Precise predictions for double-Higgs production via vector-boson fusion

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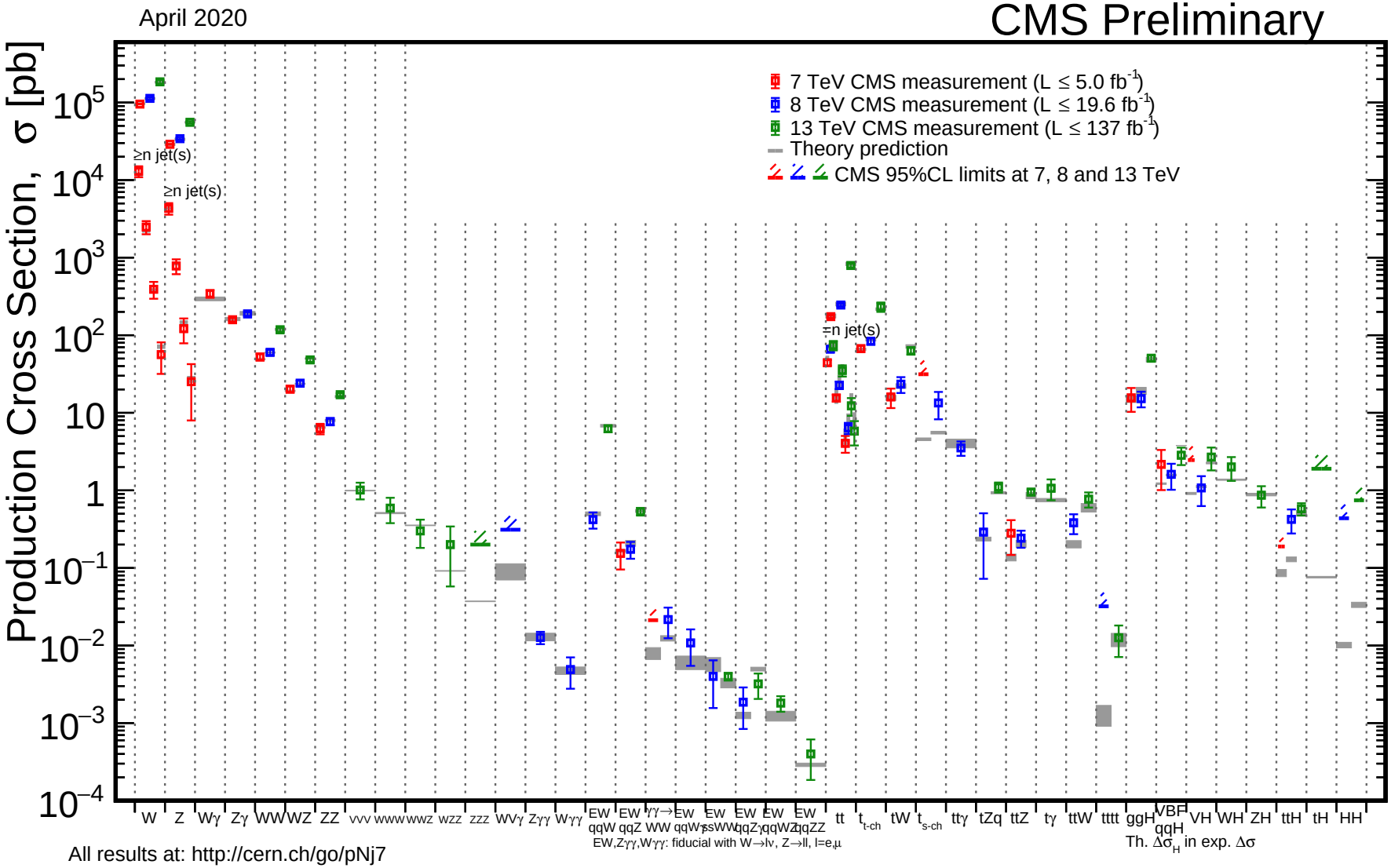
LHC: Great tool to probe fundamental interactions at high energies
$\rightarrow$ Great to measure Higgs bosons

- Main discovery of the LHC!
  $\rightarrow$ focus on the measurements of its properties

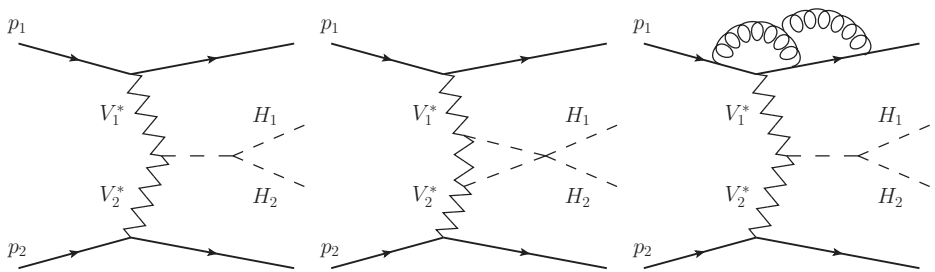


All results at: http://cern.ch/go/pNj7

→ **Large variety of Higgs processes ...**
.. with very different phenomenology!

