# Search for a High Mass SM Higgs Boson at the Tevatron

**The XXIV Rencontres de Physique de la Vallée d'Aoste**


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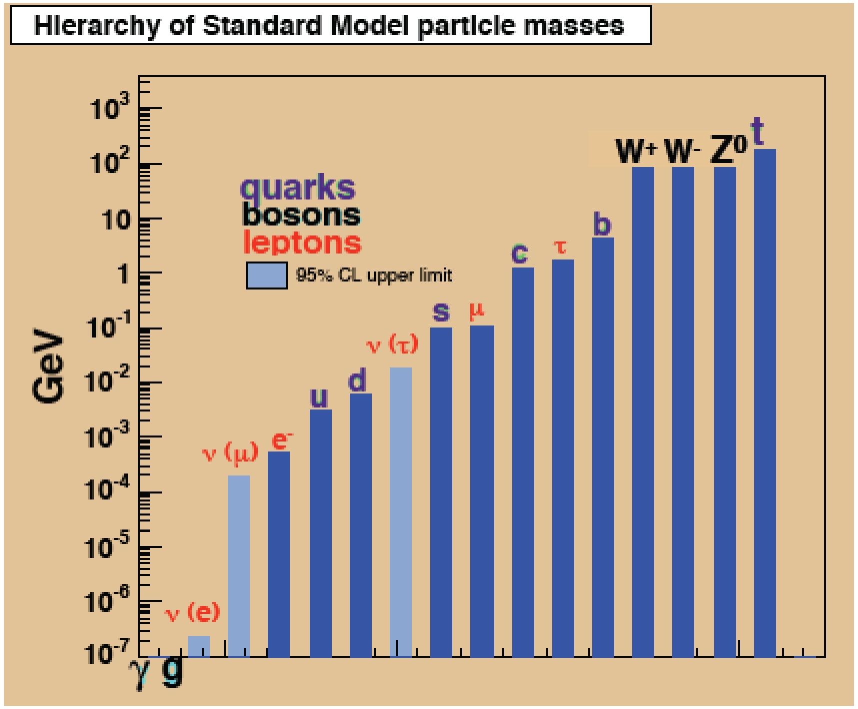
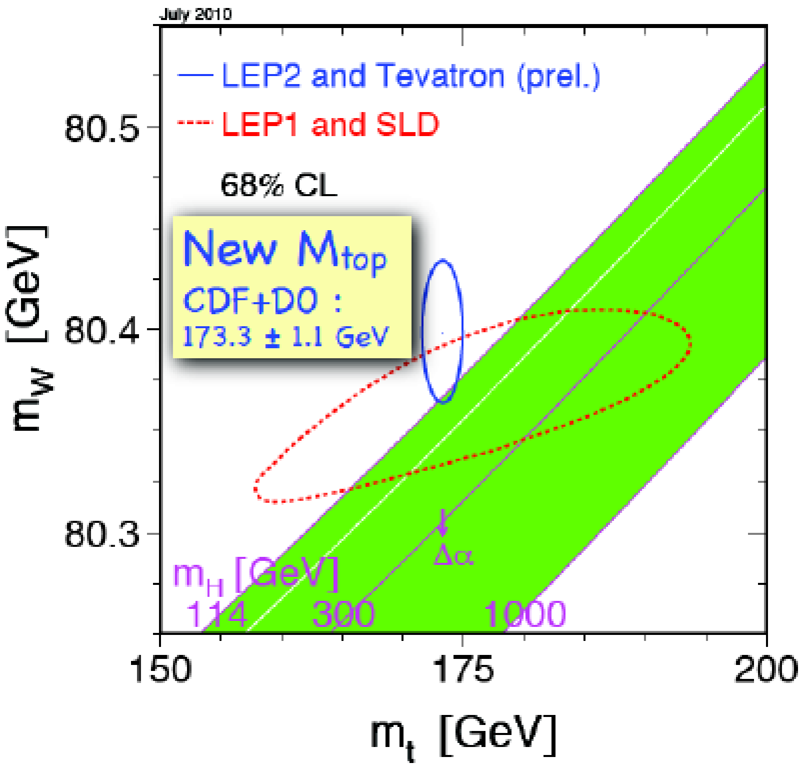
On behalf of the CDF and DØ collaborations

# Higgs Introduction

- Higgs Mechanism predicts the existence of a new particle
- Generates Fermion masses through interaction with Higgs field
- Breaks electroweak symmetry (W/Z bosons acquire mass) through degrees of freedom of Higgs field
- We don't know exactly what the mass ($m_H$) of the Higgs boson is



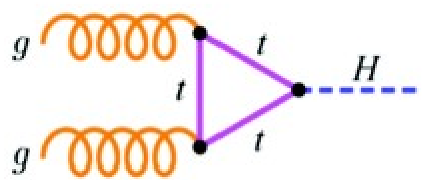




- Direct search at LEP found excess around 115GeV, but not statistically significant
  - $M_H \geq 114.4$GeV @ 95% CL
- $M_W$ and $M_t$ constraints and indirect constraints on $M_H$ from global EW fits prefer a light Higgs boson:
  - $M_H = 87^{+35}_{-26}$ GeV
  - $M_H < 186$ GeV @ 95% CL

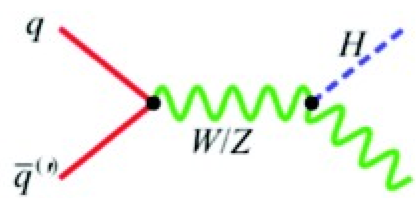
# Low vs High Mass

Higgs production
at the Tevatron:

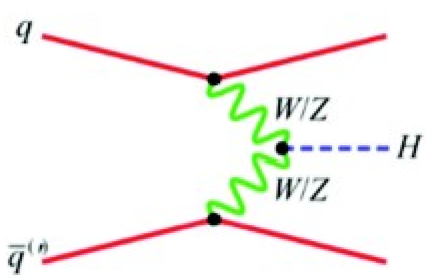
$$\sigma(gg \rightarrow H) = 0.2 \; - \; 1 \text{ pb}$$

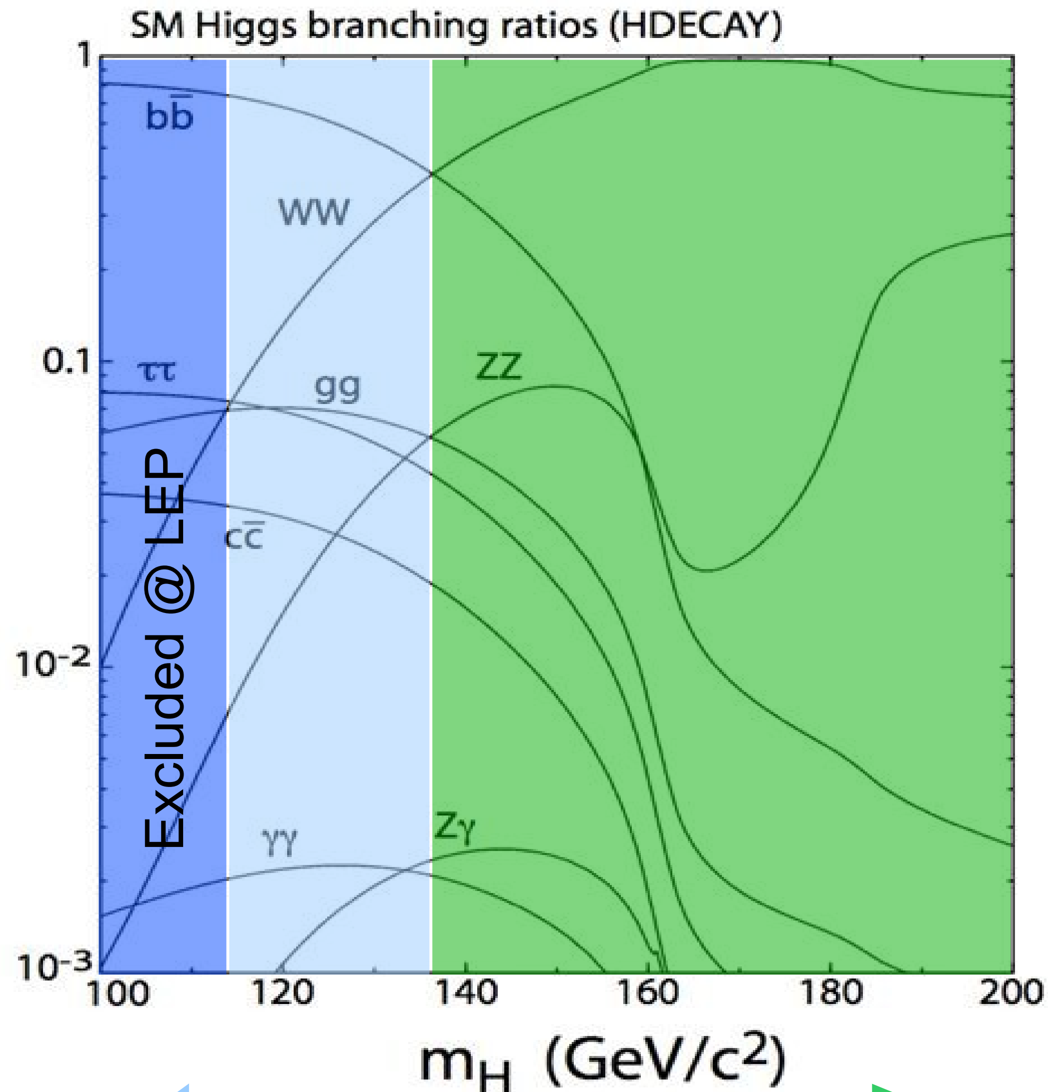



$$\sigma(q\bar{q} \rightarrow VH) = 0.01 \; - \; 0.3 \text{ pb}$$




$$\sigma(q\bar{q} \rightarrow q\bar{q}H) = 0.01 \; - \; 0.1 \text{ pb}$$



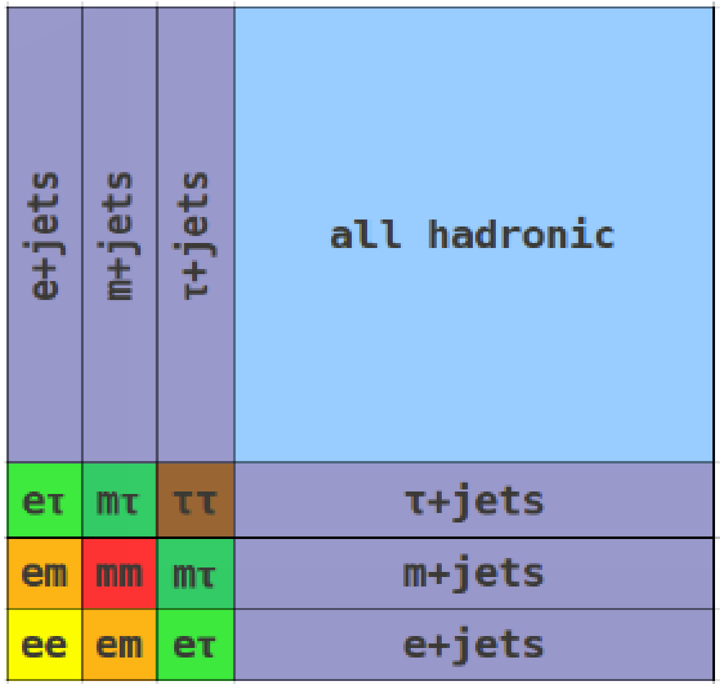




$H \rightarrow bb$ $\quad$ $H \rightarrow WW^*$

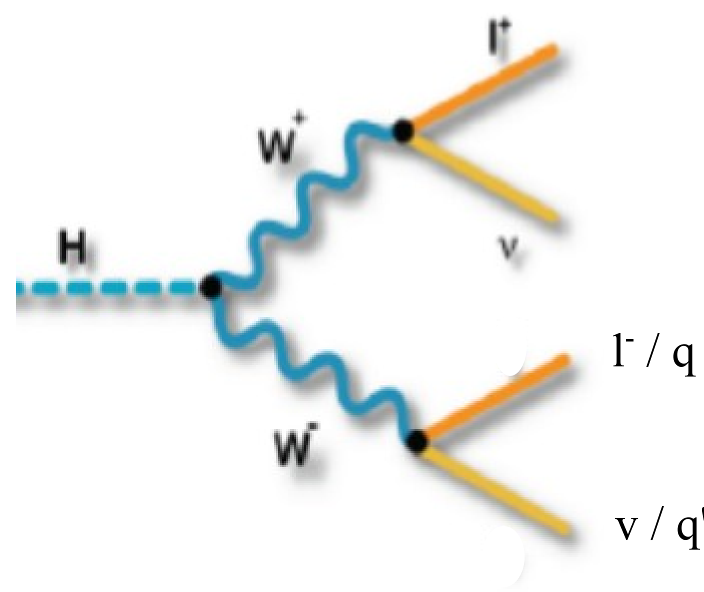
$H \rightarrow WW^*$ dominant for $M_H > 135$GeV

Tevatron definition of “High Mass”

# H→WW* Final States




- *"Leave no stone unturned"*
- Hadron collider environment requires that at least one W decays leptonically
- Most sensitive channel is lνlν
- We recently included lνqq
- "All leptonic" final state (lνlν) has a small BR but provides a very clean signal: 2 high $p_T$ leptons and missing $E_T$
- "Semi leptonic" final state (lνqq) has a large BR but much larger backgrounds which are more difficult to model



# Tevatron High Mass Program

| | |
|---|---|
| **CDF** | |
| OS - 0 jet 5.9 - $fb^{-1}$ | |
| OS - 1 jet | |
| OS - 2+ jets | |
| low $M_{\ell\ell}$ | |
| Same Sign | |
| Trileptons (noZ) | |
| Trileptons (Z - 1j) | |
| Trileptons (Z - 2+j) | |
| hadronic $\tau$ | |
| **D0** | |
| $ee + \mu\mu + e\mu$ - 5.4 $fb^{-1}$ | |
| $e\mu$ - 6.7 $fb^{-1}$ | |
| Same Sign | 5.4 $fb^{-1}$ |
| $\ell\nu jj$ | 5.4 $fb^{-1}$ |

- *"Divide and conquer"*
- We create as many sub-channels as is feasible
- Allows us to tune our multivariate discriminants on different mixes of signal and background contributions

# Tevatron High Mass Program

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| Same Sign | 5.4 $fb^{-1}$ |
| $\ell\nu jj$ | 5.4 $fb^{-1}$ |

Di-lepton + missing $E_T$ signature

$$gg \to H \to WW^* \to \ell^+\ell^-\nu\bar{\nu}$$

where $\ell^\pm = e, \mu$ or $\tau$

in the final states $e^+e^-$,

$e^\pm\mu^\mp$ and $\mu^+\mu^-$

Includes contributions from vector boson fusion (VBF) and associated production (VH).

# Tevatron High Mass Program

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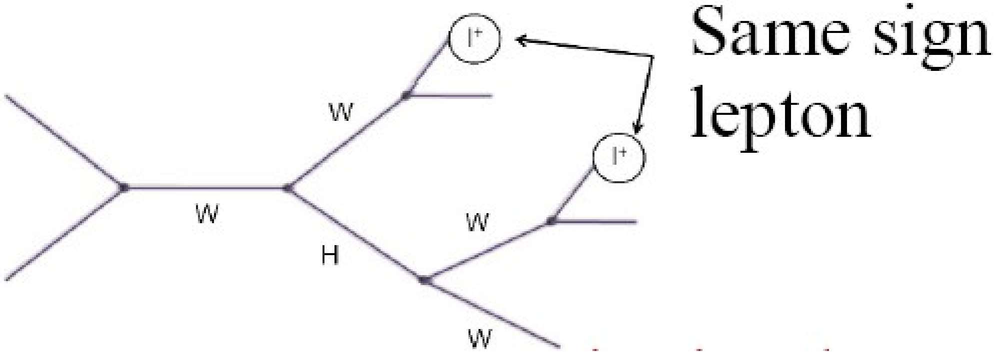
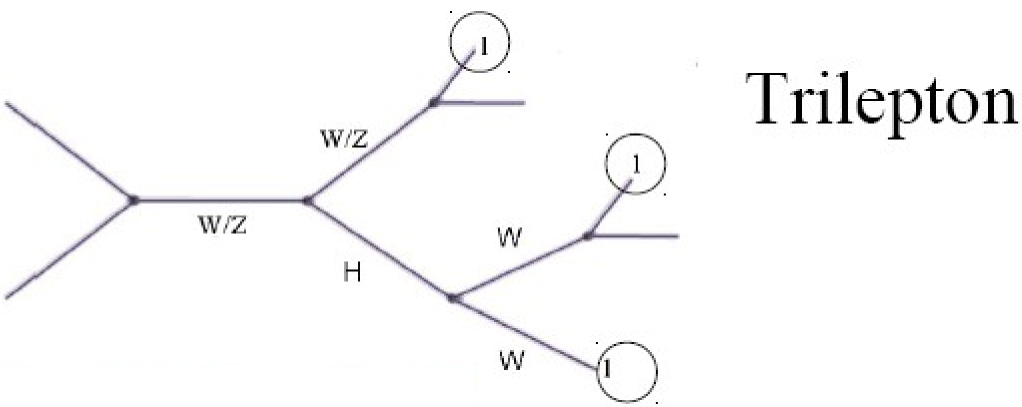
| Same Sign | 5.4 $fb^{-1}$ |
| $\ell\nu jj$ | 5.4 $fb^{-1}$ |

