High Mass Higgs at the Tevatron

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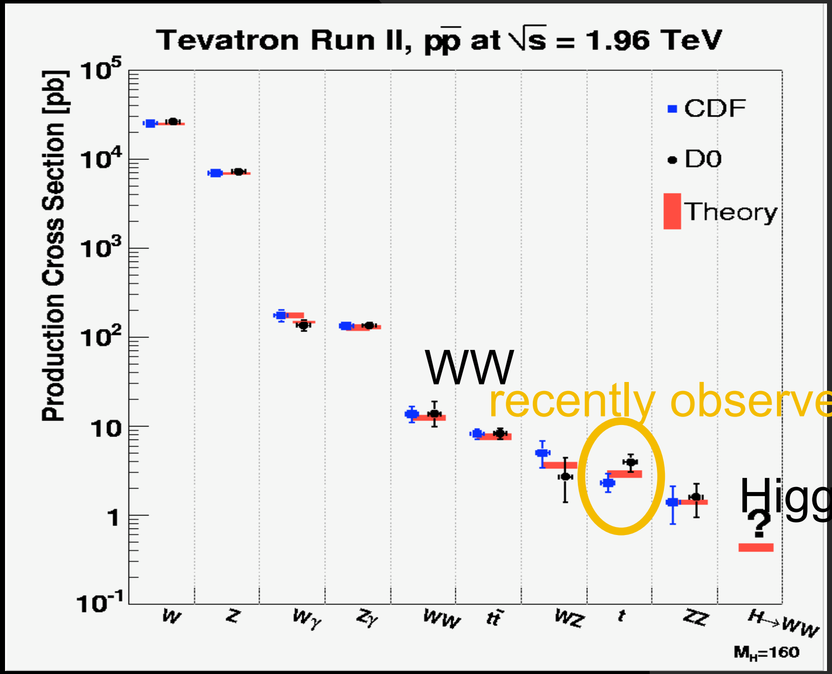
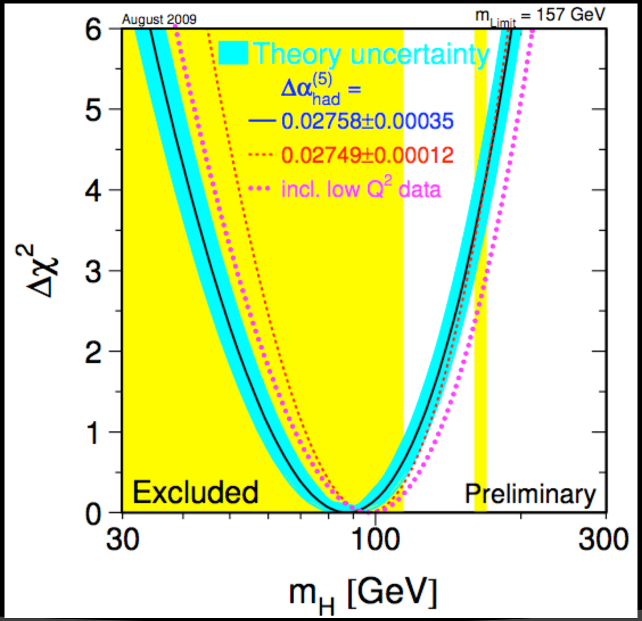
(FNAL)
On behalf of CDF and D0 collaborations

- Tevatron experiments probe production processes covering many orders of magnitude in cross section
- Many discoveries

  WZ, ZZ, single top
- Now reached sub-pb x-section sensitivity
- Looking for Standard Model Higgs as well as new physics beyond SM





Higgs:

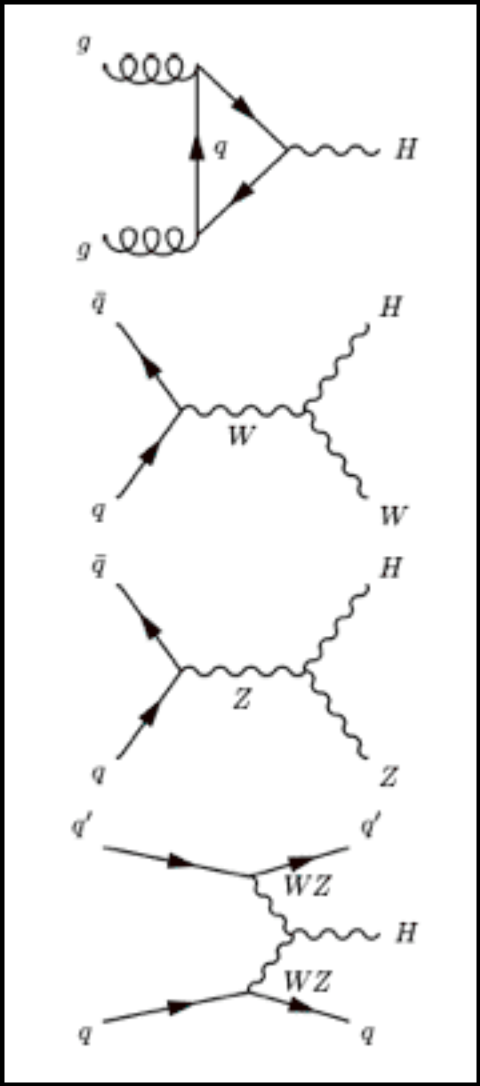
Direct search at LEP:

m_H>114 GeV @ 95%CL

Including indirect electroweak constraints

m_H<185 GeV @ 95%CL

SM Higgs at the Tevatron



@Mh=160 GeV

ggH (78 %)

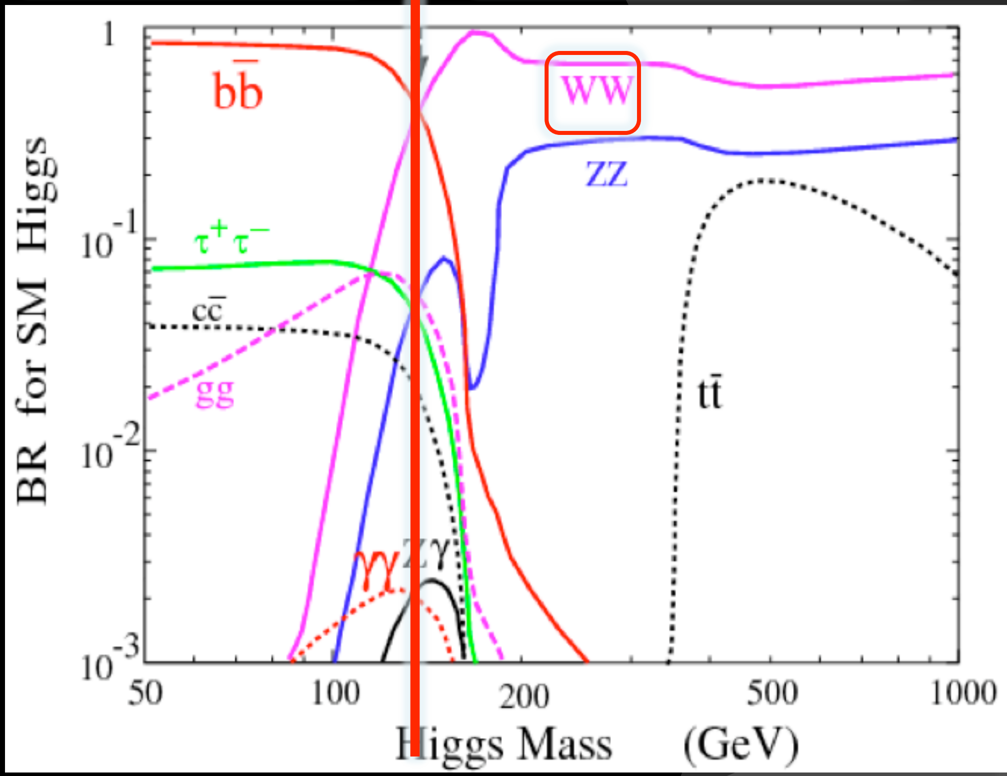
WH (9 %)

ZH (6 %)

VBF (7 %)

