W and Top Mass Measurements at the Tevatron

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For the CDF and D0 Collaborations

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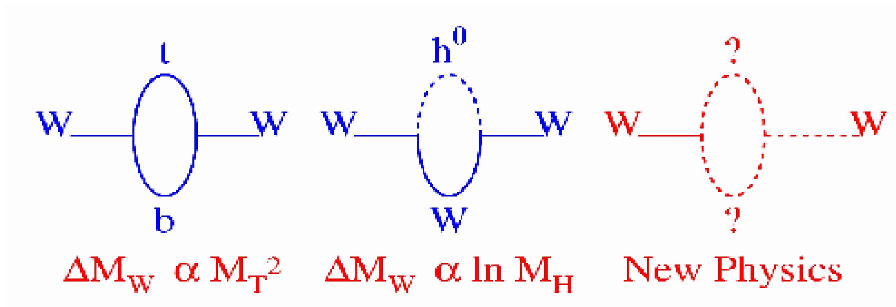
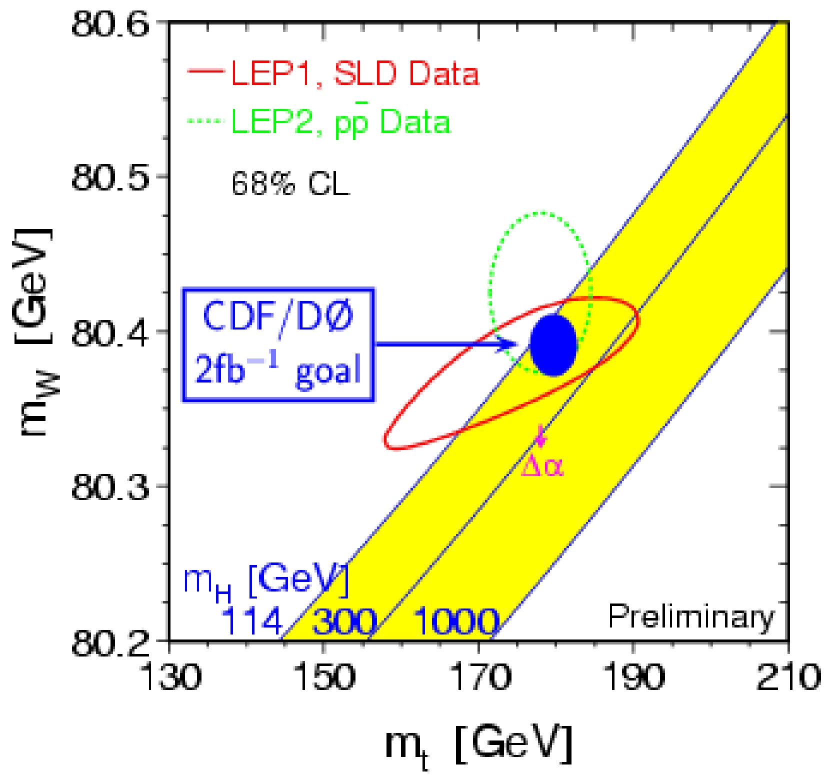
Why Measure W and Top Mass?

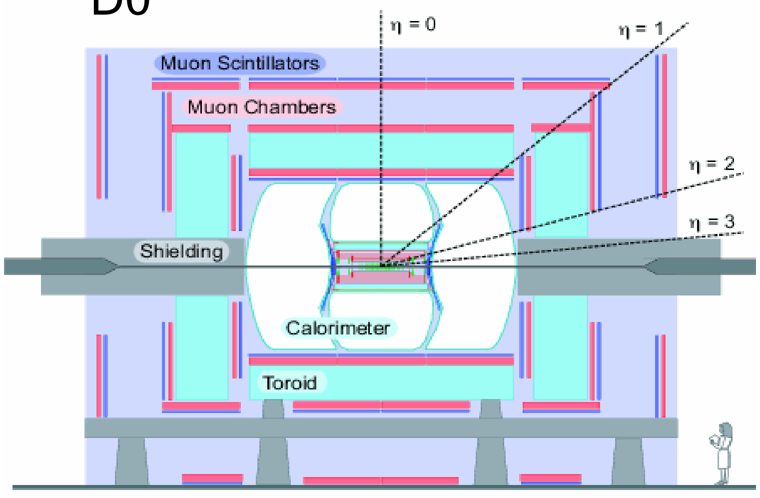


- W mass
  - corrections from top and Higgs
- Top Mass
  - Yukawa coupling close to unity
  - important in radiative corrections to electroweak measurements
- Goal: constrain $\Delta M_h/M_h$ to 35% in Run2
  - 3 GeV top mass measurement
  - 40 MeV W mass



