Università degli Studi di Milano

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Prospects on MW measurements

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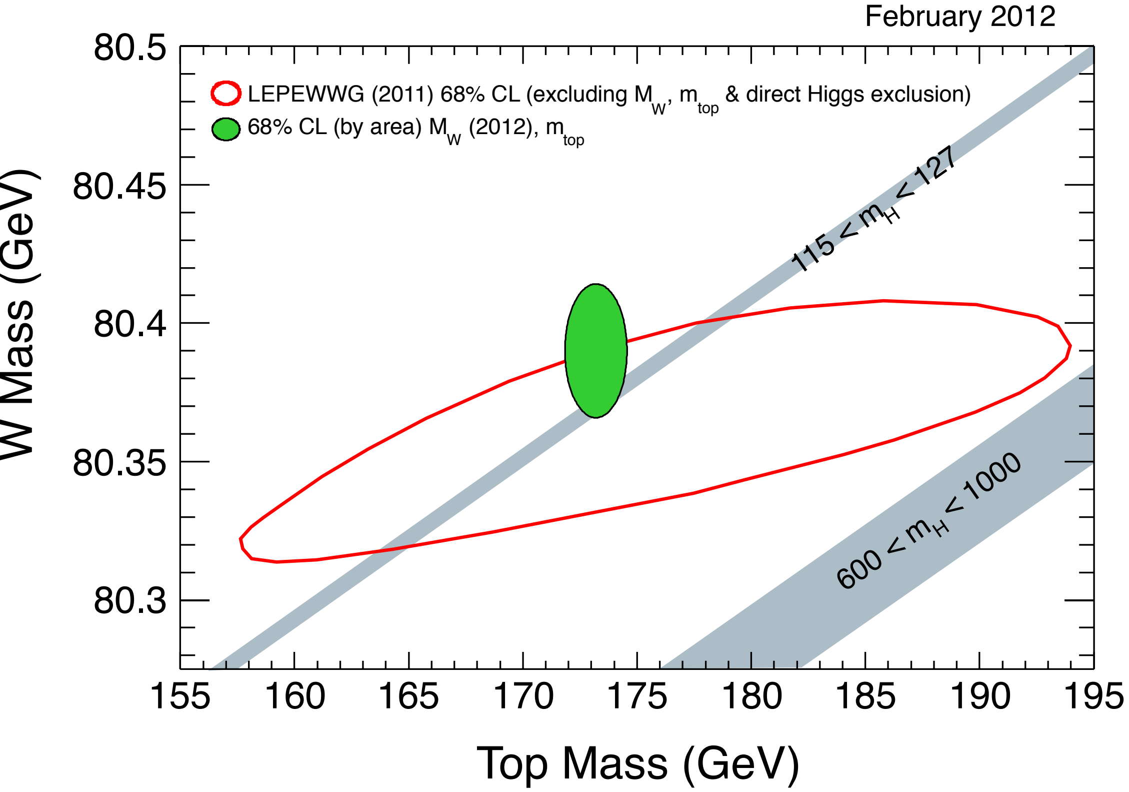
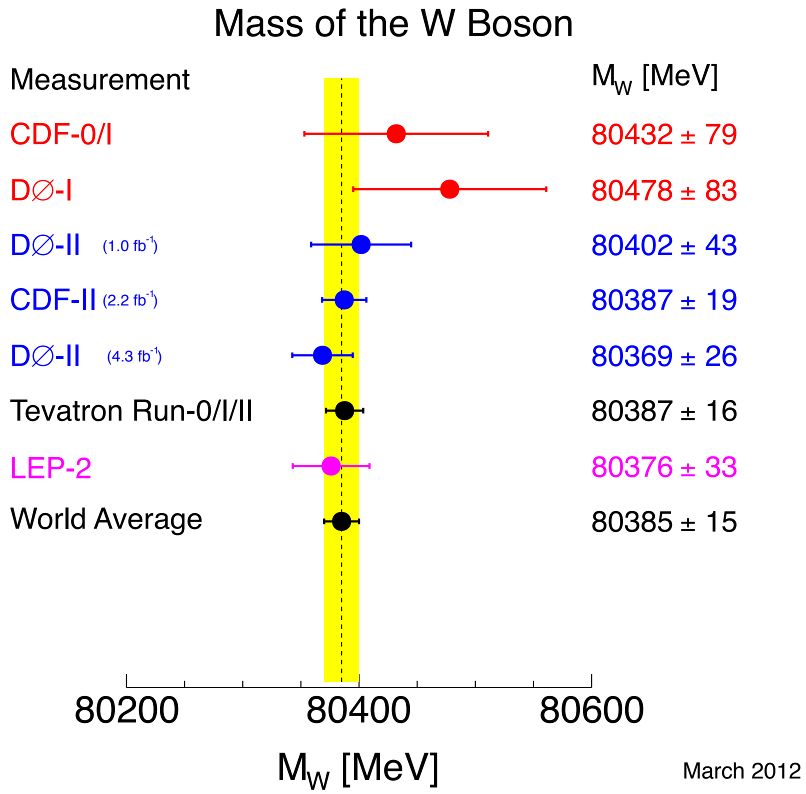
Plan of the talk

- observables relevant for the MW measurement
- relevance of different classes of radiative corrections and their impact on the MW measurement
- the POWHEG implementation of exact NLO-QCD and NLO-EW corrections
  to both charged current and neutral current Drell-Yan, matched with QCD and QED showers
- QCD and EW uncertainties
- PDF uncertainties

Motivations

A precise measurement of MW provides a crucial test of the SM





Motivations

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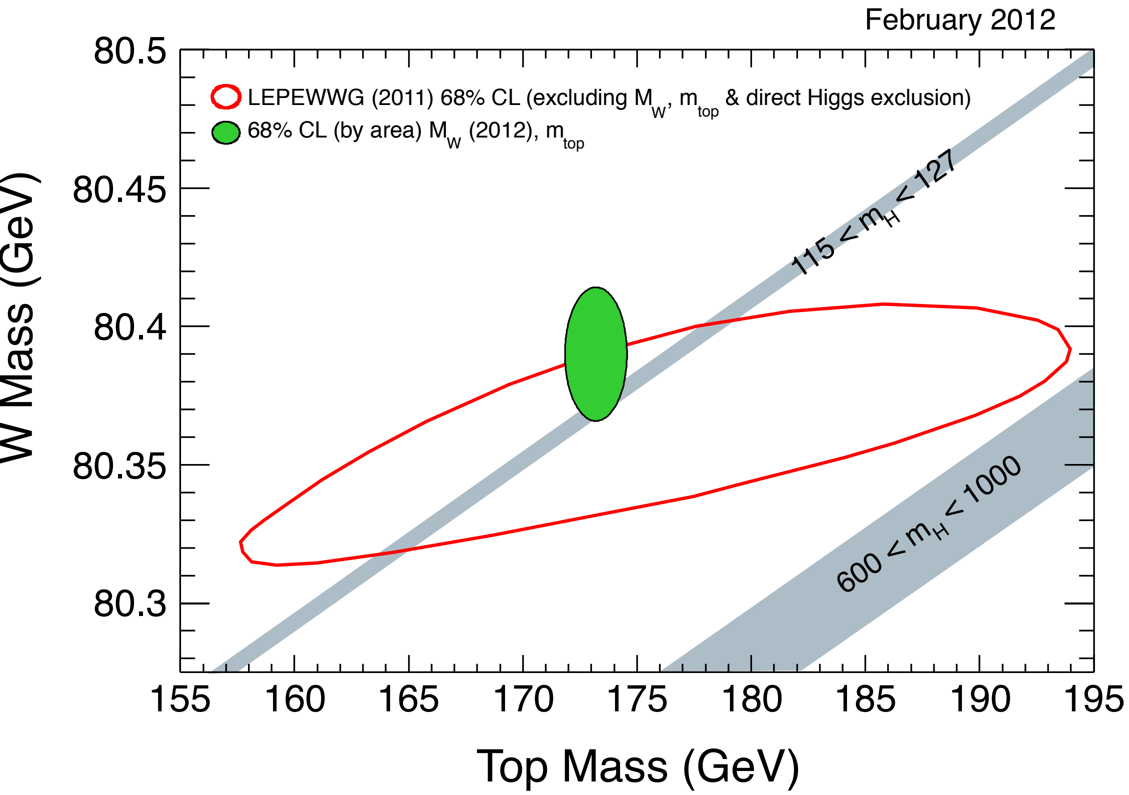
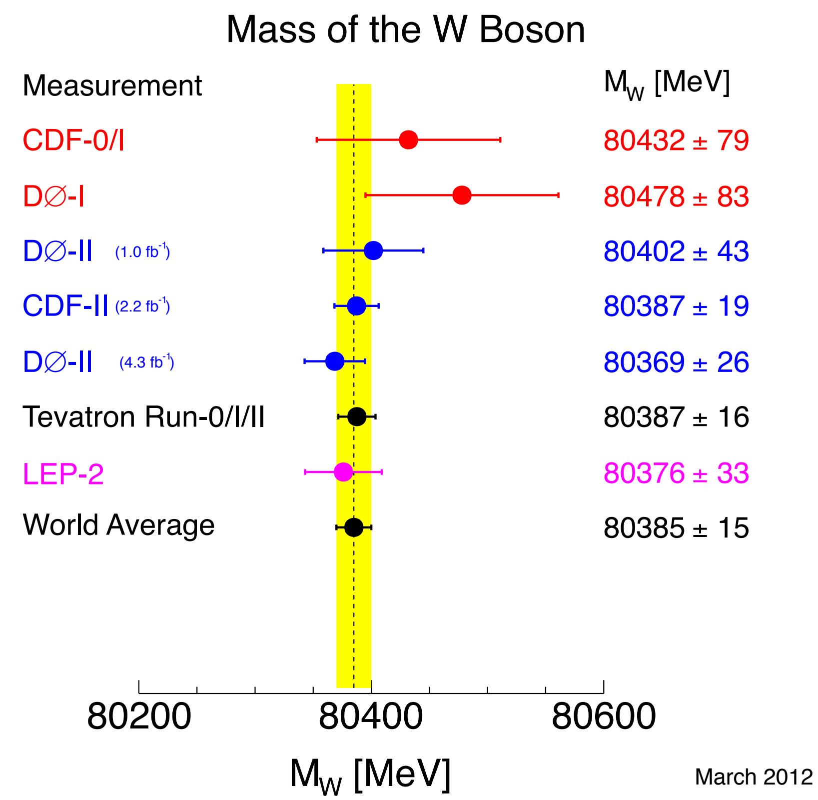
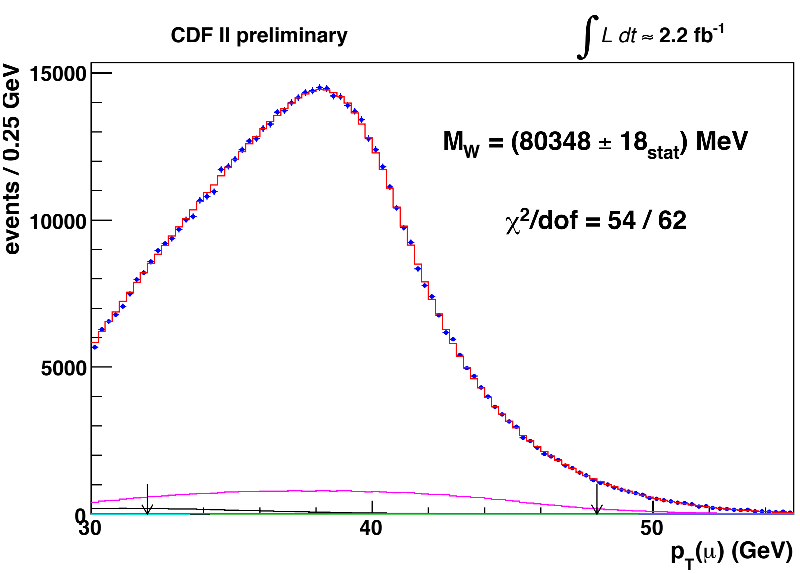
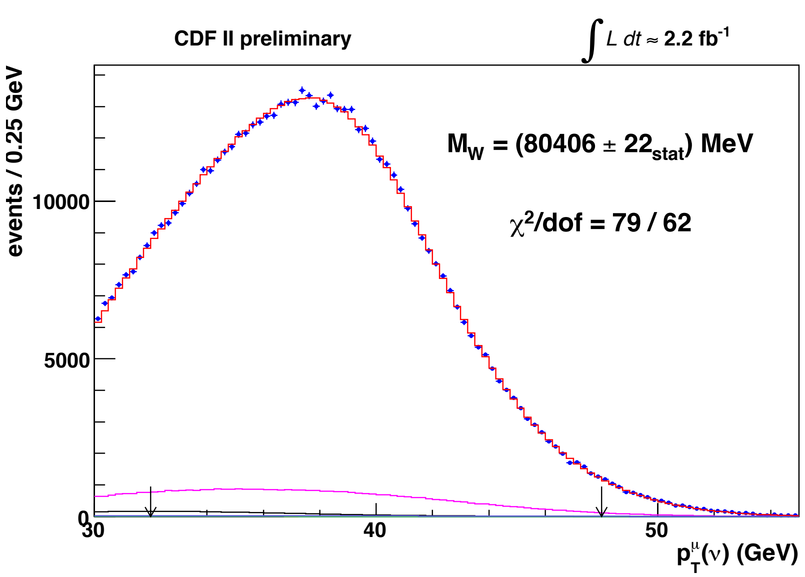
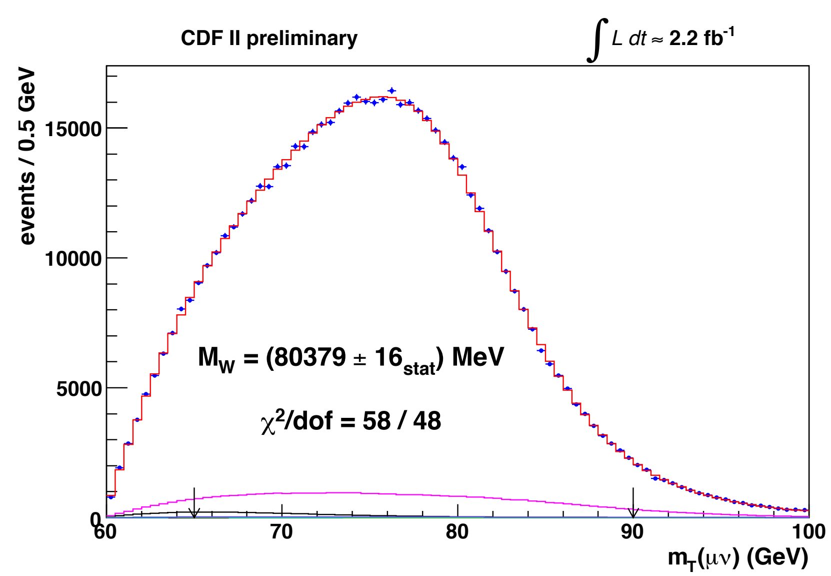




MW is extracted with a template fit technique of various distributions of CC-DY
An event generator that includes the best available results in terms of radiative corrections is necessary to minimize the theoretical systematic error in the fit





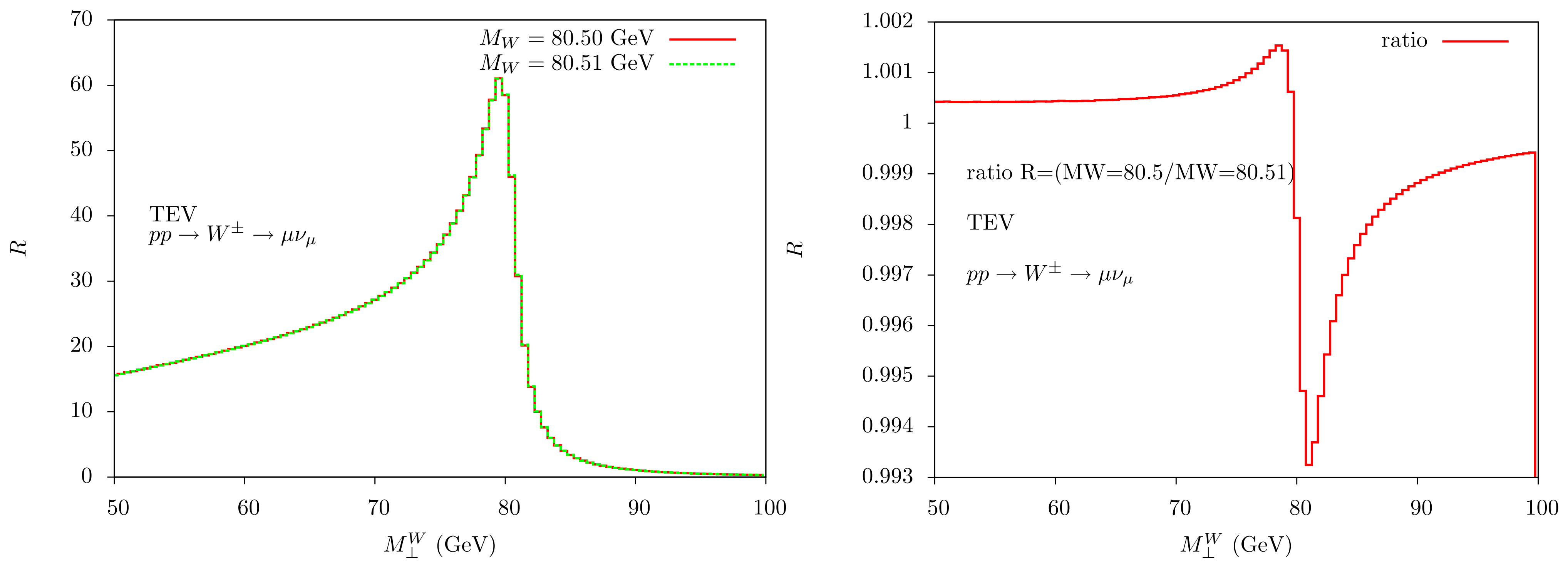


Template fit and theoretical accuracy

In a template fit approach

- the best theoretical prediction for a distribution is computed several times, with different values of MW
- each template is compared to the data
- the measured MW is the one of the template that maximizes the agreement with the data

Which level of accuracy do we need?



