Search for High Mass Higgs at CDF

Mark Neubauer

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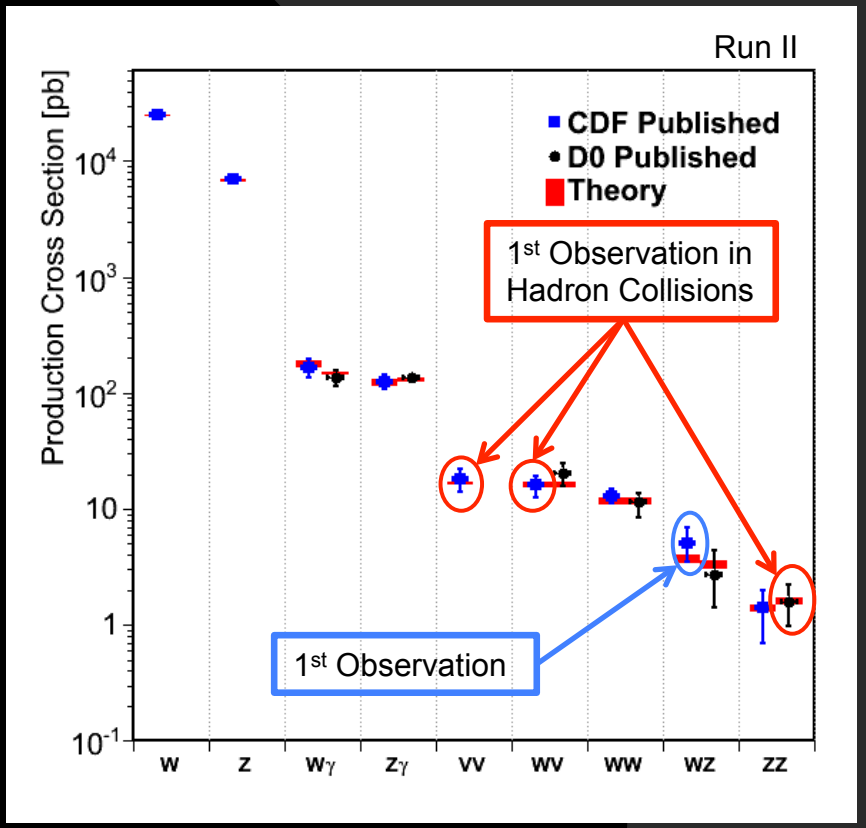
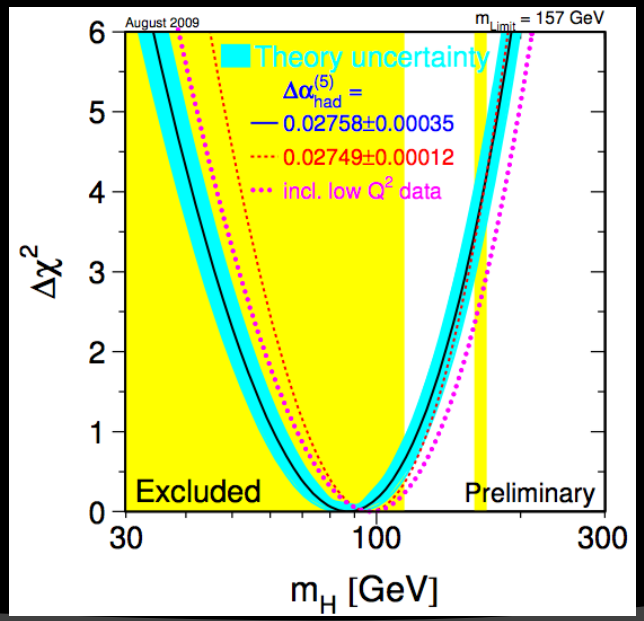
On behalf of the CDF Collaboration

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

  WZ, ZZ, single top
- Now reached sub-picobarn cross section sensitivity





SM Higgs:

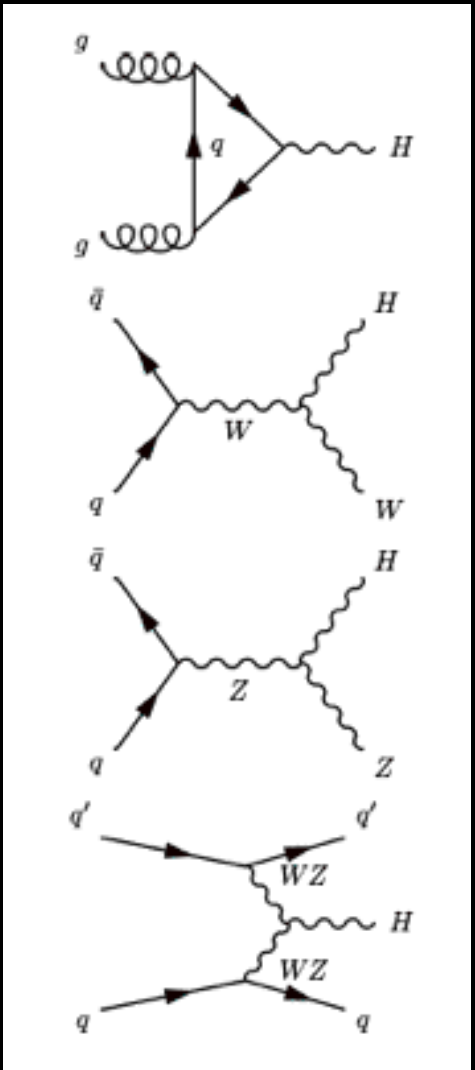
Direct search at LEP:

$m_H > 114$ GeV @ 95%CL

Including indirect electroweak constraints

$m_H < 186$ GeV @ 95%CL

SM Higgs at the Tevatron



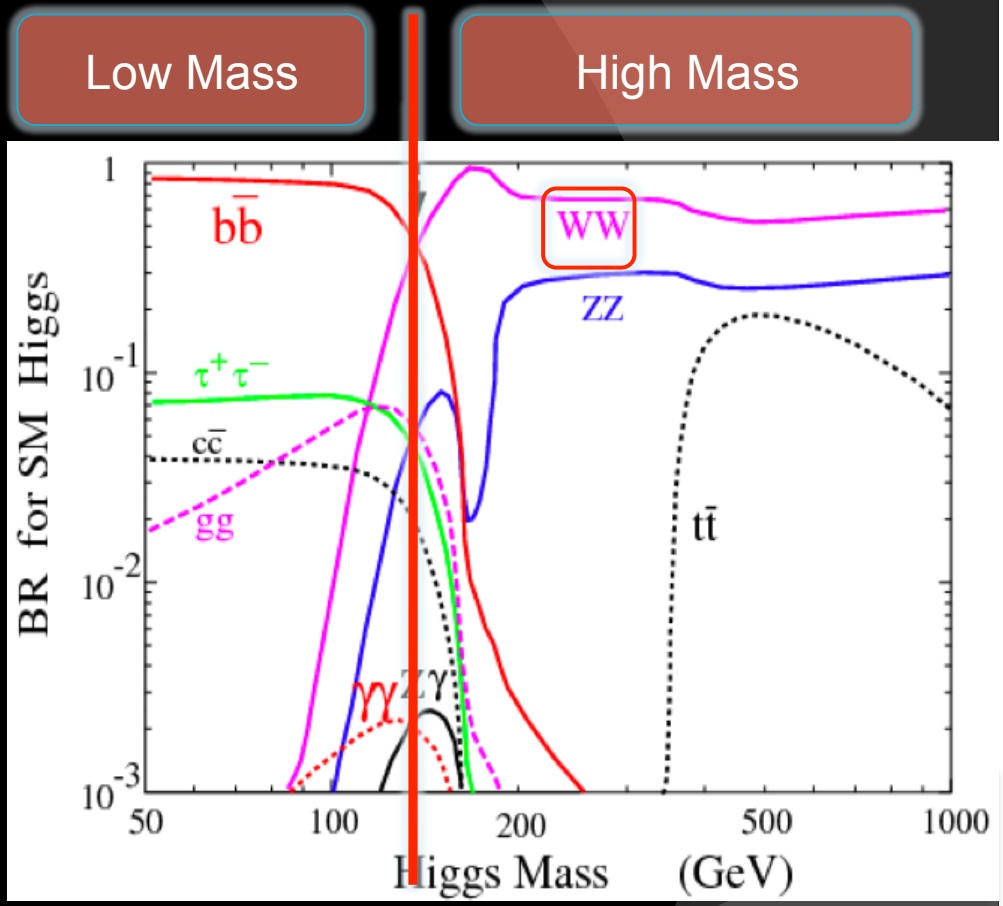
@M_h=160 GeV

ggH (78 %)

WH (9 %)

