Recent Top/EW Results from CDF

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For the CDF Collaboration

Introduction

- The nature of electroweak symmetry breaking is one of the top unsolved problems in particle physics
- Whatever the mechanism, high mass objects are the right laboratory to study it
  - Gauge bosons and top quarks
- CDF is performing a wide variety of measurements within the top/EW arena
- Results shown today are just a sample of the work going on

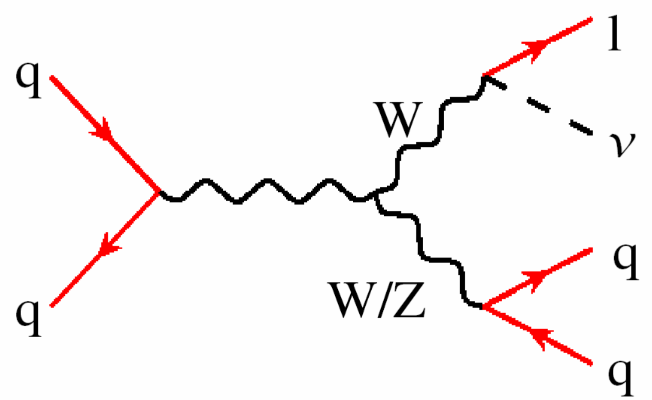
- Electroweak results
  - WW/WZ $\rightarrow$ lν + 2 jets
  - W charge asymmetry
- Top results
  - Top production cross section
    - B-Tagging
    - Kinematic fitting
  - Anomalous semileptonic decays
  - Top mass measurements
    - Template fitting
    - Matrix element methods

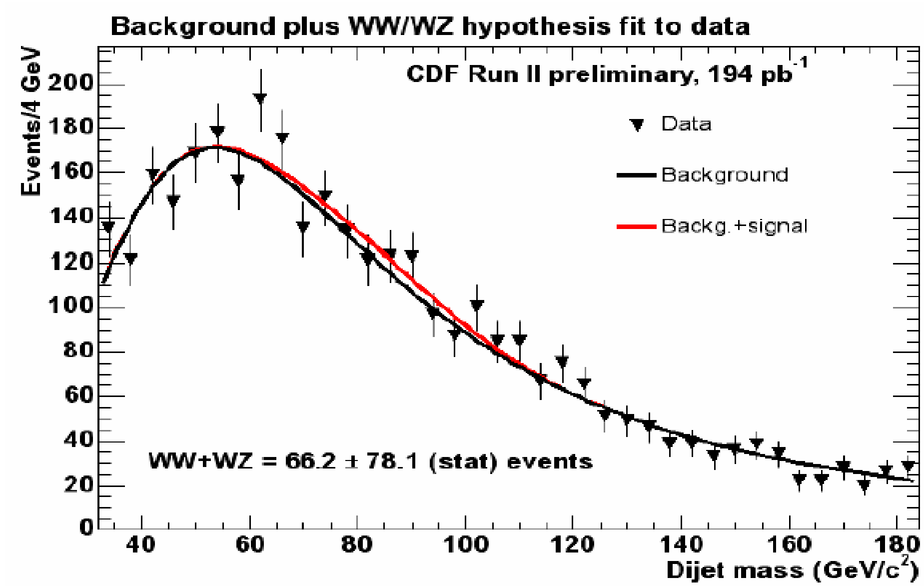
Diboson Production

- CDF has two RunII (200 pb^{-1}) measurements of σ_{WW}
  - Cross sections consistent with the expected value of ~13 pb
- Still no observation of WZ/ZZ
  - $\sigma < 15.2\ pb^{-1}$
- CDF has recently performed a search for WW/WZ production, where $W \rightarrow l\nu$ (l=e,μ) and W/Z decays hadronically into two jets
  - Higher branching ratio but also much higher backgrounds
  - Dominant background is W+2p production, which is constrained by fitting to dijet mass sidebands
- Fitting signal+background to signal region returns

$$N_{sig} = 66 \pm 78 \pm 34\ (N_{SM} = 91)$$
$$N_{sig} < 40\ \text{pb}\ (95\%\ \text{CL})$$

$$\sigma_{WW}^{DIL} = 14.6^{+5.8}_{-5.1}(stat)^{+1.8}_{-3.0}(syst) \pm 0.9(lum)\ \text{pb}$$
$$\sigma_{WW}^{LTRK} = 24.2 \pm 6.9(stat)^{+5.2}_{-5.7}(syst) \pm 1.5(lum)\ \text{pb}$$

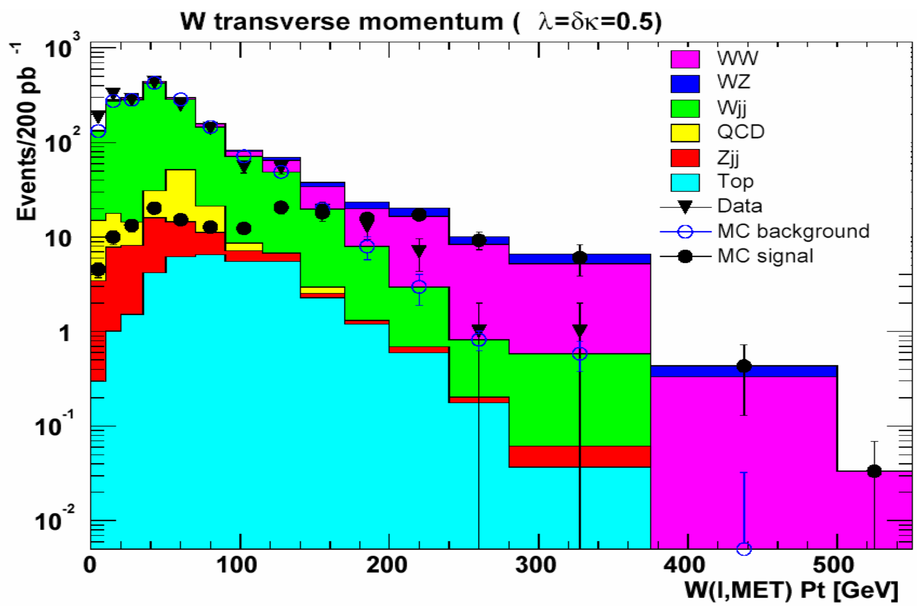


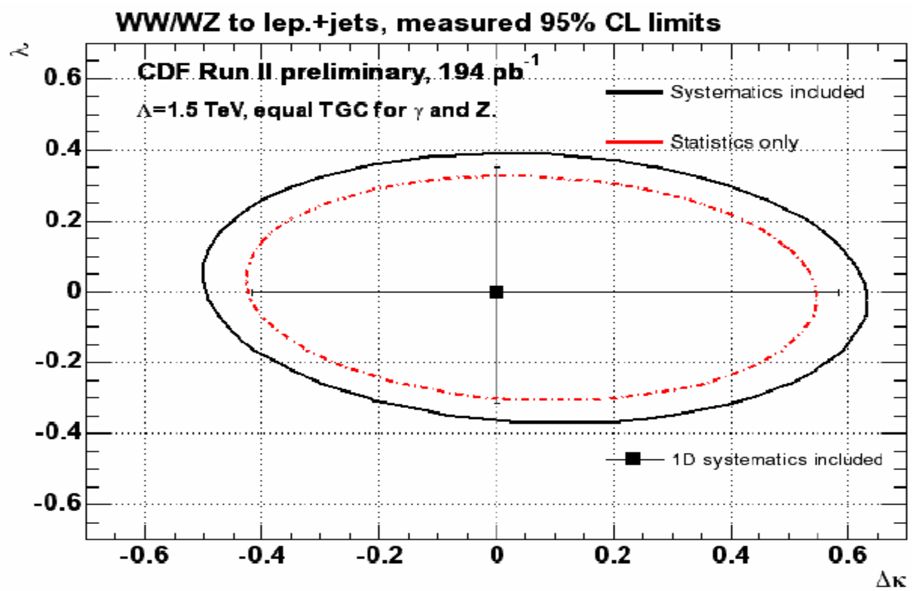


Anomalous Couplings

- There are other things you can do with a WW sample besides measure a cross section
  - Test for anomalous triple-gauge-boson couplings
- In one “standard” SM extension, anomalous interaction terms are parametrized by $\Delta\kappa$ and λ
- The P_T of the W formed from the lepton and the missing E_T (ν) is found to be the most sensitive probe – anomalous VV pairs are produced with high P_T
- 95% CL limits obtained are:

$$-0.42 < \Delta\kappa < 0.58$$
$$-0.32 < \lambda < 0.35$$



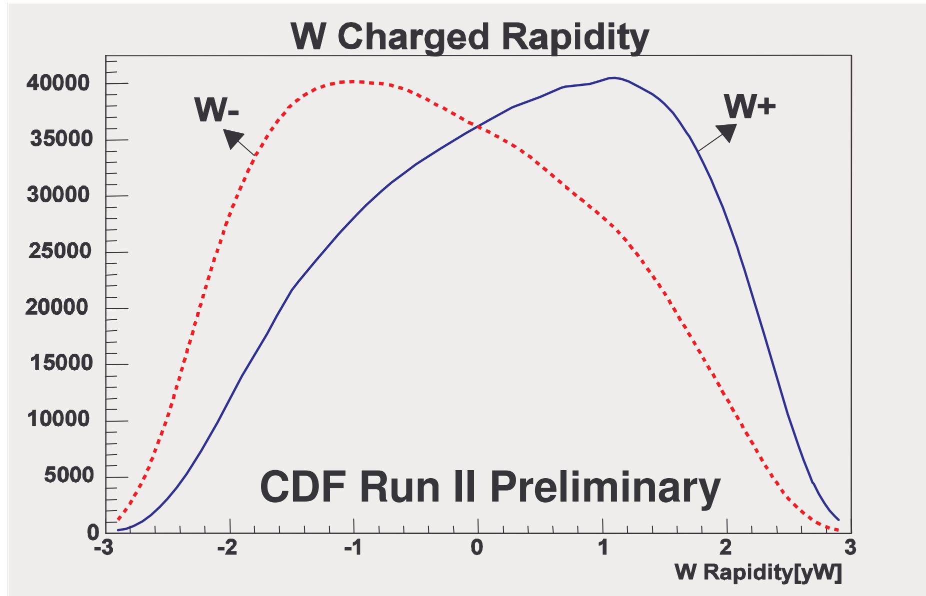


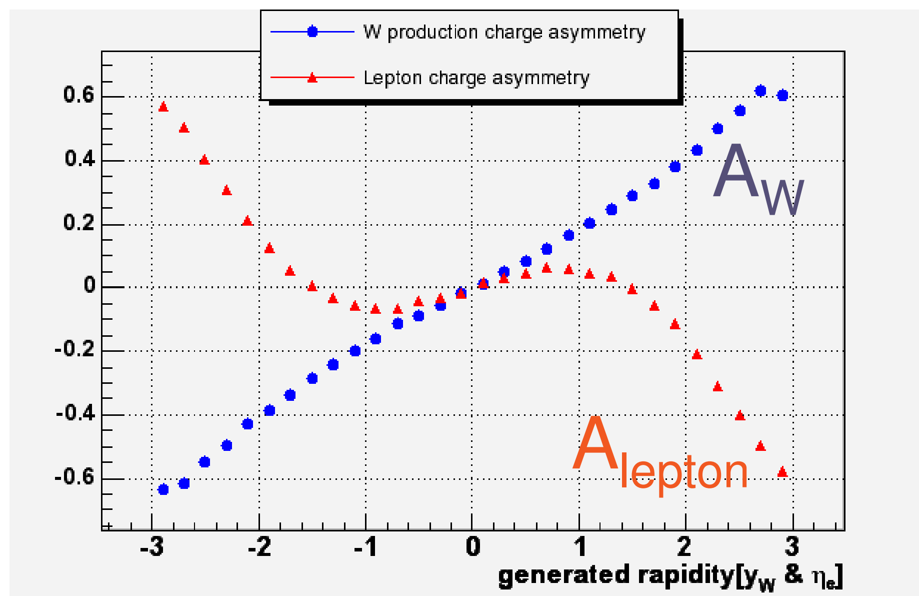
W Charge Asymmetry

- The asymmetry in x between up and down quarks in the proton results in a charge asymmetry in W rapidity

$$A(y_W) = \frac{d\sigma_+/dy_W - d\sigma_-/dy_W}{d\sigma_+/dy_W + d\sigma_-/dy_W}$$

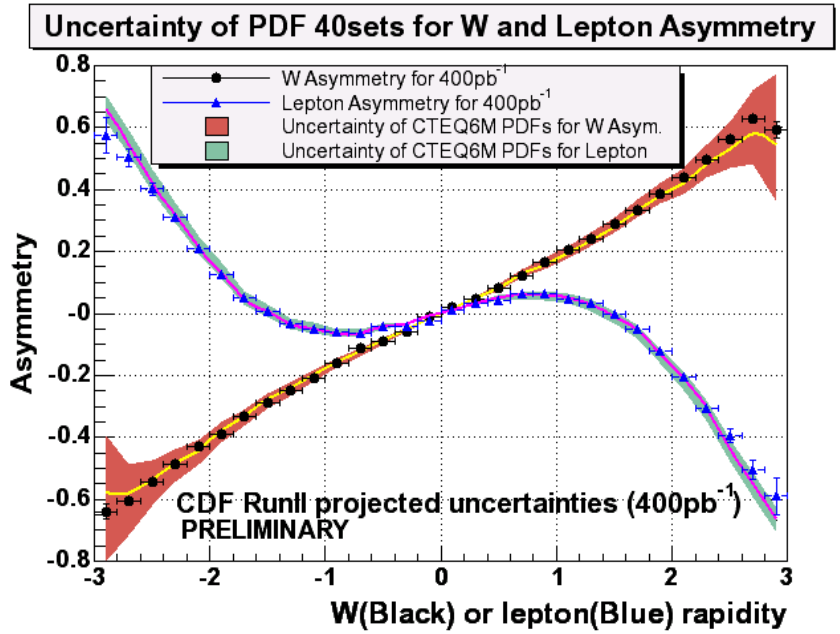
  - Sensitive to PDFs
- Have previously measured lepton rapidity asymmetry rather than A_W (CDF RunII results already published in PRD)
  - However, the underlying W asymmetry is distorted by the angular structure of W decays (charged lepton comes out opposite to W direction)
- Because the true W asymmetry tends to be larger, it is a more statistically powerful probe

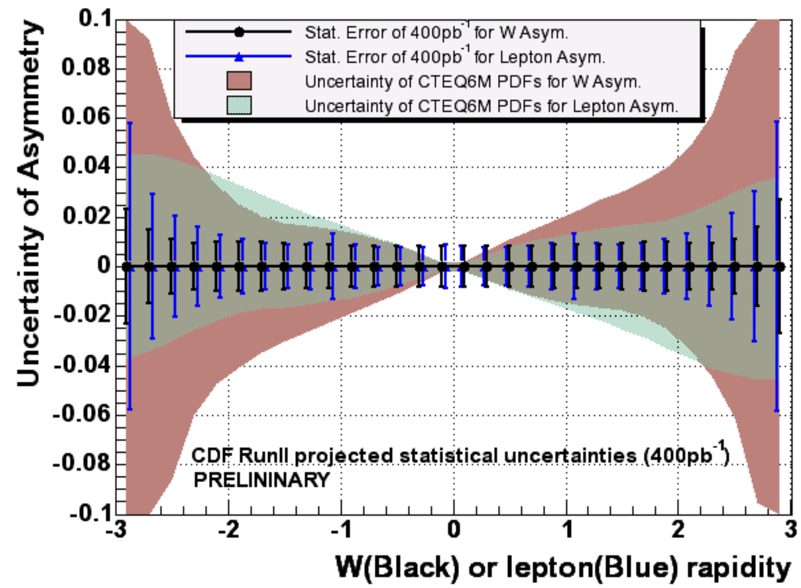




W Charge Asymmetry (2)

