A Five Year Plan for CDF

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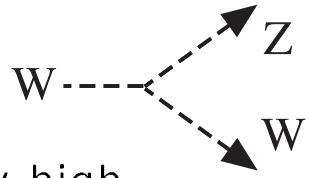
1. CDF Physics
2. Run 1 Status
3. Run 2 Proposal
4. Financial and Personnel Requirements

TRIUMF
September 30, 1995

Physics at 2 TeV

$p\bar{p}$ collisions at 1.8 TeV open unique window onto:

- $W^{\pm}$, Z° and γ production
- Perturbative QCD tests
- Heavy (b and c) quark production & spectroscopy
- Top Quark Physics
- EWK tests: M_W, WWZ couplings, Γ_W
- New physics: SUSY, compositeness, $H^{\pm}$, technicolor



Many new vistas open up with very high sensitivity (0.1 $\rightarrow\sim$ 1 fb^{-1})

- Detect $\lesssim$ 0.01 pb cross sections
- Explore higher-order EWK processes
- Extend “mass reach” for new phenomena by $\sim\times2$
- High statistics b and t physics

CDF Run 1 Physics

CDF collaboration has well established track record

- Operates detector at Fermilab Tevatron Collider
- Collaboration consists of $\sim$ 450 physicists and 35
- Involves groups from five countries

CDF is just finishing a three-year run (1A and 1B)

- In 1992-93, collected $\sim$ 20 pb^{-1} (Run IA)
- Since 1994, have collected $\sim$ 100 pb^{-1}(Run 1B)
  - Run 1B continuing through February 1996
  - Ultimate goal is $\sim$ 150 pb^{-1}

Many new results have already been published

- New measurement of M_W and Γ_W
- Discovery of top
- Wealth of bottom physics

$\boxed{W \text{ Mass Measurement}}$

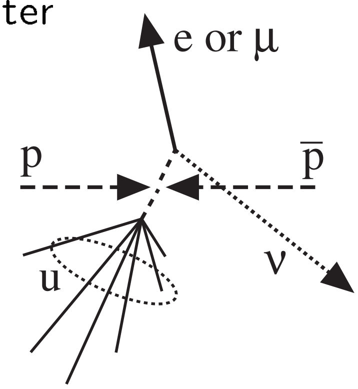
W production cross section is ~ 20 nb at Tevatron

- Can readily observe $W \to e\nu_e$ and $W \to \mu\nu_\mu$
- Select high E_T electron or muon
- Require significant $\not{E}_T$ to tag neutrino

Can extract M_W from transverse mass distribution

$$M_T = \sqrt{2E_T \not{E}_T(1 - \cos\phi_{l\nu})}$$

- Sensitive to performance of entire calorimeter
- Sensitive to structure functions



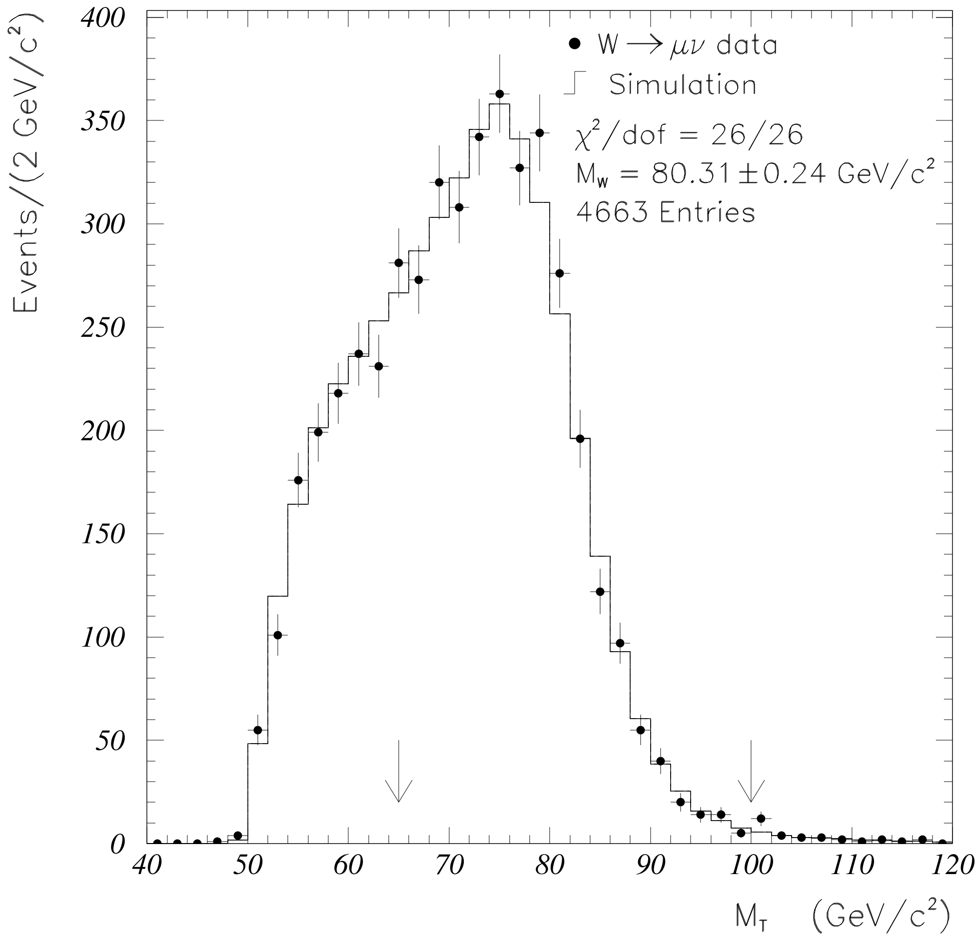
Fit $65 < M_T < 100$ GeV to predicted lineshape

