Electroweak Physics at the Tevatron

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Particle Physics at the Millennium

Aspen Winter Workshop 2001

Outline

Introduction

The W mass

The top mass

Single top production

Outlook for Run II

EW Physics intro

- Remarkable success of the standard model for three decades
- The last constituents that were found, the vector bosons and the top quark, provide striking evidence for SM
- Higgs sector remains unexplored: Fundamental question of particle masses. Clues from top and W measurements.
- Physics beyond the SM

Why W mass

At the Tevatron, W bosons are predominantly produced via qq'->W

$$m_W = \left(\frac{\pi\alpha\left(m_Z^2\right)}{\sqrt{2}G_F}\right)^{1/2} \frac{1}{\sin\theta_w\sqrt{1-\Delta r_W}}$$

Δr_W due to electroweak radiative corrections, dominated by top and Higgs.

Define $\rho = \frac{m_W^2}{m_Z^2\cos^2\theta_w}$

$\rho - 1 \sim m_t^2$ Due to top quark loop

$\rho - 1 \sim \ln m_H^2$ Due to Higgs loop

m_W provides stringent test of SM and together with m_t constrains m_H.

W mass measurement strategy

- Use leptonic decays: W->e ν or W->μ ν (CDF)
- Use transverse W mass to infer invariant W mass

$$m_T^W = \sqrt{2 p_T^l p_T^\nu (1 - \cos\Delta\Phi_{l,\nu})}$$

Can also use p_T^l

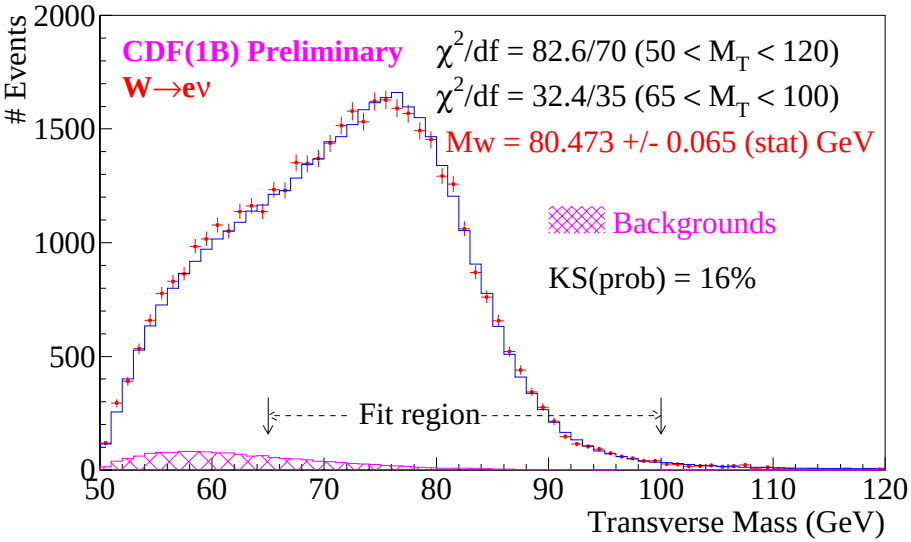
$$\vec{p}_T^{\,\nu} = -\vec{p}_T^{\,l} - \vec{u}_T$$

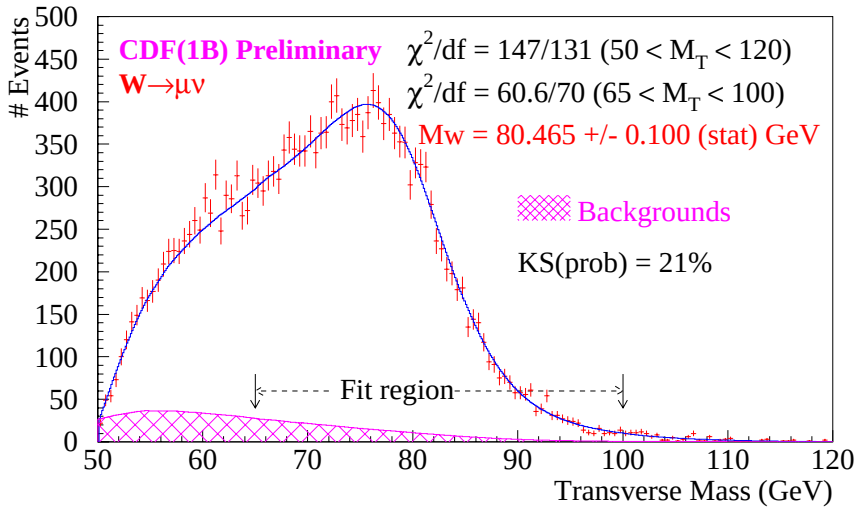
with $\vec{u}_T = \sum_i E_i \sin\theta_i \hat{u}_i^T$

Sum of transverse momenta of all particles recoiling against the W

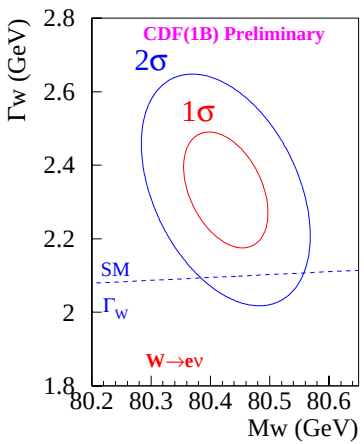
- Event selection requires high pt lepton, large missing ET and small recoil energy
- Important to correctly model the production dynamics of the W, the recoil, and the detector response

