Guido Montagna
guido.montagna@pv.infn.it
Department of Nuclear and Theoretical Physics, Univ. of Pavia
INFN, Sezione di Pavia

Higher-order QED Corrections to W-Boson Mass Determination at Hadron Colliders

Based on hep-ph/0303102
with C.M. Carloni Calame, O. Nicrosini and M. Treccani

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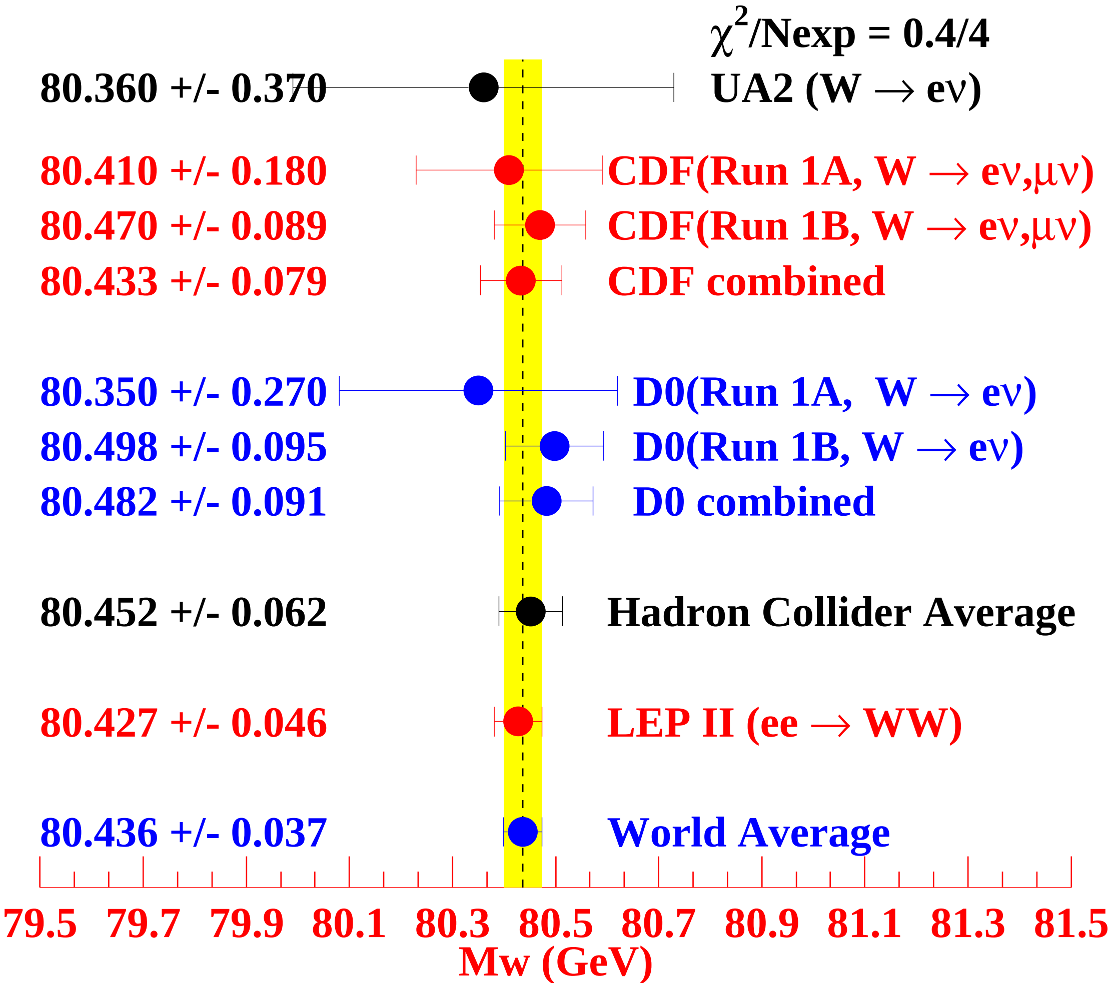
The W Mass

- The precise M_W (and M_{top}) measurement will highly improve the indirect bound on M_H
- Present experimental status

