# *Prospects for Higgs in Run II at the Tevatron*

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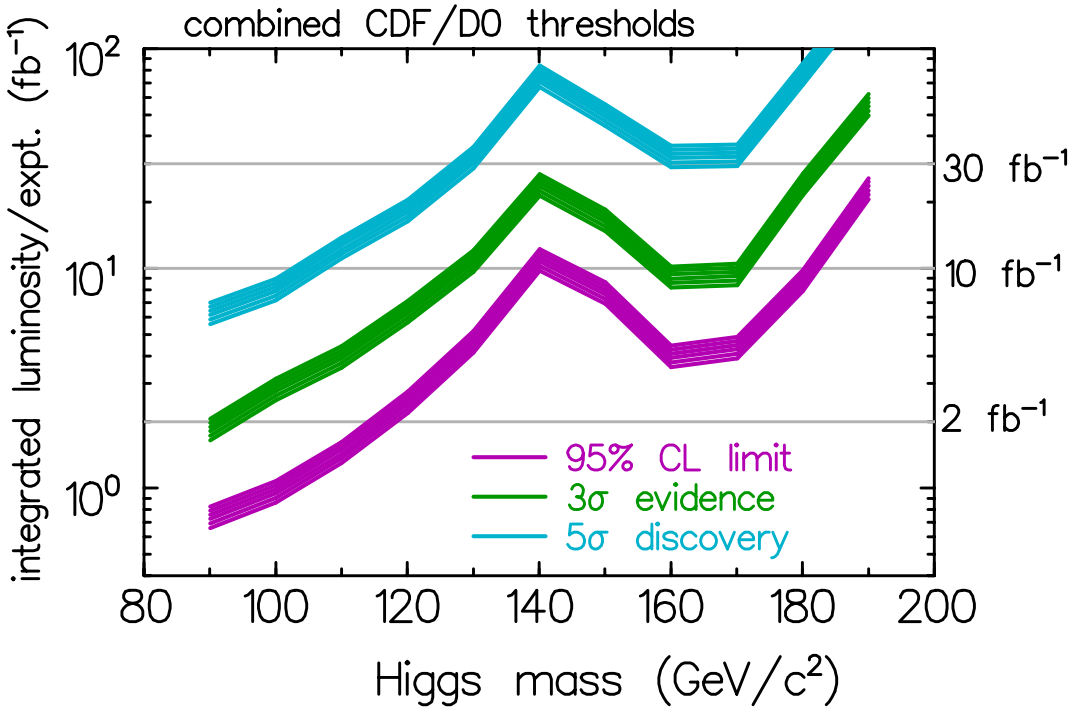
- Introduction
- Higgs Production and Decay
- Critical Components
  - b-quark tagging
  - Dijet Mass Distribution
- WH Mode
- ZH Mode
- Summary of Sensitivity

**Reevaluation Study (2003)**
**Fermilab-Pub-03/320-E:**

Study from 1998-99

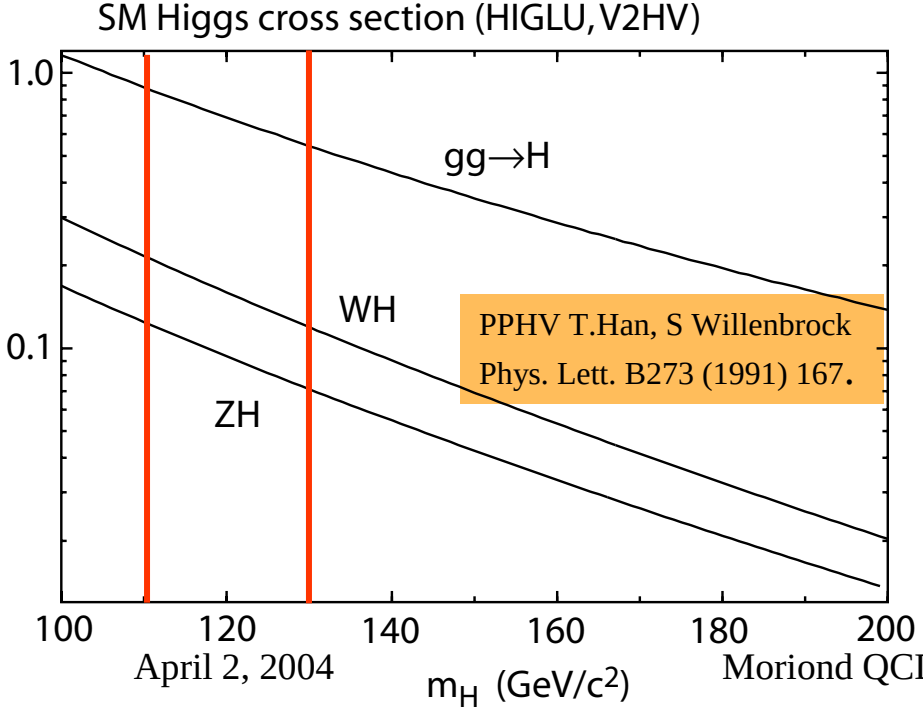



"**Report of the Higgs Working Group of the Tevatron Run 2 SUSY/Higgs Workshop**". M. Carena, J.S. Conway, H.E. Haber, J.D. Hobbs, *et al*, hep-ph/0010338

