Precision calculations and Monte Carlo generators for Drell-Yan processes

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Workshop sui Monte Carlo, la Fisica e le Simulazioni a LHC
Frascati, 22-24 Maggio, 2006

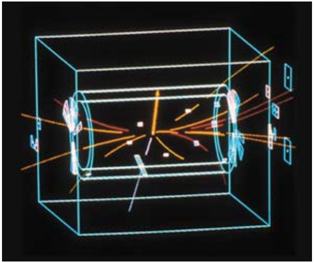
In collaboration with
C.M. Carloni Calame, O. Nicrosini, G. Polesello, A. Vicini

and based on work and discussions with
A. Arbuzov, U. Baur, S. Dittmaier, S. Jadach, M. Krämer, F. Piccinini, W. Płaczek, M. Treccani, D. Wackeroth

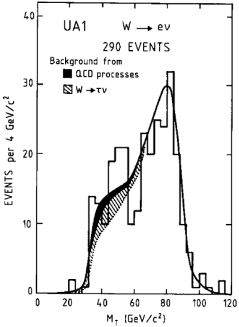
At CERN, 20 years ago...

The Nobel Prize in Physics 1984

One of the first W particles



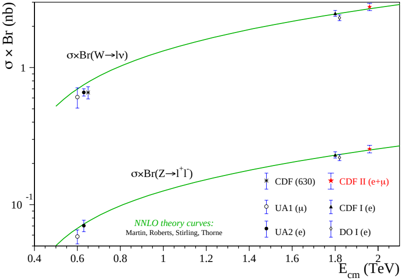
“for their decisive contributions to the large project, which led to the discovery of the field particles W and Z, communicators of weak interaction"

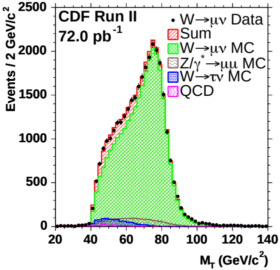


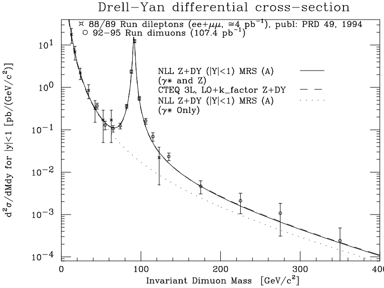
D. Denegri
The discovery of the W and Z
Physics Report **403** (2004) 107

The Drell-Yan today

CDF Collaboration, hep-ex/0508029

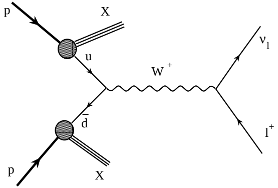






Physics motivations

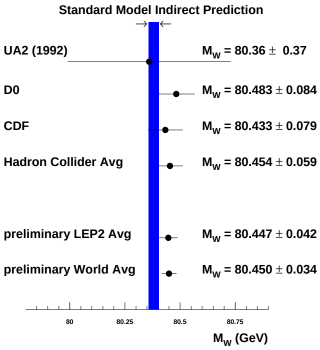
Single W/Z boson production: clean process with a large cross section ($\sim 300(35) \times 10^6$ events/year for $\mathcal{L}_{\rm LHC} = 10\ fb^{-1}$). It is useful



- to derive precise measurements of the electroweak parameters $M_W, \Gamma_W, \sin^2\theta^\ell_{\rm eff}$. Relevant observables: leptons' transverse momentum p^ℓ_T, W transverse mass M^W_T, forward-backward asymmetry A^Z_{FB}...
- to monitor the collider luminosity (with $\sim 1\%$ precision) and constrain the parton distribution functions (PDFs). Relevant observables: total cross section, W rapidity y_W...
- to search for new physics. Relevant observables: invariant mass distribution $M^Z_{\ell\ell}$ in the high tail...

- Present experimental status

TeVEWWG, Phys. Rev. **D70** (2004) 092008



Future goals:

Target ΔM_W precision:

- ⋆ Tevatron RunII $\Rightarrow$ 27 MeV
- ⋆ LHC $\Rightarrow$ 15 MeV

Target $\Delta\Gamma_W$ precision:

- ⋆ Tevatron RunII $\Rightarrow$ 30 MeV
- ⋆ LHC $\Rightarrow$ $\leq$ 30 MeV

- At the Tevatron, electroweak corrections shift M_W by ~ 100 MeV

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

The theoretical cross section

$$A + B \to W \to \ell \nu_l X$$
$$A + B \to Z \to \ell^+ \ell^- X$$

$$\sigma(s) = \sum_{a,b} \int_0^1 dx_1\, dx_2 (f_{a/A}(x_1, \mu_F)\, f_{b/B}(x_2, \mu_F) + (x_1 \leftrightarrow x_2))\, \sigma(\hat{s})$$

- $\sigma(\hat{s})$: parton-level cross section, at reduced c.m. energy $\hat{s} = x_1 x_2 s$ ($\sqrt{\hat{s}} \sim M_{W,Z}$), including
  - ⋆ perturbative QCD contributions
  - ⋆ electroweak corrections
- $f_{a(b)}/(A,B)(x_i, \mu_F)$: PDFs of the initial-state partons with momentum fractions x_i inside the proton(antiproton) $A \& B$, depending on a factorization scale μ_F to reabsorb universal initial-state mass singularities. Typically: $\mu_F = M_{W,Z}$

Higher-order QCD&QCD generators

- NLO/NNLO corrections to W/Z total production rate

  G. Altarelli, R.K. Ellis, M. Greco and G. Martinelli, Nucl. Phys. **B246** (1984) 12

  R. Hamberg, W.L. van Neerven, T. Matsuura, Nucl. Phys. **B359** (1991) 343

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

- resummation of leading/next-to-leading p_T^W/M_W logs (RESBOS)

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

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

  S. Frixione and B.R. Webber, JHEP **0206** (2002) 029

- NNLO corrections to W/Z rapidity distribution (VRAP)