W mass: Measurement

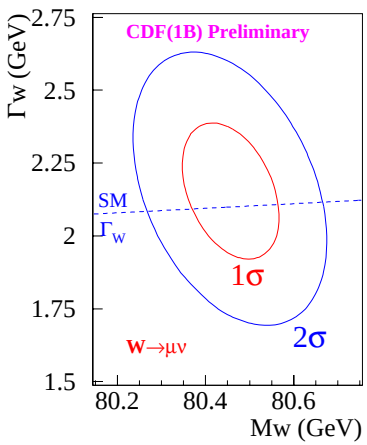




electrons



muons



m_W(CDF, Run I) = 80.433+/-0.079 GeV

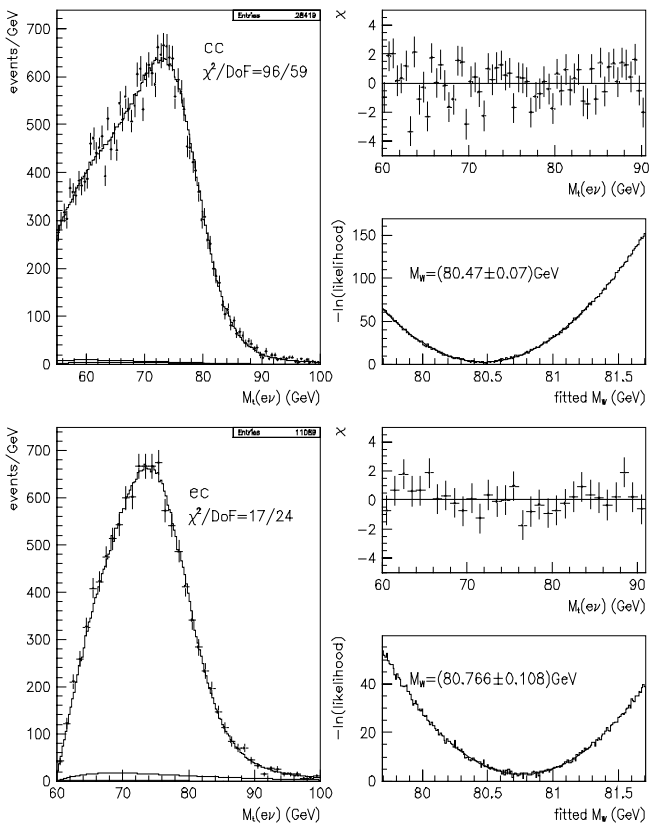
CDF errors

Error Source	W-> eν	W->μν
Statistics	65	100
Lepton Scale	75	85
PTW, Recoil Model	40	40
PDFs	15	15
Higher order QED	20	10
Lepton Resolution	25	20
Trigger + Selection Bias	-	15+10
Backgrounds	5	25
Total(Syst except scale)	54	57
Total	113	143

Dominant systematic

CC and EC W mass

D0 uses central (CC) and forward (EC) electrons



Advantage of including forward electrons:

Larger statistics

Reduced PDF uncertainties

Mw(D0)= 80.482+/-0.091 GeV

W mass errors

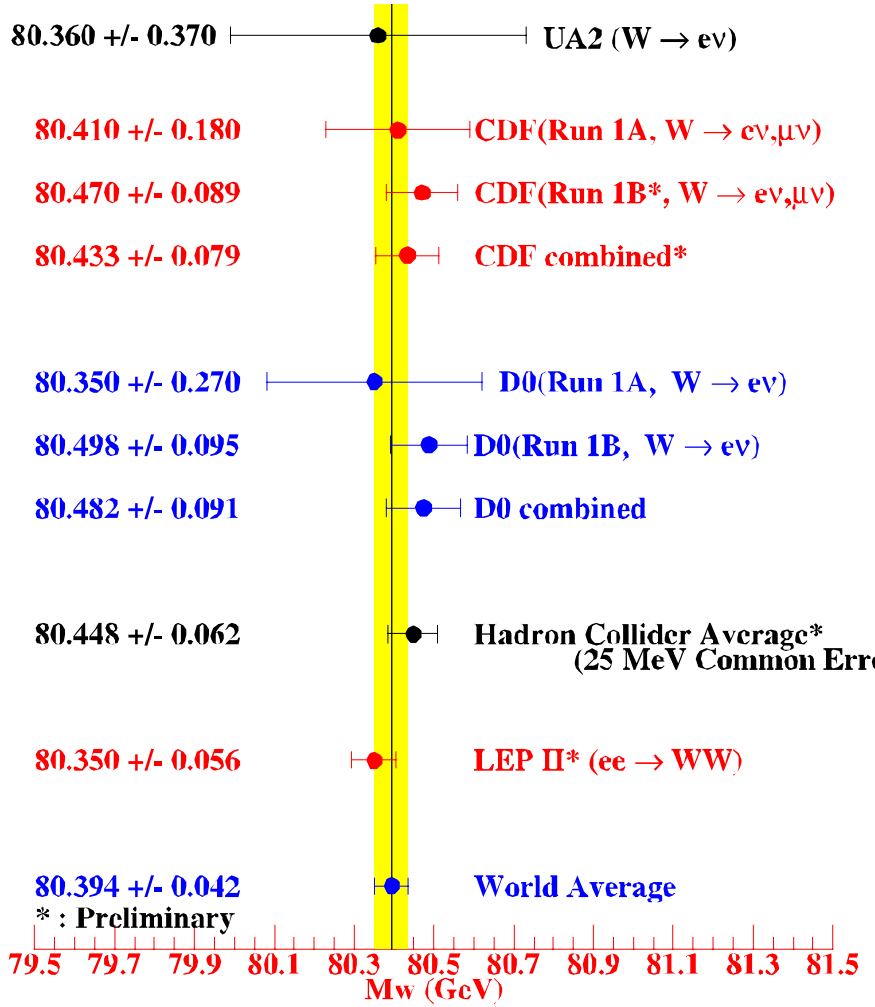
Source	EC	EC+CC
W statistics	108	61
Z statistics	181	59
Calorimeter linearity	52	25
Calorimeter uniformity	-	8
Electron Resolution	42	19
Electron angle calibration	20	10
Recoil response	17	25
Recoil resolution	42	25
Electron removal	4	12
Trigger and selection bias	5	3
Backgrounds	20	9
PDFs	17	7
Parton luminosity	2	4
PT(W)	25	15
Γ(W)	10	10
Radiative decays	1	12

$m_T + p_T(e) + p_T(\nu)$

Combine central W->eν with the EC result.

Correlations are taken into account, often reduce systematic errors.