VBF HH at NNLO QCD + NLO EW

→ Higgs self-coupling + extra handle with tagging jets



In **[Dreyer, Karlberg, Lang, MP; 2005.13341]**:

- Full NLO QCD + EW (**new**) from MoCaNLO+Recola [Actis et al.; 1605.01090]
- NNLO QCD corrections [Dreyer, Karlberg; 1811.07918] from proVBFHH
- Non-factorisable corrections at NNLO [Dreyer, Karlberg, Tancredi; 2005.11334]
  → Frédéric's talk

Already available:

- NLO QCD + PS [Frederix et al.; 1401.7340]
- N^{3}LO QCD (inclusive) [Dreyer, Karlberg; 1811.07906]

Double Higgs production via VBF at the LHC

$$\mathrm{pp} \to \mathrm{HHjj}$$

- LO at $\mathcal{O}\left(\alpha^4\right)$
  In addition to VBF contributions: $\mathrm{pp} \to V\mathrm{HH} \to \mathrm{HHjj}$
  (Higgs-Strahlung contributions)
  $\to$ $\mathrm{pp} \to \mathrm{HHjj} = \mathrm{VBF} + V\mathrm{HH}$

$$K_{\mathrm{full/VBF}} = \frac{d\sigma_{\mathrm{LO}}^{\mathrm{full}}}{d\sigma_{\mathrm{LO}}^{\mathrm{VBF}}}$$

Double Higgs production via VBF at the LHC

- Full NLO QCD at $\mathcal{O}\left(\alpha_s \alpha^4\right)$
  $\rightarrow$ all real QCD radiations and all virtual diagrams included
- NNLO QCD in VBF approximation at $\mathcal{O}\left(\alpha_s^2 \alpha^4\right)$
  $\rightarrow$ does not include gluon exchange between quark lines

$$\sigma_{\text{NNLO QCD}} = \sigma_{\text{LO}}^{\text{full}} + \delta_{\text{NLO QCD}}^{\text{full}} + K_{\text{full/VBF}} \delta_{\text{NNLO QCD}}^{\text{VBF}},$$

- NLO EW at $\mathcal{O}\left(\alpha^4\right)$
  all real photon corrections and virtual diagrams included
  photon-induced contributions neglected

$$\sigma_{\text{NNLO QCD}\times\text{NLO EW}} = \sigma_{\text{NNLO QCD}} \left(1 + \frac{\delta_{\text{NLO EW}}^{\text{full}}}{\sigma_{\text{LO}}^{\text{full}}}\right)$$

$\rightarrow$ as in the Higgs cross-section working group report for VBF

Set-up

Input:

- LHC at $\sqrt{s} = 14\,\text{TeV}$
- PDF: NNPDF31_nnlo_as_0118_luxqed [NNPDF; 1712.07053]
- $\mu = \sqrt{\frac{M_\text{H}}{2}\sqrt{\left(\frac{M_\text{H}}{2}\right)^2 + p^2_{\text{T,HH}}}}$

Event selection:

- $p_{\text{T,j}} > 25\,\text{GeV} \quad \text{and} \quad |y_\text{j}| < 4.5$
- $m_{\text{j}_1\text{j}_2} > 600\,\text{GeV} \quad \text{and} \quad |y_{\text{j}_1} - y_{\text{j}_2}| > 4.5$
- No cuts on the Higgs bosons

