Searches for a High Mass Higgs Boson at the Tevatron

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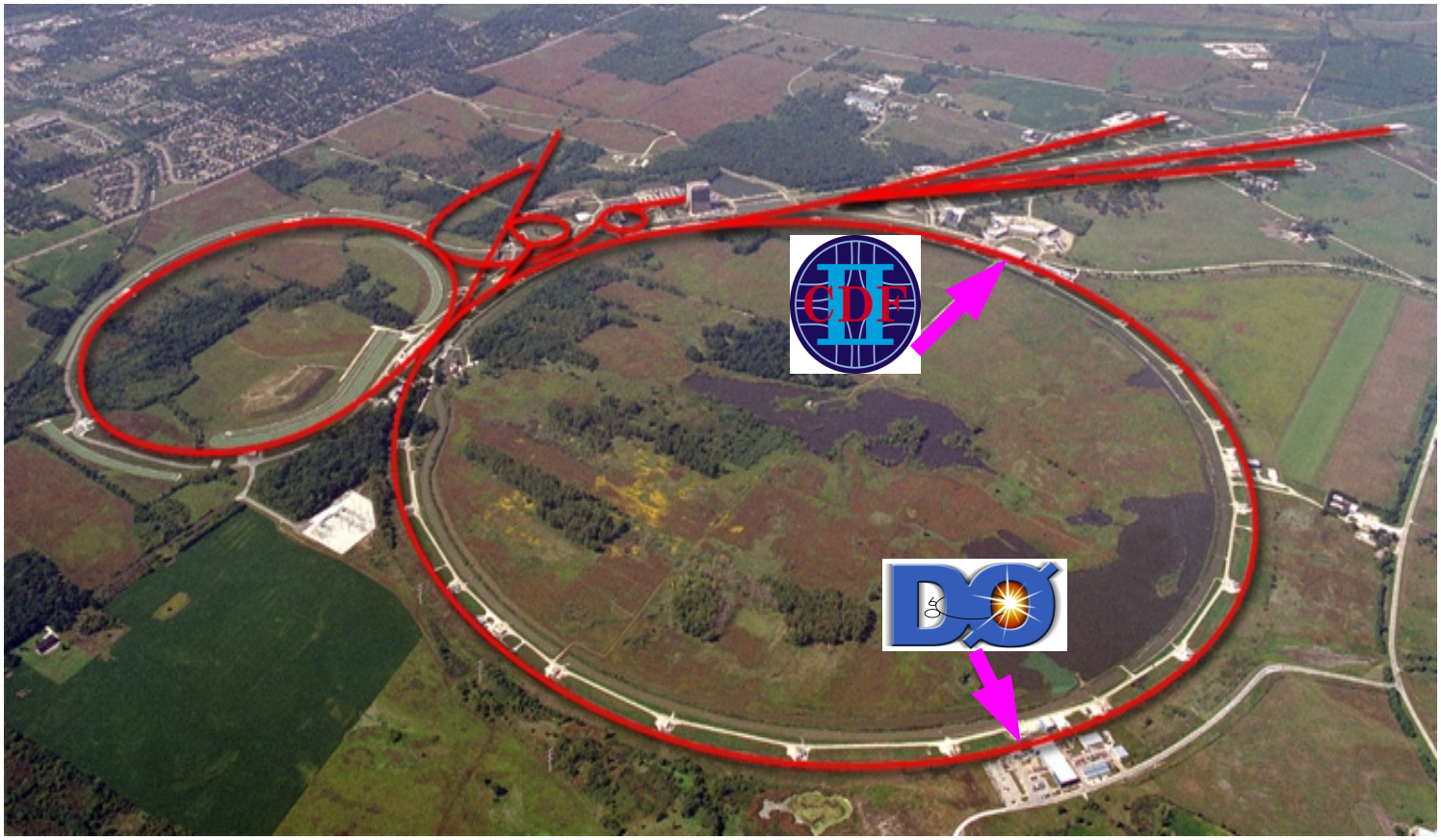
On behalf of the CDF and D0 Collaborations

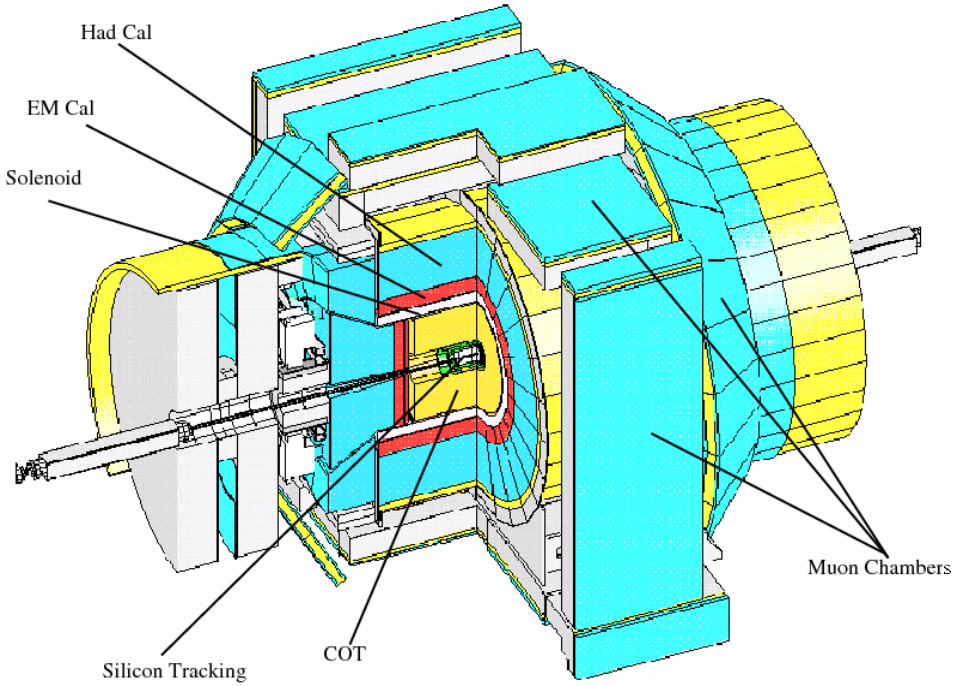
Tevatron Accelerator

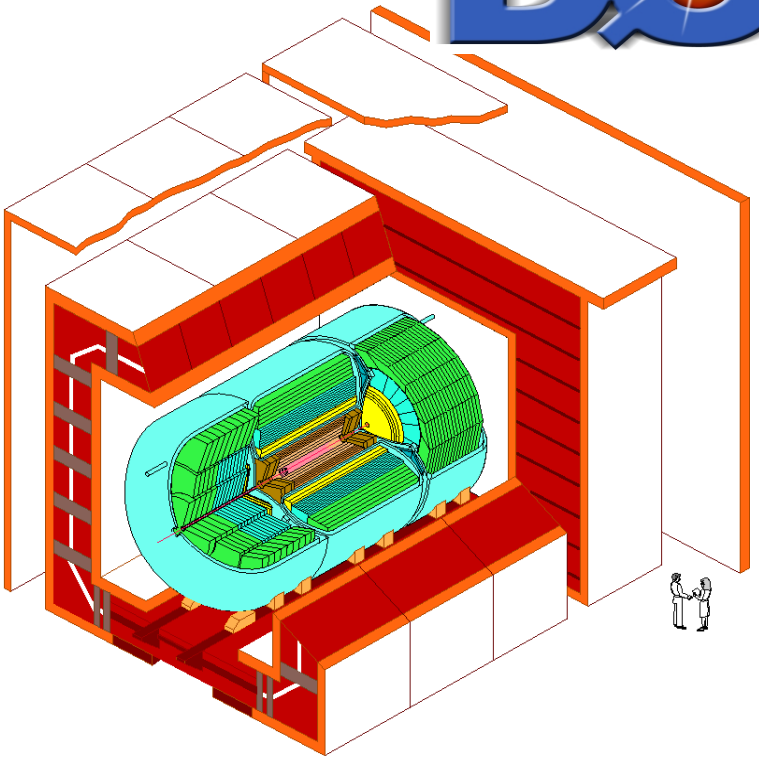
Collide $p\bar{p}$ at $\sqrt{s}$ = 1.96 TeV

2 Experiments CDF and D0

Both experiments have acquired > 5 fb^{-1}







CDF

Silicon inner tracker, wire drift chamber outer

EM (lead-scintillator) and had calorimeters (iron-scintillator)

Muon coverage $|\eta| < 1.5$

D0

Silicon inner tracker, fiber outer tracker

LAr-U calorimeter

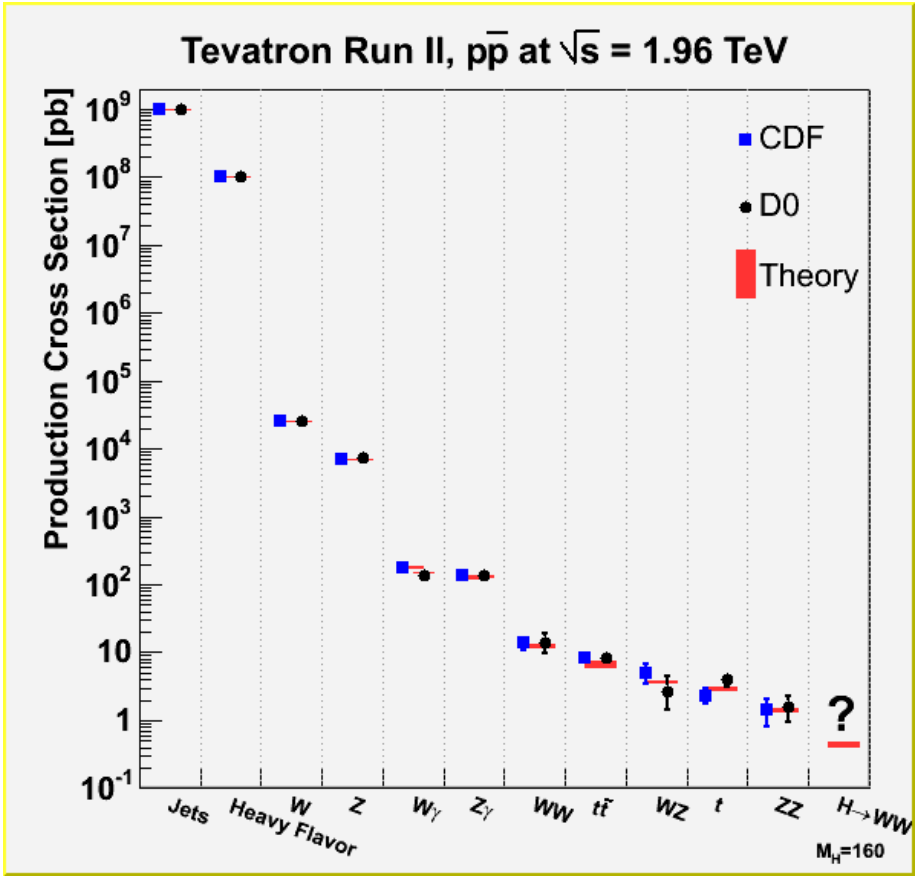
Good muon coverage $|\eta| < 2$

CDF and D0 probe Standard Model in several sectors

- Many discoveries

  tt, WW,WZ,ZZ, single top

- Measure processes w/ pb cross sections!
- CDF and D0 are now sensitive enough to see SM Higgs



Direct Higgs searches at LEP

Exclude Higgs of M_H < 114.4 GeV

at 95% C.L.

