Anomalous Top Couplings in Single Top Production at DØ

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on behalf of the DØ collaboration
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SUSY 2011

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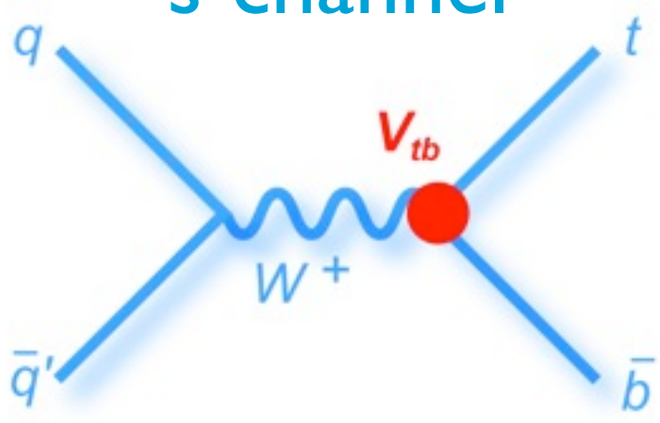
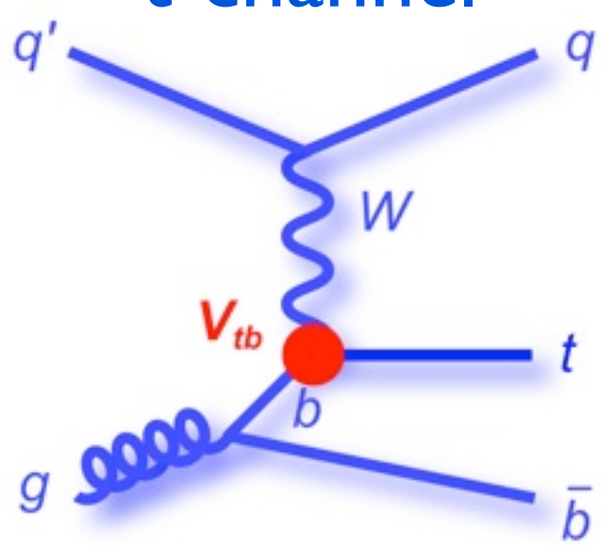
Motivation

s-channel



σ_{SM} = 1.04 ± 0.04 pb

t-channel



σ_{SM} = 2.26 ± 0.12 pb

M_{top} = 172.5 GeV

N. Kidonakis, PRD 74.114012 (2006)

- New physics such as SUSY can have new scalar bosons or modify couplings ⇒ changing XS or angular distributions
- EW single top production
  - sensitive to the *Wtb* couplings ($\sigma_{\text{single top}} \propto |V_{tb} \cdot f|^2$)
- Two dominant production modes at Tevatron: *s*- and *t*- channel
- Recent precise single top production measurements by DØ:
  - arXiv:1105.2788 & arXiv:1108:3091

Anomalous *Wtb* Couplings

- The most general, lowest dimension *Wtb* vertex:

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(L_V P_L + R_V P_R)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(L_T P_L + R_T P_R)tW_{\mu}^{-} + h.c.$$

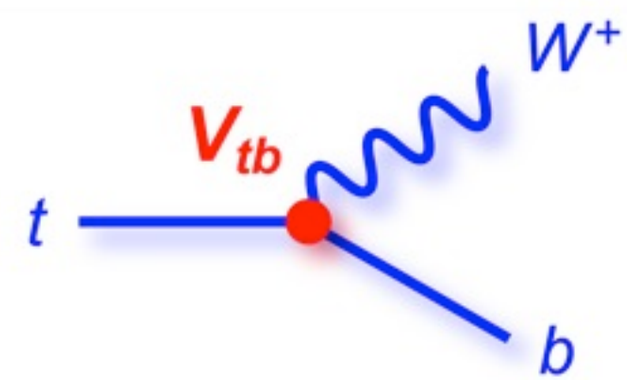
Left-handed vector $L_V = V_{tb} \cdot f_{L_V}$

Right-handed vector $R_V = V_{tb} \cdot f_{R_V}$

Left-handed tensor $L_T = V_{tb} \cdot f_{L_T}$

Right-handed tensor $R_T = V_{tb} \cdot f_{R_T}$

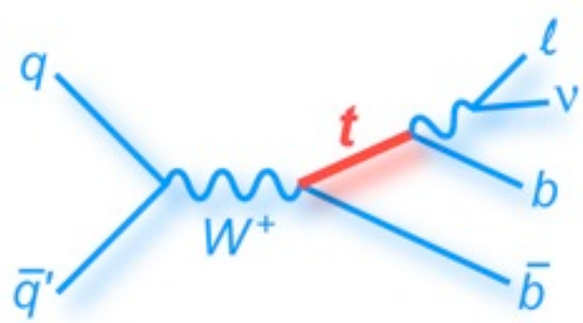
$$\mathrm{SM}: L_V \equiv |V_{tb}| \simeq 1 \text{ and } R_V = L_T = R_T = 0$$



- Constrain RH vector and tensor couplings:
  - $b \to s\gamma$ branching ratio, $|R_V| \leq 0.04$ (PLB **457**, 334, 1999)
- Constrain the ratio of different couplings:
  - *W* helicity in top quark decay (PRL **102**, 092002, 2009)

