QCD with W&Z Bosons at the Tevatron

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Outline

Introduction

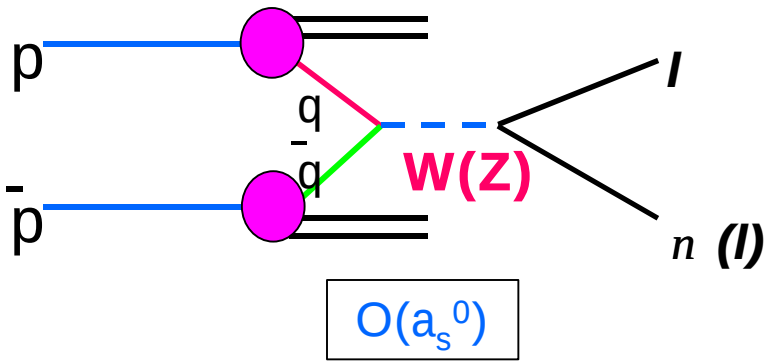
W/ Z Cross Section

W Width

W/Z Transverse Momentum

W Angular Distribution

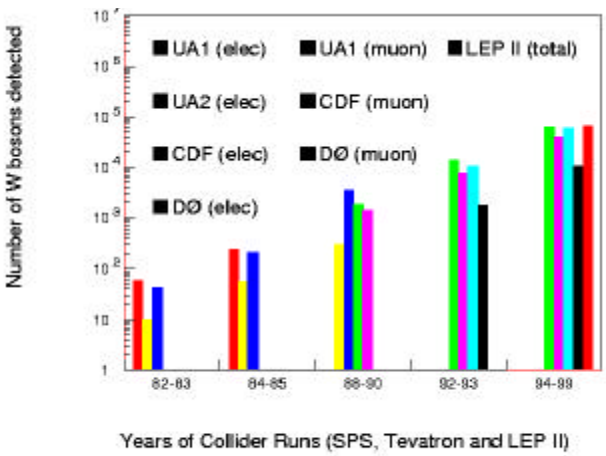
Introduction to W & Z Production at the Tevatron



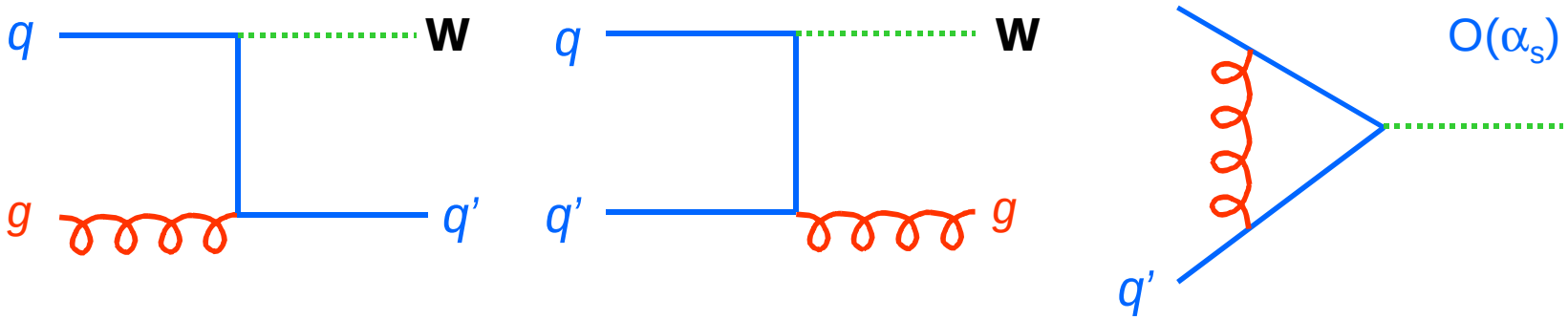
- Production dominated by $q\bar{q}$ annihilation
- Due to very large $pp \rightarrow jj$ production, need to use leptonic decays
  - $W \rightarrow l\nu$ (BR ~ 11% per mode)
  - $Z \rightarrow ll$ (BR ~ 3% per mode)
- Distinctive event signatures
  - High P_T isolated leptons (e or μ)
  - One high P_T 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 $O(\alpha_s)$



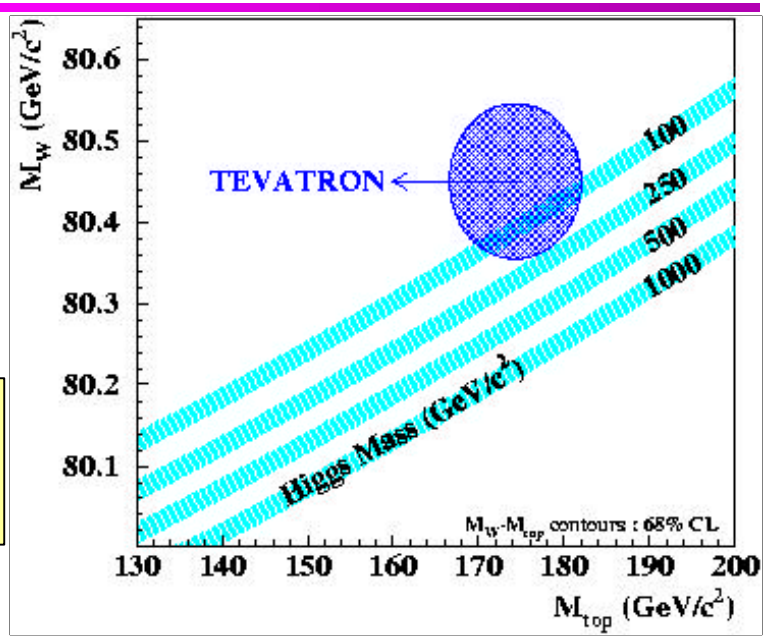
Modifications due to QCD corrections:

- **Boson produced with transverse momentum ($< P_T >$ ~ 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**

Connections between W,Z Production, QCD and New Physics

W mass + top mass: Constrain Higgs mass

Current DØ δM_W ~ 5 -40 MeV from P_T^W model
δM_W = 10 MeV $\Rightarrow \delta M_H / M_H$ = 14%



Need precise model of W production and decay for Monte Carlos

W mass measurements require low P_T^W

NLO QCD

Resummation techniques

Non-perturbative QCD

W/Z Cross Section

f^{W}_{QCD}=5% (14%) CC (EC)

f^{Z}_{QCD}=2%, 7%, 5%

(CC,CC), (CC,EC), (EC,EC)

Backgrounds

$$s\,(p\bar{p} \rightarrow B + X)B_R(B \rightarrow l_1 l_2) = \frac{N_{obs} - N_{bkgd}}{A \times e \times L}$$

