RUTGERS
THE STATE UNIVERSITY
OF NEW JERSEY

A Measurement of the ttbar Cross Section and the Top Quark Mass in the Hadronic τ + Jets Channel at CDF

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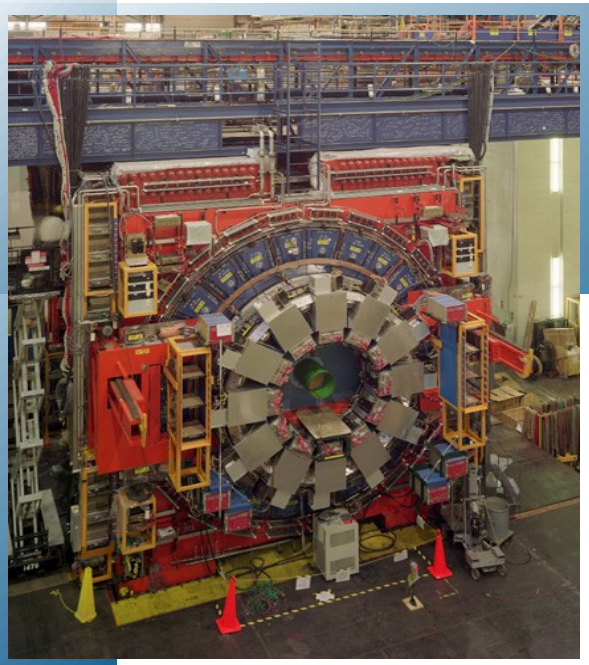
Rutgers University

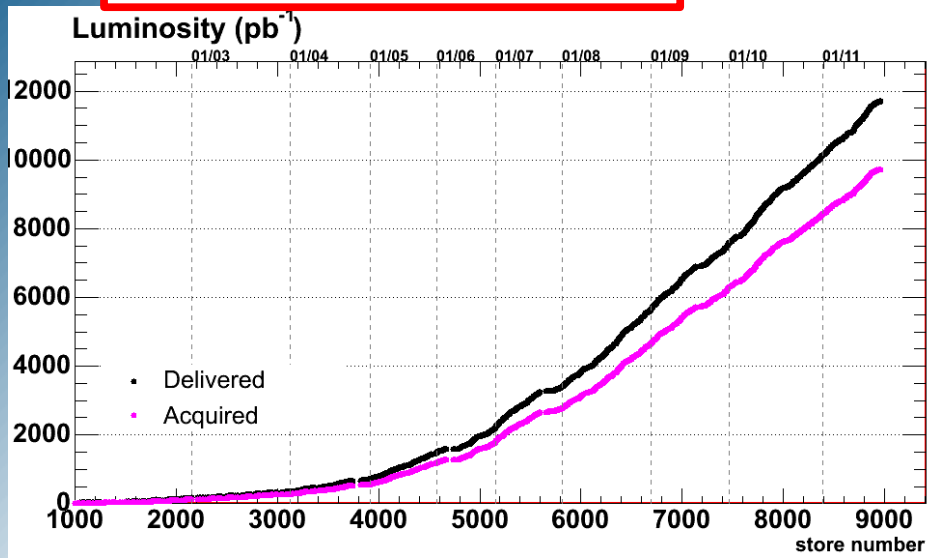
On behalf of the CDF Collaboration

http://www-cdf.fnal.gov/physics/new/top/2011/meatv3_tau_public/index.html

CDF Detector



Luminosity:
Delivered: 11.6 fb^{-1}
Acquired: 9.7 fb^{-1}



- Tevatron
  - 1.96 TeV Collider outside of Chicago, IL
- CDF Detector:
  - Silicon Detector
    - high precision tracking and secondary vertex detection
  - Tracking Chamber
  - Solenoid
  - EM and Hadronic Calorimeters
  - Muon wire chambers

Summer 10 World Average Mass: 5.6 fb^{-1}

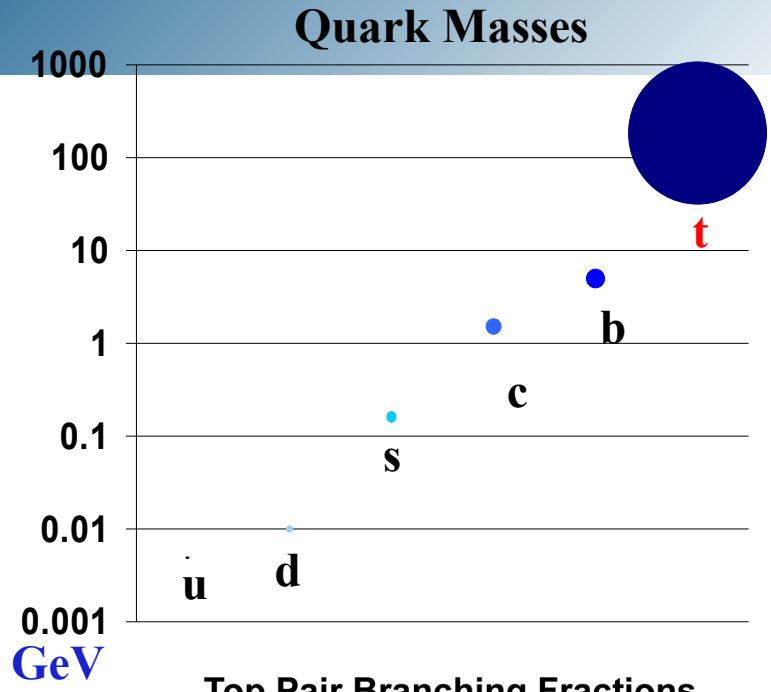
173.3 ± 0.6(stat) ± 0.9 (syst) GeV

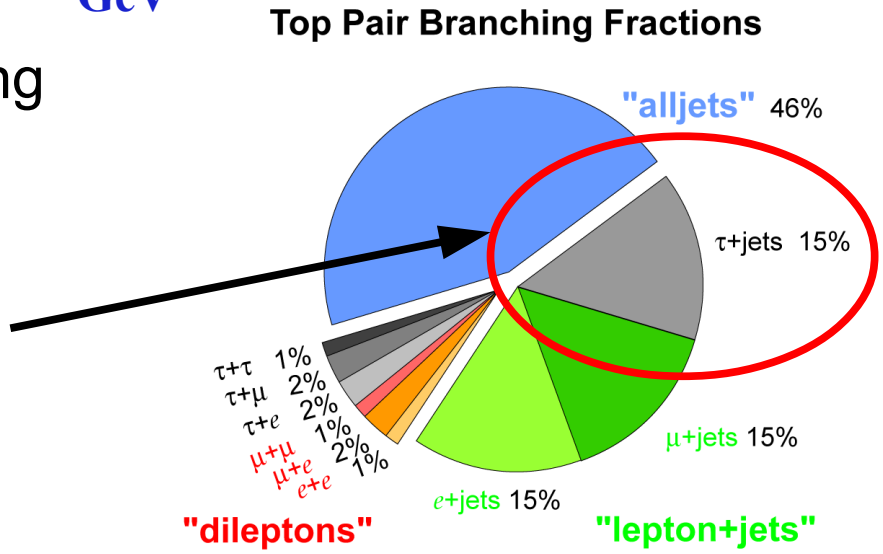
173.3 ± 1.1 GeV

ArXiv:1007.3178

Top Quark and taus

- **Top Quark:**
  - Discovered during Run I at the Tevatron in 1995
  - Only quark to decay before it hadronizes
  - Has a Yukawa coupling to the Higgs of ~1
  - Constrains the Higgs mass along with W
- **Taus:**
  - First top mass measurement in tau decay channel
  - Channel for new physics
    - Ex: $t \rightarrow H^{+}b$





