RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

NLO EW Correction in WW/ZZ and Prophecy4f

Alexander Mück
RWTH Aachen University

for the Prophecy4f Team:
A. Denner (Würzburg), S. Dittmaier (Freiburg)

Higgs (N)NLO MC and Tools Workshop for LHC RUN-2
CERN, December 18th 2014

RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

Outline

Prophecy4f

- MC tool for on-shell Higgs-boson decay to 4 fermions

$$\mathrm{H} \to \mathrm{WW/ZZ} \to 4\mathrm{f}$$

- features and limitations

$\mathrm{pp} \to \mathrm{WW/ZZ}$

- Electroweak corrections
- diboson production, no focus on Higgs background

RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

Prophecy4f

based on A. Bredenstein, A. Denner, S. Dittmaier, M.M. Weber
[hep-ph/0604011,0607060,0611234]

Prophecy4f is a Monte Carlo program for

$$\mathrm{H} \to \mathrm{WW/ZZ} \to 4 \text{ fermions}$$

- the Higgs boson is on-shell

  (for gauge invariant EW corrections)

  (via on-shell projection also for narrow Higgs resonance)
- no on-shell approx. for the intermediate vector bosons ,

  i.e. $\mathrm{H} \to \mathrm{W^*W^*/Z^*Z^*} \to 4$ fermions
- for all four-fermion final states

  (fermions in massless approximation)
- download the latest version Prophecy4f 2.0.1:

  http://omnibus.uni-freiburg.de/∼sd565/programs/prophecy4f/prophecy4f.html

RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

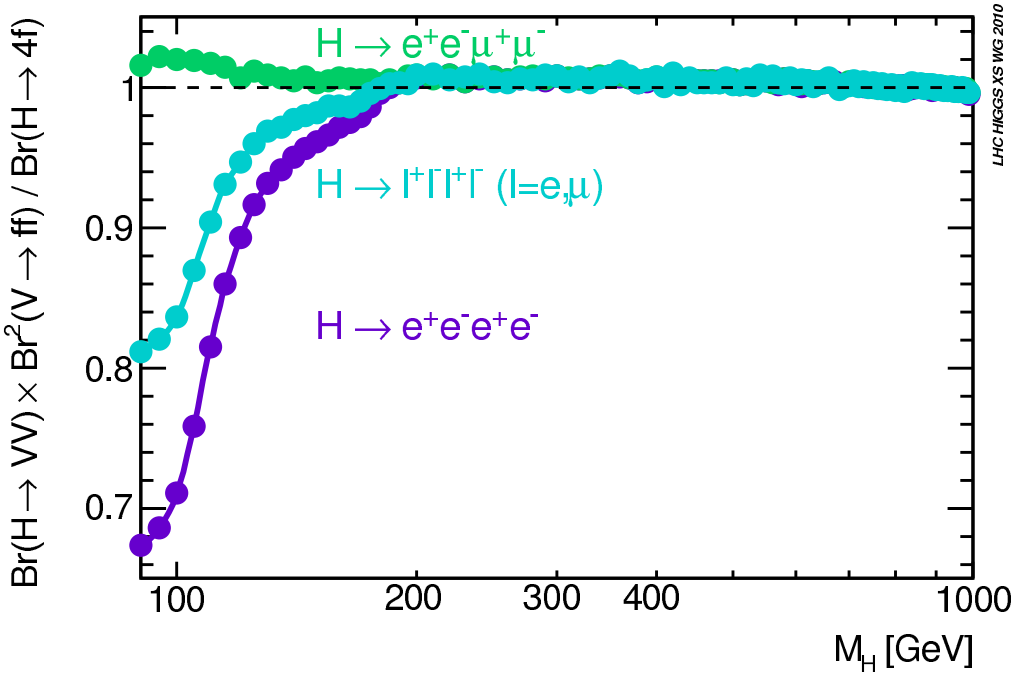
Prophecy4f

based on A. Bredenstein, A. Denner, S. Dittmaier, M.M. Weber
[hep-ph/0604011,0607060,0611234]

- NLO QCD and electroweak corrections in the SM
  → complex-mass scheme for resonances
  → G_μ scheme as input-parameter scheme
- includes all interferences and off-shell effects at NLO
- fully differential partial width for all 4f final states
  → unweighted events for leptonic final states
  → binned distributions for other final states
- BSM: 4th fermion generation
  (anomalous HWW and HZZ couplings work in progress)

