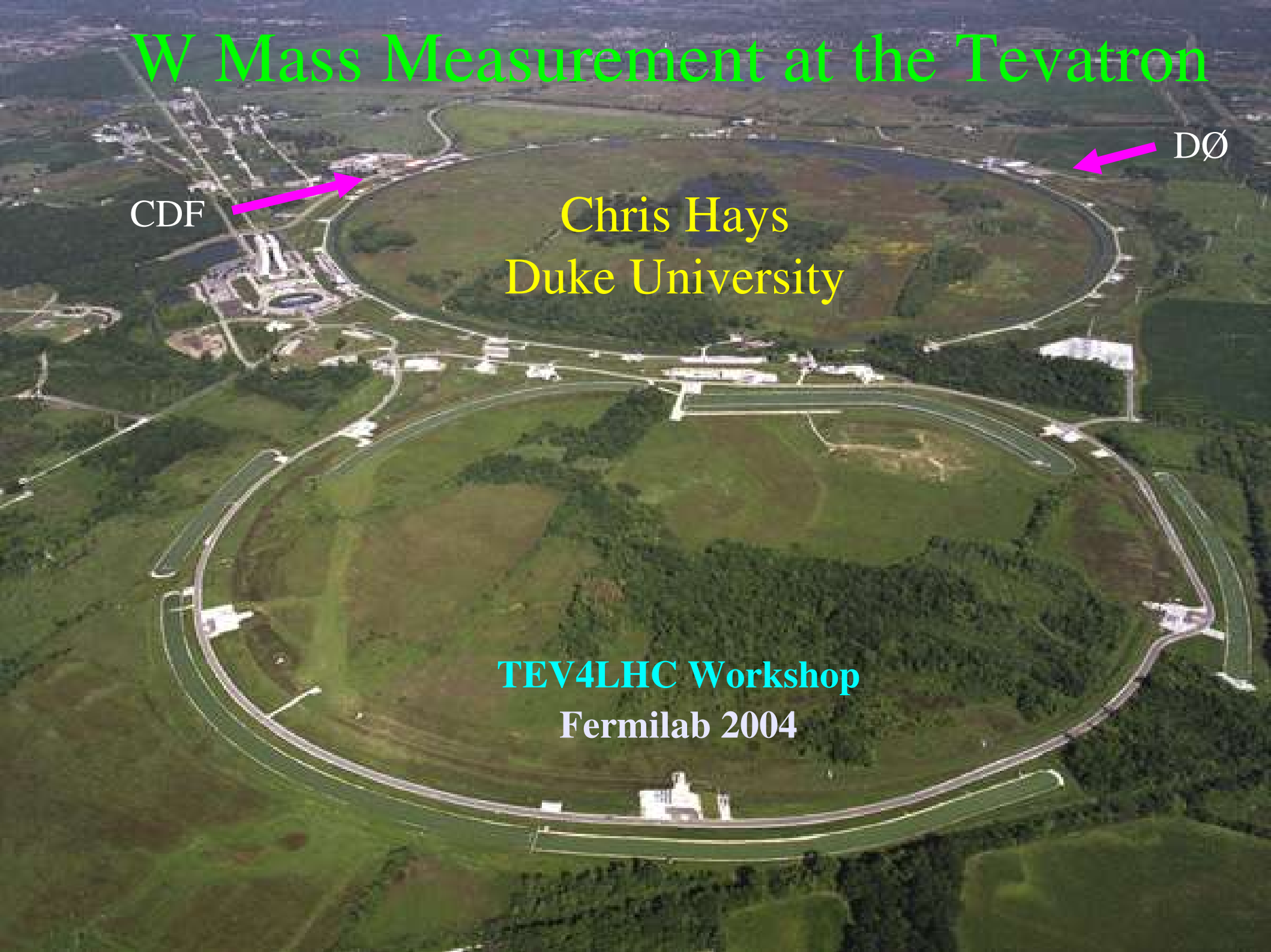
W Mass Measurement at the Tevatron

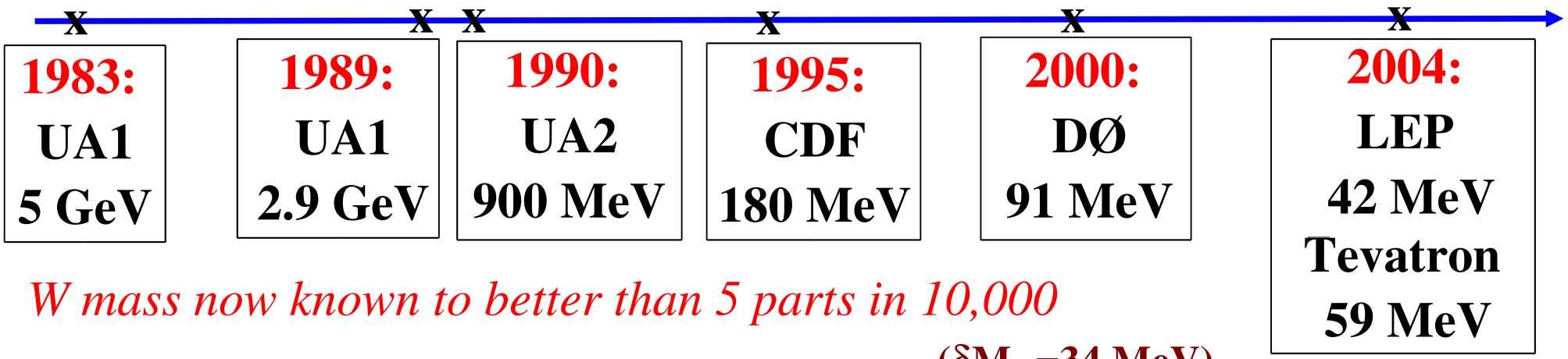


Chris Hays
Duke University

TEV4LHC Workshop
Fermilab 2004

Past, Present, and Future

Precision of direct measurements:



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

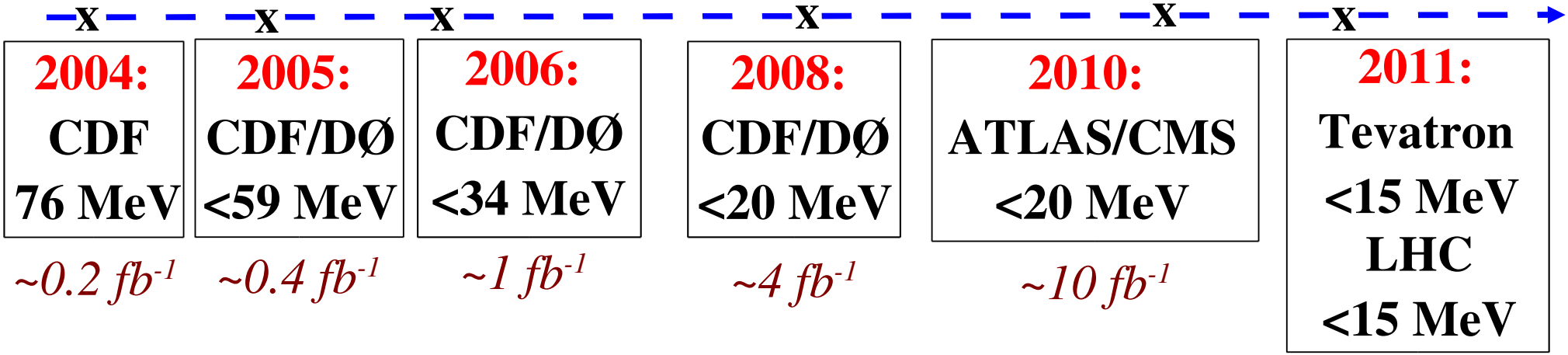
(δM_W=34 MeV)

CDF: 79 MeV

DØ: 84 MeV

Looking forward:

* Tevatron Run 2 has quadrupled Run 1 CDF, DØ data sets
* CDF has analyzed first 200 pb^{-1} of data and determined uncertainties



