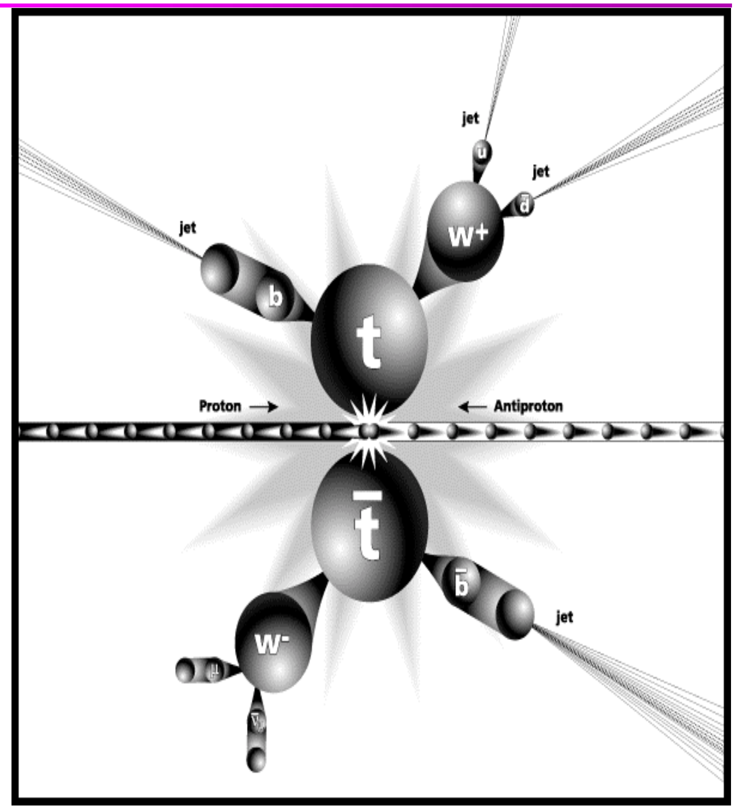
Top Quark Physics and Higgs Searches in Run 2 at the Tevatron

- Introduction
- Top Rates/Measurements
  - Where could Advanced Algorithms be useful?
- Single Top Quark Search
  - Dzero and CDF Results with Neural Nets.
- Higgs Searches



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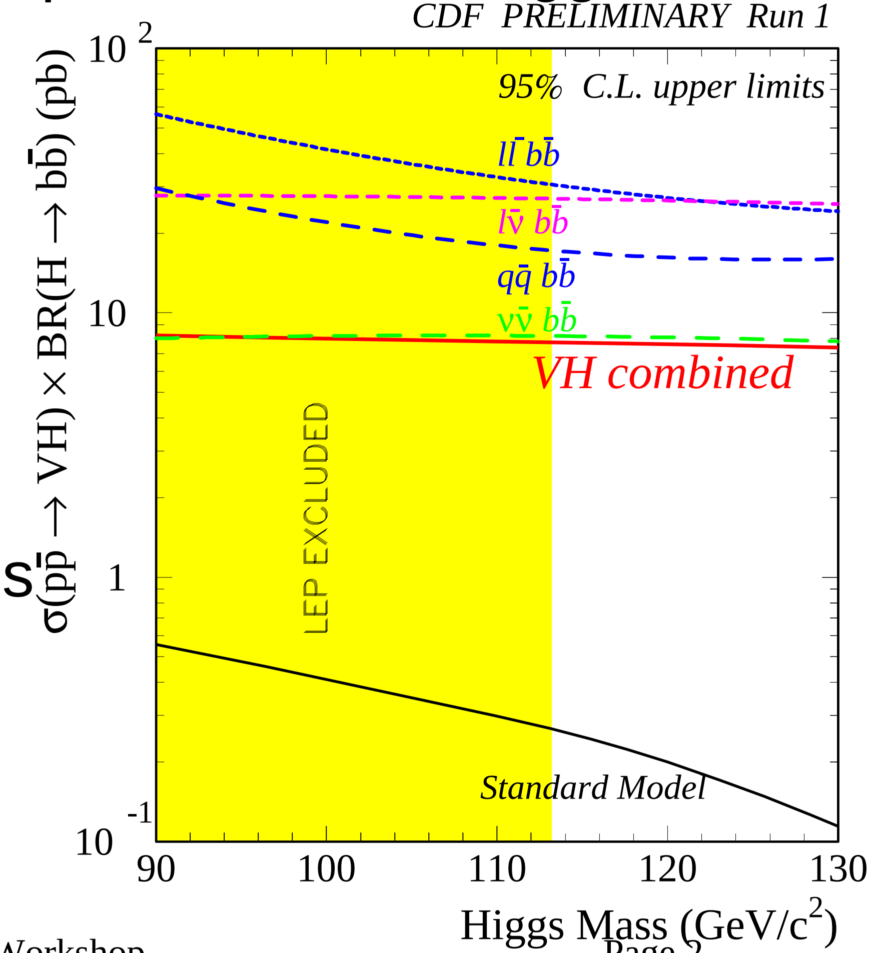
What makes top and higgs Tough

- The creation of $t\bar{t}$ pairs, single top quarks, and the higgs boson are very rare processes:
  - tt Cross Section: 6.8 pb
  - Single Top Cross Section: ~2.5 pb
  - Higgs Cross Section: >> 1 pb
- The backgrounds are large.
  - W+Jet Production: ~100 pb (>2j)
  - Multijet
- In order to reduce the backgrounds tight selection and very specific decay modes must be used.
  - Leptonic Decay of the W
  - B-tagging Required



Top Physics in Run 2

- The collection of 2 fb^{-1} of integrated luminosity will allow us to explore the top quark in much greater detail than in Run 1.
  - However, the statistics are still low!
- From the CDF Run 2(a) TDR (Based on Traditional Analyses)

Decay Channel	Event Yield (2 fb^{-1})
Produced tt	13,600
Dilepton (ee,μμ,eμ)	155
Tau Dileptons (eτ,μτ)	19
e,μ + >=3 jets	1520
e,μ + >=3 jets+>=1 b-tag	990
mass sample w/ >=1 b-tag	790
mass sample w/ >=2 b-tags	240

Estimated Sensitivities of Top Measurements

- From CDF Run 2(a) TDR

Measurement	Est. Uncertainty
M_t	2-3 GeV/c^2
$\delta\sigma_{tt}$	9%
$\delta[\sigma_{ll}/\sigma_{l+j}]$	12%
$\delta[B(t\rightarrow Wb)/B(t\rightarrow WX)]$	2.8%
$\delta[B(t\rightarrow Wb)/B(t\rightarrow Xb)]$	9%
$\delta[B(t\rightarrow W_{long})]$	5.5%
+ others…	

- Searches:
  - Single Top Production (cross section, V_{tb})
  - X->tt
  - Rare Decays

Where Can Advanced Algorithms be useful?

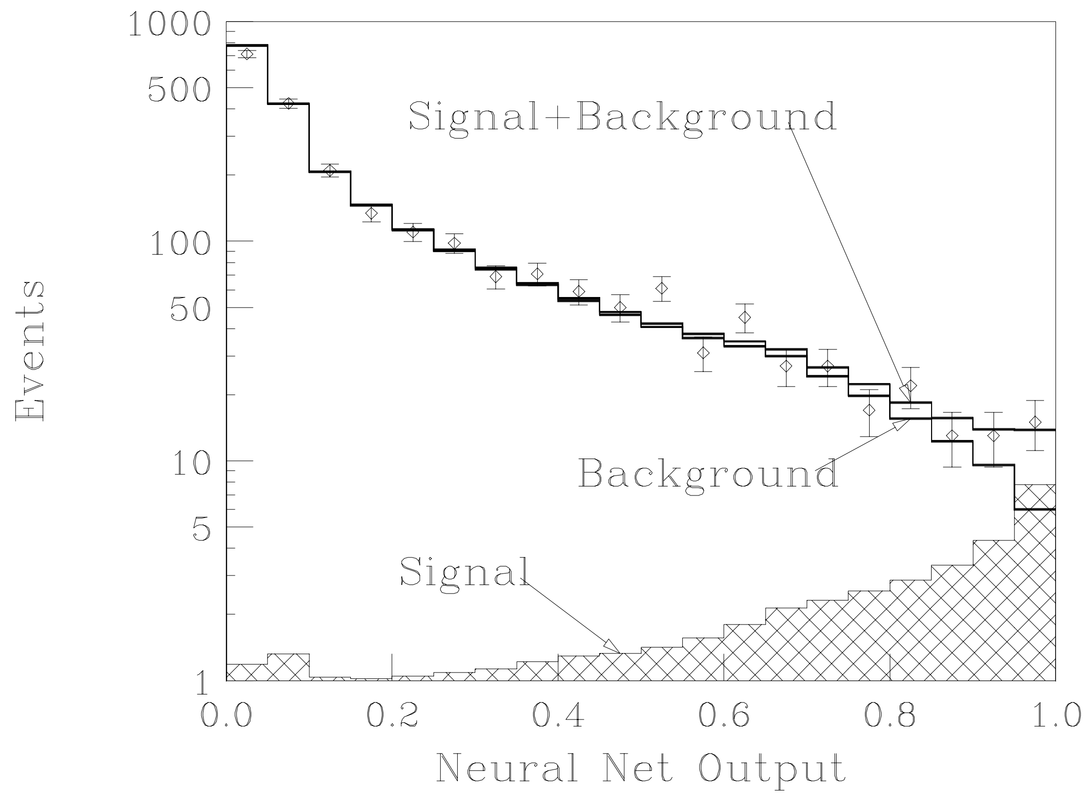
- Analyses where backgrounds are high even with the usual tight selection (W-> lep, b-tagging), ***for example***:
  - Single Top Quark Search
  - Tau decay modes
  - All Hadronic Decay Mode
    - D0: Phy Rev. Lett 82 (1999) 4975
    - CDF TOTEM Analysis
  - Search for X->tt

Understanding rates into different decay channels tells us about how the top is decaying

- As a tool (not necessarily end result)
  - Fitting of complex multi-dimensional templates (p.d.f.)

