Single-Top at CDF

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for the CDF Single-top Group

TeV4LHC meeting

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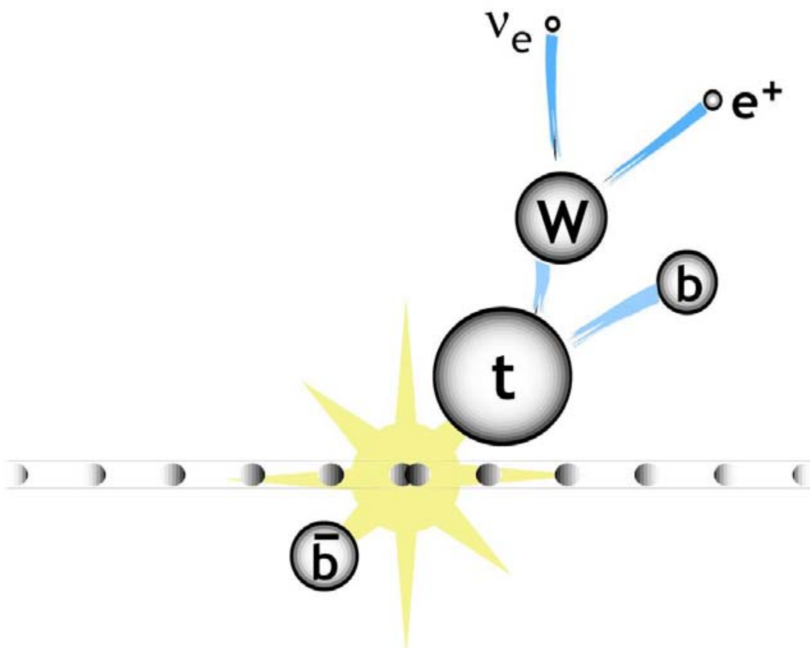
First Run II Analysis

- Phys.Rev.D71:012005,2005

- Look in the **W+2 jets** channel:
  - 1 lepton with E_T>20 GeV, |η|<1.0
  - missing transverse energy: MET>20 GeV
  - 2 jets : E_T> 15 GeV, |η| < 2.8
  - at least one b-tag (displaced sec. vertex)
  - Veto Z, dilepton, conversion events

- Topological cuts:
  - 140 < $M_{l\nu b}$ <210 GeV/c^2
    (combined and separate searches)
  - leading jet E_T > 30 GeV
    (separate search for t-channel only)

