The Precision Measurement of the W Mass using the DØ Detector

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- **The electroweak Standard Model (SM)**
- **Measurements of:**
  - W **&** Z **production cross sections**
  - Γ_W
  - W **mass**
- **Comparisons to other measurements and SM**
- **Future Prospects**

Los Alamos National Laboratory

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ElectroWeak Standard Model

- Glashow, Weinberg, Salam (1967-1968)
  - SU(2)× U(1) model of electroweak interactions

- massless interacting vector particles: W^1, W^2, W^3, B
  (Yang-Mills)
  W°, B mix to produce γ, Z° with mixing angle θ_W

  $$\gamma = \sin\theta_W W^\circ + \cos\theta_W B; \;\; Z^\circ = \cos\theta_W W^\circ - \sin\theta_W B$$

  - interactions mediated by $\gamma, W^\pm, Z$

- gauge symmetry of electroweak model implies:
  W, Z and fermions have $mass = 0$

→ break the electroweak symmetry by introducing Higgs boson:

Higgs' mechanism gives mass to $W^\pm, Z$ and fermions

Verification of ElectroWeak theory

- ⋆ existence of neutral weak currents (1973 - CERN)
- ⋆ ratio of neutral-current to charged-current events (1973 - CERN)
- ⋆ interference between electromagentic and neutral weak currents (1978 - SLAC) - parity violation in what seemed to be purely QED interaction
- ⋆ discovery and properties of W, Z (1983 - UA1,UA2 at CERN)

$\Longrightarrow$ **SM has survived all experimental tests so far!**

⋆ **TOP quark recently (1995) discovered at Fermilab**

DØ and CDF current results
(from DPF in August 96):

DØ $\rightarrow M_T = 169 \pm 11$ **GeV**
CDF $\rightarrow M_T = 176.8 \pm 6.5$ **GeV**
Combined $\rightarrow M_T = 175 \pm 6$ **GeV**

⋆ **Higgs (H) is only undiscovered SM particle**

ElectroWeak Standard Model

Specified by 3 parameters:

- $\alpha = (137.03599 \pm .09)^{-1}$ $\quad (\delta\alpha/\alpha = 0.045\ ppm)$
  but $\alpha(M_Z^2) \approx 1/128$ known to $(\delta\alpha/\alpha \approx 700\ ppm)$

- $G_F = (1.16639 \pm .00002) \times 10^{-5}\mathrm{GeV}^{-2}$
  $(\delta G_F/G_F = 17\ ppm)$

- $M_Z = 91.1863 \pm .0020\mathrm{GeV}$ $\quad (\delta M_Z/M_Z = 22\ ppm)$

Then can evaluate

$$M_W = A/\sin\theta_W$$

$$M_Z = A/\sin\theta_W\cos\theta_W$$

where

$$A = (\pi\alpha/\sqrt{2}G_F)^{1/2}$$

EW Radiative Corrections:

$\longrightarrow$ Data is sufficiently precise - must include radiative corrections

define: (on-shell scheme, Sirlin)

$$sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$$

then lump radiative corrections into Δr

$$M_W = \frac{A_o}{\sin\theta_W(1-\Delta r)^{1/2}} \quad \text{with} \quad A_o = (\frac{\pi\alpha}{\sqrt{2}G_F})^{1/2}$$

$\Rightarrow$ Dominate contributions to Δr due to

- running of $\alpha \longrightarrow \alpha(M_Z^2)$ - vacuum polarization diagrams
- W, Z self-energy diagrams
- bosonic loop diagrams

$\Longrightarrow$ can write as

$$\Delta r \sim \Delta r_o - \rho_t / \tan\theta_W \quad \text{with}$$

$$\Delta r_o \approx 1 - \frac{\alpha}{\alpha(M_Z)} \approx 0.06 \quad \text{and}$$

$$\rho_t \approx 0.01 (M_T / 180 \text{ GeV})^2$$

also contributions from bosonic loops which $\propto$ ($\ln M_H$)

Motivation

⇒ **Precision Measure of M_W**

- ⋆ **test of SM at level of radiative corrections**
  → sensitive to m_t and M_H

- ⋆ **Improvement in precision can further constrain allowed values of M_H in SM or parameter space of other models**

- ⋆ **A precise value of M_W from direct measurement could contradict the value determined indirectly, indicating breakdown of SM**

Fermilab $p\bar{p}$ Tevatron Collider

$\Rightarrow$ **Oct. 1985 - test run**

$\Rightarrow$ **1987 - first operating run (CDF only),** $\mathcal{L} \approx 4.3\ pb^{-1}$

$\Rightarrow$ **1992-1993: Run 1A,** $\mathcal{L} \approx 15\ pb^{-1}$

$\Rightarrow$ **1994-1995: Run 1B,** $\mathcal{L} \approx 89\ pb^{-1}$

$\Rightarrow$ **1999? start Run 2,** $\mathcal{L} \approx 2000\ pb^{-1}$

Peak/Average luminosity:

Run 1A, $\approx 0.8 \times 10^{31}(cm^{-2}s^{-1})$ **...** $< \mathcal{L} > \approx 3 \times 10^{30}$
Run 1B, $\approx 2.4 \times 10^{31}(cm^{-2}s^{-1})$ **...** $< \mathcal{L} > \approx 8 \times 10^{30}$

900 GeV protons **900 GeV anti-protons**

DØ Detector at Fermilab:

$\rightarrow$ **large multi-purpose detector designed to study top, electroweak, QCD, new physics, etc.**

$\star$ **mid 1984, experiment approved**

$\star$ **Feb 1992, detector completed**

$\star$ **May 1992, first collisions**

$\star$ **Aug 1992, commissioning completed, run 1 starts**

Inclusive W and Z Production

$\Longrightarrow$ $p\bar{p} \rightarrow W + X$ $\qquad$ $p\bar{p} \rightarrow Z + X$

$X \rightarrow$ have extra hadronic activity in event due to recoil to the W or Z **plus**

$\rightarrow$ have underlying event energy:
interactions among spectator partons
and detector noise

At $\sqrt{s} = 1.8$ TeV: valence-sea contribution $\approx 55\%$
sea-sea contribution $\approx 20\%$

$\Longrightarrow$ detect W and Z via their leptonic decays

- cleaner signature
- lower background

$W \rightarrow l\nu$ signature: high p_T lepton + large $\not{E}_T$
$Z \rightarrow ll$ signature: 2 high p_T leptons

Inclusive W and Z Production

Event Selection

electrons:

$|\eta| < 1.2$ or $1.5 < |\eta| < 2.5$

$W \to e\nu : E_T^e > 25$, $\not{E}_T > 25$ GeV

$Z \to ee : E_T^e > 25$ GeV

muons:

$|\eta| < 1.0$

$W \to \mu\nu : p_T^{\mu} > 20$, $\not{E}_T > 20$ GeV

$Z \to \mu\mu : p_T^{\mu 1} > 20$, $p_T^{\mu 2} > 15$ GeV

$$\sigma \cdot B = \frac{N_{obs} - N_{bkg}}{A\epsilon\mathcal{L}}$$

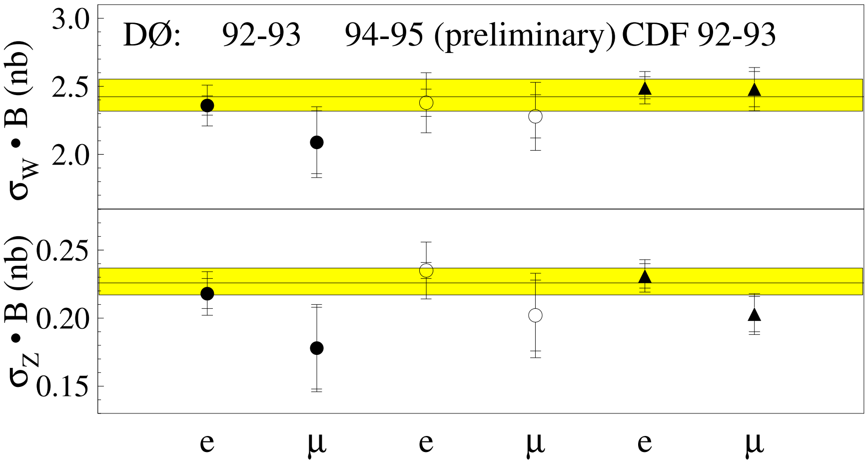
DØ 1B - Preliminary Results

	$W \to e\nu$	$Z \to ee$	$W \to \mu\nu$	$Z \to \mu\mu$
# events	59579	5702	4477	173
Background(%)	$8.1 \pm 0.9\%$	$4.8 \pm 0.5\%$	$18.6 \pm 2.0\%$	$8.0 \pm 2.1\%$
Acceptance(%)	$43.4 \pm 1.5\%$	$34.2 \pm 0.5\%$	$20.1 \pm 0.7\%$	$5.7 \pm 0.5\%$
Efficiency(%)	$70.0 \pm 1.2\%$	$75.9 \pm 1.2\%$	$24.7 \pm 1.5\%$	$43.2 \pm 3.0\%$
$\mathcal{L}$ (pb^{-1})	75.9 ± 6.4	89.1 ± 7.5	32.0 ± 2.7	32.0 ± 2.7
$\sigma \cdot B$ (stat)	2.38 ± 0.01	$0.235 \pm .003$	2.28 ± 0.04	$0.202 \pm .016$
(syst) (lum) [nb]	$\pm 0.09 \pm 0.20$	$\pm .005 \pm .020$	$\pm 0.16 \pm 0.19$	$\pm .020 \pm .017$

DØ1A [PRL 75, 1456(1995)]

$\sigma \cdot B$ (stat)	2.36 ± 0.02	$0.218 \pm .008$	2.09 ± 0.06	$0.178 \pm .022$
(syst) (lum) [nb]	$\pm 0.07 \pm 0.13$	$\pm .008 \pm .012$	$\pm 0.22 \pm 0.11$	$\pm .021 \pm .009$

Inclusive W and Z Production



Results consistent with SM predictions (band)

Cross sections calculated to $\mathcal{O}(\alpha_s^2)$ using CTEQ2M - (van Neerven *et al.*, Nucl. Phys. B382, 1992)

Indirect Measurement of W Width

measure ratio - many errors cancel

$$R_{e+\mu} = \frac{\sigma_W \cdot B(W \to l\nu)}{\sigma_Z \cdot B(Z \to ll)} = 10.32 \pm 0.43$$

and extract

$$B(W \to l\nu) = \frac{B(Z \to ll)\sigma_Z}{\sigma_W} \cdot R_{e+\mu} = 10.44 \pm 0.44\%$$

inputs: $\frac{\sigma_W}{\sigma_Z} = 3.33 \pm 0.03 \to$ from theory (pdfs dominate error)
$B(Z \to ll) = (3.367 \pm 0.006)\% \to$ LEP

and use

$$\Gamma_W = \frac{\Gamma(W \to l\nu)}{B(W \to l\nu)}$$

input: $\Gamma(W \to l\nu) = 225.2 \pm 1.5$ MeV $\to$ SM prediction
(Rosner *et al.*, PRD49 (1994) 1363)