Summary of W mass



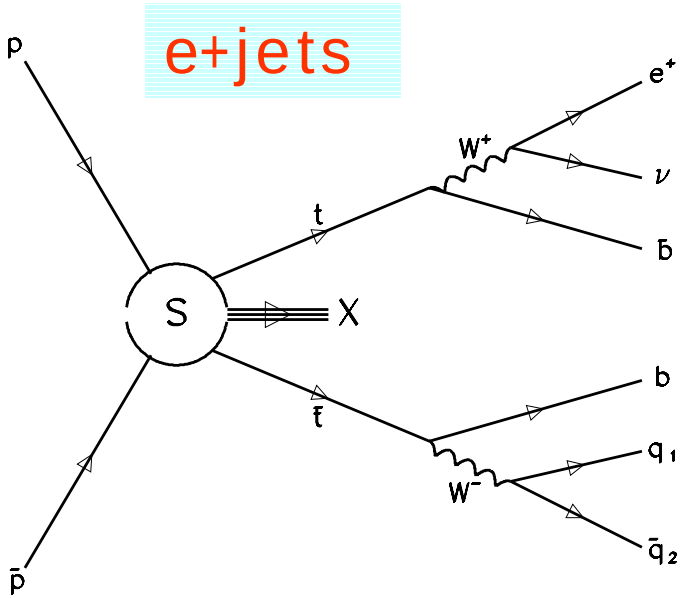
Hadron Collider combined: 80.448+/-0.062 GeV

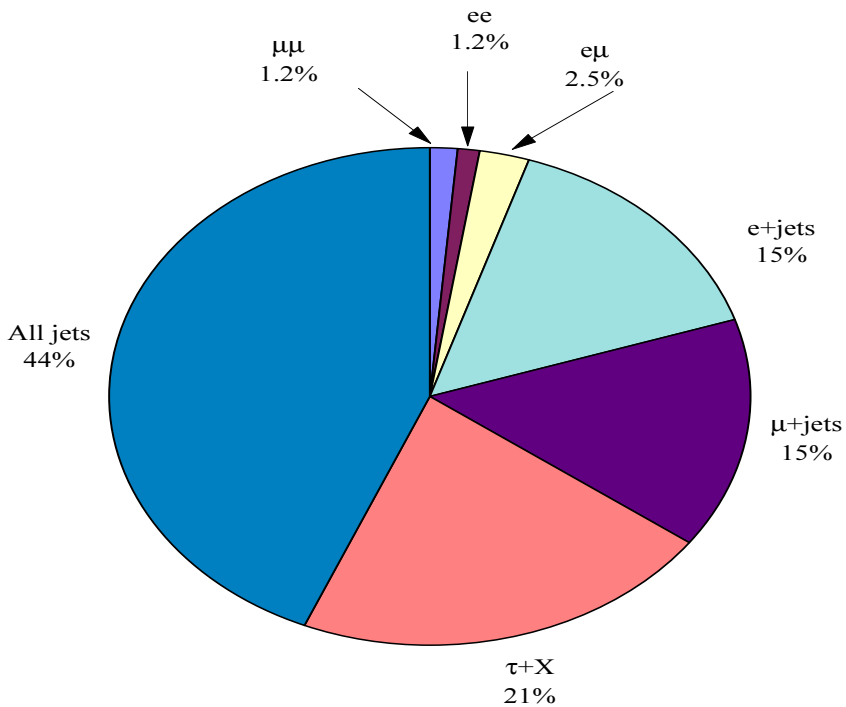
top mass: intro

Motivation:

- Fundamental parameter of SM
- Needed to determine top quark coupling to Higgs $t\bar{t}H \sim m_t^2/m_W^2$
- Radiative corrections sensitive to top mass: for example the one loop corrections to the W mass depend on m_W, m_Z, m_H, m_t
  ->precise m_W and m_t measurements -> m_H
- Any theory of unification needs to accurately predict fermion masses.