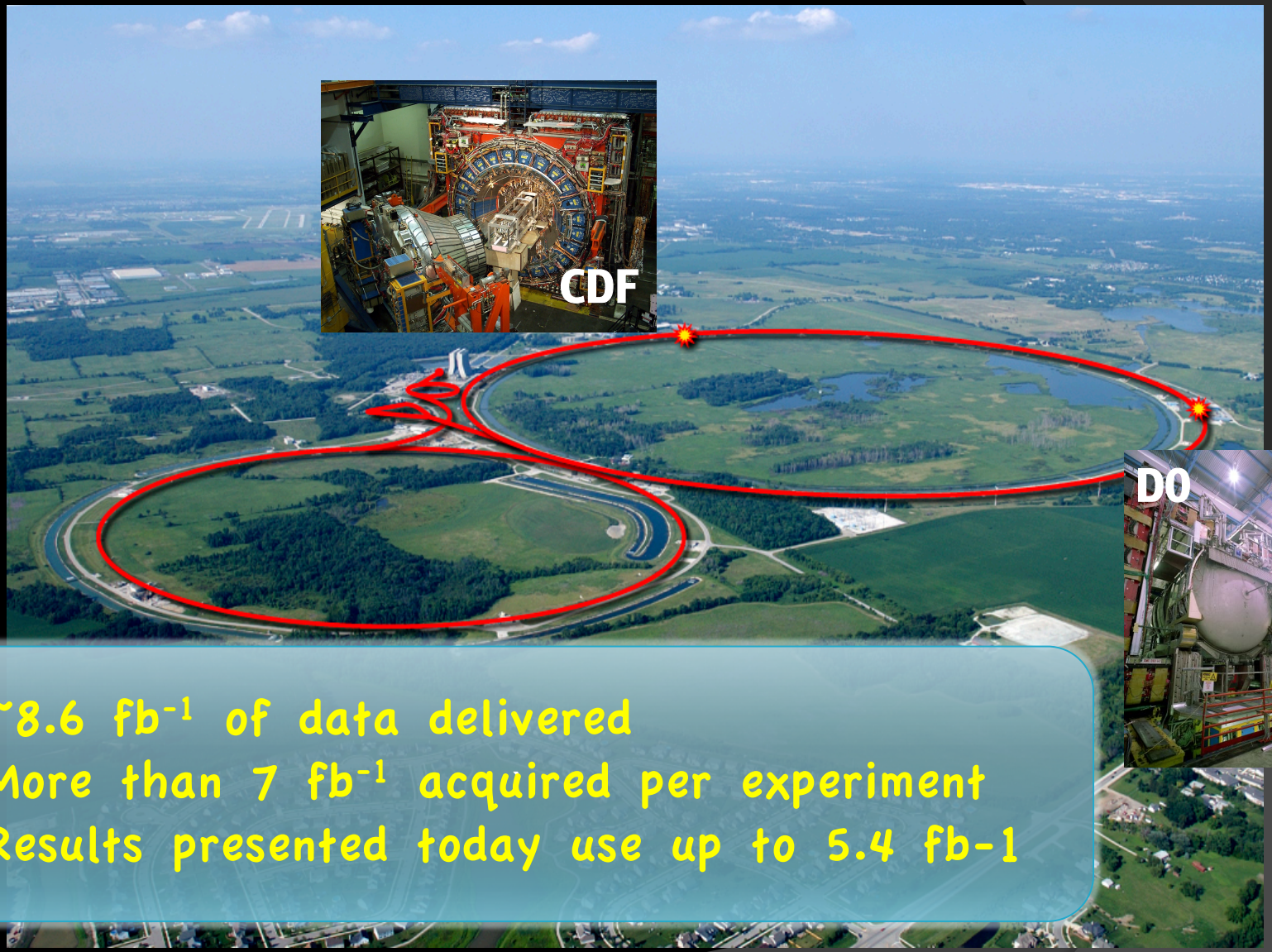
ZH (6 %)

WBF (7 %)



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

Tevatron, CDF, D0



~8.6 fb^{-1} of data delivered
More than 7 fb^{-1} acquired per experiment
Results presented today use up to 5.4 fb-1

Candidate Selection

- Focus on $WW \rightarrow (e^{\pm}e^{\mp}, e^{\pm}\mu^{\mp}, \mu^{\pm}\mu^{\mp}, e^{\pm}\tau^{\mp}, \mu^{\pm}\tau^{\mp}) + \nu's$
- Separate channels by N_{jets}
- Triggered on high p_T electron or muon
- Events with ≥ 2 opposite charge high p_T leptons and W-like missing E_T

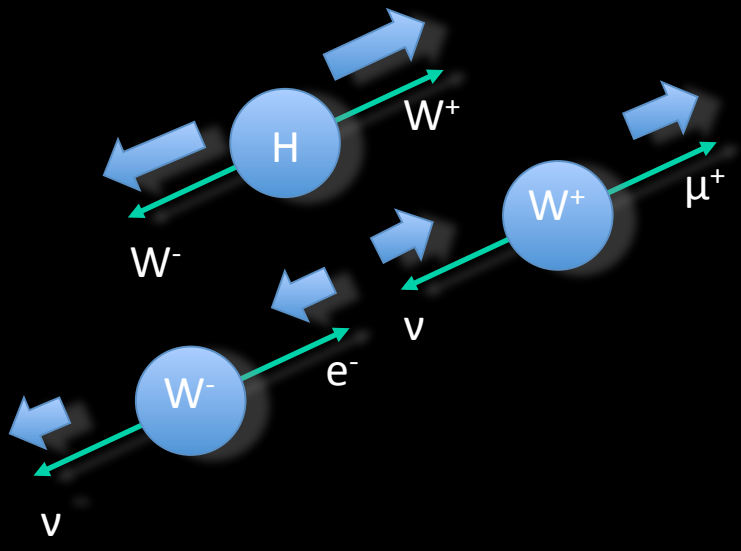
Backgrounds

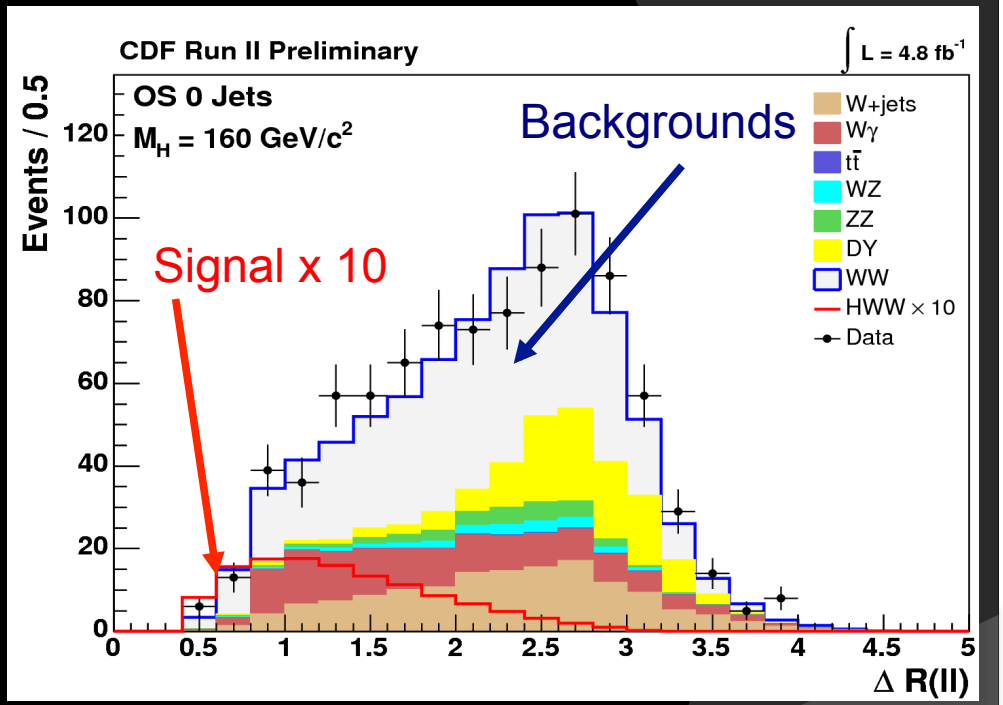
- After selection, the main backgrounds are due to:
  - Diboson production - WW, WZ, ZZ
  - W+jets where a jet fakes a lepton
  - W+γ where the photon fakes a lepton
  - ttbar and single top