Indirect Measurement of W Width

DØ 1A Result [PRL 75, 1456(1995)]

$$\Gamma_W = 2.044 \pm 0.093 \text{ GeV}$$

DØ 1B Result [Preliminary]

$$\Gamma_W = 2.159 \pm 0.092 \text{ GeV}$$

Standard Model Prediction

$$\Gamma_W = 2.077 \pm 0.014 \text{ GeV}$$

$\Rightarrow$ Comparison of world average (not including 1B result) $\Gamma_W = 2.062$ with SM prediction gives limit on unknown decay modes of W:

95% CL upper limit of $\Delta\Gamma < 109$ MeV on unexpected decays

M_W - Direct Measurement by DØ

$\Rightarrow$ **Analysis based on Run 1A data sample (published)**
- **PRL 77 (1996) 3309**
- **PRD in progress**
- $\star$ **will concentrate on this measurement**

$\Rightarrow$ **Preliminary results based on Run 1B data**

$\Rightarrow$ **Preliminary results using ratio method**

$\Rightarrow$ **Comparisons to other Measurements**

$\Rightarrow$ **Standard Model Implications**

$\Rightarrow$ **Future**

$\star$ **for M_W measurement use data samples:**

$W \rightarrow e\nu$ **(BR $\approx$ 10%) and** $Z \rightarrow ee$ **(BR $\approx$ 3%)**

$\rightarrow$ **require electrons in central region**

This is a calorimetric measurement!

M_W - Quantities Measured

Measured in calorimeter (includes underlying event and detector noise):

$\rightarrow$ electron energy $\vec{E}(e)$

$\rightarrow$ missing transverse energy ($\vec{\not{E}}_T$) in event

$\star$ missing longitudinal energy not known

because particles escape down beamline

$$\rightarrow \text{have } \vec{\not{E}}_T \equiv \vec{E}_T(\nu) = -\vec{E}_T(e) - \vec{E}_T(R)$$

therefore can determine recoil transverse energy $\vec{E}_T(R)$

$\rightarrow$ Cannot reconstruct W invariant mass

Instead study E_T^e and M_T^W distributions:

At current luminosities, best to use M_T^W

Measure:

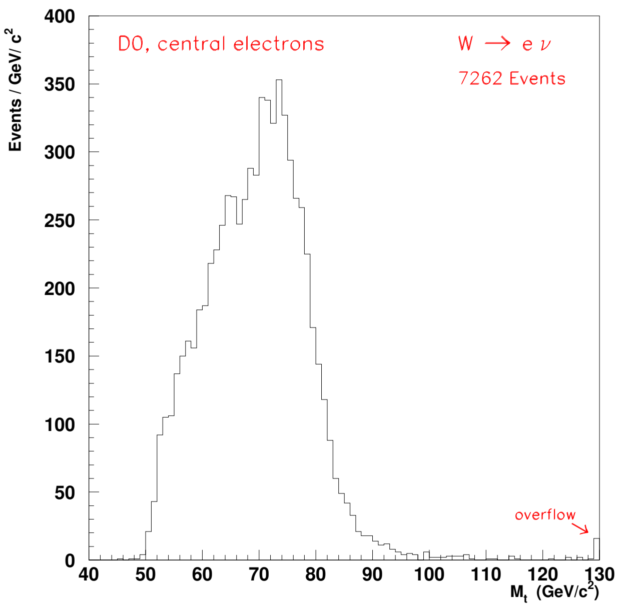
transverse mass of W and invariant mass of Z

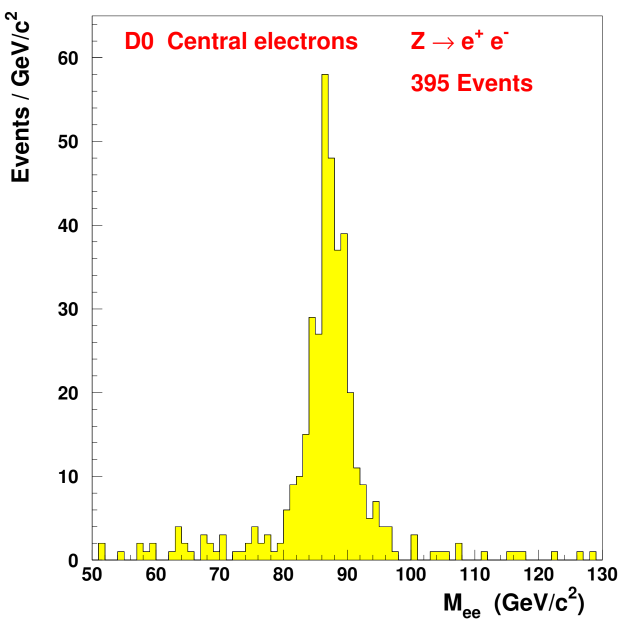
$$M_T^W = \sqrt{2E_T^e E_T^\nu (1 - \cos\varphi)} \qquad M_Z = \sqrt{2E^{e1}E^{e2}(1 - \cos\varphi)}$$

M_W - Event Sample

		# events: 1A	1B
$W \to e\nu$		7234	32856
⋆ e in CC:	$\lvert\eta\rvert < 1.2$		
⋆ electron:	$p_T^e > 25$ GeV		
⋆ neutrino:	$\not{E}_T > 25$ GeV		
⋆ W transverse momentum:	$P_T^W < 30$ GeV		
⋆ transverse mass (1A)	$50 < M_T^W < 110$ GeV		
$Z \to ee$		366	1562
⋆ e's in CC:	$\lvert\eta\rvert < 1.2$		
⋆ 2 isolated electrons:	$p_T(e) > 25$ GeV		
⋆ invariant mass (1A)	$70 < M_Z < 110$ GeV		

Run 1A - spectra:





⋆ Also have data sample of $Z \to ee$ in EC/EC and CC/EC

- to ensure equivalent event topologies for some studies

M_W - Measurement Technique

No analytic description of the $M_T(W)$ distribution... therefore

- **model data with fast Monte Carlo simulation**
  - **model detector effects and variables** *as measured in data*!
  - **most corrections made to MC instead of data**
- **generate $M_T(W)$ distributions as a function of M_W**
  - **do for 21 values of M_W, 100 MeV apart**
- **extract value of M_W by doing event-by-event max-likelihood fit of data to simulation**
- **backgrounds included during fitting**

M_W - Fast Monte Carlo

⋆ **main components of MC listed below**

⋆ **will discuss parts with largest errors**

- W production and decay $\longrightarrow$ to get $\vec{P}_T(e)$ & $\vec{P}_T(W)$
- electron and hadronic energy scale
- energy & angular resolution
- additional energy due to underlying event
- selection biases & efficiencies
- kinematic cuts

(Z events modelled in analagous way)

$\Rightarrow$ **Points to Note!!**

$\longrightarrow$ **calibrate EM calorimeter response to Z's**

$\longrightarrow$ **measure ratio of W/Z mass**
(reduces systematic errors):

$$M_W = \frac{M_W^{meas}}{M_Z^{meas}} \cdot M_Z^{LEP}$$

$\longrightarrow$ **use $Z \to ee$ and other data to set most parameters**

$\longrightarrow$ **systematic errors set using large statistics samples of MC data - vary parameter within its errors**

M_W -Monte Carlo W Production

- Events generated using Ladinsky-Yuan (NLO) with MRSA pdf [PRD 50,4239(1994)]

$$\frac{d^2\sigma}{dp_T(W)dy(W)}$$

- W resonance generated with relativistic Breit-Wigner, skewed by mass dependence of parton luminosity:

$$\frac{d\sigma}{dm} \sim \frac{e^{-\beta\cdot m}}{m} \cdot \frac{m^2}{(m^2 - M^2)^2 + \frac{m^4\Gamma^2}{M^2}}$$

- angular decay of W, respecting polarization

$$\frac{d^2\sigma}{dy d\cos\theta} \sim (1-\cos\theta_{cm})^2 \cdot (\frac{1}{2}\frac{d\sigma_s^{W+}}{dy} + \frac{d\sigma_v^{W+}}{dy}) + (1+\cos\theta_{cm})^2 \cdot (\frac{1}{2}\frac{d\sigma_s^{W+}}{dy})$$

- radiative decays: $W \to e\nu\gamma$ generated according to Berends & Kleiss [Z. Phys. C 27, 365(1985)]

- τ decays: $W \to \tau\nu \to e\nu\nu\nu$
  generated in MC - cannot differentiate in data from $W \to e\nu$

- boost decay products to lab frame

  - have $\vec{p}(e), \vec{p}_T(W) = -\vec{p}_T(R)$ and then

    infer: $\vec{p}_T(\nu) = -\vec{p}_T(R) - \vec{p}_T(e)$

M_W - $p_T(e)$ energy scale

→ **Absolute calibration of calorimeter not known**

→ **Measure ratio**

$$\left(\frac{M_W}{M_Z}\right) \cdot M_Z^{\mathrm{LEP}}$$

→ **Determine EM energy scale using J/ψ, π^0, and Z event samples**

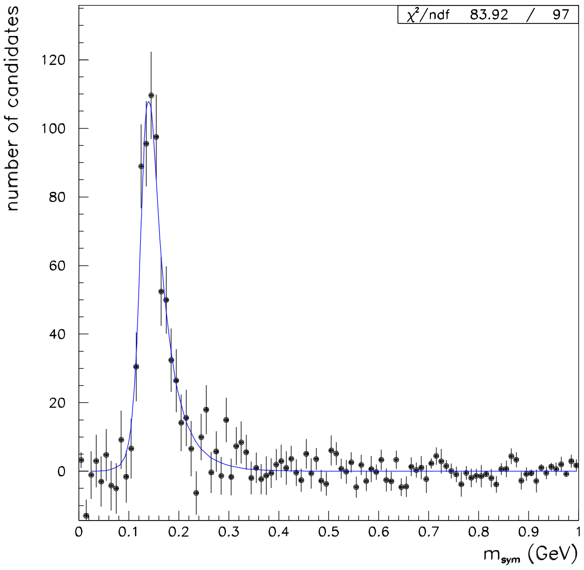
→ **EM energy response:**

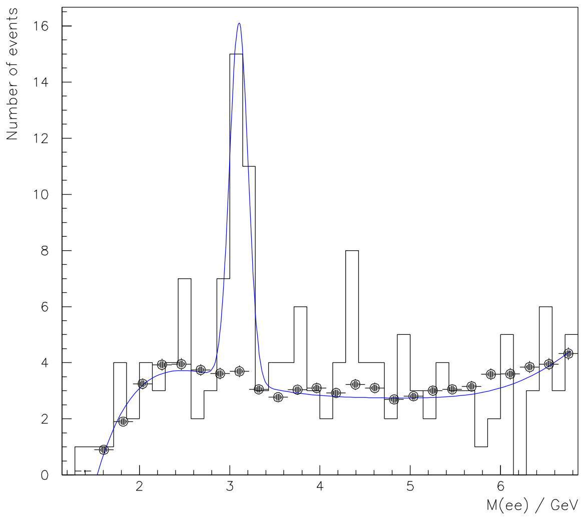
$$E^{meas} = \alpha E^{true} + \delta$$

$$M_{meas} = \alpha M_{true} + \delta f \qquad f = \frac{2(E_1 + E_2)}{M} \sin^2 \frac{\gamma}{2}$$