- 5718 electron events
- 3268 muon events

Fit to Muon Data

Results of fit to muon data

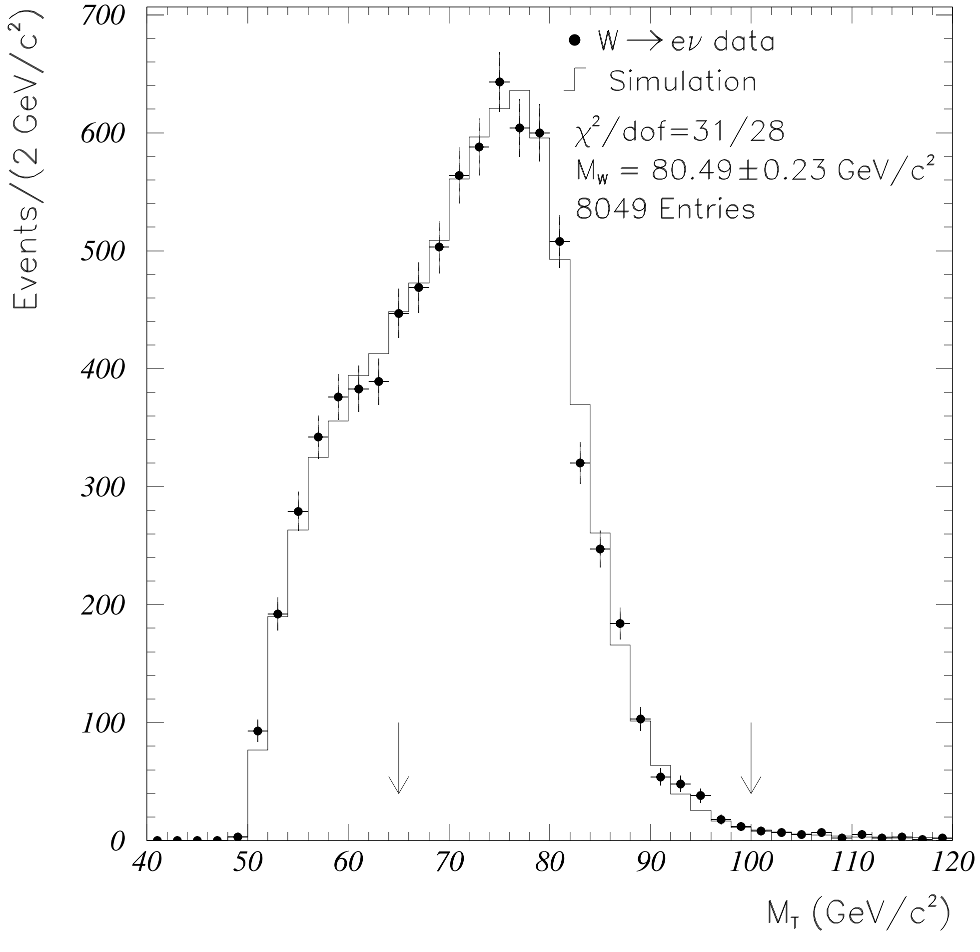
$$M_W = 80.310 \pm 0.205 \pm 0.130 \text{ GeV/c}^2$$



Fit to Electron Data

Results of fit to electron data

$$M_W = 80.490 \pm 0.145 \pm 0.175 \text{ GeV/c}^2$$



Systematic Uncertainties on W Mass

Control of systematics most challenging aspect

1. Energy and momentum scale (120 and 45 MeV/c^2)
    - Determined using $\Upsilon/\psi \rightarrow \mu^+\mu^-$ and $Z \rightarrow \mu^+\mu^-/e^+e^-$
    - calorimeter scale set by tracking system
2. Resolution function of "detector" ($\sim$ 80 MeV/c^2)
    - Constrained by studies of Z events
3. Uncertainies in "recoil" system physics ($\sim$ 60 MeV/c^2)
    - Limited by statistics on Z sample
4. Structure functions (50 MeV/c^2)
    - Use MRS D_-' as default
    - Check variation caused by other choices

