

WH/ZH Higgs cross section group

Status and plans

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CERN Higgs Cross Section Workshop

Outline

- ◆ General plans (from the Freiburg workshop)
- ◆ Status and results
- ◆ Next steps...

General workplan - Main items (I)

- ◆ Obtain updated estimate of inclusive cross sections for $pp \rightarrow WH$ and $pp \rightarrow ZH$ production, using following computations:
 - ◆ 1) NNLO QCD [Brein, Djouadi, Harlander]
 - ◆ 2) NLO QCD+EW [Ciccolini, Dittmaier, Kramer], available in HAWK
- ◆ Release a public version of these codes.
- ◆ with input parameters and uncertainties evaluated according to the LHC working group prescription
- ◆ Compare NLO result with:
 - ◆ 3) V2HV [Spira, Han, Willenbrock]
 - ◆ 4) MCFM [Campbell, Ellis]
- ◆ Understand disagreement between 2) and 3)

General workplan - Main items (II)

- ◆ Assess differential cross sections in the following variables (same for ZH):

• p_T (Higgs)	• p_T (add. jet)	• $m(WH)$
• $p_T(W)$	• η (add. jet)	
• η (Higgs)	• $\Delta\phi(W, Higgs)$	
• $\eta(W)$	• $\Delta\eta(W, Higgs)$	

- ◆ comparing:
 - ◆ $2 \rightarrow 3$ parton level prediction of NLO QCD + EW code
 - ◆ matched NLO / parton shower prediction using:
 - ◆ MC@NLO [Frixione, Webber]
 - ◆ POWHEG (Higgs processes by [Hamilton, Richardson, Tully])
 - ◆ LO parton shower (motivate / demotivate K factors)
- ◆ Repeat the same exercise for the high p_T region ($p_T(H) > 200$ GeV)
- ◆ interesting for $W/ZH \rightarrow bb$ at high p_T ($> 3\sigma$ at $\sqrt{s} = 14$ TeV with 30 fb^{-1})

Status and results (I)

- Updated evaluation of NLO EW corrections for $\sqrt{s} = 7$ and 10 TeV

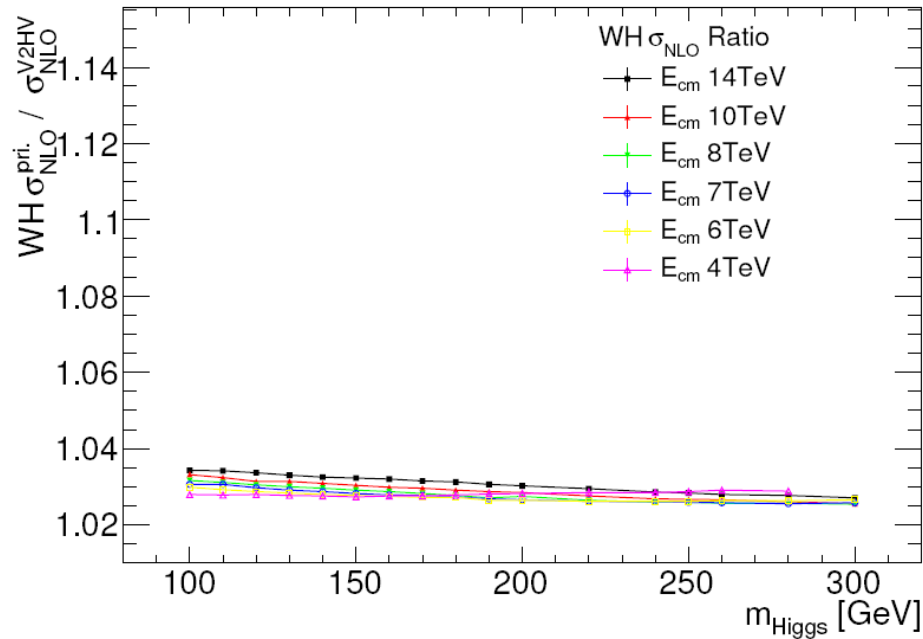
$$\sigma = \sigma_0 \cdot (1 + \delta^{QCD}) \times (1 + \delta^{EW})$$

pp -> ZH			pp -> W+H		
MH/GeV	delta(EC=7TeV)	delta(EC=10TeV)	MH/GeV	delta(EC=7TeV)	delta(EC=10TeV)
110	-5.0%	-5.1%	110	-6.1%	-6.2%
115	-5.1%	-5.1%	115	-6.5%	-6.5%
120	-5.1%	-5.1%	120	-6.7%	-6.8%
125	-5.1%	-5.2%	125	-6.7%	-6.8%
130	-5.2%	-5.3%	130	-6.9%	-7.0%
135	-5.3%	-5.3%	135	-7.2%	-7.4%
140	-5.4%	-5.5%	140	-7.6%	-7.7%

