W Production and Mass at the Tevatron

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on behalf of the CDF and DØ Collaborations

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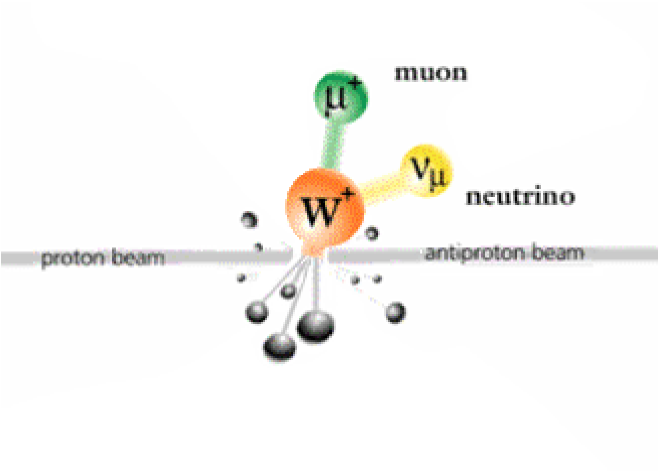
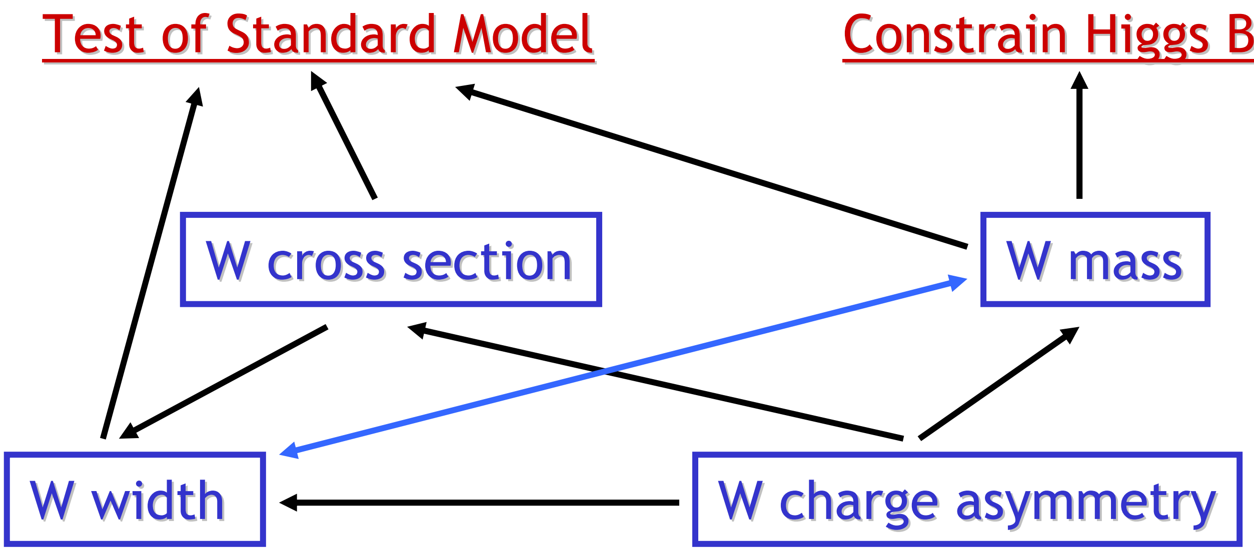
Outline

1. W Physics at the Tevatron
2. W Production Cross-Section at the Tevatron
3. W Width
4. W Charge Asymmetry
5. W Mass
6. Summary/Outlook



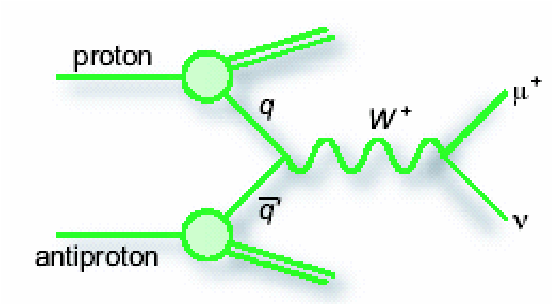
W Boson Physics at the Tevatron

- Z properties known to very high precision from LEP
- <u>Goal:</u>
- Match precision measurements for charged EWK carriers
- Tevatron is for the next few years the only accelerator that can produce Ws directly

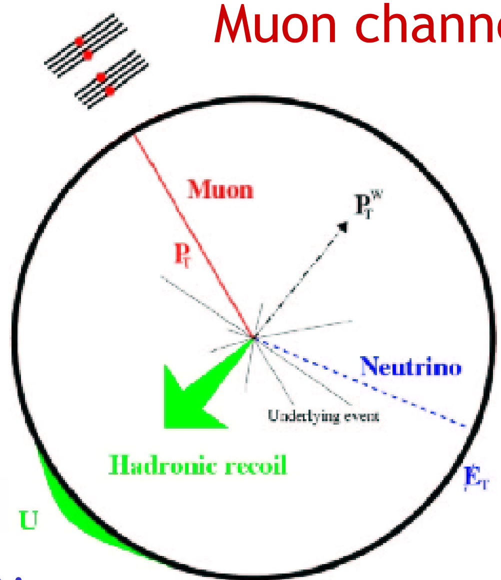


W Boson Production at the Tevatron

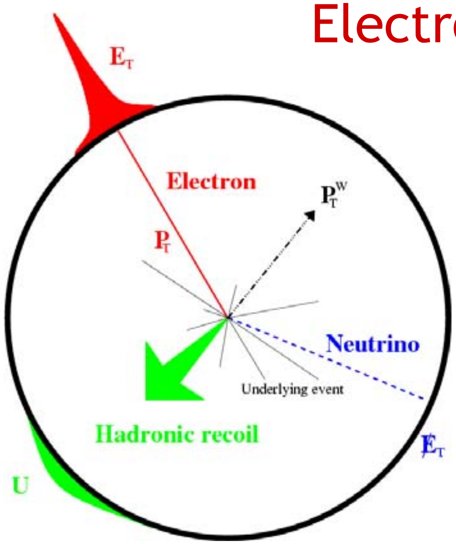
Use clean W production signatures (leptonic decays):

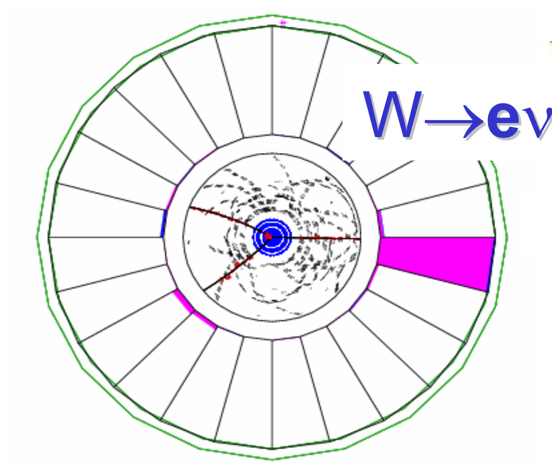


Muon channel



Electron channel

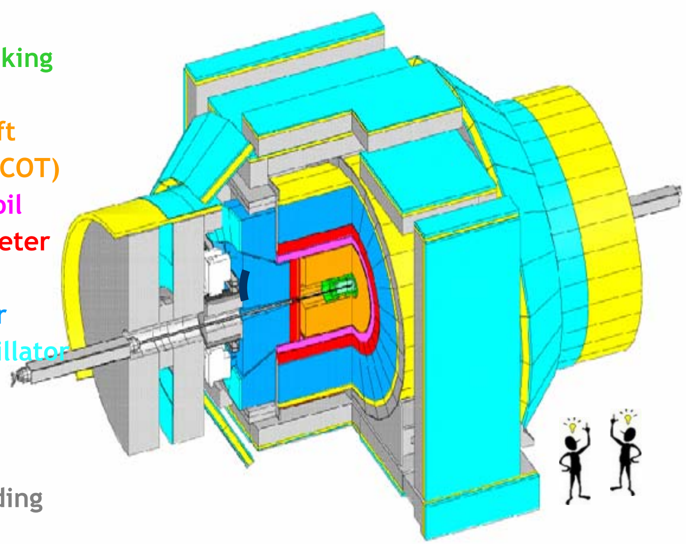


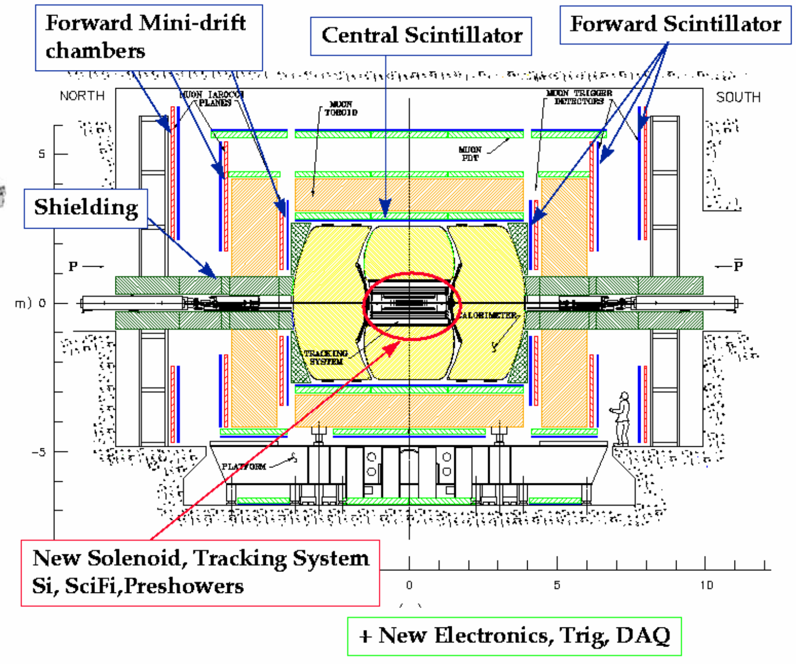


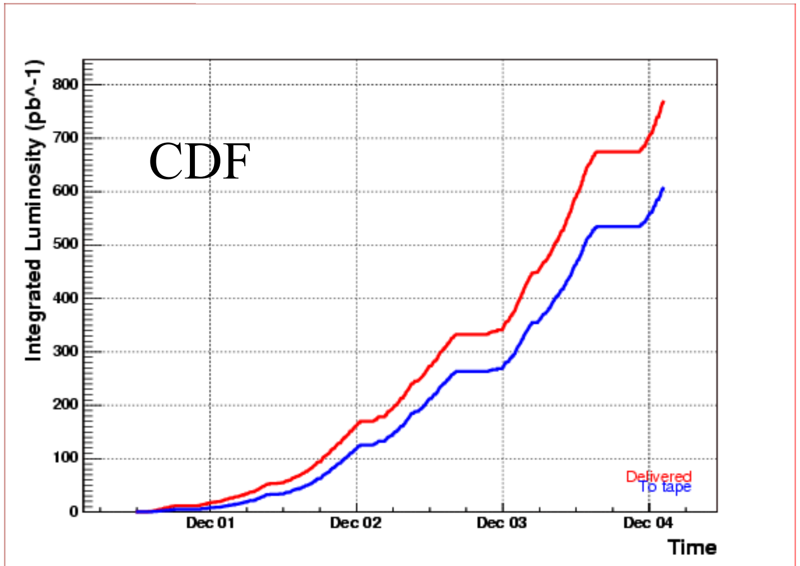
Isolated, high pt lepton with large missing transverse momentum

CDF and DØ at the Tevatron

- Silicon tracking detectors
- Central drift chambers (COT)
- Solenoid Coil
- EM calorimeter
- Hadronic calorimeter
- Muon scintillator counters
- Muon drift chambers
- Steel shielding