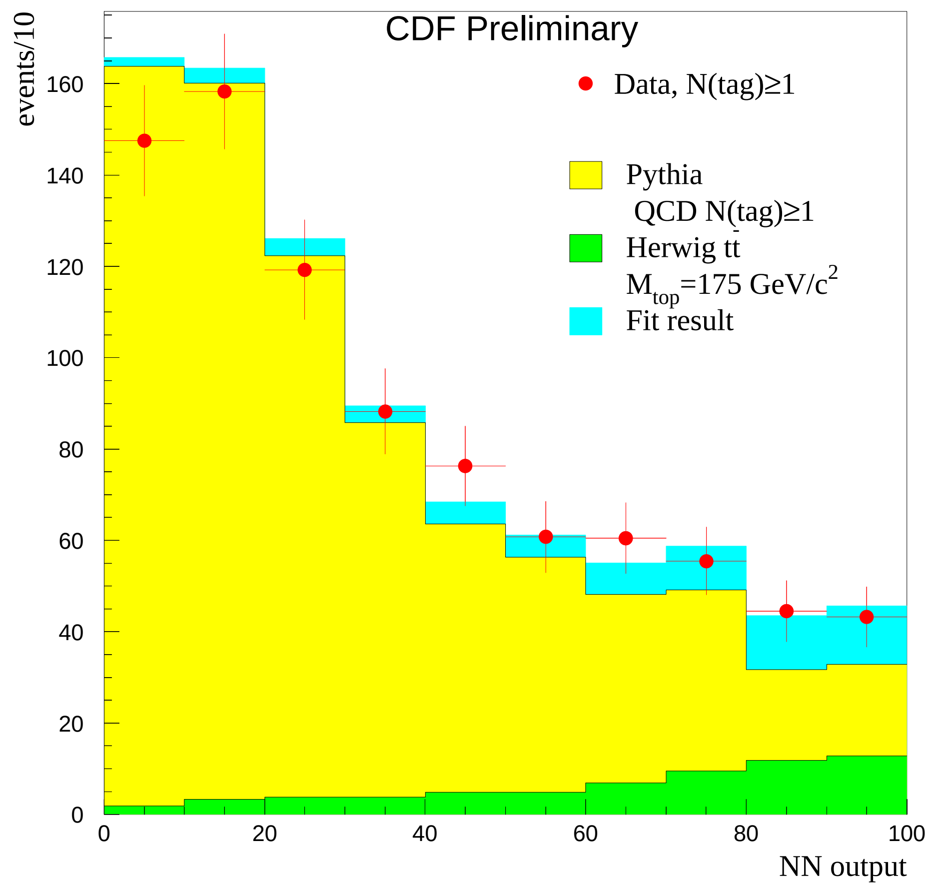
All Hadronic Decay Mode Cross Section (DØ)

- Preliminary event selection includes
  - 6 or more jets
  - soft muon b-tag
- Two NN are used
  - First has 10 inputs involving energy flow.
    - e.g jet E_T, Sphericity
  - Second uses output of first NN, P_T soft m, mass and jet shape.
- $\sigma_{tt} = 5.9 \pm 1.2 \pm 1.1$ pb



All Hadronic Decay Mode Cross Section (CDF)

- Preliminary event selection includes
  - 6 or more jets
  - displaced Vtx b-tag
- Analysis used TOTEM card (hardware implementation of NN)
- σ_{tt} = 8.6 +/- 1.9 +/- 1.5 pb



Template Fitting (e.g. Top Mass)

- Many analyses (e.g. Top Mass fitting) require templates that give the reconstructed quantities versus the desired parameters.
- There is not always an obvious mathematical functional form to parameterize the templates. Neural Net fitting may be a nice option.

ALEPH: HZ⟶$q\bar{q}b\bar{b}$ Search

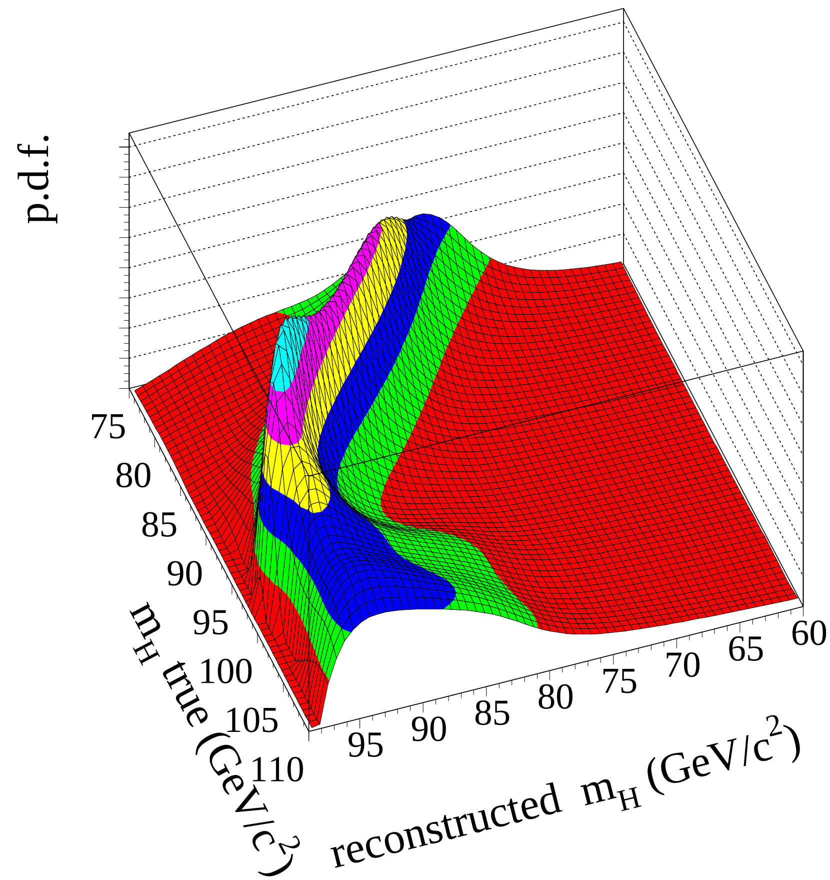
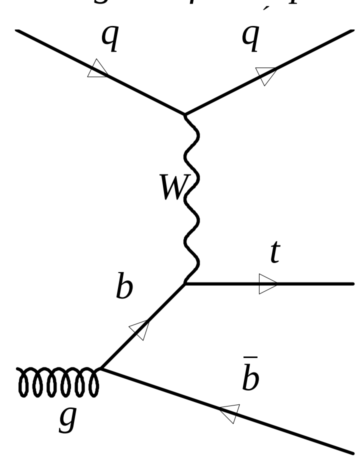


Figure 5: The two-dimensional function, $f(m_H^{reco}, m_H)$, representing the p.d.f. of the reconstructed Higgs mass as a function of the mass m_H, for the channel HZ → $q\bar{q}b\bar{b}$.

