W Boson Production and Decay Studies at the Tevatron

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for
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- Γ_W
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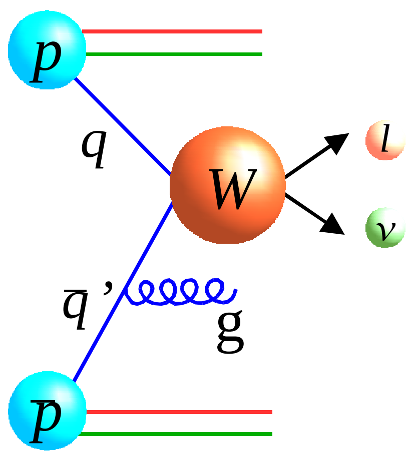
W Bosons at the Tevatron

- W Production at the Tevatron
  - Dominated by $q\bar{q}'$ annihilation
  - Can be accompanied by jets



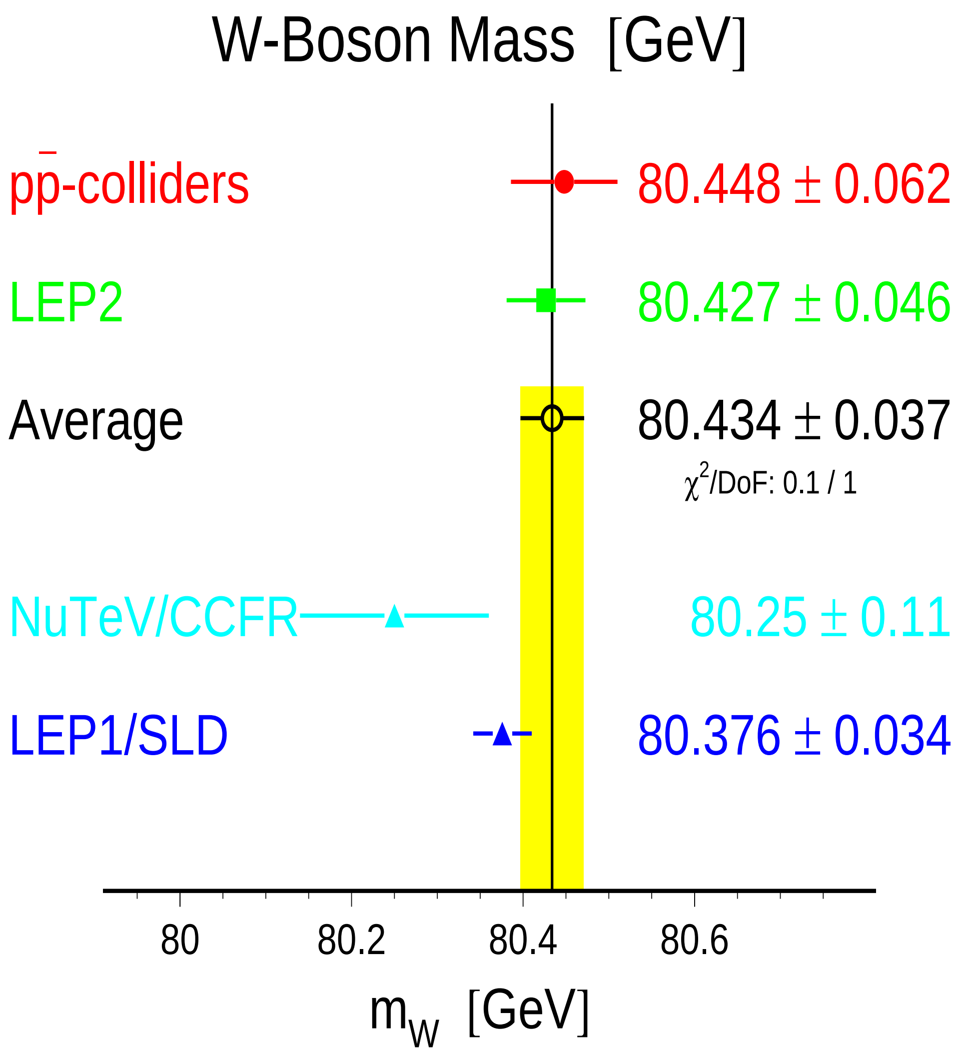
  - Concentrate on leptonic decays
    - W→jj signal is overwhelmed by QCD dijet production
    - $W \to e\nu_e$, $\mu\nu_\mu$, $\tau\nu_\tau$ (BR~11% per mode)
    - Transverse momentum imbalance
    - High P_T lepton

