

Report on the comparison of codes for the simulation of Drell-Yan processes

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participants:

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G.Montagna, A.Mueck, P.Nason, O.Nicrosini, F.Petriello, F.Piccinini, W.Plazczek, E.Re, A.A.Sapronov,
A.Vicini, D.Wackerroth, Z.Was,...

Motivations

- The measurement of EW parameters is precision physics which requires the understanding, both theoretical and experimental, of the observables at the per mille level
- The perfect tool that includes all the available informations in a unique framework does not exist
- The detailed comparison of the different available simulation codes can help to merge coherently their content

- Two codes that have the same perturbative approximation, the same input parameters (couplings, masses, PDFs), the same setup (choice of scales, acceptance cuts), should yield exactly the same results, within the accuracy of the numerical integration.

- The results of different codes can be meaningfully combined only if they satisfy the previous point (in their common part).

Goals

- to verify at any time that a given code works properly according to what its authors have foreseen, producing public benchmarks
- to demonstrate explicitly the level of agreement of different codes that include identical subsets of radiative corrections
- to expose the impact of different subsets of higher-order corrections and of differences in their implementations
- to discuss the impact of some recipes used to combine different sets of radiative corrections

Strategy

- 1) **tuned comparison** of the codes
= technical check that they agree,
when they use the same setup and with the same perturbative approximation
- 2) definition of a suitable input scheme
that minimizes the size of higher-order corrections and
still allows for the comparison of QCD and EW predictions
in this scheme, **fixed-order benchmark results** with (N)NLO accuracy
- 3) quantitative evaluation of the **size of higher-order corrections**, **beyond NLO results**
sensible comparison of the impact of different h.o. QCD and EW subsets
expressed as percentage variations with respect to the benchmarks
- 4) comparison of different recipes of **combination of h.o. corrections**, e.g. QCD and EW

Participants

- NNLO QCD: DYNNLO, FEWZ, SHERPA M.Grazzini, D.de Florian, G.Ferrera; F.Petriello, Y.Li; S.Hoeche, Y.Li, S.Prestel
- NLO QCD \otimes Parton Shower: POWHEG, SHERPA S.Alioli, P.Nason, E.Re; S.Hoeche, Y.Li, S.Prestel
- NNLO QCD \otimes Parton Shower: SHERPA S.Hoeche, Y.Li, S.Prestel
- QED PS/SF: HORACE, PHOTOS, RADY G.Montagna, O.Nicrosini, A.Vicini; Z.Was; S.Dittmaier, M.Krämer, A.Mück
- NLO EW: HORACE, RADY, SANC, WINHAC, WZGRAD G.Montagna, O.Nicrosini, A.Vicini; A.Arbutov, D.Bardin, S.Bondarenko, L.Kalinowskaya; W.Plazek; S.Dittmaier, M.Krämer, A.Mück; D.Wackerroth
- NLO EW \otimes QED PS/YFS/SF: HORACE, RADY, WINHAC G.Montagna, O.Nicrosini, A.Vicini; W.Plazek; S.Dittmaier, M.Krämer, A.Mück
- NLO QCD+NLO EW: RADY, SANC, POWHEG_BMNNP, POWHEG_BW S.Dittmaier, M.Krämer, A.Mück; A.Arbutov, D.Bardin, S.Bondarenko, L.Kalinowskaya; L.Barze, G.Montagna, P.Nason, O.Nicrosini, F.Piccinini; C.Bernaciak, D.Wackerroth
- NNLO QCD+NLO EW: FEWZ F.Petriello, Y.Li
- (NLO QCD+NLO EW) \otimes Pythia: POWHEG_BMNNP, POWHEG_BW L.Barze, G.Montagna, P.Nason, O.Nicrosini, F.Piccinini; C.Bernaciak, D.Wackerroth
- (NLO QCD+NLO EW) \otimes Pythia \otimes PHOTOS: POWHEG_BMNNP L.Barze, G.Montagna, P.Nason, O.Nicrosini, F.Piccinini

Tuned comparisons: the setup

- numerical values of all the input parameters

$$\begin{aligned}
 G_\mu &= 1.1663787 \times 10^{-5} \text{ GeV}^{-2}, & \alpha &= 1/137.035999074, & \alpha_s &\equiv \alpha_s(M_Z^2) = 0.12018 \\
 M_Z &= 91.1876 \text{ GeV}, & \Gamma_Z &= 2.4952 \text{ GeV} \\
 M_W &= 80.385 \text{ GeV}, & \Gamma_W &= 2.085 \text{ GeV} \\
 M_H &= 125 \text{ GeV}, \\
 m_e &= 0.510998928 \text{ MeV}, & m_\mu &= 0.1056583715 \text{ GeV}, & m_\tau &= 1.77682 \text{ GeV} \\
 m_u &= 0.06983 \text{ GeV}, & m_c &= 1.2 \text{ GeV}, & m_t &= 173.5 \text{ GeV} \\
 m_d &= 0.06984 \text{ GeV}, & m_s &= 0.15 \text{ GeV}, & m_b &= 4.6 \text{ GeV} \\
 |V_{ud}| &= 0.975, & |V_{us}| &= 0.222 \\
 |V_{cd}| &= 0.222, & |V_{cs}| &= 0.975 \\
 |V_{cb}| = |V_{ts}| = |V_{ub}| &= & |V_{td}| = |V_{tb}| &= 0
 \end{aligned} \tag{2}$$

- input scheme (α_0, M_W, M_Z)

(choice motivated by the existence of earlier detailed comparisons)

- PDF set MSTW2008nlo (MSTW2008nnlo for NNLO-QCD results), MSbar factorization

- scales: $\mu_r = \mu_f = M(l \text{ nu})$ in DY-CC, $\mu_r = \mu_f = M(l+l^-)$ in DY-NC

$$\begin{aligned}
 \text{Tevatron : } & p_T(\ell) > 25 \text{ GeV}, & |\eta(\ell)| < 1, & \cancel{p}_T > 25 \text{ GeV}, & \ell &= e, \mu, \\
 \text{LHC : } & p_T(\ell) > 25 \text{ GeV}, & |\eta(\ell)| < 2.5, & \cancel{p}_T > 25 \text{ GeV}, & \ell &= e, \mu, \\
 \text{LHCb : } & p_T(\ell) > 20 \text{ GeV}, & 2 < \eta(\ell) < 4.5, & \cancel{p}_T > 20 \text{ GeV}, & \ell &= e, \mu(\gamma)
 \end{aligned}$$

- acceptance cuts

- distinction between electrons and muons in final state

Tevatron and LHC	
electrons	muons
combine e and γ momentum four vectors, if $\Delta R(e, \gamma) < 0.1$	reject events with $E_\gamma > 2 \text{ GeV}$ for $\Delta R(\mu, \gamma) < 0.1$
reject events with $E_\gamma > 0.1 E_e$ for $0.1 < \Delta R(e, \gamma) < 0.4$	reject events with $E_\gamma > 0.1 E_\mu$ for $0.1 < \Delta R(\mu, \gamma) < 0.4$

Tuned comparison: total cross sections

code	LO	NLO QCD	NLO EW μ	NLO EW e	NNLO QCD
HORACE	2897.38(8)	×	2988.2(1)	2915.3(1)	×
WZGRAD	2897.33(2)	×	2987.94(5)	2915.39(6)	×
RADY	2897.35(2)	2899.2(4)	2988.01(4)	2915.38(3)	×
SANC	2897.30(2)	2899.7(6)	2987.77(3)	2915.00(3)	×
DYNNLO	2897.32(5)	2899(1)	×	×	
FEWZ	2897.2(1)	2899.4(3)	×	×	3012(2)
POWHEG-w	2897.34(4)	2899.41(9)	×	×	×
POWHEG_BW	2897.4(1)	2899.2(3)	2987.5(6)		×
POWHEG_BMNNP	2897.36(5)		2988.49(7)		×

Table 3: Tuned comparison of total cross sections (in pb) for $pp \rightarrow W^+ \rightarrow l^+ \nu_l + X$ at the 8 TeV LHC, with ATLAS/CMS cuts and *bare* leptons.

code	LO	NLO QCD	NLO EW μ	NLO EW e	NNLO QCD
HORACE	2008.84(5)	×	2076.48(9)	2029.15(8)	×
WZGRAD	2008.95(1)	×	2076.51(3)	2029.26(3)	×
RADY	2008.93(1)	2050.5(2)	2076.62(2)	2029.29(2)	×
SANC	2008.926(8)	2050.5(4)	2076.56(2)	2029.19(3)	×
DYNNLO	2008.89(3)	2050.2(9)	×	×	
FEWZ	2008.9	2049.9(2)	×	×	2104(1)
POWHEG-w	2008.93(3)	2050.14(5)	×	×	×
POWHEG_BW					×
POWHEG_BMNNP	2008.94(3)		2078.03(2)		×

Table 5: Tuned comparison of total cross sections (in pb) for $pp \rightarrow W^- \rightarrow l^- \bar{\nu}_l + X$ at the 8 TeV LHC, with ATLAS/CMS cuts and *bare* leptons.

code	LO	NLO QCD	NLO EW μ	NLO EW e	NNLO QCD
HORACE	431.033(9)	×	438.74(2)	422.08(2)	×
WZGRAD	431.048(7)	×	439.166(6)	422.78(1)	×
RADY	431.047(4)	458.16(3)	438.963(4)	422.536(5)	×
SANC	431.050(2)	458.20(5)	439.004(5)	422.56(1)	×
DYNNLO	431.043(8)	458.2(2)	×	×	
FEWZ	431.00(1)	458.1			469.5(3)
POWHEG-z	431.08(4)	458.19(8)	×	×	×
POWHEG_BMNNP	431.046(9)				×

Table 7: Tuned comparison of total cross sections (in pb) for $pp \rightarrow \gamma, Z \rightarrow l^- l^+ + X$ at the 8 TeV LHC, with ATLAS/CMS cuts and *bare* leptons.

code	LO	NLO-EW μ calo	NLO EW e calo
HORACE	2897.38(8)	2899.0(1)	3003.5(1)
WZGRAD	2897.33(2)	2898.33(5)	3003.33(6)
RADY	2897.35(2)	2898.37(4)	3003.36(4)
SANC	2897.30(2)	2898.18(3)	3003.00(4)

Table 4: Tuned comparison of total cross sections (in pb) $pp \rightarrow W^+ \rightarrow l^+ \nu_l + X$ at the 8 TeV LHC, with ATLAS/CMS cuts and *calorimetric* leptons.

