Higher order QCD+EW predictions for Diboson processes

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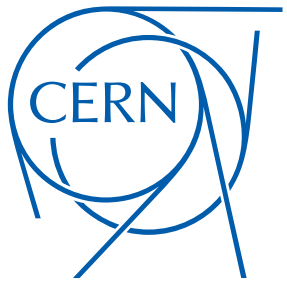
CERN

HL/HE–LHC WG1 Meeting – Electroweak physics



NNLO QCD and NLO EW HL/HE–LHC

NNLO QCD

- diboson production — Grazzini, Kallweit, Wiesemann

NLO EW

- diboson production — Kallweit, Linder, Pozzorini, MS
- $\gamma\gamma + V$ production — Greiner, MS

for both HL–LHC and HE–LHC

NNLO QCD results

process (${process_id})	σ_{LO}	σ_{NLO}	σ_{loop} ($\sigma_{\text{loop}}/\Delta\sigma^{\text{ext}}_{\text{NNLO}}$)	$\sigma^{r_{\text{cut}}}_{\text{NNLO}}$	$\sigma^{\text{extrapolated}}_{\text{NNLO}}$	K_{NLO}	K_{NNLO}	
$pp \to \gamma\gamma$ (ppaa02)	$5.592(1)^{+10\%}_{-11\%}$ pb	$25.75(1)^{+8.8\%}_{-7.5\%}$ pb	$2534(1)^{+24\%}_{-17\%}$ fb (17.4%)	$40.86(2)^{+8.7\%}_{-7.2\%}$ pb	$40.28(30)^{+8.7\%}_{-7.0\%}$ pb	+361%	+56.4%	13 TeV
$pp \to \gamma\gamma$ (ppaa02)	$10.34(0)^{+15\%}_{-15\%}$ pb	$54.63(5)^{+9.9\%}_{-11\%}$ pb	$6701(17)^{+24\%}_{-17\%}$ fb (17.4%)	$88.76(30)^{+9.1\%}_{-7.4\%}$ pb	$88.45(51)^{+9.0\%}_{-7.4\%}$ pb	+428%	+61.9%	27 TeV
$pp \to ZZ$ (ppzz02)	$9.845(1)^{+5.2\%}_{-6.3\%}$ pb	$14.10(0)^{+2.9\%}_{-2.4\%}$ pb	$1361(1)^{+25\%}_{-19\%}$ fb (52.9%)	$16.68(1)^{+3.2\%}_{-2.6\%}$ pb	$16.67(1)^{+3.2\%}_{-2.6\%}$ pb	+43.3%	+18.2%	13 TeV
$pp \to ZZ$ (ppzz02)	$23.59(1)^{+10\%}_{-11\%}$ pb	$35.56(2)^{+3.2\%}_{-4.1\%}$ pb	$4821(11)^{+25\%}_{-18\%}$ fb (52.9%)	$44.36(17)^{+4.2\%}_{-3.4\%}$ pb	$44.46(33)^{+4.3\%}_{-3.5\%}$ pb	+50.7%	+25.0%	27 TeV
$pp \to W^+W^-$ (ppwxw02)	$66.64(1)^{+5.7\%}_{-6.7\%}$ pb	$103.2(0)^{+3.9\%}_{-3.1\%}$ pb	$4091(3)^{+27\%}_{-19\%}$ fb (29.5%)	$117.1(1)^{+2.5\%}_{-2.2\%}$ pb	$117.1(1)^{+2.5\%}_{-2.2\%}$ pb	+54.9%	+13.4%	13 TeV
$pp \to W^+W^-$ (ppwxw02)	$152.5(0)^{+10\%}_{-11\%}$ pb	$254.7(2)^{+4.4\%}_{-4.6\%}$ pb	$13.87(3)^{+27\%}_{-19\%}$ pb (29.5%)	$300.4(1.1)^{+3.3\%}_{-3.0\%}$ pb	$299.8(1.3)^{+3.3\%}_{-2.9\%}$ pb	+67.0%	+17.7%	27 TeV
$pp \to e^-\mu^-e^+\mu^+$ (ppemexmx04)	$11.34(0)^{+6.3\%}_{-7.3\%}$ fb	$16.87(0)^{+3.0\%}_{-2.5\%}$ fb	$1.971(1)^{+25\%}_{-18\%}$ fb (57.6%)	$20.30(1)^{+3.5\%}_{-2.9\%}$ fb	$20.30(1)^{+3.5\%}_{-2.9\%}$ fb	+48.8%	+20.3%	13 TeV
$pp \to e^-\mu^-e^+\mu^+$ (ppemexmx04)	$22.49(1)^{+11\%}_{-12\%}$ fb	$35.78(3)^{+3.4\%}_{-4.5\%}$ fb	$6.140(20)^{+25\%}_{-18\%}$ fb (57.6%)	$45.78(21)^{+4.6\%}_{-3.8\%}$ fb	$45.28(83)^{+4.4\%}_{-3.6\%}$ fb	+59.1%	+26.6%	27 TeV
$pp \to e^-\mu^+\nu_\mu\bar{\nu}_e$ (ppemxnmnex04)	$232.9(0)^{+6.6\%}_{-7.6\%}$ fb	$236.1(1)^{+2.8\%}_{-2.4\%}$ fb	$26.93(1)^{+27\%}_{-19\%}$ fb (94.3%)	$264.7(1)^{+2.2\%}_{-1.4\%}$ fb	$264.6(2)^{+2.2\%}_{-1.4\%}$ fb	+1.34%	+12.1%	13 TeV
$pp \to e^-\mu^+\nu_\mu\bar{\nu}_e$ (ppemxnmnex04)	$439.0(1)^{+11\%}_{-12\%}$ fb	$429.0(4)^{+3.5\%}_{-3.2\%}$ fb	$79.19(9)^{+27\%}_{-19\%}$ fb (94.3%)	$507.0(1.4)^{+3.2\%}_{-2.1\%}$ fb	$507.5(1.9)^{+3.3\%}_{-2.1\%}$ fb	−2.27%	+18.3%	27 TeV
$pp \to e^-\mu^-e^+\bar{\nu}_\mu$ (ppemexnmx04)	$11.50(0)^{+5.7\%}_{-6.8\%}$ fb	$23.55(1)^{+5.5\%}_{-4.5\%}$ fb	—	$26.15(1)^{+2.2\%}_{-2.1\%}$ fb	$26.15(2)^{+2.3\%}_{-2.1\%}$ fb	+105%	+11.1%	13TeV
$pp \to e^-\mu^-e^+\bar{\nu}_\mu$ (ppemexnmx04)	$23.18(4)^{10.9\%}_{11.5\%}$ fb	$53.21(9)^{+6.1\%}_{-5.3\%}$ fb	—	$62.18(65)^{+2.2\%}_{-3.2\%}$ fb	$62.07(84)^{+2.3\%}_{-3.1\%}$ fb	+129.5%	+16.6%	27 TeV