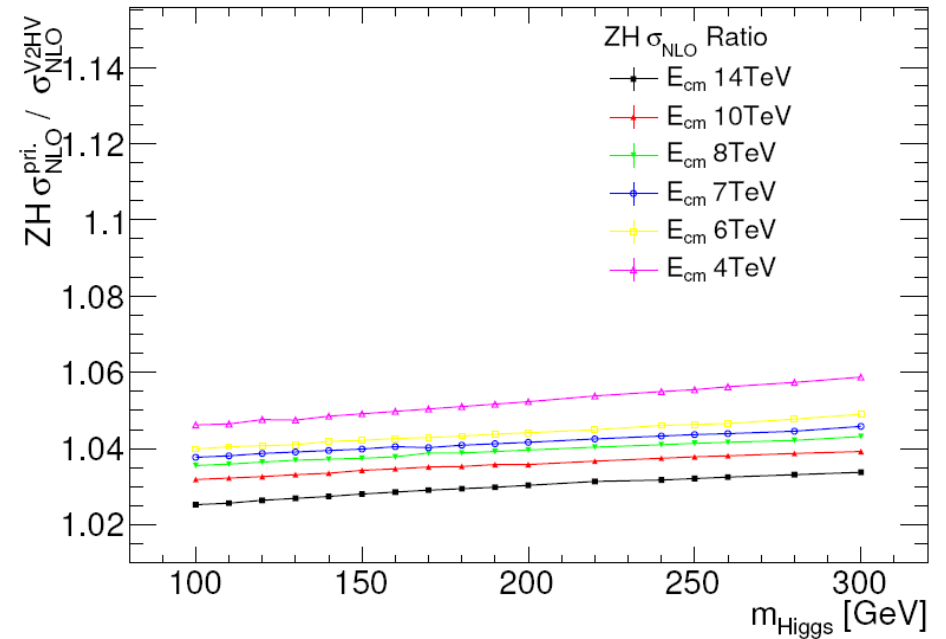
[Ciccolini, Dittmaier, Kraemer]

- Uncertainties still to be evaluated according to PDF4LHC prescription.
- This computation will be included in the next public release of HAWK (v. 2.0).

Status and results (II)