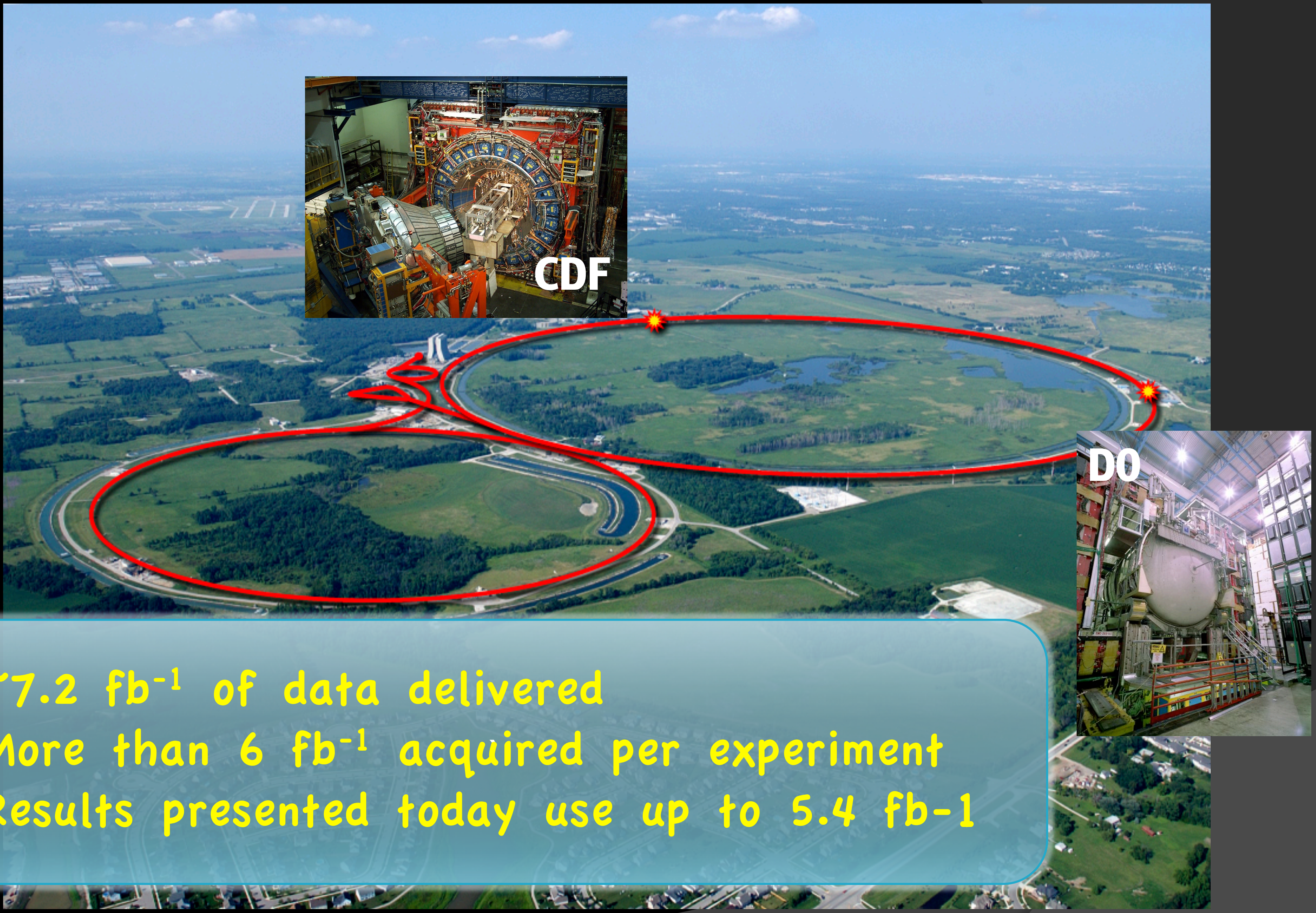
Low Mass

High Mass



- WW dominates at M_H > 135 GeV
- Contributes to Higgs searches down to 120 GeV/c^2

Tevatron, CDF, D0

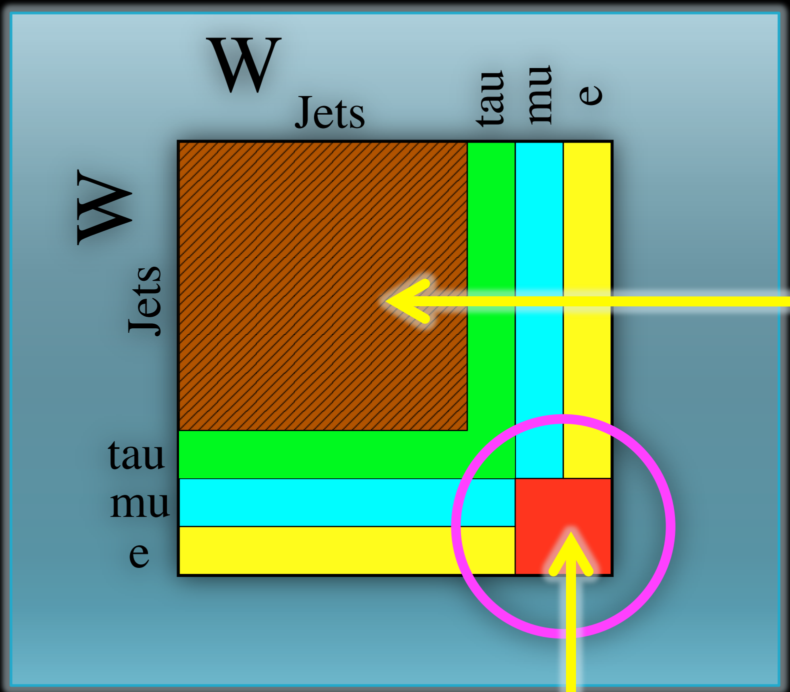


~7.2 fb^{-1} of data delivered

More than 6 fb^{-1} acquired per experiment

Results presented today use up to 5.4 fb-1

H→WW Final States



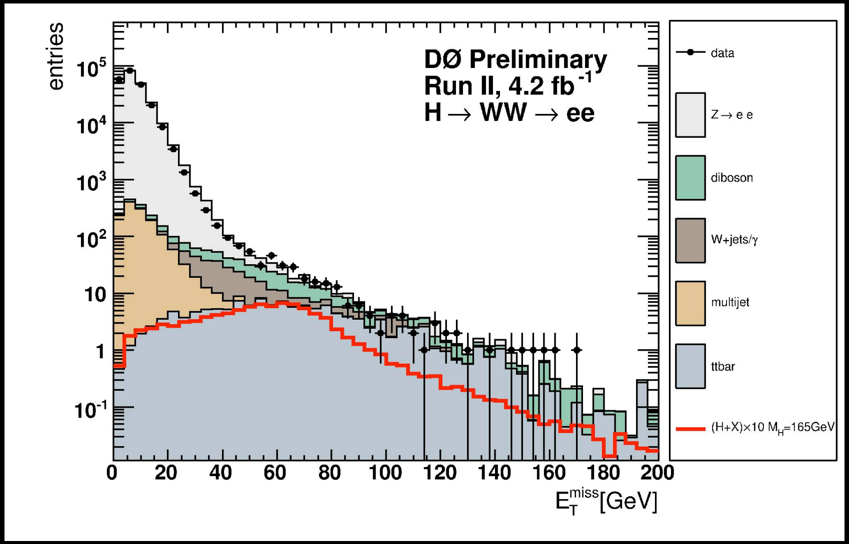
BR(W→hadrons)~68%
But large QCD background
Not used now

We select both W decaying leptonically:

- BR(WW→ee,μμ,eμ)~6%
- Easy and clean triggers on single electron or muon
- Partially includes τ's

Physics Backgrounds

- Z->ll is the largest background but suppressed by requiring large missing E_T:



- After the suppression, the main backgrounds are:
  - Diboson production – WW, WZ, ZZ
  - W+jets where a jet fakes a lepton
  - W+γ where the photon fakes a lepton
  - tt and single top

Modeling:

WW
MC@NLO at CDF
Pythia/MC@NLO at D0

Z->ll
Pythia at CDF
Alpgen at D0

W+jets
data-driven at CDF
Aplgen at D0

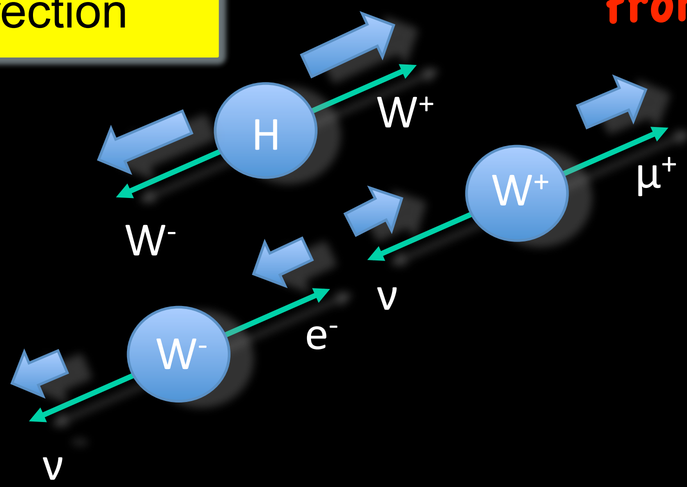
W+gamma
Baur at CDF
Pythia at D0

ZZ, WZ, tt, single top & Signal
Pythia

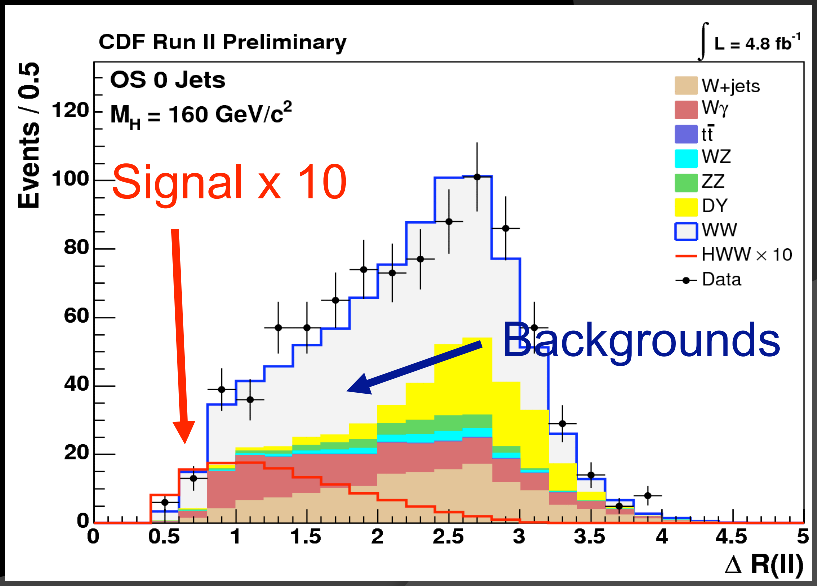
Signature

- Two opposite charge isolated electrons or muons
- Significant missing transverse energy
- Broad invariant mass spectrum