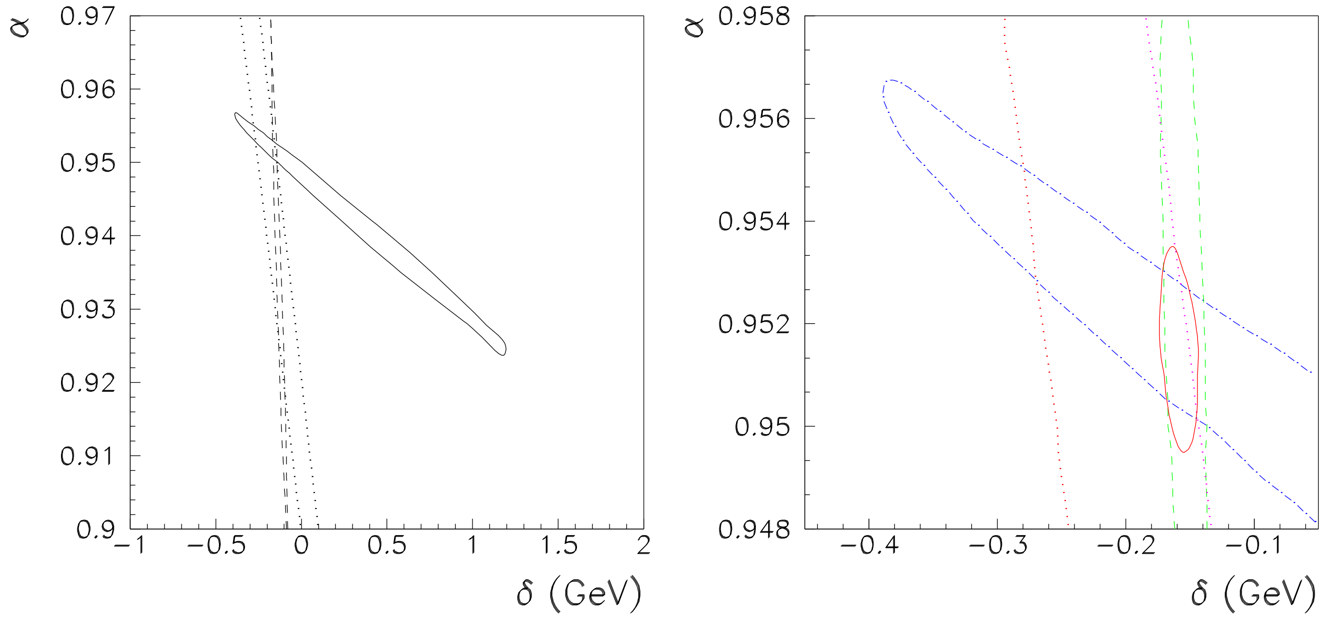
⋆ **π^0 & J/ψ events determine δ**

⋆ **Z data determines α**





M_W - $P_T(e)$ Scale



Measure Ratio:

$$\left(\frac{M_W}{M_Z}\right)^{meas} = \left(\frac{M_W}{M_Z}\right)^{true}\left[1 + \frac{\delta}{\alpha}\cdot\frac{(f_W\cdot M_Z - f_Z\cdot M_W)}{M_W M_Z}\right]$$

$\rightarrow$ **Ratio insensitive to scale (first order)**

$\frac{\partial M_W}{\partial \alpha} \approx 0$ **if** $\delta = 0$

- **error from offset suppressed**

$\frac{\partial M_W}{\partial \delta} \approx \frac{f}{\alpha}\cdot\frac{(M_Z - M_W)}{M_Z}$

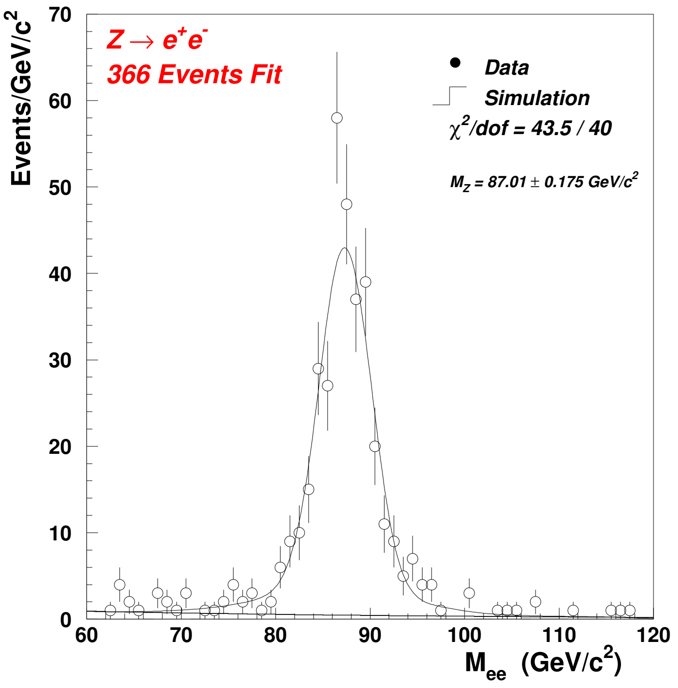
$\alpha = 0.9514 \pm 0.0018$ $\qquad$ $\delta = -0.158 \pm 0.015\,^{+.030}_{-.210}$ GeV

error on M_W due to EM scale: $\sigma(M_W) = 160$ MeV

run 1B: $\sigma(M_W) = 80$ MeV

$\star$ **error dominated by Z statistics**

M_W - $P_T(e)$ Scale and Resolution



Use $Z \to ee$ events:

- peak of M_Z sets EM scale: $\alpha = .95$
- width of M_Z constrains EM energy resolution:

EM Energy resolution:

$$\frac{\Delta E}{E} = \sqrt{C^2 + (\frac{S}{\sqrt{E_T}})^2 + (\frac{N}{E})^2}$$

from test beam have: $S = 0.13$ **and** $N = 0.4$
from Z **data have:** $C = (1.5\ ^{+0.6}_{-1.5})\%$
error due to EM energy resolution: $\sigma(M_W) = 70$ MeV

Underlying Event Correction to $P_T(e)$

Electron energy measured in
$\Rightarrow$ cone of 5×5 towers of size $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

- energy flows into cluster that is *not* due to electron from:
  - spectator interactions
  - recoil energy leaking into cluster
  - electron energy below zero-suppression cut-off
  - zero-suppression of asymmetric pedestal

Corrections obtained from
$\star$ comparing suppressed and non-suppressed minbias data
$\star$ rotating away from e in W events

Corrections in electron direction:

$$P_T(e)^{meas} = P_T(e) + U(e) + P_T^{rec}(e) - U_{zs} = P_T(e) + 212 \text{ MeV}$$

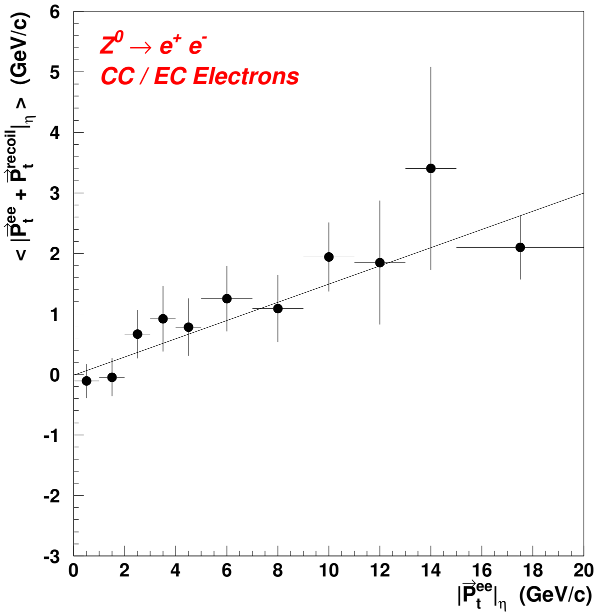
error due to underlying event modelling: $\sigma(M_W) = 35$ MeV

M_W - $\vec{P}_T(R)$ Scale

$\Longrightarrow$ hadronic energy scale relative to EM scale

$\Longrightarrow$ Z events - measure $P_T(Z)$ from ee or the recoil:

$$\eta\text{−balance} \equiv [\vec{P}_T(ee) + \vec{P}_T(R)] \cdot \hat{\eta} \quad \text{vs} \quad \vec{P}_T(ee)$$



$$\Rightarrow P_T(R) = (0.83 \pm 0.04) P_T(ee)$$

error due to hadronic energy scale: $\sigma(M_W) = 50$ MeV

M_W - $\vec{P}_T(R)$ Energy Resolution

$\Longrightarrow$ use jet resolution from test beam:

$$S = 0.80 \pm 0.20,\ N = 1.5,\ C = 0.04$$

error due to hadronic energy resolution: $\sigma(M_W) = 65$ MeV

M_W - $\vec{P}_T(R)$ Resolution and Underlying Event

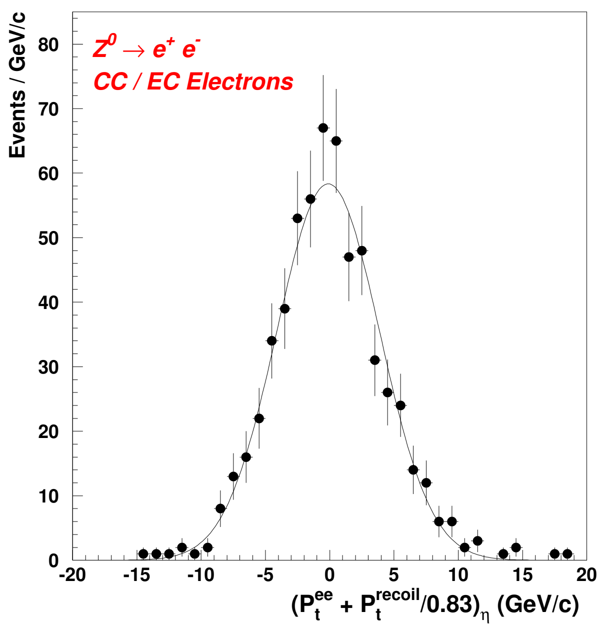
Underlying event affects magnitude and smears the $\vec{P}_T(R)$