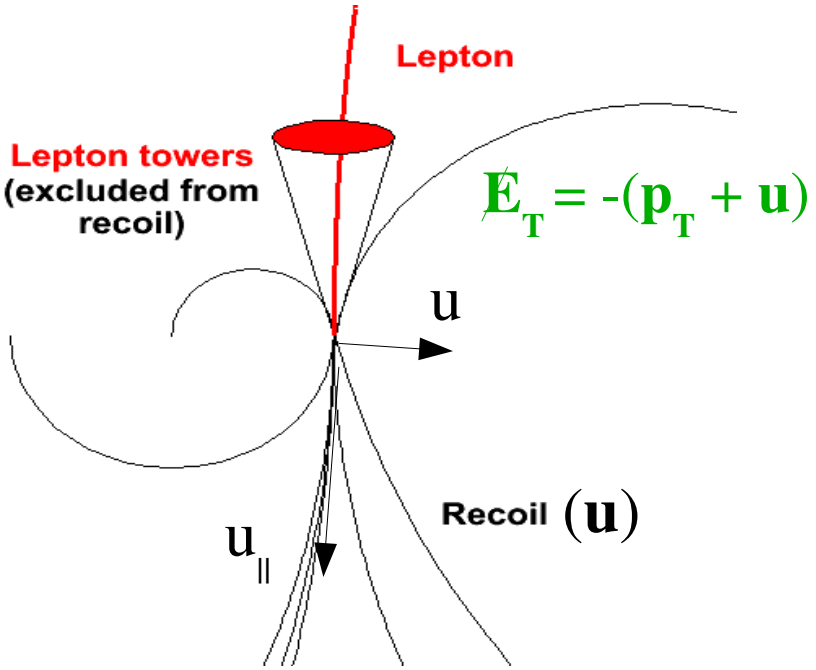
W Mass Fit Distributions

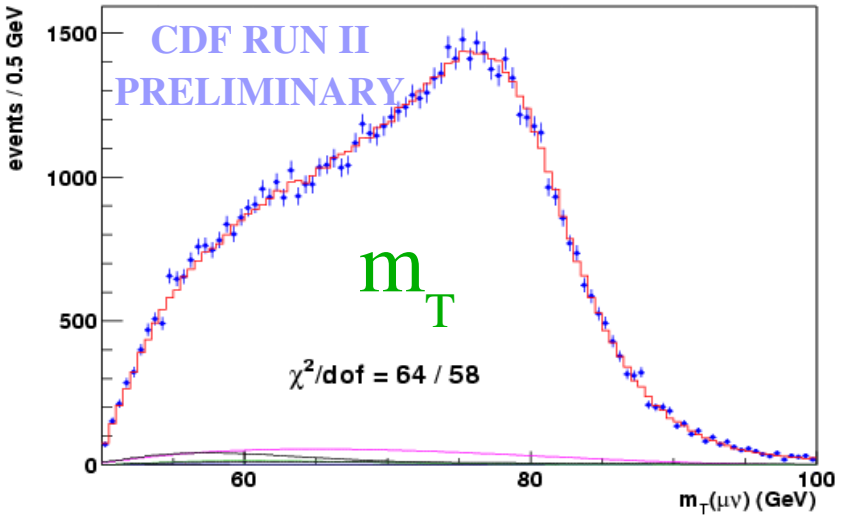
Transverse mass

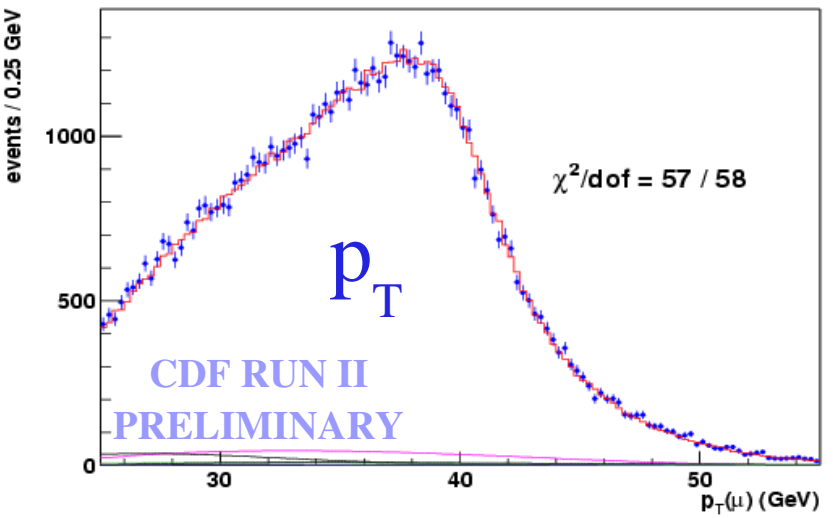
* $m_T^2 = 2p_T \not{E}_T(1-\cos(\Delta\phi))$
* $m \sim 2\ p_T + u_{\parallel}$
* Low sensitivity to p_T^W
* Recoil modelling crucial

Lepton p_T

* $m \sim 2\ p_T$
* Insensitive to recoil
* p_T^W modelling crucial







CDF Run 2 Uncertainties

Tower removal:

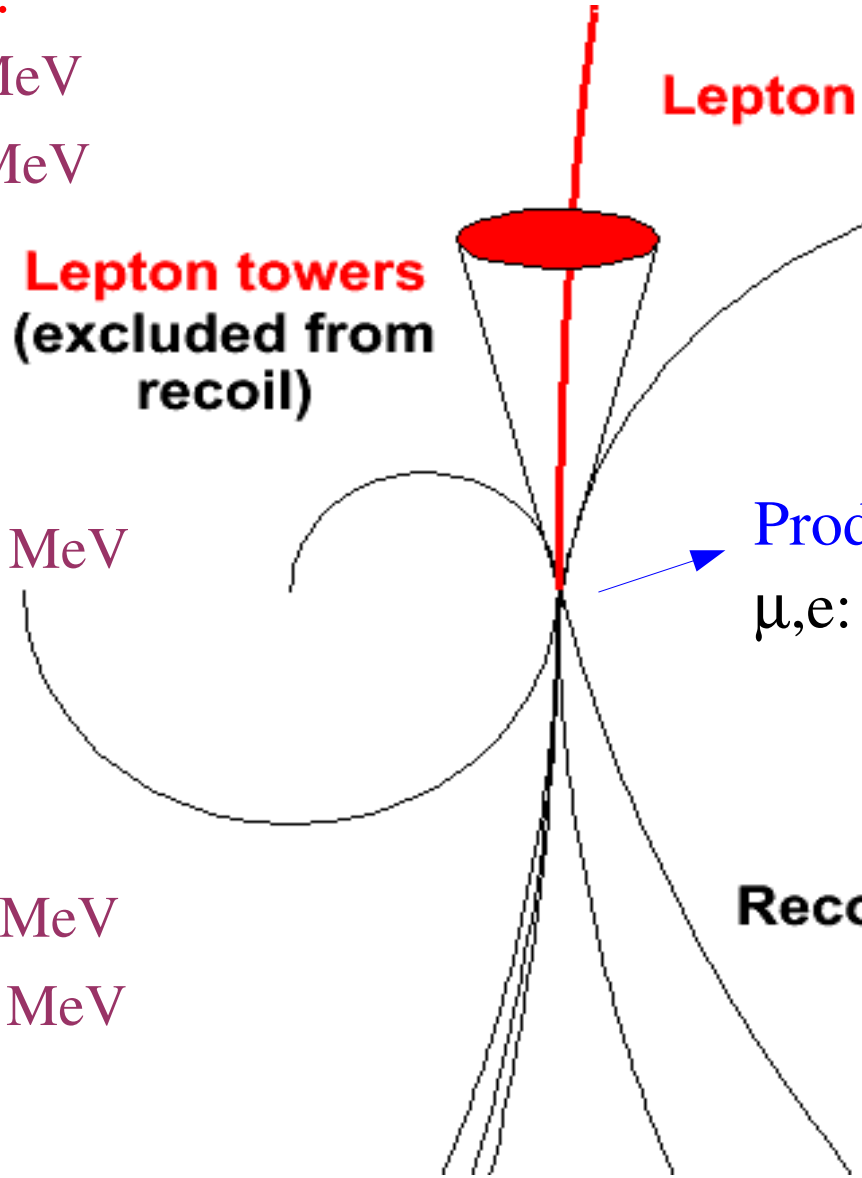
μ: $\delta M_W = \pm$ 10 MeV

e: $\delta M_W = \pm$ 20 MeV

Scale and resolution:

μ: $\delta M_W = \pm$ 30 MeV

e: $\delta M_W = \pm$ 70 MeV



Transverse mass fit

Backgrounds:

μ,e: $\delta M_W = \pm$ 20 MeV

Production and decay model:

μ,e: $\delta M_W = \pm$ 30 MeV

CDF RUN II
PRELIMINARY

Statistics:

μ: $\delta M_W = \pm$ 50 MeV

e: $\delta M_W = \pm$ 45 MeV

Scale and resolution:

μ,e: $\delta M_W = \pm$ 50 MeV

Production and Decay Model Uncertainties

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

CDF RUN II
PRELIMINARY

Parton Distribution Functions

Uncertainty determined from
CTEQ eigenvectors + MRST
W charge asymmetry
will reduce uncertainty

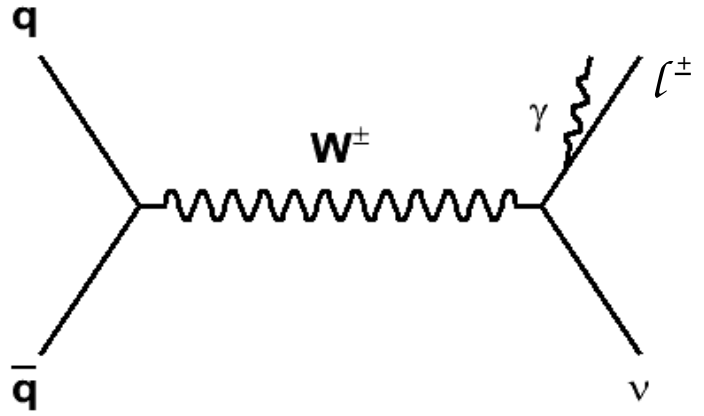
→ $\delta M_W \sim 5$ MeV with 4 fb^{-1}

LHC: No charge asymmetry
Constrain PDFs with lepton
distributions from *W* and *Z*

→ $\delta M_W \sim 10$ MeV achievable

QED Radiative Corrections

Single-photon FSR modelled



2-photon FSR needs to be added

→ $\delta M_W \sim 5$ MeV with 4 fb^{-1}
(also at LHC)

Production and Decay Model Uncertainties

p_T^W Model

Uncertainties determined from RESBOS parameters g_1, g_2, g_3

Parameters constrained by Run 1 Z p_T distribution

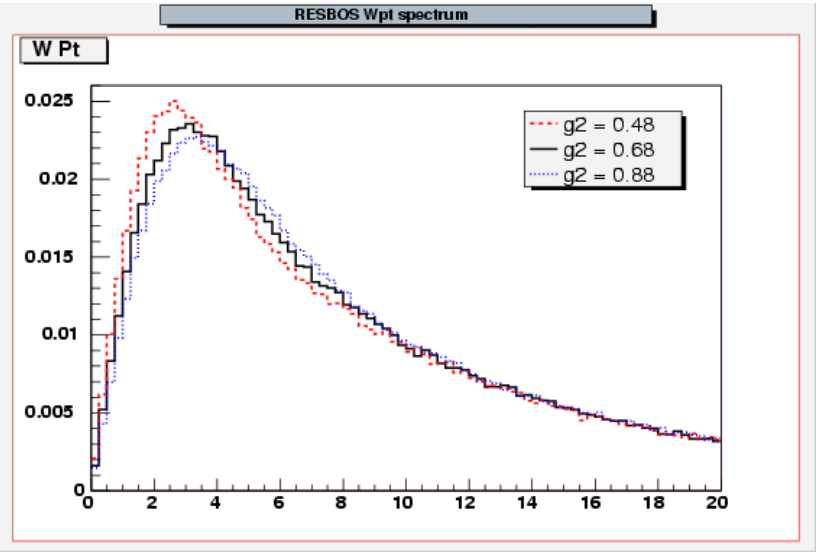
$g_2 = 0.68 \pm 0.12$ GeV^2

$g_3 = -0.60 \pm 0.30$

CDF RUN II PRELIMINARY

p_T fit: $\delta M_W = \pm 27$ MeV

m_T fit: $\delta M_W = \pm 13$ MeV



→ $\delta M_W \sim 5$ MeV with 4 fb^{-1} (p_T fit: 10 MeV)

LHC: Large *Z* statistics

→ $\delta M_W \sim 5$ MeV achievable (also for p_T fit)

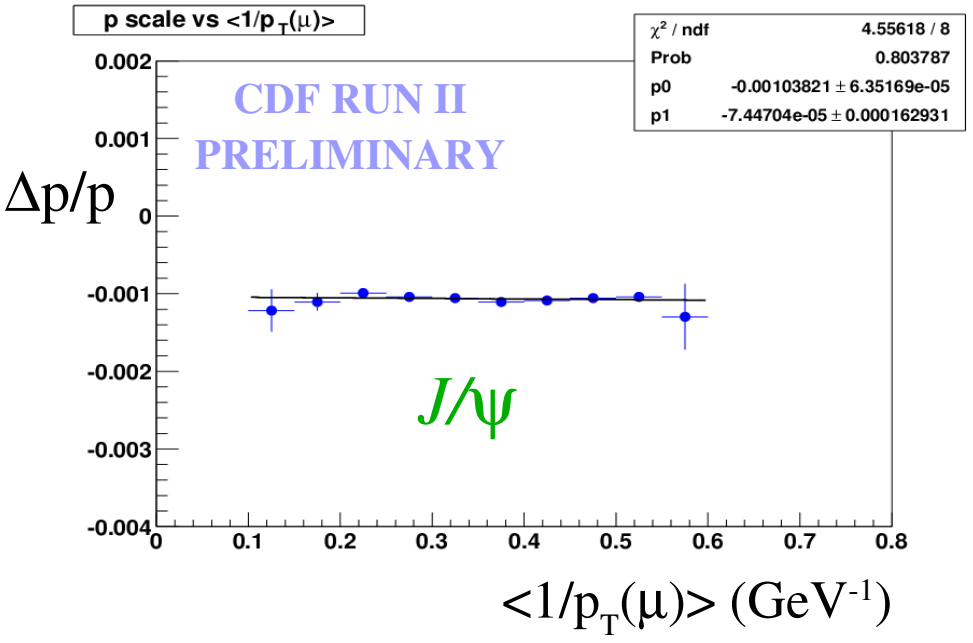
Γ_W

70 MeV uncertainty from world average of direct measurements

→ $\delta M_W \sim 5$ MeV with 4 fb^{-1}
(also at LHC)