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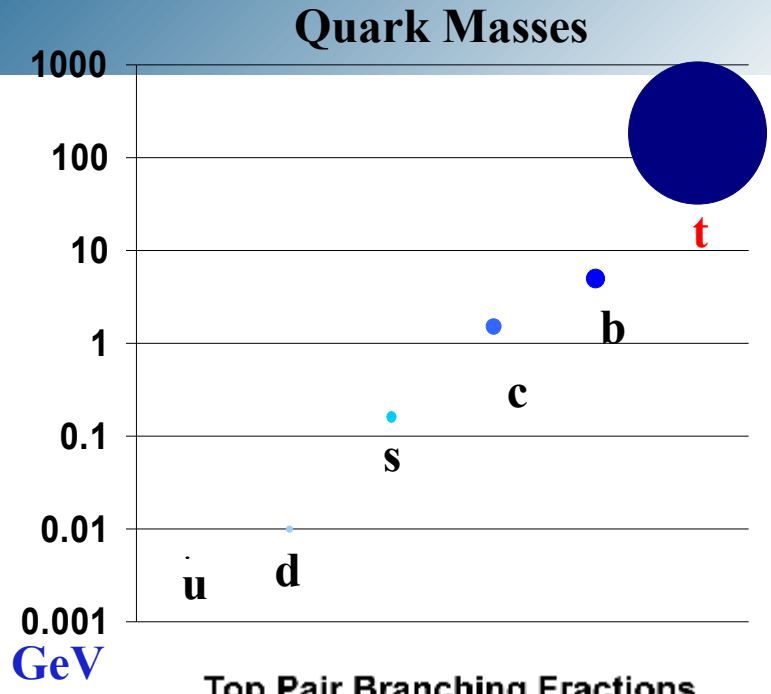
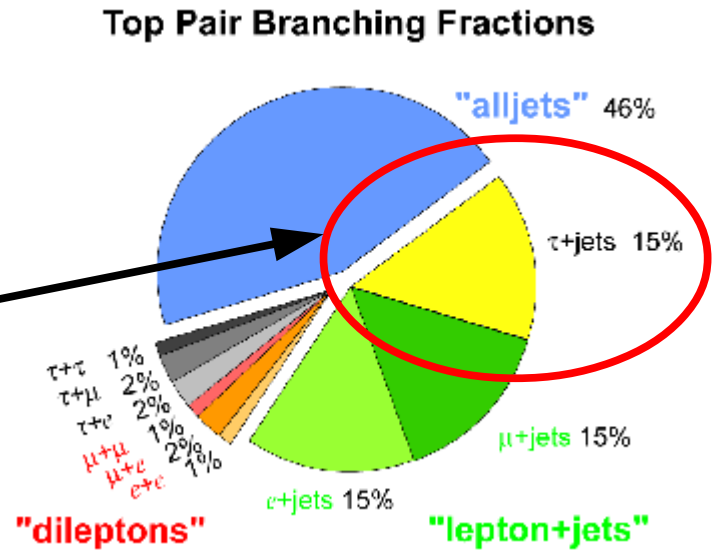
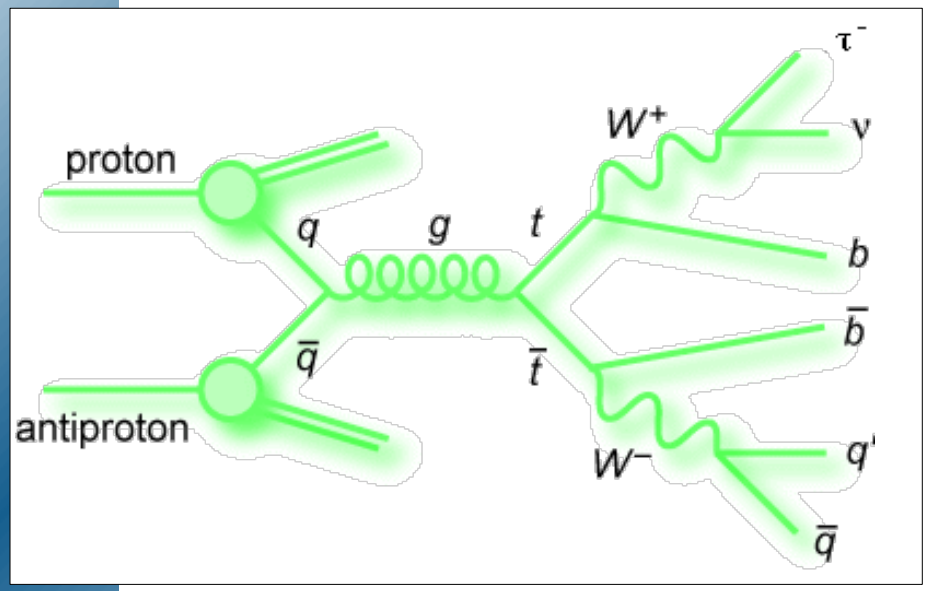
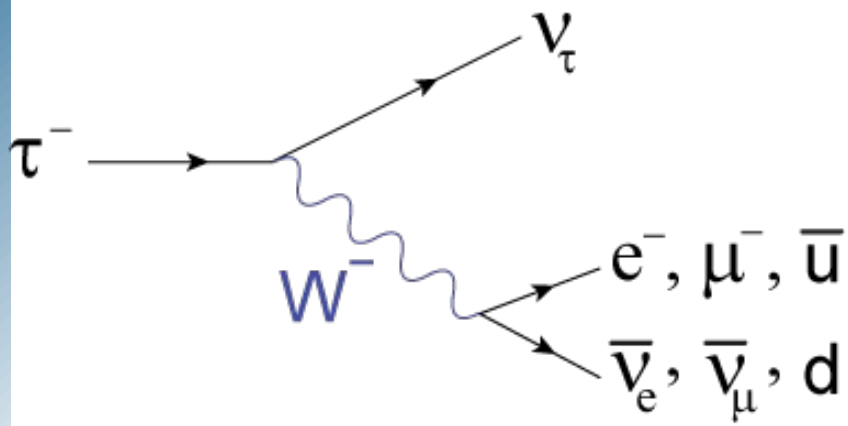




Event Selection
2.2 fb^{-1}

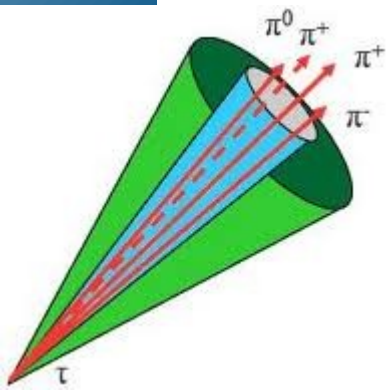




- **Looking for hadronic τ + jets top decay:**
  - 4 jets with E_t > 20 GeV
    - at least 1 b-tagged
  - Missing E_t > 20 GeV
  - **1 hadronically decaying τ**
    - **E_t > 25 GeV**
    - **Looks like narrow jet**
    - **1 or 3 tracks**
- Leptonically decaying taus:
  - May be included in standard lepton analyses

What is Different About Taus?

- **Taus are harder to measure than e or μ**
  - Hadronically decaying tau includes a neutrino
  - Now ttbar decay has 2 neutrinos
  - **Solution: Scan Method to reconstruct neutrino from tau decay**



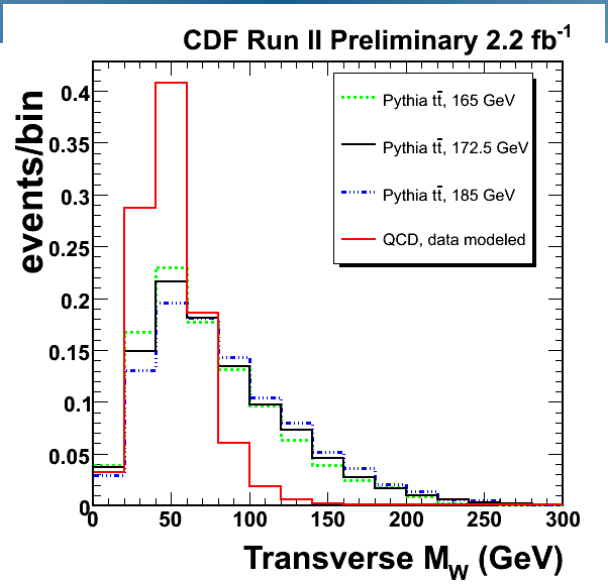
  - 4D scan over both neutrino angles ($\eta_1, \varphi_1, \eta_2, \varphi_2$)
  - Use W and τ mass to solve for ν^E_1 and ν^E_2
  - Compare predicted missing E_t to measured to determine most likely neutrino angles

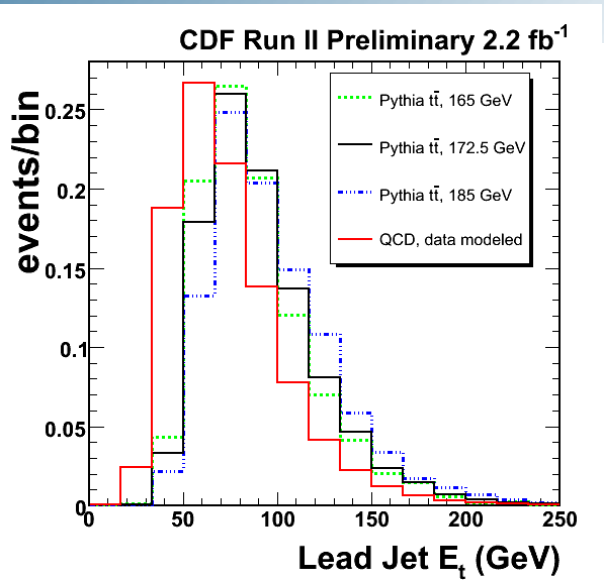
- **Hadronically decaying tau is essentially a narrow jet**
  - Large QCD Background
  - **Solution: Neural Network to Remove QCD**