top decay channels



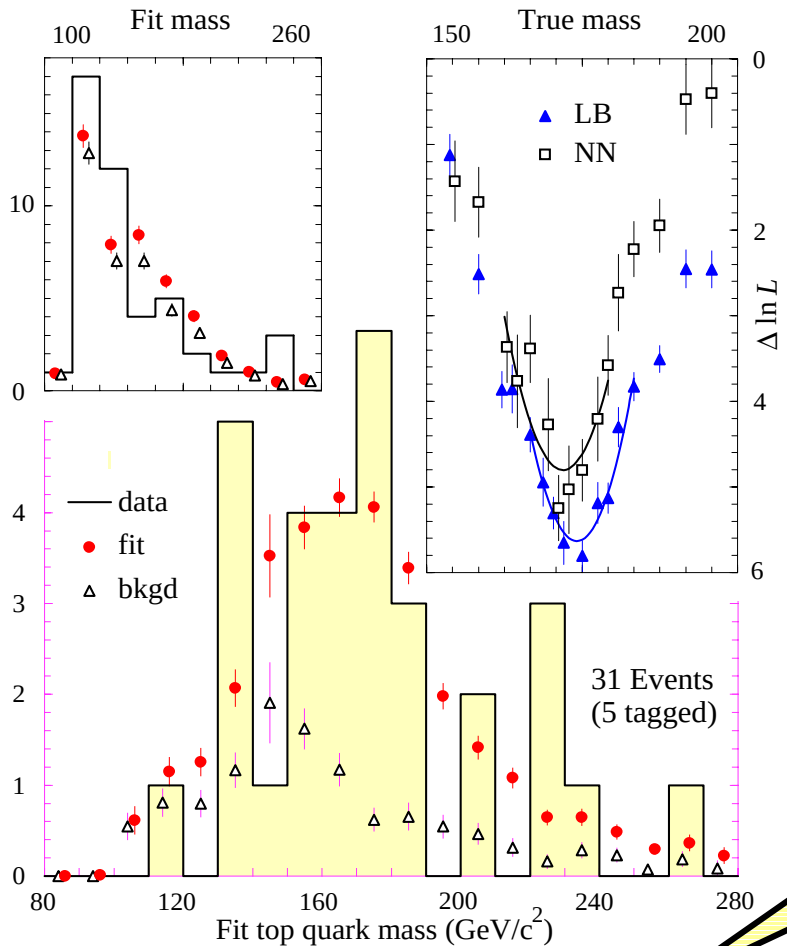


all Jets: large cross section but large backgrounds

Lepton + Jets: best channel: lower cross section but moderate backgrounds

Dilepton: small cross section, underconstrained fit

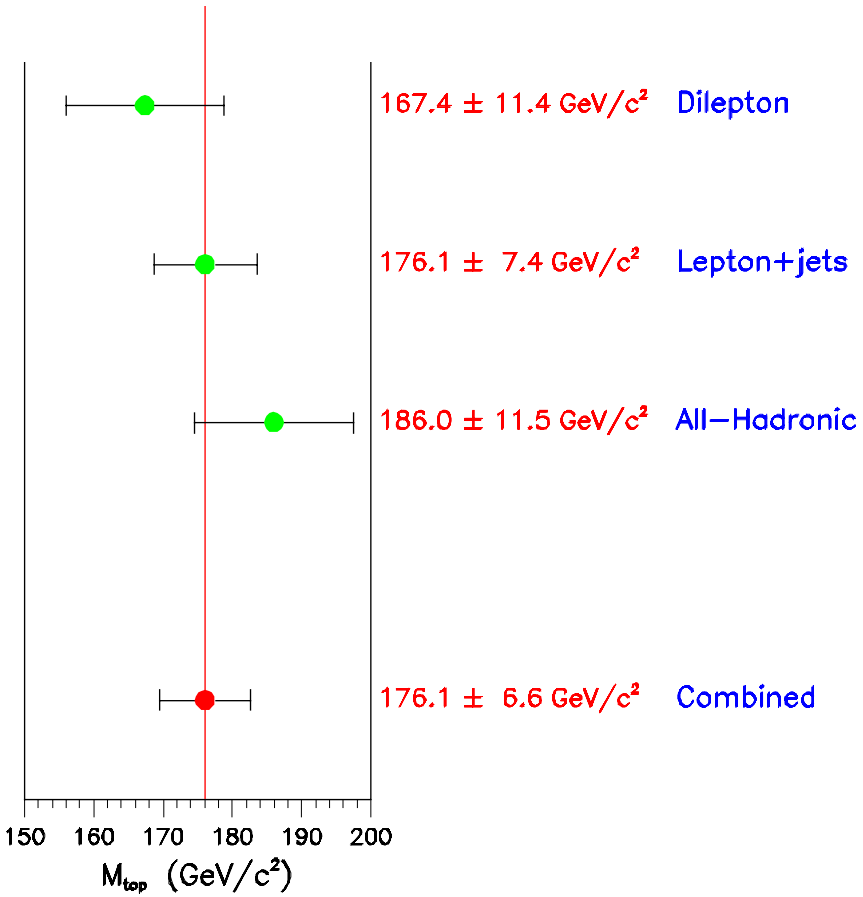
top mass: D0 (lepton+jets)



4.0 GeV from Jet energy scale

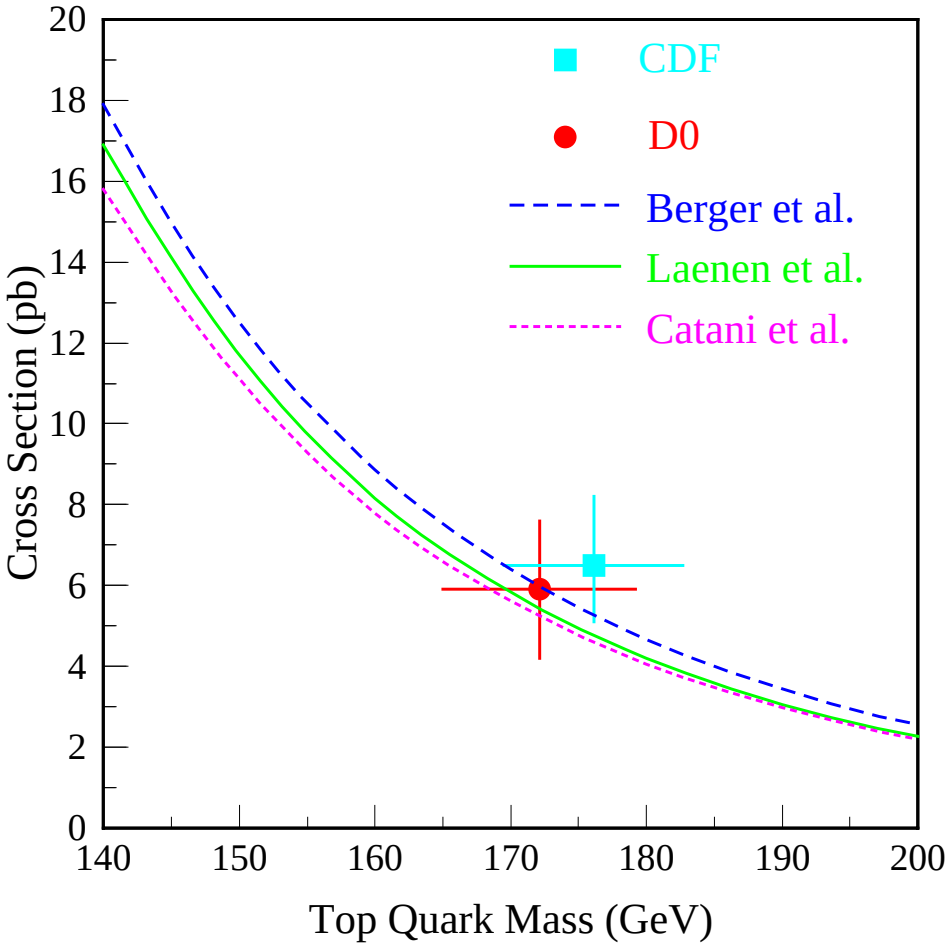
m_t=173.3+/-5.6(stat.)+/-5.5(syst.)GeV

top mass: CDF


167.4 ± 11.4 GeV/c²
Dilepton
176.1 ± 7.4 GeV/c²
Lepton+jets
186.0 ± 11.5 GeV/c²
All−Hadronic
176.1 ± 6.6 GeV/c²
Combined
150
160
170
180
190
200
M_top (GeV/c²)