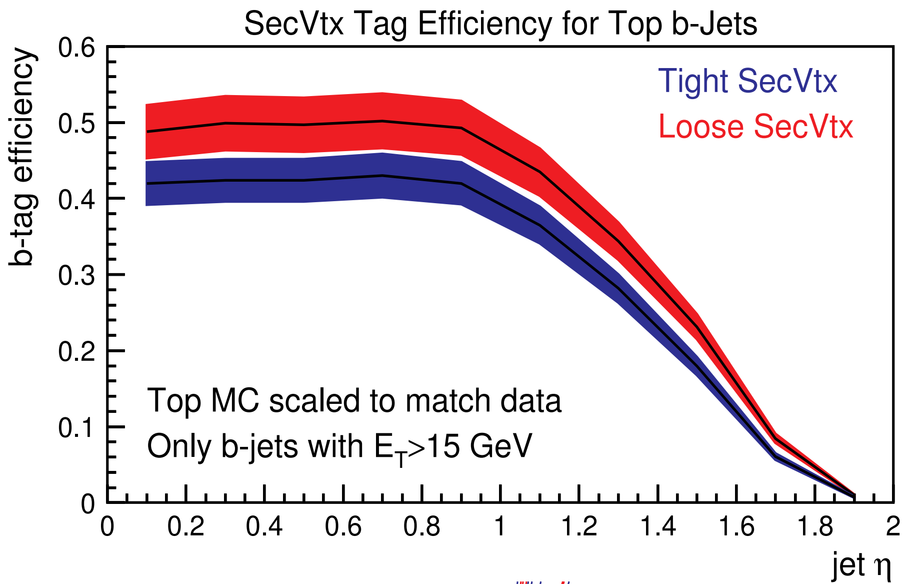
- Using the W mass one can solve for the neutrino P_z up to a twofold ambiguity
- Weight the two solutions according to their likelihood, based on the decay angle $\cos\theta^*$ and cross section $\sigma(y_W)$
- One complication is that $\sigma(y_W)$ depends on the asymmetry that's being measured!
  - Iterate until the best description of the data is obtained
- A Monte Carlo sensitivity study shows that the resulting W asymmetry is much more powerful at discriminating between various PDF sets than the lepton rapidity asymmetry
- Preliminary evaluations of systematic errors indicate that they should be small compared to statistics
- Still a little work to do on backgrounds and lepton charge misidentification

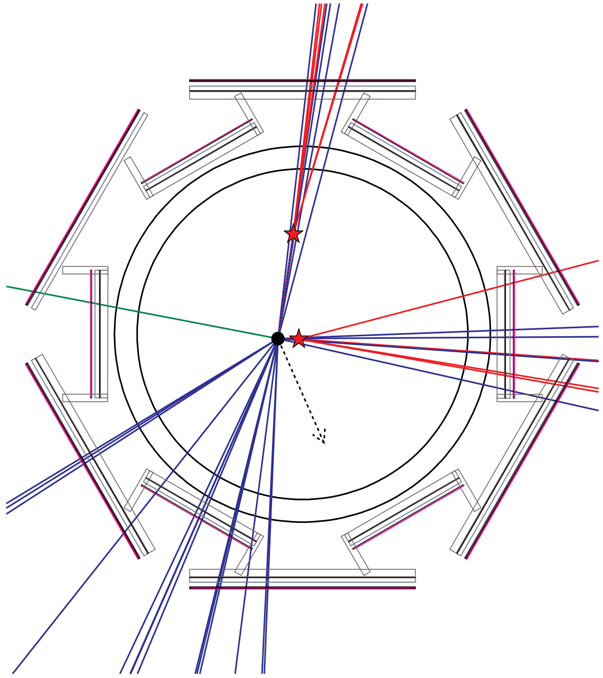




Top Event Selection

- Top quarks are (usually) pair-produced at the Tevatron and decay $t \rightarrow Wb$ ~100% of the time in the SM
- Top event selection is based on the decays of the W's
  - Dilepton: require two high-P_T leptons, large missing E_T from the neutrinos, and at least two jets
  - Lepton+jets: require one high-P_T lepton, large missing E_T, and at least three jets
- The signal/background can be enhanced by tagging one or more of the jets as a b-jet, using displaced tracks, reconstructed vertices, or lepton tags
  - Improved forward tracking has extended our displaced-vertex tagging coverage vs jet pseudorapidity
  - Event tagging efficiency for t-tbar is ~60%, with ~0.5% per-jet mistag rate for the vertex tagger

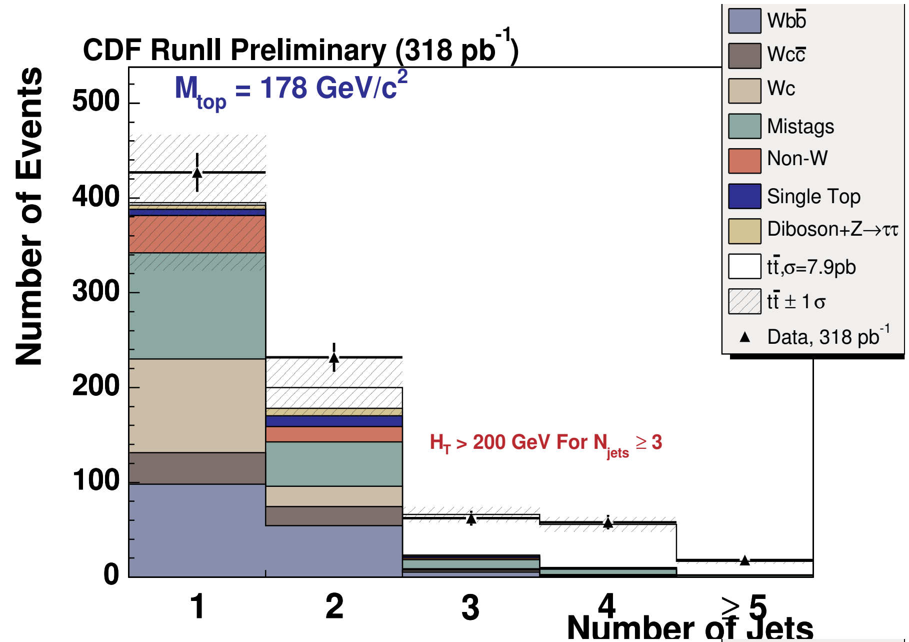


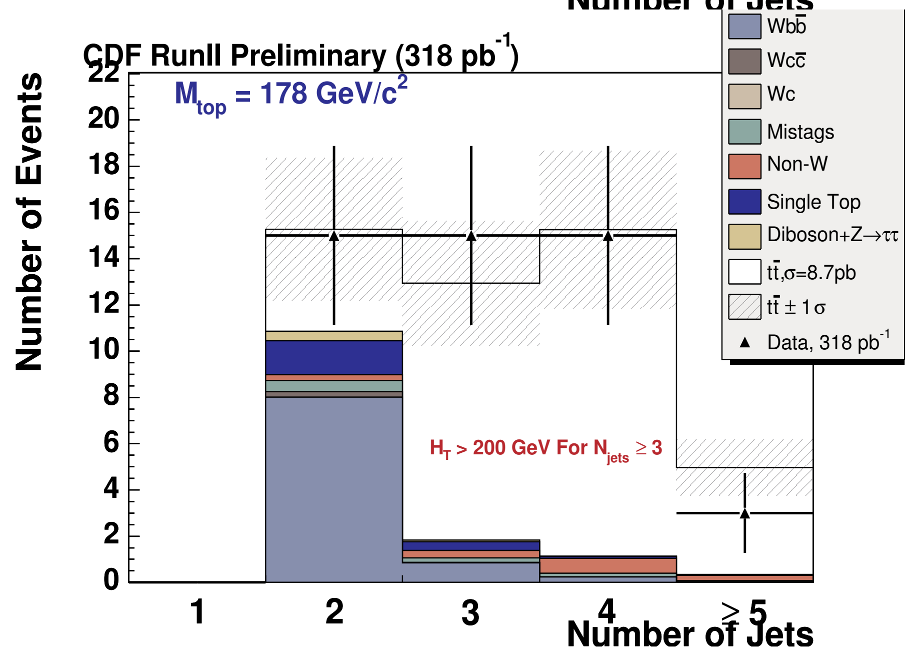


Top Cross Section with B-Tagging

- This result uses the lepton+jets selection, and requires either:
  - ≥1 b-tagged jets
    - S/B = 102/36
  - ≥2 b-tagged jets
    - S/B = 29.7/3.3
- Signal region is ≥3 jets, lower multiplicity bins are control regions to test background estimation
- Dominant background comes from W+jets, where the jets are true tagged heavy flavor or mistagged light flavor
- Cross sections for 318 pb^{-1} are:

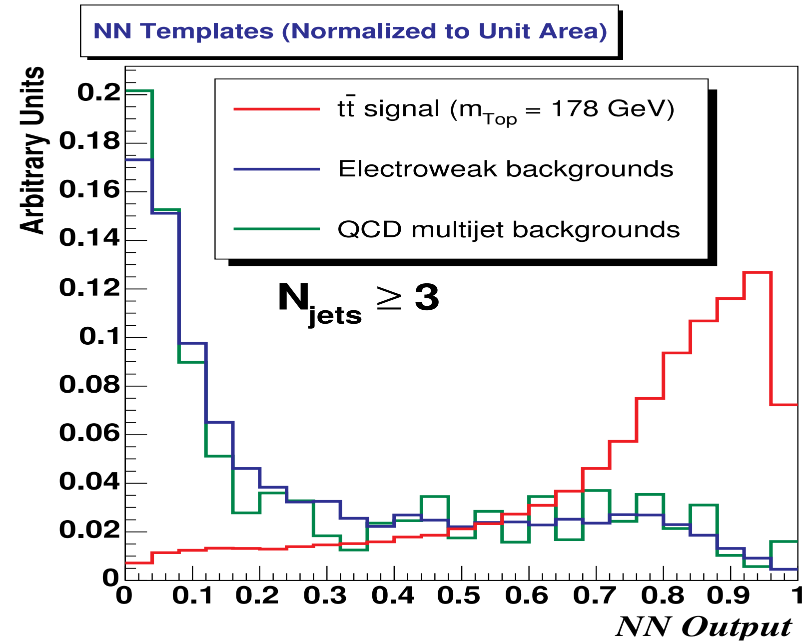
$$\sigma_{tt} = 7.9 \pm 0.9 \pm 0.9 \text{ pb } (\geq 1 \text{ tag})$$
$$\sigma_{tt} = 8.7 \pm 1.7 \pm 1.5 \text{ pb } (\geq 2 \text{ tag})$$





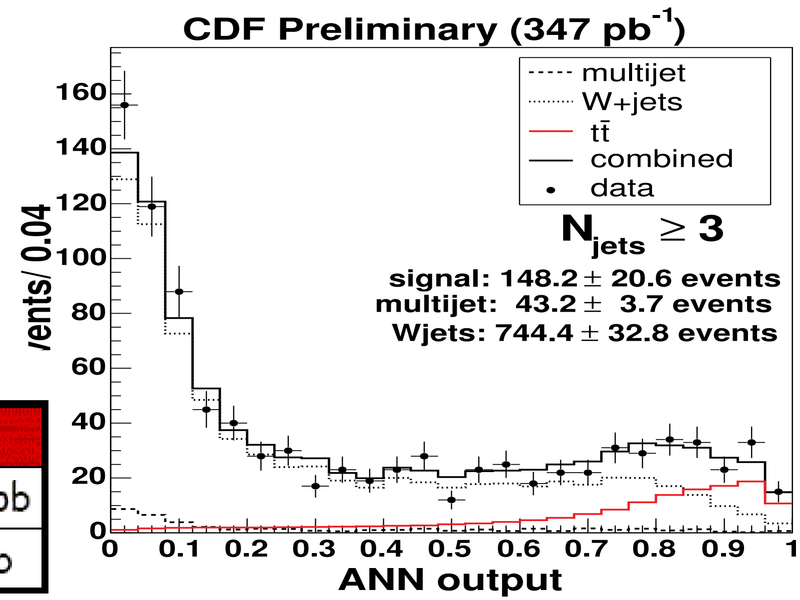
Top Cross Section with Kinematics

- We also measure a top cross section using the inclusive lepton+jets selection without requiring any b-tagging
- Signal/background is lower, have to separate using a fit rather than just counting
- A neural network trained to separate top from W+jets events is used
- An "EW background" template is formed by passing W+3p, Wbb+1p, WW+1p, etc, MC events through the network, and weighting by their SM cross sections
- The QCD template is derived from events in the data where the lepton is not isolated, and fixed in the fit at the measured level of 4.6%



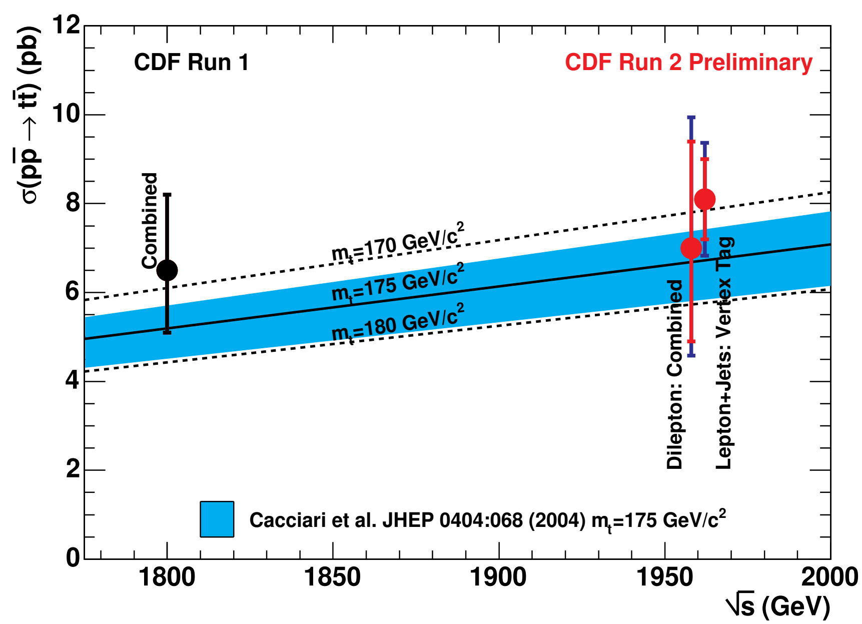
CDF Preliminary (347 pb^{-1})

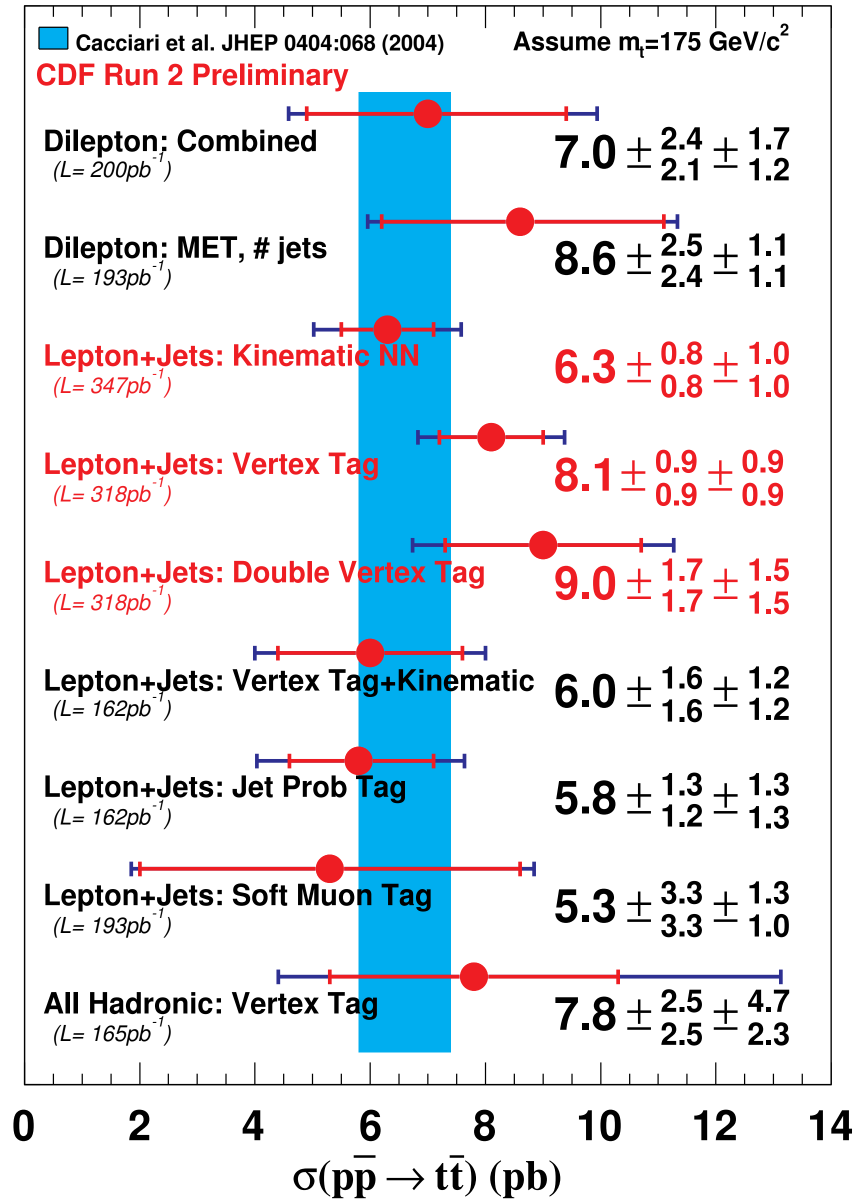
Sample	Events	Fitted $t\bar{t}$	$\sigma(t\bar{t})$
$W+\geq 3$ jets	936	148.2 ± 20.6	$6.0 \pm 0.8 \pm 1.0$ pb
$W+\geq 4$-Jet	210	80.9 ± 15.0	$6.1 \pm 1.1 \pm 1.4$ pb



