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Correzioni multifotoniche alla produzione di W & Z ai collider adronici

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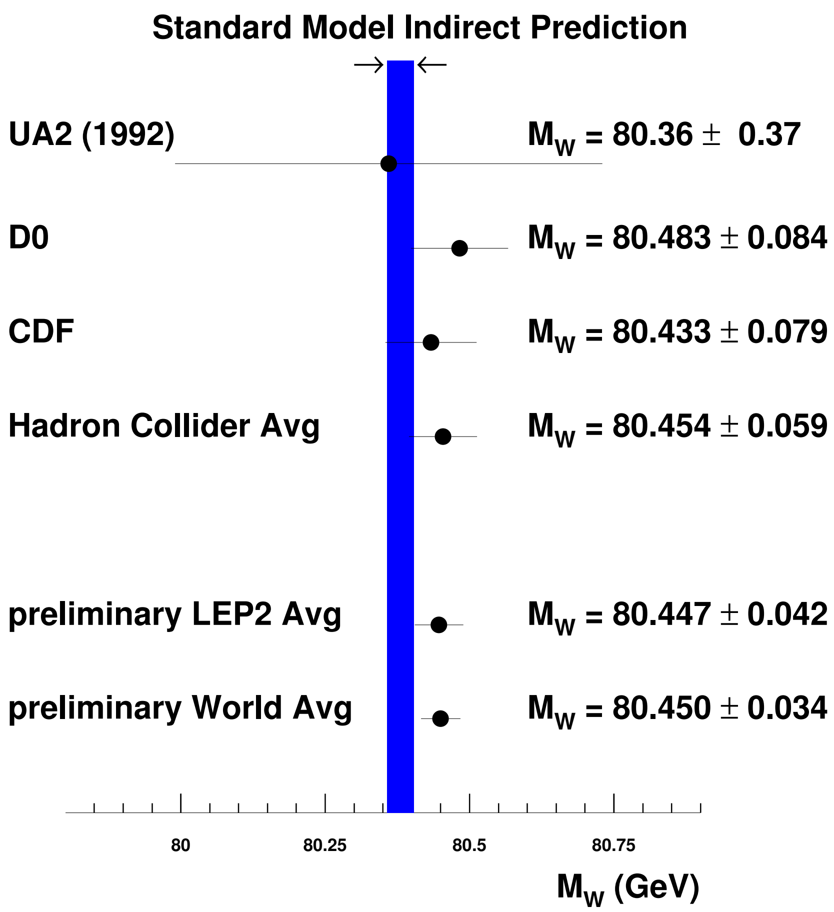
Outline

- ⋆ Motivations for RC to W/Z production
- ⋆ Theoretical calculation & tools
  - √ QCD corrections (briefly)
  - √ Electroweak corrections
- ⋆ The event generator HORACE for higher order QED corrections
  - √ tuned comparisons with WINHAC
  - √ estimating h.o. QED shifts on M_W and M_Z and their effects on distributions
- ⋆ Conclusions

Motivations

- Precise measurements require precise calculations
- The precise M_W (and M_{top}) measurement will highly improve the indirect bound on M_H via RC ($\Delta M_H \sim 35\%$ if $\Delta M_W = 30$ MeV and $\Delta M_{top} = 2$ GeV)
- Present experimental status and future goal:



Target precision for ΔM_W

- ⋆ Tevatron RunII $\lesssim$ 30 MeV
- ⋆ LHC $\Rightarrow$ 15 MeV

$\Rightarrow$ $\Delta M_W / M_W = \mathcal{O}(1 \times 10^{-4})$

$\Rightarrow$ M_W measured preferably from M_T^W distribution

Motivations (II)

- σ_W (and σ_Z) can be used to monitor hadron and parton luminosities and/or determine PDF

Dittmar, Pauss, Zurcher, Phys. Rev. **D56** (1997) 7284; Khoze *et al.*, Eur. Phys. J. **C19** (2001) 313;

Giele, Keller `hep-ph/0104053`; Frixione, Mangano, JHEP **0405** (2004) 056

$$\sigma^{theory}(W) = \sum_{ij} \mathcal{P}_{ij} \otimes \hat{\sigma}_{ij} = \sigma^{exp}(W) = \frac{N_W}{BR(W \to \ell\nu) \int \mathcal{L}dt \ A_W}$$

- measure Γ_W with $\Delta\Gamma_W \simeq 50$ MeV (from W/Z cross section ratio)

- Z data are used to calibrate detectors (lepton scale and resolution): a precise simulation is mandatory for accurate M_W measurement

- $p_\perp^W$ can be simulated measuring $p_\perp^Z$

- $\sin^2\theta^{lept.}_{eff.}$ can be measured from A_{FB} at the Z pole

- the M_T^W/M_T^Z ratio can be used to measure M_W. This method is competitive at high luminosities

QCD calculations & tools

- resummation of leading and next-to-leading p_T^W/M_W logarithms, implemented in RESBOS

C. Balazs and C.P. Yuan, Phys. Rev. **D56** (1997) 5558

- NLO corrections merged with the HERWIG Parton Shower (MC@NLO)

S. Frixione and B.R. Webber, JHEP **0206** (2002) 029 and hep-ph/0402116

- NNLO corrections to W/Z production total cross sections

R. Hamberg, W.L. van Neerven, T. Matsuura, Nucl. Phys. **B359** (1991) 343
W.L. van Neerven and E.B. Zijlstra, Nucl. Phys. **B382** (1992) 11

R.V. Harlander and W.B. Kilgore, Phys. Rev. Lett. **88** (2002) 201801

- NNLO corrections to W/Z rapidity distribution

C. Anastasiou *et al.* , Phys. Rev. **D69** (2004) 094008

$\longrightarrow$ notice that

$$\frac{\alpha_s^2}{\pi^2} \sim \frac{\alpha_{qed}}{\pi}$$

Status of $\mathcal{O}(\alpha)$ electroweak calculations & tools

- QED corrections to W and Z boson decay

  $\longrightarrow$ Berends, Kleiss, Revol, Vialle, Z. Phys. **C27** (1985) 155; Berends, Kleiss, *ibidem* 365

- Electroweak corrections to W production and decay

  $\star$ Pole approximation

  $\longrightarrow$ Wackeroth and Hollik, Phys. Rev. **D55** (1997) 6788

  $\longrightarrow$ Baur, Keller, Wackeroth, Phys. Rev. **D59** (1999) 013002 $\longrightarrow$ `WGRAD`

  $\star$ Complete $\mathcal{O}(\alpha)$ corrections

  $\longrightarrow$ Dittmaier and Krämer, Phys. Rev. **D65** (2002) 073007

  $\longrightarrow$ Baur and Wackeroth, Phys.Rev. **D70** (2004) 073015 $\longrightarrow$ `WGRAD2`

- Electroweak corrections to Z production and decay

  $\star$ $\mathcal{O}(\alpha)$ photonic corrections

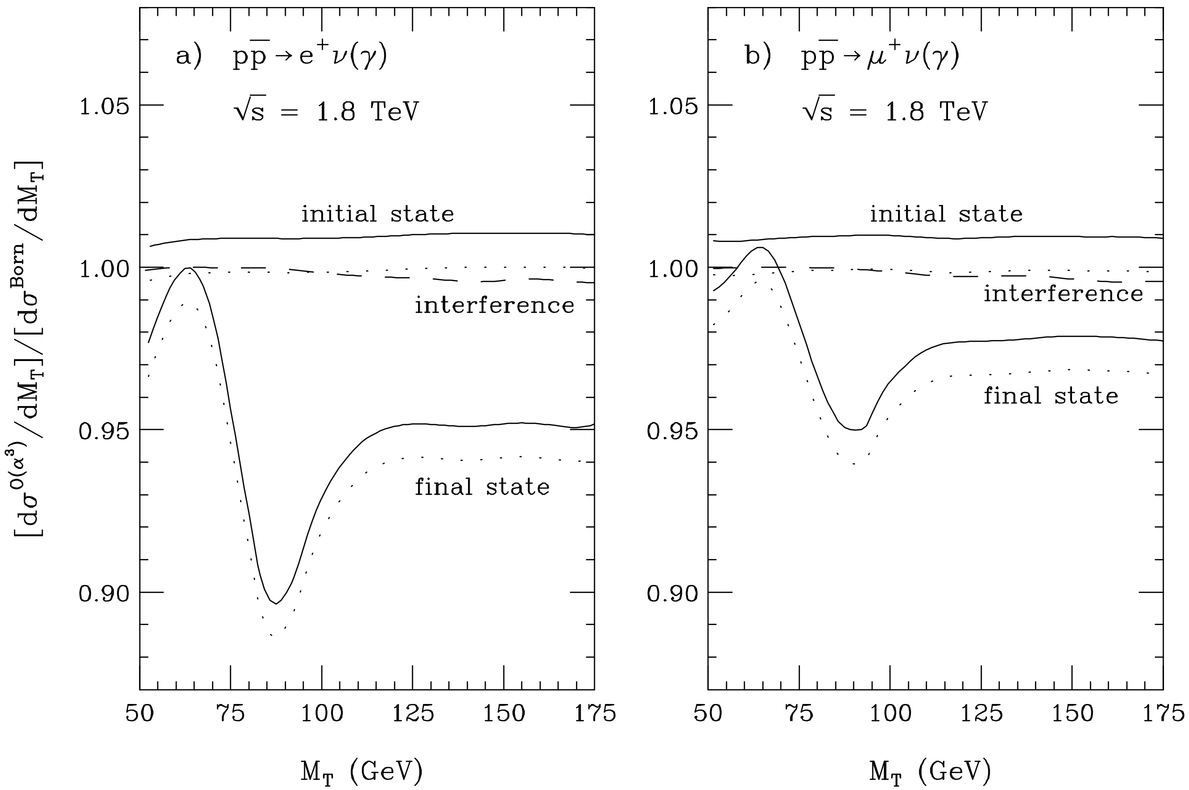
  $\longrightarrow$ Baur, Keller, Sakumoto, Phys. Rev. **D57** (1998) 199 $\longrightarrow$ `ZGRAD`

  $\star$ Complete $\mathcal{O}(\alpha)$ corrections $\longrightarrow$ `ZGRAD2`

  $\longrightarrow$ Baur, Brein, Hollik, Schappacher, Wackeroth, Phys. Rev. **D65** (2002) 033007

Initial vs final state photonic corrections

U. Baur, S. Keller, D. Wackeroth, Phys. Rev. **D59** (1999) 013002



- initial-state radiation and initial-final-state interference do not modify the shape of the distributions and are at the 1% level (or below)
- final-state radiation does modify the shape of the distributions and is important because it contains mass logarithms of the form $\log(\hat{s}/m_\ell^2)$

Higher order final-state QED corrections

- Why worrying about FS higher-order QED corrections?
  - $\longrightarrow$ $\mathcal{O}(\alpha)$ FS QED radiation changes by several % the shape of the relevant distributions
  - $\longrightarrow$ single photon emission induces W/Z mass shift at the 0.1% level ($\sim$ 100 MeV)
  - $\longrightarrow$ a shift due to multiple photons at the 0.01% level can be expected
  - $\longrightarrow$ presently, it is a theoretical systematic error