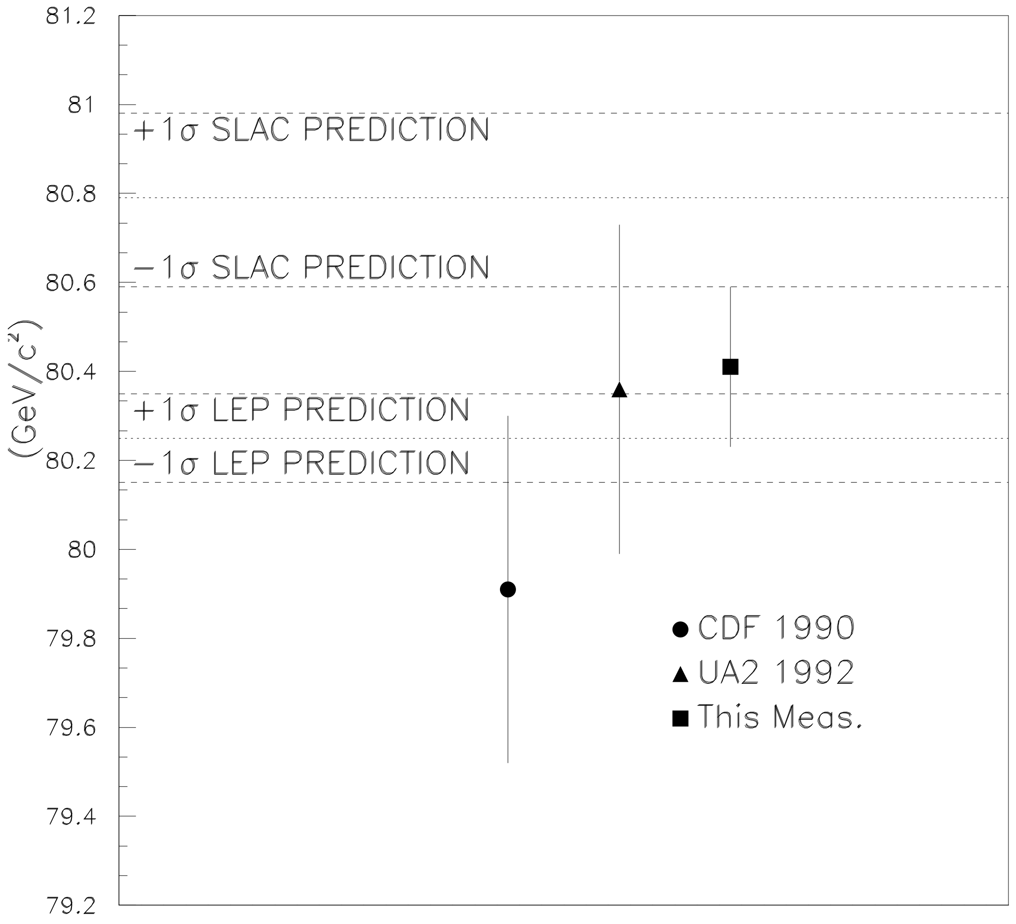
Accounting for correlations in these uncertainties

