W Boson mass and width measurements at the Tevatron
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Moriond QCD, March 2007

# Why measure the W mass/width?

Measured to 0.015%

Measured to 0.002%

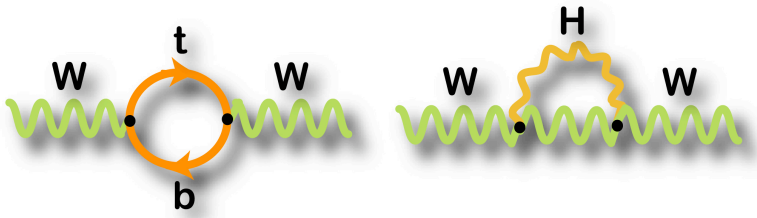
Measured to 0.036%

$$M_W^2 = \frac{\pi\alpha(M_Z^2)}{\sqrt{2}G_F} \frac{1}{(1-(M_W^2/M_Z^2))} \frac{1}{(1-\Delta r)}$$

Measured to 0.0009%

$\Delta r$: O(3%) radiative corrections dominated by *tb* and Higgs loops

$\Delta M_W \propto M_{top}^2$



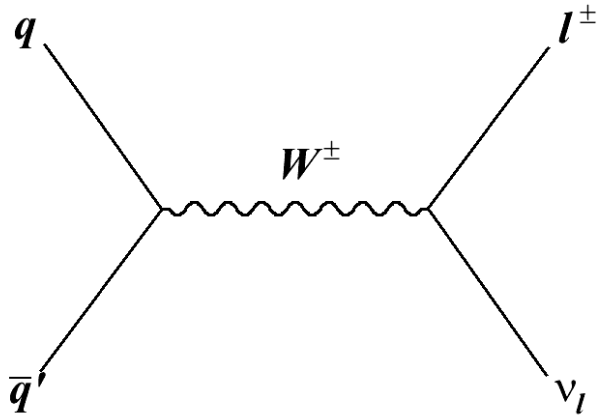

$\Delta M_W \propto \ln M_H$

$\therefore$ we can constrain $M_H$ by precisely measuring $M_W$ and $M_{top}$ :

Measuring W width ($\Gamma_W$) tests the SM.

$\Gamma_W$ is an input to the $M_W$ measurement: $\Delta M_W \approx \Delta\Gamma_W / 7$.

# W production at the Tevatron

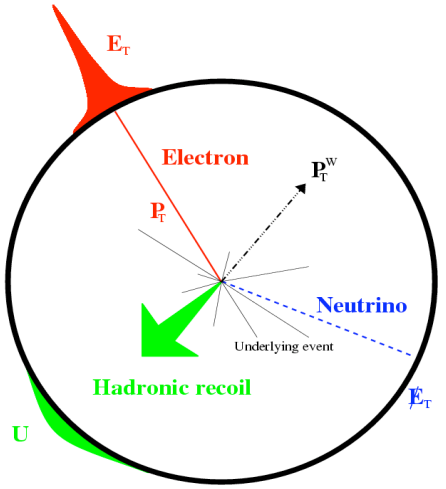



The measurements are performed in the $\mu\nu_\mu$ and $e\nu_e$ channels using 200pb$^{-1}$ (350pb$^{-1}$) for $M_W$ ($\Gamma_W$)

$$m_T = \sqrt{2 p_T^{\,l} p_T^{\,\nu} (1 - \cos\phi_{l\nu})}$$

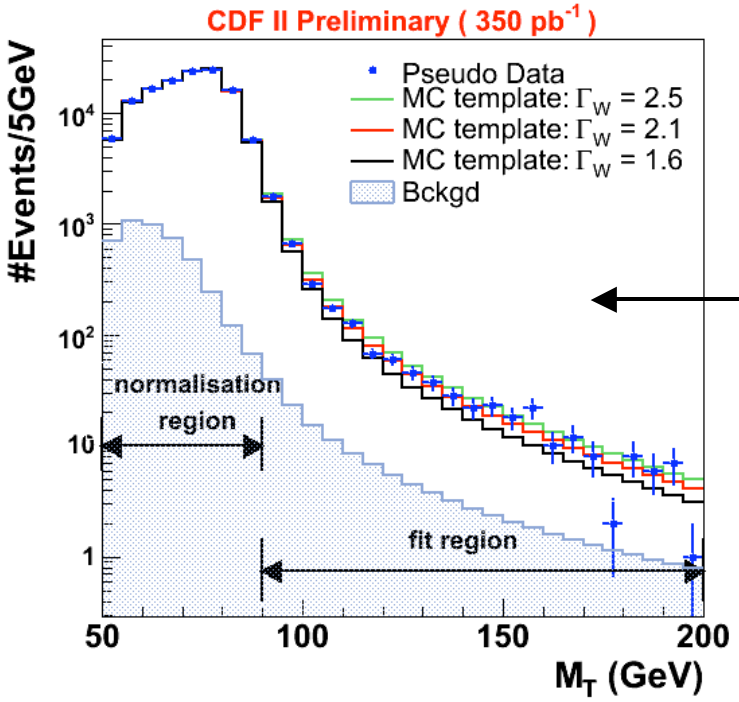
μ-channel: central tracker
e-channel: EM calorimeter

