SM Higgs Searches at the Tevatron

high mass

M. Bauce

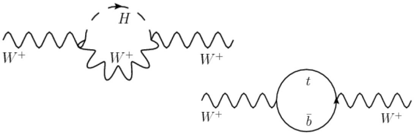
on behalf of CDF and D0 collaborations

Aspen 2011

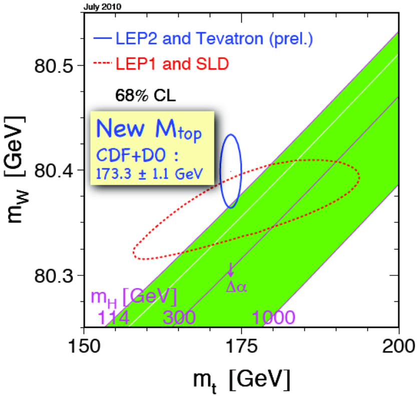
M_H is not predicted by the SM, experimental determination:

Direct LEP searches:
- $m_H \geq 114$ GeV/c^2 @ 95% CL

EWK constraints:
- $\ln m_H \propto \Delta M_W \propto M_t^2$



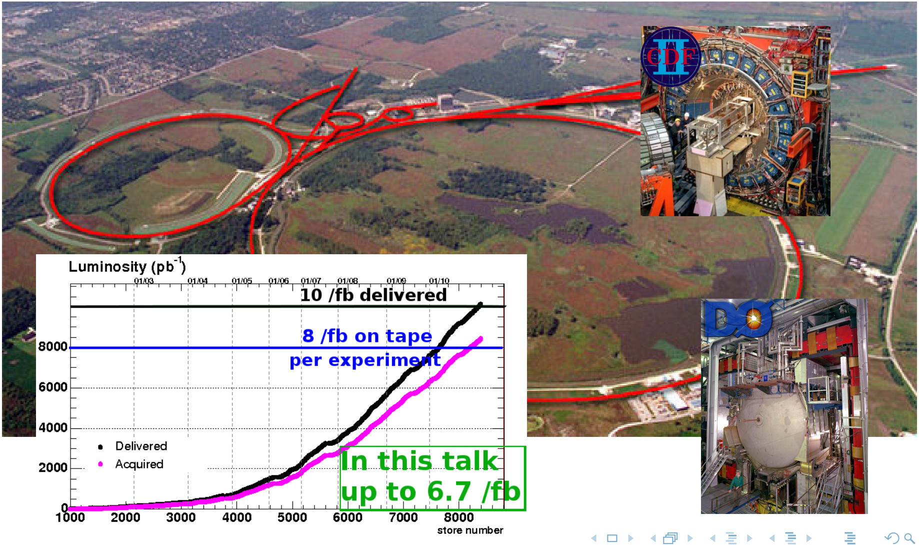
Precision EWK fits (LEP+Tevatron):
- $m_H \leq 186$ GeV/c^2 @ 95% CL



- **Tevatron searches**

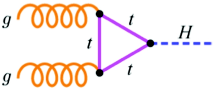
Tevatron, CDF and D0

$p\bar{p}$ **collisions at** $\sqrt{s}$= **1.96 TeV,** $\mathcal{L}_{inst} \sim 4{\cdot}10^{32}$ **cm**$^{-2}$**s**$^{-1}$

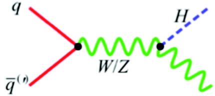


Higgs production and decay

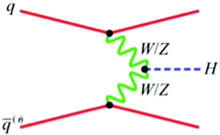
$$\sigma(gg \to H) = 0.2 \;-\; 1 \text{ pb}$$

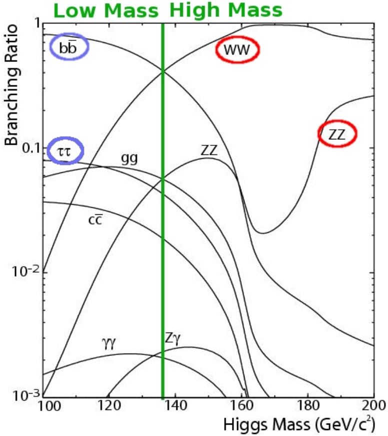


$$\sigma(q\bar{q} \to VH) = 0.01 \;-\; 0.3 \text{ pb}$$



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

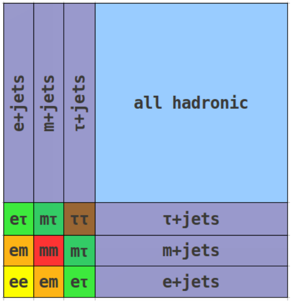




High mass region, $m_H \geq$135 GeV/c^2

- Dominant decay to WW
- $H \to ZZ$ sub-dominant, interesting with increased data sample.

$H \to WW$ final states



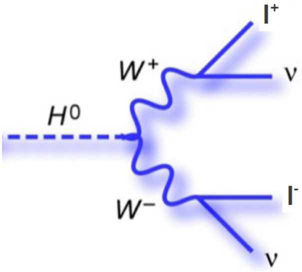
- At a hadron collider it's hard to exploit the all-hadronic final state. (not yet done)
- At least a lepton (e,μ) and/or $\not\!\!E_T$ need to be required to suppress QCD background

The most sensitive channel is $\ell\nu\ell\nu$,

▶ look for 2 high-p_T leptons and $\not\!\!E_T$

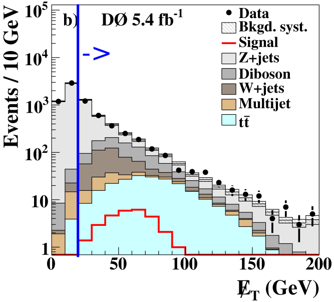
Additional contribution from:

