

Low Mass Standard Model Higgs Boson Searches at the Tevatron

Andrew Mehta



On behalf of the CDF and
D0 Collaborations



Physics at LHC, Split, Croatia, September 29th 2008

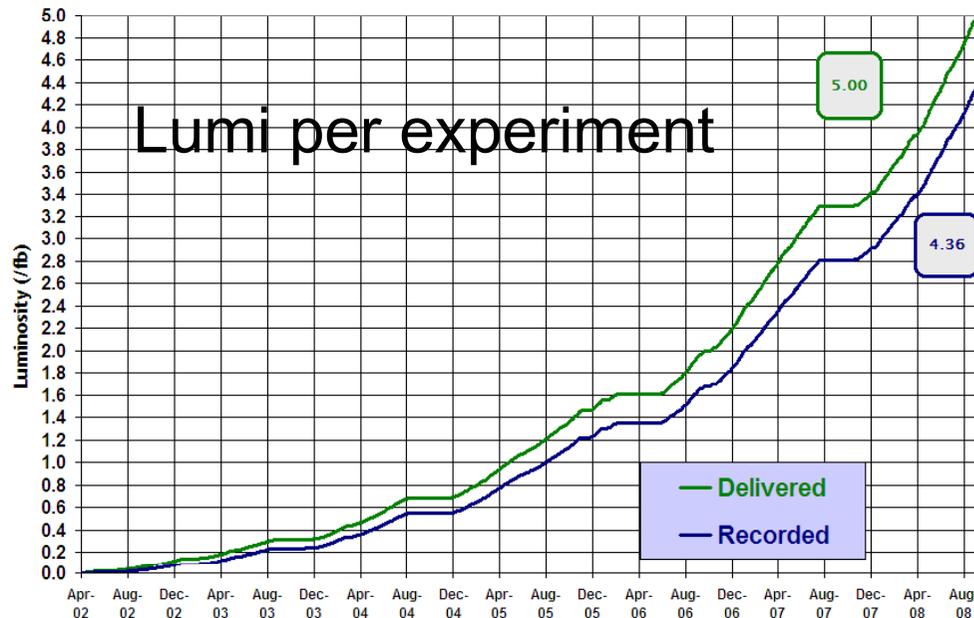
Tevatron

- Tevatron is running really well:



Run II Integrated Luminosity

19 April 2002 - 20 September 2008



Analyses in this talk use 0.9 - 2.7 fb⁻¹ per experiment

Expect 6-8 fb⁻¹ datasets by end of 2009 + possibly run in 2010

Data analysed with 2 multipurpose detectors CDF and D0:

EM +had calorimeters for e +jet id

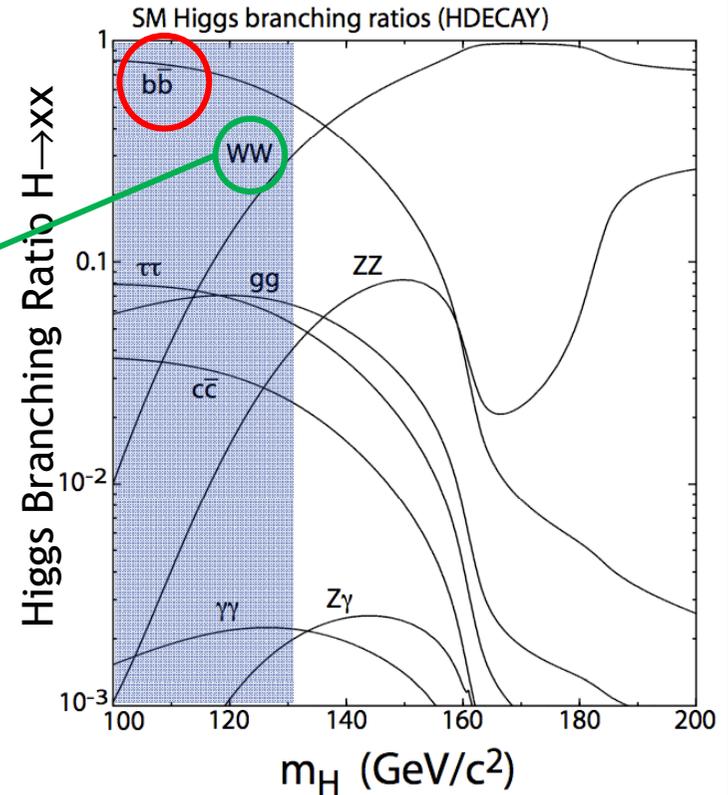
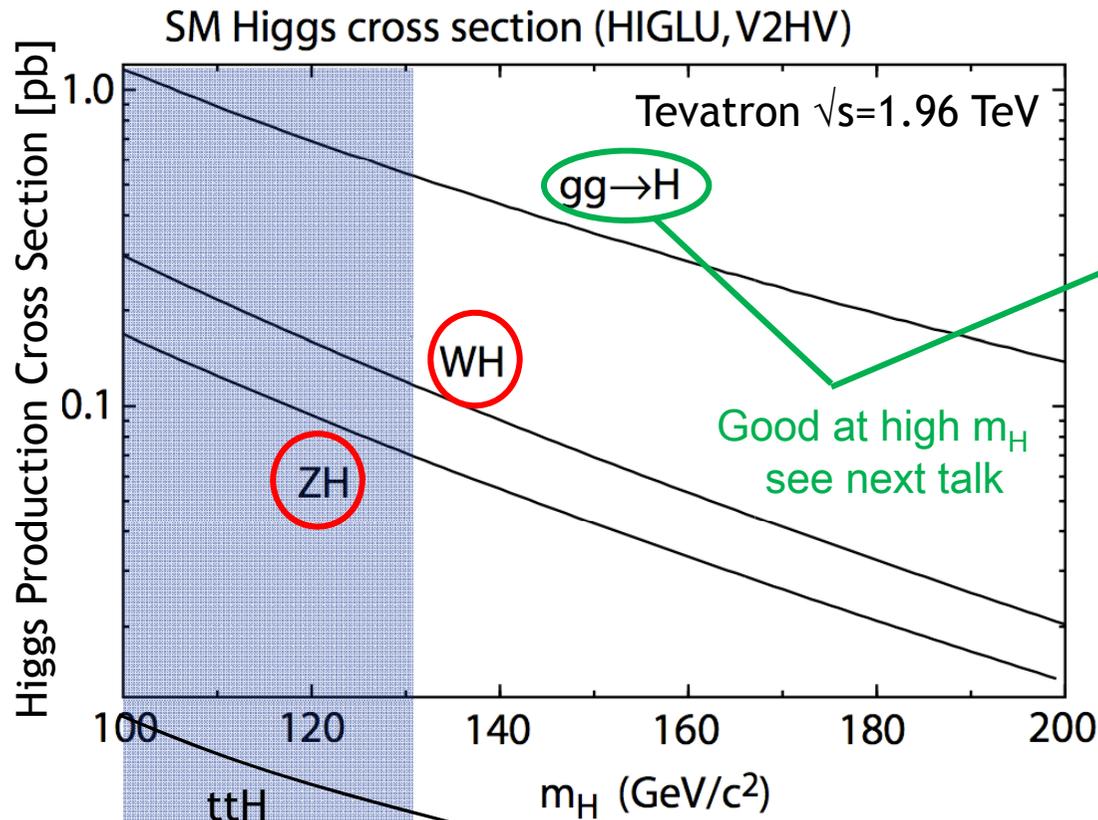
Muon detectors