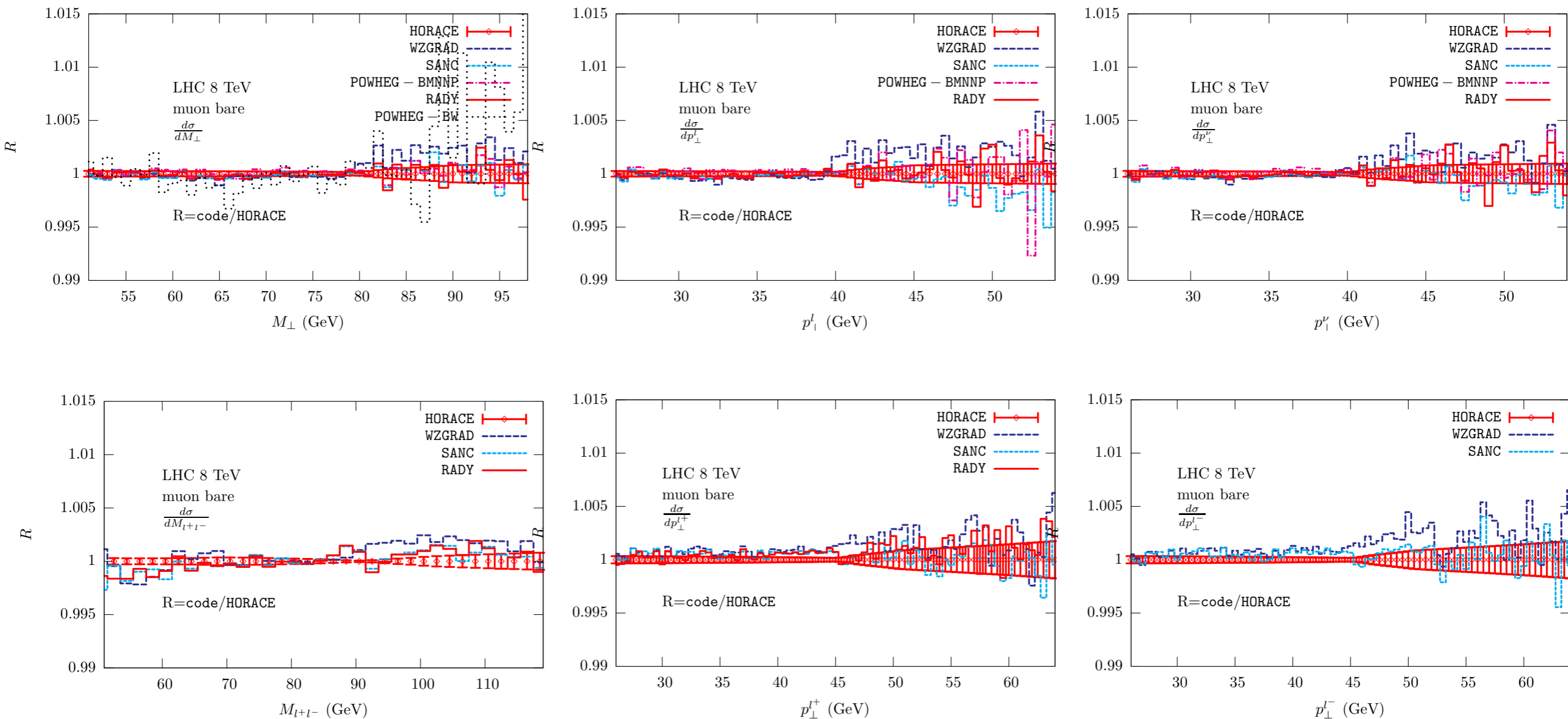
code	LO	NLO-EW μ calo	NLO EW e calo
HORACE	2008.84(5)	2013.67(7)	2085.42(8)
WZGRAD	2008.95(1)	2013.42(3)	2085.26(3)
RADY	2008.93(1)	2013.49(2)	2085.37(2)
SANC	2008.926(8)	2013.48(2)	2085.24(4)

Table 6: Tuned comparison of total cross sections (in pb) for $pp \rightarrow W^- \rightarrow l^- \bar{\nu}_l + X$ at the 8 TeV LHC, with ATLAS/CMS cuts and *calorimetric* leptons.

code	LO	NLO-EW μ calo	NLO EW e calo
HORACE	431.033(9)	407.67(1)	439.68(2)
WZGRAD	431.048(7)	407.852(7)	440.29(1)
RADY	431.047(4)		440.064(5)
SANC	431.050(2)	407.687(5)	440.09(1)

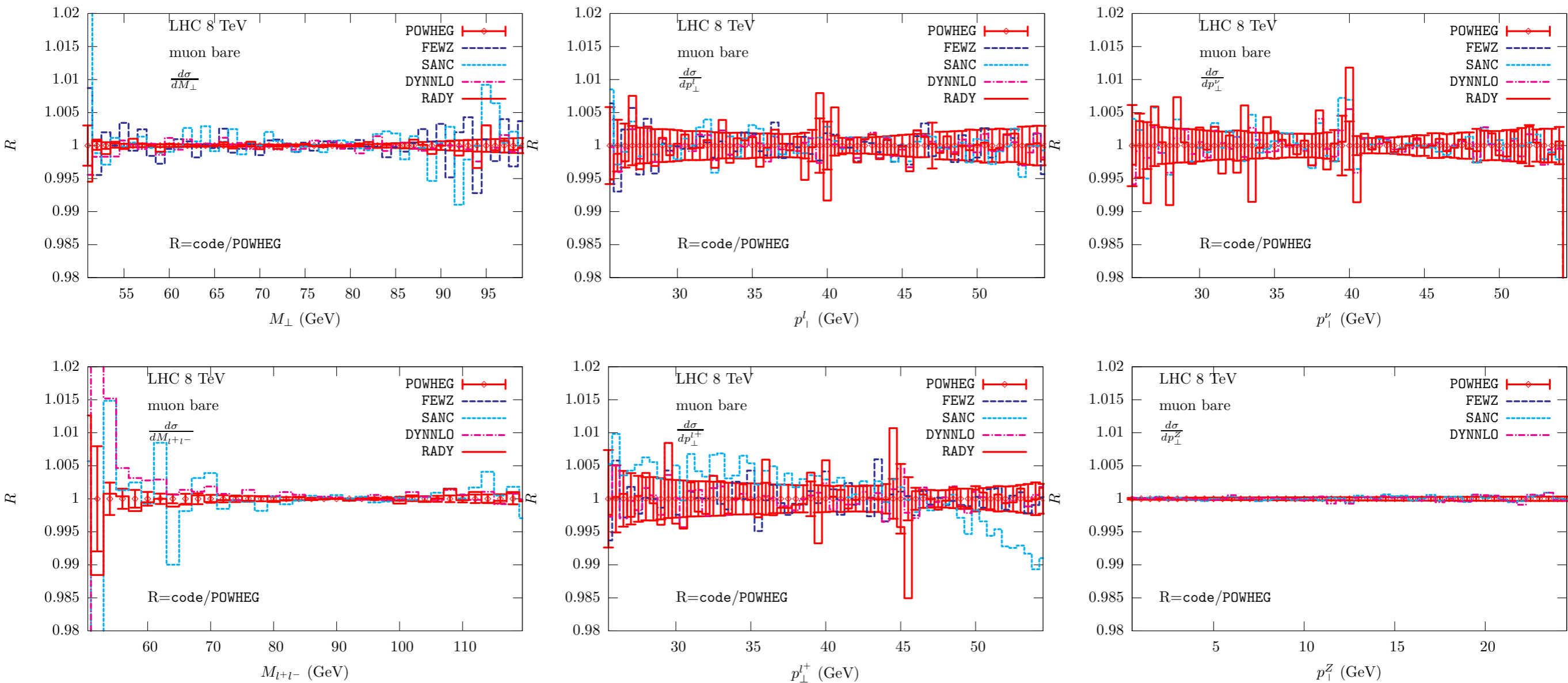
Table 8: Tuned comparison of total cross sections (in pb) for $pp \rightarrow \gamma, Z \rightarrow l^+ l^- + X$ at the 8 TeV LHC, with ATLAS/CMS cuts and *calorimetric* leptons.

Tuned comparison: differential distributions EW



- agreement at the per mil level at the jacobian peak, deviations are smaller than 5 per mil in the tails

Tuned comparison: differential distributions QCD



- agreement at the per mil level at the jacobian peak,
statistical fluctuations in any case smaller than 5 per mil

Input schemes and recommended, benchmark, choice

(g, g', v) must be expressed in terms of physical observables

Gmu scheme: (G_μ, m_W, m_Z)

most natural choice to parametrize EW processes

Gmu expresses the strength of the CC interaction and reabsorbs in its definition large rad.corr.

drawback: the coupling of the photon $\alpha_\mu \sim 1/132$ is larger than $\alpha(0) \sim 1/137$ “natural” value for an on-shell photon

$\alpha(0)$ scheme: $(\alpha(0), m_W, m_Z)$

it solves the problem of the photon coupling but

-it introduces a dependence on the light-quark masses
-it leaves large logarithmic rad.corr. in higher orders

→ not recommended

modified Gmu scheme: recommended solution

the LO couplings are evaluated with Gmu

the NLO-EW corrections are evaluated with $\alpha(0)$

in the NLO-EW calculations, the $O(\alpha)$ relation $G_\mu/\sqrt{2} = g^2/(8 m_W^2) (1 + \Delta r)$ must be used to avoid double counting with the diagrammatic contribution

this choice simultaneously assigns to the real-photon coupling its “natural” value and reabsorbs large rad.corr. in the Gmu definition
does not depend on the light-quark mass values

Benchmark numbers: the setup

same inputs and setup as in the tuned comparison, with few exceptions:

constant width approach for W and Z

$$\begin{aligned} M_Z &= 91.1535 \text{ GeV}, & \Gamma_Z &= 2.4943 \text{ GeV} \\ M_W &= 80.358 \text{ GeV}, & \Gamma_W &= 2.084 \text{ GeV} \end{aligned}$$

additional cut on the lepton-pair transverse mass, in the CC processes $M_{\perp}(l\nu) > 40 \text{ GeV}$

input scheme: modified Gmu scheme

Benchmark numbers: NLO total cross sections

code	LO	NLO QCD	NLO EW μ	NLO EW e calo	NNLO QCD
HORACE	3109.65(8)	×	3022.8(1)		×
WZGRAD	3109.66(3)	×	3022.68(4)		×
RADY					×
SANC	3109.66(2)		3022.53(4)	3038.91(5)	×
DYNNLO		3092.3(9)	×	×	3210(15)
FEWZ		3089.1(3)	×	×	3206(2)
POWHEG-w		3090.4(2)	×	×	×
POWHEG_BW					×
POWHEG_BMNNP					×

Table 9: $pp \rightarrow W^+ \rightarrow l^+ \nu_l$ cross sections (in pb) at the 8 TeV LHC, with ATLAS/CMS cuts and bare leptons.

code	LO	NLO QCD	NLO EW μ	NLO EW e calo	NNLO QCD
HORACE	2156.36(6)	×	2101.17(8)		×
WZGRAD	2156.48(1)	×	2101.23(2)		×
RADY					×
SANC	2156.46(2)		2101.31(4)	2110.69(4)	×
DYNNLO		2189.3(7)	×	×	2233(8)
FEWZ		2187.1(1)	×	×	2238(1)
POWHEG-w		2187.72(6)	×	×	×
POWHEG_BW					×
POWHEG_BMNNP					×

Table 10: $pp \rightarrow W^- \rightarrow l^- \bar{\nu}_l$ cross sections (in pb) at the 8 TeV LHC, with ATLAS/CMS cuts and bare leptons.

code	LO	NLO QCD	NLO EW μ	NLO EW e calo	NNLO QCD
HORACE	462.663	×	443.638		×
WZGRAD	462.681(3)	×	443.726(5)		×
RADY					×
SANC	462.675(2)		443.794(4)		×
DYNNLO		491.94(5)	×	×	501.6(4)
FEWZ		491.62(4)			504.6(3)
POWHEG-z		491.744(4)	×	×	×
POWHEG_BMNNPV					×