- hadronic τ's final states: $\ell\nu\tau\nu$
- semi-leptoni decay: $\ell\nu jj$



Background processes

- **Drell-Yan:** $Z \to \ell\ell$ is the dominant background, suppressed requiring significant $\not{E}_T$



After Drell-Yan suppression, the other backgrounds are:

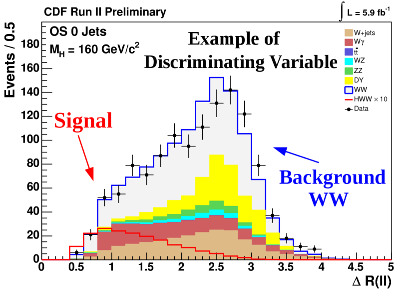
- **Heavy Dibosons** - WW, WZ, ZZ: modeled with PYTHIA
- **W/Z+jets**, with the jet faking a lepton:
  data driven modeling at CDF, ALPGEN at D0
- **Wγ**, with γ faking a lepton:
  BAUR at CDF, PYTHIA at D0
- **$t\bar{t}$** and **single top**: modeled with PYTHIA

All cross sections normalized to NLO calculations

- Two opposite charge isolated leptons
- Significant amount of unbalanced transverse energy
- $M_{\ell\ell}$ $\geq$16 GeV/c^2 to reduce background from heavy flavor
  - CDF analyzes separately $M_{\ell\ell}$ $\leq$16 GeV/c^2 region

Need to distinguish the signal from uncorrelated WW production

The spin-0 Higgs boson lead to angular correlated W's
$\rightarrow$ the two leptons in the final state tend to have small opening angles



Analysis strategy

- Initial sample $S/\sqrt{B} \sim 0.6$: a counting experiment is not enough!
- Both experiments uses **Multivariate Analysis Techniques** (MVA) to enhance signal to background separation:
  - **Matrix Element** calculation (ME), **Neural Network** (NN) and **Boosted Decision Trees** (BDT).
  - Multivariate discriminant for each analysis channel and m_H hypothesis.
- Separate analysis into channels for specific optimization:
  - **CDF** - by **jet multiplicity**: 0, 1 and 2 or more jets
  - **D0** - by **dilepton flavor**: ee, $e\mu$, $\mu\mu$
- Use kinematic control samples to check background modeling
- Validate search techniques by measuring SM processes cross section: WW, WZ, ZZ

CDF event selection

0 jets

CDF Run II Preliminary $\int \mathcal{L} = 5.9\ \text{fb}^{-1}$			
$M_H = 165\ \text{GeV}/c^2$			
$t\bar{t}$	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
$gg \to H$	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		

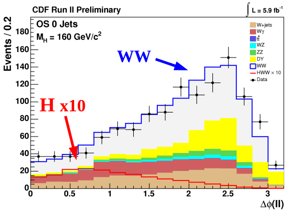
1 jet

CDF Run II Preliminary $\int \mathcal{L} = 5.9\ \text{fb}^{-1}$			
$M_H = 165\ \text{GeV}/c^2$			
$t\bar{t}$	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		

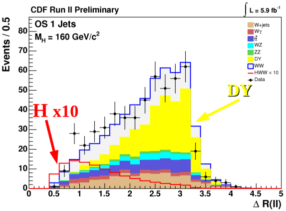
2 or more jets

CDF Run II Preliminary $\int \mathcal{L} = 5.9\ \text{fb}^{-1}$			
$M_H = 165\ \text{GeV}/c^2$			
$t\bar{t}$	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		

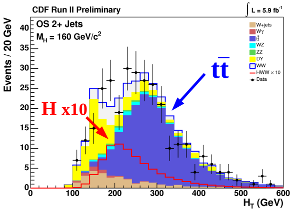
OS 0 Jets



OS 1 Jet

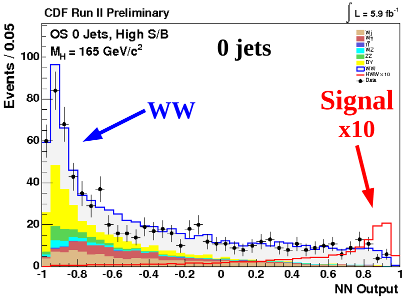


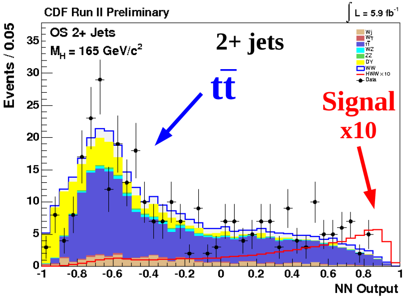
AllSB-2JOS



Signal Extraction

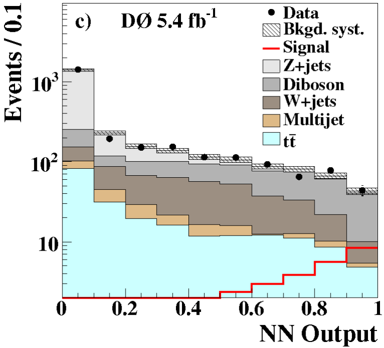
- Use a Neural Network to extract the signal, optimization for each subchannel:
  - different dominant background
  - different kinematic variable used
    (e.g. lepton p_T's, angular distribution, global event properties)
- NN training for each sub-channel and for 19 considered m_H.





$\sigma(p\bar{p} \to H)$ limits extracted from discriminant Signal and Background distributions.