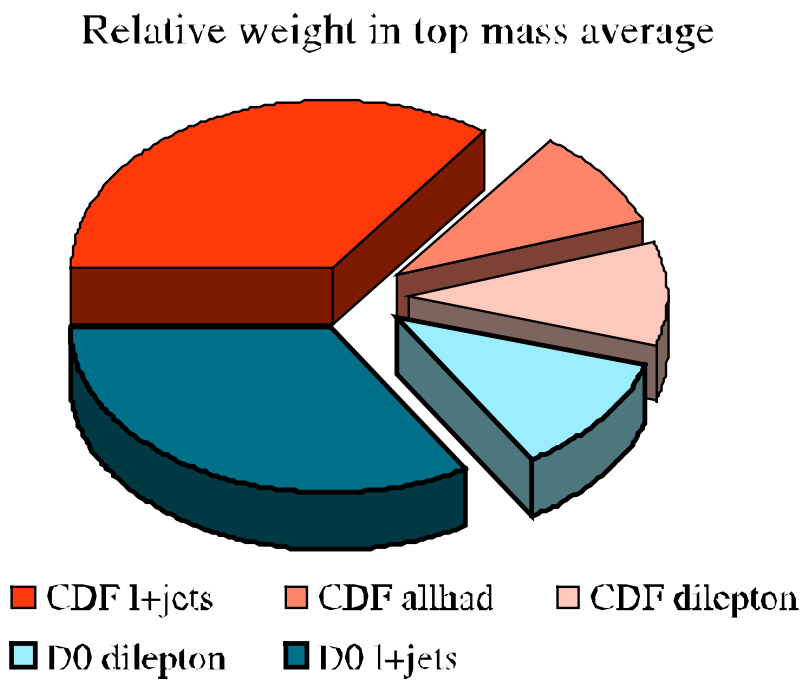
top mass D0 and CDF

Both measurements agree within errors and with theory.