CDF Run 2 Muon Momentum Calibration

Set momentum scale using J/ψ and upsilon decays to muons



Uncertainty from difference in scales:

$\delta M_W = \pm$ 15 MeV

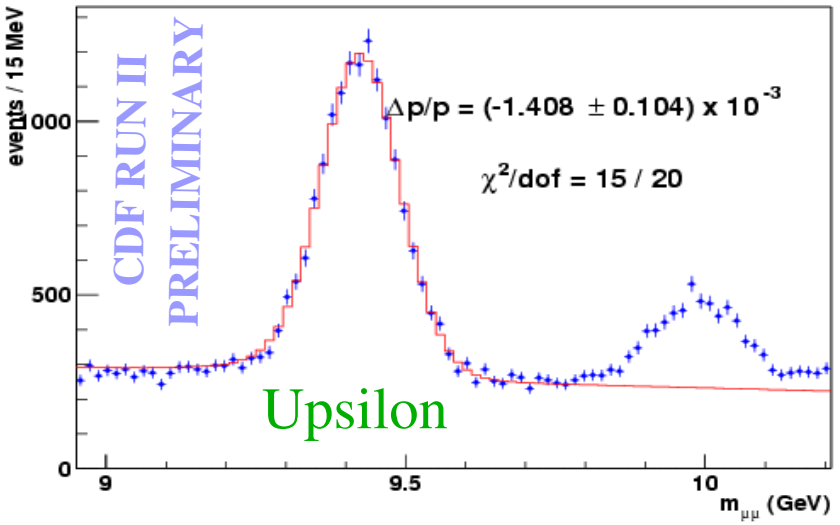
Post-alignment-correction uncertainty:

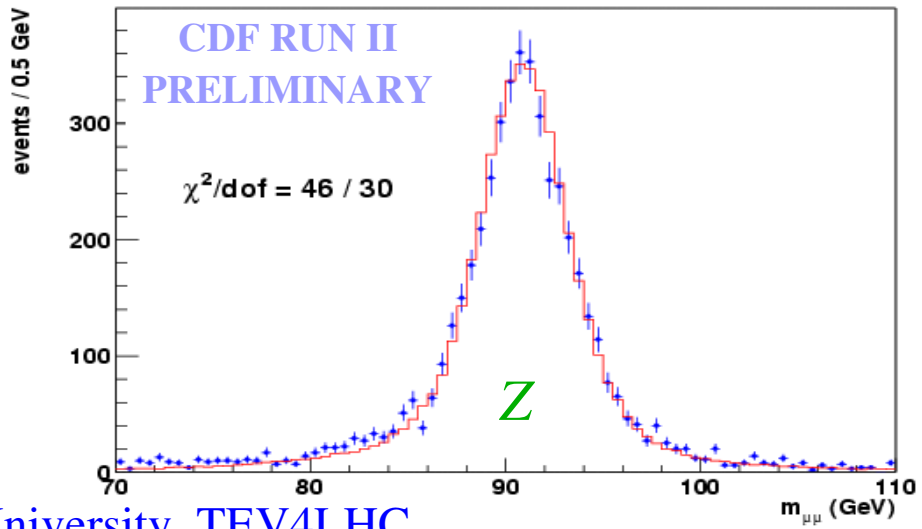
$\delta M_W = \pm$ 20 MeV

Resolution uncertainty (from *Z* decays):

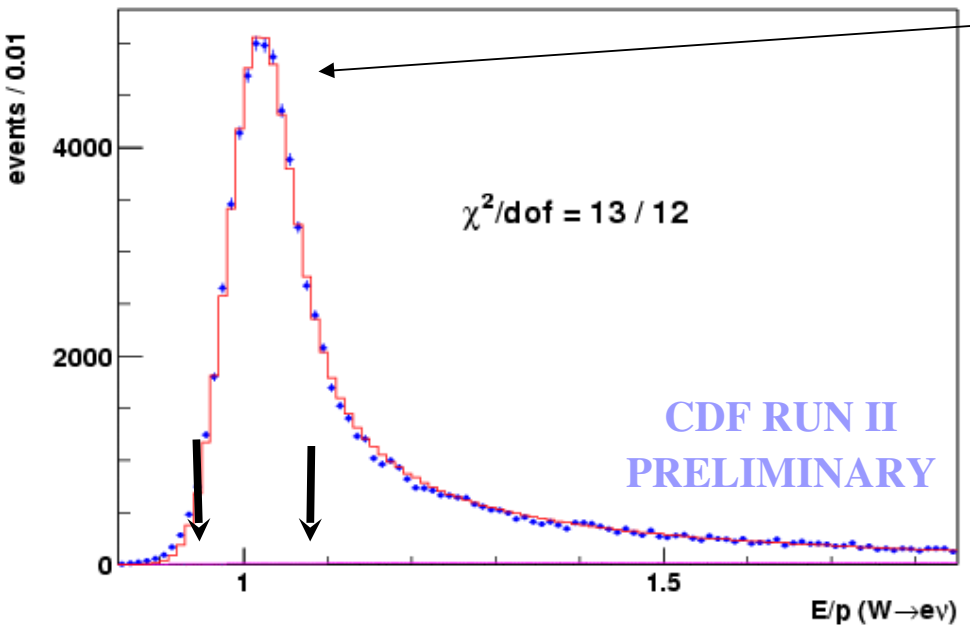
$\delta M_W = \pm$ 12 MeV

→ $\delta M_W \sim$ 5 MeV with 4 fb^{-1} (also at LHC)





