Precision Electroweak Results [& Searches for New Physics] at CDF

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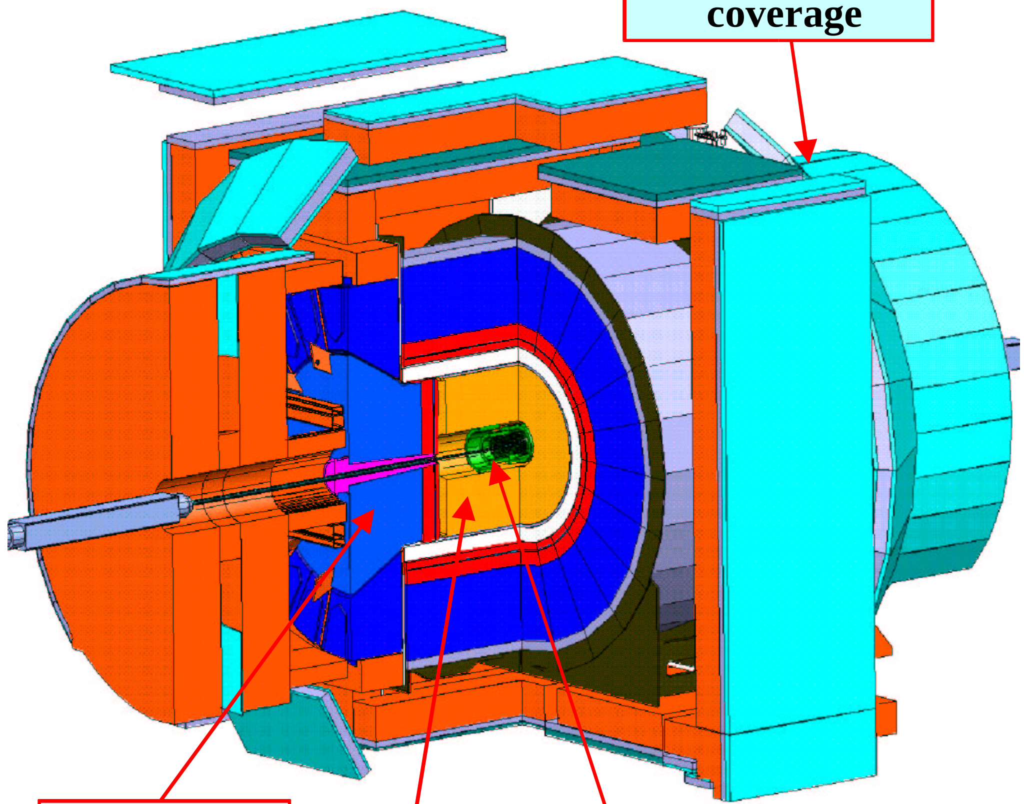
for the CDF Collaboration

- Performance of the Tevatron/CDF.
- W & Z Cross Section Measurements.
- Drell−Yan Physics.
- Taus.
- "R" and the Width of the W.
- Di−boson Production.
- M_W and Γ_W Combined Results.
- Conclusions.

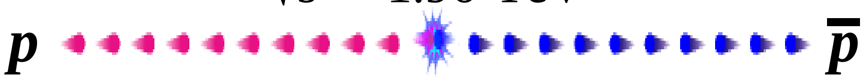


CDF Run 2 Detector :

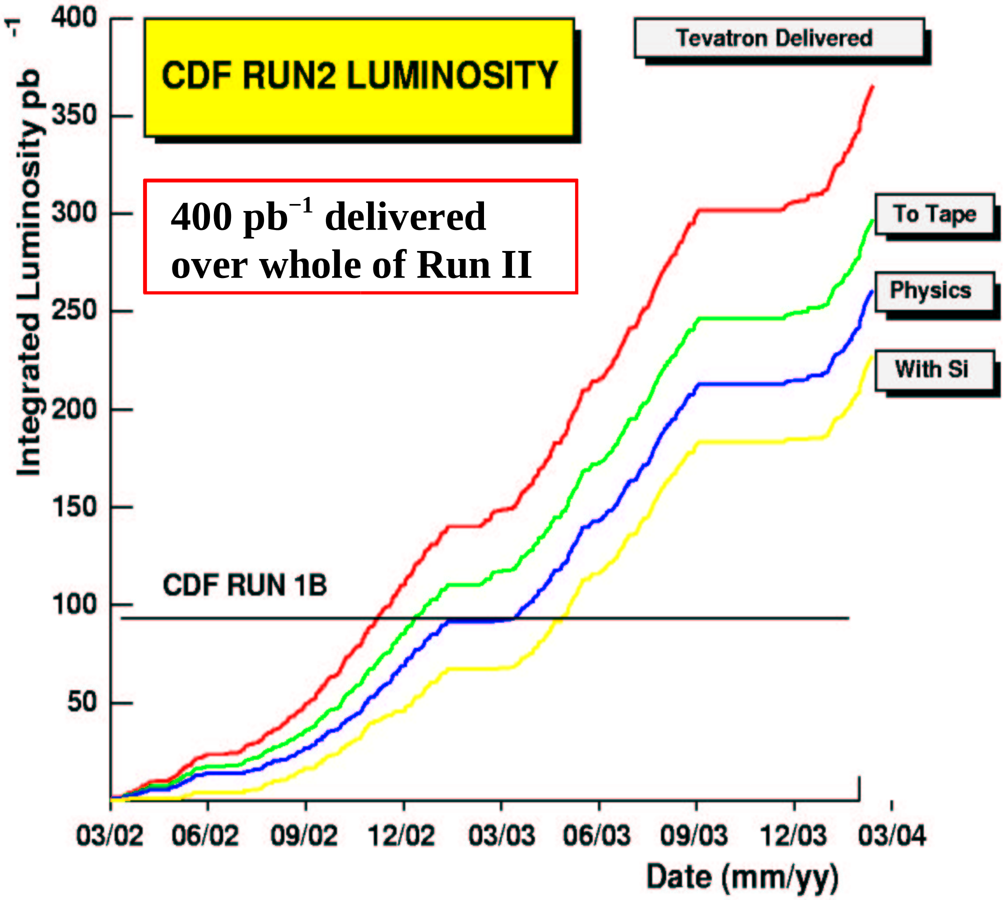
- Largely new detector.
- New trigger system : displaced tracks, taus, etc.
- Data handling : ≈ 0.5 PetaBytes/year processed and analysed.

Tevatron Performance

$\sqrt{s} = 1.96$ TeV



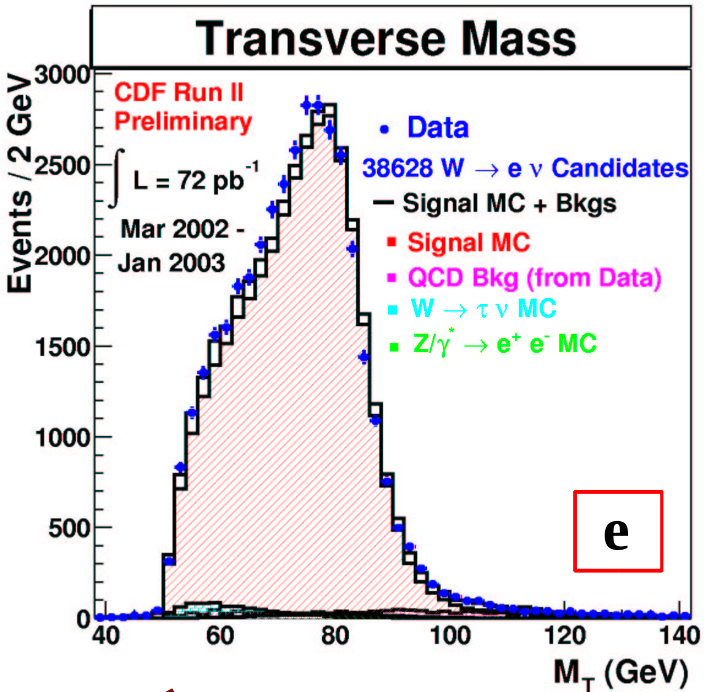
- Accelerator performance in 2004 is excellent. "Design goals" surpassed.
- Peak luminosity $6.1\times10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (5th Feb ’04)
- CDF takes data with efficiency > 85%.
- Beam conditions good : silicon is typically integrated for the entire store.



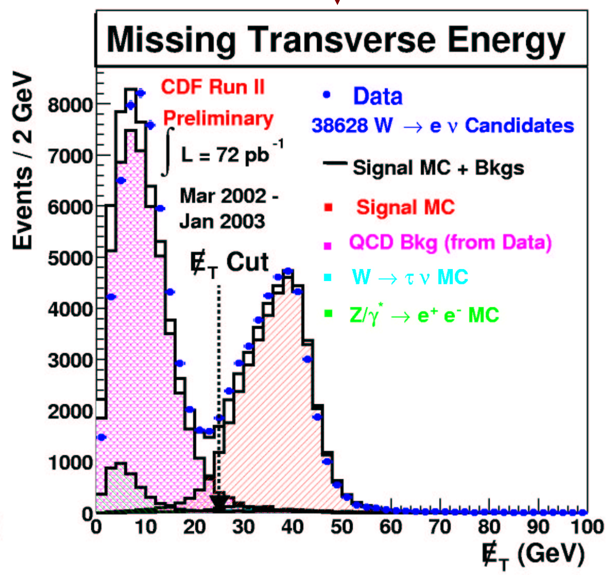
CDF now collects ~ 1pb^{-1}/day :

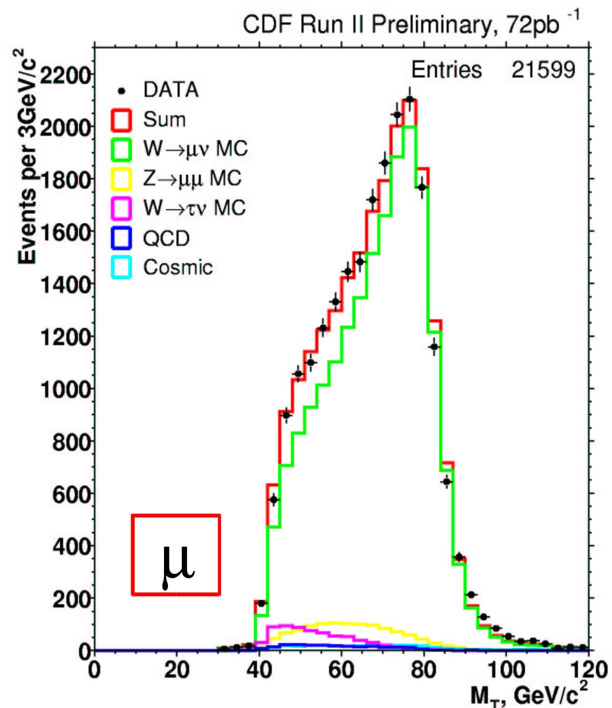
Process	Events/Week
$t\bar{t}$	50
$W\rightarrow e\,\nu_e$	18,000
$Z\rightarrow e^+e^-$	1700
WW	90
$W\gamma\rightarrow e\,\nu\,\gamma$ (high–$p_T\gamma$)	130
$g\,g\rightarrow H$ (M_H=115 GeV)	6