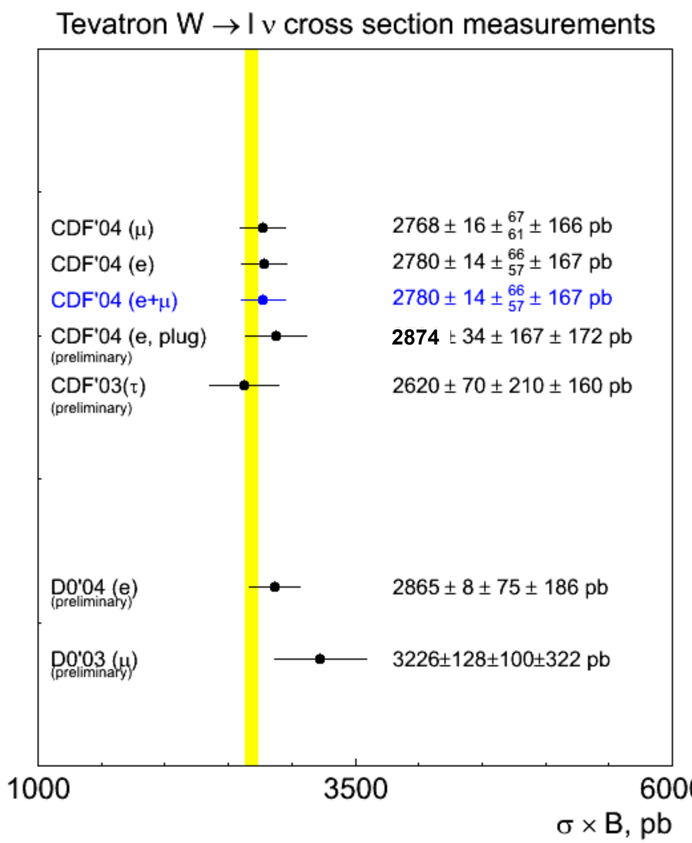


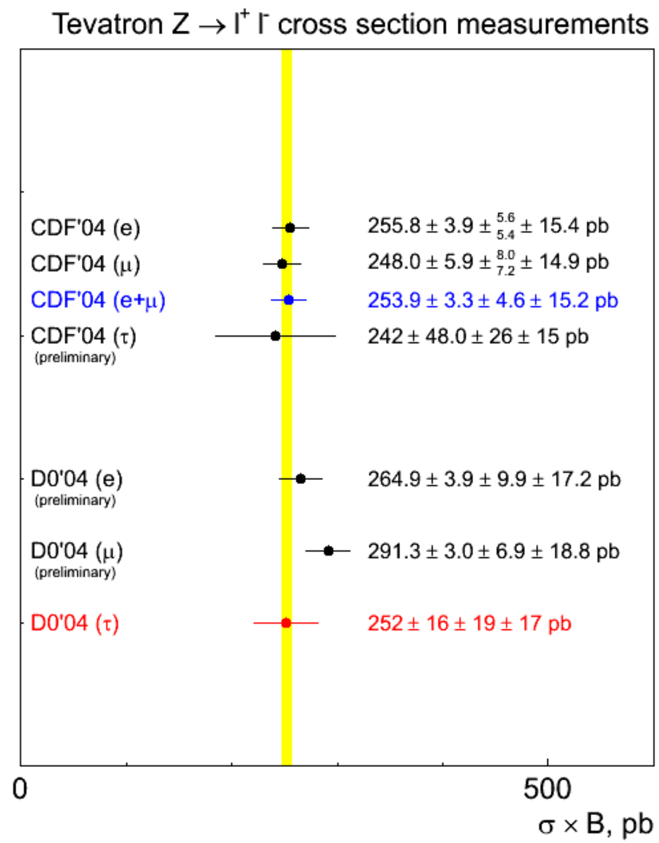




- *CDF and DØ are running well*
- Tevatron delivered ~800 pb^{-1}
- CDF and DØ ~600 pb^{-1} on tape
- Peak luminosities > $1*10^{32}/cm^2/s$
- high luminosity upgrades (trigger/DAQ) finalized and on schedule

Inclusive $p\bar{p} \rightarrow W/Z + X$ Cross-Section at the Tevatron





Overall good agreement with the NNLO calculations

Accuracy limited by the systematic effects

- Uncertainties (~6%) dominated by luminosity measurements (correlated)
- Other systematics dominated by PDF uncertainties (~2%)

Lepton Universality in W Decays

From the measurements of the $W \rightarrow e\nu$ and $W \rightarrow \mu\,\nu$ cross sections obtain cross section ratio U:

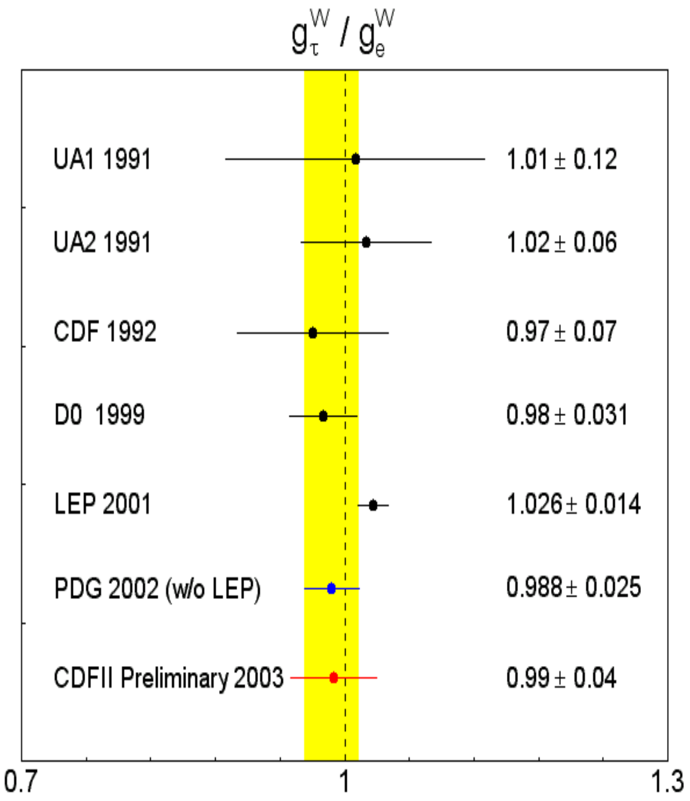
$$U = \frac{\sigma.Br(W\to\mu\nu)}{\sigma.Br(W\to e\nu)} = \frac{\Gamma(W\to\mu\nu)}{\Gamma(W\to e\nu)} = \frac{g_\mu^2}{g_e^2}$$

Many systematic uncertainties cancel out

$$\frac{g_\mu}{g_e} = 0.998 \pm 0.012$$

In the same way from $W \rightarrow e\nu$ and $W \rightarrow \tau\,\nu$ cross sections:

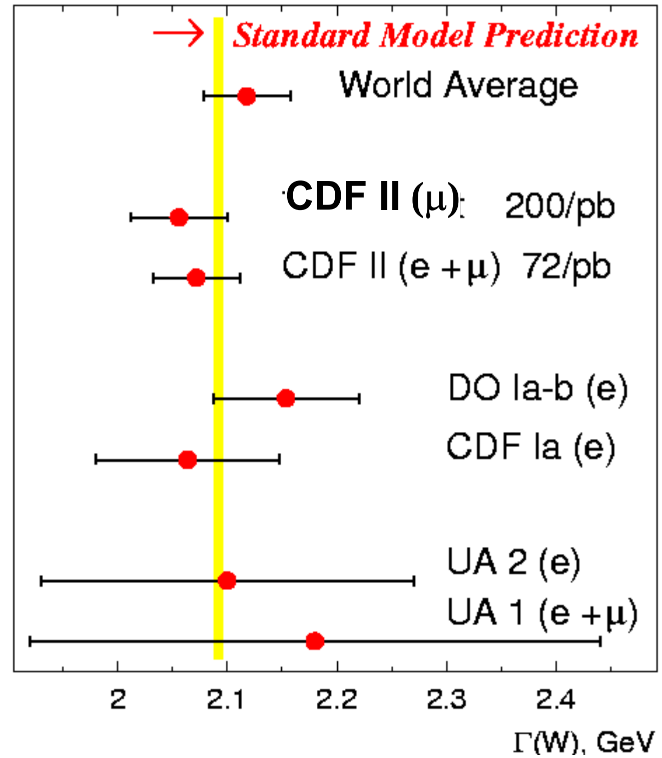
$$\frac{g_\tau}{g_e} = 0.99 \pm 0.02_{stat} \pm 0.04_{syst}$$



Indirect W Width

R: cross section ratio measurement:

$$R = \frac{\sigma.Br(W\text{->}l\nu_l)}{\sigma.Br(Z\text{->}ll)}$$



Many systematic uncertainties cancel out (e.g. luminosity)

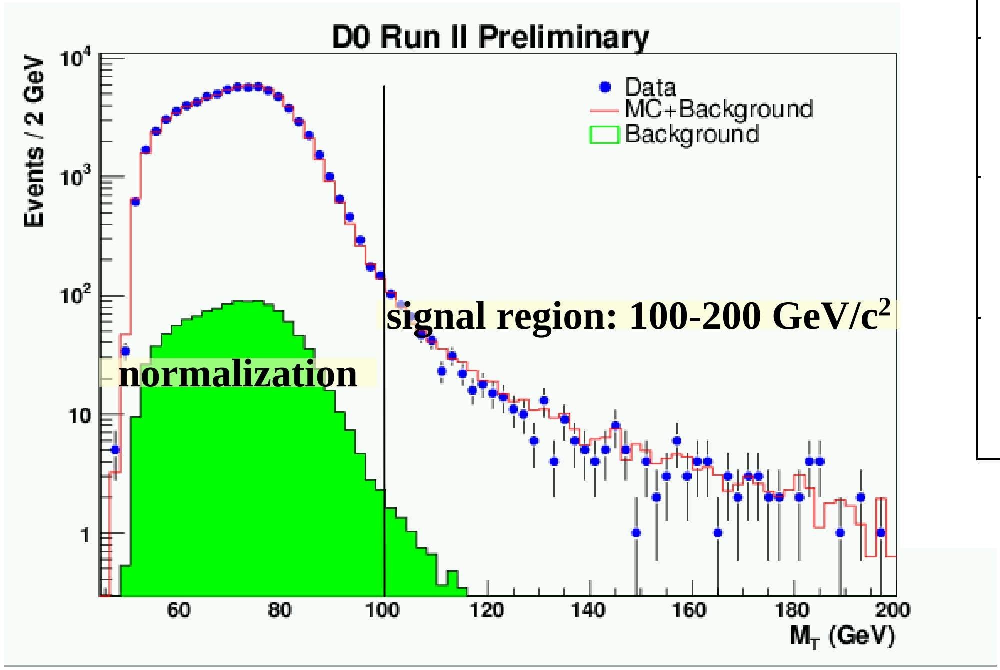
$$R = \frac{\sigma(pp\text{->}W)}{\sigma(pp\text{->}Z)} \frac{\Gamma(Z)}{\Gamma(Z\text{->}ll)} \frac{\Gamma(W\text{->}l\nu_l)}{\Gamma(W)}$$

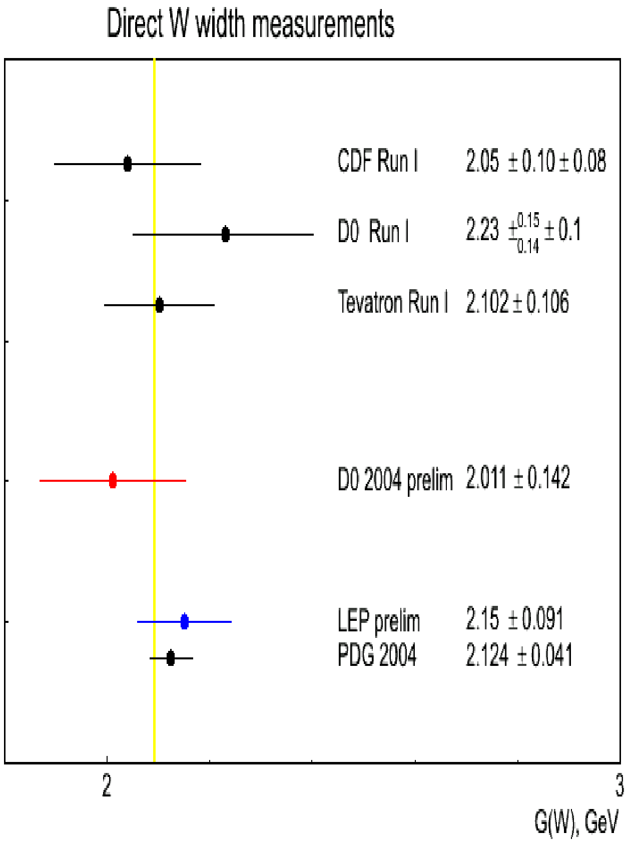
Allows for an internal consistency check of the Standard Model with direct Γ(W) measurement

Channel	Γ(W) (MeV)	∫Ldt(pb^{-1})
e + μ	2079±41	72
μ	2056±44	194
World Avg	2124±41	

