Electroweak Measurements from Run II at the Tevatron

Presented on behalf of CDF and DØ
by:

Terry Wyatt
University of Manchester, UK

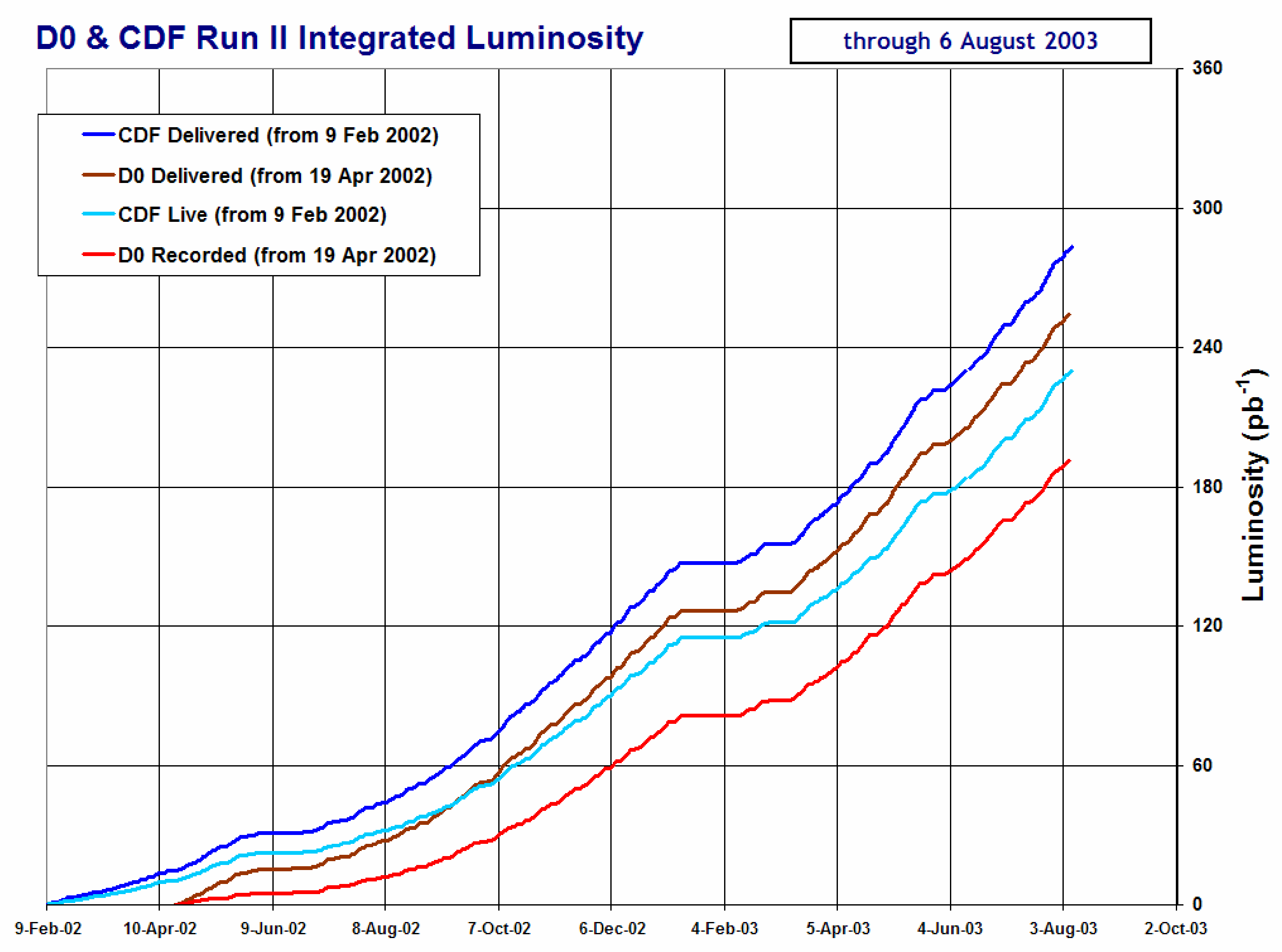
With special thanks to the other members of the Tevatron Electroweak Working Group:
Sarah Eno, Harald Fox, Martin Grünewald, Eva Halkiadakis, Eric James, Ashutosh Kotwal, Giulia Manca, Sean Mattingly, Pasha Murat, Emily Nurse, Michael Schmitt, Georg Steinbrück, Paul Telford, Alexei Varganov, Marco Verzocchi, Junjie Zhu

Overview

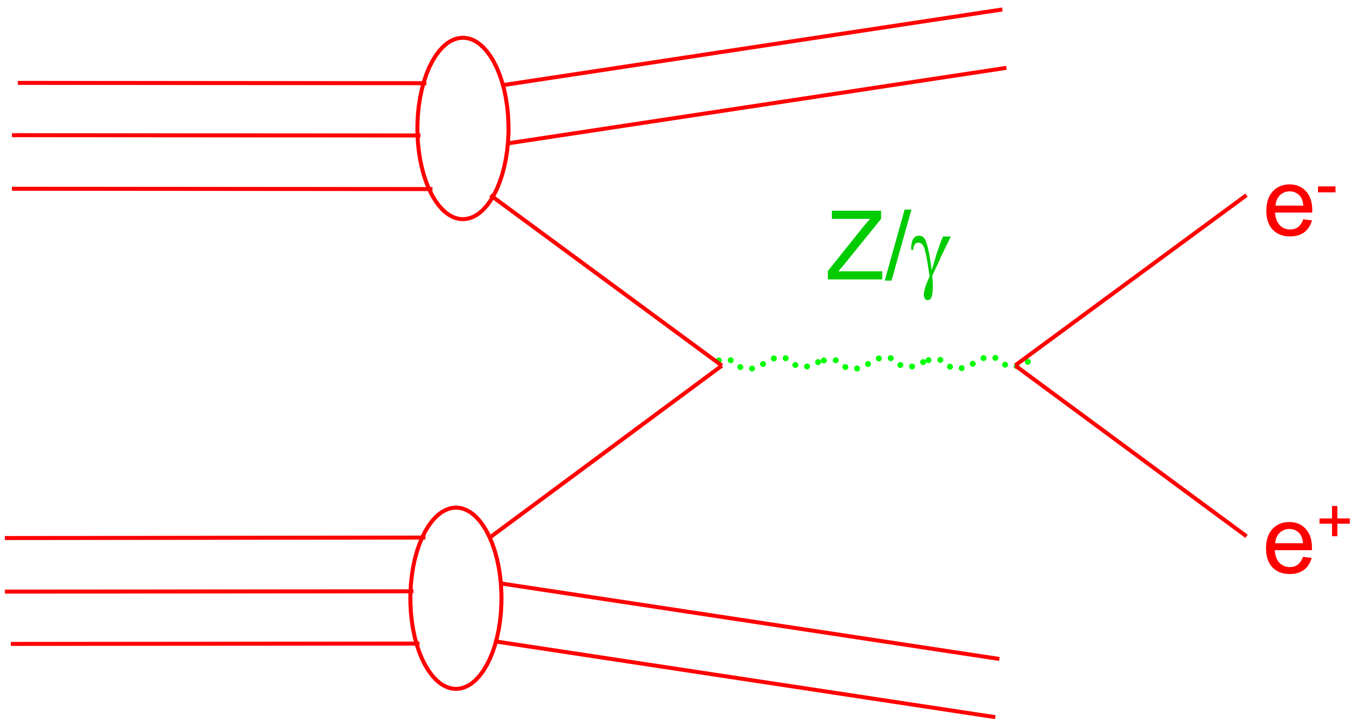
- Introduction
- Measurements of:
  - $\sigma_Z \bullet Br(Z \to l^+ l^-)$
  - $\sigma_W \bullet Br(W \to l\nu)$
- CDF + DØ combinations:
  - $\sigma_Z \bullet Br(Z \to l^+ l^-)$, $\sigma_W \bullet Br(W \to l\nu)$
  - $R = \dfrac{\sigma_W \bullet Br(W \to l\nu)}{\sigma_Z \bullet Br(Z \to l^+ l^-)}$
- Other measurements with W and Z
- Di-boson production
- Summary and Outlook