Same Sign Lepton and Trilepton channels from associated production



# Tevatron High Mass Program

| | |
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| **CDF** | |
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| Same Sign | 5.4 $\text{fb}^{-1}$ |
| $\ell\nu jj$ | 5.4 $\text{fb}^{-1}$ |

Tau and semi-leptonic channels

Hadronically decaying tau:

$$H \rightarrow WW \rightarrow \ell\nu\tau\nu$$

Semi-leptonic final state:

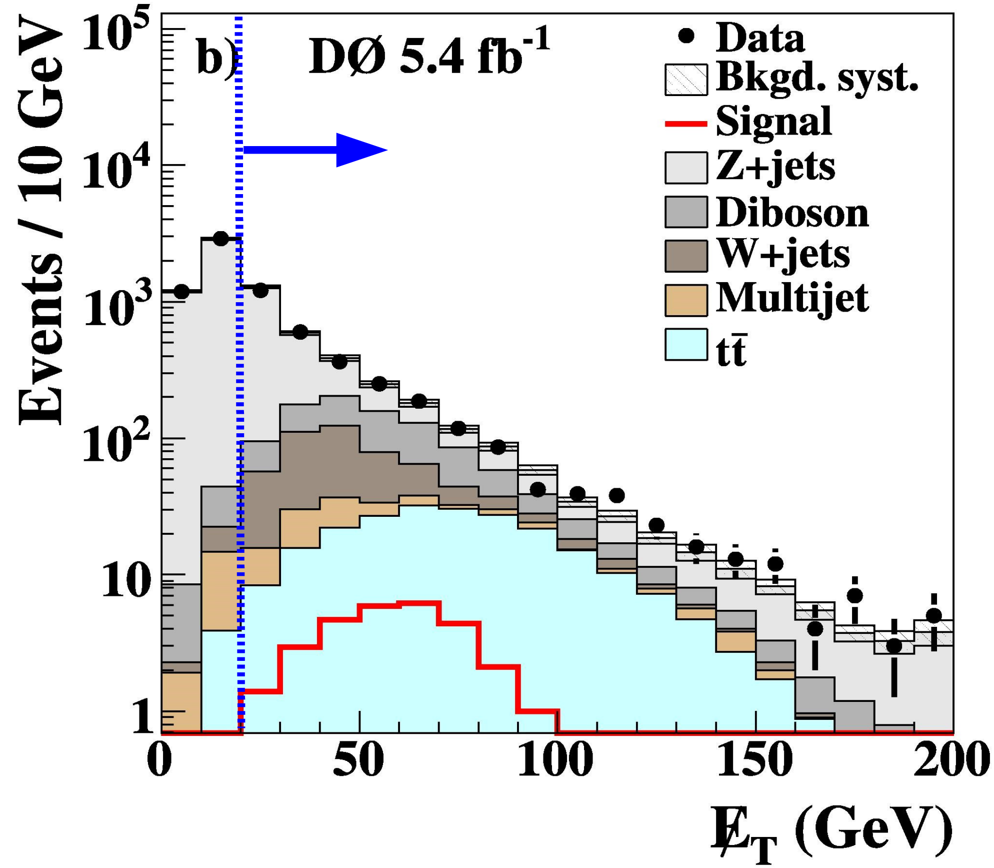
$$H \rightarrow WW \rightarrow \ell\nu jj$$

# Di-lepton + missing $E_T$ signature

$$gg \rightarrow H \rightarrow WW^* \rightarrow \ell^+\ell^-\nu\bar{\nu}$$

# Backgrounds

- Dominant background is from Drell-Yan (Z→ll) and can be suppressed by cutting on missing $E_T$
- Dibosons (mainly WW): modeled with PYTHIA
- W/Z+jets, with jet faking a lepton: modeled with data at CDF and ALPGEN at DØ
- Wγ, with γ faking a lepton: BAUR at CDF, PYTHIA at DØ
- ttbar and single-top: modeled with PYTHIA

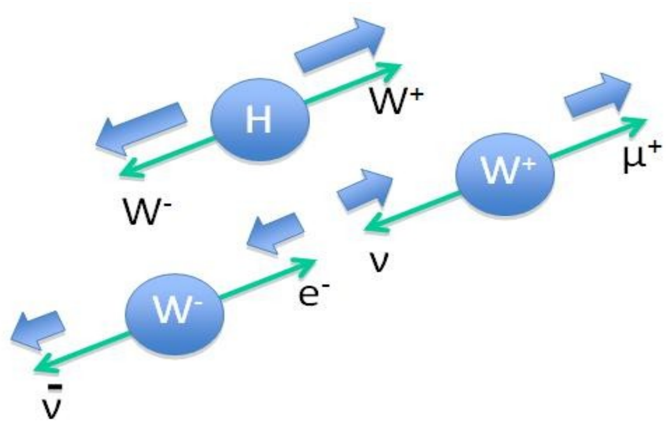


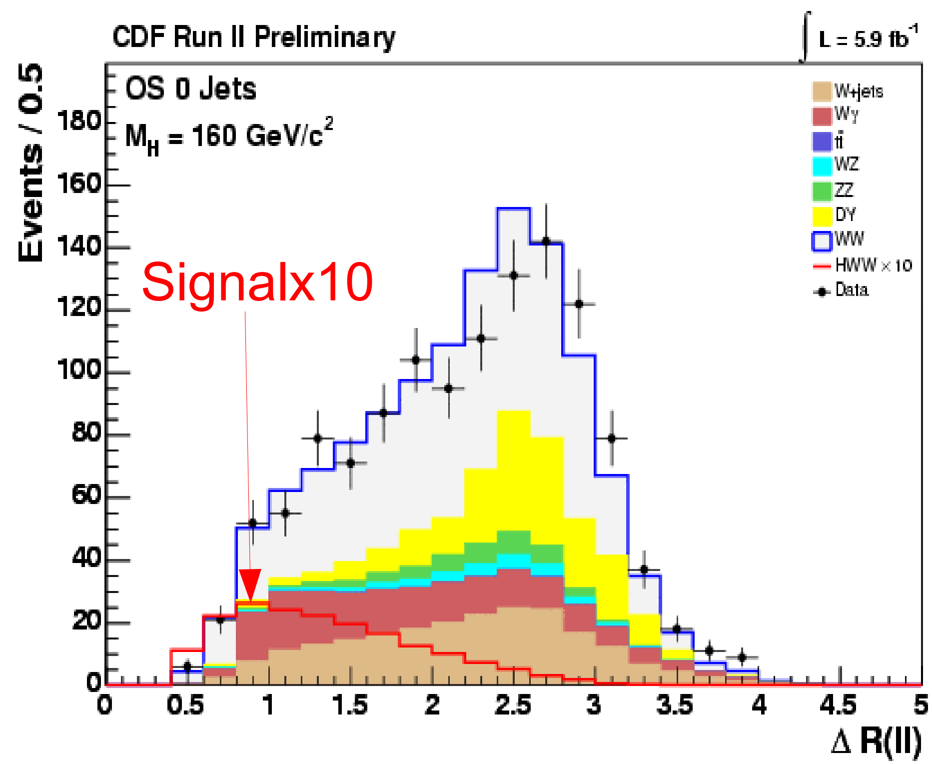

All cross section normalized to NLO calculations

# Event Selection

- 2 high $p_T$ isolated leptons
- Significant amount of missing $E_T$
- $M_{ll} \geq 16$GeV to reduce background from $W\gamma$ (CDF)

Take advantage of spin correlations:
- Di-lepton pairs from signal more aligned
- Di-lepton pairs from SM backgrounds more back-to-back
- Main discriminant against irreducible background from non-resonant W pair production

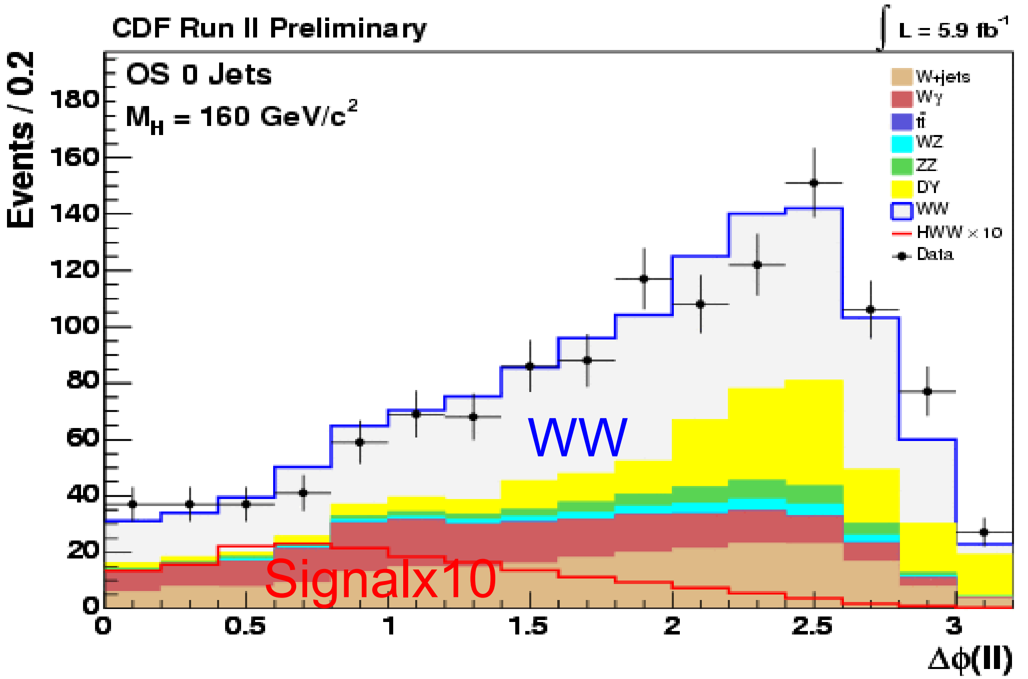


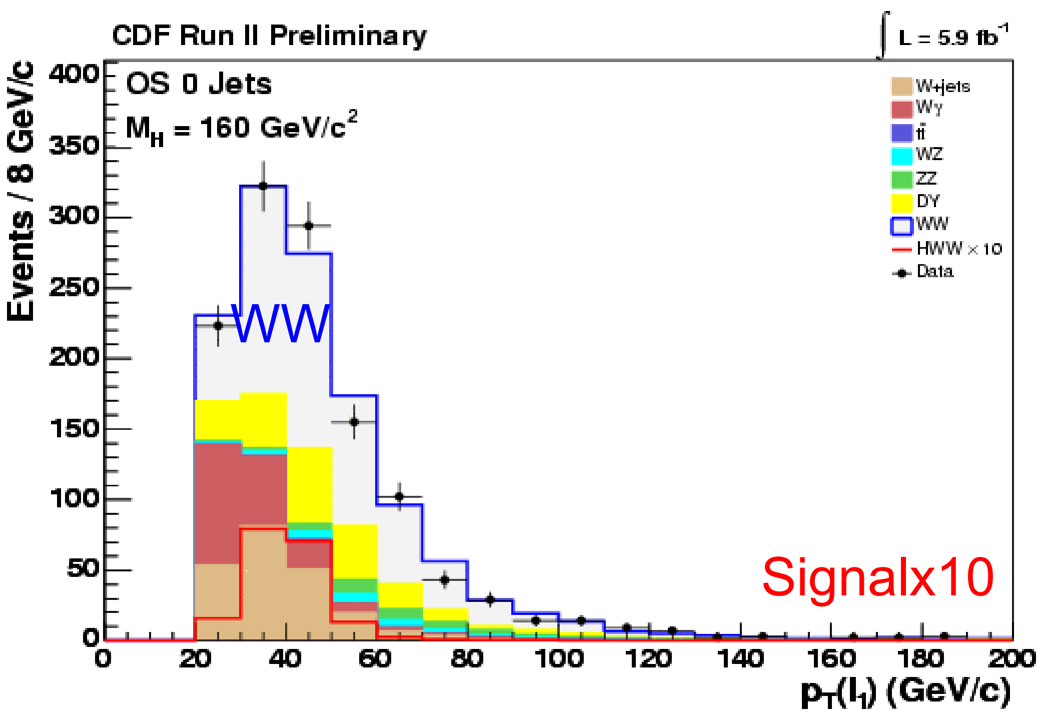



# Signal Extraction

- Very low S/√B ratios make it impossible to perform cut-based analyses, i.e., no counting experiment
- Requires the use of Multivariate Analysis Techniques (MVA) for signal extraction:
  - Matrix Element calculation (ME), Neural Network (NN) and Boosted Decision Trees (BDT)
  - MVA optimized for each sub-channel and Higgs mass hypothesis
  - Input parameters: event topology, kinematics, …
  - MVA outputs are used as input to derive limits
- Separate analyses into sub-channels for optimization:
  - CDF: by jet multiplicity (0, 1, 2+)
  - DØ: by dilepton flavor (ee, $\mu\mu$, e$\mu$)

# H→WW→lνlν: OS Lepton + 0 jets




5.9 $fb^{-1}$ data set

Further split into sub-samples with loose and tight lepton ID

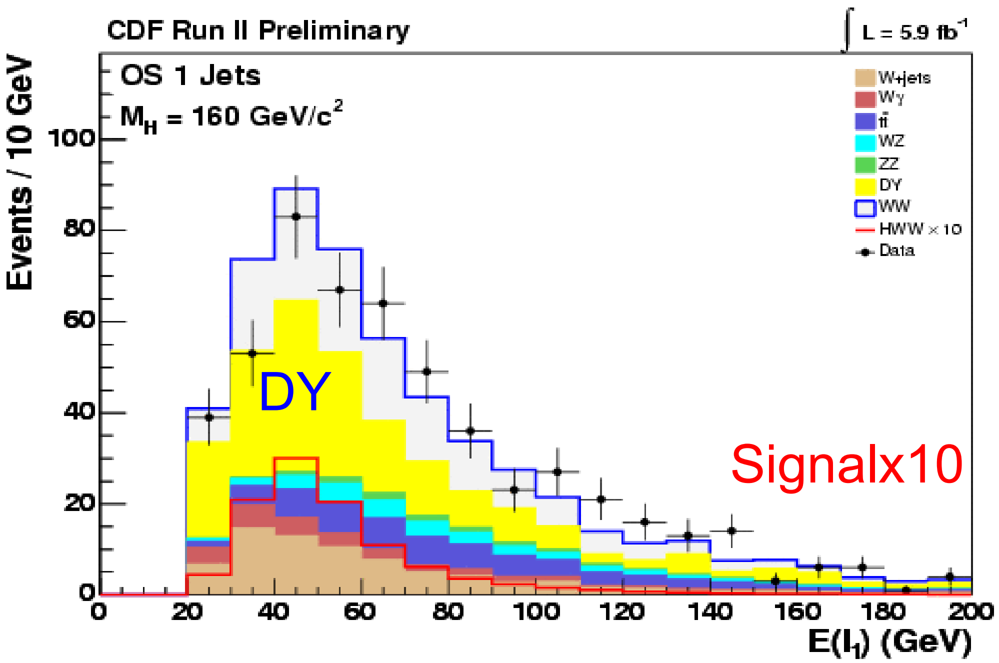
Uses likelihood ratios based on ME calculation as additional MVA input

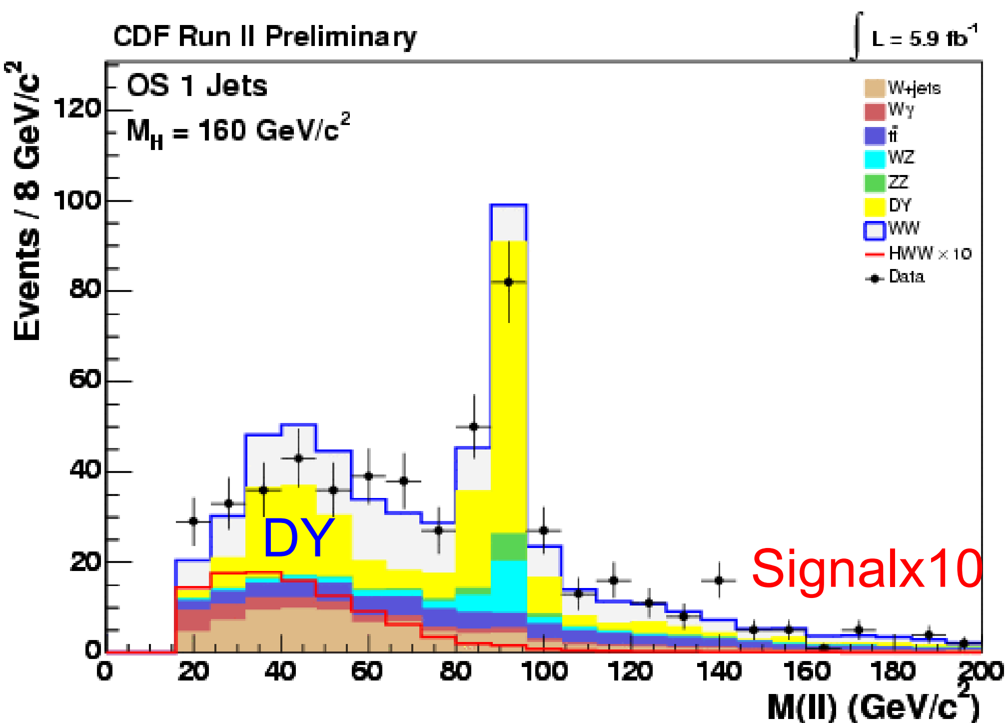
CDF Run II Preliminary $\int \mathcal{L} = 5.9\ fb^{-1}$

| $M_H = 165$ GeV/$c^2$ | | | |
|---|---|---|---|
| $t\bar{t}$ | 2.23 | ± | 0.66 |
| $DY$ | 227 | ± | 62 |
| $WW$ | 563 | ± | 56 |
| $WZ$ | 25.5 | ± | 3.8 |
| $ZZ$ | 38.3 | ± | 5.4 |
| $W$+jets | 215 | ± | 51 |
| $W\gamma$ | 155 | ± | 22 |
| **Total Background** | 1226 | ± | 120 |
| $gg \rightarrow H$ | 16.9 | ± | 3.0 |
| $WH$ | 0.410 | ± | 0.070 |
| $ZH$ | 0.416 | ± | 0.059 |
| $VBF$ | 0.140 | ± | 0.028 |
| **Total Signal** | 17.8 | ± | 3.1 |
| **Data** | 1230 | | |

