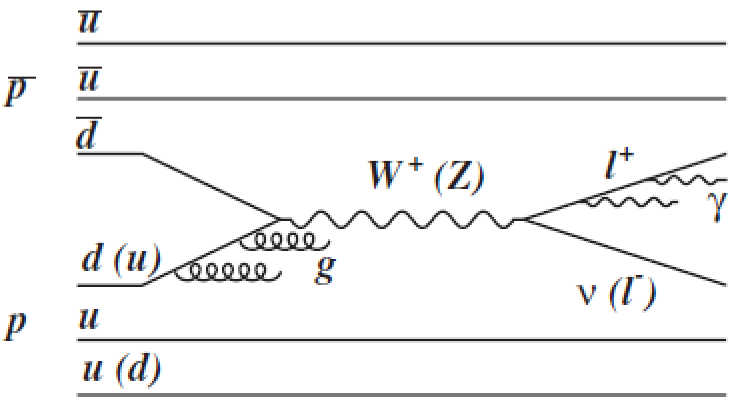


Modelling W and Z production for m_W at the Tevatron

Chris Hays, Oxford University

Aspects of production and decay

PDFs

Boson p_T

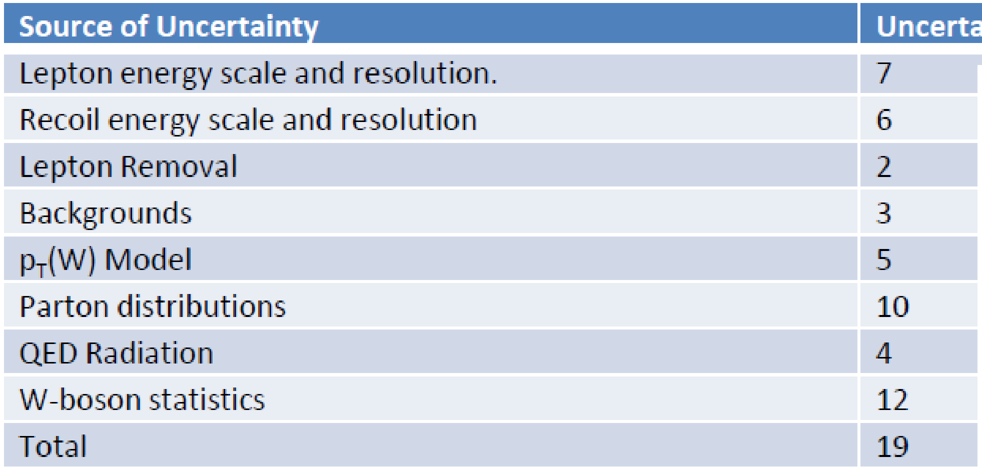
Boson decay

Final state radiation

PDFs

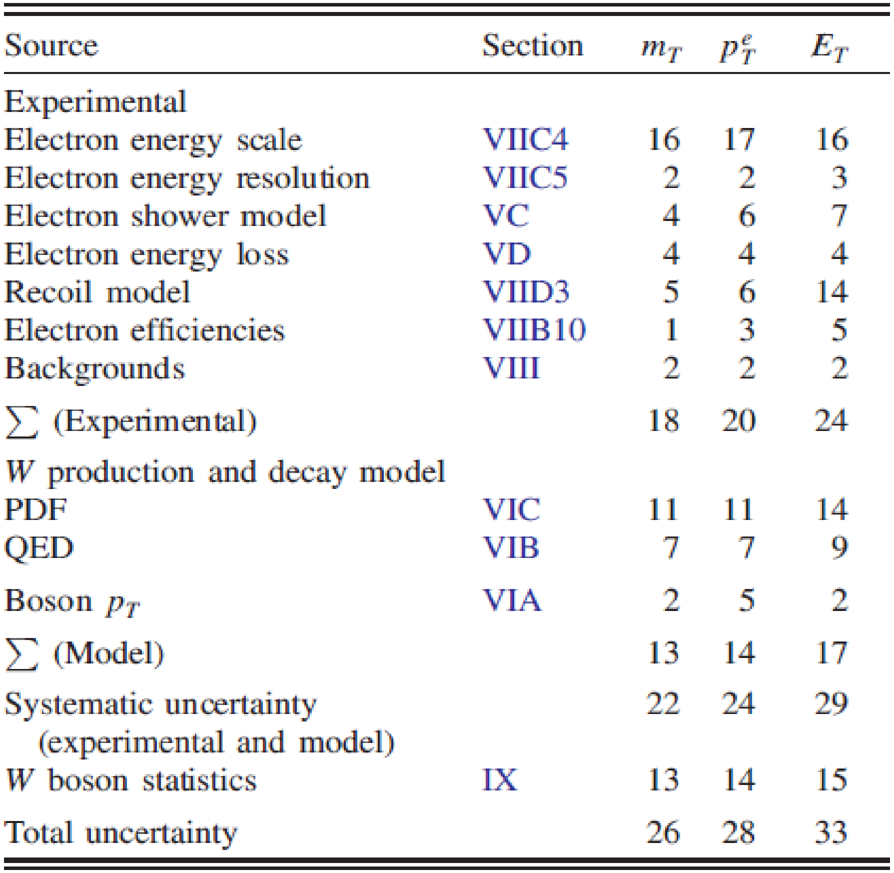
Largest single source of systematic uncertainty at the Tevatron