×2.2

×2.7

×2.6

×2.3

×1.9

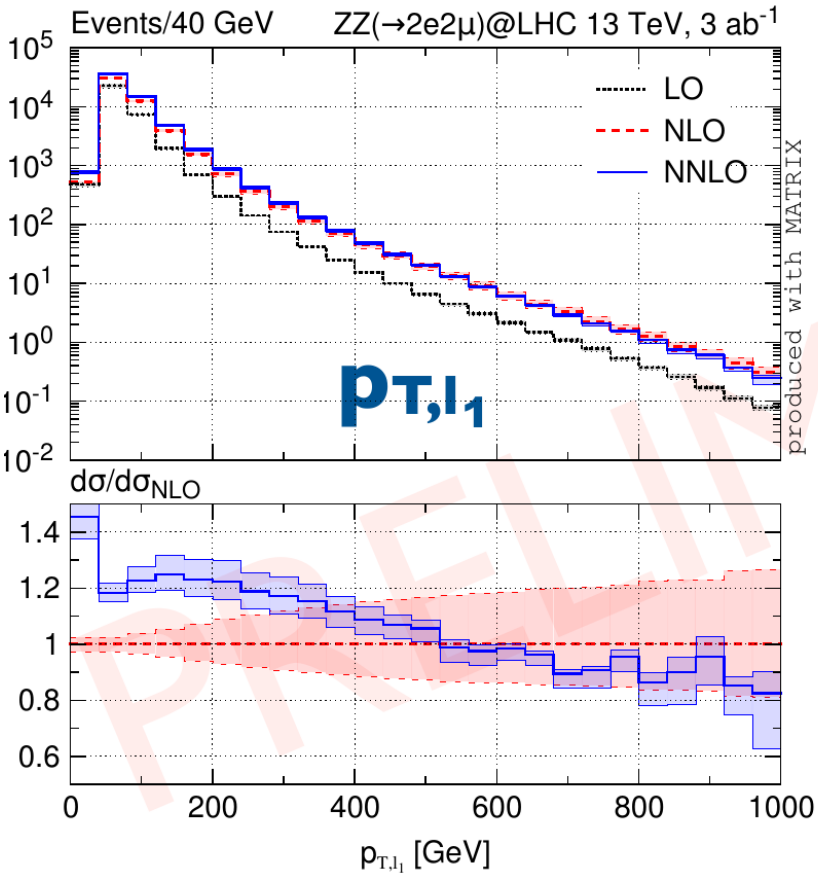
×2.4

on-shell

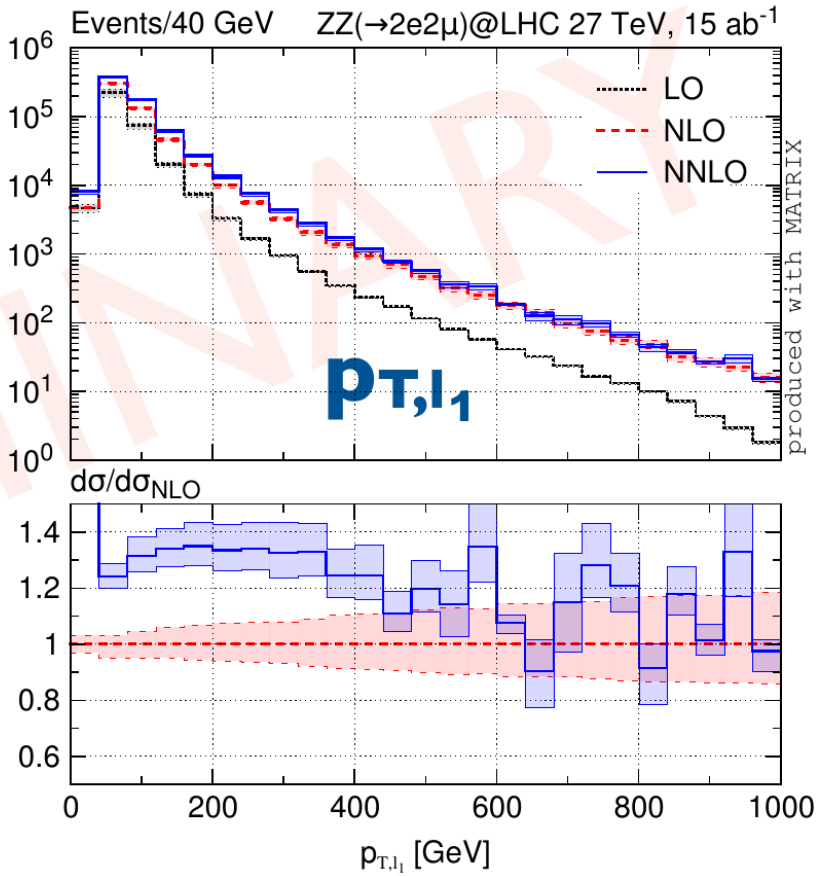
off-shell

NNLO QCD results – ZZ

13 TeV, 3 ab^{-1}



27 TeV, 15 ab^{-1}



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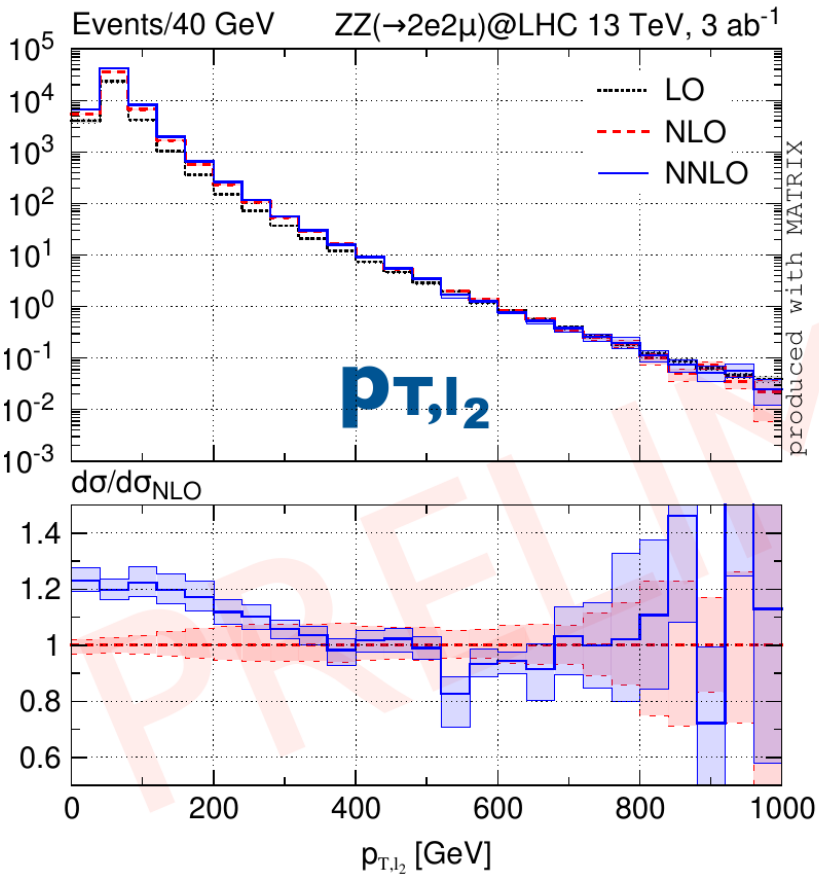

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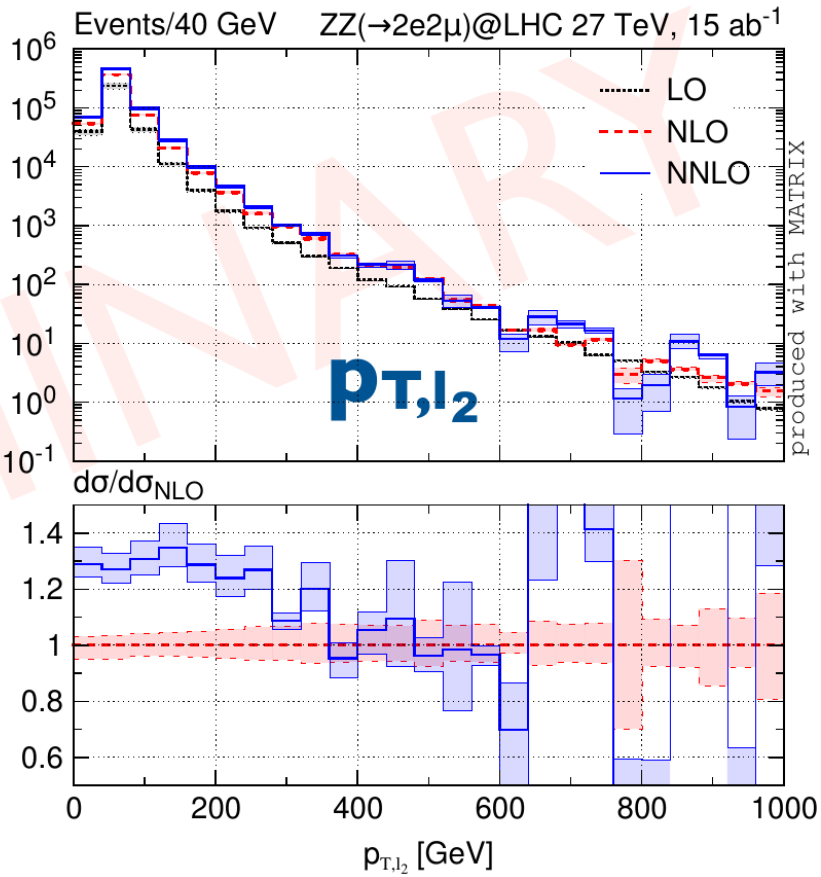