inferred from missing transverse energy

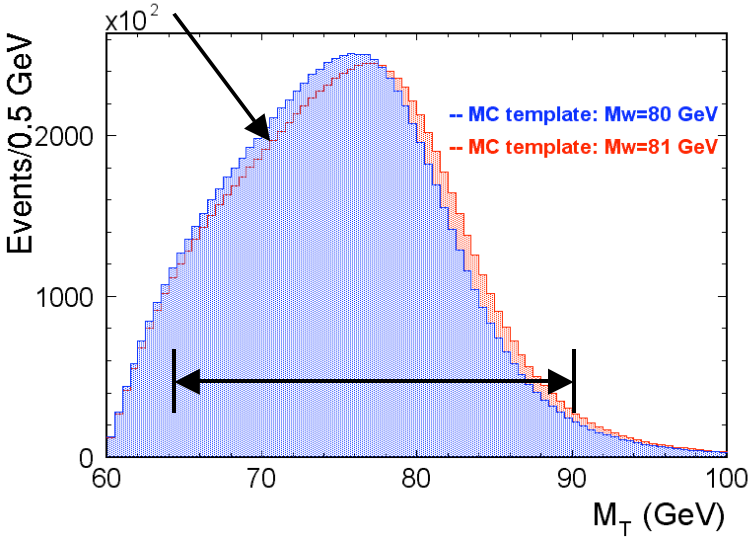


# Analysis strategy

$\Gamma_W$ templates




- Simulate $M_T$ distribution with a dedicated *fast* parameterised MC (using Breit-Wigner lineshape).
- MC simulates QCD(RESBOS) and QED(WGRAD) corrections.
- Utilise well understood data samples to calibrate detector to high precision.
- Fit templates (with $M_W/\Gamma_W$ varying) to the data:
  - $\Gamma_W$ fit range: 90-200 GeV
  - $M_W$ fit range:65-90 GeV




$M_W$ templates

# Sources of systematic error

- The mass/width analyses are very similar with different dominant systematics:
  - Momentum scale/resolution
  - Calorimeter scale/resolution
  - Hadronic recoil
  - Backgrounds

mass

width

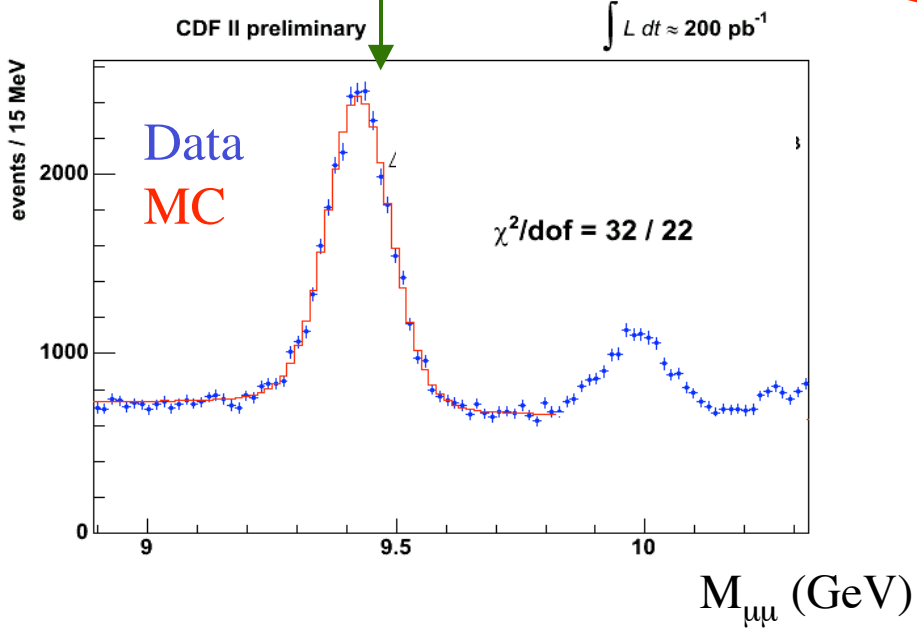
- Current world average uncertainties:
  - $\Delta M_W$ = 29 MeV
  - $\Delta \Gamma_W$ = 60 MeV

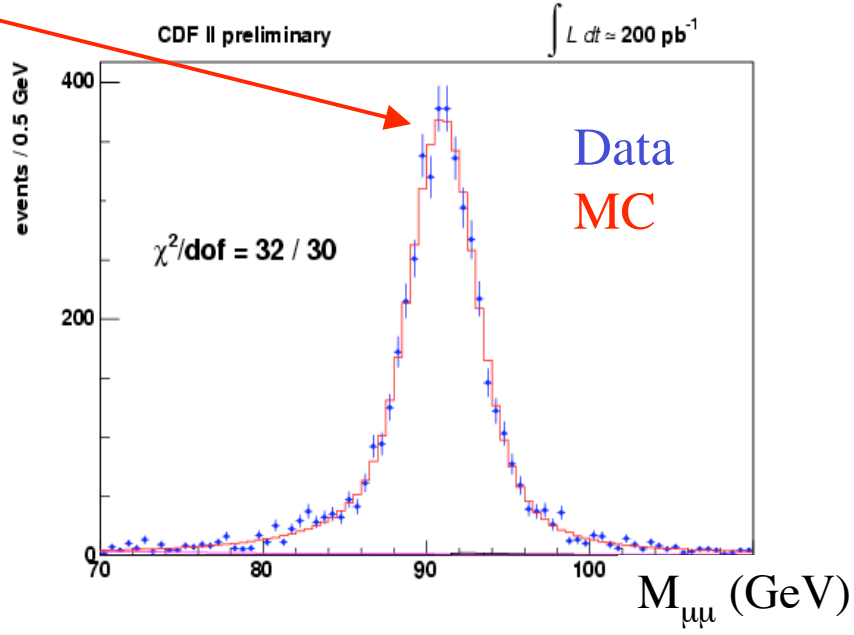
# Lepton momentum calibration ($p_T^{\mu}$)

Momentum scale set with di-muon resonance peaks in data:

$J/\Psi \rightarrow \mu\mu$; $\Upsilon(1S) \rightarrow \mu\mu$; $Z \rightarrow \mu\mu$