Combined top mass: relative weights

Combining the various D0 and CDF experiments with their relative weights

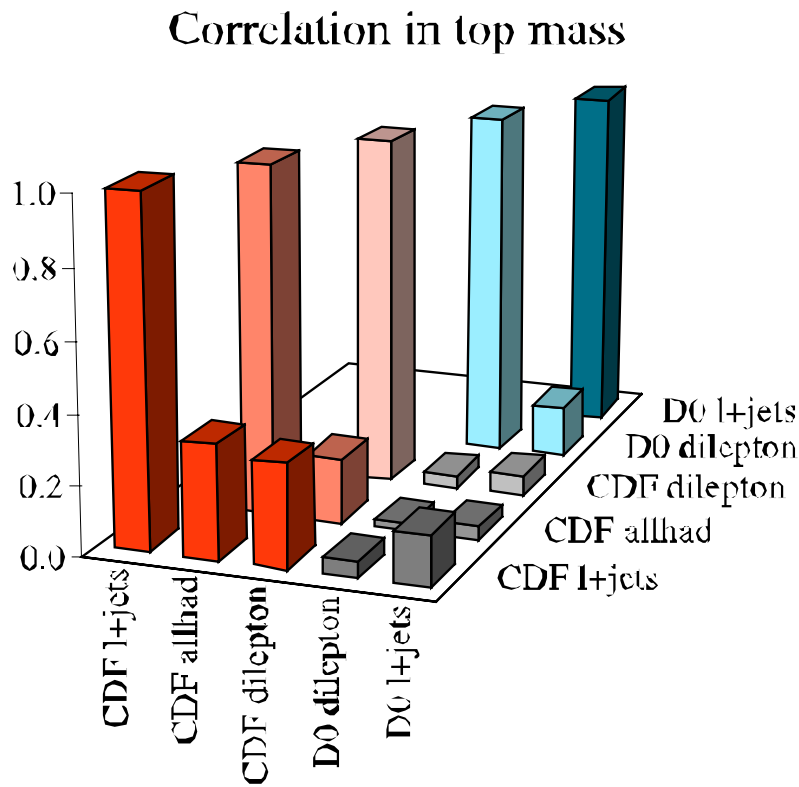


Combined top mass: correlations

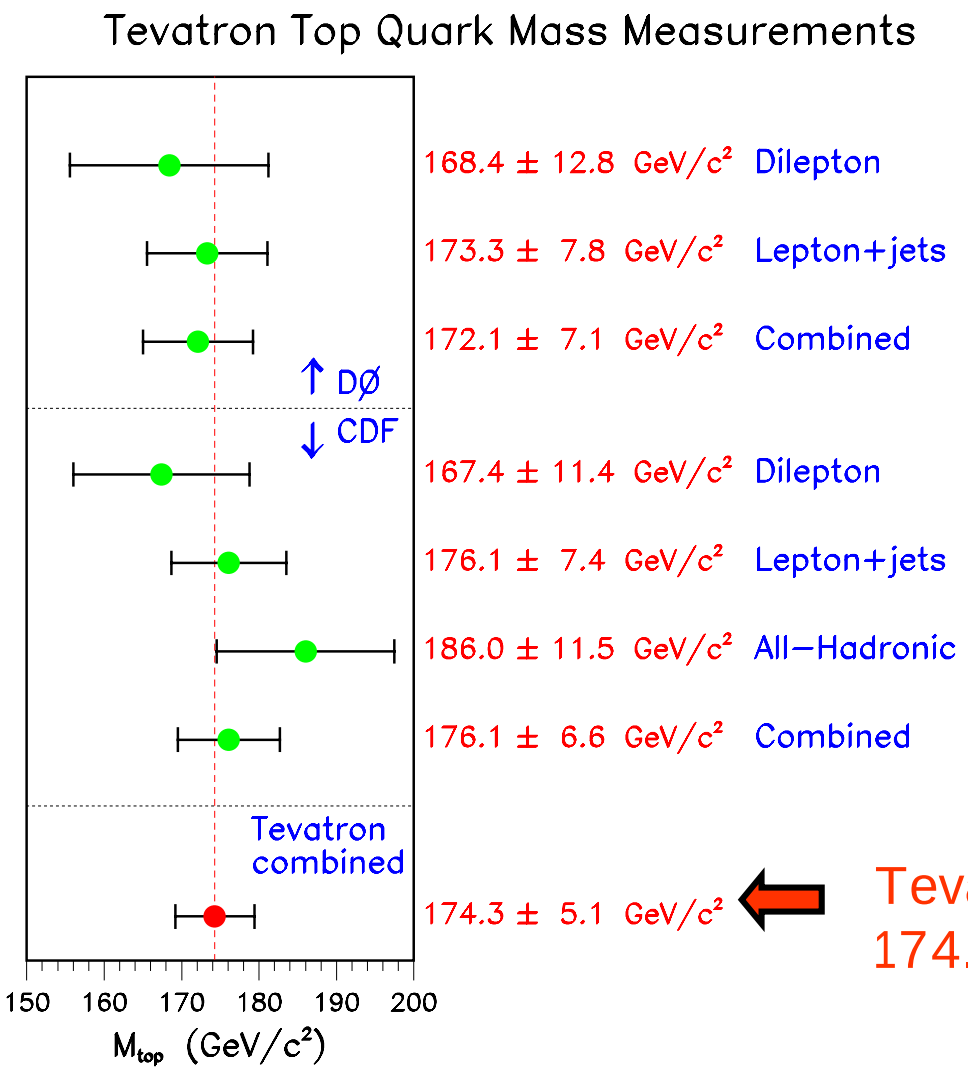
All correlations have been taken into account.

Important to correctly estimate the combined error.