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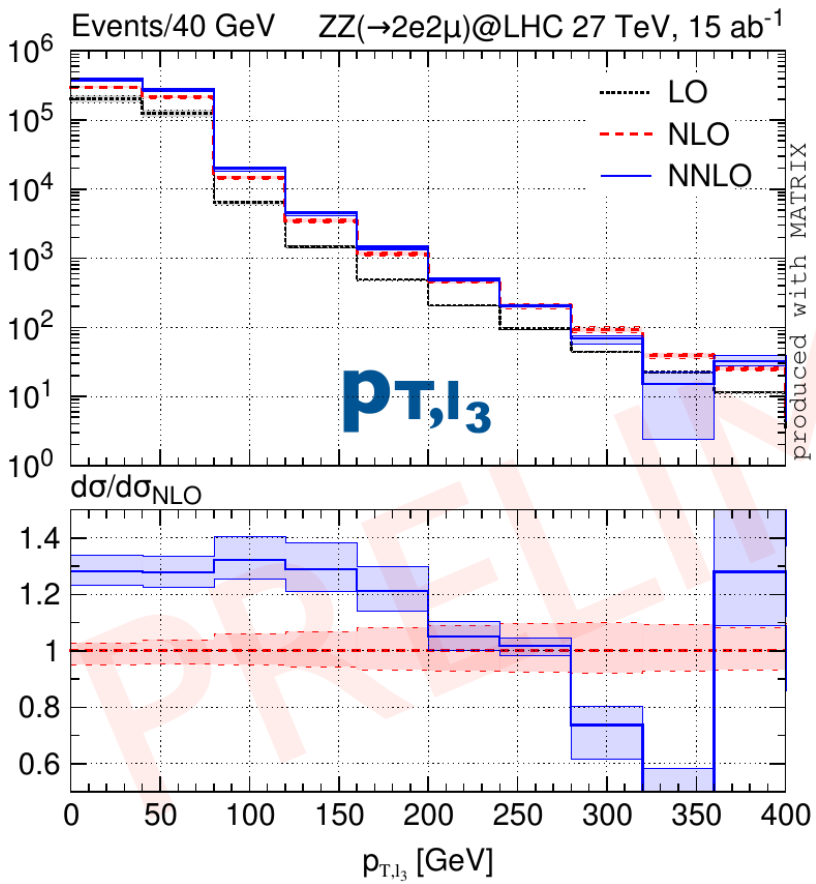
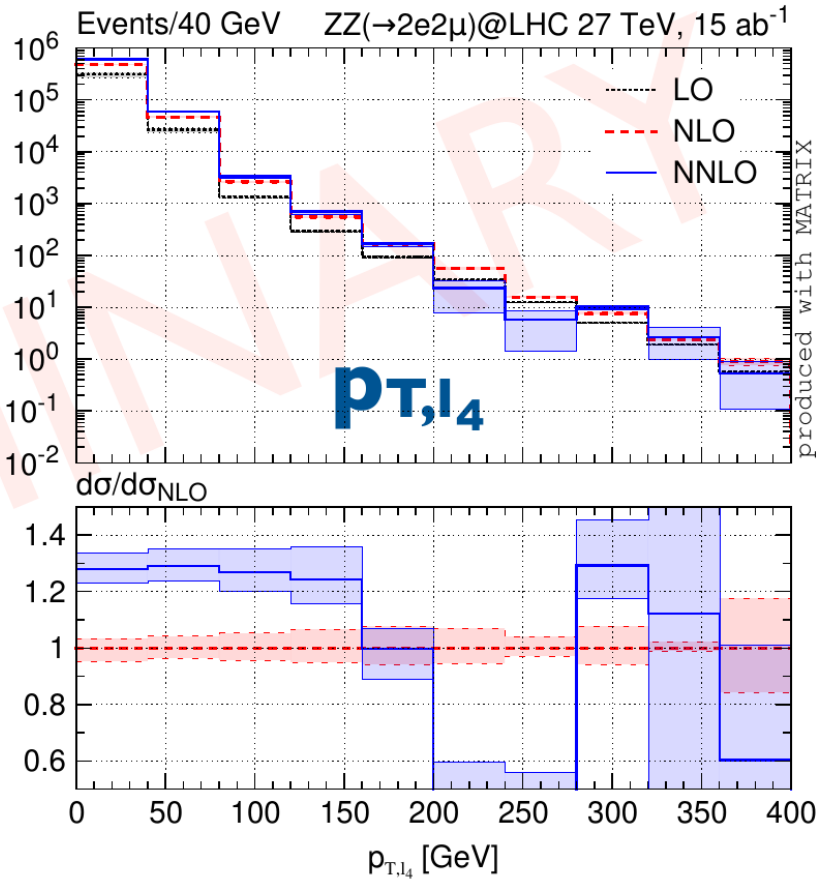
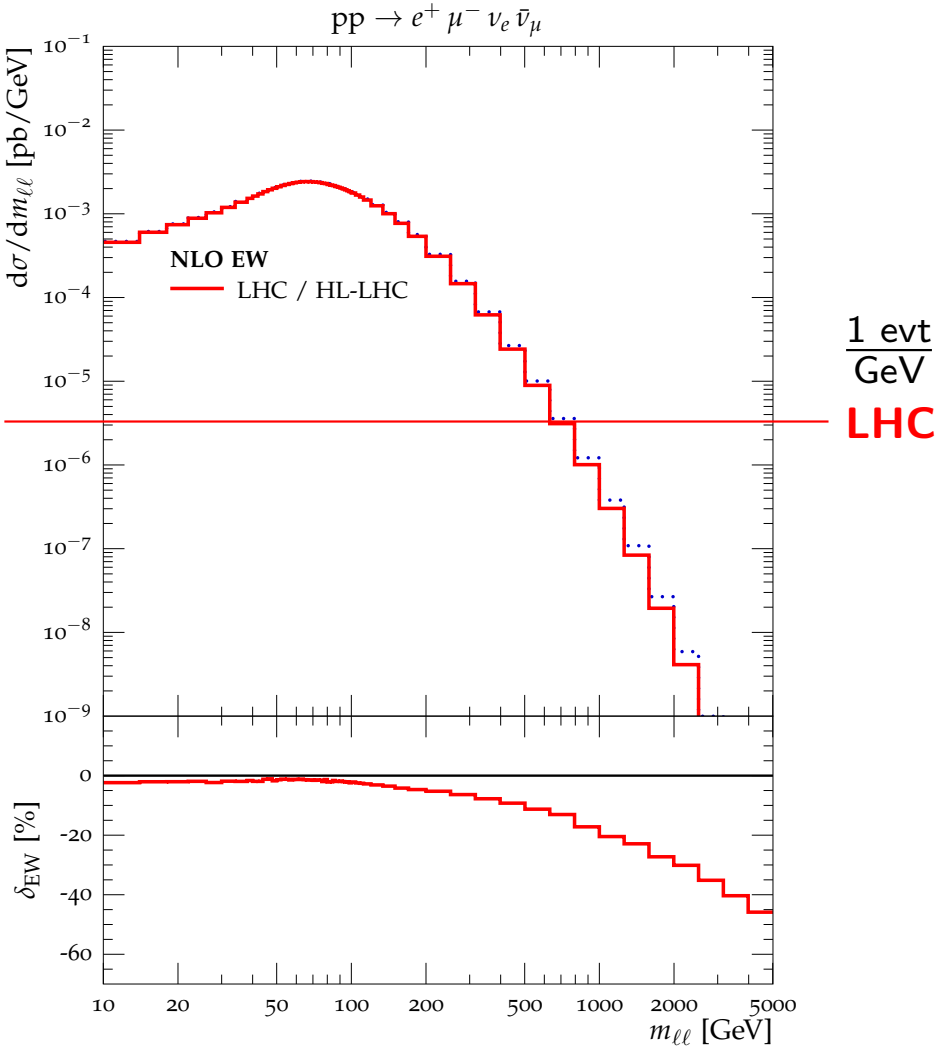