The measured MW value does not depend on the normalization of the distributions but rather on their shape

If we aim at measuring MW with 10-15 MeV of error, are we able to control the shape of the distributions and the theoretical uncertainties at the few per mille level?

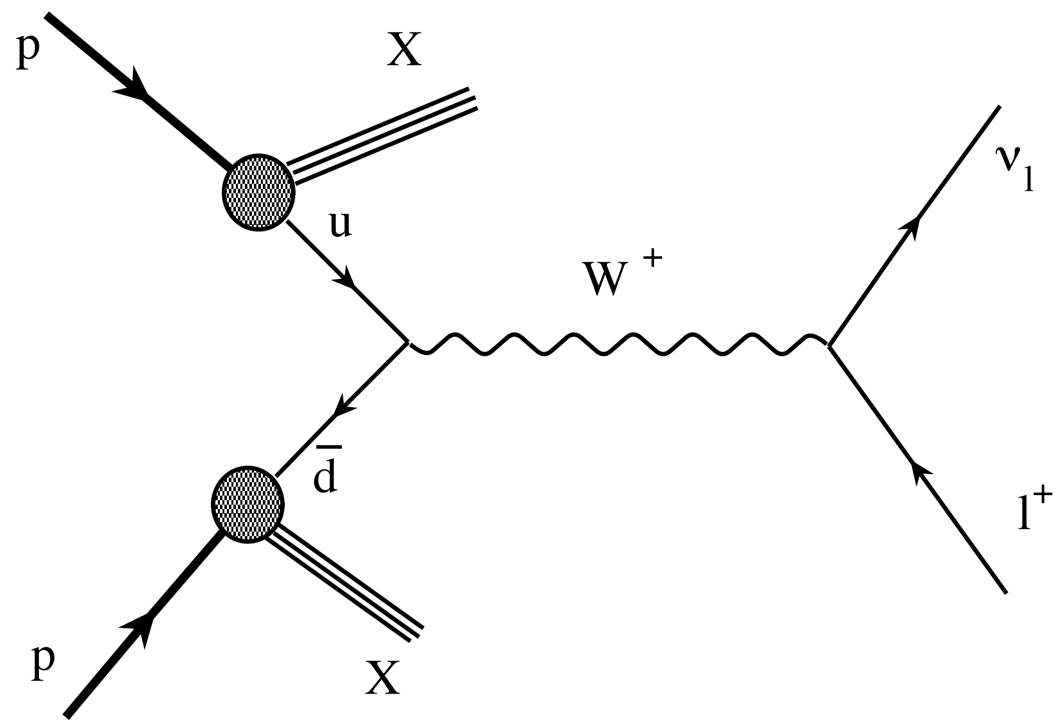
Perturbative expansion of the Drell-Yan cross section

$$\sigma_{tot} = \sigma_0 + \alpha_s \sigma_{\alpha_s} + \alpha_s^2 \sigma_{\alpha_s^2} + \ldots$$
$$+ \alpha \sigma_\alpha + \alpha^2 \sigma_{\alpha^2} + \ldots$$
$$+ \alpha\alpha_s\, \sigma_{\alpha\alpha_s} + \alpha\alpha_s^2\, \sigma_{\alpha\alpha_s^2} + \ldots$$

QCD

EW

mixed QCDxEW



Which corrections modify the shape of the distributions?
affect the extraction of MW?

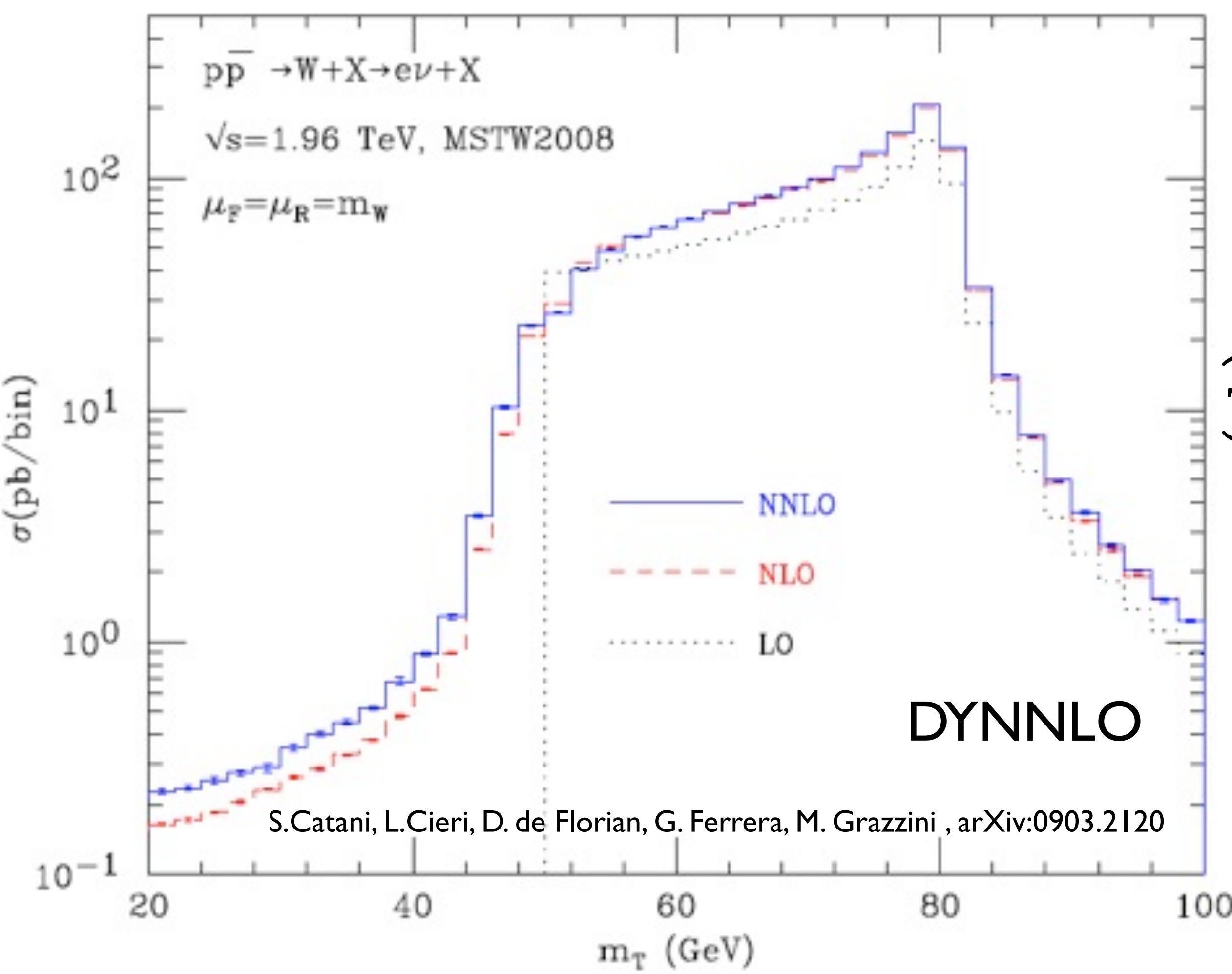
Perturbative expansion of the Drell-Yan cross section

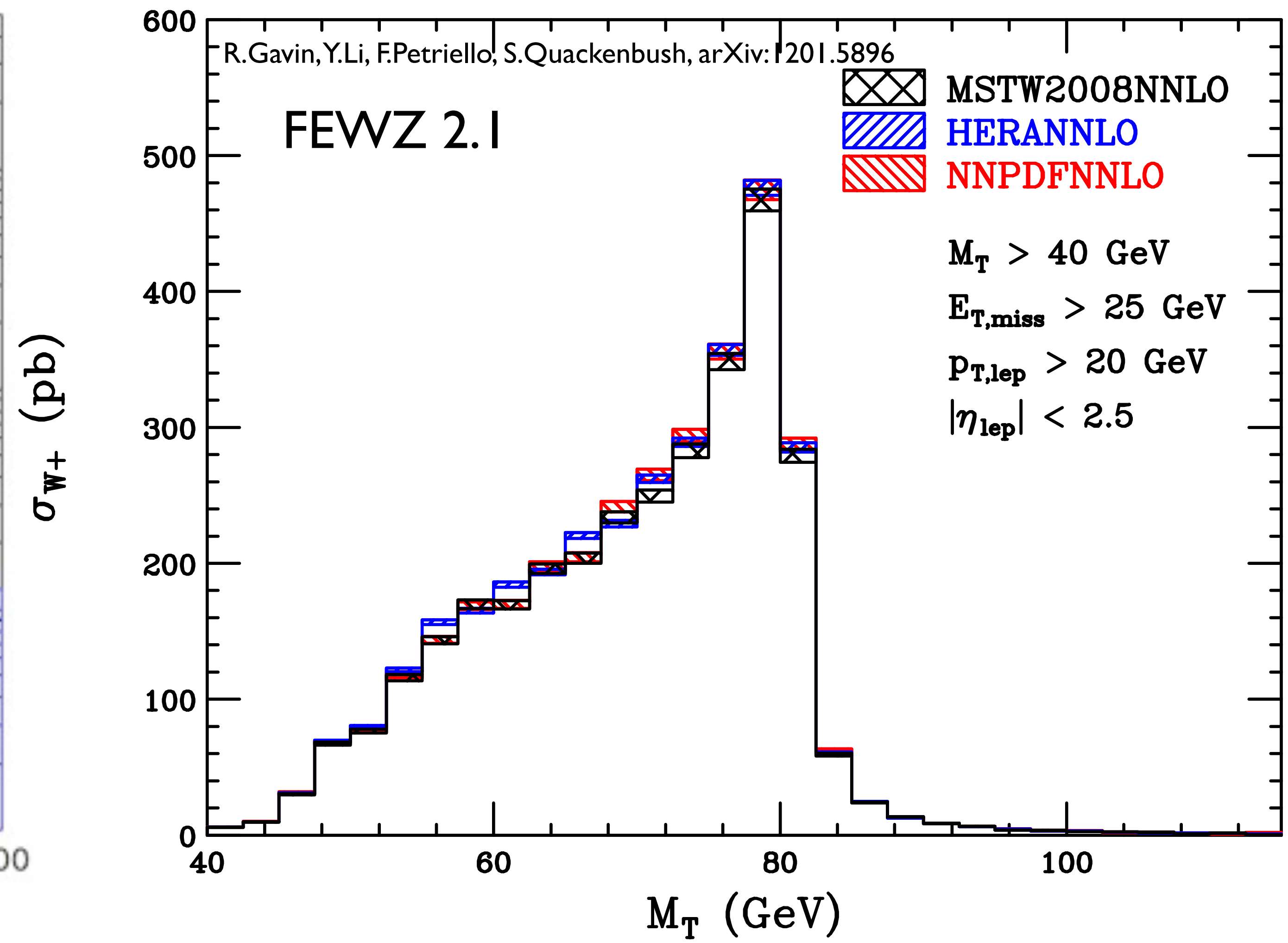
$$\sigma_{tot} = \sigma_0 + \boxed{\alpha_s \sigma_{\alpha_s} + \alpha_s^2 \sigma_{\alpha_s^2}} + \ldots$$
MCFM,FEWZ,DYNNLO

$$+ \boxed{\alpha \sigma_\alpha} + \alpha^2 \sigma_{\alpha^2} + \ldots$$
WGRAD, RADY, HORACE, SANC

$$+ \alpha\alpha_s\, \sigma_{\alpha\alpha_s} + \alpha\alpha_s^2\, \sigma_{\alpha\alpha_s^2} + \ldots$$

Fixed order corrections exactly evaluated and available in simulation codes





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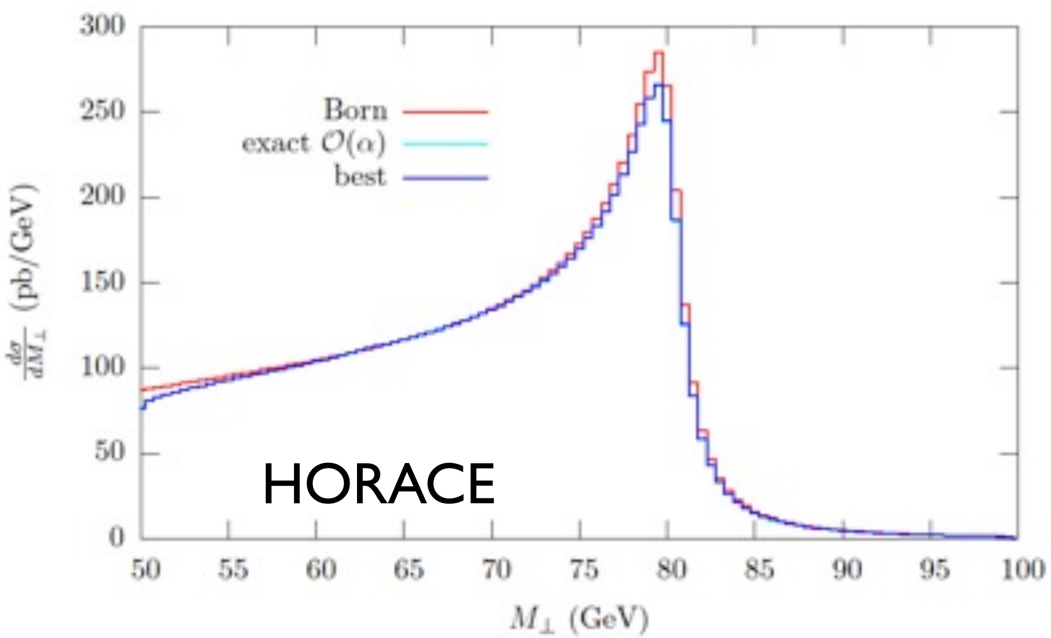
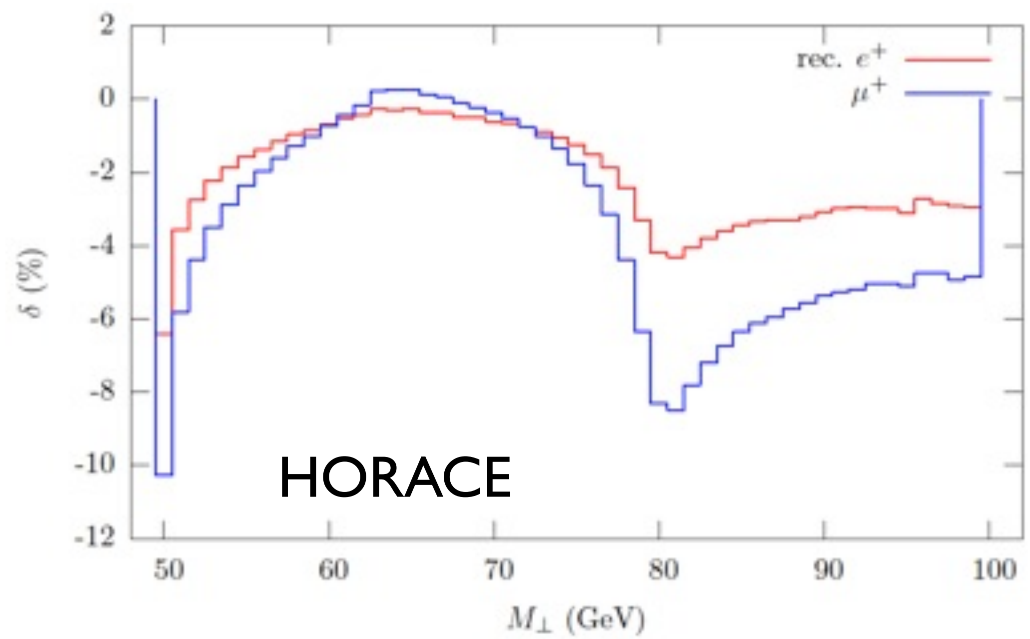