Direct W Width

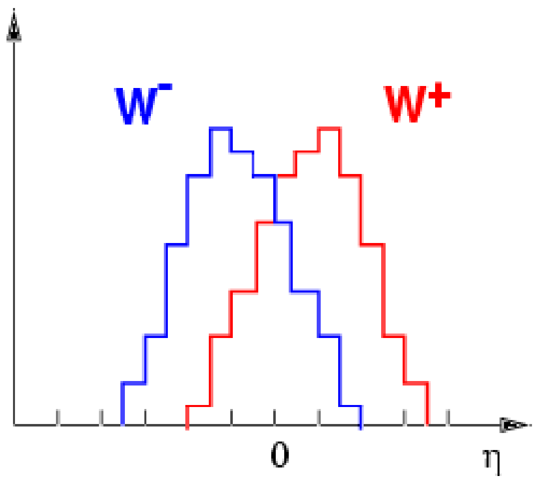
- DØ summer 2004, 177pb^{-1}
- Measurement in W->eν channel
- Normalization: $50<M_T<100$ GeV/c^2
- 625 events $100<M_T<200$ GeV/c^2





W Charge Asymmetry

Use Ws to probe the proton structure

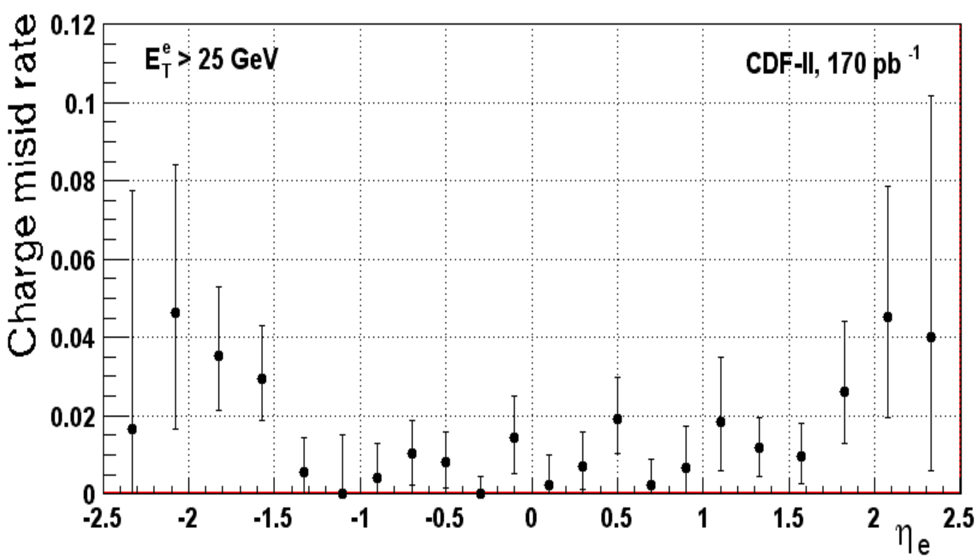


production asymmetry in ppbar->WX

is sensitive to **u/d**

$$A(y_W) = \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy}$$

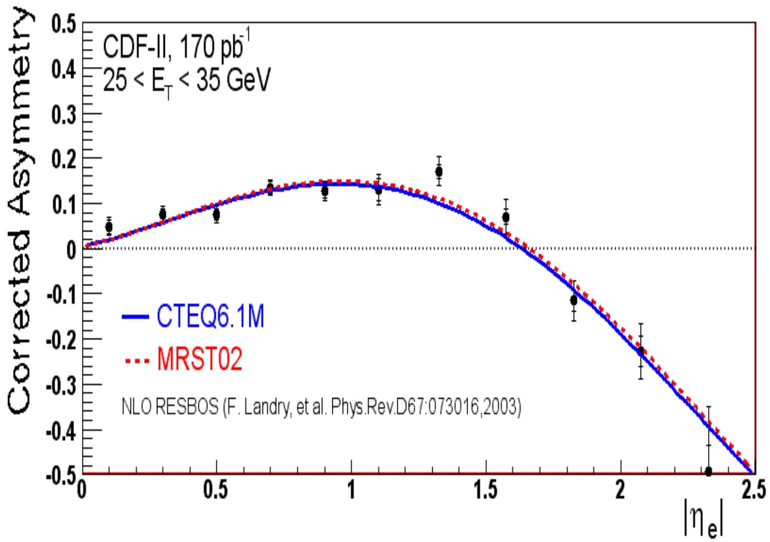
- identification of the lepton charge is the key
- misID probability ~4% at |η| ~ 2

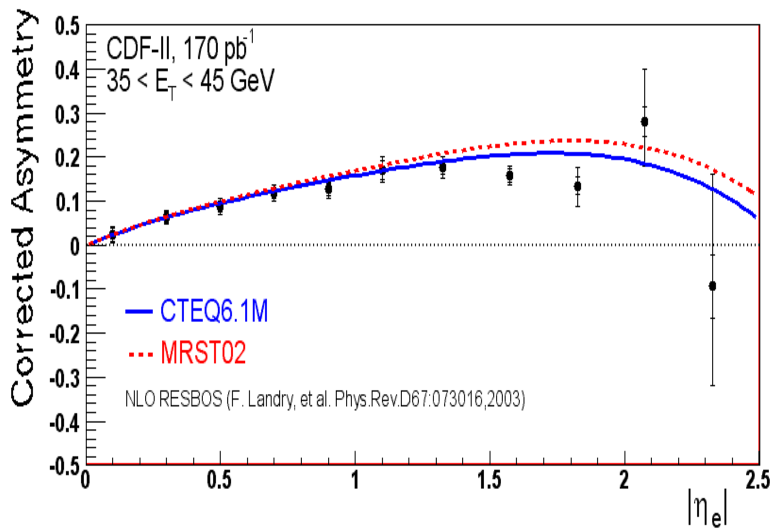


W Charge Asymmetry

- Observable quantity is electron rapidity
- Convolution of W production asymmetry and V-A decay

$$A(\eta_l) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta}$$





Bin data in P_T (2 bins) to increase sensitivity

Submitted: hep-ex/0501023

W Mass Measurement

Precision of direct measurements:

1983:	1989:	1990:	1995:	2000:	2004:
UA1	UA1	UA2	CDF	DØ	LEP
5 GeV	2.9 GeV	900 MeV	180 MeV	91 MeV	42 MeV
					Tevatron 59 MeV

CDF: 79 MeV
DØ: 84 MeV

W mass now known to better than 5 parts in 10,000

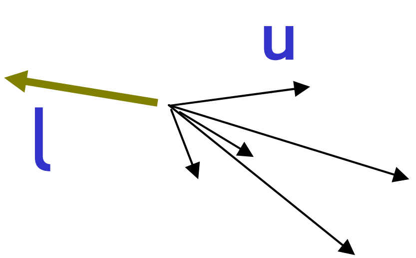
Looking forward:

Tevatron Run 2 has now 6 times Run 1 CDF, DØ data sets

CDF has analyzed first 200 pb^{-1} of data and determined uncertainties

→ Momentum scale measured to better than 3 parts in 10,000

→ Hadronic recoil understood to better than 50 MeV



First Run 2 W mass measurement coming soon

Outline W Mass Measurement

W mass is extracted from transverse mass distribution

$$m_T = \sqrt{[E_T(l) + E_T(\nu)]^2 - [\vec{p}_T(l) + \vec{p}_T(\nu)]^2}$$

Two important analysis components

Detector Calibration

- Calorimeter energy scale
- Tracking momentum scale

Fast Simulation

- NLO event generator
- Model detector effects

Data

W Mass templates

+ Backgrounds

Binned likelihood fit

W Mass

Run 2 W Mass Status

~200 pb^{-1} of data analyzed

- First-pass of analysis complete, uncertainties determined
- Cross-checks ongoing
- W mass fit results blinded with hidden offset

Production and Decay Model Uncertainties

CTEQ6

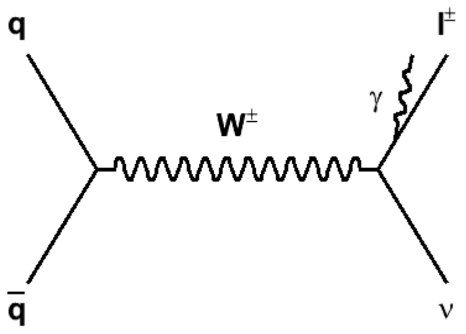
WGRAD

RESBOS

Source	μ [MeV]	e
Parton Distribution Functions	15	15
QED Radiative Corrections	20	15
W p_T model	13	13
Γ_W	12	12

Dominated by 2-photon FSR

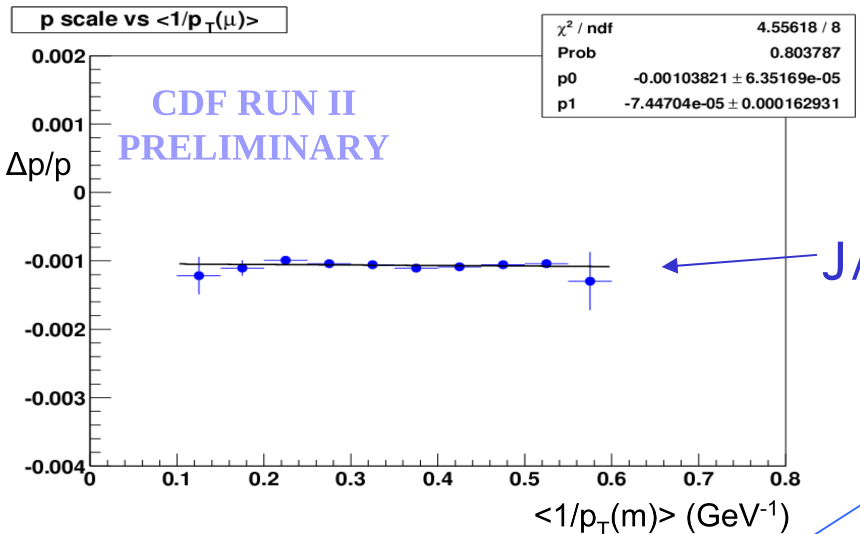
CDF RUN II PRELIMINARY



Constrained by Run 1 $p_T(Z)$ measurement

Run 2 Momentum Calibration

Set momentum scale using J/ψ and Υ(1S) decays to muons

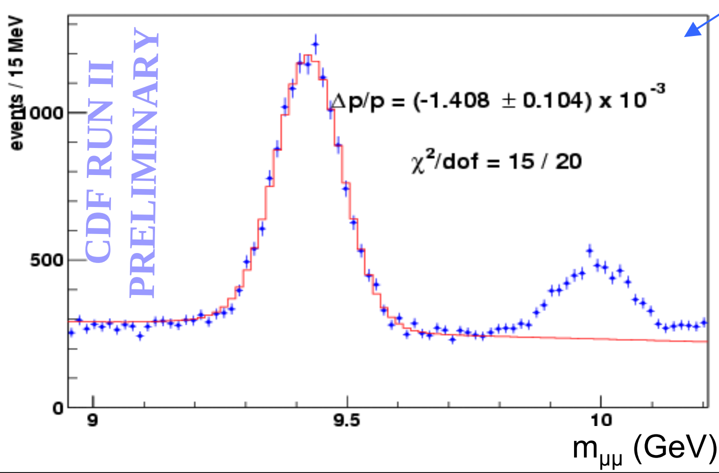


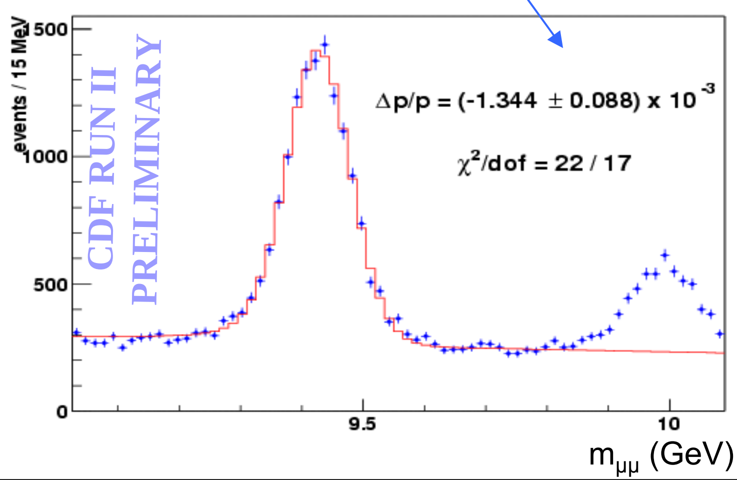
momentum scale measured to 3 parts in 10,000

