W Mass and Width Measurements at the Tevatron

Sub-Z Workshop

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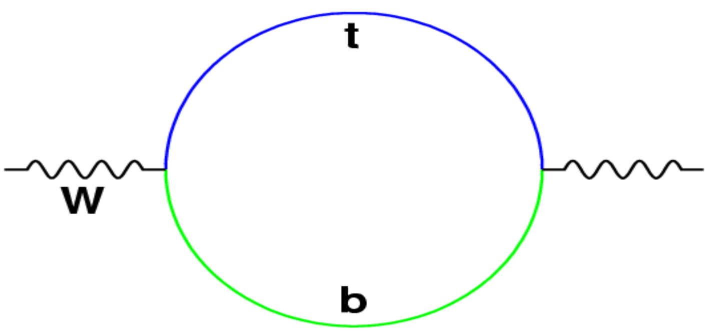
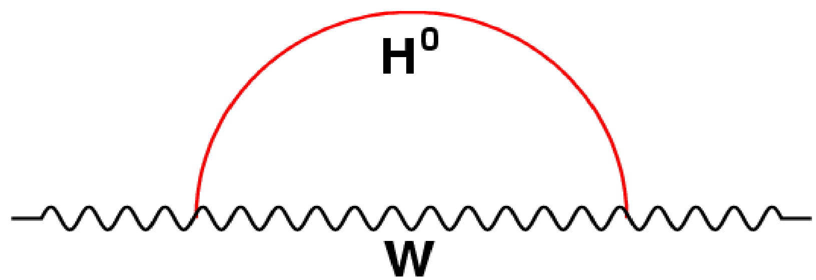
- Motivation
- Summary of Run 1 measurements
- Scaling of uncertainties in Run 2
- Summary

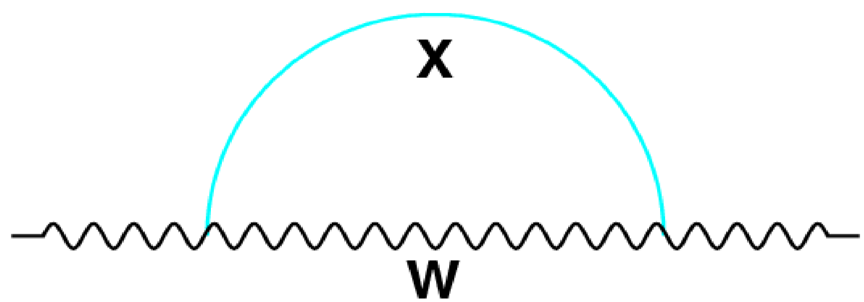
Motivation

- The W boson mass constrains $\rho = (M_W / M_Z \cos\theta_W)^2$
  - Unity at tree level
  - Radiative corrections from top quark, Higgs loops





- Contributions from new particles coupling to W's (example of quantum loop effect at $Q = M_W$)



Motivation

- $\Delta\rho = \rho - 1$ has
  - Quadratic top mass dependence
  - Logarithmic Higgs mass dependence (due to spin=0)
  - Sensitive to SuperSymmetric particles and exotica
- Current SM Higgs fit: $M_H = 91^{+55}_{-36}$ GeV (LEP Collaborations and LEPEWWG, hep-ex/0312023)
- Δm_{top} and $\Delta\alpha_{EM}(M_Z)$ contribute to Δm_H uncertainty equivalent to ΔM_W~26 MeV and ~15 MeV respectively
- Current world (Tevatron) average ΔM_W ~ 40 (60) MeV
  => need improvement in M_W precision

