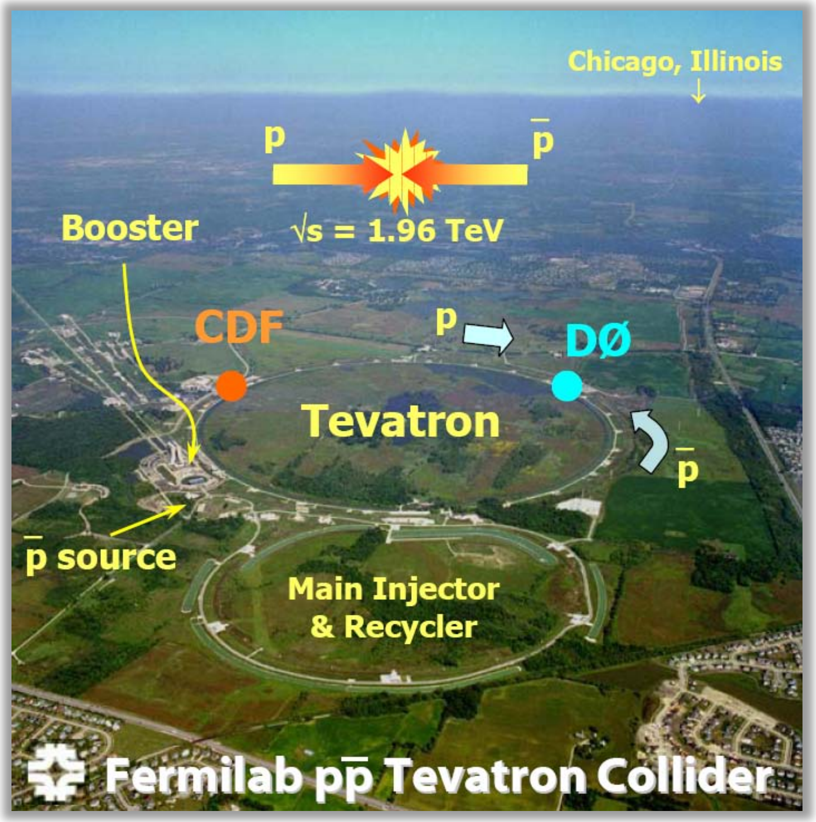
# Higgs Searches at the Tevatron: Low mass primary channels

On behalf of CDF and D0 collaborations

Taka Yasuda
Fermilab

# Outline of Talk

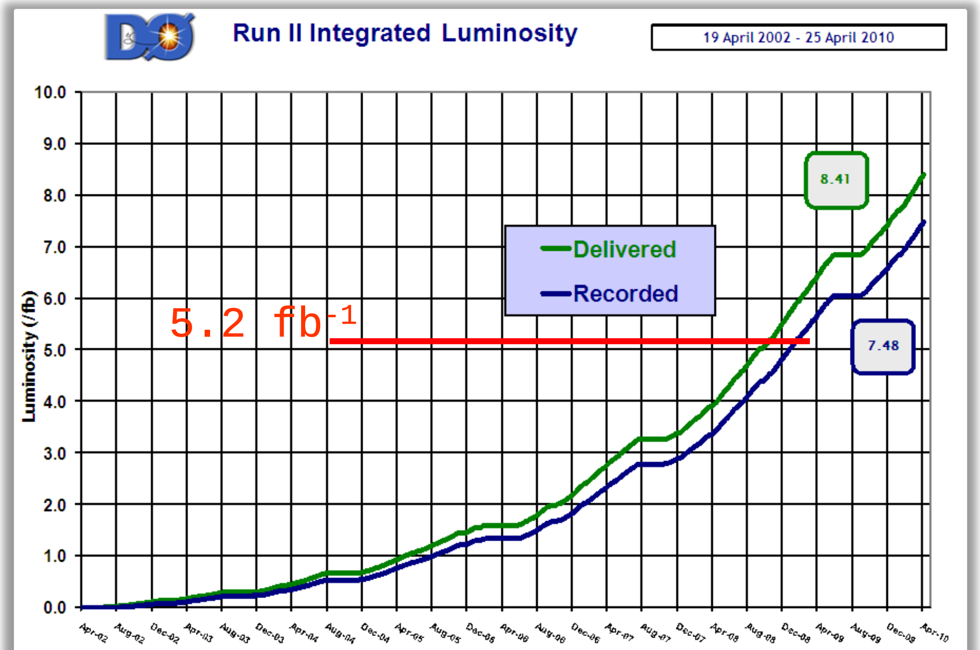
- Introduction
- Standard Model Higgs boson
- B-tagging
- Searches for the SM Higgs boson
  - $WH \rightarrow l\nu bb$
  - $ZH \rightarrow llbb$
  - $ZH \rightarrow \nu\nu bb, WH \rightarrow (l)\nu bb$
- Putting all together
- SM Higgs prospects
- Conclusions

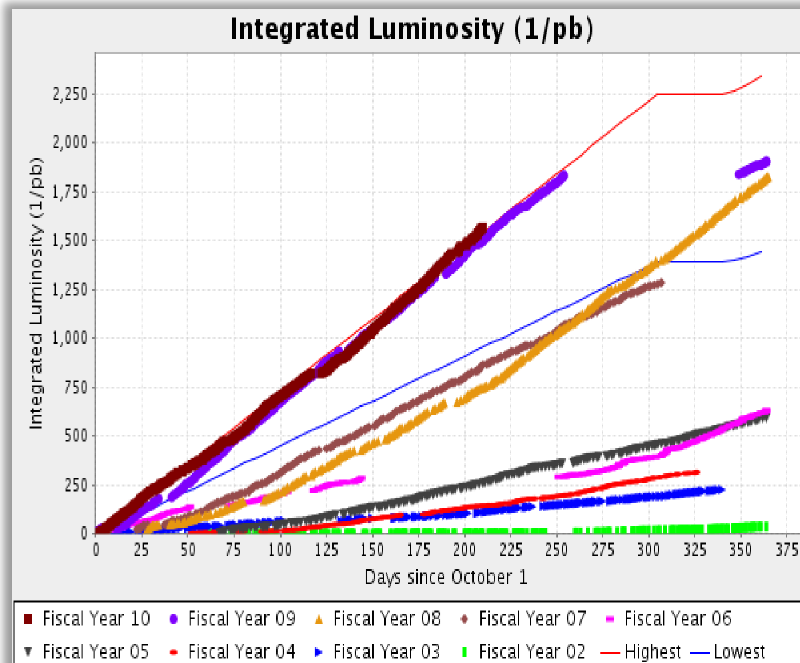


# Introduction

- Over 8.4 $fb^{-1}$ delivered and over 7.5 $fb^{-1}$ recorded per expt by May, 2010.
- Expect ~9 $fb^{-1}$ by Jun 2010

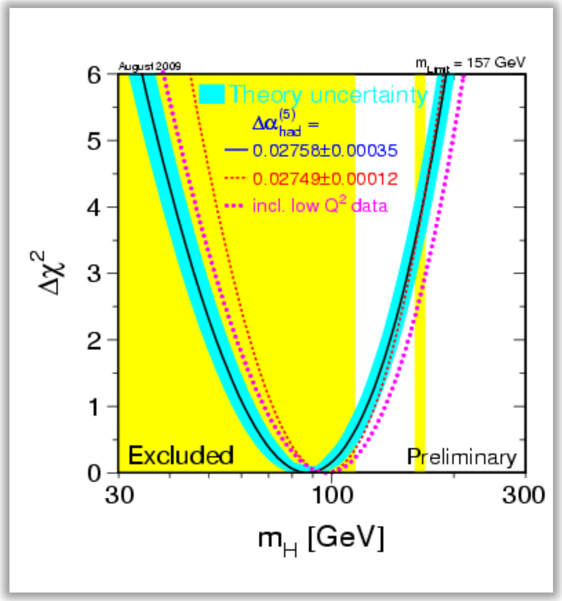
Tevatron and CDF/D0 both running extremely well