The change of the final state lepton distribution yields a huge shift in the extracted MW value

$$\Delta M_W^\alpha = 110 \text{ MeV}$$

Perturbative expansion of the Drell-Yan cross section

$$\sigma_{tot} = \sigma_0 + \boxed{\alpha_s \sigma_{\alpha_s} + \alpha_s^2 \sigma_{\alpha_s^2}} + \ldots$$
$$+ \boxed{\alpha \sigma_\alpha} + \boxed{\alpha^2 \sigma_{\alpha^2}} + \ldots$$
$$+ \boxed{\alpha\alpha_s \, \sigma_{\alpha\alpha_s}} + \alpha\alpha_s^2 \, \sigma_{\alpha\alpha_s^2} + \ldots$$

Fixed order corrections exactly evaluated and available in simulation codes

Subsets of corrections partially evaluated or approximated

$O(\alpha^2)$

- EW Sudakov logs J.Kühn, A.Kulesza, S.Pozzorini, M.Schulze, Nucl.Phys.B797:27-77,2008, Phys.Lett.B651:160-165,2007, Nucl.Phys.B727:368-394,2005.
- QED LL
- QED NLL (approximated)
- additional light pairs (approximated)

O(αα_s)

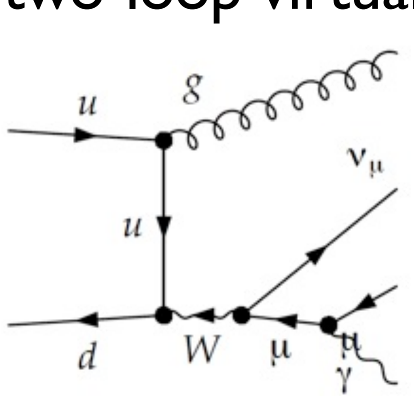
- EW corrections to ffbar+jet production
- QCD corrections to ffbar+gamma production

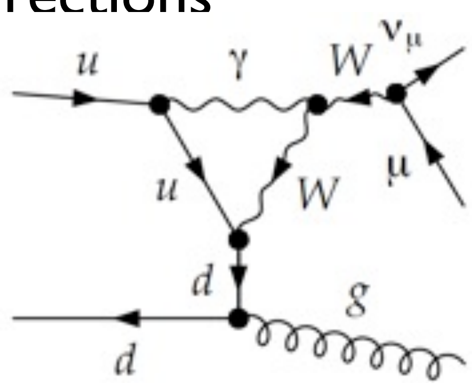
A.Denner, S.Dittmaier, T.Kasprzik, A.Mueck, arXiv:0909.3943, arXiv:1103.0914

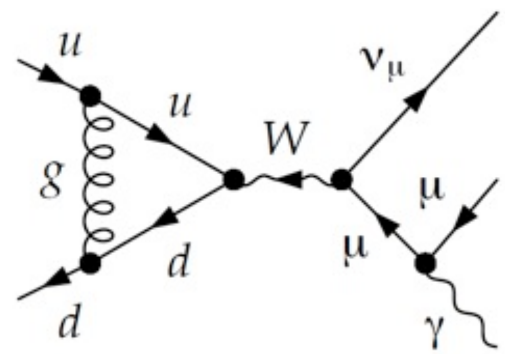
Mixed QCDxEW corrections the Drell-Yan cross section

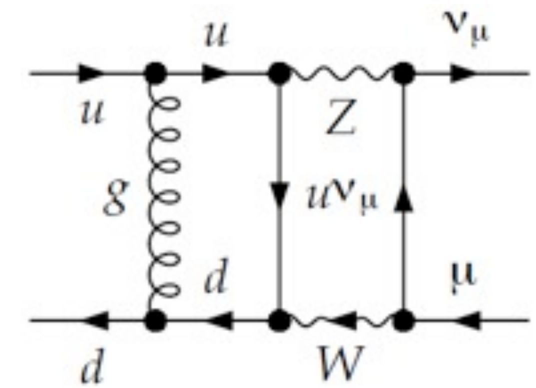
$$\sigma_{tot} = \sigma_0 + \alpha_s \sigma_{\alpha_s} + \alpha_s^2 \sigma_{\alpha_s^2} + \ldots$$
$$+ \alpha \sigma_\alpha + \alpha^2 \sigma_{\alpha^2} + \ldots$$
$$+ \boxed{\alpha \alpha_s \, \sigma_{\alpha \alpha_s}} + \alpha \alpha_s^2 \, \sigma_{\alpha \alpha_s^2} + \ldots$$

- The first mixed QCDxEW corrections include different contributions:
  - emission of two real additional partons (one photon + one gluon/quark)
  - emission of one real additional parton (one photon with QCD virtual corrections, one gluon/quark with EW virtual corrections)
  - two-loop virtual corrections







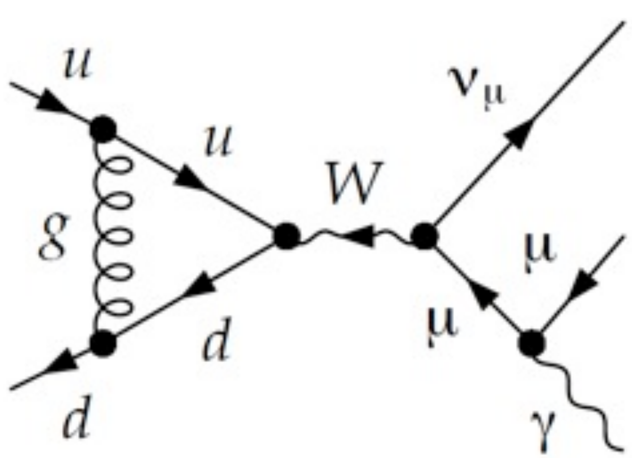


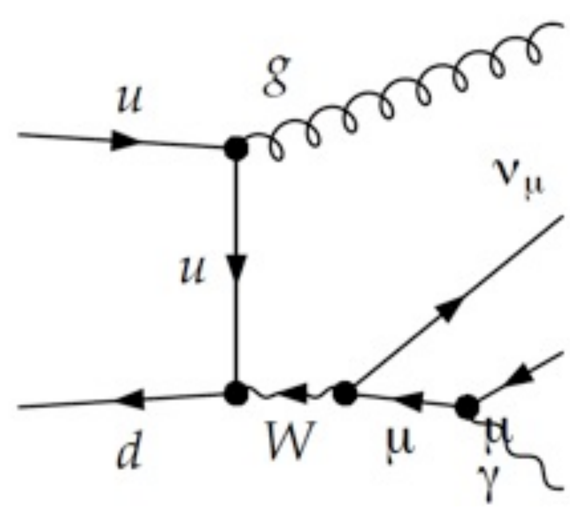
- an exact complete calculation is not yet available, neither for DY nor for single gauge boson production

  W.B. Kilgore, C. Sturm, arXiv:1107.4798

- The bulk of the mixed QCDxEW corrections, relevant for a precision MW measurement, is factorized in QCD and EW contributions:

  (leading-log part of final state QED radiation) X (leading-log part of initial state QCD radiation || NLO-QCD contribution to the K-factor)





In any case, a fixed order description of the process is not sufficient...

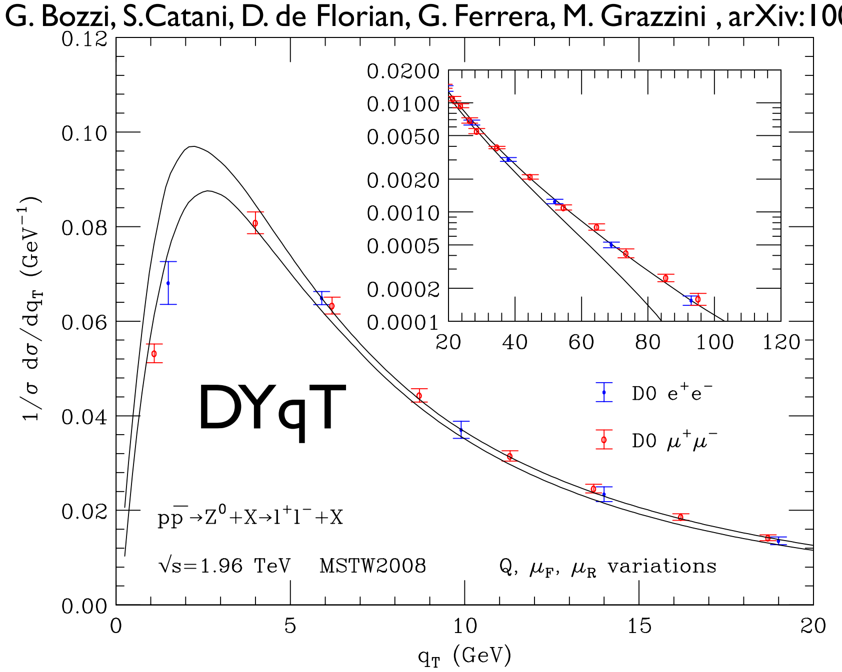
The relevance of multiple gluon/photon emission

numerical simulation of IS QCD multiple gluon emission via Parton Shower (Herwig, Pythia, Sherpa)

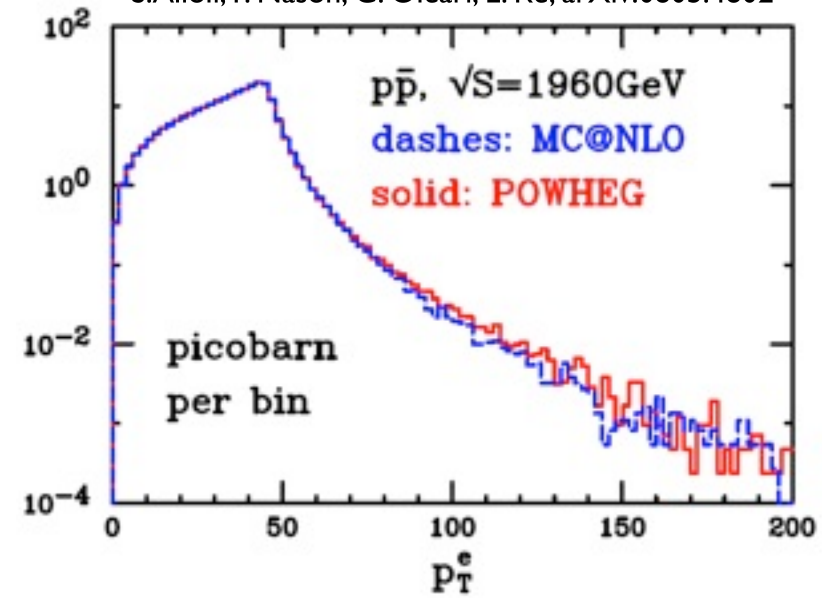
matching of NLO-QCD results with QCD Parton Shower (MC@NLO, POWHEG)

analytical resummation of initial state QCD multiple gluon emission (Resbos, DYqT)

G. Bozzi, S.Catani, D. de Florian, G. Ferrera, M. Grazzini , arXiv:1007.2351



S.Alioli, P. Nason, C. Oleari, E. Re, arXiv:0805.4802



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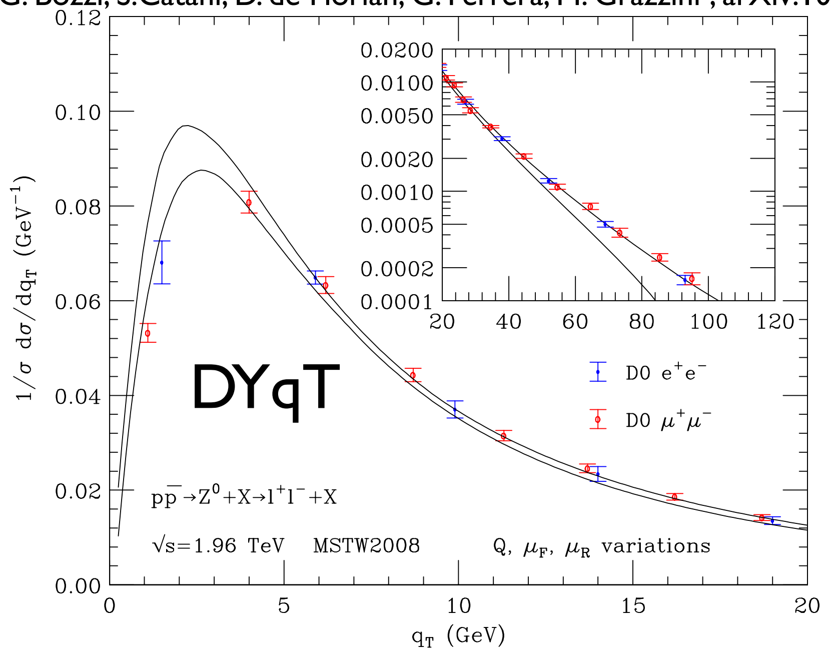

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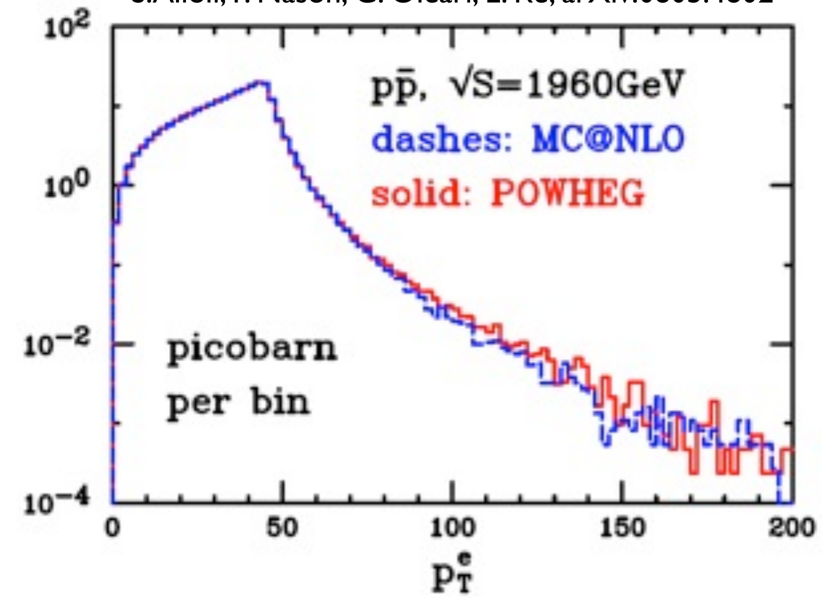
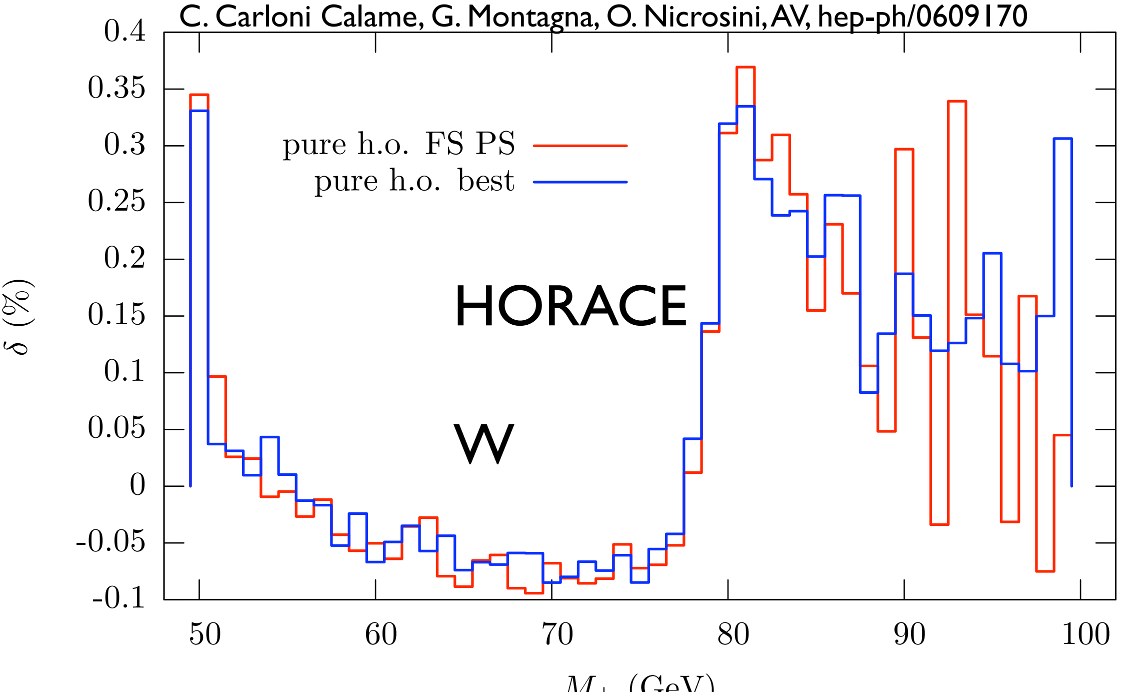


numerical simulation of final state QED multiple photon emission via Parton Shower (Photos, HORACE)

matching of NLO-EW results with complete QED Parton Shower (HORACE)

