Tevatron Higgs Sensitivity

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On behalf of the Tevatron Higgs Sensitivity Group

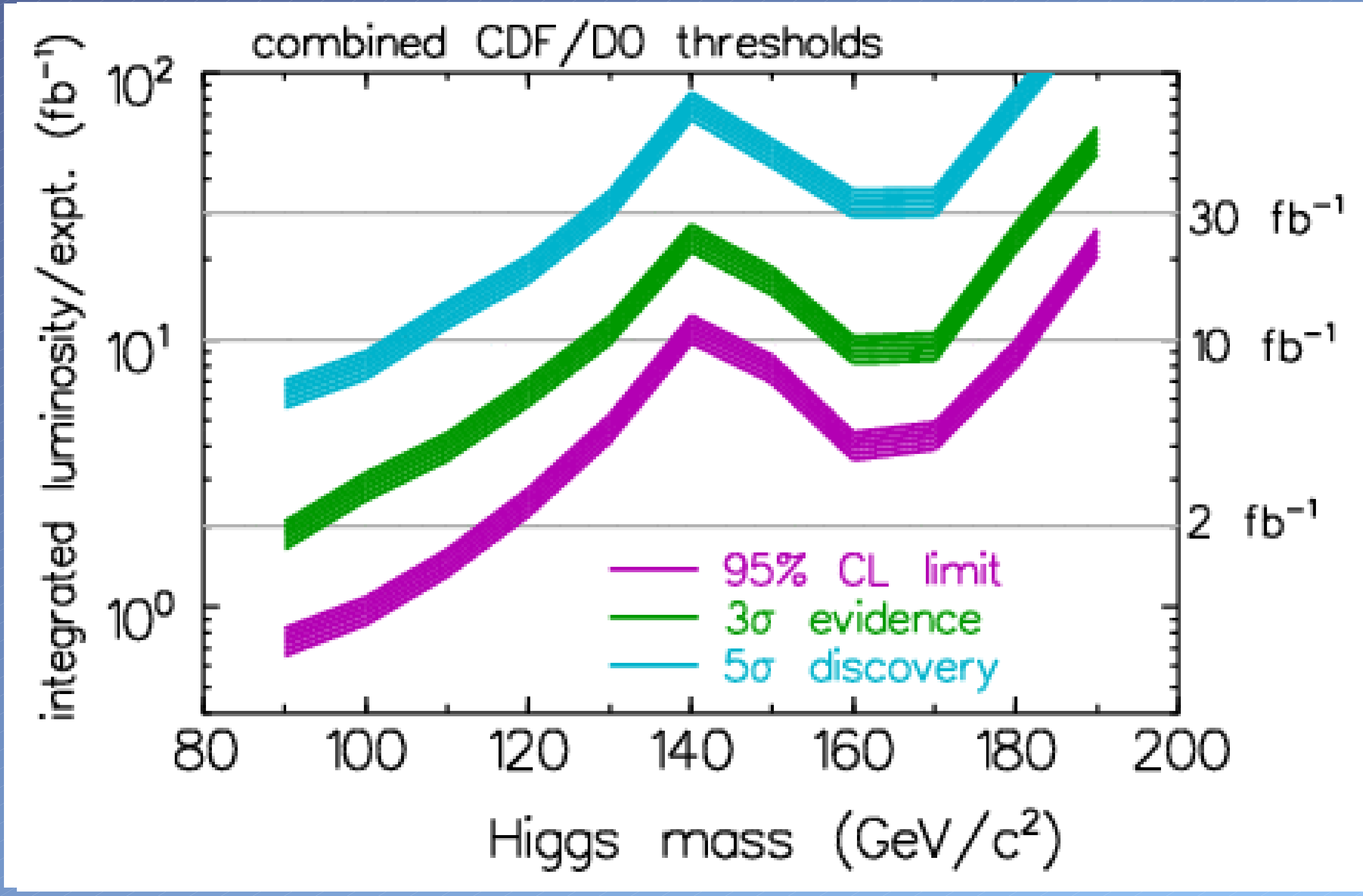
Invitation

- Tevatron Higgs search studies have gathered a lot of attention
  - SUSY/Higgs Working Group (1998)
  - Tevatron Higgs Sensitivity Group (2003)
- But the speculation is that they are too optimistic to make searches worthwhile
- I want to demonstrate that
  - Higgs searches at the Tevatron are realistic and exciting
  - The two estimates are good benchmarks
  - We really need a combination between CDF & DØ
    - Sooner is much better!

