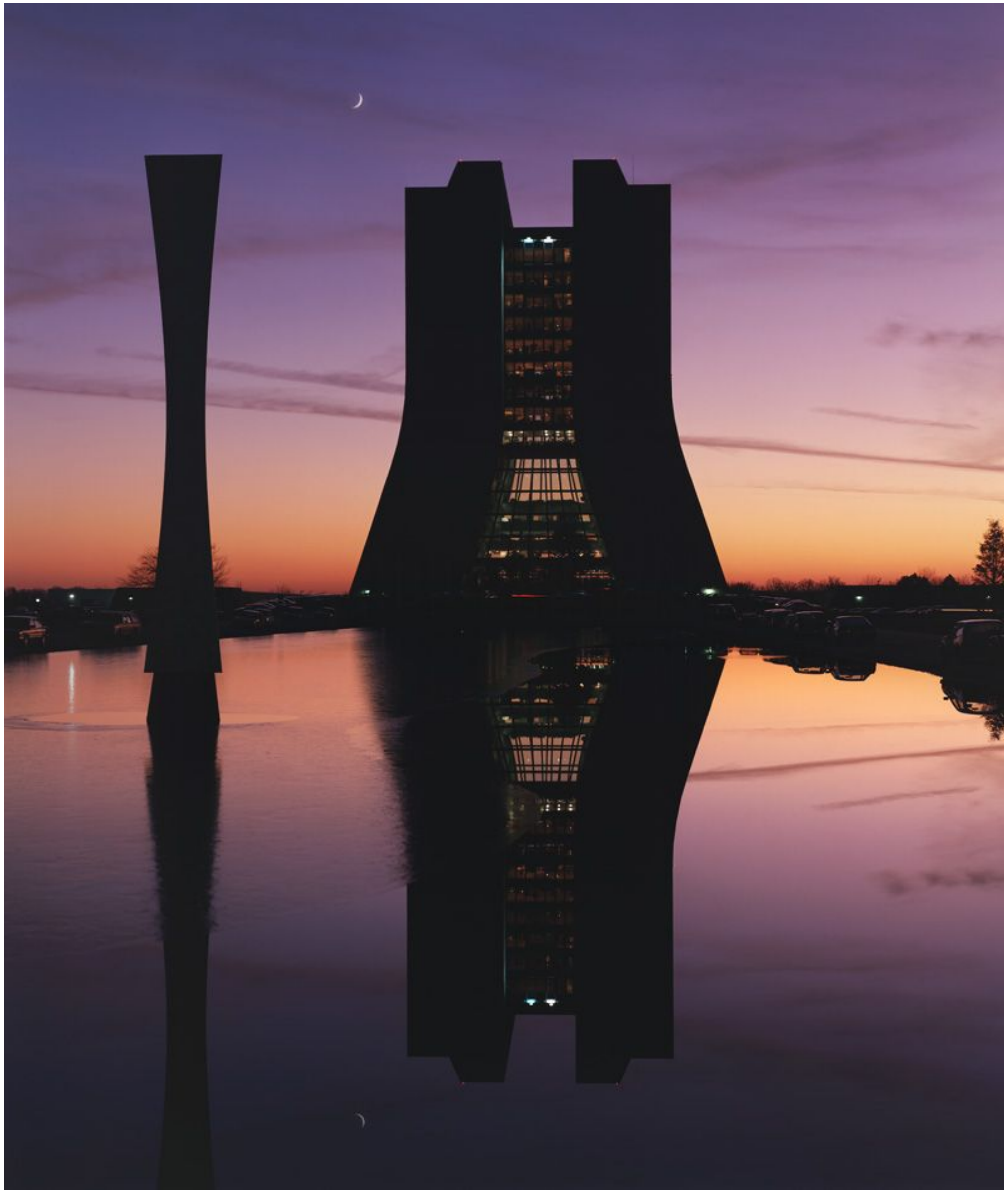
Search for a High Mass SM Higgs Boson at the Tevatron

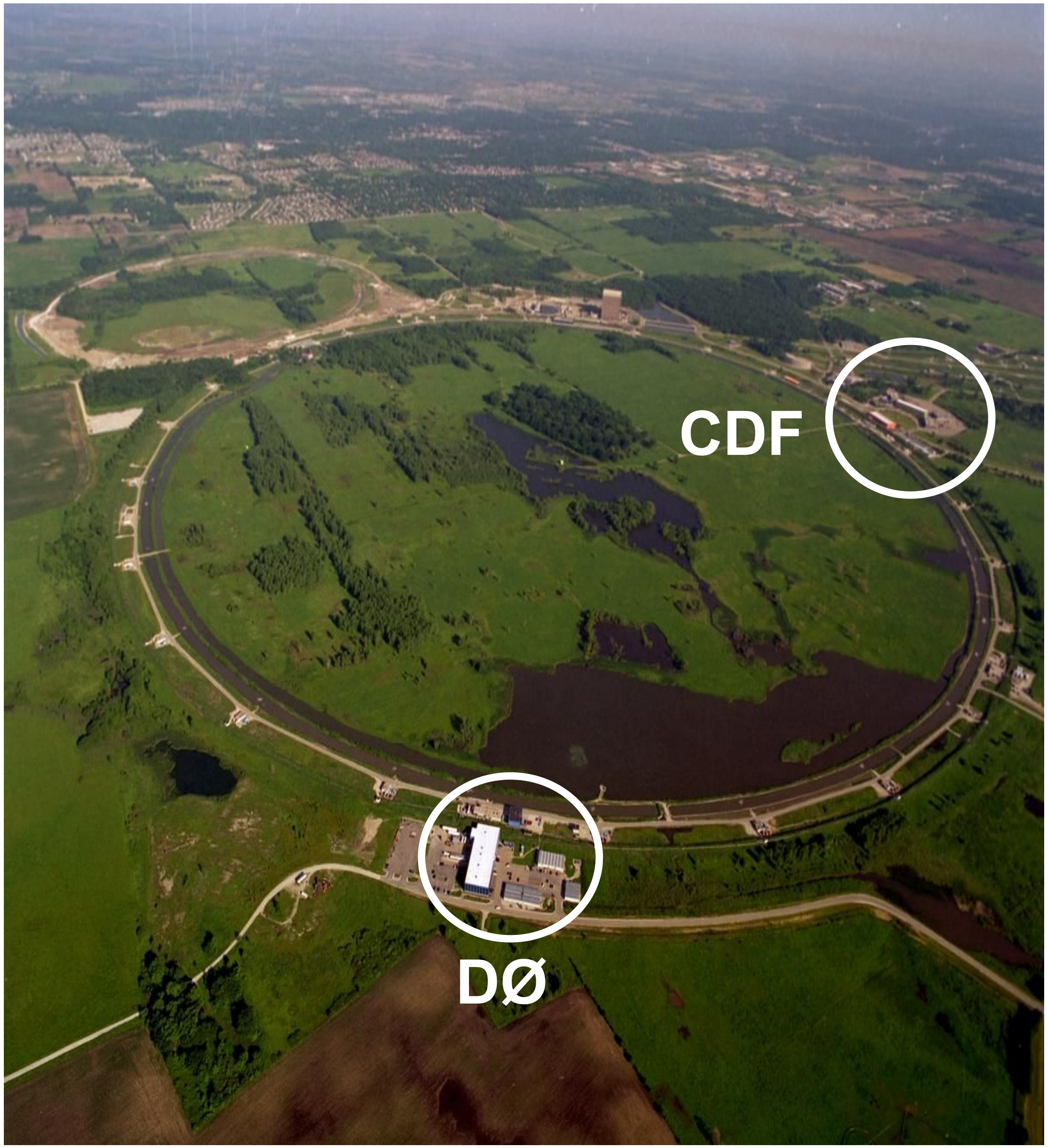


Physics at LHC 2008
Split, Croatia

Marc Buehler
University of Virginia

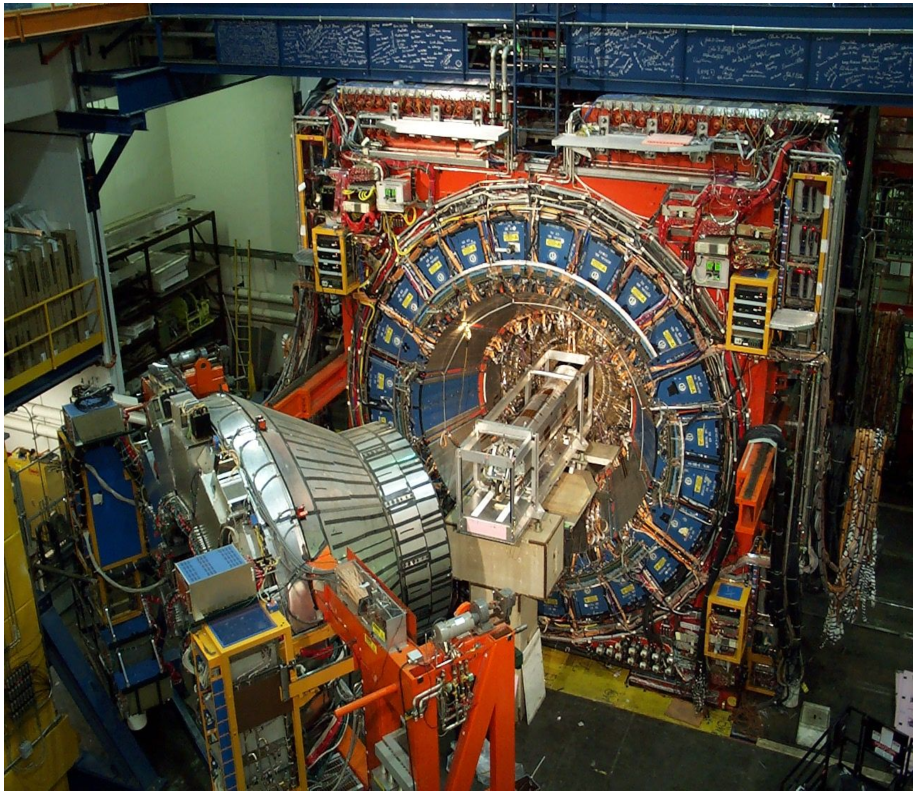
On behalf of the CDF and DØ collaborations

