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Calcoli teorici per la misura della massa del W ai collider adronici

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Outline

- ⋆ Introduction
- ⋆ Measuring M_W at hadron colliders
- ⋆ Status of RC calculation for W production
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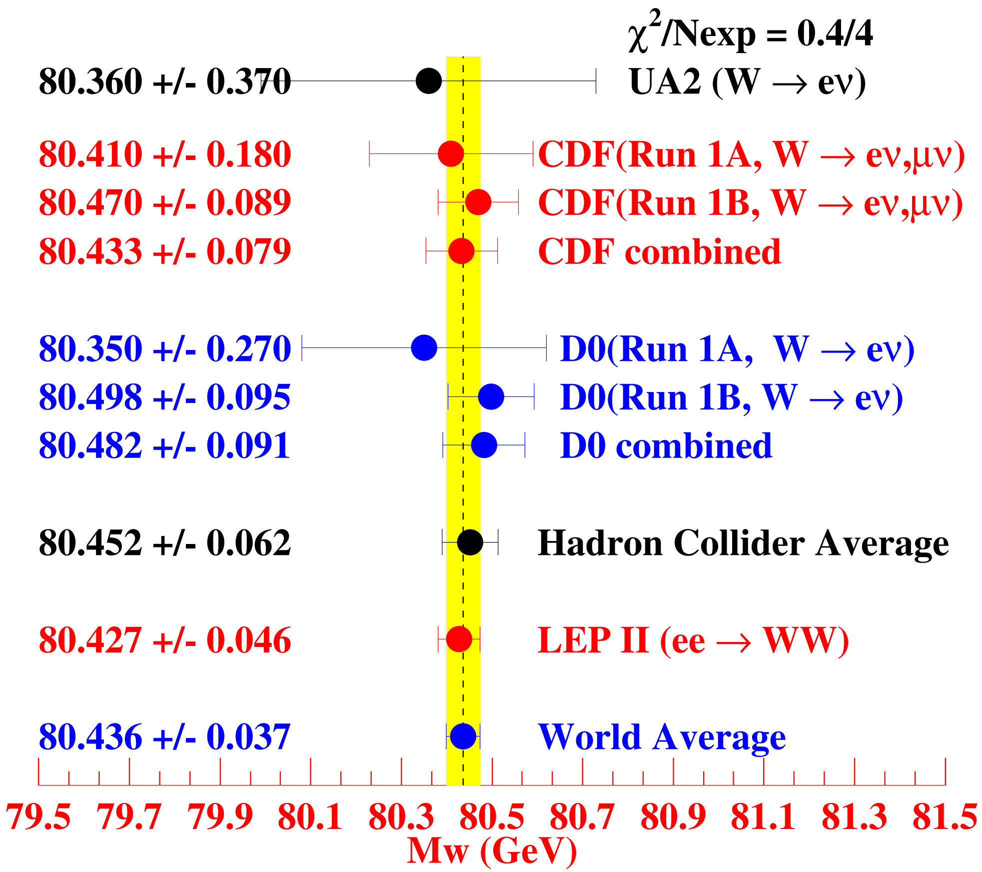
    - √ `HORACE` (Pavia group) vs `WINHAC` (Cracow group)
    - √ effects of QED exponentiation on extracted M_W
  - → phenomenology of $\mathcal{O}(\alpha)$ EW + QCD resummation
- ⋆ Conclusions

Introduction

- The precise M_W (and M_{top}) measurement will highly improve the indirect bound on M_H via RC ($\Delta M_H \sim 30\%$)
- Present experimental status and future goal:



Target precision ΔM_W at hadron colliders:

- ⋆ Tevatron RunII ⇒ 27 MeV
- ⋆ LHC ⇒ 15 MeV

Measuring M_W @ Hadron Colliders

- Experimentally, M_W is extracted from the $W \to \ell\nu_\ell$ (leptonic) decay kinematics, which presents a peak in the $p_\perp^\ell$ distribution (Jacobian peak)
- the sharpness of the Jacobian peak at $M_W/2$ is smoothed by:
  - ⋆ finite W width
  - ⋆ detector smearing effects
  - ⋆ W transverse momentum ($p_\perp^W$), which can not be precisely predicted/measured

√ the W transverse mass M_T ($M_T \approx 2p_T^\ell$) is a more reliable quantity to extract M_W, being less sensitive to the $p_\perp$ of the W

$$M_T = \sqrt{2p_\perp^\ell p_\perp^\nu (1 - \cos\phi_{\ell\nu})}$$

- The M_T^W/M_T^Z ratio method can be also used, but uncertainty is dominated by low Z statistics. It can be competitive at high luminosity

Systematic uncertainties on M_W

- *E.g.*, from CDF collaboration, PRD 64 052001 2001

Source of uncertainty	$W \to e\nu$	$W \to \mu\nu$	common
Lepton scale	75	85	
Lepton resolution	25	20	
PDFs	15	15	15
P_T^W	15	20	3
Recoil	37	35	
Higher order QED	20	10	5
Trigger & Lepton ID bias	–	$15 \oplus 10$	
Backgrounds	5	25	
Total	92	103	16

- lepton scale, P_T^W, recoil are strongly related to Z parameters extraction and statistics
- at Tevatron (RunIb CDF), $\mathcal{O}(\alpha)$ EW RC shift M_W by

