Single Top Results from CDF

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On behalf of the CDF Collaboration

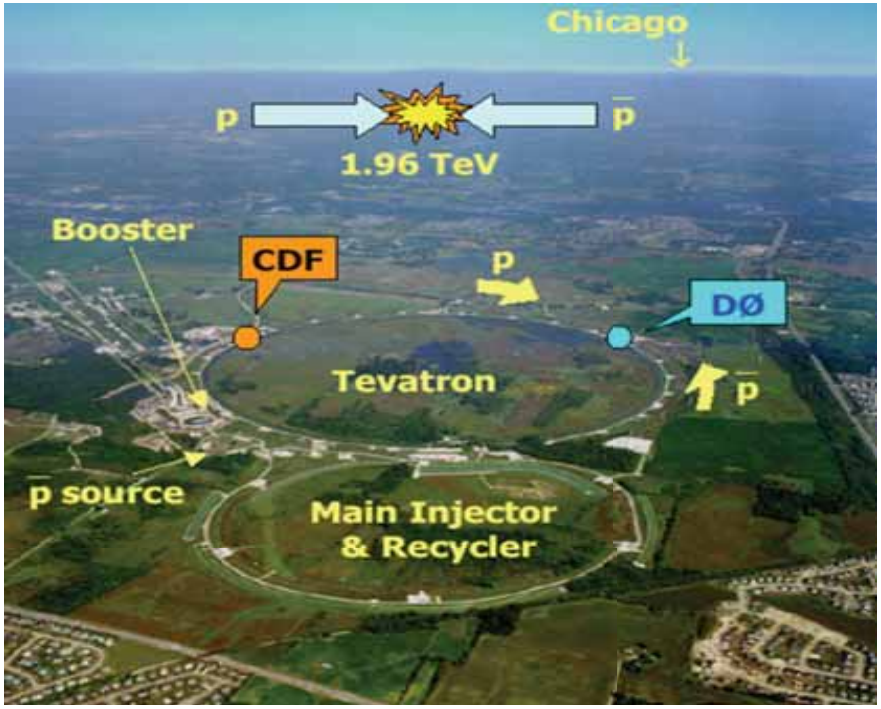
Rencontres de Moriond Electroweak Interactions and Unified Theories
La Thuile, March 12th 2007

Outline

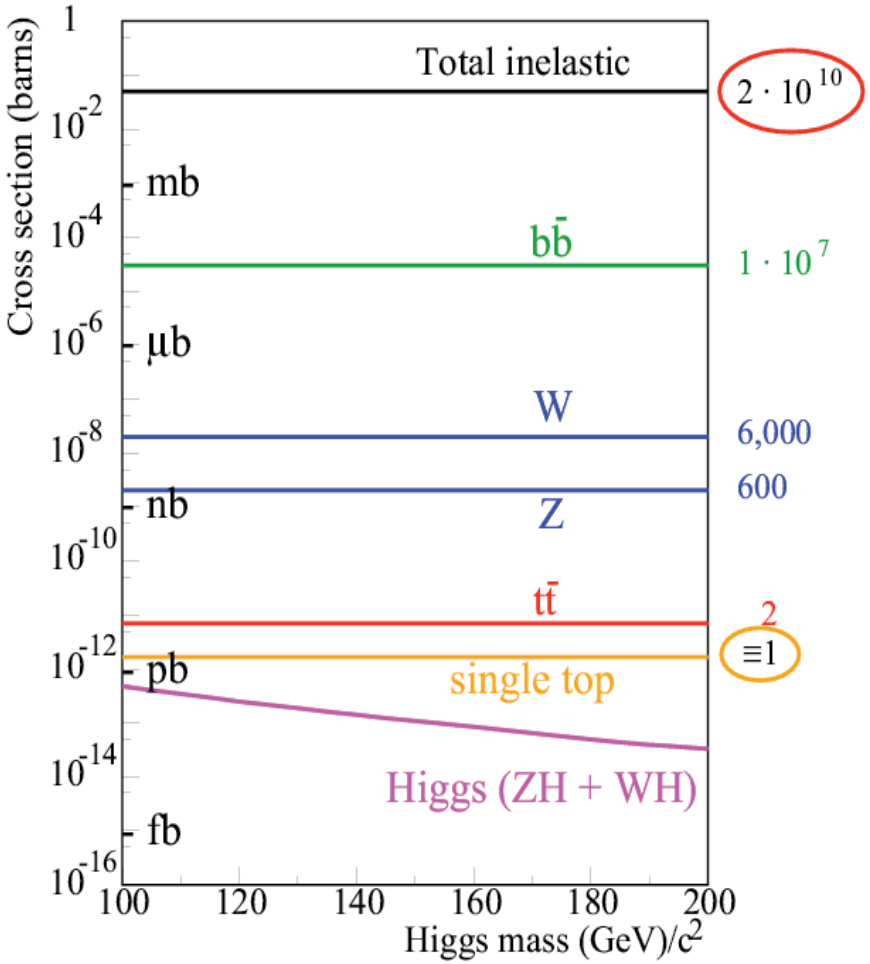
1. Top Quark Production at the Tevatron
2. Motivation for Single Top Search
3. The Experimental Challenge
4. Analysis Techniques
   - *Likelihood Function*
   - *Neural Network*
   - *Matrix Element*
5. Results
6. Search for a heavy W′ Boson
7. Conclusions

The Tevatron Collider

- Tevatron is a proton-antiproton collider with E_{CM}=1.96 TeV
- Tevatron produces per day:
  - ~ 40 top quark pair events
  - ~ 20 single top quark events

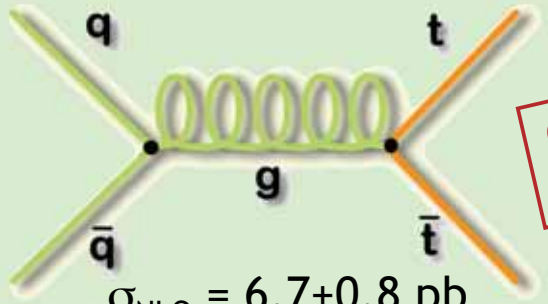


Cross Sections at √s = 1.96 TeV



Top Quark Production at the Tevatron

Top quark pair production:



Observed 1995!

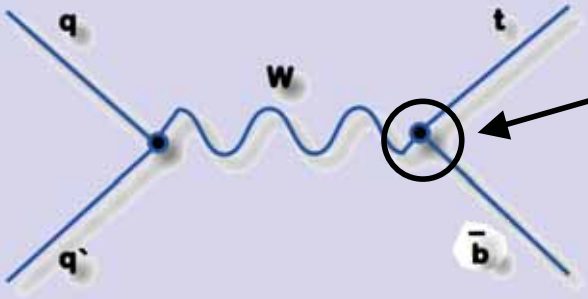
σ_{NLO} = 6.7±0.8 pb

- Sample for precision top quark mass measurements

  Current World average:

  m_{top} = 171.4 ± 2.1 GeV/c^2

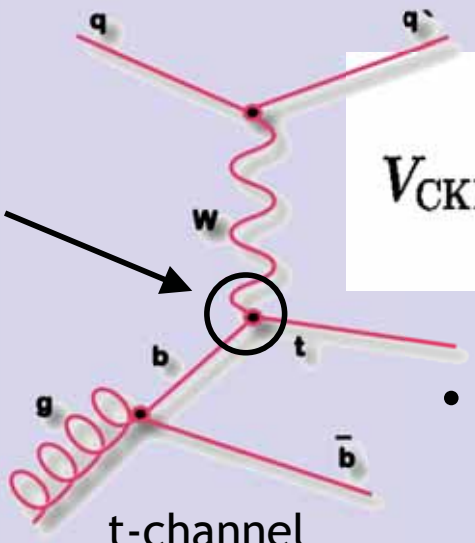
Single top quark production:



s-channel

σ_{NLO} = 0.88±0.07 pb

V_{tb}



t-channel

σ_{NLO} = 1.98±0.21 pb

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- Directly measure V_{tb}

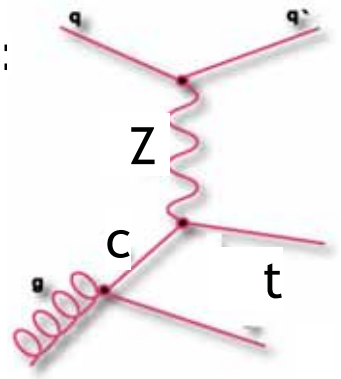
  $\sigma_{Single\ Top} \sim |V_{tb}|^2$

- Source of ~100% polarized top quarks

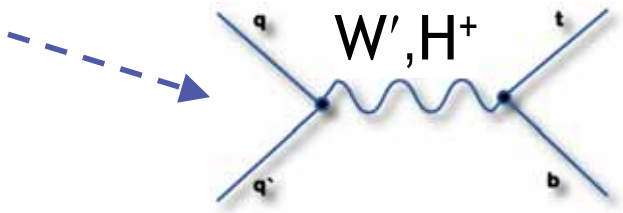
Cross-sections at m_t=175GeV/c^2, B.W. Harris *et al.*, Phys.Rev. D70 (2004) 114012, Z. Sullivan hep-ph/0408049

