Emerging Top Results from CDF II

Outline

1. Case for Studying Top
2. CDF II and the Tevatron Collider Program
3. Progress on Top Mass
4. Top Cross Section using Dileptons
5. Summary

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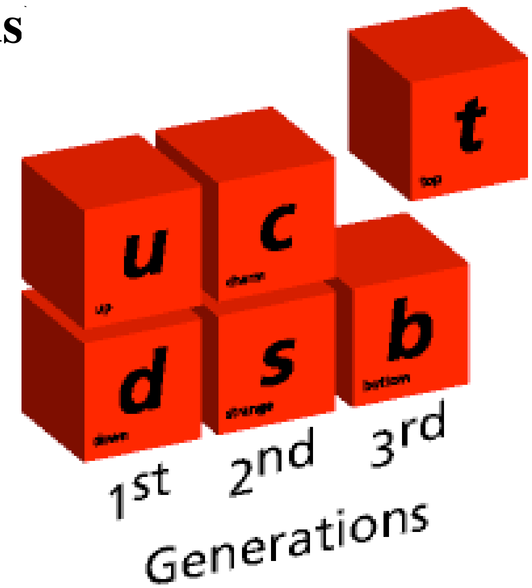
Case for Studying Top

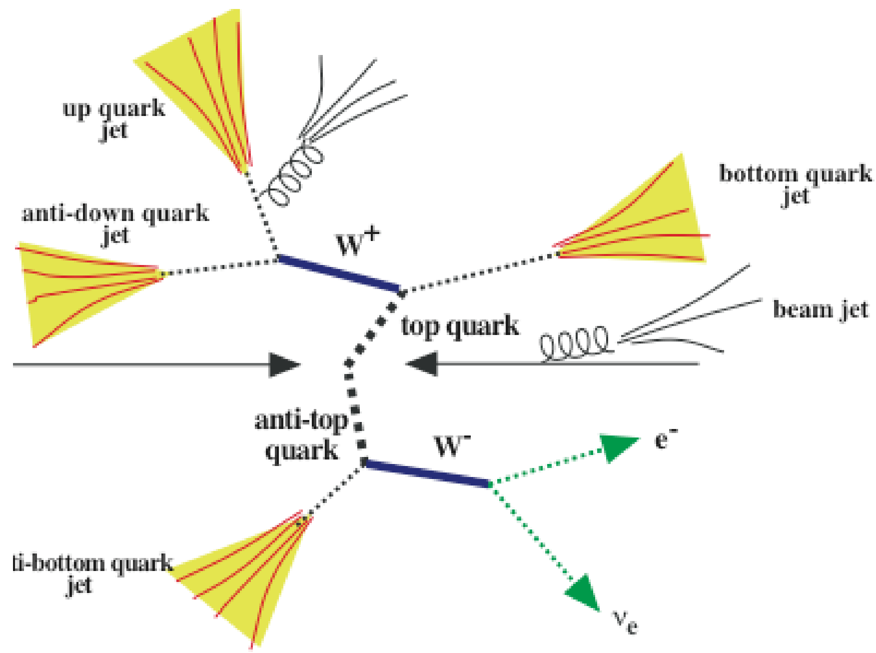
- **Discovery of the top quark in 1995**
  - **Massive new fermion (about Au nucleus**
    - Decays before interacts via QCD
    - Opportunity to study a "bare" quark
  - **Heaviest object in theory**
    - Most sensitive to "loops"
    - Insight into generation of mass in Standard Model



- **Very statistics limited**
  - **D0 and CDF collected approximately 100 pb^{-1} in Run I (1992-1996)**

Top Quark Production

- **Top is pair-produced in pp collisions**
  - **Decays into Wb**
  - **Characterize final states based on W decay**
    - Lepton+jets (44%)
    - Dileptons (9%)
    - All hadronic (54%)