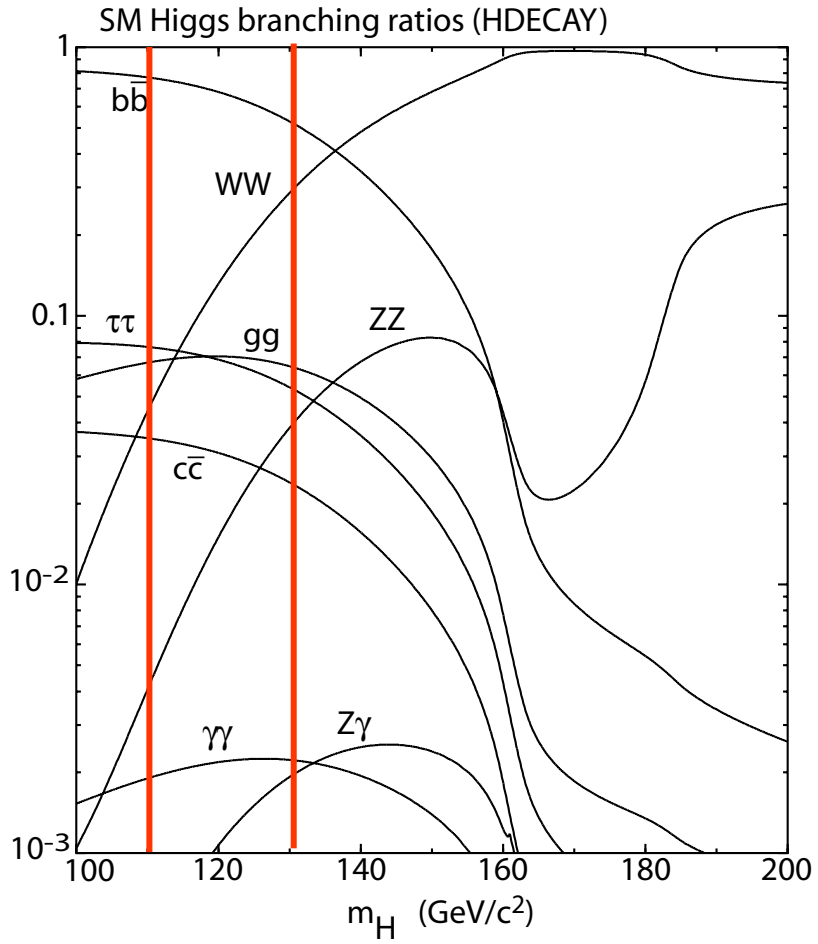
# Higgs Production and Decay at the Tevatron

- gg → H
  - σ ~ 0.7 pb
- $p\bar{p}$ → WH
  - σ ~ 0.2 pb
- $p\bar{p}$ → ZH
  - σ ~ 0.1 pb
- Other production mechanism with bbH, ttH, etc. (small)

Below ~140 GeV/$c^2$ H →$b\bar{b}$ dominates




PPHV T.Han, S Willenbrock
Phys. Lett. B273 (1991) 167.




A.Djouadi,J.Kalinowski, M. Spira
Comp. Phys. Commun 108C (1998) 56

# Final State Modes and Backgrounds

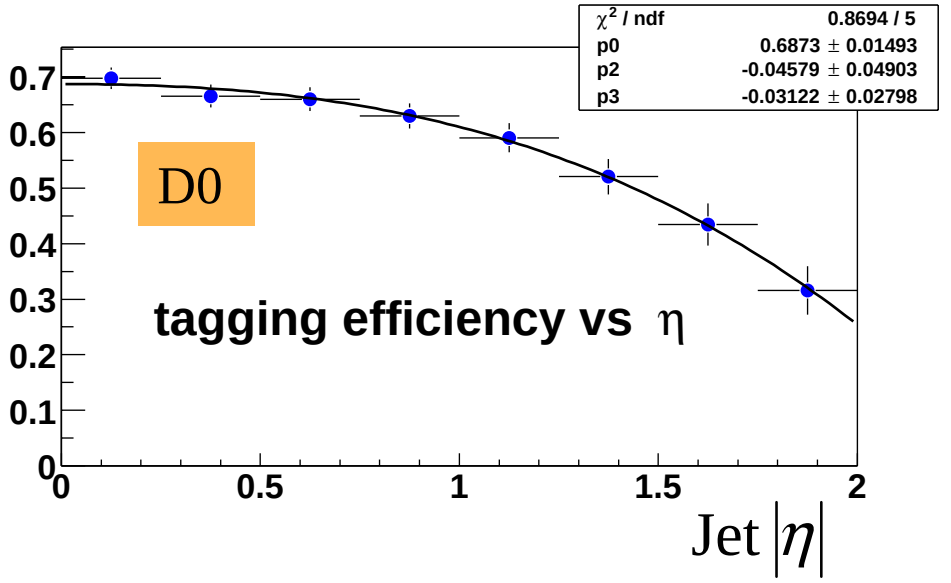
| Signal Production and Final State: | Primary Background Processes: | |
|---|---|---|
| $gg \to H \to b\bar{b}$ | QCD Dijet Background…Huge |  |
| $p\bar{p} \to WH \to q\bar{q}'b\bar{b}$ | QCD Jet Background/W+jets |  |
| $p\bar{p} \to WH \to \ell\nu b\bar{b}$ | W+b$\bar{\text{b}}$/c$\bar{\text{c}}$, Single top, t$\bar{\text{t}}$ |  |
| $p\bar{p} \to ZH \to q\bar{q}b\bar{b}$ | QCD Jet Background/W+jets |  |
| $p\bar{p} \to ZH \to \ell^+\ell^- b\bar{b}$ | W/Z+b$\bar{\text{b}}$/c$\bar{\text{c}}$, t$\bar{\text{t}}$ (Poor BR) |  |
| $p\bar{p} \to ZH \to \nu\bar{\nu}b\bar{b}$ | W/Z+b$\bar{\text{b}}$/c$\bar{\text{c}}$, t$\bar{\text{t}}$, QCD Jets |  |

