A Matrix Element Measurement of the Top Quark Mass in the Hadronic Tau + Jets Channel

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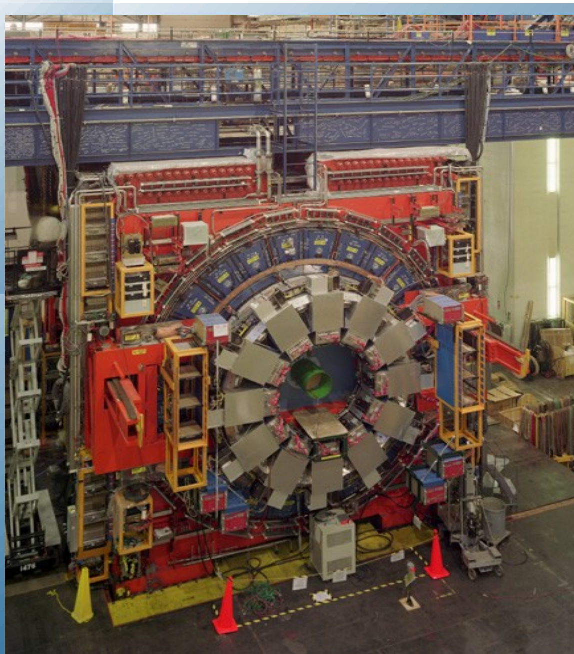
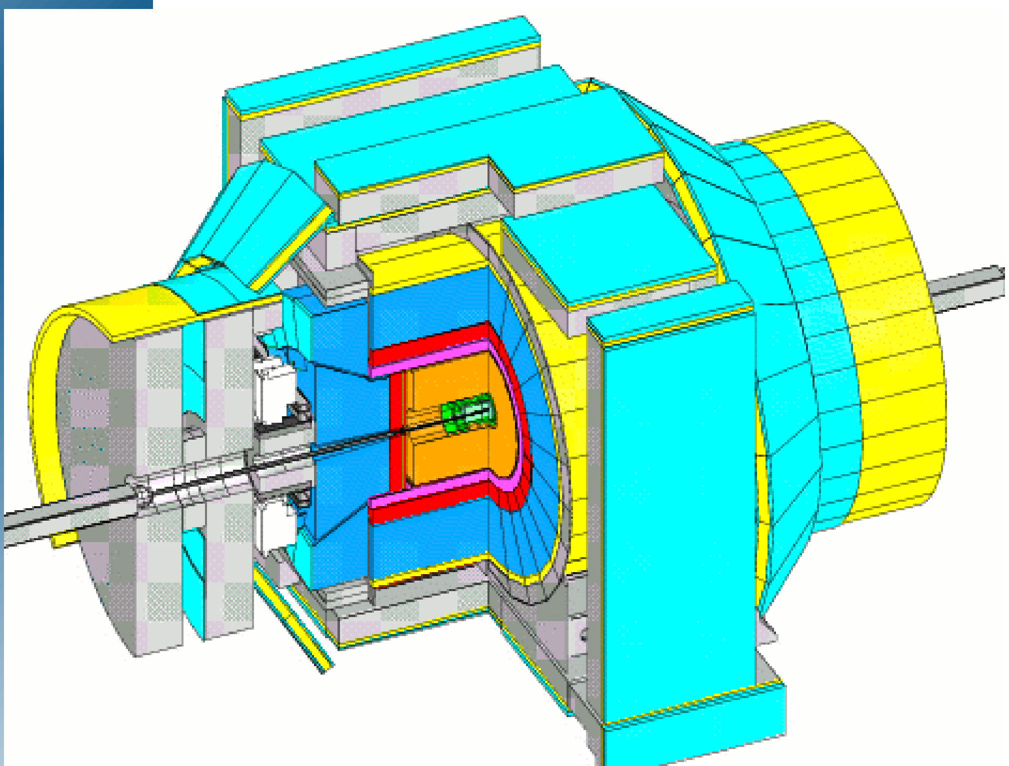
For the CDF Collaboration

CDF Detector





- 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

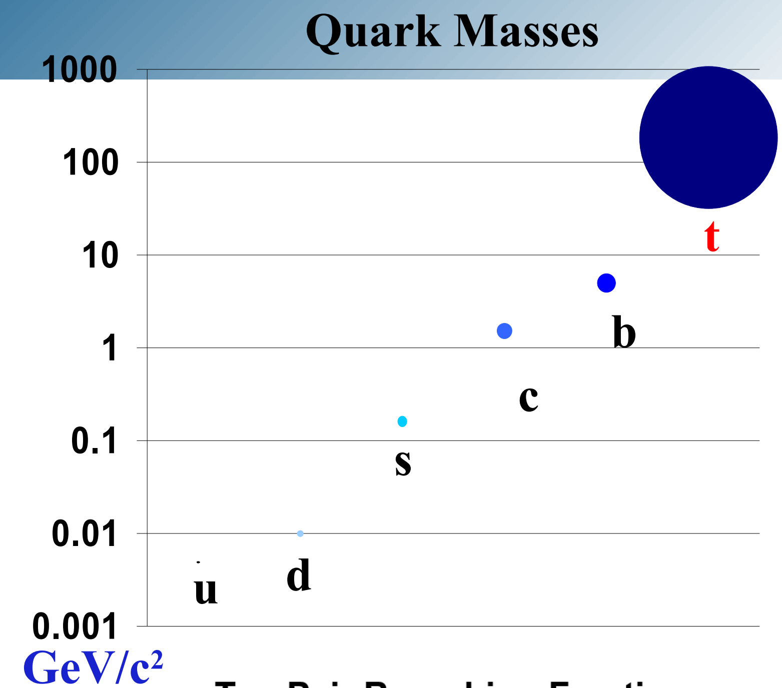
Summer 10 World Average Mass: 5.6 fb^{-1}

173.3 ± 0.6(stat) ± 0.9 (syst) GeV/c^2

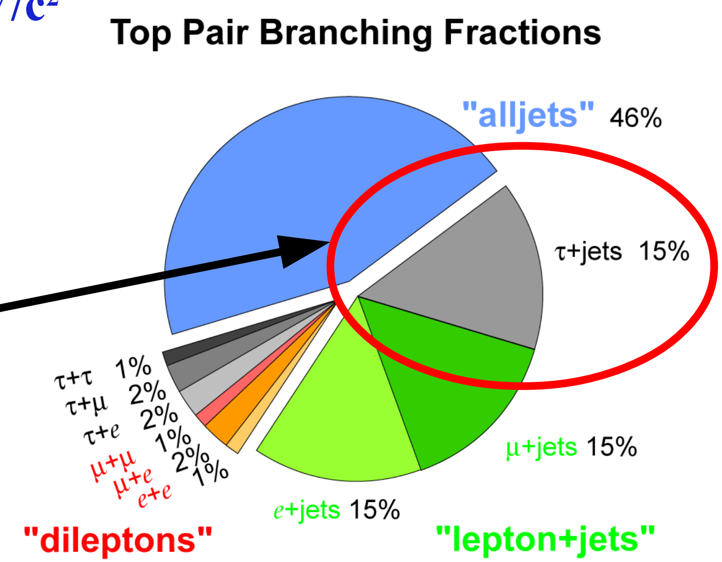
173.3 ± 1.1 GeV/c^2

ArXiv:1007.3178

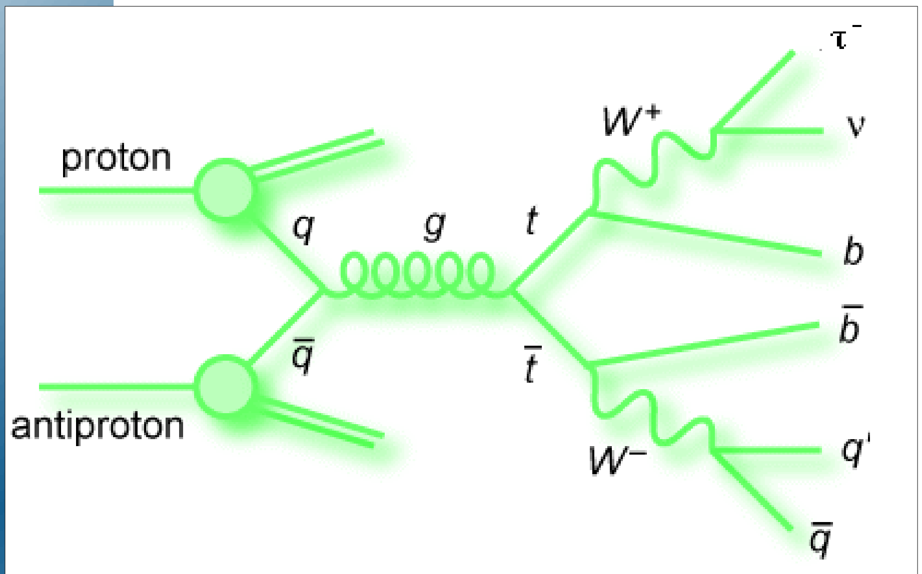
Top Quark and taus

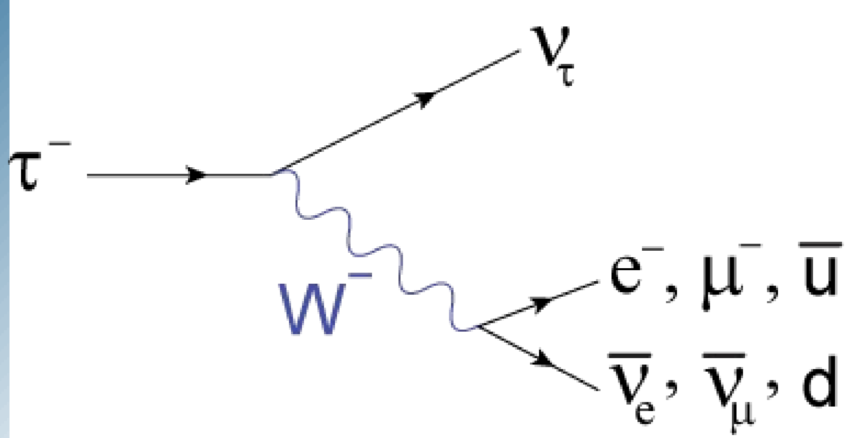


- **Top Quark:**
  - Discovered during Run I at the Tevatron in 1995
  - Only quark to decay before it hadronizes
  - Has a Yukawa coupling to the Higgs of ~1
  - Constrains the Higgs mass along with W
- **Taus:**
  - First mass measurement in tau decay channel
  - Channel for new physics
    - Ex: $t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