- Overall systematic uncertainty is 130 MeV/c^2

Summary of W Mass

Combined mass from both channels is

$$M_W = 80.41 \pm 0.18 \text{ GeV/c}^2$$



Dilepton Top Quark Search

$t\bar{t}$ decaying into 2 leptons create unique signature

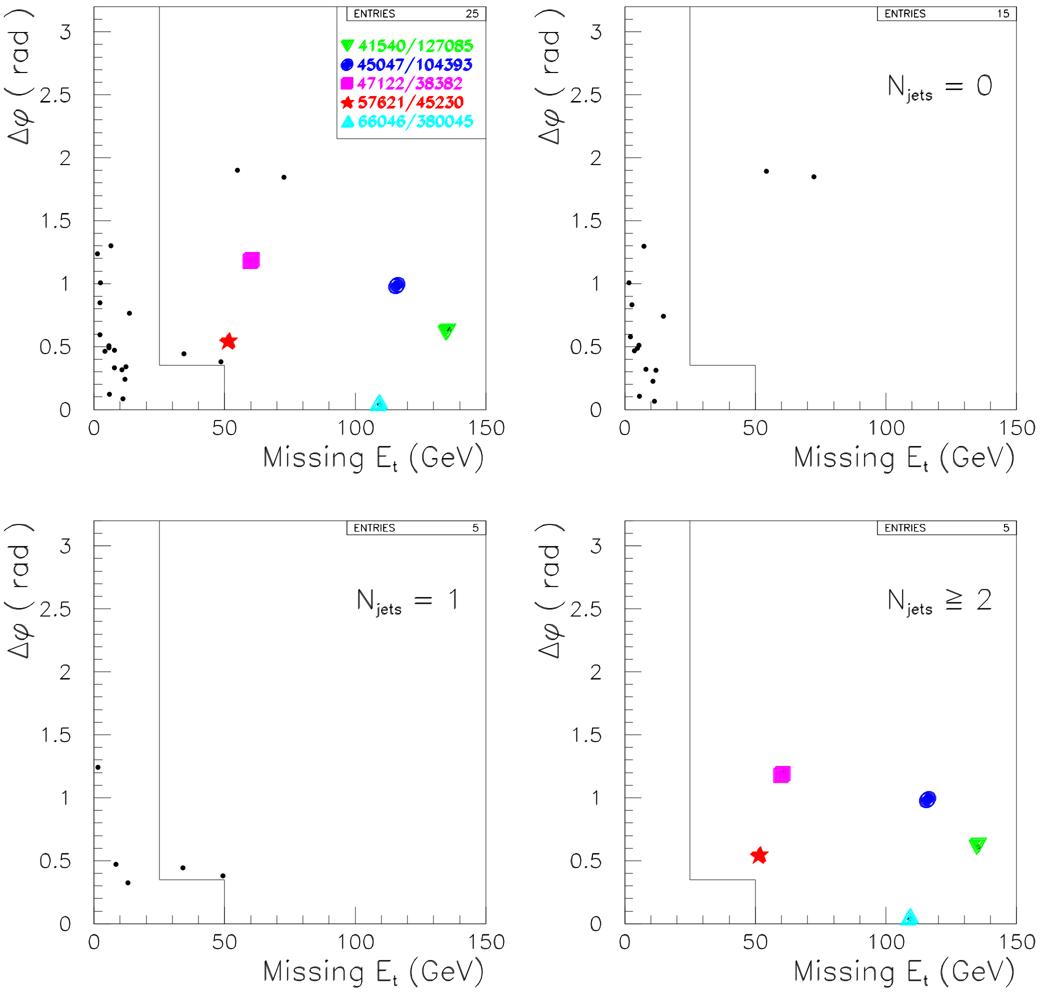
- Two charged leptons from $W^{\pm}$ decay
- Imbalance in total energy due to undetected neutrinos
- Two jets from bottom quarks

CDF performed a search requiring

- Two clean, high P_T lepton candidates
- Missing transverse energy $\not{E}_T > 25$ GeV
- Require two jets with $E_T >$ 10 GeV and $|\eta| < 2.0$
- Reject specific backgrounds (e.g. Z°)

Electron-Muon Data for Run 1A and 1B

eμ data: Δφ (MET, lepton or jet) vs Missing E_t



Summary of Dilepton Search

Observe a total of 6 candidate events

- Observe 1 $\mu^+\mu^-$ event and 5 $e\mu$ events
- Expect 1.3 ± 0.3 events from background

Background	Expected Background Rate
$Z \rightarrow \tau^+\tau^-$	0.38 ± 0.07
One or both leptons fake	0.23 ± 0.15
$b\bar{b}$	0.03 ± 0.02
WW, WZ and ZZ	0.21 ± 0.07
Drell-Yan	0.44 ± 0.28
Total	1.3 ± 0.3

Probability of background fluctuation is 3.3×10^{-3}

b Quark Tagging in W+Jet Events

Top observed in lepton+jets channel where we look for

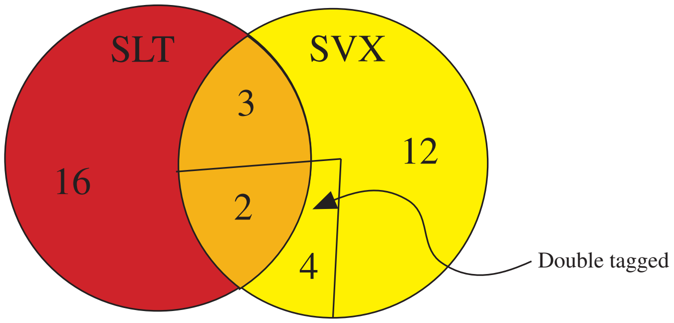
$$t \rightarrow W^{+}b \rightarrow l\nu_{l}b \quad \text{and} \quad \bar{t} \rightarrow W^{-}\bar{b} \rightarrow q\bar{q}'\bar{b}$$

Use b quark tag to get very clean $W + b+$ jets sample

- The $W + 1$ and $W + 2$ jet samples are control samples
  - Don't expect significant top contribution

Sample	SVX bkg	SVX tags	SLT bkg	SLT tags
W+1 jet	50 ± 12	40	159 ± 25	163
W+2 jet	21 ± 7	34	46 ± 7	55
W+$\geq$ 3 jet	6.7 ± 2.1	27	15.4 ± 2.3	23