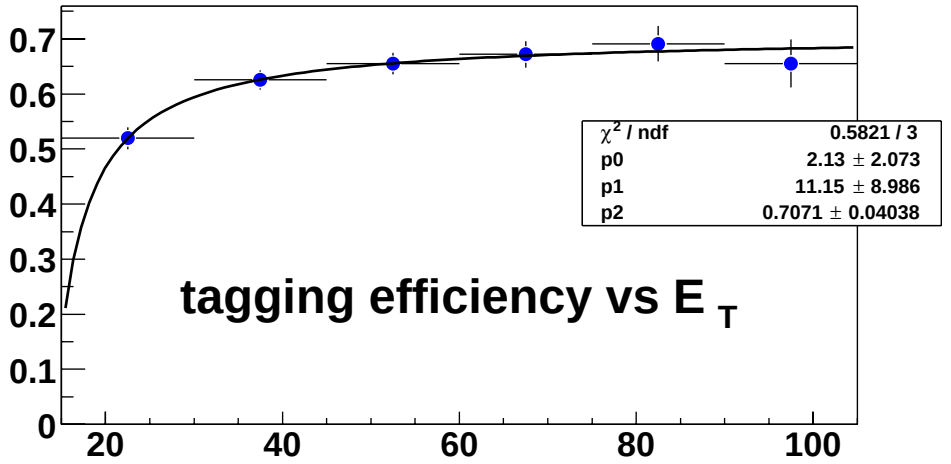
Essentials:

**Lepton Acceptance, b-tagging eff/Acceptance, dijet Mass Resolution**

# B-Tagging

- Displaced Vertex Tagging Only.
  - No b→clv tags.
- Used current algorithms
  - Extended in |η|.
- Require
  - 1st Tight Tag: Good Purity
  - 2nd Tight or Loose Tag
- Parameterize the efficiency versus $E_T$ and versus |η|.



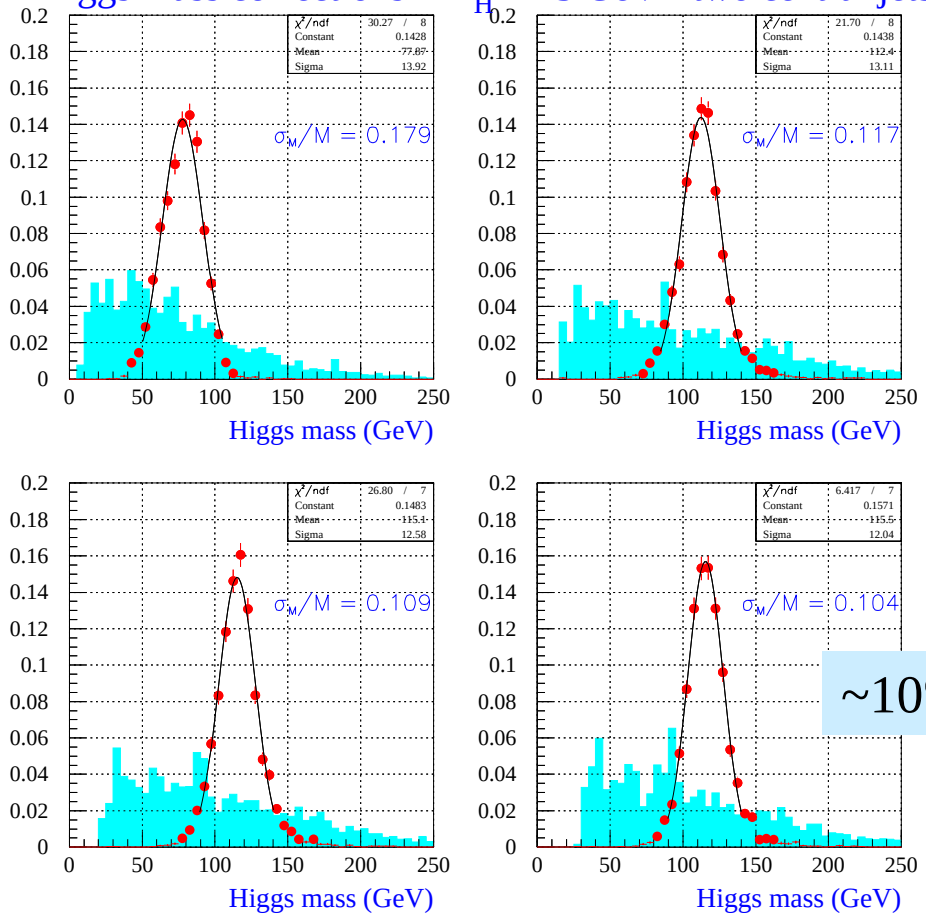



# Dijet Mass Resolution

- Dijet Mass "peak" is important
  - Excellent Resolution is essential
    - Counting events in a window
    - Fitting $M_{bb}$
  - Use as much information as possible.
- A resolution change from 10% → 12% corresponds to 20% reduction in statistical power.
  - Need 20% more integrated lum.
- Jet Corrections have been developed over many years at Tevatron.
  - Continuing to improve.
- Great Test Sample:

$$Z \rightarrow b\bar{b}$$

Higgs mass corrections - $M_H$=115 GeV - two central jets




~10%

CDF Study: Central Jets

# WH Channel

## Signature:

$$p\bar{p} \rightarrow WH \rightarrow \ell \nu b\bar{b}$$

Two high $E_T$ jets:
- Lead $E_T$ > 25 GeV
- 2nd $E_T$>10 GeV
- No 3rd $E_T$ > 20 GeV
- Central and b-tagged.

high $P_T$ e or μ:
**$P_T$>20 GeV/c**
Also allow isolated high $P_T$ track (missed e, μ, and some τ )

Large Missing Transverse Energy:
$\not\!\!E_T$ >20 (35) GeV

## Backgrounds:

tt Production

$$p\bar{p} \rightarrow t\bar{t} \rightarrow \ell \nu \, q\bar{q}' \, b\bar{b}$$

$$p\bar{p} \rightarrow t\bar{t} \rightarrow \ell \nu \, \ell\bar{\nu} \, b\bar{b}$$