Higgs Signature

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

Spin-0 Higgs leads to spin correlation:
Leptons go in the same direction





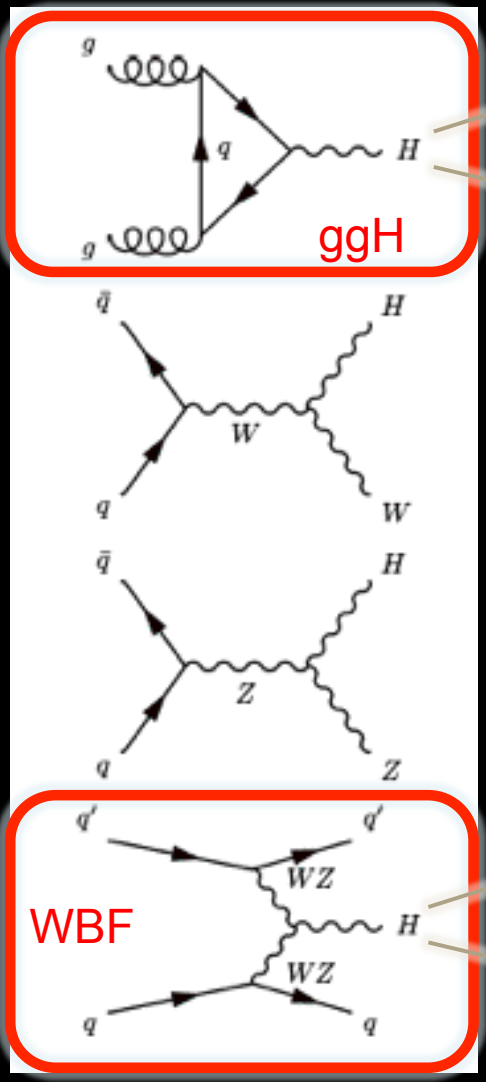
Dilepton opening angle is the strongest background discriminant

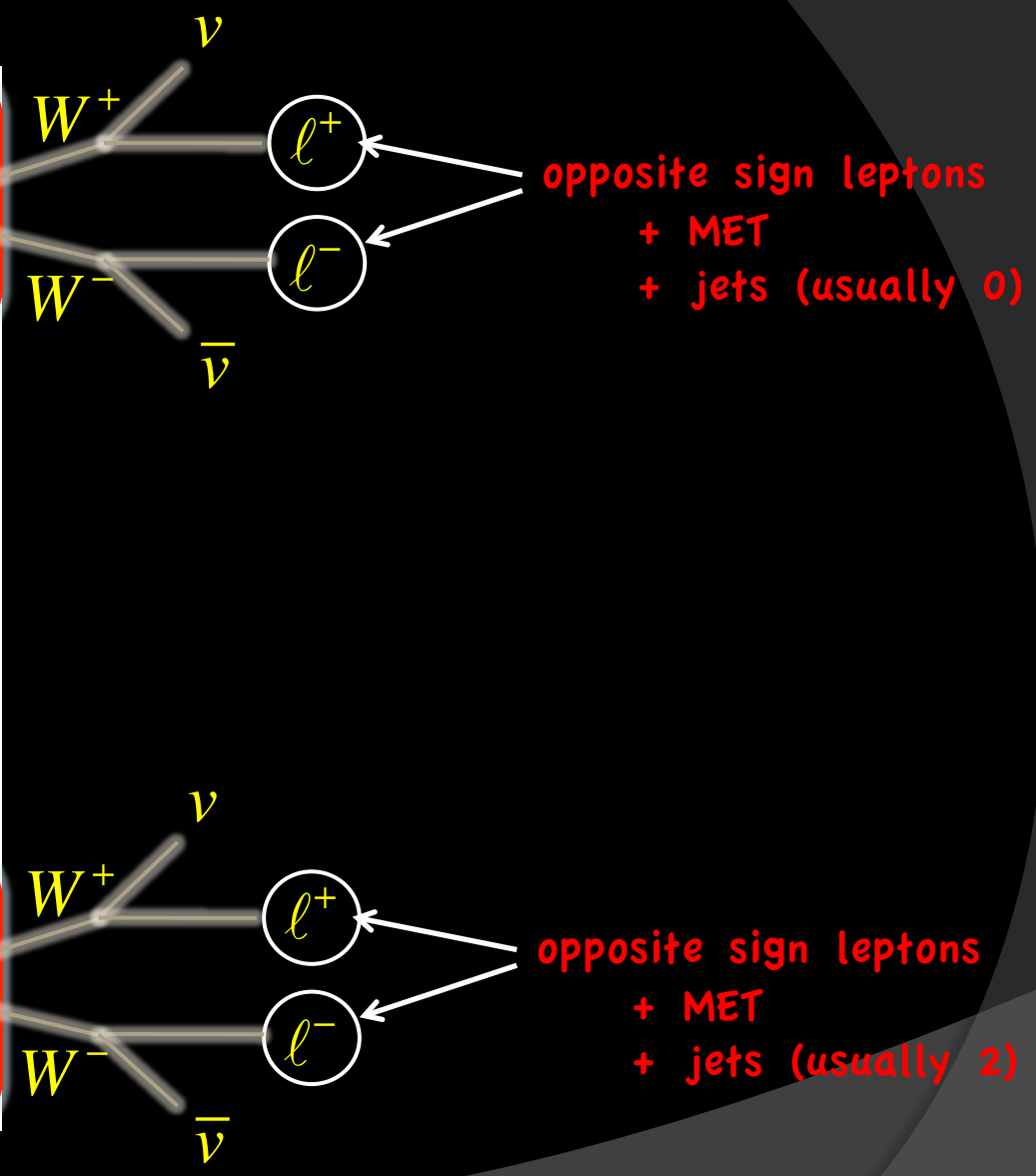
Strategy

- Simple event counting is not good enough ($S/\sqrt{B}$ too low): Use multivariate analysis (MVA) techniques to discriminate between signal and background:
  - Matrix Elements (ME), Neural Networks (NN), Boosted Decision Trees (BDT)
  - Each channel and M_H hypothesis has its own MVA template
- Many control regions to verify background modeling
- Cross section measurements of some SM processes (e.g. WW, WZ, ZZ)
- Separate analysis into channels by S/B ratio in lepton purity and jet multiplicity: 0, 1 and 2+ jets
  - Consider how ggf, WH, ZH, and WBF can feed these channels

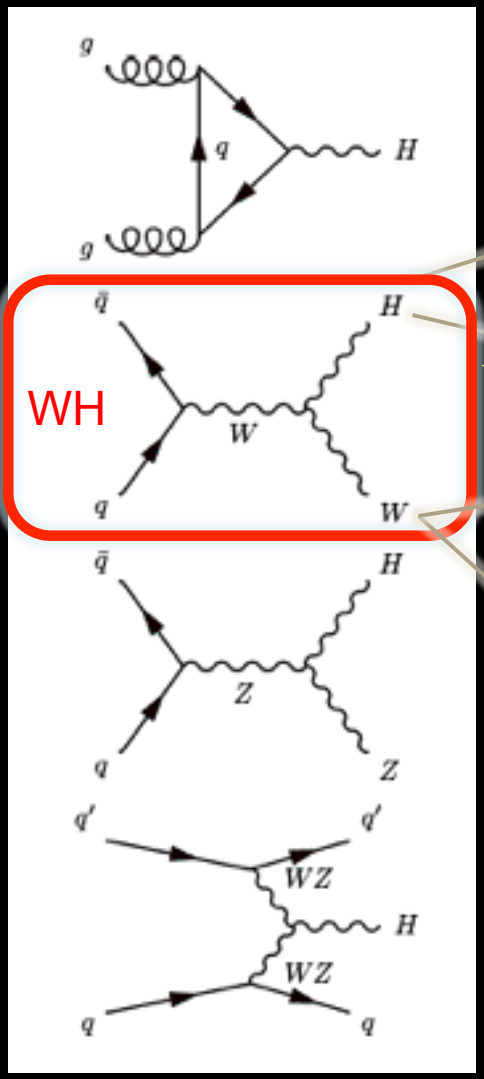
No Channel Left Behind!

ggF & WBF


g
g
q
H
ggH
$\bar{q}$
q
W
H
W
$\bar{q}$
q
Z
H
Z
q'
q'
WZ
H
WZ
WBF
q
q


ν
W^+
ℓ^+
ℓ^-
W^-
$\bar{\nu}$
opposite sign leptons
+ MET
+ jets (usually 0)
ν
W^+
ℓ^+
ℓ^-
W^-
$\bar{\nu}$
opposite sign leptons
+ MET
+ jets (usually 2)

WH (OS dileptons)