Spin correlation:
Leptons go in the same direction



Main challenge: to distinguish signal from EWK WW pair production:



Dilepton opening angle is the strongest background discriminant

Strategy

- $S/\sqrt{B}$ ~0.6, so simple counting analysis is not enough

- Both experiments use multivariate techniques to discriminate between signal and background:
  - Matrix Element (ME), Neural Networks (NN)
  - Each channel and M_H hypothesis has its own NN

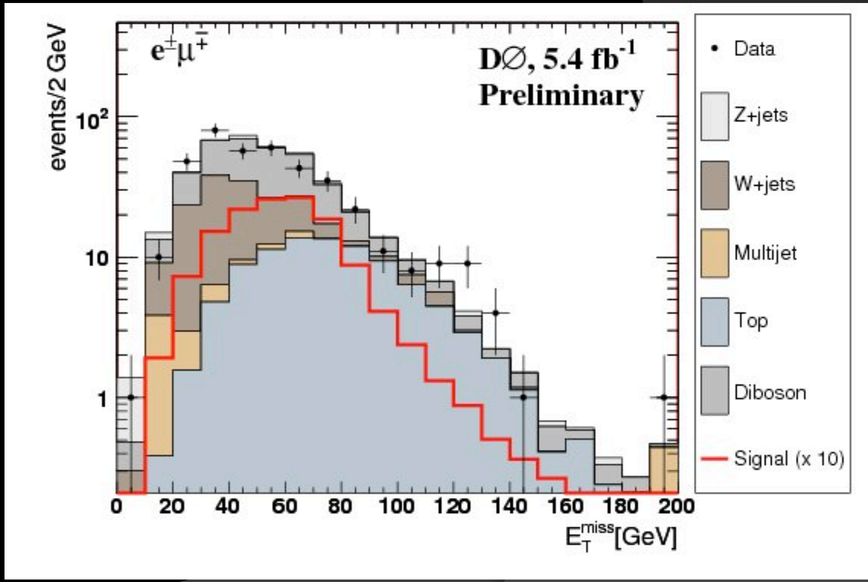
- Separate analysis into channels by S/B ratio and lepton purity
  - CDF – by jet multiplicity: 0, 1 and 2+ jets
  - D0 – by di-lepton flavor: ee, eμ, $\mu\mu$

- Many control regions to verify background modeling
- Several x-section measurements WW, ZZ, single top

D0 WW analysis

- Uses all 4 Higgs production mechanisms
- Two opposite charge leptons with pT:
  (15,15) GeV in ee channel, (15,10) GeV in eμ, and (20,10) in μμ
- Mll >15 GeV and significant missing Et

- Background composition depends on dilepton flavor:
  - electroweak WW in eμ channel



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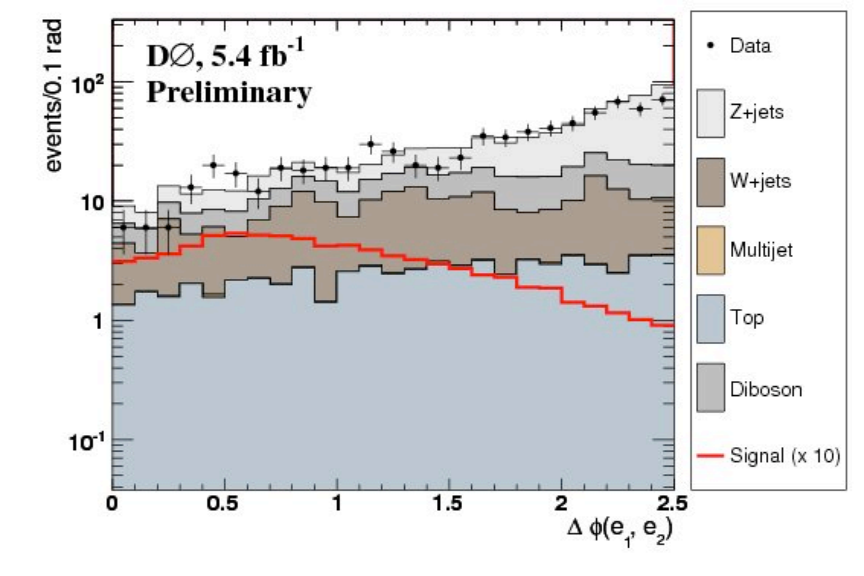


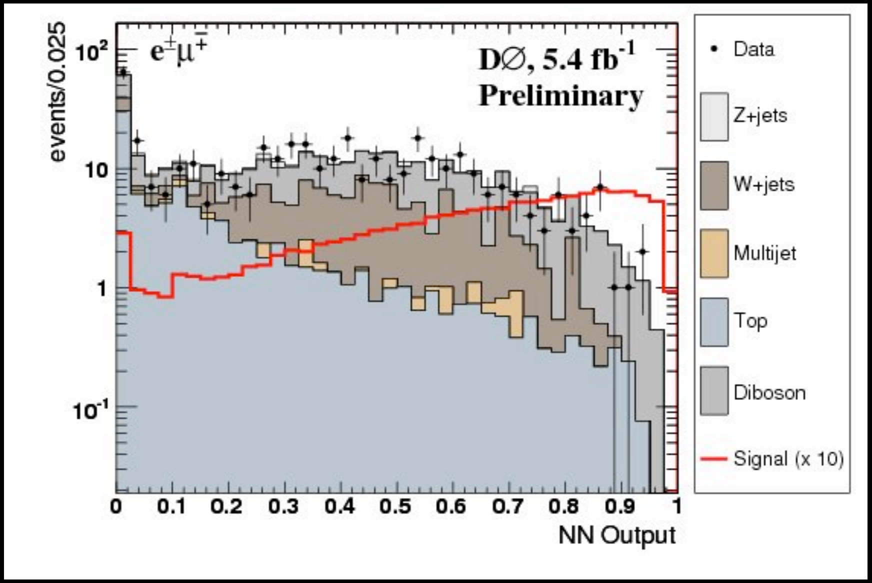
- Background composition depends on dilepton flavor:
  - electroweak WW in eμ channel
  - Z+jets is largest in ee and μμ channels (however it can be easily distinguished by low missing ET), while WW is still most difficult to separate from the signal

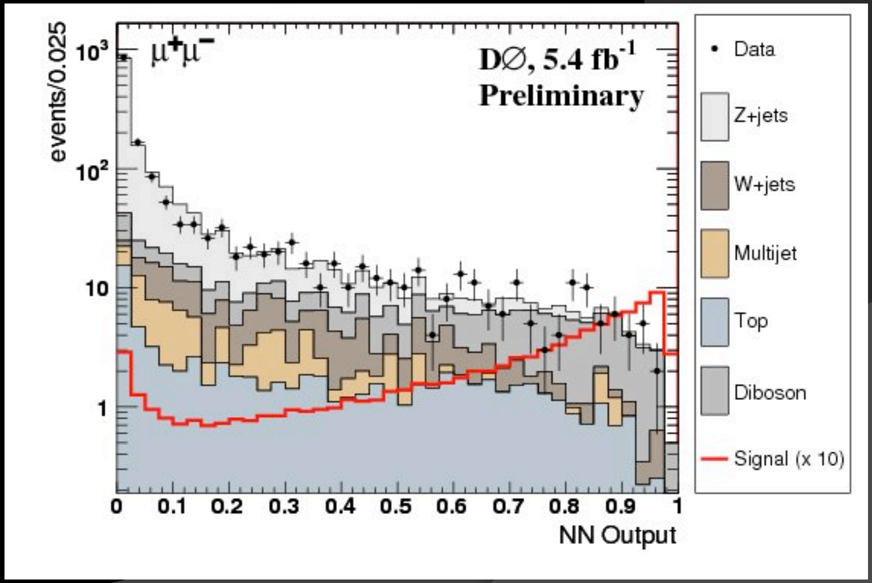
D0 WW analysis

Use Neural Network to further separate signal and background

12 topological and kinematic inputs to the NN, include:

- lepton Pts
- event properties ex. HT
- angular distributions
- N jets





CDF WW analysis

- Leptons with pT 20 and 10 GeV

  Mll >16 GeV and significant missing Et

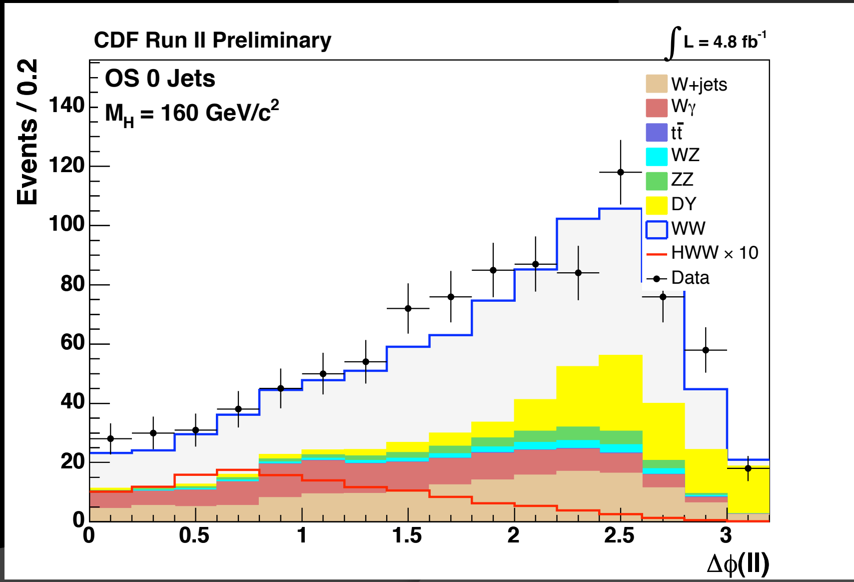
Separate 0, 1 and 2+ jet bins

0 Jets:

- Can make good use of the LO Matrix Element calculations
- Majority of signal from gluon fusion