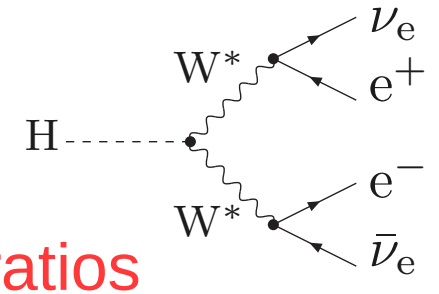
Applications

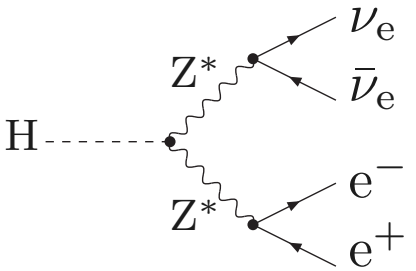
Partial widths for 4f final states from Prophecy4f:



- all off-shell effects included
- all interferences included
- used for HXSWG branching ratios

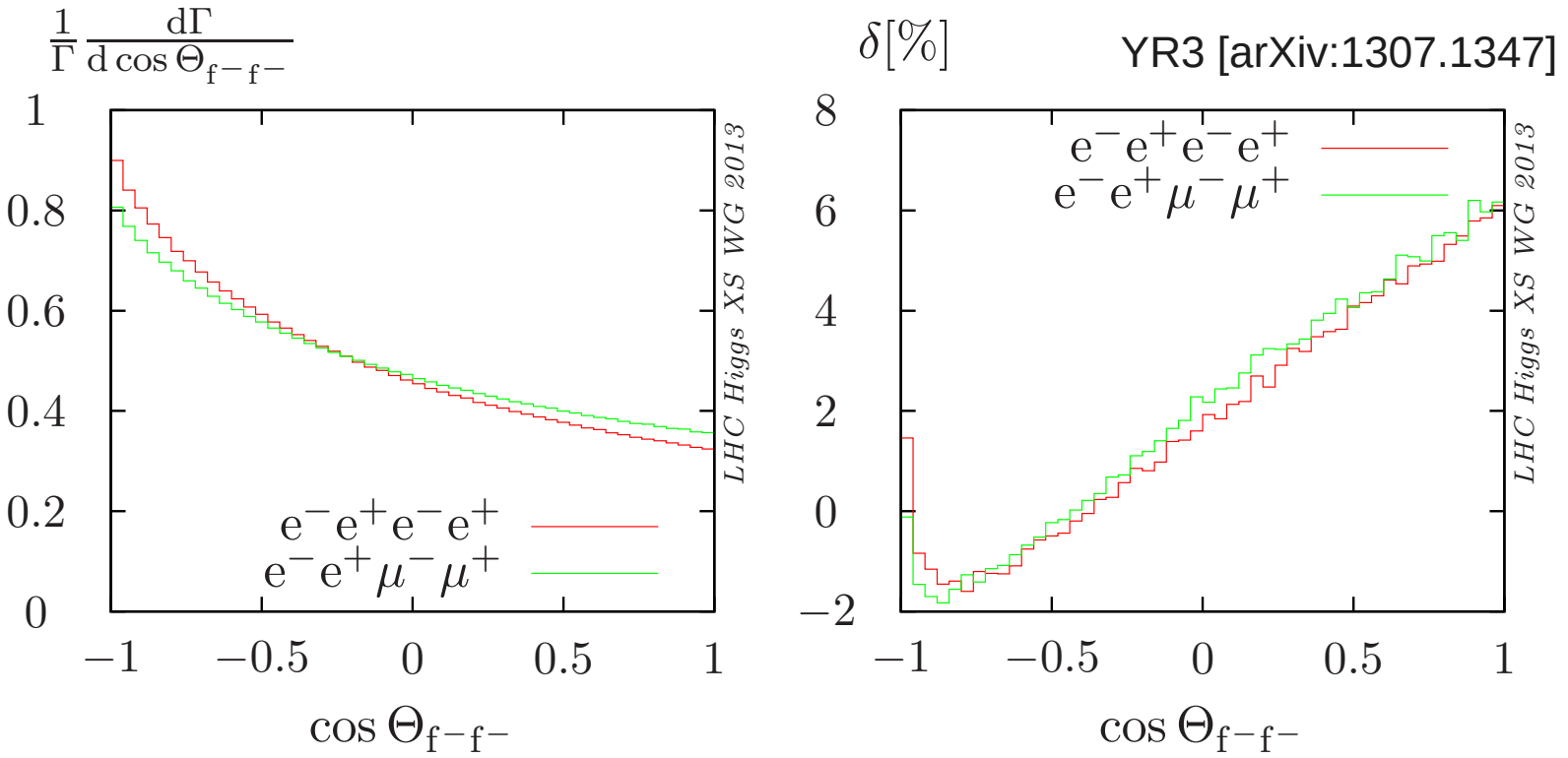
(in combination with HDecay partial widths for other channels)





Differential predictions

- Prophecy4f is fully differential



(δ: NLO EW corrections, $\cos\Theta_{f-f-}$ in Higgs rest frame, $m_H = 125$ GeV)

- unweighted events for leptonic final states

Prophecy4f

Unweighted events:

- for leptonic final states
  (semi-leptonic or hadronic final states not supported)
- there are events with negative weight
  (up to 10% for 4e final state
  $\Rightarrow$ can be avoided by eγ-recombination inside tiny technical cone)
- massless leptons for kinematics
  ($\Rightarrow$ ATLAS interface by D. Rebuzzi and M. Duehrssen)
- lepton mass important for collinear photon radiation
  (obtain $\mathrm{H} \to 4\mu$ from $\mathrm{H} \to 4\mathrm{e}$ with $m_\mathrm{e} = m_\mu$ as input)
- not matched to (QED) parton shower
  ($\Rightarrow$ switch off QED radiation in parton shower to avoid double counting)

RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

WW/ZZ production

EW corrections to WW/ZZ production at the LHC:

- logarithmically enhanced EW corrections at high energies in double-pole approximation (DPA)

  Accomando, Denner, Kaiser [hep-ph/0409247]

  Accomando, Kaiser [hep-ph/0511088]

- full NLO EW corrections for on-shell WW, WZ, ZZ

  Bierweiler, Kasprzik, Kühn [arXiv:1305.5402]

  [arXiv:1208.3147]

  Baglio, Ninh, Weber [arXiv:1307.4331]

- full NLO EW corrections for W^+W^- in DPA with leptonic W decays Billoni, Dittmaier, Jäger, Speckner [arXiv:1310.1564]

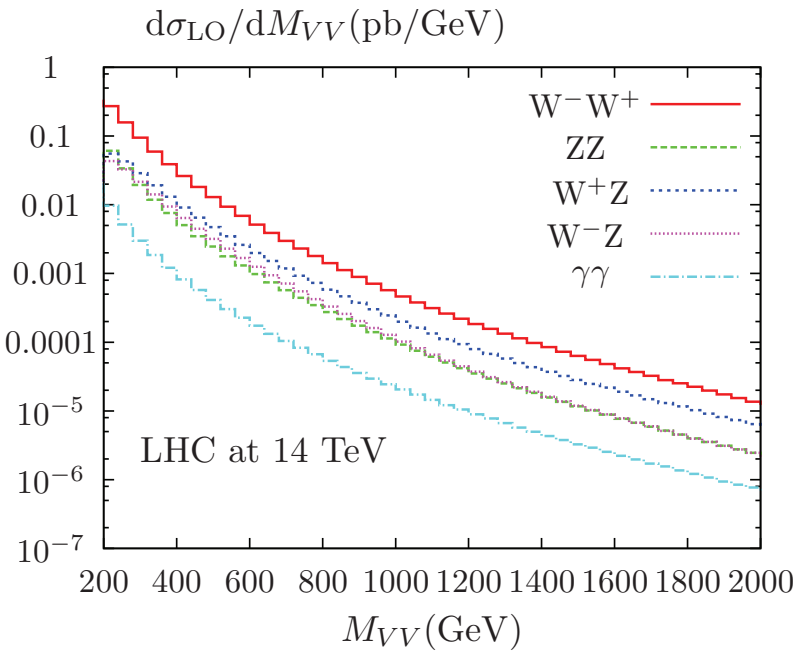
- approximate (virtual) EW corrections in Herwig++

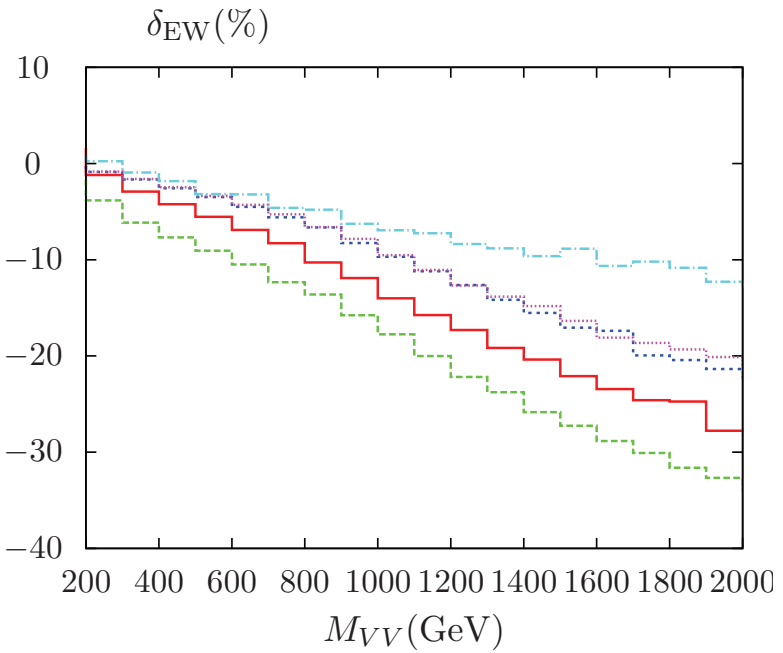
  Gieseke, Kasprzik, Kühn [arXiv:1401.3964]