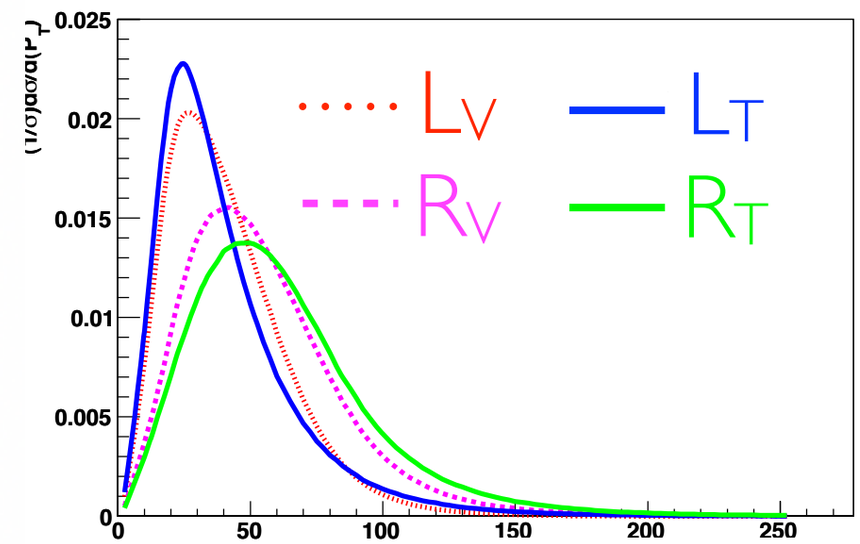
Measurement via Single Top

- Assumptions:
  - Only existing production mechanism (SM & Anom.)
  - $|V_{td}|^2+|V_{ts}|^2 << |V_{tb}|^2$
  - CP-conserving *Wtb* vertex
- Anomalous couplings in both production and decay
- Event kinematics and angular distributions sensitive to anomalous couplings

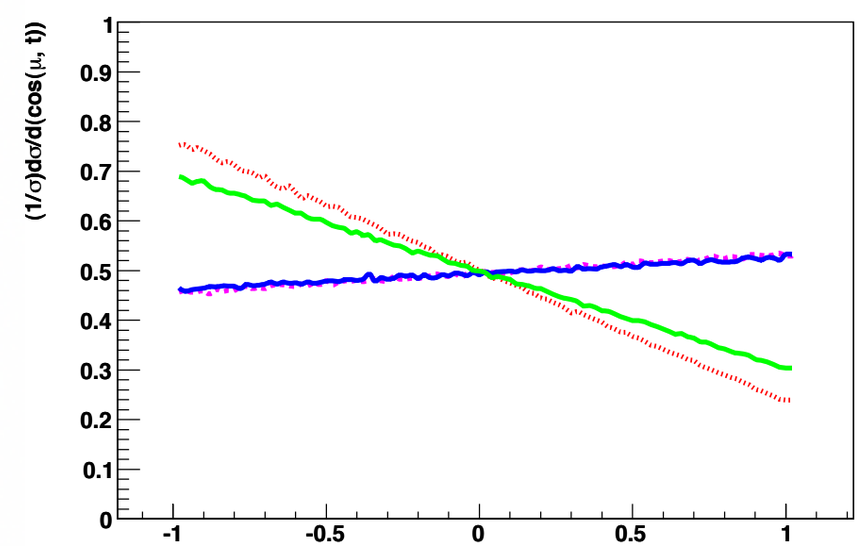


Decay Chain

MC Particle Study



$p_T(\mu)$ [GeV]



