Review of W and Z Production at the Tevatron

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(Fermilab)

For the CDF and DØ Collaborations

XXXIIIrd RENCONTRES DE MORIOND
QCD AND HIGH ENERGY HADRONIC INTERACTIONS
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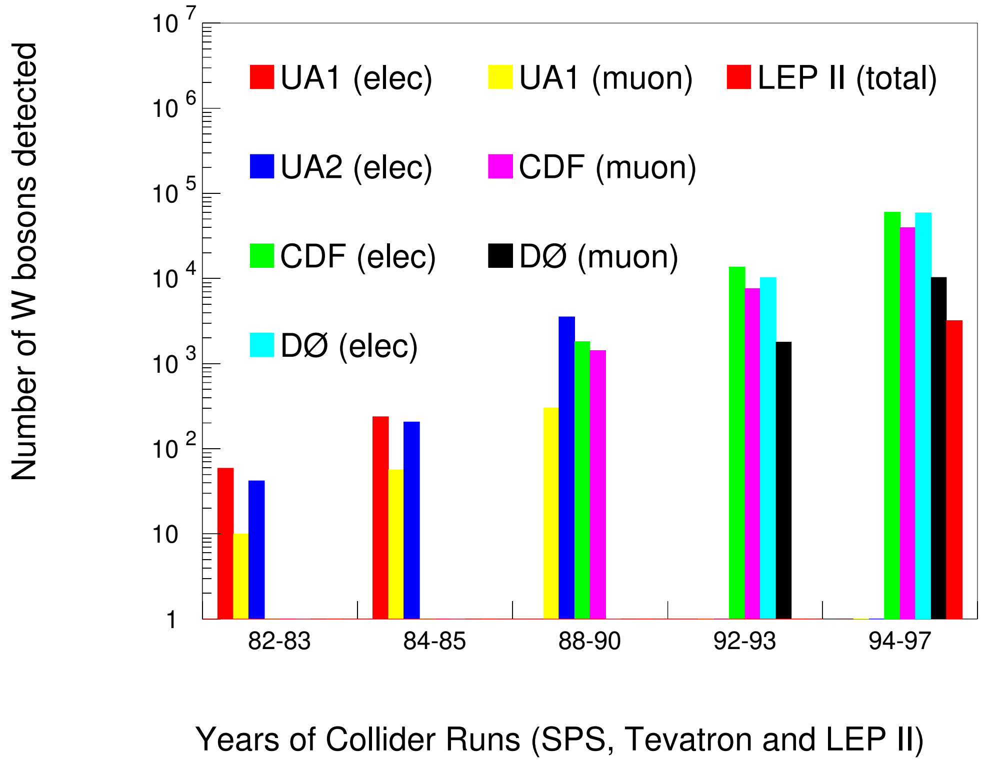
Outline

- W and Z Production x–sec
- Γ_W
- The Differential p_T^W and p_T^Z Cross–Sections
- W + Jets Production
- Conclusions and Outlook

W Bosons Detected



Tevatron Runs

- "Run 0 " $= 1988/90$, $\int \mathrm{L}dt \sim 4\mathrm{pb}^{-1}$ (CDF)
- "Run 1A" $= 1992/93$, $\int \mathrm{L}dt \sim 20\mathrm{pb}^{-1}$
- "Run 1B" $= 1994/95$, $\int \mathrm{L}dt \sim 90\mathrm{pb}^{-1}$
- "Run 1C" $= 1995/96$, $\int \mathrm{L}dt \sim 20\mathrm{pb}^{-1}$
- "Run 2" $=$ scheduled to start in 2000.

DØ W and Z inclusive samples

Event selection:

- high quality isolated leptons (e or μ)
- One high p_T lepton + Missing E_T (W)
- Two high p_T leptons (Z)

$$\varepsilon^W(e) \approx 70\%, \qquad A^W(e) \approx 45\%$$
$$\varepsilon^Z(e) \approx 76\%, \qquad A^Z(e) \approx 35\%$$

$W \to e\nu$ Backgrounds

- Major background source is QCD dijets. One jet fluctuates electromagnetically and gets selected as an electron. The mismeasured energy fakes the $\not\!\!E_T$.
- Estimate using two samples with known efficiency and rejection. Assumes that all data with $\not\!\!E_T$ < 15 GeV is background.

$$f_{QCD}(CC) \approx 4\% \qquad f_{QCD}(EC) \approx 13\%$$

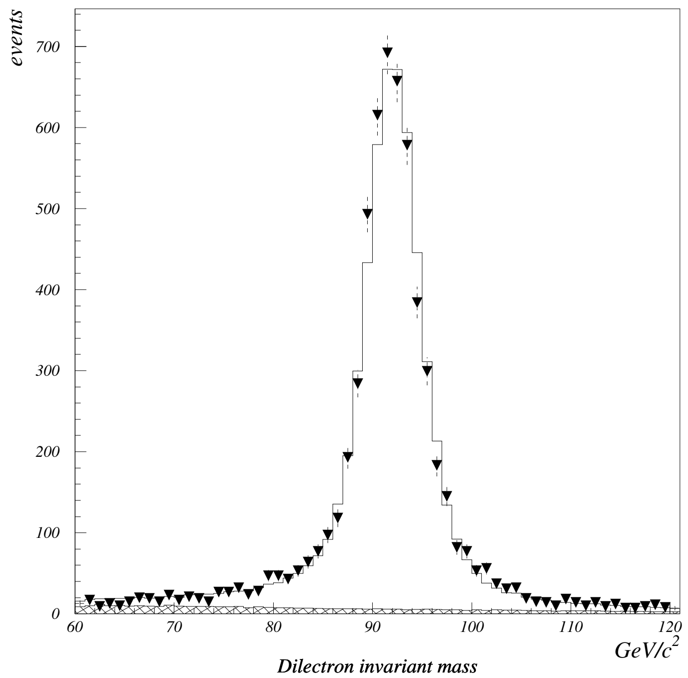
- Remaining backgrounds: $W \to \tau\nu$, $Z \to \tau\tau$ and $Z \to e\not{e}$, are estimated using Monte Carlo samples.

$$f_\tau \approx 2\% \qquad f_{Z\to e\not{e}} \approx 0.5\%$$

DØ W and Z inclusive samples (cont)

$Z \to ee$ Backgrounds

- Major background source is QCD (dijet and direct photon), with jets faking electrons.
- Estimate by fitting the data to Signal $Z \to ee$ from Monte Carlo plus Background from data.



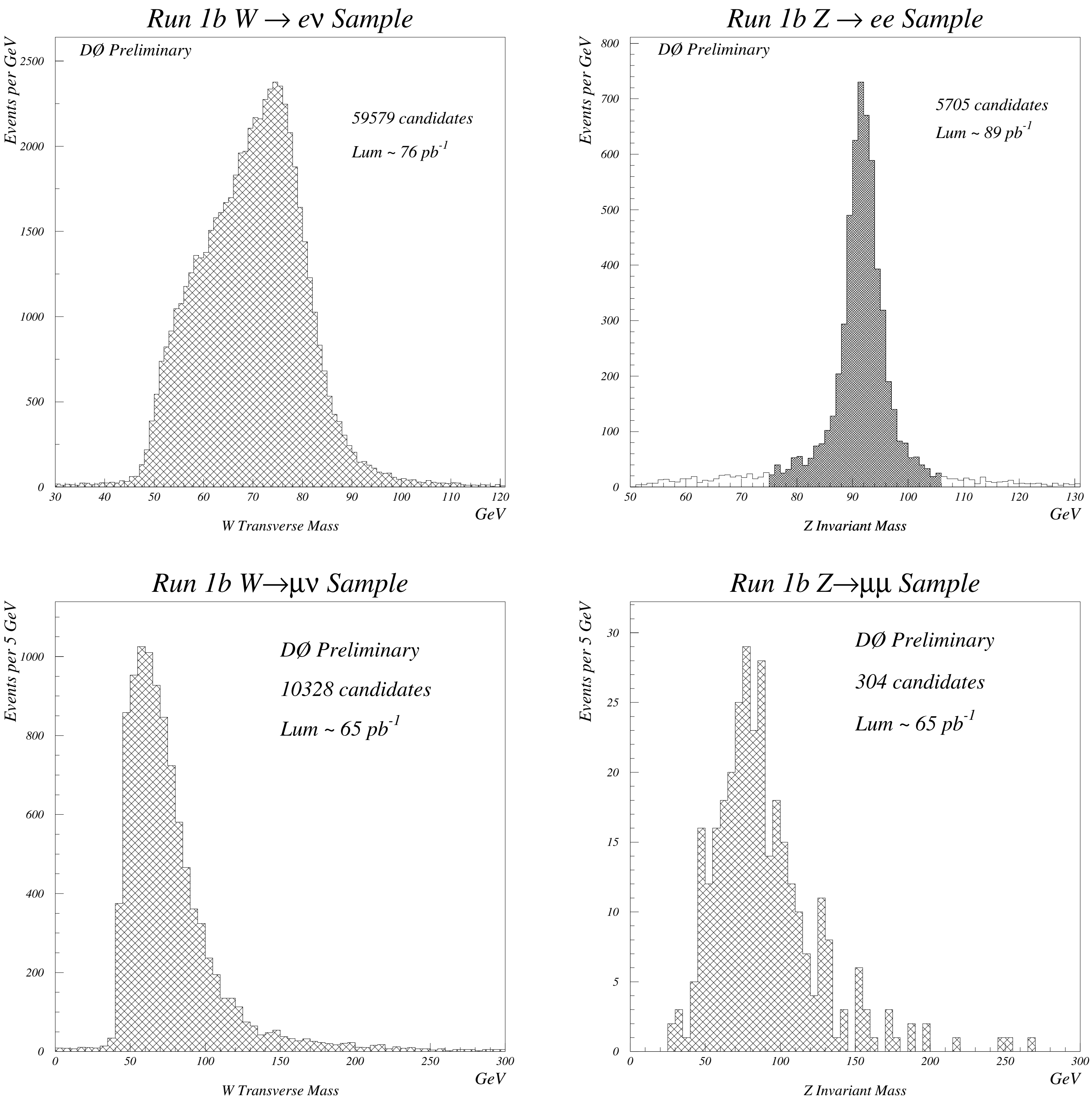
$$f_{QCD}(CC - CC) \approx 2\%$$
$$f_{QCD}(CC - EC) \approx 7\%$$
$$f_{QCD}(EC - EC) \approx 5\%$$

- Remaining backgrounds: Drell–Yan and $Z \to \tau\tau$ are estimated using Monte Carlo samples.