CDF Run II Preliminary $\int \mathcal{L} = 4.8\ \text{fb}^{-1}$			
$M_H = 165\ \text{GeV}/c^2$			
$t\bar{t}$	1.99	$\pm$	0.31
DY	128	$\pm$	30
WW	447	$\pm$	48
WZ	19.7	$\pm$	2.7
ZZ	29.9	$\pm$	4.1
W+jets	154	$\pm$	37
$W\gamma$	112	$\pm$	19
Total Background	893	$\pm$	79
$gg \to H$	12.6	$\pm$	1.7
WH	0.00	$\pm$	0.00
ZH	0.00	$\pm$	0.00
VBF	0.00	$\pm$	0.00
Total Signal	12.6	$\pm$	1.7
Data		950	

OS 0 Jets



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Separate 0, 1 and 2+ jet bins

0 Jets:

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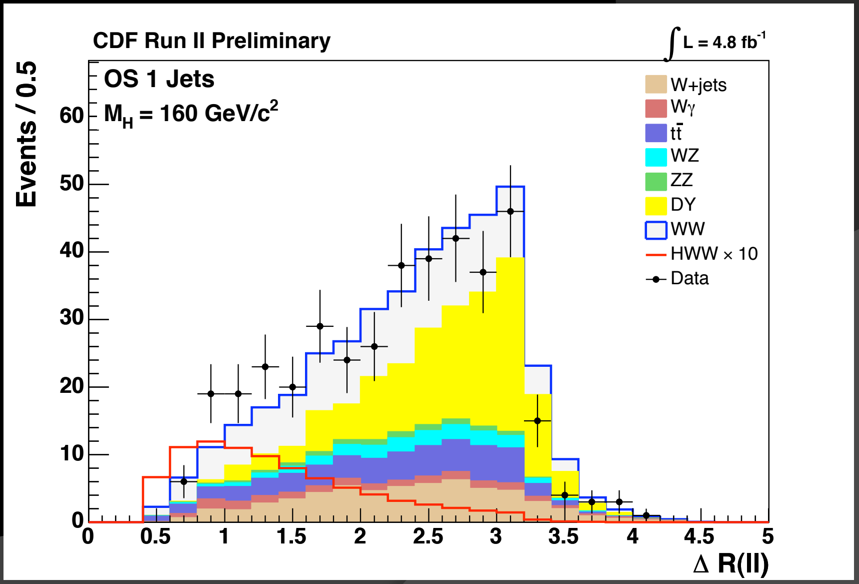
1 Jet:

- ME not so powerful here
- extra signal (VH & VBF) ~20%

CDF Run II Preliminary			$\int \mathcal{L} = 4.8$ fb^{-1}
$M_H = 165$ GeV$/c^2$			
$t\bar{t}$	48.4	±	7.6
DY	133	±	42
WW	121	±	13
WZ	20.0	±	2.7
ZZ	8.0	±	1.1
W+jets	59	±	15
$W\gamma$	16.2	±	3.6
Total Background	406	±	52
$gg \to H$	6.4	±	1.7
WH	0.87	±	0.11
ZH	0.339	±	0.044
VBF	0.565	±	0.090
Total Signal	8.2	±	1.7
Data	393		

OS 1 Jet



CDF WW analysis

- Leptons with pT 20 and 10 GeV

  Mll >16 GeV and significant missing Et

Separate 0, 1 and 2+ jet bins

0 Jets:

- Can make good use of the LO Matrix Element calculations
- Majority of signal from gluon fusion

1 Jet:

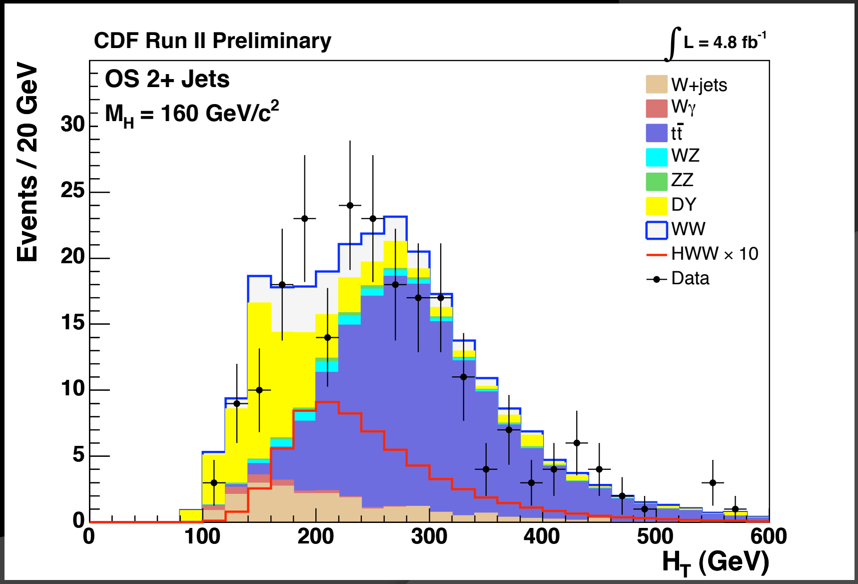
- ME not so powerful here
- extra signal (VH & VBF) ~20%

2+ Jets:

- $t\bar{t}$ is main background
- anti b-tagging helps
- extra signal (VH & VBF) ~60%

CDF Run II Preliminary	$\int \mathcal{L} = 4.8\ \text{fb}^{-1}$		
$M_H = 165\ \text{GeV}/c^2$			
tt	145	$\pm$	24
DY	51	$\pm$	17
WW	25.6	$\pm$	5.8
WZ	5.30	$\pm$	0.73
ZZ	2.36	$\pm$	0.32
W+jets	21.9	$\pm$	5.9
$W\gamma$	2.72	$\pm$	0.67
Total Background	254	$\pm$	33
$gg \to H$	2.5	$\pm$	1.7
WH	1.90	$\pm$	0.25
ZH	0.99	$\pm$	0.13
VBF	1.04	$\pm$	0.17
Total Signal	6.4	$\pm$	1.8
Data	224		

OS 2+ Jets

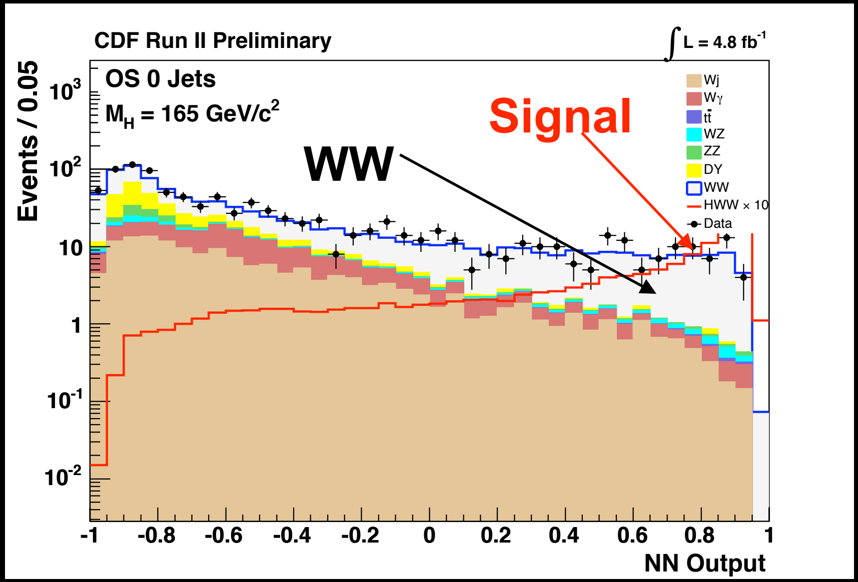


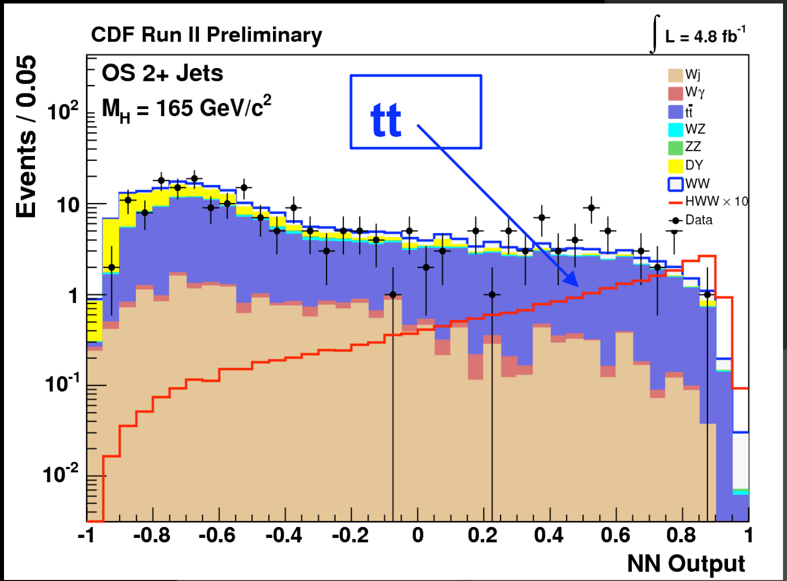
CDF WW analysis

Also uses NN to achieve best discrimination

Input variables analogous to D0

Choice of variables is optimized depending on jet multiplicity to exploit different signal vs background composition