Acceptance from fast Monte Carlo

$A^{W}(e)$~45%

$A^{Z}(e)$~35%

Efficiencies from Z->ee data

$e^{W}(e) \sim 70\%$

$e^{Z}(e) \sim 76\%$

Integrated Luminosity

Inclusive Cross Section

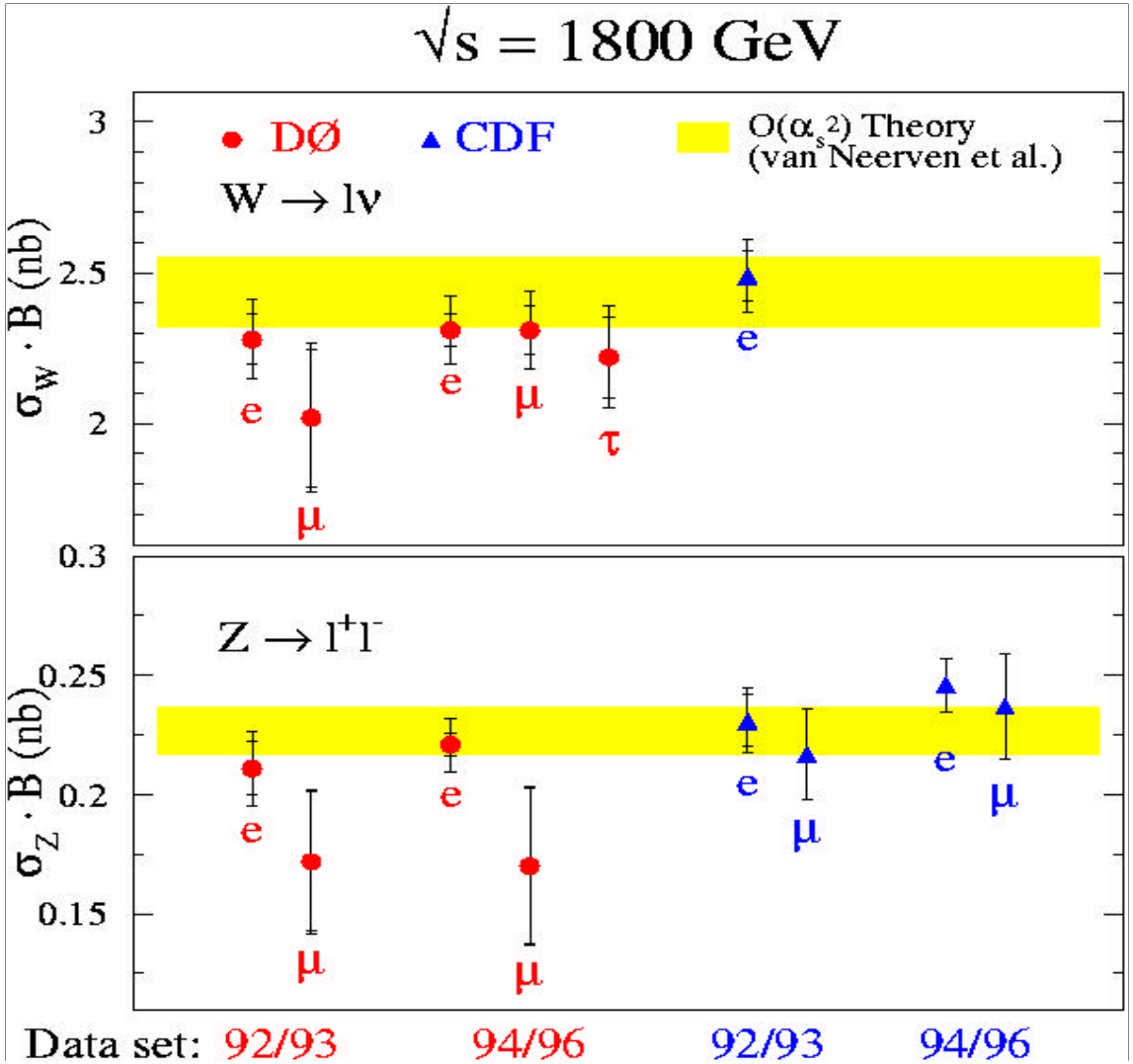
			$s(W)\times BR(W\to lu)\,(nb)$	$s(Z)\times BR(Z\to ll)\,(nb)$
NEW	DØ, e, 1b	Accepted PRD	$2.31 \pm 0.01 \pm 0.05 \pm 0.10$	$0.221 \pm 0.003 \pm 0.004 \pm 0.010$
	DØ, e, 1a		$2.28 \pm 0.02 \pm 0.08 \pm 0.10$	$0.211 \pm 0.008 \pm 0.008 \pm 0.009$
	DØ, μ, 1b	Preliminary	$2.31 \pm 0.08 \pm 0.10$	$0.170 \pm 0.023 \pm 0.023 \pm 0.007$
	DØ, μ, 1a		$2.02 \pm 0.06 \pm 0.22 \pm 0.09$	$0.172 \pm 0.022 \pm 0.021 \pm 0.008$
NEW	CDF, e, 1b	Accepted PRL		$0.246 \pm 0.005 \pm 0.003 \pm 0.010$
	CDF, e, 1a		$2.49 \pm 0.02 \pm 0.08 \pm 0.09$	$0.231 \pm 0.008 \pm 0.009$
	CDF, μ, 1b	Updated		$0.237 \pm 0.011 \pm 0.009$
	CDF, μ, 1a			$0.217 \pm 0.017 \pm 0.008$
Updated	CDF, μ, Run 1	Published		0.233 ± 0.013

- **Measurement errors:** Stat ⊕ Sys ~ 2%, Luminosity error ~ 4%
- **Theory error:** ~ 3%, NNLO, $O(\alpha_s^2)$ (Hamberg, van Neerven, Matsuura)

  Dominated by PDF's at NLO…(need NNLO)
- **NB: Luminosity determination:** L(D0) = 1.062 x L(CDF)