- Recent literature
  - $\star$ double real bremsstrahlung $q\bar{q}' \to \ell^\pm \nu\gamma\gamma$ and $q\bar{q} \to \ell^+\ell^-\gamma\gamma$ for W & Z

    Baur, Stelzer, Phys. Rev. **D61** (2000) 073007
  - $\star$ Higher-order (real+virtual) QED corrections to the leptonic boson decay
    - $\longrightarrow$ `HORACE` MC (for W & Z): QED Parton Shower

      C.M. Carloni Calame *et al.*, Phys. Rev. **D69** (2004) 037301
    - $\longrightarrow$ `WINHAC` (for W): YFS exponentiation of order α matrix element

      Jadach, Płaczek, Eur. Phys. J. **C29** (2003) 325
  - $\star$ Tuned comparison of `WINHAC` and `HORACE` for W

    C.M. Carloni Calame *et al.*, Acta Phys. Pol. **B35** (2004) 1643

Our Parton Shower approach

- Multiphoton corrections are computed by means of the QED Structure Function $D(x, Q^2)$, solution of DGLAP equation in QED.

$$Q^2 \frac{\partial}{\partial Q^2} D(x, Q^2) = \frac{\alpha}{2\pi} \int_x^1 \frac{dy}{y} P_+(y) D(\frac{x}{y}, Q^2)$$

$$P_+(x) = \frac{1+x^2}{1-x} - \delta(1-x) \int_0^1 dt P(t)$$

- Exactly solved by means of a Monte Carlo Parton Shower algorithm
- PS is "attached" to parton level process for FS radiation:
  - $\longrightarrow$ γ's multiplicity and energies given by the PS algorithm
  - $\longrightarrow$ γ's generated according to the factorized part of the W/Z radiative decay matrix element (eikonal current $\longrightarrow$ gauge invariance in the approximate ME)

$$\cos\theta_\gamma \sim -\left(\frac{p^\ell_\lambda}{p^\ell \cdot k} - \frac{Q^W_\lambda}{Q^W \cdot k}\right) \cdot \left(\frac{p^{\ell\lambda}}{p^\ell \cdot k} - \frac{Q^{W\lambda}}{Q^W \cdot k}\right) \qquad \text{(for W)}$$

$$\cos\theta_\gamma \sim -\left(\frac{p^\ell_\lambda}{p^\ell \cdot k} - \frac{p^\ell_\lambda}{p^\ell \cdot k}\right) \cdot \left(\frac{p^{\ell\lambda}}{p^\ell \cdot k} - \frac{p^{\ell\lambda}}{p^\ell \cdot k}\right) \qquad \text{(for Z)}$$

The event generator HORACE at present

The event generator HORACE (Higher Order Radiative CorrEctions) for W/Z production in Drell-Yan processes was developed

- √ parton level processes convoluted with initial state PDFs
- √ it generates unweighted events
- √ QED RC are included by means of the Parton Shower algorithm. It can be run in
  - ⋆ $\mathcal{O}(\alpha)$ mode: only QED order α corrections are included
  - ⋆ *exp.* mode: QED corrections are included up to all orders

→ of course, any experimental cut can be applied (for our studies, also a particles' smearing implemented)

⋆ it can run also in parallel mode (using MPI libraries)

Tuned Comparisons with WINHAC

C.M. Carloni Calame *et al.*, Acta Phys. Pol. **B35** (2004) 1643

- Performed during the MC4LHC workshop held at CERN in summer 2003
- Processes (with $l = e, \mu$)

$$d\bar{u} \longrightarrow W^- \longrightarrow l^- + \bar{\nu}_l \qquad\qquad pp \longrightarrow W^\pm + X \longrightarrow l^\pm + \nu_l + X$$

- Input parameters:
  G_μ scheme and fixed-width scheme, PDFs set: MRS(G) from PDFLIB

$$m_e = 0.511 \times 10^{-3}\,\mathrm{GeV}, \qquad m_\mu = 0.10565836\,\mathrm{GeV}, \qquad m_{\nu_e} = m_{\nu_\mu} = 0,$$

$$m_u = m_d = m_s = m_c = m_b = 0,$$

$$V_{ud} = 0.97483, \qquad V_{us} = 0.22290, \qquad V_{ub} = 0.00360,$$

$$V_{cd} = -0.22286, \qquad V_{cs} = 0.97398, \qquad V_{cb} = 0.04120,$$

$$V_{td} = 0.00568, \qquad V_{ts} = -0.04097, \qquad V_{tb} = 0.99914,$$

$$M_W = 80.423\,\mathrm{GeV}, \qquad M_Z = 91.1882\,\mathrm{GeV}$$

$$s_W^2 = 1 - \frac{M_W^2}{M_Z^2}, \qquad \Gamma_W = \frac{3G_\mu M_W^3}{2\sqrt{2}\pi}\left(1 + \frac{2\alpha_s}{3\pi}\right),$$

$$\alpha^{-1} = 137.03599976, \qquad G_\mu = 1.16639 \times 10^{-5}\,\mathrm{GeV}^{-2}, \qquad \alpha_s = 0.1185,$$

$$E_{\mathrm{CM}} = \sqrt{s} = 14\,\mathrm{TeV}$$

- Event selection criteria
  - the charged lepton transverse momentum: $p_T^\ell > 25\,\mathrm{GeV}$
  - the charged lepton pseudorapidity: $|\eta_\ell| < 2.4$
  - the missing transverse energy: $E_T^{\mathrm{miss}} > 25\,\mathrm{GeV}$ (we used $E_T^{\mathrm{miss}} = p_T^\nu$)
  - the size of an electron cluster (for electron–photon recombination): $\Delta\eta_e \times \Delta\phi_e = 0.075 \times 0.175\,\mathrm{rad}$, where η_e and ϕ_e are the electron pseudorapidity and azimuthal angle
  - no photon recombination with muons
  - photon transverse momentum: $p_T^\gamma > 25\,\mathrm{GeV}$ (for exclusive photonic distributions)
  - photon pseudorapidity: $|\eta_\gamma| < 2.4$ (for exclusive photonic distributions)
- Observables
  1. W-boson transverse mass: m_T^W
  2. charged lepton transverse momentum: p_T^ℓ
  3. W-boson rapidity: y_W
  4. charged lepton pseudorapidity: η_ℓ
  5. hardest photon transverse momentum: p_T^γ
  6. hardest photon pseudorapidity: η_γ

HORACE and WINHAC: total cross sections

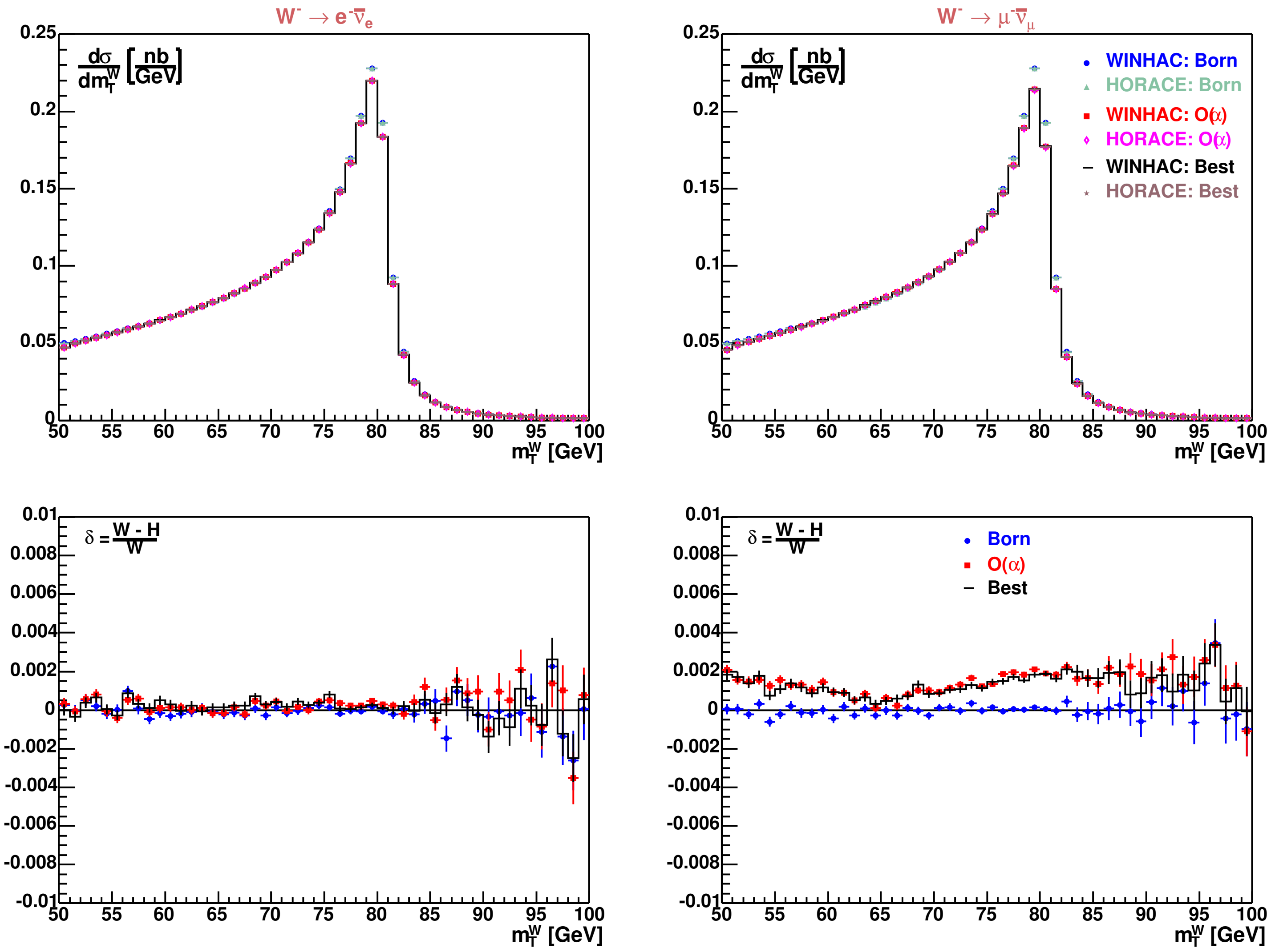
- Total cross sections comparisons, at parton (p.l.) and hadron level (h.l.). Cross sections for W^- production (in nb):