Motivation

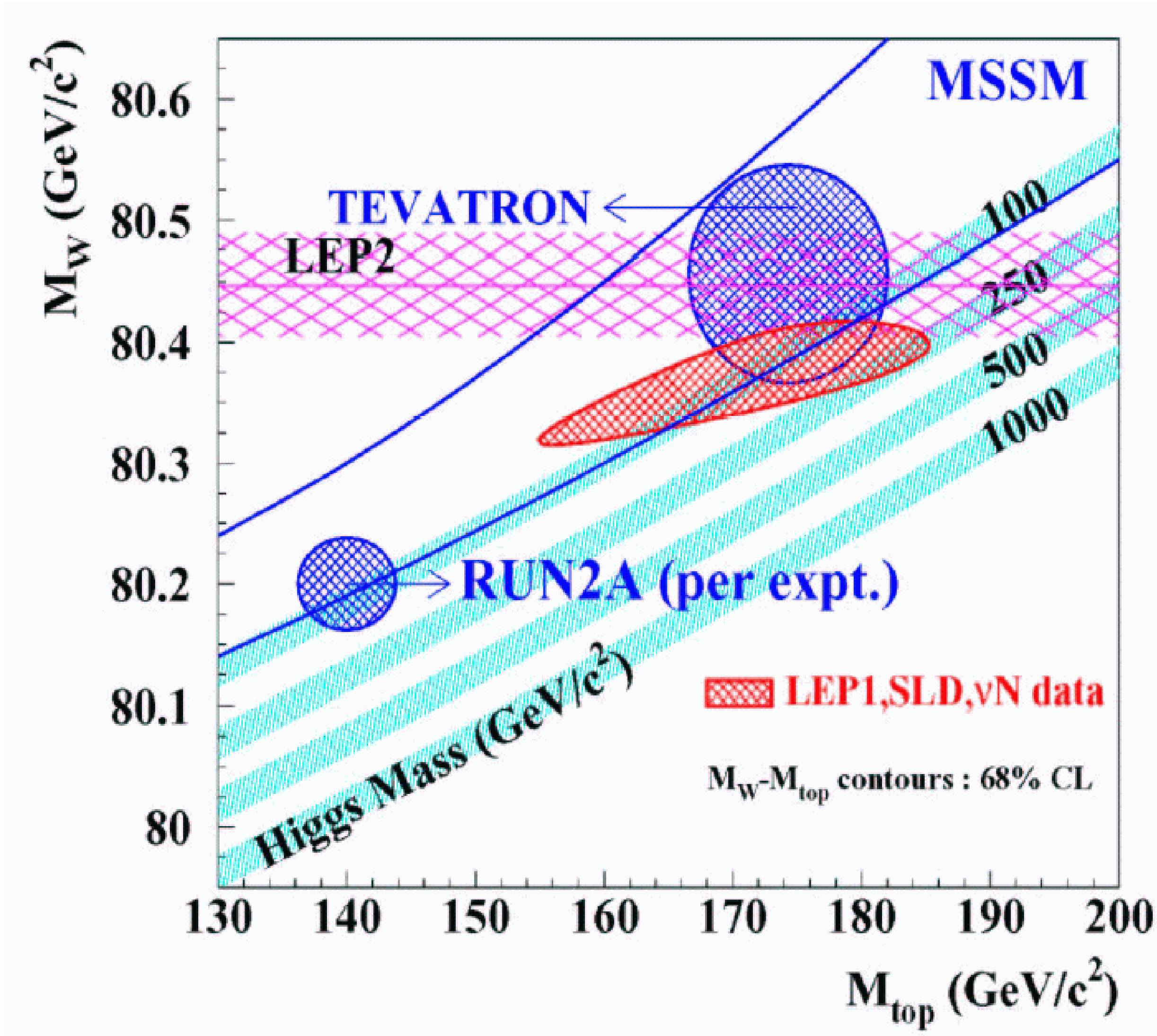
Run 2a (2 fb^{-1}) expectation shown:

ΔM_W ~ 40 MeV

Δm_{top} ~ 2.5 GeV

per experiment

can we do better?



Run 1 Results

	CDF	D0
M(W)	80.433 ± 0.079 GeV	80.483 ± 0.084 GeV
Γ(W)	2.05 ± 0.13 GeV	2.11 +0.175 -0.170 GeV