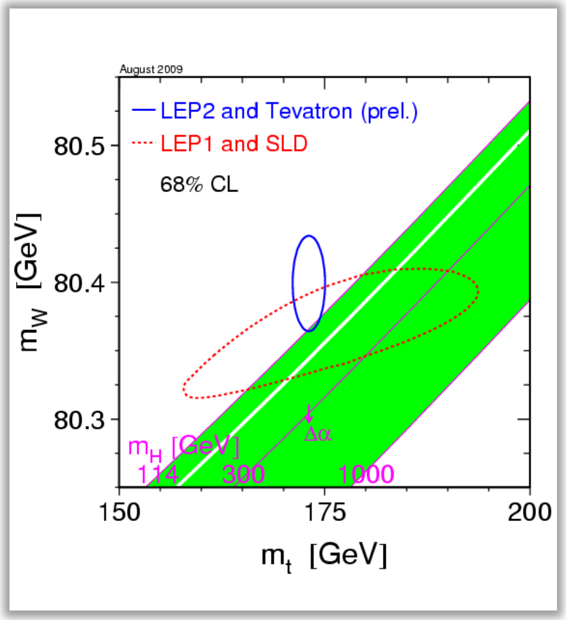


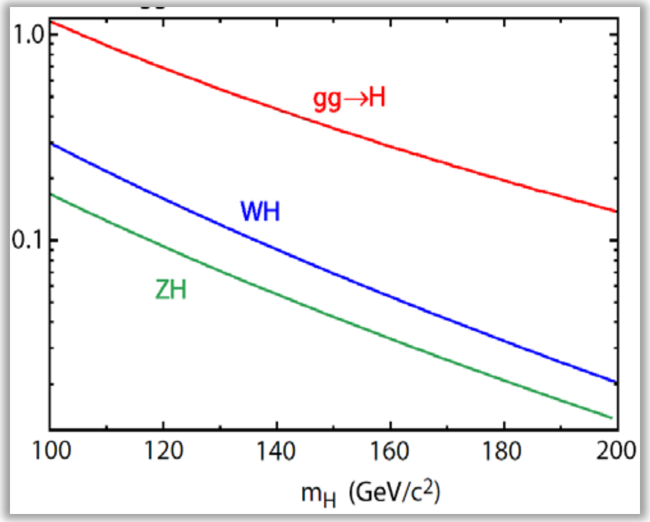
# Standard Model Higgs Boson

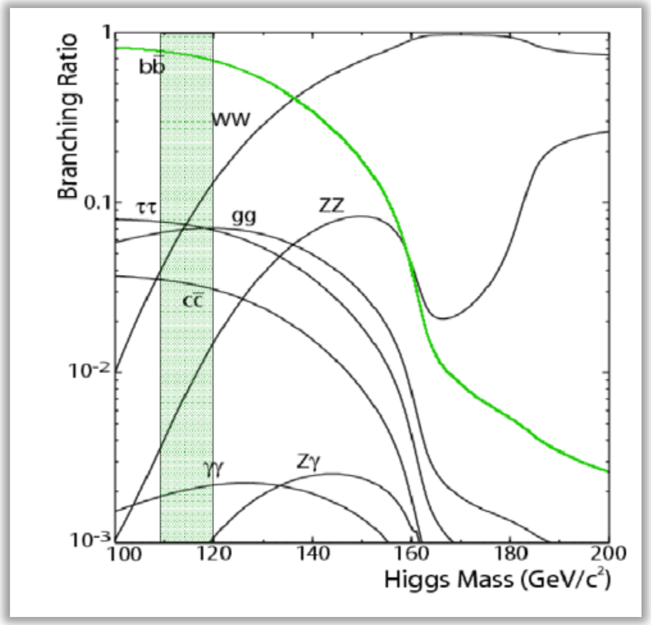
- Higgs mechanism
  - Additional scalar field in SM Lagrangian
    $\rightarrow$ mass to particles
  - Predicts neutral, spin 0 boson
    - But not its mass
- Direct searches at LEP2
  - $m_H > 114.4$ GeV @95%CL
- Improved $m_t$ & $m_w$ tighten indirect constraints:
  - $m_H < 157$ GeV @ 95%CL (EW fit)
  - Preferred $m_H = 87^{+35}_{-26}$ GeV @ 68%CL



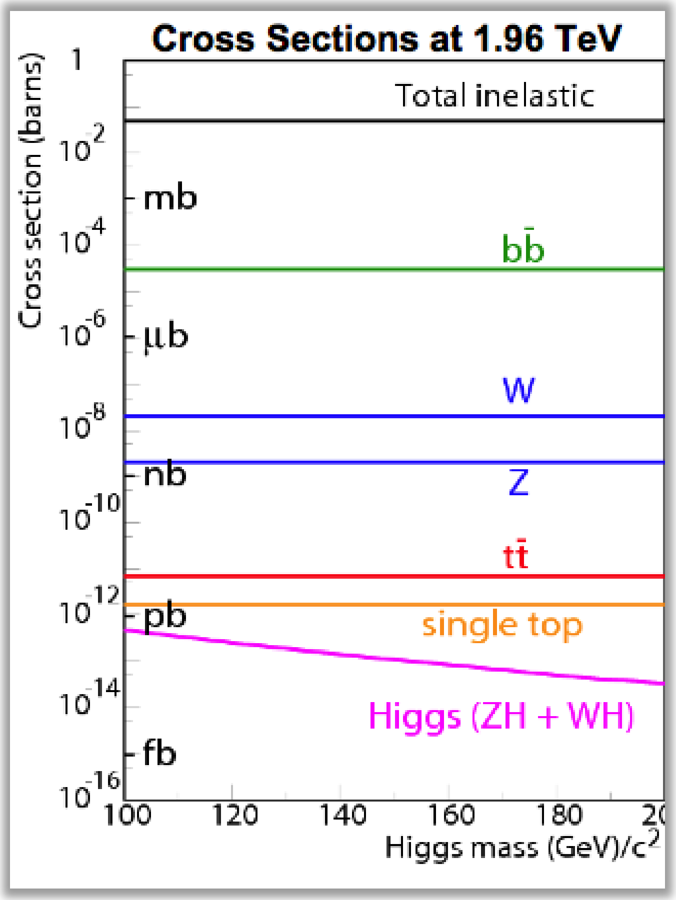
- Small production cross-sections
  - 0.1 –1 pb
- Branching ratio dictates search
- $m_H < 135$ GeV
  - gg → H → bb overwhelmed by multijet (QCD) background
  - Associated WH & ZH production with H → bb decay
- $m_H > 135$ GeV
  - gg → H → WW



# Searches

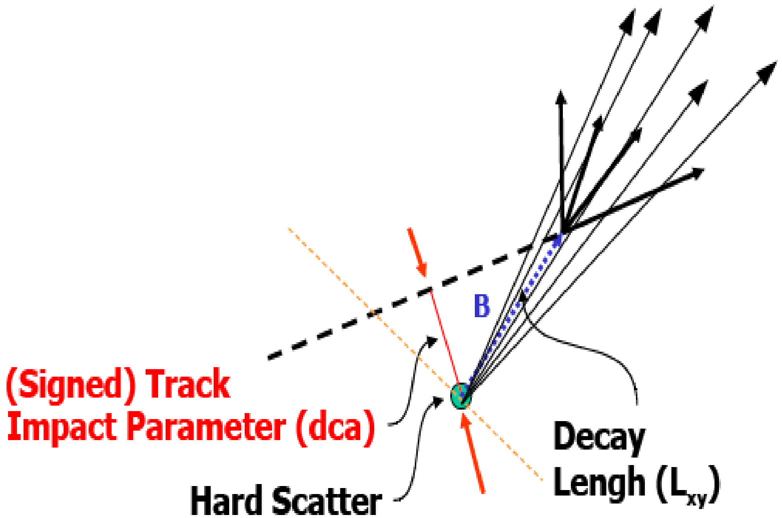
- Higgs searches at a hadron machine challenging
- Backgrounds
  - W/Z+bb, W/Z+cc, W/Z+jets, top, di-boson, multijet
- Requires
  - Efficient triggering, lepton ID, b-tagging, good jet E resolution
  - Sizeable data sets



# B-tagging

- Required for low mass $H \to bb$
  - Improves S/B by > 10
- Take advantage of relatively long lifetime of B-quarks

**Neural Net tagger**
- Combining
  - Impact Parameter based
  - Secondary Vertex reconstruction
- High efficiency, purity
- **Loose = ~50-70% eff, 1-6 % mistag**
- **Tight = ~40-50% eff, 0.5 % mistag**