$\sigma \times \mathrm{BR}(W \rightarrow l\nu)$



control of backgrounds





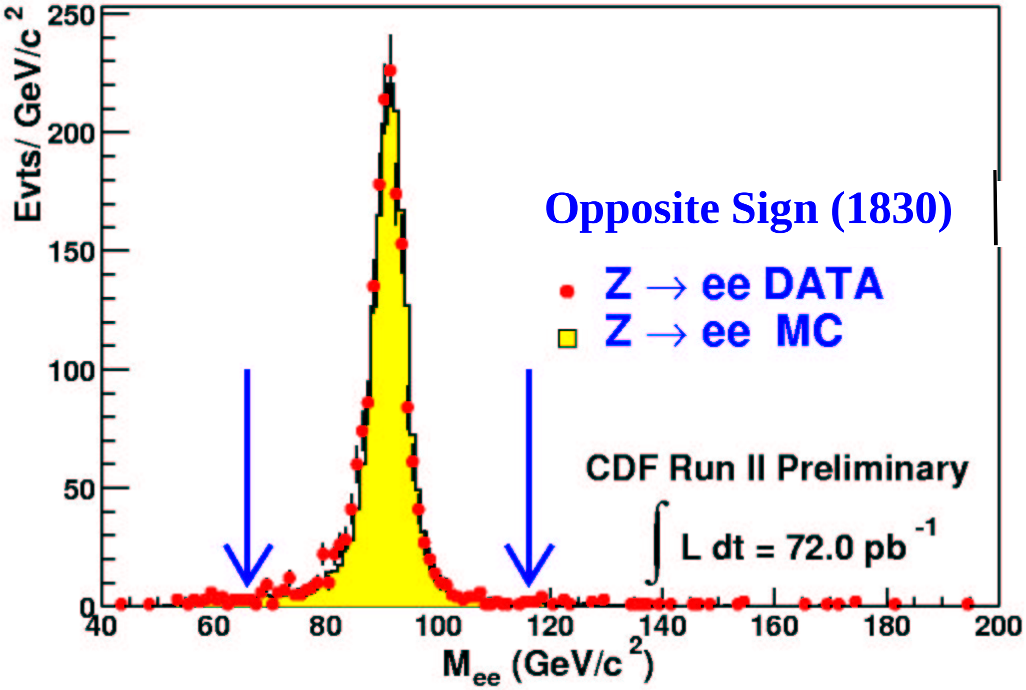
$$\sigma \times \mathrm{BR}(W \rightarrow e\nu) = 2.64 \pm 0.01_{\mathrm{STAT}} \pm 0.09_{\mathrm{SYST}} \pm 0.16_{\mathrm{LUM}}\ \mathrm{pb}$$

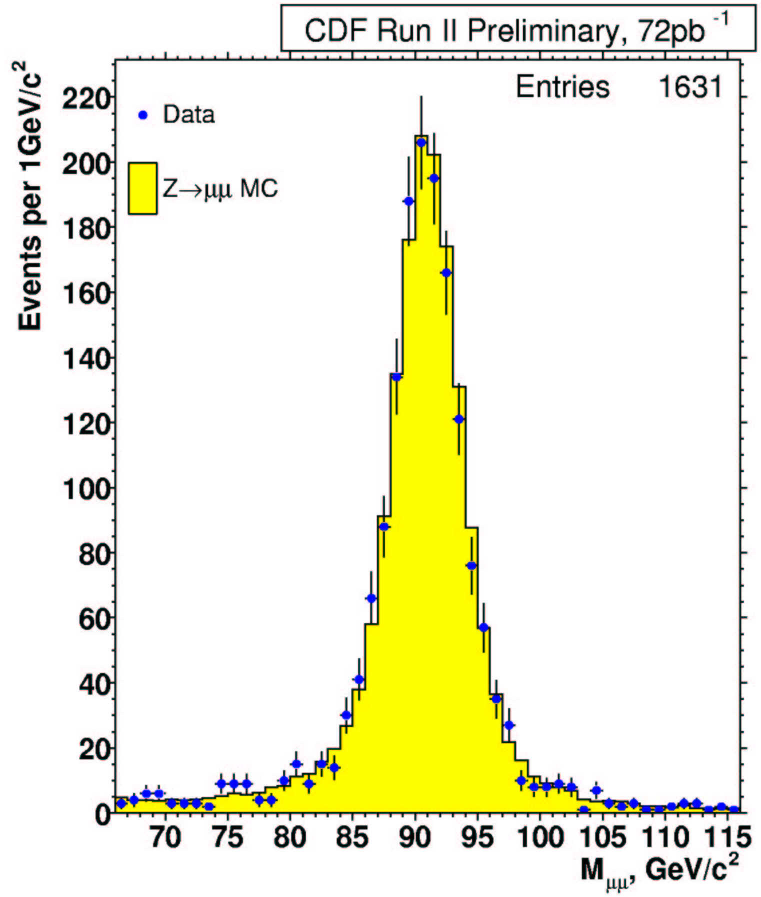
$$\sigma \times \mathrm{BR}(W \rightarrow \mu\nu) = 2.64 \pm 0.02_{\mathrm{STAT}} \pm 0.12_{\mathrm{SYST}} \pm 0.16_{\mathrm{LUM}}\ \mathrm{pb}$$

Backgrounds (QCD, $W \rightarrow \tau\nu$, Z, cosmics) : 6% (e), 11% (μ).

Important systematics : PDF’s, Energy Scales, Material Description

$\sigma \times BR(Z \rightarrow l^+l^-)$





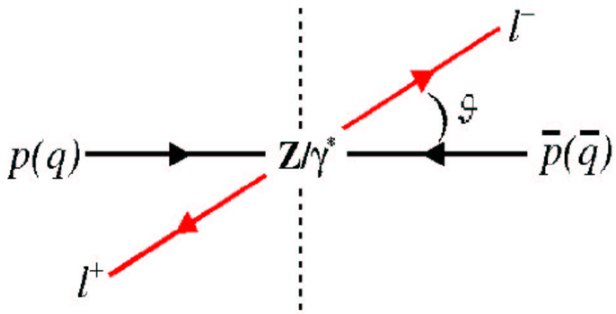
Very low backgrounds (QCD, $Z \rightarrow \tau\tau$, cosmics) : < 1%
Important systematics : PDF's, Material Descriptions

$$\sigma \times BR(Z \rightarrow ee) = 267.0 \pm 6.3_{STAT} \pm 15.2_{SYST} \pm 16.0_{LUM}\ \text{pb}$$

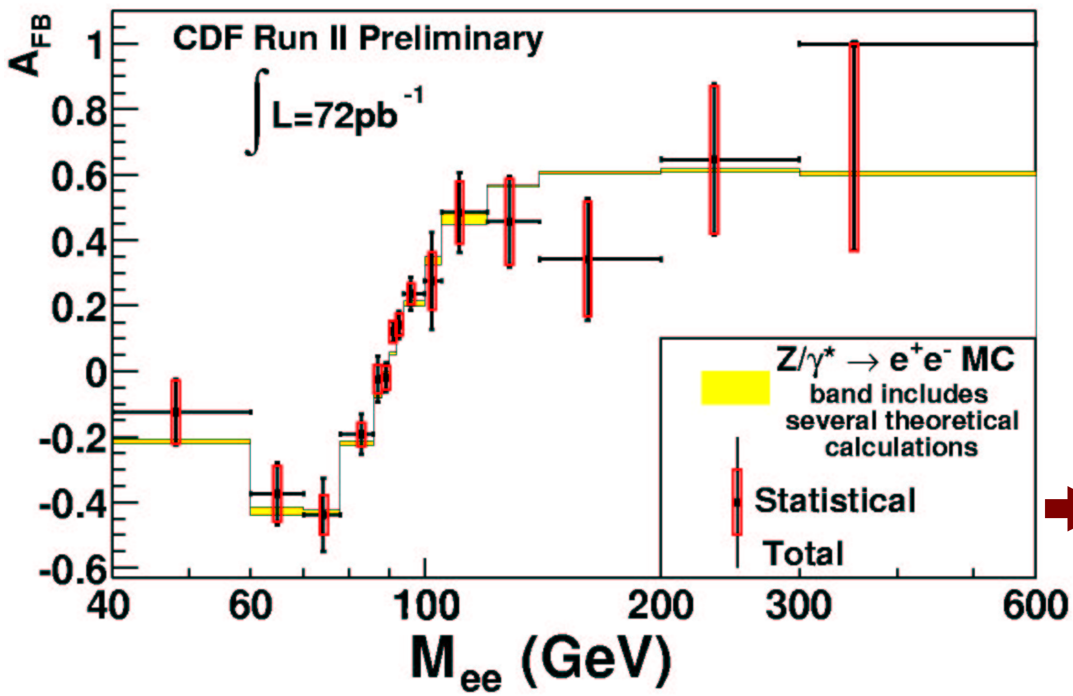
$$\sigma \times BR(Z \rightarrow \mu\mu) = 246 \pm 6_{STAT} \pm 12_{SYST} \pm 15_{LUM}\ \text{pb}$$

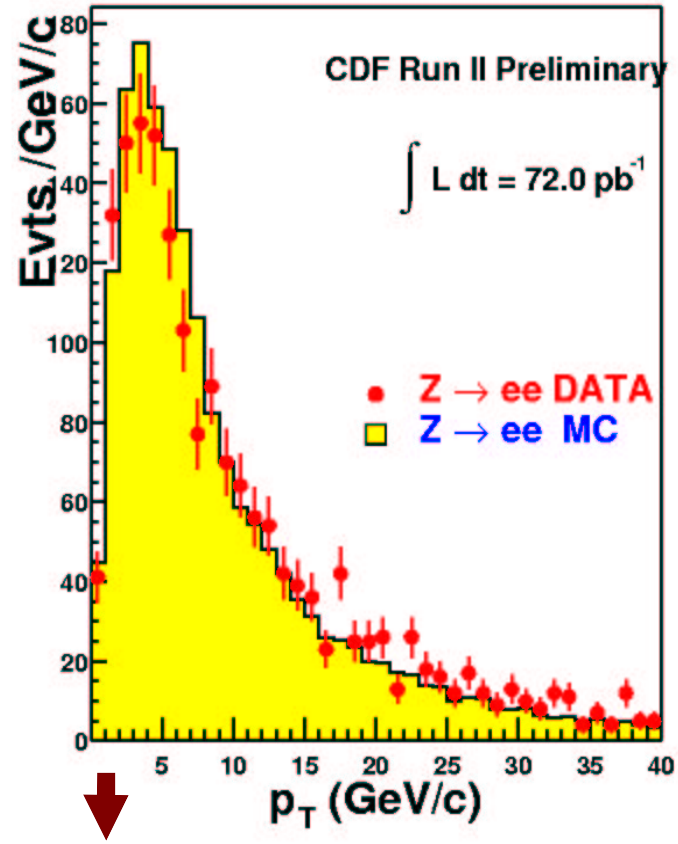
Extended measurements of σ(W) & σ(Z) are well advanced