- Backgrounds: non-top and $t\bar{t}$

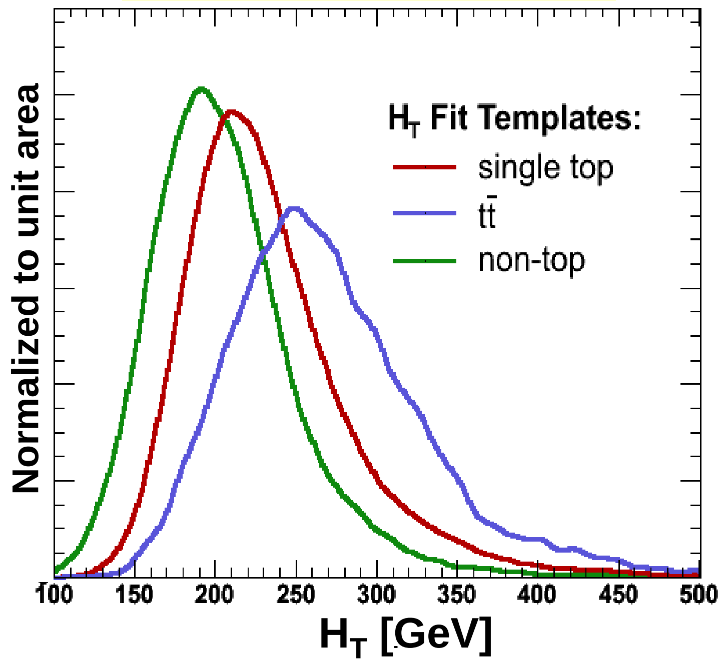


Single-Top Analyses

- Two distinct analyses: combined and separate searches
- <u>Combined Search:</u>
  - Signal: s-channel and t-channel single-top events
  - Both cross-sections proportional to $|V_{tb}|^2$
  - Exploits distributions similar for s- and t-channels:
    - H_T = the total transverse energy in the event (E_T^{lep} + MET + ΣE_T^{jet})
- <u>Separate Search:</u>
  - 1. Signal = t-channel (s-channel is a background)
    - FCNC couplings, anomalous V+A contributions to the W-t-b vertex, etc.
    - Q•η variable (Q = lepton charge, η = pseudorapidity of non b-tagged jet)
    - Q•η asymmetric in t-channel events: N(Q•η>0) = 2* N(Q•η<0)
  - 2. Signal = s-channel (t-channel is a background)
    - Heavy charged vector bosons W', CP-violation effects within MSSM, Kaluza-Klein excited W-boson within MSSM
    - Double b-tags – simple counting

Combined Search

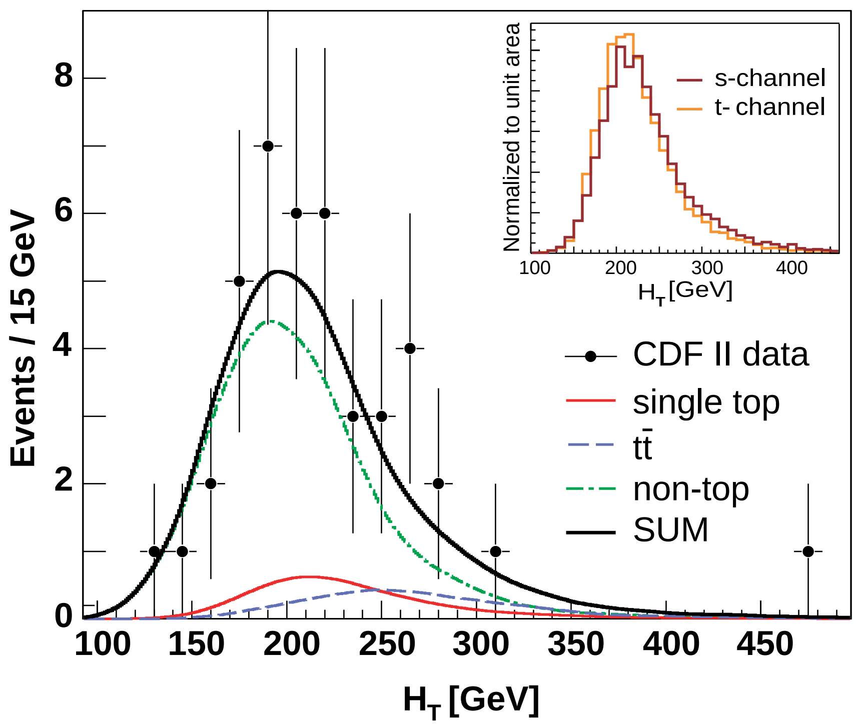
- Two-variable analysis: cut on reconstructed top mass $M_{l\nu b}$ then fit the total transverse energy H_T



S/B = 12 %

Process	Number of events/162 pb^{-1}
$t\bar{t}$	3.8 ± 0.9
Non-top	30.0 ± 5.8
Sum Background	33.8 ± 5.9
t-channel	2.8 ± 0.5
s-channel	1.5 ± 0.2
Sum Single-Top	4.3 ± 0.5
Sum Expected	**38.1 ± 5.9**
Observed	**42**