Top Cross Section Summary

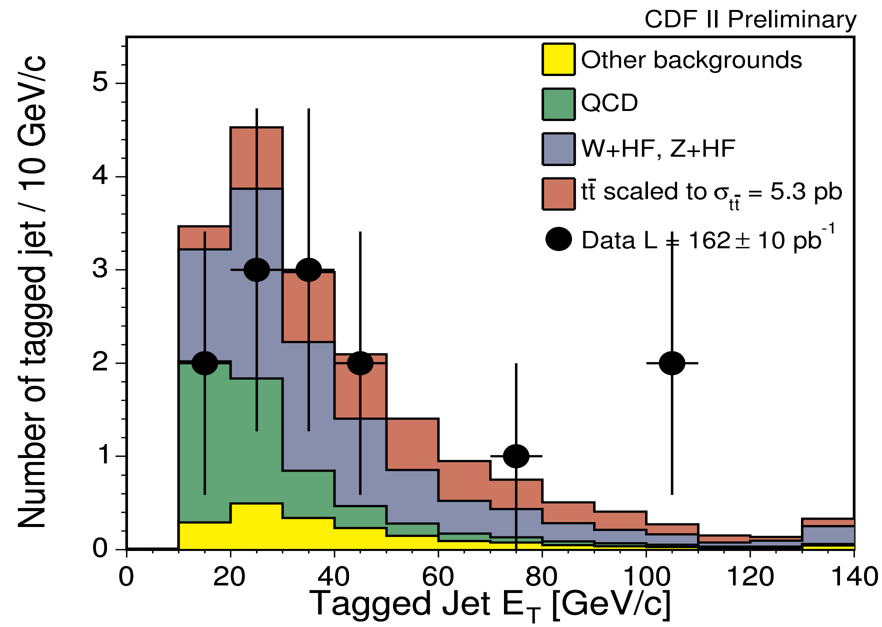
- For comparison purposes we evolve all cross sections to m_t = 175 GeV/c²
  - Increases values by ~0.2 pb compared to m_t = 178 GeV/c²
- Updated results in the dilepton and all-hadronic decay channels and using the jet probability tagger soon
- Working on a combination of the results

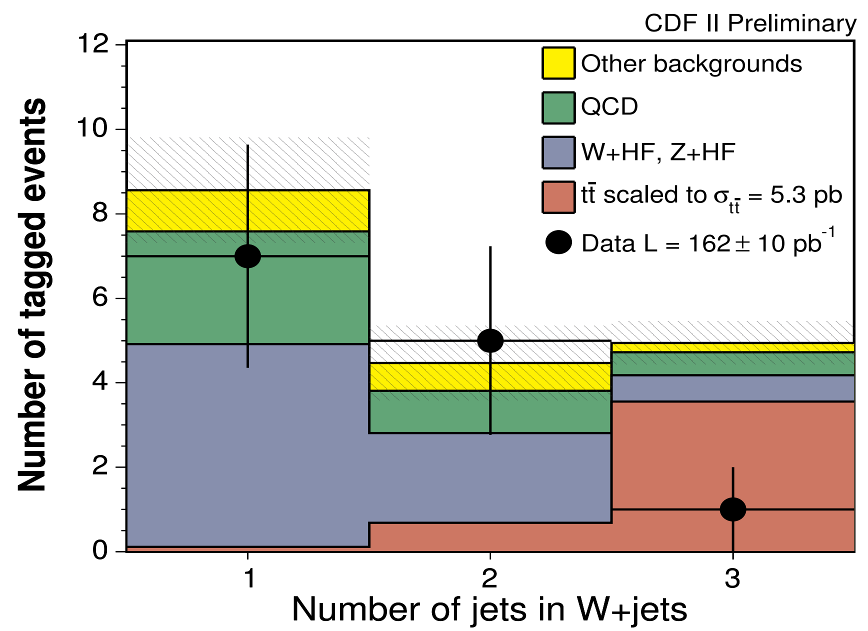




Anomalous Semileptonic Decays

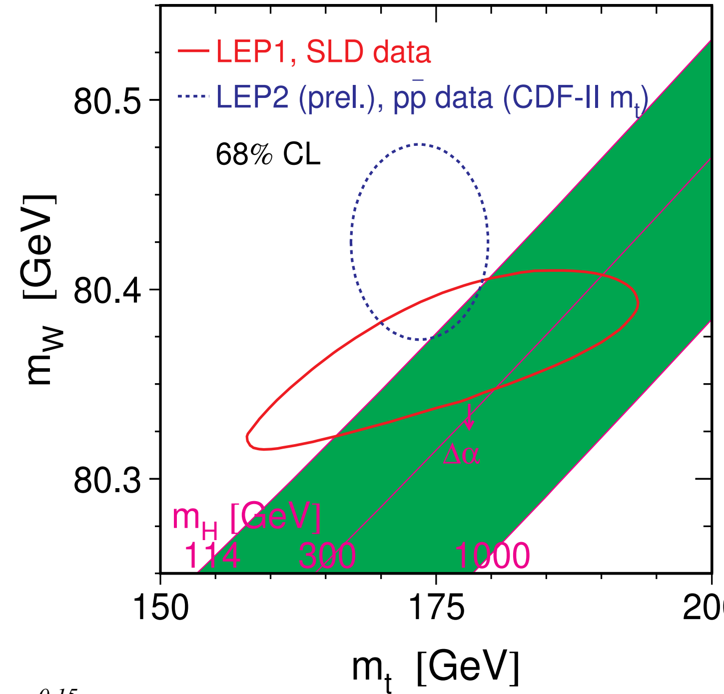
- In Run I, CDF observed an excess of events in W+jets where a jet was tagged with both the displaced-vertex and "soft lepton" taggers (Phys. Rev. D69, 072004)
- An example scenario that could produce such an effect is light sbottom production
- Take a look in the Run II sample using the displaced-vertex and soft muon taggers
- Analysis is very similar to the b-tagged top cross section measurements, just have to work out the efficiency and mistag correlations between the two taggers
- In 162 pb^{-1} we see no evidence for anomalous production so far
- Work is progressing to turn this into cross section X BR limits

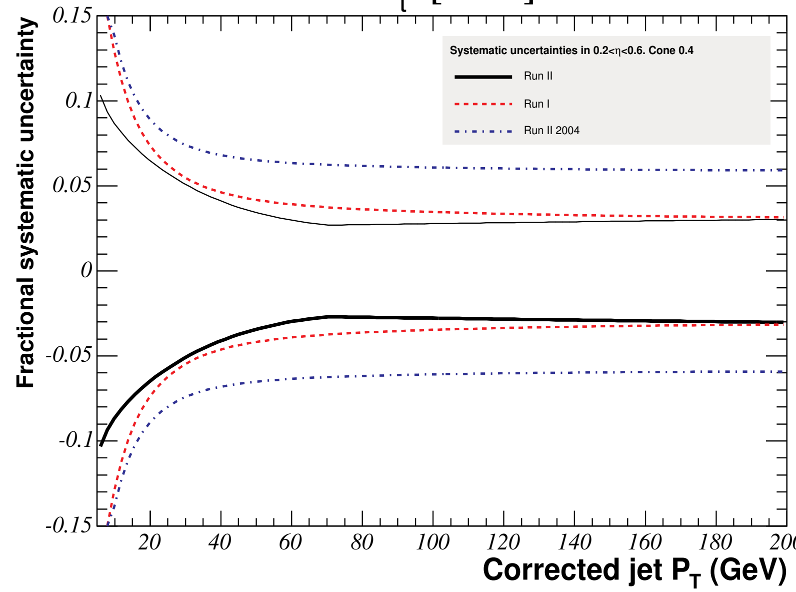




Top Mass Measurements

- The mass of the top quark is a most interesting SM parameter
  - Can be predicted from a fit to the LEP/SLD Z-pole measurements
  - Along with M_W, constrains the SM Higgs mass
- Measurements can be roughly divided into two categories
  - Template methods: Reconstruct a top mass for each event in the sample, then compare to MC templates constructed with different top masses and interpolate to the best match
  - Matrix element methods: Using differential cross sections, calculate a probability for each event as a function of m_t, choose the mass that maximizes the likelihood of the entire sample
- No matter how you do it, limiting systematic uncertainty is the energy scale of jets in the calorimeter