- Analyse separately ("tight") single & ("loose") double tags

# Analysis Method

- Advanced analysis techniques to set limits
  - Analyses use multivariate techniques
    - Output from Neural net (NN), Matrix element (ME), Boosted decision tree (BT), or Random Forest as the final discriminant to set the cross section limit

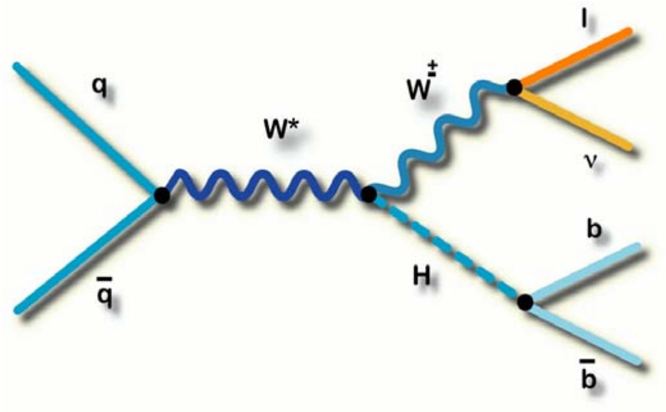
- Regular Tevatron combinations
  - Having two experiments helps.

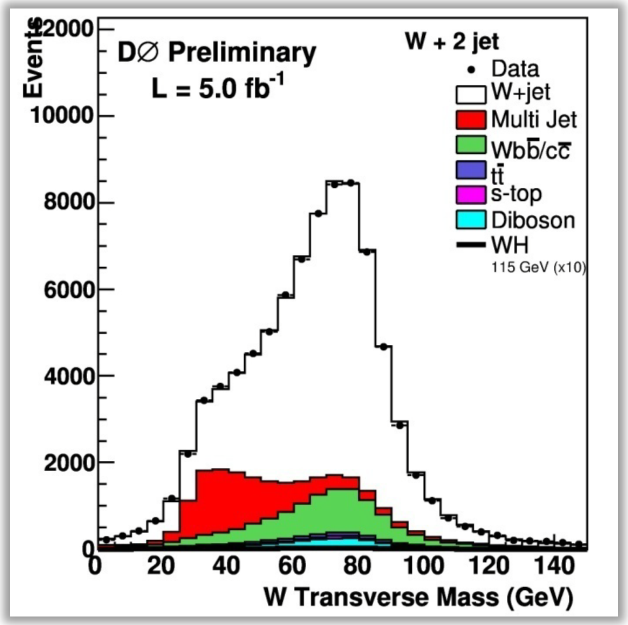
# Sytematics

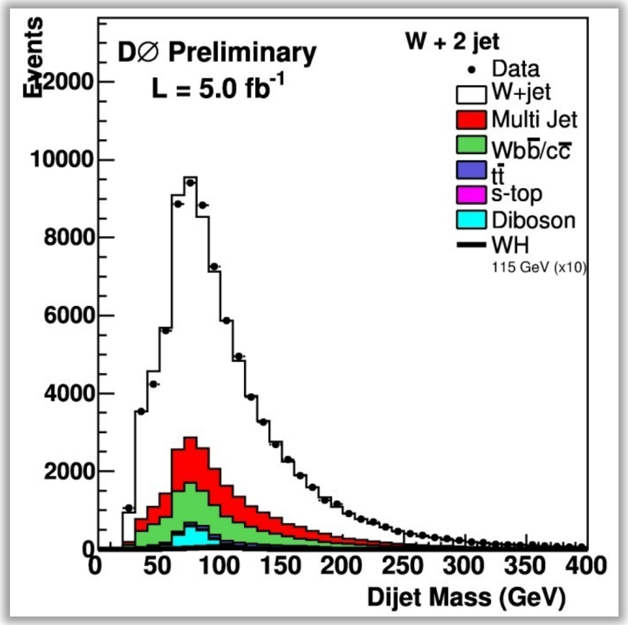
- As the collected data increases, so does the importance of systematics.
  - Flat systematcis on the final discriminant
    - Luminosity
    - Lepton ID efficiencies
    - Theoretical cross sections
    - Z+HF cross section ~20%
  - Shape dependent systematics on the final discriminant
    - Jet systematics
    - B-tagging systematics
    - Trigger modeling systematics
    - W/Z+jets kinematics modeling
      - W/Z pT
      - Alpgen scale
      - Alpgen-pythia matching scheme
    - PDF

# WH→lνbb

- Higher cross section
  - Use electron and muon channels
- Selection
  - Isolated single lepton, missing $E_T$ (MET), 2 or 3 high $p_T$ jets with 1 or 2 jets b-tagged

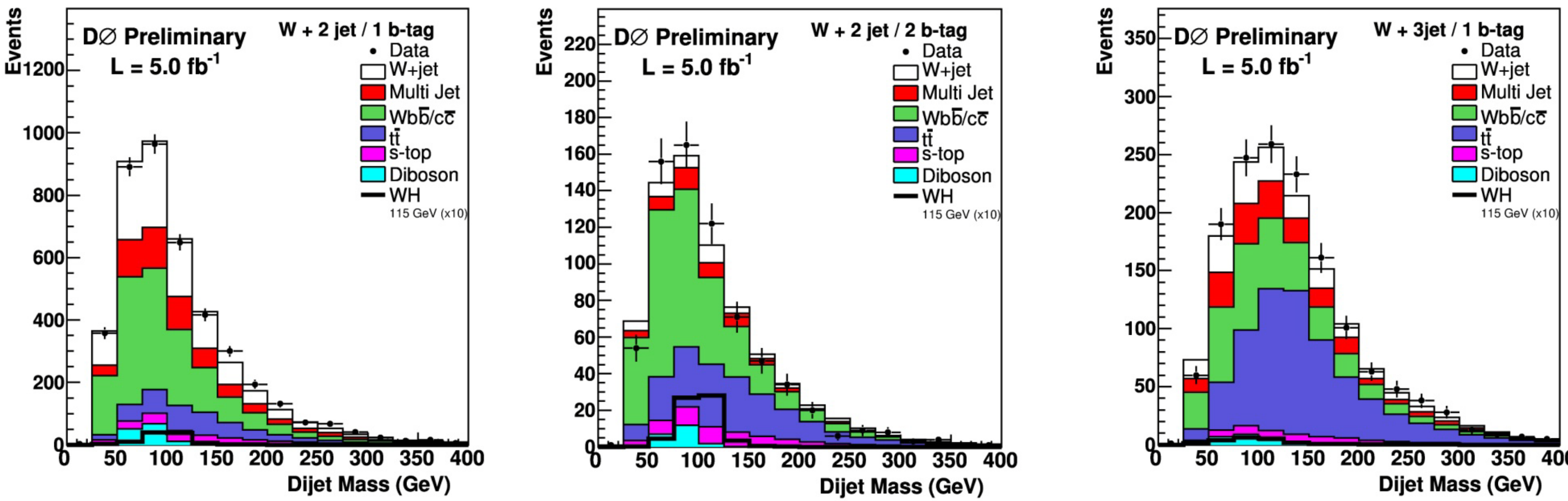


# WH→lνbb

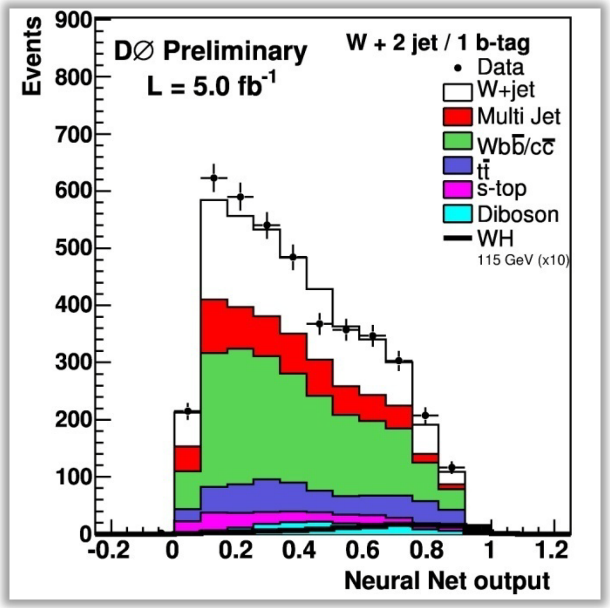
- Analyses
  - Separate 1 “tight” &  2 “loose” b-tag channels
  - Apply corrections for jet kinematcal dist.