NLO EW results – WW



$\frac{1\ \text{evt}}{\text{GeV}}$ **LHC**

- increased reach with increased luminosity
  $13\,\text{TeV} \Rightarrow 14\,\text{TeV}$
  $300\,\text{fb}^{-1} \Rightarrow 3\,\text{ab}^{-1}$
- increased reach with increased collider energy
  $14\,\text{TeV} \Rightarrow 27\,\text{TeV}$
  $3\,\text{ab}^{-1} \Rightarrow 12\,\text{ab}^{-1}$

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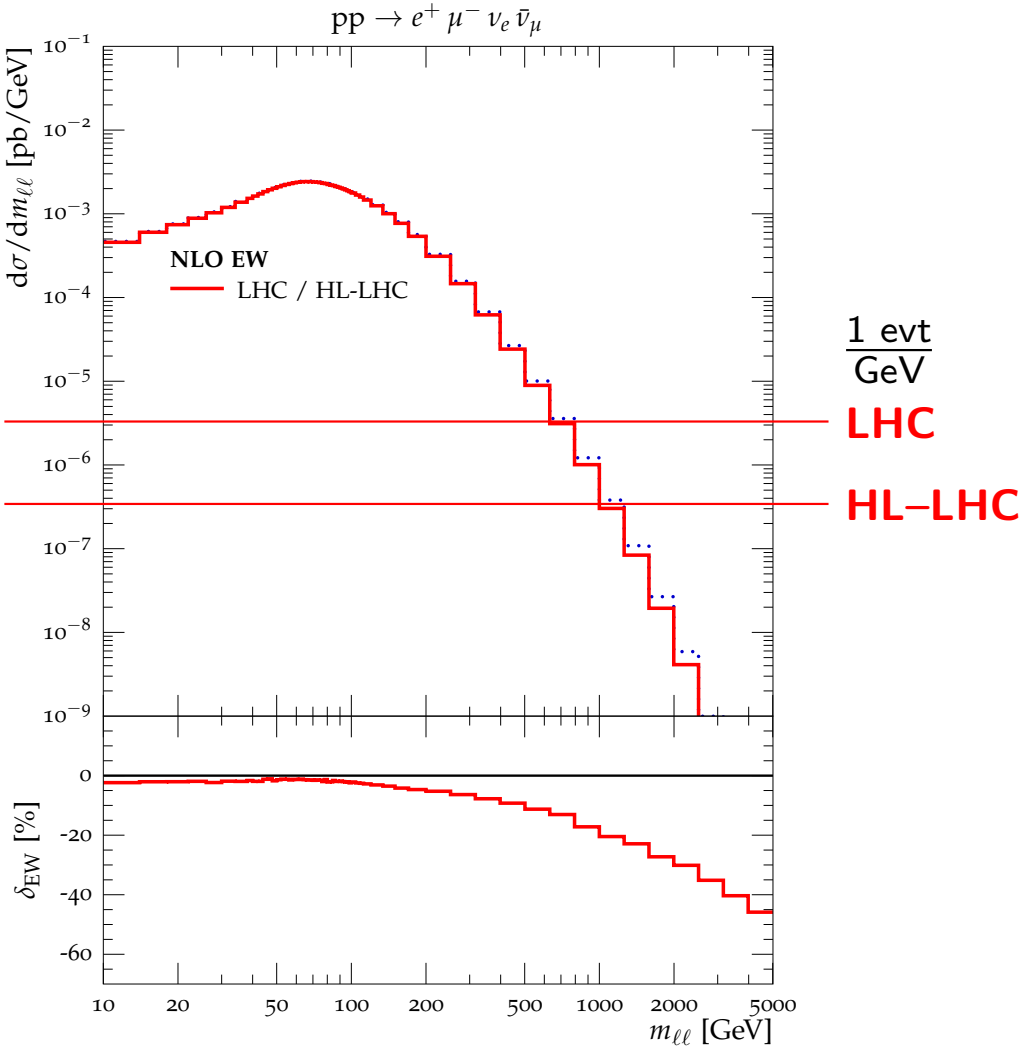

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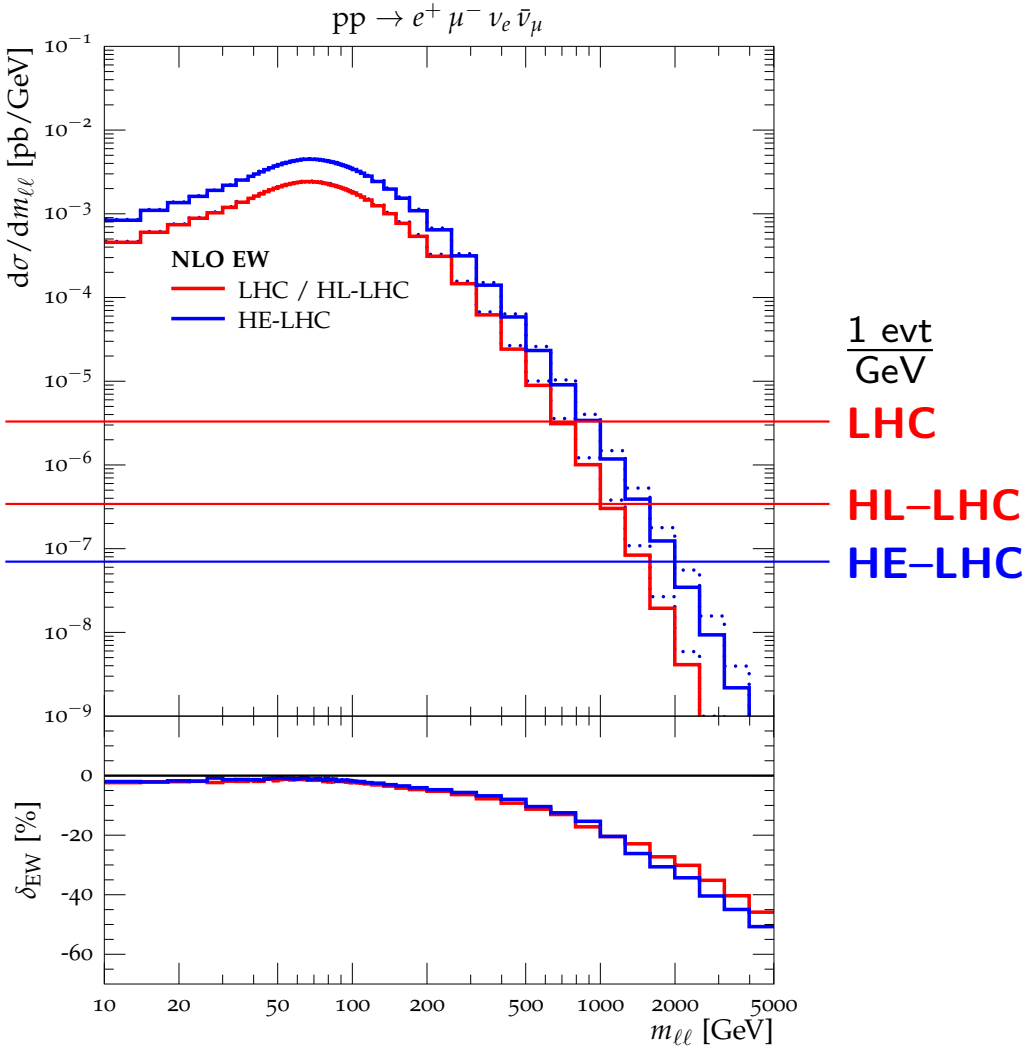