C. Carloni Calame, G. Montagna, O. Nicrosini, AV, hep-ph/0609170



Shift induced in the extraction of MW from higher order QED effects

$$\Delta M_W^{\alpha} = 110 \text{ MeV}$$

$$\Delta M_W^{exp} = -10 \text{ MeV}$$

Combining QCD + EW corrections: $\mathcal{O}(\alpha\alpha_s)$ ambiguities

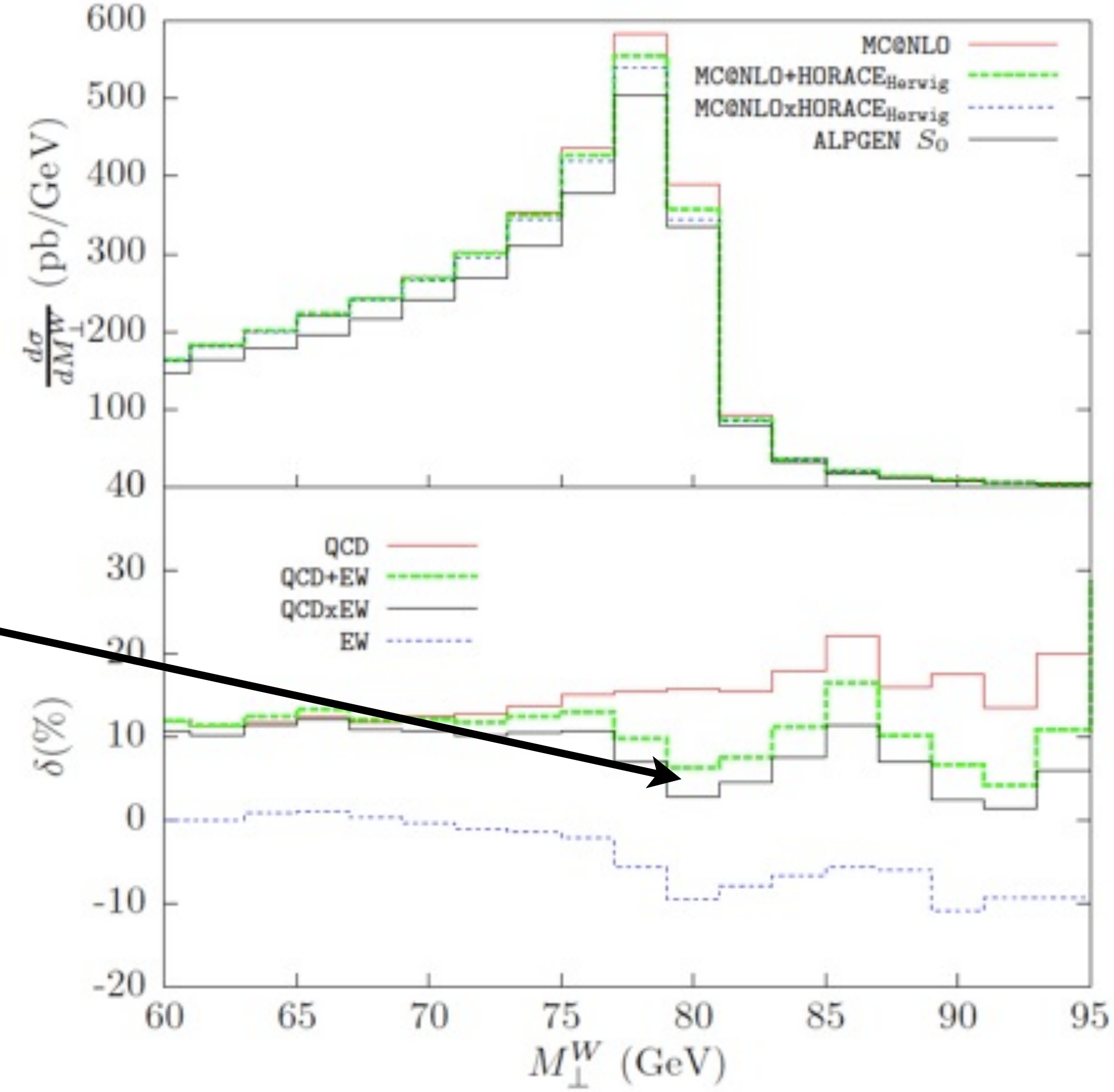
G. Balossini, C.M.Carloni Calame, G.Montagna, M.Moretti, O.Nicrosini, F.Piccinini, M.Treccani, A.Vicini, JHEP 1001:013, 2010

factorized prescription

$$\left[\frac{d\sigma}{d\mathcal{O}}\right]_{QCD\otimes EW} = \left(1 + \frac{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{MC@NLO} - \left[\frac{d\sigma}{d\mathcal{O}}\right]_{HERWIG\ PS}}{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{LO/NLO}}\right) \times \left\{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{EW}\right\}_{HERWIG\ PS}$$

additive prescription

$$\left[\frac{d\sigma}{d\mathcal{O}}\right]_{QCD\oplus EW} = \left\{\frac{d\sigma}{d\mathcal{O}}\right\}_{QCD} + \left\{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{EW} - \left[\frac{d\sigma}{d\mathcal{O}}\right]_{Born}\right\}_{HERWIG\ PS}$$



- the factorized and the additive formulae differ by few per cent
- different inclusion of higher orders $\mathcal{O}(\alpha_s^2)$ and $\mathcal{O}(\alpha\alpha_s)$
- the POWHEG formulation offers another recipe to combine the QCD and EW corrections

CC and NC Drell-Yan in POWHEG with exact NLO-(QCD+EW)

POWHEG, CC-DY: NLO-(QCD+EW) matched with QCD/QED Parton Shower

Bernaciak, Wackeroth, arXiv:1201.4804

Barzè, Montagna, Nason, Nicrosini, Piccinini, arXiv:1202.0465

POWHEG, NC-DY: NLO-(QCD+EW) matched with QCD/QED Parton Shower

Barzè, Montagna, Nason, Nicrosini, Piccinini, Vicini, arXiv:1302.4606

http://powhegbox.mib.infn.it/

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

(differential)
overall normalization factor
exact NLO QCD+EW accuracy
(Born+virtual+integrated real)

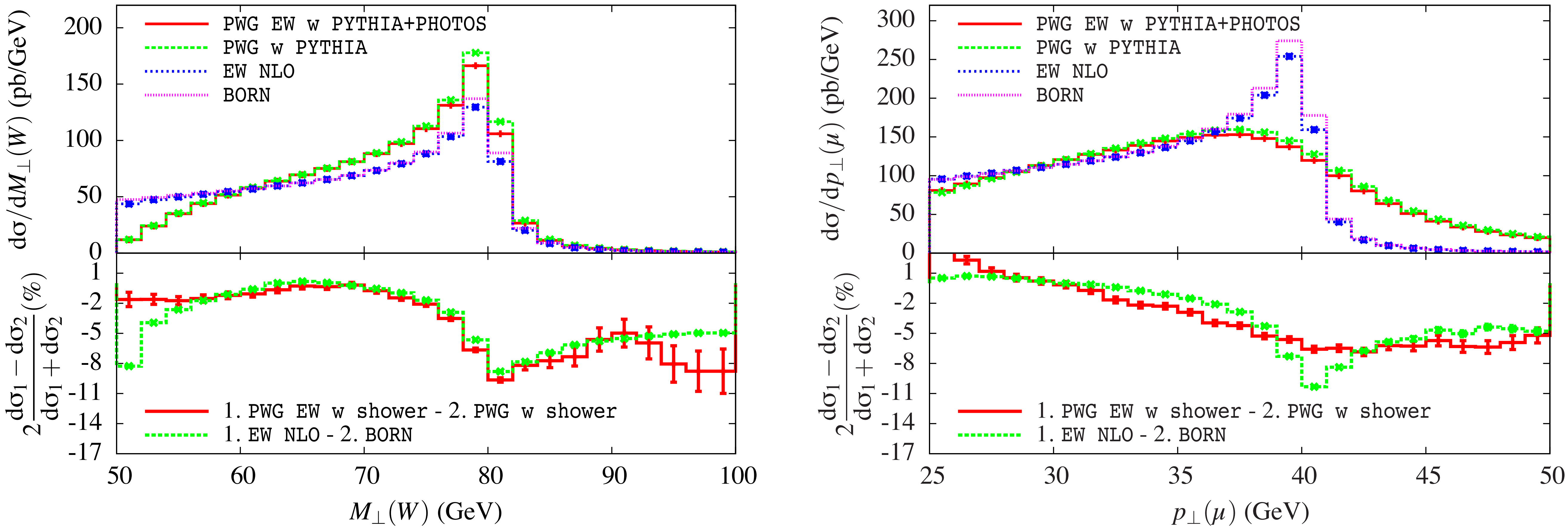
no emission probability
(Sudakov form factor)

exact emission probability of one parton
(either one photon or gluon or quark)
requested to be the hardest emission
(Sudakov form factor)

- the events generated in this way are then passed to PYTHIA/HERWIG for QCD and QED showering
- the effect of radiative corrections on the distributions is ruled by the (modified) Sudakov form factor and is factorized w.r.t. the lowest order kinematics B

CC-DY: QCD+EW effects

Barzè, Montagna, Nason, Nicrosini, Piccinini, arXiv:1202.0465



- FSR multiple photon radiation included with PHOTOS

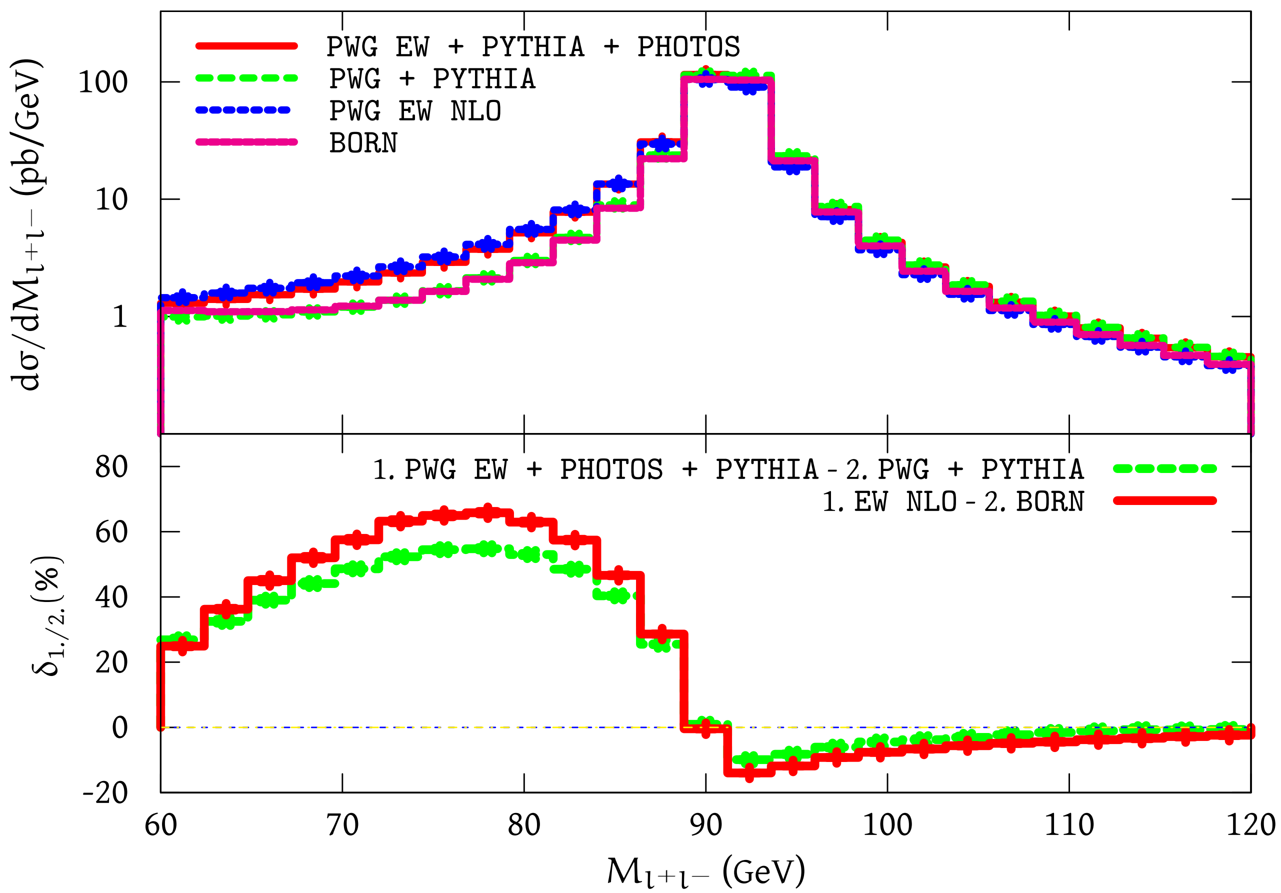
- transverse mass stable against QCD corrections → NLO-EW effects are preserved after showering
- the lepton transverse momentum is more sensitive to multiple gluon radiation
  the sharp peak due to EW corrections is reduced by the QCD-Parton Shower

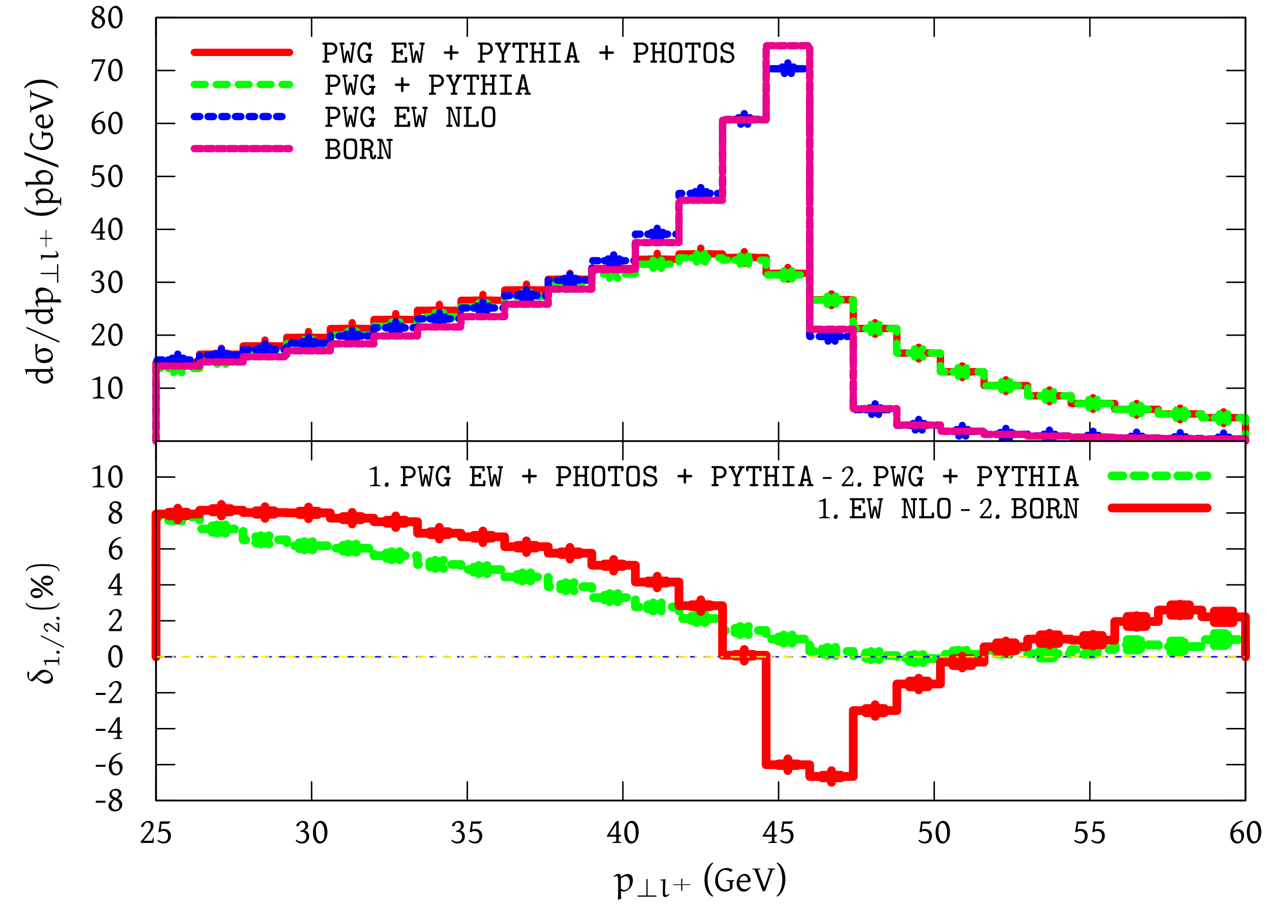
- the interplay between QCD and EW corrections yields effects at the per cent level

- leading higher-order mixed O(αα_s) corrections are taken into account
  together with the proper matching of NLO-(QCD+EW) matrix elements and (QCD+QED) Parton Shower

NC-DY: QCD+EW effects

Barzè, Montagna, Nason, Nicrosini, Piccinini, Vicini, arXiv:1302.4606





- the lepton transverse momentum is very sensitive to multiple gluon radiation

- the sharp peak due to EW corrections is reduced by the interplay with the QCD-Parton Shower;
  factorizable O(αα_s) corrections are at the level of 7%