Event Selection

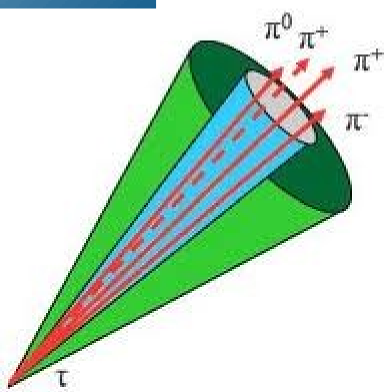




- **Looking for hadronic τ + jets top decay:**
  - 4 jets with E_t > 20 GeV
    - at least 1 b-tagged
  - Missing E_t > 20 GeV
  - **1 hadronically decaying τ**
    - **E_t > 25 GeV**
    - **Looks like narrow jet**
    - **1 or 3 tracks**
- Leptonically decaying taus:
- May be included in standard lepton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

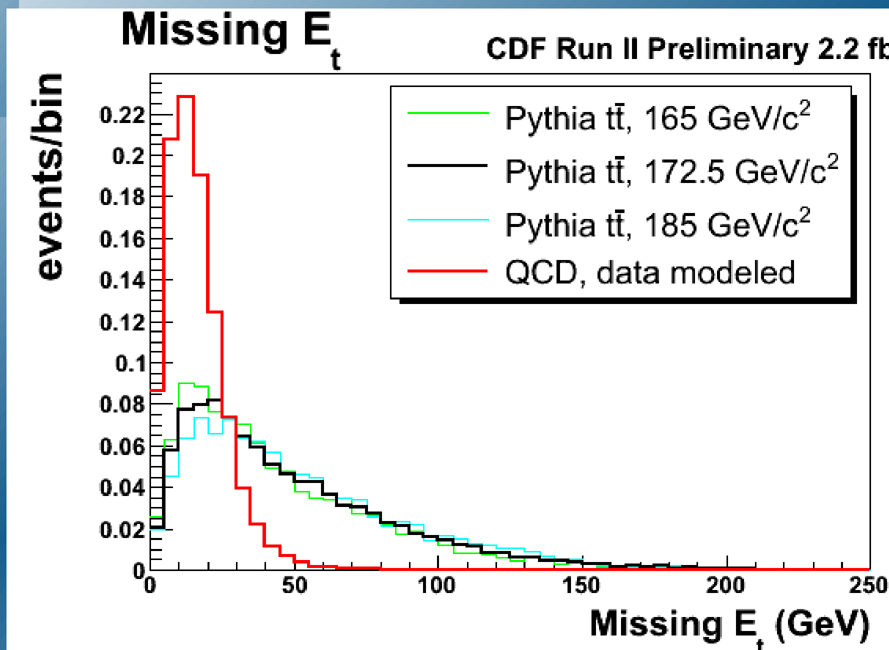
What is Different About Taus?

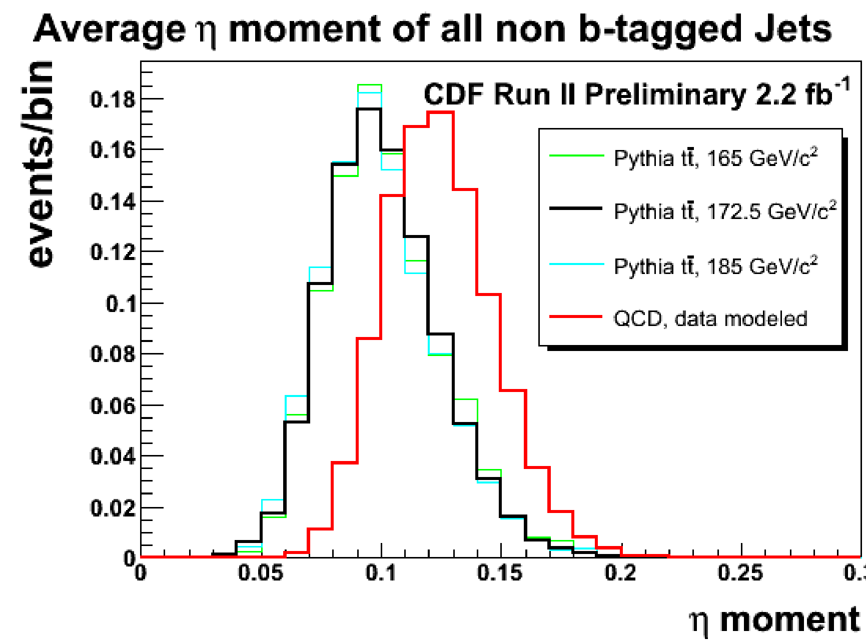
- **Taus are harder to measure than e or μ**
  - Hadronically decaying tau includes a neutrino
  - Now ttbar decay has 2 neutrinos
  - **Solution: Scan Method to reconstruct neutrino from tau decay**
    - 4D scan over both neutrino angles ($\eta_1,\varphi_1,\eta_2,\varphi_2$)
    - Use W and τ mass to solve for ν^E_1 and ν^E_2
    - Compare predicted missing E_t to measured to determine most likely neutrino angles

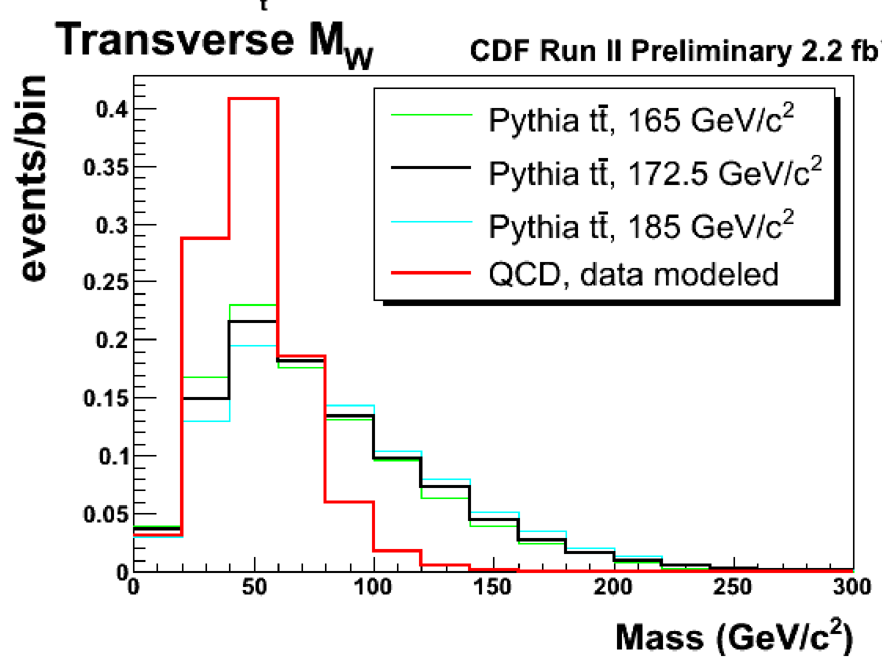


- **Hadronically decaying tau is essentially a narrow jet**
  - Large QCD Background
  - **Solution: Neural Network to Remove QCD**

Neural Network Input

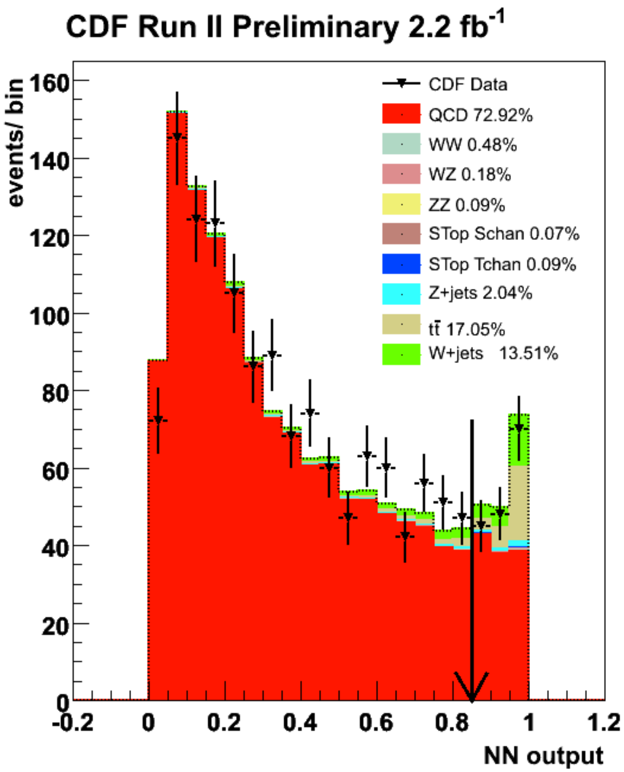


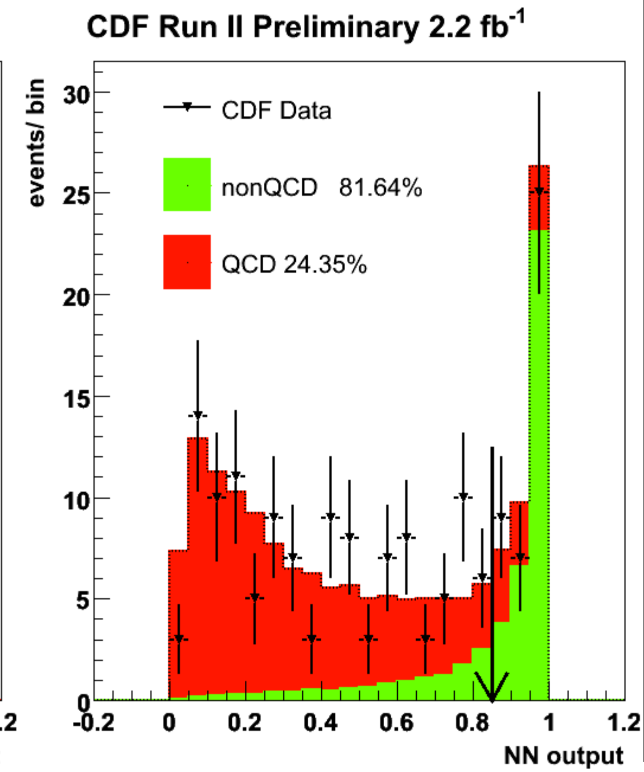




Fitting the Neural Network Output

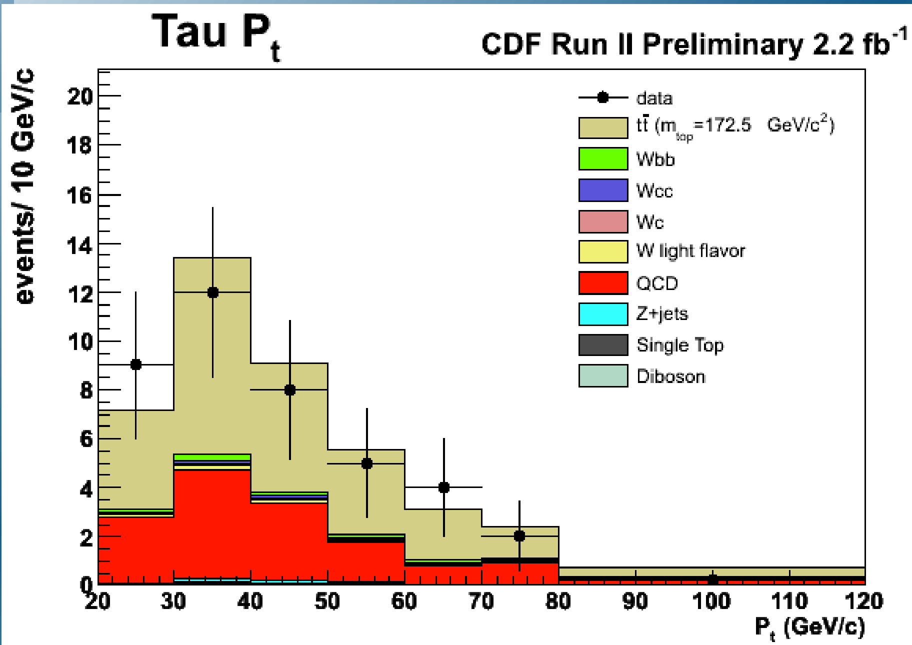
- Diboson, Single top, Z+jets, and ttbar contributions determined by cross section and MC acceptance
- QCD and W+jets contributions determined by fitting shapes to data