Drell−Yan Measurements



$$A_{FB} = \frac{\sigma(\cos\vartheta > 0) - \sigma(\cos\vartheta < 0)}{\sigma(\cos\vartheta > 0) + \sigma(\cos\vartheta < 0)}$$

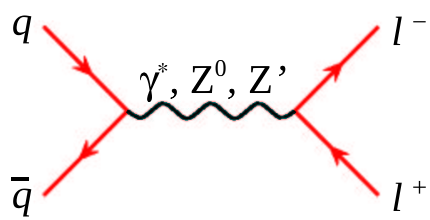


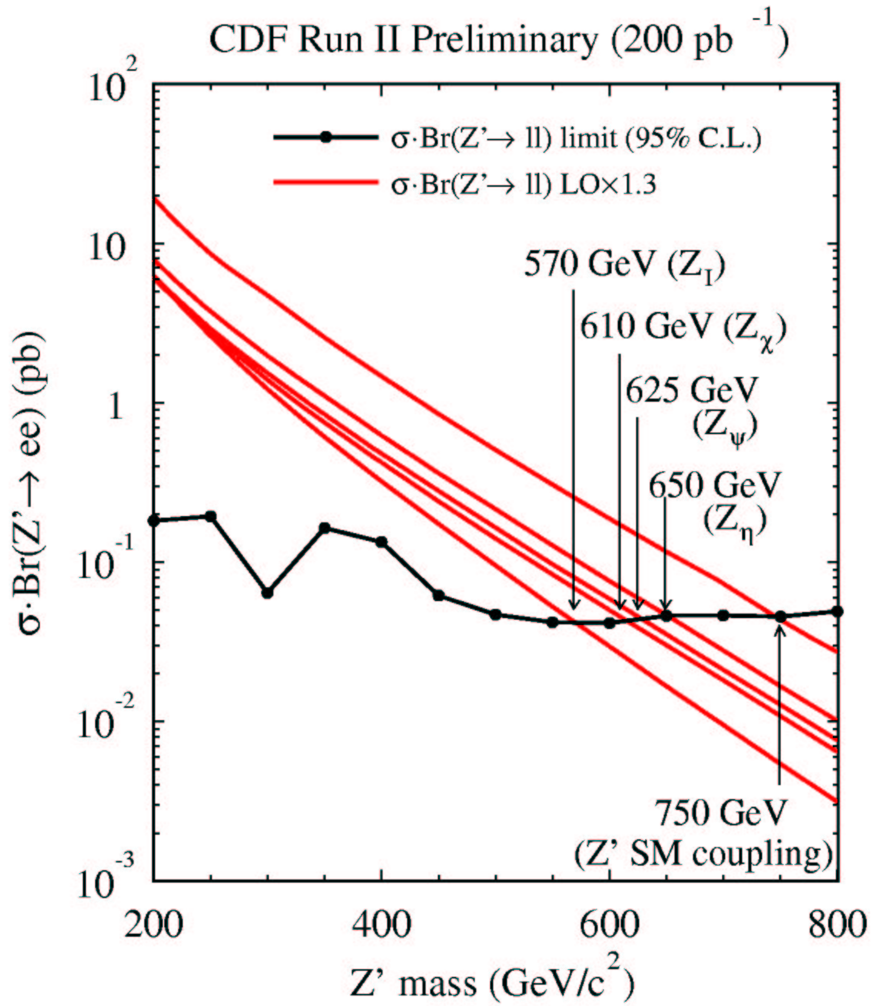


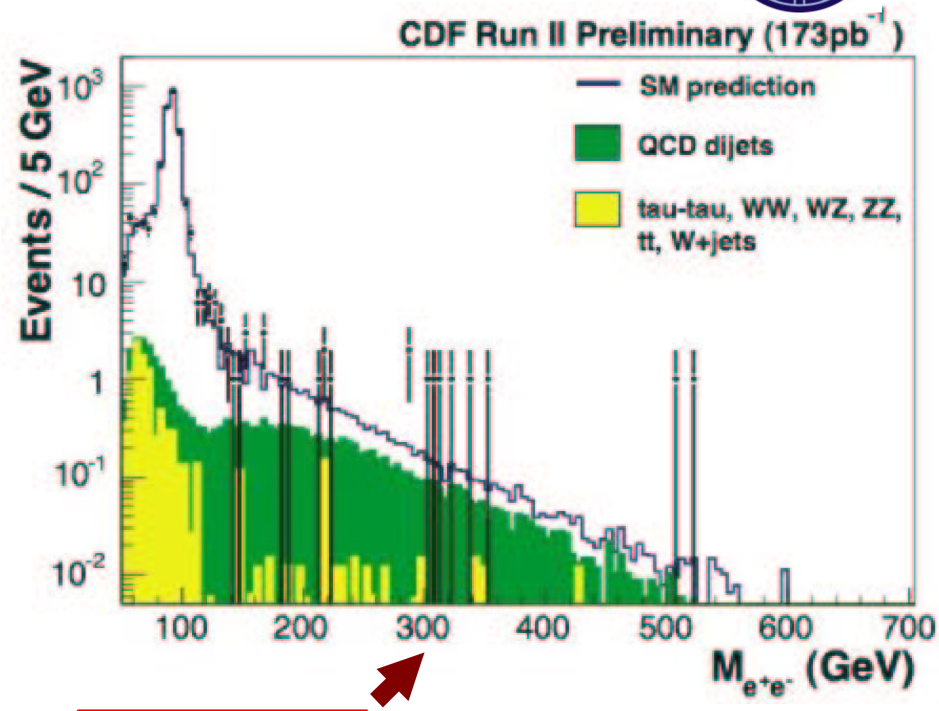
- Production properties : eventually feed into precision measurements (M_W)

- $|\eta^e|<3.0$: using full detector coverage
- extract quark, lepton couplings & $\sin^2\vartheta_W$
- sensitive to new physics

Searches in Dilepton Events

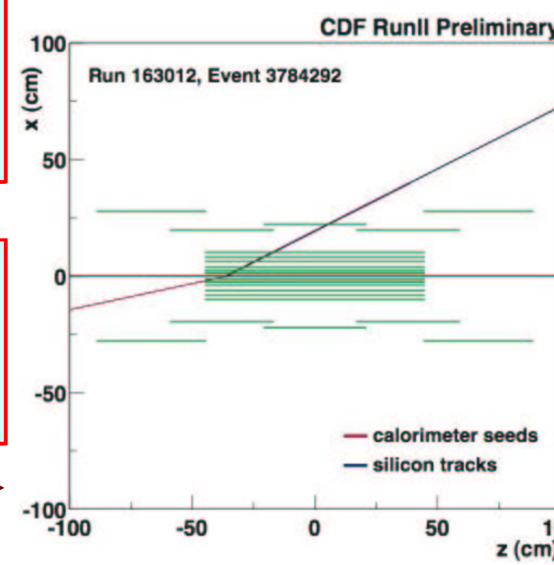




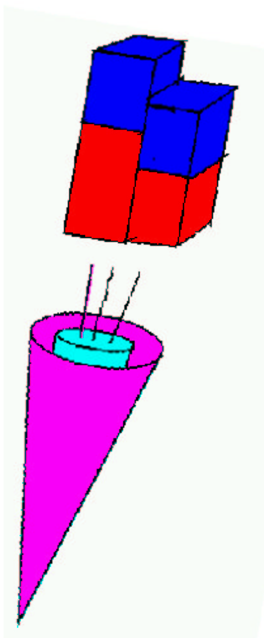


Forward electrons :
$1.2 < |\eta| < 2.5$

Calorimeter seeded Si tracking



Taus



Triggers :

(1) $\tau \to$hadrons + missing$-E_T$ (2) di$-\tau$ (3) lepton + track

Reconstruction :

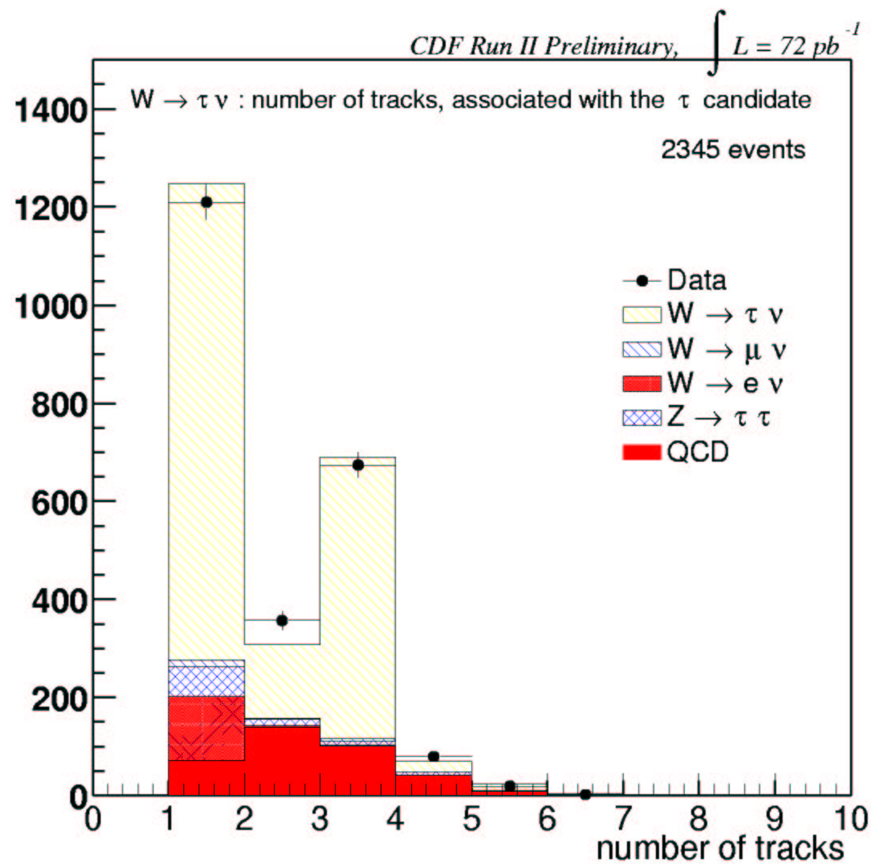
- Count tracks in τ–cone (10°) and require no tracks in isolation cone (30°)
- Reconstruct π^0 candidates in shower max detector
- Require combined mass to be < 1.8 GeV

- $\tau \to$hadrons
  - $|\eta|<1.0$
  - $E_T>25$ GeV
- missing$-E_T>25$ GeV

$$\sigma \times \mathbf{BR(W \to \tau\nu) = 2.62 \pm 0.07_{STAT} \pm 0.21_{SYST} \pm 0.16_{LUM}\ pb}$$