NOT conservative to overestimate the correlations



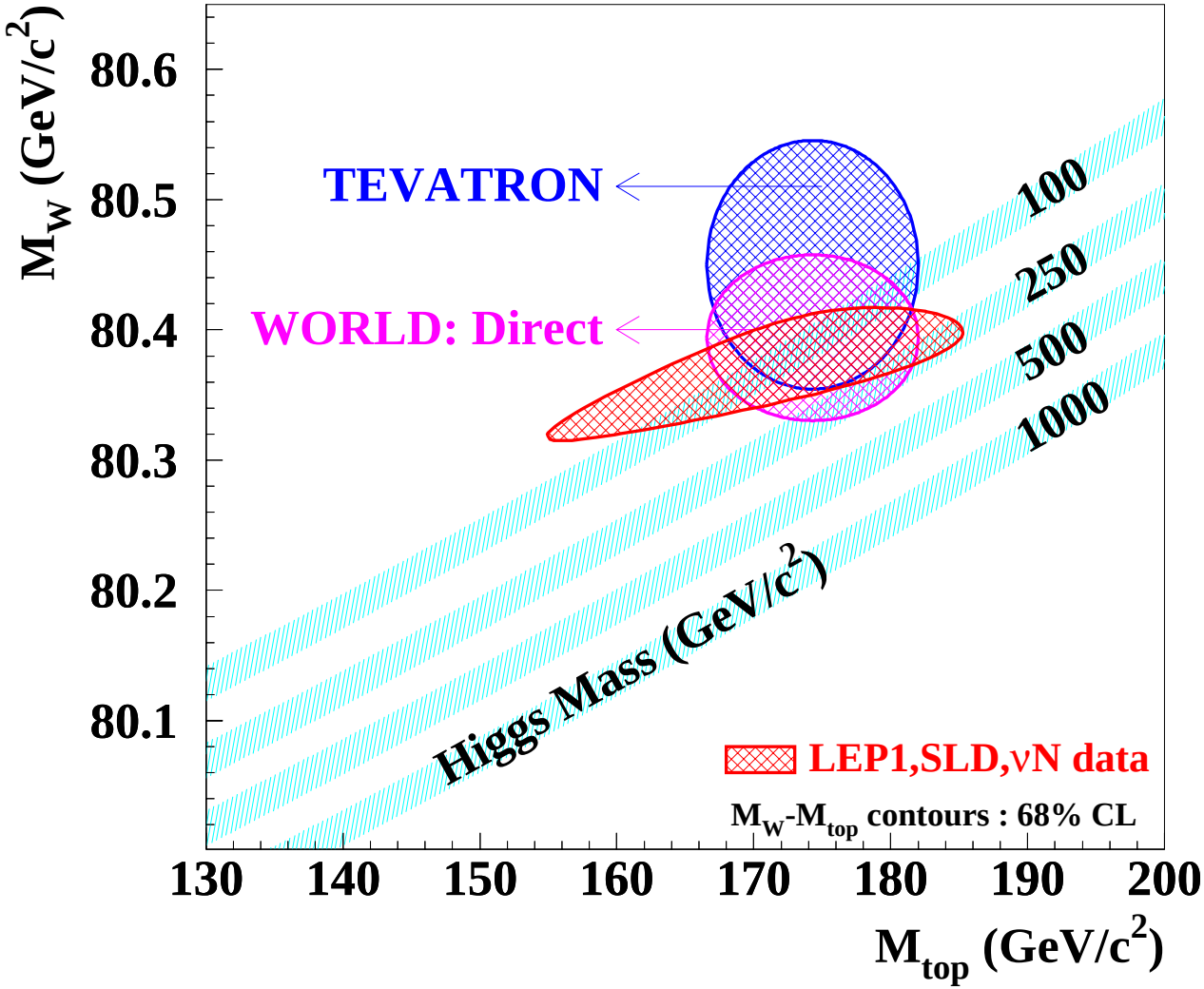
top mass D0 and CDF



Top mass measured to 3% ➔ Best measured mass of all quarks

Tevatron combined: 174.3+/-5.1 GeV

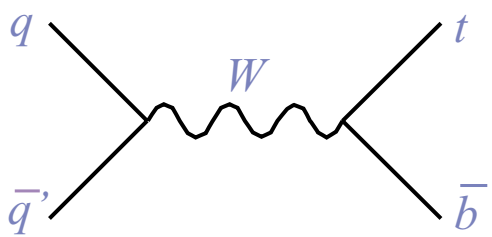
All in perspective



Powerful constraint on Higgs mass

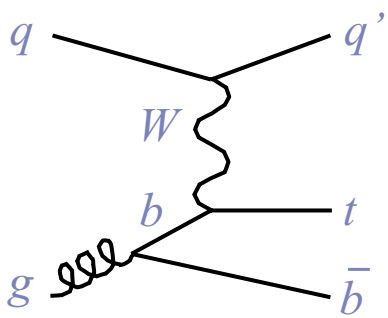
Single top: intro

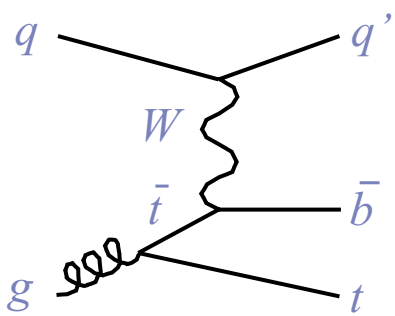
- Measurement of V_{tb}
- Partial width $\Gamma(t \to WX)$
- It's a standard model process



Electroweak Single Top

$\sigma_{single\ t} = 1/2\ \sigma_{tt}$

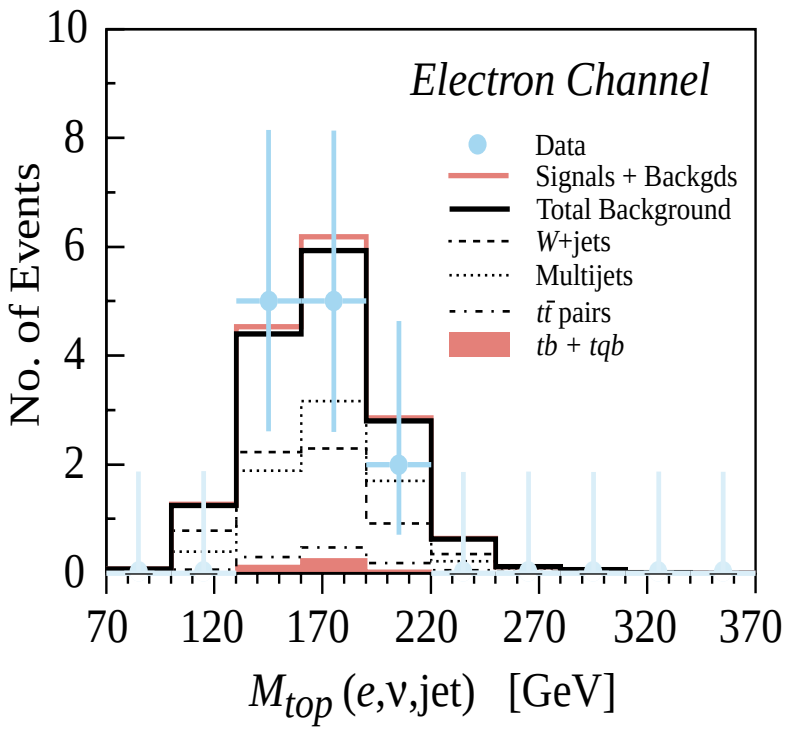


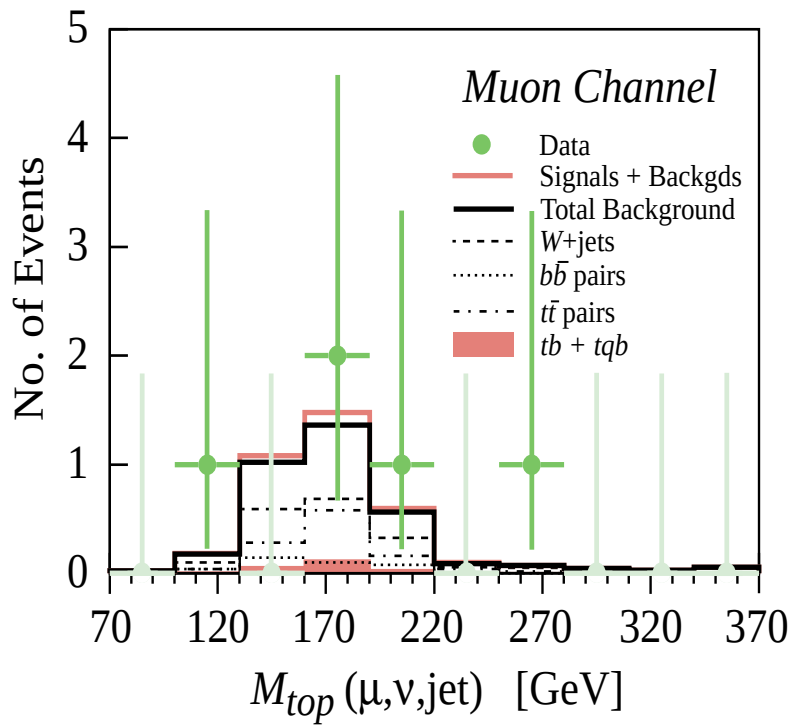


Problem: W+2 jets sample has large QCD background.

(ttbar: W+4 jets)

Single top at D0





Data consistent with background in Run I.

Cross section limit: $\sigma_{\text{single top}} < 39/58$ pb for s/t channel

Run II: definition

Run IIa: 2 fb^{-1} ⇦ Starting March 1!

Run IIb: >15 fb^{-1} ⇦ 2004 until the turn on of LHC

$\sqrt{s} = 2.0\ \mathrm{TeV}$ ⇦ σ(ttbar) increased by 40 %

How much can we improve on m_W and m_t?