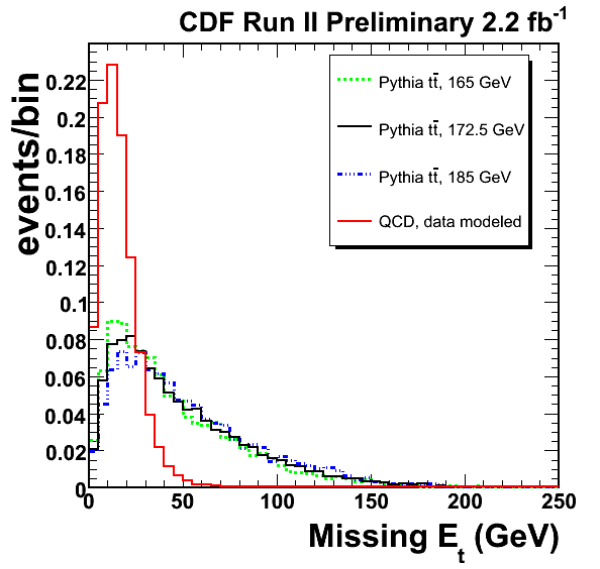
Neural Network Input

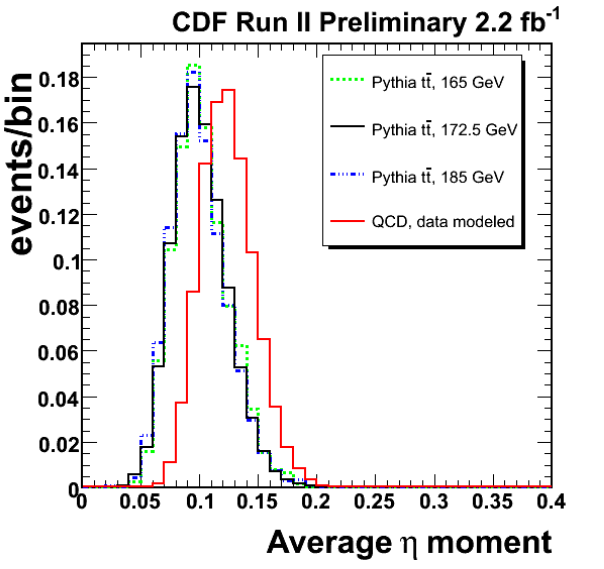
NN used to reduce QCD

ttbar shapes largely independent of top mass







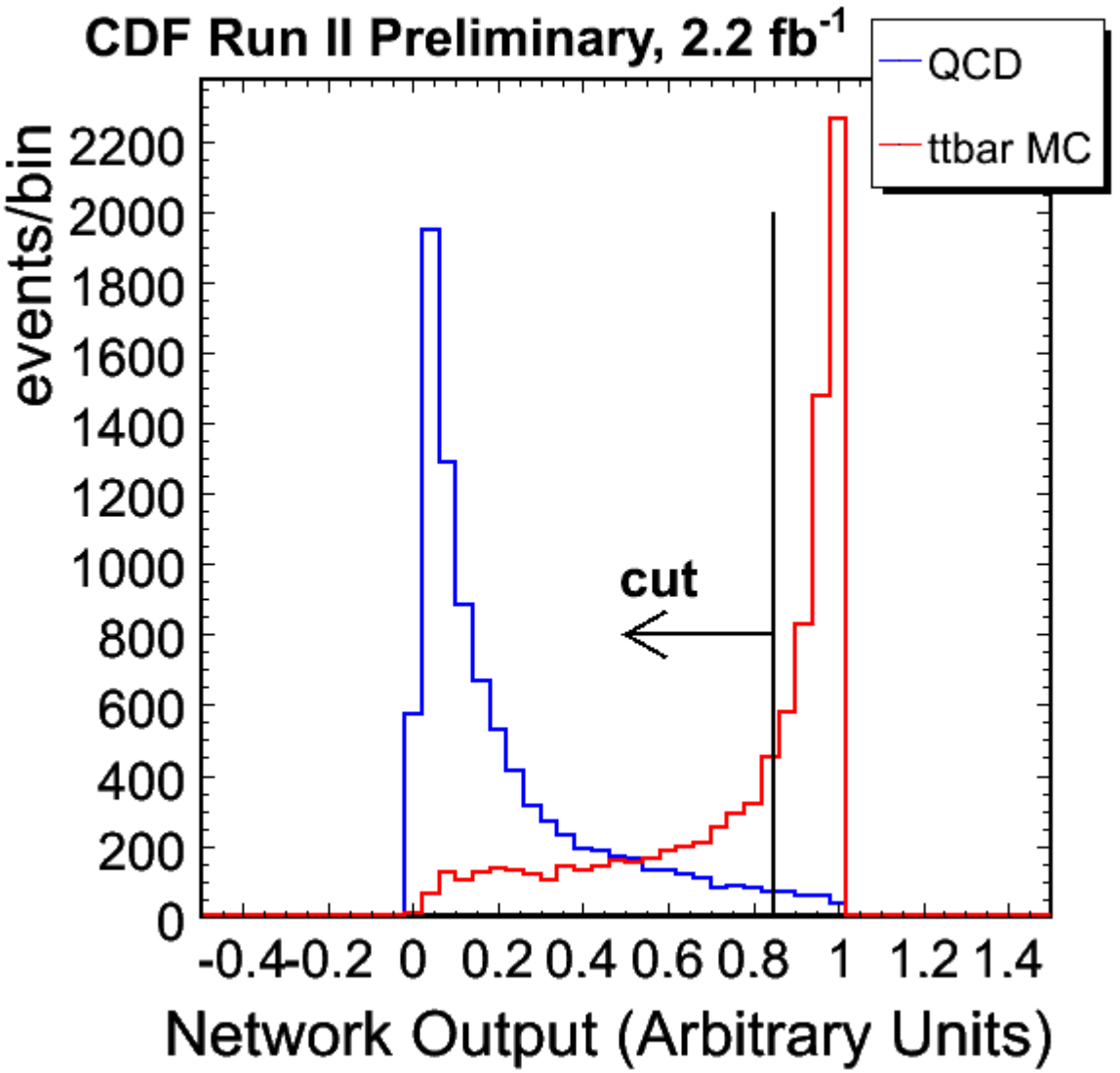


Neural Network Output

- Cut on NN to reduce QCD
- Optimize NN cut to maximize

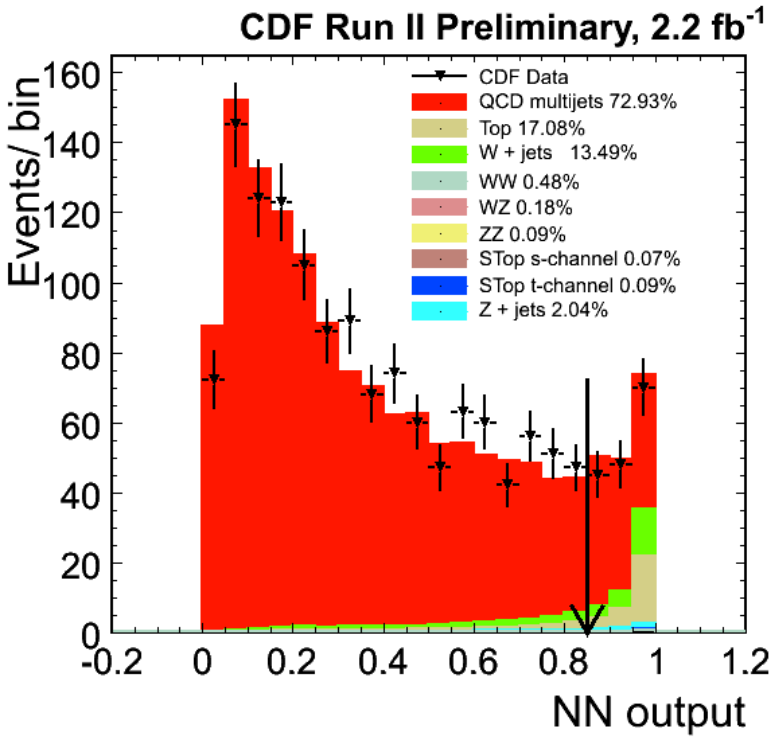
$$\frac{S}{\sqrt{S+B}}$$

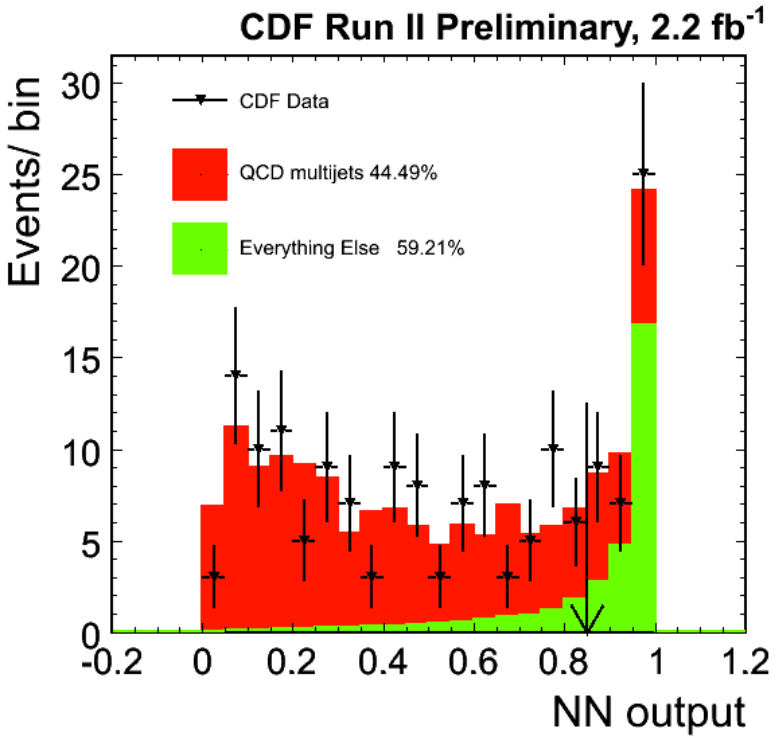
- Find optimal NN cut at 0.85



Fitting the Neural Network Output

- Diboson, Single top, Z+jets, and ttbar contributions determined by cross section and MC acceptance
- QCD and W+jets contributions determined by fitting shapes of NN output to data in non b-tag and b-tag samples





Assume ttbar xsec of 7.4 pb and top mass of 172.5 GeV

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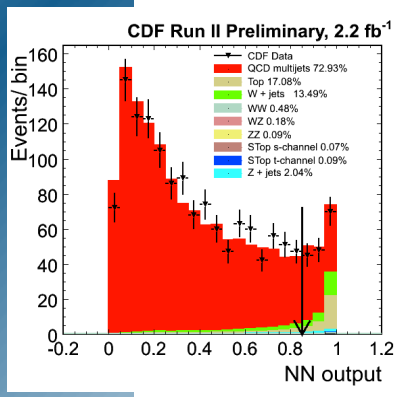
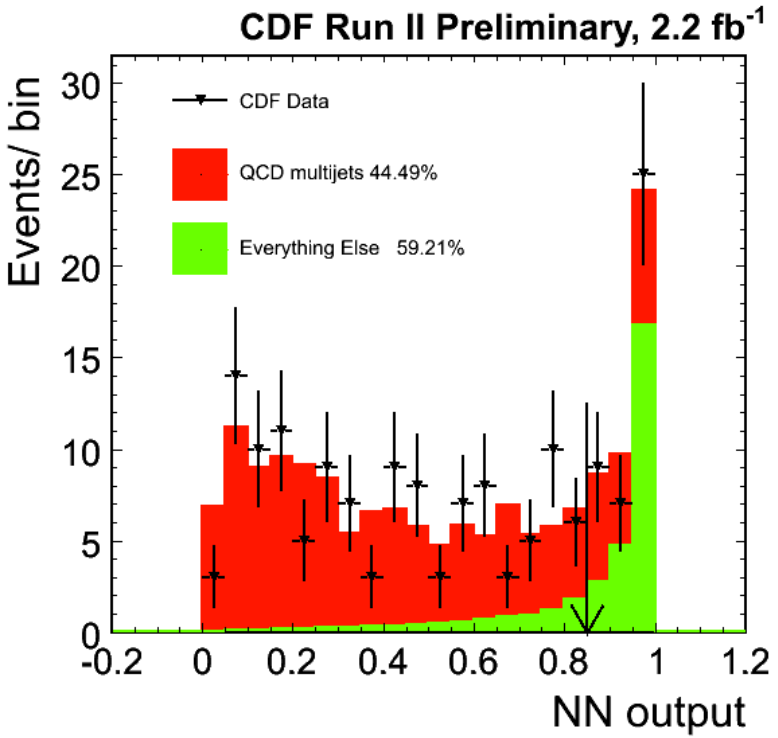


CDF Run II Preliminary 2.2 fb^{-1}			
Source	**Number of Events**		
Diboson	0.2	±	< 0.1
Single Top	0.2	±	< 0.1
Z + jets	0.3	±	< 0.1
Wbb	0.6	±	0.5
Wcc	0.3	±	0.3
Wc	0.2	±	0.1
W+jets (light)	0.5	±	0.6
QCD	18.2	±	4.1
ttbar	18.2	±	2.8
Total Prediction	38.7	±	5.1
Observed	41.0		