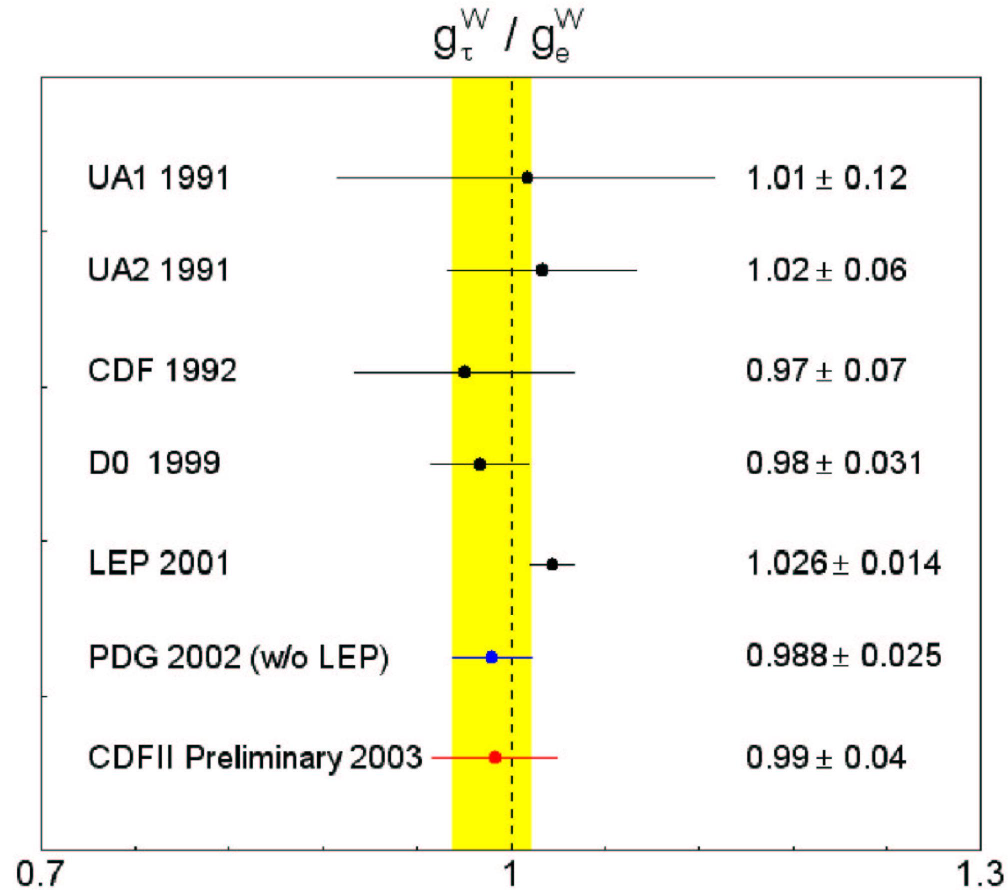
Backgrounds : ~ 25%

Systematics : τ ID, bkgnd, PDF's & e−scales

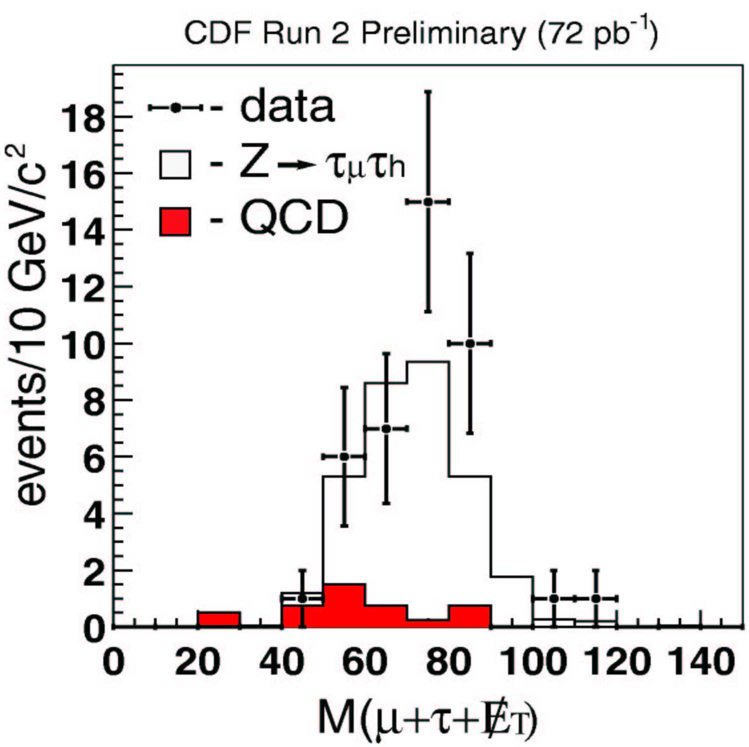


Taus

Comparison with electron channel (taking care to cancel as many systematics as possible) provides a test of lepton universality

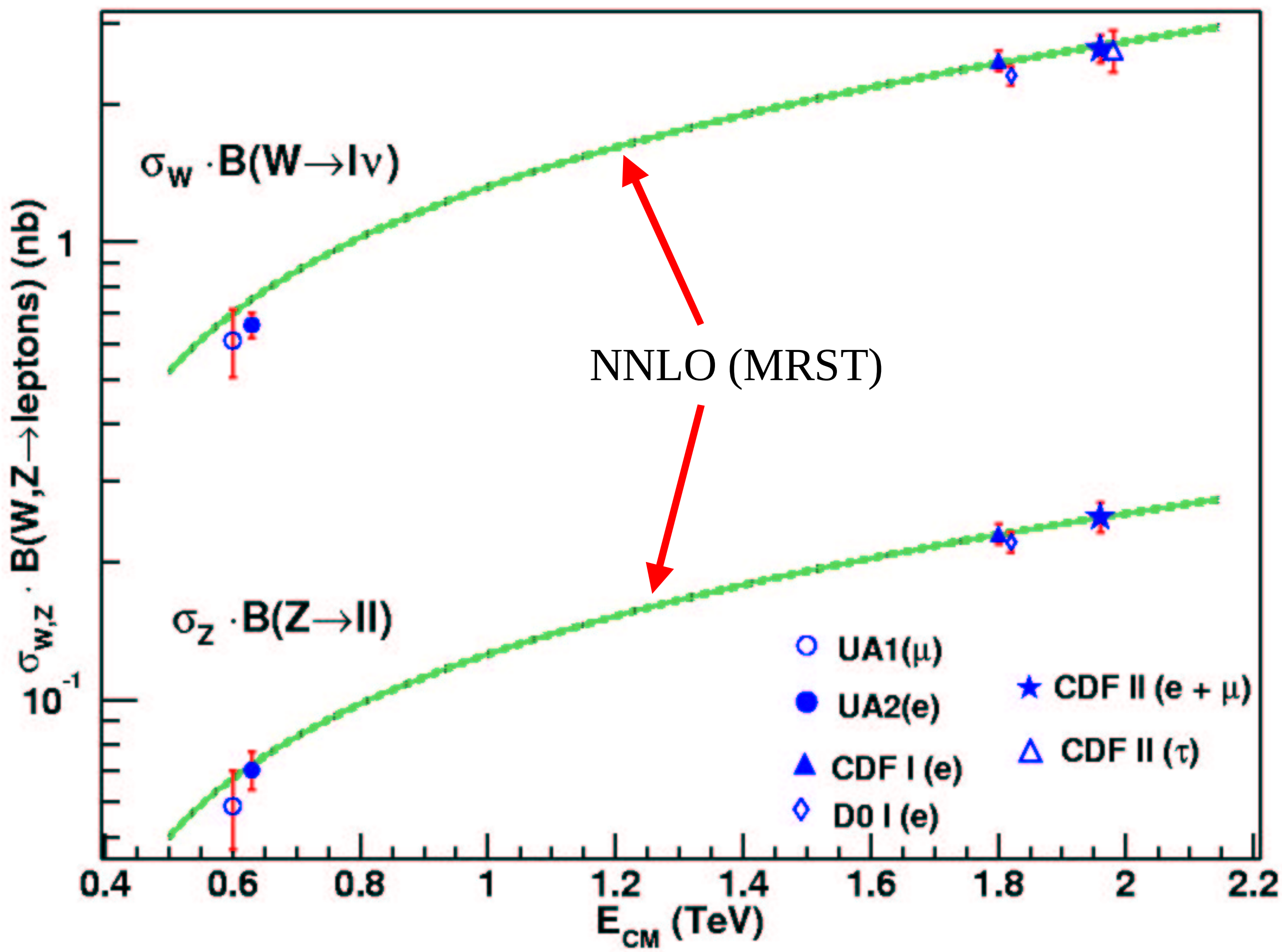


First look at $Z \rightarrow \tau\tau$:



- These measurements are providing a benchmark for analysis of events containing τ leptons.
- Very exciting to apply techniques to exotics searches, especially Higgs and SUSY.

Cross−Section Ratio



$$R = \frac{\sigma_W \times BR(W \to l\,\nu)}{\sigma_Z \times BR(Z \to l^+ l^-)} = 10.54 \pm 0.18(\text{stat.}) \pm 0.33(\text{syst.})$$

- e, μ combined
- correlated systematics fully taken into account

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

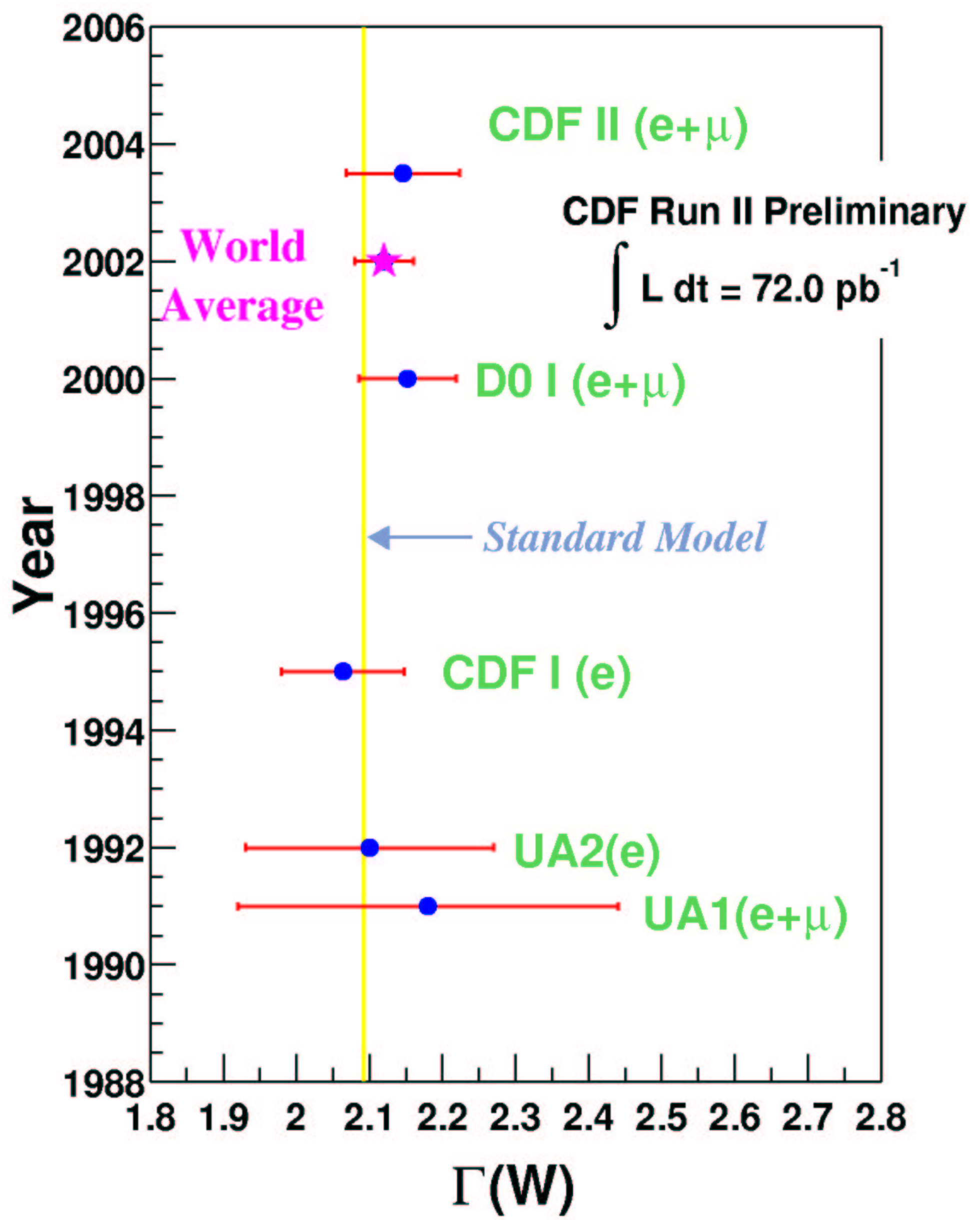
$$= \frac{\sigma_W}{\sigma_Z} \frac{\Gamma_Z}{\Gamma(Z \to l^+ l^-)} \frac{\Gamma(W \to l\nu)}{\Gamma_W}$$