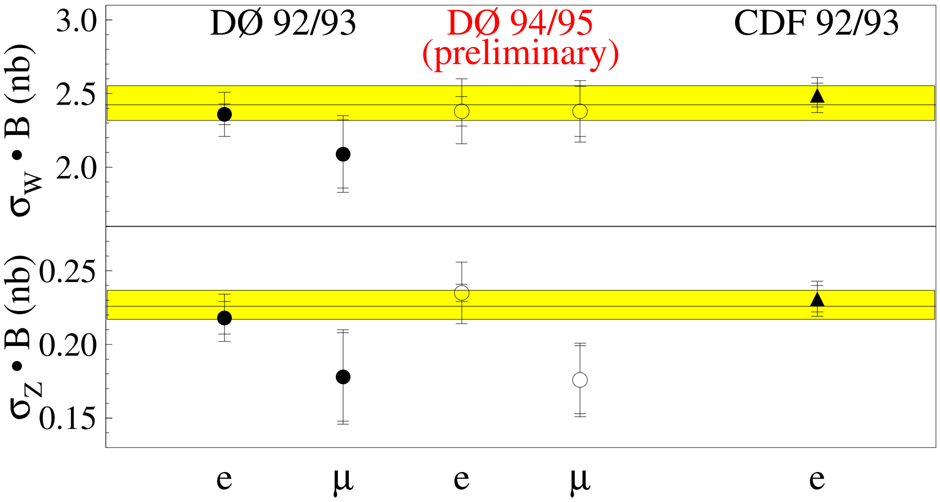
$f_{DY} \approx 1\%$ $f_{Z \to \tau\tau}$ = negligible

W and Z candidates samples

(DØ Run 1B, preliminary)



W and Z cross sections



- Theory: $O(\alpha_s^2)$, Hamberg, van Neerven & Matsuura, NP B359, 313; van Neerven & Zijlstra, NP B382, 11.
- Dominant uncertainties:
  - Data: luminosity ($\approx 8\%$)
  - Theory: parton distribution functions ($\approx 3\%$)

DØ Run 1B (prelim), uncertainties: stat., syst., lum.

$$\sigma \cdot B(W \to e\nu) = 2.38 \pm 0.01 \pm 0.09 \pm 0.20\text{nb}$$

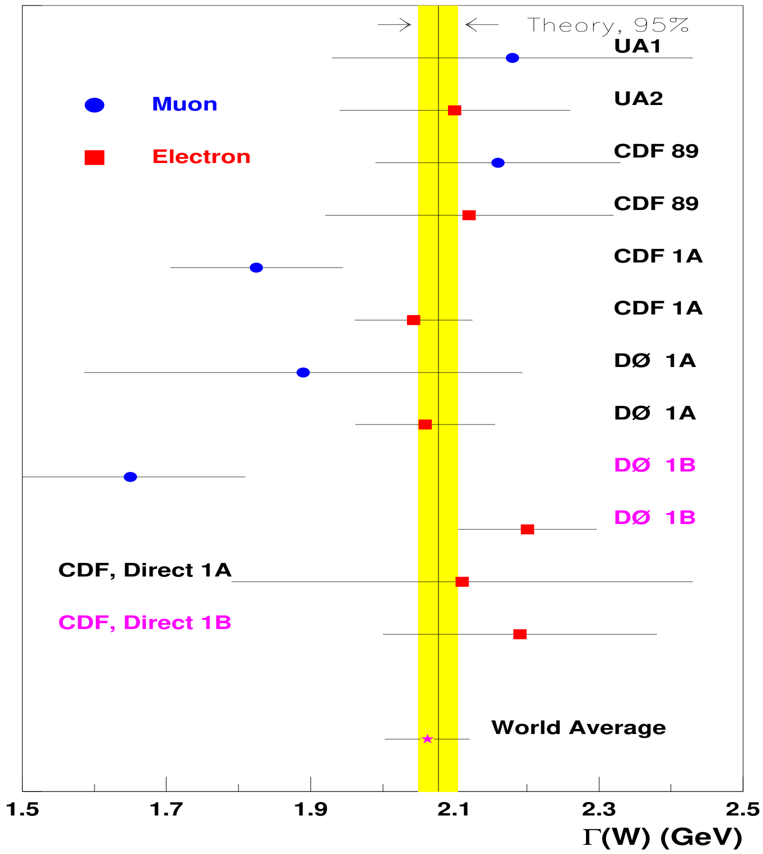
$$\sigma \cdot B(W \to \mu\nu) = 2.38 \pm 0.03 \pm 0.17 \pm 0.13\text{nb}$$

$$\sigma \cdot B(Z \to ee) = 0.235 \pm 0.003 \pm 0.005 \pm 0.020\text{nb}$$

$$\sigma \cdot B(Z \to \mu\mu) = 0.176 \pm 0.011 \pm 0.020 \pm 0.009\text{nb}$$

Expect systematic uncertainty to be reduced to $\approx 2\%$ in the Cross–Sections and to $\approx 1\%$ in the Ratio.

Cross Section Ratio (Γ_W)



$$R_\ell = \frac{\sigma(W)}{\sigma(Z)} \cdot \frac{B(W \to \ell\nu)}{B(Z \to \ell\ell)} = \frac{\sigma(W)}{\sigma(Z)} \cdot \frac{\Gamma(W \to \ell\nu)}{B(Z \to \ell\ell)} \cdot \frac{1}{\Gamma(W)}$$

DØRun 1B (preliminary): $R_\ell = 10.48 \pm 0.43$

- $\sigma(W)/\sigma(Z)$ from theory, $B(Z)$ from LEP/SLC:
  - $B(W \to \ell\nu) = (10.59 \pm 0.44)\%$
- assume $\Gamma(W \to \ell\nu)$ as well:

$\boxed{\Gamma(W) = 2.126 \pm 0.092 \text{ GeV}}$

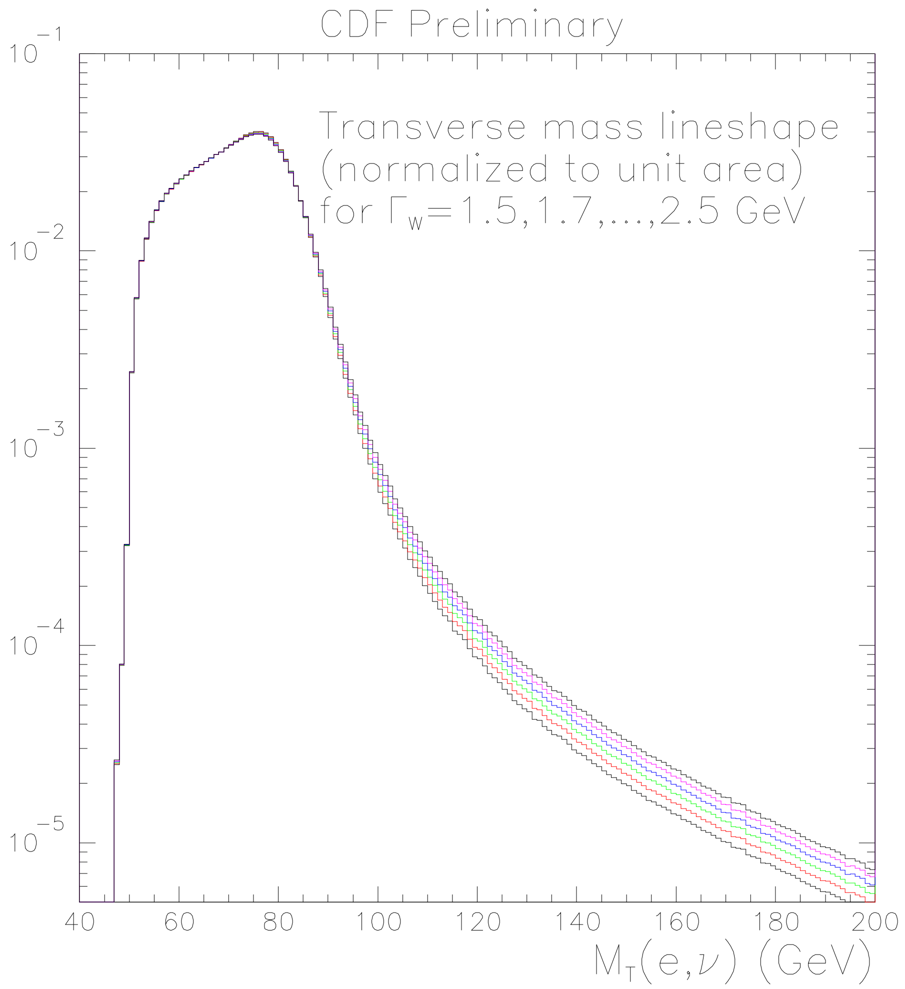
(SM: 2.077 ± 0.014 GeV)

World Average: 2.062 ± 0.059 GeV

Unexpected Decays:109 MeV

Direct Measurement of Γ_W

- Direct Measurement avoids using theoretical inputs.
- Explores the region above W pole where new physics could appear.



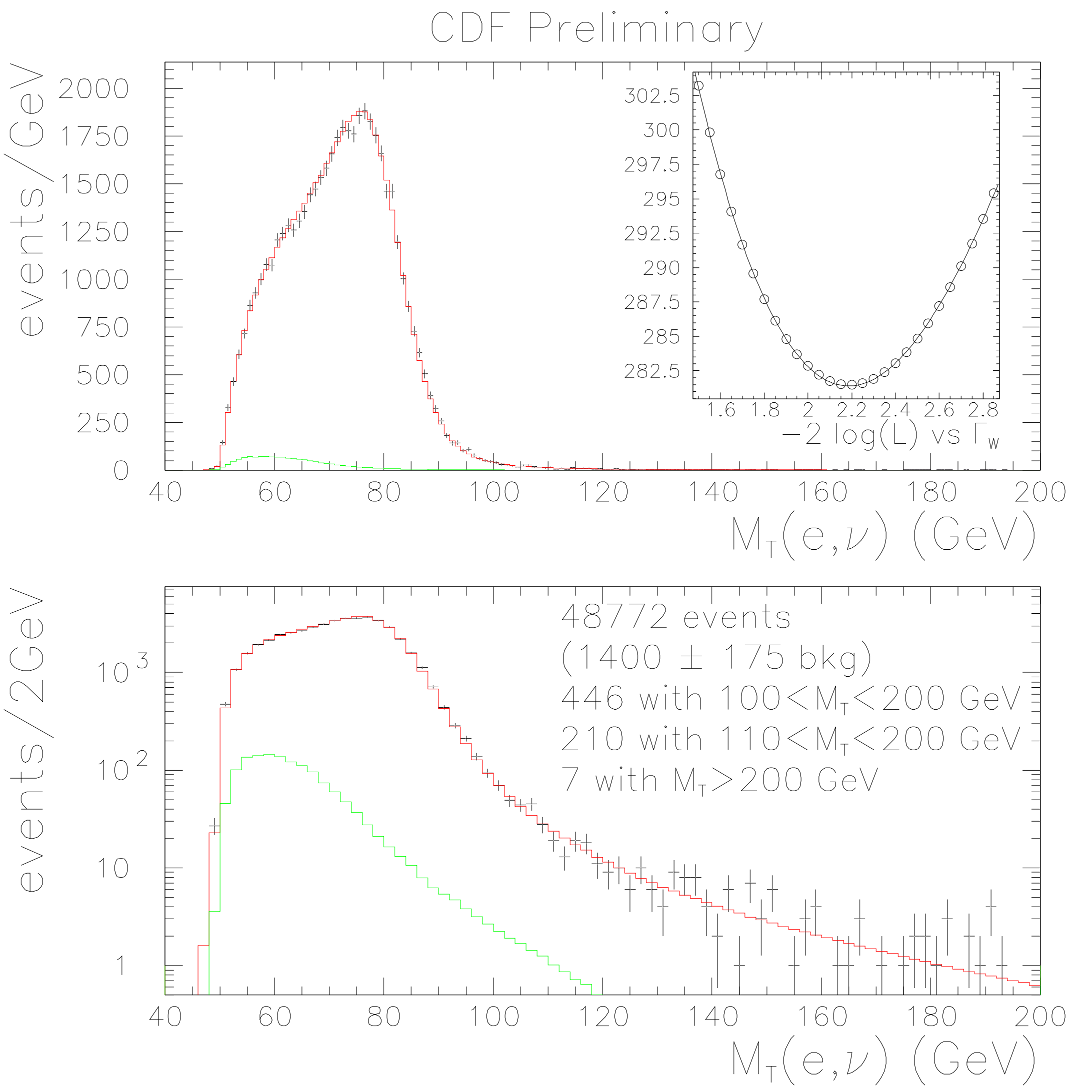
- Lineshape shown from Monte Carlo including Detector response and event selection for different Γ_W
- The tail region of M_T^W is sensitive to $\Gamma_W \Rightarrow$ can use to extract Γ_W