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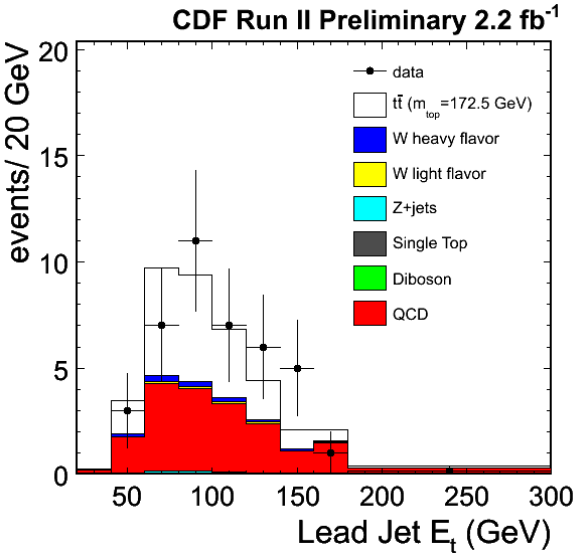
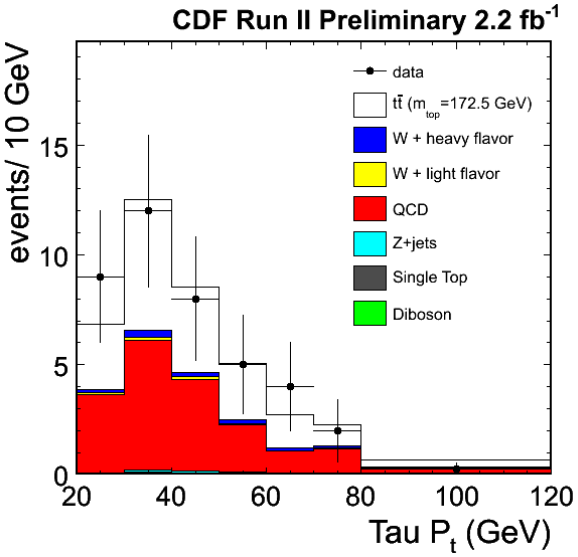
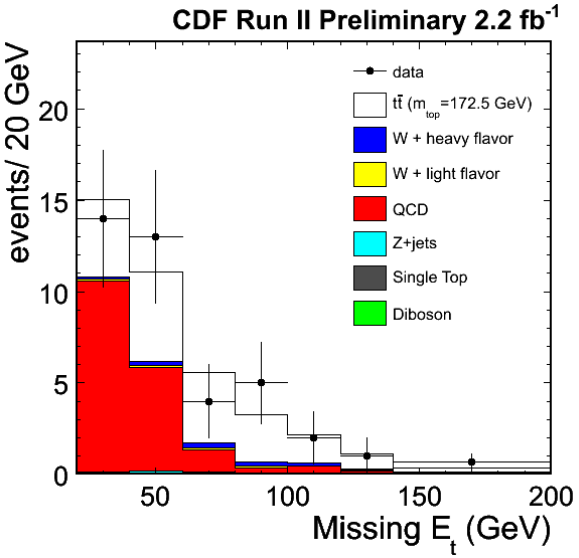
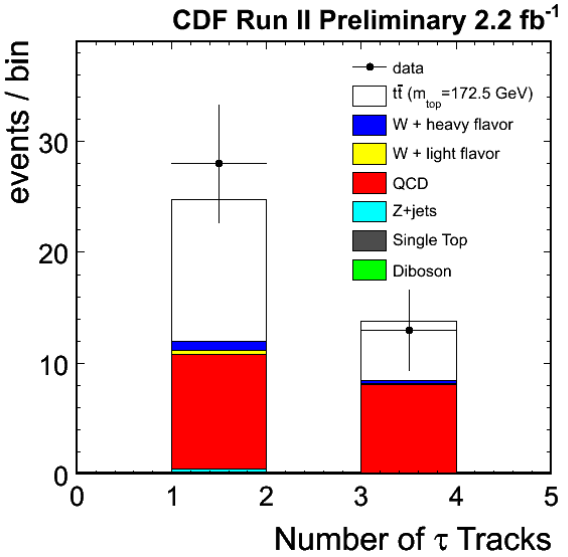
Kinematic Distributions









Cross Section Measurement

- Cross section is calculated as: $\sigma = \frac{N_{data} - N_{bkgd}}{A \cdot \epsilon \cdot \mathcal{L}}$
- Note: in this analysis, N_{bkgd} depends on the ttbar cross section.
- Build a Poison Likelihood Function:

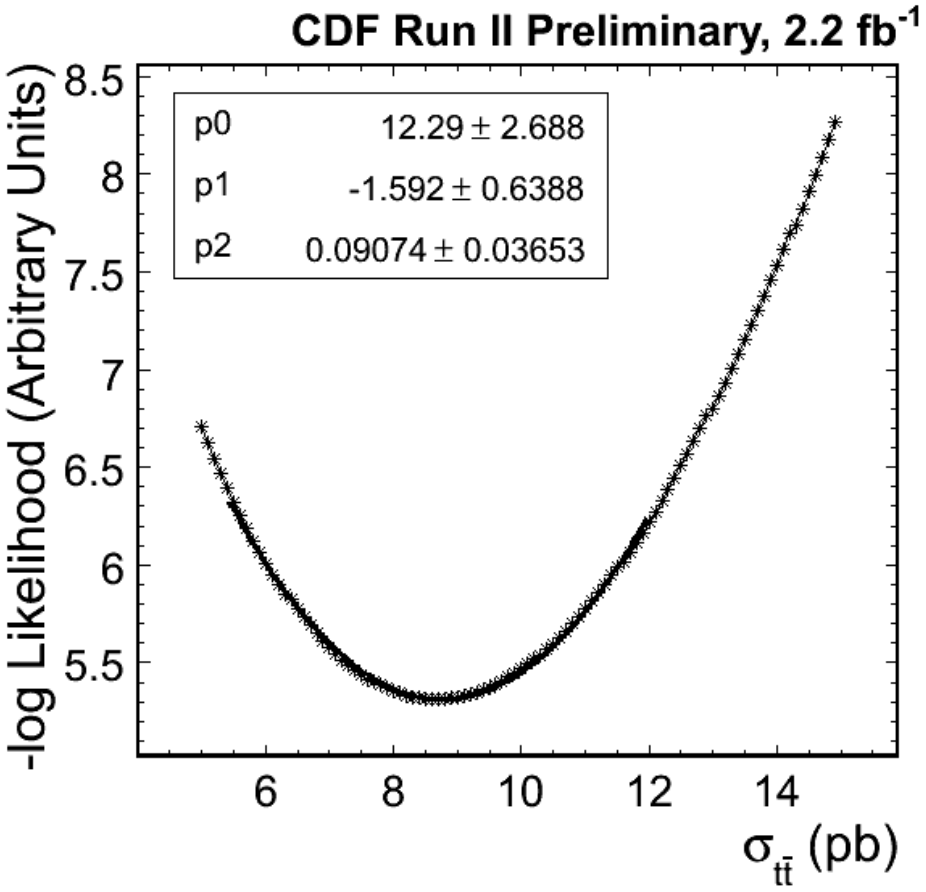
$$-2 \cdot lnL = -2 \cdot (N_{data} \cdot ln\,(\sigma_{t\bar{t}} \cdot D + N_b(\sigma_{t\bar{t}})) - ln\,(N_{data}!) - (\sigma_{t\bar{t}} \cdot D + N_b(\sigma_{t\bar{t}})))$$

where D = $A \cdot \epsilon \cdot \mathcal{L}$

- Scan a range of potential ttbar cross sections and fit with 2nd order polynomial

Cross Section Result

- **τ + jets Result (2.2 fb^{-1}):**
  - 8.8 ± 3.3 (stat) ± 2.7 (syst) pb
  - CDF Combination (4.6 fb^{-1}): 7.5 ± 0.5 pb



CDF Run II Preliminary, 2.2 fb^{-1}

Systematic	$\delta\sigma$ (pb)	$\delta\sigma/\sigma$ (%)
Jet Energy Scale	0.6	6.9
IFSR	0.5	5.7
Color Reconnection	0.4	4.6
Tagging	0.4	4.6
Mistag Matrix	0.1	1.1
QCD Fraction	1.7	19.5
K-Factor	0.1	1.1
Parton Showering	1.7	19.5
Lepton ID	0.2	2.3
Trigger Efficiency	0.1	1.1
PDF	0.5	5.7
Luminosity	0.6	6.9
Total	2.7	31.0

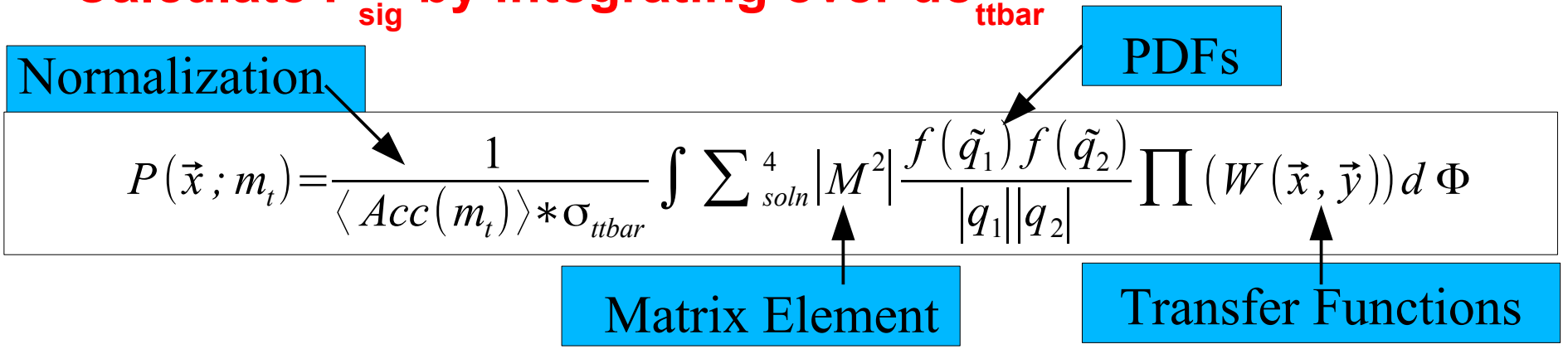
Top Quark Mass Measurement

- ttbar cross section measurement consistent with standard model
- Now move to mass measurement

Matrix Element Technique

$$P(\vec{x};\alpha) = c_s P_{t\bar{t}}(\vec{x};M_{top}) + A_{bkgd}(1-c_s) P_{W+jets}(\vec{x})$$

- **Build likelihood function from signal and bkgd probabilities**
- **Constrain c_s to expected signal fraction from slide 9**
- **Calculate P_{sig} by integrating over $d\sigma_{ttbar}$**

