Inclusive W and Z cross sections at the Tevatron

Victoria Martin
Northwestern University
Of behalf of the CDF and DØ collaborations

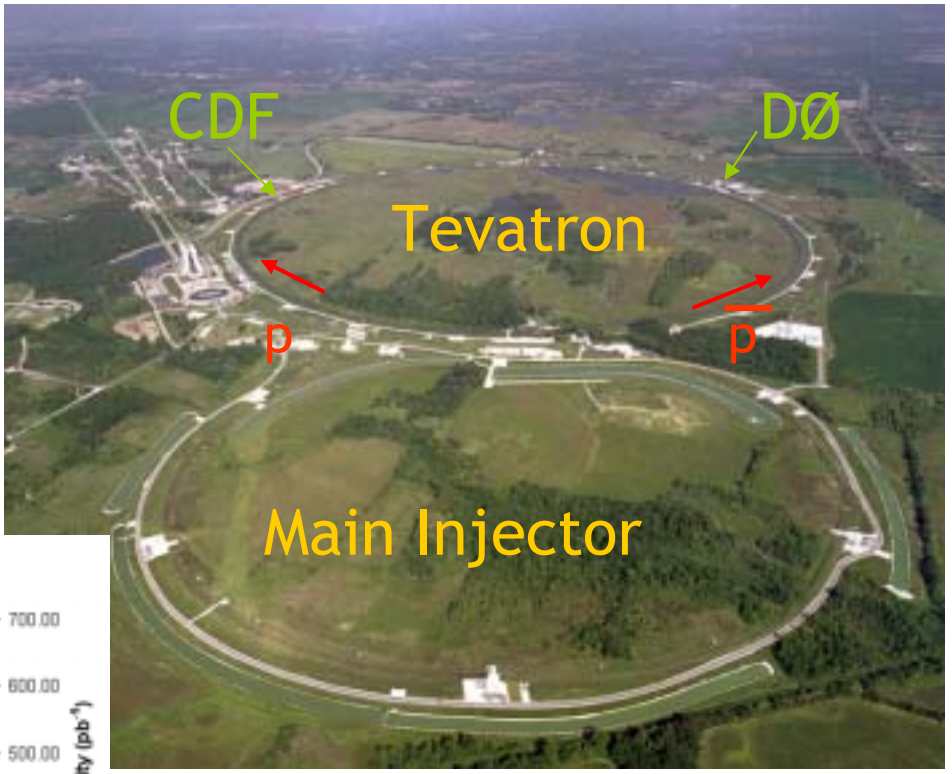
Meeting of The Division of Particles and Fields of the APS, 2004

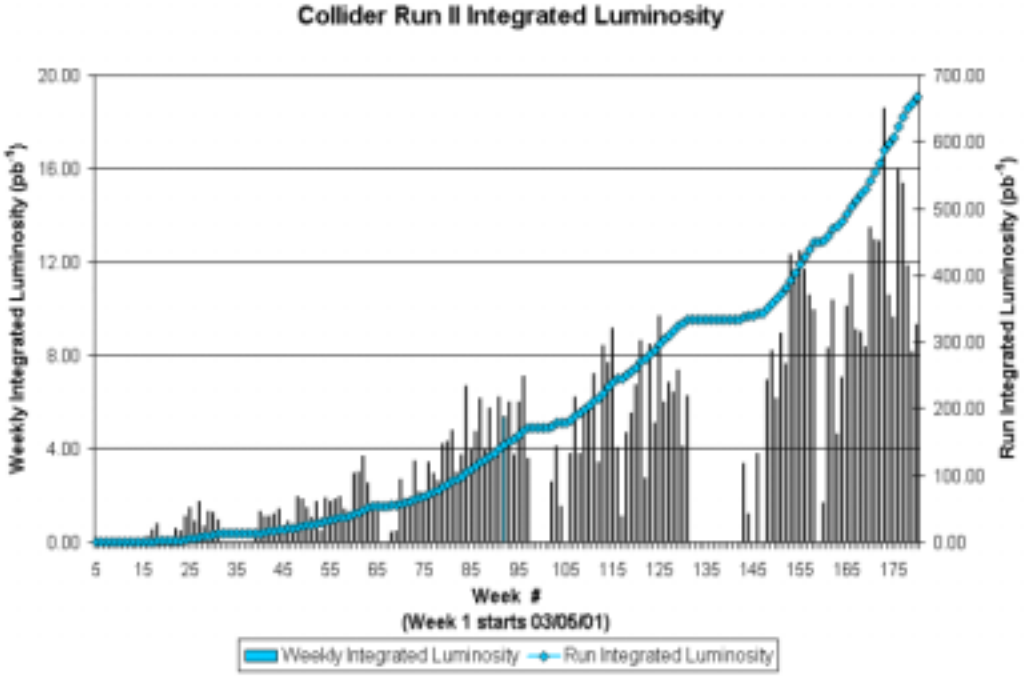
Contents

- What's so interesting about inclusive $W^{\pm}$, Z^0 cross sections?
- Fermilab Tevatron, DØ and CDF detectors
- Reconstruction, efficiencies, backgrounds
- Systematic uncertainties
- Estimating PDF uncertainties
- Cross Section Results
- R and $\Gamma(W)$
- Future Plans and Conclusions

Fermilab Tevatron and Luminosity

- $\sqrt{s}$=1960 TeV p $\bar{p}$ collider
- Upgraded in 2000
- Two collision points: CDF and DØ
- Luminosity uncertainty is 6%.
  Limited by:
  - Knowledge of inelastic cross section
  - Acceptance of luminosity counters