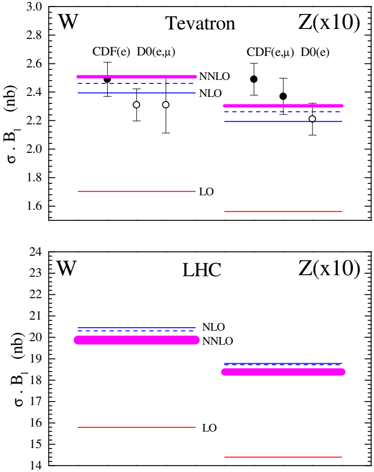
  C. Anastasiou *et al.* , Phys. Rev. **D69** (2004) 094008

  K. Melnikov and F. Petriello, `hep-ph/0603182`

- Matrix elements Monte Carlos (`Alpgen,Sherpa...`) matched with vetoed Parton Showers

QCD predictions for W/Z total rates

A.D. Martin *et al.*, Eur. Phys. J. **C19** (2001) 313

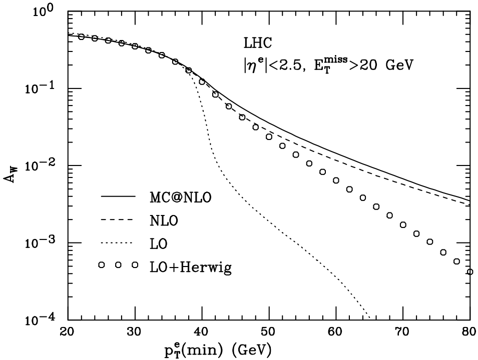


- Good convergence of α_s expansion. NLO-NNLO difference $\sim$ 2% at the LHC

MC@NLO corrections to acceptances

S. Frixione and M.L. Mangano, JHEP **0405** (2004) 056

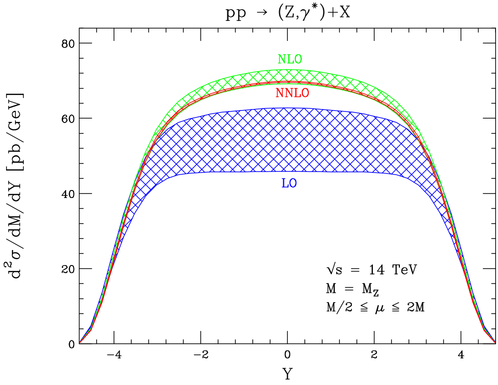
$$\sigma^{\exp}(W) = \frac{1}{\mathrm{BR}(W \to l\nu)} \frac{1}{\int \mathcal{L} dt} \frac{N^{\mathrm{obs}}}{A_W}$$



- Overall QCD uncertainty (NLO + Parton Shower corrections, spin correlations, PDFs and scale uncertainties) at $\sim 2\%$ level

High-precision QCD: W/Z rapidity @ NNLO

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

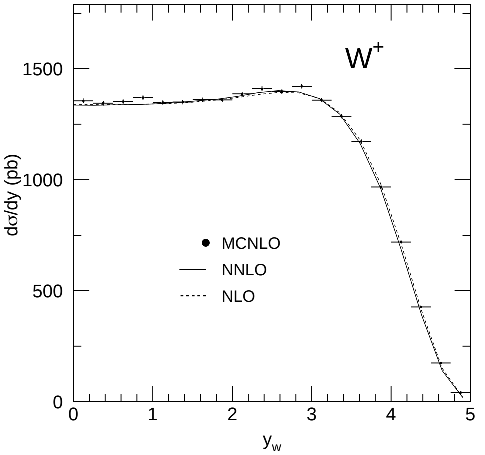


- First calculation of a differential distribution at NNLO in α_s. NNLO corrections at $\sim 2\%$ at the LHC and residual scale dependence below 1%.
- $\mathcal{O}(\alpha_S^2) \approx \mathcal{O}(\alpha_{\rm em}) \rightarrow$ need to worry about electroweak corrections!

NNLO QCD vs MC@NLO

Courtesy of G. Polesello!

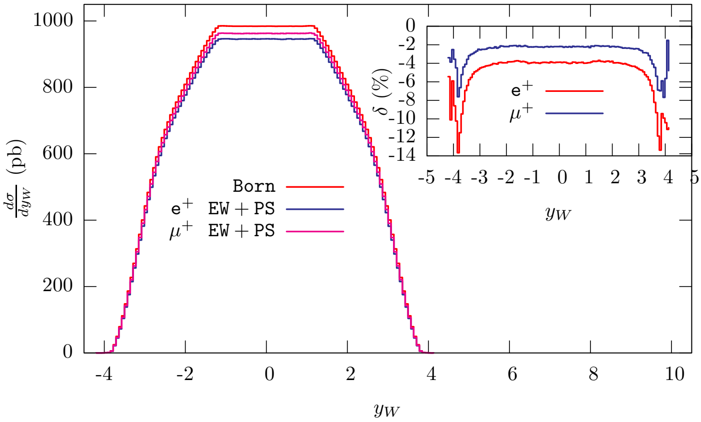
See also K. Melnikov and F. Petriello, `hep-ph/0603182`



- For an appropriate choice of the (factorization) scale, NNLO and MC@NLO agree well! (inclusive sample)

Electroweak corrections to luminosity: New!

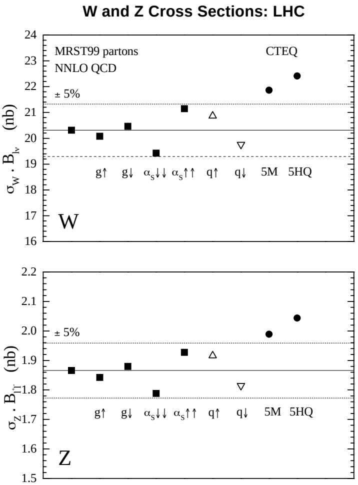
C.M. Carloni Calame *et al.*, to appear

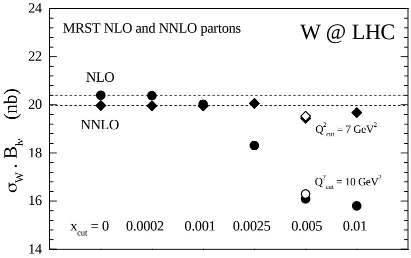


- NLO electroweak corrections to W rapidity are of the same order (or larger!) than NNLO QCD $\rightarrow$ relevant for precise luminosity!