Tevatron Collider in Run II



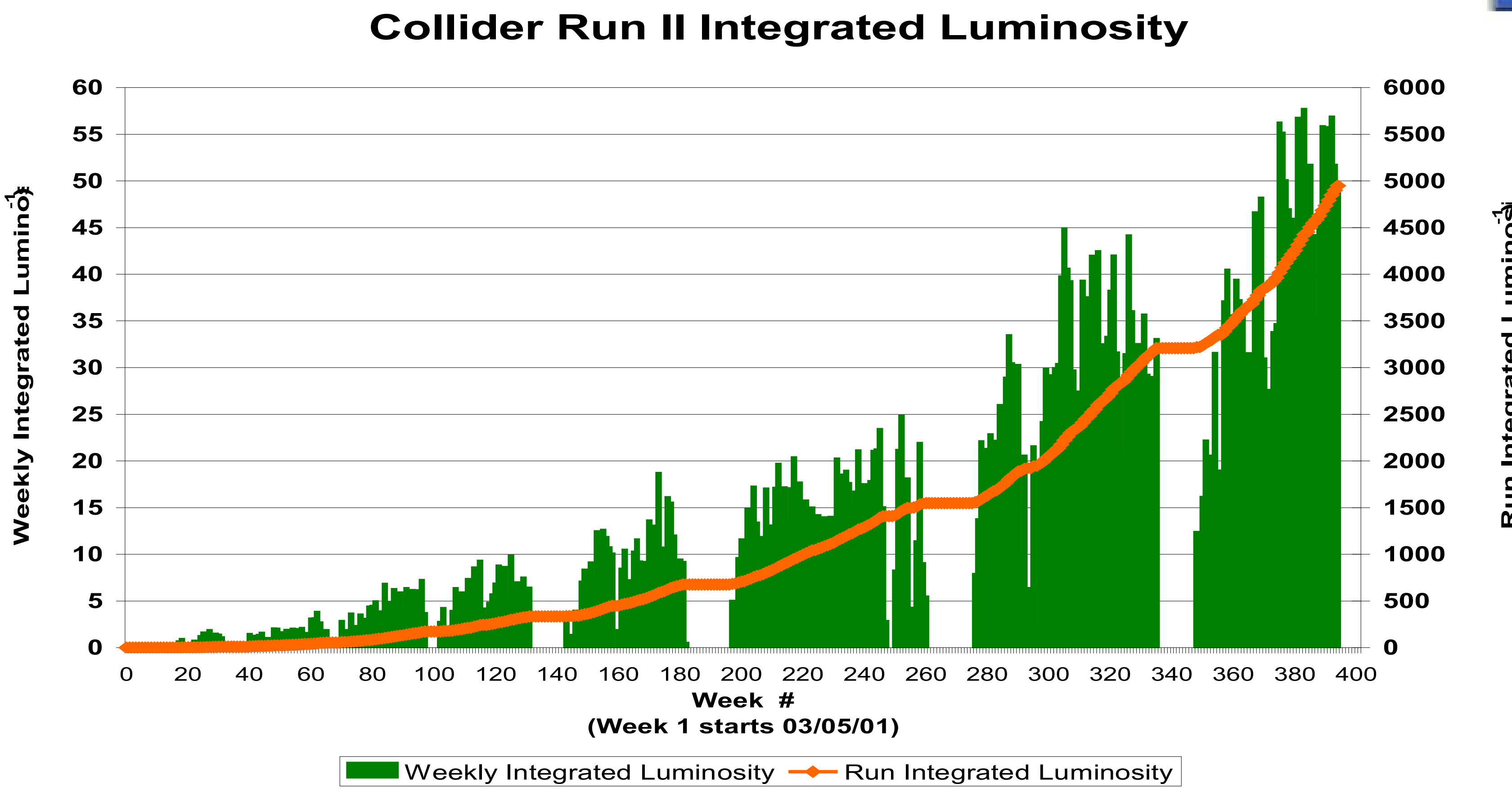
- Run II ongoing since 2001
- Colliding protons and antiprotons at $\sqrt{s}$=1.96TeV
- Delivers a dataset equal to Run I (~100pb^{-1}) every 2 weeks per detector
- Total delivered integrated luminosity for Run II is >5fb^{-1} per detector
- **Still the high energy frontier**

The CDF II and DØ Detectors



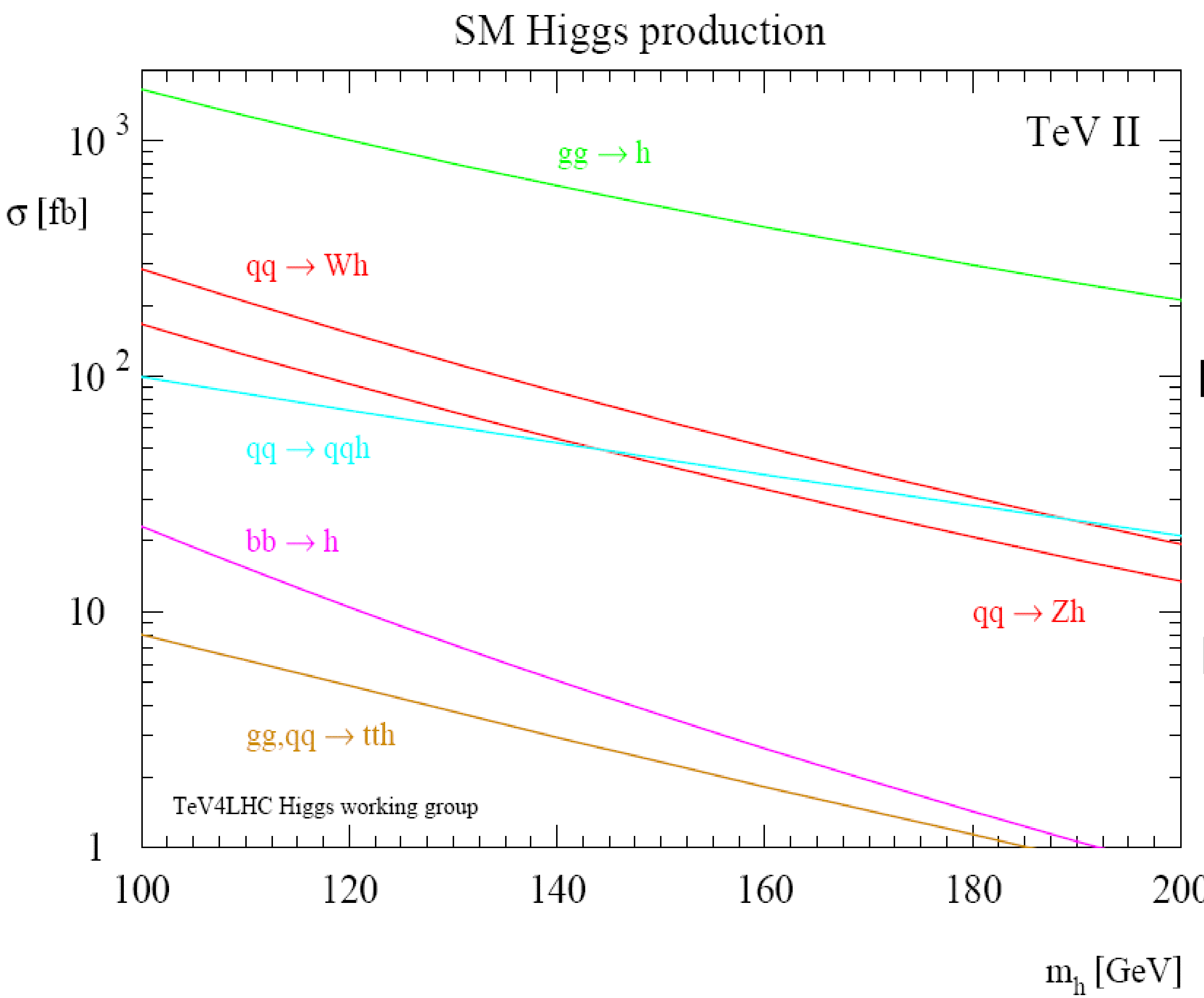
- 5k ton multi-purpose detectors
- Silicon detectors and Drift Chamber (CDF)/Fiber Tracker (DØ) in solenoidal magnetic fields
- Sampling calorimeters surround the superconducting solenoid magnets
- Muon systems consist of scintillators and drift chambers

The Dataset

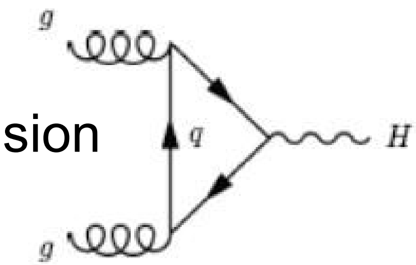


- Accelerator is running very well
- Both detectors are recording data with high efficiency
- Results presented here are based on 1-3fb^{-1}
- We have more data waiting to be analyzed (>4fb^{-1} data set)

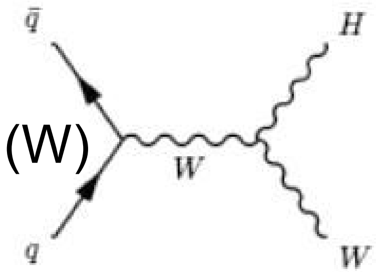
Higgs Production and Decay



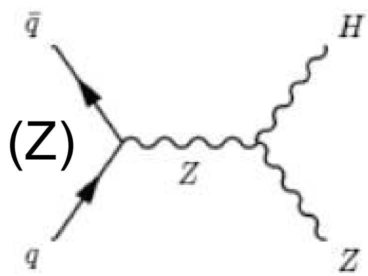
Gluon Fusion



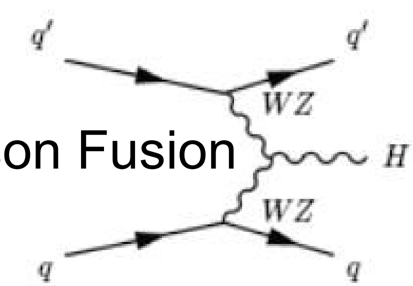
Higgs Strahlung (W)



Higgs Strahlung (Z)