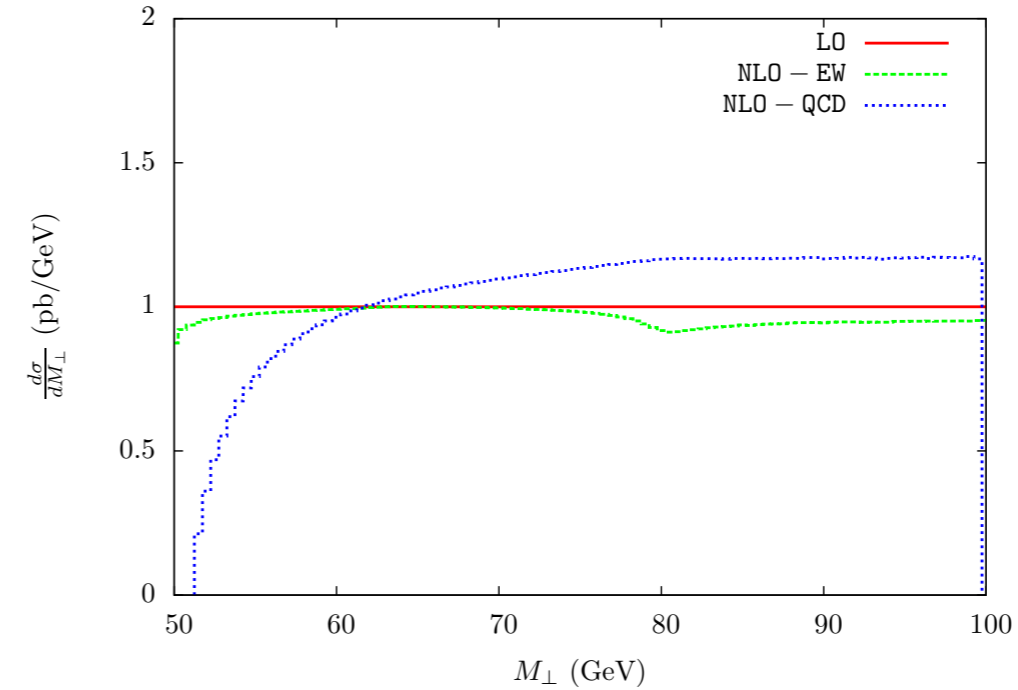
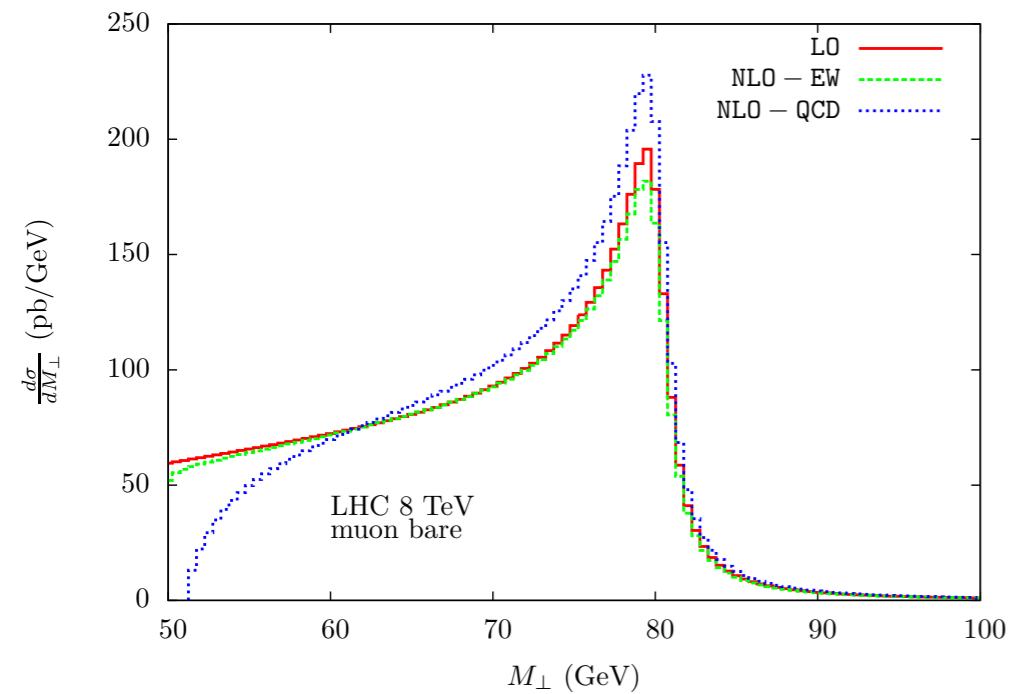
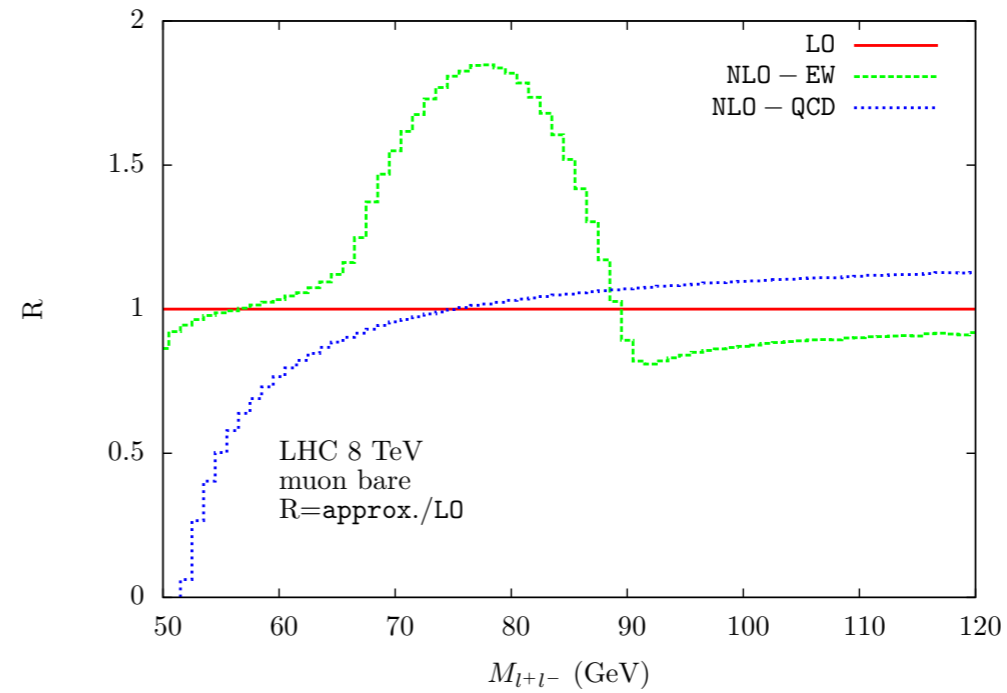
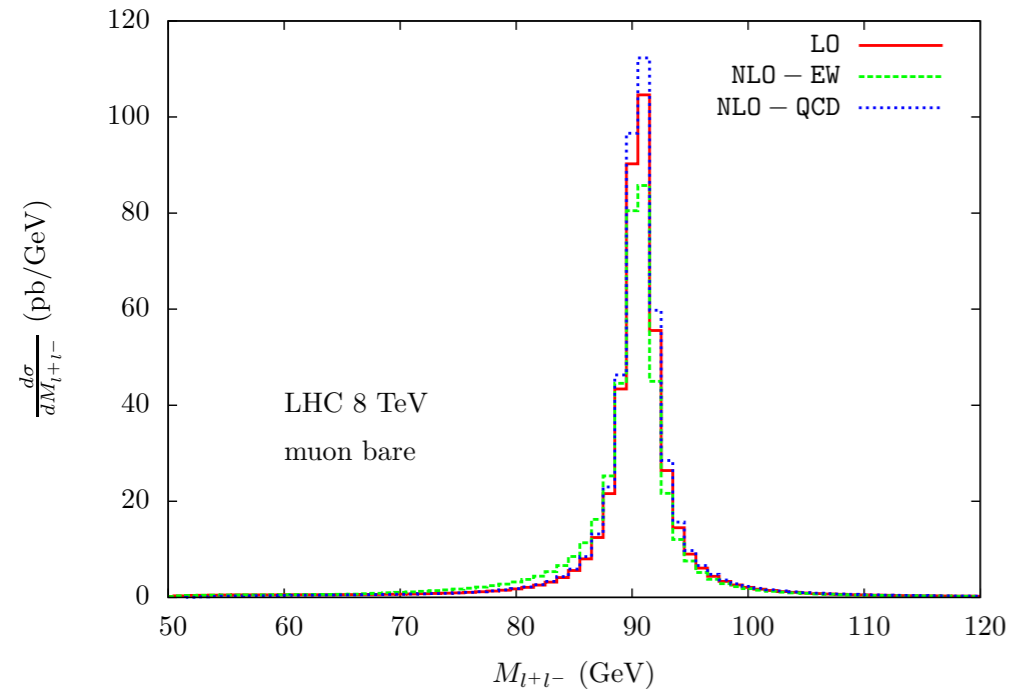
Table 11: $pp \rightarrow \gamma, Z \rightarrow l^- l^+$ cross sections (in pb) at the 8 TeV LHC, with ATLAS/CMS cuts and bare leptons.

input scheme: modified Gmu scheme

in (quick) progress:

collection of all the numbers to fill these tables

Benchmark numbers: NLO differential distributions



the different codes agree in the prediction of the NLO-QCD and NLO-EW corrections in the modified Gmu input scheme

benchmark tables for the main observables can serve as a test of the use of the codes

from this solid starting point it is possible to quantify the impact of h.o. rad.corr.

Radiative corrections: higher order QCD effects

the QCD expansion can be organized with respect to $L_V \equiv \log \left(\frac{p_{\perp}^V}{M_V} \right)$

$$\begin{aligned}
 \sigma &= \sigma_0 + \\
 &A_1 \alpha_s L_V + B_1 \alpha_s + \longleftarrow \text{NLO-QCD} \\
 &A_2 \alpha_s^2 L_V^2 + B_2 \alpha_s^2 L_V + C_2 \alpha_s^2 + \longleftarrow \text{NNLO-QCD} \\
 &A_3 \alpha_s^3 L_V^3 + B_3 \alpha_s^3 L_V^2 + C_3 \alpha_s^3 L_V + D_3 \alpha_s^3 + \dots \longleftarrow \text{NNNLO-QCD} \\
 &\quad \uparrow \quad \quad \uparrow \quad \quad \uparrow \\
 &\quad \text{LL-QCD} \quad \text{NLL-QCD} \quad \text{NNLL-QCD} \quad \dots
 \end{aligned}$$

the first row NLO-QCD is common and tested at high precision for all the QCD codes
the second row has been accurately tested with 3 available codes

we can evaluate the size of some subsets of h.o. corrections, like e.g.:

NNLO-QCD

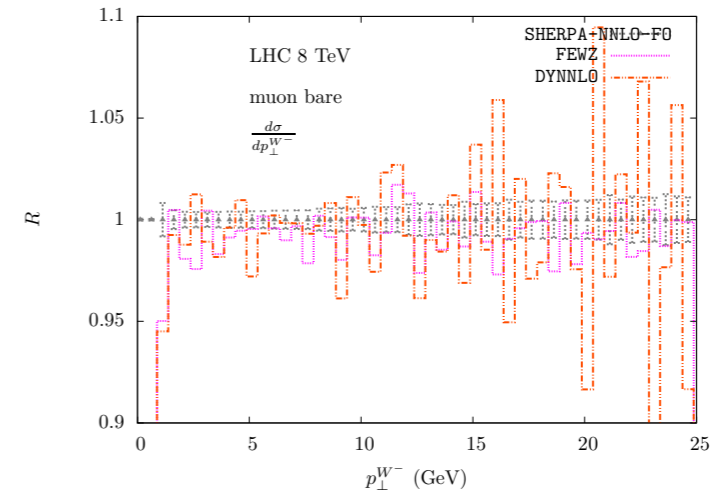
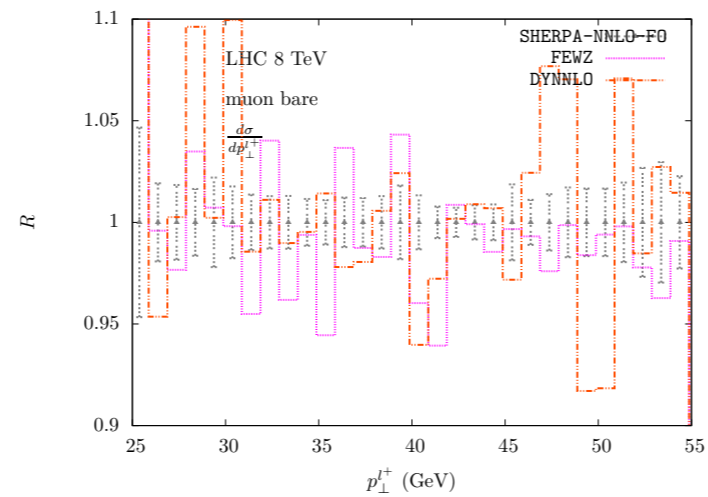
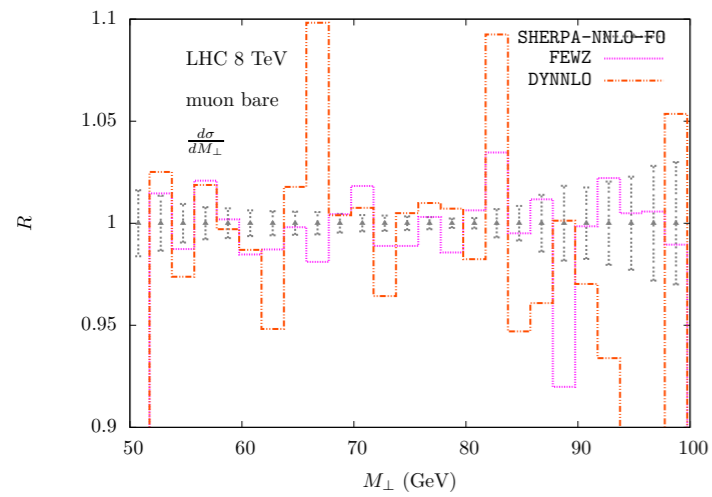
(N)LL-QCD resummed via Parton Shower