	Born		$\mathcal{O}(\alpha)$		with higher orders	
	HORACE	WINHAC	HORACE	WINHAC	HORACE	WINHAC
p. l. e^- (no cuts)	8.8872	8.8872(2)	8.8872	8.8855(1)	8.8872	8.8840
p. l. μ^- (no cuts)	8.8872	8.8872(1)	8.8863	8.8853(1)	8.8863	8.8844
h. l. e^- (no cuts)	7.7331(4)	7.7332(1)	7.7331(4)	7.7317(1)	7.7325(4)	7.7304
h. l. μ^- (no cuts)	7.7332(4)	7.7332(1)	7.7332(4)	7.7316	7.7328(4)	7.7307
h. l. e^- (with cuts)	3.2363(1)	3.2363(1)	3.1871(1)	3.1878(1)	3.1870(1)	3.1876(1)
h. l. μ^- (with cuts)	3.2363(1)	3.2363(1)	3.1599(1)	3.1642(1)	3.1601(1)	3.1641(1)

- Differences are at the $10^{-4} \div 10^{-3}$ level

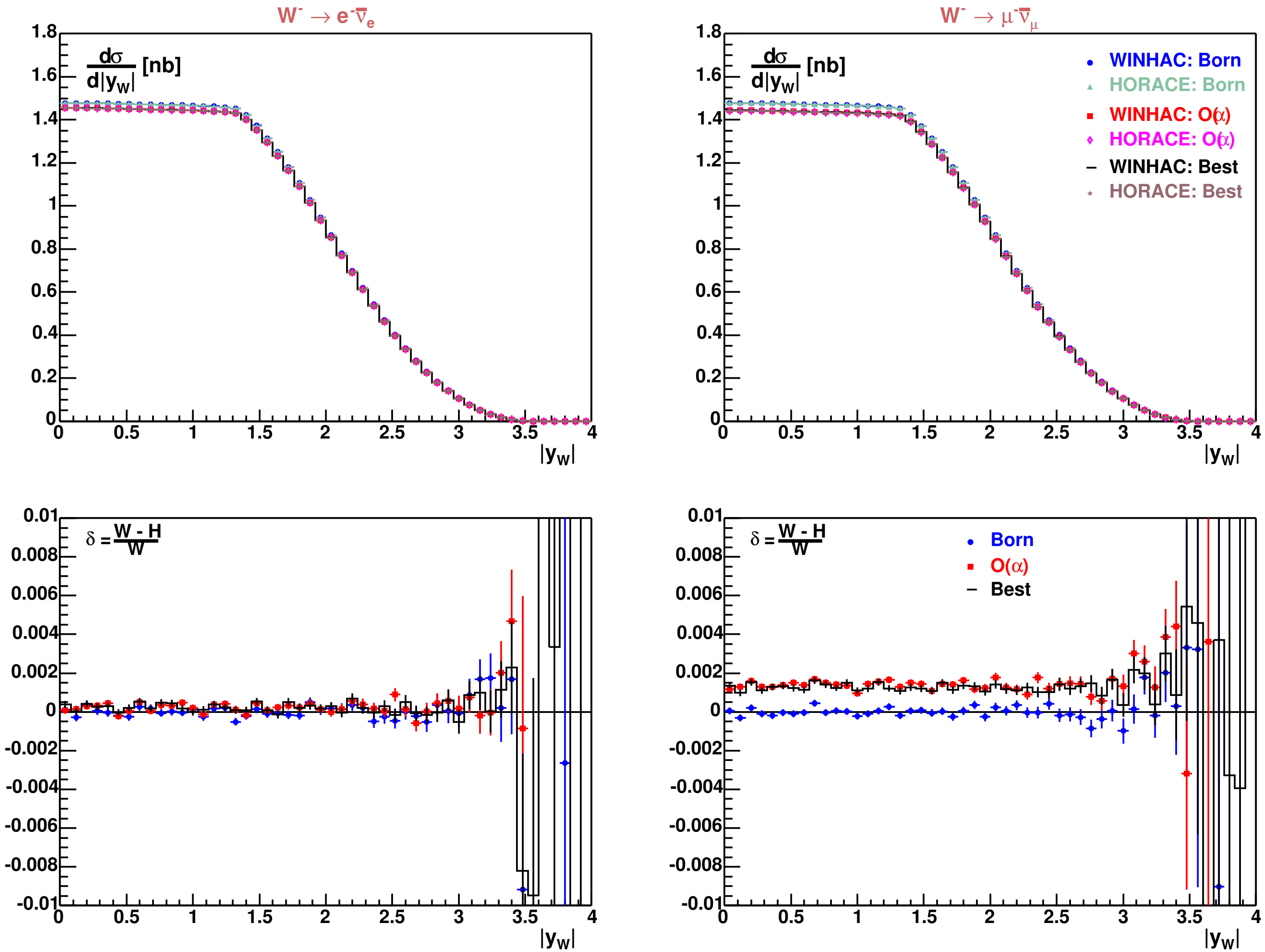
⋆ Effect of QED RC on integrated cross section with cuts at 1.5% for e^- and 2.3% for μ^-

HORACE and WINHAC: differences on M_T^W



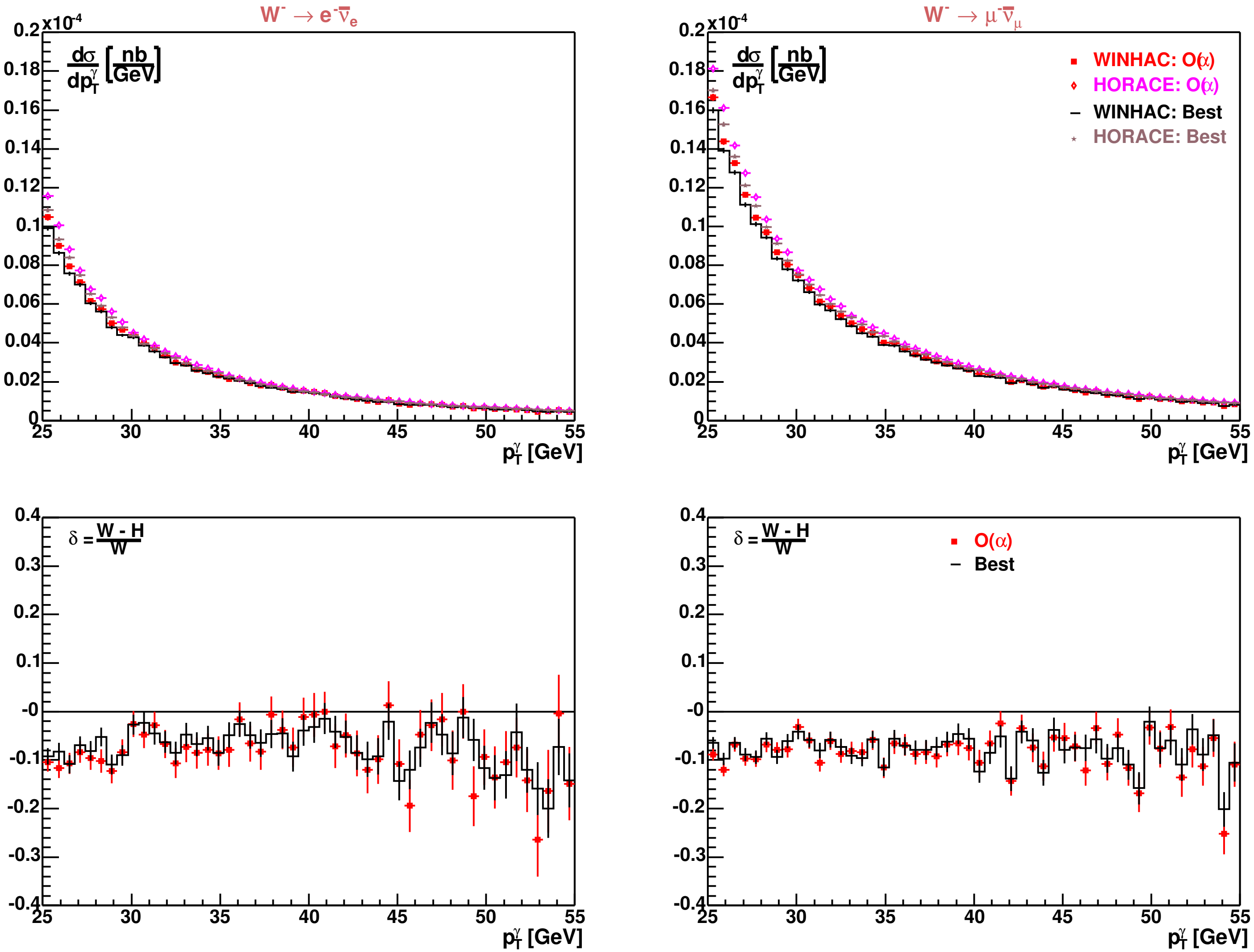
- Flat $\mathcal{O}(\alpha)$ differences at 0.2% level for μ. Same relative effect of QED exponentiation

HORACE and WINHAC: differences on W rapidity



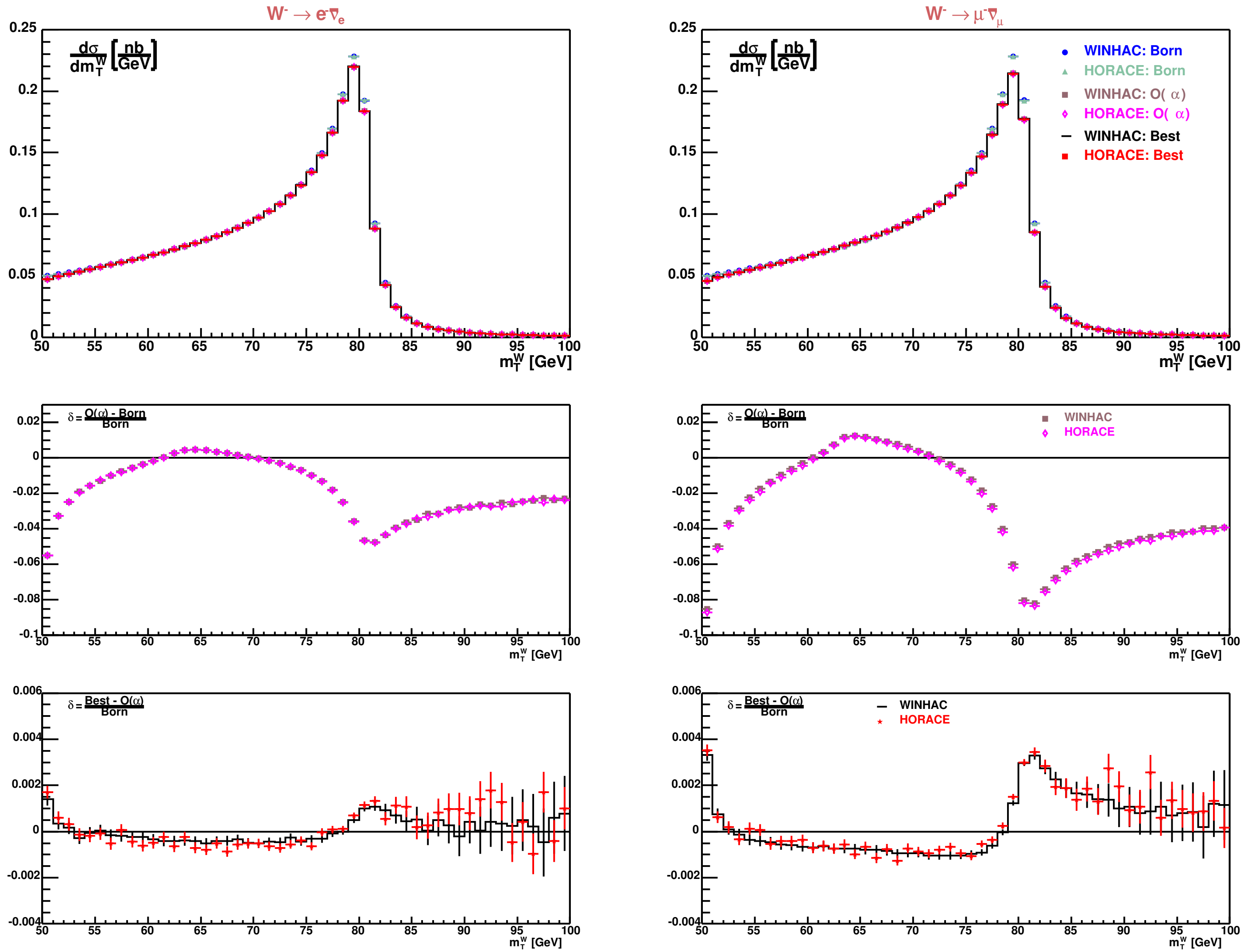
- Flat $\mathcal{O}(\alpha)$ differences at 0.2% level for μ. Same relative effect of QED exponentiation