Scintillator fiber/drift chamber

Silicon vertex detectors for b tagging



Higgs Production at the Tevatron and Decay



Main channels at low $m_H < 130$ GeV

$WH \rightarrow l\nu bb$

$ZH \rightarrow llbb, \nu\nu bb$

Additional low mass search channels:

- $WH \rightarrow \tau\nu bb$
- $VH \rightarrow qqbb$
- $H \rightarrow \tau\tau$ (with jets)
- $H \rightarrow \gamma\gamma$
- $t\bar{t}H \rightarrow l\nu bbb\bar{b}qq$

Dominant $gg \rightarrow H$, $H \rightarrow bb$ has massive background



The Challenge

Higgs production is very rare.
Careful analysis to separate signal from background.

1. Trigger

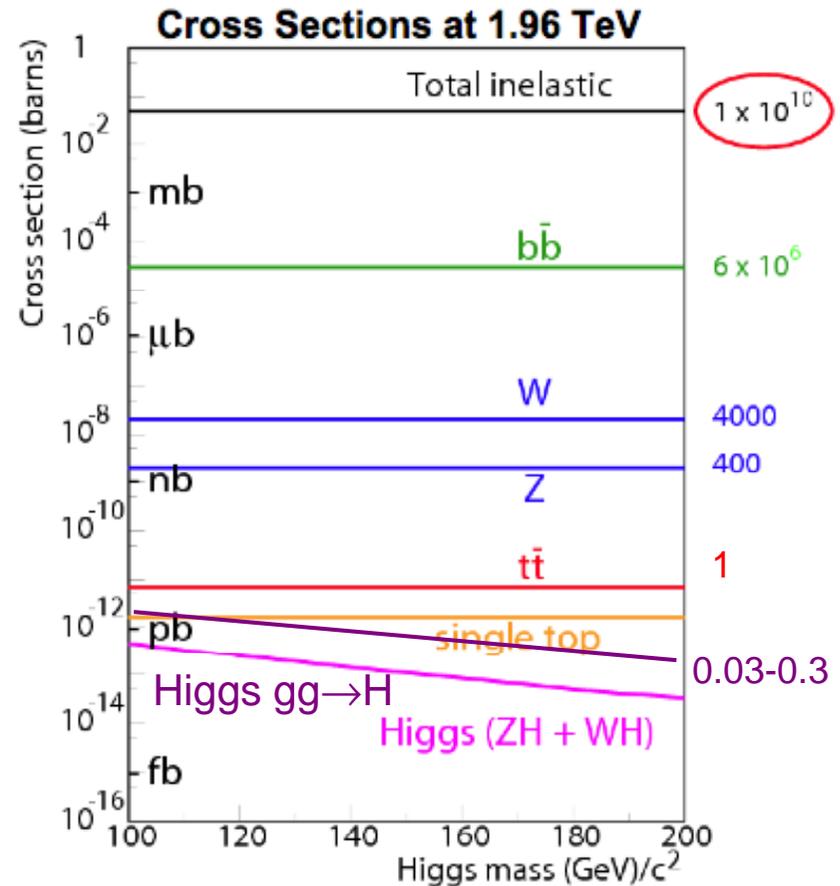
- High p_T e, μ triggers
- MET + Jets triggers
- Track + MET + Ecal τ -trigger

2. Reconstruct final state

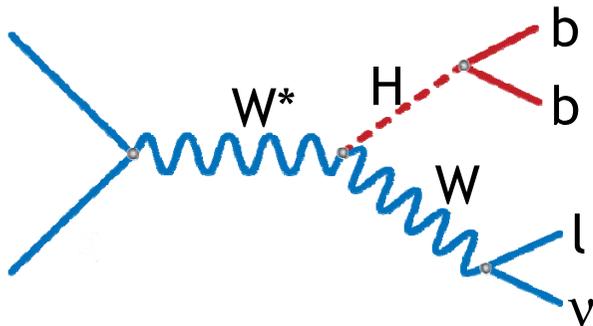
- Leptons
- Efficient b-tagging
- Good jet resolution
- MET reconstruction

3. Separate signal and background

- Measure backgrounds
- Advanced analysis tools to separate signal from background (NN, ME, BDT)



$WH \rightarrow l \nu b b$



- ◆ 1 lepton+MET+ 2 b jets final state
- ◆ About 3-4 evts / 1fb^{-1}
- ◆ Most sensitive channel at low mass at present

Main background $W+bb$



NN Inputs:

$$P_T^{j1}, P_T^{j2}, \Delta R_{jj}, \Delta\phi_{jj},$$

$$P_T^{jj}, M_{jj}, P_T^{\ell-MET}$$



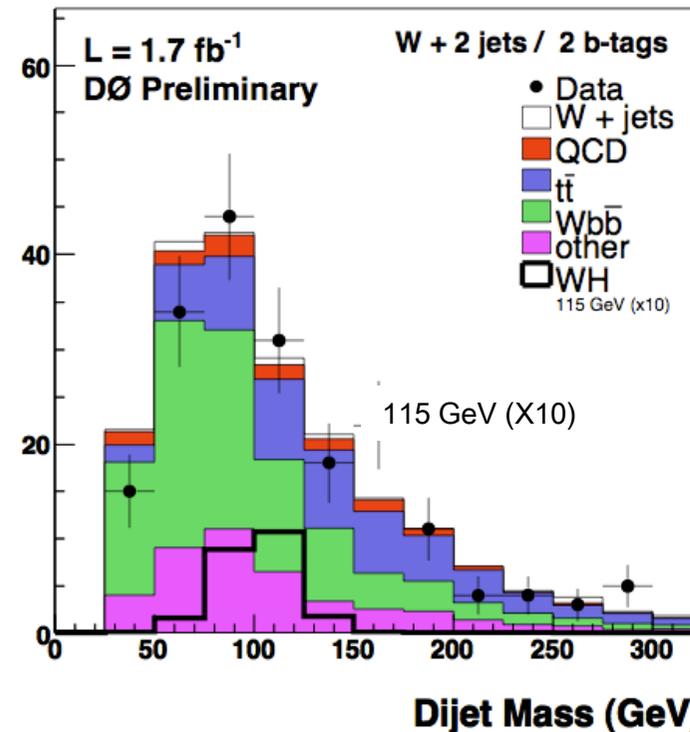
NN Inputs:

$$M_{jj}, P_T^{imb}, P_T^{sys},$$

$$M_{\ell\nu j}^{min}, \Delta R_{\ell\nu}, E_T^{jets}$$

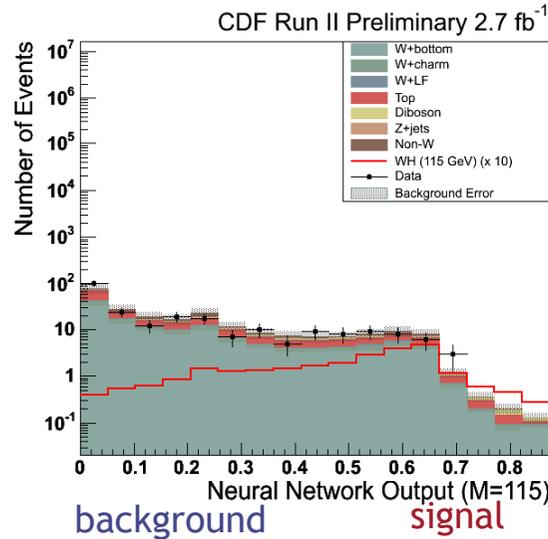
Analysis Technique

- ◆ Loose double or tight single b tagging
- ◆ Lepton ID enhanced with isolated tracks, forward e + extended muons
- ◆ Include W+3 jet data
- ◆ NN discriminator
- ◆ ME+BDT

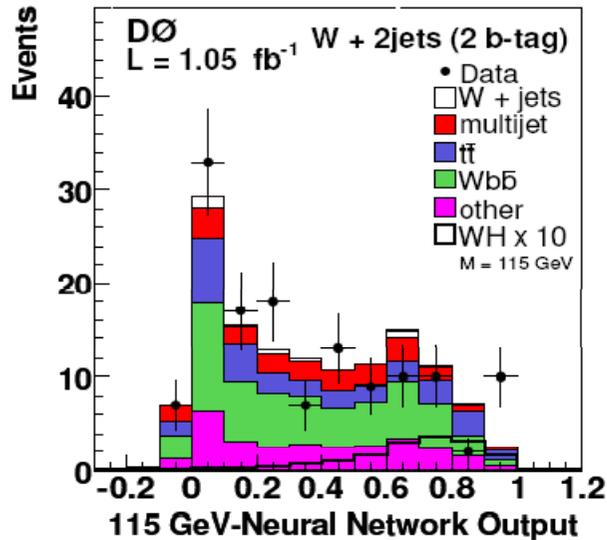
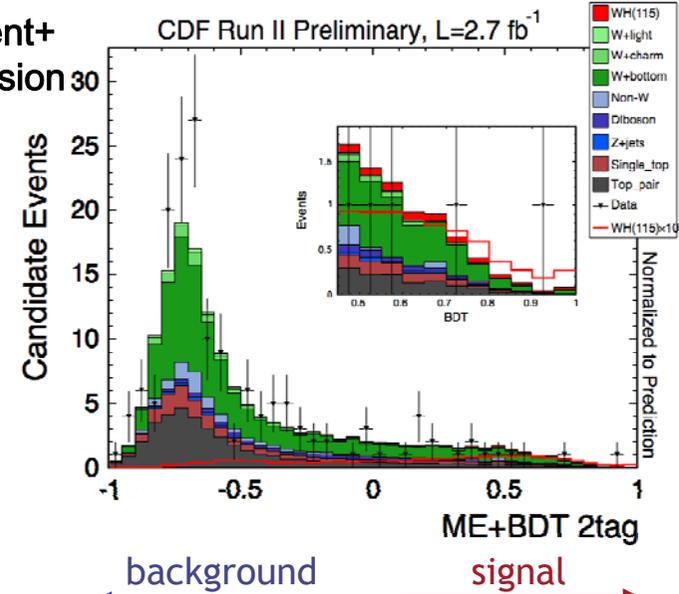


$WH \rightarrow l \nu b b$

Neural Network



Matrix Element+ Boosted Decision Tree

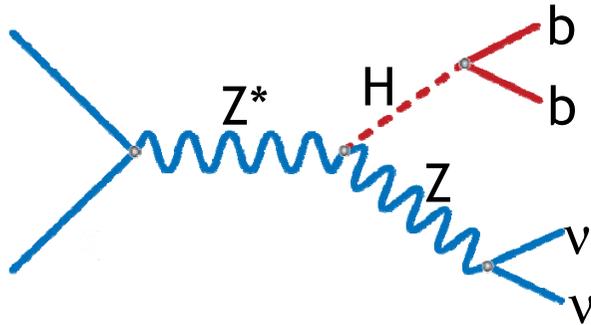


Results at $m_H = 115\text{GeV}$: 95%CL Limits/SM

Analysis	Lum (fb ⁻¹)	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.7	8.3	5.8	5.0
CDF ME+BDT	2.7	7.8	5.6	5.7
DØ NN	1.7	7.5	8.5	9.3