Direct Measurement of Γ_W (cont)

- $M_T(e,\nu)$ lineshape modelled with W mass fast MC:
  - M^W from momentum dependent Breit–Wigner $\times$ Parton Luminosity Function.
  - y and p_T distribution from Ladinsky–Yuan (small p_T) and NLO pQCD (large p_T).
  - W decay from E. Mirkes ($e\nu$) and Berends and K-leiss ($e\nu\gamma$.)
  - Standard CDF W mass measurement detector simulation.
- Fit M_T^W data distribution in $110 < M_T^W < 200$ GeV window to a signal MC + background prediction for different Γ_W.
- Dominating uncertainties:
  - Backgrounds (40 MeV)
  - Recoil Modelling (55 MeV)
  - EM scale (55 MeV)
  - W mass and p_T^W spectrum (25 MeV)

Direct Measurement of Γ_W

(CDF Run 1B, preliminary)



$$\Gamma_W = 2.19 \pm 0.17(stat) \pm 0.09(syst) \text{ GeV}$$

(SM: $\Gamma(W) = 2.077 \pm 0.014$ GeV)

Differential p_T^W and p_T^Z Cross Section

Introduction to Theory

Theoretical Calculations for $(d^2\sigma)/(dp_T d_Y)$ use:

- Perturbative QCD at Large $p_T (p_T \geq 50$ GeV)

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

- Resum $(ln(Q^2/p_T^2))$ at Small $p_T (p_T \leq 10$ GeV)

  $\frac{d^2\sigma}{dp_T d_Y} \sim \int d^2b \, e^{i\vec{b}\cdot\vec{Q_T}} \, W(b\prime) \, e^{-S(b)}$

  Altarelli, Ellis, Greco, Martinelli (84);

  Collis, Soper, Sterman (85).

- Parametrize the Non–Perturbative Contribution

  $S(b) = g_1 b^2 + g_2 b^2 \, ln(b_{max} Q/2)$ (DWS,AK)

  $S(b) = g_1 b^2 + g_2 b^2 \, ln(b_{max} Q/2) + g_1 g_3 b \, ln(100 x_a x_b)$ (LY)

  $S(b) = g b^2$ (ERV)

  Davies, Webber, Stirling (85); Arnold–Kauffman (91); Ladisky–Yuan (94); Ellis, Ross, Veseli (97).

- Match the two p_T regions

  Arnold–Kauffman (91)

- Knowledge of W/Z production is the foundation for many searches for new physics, and a source of systematic uncertainty in W Mass and Direct Width measurements.

Differential p_T^W and p_T^Z Cross Section

Need to determine all quantities as a function of p_T

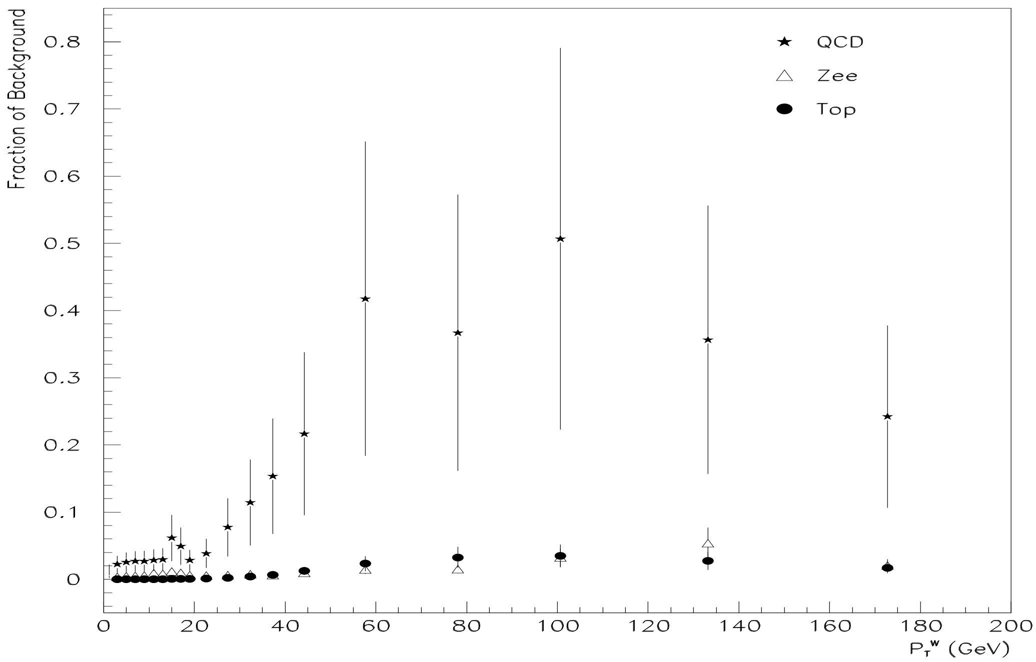
- Measure

$$\frac{d\sigma}{dP_T}(i) = \frac{N_{obs}(i) - N_{bkgd}(i)}{A_i \varepsilon(i) \Delta Bin(i) Br(e) \mathcal{L}}$$

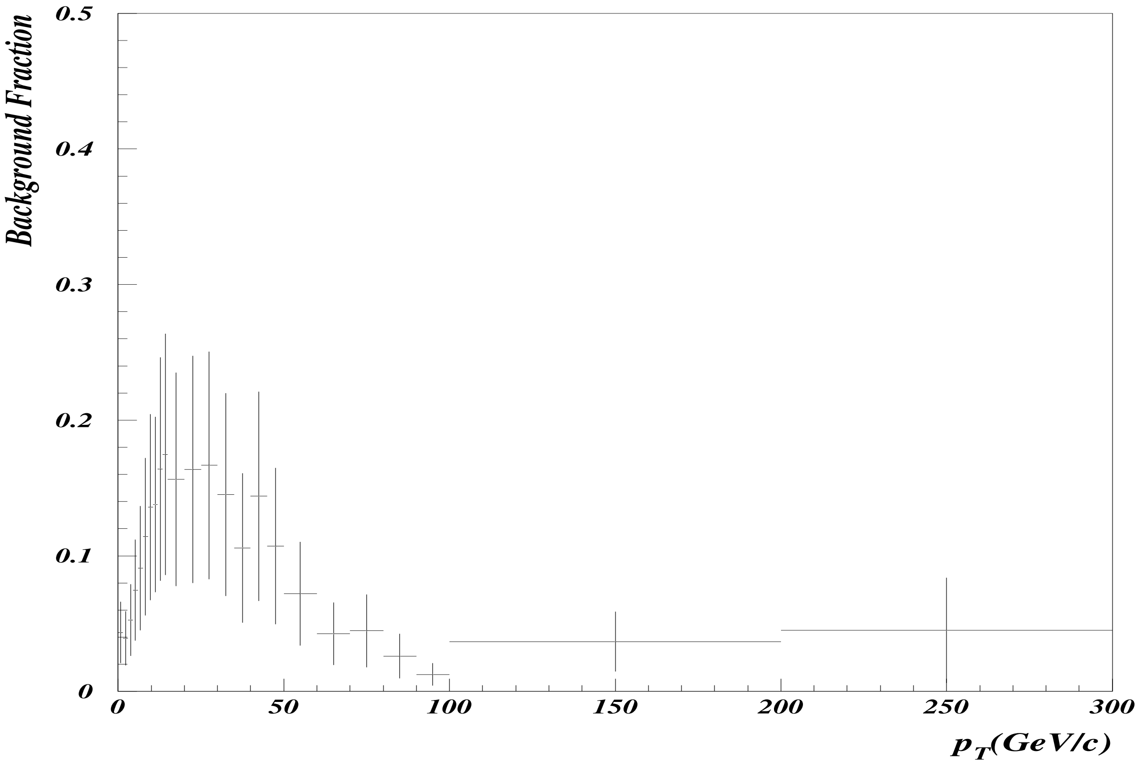
- Acceptance vs p_T obtained from fast Monte Carlo
- Efficiency vs p_T obtained from HERWIG $Z \to ee$ with full DØ detector simulation and overlayed zero bias events
- Primary background is QCD: amount vs p_T obtained from data
- Data samples: Run 1A (CC) $W \to e\nu$ (7132 events),
  Run 1B/1C $Z \to ee$ (6407 events)
- For current analyses, measured p_T is compared to smeared theory: focus on shape comparisons.
- Previous Measurements: UA1, UA2, CDF (Run 0)