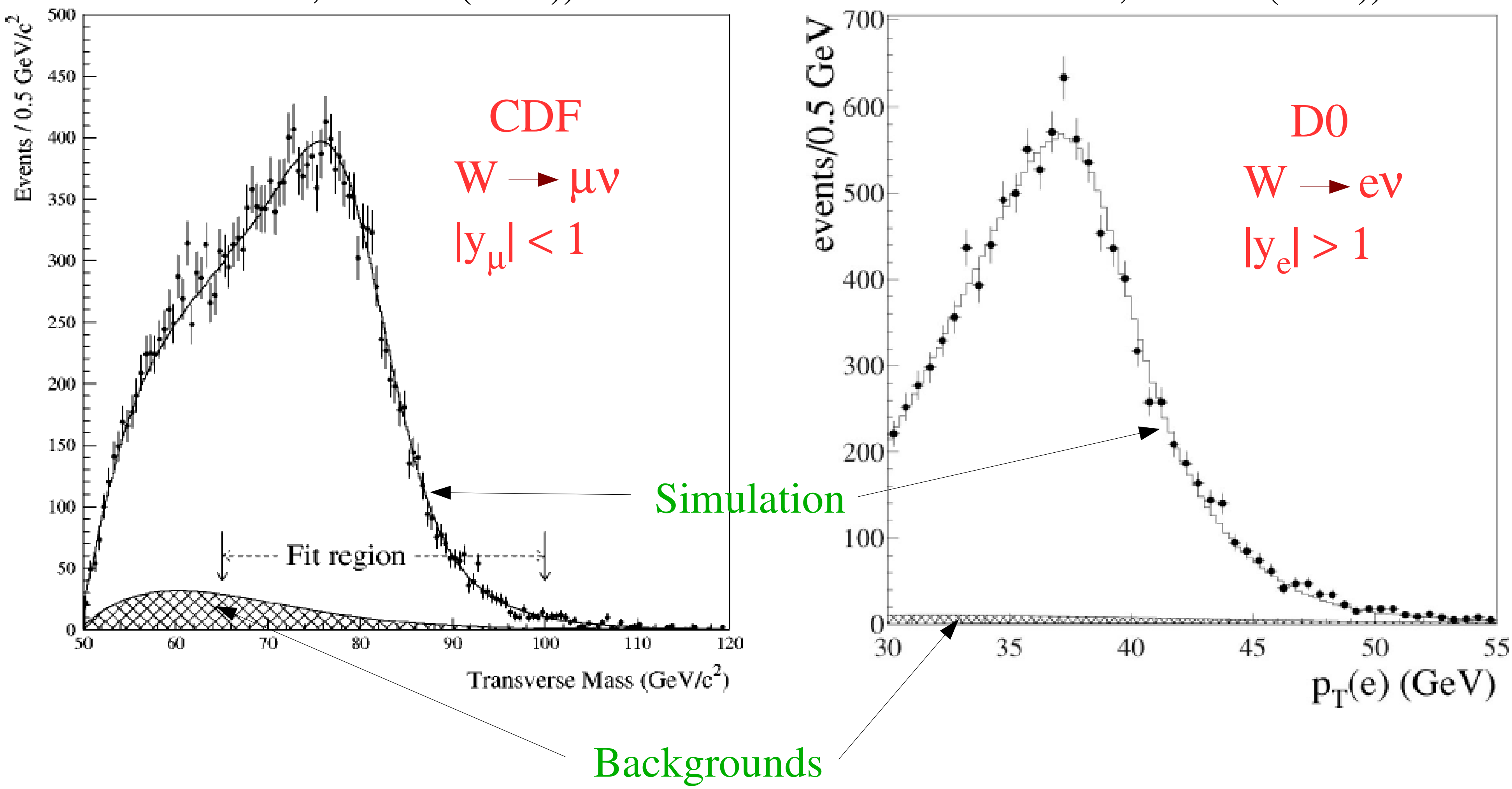
- Integrated luminosity ~ 110 pb^{-1} per experiment
- CDF used electron and muon channel decays of W bosons
- D0 used electron channel with central and forward coverage

Run 1 W Mass Fits

Examples of W transverse mass and lepton transverse momentum fits:

PRD 64, 052001 (2001))

PRD 62, 092006 (2000))