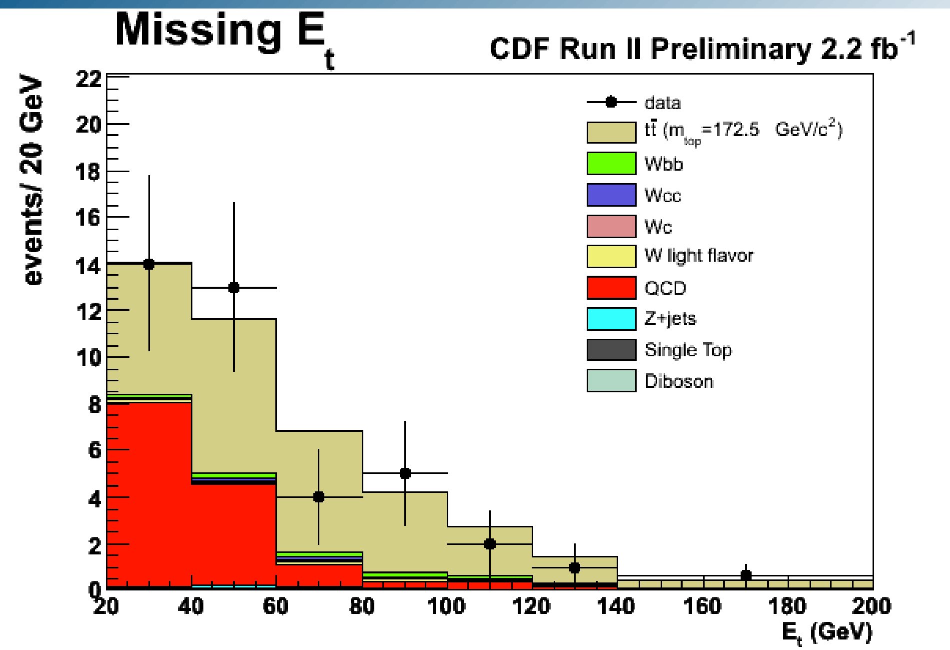


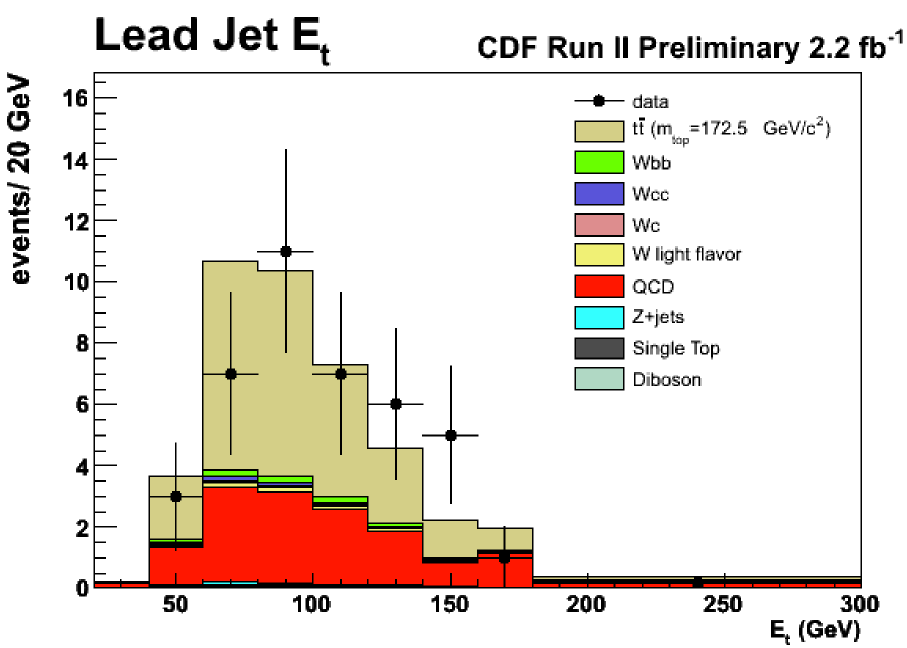


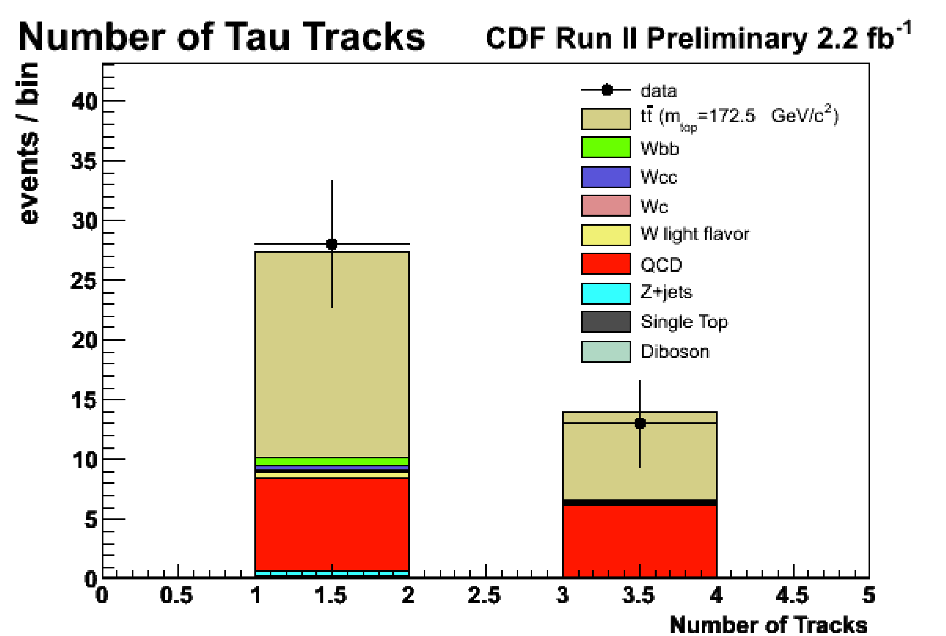
CDF Run II Preliminary 2.2 fb^{-1}			
Source	**Number of Events**		
Diboson	0.2	±	0.0
Single Top	0.2	±	0.0
Z + jets	0.3	±	0.1
Wbb	0.6	±	1.9
Wcc	0.4	±	1.1
Wc	0.2	±	0.5
W+jets (light)	0.5	±	2.6
QCD	10.0	±	8.0
ttbar	17.8	±	3.9
Total Prediction	30.0	±	9.6
Observed	41.0		

Event Variable Plots









Matrix Element Technique

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

- **Build likelihood function from signal and bkgd probabilities**
- **Calculate P_{sig} by integrating over $d\sigma_{ttbar}$**

$$P(\vec{x};m_t)=\frac{1}{\langle Acc(m_t)\rangle * \sigma_{ttbar}}\int\sum_{soln}^{4}|M^2|\frac{f(\tilde{q}_1)f(\tilde{q}_2)}{|q_1||q_2|}\prod(W(\vec{x},\vec{y}))\,d\Phi$$

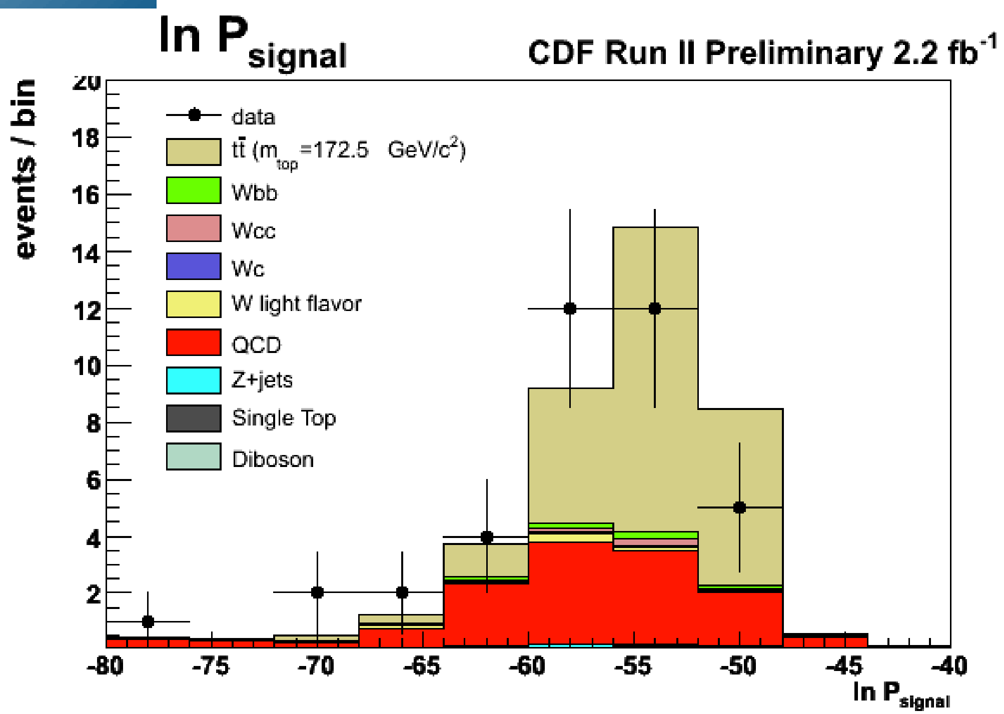
- Normalization: $\frac{1}{\langle Acc(m_t)\rangle * \sigma_{ttbar}}$
- PDFs: $f(\tilde{q}_1)f(\tilde{q}_2)$
- Matrix Element: $|M^2|$
- Transfer Functions: $W(\vec{x},\vec{y})$