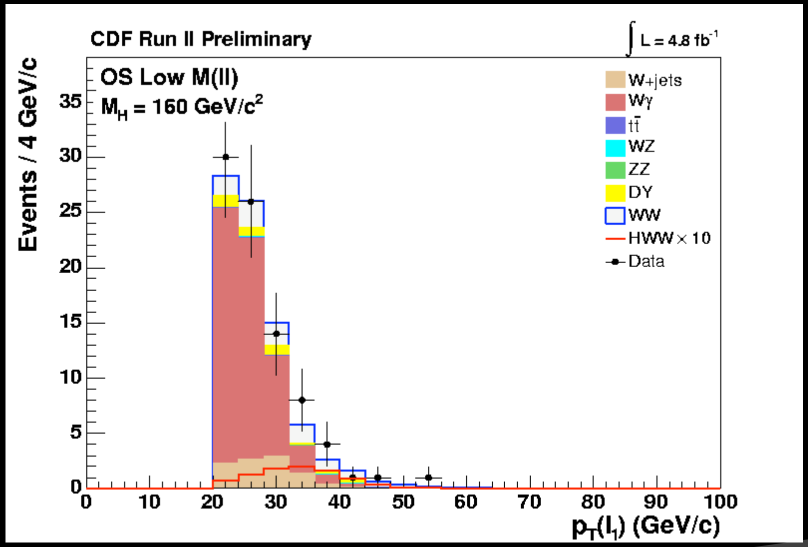


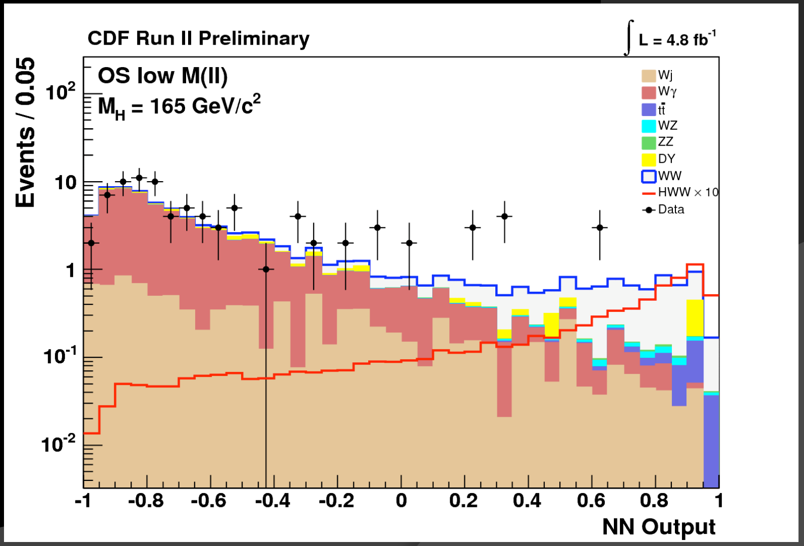
CDF low Mll analysis

- Similar event selection, but Mll<16 GeV/c2
- Different background composition:
  - dominant background W+γ where γ fakes a lepton
- Similar techniques (NN) applied
  - lepton Pt- one of the most powerful variables

CDF Run II Preliminary	$\int \mathcal{L} = 4.8\ \text{fb}^{-1}$		
$M_H = 165\ \text{GeV}/c^2$			
$t\bar{t}$	0.330	±	0.052
DY	3.56	±	0.85
WW	10.9	±	1.3
WZ	0.284	±	0.041
ZZ	0.107	±	0.015
W+jets	9.9	±	2.4
$W\gamma$	55.9	±	6.7
Total Background	80.9	±	7.3
$gg \to H$	0.75	±	0.12
Total Signal	0.75	±	0.12
Data	85		

OS low M(ll)





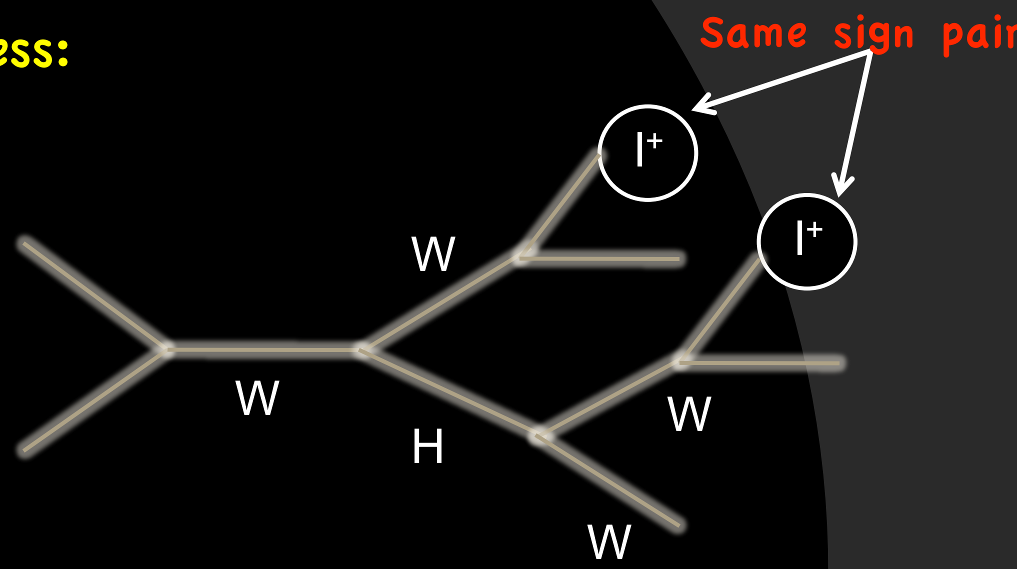
Additional Acceptance

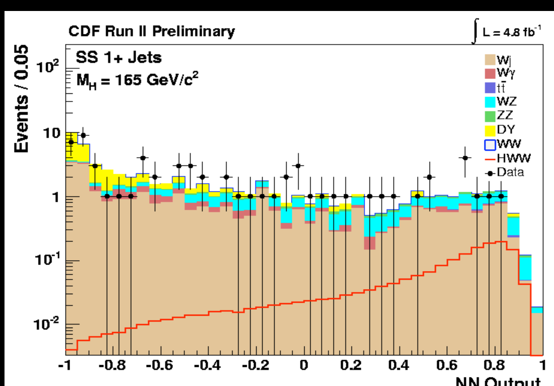
Select two same-sign leptons two increase signal acceptance

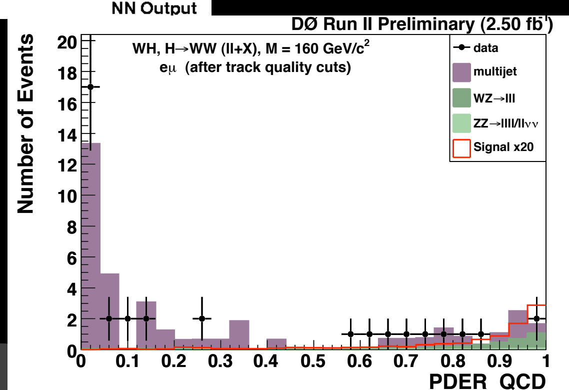
- Main contributing signal process:

  WH➔ WWW➔ ll+X

- Main backgrounds:
  - lepton charge misID
  - jets faking leptons







- CDF Same-Sign analysis uses 4.8 fb-1 of data and techniques are similar to opposite sign analysis
- D0 analysis uses 3.6 fb-1 and likelihood discriminant
- This channel adds ~10% to sensitivity at high mass

Changes since Spring 2009

CDF:

- Increased dataset from 3.6 to 4.8 fb^{-1}
- Likelihood based central electron ID
  - 10% improvement in efficiency with same fake rate
- Additional triggerable muon categories
- Low Mll analysis
- gg->H x-section systematic uncertainty depends on Njets

DO:

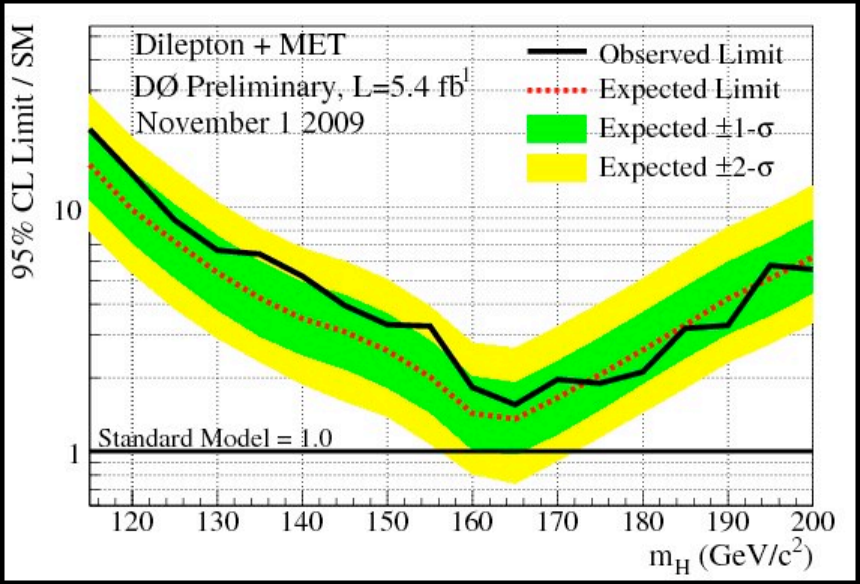
- Increased dataset in ee and $e\mu$ channels from 4.2 to 5.4 fb-1 and in $\mu\mu$ channel from 3.0 to 5.4 fb-1
- New Neural Network
- Improved background modeling
- Small changes in systematics