Combined Search Results

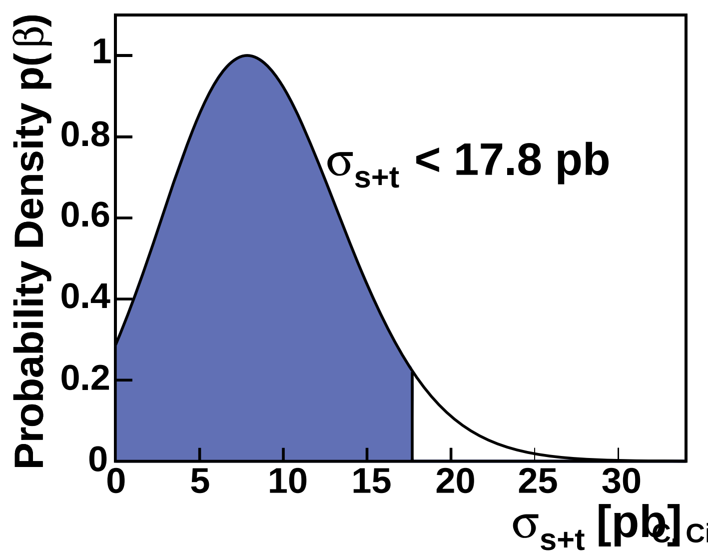


A-priori, no syst: 12.4 pb

A-priori, w/ syst: 13.6 pb

A-posteriori w/ syst: 17.8 pb

MPV(β units)	MPV(pb)
$2.7^{+1.8}_{-1.7}$	$7.7^{+5.1}_{-4.9}$



Event Count: Separate Search

Process	Number of events	
	1-b-tag-bin	2-b-tag-bin
$t\bar{t}$	3.2 ± 0.7	0.60 ± 0.14
Non-top	23.3 ± 4.6	2.59 ± 0.71
Sum Background	26.5 ± 4.7	3.19 ± 0.72
t-channel	2.7 ± 0.4	0.02 ± 0.01
s-channel	1.1 ± 0.2	0.32 ± 0.05
Sum Single-Top	3.8 ± 0.5	0.34 ± 0.05
Sum Expected	30.3 ± 4.7	3.53 ± 0.72
Observed	33	6

Separate Search Results

t-channel:

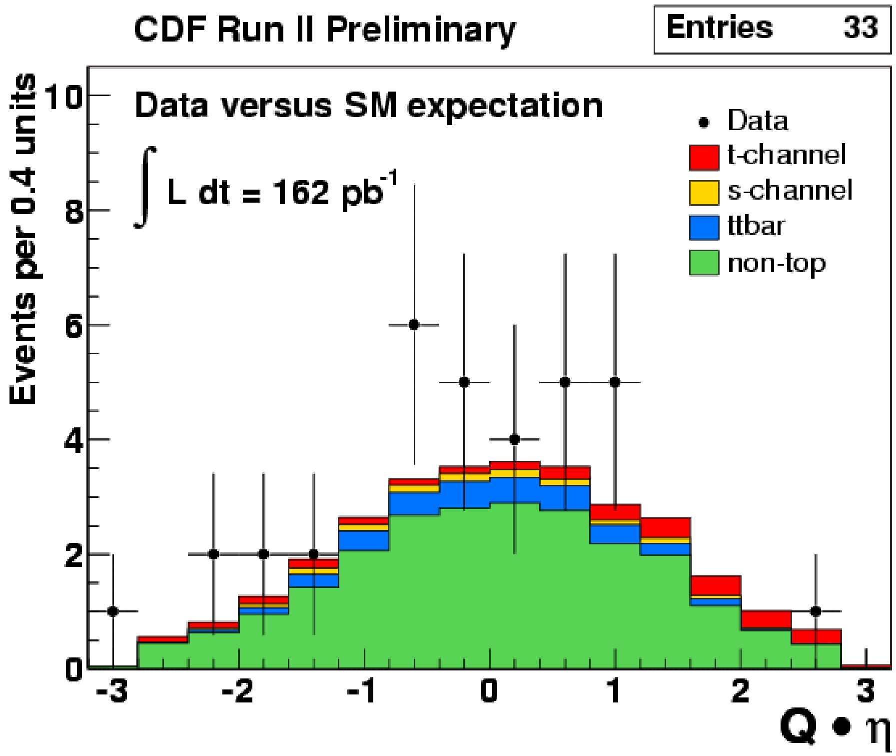
A-priori: 11.2 pb

A-posteriori: 10.1 pb

s-channel:

A-priori: 12.1 pb

A-posteriori: 13.6 pb



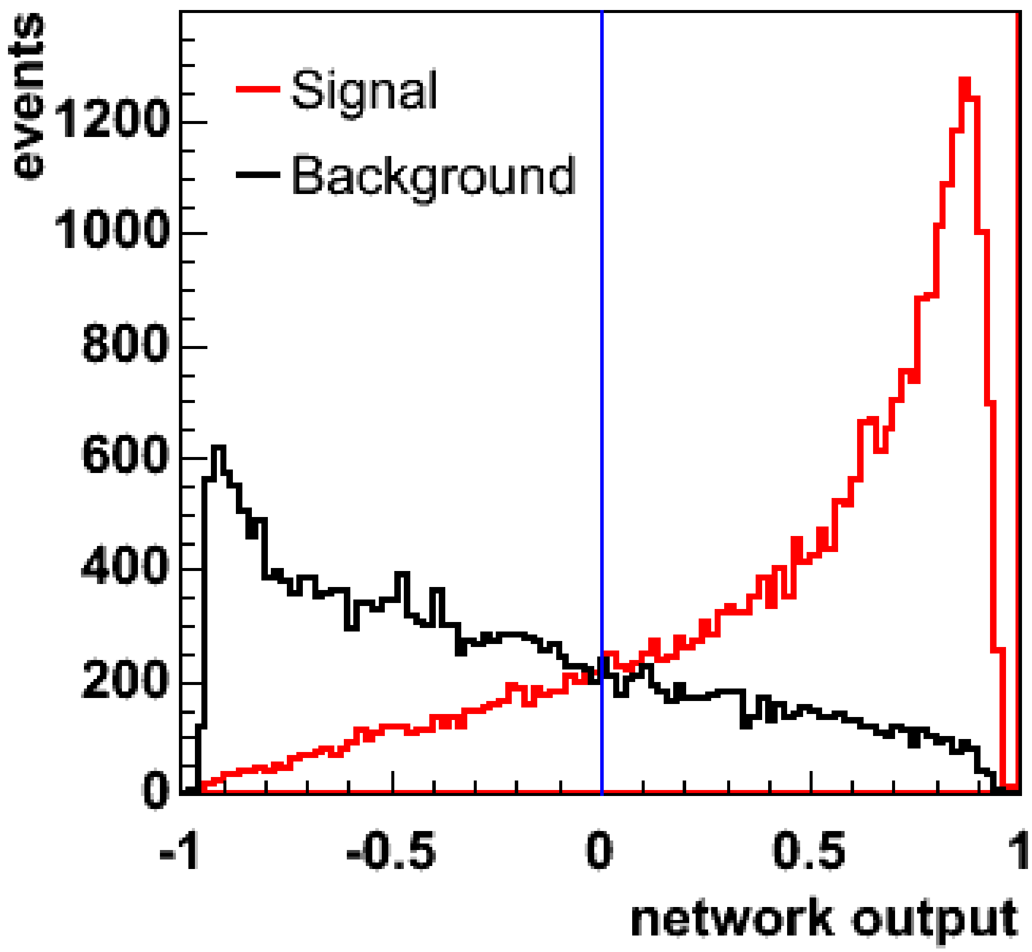
Channel	MPV(β units)	MPV(pb)
t-channel	$0.0^{+2.4}_{-0.0}$	$0.0^{+4.7}_{-0.0}$
s-channel	$5.2^{+4.3}_{-4.3}$	$4.6^{+3.8}_{-3.8}$

Next Steps?

- Dec 04 CDF Workshop
  - Make sure we model signal correctly
    - Z. Sullivan, T. Stelzer, E. Boos, S. Slabospitsky
  - Plan for the next iteration
    - Increase acceptance
    - Increase S/B
    - Mulivariate techniques
- Next publication - aim for observation:
  - Previously: set limits on anomalously high signal rates
    - Null hypothesis: background+SM single-top
    - Test hypothesis: background+very large signal rates
  - Currently:
    - Null hypothesis: backgrounds only, no signal
    - Test hypothesis: background + SM signal

NN b-tagging

t-channel	5%
s-channel	3%
$t\bar{t}$	11%
$Wb\bar{b}$	32%
$Wc\bar{c}$	12%
Wc	12%
Mistags (*u,d,s*)	25%