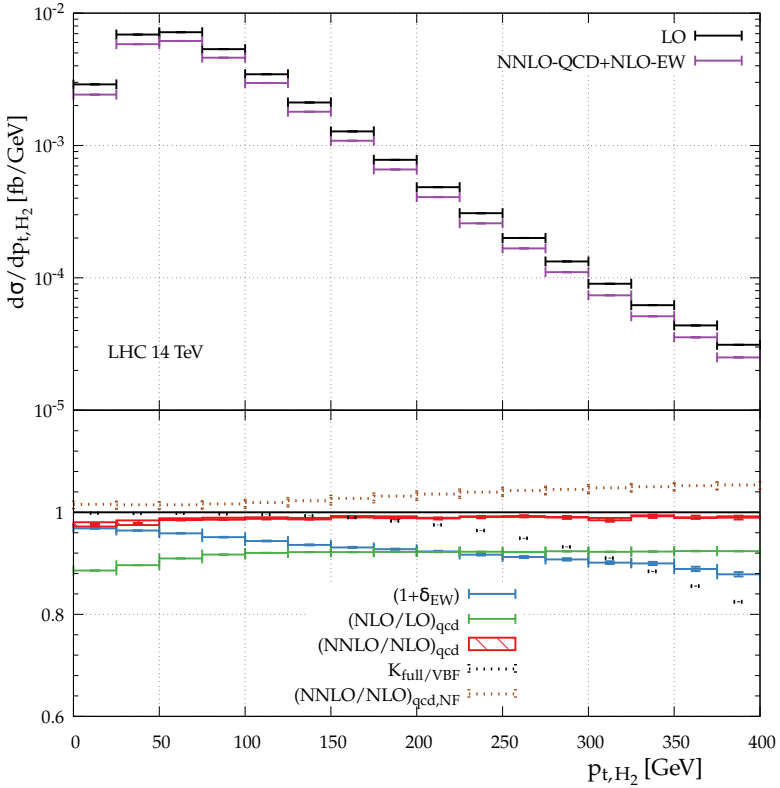
$\rightarrow$ Exclusive cuts to ensure reliable VBF approximation

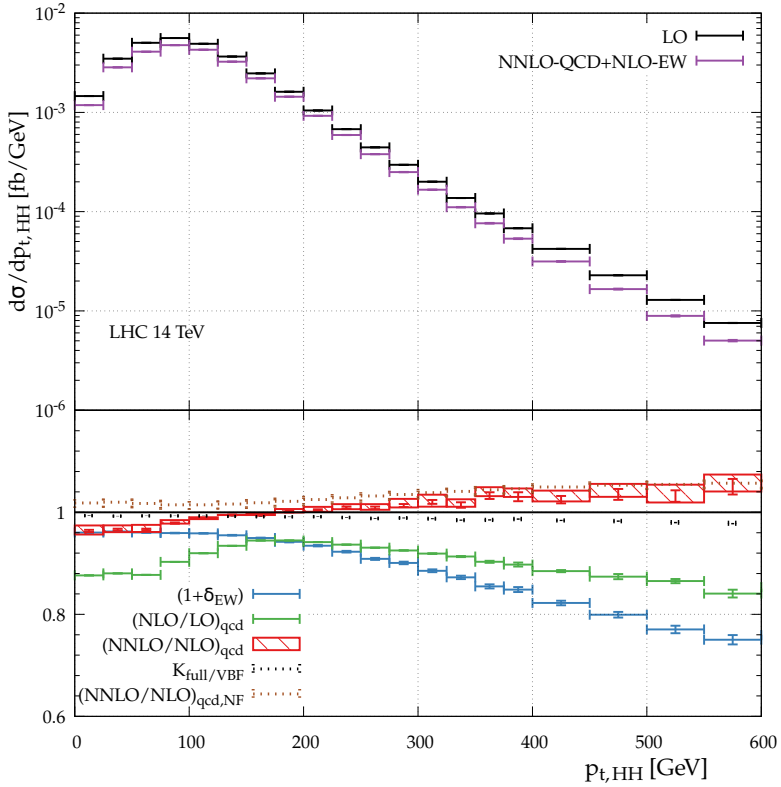
Cross sections

$\sigma_{\text{LO}}^{\text{full}}$	$\delta_{\text{NLO QCD}}^{\text{full}}$	$\delta_{\text{NNLO QCD}}^{\text{VBF}}$	$\delta_{\text{NLO EW}}^{\text{full}}$	$\sigma_{\text{NNLO QCD}\times\text{NLO EW}}$ [fb]
$0.78444(9)^{+0.0825}_{-0.0694}$	$-0.07110(13)$	$-0.0115(5)$	$-0.0476(2)$	$0.6684(5)^{+0.002}_{-0.0004}$
$^{+10.5\%}_{-8.8\%}$	-9.1%	-1.5%	-6.1%	$-14.8\%^{+0.3\%}_{-0.06\%}$

- Non-factorisable corrections: 0.01237(2) *i.e.* +1.7%
- NLO EW corrections of the order of NLO QCD and larger than NNLO QCD
  → Typical size of EW corrections
  (−5% for VBF [Ciccolini, Denner, Dittmaier; 0710.4749])
  → As opposed to intrinsic large EW corrections in VBS
  [Biedermann, Denner, MP; 1611.02951]
- Measurable at the High-luminosity LHC