Background fractions vs p_T

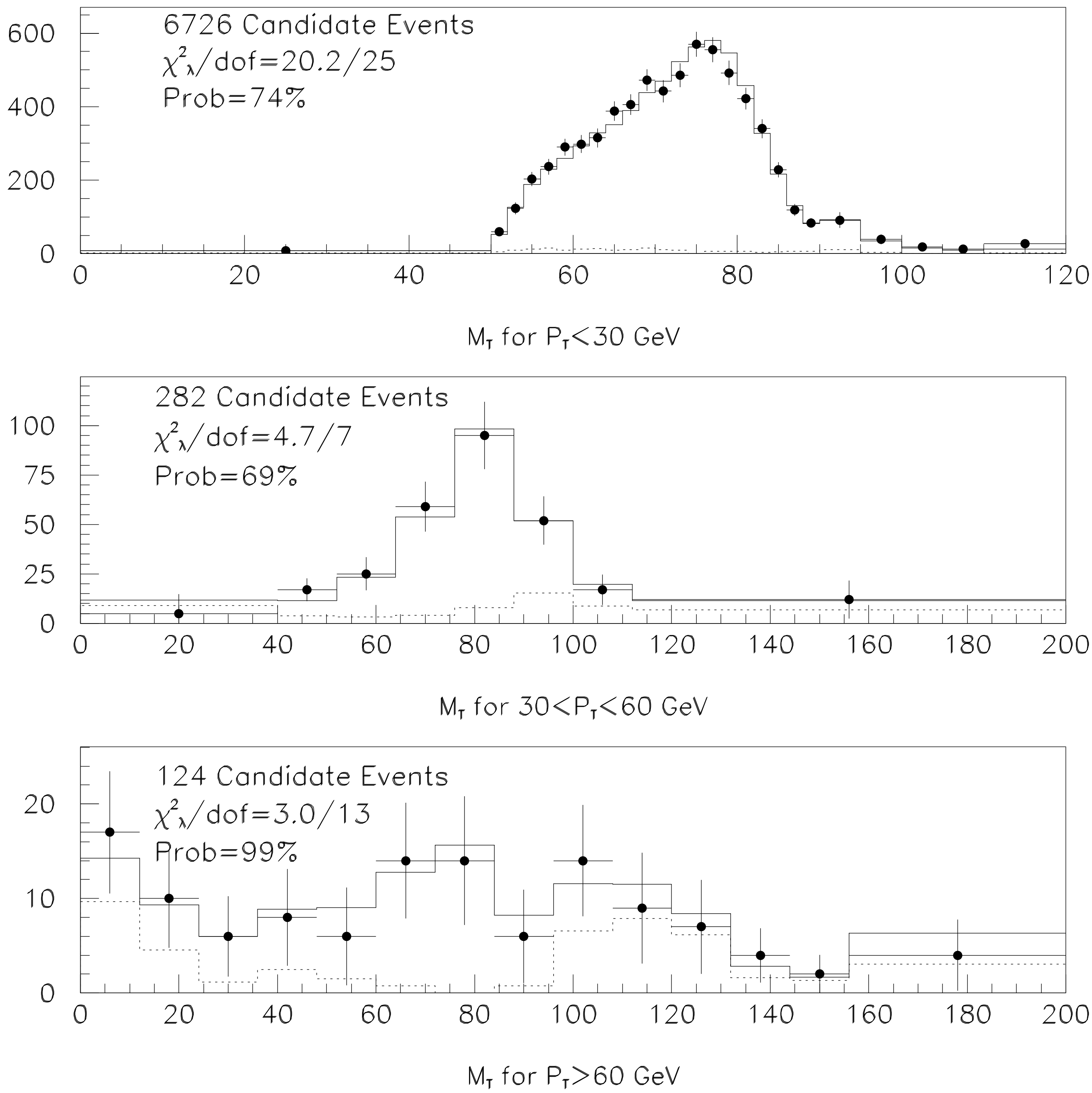
W



Z

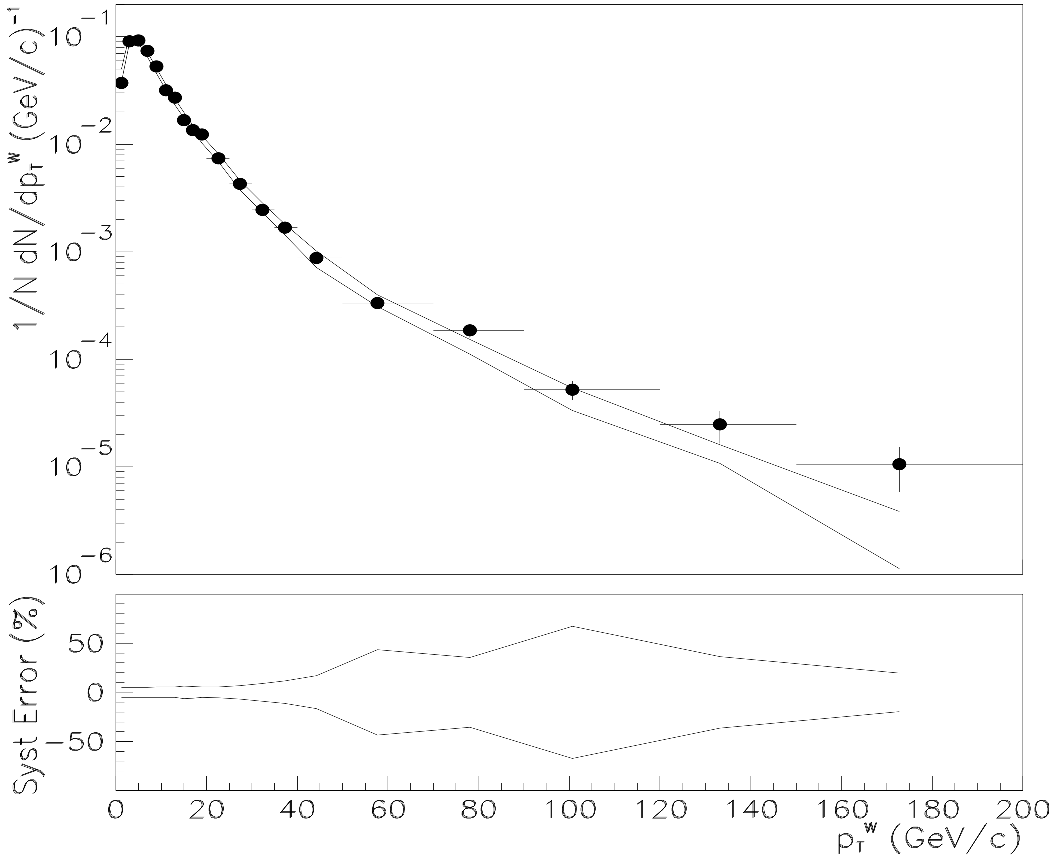


QCD background to p_T^W: Cross Check

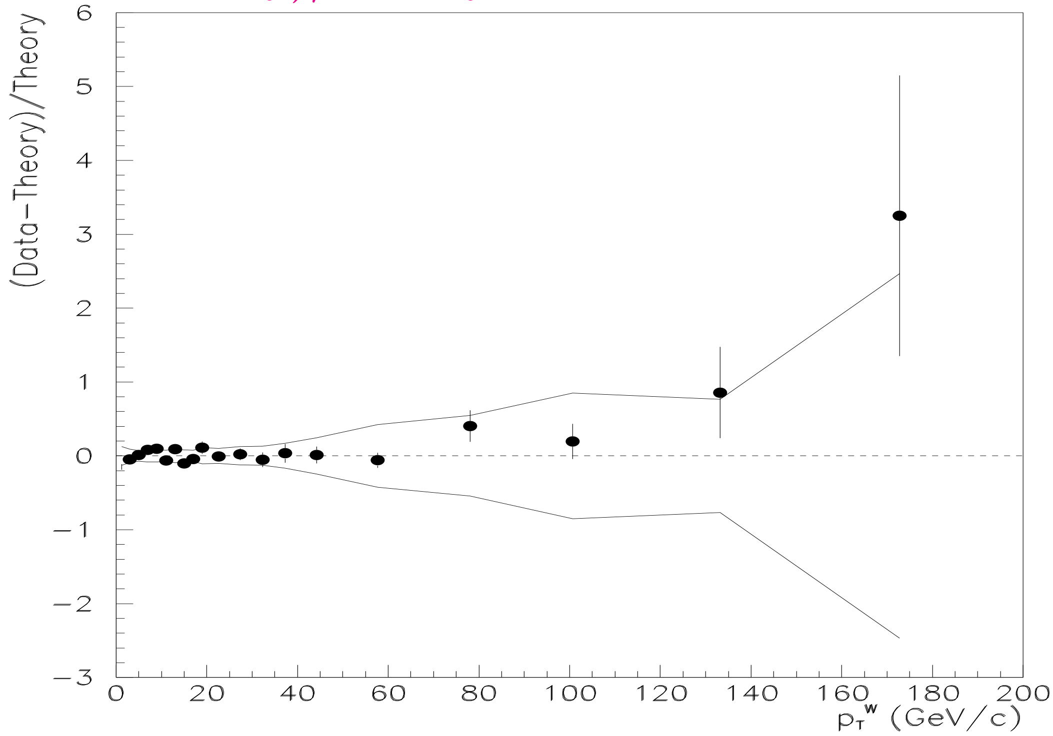


$\chi^2_\lambda = 2\Sigma(e_i - o_i + o_i\, ln(o_i/e_i))$, **Baker & Cousins, NIM 221 (1984)**

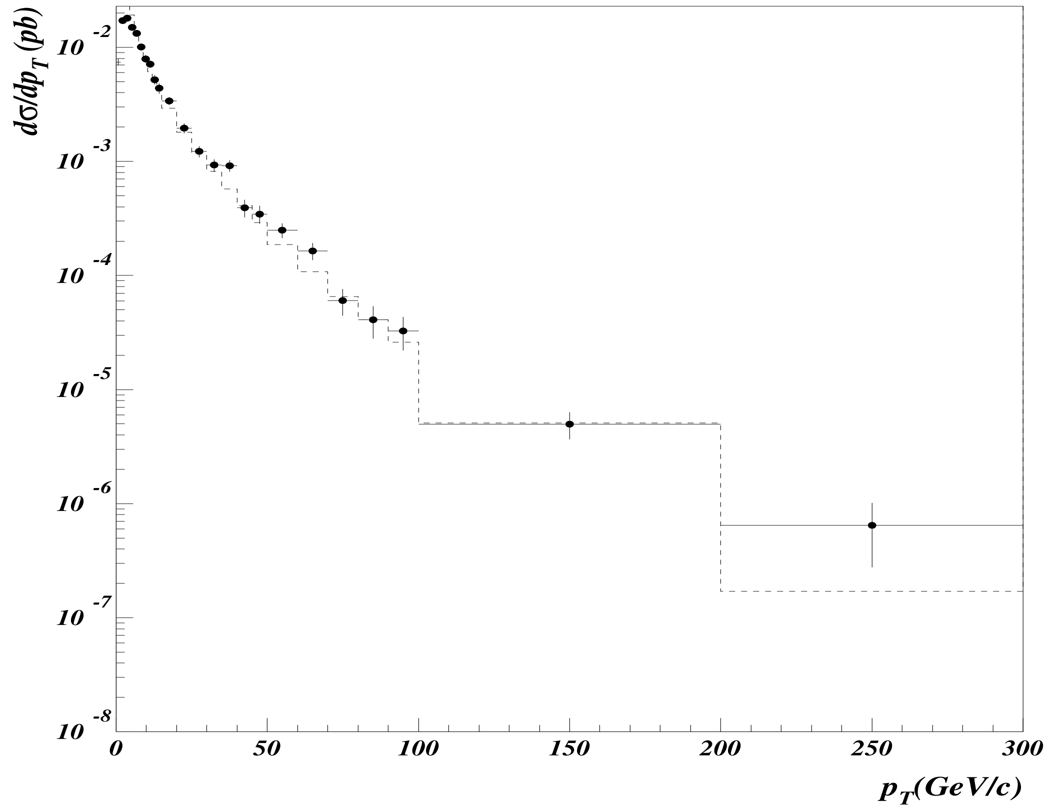
p_T^W (DØ Run 1A, submitted to PRL)



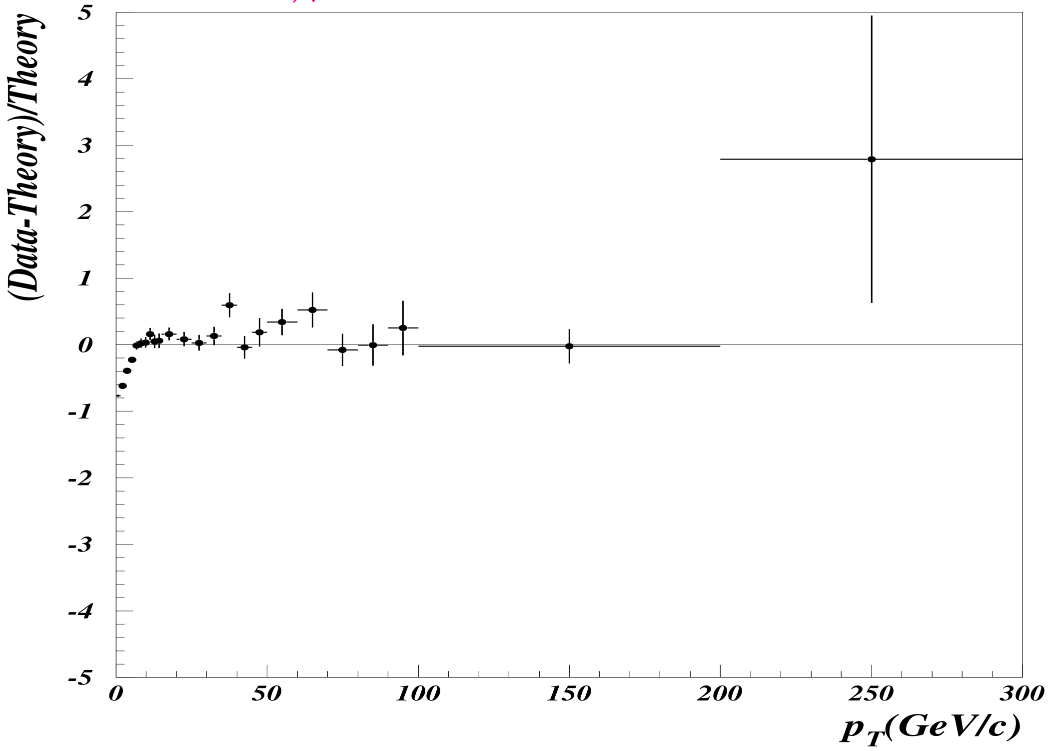
(Data − Theory)/Theory



p_T^Z (DØ Run 1B/1C preliminary)