WW/ZZ production

NLO EW corrections to on-shell diboson production:

Bierweiler, Kasprzik, Kühn [arXiv:1305.5402]



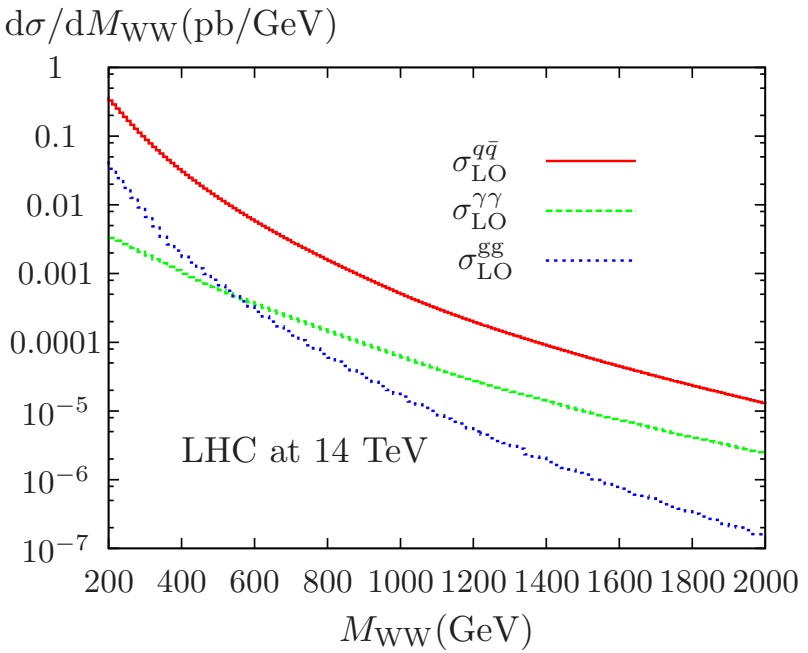


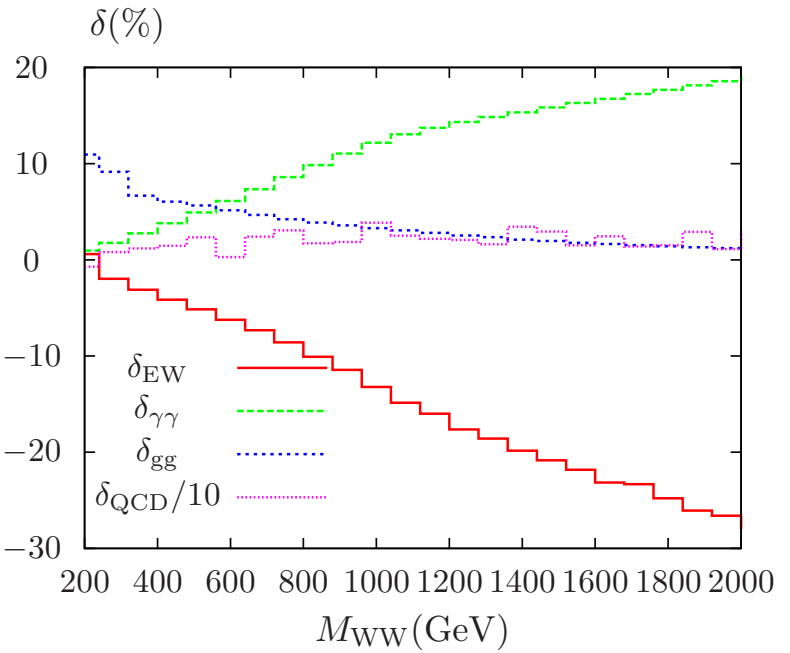
⇒ large EW logarithms at large energies

WW/ZZ production

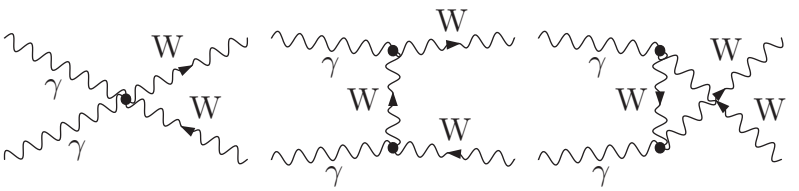
NLO EW corrections to on-shell diboson production:

Bierweiler, Kasprzik, Kühn [arXiv:1208.3147]