CDF, D0, Tevatron

D0



Run II upgrades

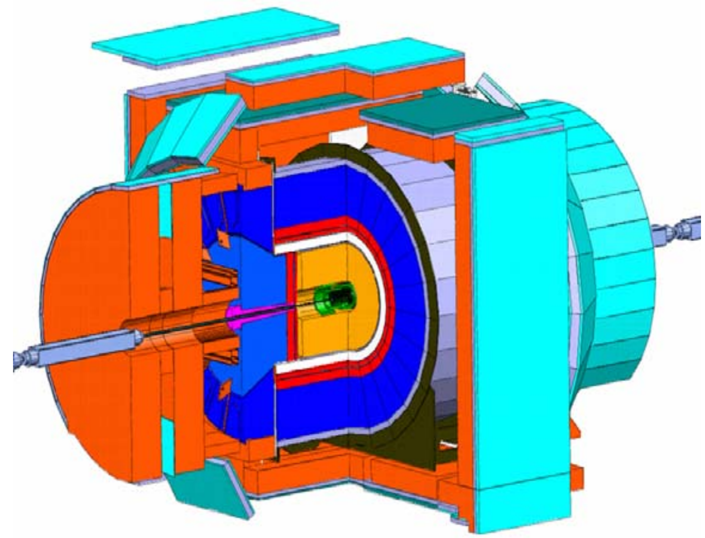
New Si, central tracking

Forward muon systems

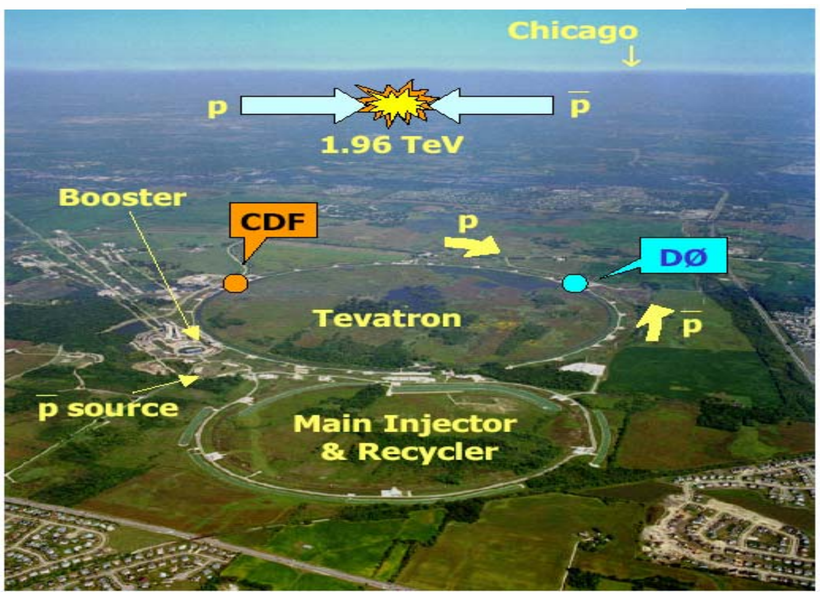
Trigger/DAQ

CDF: forward calorimeter

D0: new 2T magnet



CDF



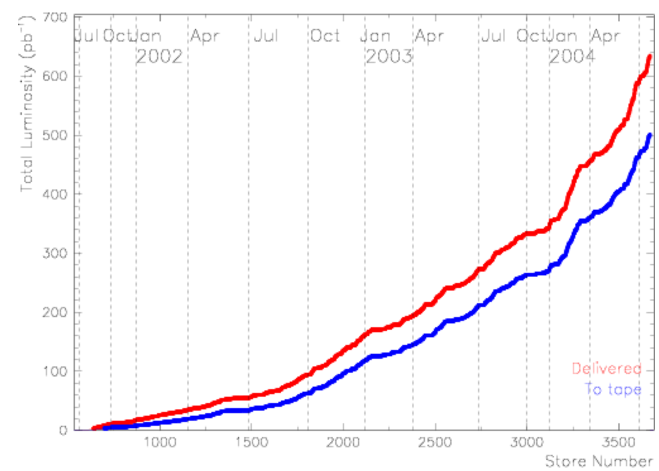
Data samples

About 500 pb^{-1} on tape now

Results here cut off in SEP-2003

150-200 pb^{-1}

Run 1 ≈100 pb^{-1}



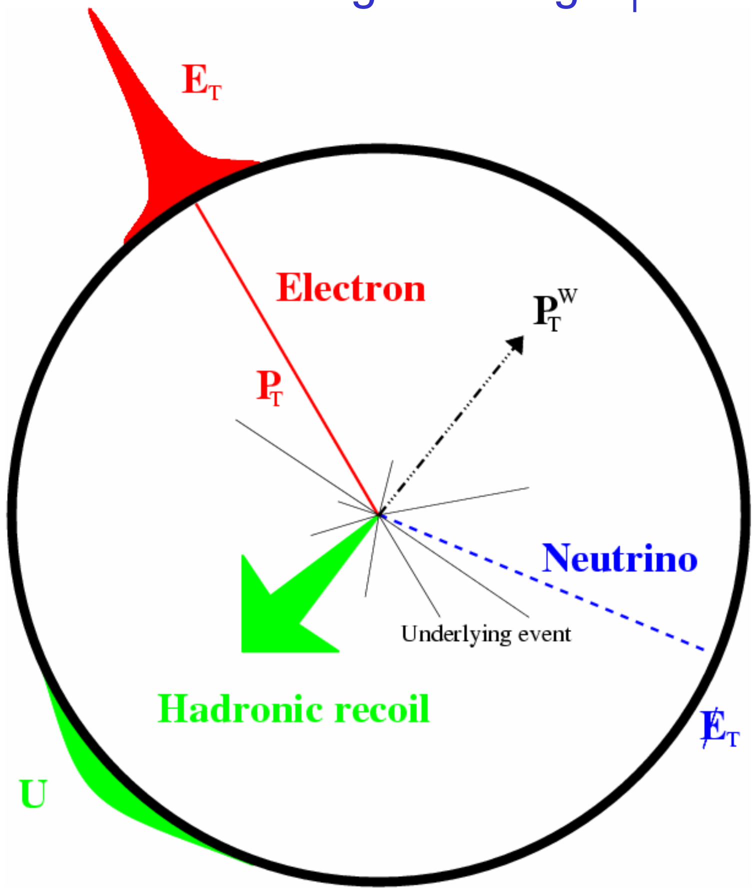
W - Samples and Backgrounds

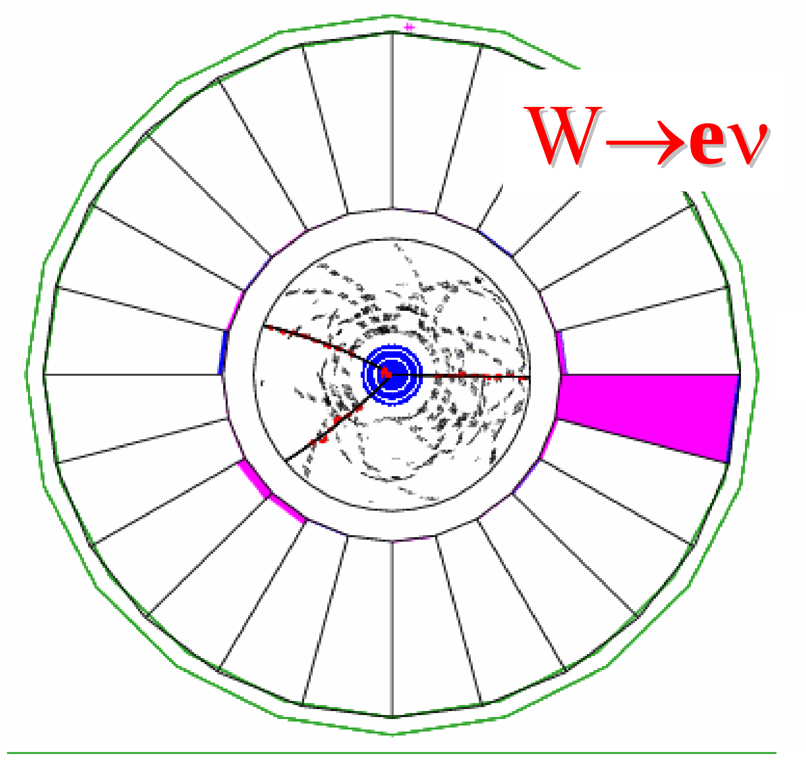
W selection

- one lepton (e or μ)
  - high Pt
  - isolated
- large Missing E_T

Backgrounds

- QCD: fake leptons
- Z→ (ee) μμ
- W→τν
- Cosmics (muon channel)
- Kaon decay in flight