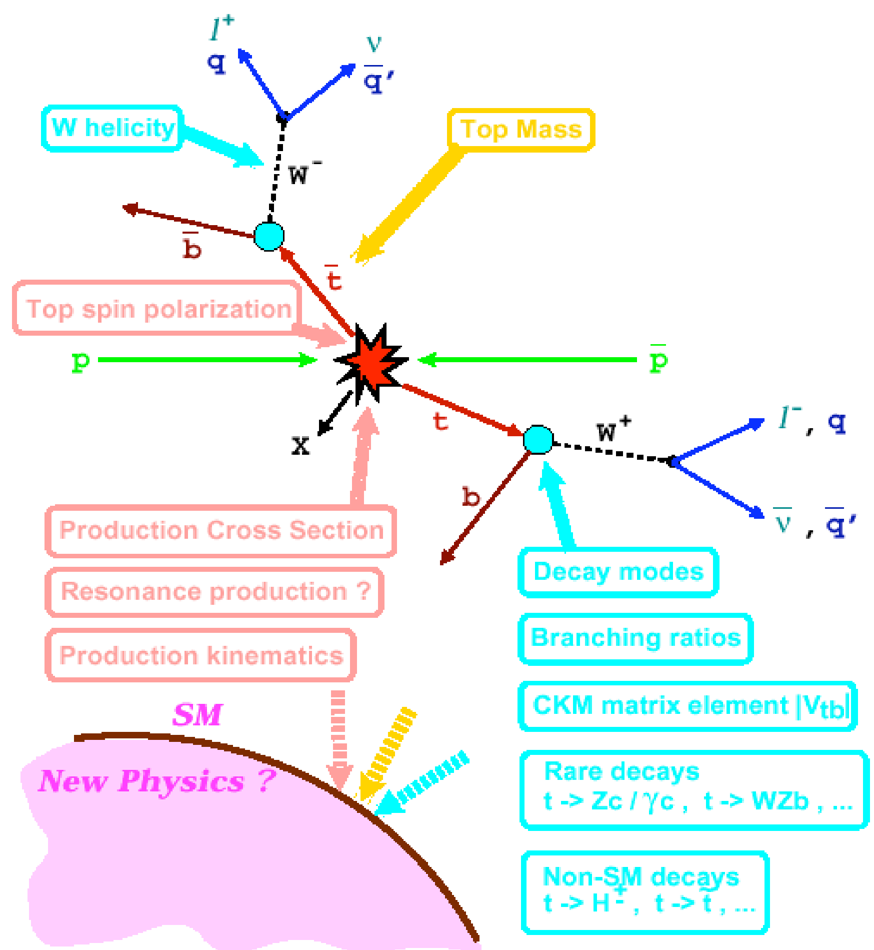
- **At 1.8 TeV,**

$$\sigma_{t\bar{t}} \approx 5 \text{ pb}$$

  - **Results in about 500 events produced in Run I**

Using Top as a Standard Model Laboratory

- **Top provides a broad physics program**
  - **Production & decay**
    - Cross sections
    - Branching ratios
    - Helicity
  - **Top quark mass**
    - Test of EWK radiative corrections
  - **Single top production**
    - Top quark width
  - **New phenomena**
    - Rare decays
    - Unusual events

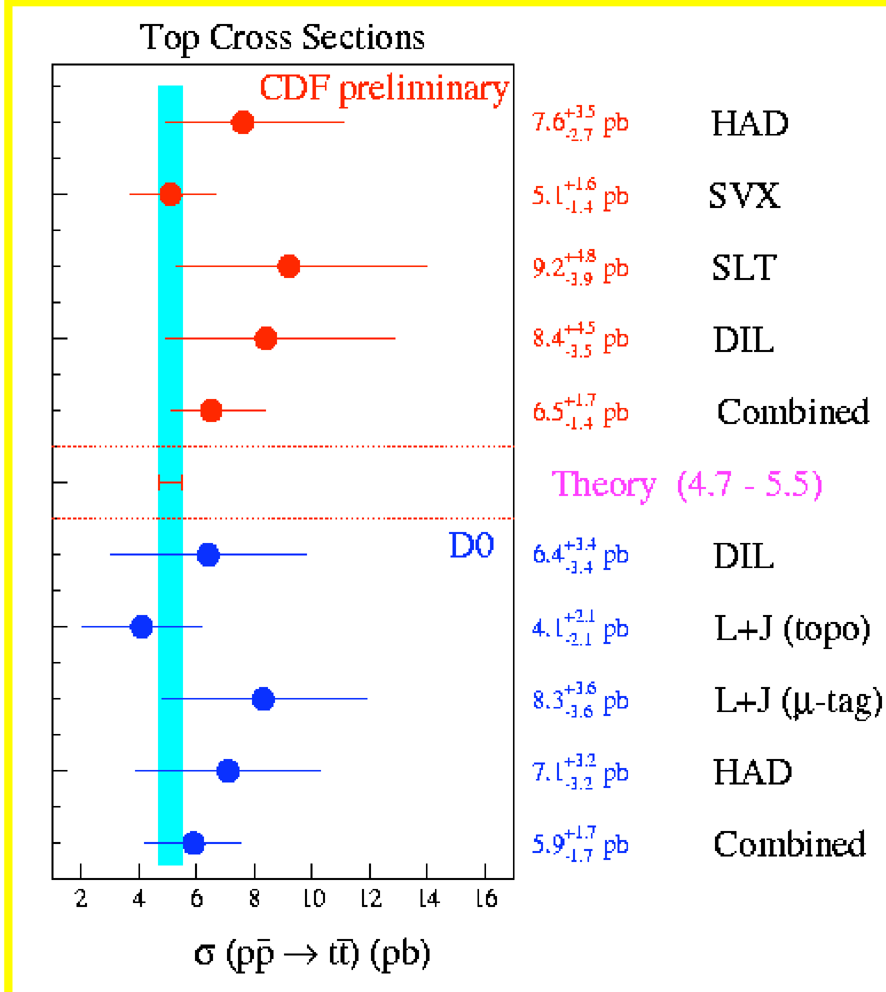


Run I Top Quark Cross Section

- **Observed top in all the expected channels**
  - **Combined result had precision of 20-25%**
  - **In good agreement with theoretical prediction**
  - **Also provides a very crude test of the decay rates**

$$t \to W\,b \text{ vs } X\,b$$

$$t \to W\,b \text{ vs } W\,q$$



Run I Top Quark Mass Results

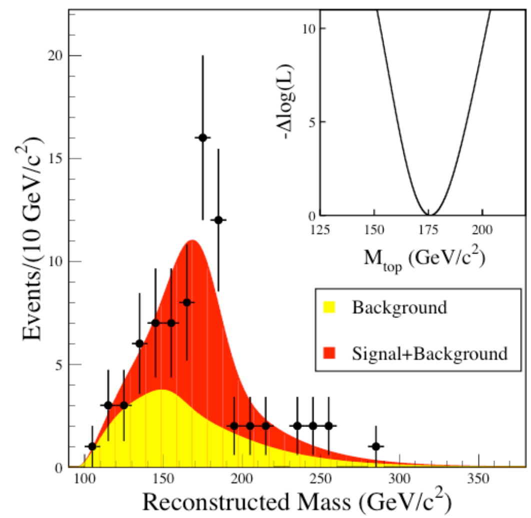
- In W+4 or more jet sample
  - Had 76 events with at least one “b tag” or 4 energetic jets