ν

W^+

ℓ^+

ℓ^-

W^-

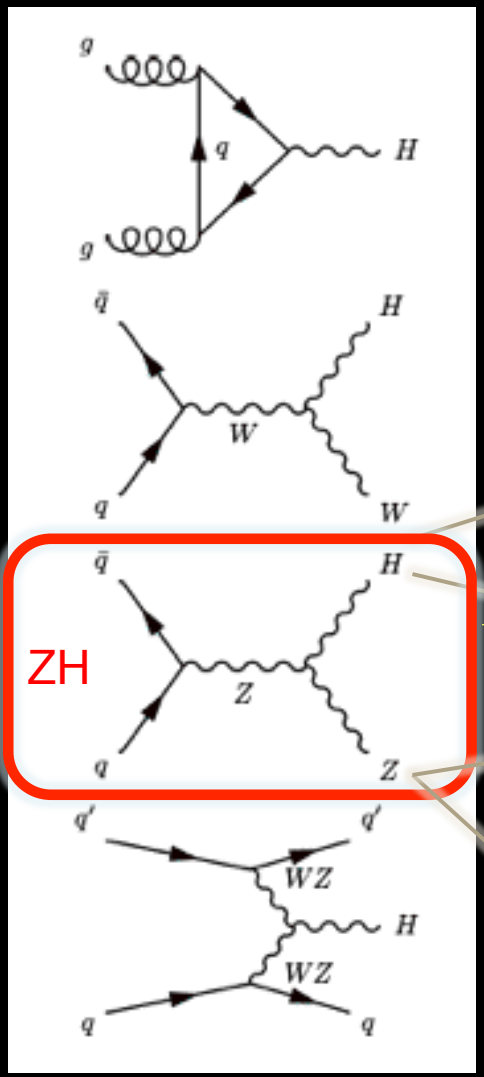
$\bar{\nu}$

$\bar{q}$

q

opposite sign leptons
+ MET
+ jets (usually 2)

ZH (OS dileptons)



W^+ ν ℓ^+

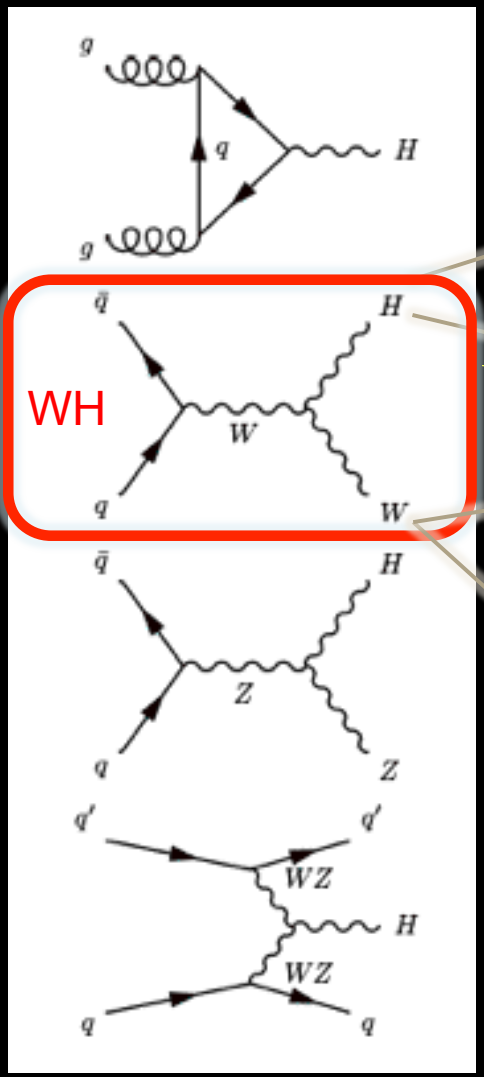
W^- $\bar{\nu}$ ℓ^-

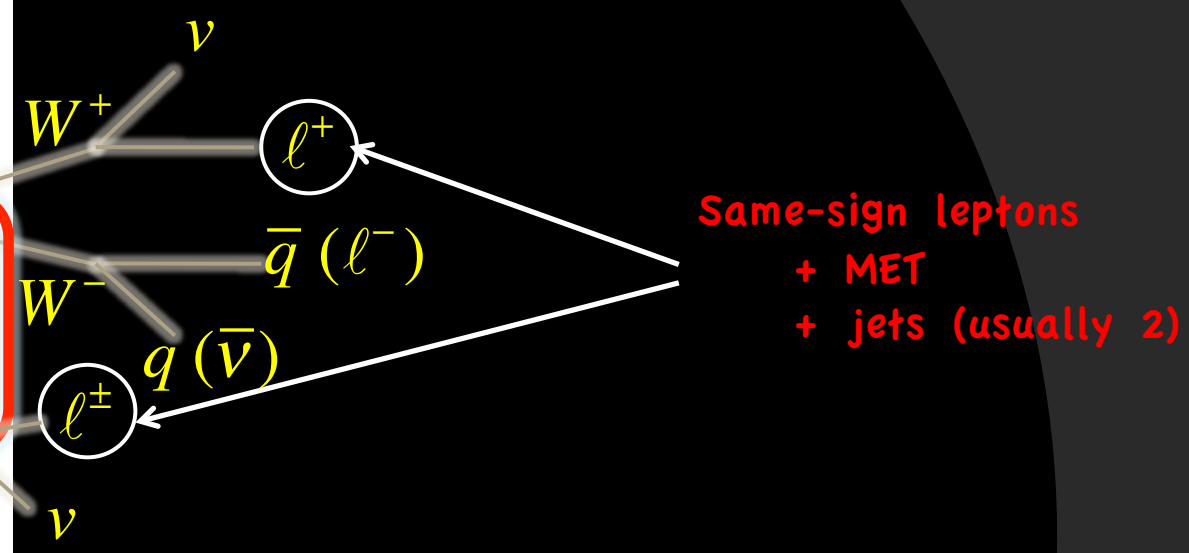
$\bar{q}$

q

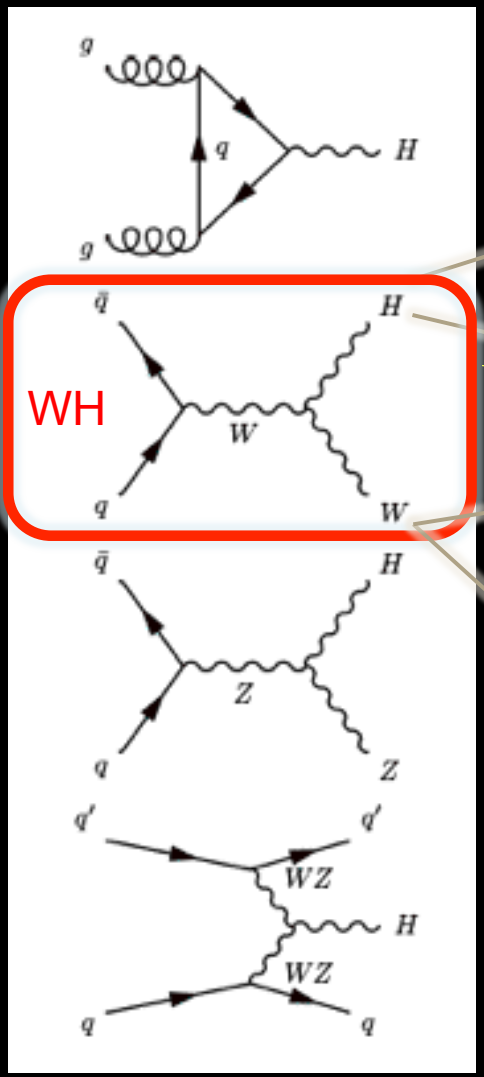
opposite sign leptons
+ MET
+ jets (usually 2)

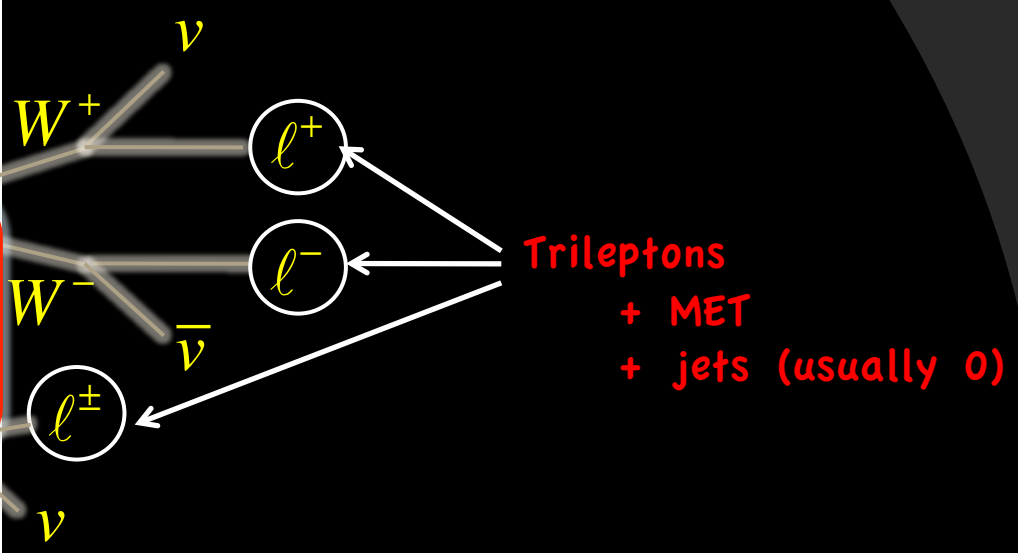
WH (SS dileptons)