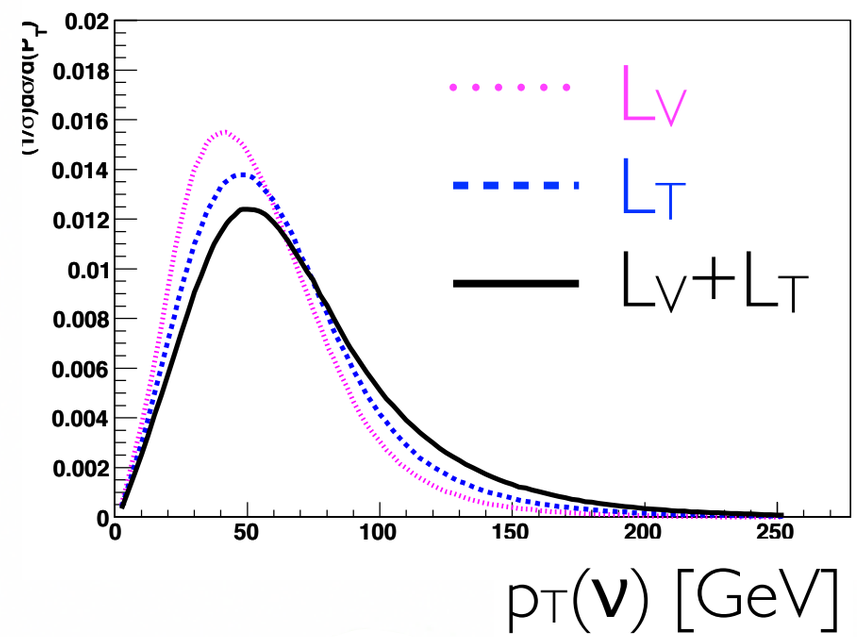
$\cos(\mu, t)$

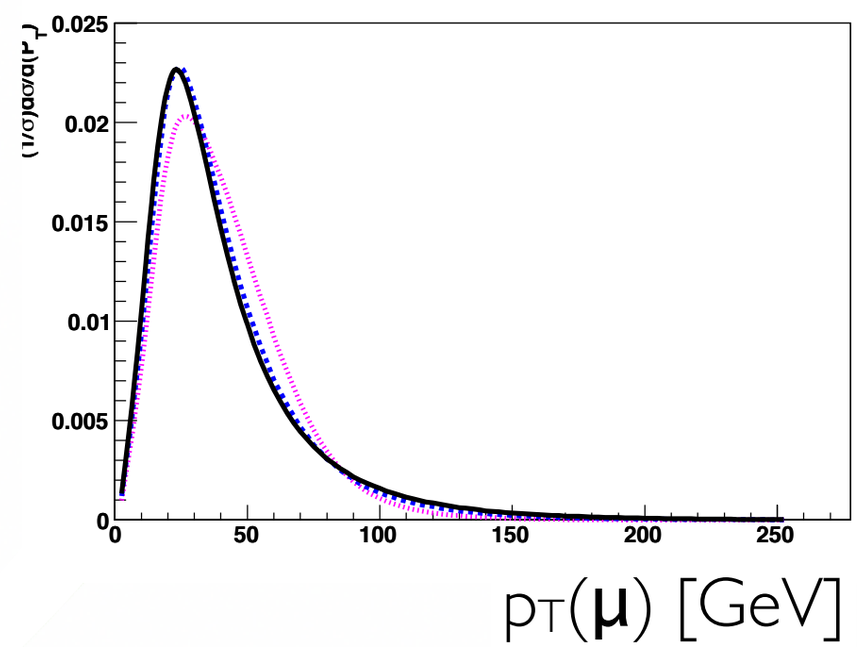
Strategies - Three Scenarios

- Search strategies: Pair the L_V coupling with each of other three
  - (L_V, L_T); $L_V = L_T = 1$; $R_V = R_T = 0$
  - (L_V, R_V); $L_V = R_V = 1$; $L_T = R_T = 0$
  - (L_V, R_T); $L_V = R_T = 1$; $R_V = L_T = 0$
- (L_V, L_T): also consider the non-negligible interference $L_V + L_T$
- Theoretical cross sections (pb)