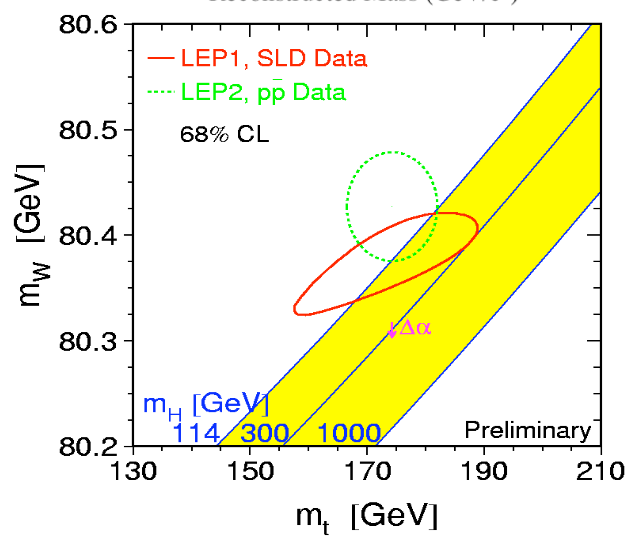
$$M_{top} = 175.9 \pm 7.1\,\mathrm{GeV/c^2}$$

- Combined Tevatron result

$$M_{top} = 174.3 \pm 5.1\,\mathrm{GeV/c^2}$$

- Combined with M_W
  - Test of entire EWK theory
  - Indirect measurement of Higgs mass



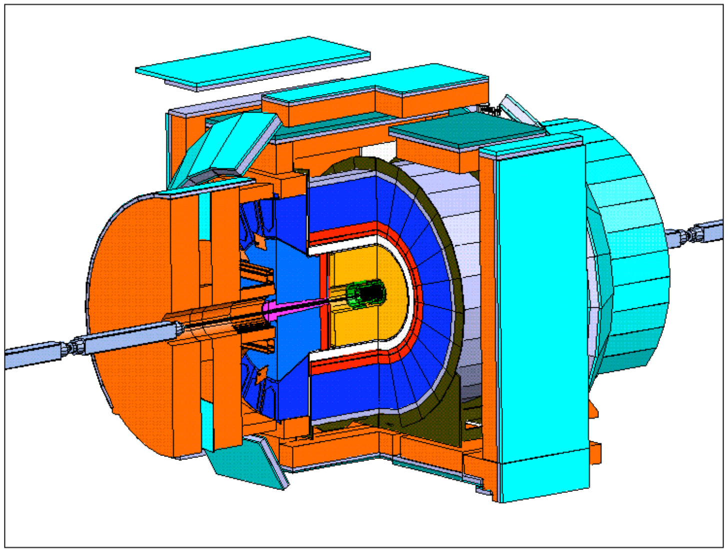


Fermilab Run II Program

- **Fermilab has upgraded Tevatron**
  - **Commissioned Main Injector**
    - Improved Tevatron injection
    - Higher pbar production (x10)
    - Increased bunches (6 to 36)
  - **Tevatron Improvements**
    - Energy: 1.8 to 1.96 TeV
    - Design L of 5×10^{31} $cm^{-2}s^{-1}$
  - **Slow turn-on but recent performance very promising**
    - Started commissioning in March 2001
    - Have now reached 75% of design goal for integrated luminosity/week
      - **Last Thursday, achieved store with 6.2×10^{31} $cm^{-2}s^{-1}$**

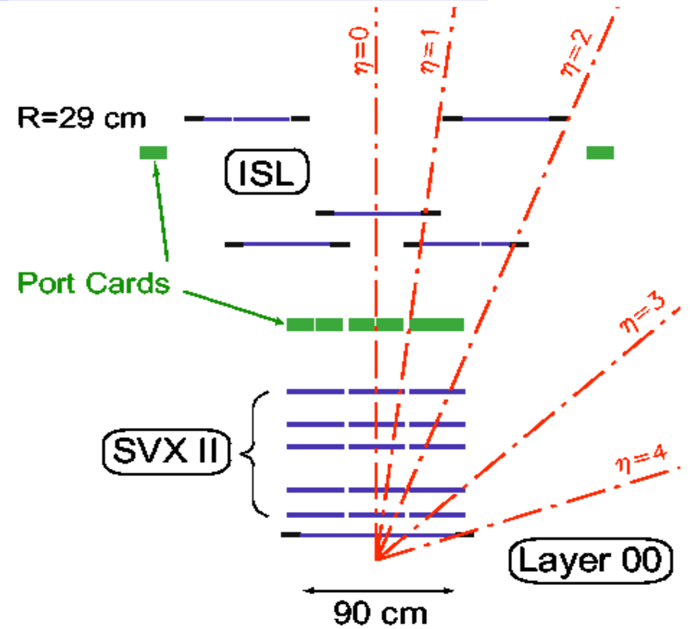
CDF II Detector

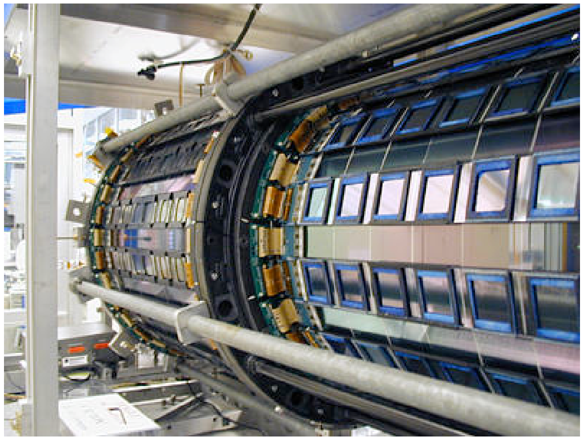
- **Upgraded CDF Detector**
  - **Tracking**
    - New 7-layer SVX system
    - Central Outer Tracker
  - **Calorimetry**
    - New Sci-fi Plug Calorimeter
    - New readout and electronics
  - **Improved muon coverage**
    - Scintillator trigger paddles
    - Completed CMX
  - **New trigger and readout system**
    - SVX impact trigger commissioned
    - Goal is to trigger and readout efficiently at >50 Hz



