UNIVERSITÀ DEGLI STUDI
DI MILANO

INFN
Istituto Nazionale
di Fisica Nucleare

Drell-Yan processes at the LHC

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CERN, February 22nd 2008

with: C. M. Carloni Calame, G. Montagna, O. Nicrosini,
G. Balossini, F. Piccinini, M. Moretti, M. Treccani

papers: CMCC, GM, ON, AV: JHEP 0612:016 (2006), JHEP 0710:109 (2007)

workshop proceedings: hep-ph/0604120 (Les Houches, Physics at TeV colliders 2005)
arXiv:0705.3251 (TeV4LHC: top and EW working group)

ongoing workshop : Les Houches, Physics at TeV colliders 2007

Outline

- accuracy goals

- HORACE : Charged and Neutral Current Drell-Yan
  photon induced subprocesses with MRST2004QED

- combining QCD and EW radiative corrections
  gauge boson rapidity, lepton pseudorapidity, charge asymmetry
  other observables

- uncertainties due to the *pdf* (CTEQ6.1 / MRST2001E, CTEQ6.5 / MRST2006)

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- several higher-order corrections induce effects at the few per cent level on the distributions, comparable to the NNLO corrections, which may have an impact on the extraction of the *pdf*
  - different QCD resummations and matching (e.g. Herwig vs Pythia shower; Resbos soft-gluon resummation a la CSS)
  - O(α) EW corrections
  - multiple-photon radiation via PS
  - mixed QCD-EW effects
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- the uncertainties due to the experimental errors on the data used to extract the *pdfs* set the scale of relevance of new missing higher order corrections
- need of a combination QCD+EW at the event generator level
  for precision studies at the W,Z resonances
  to accurately constrain the *pdfs*

Drell-Yan Charged and Neutral Current processes in HORACE

C.M.Carloni Calame, G.Montagna, O.Nicrosini, A.Vicini

- http://www.pv.infn.it/hepcomplex/horace.html

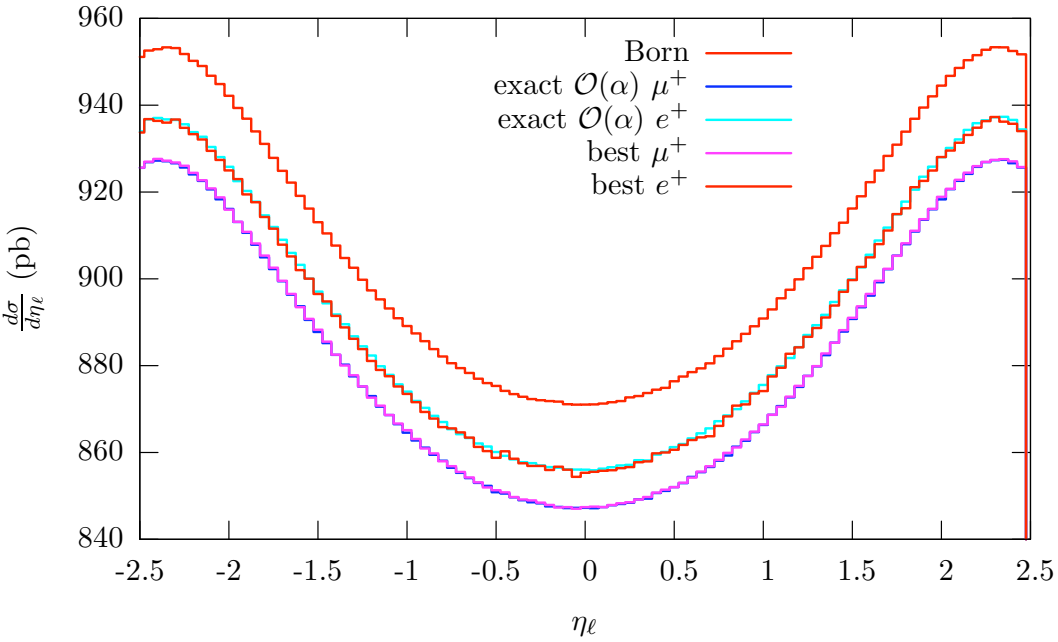
- true, fully exclusive event generator
  events saved in a Les Houches compliant form
  interfaced to LHAPDF package
  easy to interface to QCD showering programs like HERWIG or PYTHIA

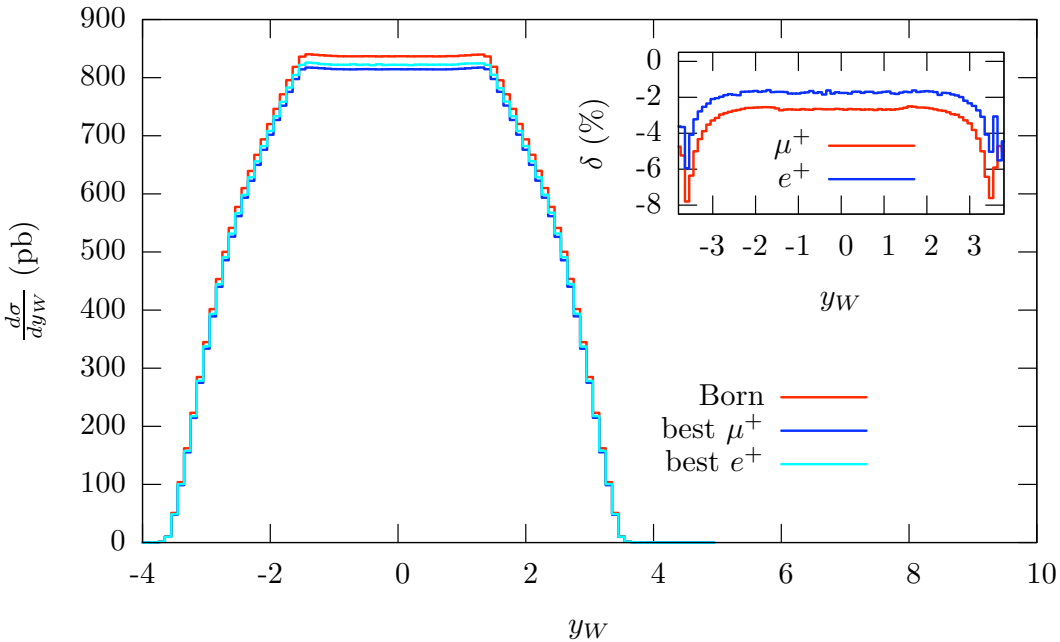
- exact O(α) EW corrections
  virtual corrections (EW Sudakov logs)
  real bremsstrahlung corrections (radiative return, shape of resonance)
  photon-induced processes (possible with MRST2004QED)
  matched with

  multiple photon radiation
  QED Parton Shower describing photon emission in LL approximation
  (initial and final state)

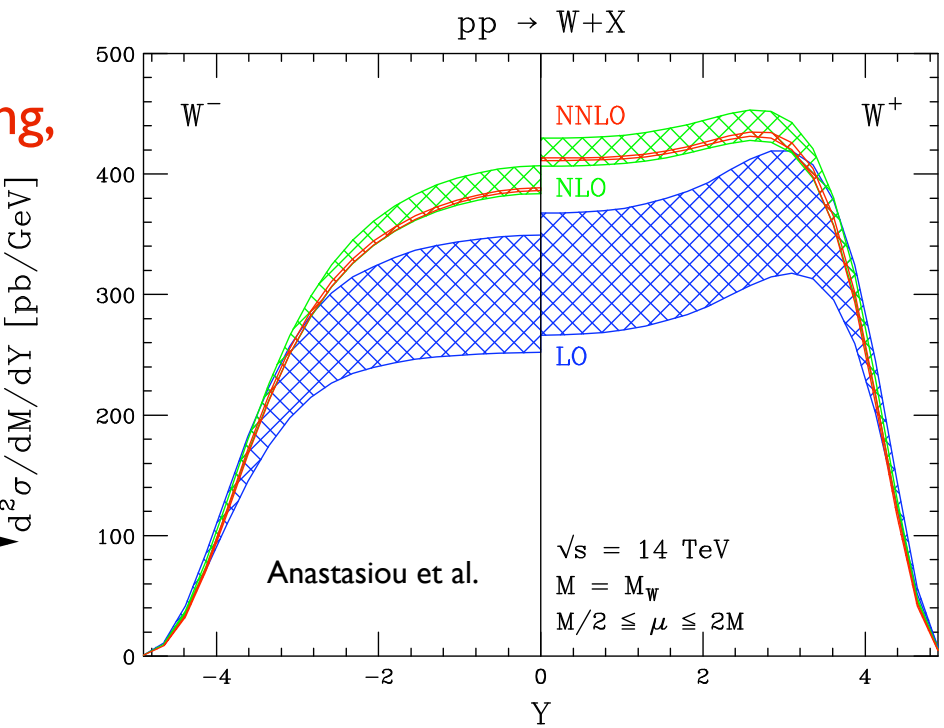
  in progress: inclusion of 2-loop EW Sudakov logs

W-rapidity and lepton pseudo-rapidity distributions (LHC)