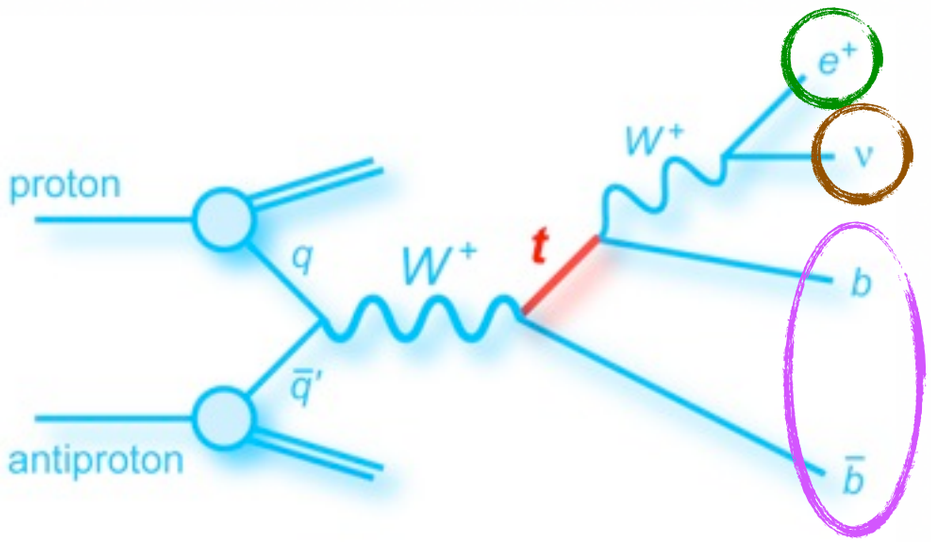
L_V	3.3	R_V	3.07
L_T	10.6	R_T	9

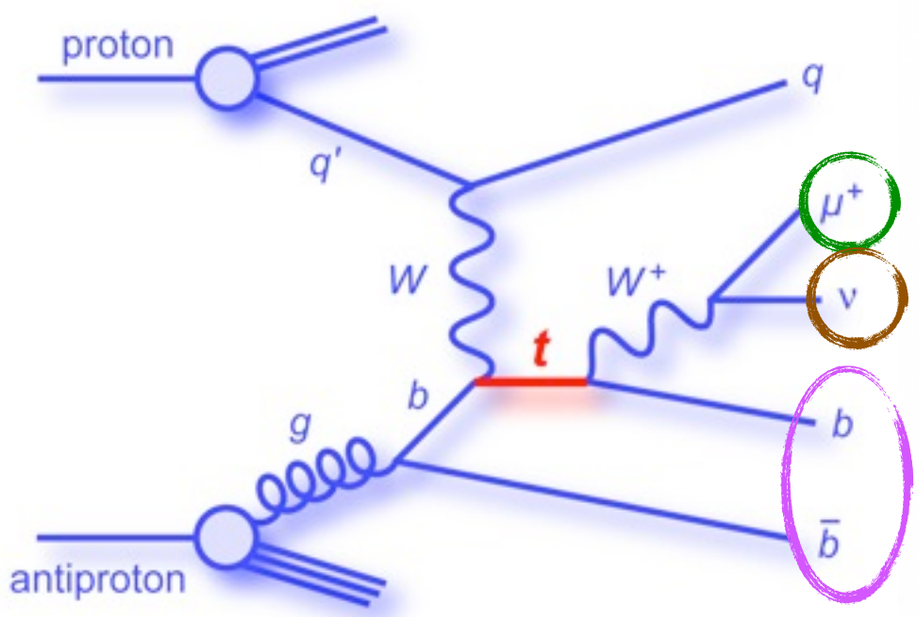
MC for $L_V + L_T$ interference





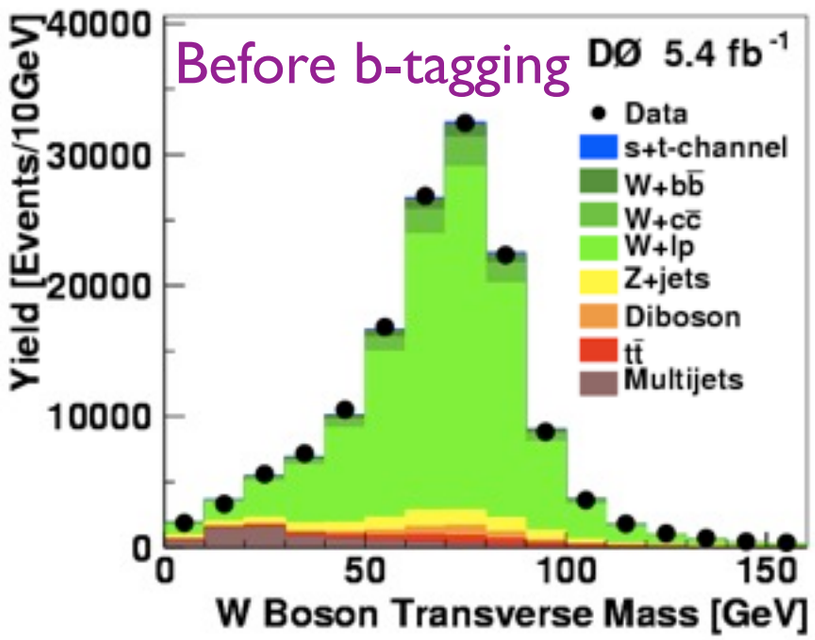
Event Selection

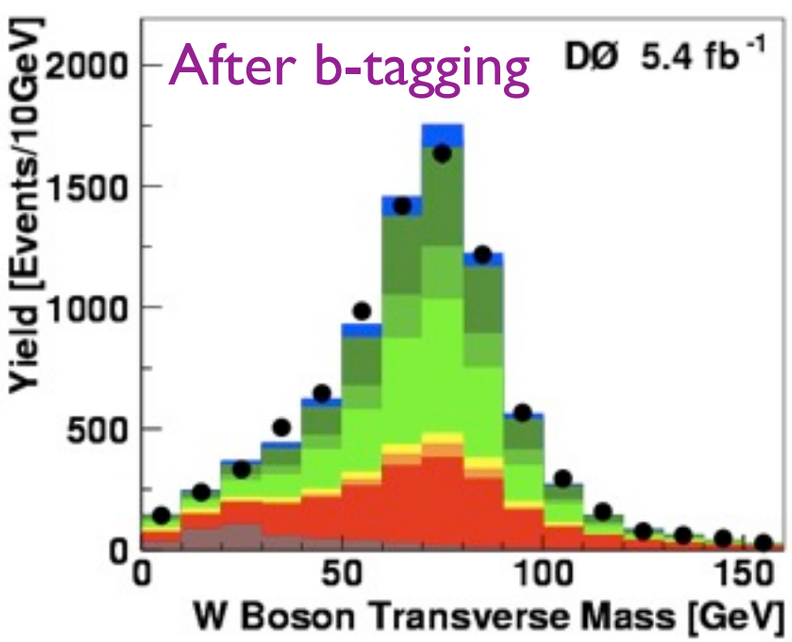




- 5.4 fb^{-1} dataset, Ref. Victor's Talk
- One high p_T isolated electron or muon: $p_T > 15$ GeV
  - electron: $|\eta| < 1.1$
  - muon: $|\eta| < 2.0$
- Large missing energy (> 20 GeV)
- Two, three, or four jets
  - $p_T > 15$ GeV, $|\eta| < 3.5$
  - The leading jet $p_T > 25$ GeV
- Total transverse energy (H_T) cut (120 GeV) to reject background
- Require one or two b-tagged jets

Signal & Background Modeling





- Signals: CompHEP+Pythia
  - CompHEP allows L_V+L_T samples
- W+jets and ttbar: Alpgen+Pythia
- Multijets: Data with none-isolated lepton
- Normalize W+jets and Multijets to data (before *b*-tagging)
- After *b*-tagging,
  - SM Signal: Background = 1:20
- More details in Victor's Talk, arXiv: 1105.2788 & arXiv:1108:3091

Event Yields & Samples

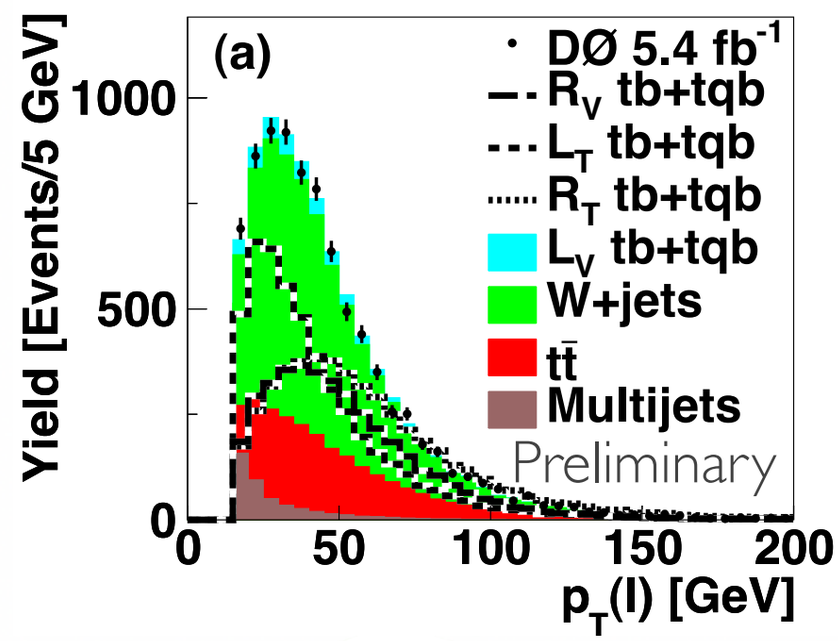
Channel	Event Yields
L_V (SM) single top	399 ± 1.3
L_T single top	1381 ± 6.9
L_V+L_T single top	1478 ± 6.6
R_V single top	366 ± 1.6
R_T single top	1400 ± 7.2
W+jets	4943 ± 598
Z+jets, dibosons	576 ± 113
ttbar pairs	2124 ± 383
Multijets	451 ± 56
Total SM prediction	8492 ± 987
Data	8471