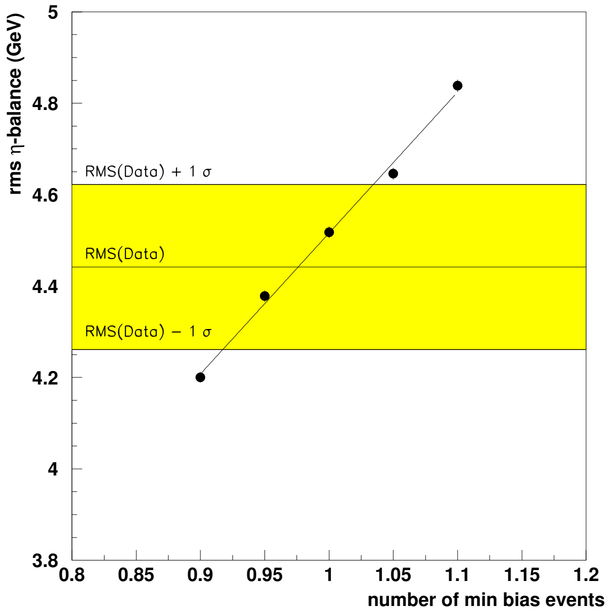
$$\vec{P}_T(\nu) = \vec{P}_T(W) - \vec{P}_T(e) = -\vec{P}_T(R) - \vec{P}_T(e)$$

model in MC as measured in data:

$$\vec{P}_T(R)^{meas} = \vec{P}_T(R) + C \cdot \vec{U}_{mb}(tot) - U(\hat{e})$$

- $\vec{U}_{mb}$ is total $\vec{P}_T$ of minimum bias event - from library
- luminosity distribution of data is modelled
- C = # minbias events needed to model W underlying event
- resolution of $\eta-$balance of Z data constrains $C \rightarrow 0.98 \pm 0.06$





error due to # min bias events: $\sigma(M_W) = 60$ MeV

Errors from $P_T(W)$ spectrum and pdf's

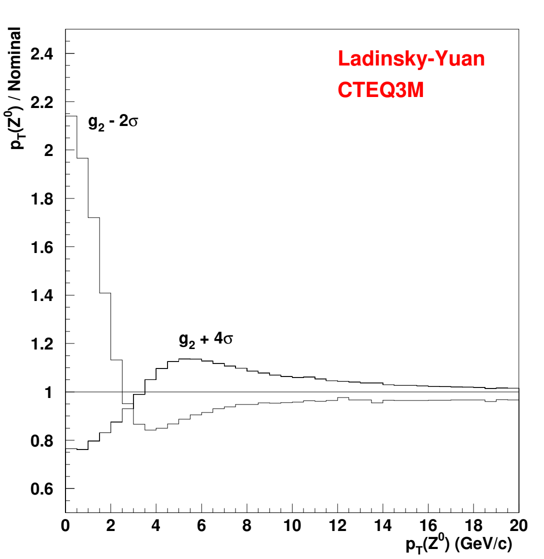
Use Ladinsky-Yuan calculation of $\frac{d^2\sigma}{dydP_T}$
- correlated with pdf choice

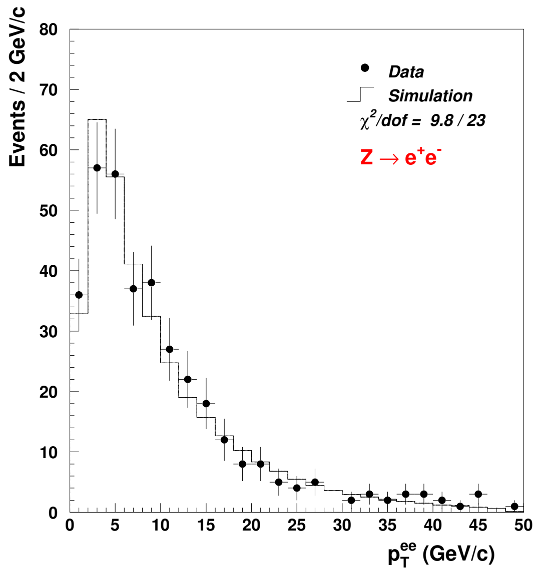
- new parametrization of non-perturbative (low P_T) region of the resummed cross section
- based on resummed calculation by Collins, Soper & Sterman
- modified to include perturbative high P_T part - Arnold & Reno

$\longrightarrow$ uses phenomenological parameters g_1, g_2, g_3 for non-perturbative region $\longrightarrow$ P_T^Z most sensitive to g_2

$\longrightarrow$ constrain model using $P_T(Z)$ spectrum from data

$\star$ data allows $g_2 - 2\sigma$ to $g_2 + 4\sigma$

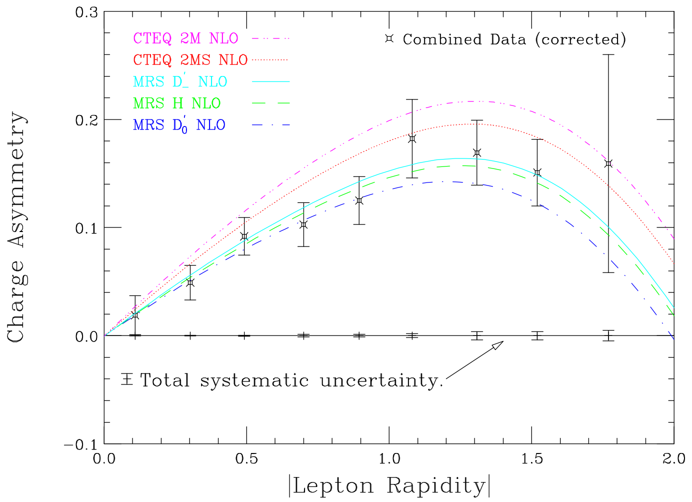




M_W - $P_T(W)$ spectrum and pdf's

$\star$ CDF W-Asymmetry data constrains pdf's

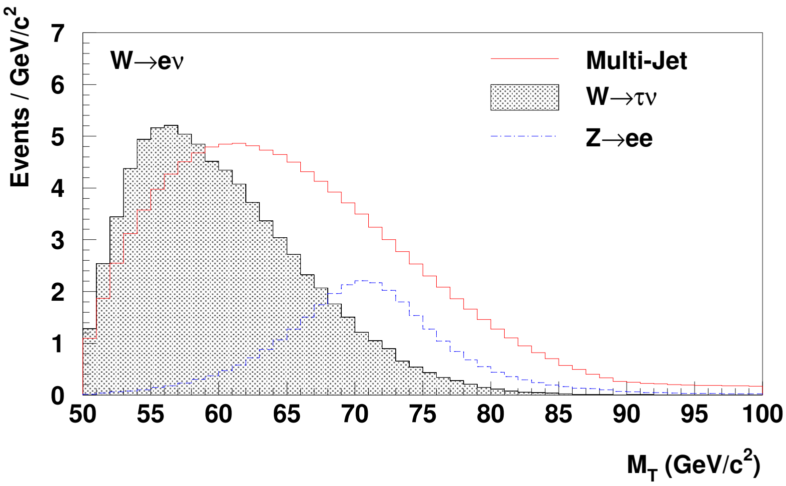
$\longrightarrow$ Allow W-Asymmetry to vary by $\pm 1\sigma$



Obtain new parameterizations in which pdf & input spectrum - constrained by data - were varied simultaneously $\longrightarrow$

error due to theory
($P_T(W)$ spectrum and pdfs): $\sigma(M_W) = 65$ MeV

M_W - Backgrounds



$\Rightarrow$ Backgrounds included in likelihood fitting procedure

multi – jet $\Rightarrow$ QCD event with $\not{E}_T$ and where one jet fakes an electron

$Z \rightarrow ee \Rightarrow Z$ event in which one electron lost

$\Rightarrow$ Included in MC event generation:

$W \rightarrow \tau\nu \Rightarrow$ indistinguishable from $W \rightarrow e\nu$ events

background	fraction (%)
QCD multi-jet	1.6 ± 0.8
$Z \rightarrow ee$	0.45 ± 0.04
$W \rightarrow \tau\nu \rightarrow e\nu\nu\nu$	1.1 ± 0.1

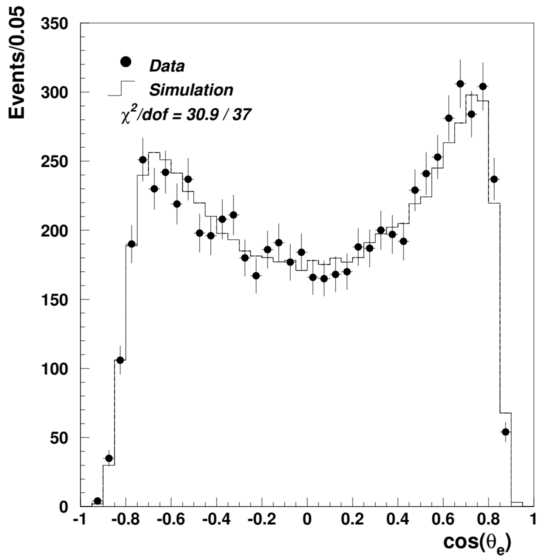
error due to shape and size of backgrounds: $\sigma(M_W) = 35$ MeV