OS 0 Jets

# H→WW→lνlν: OS Lepton + 1 jet




5.9 $fb^{-1}$ data set

Further split into sub-samples with loose and tight lepton ID

Gains ~20% in signal from associated production and VBF

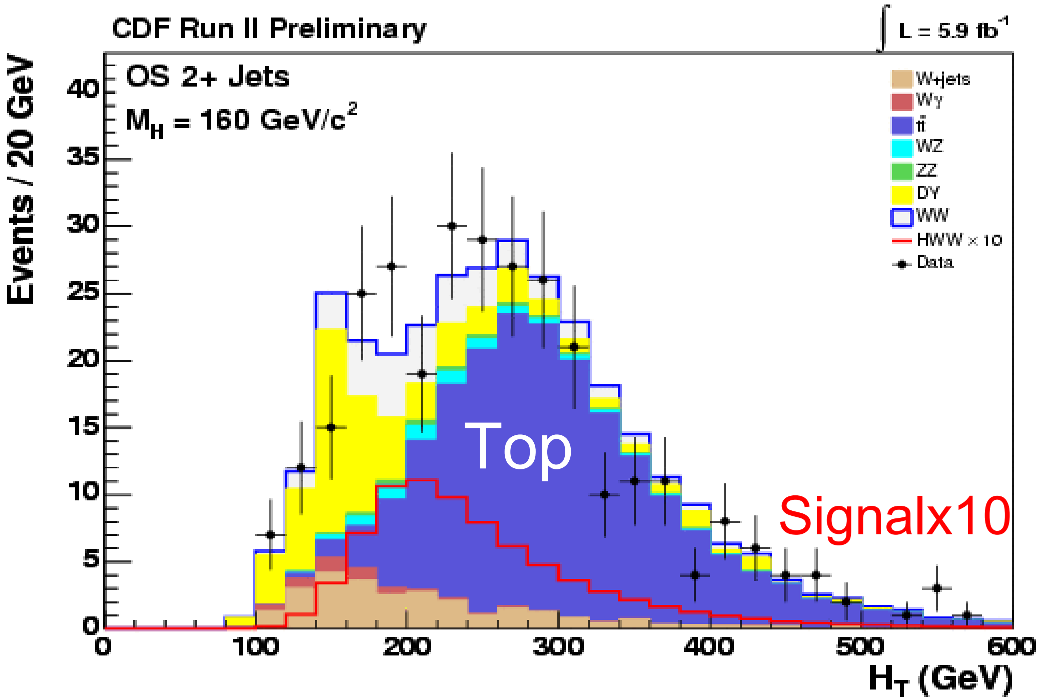
CDF Run II Preliminary $\int \mathcal{L} = 5.9\ fb^{-1}$

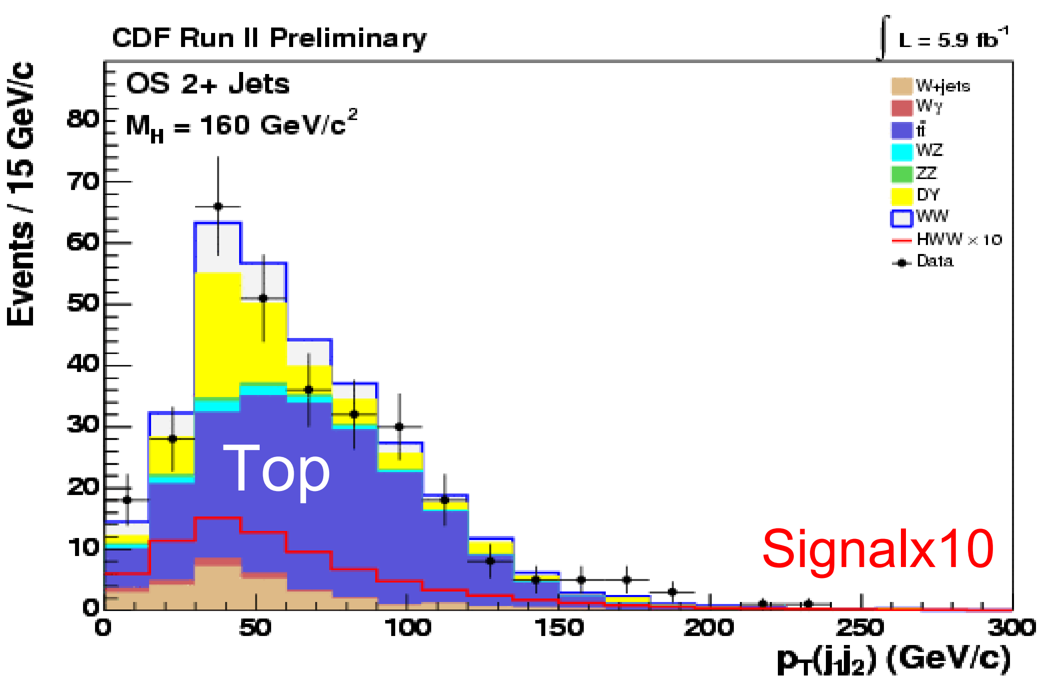
$M_H = 165\ GeV/c^2$

| | | | |
|---|---|---|---|
| $t\bar{t}$ | 56 | ± | 11 |
| $DY$ | 218 | ± | 49 |
| $WW$ | 151 | ± | 18 |
| $WZ$ | 25.4 | ± | 3.5 |
| $ZZ$ | 10.3 | ± | 1.5 |
| $W$+jets | 77 | ± | 20 |
| $W\gamma$ | 25.1 | ± | 4.3 |
| **Total Background** | 563 | ± | 69 |
| $gg \to H$ | 8.0 | ± | 2.4 |
| $WH$ | 1.13 | ± | 0.18 |
| $ZH$ | 0.439 | ± | 0.066 |
| $VBF$ | 0.74 | ± | 0.13 |
| **Total Signal** | 10.3 | ± | 2.5 |
| **Data** | 533 | | |

OS 1 Jet

# $H \to WW \to l\nu l\nu$: OS Lepton + ≥ 2 jets




$5.9\ fb^{-1}$ data set

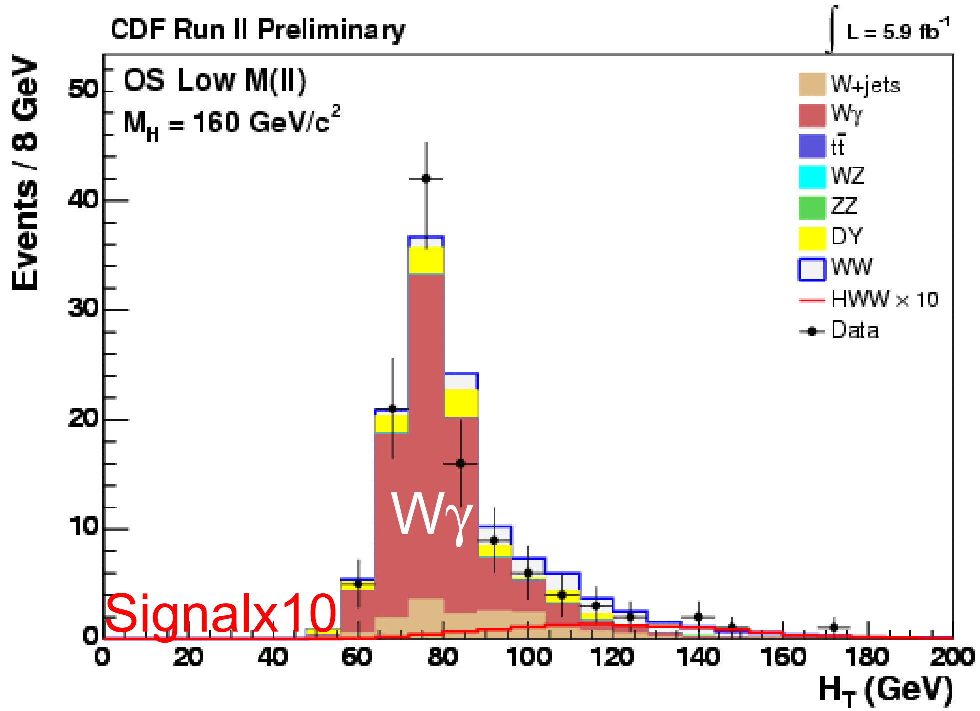
In order to suppress the dominant ttbar background all events with a tight secondary vertex b-tag are rejected

CDF Run II Preliminary $\int \mathcal{L} = 5.9\ fb^{-1}$

| $M_H = 165\ GeV/c^2$ | | | |
|---|---|---|---|
| $t\bar{t}$ | 169 | ± | 24 |
| $DY$ | 80 | ± | 31 |
| $WW$ | 33.6 | ± | 6.1 |
| $WZ$ | 6.8 | ± | 1.3 |
| $ZZ$ | 3.10 | ± | 0.57 |
| $W$+jets | 26.7 | ± | 7.5 |
| $W\gamma$ | 4.4 | ± | 1.2 |
| **Total Background** | 324 | ± | 50 |
| $gg \to H$ | 2.6 | ± | 1.8 |
| $WH$ | 2.50 | ± | 0.35 |
| $ZH$ | 1.28 | ± | 0.17 |
| $VBF$ | 1.37 | ± | 0.23 |
| **Total Signal** | 7.8 | ± | 2.0 |
| **Data** | 307 | | |

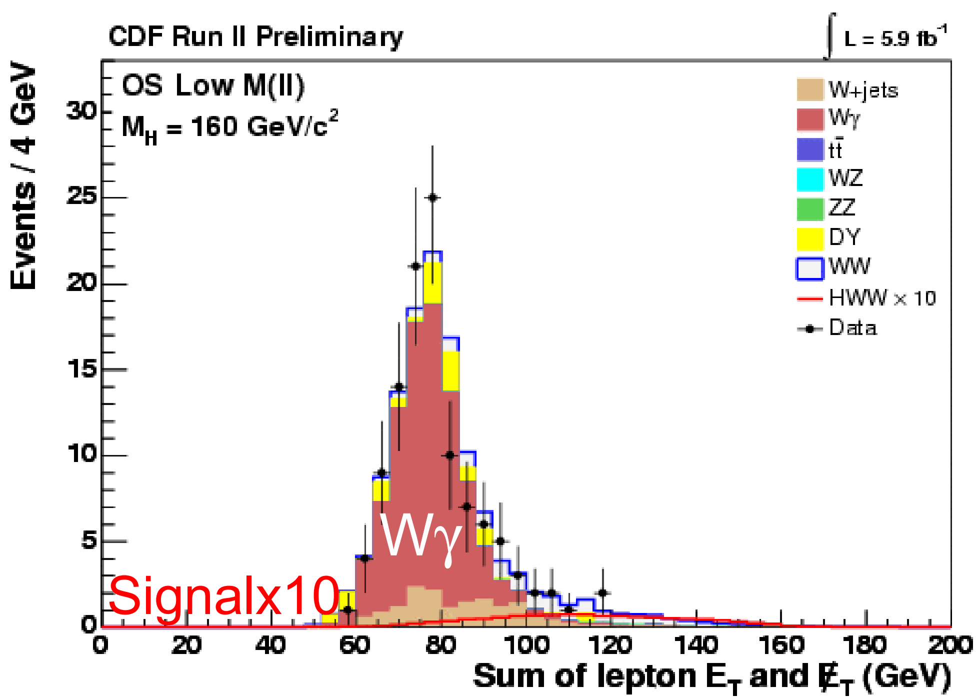
AllSB-2JOS

# H→WW→lνlν: Low $M_{ll}$




5.9 $fb^{-1}$ data set

To increase signal acceptance events that fail the $M_{ll} \geq 16$GeV requirement are considered separately

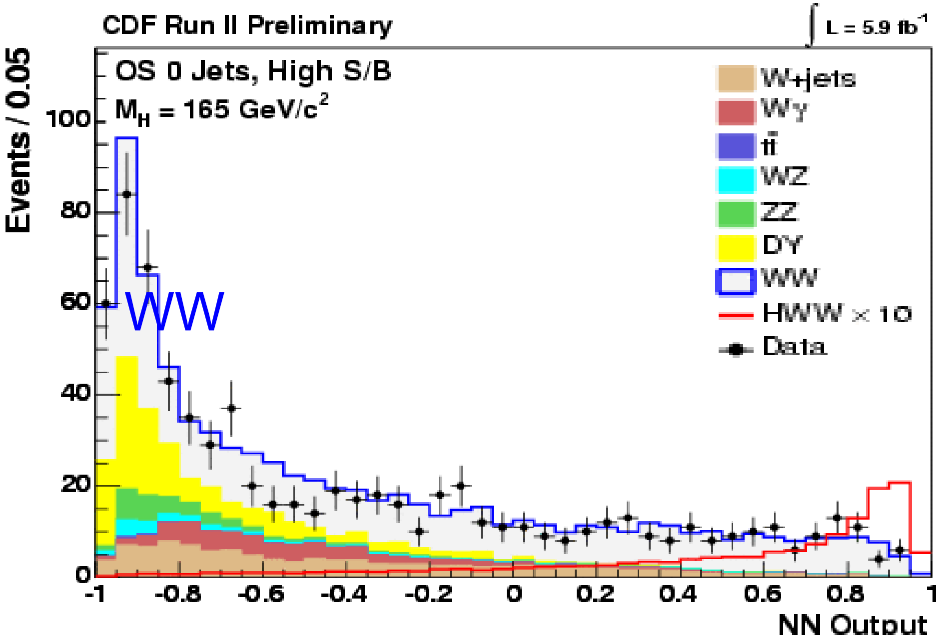


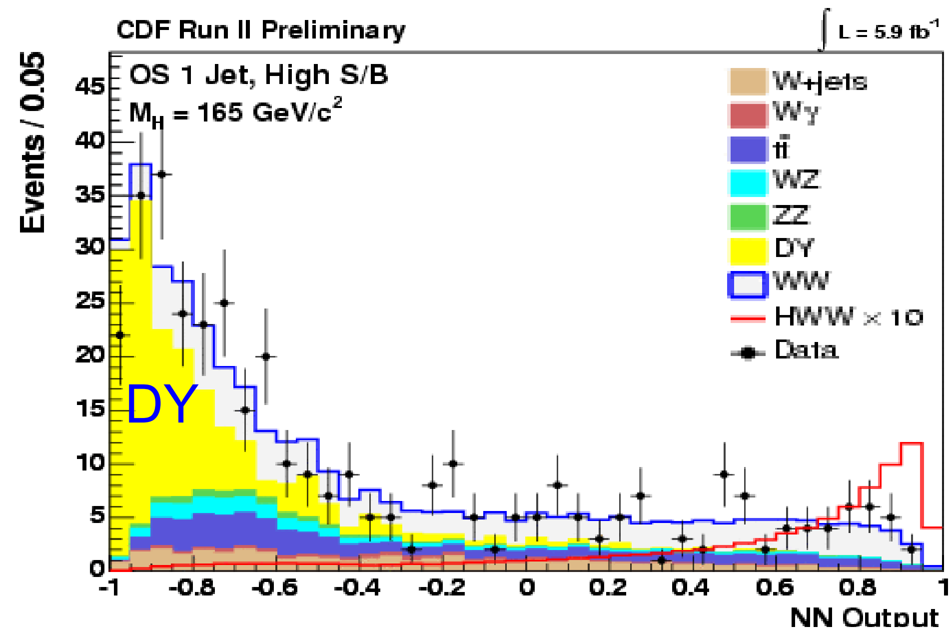

| CDF Run II Preliminary | $\int \mathcal{L} = 5.9\ fb^{-1}$ | | |
|---|---|---|---|
| $M_H = 165\ GeV/c^2$ | | | |
| $t\bar{t}$ | 0.55 | ± | 0.10 |
| $DY$ | 4.35 | ± | 0.78 |
| $WW$ | 13.8 | ± | 1.3 |
| $WZ$ | 0.371 | ± | 0.052 |
| $ZZ$ | 0.139 | ± | 0.019 |
| $W$+jets | 16.2 | ± | 3.0 |
| $W\gamma$ | 76.8 | ± | 7.7 |
| **Total Background** | 112.2 | ± | 8.6 |
| $gg \rightarrow H$ | 1.00 | ± | 0.20 |
| **Total Signal** | 1.00 | ± | 0.20 |
| **Data** | 112 | | |