W+Jets

$$p\bar{p} \rightarrow Wb\bar{b} \rightarrow \ell \nu \, b\bar{b}$$

$$p\bar{p} \rightarrow Wc\bar{c} \rightarrow \ell \nu \, c\bar{c}$$

$$p\bar{p} \rightarrow Wq\bar{q}' \rightarrow \ell \nu \, q\bar{q}'(gg)$$

Single Top

$$p\bar{p} \rightarrow W^* \rightarrow t\bar{b} \rightarrow \ell \nu b \; \bar{b}$$

$$p\bar{p} \rightarrow "Wg" \rightarrow t\bar{b} \rightarrow \ell \nu b \; \bar{b}$$

Diboson

$$p\bar{p} \rightarrow WZ \rightarrow \ell \nu \, b\bar{b}$$

# Event Rates / fb$^{-1}$

Rates determined from a combination of MC and data.

| | No Mass Window | Mass Window |
|---|---|---|
| WH (115 GeV) | 2.86 | 2.50 |
| Wbb | 108. | 13.8 |
| Wcc | 3.5 | 0.44 |
| Wqq | 3.8 | 0.49 |
| tt | 46.7 | 10.0 |
| t(W*) | 15.9 | 3.5 |
| t(Wg) | 5.40 | 1.1 |
| WZ | 5.90 | 1.0 |
| Total Bkg | 189. | 30.3 |
| $S/\sqrt{B}$ | 0.21 | 0.45 |
| $S/B$ | 0.015 | 0.082 |

Efficiency tied to Run 2 data!

SHWG Report tended to quote numbers inside a mass window.

This is hard!

# Advanced Analysis

- The above selection does not include any advanced analysis such as a neural network to help improve the S/B.
  - SHWG reported that NN helped beat down backgrounds.
  - Run I analyses showed a NN could help.
  - The ZH analysis has a NN which helped in that channel.
- Added a NN that is nearly identical to the one used for the ZH channel (more later)
  - Determined extra rejection against backgrounds.

| | $\varepsilon_{NN}(\%)$ |
|---|---|
| WH | 94 |
| $t\bar{t}$ | 39 |
| t(W*) | 64 |
| t(Wg) | 62 |
| Wbb | 62 |
| WZ | 90 |

Events/fb$^{-1}$ inside Mass Window:

Signal: 2.5 → 2.4

Bck: 30.3 → 16.8

# ZH Channel

## Signature:

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

Two high $E_T$ jet that should be consistent with coming from b-quarks

No high $P_T$ e or μ.

Large Missing Transverse Energy
- $\not\!\!E_T > 25$ GeV

-Veto Energetic 4th Jet
- $H_T < 200$ GeV
- Satisfies Neural Net

## Backgrounds:

Generic QCD

$$p\bar{p} \rightarrow QCD \rightarrow "\nu\nu" b\bar{b}$$

tt Production

$$p\bar{p} \rightarrow t\bar{t} \rightarrow \ell\nu\, q\bar{q}'\, b\bar{b}$$

$$p\bar{p} \rightarrow t\bar{t} \rightarrow \ell\nu\, \ell\bar{\nu}\, b\bar{b}$$

Z/W+Jets

$$p\bar{p} \rightarrow Zb\bar{b} \rightarrow \nu\bar{\nu}\, b\bar{b}$$

$$p\bar{p} \rightarrow Zc\bar{c} \rightarrow \nu\bar{\nu}\, c\bar{c}$$

$$p\bar{p} \rightarrow Zq\bar{q}' \rightarrow \nu\nu\, q\bar{q}'(gg)$$

W+Jets, miss charged lepton

Single Top

$$p\bar{p} \rightarrow W^* \rightarrow t\bar{b} \rightarrow \ell\nu b\ \bar{b}$$

$$p\bar{p} \rightarrow "Wg" \rightarrow t\bar{b} \rightarrow \ell\nu b\ \bar{b}$$