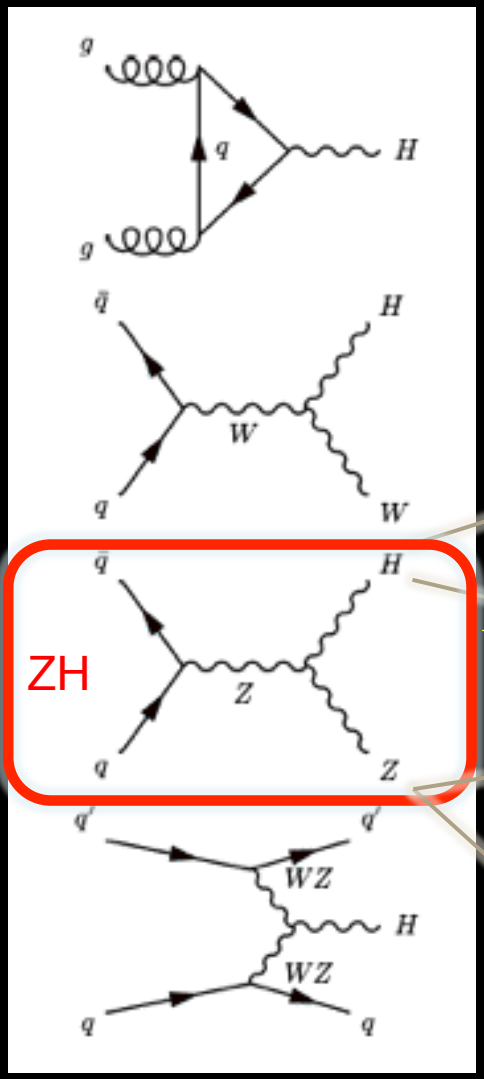


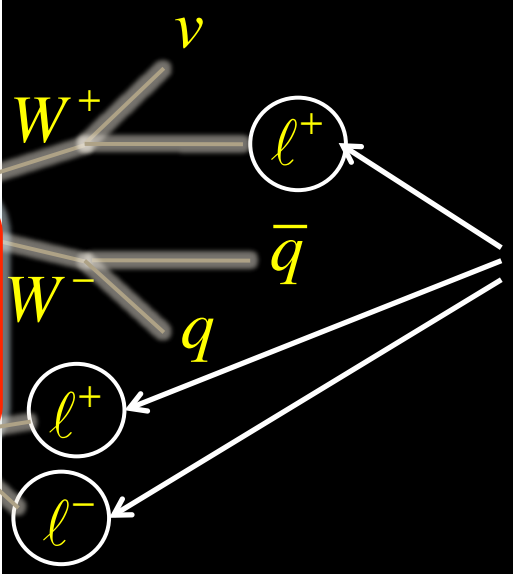
WH (trileptons)





ZH (trileptons)





Trileptons
+ MET
+ jets (usually 2)

OS dilepton + 0 jets:

- Make good use of ME calculations (LO)
- Majority of signal from gluon fusion

OS dilepton + 1 jet:

- Extra tt backgrounds
- Extra signal (VH & WBF): ~20%

OS dilepton + ≥ 2 jets:

- tt is main background (anti b-tagging!)
- Extra signal (VH & WBF) ~60%

OS dilepton (M_{ll}<16 GeV) + 0,1 jet:

- W+γ (fake e) dominant background
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SS dilepton + ≥ 1 jet:

- Charge mis-ID and W+jets (fake e,μ) Bkgs
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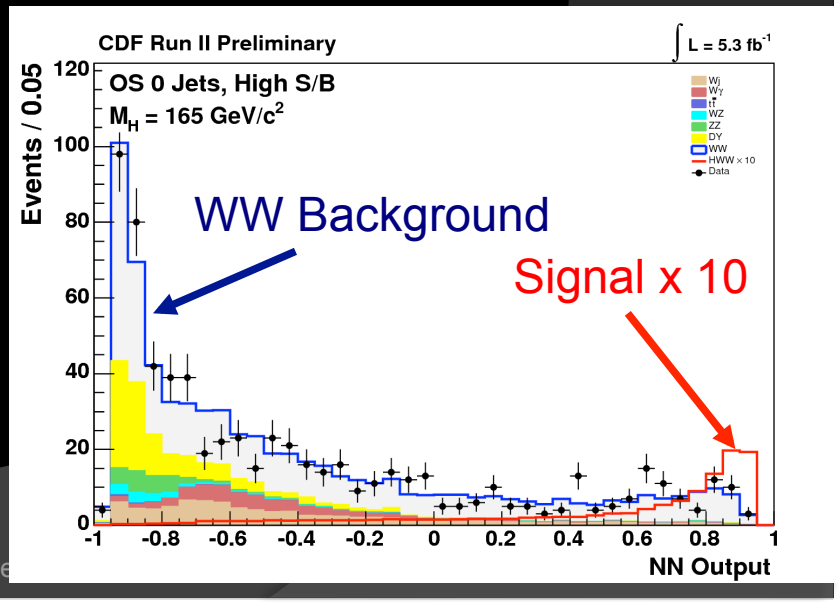
Hadronic taus…

CDF Run II Preliminary	$\int \mathcal{L} = 5.3$ fb^{-1}		
$M_H = 165$ GeV/c^2			
$t\bar{t}$	2.32	±	0.93
DY	156	±	52
WW	508	±	57
WZ	22.8	±	3.7
ZZ	34.2	±	5.0
W+jets	196	±	45
$W\gamma$	142	±	23
Total Background	1060	±	110
$gg \to H$	15.1	±	2.3
WH	0.364	±	0.072
ZH	0.373	±	0.055
VBF	0.126	±	0.029
Total Signal	16.0	±	2.4
Data	1107		

OS 0 Jets



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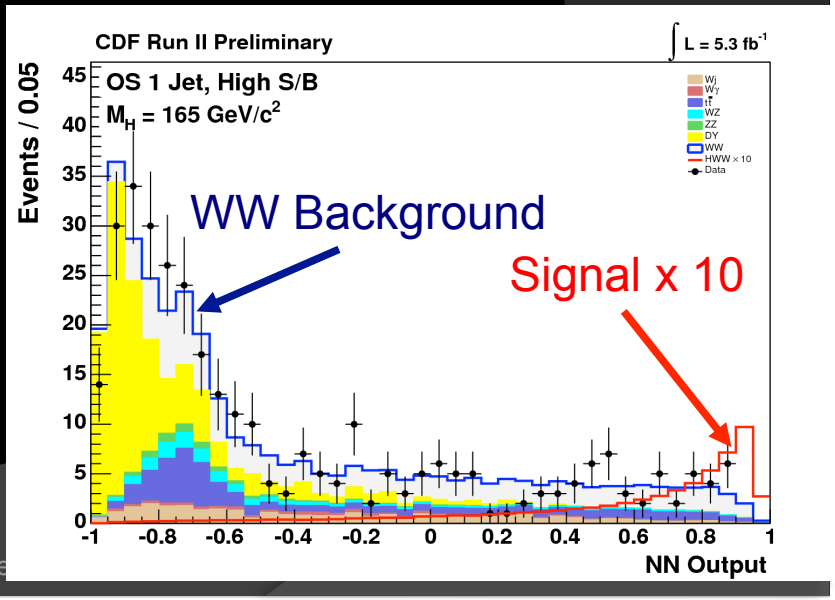
CDF Run II Preliminary	$\int \mathcal{L} = 5.3$ fb^{-1}		
$M_H = 165$ GeV/c^2			
$t\bar{t}$	56	±	13
DY	162	±	39
WW	139	±	18
WZ	22.6	±	3.1
ZZ	9.2	±	1.4
W+jets	76	±	18
$W\gamma$	23.1	±	4.8
Total Background	487	±	64
$gg \to H$	7.1	±	1.9
WH	1.01	±	0.18
ZH	0.392	±	0.064
VBF	0.66	±	0.12
Total Signal	9.2	±	2.0
Data	472		