D0



Source of Uncertainty	Uncertainty (MeV)
Lepton energy scale and resolution.	7
Recoil energy scale and resolution	6
Lepton Removal	2
Backgrounds	3
$p_T(W)$ Model	5
Parton distributions	10
QED Radiation	4
W-boson statistics	12
Total	19

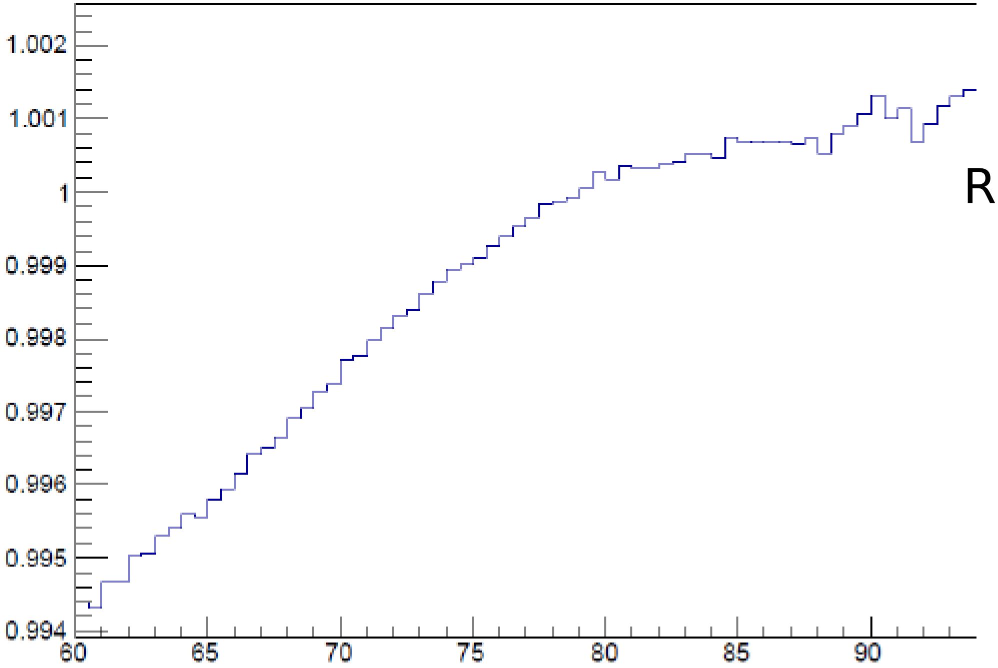
CDF



Source	Section	m_T	p_T^e	E_T
Experimental				
Electron energy scale	VIIC4	16	17	16
Electron energy resolution	VIIC5	2	2	3
Electron shower model	VC	4	6	7
Electron energy loss	VD	4	4	4
Recoil model	VIID3	5	6	14
Electron efficiencies	VIIB10	1	3	5
Backgrounds	VIII	2	2	2
$\sum$ (Experimental)		18	20	24
W production and decay model				
PDF	VIC	11	11	14
QED	VIB	7	7	9
Boson p_T	VIA	2	5	2
$\sum$ (Model)		13	14	17
Systematic uncertainty (experimental and model)		22	24	29
W boson statistics	IX	13	14	15
Total uncertainty		26	28	33

Affects the fit through acceptance:
bigger longitudinal boost →
fewer forward (low-p_T) leptons →
mass fit will be high