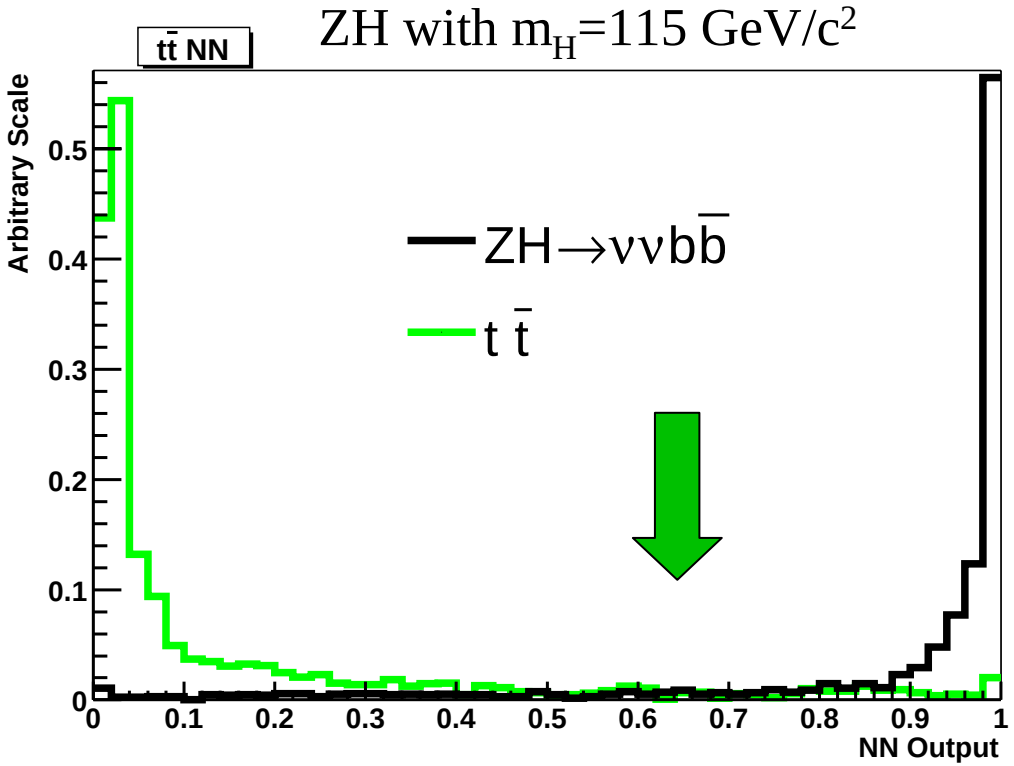
Diboson

$$p\bar{p} \rightarrow WZ \rightarrow \ell\nu\, b\bar{b}$$

$$p\bar{p} \rightarrow ZZ \rightarrow \nu\bar{\nu}\, b\bar{b}$$

# Neural Network in ZH

- A neural network was developed to separate tt from signal.
- Variables:
  - $H_T$
  - Largest $P_T$ of untagged jet.
  - Aplanarity of n-jet sys.
  - Net $P_T$ imbalance of $\not\!\!E_T - b\bar{b}$ system.
  - First 4 transverse-modified Fox-Wolfram (FW) moments.
- Arch of NN: 8 x 16 x 1




- A different NN was trained for each mass.
- NN also did a reasonable job of rejecting other backgrounds.

# Event Rates / $fb^{-1}$

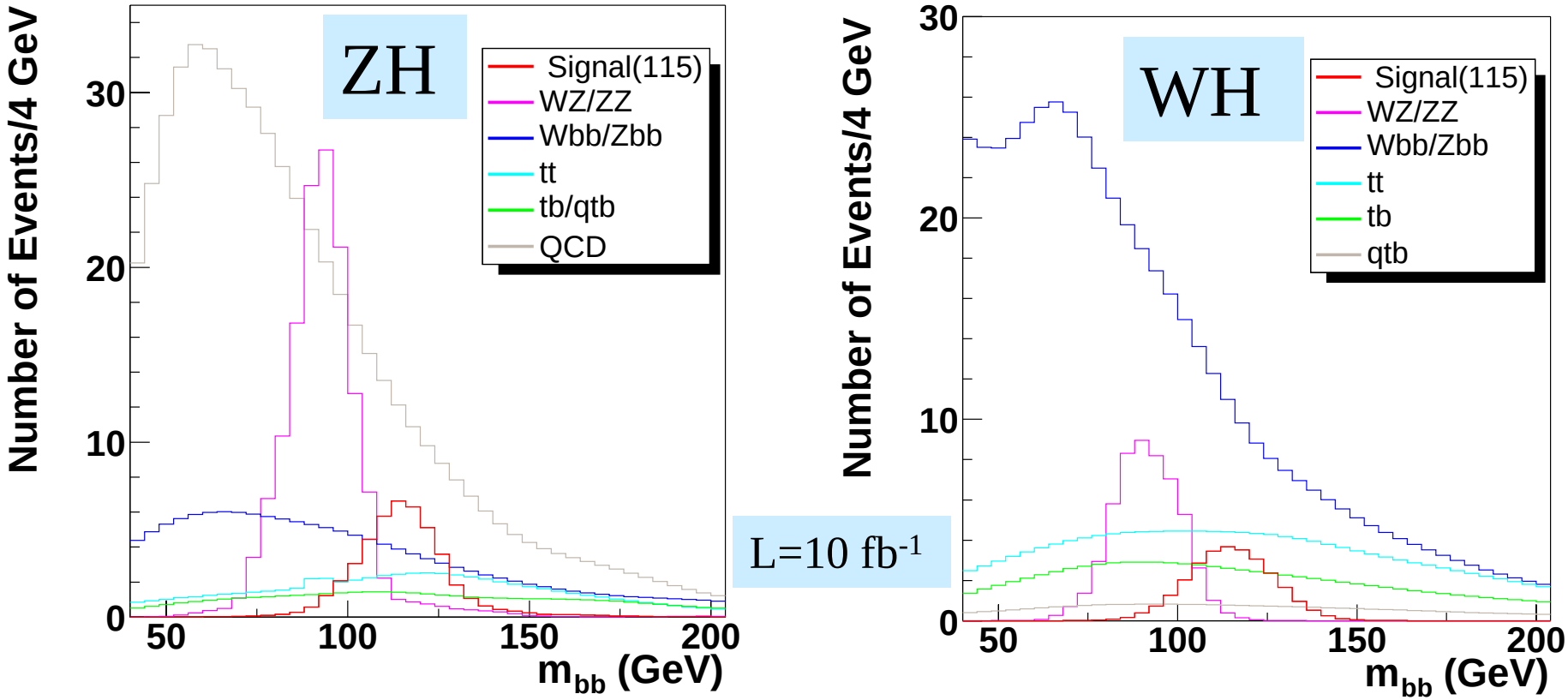
Rates determined from a combination of MC and data.

Missed Chg Lepton

| | No Mass Window | Mass Window |
|---|---|---|
| WH Signal(115) | 1.7 | 1.5 |
| ZH Signal(115) | 2.5 | 2.3 |
| Total Signal | 4.2 | 3.8 |
| tt | 8.8 | 2.2 |
| t(W*) | 3.3 | 0.7 |
| t(Wg) | 2.4 | 0.5 |
| W/Z bb | 22.3 | 3.3 |
| WZ/ZZ | 16.5 | 2.7 |
| QCD | 61.2 | 10.2 |
| Total Bkg | 114 | 19.6 |
| $S/\sqrt{B}$ | 0.39 | 0.85 |
| $S/B$ | 0.037 | 0.19 |

# $m_{bb}$ Invariant Mass Spectra

- We consider the full $m_{bb}$ spectrum rather than just a window.
- Consider it bin by bin (e.g. perform a fit).
- Uncertainty in overall background rate can be constrained by “side-bands”