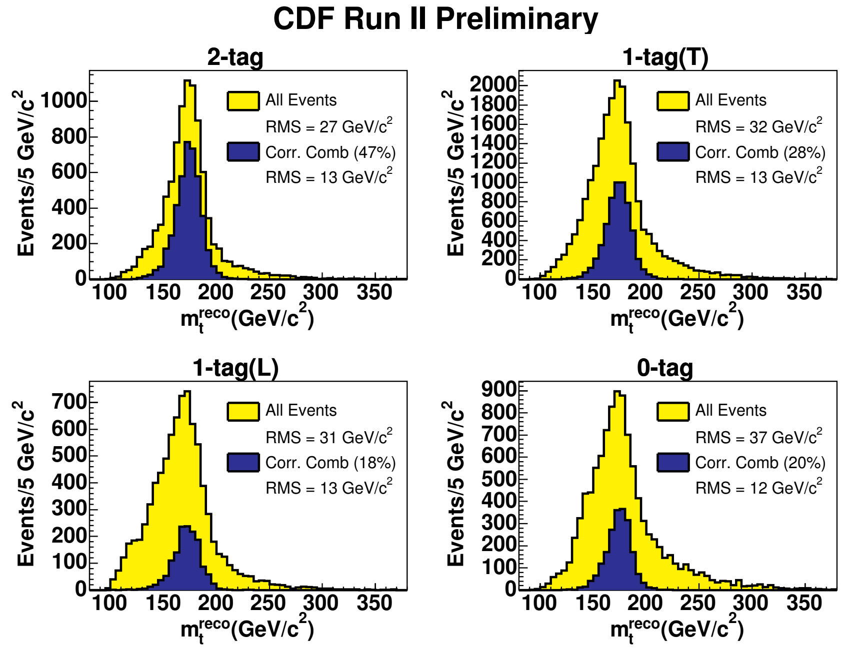
Lepton+Jets Template Method

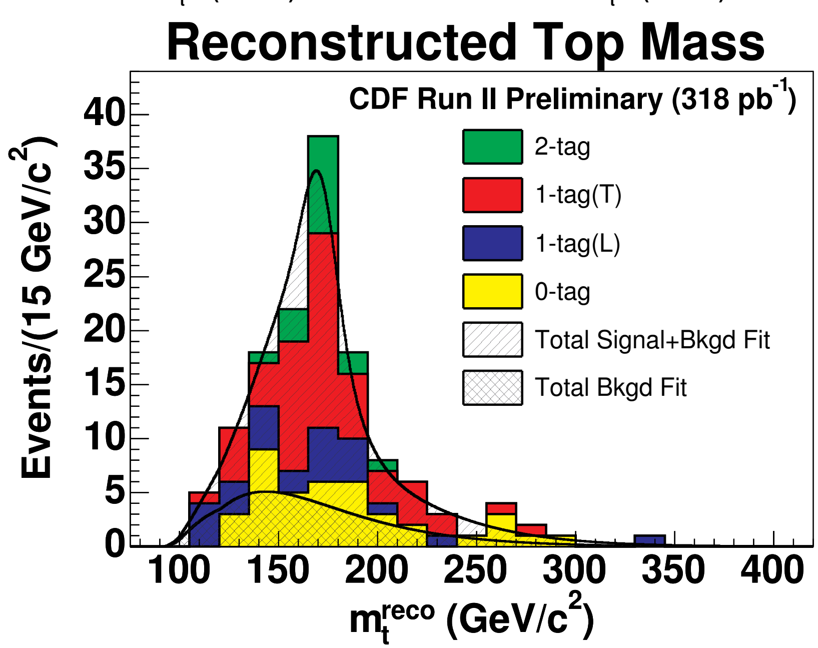
- Lepton+jets selection with $\geq$4 jets
- Determine the jet assignments using a χ^2 function, imposing W mass constraints and requiring the two top masses to be equal
- B-tagging reduces permutations
- Jet energies are allowed to float within their resolutions
- Can optionally float the overall jet energy scale (with a constraint) – use the W mass to improve the precision
- Configuration with the lowest χ^2 used to compute the top mass for each event
- Build templates for various top masses and also for the background, and find the best fit

stat JES syst

$$m_t = 173.5^{+2.7}_{-2.6} \pm 2.5 \pm 1.7 \text{ GeV}/c^2$$

$$m_t = 173.5^{+4.1}_{-4.0} \text{ GeV}/c^2$$

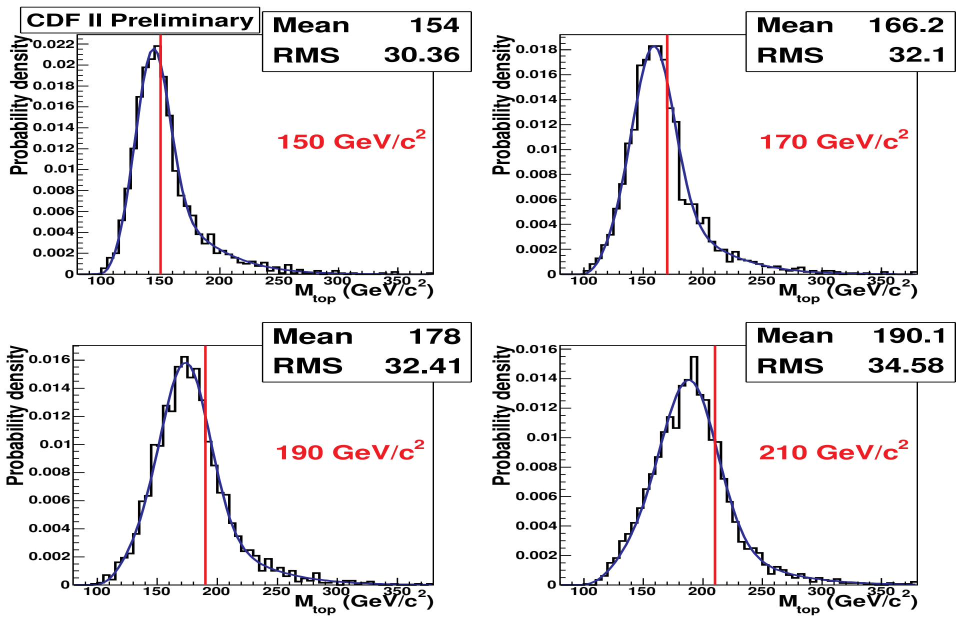


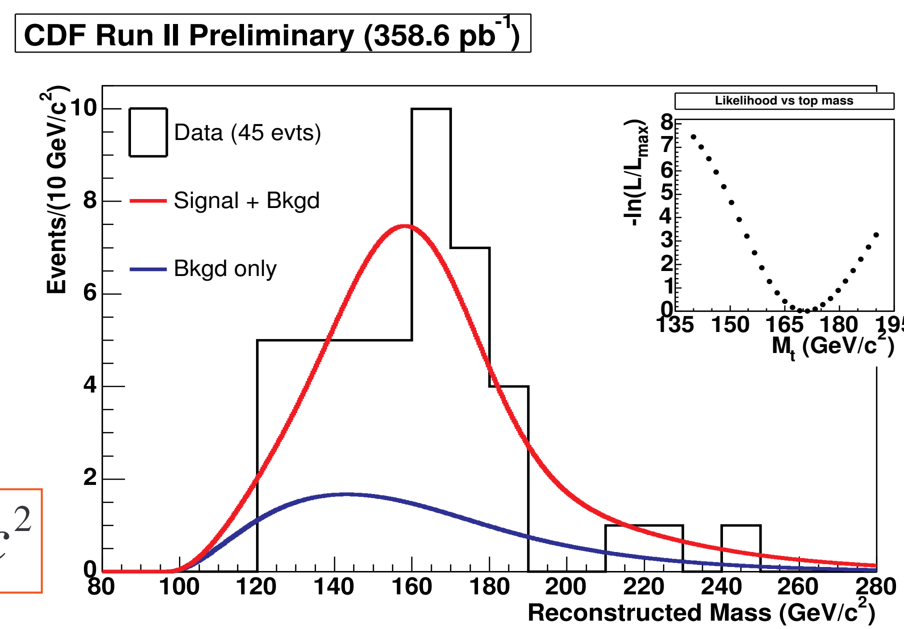


Dilepton Template Method

- Template-based methods can also be used in the dilepton decay channel
  - With two neutrinos, it's not possible to reconstruct the t-tbar system – have to make an assumption ($\eta(\nu)$, $\phi(\nu)$, $P_z(tt)$)
  - Samples are smaller than in lepton+jets (S/B = 33/13)
- Scan over possible pseudorapidity values for each of the two neutrinos
- For each pair of neutrino η, compute the likelihood to get the observed missing-E_T as a function of m_t
- Integrate over neutrino η's to get a likelihood curve for each event vs m_t
  - Choose the most probable m_t for each event
- Rest of the analysis proceeds exactly as for the lepton+jets template result

$$m_t = 170.6^{+7.1}_{-6.6}(stat) \pm 4.4(syst)\ \mathrm{GeV}/c^2$$





Dynamical Likelihood Method

- Template methods give you one top mass value per event, but don't make use of how "top-like" the events are
- Matrix element methods incorporate more information by using a differential cross section to characterize the likelihood of each event given a value of m_t
- Multiply all resulting event probabilities to get a sample likelihood and maximize vs m_t
- A leading-order matrix element doesn't exactly describe top events
  - Make a ~2 GeV/c² correction to the fitted m_t
- Only b-tagged lepton+jets events with exactly four jets (63 vs 138)

$$L^i(M_{top}) = \sum_{I_t}\sum_{I_s}\int \frac{2\pi^4}{Flux} F(z_a, z_b, p_T)\,|M|^2\, w(\mathbf{x},\mathbf{y})\,d\mathbf{x}$$