**p scale known to 0.021%**




Momentum resolution from width of distributions

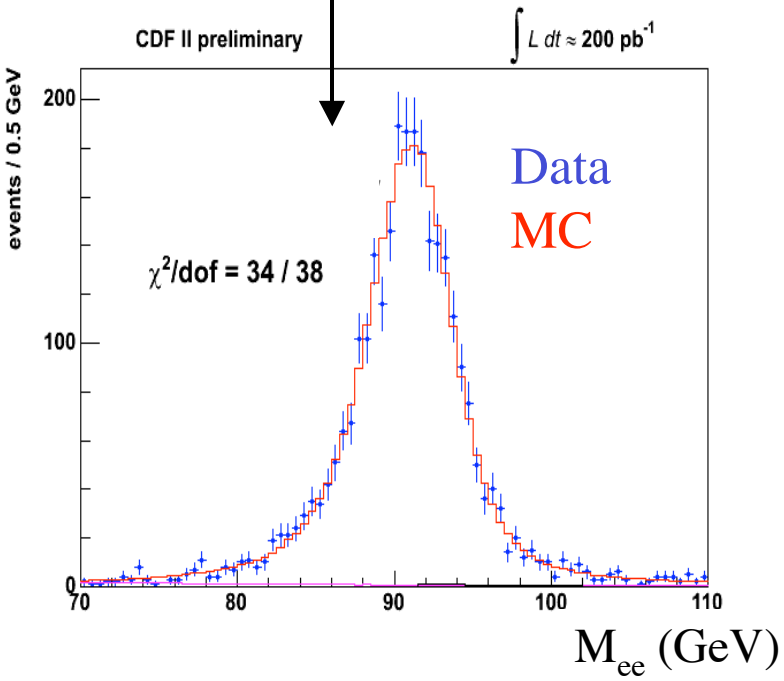
| scale: | resolution: |
|---|---|
| $\Delta M_W$ ($\mu$) = 17 MeV | $\Delta M_W$ ($\mu$) = 3 MeV |
| $\Delta\Gamma_W$ ($\mu$) = 17 MeV | $\Delta\Gamma_W$ ($\mu$) = 26 MeV |

# Electron energy calibration ($p_T^e$)

Calorimeter scale and resolution set using:

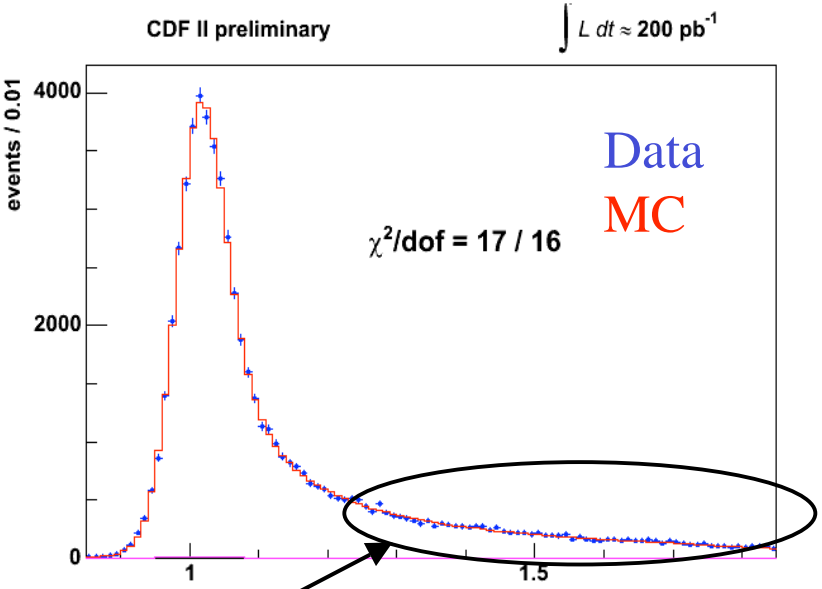
- E/p in $W \to e\nu$ data
- $M_{ee}$ in $Z \to ee$ data

**E scale known to 0.034%**




E

p




Energy loss in tracker (bremsstrahlung)