(a) WH

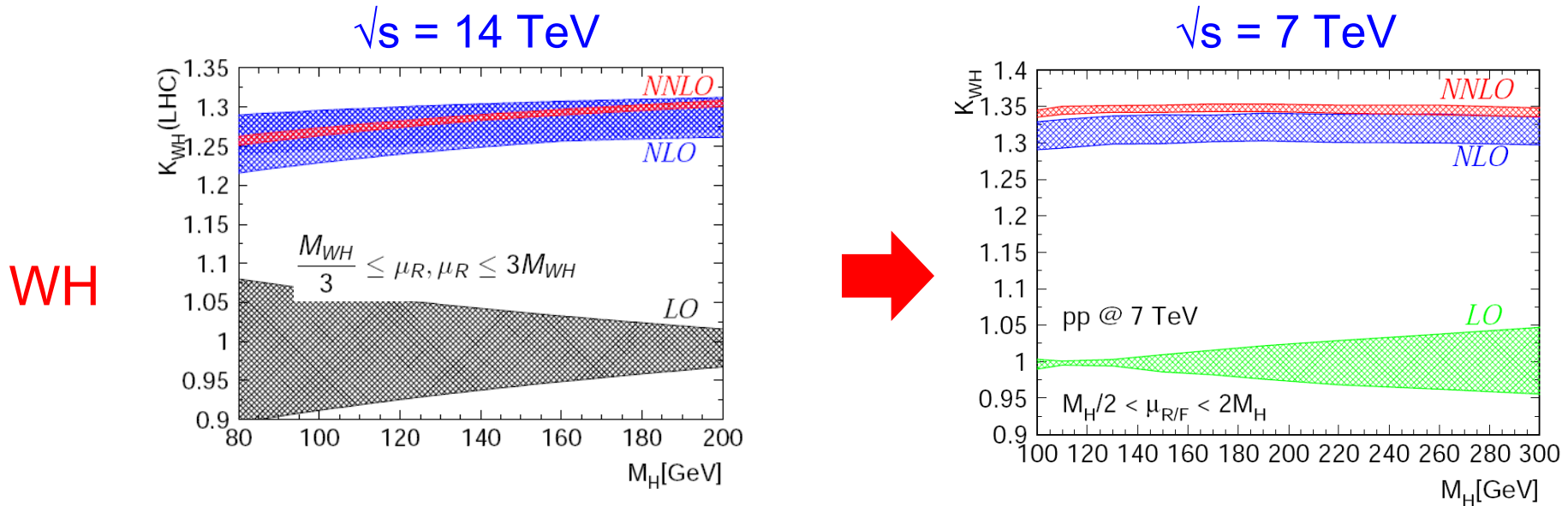


(b) ZH

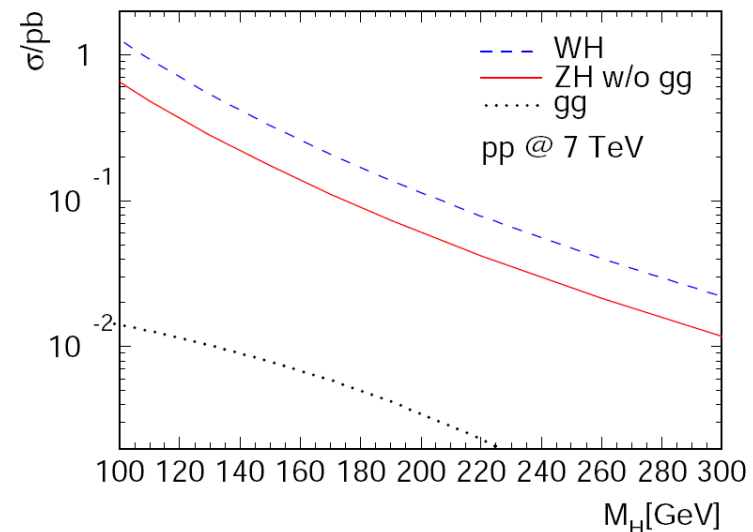
- ◆ Difference in cross section between HAWK and V2HV code is now understood: CKM matrix not implemented yet in V2HV, explains $\sim 3\%$ difference we see.

Status and results (III)

- Updated K factors (at $\sqrt{s} = 7$ TeV) for the NNLO QCD calculation [R. Harlander]



- Updated cross sections, still based on MSTW2008 PDFs (as suggested by PDF4LHC)
- Scale variation uncertainties evaluated
- PDF and α_s scale uncertainty evaluated for WH, being done right now for ZH



Next steps...

- ◆ NNLO QCD
 - ◆ Finish evaluation of PDF and α_s scale uncertainty [Harlander]
 - ◆ Separate W^+ and W^- contributions [Kraemer]
- ◆ NLO QCD + EW
 - ◆ generalization of HAWK to describe $pp \rightarrow WH/ZH \rightarrow H + 2 \text{ leptons}$ [Denner, Dittmaier, Kallweit, Mueck]
 - ◆ will allow to predict differential distributions after phase space cuts
- ◆ Differential distributions, once obtained, to be then compared to:
 - ◆ **MC@NLO**
(will have valuable support of V. Del Duca, S. Frixione and B. Webber, who joined the working group)
 - ◆ **POWHEG**
 - ◆ LO (HERWIG or PYTHIA)
- ◆ Plan is to have results for the workshop in Bari.