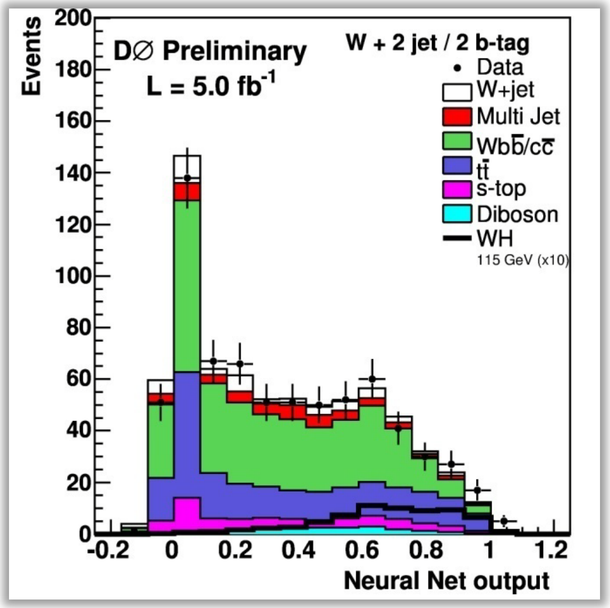



| | Number of b-tagged events | |
|---|---|---|
| | CDF(4.8 $fb^{-1}$) | D0(5.0 $fb^{-1}$) |
| Data | 5632 | 6654 |
| Background | 5666 | 6633 |
| WH($m_h$=115 GeV) | 18.6 | 19.3 |

# WH→lνbb

- Setting limits
  - 2 Jet and 3 jet events treated separately
  - D0: Neural Net based on kinematical variables
  - CDF: Discriminant based on ME probabilities



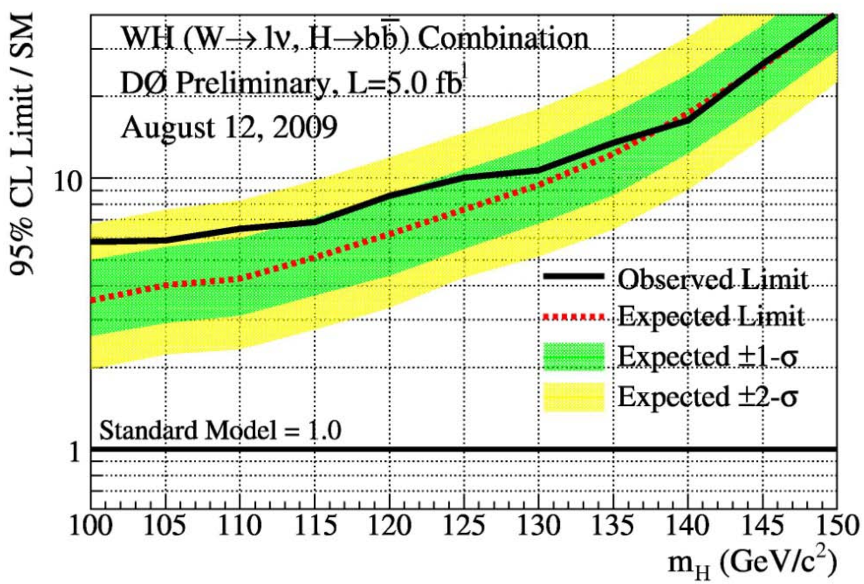



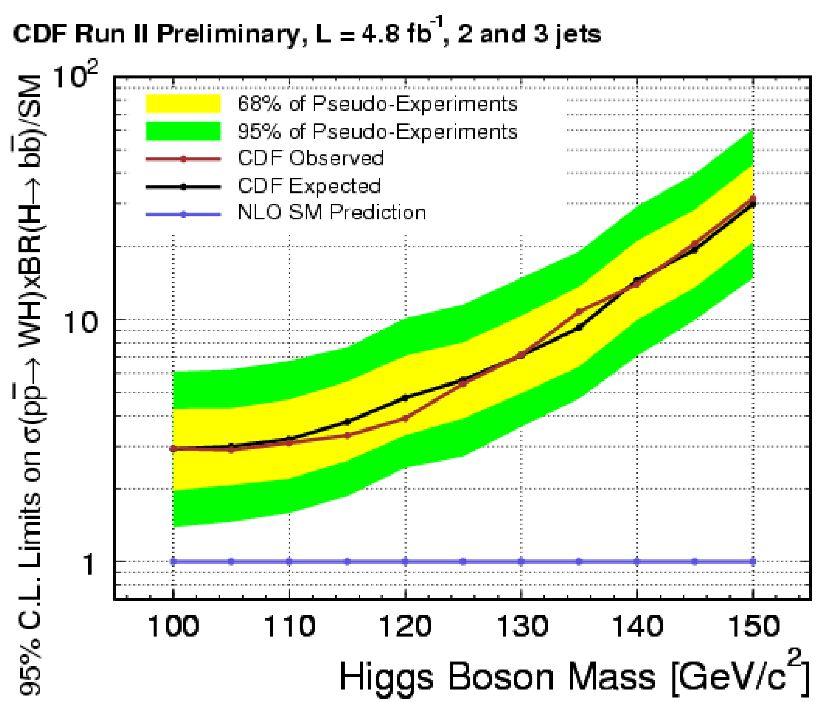
# WH→lνbb

- No significant excess
- Cross section limits derived from NN/ME discriminants

For $m_H$=115 GeV

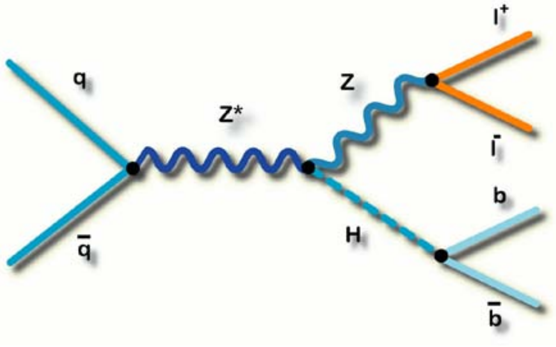
| | Lum | Exp/SM | Obs/SM |
|---|---|---|---|
| D0 | 5.0 $fb^{-1}$ | 5.1 | 6.9 |
| CDF | 4.8 $fb^{-1}$ | 3.8 | 3.3 |

