Experimental Summary

There is now published or preliminary data on

- Top Cross Section

$$\sigma_{t\bar{t}} = 7.6^{+2.4}_{-2.0} \text{ pb (CDF)}$$
$$\sigma_{t\bar{t}} = 6.3 \pm 2.2 \text{ pb (D}\emptyset\text{)}$$

- Top Mass

$$M_{\text{top}} = 176 \pm 8 \pm 10 \quad \text{GeV/c}^2 \text{ (CDF)}$$
$$M_{\text{top}} = 199^{+19}_{-21} \pm 22 \quad \text{GeV/c}^2 \text{ (D}\emptyset\text{)}$$

- Top branching fractions $BR(t \to W^+ b)$

$$\mathcal{R} = 0.87^{+0.13}_{-0.30}(\text{stat})^{+0.13}_{-0.11}(\text{syst})$$

Much remains to be done....a not-so-complete list

- Search for rare decays (eg. $t \to Z/\gamma q$)
- Study detailed properties of the t quark
  - Production properties (eg, $\sigma_{t\bar{t}}$, A_{LR})
- Search for new gauge bosons coupling to $t\bar{b}$
  - SUSY Higgs
  - Longitudinal W's
- Look for new physics coupling to t or $t\bar{t}$

These will require high statistics samples of $t\bar{t}$ events

$\boxed{\textbf{How To Optimise Top Physics?}}$

More statistics an obvious place to push

- Increase integrated luminosity $\int \mathcal{L}\,\mathrm{dt}$
  - More running time
  - Upgraded Tevatron
  - LHC in next decade

- Improved detector tagging capability
  - b tagging via SVX works extremely well
  - Increase coverage at CDF (only $\sim$ 50% now)
  - Add capability to DØ

- Increase collision energy
  - Increase from 1.8 to 2.0 TeV yields 40% more $t\bar{t}$
  - LHC energy of 14 TeV yields $\times$100

Basic detection techniques hard to improve upon

- Sorting out jets remains messy
- With higher statistics, can choose cleaner subsamples
  - High p_T top quark events
  - Allows complementary analysis techniques

Future Hadron Machines

Have to consider upgraded Tevatron and LHC

Machine	Year	Energy (TeV)	$\int \mathcal{L}\,dt$ (fb^{-1})
Tevatron Run I	1996	1.8	~ 0.15
Tevatron Run II	1999	2.0	1
Tevatron Run III	2003	2.0?	$30 - 100$?
LHC	2005	8-14	$100 - 1000$?

Use as framework to look at impact on top physics

- No imponderable technical hurdles to overcome
- Tevatron Run II is happening
  - Run III depends on running schedule and LHC
  - Other proposals being kicked around

Tevatron Collider Development

The immediate next step is the Main Injector Project

- Improvements are Main Injector and $\bar{p}$ source
  - Overcomes proton density limitation in Main Ring
  - Higher acceptance into Collider
- Typical luminosity will increase $\times 4$ to 10^{32} cm^{-2}s^{-1}
  - Bunch spacing goes from 3000 ns to 396 ns
  - 50% more protons/bunch
- $\sqrt{s}$ will increase from 1.8 to 2 TeV
- Limitation will be on $\bar{p}$/bunch
- Plan on going to 132 ns bunch spacing later

The Main Injector construction is well underway

- Will be doing some machine studies in fall 1995
- Fixed target run in 1996
- Expect to start commissioning in late 1998

Future Collider Developments

Tevatron Run III has a goal of $\mathcal{L} = 10^{33}$ cm^{-2}s^{-1}

- Achieve much of this with increases in $\bar{p}$ flux
- Would provide $\sim$ 10 fb^{-1} per year
- Competitive with LHC in early years of operation(?)

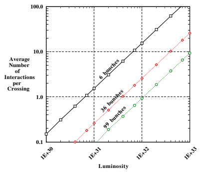
LHC will blow the socks off Tevatron once running

- Luminosity from 10^{33} to 10^{34} cm^{-2}s^{-1}
- Center of mass energy from 8 TeV to 14 TeV
- Enormous production cross section advantage
- Issue is only timescale ($\geq$ 2004)

LHC programme combines both increased $\mathcal{L}$ and $\sqrt{s}$

- Both detectors (ATLAS and CMS) suited for top studies
- Definitive top physics measurements will be done
- Huge source of $t\bar{t}$ events
- Form significant background to $H \rightarrow W^+W^-$ search