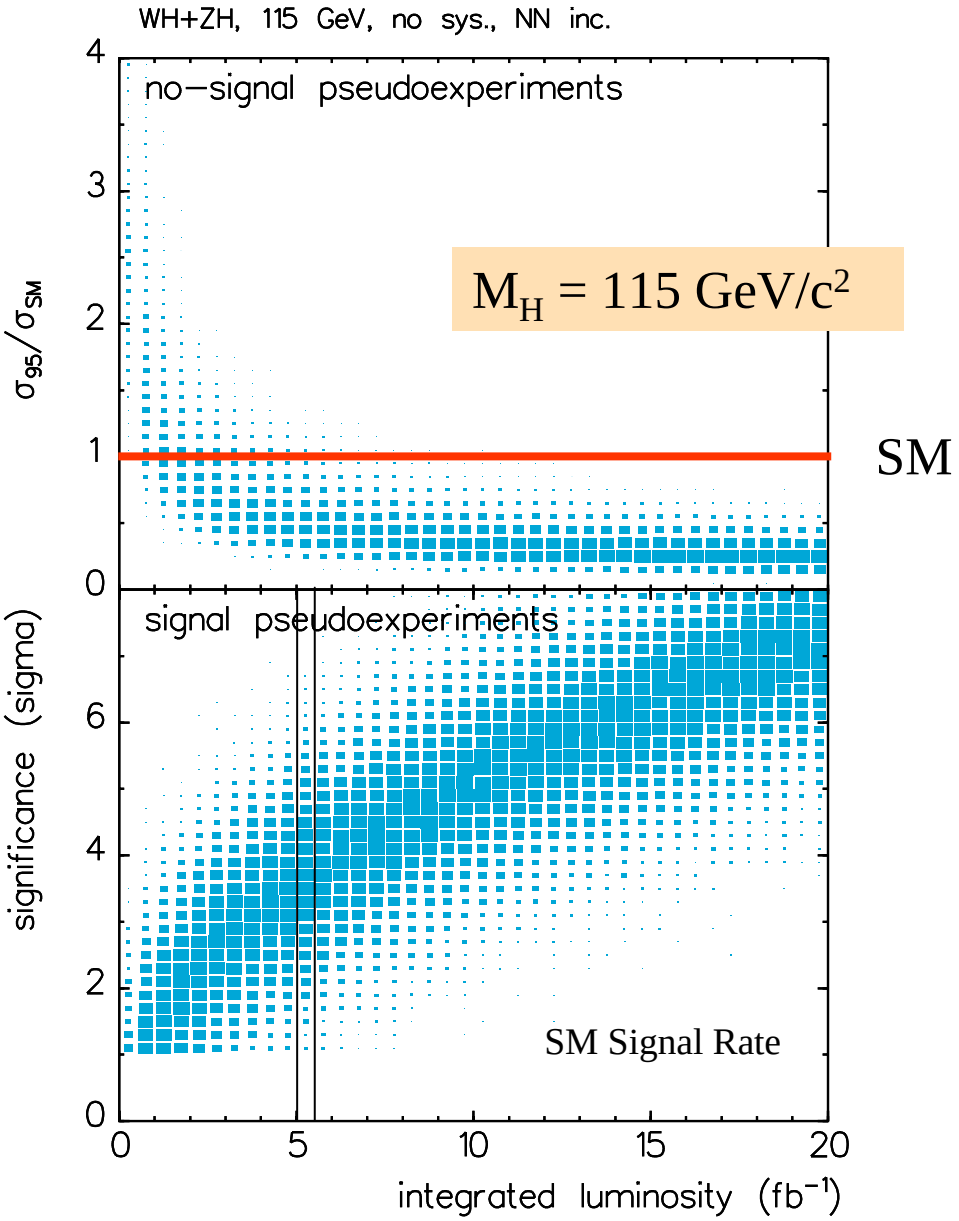


# Extracting Luminosity Thresholds

- To quantify our sensitivity we would like to know how much luminosity **per experiment** is required to:
  - Exclude (95% CL) the existence of the SM Higgs at the certain mass.
    - This is based on the theoretical cross section.
  - Observe a 3σ excess of events.
    - Consistent with having a Higgs decay (i.e. mass "bump").
  - Observe a 5σ excess of events.
- We want a method that can easily "sum" over different channels and CDF and D0 data.
  - Note: it will be extremely difficult to see 3σ or 5σ excesses in individual channels for individual experiments.
  - We assume:
    2*(WH w/ CDF) + 2*(ZH w/ D0) = (WH+ZH w/ CDF)+ (WH+ZH w/ D0)
  - Add in effect of ZH→llbb by using effective sensitivity from SHWG.
    - Acts as additional scale factor of 1.33 on ZH channel.