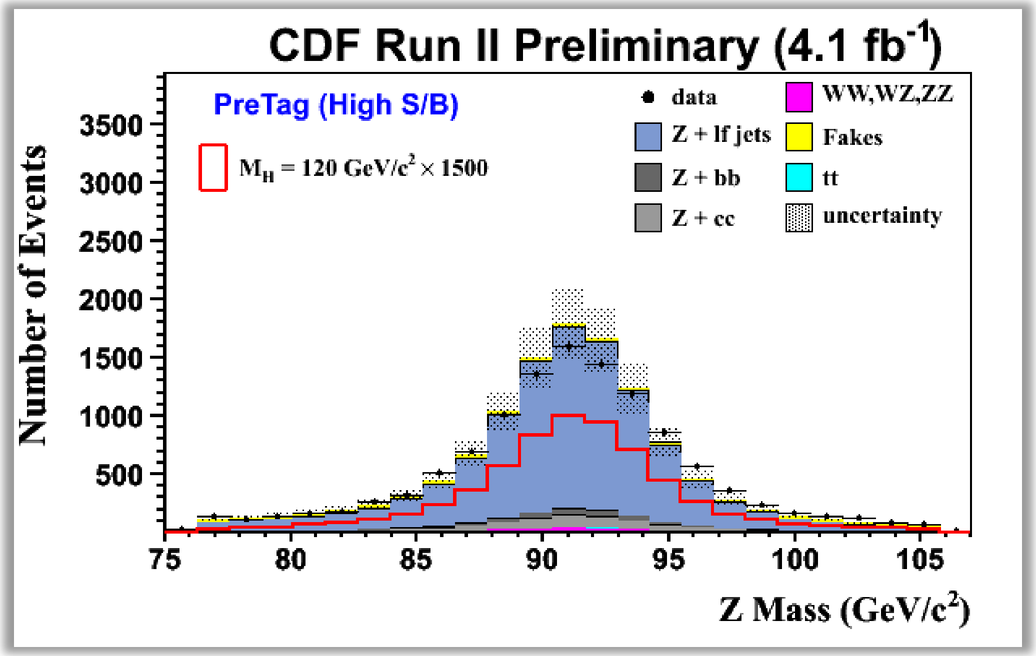


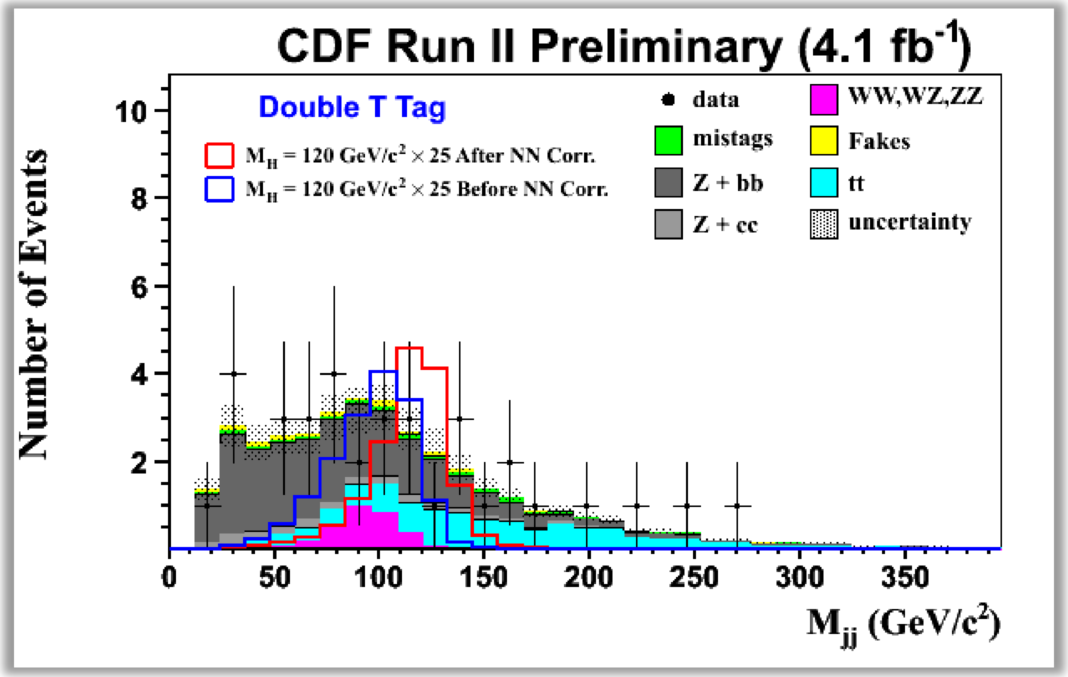
# ZH→llbb

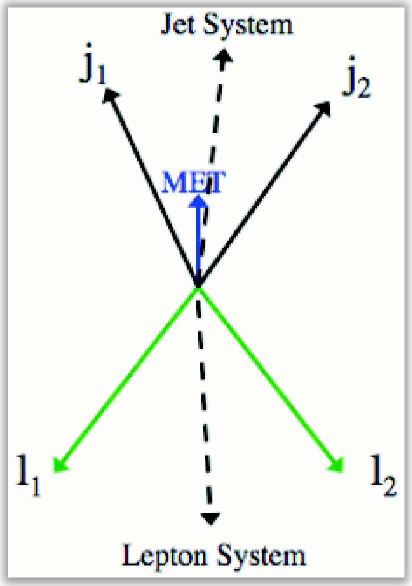
- Cleanest channel, but low cross section x BR
- Selection:
  - 2 Isolated leptons
  - 2 or 3 high $p_T$ jets with 1 or 2 jets b-tagged



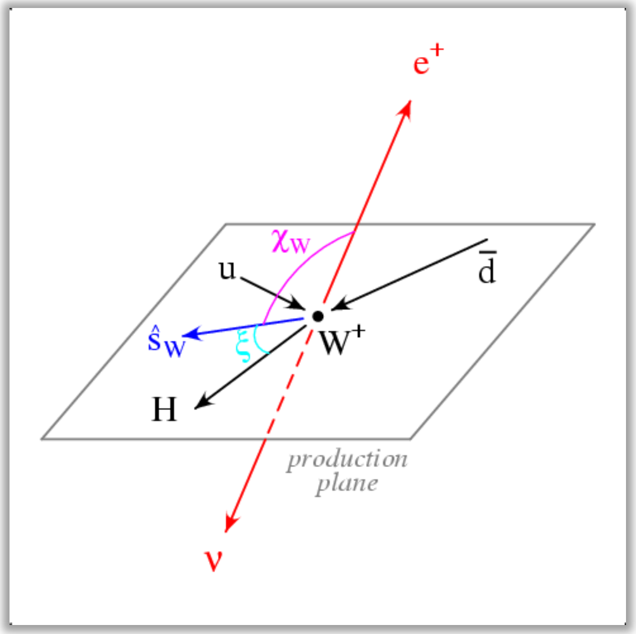
- Improving dijet mass resolution
  - Constrain MET within the MC measured distribution to improve jet E resolution
    - CDF: NN based correction
    - D0: Constrained kinematic fit



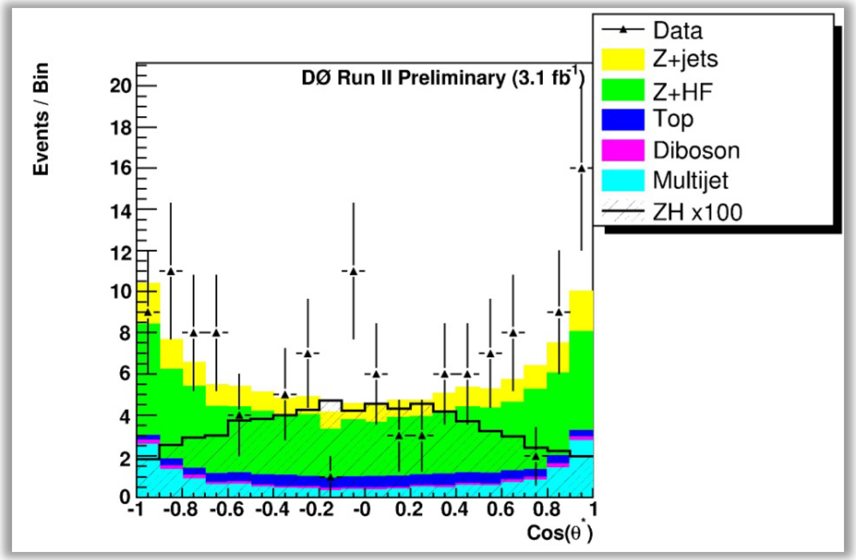
# ZH→llbb

- Spin-Angular correlation variable
  - Take advantage of difference between W/Z+H(→bb) and W/Z+bb(gluon splitting)



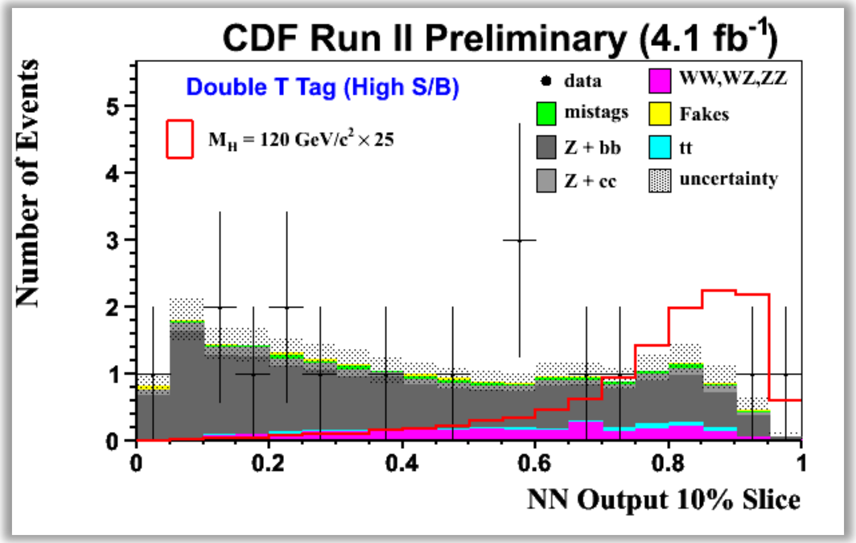

Angles in W rest-frame

S. Parke & S Veseli
PRD vol. 60, 093003



# ZH→llbb

- Discriminant
  - D0: Boosted Decision Tree
  - CDF: 2-D NN based on flavor separator NN and ME probabilities