all the effects shown in the next slides are of $O(\alpha_s^2)$ and higher

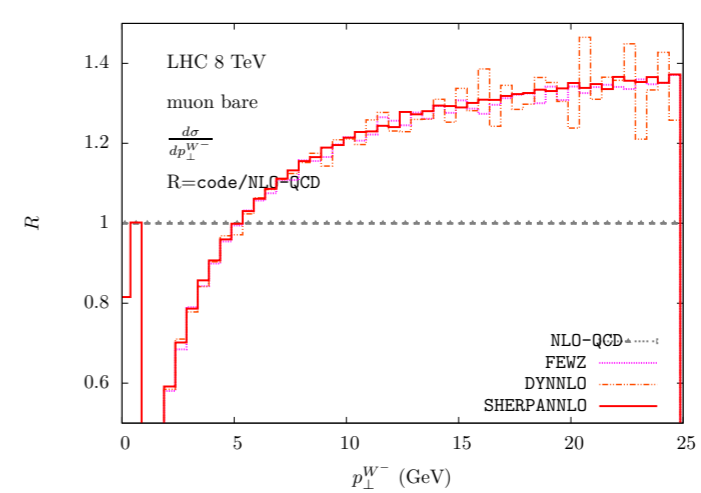
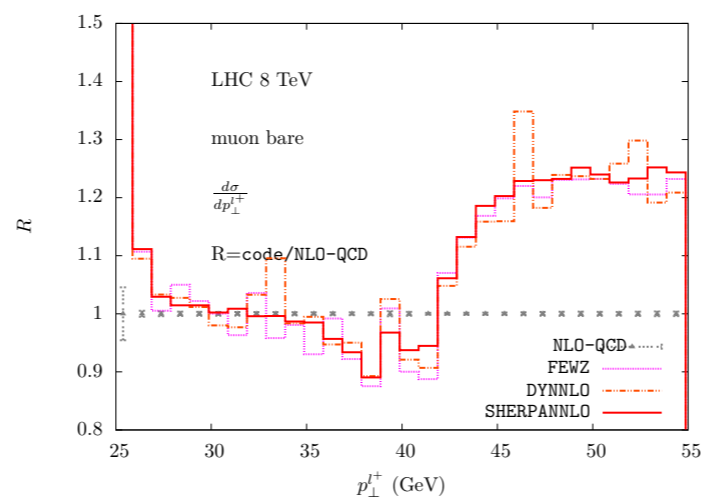
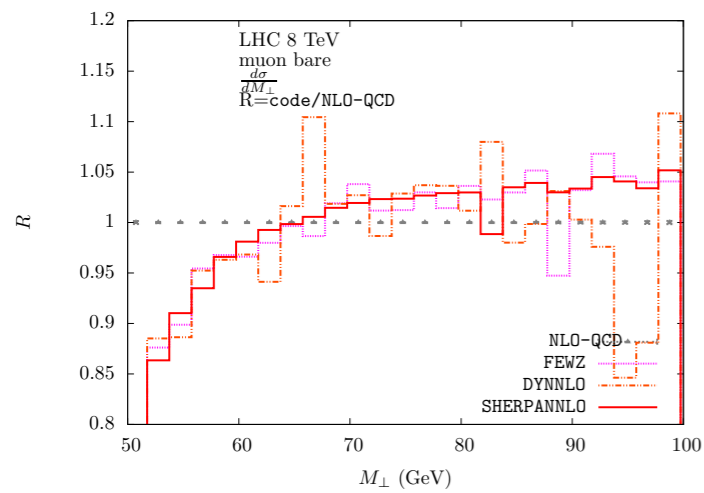
caveat

the representation of the higher-order effects is a delicate issue, that depends on the observable
when the resummation is needed, fixed-order corrections are meaningless

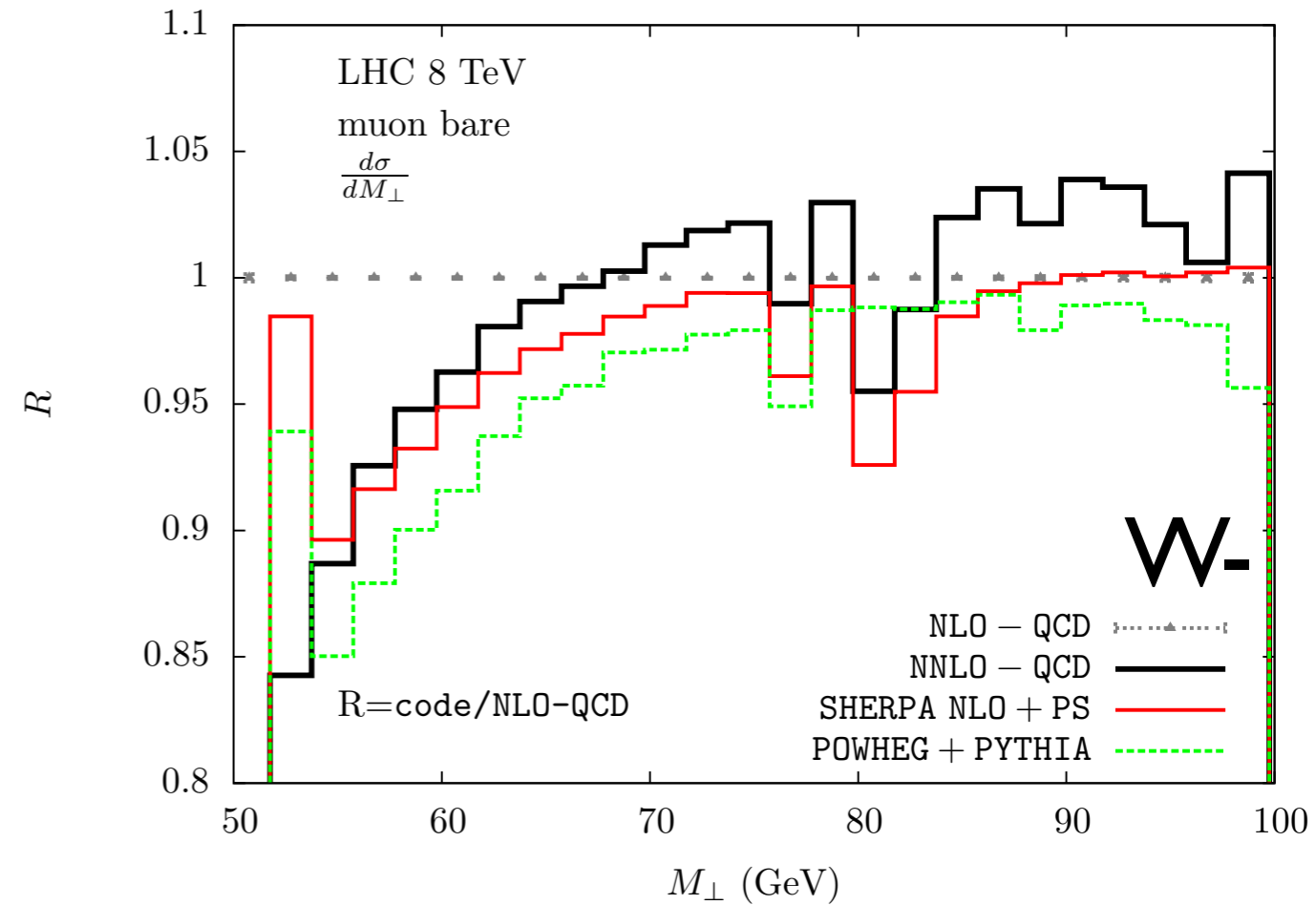
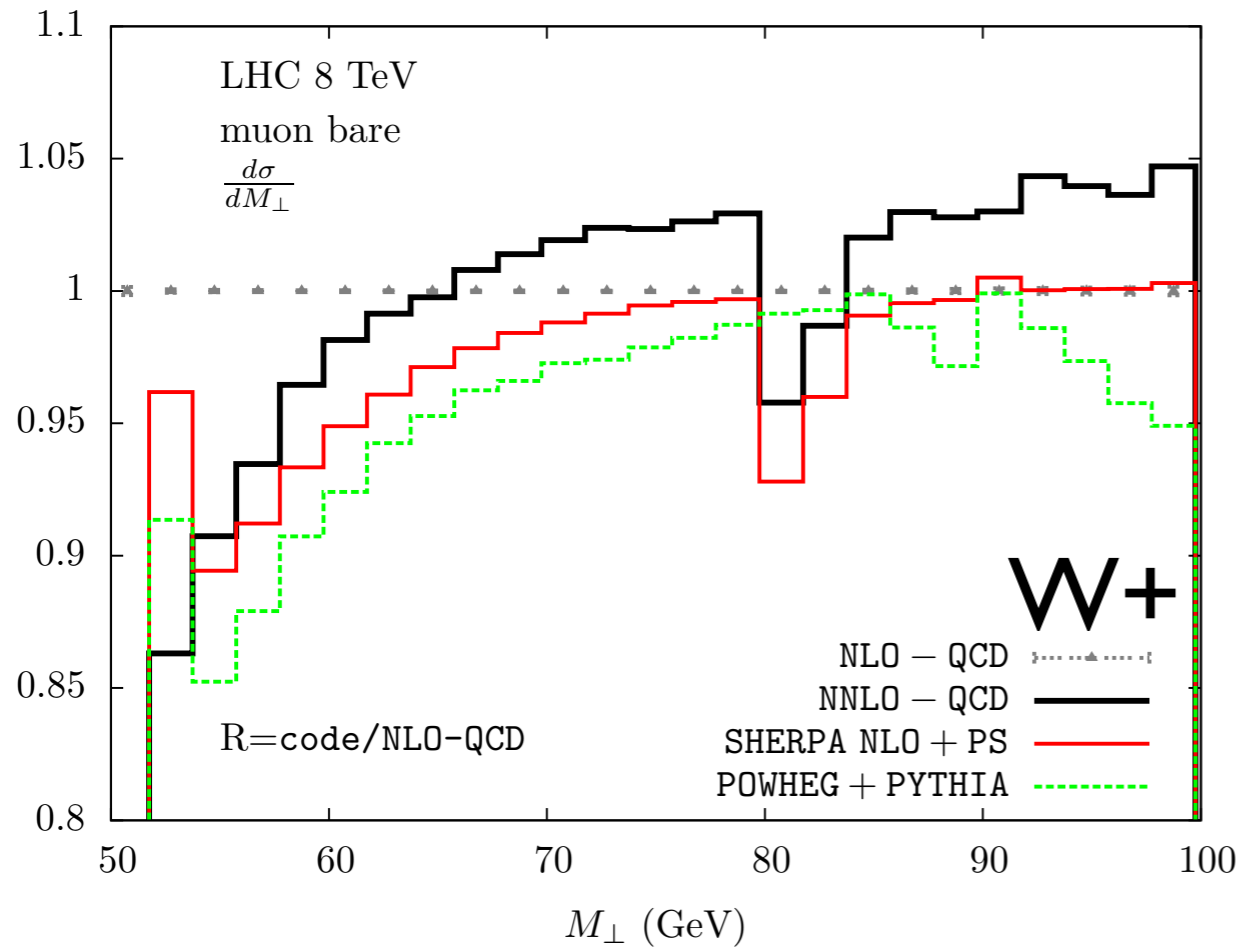
Updates since June: tuned comparison at NNLO-QCD



- comparison of fixed-order NNLO-QCD results (3 codes)
- good agreement, but the simulations are very demanding in terms of CPU