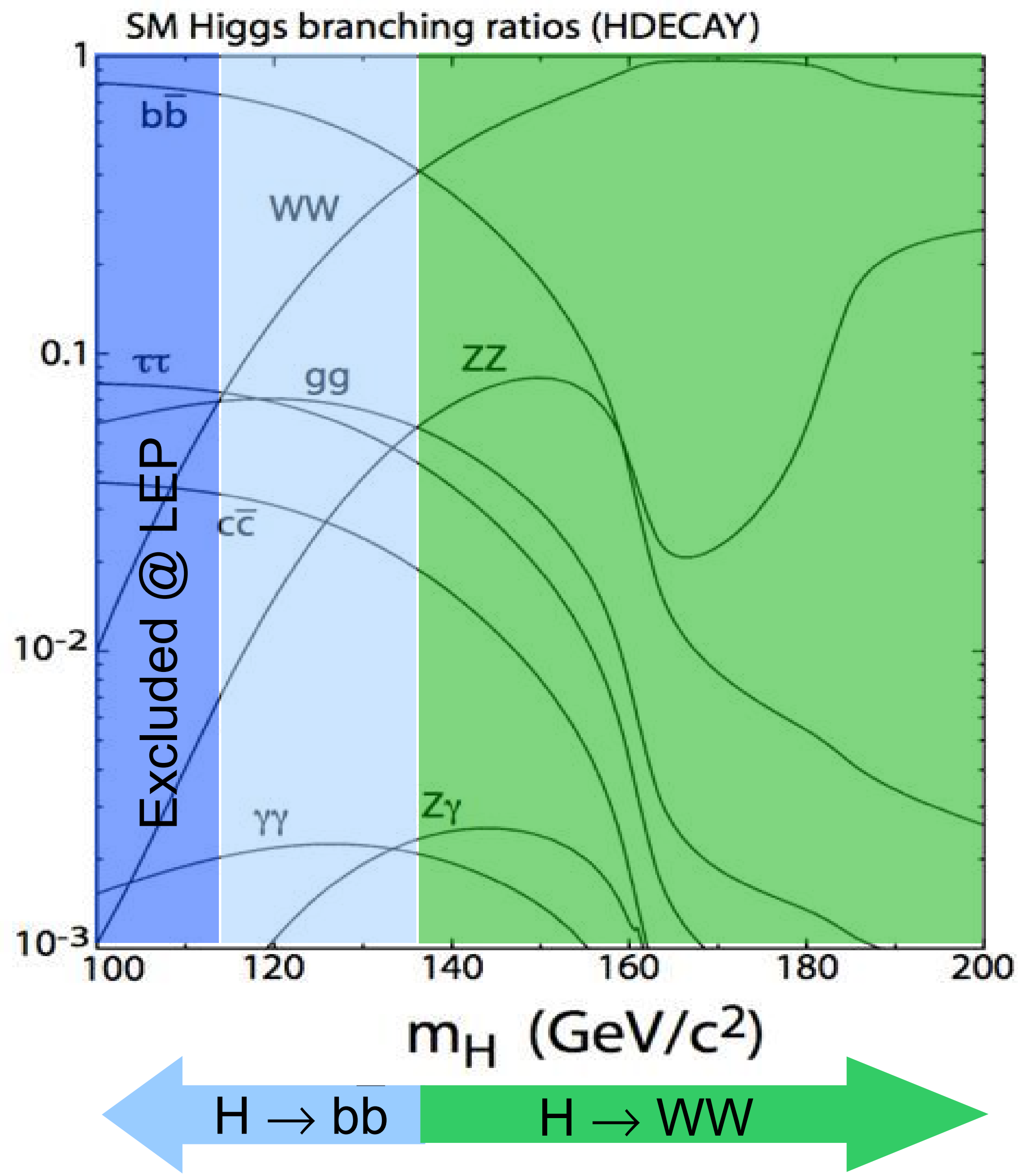


Vector Boson Fusion



Higgs Production and Decay

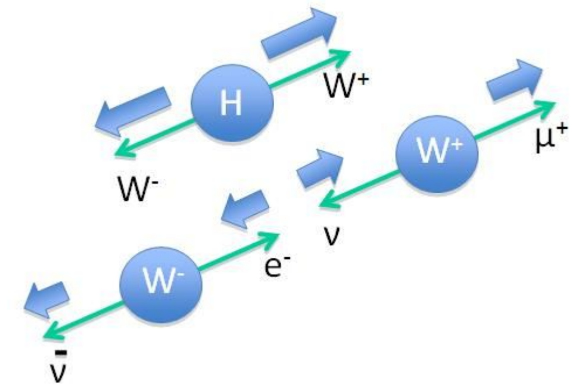
- Search strategy at the Tevatron:
  - m_H < 135 GeV:
    - See Andrew's talk
  - m_H > 135 GeV:
    - Dominated by gg → H production with decay to WW
    - Final state leptons help to keep multijet background (QCD) low
    - Adding Higgs Strahlung and VBF to gain additional sensitivity (H → WW)
    - Will present results for
      $H \rightarrow WW \rightarrow l\nu l\nu$
      and
      $W^{\pm}H \rightarrow W^{\pm}W^{*}W^{*} \rightarrow l^{\pm}l^{\pm}+X$

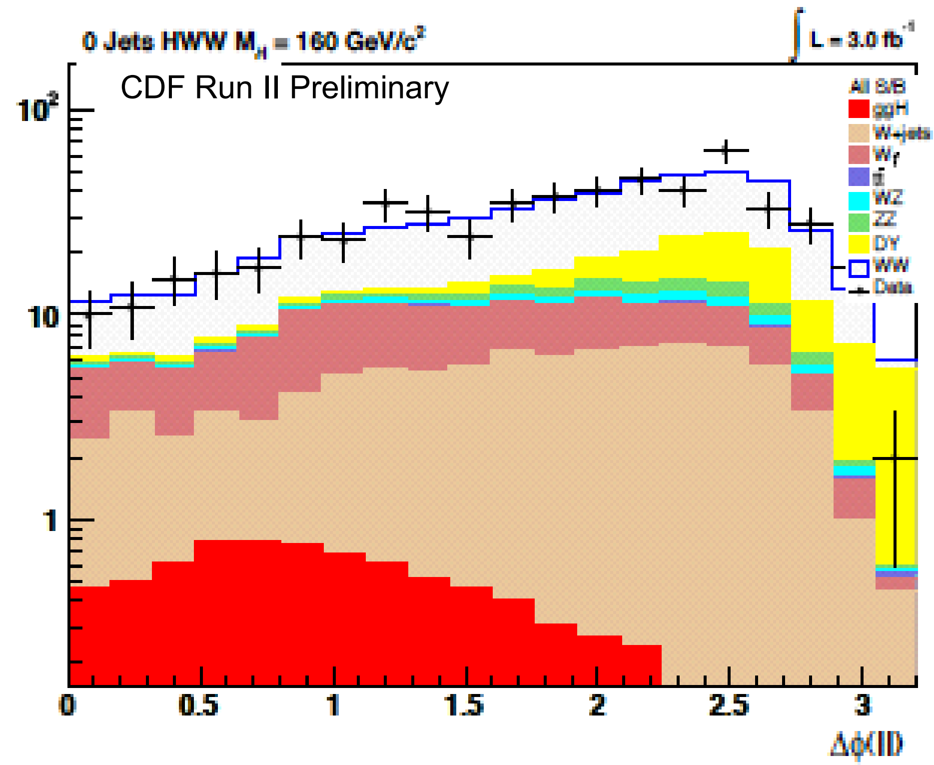


$H \rightarrow WW \rightarrow l\nu l\nu$ ($l = e, \mu$)

$H \rightarrow WW \rightarrow l\nu l\nu$ ($l=e,\mu$)

- Most sensitive Higgs search channel at the Tevatron
- Both experiments are approaching SM sensitivity
- H produced via gluon fusion, VBF, Higgs Strahlung
- Signature: 2 high p_T leptons and MET
  - $e\mu/ee/\mu\mu$ + MET final states
- Main backgrounds:
  - WW, top, $Z \rightarrow ll$, W+Jets
- Can take advantage of spin correlation
- Both CDF and DØ use $3 fb^{-1}$ data sets
- Final discriminants are NN outputs based on kinematic variables and ME likelihoods





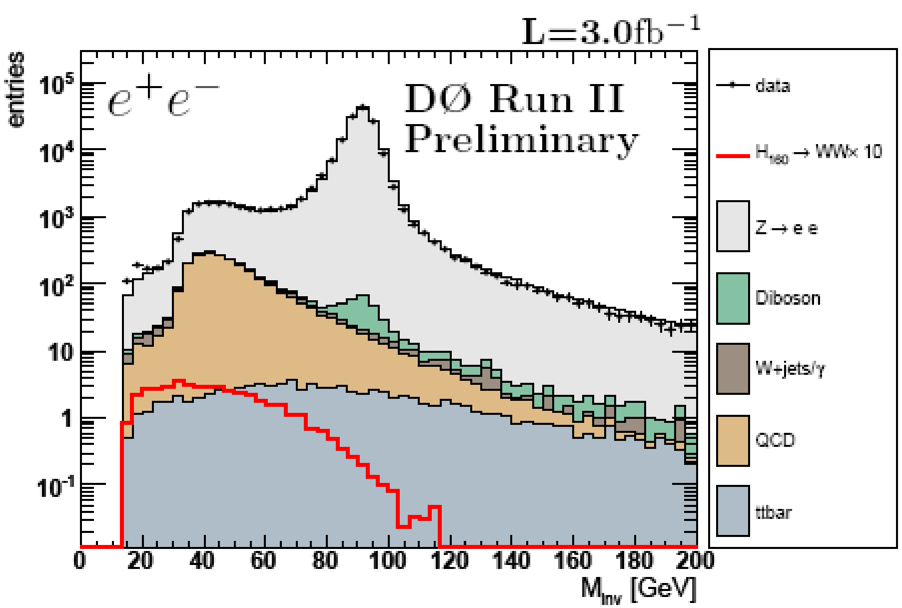
$H \rightarrow WW \rightarrow l\nu l\nu$ ($l=e,\mu$)

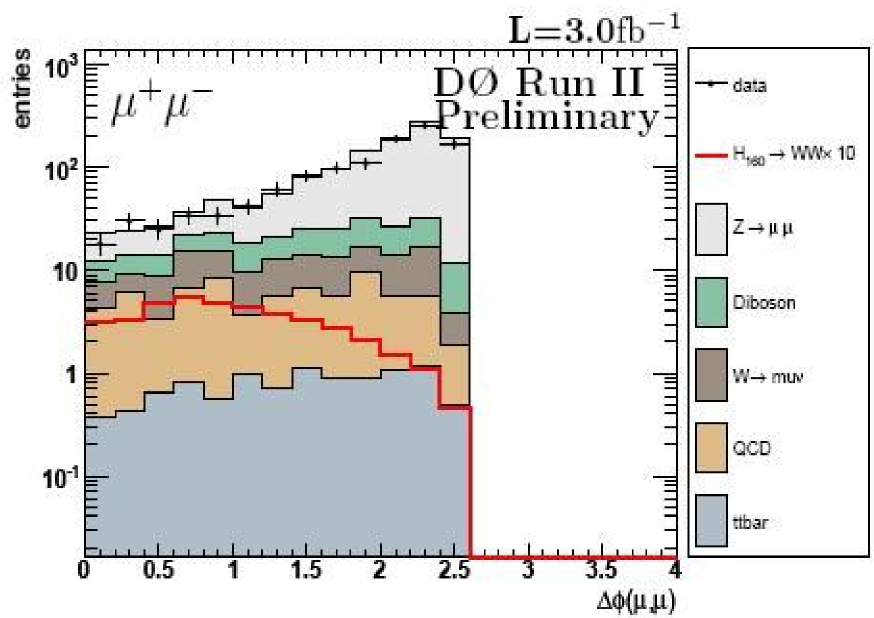
Loose preselection:

- Trigger on high P_T lepton
- $P_T^{\mu} > 10$ GeV
- $P_T^{e} > 15$ GeV
- Isolation cuts
- Opp Charge leptons
- $M_{ll} > 15$ GeV

Final selection:

Final state	$e\mu$	ee	$\mu\mu$
$\not{E}_T$ (GeV)	> 20	> 20	> 20
$\not{E}_T^{scaled}$	> 7	> 6	> 5
$M_t^{min}(l,\not{E}_T)$ (GeV)	> 20	> 30	> 20
$\Delta\phi(l,l)$	< 2.0	< 2.0	< 2.5





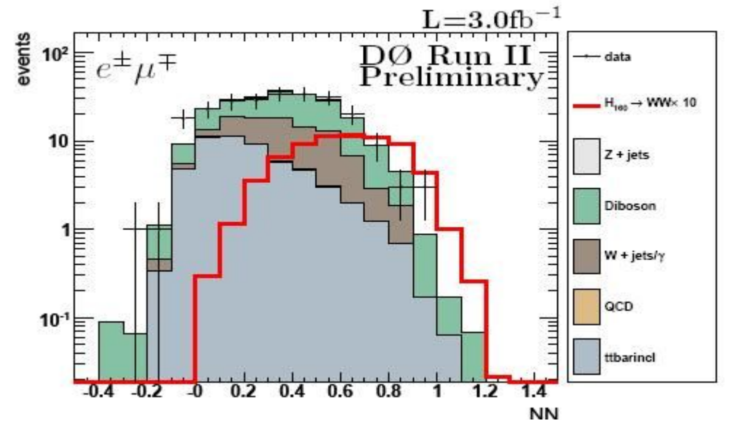
$H \to WW \to l\nu l\nu$ ($l=e,\mu$)