PDFs and total rates

A.D. Martin *et al.*, Eur. Phys. J. **C35** (2004) 325
A.D. Martin *et al.*, Eur. Phys. J. **C14** (2000) 133

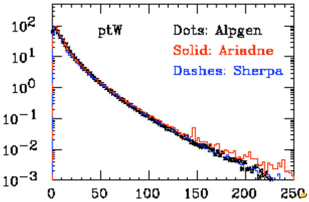


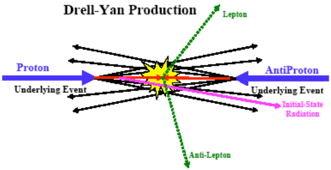


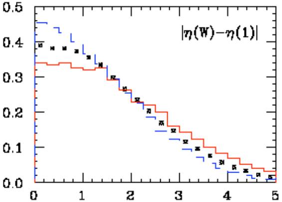
- Present PDFs uncertainty $\sim 3\%$ (or larger!) at the LHC

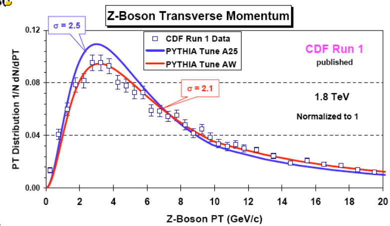
W/Z transverse momentum

S. Höche *et al.*, `hep-ph/0602031`
R. Field, talk at TeV4LHC workshop, Fermilab





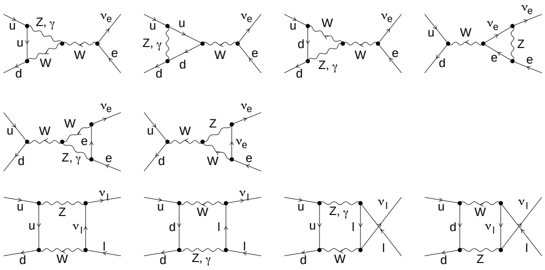




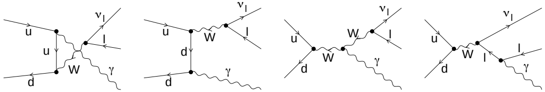
- The modeling of W/Z transverse momenta is a key ingredient underlying most of the precision studies $\rightarrow$ validation and tuning of Monte Carlos on Tevatron data is crucial for LHC

Electroweak Feynman diagrams

- virtual one-loop corrections (⟶ electroweak Sudakov logs)



- bremsstrahlung corrections (⟶ collinear singularities)

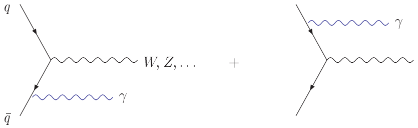


NLO electroweak calculations

...before very recent progress

- Electroweak corrections to W production
  - ⋆ Pole approximation $(\sqrt{\hat{s}} = M_W)$
    - → D. Wackeroth and W. Hollik, Phys. Rev. **D55** (1997) 6788
    - → U. Baur, S. Keller, D. Wackeroth, Phys. Rev. **D59** (1999) 013002 (WGRAD)
  - ⋆ Complete $\mathcal{O}(\alpha)$ corrections
    - → V.A. Zykunov *et al.*, Eur. Phys. J. **C3** (2001) 9
    - → S. Dittmaier and M. Krämer, Phys. Rev. **D65** (2002) 073007
    - → U. Baur and D. Wackeroth, Phys. Rev. **D70** (2004) 073015
- Electroweak corrections to Z production
  - ⋆ $\mathcal{O}(\alpha)$ photonic corrections
    - → U. Baur, S. Keller, W.K. Sakumoto, Phys. Rev. **D57** (1998) 199 (ZGRAD)
  - ⋆ Complete $\mathcal{O}(\alpha)$ corrections
    - → U. Baur, O. Brein, W. Hollik, C. Schappacher, D. Wackeroth, Phys. Rev. **D65** (2002) 033007

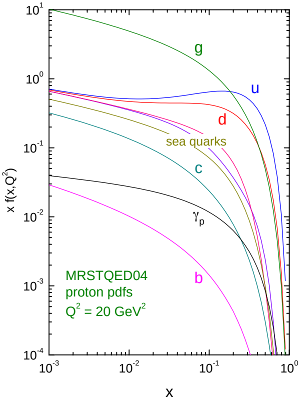
- QED initial-state collinear singularities are universal → can be absorbed into PDFs, as in QCD



$$f(x) \quad \rightarrow \quad f(x,\mu_F^2) - \int_x^1 \frac{dz}{z}\, f\left(\frac{x}{z},\mu_F^2\right)\, \frac{\alpha}{2\pi}\, Q_q^2$$
$$\times \left\{ \ln\left(\frac{\mu_F^2}{m_q^2}\right) \left[P_{ff}(z)\right]_+ - \left[P_{ff}(z)\left(2\ln(1-z)+1\right)\right]_+ + C(z) \right\}$$

$$C(z) = \begin{cases} 0 & \overline{\text{MS}} \\ \left[P_{ff}(z)\left(\ln\left(\frac{1-z}{z}\right) - \frac{3}{4}\right) + \frac{9+5z}{4}\right]_+ & \text{DIS} \end{cases}$$

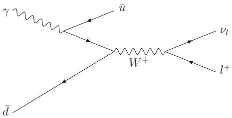
QED-improved PDFs

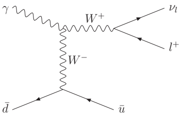


- effect of QED evolution on PDFs through DGLAP equation is small ($\sim$ 0.1% for $x < 1$)

H. Spiesberger, Phys. Rev. **D52** (1995) 4936
M. Roth and S. Weinzierl, Phys. Lett. **B590** (2004) 190
A.D. Martin *et al.*, Eur. Phys. J. **C39** (2005) 155

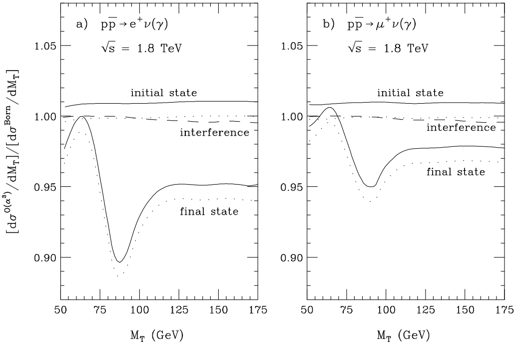
- dynamic generation of photon parton distribution $\rightarrow$ photon induced processes enter the game