PDFs

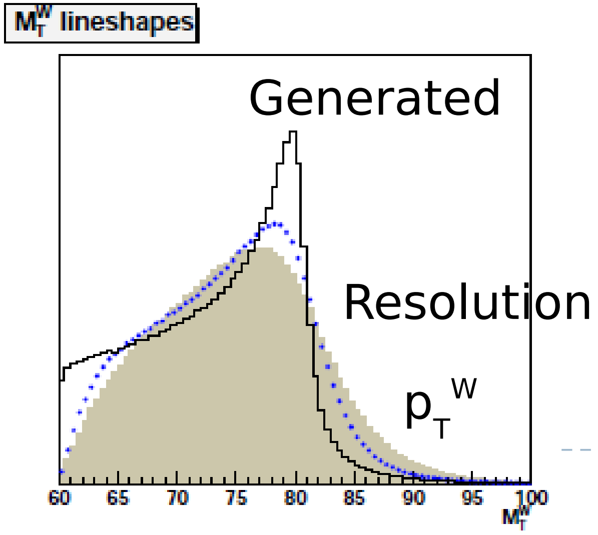


Example:
CT10 PDF set: m_T distribution
Ratio of 26th eigenvector to nominal
+15 MeV effect on m_W

[bigger longitudinal boost →
fewer forward (low-p_T) leptons →
mass fit will be high]

Mass sensitivity dominated by events with m_T ~ 80 GeV

Resolution increases sensitivity to PDFs



PDFs

Uncertainties evaluated using CTEQ6.1 (D0) or CTEQ 6.6 (CDF)

Scaled to 68% CL

Evaluated using LO model (D0: Pythia, CDF: Horace)

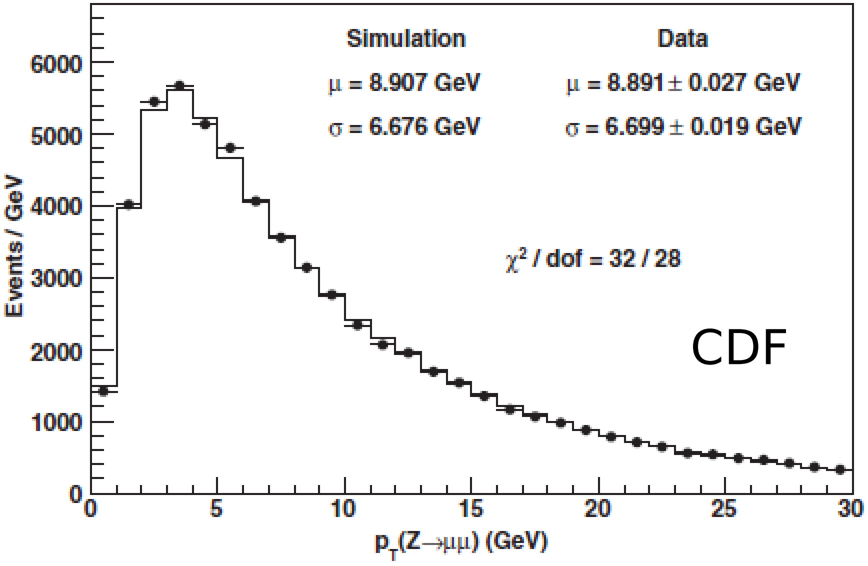
Empirical p_T distribution

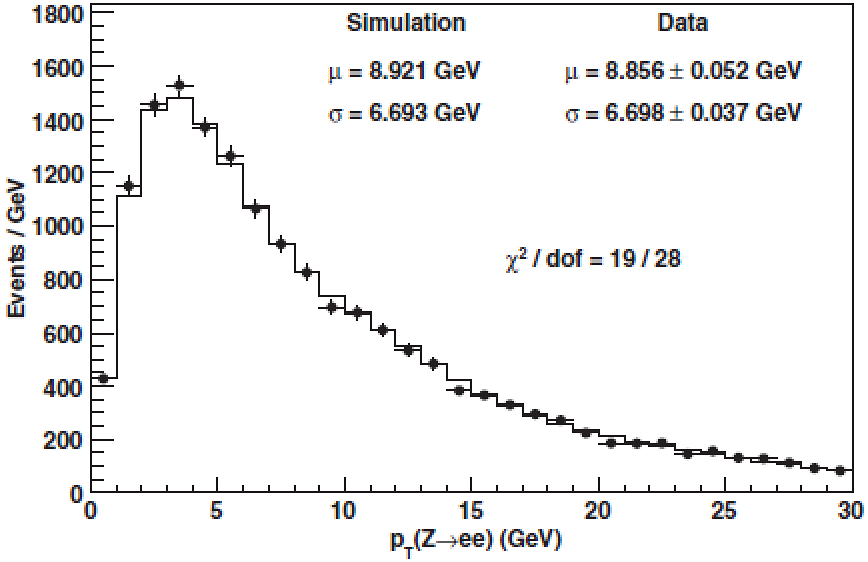
CDF: compare with MSTW2008, reweighted RESBOS

CTEQ 6.6: No Tevatron Run 2 W charge asymmetry data!