Delivered and Collected Luminosity

Tevatron Run II: proton-antiproton collisions at 1.96 TeV

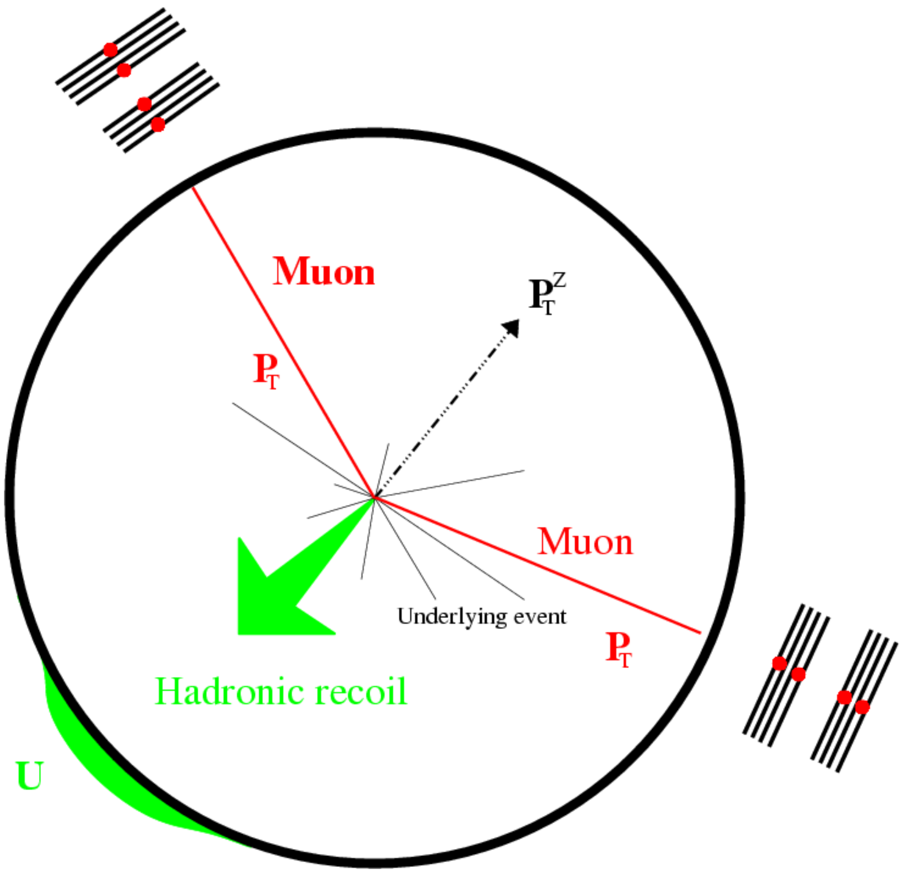


W and Z Production



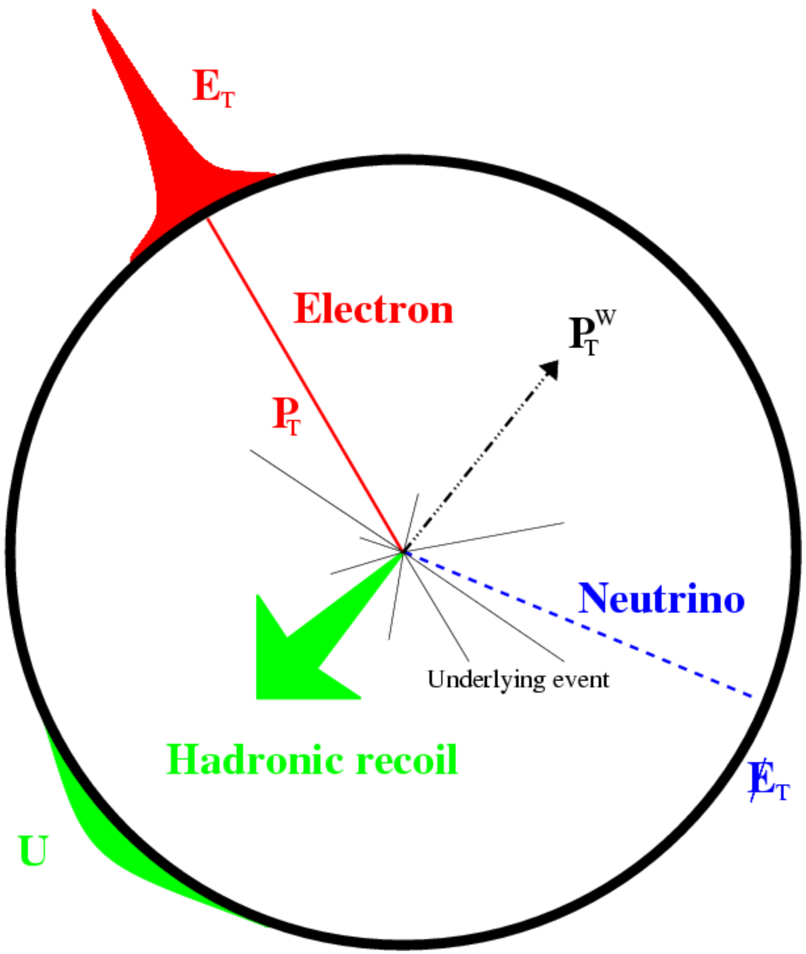
- Need accurate knowledge of PDFs:
  - modify longitudinal boost ⟶ experimental acceptance
- "Correct" for photon: $N_Z = N_{cand} \cdot [\sigma_Z/\sigma_{Z\gamma}]_{MC}$

Experimental Signature: $Z \rightarrow l^+l^-$



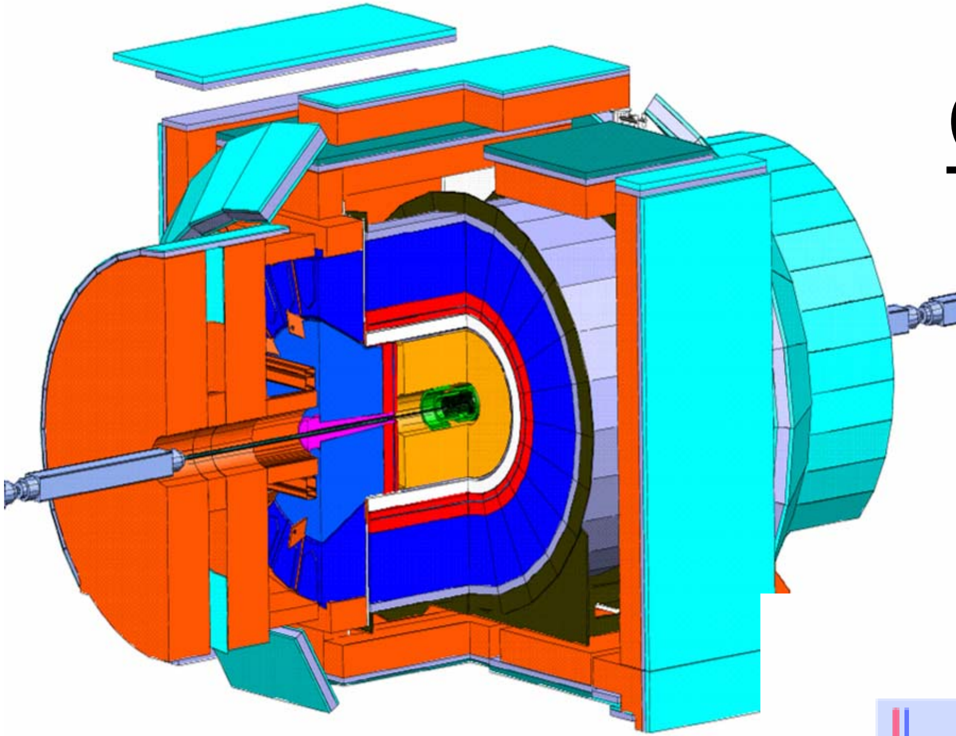
- pair of charged leptons:
  - high p_T
  - isolated
  - opposite-charge
- redundancy in trigger and offline selection
- low backgrounds
- control of systematics

Experimental Signature: W→lν



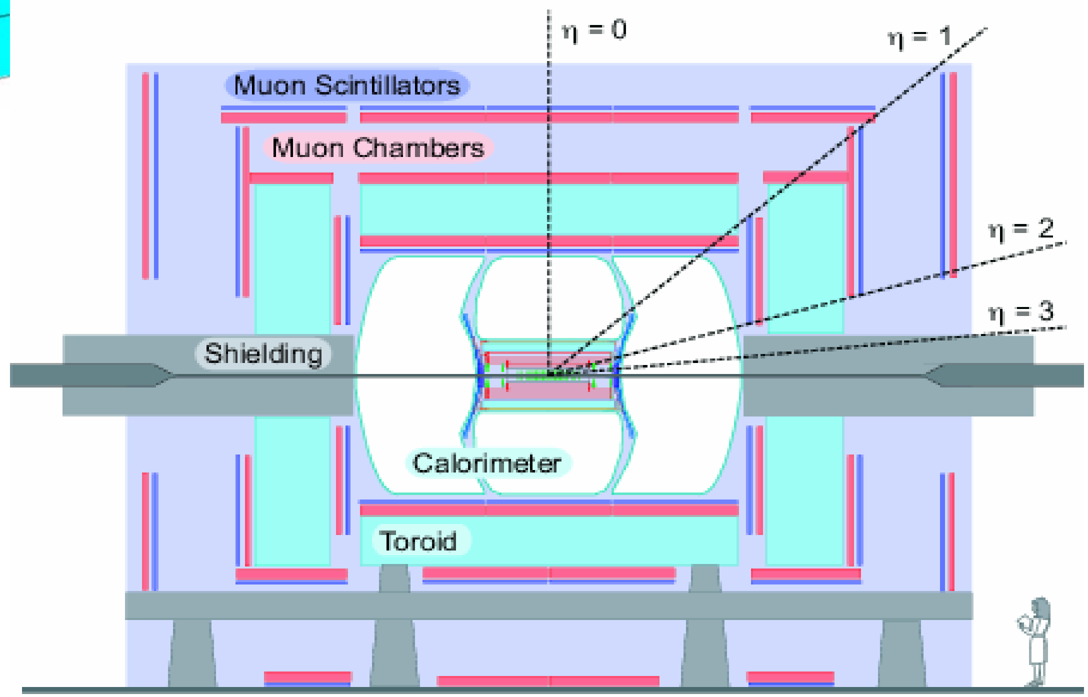
- single charged lepton:
  - high p_T
  - isolated
- E_T^{miss} (from neutrino)

- less redundancy in trigger and offline selection
- more difficult to control backgrounds and systematics
- need to understand hadronic recoil
- but more 'interesting' than Z! (post-LEP)
- σ•Br 10 times larger than Z



CDF

DØ



η = 0
η = 1
η = 2
η = 3
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid

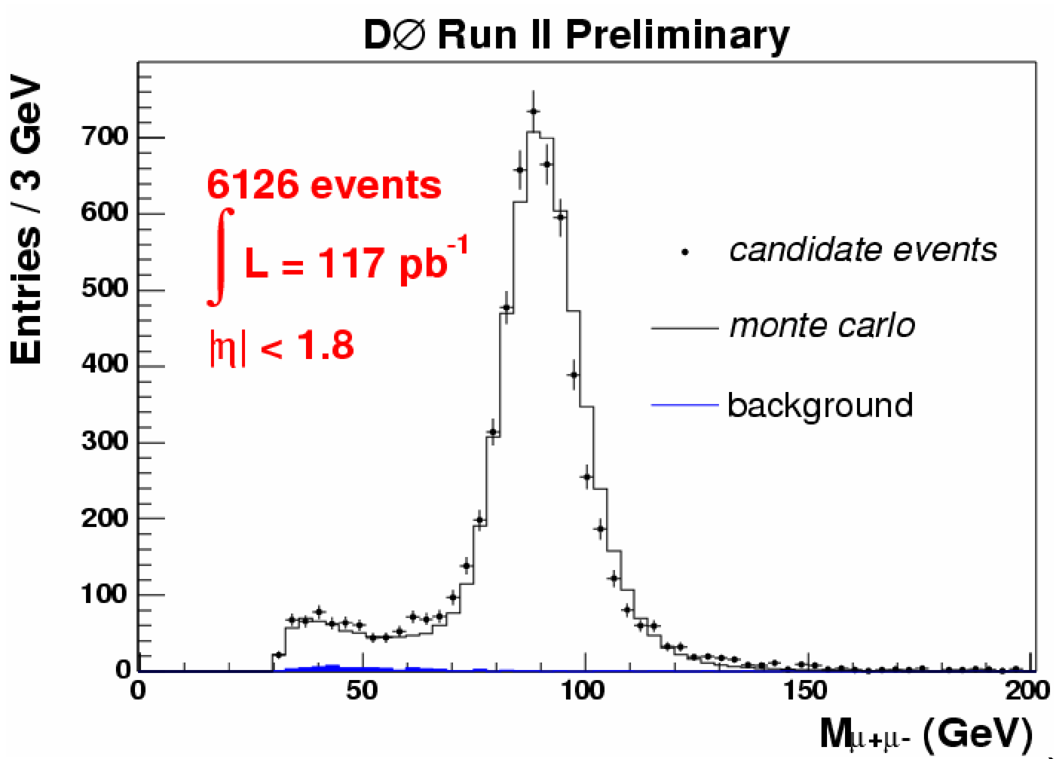
DØ $Z \to \mu^+\mu^-$ (updated for this conference)

Event selection:

- Two central tracks:
  - 'loose' μ-id
  - $p_T > 15$ GeV
  - opposite charge
  - $|\eta| < 1.8$
- $M_{\mu\mu} > 30$ GeV
- Cosmic veto
- ≥ 1 isolated μ

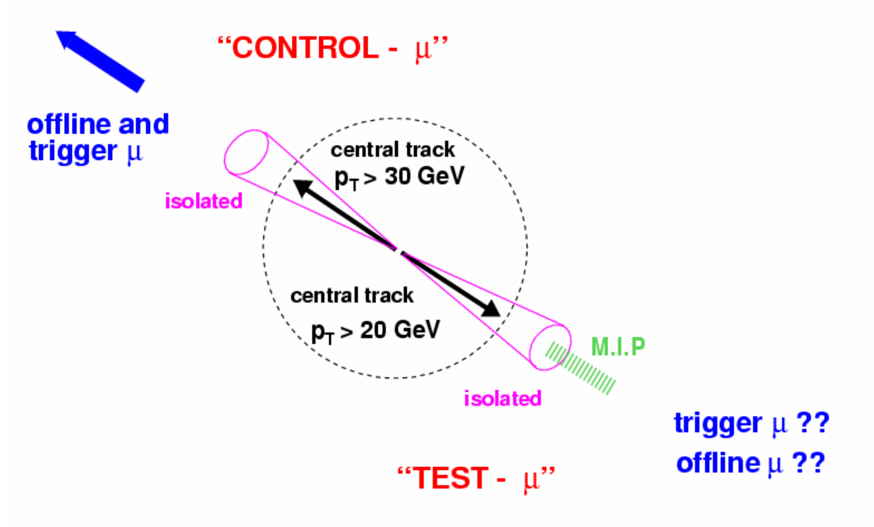
- Dominant systematics:
  - luminosity: 10%
  - efficiency measurements from $Z \to \mu^+\mu^-$ data: 3.3% (statistics limited)

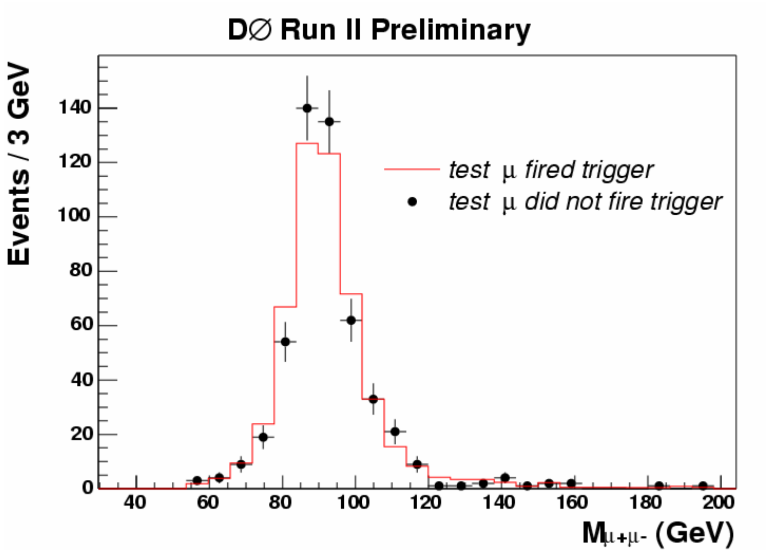
- $N_{cand} = 6126$
- $\int \mathcal{L} = 117\ pb^{-1}$
- Backgrounds:
  - QCD: $(0.6 \pm 0.3)\%$
  - $Z \to \tau^+\tau^-$: $(0.5 \pm 0.1)\%$
- $\varepsilon_{total} = 19\%$

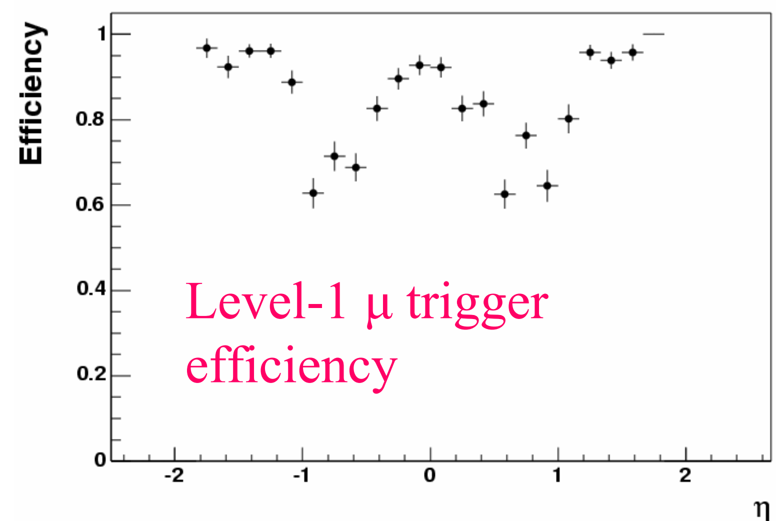


Measuring Efficiencies using the $Z \to \mu^+\mu^-$ data

- There are two μ's
- The backgrounds are low
- Can select pure Z sample with even looser cuts on one μ







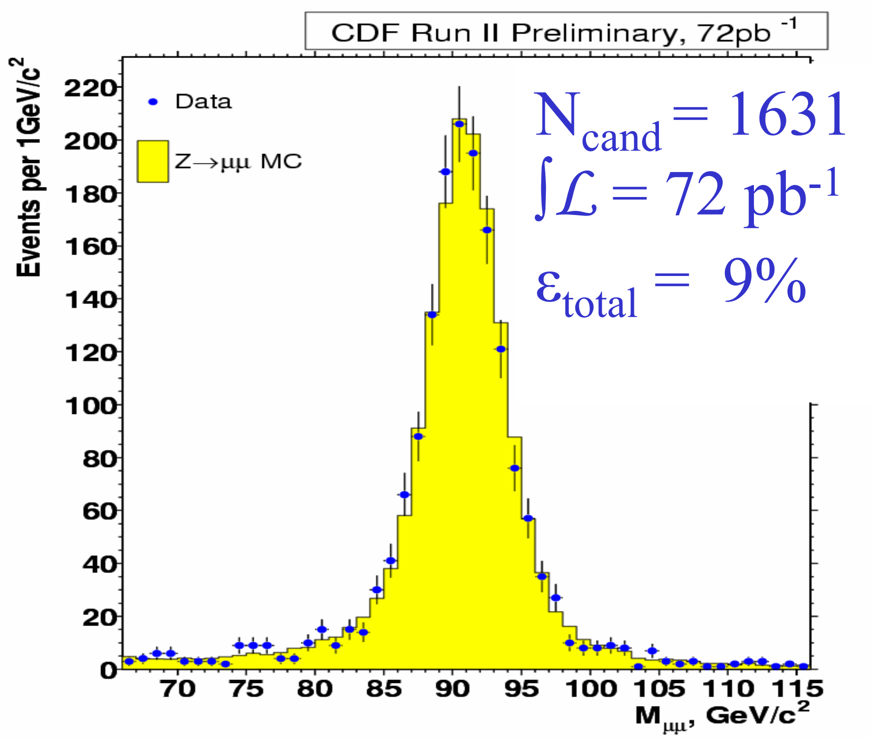
$$\sigma_Z \bullet Br(Z \to \mu^+\mu^-) = 261.8 \pm 5.0 \pm 8.9 \pm 26.2 \text{ pb}$$

stat. syst. lumi.

CDF: $Z \to \mu^+\mu^-$

Event selection:

- Two central tracks:
  - $p_T > 20$ GeV
  - opposite charge
  - minimum ionizing in CAL
  - at least one $|\eta| < 0.6$
  - both $|\eta| < 1.0$
- $66 < M_{\mu\mu} < 116$ GeV
- Cosmic veto
  - cosmic background (0.9 ± 0.9) %



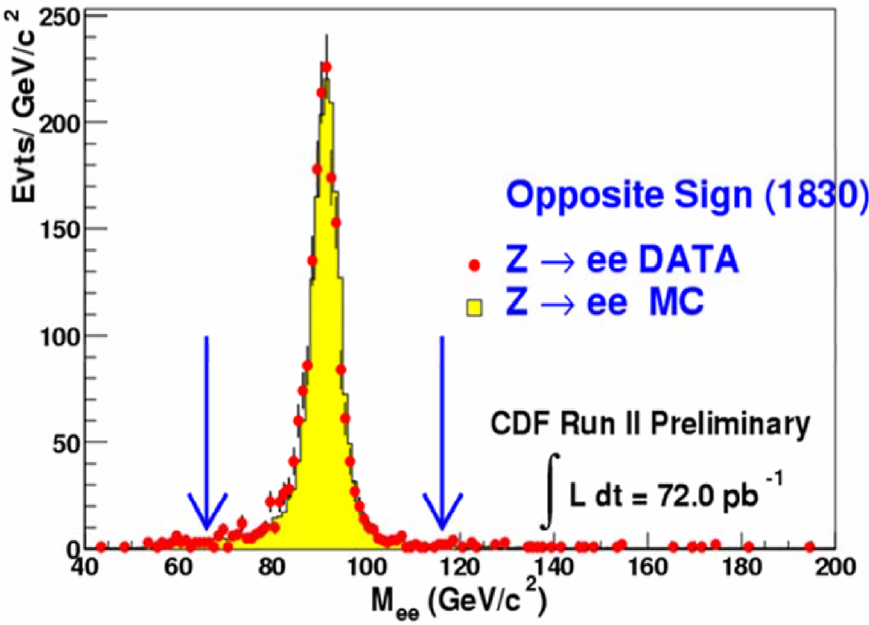
- Largest systematics:
  - luminosity: 6%
  - PDFs: 3%

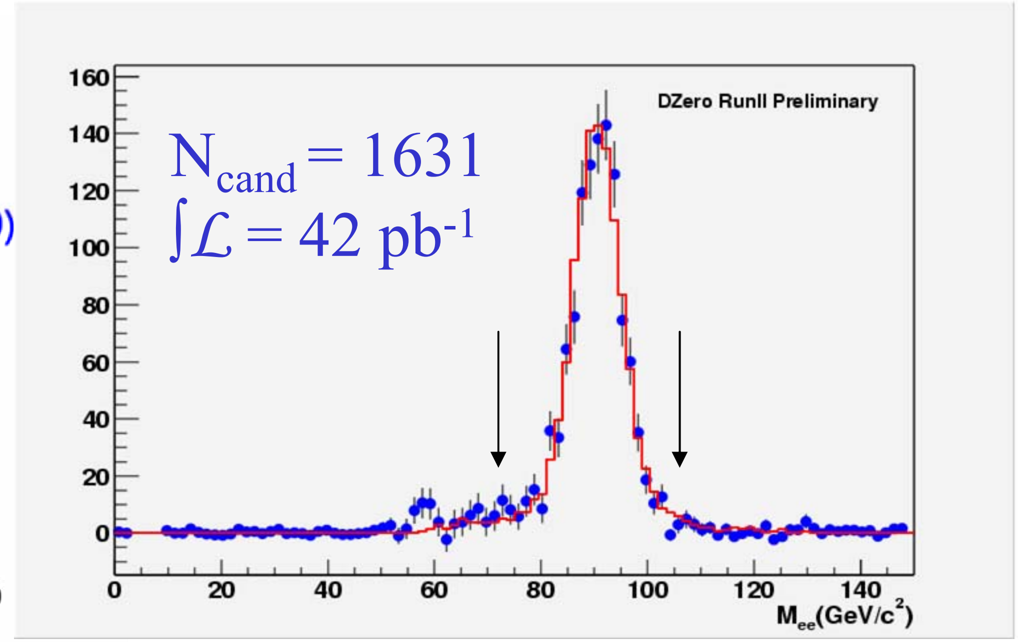
$$\sigma_Z \cdot Br(Z \to \mu^+\mu^-) = 246 \pm 6 \pm 12 \pm 15 \text{ pb}$$

stat. syst. lumi.