HORACE and WINHAC: differences on hardest photon p_T



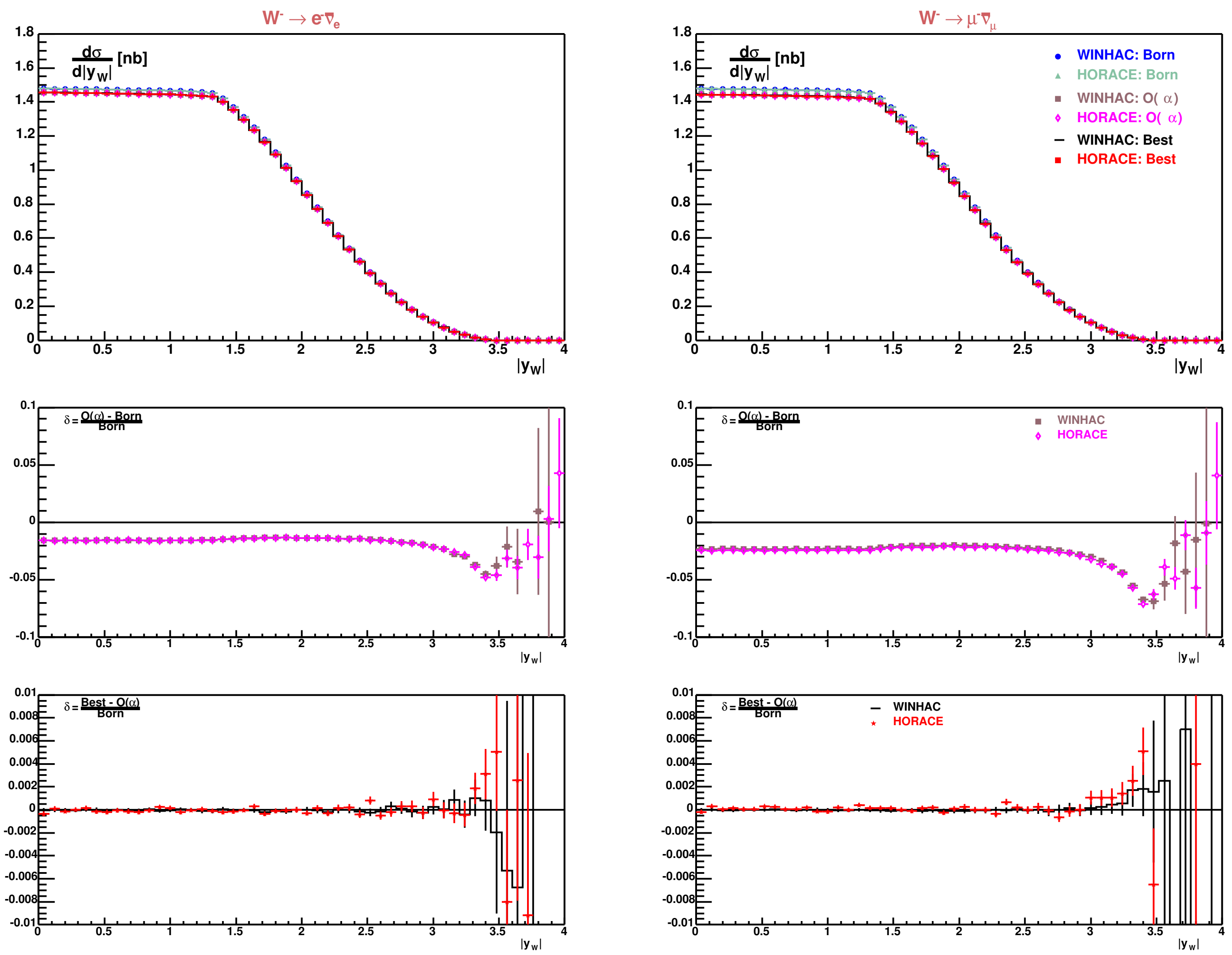
- Radiative event $W \to \ell\nu\gamma + (n\gamma)$
- Flat differences at some per cent level

HORACE and WINHAC: QED effects on W transverse mass



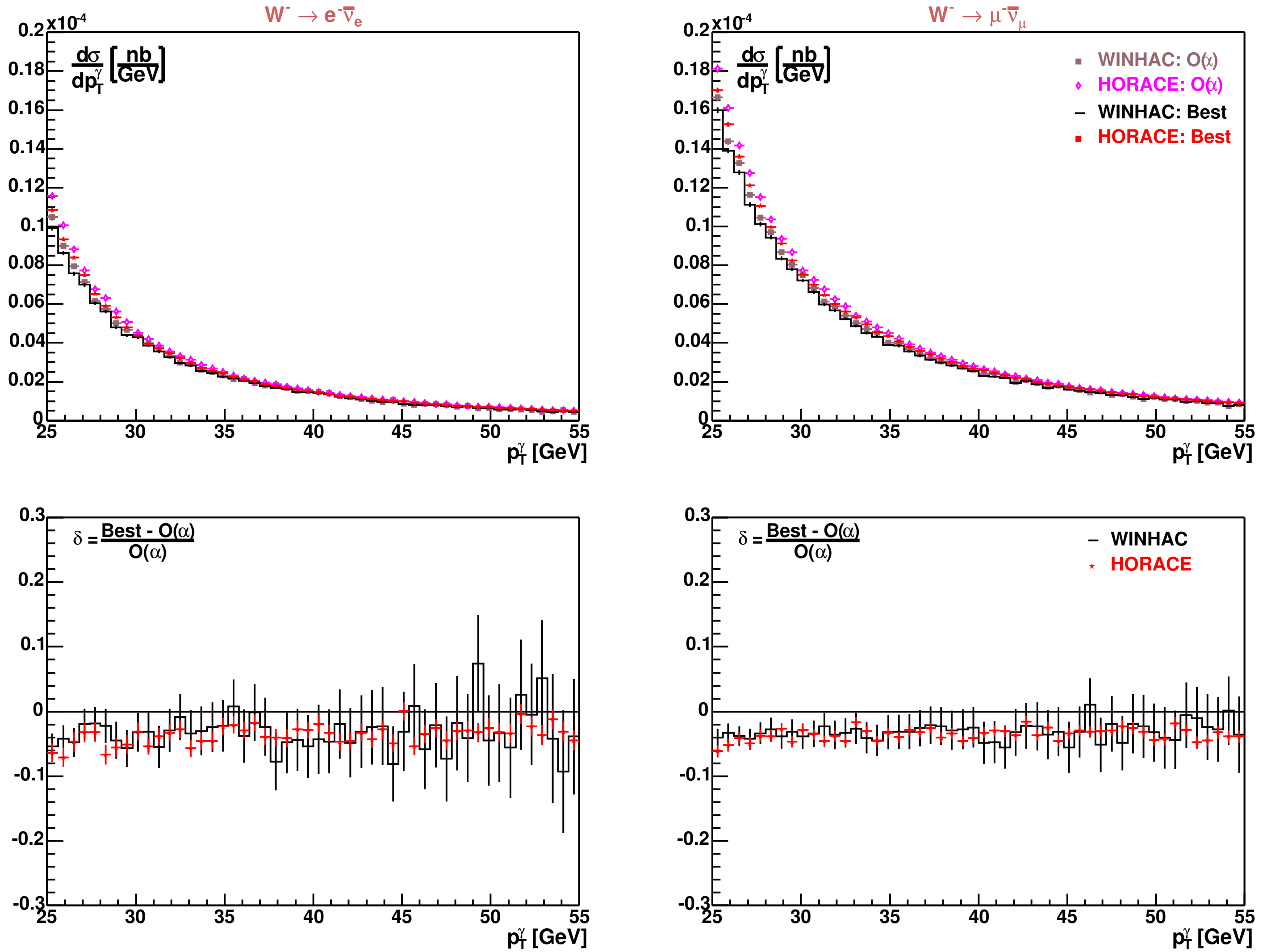
- $\mathcal{O}(\alpha)$ corrections at 5%(10%) level for $e(\mu)$, higher-order effects at 0.2%(0.5%) level for $e(\mu)$ around the W peak

HORACE and WINHAC: QED effects on W rapidity



- $\mathcal{O}(\alpha)$ corrections at 2-5% level both for e/μ, very small effect of QED exponentiation

HORACE and WINHAC: QED effects on hardest photon p_T



- Radiative event $W \to \ell\nu\gamma + (n\gamma)$
- QED exponentiation at a few % level

Neutral current case

Z simulation setup (see hep-ph/0502218)

- Input parameters (Born $\rightarrow$ EBA) and cuts

$p\bar{p}$ collisions at $\sqrt{s} = 2$ TeV. CTEQ6 PDF's at LO

$$p_T(\ell^{\pm}) > 25 \text{ GeV} \qquad |\eta(\ell^{\pm})| < 1.2$$

$$m_e = 0.511 \times 10^{-3} \text{ GeV} \qquad m_\mu = 0.10565836 \text{ GeV}$$

$$\alpha^{-1} = 137.03599976 \qquad G_\mu = 1.16639 \times 10^{-5} \text{ GeV}^{-2}$$

$$M_Z = 91.1876 \text{ GeV} \qquad \sin^2\theta_W^{\text{eff}} = 0.23150 \qquad \Gamma_Z = 2.4952 \text{ GeV}$$