  D0 uses world avg. $\sigma(p\bar{p})_{inel}$, CDF uses CDF measurement

Inclusive Cross Section



- **Measurement errors:**
  - Stat ⊕ Sys ~ 2%,
  - Luminosity error ~ 4%

- **Theory error:**

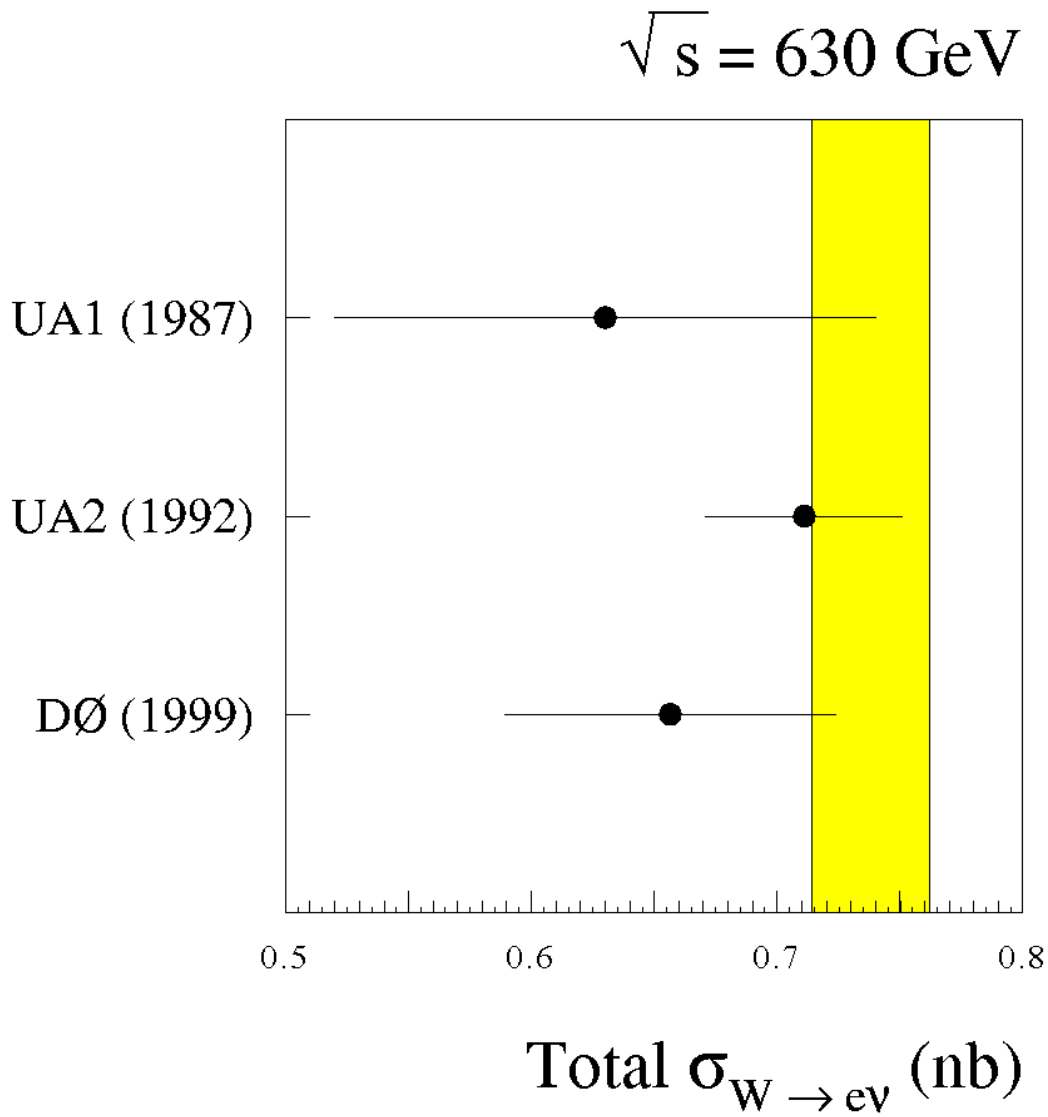
  ~ 3%, NNLO, $O(\alpha_s^2)$

  Dominated by PDF's at NLO…

  (need NNLO)

L(D0) = 1.062 x L(CDF)
D0 uses world avg. $\sigma(pp)_{inel}$, CDF uses CDF measurement

W Cross Section at 630 GeV



Short Run with L=505nb^{-1}

$$s_{W \to en} = 658 \pm 67\, pb$$

Measurement of the W Width

Measured:

$$s\,(p\bar{p} \to W + X) \times BR(W \to lu)$$

$$s\,(p\bar{p} \to Z + X) \times BR(Z \to ll)$$

Form ratio:

$$R \equiv \frac{s\,(p\bar{p} \to W + X) \times BR(W \to lu)}{s\,(p\bar{p} \to Z + X) \times BR(Z \to ll)}$$

$$= \frac{s\,(W)}{s\,(Z)} \times \frac{\Gamma(Z)}{\Gamma(Z \to ll)} \times \frac{\Gamma(W \to lu)}{\Gamma(W)}$$

SM EW

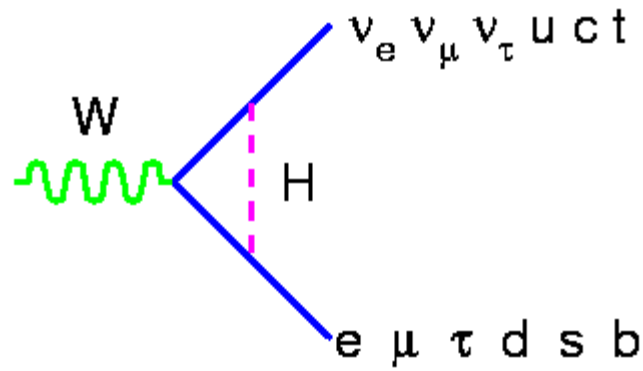
Perturbative QCD

LEP measurement

W Width

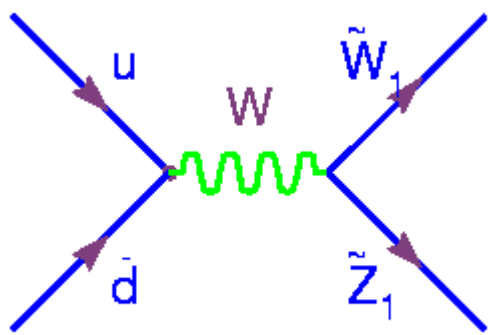
Indirect vs Direct W Width

Vertex Corrections: same for quarks and leptons, so cancel in BR(W $\rightarrow$ lν)



Rosner, Worah, Takeuchi, hep-ph/9309307

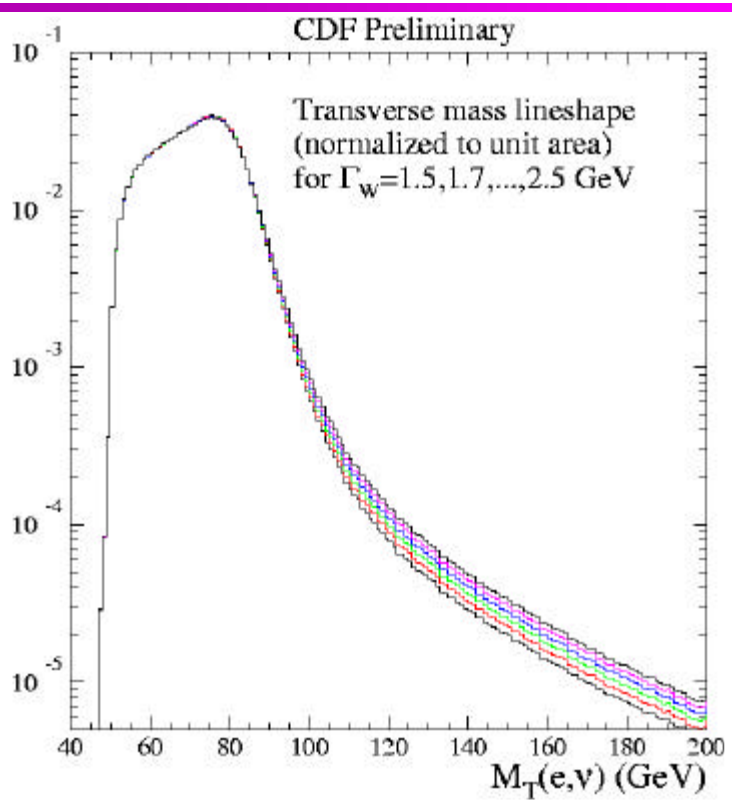
W decays:

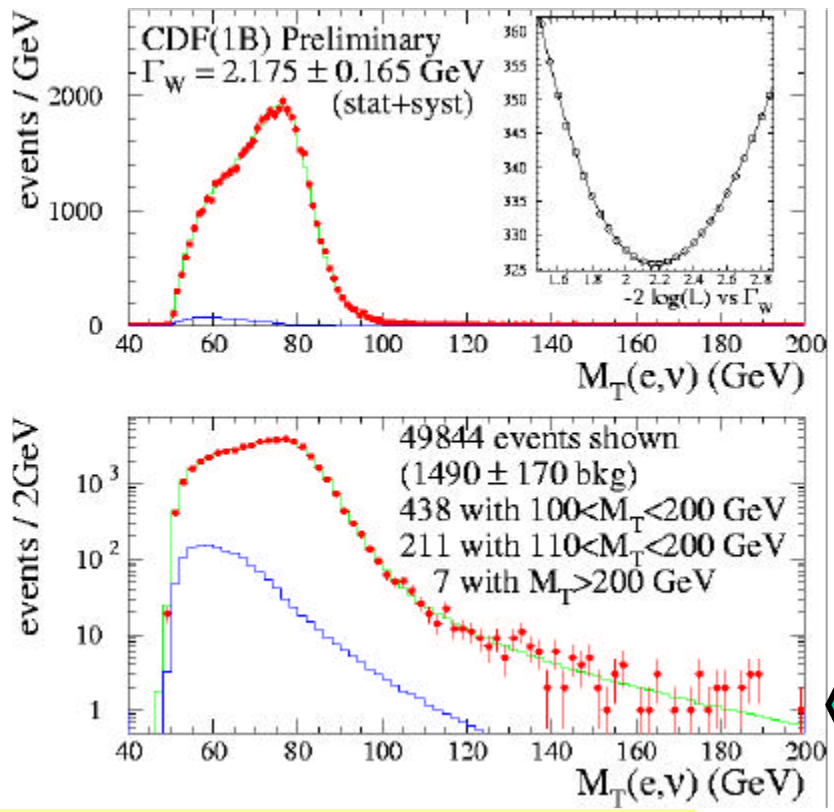


Kalinowski and Zerwas hep-ph/9702386

Indirect has no sensitivity to corrections to the coupling of the W to fermions, but is sensitive to possible non-standard model decay modes of the W.

Direct W Width





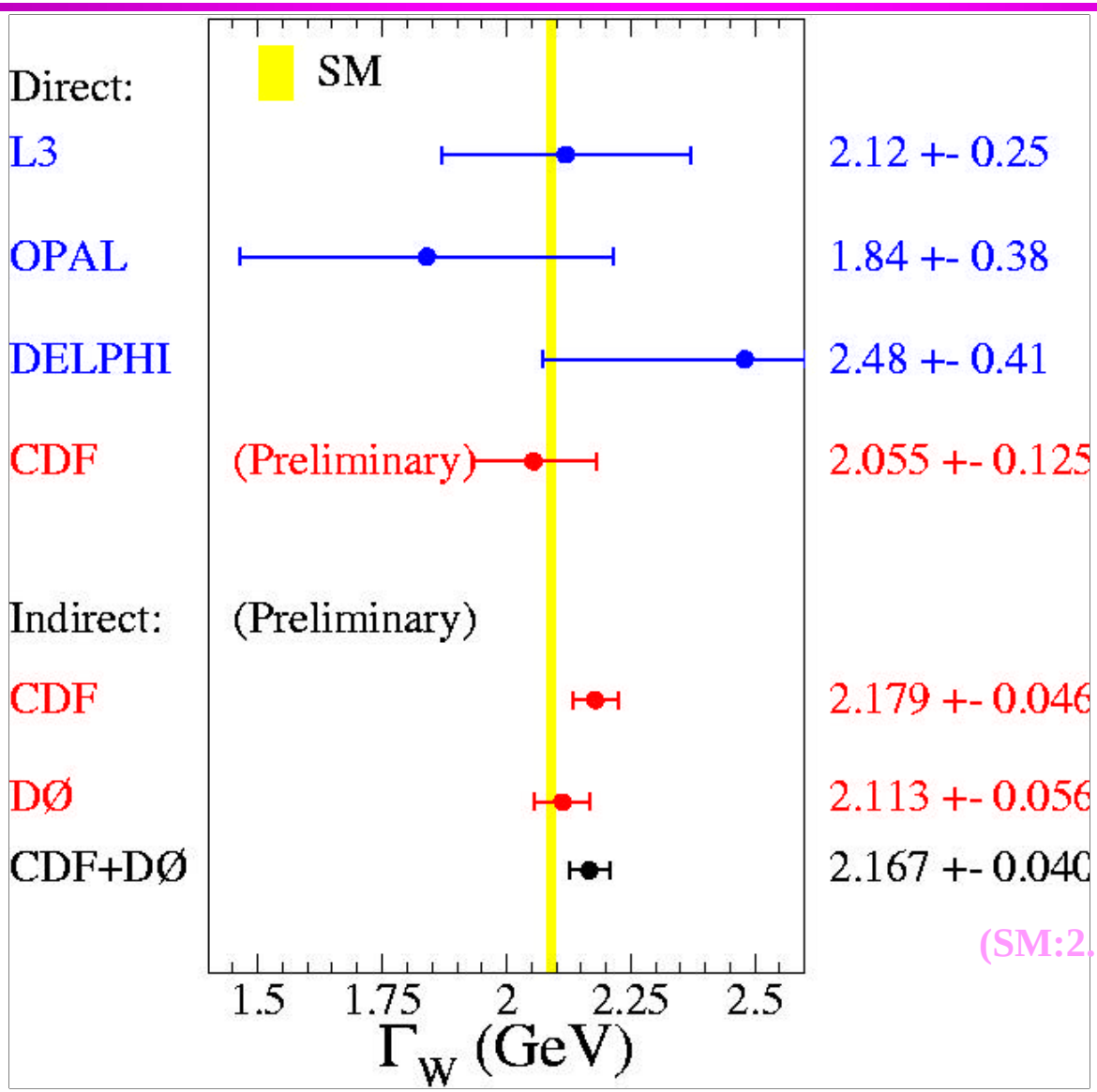
Likelihood fits above 100 GeV

Use Tail of m_T spectrum to extract width:

dominated by Breit-Wigner and not Detector Res.

Less Model dependent than indirect measurement!

W Width



e+μ

NEW

2 σ difference

(SM:2.094 ± 0.008)

W, Z p_T Theory

$$\frac{ds}{dq_T^2} \sim \frac{a_s}{q_T^2}\ln\left(\frac{Q^2}{q_T^2}\right)\left[v_1 + v_2 a_s \ln^2\left(\frac{Q^2}{q_T^2}\right)\right]$$

- **Large PT 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:

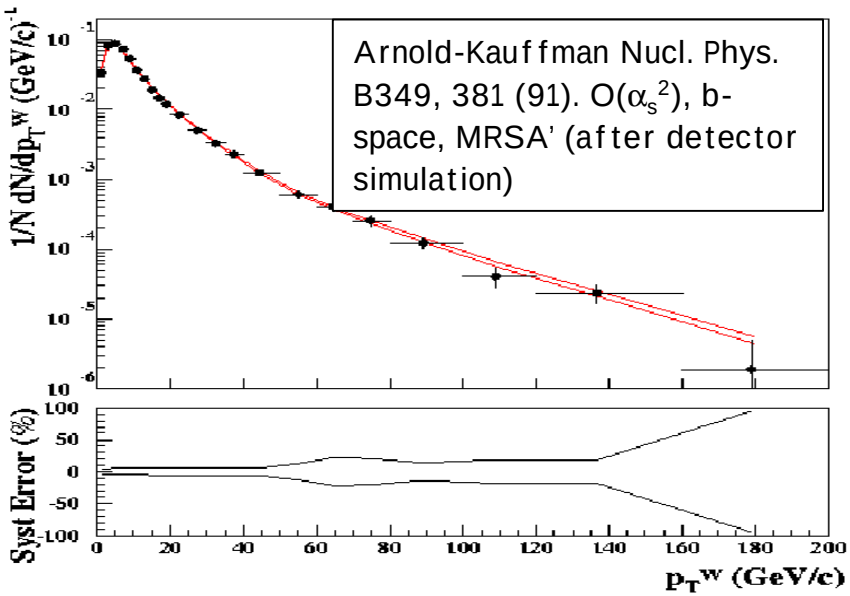
  Parisi-Petronzio (79); Davies-Stirling (84); Collins-Soper-Sterman (85); Davies, Webber, Stirling (85); Arnold- Reno-Ellis (89); **AK**: Arnold-Kauffan (91); **LY**: Ladinsky-Yuan (94)