CDF and DØ $Z \to e^+e^-$

Two isolated electrons, $E_T > 25$ GeV, $|\eta| < 1.1$





CDF: $\sigma_Z \bullet Br(Z \to e^+e^-) = 267.0 \pm 6.3 \pm 15.2 \pm 16.0$ pb

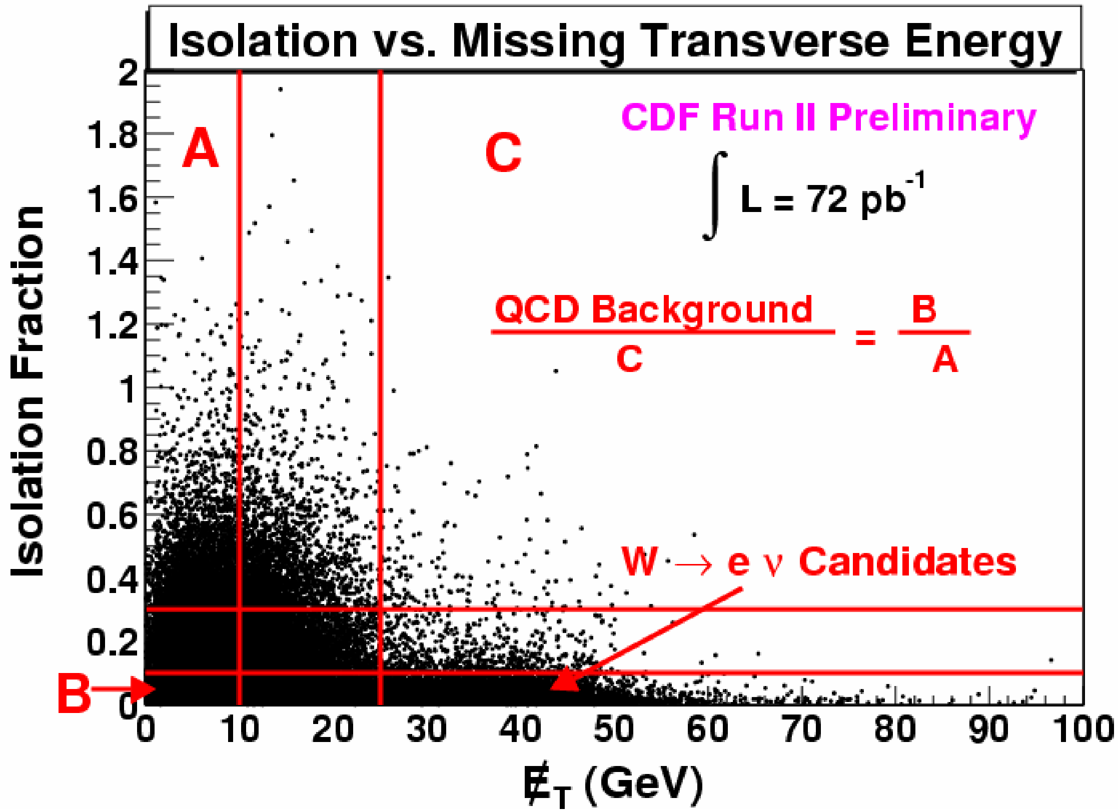
DØ: $\sigma_Z \bullet Br(Z \to e^+e^-) = 275 \pm 9 \pm 9 \pm 28$ pb

stat. syst. lumi.

CDF: $W \to e\nu$

- $p_T(e) > 25$ GeV
- $E_T^{miss} > 25$ GeV
- $N_{cand} = 38628$

- QCD background estimate
  - $(3.5 \pm 1.7)\%$



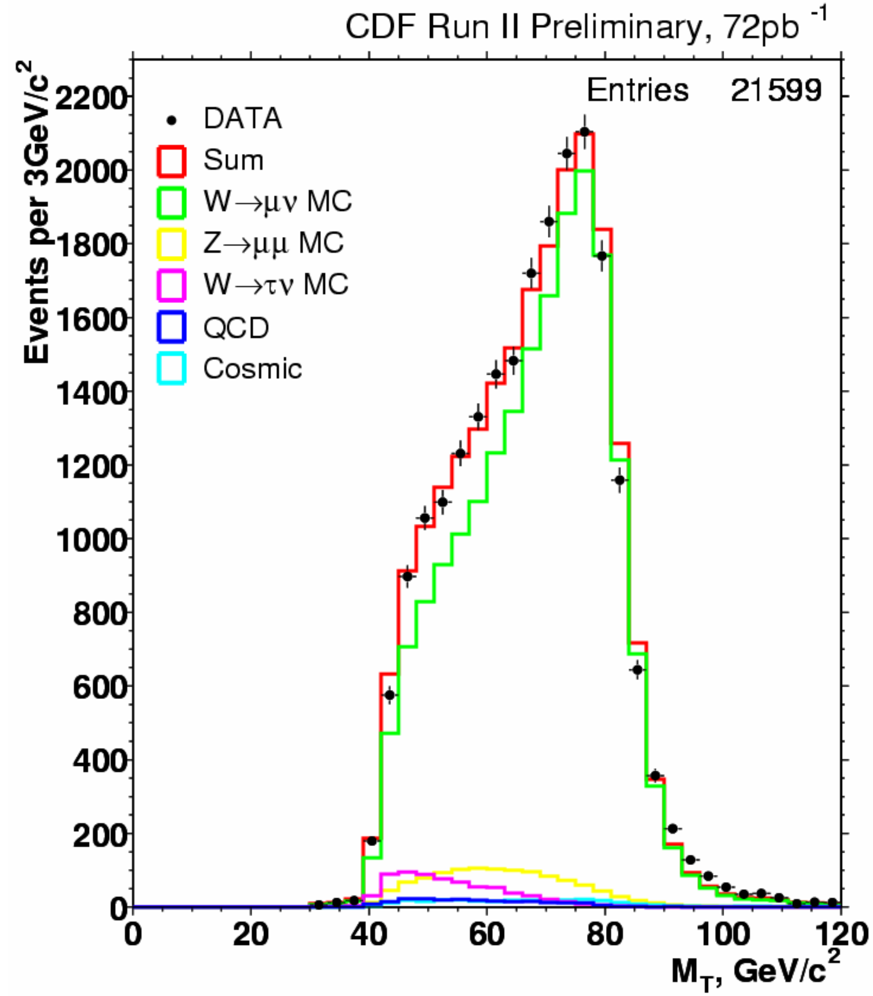
$\sigma_W \cdot Br(W \to e\nu) = 2.64 \pm 0.01 \pm 0.09 \pm 0.16$ nb

stat. syst. lumi.

CDF: $W \rightarrow \mu\nu$

- $p_T(\mu) > 20$ GeV
- $E_T^{miss} > 20$ GeV
- $N_{cand} = 21599$
- Backgrounds: $(10.8 \pm 1.1)\%$

- Systematics:
  - PDFs 2.6%
  - hadronic recoil 1.6%



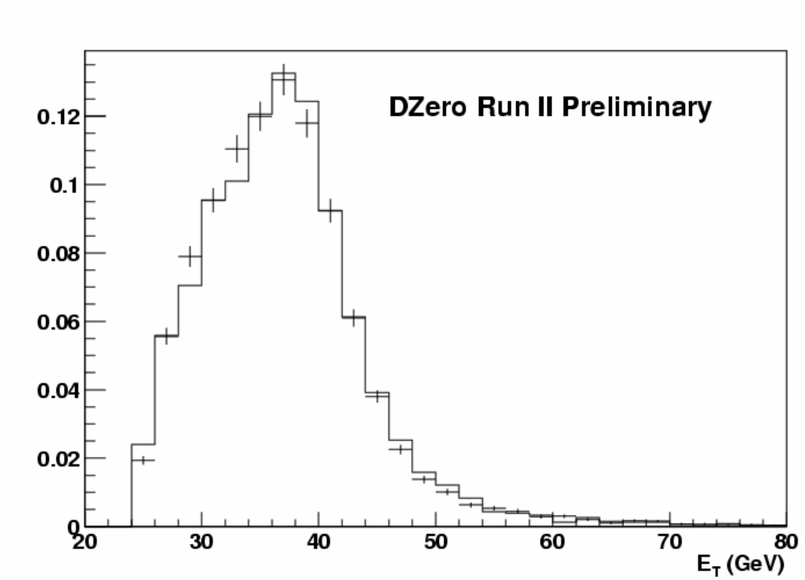
$\sigma_W \bullet Br(W \rightarrow \mu\nu) = 2.64 \pm 0.02 \pm 0.12 \pm 0.16$ nb

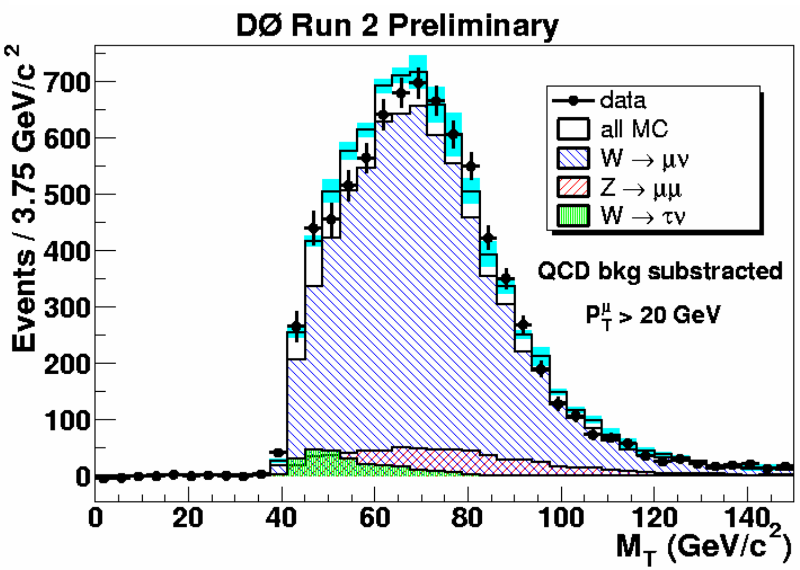
stat. syst. lumi.