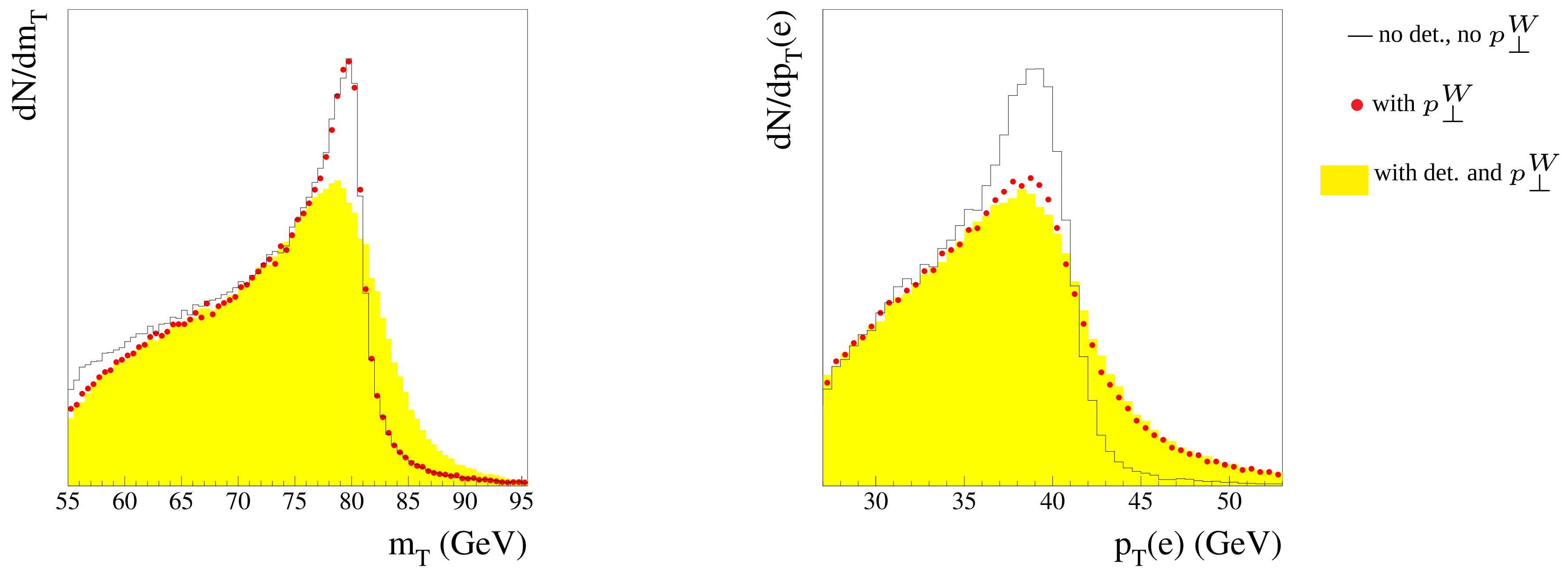


- Target precision for ΔM_W
  - ⋆ Tevatron RunIIa ⇒ 27 MeV
  - ⋆ Tevatron RunIIb ⇒ 16 MeV
  - ⋆ LHC ⇒ 15 MeV

Measuring M_W @ Hadron Colliders

- M_W is extracted from the $W \to \ell\nu_\ell$ decay kinematics (Jacobian peak)
- the transverse mass M_T is the preferred quantity to extract M_W

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



- M_W measurements requires precise theoretical predictions, including radiative corrections

Theoretical calculations

- order α electroweak corrections are known exactly

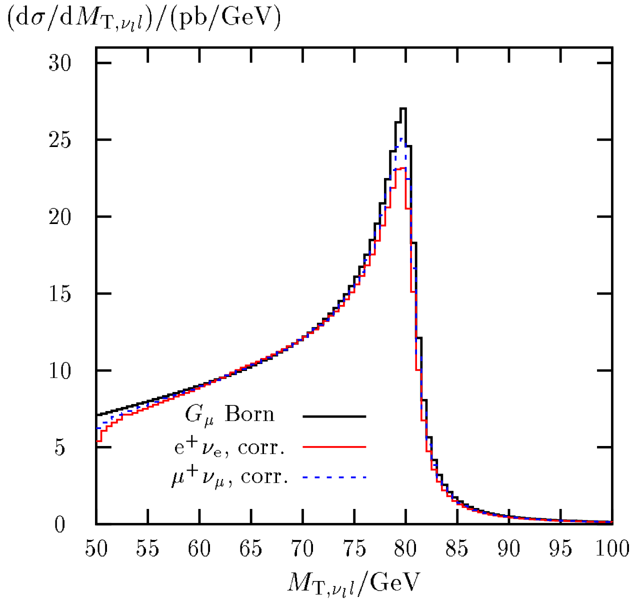
U. Baur, S. Keller, D. Wackeroth, PRD 59, 013002 (1999)