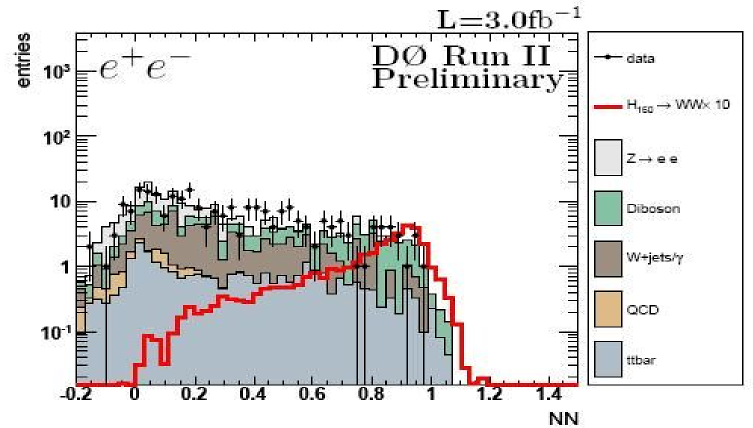
Expected and observed number of events at the NN input stage:

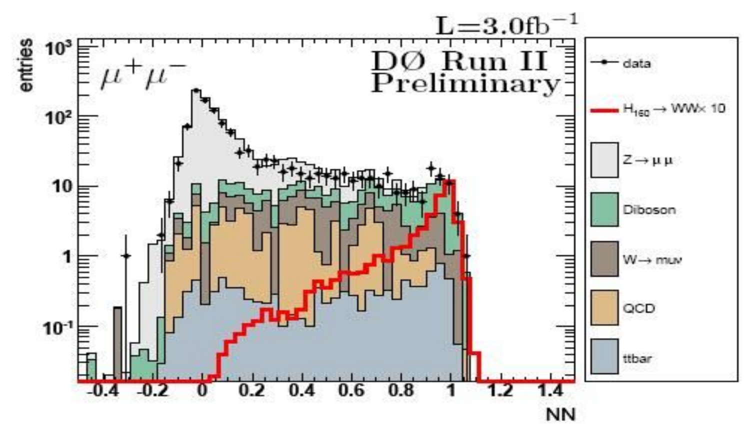
	$e\mu$ pre-selection	$e\mu$ final	ee pre-selection	ee final	$\mu\mu$ pre-selection	$\mu\mu$ final
$Z \to ee$	209.0 ± 3.0	0.72 ± 0.16	160463 ± 264	73.6 ± 5.1	–	–
$Z \to \mu\mu$	151.1 ± 0.6	2.14 ± 0.06	-	-	256432 ± 230	957 ± 14
$Z \to \tau\tau$	2312 ± 2	2.45 ± 0.05	835 ± 8	1.0 ± 0.3	1968 ± 11	5.5 ± 0.5
$t\bar{t}$	187.5 ± 0.2	54.2 ± 0.1	96.9 ± 0.2	28.5 ± 0.1	19.4 ± 0.1	10.1 ± 0.1
$W + jets$	163.4 ± 5.3	60.1 ± 3.2	174 ± 7	72.0 ± 4.3	149 ± 3	85.8 ± 2.1
WW	285.6 ± 0.1	108.0 ± 0.1	127.5 ± 0.4	45.7 ± 0.2	162.9 ± 0.5	91.3 ± 0.3
WZ	14.8 ± 0.1	4.9 ± 0.1	89.6 ± 0.8	7.6 ± 0.2	51.6 ± 0.5	16.2 ± 0.3
ZZ	3.47 ± 0.01	0.49 ± 0.01	73.5 ± 0.3	5.4 ± 0.1	43.0 ± 0.2	13.5 ± 0.1
Multi-jet	190 ± 168	1 ± 8	2322 ± 193	4.3 ± 8.3	945 ± 31	63.6 ± 8.0
Signal ($m_H = 160$ GeV)	9.0 ± 0.1	6.9 ± 0.1	4.40 ± 0.01	3.49 ± 0.01	4.7 ± 0.1	4.09 ± 0.06
Total Background	3516 ± 168	234 ± 9	164181 ± 327	238 ± 11	259770 ± 232	1242 ± 16
Data	3706	234	164290	236	263743	1147

H→WW→lνlν (l=e,μ)

- Neural Network:
  - NN trained for each Higgs mass in 5 GeV steps for each channel
  - Outputs of NN distribution used to set limits
  - ~30% more sensitive than cut-based analysis





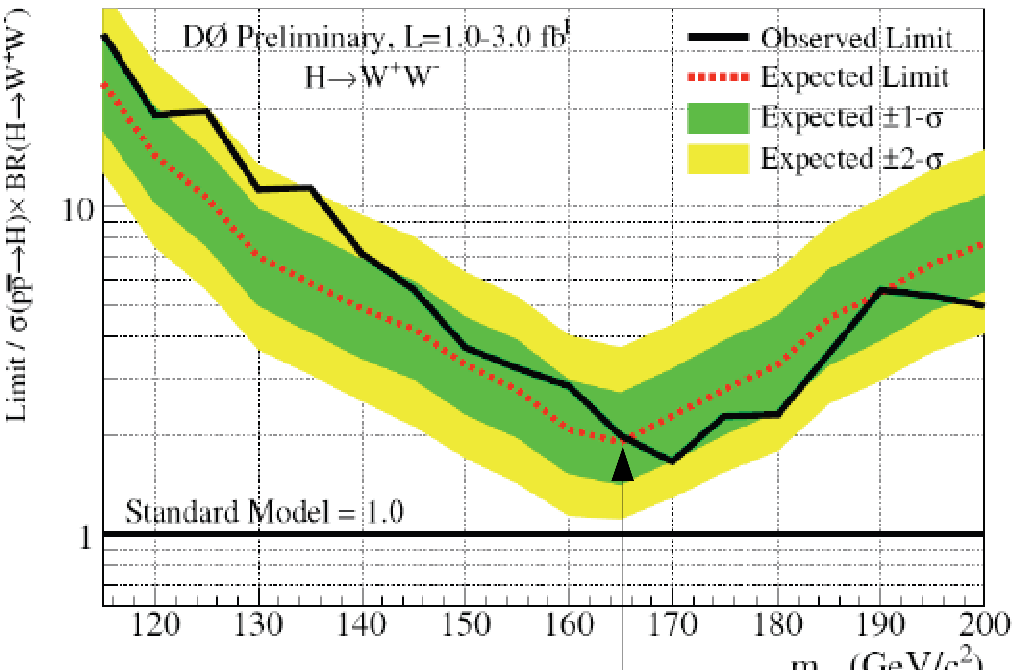


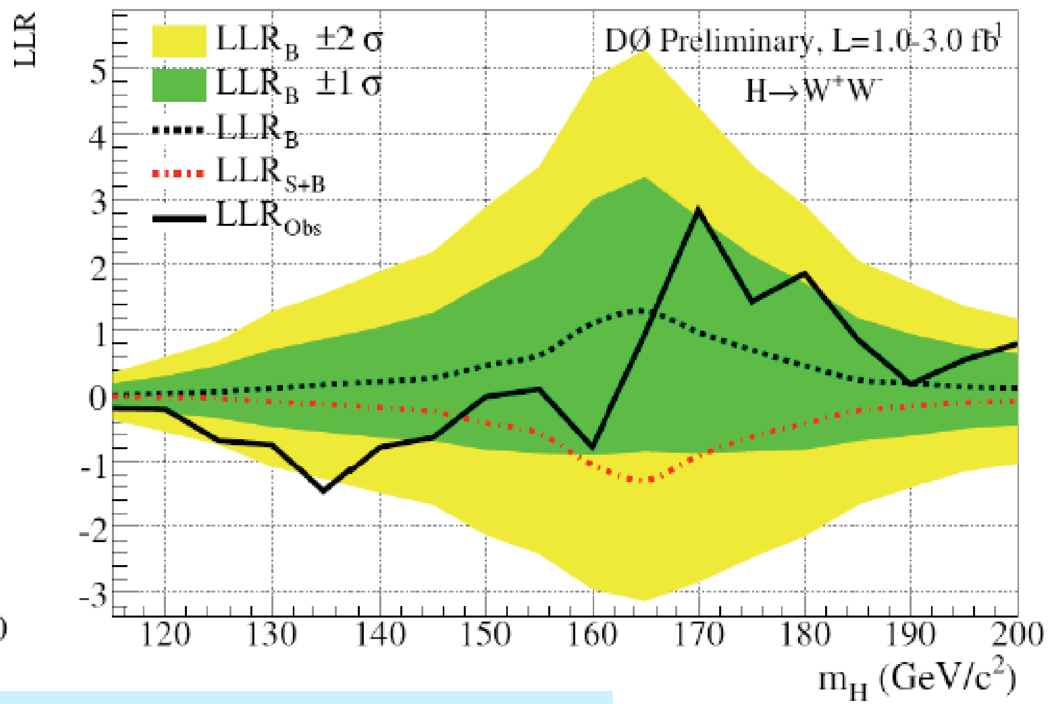
Input variables for the NN:

Object Variables	Event Var	Topo Var
P_T^{l1} & P_T^{l2}	$M_{inv}(l,l)$	$\Delta\phi(l,l)$
Σ lepton P_T	$M_t^{min}(l,\not\!E_T)$	$\Delta\phi(\not\!E_T,l_1)$
Σ jet P_T (H_T)	$\not\!E_T$	$\Delta\phi(\not\!E_T,l_2)$
Lepton Quality	$\not\!E_t^{scalar}$	

$H \to WW \to l\nu l\nu$ ($l=e,\mu$)