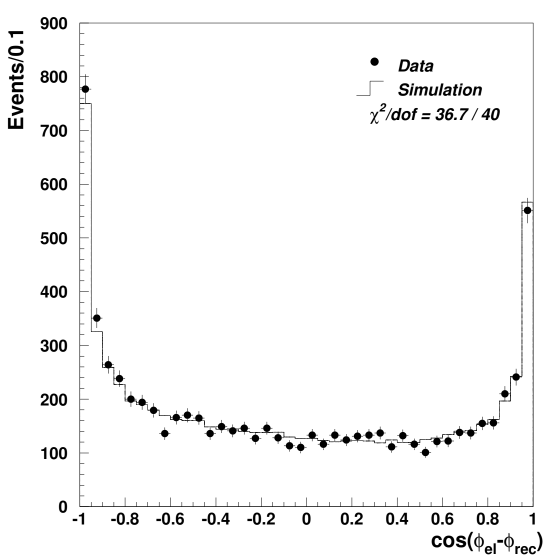
Comparison of Data and MC

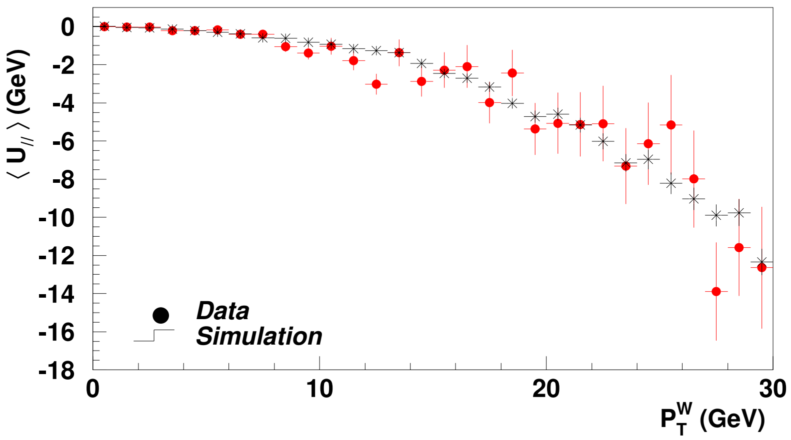
⋆ $U_{\parallel} = \vec{P}_T^{Rec} \cdot \hat{e} \longrightarrow$ hadronic energy in electron direction

⋆ A bias in $U_{\parallel}$ directly affects the M_T spectrum

⋆ $U_{\parallel}$ is sensitive to the recoil resolution

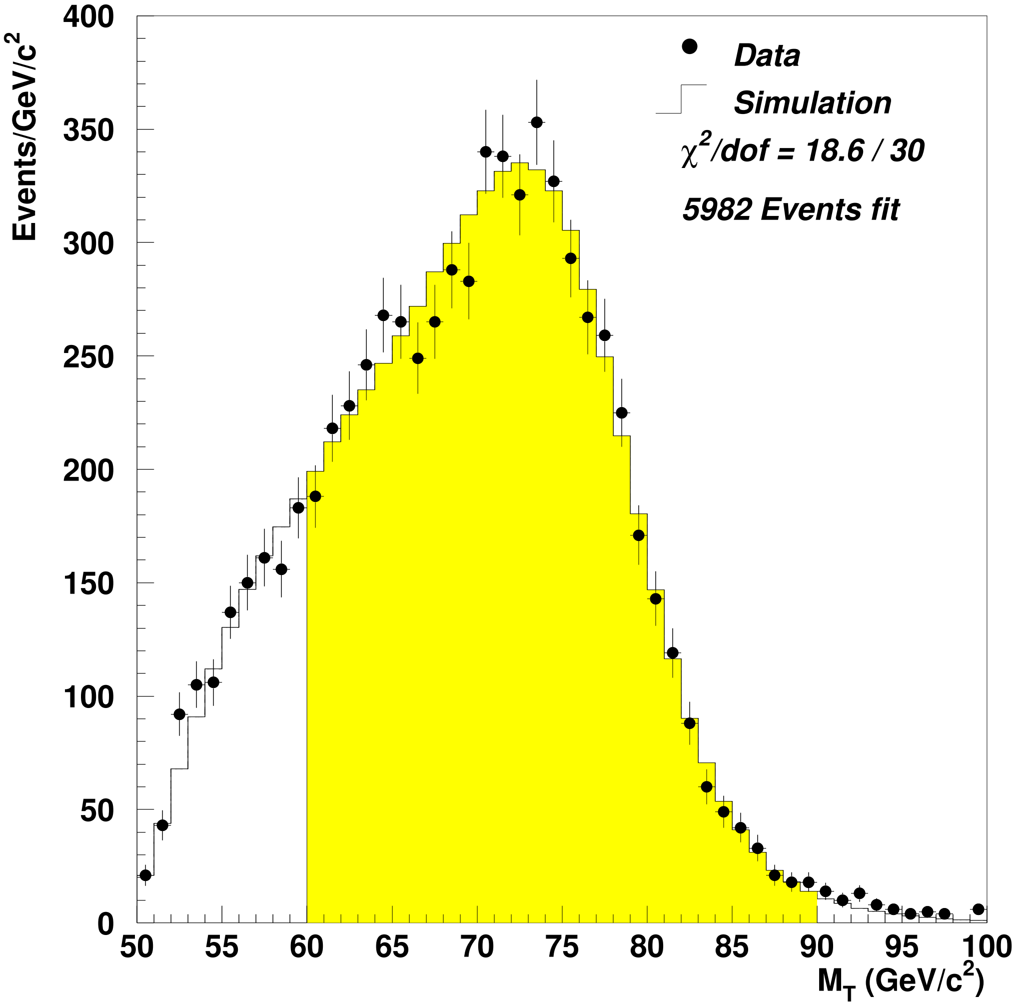






M_W - from Fit to Transverse Mass

perform unbinned maximum likelihood fit from $60 - 90$ GeV



$$M_W(\mathrm{Run1A}) = 80.350 \pm 0.140\ \mathrm{GeV}/\mathrm{c}^2$$

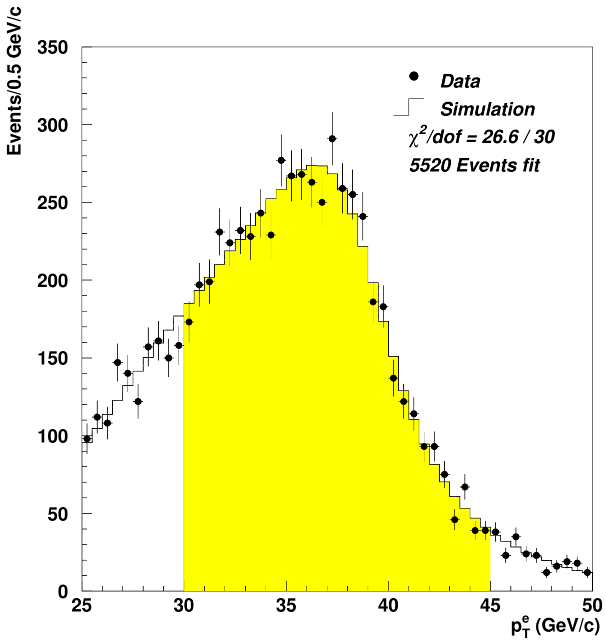
M_W - Summary of Errors on Fit to $M_T(W)$

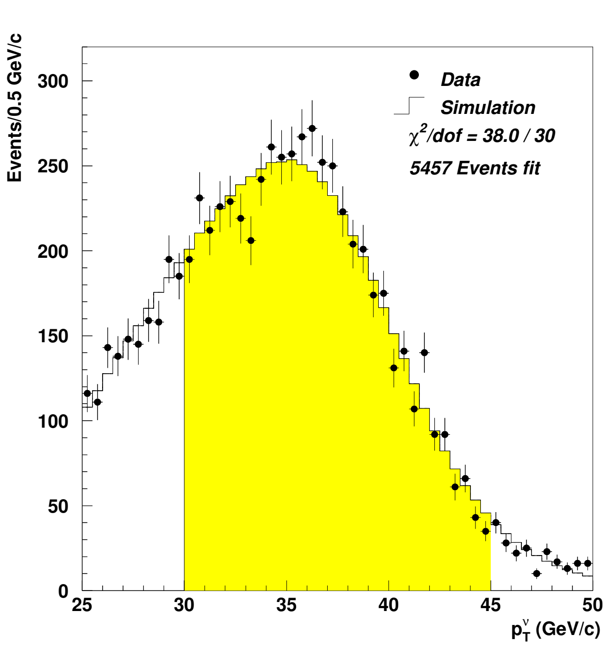
Source	$\sigma M(W)$ (MeV) Run 1B	Run 1A
Statistical	70	140
Energy Scale	80	160
Systematic	130	165
EM Energy Resolution	30	70
Hadronic Energy Resolution	20	65
P_T^W, pdf	65	65
# of Min. Bias Events	40	60
Hadronic Energy Scale	30	50
Electron Angle Calibration	40	50
Underlying Event	30	35
Backgrounds	15	35
Efficiencies	20	30
W Width	10	20
Radiative Decays	20	20
Non-Uniform energy response (η)	10	10
Fit Error	5	5
Luminosity Dependence*	70	
Total	170	270

$$M_W(\text{Run1A}) = 80.350 \pm 0.140(stat.) \pm 0.160(scale) \pm 0.165(syst.)\ \text{GeV/c}^2$$

$$M_W(\text{Run1B}) = 80.380 \pm 0.070(stat.) \pm 0.080(scale) \pm 0.130(syst.)\ \text{GeV/c}^2$$