Recent studies with Powheg:
CT10 shows similar uncertainties (still little charge asymmetry data)
Uncertainties can be reduced by optimizing fit ranges

Boson p_T

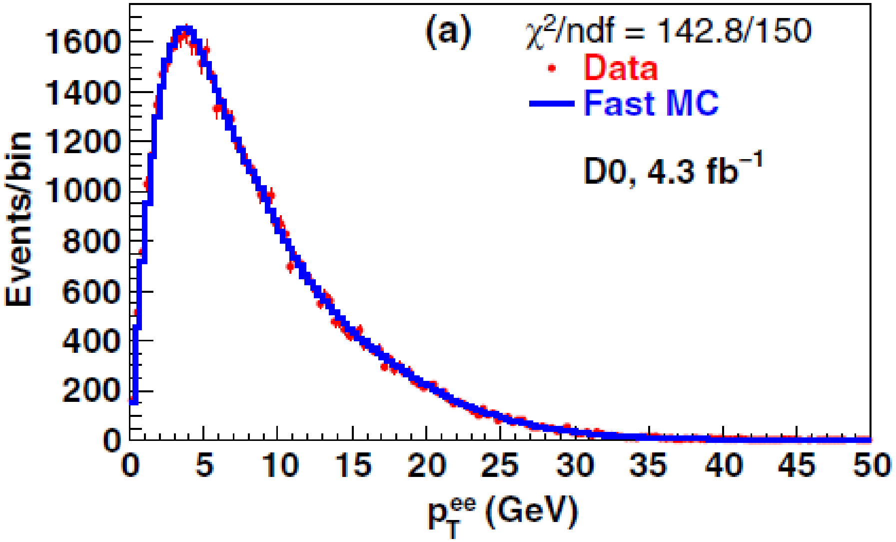




Model boson p_T with RESBOS

NLO+NNLL with non-perturbative parameters

Tuned RESBOS models Z data well



Dominated by non-perturbative and resummed regions

Boson p_T

RESBOS non-perturbative function:

$$S = \left[g_1 - g_2 \log\left(\frac{\sqrt{\hat{s}}}{2Q_0}\right) - g_1 g_3 \log(100 x_j x_k)\right] b^2$$

g_2 affects position of p_T peak: most important parameter for mW

g_2 fit using Z data (CDF) or global fit (D0), with corresponding uncertainty of 0.013 (CDF) or 0.02 (D0)

g_2 changes by up to 0.05 with PDF set: p_T fit tied to a given PDF set

CDF varies g_3 by 0.3 (global fit), obtains uncertainty equivalent to g_2 variation of 0.007

Uncertainties (p_T fit): 3 MeV (CDF), 5 MeV (D0)

Boson p_T

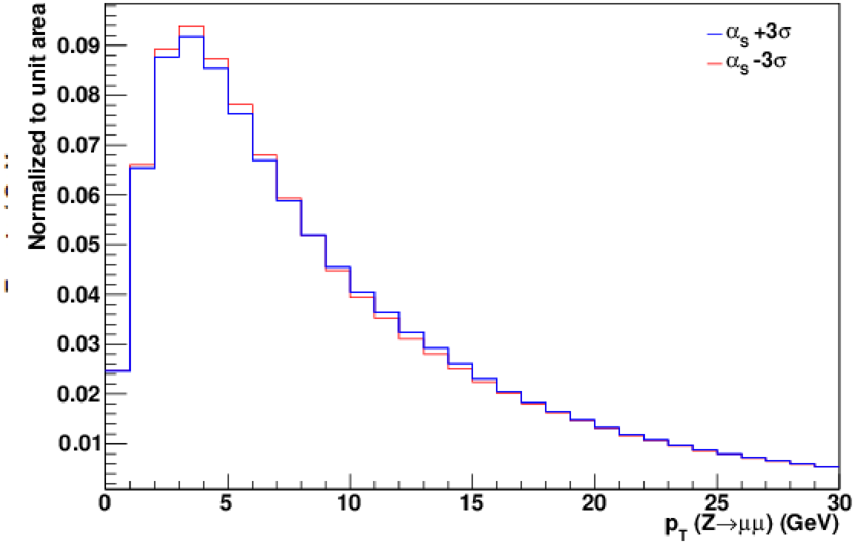
Uncertainty at higher boson p_T due to resummation