SUSY/Higgs Working Group
- 1998 -

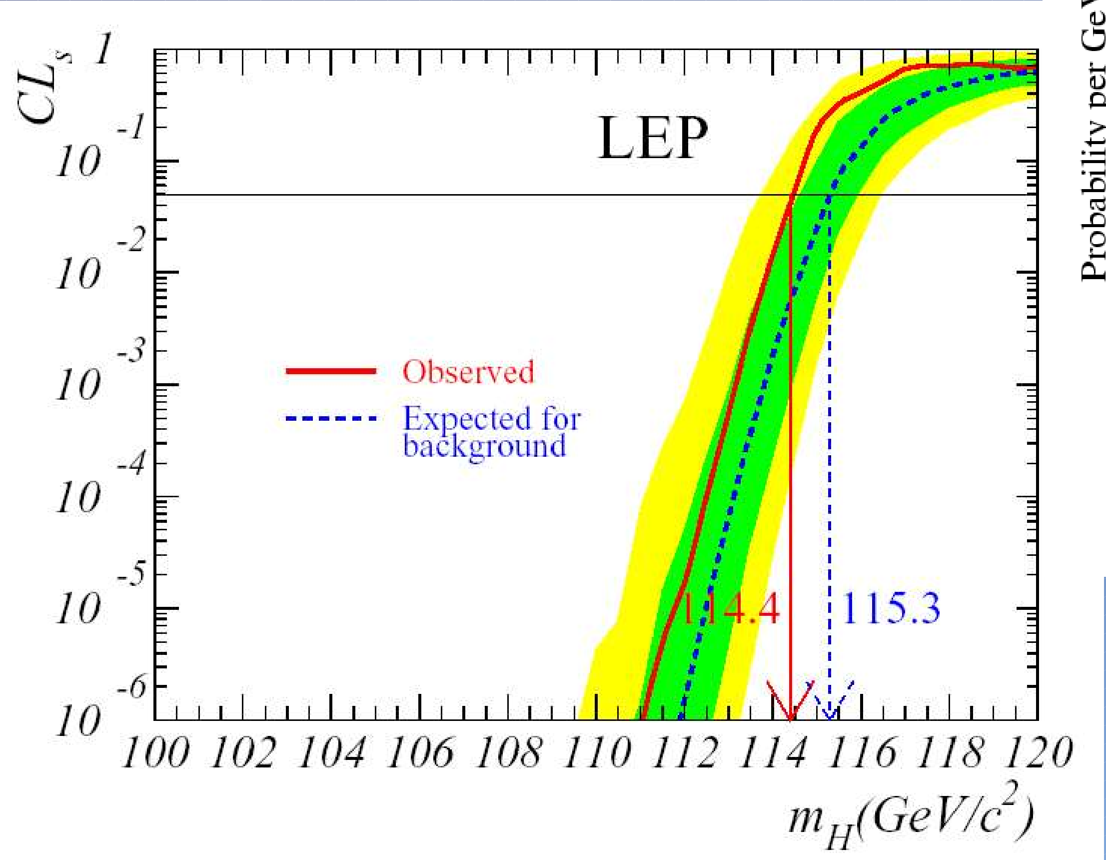
- ✗ SHWG covered most of the Higgs production and decay channels
- ✗ Used parameterized simulations for an *average* FNAL detector performance
- ✗ Very complete study using the resources available