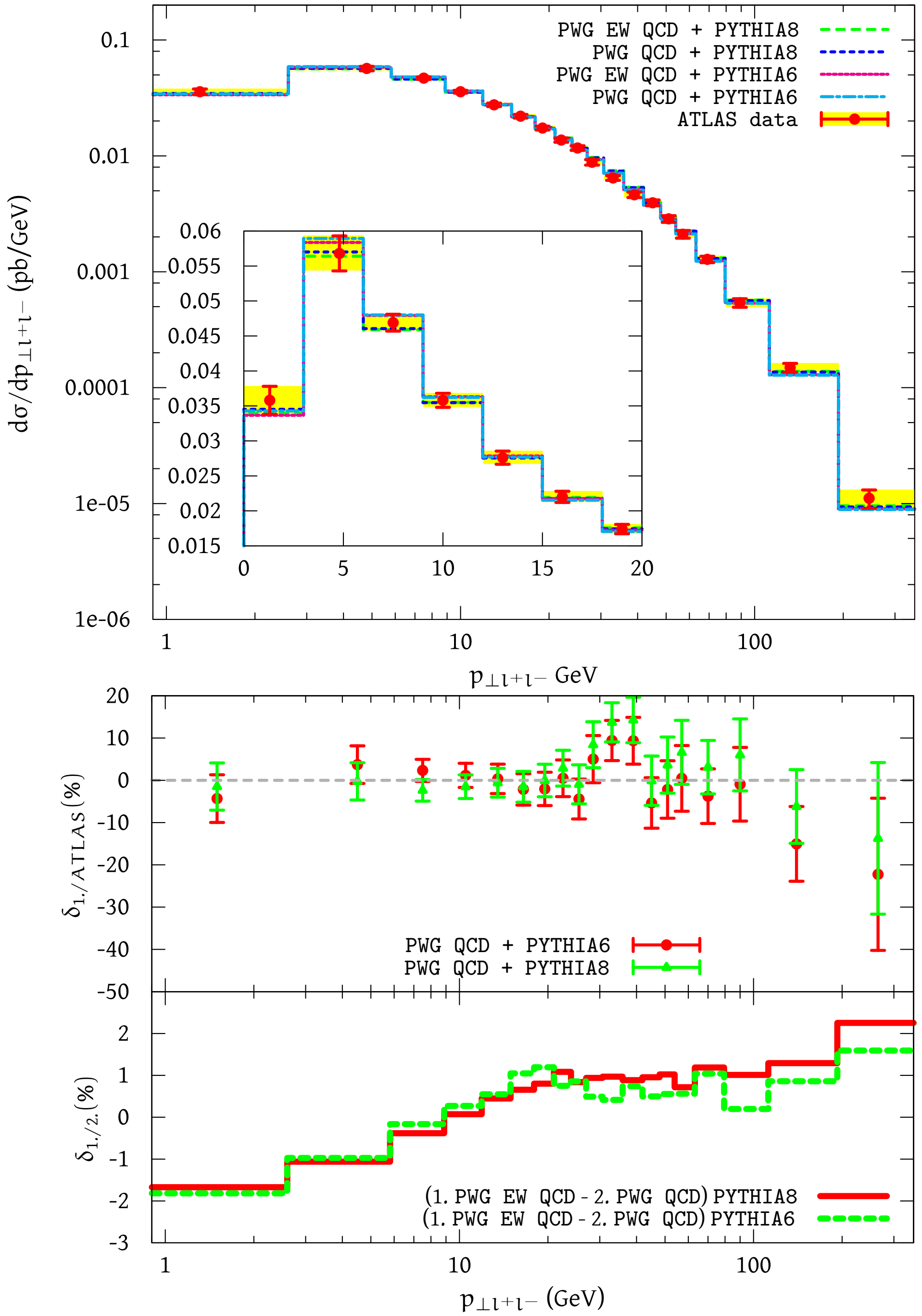
- an additive prescription to combine QCD+EW effects instead preserves the peak

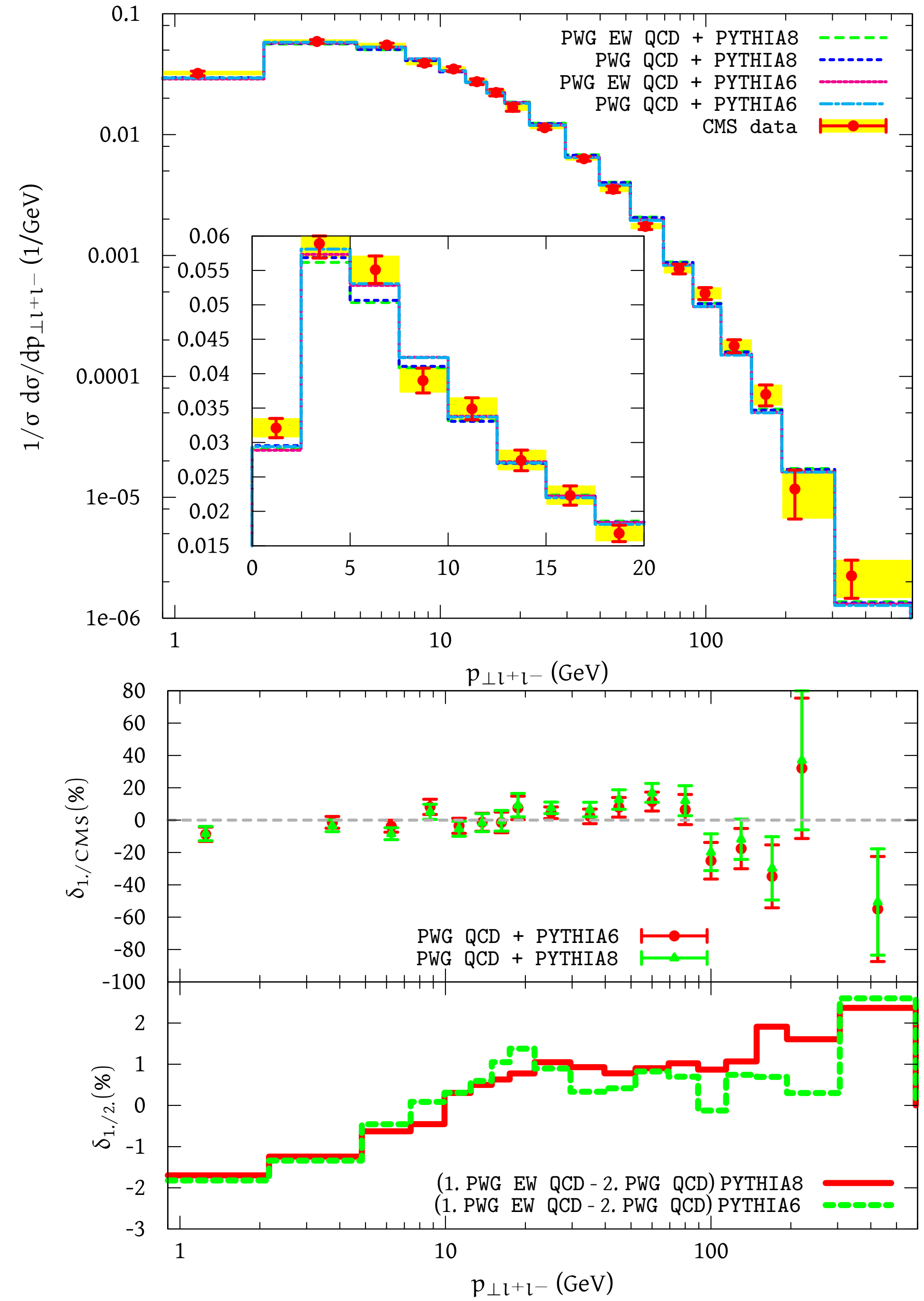
the fixed-order QCD description of the lepton transverse momentum distribution is poor, a resummation is needed

the combination of NLO-EW effects with multiple gluon emission strongly smears both
the NLO-QCD fixed order spectrum and the peaked NLO-EW correction

NC-DY: QCD+EW effects lepton-pair transverse momentum

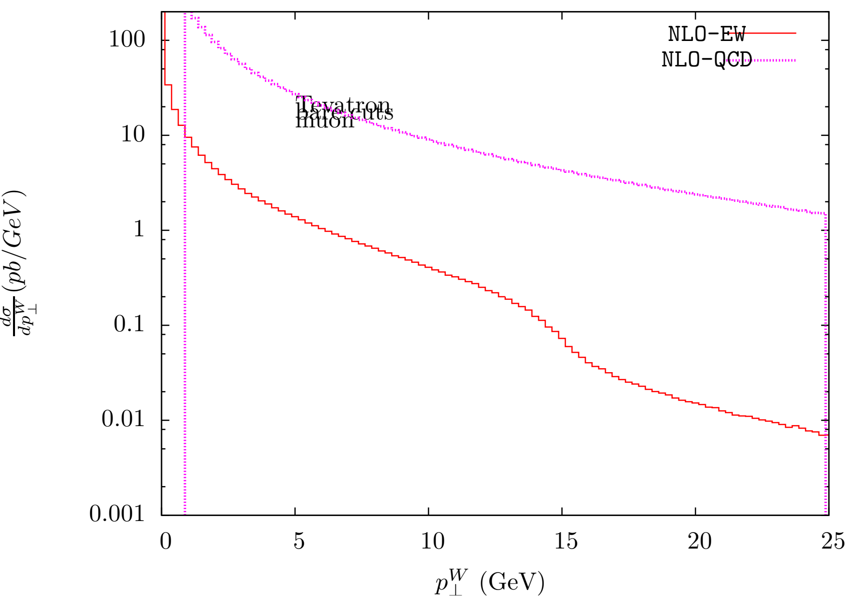
Barzè, Montagna, Nason, Nicrosini, Piccinini, Vicini, arXiv:1302.4606

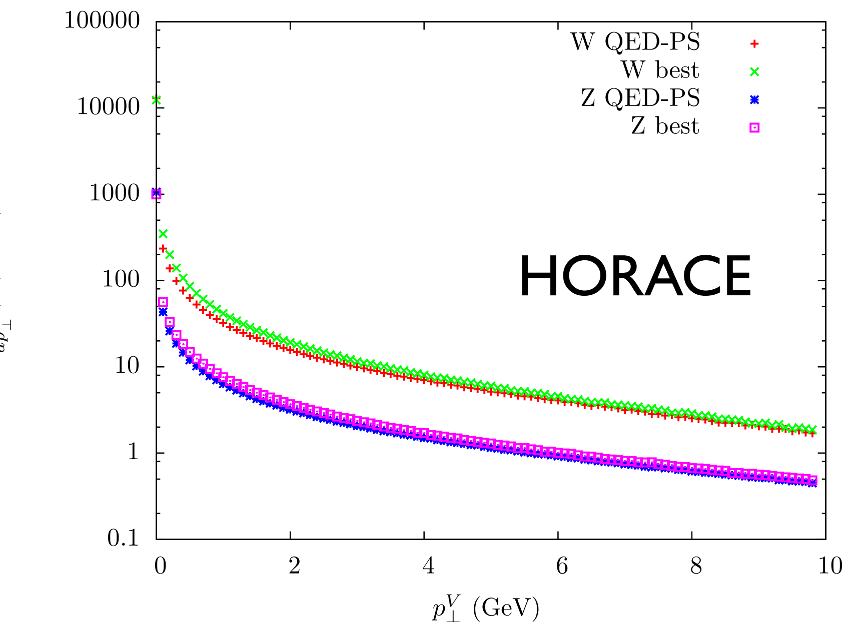




- the description of the lepton-pair transverse momentum distribution data is in general good
- default values for the non-perturbative parameters in PYTHIA6 and PYTHIA8 have been used (further tuning possible)
- full NLO-EW matrix element → bulk of the QED effects on ptZ; multiple photon radiation has negligible impact
- QED radiation affects differently ptW and ptZ, both in its FSR and in its ISR components

QED induced W(Z) transverse momentum





Uncertainty on ptW directly translates into an uncertainty on MW.

Photon radiation yields a tiny gauge boson transverse momentum.

The gauge boson transverse momentum is different in the CC and NC channels because of the different flavor structure.

A possible estimate of the "non-final state" component differs in the 2 cases by 54 (Z) - 33 (W) = 21 MeV

$\langle p_\perp^V \rangle =$

Z FSR-PS	0.409	GeV
Z best	0.463	GeV
W FSR-PS	0.174	GeV
W best	0.207	GeV

The fit of the non-perturbative PYTHIA parameters from the Z transverse momentum should be done using POWHEG (QCD+EW) + PYTHIA,
in order to remove completely the EW corrections to the NC channel from the tuning
→ the PYTHIA parameters will encode only non-perturbative QCD information

In the simulation of the CC channel,
the use of POWHEG (QCD+EW), with the above PYTHIA parameters,
will yield the proper combination of QCD and EW effects

Ambiguities affecting the shape of the ptV distribution

The prediction of the ptV distribution depends on the:

- logarithmic accuracy of the resummation
  uncertainty parametrized by the resummation scale Q (analytical approach)

- prescription to match fixed-order results and Parton Shower
  variation of *hfact* in the general formulation of NLO-matched Shower MC

- QED and mixed QCDxQED effects

Any choice of the scale Q or of the factor *hfact,* for a given PDF set,
will then require a corresponding tuning of the model dependent part of the simulation;
We should not discard the QCD theoretical uncertainties!

- non-perturbative "intrinsic" transverse momentum component
  measured from ptZ; validity of the extrapolation to a different phase-space?

- PDF set choice: partial correlation between ptZ and ptW, in particular via the gluon density

Classification of EW radiative corrections

Barzè, Bizjak, Montagna, Nicrosini, Piccinini, Vicini, in preparation

- each set of radiative corrections induces a distortion of the shape of the observables
- with a template-fit approach, the distortion of the shape is translated into a MW shift
- study performed in the Tevatron setup (energy and acceptance cuts)

- the available subsets of corrections MUST be included in the analysis

			m_T		p_T^l		$\not\!\!E_T$	
line	approximation 1	approximation 2	e	μ	e	μ	e	μ
1	BORN	LL1γ	-143 ± 3.1	-148 ± 2.1	-167 ± 3.7	-198 ± 3.1	-104 ± 4.0	-89 ± 2.5
2	BORN	LL$n\gamma$	-138 ± 3.1	-138 ± 2.1	-162 ± 3.7	-184 ± 3.1	-104 ± 4.0	-85 ± 2.5
3	LL1γ	LL$n\gamma$	5 ± 3.5	10 ± 2.3	5 ± 4.4	15 ± 3.3	1 ± 4.5	5 ± 2.5
4	BORN	$\mathcal{O}(\alpha)$	-147 ± 2.8	-153 ± 2.5	-174 ± 3.5	-208 ± 3.5	-105 ± 3.7	-91 ± 2.8
5	BORN	MATCH	-137 ± 3.0	-138 ± 3.4	-163 ± 3.7	-190 ± 3.4	-96 ± 4.0	-78 ± 2.7
6	$\mathcal{O}(\alpha)$	MATCH	11 ± 3.0	12 ± 3.0	11 ± 3.5	16 ± 3.3	12 ± 4.0	13 ± 3.8
7	LL1γ	$\mathcal{O}(\alpha)$	-1 ± 3.4	-3 ± 2.5	-3 ± 4.1	-5 ± 3.7	-1 ± 4.4	-1 ± 3.0
8	LL$n\gamma$	MATCH	4 ± 3.5	5 ± 2.4	4 ± 4.2	2 ± 3.5	10 ± 4.5	10 ± 2.8

			m_T	
line	approximation 1	approximation 2	e	μ
1	exp–LL	exp–LL + e^+e^-	-2	-3
2	exp–LL	exp–LL + e^+e^- + $\mu^+\mu^-$	-3	-3