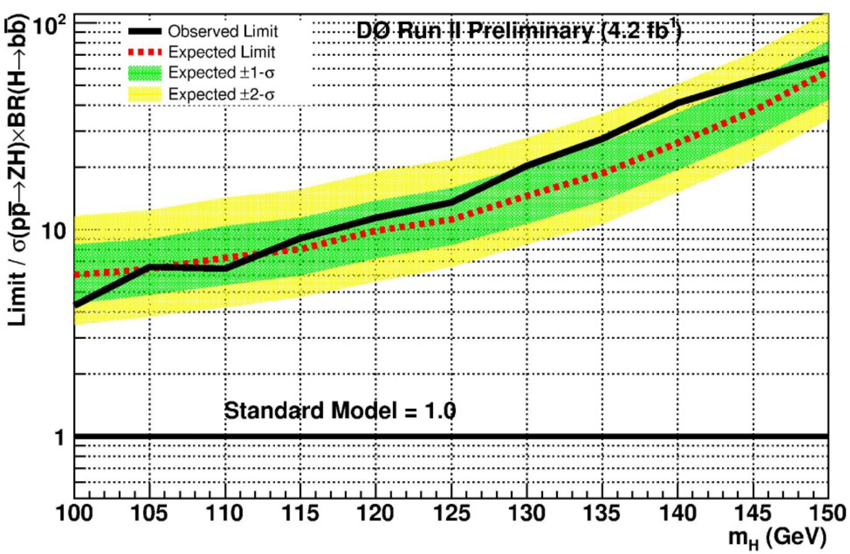

| | Number of b-tagged events | |
|---|---|---|
| | CDF(4.1 $fb^{-1}$) | D0(4.2 $fb^{-1}$) |
| Data | 485 | 332 |
| Background | 448.2 | 317.3 |
| ZH($m_h$=115 GeV) | 2.5 | 1.2 |

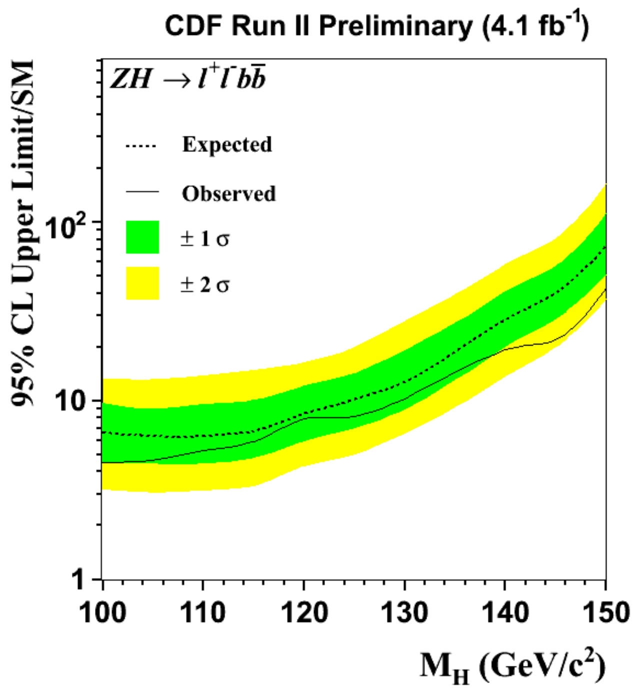
# ZH→llbb

- Cross section limits

For $m_H$=115 GeV

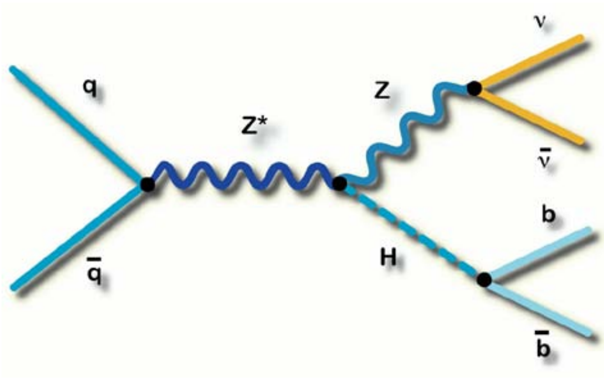
| Experiment | Lum | Exp/SM | Obs/SM |
|---|---|---|---|
| D0 | 4.2 $fb^{-1}$ | 8.0 | 9.1 |
| CDF | 4.1 $fb^{-1}$ | 6.8 | 5.9 |

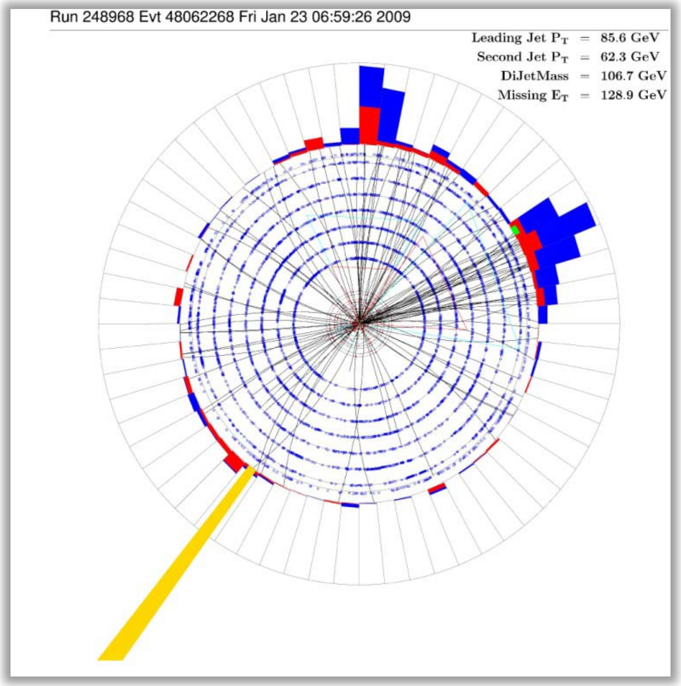


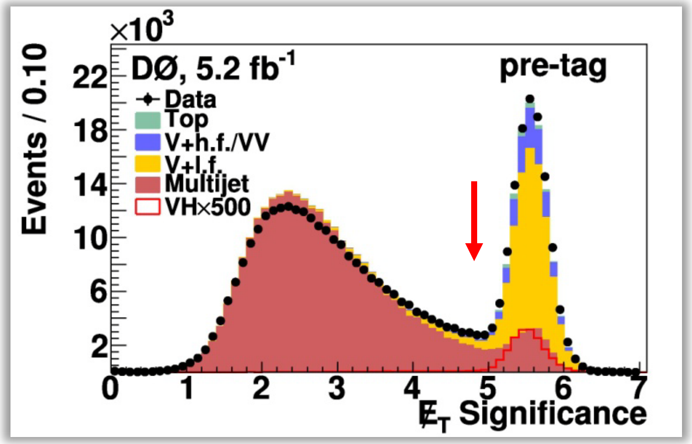
# $ZH \rightarrow \nu\nu bb, WH \rightarrow (l)\nu bb$