Limitations to Luminosity Increase



Significant limitations to increasing $\mathcal{L}$

- Number of interactions/crossing becomes an issue
- Can't afford to build new detectors
- Have to adabiatically approach higher $\mathcal{L}$

$\boxed{\textbf{Run II CDF Detector Upgrades}}$

CDF is being refurbished

- New electronics needed for shorter bunch spacing
- Longer SVX detector with almost complete coverage
  - Deadtimeless readout
- New calorimeter in Plug/Forward region
  - scintillator tile with fibre readout
- Enhanced μ coverage (fill gaps)
- Items under consideration
  - Central tracking system not likely to survive
  - Add scintillating fibre intermediate tracker
  - Particle ID system (TOF or RICH?)

Overall upgrade project is $\sim$ \$40M effort

- Will be tough to get done in time

D∅ Upgrades for Run II

D∅ is metamorphising into a magnetic spectrometer

- Adding a solenoid and new central tracker
- Rebuilding front-end for 396 and 132 ns operation
- Adding SVX detector for b tagging
- Improvements in triggering

Collaboration eager to get this device on-line

- Makes it at least as “good” a detector as CDF
- Can compete in both the low and high p_T physics programmes

Top Physics Impact

Biggest impact Run II will have is increased statistics

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

Can look at the obvious physics measurements

- $\sigma_{t\bar{t}}$
- M_{top}
- Branching ratios and V_{tb}
- Search for new physics

Can make extrapolations based on Run I experience

Run II Top Yields

Can estimate what we should expect in next five years

- Use known yields for Run I
- $W+\geq 4$ jet sample has S/N$\gtrsim 2$
- Add in additional tagging capability

Channel	1 fb−1	10 pb^{-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

Cross section measurement will scale with sensitivity

- Statistical uncertainty $\sim 5\%$ range
- Most systematic uncertainties scale with sample size
  - integrated luminosity an exception – $\sim 3\%$
- Overall uncertainty $\pm 5\,(\text{stat}) \pm 7\,(\text{syst})\%$
  - Currently theoretical uncertainty is $\sim \pm 20\%$

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

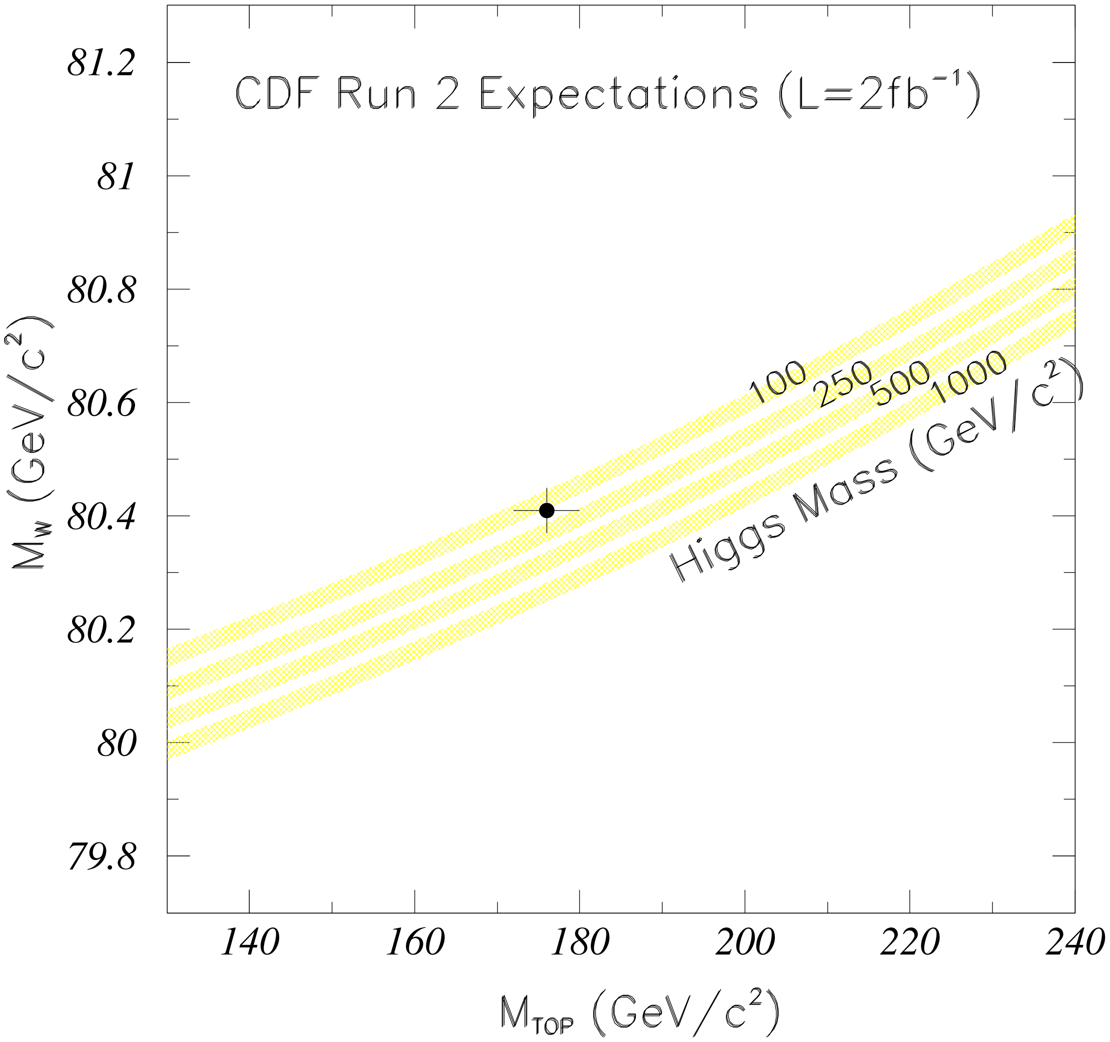
- Best control is $W \rightarrow q\bar{q}'$ signal
- Also have $Z + 1$ and $\gamma + 1$ jet as one calibration
- Expect to reduce σ_{jet} to ~ 5 GeV/c^2 in Run I
  - Use W signal and higher statistics control samples
- Should scale as $1/\sqrt{\mathcal{L}}$
  - Experience of W mass instructive
  - Should 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 $BR(t \to W^+b)$
- Will remain dominated by statistical uncertainties
  - Biggest systematic uncertainty is tagging efficiency
  - Will have $\sim 10^7$ $B \to lX$ 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 $1/\sqrt{\mathcal{L}}$