D0 main analyses



◀ ee + $\mu\mu$ using **5.4 fb^{-1}**

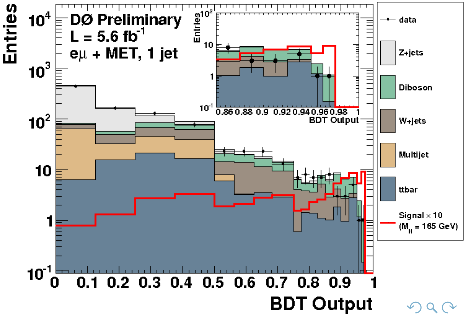
Separately trained Neural Network, output combined:

- 12 topological and kinematic input variables

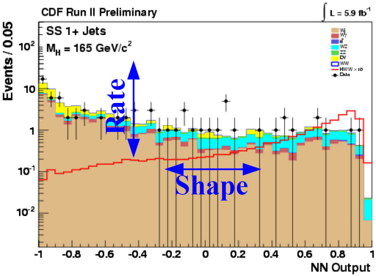
eμ ch. extended to **6.7 fb^{-1}** ▶

$e\mu$ channel: $S/\sqrt{B}$ ~0.7

Boosted Decision Tree used for Signal extraction.



Systematic uncertainties



Systematic on signal and background modeling can affect:

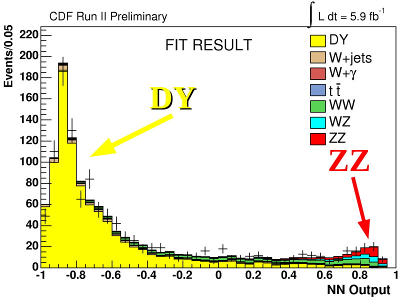
- Template normalization (*rate*)
- MVA discriminant output distribution (*shape*)

Main uncertainty sources	Signal	Background
Cross section	5%-65%	
NLO Diagrams	5%-11%	
Jet E_T	3%-30%	
Luminosity	7%	
DY $\not{E}_T$ modeling		26%
Fake leptons modeling		11%
$W\gamma$ data driven modeling		28%

Extract the Limit: likelihood fit to the *discriminant* output distribution considering systematic uncertainties.

Analysis techniques validation

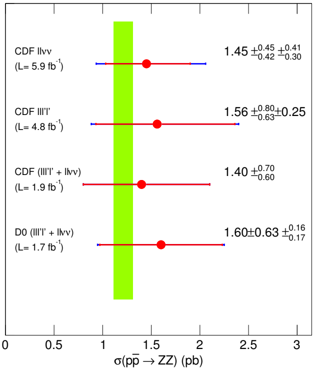
Measurement of ZZ production cross section in the $\ell\ell\nu\nu$ decay channel.



In a sample with dominant Drell-Yan background ($S/\sqrt{B} \sim 1.5$) use a NN to extract the ZZ signal.

$$\sigma(p\bar{p} \to ZZ) = 1.45^{+0.60}_{-0.51}\ \text{pb}$$

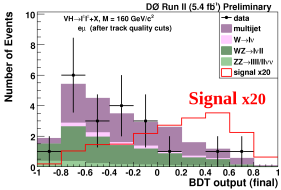
$$\sigma(p\bar{p} \to ZZ)_{NLO} = 1.21\ \pm\ 0.05\ \text{pb}$$



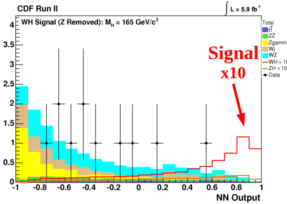
Tevatron most precise measurement.

Increase acceptance

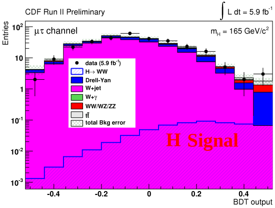
- **Two like-sign leptons in the final state:** $+5\%$ signal
  - Dominant signal contribution from $VH \to VWW$
  - Background from: wrong charge reconstruction, jet faking lepton



- **Three lepton final state:** $+3\%$ signal
  - Signal: $VH \to VWW$
  - Background from EWK WZ



- **Hadronic decaying τ's:** $H \to WW \to \ell\nu\tau\nu$
  - 5% of WW decays
  - Background from $W + jets$ with jet faking τ



Semi-leptonic final state

D0 carried out a search for $H \to WW \to \ell\nu jj$ using 5.4 fb^{-1}.

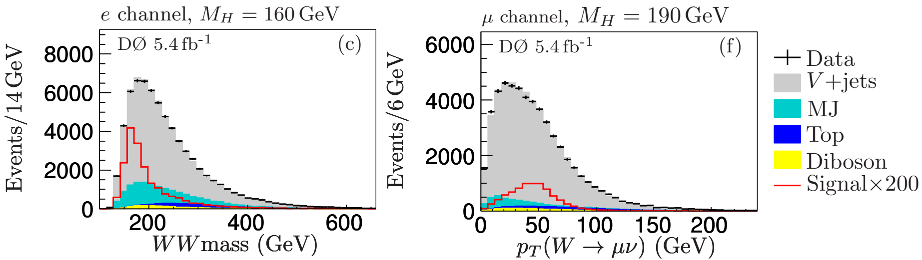
Signature: one high-p_T lepton, large $\not{E}_T$, two jets

- BR($WW \to \ell\nu jj$)$\sim$ 27%
- **Select events with:**
  - One isolated electron or muons
  - 2 well reconstructed jets ($E_T \geq$20 GeV)
  - $\not{E}_T \geq$15 GeV, $m_T(W) + 0.5\not{E}_T \geq$40 GeV

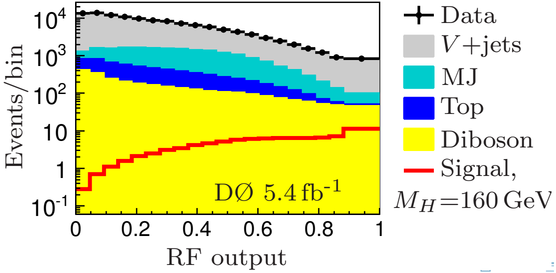
Process	e channel	μ channel
$gg \to H$	46.3	34.7
$qq \to qqH$	6.4	4.4
V+jets	52158	47970
Multijet	11453	2720
top	2433	1598
Dibosons	1584	1273
Data	67627	52433

- Large **W+jets background**: $S/\sqrt{B} \sim 0.26$ (m_H= 165 GeV/c^2)
- Other backgound from QCD multi-jet $\to$ fake leptons
  - Multijet background tuned from data in kinematic control region.