OS 1 Jet



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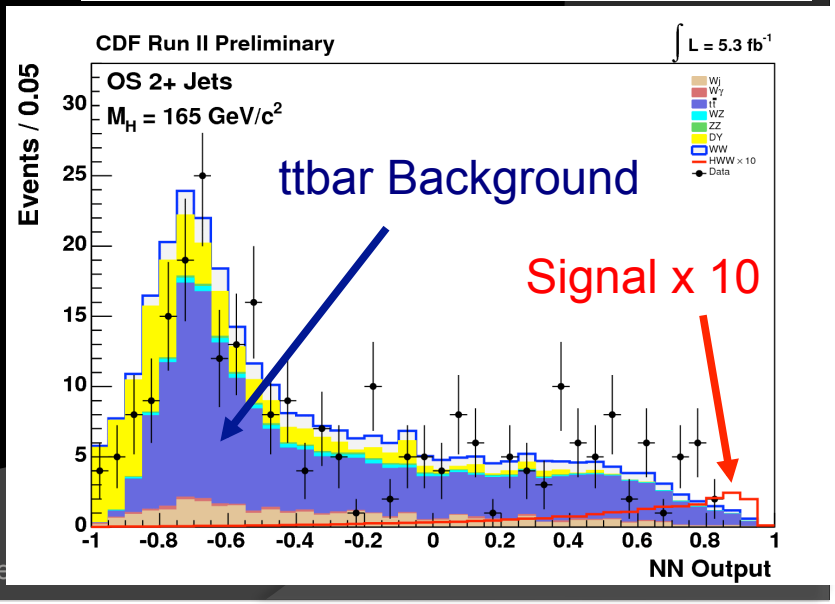
Hadronic taus…

CDF Run II Preliminary $\int \mathcal{L} = 5.3\ \mathrm{fb}^{-1}$

$M_H = 165\ \mathrm{GeV}/c^2$

$t\bar{t}$	163	±	27
DY	60	±	28
WW	29.4	±	6.9
WZ	6.1	±	1.4
ZZ	2.75	±	0.60
W+jets	27.8	±	6.9
$W\gamma$	4.1	±	1.4
Total Background	293	±	50
$gg \to H$	2.3	±	1.7
WH	2.23	±	0.32
ZH	1.14	±	0.15
VBF	1.23	±	0.21
Total Signal	6.9	±	1.9
Data	264		

OS 2+ Jets



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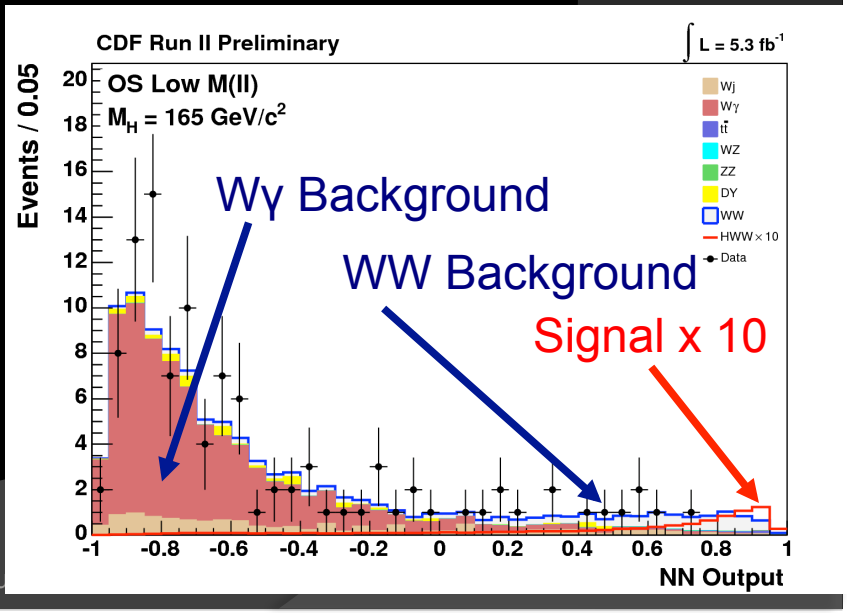
Hadronic taus…

CDF Run II Preliminary	$\int \mathcal{L} = 5.3$ fb^{-1}		
$M_H = 165$ GeV/c^2			
$t\bar{t}$	0.384	±	0.092
DY	3.67	±	0.88
WW	12.6	±	1.5
WZ	0.329	±	0.049
ZZ	0.123	±	0.018
W+jets	12.6	±	2.4
$W\gamma$	69.3	±	7.7
Total Background	99.0	±	8.4
$gg \to H$	0.89	±	0.15
Total Signal	0.89	±	0.15
Data	104		

OS Low M(ll)



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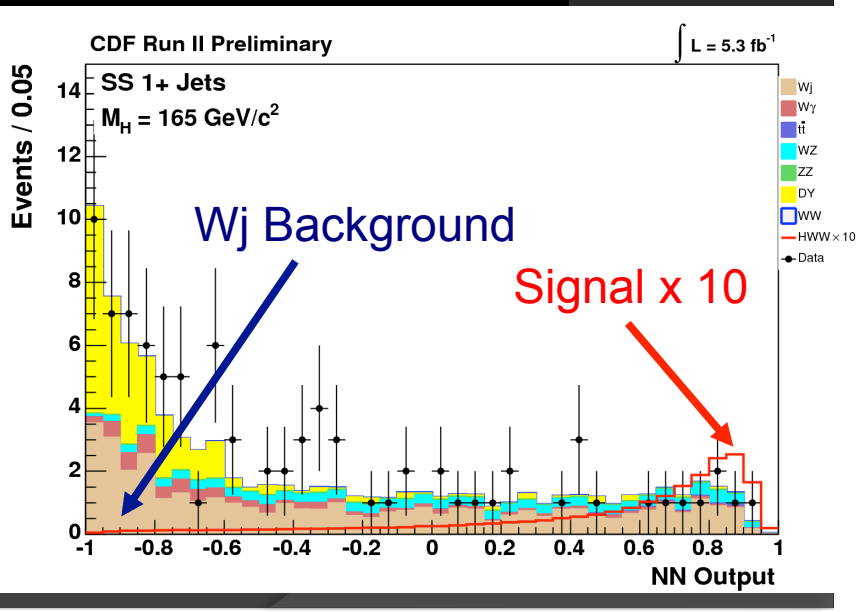
Hadronic taus…

CDF Run II Preliminary $\int \mathcal{L} = 5.3\ \text{fb}^{-1}$

$M_H = 165\ \text{GeV}/c^2$

$t\bar{t}$	0.41	±	0.12
DY	23.3	±	8.1
WW	0.064	±	0.021
WZ	10.4	±	1.5
ZZ	1.88	±	0.27
W+jets	39	±	13
$W\gamma$	6.5	±	1.2
Total Background	81	±	16
WH	1.83	±	0.24
ZH	0.292	±	0.038
Total Signal	2.13	±	0.28
Data		88	

SS 1+ Jets



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SS dilepton + ≥ 1 jet:

- Charge mis-ID and W+jets (fake e,μ) Bkgs
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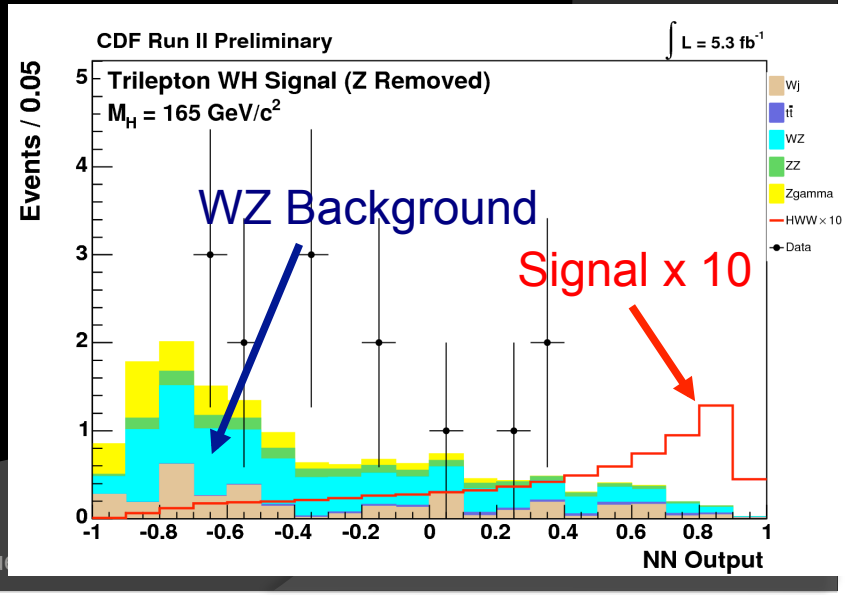
Trileptons:

- WZ is main background
- Extra signal (WH & ZH)