- NN outputs used to set limits at 95% CL
- Combined lepton sample





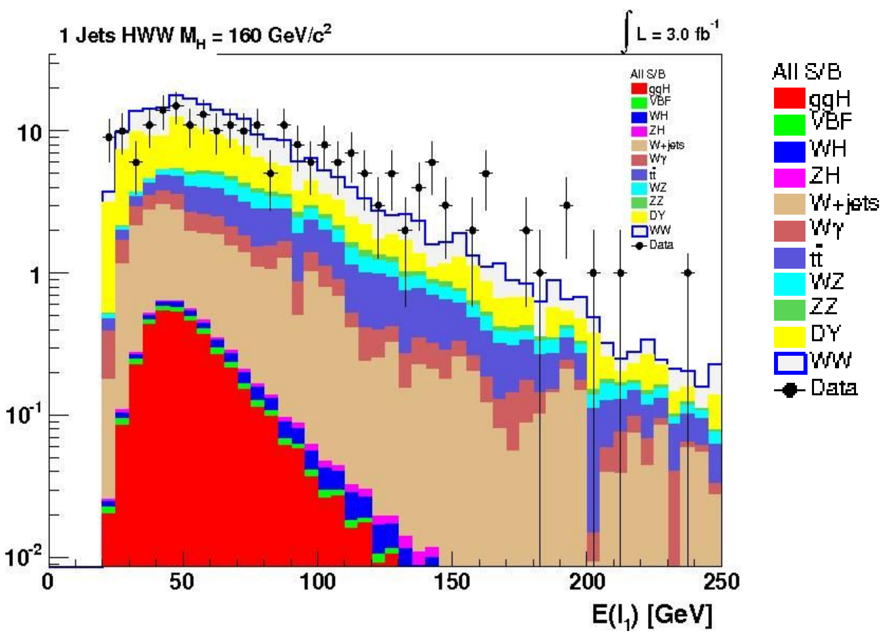
m_H=165GeV: Exp 1.9xSM, Obs 2.0xSM

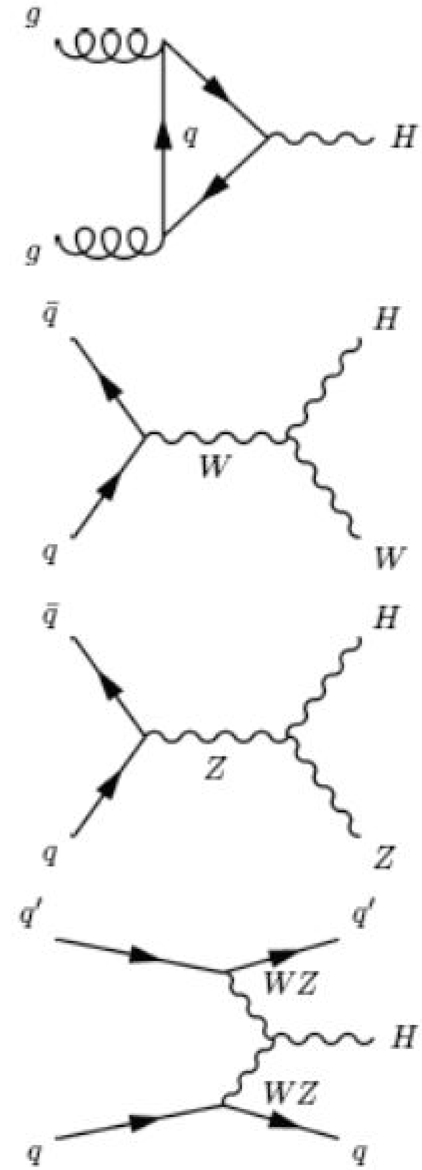
H→WW→lνlν (l=e,μ)

- CDF separates all H→WW events into non-overlapping sub-samples:
  - Separate sub-samples for 0, 1, 2+ jet events
    - 0-jet sample is pure gluon fusion
    - 1-jet and 2(+)-jet sample add Higgs Strahlung and VBF (not included in DØ analysis yet)

Event Selection:

- Trigger High P_T lepton
- $P_T^{l1} > 20$ GeV
- $P_T^{l2} > 10$ GeV
- Opp Charge leptons
- $M_{ll} > 16$ GeV
- $P_T^{jet} > 15$ GeV
- $\not{E}_T^{spec} > 25$ (ee,μμ)
- $\not{E}_T^{spec} > 15$ (eμ)



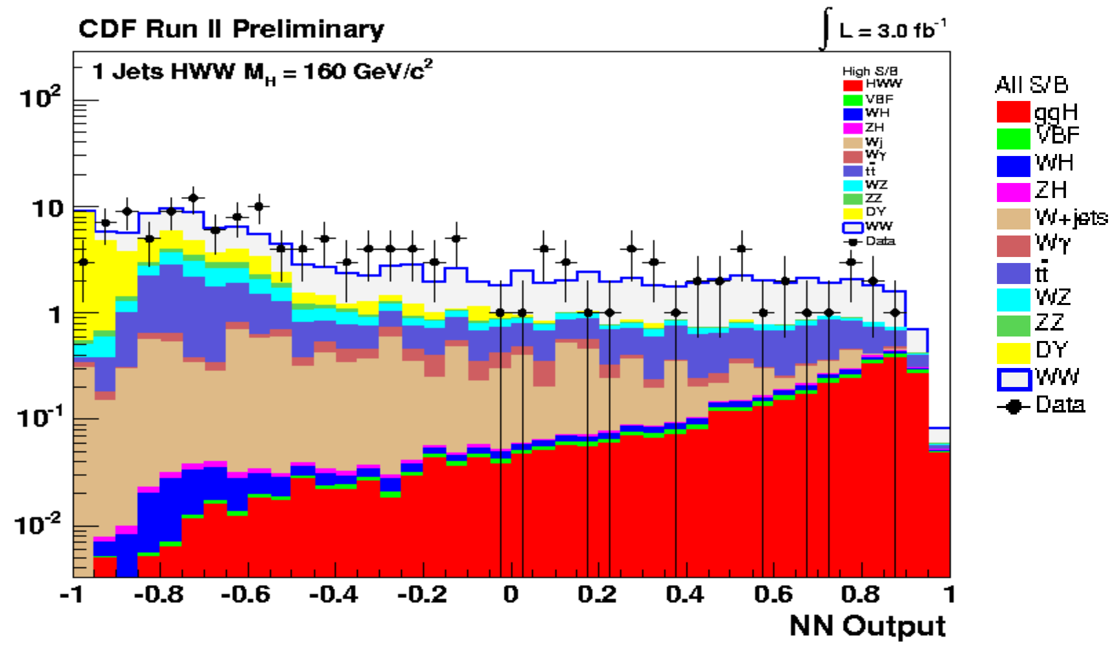


H→WW→lνlν (l=e,μ)

1- jet Sample

$M_H = 160\ \mathrm{GeV}/c^2$	
$t\bar{t}$	24.57 ± 4.77
DY	71.21 ± 16.19
WW	75.10 ± 10.11
WZ	12.71 ± 2.02
ZZ	4.53 ± 0.72
W+jets	26.23 ± 6.78
$W\gamma$	11.35 ± 3.00
Total Background	**225.69 ± 28.21**
$gg \to H$	4.08 ± 0.63
WH	0.57 ± 0.08
ZH	0.21 ± 0.03
VBF	0.33 ± 0.05
Total Signal	**5.18 ± 0.69**
Data	**227**

HWW 1 Jet



Event yield before NN (M_H=160 GeV)

Jet bin	Nsig	Nbkgd	Ndata
0	8.4±1.3	540±65	552
1	5.2±0.7	226±28	227
2	3.9±0.5	129±20	139

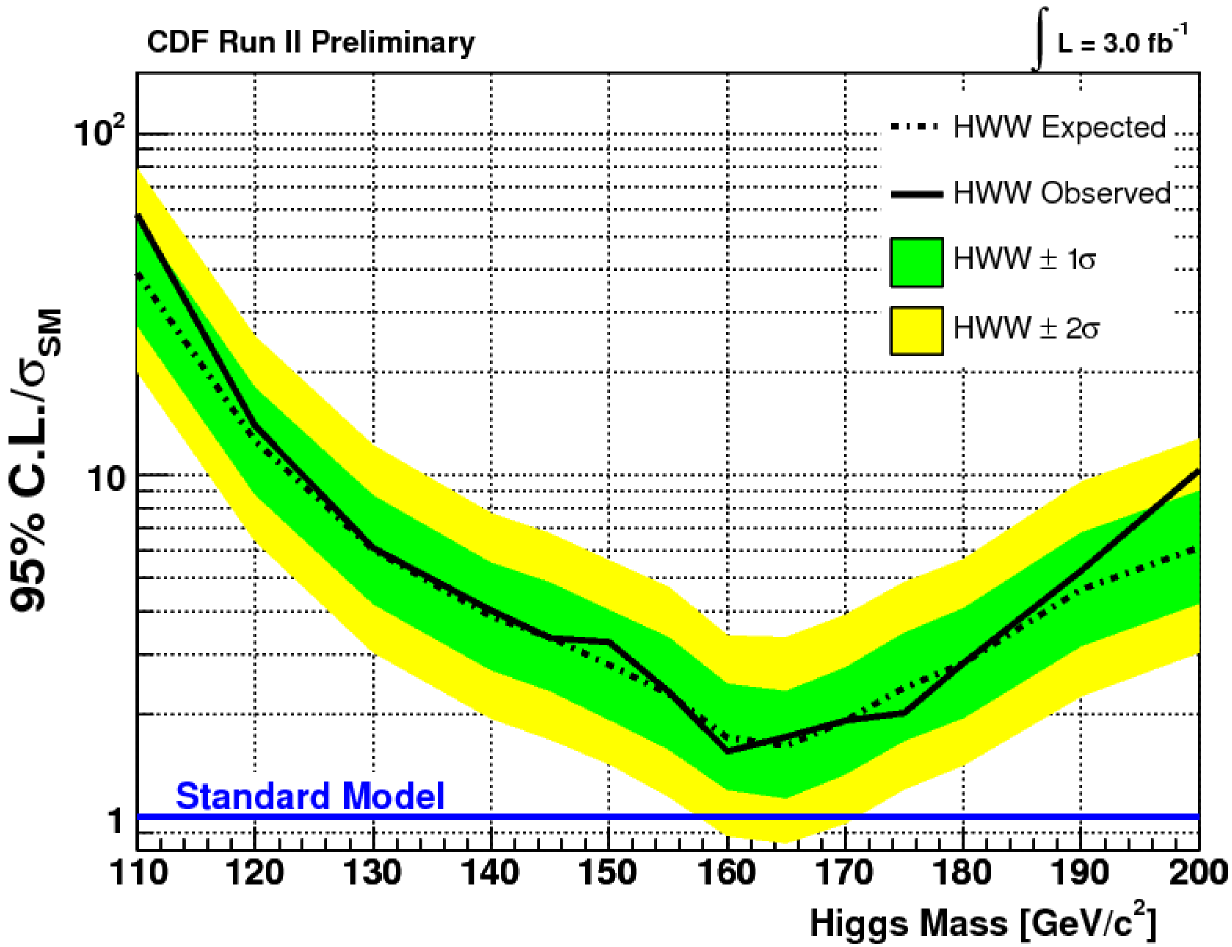
Neural Net Inputs

$\Delta R(l,l)$, $M_T(ll,\not{E}_T)$, M_{ll}, $\not{E}_t^{spec}$

$E(l_1)$, $P_T(l_1)$, $P_T(l_2)$, H_T

$H \to WW \to l\nu l\nu$ ($l=e,\mu$)