Electroweak vs final-state photon corrections

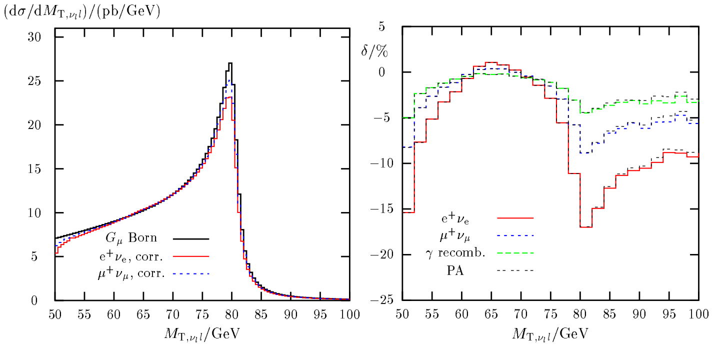
U. Baur, S. Keller, D. Wackeroth, Phys. Rev. **D59** (1999) 013002



- electroweak corrections (dashed line) are dominated by final-state photon radiation (solid line) within $\sim$ 1% around the W peak
- final-state photon radiation modifies the shape of the distributions and is important because it contains mass logarithms of the form $\log(\hat{s}/m_\ell^2)$

Photon radiation and lepton identification

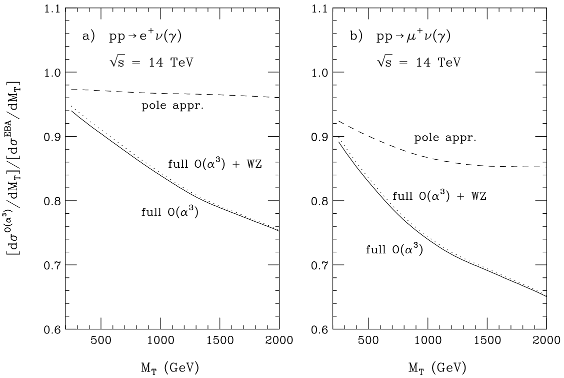
S. Dittmaier and M. Krämer, Phys. Rev. **D65** (2002) 073007



- Lepton identification requirements (and detector effects) strongly affect final-state photon radiation (“the KLN theorem at work”)
- Pole approximation agrees with the full calculation within a few 0.1% around the W resonance

Electroweak Sudakov logs

U. Baur *et al.*, Phys. Rev. **D65** (2002) 033007
U. Baur and D. Wackeroth, Phys. Rev. **D70** (2004) 073015



- Pole approximation fails for $M_T \gg M_W$, due to large Sudakov electroweak logs $\propto (\alpha/\pi)\log^2(\hat{s}/M_W^2) \rightarrow$ Important for new physics searches!
- Need to resum large Sudakov electroweak logs!

- **Dittmaier-Krämer**: complete $\mathcal{O}(\alpha)$ corrections to W, photon induced processes
- **HORACE**: complete $\mathcal{O}(\alpha)$ & multi-photon corrections to W, multi-photon corrections to Z

  Carloni Calame, Montagna, Nicrosini, Treccani, Vicini
  Phys. Rev. **D69** (2004) 037301 and JHEP **05** (2005) 019

- **Sanc**: complete $\mathcal{O}(\alpha)$ corrections to W/Z

  Andonov, Arbuzov, Bardin, Bondarenko, Christova, Kalinovskaya, Nanava, Sadykov
  Eur. Phys. J. **46** (2006) 407

- **WGRAD/ZGRAD**: complete $\mathcal{O}(\alpha)$ corrections to W/Z

  Baur, Keller, Wackeroth

Detector modeling and lepton identification

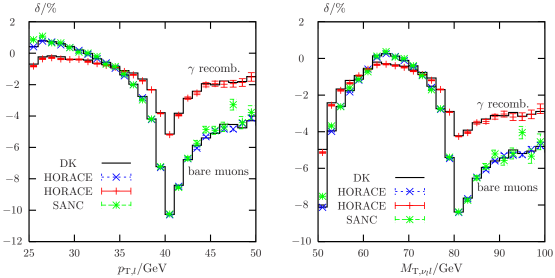
1. $\sqrt{s} = 14$ TeV $\quad p_{T,l} > 25$ GeV $\quad \not{p}_T > 25$ GeV $\quad |\eta_l| < 1.2$
2. $R_{l\gamma} = \sqrt{(\eta_l - \eta_\gamma)^2 + \phi_{l\gamma}^2} \leq 0.1 \Rightarrow$ electron/photon recombination

Les Houches tuned comparisons

$pp \to \nu_l l^+ (+\gamma)$ @ $\sqrt{s} = 14$ TeV (with MRSTQED04)

$p_{T,l}$/GeV	25–∞	50–∞	100–∞	200–∞	500–∞	1000–∞
σ_0/pb						
DK	2112.2(1)	13.152(2)	0.9452(1)	0.11511(2)	0.0054816(3)	0.00026212(1)
HORACE	2112.21(4)	13.151(6)	0.9451(1)	0.11511(1)	0.0054812(4)	0.00026211(2)
SANC	2112.22(2)	13.1507(2)	0.94506(1)	0.115106(1)	0.00548132(6)	0.000262108(3)
WGRAD	2112.3(1)	13.149(1)	0.94510(5)	0.115097(5)	0.0054818(2)	0.00026209(2)
$\delta_{e+\nu_e}$/%						
DK	−5.19(1)	−8.92(3)	−11.47(2)	−16.01(2)	−26.35(1)	−37.92(1)
HORACE	−5.23(1)	−8.98(1)	−11.49(1)	−16.03(1)	−26.36(1)	−37.92(2)
WGRAD	−5.10(1)	−8.55(5)	−11.32(1)	−15.91(2)	−26.1(1)	−38.2(2)
$\delta_{\mu+\nu_\mu}$/%						
DK	−2.75(1)	−4.78(3)	−8.19(2)	−12.71(2)	−22.64(1)	−33.54(2)
HORACE	−2.79(1)	−4.84(1)	−8.21(1)	−12.73(1)	−22.65(1)	−33.57(1)
SANC	−2.80(1)	−4.82(2)	−8.17(2)	−12.67(2)	−22.63(2)	−33.50(2)
WGRAD	−2.69(1)	−4.53(1)	−8.12(1)	−12.68(1)	−22.62(2)	−33.6(2)
δ_{recomb}/%						
DK	−1.73(1)	−2.45(3)	−5.91(2)	−9.99(2)	−18.95(1)	−28.60(1)
HORACE	−1.77(1)	−2.51(1)	−5.94(1)	−10.02(1)	−18.96(1)	−28.65(1)
SANC	−1.89(1)	−2.56(1)	−5.97(1)	−10.02(1)	−18.96(1)	−28.61(1)
WGRAD	−1.71(1)	−2.32(1)	−5.94(1)	−10.11(2)	−19.08(3)	−28.73(6)
$\delta_{\gamma q}$/%						
DK	+0.071(1)	+5.24(1)	+13.10(1)	+16.44(2)	+14.30(1)	+11.89(1)