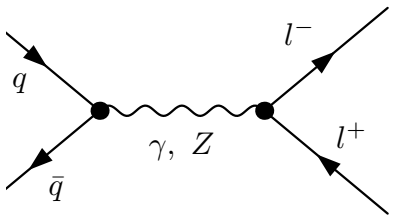




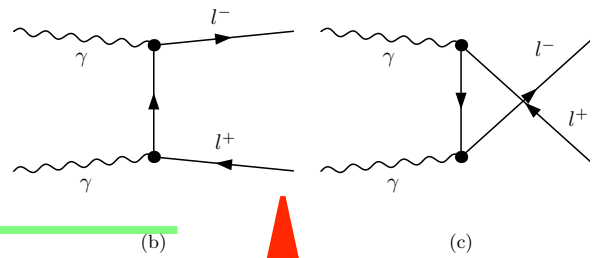
- relevant for acceptances, luminosity monitoring, *pdfs* constraining
- (flat) correction factor ranges from -2% (W) to -4% (lepton)
- of the same order of present NNLO-QCD uncertainty

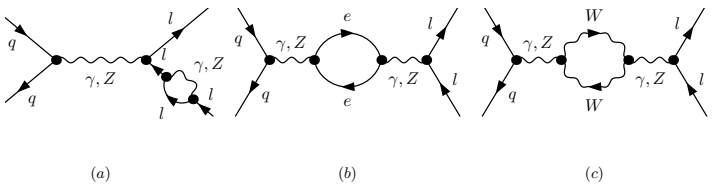


The partonic process $q\bar{q} \to l^+l^-(1\gamma)$ at $\mathcal{O}(\alpha)$

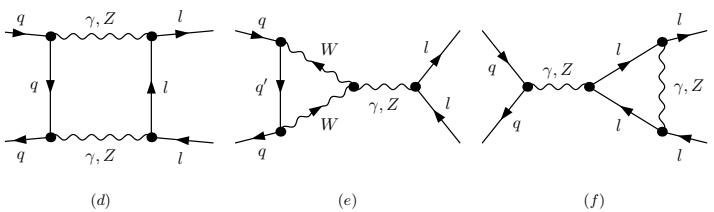


Born

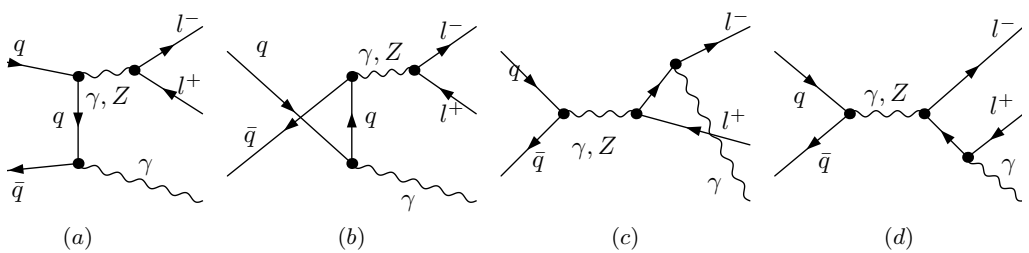




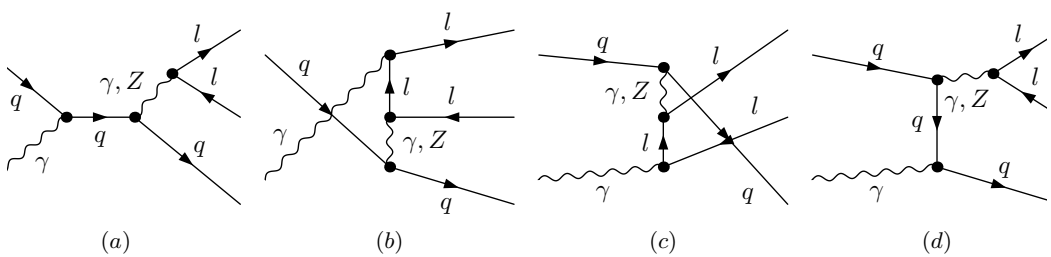
O(α) virtual



MRST2004QED

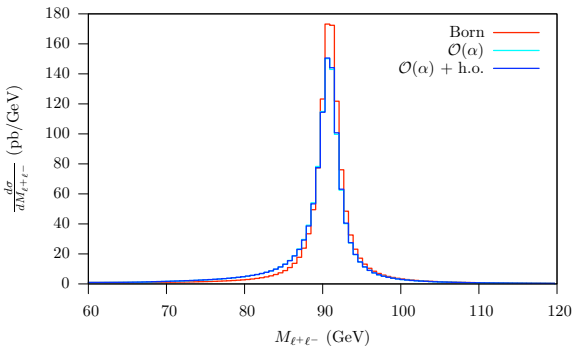


O(α) real bremsstrahlung

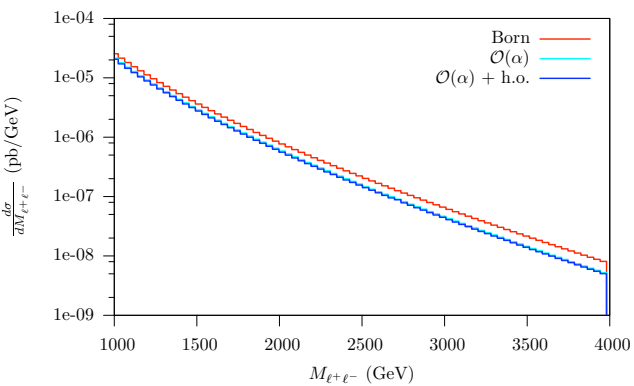


O(α) photon induced

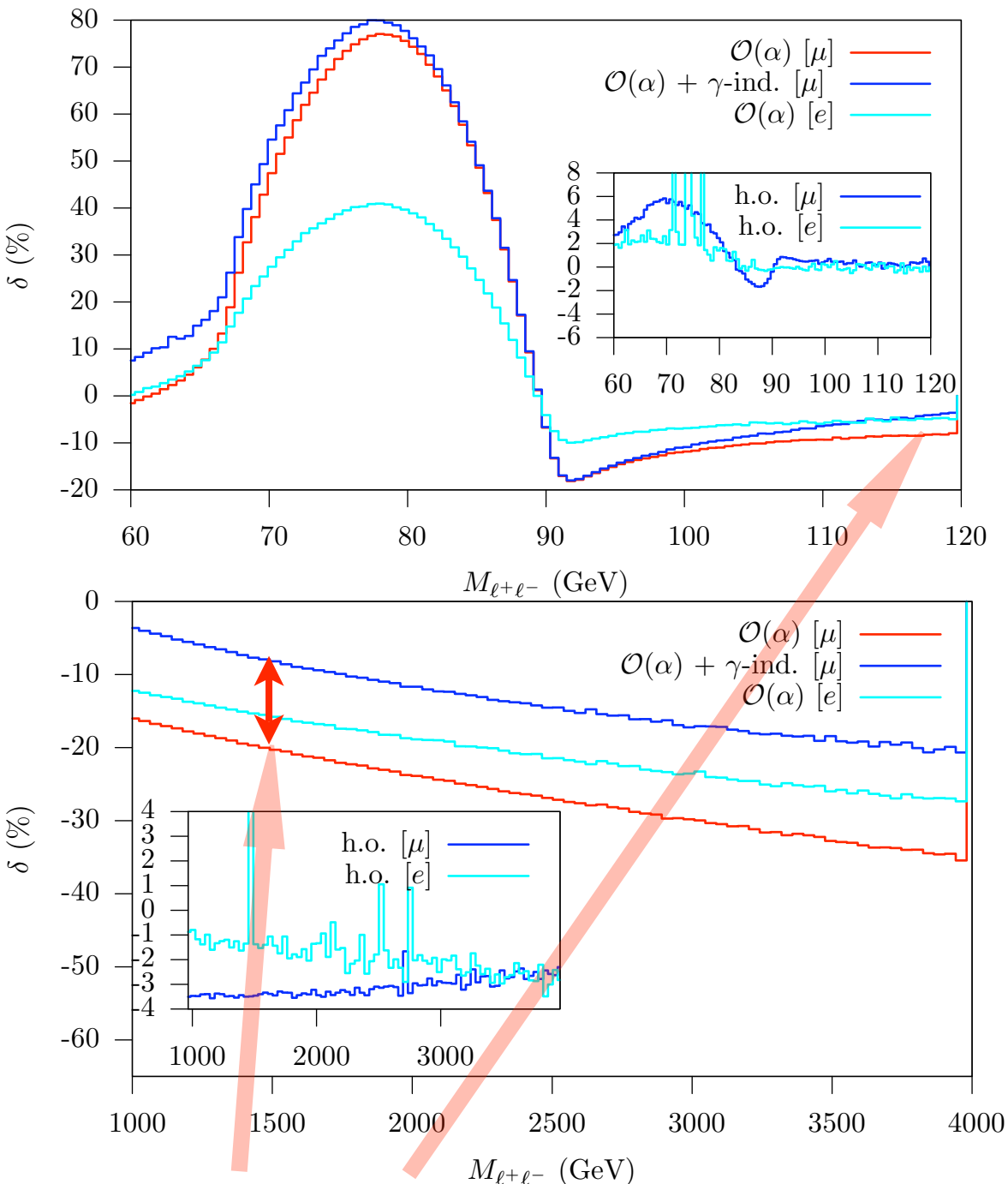
Z invariant mass distribution



- huge radiative corrections below the Z peak (final state radiation)

