HH QCD and EW higher-order corrections and theory uncertainties

Marco Bonetti

Summary of CERN Report 5 - *HH* physics at 14 TeV

22nd Workshop of the LHC Higgs Working Group

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The hunt for double Higgs

$$V(H) = \frac{m_H^2}{2} H^2 + \lambda H^3 + \lambda_4 H^4 \ [+ \dots]$$

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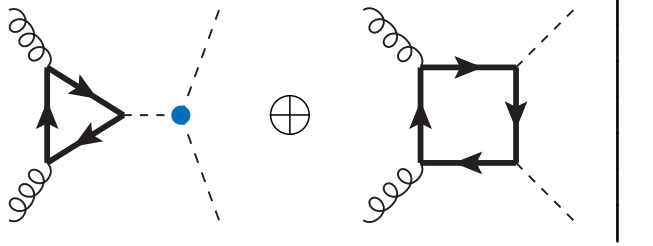

- Direct access to λ
- λ steers large cancellations

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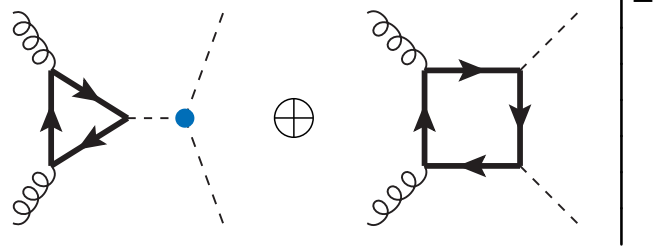

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Experimental constraints

ATLAS: $\kappa_\lambda \in [-1.4, 6.1]$

CMS: $\kappa_\lambda \in [-1.24, 6.49]$

HL-LHC @ 5% th: $\kappa_\lambda \in [0.1, 2.3]$

The menu

1. QCD corrections
   - NLO
   - NNLO
   - N^3LO
2. Top quark mass uncertainties
3. Electroweak corrections

QCD corrections: exact NLO $+65\%\,\sigma_{LO}\ \pm 13\%$

- Full NLO QCD + PS [Borowka, Greiner, Heinrich, Jones, Kerner, Schlenk, Schubert, Zirke]
  - Sector decomposition, grids available
- Full NLO with m_t & m_H [Baglio, Campanario, Glaus, Mühlleitner, Ronca, Spira, Streicher]
  - Feynman parameters, end-point, Richardson extr.
- Small p_{TH}, small m_t [Bonciani, Degrassi, Giardino, Gröber, Bagnaschi]
  - Small $p_{TH} \cup$ small m_T and Padé approximants
- ggxy [Davies, Schönwald, Steinhauser, Stremmer]
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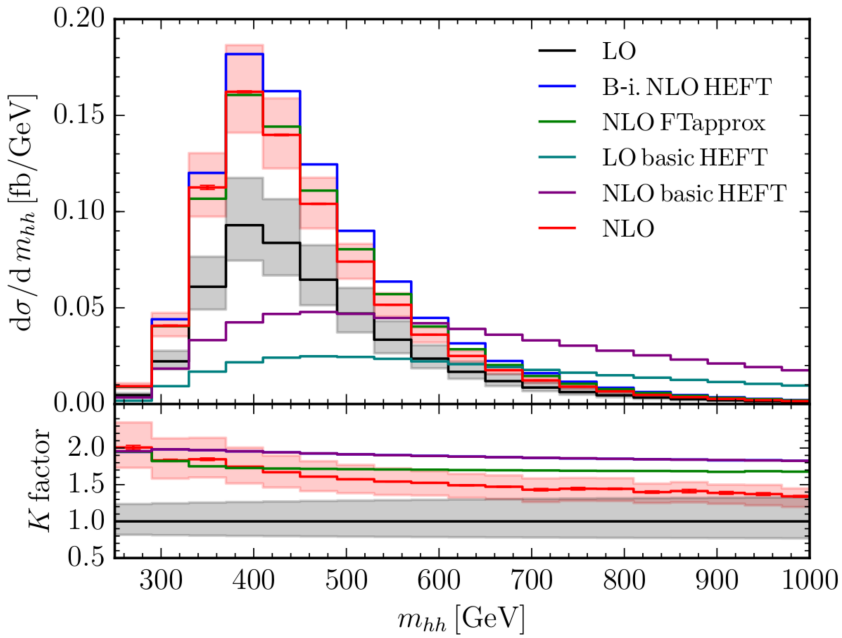