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



- Event kinematics input in Decision Tree Random Forest
  - Separate optimization for e+jets and μ+ jets



Channel results 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 τ	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

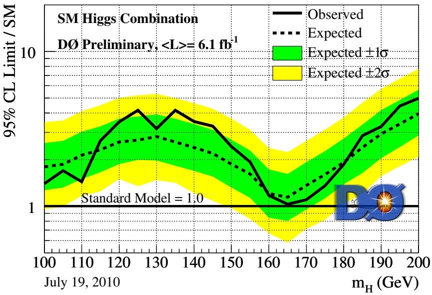
From each channel discriminant distribution is extracted a limit on SM Higgs production using a bayesian approach.

The several channels are combined taking into account for appropriate correlations.

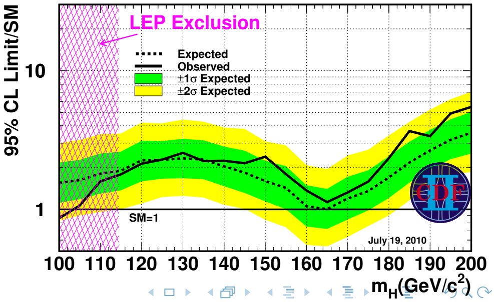
Experiments Combination

- $ee + \mu\mu$ with 5.4 fb^{-1}
- $e\mu$ with 6.7 fb^{-1}
- Same Sign with 5.4 fb^{-1}
- $\ell\nu jj$ with 5.4 fb^{-1}
- $\ell\nu\ell\nu$ with 5.9 fb^{-1}
- Same sign with 5.9 fb^{-1}
- Trilepton with 5.9 fb^{-1}
- $\ell\nu\tau_{had}\nu$ with 5.9 fb^{-1}

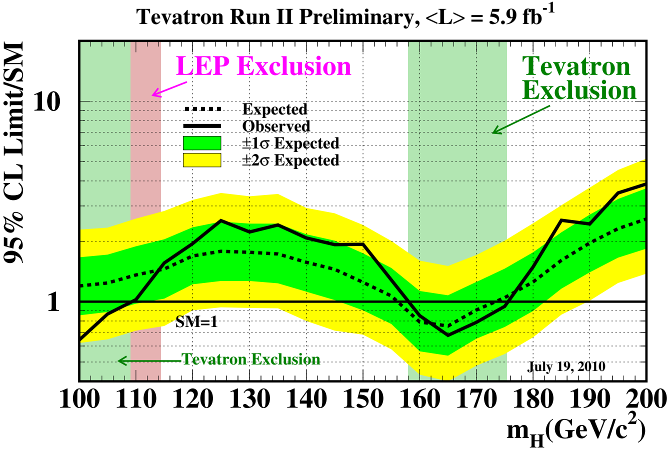
D0 almost achieved observed exclusion @ 165 GeV/c^2



CDF reached expected exclusion @ 165 GeV/c^2



Tevatron Combination

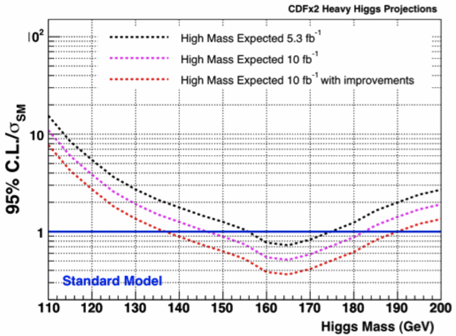


SM Higgs exclusion between 158 and 175 GeV/c^2

Conclusions & Perspectives

- All the analysis presented will be updated with new data: follow up at Moriond '11 conference
- New ongoing analyses searching for $H \to ZZ$
  - exploit $\ell\ell\nu\nu$, $\ell\ell jj$, $\nu\nu b\bar{b}$ channels
- Soon will be available 10 fb^{-1} of data per experiment:

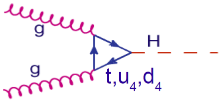
  some analysis will almost double their data sample.