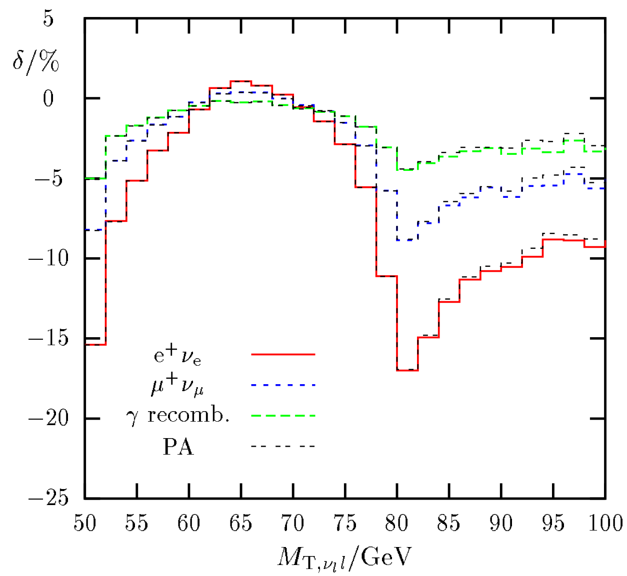
S. Dittmaier, M. Krämer, PRD 65, 073007 (2002)

- they shift the extracted W mass by $\mathcal{O}(100)$ MeV

electron channel: 65 ± 20 MeV
muon channel: 168 ± 20 MeV

- the effect is mainly due to final-state photonic radiation and depends on lepton identification requirements and detector effects





Systematic uncertainties (MeV/c^2)

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

CDF collaboration
PRD 64, 052001 (2001)

- Recent work on higher-order QED corrections

$\longrightarrow$ double bremsstrahlung $q\bar{q}' \to \ell^\pm \nu\gamma\gamma$ and $q\bar{q} \to \ell^+\ell^-\gamma\gamma$ cross sections

Baur, Stelzer, PRD 61, 073007 (2000)

$\longrightarrow$ YFS exponentiation and WINHAC generator

Jadach, Płaczek, `hep-ph/0302065`

Our approach

C.M. Carloni Calame *et al*, `hep-ph/0303102`

- Higher-order real and virtual photonic corrections are computed by means of the QED Structure Function $D(x, Q^2)$, which is the solution of DGLAP equation in QED

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

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

- It can be exactly solved by means of a Monte Carlo Parton Shower algorithm

C.M. Carloni Calame *et al*, NPB 584, 459 (2000)

- At the moment, we consider only radiation from final-state lepton, because
  - ⋆ large logs from initial-state-radiation can be re-absorbed in PDFs
  - ⋆ final-state lepton radiation significantly distorts the M_T spectrum

The event generator HORACE

The formulation is available as a MC event generator for W production at hadron colliders
HORACE

- it is interfaced to PDFs (CTEQ6, MRST2001, PDFLIB)
- lepton identification requirements and detector resolution effects can be accounted for
- photonic corrections are included to all orders and at order α in the Parton Shower algorithm

Comparison with WGRAD by Baur, Keller, Wackeroth. Cross sections in pb

	$\sqrt{s}$ = 2 TeV		$\sqrt{s}$ = 14 TeV	
	e	μ	e	μ
WGRAD Born	441.7(1)		1906(1)	
WGRAD $\mathcal{O}(\alpha)$	418.3(4)	429.4(3)	1800(2)	1845(2)
WGRAD $\mathcal{O}(\alpha)$ 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)

QED Corrections to the Fitted W Mass

We perform χ^2 fits to Monte Carlo pseudo-data for the M_T spectrum, imposing realistic selection criteria:

- $\sqrt{s} = 2$ TeV $\quad p_T(l) > 25$ GeV $\quad |\eta(l)| < 1.2 \quad \not{p}_T > 25$ GeV
- lepton identification requirements based on Tevatron analyses (e.g., if $\Delta R_{e\gamma} = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.2$, e and γ momenta are recombined)
- particles' momenta are smeared according to RunII DØ detector specifications

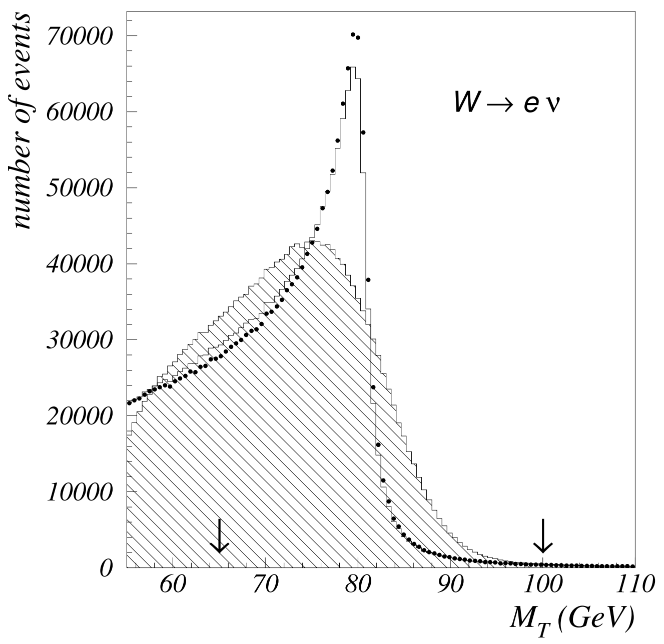
$$\chi^2(M_W) = \sum_{i=bins} (\sigma_{i,exp} - \sigma_{i,\alpha})^2 / (\Delta\sigma^2_{i,exp} + \Delta\sigma^2_{i,\alpha})$$

histogram: no lepton identification criteria, no detector effects

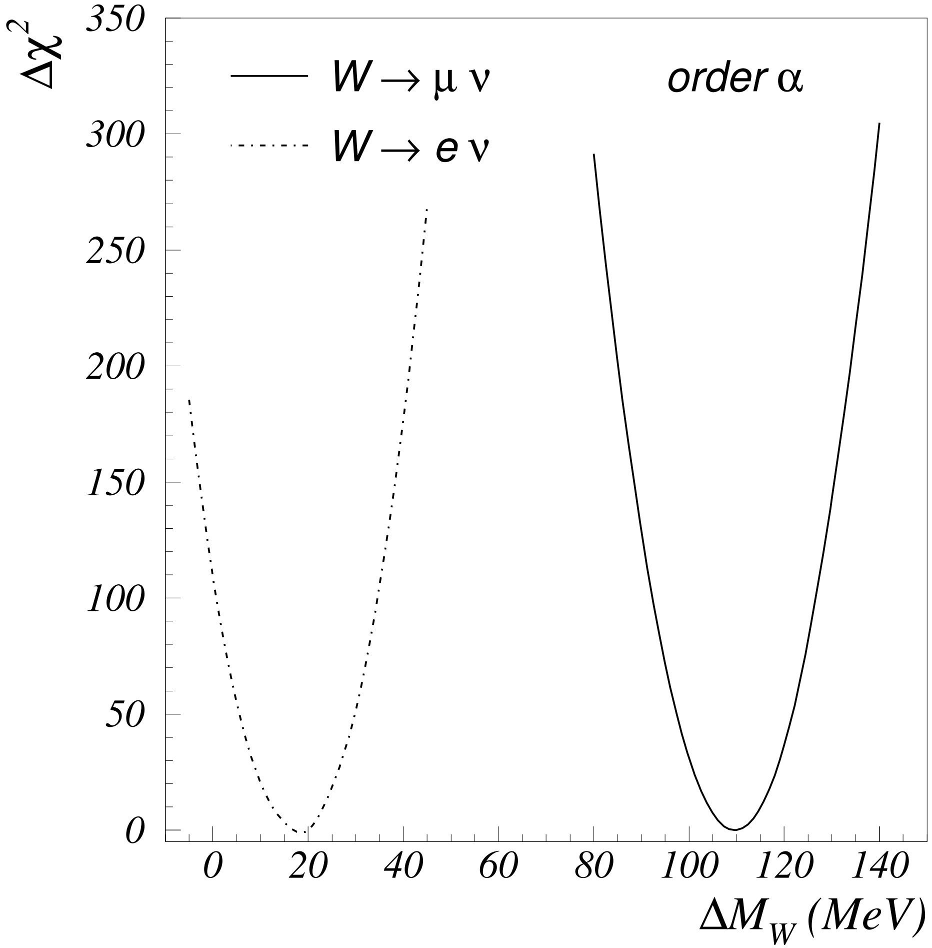
markers: with lepton identification criteria