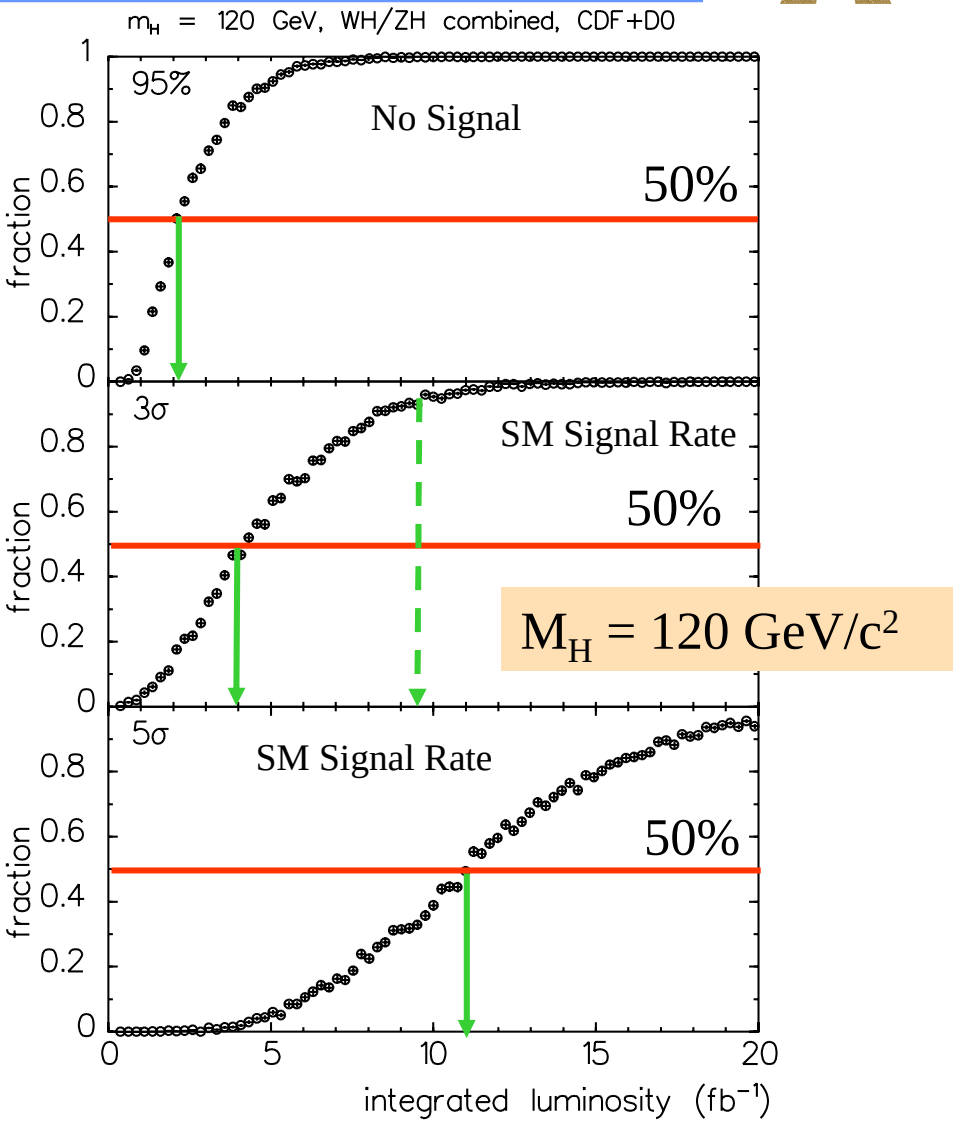
# Scatter Plot of Possible Outcomes

- Use Pseudoexperiments.
- Plots:
  - x-axis: Scan in integrated luminosity per experiment.
  - y-axis:
    - $\sigma_{95}/\sigma_{sm}$
    - Significance "N$\sigma$"
  - Scatter of many pseudo experiments
- Observations:
  - Broad range of statistical outcomes.
  - With 5 $fb^{-1}$ can get anywhere from <2$\sigma$ excess to >6$\sigma$ excess.