M_W Fits to Transverse Momenta $\rightarrow$ Consistency Check



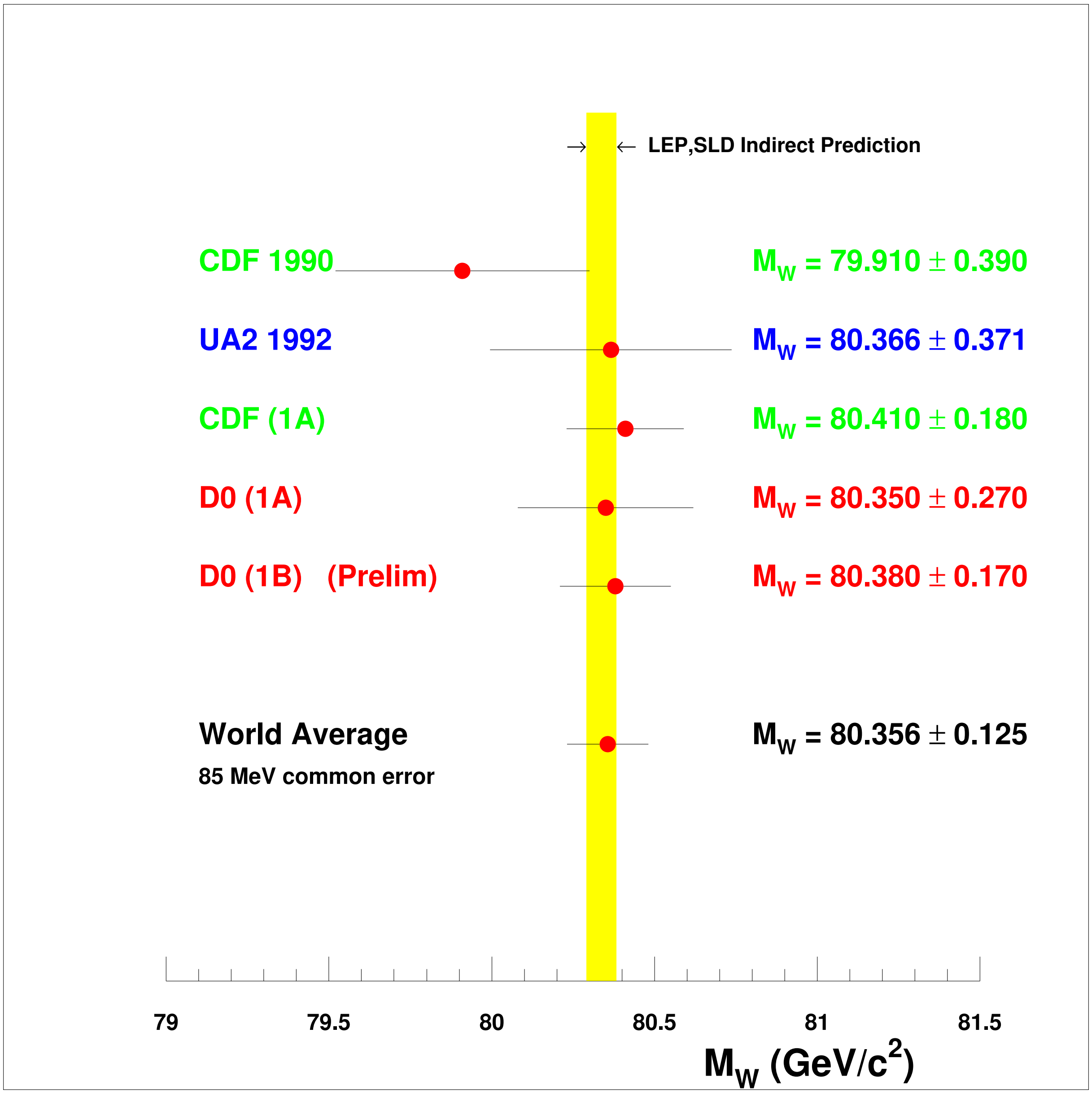


$$\mathrm{P_T(e)fit} \Rightarrow M_W = 80.300 \pm 0.190(stat.)\ \mathrm{GeV/c^2}$$

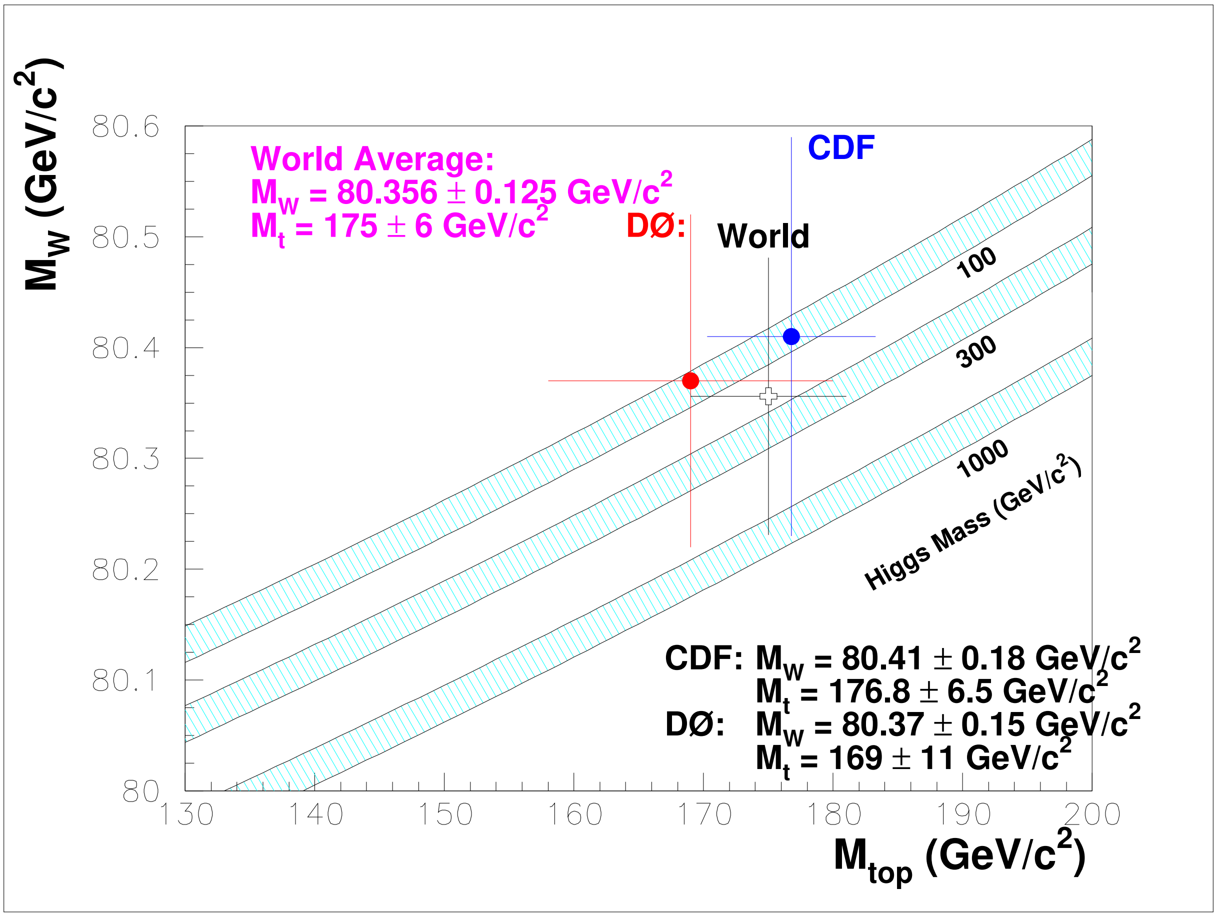
$$\mathrm{P_T(\nu)fit} \Rightarrow M_W = 80.045 \pm 0.260(stat.)\ \mathrm{GeV/c^2}$$

systematic error on $P_T(\nu)$ large

Current Results of M_W



Constraints on Higgs Mass



Indirect Measurements of M_W

from LEP ElectroWeak Working Group,

shown at ICHEP(July) & DPF96(Aug)
(Fnal-conf-96/354 & CERN-PPE/96-183)

Do global fits of all LEP/SLD data to SM calculations to obtain

- optimum values
- estimate of free parameters

$\Rightarrow$

$$m_t = 177^{+7}_{-8}{}^{+17}_{-19}$$

$$M_W = 80.337 \pm 0.041^{+0.010}_{-0.021}$$

SM fits for m_t, α_s use all LEP & SLD data, derive M_W
central value assumes $M_H = 300$ GeV
2nd error: $60 < M_H < 1000$ GeV

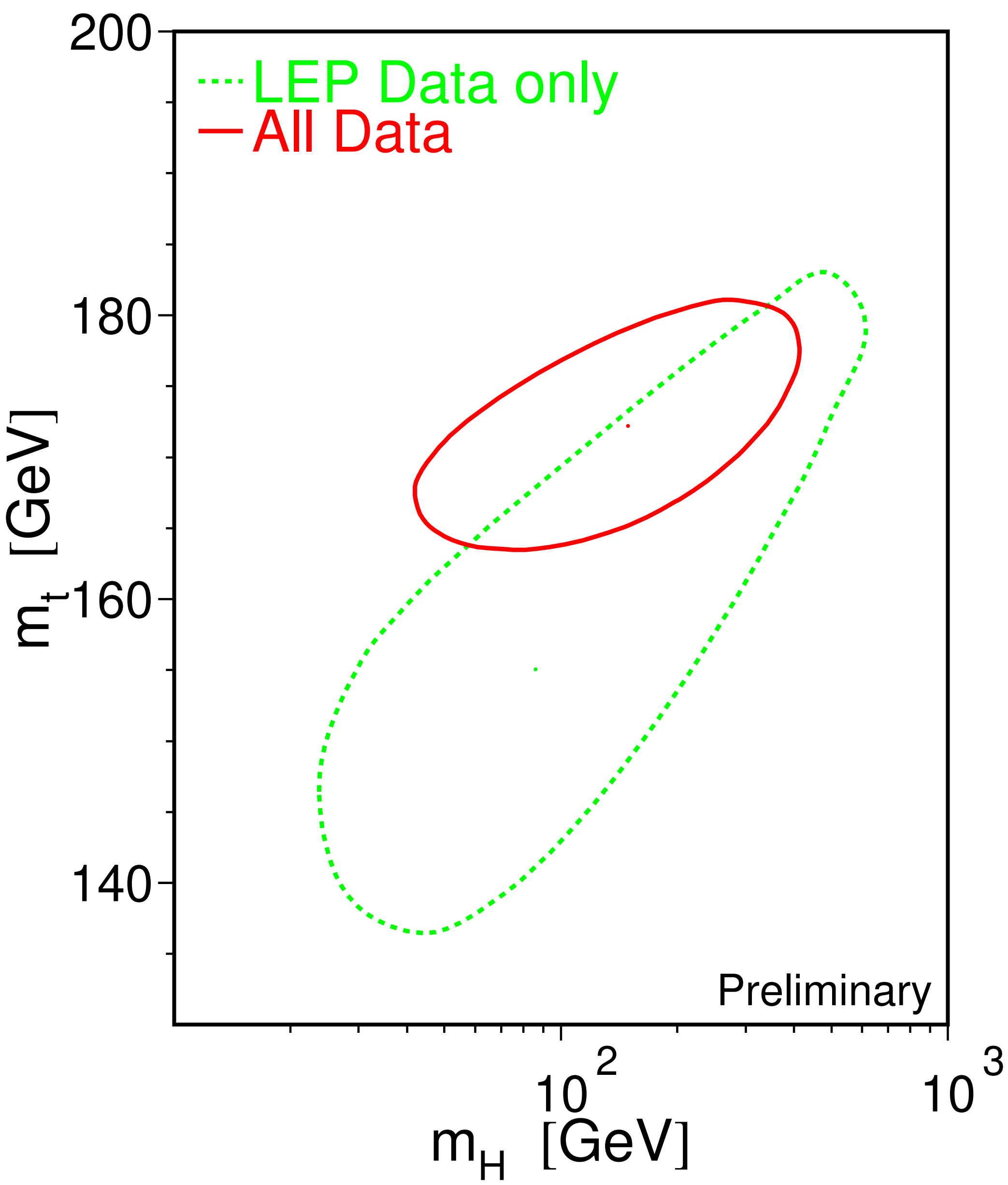
!! direct $m_t = 175 \pm 6$ - more precise than indirect !!

