Vector Boson Production at the Tevatron

Recent Results
from Run1 data

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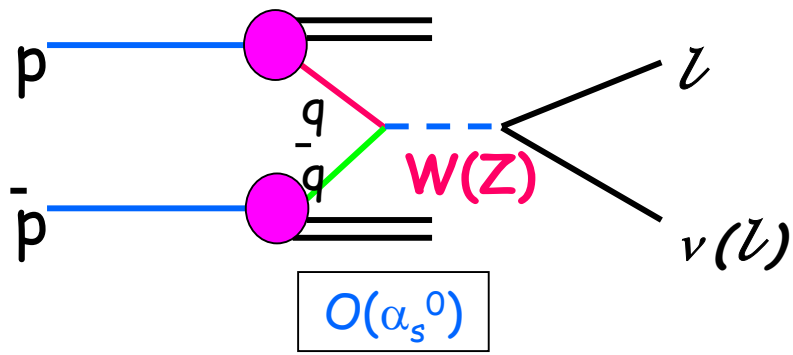
Outline

- Differential W and Z Cross Sections and their Ratio
- Studies of Drell-Yan Continuum
- Direct Photon Differential Cross sections

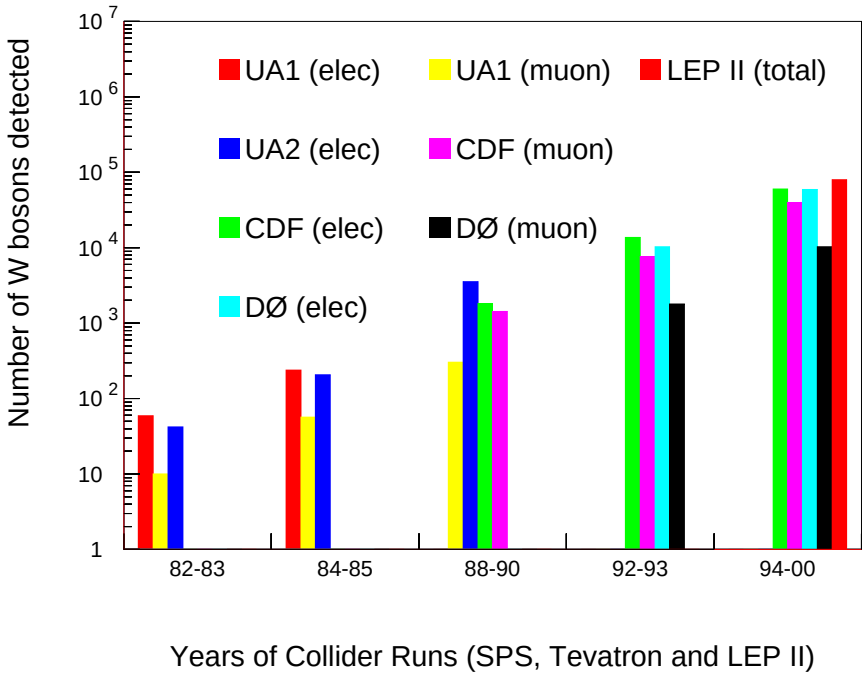
Introduction to W & Z Production at the Tevatron



- Production dominated by $q\bar{q}$ annihilation
- Due to very large $pp \rightarrow jj$ production, need to use leptonic decays
  - $W \rightarrow l\nu$ (BR ~ 11% per mode)
  - $Z \rightarrow ll$ (BR ~ 3% per mode)
- Distinctive event signatures
  - High P_T isolated leptons (e or μ)
  - One high P_T lepton + Missing E_T (W)
  - Two high P_T leptons (Z)
- Low backgrounds
- Large samples
- Well understood EW vertex

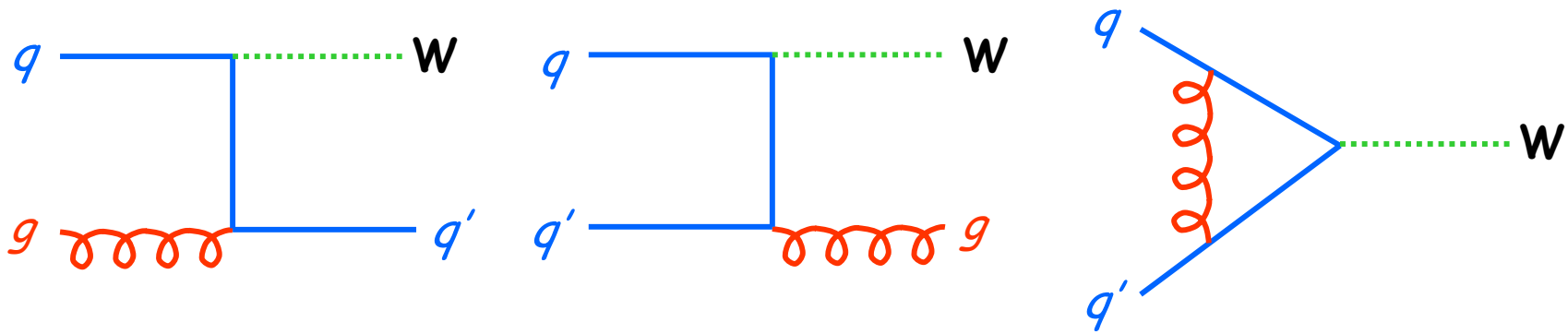
➔ Test QCD

W Bosons Detected



QCD Corrections: $O(\alpha_s)$

$O(\alpha_s)$



Modifications due to QCD corrections:

- Boson produced with transverse momentum ($\langle P_T \rangle \sim 10$ GeV)
- Boson + jet events possible (W + 1 jet ~ 7%, $E_T^{jet} > 25$ GeV)
- Inclusive cross sections larger (K factor ~ 18%)
- Boson decay angular distribution modified

Introduction to W, Z P_T Theory

$$\frac{d\sigma}{dp_T^2} \sim \frac{\alpha_s}{p_T^2} \ln\left(\frac{Q^2}{p_T^2}\right)\left[\nu_1 + \nu_2 \alpha_s \ln^2\left(\frac{Q^2}{p_T^2}\right)\right]$$

- **Large P_T region** ($P_T \geq 30$ GeV): Use pQCD, $O(\alpha_s^2)$ calculations exist

  Ellis, Martinelli, Petronzio (83); Arnold & Reno (89);
  Arnold, Ellis, Reno (89); Gonsalves, Pawlowski, Wai (89)

- **Small P_T region** ($\Lambda_{QCD} < P_T < 10$ GeV): Resum large logs

  Altarelli, Ellis, Greco, Martinelli (84); Collins, Soper, Sterman (85)

- **Very low P_T region** ($P_T \sim \Lambda_{QCD}$): Non-perturbative parameters extracted from data

  b-space:

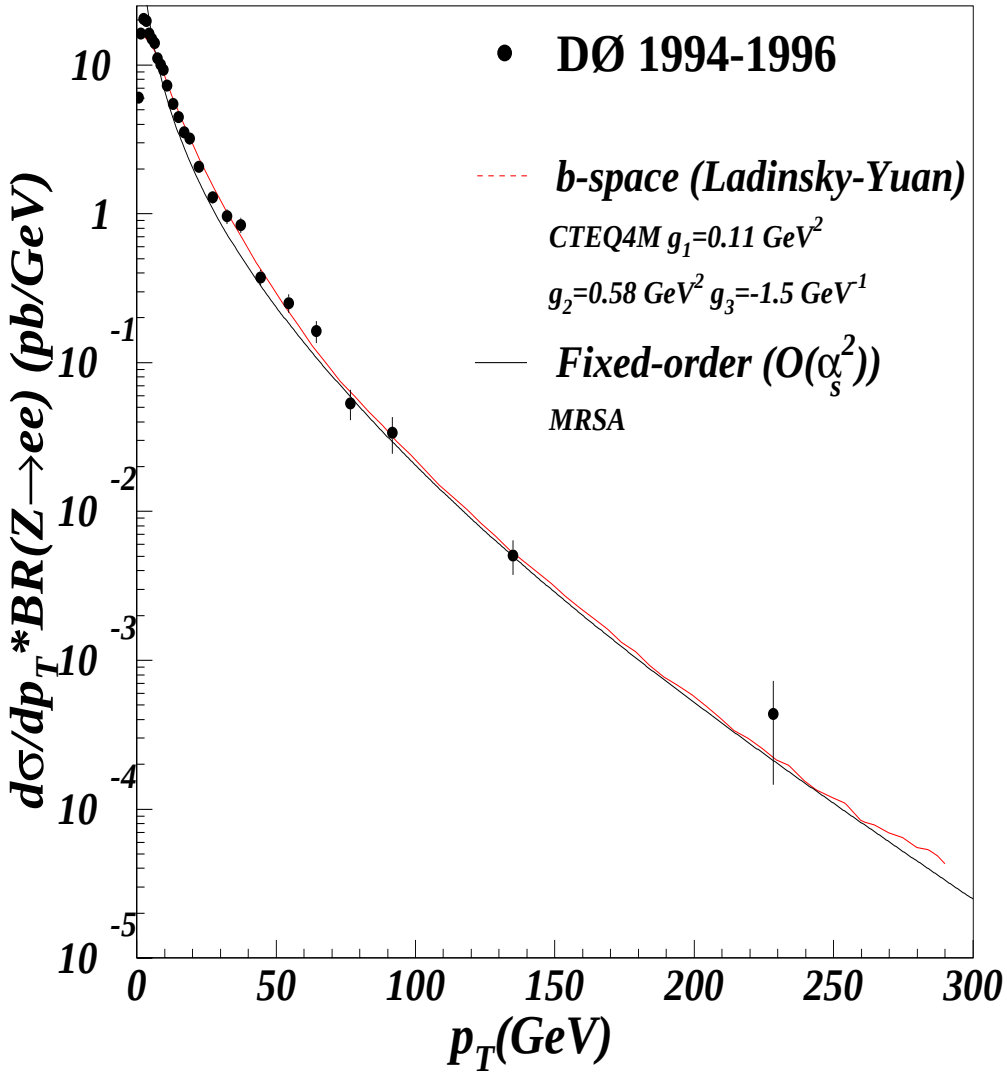
  Parisi-Petronzio (79); Davies-Stirling (84); Collins-Soper-Sterman (85); Davies, Webber, Stirling (85); Arnold- Reno-Ellis (89); **AK**: Arnold-Kaufann (91); **LY**: Ladinsky-Yuan (94)

  pt-space:

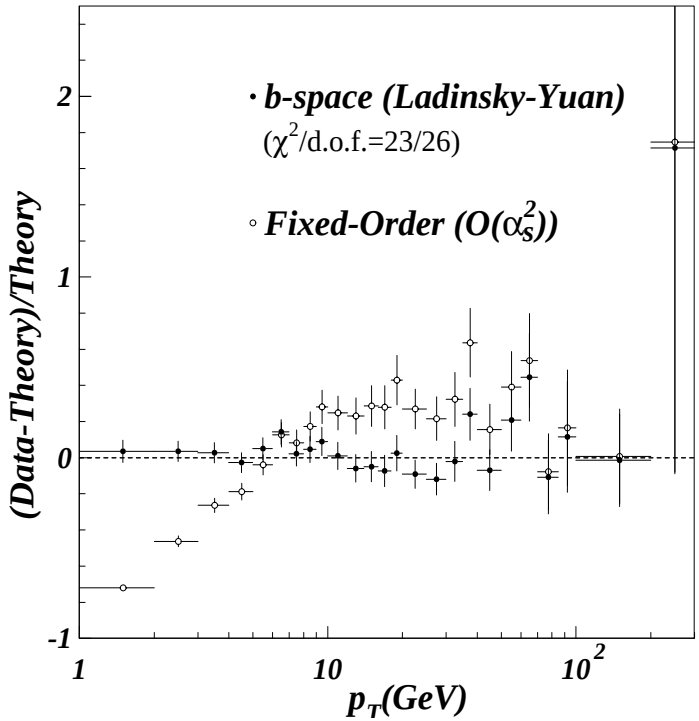
  Dokshitser-Diaknov-Troian (80); Ellis-Stirling (81); Altarelli-Ellis-Greco-Martinelli (84); Gonsalves-Pawlowksl-Wai (89); **ERV**: Ellis-Ross-Veseli (97); Ellis-Veseli (98)

DØ Z P_T measurement

PRD 61, 32004 (2000) & PRL 84, 2792 (2000)

