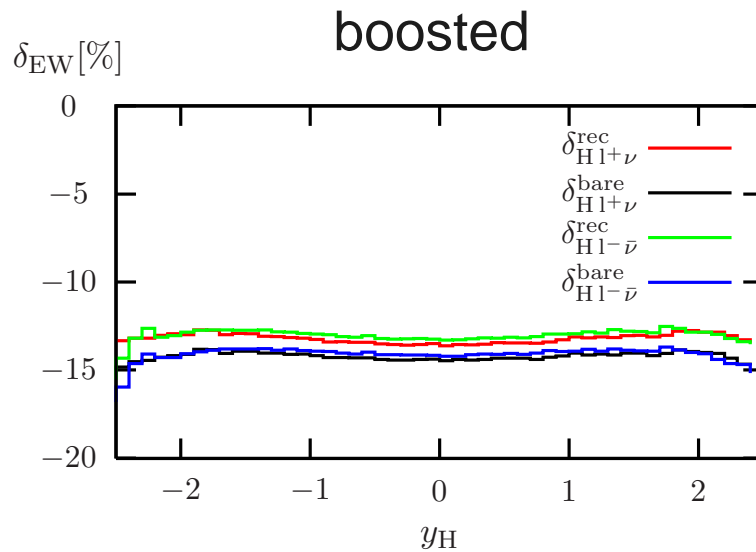
different lepton–photon recombination: rec for electrons
bare for muons

EW corrections

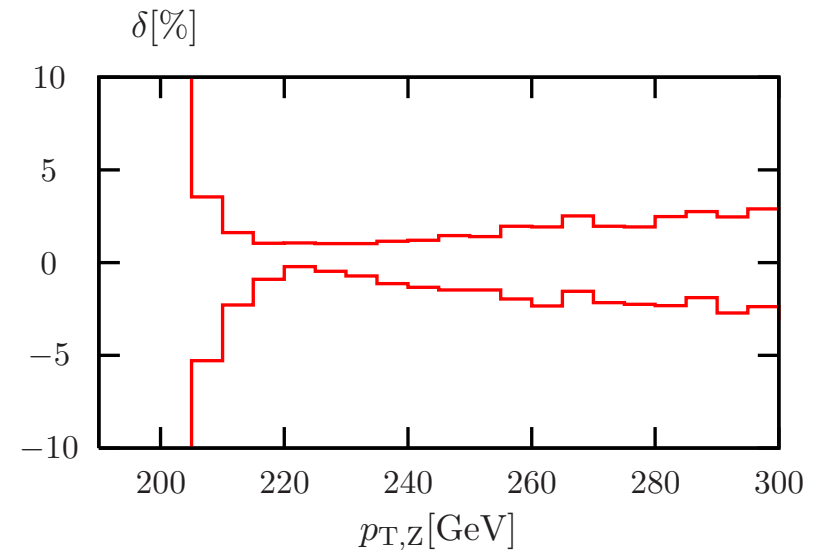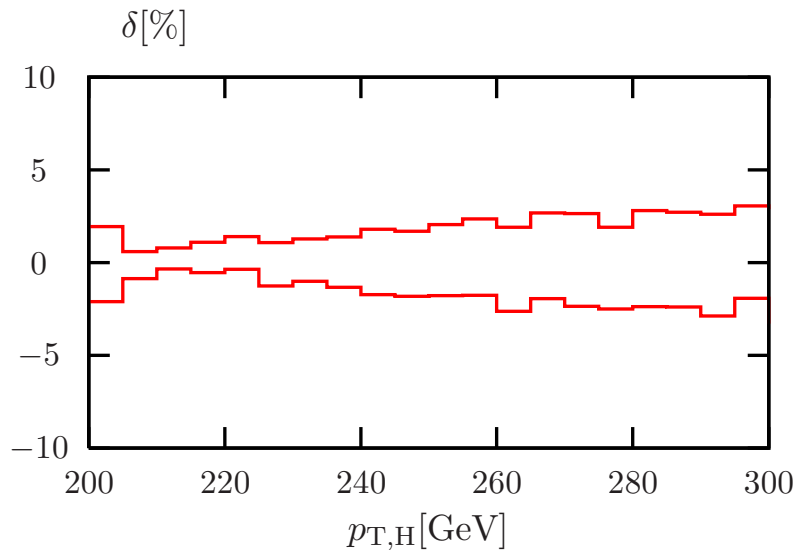larger EW corrections for boosted Higgs:

Error estimates

Scale variation:

vary μ_{F} and μ_{R} independently by a factor 2

no large variations in distributions (if not expected)

at NNLO: error estimate $\pm 2\%$

here: relative error bands for ZH at NLO

Error estimates

Scale variation:

vary μ_F and μ_R independently by a factor 2

no large variations in distributions (if not expected)

at NNLO: error estimate $\pm 2\%$
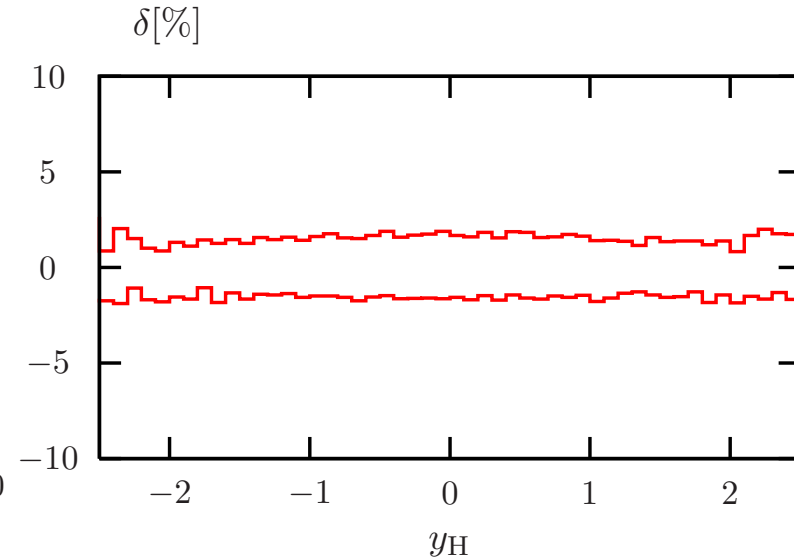
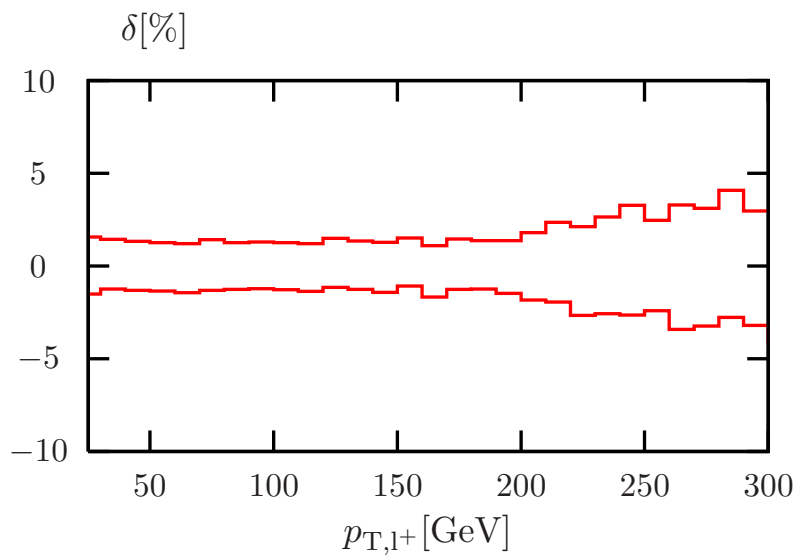here: relative error bands for ZH at NLO

PDF error:

PDF sets: MSTW2008 68% CL

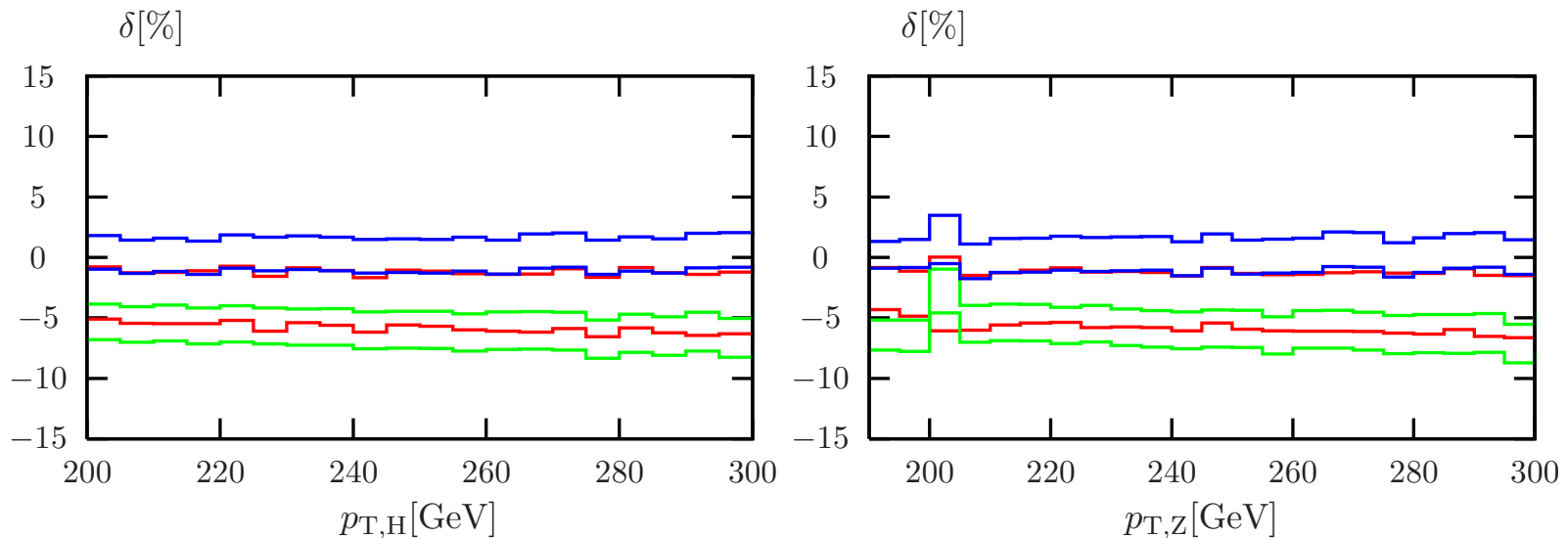CTEQ66 rescaled to 68 % CL

NNPDF2.0 68% CL

flat for p_T distributions, non-trivial for Higgs rapidity y_H

no NNLO estimate ($\Rightarrow$ expensive in runtime)

here: relative error bands for ZH at NLO

RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

Error estimates

PDF error:

PDF sets: MSTW2008 68% CL

CTEQ66 rescaled to 68 % CL

NNPDF2.0 68% CL

flat for p_T distributions, non-trivial for Higgs rapidity y_H

no NNLO estimate ($\Rightarrow$ expensive in runtime)

here: relative error bands for ZH at NLO
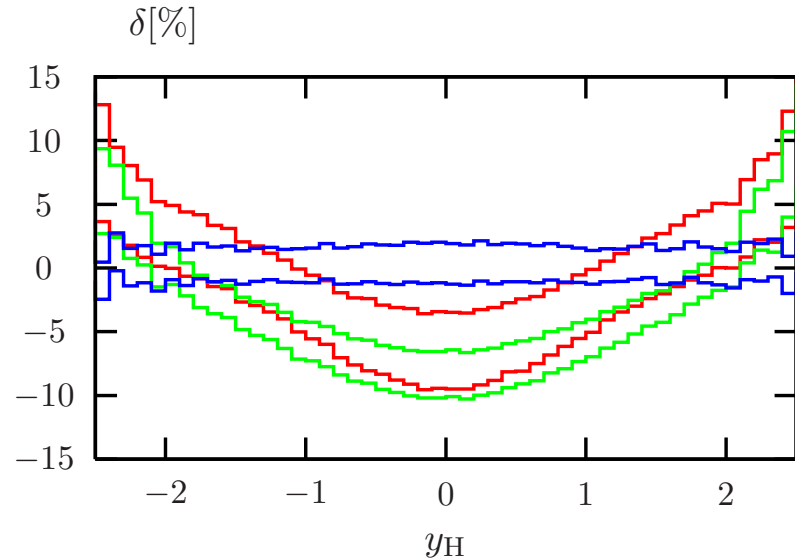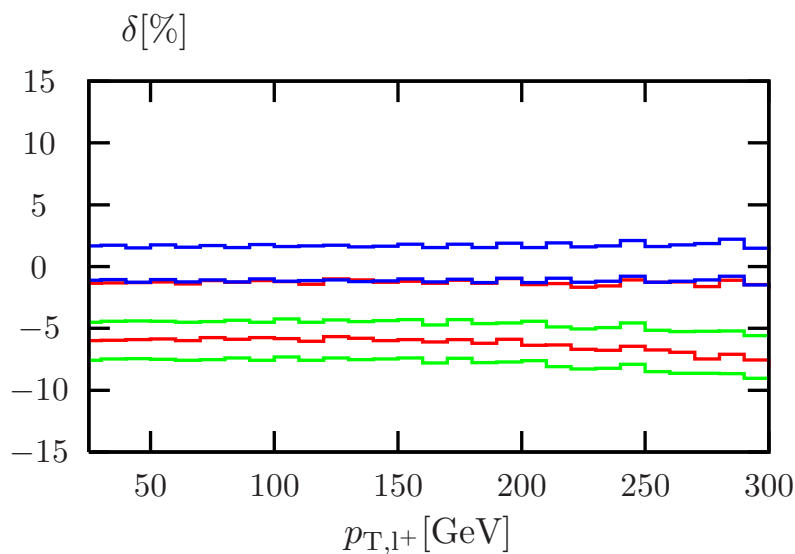
Summary and Questions

since last meeting:

- **new** NNLO **contributions** calculated

- fully **differential NNLO** for Drell-Yan contributions

- fully **differential EW** NLO corrections

for **YR2**:

- setup (cuts) ok?

- different distributions, Higgs masses?
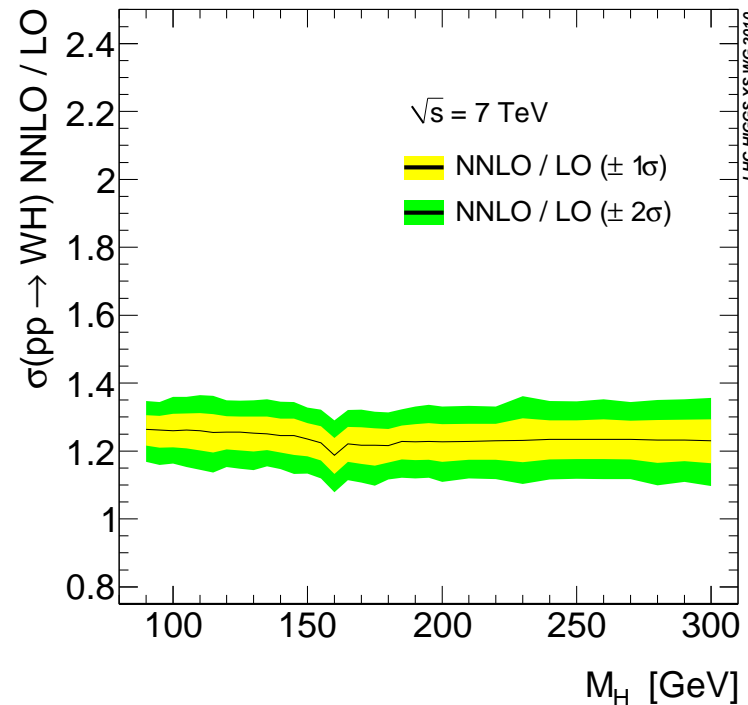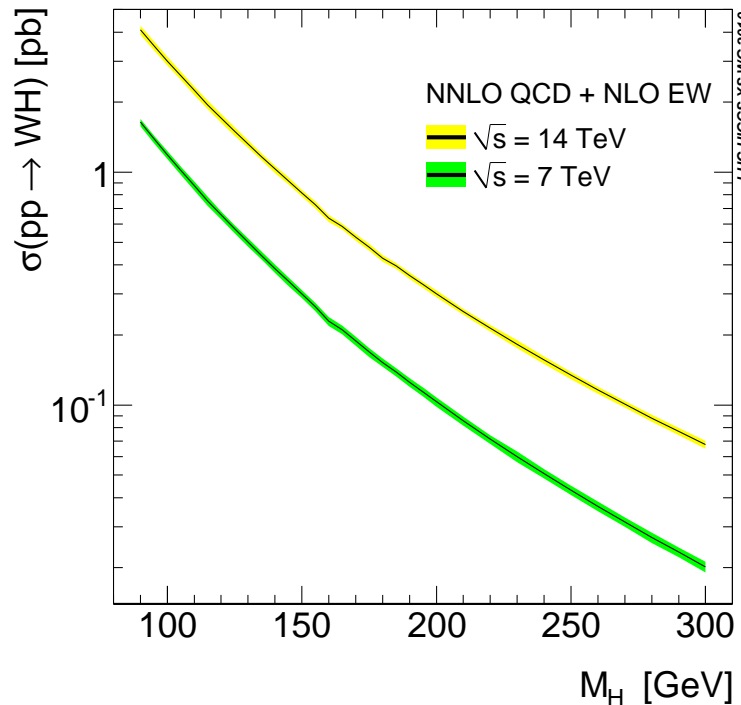
- presentation of differential error estimate?

Back-up slides

RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

Inclusive Prediction in YR1

Total cross section:

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

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

unphysical spikes: thresholds in EW corr. $\rightarrow$ will disappear in HAWK

EW corrections for boosted Higgs? $\rightarrow$ new HAWK version