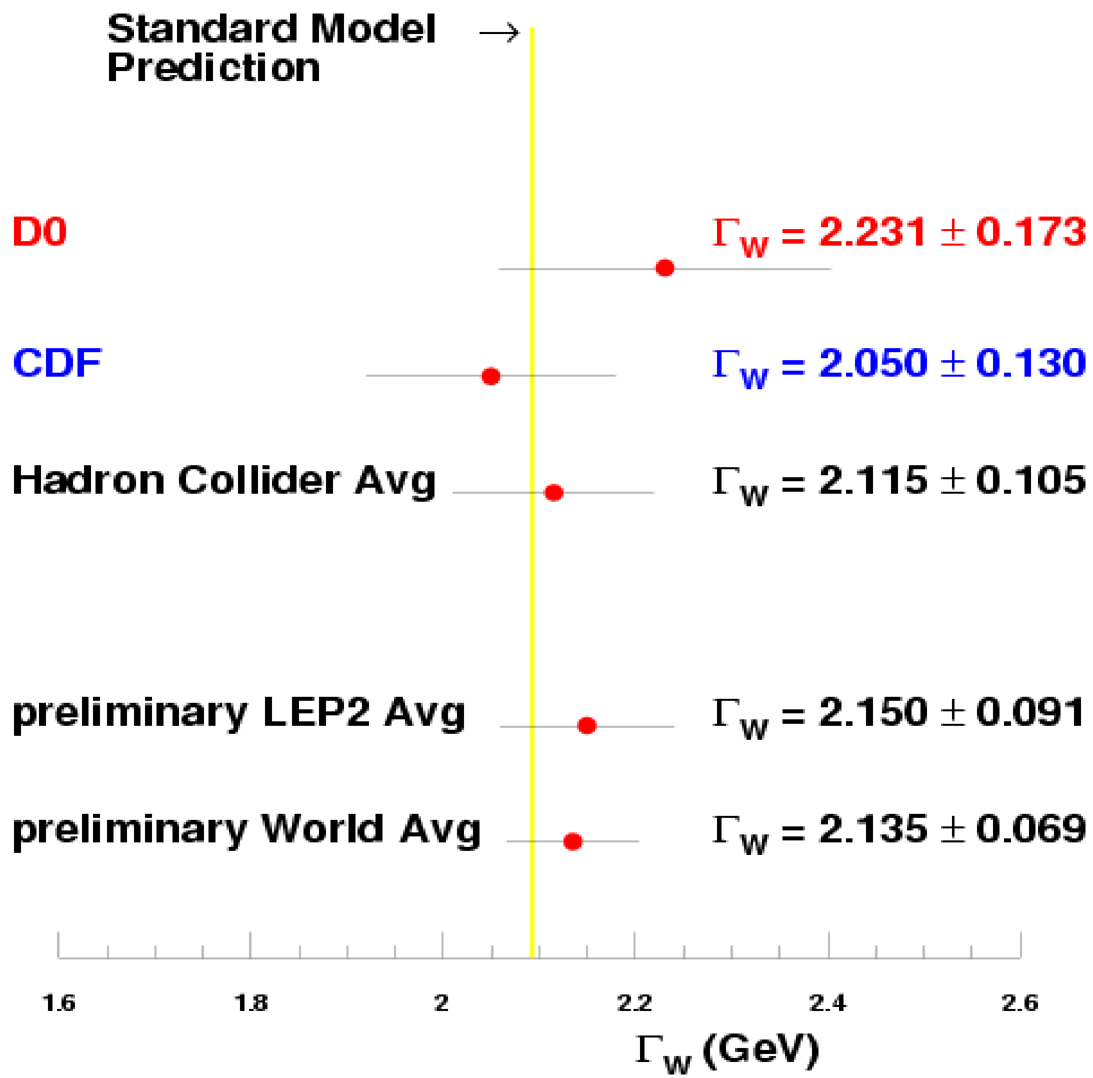


Run 1 Results

- Tevatron (CDF and D0) Averages:
  - $M_W = 80.456 \pm 0.059$ GeV (19 MeV correlation)
  - $\Gamma_W = 2.115 \pm 0.105$ GeV (26 MeV correlation)
  - Correlated uncertainties due to QED radiative corrections, parton distribution functions, and W mass/width inputs
- Joint $M_W - \Gamma_W$ combination (no external W mass or width information used):
  - $M_W = 80.452 \pm 0.060$ GeV
  - $\Gamma_W = 2.105 \pm 0.106$ GeV
  - Correlation coefficient = -0.17
- Analysis of correlations and Tevatron combined results published (hep-ex/0311039, accepted by PRD) by CDF, D0 & TeV-EWWG