- Test of EW/QCD corrections
  - Typical two scale problem: M_W, P_T^W
  - Test perturbative + resummation + non−perturbative calculations
  - Constrain structure functions
- W selection
  - $\int L dt \sim 100 pb^{-1}$
  - isolated lepton, $E_T > 25$ GeV
  - $\not{E}_T > 25$ GeV
  - Mass samples (Run 1b)
    - 44k (CDF)
    - 39k (DØ)
  - Cross section samples (Run 1b)
    - 42k (CDF)
    - 67k (DØ)

W Studies at the Tevatron

- W mass
  - D0: PRL 84 222 (2000), PRL 80 3008 (1998), PRD 58 092003 (1998), PRL 77 3309 (1996)
    CDF: hep−ex/ 0007044, PRD 52 4784 (1995), PRL 75 11 (1995)
- W production cross section
  - D0: PRL 75 1456 (1995), PRD 60 052003 (1999);
    CDF: PRL 76, 3070 (1996), PRD 52, 2624 (1995), PRL 69, 28 (1992).
- P_T of W − D0: PRL. {80} 5498 (1998); CDF: PRL 66, 2951 (1991)
- W+ jets properties − CDF: PRL 81, 1367 (1998), PRL 79, 4760 (1997)
- W charge asymmetry −CDF: PRL 81 5754 (1998), PRL 74 850 (1995)
- W width
  - D0: PRD 61 072001 (2000) CDF: FERMILAB−PUB−00/085−E submitted to PRL, PRL 74 341 (1995)
- Lepton universality−D0: PRL 84 5710 (2000) CDF: PRL 68 3389 (1992).
- Lepton angular distribution from W decay
- Rare decays −CDF: PRD58, Rapid Comm. 091101 (1998). PRD58, Rapid Comm. 031101 (1998).

W Mass



- Hadron Collider numbers are final and have not changed since last year

CDF: 80.433 ± 0.079 GeV

DØ: 80.482 ± 0.091 GeV

- Error dominated by energy scale uncertainty

W Production Cross Section

- Test of QCD
  - $O(\alpha_s^2)$ calculations [Hamberg, van Neerven & Matsuura]
- Possible source of more precise luminosity measurement in Run II
- Ratio of cross sections measures $B(W\to e\nu)$ and $\Gamma(W)$

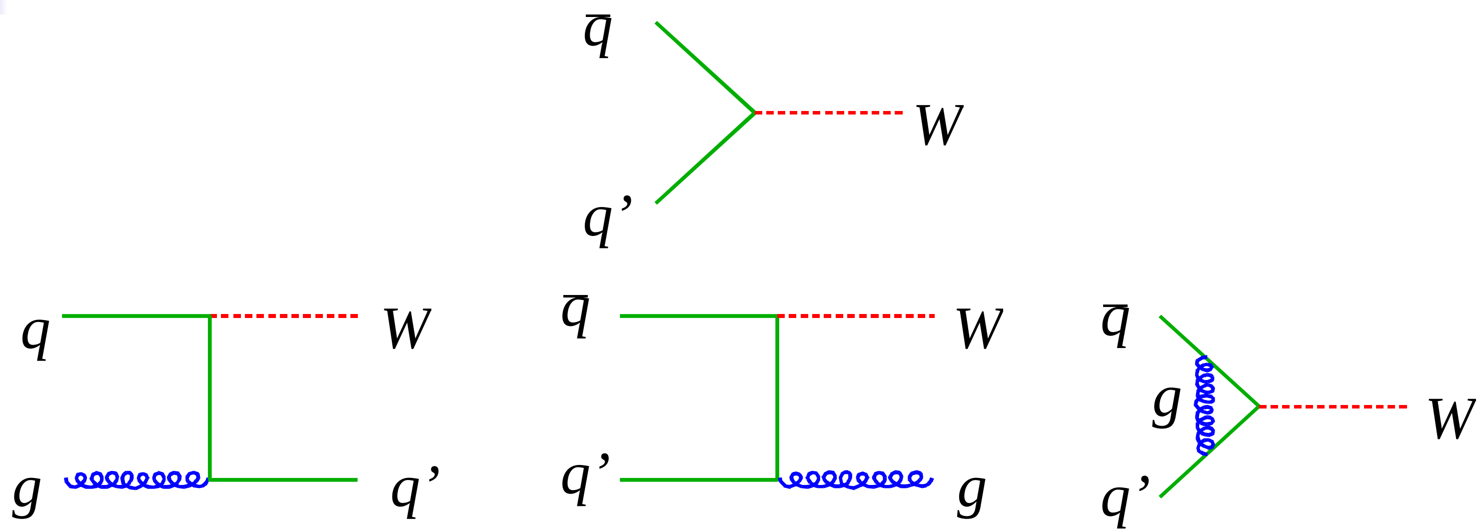
measure

$$\frac{\sigma_W B(W\to e\nu)}{\sigma_Z B(Z\to e^+e^-)} = \frac{\sigma_W}{\sigma_Z}\frac{1}{B(Z\to e^+e^-)}\frac{\Gamma(W\to e\nu)}{\Gamma(W)}$$