- Probability of background fluctuation is 1×10^{-6}
  - Combining SVX, SLT and DIL channels
- Agrees well with expected rate from $t\bar{t}$ production



Measurement of Top Mass

We use event kinematics to estimate top quark mass

- Require events to have a fourth jet
  - Require $E_T > 8$ and $|\eta| < 2.4$ for 4rth jet
  - High efficiency ($\sim 85\%$ for $t\bar{t}$)
- Combine all possible jet pairs to form $W \to q\bar{q}$
  - Choose one with best χ^2
  - Require $\chi^2 < 10$
- Use b-tag information to identify b quark jet
- Fit events requiring kinematic constraints

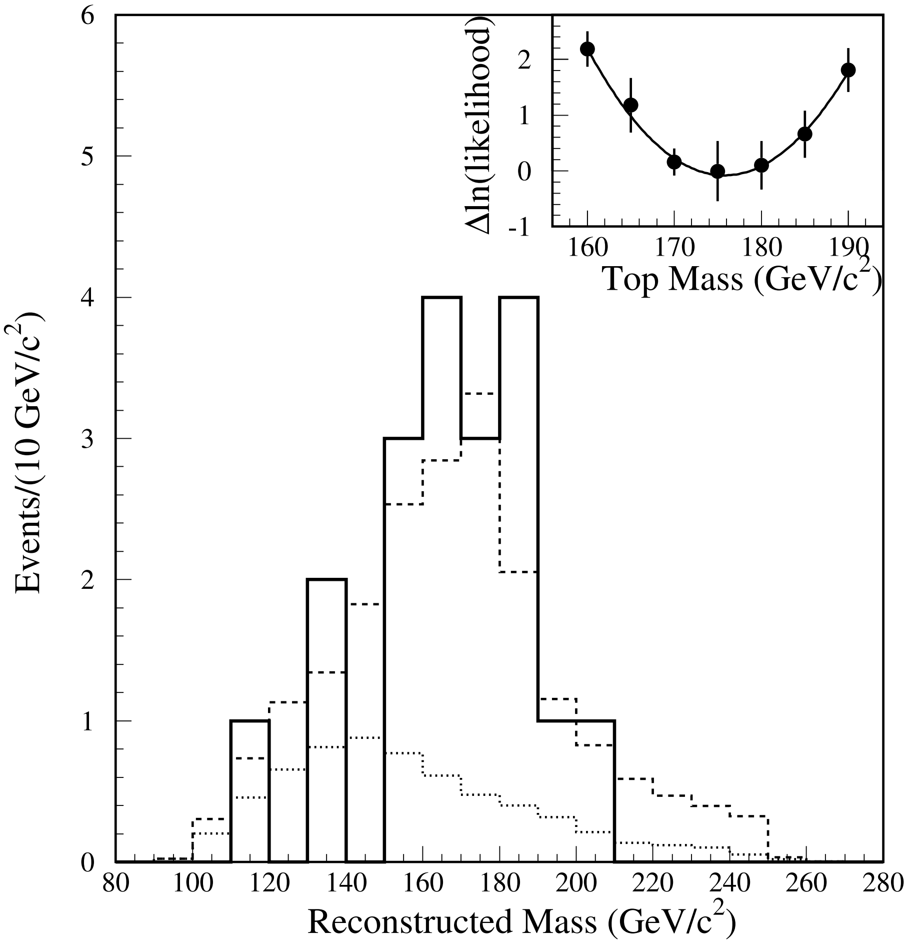
This selection leaves us with 19 tagged events

- Estimate background to be $6.9^{+2.5}_{-1.9}$ events
  - Primarily QCD W+jet

Result of Mass Fits

The fitted mass for the 19 events is consistent with $t\bar{t}$

- Probability that background would fluctuate to give peak with similar significance is $< 2 \times 10^{-2}$