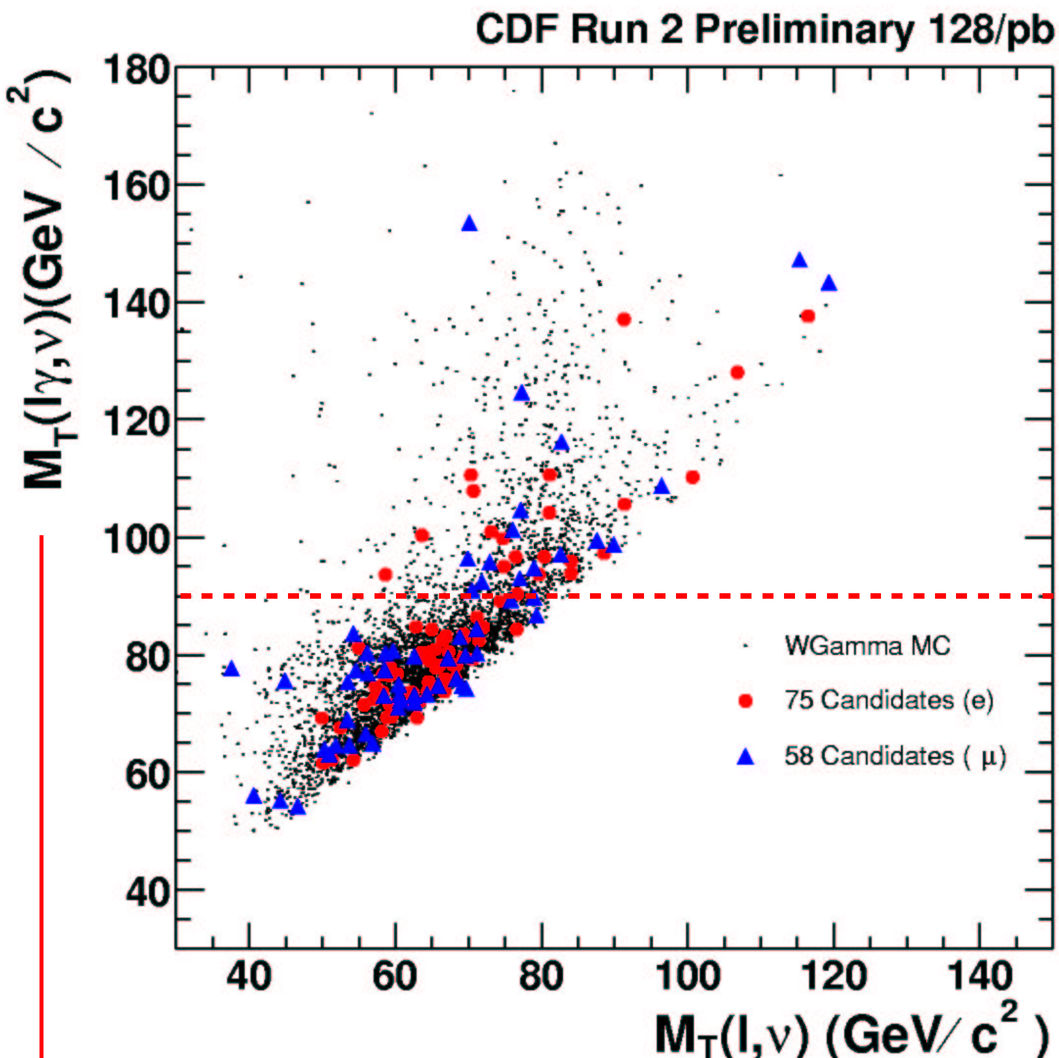
SM : 3.361 ± 0.024

SM : 226.4 ± 0.3 MeV

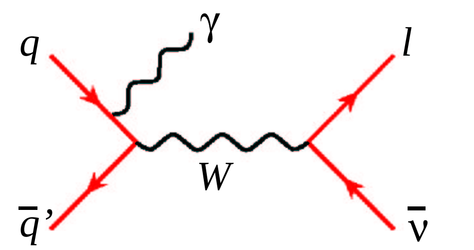
LEP

$$\Gamma_W(\text{indirect}) = 2.146 \pm 0.078 \text{ GeV}$$

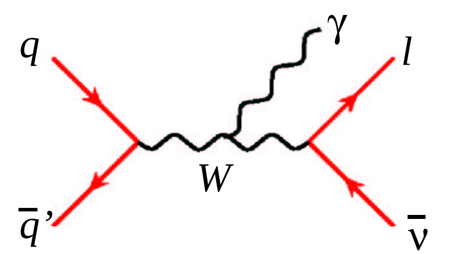




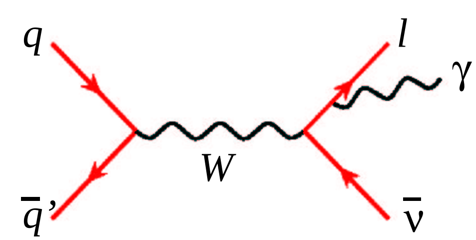
"cluster transverse mass"



ISR



WWγ



FSR

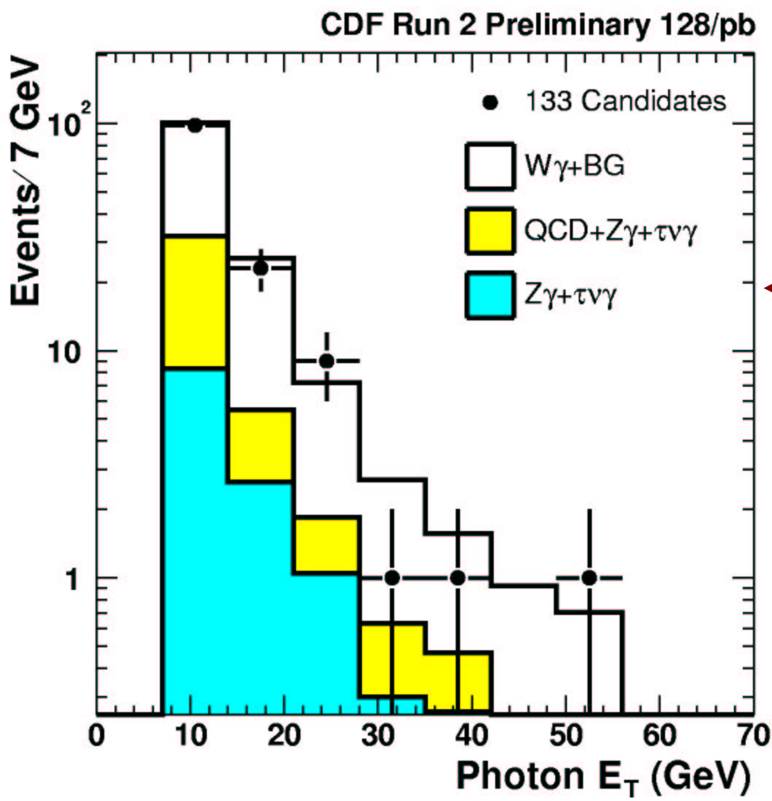
W+γ

- First select $W \to l\nu$ events :
  - Electrons : E_T>25 GeV; missing−E_T>25 GeV
  - Muons : E_T>20 GeV; missing−E_T>20 GeV
- Then look for additional photons :
  - E_T(photon) > 7 GeV
  - $|\eta^\gamma| < 1.1$
  - $\Delta R(l,\gamma) > 0.7$

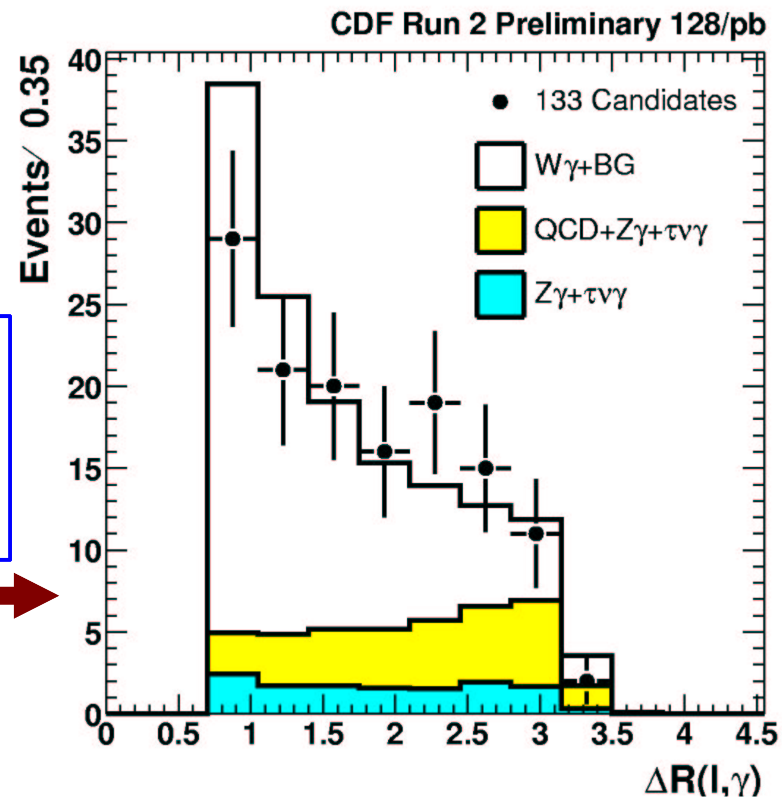
$$\sigma(W\gamma) \times BR(W \to l\nu) = 17.2 \pm 2.2_{STAT} \pm 2.0_{SYST} \pm 1.1_{LUM}\ \text{pb}$$