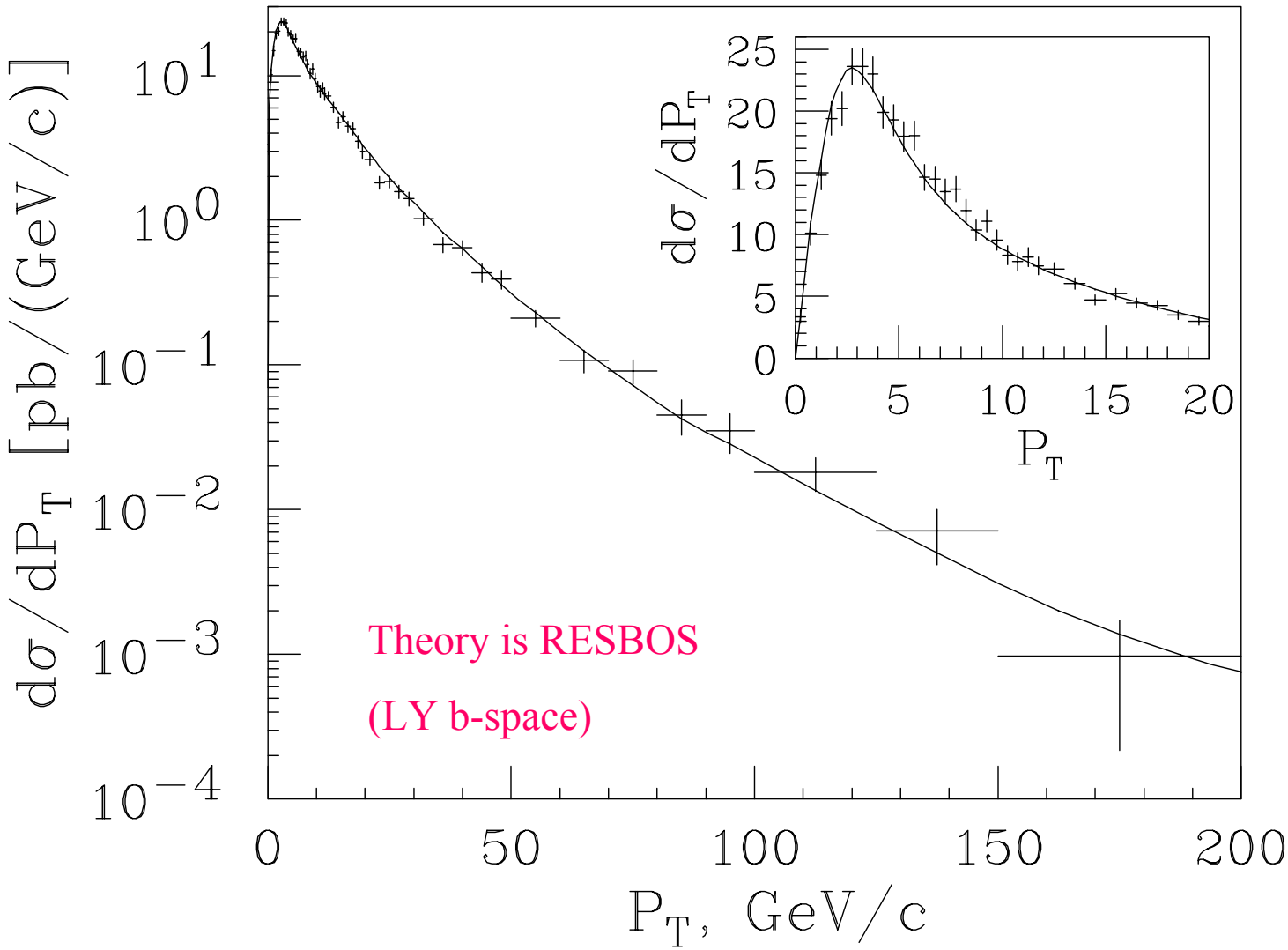


$$\frac{d\sigma}{dp_T^i} = \frac{d_i - b_i}{a_i \times \varepsilon_i \times L \times \Delta p_T^i}$$



CDF Z P_T measurement

PRL 84, 845(2000)



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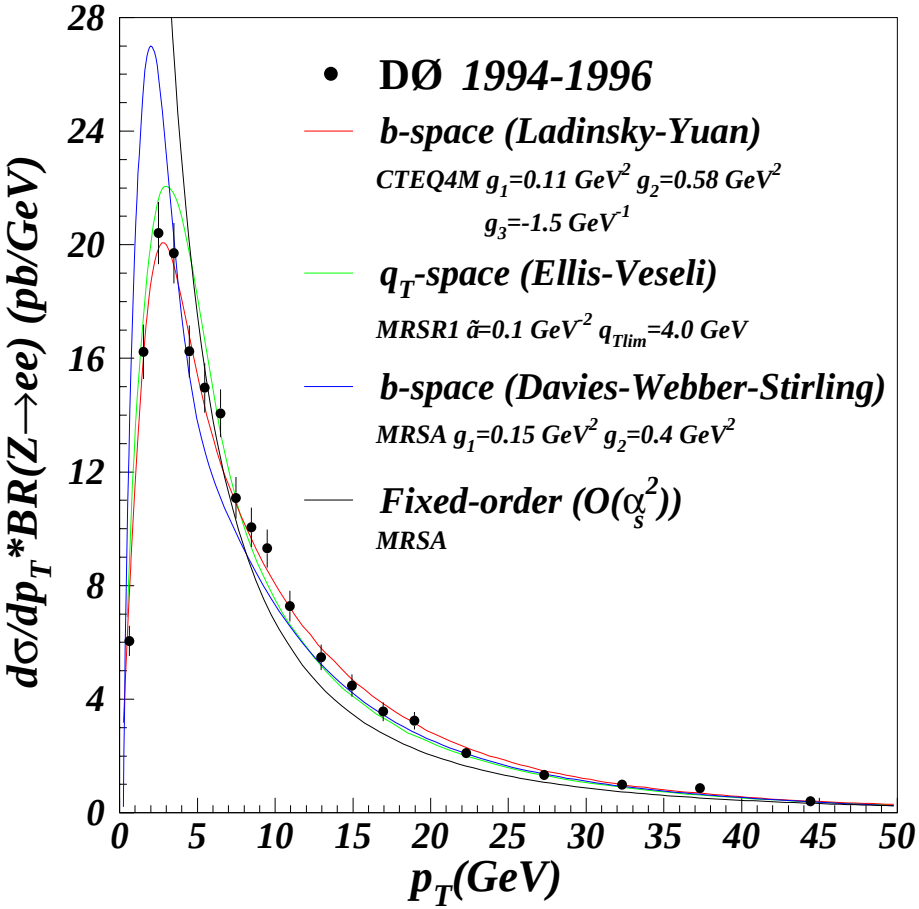
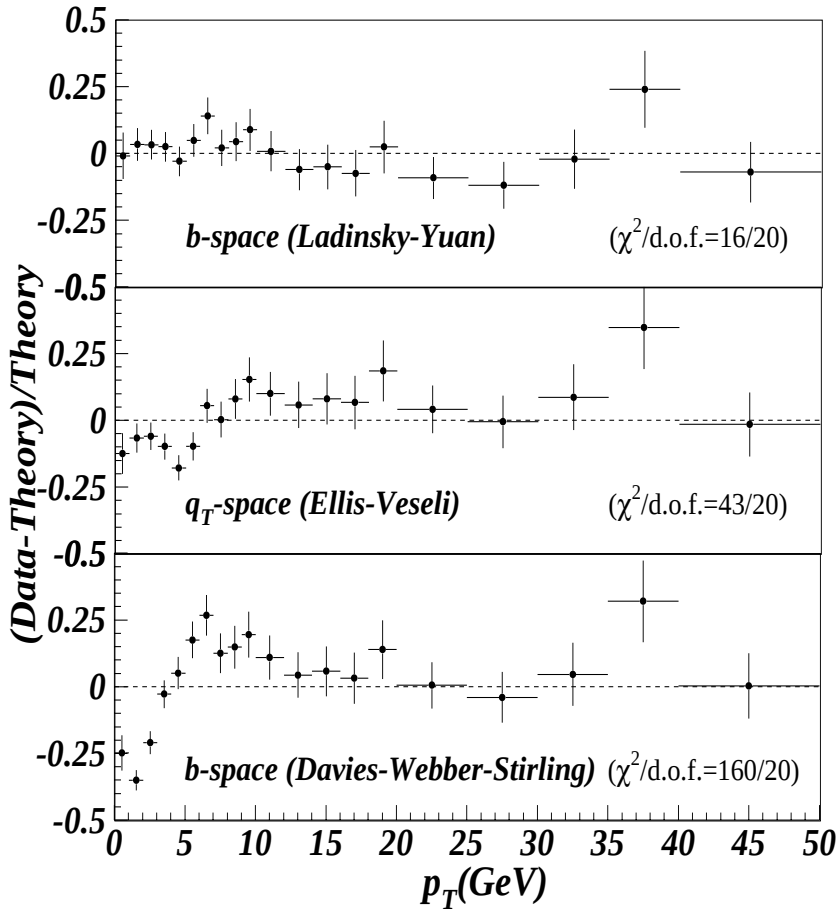