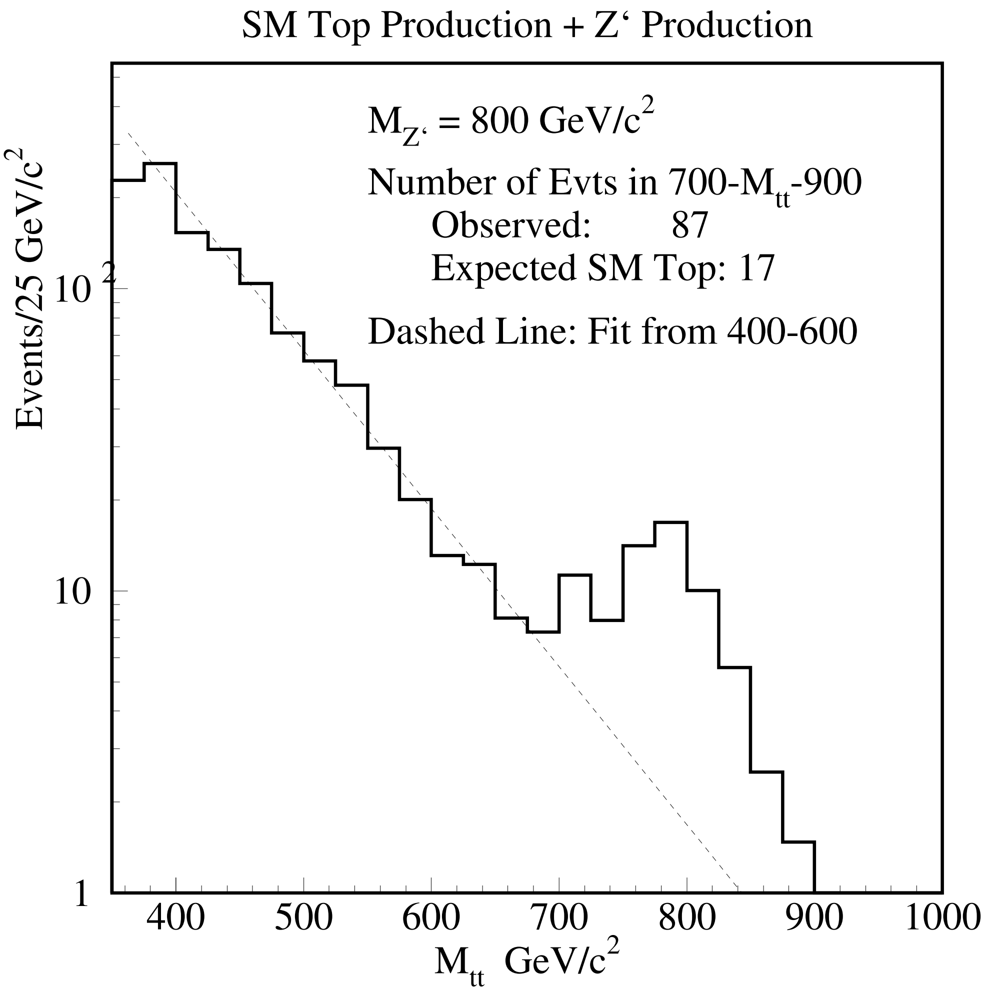
With earlier assumption about V_{ts} and V_{td}