Both experiments achieve ~20% improvement in expected sensitivity over most of the mass range

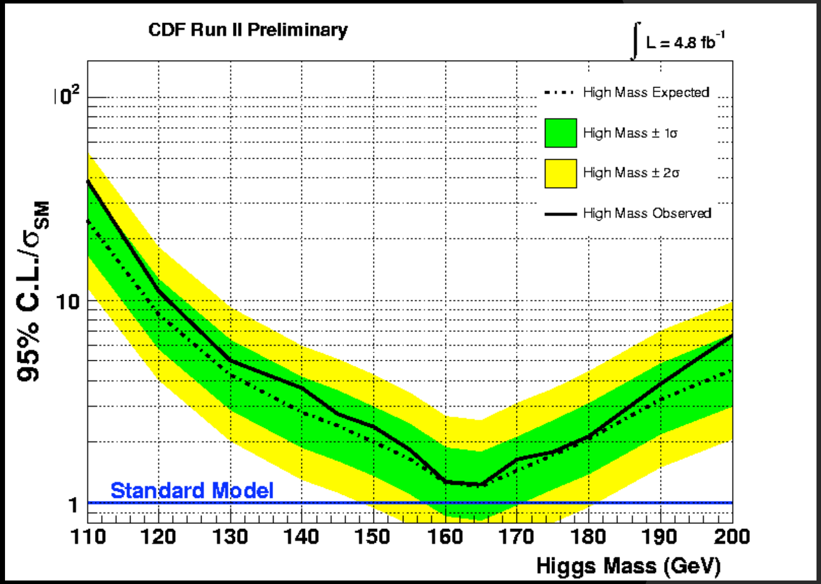
Results

Use NN output distributions to calculate 95% CL upper limits in the $110 < m_H < 200$ GeV/c^2 mass range

D0 uses CLs approach



CDF uses a Bayesian method



At Mh=165 GeV

Reaching SM sensitivity:

CDF: Exp/σ_{SM}: 1.19
Obs/σ_{SM}: 1.18

D0: Exp/σ_{SM}: 1.36
Obs/σ_{SM}: 1.55

Tevatron High Mass Combination

CDF and D0 combination:

- Not just √2 factor, many systematics are correlated between experiments
- Combined using Bayesian and CLs methods – similar results
- Uses new gg->H x-sections as calculated by Florian *et* Grazzini (*arXiv:0901.2427*), Anastasiou *et al.* (*arXiv:0811.3458*)

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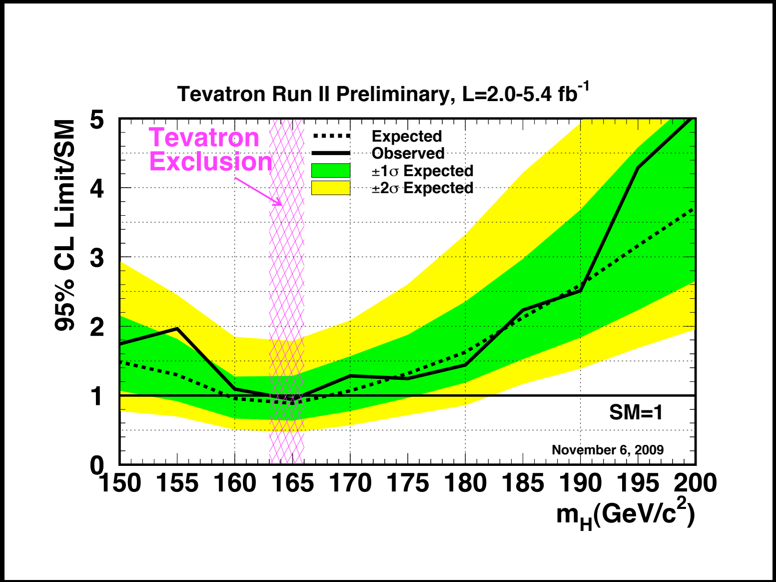
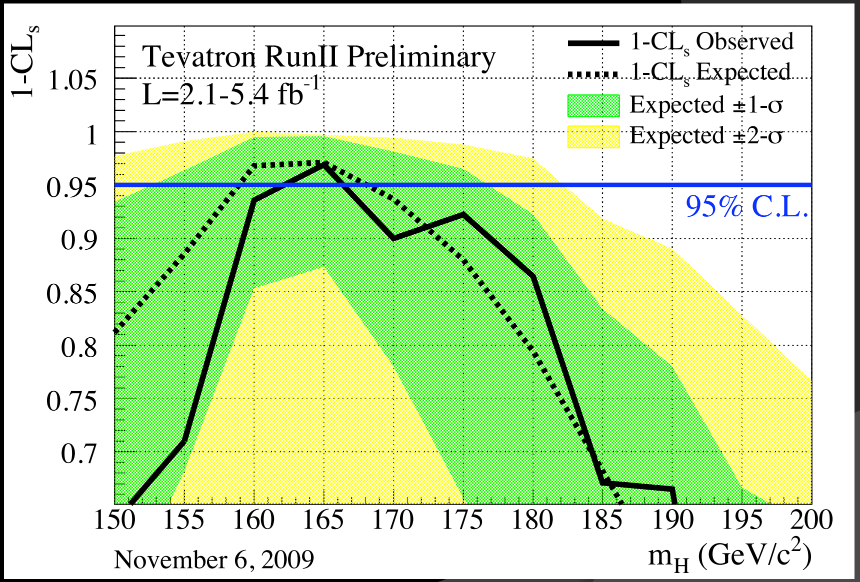
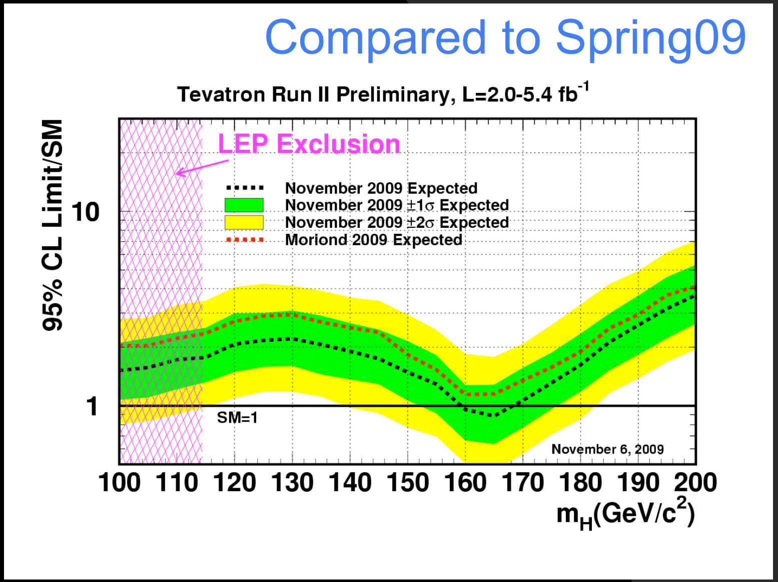




We exclude SM Higgs in mass range 163-166 GeV/c² at 95% CL

Expected exclusion range 159-168 GeV/c2

Future Prospects

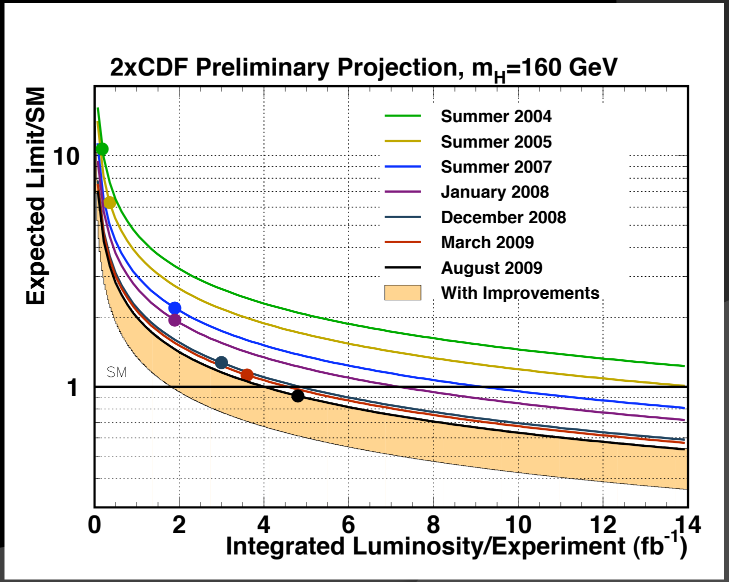


More data

- up to 10 fb-1 recorded data is expected per experiment by the end of run II (20 fb-1 combined!)