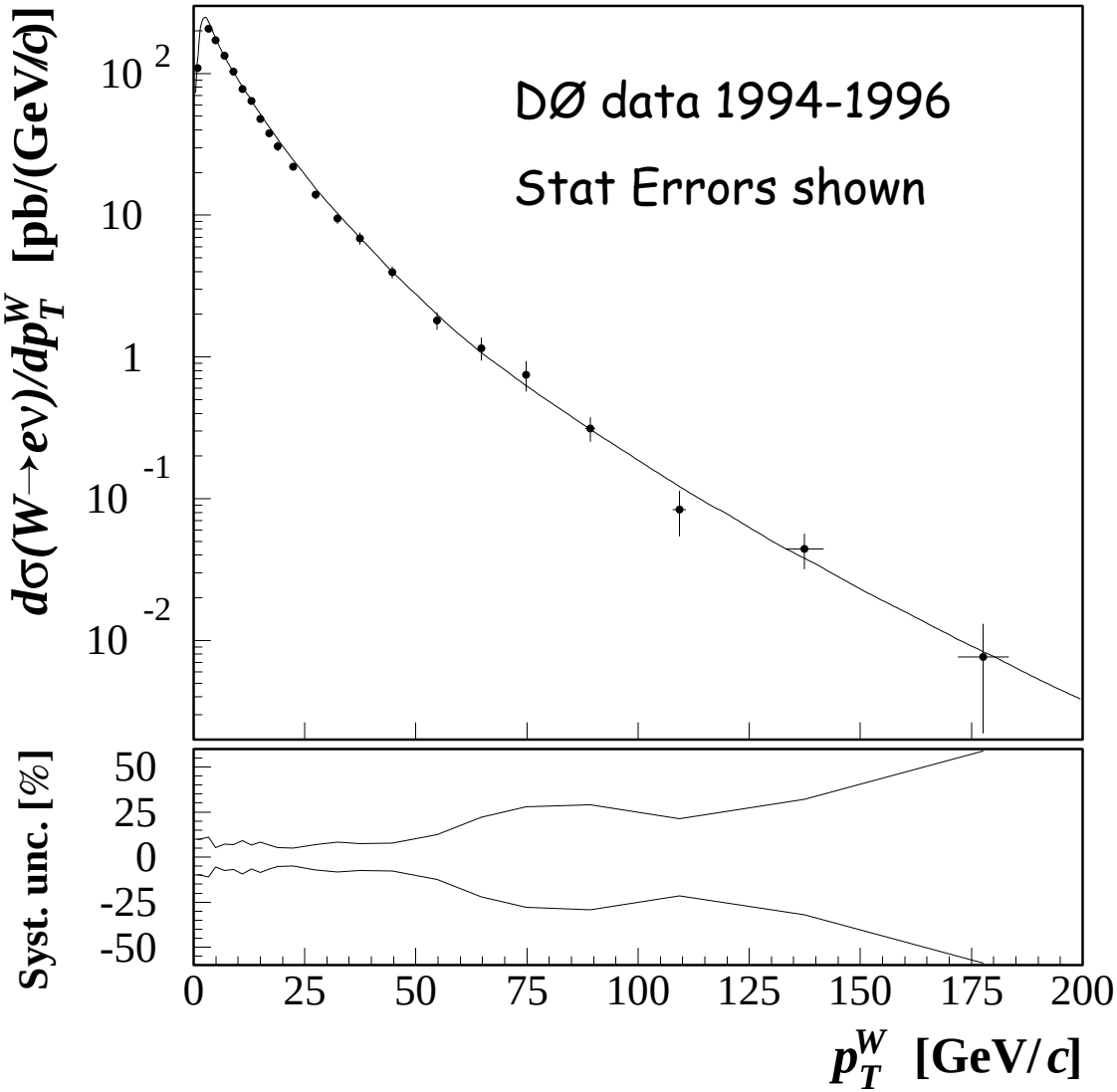


Data resolution allows to discriminate between different models for VB production.

DØ data compared to PUBLISHED parameterizations

DØ W P_T measurement

Phys. Lett. B 513, 292 (2001)



- DØ data compared to Ladinsky-Yuan b-space with parameters fitted to DØ $Z\to ee$ distribution

(g_2=0.59 ± 0.06 GeV²)

4.4% normalization uncertainty in luminosity not shown

Fractional Systematic Uncertainies

W & Z P_T Ratio Measurement

We define the ratio of differential cross sections for the scaled W & Z boson transverse momentum, p_T^W/M_W and p_T^Z/M_Z

$$R_{p_T} = \left[\frac{d\sigma^W}{d\left(p_T^W/M_W\right)}\right] / \left[\frac{d\sigma^Z}{d\left(p_T^Z/M_Z\right)}\right]$$

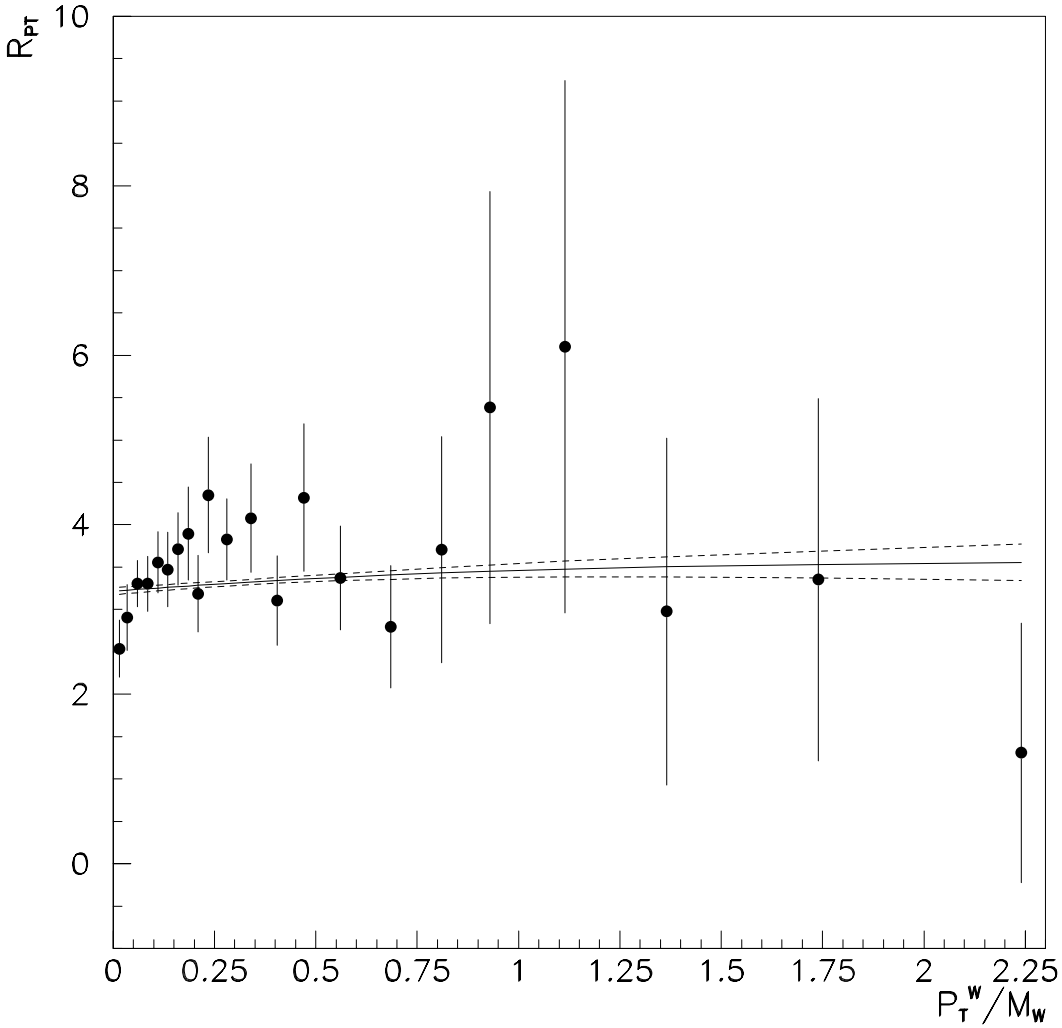
<u>Experiment:</u> the 4.3% luminosity error (dominant in both the W_{pT} & Z_{pT} measurements) cancels in the ratio

<u>Theory:</u> radiative corrections cancel $\rightarrow$ pure perturbative calculation

pQCD prediction (PRD 57, 4433, 1998)

W & Z P_T Ratio Measurement

Phys. Lett. B 517, 299 (2001)



Measured ratio (dots) compared to pQCD calculation (solid line) with uncertainty from MC integration (dash)

Good agreement with pQCD (χ^2=18.7/ 21).