- Perfect agreement between independent calculations!



$M_{\mathrm{T},\nu_l l}/\mathrm{GeV}$	50–∞	100–∞	200–∞	500–∞	1000–∞
$\delta_{\mathrm{rec}}/\%$	$-1.73(1)$	$-3.43(2)$	$-6.52(2)$	$-12.55(1)$	$-19.51(1)$
$\delta_{\gamma q}/\%$	$+0.0567(3)$	$+0.1347(1)$	$+0.2546(1)$	$+0.3333(1)$	$+0.3267(1)$

Multiple photon corrections

- double bremsstrahlung $q\bar{q}' \to \ell^{\pm}\nu\gamma\gamma$ and $q\bar{q} \to \ell^{+}\ell^{-}\gamma\gamma$ corrections to W/Z production

U. Baur and T. Stelzer, Phys. Rev. **D61** (2000) 073007

- Higher-order (real+virtual) QED corrections to W/Z production
  - $\longrightarrow$ HORACE (Pavia): QED Parton Shower (+ NLO electroweak to W now)

C.M. Carloni Calame *et al.*, Phys. Rev. **D69** (2004) 037301
C.M. Carloni Calame *et al.*, JHEP **05** (2005) 019

  - $\longrightarrow$ WINHAC (Cracow): YFS exponentiation

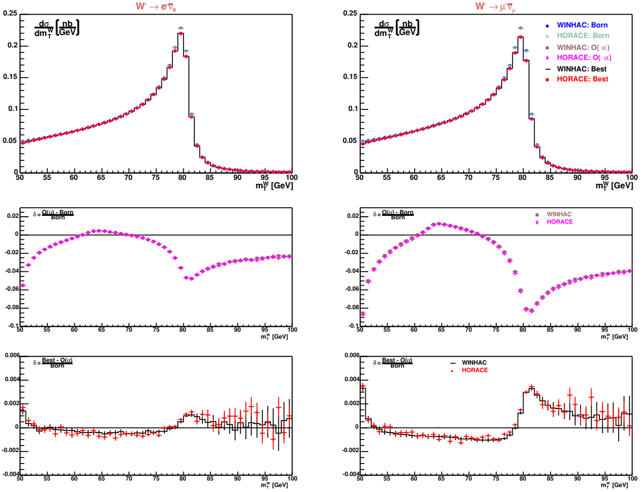
S. Jadach and W. Płaczek, Eur. Phys. J. **C29** (2003) 325

- Very recent effort to update HERWIG(++) (with SOPHTY, based on YFS exponentiation) and PHOTOS, to improve the treatment of multi-photon radiation

K. Hamilton and P. Richardson, hep-ph/0603034
P. Golonka and Z. Was, Eur. Phys. J. **C45** (2006) 97

HORACE vs WINHAC

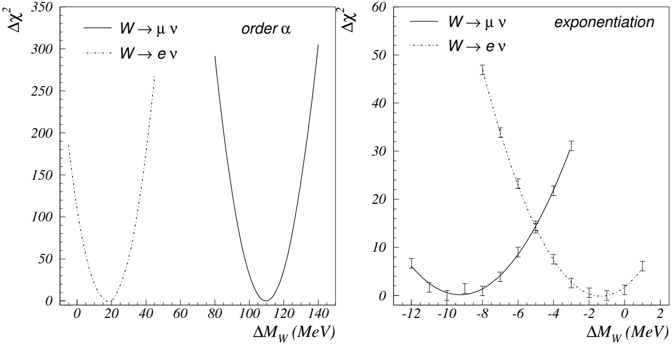
C.M. Carloni Calame *et al.*, Acta Phys. Pol. **B35** (2004) 1643



- Same effect of multiple photon radiation $\sim$ 0.5% around W peak

Why higher-order QED is important: W mass

C.M. Carloni Calame *et al.*, Phys. Rev. **D69** (2004) 037301



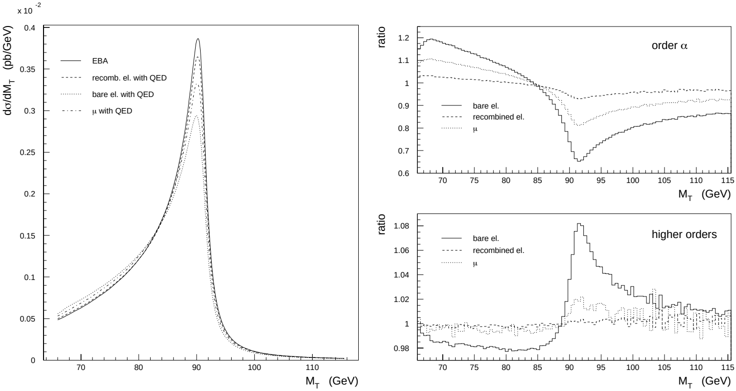
$\Delta M_W^{\alpha,e} \sim 20$ MeV
$\Delta M_W^{\alpha,\mu} \sim 110$ MeV

$\Delta M_W^{\infty,\mu} \sim 10$ MeV
$\Delta M_W^{\infty,e} \sim 2$ MeV

- W-mass shift due to multiphoton radiation is about 10% of that caused by one photon emission $\to$ non-negligible for W mass!