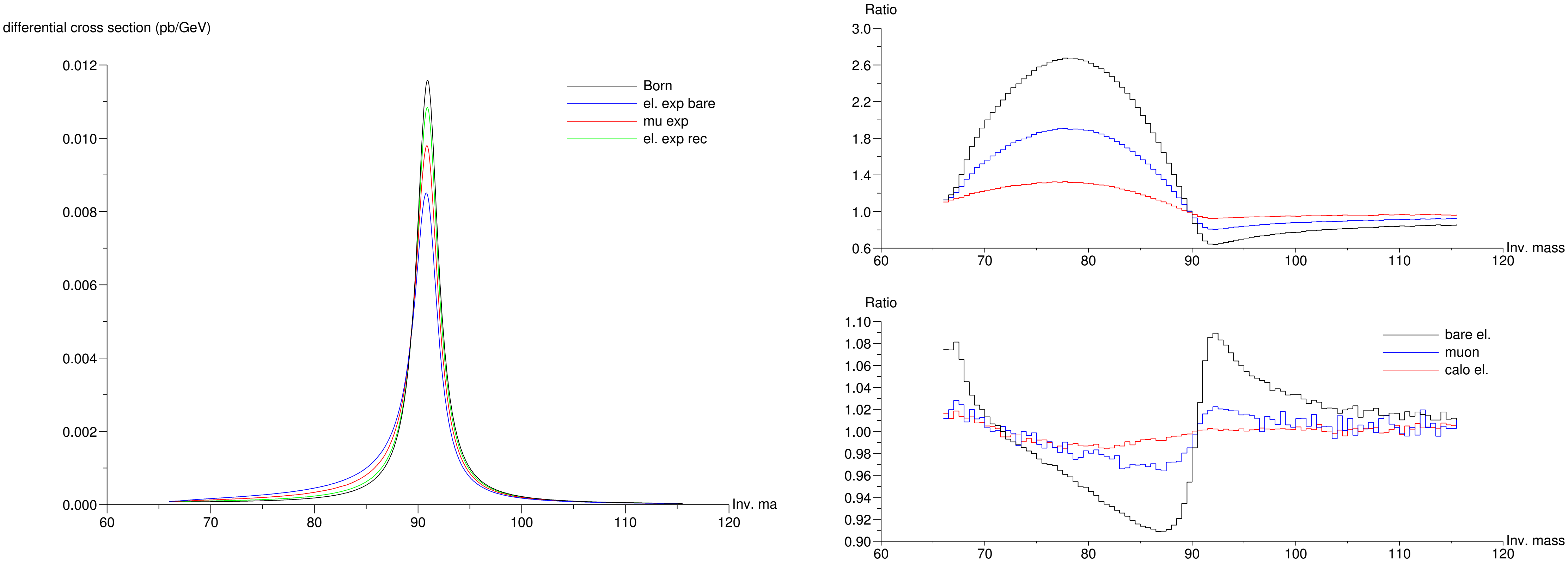
$$\alpha \rightarrow \frac{\alpha}{1-\Delta\alpha} \qquad \Gamma_Z \rightarrow \Gamma_Z \frac{s}{M_Z^2}$$

- Particle's ID requirements ($\Delta R = \sqrt{\Delta\eta^2_{\ell\gamma} + \Delta\phi^2_{\ell\gamma}}$)

	$\ell =$ electron	$\ell = \mu$
recombined	$\Delta R < 0.2$ or $0.2 < \Delta R < 0.3$ if $E_\gamma > 0.15 E_e$	
rejected	$0.1 < \Delta R < 0.4$ and $E_\gamma > 0.15 E_e$	$\Delta R < 0.2$ if $E_\gamma > 2$ GeV or $0.2 < \Delta R < 0.6$ if $E_\gamma > 6$ GeV

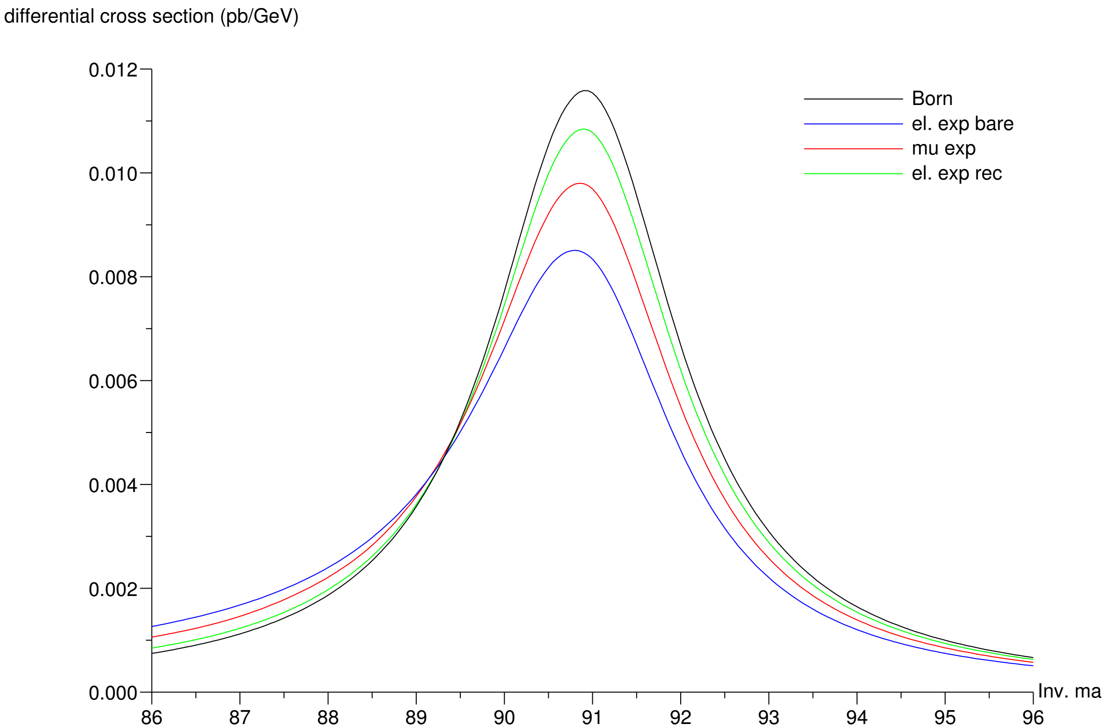
- particles' momenta can be smeared similarly to RunII DØ detector specifications

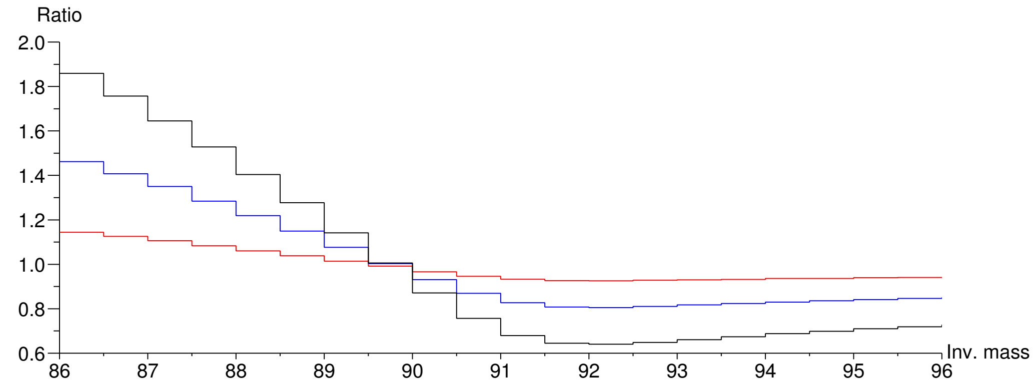
QED effects on Z line shape

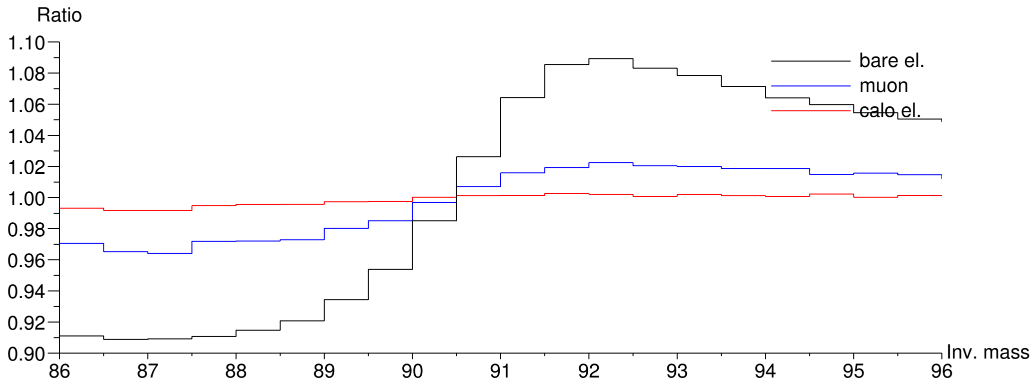


- → Detector effects are switched off
- → $\mathcal{O}(\alpha)$ corrections are large in the lower tail
- → QED exponentiation at some % in the peak region: 10% for bare e, 3% for μ, 1% for recombined e

QED effects on Z line shape (zoom)