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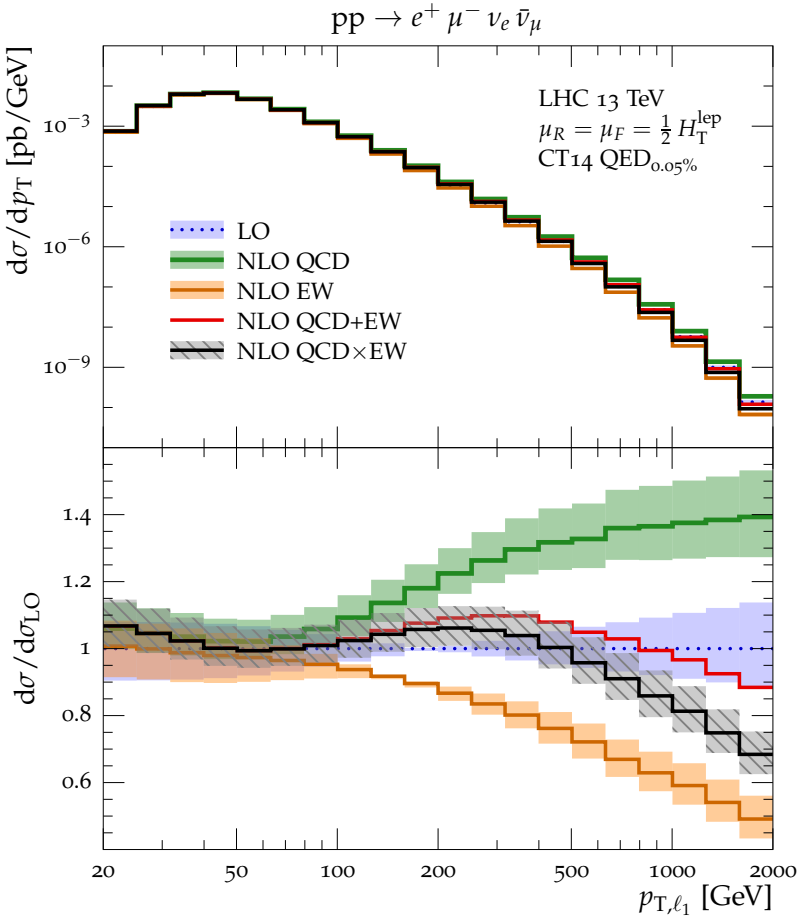
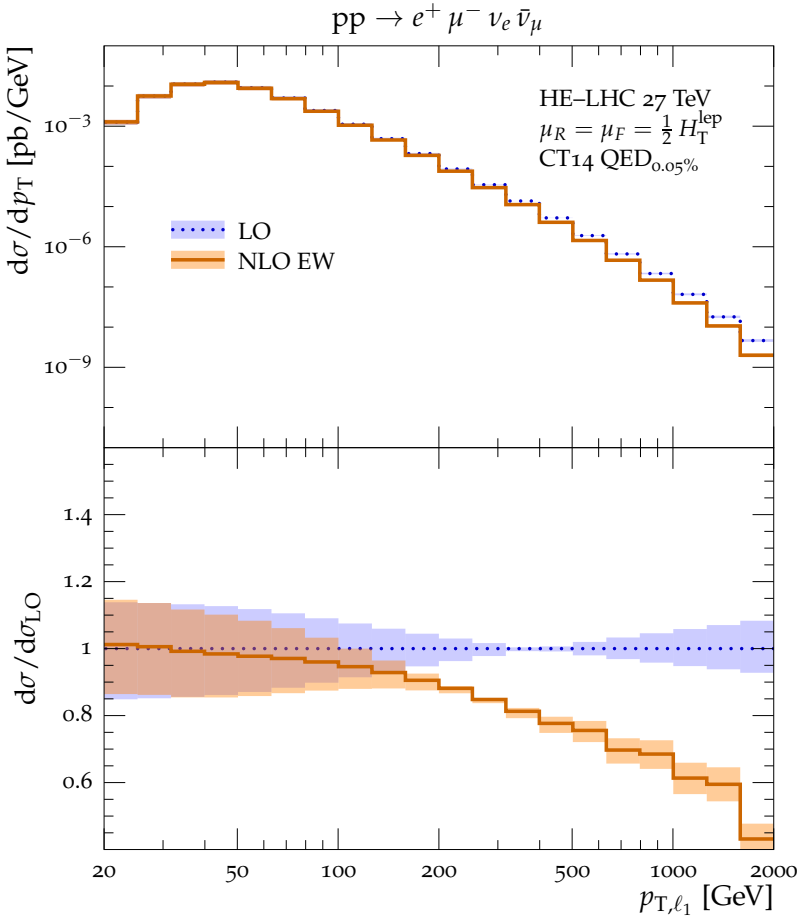
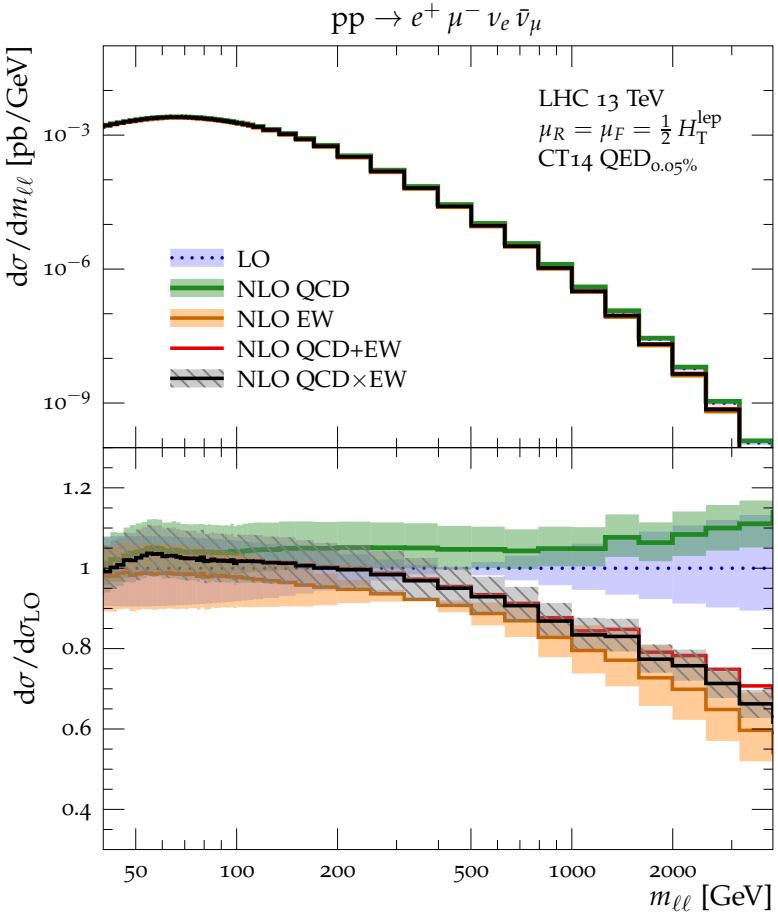
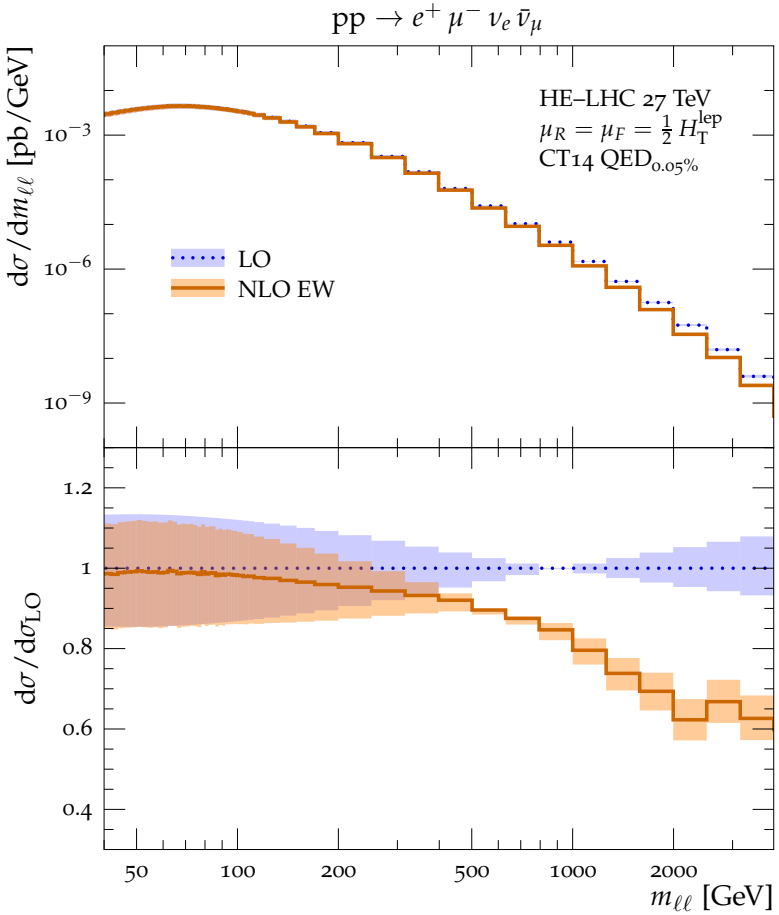