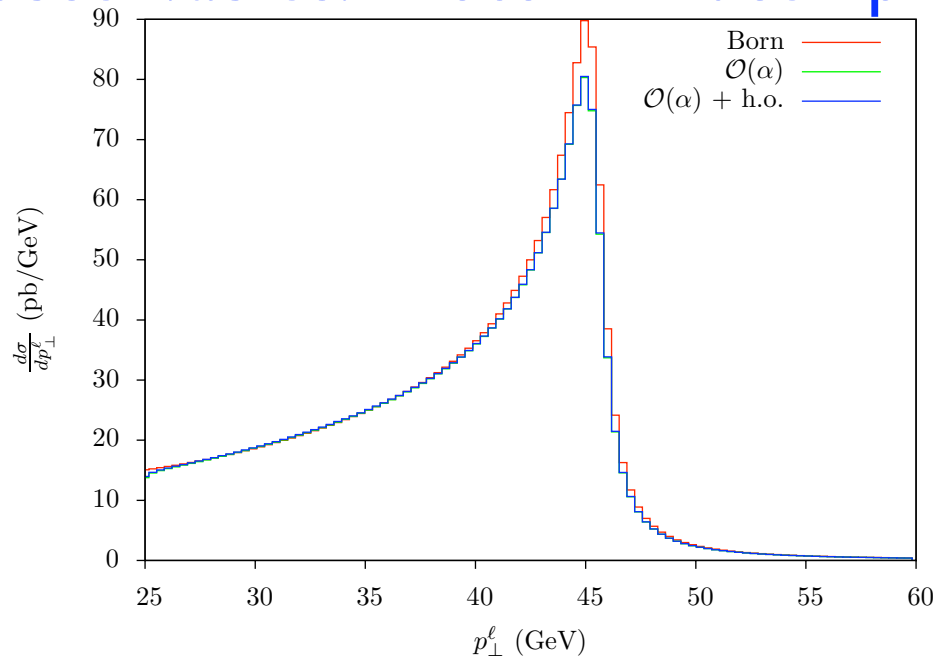


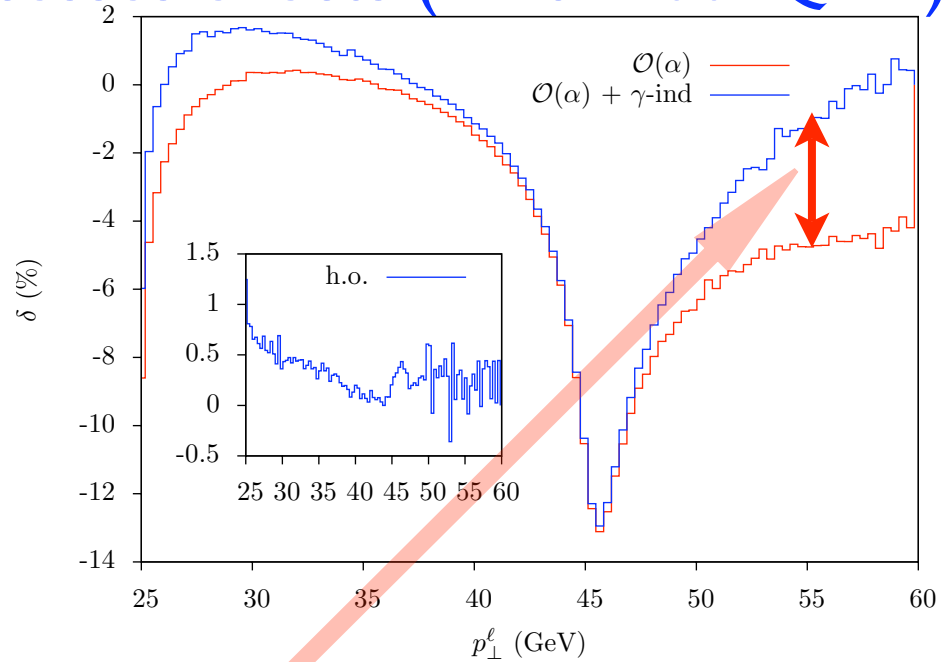
- in the large mass tail, large negative corrections (EW Sudakov logs)

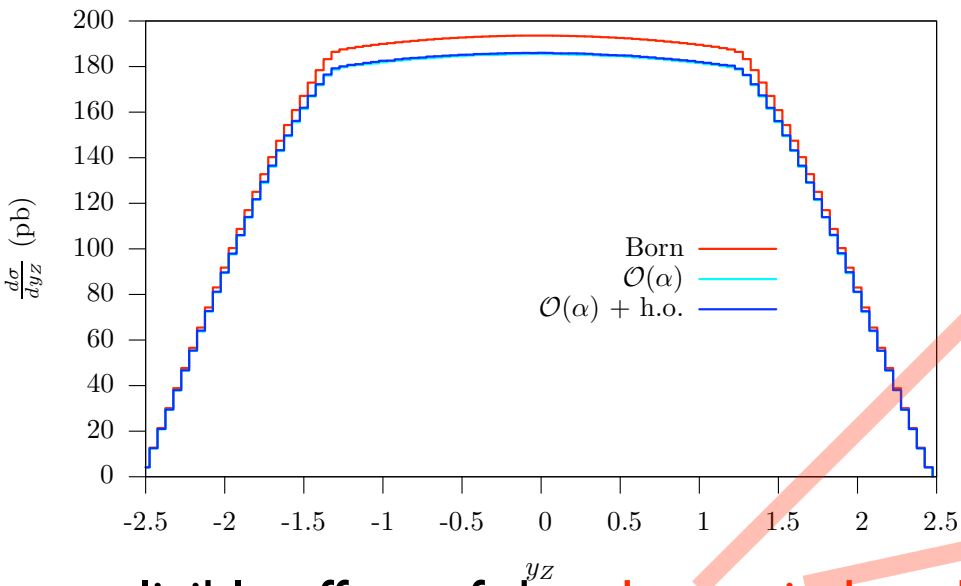


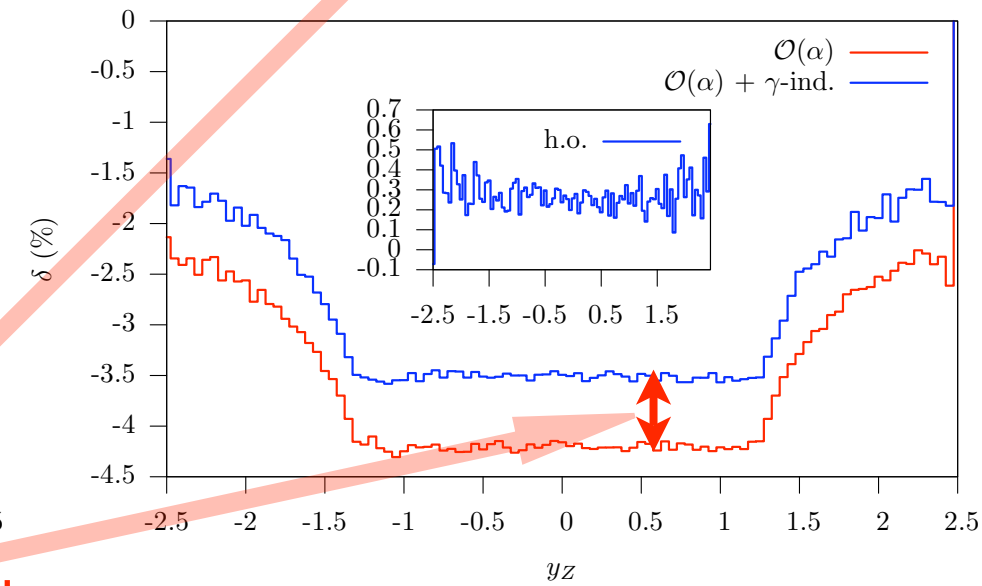
- not negligible effect of (tree-level) photon-induced subprocess

Z observables: Photon-induced processes effects (MRST2004QED)









- not negligible effect of the photon-induced processes:
  new partonic subprocesses → positive contribution which partially compensates the negative EW corrections

Combining QCD and EW corrections

in collaboration with C. M. Carloni Calame, G. Balossini, G. Montagna, O. Nicrosini, F. Piccinini, M. Moretti, M. Treccani

- First attempt: combination of soft-gluon resummation with final state QED corrections Q.-H. Cao and C.-P. Yuan, Phys. Rev. Lett. **93** (2004) 042001 ResBos-A

- Additive combination of QCD and EW corrections:

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

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- QCD = ALPGEN (with CKKM-MLM Parton Shower matching), ResBos-CSS, MC@NLO, FEWZ, MCFM

- EW = HORACE interfaced with HERWIG QCD Parton Shower

  NLO-EW corrections convoluted with QCD PS ⇒ inclusion of $\mathcal{O}(\alpha\alpha_s)$ terms

  not reliable when hard non collinear radiation is important

- Beyond the additive approximation, a full 2-loop $\mathcal{O}(\alpha\alpha_s)$ calculation is needed

see: J.H. Kühn, A.Kulesza, S.Pozzorini, M.Schulze, hep-ph/0703283
W. Hollik, T.Kasprzik, B.A. Kniehl, arXiv:0707.2553

Monte Carlo tuning

Monte Carlo	ALPGEN	FEWZ	HORACE	ResBos-A
$\sigma_{\rm LO}$ (pb)	906.3(3)	906.20(16)	905.64(4)	905.26(24)

Table: MC tuning at the Tevatron for the LO cross section of the process $p\bar{p} \to W^{\pm} \to \mu^{\pm}\nu_{\mu}$, using CTEQ6M with $\mu_R = \mu_F = \sqrt{x_1 x_2 s}$

Monte Carlo	ALPGEN	FEWZ	HORACE
$\sigma_{\rm LO}$ (pb)	8310(2)	8304(2)	8307.9(2)

Table: MC tuning at the LHC for the LO cross section of the process $pp \to W^{\pm} \to \mu^{\pm}\nu_{\mu}$, using MRST2004QED with $\mu_R = \mu_F = \sqrt{p^2_{\perp,W} + M^2_W}$