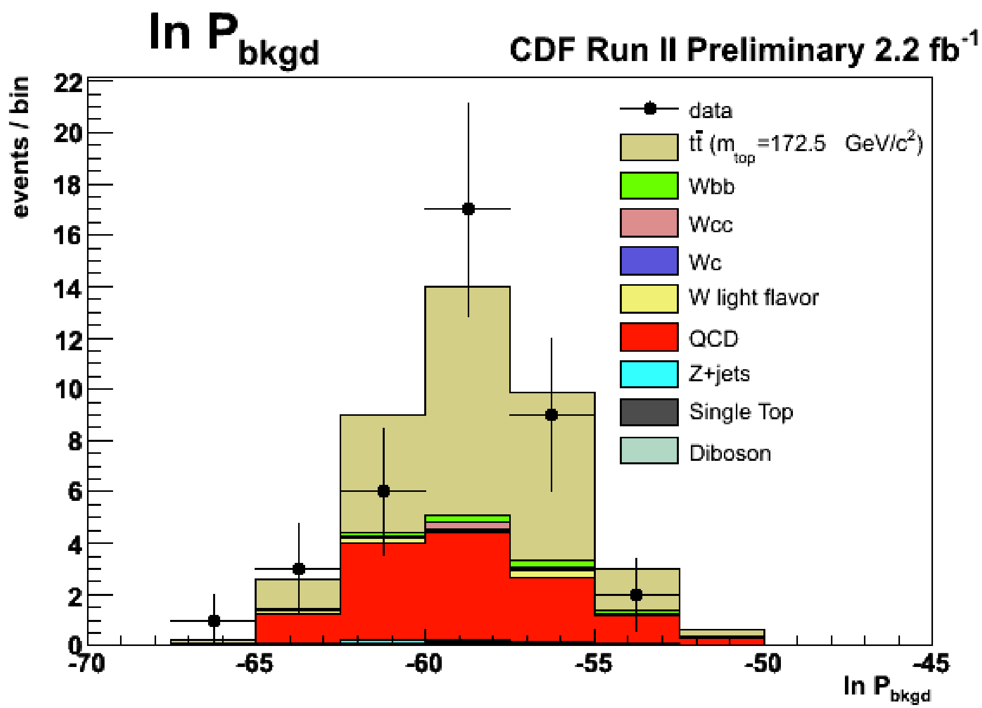
- M calculated using parton level quantities from integration
- Integrate over m^2_{Whad}, m^2_{Wlep}, ρ_{jet1}, $\cos\alpha_{12}$, $\cos\alpha_{Wbhad}$
- Similar expression for background probability:
  - **Use W+4jets matrix element**
  - **Integrate over E_{jet1}, E_{jet2}, E_{bhad}, E_{blep}, p^z_ν**

Data Probabilities

Signal and Background Probabilities:

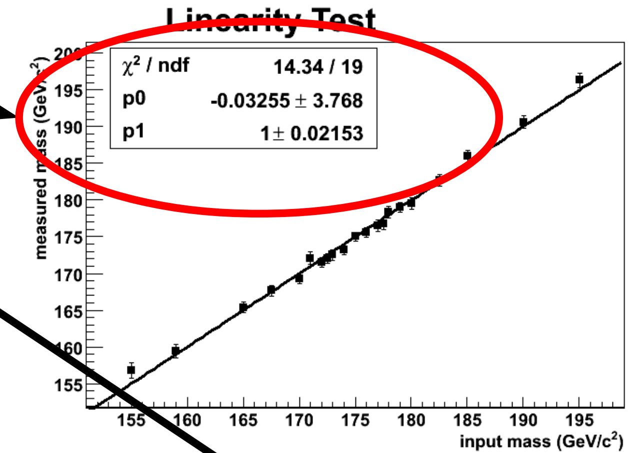
Signal is taken from highest Probability point in M_{top}

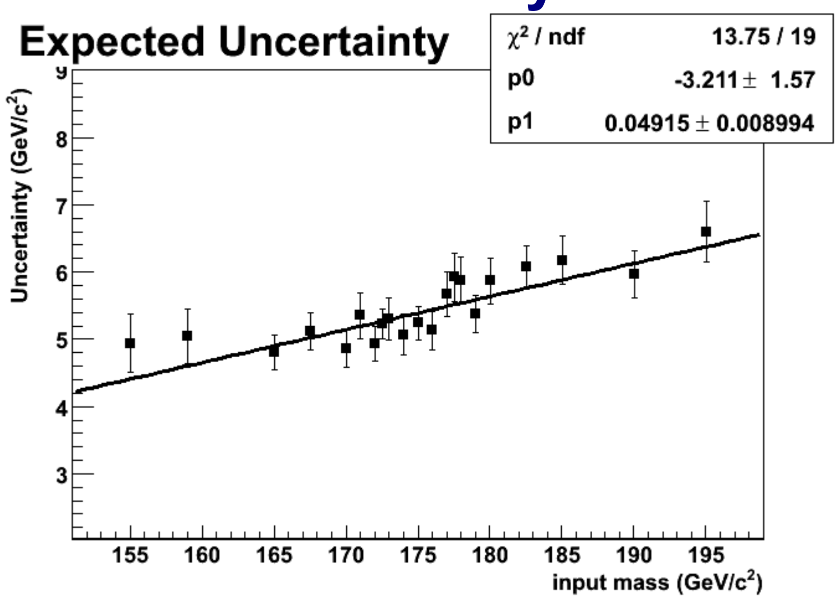


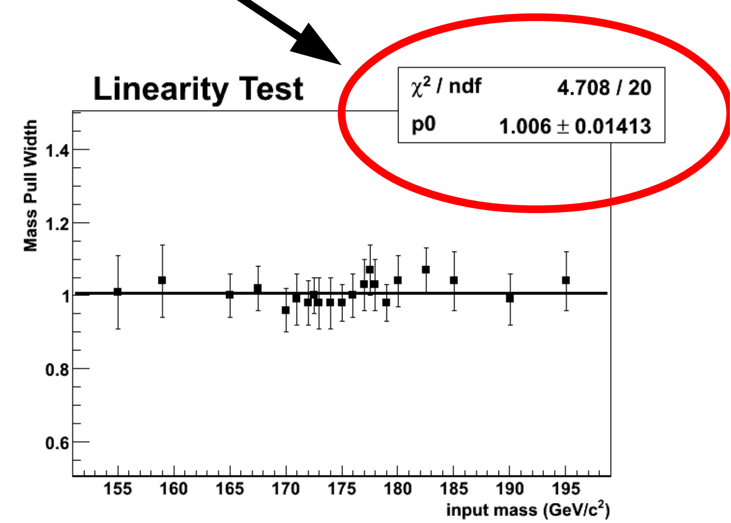


Linearity and Uncertainty:

- 21 MC samples with mass ranging from 155 to 195 GeV/c^2
- All pseudo-experiments with fully simulated backgrounds
  - **Mass measurement is unbiased**
  - **Pull Widths consistent with 1**
- **Central Values of M_{top} expect statistical uncertainty of ~5.3 GeV/c^2**







Systematic Uncertainties

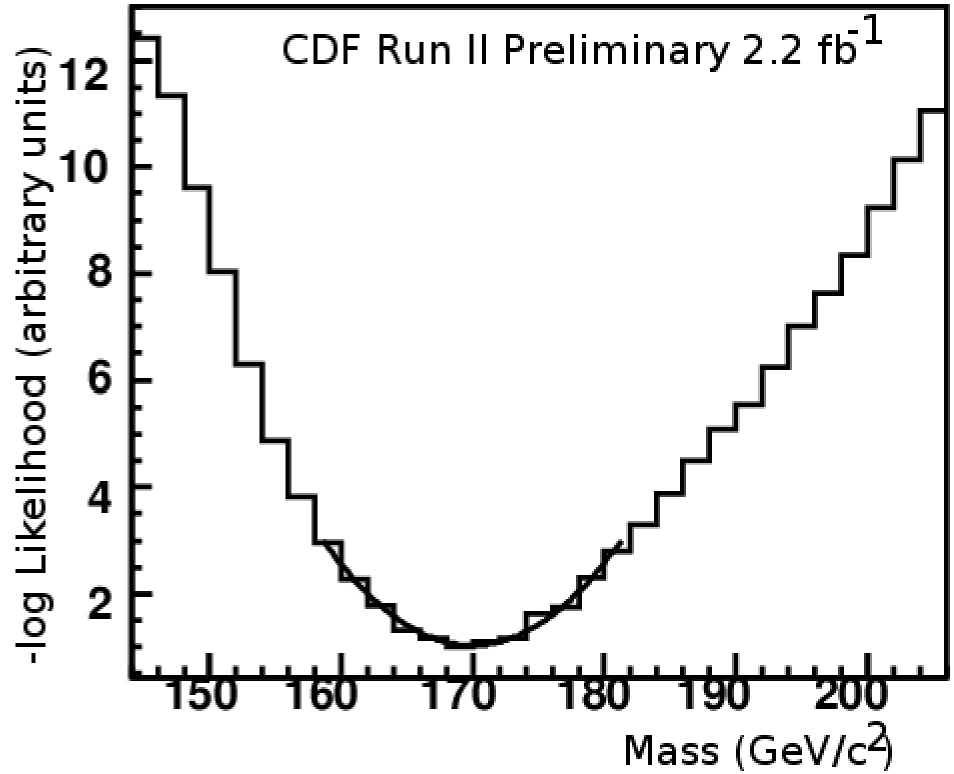
CDF Run II Preliminary 2.2 fb^{-1}

Source	Result (GeV/c^2)
JES	3.46
MC Generator	0.65
ISR/FSR	0.33
Color Reconnection	0.46
Background Fraction	0.24
MC Statistics	0.17
PDF	0.08
gg fusion	0.14
B-jet	0.48
Lepton p_T	0.11
Pileup	0.59
Calibration	0.30
Total	3.7

Systematic uncertainty dominated by Jet Energy Scale

Result

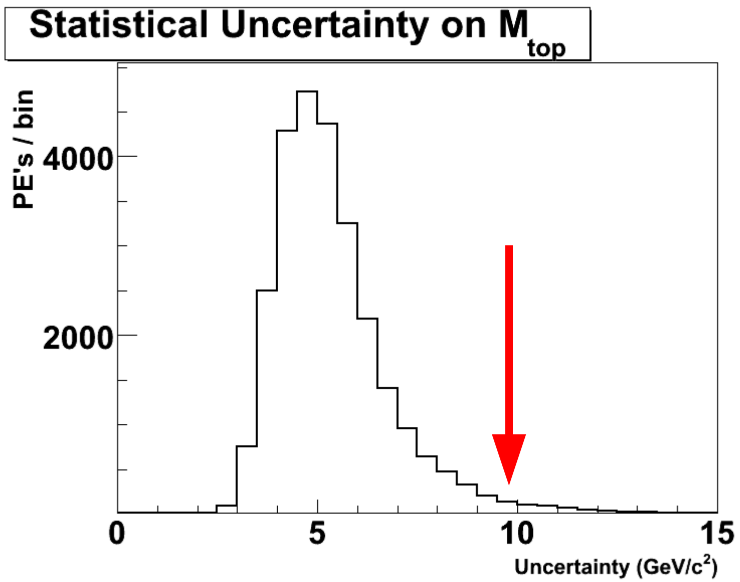
Displayed likelihood function is precalibration