Results presented today – **integrated luminosity up to 4.2 fb^{-1}**

Both experiments have collected **> 5 fb^{-1}**

Higgs Production at the Tevatron

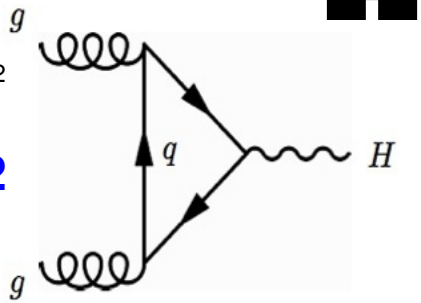
Four main production mechanisms

Gluon fusion dominant process at Tevatron

Associated production (WH, ZH) and vector boson fusion also contribute

σ*Br(pb)
165 GeV/c²

0.372



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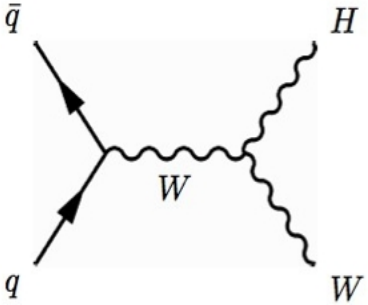

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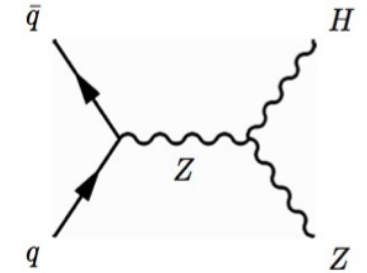

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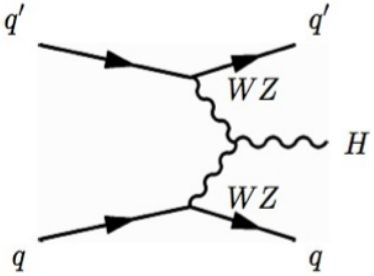
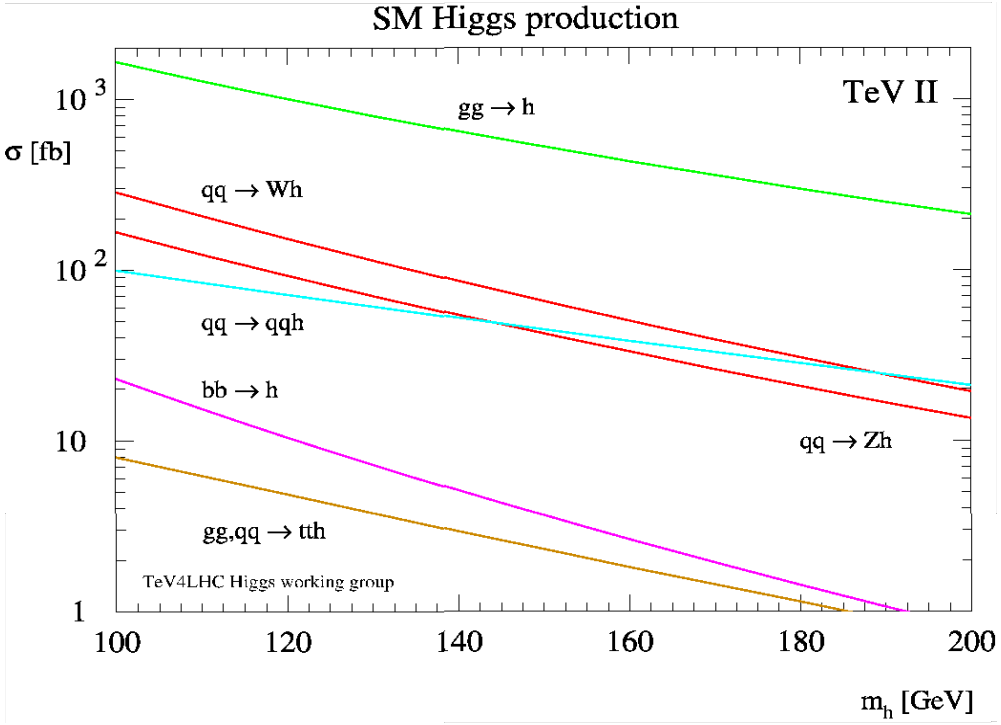




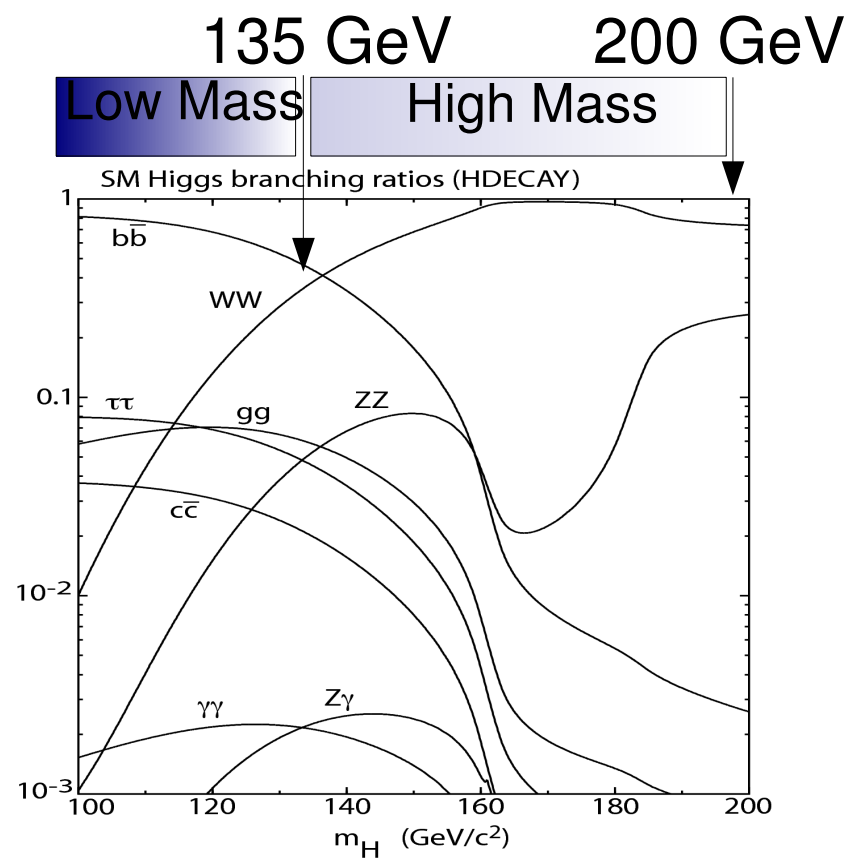
SM Higgs Decay modes

- Higgs decay modes depend on Higgs mass m_H
- For $gg \rightarrow H \rightarrow WW^*$

  Peak sensitivity at $M_H \sim 160$
- WW^* decay modes
  - Hadronic W decay modes have large QCD bkg
  - Dilepton (e, μ): BR ~ 6%
    - Sensitive to $\tau \rightarrow (e, \mu)$
    - Small BR, but... clean,
    - easy to trigger

High mass Higgs search:

$H \rightarrow WW^* \rightarrow l\,\nu\,l\,\nu$ (l = e or μ)



H → WW* → l ν l ν Signature

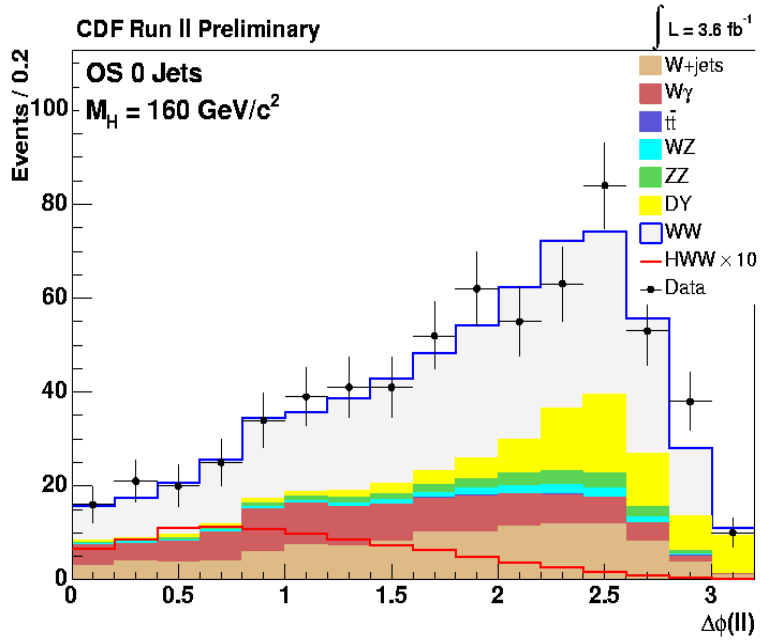
Decay kinematics

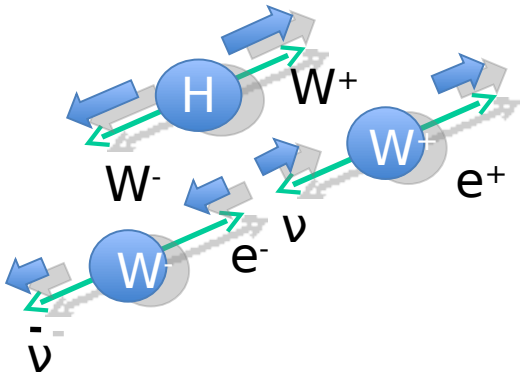
2 opposite sign high p_T leptons(e or μ)

Large missing transverse energy

Broad invariant mass spectrum

WW pair from spin-0 Higgs boson:





Spin correlation:
Leptons go in the same direction

Δφ best background discriminant

$H \rightarrow WW^* \rightarrow l\,\nu\,l\,\nu$ Backgrounds

For $gg \rightarrow H \rightarrow WW^* \rightarrow l\nu l\nu$

Main background is $Z/\gamma \rightarrow ll$

CDF & D0 suppress this by requiring large missing E_T

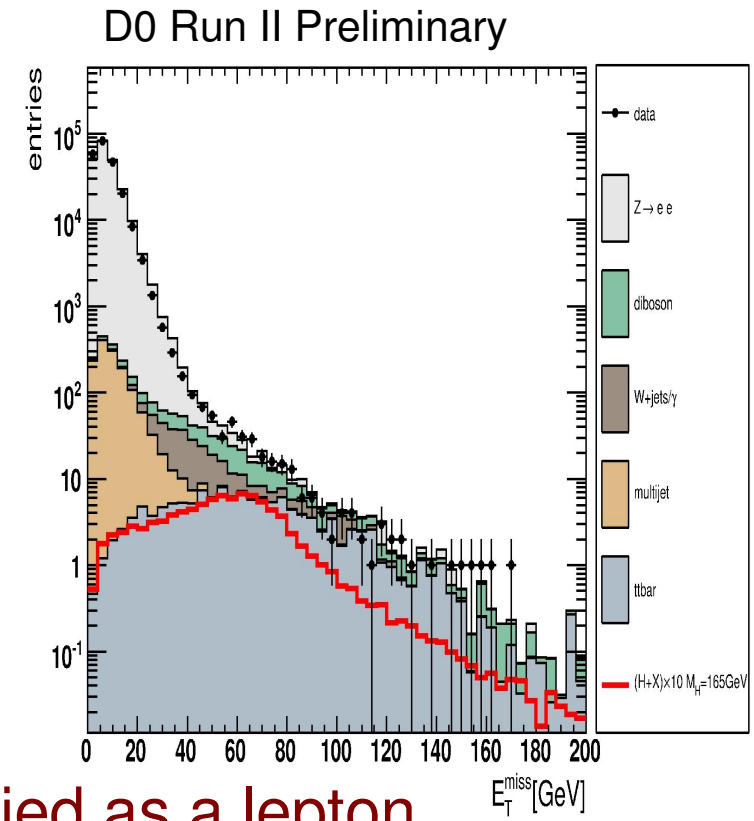
After Drell-Yan suppression the main backgrounds are:

Diboson production (WW,WZ,ZZ)

tt and single top

W + jets – where a jet is misidentified as a lepton

$W\gamma$ – where the photon is misidentified as a lepton



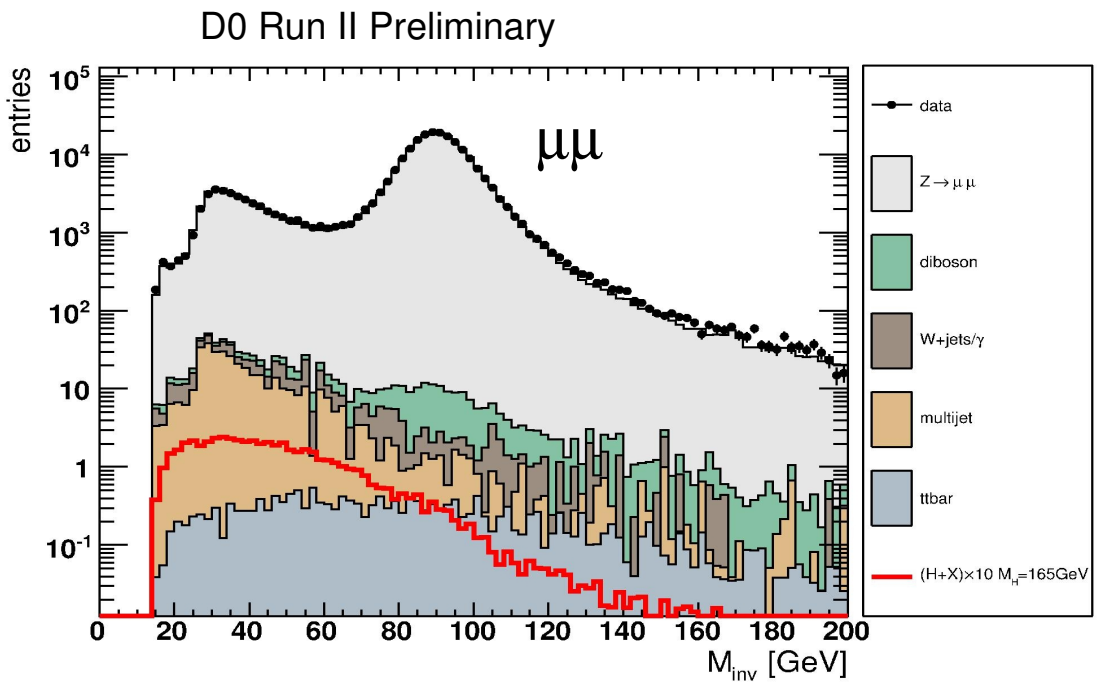
$H \rightarrow WW^* \rightarrow l\,\nu\,l\,\nu$ PreSelection

Separate by dilepton type (ee,eμ,μμ)

- Two opposite charge leptons
- Isolation cuts
- $M_{ll} > 15$ GeV/c^2

Trigger on one high-p_T lepton

- $p_T(\mu)>10$ GeV/c, $p_T(e)>15$ GeV/c
- In μμ evts: $N_{jets} < 2$ ($P_T^{jet}>15$ GeV/c), $\Delta R(\mu,jet)>0.1$ $P_T^{\mu}>15$/c (leading μ)



Z/γ background still dominant other cuts needed:*

$H \rightarrow WW^* \rightarrow l\,\nu\,l\,\nu$ Selection

Additional Cuts required to reduce large Z/γ^* backgrounds

Final State	$e\mu$	ee	$\mu\mu$
Missing Transverse Energy $\not{E}_T$ (GeV)	> 20	> 20	
$\not{E}_T^{Scaled}$ (correct mismeasured jets) (GeV)	> 6	> 6	
$M_T^{min}(l,\not{E}_T)$ (GeV)	> 20	> 20	
$p_T\mu\mu$ (GeV) for njet = 0 $\not{E}_T$ (GeV) for njet = 1			> 20 > 20
$\Delta\phi(l,l)$	< 2	< 2	< 2.5

Expected/Observed number of Events

D0 Run II Preliminary

	ee	eμ	μμ
Z/γ*(ee)	***108±14***	$0.0^{+0.1}_{-0.0}$	-
Z/γ*(μμ)	-	5.8±0.1	***3921±22***
Z/γ*(ττ)	1.4±0.5	7.3±0.1	66±2
ttbar	39.9±0.8	82.5±0.2	12.55±0.04
W+jets	98±3	78.6±2.8	134±5
WW	66.8±1.6	***154.7±0.1***	92.8±0.3
WZ	9.68±0.05	6.6±0.1	19.4±0.3
ZZ	7.68±0.07	0.60±0.01	15.1±0.1
Multijet	$1.7^{+2.0}_{-1.7}$	$1.1^{+9.6}_{-1.1}$	64±8
Signal(M_H= 165 GeV	**6.13±0.01**	**12.2±0.1**	**4.85±0.01**
Total Background	332±15	337±10	4325±24
Data	336	329	4084

$H \rightarrow WW^* \rightarrow l\,\nu\,l\,\nu$ Neural Nets

Expect ~23 Higgs events over ~4994 background

Train one NN for each dilepton channel at each Higgs mass (5 GeV steps)

Three classes of input variables:

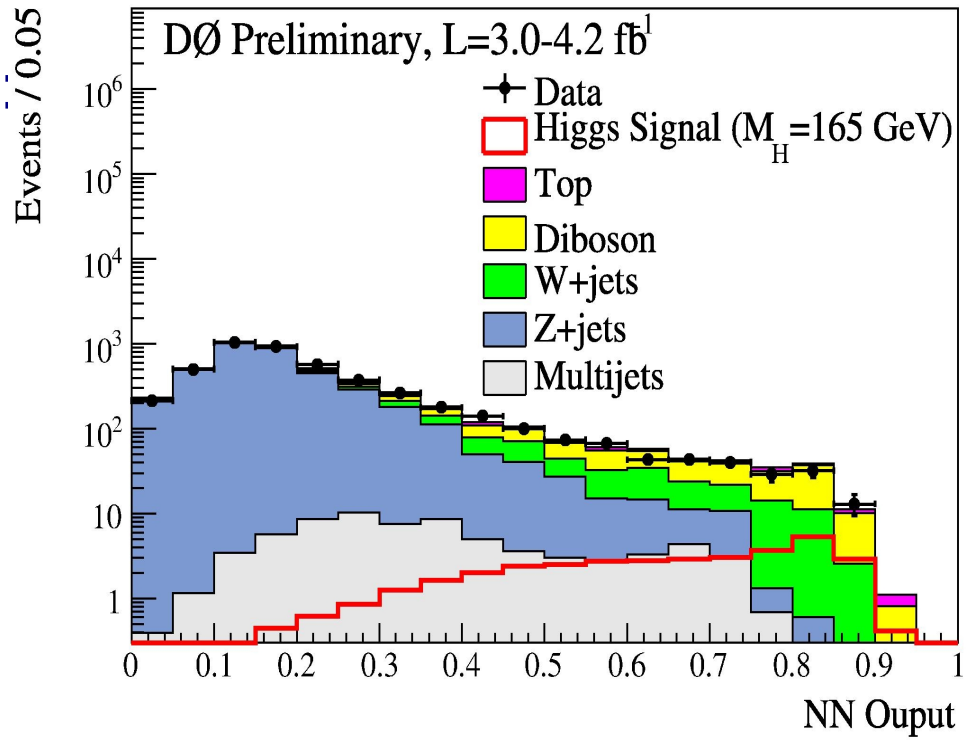
Lepton-specific ($p_T(l)$, ...)

Kinematics ($H_T=\sum_i |p_T(jet_i)|$, E_T, ...)

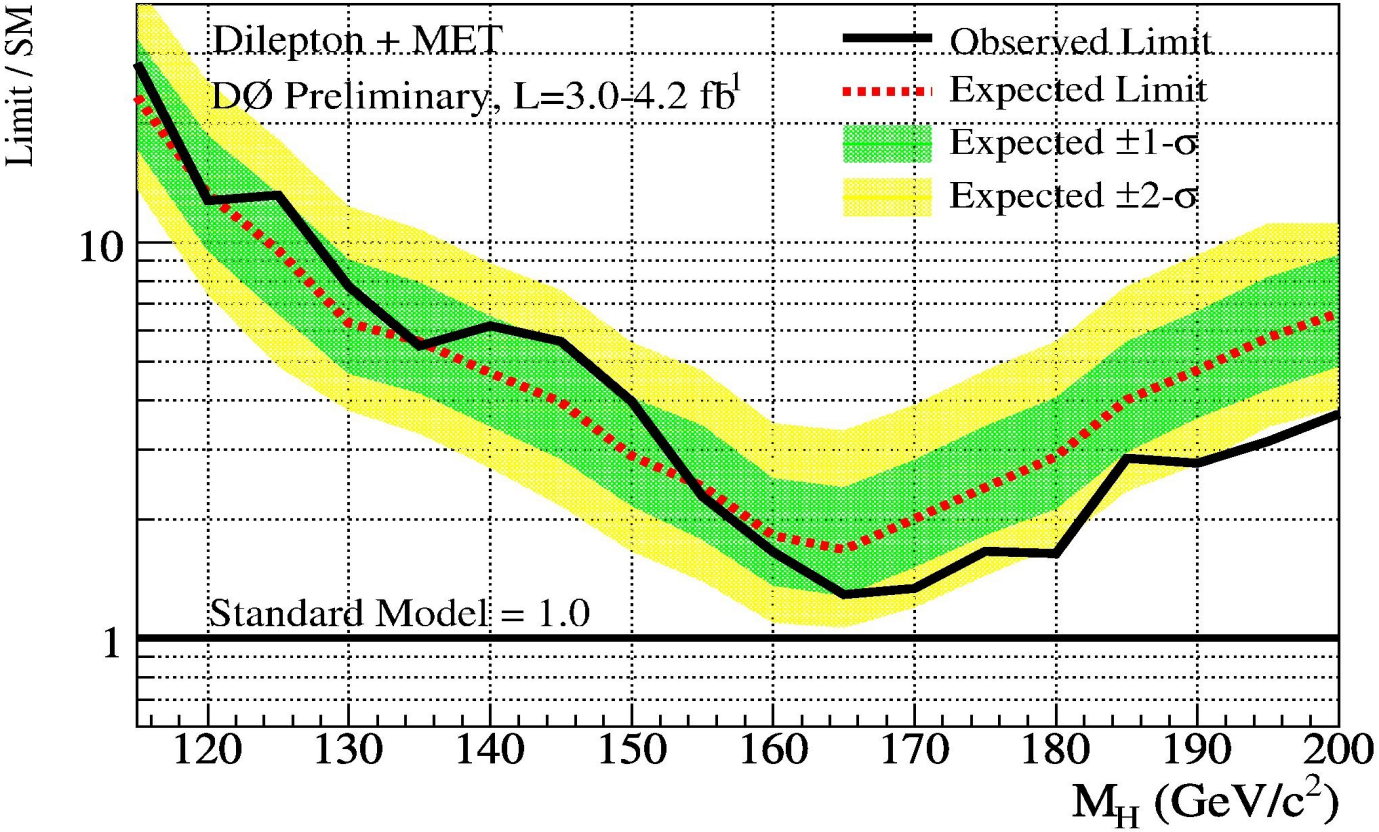
Angular ($\Delta\phi(l,l)$, $\Delta\phi(l,E_T)$, ...)