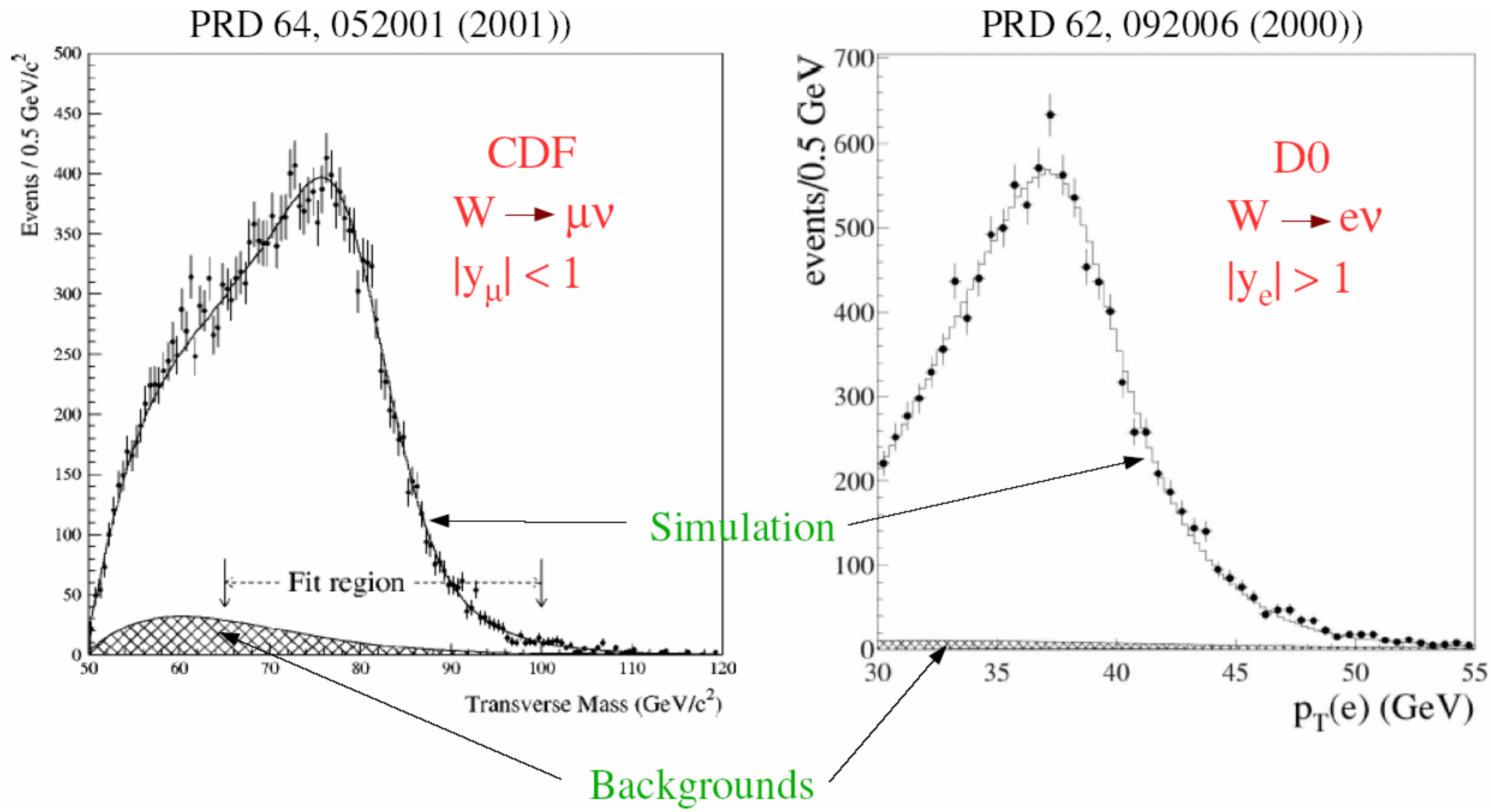




W Mass - Measurement Technique

Fit Jacobian edge of W Transverse mass or Lepton Pt or Missing Transverse Energy

$$M_T = \sqrt{2\, p_T^l \;\; p_T^\nu (1 - \cos\varphi_{l\nu})}$$

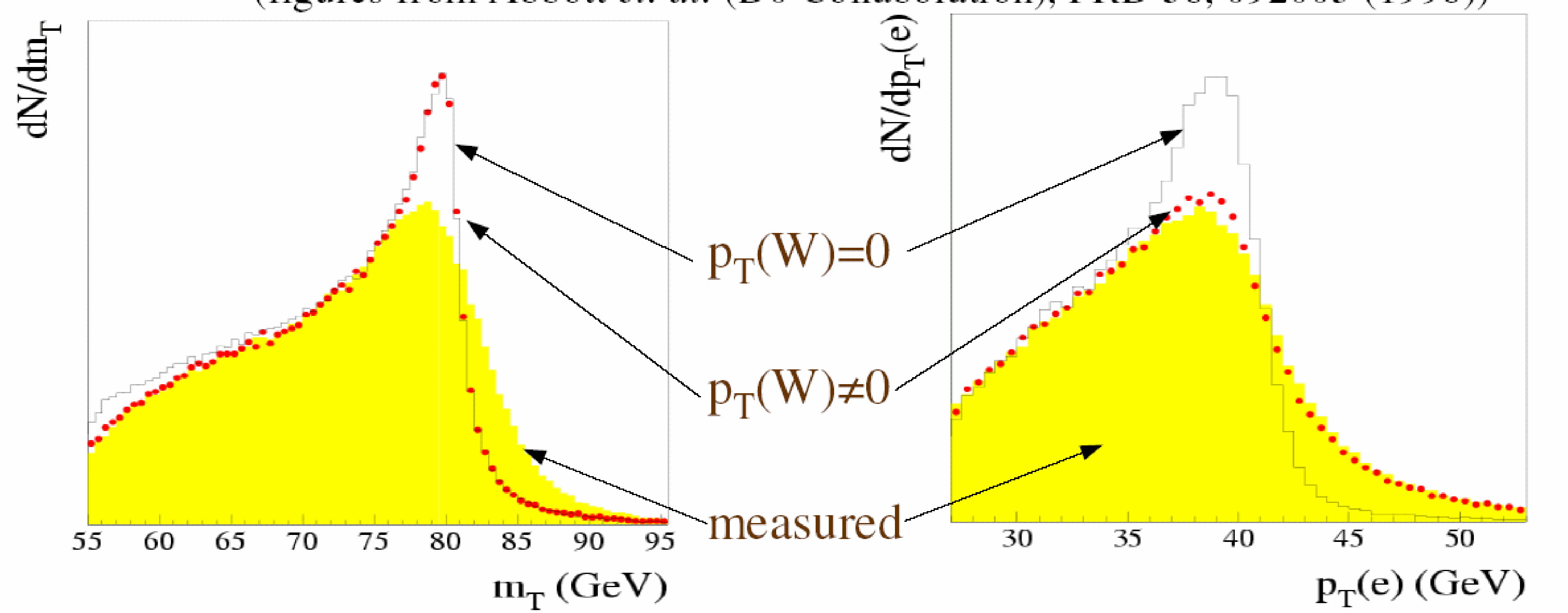


W Pt and Recoil Model

- M_T insensitive to W Pt to first order, but neutrino Pt depends on calorimeter response to hadronic activity and multiple interactions
- Pt(lepton) insensitive to hadronic response, but need theoretical model of W Pt

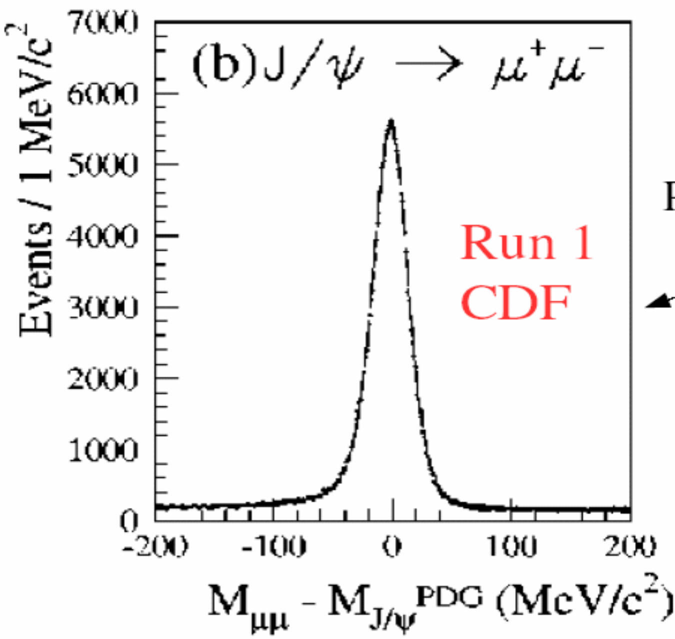
For both cases use Z→ll data to measure hadronic recoil. Fit provides parameterization of non-perturbative QCD contribution to Pt

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



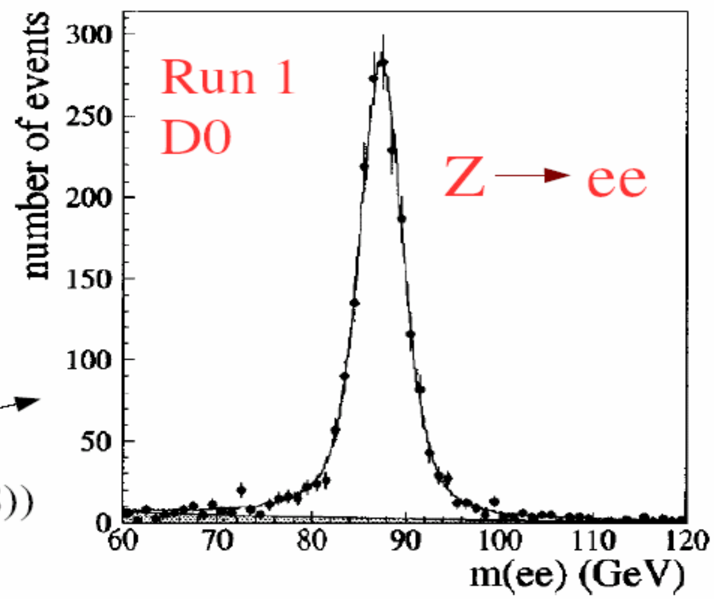
W Mass - Energy Scale Calibration

- Study tracking momentum and calorimeter energy scale and resolution
- Use J/ψ, Υ, Z resonances
- Ultimately limited by sample size of Z decays