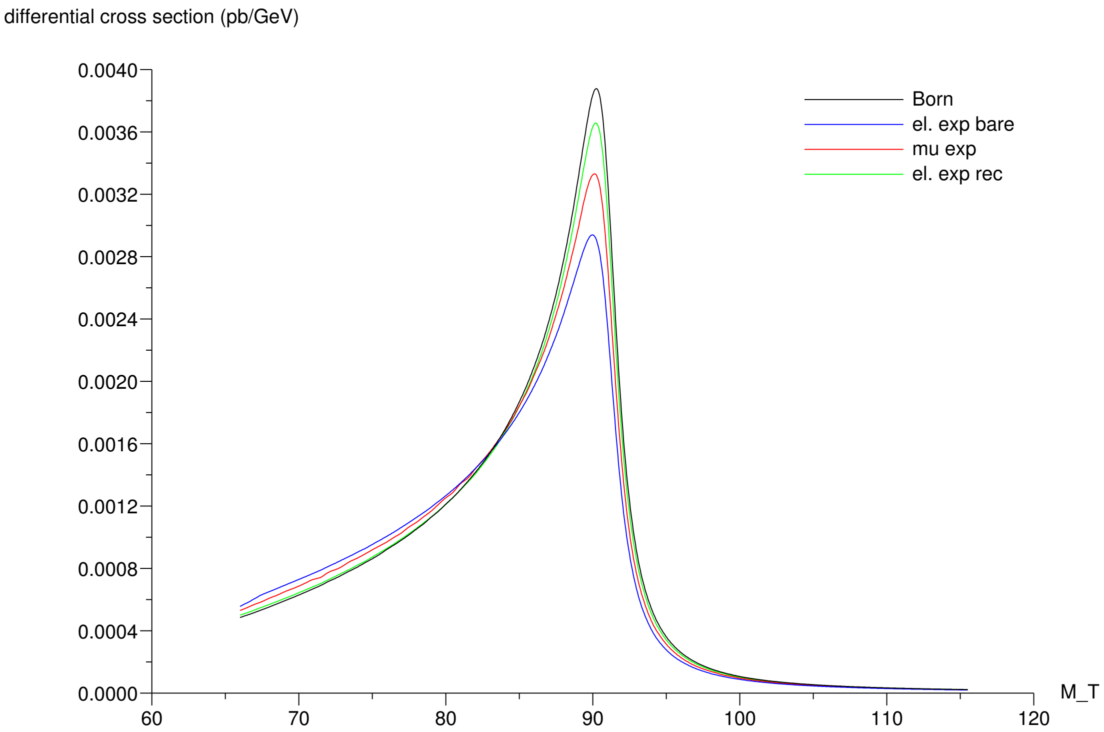


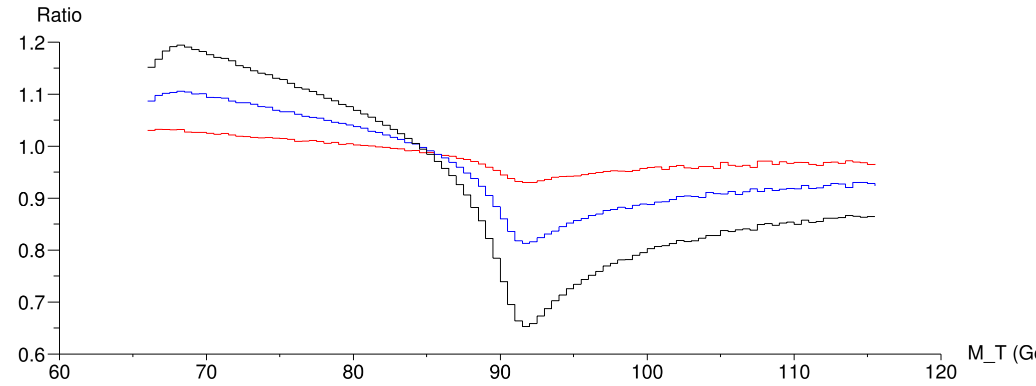


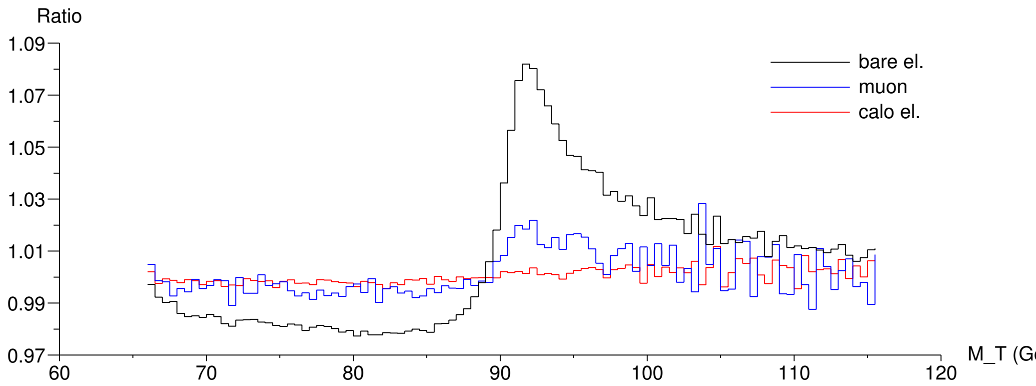
$\longrightarrow$ $\mathcal{O}(\alpha)$ corrections at some 10% near the peak