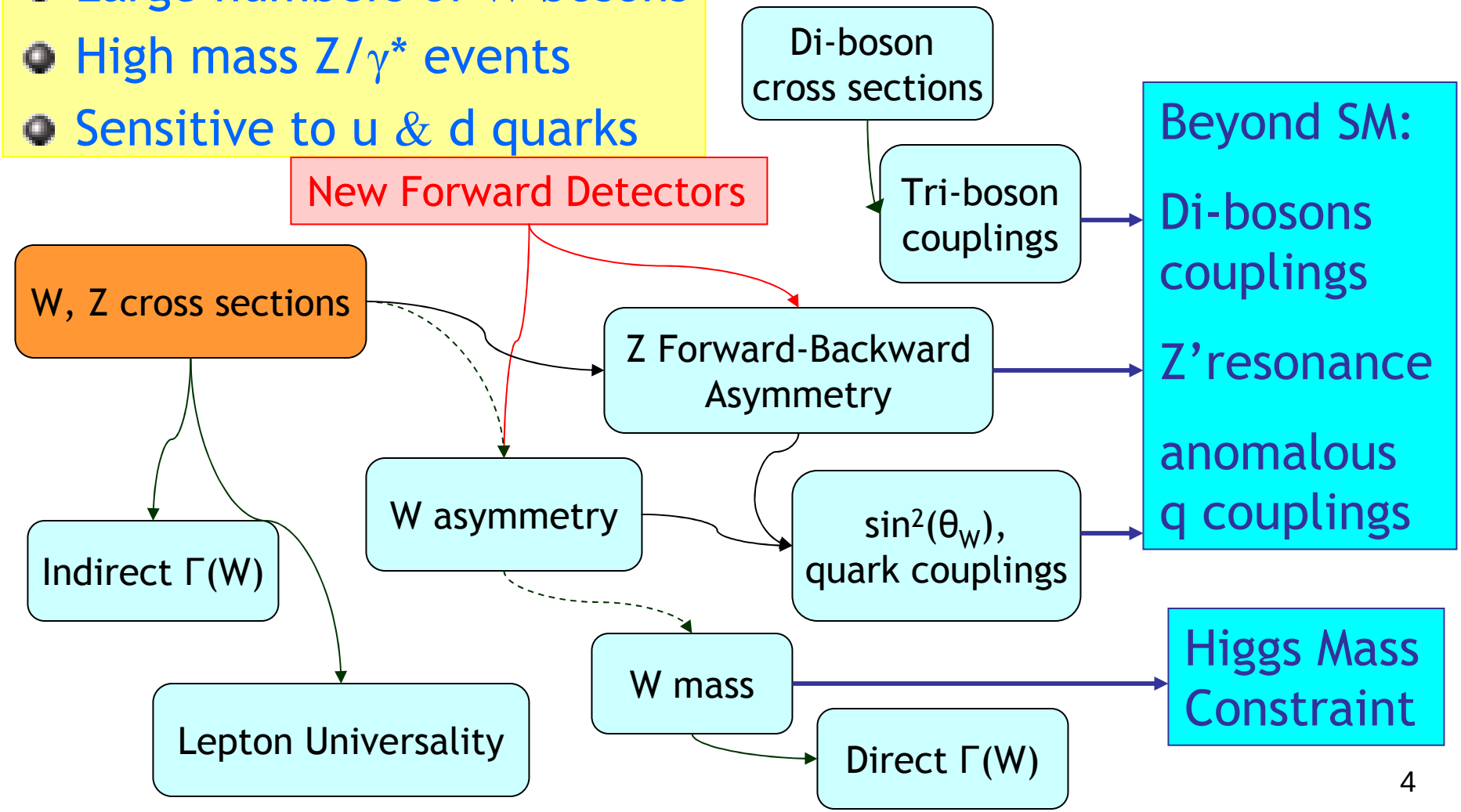




- Current luminosity: 680 pb^{-1}
- Luminosity on tape: ~500 pb^{-1}
- Measurements presented here: ~60 pb^{-1} to ~200 pb^{-1}

Why W and Z Physics at RunII?

- Large numbers of W bosons
- High mass Z/γ^* events
- Sensitive to u & d quarks



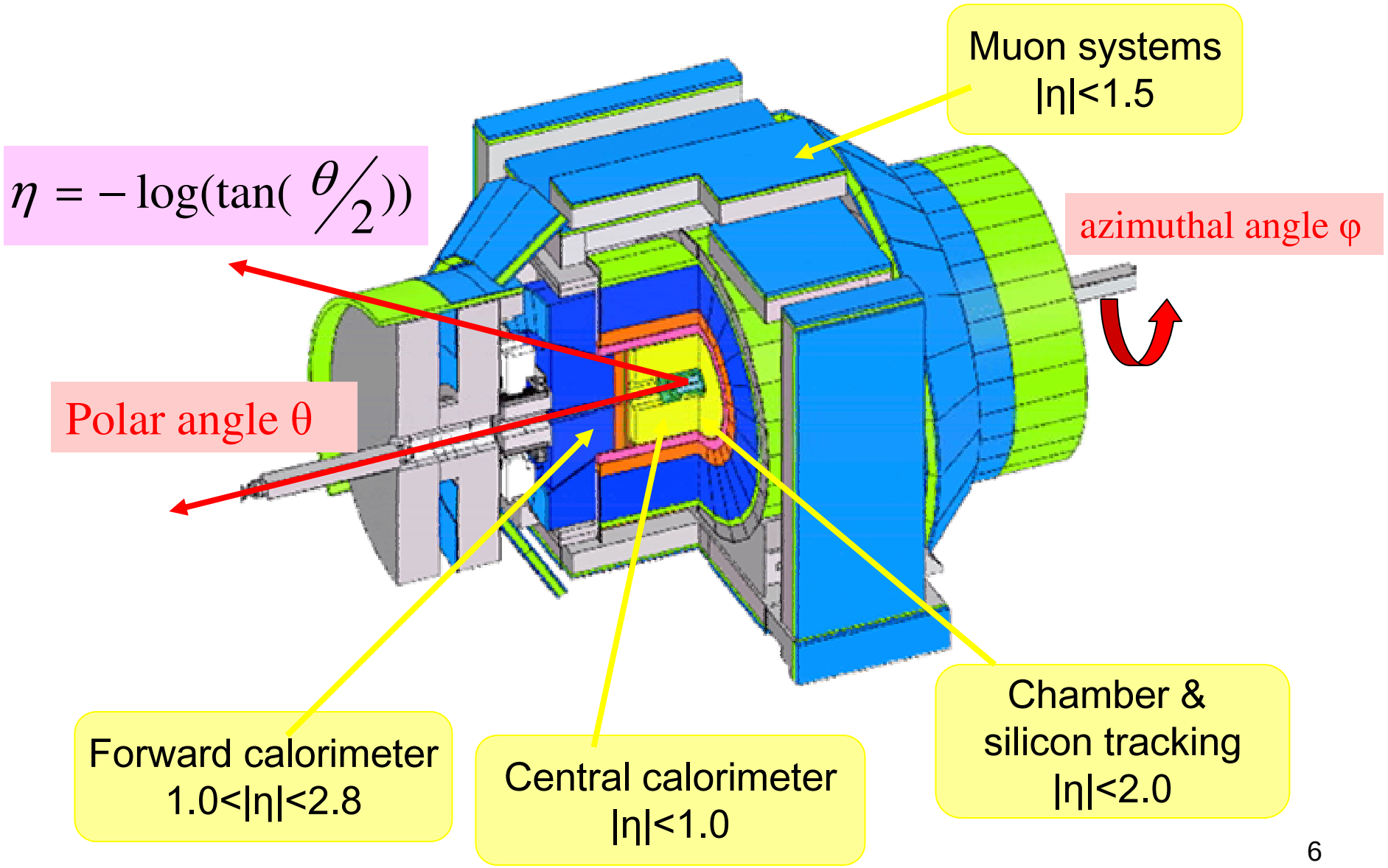
Cross Section Calculation

$$\sigma \cdot \mathrm{BR} = \frac{N_{cand} - N_{backg}}{L \cdot A \cdot \varepsilon}$$

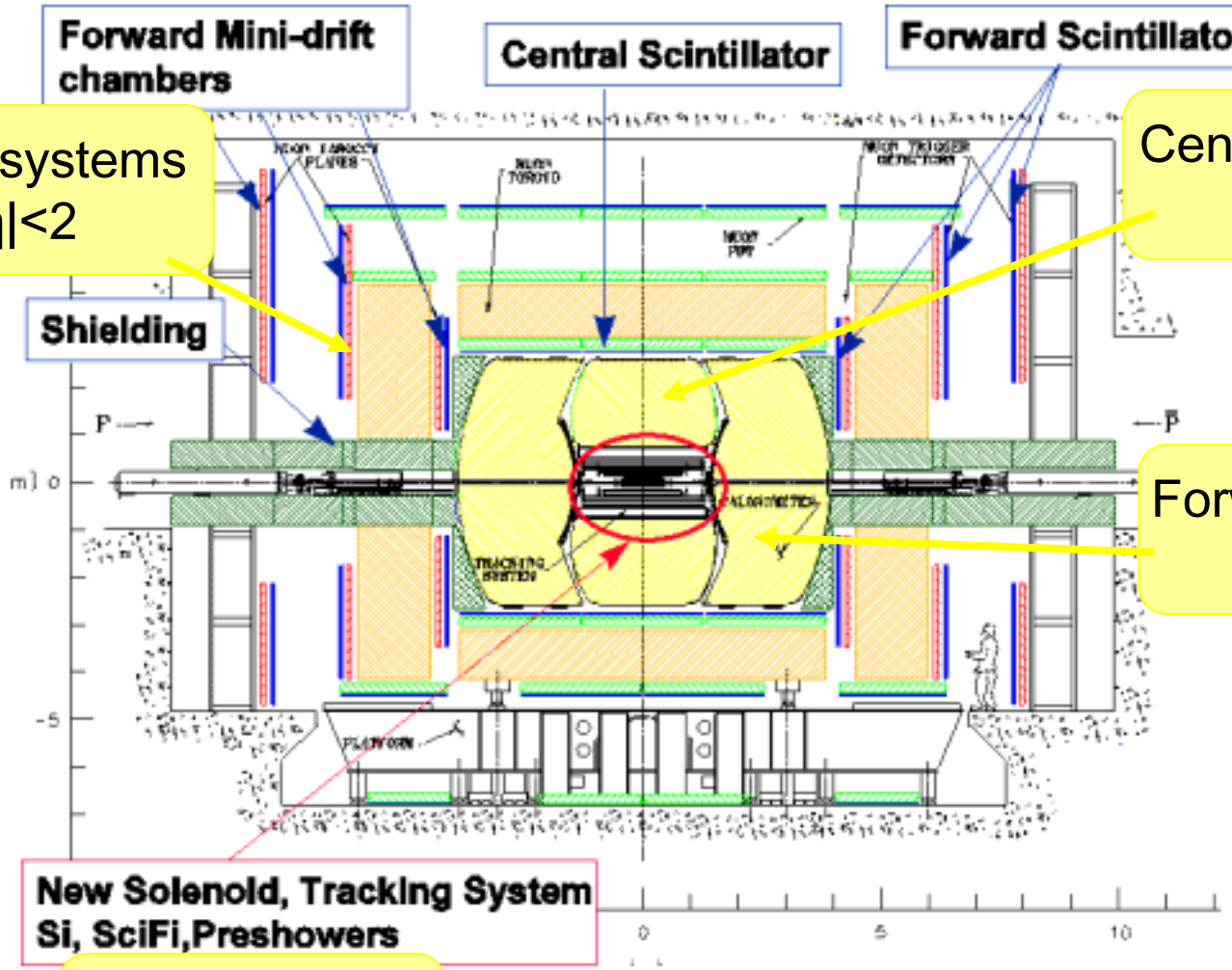
- N_{cand}: *Number of candidate events*
- N_{backg}: *Estimated number of background events*
- L: *Integrated luminosity*
- $A \cdot \varepsilon$: *Acceptance X efficiency*