**scale:**

$\Delta M_W$ (e) = 30 MeV

$\Delta \Gamma_W$ (e) = 17 MeV

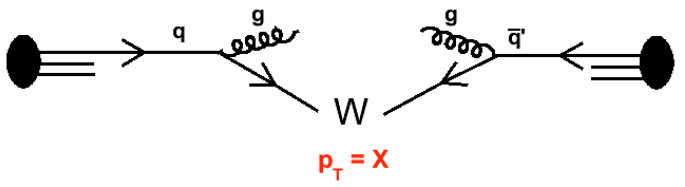
**resolution:**

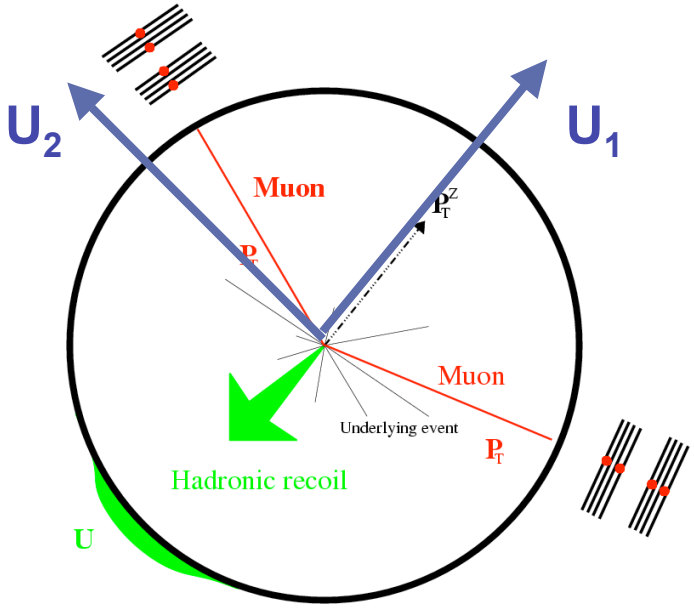
$\Delta M_W$ (e) = 3 MeV

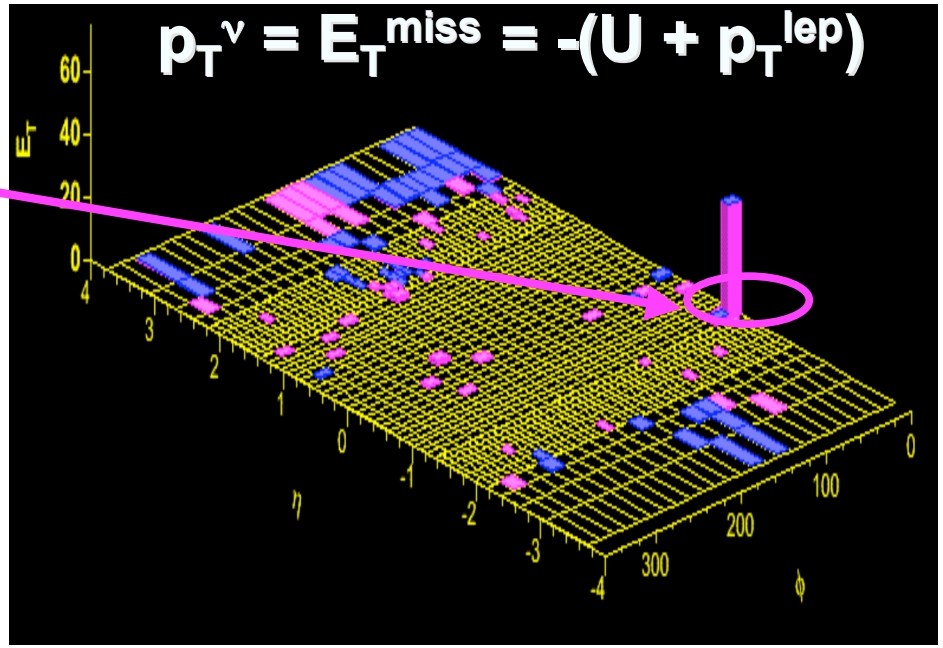
$\Delta \Gamma_W$ (e) = 31 MeV

# Hadronic Recoil: U ($p_T^{\nu}$)

- $U=(U_x, U_y)=\sum_{towers} E\sin\theta\,(\cos\varnothing, \sin\varnothing)$
- Vector sum over calorimeter towers
  - Excluding those surrounding lepton

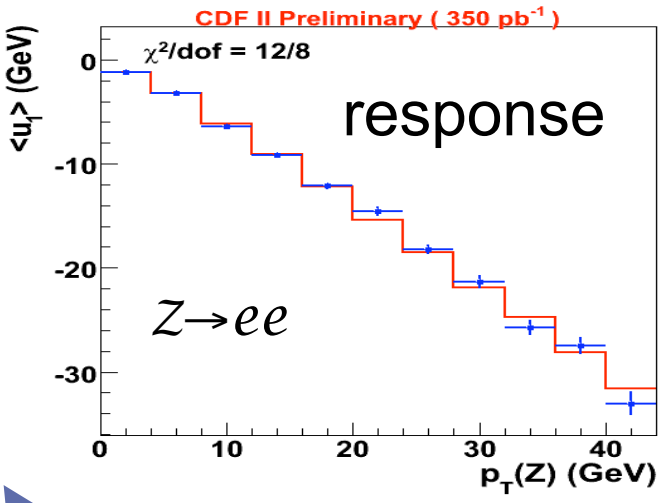


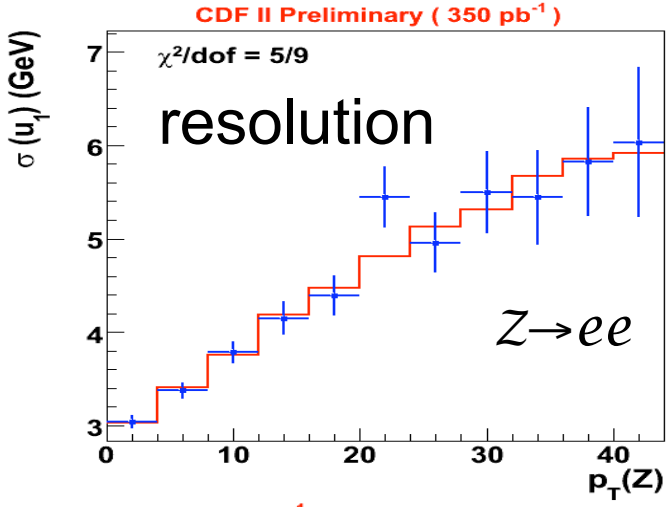



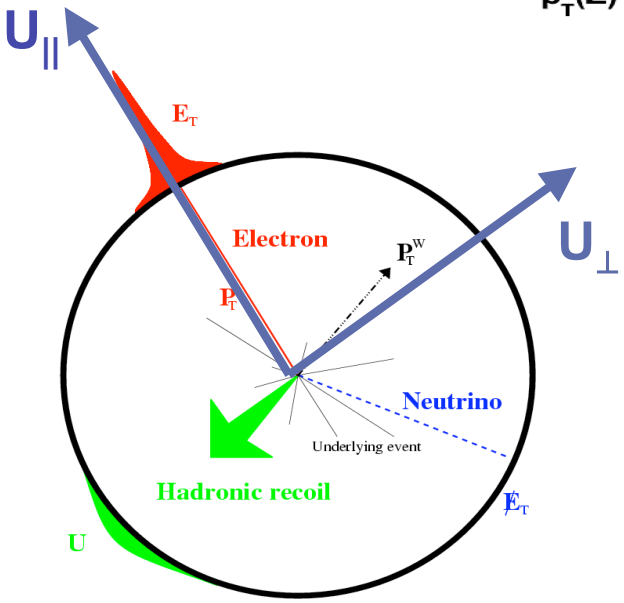

- U split into components parallel ($U_1$) and perpendicular ($U_2$) to Z $p_T$
- 7 parameter model describes the recoil response and resolution: fit to Z data