NN output dist. used for limits

Limits calculated using Modified Frequentist (CL_s)



H → WW* → l ν l ν Limits



For M_H = 165

Exp limit 1.7 x σ_{SM}

Obs limit 1.3 x σ_{SM}

Use latest theoretical inputs including:
σ(gg→H) by C. Anastasiou, R. Boughezal and F. Petriello ;
and de Florian & Grazzini w/ MSTW 2008 NNLO PDF set

CDF High mass Higgs analyses

Separate analysis by number of jets (0, 1, and ≥2)

Trigger on one high-p_T lepton

$p_T(l_1) > 20$ GeV, $p_T(l_2) > 10$ GeV

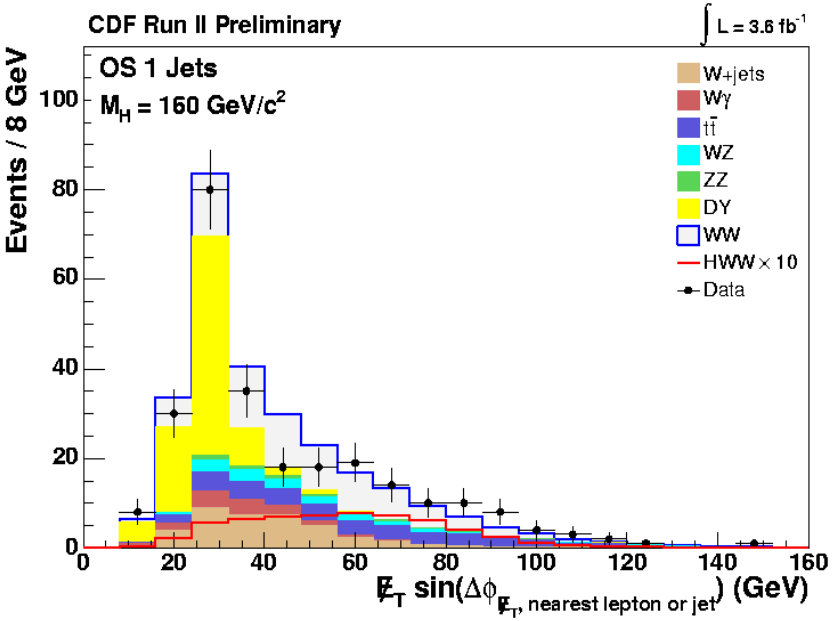
Two opposite charge leptons

$M_{ll} > 16$ GeV/c^2

$\not{E}_T^{spec} > 25$ GeV (ee, μμ)

$\not{E}_T^{spec} > 15$ GeV (eμ)

($\not{E}_T^{spec} = \not{E}_T * \sin(\Delta\phi(\not{E}_T$, nearest lepton or jet)))



Separate by lepton quality into high and low S/B regions

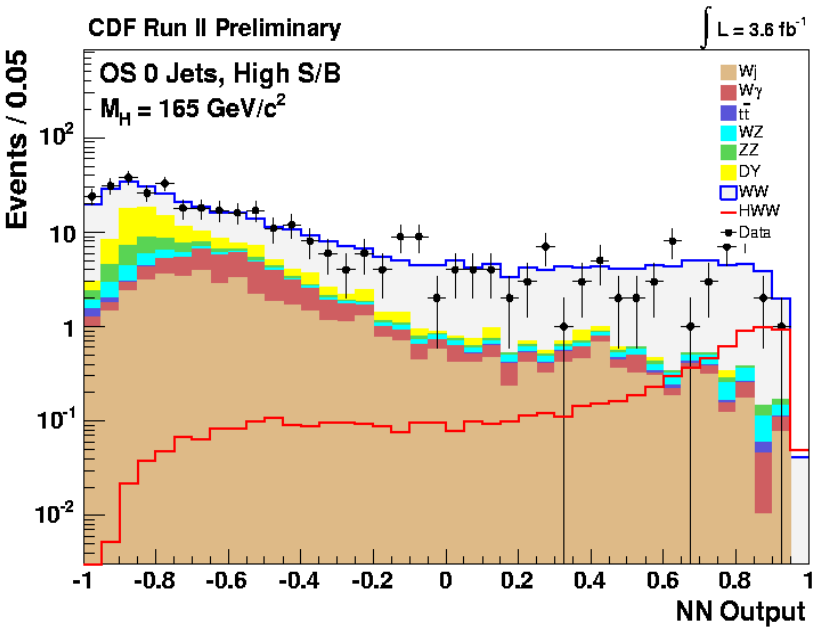
CDF High mass Higgs 0-jet analysis

Use a NN to separate Signal from Background

Only consider gg→H production

Inputs to the NN

Kinematic variables and Matrix Element calculations



High S/B, Low S/B based on lepton purity

CDF Run II Preliminary $\int \mathcal{L} = 3.6$ fb^{-1}			
$M_H = 160$ GeV/c^2			
$t\bar{t}$	1.12	$\pm$	0.18
DY	47.2	$\pm$	10.9
WW	234	$\pm$	26
WZ	9.8	$\pm$	1.3
ZZ	15.4	$\pm$	2.1
W+jets	45	$\pm$	12
$W\gamma$	25.6	$\pm$	6.9
Total Background	377	$\pm$	39
$gg \to H$	7.7	$\pm$	1.2
Total Signal	7.7	$\pm$	1.2
Data	380		

OS 0 Jets, HighSB

CDF Run II Preliminary $\int \mathcal{L} = 3.6$ fb^{-1}			
$M_H = 160$ GeV/c^2			
$t\bar{t}$	0.229	$\pm$	0.036
DY	32.5	$\pm$	7.5
WW	83.9	$\pm$	9.3
WZ	4.03	$\pm$	0.55
ZZ	5.31	$\pm$	0.73
W+jets	68	$\pm$	15
$W\gamma$	66	$\pm$	18
Total Background	260	$\pm$	30
$gg \to H$	1.77	$\pm$	0.26
Total Signal	1.77	$\pm$	0.26
Data	274		

OS 0 Jets, LowSB

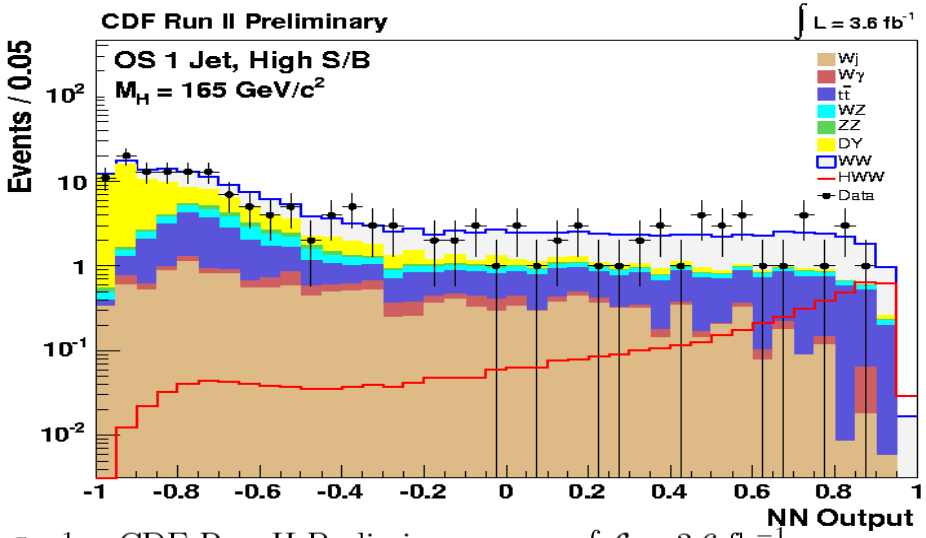
CDF High mass Higgs 1jet Analysis

Primary signal process - gg→H

Include (Z/W) H and VBF Higgs production processes

kinematic input variables to Neural Network

High S/B, Low S/B based on lepton purity



CDF Run II Preliminary	$\int \mathcal{L} = 3.6$ fb^{-1}		
$M_H = 160$ GeV/c^2			
$t\bar{t}$	28.7	±	4.5
DY	58	±	18
WW	64.6	±	6.9
WZ	9.9	±	1.4
ZZ	4.06	±	0.56
W+jets	14.7	±	4.6
$W\gamma$	3.05	±	0.93
Total Background	183	±	23
$gg \to H$	3.88	±	0.59
WH	0.542	±	0.071
ZH	0.200	±	0.026
VBF	0.320	±	0.051
Total Signal	4.94	±	0.64
Data	168		

OS 1 Jet, HighSB

CDF Run II Preliminary	$\int \mathcal{L} = 3.6$ fb^{-1}		
$M_H = 160$ GeV/c^2			
$t\bar{t}$	6.19	±	0.97
DY	27.3	±	8.6
WW	20.7	±	2.2
WZ	4.61	±	0.63
ZZ	1.42	±	0.19
W+jets	24.9	±	5.5
$W\gamma$	10.2	±	3.1
Total Background	95	±	12
$gg \to H$	0.81	±	0.12
WH	0.120	±	0.016
ZH	0.0439	±	0.0057
VBF	0.0608	±	0.0097
Total Signal	1.04	±	0.13
Data	94		

OS 1 Jet, LowSB

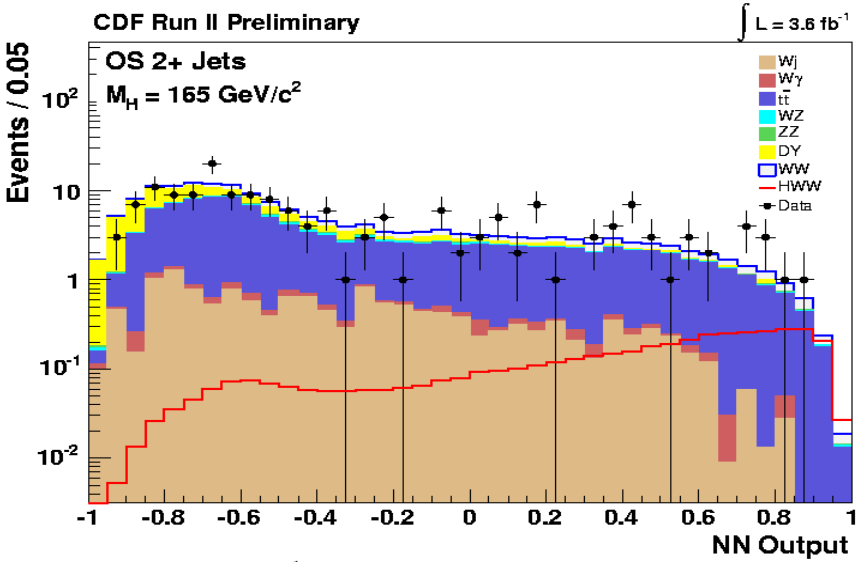
CDF High mass Higgs 2+ Jet Analyses

Primary signal process - gg→H

Include (Z/W) H and VBF Higgs production processes

62% of all signal events

kinematic input variables to Neural Network



CDF Run II Preliminary	$\int \mathcal{L} = 3.6$ fb^{-1}		
$M_H = 160$ GeV/c^2			
$t\bar{t}$	100	$\pm$	17
DY	33	$\pm$	11
WW	17.6	$\pm$	4.0
WZ	3.76	$\pm$	0.52
ZZ	1.62	$\pm$	0.22
W+jets	14.7	$\pm$	4.0
$W\gamma$	2.12	$\pm$	0.70
Total Background	173	$\pm$	23
$gg \to H$	1.75	$\pm$	0.30
WH	1.39	$\pm$	0.18
ZH	0.693	$\pm$	0.090
VBF	0.70	$\pm$	0.11
Total Signal	4.53	$\pm$	0.52
Data	169		

OS 2+ Jets

WH→WWW→$l^{\pm}$ $l^{\pm}$ +X (same sign)

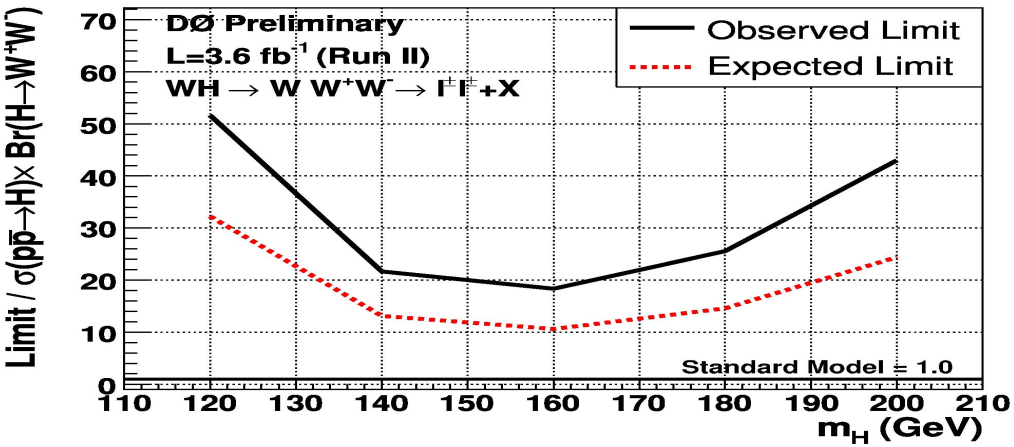
WH → WWW → $l^{\pm}$ $l^{\pm}$ + X

Signature is like-sign dileptons

Main Background:

multijet lep. misidentification (D0),

W+jets lep. misidentification (CDF)