- Look for W and Z decays to leptonic final states
  - need to reconstruct e, μ, τ, ν
  - requires good calorimeter, muon and tracking coverage

CDF Run II Detector

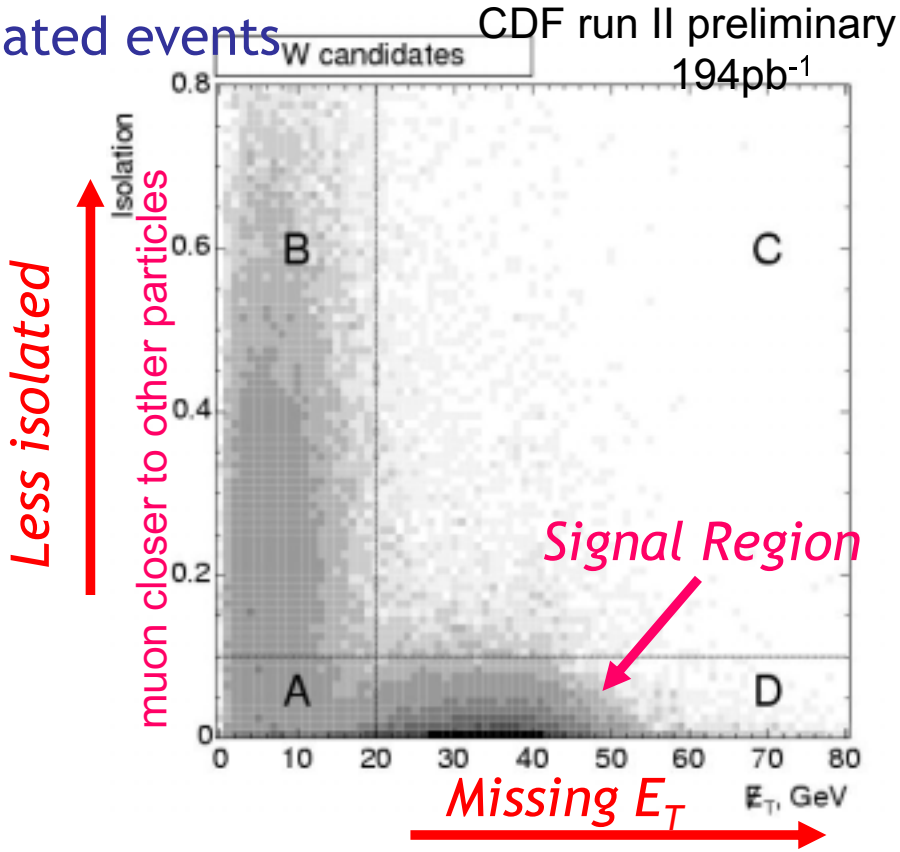


DØ Detector


Forward Mini-drift chambers
Central Scintillator
Forward Scintillator
Muon systems
|η|<2
Central Calorimeter
|η|<1.0
Shielding
Forward Calorimeter
1.0<|η|<4.0
New Solenoid, Tracking System
Si, SciFi,Preshowers
Silicon tracking
|η|<3
+ New Electronics, Trig, DAQ

Backgrounds

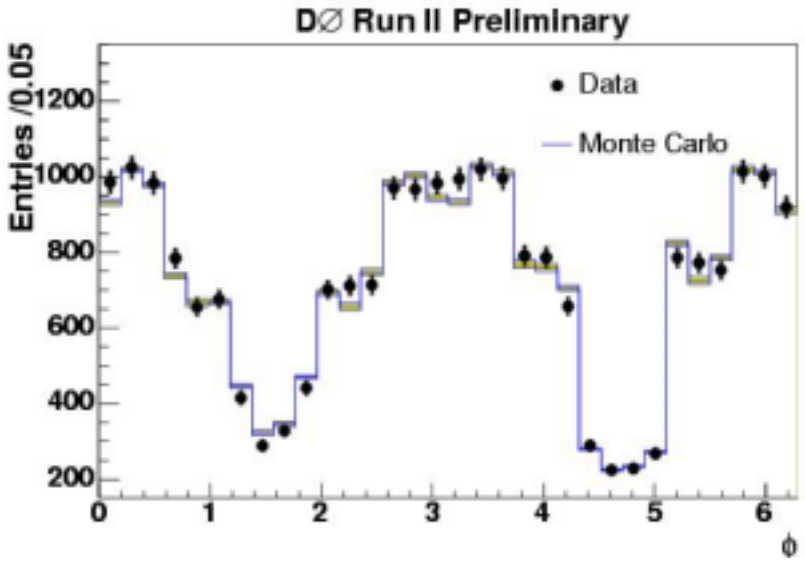
- 3 main background sources:
  - QCD processes
    - jet looks like a lepton
    - signal events tend to have isolated ℓ
      - ℓ is further from other detector activity
    - look at isolated and non-isolated events
- Other EW processes
  - calculate from MC
- Cosmics (in μ channel)
  - require small cda between μ and beam spot (CDF/DØ)
  - reconstruct cosmic tracks (CDF)
  - residual background very small (<1%)