The determination of $sin^2\theta_W$ from νN scattering, when combined with M_Z gives (from NuTeV $\rightarrow$ Fnal-conf-96/227-E)

$$M_W = 80.46 \pm 0.25 \text{ GeV}$$

$\Rightarrow$ A precise value of M_W from a direct measurement could contradict the value determined indirectly from the global fit, thus indicating a breakdown of the SM

m_t vs m_H - from LEP EWWG



- shows large correlation between m_t and m_H
- SM fit for m_t, α_s and m_H $\Rightarrow$

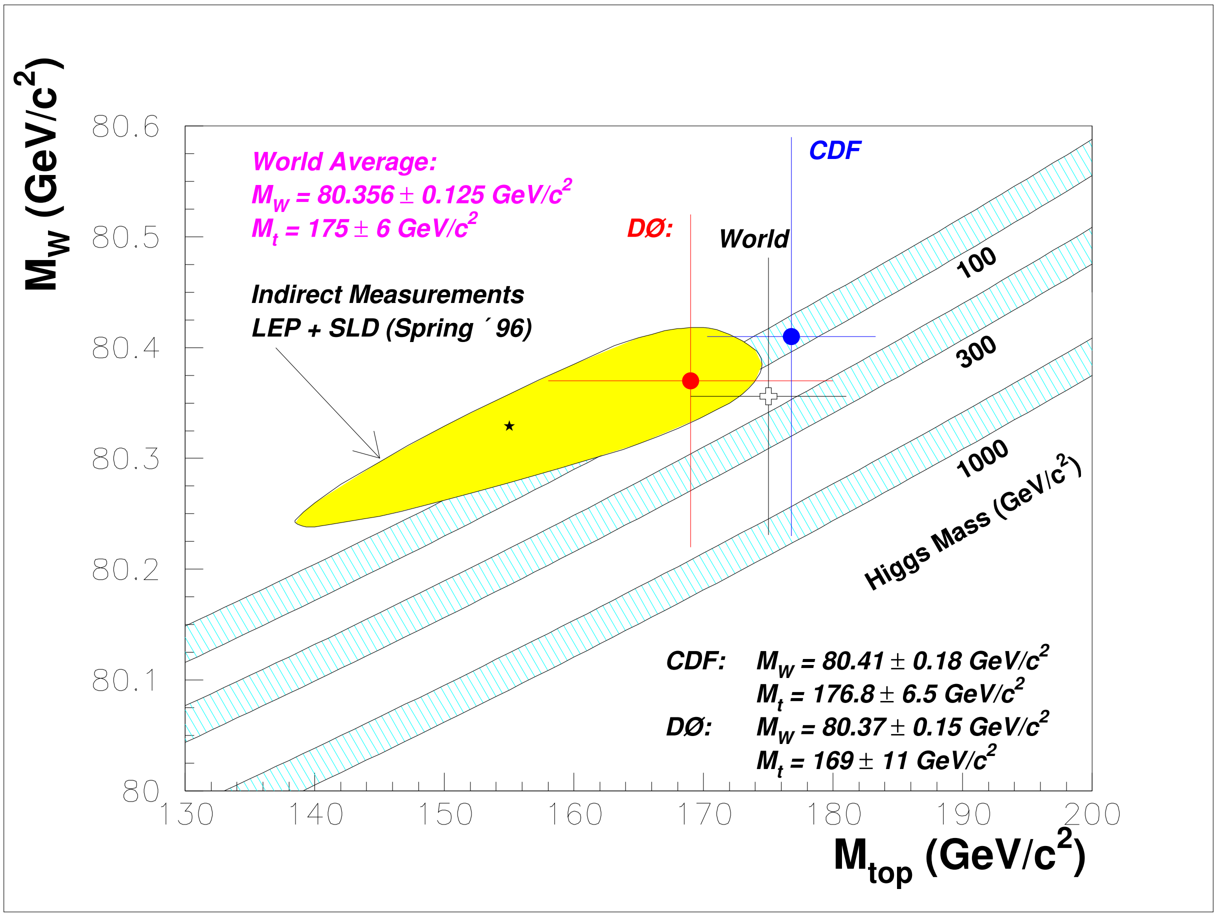
	LEP data only	all data + m_t
m_t	155^{+18}_{-13}	172 ± 6
m_H	86^{+202}_{-51}	149^{+148}_{-82}

- LEP data prefer light top and Higgs

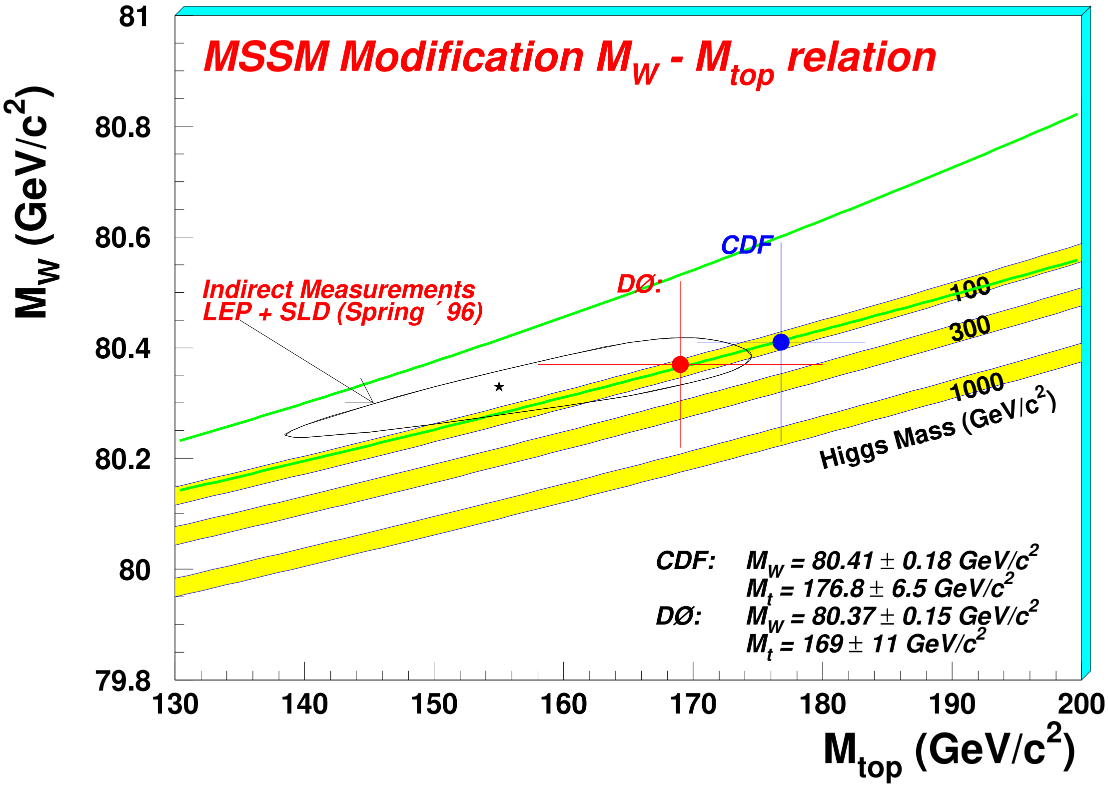
Current Electroweak results from LEP/SLD:
(LEP ElectroWeak Working Group, summer 1996)
[CERN-PPE/96-183]

	Measurement with Total Error	Standard Model	Pull
a) LEP			
line-shape and lepton asymmetries:			
M_Z [GeV]	91.1863 ± 0.0020	91.1861	0.1
Γ_Z [GeV]	2.4946 ± 0.0027	2.4960	-0.5
σ^0_{had} [nb]	41.508 ± 0.056	41.465	0.8
R_l	20.778 ± 0.029	20.757	0.7
$A^{0,l}_{FB}$	0.0174 ± 0.0010	0.0159	1.4
τ polarization:			
A_τ	0.1401 ± 0.0067	0.1458	-0.9
A_e	0.1382 ± 0.0076	0.1458	-1.0
b and c quark results:			
$R_b{}^{(a)}$	0.2179 ± 0.0012	0.2158	1.8
$R_c{}^{(a)}$	0.1715 ± 0.0056	0.1723	-0.1
$A^{0,b}_{FB}$	0.0979 ± 0.0023	0.1022	-1.8
$A^{0,c}_{FB}$	0.0733 ± 0.0049	0.0730	0.1
$q\bar{q}$ charge asymmetry:			
$sin^2\theta^{lept}_{eff}$	0.2320 ± 0.0010	0.23167	0.3
b) SLD			
$sin^2\theta^{lept}_{eff}$ (A_{LR})	0.23061 ± 0.00047	0.23167	-2.2
R_b	0.2149 ± 0.0038	0.2158	-0.2
A_b	$0.863 \pm 0.049z$	0.935	-1.4
A_c	$0.625 \pm 0.084z$	0.667	-0.5
c) p$\bar{\text{p}}$ and νN			
m_W [GeV] (p$\bar{\text{p}}$)	80.356 ± 0.125	80.353	0.0
$1 - m_W^2/m_Z^2$ (νN)	0.2244 ± 0.0042	0.2235	0.2
m_t [GeV] (p$\bar{\text{p}}$)	175 ± 6	172	0.5

M_W vs m_t - Higgs constraint



M_W vs m_t - beyond SM



LEP2 - new direct M_W !

summer 1996 - e^+e^- at $\sqrt{s} = 161.3$ GeV

$\Rightarrow$ determine M_W from turn-on of cross section

- measure event rate of W^+W^- pairs as function of beam $\sqrt{s}$

updated value as of Nov 96:

$$M_W(\text{LEP2}) = 80.4 \pm 0.2 \pm 0.1 \text{ GeV}$$

Now running at $\sqrt{s} = 175$ and $\sqrt{s} = 192$ until 500 pb^{-1} for each of the 4 experiments

Other direct M_W methods:

- direct reconstruction of decay products

  $W^+W^- \rightarrow q\bar{q}q\bar{q}$ - interconnection effects

  $W^+W^- \rightarrow qqe\nu$

- lepton end-point energy

  $W^+W^- \rightarrow q\bar{q}l\nu$

Summary of W Mass Measurements

- **DØ 1996, (Run 1A - Published)** 5928 $W^{e\nu}$ **events**

$$M_W = 80.350 \pm 0.270 \text{ GeV/c}^2$$

- **DØ 1996, (Run 1B - Preliminary)** 32856 $W^{e\nu}$ **events**

$$M_W = 80.380 \pm 0.170 \text{ GeV/c}^2$$

- **DØ 1996, (Run 1A & 1B combined - Preliminary) Currently World's Best Measurement!**

$$M_W = 80.370 \pm 0.150 \text{ GeV/c}^2$$

- **CDF 1995 (Run 1A)** 3268 $W^{\mu\nu}$ **and** 5718 $W^{e\nu}$ **events**

$$M_W = 80.410 \pm 0.180 \text{ GeV/c}^2$$

- **New World Average***

$$M_W = 80.356 \pm 0.125 \text{ GeV/c}^2$$

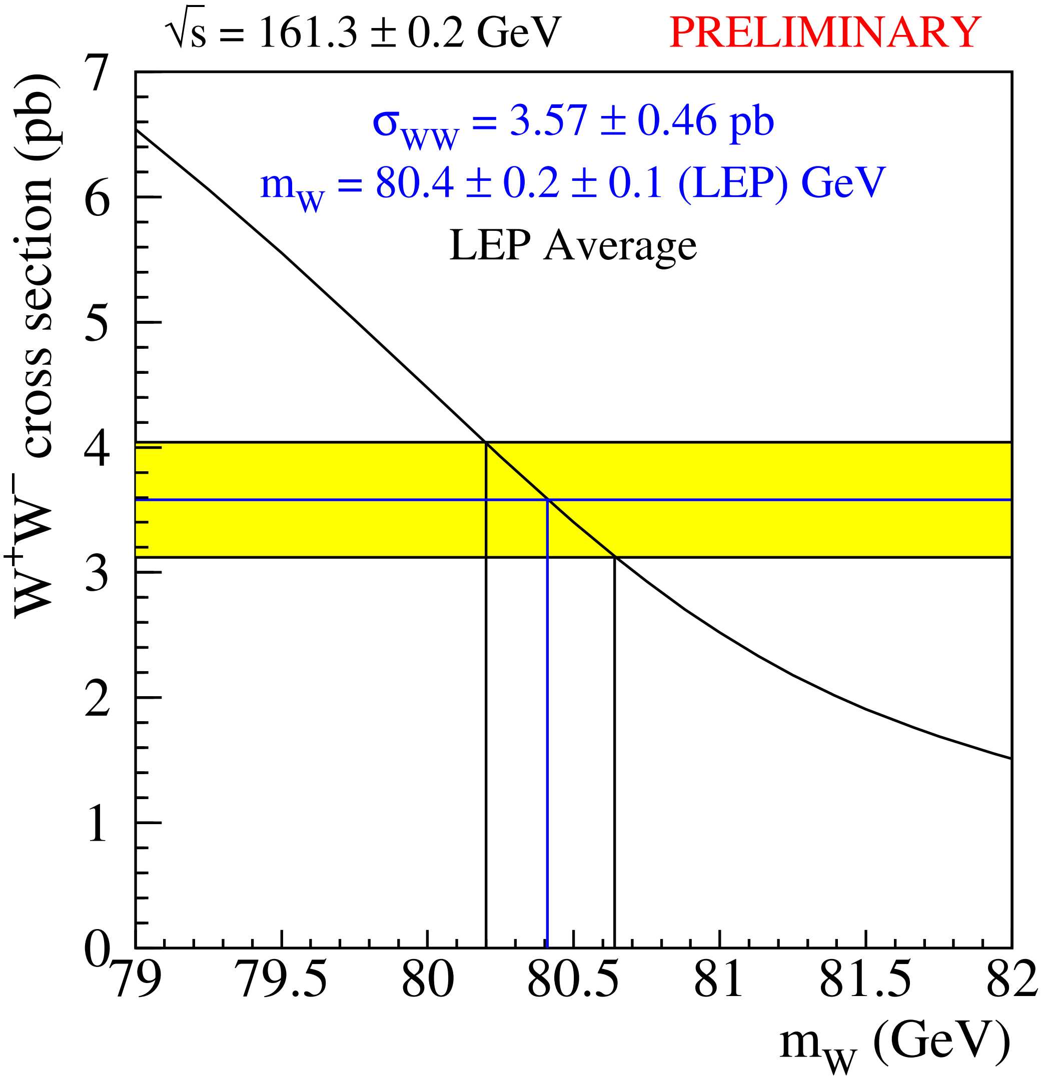
* $\rightarrow$ includes above plus values from CDF(1990) and UA2(1992)

- **LEP1 & SLD (Indirect Measurement)**

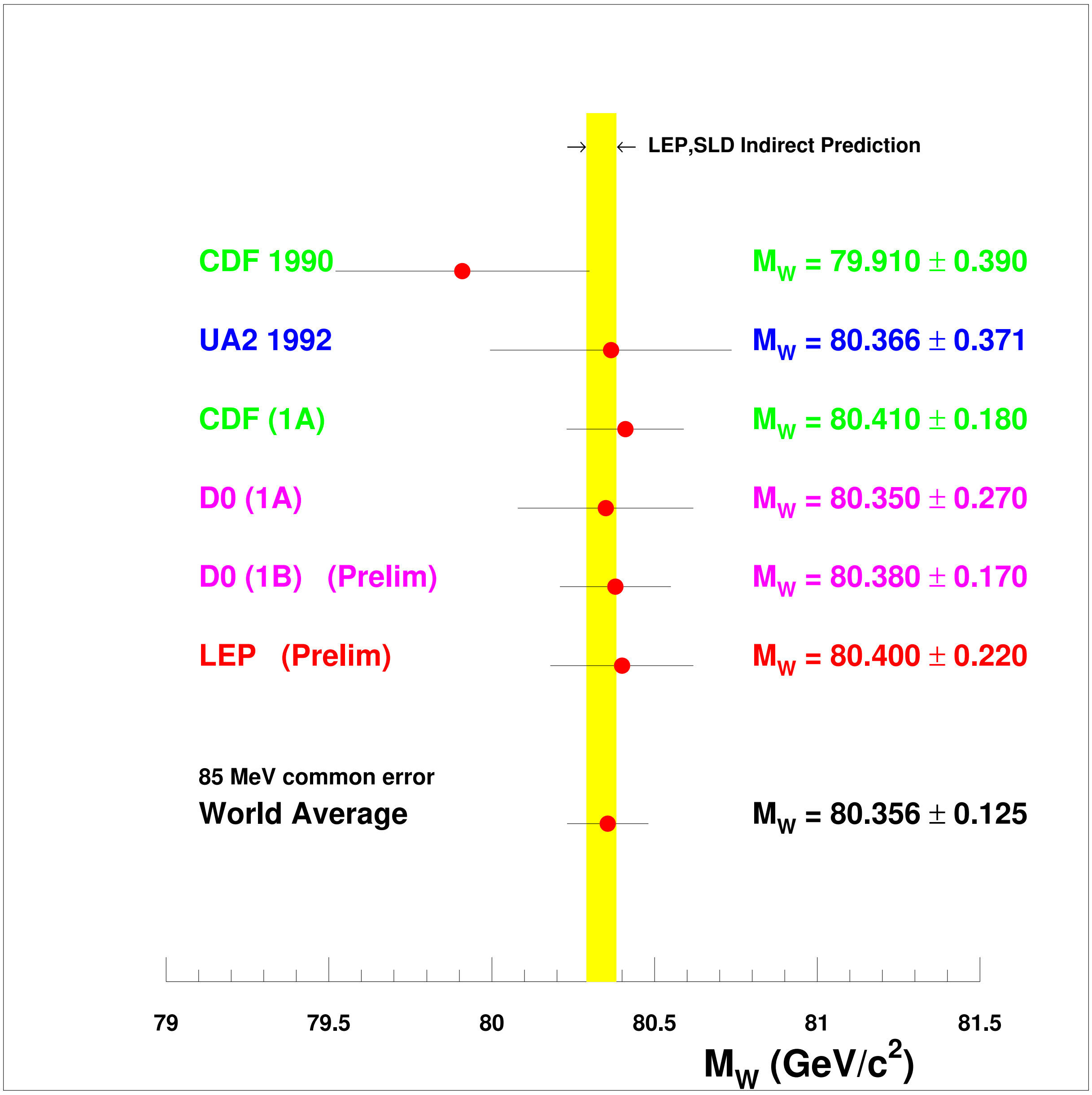
$$M_W = 80.337 \pm 0.041^{+0.010}_{-0.021} \text{ GeV/c}^2$$

- **LEP2 - Direct Measurement**

$$M_W = 80.4 \pm 0.22 \text{ GeV/c}^2$$



LEPC 8 Oct 96
LEP EW Working Group



LEP,SLD Indirect Prediction
CDF 1990
$M_W = 79.910 \pm 0.390$
UA2 1992
$M_W = 80.366 \pm 0.371$
CDF (1A)
$M_W = 80.410 \pm 0.180$
D0 (1A)
$M_W = 80.350 \pm 0.270$
D0 (1B) (Prelim)
$M_W = 80.380 \pm 0.170$
LEP (Prelim)
$M_W = 80.400 \pm 0.220$
85 MeV common error
World Average
$M_W = 80.356 \pm 0.125$
79
79.5
80
80.5
81
81.5
M_W (GeV/c^2)

Conclusions - M_W at DØ

- have collected ≈ 100 pb^{-1} of data in Runs 1A & 1B

- from analysis of Run 1A data sample
  $\Rightarrow$ measured W mass (e channel)

$$M_W = 80.350 \pm .270 \text{ GeV}$$

- Run 1B preliminary result: $M_W = 80.380 \pm .170$ GeV

- Currently World's Best Measurement! (Run 1A + 1B)
  $M_W = 80.370 \pm .150$ GeV

- New World Average: $M_W = 80.356 \pm .125$ GeV

- for final Run 1B result expect
  - will further reduce errors to due to production model and luminosity dependence
  - adding $W \rightarrow e\nu$ events in forward region
    $\rightarrow$ DØ error ≈ 120 MeV

- Tevatron Run 1 - expect to know W mass to ≈ 100 MeV!

Many exciting things happening in the world of ElectroWeak Precision Measurements!

Future M_W Measurements

- Tevatron Run 1 - DØ& CDF: $\Delta M_W \approx 80$ MeV
- Tevatron Run 2: $\Delta M_W \approx 40$ MeV $\rightarrow$ by 2000?
- Tevatron Run 2: $\Delta m_t \approx 3$ GeV
- LEP2: $\Delta M_W \approx 45$ MeV

From LEP2 EWWG - Feb 1996
constraints on M_H

	$M_T = 180 \pm 5$ **GeV**	
M_H**(GeV)**	$\Delta M_W = 25$ **MeV**	$\Delta M_W = 50$ **MeV**
100	**+86, -54**	**+140,-72**
300	**+196, -126**	**+323,-168**
800	**+ 538,-310**	**+958,-413**

As measurements of M_W and M_T become more precise, we will further constrain the M_H