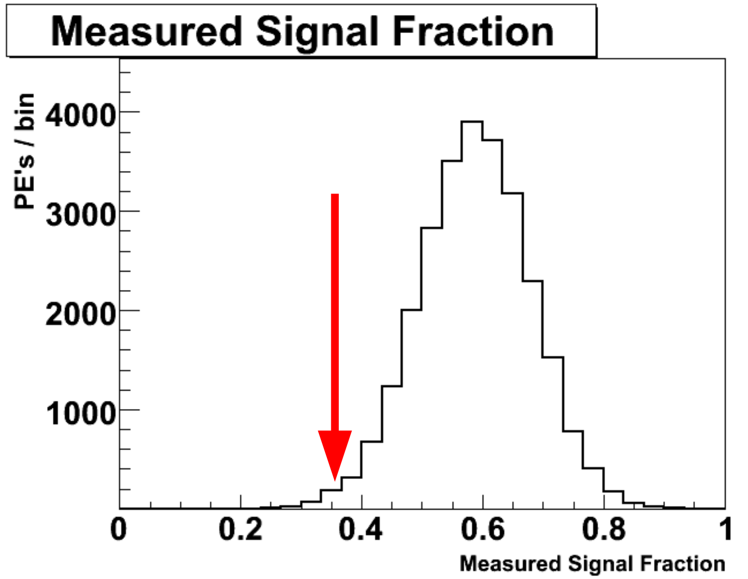


- **Result (2.2 fb^{-1}):**
  - **173.6 ± 10.1 (stat) ± 3.7 (syst) GeV/c^2**
  - **173.6 ± 10.8 GeV/c^2**
- Summer 2010 World Average (5.6 fb^{-1}):
  - 173.3 ± 1.1 GeV/c^2
- Measurement will not improve world average, but **proves we can do complicated physics with taus**

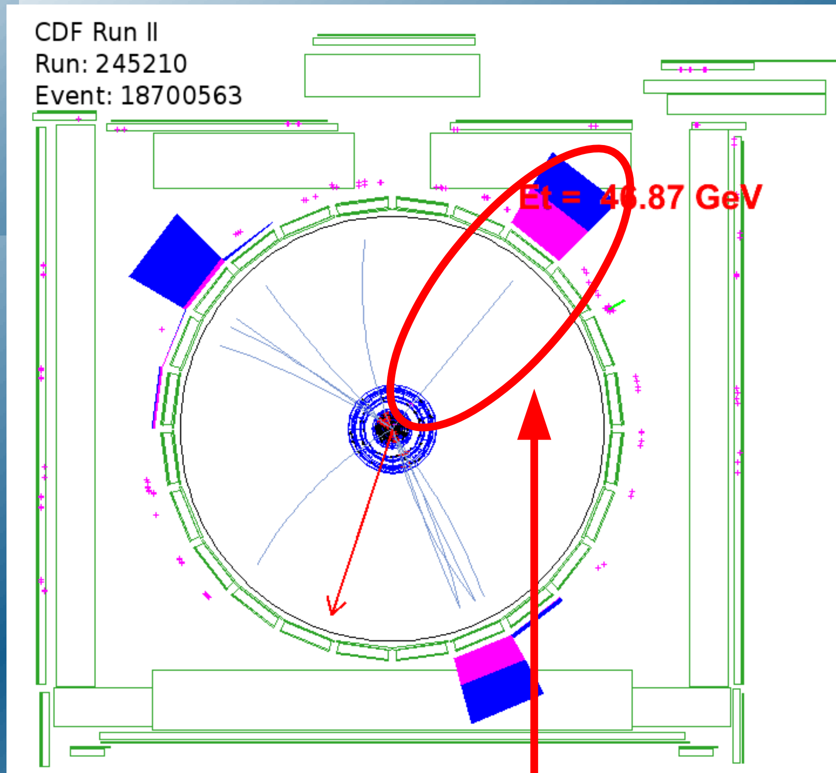
Revisiting Expected Uncertainty

- **Statistical Uncertainty**
  - **Expected ~ 5.3 GeV/c^2**
  - **Measured 10.1 GeV/c^2**
- **Signal Fraction**
  - Ran psuedo-experiments with 0.59 signal fraction
  - **Measured low side tail**
  - **~3% chance**



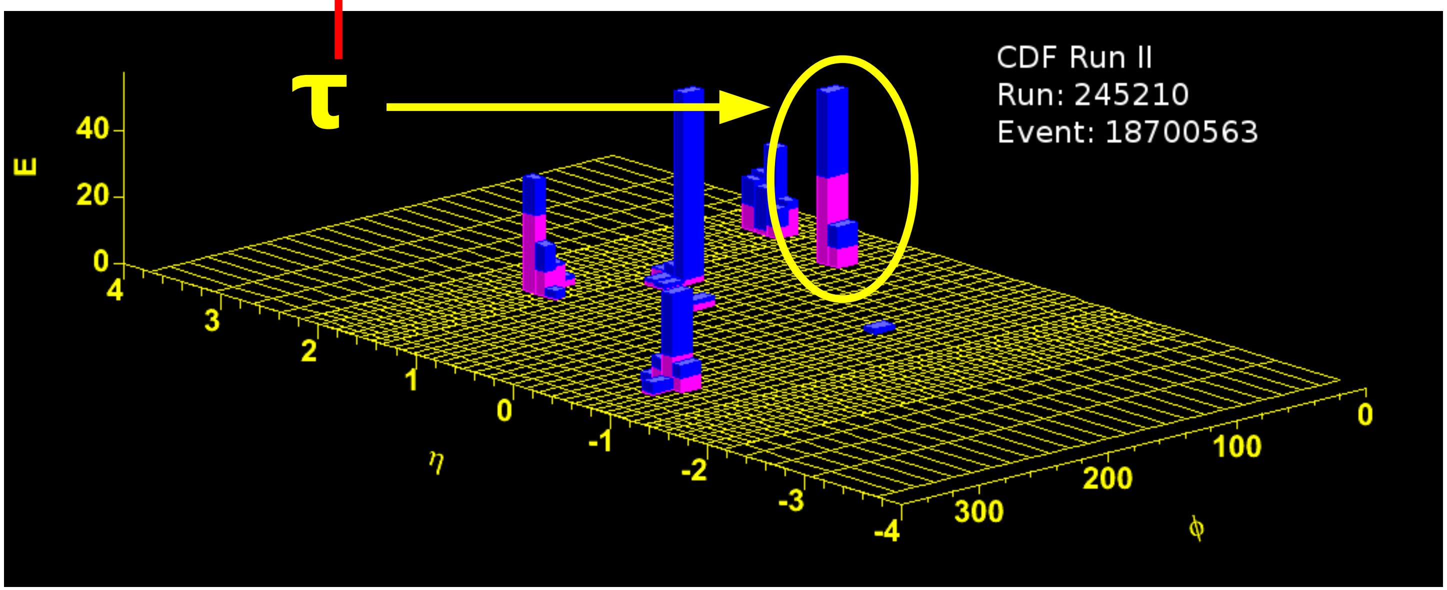


Event Display



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

- **First top mass measurement using directly identified tau events (2.2 fb^{-1} of data)**
  - **173.6 ± 10.1 (stat) ± 3.7 (syst) GeV/c^2**
  - **173.6 ± 10.8 GeV/c^2**
- Measurement agrees with World Average
- Agrees with top mass measured in other decay channels
- **Taus are useful tools for identifying new physics**
  - **We can use taus even in high jet multiplicity environments**

BACKUP

Neural Network

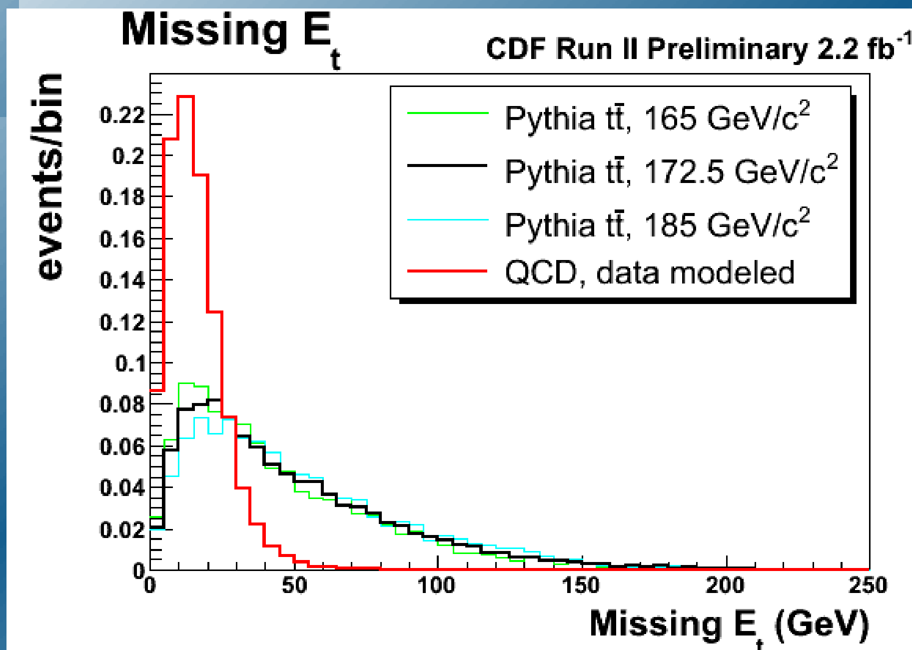
- Trained a NN to distinguish QCD in tau + 4 jet events
  - Trained at pretag with no missing Et cut
  - QCD tau fakes set as type 0, ttop25 type 1
  - Ratio of ttbar:QCD - 1:1
  - Used a TMultilayerPerceptron network
  - 2 hidden layers with 10 and 4 nodes