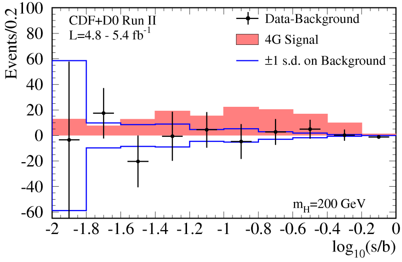


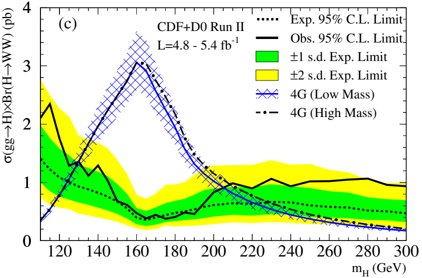
BACKUP MATERIAL

Higgs searches within 4^{th} generation model

- 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



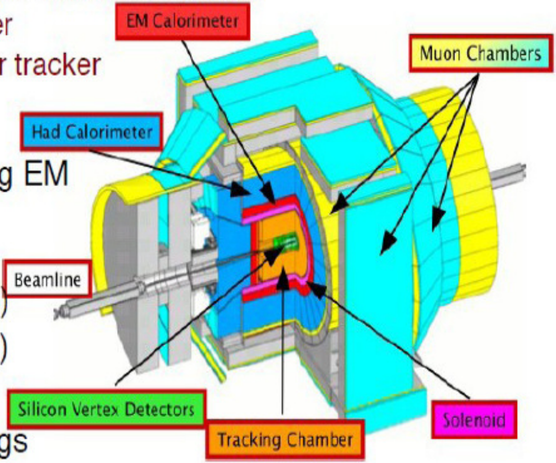




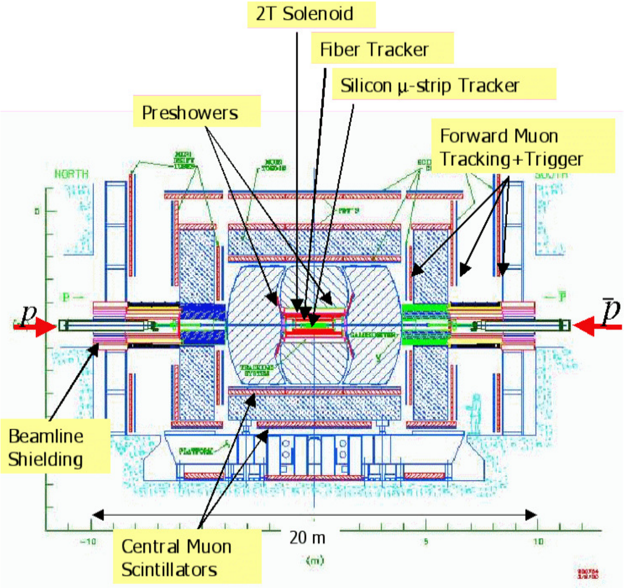
CDF+D0 combined exclusion: 131$\leq m_H \leq$208 GeV/c^2 95% CL (for infinite mass scenario)

CDF experiment

- General multipurpose detector
  - Excellent tracking and mass resolution:
    - Silicon inner tracker
    - Drift chamber outer tracker
- Calorimeters
  - Segmented sampling EM and Hadronic
- Muon chambers
  - CMU/CMP ($|\eta| < 0.6$)
  - CMX ($0.6 < |\eta| < 1.0$)
- Complex geometry
  - Try to maximize Higgs acceptance



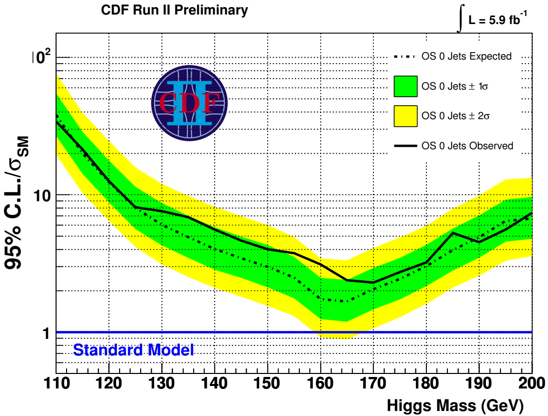
D0 experiment



- New in RunII
  - Tracking in B-field
  - Silicon detector
  - fiber tracker
- Upgraded for Run II
  - Calorimeter,
  - muon system
  - DAQ/trigger
- RunIIb (2006):
  - Silicon layer 0
  - Cal Trigger
- Typical coverage
  - Muons $\eta < 2$
  - Electrons
    - $\eta<1.1$
    - $1.5<\eta<2.5$
  - Jets $\eta< 2.5$

CDF results: 0,1,2+ jets

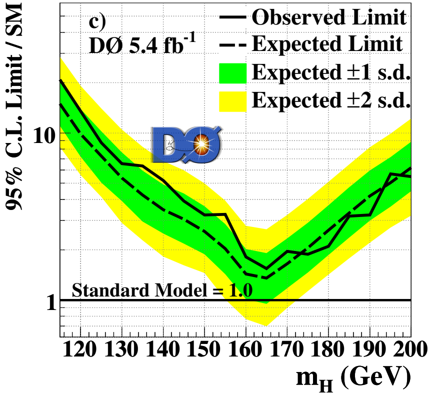
- Analysis using 5.9 fb^{-1} of data



95% CL limits, m_H=165 GeV/c^2

- **0 jet channel**: $2.39_{obs}(1.67_{exp}) \times\sigma_{SM}$
- **1 jet channel**: $2.46_{obs}(2.35_{exp}) \times\sigma_{SM}$
- **2+ jet channel**: $3.16_{obs}(6.14_{exp}) \times\sigma_{SM}$
- $M_{\ell\ell} \leq$ **16 GeV/c^2**: $7.21_{obs}(11.2_{exp}) \times\sigma_{SM}$

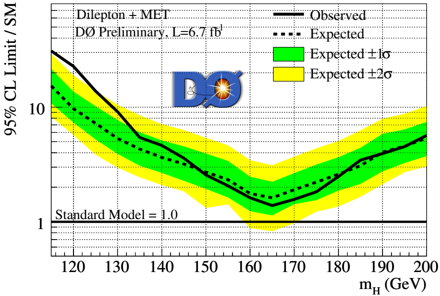
▼ $ee + e\mu + \mu\mu$, using 5.4 fb^{-1}



95% CL limit, m_H= 165 GeV/c^2

1.55_{obs} (1.36_{exp}) $\times\sigma_{SM}$

▼ $e\mu$ extended up to 6.7 fb^{-1}



95% CL limit, m_H= 165 GeV/c^2

1.39_{obs} (1.62_{exp}) $\times\sigma_{SM}$

Expected sensitivity in $e\mu$ increased by ~18%

Separate optimization: $M_{\ell\ell} \leq 16$ GeV/c^2

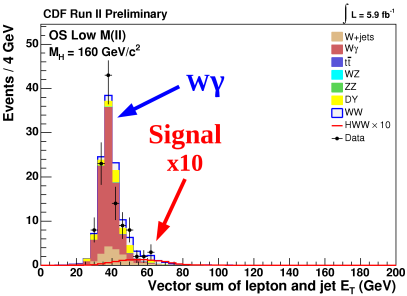
Same event selection, but with $M_{\ell\ell} \leq 16$ GeV/c^2:

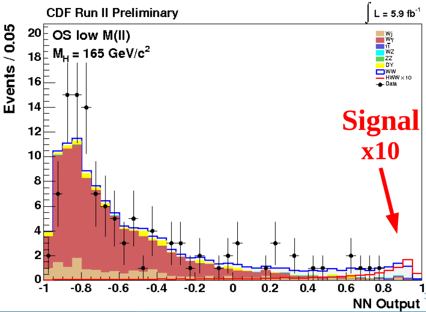
- Dominant background from $W\gamma$ with the photon faking a lepton
- Neural Network training for signal extraction

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

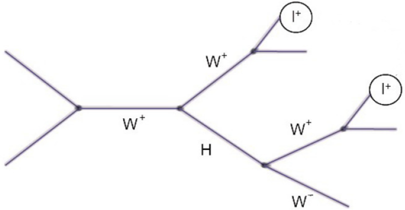
$M_H = 165$ GeV/c^2			
$t\bar{t}$	0.55	±	0.10
DY	4.35	±	0.78
WW	13.8	±	1.3
WZ	0.371	±	0.052
ZZ	0.139	±	0.019
W+jets	16.2	±	3.0
$W\gamma$	76.8	±	7.7
Total Background	112.2	±	8.6
$gg \to H$	1.00	±	0.20
Total Signal	1.00	±	0.20
Data	112		

AllSB-lowMll



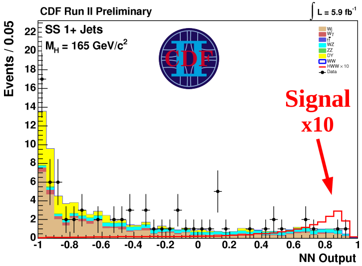


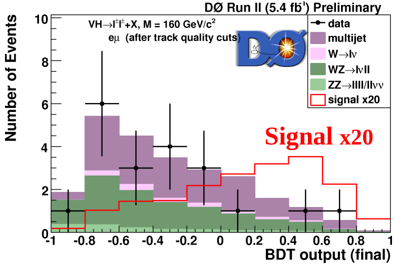
Two like-sign leptons in the final state.



Main signal contribution from associated production:
$VH \rightarrow VWW \rightarrow \ell^{\pm}\ell^{\pm} + X$
Dominant backgrounds:

- wrong reconstructed lepton charge
- jets faking leptons



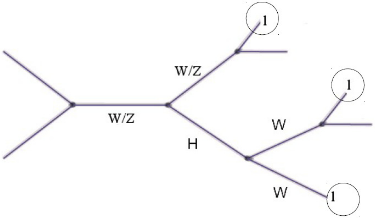


CDF: analysis similar to unlike-sign channels.

D0: two consecutive BDT against instrumental and physical backgrounds.

Trileptons

Three leptons in the final state.



Signal from associated production

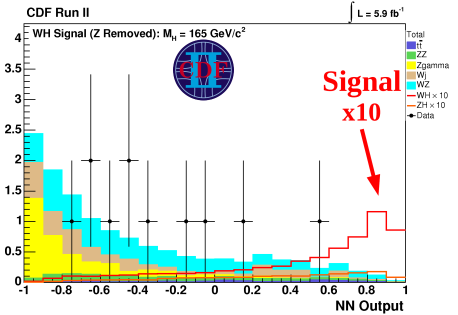
Dominant backgrounds from WZ

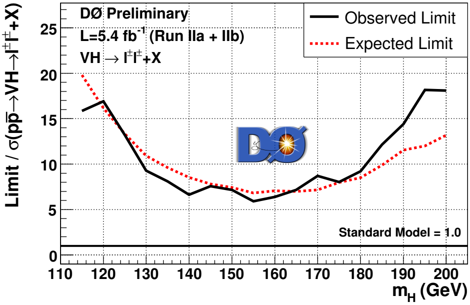
3 sub-channels to exploit different event topologies.

NN for signal extraction.

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

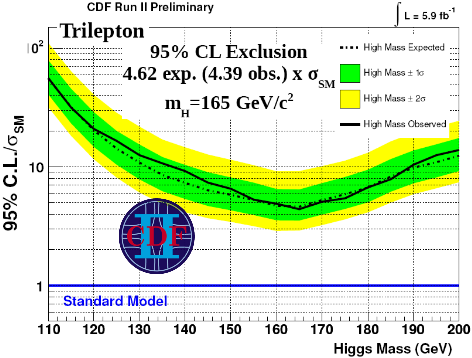
$M_H = 165\ \text{GeV}/c^2$	noZ	inZ 1 jet	inZ 2+ jets
$t\bar{t}$	0.37 ± 0.11	0.067 ± 0.030	0.084 ± 0.022
WZ	5.35 ± 0.76	8.5 ± 1.4	2.30 ± 0.52
ZZ	1.30 ± 0.18	3.97 ± 0.57	1.34 ± 0.26
W+jets	2.92 ± 0.72	5.1 ± 1.3	1.41 ± 0.36
$Z\gamma$	3.13 ± 0.62	4.14 ± 0.85	1.42 ± 0.38
Total Background	13.1 ± 1.5	21.8 ± 2.7	6.5 ± 1.1
WH	0.611 ± 0.084	0.0280 ± 0.0046	0.0085 ± 0.0017
ZH	0.159 ± 0.022	0.203 ± 0.032	0.491 ± 0.072
Total Signal	0.77 ± 0.11	0.231 ± 0.035	0.500 ± 0.73
Data	11	26	16