$ZH \rightarrow \nu \nu b b$

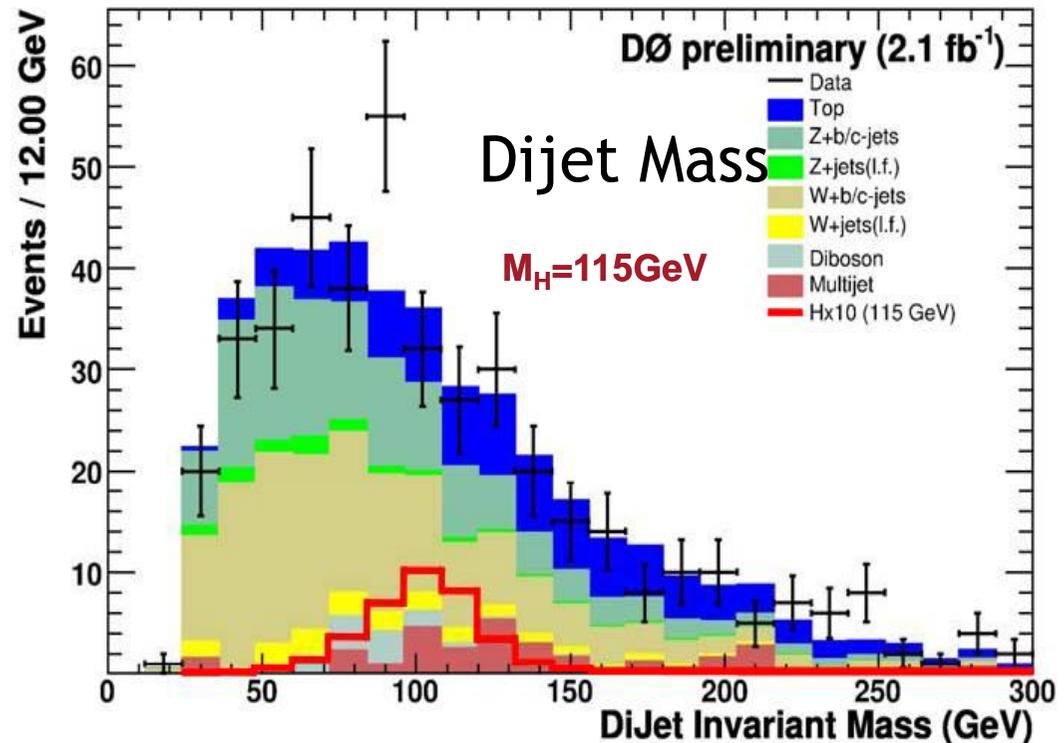


Analysis Technique

- ◆ Use data to estimate multijet background
- ◆ Add 3rd jet to get acceptance for $WH \rightarrow \tau \nu b b$ (CDF) or dedicated analysis (D0)
- ◆ CDF adds tracks to jets to improve resolution (H1 alg)
- ◆ D0: BDT with 24 inputs
- ◆ CDF: Uses NNs

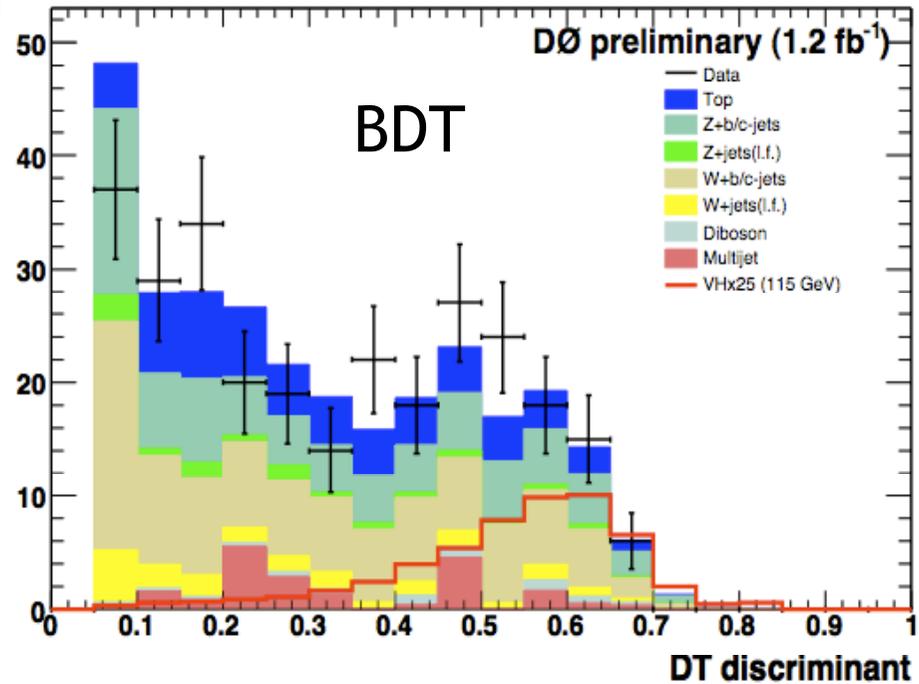
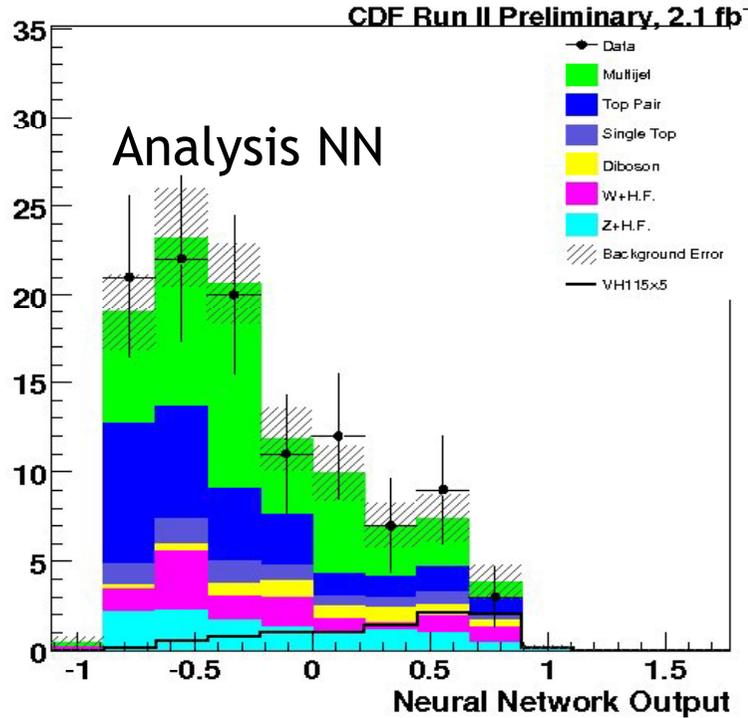
- ◆ Large MET + 2 b jets
- ◆ Also add $WH \rightarrow (l) \nu b b$ when lepton is missed
- ◆ $\sim 3-4$ evts / fb^{-1}

Main backgrounds Z+bb,
W+bb, multijets



$ZH \rightarrow \nu\nu b\bar{b}$

NN Output, Signal Region, ST+ST

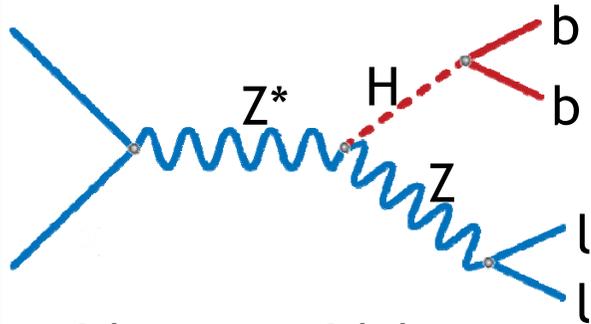


Results at $m_H = 115\text{GeV}$: 95%CL Limits/SM

Analysis	Lum (fb ⁻¹)	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.1	7.3	6.3	7.9
DØ BDT	2.1	3.7	8.4	7.5