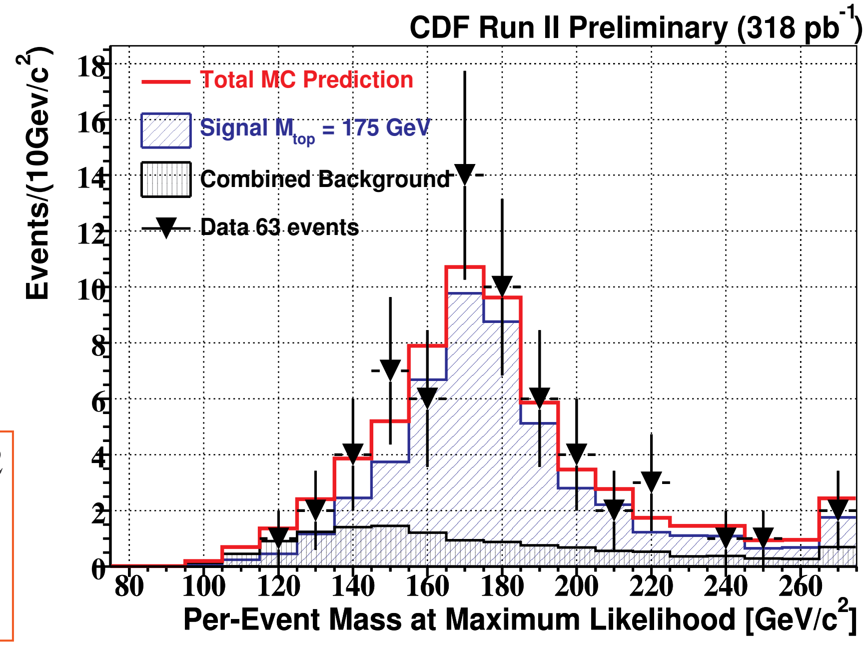
L^i = likelihood for event i

F = parton dist. function for tt system p_T

M = production+decay matrix element

w = partons x ←→ observables y

Sums are over jet/parton assignments and the two neutrino P_z solutions



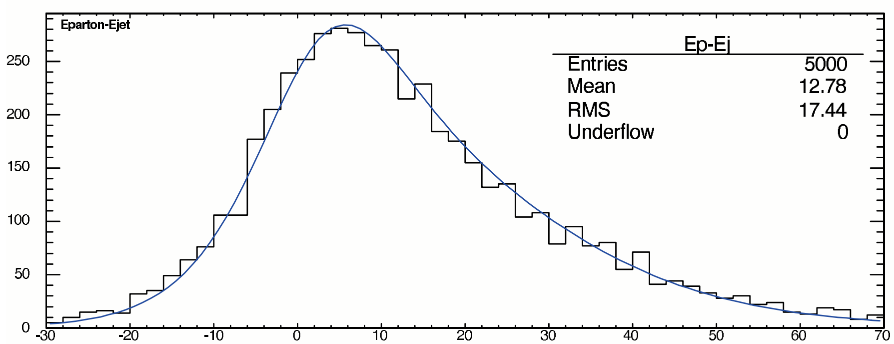
$$m_t = 173.8^{+2.7}_{-2.5}(stat) \pm 3.3(syst)\ \text{GeV}/c^2$$

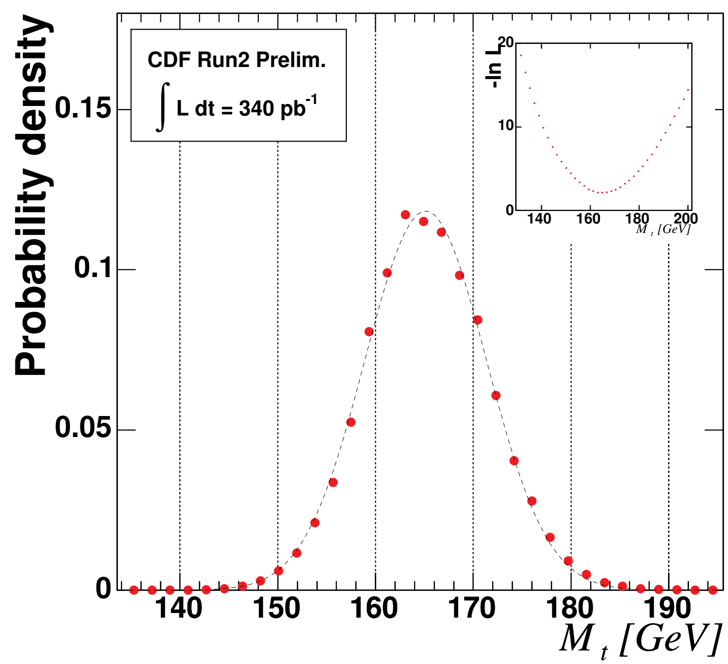
$$m_t = 173.8^{+4.3}_{-4.1}\ \text{GeV}/c^2$$

Dilepton Matrix Element

$$P(y\,|\,m_t) \approx \sum \int F(z_a, z_b, p_T)\,|M(m_t)|^2\, w(x, y)\,dx$$

- Matrix element method applied for the first time to dilepton events
  - Same problem of two neutrinos
  - Solution is to integrate over their momenta → vector of observables *y* will be smaller than parton vector *x* in this case
- In addition to signal, these results also use differential cross sections for the background processes WW, Drell-Yan, and W+jets (fake lepton)
- Calculate probabilities for each event to be any of the signal or background types
- Combined likelihood is a sum of signal and background probabilities, weighted by the expected number of each type
- Make a ~1 GeV/c² correction for non-LO-ness of real top events