Higher-order QED corrections to Z production: M_T^Z

C.M. Carloni Calame *et al.* JHEP **05** (2005) 019



- Multiple photon corrections to Z production are also needed

C.M. Carloni Calame *et al.*, to appear

- NLO ($\mathcal{O}(\alpha)$) electroweak cross section

$$d\sigma^{\alpha}_{\rm ew} \equiv d\sigma^{\alpha,ex} \equiv d\sigma^{\alpha,ex}_{SV} + d\sigma^{\alpha,ex}_{H}$$

- $\mathcal{O}(\alpha)$ Parton Shower (PS) cross section

$$d\sigma^{\alpha,PS} = [\Pi_S(Q^2)]_{\mathcal{O}(\alpha)} d\sigma_0 + \frac{\alpha}{2\pi} P_{ff}(x) I(k) dx\, dc\, d\hat{\sigma}_0 = \equiv d\sigma^{\alpha,PS}_{SV} + d\sigma^{\alpha,PS}_{H}$$

- Resummed PS

$$d\sigma^{\infty}_{PS} = \Pi_S(Q^2)\, F_{sv}\, \sum_{n=0}^{\infty} d\hat{\sigma}_0 \frac{1}{n!} \prod_{i=0}^{n} \left[\frac{\alpha}{2\pi} P_{ff}(x_i) I(k_i) dx_i dc_i\, F_{H,i} \right]$$

where $F_{SV} = 1 + \frac{d\sigma^{\alpha,ex}_{SV} - d\sigma^{\alpha,PS}_{SV}}{d\sigma_0}$ and $F_{H,i} = 1 + \frac{d\sigma^{\alpha,ex}_{H,i} - d\sigma^{\alpha,PS}_{H,i}}{d\sigma^{\alpha,PS}_{H,i}}$

Matching NLO electroweak with QED Parton Shower

C.M. Carloni Calame *et al.*, to appear

- NLO ($\mathcal{O}(\alpha)$) electroweak cross section

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- Resummed PS + NLO electroweak

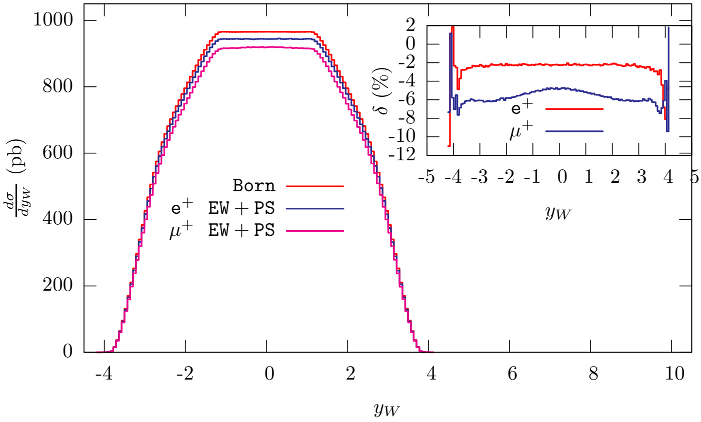
$$d\sigma^{\infty}_{\rm matched} = \\ \Pi_S(Q^2)\; F_{sv}\; \sum_{n=0}^{\infty} d\hat{\sigma}_0 \frac{1}{n!} \prod_{i=0}^{n} \left[\frac{\alpha}{2\pi} P_{ff}(x_i) I(k_i) dx_i dc_i\; F_{H,i} \right]$$

where $F_{SV} = 1 + \frac{d\sigma^{\alpha,ex}_{SV} - d\sigma^{\alpha,PS}_{SV}}{d\sigma_0}$ and $F_{H,i} = 1 + \frac{d\sigma^{\alpha,ex}_{H,i} - d\sigma^{\alpha,PS}_{H,i}}{d\sigma^{\alpha,PS}_{H,i}}$

Electroweak + PS corrections to W rapidity: New!

C.M. Carloni Calame *et al.*, to appear

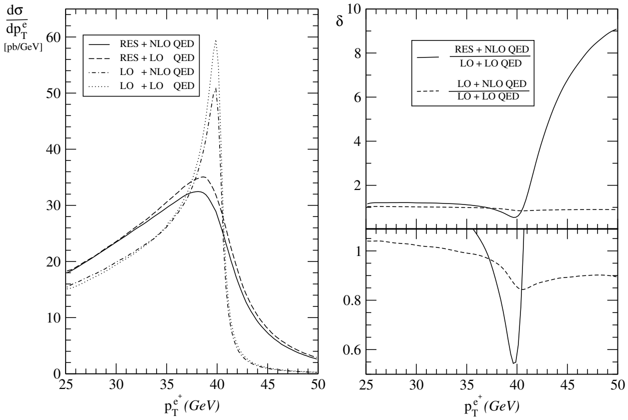
Including detector effects



- Electroweak (+ QED PS) corrections to W rapidity are of the same order (or larger!) than NNLO QCD and PDFs uncertainty $\rightarrow$ relevant for precise luminosity!

Matching QCD with NLO QED: p_T^ℓ

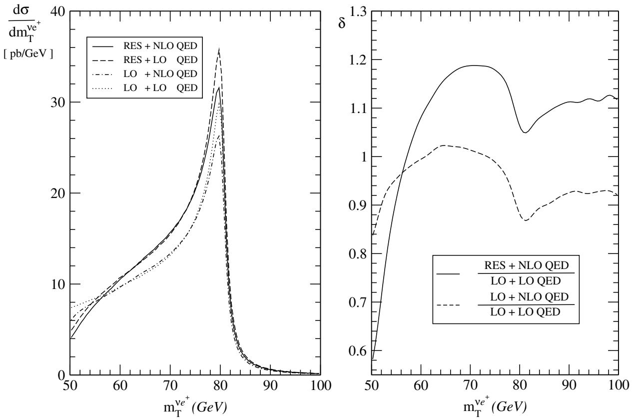
Q.-H. Cao and C.-P. Yuan, Phys. Rev. Lett. **93** (2004) 042001



- QCD resummation and NLO QED differently modify the shape of p_T^ℓ and reach $\sim 45\%$ $\rightarrow$ need to merge QCD and EW generators!