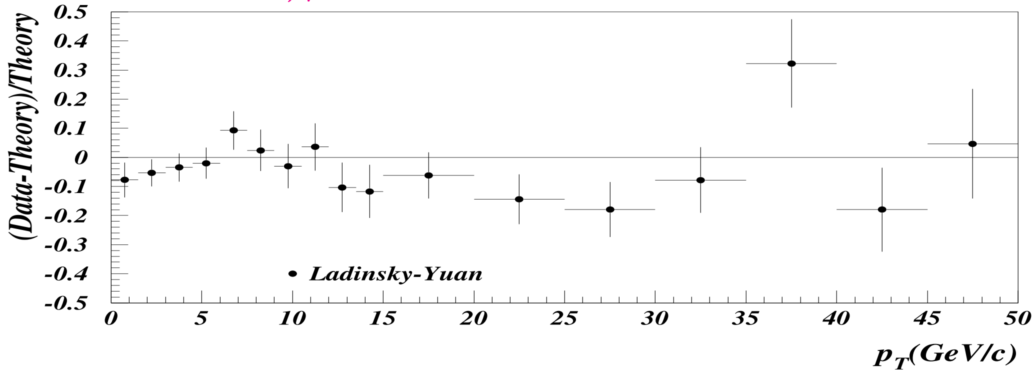


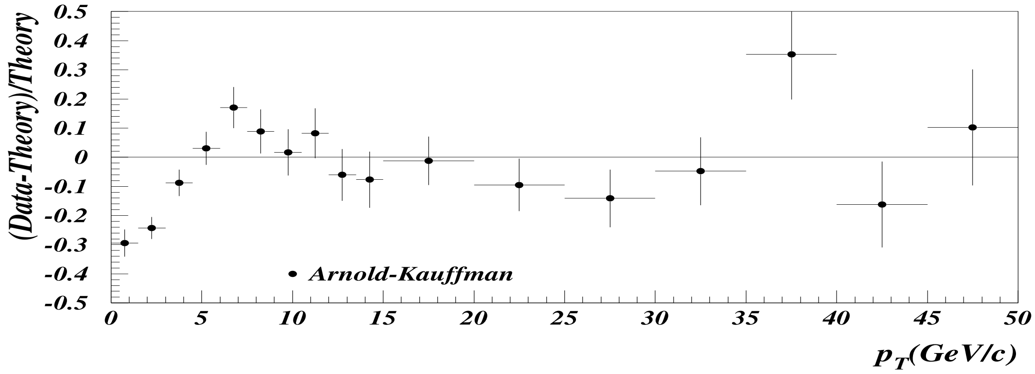
(Data − Theory)/Theory



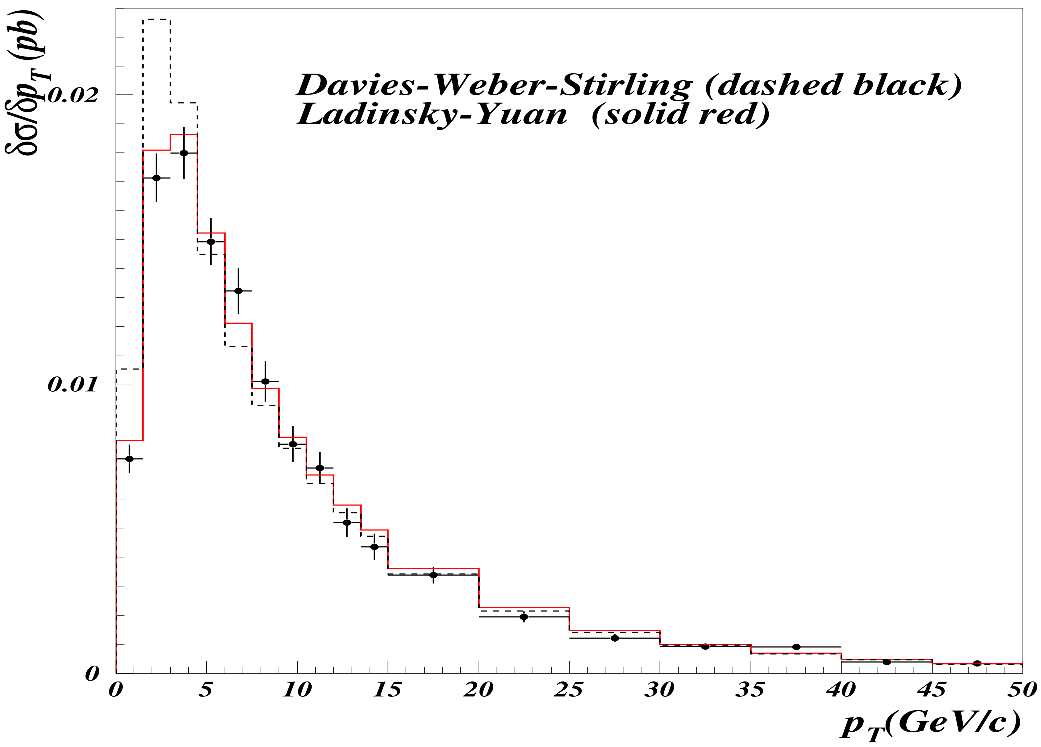
p_T^Z (DØ Run 1B/1C preliminary)

(Data – Theory)/Theory





$d\sigma/dp_T$ (pb)



Properties of $W+$ Jets Events

- Measure
  - $\sigma_e^n \equiv p\bar{p} \to W+ \geq n$ Jet Cross Sections, $n = 1, 4$.
  - $R_{10} \equiv \frac{\sigma_e(W+\geq 1 \text{ Jet})}{\sigma_e(W)}$ vs Jet E_T^{min} (15-95 GeV)
- Compare
  - σ_e^n to “enhanced” LO QCD (ELO)
  - R_{10} to NLO QCD (DYRAD)
- Event Selection
  - Restrict analysis to central electrons in η
  - Jets reconstructed using 0.4 fixed cone algorithm
  - Jet $E_T > 15$ GeV, $\eta_{\text{Jet}} < 2.4$, $\Delta\text{R}(e, \text{Jet}) > 0.52$
- Acceptance $\times$ Efficiency calculated from ELO
  - VECBOS MC calculates the LO Matrix Elements
  - HERWIG: gluon radiation and fragmentation
  - Full CDF Detector Simulation
  - p_T^W distribution weighted to match the data

Properties of $W+$ Jets Events (cont)

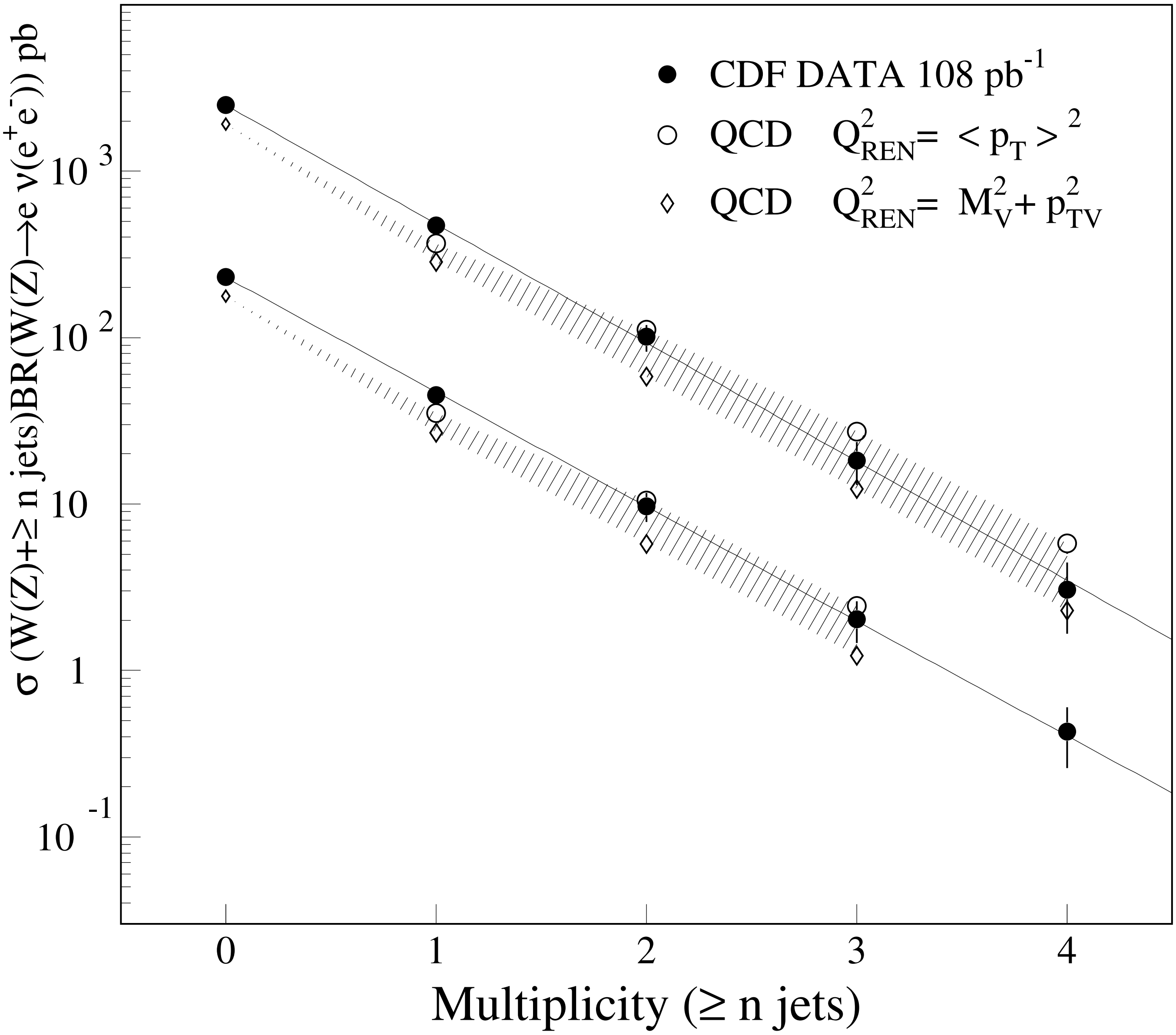
σ_e^n

- Backgrounds
  - QCD multijet (2.9% to 27%)
  - $W \to \tau\nu$, $Z \to \tau\tau$, $Z \to e\not{e}$ (3%)
  - Top, Diboson (0.1% to 17%)
- Efficiency $\times$ Acceptance $\approx$ 20%