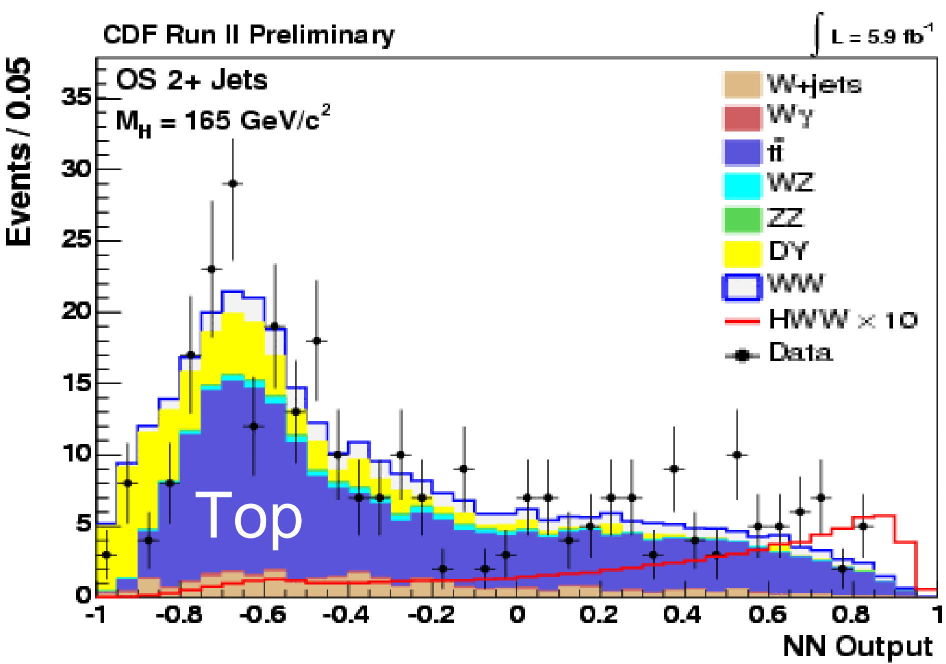
AllSB-lowMll

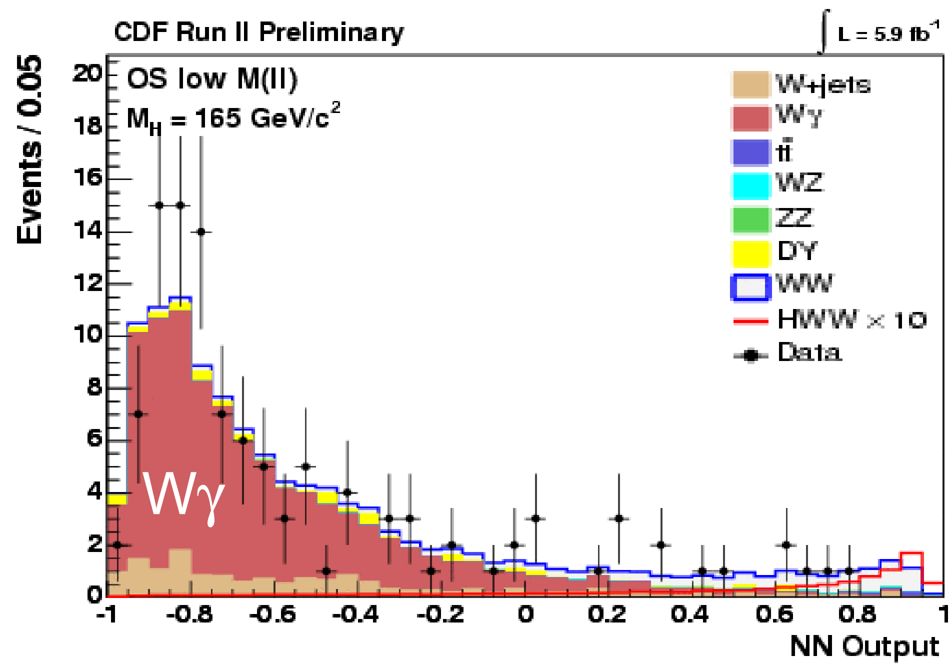
# H→WW→lνlν: Signal Extraction

Using a NN to extract a signal
Separate NNs are trained for each sub-channel and each Higgs mass point



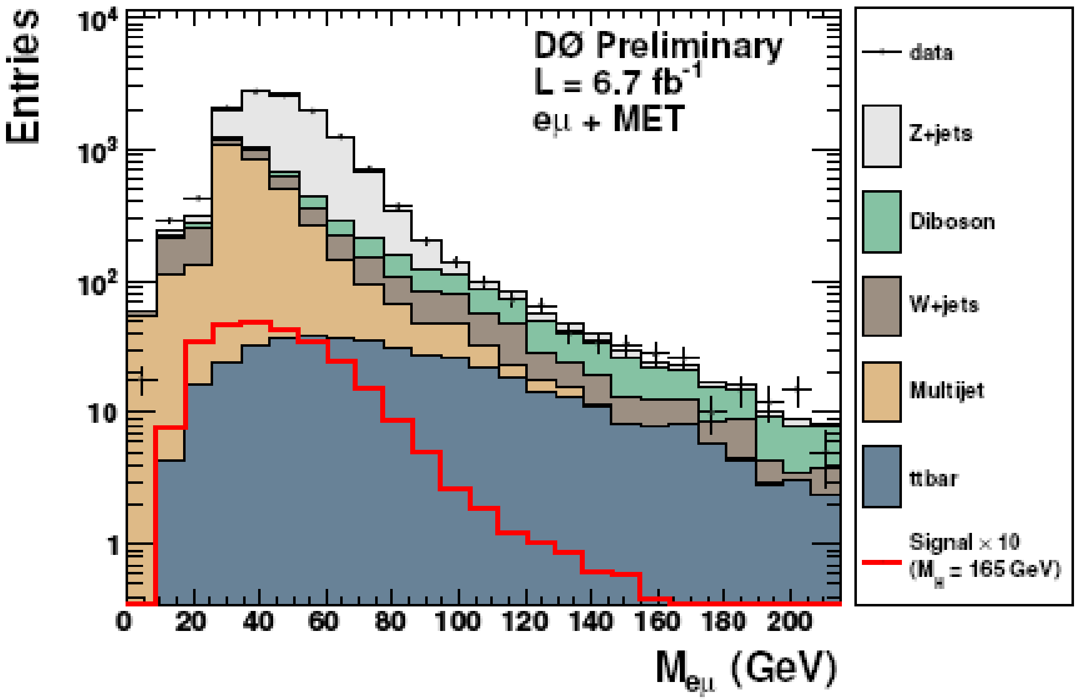



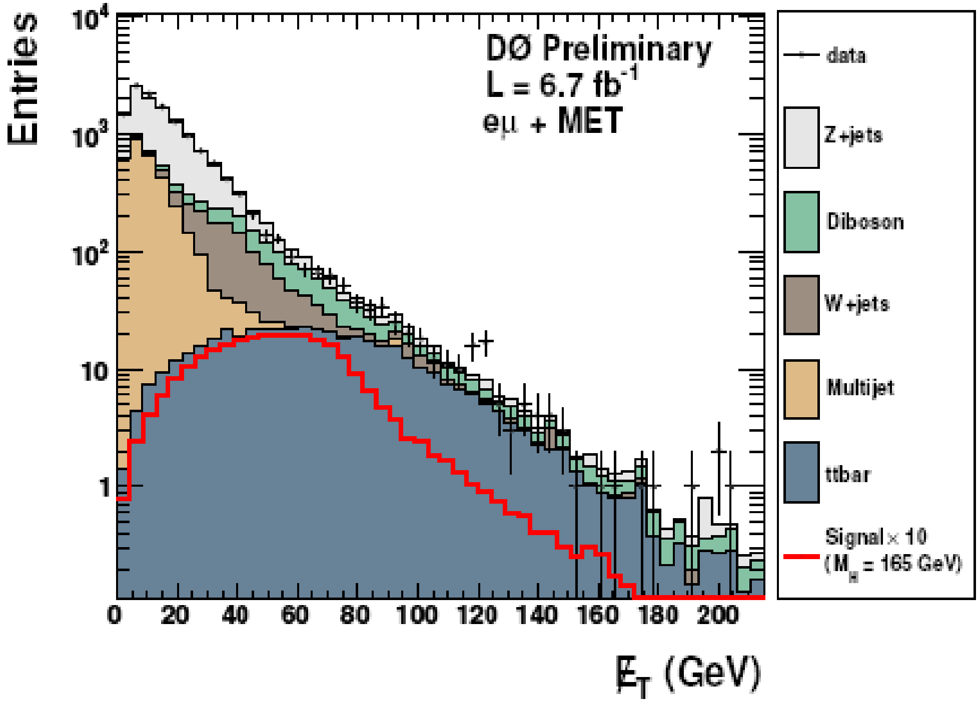



# $H \to WW \to \mu\nu e\nu$

6.7 $fb^{-1}$ data set

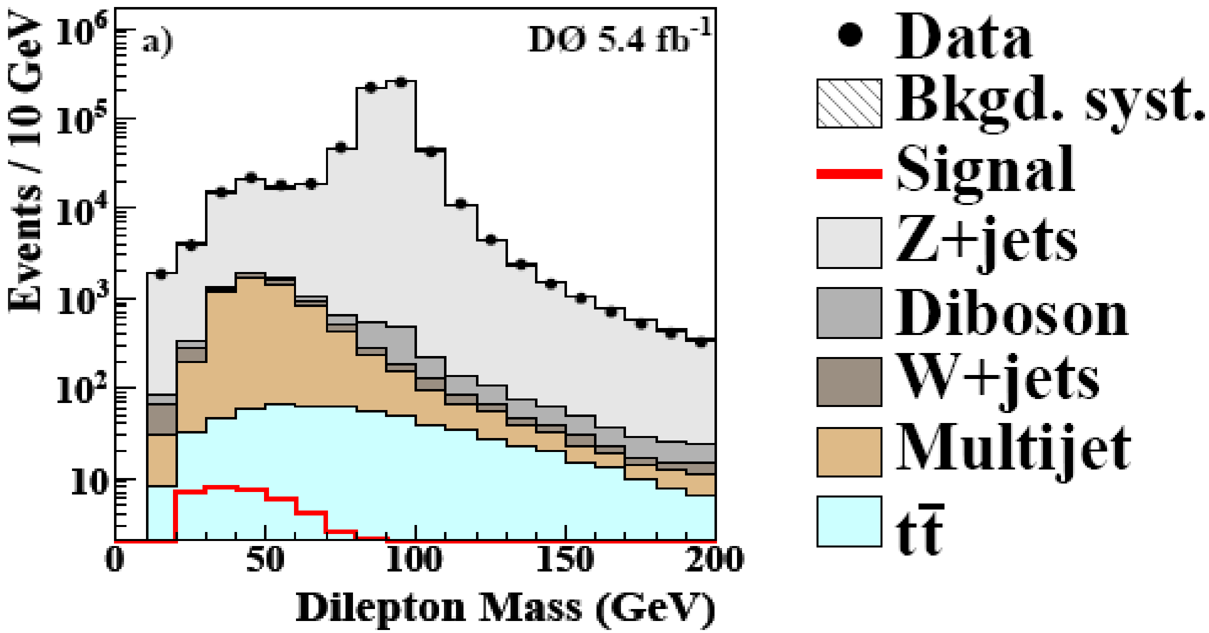
Split into sub-channels by jet multiplicity



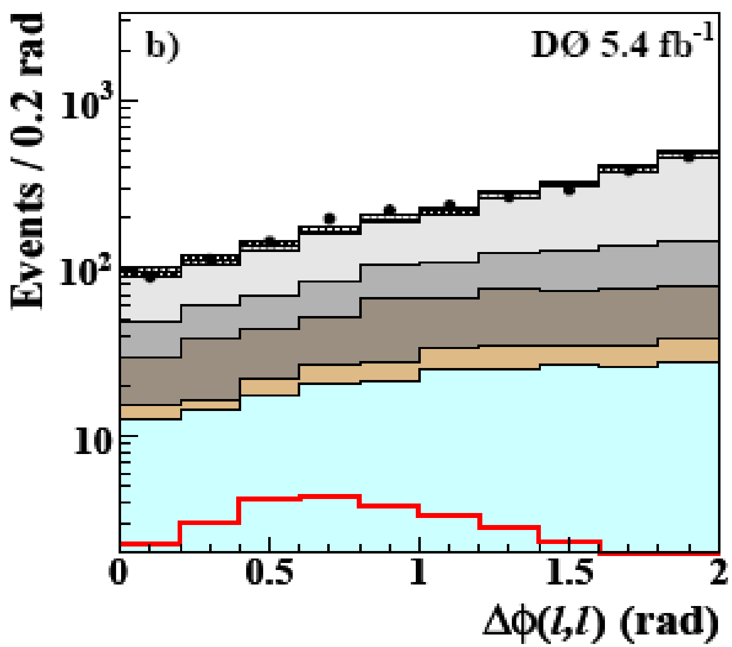

| | Data | Signal | Total Background | $Z \to ee$ | $Z \to \mu\mu$ | $Z \to \tau\tau$ | $t\bar{t}$ | $W + jets$ | $WW$ | $WZ$ | $ZZ$ | Multi-jet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 jets | 2662 | 13.2 | 2838±224 | 8.9 | 172.2 | 1318 | 10.8 | 684.2 | 447.0 | 16.5 | 2.2 | 177.8 |
| 1 jet | 1164 | 7.9 | 1132±91 | 4.8 | 40.6 | 585.5 | 107.6 | 147.6 | 99.0 | 6.5 | 1.6 | 138.4 |
| ≥ 2 jets | 636 | 4.8 | 594±58 | 2.3 | 14.4 | 162.8 | 300.6 | 38.1 | 21.9 | 2.7 | 1.4 | 49.2 |