Same Sign

Trilepton



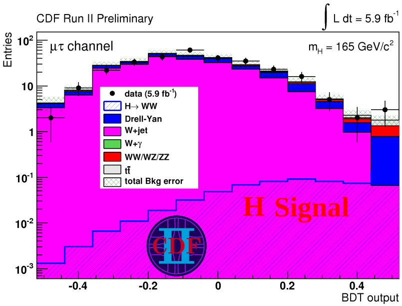
95% CL limits, m_H=165 GeV/c^2

DØ: 7.2_{obs} (7.0_{exp}) $\times\sigma_{SM}$ (5.4 fb^{-1})

CDF: 5.9_{obs} (4.9_{exp}) $\times\sigma_{SM}$ (5.9 fb^{-1})

Hadronic τ's final states

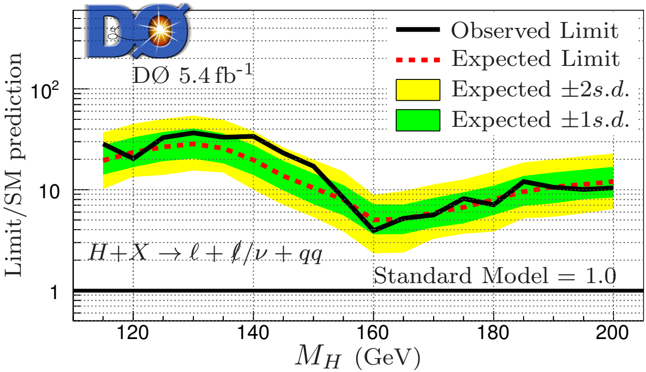
- Events with one e/μ, and $\tau \rightarrow$hadrons
  - ~ 5 % of WW final states
  - Signal acceptance limited by τ reconstruction efficiency
- Main background from W+jets: jet faking a τ



CDF Run II Preliminary		$\int \mathcal{L} = 5.9$ fb^{-1}	
$m_H = 160$ GeV/c^2			
dijet, γ+ jet	9	$\pm$	27
$Z \rightarrow \tau\tau$	0.8	$\pm$	0.4
$Z \rightarrow \ell\ell$	48.8	$\pm$	6.4
W+jets	624	$\pm$	77
Wγ	3.3	$\pm$	0.4
Diboson (WW, WZ, ZZ)	25.3	$\pm$	2.7
$t\bar{t}$	15.5	$\pm$	2.8
Total Background	726	$\pm$	82
$gg \rightarrow H$	1.08	$\pm$	0.10
WH	0.261	$\pm$	0.026
ZH	0.167	$\pm$	0.017
VBF	0.095	$\pm$	0.011
Total Signal	1.60	$\pm$	0.11
Data		741	

- Signal separation with a BDT
  - optimize separately $e\tau$ and $\mu\tau$
  - Use τ ID and event kinematic variables

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



95% CL limits, m_H=165 GeV/c²

- 5.2_{obs} (5.1_{exp}) $\times\sigma_{SM}$ (5.4 fb^{-1})

CDF $H \to WW \to \ell\nu\ell\nu$ - 0 jet channel

Uncertainty Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet	$gg \to H$	WH	ZH	VBF
Cross Section											
Scale								7.0%			
PDF Model								7.6%			
Total	*6.0%*	*6.0%*	*6.0%*	10.0%					**5.0%**	**5.0%**	10.0%
Acceptance											
Scale (leptons)								1.7%			
Scale (jets)	*0.3%*							1.5%			
PDF Model (leptons)								2.7%			
PDF Model (jets)	*1.1%*							5.5%			
Higher-order Diagrams		*10.0%*	*10.0%*	10.0%		10.0%			**10.0%**	**10.0%**	**10.0%**
$\not\!\!E_T$ Modeling					19.5%						
Conversion Modeling						10.0%					
Jet Fake Rates											
(Low S/B)							22.0%				
(High S/B)							25.0%				
Jet Energy Scale	*2.6%*	*6.1%*	*3.4%*	*26.0%*	*17.5%*	*3.1%*		*5.0%*	*10.5%*	*5.0%*	*11.5%*
Lepton ID Efficiencies	*3.0%*	*3.0%*	*3.0%*	*3.0%*	*3.0%*			*3.0%*	*3.0%*	*3.0%*	*3.0%*
Trigger Efficiencies	*2.0%*	*2.0%*	*2.0%*	*2.0%*	*2.0%*			*2.0%*	*2.0%*	*2.0%*	*2.0%*
Luminosity	*5.9%*	*5.9%*	*5.9%*	*5.9%*	*5.9%*			*5.9%*	*5.9%*	*5.9%*	*5.9%*

D0 $H \to WW \to \ell\nu\ell\nu$

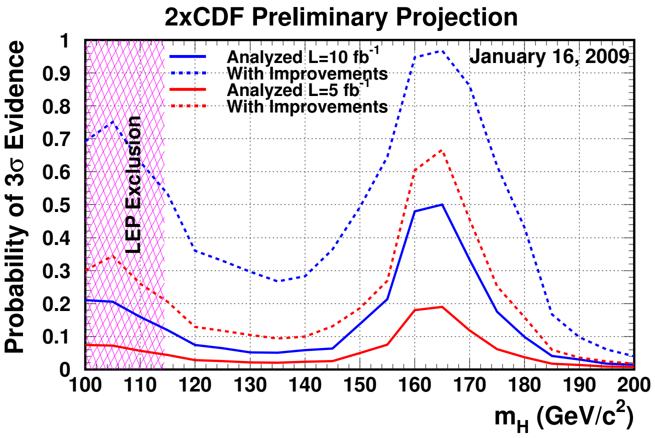
	Σ Bkgd	Signal	$Z+jets/\gamma$	$W+jets/\gamma$	$t\bar{t}$	Diboson	Multijet	Nature
Lepton identification	±4	±4	±4	±4	±4	±4	-	N
Lepton momentum resolution	±2	±2	±1	±1	±1	±2	-	D
Jet energy scale	±4	±1	±8	±1	±1	±1	-	D
Jet energy resolution	±3	±1	±4	±2	±1	±1	-	D
Jet identification	±4	±1	±6	±4	±1	±1	-	D
$Z-p_T$ correction	±1	-	±3	-	-	-	-	D
$W-p_T$ correction	±1	-	-	±2	-	-	-	D
Diboson NLO correction	±1	±1	-	-	-	±1	-	D
Multijet Normalization e^+e^-	±2		-	-	-	-	±20	N
Multijet Normalization $e^\pm\mu^\mp$	±1		-	-	-	-	±10	N
Multijet Normalization $\mu^+\mu^-$	±2		-	-	-	-	±20	N
Cross section	±7	±10	±6	±6	±10	±6	-	N
PDF	± 1	±1	-	-	-	-	-	N
Luminosity	±6.1	±6.1	-	-	-	-	-	N