⇒ large photon-induced $\gamma\gamma \to \mathrm{WW}$ contribution

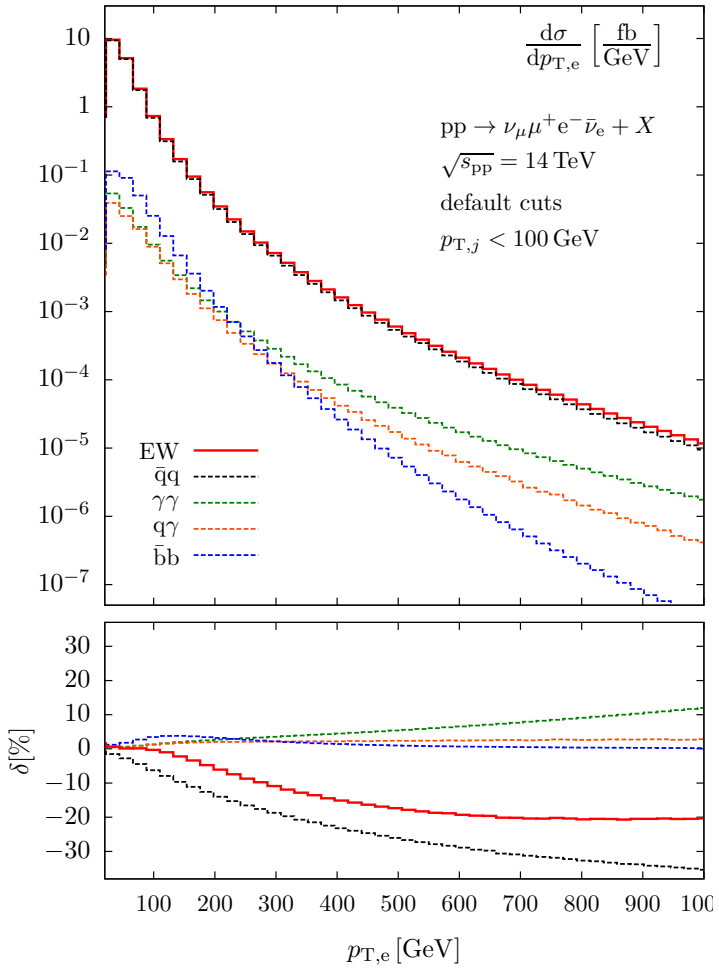


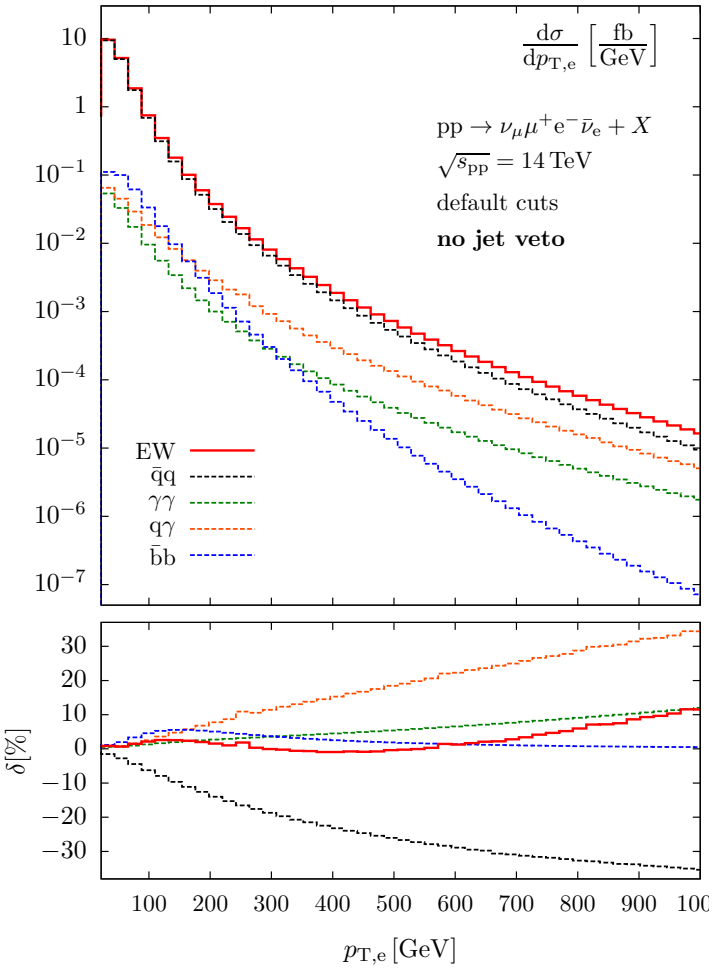
(without jet veto also large γq contribution Baglio et al. [arXiv:1307.4331])

WW/ZZ production

NLO EW corrections to $\mathrm{pp} \to \nu_\mu \mu^+ e^- \bar{\nu}_e$ in DPA:

Billoni, Dittmaier, Jäger, Speckner [arXiv:1310.1564]