$\Delta M_W = \pm 25$ MeV

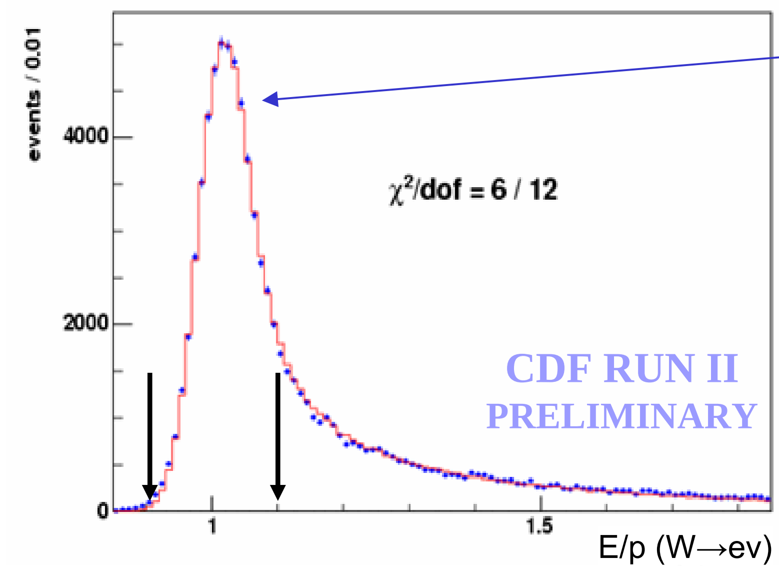
J/ψ mass independent of muon P_T

Upsilon mass consistent using beam-constrained or non-beam-constrained tracks





Run 2 Energy Calibration

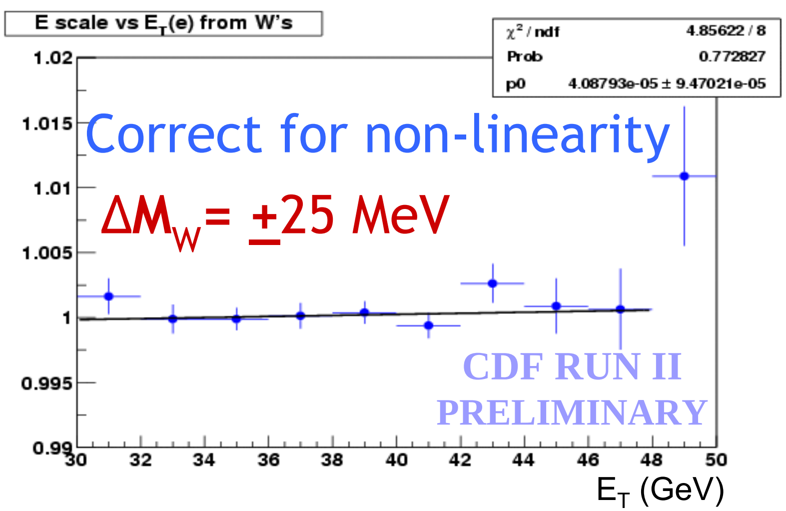


Set energy scale using *E/p* peak

$\Delta M_W = \pm 35$ MeV

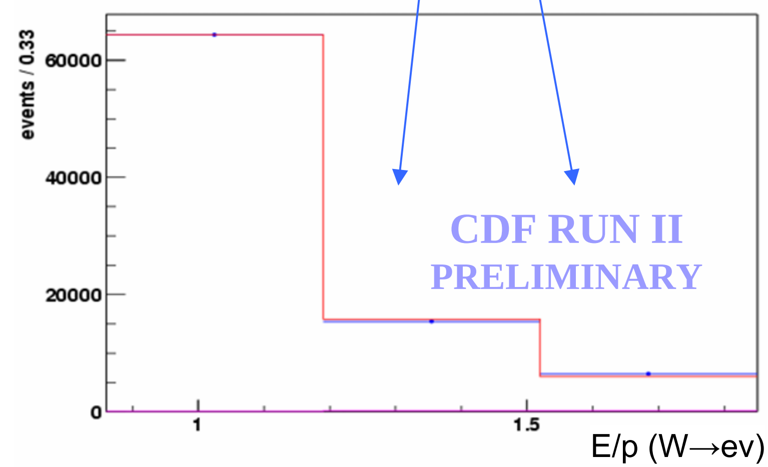
Tune upstream passive material using tail of *E/p* distribution

$\Delta M_W = \pm 55$ MeV



Correct for non-linearity

$\Delta M_W = \pm 25$ MeV



Run 2 Z Mass Cross Check

Use Z mass fits for tuning and cross-checks

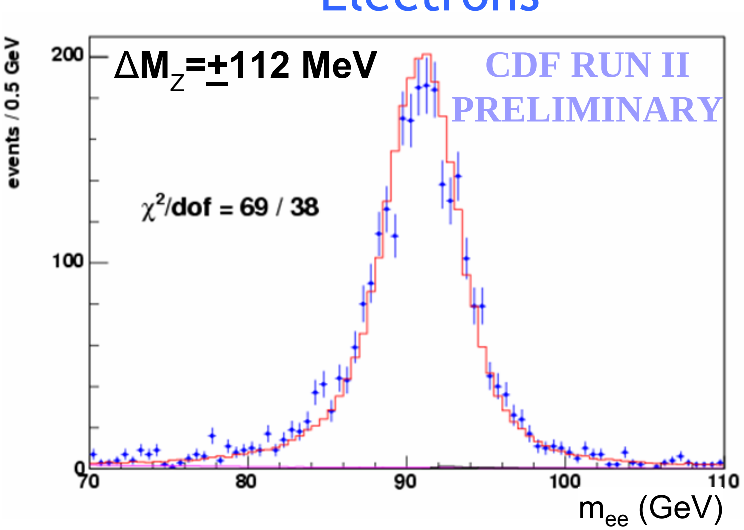
Tuning:

- Tracking hit resolution
- Recoil Model

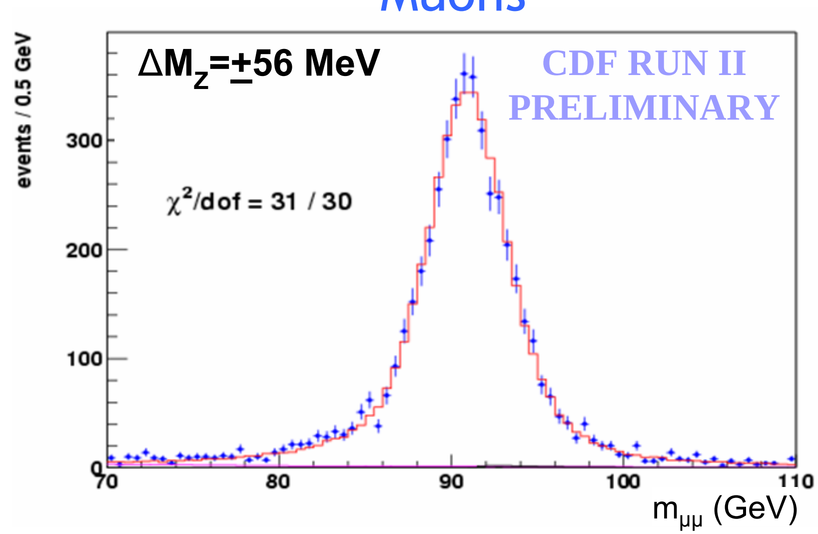
Cross-check:

- Energy scales
- QED FSR

Electrons



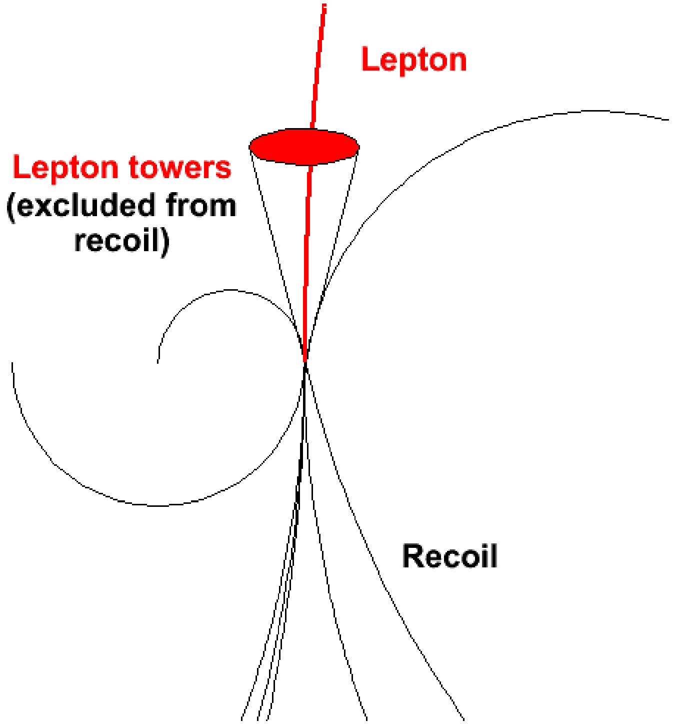
Muons

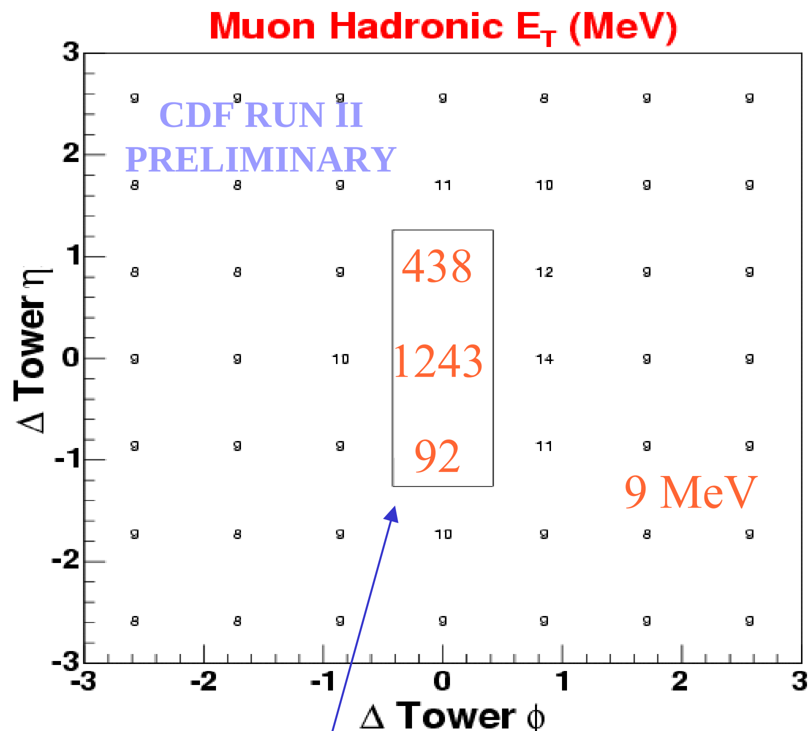


Run 2 Recoil Measurement

Measure hadronic recoil by summing over all calorimeter towers

Remove towers with energy deposited by lepton





Estimate removed recoil energy using towers separated in Φ

Removed muon towers

$\Delta M_W = \pm 10$ MeV

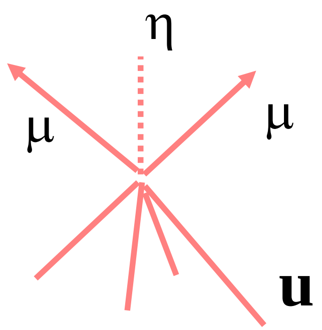
Recoil Model

Parametrize hadronic response:

$$R = \frac{\mathbf{u}_{meas}}{\mathbf{u}_{true}}$$

$\mathbf{u}_{true}$ given by $p_T(Z)$

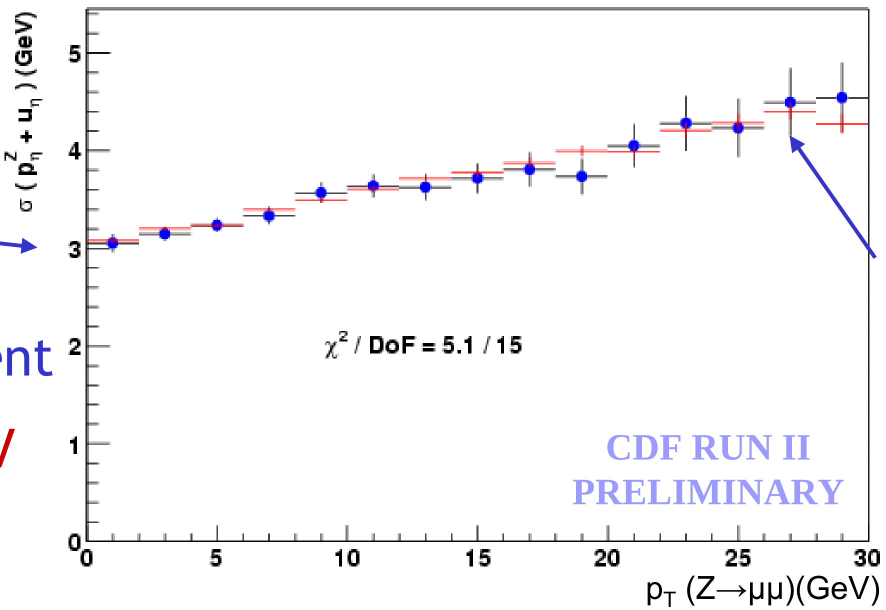
$\Delta M_W = \pm 20$ MeV



Tune parameters using Z events:

Resolution at low $p_T(Z)$ dominated by underlying event

$\Delta M_W = \pm 42$ MeV



Resolution at high $p_T(Z)$ dominated by jet resolution

Model underlying event with min-bias data (inelastic collisions)

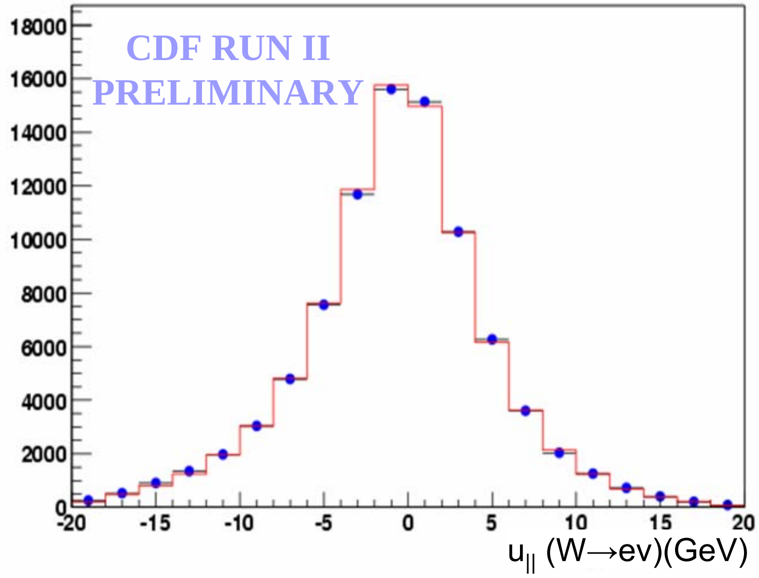
Recoil Check in W Events

Any bias in recoil along lepton direction ($u_{||}$) causes bias in W mass

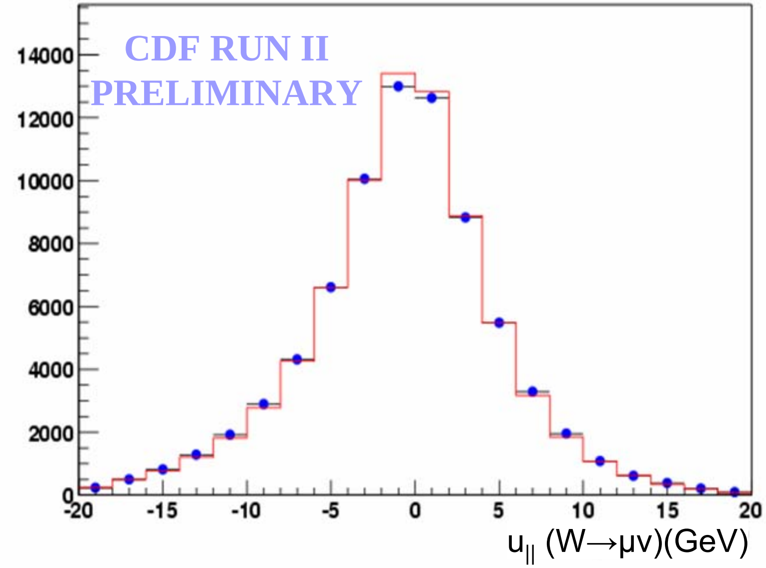
Simulation includes:

- Tower-removal correction
- Backgrounds
- Inefficiencies as function of $u_{||}$

Electrons



Muons



Means of simulation and data agree within uncertainties

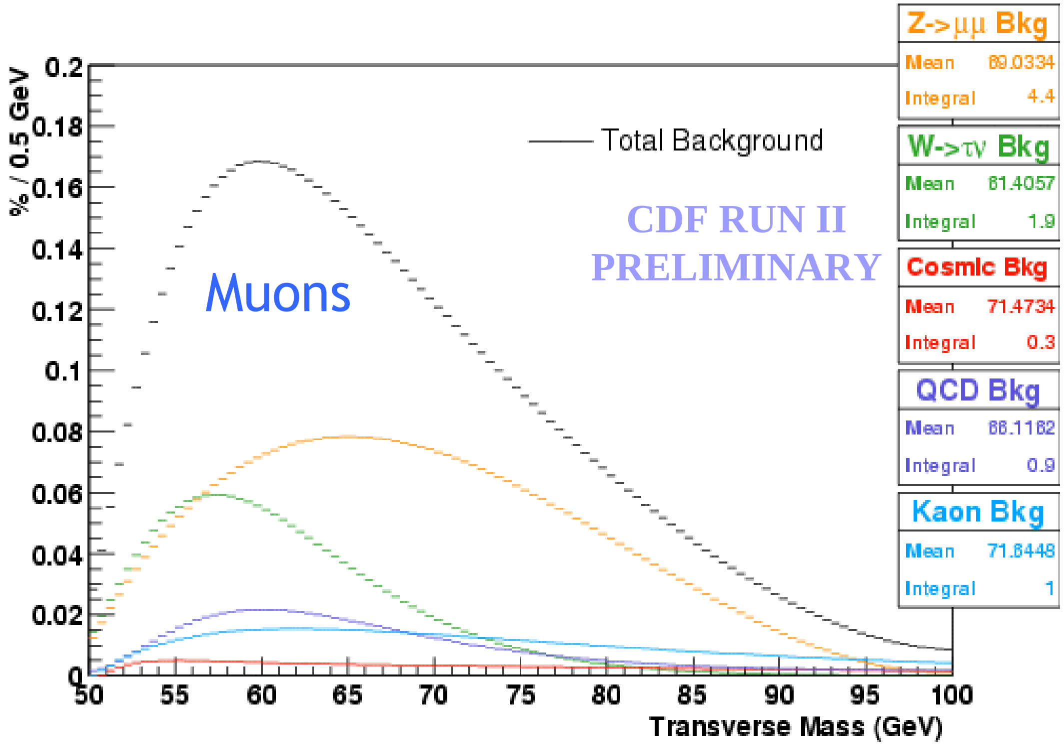
Backgrounds

Muons

Background	%
Hadronic Jets	0.9 ± 0.5
Kaons	1.0 ± 1.0
Cosmic Rays	0.3 ± 0.1
$Z \longrightarrow \mu\mu$	4.4 ± 0.2
$W \longrightarrow \tau\nu$	1.9 ± 0.1

Electrons

Background	%
Hadronic Jets	1.1 ± 0.4
$Z \longrightarrow ee$	0.27 ± 0.03
$W \longrightarrow \tau\nu$	1.9 ± 0.1

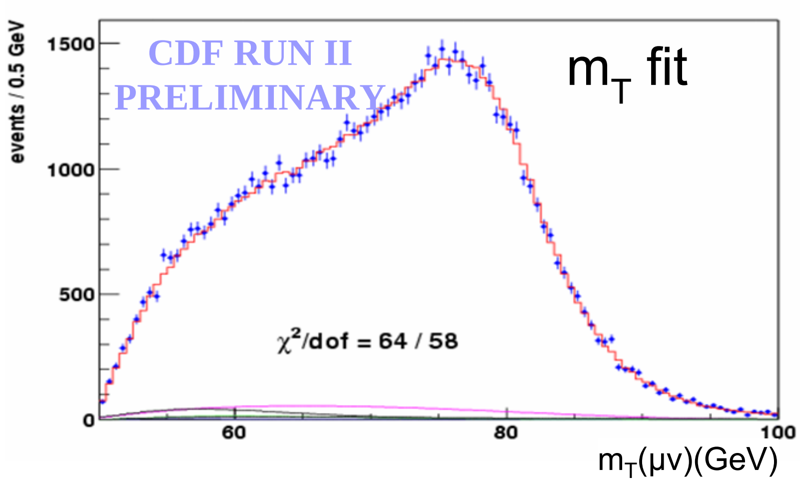


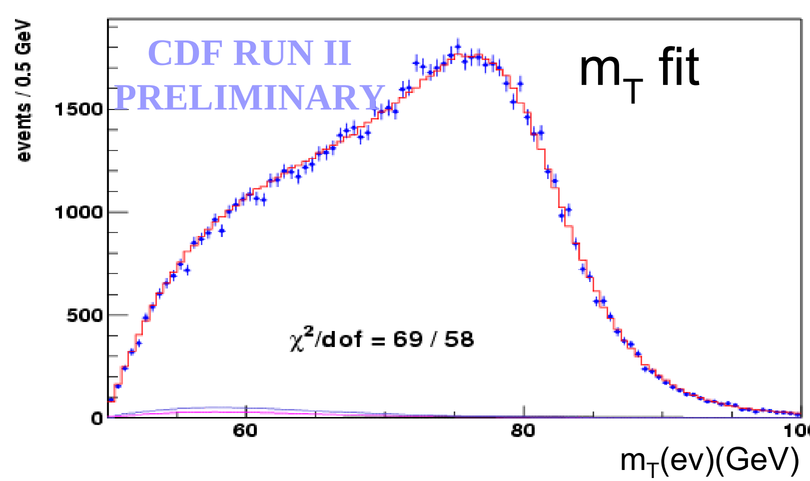
$\Delta M_W = \underline{+}\ 20$ MeV

W Mass Measurement

Muons

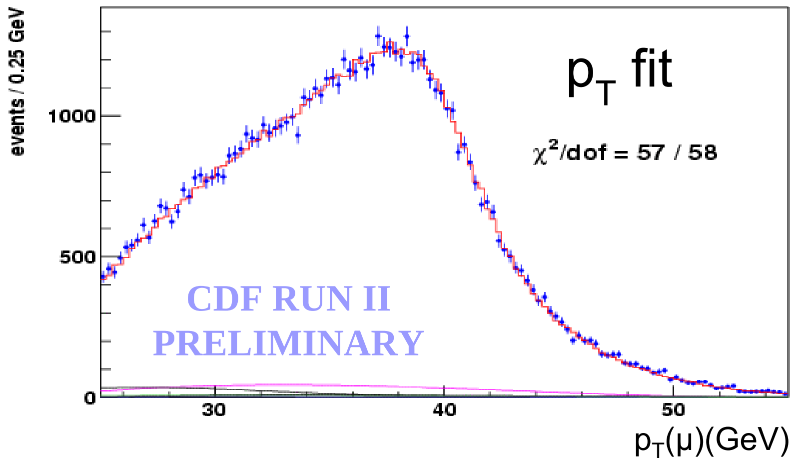
Electrons

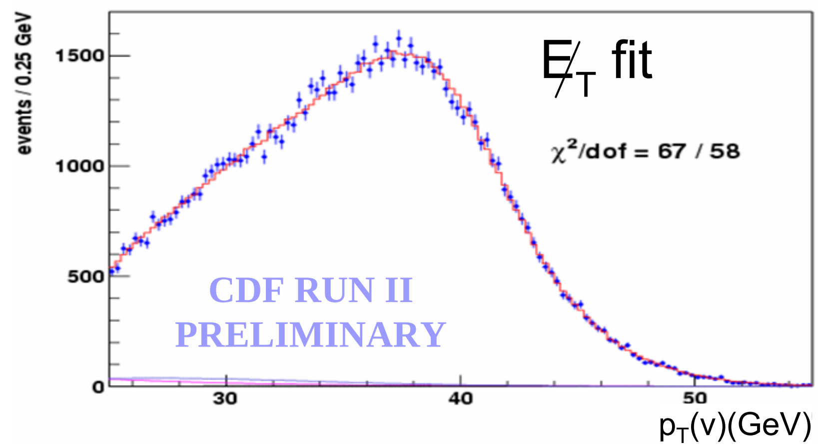




Good x^2/dof for fits

Fits still blinded





W Mass Measurement

Systematic	Electrons (Run 1b)	Muons (Run 1b)
Lepton Energy Scale and Resolution	70 (80)	30 (87)
Recoil Scale and Resolution	50 (37)	50 (35)
Backgrounds	20 (5)	20 (25)
Statistics	45 (65)	50 (100)
Production and Decay Model	30 (30)	30 (30)
Total	105 (110)	85 (140)