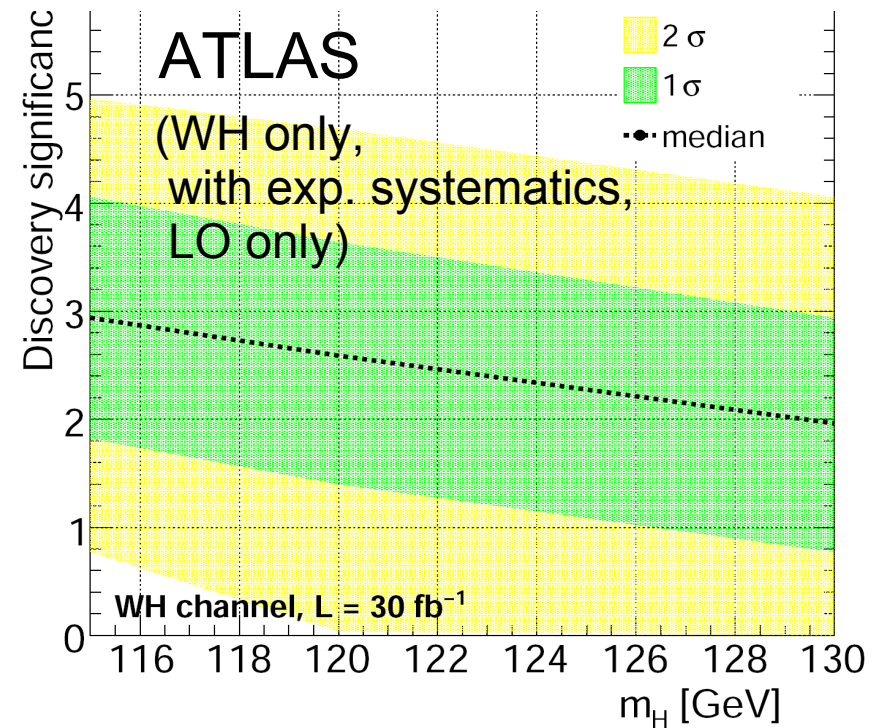
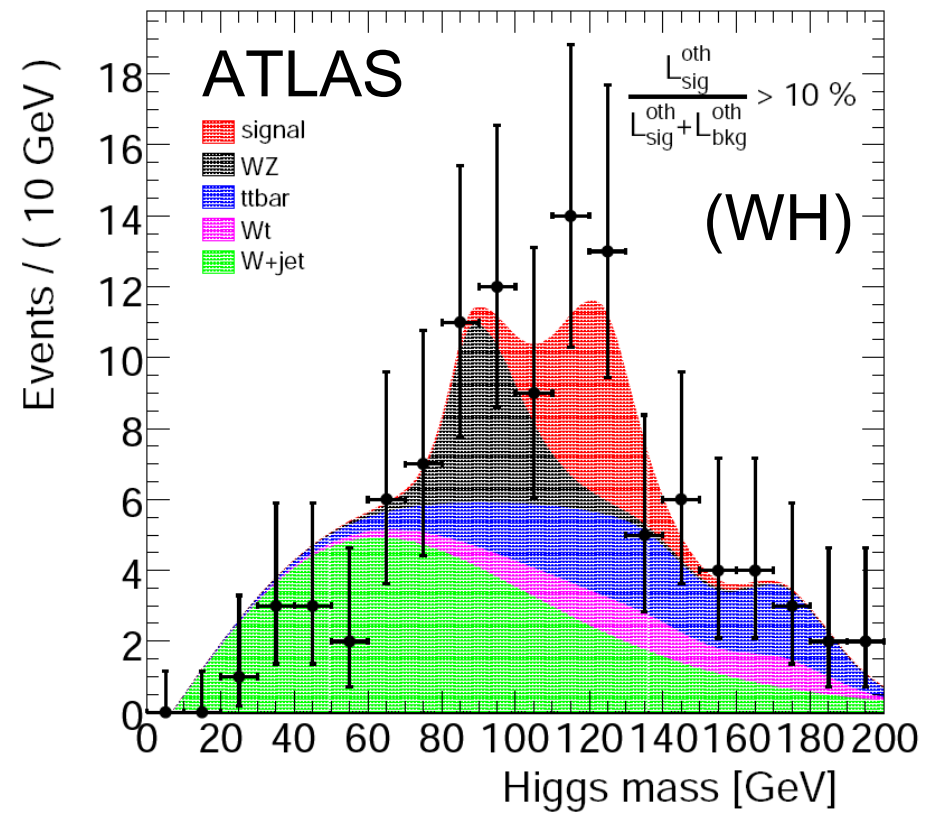
Summary

- ◆ Good progress on theory side
 - ◆ Results for inclusive cross section computation (NNLO and NLO QCD+EW) should be ready soon
 - ◆ New version of HAWK will allow to apply all needed phase space cuts and to obtain planned differential cross section distributions
- ◆ Less progress on experimental side (got “distracted” by data results to be presented at ICHEP), but planning to catch up !
 - ◆ Plan is to compare parton level prediction with prediction of matched NLO + parton shower codes and start working actively with involved Monte Carlo experts
 - ◆ Plan is to try to disentangle the various effects (i.e. EW corrections or higher order leading logs from showers) in order to possibly get correction factors as a function of specific kinematic variables (i.e. $p_T(H)$) to apply on the NLO parton shower MC to properly describe the NLO QCD+EW FO result.
 - ◆ Will organize WH/ZH meetings to discuss these issues...