extract

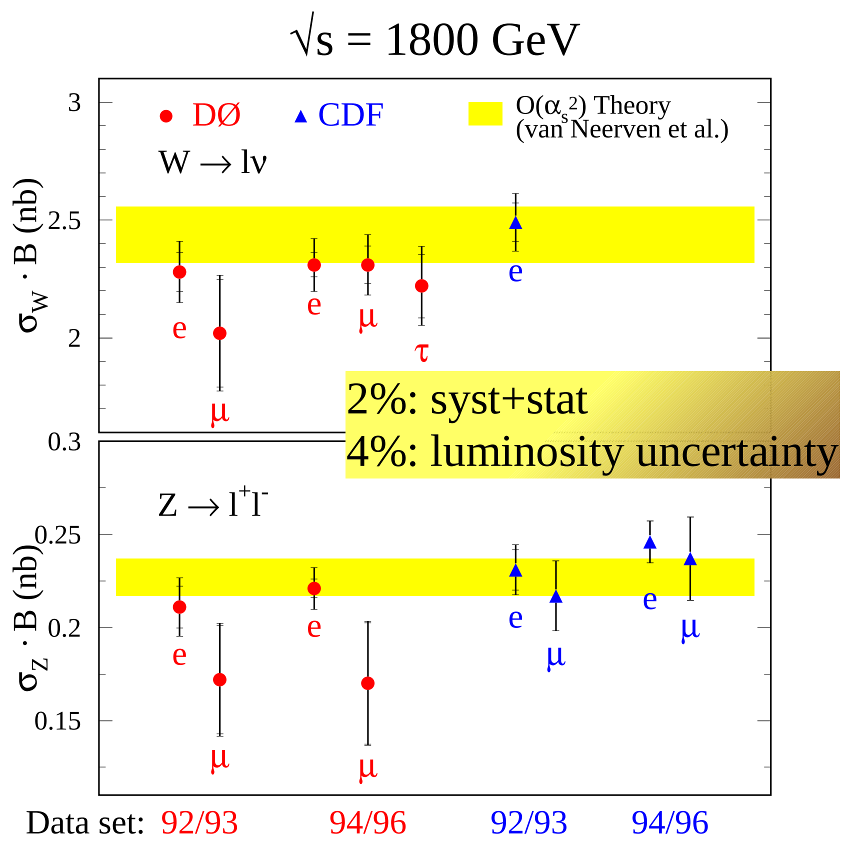
- σ_W/σ_Z from theory (±1.5%) [Hamberg, van Neerven & Matsuura]
- $B(Z\to e^+e^-)$ from LEP (±0.2%)
- $\Gamma(W\to e\nu)$ from theory (±0.4%) [Rosner, Worah, Takeushi]
- More precise than direct Γ(W) measurement