electron channel: 65 ± 20 MeV

muon channel: 168 ± 20 MeV

⋆ the shifts are mainly due to QED FS corrections

Literature of EW RC

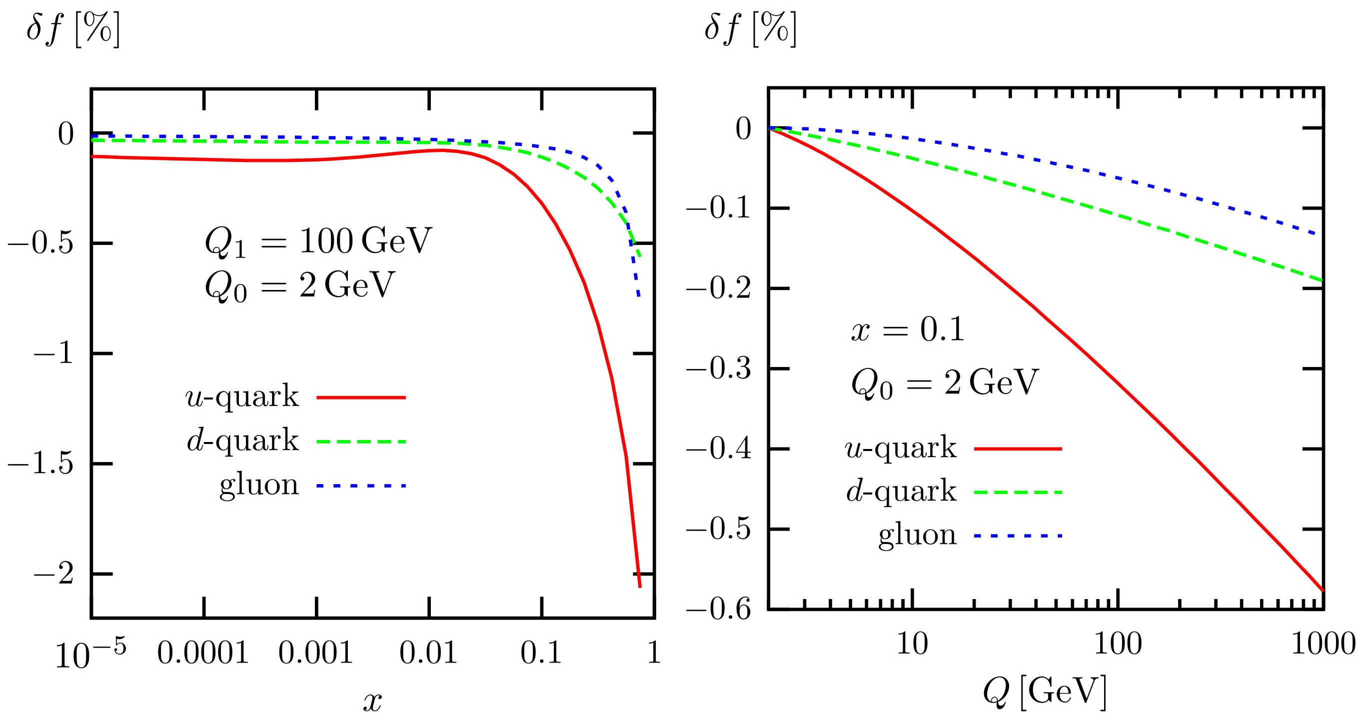
- order α EW RC to W production at hadron colliders:
  - ⋆ resonant W approximation (pole approximation)
    - → D. Wackeroth, W. Hollik, PRD 55 6788 1997
    - → U. Baur, S. Keller, D. Wackeroth, PRD 59 013002 1999
  - ⋆ complete $\mathcal{O}(\alpha)$ corrections
    - → S. Dittmaier, M. Krämer, PRD 65 073007 2002
- order α EW RC to Z production:
  - ⋆ $\mathcal{O}(\alpha)$ photonic RC
    - → U. Baur, S. Keller, W.K. Sakumoto PRD, 57 199-215 1998
  - ⋆ full $\mathcal{O}(\alpha)$ EW RC
    - → U. Baur, O. Brein, W. Hollik, C. Schappacher, D. Wackeroth, PRD, 65 033007 2002
- beyond order α:
  - ⋆ QED Parton Shower approach (for W and Z), implemented in `HORACE`
    - → C.M.C.C. et al., PRD, 69 037301 2004
  - ⋆ YFS exponentiation approach (for W), implemented in `WINHAC`
    - → S. Jadach, W. Płaczek, EPJC, 29 325-339 2003

Initial state photonic corrections

H. Spiesberger, PRD 52, 4936-4940, 1995

M. Roth and S. Weinzierl, `hep-ph/0403200`

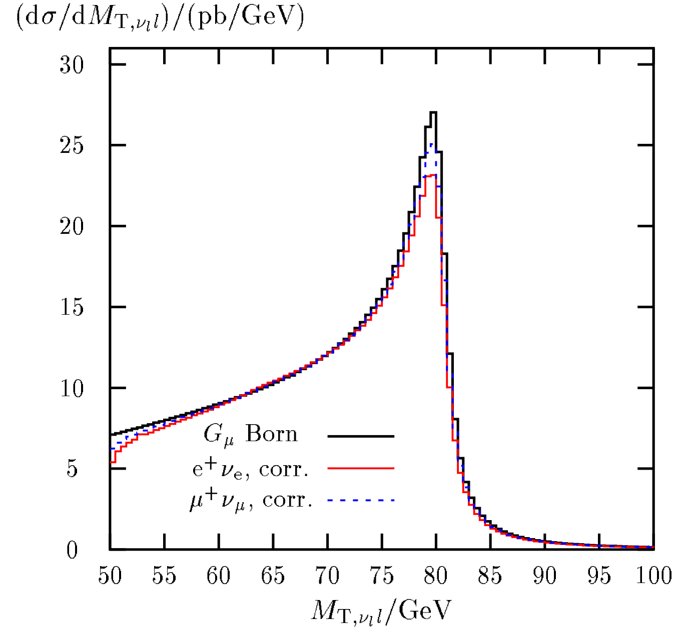
- QED corrections due to γ emission from IS contain factorizable mass singularities
- they have to be absorbed by a redefinition (*renormalization*) of PDFs
- the DGLAP evolution must contain a QED term and fits to data should include QED contributions (PDFs will depend on a factorization scale μ^2)

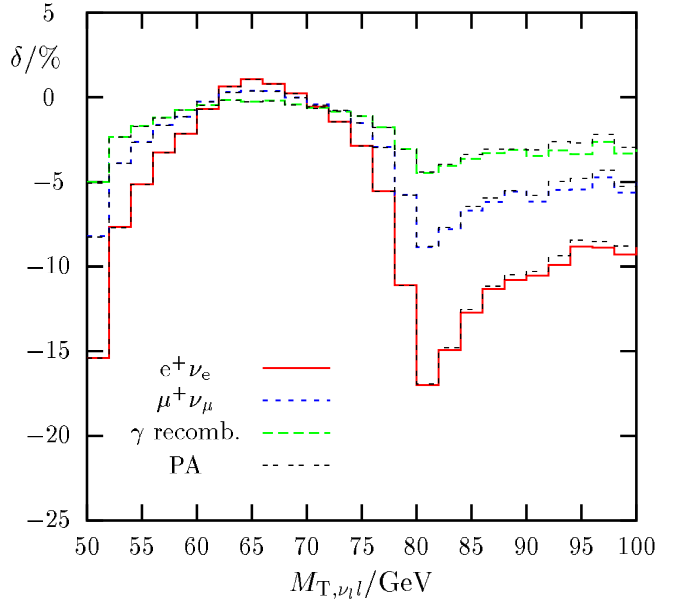


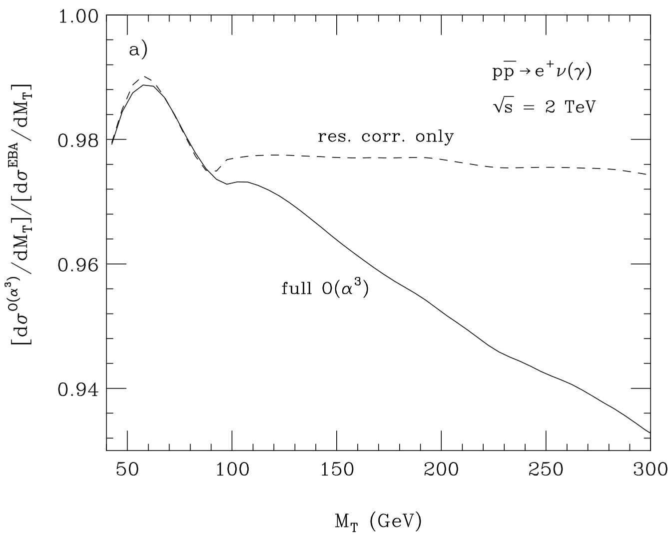
→ However, IS QED RC are "small" for W (Z) production