ZH → ll bb



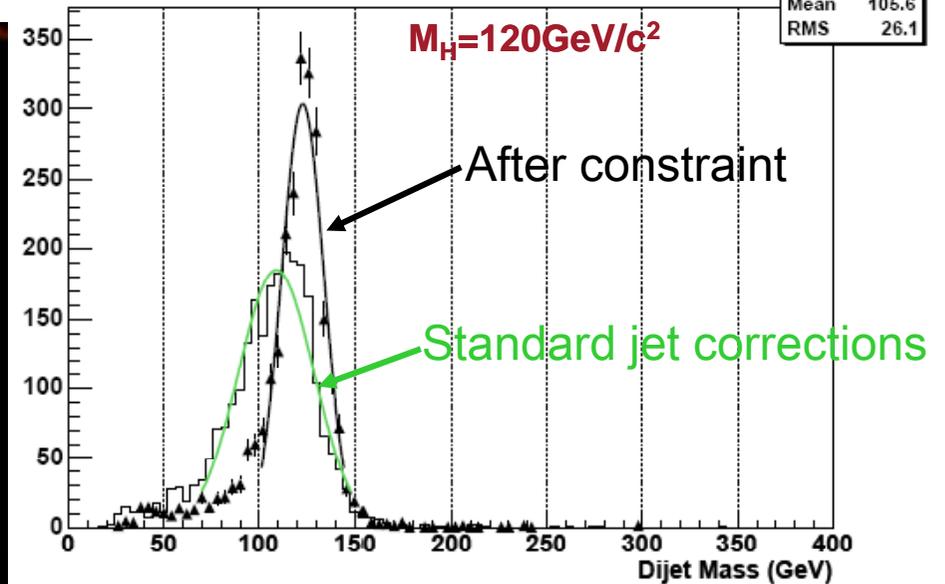
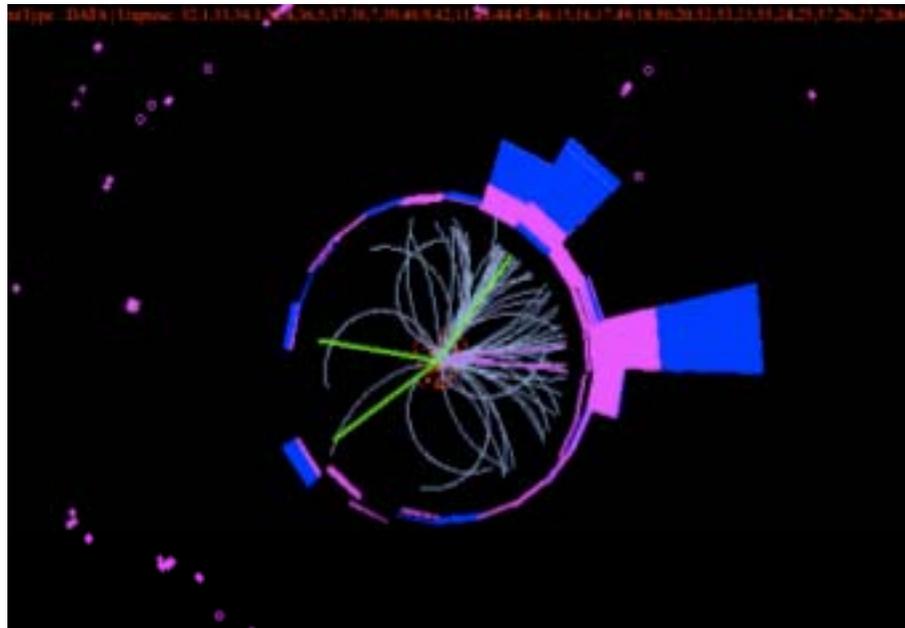
- ◆ 2 leptons + 2 b jets
→ Cleanest signature!
- No MET, can fully reconstruct event
- ◆ About 1 event / 1fb⁻¹

Analysis

- ◆ Improved dijet mass resolution with no MET constraint
- ◆ Loose double/tight single b tagging
- ◆ CAL/track only leptons
- ◆ NN, BDT, ME techniques

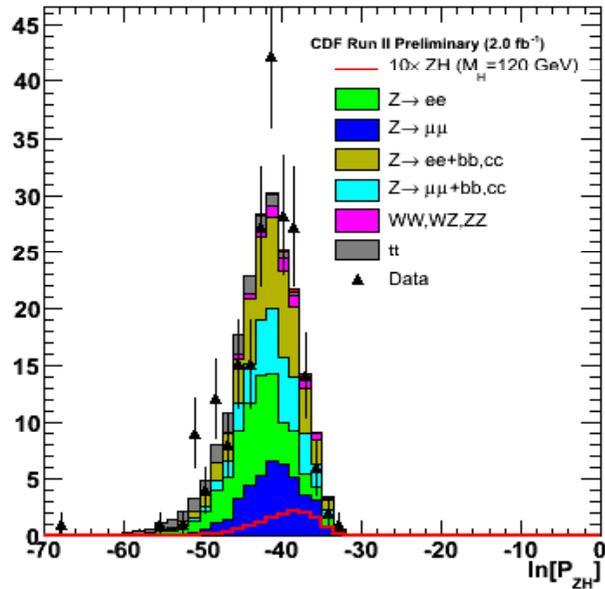
Main background Z+bb

Improvement in mass resolution



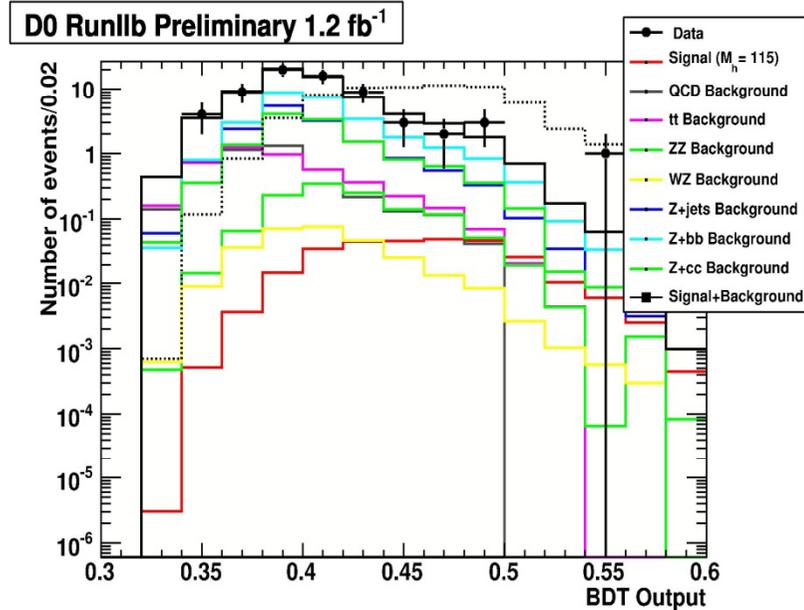
$ZH \rightarrow llbb$

Matrix Element



Limit as good per fb⁻¹ as
WH channel

Boosted decision tree

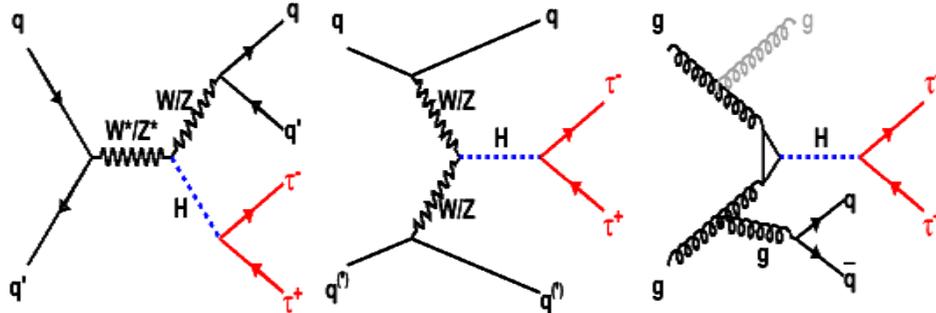


Results at m_H = 115 GeV: 95%CL Limits/SM

Analysis	Lum (fb ⁻¹)	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.4	1.8	11.8	11.6
CDF ME(120)	2.0	1.4	15.2	11.8
DØ NN,BDT	2.3	2.0	12.3	11.0