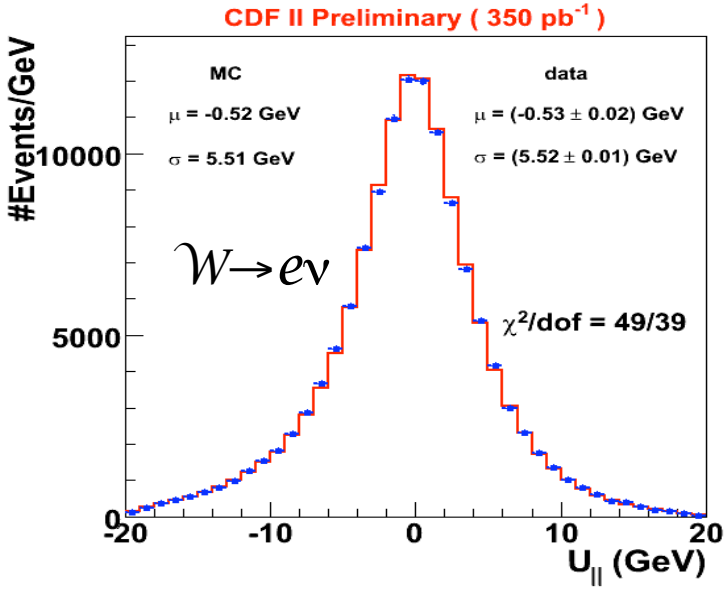
# Hadronic Recoil: U ($p_T^{\nu}$)




Data
MC




$\Delta M_W$ ($\mu$) = 12 MeV

$\Delta \Gamma_W$ ($\mu$) = 49 MeV

$\Delta M_W$ (e) = 14 MeV

$\Delta \Gamma_W$ (e) = 54 MeV

# Backgrounds

- Electroweak backgrounds ($Z \to ll$, $W \to \tau\nu$) found from full GEANT MC samples.
- Data used to estimate:
  - multijet : Fit low $E_T^{miss}$ distribution.
  - kaons decaying-in-flight to $\mu$ : Fit high $\chi^2_{track}$ distribution.