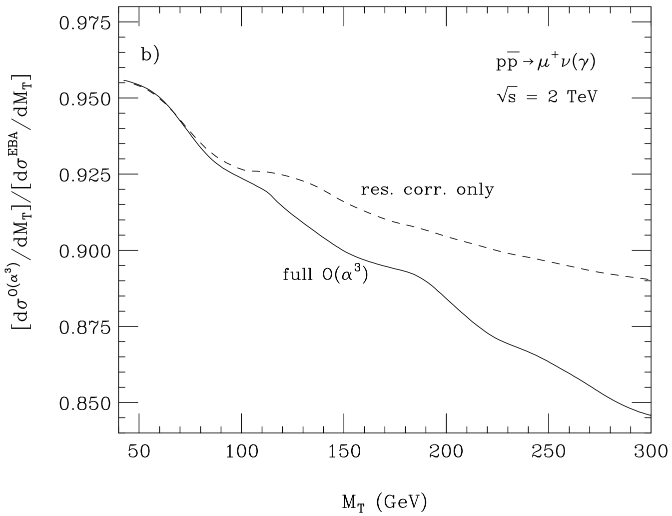
EW $\mathcal{O}(\alpha)$ corrections

- effects on M_T distribution (from Dittmaier et al. and from Baur et al.)









⋆ pole approx. fails for $M_T \gg M_W$, due to large Sudakov-like logs

Higher Order QED corrections

- HO QED corrections can give sizeable effects on M_W (or M_Z) if $\Delta M_W \simeq 20$ MeV
- HO QED RC for the leptonic W decay are included in two MC event generators:

$\rightarrow$ `HORACE`: QED Parton Shower, with improved photonic angular spectrum

$$\cos\theta_\gamma \sim \left(\frac{p}{p \cdot k} - \frac{Q}{Q \cdot k}\right)^2$$

C.M. C.C., G. Montagna, O. Nicrosini, M. Treccani, PRD, 69 037301 2004

$\rightarrow$ `WINHAC`: YFS exponentiation of "exact" order α matrix element

S. Jadach and W. Płaczek, EPJC, 29 325-339 2003

- A tuned comparison of the two codes, at parton and hadron level, was performed during the MC4LHC workshop

C.M. C.C. et al., `hep-ph/0402235`, to be published in Acta Phys. Pol. **B**

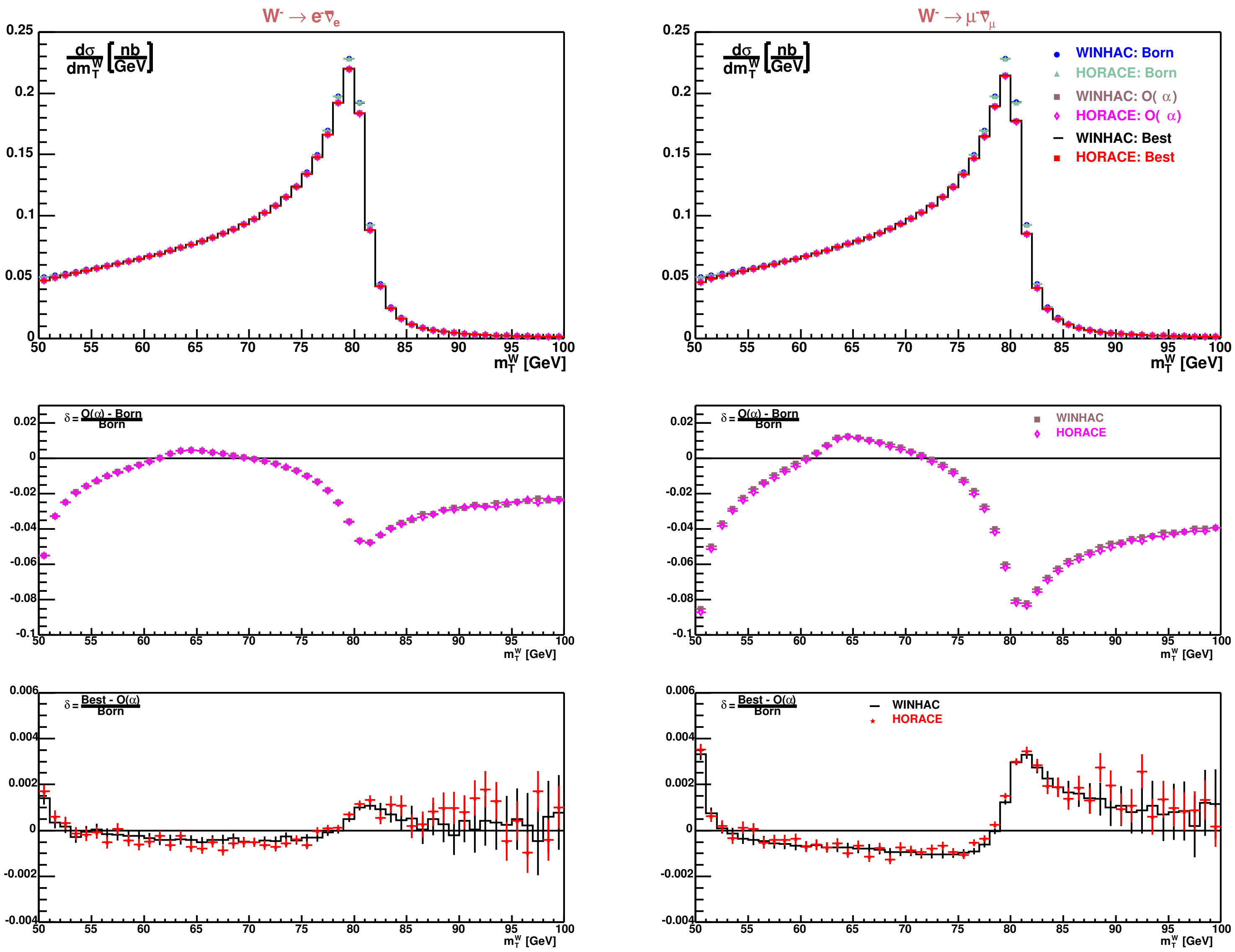
HORACE and WINHAC

- Total cross sections comparisons, at parton (p.l.) and hadron level (h.l.)

  e.g., cross sections for W^- production (in nb):