Monte Carlo	$\sigma^{\rm Tevatron}_{\rm NLO}$(pb)	$\sigma^{\rm LHC}_{\rm NLO}$(pb)
MC@NLO	2638.8(4)	20939(19)
FEWZ	2643.0(8)	21001(14)

Table: MC tuning for MC@NLO and FEWZ NLO inclusive cross sections of the process $\overset{(-)}{p}\overset{}{p} \to W^{\pm} \to \mu^{\pm}\nu_{\mu}$, with CTEQ6M (Tevatron) and MRST2004QED (LHC)

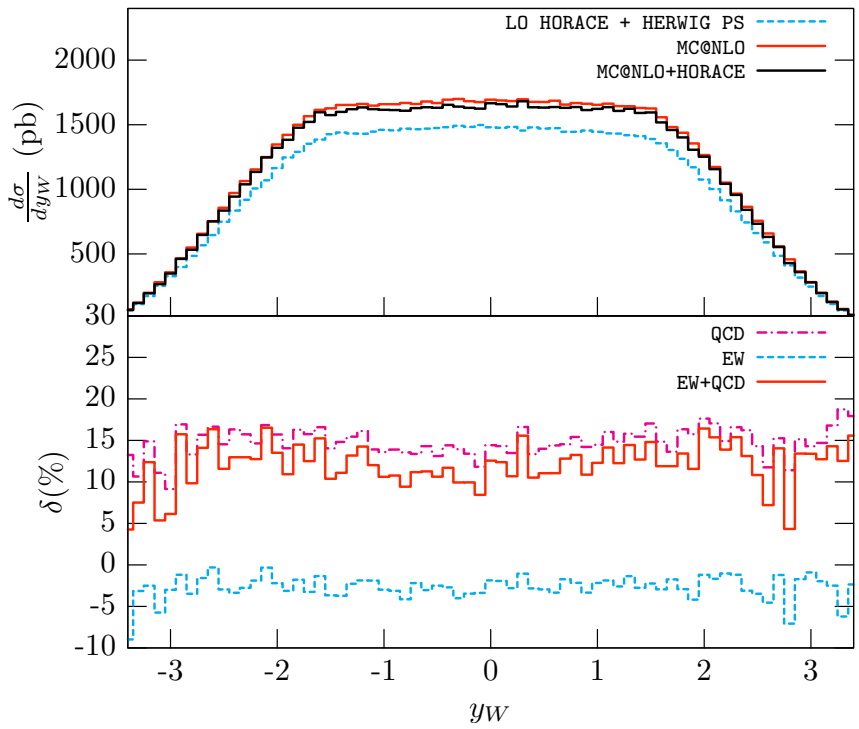
- ⋆ After appropriate "tuning", and with same input parameters and cuts, Monte Carlos agree at $\sim 0.1\%$ level (or better)

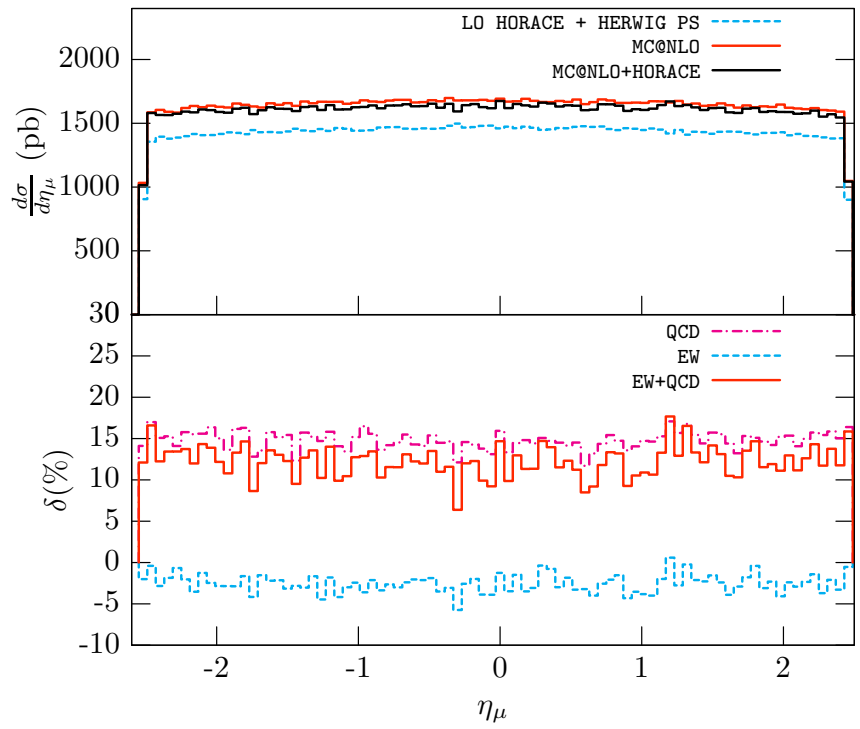
Event selection

leptons: $p_{\perp,l}$ and $p_{\perp,\nu} > 25\text{GeV}, \ |\eta_l| < 2.5$

jets: $p^j_{\perp} > 20\text{GeV}, \quad |\eta_j| < 5, \quad \Delta R_{jj} > 0.7$

W observables: W rapidity and lepton pseudo-rapidity distribution





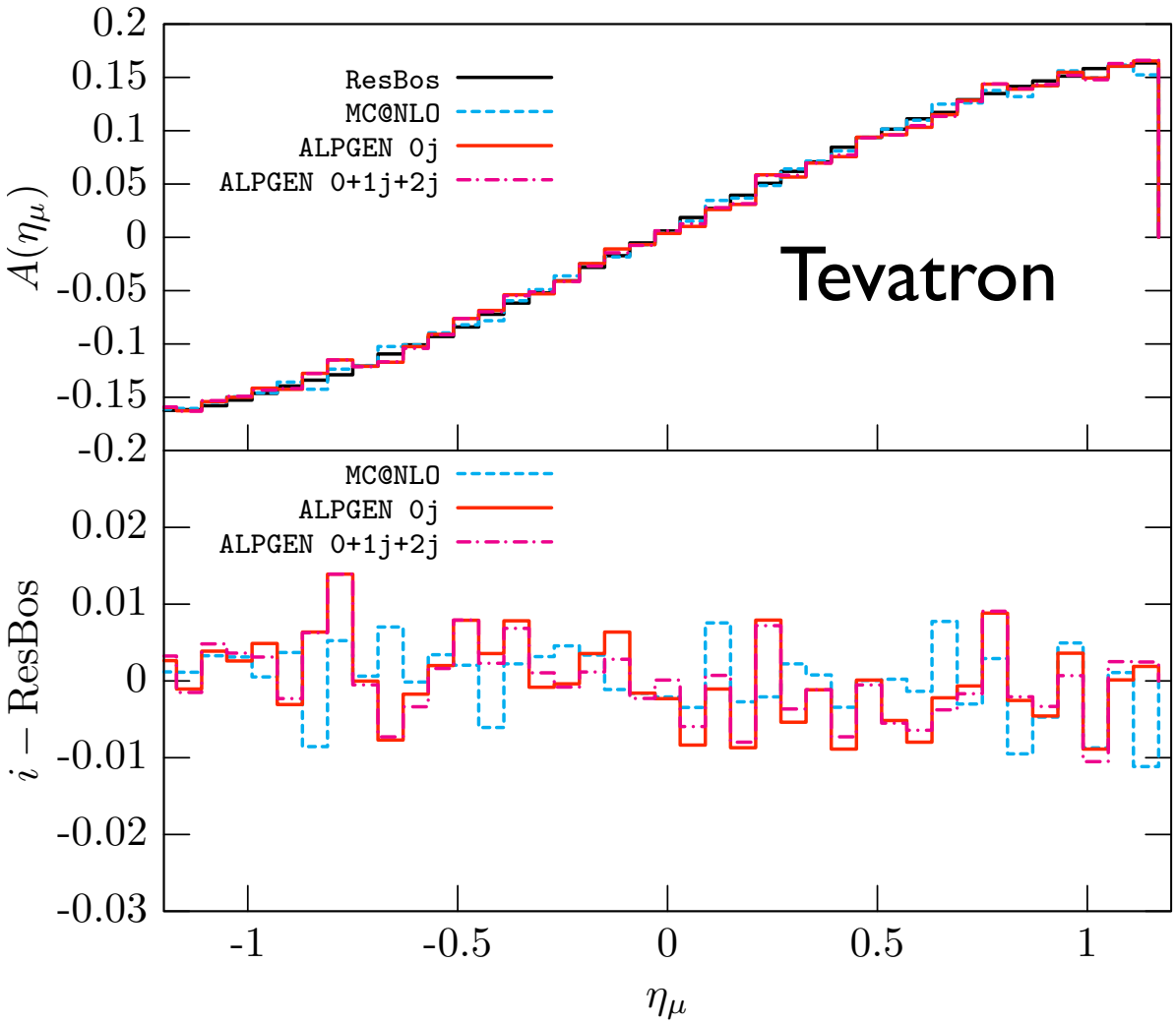
Both QCD and EW corrections are quite flat

partial cancellation +15 -3 %

The deltas are defined in unit (Born+PS)

Charge asymmetry

$$A(\eta_\mu) = \frac{d\sigma^+/d\eta_\mu - d\sigma^-/d\eta_\mu}{d\sigma^+/d\eta_\mu + d\sigma^-/d\eta_\mu}$$