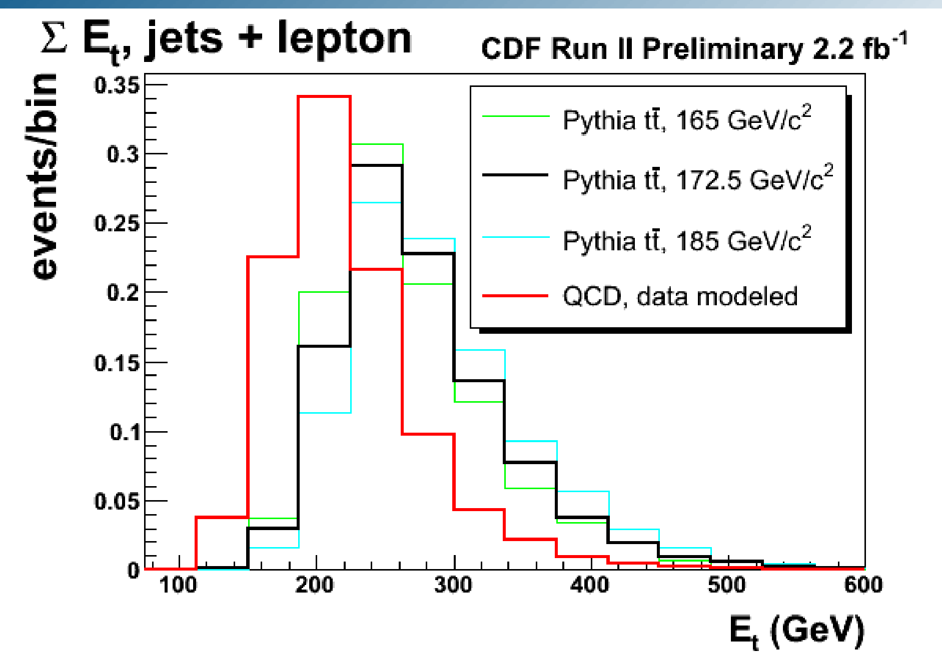
NN Input Variables

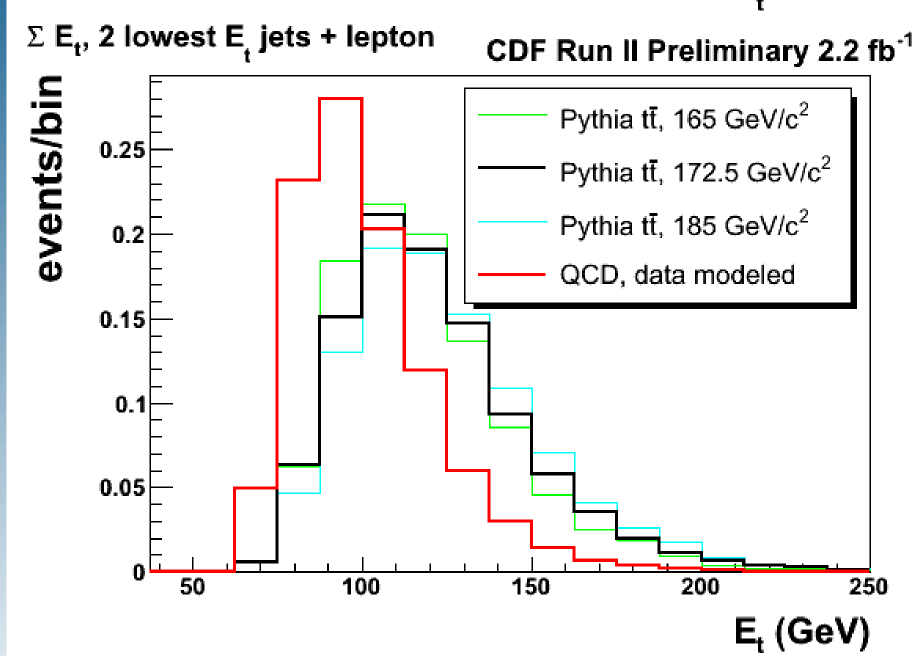
Use 8 varibles:

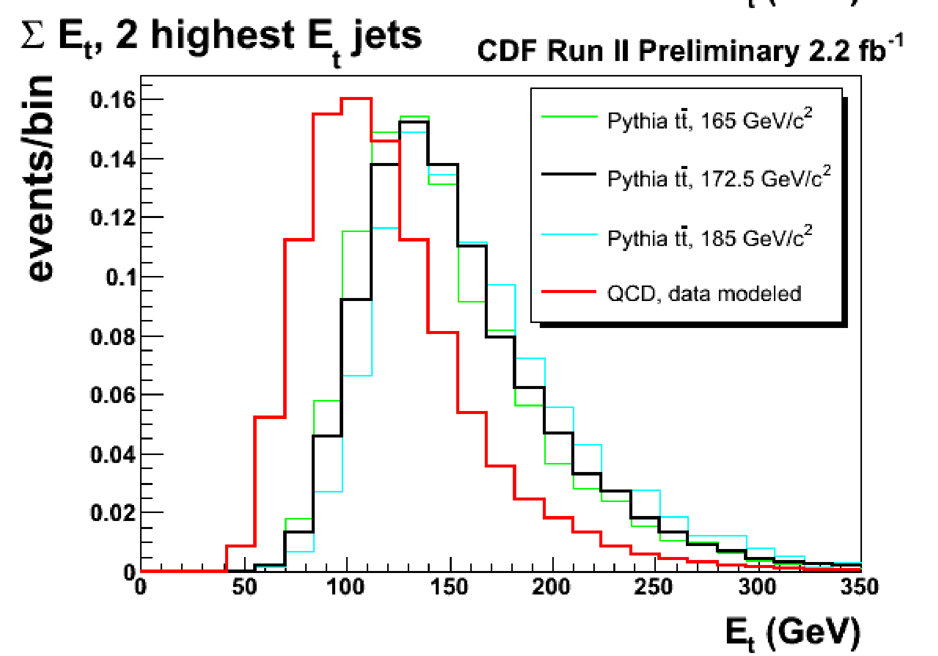
- MEt
- Σ Et tau + jets
- Σ Et tau + 2 lowest jets
- Σ Et 2 hardest jets
- Transverse M_W
- Lead Jet Et
- Average Eta Moment
  - Consider non btagged jets
- Lowest Dalitz Variable