- xs increase in identical fiducial region: inclusive ~ 2, with $p_T > 500\,\text{GeV} \sim 5.5$
- EW corrections very similar (at least in Sudakov regime where large)

NLO EW results – WW





- xs increase in identical fiducial region:
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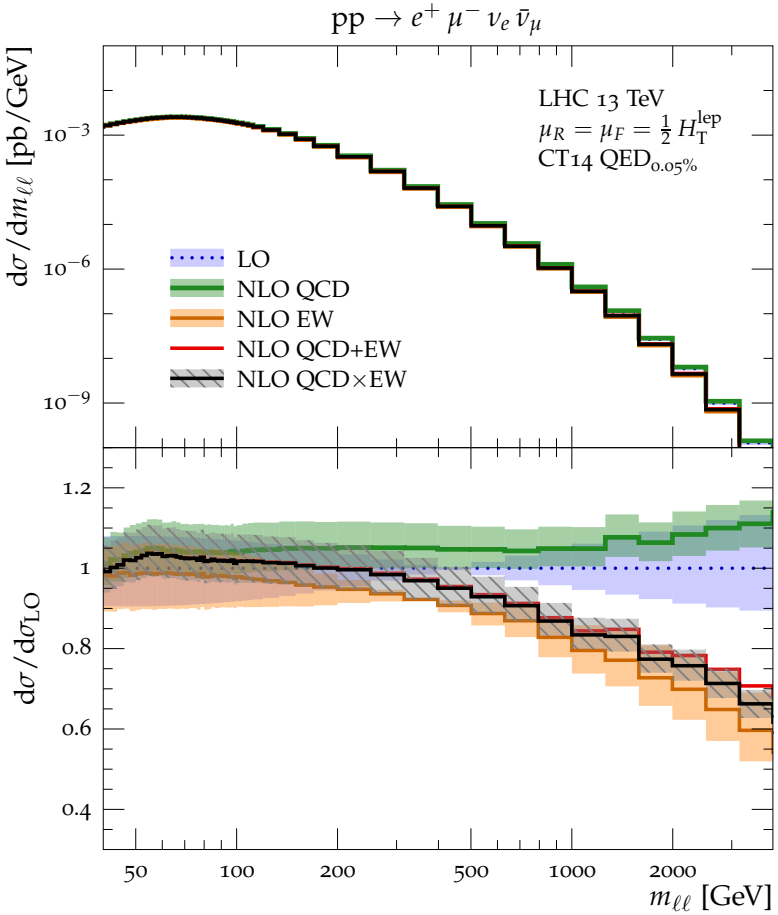
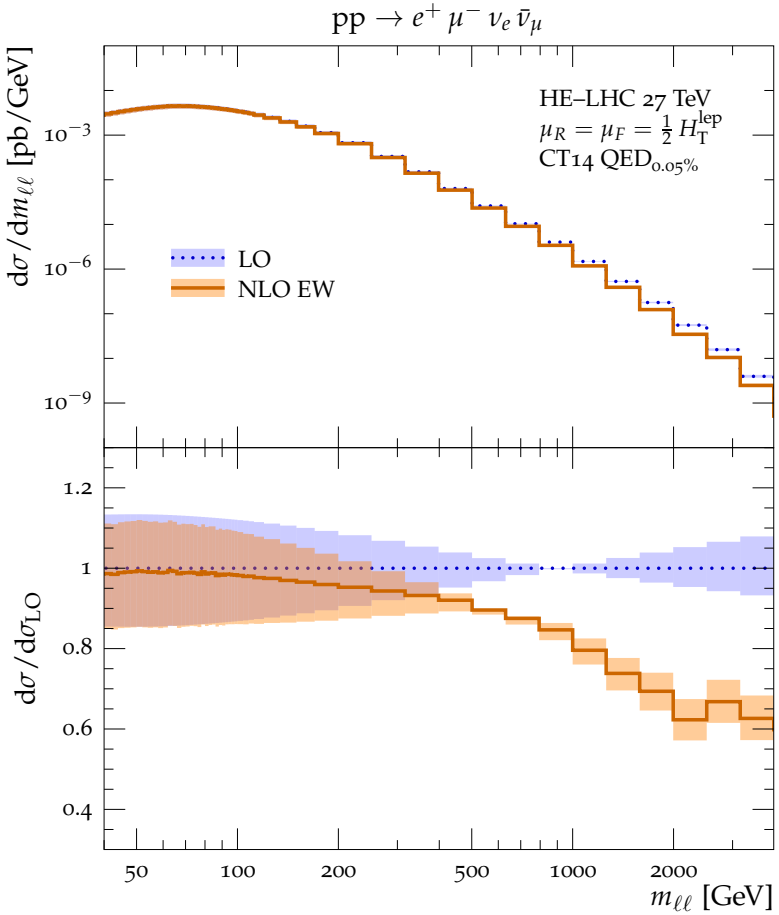
NLO EW results – WW