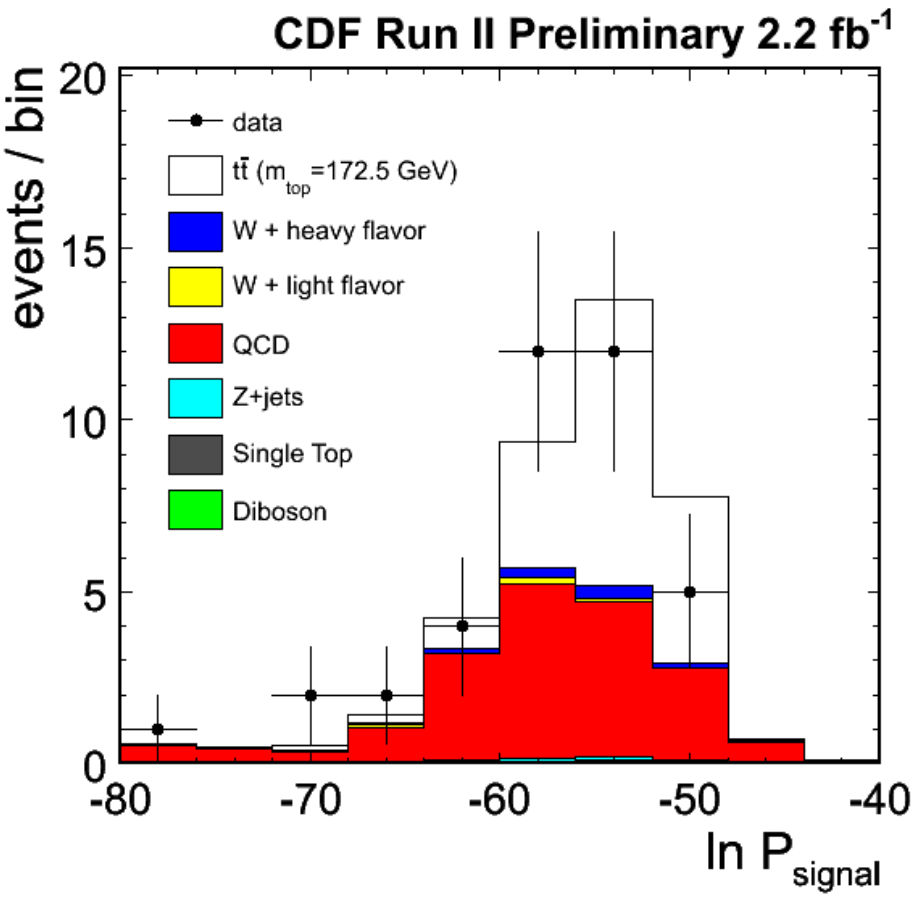


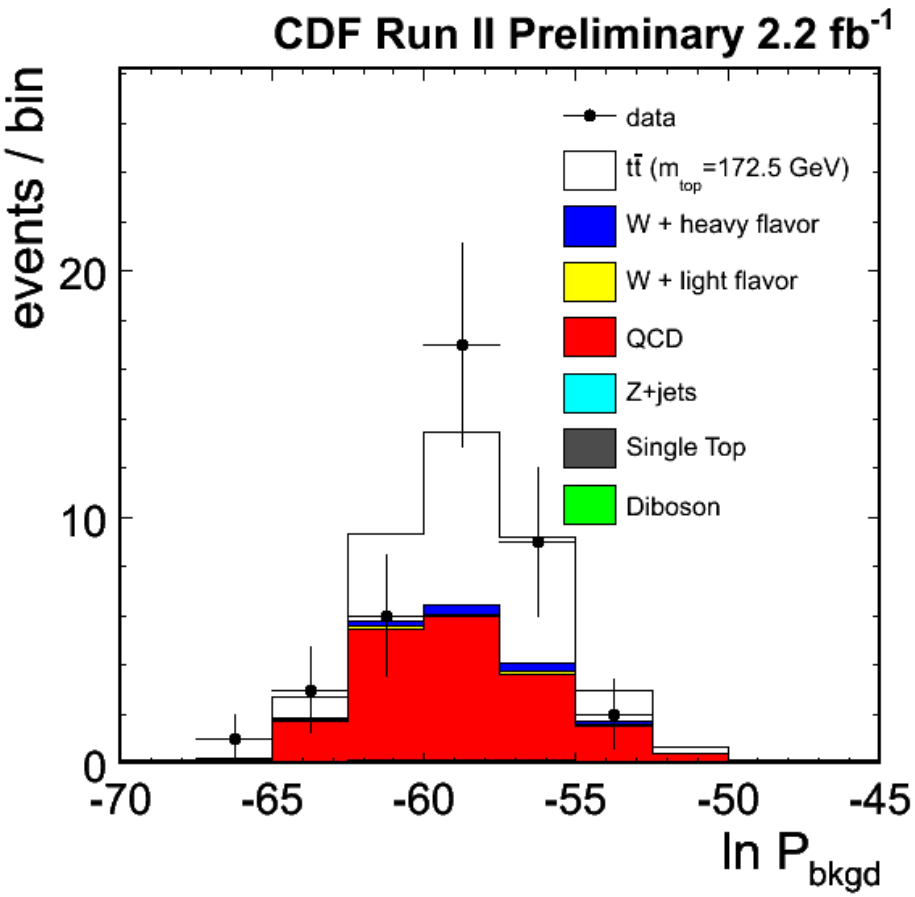
- M calculated using parton level quantities from integration
- Integrate over m^2_{Whad}, m^2_{Wlep}, ρ_{jet1}, $\cos\alpha_{12}$, $\cos\alpha_{Wbhad}$
- Similar expression for background probability:
  - **Use VECBOS W+4jets matrix element**
  - **Integrate over E_{jet1}, E_{jet2}, E_{bhad}, E_{blep}, p^z_ν**

Data Probabilities

Signal and Background Probabilities:

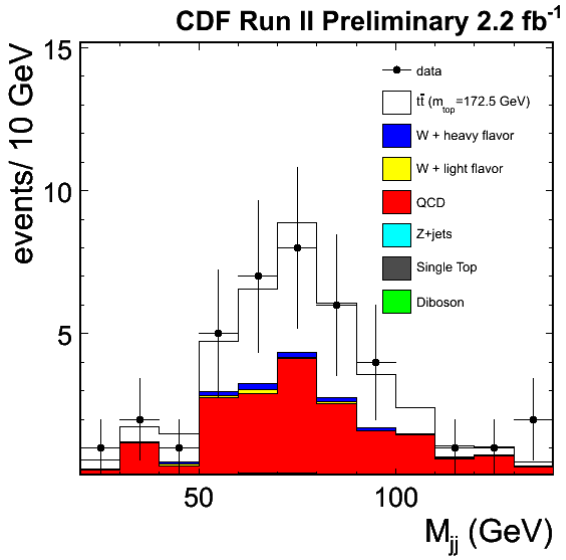
Signal is taken from highest probability point in M_{top}

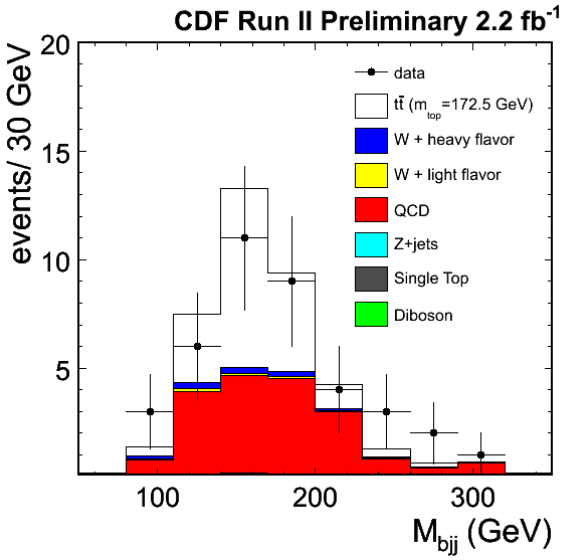


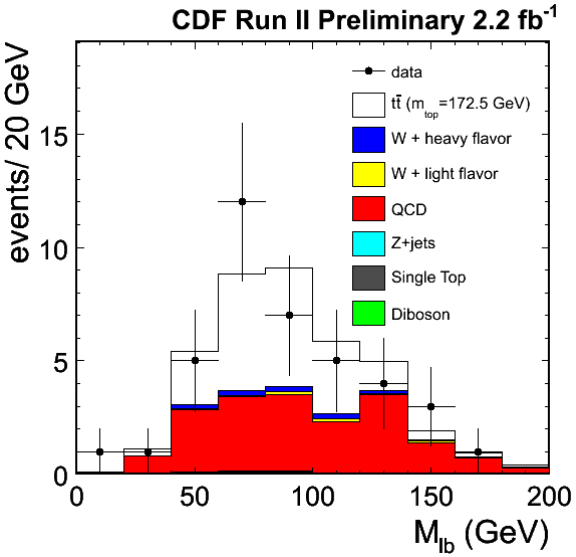


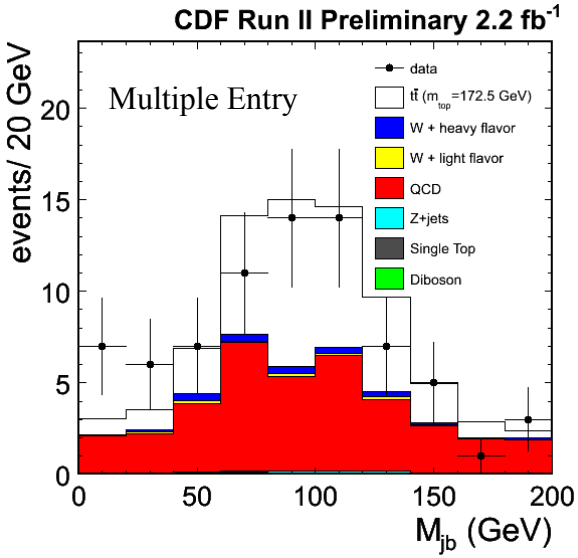
Matrix Element Validation

- Select most probable jet combination from signal probability
- Look at interesting mass variables:
  - Hadronic side W
  - Hadronic side Top
  - Mass of lepton and lep side b
  - Mass of lq jet and hadronic side b