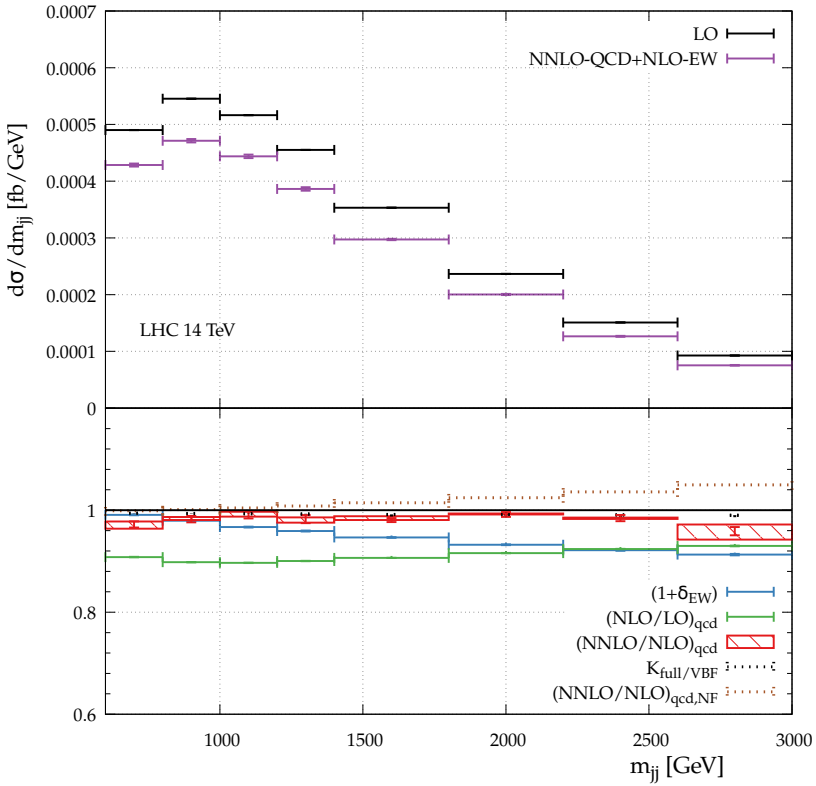
Differential distributions (1)

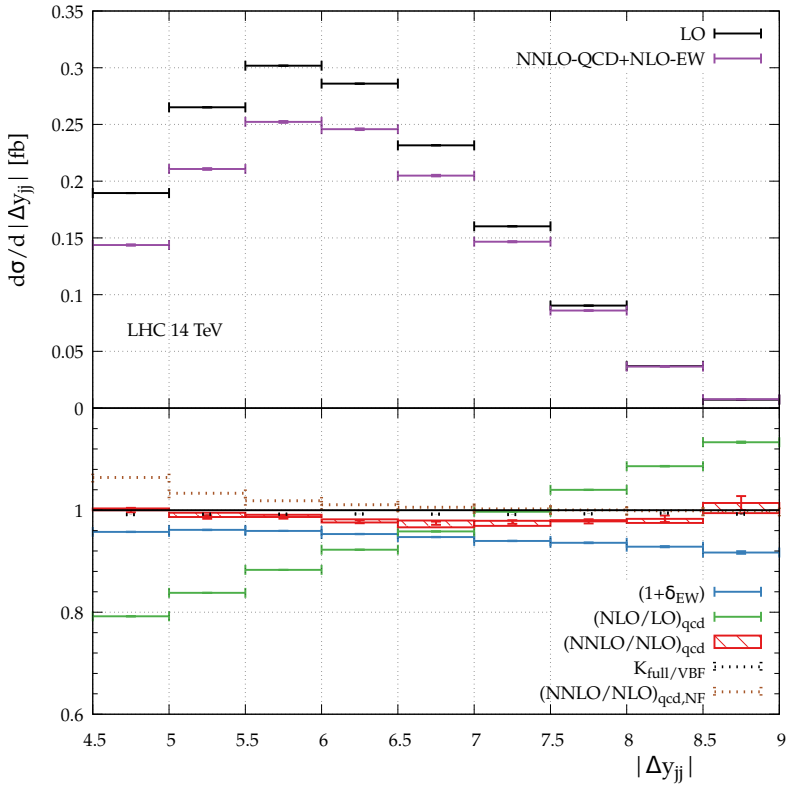




- Effect of VBF approximation up to 20%
- EW Sudakov logarithms in tails of distributions: -25%

Differential distributions (2)





- Important distributions for VBF: m_{jj} and $|\Delta y_{jj}|$
- Corrections at the level of 10/20%
- More distributions in [Dreyer, Karlberg, Lang, MP; 2005.13341]

Summary

NNLO QCD + NLO EW for VBF HH
[Dreyer, Karlberg, Lang, MP; 2005.13341]

- State of the art predictions at fixed order
- Quantifies VBF approximation
- NLO EW corrections of the order of the QCD ones

Thank you