Silicon Tracking Systems

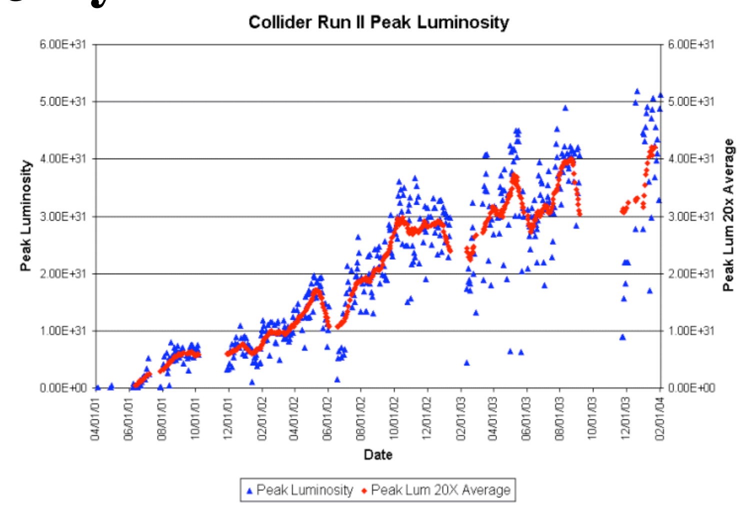
- 7-8 layer tracker
  - SVX II (5 layers)
  - L00 (on beampipe)
  - ISL (extends coverage)
- SVT tracking trigger
  - L1: charged particle trigger
  - L2: identify secondary vertices
- System working very well
  - Challenge is managing radiation environment
  - Plan is to operate with detector through Run II



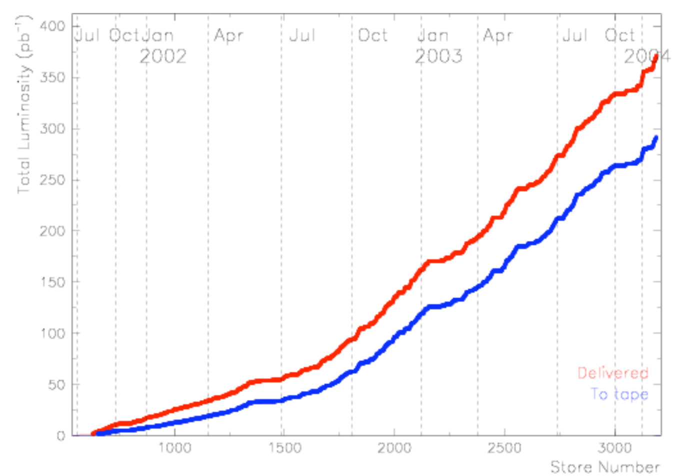


Data Taking Progress

- Starting Run II Officially in July 2002
  - Detector now running well
  - Challenges have been:
    - Tevatron performance
    - Silicon operation
    - Understanding calorimeter energy calibrations

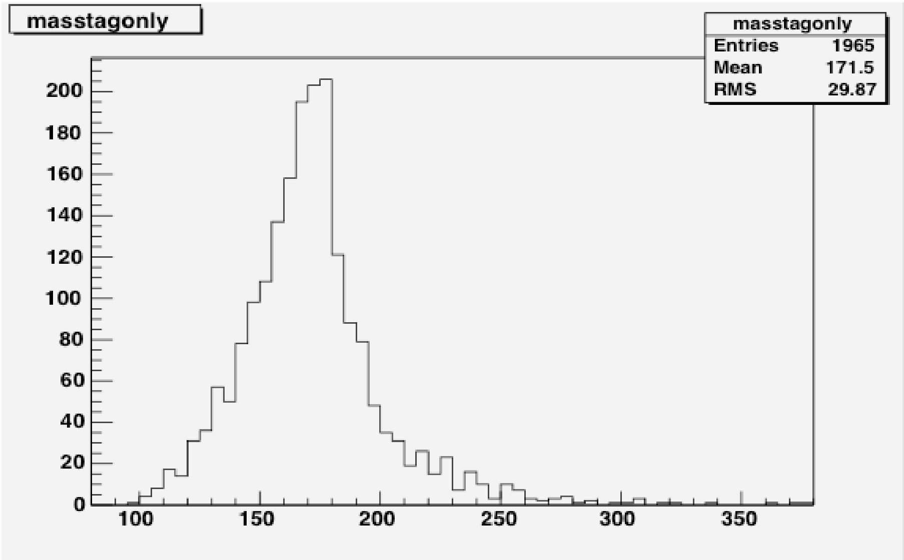


Calendar Year	Collected (fb-1)	Total (fb-1)
2002	**0.12**	**0.13**
2003	**0.13**	**0.26**
2004	**0.06** + 0.23	0.55
2005	0.6	1.1
2006	0.8	2
2007	1	3
2008	>1	>4