$\longrightarrow$ QED exponentiation at some % in the peak region

QED effects on Z transverse mass



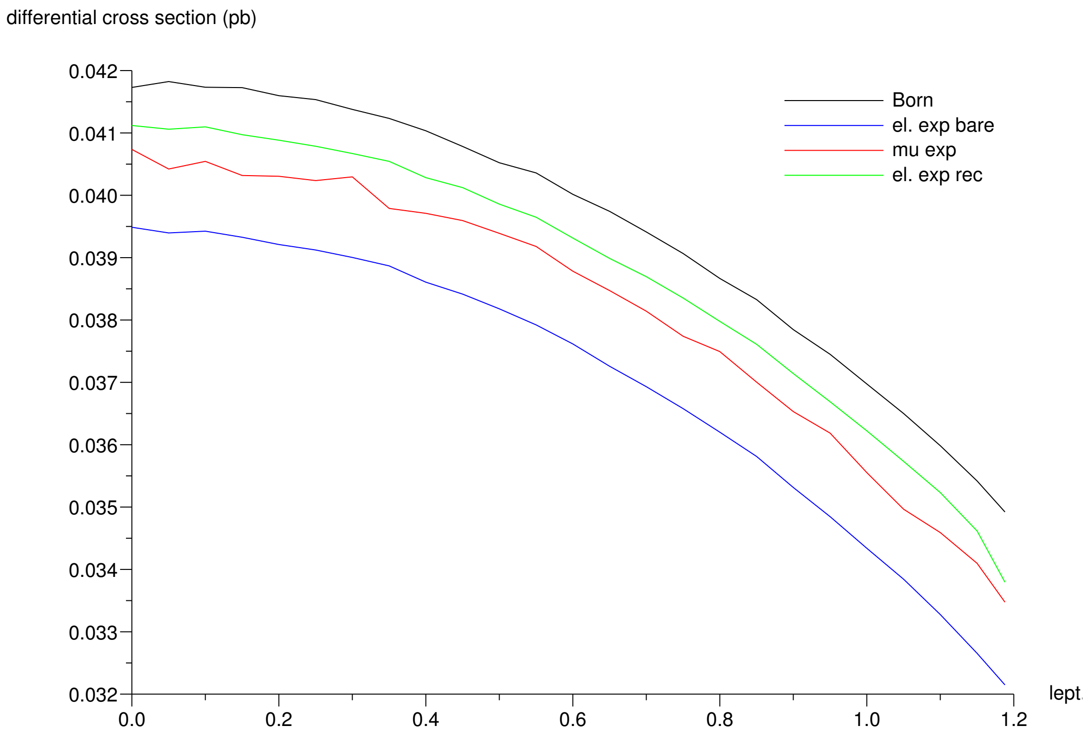


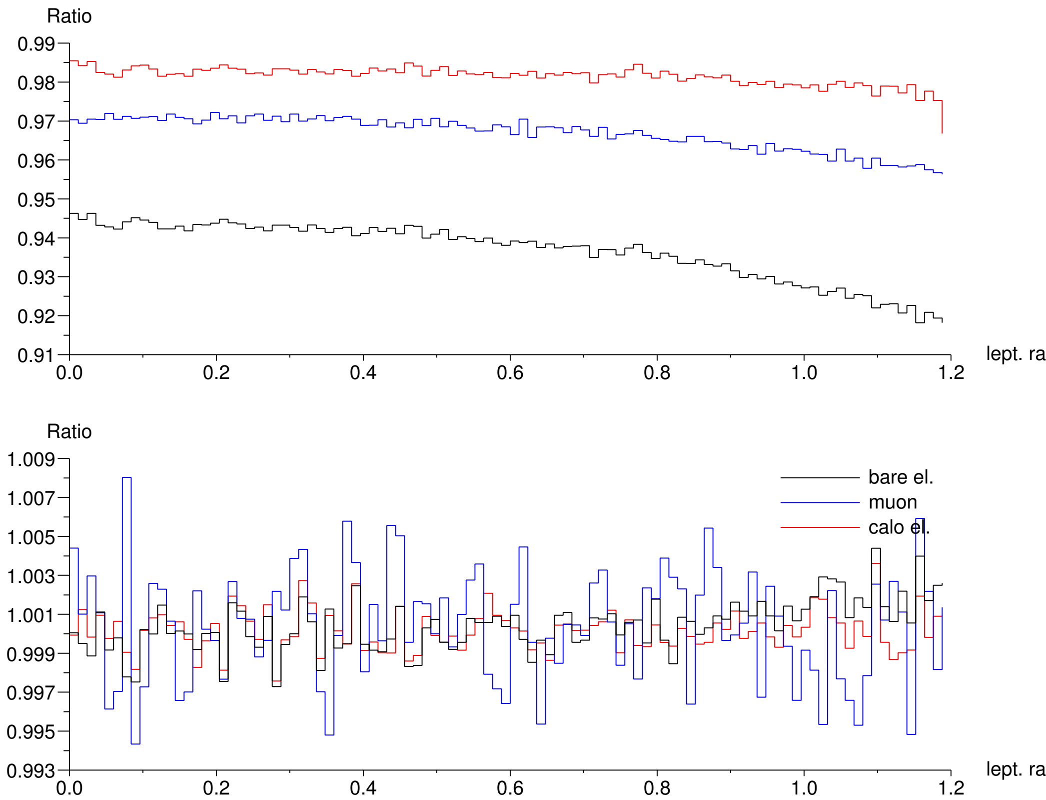


$\longrightarrow$ $\mathcal{O}(\alpha)$ corrections at a few 10% on the peak

$\longrightarrow$ QED exponentiation at some % in the peak region

QED effects on η_ℓ in Z decay

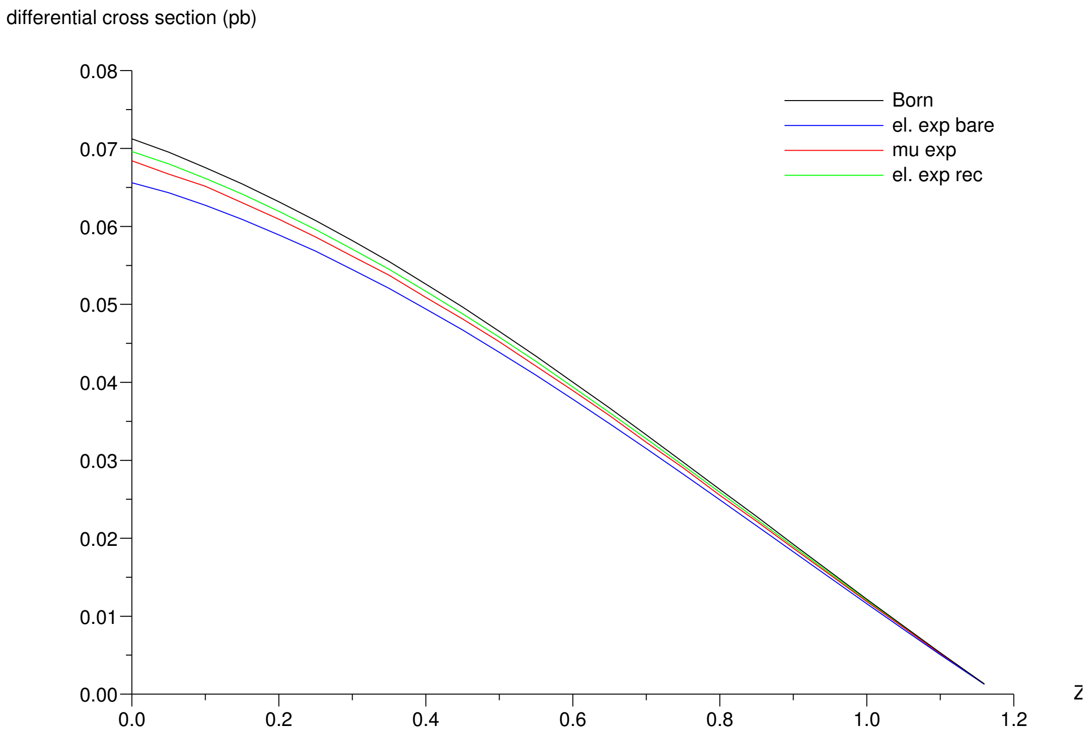


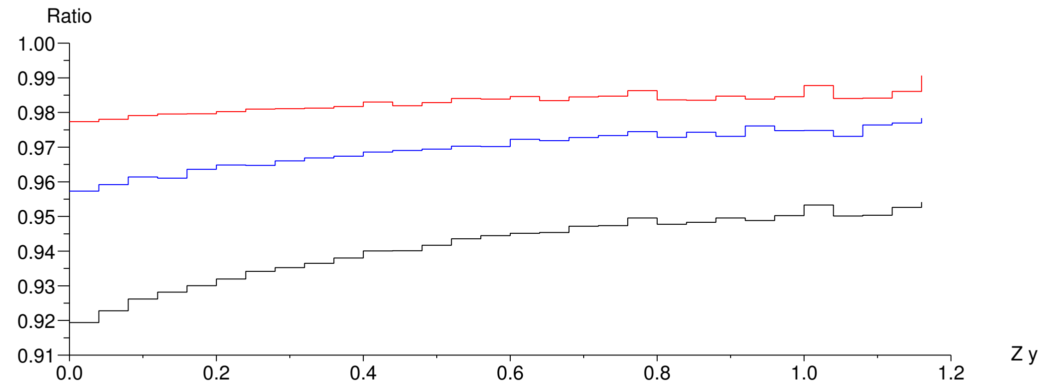


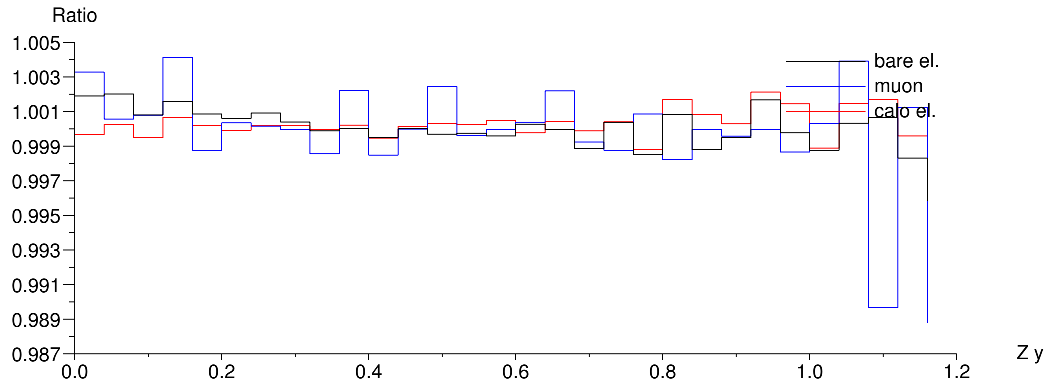
$\longrightarrow$ flat $\mathcal{O}(\alpha)$ corrections at a few %

$\longrightarrow$ QED exponentiation is almost negligible

QED effects on Z rapidity



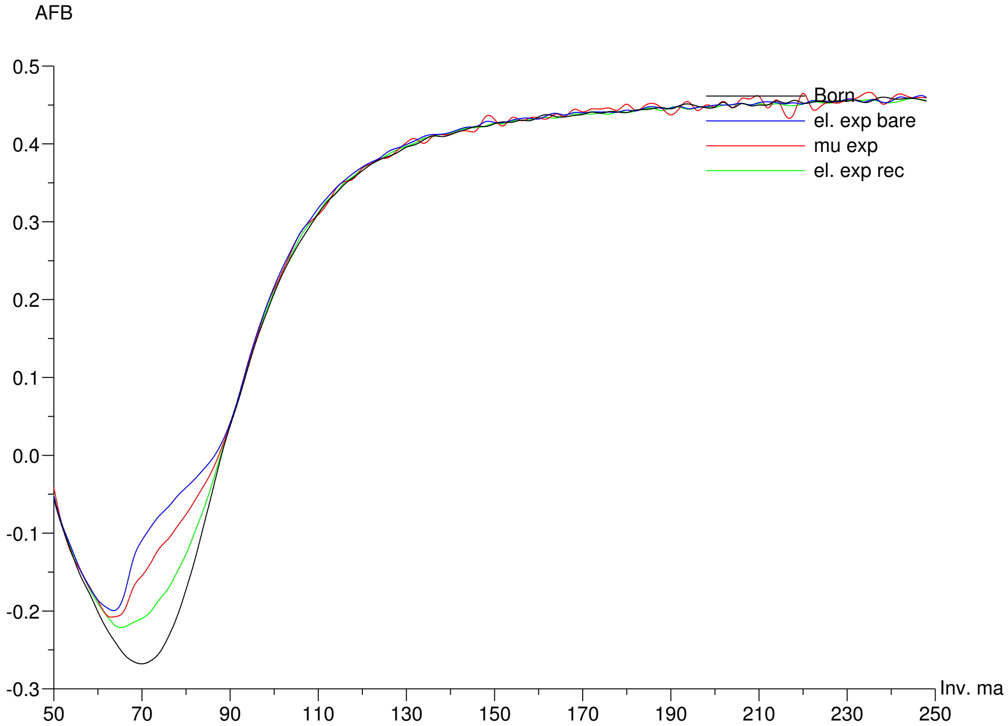


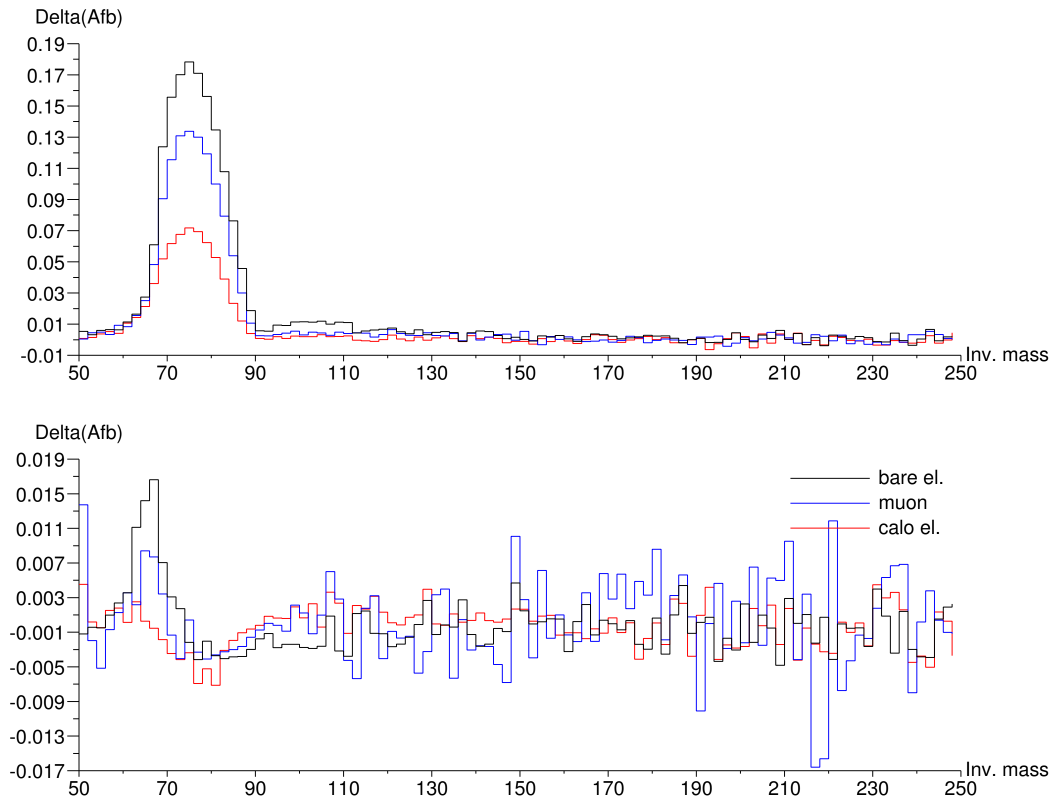


→ $\mathcal{O}(\alpha)$ corrections at few %

→ QED exponentiation is almost negligible

QED effects on A_{FB}



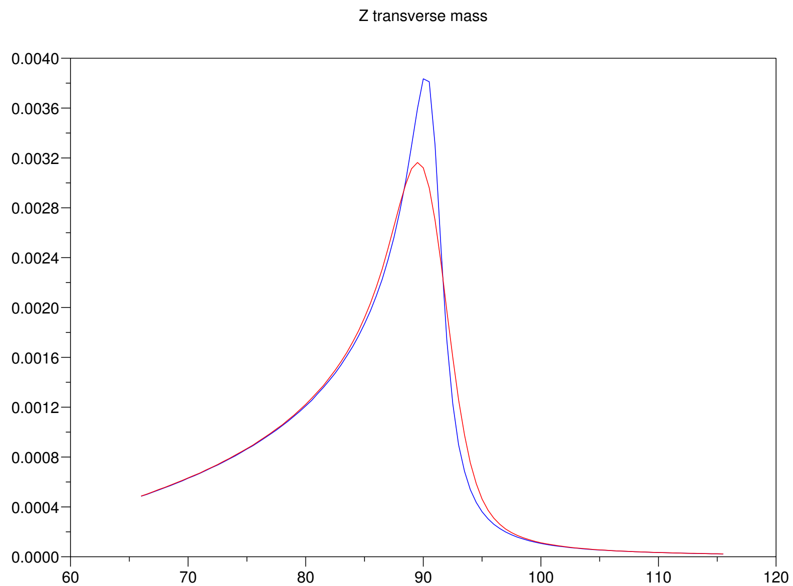


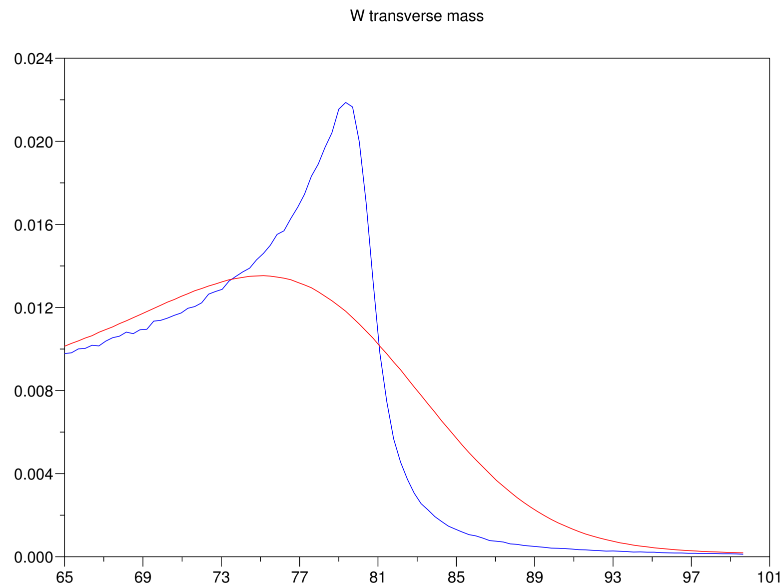
$\longrightarrow$ small effect of QED exponentiation