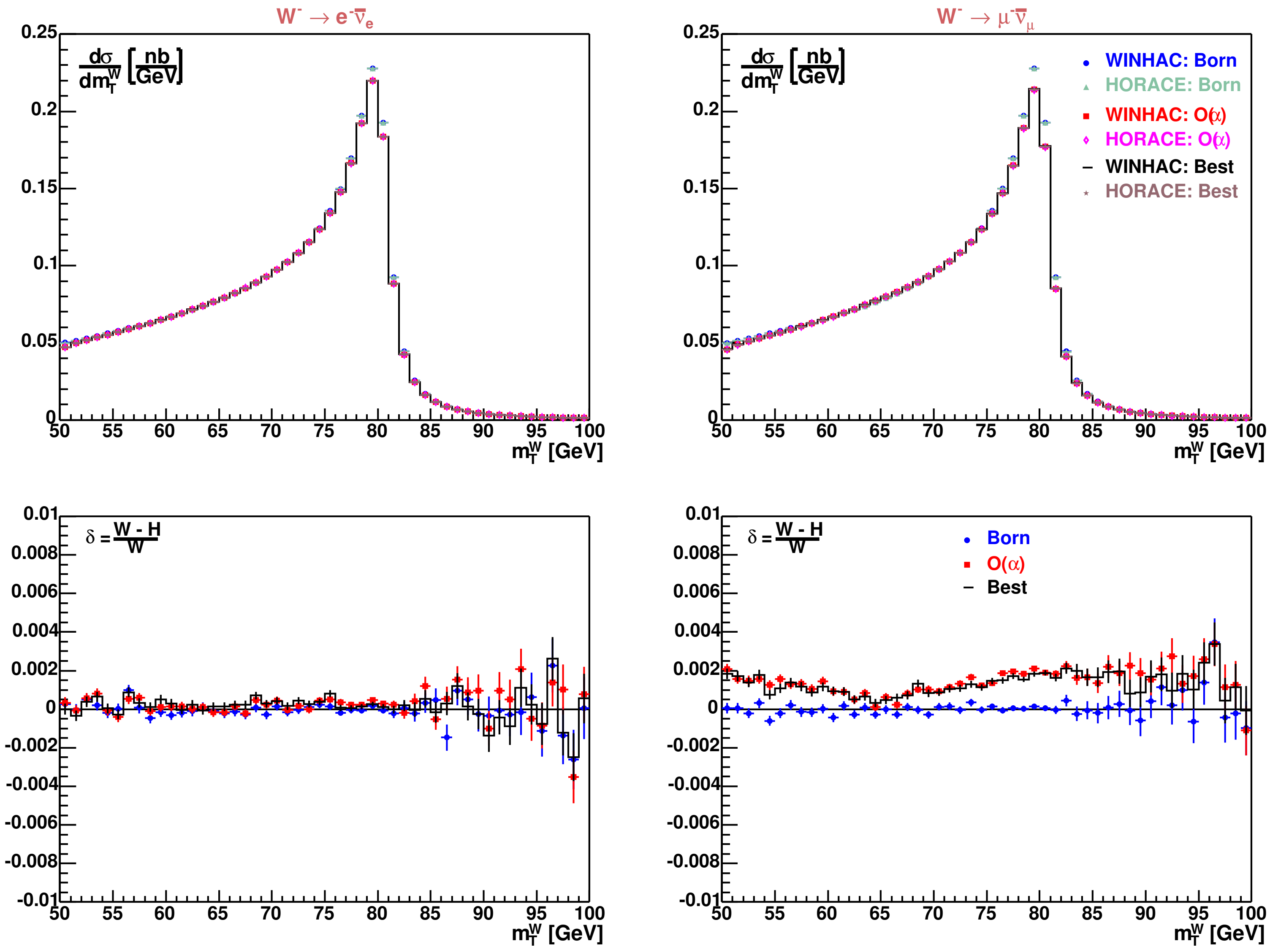
	Born		$\mathcal{O}(\alpha)$		with HO	
	HORACE	WINHAC	HORACE	WINHAC	HORACE	WINHAC
p. l. e^- (no cuts)	8.8872	8.8871(2)	8.8872	8.8855(1)	8.8872	8.8840
p. l. μ^- (no cuts)	8.8872	8.8871(1)	8.8869	8.8853(1)	8.8869	8.8844
h. l. e^- (no cuts)	7.7331(4)	7.7331	7.7331(4)	7.7317(1)	7.7325(4)	7.7304
h. l. μ^- (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)	3.1869(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)