Sensitivity to New Physics and WH

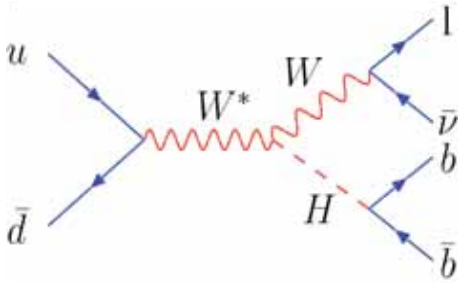
- Single top rate can be altered due to the presence of New Physics:
  - t-channel signature: Flavor changing neutral currents (*t-Z/γ/g-c* couplings)

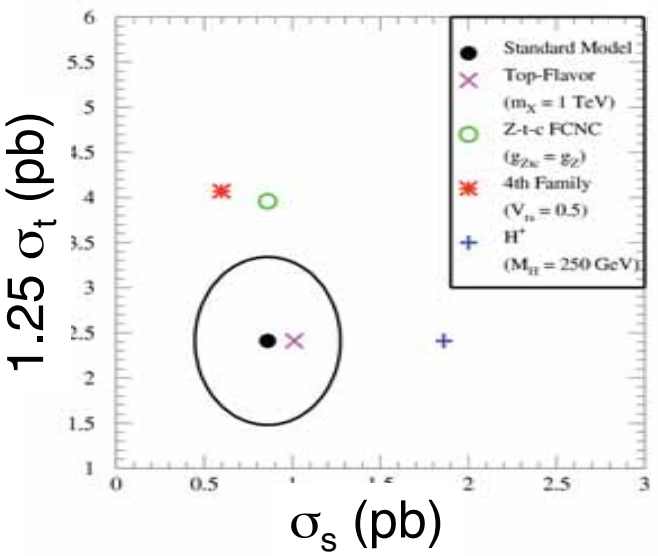


  - s-channel signature: Heavy *W'* boson (later), charged Higgs H^+, Kaluza Klein excited W_{KK}



- s-channel single top has the same final state as WH→lνbb
- Same analysis tools can be applied!



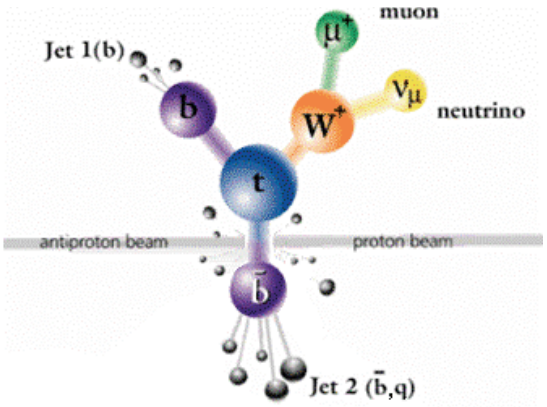


Tait, Yuan PRD63, 014018(2001)

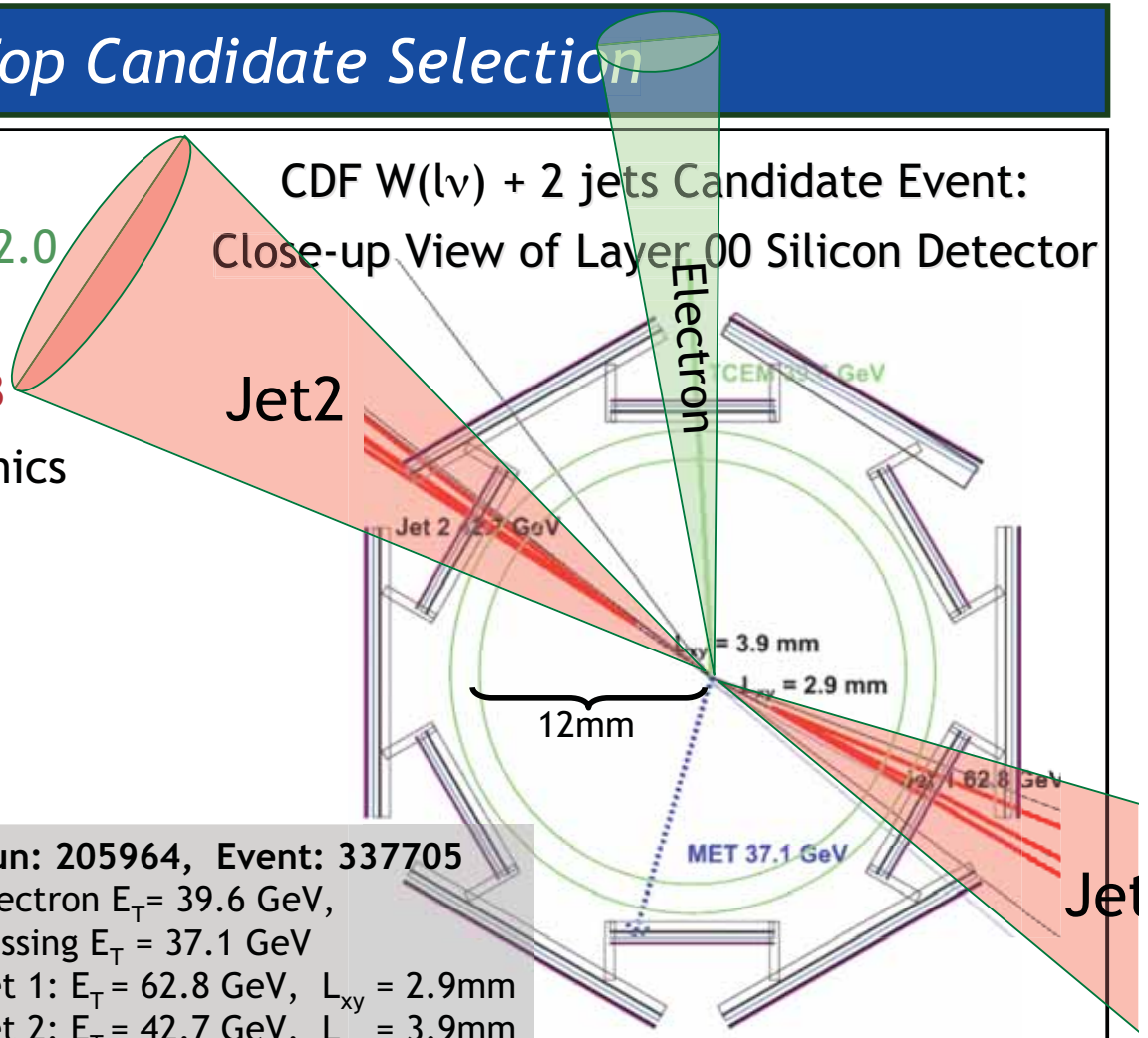
Single Top Candidate Selection

Event Selection:

- 1 Lepton, E_T >15 GeV, $|\eta|$< 2.0
- **Missing E_T** (MET) > 25 GeV
- **2 Jets,** E_T > 15 GeV, $|\eta|$< 2.8
- **Veto** QCD, Conversions, Cosmics
- **At least one b-tagged jet,** (secondary vertex tag)



CDF W(lν) + 2 jets Candidate Event:
Close-up View of Layer 00 Silicon Detector



Run: 205964, Event: 337705
Electron E_T= 39.6 GeV,
Missing E_T = 37.1 GeV
Jet 1: E_T = 62.8 GeV, L_{xy} = 2.9mm
Jet 2: E_T = 42.7 GeV, L_{xy} = 3.9mm

Number of Events / 955 pb^{-1}	Single Top	Background	S/B	S/√B
W(lν) + 2 jets	74	15500	~1/210	~ 0.6
W(lν) + 2 jets + b-tag	38	540	~1/15	~ 1.6

Background Estimate

Top/EWK (WW/WZ/Z→ττ, ttbar)

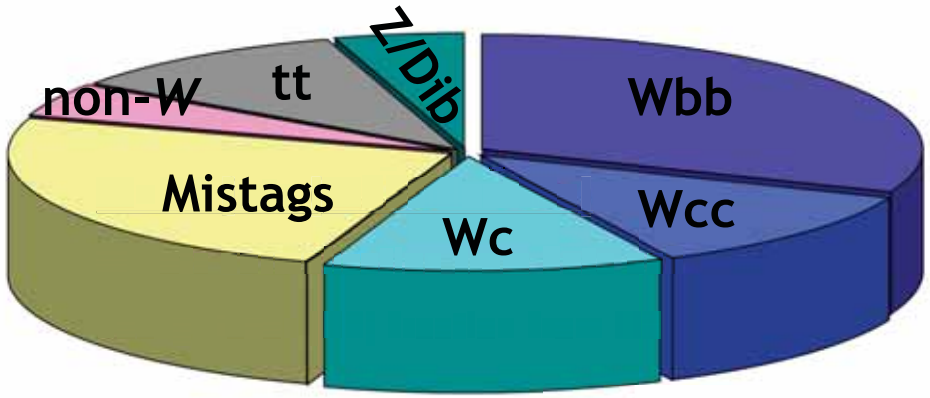
- MC normalized to theoretical cross-section

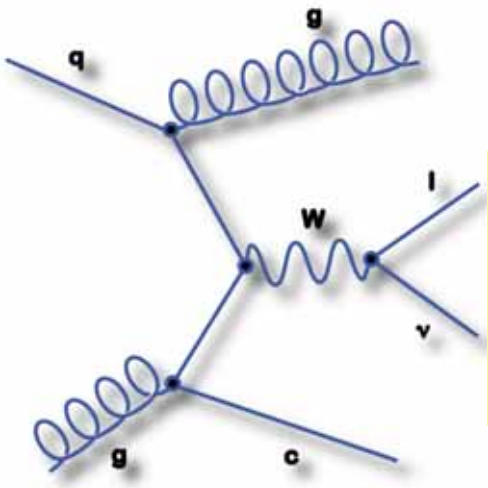
W+HF jets (Wbb/Wcc/Wc)