**predominantly multijets**

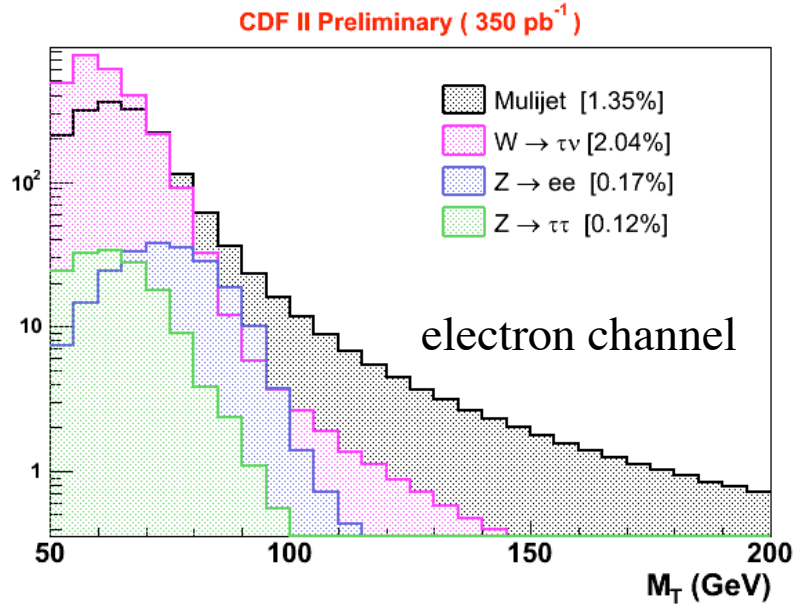
$\Delta M_W$ (e) = 8 MeV

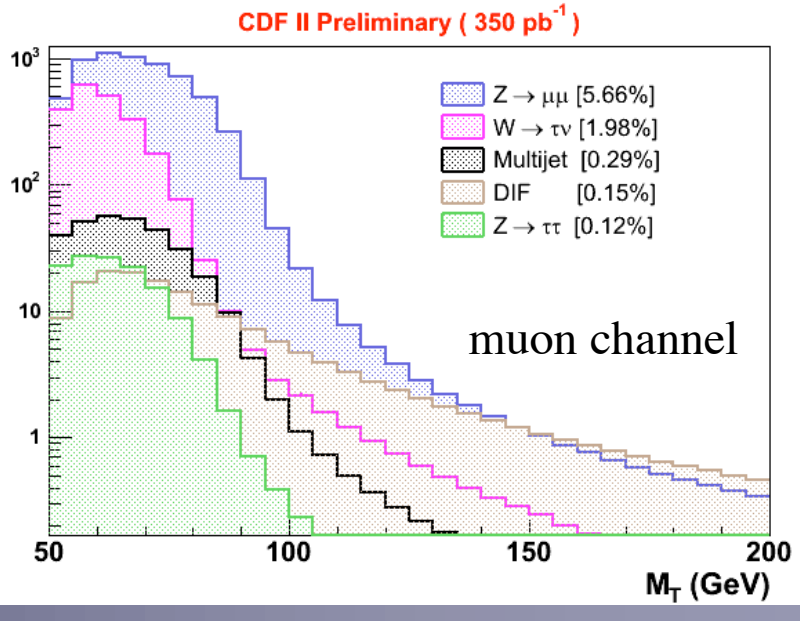
$\Delta \Gamma_W$ (e) = 32 MeV

**predominantly kaons**

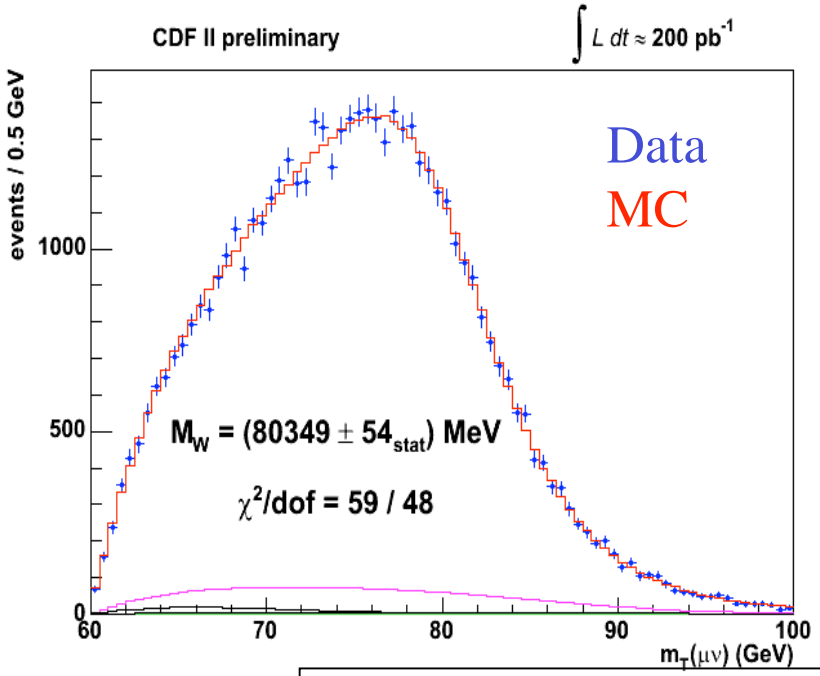
$\Delta M_W$ ($\mu$) = 9 MeV

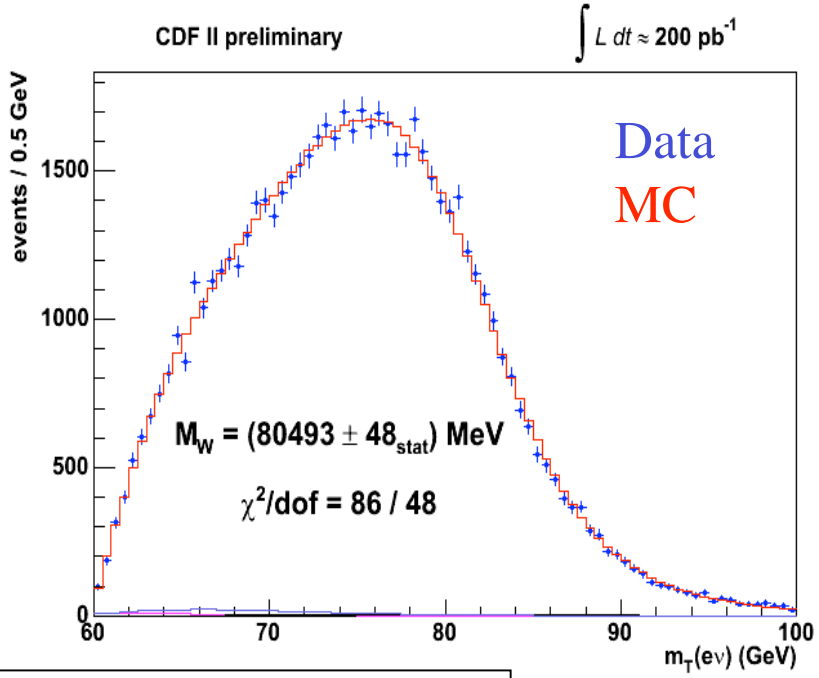
$\Delta \Gamma_W$ ($\mu$) = 33 MeV



# Results: $M_W$ fits



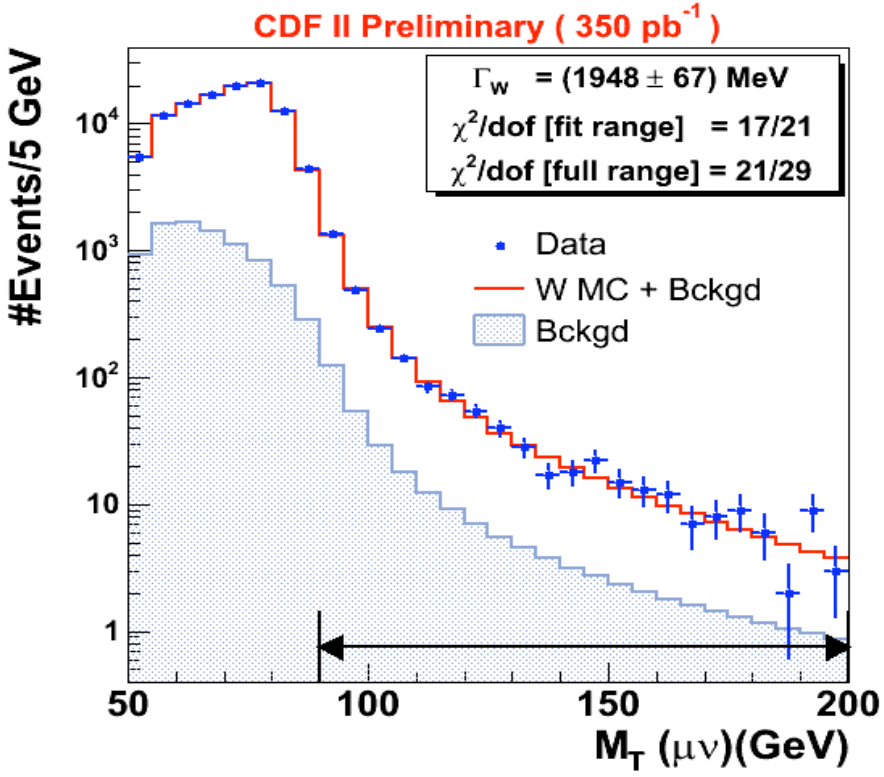

**$M_W$ = 80417 ± 48 (stat + syst) MeV**

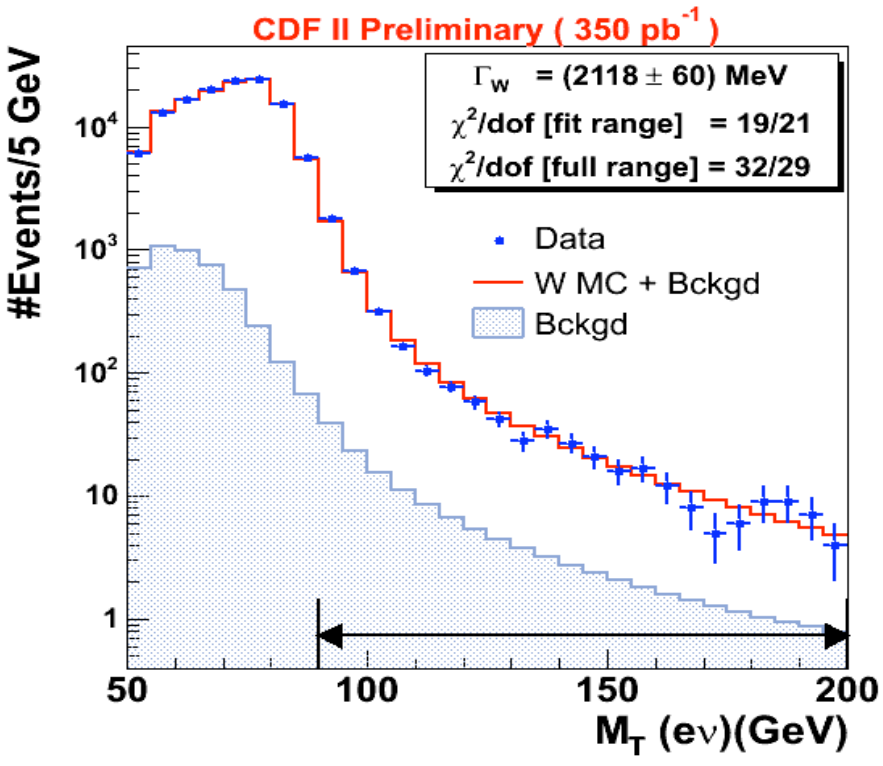
e + μ combination P($\chi^2$) = 7%

Include fits to $p_T^{\ell}$ and $p_T^{\nu}$:

**$M_W$ = 80413 ± 48 (stat + syst) MeV**

# Results: $\Gamma_W$ fits




**$\Gamma_W$ = 2032 ± 71 (stat + syst) MeV**

e + μ combination P($\chi^2$) = 20%