HORACE and WINHAC: distributions



- for e^-, a calorimetric ES criterium is used

HORACE and WINHAC: differences

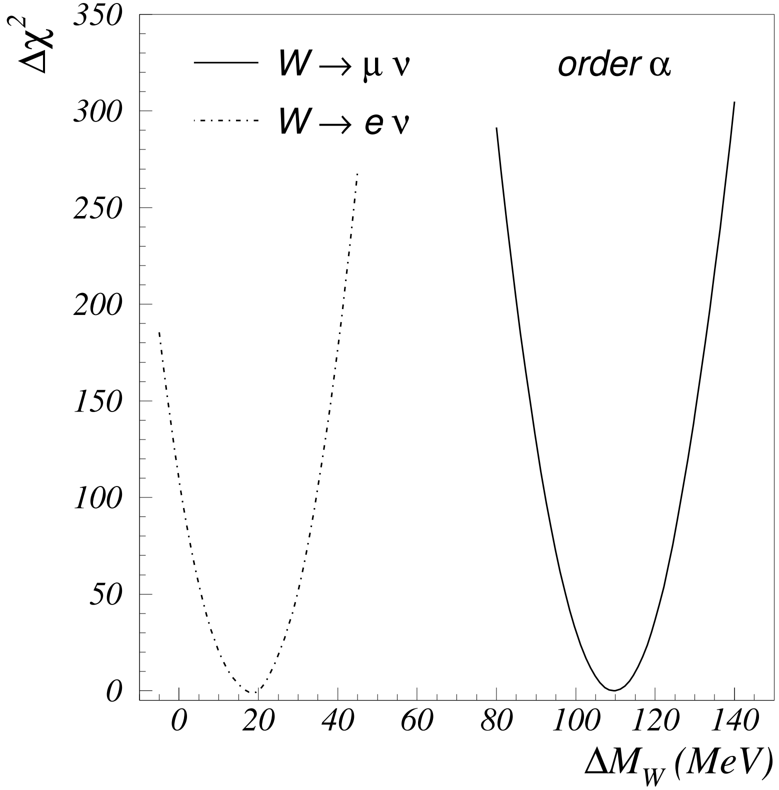


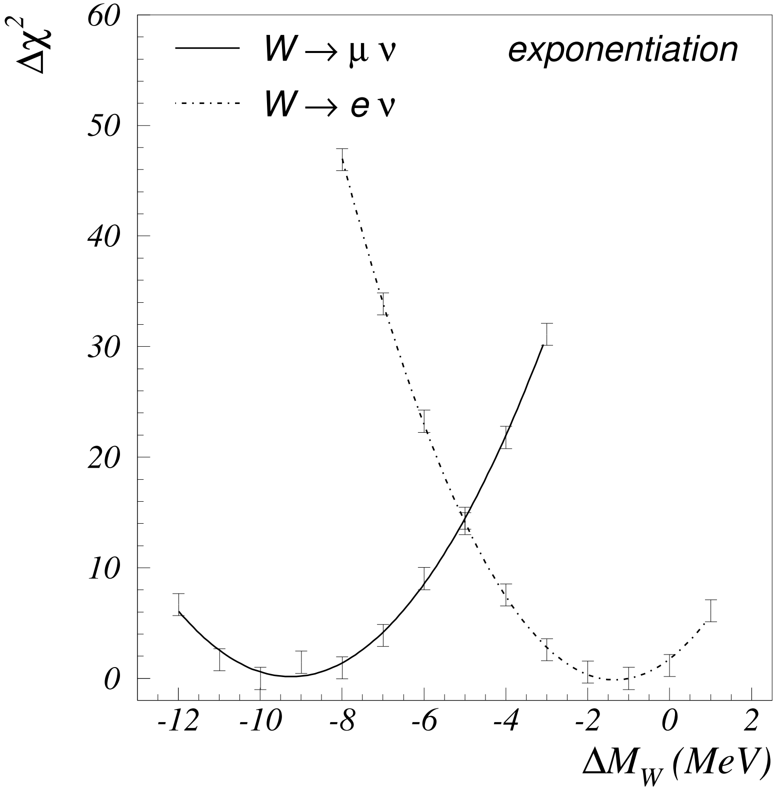
- expected differences at $\mathcal{O}(\alpha)$. The relative effect of exponentiation is the same.

W mass shifts: HO QED corrections

C.M. C.C. et al, PRD, 69 037301 2004

- By means of HORACE, we studied the shifts due to HO QED RC on the extracted M_W
- Performing a "pseudo-experiment", we quantified the induced shift (by a χ^2 minimization)
  - ⋆ realistic ES criteria and particle's ID requirements were used





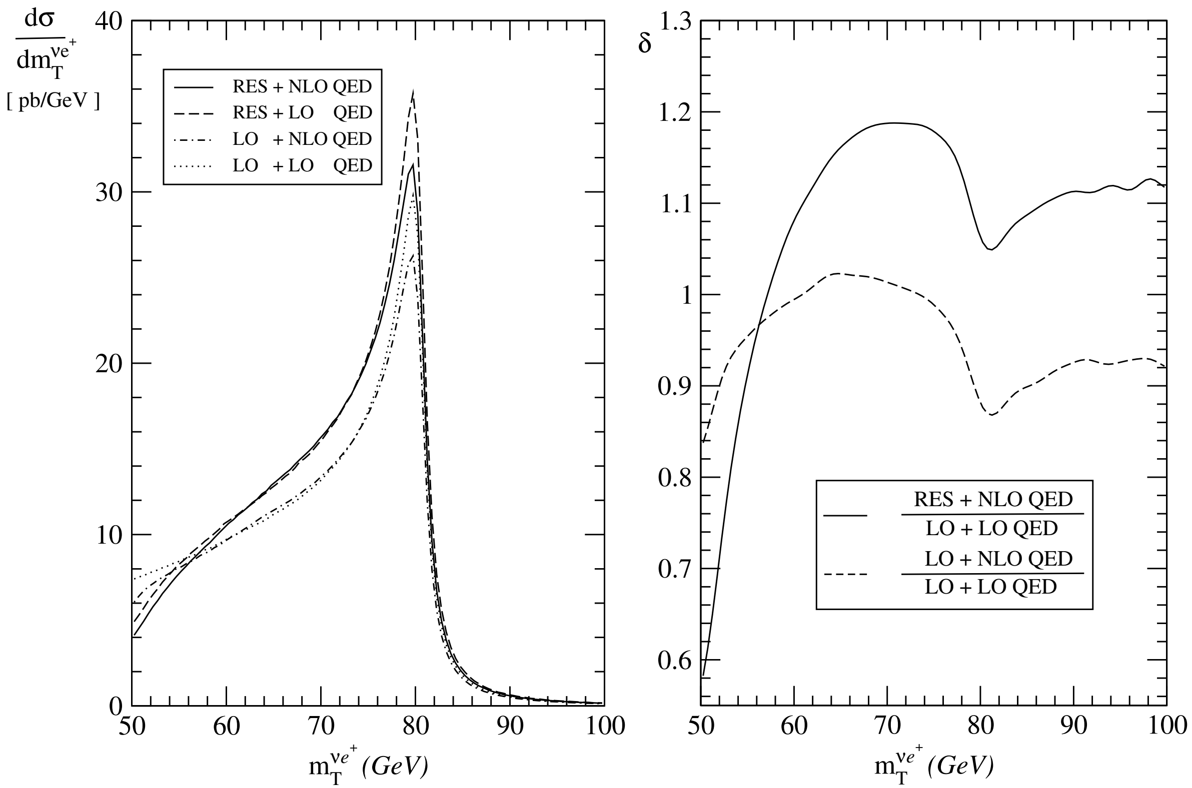
$$\Delta M_W^{\alpha,e} \sim 20 \text{ MeV} \qquad \Delta M_W^{\infty,\mu} \sim 10 \text{ MeV}$$

$$\Delta M_W^{\alpha,\mu} \sim 110 \text{ MeV} \qquad \Delta M_W^{\infty,e} \sim 2 \text{ MeV}$$