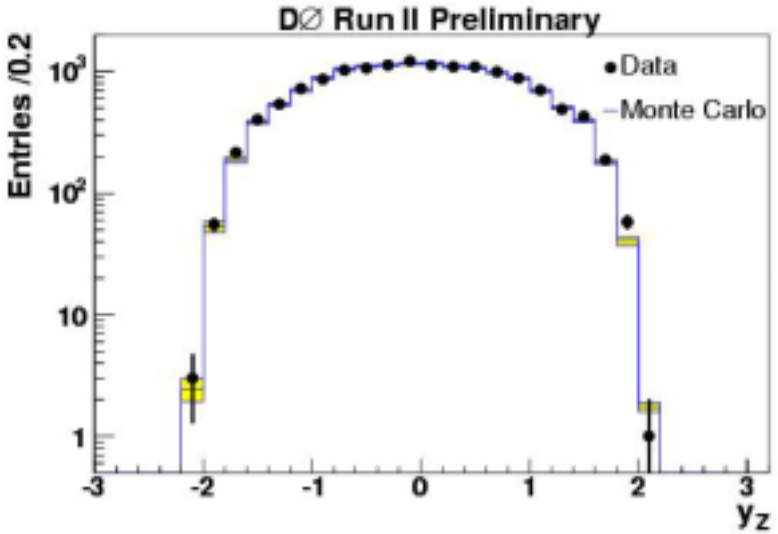


Acceptance and Efficiency

- Geometric acceptance calculated from Pythia or Herwig MC
- Use NLO CTEQ5 PDFs

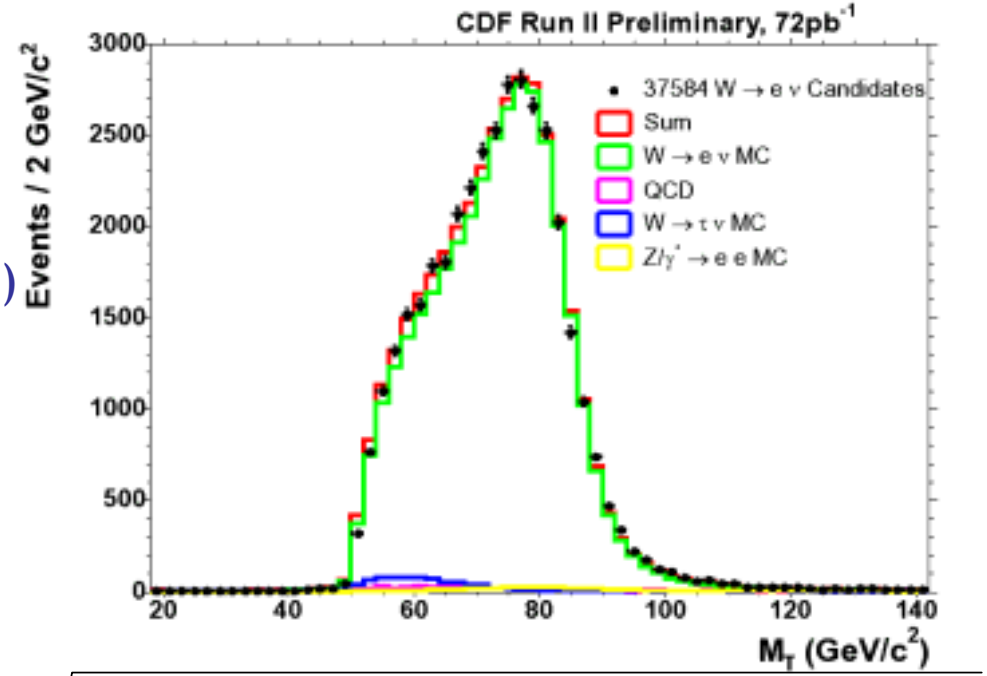
- All other efficiencies calculated from data
  - Many efficiencies measured from $Z \rightarrow \ell^+\ell^-$ events
  - 1st ℓ is identified, test the 2nd ℓ





W→ℓν Inclusive Cross Section

- W→e ν reconstruction:
  - missing-E_T>25GeV
  - CDF: 1 central electron (|η|<1.0) or 1 forward electron (1.0<|η|<3.2)
  - with matching track
  - DØ: 1 central electron (|η|<1.05)
  - no track requirement
- W→μν reconstruction:
  - missing-E_T>20GeV
  - 1 muon (|η|<0.6) with track

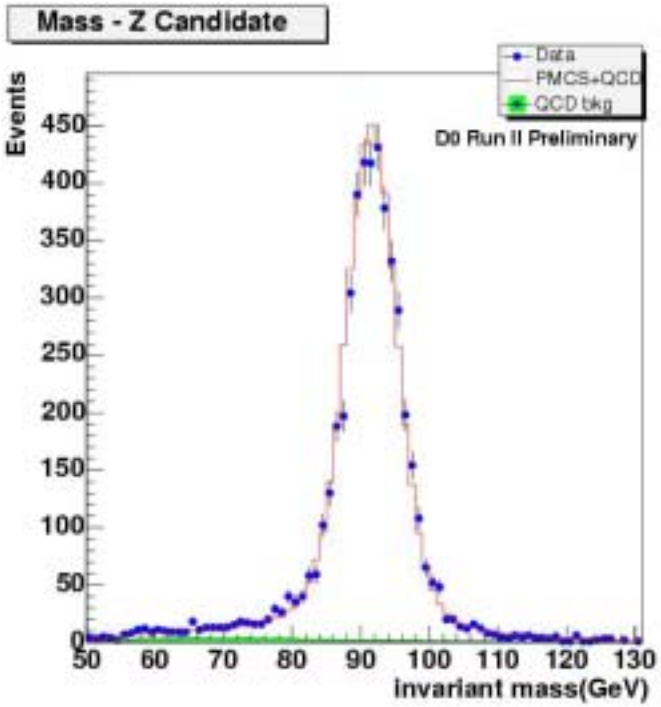


$$M_T = \sqrt{(E_T(\ell)+E_T(\nu))^2-(p_x(\ell)+p_x(\nu))^2-(p_y(\ell)+p_y(\nu))^2}$$

		Events	Background	A·ε
CDF central W→eν	72pb^{-1}	37584	(4.4±0.8)%	(18.0±0.4)%
CDF forward W→eν	64pb^{-1}	10461	(8.7±0.6)%	(5.2±0.2)%
CDF W→μν	194pb^{-1}	57109	(7.3±0.5)%	(9.6±0.2)%
DØ W→eν	177pb^{-1}	175572	(33.6±0.4)%	(22.6±0.5)%

$Z \rightarrow e^+e^-$ results

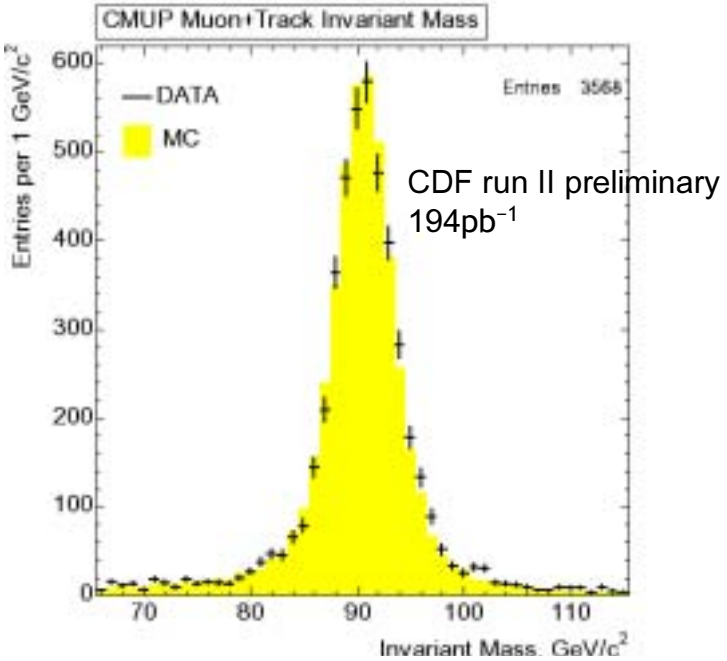
- CDF reconstruction:
  - 2 central electrons ($|\eta|<1.0$), both with matching tracks
  - 1 central electron ($|\eta|<1.0$) with matching track, plus 1 forward electron ($1.0<|\eta|<3.2$)
  - $66<m(ee)/GeVc^{-2}<116$
- DØ reconstruction:
  - 2 central electrons ($|\eta|<1.05$)
  - at least 1 matching track
  - $70<m(ee)/GeVc^{-2}<110$
- Correct σ for DY

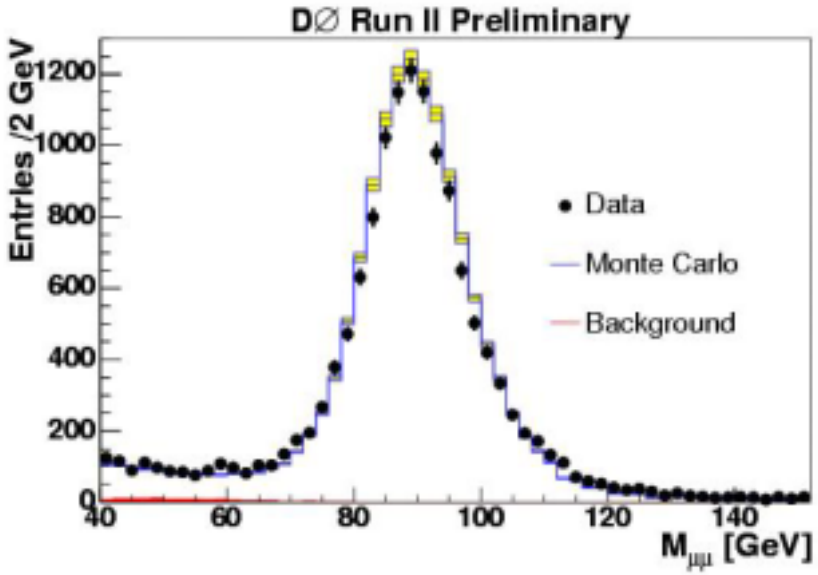


	Events	A·ε
CDF 72pb^{-1}	4242	(22.7±0.5)%
DØ 177pb^{-1}	4712	(9.6±0.4)%

$Z \rightarrow \mu^+\mu^-$ results

- CDF reconstruction:
  - 1 central muon ($|\eta|<0.6$) with matching track
  - 1 additional central track ($|\eta|<1.0$)
  - $66<m(\mu\mu)/GeVc^{-2}<116$
- DØ reconstruction:
  - 2 muons, both matched to tracks
  - $m(\mu\mu) > 40\ GeV/c^2$
- <2% background
- Correct σ for DY