- HTL underestimate NLO

m_t essential for accurate predictions

QCD corrections: approximate NNLO $+26\%\,\sigma_{LO}$ $\pm 2.6\%$

- NNLO $\text{FT}_{\text{approx}}$ [Grazzini, Heinrich, Jones, Kallweit, Kerner, Lindert, Mazzitelli]

  If not known: $\mathcal{B}^{\text{FT}_{\text{approx}}}_{gg\to X} = \mathcal{B}^{m_t\to\infty}_{gg\to X}\left(\mathcal{B}^{\text{Born}}_{gg\to X}/\mathcal{B}^{\text{Born},m_t\to\infty}_{gg\to X}\right)$

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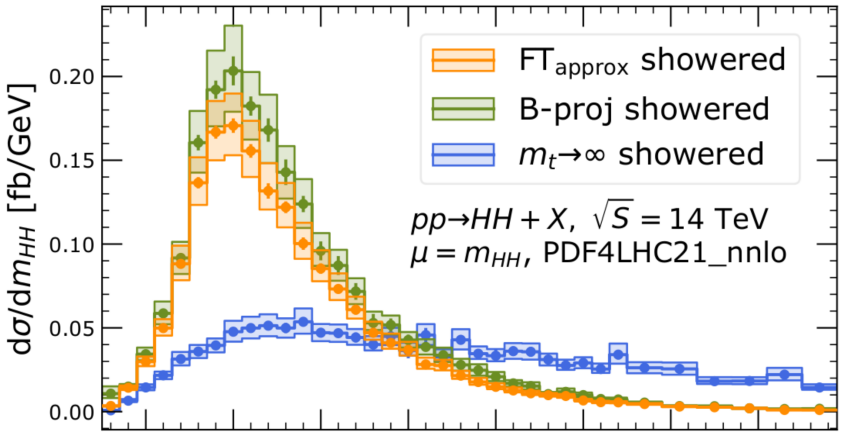
- Geneva with parton showers [Alioli, Marinelli, Napoletano]



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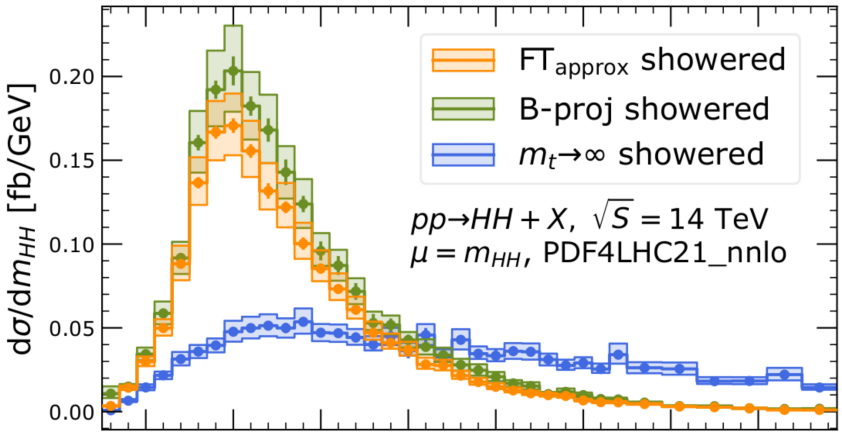