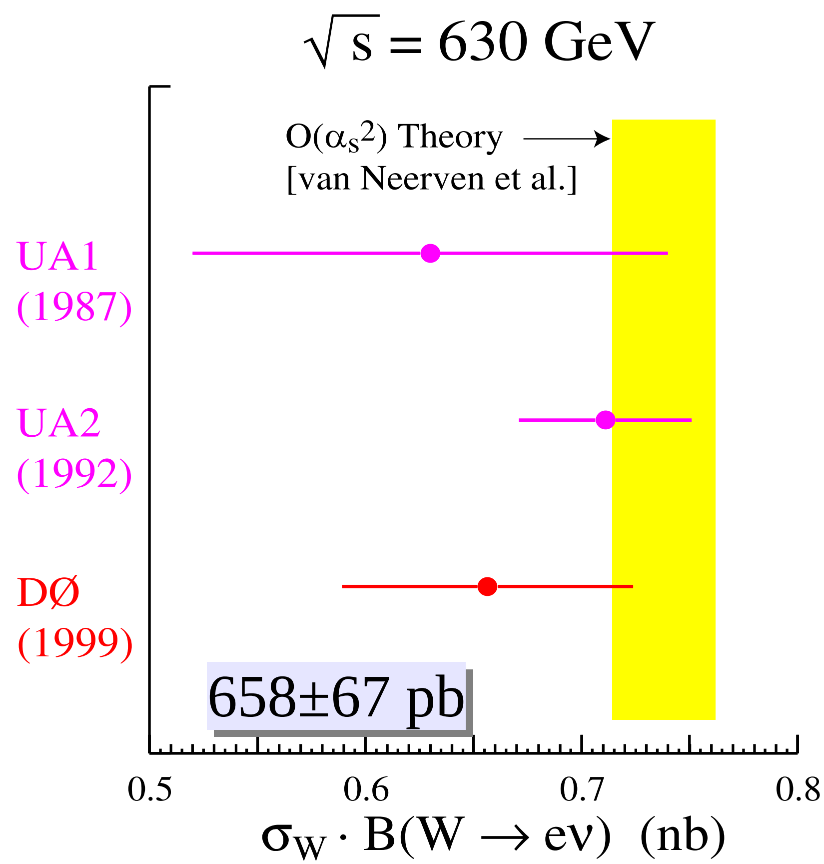
W Production



- NLO corrections impart transverse momentum to W
- The production cross section increases: K−factor=1.2
- Changes the lepton angular distribution from the naïve tree level diagrams
  - At the tree level, the lepton decays with ~ $(1\pm \cos\theta)^2$ w.r.t. the beam axis
- Theoretic calculations
  - Total cross section: NNLO $O(\alpha_s^2)$ [Hamberg, van Neerven, Matsuura]
  - Angular distribution: NLO [E. Mirkes]

Cross Section Results



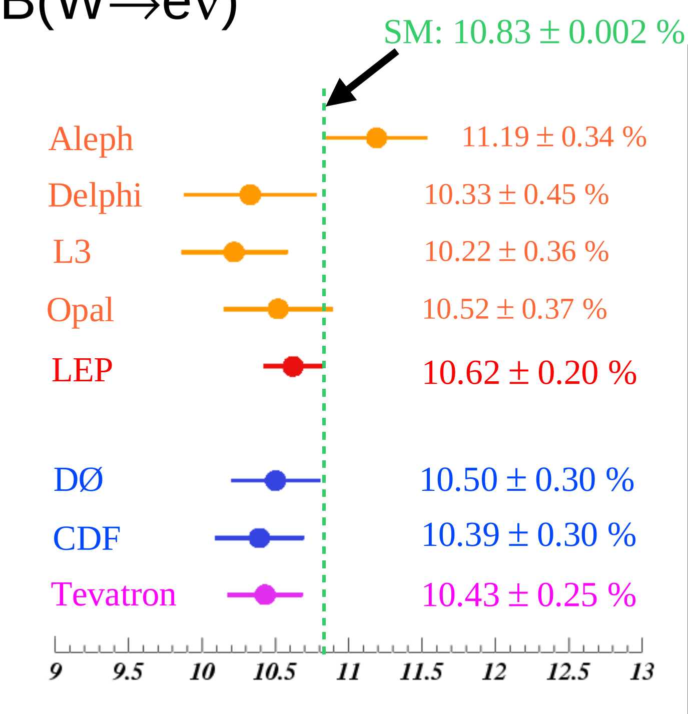


- 4% theoretical uncertainty from choice of PDF, α_s, μ_{ren} and μ_{fac} scales
  - Divide CDF cross section by 1.062 to get D0 normalization – due to different pp–bar cross–section used

Width of the W Boson (Γ_W)

- $R=\sigma_W \cdot B(W\to e\nu)/\sigma_Z \cdot B(Z\to ee)$
  - Luminosity uncertainty is canceled completely and a lot of systematic uncertainties are reduced
  - Theoretical uncertainty is also smaller
  - Combined R=10.42 ± 0.18
    - CDF: *10.38 ± 0.14(stat) ± 0.17(syst)*
    - DØ: *10.43 ± 0.14(stat) ± 0.21(syst)*
  - σ_W/σ_Z=3.362 ± 0.015
  - $\sin^2\theta_{eff}$ variation ~1.5% error
  - $B(Z\to ee)$ = 3.366 ± 0.008 %
  - $\Gamma(W\to e\nu)$ = 226.4 ± 0.7 MeV