CDF RUN II PRELIMINARY

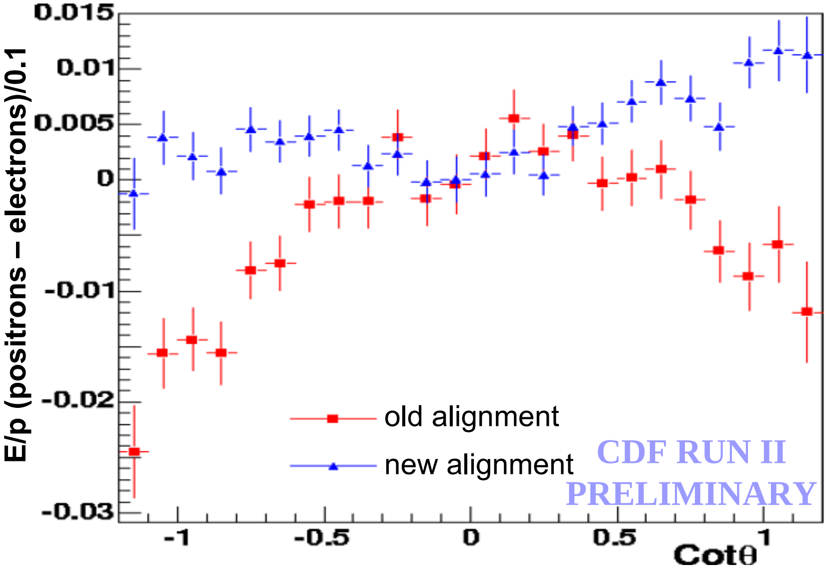
Total uncertainty (76 MeV) already lower than Run 1 (79 MeV)

Work in progress to reduce systematic uncertainty:

- Recoil resolution (hard interaction)
- Passive material upstream

Alignment of COT performed using cosmic rays

- NEW: adjust COT wire position along the beam axis
- Charge bias reduced by factor of 3 (consistent with no bias)



Summary/Outlook

Summary:

Very successful W boson program at the Tevatron

- Inclusive cross section in agreement with SM expectations with high precision
- Competitive measurement for W width and lepton universality
- W charge asymmetry measurement ⟶ eager to see new PDFs
- W mass analysis about to be completed

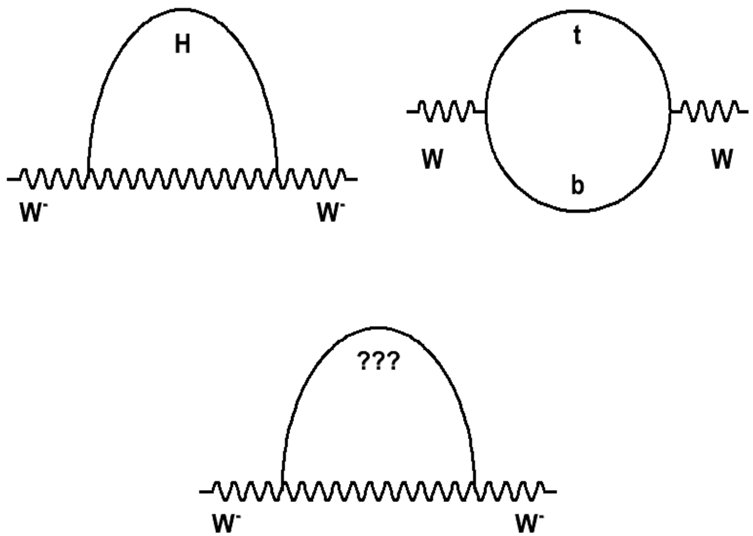
Outlook:

In Run 1, ΔM_W and $\Delta\Gamma_W$ followed $\sqrt{L}$ scaling:

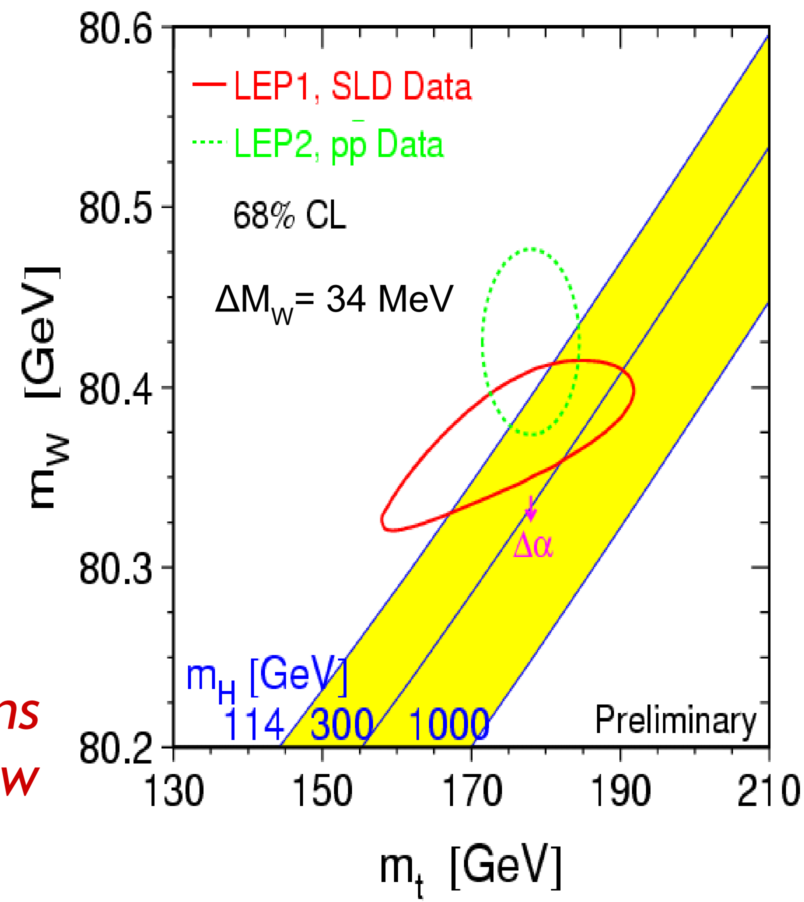
- Most systematic uncertainties scale with available collider data
- Theory input to production model will become important ~1 fb^{-1}
- In Run 2, could reach ΔM_W~30-40 MeV, $\Delta\Gamma_W$~50 MeV with 2 fb^{-1}

Backup Slides

W propagator includes H, tb, hypothetical new particle loops

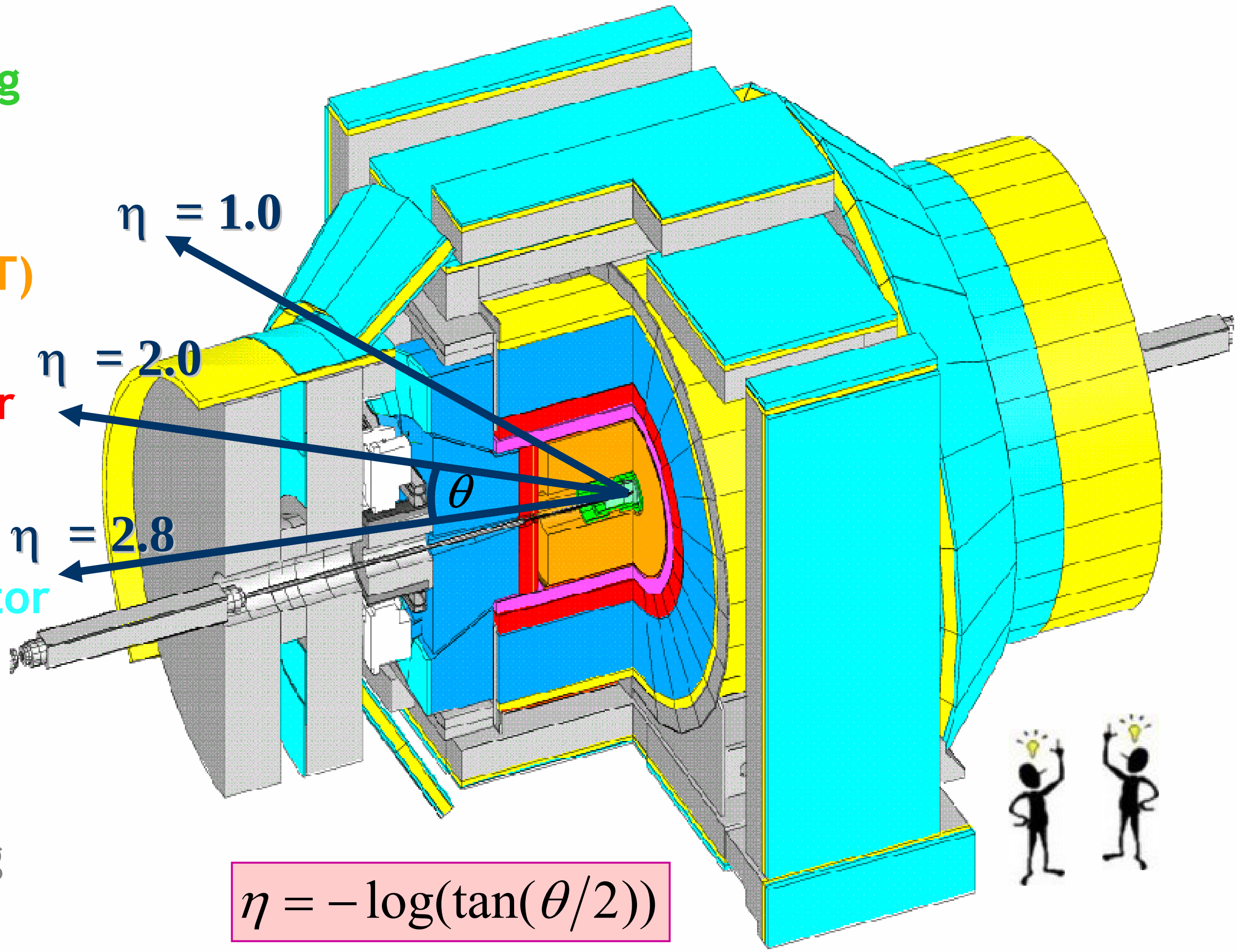


Precise knowledge of M_W constrains SM M_H, as well as hypothetical new particles