Likelihood Analysis

- Kinematic fitter: allow p_b, η_b, ϕ_b and E_T^ν, ϕ^ν to vary within uncertainties

$$\chi_m^2 = \frac{(\eta_b^{fit} - \eta_b^{meas})^2}{\sigma_{\eta_b}^2} + \frac{(\phi_b^{fit} - \phi_b^{meas})^2}{\sigma_{\phi_b}^2} + \frac{(p_b^{fit} - p_b^{meas})^2}{\sigma_{p_b}^2} + \frac{(p_{t\nu}^{fit} - \not{E}_t^{meas})^2}{\sigma_{E_t}^2} + \frac{(m_t^{fit} - m_t^{meas})^2}{(0.5GeV)^2}$$

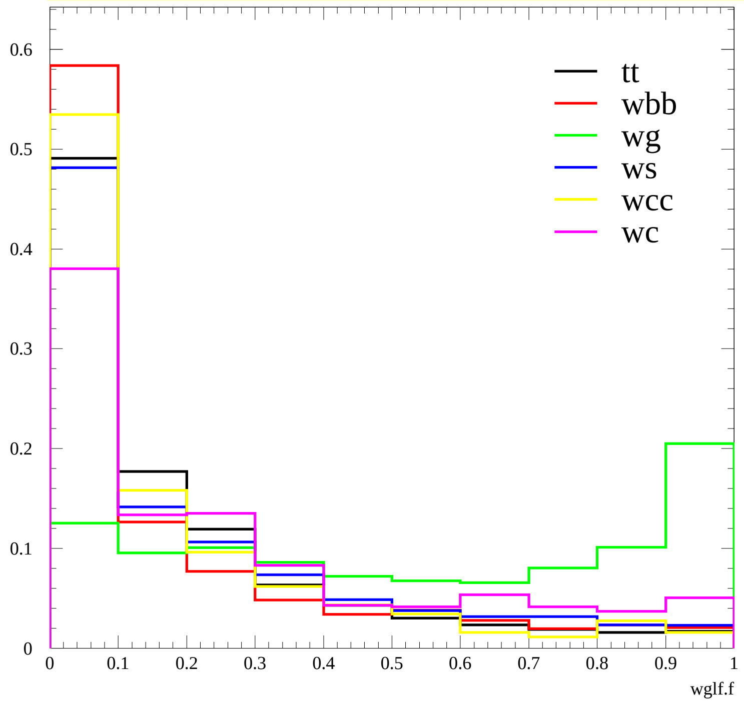
- 4 fits: 2 b-jet assignment + 2 p_z solutions
- Can use this χ^2 for – choosing the b from top (~80% correct)
- Calculate matrix element-like quantities
- Then, form a combined probability
  - Different variables for t-channel and s-channel

$$p_i^j(x_i) = \frac{f_i^j(x_i)}{\sum_{k=1}^{3} f_i^k(x_i)} \qquad L^j(\vec{x}) = \frac{\prod_{i=1}^{n_{\text{var}}} p_i^j(x_i)}{\sum_{k=1}^{3}\prod_{i=1}^{n_{\text{var}}} p_i^k(x_i)}$$