Stability of the prediction w.r.t. different generators

The asymmetry is large and changes sign

Charge asymmetry

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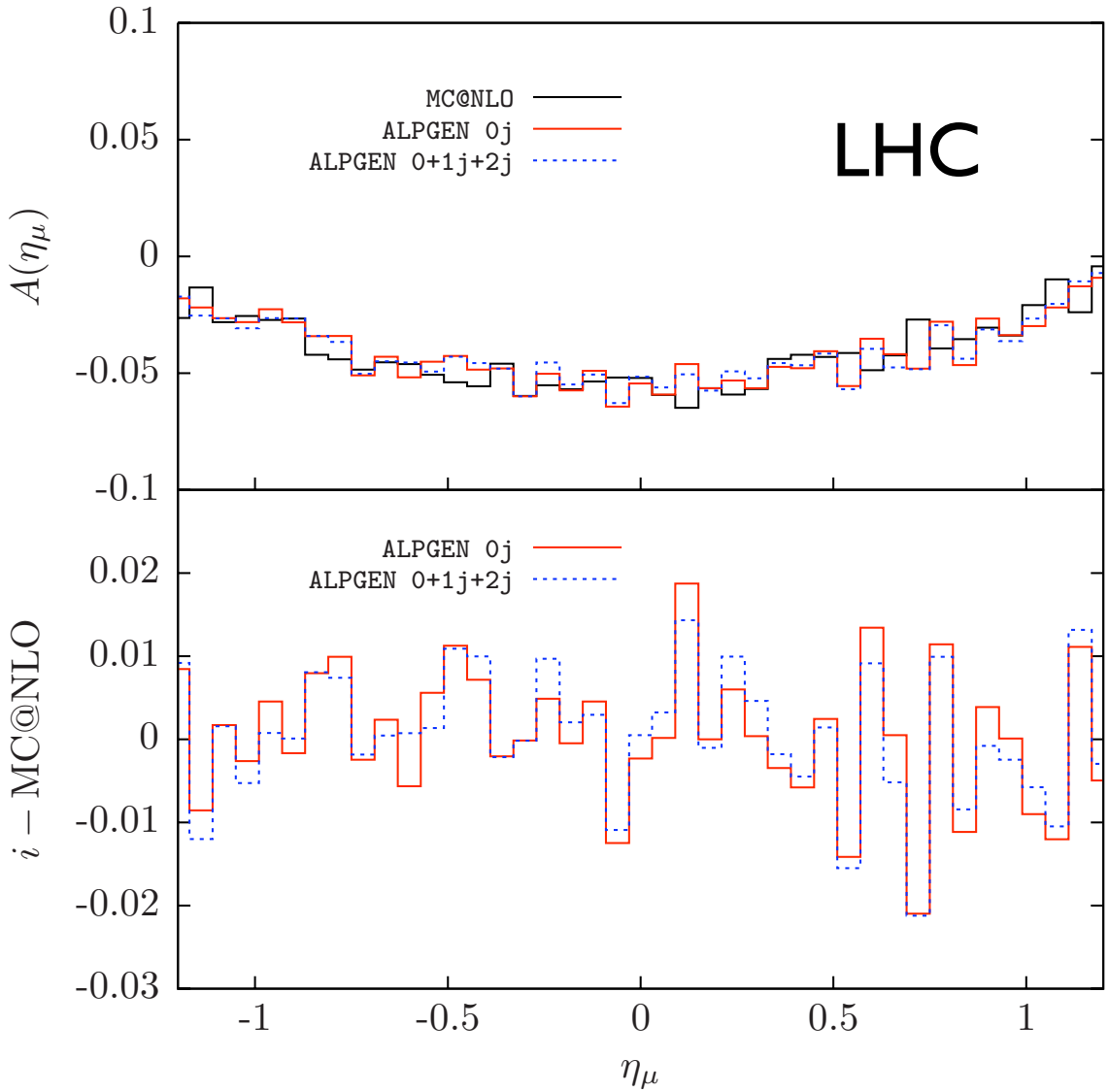


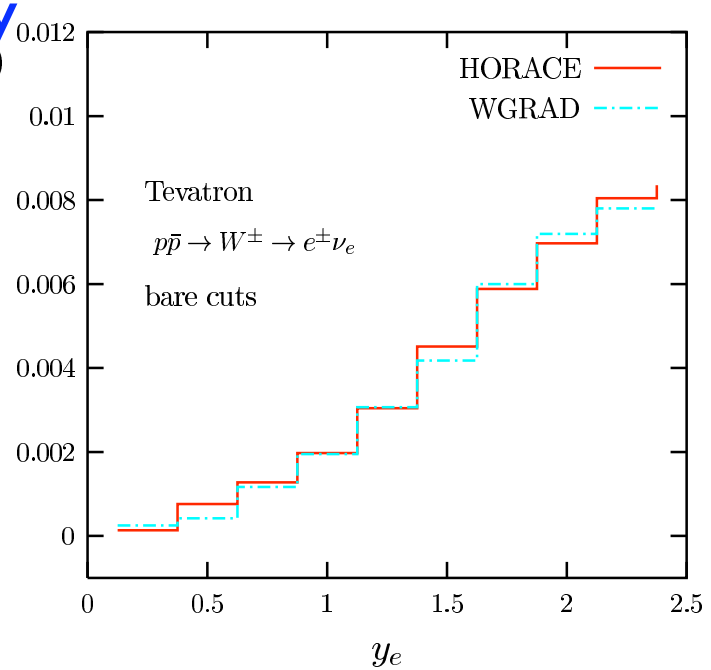
good agreement of MC@NLO and ALPGEN

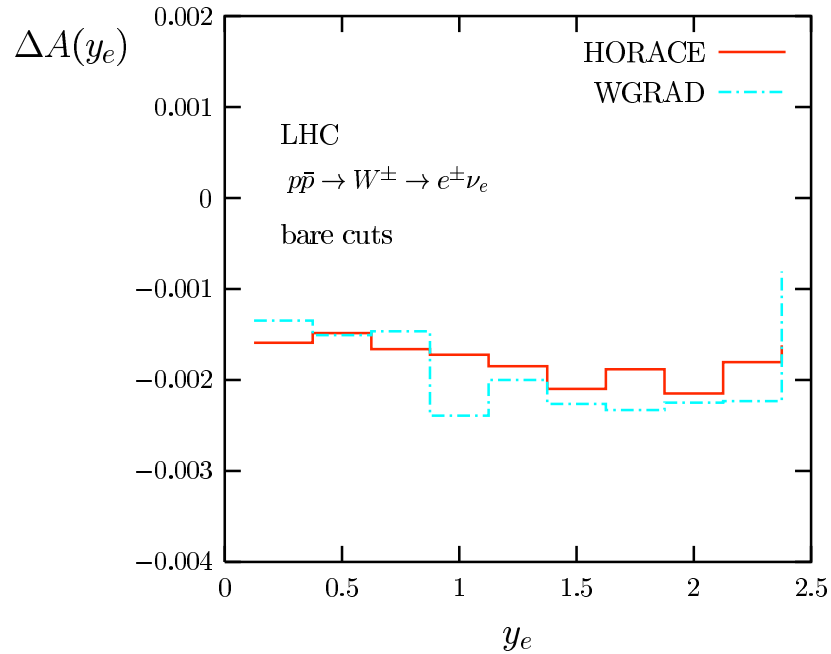
Comparison only of the shapes

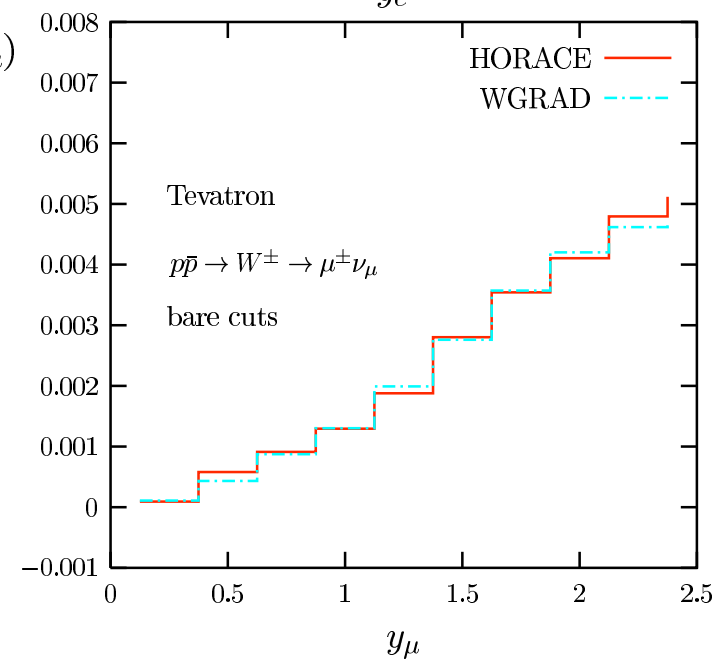
The asymmetry is smaller than at the Tevatron and always negative