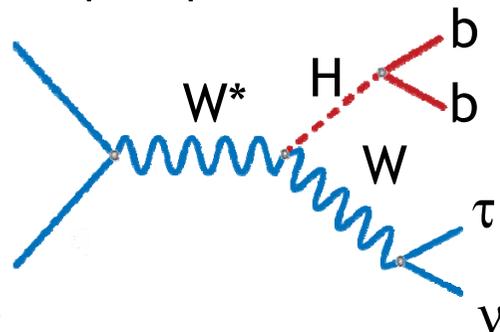


Other channels sensitive at low mass



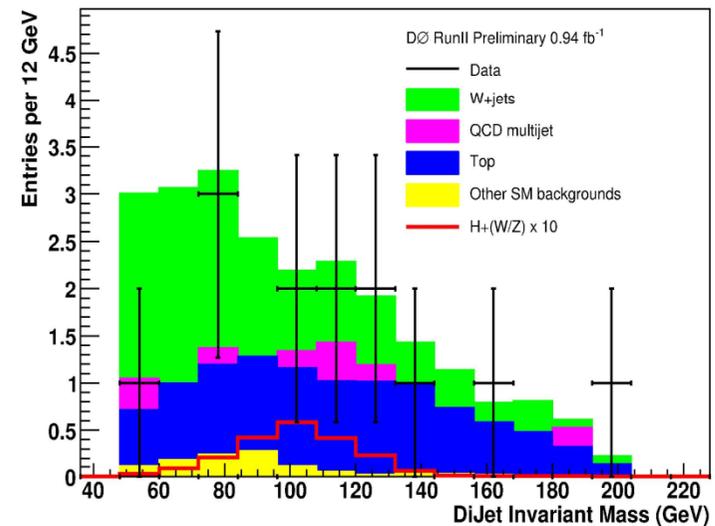
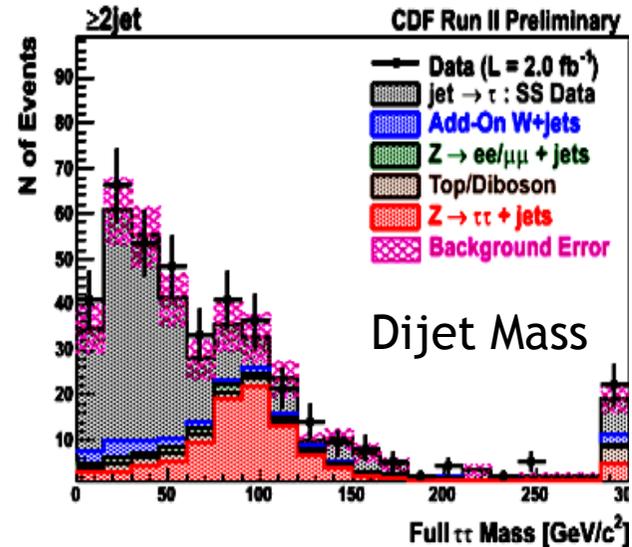
Analysis Technique

- ◆ Signature τ had+ τ lep+2 jets
- ◆ Simultaneous search in
WH+ZH+VBF+ggH
- ◆ Use NN to extract signal
- ◆ Good proof of principle for LHC

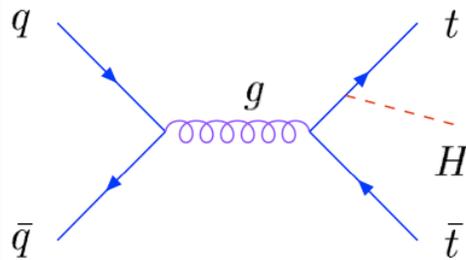


Analysis Technique

- ◆ Hadronic τ + MET + 2 b jets
- ◆ Use Dijet mass to extract signal

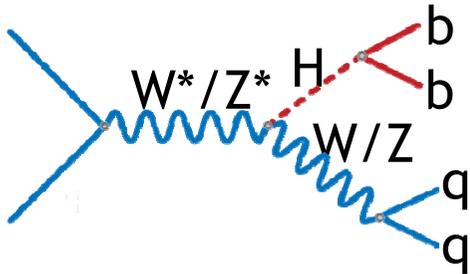


Other channels sensitive at low mass



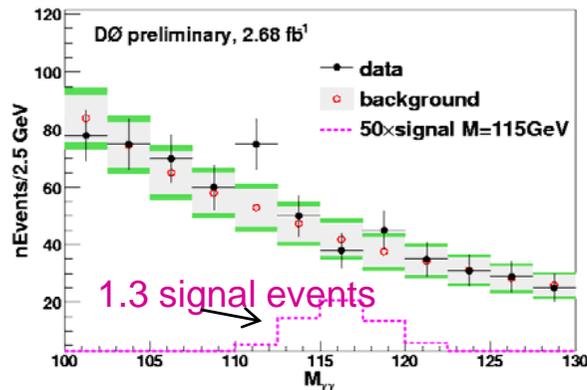
Analysis Techniques

- ◆ 1 lepton + MET + 4 or ≥ 5 jets
- ◆ Separate events into
- ◆ 1,2,3, ≥ 3 b tags
- ◆ Use scalar sum of jets (H_T) to extract signal