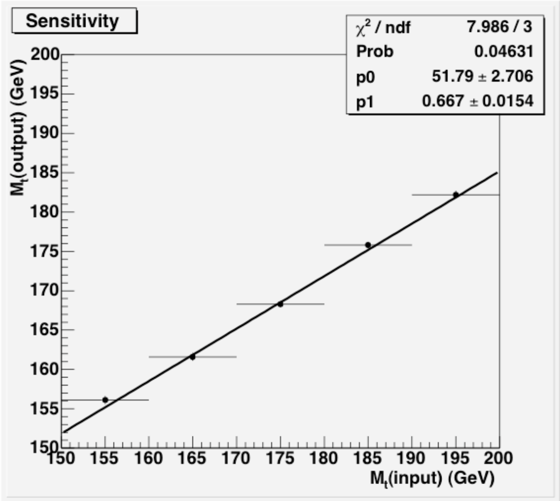
Reconstructing Top Quarks

- Technique developed in Run I
  - Require electron or muon with $E_t > 20$ GeV
  - Require Missing $E_t > 20$ GeV
  - Require at least 4 jets
    - At least 3 with $E_t > 15$ GeV & 4th with $E_t > 8$ GeV
    - At least one jet b-tagged with secondary vertex
- Perform χ^2 fit
  - Constrain
    - Equal top masses
    - W daughter masses
  - Select assignment of jets-to-partons with minimum χ^2
    - Require $\chi^2 < 10$
  - Dominated by jet combinatorics
    - Correct jets chosen 45% of the time

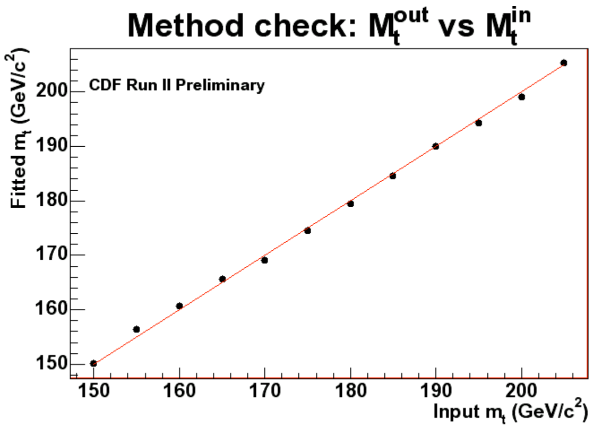


Extracting a Top Mass

- Use histogram of "best mass" from each event
  - Sensitive to top mass
  - Interpret it as a combination of
    - Signal events
    - Background events
      - Primarily W+jets
  - Perform likelihood fit to sum of two components

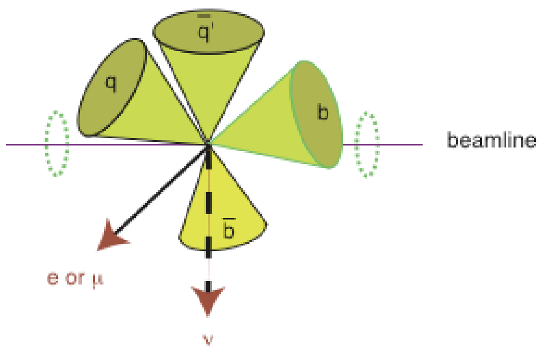


- Check the procedure
  - Use "pseudo-experiments"
    - Vary reconstruction techniques
    - Vary MC assumptions
    - Check for biases



Systematic Uncertainties

- Largest source is jet energy scale
  - Absolute calibration of calorimeter
  - Jet fragmentation effects
- QCD effects in production & decay
  - Initial state and final state radiation
- Parton distributions
  - Affect the distribution
- MC modelling
  - Variations in Q^2 scale
  - Choice of generators



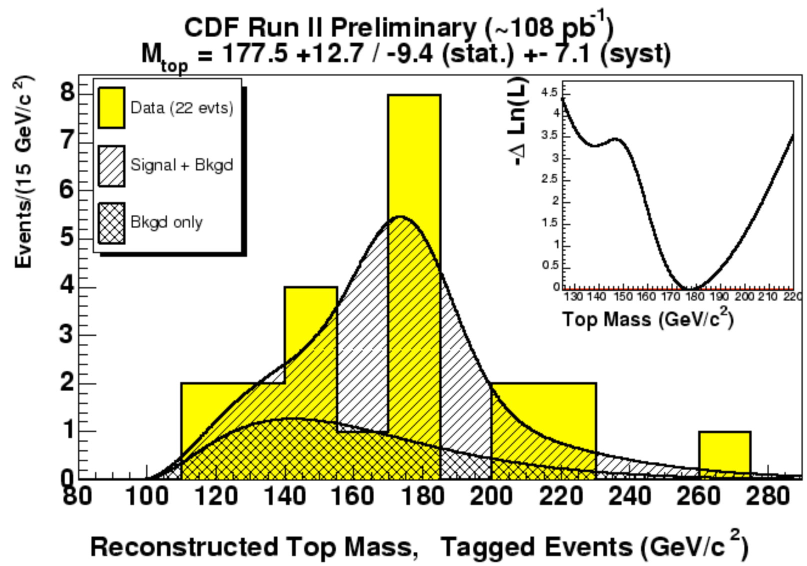
Source	Uncertainty (GeV)
Jet scale	6.2
Final State Radiation	2.2
Parton distributions	2.0
Initial State Radiation	1.3
MC modelling	1.0
Generator uncertainties	0.6
Background	0.5
B-tagging	0.1
Total	7.1