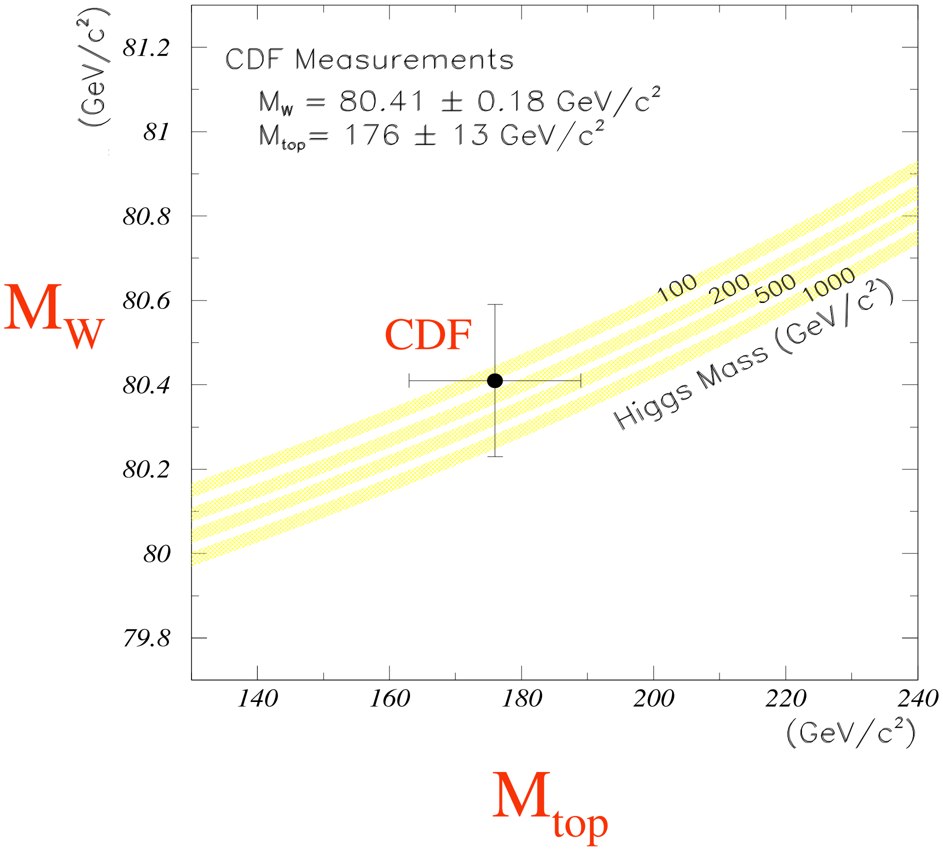


$$M_{top} = 176 \pm 8 \pm 10 \quad \mathrm{GeV/c^2}$$

How Does It All Fit in the SM?

Interesting that everything now points to heavy top

W Mass vs. Top Mass



CDF Long-Range Plan

We have short run in fall (Run 1C)

- Will increase Run 1 data sample to ~ 150 pb^{-1}
- End in Feburary 1996

Collider programme starts up in early 1999

- Expect to achieve luminosities of 2×10^{32} cm^{-2}s^{-1}
- Bunch spacing reduces to 396 and then 132 ns
- 2-year run will collect ~ 2 fb^{-1}

Collaboration has to upgrade detector over next 4 years

- New plug/forward calorimeter (SciFi)
- SVX II: 5-layer double-sided detector
- Intermediate Fibre Tracker (IFT): 6 layers of SciFi
- Extension of muon coverage (complete azimuthal coverage and move FMU system closer)
- New electronics, Trigger, DAQ, Online and Offline systems
- New central tracking detector

Top Physics Impact

Biggest impact Run 2 will have is increased statistics

- $\times 5-10$ in integrated luminosity
- More complete b tagging

Top yields can be reliably estimated from Run 1 data

Channel	1 fb^{-1}	10 fb^{-1}
Tagged $W+\geq$ 4 jets	600	6000
Double tagged $W+\geq$ 4 jets	300	3000
Tagged Dilepton events	100	1000
$Z+\geq$ 4 jet events	200	2000

Most measurements will scale with sensitivity

- $\sigma_{t\bar{t}}$ uncertainty $\pm 5\,(\text{stat}) \pm 7\,(\text{syst})\%$
  - Currently theoretical uncertainty is $\sim \pm 20\%$
- M_{top} measurement is systematics limited

$$\delta(M_{\text{top}}) \sim 3\ \text{GeV/c}^2$$

How Well Can We Measure M_{top}?

Top mass statistical uncertainty will go like $1/\sqrt{\mathcal{L}}$

- Will go down to ~ 2 GeV/c^2 for Run II
- Reduce by using dileptons or multijet events?