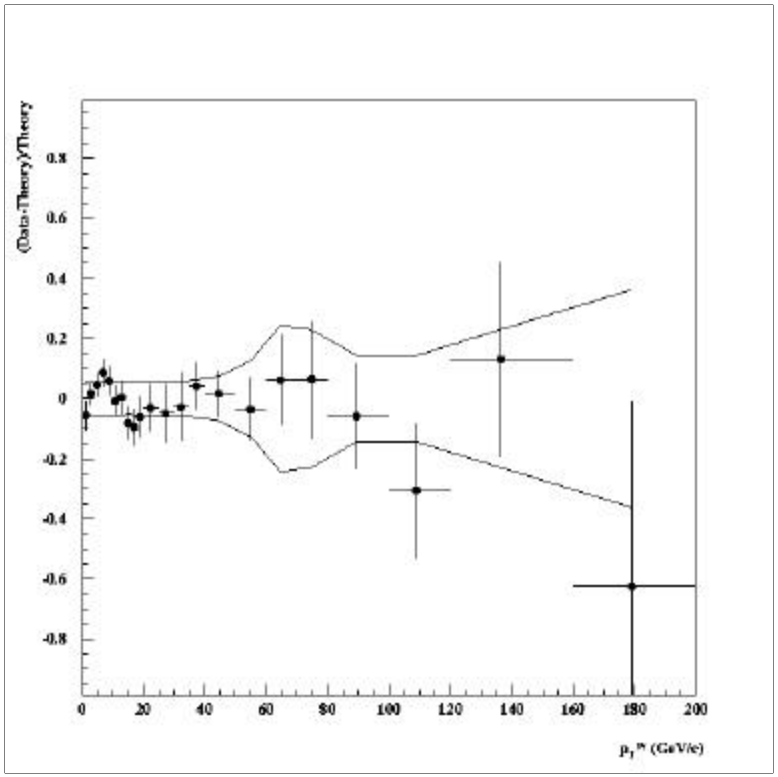
  qt-space:

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

W p_T and Theory

preliminary



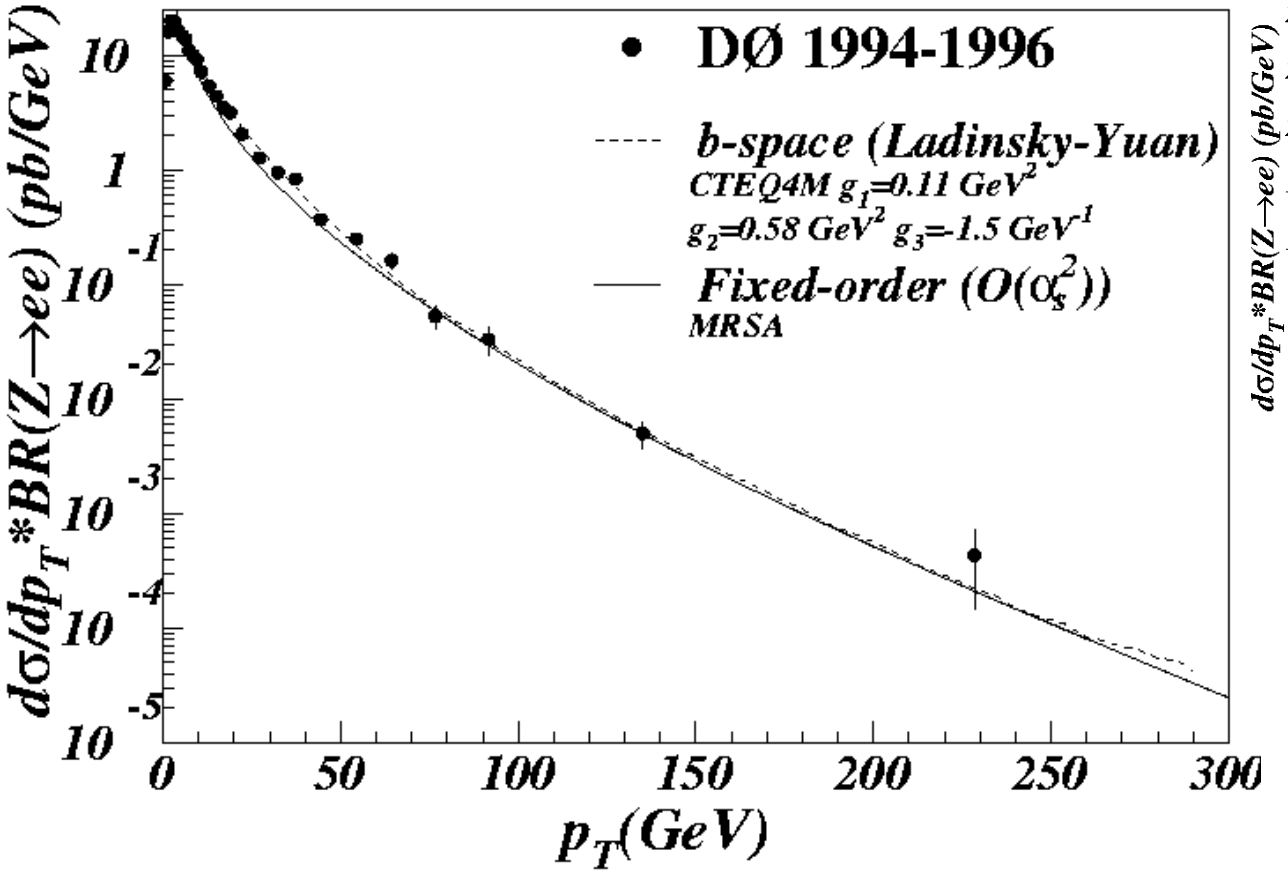


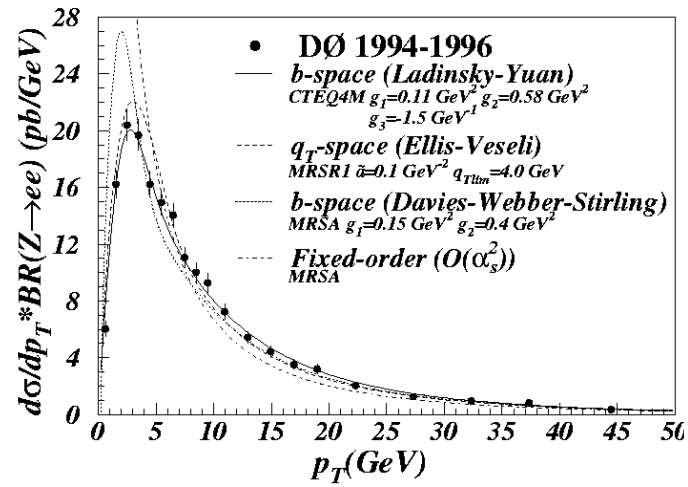
χ^2/dof = 10/21

Resolution effects dominate at low P_T
High P_T dominated by statistics & backgrounds