# Systematic uncertainties

## $M_W$ uncertainties

CDF II preliminary — L = 200 pb$^{-1}$

| $m_T$ Uncertainty [MeV] | Electrons | Muons | Common |
|---|---|---|---|
| Lepton Scale | 30 | 17 | 17 |
| Lepton Resolution | 9 | 3 | 0 |
| Recoil Scale | 9 | 9 | 9 |
| Recoil Resolution | 7 | 7 | 7 |
| $u_{\parallel}$ Efficiency | 3 | 1 | 0 |
| Lepton Removal | 8 | 5 | 5 |
| Backgrounds | 8 | 9 | 0 |
| $p_T(W)$ | 3 | 3 | 3 |
| PDF | 11 | 11 | 11 |
| QED | 11 | 12 | 11 |
| Total Systematic | 39 | 27 | 26 |
| Statistical | 48 | 54 | 0 |
| Total | 62 | 60 | 26 |

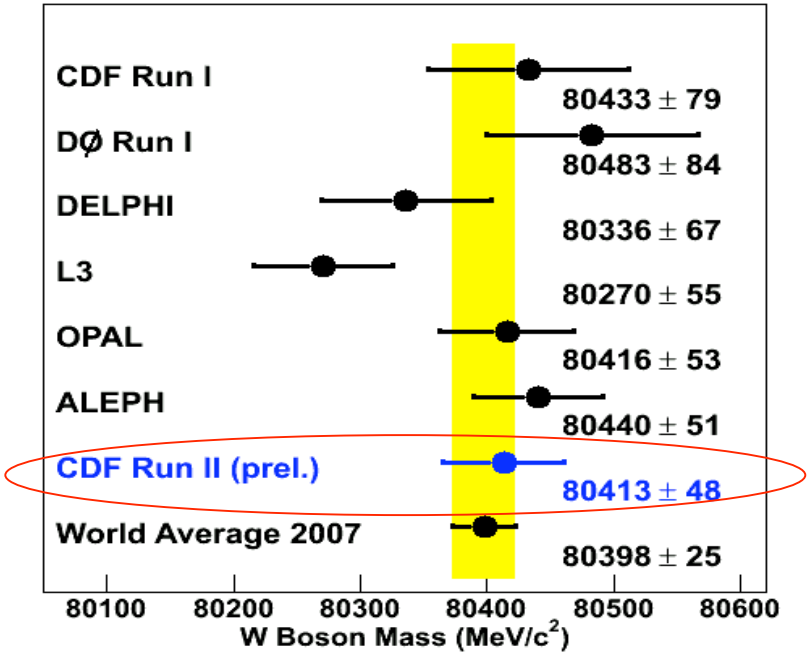
## $\Gamma_W$ uncertainties

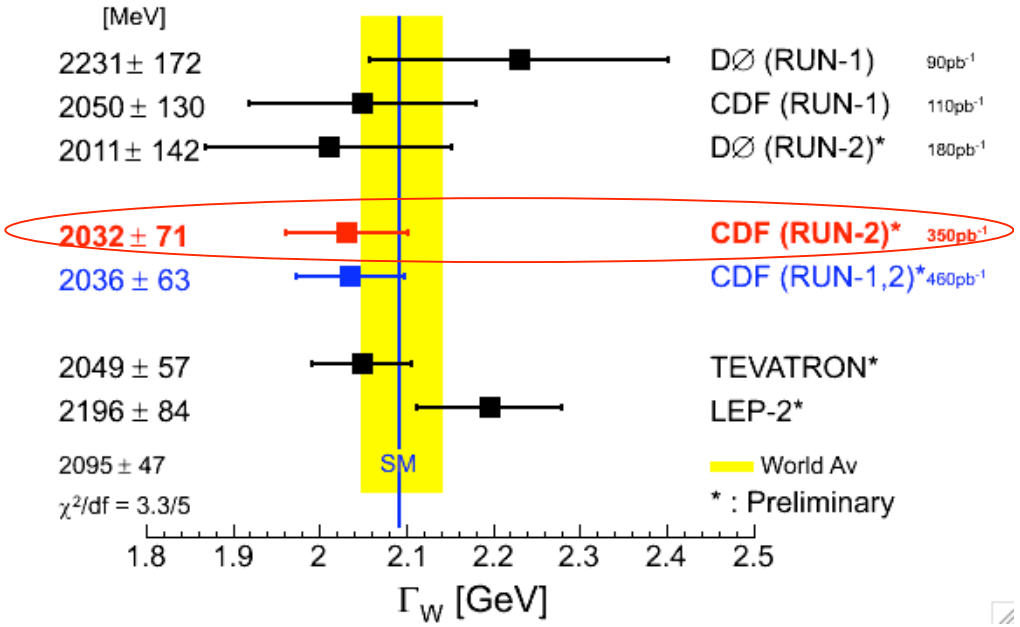
CDF Run II Preliminary (350 pb$^{-1}$)