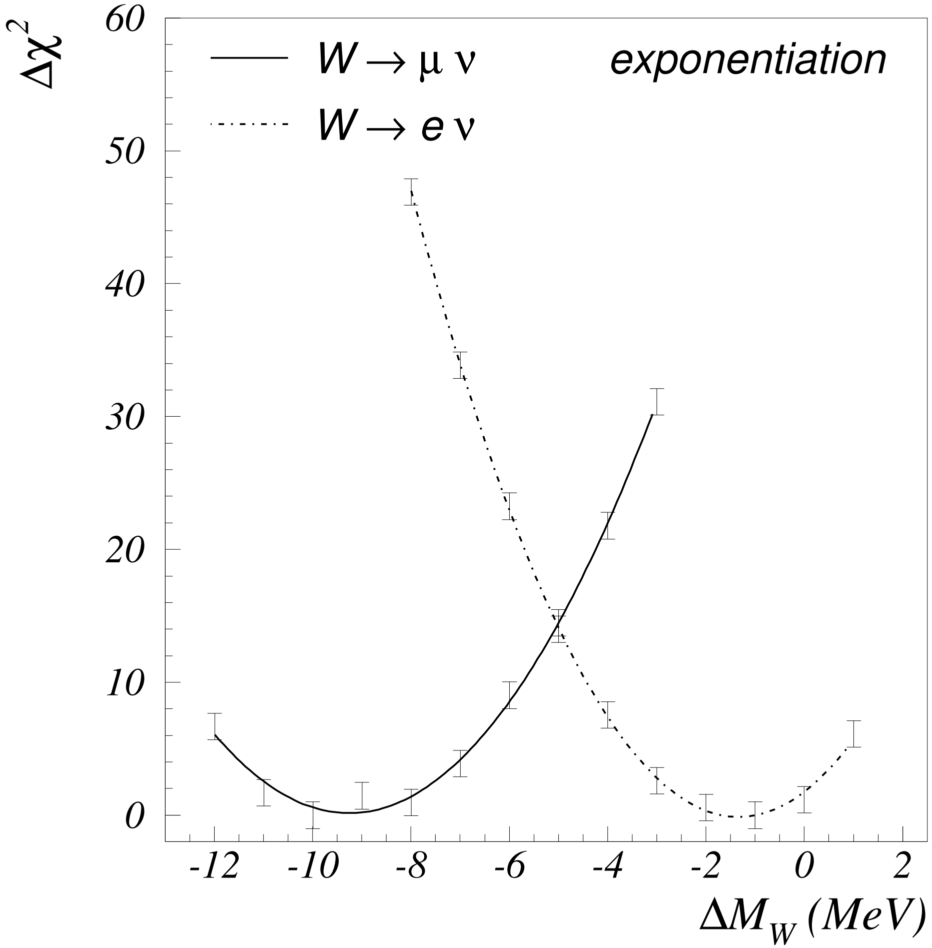
shaded: with lepton identification criteria and detector effects