- NN outputs used to set limits at 95% CL
- Combined jet sample

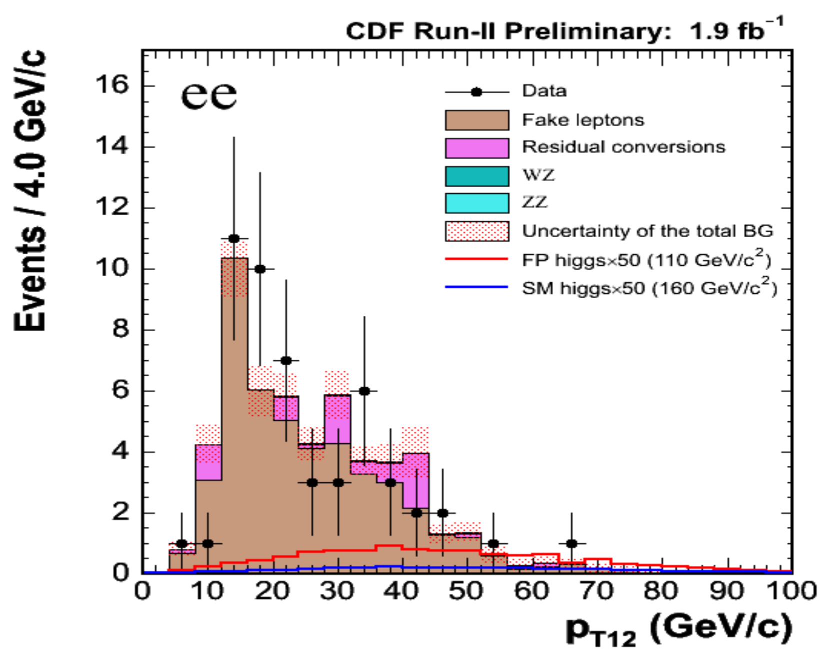


m_H=165GeV:
Exp 1.62xSM
Obs 1.72xSM

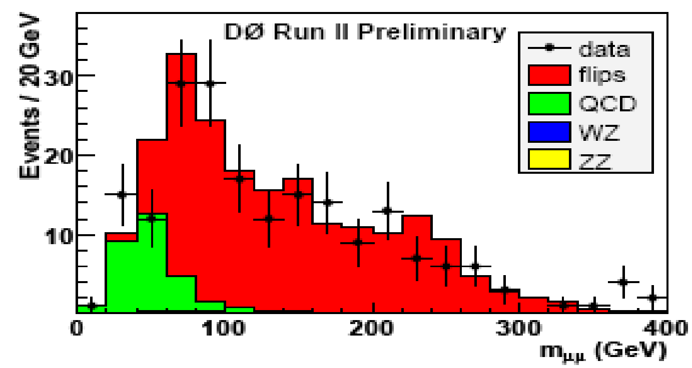
$$W^{\pm}H \rightarrow W^{\pm}W^*W^* \rightarrow l^{\pm}l^{\pm}+X$$

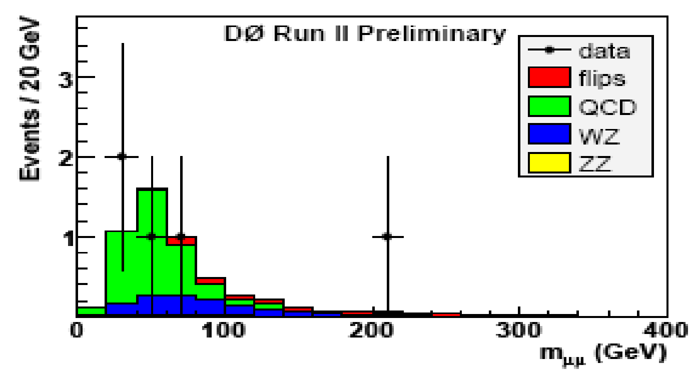
$W^{\pm}H \rightarrow W^{\pm}W^{*}W^{*} \rightarrow l^{\pm}l^{\pm}+X$

- CDF (DØ) data sample: 1.9fb^{-1} (1fb^{-1})
- Event selection requires two like sign isolated high p_T electrons/muons with good track quality cuts to reduce charge flip probability
- Largely reduced SM backgrounds due to like sign requirement
- Instrumental backgrounds (charge flips, muons from $\pi^{\pm}$ and $K^{\pm}$, etc) are estimated from data



Data vs Bkgd after baseline selection:

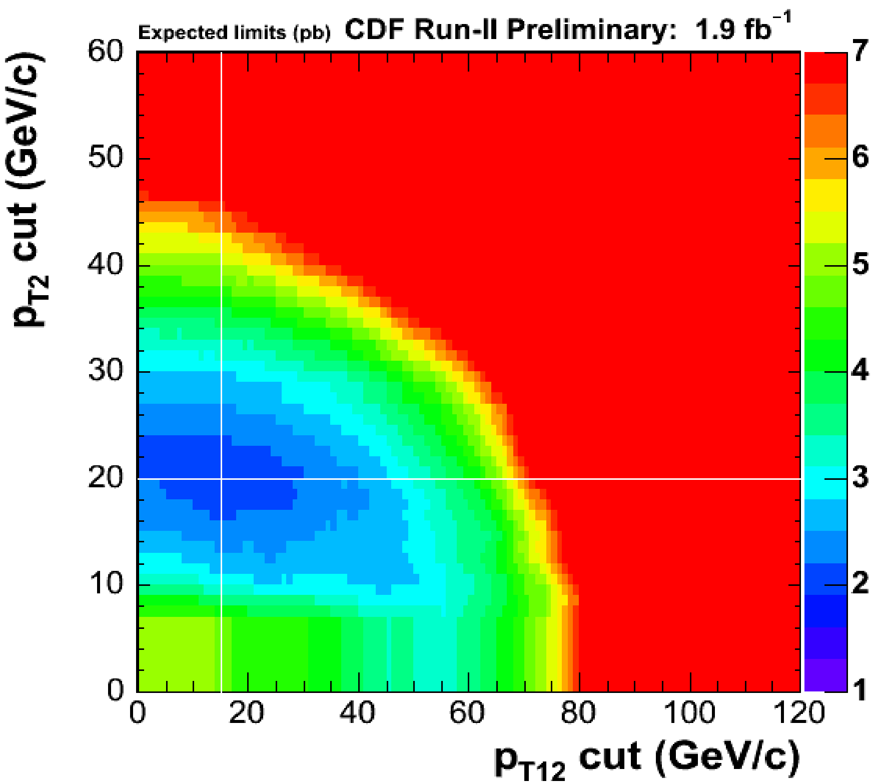




Dilepton invariant mass before (top) and after (bottom) applying track quality cuts

$W^{\pm}H \rightarrow W^{\pm}W^{*}W^{*} \rightarrow l^{\pm}l^{\pm}+X$

- To get the minimized expected upper limit on the production cross section times branching fraction:
  - DØ builds a likelihood
  - CDF uses a 2D cut: 2nd lepton p_T vs dilepton system p_T



Expected (observed) upper limits on $\sigma(WH) \rightarrow BR(H \rightarrow WW)$ at the 95% CL for m_H=160GeV:

CDF : 1.5 (1.5) pb

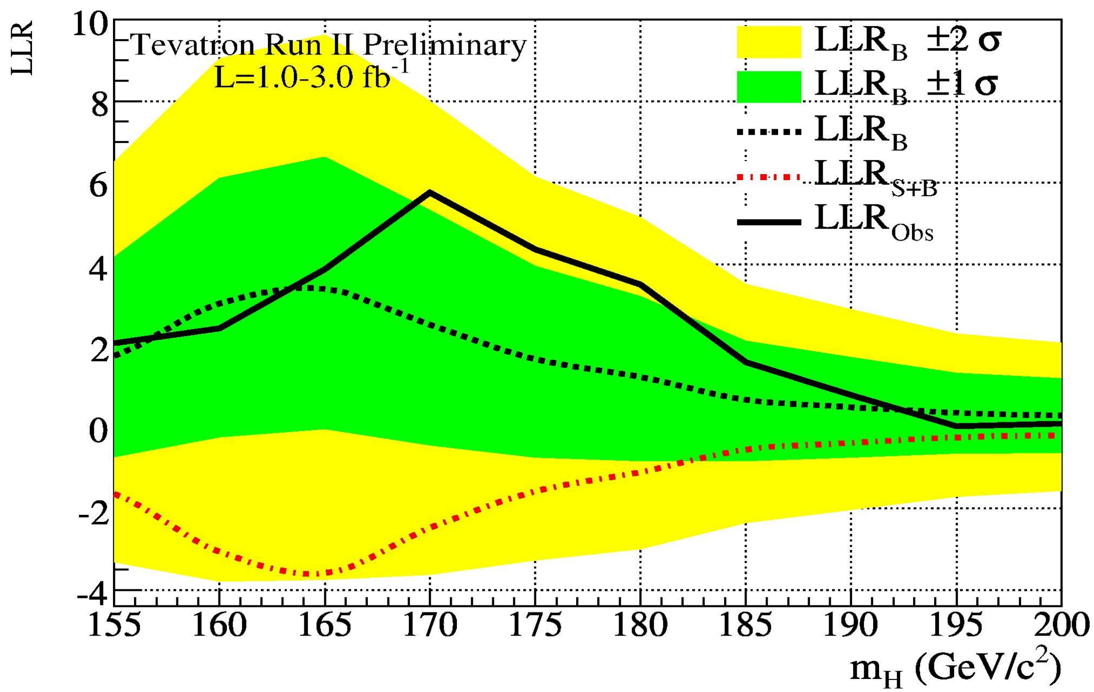
DØ : 0.9 (1.2) pb

Expected theoretical cross section x BR ~ 0.05pb

Tevatron Higgs Combination

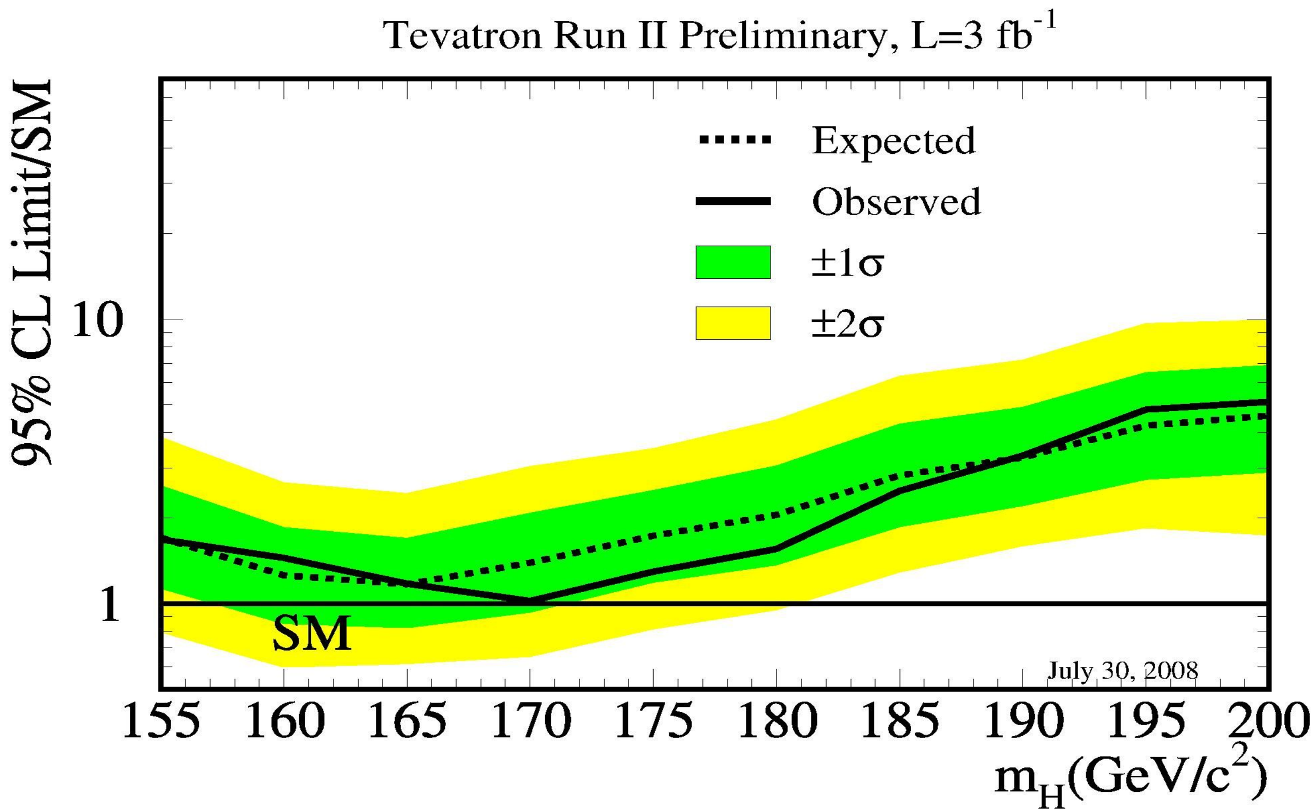
Tevatron Higgs Combination

- Performed cross checks to verify independence of statistical formulation, using Bayesian and Modified Frequentist approaches. They give similar results within 10%.
- Taking into account the correlation of systematic uncertainties (internally and between the experiments)
- Check sensitivity vs m_H by studying LLR for different hypotheses:



Tevatron Higgs Combination

- Combination results for each experiment for ratios of 95% CL observed (expected) limits to the SM cross section:
  - m_H=165GeV:
    - CDF: 1.6 (1.6)
    - D0: 2.0 (1.9)
  - m_H=170GeV:
    - CDF: 1.8 (1.9)
    - D0 : 1.7 (2.3)
- Combined result:
  - mH=165GeV:
    - 1.2 (1.2)
  - mH=170GeV:
    - 1.0 (1.4)



We exclude at the 95% CL the production of a SM Higgs boson with mass of 170 GeV/c^2

Summary

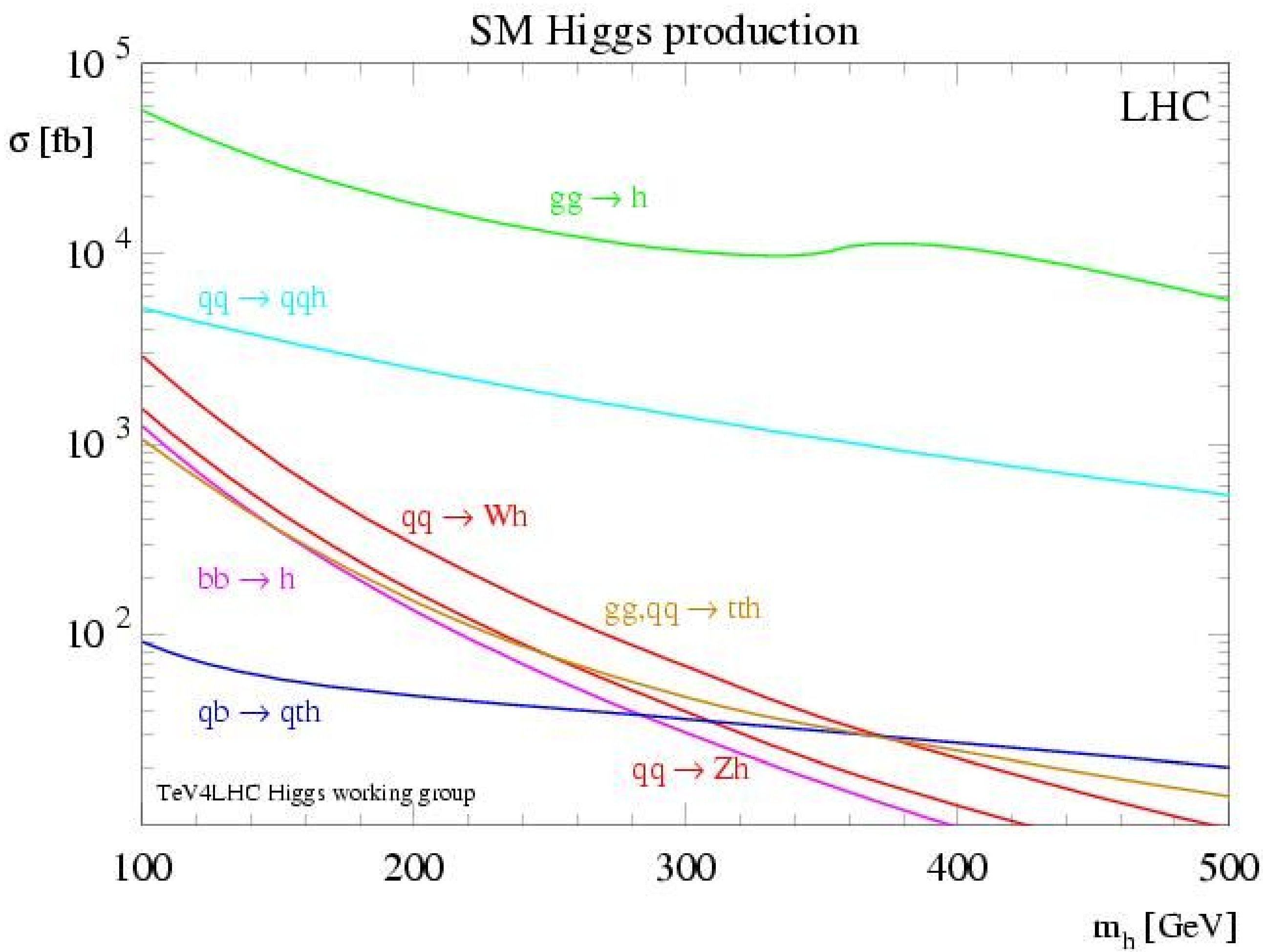
- We presented results from searches for a SM Higgs Boson that are sensitive to a high mass Higgs
- This is the first exclusion of a SM Higgs beyond the LEP limit at a Hadron collider
- Things are very exciting as we continue to accumulate more data, improve analyses, and add new channels

Summary

- We presented results from searches for a SM Higgs Boson that are sensitive to a high mass Higgs
- This is the first exclusion of a SM Higgs beyond the LEP limit at a Hadron collider
- Things are very exciting as we continue to accumulate more data, improve analyses, and add new channels
- The Tevatron has begun to close in on the Higgs

Backup

SM Higgs Production at the LHC



$H \to WW \to l\nu l\nu$ ($l=e,\mu$)

- DØ systematics:
  - Largest uncertainties are associated with lepton measurement and acceptance: 2-11% (depending on final state)
  - Uncertainties on cross sections for simulated backgrounds: 6-18%
- CDF systematics:
  - Largest uncertainty from MC modeling: ~5%
  - For simulated backgrounds, uncertainties on expected rates range from 11-40% (depending on background)
  - The backgrounds with the largest uncertainties are in general quite small

H→WW→lνlν (l=e,μ)

Expected and observed yields for background and signal for events with

0 jets

$M_H = 160$ GeV/c^2	
$t\bar{t}$	0.96 ± 0.19
DY	66.88 ± 15.20
WW	280.42 ± 38.99
WZ	12.17 ± 1.93
ZZ	17.29 ± 2.74
W+jets	83.61 ± 20.09
$W\gamma$	79.15 ± 21.12
Total Background	**540.48 ± 64.81**
$gg \to H$	8.38 ± 1.29
Total Signal	**8.38 ± 1.29**
Data	**552**

HWW 0 Jet

1 jet

$M_H = 160$ GeV/c^2	
$t\bar{t}$	24.57 ± 4.77
DY	71.21 ± 16.19
WW	75.10 ± 10.11
WZ	12.71 ± 2.02
ZZ	4.53 ± 0.72
W+jets	26.23 ± 6.78
$W\gamma$	11.35 ± 3.00
Total Background	**225.69 ± 28.21**
$gg \to H$	4.08 ± 0.63
WH	0.57 ± 0.08
ZH	0.21 ± 0.03
VBF	0.33 ± 0.05
Total Signal	**5.18 ± 0.69**
Data	**227**

HWW 1 Jet

2+jets

$M_H = 160$ GeV/c^2	
$t\bar{t}$	70.34 ± 14.46
DY	27.74 ± 6.75
WW	15.68 ± 2.47
WZ	3.33 ± 0.53
ZZ	1.35 ± 0.21
W+jets	8.38 ± 2.27
$W\gamma$	1.80 ± 0.47
Total Background	**128.62 ± 20.19**
$gg \to H$	1.52 ± 0.26
WH	1.18 ± 0.16
ZH	0.59 ± 0.08
VBF	0.61 ± 0.10
Total Signal	**3.90 ± 0.45**
Data	**139**

HWW ≥ 2 Jets

$W^{\pm}H \rightarrow W^{\pm}W^{*}W^{*} \rightarrow l^{\pm}l^{\pm}+X$

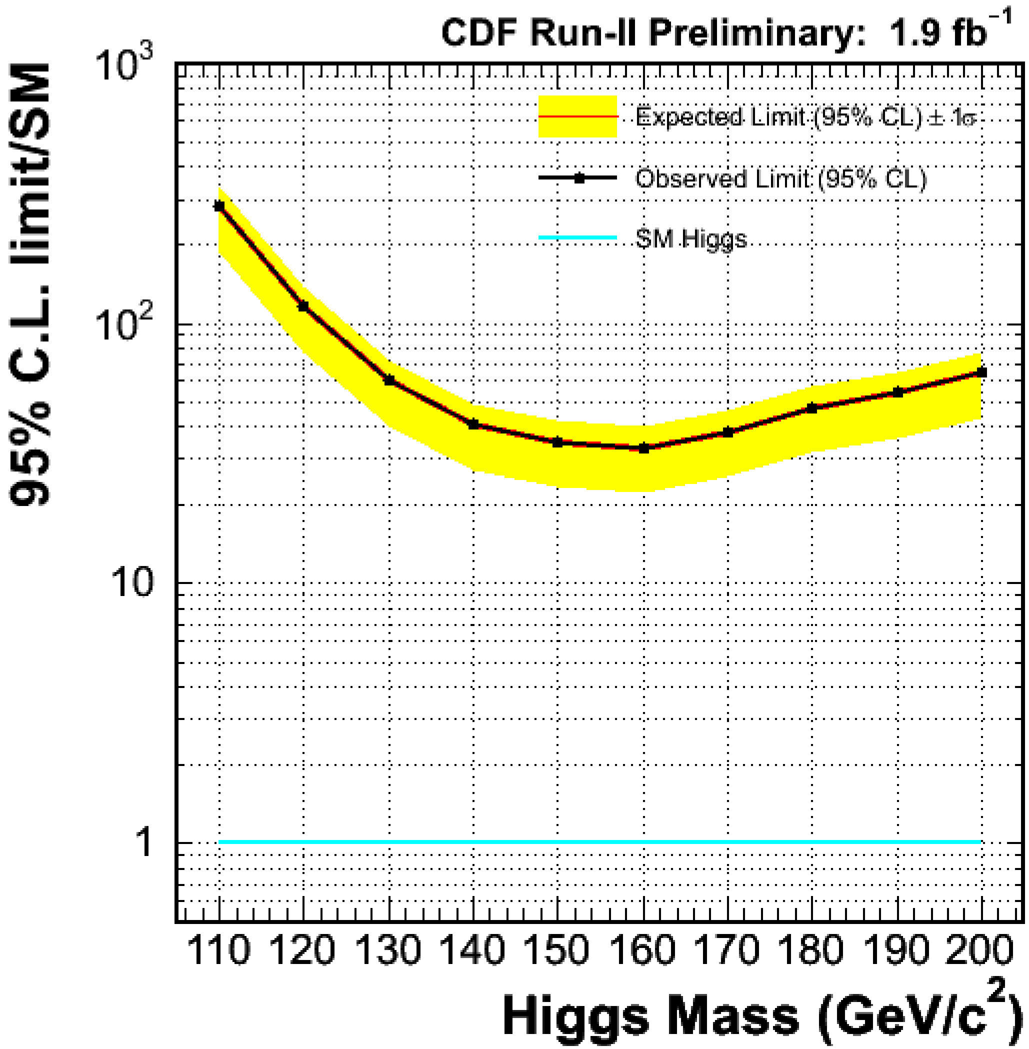
TABLE I: The number of observed and predicted events after all selection cuts.