Z p_T

Data corrected for resolution effects





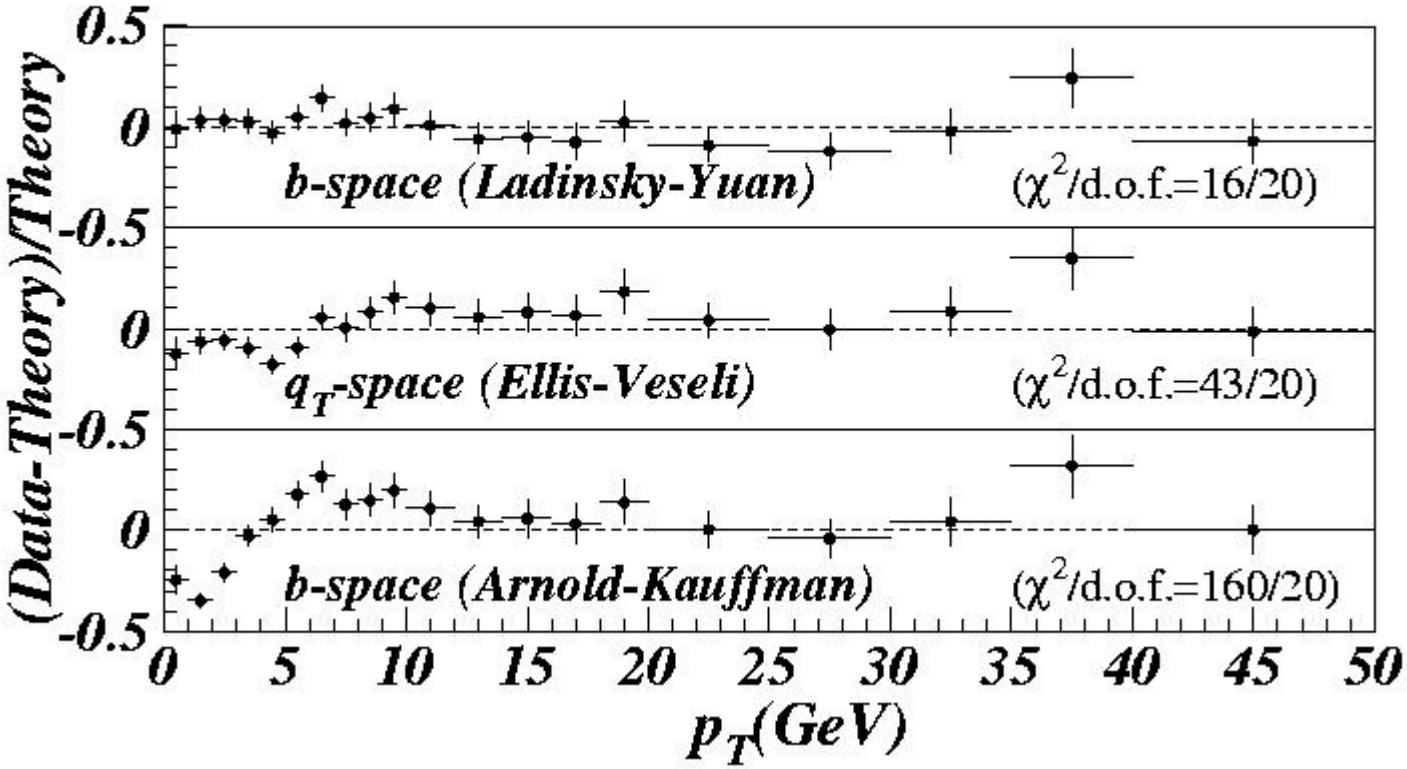
Less dominated by detector res. at low p_T