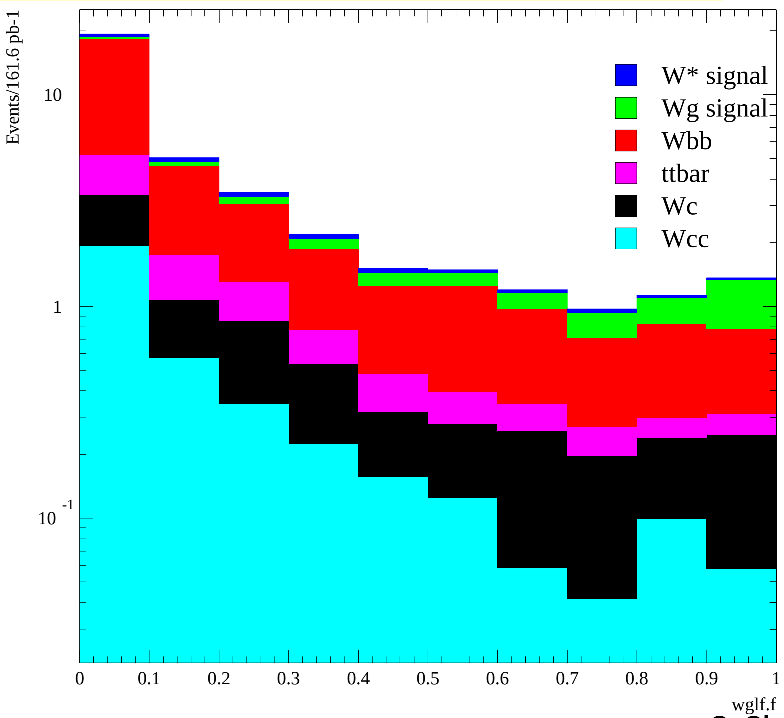
Likelihood Method

- 6 Variables: $M_{l\nu b}$, ME(t-chan), $\cos(\theta^{l,jet})$, M_{jj}, H_T, $Q^*\eta$
- Using the 4.11 samples, need 1.7 fb^{-1} for a 3σ evidence on the t-channel. For s-channel, need good variables…