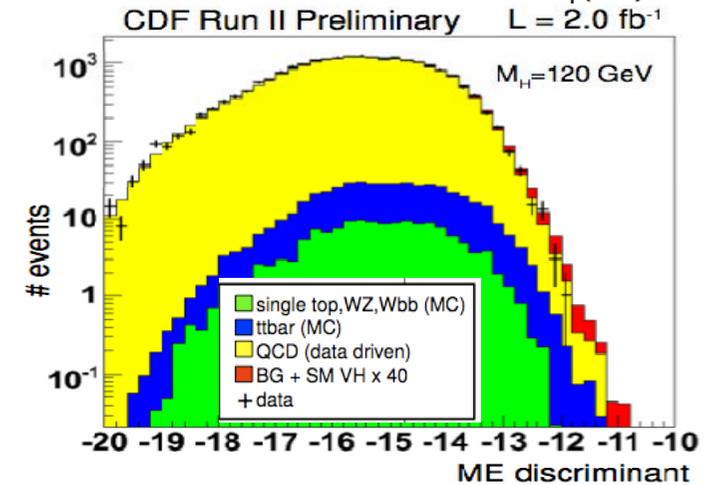
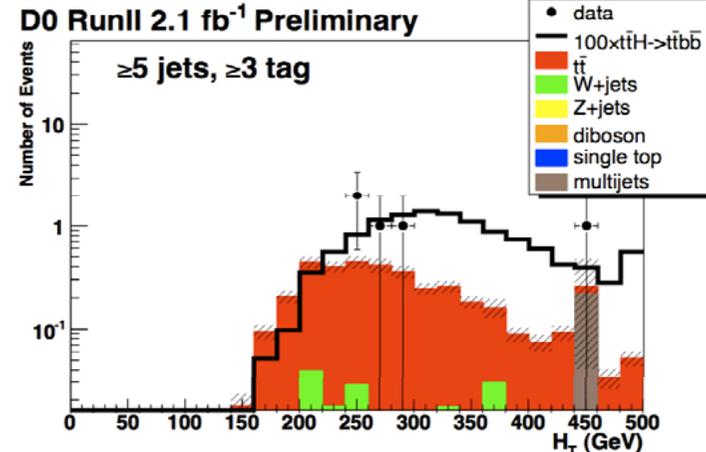


- ◆ 4 jets, ≥ 2 b jets
- ◆ Large BR of $W/Z \rightarrow qq$
- ◆ Large multijet background
- ◆ Use matrix element to extract signal

$H \rightarrow \gamma\gamma$



- ◆ 2 photons
- ◆ NN photon id
- ◆ Low BR $H \rightarrow \gamma\gamma$
- ◆ Background QCD $\gamma\gamma, \gamma\text{jet}$
- ◆ Use di-photon mass to extract signal



Summary of Analyses

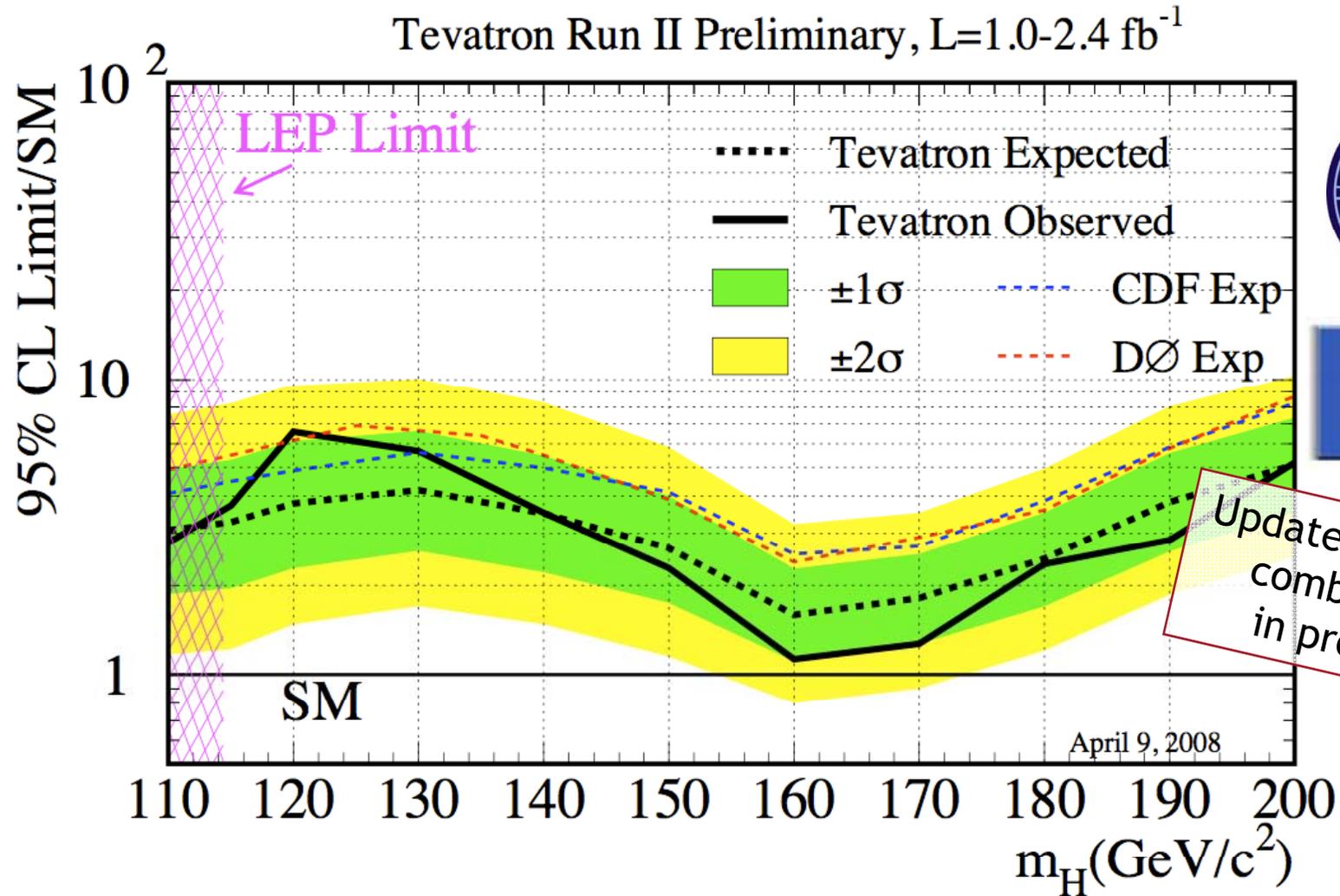
Channel	CDF	D0
	95% C.L. Limits $\sigma \cdot \text{BR} / \text{SM obs (exp)}$	95% C.L. Limits $\sigma \cdot \text{BR} / \text{SM obs (exp)}$
WH \rightarrow lvbb (NN)	5.0 (5.8) 2.7fb⁻¹	9.3 (8.5) 1.7fb⁻¹
WH \rightarrow lvbb (ME+BDT)	5.7 (5.6) 2.7fb⁻¹	
WH \rightarrow τ vbb (NN)	-	35.4 (42.1) 0.9fb⁻¹
VH \rightarrow qqbb (ME)	37.0 (36.6) 2.0fb⁻¹	-
ZH \rightarrow llbb (NN)	11.6 (11.8) 2.4fb⁻¹	11.0 (12.3) 2.3fb⁻¹
ZH \rightarrow llbb (ME) <small>($m_H=120$ GeV)</small>	14.2 (15.0) 2.0fb⁻¹	
ZH \rightarrow vv/WH \rightarrow (l) vbb (NN)	7.9 (6.3) 2.1fb⁻¹	7.5 (8.4) 2.1fb⁻¹
ttH \rightarrow lvbbbbqq	-	63.9 (45.3) 2.1fb⁻¹
H \rightarrow $\gamma\gamma$	-	30.8 (23.2) 2.7fb⁻¹
H \rightarrow $\tau\tau$	30.5 (24.8) 2.2fb⁻¹	-
Combined	4.2 (3.6)	5.3 (4.6)

Also WW contributes in the low mass region



Tevatron Combination

- Status of April 9th 2008 -



Updated Tevatron combination in progress!