- W+jets normalization from data and heavy flavor (HF) fractions from ALPGEN Monte Carlo, calibrated in generic multijet data

Non-*W (QCD)*

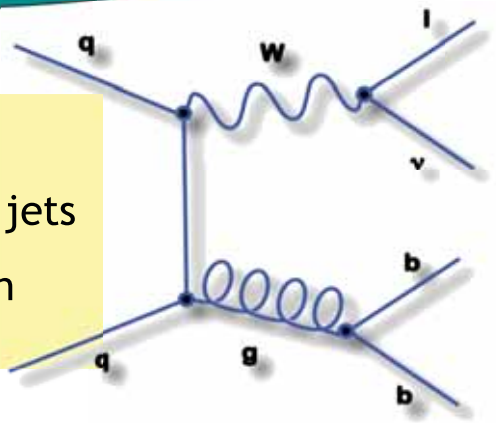
- Multijet events with semileptonic *b*-decays or mismeasured jets
- Fit low missing E_T data and extrapolate into signal region





Mistags (W+2jets)

- Falsely tagged light quark or gluon jets
- Mistag probability parameterization obtained from inclusive jet data

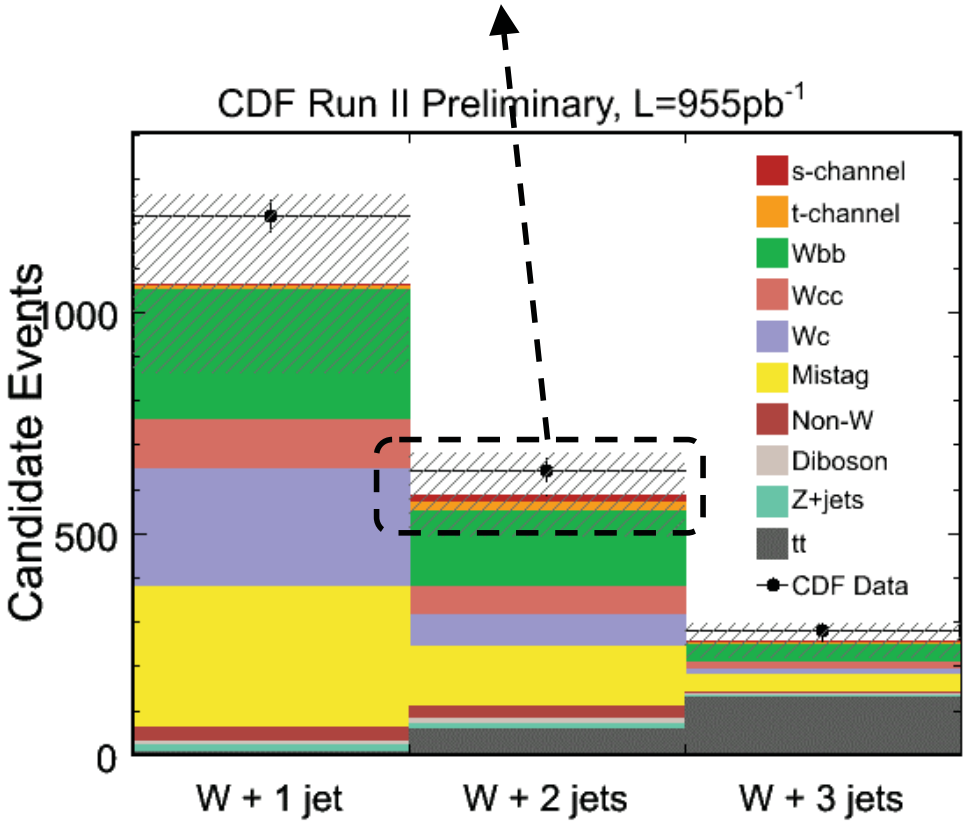


Signal and Background Event Yield

CDF Run II Preliminary, L=955 pb^{-1}
Event yield in W + 2 jets

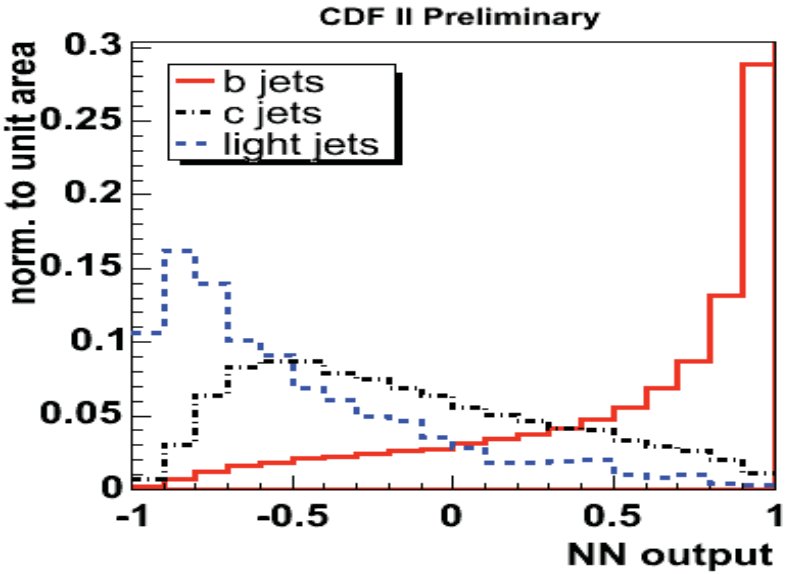
s-channel	15.4 ± 2.2
t-channel	22.4 ± 3.6
tt	58.4 ±13.5
Diboson	13.7 ± 1.9
Z + jets	11.9 ± 4.4
Wbb	170.9 ± 50.7
Wcc	63.5 ± 19.9
Wc	68.6 ± 19.0
Non-*W*	26.2 ± 15.9
Mistags	136.1 ± 19.7
Single top	37.8 ± 5.9
Total background	549.3 ± 95.2
Total prediction	587.1 ± 96.6
Observed	644

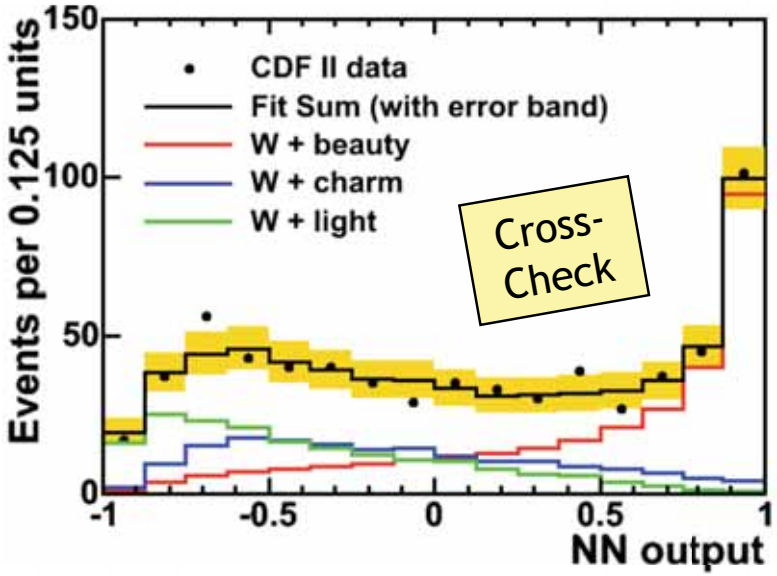
Single top hidden behind
background uncertainty!
→ Makes counting experiment impossible!



Jet Flavor Separation

- Train Neural Network with secondary vertex tracking information (25 input variables) to distinguish b/c/light quark jets
- Optain good jet-flavor separation!
- Tool used in all single top analyses
- Improves sensitivity by ~15-20%!





Cross-check W+jets composition

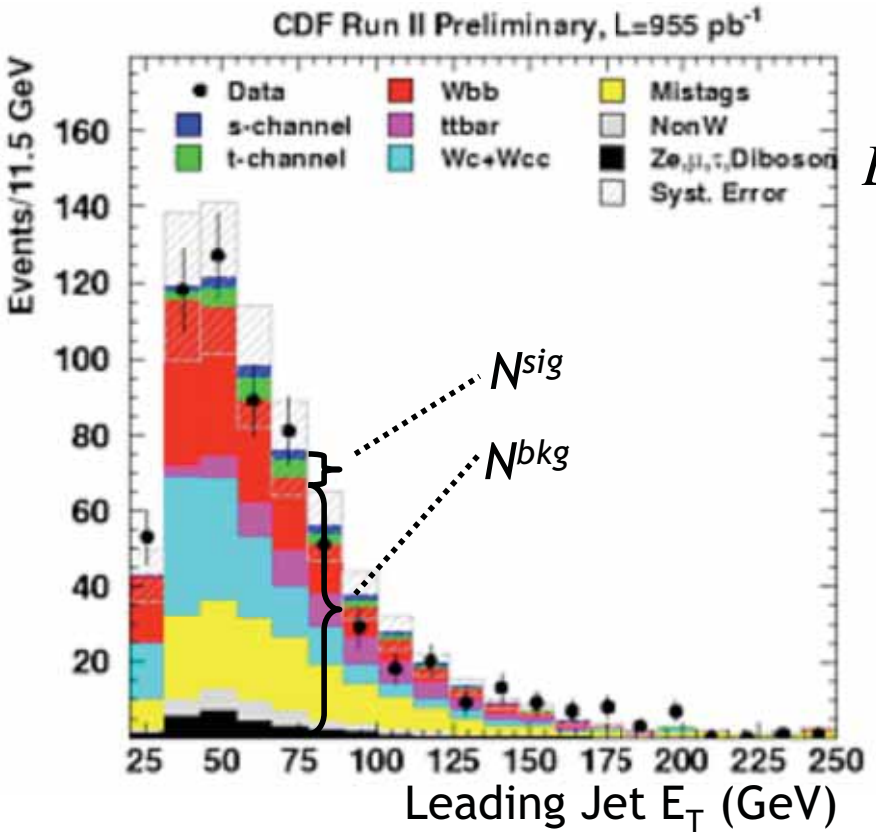
	Background Estimate	Neural Network Fit
W+bottom	299.0 ± 56.8	292.8 ± 26.3
W+charm	148.1 ± 39.4	171.6 ± 53.8
Mistags	140.0 ± 19.8	179.5 ± 42.5
Sum	587.1 ± 96.6	644.0