⋆ much larger shifts are found if particle's ID are neglected

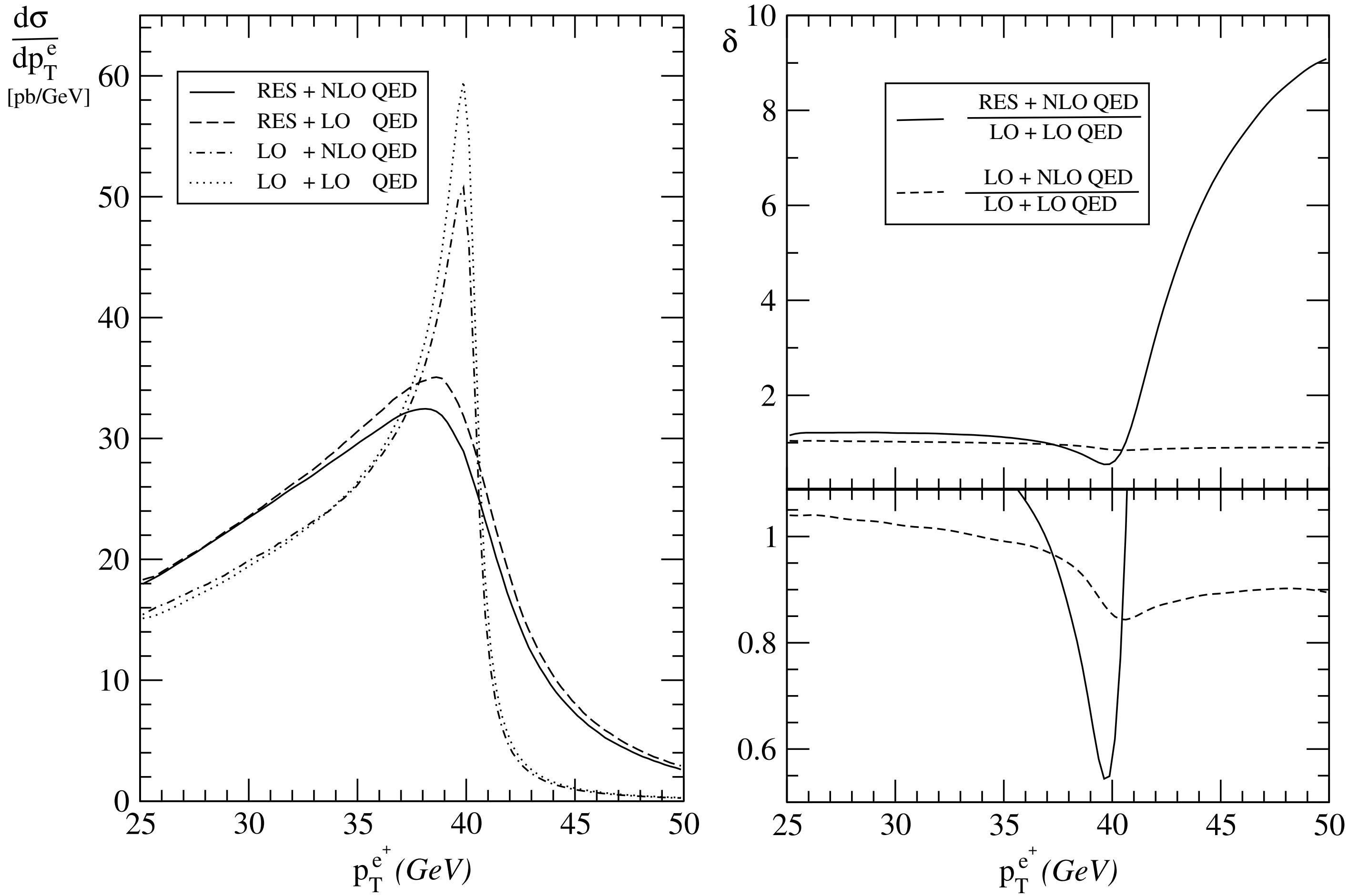
FS QED + IS QCD resummation

- A merging of EW RC and QCD resummation is needed $(\alpha/\pi \approx (\alpha_s/\pi)^2)$
- Cao and Yuan (hep-ph/0401026 and hep-ph/0401171) included in the MC RESBOS (by Balazs and Yuan, PRD 56 5558 1997) the QED $\mathcal{O}(\alpha)$ corrections
  - ⋆ resummation of soft gluons ($\Rightarrow p_\perp^W$ generation)
  - ⋆ bulk of EW radiative corrections: final-state QED $\mathcal{O}(\alpha)$ corrections



FS QED + IS QCD resummation (II)

- $p_\perp^\ell$ is more sensitive to $p_\perp^W$ than M_T



⋆ Qualitatively, same conclusions hold for LHC

⋆ Detector and/or particle's ID are neglected in this analysis

Conclusions

- M_W will be measured with a target precision of 15 - 20 MeV.
- this is a challenging task, both from the theoretical and experimental point of view
- for W (and Z!!) production, theoretical systematics must be well under control:
  - ⋆ full EW $\mathcal{O}(\alpha)$ corrections are available, final state photonic corrections are dominant
  - ⋆ at CDF, EW RC shift M_W by $\sim$ 100 MeV
- a source of the systematic uncertainty on M_W comes from HO photonic RC
  - ⋆ the MCs `HORACE` and `WINHAC` include QED HO RC
  - ⋆ HO RC shift the extracted M_W by $\sim$10 MeV for muons and $\sim$2 MeV for electrons
- Cao and Yuan merged QCD resummation and $\mathcal{O}(\alpha)$ QED FS corrections
- Future work (Pavia group):
  - ⋆ extend the study of HO RC to Z production
  - ⋆ merging of the exact $\mathcal{O}(\alpha)$ EW RC in `HORACE`

Higher Order QED corrections

- HO QED corrections can give sizeable effects on M_W (or M_Z) if $\Delta M_W \simeq 20$ MeV
- HO photonic corrections can be easily computed, in LL approximation, by means of the QED Structure Function $D(x, Q^2)$
- $D(x, Q^2)$ is the solution of DGLAP equation in QED:

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

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

- non-singlet fermion SF $D(x, Q^2)$ accounts for universal virtual and real photonic RC, in collinear approximation, up to all orders of PT
- attaching a SF to each external charged particle allows to account for QED RC in LL approximation

Our approach

- As in QCD, the QED DGLAP equation can be exactly solved by means of the

  Parton Shower algorithm

  ⋆ it allows an exclusive photons generation (angular variables can be recovered)

  ⋆ a full "radiation" event simulation can be done

- in order to study the HO relative effect, the PS can be run

  ⋆ up to all orders or

  ⋆ at order α, by a "truncated" algorithm which (consistently) stops at first branching

  by comparing full PS to $\mathcal{O}(\alpha)$ PS the effects of HO QED corrections can be estimated

- At the moment, we consider only radiation from final-state lepton, being the most important for the relevant distributions

  $\longrightarrow$ gauge-invariance is broken at non-log level, which is beyond the accuracy of the approach

The event generator HORACE

The event generator HORACE (Higher Order Radiative CorrEctions) for W and (preliminary!) Z production in Drell-Yan processes has been written

- $\surd$ it can generate unweighted events
- $\surd$ it is interfaced to PDFs (CTEQ6, MRST2001, PDFLIB,...)
- $\surd$ detector resolution effects can be accounted for by smearing particles' momenta
- $\surd$ any experimental cut can be applied, and, in particular, lepton ID requirements can be implemented
- $\surd$ LL photonic RC are included by means of the Parton Shower algorithm. It can be run in
  - $\star$ $\mathcal{O}(\alpha)$ mode: LL order α corrections are included
  - $\star$ *exp.* mode: LL corrections are included up to all orders
- $\star$ it can run in parallel mode (using MPI libraries)

Estimating HO RC effect on the fitted M_W

First step is verifying the shift due to $\mathcal{O}(\alpha)$ corrections, according to the following procedure:

1. generate a sample of pseudo-data at Born level (i.e., without QED corrections) for a reference W mass, M_W^{ref}
2. consider the M_T spectrum and bin it into 100 bins within the fit region 65 - 100 GeV
3. consider N different W mass values around M_W^{ref} and generate N $\mathcal{O}(\alpha)$-corrected M_T spectra
4. for each mass, calculate the χ^2 between $\mathcal{O}(\alpha)$ and Born spectra

$$\chi^2(M_W) = \sum_{i=bins} (\sigma_{i,\alpha} - \sigma_{i,Born})^2 / (\Delta\sigma^2_{i,\alpha} + \Delta\sigma^2_{i,Born})$$