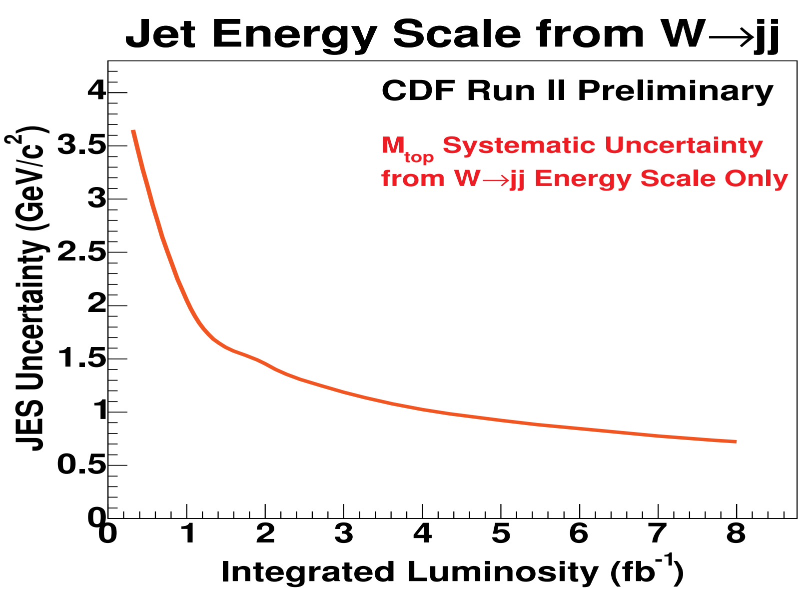


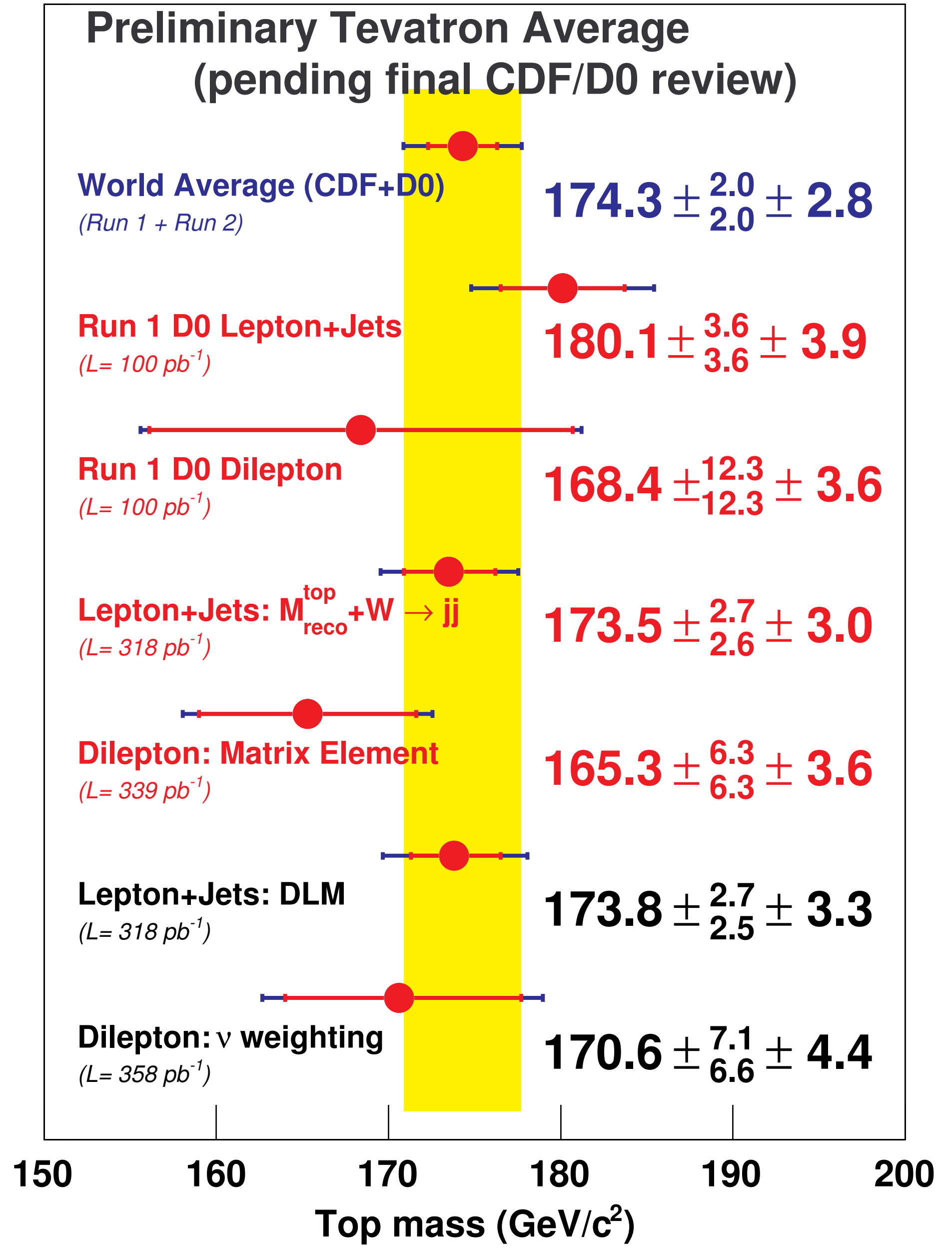


$$m_t = 165.3 \pm 6.3(stat) \pm 3.6(syst)\ \mathrm{GeV}/c^2$$

Top Mass Summary

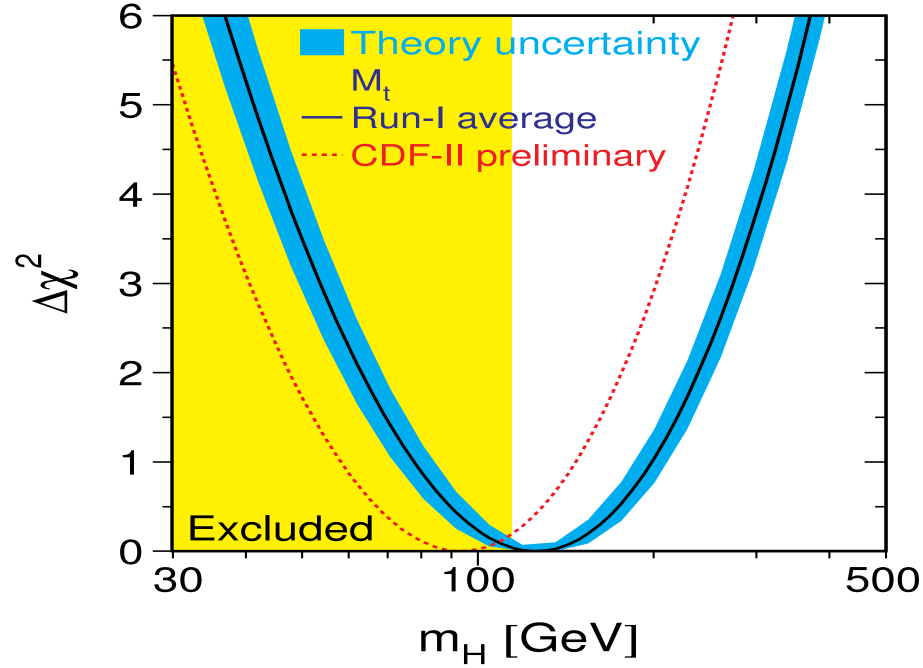
- TevEWWG has produced a new average
  - δm_t = 3.4 GeV/c² (was 4.3 in RunI)
  - Currently using most precise single measurement per decay channel from each experiment
  - Work ongoing to combine results within each channel (including CDF results from RunI)
- Floating JES is limited by statistics – can reach our RunII goal of δm_t = 2-3 GeV/c²

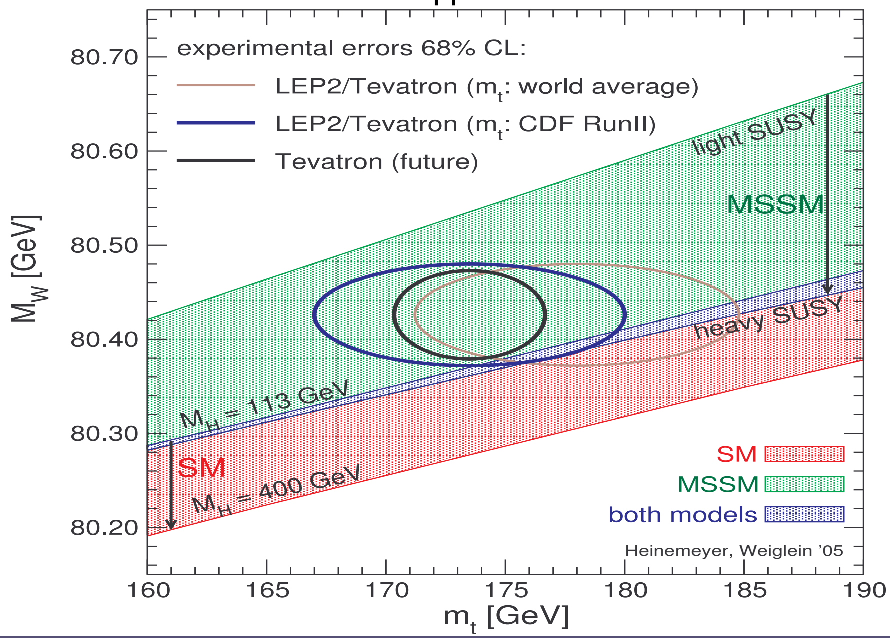




Top Mass Interpretation

- Martin Grunewald was kind enough to prepare a blueband plot using the new CDF m_t result (lepton+jets only)
  - $m_H = 94{+}54{-}35$ GeV/c²
  - $m_H < 208$ GeV/c² @ 95% CL
- The fit is moving further into the LEP-II excluded region but of course there is still plenty of probability outside of it
- Similar fits can be done in the context of the MSSM (thanks to Sven Heinemeyer and Georg Weiglein)
- The new m_t prefers a lower mass scale for SUSY particles, which could be good news for Tevatron discovery prospects (or bad news for the MSSM)





Summary

- CDF has a wide array of RunII top/EW analyses using 200-300 pb^{-1} either published or in progress
  - EW: 5 published, 1 submitted, 2 in preparation
  - Top: 5 published, 3 submitted, 9 in preparation
- As sample sizes increase to the multi-fb^{-1} range, can perform more intensive studies of the particle and event properties
  - W mass, W width (from R), gauge boson couplings
  - Top mass, charge, spin, branching ratios
  - Single-top production
  - Search for WW and tt resonances
- Analysis strategies will evolve to lessen/avoid the current limiting systematic errors
- We have come a long way but it's just the beginning