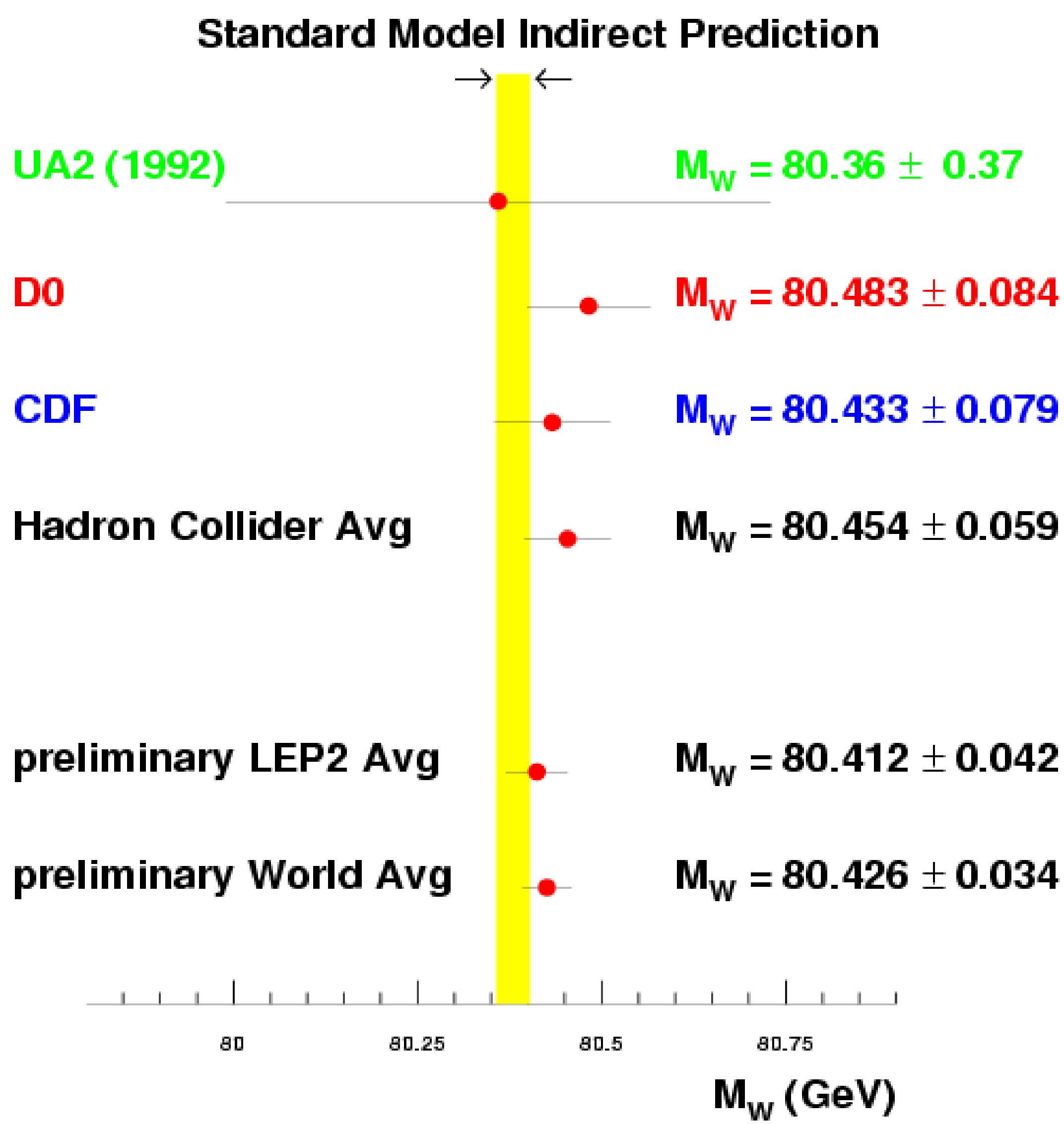
Run 1 Results

- Γ_W is consistent with the standard model



Run 1 Results

- M_W favors low Higgs mass

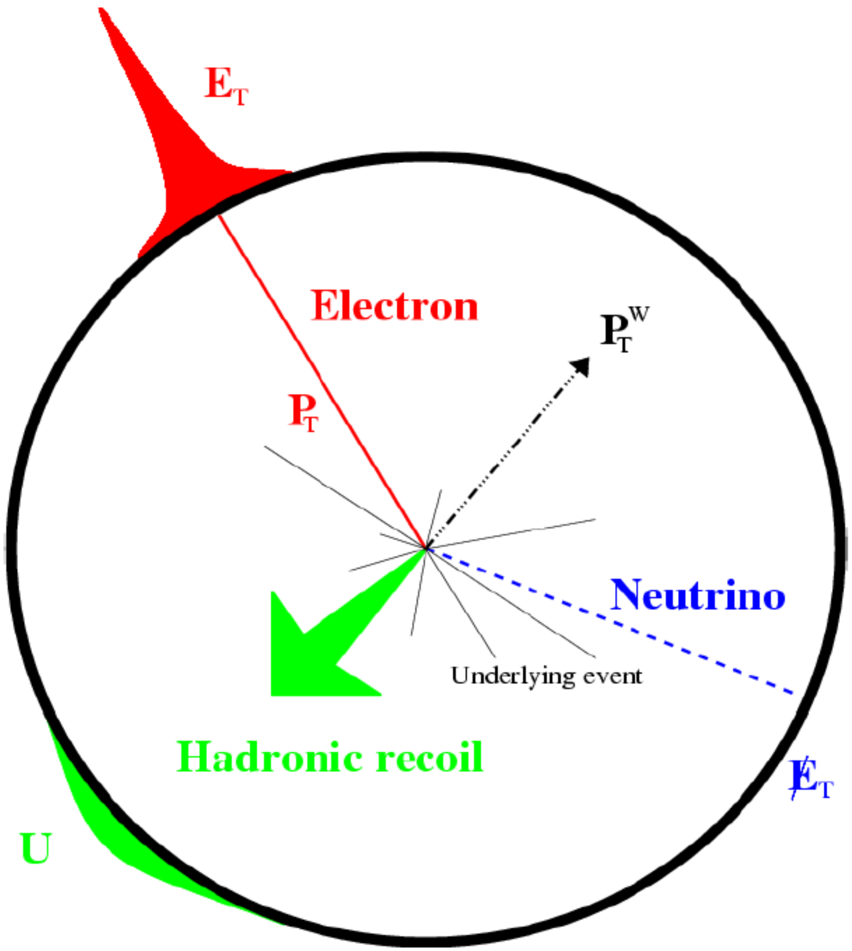


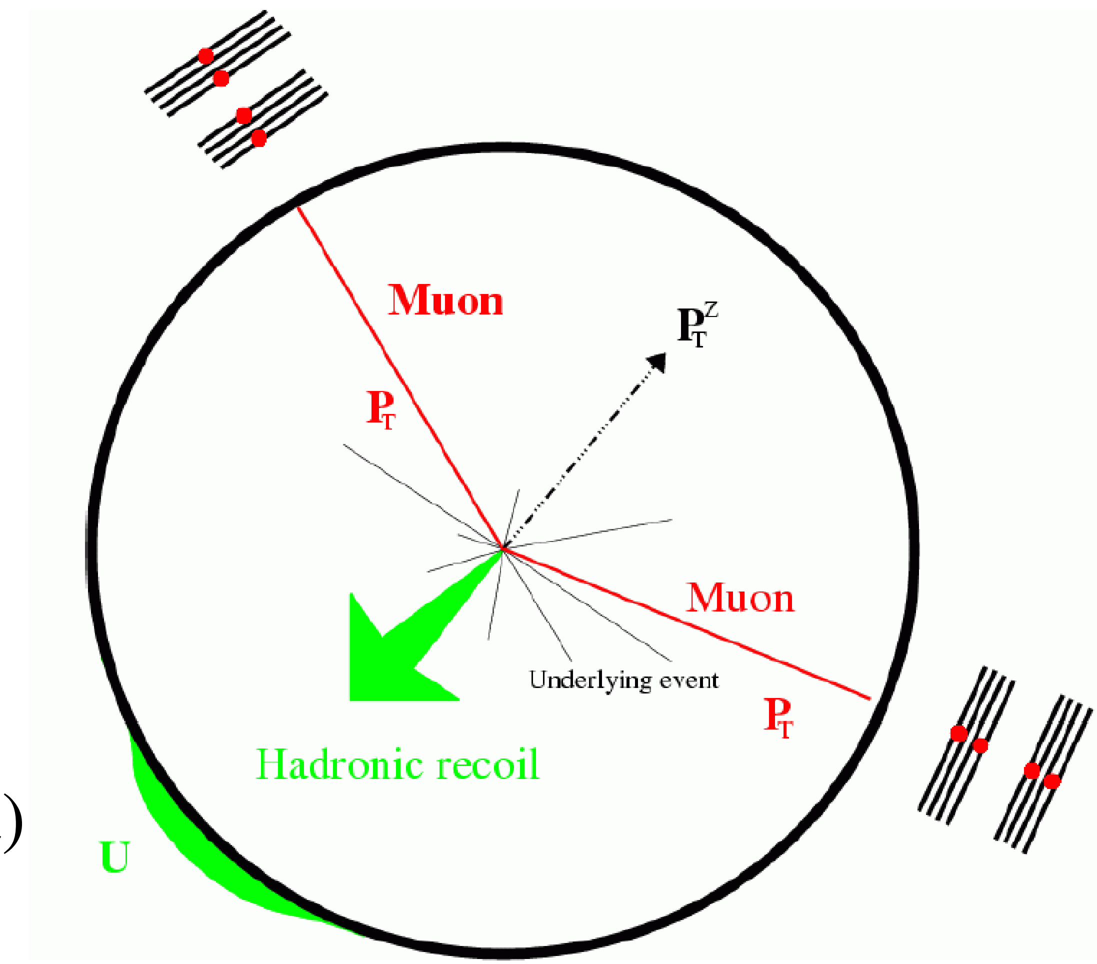
Run 2 Prospects

- Scaling of ΔM_W and $\Delta\Gamma_W$ with integrated luminosity:
  - During 1987-1995 running period, integrated luminosity per collider experiment increased from 4 pb^{-1} → 20 pb^{-1} → 110 pb^{-1}
  - ΔM_W reduced correspondingly: ~400 MeV → 150 MeV → 60 MeV, following $L^{-1/2}$ scaling
- Systematics constrained with collider data
- Continuation of this trend could lead to ΔM_W ~ 15 MeV, $\Delta\Gamma_W$ ~ 25 MeV with 2fb^{-1}