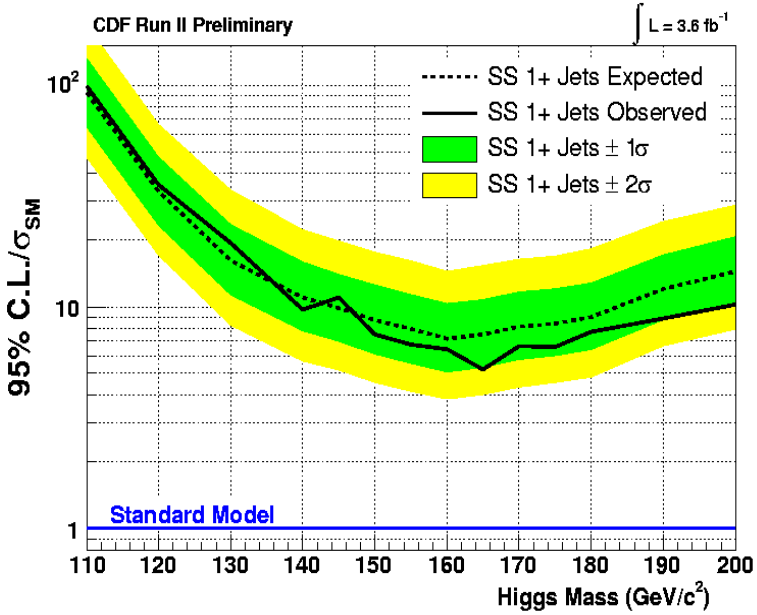


D0 analysis uses 3.6 fb^{-1}

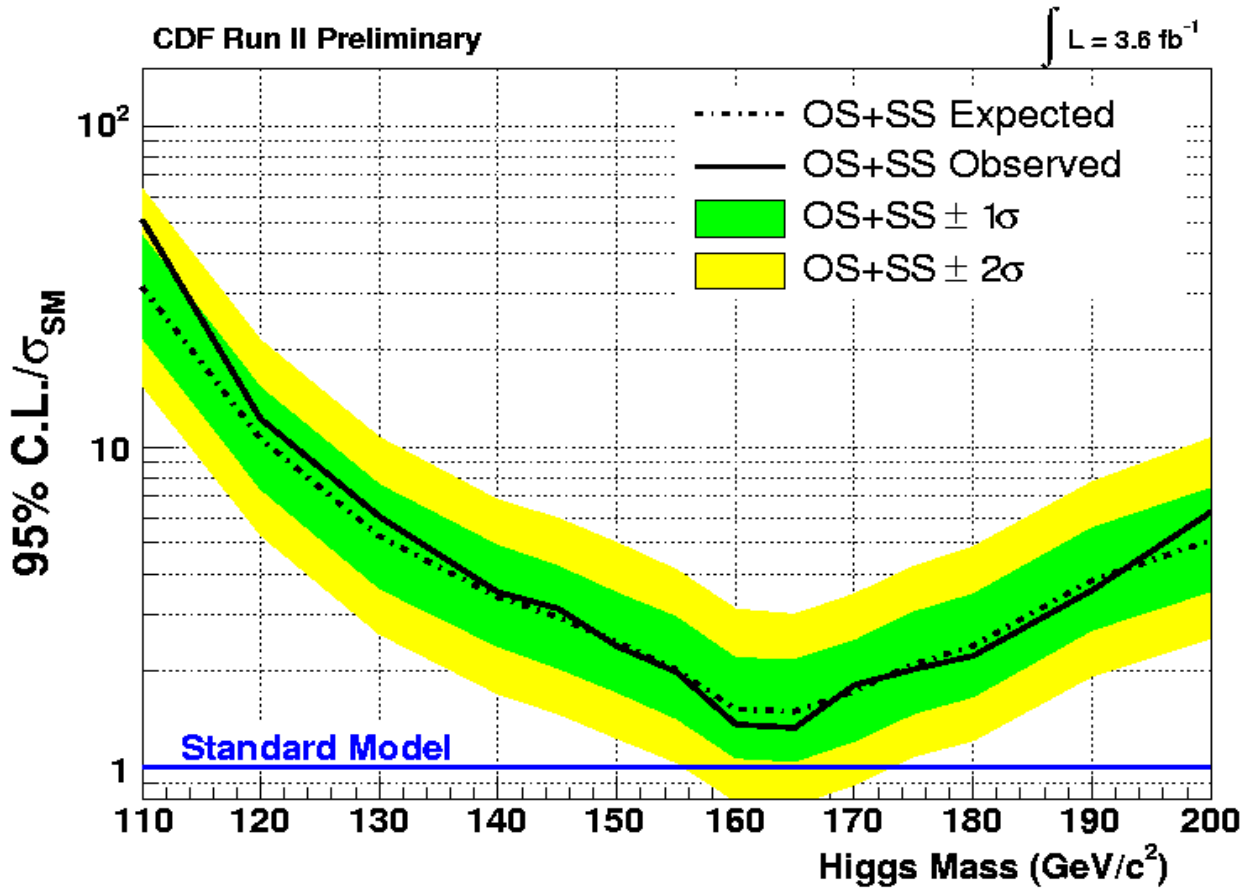
Results at 160: 18.4 (10.7) xσ_{SM} obs. (expected)

CDF analysis uses 3.6 fb^{-1}

Results at 160: 6.4 (7.2) xσ_{SM} obs. (expected)



CDF H → WW* Limits



Combined analyses (opposite sign dileptons and same sign dilepton analysis) into one result

At M_H = 165,

Exp limit - 1.5xσ_{SM}

Obs limit- 1.3xσ_{SM}

Use latest theoretical inputs including:

σ(gg→H) by C. Anastasiou, R. Boughezal & F. Petriello - and de Florian & Grazzini w/ MSTW 2008 NNLO PDF set

Method for Combination

At Tevatron: **High background (BG) and sizable systematic uncertainties**
→ Test **BG(b)** only and **BG+signal (s+b)** hypotheses
using **Poisson statistics accounting for systematic uncertainties.**

- We use two methods
  - Bayesian method (CDF) : Bayesian integration over likelihoods

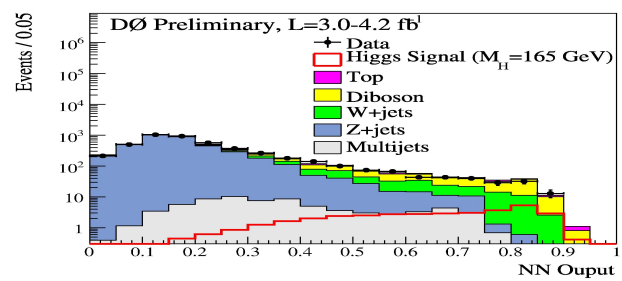
$$\mathcal{L}(R,\vec{s},\vec{b}|\vec{n},\vec{\theta}) \times \pi(\vec{\theta}) = \prod_{i=1}^{N_C}\prod_{j=1}^{Nbins} \mu_{ij}^{n_{ij}} e^{-\mu_{ij}}/n_{ij}! \times \prod_{k=1}^{n_{np}} e^{-\theta_k^2/2}$$

  - Modified Frequentist method, CLs (DØ)

$$LLR = -2\ln\frac{p(\text{data}|H_1)}{p(\text{data}|H_0)}, \quad CL_b = p(LLR \geq LLR_{obs}|H_0) \quad CL_{s+b} = p(LLR \geq LLR_{obs}|H_1) \quad CL_s = \frac{CL_{s+b}}{CL_b}$$

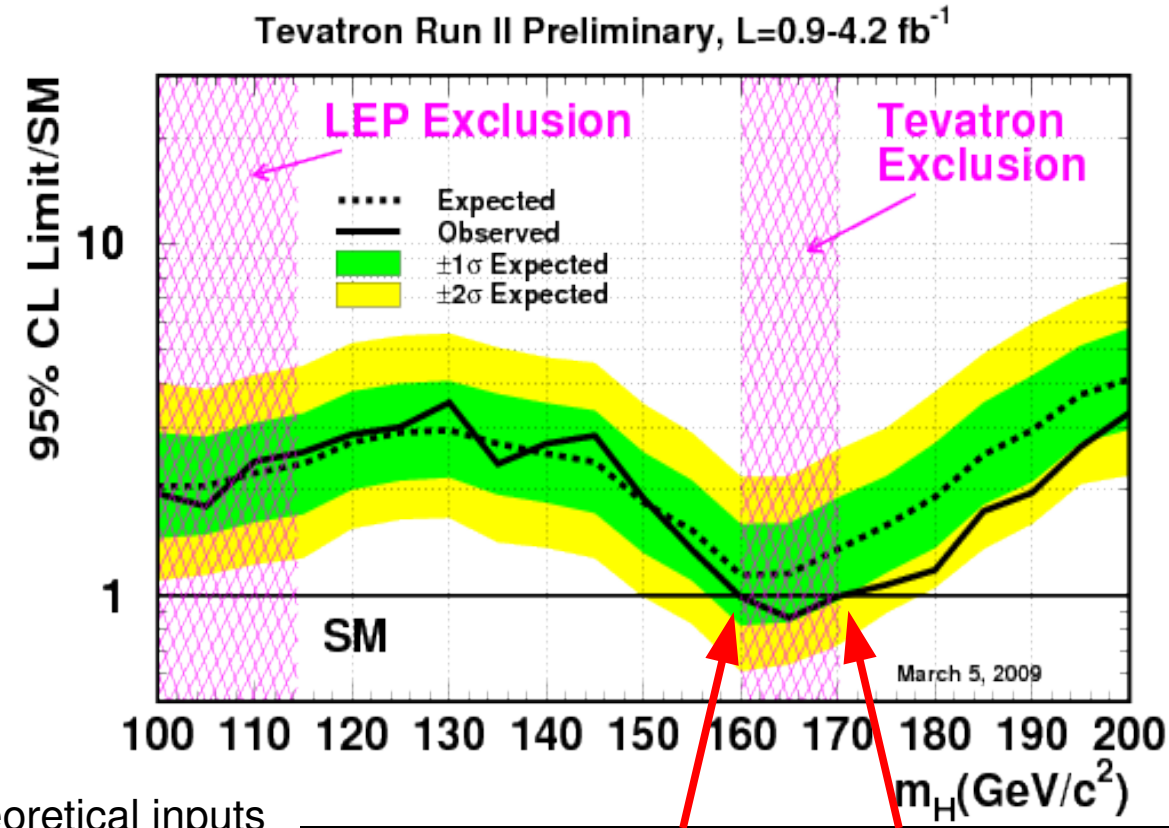
- Both methods use differential distributions, not only integrated yields.

DØ H→WW*



There are 6 inputs from CDF and 4 inputs from DØ, they are orthogonal inputs.