Need to investigate theory dependence with PDFs and possible non-perturbative effects.

W & Z P_T Ratio Measurement

Use method in Phys. Rev. D 57, 4433 (1998) to predict W boson transverse momentum from measured Z boson p_T and pQCD Ratio:

$$\frac{d\sigma^W}{dp_T^W}\Big|_{predicted} = \frac{M_Z}{M_W} \times R_{p_T}^{theory} \times \frac{d\sigma^Z}{dp_T^Z}\Big|_{measured}^{p_T^Z = \frac{M_Z}{M_W} p_T^W}$$

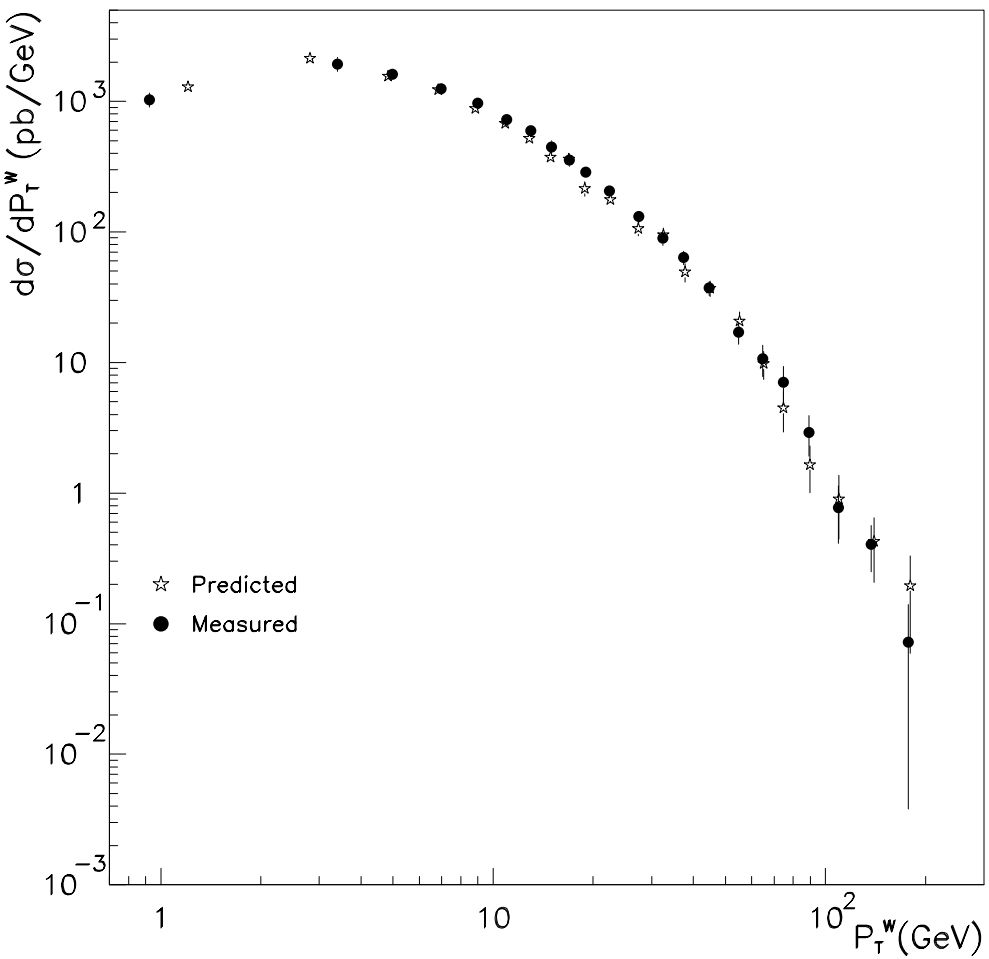
with no need to introduce resummation calculations and non-perturbative parameters at low pT

The method reduces theoretical uncertainties in the W_{pT} with respect to the standard method:

- Error now dominated by limited number of Z events (higher stats expected in Run II)

W & Z P_T Ratio Measurement

Phys. Lett. B 517, 299 (2001)



Measured Wp_T (solid circles) compared to prediction from pQCD calculation and measured Zp_T (open stars)

Predicted W_{pT} agrees well with D0 measurement (K-S probab κ =1)

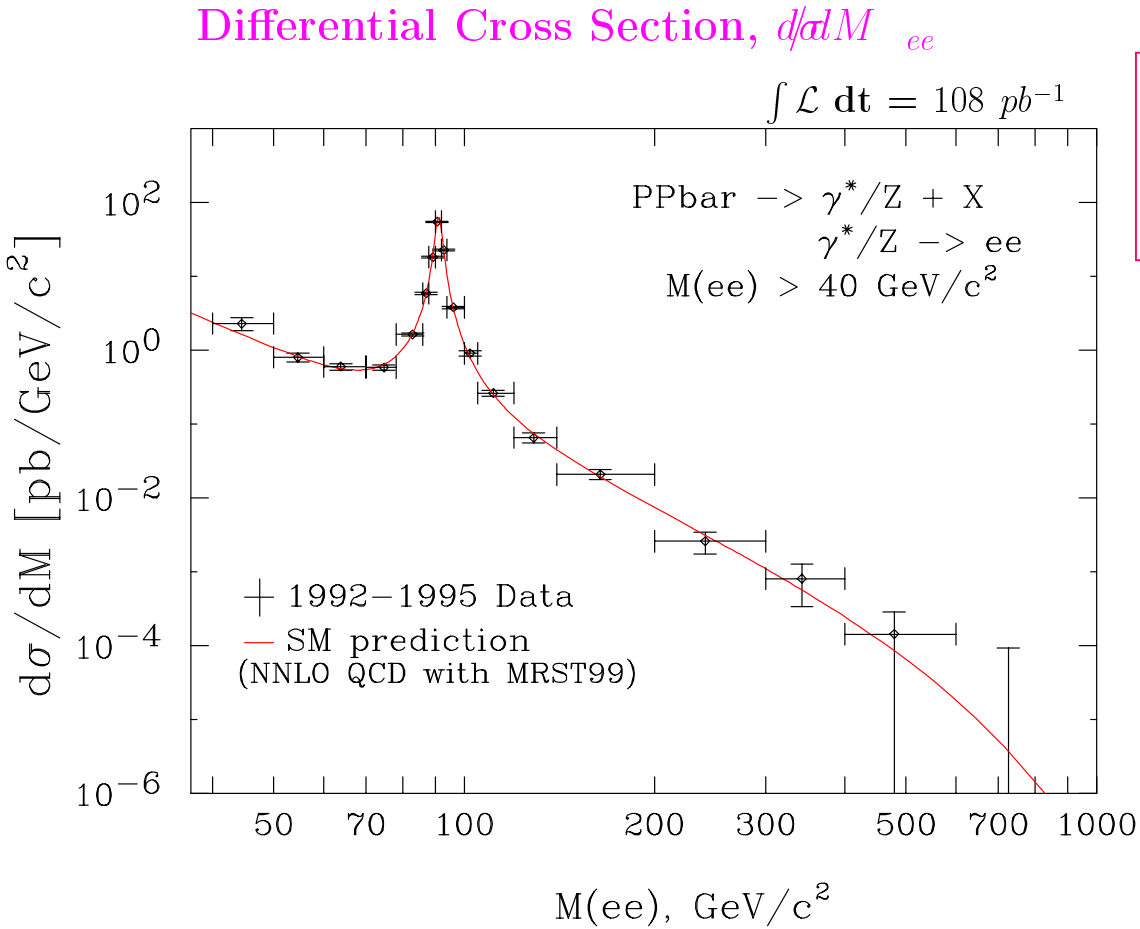
Method in PRD 57, 4433 (1998) should lead to smaller errors in W mass and width compared to current methods (using high stat Z samples in Run II)