t-channel Likelihood function



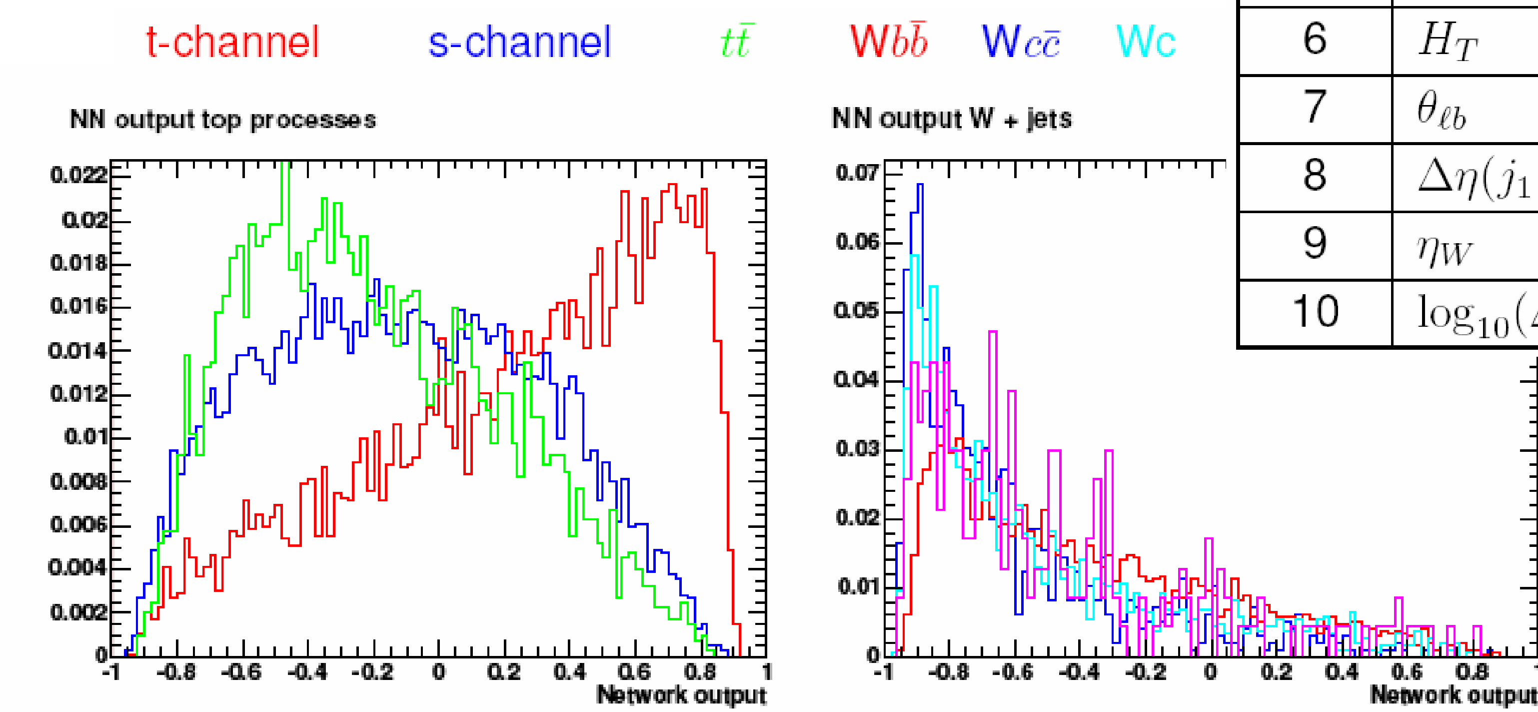
t-channel Likelihood function



Neural-network Method

- 3-layer Neural Network
- NeuroBayes@ program
  - (Run I single-top PRD: JETNET)
- 15 variables input to 3-layer net
- Best 10 variables:

Rank	Variable	Relev. σ
1	$M_{\ell\nu b}$	45.0
2	M_{jj}	30.8
3	$Q \cdot \eta$	18.5
4	ANN b-tag	17.6
5	$\cos\theta_W$	16.4
6	H_T	9.8
7	$\theta_{\ell b}$	5.9
8	$\Delta\eta(j_1, j_2)$	4.9
9	η_W	4.0
10	$\log_{10}(\Delta_{23})$	3.7

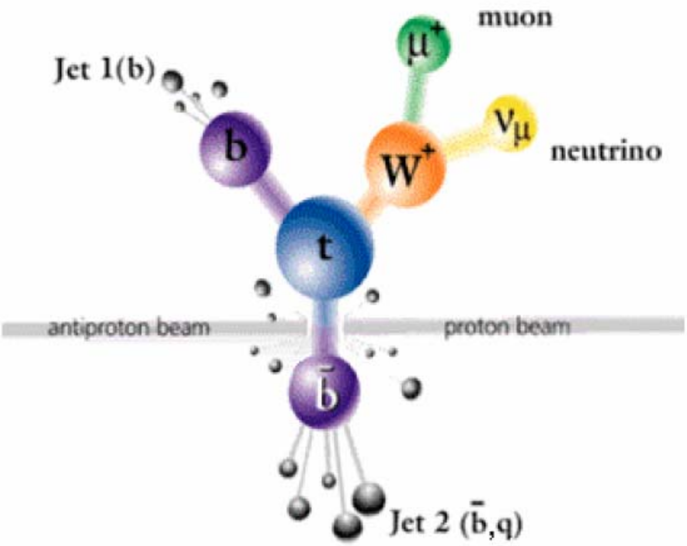


Neural-Network Method

- Use of ANN for single top search seems very promising.
  Improvement of +32% in $S/\sqrt{B}$.
  3 σ significance with 1.5 fb^{-1}.
- Use more variables, e.g. polarization, and improve variables, e.g. use $M_{\ell\nu b}$ from kinematic fit.
- Implement two-step approach: (1) cut on combined ANN to reduce background, (2) separate into t- and s-channel with additional networks.