PRD 64, 052001 (2001))

PRD 58, 092003 (1998))



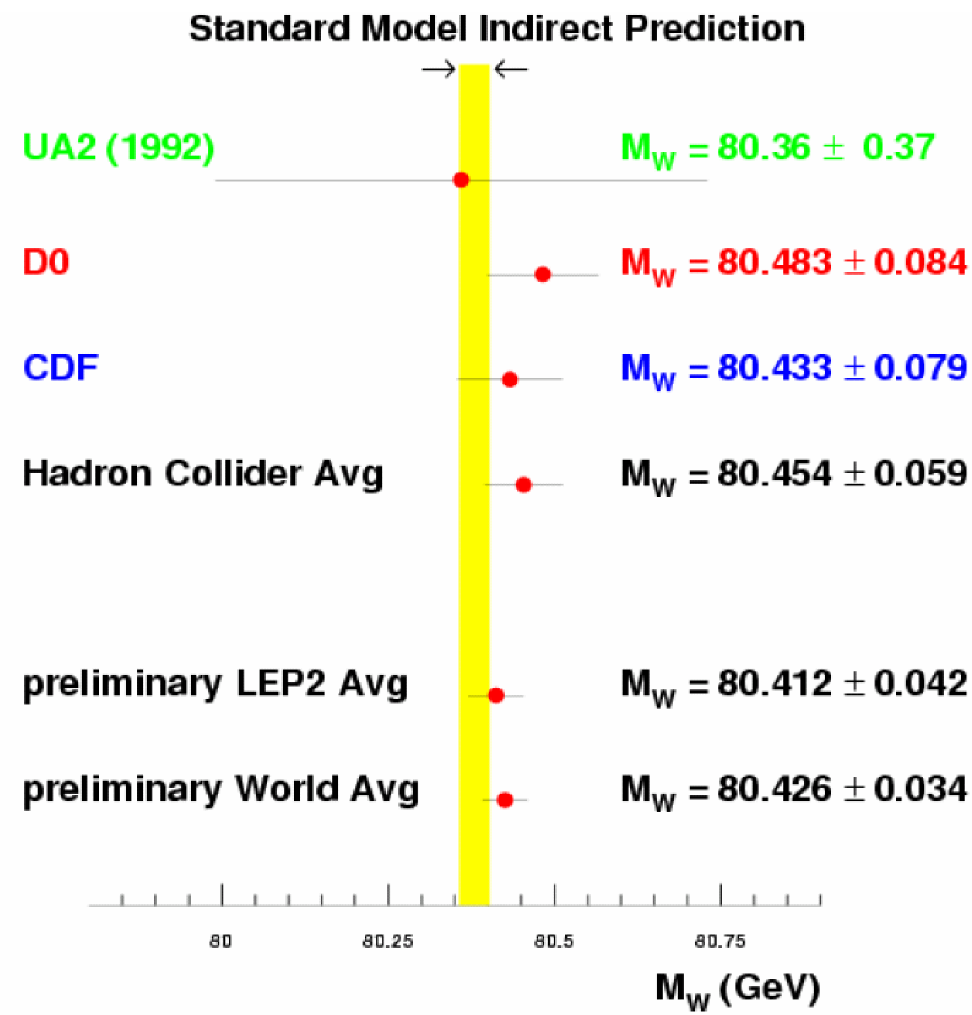
W Mass - Uncertainties

- Final state photon QED radiation gives 100 MeV shift to mass
- Angular Acceptance cuts (η) gives sensitivity to longitudinal momentum - depends on Parton distribution functions
- Uncertainty from background (few % level) normalization and shape

Run I 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
$\Gamma(W)$	10	10	10

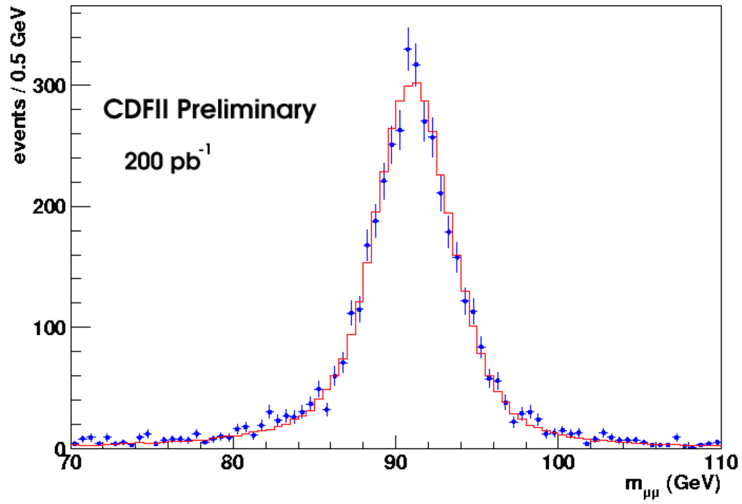
(Correlated uncertainties)

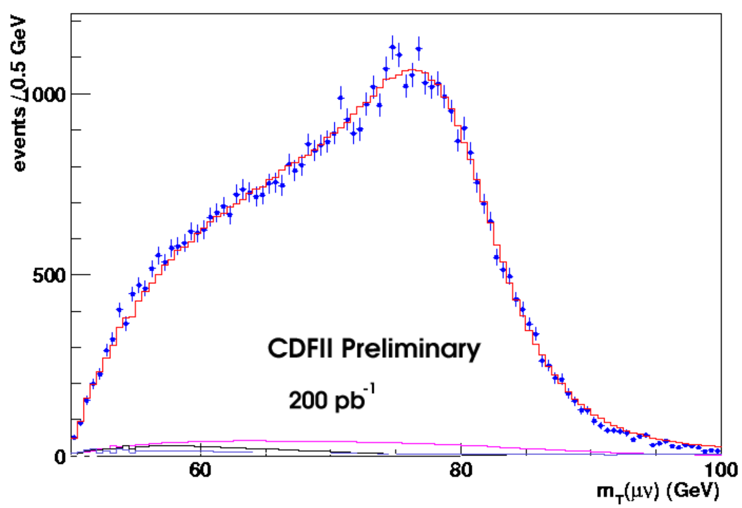
W Mass - Run I Results



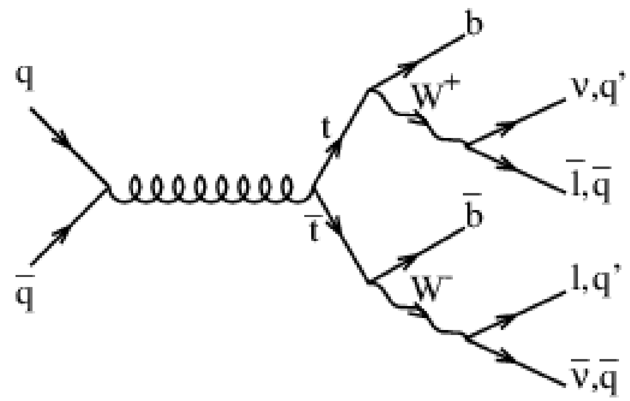
W Mass - Run 2 Results and Prospects

- Look for first CDF Run 2 result at ICHEP
  - Sample size of 200 pb^{-1}
- Goal with 2 fb^{-1} is total error of 40 MeV per experiment