Single Top Production

- Predicted by standard model. Direct probe of the strength (V_{tb}) of the electroweak vertex t-W-b. **Background for Higgs events.**
- W-gluon fusion (t-channel):
  - Hard b-jet, W decay products, soft b-jet(usually lost), light q jet
  - σ = 1.47±0.22 pb (Stelzer *et al*)
- s-channel W*:
  - 2 hard b-jets, W decay products
  - σ = 0.75±0.12 pb (Smith *et al*)

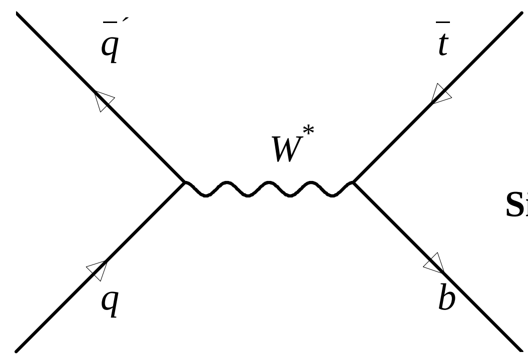
W-gluon fusion process



Signal is W+b+q

Tends to be "forward"

s-channel W process*

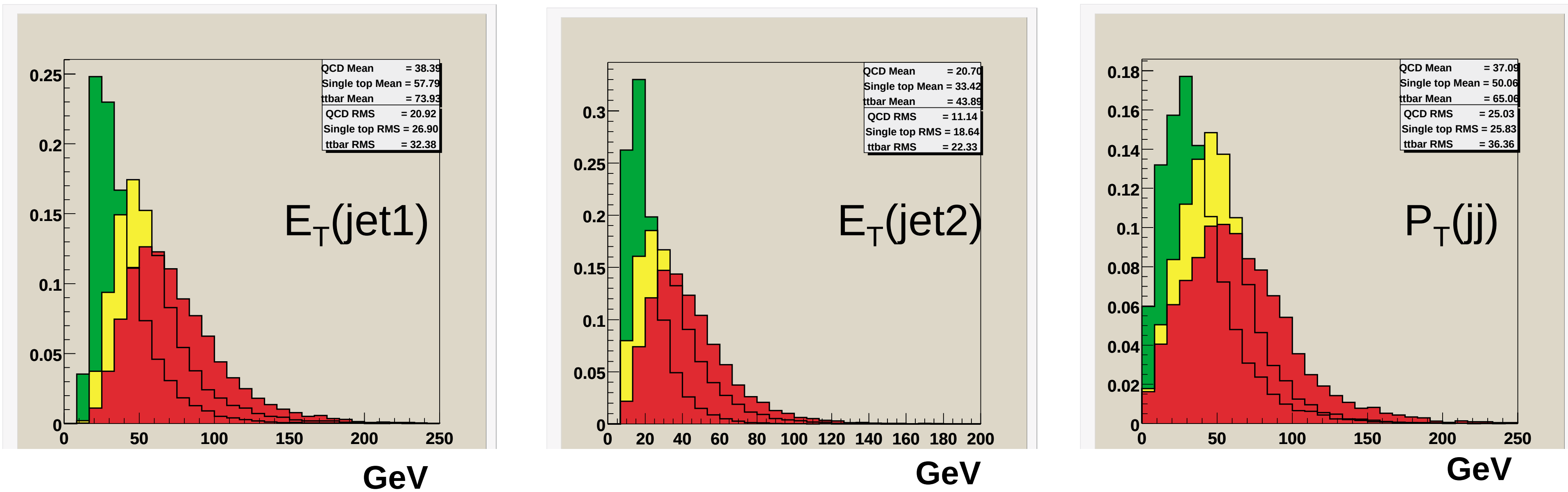


Signal is W+b+$\bar{b}$

Backgrounds for Single Top Quark

- The backgrounds to Single Top Production are substantial.
  - $Wb\bar{b}$ (& $Wc\bar{c}$): same final state particles:
    - Lepton+Neutrino from real W boson
    - Jets tagged as “b”-quarks.
    - $M_{wb} \neq M_{top}$ (In general)
  - tt Production:
    - Lepton+Neutrino from real W boson
    - Jets tagged as “b”-quarks
    - Real top quark! $M_{wb} = M_{top}$
  - Others at a lower rate (e.g. WZ w/ $Z \rightarrow b\bar{b}$)

Representative Kinematic Distributions



- non-top background
- $t\bar{t}$ background
- signal

All histograms normalized to unit area for comparison

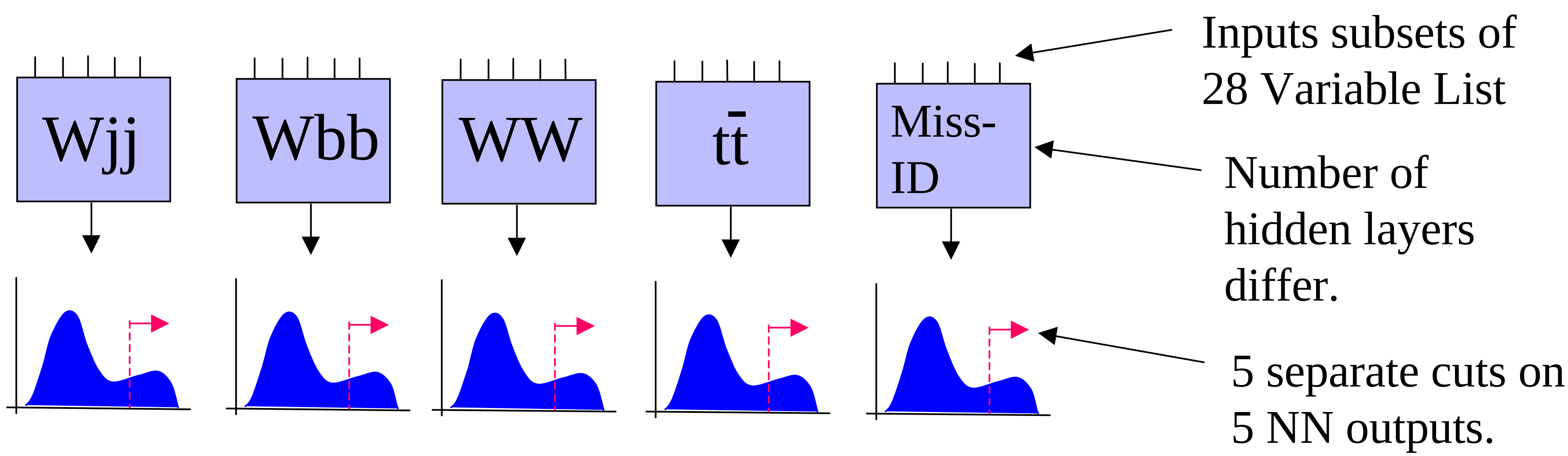
Single Top Measurements

- SM for the Run 1 Tevatron: $\sigma_{s.t.}$~2.2 pb (CDF $t\bar{t}$: σ_{tt}=6.5 pb)
- DØ analyses:
  - Phys.Rev.D **63**: 031101, 2001 (high-P_T *e* or μ, μ tag, E_T sum cuts)
  - Phys.Lett.B **517**: 282, 2001 (high-P_T *e* or μ, tag/notag, Neural Nets array)
- CDF analyses:
  - Phys.Rev.D **65**: 091102, 2002 (high-P_T lepton, *b* tag, $M_{l\nu b}$ cut, 2-tags)
  - NN search (preliminary results)

Analysis	W* (95% C.L. limit in *pb*)	W-g (95% C.L. limit in *pb*)
DØ (1)	39	58
DØ (2)	17	22
CDF (1)	18	13

Single Top Quark Search by DØ

- Search for tb (s-channel) and tqb (t-channel) separately.
- Sample selection starts with initial cuts requiring a lepton+$\not{E}_T$ and jet activity. Sample both with and without b-tagging (via soft μ) are considered.
- Structure of NN Search: 5 Parallel Networks