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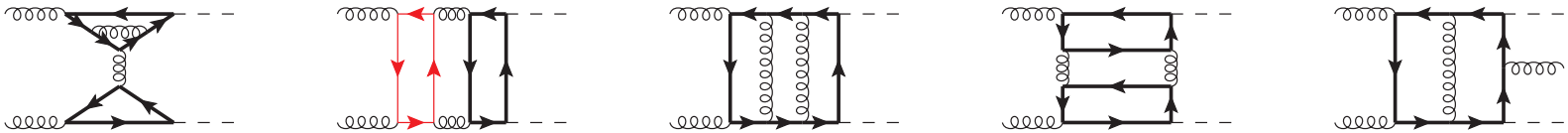
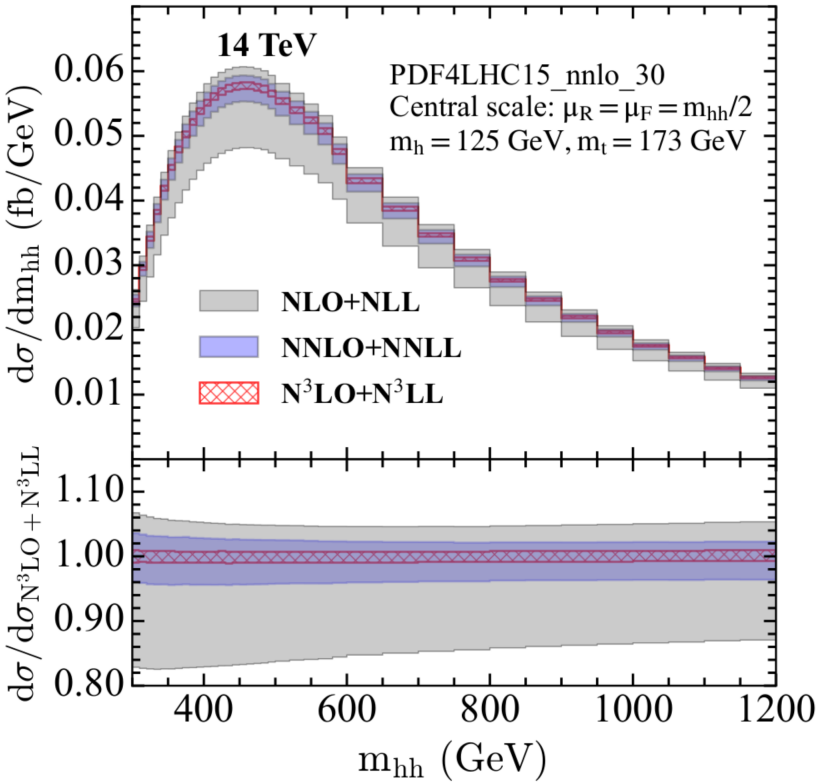
- Full m_t [Davies, Schönwald, Steinhauser, Vitti] – small p_{TH}



$N_c \to \infty$ NO NO

QCD corrections: NNNLO

$+6\%\,\sigma_{LO}\ \pm 0.9\%$



- $m_t \to \infty$ [Chen, Li, Shao, Wang]
  - No shape distortions from QCD
- N^{3}LO + N^{3}LL [A H, Shao]
  - PDF-enhanced threshold logs
  - Resummation scheme $\sim$ independent
- Partial m_t [A H, Chen, Li, Shao, Wang]
  - Reweighted by $\sigma_{\rm NLO}/\sigma_{\rm NLO}^{m_t\to\infty}$

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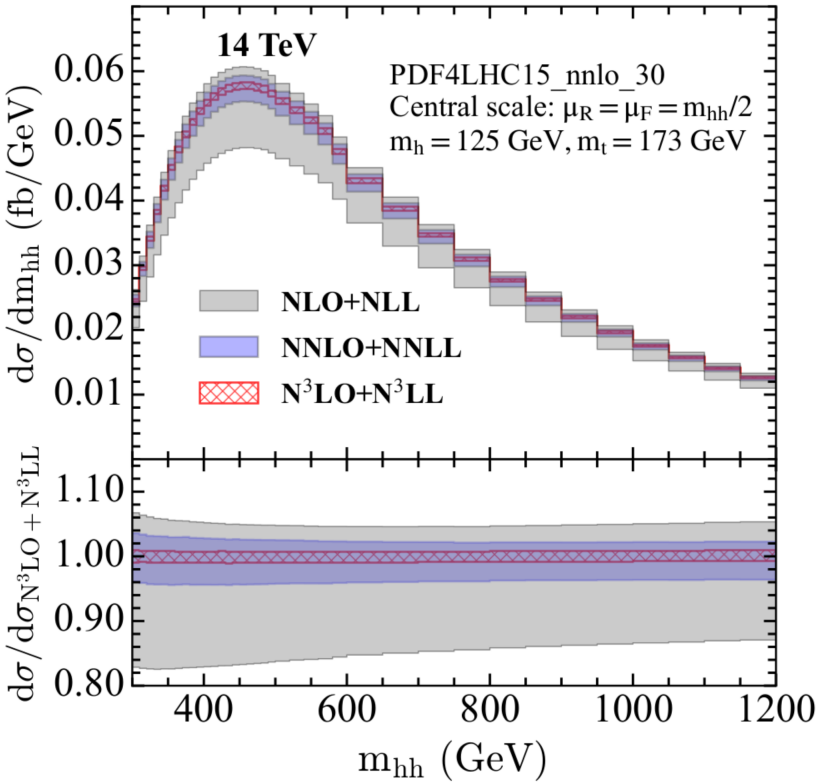