BACKUP

WH/ZH analysis at high p_T

- ◆ A lot of interest in the cross-section predictions for the high p_T region:
- ◆ Combined sensitivity to Higgs boson of WH/ZH analysis with $H \rightarrow b\bar{b}$ has been studied in both ATLAS and CMS, with promising results ($>3\sigma$ at $\sqrt{s}=14$ TeV with 30 fb^{-1})
- ◆ Particularly important:
 - ◆ to estimate EW corrections at high p_T (Higgs), which might be large



WH/ZH analysis at high p_T (II)

- ◆ Will evaluate same differential distributions but in relevant phase of space region of high p_T analysis:

- $p_T(W/Z) > 200$ GeV
- $p_T(b) > 20$ GeV
- $p_T(bb) > 200$ GeV
- $DR(bb) < 1.2$
- $p_T(\text{add.jet}) < 60$ GeV
- $|\eta(W/Z)| < 2.5$
- $|\eta(b)| < 2.5$
- $|\eta(\text{jet})| < 5$

- ◆ Use k_T algorithm with size 0.3 and E-invariant scheme (to resolve part of jet substructure)
- ◆ Analogous to Les Houches 2009 study for $W+bbbar$ (L. Reina, D. Wackerroth, F. Febres Cordero, G.P)

WH/ZH at LO and interference term

- ◆ Plan is to cross-check interference term between different channels (e.g. WH and WZ)
- ◆ For the specific case of $H \rightarrow b\bar{b}$:
 - ◆ Consider effect of non-resonant diagrams, considering separately all diagrams giving rise to $lvb\bar{b}$ or to $lb\bar{b}$ or to $vb\bar{b}$
 - ◆ Could produce already proposed distributions with MadGraph or CompHep
 - ◆ e.g. for $lvb\bar{b}$
 - ◆ ~300 diagrams, ~40 of each with intermediate Higgs
 - ◆ Alexander Cheplakov and a student (working on this channel for angular correlation studies) could easily produce these distributions

Interest from LHCb?

- ◆ Clara Matteuzzi is the contact person for LHCb
- ◆ Very specific region of phase space:
 - ◆ Look for $H \rightarrow b\bar{b}$ (excellent b-tagging performance)
 - ◆ $1.9 < \eta < 4.9$
 - ◆ Trigger on lepton with $p_T > 12-15$ GeV
- ◆ Estimate WH cross section @ NLO QCD (+EW?) in this region of phase space

People involved / interested

- ◆ CMS
 - ◆ Jim Olsen (contact person)
 - ◆ David Lopes Pegna
- ◆ ATLAS
 - ◆ Giacinto Piacquadio (contact person)
 - ◆ Alexander Cheplakov
- ◆ LHCb
 - ◆ Clara Matteuzzi (contact person)
- ◆ Theory
 - ◆ Stefan Dittmaier (contact person)
 - ◆ Robert Harlander (contact person)
 - ◆ Michael Kraemer
 - ◆ Vittorio Del Duca
 - ◆ Stefano Frixione
 - ◆ Bryan Webber