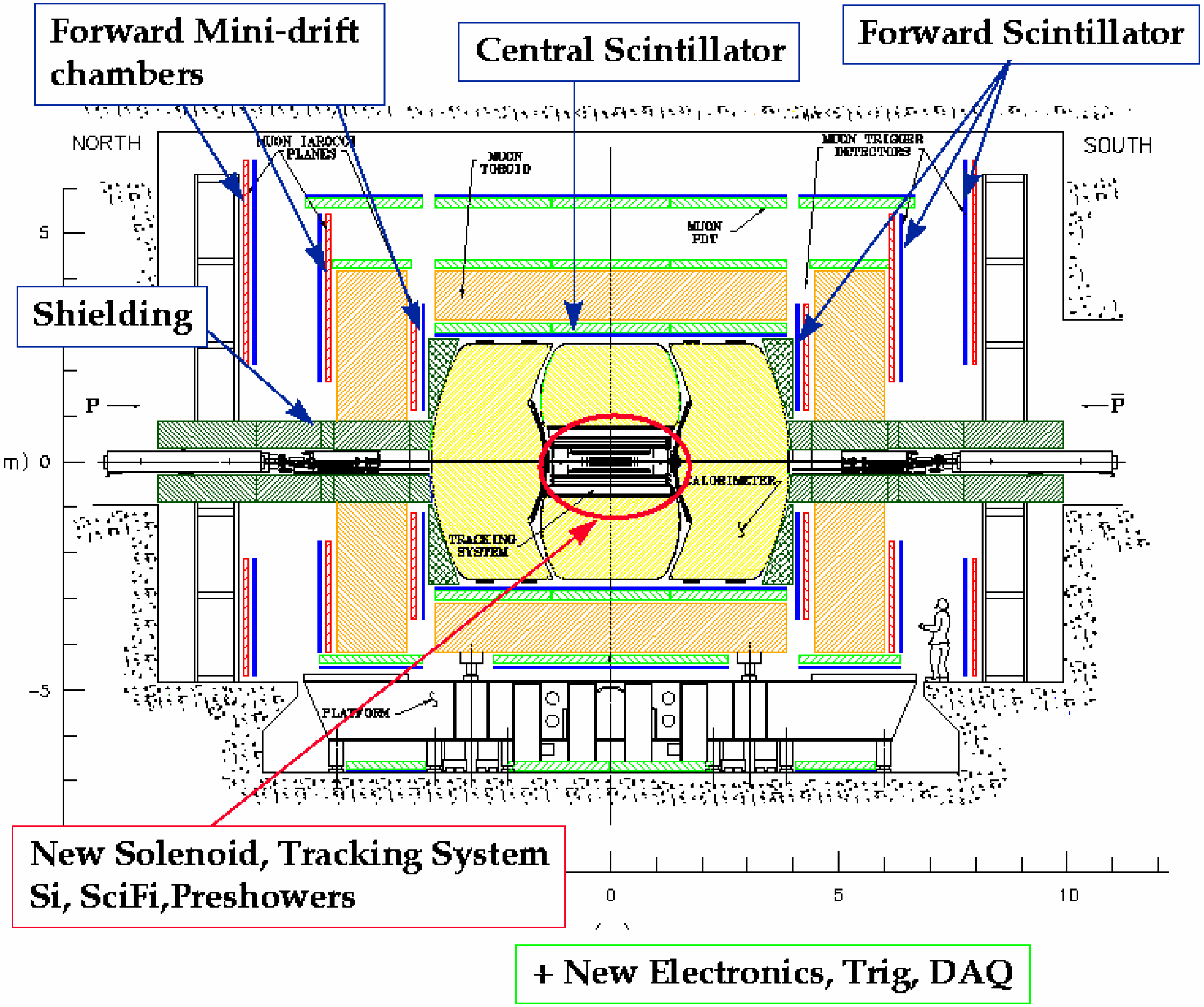
CDF Detector

- Silicon tracking detectors
- Central drift chambers (COT)
- Solenoid Coil
- EM calorimeter
- Hadronic calorimeter
- Muon scintillator counters
- Muon drift chambers
- Steel shielding



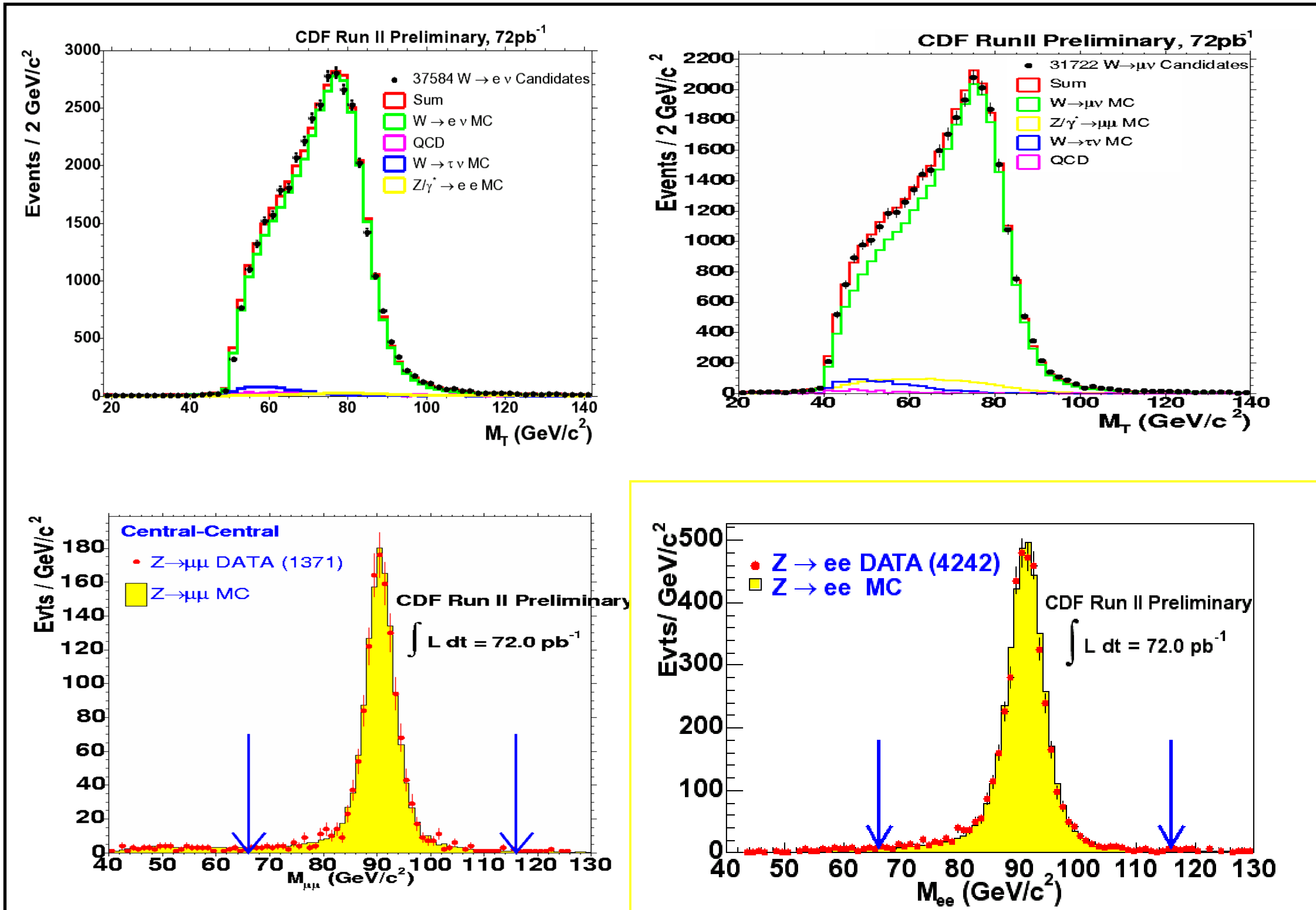
$$\eta = -\log(\tan(\theta/2))$$

D0 Detector



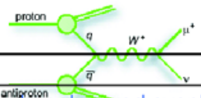
Forward Mini-drift chambers
Central Scintillator
Forward Scintillator
Shielding
NORTH
SOUTH
MUON IAROCCI PLANES
MUON TOROID
MUON TRIGGER DETECTORS
MUON PDT
CALORIMETER
TRACKING SYSTEM
PLATFORM
P
$\overline{P}$
New Solenoid, Tracking System
Si, SciFi,Preshowers
+ New Electronics, Trig, DAQ

W/Z Cross Section Data-MC



Cross Section Summary

Inclusive W Cross Section

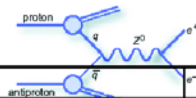


	e	μ
Number observed events	37584	31722
Estimated Bkg events	1656 ± 300	2990 ±140
Acceptance	0.2397 ± 0.0036	0.1970 ± 0.0025
Efficiency	0.749 ± 0.009	0.732 ± 0.013
Luminosity	72.0 ± 4.3 pb^{-1}	72.0 ± 4.3 pb^{-1}

σ_W (μ)	2768 ±16 stat ± 64syst ±166 lum (pb)
σ_W (e)	2780 ±14 stat ± 60 syst ±167 lum (pb)
σ_W (e+μ)	2775 ±10 stat ± 53 syst ±167 lum (pb)

NNLO @ √s=1.96 TeV: 2687 ± 54 pb (Stirling, van Neerven)

Inclusive γ^*/Z Cross Section



	e	μ
Number observed events	4242	1785
Estimated Bkg events	62 ± 18	13 ±13
Acceptance	0.3182 ± 0.0040	0.1392 ± 0.0027
Efficiency	0.713 ± 0.012	0.713 ± 0.015
Luminosity	72.0 ± 4.3 pb^{-1}	72.0 ± 4.3 pb^{-1}

$\sigma_{\gamma^*/Z}$ (μ)	248.0 ±5.9 stat ± 7.6 syst ±14.9 lum (pb)
$\sigma_{\gamma^*/Z}$ (e)	255.8 ±3.9 stat ± 5.5 syst ±15.4 lum (pb)
$\sigma_{\gamma^*/Z}$ (e+μ)	254.9 ±3.3 stat ± 4.6 syst ±15.2 lum (pb)

NNLO @ √s=1.96 TeV: 251.3 ± 5.0 pb (Stirling, van Neerven)

Summary of Extracted Quantities

$$Br(W \to \ell\nu) = \frac{N_W(1-b_W)}{N_Z(1-b_Z)} \frac{\epsilon_Z}{\epsilon_W} \left(\frac{A_Z \sigma_Z^{\rm th}}{A_W \sigma_W^{\rm th}}\right) Br(Z \to \ell^+\ell^-)$$

$$\Gamma_W = 3\Gamma_W^0 + 3\left(1 + \frac{\alpha_s}{\pi} + 1.409(\frac{\alpha_s}{\pi})^2 - 12.77(\frac{\alpha_s}{\pi})^3\right) \sum_{[\text{no top}]} |V_{qq'}|^2 \Gamma_W^0$$

Total width depends on EWK parameters and first two rows of CKM matrix element. V_{cs} has largest uncertainty → use Γ_W measurement to constrain it.

quantity	our measurement	world average	SM value
$Br(W \to \ell\nu)$	0.1089 ± 0.0022	0.1068 ± 0.0012	0.1082 ± 0.0002
Γ_W (using $Br(Z \to \ell^+\ell^-)$) (MeV)	2078.8 ± 41.4	2118 ± 42	2092.1 ± 2.5
M_W (GeV) [M_W not in PRL]	80.26 ± 0.52	80.423 ± 0.039	80.391 ± 0.019
Γ_W/Γ_Z	0.833 ± 0.017	0.849 ± 0.017	0.838 ± 0.001
V_{cs}	0.967 ± 0.030	0.996 ± 0.013	N/A
$g_{W\mu}/g_{We}$	0.998 ± 0.012	0.993 ± 0.013	1