← additional lepton-pair emission simulated in HORACE

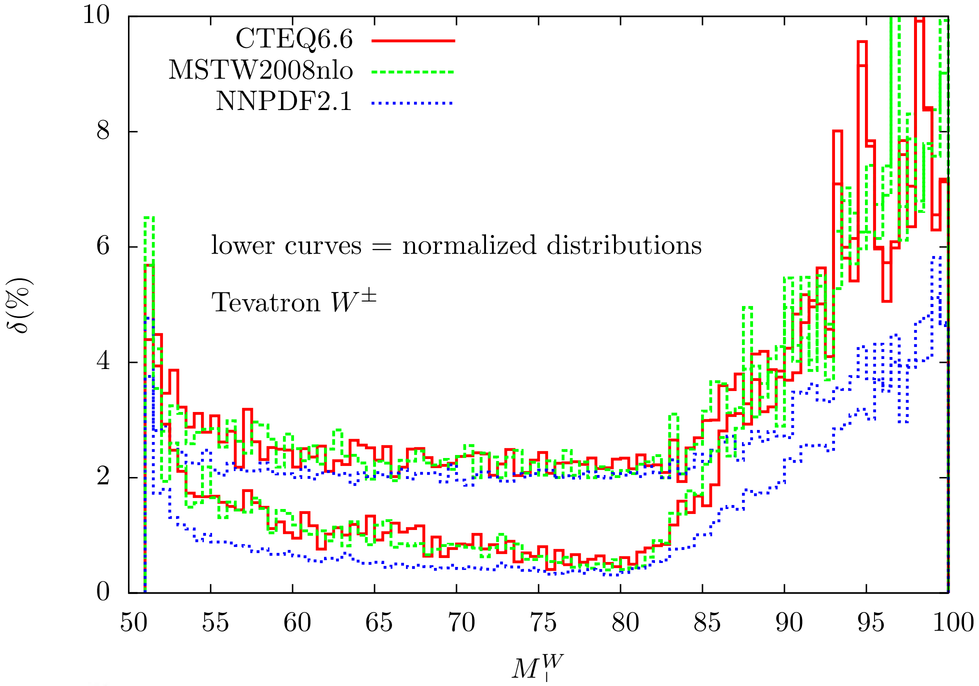
- an estimate of remaining sources of uncertainty can enter in the theoretical systematic error

			m_T		p_T^l		$\not\!\!E_T$	
line	approx.1	approx.2	e	μ	e	μ	e	μ
1	exp–LL $\kappa = 1.5$	exp–LL $\kappa = 1$	4.0	5.9	4.0	7.7	2.4	3.8
2	$\mathcal{O}(\alpha)$ LL $\kappa = 1.5$	$\mathcal{O}(\alpha)$ LL $\kappa = 1$	1.9	4.8	1.8	5.9	1.5	2.3
	$\Delta M_W{}^{\alpha^2}$	according to Eq. (25)	2.1	1.1	2.2	1.8	0.9	1.5

			m_T		p_T^l		$\not\!\!E_T$	
line	approx. 1	approx. 2	e	μ	e	μ	e	μ
1	$\mathcal{O}(\alpha)$ α_0	$\mathcal{O}(\alpha)$ $G_\mu - I$	- 9.0	-11.6	-10.8	-11.8	- 2.8	- 7.4
2	$\mathcal{O}(\alpha)$ α_0	$\mathcal{O}(\alpha)$ $G_\mu - II$	1.2	-0.3	-0.2	0.2	1.7	-0.7
3	$\mathcal{O}(\alpha)$ $G_\mu - I$	$\mathcal{O}(\alpha)$ $G_\mu - II$	10.1	11.2	10.6	12.0	4.4	6.6
4	matched α_0	matched $G_\mu - I$	-0.1	-0.1	0.0	-1.1	2.0	1.8
5	matched α_0	matched $G_\mu - II$	1.7	1.1	1.3	-0.3	4.0	2.6
6	matched $G_\mu - I$	matched $G_\mu - II$	1.8	1.2	1.0	0.8	2.0	0.9

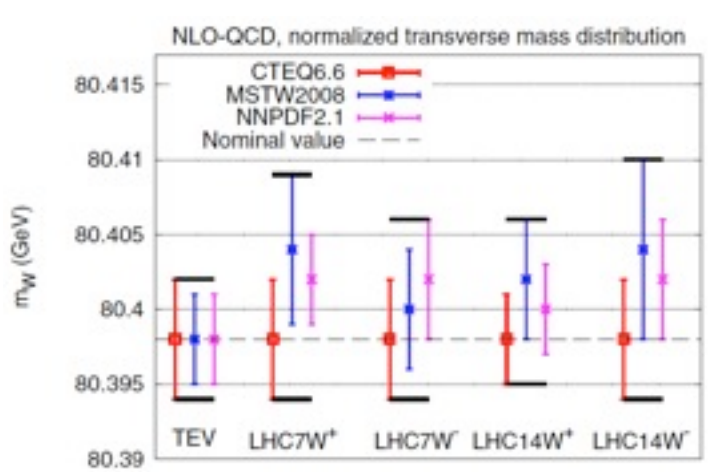
PDF error on MW from transverse mass distribution

Bozzi, Rojo, Vicini, arXiv:1104.2056



- the PDF effect on MW is obtained by studying the transverse mass normalized distributions: different PDF normalization should NOT be accounted for by a MW shift
- templates and pseudodata computed with the same generator in the same experimental setup: in first approximation the PDF effects factorize w.r.t. all the other theoretical and experimental factors

	CTEQ6.6		MSTW2008		NNPDF2.1		
	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$\delta_{\rm pdf}^{\rm tot}$
Tevatron, $W^\pm$	80.398 ± 0.004	1.42	80.398 ± 0.003	1.42	80.398 ± 0.003	1.30	4
LHC 7 TeV W^+	80.398 ± 0.004	1.22	80.404 ± 0.005	1.55	80.402 ± 0.003	1.35	8
LHC 7 TeV W^-	80.398 ± 0.004	1.22	80.400 ± 0.004	1.19	80.402 ± 0.004	1.78	6
LHC 14 TeV W^+	80.398 ± 0.003	1.34	80.402 ± 0.004	1.48	80.400 ± 0.003	1.41	6
LHC 14 TeV W^-	80.398 ± 0.004	1.44	80.404 ± 0.006	1.38	80.402 ± 0.004	1.57	8

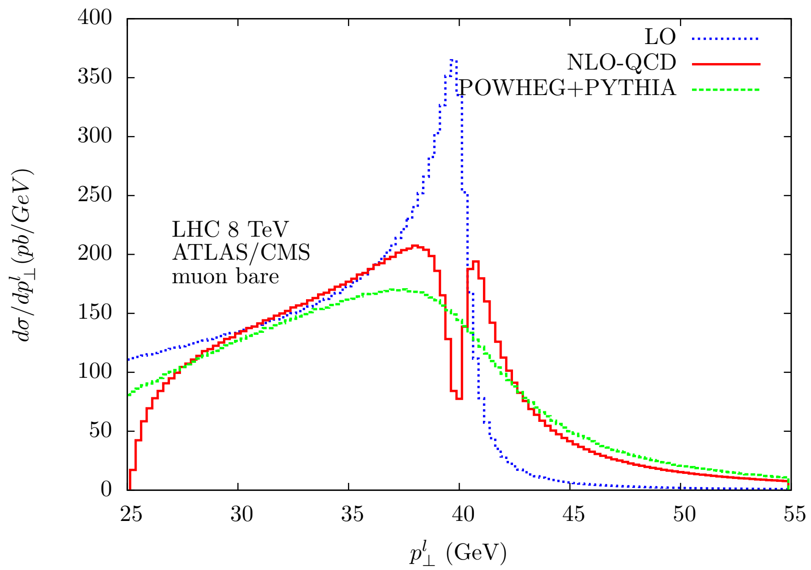


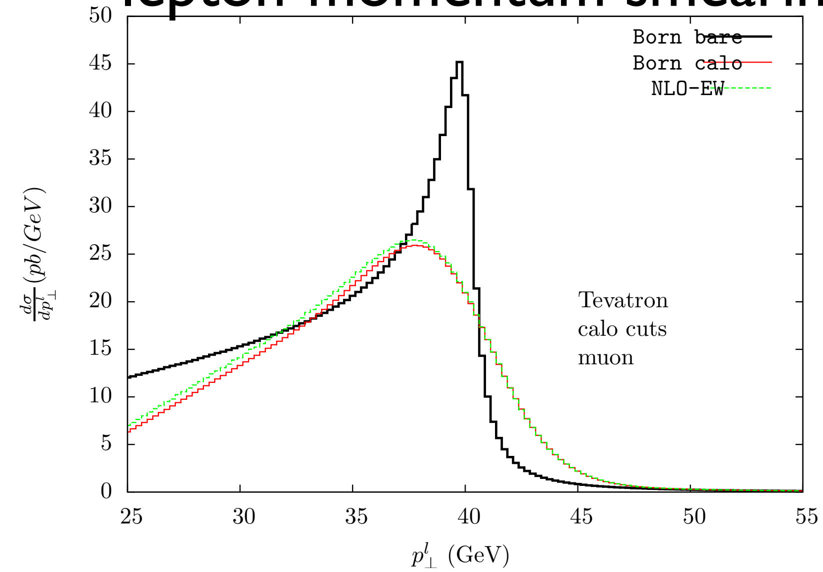
- the accuracy of the templates, to avoid spurious fluctuations, is very important because many effects are of O(5 MeV): it is a highly demanding task from the computational point of view, already at NLO-QCD
- for the transverse mass distribution, a fixed order NLO-QCD analysis is sufficient to assess this uncertainty
- if confirmed, the PDF error is moderate at the Tevatron, but also at the LHC, even before the use of the LHC data

PDF error on MW from lepton transverse momentum distribution

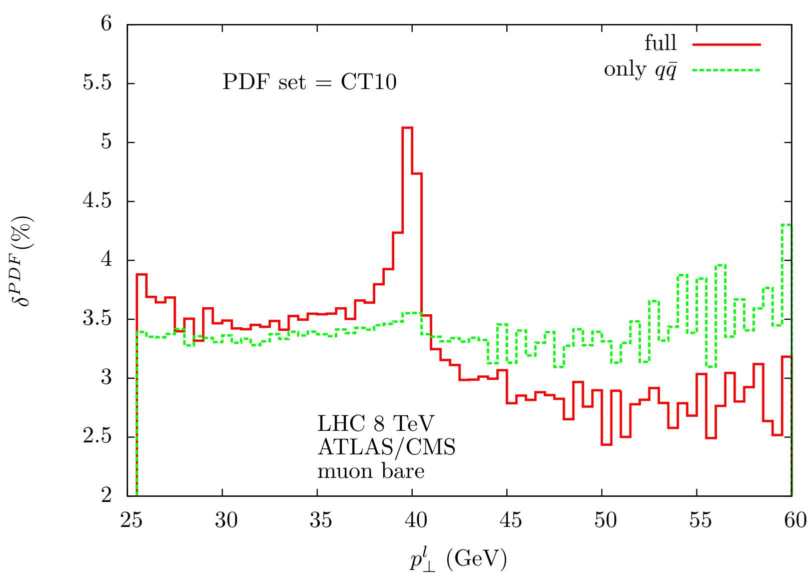
- lepton transverse momentum distribution sensitive to the details of QCD radiation

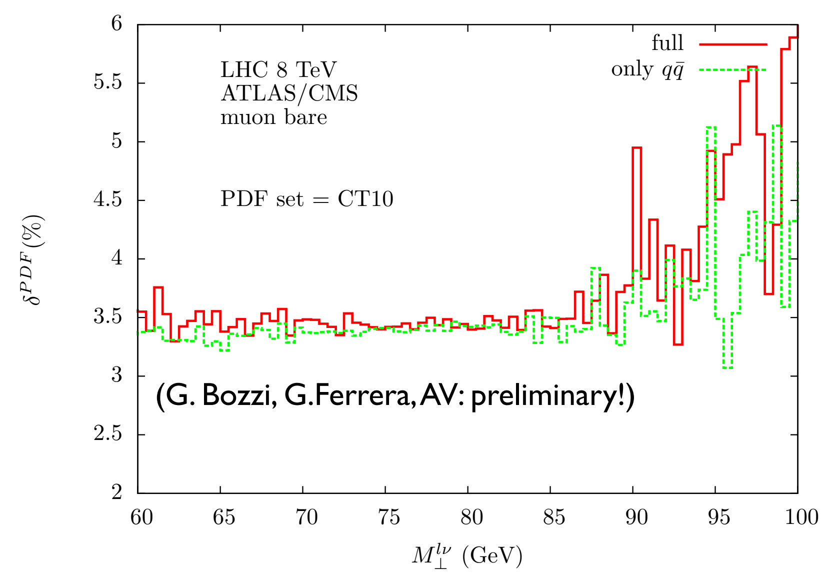
lepton-momentum smearing effects





- at NLO-QCD gluon-quark subprocesses yield an important contribution
  → the gluon PDF uncertainty is more pronounced than in the transverse mass case
- the PDF uncertainty due to quarks is rather flat over the entire range of the distribution
- the effect of the momentum smearing has to be included in the templates used in the MW fit, to isolate the pure PDF contribution to the uncertainty



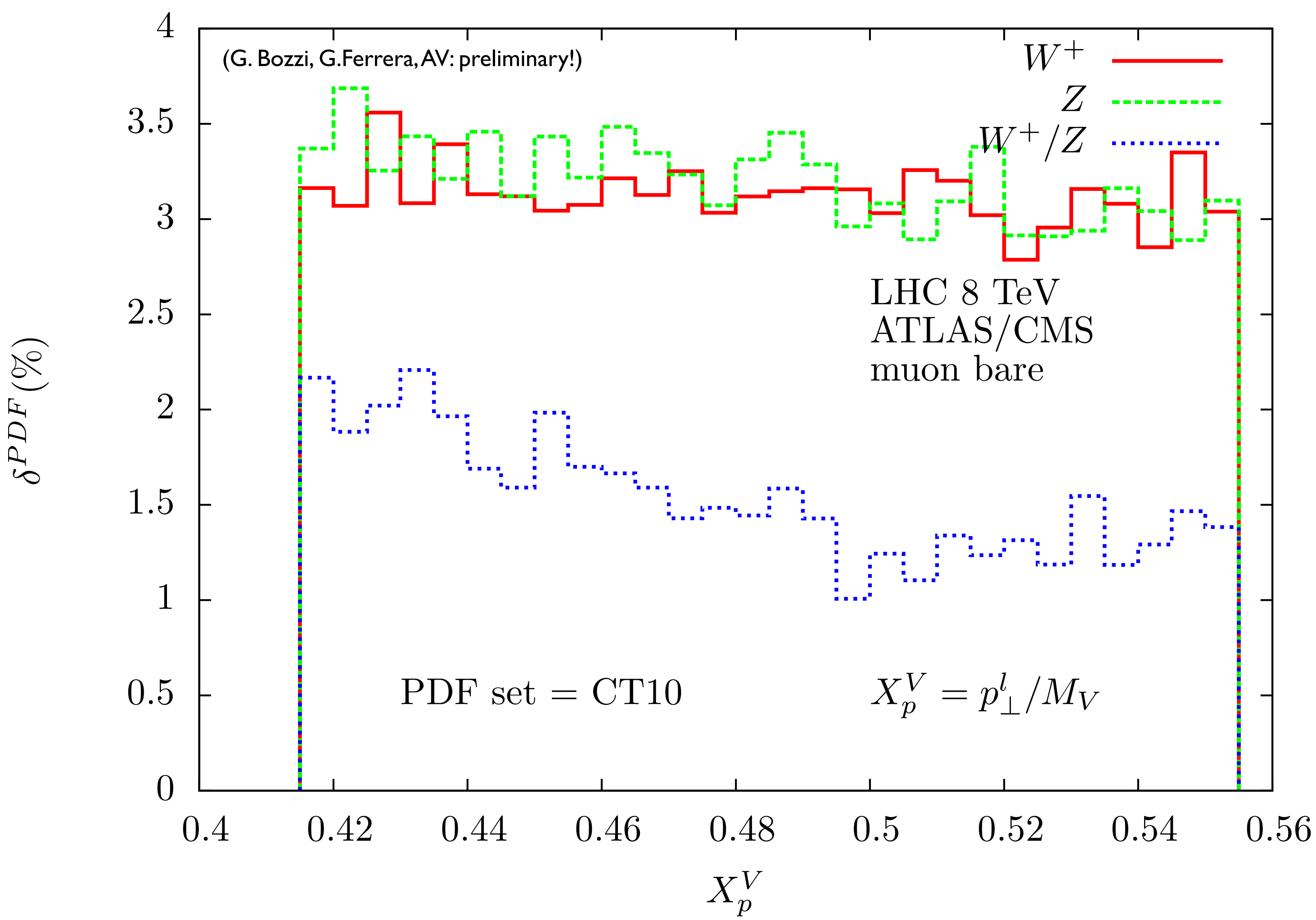


- caveat: 1) the above uncertainties have been computed with DYNNLO at NLO-QCD
  2) only the full process has a well defined physical meaning

take these plots only as motivation for a complete study

PDF error on MW from lepton transverse momentum distribution

a preliminary study with DYqT shows that it is possible to partially get rid of the PDF uncertainty
(e.g. of the quark-gluon luminosity)
by studying appropriate ratios of observables
which should preserve the sensitivity to MW (in progress)



$$\frac{d\sigma}{dX_p^V}$$

these results are obtained with DYqT
including the resummation with (LO+NLL)-QCD
accuracy of log(ptV/MV)
including the gluon-induced subprocesses

the W+ distribution is sensitive to MW (jacobian peak corresponding to Xp=0.5)

the Z distribution is weakly sensitive to MW (couplings), but probes similar *x* PDF ranges

It is crucial to have a precise assessment of the PDF uncertainty affecting MW in the lepton-pt case
to understand if this is a potential bottleneck of the analysis

Conclusions

The MW measurement with 10 (or even 5) MeV of final error is a very ambitious task which requires a thorough discussion of several sources of theoretical systematic error

- different behaviour of observables inclusive *vs* more exclusive w.r.t. QCD radiation
  relevance of QED radiation beyond LL-accuracy, including matching with exact NLO-EW results

- full NLO-(QCD+EW) matrix elements, matched with QCD+QED showers, are available in POWHEG both in CC and in NC

- matching resummation/Parton Shower with fixed order results introduces some ambiguities which affect the shape of ptV distribution (and in turn of pt_l or MT_W and in turn of MW)

- the merging procedure to combine QCD and EW corrections may follow different prescriptions yielding different results → need for a full $O(\alpha\alpha_s)$ calculation
  POWHEG QCD+EW provides a motivated *Ansatz* that includes systematically several higher-order mixed contributions

- PDF uncertainties are quite under control in the transverse mass case
  require a better understanding of the gluon density in the lepton transverse momentum distribution