Drell-Yan Continuum Production

- Measurements of the mass dependence ($d\sigma/dM$) and rapidity distribution ($d\sigma/dy$) of the production cross section $p\bar{p} \rightarrow e^+ e^- + X$ and the forward-backwards asymmetry (A_{FB})
- Improve published results by
  - Using electrons in the plug ($1.1<|\eta|<2.4$) and forward ($2.2<|\eta|<4.2$) calorimeters.
  - Reduced backgrounds in the forward region (tighter tracking cuts)
  - QED radiative corrections for the change in mass from the emission of the final state photons allows measurement of A_{FB} in small bins over a large range of mass.
- Compare to Standard Model Drell-Yan predictions and search for evidence of new interactions
  - additional gauge bosons
  - quark-lepton compositeness
  - exchange of R-parity violating SUSY particles
  - leptoquarks
  - extra dimensions

Mass dependence of the production cross section

Phys. Rev. Lett. 87, 131802 (2001)



$$\frac{d\sigma}{dM_i} = \frac{d_i - b_i}{a_i \times \varepsilon_i \times L \times \Delta M_i}$$

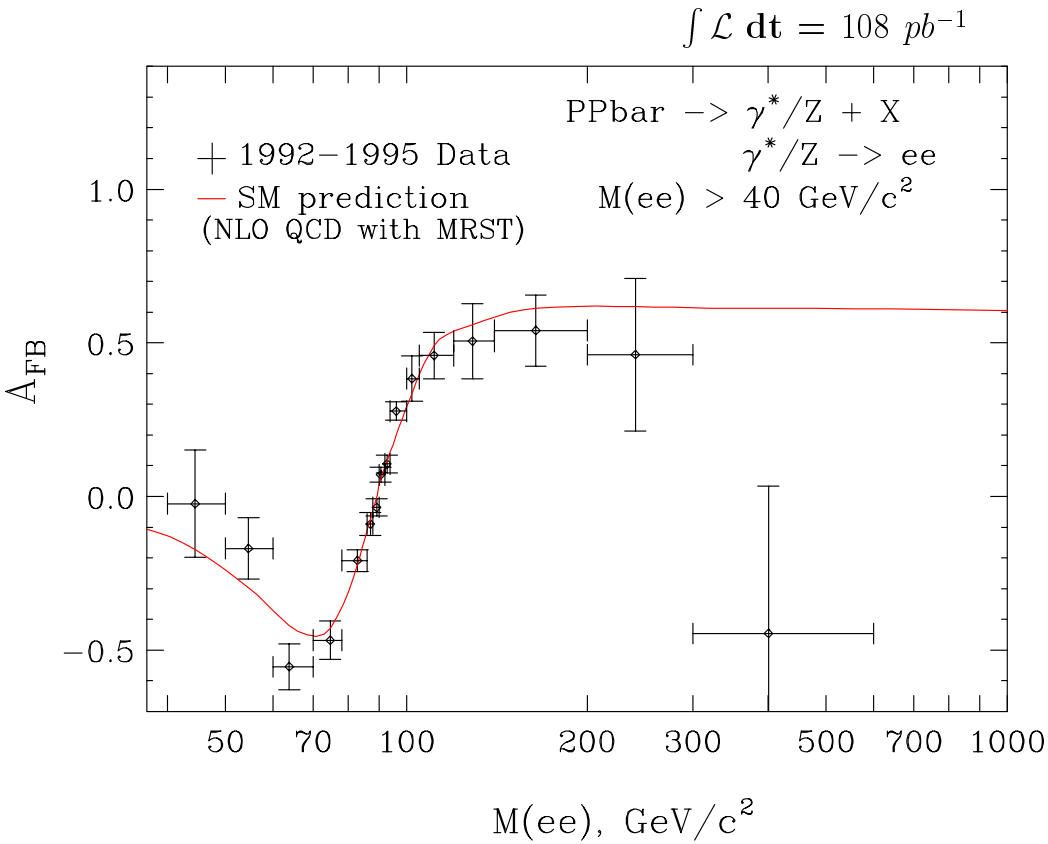
Good agreement with SM prediction

Solid line is NNLO QCD calculation with MRST99 (NLO) PDFs, scaled up by a factor 1.11.

Mass dependence A_{FB}
PRL 87, 131802 (2001)

$$A^i_{FB} = \frac{\left(\frac{d\sigma}{dM_i}\right)^+ - \left(\frac{d\sigma}{dM_i}\right)^-}{\left(\frac{d\sigma}{dM_i}\right)^+ + \left(\frac{d\sigma}{dM_i}\right)^-}$$