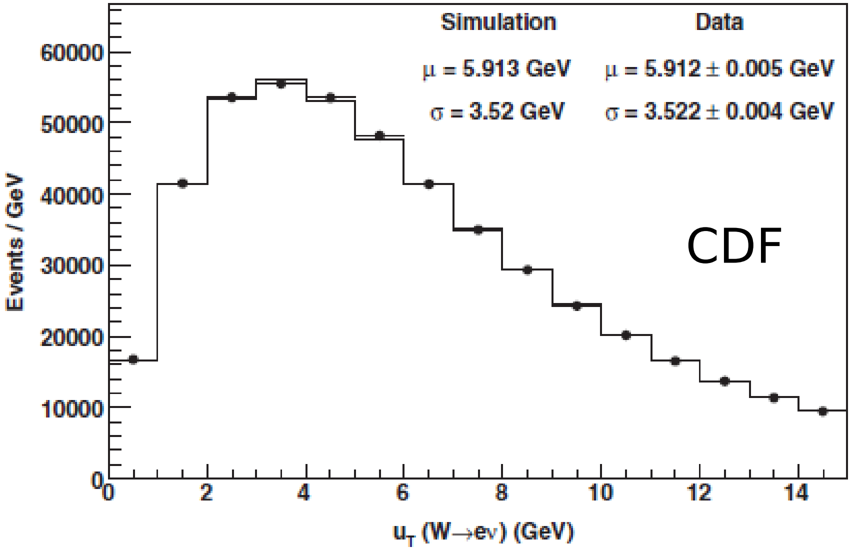
CDF: vary α_s as proxy for perturbative effects

Resulting uncertainty corresponds to 8 MeV on p_T fit

g_2 and α_s anticorrelated (correlation coefficient -0.71)

Also studied diffractive & photon-induced events: could affect transfer of g_2 from Z to W





Boson decay

Boson polarization affects relative position of recoil and lepton

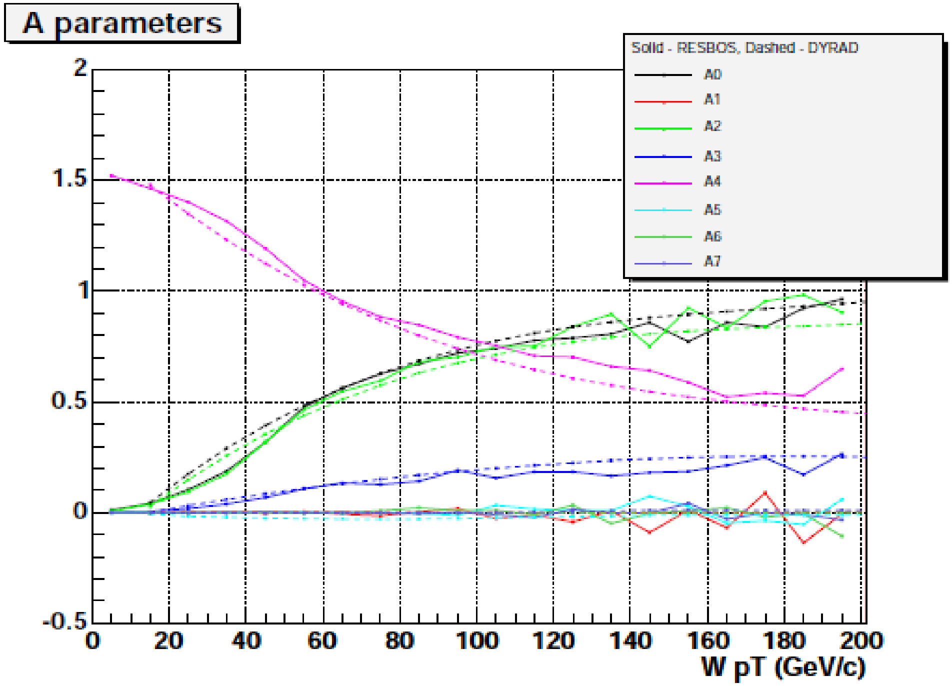
Bias in recoil projected on lepton leads to bias in m_W from m_T fit