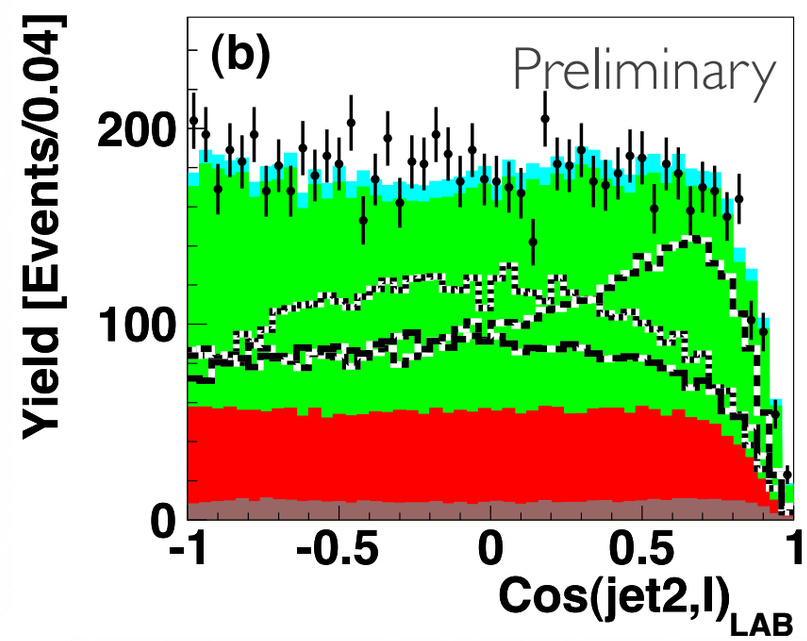
- Samples in each scenario:
  - (L_V, L_T): L_V, L_T, & L_V+L_T
  - (L_V, R_V): L_V & R_V
  - (L_V, R_T): L_V & R_T
- For increasing sensitivity, divide into 6 channels by
  - 2 jets, 3 jets, and 4 jets
  - 1 *b*-tagged & 2 *b*-tagged

Multivariate Analysis - BNN

- Bayesian Neural Networks: To separate signals from backgrounds
- BNN training:
  - Object 4-momenta
  - Angular variables based on *t* spin and *W* helicity
- For each scenario,
  - Signal: Anomalous coupling sample, $L_T/R_V/R_T$
  - SM single top, L_V, included in backgrounds