W and Z production at the Tevatron

Isolated, high p_T leptons,
missing transverse momentum in W's





Typically small hadronic (jet) activity

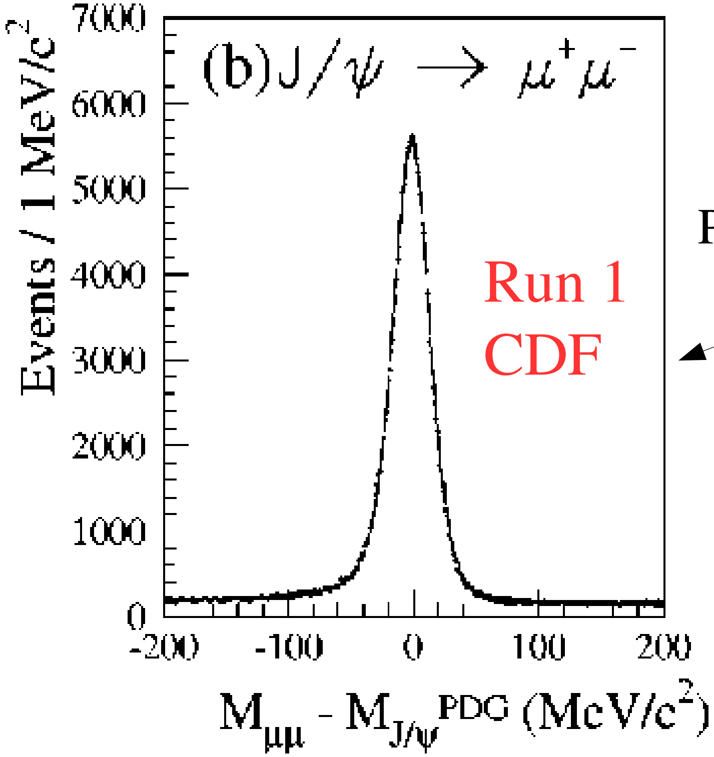
Run 1 W Mass
Systematic Uncertainties (MeV)

	CDF μ	CDF *e*	D0 *e*
W statistics	100	65	60
Lepton energy scale	85	75	56
Lepton resolution	20	25	19
Recoil model	35	37	35
pT(W)	20	15	15
Selection bias	18	-	12
Backgrounds	25	5	9
Parton dist. Functions	15	15	8
QED rad. Corrections	11	11	12
Γ(W)	10	10	10

(Correlated uncertainties)

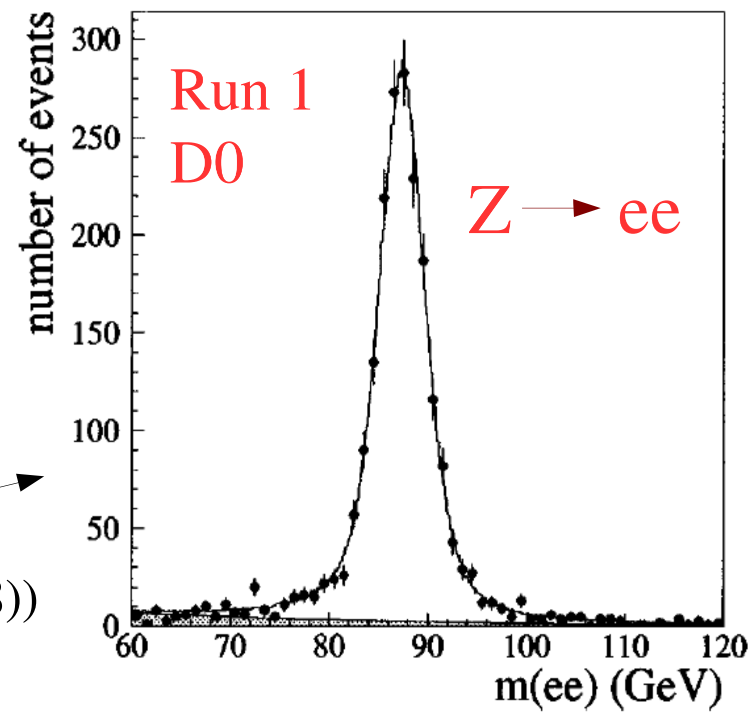
Lepton Energy Scale & Resolution (Tracking, Calorimetry)

- Dominant systematic in the W mass and width measurement
- Most time and effort spent on detector calibration
- Ultimate energy scale verification provided by resonance mass measurements (π^0, J/ψ,Y, *Z*): statistics-limited



PRD 64, 052001 (2001))

PRD 58, 092003 (1998))