Hadronic taus…

CDF Run II Preliminary	$\int \mathcal{L} = 5.3$ fb^{-1}		
$M_H = 165$ GeV/c^2			
$t\bar{t}$	0.39	±	0.12
WZ	7.01	±	0.96
ZZ	1.49	±	0.20
WW/Z+jets	3.22	±	0.72
$Z\gamma$	2.47	±	0.44
Total Background	14.6	±	1.5
WH	0.584	±	0.076
ZH	0.182	±	0.024
Total Signal	0.766	±	0.100
Data	14		

Trilepton NoZ



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SS dilepton +

- Charge mis-ID ar
- Extra signal (WH

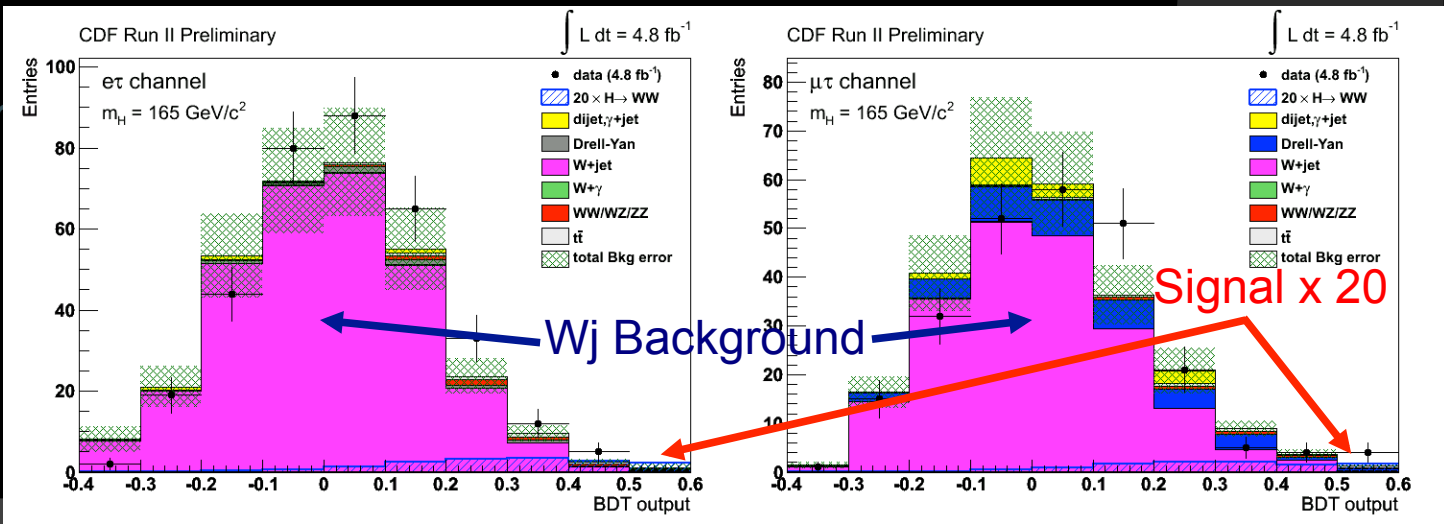
Trileptons:

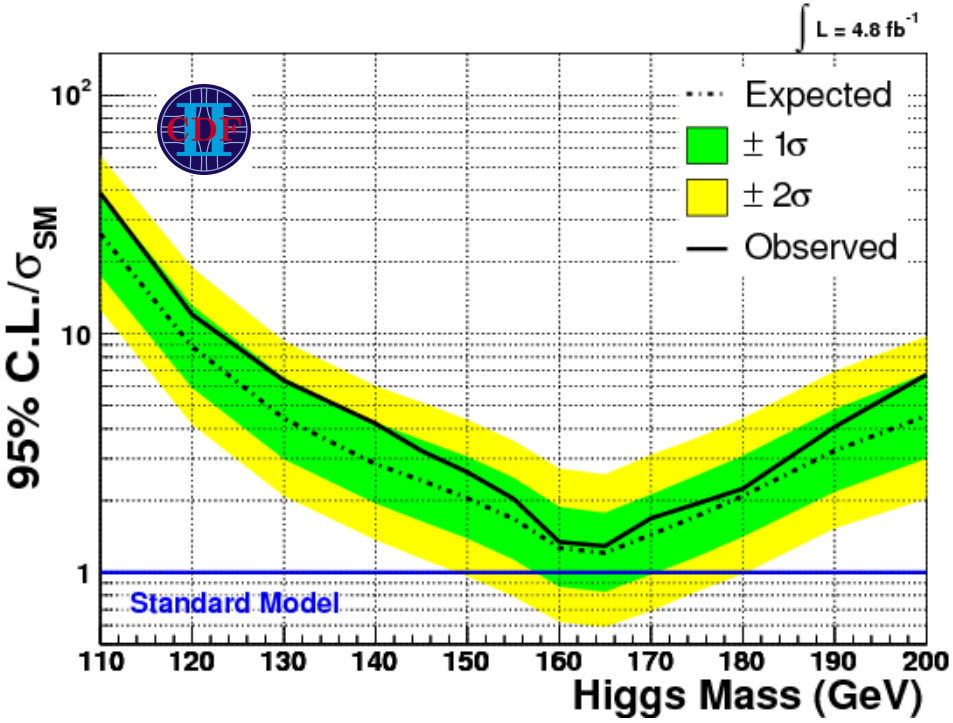
- tt is main backg
- Extra signal (WH

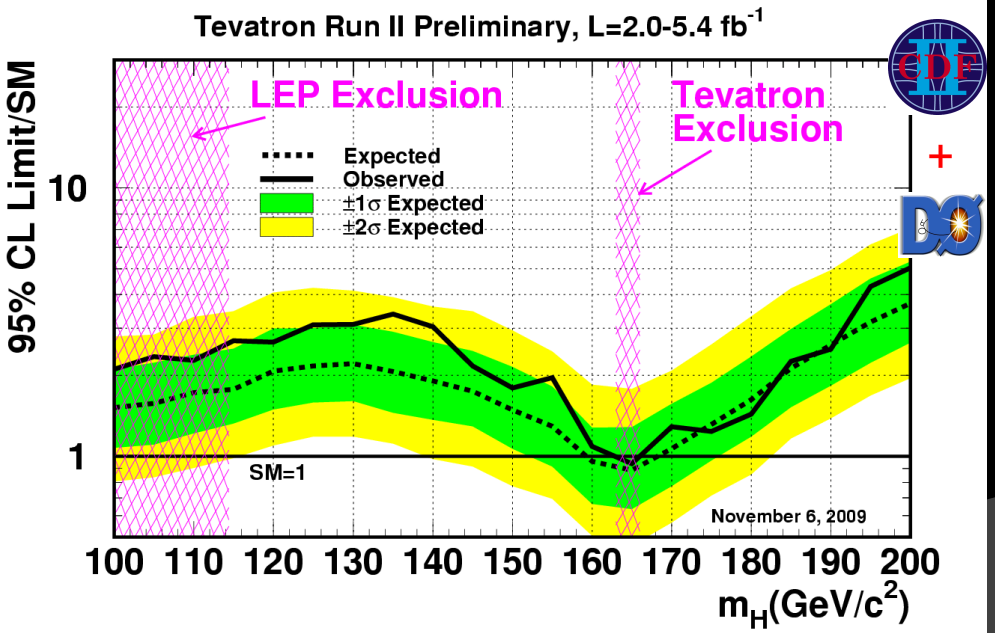
Hadronic τ's!