Neural Network Input Variables

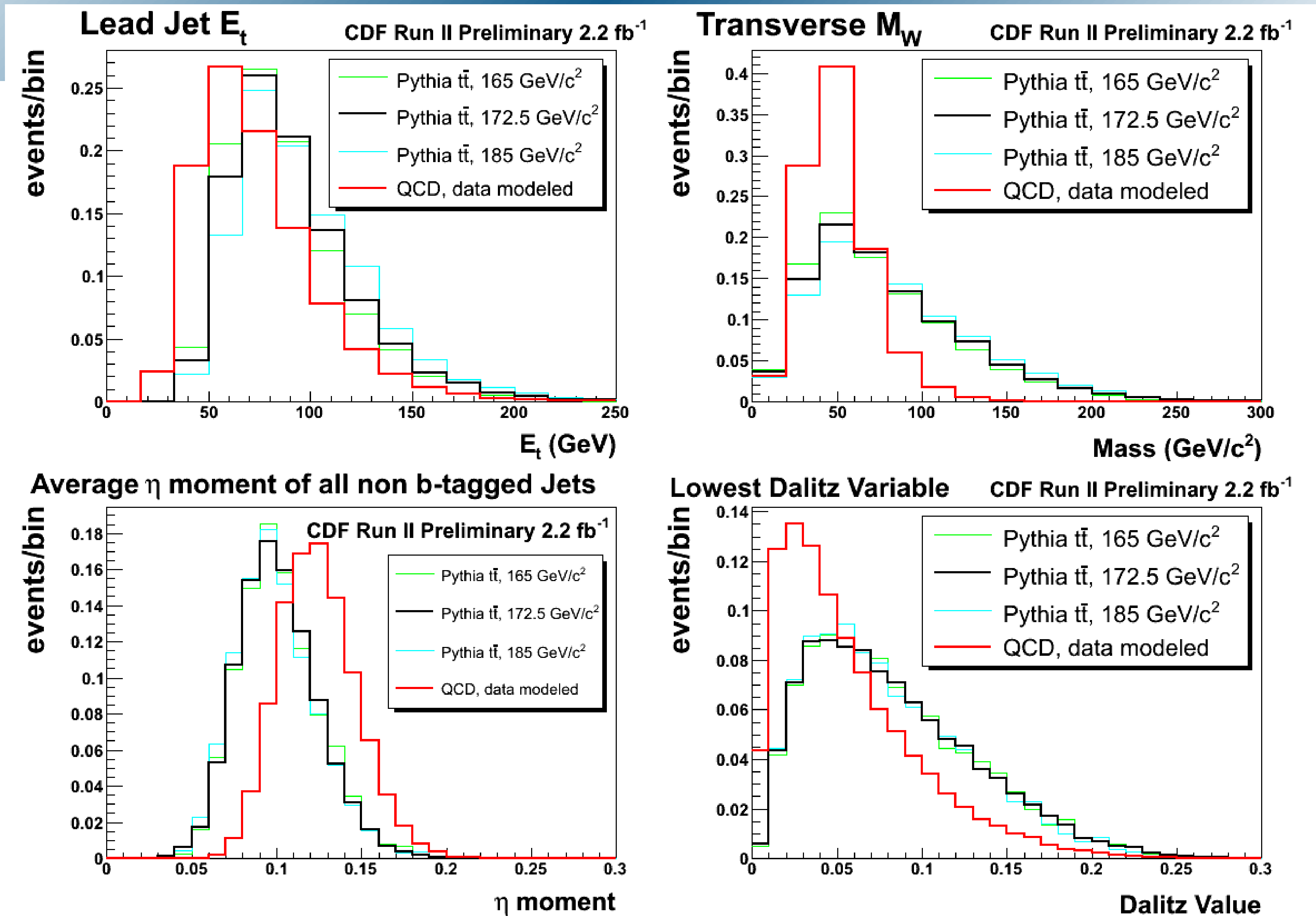




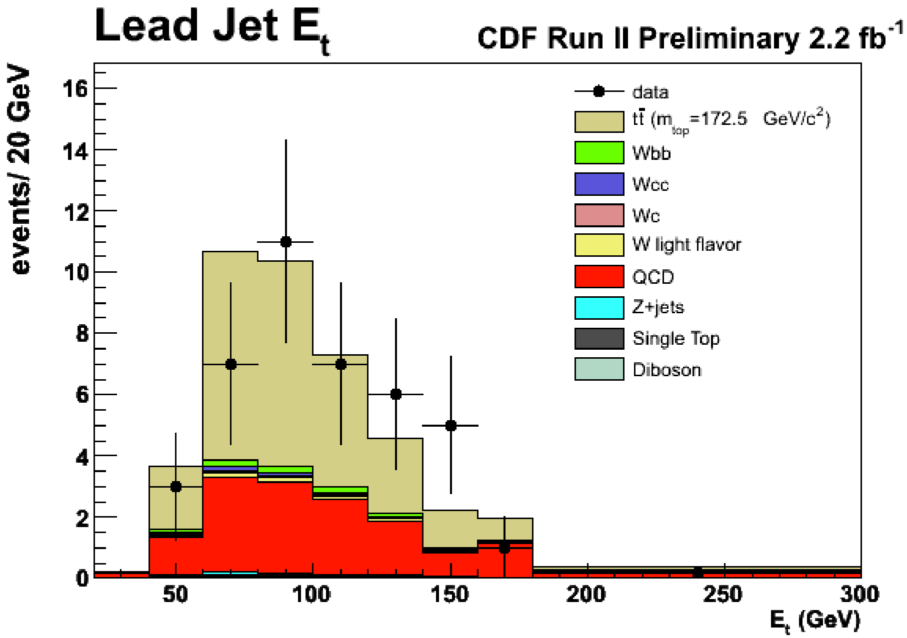


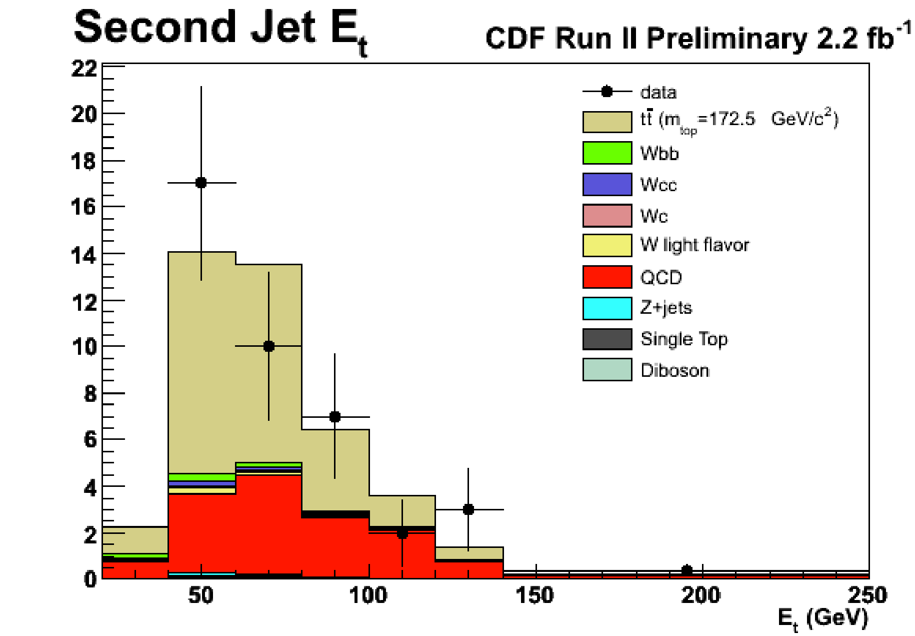


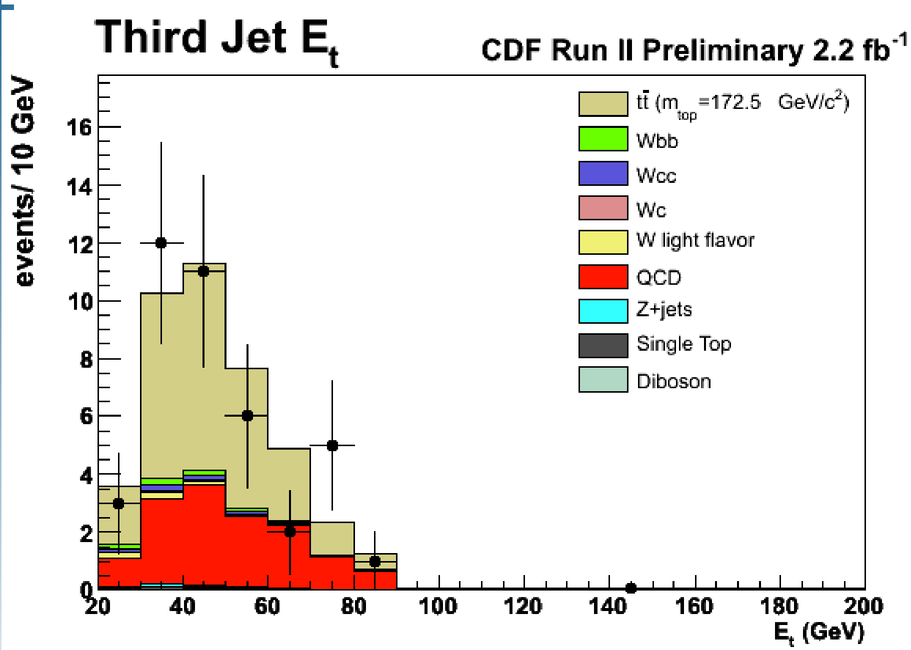
Neural Network Input Variables

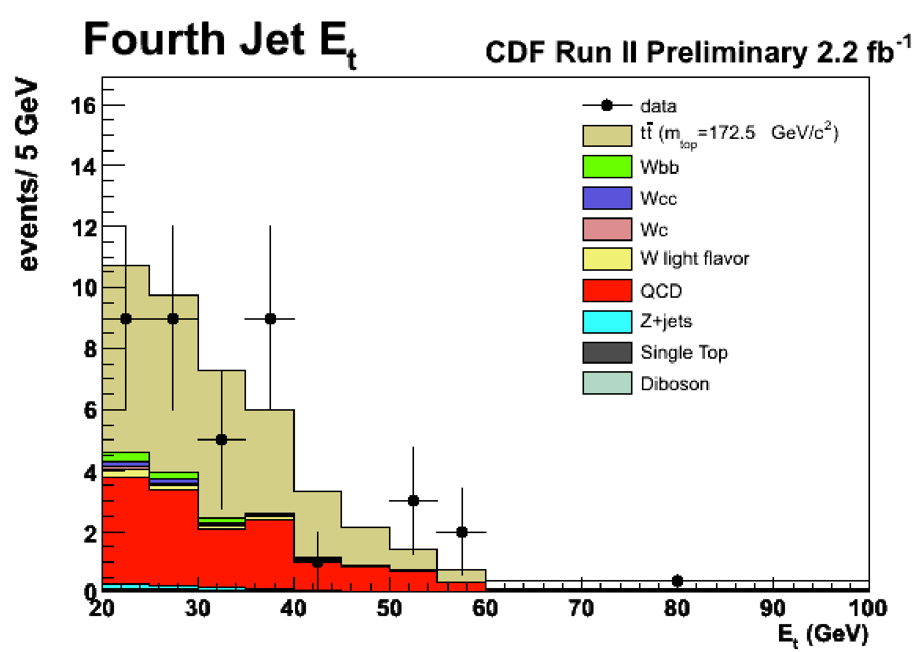


Event Variable Plots









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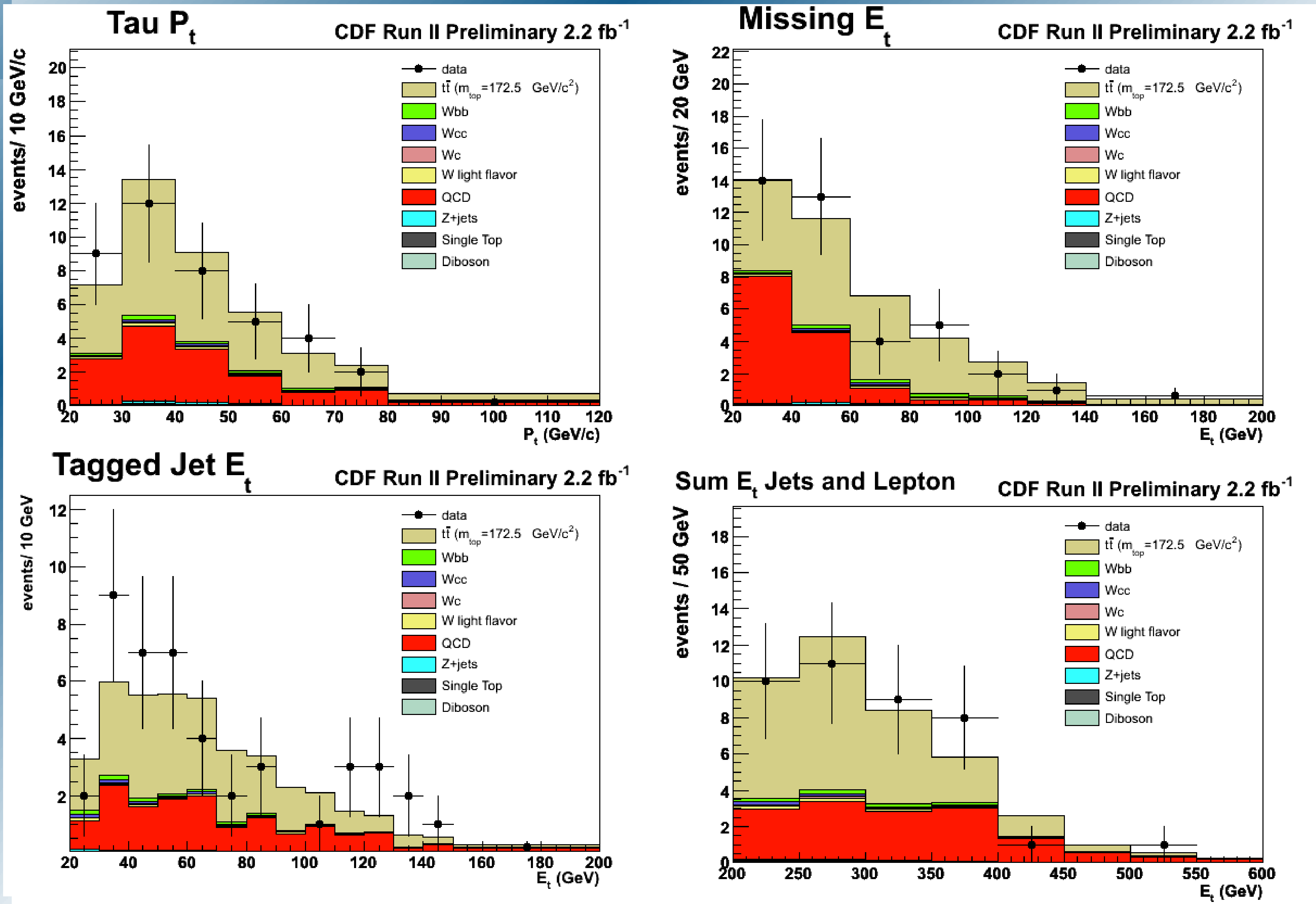

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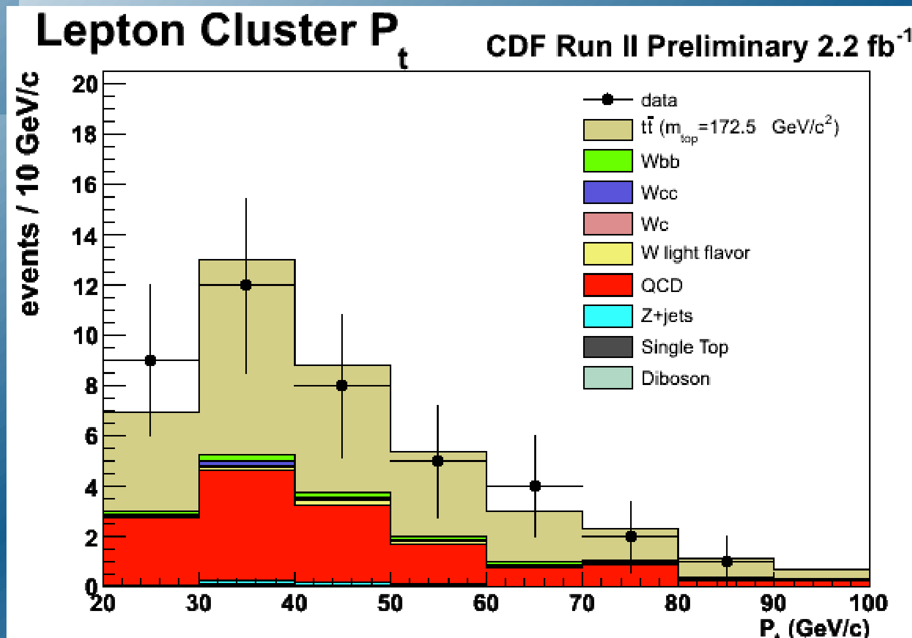