Estimate of RC effects on the fitted W & Z masses

By means of HORACE, we estimated the shifts induced on extracted boson masses by RC

- given a pseudo-data distribution (M_T^W,M^Z), we fit it with RC corrected distributions:
  - ⋆ we generate RC corrected distributions for N different masses
  - ⋆ we calculate the χ^2 for each of them w.r.t. the pseudo-data
  - ⋆ at the minimum χ^2 we read the shift
  - ⋆ the same procedure to quantify $\mathcal{O}(\alpha)$ and HO shifts
- the exact value of the shift depends on cuts, particles' ID and smearing!
  - ⋆ e.g., M_T for Z & W with and without smearing





W & Z mass shifts estimate

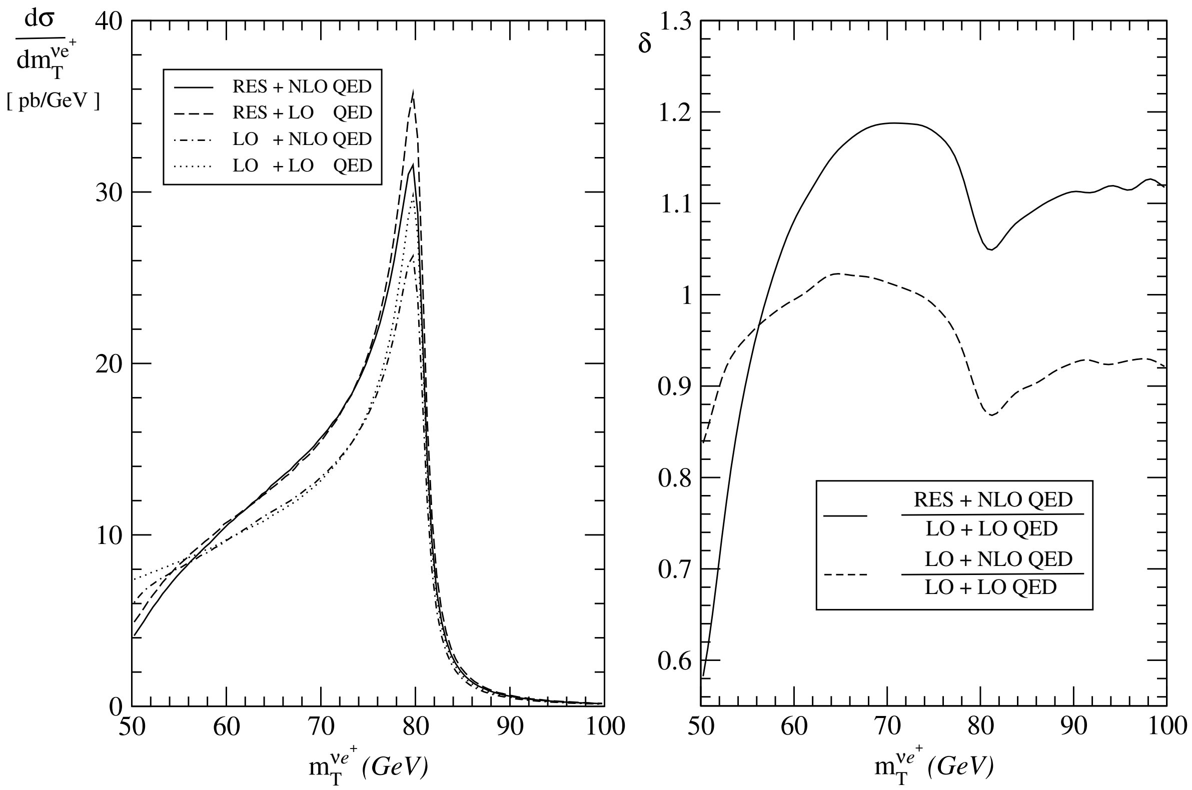
$\longrightarrow$ the χ^2 fit shows (with "our" simplified detector!)

Particle	Smearing	Lepton ID	ΔM_Z^{α}(MeV)	$\Delta M_Z^{\mathrm{h.o.}}$(MeV)	ΔM_W^{α}(MeV)	$\Delta M_W^{\mathrm{h.o.}}$(MeV)
e	✗	✗	595	-135		
μ	✗	✗	270	-31		
e	✗	✓	75	-5		
μ	✗	✓	215	-28		
e	✓	✗	780	-159	400	-40
μ	✓	✗	565	-49	220	-10
e	✓	✓	105	-6	20	-2
μ	✓	✓	420	-44	110	-10

- ⋆ detailed simulation performed for the TeVatron. For the LHC, the results are similar
- ⋆ higher orders reduce the $\mathcal{O}(\alpha)$ effect
- ⋆ $|$higher orders$| \sim 10\% \times \mathcal{O}(\alpha)$
- ⋆ the shifts significantly depend on the detector details... ;-)

FS QED + IS QCD resummation (for W)

- A unified MC including both EW and QCD corrections would be very helpful
- Cao and Yuan (PRL 93 042001 (2004) and `hep-ph/0401171`) included in `RESBOS` (Balazs and Yuan, PRD 56 5558 1997) the QED $\mathcal{O}(\alpha)$ corrections of `WGRAD`
  - ⋆ resummation of soft gluons ($\Rightarrow p_\perp^W$ generation)
  - ⋆ bulk of EW radiative corrections: final-state QED $\mathcal{O}(\alpha)$ corrections



Conclusions

- The Drell-Yan-like production of single W/Z boson is a process relevant for many aspects of the physics programme of hadron colliders
- Recent big theoretical effort towards high-precision predictions, including higher-order QCD and electroweak corrections, to keep under control theoretical systematics
- Full $\mathcal{O}(\alpha)$ EW corrections are available and are dominated by FS photonic corrections
- We focused on multi-photon corrections:
  - $\longrightarrow$ the MC `HORACE` developed (for W&Z). QED radiation included by means of a PS
  - $\longrightarrow$ for W, tuned and detailed comparisons with `WINHAC`
  - $\longrightarrow$ W/Z-mass shift due to higher-orders is about 10% of that due to $\mathcal{O}(\alpha)$ (with simplified detector effects!)
- Work in progress: include the exact $\mathcal{O}(\alpha)$ electroweak corrections in `HORACE` (in collaboration with A. Vicini)
- It's necessary to combine EW and QCD corrections in a "unified" generator

HORACE cross-checks

- for $W^{(+)}$ cross-checked with WGRAD (Baur, Keller, Wackeroth)

	TeVatron		LHC	
(cross sections in pb)	e	μ	e	μ
WGRAD Born	441.7(1)		1906(1)	
WGRAD	418.3(4)	429.4(3)	1800(2)	1845(2)
WGRAD final-state	419.7(1)	430.0(1)	1808(1)	1854(1)
HORACE Born	441.6(1)		1905(1)	
HORACE $\mathcal{O}(\alpha)$	419.4(1)	429.9(1)	1806(1)	1853(1)
HORACE exponentiated	419.5(1)	430.0(1)	1808(1)	1853(1)

$\longrightarrow$ $\mathcal{O}(\alpha)$ corrections $\sim 5\%$

- for Z checking versus ZGRAD2 (Baur et al.) is in progress

$\longrightarrow$ preliminary results for e^+e^- at the TeVatron

(cross sections in pb)	Born	FS $\mathcal{O}(\alpha)$
ZGRAD2	51.625(5)	47.72(4)
HORACE	51.639(5)	47.621(1)

HORACE versus B&K (Z. Phys. C27 (1985) 365)

- $\mathcal{O}(\alpha)$ Z at parton level, $\sqrt{s} = 90$ GeV, $k_0 = E_\gamma / E_{beam}$
- $R = \sigma(k > k_0)/\sigma_0$

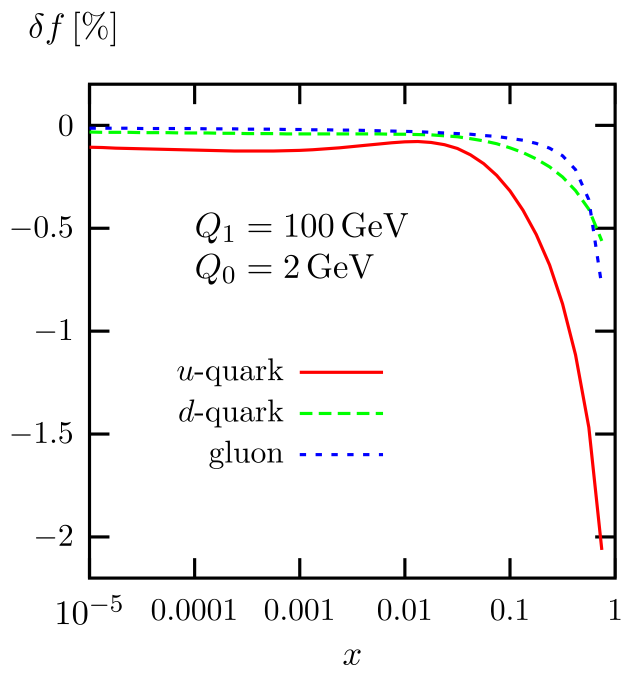
k_0	e		μ	
	HORACE	B&K	HORACE	B&K
0.01	0.416	0.411	0.224	0.220
0.05	0.246	0.242	0.133	0.129
0.10	0.178	0.173	0.096	0.090
0.15	0.139	0.135	0.075	0.071
0.20	0.113	0.109	0.061	0.057
0.30	0.079	0.075	0.042	0.039
0.40	0.056	0.054	0.030	0.028
0.50	0.041	0.038	0.022	0.020
0.60	0.029	0.027	0.016	0.014
0.70	0.020	0.018	0.011	0.009
0.80	0.012	0.011	0.006	0.005
0.90	0.006	0.005	0.003	0.002

Initial-state photonic corrections & PDFs

H. Spiesberger, Phys. Rev. **D52** (1995) 4936

M. Roth and S. Weinzierl, Phys. Lett. **B590** (2004) 190

- QED radiation off quarks give rise to factorizable and universal mass singularities
- they can be absorbed by a redefinition (*renormalization*) of PDFs, in analogy to QCD, introducing a dependence on a QED factorization scale
- the DGLAP evolution must contain an additional term proportional to α_{QED} and fits to data should include QED contributions (now included in MRST, `hep-ph/0411040`)



- QED terms modify PDFs at the 0.1% level for $x < 1 \Rightarrow$ “small” for W/Z production