Preliminary Top Mass

- Have 22 events from 108 pb-1
  - Estimate background of 5.9±2.1 events
- Likelihood fit:

$$M_{top} = 177.5^{+12.7}_{-7.1} \pm 7.1\,\mathrm{GeV/c^2}$$

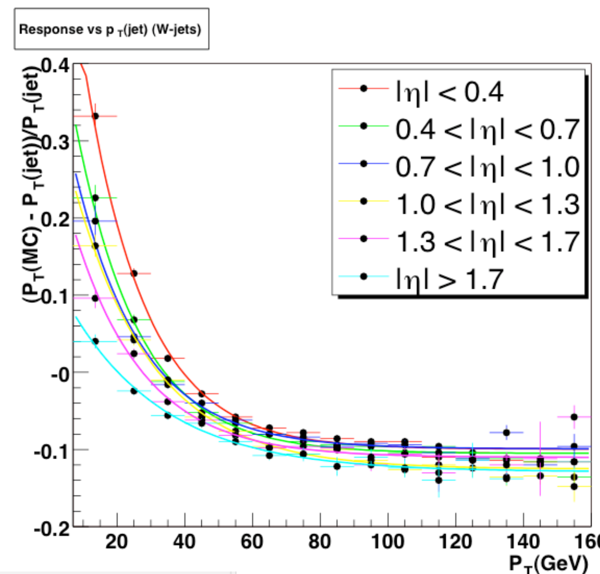
  - Note asymmetric uncertainty
  - Larger (20%) than expected but consistent

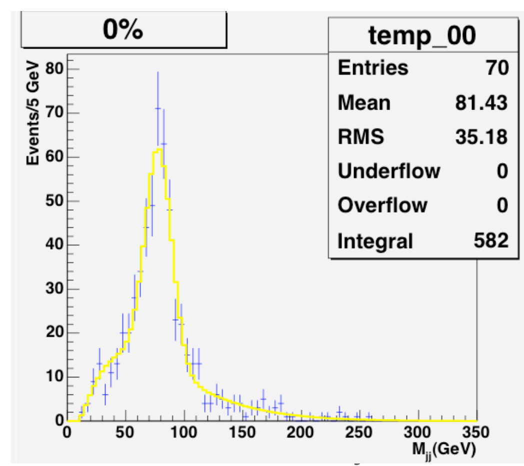


- Systematic uncertainties
  - Dominated by jet energy scale uncertainty

Future Progress

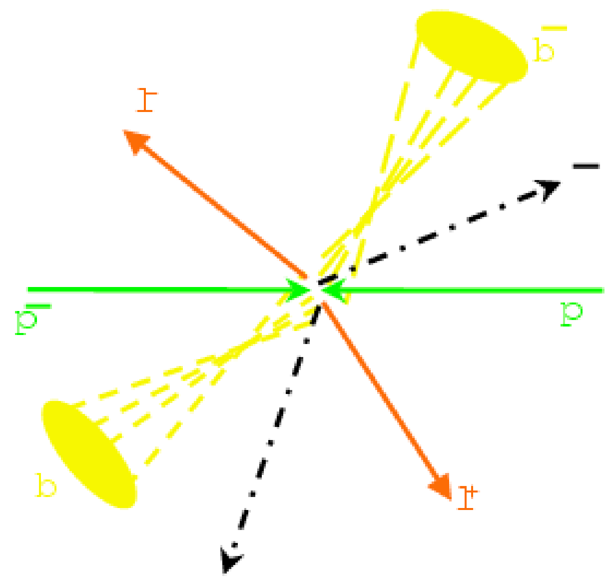
- **Have more data (200 pb-1) under analysis**
  - Planning to publish on this data set
- **Working on absolute energy scale**
  - Z+jet and □+jet balancing
  - Simulation tuning
- **Using dijet mass from W decay**
  - Relax top mass and W mass constraint
  - Can measure energy scale < 5%
  - Not MC limited!





Top Dilepton Analysis

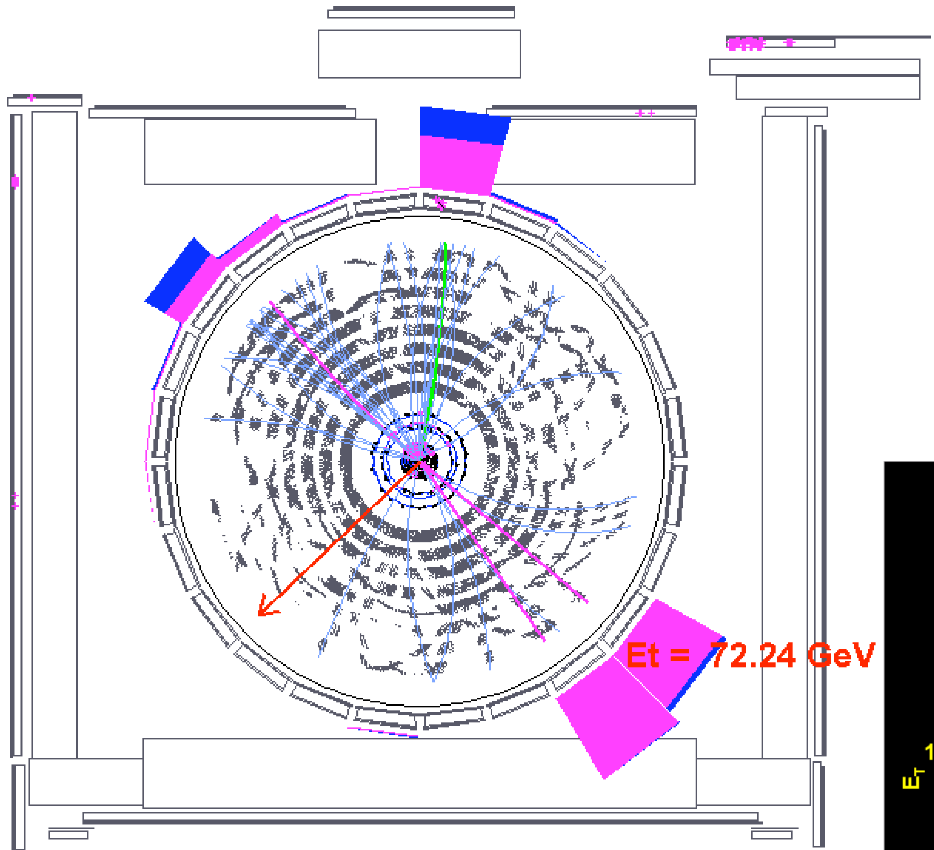
- **Dilepton signature cleanest**
  - **Can get very good S/N (> 5)**
  - **Very statistics limited**
    - Run I saw 6 events with background of < 2
- **Background sources**
  - **Drell-Yan production**
    - Use missing Et signature
    - Require jets
  - **Di-boson (W^+W^-) production**
    - Similar to Drell-Yan
  - **Fake leptons**
    - Optimize lepton requirements to optimize signal to background