R_{10}

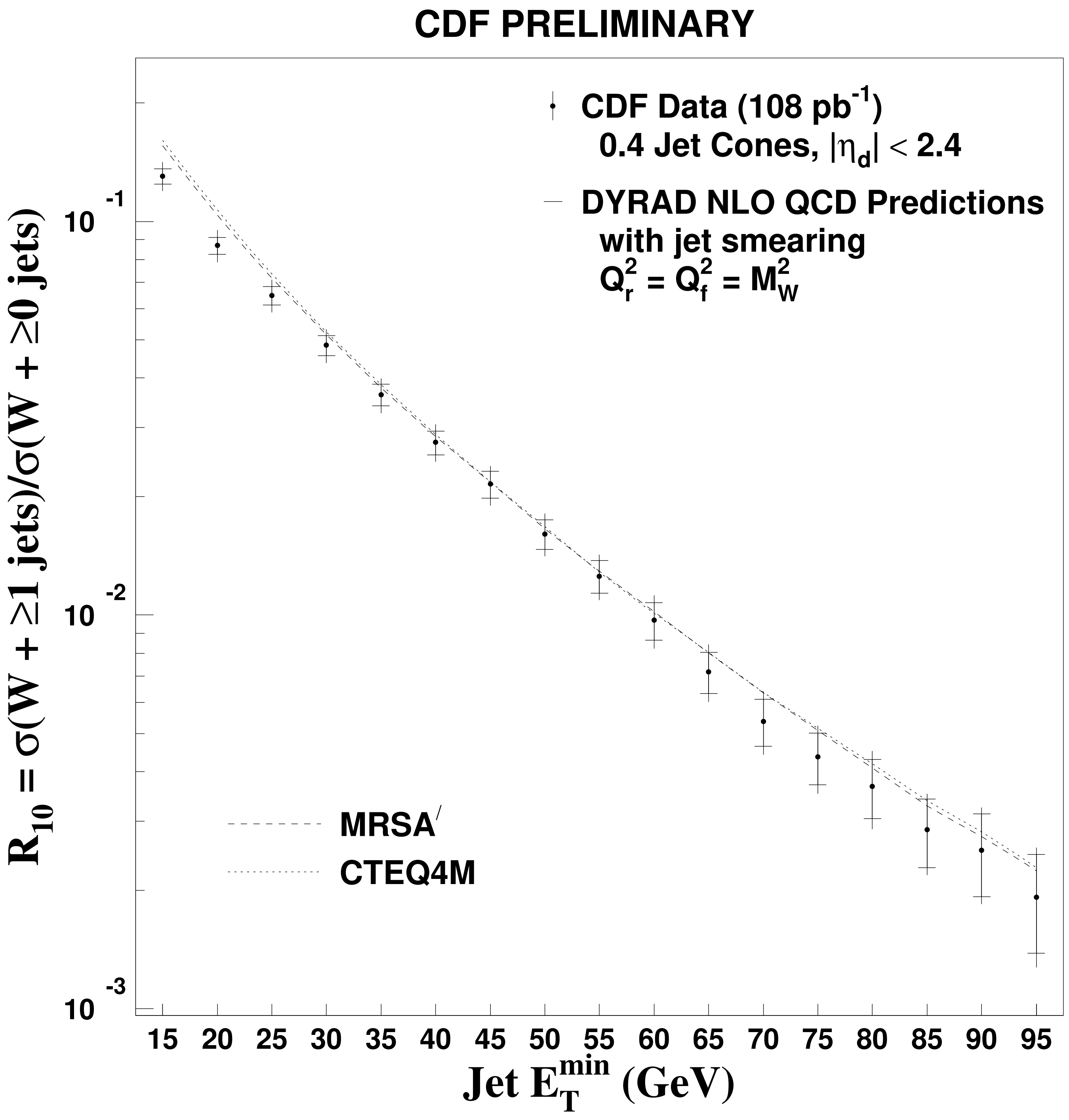
- W sample
  - Total Background $\approx$ 6%
  - Efficiency $\times$ Acceptance $\approx$ 20%
- $W+ \geq 1$ Jet sample
  - Backgrounds
    - QCD multijet (13% to 28%)
    - $W \to \tau\nu$, $Z \to \tau\tau$, $Z \to e\not{e}$ (5% to 13%)
    - Top, Diboson (0.4% to 8%)
    - $W\gamma$ (4% to 0.4%)
  - Efficiency $\times$ Acceptance: 19% to 26%

Measurement of $\sigma_n^e(W + n \text{ Jets})$

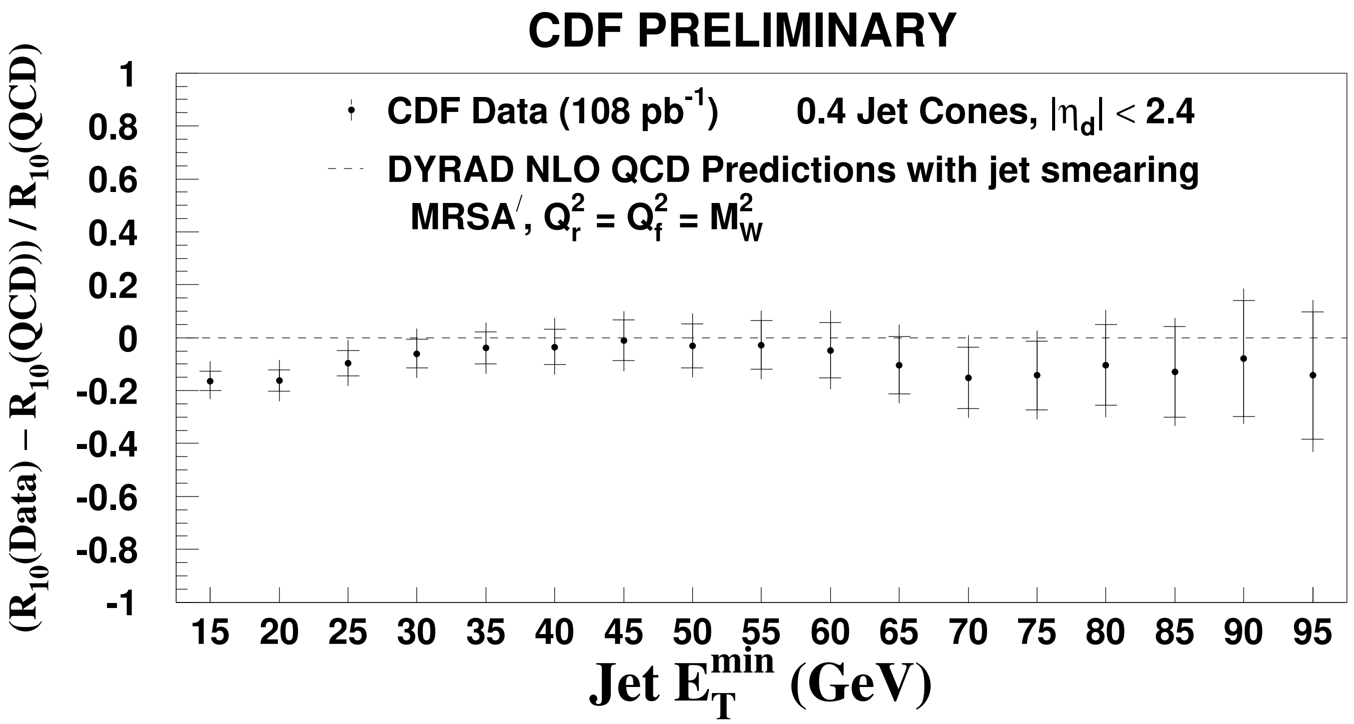


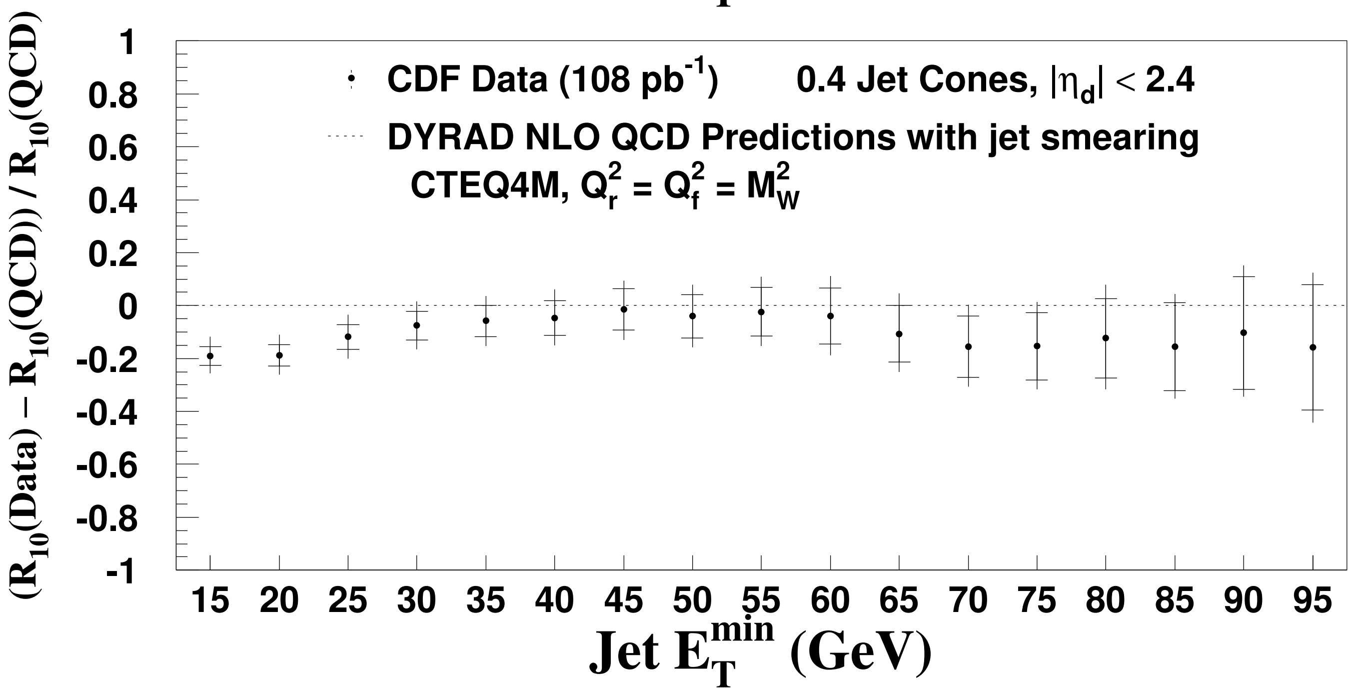
$W + n$ Jets: F. Abe *et al,* Phys. Rev. Lett. **79,** 1997.
$Z + n$ Jets: F. Abe *et al,* Phys. Rev. Lett. **77,** 1996.