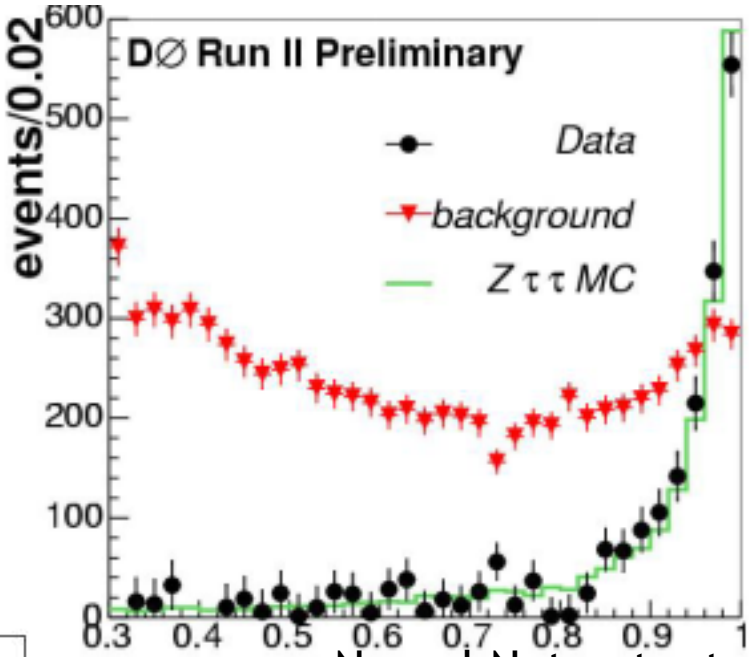


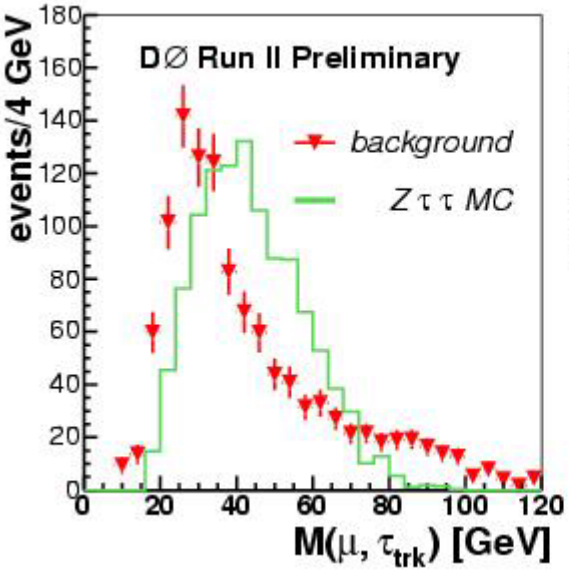


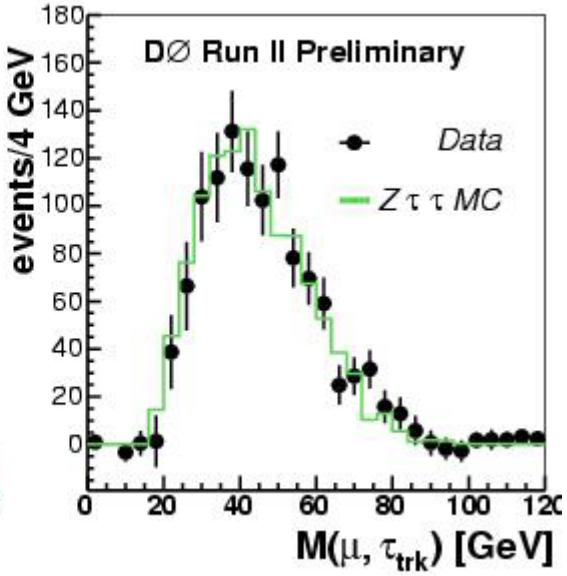
	Events	A·ε
CDF 194pb^{-1}	3568	(7.3±0.2)%
DØ 148pb^{-1}	14352	22.1% to 31.6% (t-dep)

DØ: reconstructing τ

- Use Neural Net to separate τ from background
  - NN detects $\tau \to$ hadrons ν_τ , $\tau \to e\nu_e\nu_\tau$
  - input: EM energy and track p_T distributions
  - trained on MC, cut NN>0.8



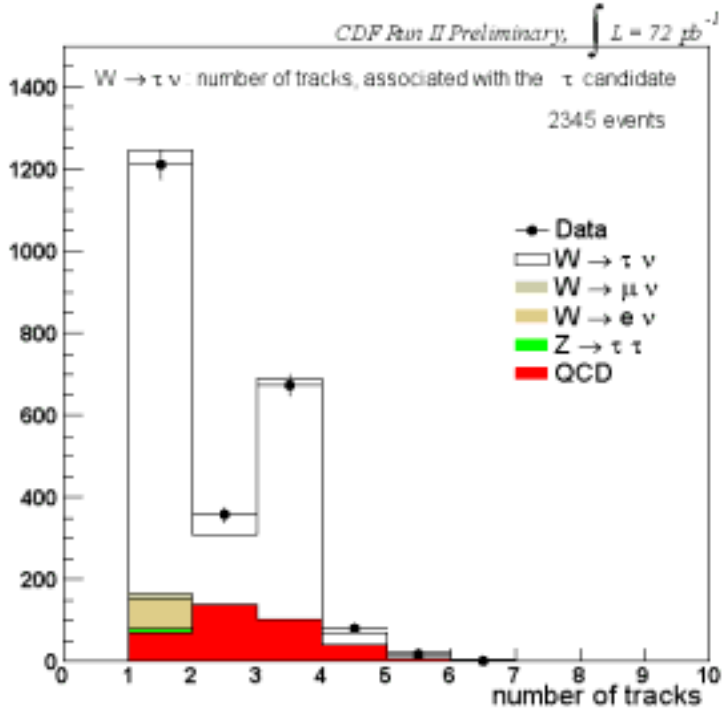


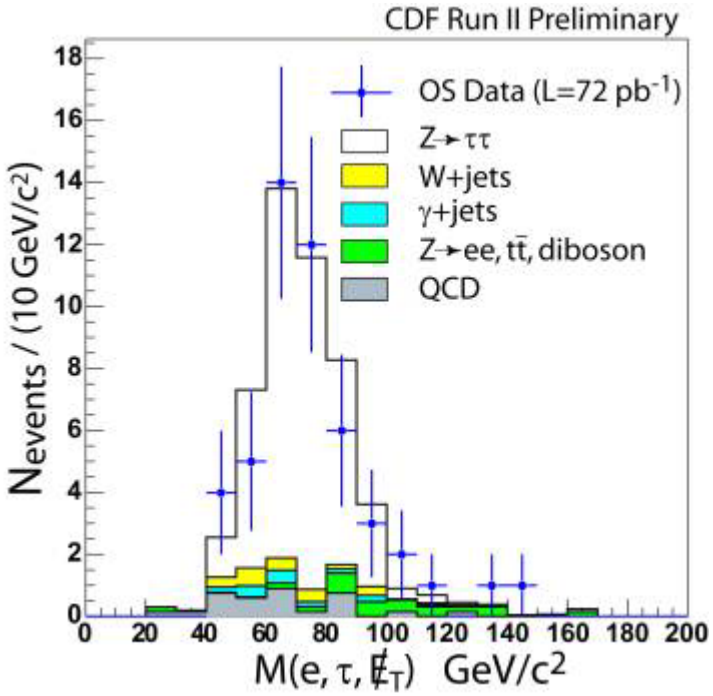


- $Z \to \tau^+\tau^-$ signal
  - 1 NN τ and 1 $\tau \to \mu\nu\nu$
  - 1946 events found in 207pb^{-1}
  - (55±2)% background from misidentified τ's
  - $A \cdot \varepsilon$ = (1.65±0.09)%