Ratio

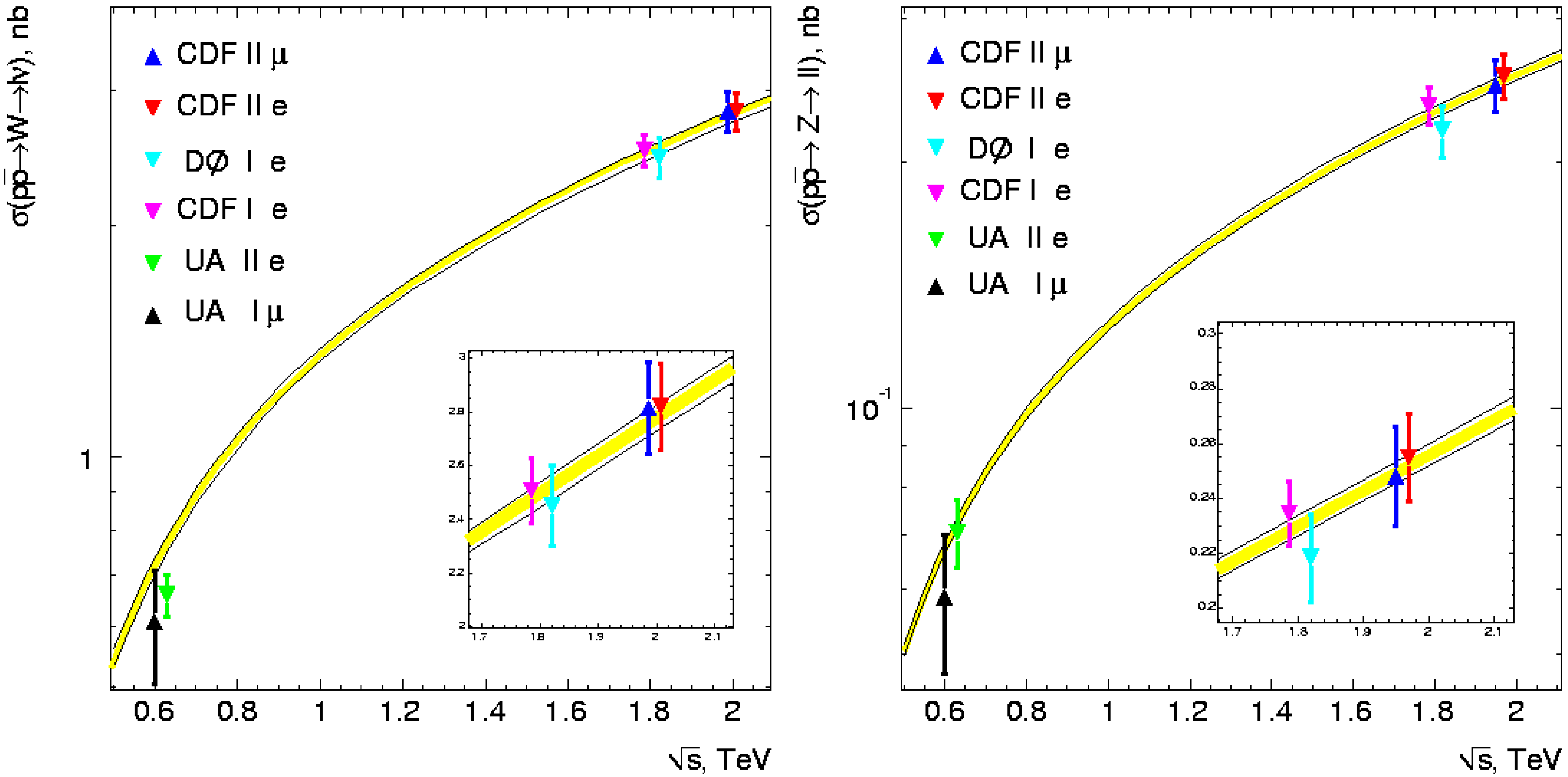
$$R = \frac{\sigma \cdot Br(p\bar{p} \to W \to \ell\nu)}{\sigma \cdot Br(p\bar{p} \to Z \to \ell^+\ell^-)} = \frac{\sigma(p\bar{p} \to W)}{\sigma(p\bar{p} \to Z)} \times \frac{\Gamma_Z}{\Gamma_Z(\ell^+\ell^-)} \times \frac{\Gamma_W(\ell\nu)}{\Gamma_W}$$

- From our $\gamma^*/Z^0 \to \ell^+\ell^-$ cross section we extract the Z^0 only component(factor calculated to be 1.004 ±0.001 in 66-116 GeV mass window).
- Individual R measurements are combined (instead of taking ratio of combined cross sections).

R (μ)	11.12 ±0.27stat ± 0.18 syst
R (e)	10.82 ±0.18 stat ± 0.16 syst
R (e+μ)	10.92 ±0.15 stat ± 0.14 syst

NNLO @ √s=1.96 TeV: 10.69 ± 0.08 (Stirling, van Neerven)

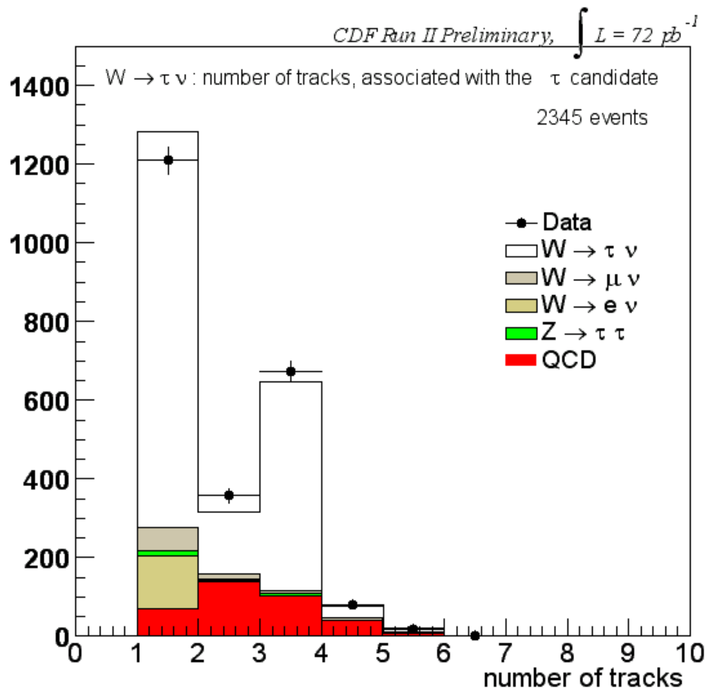
W/Z Cross Section vs √s

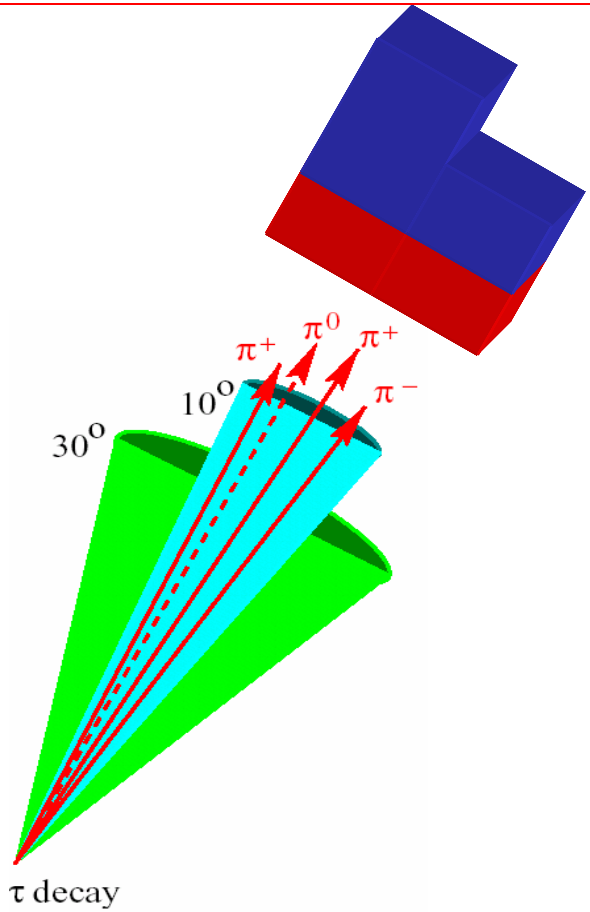


$W\to\tau\nu$

- **Tau reconstruction:**
  - Count tracks in 10º t -cone and veto tracks in 30º isolation cone
  - Reconstruct p^0 candidates in Shower Max detector
  - Combined mass < m(tau)

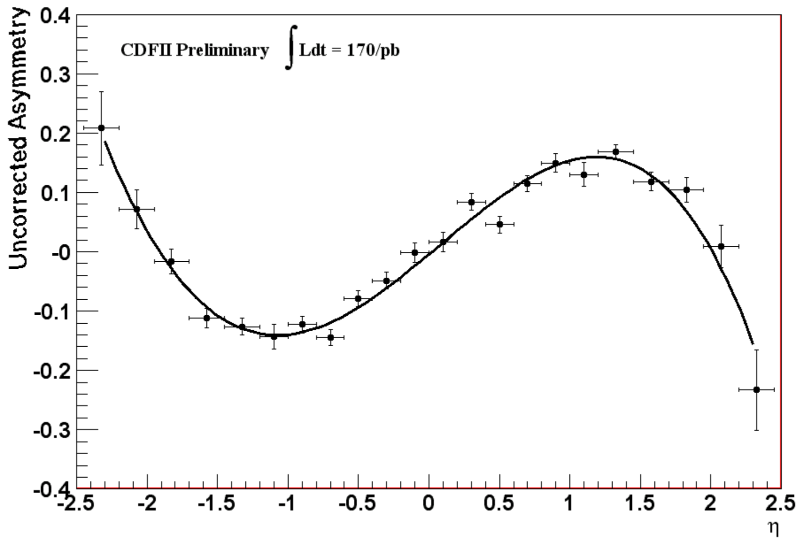
$W\to\tau\nu_t$: 2345 in ~72 pb^{-1}
Background ~ 26 % (dominated QCD)





$\sigma\cdot BR(W\to t\nu) = 2.62 \pm 0.07_{stat} \pm 0.21_{sys} \pm 0.16_{lum}$ nb

W Charge Asymmetry

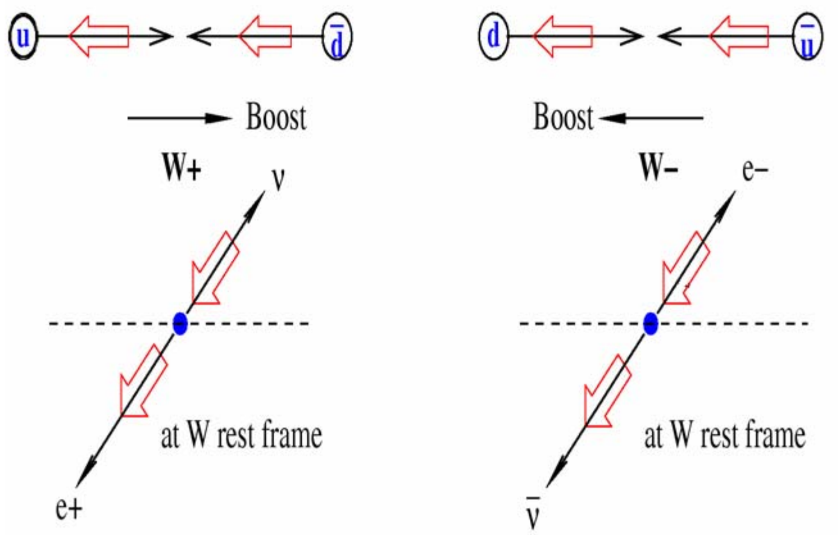


Corrections to extract asymmetry:

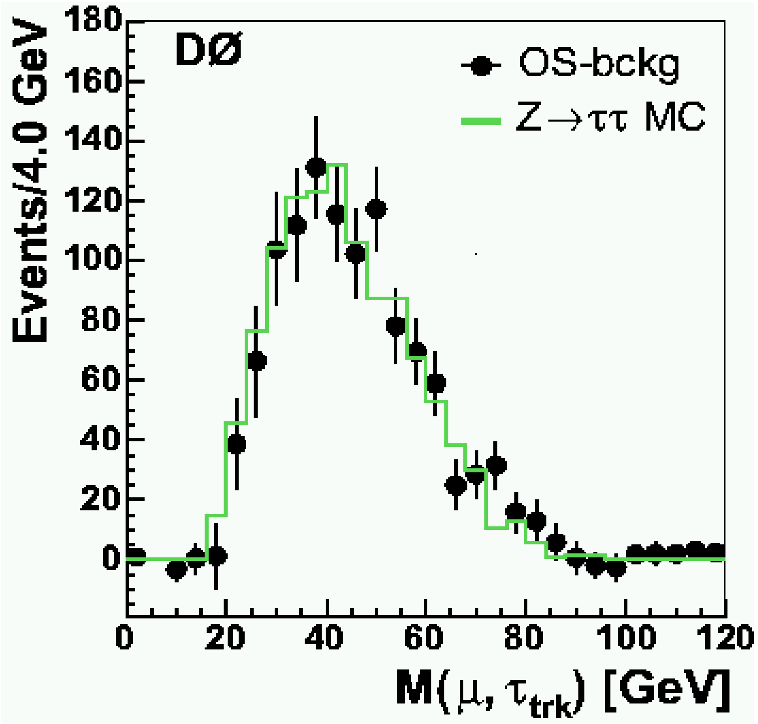
- Charge misidentification rate.
- Background subtraction.

Measured in each η bin

Both bias the asymmetry low → dilution.



DØ Z->ττ Cross Section



L=226 pb^{-1}

- Muon trigger
- neural network-based τ ID
- cut NN > 0.8
- S/B ~ 1
- Z->ττ signal: **914+/-24**

For m(ττ)>60 GeV/c²:

$\sigma \cdot B(Z \rightarrow \tau\tau) = 252 \pm 16_{stat} \pm 19_{syst} \pm 17_{lum}$ pb

γ* removed:

$\sigma \cdot B(Z \rightarrow \tau\tau) = 237 \pm 15_{stat} \pm 18_{syst} \pm 16_{lum}$ pb

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