CDF Run II Preliminary $\int \mathcal{L} = 4.8$ fb^{-1}			
$m_H = 165$ GeV/c^2			
dijet, γ+ jet	15	±	25
$Z \to \tau\tau$	1.18	±	0.35
$Z \to \ell\ell$	38.9	±	3.7
W+jets	505	±	65
Wγ	1.29	±	0.17
Diboson (WW, WZ, ZZ)	6.85	±	0.72
$t\bar{t}$	6.98	±	0.86
Total Background	575	±	63
$gg \to H$	0.923	±	0.092
WH	0.201	±	0.021
ZH	0.130	±	0.013
VBF	0.082	±	0.009
Total Signal	1.336	±	0.095
Data	604		

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







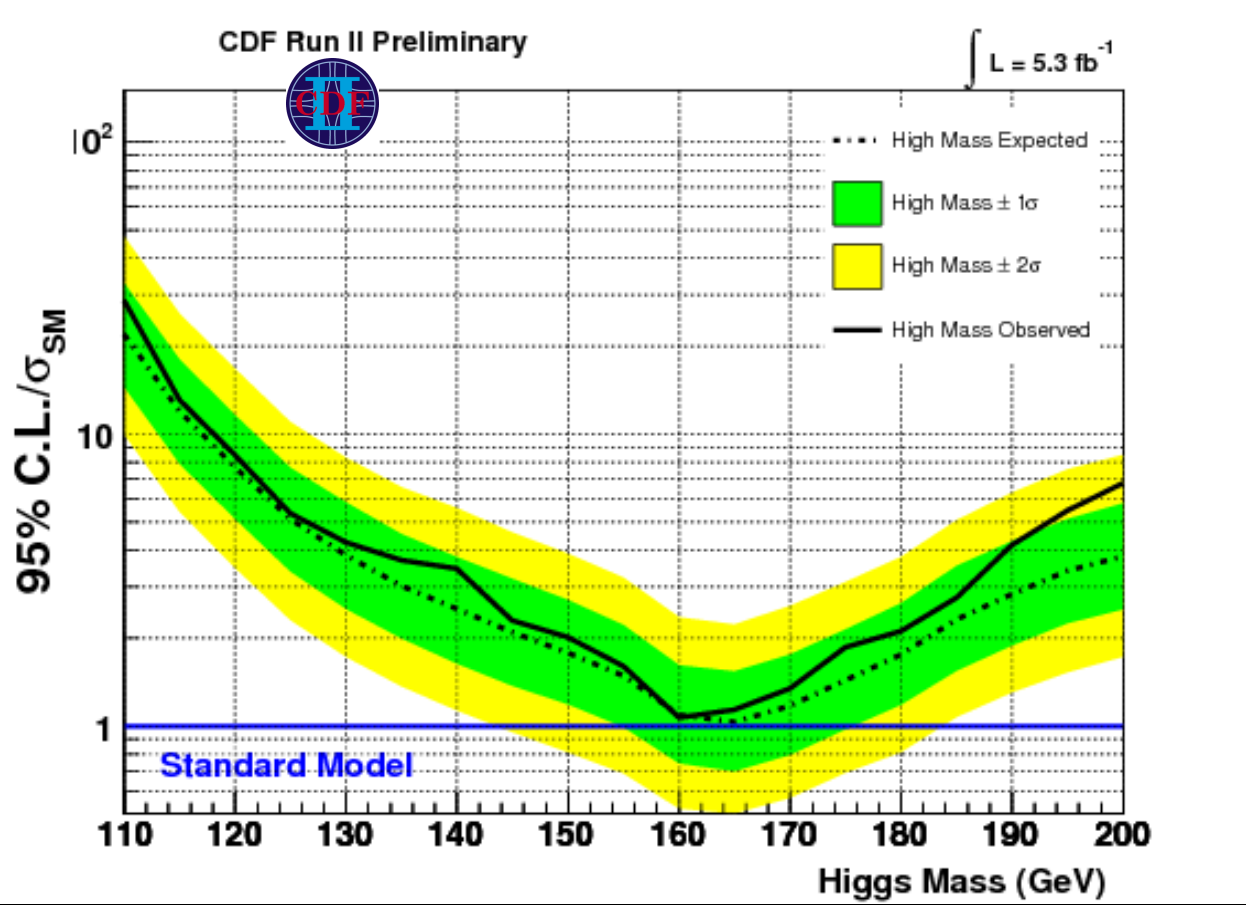
Previously published limits on SM Higgs Production

T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **104**, 061803 (2010).

SM Sensitivity: 159-169 GeV/c^2!

SM Exclusion: 162-166 GeV/c^2!

T. Aaltonen *et al.*, (CDF and DØ Collaborations), Phys. Rev. Lett. **104**, 061802 (2010).



Improvements over published results

4.8→5.3 fb^{-1}: 5% better

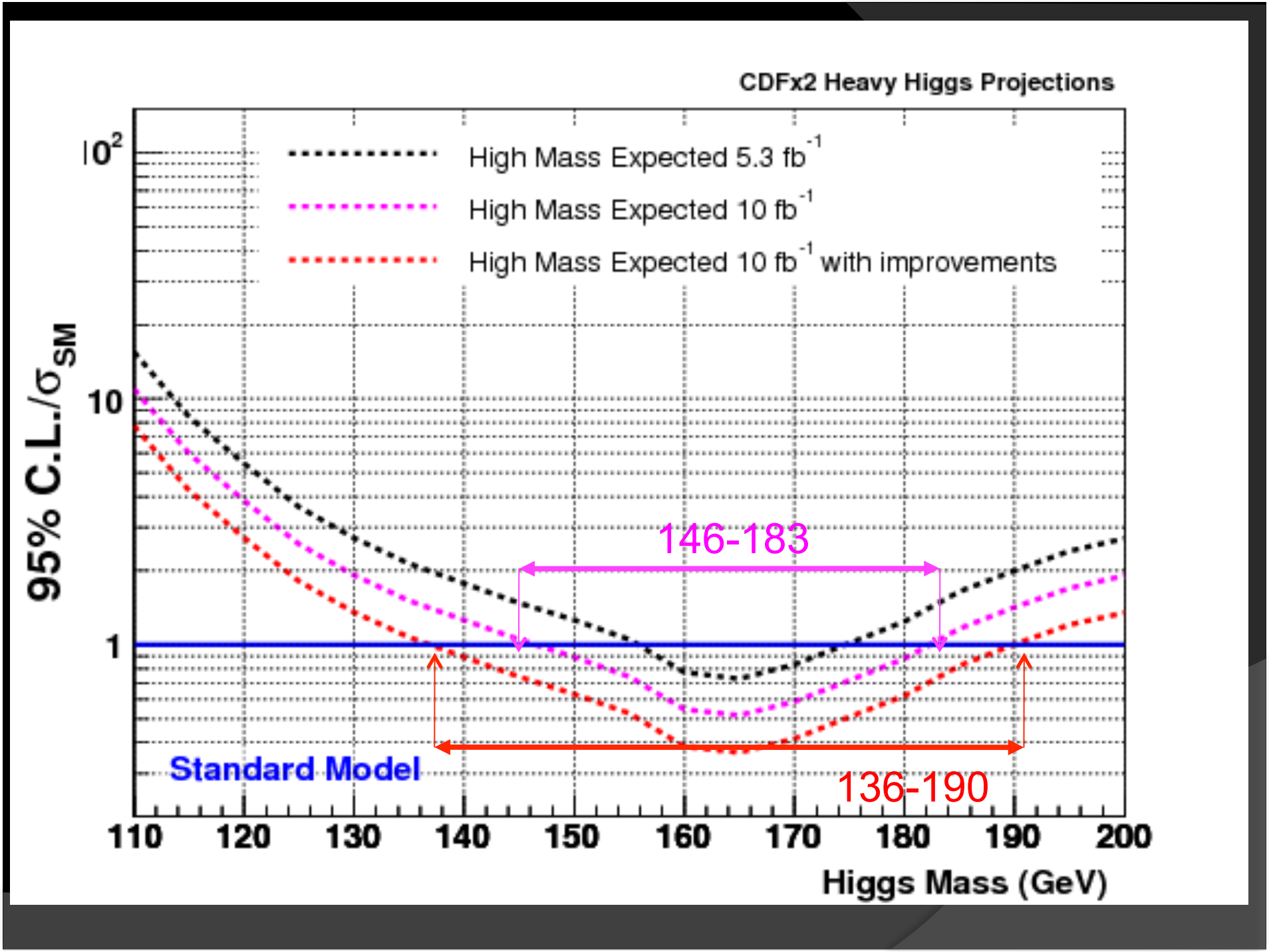
Optimized e^- selection

Add Trileptons, Low M_{ll} , VH, WBS for 0 Jet

All together: 15% better!

Improvements continue (τ modes add few %)

For M_H=165 GeV/c^2	Expected	Observed
CDF New	1.03	1.13
CDF Pub	1.20	1.29


CDFx2 Heavy Higgs Projections
10^2
10
1
95% C.L./σ_{SM}
High Mass Expected 5.3 fb^{-1}
High Mass Expected 10 fb^{-1}
High Mass Expected 10 fb^{-1} with improvements
146-183
136-190
Standard Model
110
120
130
140
150
160
170
180
190
200
Higgs Mass (GeV)

Summary

- "No channel left behind" strategy successful: different, backgrounds, systematics, S/B and many channels.
- Combined Tevatron results exclude the Standard Model Higgs at 95% CL for $162 \leq M_H \leq 166$ GeV/c^2.
- Updated CDF results: sensitivity close to 95% CL exclusion for M_H=160-165 GeV/c^2.
- The High mass sensitivity will be expanded: 2 x CDF gives 146-183 GeV/c^2 if no improvements, 136-190 GeV/c^2 with improvements.
- Both experiments have almost 9 fb^{-1} delivered! May have 12 fb^{-1} by the end of Run II!