arrows: fitting region, 65 GeV $< M_T <$ 100 GeV



W mass shifts





$\Delta M_W^{\alpha,e} \sim \ 20$ MeV

$\Delta M_W^{\alpha,\mu} \sim 110$ MeV

$\Delta M_W^{\infty,e} \sim \ 2$ MeV

$\Delta M_W^{\infty,\mu} \sim 10$ MeV

Same conclusions for the LHC

Conclusions

- at future hadron collider experiments, the W-boson mass will be measured with a target precision of 15 - 30 MeV
- a (reducible) source of systematic uncertainty on M_W comes from higher-order photonic corrections, which are presently estimated to be 10 - 20 MeV
- the effect of higher-order QED corrections has been evaluated in a Parton Shower approach
  - ⋆ the shifts are found to be
    - √ 10 MeV for muons
    - √ 2 MeV for electrons
  - ⋆ the shifts depend on lepton identification criteria and detector effects ⇒ full detector simulation required
- Future work
  - ⋆ merging exact $\mathcal{O}(\alpha)$ electroweak corrections with QED exponentiation
  - ⋆ study of higher-order corrections to Z production at hadron colliders

QED Corrections and the Fitted W Mass

Impact of higher-order photonic corrections on M_W quantified by means of a simulated experiment. Shift due to $\mathcal{O}(\alpha)$ corrections

1. generate a sample of pseudo-data at Born level 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

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

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

Same procedure for higher-order corrections, replacing

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

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

Simulation details for M_W extraction

The simulation has been performed imposing realistic selection 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 identification 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

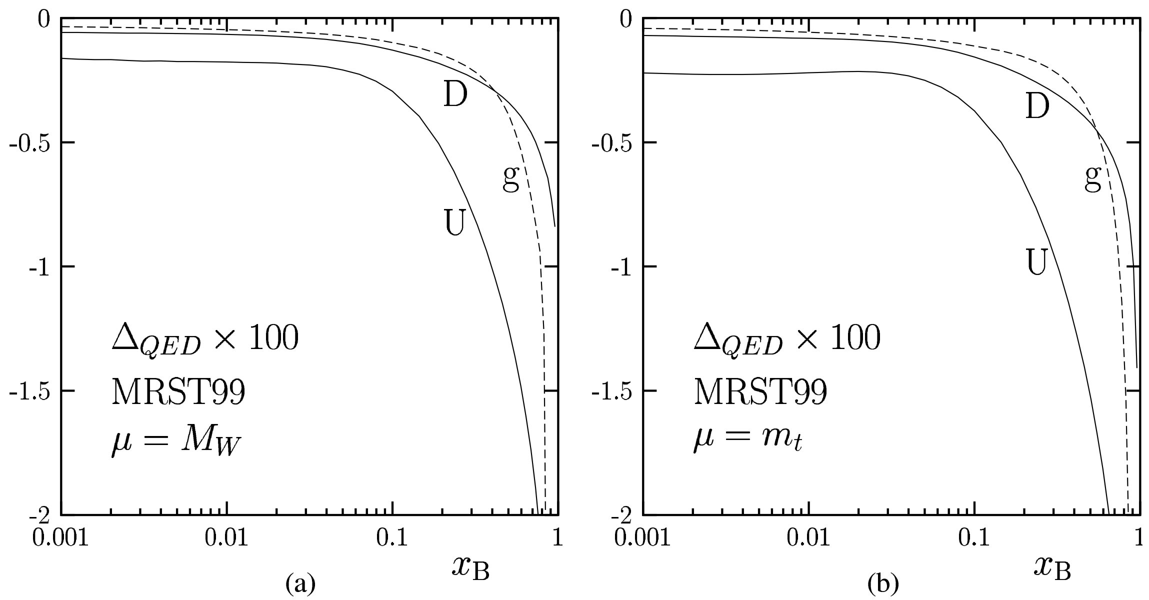
- particles' momenta are smeared according to RunII DØ detector specifications
- the conclusions do not change for pp at $\sqrt{s} = 14$ TeV (but using the same cuts and "detector"!)