Many analysis improvements:

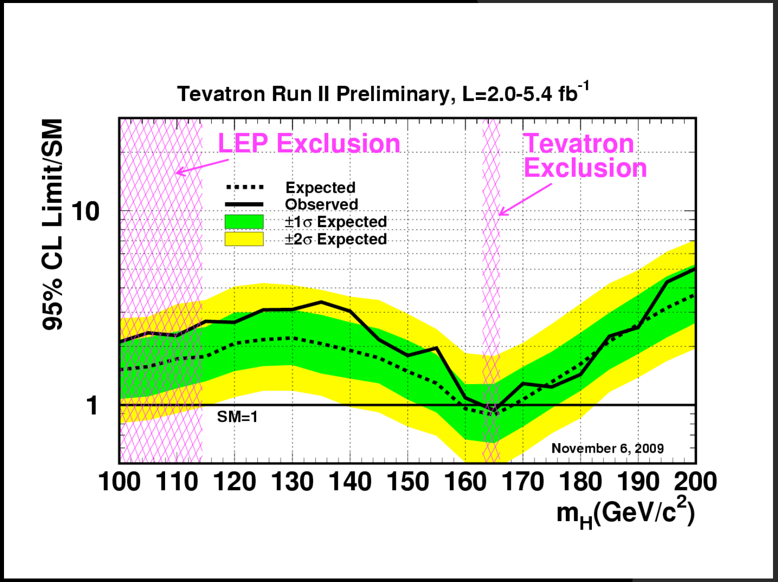
- hadronic taus
- trileptons
- H->WW->jjlν
- new triggers
- ….



Conclusions

- Great results from both experiments in both low and high mass sectors
- SM Higgs exclusion in the range 163-166 GeV/c2 @95% CL
- Expected exclusion range 159-168 GeV/c2

- Better than 2.2xSM sensitivity at all masses below 185 GeV



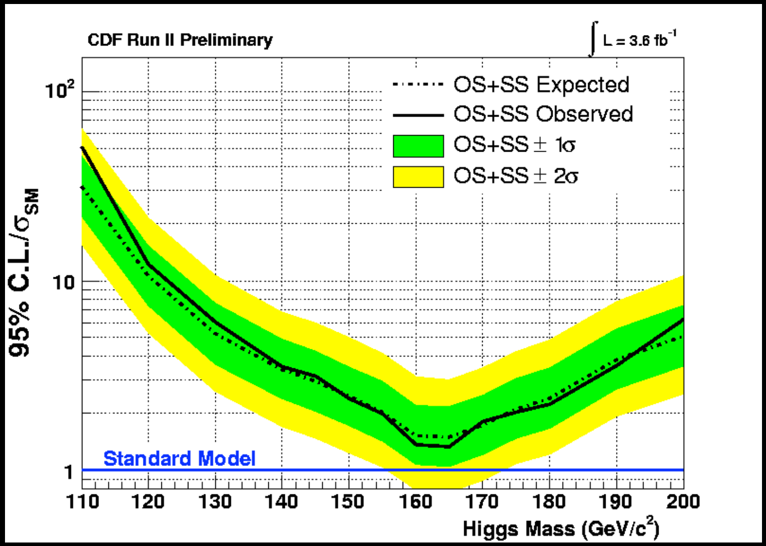
- Stay tuned for further Tevatron improvements in Higgs searches

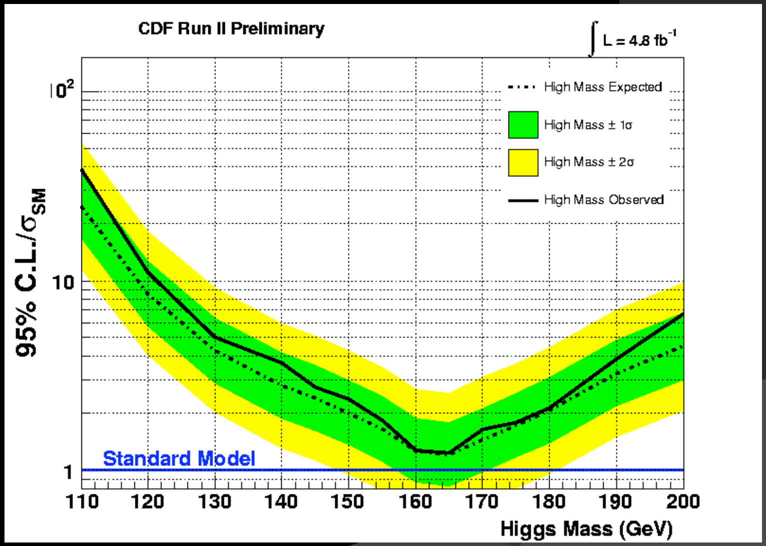
Backup

CDF old vs new results

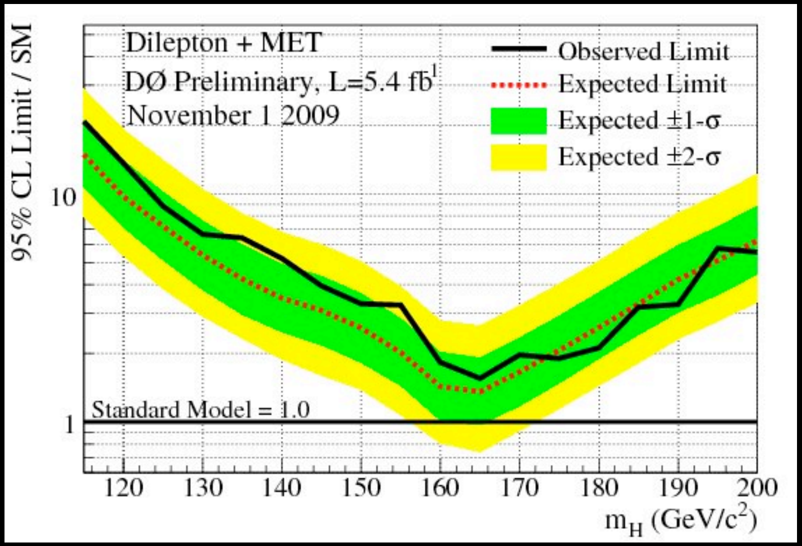
Spring 2009:
At Mh=165 GeV
Exp/σ_{SM}: 1.61
Obs/σ_{SM}: 1.46