Systematic uncertainty driven by jet reconstruction

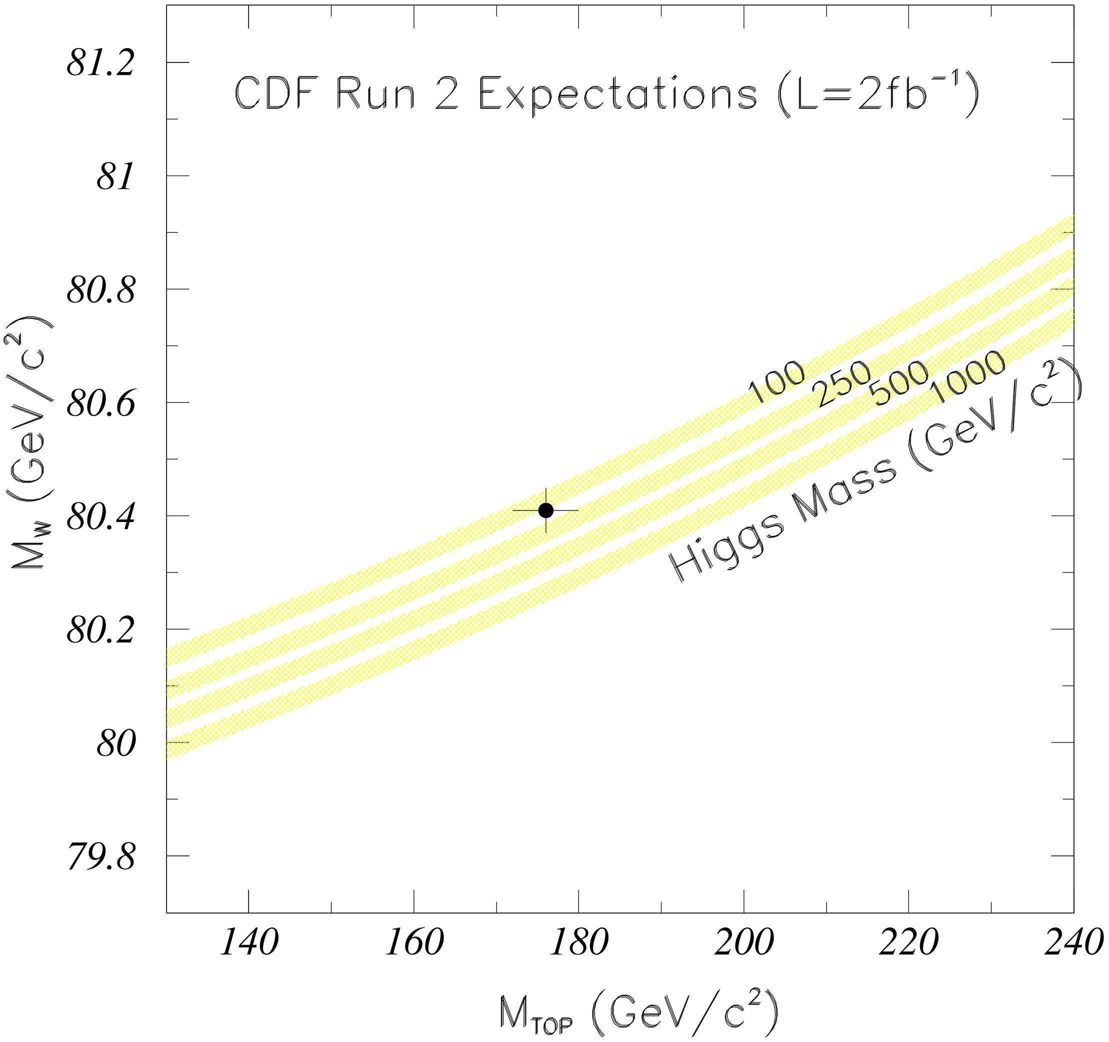
- Best control is $W \rightarrow q\bar{q}'$ signal
- Also have $Z + 1$ and $\gamma + 1$ jet as one calibration
- Expect to reduce σ_{jet} to ~ 5 GeV/c^2 in Run I
  - Use W signal and higher statistics control samples
- Should scale as $1/\sqrt{\mathcal{L}}$
  - Experience of W mass instructive
  - Should be able to get to $\sim 1.5 - 2.0$ GeV/c^2

Other uncertainties (6.4 GeV/c^2) should scale

- knowledge of background shape and b tagging bias
- These should reduce to ~ 1.7 GeV/c^2
- Gives total systemaatic uncertainty of 2.4 GeV/c^2

$$\delta(M_{\text{top}}) \sim 3 \text{ GeV/c}^2$$

Run II M_{top} and M_W measurements will constrain SM



How About V_{tb}?

Limits on V_{tb} depend on V_{ts} and V_{td}

- Best to quote uncertainty on $BR(t \rightarrow W^{+}b)$
- Will remain dominated by statistical uncertainties
  - Biggest systematic uncertainty is tagging efficiency
  - Will have $\sim 10^{7}$ $B \rightarrow lX$ events to measure this

Uncertainty from $W+$ jets measurement is $\sim \pm 20\%$

- Should get to statistical uncertainty of $\sim \pm 3\%$
- Dileptons will measure BR to $\sim \pm 4\%$
- Should continue to scale with $1/\sqrt{\mathcal{L}}$