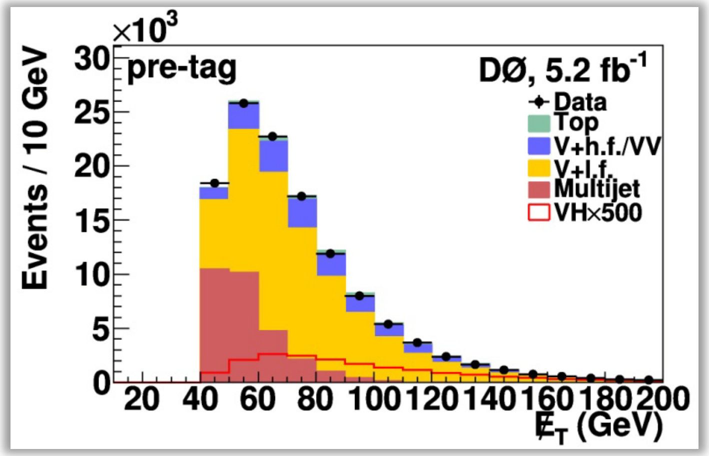
- Large cross section x BR & acceptance, but hard
  - No visible lepton & only jets
  - Large contribution from WH (~50 %)
- Selection
  - Two jets (not back-to-back: $\Delta\phi(j_1,j_2)<165^o$)
  - Large MET (not aligned in $\phi$ with jets)
  - MET calculated from calorimeter energy and calculated from tracks

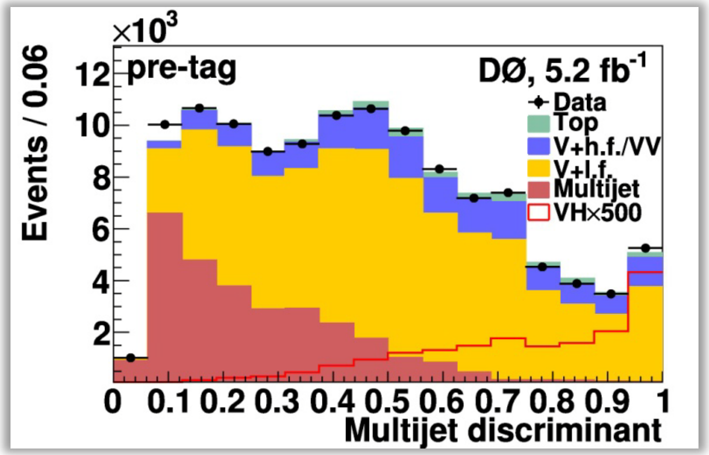


- Background rejection
  - Specialized DT(D0) or NN(CDF) for multijet background rejection

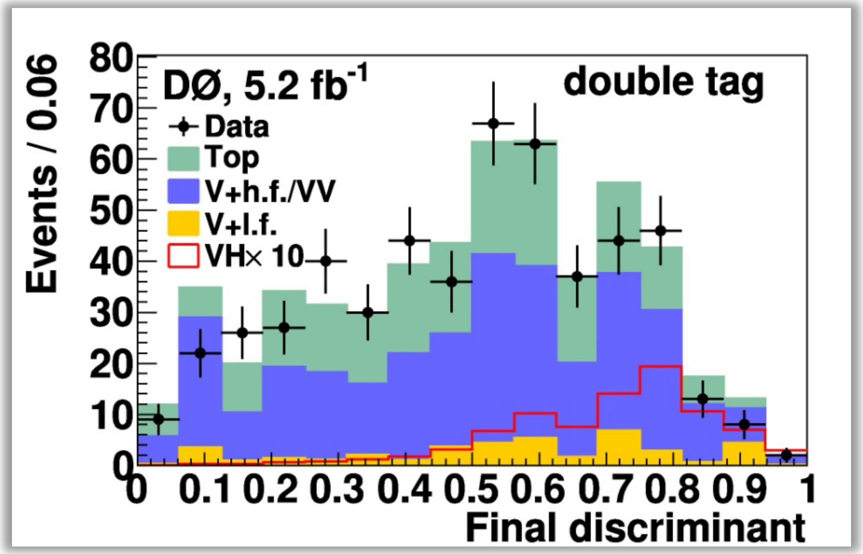


# ZH→ννbb, WH→(l)νbb

- Limit calculation with advanced analysis technique
  - Specialized DT(D0) or NN(CDF) for SM background rejection
  - Modified frequentist approach(D0) and Bayesian(CDF)



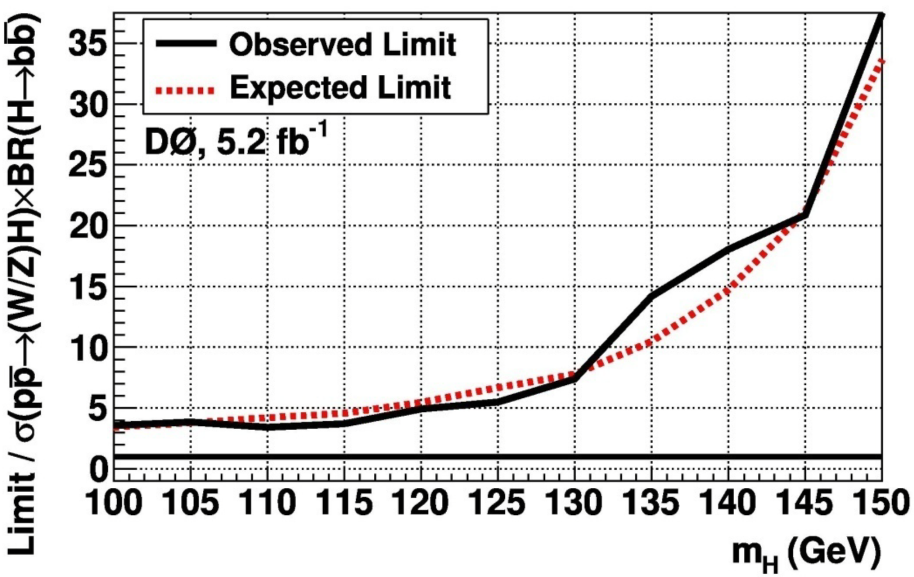

| | Number of b-tagged events | |
|---|---|---|
| | CDF(3.6 $fb^{-1}$) | D0(5.2 $fb^{-1}$) |
| Data | 2787 | 2226 |
| Background | 2901 | 2368 |
| W/ZH ($m_h$=115 GeV) | 12.4 | 16.5 |

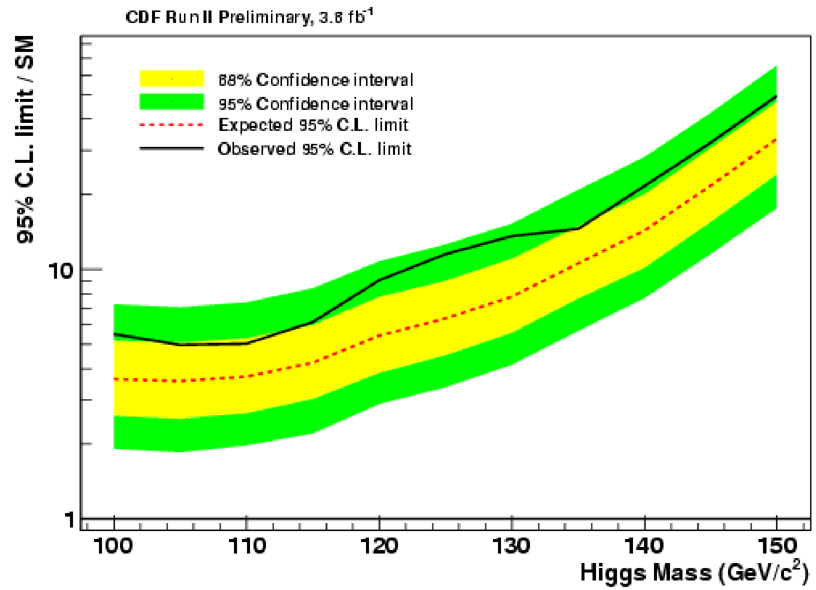
# ZH→ννbb, WH→(l)νbb

- Cross section limits

For $m_H$=115 GeV

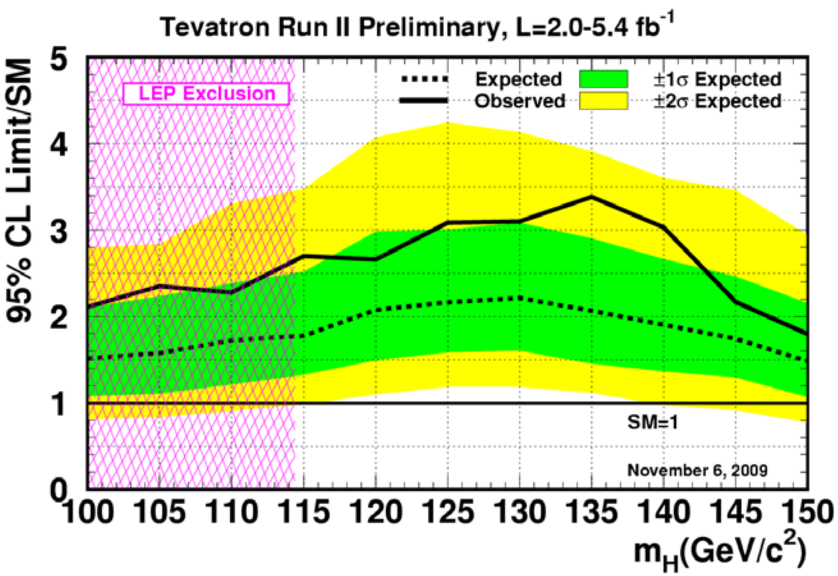
| Experiment | Lum | Exp/SM | Obs/SM |
|---|---|---|---|
| D0 | 5.2 $fb^{-1}$ | 4.6 | 3.7 |
| CDF | 3. 6 $fb^{-1}$ | 4.2 | 6.1 |