More sensitive to theory than W

PRD 61 (2000) + Submitted to PRL

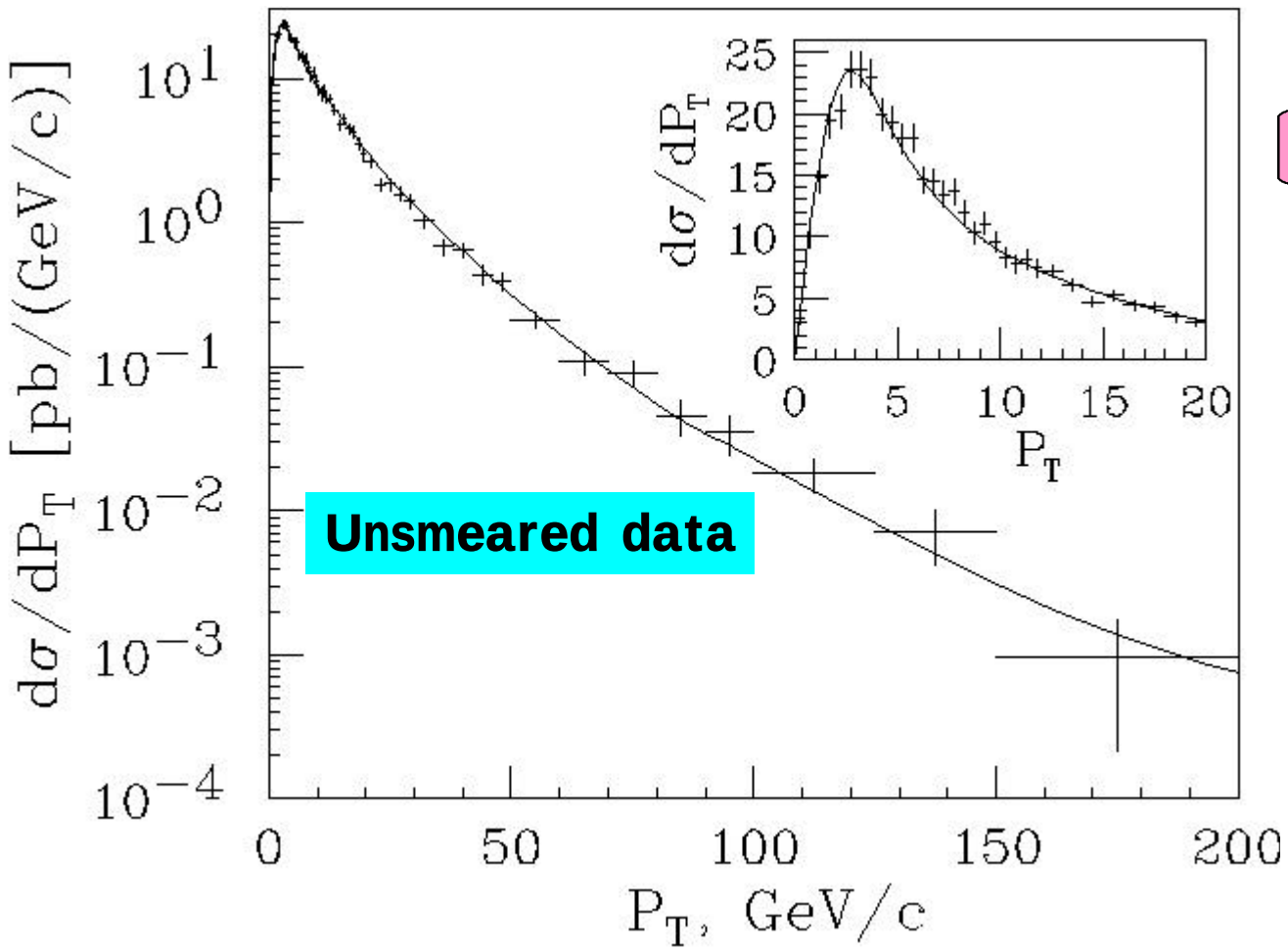
Z p_T: Data-Theory/Theory

Compared to published parameters, could be refitted



Z p_T Shape

Ladinski-Yuan normalized to data



CDF and D0 agree

CTEQ4M
structure functions

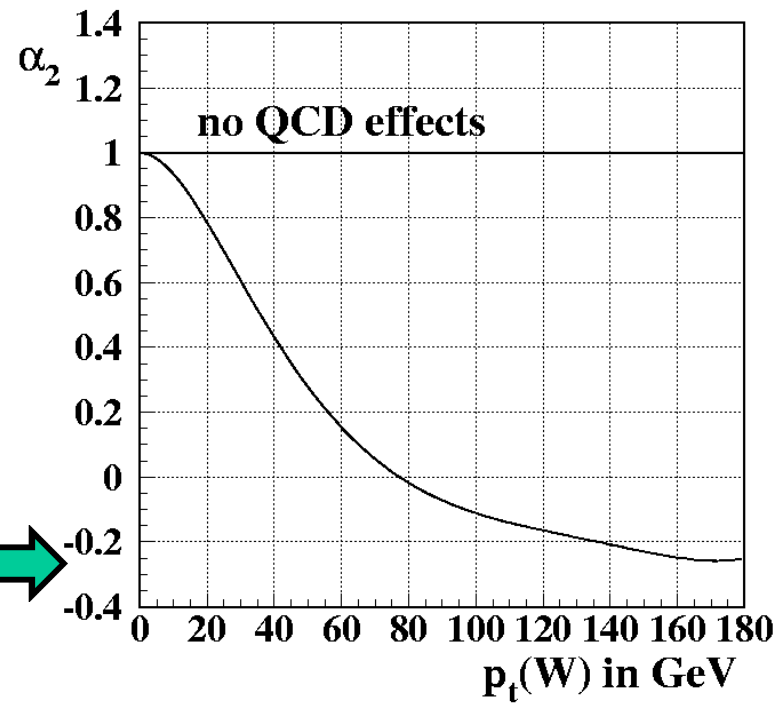
W Angular Decay Distribution

$$\frac{ds}{dp_T d\cos q^*} \propto 1 + a_1 \cos q^* + a_2 \cos^2 q^*$$

$$a_i = a_i(p_T)$$

E. Mirkes. Nucl. Phys., **B387** 3 (1992)

Similar for α_1

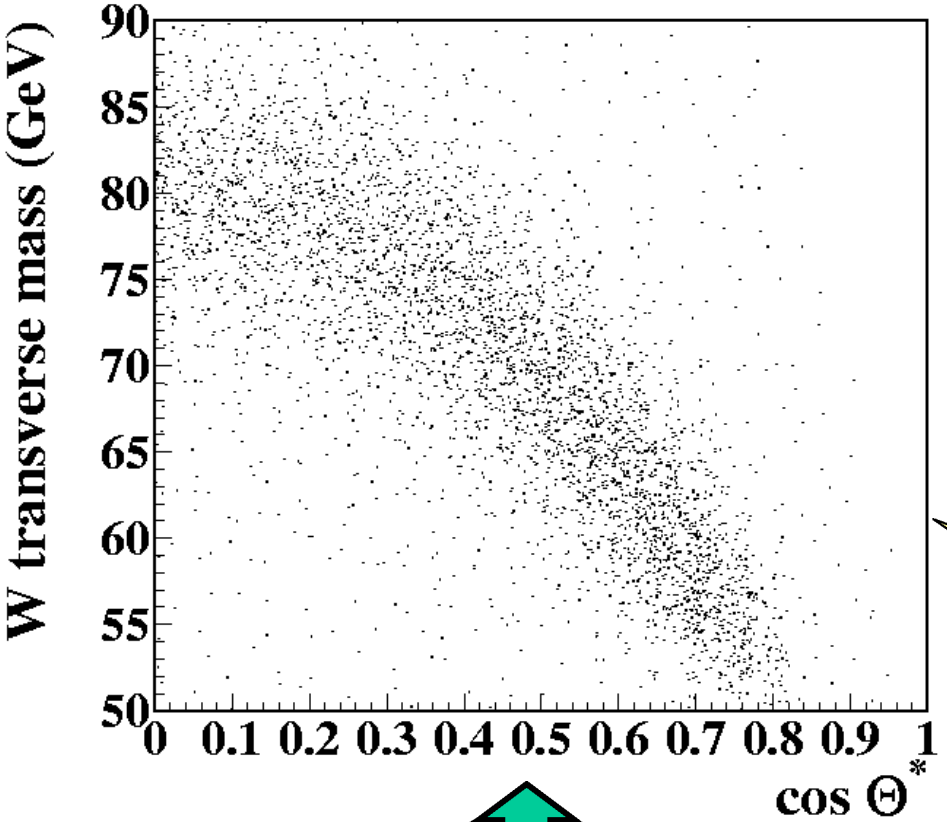


Independent test of QCD corrections

Spin Structure of W Production and Decay

Correction to W Mass Measurement O[40 MeV]