- purely EW corrections, including several $O(\alpha^2)$ subsets of corrections, are quite under control, with a residual uncertainty at the level of 5 MeV

- a detailed tune of PYTHIA parameters must be performed with POWHEG QCD+EW NC and the result consistently applied to the CC process

- the fitting procedure introduces its own systematic error in the MW determination

back-up slides

Inclusion in POWHEG of the exact O(α) corrections (NLO-EW)

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

- 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 relevant in the distributions
  in particular the bulk of the O(αα_s) corrections
  (but it has NOT O(αα_s) accuracy)

- difference with respect to

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

1) purely additive prescription

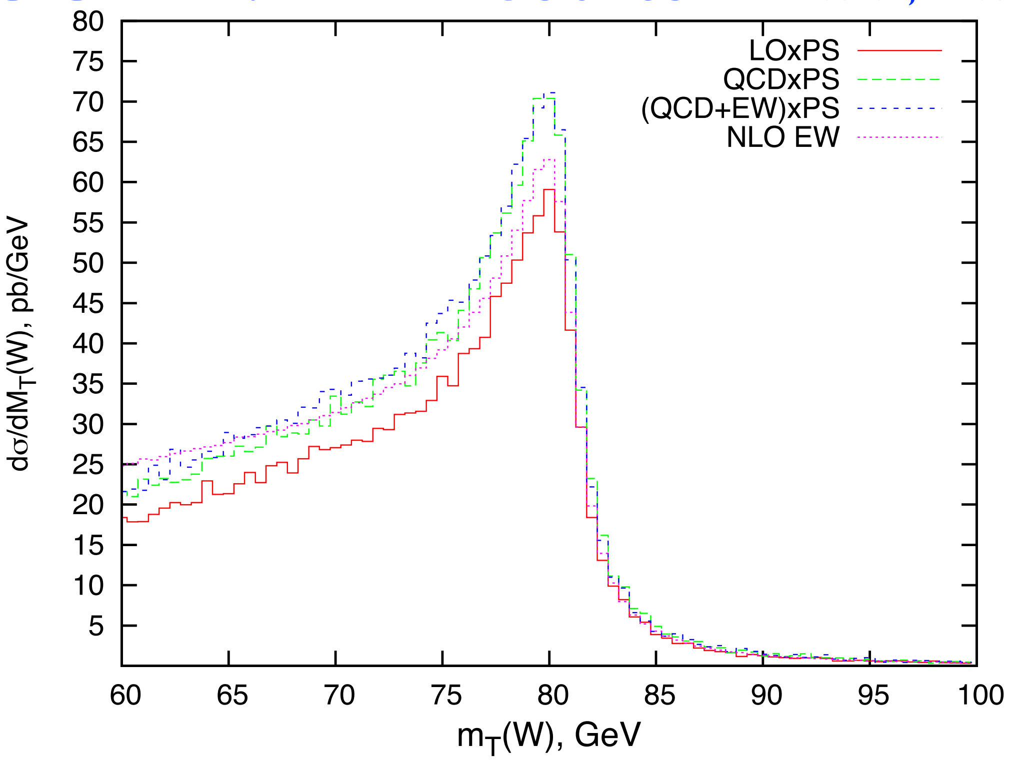
$$\mathcal{O} = \mathcal{O}_{LO}\left(1 + \delta_{QCD}^{NLO+NNLO}\right)\left(1 + \delta_{EW}^{NLO}\right)$$

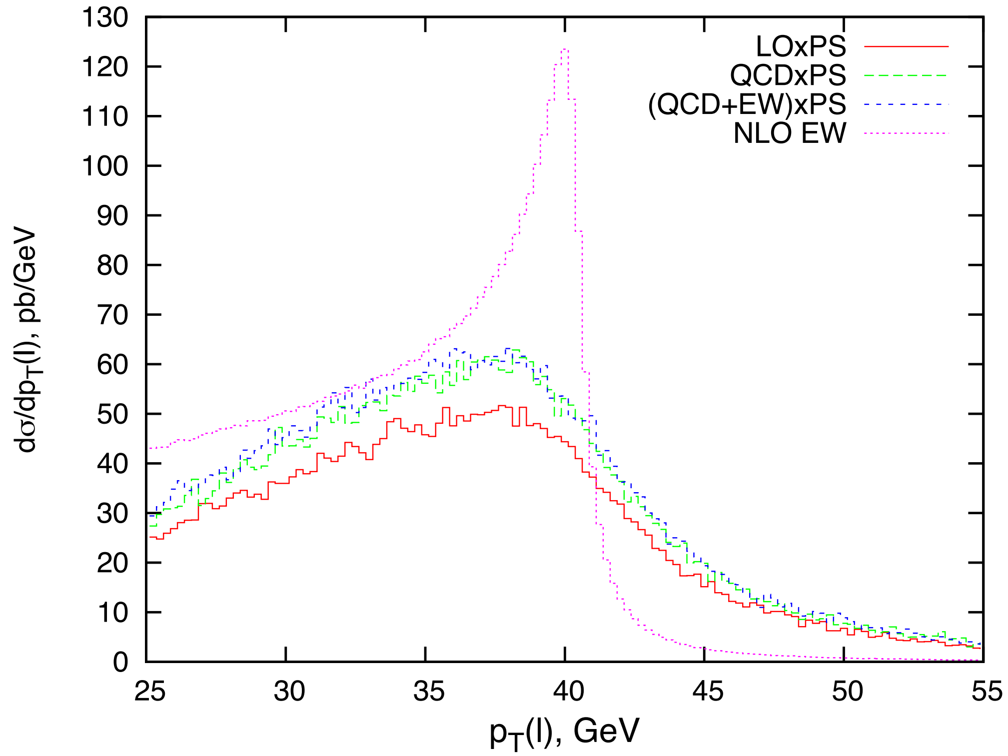
2) factorized use of (differential) K-factors

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

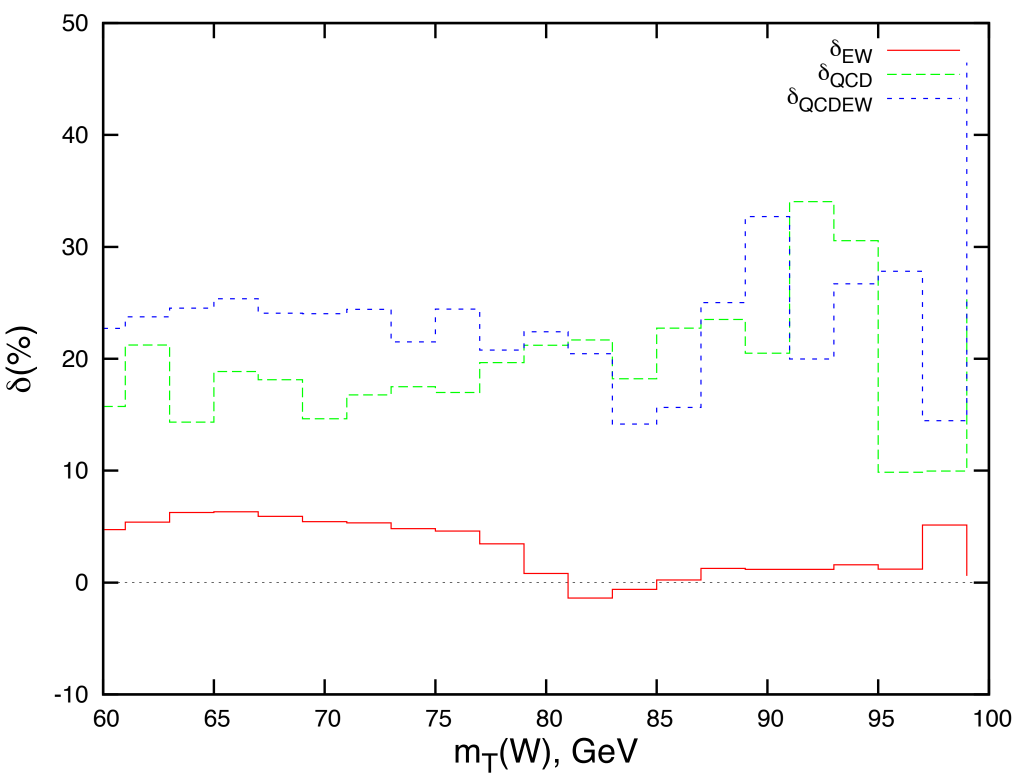
- the subtraction of IS QED collinear singularities is consistent only with MRST2004QED,
  where the evolution kernel of the parton densities includes also a QED term;
  updated PDF set including QED effects will be welcome!

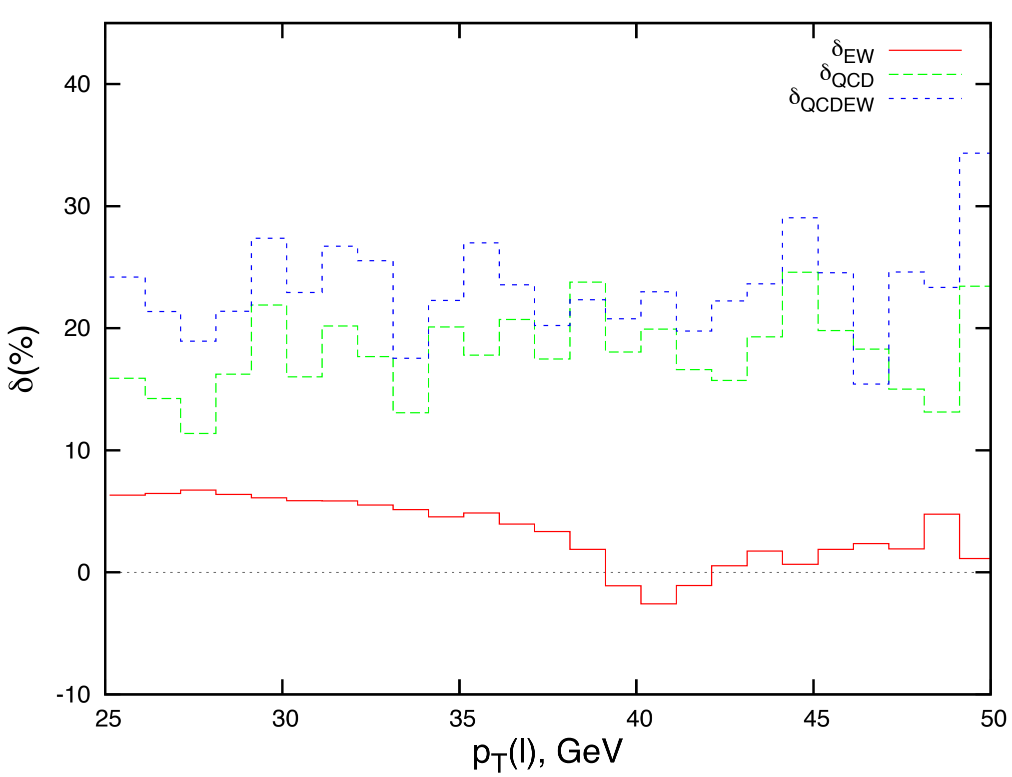
CC-DY: BW results Bernaciak, Wackeroth, arXiv:1201.4804 LHC muon bare





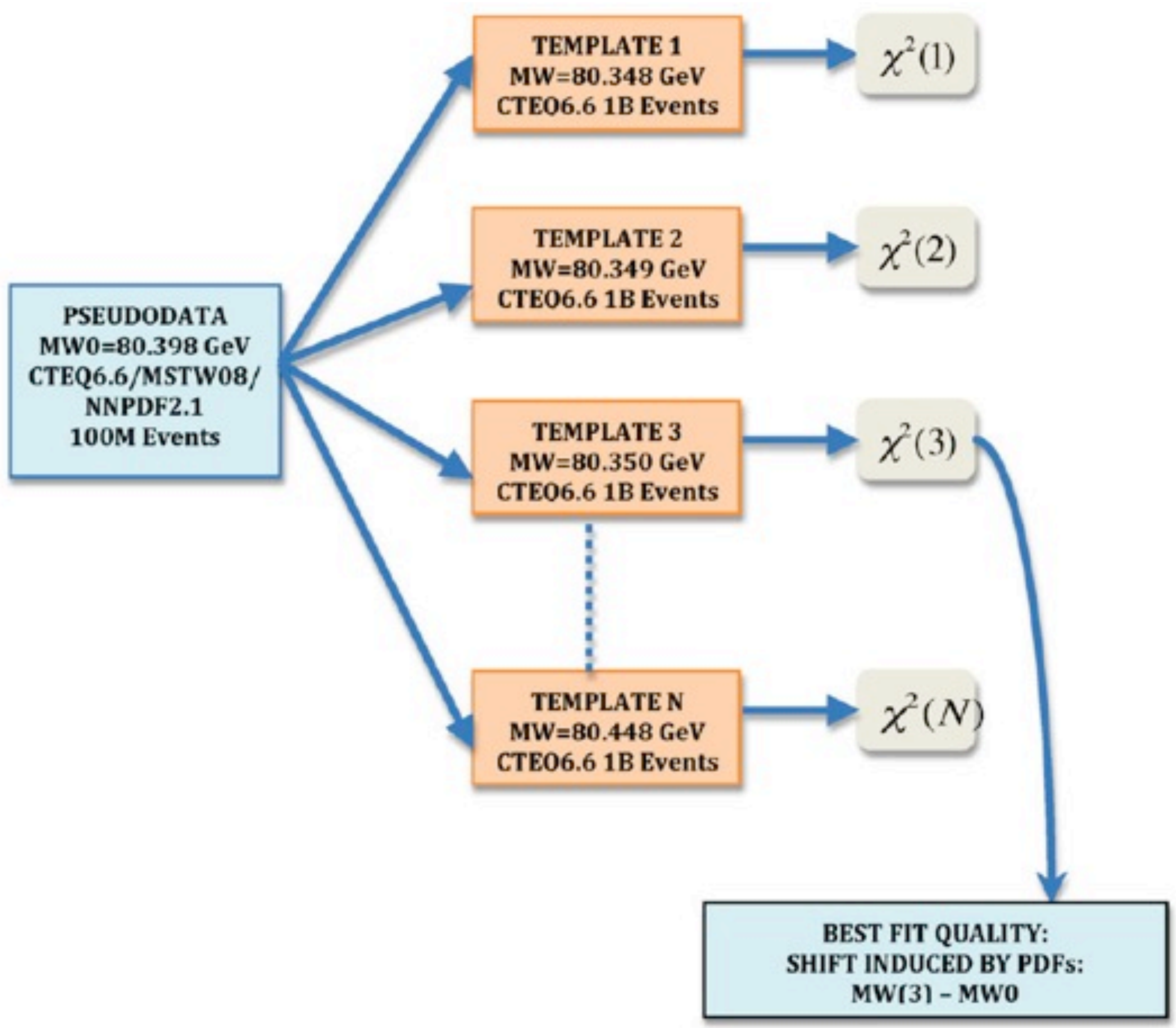
- all the results in the α_0 input scheme
- the pure NLO-EW curves do NOT include the QCD Parton Shower (δ is relative to pure LO)
- the (QCD+EW)xPS results include only the QCD Parton Shower
- QCD corrections tend to be flat over the whole MT range
- the sharp peak of lepton pt distribution due to EW corrections is reduced by the QCD-Parton Shower





Estimate of the error on MW induced by the PDFs (G. Bozzi et al, arXiv:1104.2056)

- each PDF replica is used to generate a set of pseudodata, with a fixed value MW_0
- a very accurate set of template distributions has been prepared, varying only MW, with a reference(CTEQ6.6) PDF replica
- when pseudodata generated with the reference replica are fitted, the nominal value MW_0 is found (sanity check)
- the same code, DYNNLO, has been used to generate both, pseudodata and templates → only effect probed is the PDF one



- the MW shift expresses the distance between the PDF replica under study and the reference replica
- the PDF error is obtained combining the different MW results from each replica, according to the formulae recommended by the PDF collaborations