Top Quark Decay



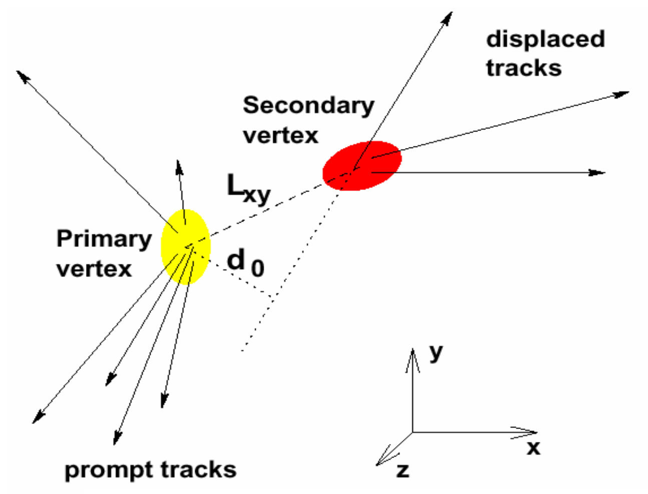
W decay defines top quark pair samples

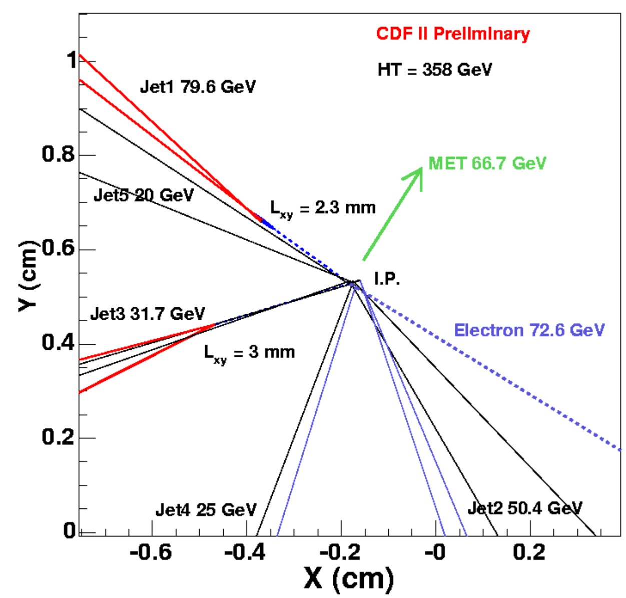
•Dilepton (e,μ)	BR=5% (low background)
•Lepton (e,μ) +jets	BR=30% (W+jets background)
•All jets	BR=44% (very large QCD background)
• τ_{had}+X	BR=21% (taus are hard)

Reconstruct Top Mass in Lepton+jets, Dilepton and All jets samples

Top Lepton + Jets Sample

- Event Selection:
  - electron or muon with Pt> 20 GeV
  - Missing Et > 20 GeV
  - 3 jets with Et > 15 GeV
  - 4th jet with Et > 8 GeV
  - Require jet with displaced vertex
    - Changes S/B from 1/4 to 3/1
  - 28 events with bkg of 7.0 ± 0.8
- Backgrounds:
  - Wbb, Wcc, Wc events
  - QCD
  - W+(mistagged light quark jets)
  - WW,WZ, single top





Top Mass Reconstruction

Lepton+4 jet events

4 jets = 12 possible jet-parton combinations x 2 solutions for neutrino p_z

Use χ^2 with 5 constraints:

$M_{l\nu}=M_W$, $M_{jj}=M_W$, $M_{t1}=M_{t2}$, p_T balance

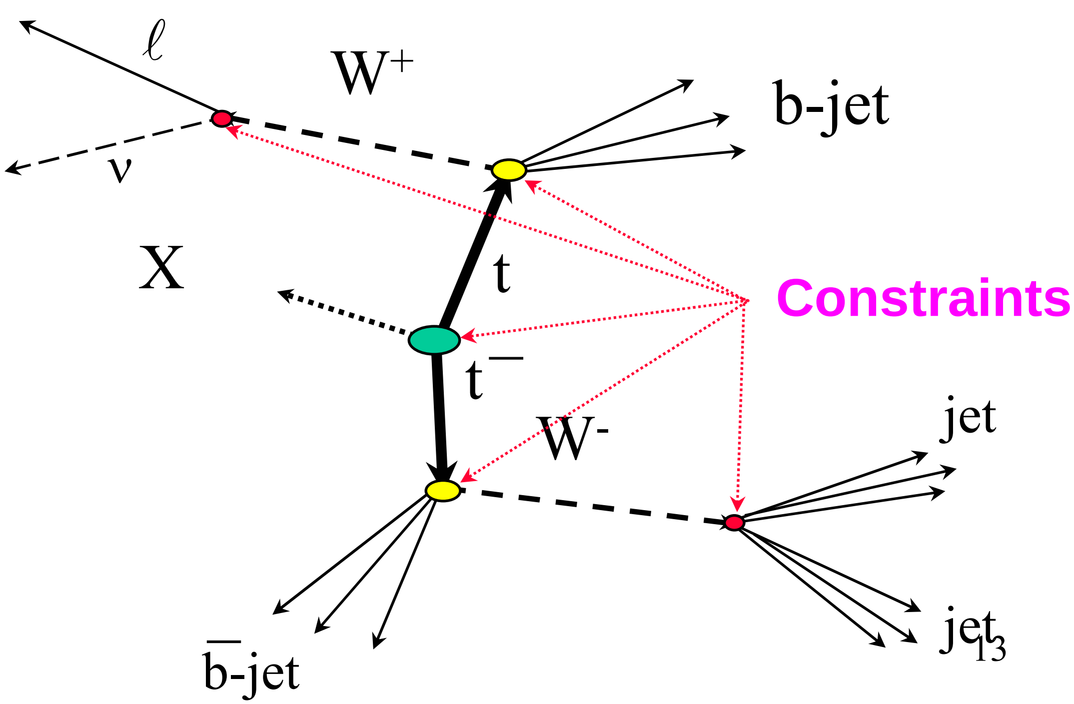
(χ^2 overconstrained by 2 parameters)

$$\chi^2 = \sum_{\ell,jets} \frac{\left(\hat{P}_T - P_T\right)^2}{\sigma^2_{P_T}} + \sum_{i=x,y} \frac{\left(\hat{U}_i^{\prime} - U_i^{\prime}\right)^2}{\sigma^2_{U_i^{\prime}}} + \frac{(M_{\ell\nu} - M_W)^2}{\sigma^2_{M_W}} + \frac{(M_{jj} - M_W)^2}{\sigma^2_{M_W}} + \frac{(M_{\ell\nu j} - M_t)^2}{\sigma^2_{M_t}} + \frac{(M_{jjj} - M_t)^2}{\sigma^2_{M_t}}.$$