DØ: $W \to e\nu$ and $W \to \mu\nu$

- $p_T(e) > 25$ GeV
- $E_T^{miss} > 25$ GeV
- $N_{cand} = 27370$
- $\int \mathcal{L} = 42\ pb^{-1}$

- $p_T(\mu) > 20$ GeV
- $E_T^{miss} > 20$ GeV
- $N_{cand} = 8302$
- $\int \mathcal{L} = 17\ pb^{-1}$





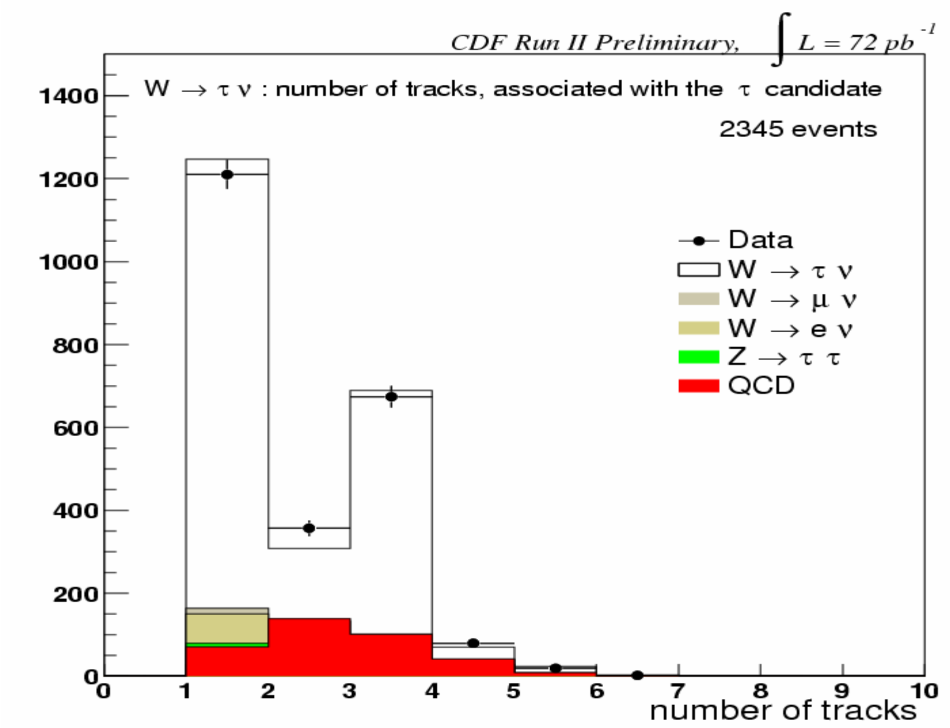
$\sigma_W \cdot Br(W \to e\nu) = 2.884 \pm 0.021 \pm 0.128 \pm 0.284$ nb

$\sigma_W \cdot Br(W \to \mu\nu) = 3.226 \pm 0.128 \pm 0.100 \pm 0.322$ nb

stat. syst. lumi.

CDF: $W \rightarrow \tau\ \nu$

- Look for jet within narrow 10 degree cone
- Isolated within wider 30 degree cone
- $p_T(\tau) > 25$ GeV
- $E_T^{miss} > 25$ GeV
- $N_{cand} = 2345$



$\sigma_W \bullet Br(W \rightarrow \tau\nu) = 2.62 \pm 0.07 \pm 0.21 \pm 0.16$ nb

stat. syst. lumi.

Comparing and Combining σ • Br (W,Z) Measurements from CDF and DØ

- Luminosity determination:
  - measure total rate of inelastic pp collisions
- $\sigma_{inelastic}$
  - measurements by CDF and E811 @ 1.8 TeV disagree at ~3σ level
  - different methods of averaging CDF and E811 give values in the range:
    - $59.1 < \sigma_{inelastic} < 60.7$ mb (extrapolated to 1.96 TeV) (2.7% difference)
- For σ • Br (W,Z) results quoted above:
  - CDF uses $\sigma_{inelastic} = 60.7$ mb
  - DØ uses $\sigma_{inelastic} = 57.6$ mb (5.3% difference)

Comparing and Combining σ • Br (W,Z) Measurements from CDF and DØ

For "my combinations"§ presented below I have chosen to:

- Scale reported σ • Br (W,Z) values to correspond to consistent value of $\sigma_{inelastic}$
  - Arbitrarily chose: $\sigma_{inelastic}$ = 60.7 mb
  - Multiply σ • Br (DØ) by factor 1.053
- Quote additional 2.7% syst. error to cover ambiguity in choice of $\sigma_{inelastic}$
  - total error of (4 + 2.7 = 4.8)% assumed for $\sigma_{inelastic}$
  - 100% correlated between CDF and DØ
- PDFs next most significant error (1—3)%

N.B.

§ These issues have been discussed within Tevatron EWWG, but ….

§ No official policy yet agreed by CDF and DØ

§ "my combinations" should be taken as the responsibility of a review speaker: not official CDF / DØ results

Standard Model:

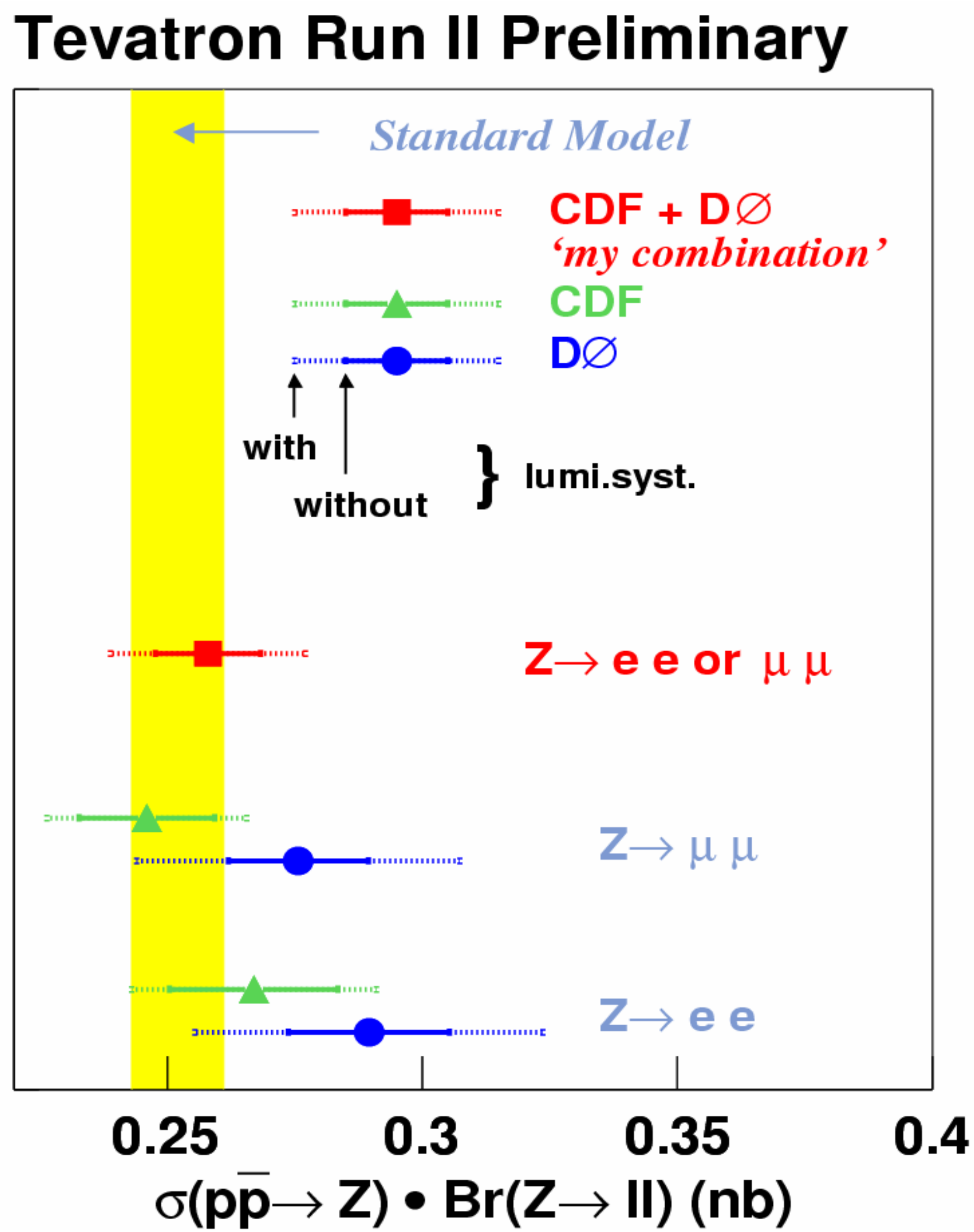
$\sigma_Z \bullet Br(Z\rightarrow l^+l^-)$ = 252 ± 9 pb

- NNLO calculation
  [Nucl.Phys. **B359** (1991) 343]
- NNLO MRST2002 PDFs
- 3.5% uncertainty assessed using CTEQ error PDFs
  [But also see talk by Robert Thorne at this conference]
- LEP $Br(Z\rightarrow l^+l^-)$ = .03366 ± .00002

Tevatron Average

$\sigma_Z \bullet Br(Z\rightarrow l^+l^-)$ = 258 ± 10 ± 16 pb
expt. lumi.

expt. error from counting Z's
→ statistics limited



Standard Model:

$\sigma_W \bullet Br(W \to l\nu) = 2.72 \pm 0.10$ nb

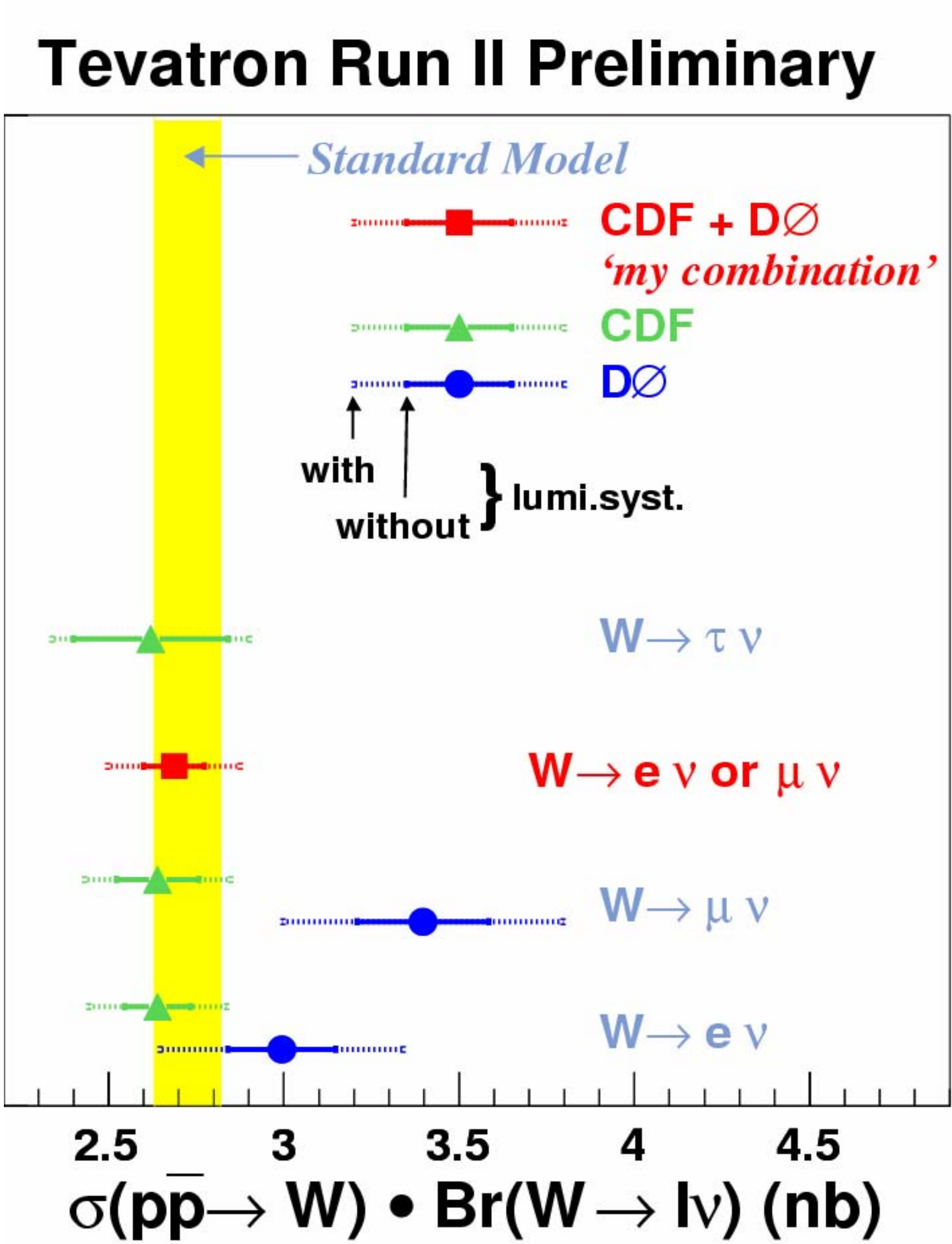
- NNLO calculation [Nucl.Phys. **B359** (1991) 343]
- NNLO MRST2002 PDFs
- 3.5% uncertainty assessed using CTEQ error PDFs
- SM $Br(W \to l\nu) = .1082 \pm .0002$

Tevatron Average

$\sigma_W \bullet Br(W \to l\nu) = 2.69 \pm 0.09 \pm 0.17$ nb
expt. lumi.

N.B. expt. error will always be smaller than lumi.

In the future we can use $\sigma \bullet Br(W,Z)$ to determine the luminosity

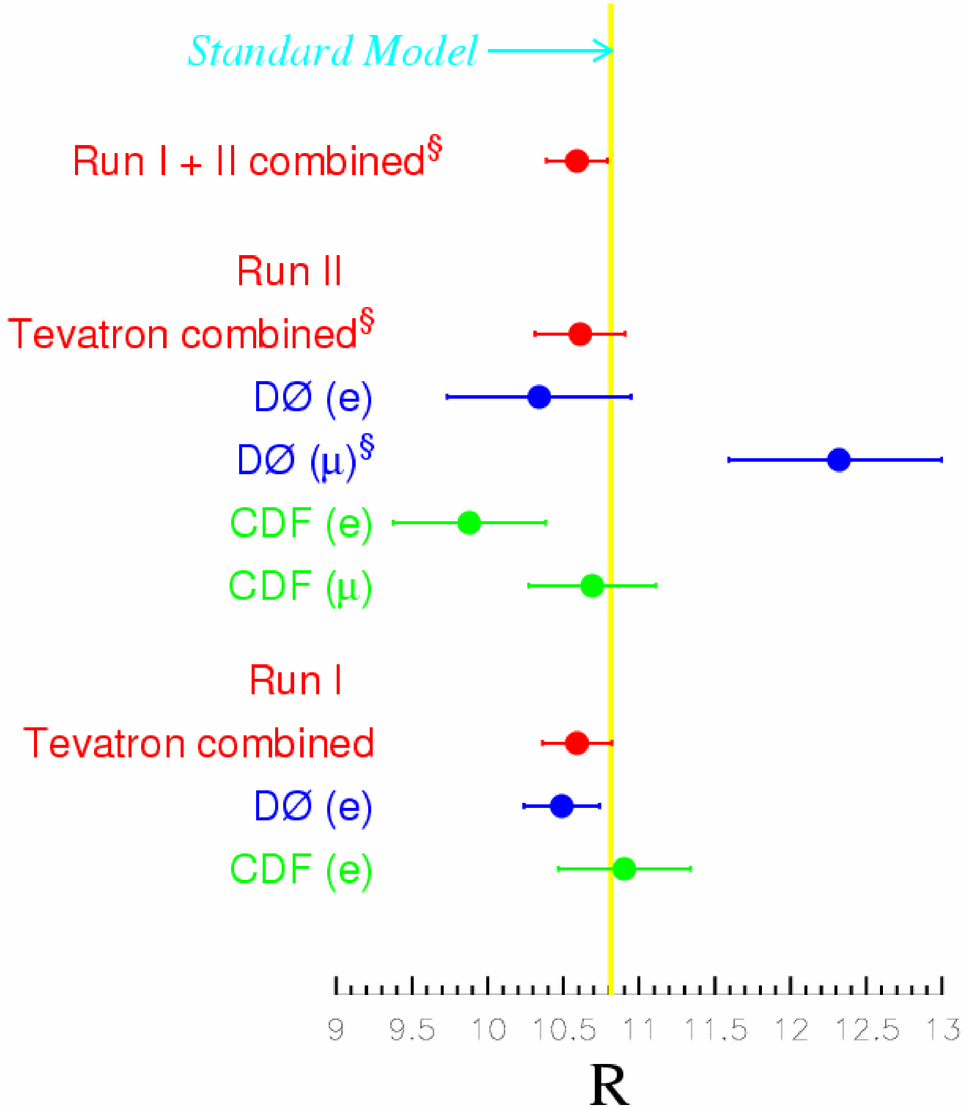


$$R = \frac{\sigma_W \bullet Br(W \rightarrow l\nu)}{\sigma_Z \bullet Br(Z \rightarrow l^+l^-)}$$

- Luminosity error cancels
- Other important systematics partially cancel:
  - PDFs
  - Experimental: high p_T, isolated leptons
- Tevatron EWWG:
  - Evaluated correlated systematics
  - Performed 'official' average of CDF(e,μ) and DØ(e) — shown at EPS-Aachen
- Update including DØ(μ) here

Tevatron measurements of

$R = \sigma \times Br(W \to l\nu) / \sigma \times Br(Z \to ll)$



§ 'my combination'

10.59 ± 0.20 Run (I + II)

10.61 ± 0.30 Run II

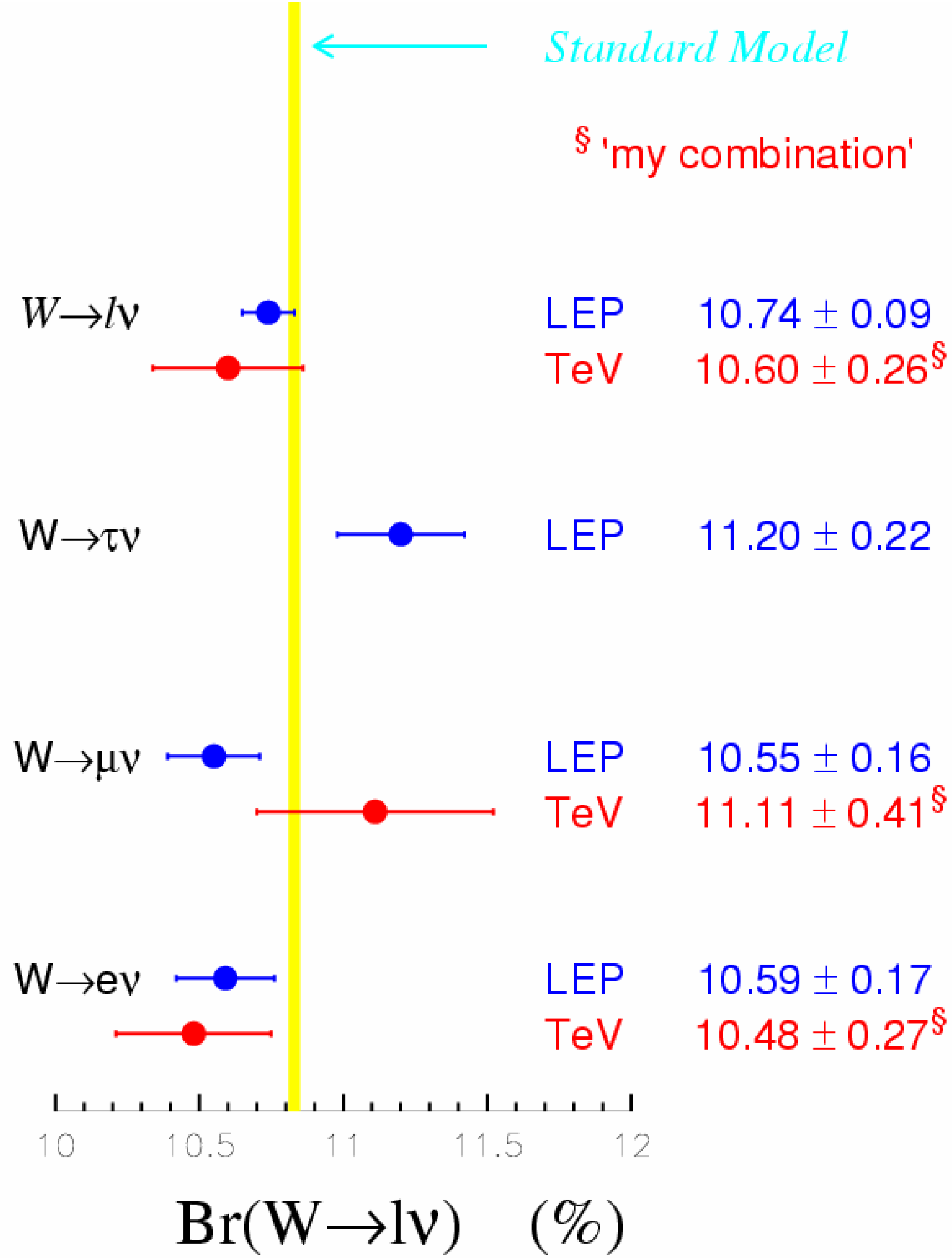
Indirect measurement of Br(W→lν)

measure

$$R = \frac{\sigma_W}{\sigma_Z} \frac{Br(W \to l\nu)}{Br(Z \to l^+l^-)}$$

NNLO calculation

LEP



Indirect measurement of Γ_W

- $Br(W \to l\nu) = \Gamma(W \to l\nu) / \Gamma_W$

↑ SM

Tevatron combined result§:

$\Gamma_W = 2.135 \pm 0.053$ GeV

cf LEP+Tevatron direct measurements:

$\Gamma_W = 2.139 \pm 0.069$ GeV

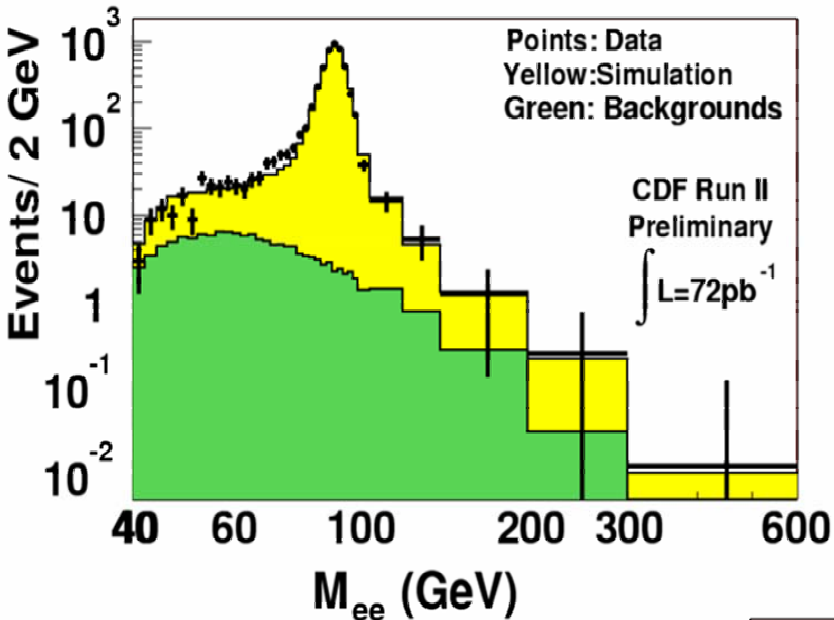
Promising future for such measurements with ~2 fb^{-1}:

- $O(10^6)$ $W \to l\nu$ events per channel per experiment
- $O(10^5)$ $Z \to l^+l^-$ events per channel per experiment for calibration
- LEP2: $O(10^3)$ $W \to l\nu$ decays per channel per experiment

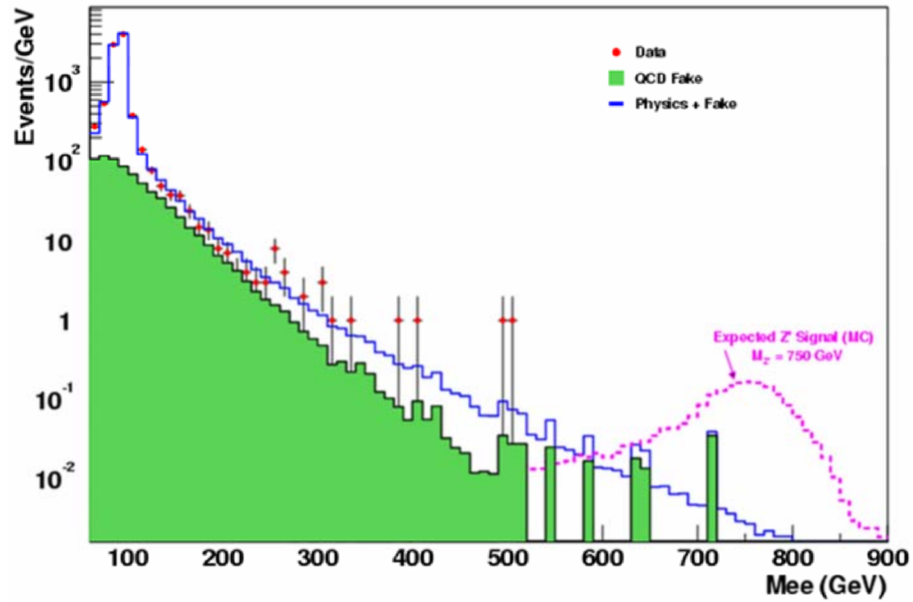
§ "my combination"

Other measurements with W, Z events

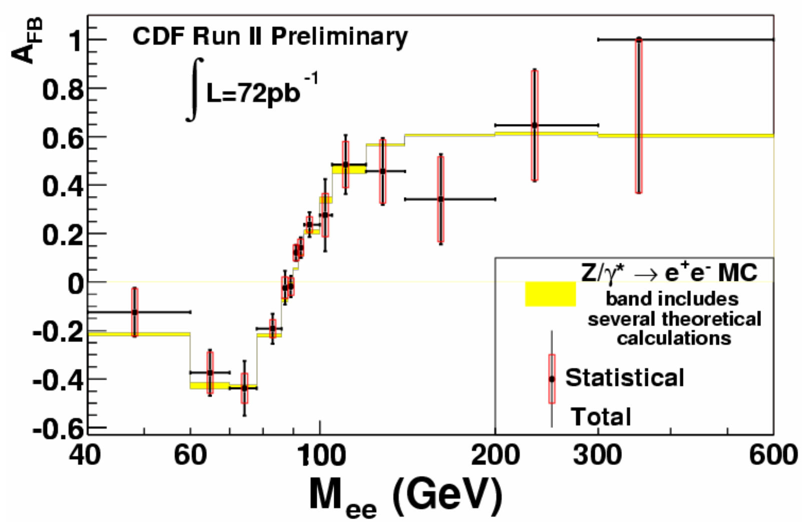
- High mass tail of Z



DØ Run II Preliminary

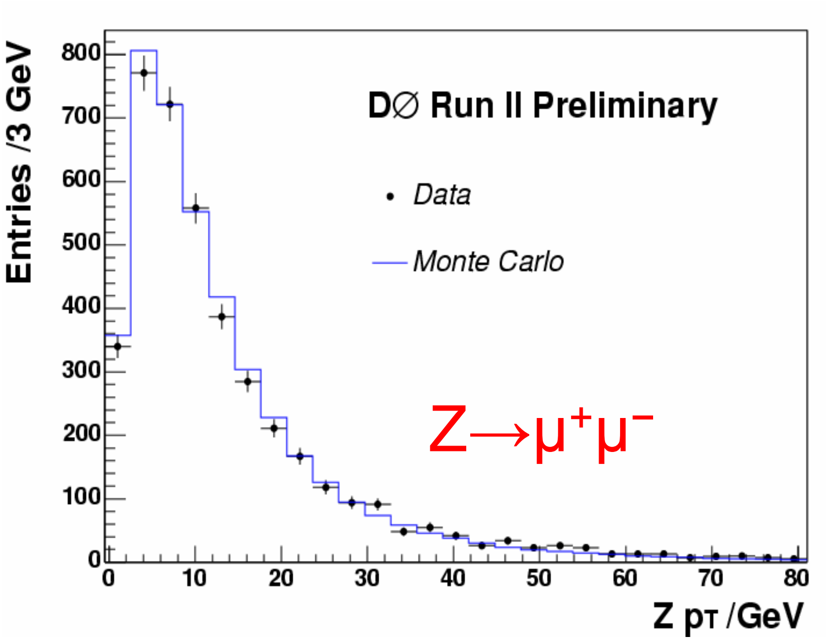


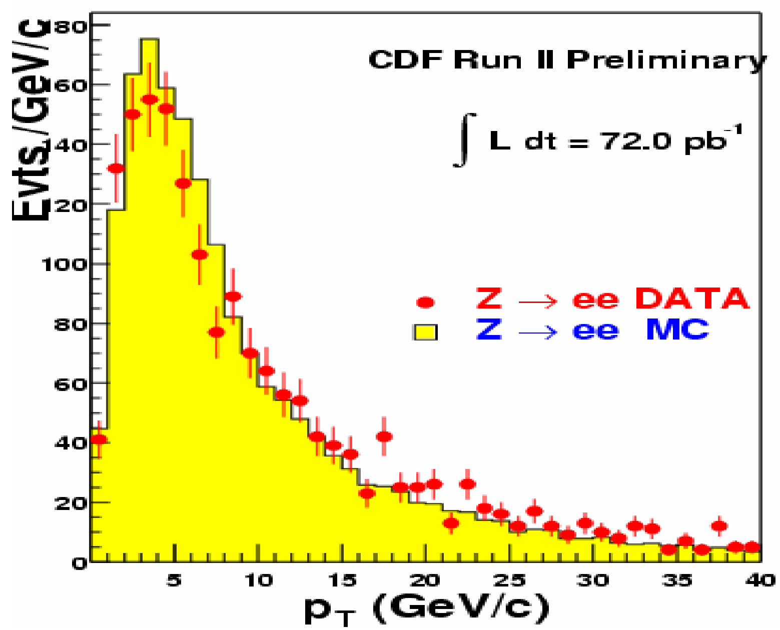
- Forward-backward asymmetry



Other Measurements with W,Z Events

- Data/MC comparisons for $p_T(Z)$





→ probe QCD phenomenolgy

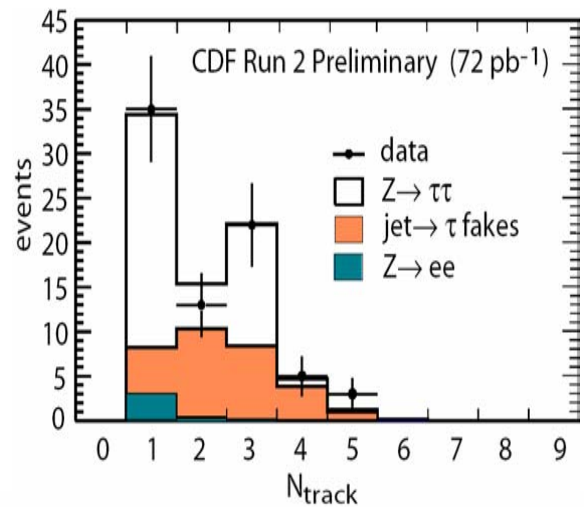
Many more such measurements to come:

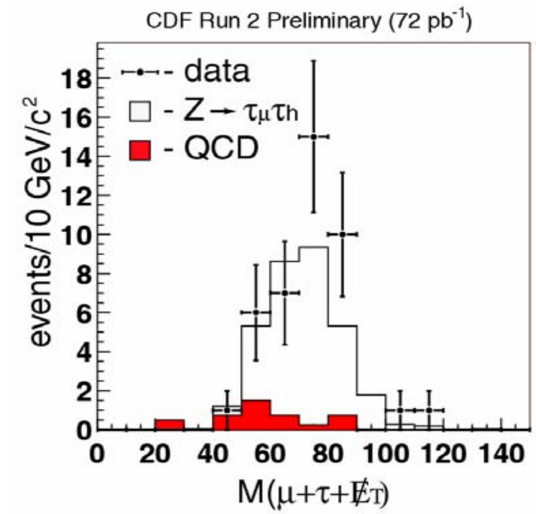
e.g, W/Z rapidity → probe PDFs

Looking for $Z \to \tau^+\tau^-$

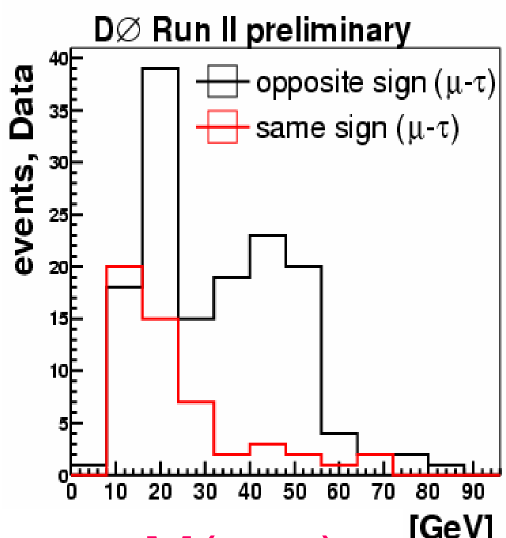
- Look for isolated, high p_T e or μ opposite narrow hadronic jet

CDF

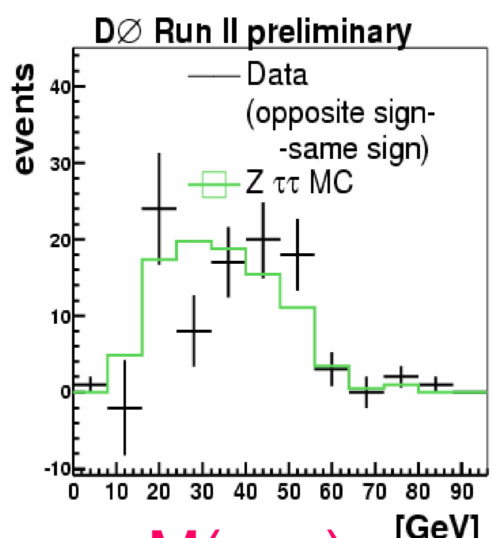




DØ



M(μ−τ)



M(μ−τ)

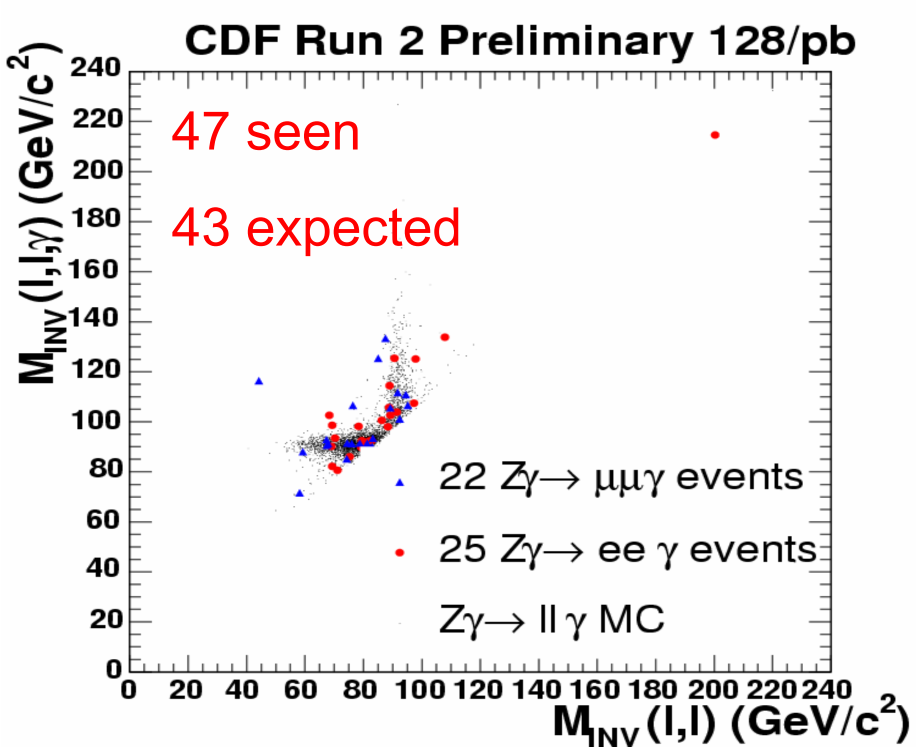
- small numbers of candidates
- rates consistent with expectations

CDF Wγ, Zγ Events

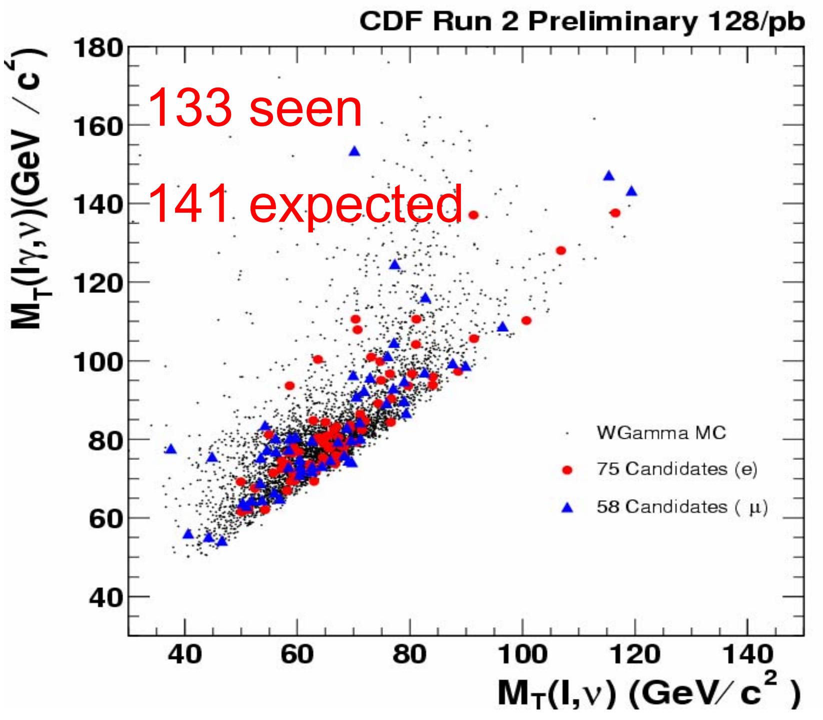
(updated for this conference)
$\int \mathcal{L} = 128$ pb-1

- Require central γ
- $E_T(\gamma) > 7$ GeV
- $\Delta R(l-\gamma) = \sqrt{(\Delta\eta^2+\Delta\Phi^2)} > 0.7$

σ • Br quoted for these cuts



σ • Br = 5.8 ± 1.0 (stat.) ± 0.4 (syst.) ± 0.4 (lumi.) pb



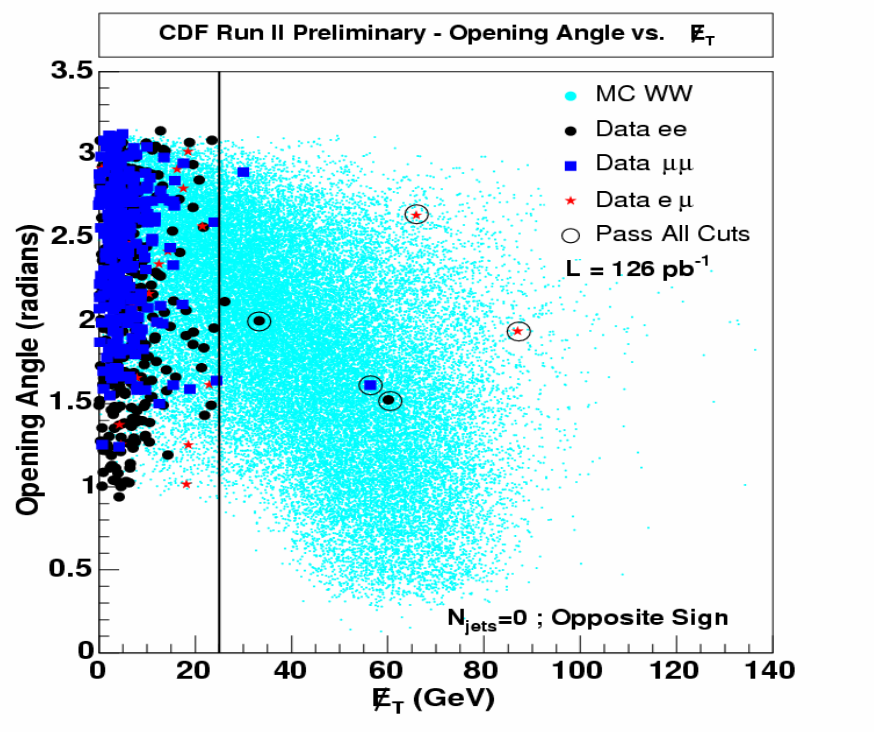
σ • Br = 17.2 ± 2.2 (stat.) ± 2.0 (syst.) ± 1.1(lumi.) pb

CDF W W Search

(updated for this conference)

- isolated lepton pair
- opposite-charge, high p_T
- E_T^{miss}
- Z veto
- veto events with jets
- $\int \mathcal{L} = 126\ pb^{-1}$
- 5 events seen
- 9.2 events expected

(2.3 background, 6.9 ± 1.5 $W\,W \rightarrow l\nu\ l\nu$)



$$\sigma_{meas}^{p\bar{p}\rightarrow WW} = 5.1^{+5.4}_{-3.6}\ \text{(stat)}\ \pm\ 1.3\ \text{(syst)}\ \pm\ 0.3\ \text{(lumi)}\ \text{pb}\ .$$

$$\sigma_{theo:NLO}^{p\bar{p}\rightarrow WW} = 13.25 \pm 0.25\ \text{pb}\quad \text{J.M.Campbell, R.K.Ellis}\quad \text{hep-ph/9905386}$$

Summary, Outlook

- EW analyses with Run II $\int\mathcal{L}$ > 100 pb^{-1} becoming available
- Detectors/triggers/simulations becoming better understood $\longrightarrow$ entire physics programme benefits
- Looking forward to a flood of new EW results this autumn:
  - σ • Br (W,Z) and ratios
  - QCD of W,Z production
- Tevatron EWWG becoming very active
  - Need more streamlined procedure for CDF/DØ to approve combinations of updated measurements
    - once combination methods are well-established