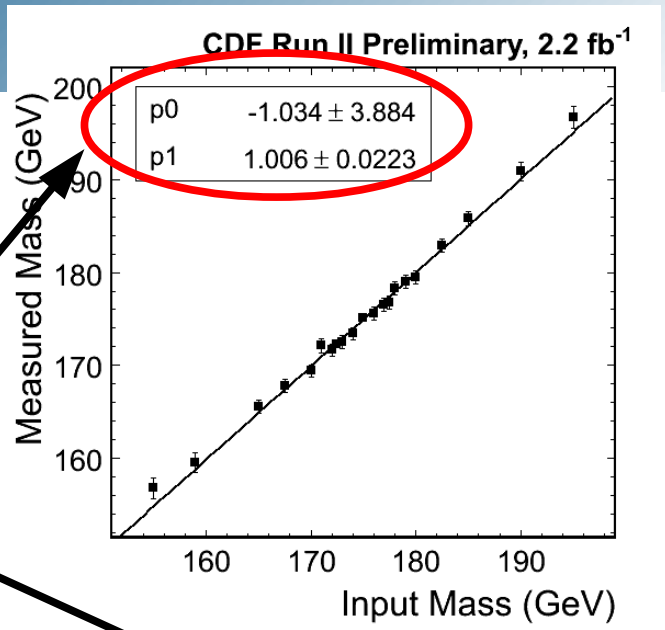


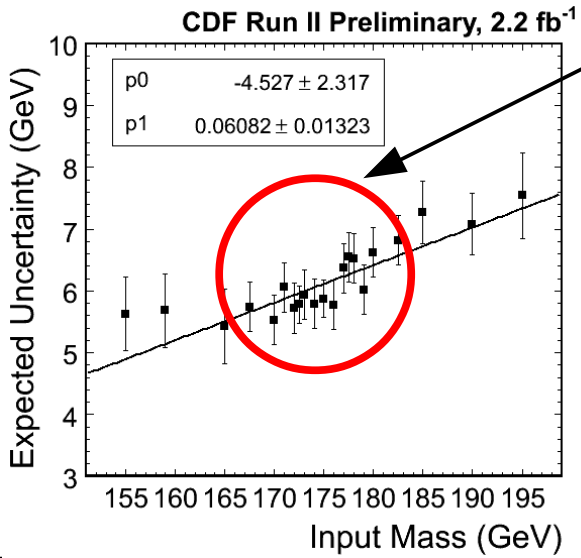


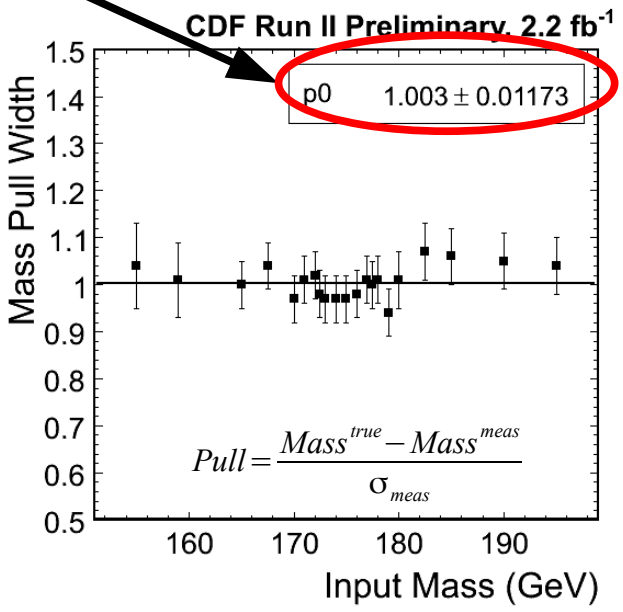


Linearity Checks and Expected Uncertainty

- Use 21 MC samples with mass ranging from 155 to 195 GeV
- Throw pseudo-experiments with fully simulated backgrounds
  - **Mass measurement is unbiased**
  - **Pull widths consistent with 1**
- **At M_{top} = 172.5 GeV expect statistical uncertainty of ~6 GeV**







Systematic Uncertainties

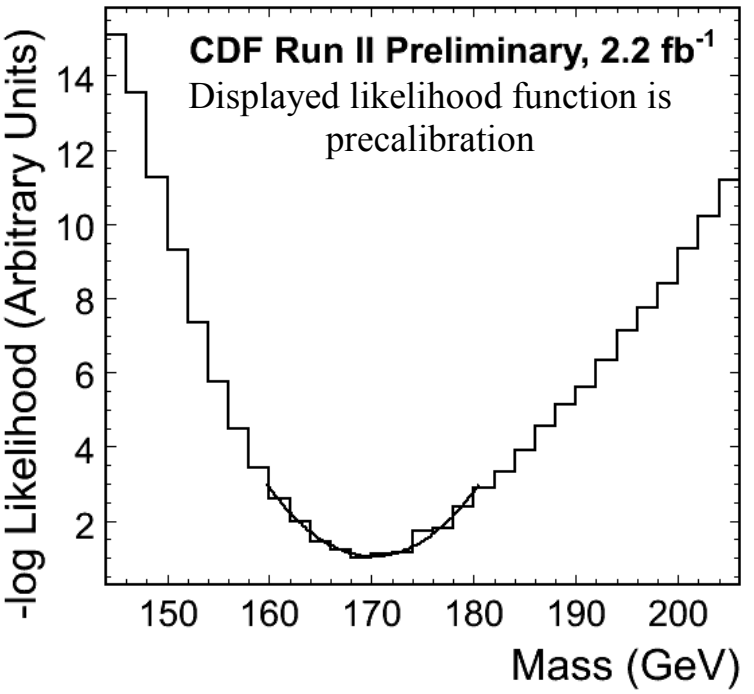
CDF Run II Preliminary, 2.2 fb^{-1}

Source	Result (GeV)
JES	3.37
MC Generator	0.50
ISR/FSR	0.34
Color Reconnection	0.50
Background Fraction	0.47
MC Statistics	0.14
PDF	0.12
gg fusion	0.17
B-jet	0.39
Lepton p_T	0.19
Pileup	0.95
Calibration	0.17
Total	3.7

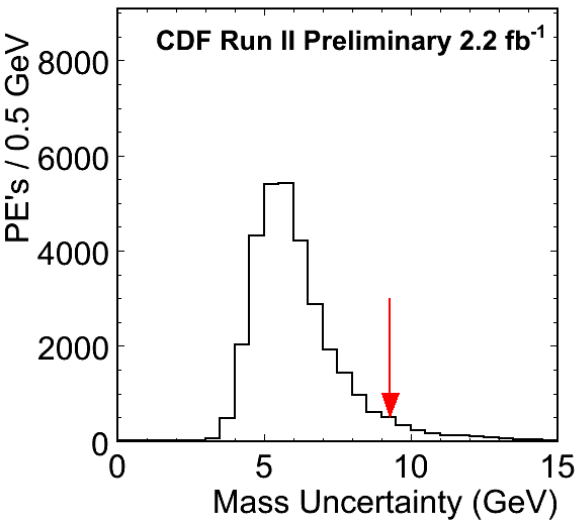
Systematic uncertainty dominated by Jet Energy Scale

Top Mass Result

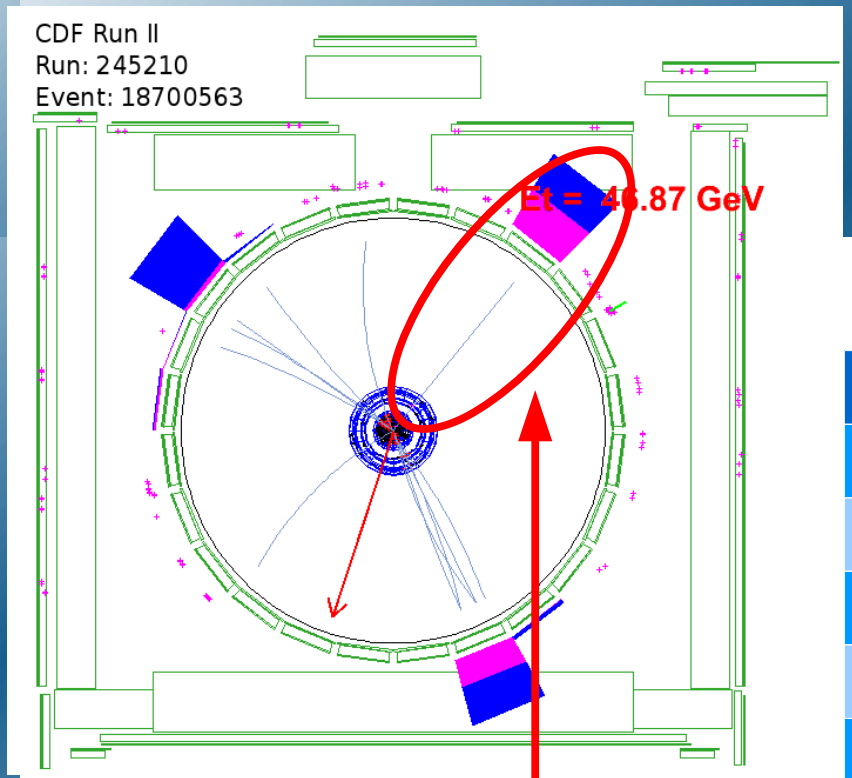
- First measurement of the top quark mass in τ + jets channel
- Result (2.2 fb^{-1}):
  - 172.7 ± 9.3 (stat) ± 3.7 (syst) GeV
  - 172.7 ± 10.0 GeV
- Summer 2010 World Average (5.6 fb^{-1}):
  - 173.3 ± 1.1 GeV
- Demonstrates that we can do complicated physics with taus