- $B(W\to e\nu)$

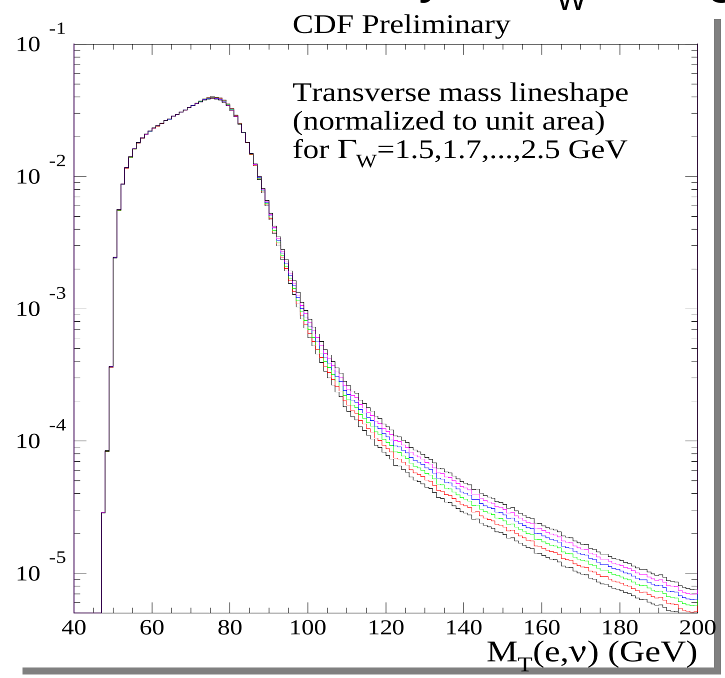


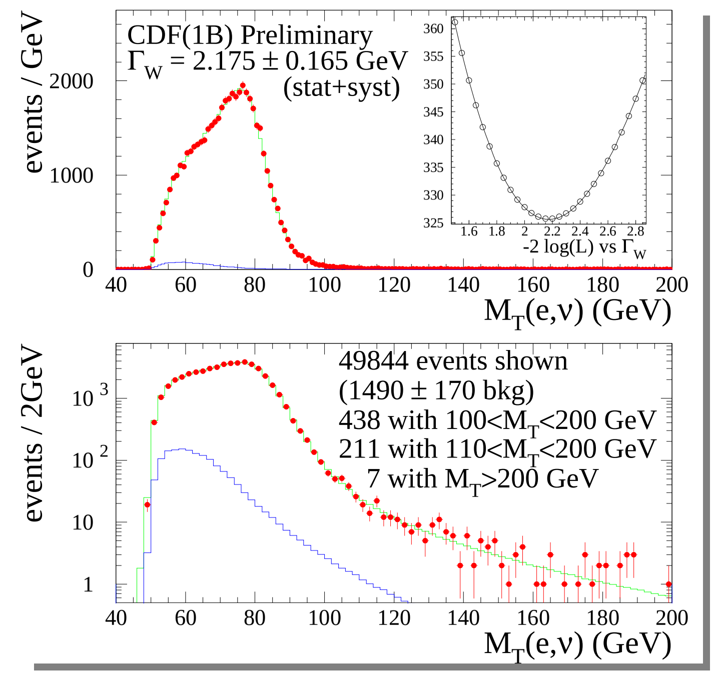
- Indirect measurement of Γ_W
  - *2.113 ± 0.056 GeV* (DØ 1a+1b)
  - *2.171 ± 0.052 GeV* (CDF 1a+1b)