W Angular Decay Distribution



angle cannot be measured directly use correlation with transverse mass

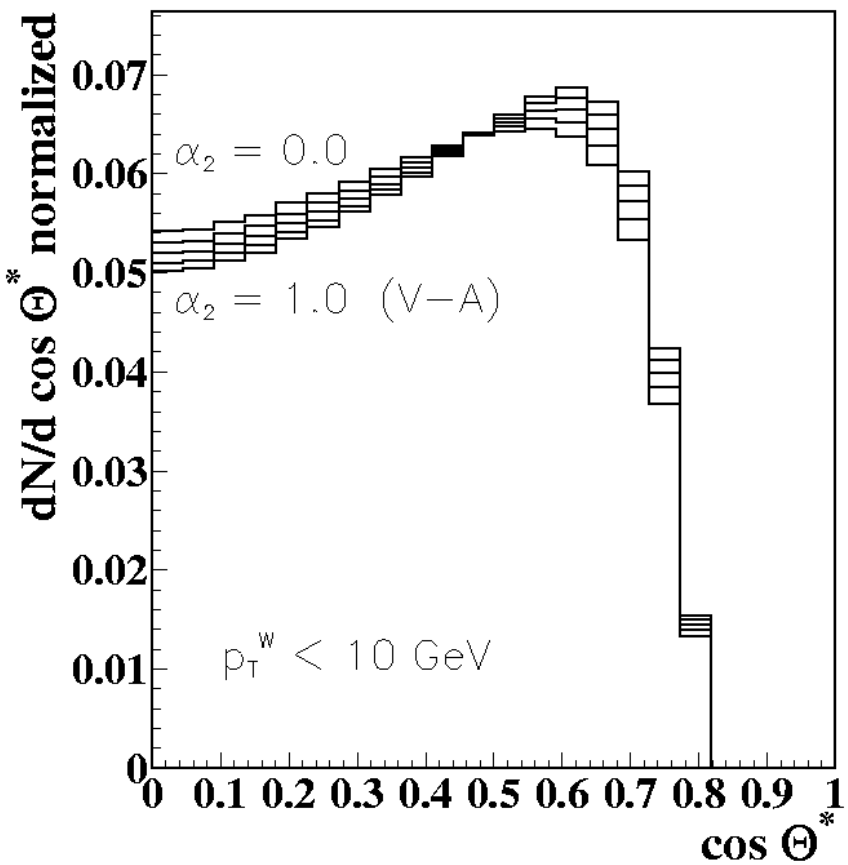
wrong angular distribution=> M_W off

From Monte Carlo

W Angular Method

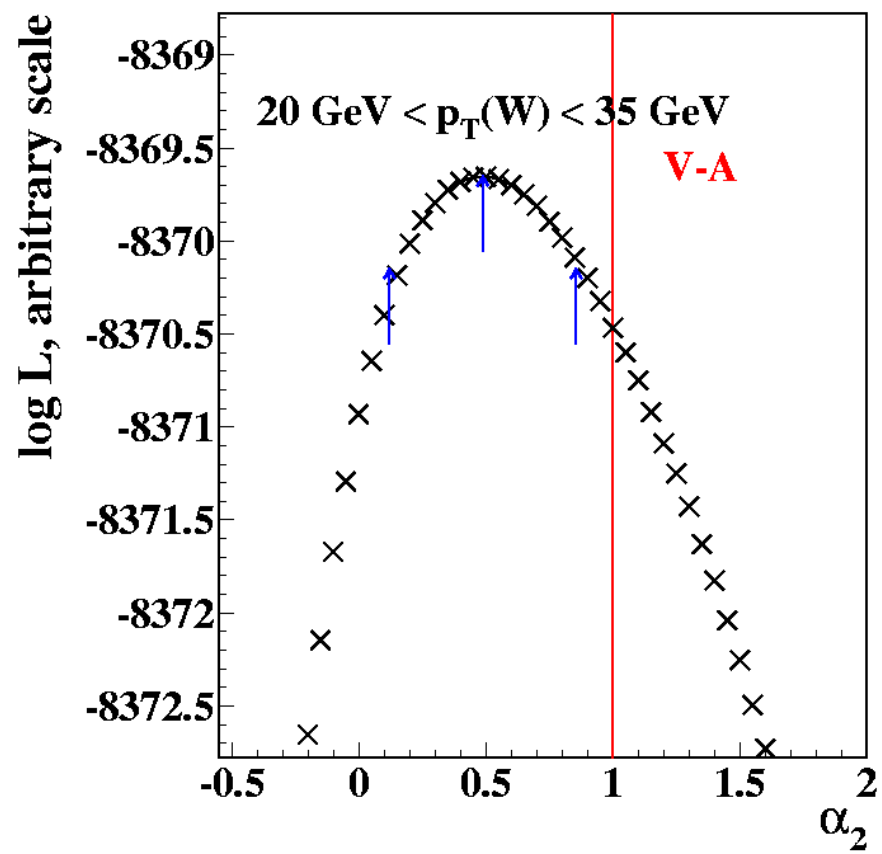
Use Bayesian approach

$$f(\cos q^* \mid M_T^W) = \frac{g(M_T^W \mid \cos q^*)h(\cos q^*)}{N}$$

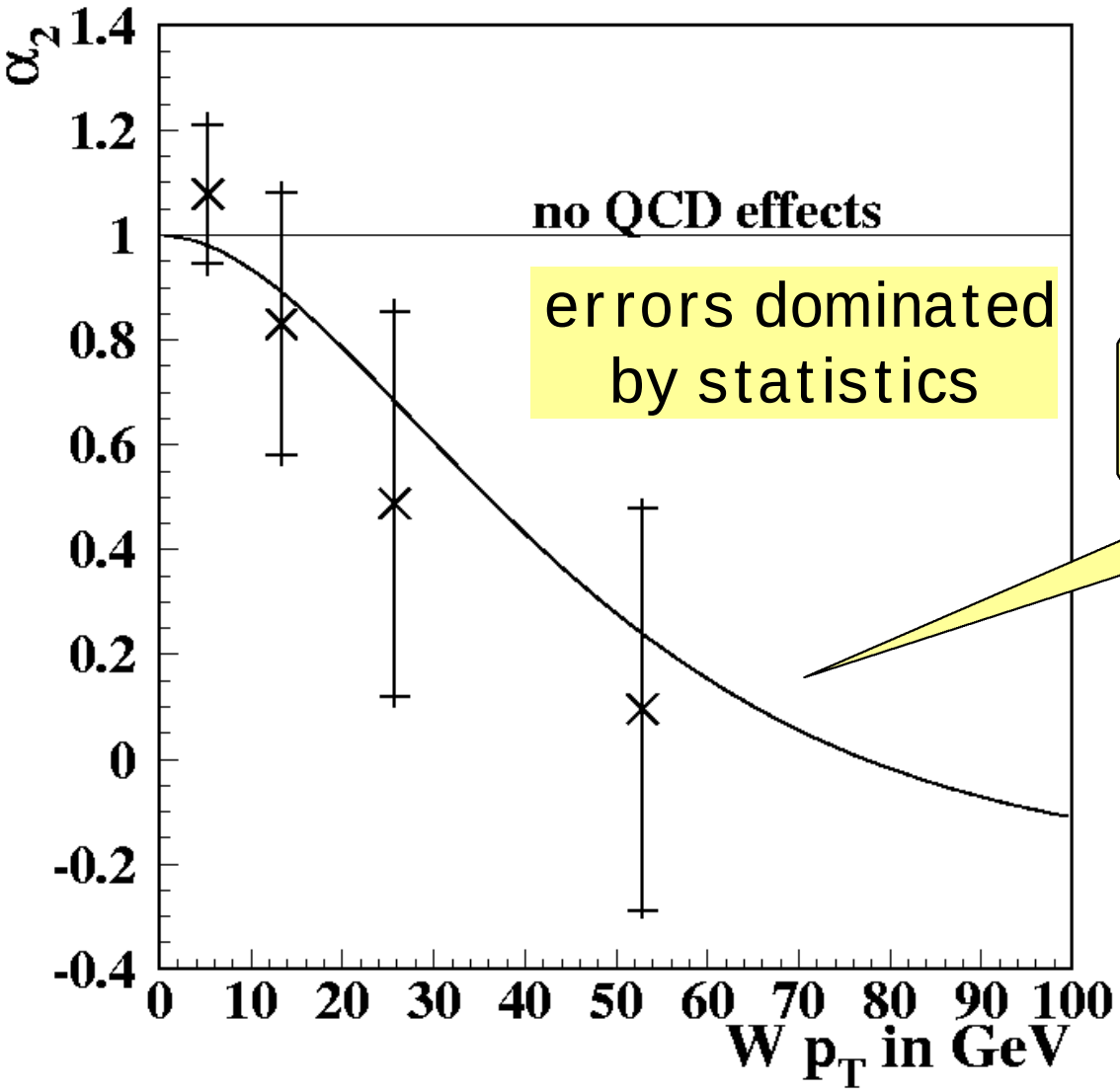


Log Likelihood Method

$$\log L = \sum_{\cos q^* bins} n_i \log p_i$$



W Angular Result



errors dominated by statistics

preliminary

QCD preferred: 2.3 σ effect

Summary

- Measured Inclusive W and Z Cross Sections and W Width
  - Direct and Indirect W Width
  - W Cross section at 1800 and 630 GeV
- W, Z p_T Distributions measured
  - CDF & D0 Measurements over a wide range of p_T
  - Testing NLO QCD + Resummation + Non-Perturbative Models
- Measured the Angular Distribution in W Decays
  - NLO QCD preferred by 2.3 σ