CDF Run 2 Electron Calibration

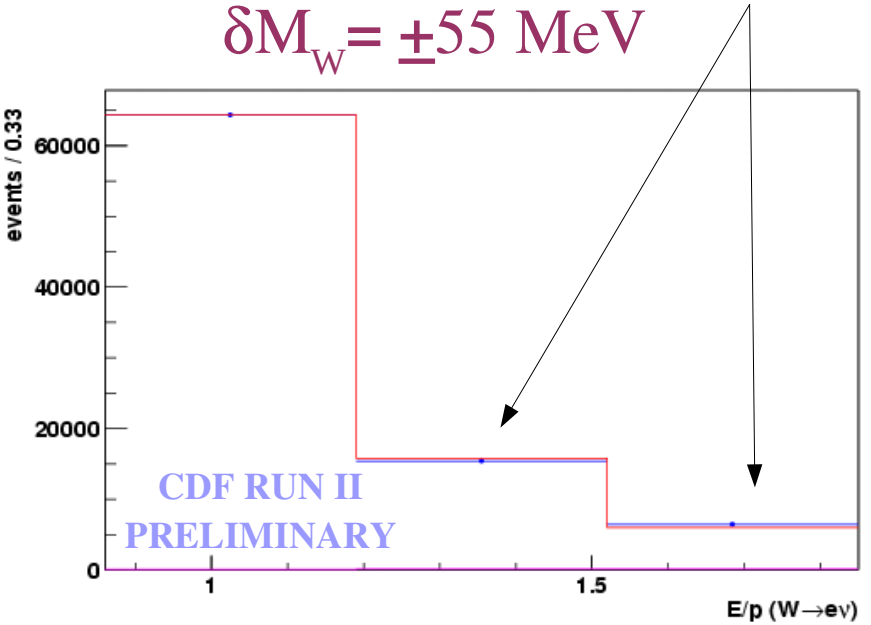


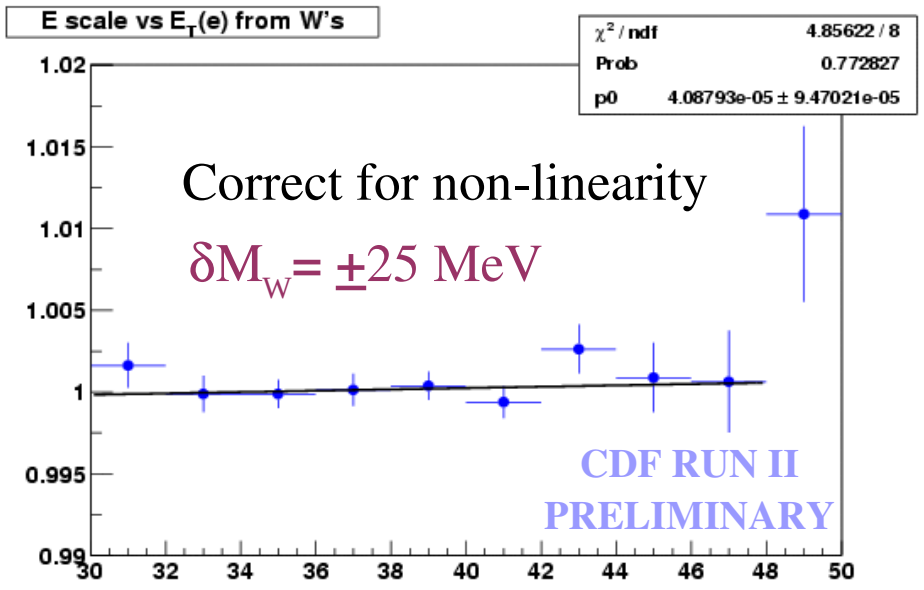
Set energy scale using *E/p* peak

$\delta M_W = \pm 35$ MeV

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

$\delta M_W = \pm 55$ MeV





Resolution uncertainty (from *Z* decays):

$\delta M_W = \pm 12$ MeV

→ $\delta M_W \sim 15$ MeV with 4 fb^{-1} (also at LHC)