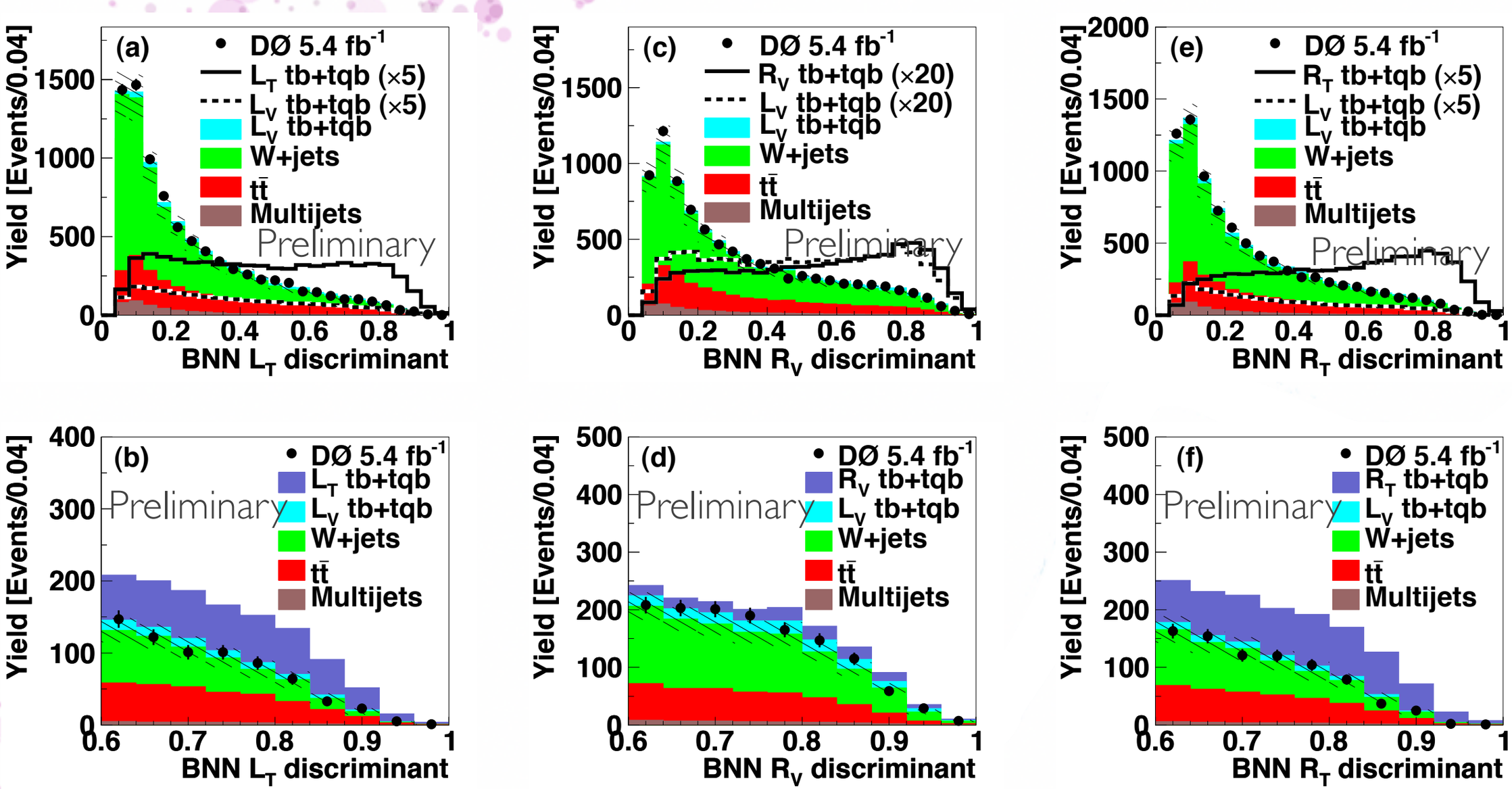
Some input variables





BNN Outputs

- Data is modeled well by MC simulation
- Signal is enhanced in the high discriminant region



Systematic Uncertainties

- Main systematics:
  - The same as the SM single top measurement
- Additional systematics:
  - Signal cross sections: 3.8% for *s*-ch and 5.3% for *t*-ch
  - Mixed couplings in top production and decay: 15% uncertainty in signal modeling

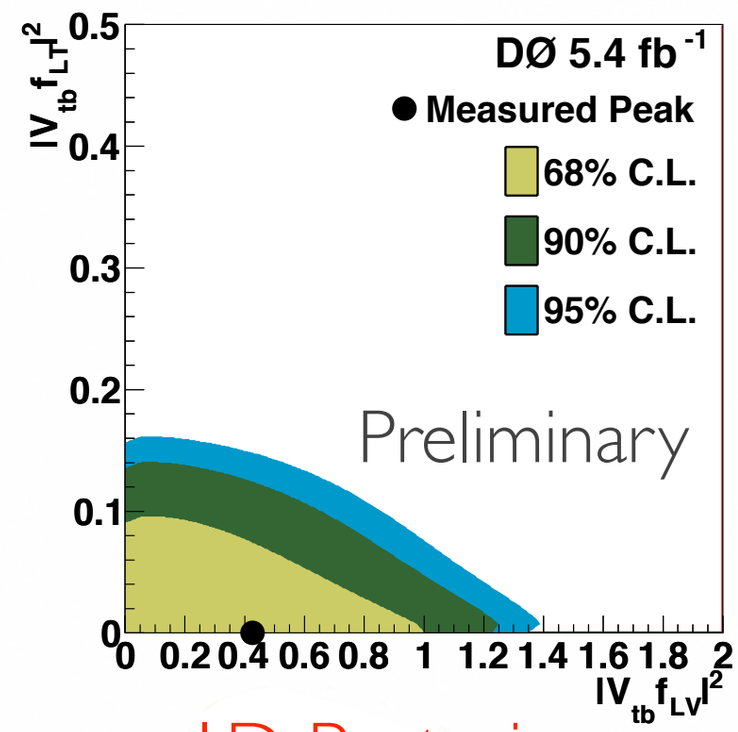
The most important systematic uncertainties

W+Jets flavor scales	12%
Jet Energy Scale	<15%
Jet Energy Resolution	<12%
b-jet Taggability	22%
b-tagging	<14%
Mixed couplings	15%

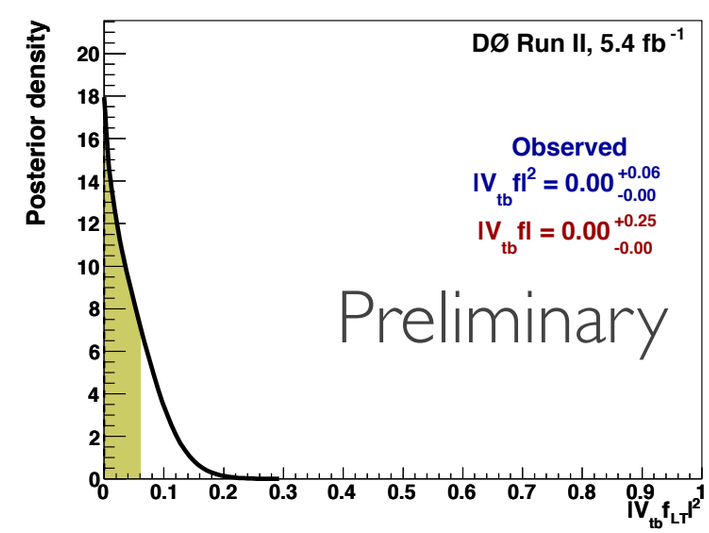
Coupling Measurement

- Bayesian statistics approach
  - Binned likelihood on the discriminants
- 2D posterior probability as a function of $|V_{tb} \cdot f_{LV}|^2$ & $|V_{tb} \cdot f_X|^2$
- Integrate over $|V_{tb} \cdot f_{LV}|^2$ to obtain 1D posterior of $|V_{tb} \cdot f_X|^2$
- Measure the anomalous couplings according to the 1D posterior
- Uncertainties and their correlations taken into account