Radiative corrections: higher order QCD effects, transverse mass



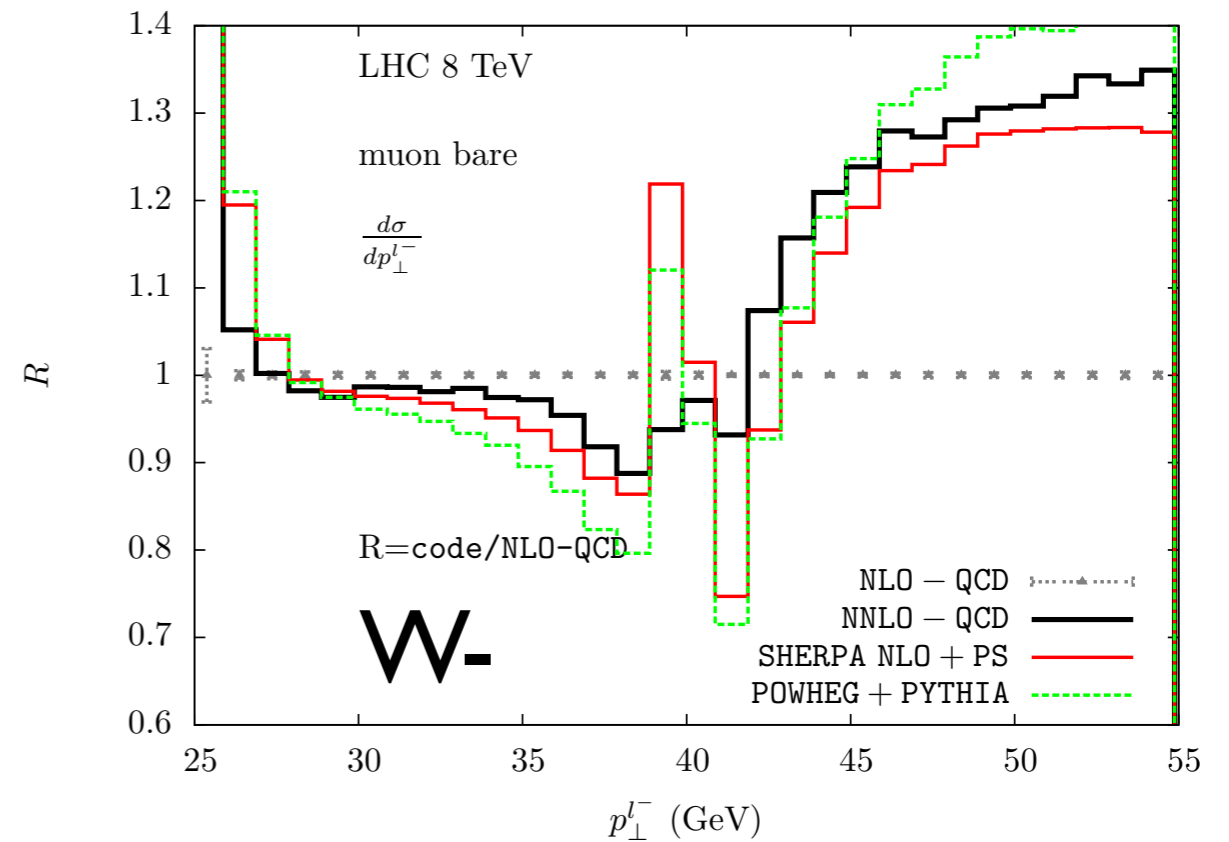
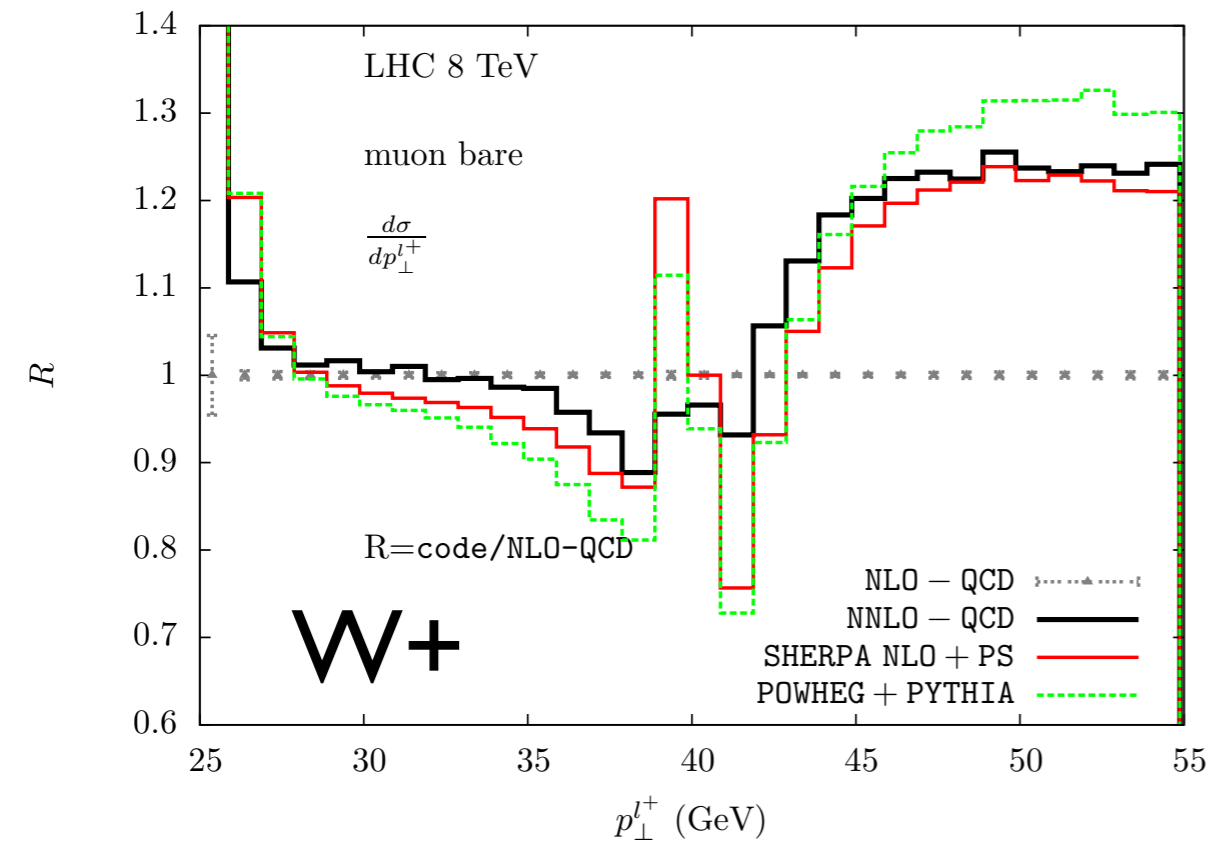
the available NNLO-QCD codes agree within statistical uncertainties

no log enhancement \rightarrow the QCD corrections are slowly varying in the whole mass region

the QCD-PS on top of NLO has an effect only because of the acceptance cuts

small, quite flat, NNLO-QCD K-factor

Radiative corrections: higher order QCD effects, lepton p_t

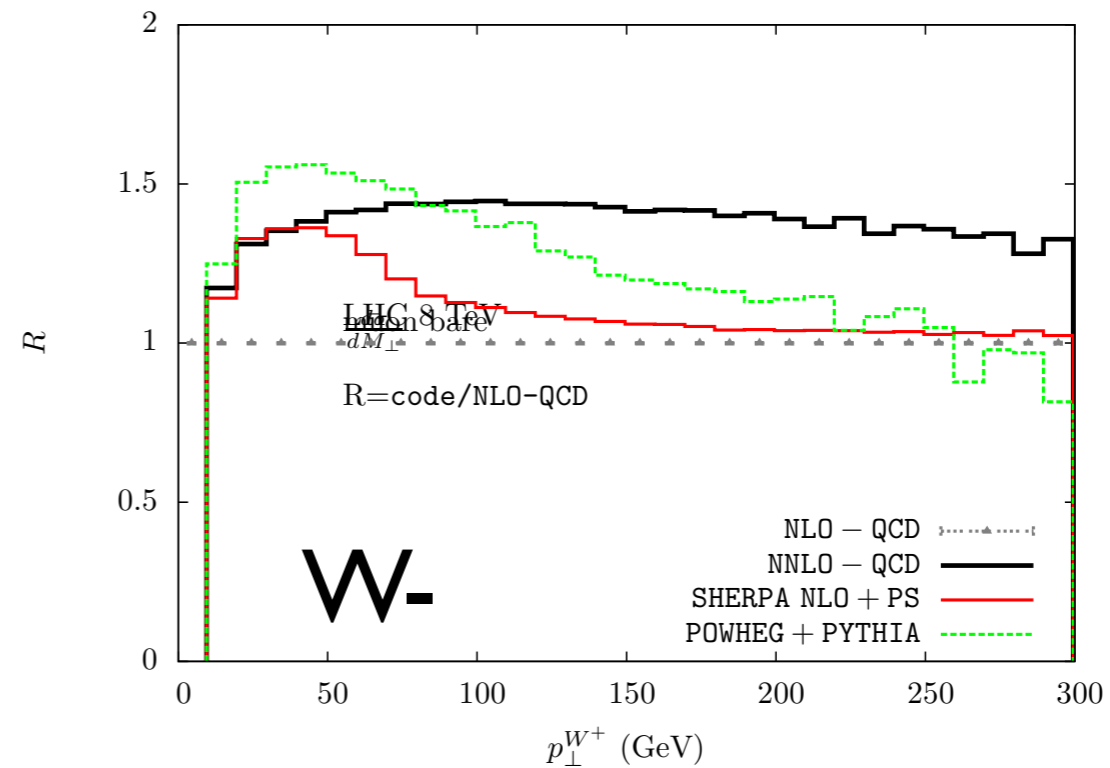
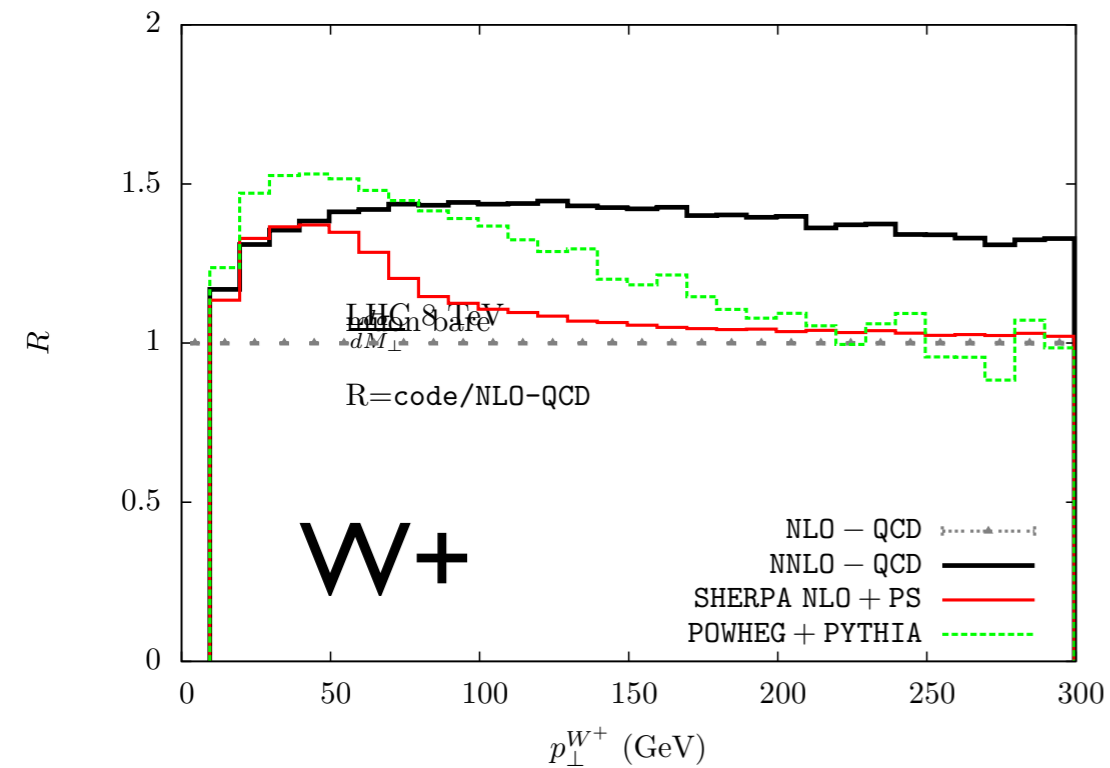


excluding the jacobian peak region,
where only a resummed expression makes sense,
SMC follow the NNLO curve

the h.o. effects are sizeable $O(30\%)$ above the jacobian peak

several % of the difference between POWHEG+PYTHIA and SHERPA

Radiative corrections: higher order QCD effects, lepton-pair p_t



the three available NNLO-QCD codes agree within statistical uncertainties

the fixed-order distributions are divergent for vanishing lepton-pair transverse momentum
→ the comparison NNLO/NLO is not sensible

at large transverse momentum, POWHEG tends to the fixed order distribution

Radiative corrections: higher order EW effects

the NLO-EW is common and tested at high precision for all the EW codes

we can evaluate the size of some subsets of h.o. corrections, like e.g.:

- h.o. via renormalization

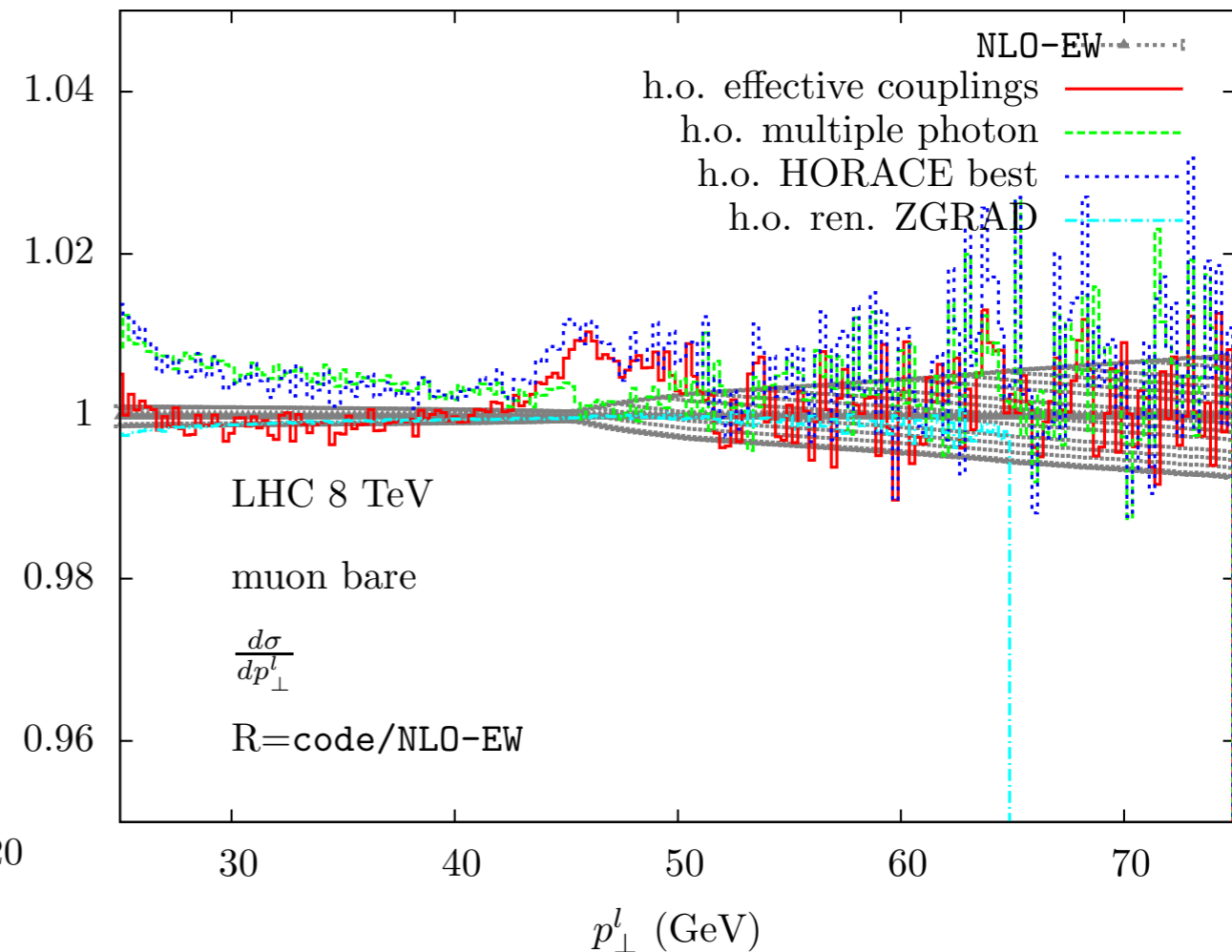
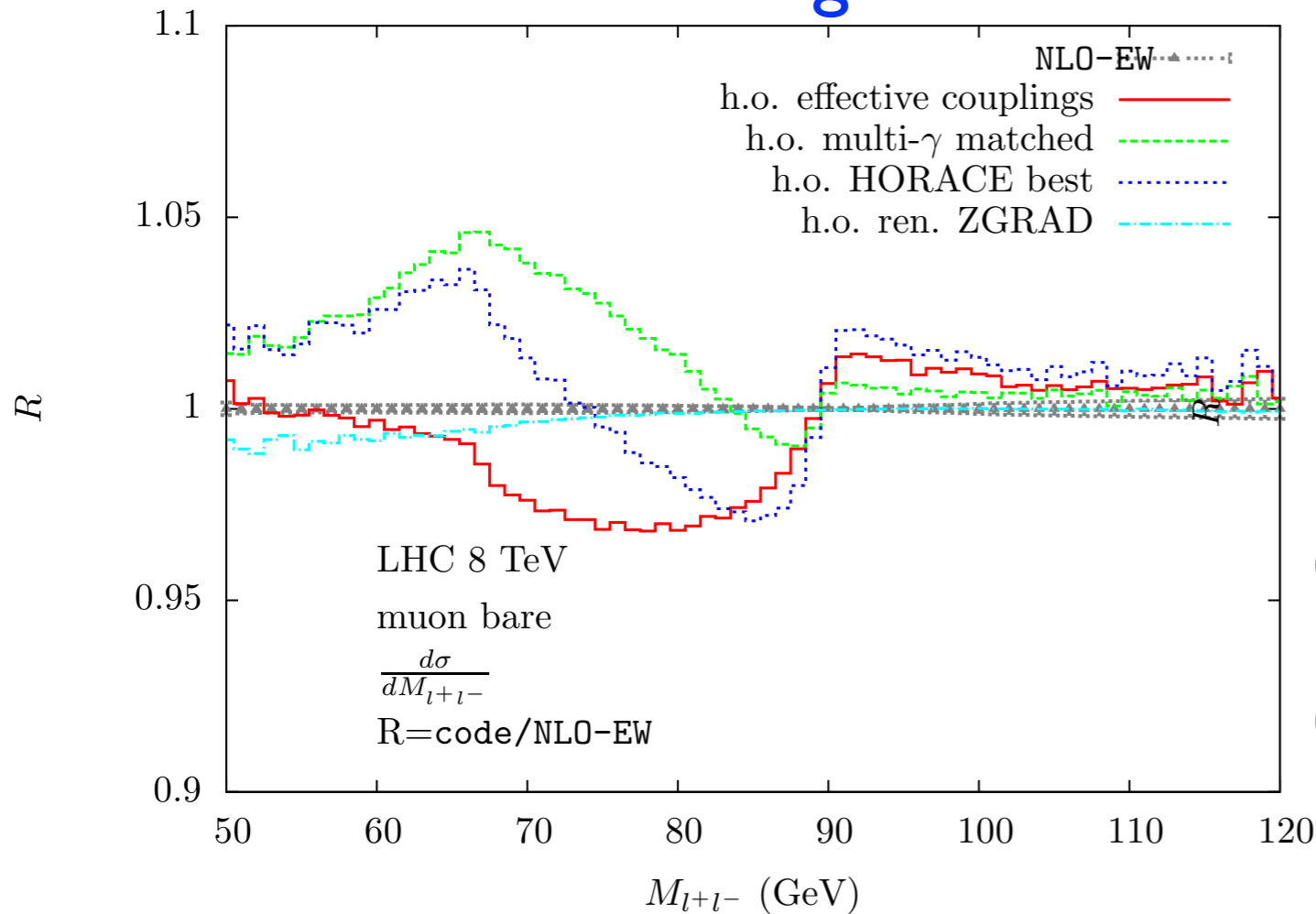
- h.o. via running effective couplings

- effects of multiple photon radiation matched with NLO-EW

- ...

all the effects shown in the next slides are of $O(\alpha^2)$ and higher

Radiative corrections: higher order EW effects



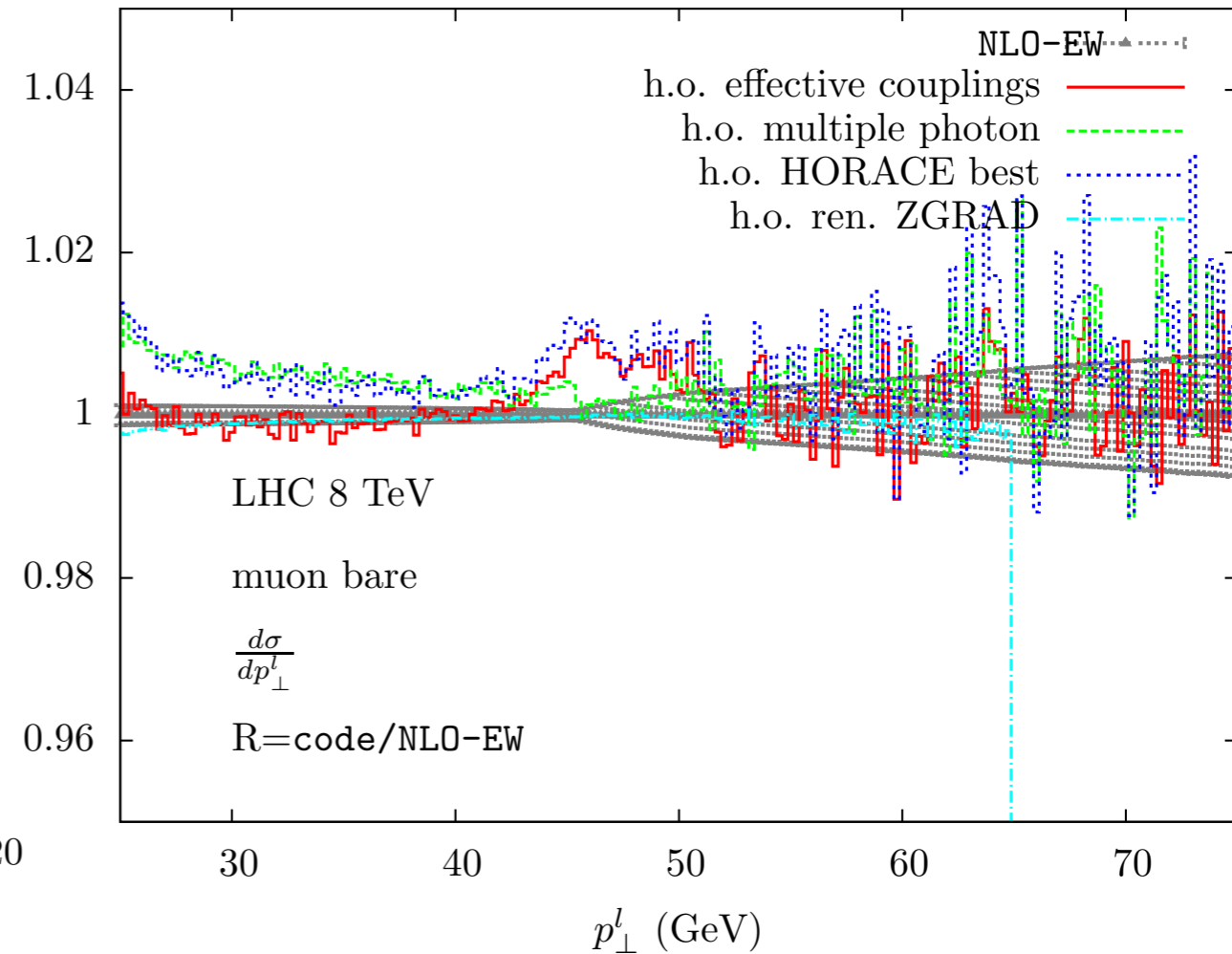
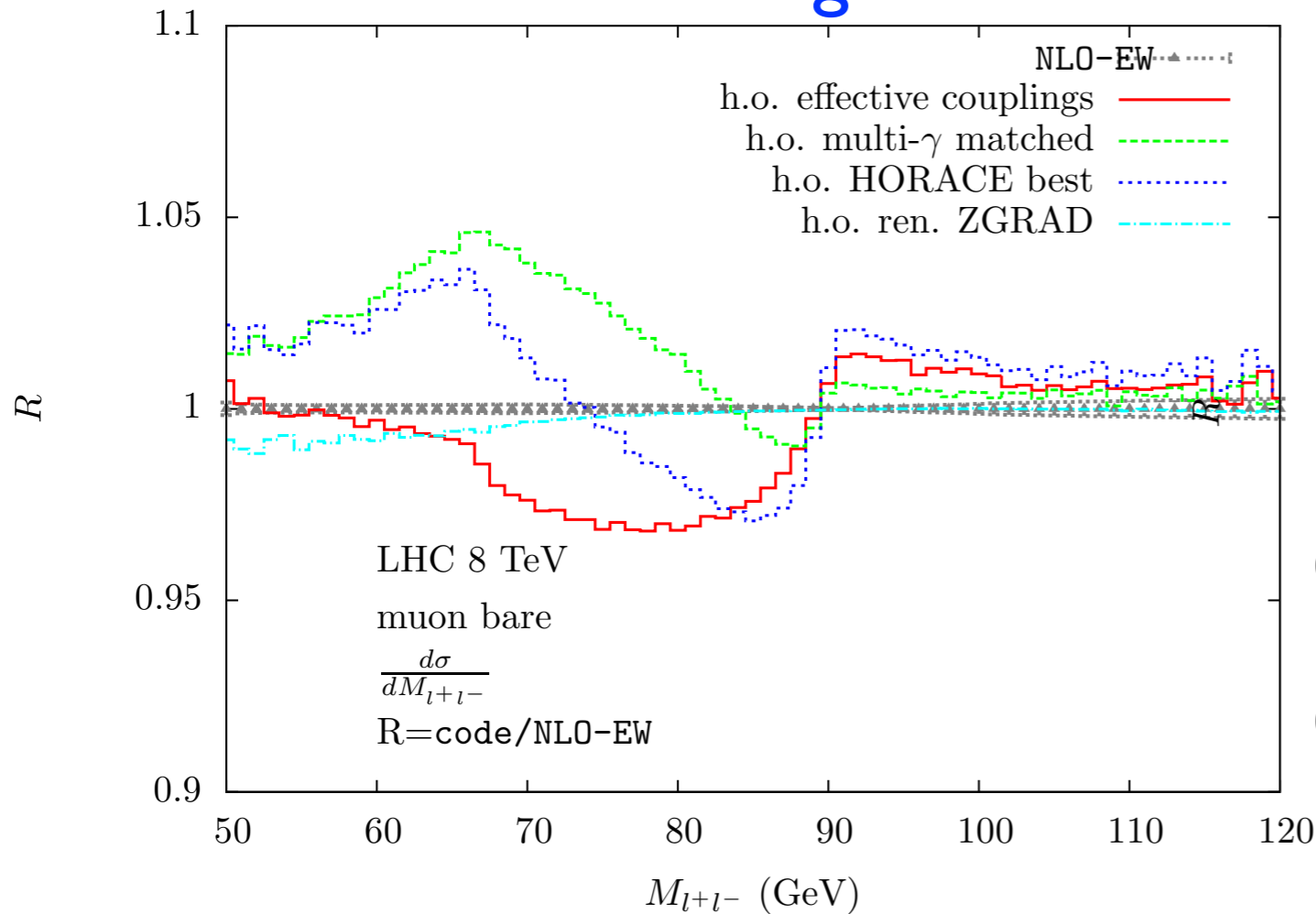
all the effects shown are of $\mathcal{O}(\alpha^2)$ and higher; preliminary first examples