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N^{3}LO PDFs

- 4-loop splitting functions
- N^{3}LO processes

} aN3LOPDF

Top-quark mass effects

$20\%\,\sigma_{NLO}$

- m_t sensible to scheme and scale

[Baglio, Campanario, Glaus, Mühlleitner, Ronca, Spira, Streicher]

$$F^{\text{LO}} \xrightarrow{s\to\infty} \frac{m_t^2}{s} c^{\text{LO}}$$

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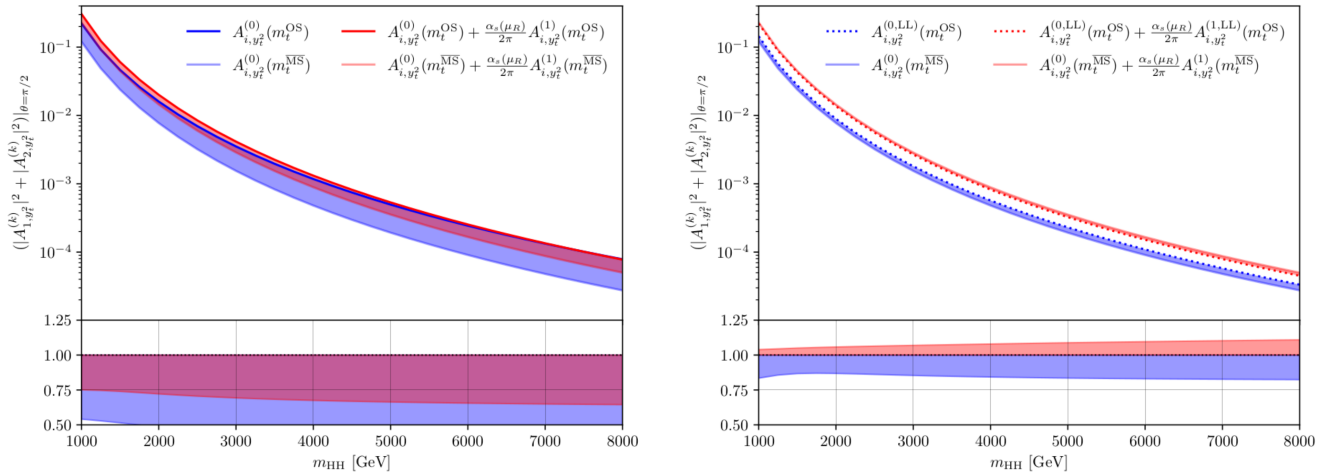
- LP LL are universal: resummed

[Jaskiewicz, Jones, Szafron, Ulrich]



Electroweak corrections: NLO

$-4.5\%\,\sigma_{LO}$

- Full NLO EW [Bi, Huang, Huang, Ma, Yu]
  - Shape distortion
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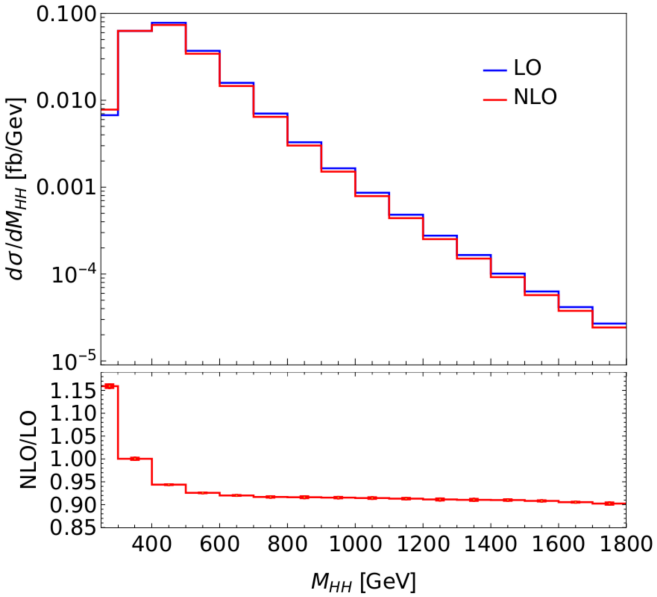