Expected Statistical Uncertainty from PE's at 172.5 GeV

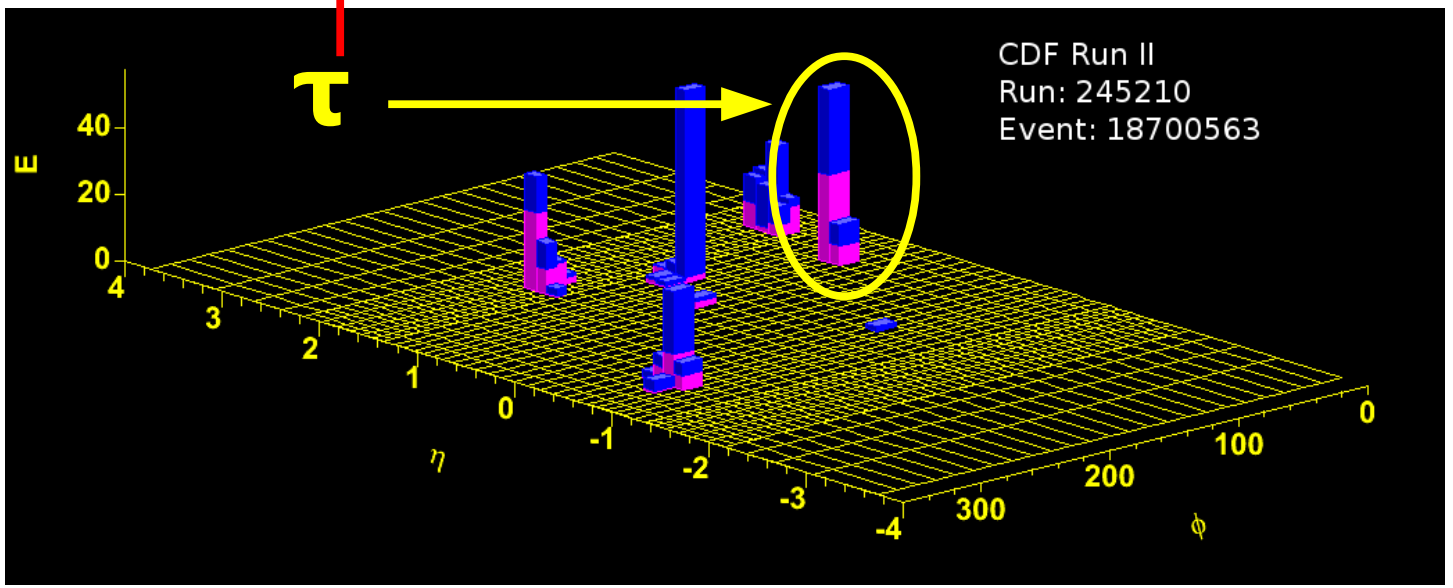


τ + jets Event Display



CDF Run II Preliminary 2.2 fb^{-1}

	Pt	Eta	Phi
Tau	65.6	0.82	50.6
Btagged Jet	53.6	-0.69	295.6
Jet	59.6	1.13	146.8
Jet	47.6	1.70	37.3
Jet	36.8	1.63	218.5



Conclusion

- **ttbar Cross Section measured in τ + jets channel**
  - **8.8 ± 3.3 (stat) ± 2.7 (syst) pb**
- **First top mass measurement using directly identified tau events (2.2 fb^{-1} of data)**
  - **172.7 ± 9.3 (stat) ± 3.7 (syst) GeV**
  - **172.7 ± 10.0 GeV**
  - Measurements agree with World Averages
  - Agree with measurements in other decay channels
- **We can use taus even in high jet multiplicity environments**
- **Taus are useful tools for identifying new physics**

http://www-cdf.fnal.gov/physics/new/top/2011/meatv3_tau_public/index.html

BACKUP

Neural Network

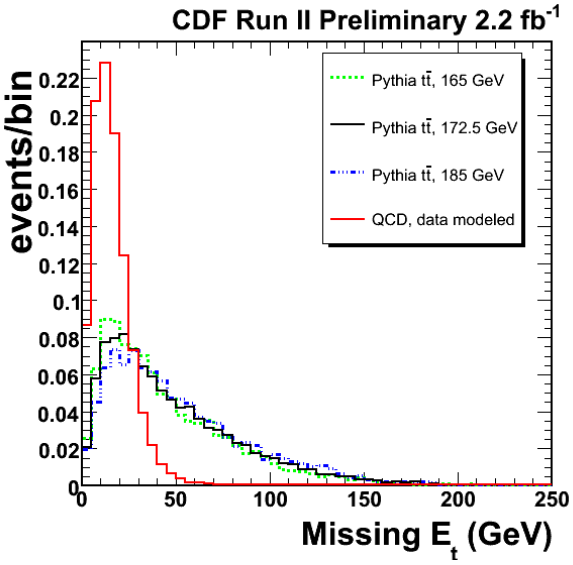
- Trained a NN to distinguish QCD in tau + 4 jet events
  - Trained at pretag with no missing Et cut
  - QCD tau fakes set as type 0, ttop25 type 1
  - Ratio of ttbar:QCD - 1:1
  - Used a TMultilayerPerceptron network
  - 2 hidden layers with 10 and 4 nodes

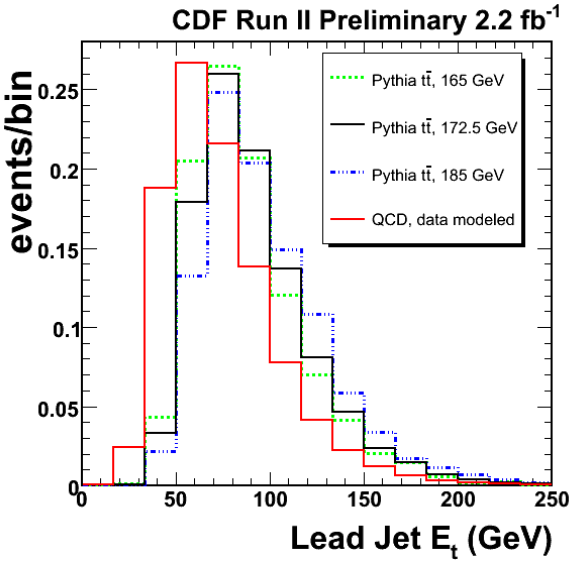
NN Input Variables

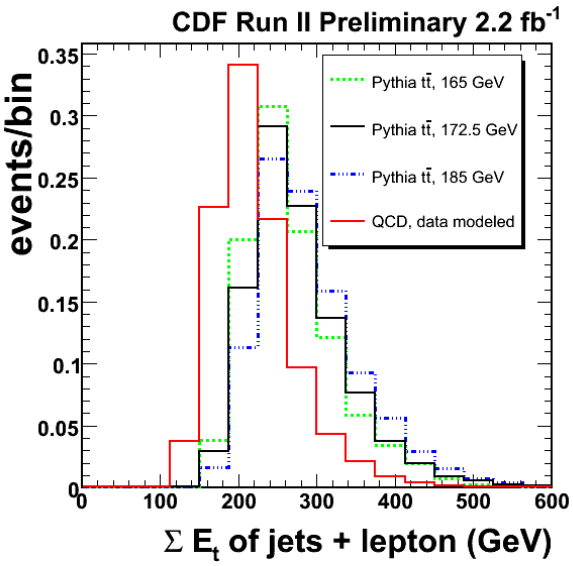
Use 8 varibles:

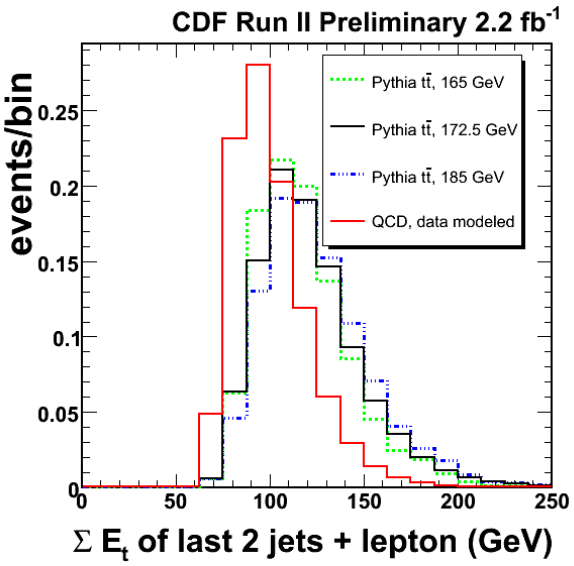
- MEt
- Σ Et tau + jets
- Σ Et tau + 2 lowest jets
- Σ Et 2 hardest jets
- Transverse M_w
- Lead Jet Et
- Average Eta Moment
  - Consider non btagged jets
- Lowest Dalitz Variable