- For E_T(photon) > 7 GeV and $\Delta R(l,\gamma) > 0.7$:

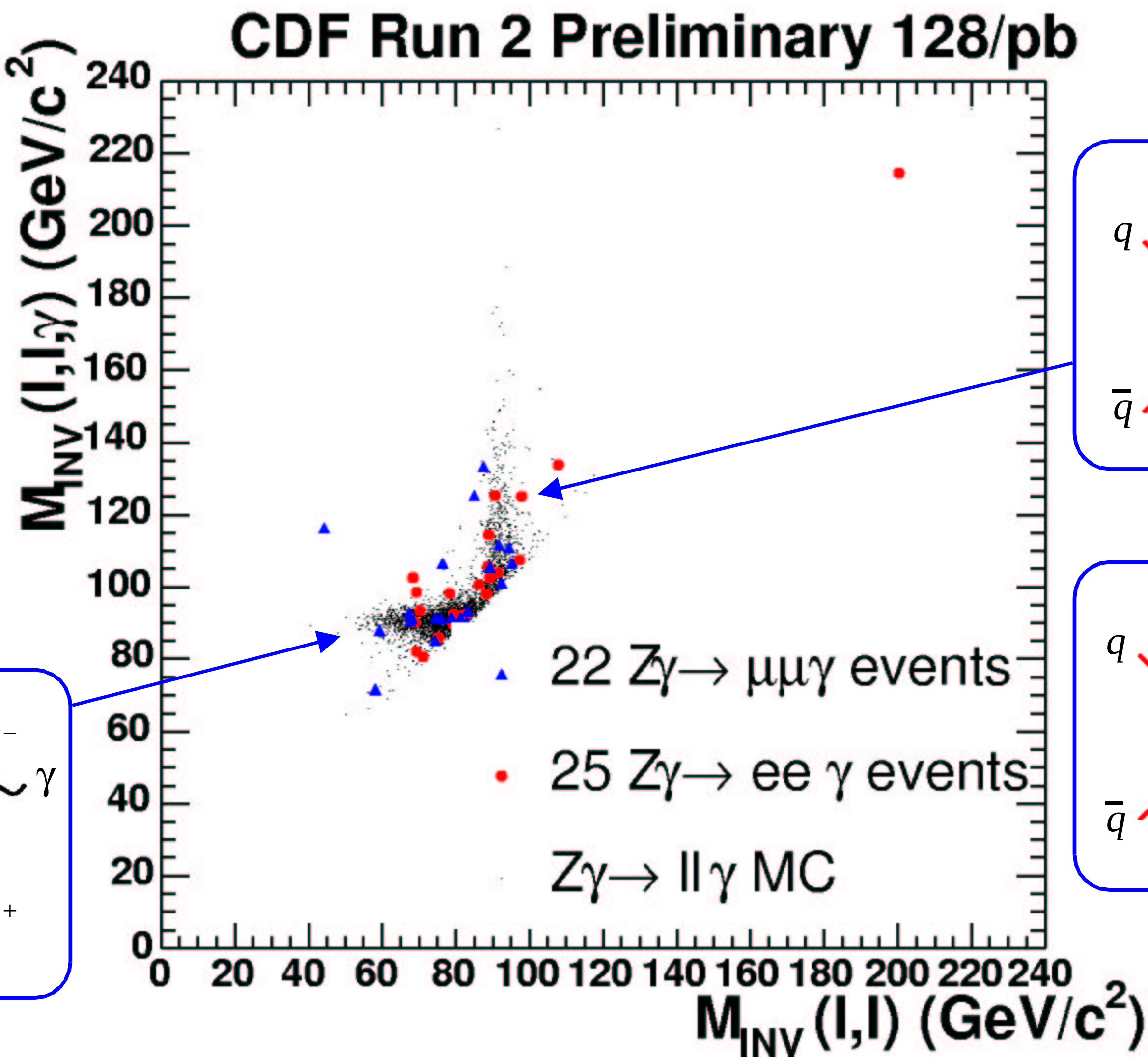
  $\sigma(W\gamma) \times BR(W \to l\nu)$ (Theory) = 18.6 ± 1.3 pb

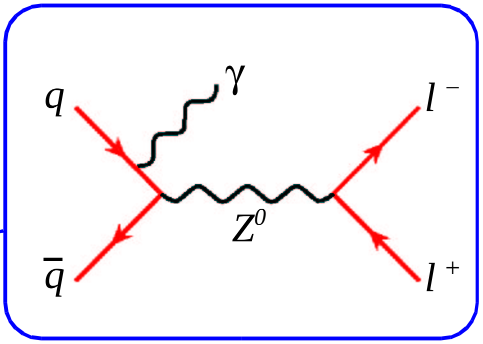


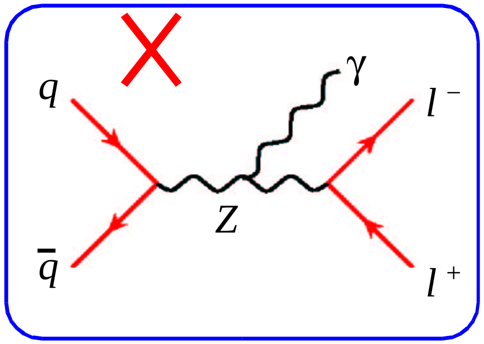
data well described over all photon E_T's and separations

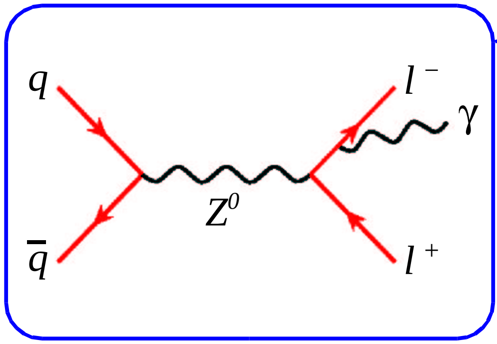


Z+γ


CDF Run 2 Preliminary 128/pb
$M_{INV}(l,l,\gamma)$ (GeV/c^2)
$M_{INV}(l,l)$ (GeV/c^2)
22 Zγ→ μμγ events
25 Zγ→ ee γ events
Zγ→ ll γ MC


q
γ
l⁻
Z⁰
q̄
l⁺


q
γ
l⁻
Z
q̄
l⁺

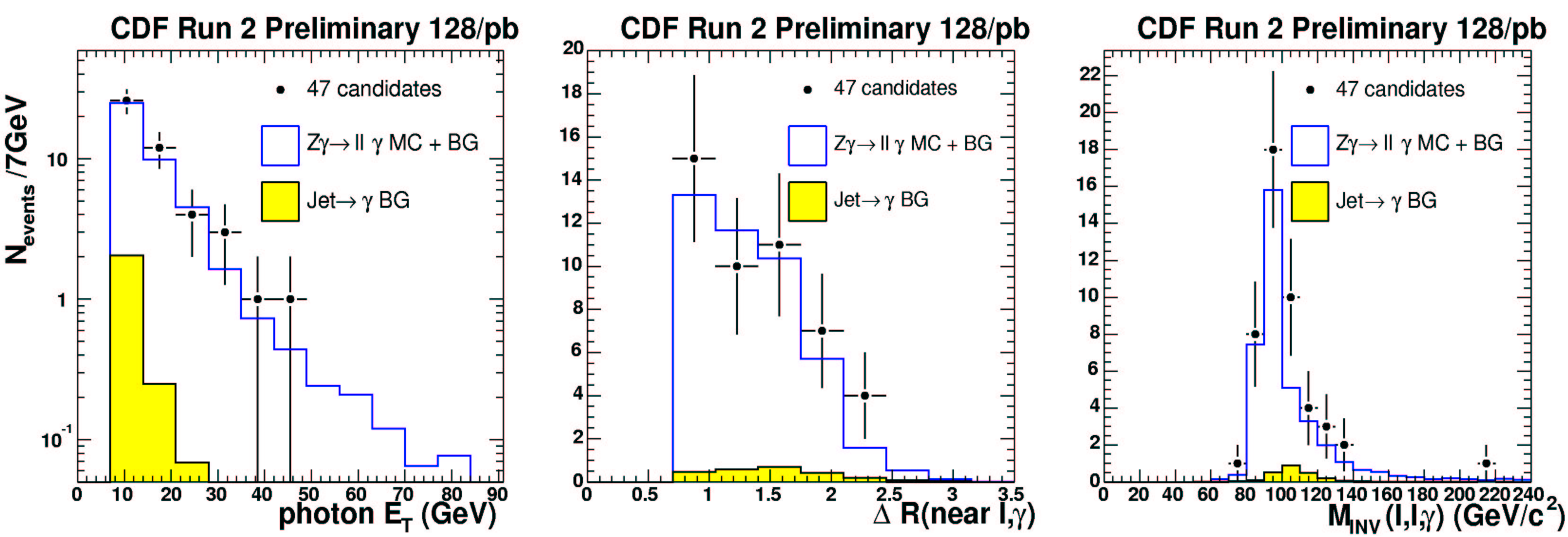

q
l⁻
γ
Z⁰
q̄
l⁺

Z+γ

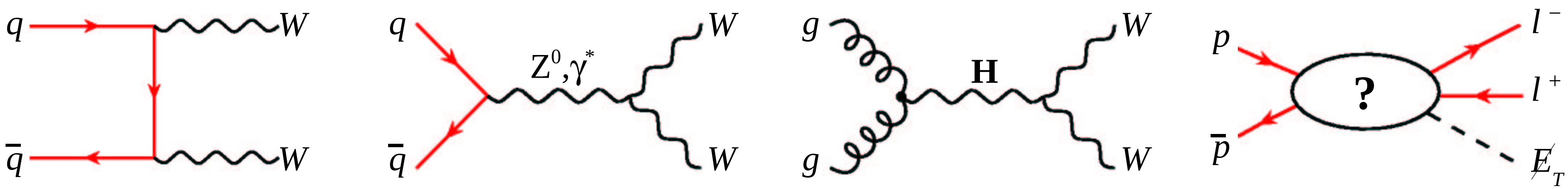
$$\sigma(Z\gamma) \times BR(Z \rightarrow l^+l^-) = 5.8 \pm 0.8_{STAT} \pm 0.3_{SYST} \pm 0.4_{LUM}\ \text{pb}$$

- For E_T(photon) > 7 GeV and $\Delta R(l,\gamma) > 0.7$:
  $\sigma(Z\gamma) \times BR(Z \rightarrow l^+l^-)$ (Theory) = 5.3 ± 0.4 pb

- Now V+γ cross−sections well established, we are :
  - extending acceptance
  - optimising sensitivity to anomalous couplings and new physics
  - testing the Standard Model in ways unique to the Tevatron (e.g. observing the radiation amplitude zero in W+γ production).