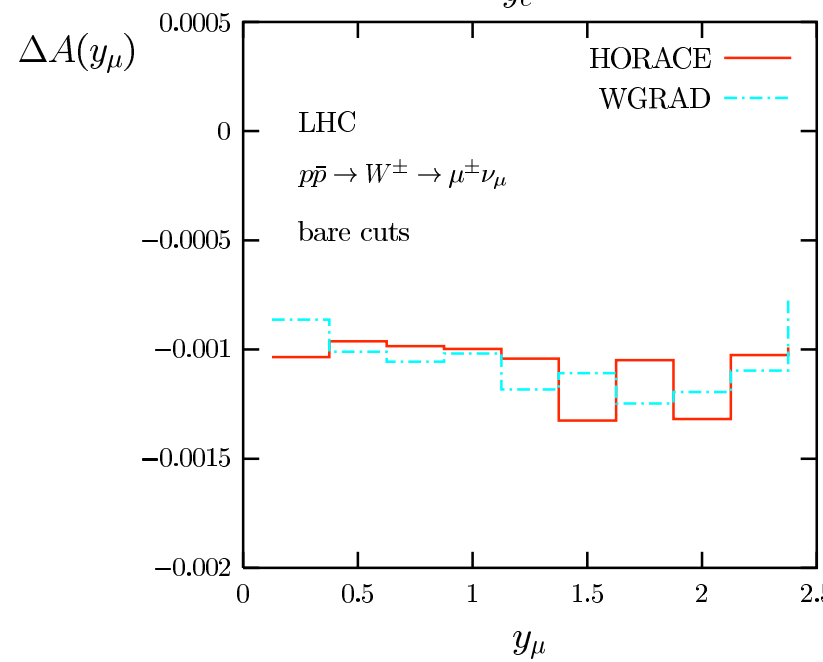
Charge asymmetry

(TEV4LHC workshop)





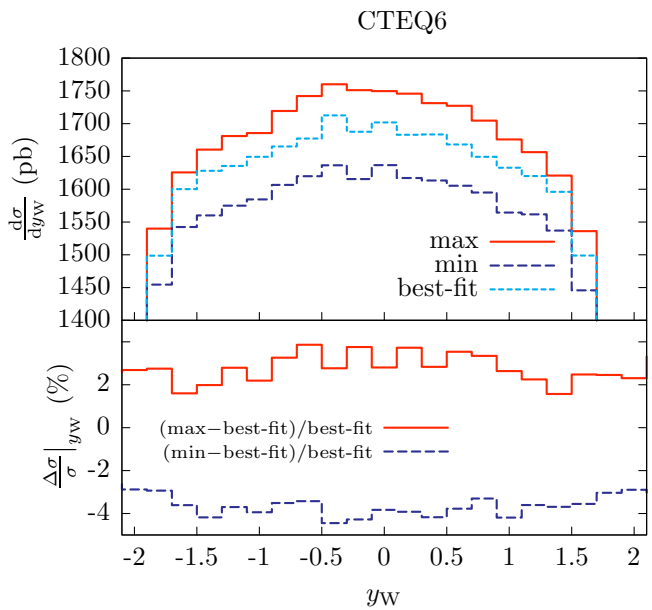


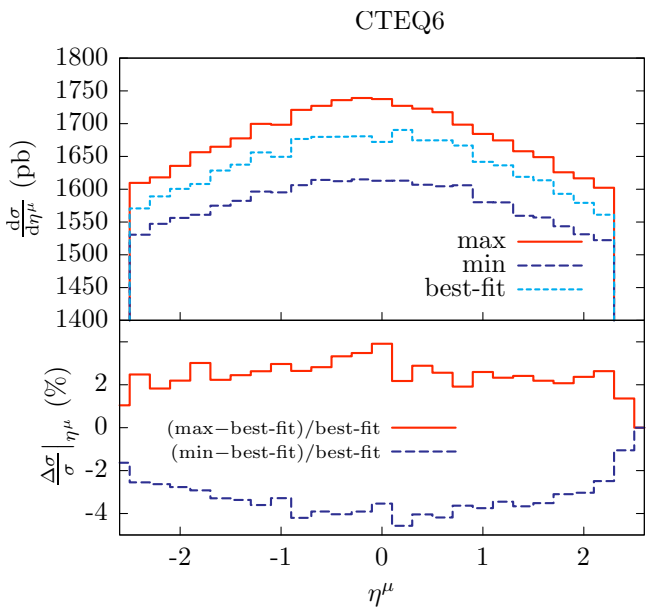


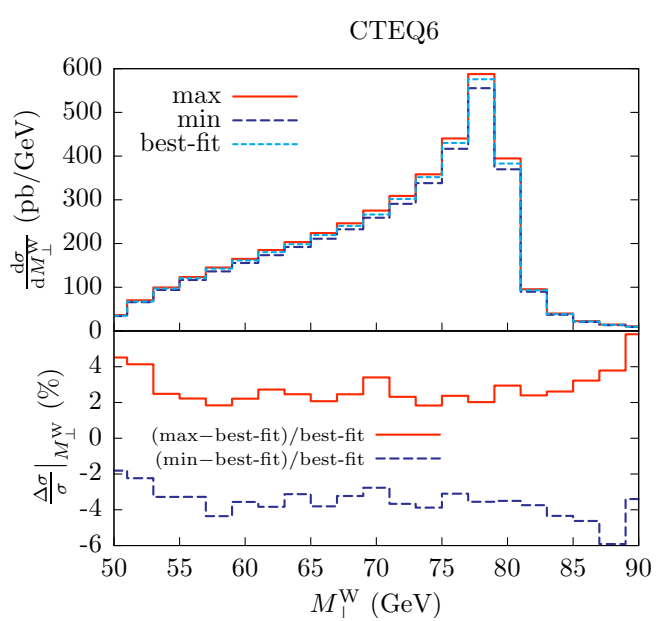
O(α) EW effects are moderate in size and well under control.