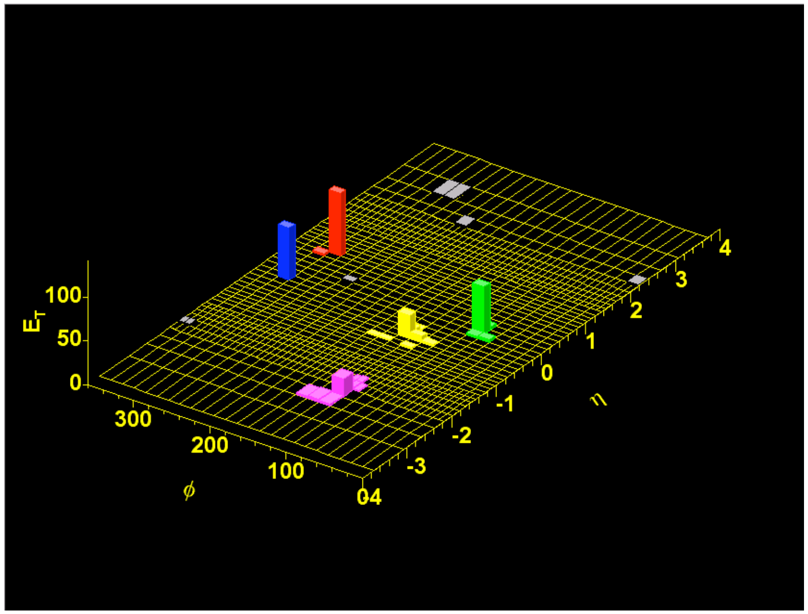
Lepton Requirements

- **Employed a new strategy**
  - **One well-identified lepton with E_T > 20 GeV**
    - Employ SVX-ISL tracks & plug EM calorimeter
  - **Second lepton identified using only charged track ("tl")**
    - Require p_T>20 GeV/c and $|\eta|$<1.5
    - Measure fake rate in data (< 1%)
  - **Require event topology cuts to separate top from other backgrounds**
    - Missing E_T > 25 GeV
      - **Require E_T > 40 GeV if dilepton pair mass in Z region**
    - Require at least 2 jets with E_T > 20 GeV and $|\eta|$<2
- **Results in x2 improvement compared to Run I**
  - **With 200 pb^{-1}, results in x4 in Run I statistics**

Run 153374 Event 2276742



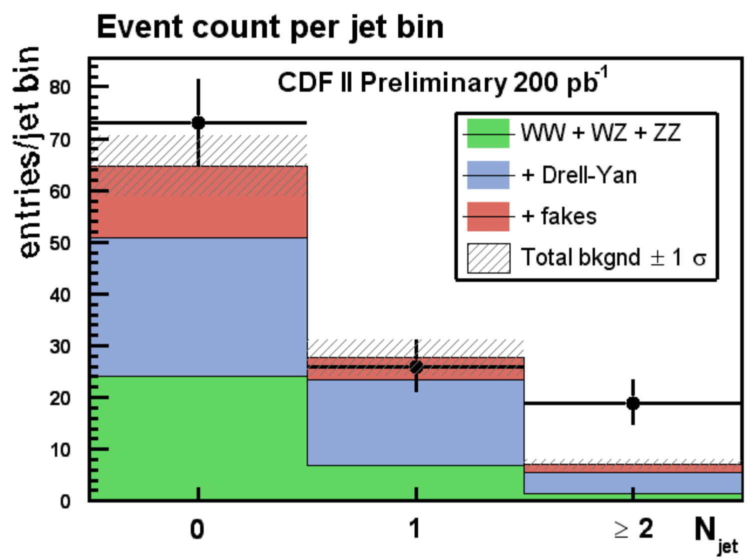
- CEM TCL, *tl* electron-like
- MET = 58.9 GeV (ϕ=245º)



- CEM TCL E_T = 72.6 GeV(ϕ=305º)
- *tl* p_T = 63 GeV, (ϕ=320º)

Dilepton Yields

- Look at event rates
  - As N_{jet} varies, S/B changes
  - Strong consistency check
    - Drell-Yan still has largest uncertainty



	Njet=0		Njet = 1		Njet >= 2	
	Events	Uncertainty	Events	Uncertainty	Events	Uncertainty
Drell-Yan	26.8	5.7	16.6	3.4	4.3	1.0
Fakes	13.8	1.6	4.2	0.5	1.5	0.2
Di-boson	24.1	0.6	6.9	0.3	1.2	0.2
Total background	64.7	5.9	27.6	3.5	7.1	1.0
Observed	73		26		19	
Top (6.7 pb)	0.3	0.0	3.4	0.1	11.5	0.2

Sources of Systematic Uncertainties

- **Signal uncertainties**
  - Largest is lepton ID efficiency
  - Final state radiation arises in jet counting
  - Parton distribution functions are also a significant source
- **Background uncertainties**
  - Lepton ID comes in
  - Di-boson MC uncertainties
  - Drell-Yan a challenge
    - Use Z to normalize
    - MC to extrapolate to other dilepton masses