5. at the minimum of the χ^2 distribution, read the M_W shift

For HO corrections, the procedure is the same, but

Born $\Rightarrow \mathcal{O}(\alpha)$

$\mathcal{O}(\alpha) \Rightarrow$ all orders

Simulation details for M_W extraction

The simulation has been performed imposing realistic ES criteria:

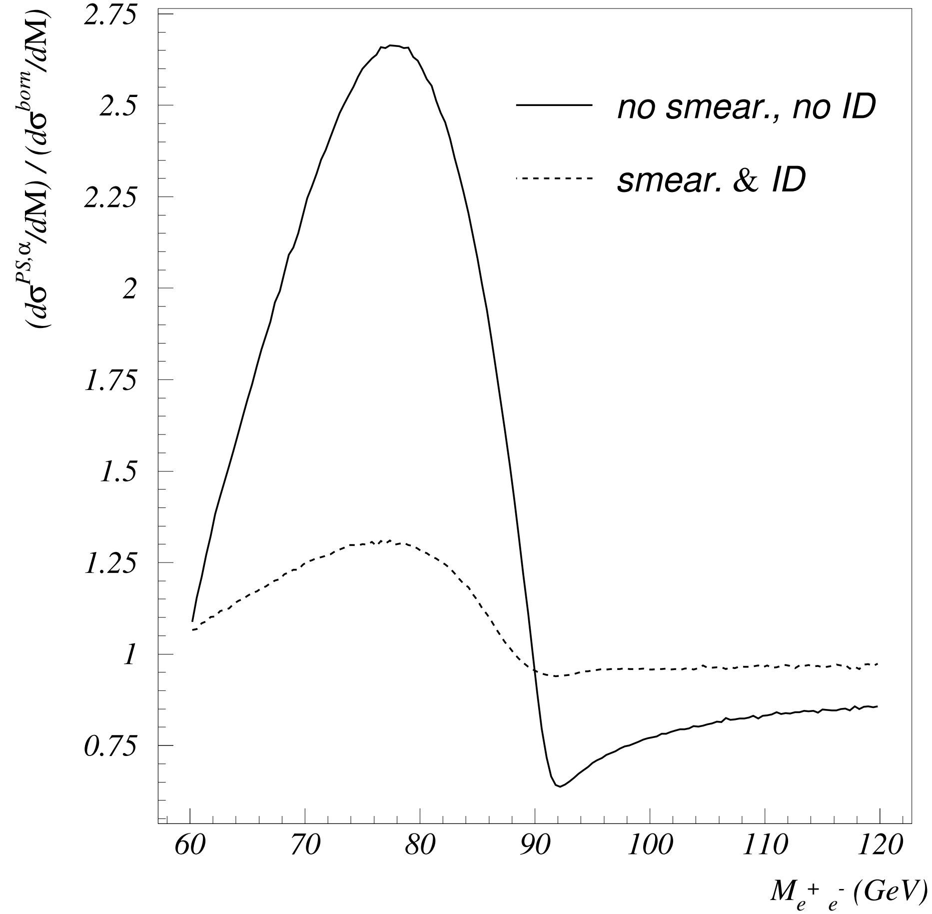
- $p\bar{p}$ at $\sqrt{s} = 2$ TeV
- $p_T(l) > 25$ GeV $\quad |\eta(l)| < 1.2 \quad \not{p}_T > 25$ GeV
- lepton ID requirements based on Tevatron analyses $(\Delta R = \sqrt{\Delta\eta^2_{\ell\gamma} + \Delta\phi^2_{\ell\gamma}})$

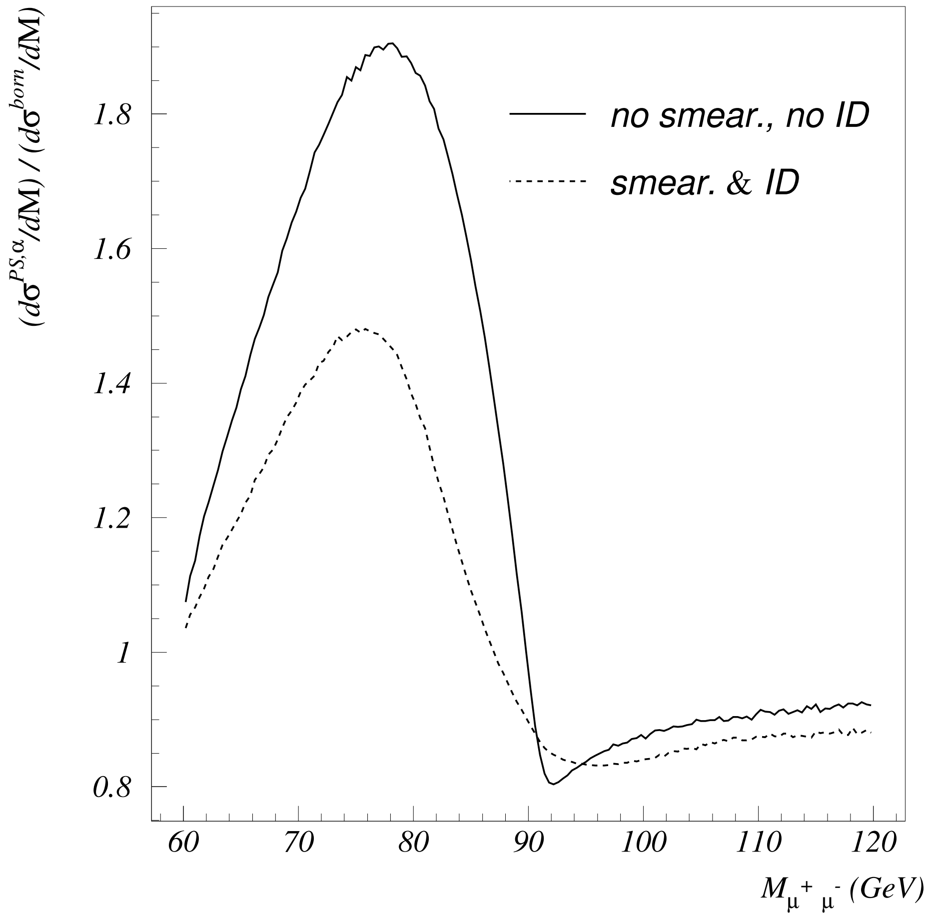
	electron	muon
recombined	$\Delta R < 0.2$ or $0.2 < \Delta R < 0.3$ if $E_\gamma > 0.15 E_e$	
rejected	$0.1 < \Delta R < 0.4$ and $E_\gamma > 0.15 E_e$	$\Delta R < 0.2$ if $E_\gamma > 2$ GeV or $0.2 < \Delta R < 0.6$ if $E_\gamma > 6$ GeV

- particles' momenta are smeared according to RunII DØ detector specifications
- the conclusions do not significantly change for pp at $\sqrt{s} = 14$ TeV (but using the same cuts and "detector"!)