Likelihood Analysis

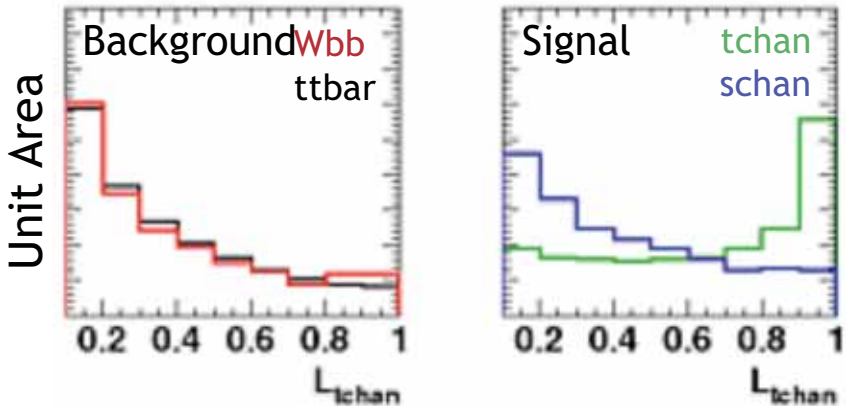
Neural Network Analysis

Matrix Element Analysis

The Likelihood Function Analysis



$$LF(\vec{x}) = \frac{\prod_{i=1}^{n_{var}} p^i_{sig}(x_i)}{\prod_{i=1}^{n_{var}} p^i_{sig}(x_i) + \prod_{i=1}^{n_{var}} p^i_{bkg}(x_i)}$$



$$p_i^{sig} = \frac{N_i^{sig}}{N_i^{sig} + N_i^{bkg}}$$

i, indexes input variable

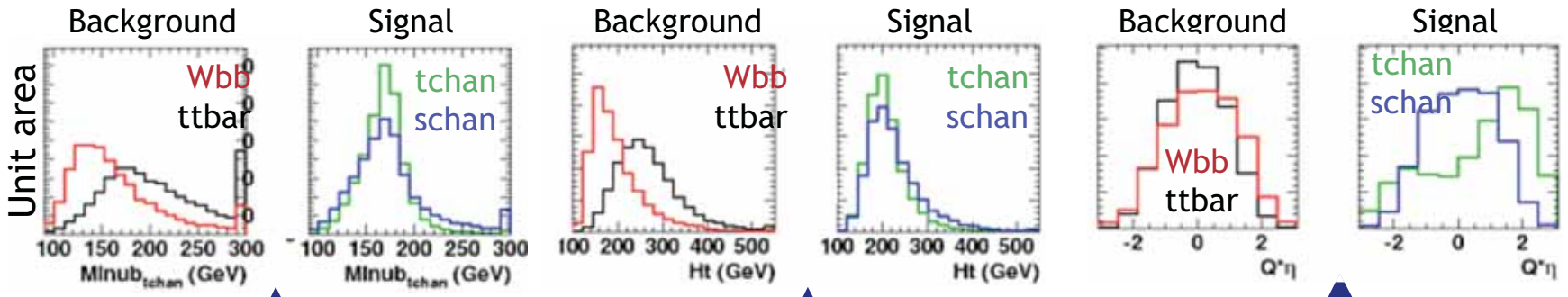
Uses 8 (5) kinematic variables for t-channel (s-channel) Likelihood Function

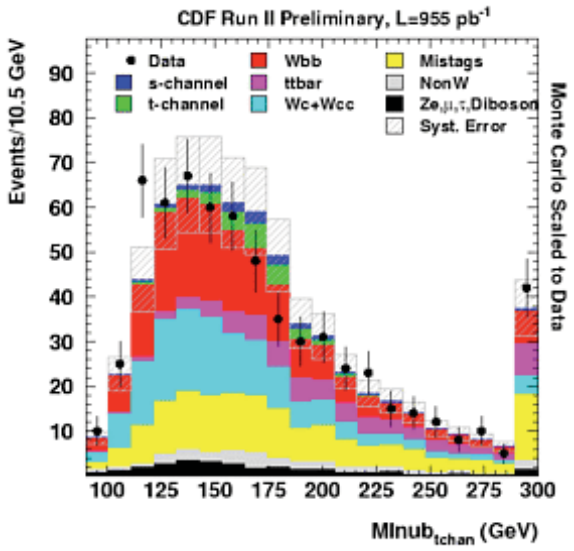
I.e. *M(Wb), H_T, QxEta, Neural Network flavor separator, Madgraph Matrix Elements etc.*

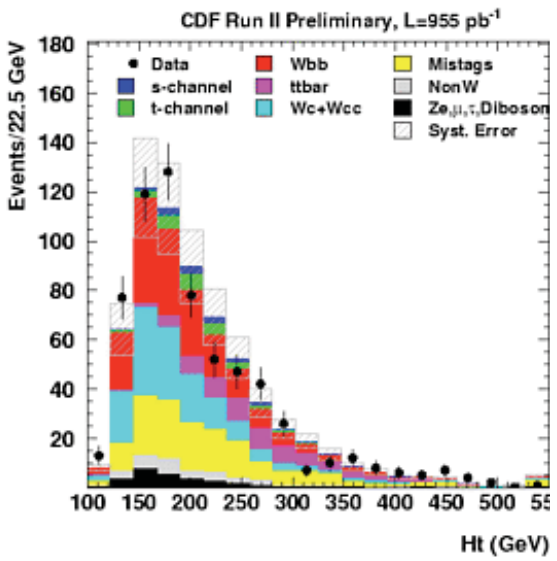
Expected signal significance: 2.0 σ

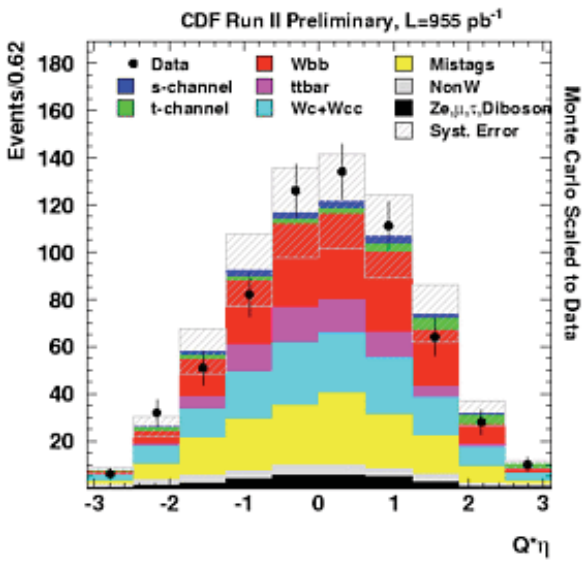
Kinematic Variables

Mass(W,b) $H_T = \Sigma E_T$(lepton,MET,Jets) QxEta(un-tagged jet)