CDF Run 2 Recoil Measurement

Measure hadronic recoil by summing over all calorimeter towers

* Remove towers with energy deposited by lepton

0.1 x 0.25 η–ϕ

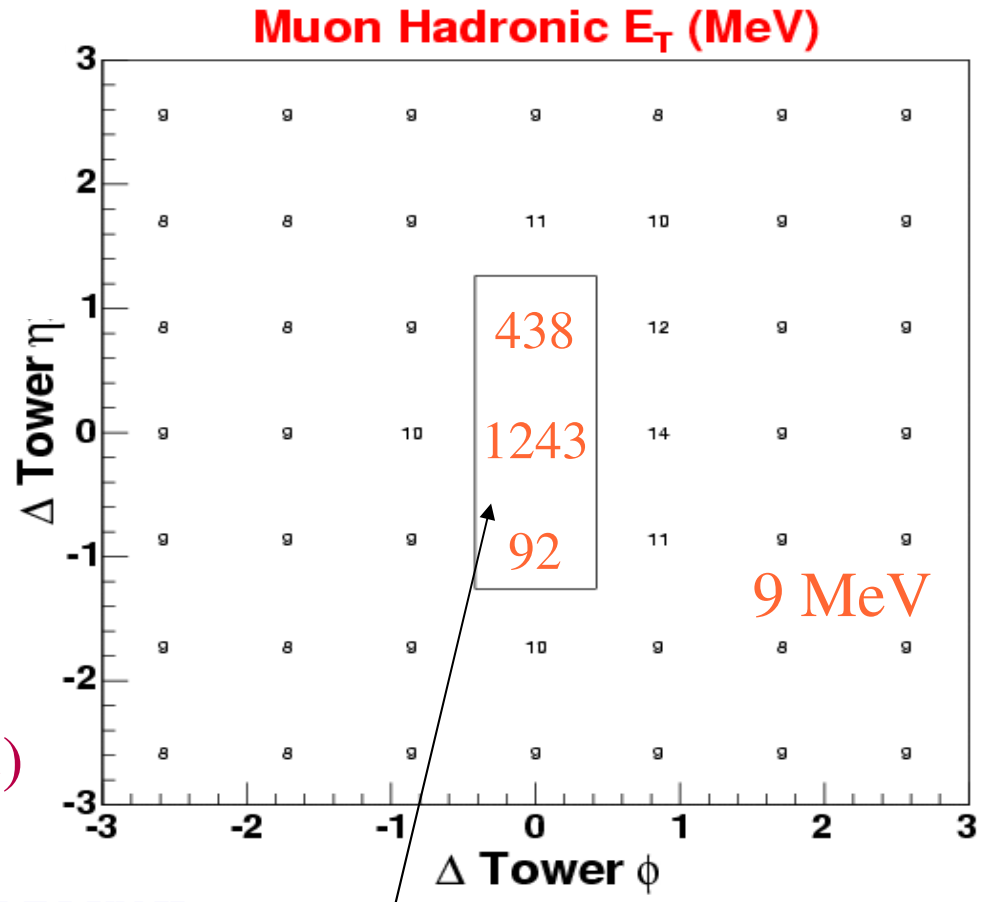
Estimate removed recoil energy using towers separated in ϕ

μ: $\delta M_W = \pm 10$ MeV

e: $\delta M_W = \pm 20$ MeV

→ $\delta M_W \sim 5$ MeV with 4 fb^{-1}

(also at LHC)



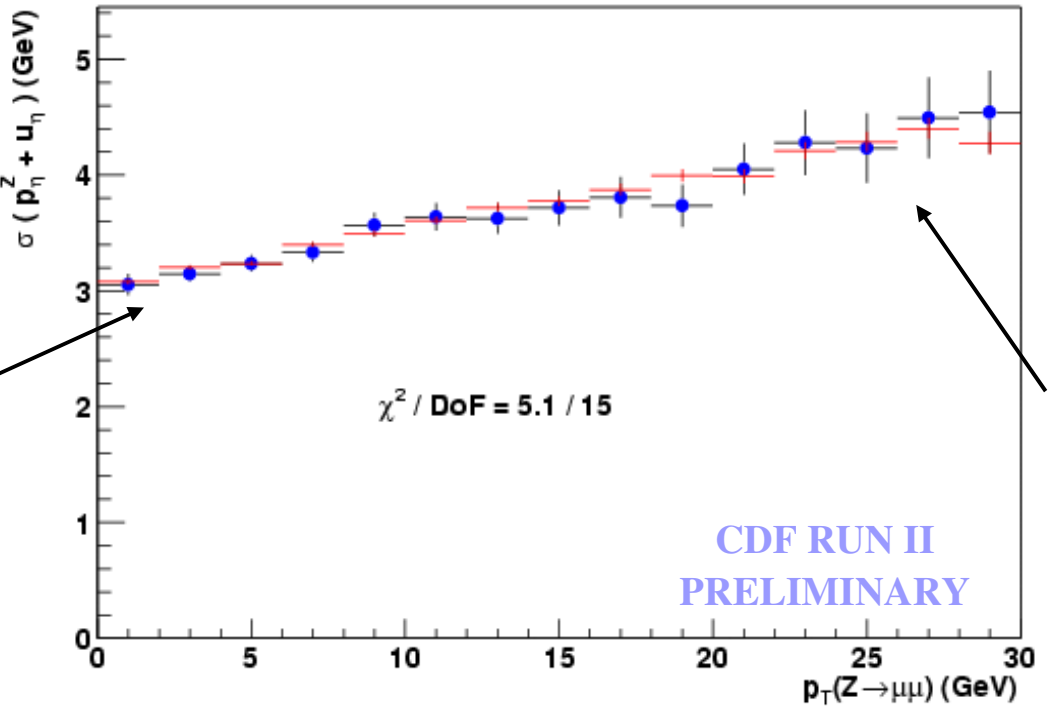
CDF Run 2 Recoil Model

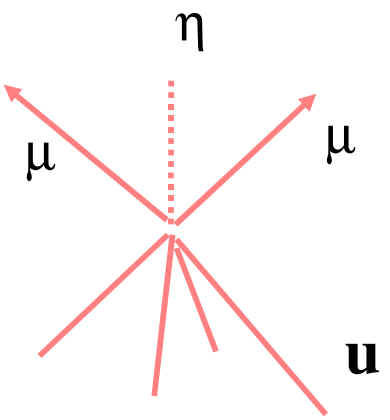
* Parametrize hadronic response: $R = \mathbf{u}_{meas}/\mathbf{u}_{true}$ ← $\mathbf{u}_{true}$ given by $p_T(Z)$