Polarization coefficients parametrized in Collins-Soper frame:

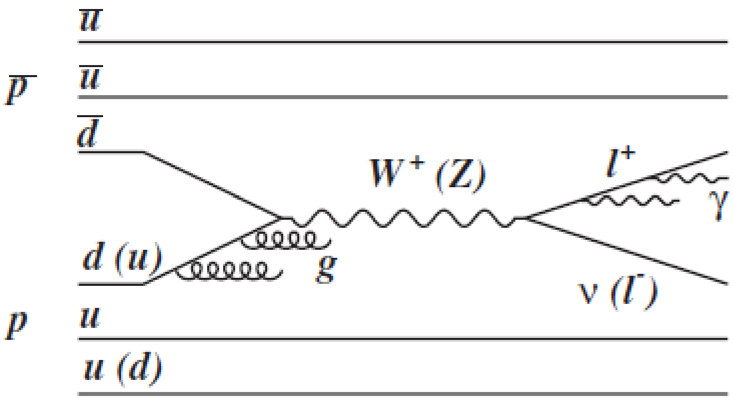
$$\begin{aligned}\frac{d\sigma}{d\Omega} \propto (1+\cos^2\theta) &+ \frac{1}{2}A_0(1-3\cos^2\theta)\\ &+ A_1\sin 2\theta\cos\phi + \frac{1}{2}A_2\sin^2\theta\cos 2\phi\\ &+ A_3\sin\theta\cos\phi + A_4\cos\theta + A_5\sin^2\theta\sin 2\phi\\ &+ A_6\sin 2\theta\sin\phi + A_7\sin\theta\sin\phi,\end{aligned}$$

RESBOS validated with DYRAD (NLO W+jet) for p_T>15 GeV

Consistency to 3 MeV on m_W



QED modelling and uncertainties



Tools:

W/ZGRAD: Complete NLO EWK

PHOTOS: Resummed QED FSR matched to NLO QED

HORACE: Resummed QED matched to complete NLO EWK

Effective radiator approximation: γ→ee splitting of radiated photons

QED modelling and uncertainties at D0

FSR QED radiation modelled by PHOTOS

Produce pseudoexperiments with full NLO electroweak corrections

Fits to PHOTOS templates lead to 5 MeV uncertainty on m_W

Also vary energy cutoff in WGRAD: 2 MeV uncertainty in m_T fit

Vary electron clustering size: 1 MeV in m_T fit

Total uncertainty 7 MeV

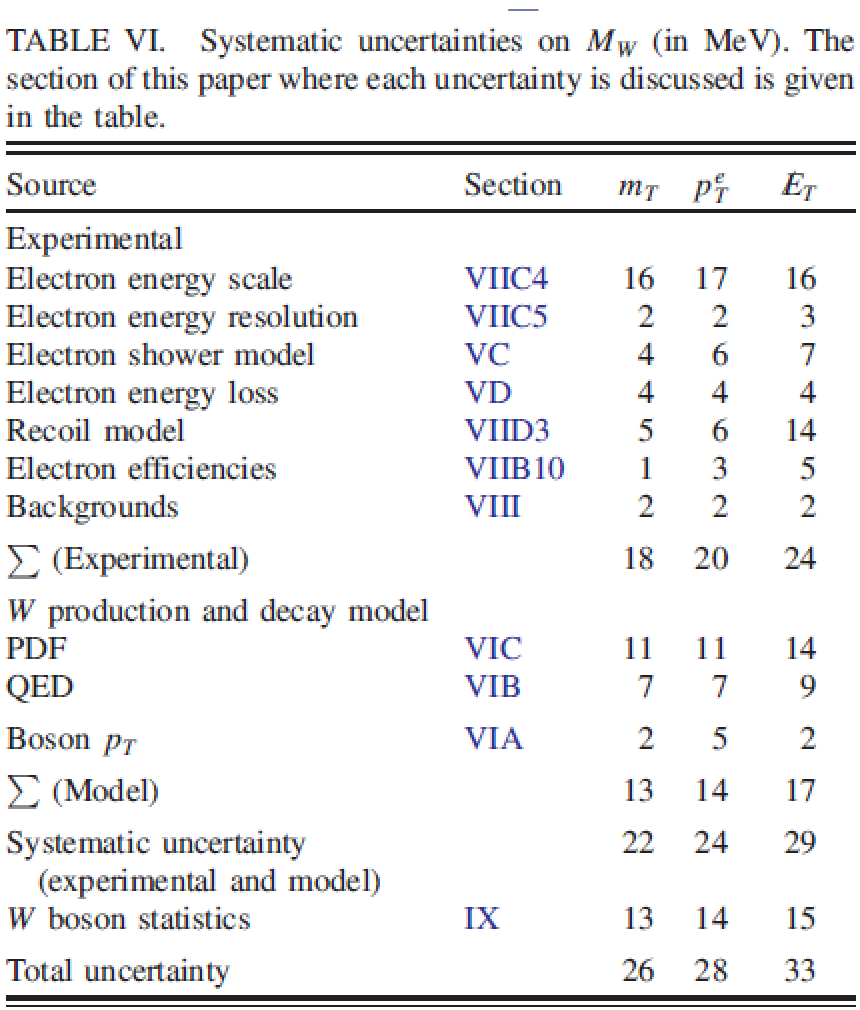


TABLE VI. Systematic uncertainties on M_W (in MeV). The section of this paper where each uncertainty is discussed is given in the table.

Source	Section	m_T	p_T^e	$\not\!\!E_T$
Experimental				
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QED modelling and uncertainties at CDF

Events simulated with RESBOS+PHOTOS

Up to four photons, with photon energy cutoff of 0.4 MeV

PHOTOS includes reweighting to reproduce NLO QED calculation

Calibrate to HORACE matched to complete NLO EWK

Two-step process:

(1) Fit HORACE FSR data to PHOTOS FSR template

(2) Fit HORACE matched data to HORACE FSR template

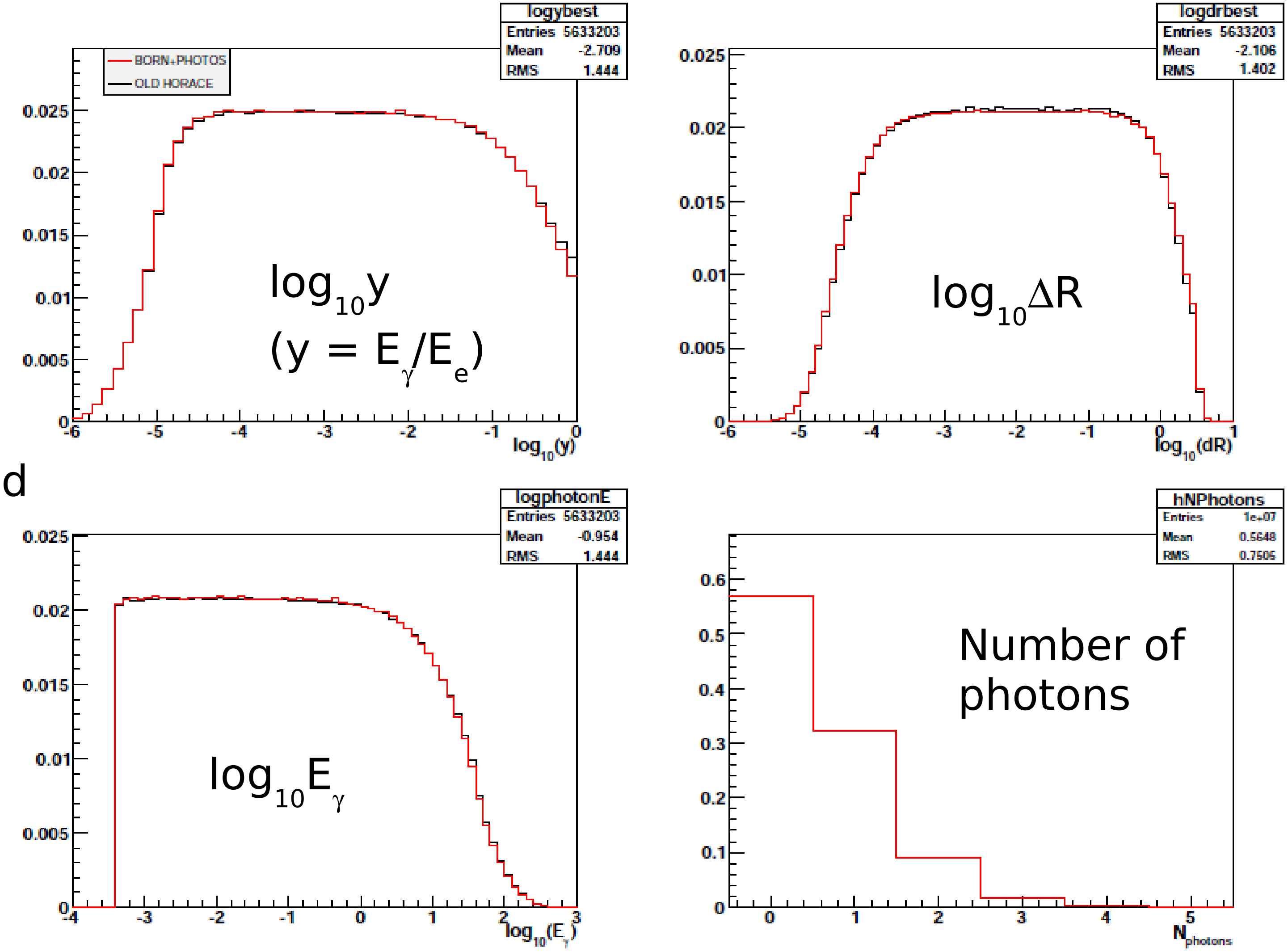
Model $\gamma \rightarrow ee$ splitting using effective radiator approximation