Current:
At Mh=165 GeV
Exp/σ_{SM}: 1.19
Obs/σ_{SM}: 1.18

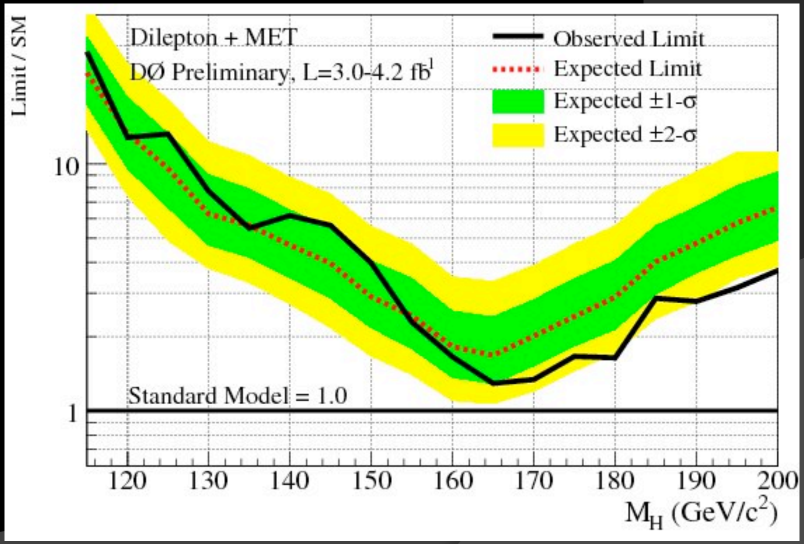




D0 old vs new results

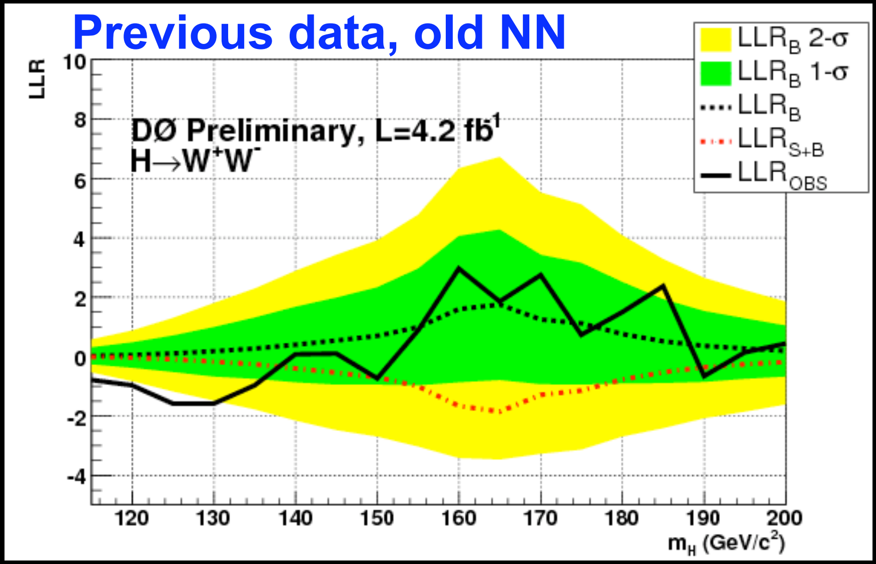


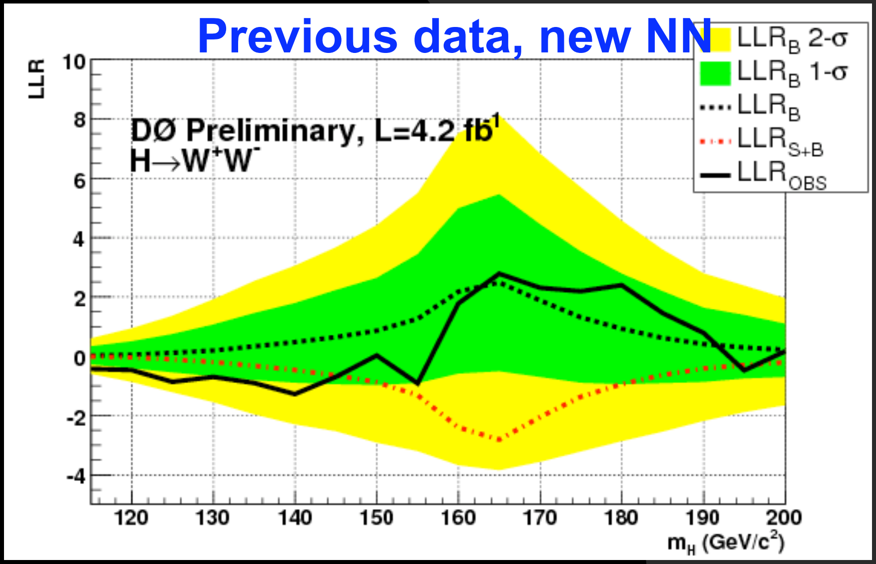
Current result at 165 GeV
1.36 (expected)
1.55 (observed)



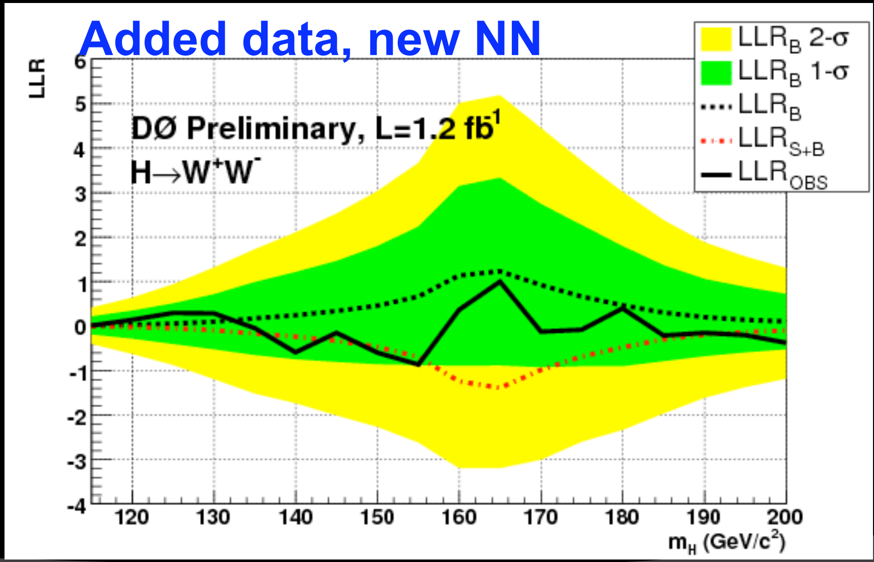
Previous result at 165 GeV
1.7 (expected)
1.3 (observed)

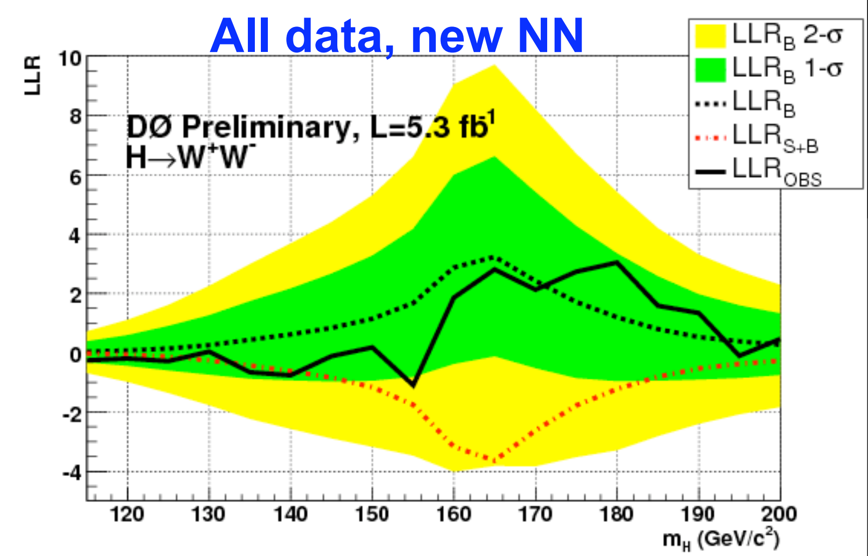
D0 Results comparison





NO SYSTEMATICS!





CDF Systematics

H → WW 0 Jet Systematics

0 Jet Uncertainties	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet	$gg \to H$	WH	ZH	VBF
Cross Section											
Scale								10.9%			
PDF Model								5.1%			
Total	*10.0%*	*10.0%*	*10.0%*	15.0%	5.0%	10.0%		12.0%			
Acceptance											
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%	20.0%	1.0%		1.0%			
Conversion Modeling						20.0%					
Jet Fake Rates											
(Low S/B)							21.5%				
(High S/B)							27.7%				
MC Run Dependence	3.9%			4.5%		4.5%		3.7%			
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	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%		5.9%			

D0 Systematics

Sample of systematics considered

Systematic Uncertainty	Type	Value
Jet Energy Scale	Shape & Norm	3-17
Jet ID Efficiency	Shape & Norm	6-18
Jet Resolution	Shape & Norm	2
Cross Sections	Flat Norm	6-10
Multijet Background	Flat Norm	2-20
Parton Distribution Function	Flat Norm	8
Lepton ID	Flat Norm	2.5-4
Lepton Momentum Scale	Shape & Norm	2-8
p_T of WW/H/Z	Shape & Norm	1-5
Luminosity	Flat Norm	6.1

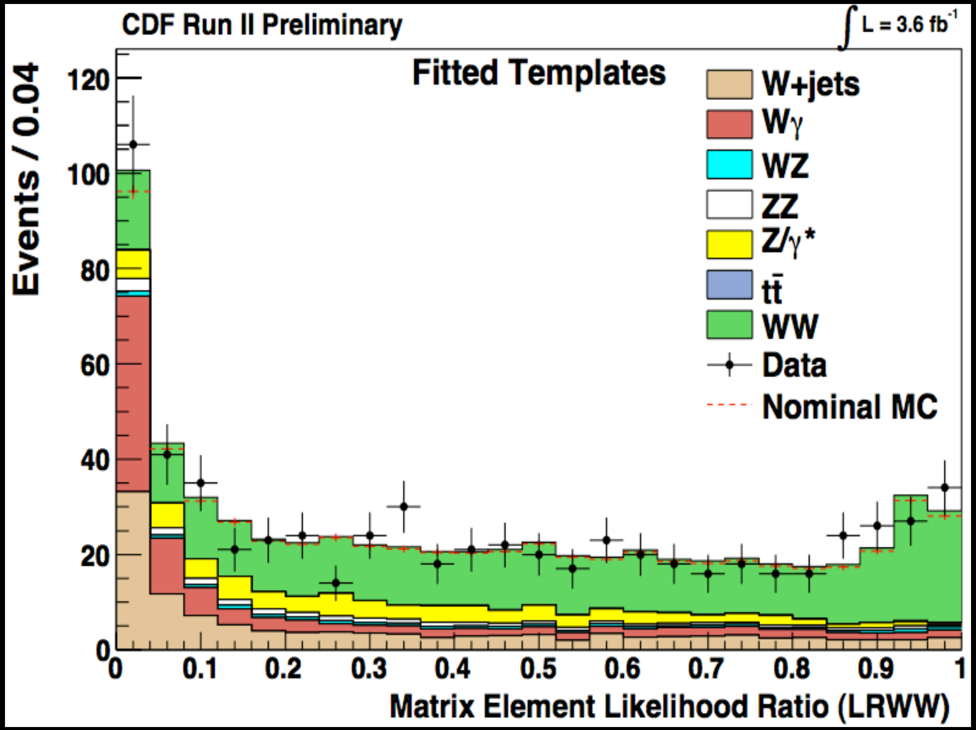
Relative uncertainty in %

WW p_T – central value from MC@NLO, ±1[illegible] from MC@NLO studies

Higgs p_T – Central value from Sherpa, ±1[illegible] from Pythia

Z p_T – Central value from DØ measurement, ±1[illegible] from Alpgen

WW Cross Section



- Measure WW cross section in 0 jet signal region
- Maximum likelihood fit to WW likelihood ratio distribution
  - Systematic uncertainties included as Gaussian constraints in fit
- New world's best measurement!
  - Good agreement with theory (11.7 pb)

$$\sigma(p\bar{p} \to WW) = 12.1 \pm 0.9\ (\text{stat.})^{+1.6}_{-1.4}\ (\text{syst.})\ [\text{pb}]$$

Syst. **includes** 5.9% luminosity uncertainty