2D Posterior

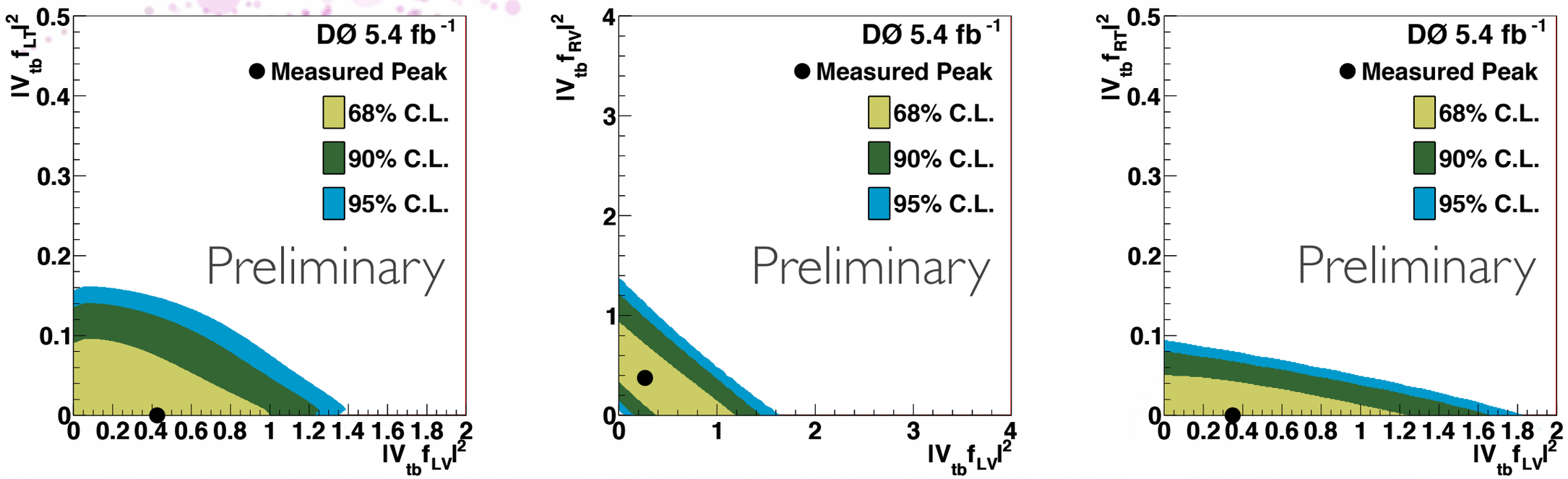


1D Posterior



Results (Preliminary)

- No evidence for anomalous couplings
- Set 95% C.L. upper limits on 1D posterior



Anomalous couplings	(L_V, L_T)	(L_V, R_V)	(L_V, R_T)
Cross Section	< 1.21 pb	< 2.81 pb	< 0.60 pb
Coupling $\lvert V_{tb} \cdot f_X \rvert^2$	< 0.13	< 0.93	< 0.06

Conclusions

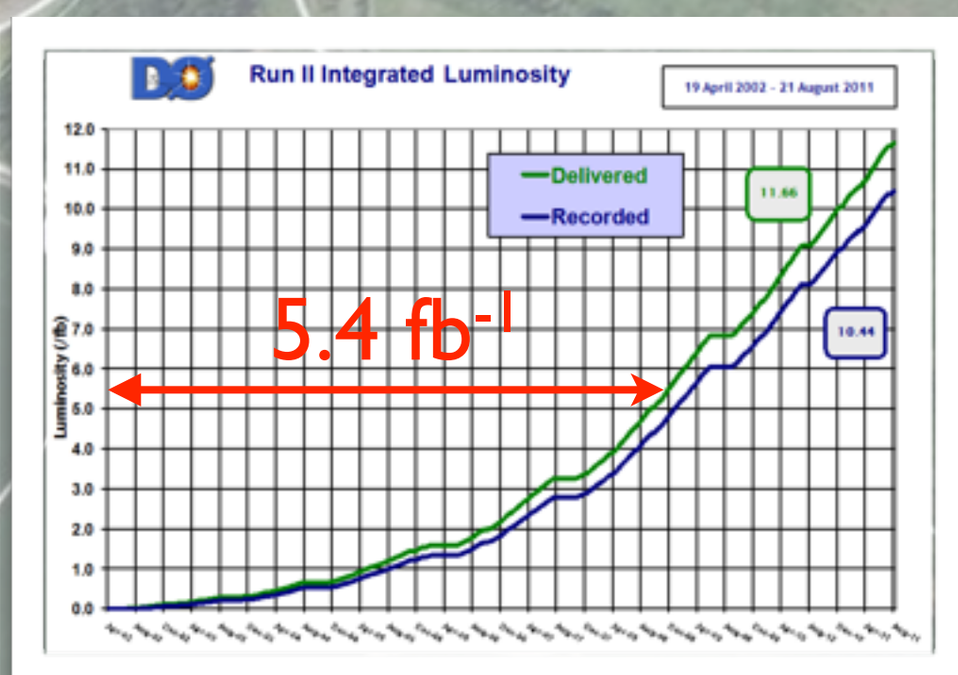
- 6 times of data (5.4 fb^{-1}) than the previous search (0.9 fb^{-1})
- Optimize the discriminants to anomalous couplings
- Data prefer the left-handed vector (SM) coupling
  - No evidence for anomalous couplings
  - Set upper limits at 95% C.L.
- Much better coupling limits than previous search