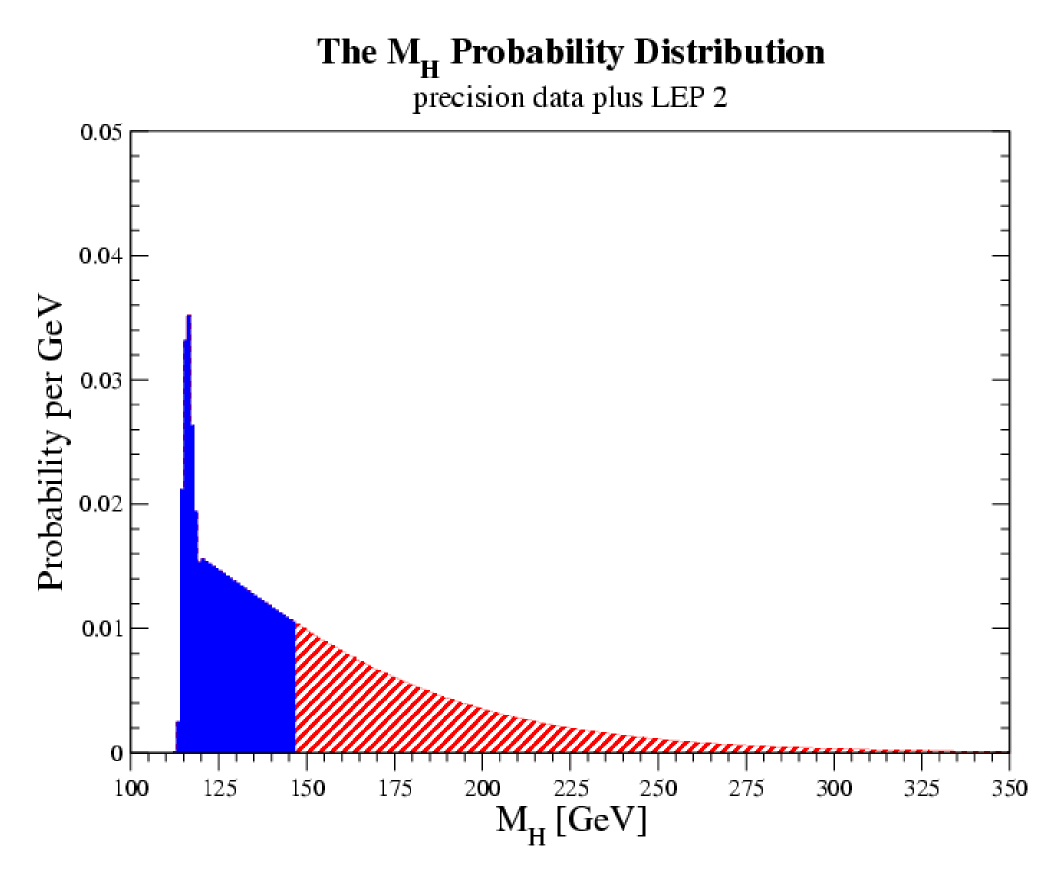
Results of the SUSY/Higgs Working Group



Evolution
1998-2004

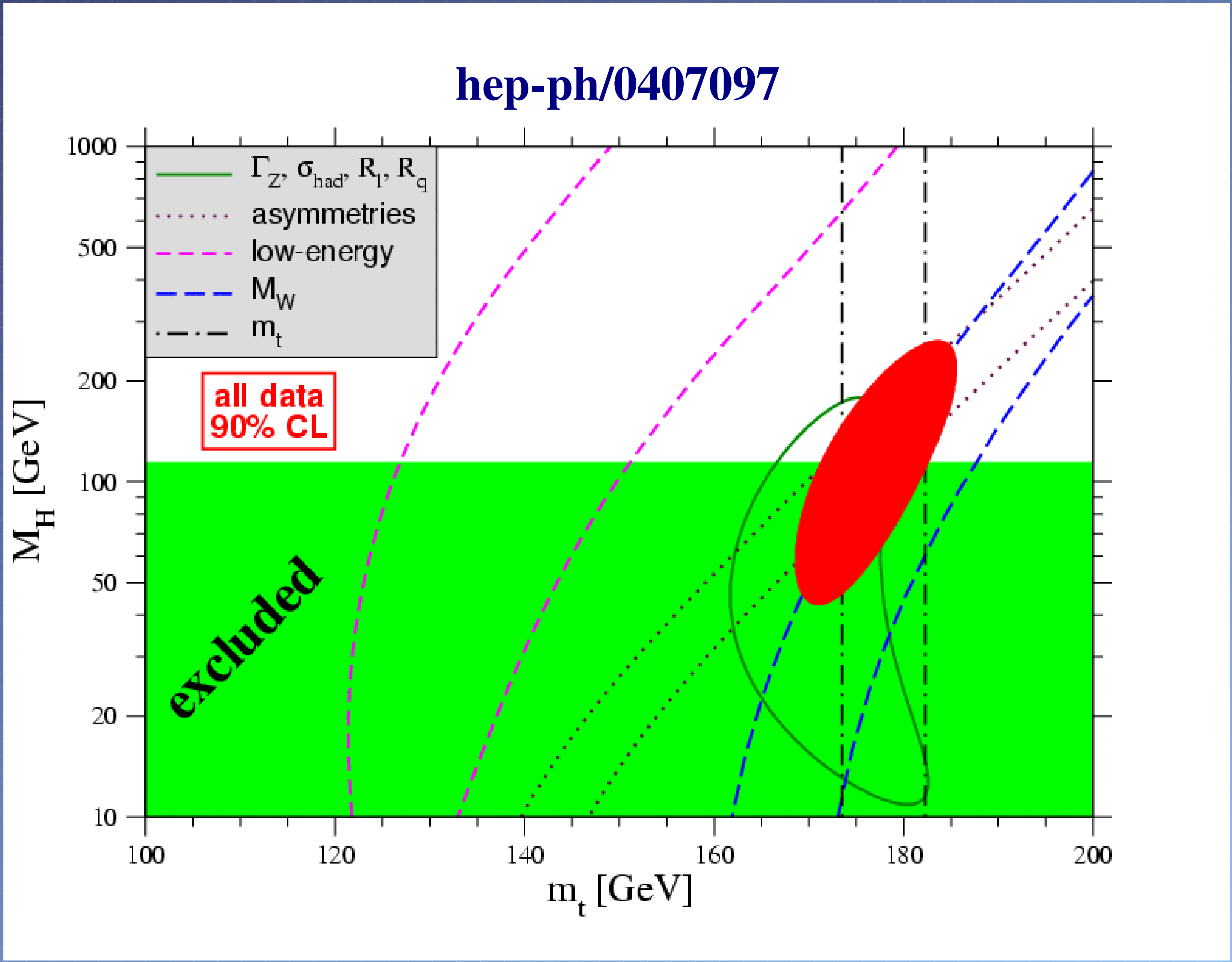
Combined LEP2 SM Higgs Result





J. Erler, hep-ph/0310202

In a Nutshell...



What *else* changed since 1998?

Things that *help*:

- Full simulation of Run II detectors (GEANT)
- Real measurements of trigger rates and efficiencies
- Greater understanding of physics processes
- Lots of *data* to make comparisons with
- More advanced analysis techniques

Things that *don't help*:

- Tevatron bunch crossing time will not be 132ns
  - Larger rate of multiple interactions
- Changes in expected cross sections

Select Cross Sections (pb)

	New	SHWG	Ratio
ZH($\nu\nu$) m_H=120 GeV	0.013	0.016	0.79
Wbb	3.40	2.53	1.34
WZ	3.20	2.81	1.14
ZZ	1.70	1.24	1.38