Matching QCD with NLO QED: M_T^W

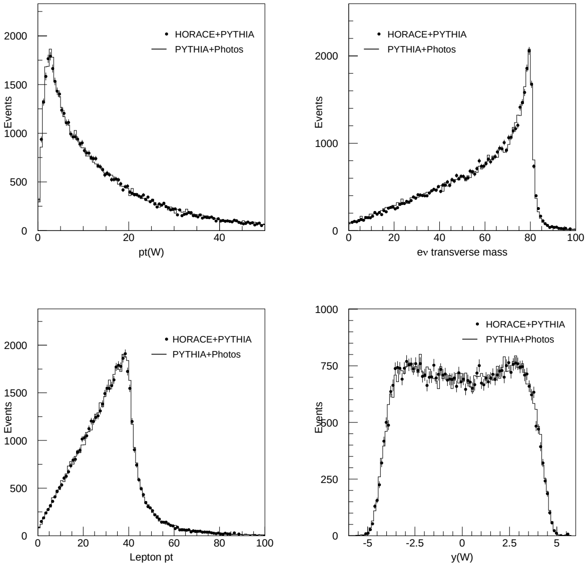
Q.-H. Cao and C.-P. Yuan, Phys. Rev. Lett. **93** (2004) 042001



- QCD resummation ($\sim +6$% at the peak) is compensated by NLO QED (~ -12%) $\rightarrow$ need to merge QCD and EW generators!!

HORACE+PYTHIA vs PYTHIA+PHOTOS: New!

HORACE group with G. Polesello



HORACE+PYTHIA vs PYTHIA+PHOTOS: New!

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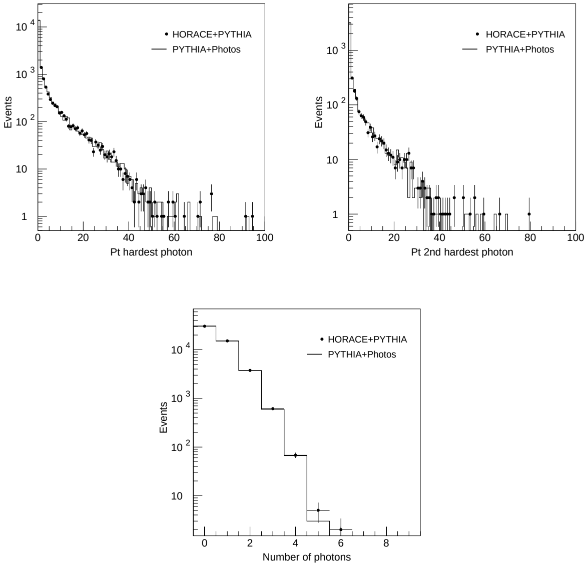


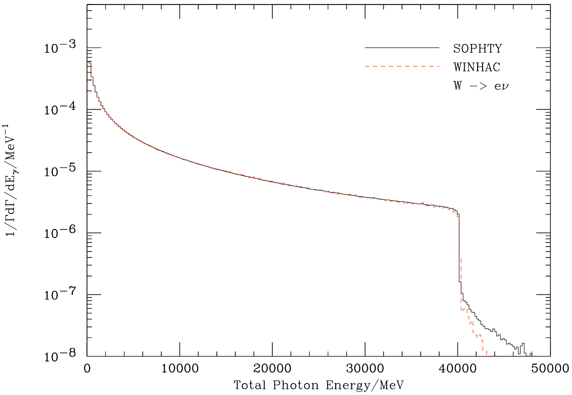
Conclusions

- Recent big theoretical effort towards high-precision predictions for Drell-Yan processes, including higher-order QCD and electroweak corrections, to keep under control theoretical systematics
- All these calculations are essential ingredients for precision studies at the LHC (and Tevatron RunII as well...)
- It's mandatory to combine electroweak and QCD corrections into a single (unified) Monte Carlo, to cover all the measurements of interest
- None of the existing generators presently includes all the necessary ingredients, but complete generators appear at the horizon...as HORACE+PYTHIA demonstrate
- Precision measurements with 1% accuracy at the LHC are very challenging!

Backup slides

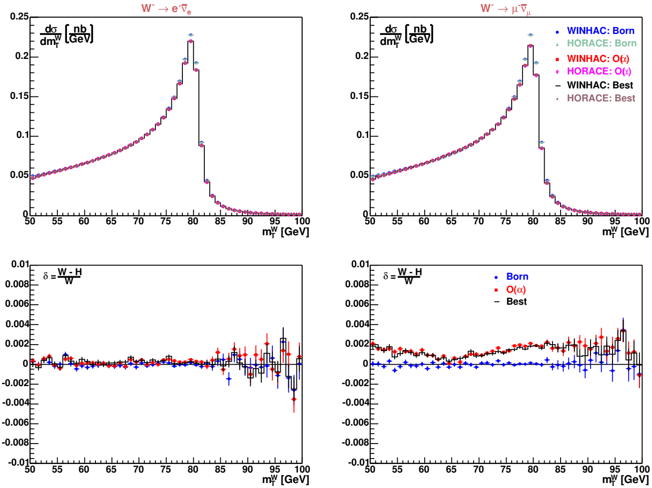
HERWIG+SOPHTY vs WINHAC

K. Hamilton and P. Richardson, hep-ph/0603034



HORACE vs WINHAC: M_T^W

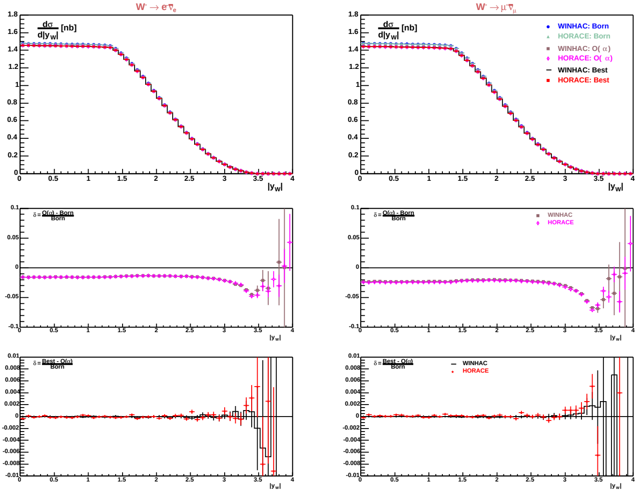
C.M. Carloni Calame *et al.*, Acta Phys. Pol. **B35** (2004) 1643