WW

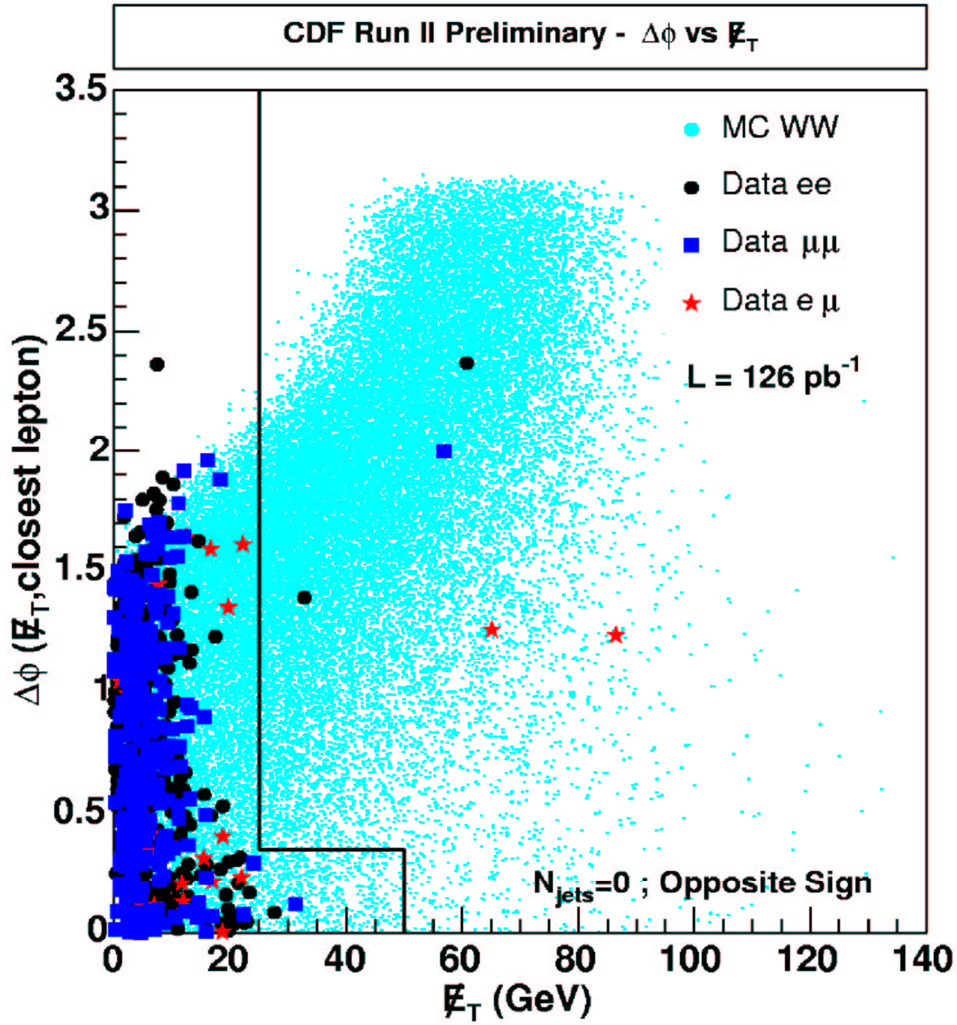


- Two isolated E_T>20 GeV leptons (e or μ) .
- Missing−E_T > 25 GeV.
- Remove events consistent with Z decay.
- Remove top background by requiring no additional jets.
- Remove fakes by requiring opposite sign.

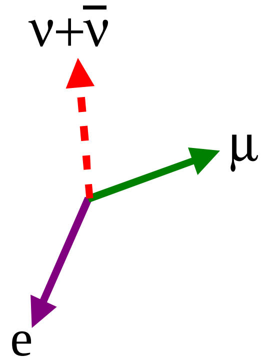
N (background)	2.34 ± 0.38
N (WW signal)	6.89 ± 1.53
N (data)	5

$$\sigma\left(WW\right) = 5.1^{+5.4}_{-3.6}\ (\text{stat}) \pm 1.3\ (\text{syst}) \pm 0.3\ (\text{lum})\ \text{pb}$$

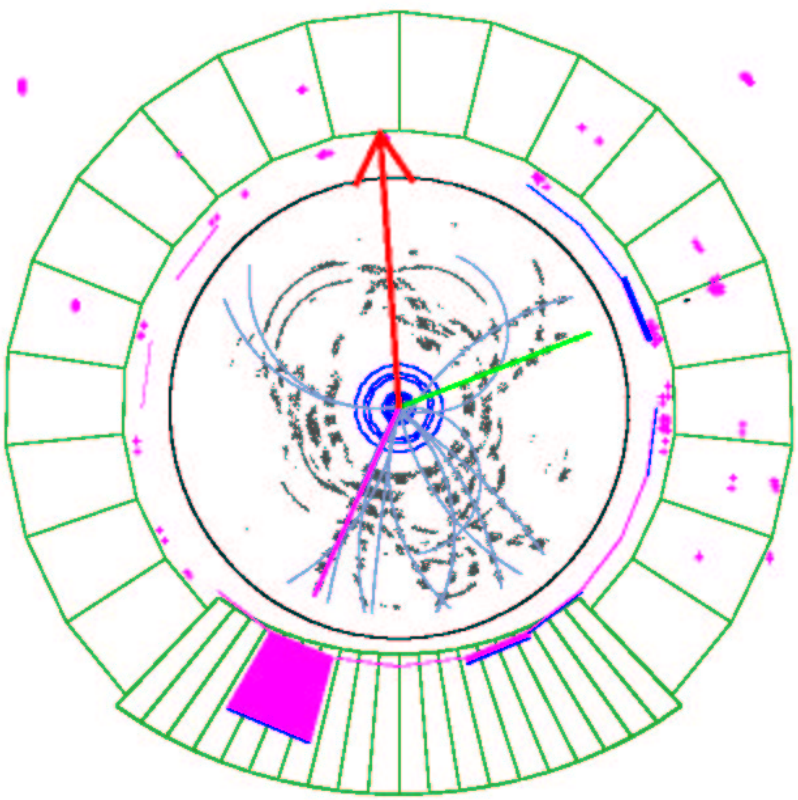
$$\sigma\left(WW\right)(\text{theory}) = 13.25 \pm 0.25\ \text{pb}$$



WW



- $e\mu$ channel has little Standard Model background
- Signal/Background $\approx$ 4

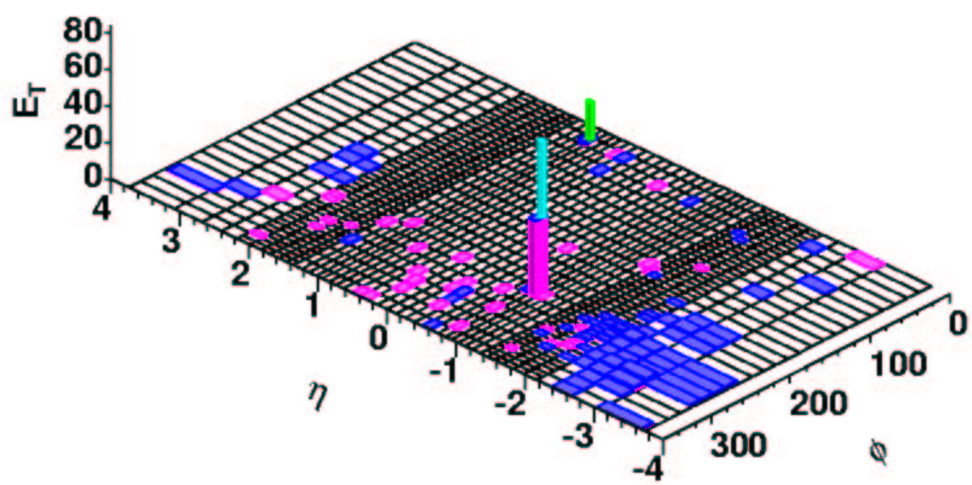


Run 155364 Event 3494901 : $WW \to e^{+}\nu_{e}\mu^{-}\bar{\nu}_{\mu}$ Candidate

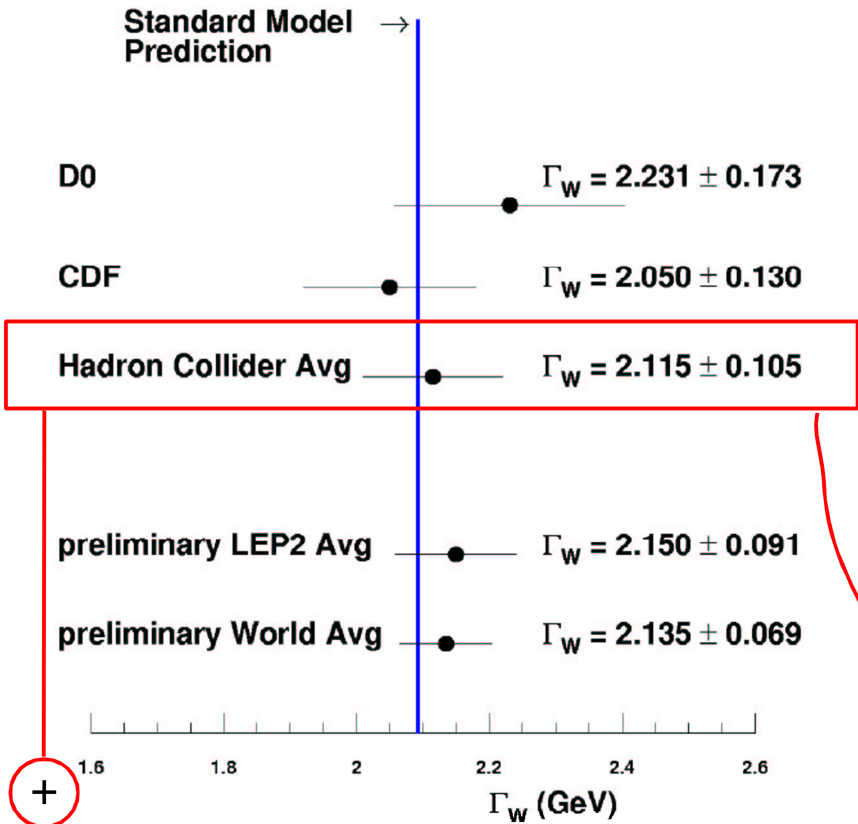
$p_T(e) = 42.0$ GeV/c; $p_T(\mu) = 20.0$ GeV/c; $M_{e\mu} = 81.5$ GeV