Agreement with on-shell calculation:

many distributions $\mathcal{O}(1\%)$

up to 3% difference for M_{WW} distribution

up to 10% for distributions when tight cuts on M_{WW} are applied

RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

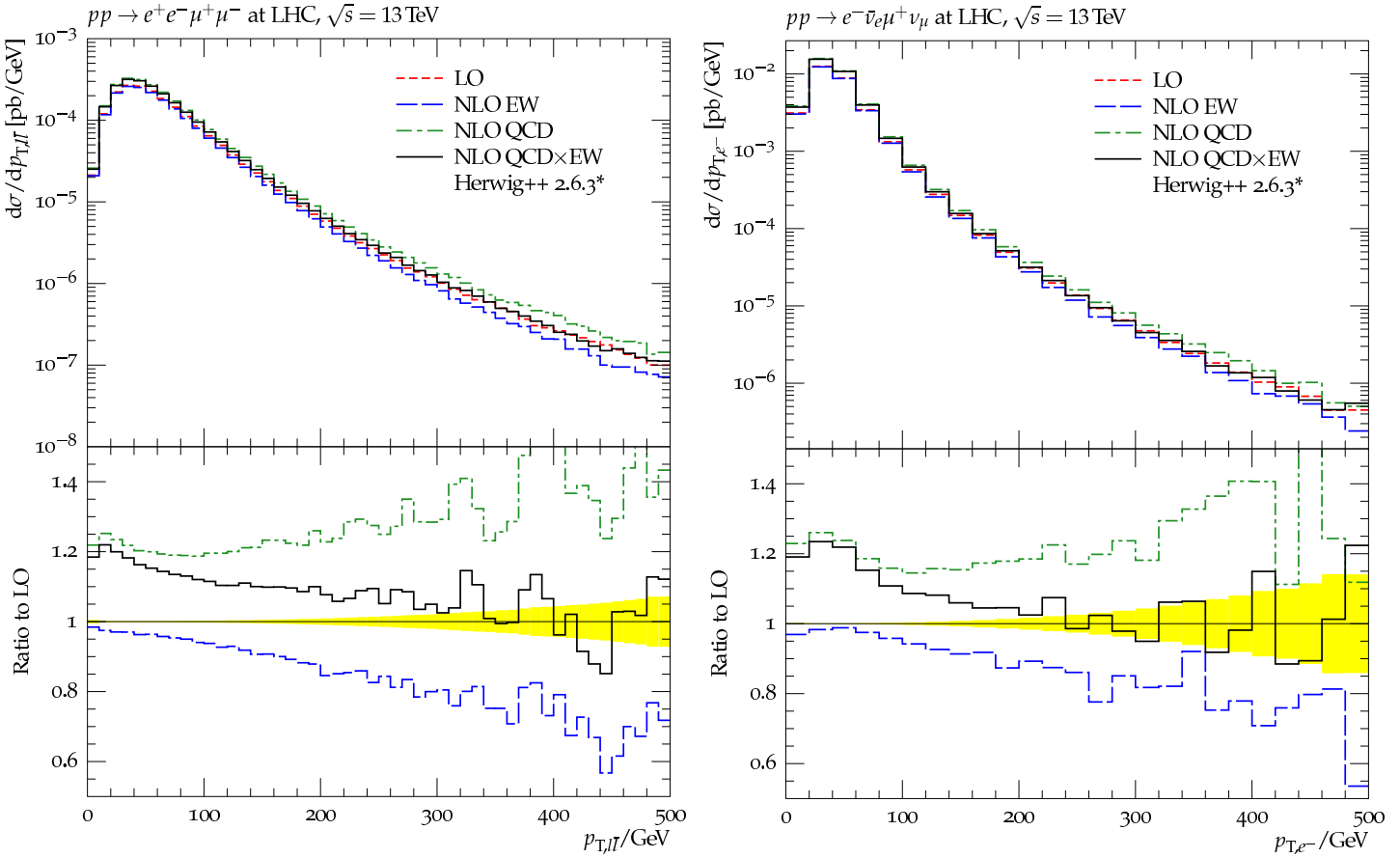
RWTH

WW/ZZ production

approximate EW corrections in HERWIG++:

Gieseke, Kasprzik, Kühn [arXiv:1401.3964]

- uses virtual EW corr. of $2 \to 2 \Rightarrow$ capture EW Logs $\Leftrightarrow$ few % acc.



RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

Summary

Prophecy4f

- MC tool for Higgs-boson decay to 4 fermions

$$\mathrm{H} \to \mathrm{WW/ZZ} \to 4\mathrm{f}$$

- including NLO EW + QCD corrections
- looking forward to Prophecy being used within ATLAS

$\mathrm{pp} \to \mathrm{WW/ZZ}$

- EW corrections available
- full off-shell calculations for EW corrections in progress
  (Denner, Dittmaier, Jäger, et al.)
- detailed study for impact on Higgs background?

RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

Back-up slides

RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

Applications

Partial widths for 4f final states from Prophecy4f:

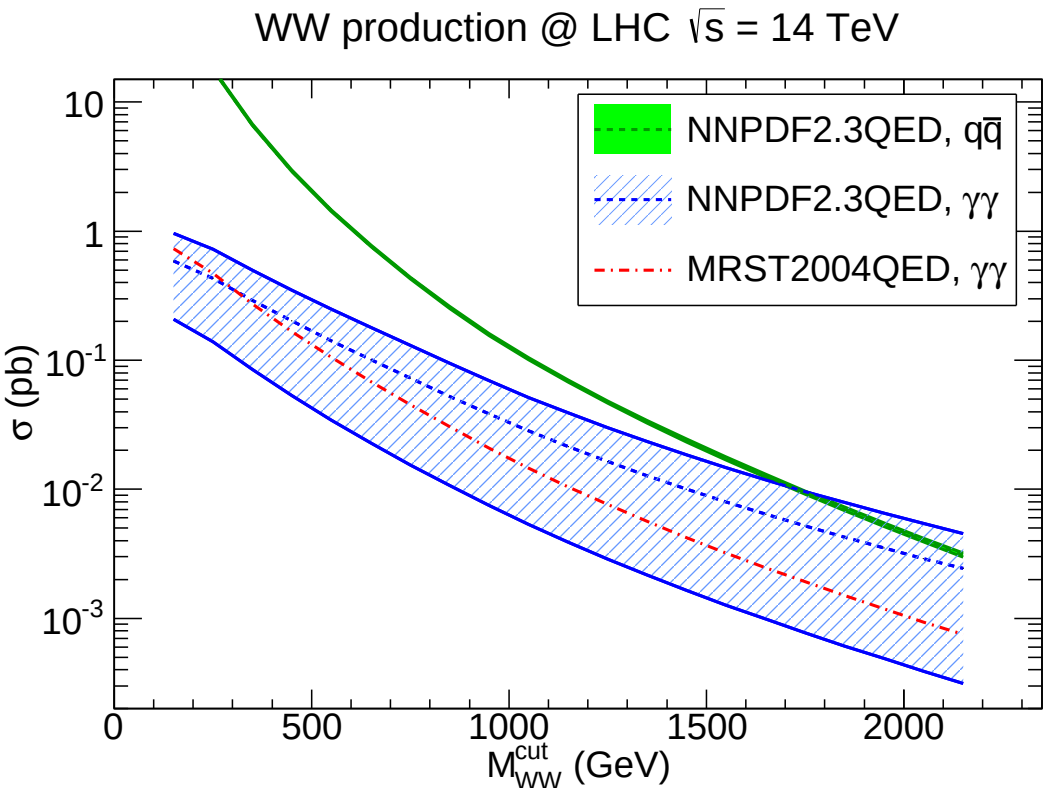
$$
\begin{aligned}
\Gamma_{4f} &= \Gamma_{\mathrm{H}\to\mathrm{W^*W^*}\to 4f} + \Gamma_{\mathrm{H}\to\mathrm{Z^*Z^*}\to 4f} + \Gamma_{\mathrm{WW/ZZ-int.}} \\
\Gamma_{\mathrm{H}\to\mathrm{W^*W^*}\to 4f} &= 9\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\mathrm{e}^+\mu^-\bar{\nu}_\mu} + 12\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\mathrm{e}^+\mathrm{d}\bar{\mathrm{u}}} + 4\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{d}}\mathrm{s}\bar{\mathrm{c}}} \\
\Gamma_{\mathrm{H}\to\mathrm{Z^*Z^*}\to 4f} &= 3\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\nu_\mu\bar{\nu}_\mu} + 3\cdot\Gamma_{\mathrm{H}\to\mathrm{e}^-\mathrm{e}^+\mu^-\mu^+} + 9\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\mu^-\mu^+} \\
&\quad + 3\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\nu_\mathrm{e}\bar{\nu}_\mathrm{e}} + 3\cdot\Gamma_{\mathrm{H}\to\mathrm{e}^-\mathrm{e}^+\mathrm{e}^-\mathrm{e}^+} \\
&\quad + 6\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\mathrm{u}\bar{\mathrm{u}}} + 9\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\mathrm{d}\bar{\mathrm{d}}} + 6\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{u}}\mathrm{e}^-\mathrm{e}^+} + 9\cdot\Gamma_{\mathrm{H}\to\mathrm{d}\bar{\mathrm{d}}\mathrm{e}^-\mathrm{e}^+} \\
&\quad + 1\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{u}}\mathrm{c}\bar{\mathrm{c}}} + 3\cdot\Gamma_{\mathrm{H}\to\mathrm{d}\bar{\mathrm{d}}\mathrm{s}\bar{\mathrm{s}}} + 6\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{u}}\mathrm{s}\bar{\mathrm{s}}} + 2\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{u}}\mathrm{u}\bar{\mathrm{u}}} \\
&\quad + 3\cdot\Gamma_{\mathrm{H}\to\mathrm{d}\bar{\mathrm{d}}\mathrm{d}\bar{\mathrm{d}}} \\
\Gamma_{\mathrm{WW/ZZ-int.}} &= 3\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\mathrm{e}^+\mathrm{e}^-\bar{\nu}_\mathrm{e}} - 3\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\mu^-\mu^+} - 3\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\mathrm{e}^+\mu^-\bar{\nu}_\mu} \\
&\quad + 2\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{d}}\mathrm{d}\bar{\mathrm{u}}} - 2\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{u}}\mathrm{s}\bar{\mathrm{s}}} - 2\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{d}}\mathrm{s}\bar{\mathrm{c}}}
\end{aligned}
$$