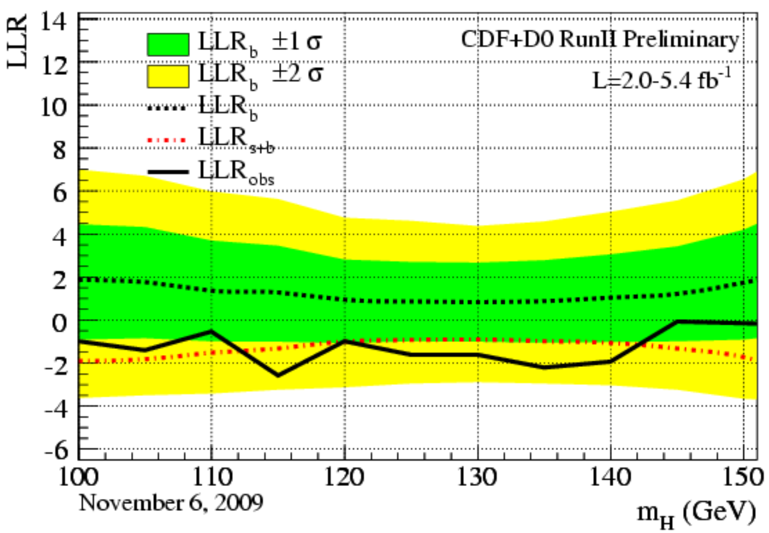


# Putting all together

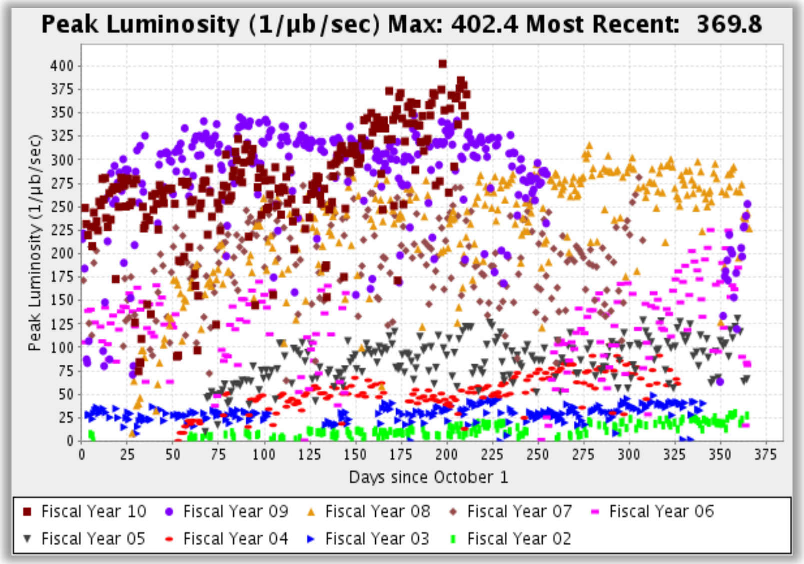
- Combine across channels within an experiment
- Combine across experiments



# Improvements in Analysis

- Improvements in analysis
  - Coping with high luminosity
    - Improved lepton ID using MVA
    - Improved vertexing
  - Expanding acceptance
    - Finding leptons in the detector gaps
      - Electrons between calorimeter gaps
      - Track only muons



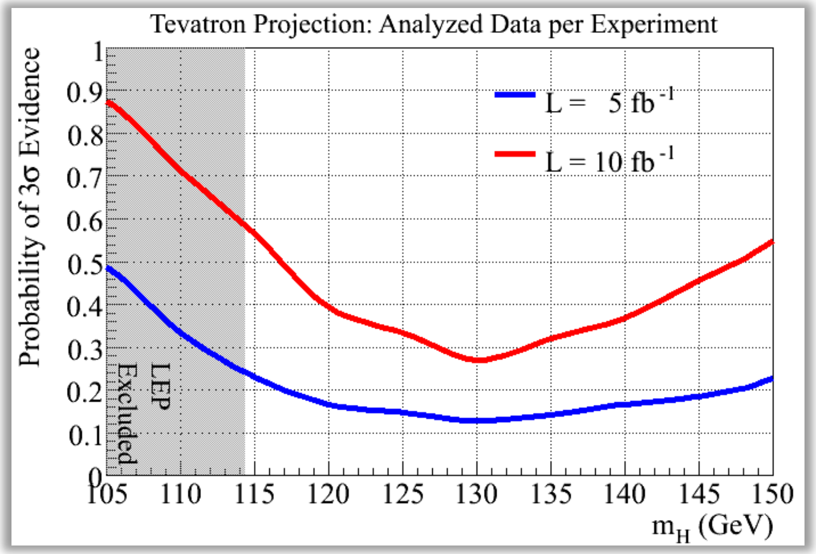
# Improvements in Analysis

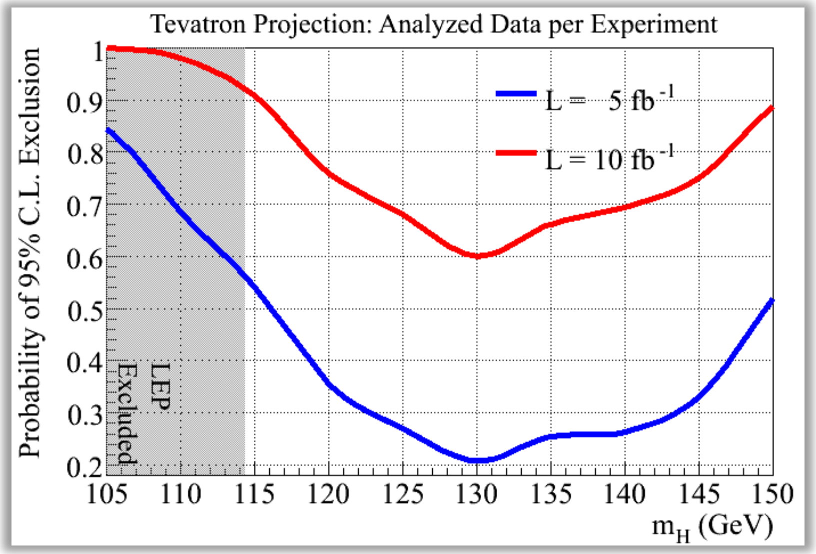
- Improved b-tagging (flavor separator)
  - Improved MVA technique
- Jet energy resolution improvement
  - Treat HF jets differently from light jets
- Improved systematics
  - Major source of degradation in sensitivity
  - Need better understanding of W/Z+HF jets properties, including cross sections
- Multivariate techniques (NN, BDT, RF, ...)

- Approaching the SM expectation
  - Rapid improvement well beyond $\sqrt{L}$ gain

# SM Higgs Prospects

- Summer 2010
  - Experiments will report results based on data of ~6 $fb^{-1}$
  - 9 $fb^{-1}$ will be delivered before 2010 shutdown (July 19)



# Conclusions

- Tevatron and CDF/ DØ experiments performing very well
  - Over $8.4 fb^{-1}$ delivered and $7.5 fb^{-1}$ recorded.
  - Analysis techniques well-developed.
  - Good understanding on the limiting factors and working on improvements.
  - Well established, common effort across the Collaborations.