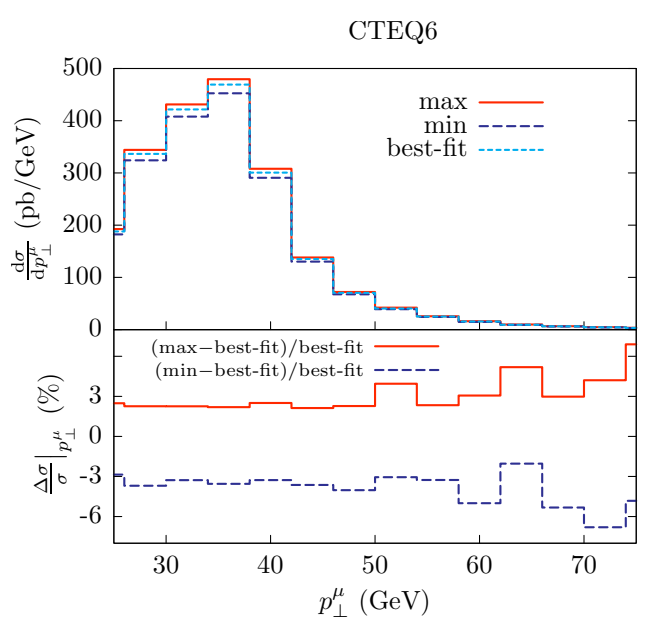
Multiple photon emission is negligible

W: uncertainties due to the *pdfs* LHC, MC@NLO, CTEQ6.1



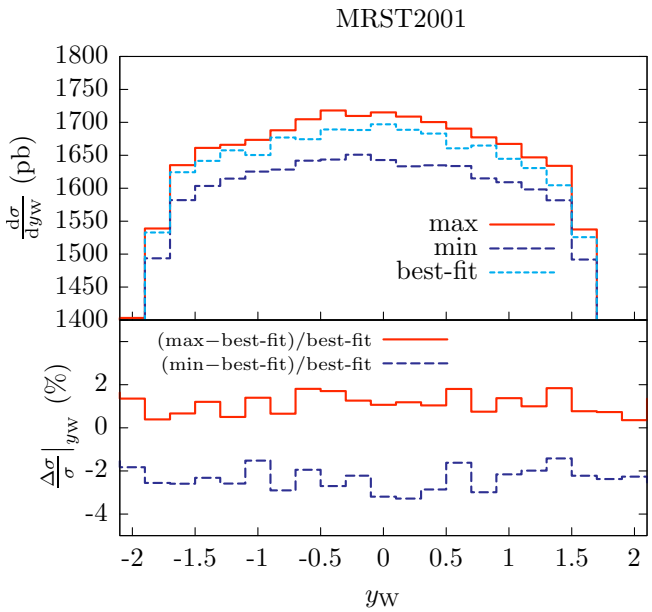


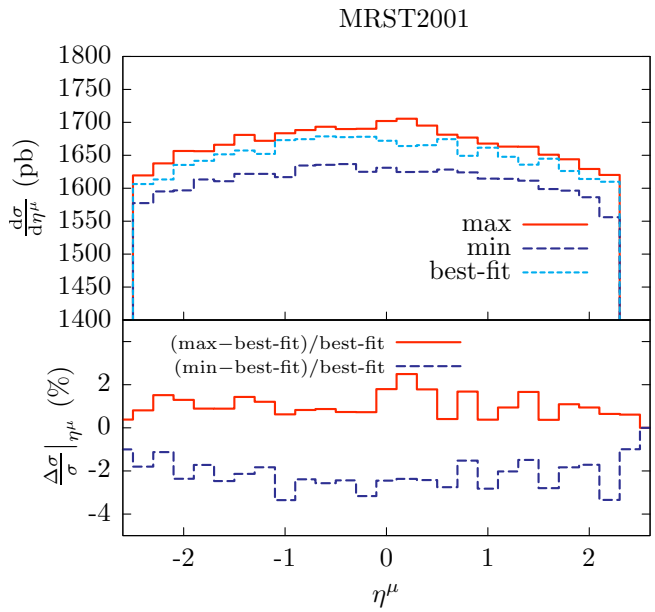


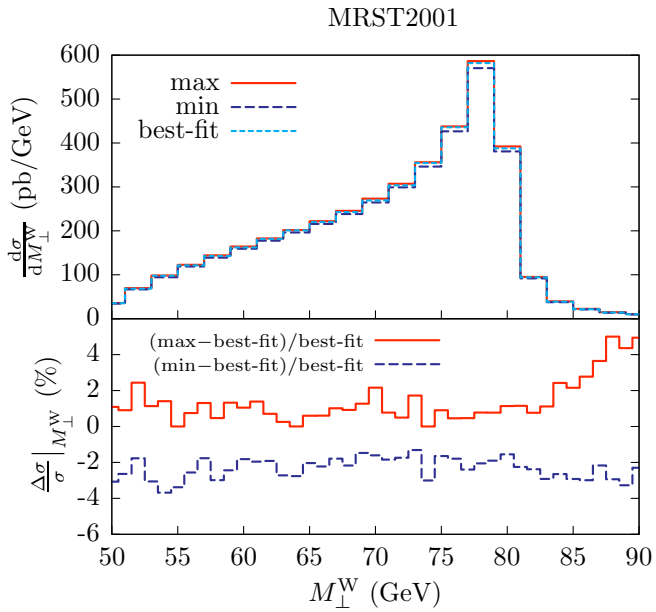


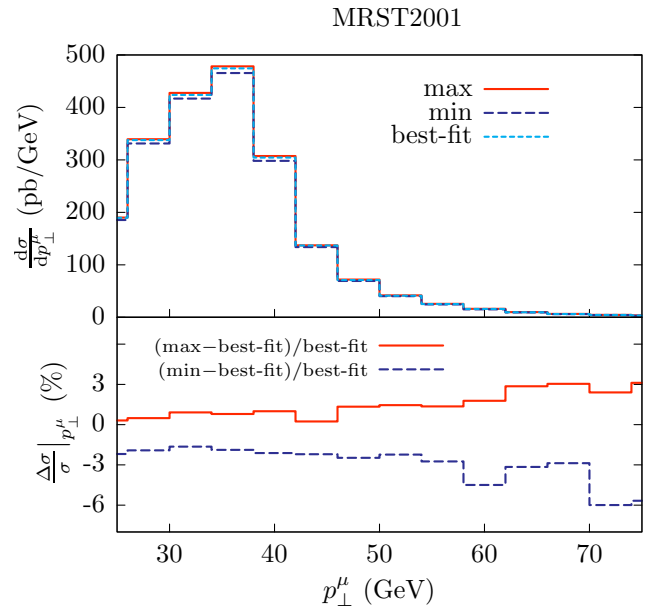
W: uncertainties due to the *pdfs* LHC, MC@NLO, MRST2001E

The spread is about 2 times smaller w.r.t. CTEQ because of the different values of the tolerance parameter