universal higher order corrections in the definition of the counterterms (light blue)

$$\delta m_Z^2 = \text{Re}(\Sigma^Z(m_Z^2)) \rightarrow \delta m_Z^2 = \text{Re}\left(\Sigma^Z(m_Z^2) - \frac{(\hat{\Sigma}^{\gamma Z}(m_Z^2))^2}{m_Z^2 + \hat{\Sigma}^{\gamma}(m_Z^2)}\right)$$

$$\frac{\delta m_Z^2}{m_Z^2} - \frac{\delta m_W^2}{m_W^2} \rightarrow \frac{\delta m_Z^2}{m_Z^2} - \frac{\delta m_W^2}{m_W^2} - \Delta\rho^{h.o.}$$

Radiative corrections: higher order EW effects



all the effects shown are of $\mathcal{O}(\alpha^2)$ and higher

h.o. via running effective couplings (red line)

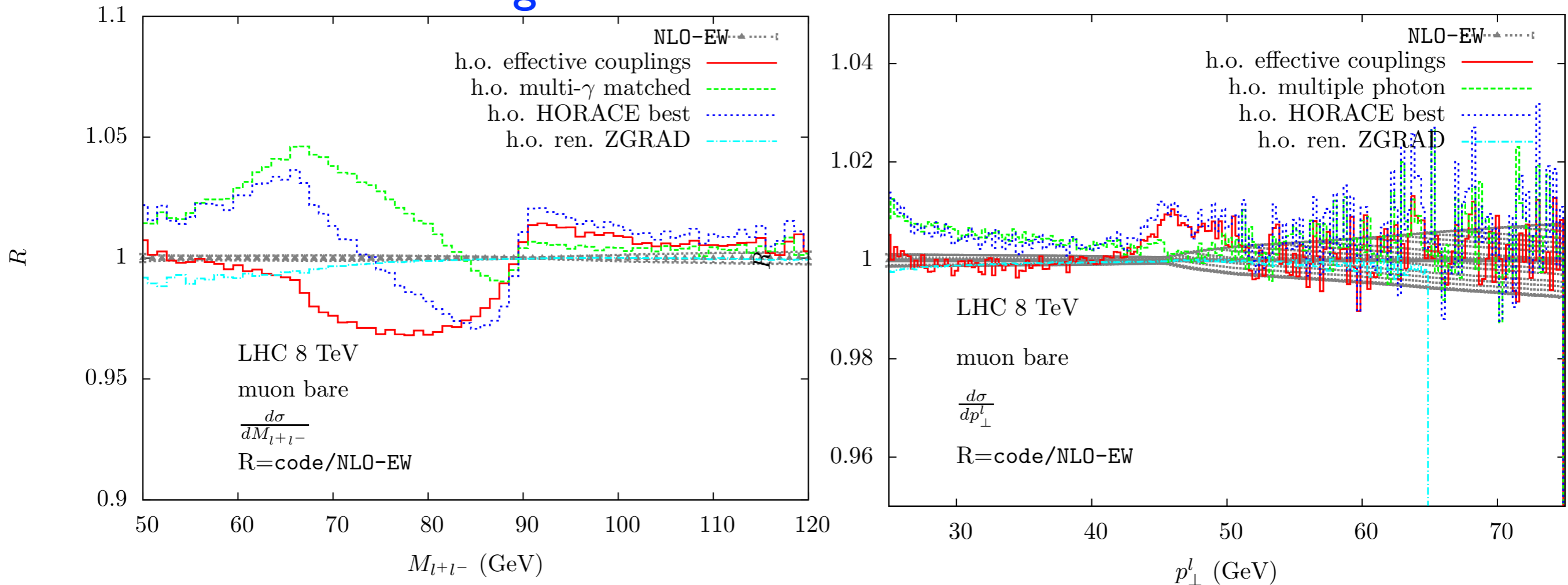
the LO couplings are dressed, avoiding double counting with the NLO-EW results

$$e^2 \rightarrow e^2(q^2) = e^2 / (1 - \Delta\alpha(q^2)) \quad G_{\mu} \rightarrow G_{\mu} \frac{\rho_{fi}(q^2)}{(1 - \delta\rho_{irr})}$$

$$\frac{ig}{c_{\theta}} \gamma^{\mu} (\tilde{v}_f - a_f \gamma_5) \quad \tilde{v}_f = T_f - 2Q_f \kappa_f(q^2) s_{\theta}^2$$

the huge radiative correction below the Z resonance amplifies the $\mathcal{O}(\alpha^2)$ effects due to the running of the photon coupling and to the modified Z couplings

Radiative corrections: higher order EW effects



all the effects shown are of $\mathcal{O}(\alpha^2)$ and higher

multiple photon radiation consistently matched with the exact NLO-EW calculation (green line)

matching of QED Parton Shower with exact NLO-EW calculation discussed in HORACE, POWHEG the complete result, physically well defined, can be consistently compared to the NLO-EW results

below the Z resonance the $\mathcal{O}(\alpha^2)$ effects of this class are at the few per cent level

Combination of QCD and EW effects

$$\begin{aligned}\sigma_{tot} = & \sigma_{LO} + \\ & \alpha\sigma_\alpha + \alpha^2\sigma_{\alpha^2} + \dots \\ & \alpha_s\sigma_{\alpha_s} + \alpha_s^2\sigma_{\alpha_s^2} + \dots \\ & \alpha\alpha_s\sigma_{\alpha\alpha_s} + \alpha\alpha_s^2\sigma_{\alpha\alpha_s^2} + \dots\end{aligned}$$

only NLO-EW, NLO-QCD and NNLO-QCD exactly known

how well can we approximate the $O(\alpha\alpha_s)$ corrections,
given the available QCD and EW codes?

how can we include resummation effects?

$$\mathcal{O} = \mathcal{O}_{LO} \left(1 + \delta_{QCD}^{NLO+NNLO} + \delta_{EW}^{NLO} \right)$$

1) purely additive prescription (at NNLO-QCD FEWZ,
at NLO-QCD SANC, RADY)

$$\mathcal{O} = \mathcal{O}_{LO} \left(1 + \delta_{QCD}^{NLO+NNLO} \right) \left(1 + \delta_{EW}^{NLO} \right)$$

2) factorized use of (differential) K-factors

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2) factorized use of (differential) K-factors

• difference with respect to

$$d\sigma = \sum_{f_b} \bar{B}^{f_b}(\Phi_n) d\Phi_n \left\{ \Delta^{f_b}(\Phi_n, p_T^{min}) + \sum_{\alpha_r \in \{\alpha_r | f_b\}} \frac{[d\Phi_{rad} \theta(k_T - p_T^{min}) \Delta^{f_b}(\Phi_n, k_T) R(\Phi_{n+1})]_{\alpha_r}^{\bar{\Phi}_n^{\alpha_r} = \Phi_n}}{B^{f_b}(\Phi_n)} \right\}$$

- POWHEG accounts for multiple emission effects
- the kinematics of multiple emissions is exact (fully differential)

- the POWHEG basic formula
 - is additive in the overall normalization,
 - it describes exactly one parton emission (photon/gluon/quark) (but NOT two partons)
 - includes in a factorized form mixed and higher order corrections via (QCD+QED)-PS in particular the bulk of the $O(\alpha\alpha_s)$ corrections (but it has NOT $O(\alpha\alpha_s)$ accuracy)

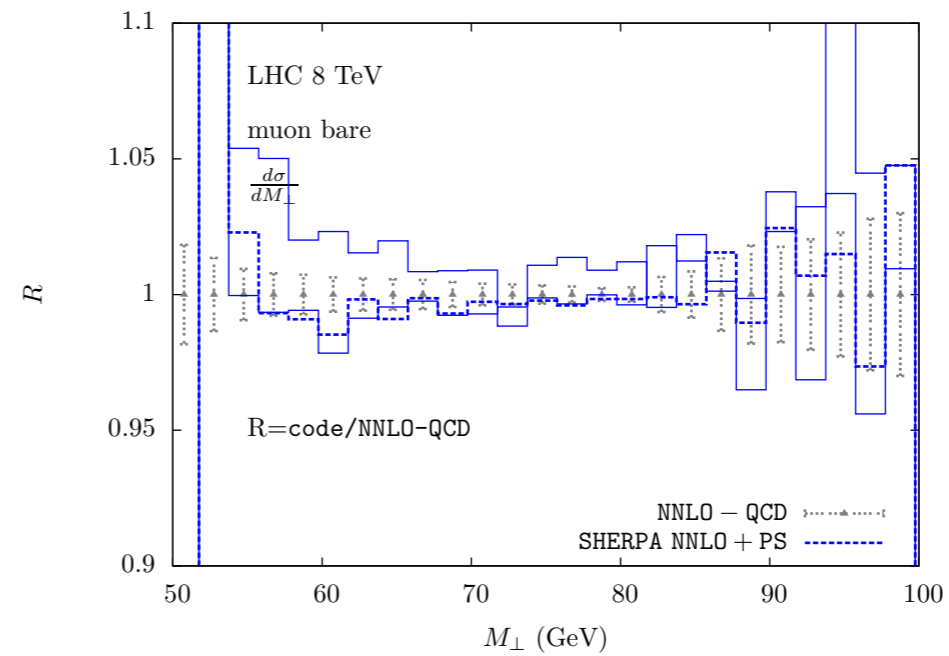
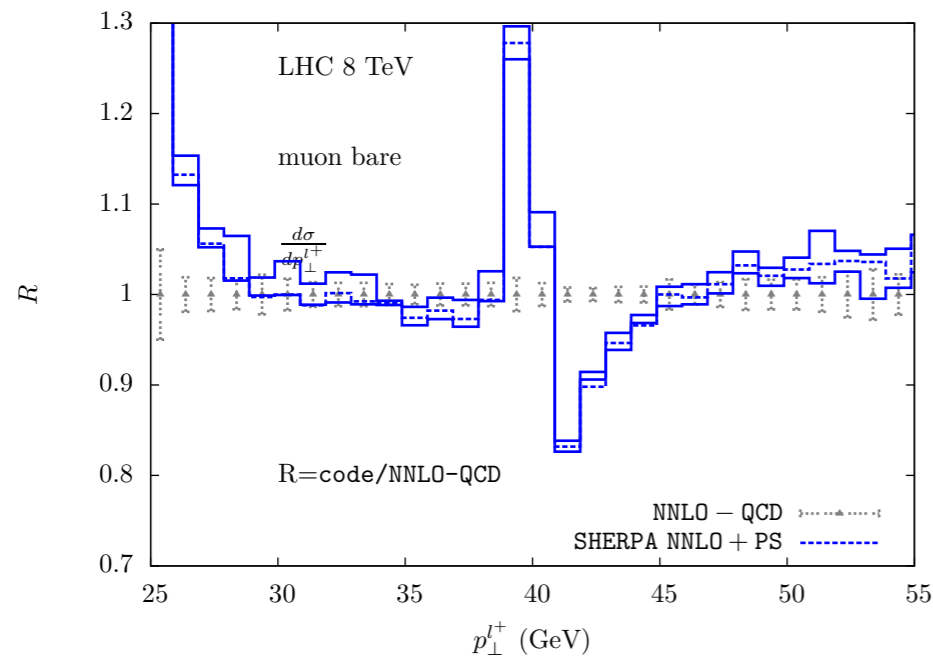
- in observables like the lepton p_T distribution, strongly sensitive to QCD showering, terms of $O(\alpha\alpha_s^p)$ completely modify the shape of the pure $O(\alpha)$ EW result