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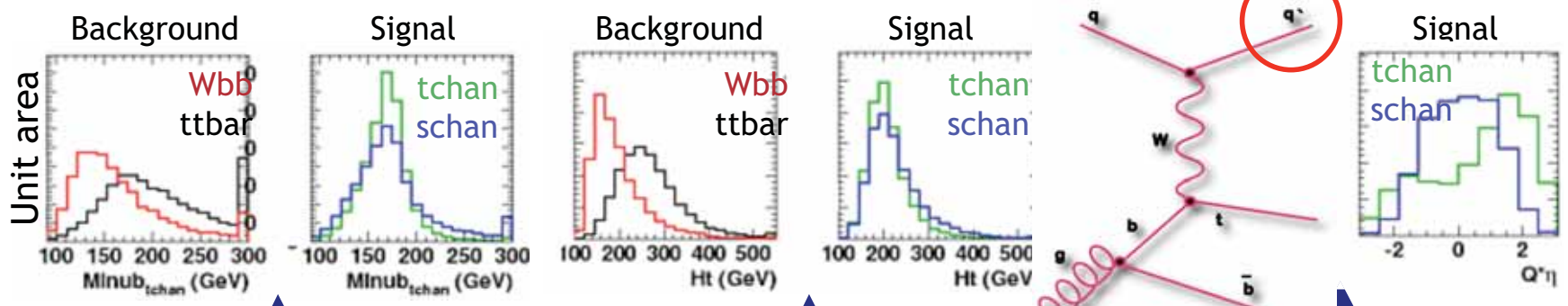
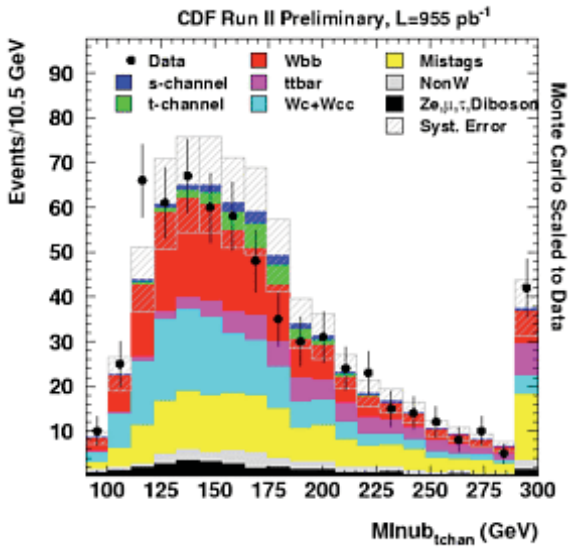
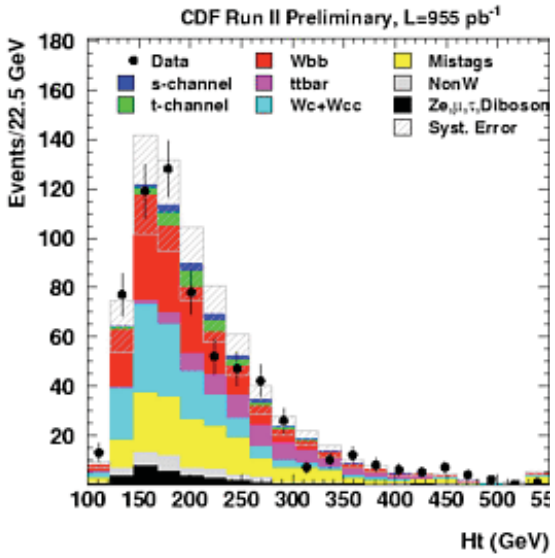
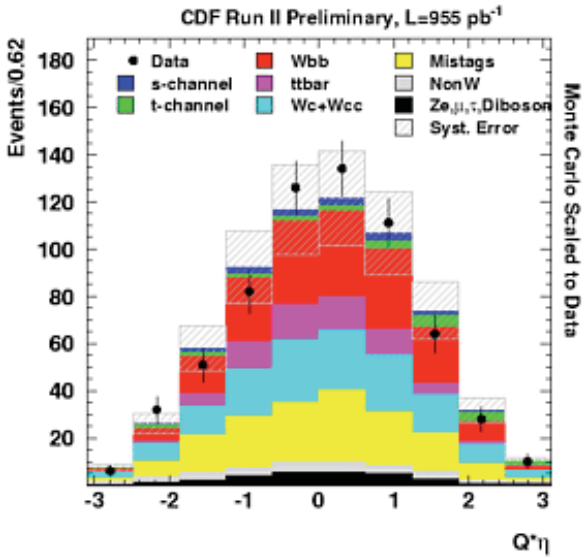








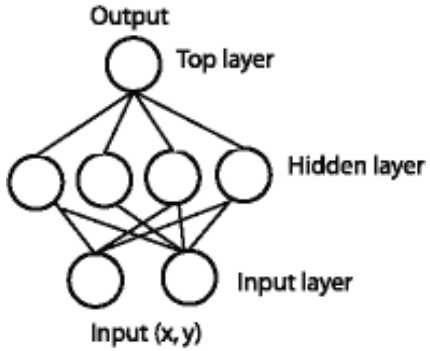
Likelihood Analysis

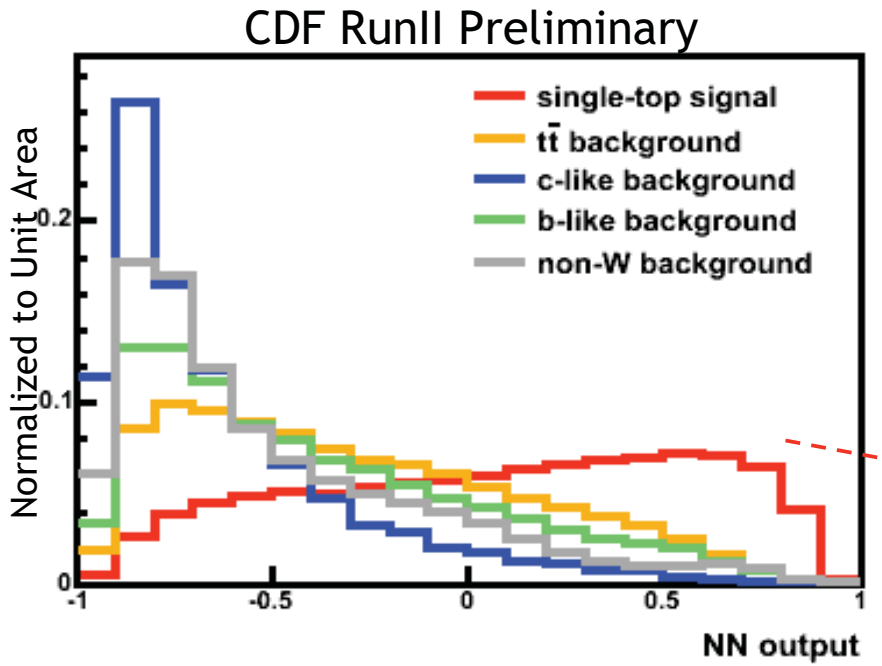
Neural Network Analysis

Matrix Element Analysis

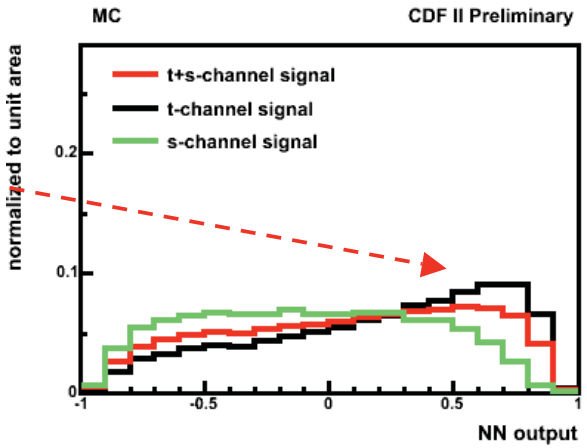
Neural Network Analysis

- NeuroBayes Neural Network
- 26 Input variables, kinematic and event shape related, including b-tagging flavor separator, M(W,b), $M(j_1,j_2)$, H_T, number of soft jets, kinematic fitter chi^2, angular variables, etc..
- Continous output between -1 (bkg like) and +1 (sig like)
- Three networks: s-channel, t-channel and combined s+t