Jet energies can vary within resolutions

Choose lowest χ^2 combination

B tagging reduces permutations

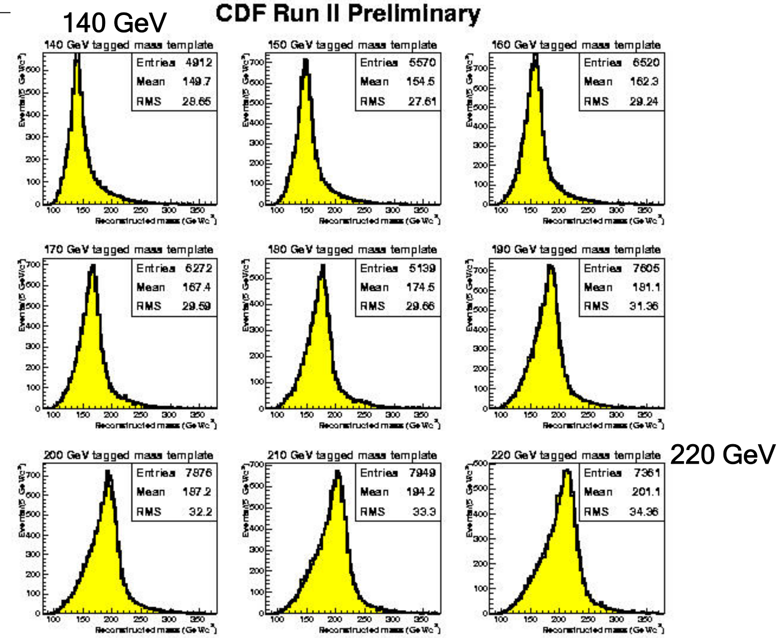


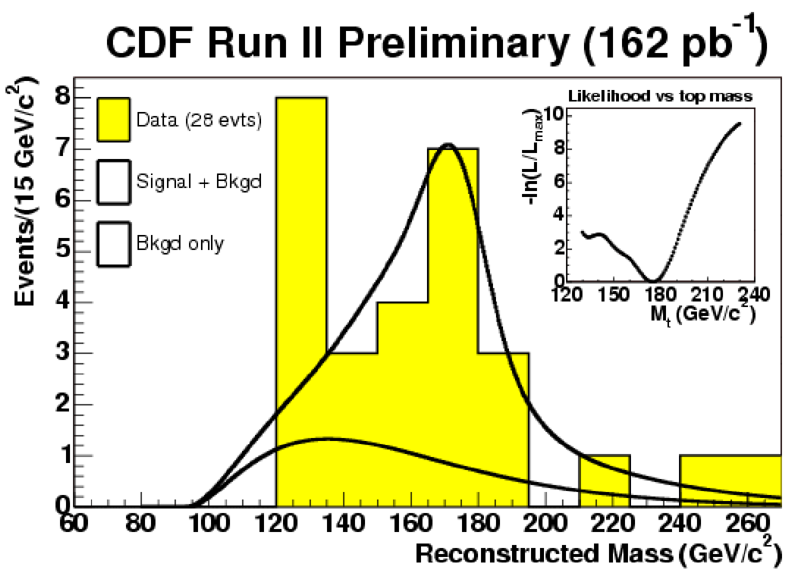
Top Mass - Template Method

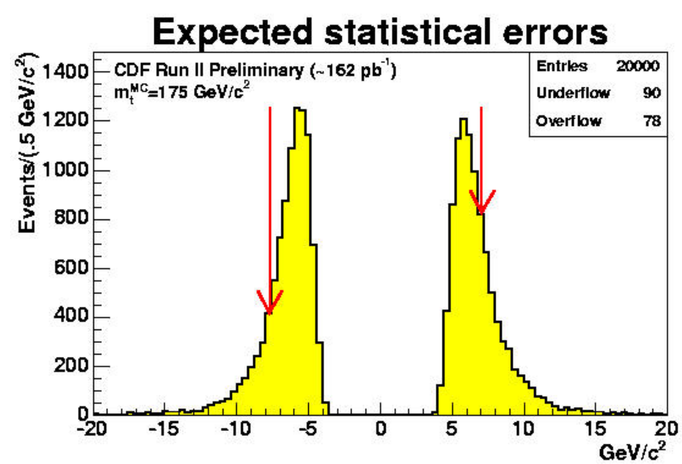
28 events with bkg of 6.8 ± 1.2

Reconstructed Mass fit to template based on MC

- Dependence of reconstructed mass on true mass parameterized from fits to MC
- Include background templates constrained to background fraction







$m_t = 174.9\,^{+7.1}_{-7.7}$ (stat) ± 6.5 (sys) GeV

Top Mass - D0 Matrix Element Method

- Use matrix element to form an event-by-event likelihood vs. $m_{t:}$
  - Uses all information in the event
  - All jet assignment permutations used
- Method applied to D0 Run 1 L+jets data sample (22 events w/o btag)
  - Statistical uncertainty reduced from 5.6(using template) to 3.6 GeV/c^2
  - Equivalent to a 2.4x larger dataset!

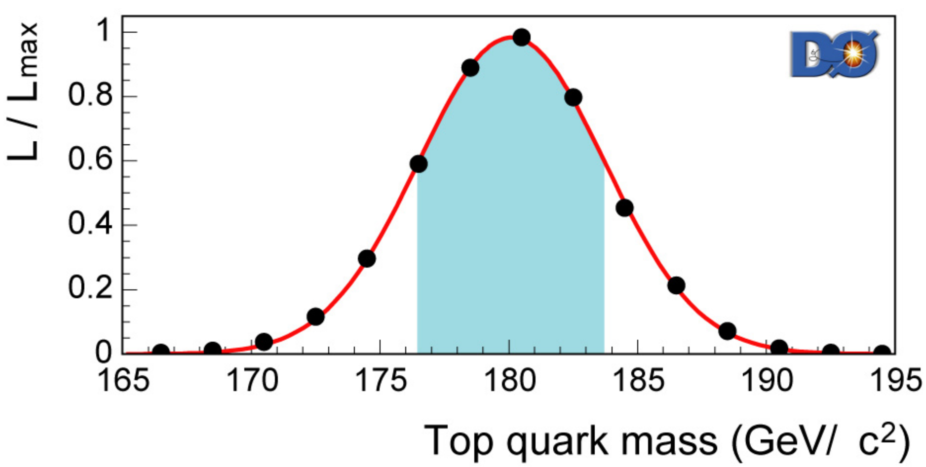
$$P(x,m_t) = \frac{1}{\sigma(m_t)} \int \underbrace{d\sigma(y,m_t)}_{\text{Phase space LO ME for top or BG (W+4j)}} dq_1 dq_2 \underbrace{f(q_1) f(q_2)}_{\text{PDFs}} \underbrace{W(x,y)}_{\text{"transfer function"}}$$

"transfer function"

Phase space
LO ME for top
or BG (W+4j)

PDFs

Probability for observable x given parton y
(Ex: quark $E_T \rightarrow$ jet E_T)
Only applied to jet energies



m_t = 180.1±3.6(stat)±3.9(syst) GeV/c^2

Published *in Nature*(**429**, pp. 638-642)

Top Mass - DLM Method

- "Dynamical Likelihood Method" K.Kondo J.Phys. Soc. 57, 4126 (1988)
- Similar to matrix element method
- Sample: 22 tagged L+4 jet events with 4.2 ± 0.8 background prediction