Signal	(%)
TCL/TPL ID	10
tl ID	6
Jet E scale	3
ISR	1
FSR	7
PDF	6

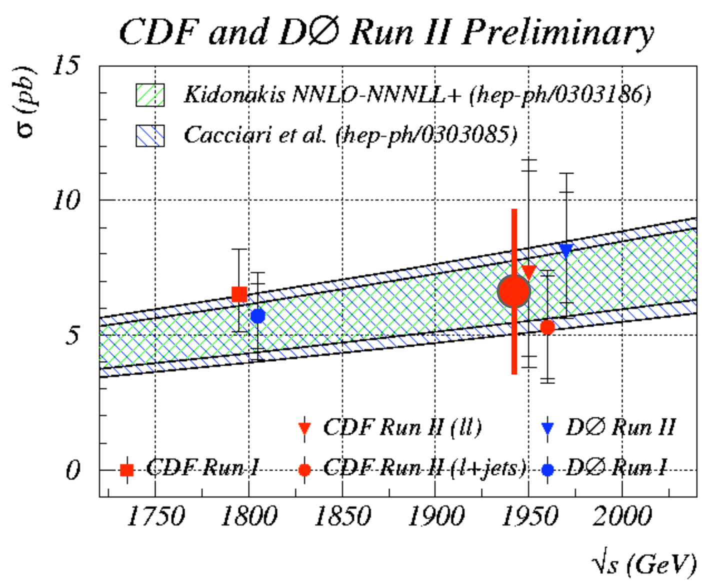
Background	(%)
TCL/TPL ID	10
tl ID	6
Jet E scale	10
Diboson MC	20
DY estimate	30
Fake	12

Top Cross Section

- Can use 19 events to estimate cross section
  - 7.1 events expected background
  - 0.88% acceptance times efficiency
  - Integrated luminosity of 200 pb^{-1}

$$\sigma_{tt} = 6.9^{+2.7}_{-2.4}(\text{stat}) \pm 1.2(\text{syst}) \pm 0.4(\text{lumi})\ \text{pb}$$

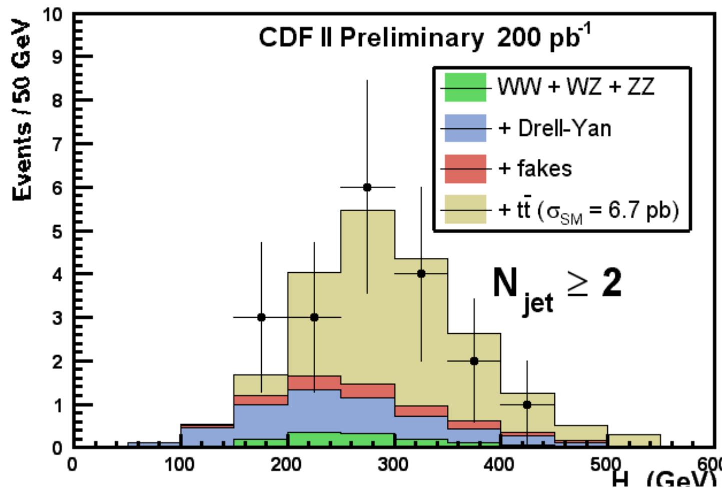
- Compares well with Standard Model prediction of 6.7 pb



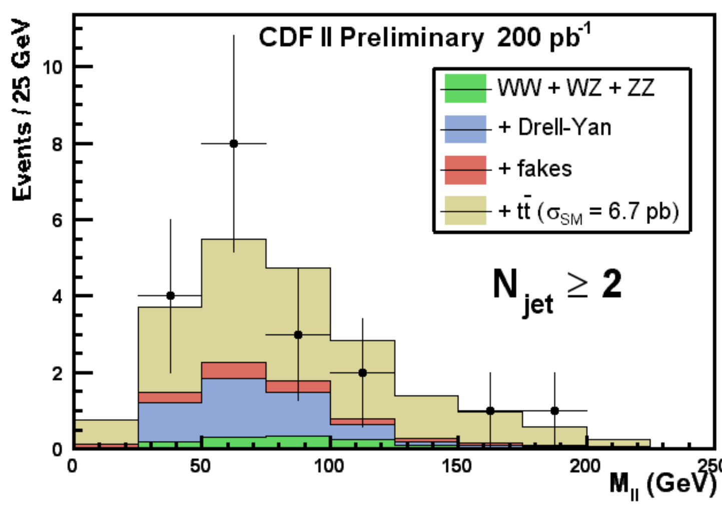
Event Properties

- Interesting to look at event properties
  - Note that Run I saw few candidate with large dilepton invariant mass
- Observed distributions are fully consistent with
  - Background sources and top signal
- No evidence of new physics
  - Cross section x2 better that earlier dilepton measurements

Total Transverse Energy (scalar sum)



Dilepton Invariant Mass



More on Dileptons

- Have ~12 top events on background of 7
  - Significantly better than Run I
  - Note measured cross section hasn’t risen appeciably
  - Provides more optimal strategy for cross section measurement
- Can extract other physics from this sample
  - “No jet” sample dominated by W^+W^-
  - Can put limits on new physics production
    - Look at tri-lepton events
- Accumulate statistics
  - Largest systematics are statistics-limited

Summary

- **Run II top physics is well underway**
  - **CDF has first measurement completed (dileptons)**
    - PRL on its way
    - No surprises -- looks like Standard Model top quark production
  - **Top mass studies are complex**
    - Making good progress, but challenge will remain understanding systematic uncertainties
- **Many studies underway**
  - **For example, single top production, top helicity, top production mechanisms, rare decays, etc.**
  - **Good prospects for now collecting high statistics**
    - Should have factor of 2.5 more by end of 2004!