Measurement of R_{10} vs E_T^{min}

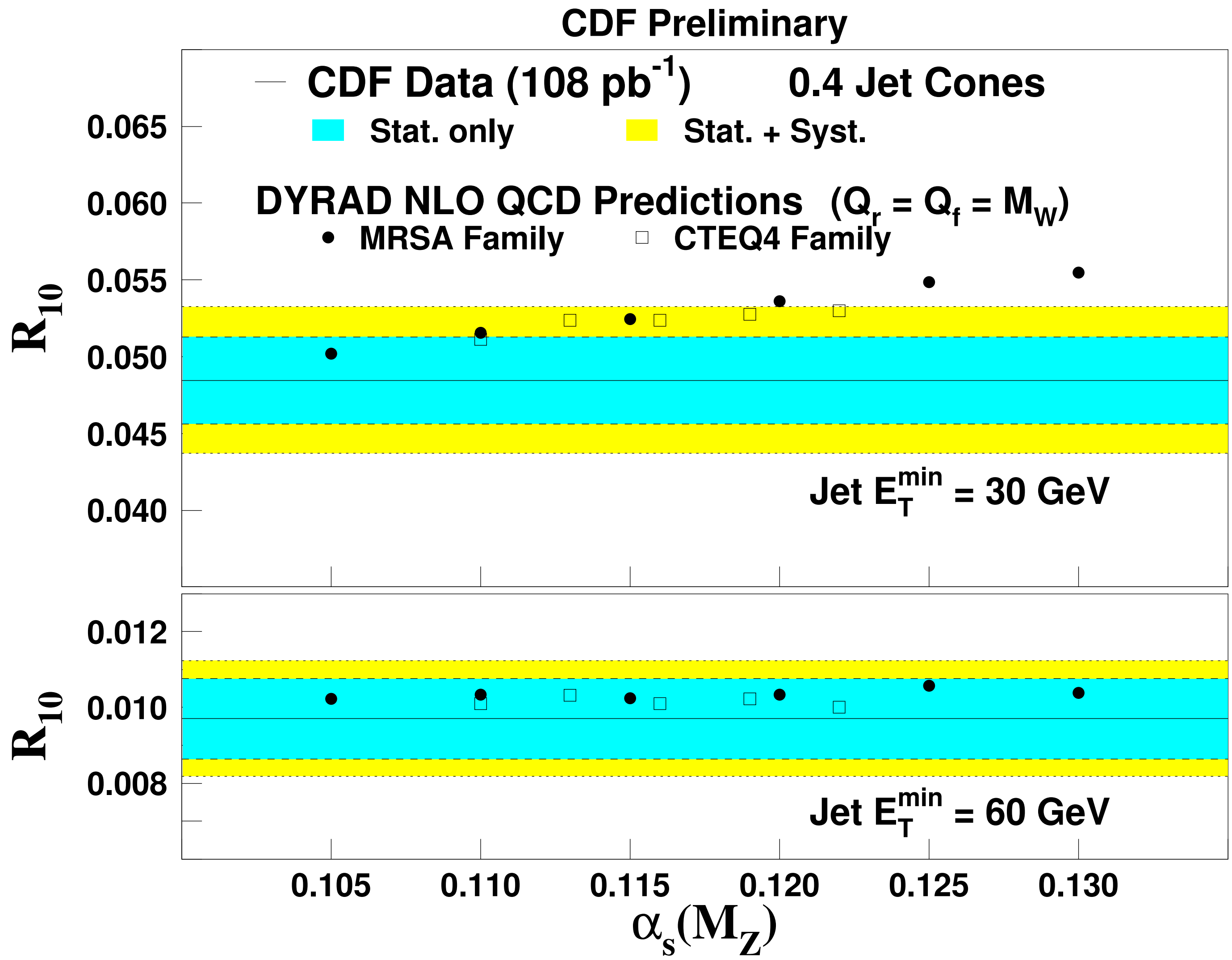


R_{10} : (Data – Theory)/Theory vs E_T^{min}





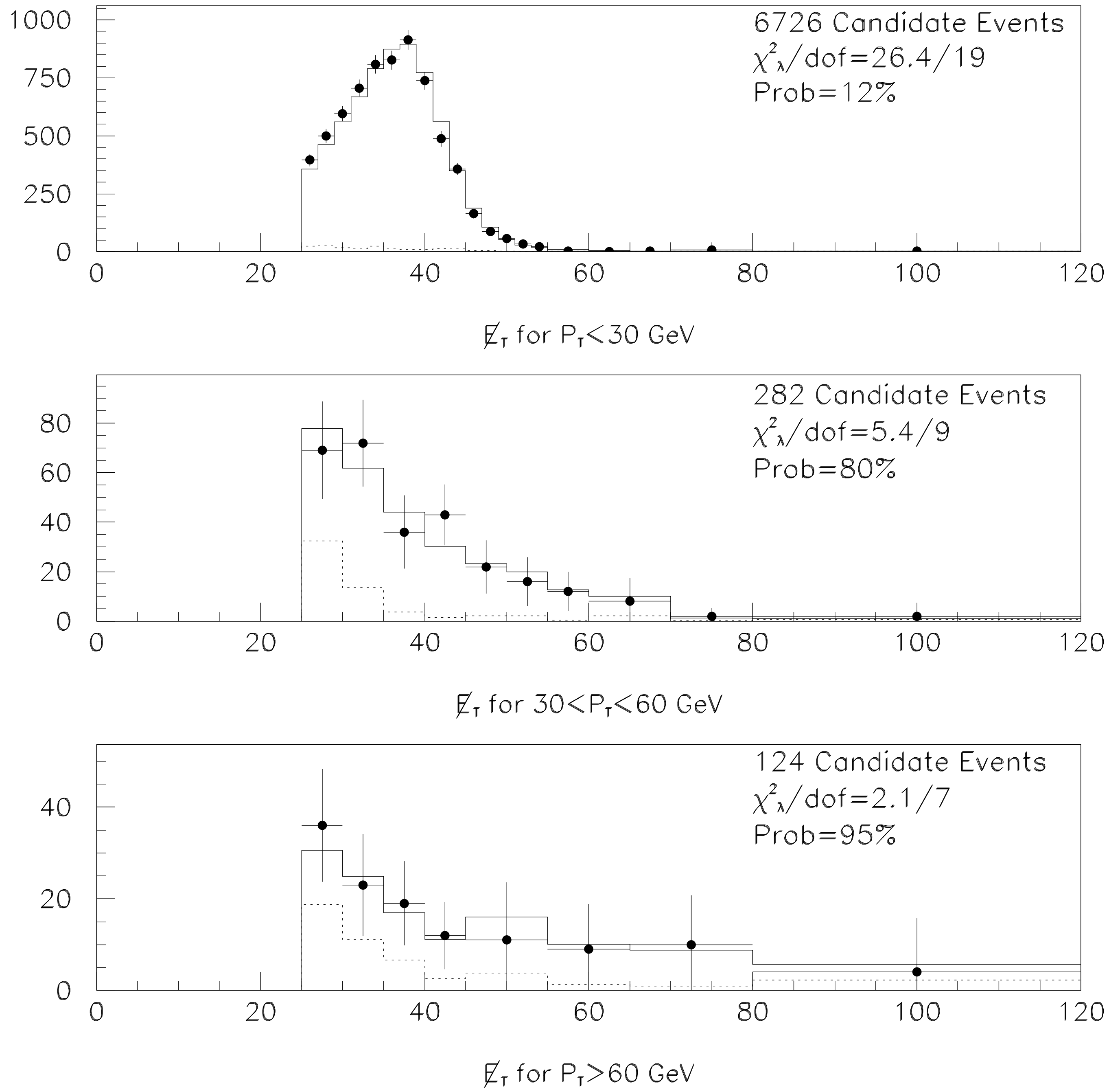
R_{10}: Variations in α_s



Conclusions and Outlook

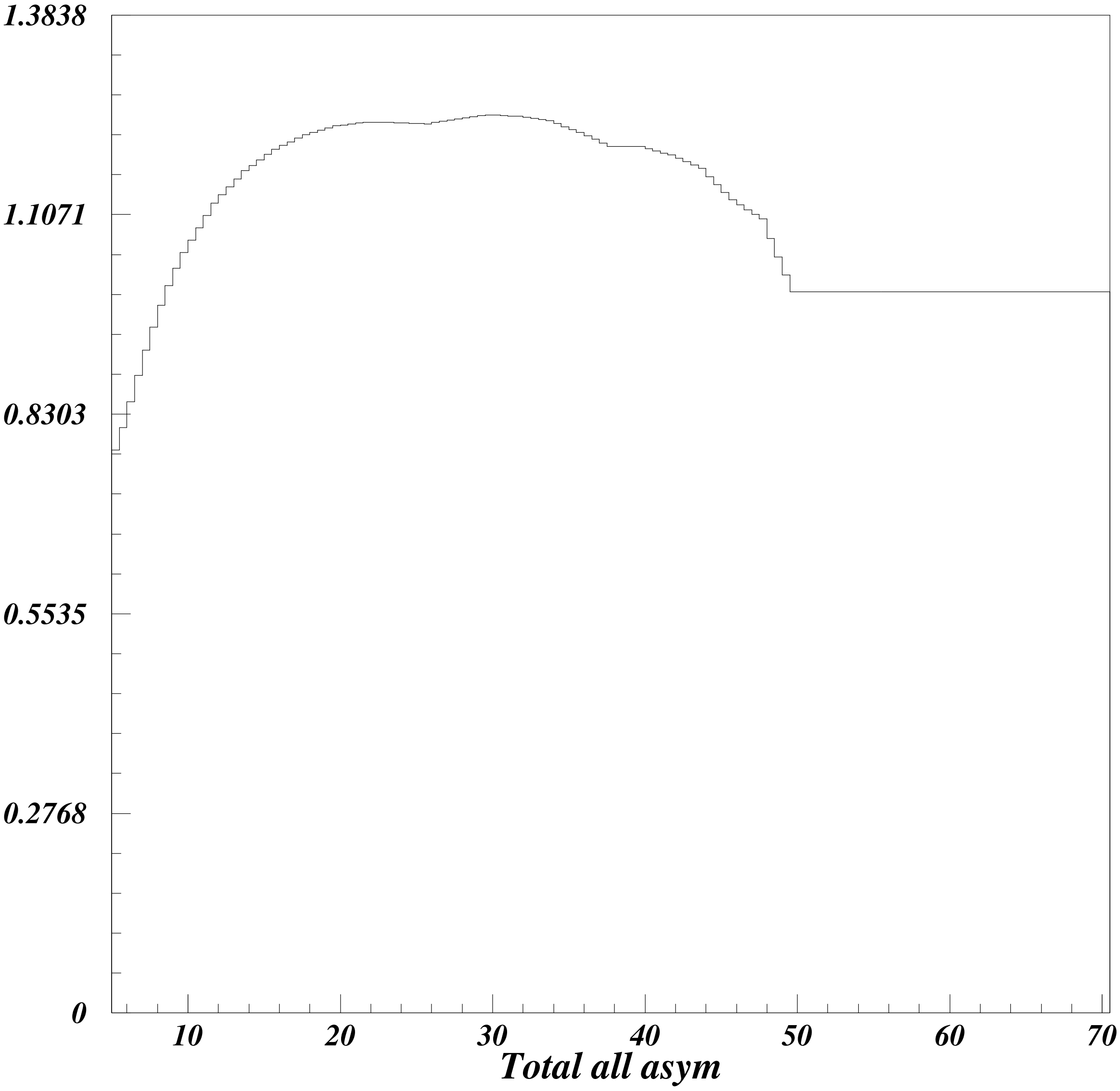
- Shown New Preliminary Tevatron (CDF and DØ) results from Run 1 data.
- $\Gamma_W(direct) = 2.19 \pm 0.17(stat) \pm 0.09(syst)$ GeV
- Measurements of p_T^W and p_T^Z consistent with the combined QCD perturbative and resummation calculations. Low p_T^Z distribution can distinguish between different phenomenological models.
- R_{10} vs Jet E_T^{min} measurement agrees with NLO QCD.
- Near Future: work on finalizing Run 1 analyses.
- **DØ and CDF are currently upgrading their detectors and expect to collect $\approx 2 fb^{-1}$ of data during Run 2 (2000–2003).**

QCD background to p_T^W: Cross Check



$\chi^2_\lambda = 2\Sigma(e_i - o_i + o_i\, ln(o_i/e_i))$, Baker & Cousins, NIM 221 (1984)