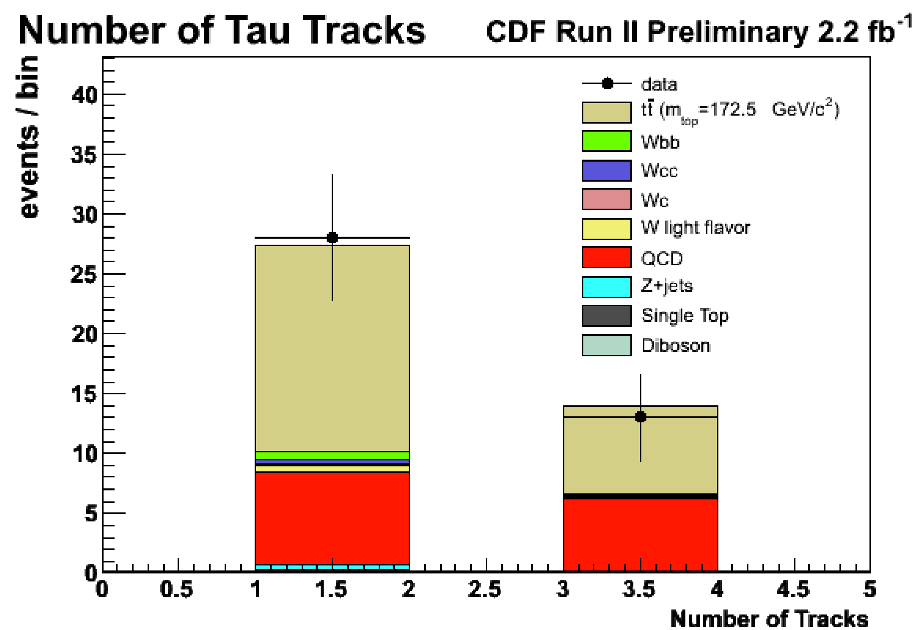

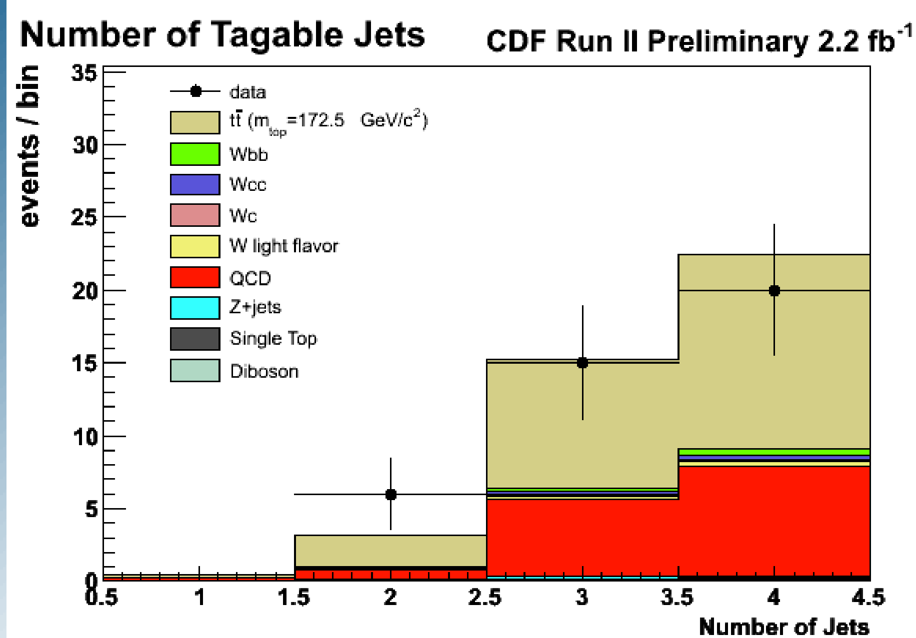

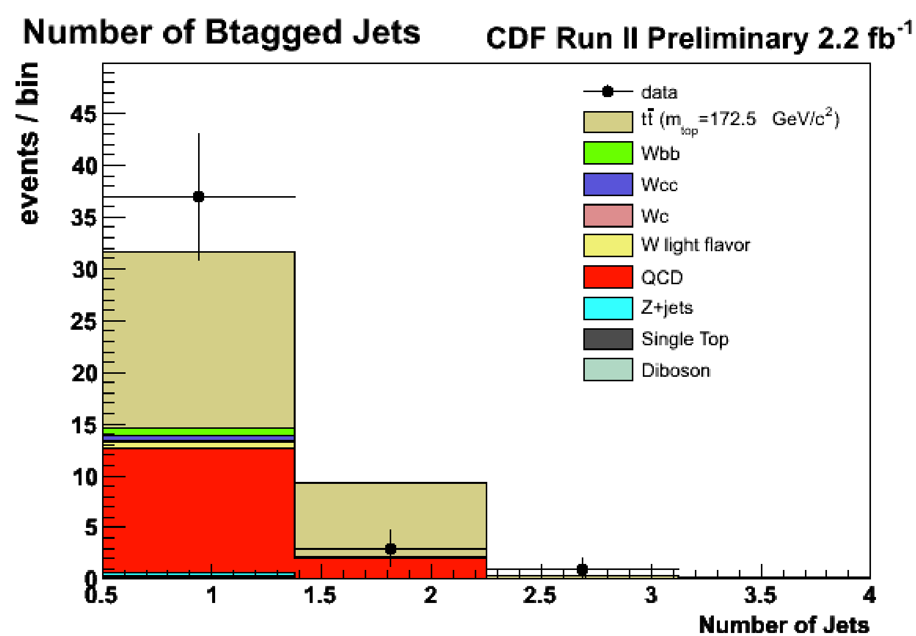

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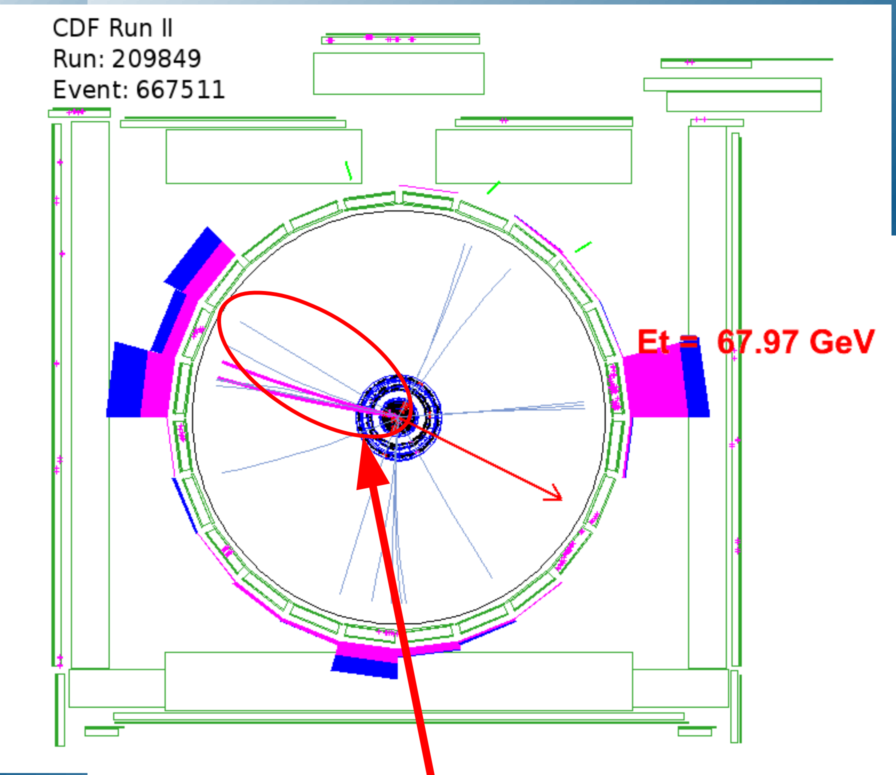
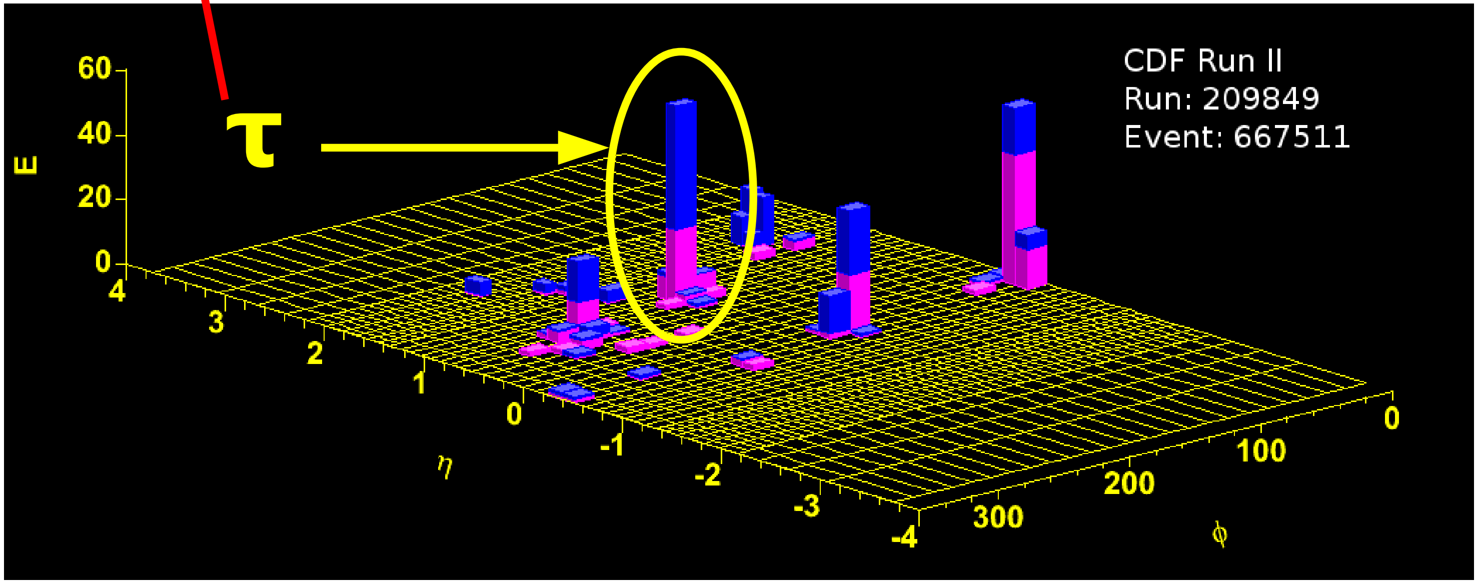


CDF Run II Preliminary 2.2 fb^{-1}

	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



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