Expected Number of Events

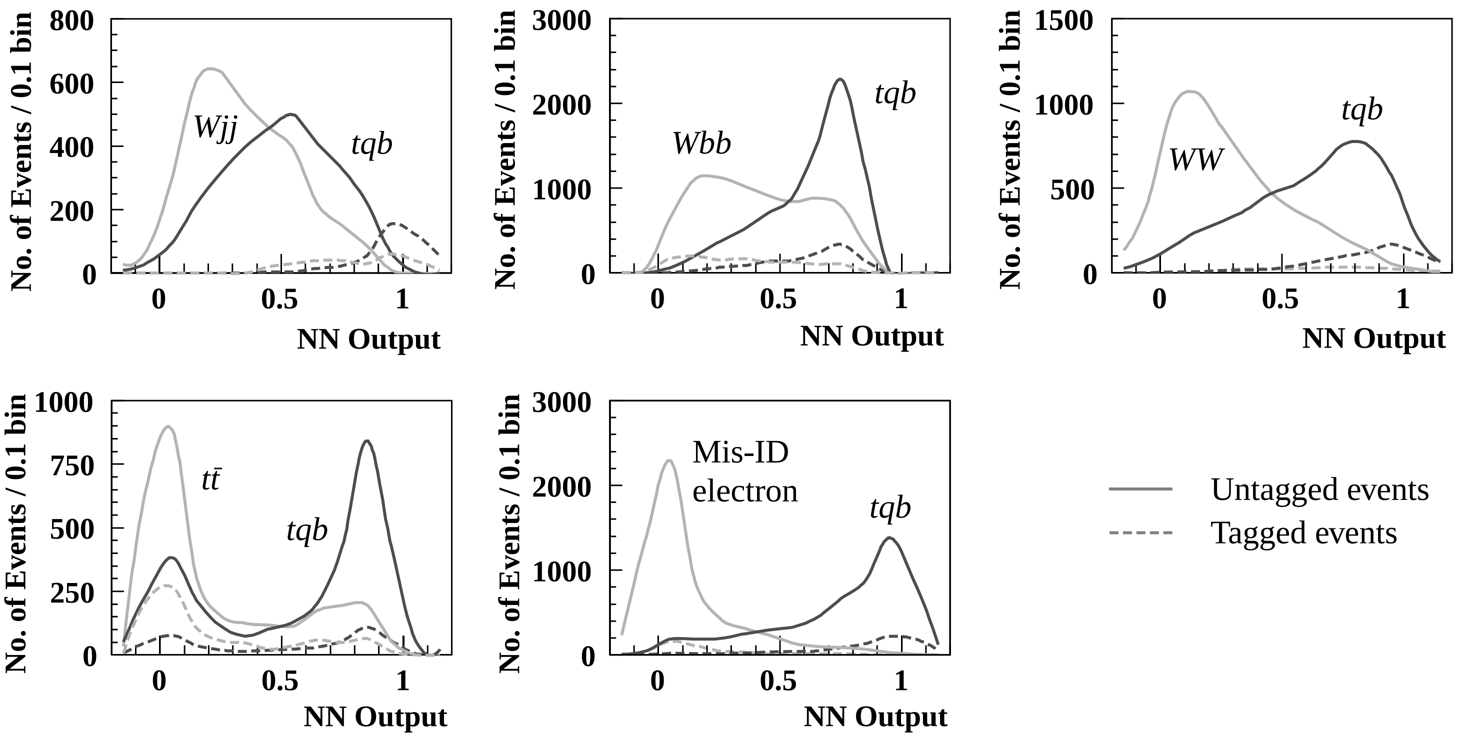
Initial Event Selection

	e+jets/notag	e+jets/tag	m+jets/notag	m+jets/tag
tb Signal	1.41 (0.25)	0.22 (0.04)	0.84 (0.16)	0.11 (0.02)
tb Background	661 (130)	16.28 (2.03)	389 (91)	5.93 (1.22)
tqb Signal	2.44 (0.43)	0.27 (0.05)	1.85 (0.34)	0.16(0.03)
tqb Background	660 (130)	16.23(2.02)	388(91)	5.88(1.22)
Data:	**558**	**14**	**398**	**14**

After NN Selection

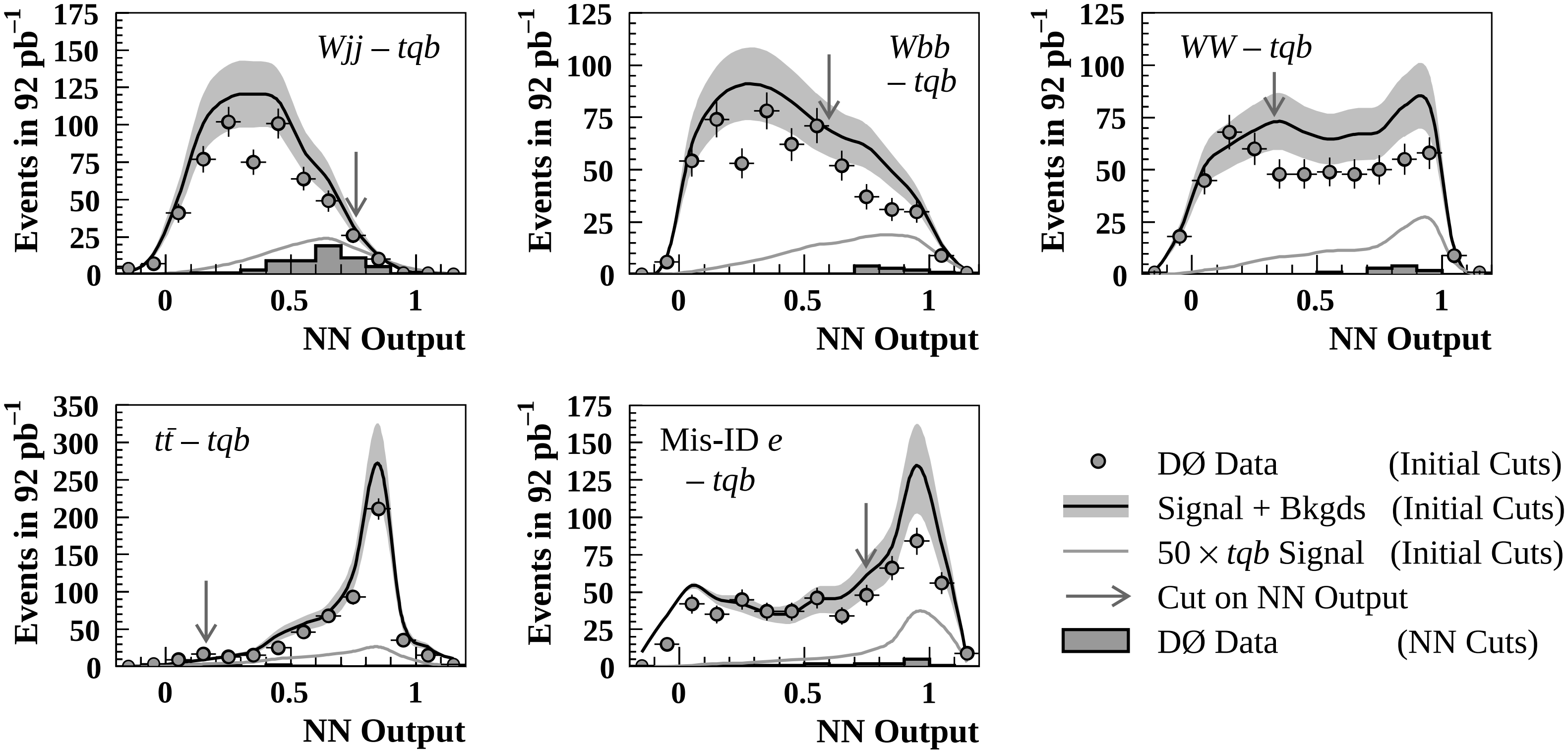
	e+jets/notag	e+jets/tag	m+jets/notag	m+jets/tag
tb Signal	0.20 (0.04)	0.14 (0.03)	0.16 (0.03)	0.08 (0.02)
tb Background	16.5 (3.83)	2.29 (0.61)	16.10 (4.66)	1.07 (0.32)
Data:	**15**	**2**	**9**	**1**
tqb Signal	0.38 (0.08)	0.17 (0.03)	0.50 (0.10)	0.11(0.02)
tqb Background	12.75 (3.58)	2.22 (0.56)	16.73 (5.13)	0.91(0.23)
Data:	**10**	**2**	**14**	**1**

Trained Neural Nets



- The output of the five neural nets for the case of e+jets channel search for tqb ("W-gluon") process.

Results on Run 1 Data



- Results of e+jets (untagged) for the tqb ("W-gluon") process.
- The cuts are chosen simultaneously selecting the set which gives the best expected limit based on MC.

D0 Results

- The procedure of examining the 5 neural networks is repeated for the different final states (e+jet (untagged), e+jet (tagged), μ+jet (untagged), μ+jet (tagged)) and different signal process (tb, tqb)
- The resulting limits are summarized in the table below.

	e+jets	m+jets	Combined
s-channel tb			
untagged	44	45	35
tagged	26	39	19
combined	22	26	**17**
t-channel tqb			
untagged	41	43	33
tagged	43	59	30
combined	27	32	**22**

CDF Search for Single Top using ANN

- Initial Event Selection Required lepton+$\not{E}_T$+b-tagged jet. The Run1 expected contributions are:
  - μ_{sig} = 4.2 single top events
  - $\mu_{non\text{-}top}$ = 43.3 non-top background events (± 8.4 events)
  - μ_{tt} = 7.4 $t\bar{t}$ events (± 2.2 events)

	W + 1 jet	W + 2 jet	W + 3jet	Total events
Single top	0.7	3.0	0.5	4.2
Non-Top	15.6	24.0	3.8	43.3
ttbar	0.3	3.7	3.5	7.4
Expected	**16.6**	**30.7**	**7.8**	**54.9**