- used for HXSWG branching ratios
  (in combination with HDecay partial widths for other channels)

NNPDF QED and W-pairs

W-pair production with NNPDF2.3 QED sets:

NNPDF [arXiv:1308.0598]
using computation by Bierweiler, Kasprzik, Kühn [arXiv:1208.3147]



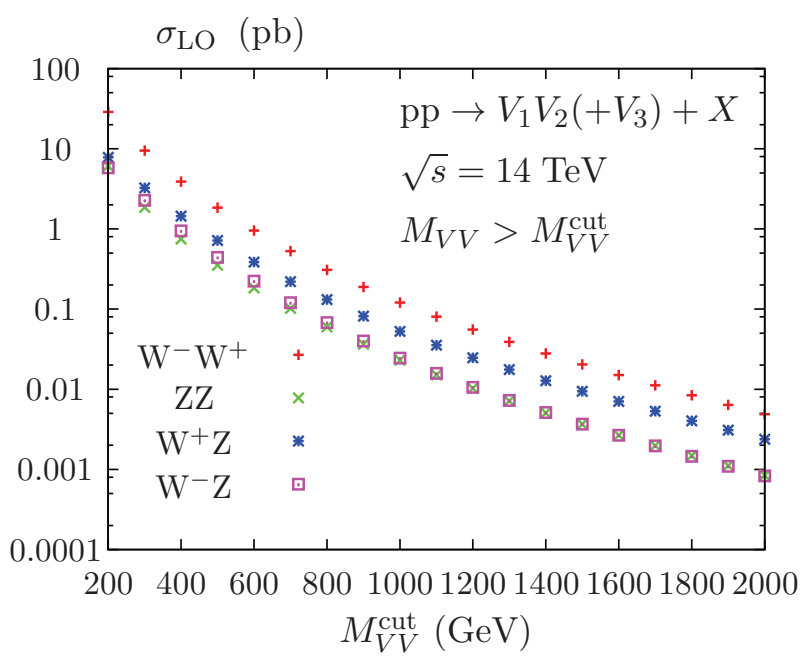
⇒ a lot to be learned about the photon PDF

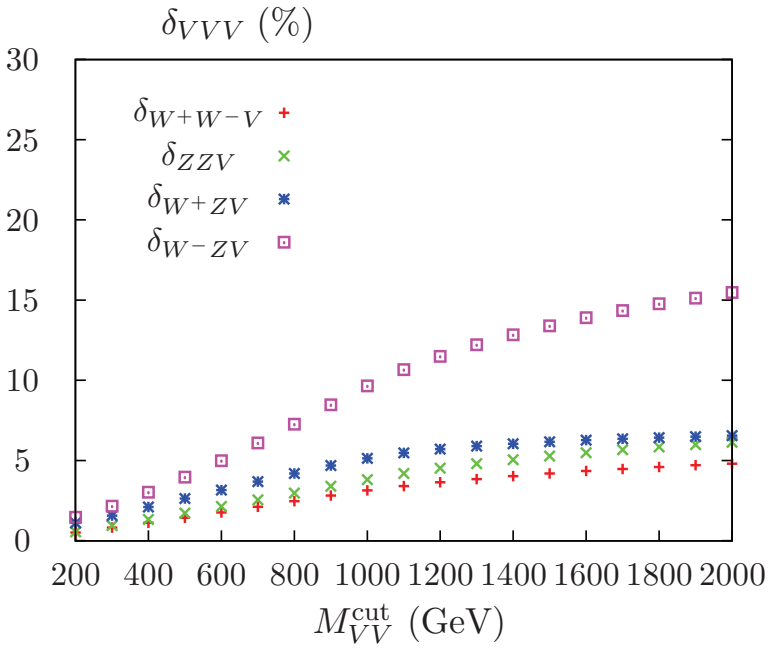
RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

WW/ZZ production

NLO EW corrections to on-shell diboson production:

Bierweiler, Kasprzik, Kühn [arXiv:1305.5402]





$\Rightarrow$ only small contribution form real emission (but for W^-Z)