$d\sigma/dp_T$: (pQCD + Resum)/(pQCD)



Acceptance correction for p_T^W

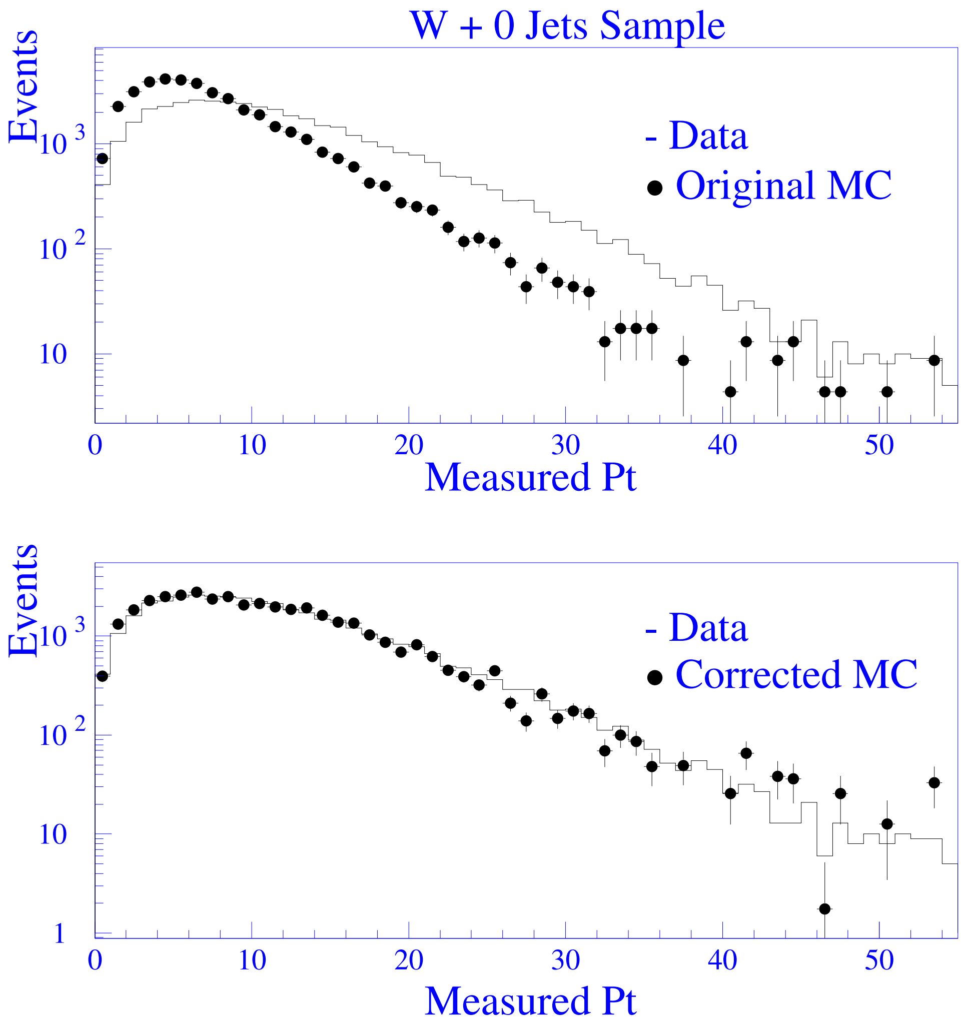
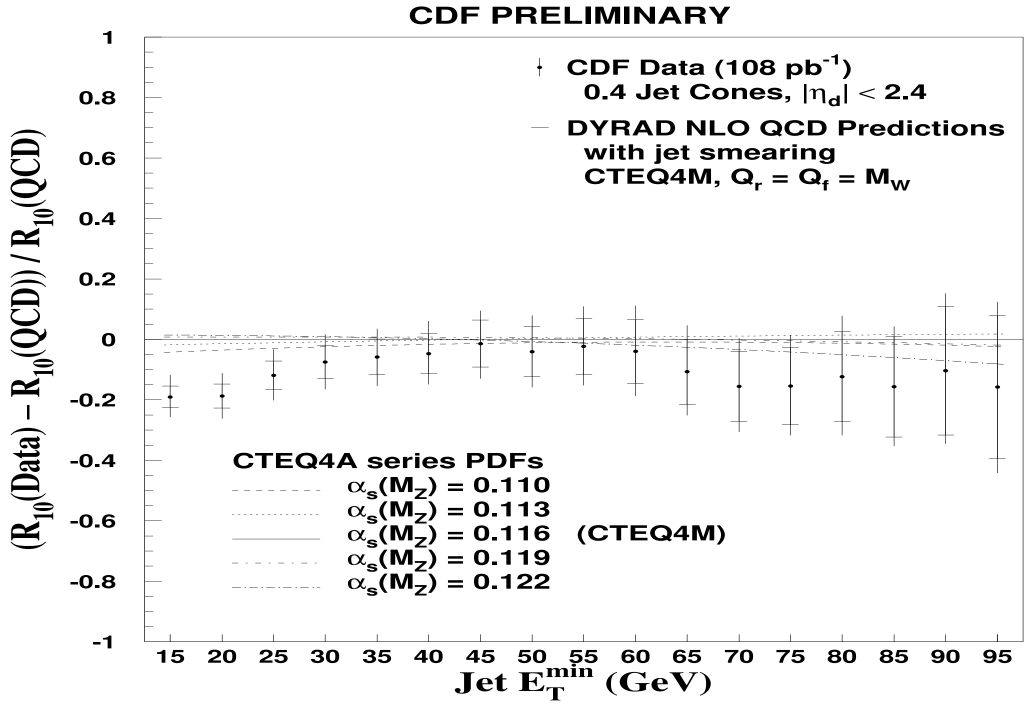
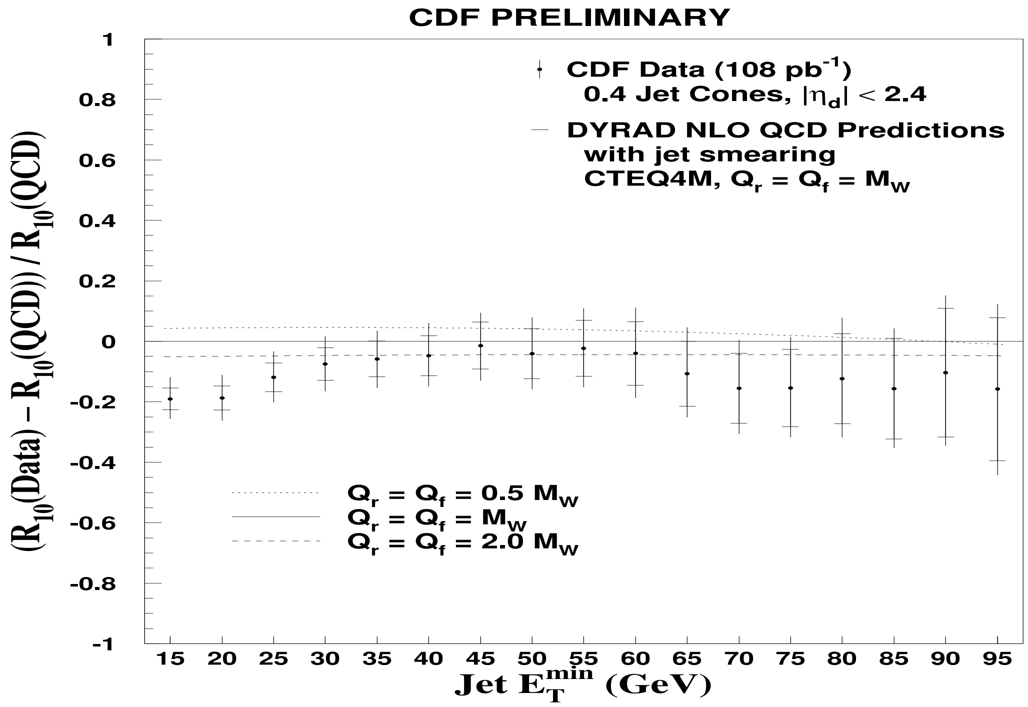


Figure C.1: The W data P_T distribution compared to our Monte Carlo "pseudo-0 jet" sample. The upper plot is the measured distribution (after QFL) for the original Monte Carlo. The lower plot includes a correction to the Monte Carlo after unfolding the data. The data are the same in both.

R_{10}: (Data - Theory)/Theory vs E_T^{min}





UA2 Extraction of α_s

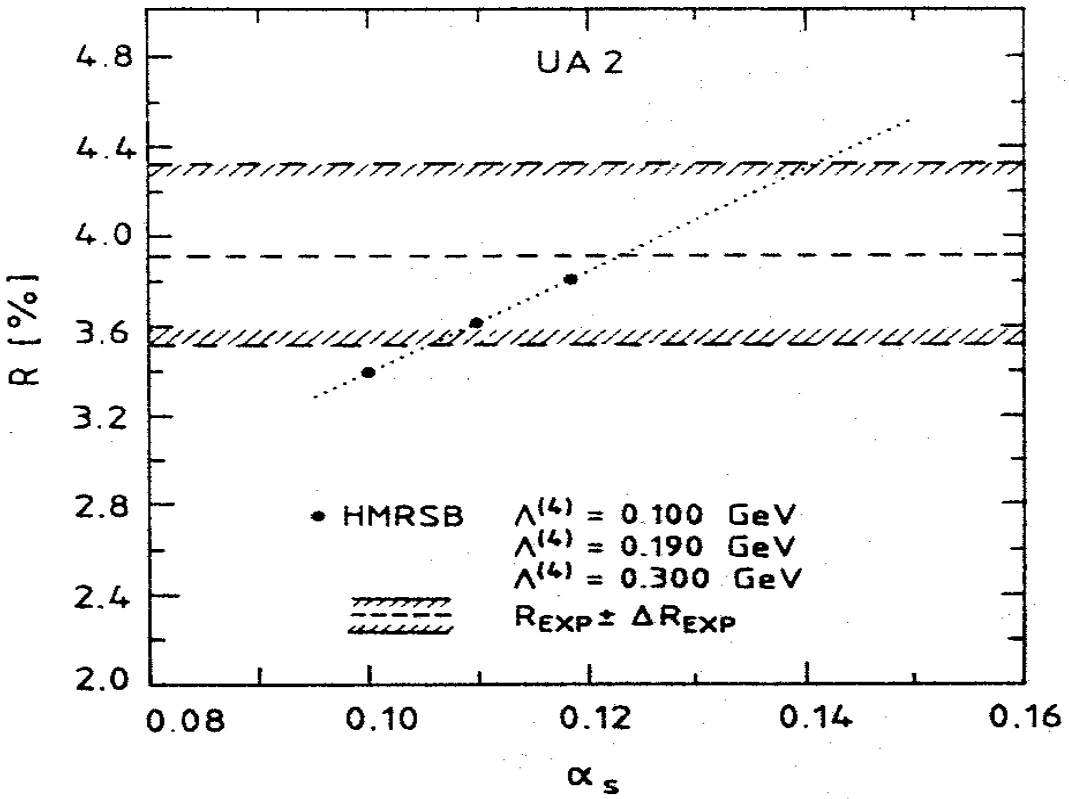


Fig. 4. $R_{\rm MC}(\alpha_s)$ compared to the experimental measurement $R_{\rm exp}$. The QCD predictions $R_{\rm MC}$ have been calculated by using three different HMRSB structure function parametrizations with three different values for Λ.

Measurement of R_{10} vs E_T^{min}