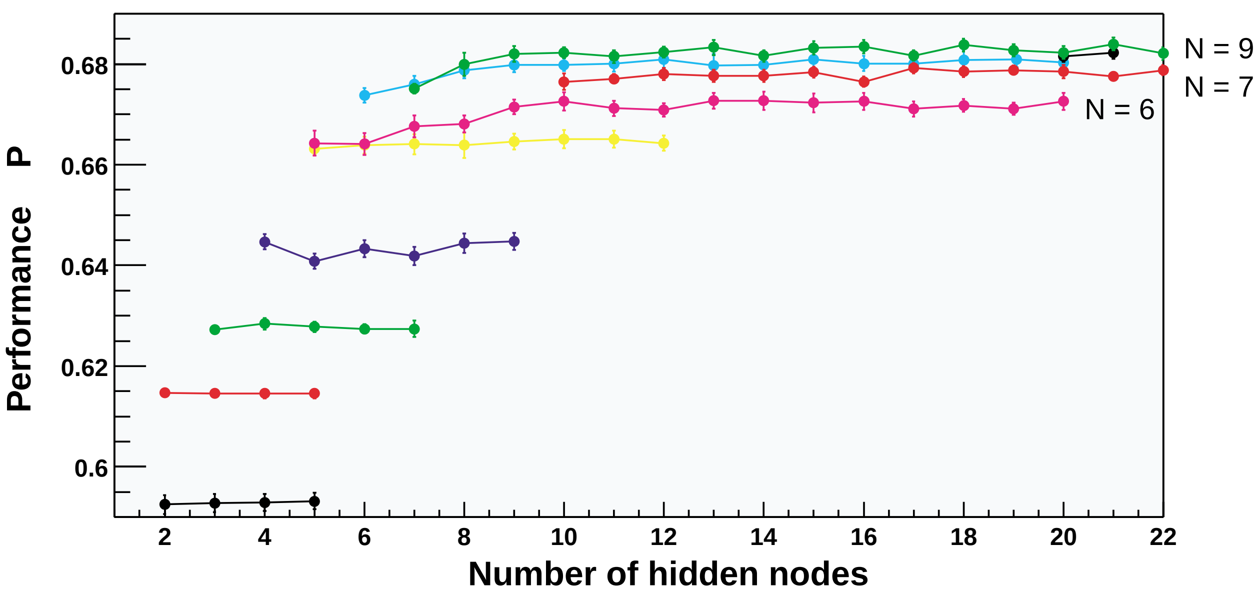
- S/B = 8% - very small (compare $t\bar{t}$ *:* S/B = 260%)
  - NN approach suitable as it combines information from many variables
  - no additional cuts - retain the 4.2 signal events (expected)

Input Selection

- Start from a large set (18 variables):
  - energies: E_T^{j1}, E_T^{j2}, E_T^{lep}, $\not{E}_T$, H_T, $\sqrt{\hat{s}}$
  - angles: η^{j1}, η^{j2}, $\cos(\theta_{lq})$, $Q\times\eta$, R_{min}
  - j-j, l-j-ν system: M^{jj}, P_T^{jj}, η^{jj}, $M^{l\nu b}$
  - jet counting: N_j, N_{j8}, $N_{b\text{-tags}}$

Settled on 7 variables
E_T^{j1}, E_T^{j2}, E_T^{lep}, E_T,
H_T, P_T^{jj}, $Q\times\eta$

CDF Preliminary



1 — H_T
2 — + E_T^{j1}
3 — + Njet
4 — E_T^{j1}, E_T^{j2}, E_T^{lep}, H_T
5 — + $\not{E}_T$
6 — + P_T^{jj}
7 — + $Q\times\eta$
9 — + M^{jj}, $M^{l\nu b}$
18 — + $\cos\theta_{lb}$, η^{j1}, η^{j2},
+ R_{min}, Njet, η^{jj}, $\sqrt{s}$, Nj8,
+ Ntags

3-Output ANN

- 3-layer network
  - 7 input variables ⇒ 7 input nodes
  - 3 categories of events ⇒ 3 output nodes
  - 17 nodes in the intermediate layer (best in the 6-20 range)

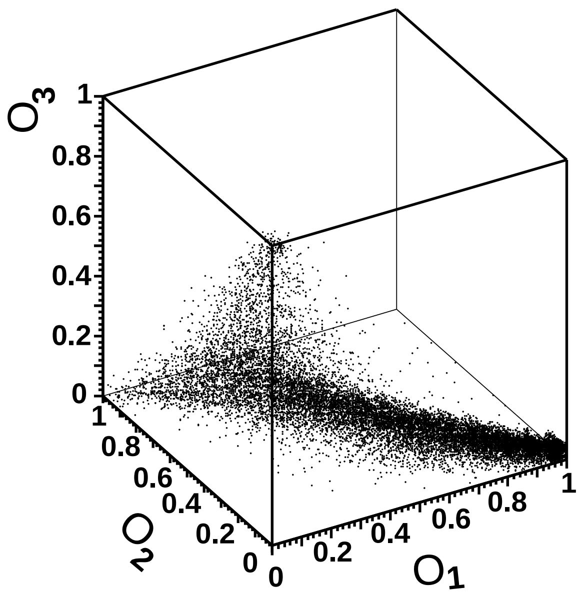
- Require:
  - $(O_1, O_2, O_3) =$ **(1, 0, 0)** for non-top
  - $(O_1, O_2, O_3) =$ **(0, 1, 0)** for Wg, W*
  - $(O_1, O_2, O_3) =$ **(0, 0, 1)** for $t\bar{t}$

- Outputs estimate Bayes a-posteriori probabilities for each class (reference: Richard&Lippmann, *Neural Computation,*1991)