With SM constraints on V_{ts} and V_{td}

- Set limit of $V_{tb} > 0.25$ at 95% CL

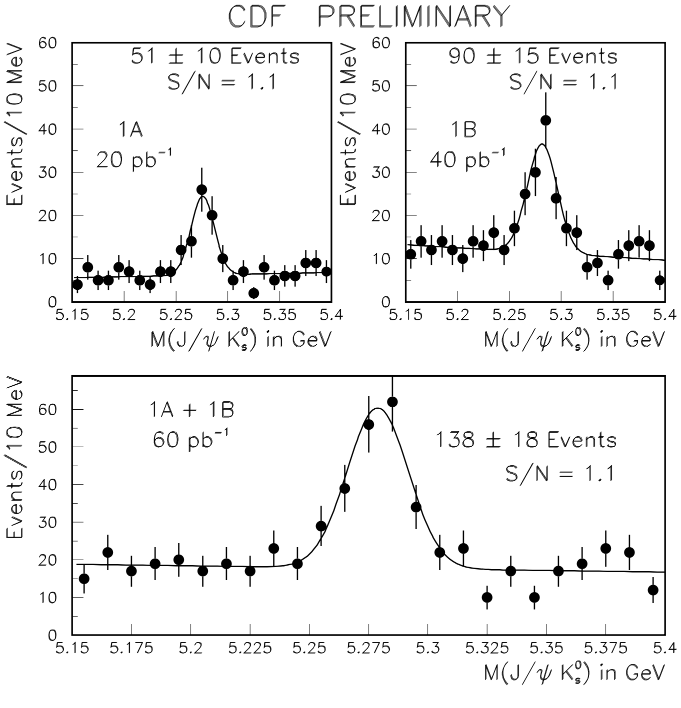
BOTTOM Physics in Run 2

Huge production cross section $\sigma_{tot} \sim 30\ \mu$b

- CDF will record $5 \times 10^6\ B \rightarrow J/\psi X$
- Will be able to nail down spectroscopy (eg., B_c)
- Goal is to measure CP violation

One example is $B_d \rightarrow J/\psi K_s^\circ$ in Run 1

- CP eigenstate: provides measure of $\sin 2\beta$
- Have 140 events in 60 pb^{-1}
  - expect to increase this to $\sim$ 20 events/pb^{-1}



IPP Role in CDF

IPP effort has been focused on t and b physics

- Involved in top quark search and kinematic analysis
- Now using top signal to search for new physics
  - $p\bar{p} \rightarrow W' \rightarrow t\bar{b}X$
  - complements another IPP analysis effort ($W' \rightarrow e^{\pm}\nu_e$)
- Have five separate b analysis projects
  1. Search for $B \rightarrow K^*\gamma$
  2. BR of B_d, B_u and B_s into $J/\psi K$, $J/\psi K^*$ and $J/\psi\phi$
  3. First high-statistics study of $B \rightarrow \psi(2S)K$ and $\psi(2S)K^*$
  4. b quark fragmentation into hadrons
  5. Study of $p\bar{p} \rightarrow \chi_c X$

For Run 2, will continue to focus on b and t physics

- Search for rare decays
- b-flavour tagging for CP studies
- High-statistics top studies

IPP Responsibilities in CDF

IPP has visible role in collaboration

- Managed Offline Software and Data Processing group
- Contributed to online software and firmware
- 2 FTE's involved in software development/maintenance
- R&D in Level 1 tracking trigger and fast RICH
  1. Have developed prototype ASIC's for L1 trigger
  2. Demonstrating fast RICH proof of principle

With new member (W. Trischuk) joining group

- Are evaluating options for Run 2 responsibilities
- Most likely involvement is in tracking upgrade
  - builds on DELPHI experience
  - possibility of replacing inner SVX layers with diamond sensors
- Will have made decision in next 6 months

Resource Commitments

Personnel involved in CDF effort is increasing

	95-96	96-97	97-98	98-99	99-00
Ragan	1.0	1.0	1.0	1.0	0.7
Sinervo	0.9	0.9	0.9	0.8	0.7
Trischuk		0.9	0.9	0.8	0.7
Total Faculty	1.9	2.8	2.8	2.6	2.1
RA	2.0	2.0	2.0	2.0	2.0
Students	6	7	8	8	8
Engineering	0.5	0.5	0.5	0.3	0.1
Total Effort	10.4	12.3	13.3	12.9	12.2

ATLAS is future project for two of us (Trischuk and Sinervo)

- focus for next two years will remain CDF
- forsee increasing role in ATLAS after 1997

Budget Projections

Budget based on existing operating support level (193K)

- require increment to support Trischuk's activity
- require equipment & computing support
  - IPP is required to make significant Run 2 investment
  - One example: 30-50% of CVD Diamond upgrade
    - commitment would be ~ 300K over 97-98 and 98-99

	95-96	96-97	97-98	98-99	99-00
Operating	**193**	300	300	250	250
Equipment	**0**	0	150	150	0
Computing	**0**	100	0	0	100
Total Budget	**193**	400	450	400	350

Other Funding Scenarios

Have considered the scenarios of constant funding, ±10%

- All of these are inconsistent with a Run 2 effort
  - Have increased FTE effort by $\sim 50\%$
  - Require equipment contribution to Run 2 detector
  - Computer facilities inadequate for Run 1 analysis

Only reasonable options are

1. Adequately fund a Run 2 effort
2. Turn IPP effort on CDF off over next 3 years

We believe that option 1) is most productive

- Some of the most exciting physics in year 2000
- Additional investment is modest and "strategic"
- Excellent background for future collider programme