| | $\Delta\Gamma_W$ [MeV] | | |
|---|---|---|---|
| | Electrons | Muons | Common |
| Lepton Scale | 17 | 17 | 12 |
| Lepton Resolution | 31 | 26 | 0 |
| Simulation | 13 | 0 | 0 |
| Recoil | 54 | 49 | 0 |
| Lepton ID | 10 | 7 | 0 |
| Backgrounds | 32 | 33 | 0 |
| $p_T(W)$ | 7 | 7 | 7 |
| PDF | 16 | 17 | 16 |
| QED | 8 | 1 | 1 |
| W mass | 9 | 9 | 9 |
| Total systematic | 78 | 70 | 23 |
| Statistical | 60 | 67 | 0 |
| Total | 98 | 97 | 23 |

# Results

World's most precise single measurements!



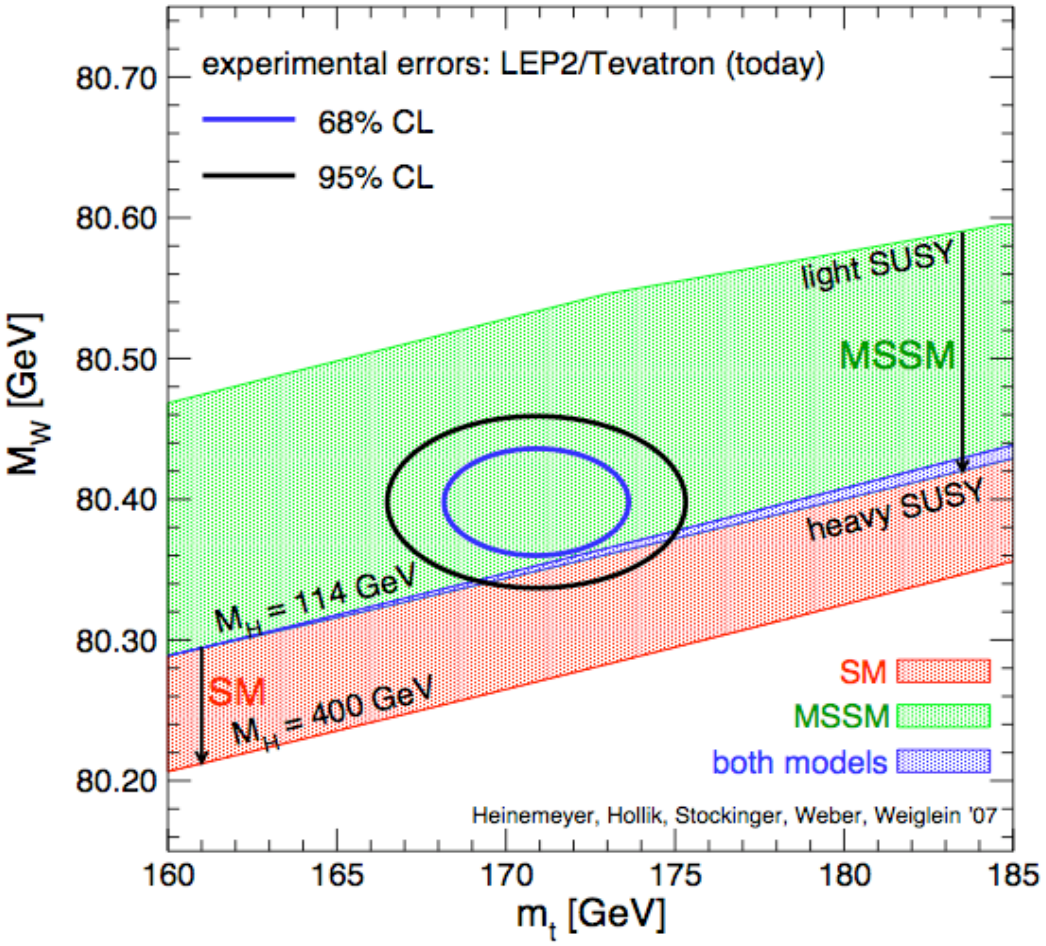

Central value increases by 6 MeV:
**80392 → 80398 MeV**

Uncertainty reduced by 15%:
**29 → 25 MeV**

Central value decreases by 44 MeV:
**2139 → 2095 MeV**

Uncertainty reduced by 22%:
**60 → 47 MeV**

# Implications




**Previous World Data :**

$m_H = 85^{+39}_{-28}$ GeV

$m_H < 166$ GeV @ 95% C.L.

**Including New $M_W$ :**

$m_H = 80^{+36}_{-26}$ GeV

$m_H < 153$ GeV @ 95% C.L.

**Including New $M_{top}$ :**

*Later this session…(M. Wang)*

**Direct search from LEP II :**

$m_H > 114.4$ GeV @ 95% C.L.

# Summary

- Two new measurements from CDF:
  - W mass : **80413 ± 48 MeV (stat + syst)**
  - W width : **2032 ± 71 MeV (stat + syst)**
- **Both are the world's most precise single measurements!!**
- Getting to this point requires a "precision" level calibration of the detector.
- Continuing to squeeze the phase space available to the SM Higgs.
- Analyses utilised 200 $pb^{-1}$ and 350 $pb^{-1}$ respectively, both CDF and DØ already have ~2 $fb^{-1}$ on tape.
- **Expect improved mass/width measurements to further test the SM and constrain $m_H$**