# $H \rightarrow WW \rightarrow l\nu l\nu$




5.4 fb$^{-1}$ data set

Separate sub-channels for ee and μμ final states

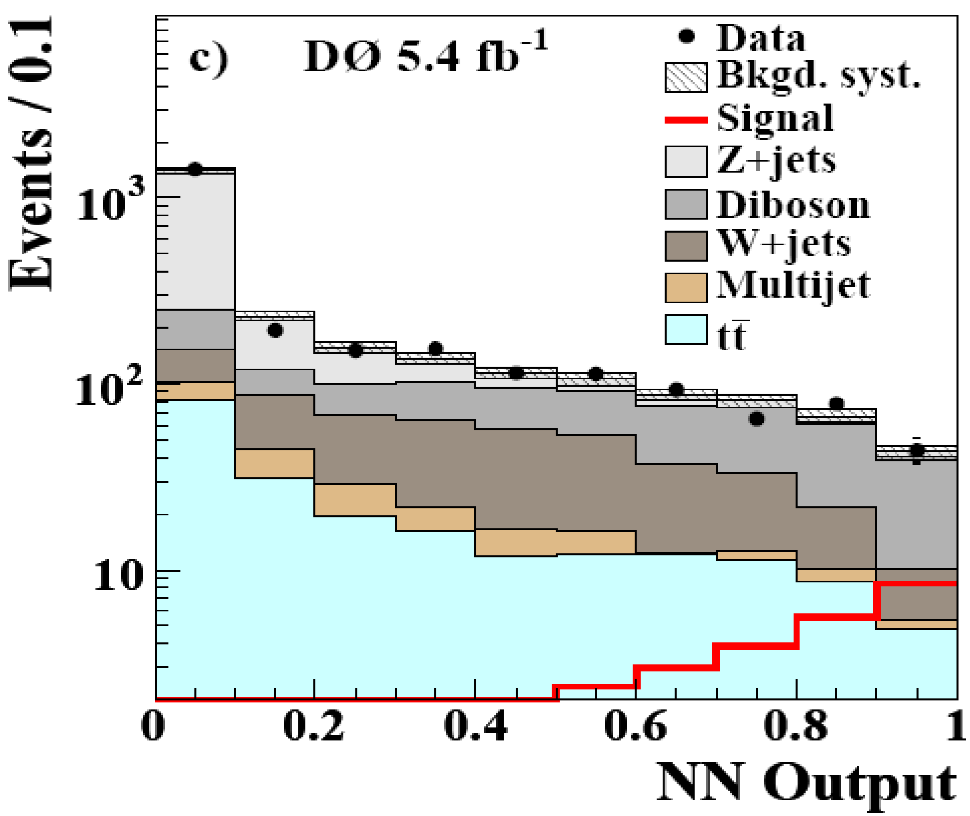


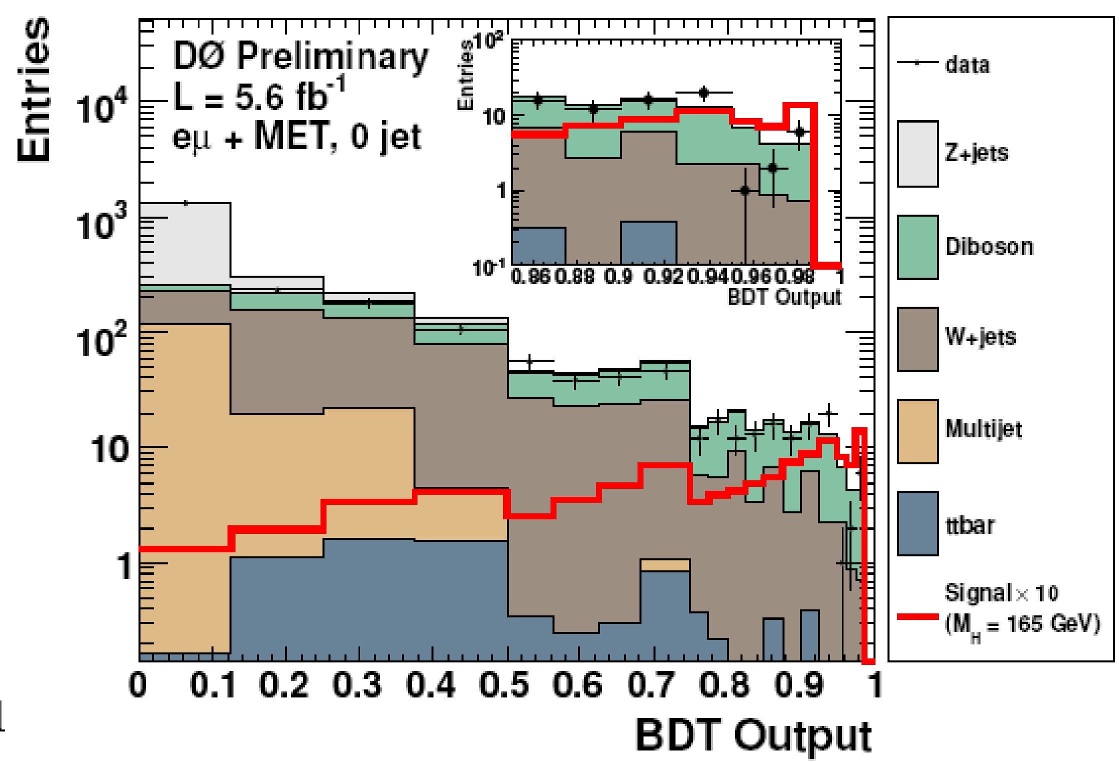

| | $e^+e^-$ Preselection | $e^+e^-$ Final selection | $\mu^+\mu^-$ Preselection | $\mu^+\mu^-$ Final selection |
|---|---|---|---|---|
| $Z/\gamma^* \rightarrow e^+e^-$ | 274886 | $158 \pm 13$ | – | – |
| $Z/\gamma^* \rightarrow \mu^+\mu^-$ | – | – | 373582 | $1247 \pm 37$ |
| $Z/\gamma^* \rightarrow \tau^+\tau^-$ | 1441 | $0.7 \pm 0.1$ | 2659 | $12.0 \pm 0.7$ |
| $t\bar{t}$ | 159 | $47.0 \pm 4.4$ | 184 | $74.6 \pm 6.8$ |
| $W + \text{jets}/\gamma$ | 308 | $122 \pm 11$ | 236 | $91.5 \pm 6.5$ |
| $WW$ | 202 | $73.9 \pm 6.4$ | 272 | $107 \pm 9$ |
| $WZ$ | 137 | $11.5 \pm 1.0$ | 171 | $21.5 \pm 2.0$ |
| $ZZ$ | 117 | $9.3 \pm 0.9$ | 147 | $18.0 \pm 1.8$ |
| Multijet | 1370 | $1.0 \pm 0.1$ | 408 | $53.8 \pm 10.3$ |
| Signal ($m_H = 165$ GeV) | 11.2 | $7.2 \pm 0.8$ | 12.7 | $9.0 \pm 1.0$ |
| Total background | 278620 | $423 \pm 19$ | 377659 | $1625 \pm 41$ |
| Data | 278277 | 421 | 384083 | 1613 |

# H→WW→lνlν: Signal Extraction

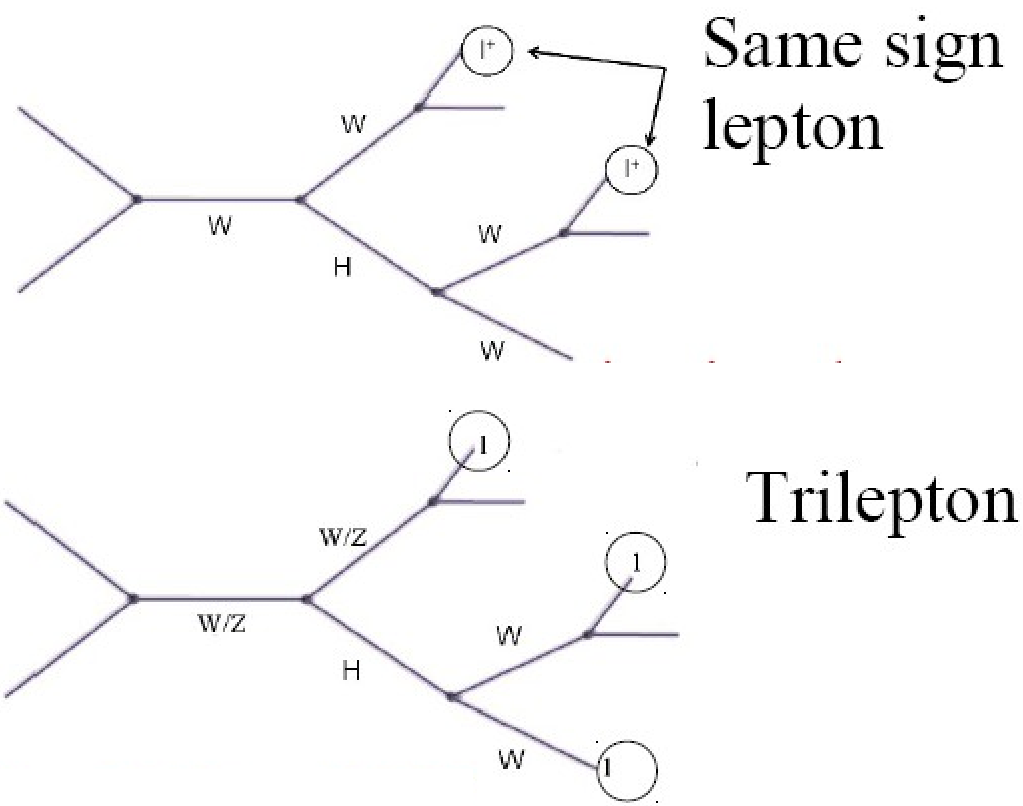
Separately trained MVAs for ee, μμ and μe final states:
- Different instrumental backgrounds
- Different lepton momentum resolutions
- Different backgrounds

MVAs:
- H → WW → lνlν: NN
- H → WW → μνeν: BDT



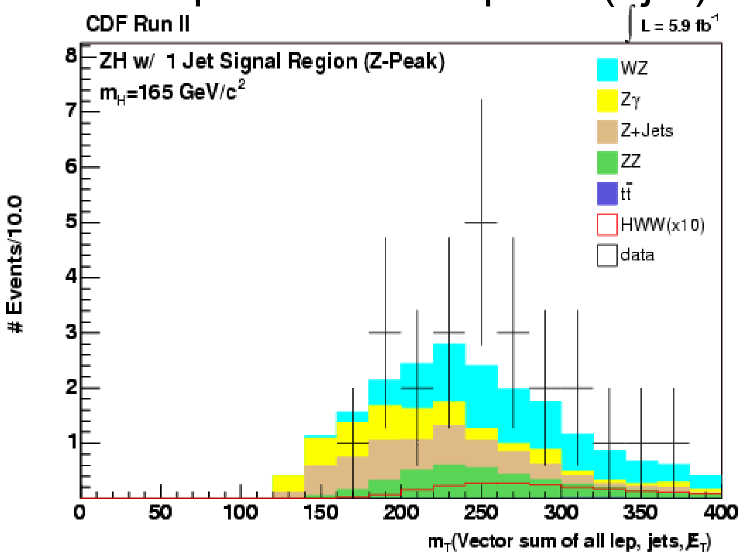
# Same Sign Lepton and Trilepton Channels from Associated Production



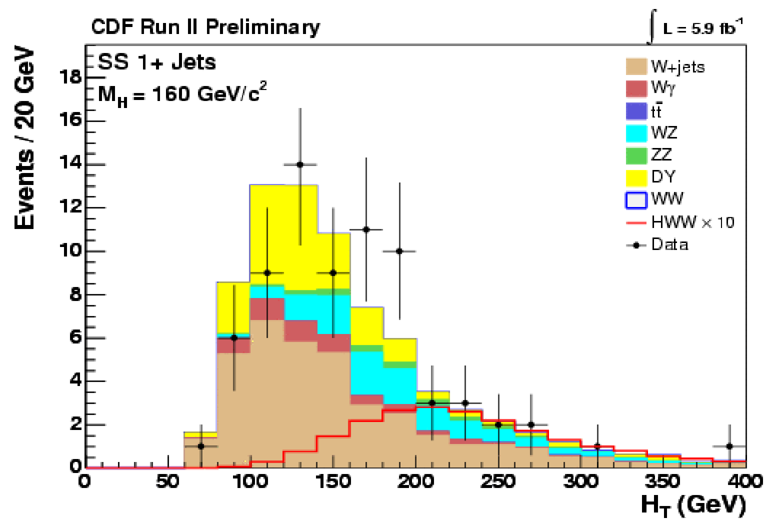
# VH→VWW: SS Lepton & Trilepton

5.9fb$^{-1}$ data set
Dominant signal contribution from VH→VWW

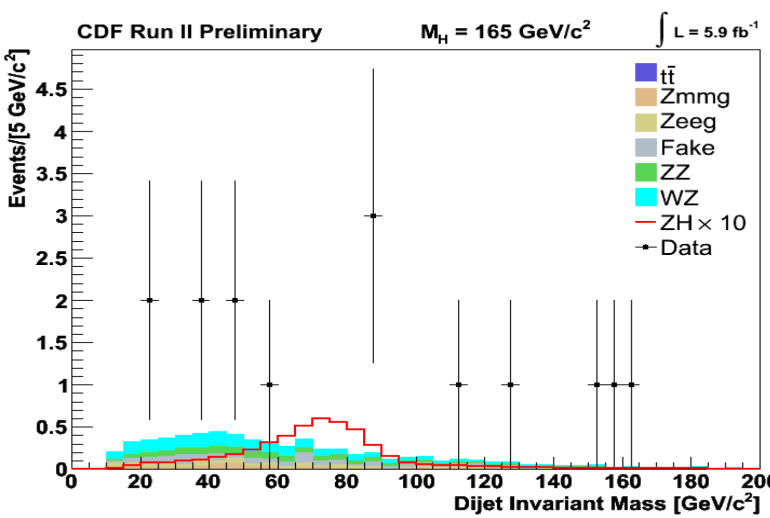
Trilepton inside Z-peak (1jet)



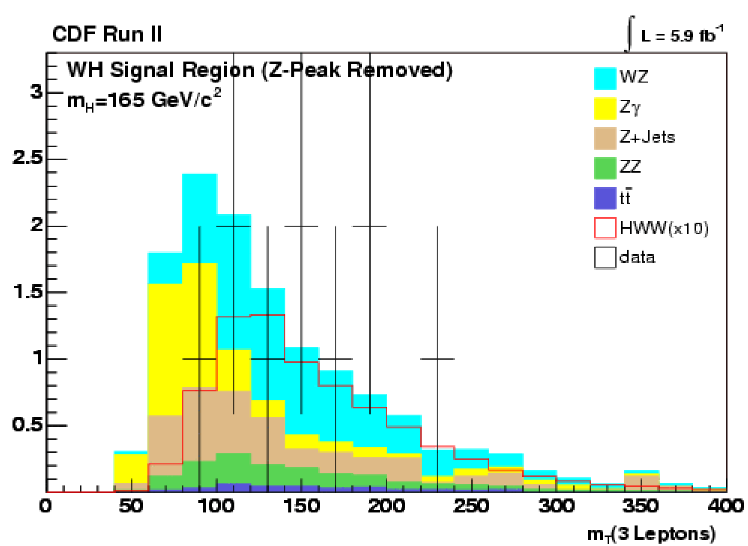

Same-sign (1+ jets)




Trilepton inside Z-peak (2+ jets)




Trilepton outside Z-peak




**Trilepton channels:**
Same-flavor opposite-sign dilepton pairs inside Z peak
→ ZH production

Same-flavor opposite-sign dilepton pairs outside Z peak
→ WH production

# VH→VWW: SS Lepton & Trilepton

Z peak removed

| CDF Run II Preliminary | | | $\int \mathcal{L} = 5.9\ \mathrm{fb}^{-1}$ |
|---|---|---|---|
| | $M_H = 165\ \mathrm{GeV}/c^2$ | | |
| $t\bar{t}$ | 0.37 | $\pm$ | 0.11 |
| $WZ$ | 5.35 | $\pm$ | 0.76 |
| $ZZ$ | 1.30 | $\pm$ | 0.18 |
| $W$+jets | 2.92 | $\pm$ | 0.72 |
| $Z\gamma$ | 3.13 | $\pm$ | 0.62 |
| **Total Background** | 13.1 | $\pm$ | 1.5 |
| $WH$ | 0.611 | $\pm$ | 0.084 |
| $ZH$ | 0.159 | $\pm$ | 0.022 |
| **Total Signal** | 0.77 | $\pm$ | 0.11 |
| **Data** | | 11 | |

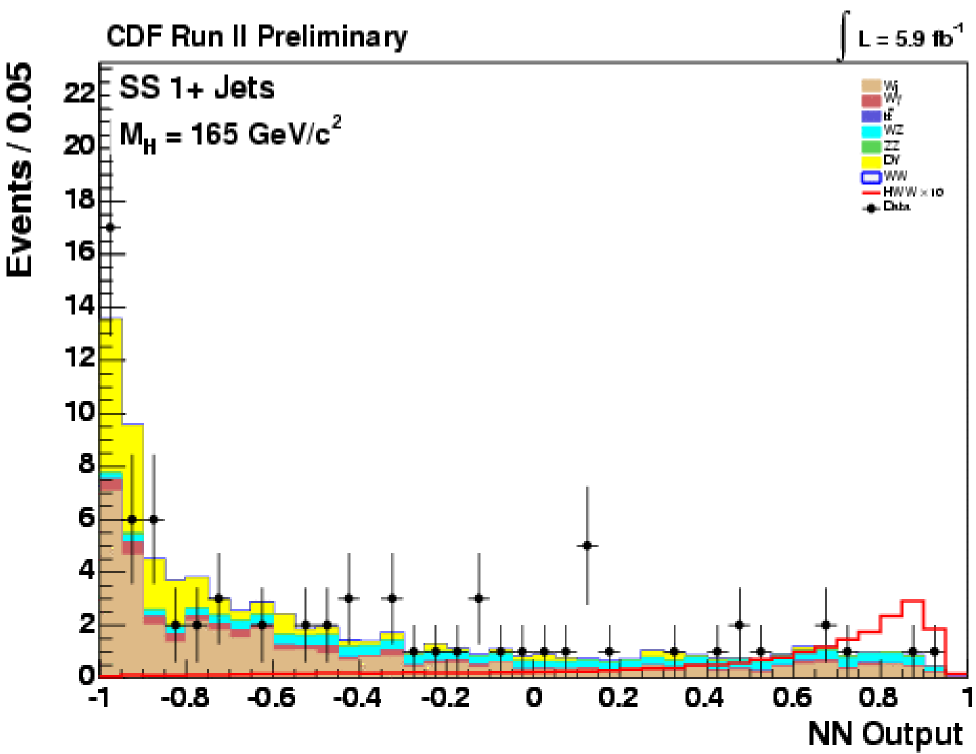
AllSB-trilepNoZ

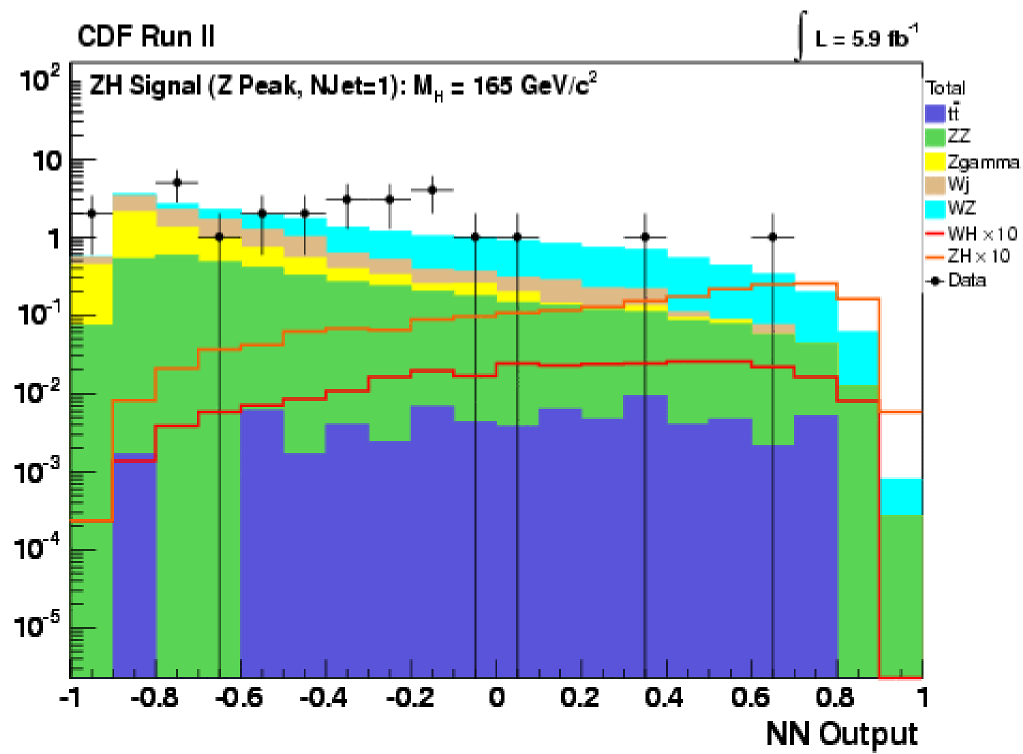
| CDF Run II Preliminary | | | $\int \mathcal{L} = 5.9\ \mathrm{fb}^{-1}$ |
|---|---|---|---|
| | $M_H = 165\ \mathrm{GeV}/c^2$ | | |
| $t\bar{t}$ | 0.067 | $\pm$ | 0.030 |
| $WZ$ | 8.5 | $\pm$ | 1.4 |
| $ZZ$ | 3.97 | $\pm$ | 0.57 |
| $W$+jets | 5.1 | $\pm$ | 1.3 |
| $Z\gamma$ | 4.14 | $\pm$ | 0.85 |
| **Total Background** | 21.8 | $\pm$ | 2.7 |
| $WH$ | 0.0280 | $\pm$ | 0.0046 |
| $ZH$ | 0.203 | $\pm$ | 0.032 |
| **Total Signal** | 0.231 | $\pm$ | 0.035 |
| **Data** | | 26 | |