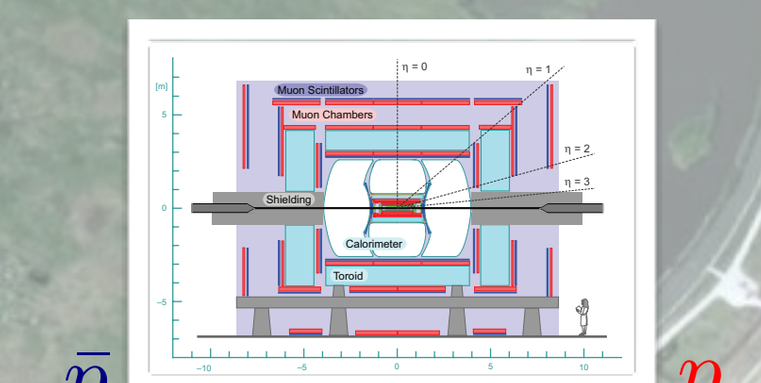
Scenario	(L_V, L_T)	(L_V, R_V)	(L_V, R_T)
Previous 0.9 fb^{-1}	< 0.5	< 2.5	< 1.4
Preliminary 5.4 fb^{-1}	< 0.13	< 0.93	< 0.06

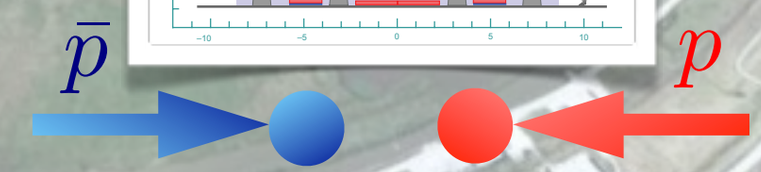
Backup Slides

Fermilab Tevatron

Proton-antiproton collider
CM energy 1.96 TeV
Initial instantaneous luminosity
often at $300\times10^{30}cm^{-2}s^{-1}$

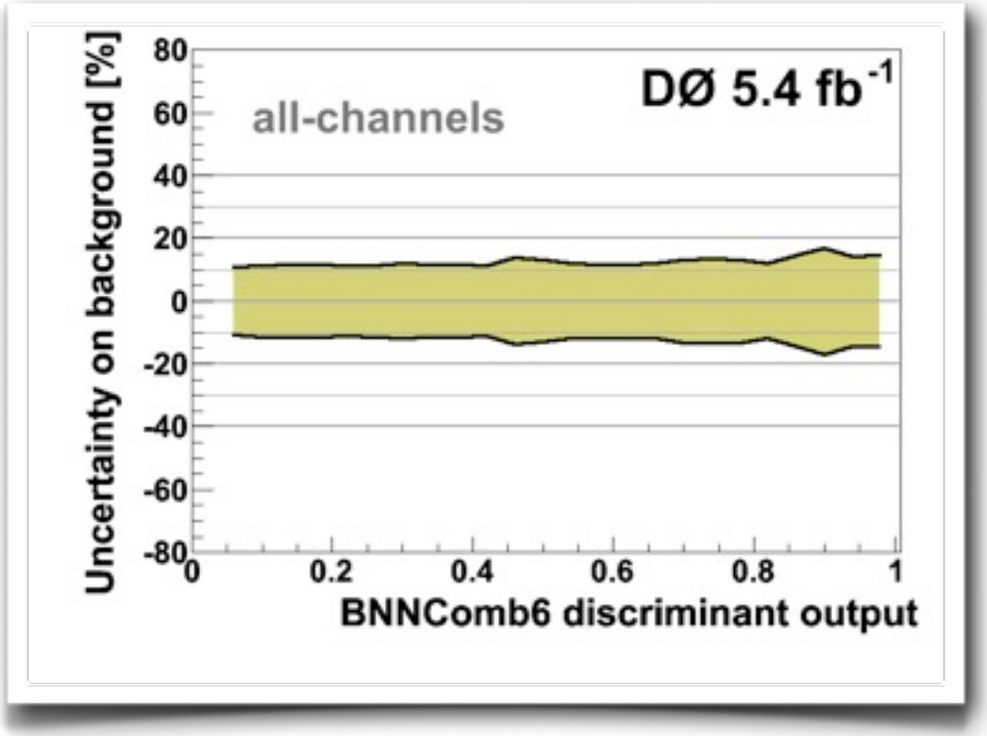






Systematic Uncertainties

- Most important ones:
  - W+jets heavy flavor scale factor (12%)
  - Jet energy scale (<15%)
  - Jet energy resolution (<12%)
  - b-jet Taggability (22%)
  - b-tagging (<14%)
  - Integrated luminosity (6%)



- New ones:
  - Color reconnection (1%)
  - Relative b / light-jet calorimeter response (<1%)
  - Higher-order jet fragmentation effects (few %)

BNN Input Variables

- An example of the BNN inputs, 2 jets and 1 *b*-tagged channel:
  - Object 4-momenta: LeptonEta, LeptonPt, METPt, DeltaPhiLeptonMET, LeadingBTaggedJetPt, LeadingBTaggedJetEta, LeadingBTaggedJetLeptonDeltaPhi, LeadingBTaggedJetBTagNN, LeadingLightQuarkJetPt, LeadingLightQuarkJetEta, LeadingLightQuarkJetLeptonDeltaPhi, LeadingLightQuarkJetBTagNN
  - Charge information: QTimesEta
  - WTransverseMass
  - Angular distribution: CosBTaggedJetLeptonBTaggedTop, CosLeptonQZBestTop, CosLeptonBTaggedTopFrameBTaggedTopCMFrame, CosLightQuarkJetLeptonBTaggedTop