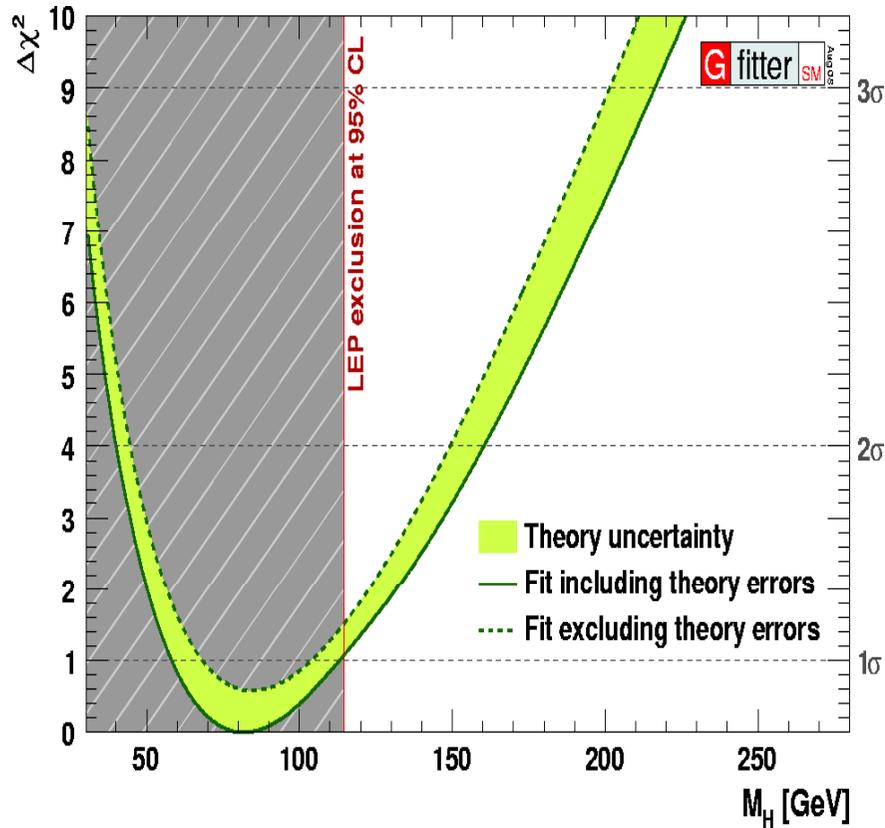


Conclusions

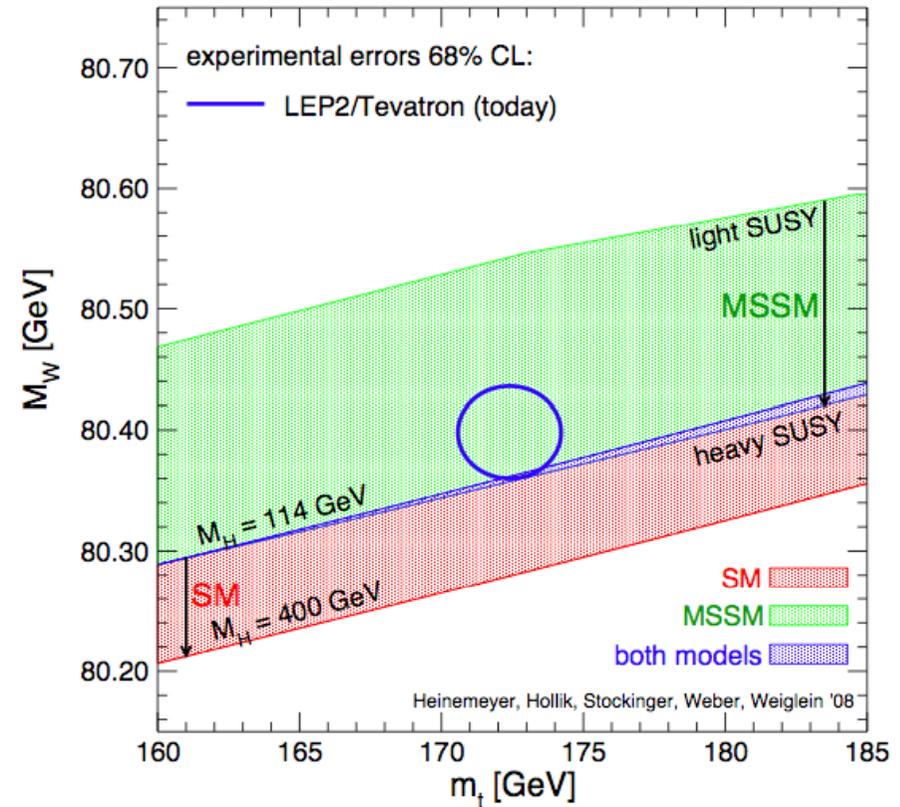
- Higgs physics at the Tevatron is getting exciting!
- Low mass region has large backgrounds, but can be suppressed by multi-variant techniques and understood in control regions
- Expected limit should fall below
~ 3 x SM for $m_H=115 \text{ GeV}/c^2$ in the next Tevatron combination
- Additional improvements actively in progress
 - Further extending signal acceptance for leptons and b tagging
 - Improved jet resolution
 - Extended b-tagging and flavour separators
- Expect 2-3 times current analyzed lumi (more if we run in 2010)
- Details on each analysis is available at:
 - CDF: <http://www-cdf.fnal.gov/physics/new/hdg/hdg.html>
 - D0: <http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm>



Indirect limits



If Higgs is Standard Model Higgs, mass is likely to be low



Supersymmetric Higgs is also low mass



Identification of b -quarks (b -tagging)

- Most sensitive channels have $H \rightarrow bb$
- Silicon detectors used to find secondary vertices
- Efficiency $\sim 40 - 70\%$
- Fake rate (mistags) typically $0.5 - 5\%$
- D0 uses Neural Network tagger based on b -lifetime information. Can use multiple operating points.
- CDF utilizes secondary vertex and Jet Probability algorithms + additional NN flavor separator
- Use either single tag or looser double tag