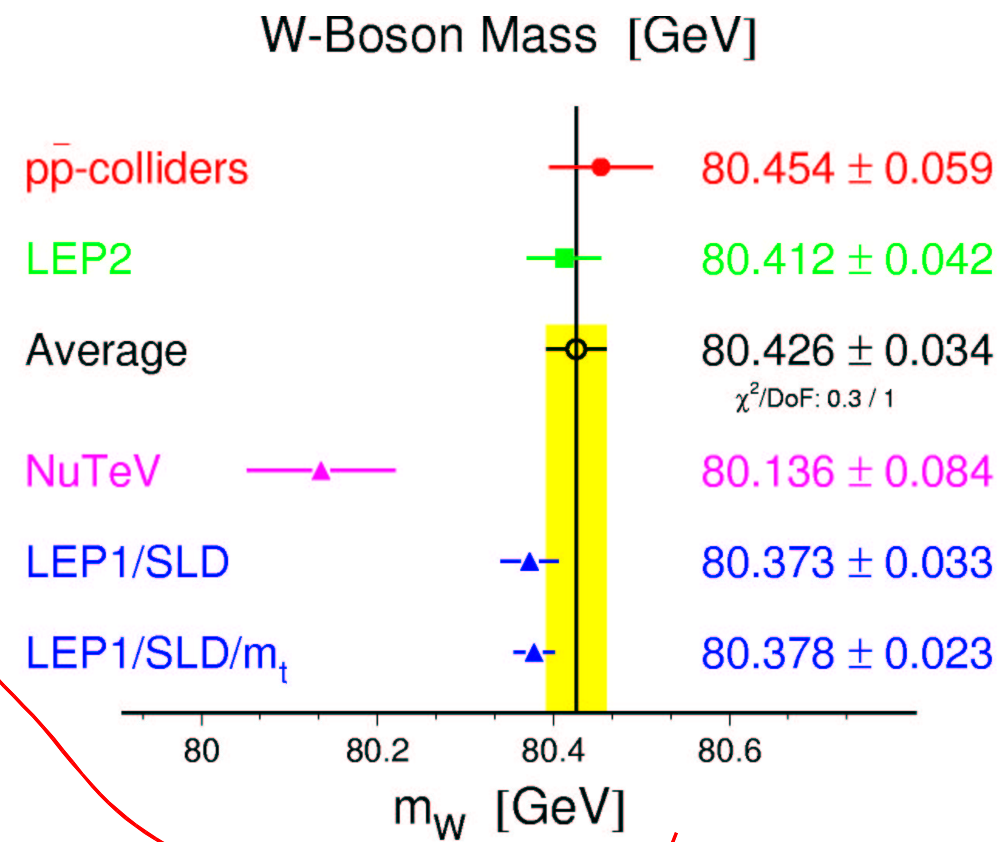
$\not{E}_T = 64.8$ GeV; $\Phi(\not{E}_T) = 1.6$

$\Delta\Phi(\not{E}_T$, lepton$) = 1.3$; $\Delta\Phi(e,\mu) = 2.4$; Opening-Angle(e,μ)=2.6



Run I : Combined W Mass & Width





D0 + CDF "Indirect" Average :

$$\Gamma_W^{\text{Tevatron}} = 2.141 \pm 0.057 \text{ GeV}$$

D0 + CDF Combined Average :

$$\Gamma_W^{\text{Tevatron}} = 2.135 \pm 0.050 \text{ GeV}$$

Combined Fit Very Consistent :

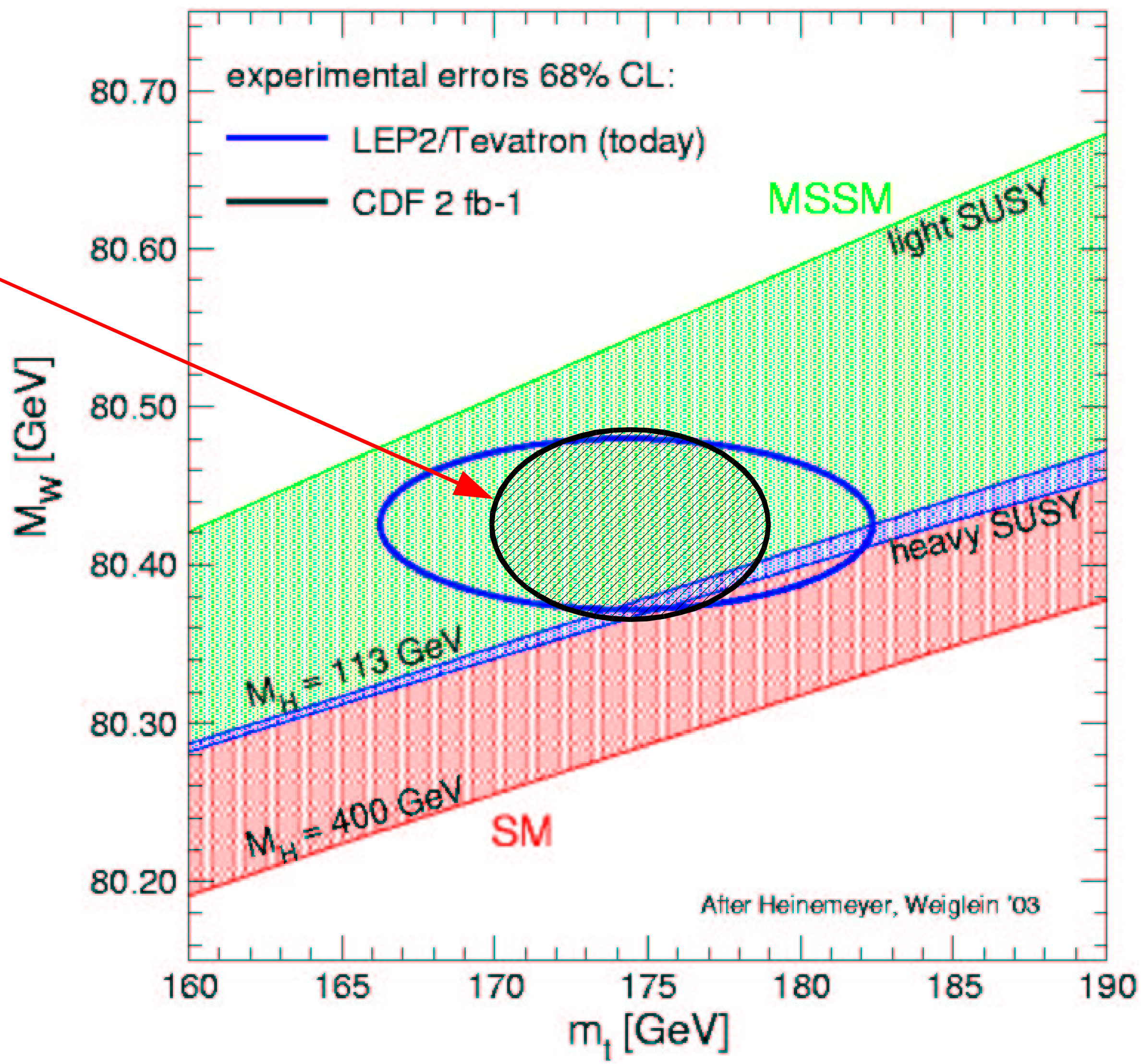
$$m_W^{\text{Tevatron}} = 80.452 \pm 0.059 \text{ GeV}$$

$$\Gamma_W^{\text{Tevatron}} = 2.102 \pm 0.106 \text{ GeV}$$

Precision Measurements in Run II

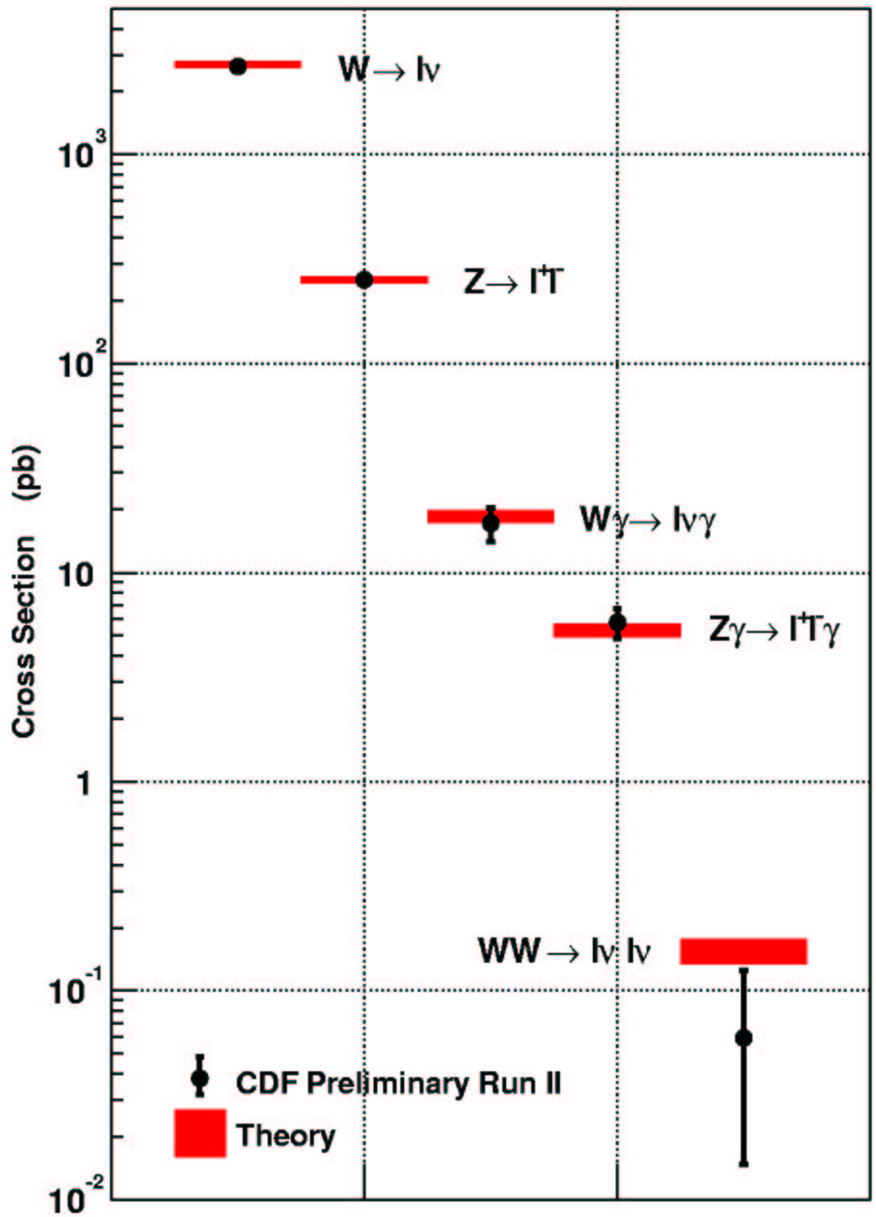
CDF *alone* with 2 fb^{-1}

- $\Delta M_W \approx 40$ MeV
- $\Delta M_{top} \approx 3$ GeV
- Similar to all current direct measurement data combined.



- With a Higgs discovery at Tevatron or LHC, these measurements will provide a powerful consistency test of the Standard Model.
- Could provide first evidence of what lies beyond the SM.
- Will be improved at LHC, but not quickly or easily.

Conclusions



- Tevatron and CDF are running very well.
- We have measured the cross sections for many electroweak processes in Run II, some with high precision.
- These measurements have set the standard for various techniques that will be applied across CDF, especially in the search for physics beyond the Standard Model :
  - lepton ID (especially taus)
  - understanding of detector
  - understanding of backgrounds
- Many electroweak measurements (esp. di−boson production) will soon become precise measurements, and are being optimised for :
  - anomalous coupling extraction
  - sensitivity to new physics contributions
- Work is well under way on Run II measurements of M_W, Γ_W, asymmetries, couplings, ...