jet to parton assignments

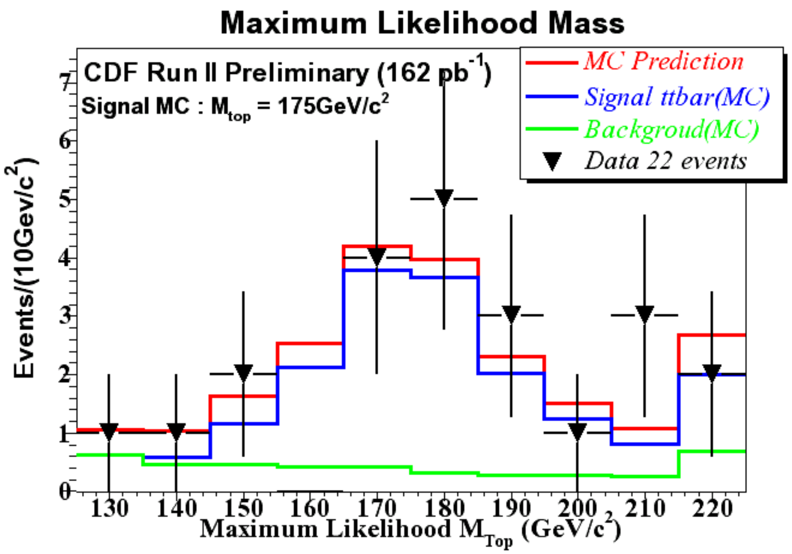
PDF's

Pt of ttbar system

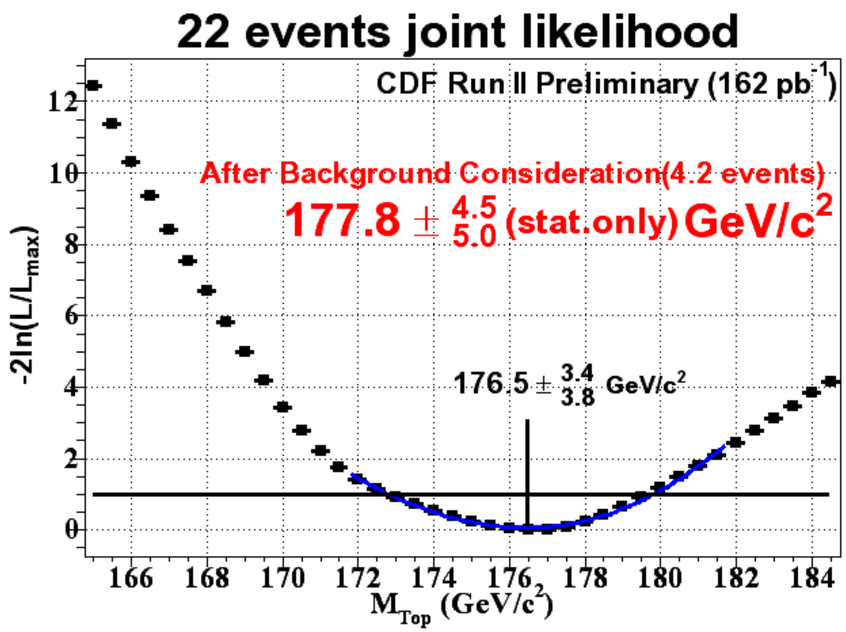
$$L^{(i)}(m_t) = \int \sum_{perm} \sum_{\nu sol.} \frac{2\pi^4}{\text{flux}} |\mathcal{M}|^2 F(z_1, z_2) f(p_t) w(\mathbf{x}, \mathbf{y}; m_t) \mathrm{d}\mathbf{x}$$

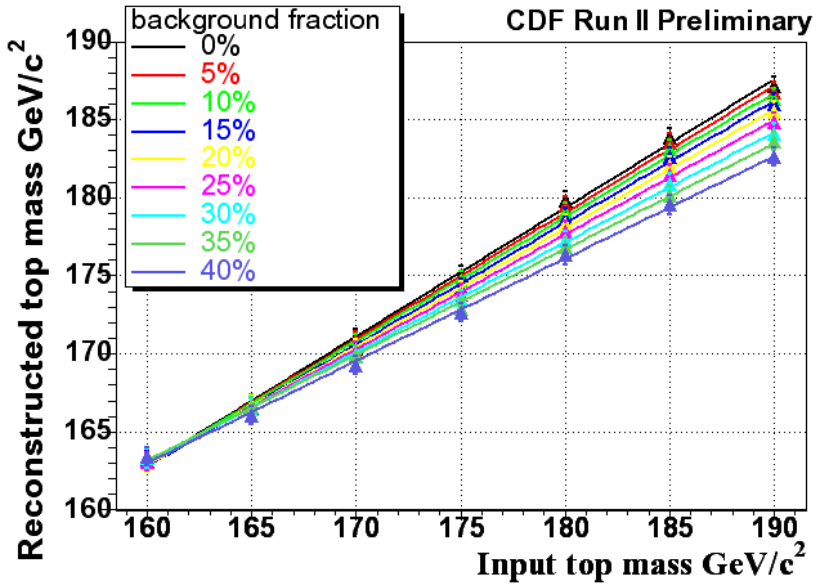
LO top ME - no bkg ME (correction required)

Transfer function: probability for parton x given reconstructed y Depends on jet Et, η and jet type (b or W jet)



Top Mass - CDF DLM Result





$$m_t = 177.8^{+4.5}_{-5.0}(stat) \pm 6.2(syst)\ \mathrm{GeV}/c^2$$

Mapping function: from measured mass to true mass for a given BG fraction(19% for b-tagged l+4j sample)

errors scale as well

Top Mass - Systematic Uncertainties

Template Method

Jet Energy Scale	6.3
Initial State Radiation	0.4
Final State Radiation	0.9
Parton Distribution Functions	0.2
Generators	0.4
Other MC Modeling	0.7
Background Shape	0.8
B-tagging	0.1
Total	6.5

Relative to Central	3.0
Central Calorimeter Response	4.6
Corrections to Hadrons (Absolute Scale)	2.2
Corrections to Partons (Out-of-Cone)	2.3
Total	6.3

Jet Energy Scale dominates

- Calibrate by test beam, single track response, $Z \rightarrow ee$, E/p for electrons
- Requires careful calorimeter simulation

- Goal: use $Z \rightarrow bb$, (trigger on b jets)
  $W \rightarrow qq$ in top event

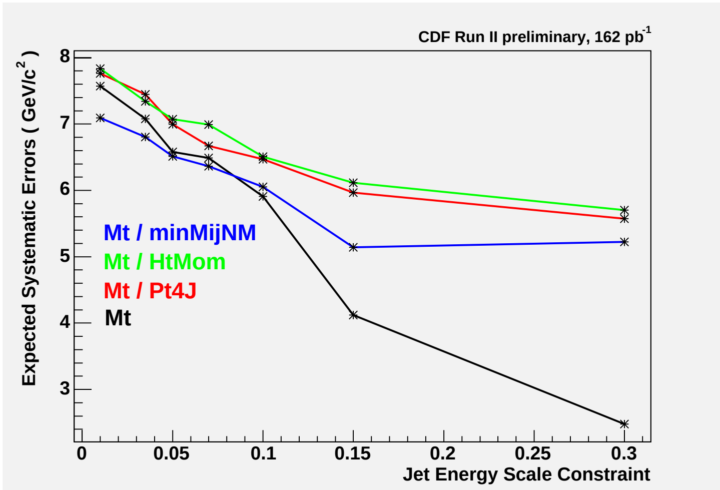
DLM Method

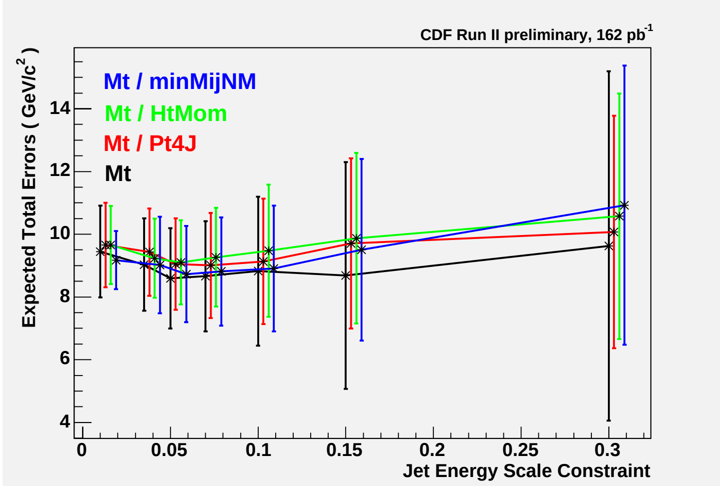
Source	Δ M_{top} GeV/c^2
Jet Energy Corrections	5.3
ISR	0.5
FSR	0.5
PDFs	2.0
Generator	0.6
Spin correlation	0.4
NLO effect	0.4
Transfer Function	2.0
Background fraction($\pm$5%)	0.5
Background modeling	0.5
Monte Carlo modeling	0.6
Total	6.2