The Stage is Set…

- ✗ The DoE requested a new estimate for Higgs search sensitivity in Run II
  - ✗ Message from LEP is clear – no individual experiment will succeed alone
- ✗ *Prescription:* Split the task between collaborations
  - ✗ **CDF: $WH \rightarrow l\nu bb$ DØ: $ZH \rightarrow \nu\nu bb$**
  - ✗ Assume equal sensitivity for each expt, combine results
- ✗ Good opportunity to force the experiments to work together and convince ourselves we can succeed

Three Important Ingredients

Dijet Mass Resolution

- Determines ultimate separation of signal and background
- Current data ~15%
  - SHWG used 10%
- What is achievable?
  - What can advanced techniques buy us?

b-quark Tagging

- Essential for reduction of non-b backgrounds
- Methodology determines overall signal rate
- Care must be taken to properly handle fake rate

Estimation of Search Sensitivity

- Shape estimation vs counting expt can change result by 30%
- Choice of final variable and/or shape estimator can vary result by 10%

Outline of the Study

1) Start with Run IIA detector simulation
2) Add additional min-bias events for higher Run IIB lumi (2×10^{32} $cm^{-2}s^{-1}$)
3) Add b-tag parameterizations
4) Introduce trigger efficiencies
5) Determine achievable dijet mass resolution and scale to this operating point
6) Calculate expected QCD background contribution from data
7) Optimize analysis for maximal sensitivity
8) Extract luminosity thresholds based on final variable distributions

Needle in a Pile of Needles

Cross Section $\times$ BR (WH $\to$ lνbb):

$\sigma \times BR(m_H = 110) = 0.22 \text{ pb} \times 0.254 = 55 \text{ fb}$
$\sigma \times BR(m_H = 120) = 0.16 \text{ pb} \times 0.224 = 36 \text{ fb}$
$\sigma \times BR(m_H = 130) = 0.12 \text{ pb} \times 0.174 = 21 \text{ fb}$

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Cross Section × BR ($ZH \rightarrow \nu\nu bb$):

$\sigma \times BR(m_H = 110) = 0.12\ pb \times 0.154 = 19\ fb$
$\sigma \times BR(m_H = 120) = 0.09\ pb \times 0.136 = 13\ fb$
$\sigma \times BR(m_H = 130) = 0.07\ pb \times 0.106 = 7.5 fb$

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Backgrounds:

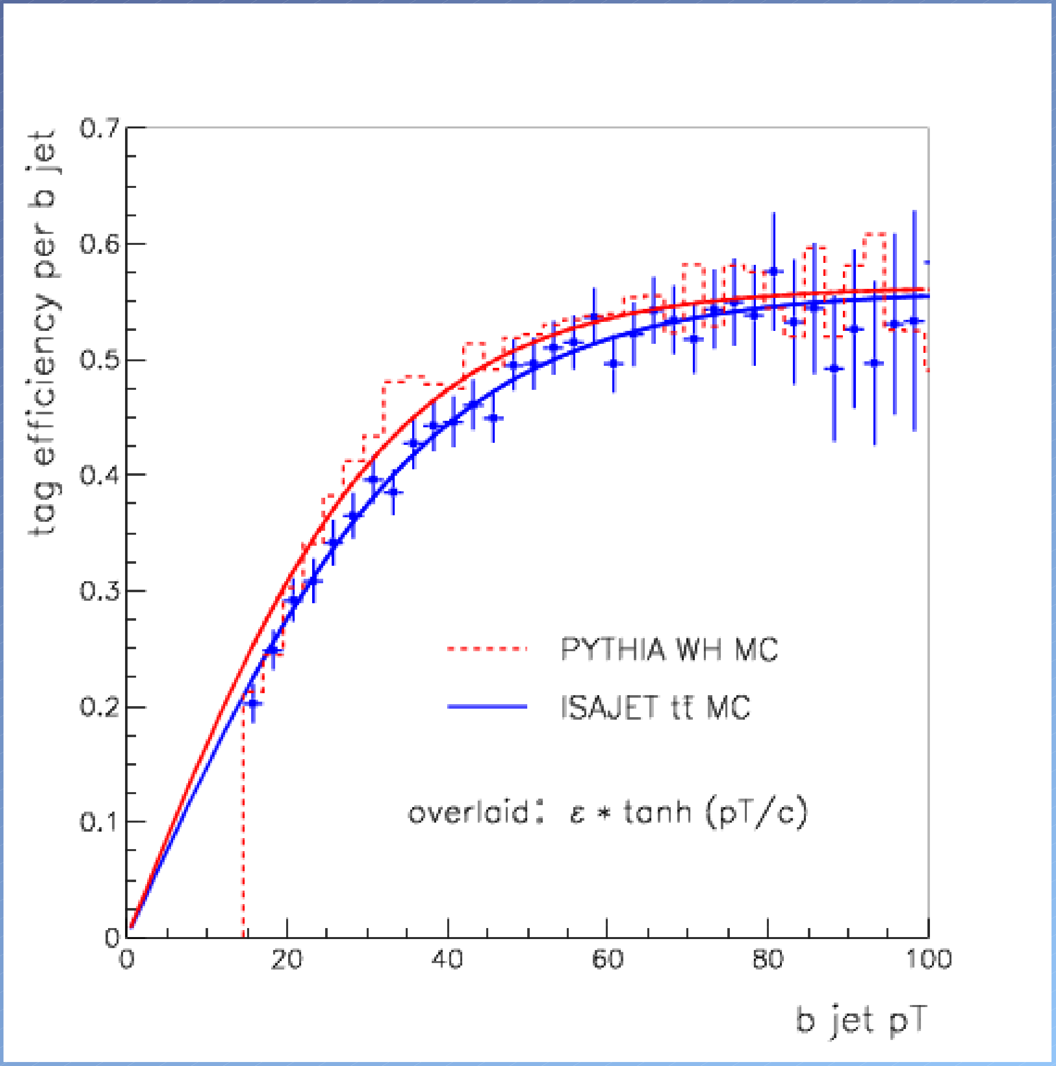
- ✗ QCD heavy-flavor
  - **$\sigma \sim$ 1-10 μb**
- ✗ W/Z + LF
  - **$\sigma \sim$ 100-200 pb**
- ✗ W/Z + HF
  - **$\sigma \sim$ 7-15 pb**
- ✗ tt, single-top
  - **$\sigma \sim$ 6-10 pb**
- ✗ WZ/ZZ
  - **$\sigma \sim$ 1-2 pb**

Gives an estimate of the uncertainty!

b-Quark Tagging: SHWG

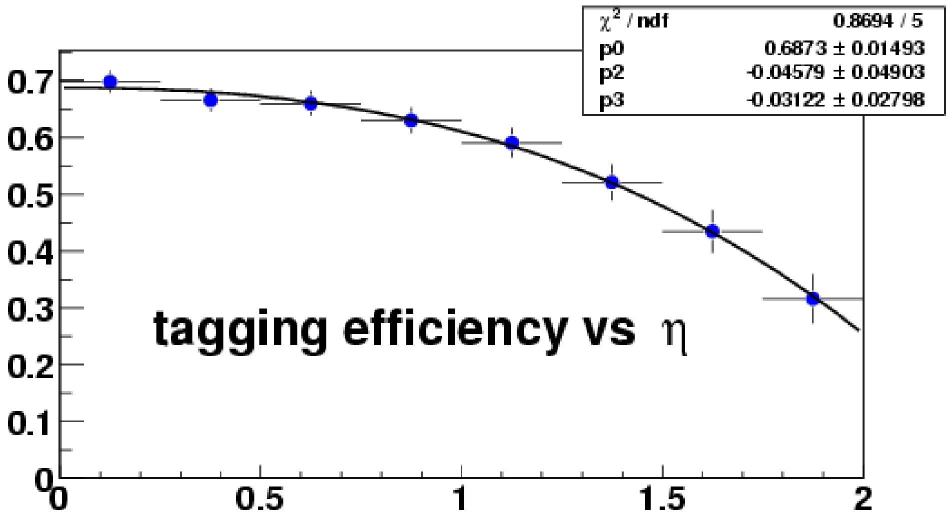
- SHWG used several different b-tagging parameterizations
  - MCFAST (shown here)
  - CDF Run I performance
  - Assumed flat η efficiency
- We used two approaches
  - **D0:** Full GEANT simulations of the Run IIB silicon
  - **CDF:** Parameterizations based on current silicon performance with extended η coverage