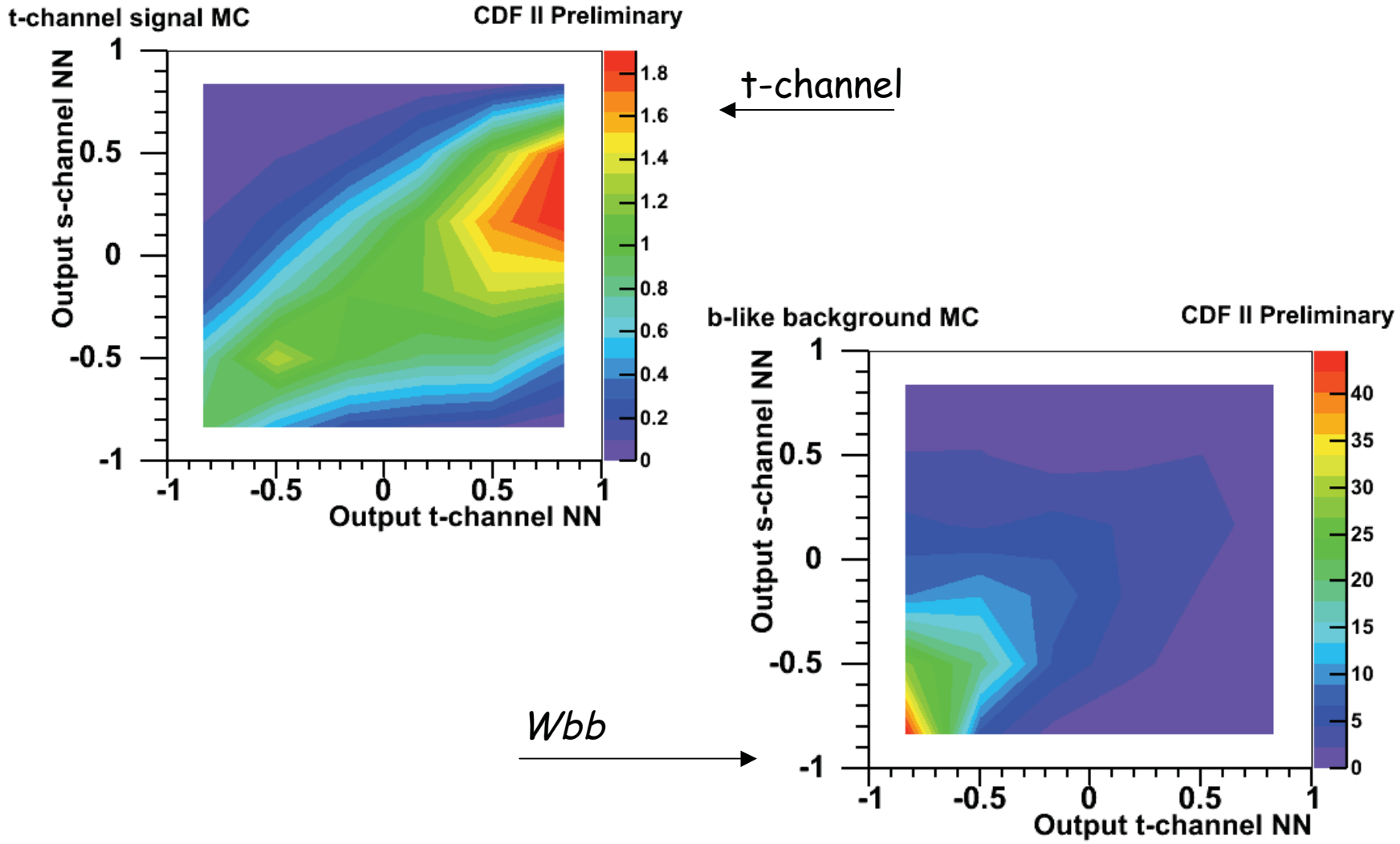




Expected signal significance: 2.6σ



Neural Network Analysis - Separate Search



- Two NN's trained separately for s-channel and t-channel (same input variables)

Likelihood Analysis

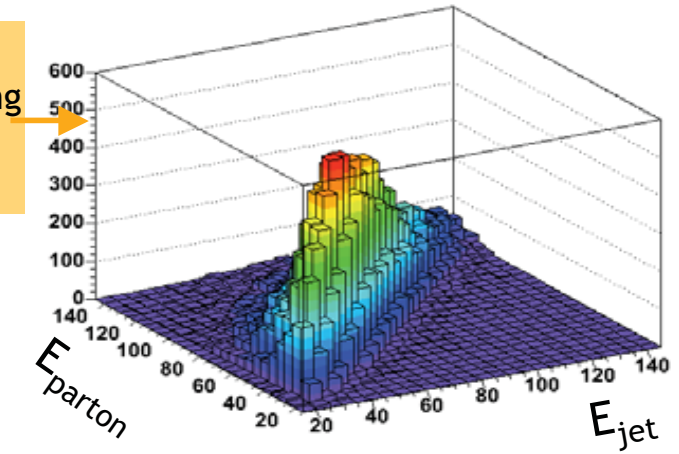
Neural Network Analysis

Matrix Element Analysis

Matrix Element Method

- Pioneered by top quark mass analyses
- Now applied to a search!
- Calculate event probability for signal and background

W(E$_{jet}$,E$_{part}$) gives the probability of measuring a jet energy E$_{jet}$ when E$_{part}$ was produced



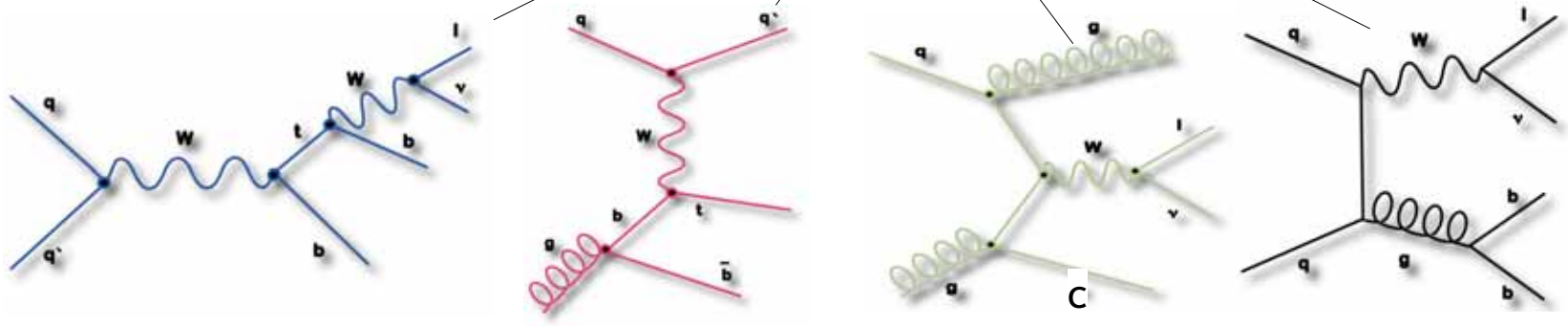
Integration over part of the phase space Φ_4

Leading Order matrix element (MadEvent)

$$P(p_l^\mu, p_{j1}^\mu, p_{j2}^\mu) = \frac{1}{\sigma}\int d\rho_{j1} d\rho_{j2} dp_\nu^z \sum_{comb} |M(p_i^\mu)|^2 \frac{f(q_1)f(q_2)}{|q_1||q_2|} \phi_4 W_{jet}(E_{jet}, E_{part})$$

Inputs only lepton and 2 jets 4-vectors!

Parton distribution functions



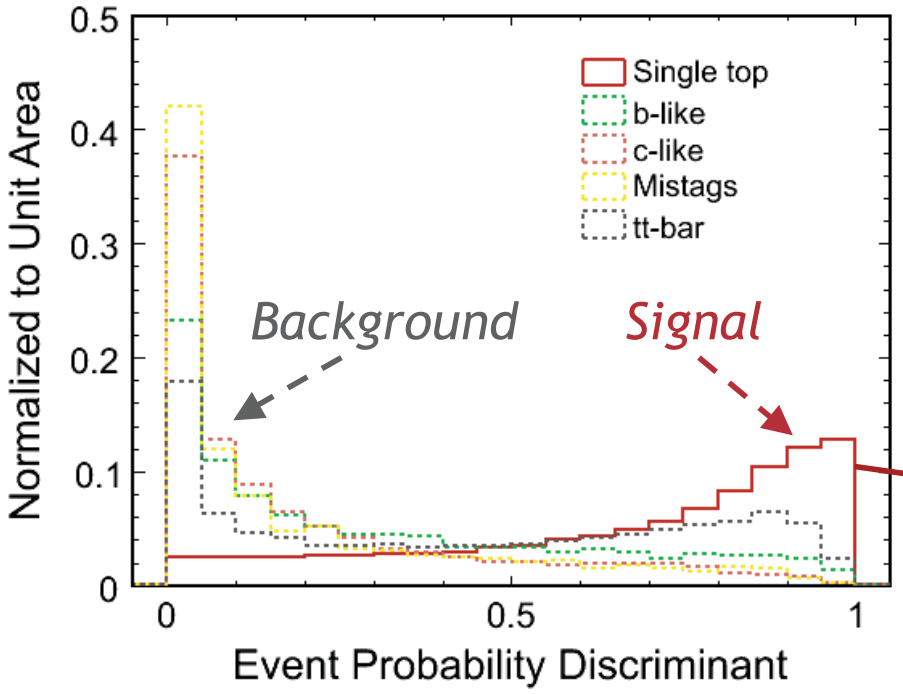
Event Probability Discriminant (EPD)

- We compute probabilities for signal and background hypothesis per event
  ⇒Use full kinematic correlation between signal and background events

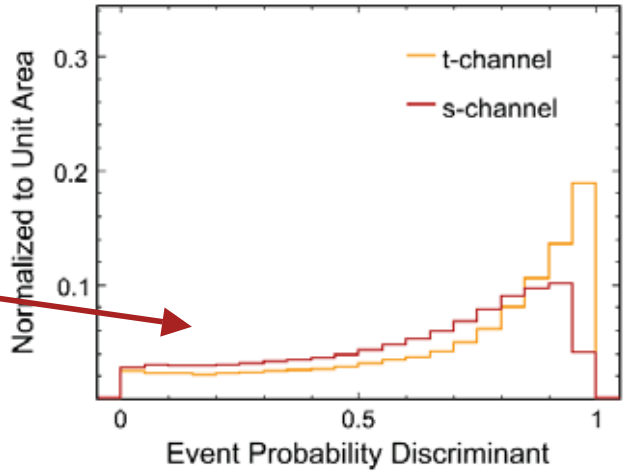
- Define ratio of probabilities as event probability discriminant (EPD):

$$EPD = \frac{b \cdot P_{\sin gletop}}{b \cdot P_{\sin gletop} + b \cdot P_{Wbb} + (1-b) \cdot P_{Wcc} + (1-b) \cdot P_{Wcj}}$$