Z production

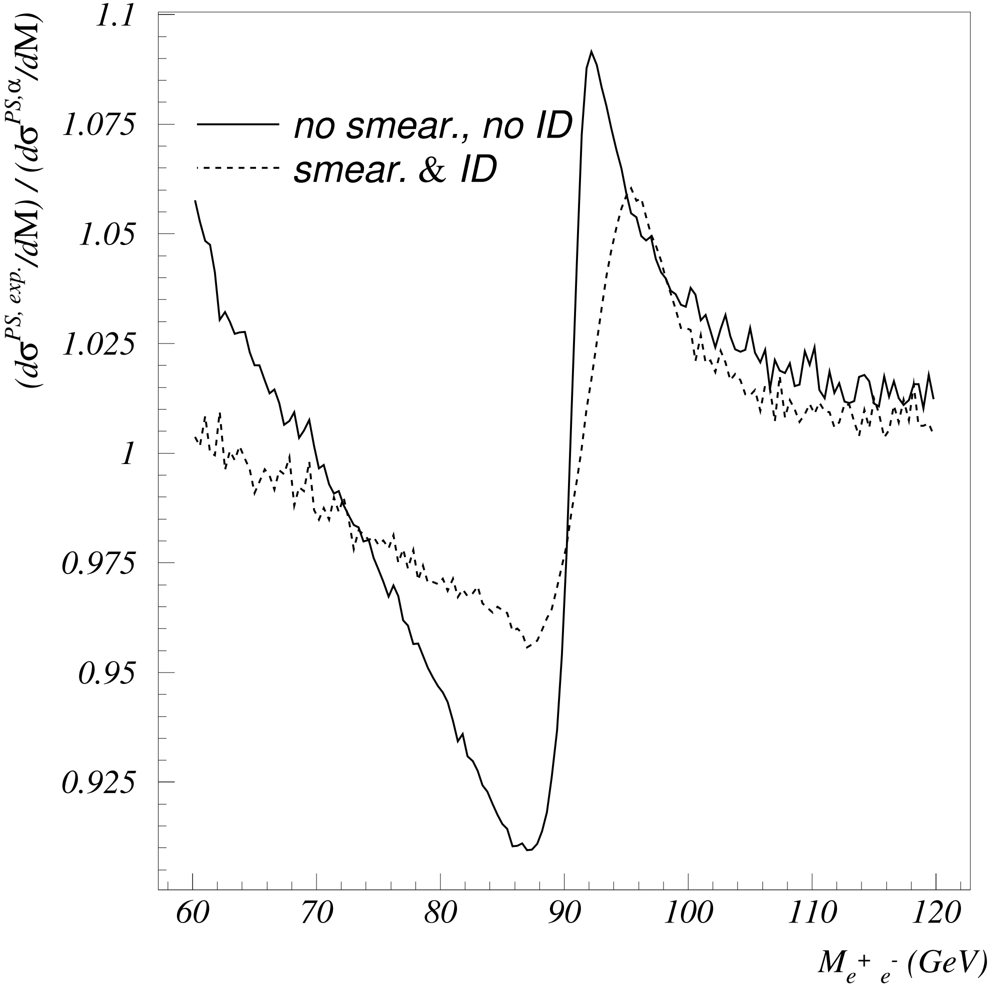
- also EW RC to Z production must be under control
  - $\longrightarrow$ $\sin^2\theta^l_{eff}$ can be measured from A_{FB} at the Z pole
  - $\longrightarrow$ lepton scale, p_T^W depend on Z-related measurements
- $\mathcal{O}(\alpha)$ QED RC to Z lineshape:

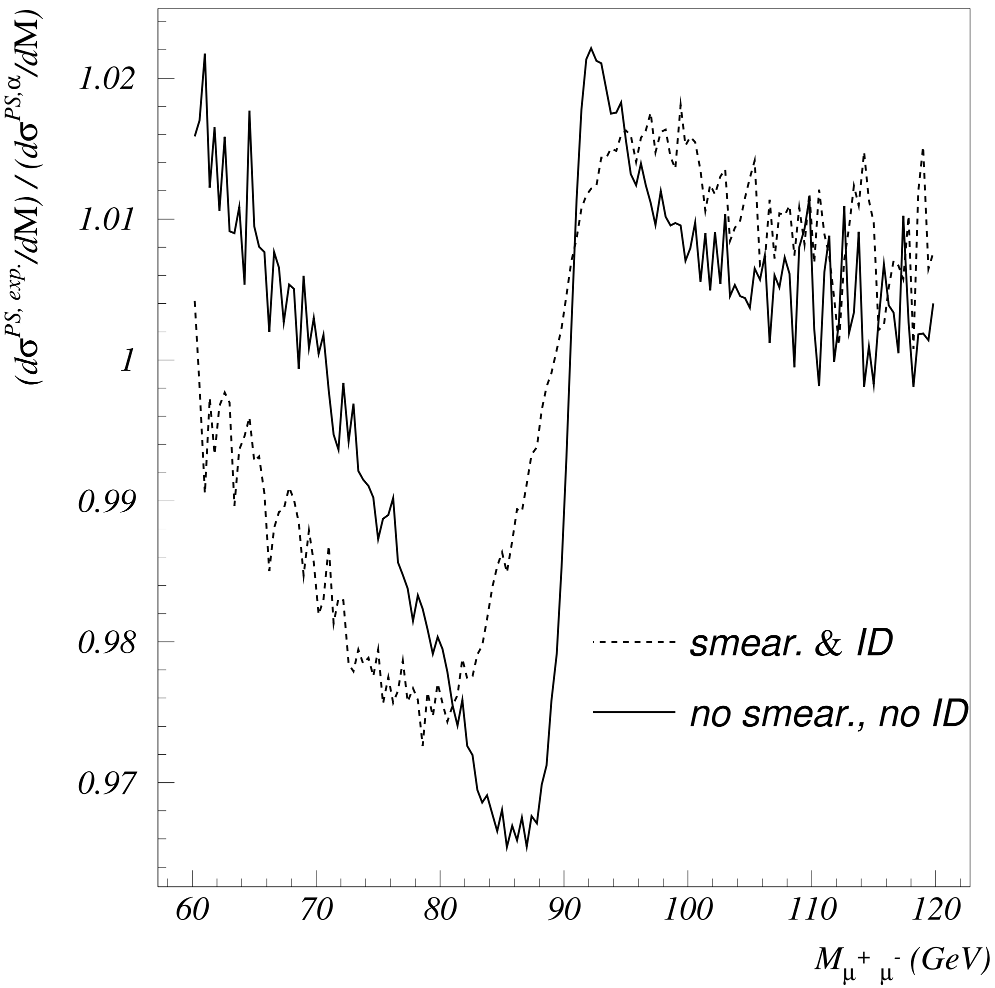




HO QED RC to Z lineshape

- effects of HO QED RC must be investigated. As for W, they can be important





√ effects on M_Z and A_{FB} are being studied: WORK IN PROGRESS!