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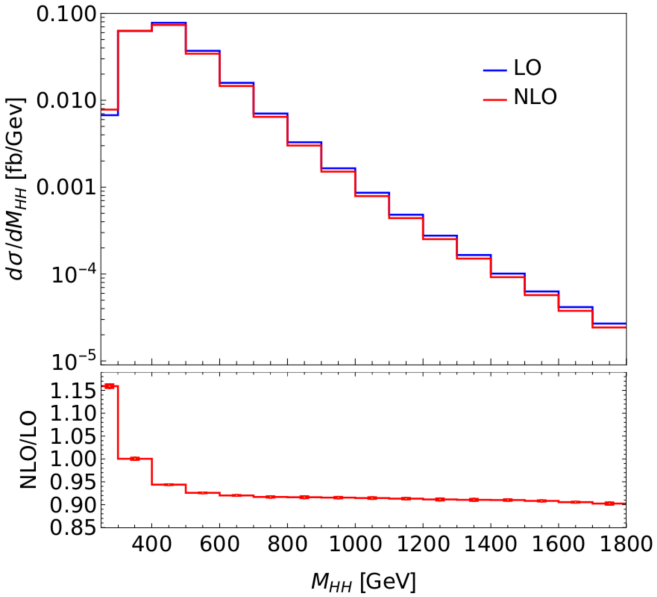
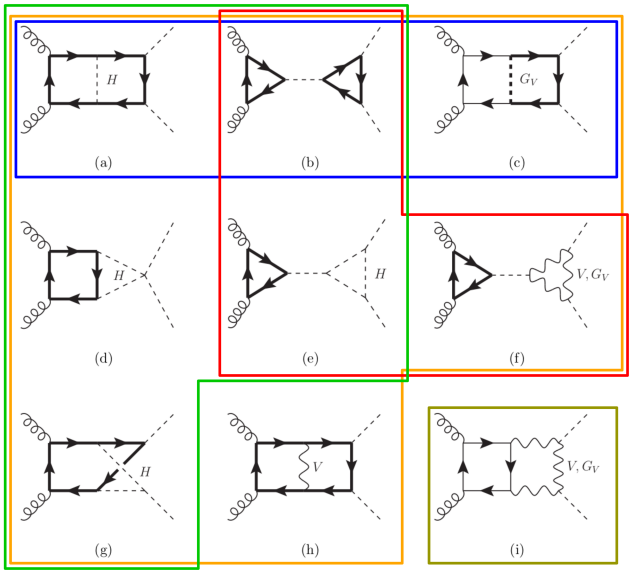


- Separate contributions



- [Bhattacharya, Campanario, Carlotti, Chang, Mazzitelli, Mühlleitner, Ronca, Schlenk, Spira]
- [Davies, Schönwald, Steinhauser, Zhang]
- [Mühlleitner, Schlenk, Spira] [Davies, Schönwald, Steinhauser, Zhang]
- [Davies, Schönwald, Steinhauser, Zhang] [Heinrich, Jones, Kerner, Stone, Vestner]
- [Bonetti, Rendler, Torres Bobadilla] [Bhattacharya, Campanario, Carlotti, Chang, Mazzitelli, Mühlleitner, Ronca, Spira]

Recommendations

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Ajjath A H, Simone Alioli, Julien Baglio, Emanuele Bagnaschi, Arunima Bhattacharya, Huan-Yu Bi, Roberto Bonciani, Marco Bonetti, Francisco Campanario, Sauro Carlotti, Jamie Chang, Long-Bin Chen, Joshua Davies, Giuseppe Degrassi, Pier Paolo Giardino, Seraina Glaus, Massimiliano Grazzini, Ramona Gröber, Gudrun Heinrich, Li-Hong Huang, Rui-Jun Huang, Sebastian Jaskiewicz, Stephen Jones, Matthias Kerner, Hai Tao Li, Jonas M. Lindert, Yan-Qing Ma, Giulia Marinelli, Javier Mazzitelli, Margarete Mühlleitner, Davide Napoletano, Philipp Rendler, Jonathan Ronca, Johannes Schlenk, Kay Schönwald, Hua-Sheng Shao, Michael Spira, Thomas Stone, Jurai Streicher, Daniel Stremmer, Robert Szafron, William J. Torres Bobadilla, Yannick Ulrich, Augustin Vestner, Jian Wang, Huai-Min Yu, Hantian Zhang

&

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