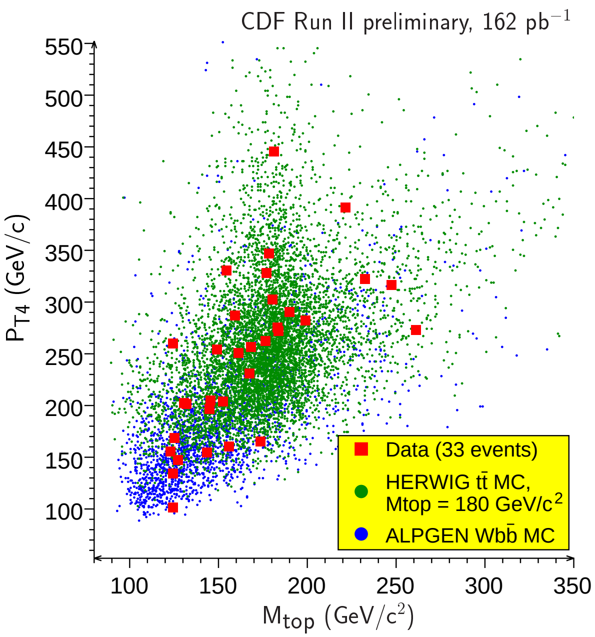
Top Mass - Multivariate Template Method

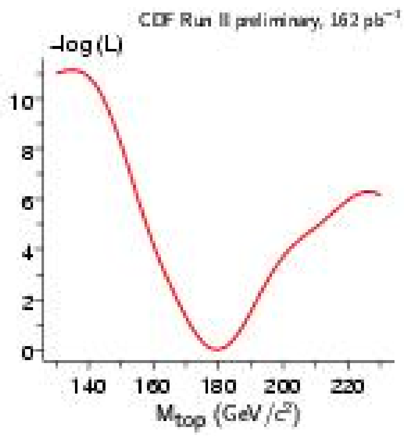
Variation on template method

- Fit for Jet Energy Scale in each event using $W \rightarrow qq$ constraint
  - Tradeoff between systematic and stat. error
- Add 2nd variable(Et sum of 4 jets) to fit for bkgnd fraction
- 33 events in sample







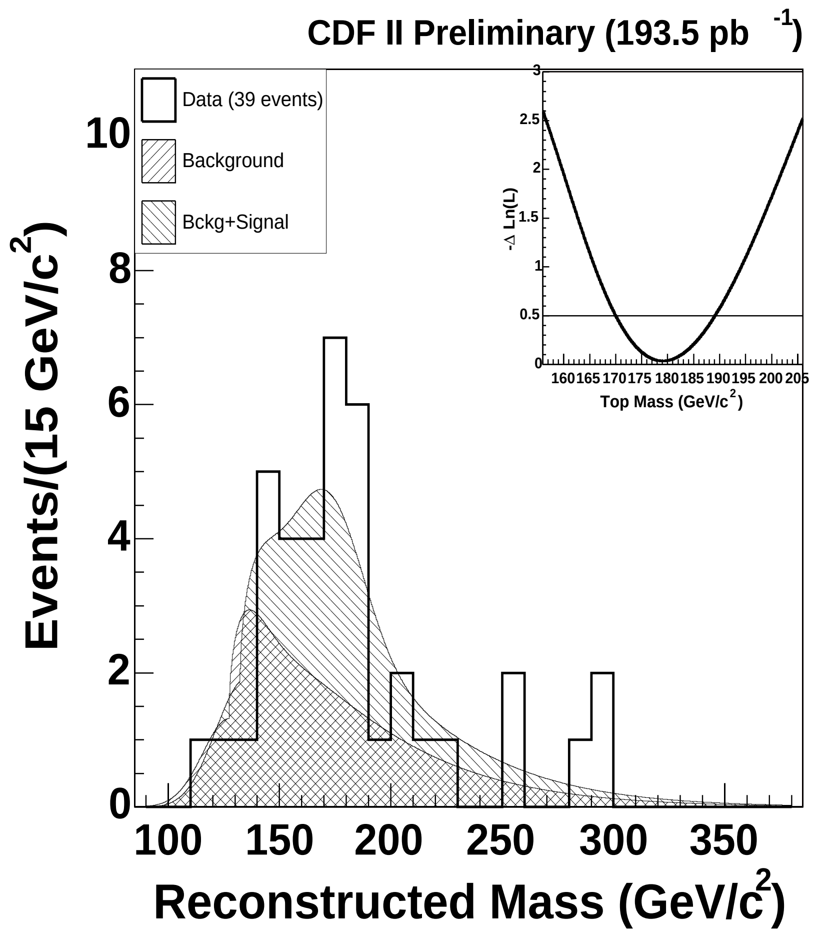


$$m_t = 179.6^{+6.4}_{-6.3}(stat) \pm 6.8(syst)\ \mathrm{GeV}/c^2$$

$$f_b = 0.34 \pm 0.14$$ background fraction

Top Mass - Untagged Sample

- Lepton + ≥ 4 jets with Et > 21 GeV
  - No tagged jets in sample
  - Exclusive to btag sample
- 39 candidates
  - 15.5 ± 3.2 background events
  - Bkgnd fraction constrained in fit
- Will be combined with tagged sample



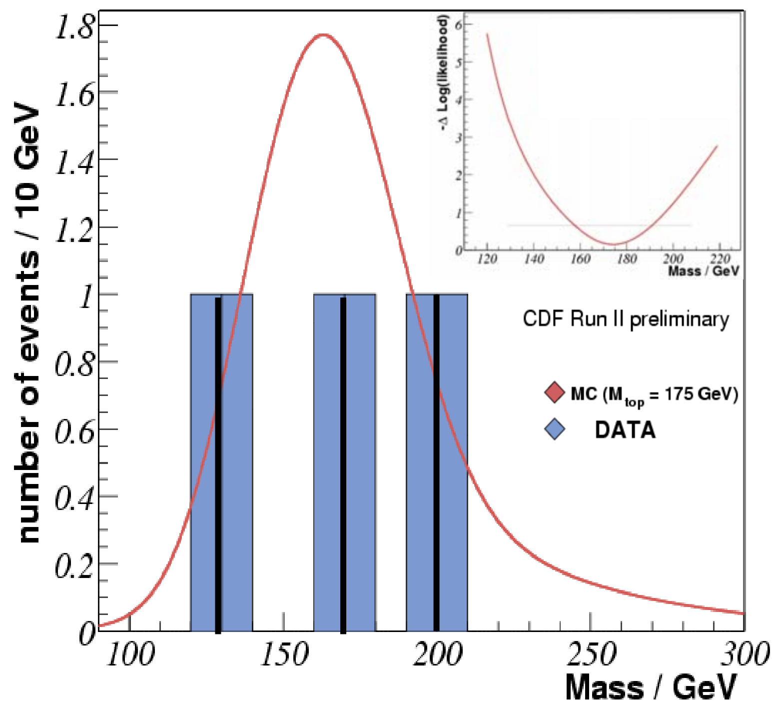
$$179.1^{+10.5}_{-9.5}\,\textbf{(stat)} \pm 8.4\,\textbf{(syst) GeV/c}^2$$

Top Mass - Dileptons

Event Selection
2 e, µ with pT > 20 GeV
≥ 2 jets with ET > 15 GeV
Missing Et > 25 GeV

2 Neutrinos means kinematics underconstrained
Rely on MC to provide last constraint on Pz of ttbar system

Result: with 126 pb^{-1}
(update coming at ICHEP)



$$175.0^{+17.4}_{-16.9}\,(stat) \pm 7.9(syst)\ GeV/c^2$$

Top Mass Run 2 - Results and Prospects

- Several CDF Run 2 top mass results using multiple methods
  - DLM method smallest apriori error
- D0 has greatly improved Run 1 result
  - Run 2 result coming soon

- Goal is 3 GeV error per experiment for Run 2
  - Priority is reducing jet energy scale systematics

- Eventually use double tag sample
  - Fewer permutations (smaller statistical error)
  - Untagged jets will calibrate energy scale using W mass
  - Smaller background
- Will combine channels into one measurement