CDF: τ results

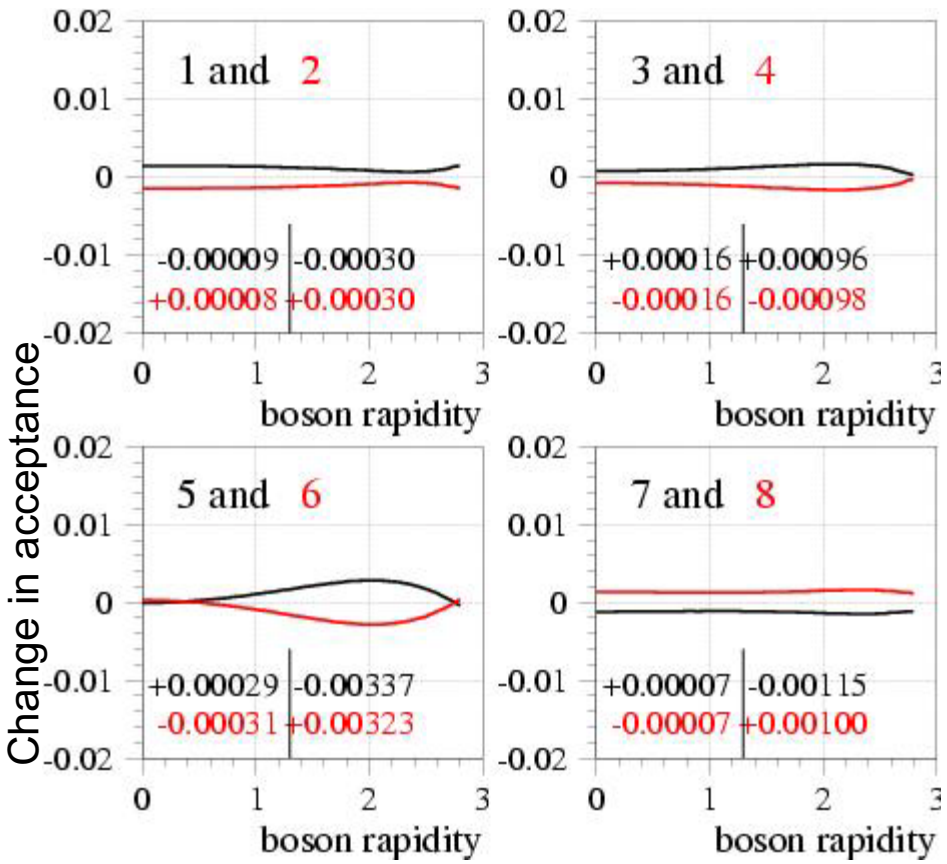
- Look for hadronic tau decays
  - Narrow isolated jet
  - Low track multiplicity
  - mass of (tracks, π^0) < m(τ)
- $Z \rightarrow \tau^+\tau^-$ signal
  - 1 hadronic τ and 1 $\tau \rightarrow e\nu\nu$ decay





	events	A·ε	backg
$Z \rightarrow \tau^+\tau^-$ 72pb^{-1}	50	~0.5%	(21±6)%
$W \rightarrow \tau\nu$ 72pb^{-1}	2345	(0.91±0.05)%	(26±3)%

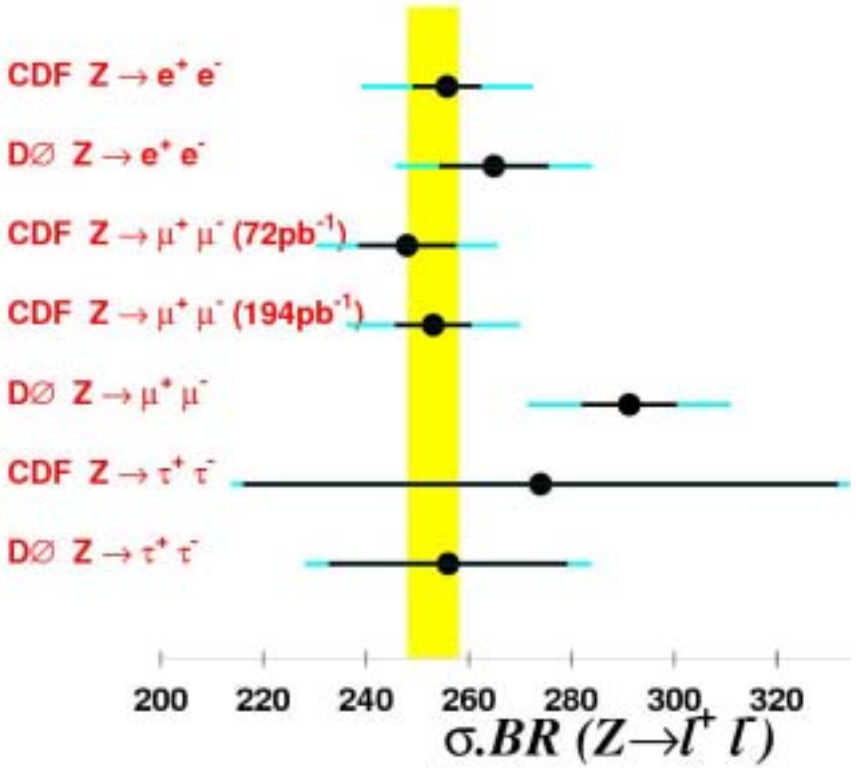
Estimating PDF Uncertainties

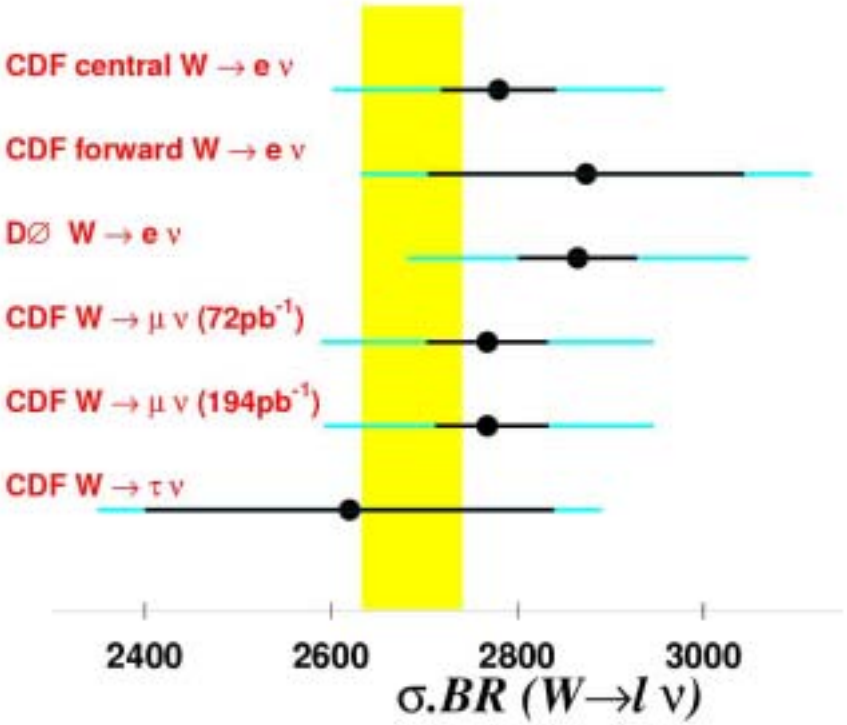


- PDF uncertainty on acceptance is largest systematic
- CTEQ suggested method
- NNLO CTEQ6L provides:
  - default PDFs
  - 20 pairs of error PDFs, corresponding to varying each parameter in 90% CL interval
- Use numerical integration to calculate change in acceptance for pair
- MRST error sets also checked