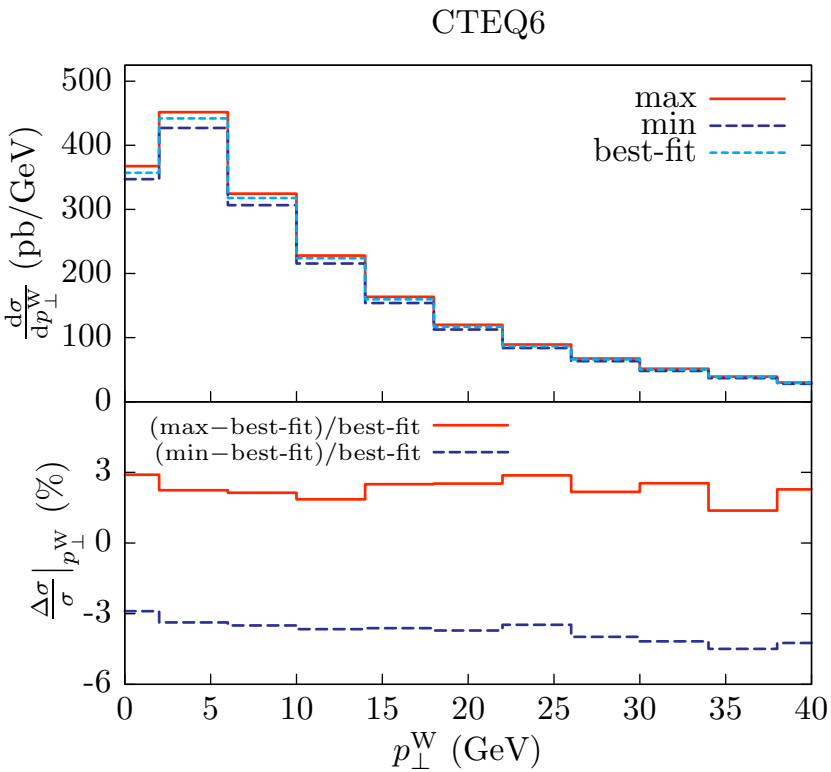


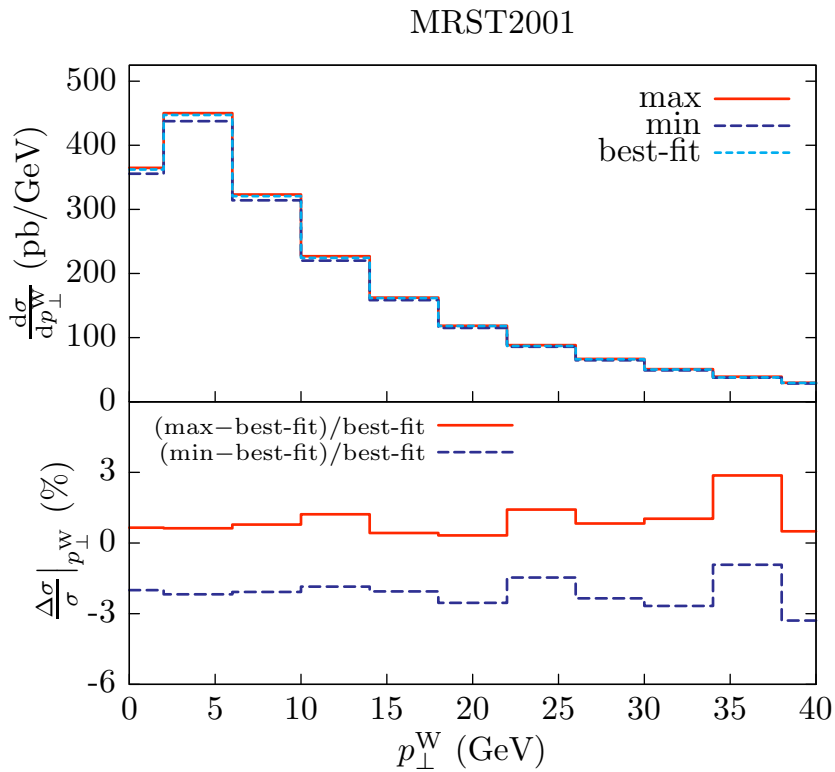






W: uncertainties due to the *pdfs* LHC, MC@NLO

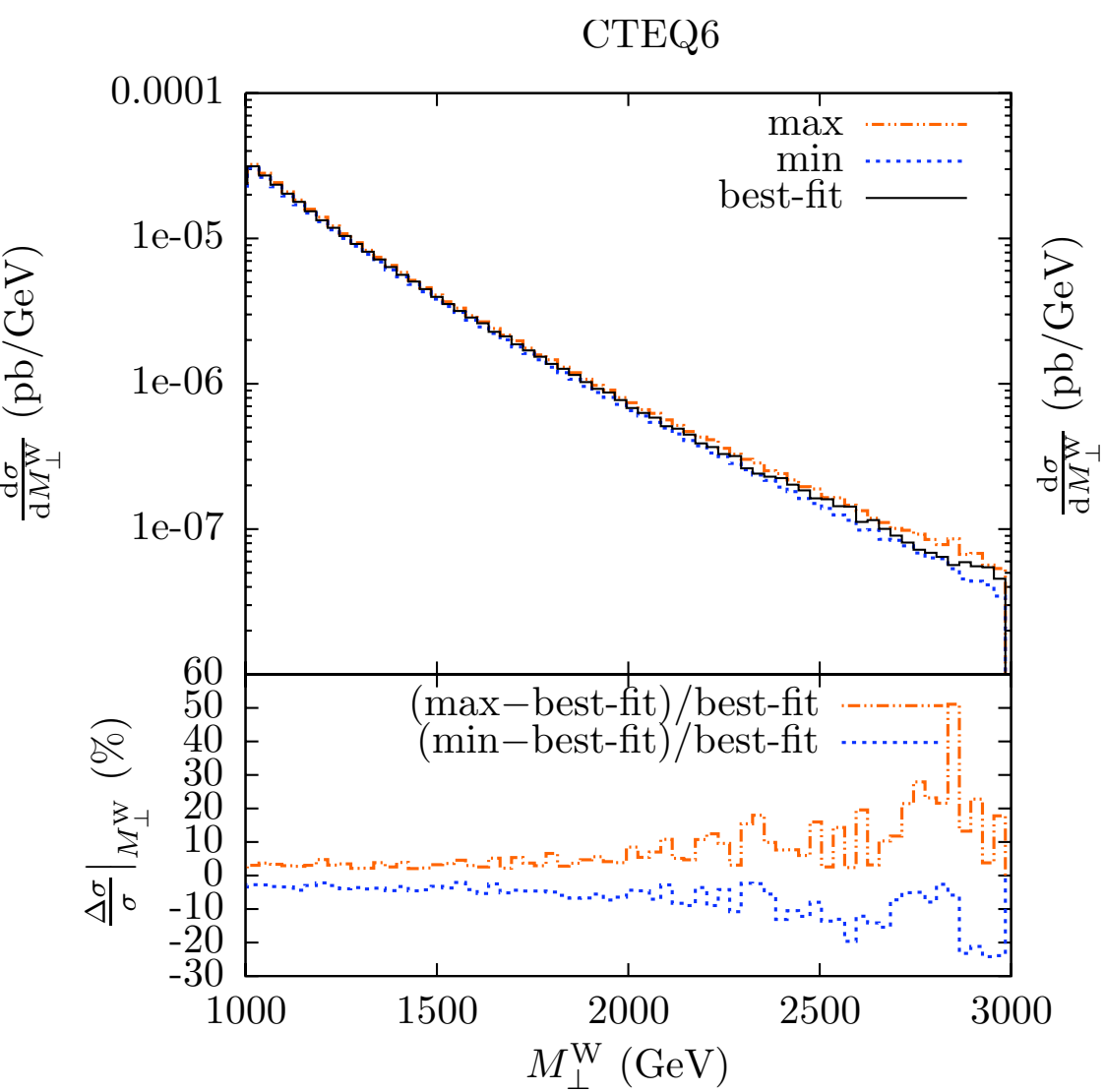


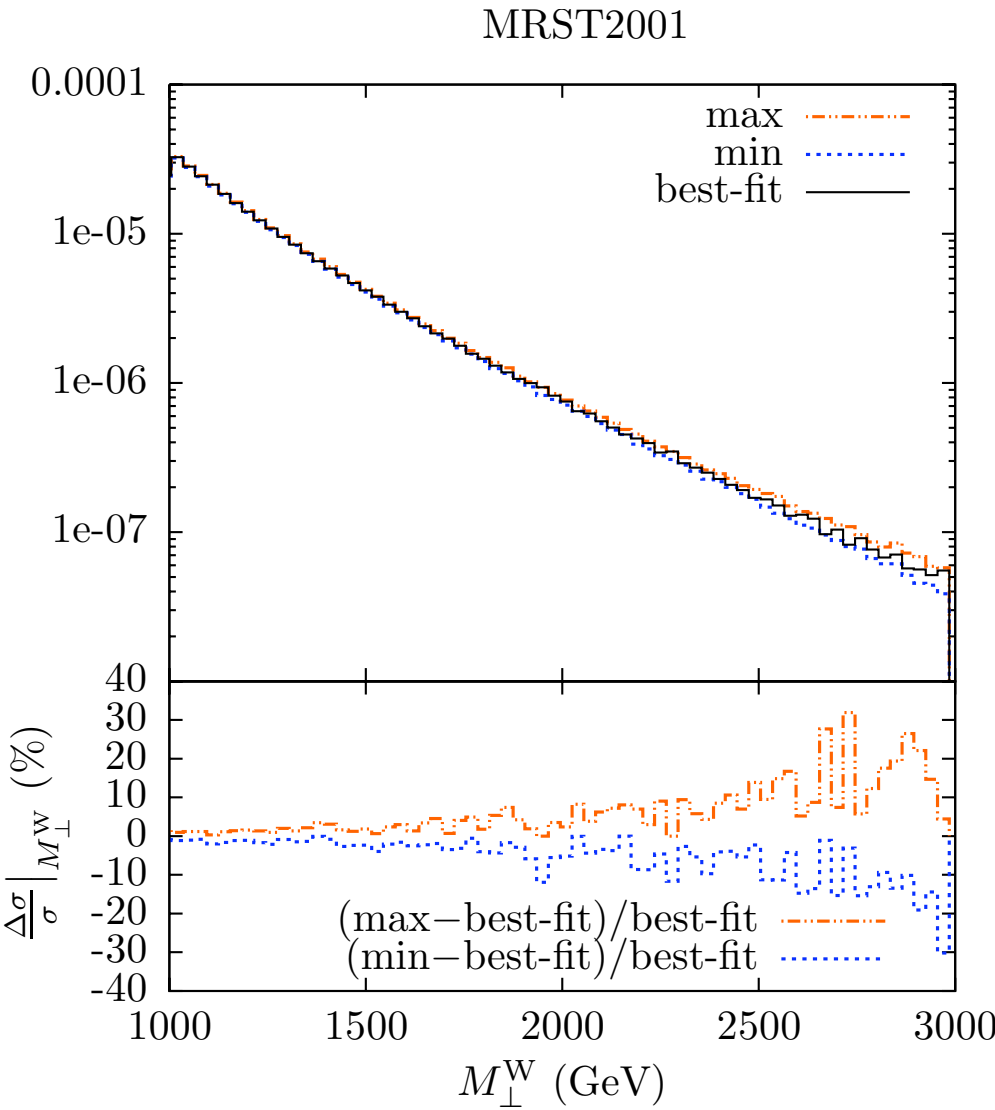


W: uncertainties due to the *pdfs* LHC, MC@NLO

Large tail of the transverse mass distribution

Sensitive to the large-*x* part of the *pdf*



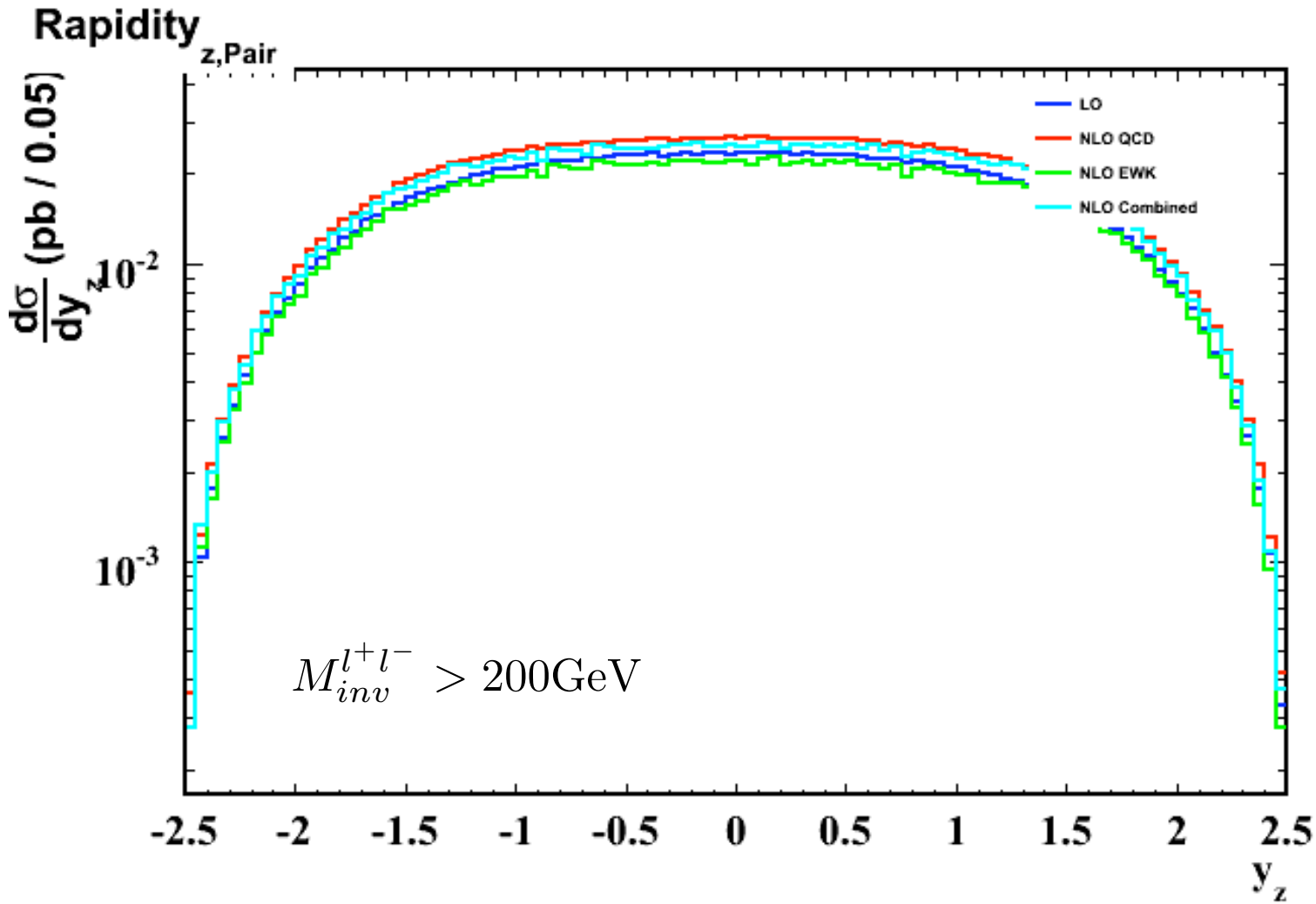


Combining QCD⊕EW corrections in the Neutral Current channel

(Les Houches Physics at TeV colliders 2007 workshop)

Very preliminary results on the large invariant mass tail

A complete study, including the Z resonance, in progress



Conclusions

- The event generator HORACE contains the state-of-the-art of the EW corrections to the Drell-Yan process (both CC and NC)

- The combination of QCD and EW corrections at the event generator level provides a realistic description of the processes:
  full analysis completed in the CC sector, in progress in the NC sector

- Several purely QCD, purely EW and mixed QCD-EW classes of corrections induce effects on the observables at the few per cent level which can be relevant for a precise determination of the *pdf* from Tevatron/LHC data

- These effects are comparable with the NNLO-QCD theoretical uncertainty and with the error bands due to the experimental data