AllSB-trilepZ1j

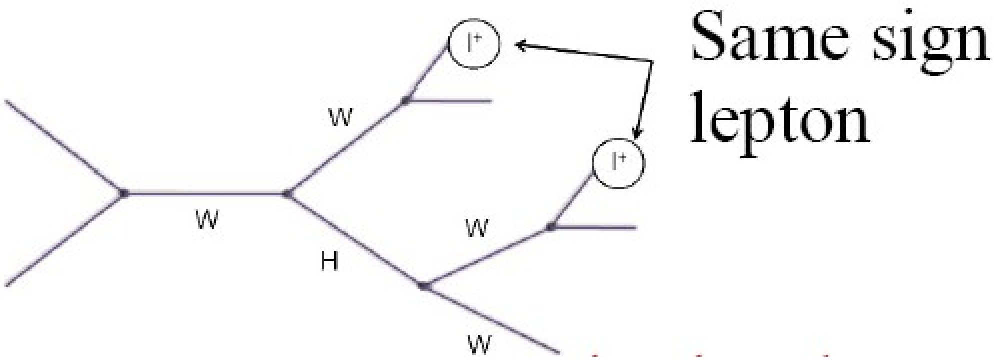
With Z peak

## NN to extract signal



# VH→VWW: SS Lepton

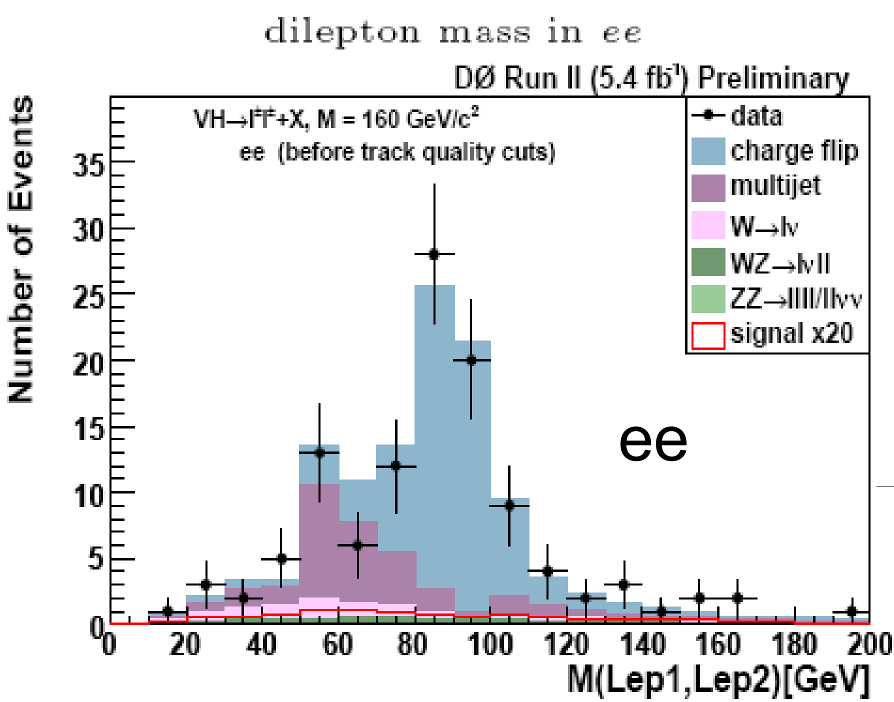



5.4fb$^{-1}$ data set

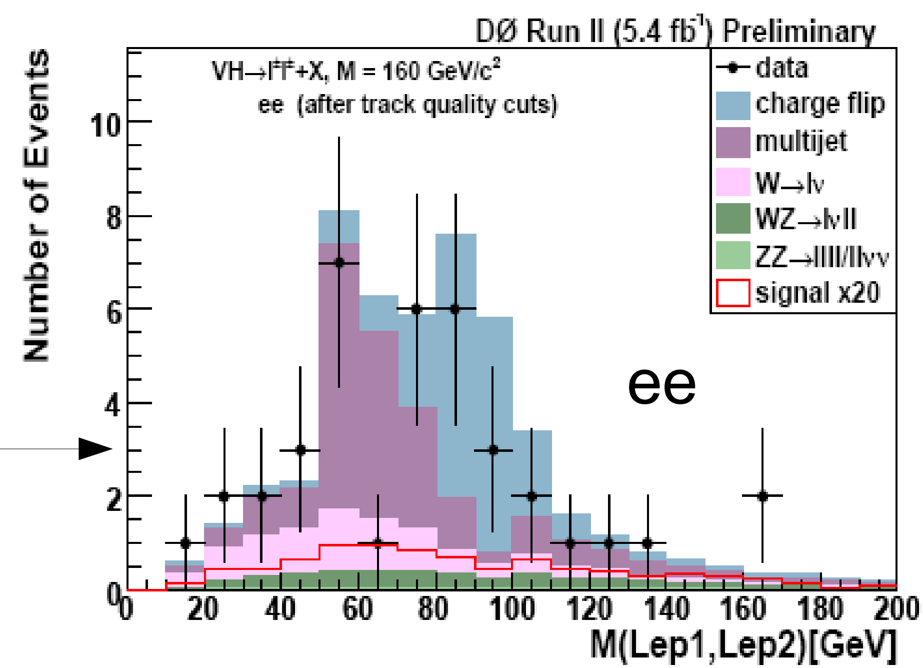
Lepton charge ID important

Backgrounds from charge flip and Multijet

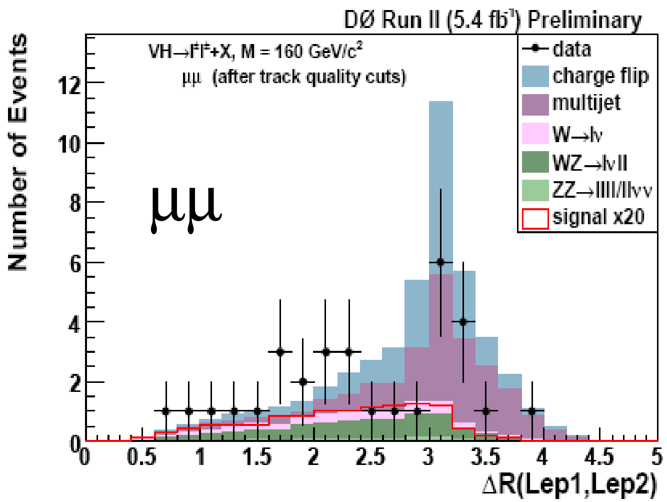
ee, μμ, eμ sub-channels

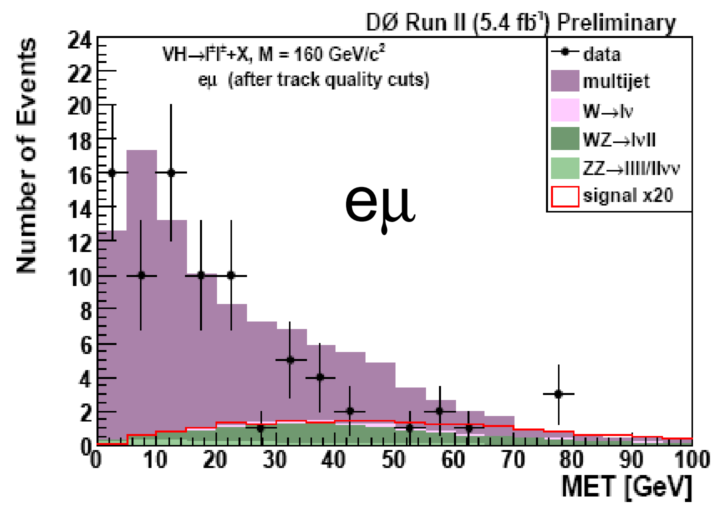



**Track Quality Cuts**

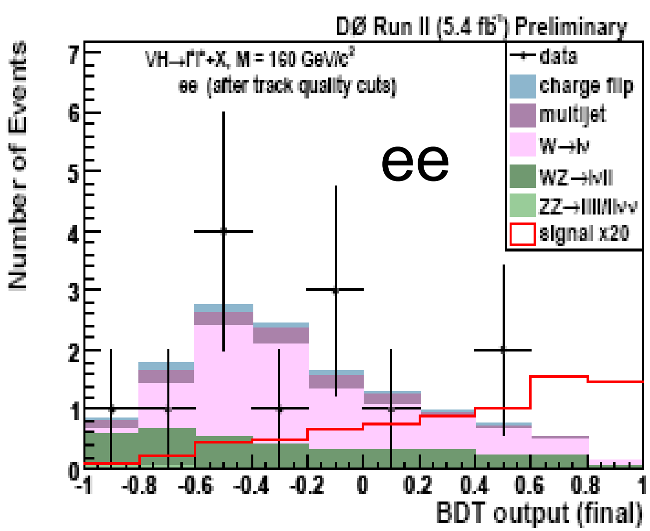


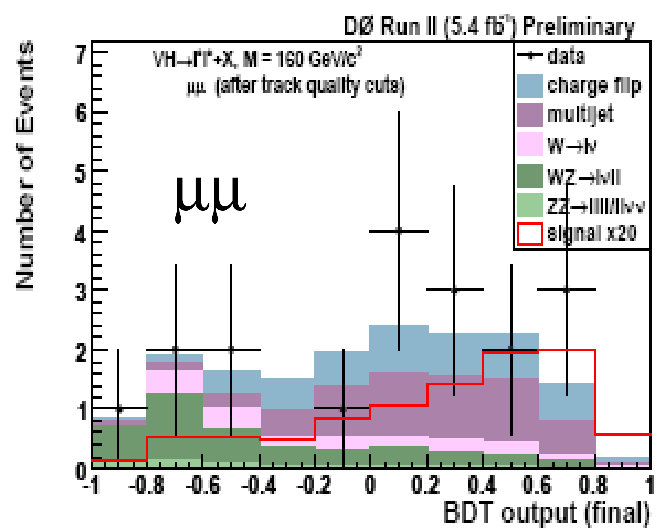
# VH→VWW: SS Lepton

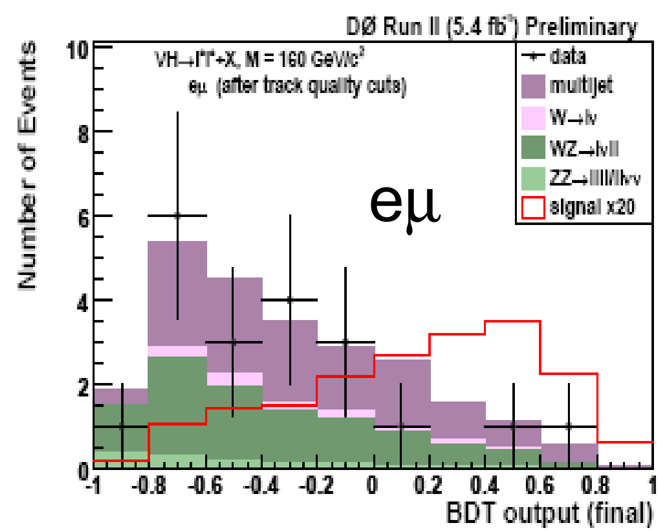



BDT used to extract signal:



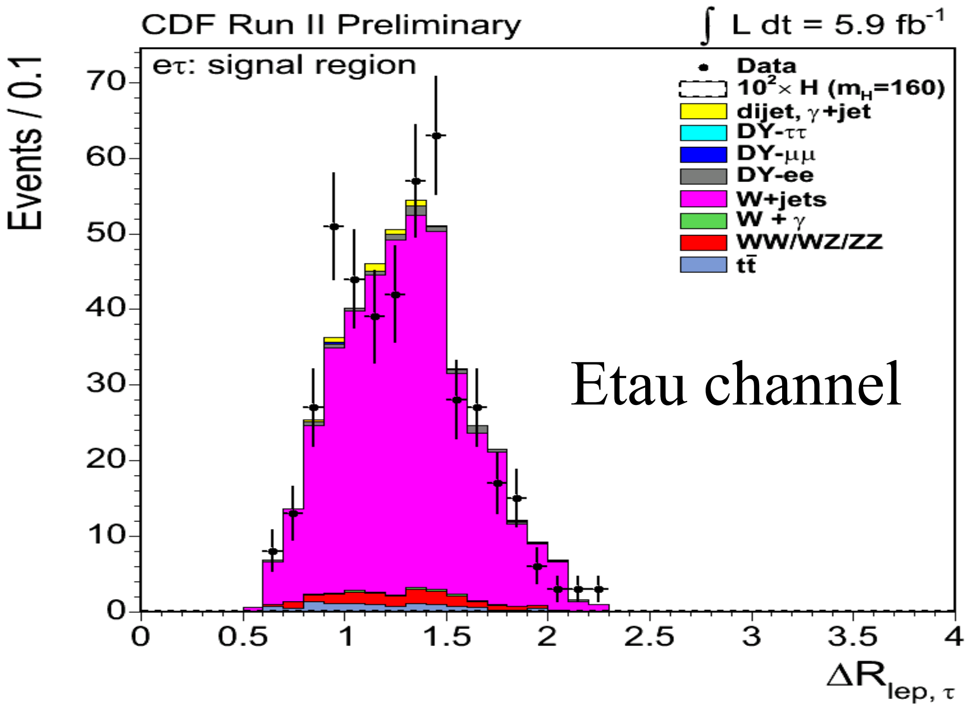



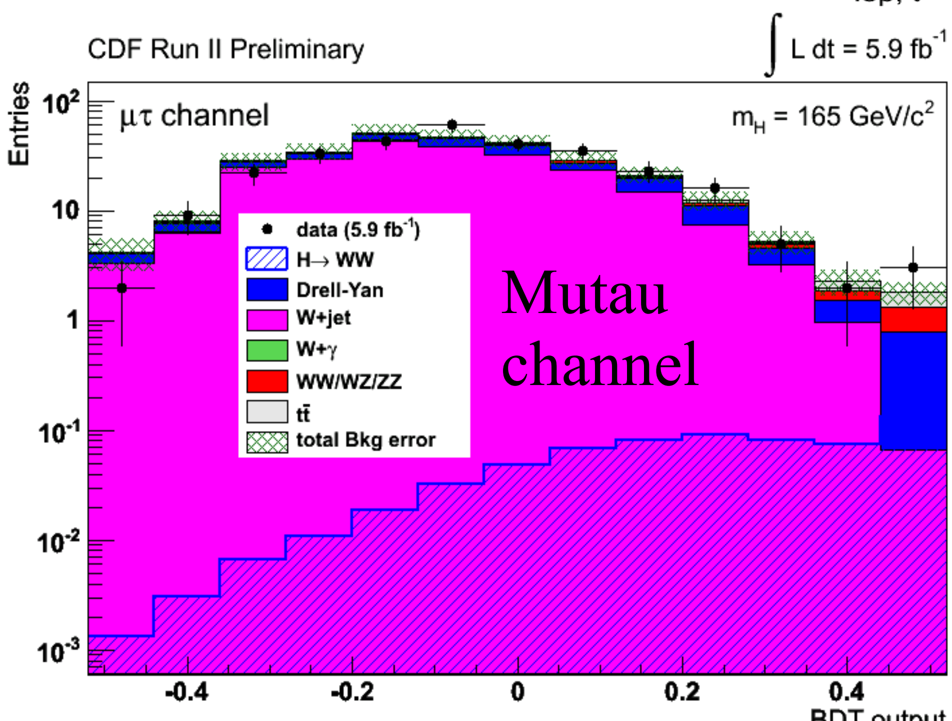
# Hadronic Tau
# and
# Semi-Leptonic Channels

$$H \to WW \to \ell\nu\tau\nu$$

$$H \to WW \to \ell\nu jj$$

# H→WW→lντ$_{had}$ν




5.9fb$^{-1}$ data set

Requires τ to decay hadronically

Two sub-channels: eτ & μτ

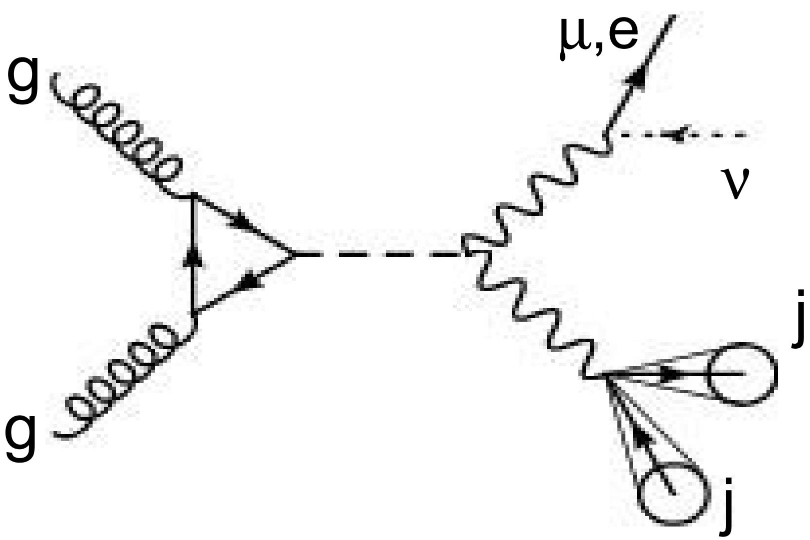
Main background from jets faking taus
Uses BDT