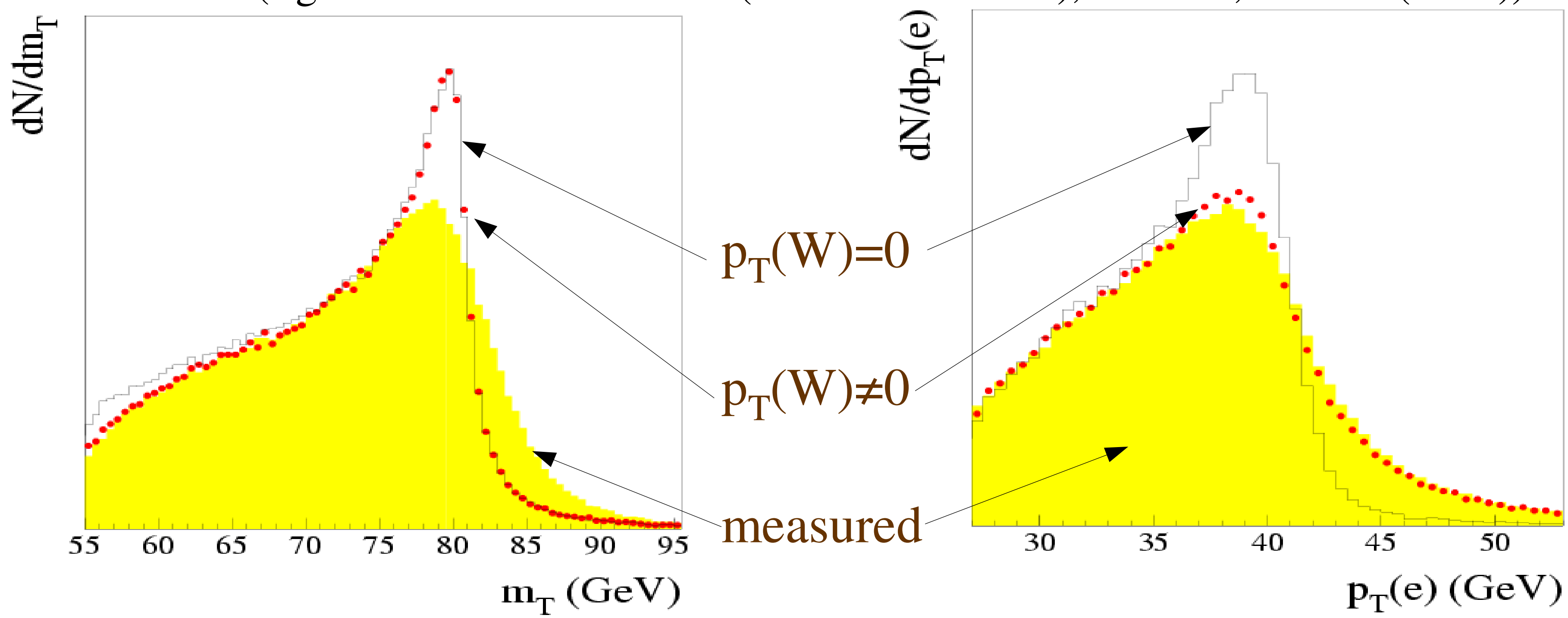


Calorimeter Recoil Model and $p_T(W)$

- W mass measured using the location of the Jacobian edge in $p_T(l)$ or m_T distribution:
  - $M_T = \sqrt{(2\, p_T^{l}\, p_T^{\nu}\, (1 - \cos \phi_{l\nu})}$
  - Insensitive to $p_T(W)$ to first order
  - Reconstruction (by conservation of momentum) of p_T^{ν} sensitive to hadronic response and multiple interactions
- Recoil model tuned using $Z \rightarrow ll$ data, statistics-limited
- Advantage of $p_T(l)$: insensitive to hadronic response modelling, but need theoretical model of $p_T(W)$
  - Use precisely measured $p_T(Z \rightarrow ll)$, statistics-limited

Calorimeter Recoil Model and $p_T(W)$

(figures from Abbott *et. al.* (D0 Collaboration), PRD 58, 092003 (1998))



- Relevant $p_T(W)$ range ~ 5-10 GeV
  - Large non-perturbative contribution
  - Potential for small difference between $p_T(W)$ and $p_T(Z)$ due to charm-induced production ($sc \rightarrow W$)

Parton Distribution Functions

- P_T^l, m_T not invariant under longitudinal boost given experimental rapidity cuts
- Forward rapidity coverage important to limit uncertainty from PDFs
  - W charge asymmetry measurement constrains *u/d* PDF ratio: statistics-limited
    - CDF measured in Run 1, new forward calorimeters in Run 2
    - D0 has forward coverage, charge measurement in Run 2
  - Use Forward W's in mass analysis
    - D0 did in Run 1, reduced PDF uncertainty (8 MeV vs 15 MeV)
- PDF fitters (MRST, CTEQ) now providing rigorous errors - consensus on "1σ" to emerge

QED Radiative Corrections

- Improvements over Run 1:
  - Complete NLO QED calculations available (U. Baur *et. al.*) for single photon emission
  - 2-photon calculations performed (Carloni Calame *et. al.*, hep-ex/0303102; Placzek & Jadach, hep-ex/0302065), predict 2-8 MeV shift in W mass
  - Combined QCD+QED (FSR γ) generator for W and Z bosons available (Cao & Yuan)
  - Independent scheme for combining generator-level QCD and QED effects in development at CDF
- Uncertainty in QED corrections not a fundamental limitation

Scaling of Systematic Uncertainties

- No show-stoppers apparent yet
- More data always welcome!

Summary

- Very successful Run 1 analyses of W boson mass and width
  - Systematic uncertainties limited by statistics of control samples
- Precise calibrations in progress of upgraded Run 2 detectors
- New developments in theoretical inputs
- Anticipate continued improvements in precision of W mass and width measurements with increasing Run 2 statistics