$\delta M_W = \pm 20$ MeV

* Resolution model incorporates terms from underlying event and jet resolution

Tune parameters using $Z \rightarrow \mu\mu$ events





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

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

$\delta M_W = \pm 42$ MeV

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

→ $\delta M_W \sim 10$ MeV with 4 fb^{-1} (also at LHC)

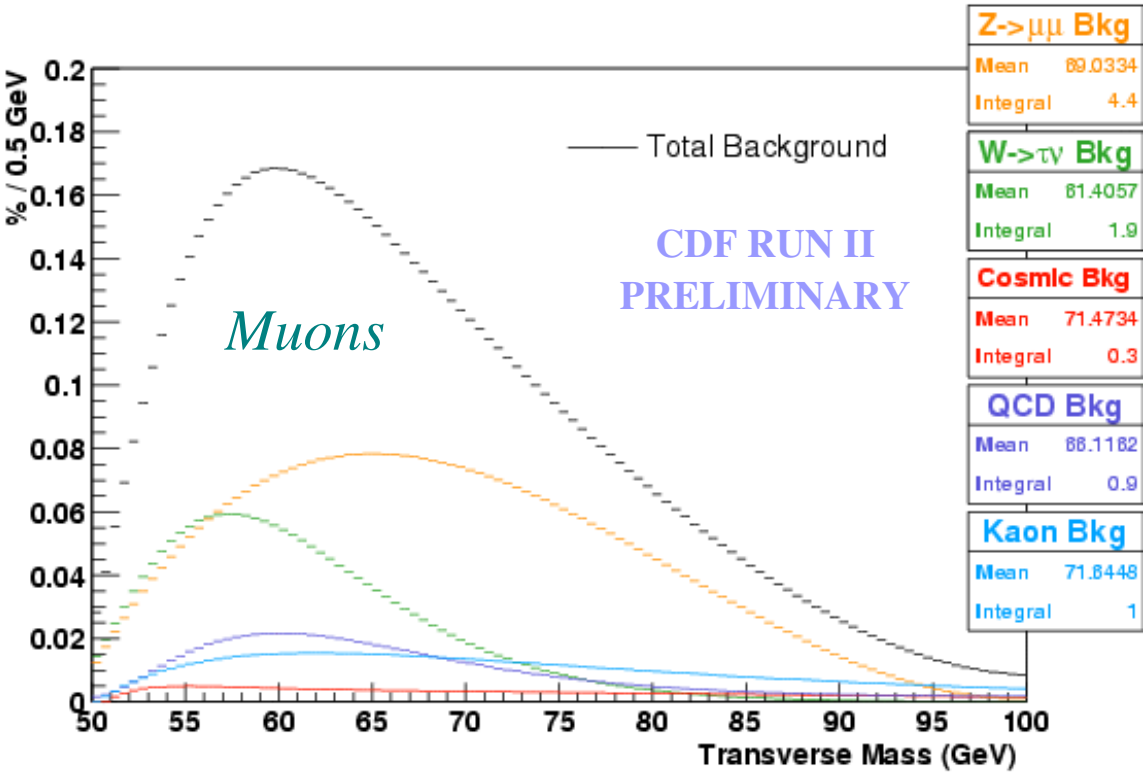
CDF Run 2 Backgrounds

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



$\delta M_W = \pm 20$ MeV

$\longrightarrow \delta M_W \sim 5$ MeV with 4 fb^{-1} (also at LHC)

Milestones

Systematic	0.2 fb^{-1} μ (e)	0.4 fb^{-1} μ (e)	1 fb^{-1} μ (e)	4 fb^{-1} μ (e)	LHC μ (e)
Lepton Energy Scale and Resolution	30 (70)	20 (50)	10 (30)	5 (15)	5 (15)
Recoil Scale and Resolution	50	30	15	10	10
Backgrounds	20	15	10	5	5
Lepton Tower Removal	10 (20)	5 (10)	5	5	5
Production and Decay Model	20	15	10	10	13
Statistics	50 (45)	35 (30)	22 (20)	11 (10)	2
Total	85 (105)	57 (70)	37 (42)	20 (24)	19 (23)
Combined e μ	76	51	32	18	18

CDF RUN II PRELIMINARY

* Improve understanding of passive material (E/p tail)
* Improve COT alignment
* Understand *W/Z* differences in recoil model
* *W* p_T constrained with *Z* p_T

* Detailed understanding of upsilon/*Z* systematics
* PDF constrained with *W* charge asymmetry
* Include 2-photon FSR

Ratio Method

Can also measure mass by measuring Z transverse mass for each lepton

W transverse mass measurement gives ratio of W to Z masses

Potentially removes energy calibration uncertainty

Lower Z statistics (not an issue at LHC)

Are there additional systematics?

p_T^W uncertainty could be larger than m_T measurement

DØ Run 1 Experience (82 pb^{-1})

Source	Uncertainty (MeV)
Statistics	211
Electron Energy Scale	5
Underlying Event	30
Zero Suppression	5
Hadronic Resolution	15
Electron Efficiency (EC vs CC)	20

Summary

Now have Run 2 experience (first milestone hit)

Most systematics shrinking with increasing data

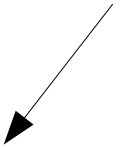
Experimental issues (CDF)

Recoil differences between W's and Z's

Electron energy calibration (passive material)

Should be soluble (still early)

Preliminary Run 2 results available



Theoretical issues

Modelling 2-photon FSR (in progress)

Update PDFs (need input from W charge asymmetry measurement)

Update p_T^W parameters (need input from Z p_T measurement)

Potential Improvements at the LHC

Can large Z statistics get recoil model below 10 MeV uncertainty?

Can PDF uncertainty get below 10 MeV?