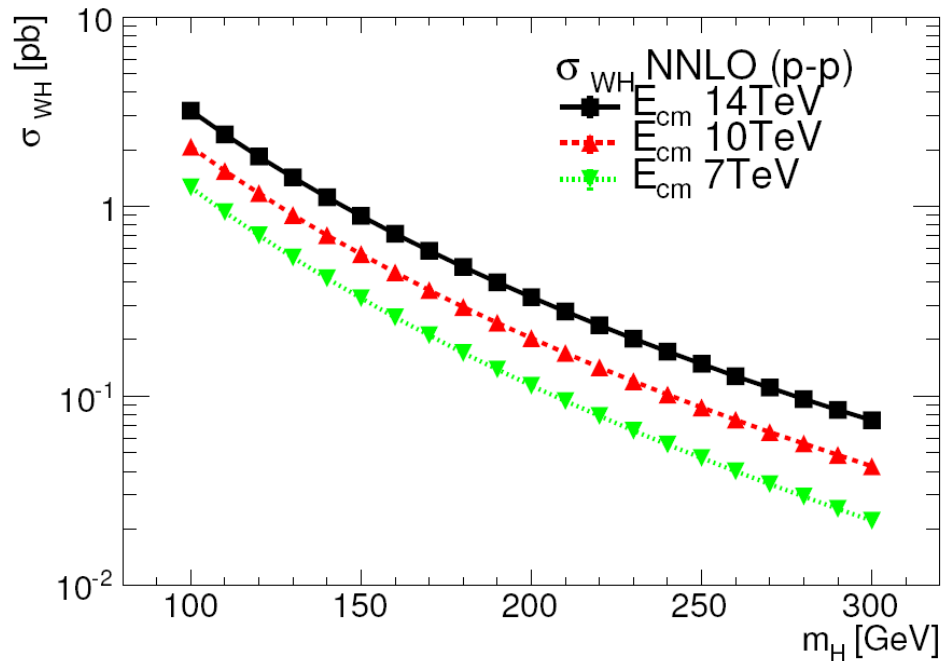
**A lot of room for other
people to contribute!**

What has been done in ATLAS (before cross section group started)

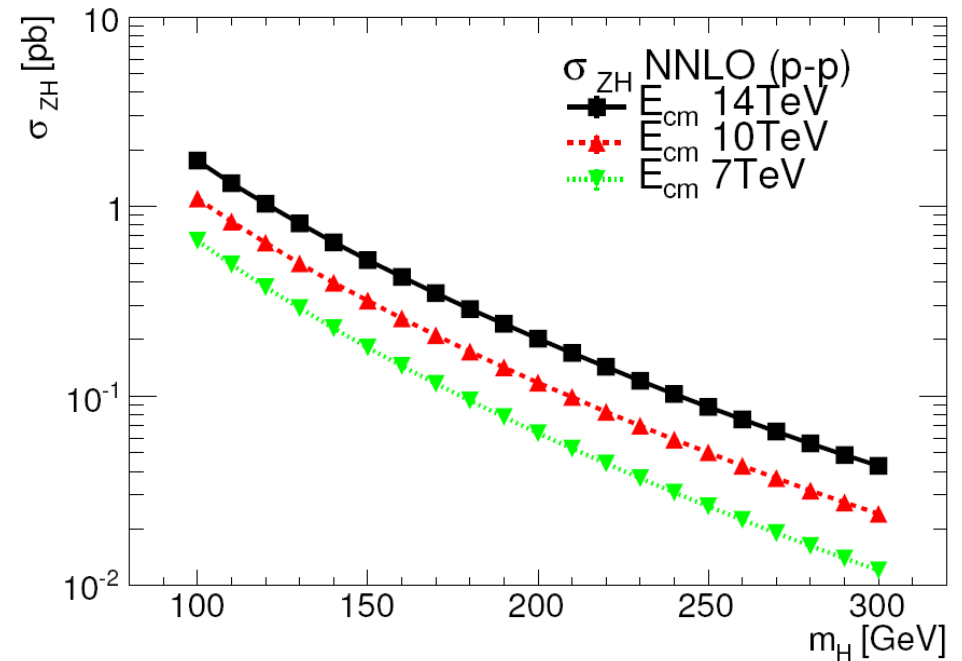
- ◆ Inclusive cross sections for WH and ZH production have been computed in collaboration with theorists, by factorizing the NLO EW and NNLO QCD corrections:
 - ◆ NNLO QCD [Brein, Djouadi, Harlander]
 - ◆ NLO EW [Ciccolini, Dittmaier, Kramer]
- ◆ using the formula:
 - ◆
$$\sigma = \sigma_0 \cdot (1 + \delta^{QCD}) \times (1 + \delta^{EW})$$
- ◆ Cross section obtained for:
 - ◆ $\sqrt{s} = 4, 6, 7, 8, 10, 14$ TeV
 - ◆ $m_H = 100 - 300$ GeV (10 GeV steps)
- ◆ and then extrapolation performed to join these points.

Result for $\sqrt{s} = 14 \text{ TeV}$

- Work done by **Huaqiao Zhang** in ATLAS in collaboration with the theorists (use of private code).



(a) WH 14 TeV



(b) ZH 14 TeV

+ the same for different center of mass energies.