SM:2.090 ± 0.008 GeV

Direct Γ_W Measurement

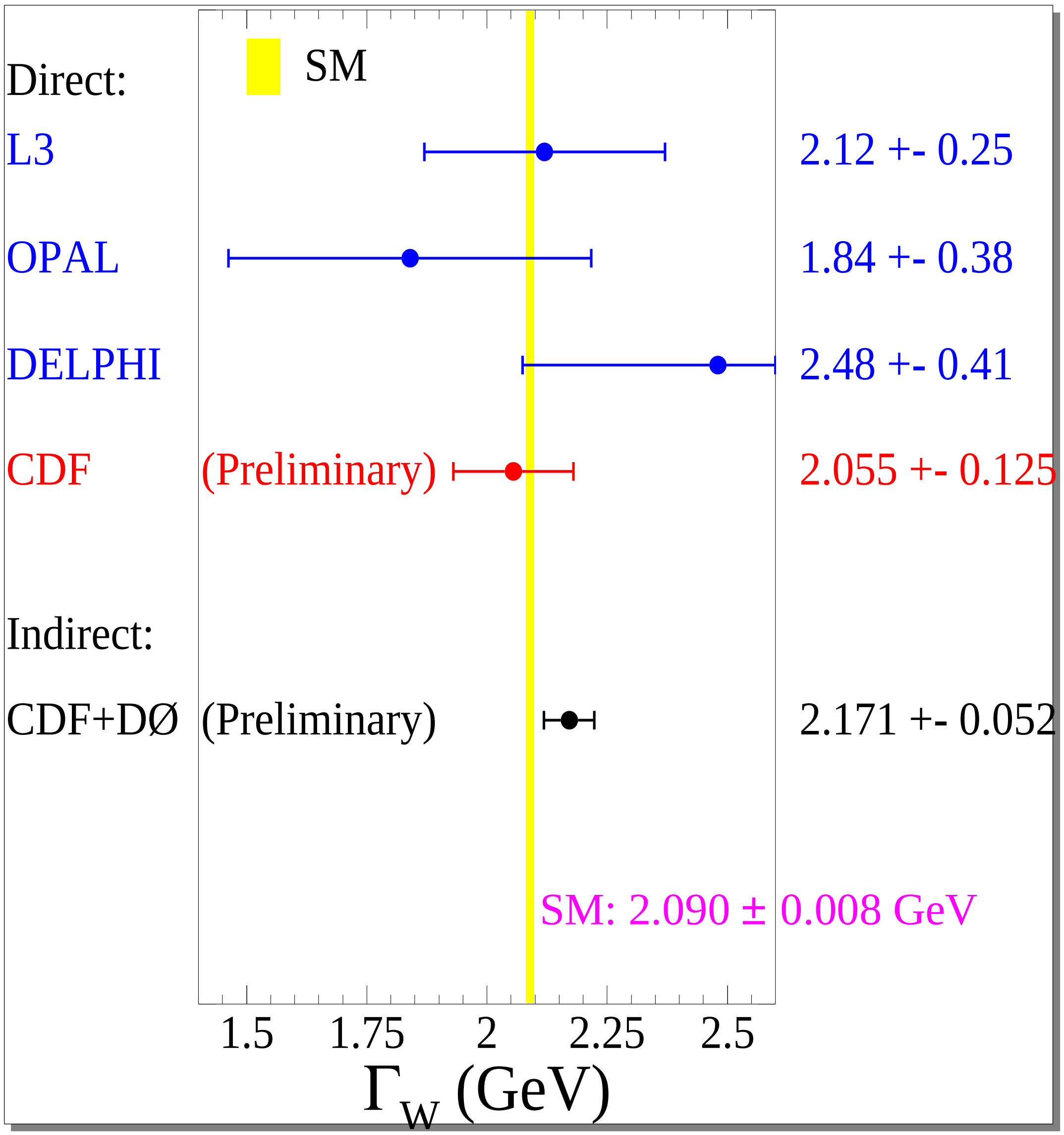
- Use fit to W transverse mass distribution
- Maximum sensitivity to Γ_W at high M_T





- ***Γ_W = 2.055 ± 0.100(stat) ± 0.075(syst)*** SM:2.090 ± 0.008 GeV
  - CDF Run 1b(e) Γ_W= 2.17 ± 0.125(stat) ± 0.105(syst)
  - CDF Run 1b(μ) Γ_W= 1.78 ± 0.195(stat) ± 0.135(syst)

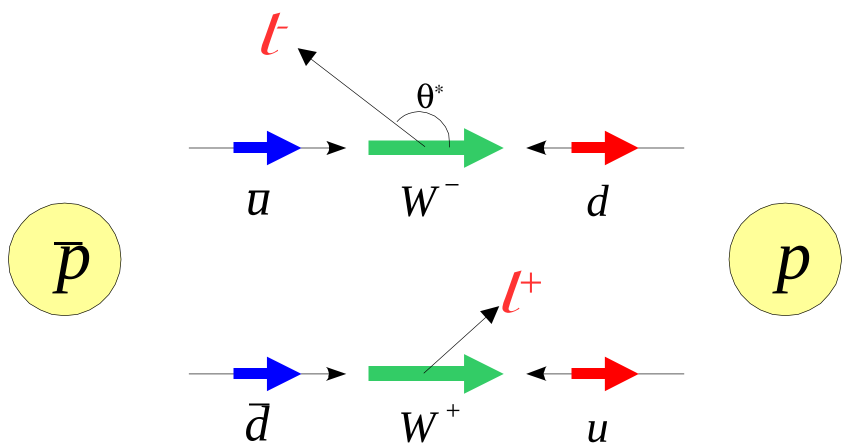
Γ_W Results



2.5% uncertainty

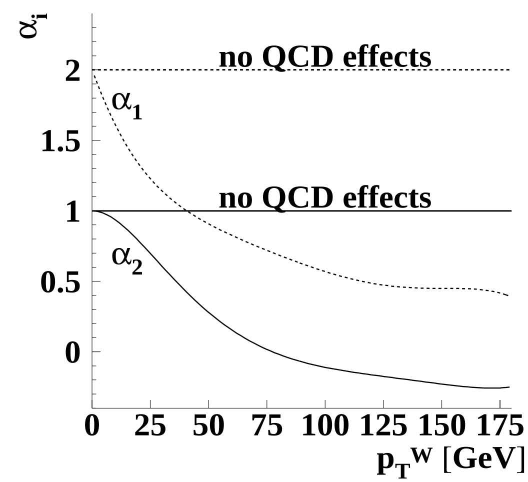
Lepton Angular Distribution (DØ)