Matching NLO calculations with resummation: DYqT

Bozzi, Catani, De Florian, Ferrera, Grazzini

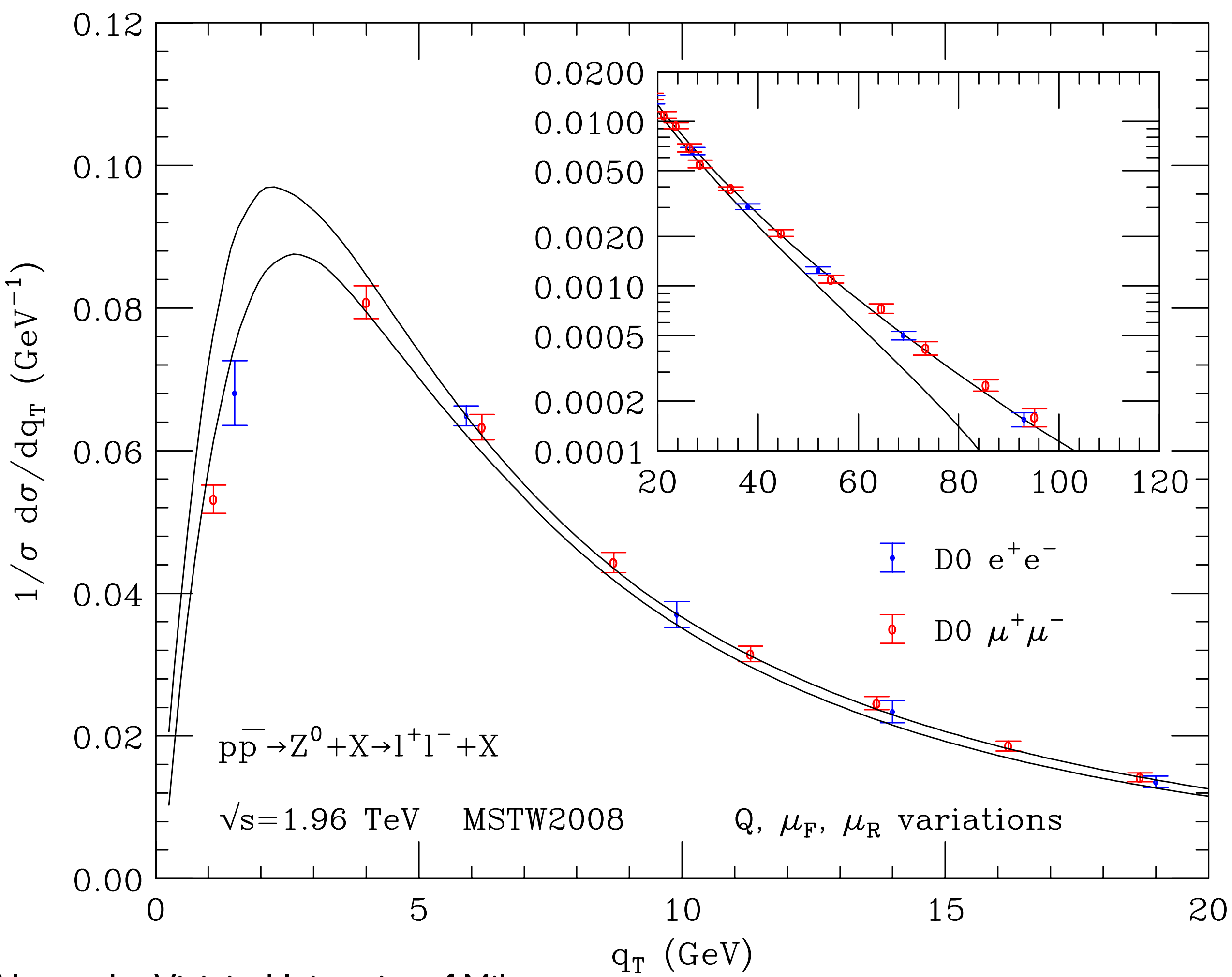
$$\frac{d\hat{\sigma}^{(\mathrm{res.})}_{V\,ab}}{dq_T^2}(q_T, M, \hat{s}; \alpha_S(\mu_R^2), \mu_R^2, \mu_F^2) = \frac{M^2}{\hat{s}} \int_0^\infty db\, \frac{b}{2}\, J_0(bq_T)\, \mathcal{W}^V_{ab}(b, M, \hat{s}; \alpha_S(\mu_R^2), \mu_R^2, \mu_F^2)\ ,$$

process dependent

$$\mathcal{W}^V_N(b, M; \alpha_S(\mu_R^2), \mu_R^2, \mu_F^2) = \mathcal{H}^V_N\left(M, \alpha_S(\mu_R^2); M^2/\mu_R^2, M^2/\mu_F^2, M^2/Q^2\right) \times \exp\{\mathcal{G}_N(\alpha_S(\mu_R^2), L; M^2/\mu_R^2, M^2/Q^2)\}\ ,$$

universal

G. Bozzi, S.Catani, D. de Florian, G. Ferrera, M. Grazzini , arXiv:1007.2351



Q is the resummation scale

the fixed order total cross section is by construction reproduced

a non-perturbative smearing factor can be applied on top of the pQCD result

Comparison between POWHEG and MC@NLO

$$d\sigma^{\rm NLO+PS} = d\Phi_B \bar{B}^s(\Phi_B)\left[\Delta^s(p_\perp^{\rm min}) + d\Phi_{R|B}\frac{R^s(\Phi_R)}{B(\Phi_B)}\Delta^s(p_{\rm T}(\Phi))\right] + d\Phi_R R^f(\Phi_R)$$

$$\bar{B}^s = B(\Phi_B) + \left[V(\Phi_B) + \int d\Phi_{R|B} R^s(\Phi_{R|B})\right]$$

R^s enters in the Sudakov form factor $\Delta^s(p_T(\Phi))$

the virtuality of the first, hardest emission is analogous to the resummation scale in DYqT, different event by event

MC@NLO

$$R^s \propto \frac{\alpha_s}{t} P_{ij}(z) B(\Phi_B)$$

$$R^f = R - R^s$$

the universal collinear splitting function is used in the Sudakov

the full matrix element R is used only in the regular part

POWHEG

$$R^s = \frac{h^2}{h^2 + p_{\rm T}^2} R\,, \qquad R^f = \frac{p_{\rm T}^2}{h^2 + p_{\rm T}^2} R$$

the scale *h* (introduced in the Higgs gluon fusion code) divides low from large ptV values

at low ptV, R tends to its collinear approximation
at large ptV the damping factor suppresses R in the Sudakov

- the two approaches exactly agree at NLO-QCD, they differ by higher order corrections

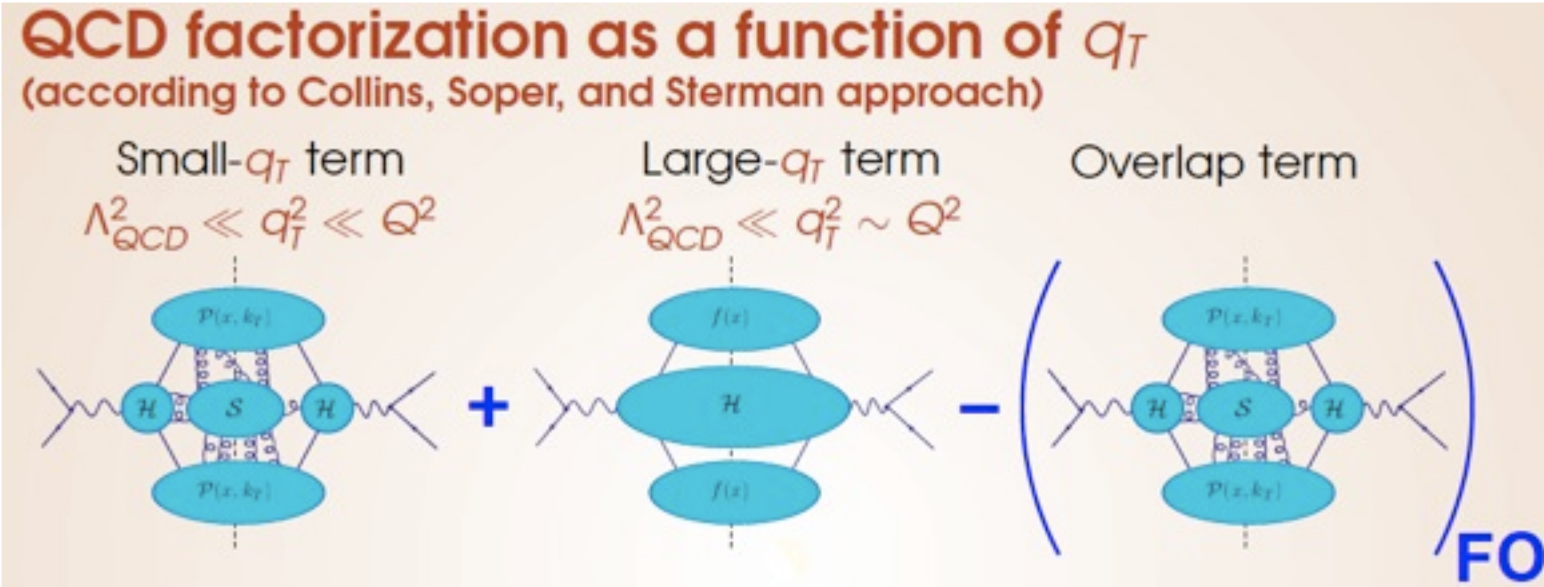
a choice of *h* that mimics a NLO+NNLL shape must be supplemented by a study on the systematics obtained by varying *h*

different choices for Rf, combined with the cross section unitarity constraint, may lead to an uncertainty band on ptH

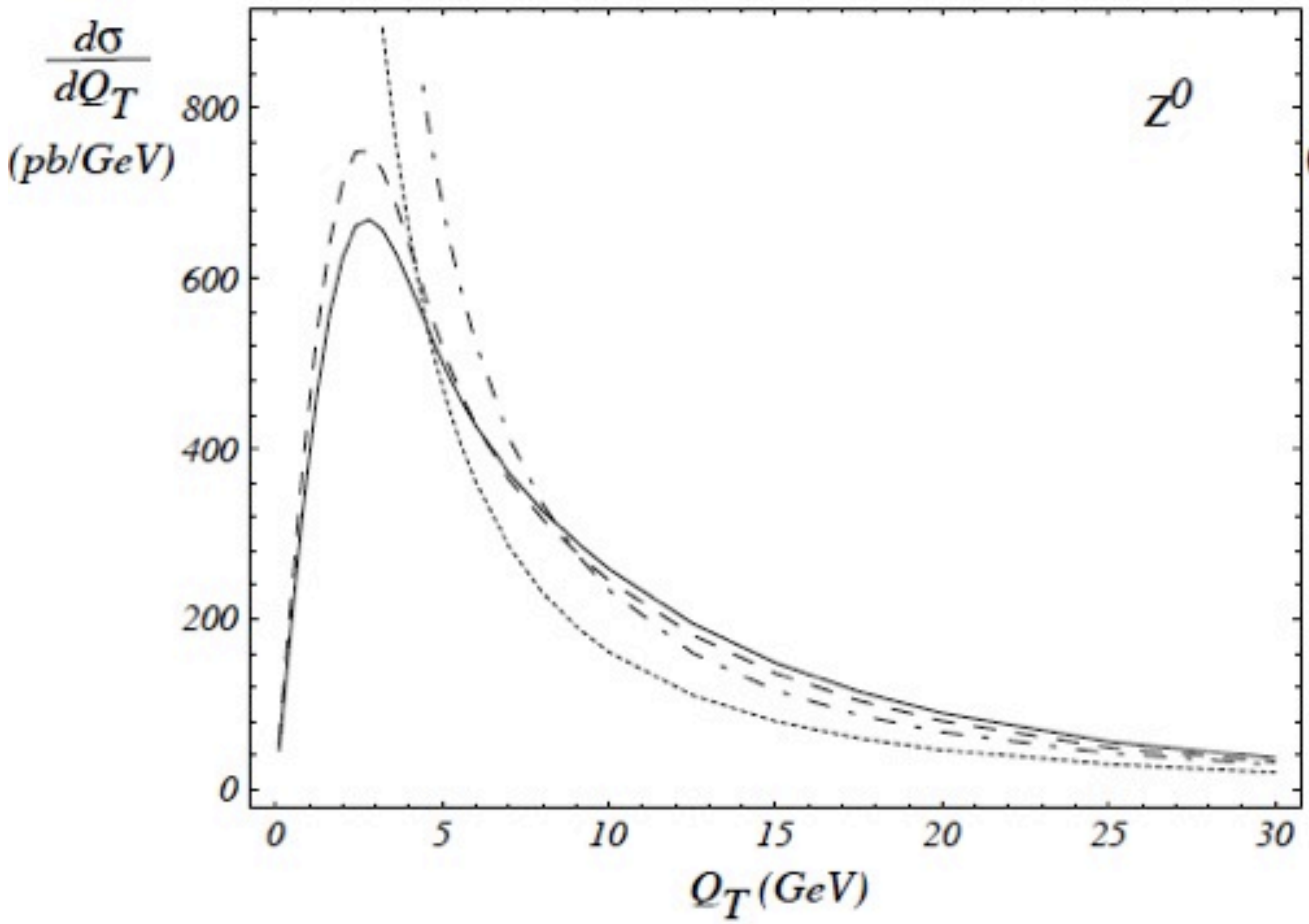
Matching NLO calculations with resummation: ResBos

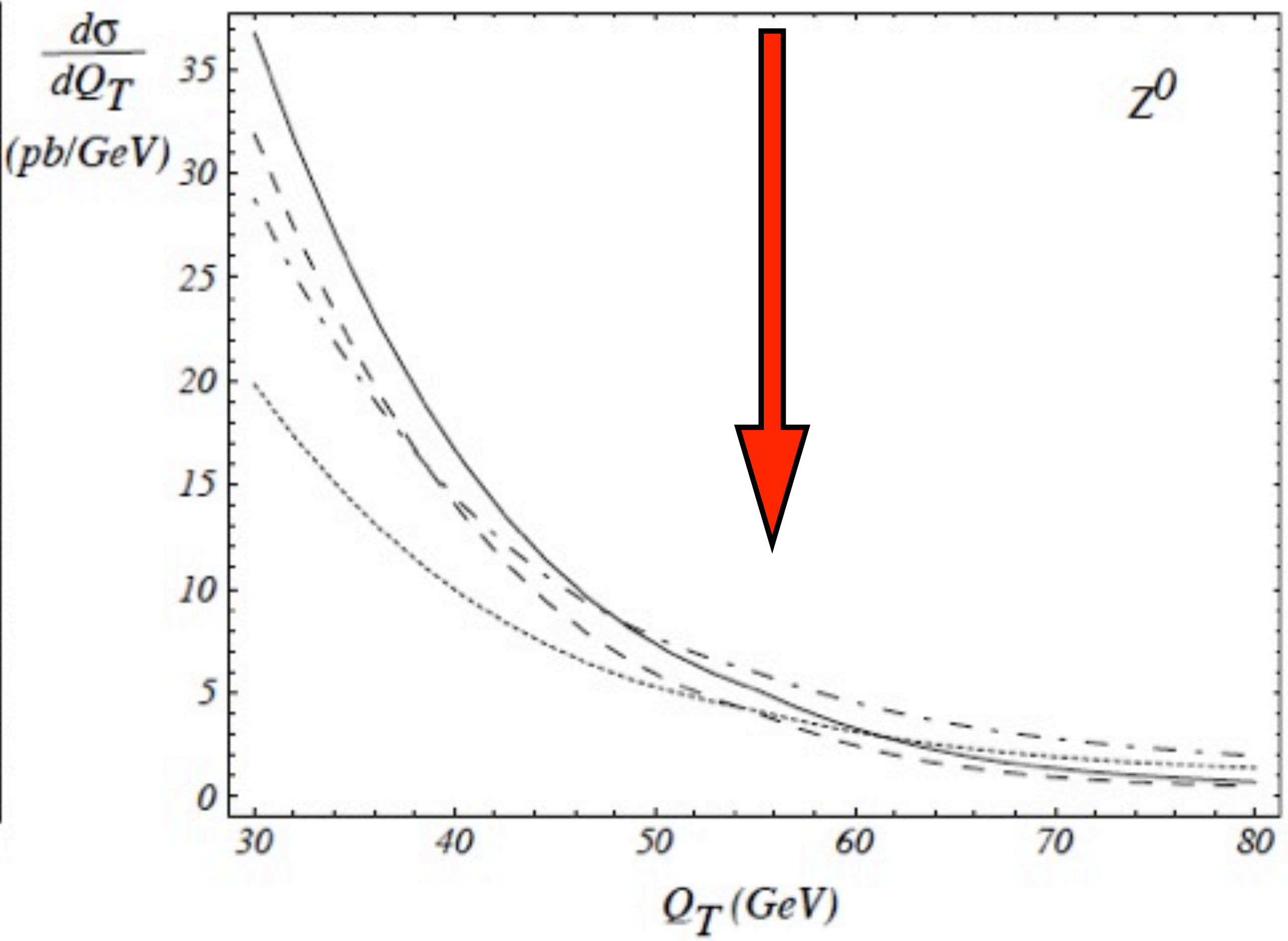
Landry, Brock, Nadolski, Yuan, Balazs

- Finite order: part of the NNLO results
  lepton spin correlation at NLO
- Resummed term *W* at NNLL
  for Sudakov factor and non-collinear *pdfs*
- Two representations of the
  hard-vertex function *H*



matching at the crossing point between resummed and fixed order results





On-going benchmarking study within the LHC-EWWG

see http://lpcc.web.cern.ch/lpcc/

- the authors of the following codes are actively participating to this study
  - HORACE, RADY, SANC, WZGRAD
  - PHOTOS, WINHAC
  - DYNNLO, FEWZ
  - POWHEG (only QCD and QCD+EW)

- in a first phase, technical agreement (same inputs ⇒ same outputs)

  at LO, NLO-QCD, NLO-EW has been reached on differential distributions at better than 0.5% level

- given this common starting point with NLO accuracy,
  we are now exploring the impact of higher order corrections (pure QCD, pure EW, mixed QCDxEW)
    - corrections available only in some codes (e.g. NNLO-QCD vs QCD-PS)
    - ambiguities which can not be fixed without an explicit full next-order calculation (e.g. EW inputs)