;b = Neural Network b-tagger output



Expected signal significance: 2.5σ



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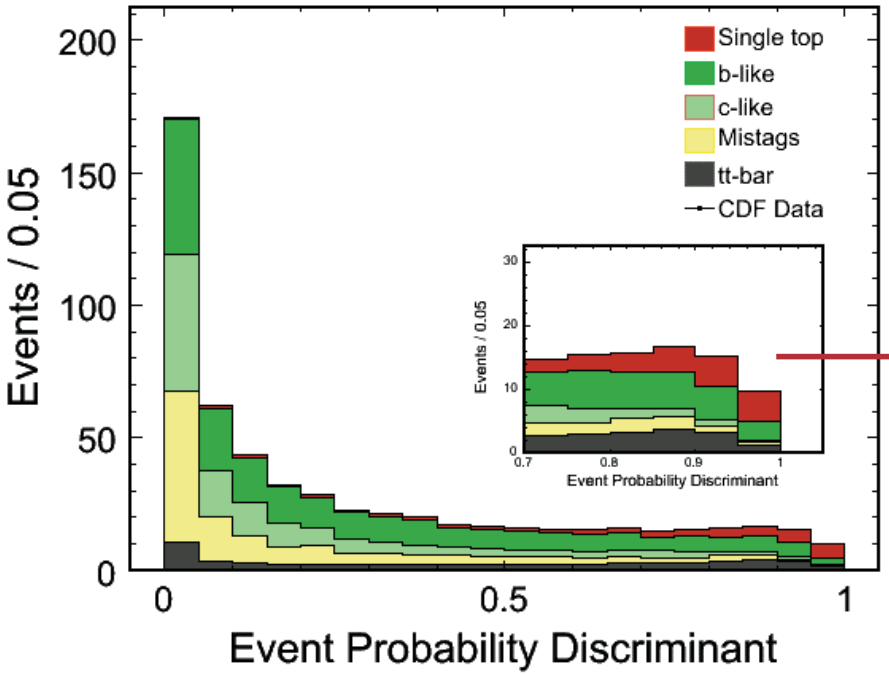

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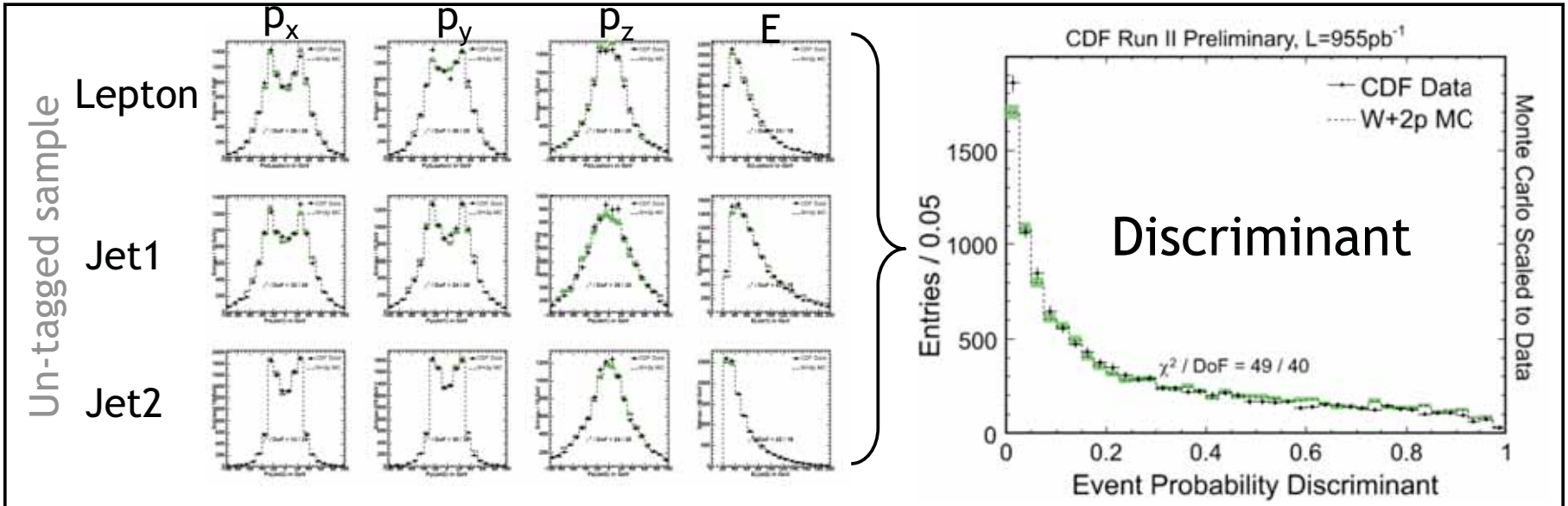
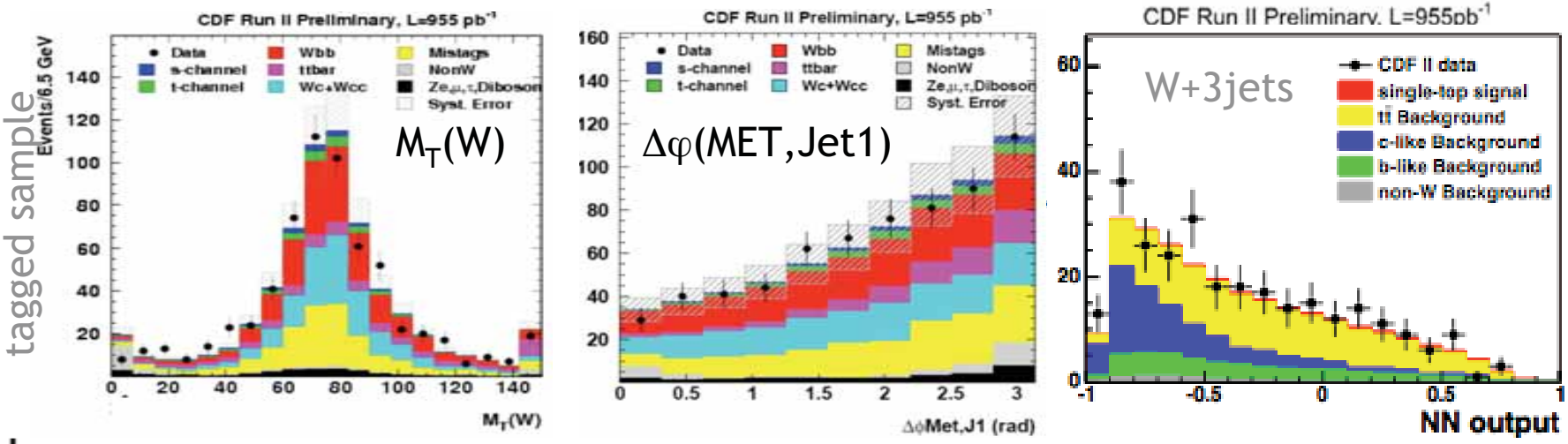
Analysis Cross-Checks



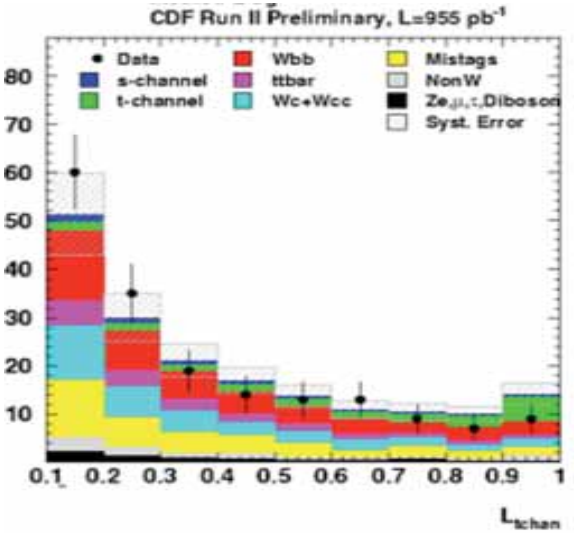
Many validation plots in signal and control samples



Results

CDF Single Top Results

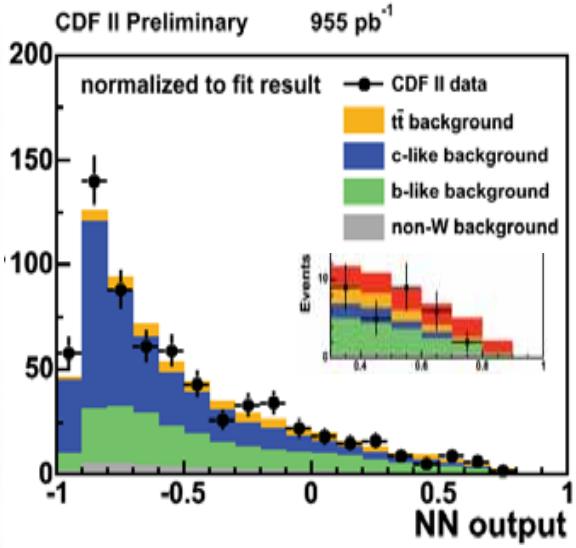
Likelihood



No evidence of signal

σ_{s+t}<2.7pb at 95% C.L.

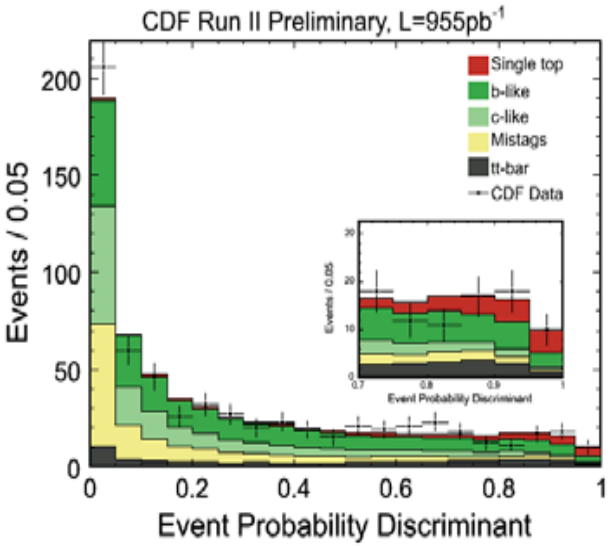
Neural Networks



No evidence of signal

σ_{s+t}<2.6pb at 95% C.L.