- $\mathcal{O}(\alpha)$ 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 vs WINHAC: W rapidity

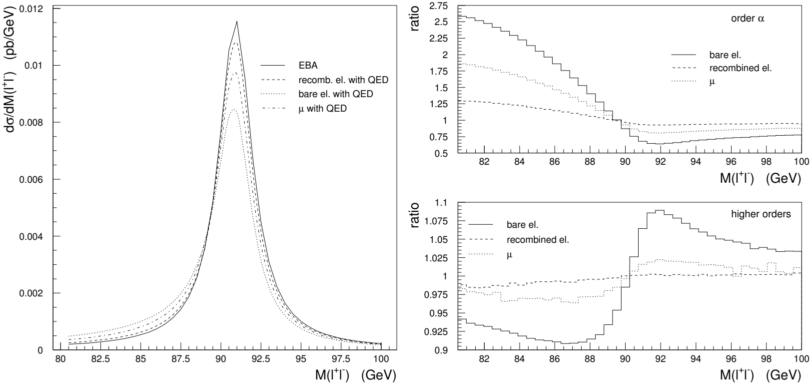
C.M. Carloni Calame *et al.*, Acta Phys. Pol. **B35** (2004) 1643



- $\mathcal{O}(\alpha)$ corrections at 2/5% level for recombined e/bare μ

Higher-order QED corrections to Z production: $M_{\ell\ell}$

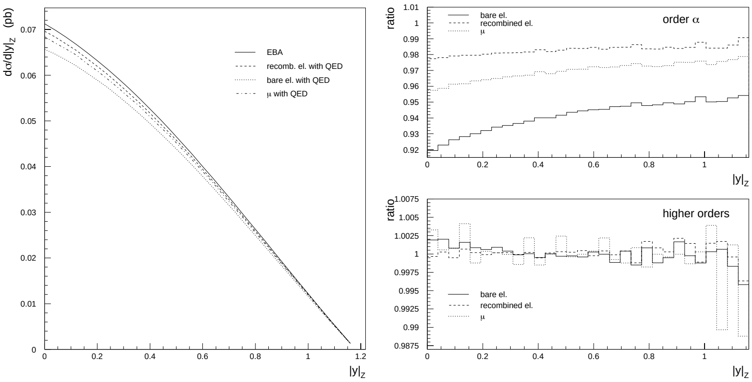
C.M. Carloni Calame *et al.* JHEP **05** (2005) 019



- Multiple photon corrections to Z production are also needed, because important W systematics are strongly related to Z parameters extraction and statistics

QED corrections to Z rapidity

C.M. Carloni Calame *et al.* JHEP **05** (2005) 019



- NLO QED corrections to Z rapidity at some per cent level

Systematic uncertainties on M_W (MeV/c^2)

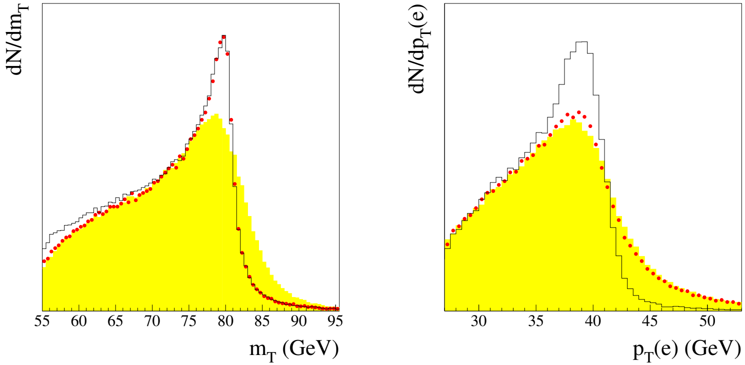
CDF collaboration, Phys. Rev. **D64** (2001) 052001

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

M_T^W vs p_T^ℓ

From DØ paper

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



The Parton Shower algorithm

- the PS is a MC solution of the QED DGLAP equation

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

- the solution can be cast in the form

$$D(x, Q^2) \;=\; \Pi_S(Q^2) \sum_{n=0}^{\infty} \int \frac{\delta(x - x_1 \cdots x_n)}{n!} \prod_{i=0}^{n} \left[\frac{\alpha}{2\pi} P(x_i)\, L\, dx_i \right]$$

  - $\Pi_S(Q^2) \equiv e^{-\frac{\alpha}{2\pi} L I_+}$ is the Sudakov form factor, $I_+ \equiv \int_0^{1-\epsilon} P(x) dx$, $L \equiv \log \frac{Q^2}{m^2}$ and ϵ soft/hard separator
- the PS MC algorithm reproduces this solution
- at NLO, the resulting cross section has a leading log accuracy

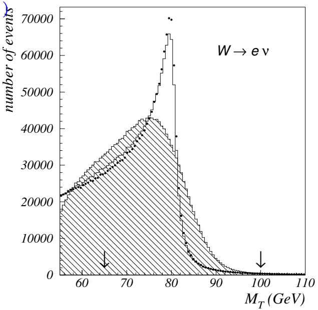
Fitting the W mass

χ^2 fits to Monte Carlo pseudo-data for the M_T^W spectrum with

- $\sqrt{s} = 2$ TeV $p_T(\ell) > 25$ GeV $|\eta(\ell)| < 1.2$ $\not{p}_T > 25$ 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



Lepton identification and detector effects

Table 1: Summary of lepton identification requirements.

Tevatron and LHC

electrons	muons
combine e and γ momentum four vectors if $\Delta R(e,\gamma) < 0.1$	reject events with $E_\gamma > 2$ GeV for $\Delta R(\mu,\gamma) < 0.1$
reject events with $E_\gamma > 0.1\ E_e$ for $0.1 < \Delta R(e,\gamma) < 0.4$	reject events with $E_\gamma > 0.1\ E_\mu$ for $0.1 < \Delta R(\mu,\gamma) < 0.4$

at the Tevatron, and the ATLAS and CMS detectors at the LHC. Uncertainties in the energy measurements of the charged leptons in the detector are simulated in the calculation by Gaussian smearing of the particle four-momentum vector with standard deviation σ which depends on the particle type and the detector. The numerical results presented here were calculated using σ values based on the DØ (or CDF) and ATLAS (or CMS) specifications.