Initial-state photonic corrections (I)

H. Spiesberger, PRD 52, 493 (1995)

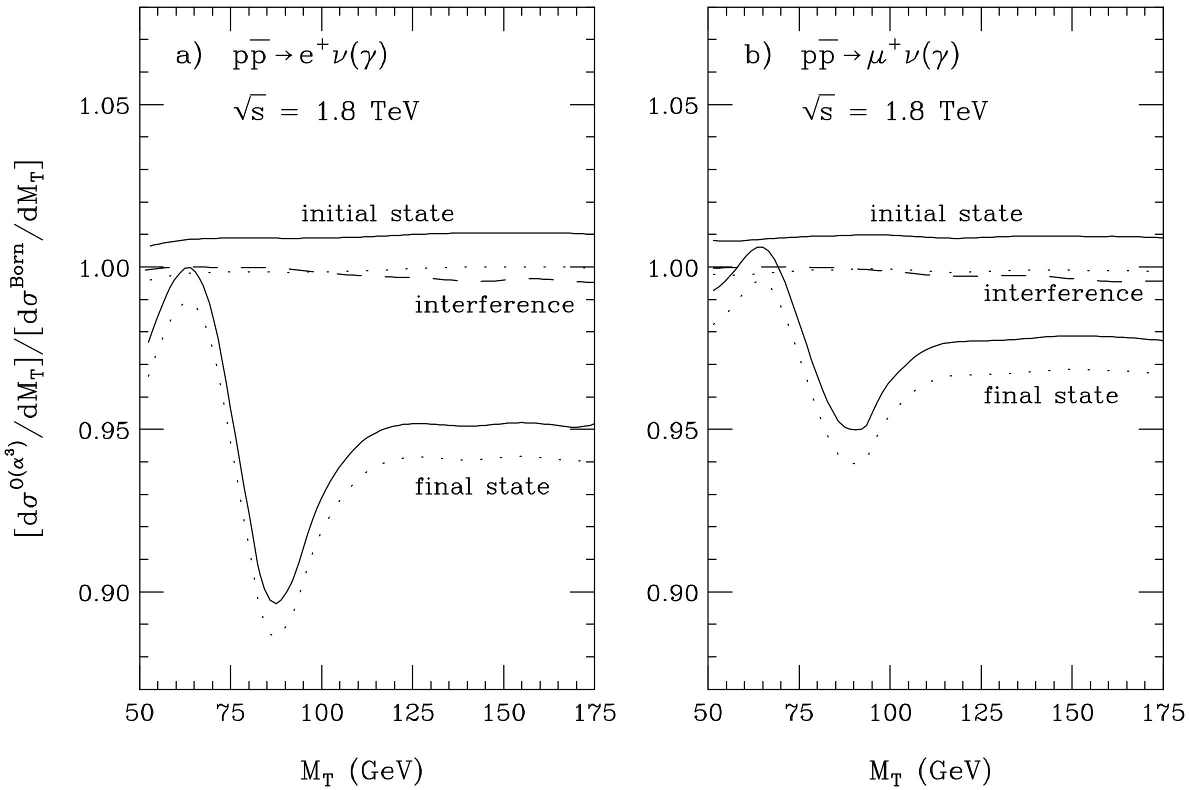
- QED radiation from quarks gives rise to factorizable and universal mass singularities
- they can be absorbed into a redefinition (*renormalization*) of PDFs, in analogy to QCD
- PDFs will depend on a factorization scale μ^2
- the DGLAP evolution equations must contain an additional term proportional to α_{QED}
- QED terms modify PDFs at the 0.1% level when $x < 1$

Not included in available PDFs



Initial-state photonic corrections (II)

U. Baur, S. Keller, D. Wackeroth, PRD 59, 013002 (1999)



- in general, initial-state radiation (as well as initial-final-state interference) does not modify the shape of the distributions
- final-state radiation does modify the shape of the distributions and strongly depends on lepton identification requirements and detector effects

The Parton Shower algorithm

- Exact numerical solution of DGLAP equation
- Exclusive photons generation by $e \to e' + \gamma$ branching kinematics

Basic ingredients

⋆ Sudakov Form Factor $\Pi(s,s') = \exp\left[-\frac{\alpha}{2\pi} \ln\frac{s}{s'} \int_0^{x_+} P(x)dx \right]$

⋆ iterative solution of DGLAP equation

$$
\begin{aligned}
&D(x,s) = \Pi(s,m^2)\delta(1-x) \\
&+\frac{\alpha}{2\pi}\int_{m^2}^{s} \Pi(s,s')\frac{ds'}{s'}\Pi(s',m^2)\int_0^{x_+} dy P(y)\delta(x-y) + \\
&+2 \;\; \text{branchings} \;\; + \;\; 3 \;\; + \;\; \cdots
\end{aligned}
$$