Neural Network Input Variables

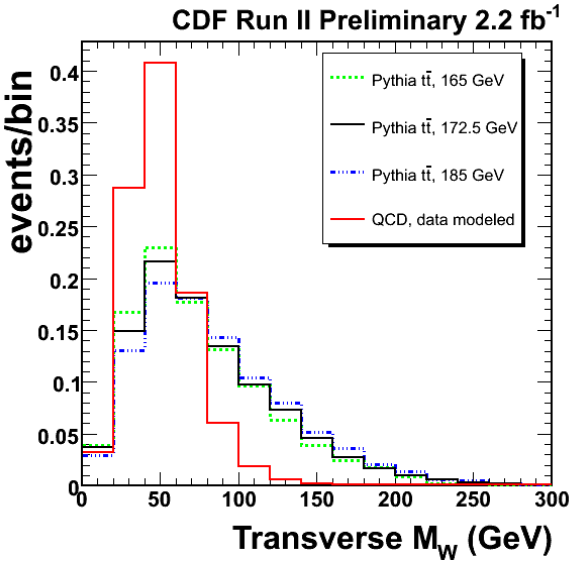


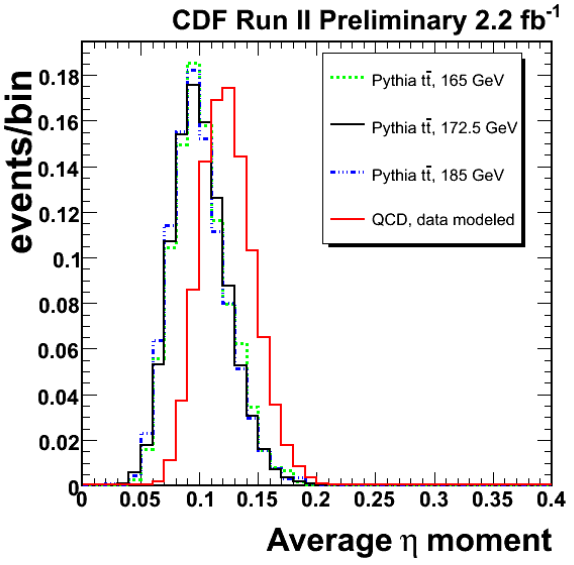


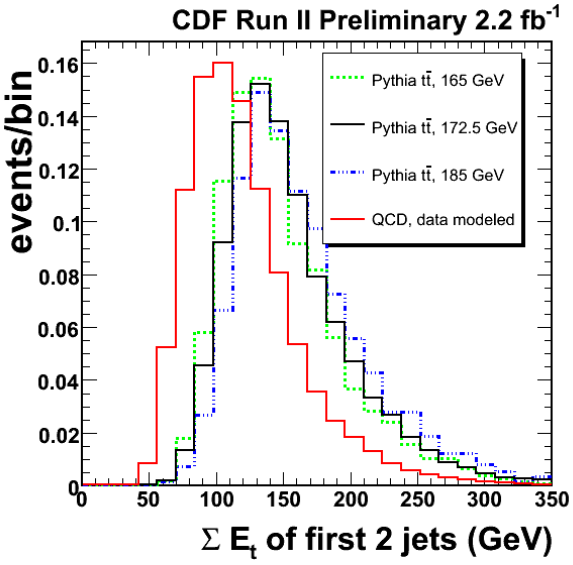


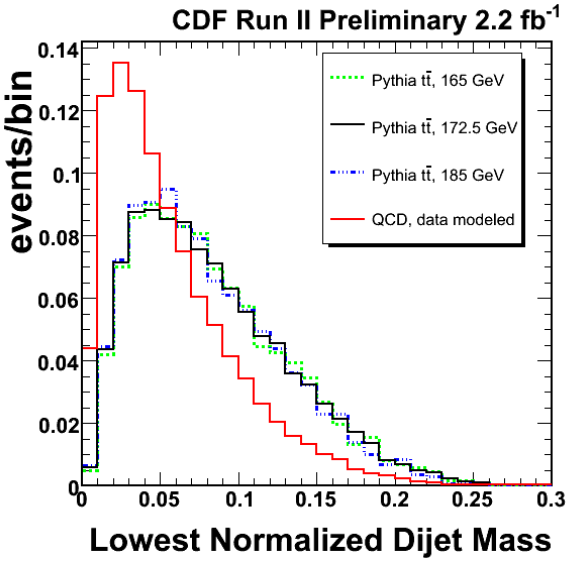


Neural Network Input Variables

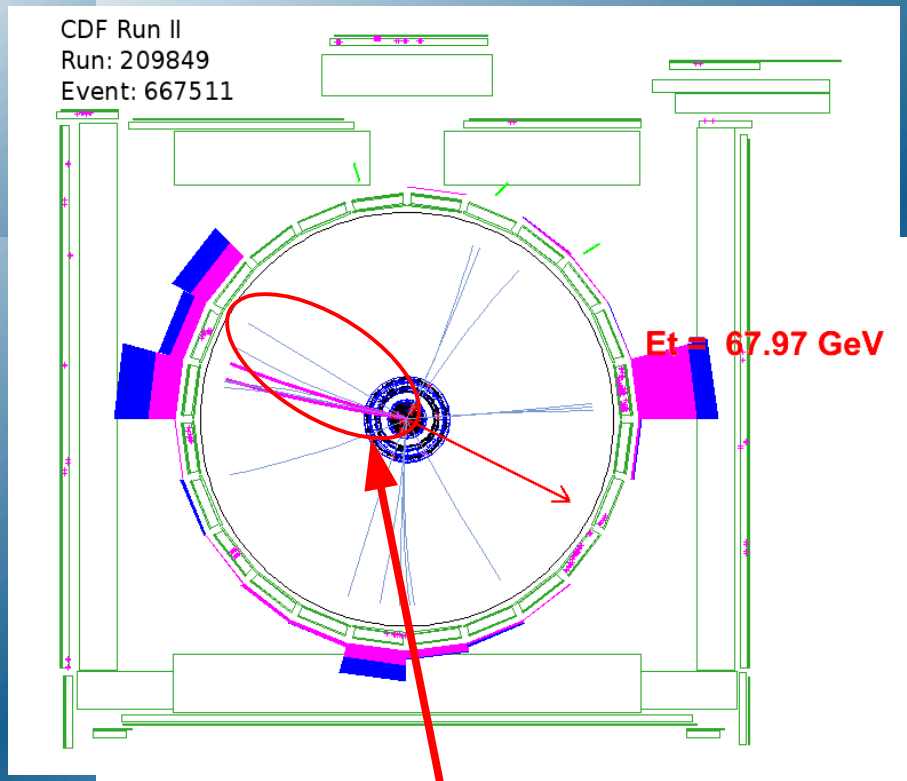






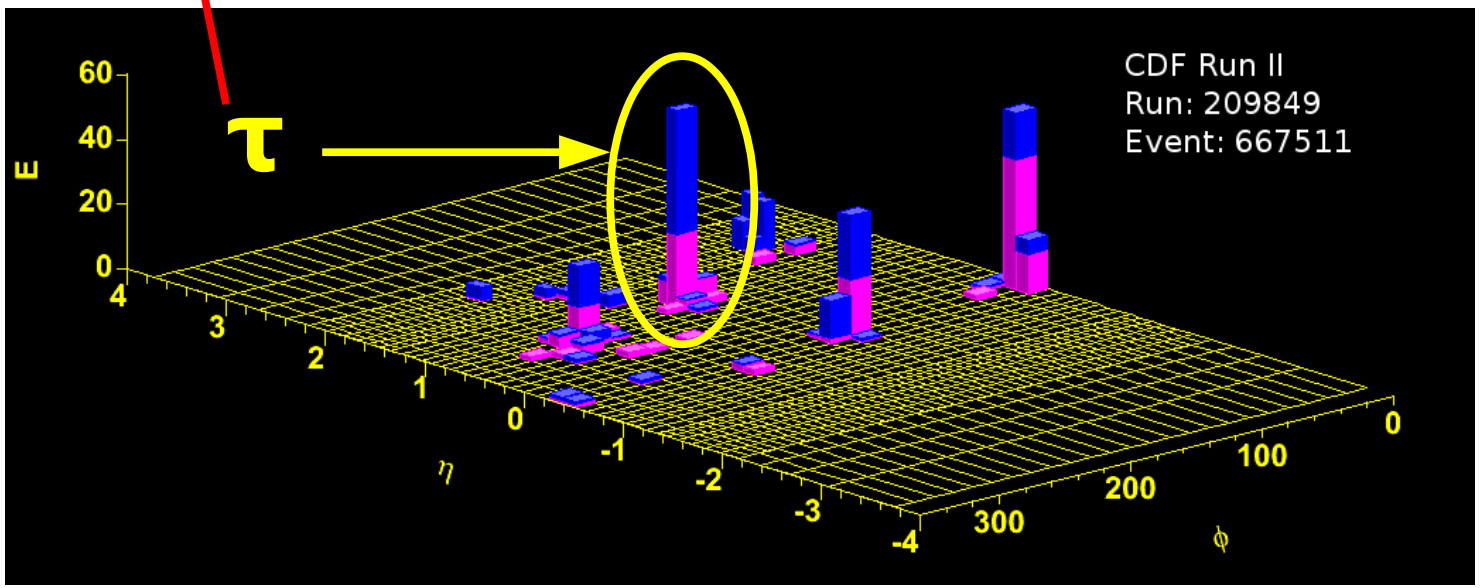


Event Display

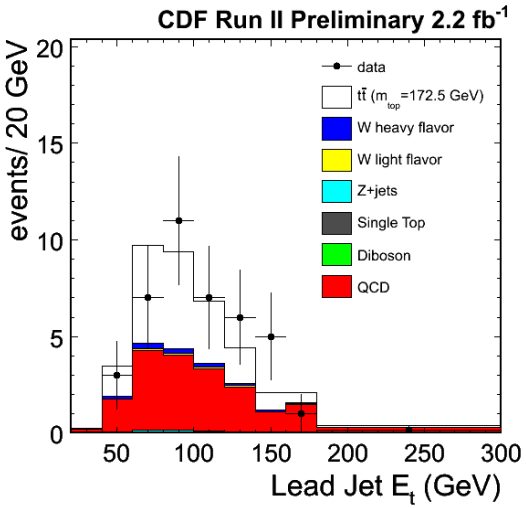


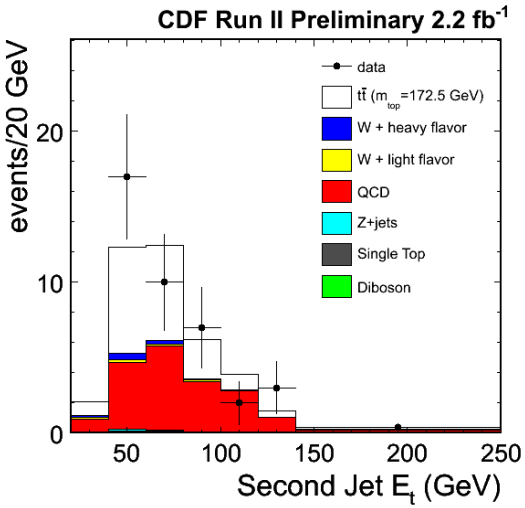
CDF Run II Preliminary 2.2 fb^{-1}

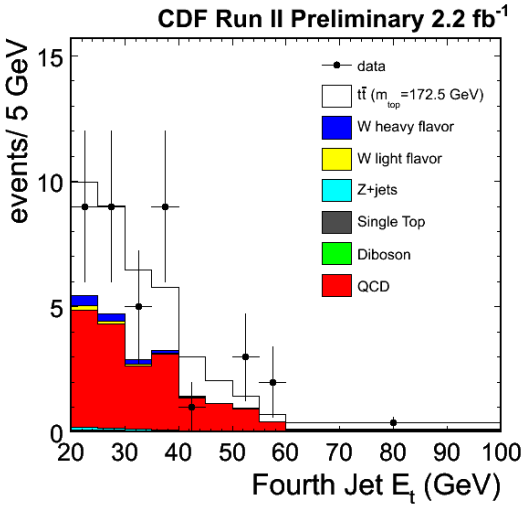
	Pt (GeV)	Eta	Phi
Tau	47.6	-0.49	147.7
Btagged Jet	55.3	0.56	265.8
Jet	86.1	-0.40	3.2
Jet	80.8	0.84	166.8
Jet	35.7	1.48	64.1

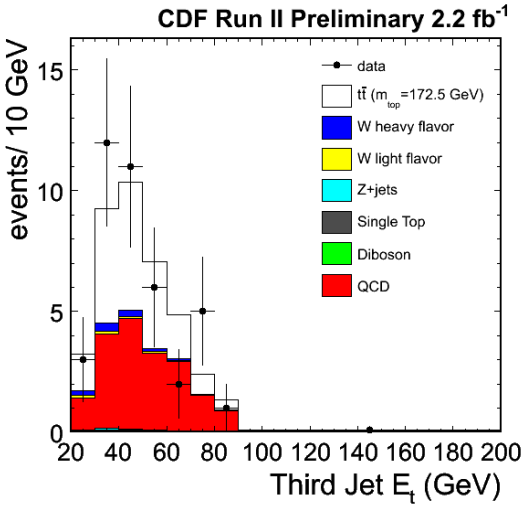


Event Variables









Transfer Functions

- Corrected jet energy is not equivalent to parton energy
- Transfer function returns probability that measured jet x resulted from parton y
- Found a bias in the angle between two hadronic side W daughter jets
- Added a transfer function for the angle between the two jets
- Similar effect with hadronic side W and b