CDF Run II Preliminary $\int \mathcal{L} = 5.9$ fb$^{-1}$

| $m_H = 160$ GeV/$c^2$ | | | |
|---|---|---|---|
| dijet, $\gamma+$ jet | 9 | ± | 27 |
| $Z \to \tau\tau$ | 0.8 | ± | 0.4 |
| $Z \to \ell\ell$ | 48.8 | ± | 6.4 |
| W+jets | 624 | ± | 77 |
| W$\gamma$ | 3.3 | ± | 0.4 |
| Diboson (WW, WZ, ZZ) | 25.3 | ± | 2.7 |
| $t\bar{t}$ | 15.5 | ± | 2.8 |
| **Total Background** | 726 | ± | 82 |
| $gg \to H$ | 1.08 | ± | 0.10 |
| $WH$ | 0.261 | ± | 0.026 |
| $ZH$ | 0.167 | ± | 0.017 |
| $VBF$ | 0.095 | ± | 0.011 |
| **Total Signal** | 1.60 | ± | 0.11 |
| **Data** | | 741 | |

$e\tau$-$\mu\tau$ channels

# $H \to WW \to l\nu jj$




5.4fb$^{-1}$ data set

First look at semi-leptonic final states: l=μ,e

Split into electron and muon sub-channels

Large branching fraction of hadronic W decays

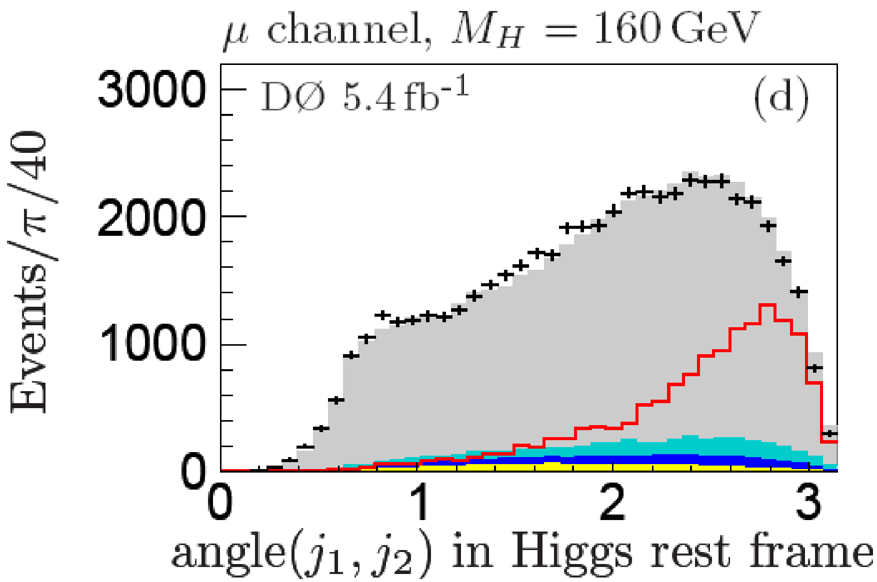
Factor of ~6 increase in Cross Section x BR

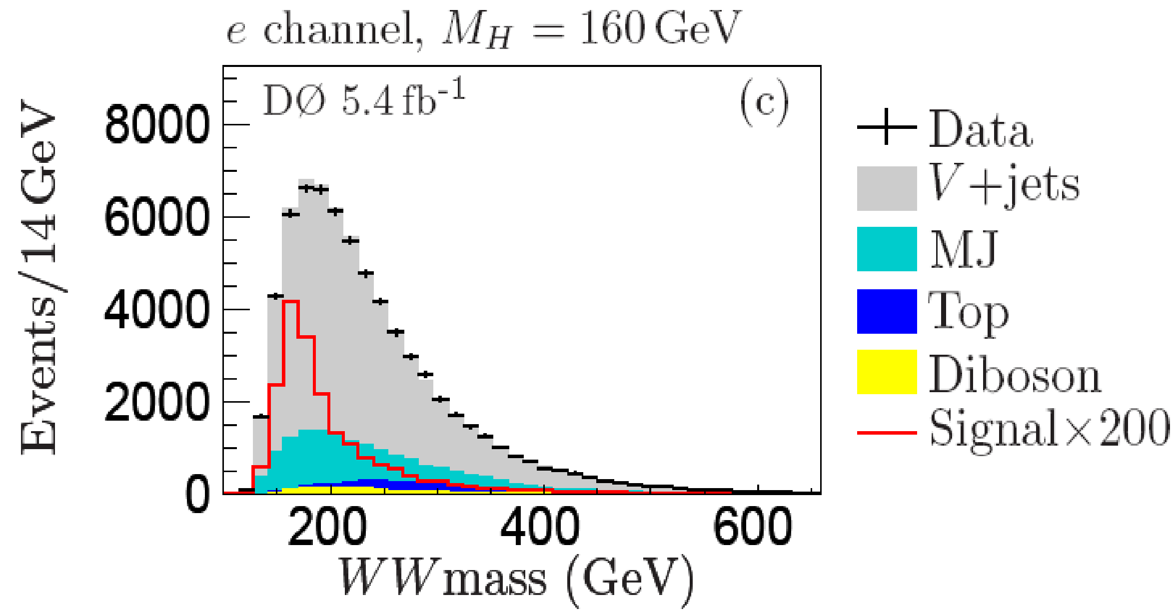
Large backgrounds from W+jets

Use W mass constraint to reconstruct neutrino $p_Z$
For $m_H$>160GeV possible to extract the mass of Higgs

| Channel | $gg \to H$ | $qq \to qqH$ | $WH$ | $V$+jets | Multijet | Top | $VV$ | Total Background | Data |
|---|---|---|---|---|---|---|---|---|---|
| Electron | 11.2/46.3/27.8 | 2.1/6.4/4.2 | 7.2/0/0 | 52158 | 11453 | 2433 | 1584 | 67627 | 67627 |
| Muon | 9.5/34.7/20.4 | 1.5/4.4/2.9 | 5.7/0/0 | 47970 | 2720 | 1598 | 1273 | 53562 | 53562 |

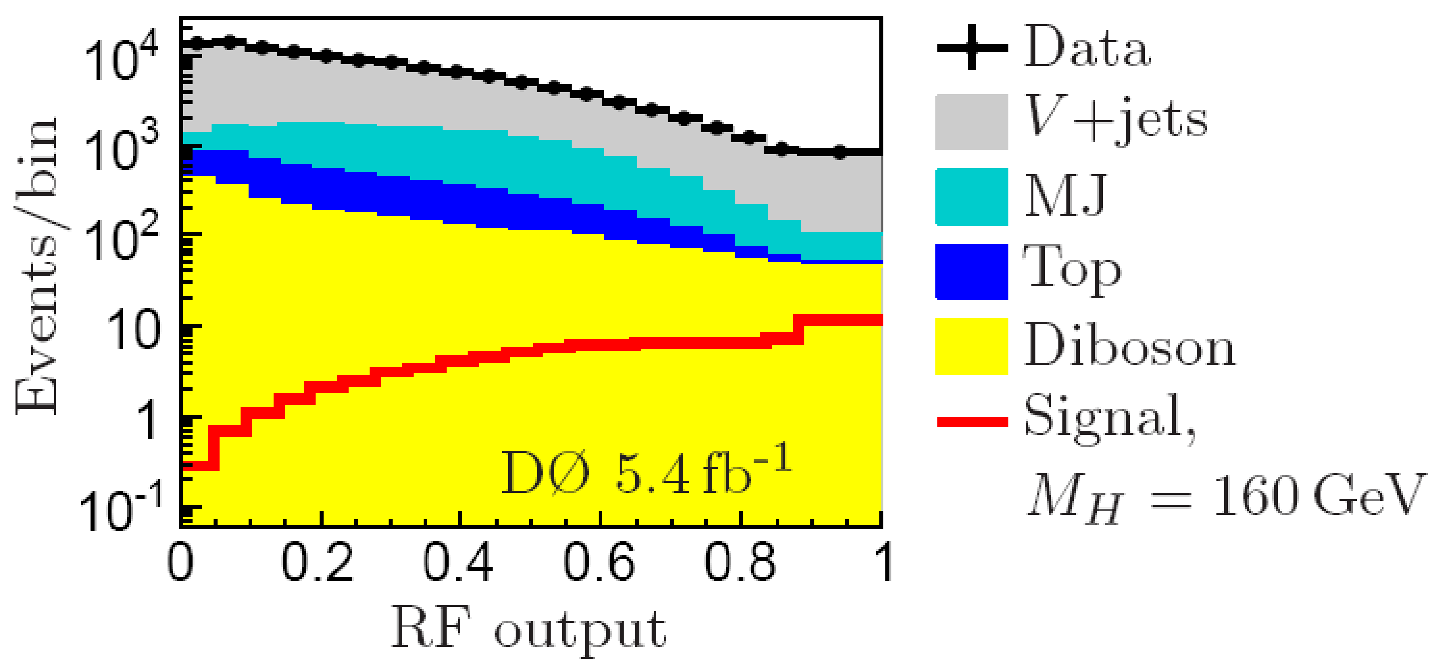
# H→WW→lνjj




Random Forest used for signal extraction

Separately optimized for electron and muon sub-channels



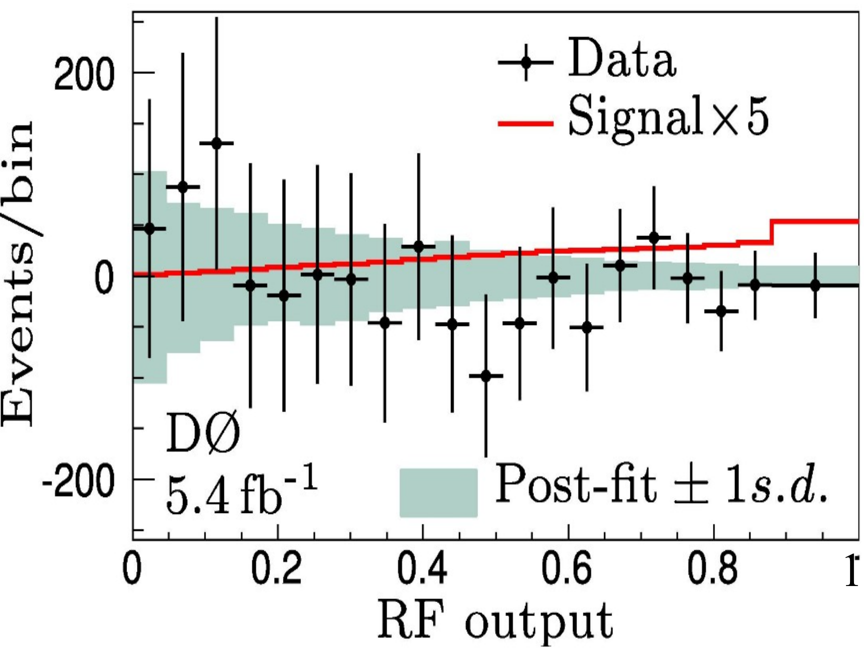
# Systematic Uncertainties

Can affect both shape and overall normalization of final discriminant

Uncertainties listed are relative changes in normalization

| Contribution | Shape | W+jets | Z+jets | Top | Diboson | $gg \to H$ |
|---|---|---|---|---|---|---|
| Jet energy scale | Y | shape only | shape only | $\pm 6.0$ | $\left(^{+3.3}_{-3.5}\right)$ | $\left(^{+3.3}_{-2.0}\right)$ |
| Jet identification | Y | shape only | shape only | $\pm 3.3$ | $\pm 1.3$ | $\pm 3.5$ |
| Jet resolution | Y | shape only | shape only | $\left(^{+0.5}_{-0.3}\right)$ | $\left(^{+1.0}_{-0.5}\right)$ | $\left(^{+2.0}_{-1.8}\right)$ |
| Association of jets with PV | Y | shape only | shape only | $\pm 3.8$ | $\pm 3.8$ | $\pm 4.8$ |
| Luminosty | - | - | $\pm 6.1$ | $\pm 6.1$ | $\pm 6.1$ | $\pm 6.1$ |
| Muon trigger | Y | $\pm 0.5$ | $\pm 0.5$ | $\pm 0.5$ | $\pm 0.25$ | $\pm 0.25$ |
| Electron identification | - | $\pm 4.0$ | $\pm 4.0$ | $\pm 4.0$ | $\pm 4.0$ | $\pm 4.0$ |
| Muon identification | - | $\pm 4.0$ | $\pm 4.0$ | $\pm 4.0$ | $\pm 4.0$ | $\pm 4.0$ |
| ALPGEN tuning | Y | shape only | shape only | - | - | - |
| Cross Section | - | $\pm 6.0$ | $\pm 6.0$ | $\pm 10.0$ | $\pm 7.0$ | $\pm 10.0$ |
| PDF | Y | $\left(^{+3.5}_{-2.5}\right)$ | $\left(^{+8.0}_{-1.5}\right)$ | $\left(^{+2.3}_{-3.6}\right)$ | $\pm 0.25$ | $\left(^{+1.8}_{-3.8}\right)$ |

| | | Multijet background | |
|---|---|---|---|
| | | Electron channel | Muon channel |
| Multijet background | Y | $\pm 6.5$ | $\pm 26.2$ |




Background subtracted data (points), 1s.d. uncertainty on background (blue band) $M_H$=160GeV signal x5 (red)