Cross Section Results

- Black: stat + syst error
- Aqua: luminosity error
- Yellow: NNLO prediction





Inclusive Cross Sections Results

CDF (central) $\sigma \cdot \mathrm{BR}(W \to e\nu) = 2780 \pm 14\,(stat) \pm 60\,(sys) \pm 167\,(lum)$ pb

CDF (forward) $\sigma \cdot \mathrm{BR}(W \to e\nu) = 2874 \pm 34\,(stat) \pm 167\,(sys) \pm 172\,(lum)$ pb

DØ $\sigma \cdot \mathrm{BR}(W \to e\nu) = 2865 \pm 8\,(stat) \pm 63\,(sys) \pm 40\,(pdf) \pm 186\,(lum)$ pb

CDF $\sigma \cdot \mathrm{BR}(W \to \mu\nu) = 2768 \pm 12\,(stat)\,{}^{+\,65}_{-\,55}\,(sys) \pm 166\,(lum)$ pb

CDF $\sigma \cdot \mathrm{BR}(W \to \tau\nu) = 2620 \pm 70\,(stat) \pm 210\,(sys) \pm 160\,(lum)$ pb

NNLO prediction
Stirling, Van Neerven

$\sigma \cdot \mathrm{BR}(p\bar{p} \to W \to \ell\nu) = 2687 \pm 54$ pb

CDF $\sigma \cdot \mathrm{BR}(Z \to e^+e^-) = 255.8 \pm 3.9\,(stat) \pm 5.5\,(sys) \pm 15.3\,(lum)$ pb

DØ $\sigma \cdot \mathrm{BR}(Z \to e^+e^-) = 255.8 \pm 3.9\,(stat) \pm 8.5\,(sys) \pm 5.1\,(pdf) \pm 15.3\,(lum)$ pb

CDF $\sigma \cdot \mathrm{BR}(Z \to \mu^+\mu^-) = 253.1 \pm 4.2\,(stat)\,{}^{+8.3}_{-6.4}\,(sys) \pm 14.9\,(lum)$ pb

DØ $\sigma \cdot \mathrm{BR}(Z \to \mu^+\mu^-) = 291.3 \pm 3.0\,(stat) \pm 6.9\,(sys) \pm 18.9\,(lum)$ pb

CDF $\sigma \cdot \mathrm{BR}(Z \to \tau^+\tau^-) = 242 \pm 49\,(stat) \pm 31\,(sys) \pm 16\,(lum)$ pb

DØ $\sigma \cdot \mathrm{BR}(Z \to \tau^+\tau^-) = 256 \pm 16\,(stat) \pm 17\,(sys) \pm 16\,(lum)$ pb

NNLO prediction
Stirling, Van Neerven

$\sigma \cdot \mathrm{BR}(p\bar{p} \to Z \to \ell\ell) = 253.1 \pm 5.0$ pb

Cross Section Ratio, R

$$R = \frac{\sigma(p\bar{p} \to W \to \ell\nu)}{\sigma(p\bar{p} \to Z \to \ell\ell)}$$

- Ratio of W and Z cross sections
  - Luminosity, and many systematics cancel

CDF (72 pb^{-1} central e, μ combined) $R = 10.92 \pm 0.15(stat) \pm 0.14(sys)$

DØ (e) $R = 10.82 \pm 0.16(stat) \pm 0.25(sys) \pm 0.13(pdf)$

NNLO prediction $R = 10.69 \pm 0.08$

BR(W→ℓν) and Γ(W)

CDF:

$$R = \frac{\sigma(p\bar{p} \to W \to \ell\nu)}{\sigma(p\bar{p} \to Z \to \ell\ell)} = 10.92 \pm 0.15(stat) \pm 0.14(sys)$$

$$R = \frac{\sigma(p\bar{p} \to W)}{\sigma(p\bar{p} \to Z)} \cdot \frac{\Gamma(Z)}{\Gamma(Z \to \ell\ell)} \cdot \frac{\Gamma(W \to \ell\nu)}{\Gamma(W)}$$

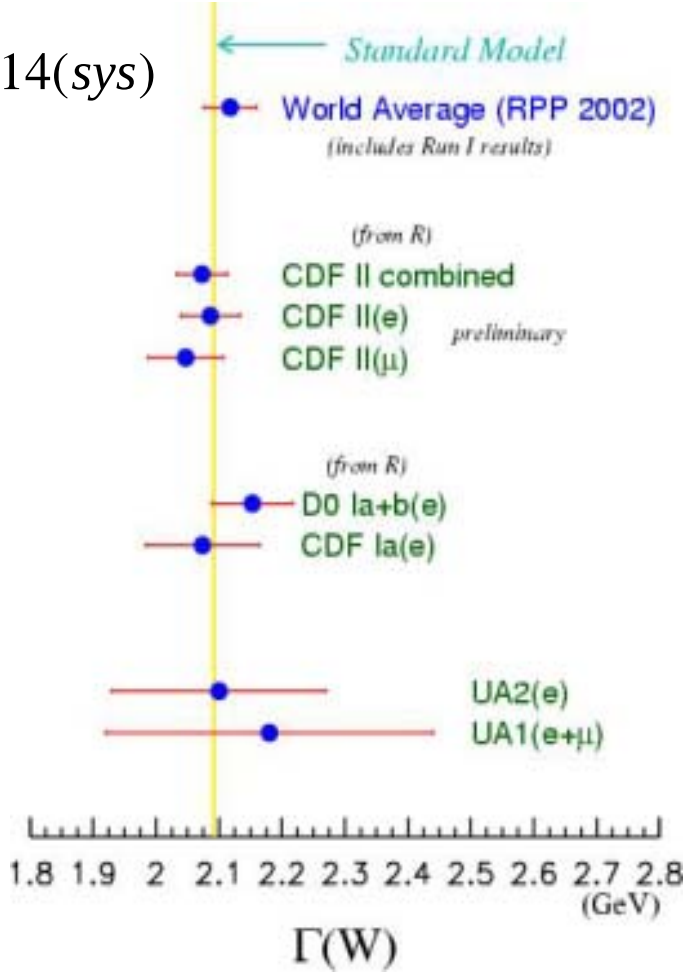
3.3677±0.024
NNLO (PDG)

From LEP:
(3.366 ± 0.002)%

$$\mathrm{BR}(W \to \ell\nu) = 0.1089 \pm 0.0022$$

Using NNLO calculation
Γ(W→ℓν)=226.4 ±0.3 MeV (PDG):