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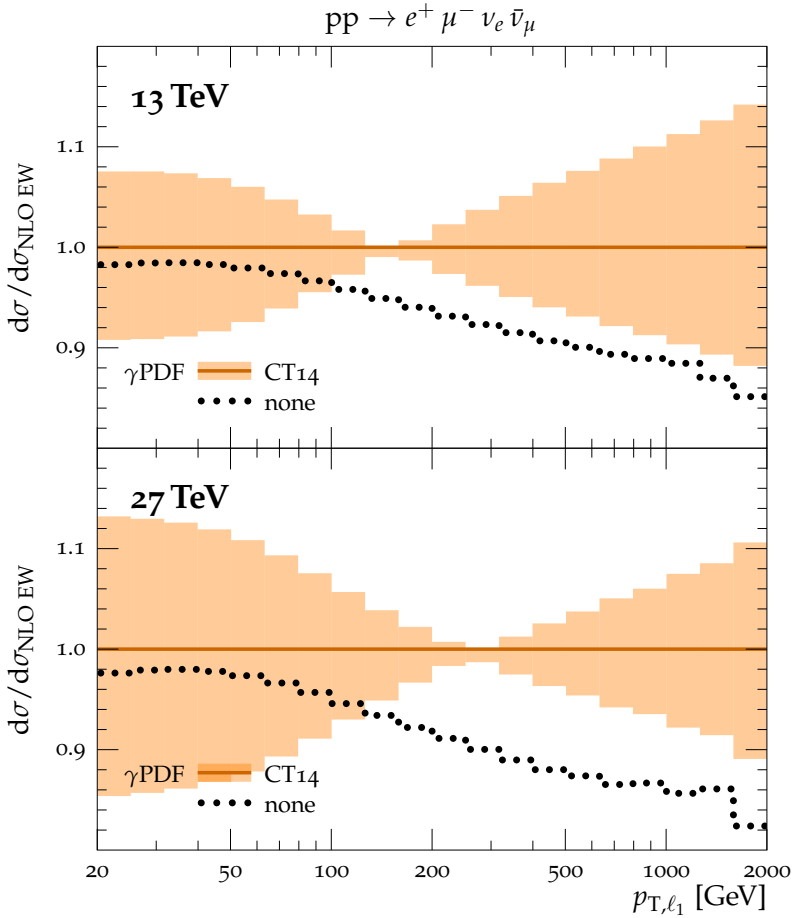
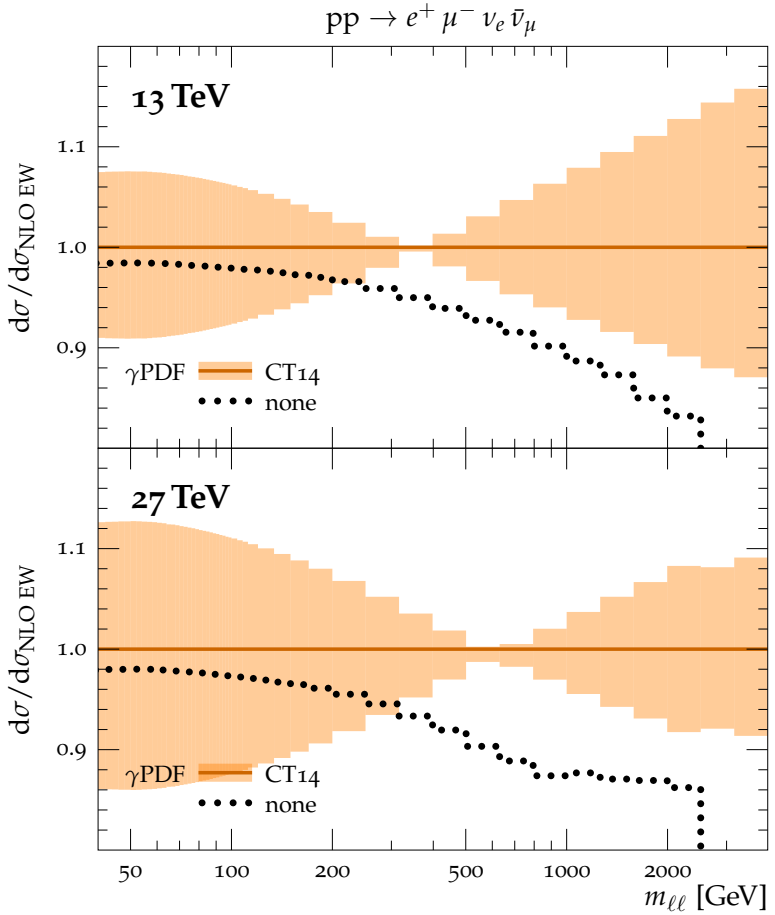
γ-PDF importance at 13 and 27 TeV