Forward-Backward Charge Asymmetry, A_{FB}

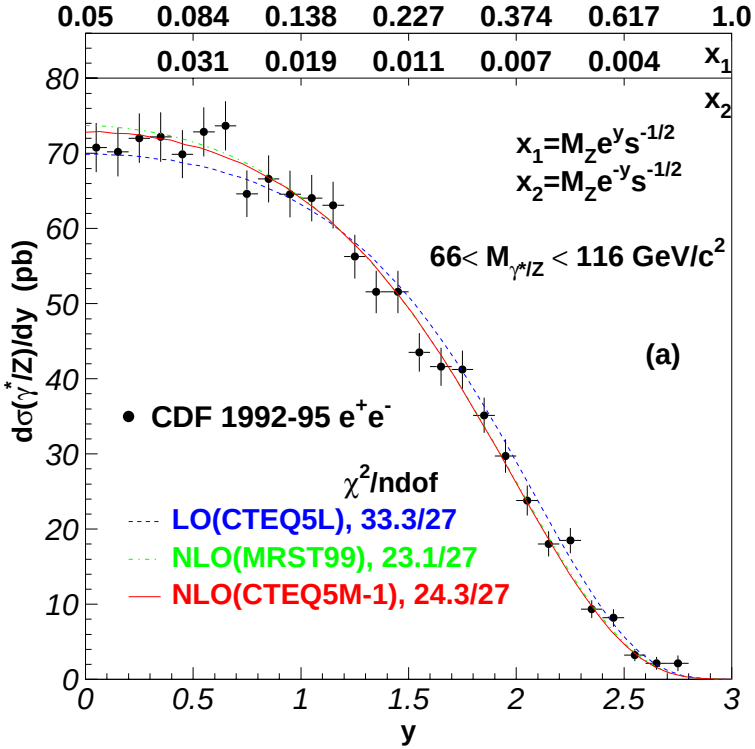


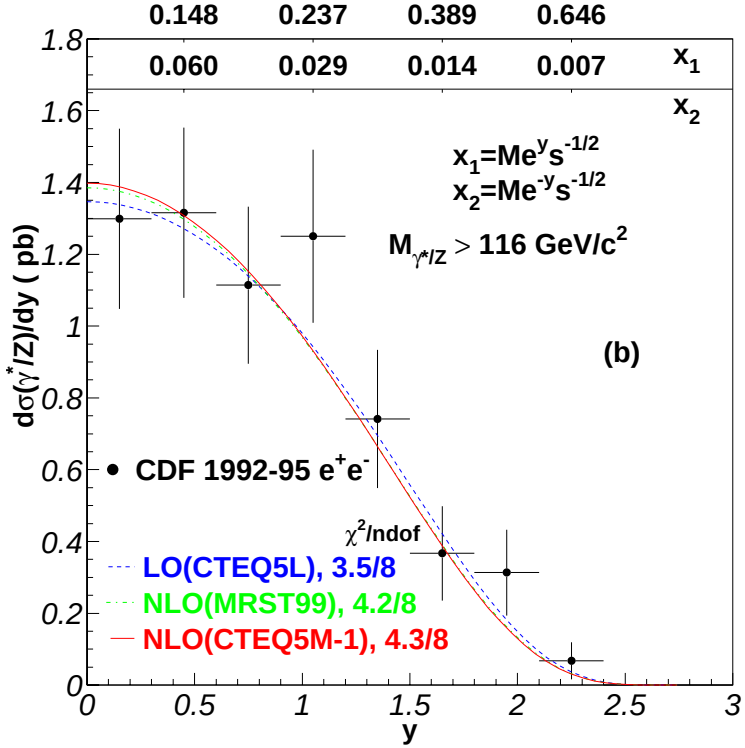
Solid line is NLO QCD calculation with MRST (NLO) PDFs

- +/- correspond to hemispheres of e wrt proton in Collins-Soper frame
- Good agreement with SM
- The highest bin (4 events - 300<Mee<600GeV) is 2.2σ below the SM prediction (probability of 2.5%)
- Negative asymmetry in this region could result from new interactions

Measurement of dσ/dy

Phys. Rev. D 63, 11101 (2001)

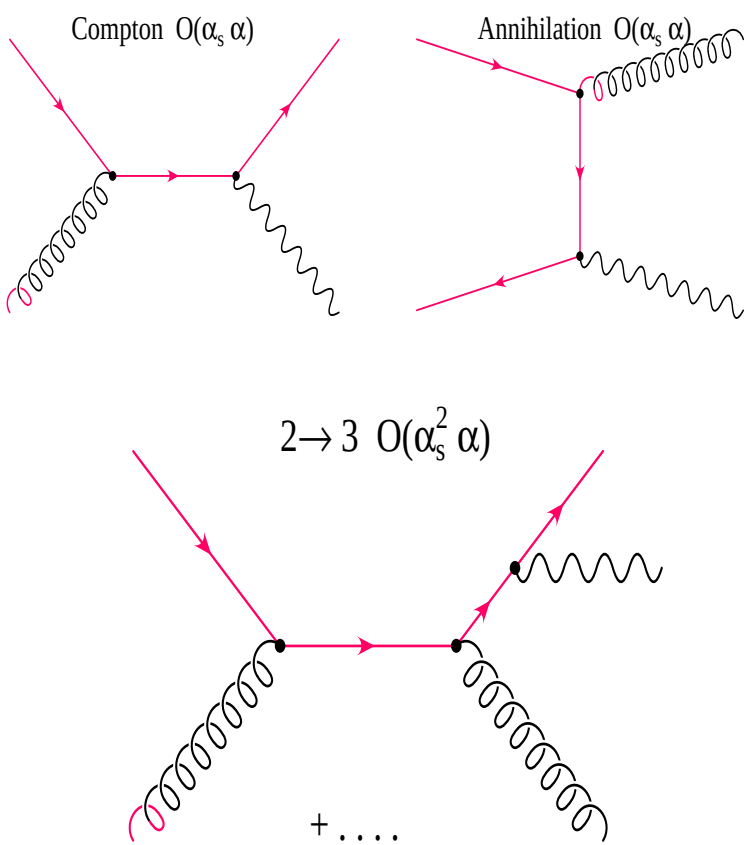




- Data shown with stat errors only
- Theory normalized to data in the Z boson mass region
- Agreement between data and NLO QCD

Model independent measurement of the total production cross section (integrating distribution) agrees with previous CDF and D0 measurements.

Ratio of Direct Photon Cross Sections at 630 & 1800 GeV



NLO diagrams contributing to γ production

- Probe pQCD without the complications from jet identification and hadronization
- Previous D0 and CDF (1.8 TeV) results reported excess of g production below ~30 GeV
- Gluon radiation (not included in NLO-QCD), PDF knowledge

D0: Ratio of dimensionless cross section

$E_T^4\, E\, d^3\sigma/d^3p$ versus $x_T=2E_T/\mathrm{sqrt}(s)$

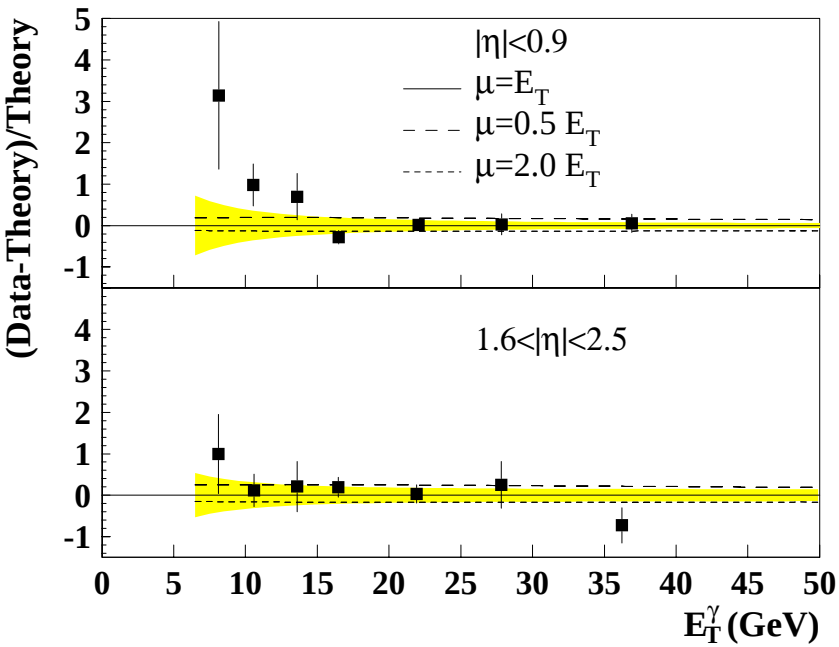
at 630 and 1800 GeV reduces systematic uncertainties and PDF sensitivity of theory