Single top: expect O(200) events, can measure a cross section, V_{tb}, and Γ(t->Wb)

Particle id improvements

Detector improvements and particle id:

- Electron (magnet, fiber tracker, preshower)
- Muon (magnet, fiber tracker)
- b (silicon tracker, e-tag)
- Jet

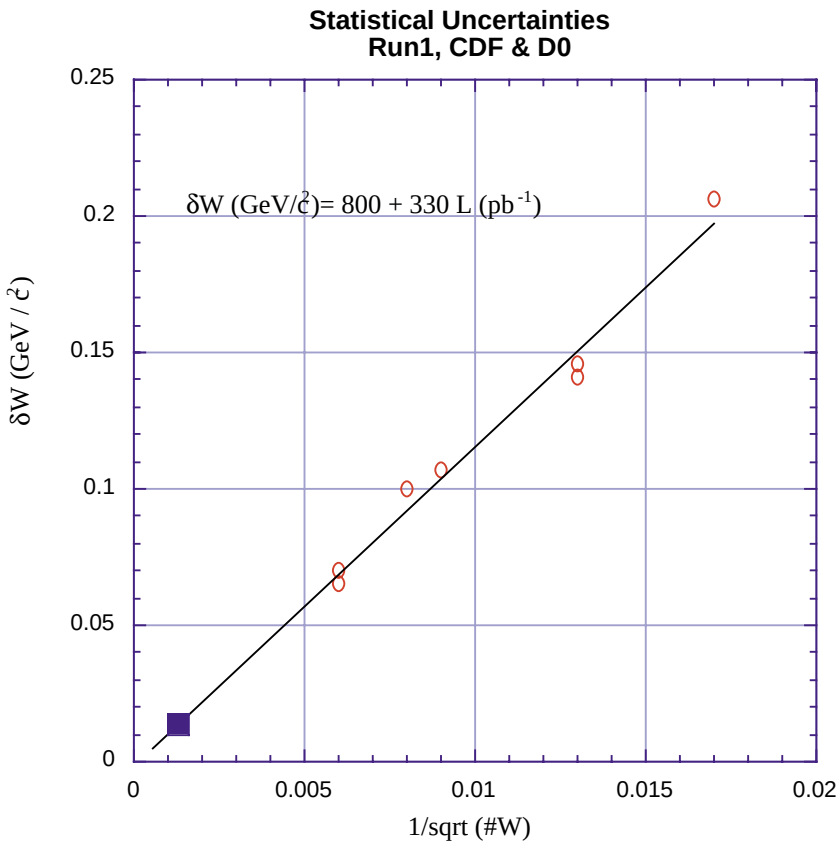
- Expect 50-100x more ttbar, ~200x more single top

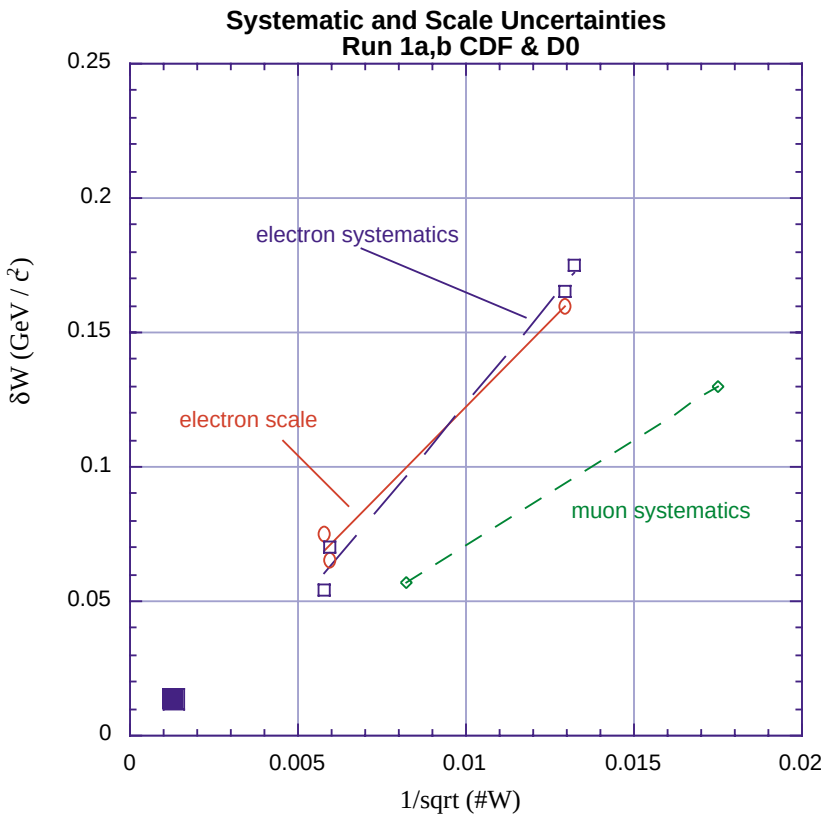
Run II: W mass

Goal: δM_W<30 MeV per experiment

Error source	Estimated error
statistics	13 MeV
Calorimeter scale	15 MeV
Non scale uncertainties	Need to be < 22 MeV
Theory: pT model Theory: PDF uncertainties	5 MeV Important! Including EC 11MeV-> 7 MeV (D0 Run I)

Run II: W mass errors





Statistical uncertainties extrapolate to 0.015 GeV

Systematic and scale uncertainties harder to estimate

Run II: top and single top

ttbar:

Expect to improve the fractional uncertainty on the top mass measurement from the current 3% (combined) to less than 2% per experiment.

Single top:

- S/B = ¼ S/sqrt(B)=4 sqrt(S+B)/S=30%
- 200 signal events in l+jets
- Fractional error on V_{tb} = 0.15
- Γ(t->Wb) to ~25 %

Summary

- Precision Measurements of m_W and m_t serve as test for SM and to constrain the Higgs mass
- Reported on D0 and CDF measurement of m_W and m_t in various channels
- Production of single top:
  - SM process
  - Measurement of V_{tb}
  - Limits in Run I, Measurement in Run II
- Run II prospects for m_W and m_t:
  - $\Delta m_W \sim 30$ MeV
  - $\Delta m_t < 2\%$
  - V_{tb} to 15 %
- Run II starts in 2 months (see Vishnu's talk about status of detector and commissioning)