- In pp−bar collision, there is a preferred W spin configuration to leading order
  - left−handed particles, right−handed anti−particles couple to W



$$\frac{d\sigma}{d(\cos\vartheta^*)} \propto (1 \pm \cos\vartheta^*)^2$$

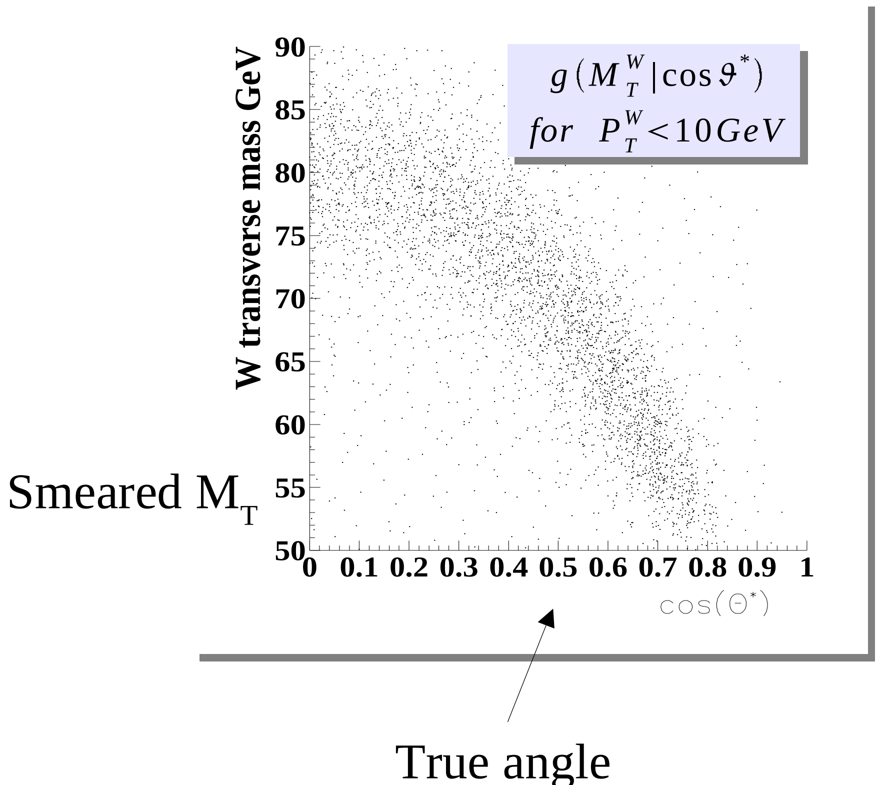
- NLO modifies this distribution to
  $1 + \alpha_1(p_T)\cos\theta^* + \alpha_2(p_T)\cos^2\theta^*$
  - α_1 needs lepton charge information
  - Analyzed in Collins−Soper frame



- Test of NLO corrections independent of inclusive measurement
- Probes spin structure of W production
- Provides a correction to W mass measurement O(40 MeV)

Lepton Angular Distribution

- Since we cannot explicitly reconstruct the rest frame of W, use correlation between M_T and $\cos\theta^*$
  - $M_T(\theta^*, \varphi^*, p_T^W)$



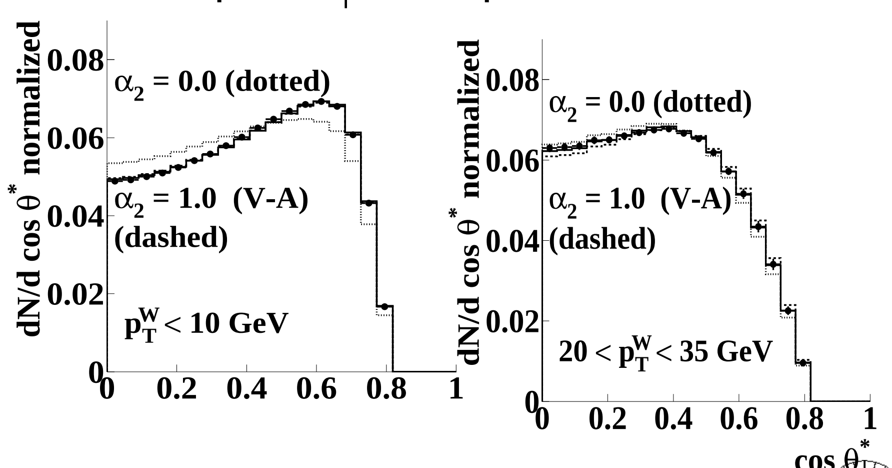
- Use Bayes theorem to invert with prior $h(\cos\theta^*) = 1 + \cos^2\theta^*$

$$f(\cos\vartheta^*|M_T) = \frac{g(M_T^W|\cos\vartheta^*)\,h(\cos\vartheta^*)}{N}$$