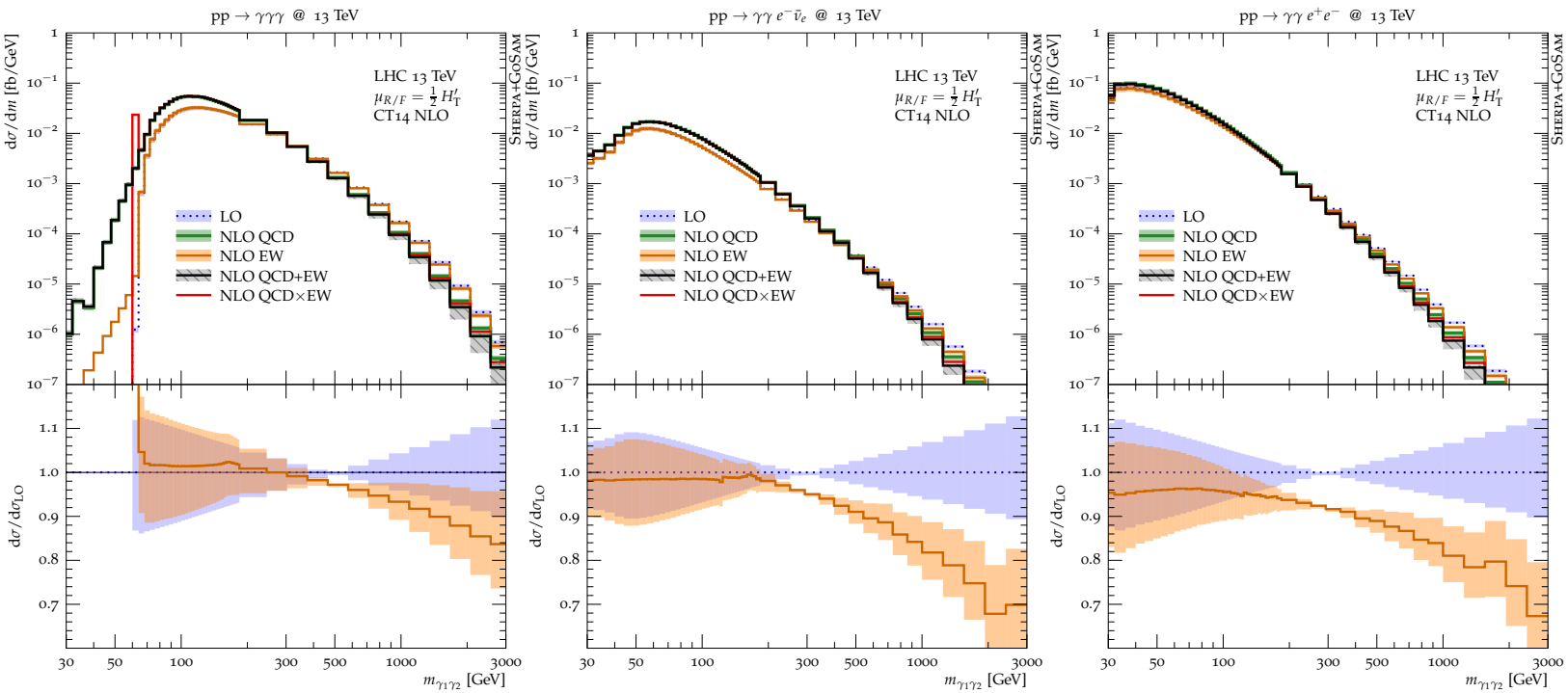




- importance of γ-PDF in same order of magnitude, but somewhat larger at 27 TeV

NLO EW results – $\gamma\gamma + V$ production

Greiner, MS arXiv:1710.11514



- higher luminosity ⇒ more events in tails
- EW correction more important

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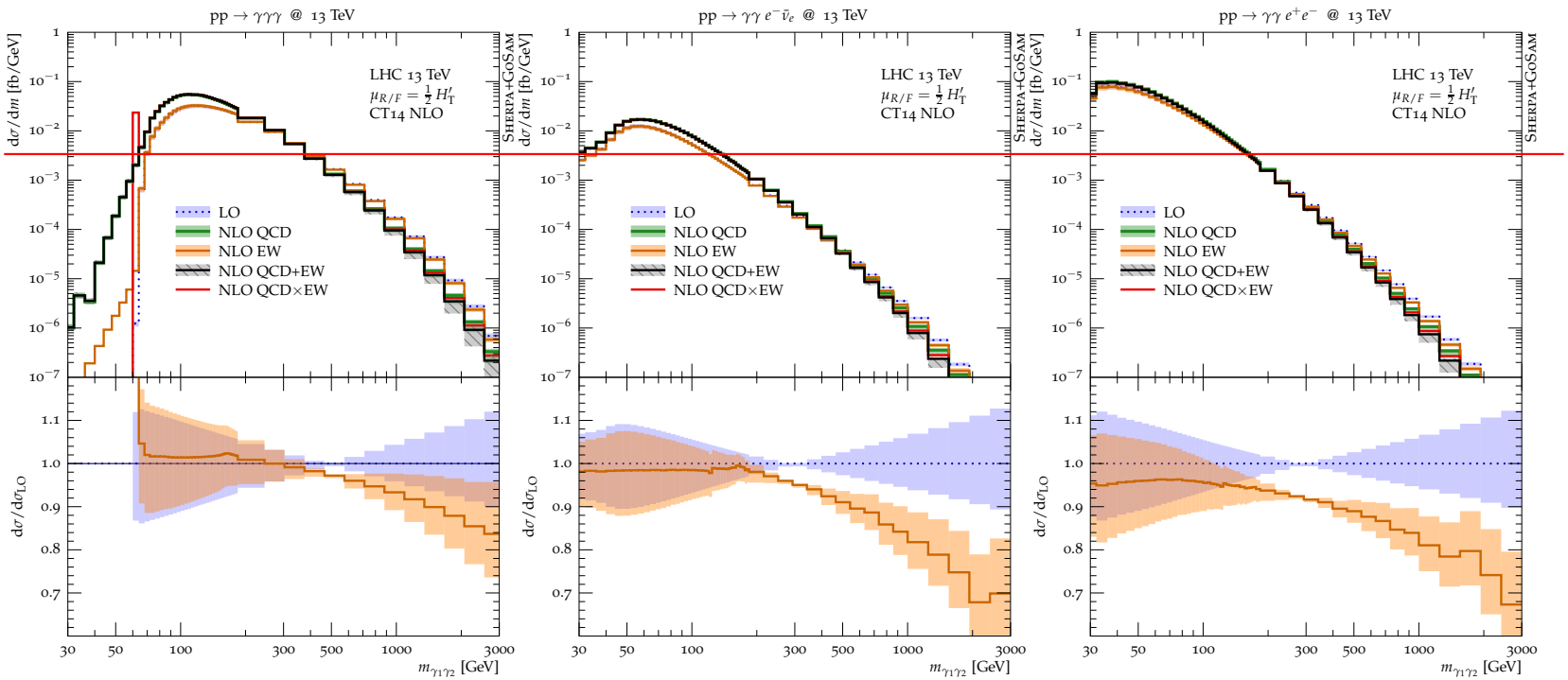

1 evt / GeV LHC

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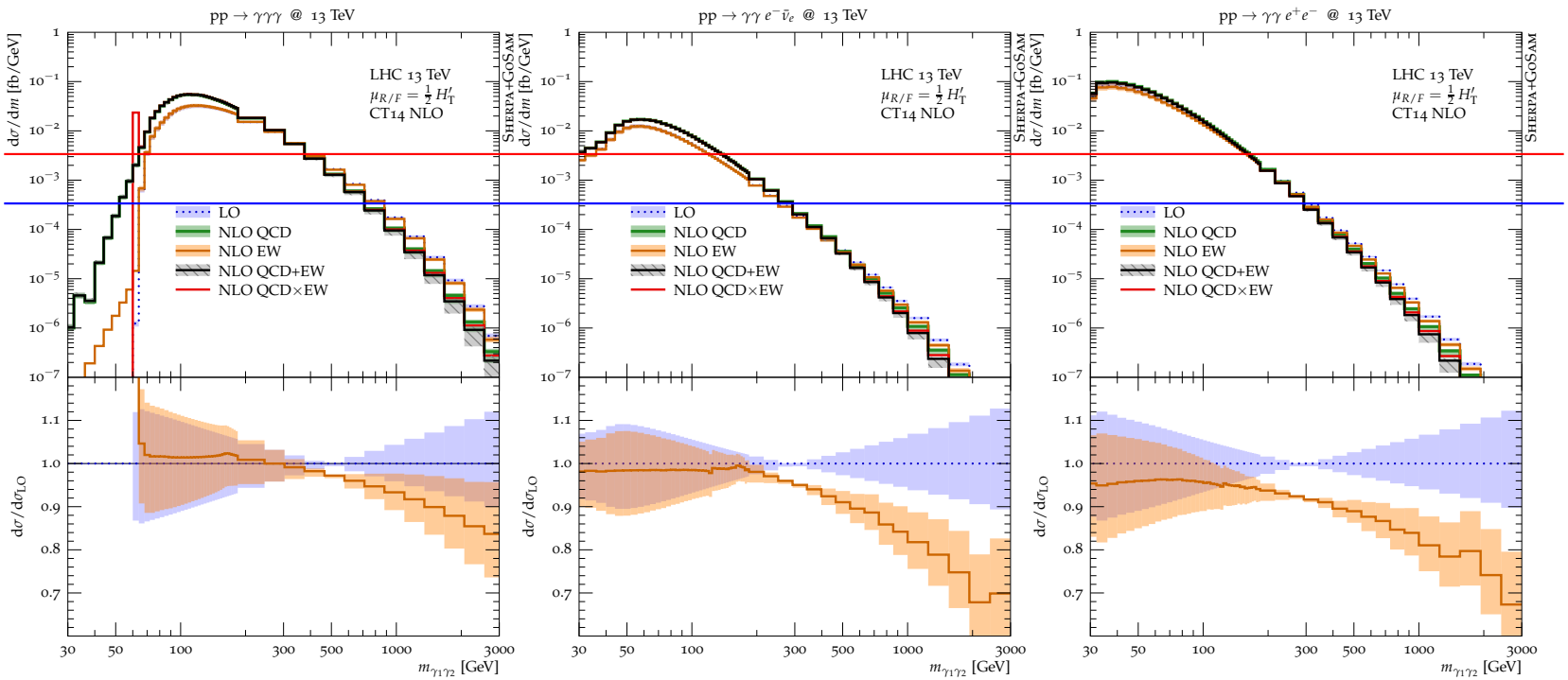

1 evt / GeV

LHC

HL–LHC

- higher luminosity ⇒ more events in tails
- EW correction more important

Planned contributions

- studies for 14 & 27 TeV:
  - NNLO QCD and NLO EW for diboson processes
    Grazzini, Kallweit, Wiesemann; Kallweit, Lindert, Pozzorini, MS
  - NLO QCD and NLO EW for $\gamma\gamma\gamma$, $\gamma\gamma\ell\ell$, $\gamma\gamma\ell\nu$
    Greiner, MS
- progressing well, many numbers already there
- anything of particular interest?

Thank you for your attention!