$$\Gamma(W) = 2079 \pm 41\ \mathrm{MeV}$$



Current World Average: 2124±41 MeV

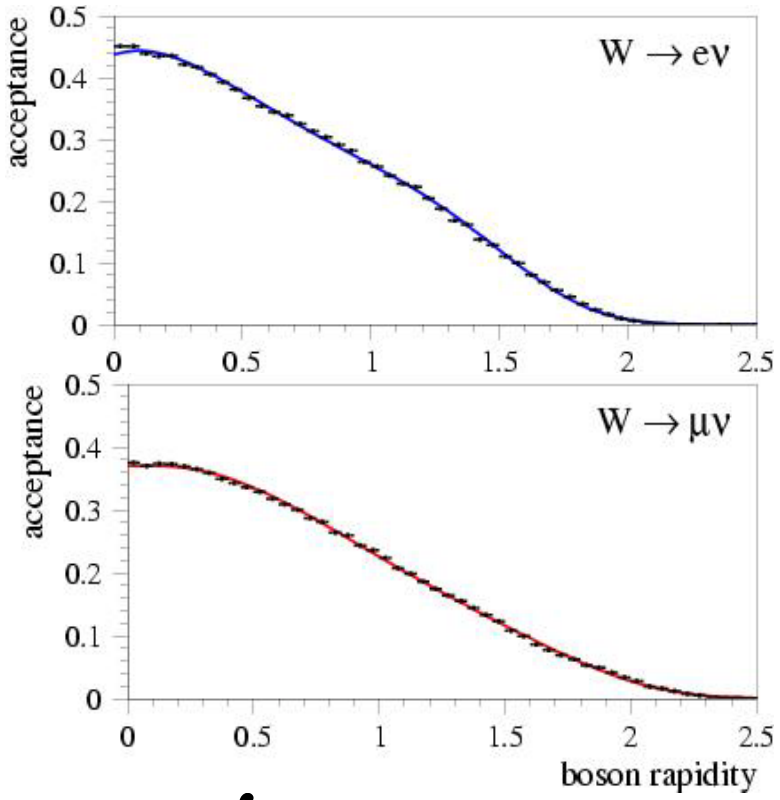
Conclusions & prospects for more data

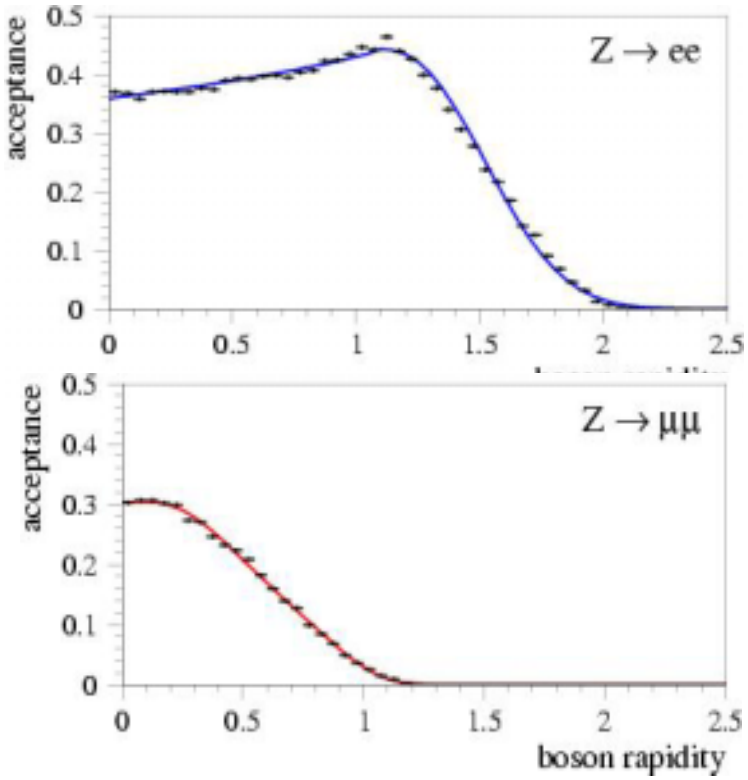
- We've measured inclusive W and Z production at the Tevatron in all 6 leptonic channels.
- More improvements will be made on R and Γ(W)
- Combine CDF and DØ results!
- Cross section measurements in e and μ channels are already systematics limited
  - Some systematic errors will reduce with statistics
  - Main uncertainty comes from PDF
- Think smarter! Select events in such a way to cancel errors
- Use W and Z cross sections for normalization?
  - Measurements have ~2% uncertainty
  - Luminosity error is 6%

Backup Slides

PDF Uncertainties II

- Acceptance as a function of boson rapidity





$$A_W \propto 4 \int_0^{y\,\max} x_a x_b u(x_a) d(x_b) A_W(y)\, dy$$

$$x_{a,b} = \frac{M_W}{\sqrt{s}} \exp(\pm y)$$

$$A_Z \propto \int_0 x_a x_b \left(C_u u(x_a) u(x_b) + C_d d(x_a) d(x_b)\right) A_Z(y)\, dy$$

Luminosity Measurement at CDF

- Luminosity (L) from Cherenkov Luminosity Counters:
- Discriminating primary (from ppbar)-secondary particles
- Time resolution

→ Well adapted for high-L collider

$$\mu_\alpha \cdot f_{BC} = \sigma_{pp} \cdot \varepsilon_\alpha^{clc} \cdot L$$

α: selection criteria for pp coll.

μ_a: #int/Bunch Crossing (BC)

f_{BC}: BC Frequency

σ_{pp}: $p\bar{p}$ inelastic cross section

ε_α^{clc} :Efficiency of CLC

Increasing Lum.

"0" hits $\mu_{clc} = -\ln\left(\frac{N_{zeroBC}}{N_{totalBC}}\right)$

#hits $\mu_{clc} = \frac{\langle N_{Hits/BC} \rangle}{\langle N_{Hits/p\bar{p}} \rangle}$

#part $\mu_{clc} = \frac{\sum A_i}{\langle A_{p\bar{p}} \rangle}$

Dominant uncertainties from:

e_a = MC simulation.

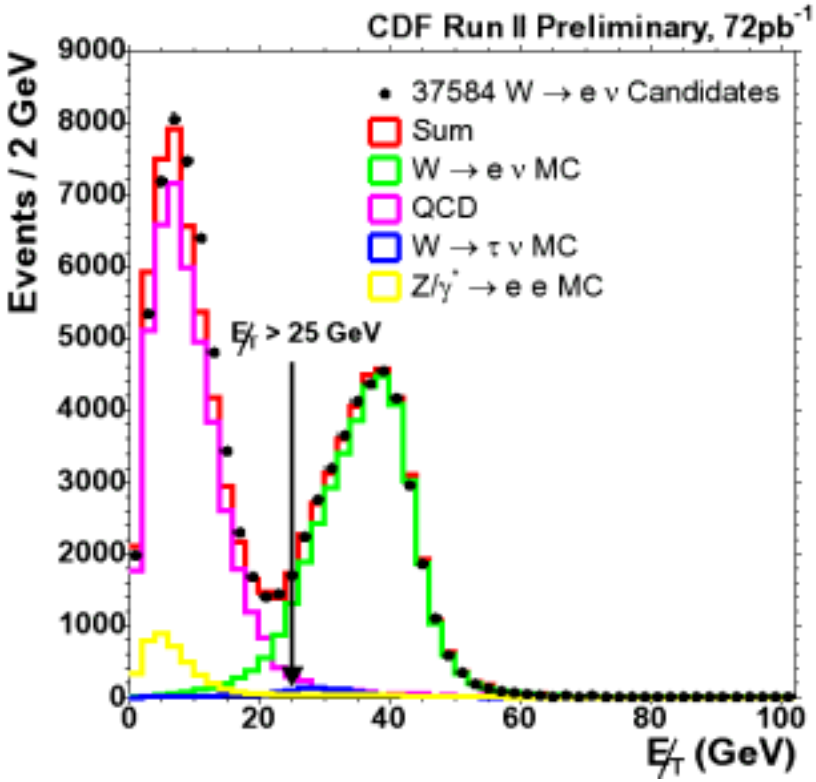
σ_{pp}= 60.4±1.4 mb (measured by CDF)

μ_{clc}: Different definitions

Systematic uncertainty ~5%

Neutrino reconstruction

- CDF and DØ are hermetic transverse to the beam
- Colliding partons have no transverse momentum
- Measure neutrinos by the amount of energy missing transverse to the beam
- For W$\rightarrow \ell\nu$ candidates calculate transverse mass (M_T) from *x* and *y* components



$$M_T = \sqrt{(E_T(\ell) + E_T(\nu))^2 - (p_x(\ell) + p_x(\nu))^2 - (p_y(\ell) + p_y(\nu))^2}$$

Systematic Uncertainties

- One example: DØ $W \rightarrow e\nu$, $Z \rightarrow e^+e^-$ cross section

Source	Relative Uncertainty (%) on σ_W	σ_Z	R
stat			
Number of Events	0.29	1.47	1.50
sys			
Stat. Error on Efficiencies	0.72	0.77	0.58
Background Subtraction	0.35	0.82	0.47
Fake Track Match Prob.	0.45	n/a	0.45
Monte Carlo Parameters	1.13	0.84	1.41
Trigger Eff	0.59	0.06	0.53
Electron ID	1.43	2.86	1.43
Track Match	0.52	0.35	0.17
Total **sys**	2.19	3.21	2.27
pdf			
PDF	1.41	1.94	1.21
lumi			
Luminosity	6.5	6.5	n/a

Cross sections already systematic limited

Largest error from PDFs, ID cuts