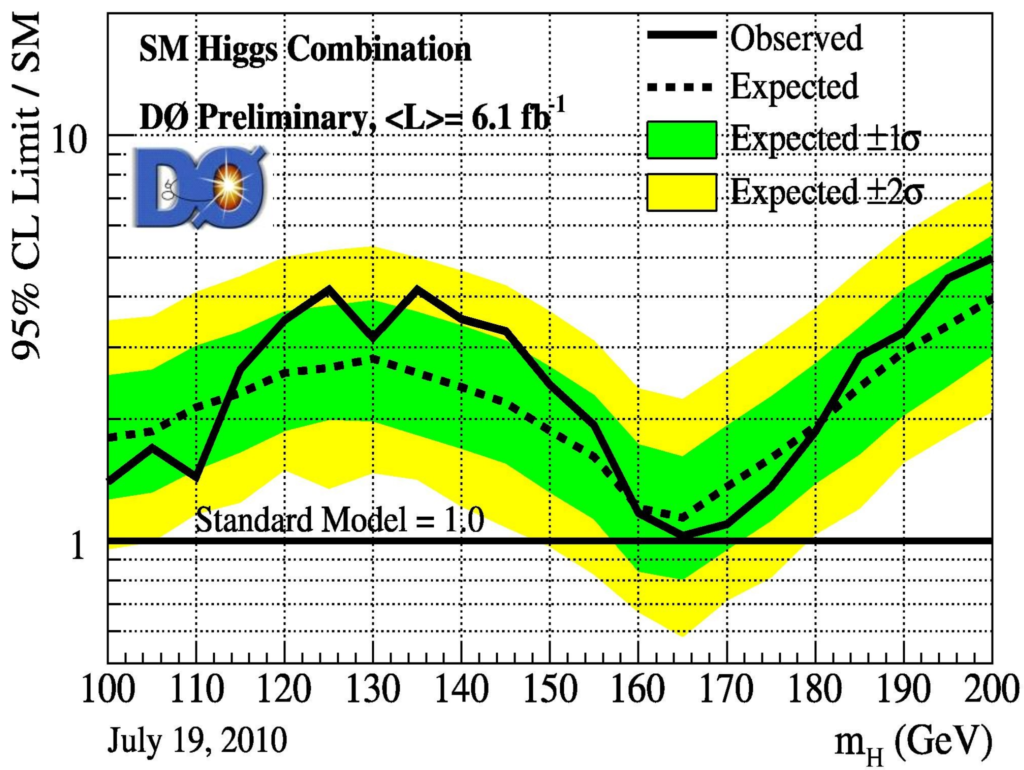
# Combination & Limits

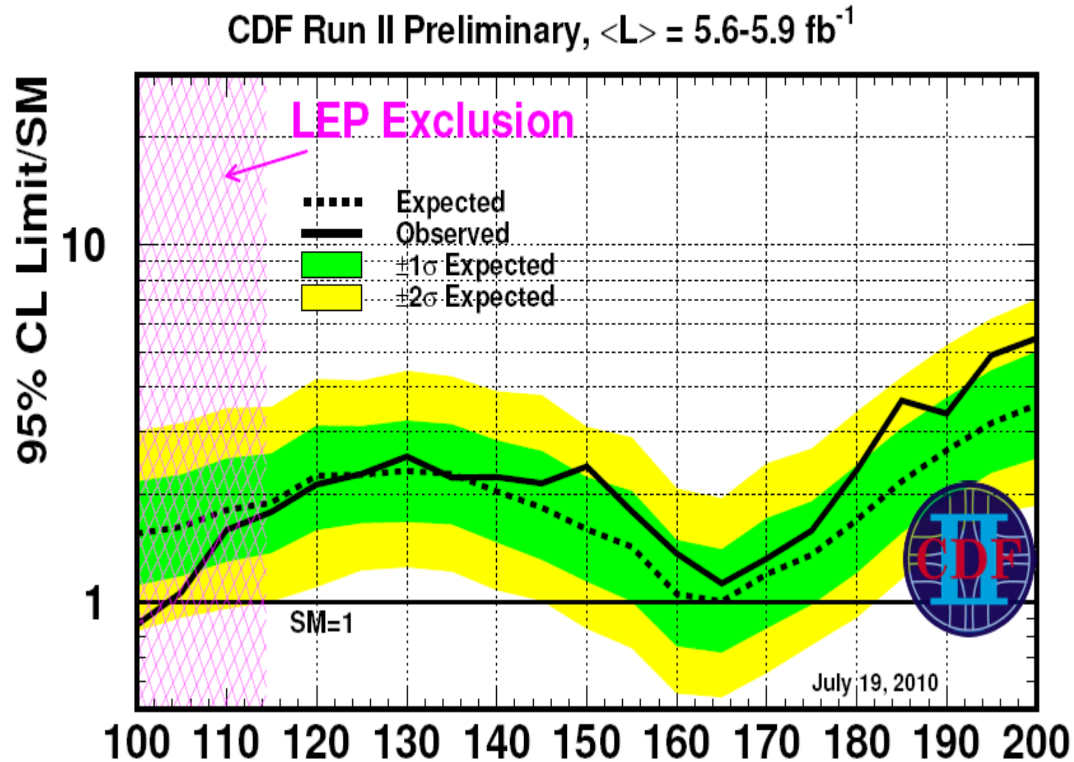
# Exclusion Limits

No significant excess of signal-like events is observed

MVA outputs used to set exclusion limits at 95% CL

Combining low mass and high mass results

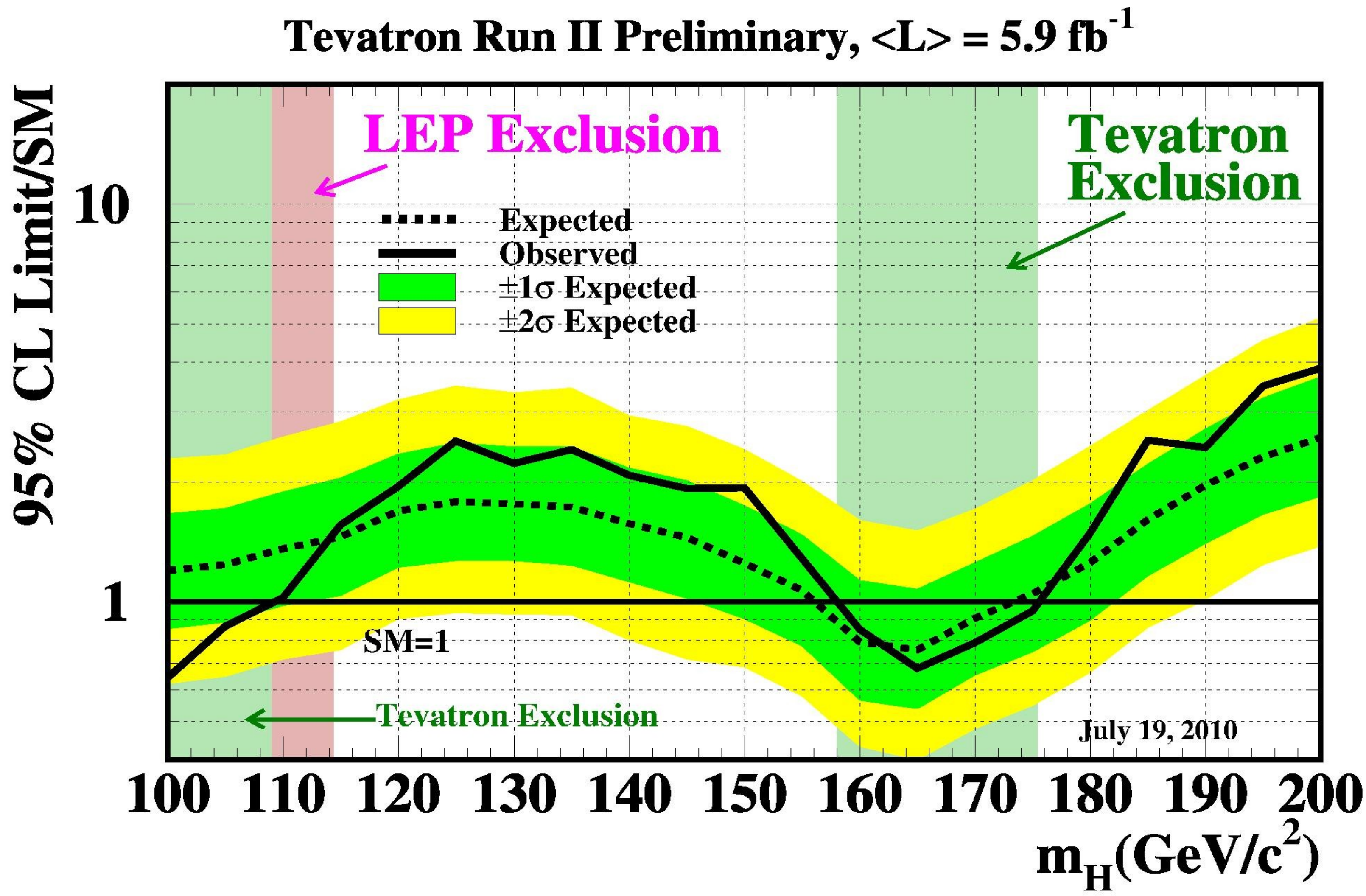



DØ almost achieves observed exclusion at $m_H$=165GeV

CDF achieved expected exclusion at $m_H$=165GeV

# Tevatron Combination

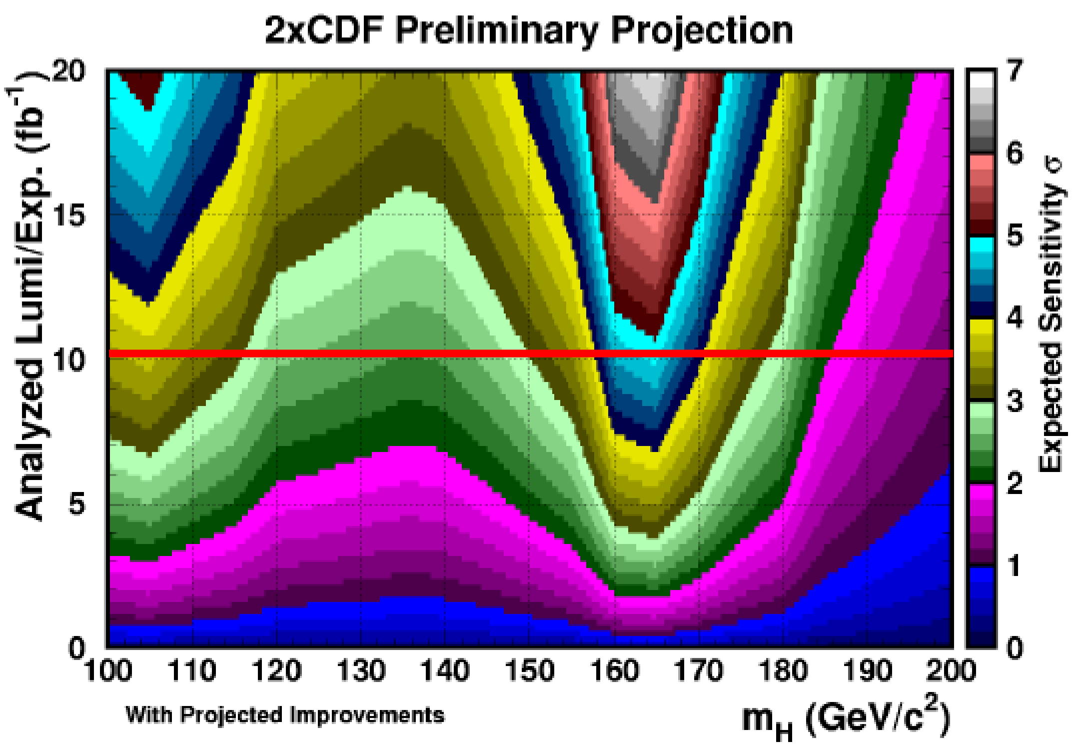



We exclude at the 95% CL the production of a SM Higgs boson in the mass range of 158 to 175 GeV

# Summary & Outlook

- Presented an overview of the Tevatron high mass SM Higgs searches
  - *Leave no stone unturned*
  - *Divide and conquer*
- Tevatron limits shown are based on ~6$fb^{-1}$
- Future prospects:

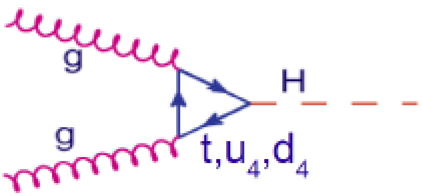
10$fb^{-1}$ by the end of Run2
>2.4σ expected sensitivity across entire mass range
3σ at 115GeV

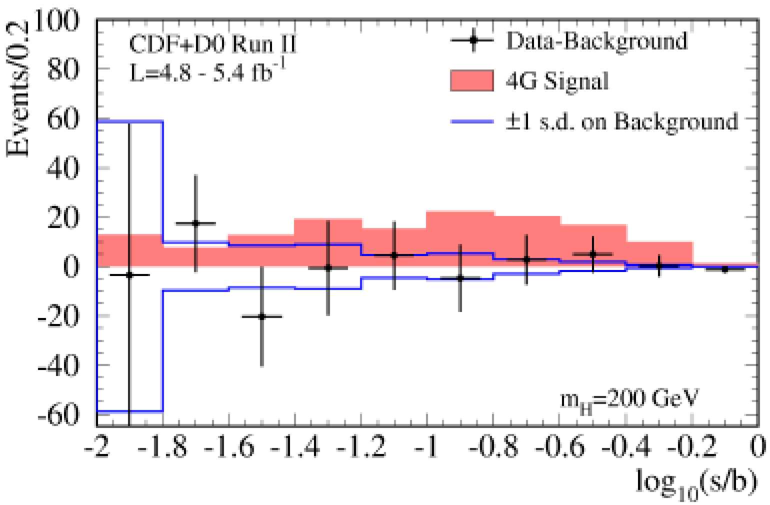


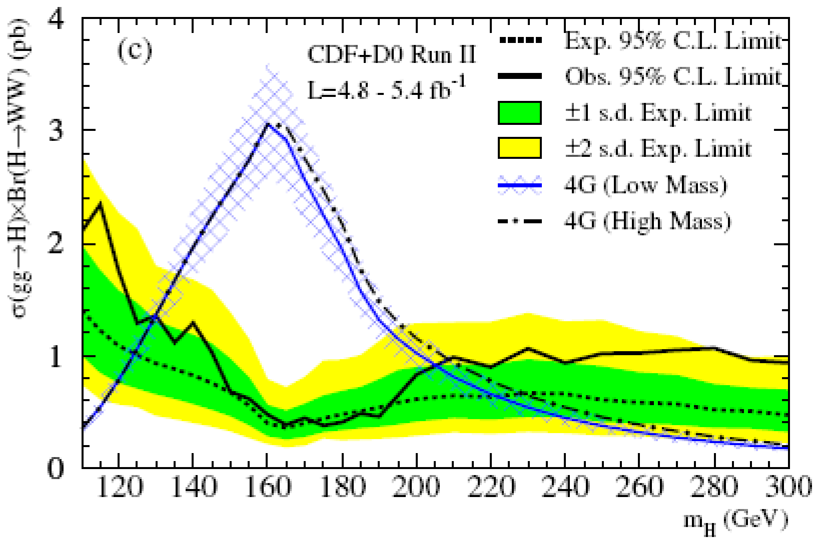
# Backup

# $4^{th}$ Generation Interpretation

- New heavy quark generation hypothesis
  - $ggH$ coupling is 3 times bigger than SM
  - 9 times larger production cross section
- dilepton+ $\not{E}_T$ channel searches similar to SM
  - Analyses re-optimized for higher $m_H$ ranges



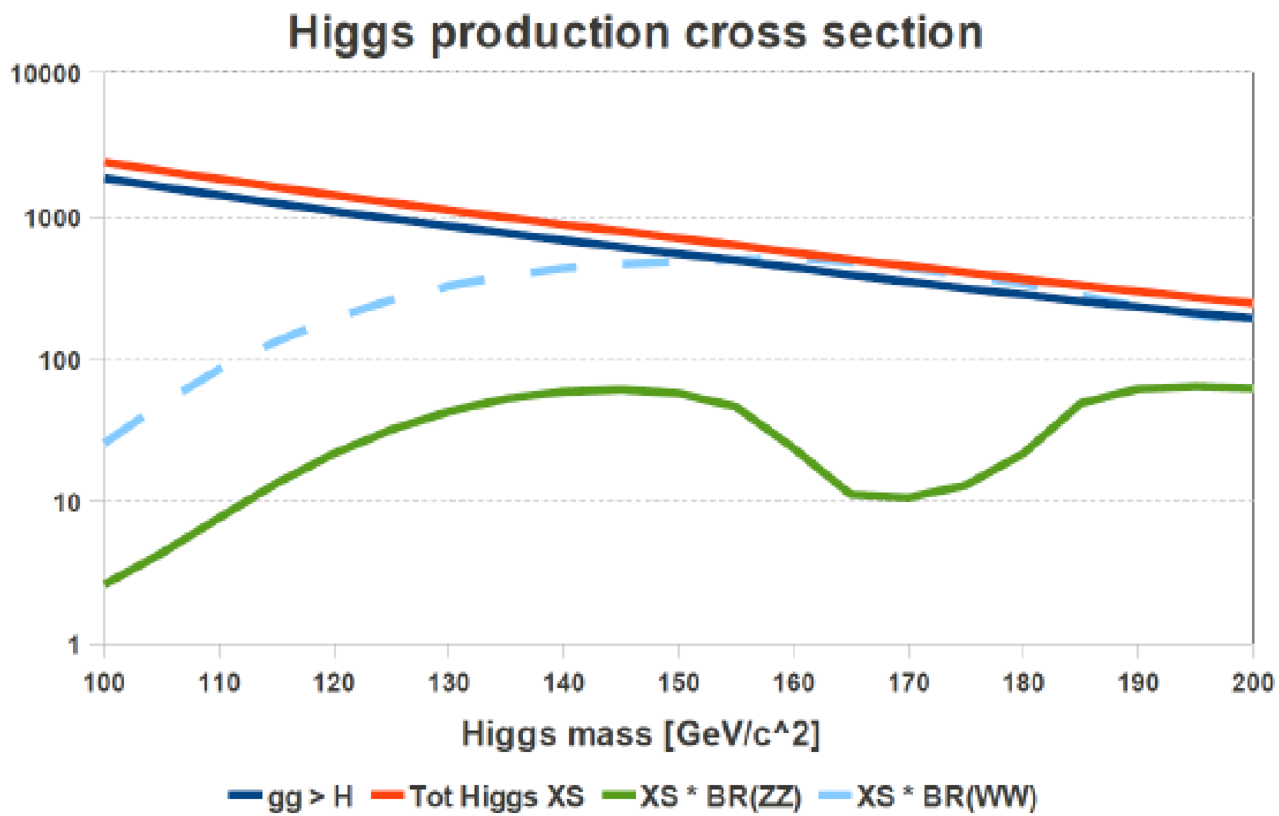

**CDF+D0 combined exclusion: 131$\leq m_H \leq$208 GeV/c$^2$ 95% CL**
**(for infinite mass scenario)**

# $H \rightarrow ZZ$

- Can significantly contribute to:

  $M_{\ell\ell} \in [140, 150]$ GeV/c$^2$

  $M_{\ell\ell} \geq 180$ GeV/c$^2$
- Can be exploited: $\ell\ell\nu\nu$, $\ell\ell jj$, $\nu\nu b\bar{b}$(, $jjb\bar{b}$)




- Large contribution to limits on Higgs searches in $4^{th}$ generation models
  - Higgs mass currently excluded up to 204 GeV/c$^2$
  - For $m_H \geq 200$ GeV, $H \rightarrow ZZ$ is as sensitive as $H \rightarrow WW$

# Search Channel Summary

| $m_H = 165$ GeV/c$^2$ | Exp. | Obs. |
|---|---|---|
| **CDF** | | |
| OS - 0 jet 5.9 - fb$^{-1}$ | 1.67 | 2.39 |
| OS - 1 jet | 2.35 | 2.46 |
| OS - 2+ jets | 3.16 | 6.14 |
| low $M_{\ell\ell}$ | 11.2 | 7.21 |
| Same Sign | 4.86 | 5.92 |
| Trileptons (noZ) | 7.37 | 7.85 |
| Trileptons (Z - 1j) | 31.8 | 36.4 |
| Trileptons (Z - 2+j) | 9.16 | 10.4 |
| hadronic $\tau$ | 14.5 | 23.5 |
| **D0** | | |
| $ee + \mu\mu + e\mu$ - 5.4 fb$^{-1}$ | 1.36 | 1.55 |
| $e\mu$ - 6.7 fb$^{-1}$ | 1.93 | 1.99 |
| Same Sign | 7.0 | 7.2 |
| $\ell\nu jj$ | 5.5 | 3.8 |

# $H \to WW \to l\nu jj$
# Signal Cross Sections

D. de Florian and M. Grazzini, Phys. Lett. B **674**, 291 (2009); C. Anastasiou, R. Boughezal, and F. Petriello, J. High Energy Phys. **04**, 003 (2009); E.L. Berger and J. Campbell, Phys. Rev. D **70**, 073011 (2004); T. Hahn *et al.*, `arXiv:hep-ph/0607308` (2006); M. L. Ciccolini, S. Dittmaier, and M. Krämer, Phys. Rev. D **68**, 073003 (2003); O. Brein, A. Djouadi, and R. Harlander, Phys. Lett. B **579**, 149 (2004); J. Baglio and A. Djouadi, J. High Energy Phys. **10**, 064 (2010); A. Djouadi, J. Kalinowski, and M. Spira, Comput. Phys. Commun. 108, 56 (1998).