Tevatron Combination

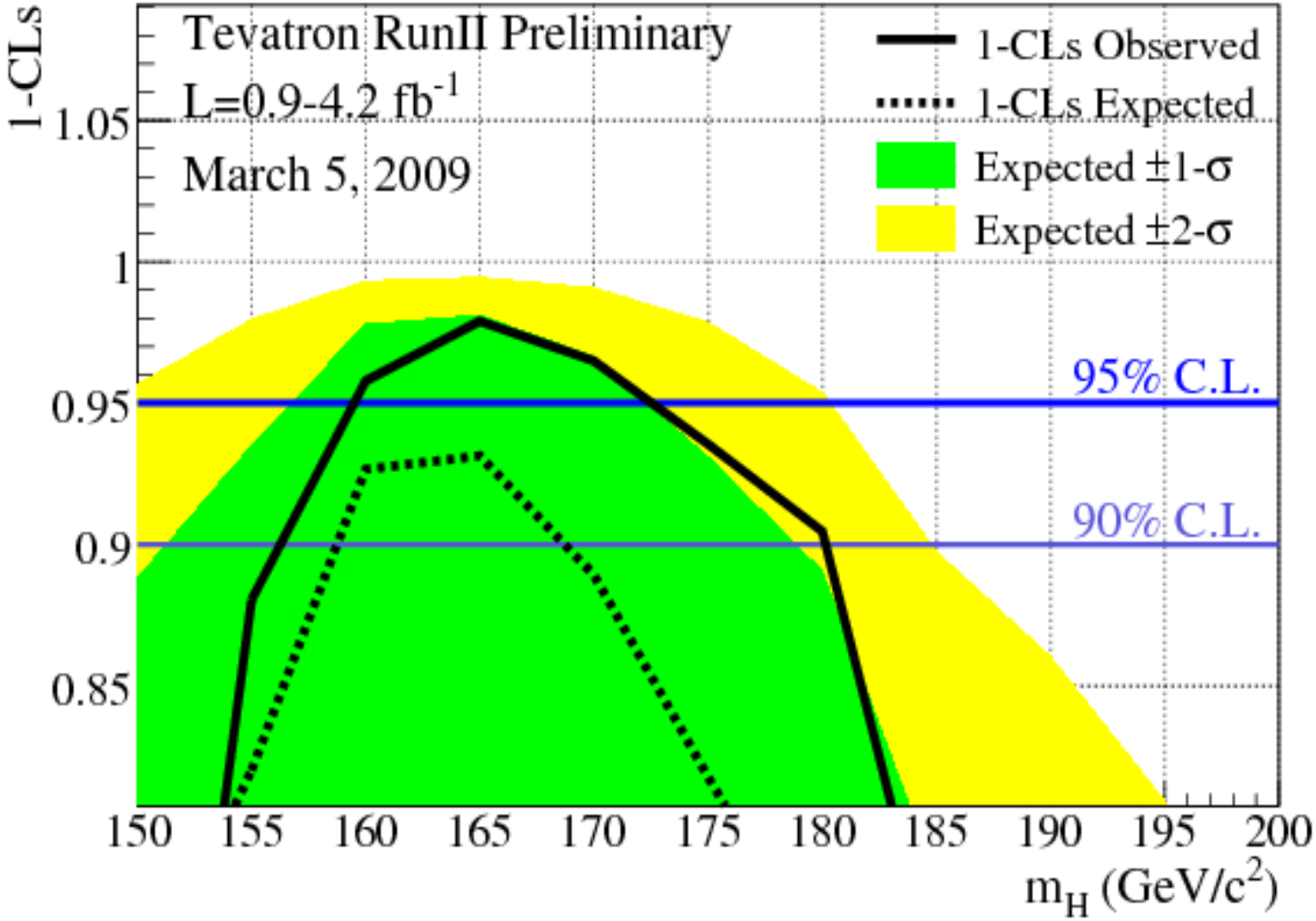


LEP Exclusion: M_H < 114.4 GeV/c^2 @ 95% CL

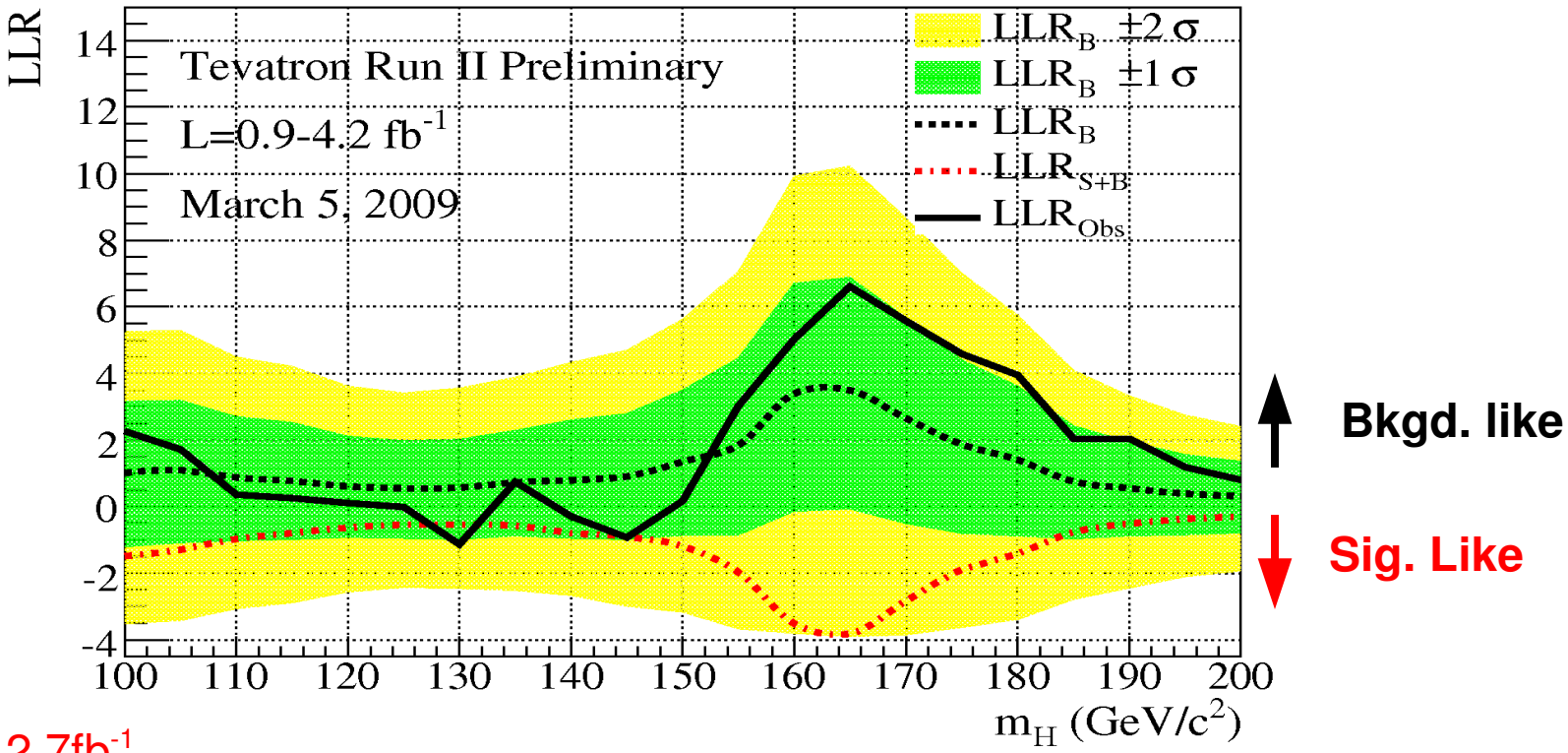
Use latest theoretical inputs including:
σ(gg→H) by C. Anastasiou, R. Boughezal & F. Petriello; and de Florian & Grazzini w/ MSTW 2008 NNLO PDF set

Bayesian	155	160	165	170	175	180	185	190	195	200
Expected	1.5	1.1	1.1	1.4	1.6	1.9	2.2	2.7	3.5	4.2
Observed	1.4	0.99	0.86	0.99	1.1	1.2	1.7	2.0	2.6	3.3
Cls	155	160	165	170	175	180	185	190	195	200
Expected	1.5	1.1	1.1	1.3	1.6	1.8	2.5	3.0	3.5	3.9
Observed	1.3	0.95	0.81	0.92	1.1	1.3	1.9	2.0	2.8	3.3

Tevatron Combination



Low Mass Tevatron Combination



$\int \mathcal{L}$ 0.9 – 2.7fb^{-1}

($H \rightarrow \gamma\gamma$ 4.2 fb^{-1})

M_H=115 obs – 2.5xσ_{SM}

expected – 2.4xσ_{SM}

exp < 3.0xσ_{SM}

(100 $\leq M_H \leq$ 150 GeV/c^2)

Bayesian	100	105	110	**115**	120	125	130	135	140	145	150
Expected	2.0	2.0	2.2	2.4	2.7	2.9	2.9	2.7	2.5	2.4	1.8
Observed	1.9	1.8	2.4	**2.5**	2.8	3.0	3.5	2.4	2.7	2.8	1.9
Cls	100	105	110	**115**	120	125	130	135	140	145	150
Expected	1.9	1.9	2.1	2.4	2.6	2.7	2.9	2.7	2.5	2.2	1.8
Observed	1.7	1.7	2.2	**2.6**	2.8	2.9	4.0	2.6	3.1	2.8	2.0

Summary

- Using combined CDF and D0 results -
  - SM Higgs is excluded with the mass range

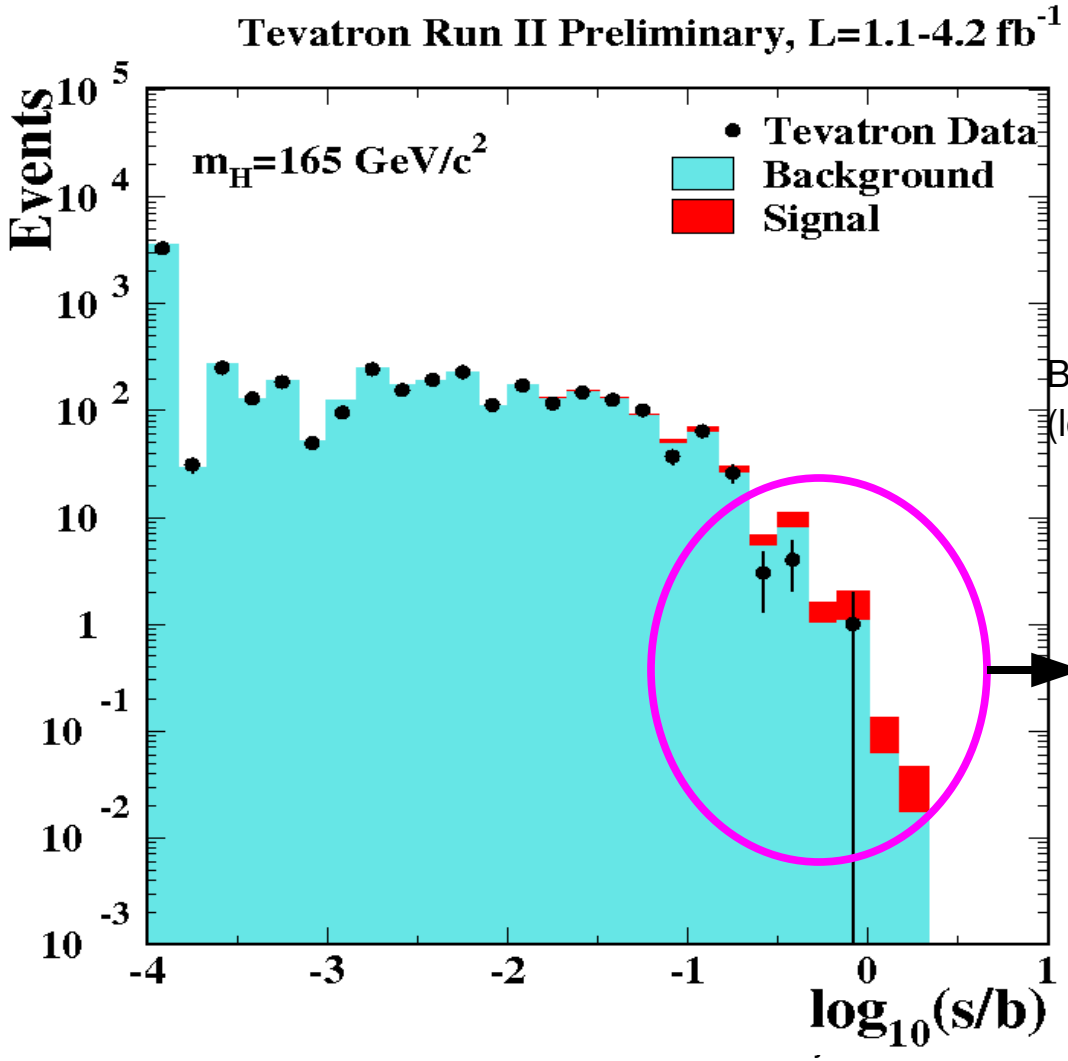
$$160 – 170\ \mathrm{GeV}/c^2\ @\ 95\%\ \mathrm{CL}$$

http://tevnphwg.fnal.gov/results/SM_Higgs_Winter_09/

- Tevatron making great strides in high mass Higgs searches
  - The machine continues to work well (Thanks to the Accelerator Division personnel)
  - Sensitivity continues to improve faster than luminosity scaling
  - Rapid incorporation of new data and analysis improvements
- Papers are in progress for both experiments
- *Look forward to seeing the first LHC results in this mass range in 2010*