Updates since June

- tuned comparison of fixed-order NNLO-QCD results (3 codes)
- huge effort of codes merging NNLO-QCD with QCD-PS results
 - NNLOPS (Karlberg, Re, Zanderighi)
 - SHERPA-NNLO + PS (Hoeche, Li, Prestel)a comparison at the level of QCD uncertainty bands is in progress
- more results describing purely EW higher-order corrections
- combination of QCDxEW corrections
 - first results showing the effects of QED final state shower on top of a NLO-QCD +QCD-PS simulation
 - final runs for the evaluation of complete NLO-(QCD+EW) showered with (QCD+QED)-PS are running now
- added a discussion on $O(\alpha^2)$ effect in pole approximation vs naive QCDxEW combinations (Dittmaier et al.)

Updates since June: matching NNLO-QCD + QCD-PS

- effects of matching in SHERPA-NNLO + PS (including renormalization/factorization scale variations)



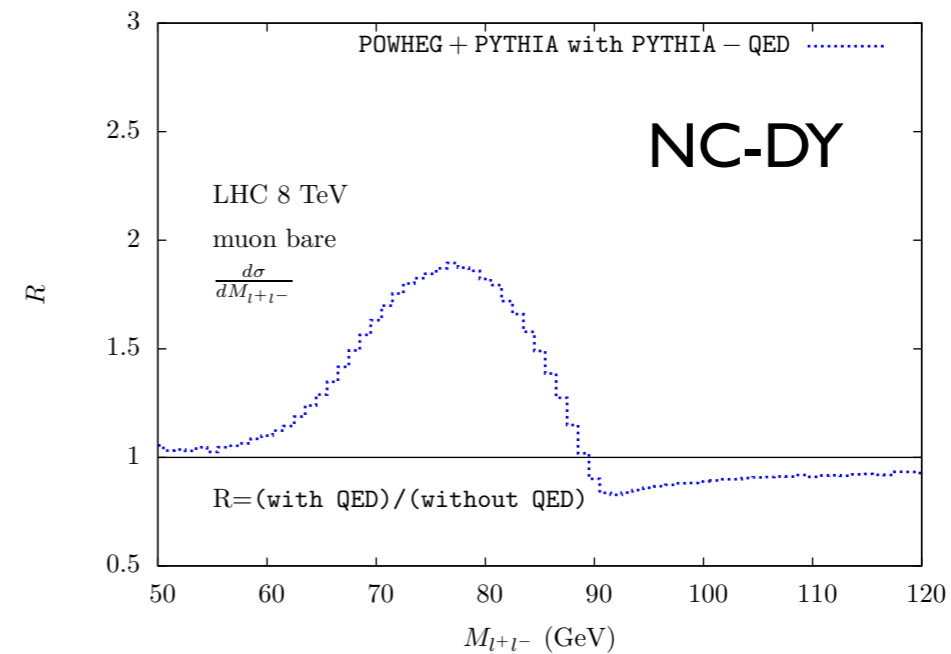
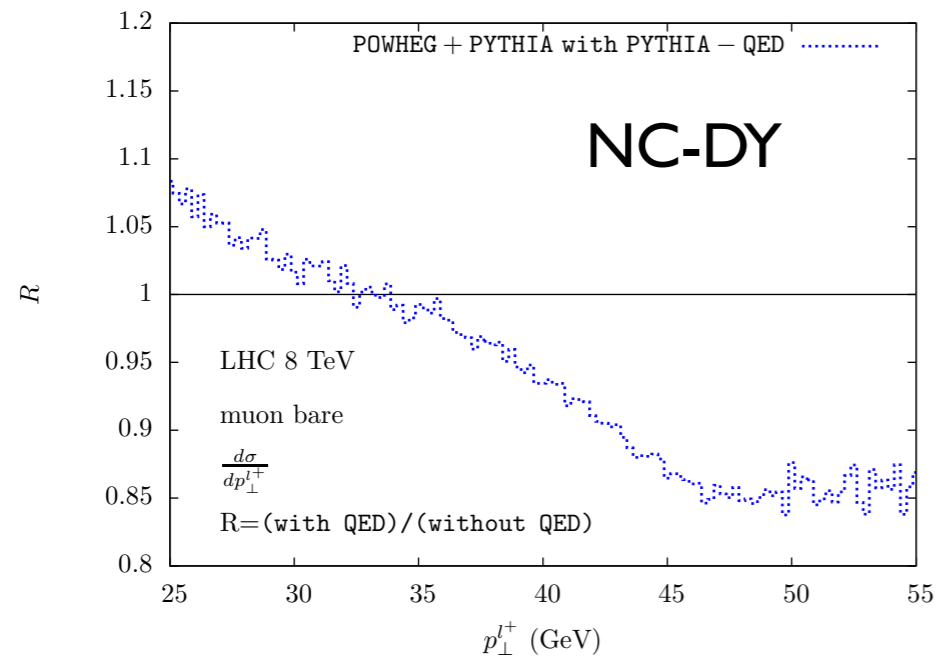
- in progress a systematic comparison with NNLOPS

- beyond fixed order, several higher-order corrections/effects mix together
 - subleading logarithmic terms included in different ways
 - different matching schemes, different matching scales
 - inclusion of non-perturbative effects (e.g. via Parton Shower)

a systematic discussion is needed to reach a definition of “uncertainty” that can be applied to the templates used to extract MW

Updates since June: inclusion of EW effects on top of (tuned) QCD

- effects of PYTHIA QED shower on top of POWHEG NLO-QCD + PYTHIA-QCD



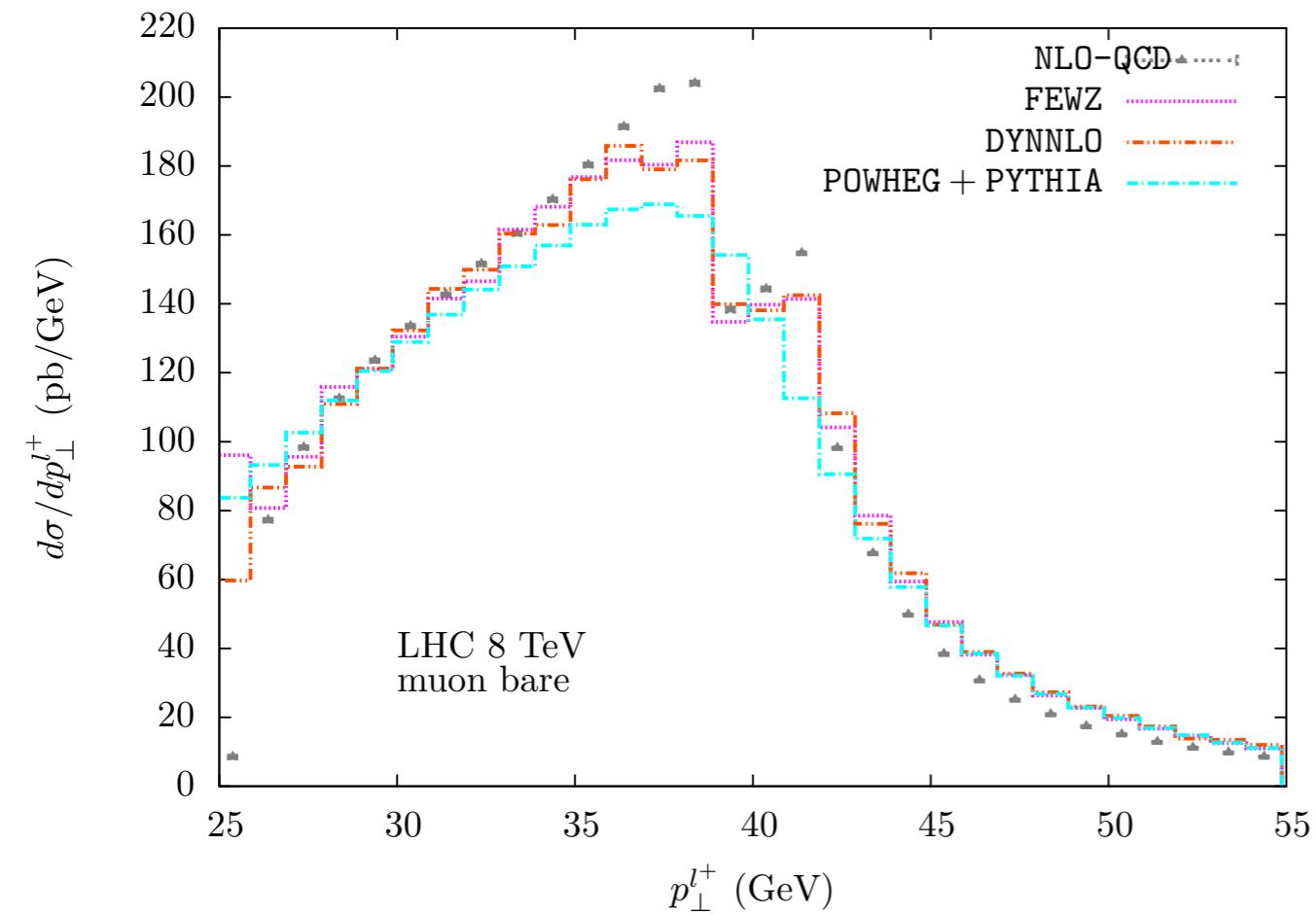
- in progress: evaluation of the full POWHEG NLO-(QCD+EW) + (QCD+QED)-PS to be compared again with POWHEG NLO-QCD + PYTHIA-QCD
- these plots show the combined effect of higher-order QED effects and of mixed QEDxQCD effects using the same PYTHIA-QCD shower the comparison of the two EW approximation is fair but the mixed QEDxQCD effects depend on the choice of PYTHIA w.r.t. a different shower

What's next

- the report is now in the final writing phase for the benchmarking part
- the comparison of results that merge NNLO-QCD fixed-order results and resummation requires a non-trivial effort before drawing any conclusion about the residual QCD uncertainty; it is a precious step towards the systematic inclusion of NNLO effects in the MW determination
- the comparison of different final state QED showers among themselves and with the complete NLO-(QCD+EW) + (QCD+QED)-PS will provide a quantitative assessment of the EW effects in presence of a “QCD environment” (cfr. H.Martinez talk), for each relevant observable
- any feedback related to the “distribution” of results, beyond the fixed-order benchmarks, is welcome

Back-up slides

Radiative corrections: higher order QCD effects, lepton p_t



the lepton transverse momentum distribution, in fixed order, shows a double peak due to the divergent contributions at vanishing gauge boson momentum

only the inclusion of multiple parton emissions, e.g. via QCD-PS, makes the shape smooth, with one peak