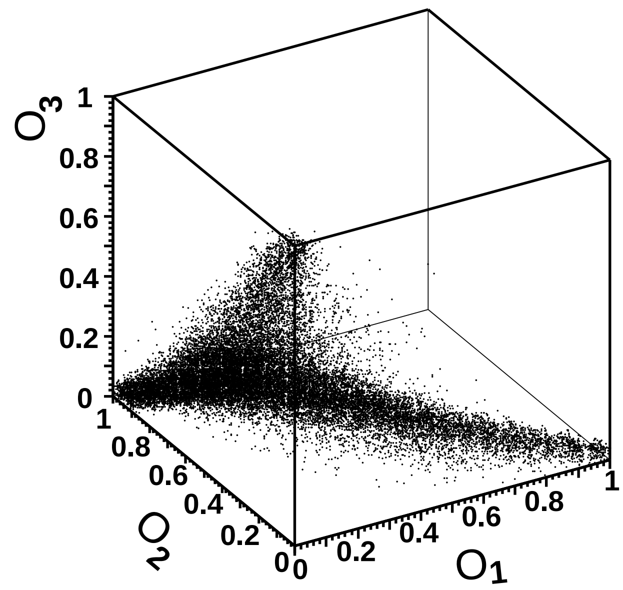
Output Distributions

Output distributions for the three MC samples

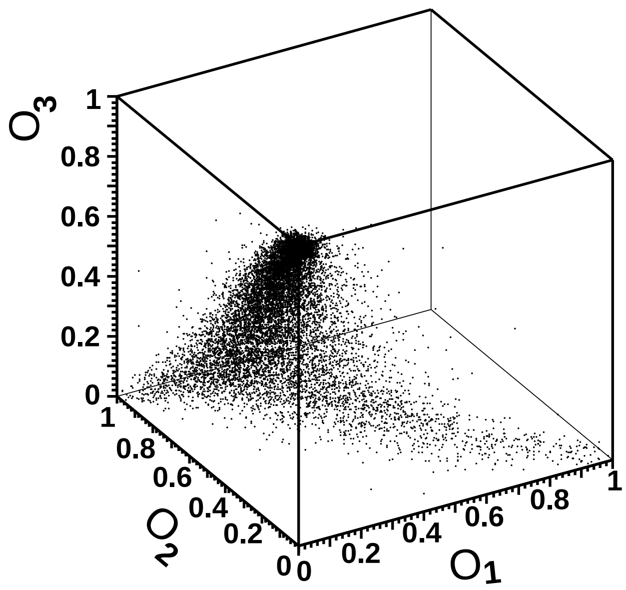
CDF Preliminary



non-top background

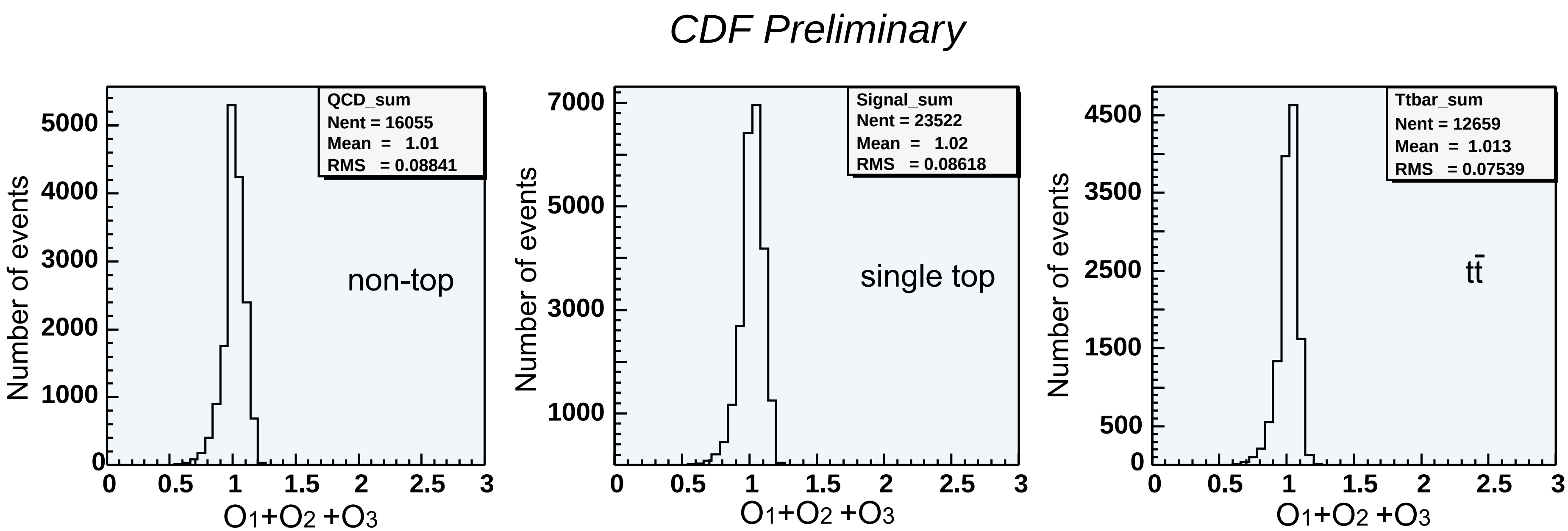


single top signal



$t\bar{t}$ background

Output Sum

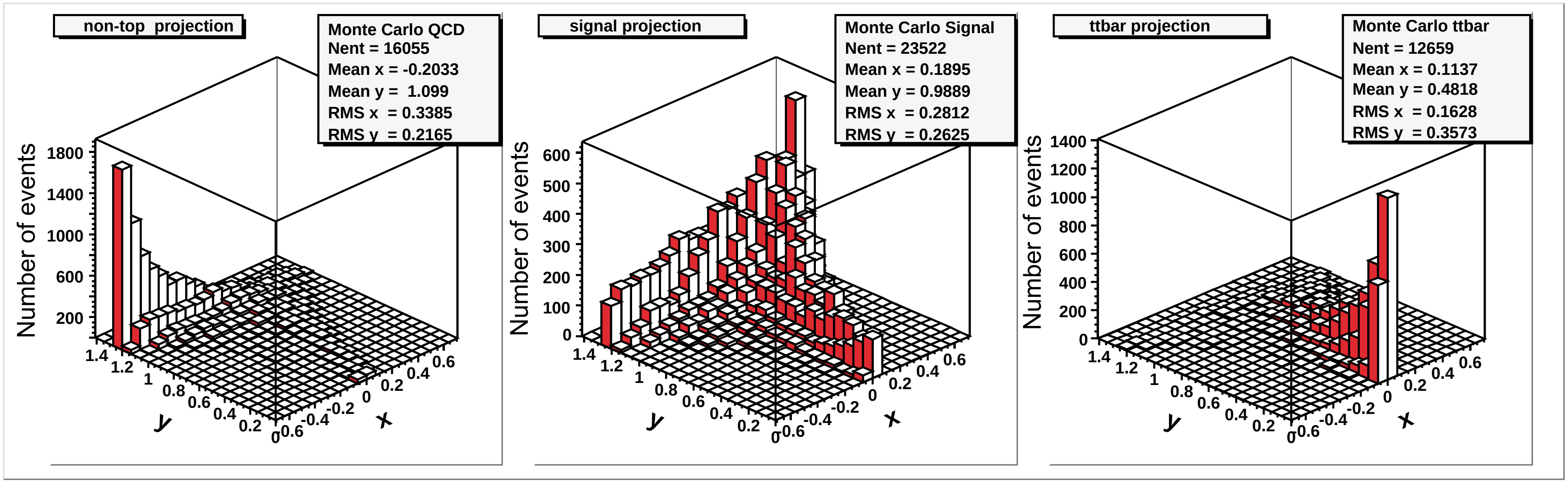


- The outputs tend to sum up to 1.0
  - $O_1 + O_2 + O_3 \approx 1$ reduces the problem to two dimensions

Output Distributions (2)

- Run MC events (signal and backgrounds) through the net, project output, and get the three “triangular” distributions:

CDF Preliminary

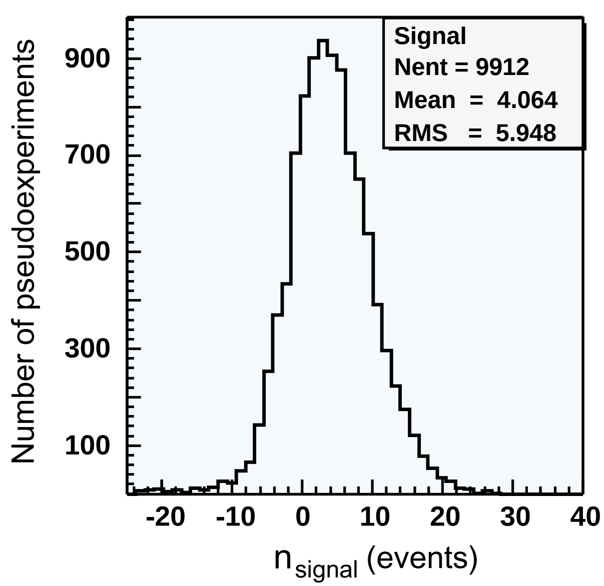


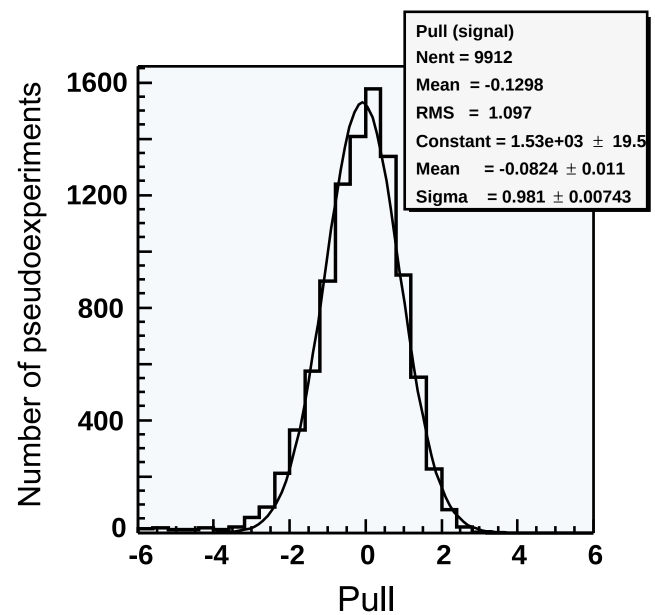
- To find the composition of a given sample, we fit its ANN output distribution as the sum of the above distributions

Run 1 Pseudo-experiments Results

- Construct fake Run 1 datasets from Poisson means: μ_{sig} = 4.2 single top events, μ_{QCD} = 43.3 non-top events, μ_{tt}= 7.4 tt events
- Signal percent uncertainty ~ 140%. We proceed to set an upper limit on Run 1 single top production.

CDF Preliminary





From the P.E. we found an *a priori* 95% CL of:

- **18.14 single top events**
- **10.5 *pb***

Run 1 Data

- The expected and observed numbers of events, after all the selection requirements

CDF Preliminary

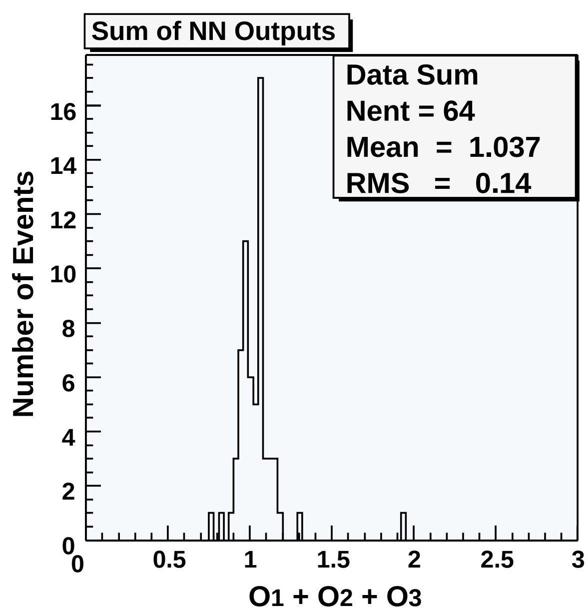
	W + 1 jet	W + 2 jet	W + 3jet	Total events
Single top	0.7	3.0	0.5	4.2
non-top	15.6	24.0	3.8	43.3
ttbar	0.3	3.7	3.5	7.4
Expected	**16.6**	**30.7**	**7.8**	**54.9**
Observed	**14**	**41**	**9**	**64**

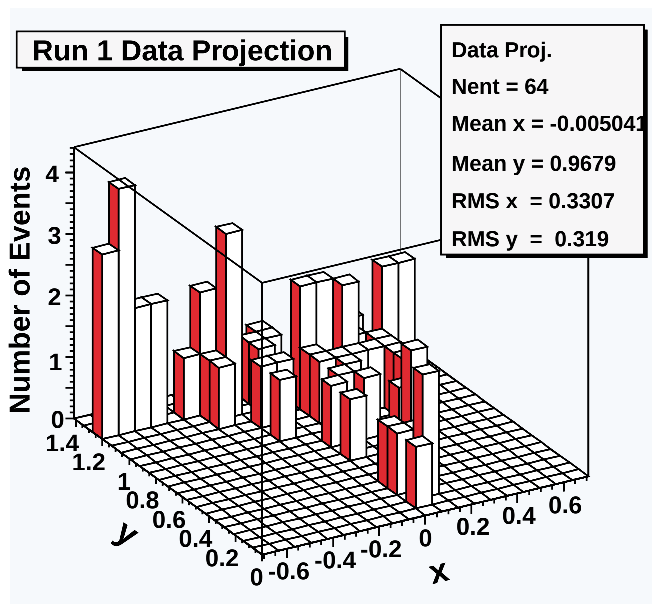
- plot NN output and fit to the Monte Carlo templates

NN Output Fit

- Run1 NN output distribution:

CDF Preliminary





A Bayesian approach yields a 95%CL upper limit on the cross section of 23.9 pb. (Includes effect of systematic uncer.)