Matrix Element Method

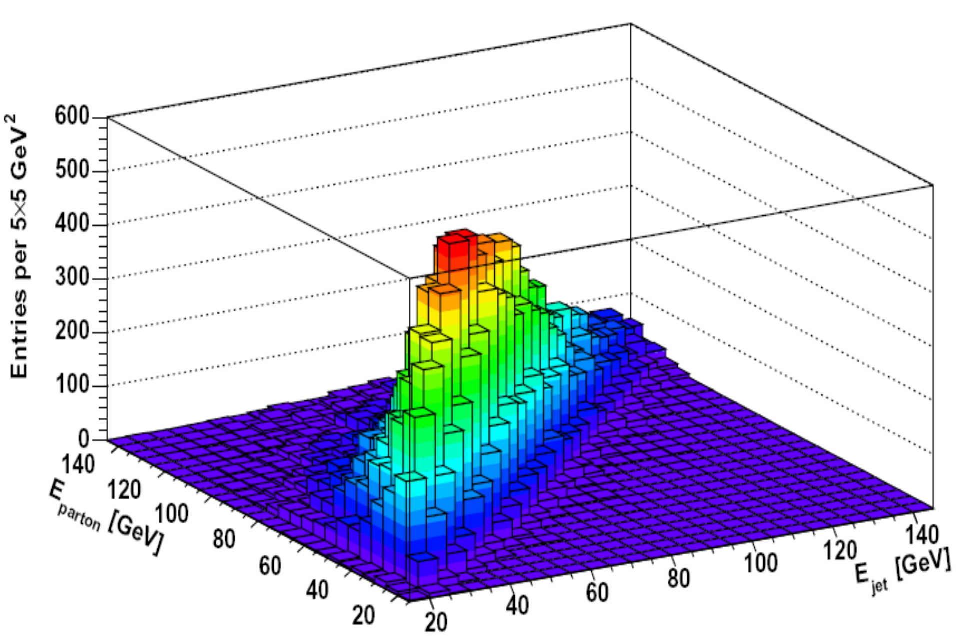
- s-channel and t-channel probabilities:
  - 2(*in*) + 12(*final*) = 14 degrees of freedom
  - 3(*e*) + 4(jet angles) + 3(P_{in}=P_{fin}) + 1(E_{in}=E_{fin}) = 11 constraints
  - 14 – 11 = 3 integrals => Integrate over neutrino p_z and jet energy of both jets
  - Change variables $p_z \rightarrow m_W$ because $|M|^2$ is almost negligible, except near the Breit-Wigner poles
  - Both neutrino solutions are considered at each integration step and sum over 2 combinations of jets

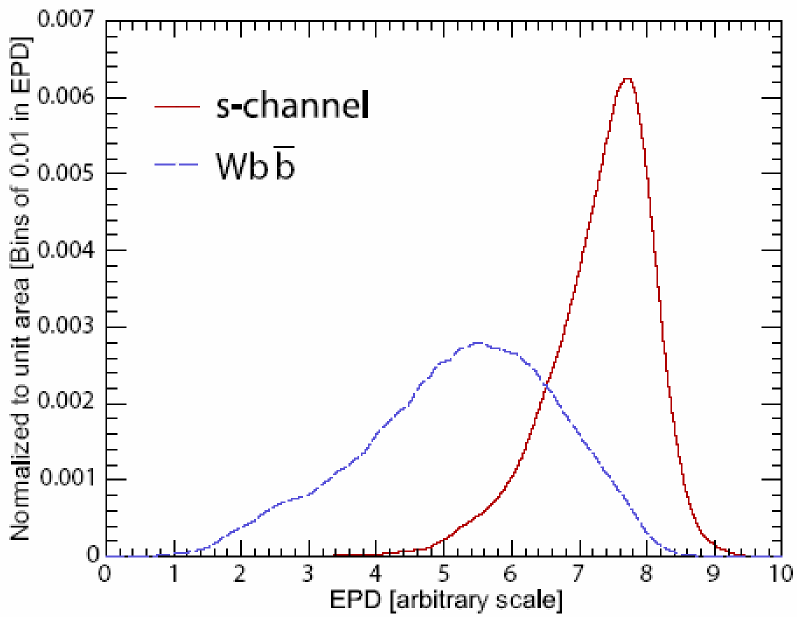


$$P(x,\alpha) = \frac{1}{\sigma} \int d\rho_b d\rho_{\bar{b}} dm_W^2 \sum_{comb,\nu} |M(\alpha)|^2 \frac{f(q_1)f(q_2)}{|q_1||q_2|} \phi_4 W_{jet}(x,y)$$

Matrix-Element Method

- Main reference: Bernd Stelzer's thesis:
  - Moved to UCLA – but still CDF.
- Matrix element from MadEvent
- Transfer functions – double Gaussian parametrization
- EPD = P_s/P_b
- Making several assumptions – 1.2 fb^{-1} for 3 σ





Conclusions

- LHC4TeV – MC help from Sergey Slabospitsky (CMS)
- In progress:
    - Increase acceptance (forward electrons)
    - Increase signal purity (NN b-tagger)
    - Use multivariate techniques:
        - Matrix element, Neural-Nets, Likelihood
- We should be ready for >1 fb^{-1} – switch to discovery mode.
- No discovery without reducing the background uncertainties