Total uncertainty 4 MeV

Comparisons of HORACE and PHOTOS

W→eν events

HORACE
run in resummed
FSR mode



HORACE calibration

Calibrated using most significant deviations in p_T or m_T fits

Resummed HORACE fit to PHOTOS:
6.9 ± 2.7 MeV (electrons)
0.7 ± 2.3 MeV (muons)

Matched HORACE fit to resummed HORACE
-4.0 ± 3.5 MeV (electrons)
-5.0 ± 2.4 MeV (muons)

Total correction:
-3 ± 4 MeV (electrons)
4 ± 4 MeV (muons)

Add a conservative 1 MeV uncertainty due to the HORACE matching prescription for the second hardest photon (i.e. using the known LL→NLO correction for hardest photon)

Effective radiator approximation

Model internal photon conversion (e.g. e→eee) using an effective radiator model due to Chen and Zerwas, PRD 12, 187 (1975)

Rate can be expressed in terms of an effective number of radiation lengths

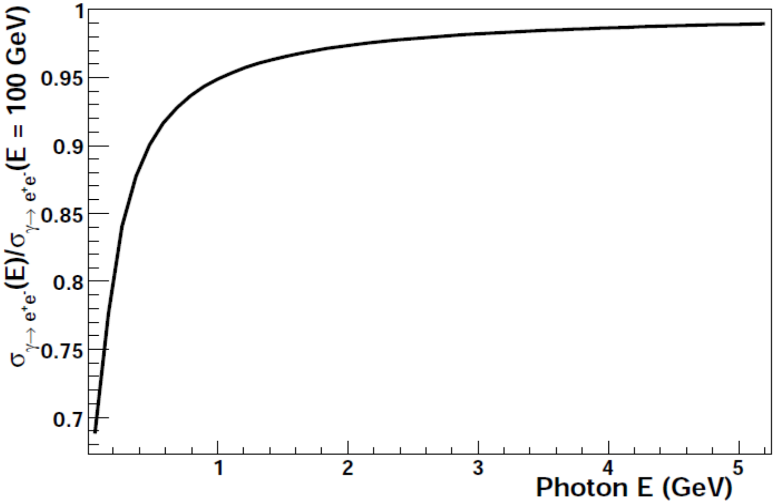
$$\Delta(x/X_0) = (\alpha_{\mathrm{EM}}/\pi)\log(E_\gamma/m_e)$$

For each photon determine the probability of internal conversion:

$$P_{\gamma\to e^+e^-}(E_\gamma \to \infty) = 1 - e^{-(7/9 - C/6)x/X_0}$$

Throw a random number to determine if photon converts; if it does, replace it with two electrons with energy fractions y and 1-y, using:

$$\frac{d\sigma}{dy} = \frac{A}{N_A X_0 \rho}\left[1 - (4/3 + C)y(1-y)\right]$$



Summary

Production model well studied at the Tevatron, uncertainties generally small

Further improvements possible

Generators with improved perturbative accuracy under study

Studies of new PDF sets the highest priority