Backup Slides

Tevatron Sensitivity at M_H = 165 GeV/c^2



Bin Center (log10(s/b))	Signal	Bkgd	S/B	Observed Data
-0.583	1.38	5.38	**0.26**	3
-0.417	3.14	7.84	**0.40**	4
-0.250	0.60	0.99	**0.61**	0
-0.083	0.92	1.07	**0.86**	1
0.083	0.073	0.060	**1.22**	0
0.250	0.028	0.017	**1.66**	0

S/B ranges ~ 1:4 to ~ 1.6 : 1
last 6 bins
(most sensitive for limit)

Standard Model and the Higgs

Standard Model needs Higgs or Higgs-like mechanism to:

Explain electroweak symmetry breaking

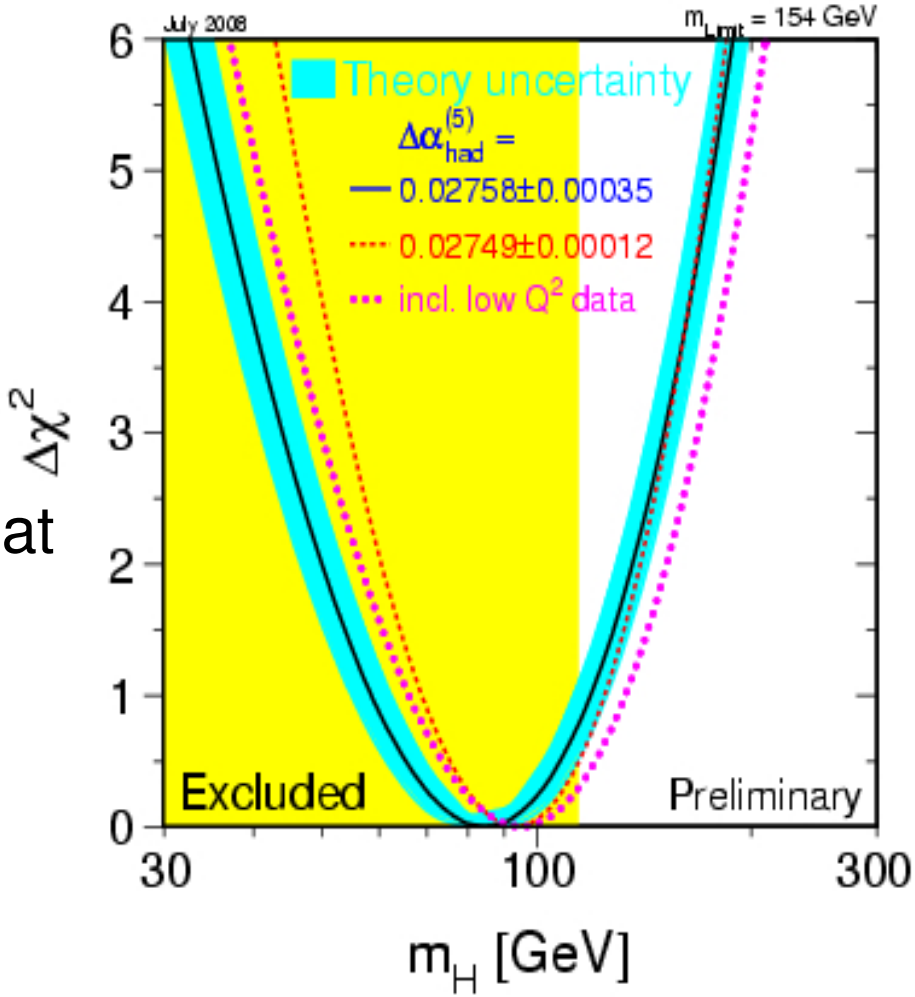
Give particles mass

Direct Higgs searches at LEP

Exclude Higgs of M_H < 114.4 GeV at 95% C.L.

Indirect constraints from electroweak data prefer lighter Higgs (M_H < 154 GeV)

Combined with LEP results upper limit of M_H < 185 GeV

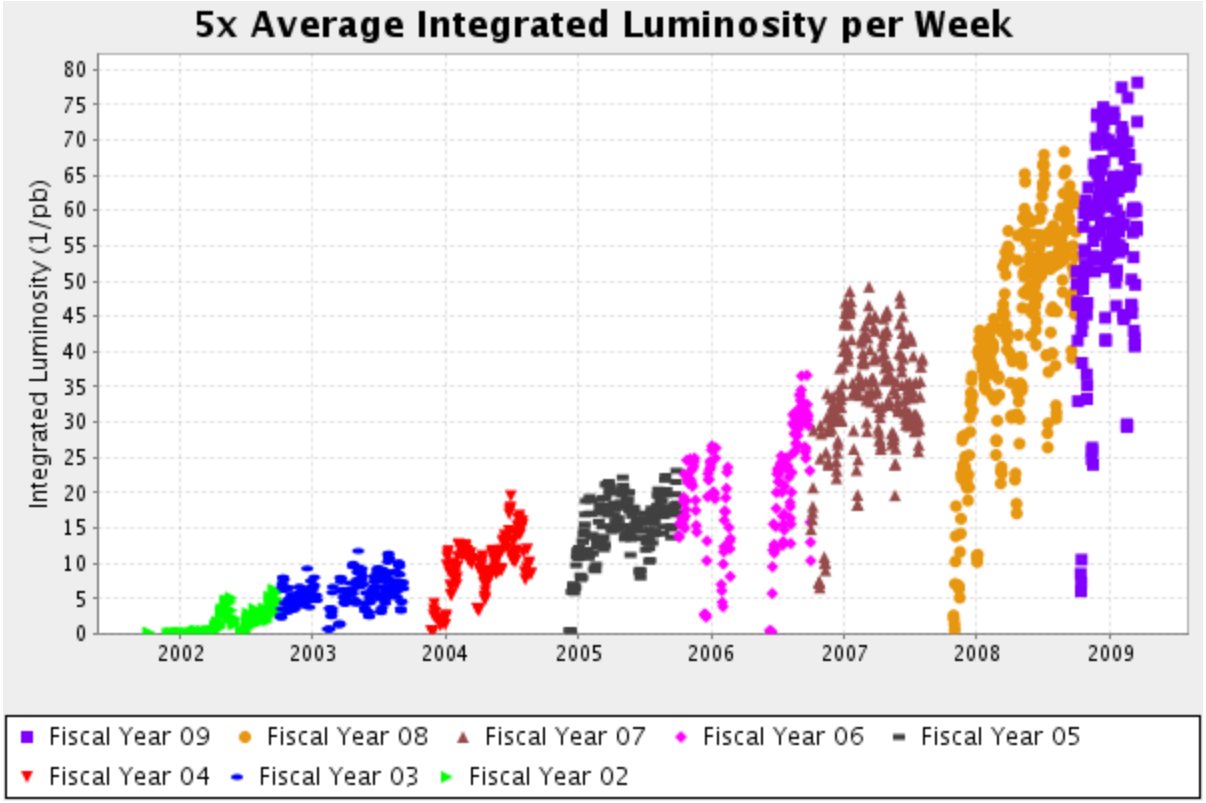


Plot from LEP EWK Working Group

Tevatron Performance

Collide pp at $\sqrt{s}$ = 1.96 TeV

Integrated over 250 pb^{-1} of data in January 2009



5 week running average of Tevatron weekly integrated luminosity by US Fiscal Year (improving steadily)

H → WW* limits

- uses same theoretical s as presented at ICHEP08

OS+SS	110	120	130	140	145	150	155	160	165	170	175	180	190	200
$-2\sigma/\sigma_{SM}$	16.26	5.45	2.62	1.71	1.44	1.23	1.00	0.75	0.74	0.85	1.00	1.17	1.82	2.39
$-1\sigma/\sigma_{SM}$	22.78	7.43	3.69	2.35	2.01	1.71	1.38	1.03	1.02	1.16	1.39	1.60	2.53	3.36
Median/$\sigma_{\mathbf{SM}}$	**32.40**	**10.79**	**5.31**	**3.36**	**2.92**	**2.44**	**1.97**	**1.47**	**1.45**	**1.66**	**2.00**	**2.31**	**3.65**	**4.89**
$+1\sigma/\sigma_{SM}$	47.08	15.64	7.66	4.86	4.20	3.52	2.87	2.14	2.08	2.38	2.88	3.36	5.33	7.11
$+2\sigma/\sigma_{SM}$	66.21	21.71	10.63	6.91	5.89	4.96	4.03	2.96	2.95	3.36	4.09	4.76	7.49	10.08
Observed/$\sigma_{\mathbf{SM}}$	**52.20**	**12.58**	**5.88**	**3.56**	**3.11**	**2.31**	**1.91**	**1.37**	**1.29**	**1.67**	**2.01**	**2.03**	**3.59**	**5.94**

Uses revised σ (gg→ H) Florian *et* Grazzini (arXiv:0901.2427)

OS All Jets	110	120	130	140	145	150	155	160	165	170	175	180	190	200
$-2\sigma/\sigma_{SM}$	18.09	5.89	2.85	1.79	1.56	1.31	1.06	0.79	0.78	0.89	1.08	1.25	2.01	2.73
$-1\sigma/\sigma_{SM}$	24.60	8.14	3.97	2.48	2.16	1.80	1.47	1.08	1.05	1.21	1.48	1.71	2.79	3.79
Median/$\sigma_{\mathbf{SM}}$	**35.10**	**11.57**	**5.66**	**3.58**	**3.10**	**2.55**	**2.08**	**1.53**	**1.49**	**1.73**	**2.11**	**2.45**	**3.99**	**5.49**
$+1\sigma/\sigma_{SM}$	50.53	16.38	8.11	5.14	4.46	3.67	3.01	2.20	2.13	2.48	3.08	3.54	5.80	7.95
$+2\sigma/\sigma_{SM}$	70.50	23.09	11.39	7.23	6.36	5.15	4.24	3.09	3.02	3.52	4.39	4.98	8.05	11.23
Observed/$\sigma_{\mathbf{SM}}$	**55.81**	**13.22**	**5.90**	**3.97**	**3.12**	**2.54**	**2.19**	**1.48**	**1.48**	**1.88**	**2.41**	**2.36**	**4.69**	**7.64**

- uses same theoretical s as presented at ICHEP08

CDF Run II Preliminary	$\int \mathcal{L} = 3.6\ \mathrm{fb}^{-1}$		
$M_H = 160\ \mathrm{GeV}/c^2$			
$t\bar{t}$	136	$\pm$	23
DY	210	$\pm$	38
WW	421	$\pm$	46
WZ	38.9	$\pm$	5.3
ZZ	29.2	$\pm$	4.0
W+jets	189	$\pm$	48
$W\gamma$	110	$\pm$	29
Total Background	1134	$\pm$	110
$gg \to H$	15.9	$\pm$	2.3
WH	3.24	$\pm$	0.42
ZH	1.13	$\pm$	0.15
VBF	1.08	$\pm$	0.17
Total Signal	21.4	$\pm$	2.5
Data	1126		

OS+SS

Uses revised σ (gg→ H)

C. Anastasiou, R. Boughezal & F. Petriello - (arXiv:0811.3458)

Florian *et* Grazzini (arXiv:0901.2427)

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OS+SS

H→WW* Systematics

Systematic uncertainties on the contributions for DØ's $H \to WW \to \ell^{\pm}\ell'^{\mp}$ channels. Systematic uncertainties are listed by name, see the original references for a detailed explanation of their meaning and on how they are derived. Systematic uncertainties shown in this table are obtained for the $m_H = 165$ GeV/c^2 Higgs selection. Uncertainties are relative, in percent and are symmetric unless otherwise indicated.