	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$
$WZ \rightarrow l\nu ll$	1.18±0.17	2.46±0.34	1.29±0.18
$ZZ \rightarrow llll$	0.10±0.01	0.16±0.02	0.07±0.01
QCD	7.4±1.1	15.4±2.8	2.8±0.9
flips	11.9±3.8	0.04±0.02	0.8+2.3−0.8
total	20.6±4.0	18.0±2.8	5.0+2.5−1.2
$WH(120) \rightarrow lljj$	0.028	0.063	0.034
$WH(120) \rightarrow lll$	0.009	0.021	0.012
$WH(140) \rightarrow lljj$	0.067	0.143	0.069
$WH(140) \rightarrow lll$	0.018	0.043	0.024
$WH(160) \rightarrow lljj$	0.077	0.161	0.082
$WH(160) \rightarrow lll$	0.021	0.046	0.026
$WH(180) \rightarrow lljj$	0.056	0.108	0.060
$WH(180) \rightarrow lll$	0.014	0.031	0.017
$WH(200) \rightarrow lljj$	0.029	0.061	0.032
$WH(200) \rightarrow lll$	0.008	0.017	0.009
data	19	15	5

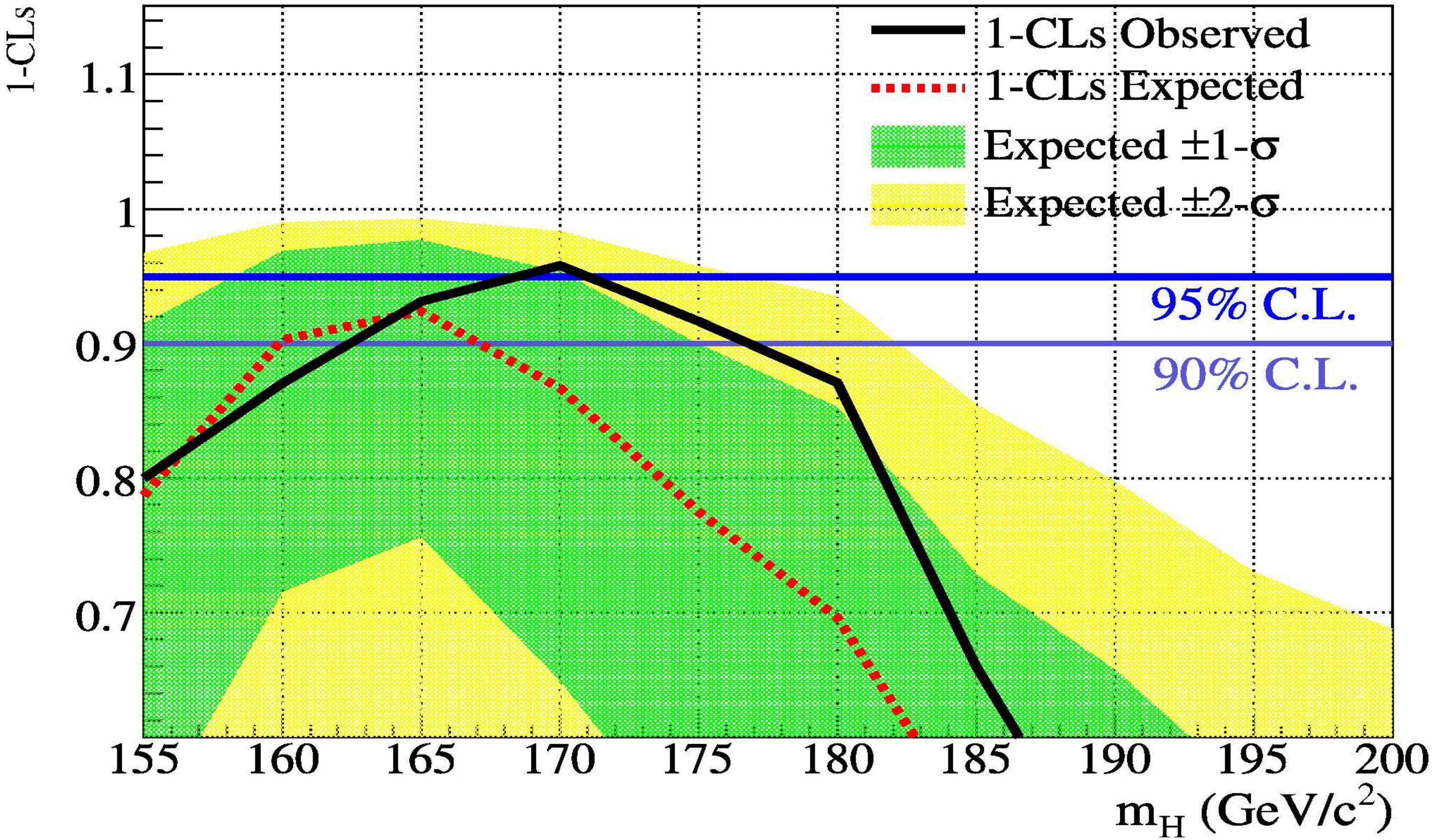
TABLE II: The expected (observed) upper limits on $\sigma(WH) \times Br(H \rightarrow WW^{*})$ at the CL=95% (pb) for individual channels and the combination.

m_H (GeV)	120	140	160	180	200
ee	2.5(4.5)	2.3(4.1)	2.1(3.6)	1.9(2.7)	1.6(2.7)
$e\mu$	1.9(1.9)	1.6(1.6)	1.5(1.4)	1.3(1.1)	1.0(0.9)
$\mu\mu$	2.2(2.4)	2.0(2.5)	1.9(2.4)	1.6(1.9)	1.4(1.7)
combined	1.1(1.5)	0.9(1.4)	0.9(1.2)	0.7(0.8)	0.6(0.8)

$W^{\pm}H \rightarrow W^{\pm}W^{*}W^{*} \rightarrow l^{\pm}l^{\pm}+X$

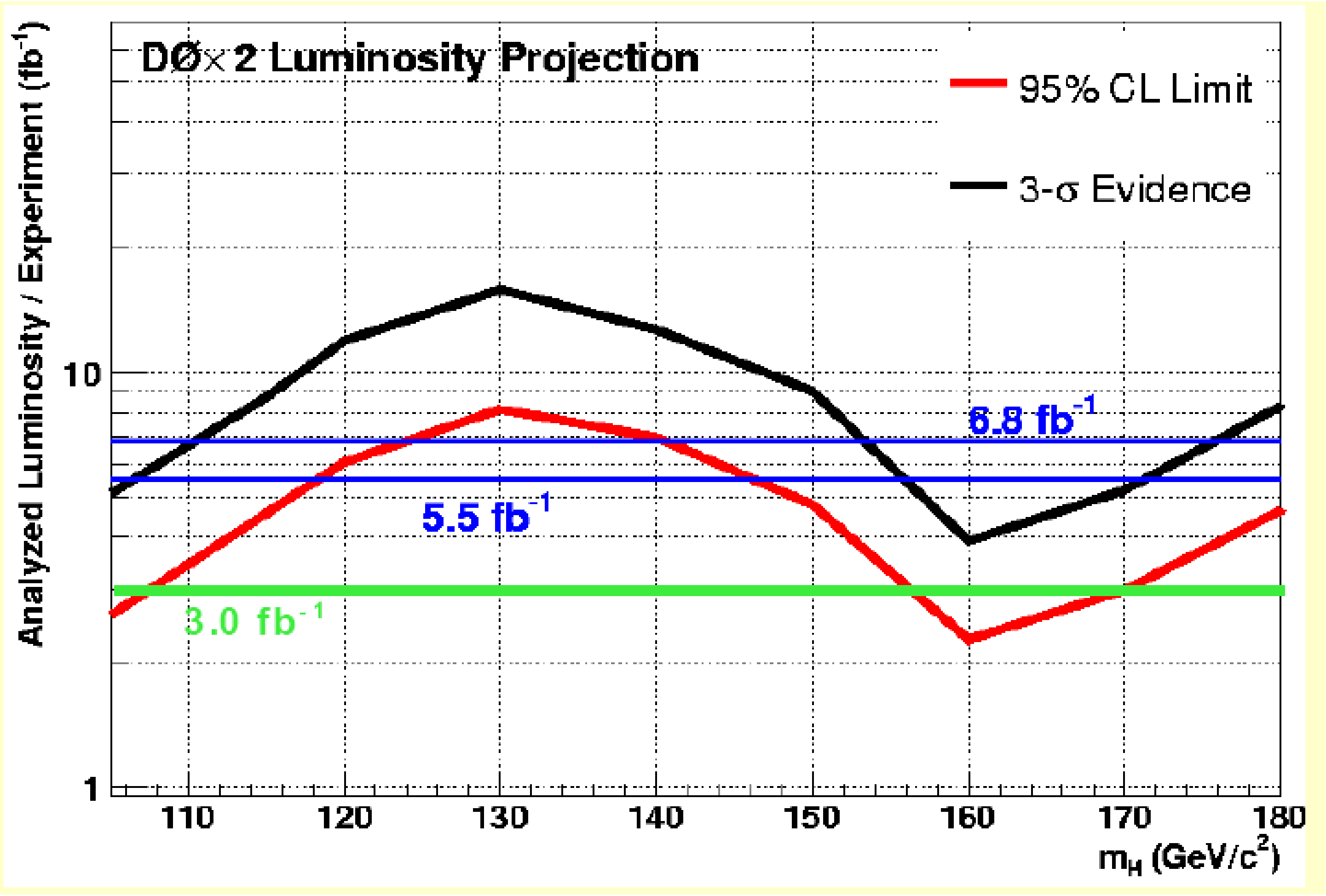


Tevatron Higgs Combination



We exlclude at 95% CL the production of a SM Higgs boson at 170 GeV, and at a wider mass range at 90% CL.

Luminosity Projection



Sensitivity Improvements

- Estimate to gain a factor of 2 beyond improvements expected from sqrt(lumi):
  - Increased lepton efficiency (10% per lepton)
  - Improved/Additional multivariate techniques (20% in sensitivity)
  - Background modeling
  - Systematics
  - B-tagging improvements
  - Dijet mass resolution