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

Searches for New Physics

The search for a new Z' drive by statistics

- Can use "Top color" model to determine sensitivity
- Will easily discover it if $M_{Z'} \lesssim 1$ TeV/c^2



Single Top Production

Single top production is expected in SM

- Expected to be $<10\%$ of $t\bar{t}$ cross section
- Could be enhanced by non-SM physics
  - For example, $W' \to t\bar{b}$

The W' process is already interesting

$$\begin{array}{ll} W' \to & t\ \bar{b} \\ & \hookrightarrow W^+ b \end{array}$$

- Would see signal in $Wb\bar{b}$ invariant mass
- Competitive with other W' searches
  - Doesn't have same S/N problem as $W' \to q\bar{q}'$
  - Higher rate than leptonic modes
  - Expect ~ 60 fb of reconstructed tagged events for 500 GeV/c^2 W'

Top Physics at the LHC

Most of the detailed top studies for LHC are now dated

- Studies at Tevatron have taken centre stage
- Run II expectations approach LHC estimates
- But huge statistics allow different techniques
  - 6000 $t\bar{t}$ events/day at 10^{33} cm^{-2}s^{-1}

Can measure M_{top} using dilepton events

$$
\begin{array}{l}
t \quad \rightarrow W^{+} b \rightarrow l'^{-} \bar{\nu}_{l'} X \\
\qquad\quad \hookrightarrow l^{+} \nu_{l}
\end{array}
$$

- Use $l^{+} l'^{-}$ invariant mass distribution
- Does not rely on jet reconstruction
- Insensitive to t p_T

ATLAS expects to achieve accuracy of $\sim \pm 2$ GeV/c^2 in M_{top}

- Similar results from other studies (CMS and SSC)
- Will become systematics limited very quickly

Branching Ratios at LHC

ATLAS (CERN/LHCC/94-43) analysed top BR measurements

- Could get $BR(t \to W^+ b)$ measured to $\sim \pm 5\%$
  - Concerned about backgrounds from $Wb\bar{b}$ and $gb \to tW^-$
  - Didn't consider making $t\bar{t}$ invariant mass cut
  - Suspect this estimate is conservative
- Sensitive to $BR(t \to Zc) \sim 10^{-5}$

Will also be sensitive to $t \to H^+ b$ via $H^+ \to \tau^+ \nu_\tau$ decays

- excess of τ jets in b-tagged $W+$ jet events
- Can measure this to $\sim \pm 3\%$
- Sensitivity depends on $\tan\beta$

Conclusions

The study of top at hadron colliders has just begun

- Have first results on 45 – 67 pb^{-1}
  - M_{top} and $t\bar{t}$ kinematics
  - Production cross section and branching ratios
- Will have 50 tagged $W \geq 4$ jet events for Run I
- Enormous increase in our understanding of
  - b-tagging for top physics
  - Mass reconstruction using jets
  - Backgrounds to $t\bar{t}$ production

Prospects for Top physics at Tevatron excellent

- Expect $\times$12 in sample size by the year 2000
- Run III might bring another $\times$10 in statistics

Action will shift to LHC in 2004-2005

- Becomes a "top factory" even in commissioning phase
- Study of top becomes essential for background control in the search for the Higgs and other new physics