Matrix Element

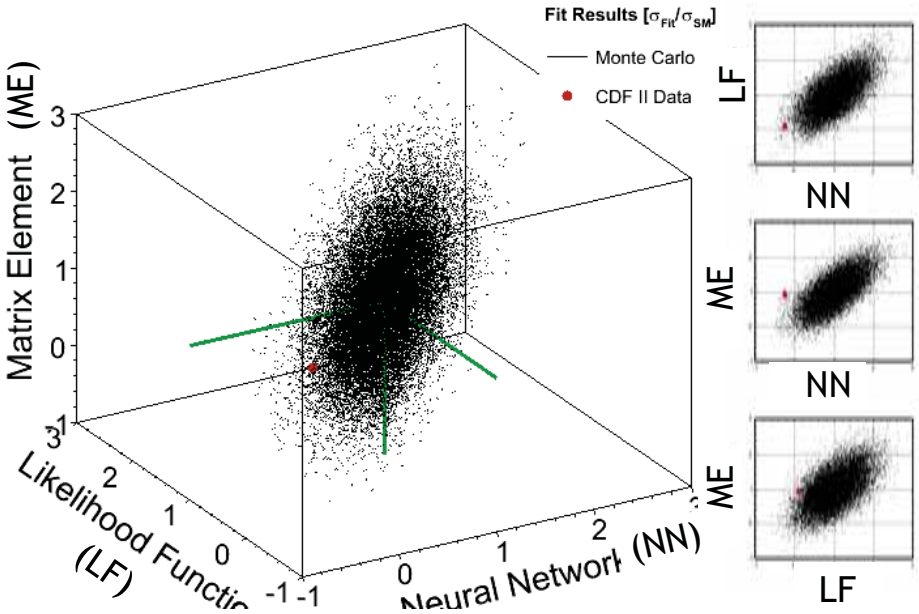


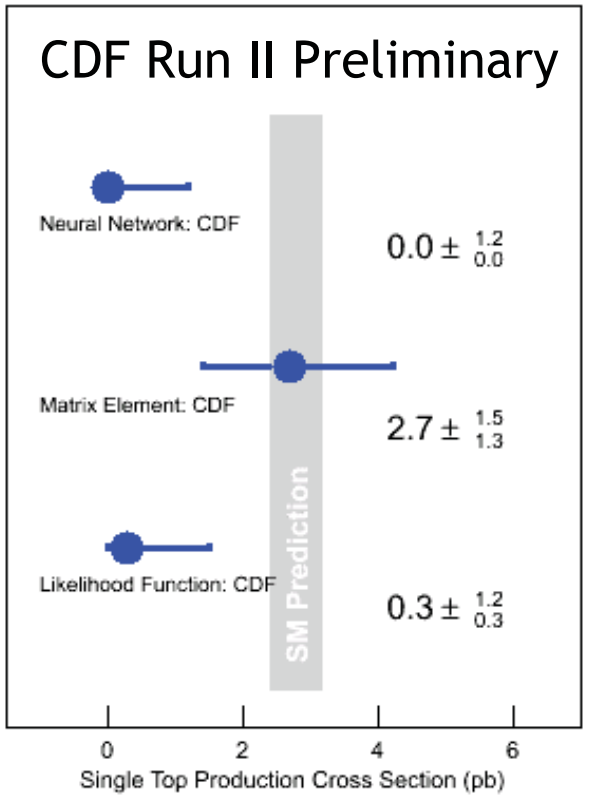
p-value = 1.0% (2.3σ)

σ_{s+t}=2.7(+1.5/-1.3)pb

Compatibility of CDF Results

- Performed common pseudo-experiments
  - Use identical events
  - ME uses only 4-vectors of lepton, Jet1/Jet2
  - LF/NN uses sensitive event variables
  - Correlation among analyses: ~60-70%
  - 1.2% of the pseudo-experiments had an outcome as different as the one observed in data (using BLUE)

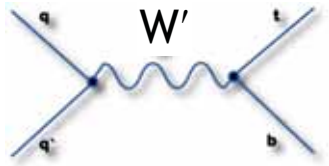




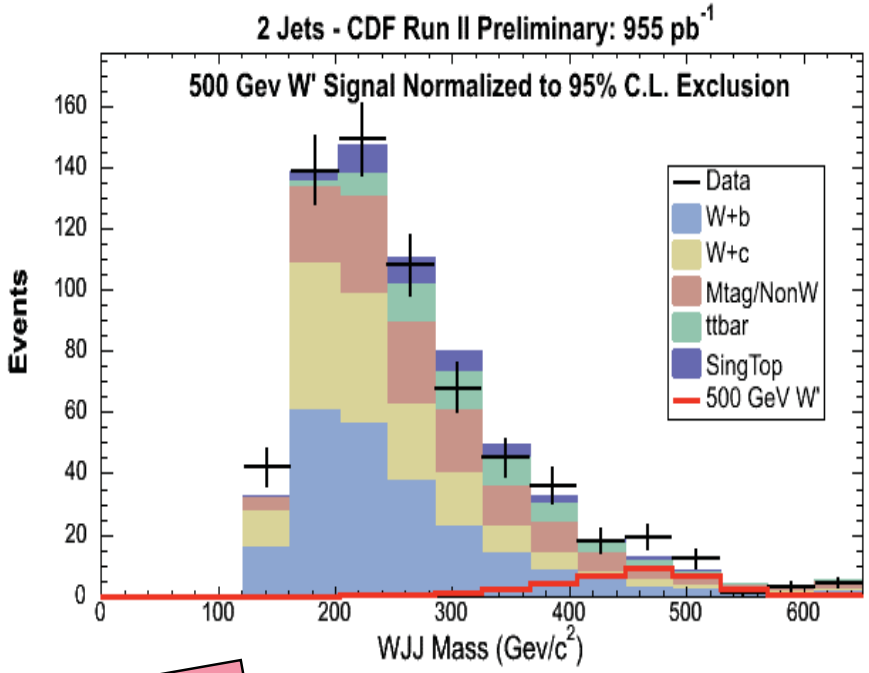
- *Extensive cross-checks performed*
- *Next round of analysis will show weather this outcome persists.*

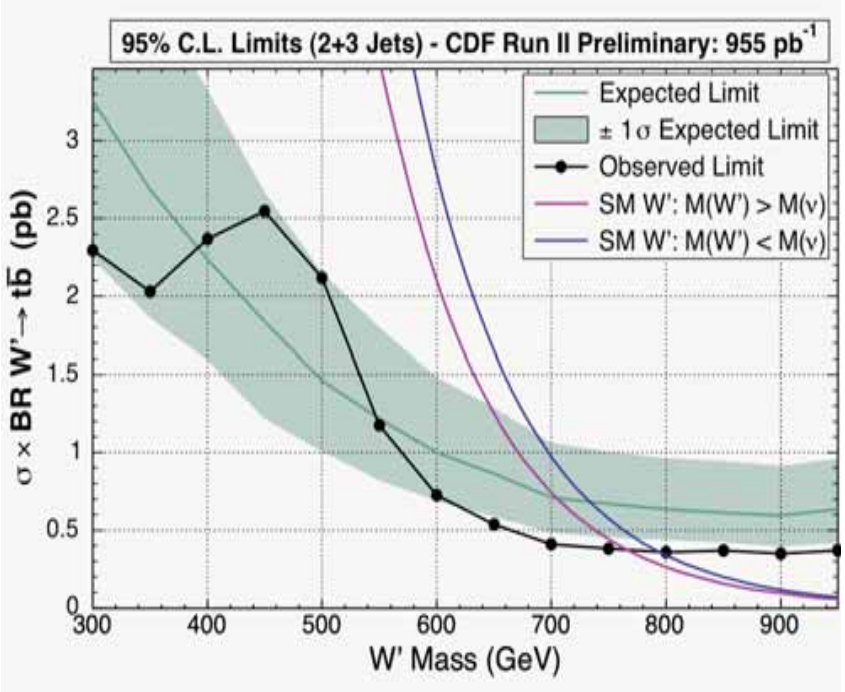
Search for Heavy W′ Boson

- Search for heavy W′ boson in W + 2, 3 jets
- Assume Standard Model coupling strengths
  (Z. Sullivan, Phys. Rev. D 66, 075011, 2002)
- Perform fit to M_{Wjj} distribution



Previous Limits:
- CDF Run I: $M(W'_R) > 566$ GeV/c^2 at 95% C.L.
- D0 Run II: $M(W'_R) > 630$ GeV/c^2 at 95% C.L.





New Result!

Limit at 95% C.L. $M(W') > 760$ GeV/c^2 for $M(W') > M(\nu_R)$

$M(W') > 790$ GeV/c^2 for $M(W') < M(\nu_R)$

Conclusions

- Single top production probes V_{tb} and is sensitive to new physics
- Presented three analyses using different techniques to separate signal from large background
  - At CDF we have a ~2.5σ sensitivity to a single top signal per analysis and ~3.0σ for a combined meta analysis using all three discriminants
  - Neural Network and Likelihood Function analysis show deficit in signal region.
  - With more data and further improvements we learn what the data is telling us
- First CDF Run II limit on heavy W′ Boson, $m_{W'}>760$ GeV/c^2 at 95% C.L.
  More searches for new phenomena in the 'single top sample' upcoming
- Exciting times! We are working towards the 2fb^{-1} analysis.
- Improved b-tagging, improved lepton acceptance etc..
- This will be the year of very interesting single top physics!