CDF: cross section $d^2\sigma/dp_T d\eta$ at 630 and 1800 GeV versus photon pT and $x_T=2p_T/\mathrm{sqrt}(s)$ give reduced sensitivity to theoretical uncertainties from scale and PDF

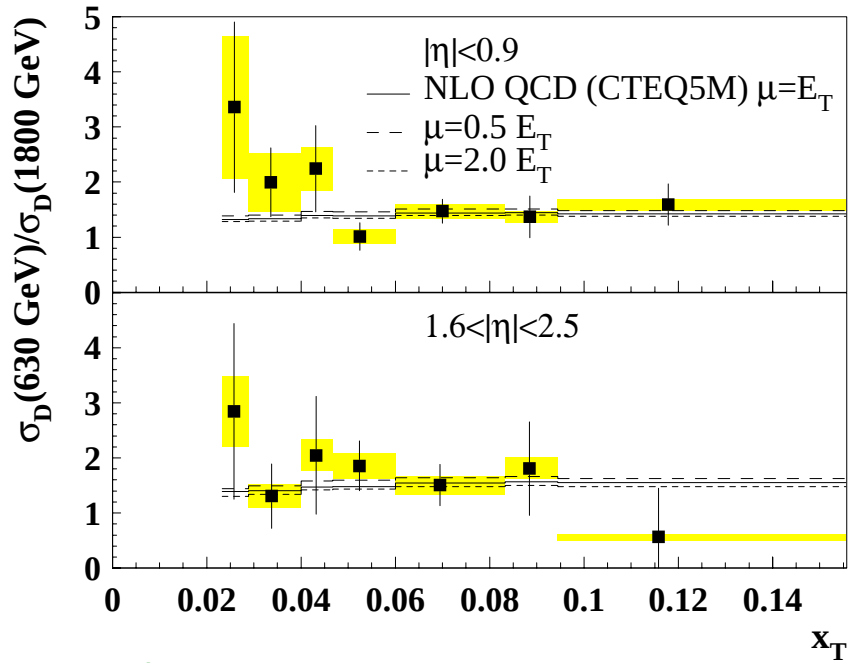
Photon Cross Sections

Phys. Rev. Lett. 87, 251805 (2001)

630 GeV Cross Sections



Ratios 630/1800



χ^2 of 11 (4.55)/7 gives 12.2% (71.4%) agreement probability in central (forward).

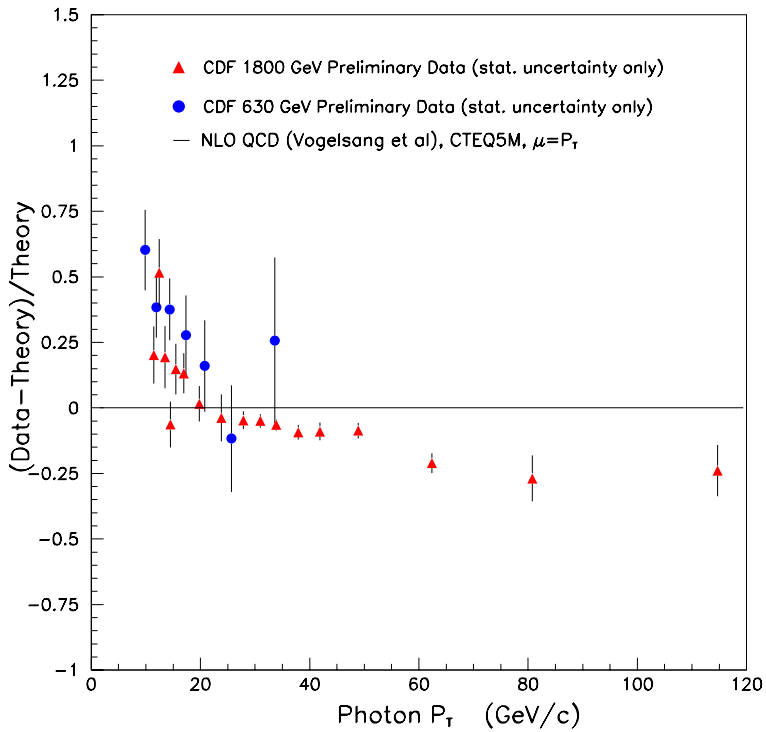
Deviations largest at low E_T

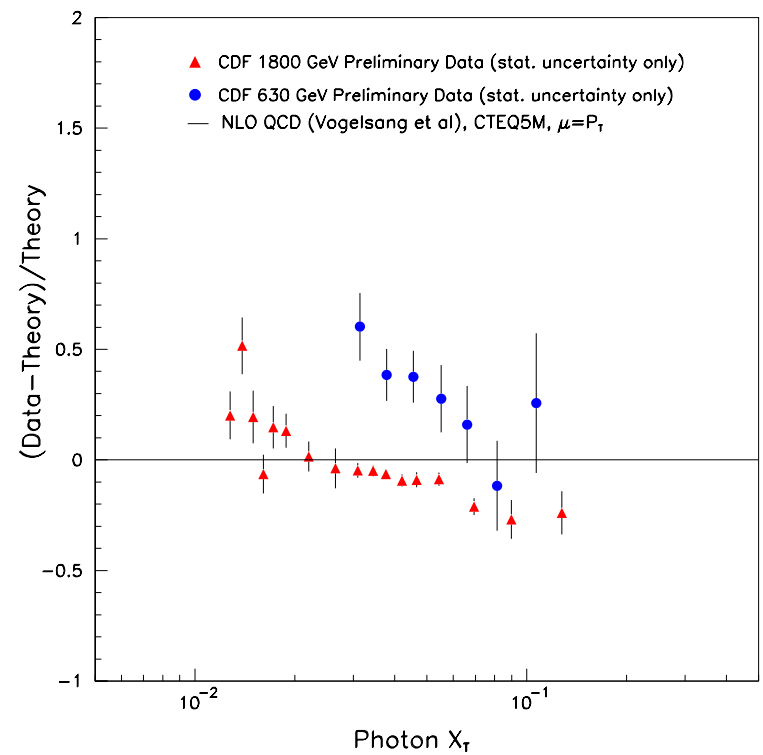
χ^2 of 6.5 (3)/7 gives 49% (89%) agreement probability in central (forward)

Data systematically higher at low E_T (not statistically significant)

Photon Cross Sections

Submitted to PRD, Fermilab-PUB 01/390-E





- Data shown with stat errors only
- Syst errors <18% (<22%) @ 1800 (630)
- Shape of data is steeper than theory
- Variations with PDFs are small

- Agreement improved by adding simplified smearing to simulate a recoil effect of the γj system consistent with that measured in Drell-Yan processes at each CME.

Summary and Prospects

- New gauge boson results in good agreement with theoretical predictions
- Continue to observe some deviation for low E_T photons – look forward to QCD calculations that include recoil effects due to soft gluon radiation.
- The study of the W, Z , γ production mechanism is important:
  - as a direct test of the Standard Model
  - to improve understanding of background in top, Higgs production
  - to control systematics in precision measurements such as the W mass

Run II has started & we expect to collect $2fb^{-1}$ during 2001-2003

Much larger number of W, Z, γ (~factor 20 with respect to Run I):

- reduce systematics in the W_{pT}, Z_{pT} measurements as well as the predictions
- Reduce uncertainties in γ cross sections (dominant error was γ purity in Run I), extend p_T reach from ~100 GeV to ~<300 GeV at 1.8 TeV, understand photon production mechanism at low pT