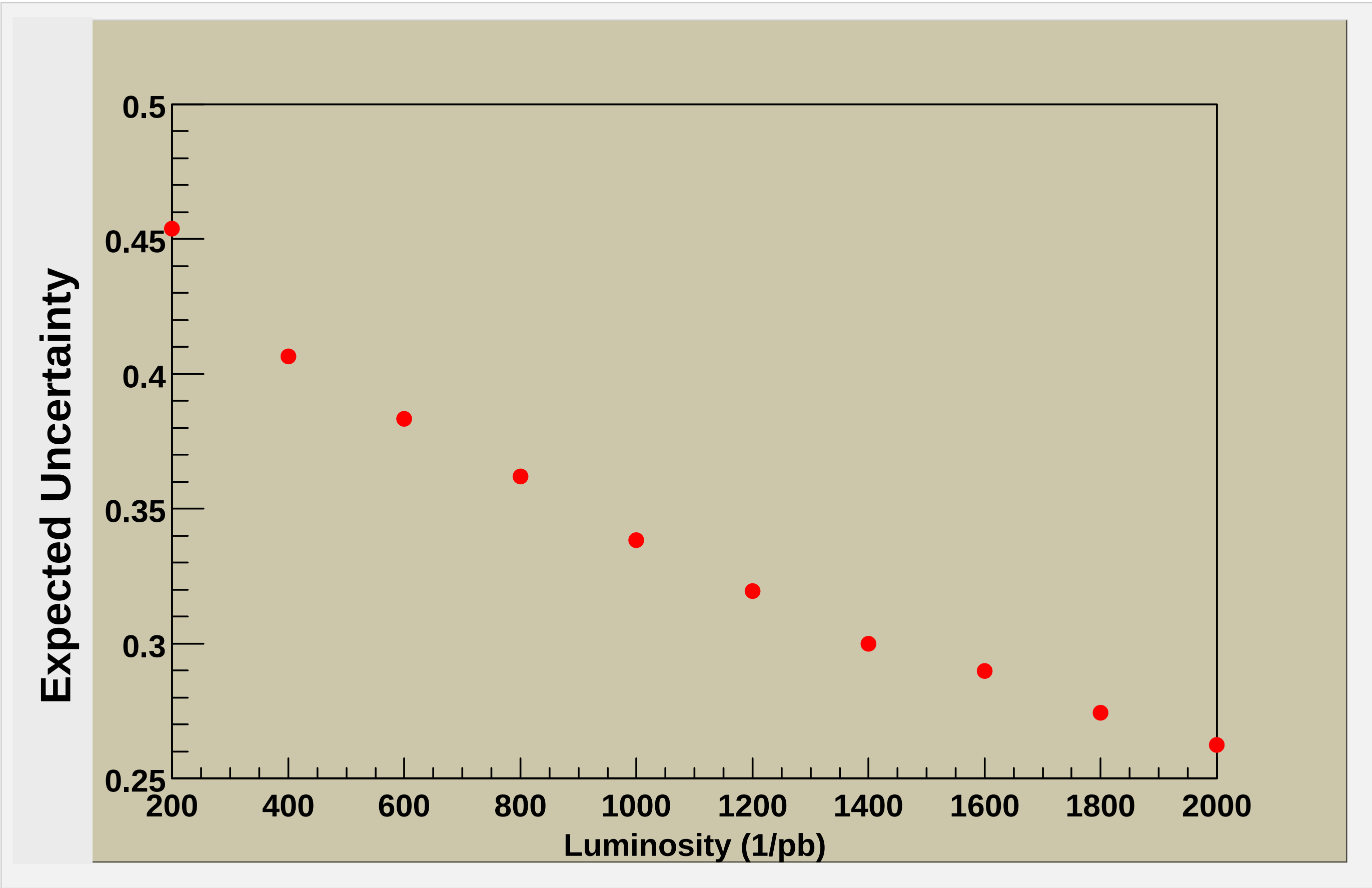
- Binned likelihood fit with Gaussian background constraints:
  - signal: 22.9 ± 7.6, non-top: 36.1 ± 6.2, ttbar: 7.6 ± 2.0
  - 5 times larger than and 2.5 σ away from the expected 4.2 events

Estimate of Single Top Yield in Run 2

- Source: S. Truitt, P. Savard : Top Thinkshop, Oct. 17, 1998
- To go from Run 1 to Run 2:
  - luminosity increase 2.0 fb^{-1} / 0.11 fb^{-1}
  - cross-section increase (40% for top, 12% for QCD background)
  - acceptance increase factor ≈ 1.9 (CDF II TDR 1996)
- Expected Run 2 contributions:
  - single top: 140 events
  - ttbar background: 340 events
  - non-top background: 1040 events
- Perform Run 2-like pseudoexperiments for different luminosity values up to 2 fb^{-1}

Run 2 Pseudoexperiment Study

- 10000 pseudoexperiments for each of ten different values of L:

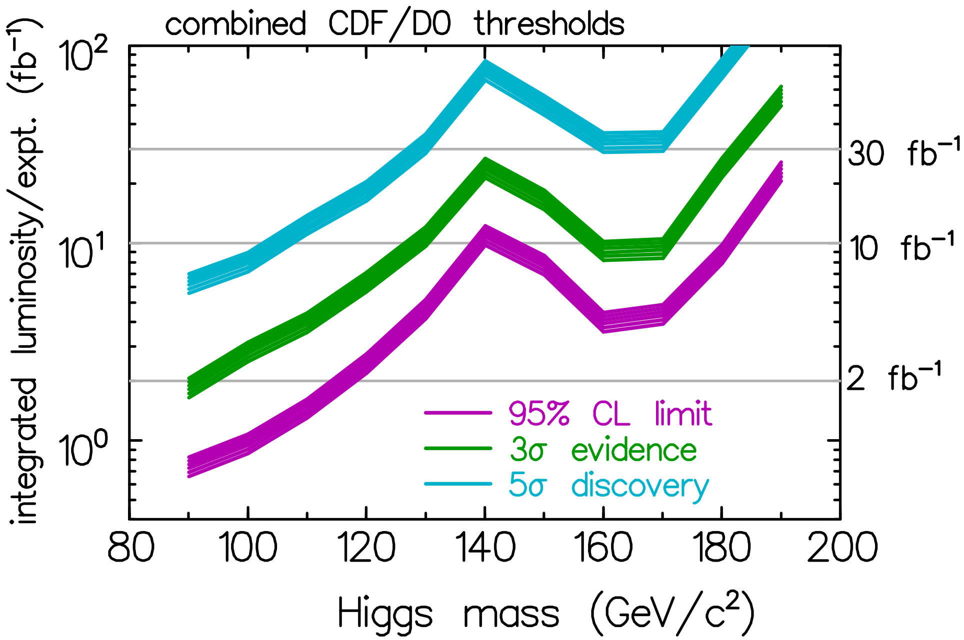


Higgs Search

- Production mode for Higgs search at the Tevatron:

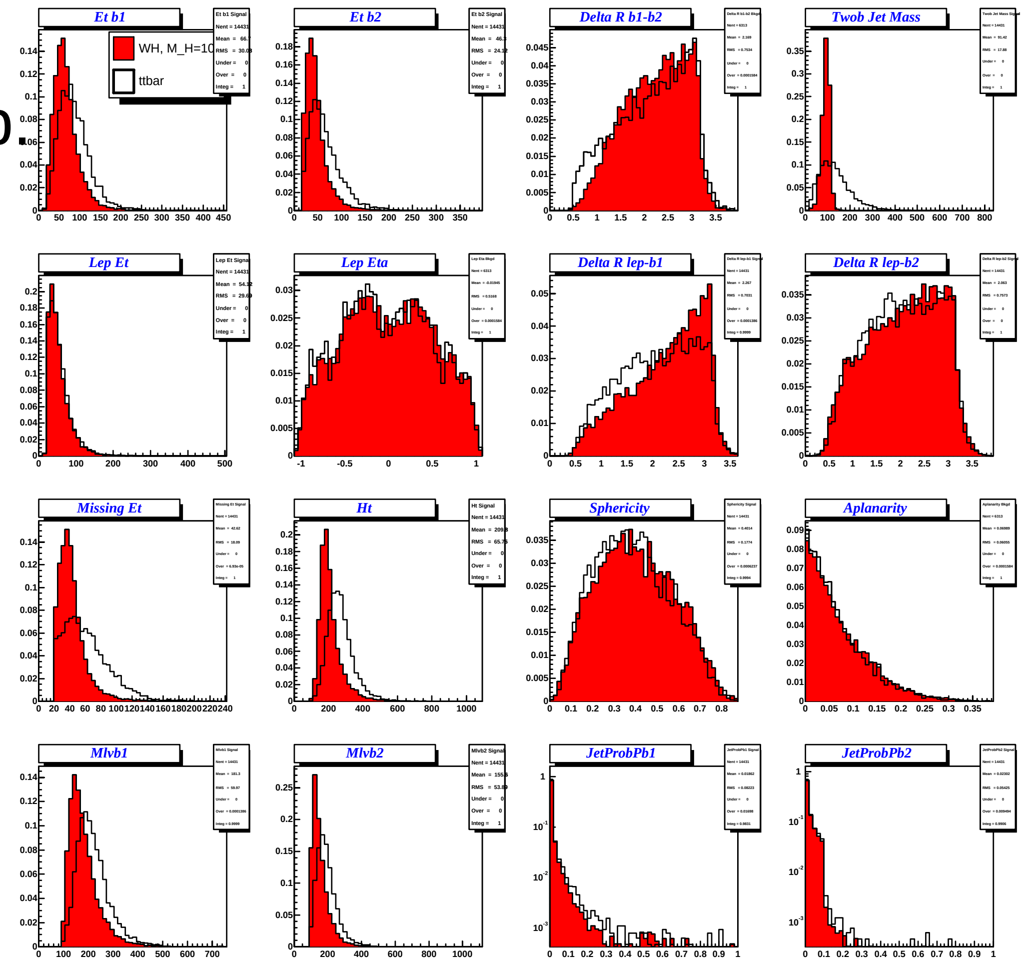
  $p\bar{p} \longrightarrow WH$ or ZH

  followed by $W \rightarrow l+\nu$, $Z \rightarrow l^+l^-$, or $Z \longrightarrow \nu\nu$
- Decay of H:
  - $M_H < 160$ $H \rightarrow bb$
  - $M_H > 2M_W$ $H \longrightarrow WW$
  - $M_H > 2M_Z$ $H \longrightarrow ZZ$
- Neural Net Analyses have focus on lower mass H.
- Large Datasets are required.



Backgrounds to Higgs

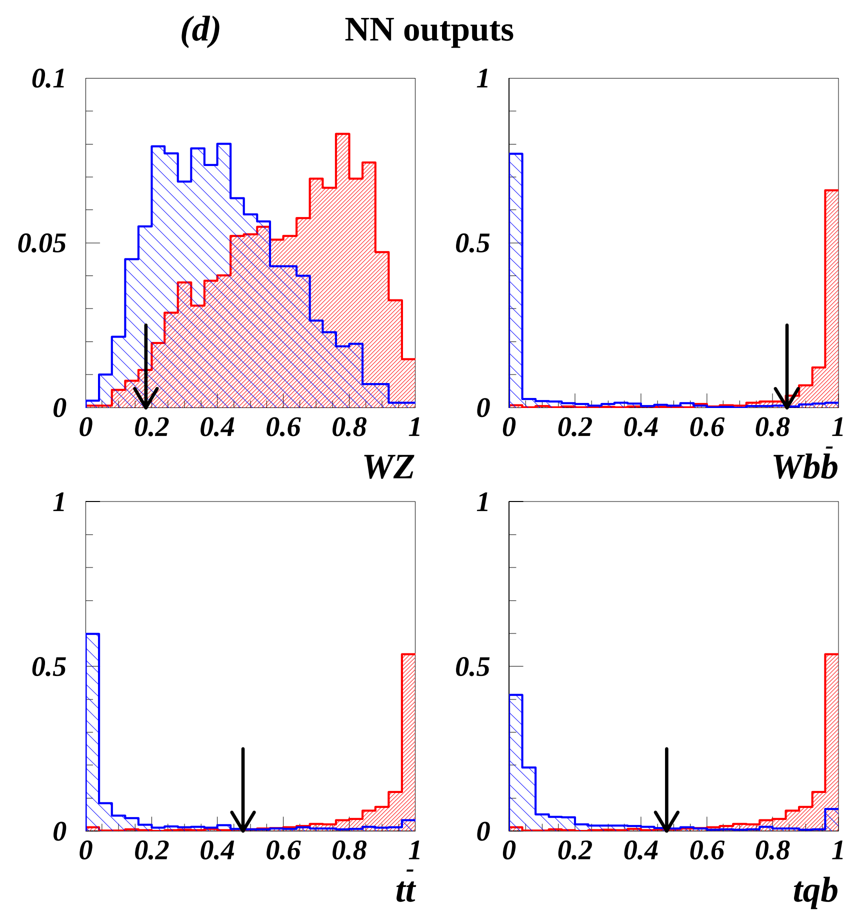
- The backgrounds are very similar to those for single top
  - WH Production Mode:
    - Wbb, Wcc
    - Single Top Quark
    - tt
    - WZ
  - ZH Production Mode:
    - Zbb, Zcc
    - tt
    - ZZ



Study of a Neural Net Higgs Search

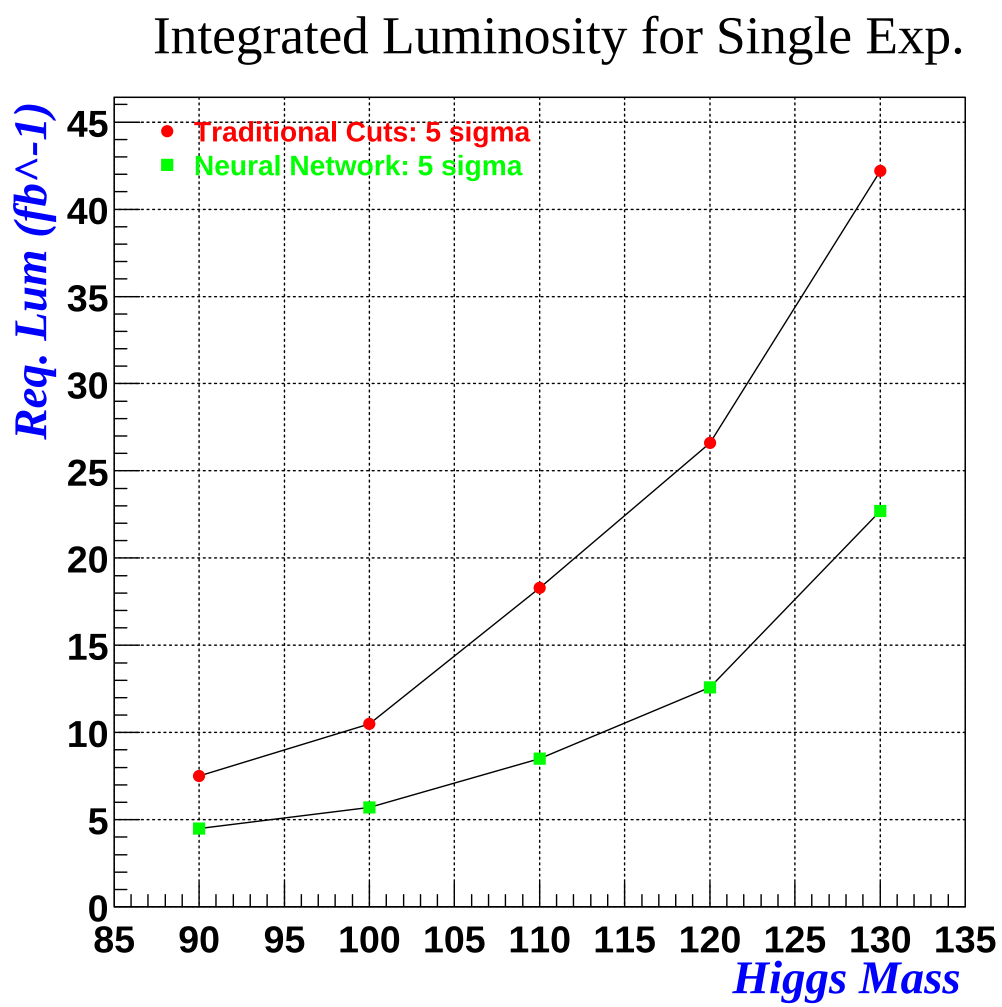
- Study of NN Search for low mass higgs (Bhat, Gilmartin, Prosper, Phy Rev D. 62, 2000)
- Analysis look at leptonic decay modes of W (e,μ) and Z (ee, μμ, νν).
- Detector Simulation:
  - Uses toy detector simulation (SHW)
  - Dijet Mass Resolution (~10%)
    - This is going to take work!

Networks for $WH \rightarrow l\nu b\bar{b}$



Reach of NN Higgs Search

- Using the decay modes mentioned the study shows the NN work seems to have a major impact.
- Hopefully the power of this holds up after more complete detector simulation and the accelerator environment of Run 2b.



Summary

- The study of the top quark and search for the Higgs Boson promises to be very exciting during Run 2.
- The processes involve small production cross sections.
- The backgrounds are challenging
  - Signal is often “between” two backgrounds.
- **Advance Analysis techniques, such as Neural Networks, are going to be essential to full exploit the data.**