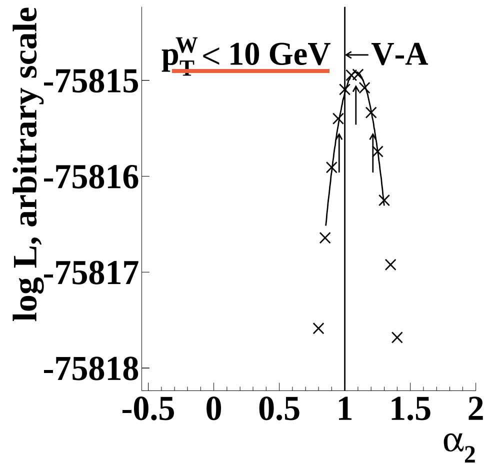
- For each $P_T(W)$ bin, plot background subtracted M_T

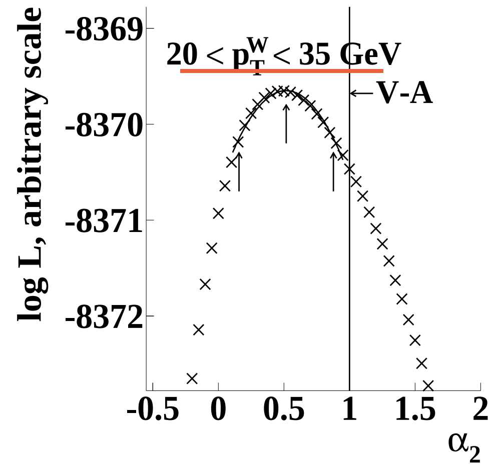
$$n_i = \sum_{M_{Tj}} N_{M_{Tj}}\, f(\cos\vartheta_i^*|M_{Tj})$$

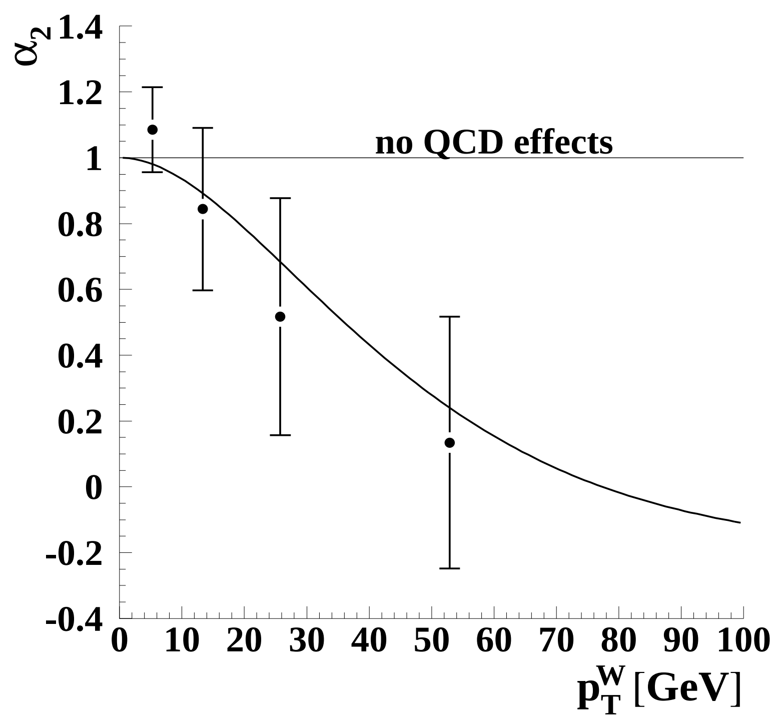
- Compare n_i to templates from MC



W Angular Result







2.3σ QCD preferred

2.3σ QCD preferred

Summary

- W Boson Physics at the Tevatron is not only electroweak but also QCD

- Consistent with EW/QCD expectations
  - W cross−section agrees with NNLO QCD
  - Indirect measurement of Γ_W
  - Lepton angular distribution agrees with expectations from QCD

- More Run I results to come
  - D0 will have a new measurement of W P_T spectrum

- In Run II (2001 ~), measurements of properties of W will be completely dominated by systematic uncertainties
  - Use W production cross−section as a normalization for other processes