D0 $H \rightarrow WW \rightarrow \ell\nu jj$

Contribution	Shape	W+jets	Z+jets	top	diboson	$gg \rightarrow H$	$qq \rightarrow qqH$	WH
Jet energy scale	Y	$\binom{+6.7}{-5.4}^S$	< 0.1	±0.7	±3.3	$\binom{+5.7}{-4.0}$	±1.5	$\binom{+2.7}{-2.3}$
Jet identification	Y	$\pm6.6^S$	< 0.1	±0.5	±3.8	±1.0	±1.1	±1.0
Jet resolution	Y	$\binom{+6.6}{-4.1}^S$	< 0.1	±0.5	$\binom{+1.0}{-0.5}$	$\binom{+3.0}{-0.5}$	±0.8	±1.0
Association of jets with PV	Y	$\pm3.2^S$	$\pm1.3^S$	±1.2	±3.2	±2.9	±2.4	$\binom{+0.9}{-0.2}$
Luminosity	N	n/a	n/a	±6.1	±6.1	±6.1	±6.1	±6.1
Muon trigger	Y	$\pm0.4^S$	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Electron identification	N	±4.0	±4.0	±4.0	±4.0	±4.0	±4.0	±4.0
Muon identification	N	±4.0	±4.0	±4.0	±4.0	±4.0	±4.0	±4.0
ALPGEN tuning	Y	$\pm1.1^S$	$\pm0.3^S$	n/a	n/a	n/a	n/a	n/a
Cross Section	N	±6	±6	±10	±7	±10	±10	±6
Heavy-flavor fraction	Y	±20	±20	n/a	n/a	n/a	n/a	n/a
PDF	Y	$\pm2.0^S$	$\pm0.7^S$	$< 0.1^S$	$< 0.1^S$	$< 0.1^S$	$< 0.1^S$	$< 0.1^S$
		Electron channel			Muon channel			
Multijet Background	Y	±6.5			±26			

Discovery potential

CDF+D0 combined:

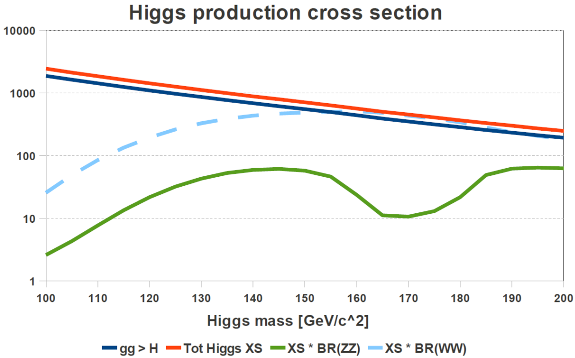


$H \to ZZ$

- 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, $H \to ZZ$ is as sensitive as $H \to WW$

Treatment of theoretical uncertainties I

- Arguments for using larger than normal scale variations (k=3 or $m_H/3 < \mu_r$, $\mu_f < 3m_H$) as opposed to standard factor of two (k=2) because of large NLO and NNLO contributions
  - Not the consensus of the theoretical community. In particular, authors of the papers from which our gluon fusion cross sections and uncertainties are taken disagree
- Arguments for additional uncertainties from Effective Field Theory (EFT) approach for integrating EWK contributions from heavy and light loop particles
  - Our quoted uncertainties do include a 1-2% contribution for this effect. If the corrections introduced by the EFT approach are removed entirely (clearly conservative), the total cross section is found to change by less than 4%
- Arguments that our PDF uncertainties should account for observed differences in cross sections obtained using our default MSTW model and the ABKM/HERAPDF models

Treatment of theoretical uncertainties II

  - ABKM and HERPDF fits do not include Tevatron jet data, which provide the best constraints on the relevant high-x gluon distributions at Tevatron energies. NLO theoretical predictions using ABKM/HERAPDF are in poor agreement with Tevatron jet data

- Arguments for accounting for correlations between scale and PDF model uncertainties
  - Our quoted scale uncertainties do include contributions from PDF model scale dependence. These contributions are found to be small in comparison with experimental uncertainties on the datasets used in the PDF model fits
- Arguments that theoretical cross section uncertainties should be added linearly even if they are not correlated
  - Our quoted scale uncertainties do include contributions from PDF model scale dependence. These contributions are found to be small in comparison with experimental uncertainties on the datasets used in the PDF model fits

Reproduction of Tevatron Limits

- Independent re-interpretations of Tevatron Higgs mass exclusion ranges should be received with skepticism
- The examples we have seen are based on incorrect assumptions regarding the experimental methodology
- Some examples of inaccurate assumptions
  - That the effect of an increase in uncertainty on a theoretical cross section can be modeled using an equivalent decrease in the central cross section value
  - That increases in cross section uncertainties assigned to background processes effect our final limits. In fact, main background contributions are constrained directly from our fit to the data more accurately than what one obtains using even our current theoretical uncertainties
  - That it is not important to account for correlations between different search channels. In fact, these correlations allow us to obtain additional constraints using the fitting procedure applied to the data