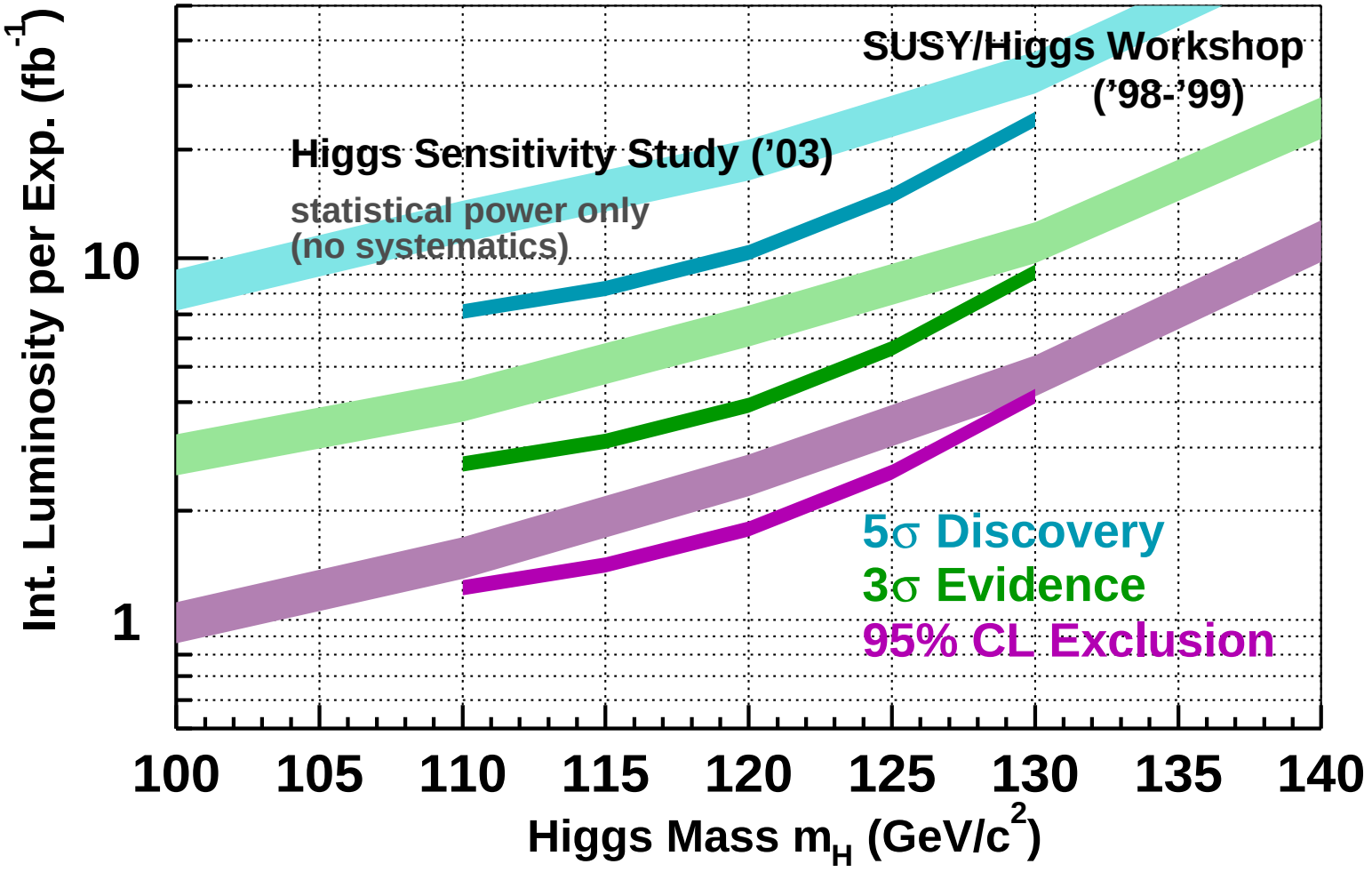


# …50% of Experiments…

- **Where do we set the Luminosity threshold for a given Higgs mass?**
- To set a threshold we must define that threshold as requiring X% of the pseudoexperiments satisfy the condition (e.g. 3σ excess)
- The SHWG Report required 50% of the pseudoexperiments satisfy the condition.
- It does matter.



# Summary Plot



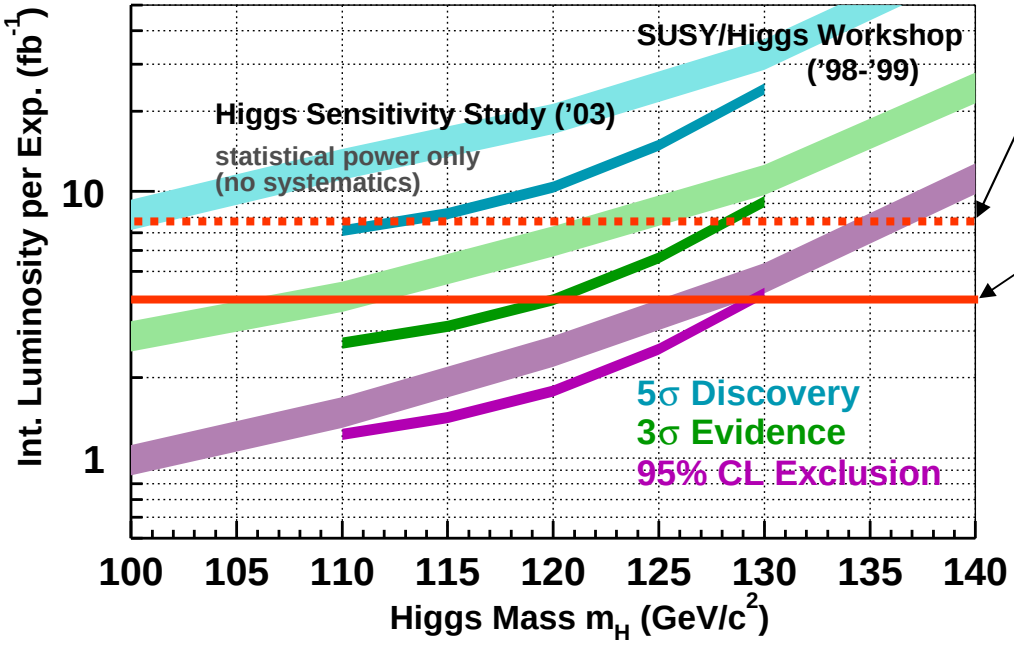
# Summary

- We reevaluated the sensitivity of the Tevatron experiments to a standard model Higgs boson.
  - Focused on the low mass region.
  - Use Run 2 detector simulations and Run 2 data
    - Improvement over study 4-5 years ago.
  - We assumed the upgrades of the Silicon would take place.
    - Canceled by FNAL Director in Sept 2003.
    - Impact (1): Degradation of silicon performance will occur over time.
      - **CDF estimates show the current device should work to about 4 $fb^{-1}$, then degrade (How fast??).**
    - Impact (2): Some indications that D0 was expecting better performance with the upgrade device.
      - **For high Pt Jet performance, not so different.**
- Results similar to SHWG Report predictions.
- **The search is underway!** (Talk by Karchilava)

# Summary(2)

Mother Nature's Random "Roll of the dice" plays a big part.

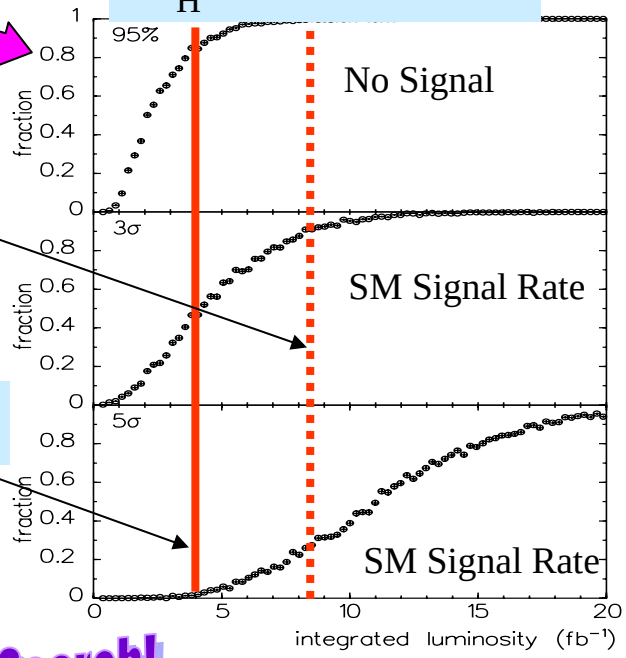
What will Tevatron Deliver?




$M_H$=120 GeV/$c^2$

8 fb$^{-1}$

4 fb$^{-1}$




Started Search!