H→WW*→$e^{\pm}e^{\mp}$

Contribution	Diboson	$Z/\gamma^* \to \ell\ell$	$W + jet/\gamma$	$t\bar{t}$	Multijet	H
Lepton ID	3	3	3	3	–	3
Momentum resolution	1	1	1	1	–	1
Jet Energy Scale	5	2	0	5	–	3
Jet identification	5	1	0	5	–	3
Cross Section/normalization	6	6	13	10	2	6
Modeling	3	5	0	0	0	3

H→WW* Systematics

Systematic uncertainties on the contributions for DØ's $H \to WW \to \ell^{\pm}\ell'^{\mp}$ channels. Systematic uncertainties are listed by name, see the original references for a detailed explanation of their meaning and on how they are derived. Systematic uncertainties shown in this table are obtained for the $m_H = 165$ GeV/c^2 Higgs selection. Uncertainties are relative, in percent and are symmetric unless otherwise indicated.

H→WW*→$e^{\pm}\mu^{\mp}$

Contribution	Diboson	$Z/\gamma^* \to \ell\ell$	$W + jet/\gamma$	$t\bar{t}$	Multijet	H
Lepton ID	1	1	1	1	–	1
Momentum resolution	1	4	1	0	–	1
Jet Energy Scale	2	2	3	5	–	3
Jet identification	0	4	1	4	–	1
Cross Section/normalization	6	6	13	10	13	6
Modeling	1	3	0	0	0	2

H→WW*→$\mu^{\pm}\mu^{\mp}$

Contribution	Diboson	$Z/\gamma^* \to \ell\ell$	$W + jet/\gamma$	$t\bar{t}$	Multijet	H
trigger	2	2	2	2	–	2
Lepton ID	3	3	3	3	–	3
Momentum resolution	2	2	2	2	–	2
Jet Energy Scale	5	2	0	5	–	3
Cross Section/normalization	6	6	13	10	2	6
Modeling	3	5	0	0	0	3

WH→WWW→$l^{\pm}$ $l^{\pm}$ +X (same sign) Systematics

Systematic uncertainties on the contributions for DØ's $WH \rightarrow WWW \rightarrow \ell'^{\pm}\ell'^{\pm}$ channel. Systematic uncertainties are listed by name, see the original references for a detailed explanation of their meaning and on how they are derived. Systematic uncertainties for WH shown in this table are obtained for $m_H = 165$ GeV/c^2. Uncertainties are relative, in percent and are symmetric unless otherwise indicated.

Contribution	WZ/ZZ	Charge flips	Multijet	WH
Luminosity	6	0	0	6
Trigger eff.	5	0	0	5
Lepton ID/Reco. eff	10	0	0	10
Cross Section	7	0	0	6
Normalization	6	0	0	0
Instrumental-ee (ee final state)	0	32	15	0
Instrumental-$e\mu$ ($e\mu$ final state)	0	0	18	0
Instrumental-$\mu\mu$ ($\mu\mu$ final state)	0	$^{+290}_{-100}$	32	0

H→WW* Systematics (0 jets)

Systematic uncertainties on the contributions for CDF's $H \to W^+W^- \to \ell^\pm\ell'^\mp$ channels with zero, one, and two or more associated jets. These channels are sensitive to WH, ZH or VBF signals. Systematic uncertainties are listed by name, see the original references for a detailed explanation of their meaning and on how they are derived. Systematic uncertainties for H shown in this table are obtained for $m_H = 165$ GeV/c^2. Uncertainties are relative, in percent and are symmetric unless otherwise indicated. Uncertainties in bold are correlated across jet bins but not across channels. Uncertainties in italics are correlated across jet bins and across appropriate channels. Monte Carlo statistical uncertainties in each bin of each template are considered as independent systematic uncertainties.

Uncertainty Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet(s)	$gg \to H$
Cross Section	*6.0*	*6.0*	*6.0*	*10.0*	5.0	*10.0*		*12.0*
Scale (leptons)								2.5
Scale (jets)								4.6
PDF Model (leptons)	1.9	2.7	2.7	2.1	4.1	2.2		1.5
PDF Model (jets)								0.9
Higher-order Diagrams	**5.5**	**10.0**	**10.0**	10.0	**5.0**	**10.0**		
Missing Et Modeling	1.0	1.0	1.0	1.0	21.0	1.0		1.0
Conversion Modeling						20.0		
Jet Fake Rates (Low/High S/B)							21.5/27.7	
$W\gamma$+jet modeling						*4.0*		
Lepton ID Efficiencies	2.0	1.7	2.0	2.0	1.9	1.4		1.9
Trigger Efficiencies	2.1	2.1	2.1	2.0	3.4	7.0		3.3
Luminosity	3.8	3.8	3.8	3.8	3.8	3.8		3.8
Luminosity Monitor	4.4	4.4	4.4	4.4	4.4	4.4		4.4

H→WW* Systematics (1 jet)

Systematic uncertainties on the contributions for CDF's $H \to W^+W^- \to \ell^\pm\ell'^\mp$ channels with zero, one, and two or more associated jets. These channels are sensitive to WH, ZH or VBF signals. Systematic uncertainties are listed by name, see the original references for a detailed explanation of their meaning and on how they are derived. Systematic uncertainties for H shown in this table are obtained for $m_H = 165$ GeV/c^2. Uncertainties are relative, in percent and are symmetric unless otherwise indicated. Uncertainties in bold are correlated across jet bins but not across channels. Uncertainties in italics are correlated across jet bins and across appropriate channels. Monte Carlo statistical uncertainties in each bin of each template are considered as independent systematic uncertainties.

Uncertainty Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet(s)	$gg \to H$	WH	ZH	VBF
Cross Section	*6.0*	*6.0*	*6.0*	*10.0*	5.0	*10.0*		*12.0*	*5.0*	*5.0*	*10.0*
Scale (leptons)								2.8			
Scale (jets)								-5.1			
PDF Model (leptons)	1.9	2.7	2.7	2.1	4.1	2.2		1.7	1.2	0.9	2.2
PDF Model (jets)								-1.9			
Higher-order Diagrams	**5.5**	**10.0**	**10.0**	10.0	**5.0**	**10.0**			*10.0*	*10.0*	*10.0*
Missing Et Modeling	1.0	1.0	1.0	1.0	30.0	1.0		1.0	1.0	1.0	1.0
Conversion Modeling						20.0					
Jet Fake Rates (Low/High S/B)							22.2/31.5				
$W\gamma$+jet modeling						*15.0*					
MC Run Dependence	1.8			2.2		2.2		2.6	2.6	1.9	2.8
Lepton ID Efficiencies	2.0	2.0	2.2	1.8	2.0	2.0		1.9	1.9	1.9	1.9
Trigger Efficiencies	2.1	2.1	2.1	2.0	3.4	7.0		3.3	2.1	2.1	3.3
Luminosity	3.8	3.8	3.8	3.8	3.8	3.8		3.8	3.8	3.8	3.8
Luminosity Monitor	4.4	4.4	4.4	4.4	4.4	4.4		4.4	4.4	4.4	4.4

H→WW* Systematics (2+ jets)

Systematic uncertainties on the contributions for CDF's $H \to W^+W^- \to \ell^\pm\ell'^\mp$ channels with zero, one, and two or more associated jets. These channels are sensitive to WH, ZH or VBF signals. Systematic uncertainties are listed by name, see the original references for a detailed explanation of their meaning and on how they are derived. Systematic uncertainties for H shown in this table are obtained for $m_H = 165$ GeV/c^2. Uncertainties are relative, in percent and are symmetric unless otherwise indicated. Uncertainties in bold are correlated across jet bins but not across channels. Uncertainties in italics are correlated across jet bins and across appropriate channels. Monte Carlo statistical uncertainties in each bin of each template are considered as independent systematic uncertainties.

Uncertainty Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet(s)	$gg \to H$	WH	ZH	VBF
Cross Section	*6.0*	*6.0*	*6.0*	*10.0*	5.0	*10.0*		*12.0*	*5.0*	*5.0*	*10.0*
Scale (leptons)								3.1			
Scale (jets)								-8.7			
PDF Model (leptons)	1.9	2.7	2.7	2.1	4.1	2.2		2.0	1.2	0.9	2.2
PDF Model (jets)								-2.8			
Higher-order Diagrams	**10.0**	**10.0**	**10.0**	10.0	**10.0**	**10.0**			*10.0*	*10.0*	*10.0*
Missing Et Modeling	1.0	1.0	1.0	1.0	32.0	1.0		1.0	1.0	1.0	1.0
Conversion Modeling						20.0					
b-tag Veto				7.0							
Jet Fake Rates							27.1				
$W\gamma$+jet modeling						*20.0*					
MC Run Dependence	1.0			1.0		1.0		1.7	2.0	1.9	2.6
Lepton ID Efficiencies	1.9	2.9	1.9	1.9	1.9	1.9		1.9	1.9	1.9	1.9
Trigger Efficiencies	2.1	2.1	2.1	2.0	3.4	7.0		3.3	2.1	2.1	3.3
Luminosity	3.8	3.8	3.8	3.8	3.8	3.8		3.8	3.8	3.8	3.8
Luminosity Monitor	4.4	4.4	4.4	4.4	4.4	4.4		4.4	4.4	4.4	4.4

WH→WWW→$l^{\pm}$ $l^{\pm}$ +X (same sign) Systematics

Systematic uncertainties on the contributions for CDF's $WH \rightarrow WWW \rightarrow \ell'^{\pm}\ell'^{\pm}$ channel. Systematic uncertainties are listed by name, see the original references for a detailed explanation of their meaning and on how they are derived. Systematic uncertainties for ZH, WH shown in this table are obtained for $m_H = 165$ GeV/c^2. Uncertainties are relative, in percent and are symmetric unless otherwise indicated. Uncertainties in bold are correlated across jet bins but not across channels. Uncertainties in italics are correlated across jet bins and across appropriate channels. Monte Carlo statistical uncertainties in each bin of each template are considered as independent systematic uncertainties.

Uncertainty Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet(s)	WH	ZH
Cross Section	*6.0*	*6.0*	*6.0*	*10.0*	5.0	*10.0*		*5.0*	*5.0*
PDF Model (leptons)	1.9	2.7	2.7	2.1	4.1	2.2		1.2	0.9
PDF Model (jets)									
Higher-order Diagrams	**10.0**	**10.0**	**10.0**	10.0	**10.0**	**10.0**		*10.0*	*10.0*
Missing Et Modeling	1.0	1.0	1.0	1.0	20.0	1.0		1.0	1.0
Conversion Modeling						20.0			
$W\gamma$+jet modeling						*16.0*			
Jet Fake Rates							30.0		
Charge Misassignment	16.5			16.5	16.5				
MC Run Dependence	1.9			1.0		2.4			
Lepton ID Efficiencies	1.9	2.9	1.9	1.9	1.9	1.9		1.9	1.9
Trigger Efficiencies	2.1	2.1	2.1	2.0	3.4	7.0		2.1	2.1
Luminosity	3.8	3.8	3.8	3.8	3.8	3.8		3.8	3.8
Luminosity Monitor	4.4	4.4	4.4	4.4	4.4	4.4		4.4	4.4