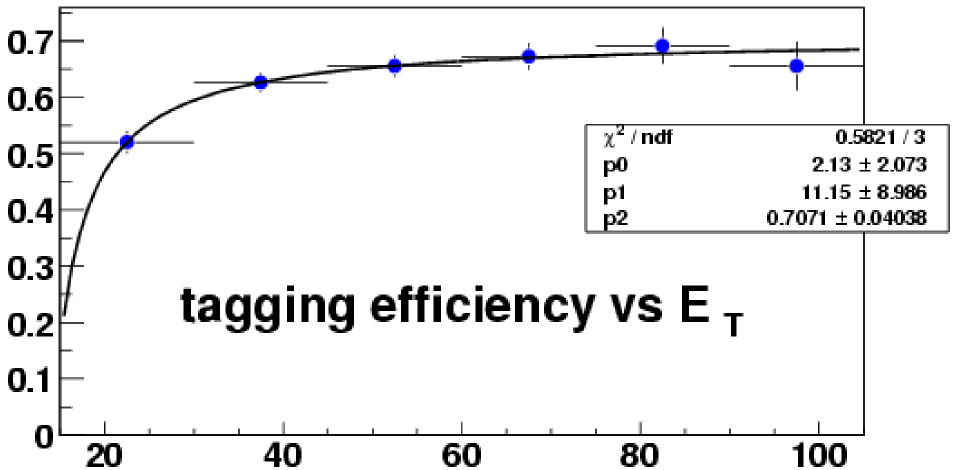
SHWG MCFAST b-Tagging



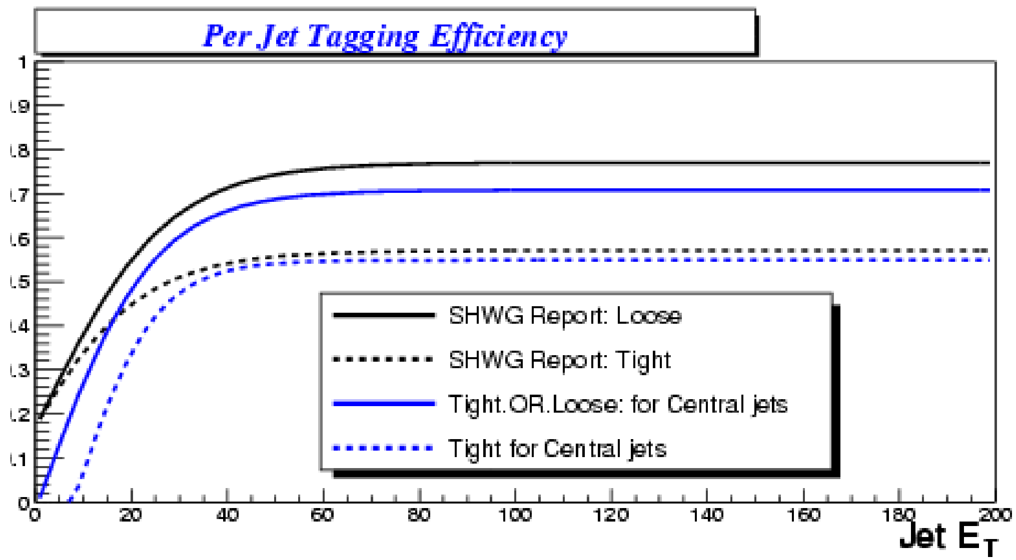
b-Quark Tagging: DØ/CDF

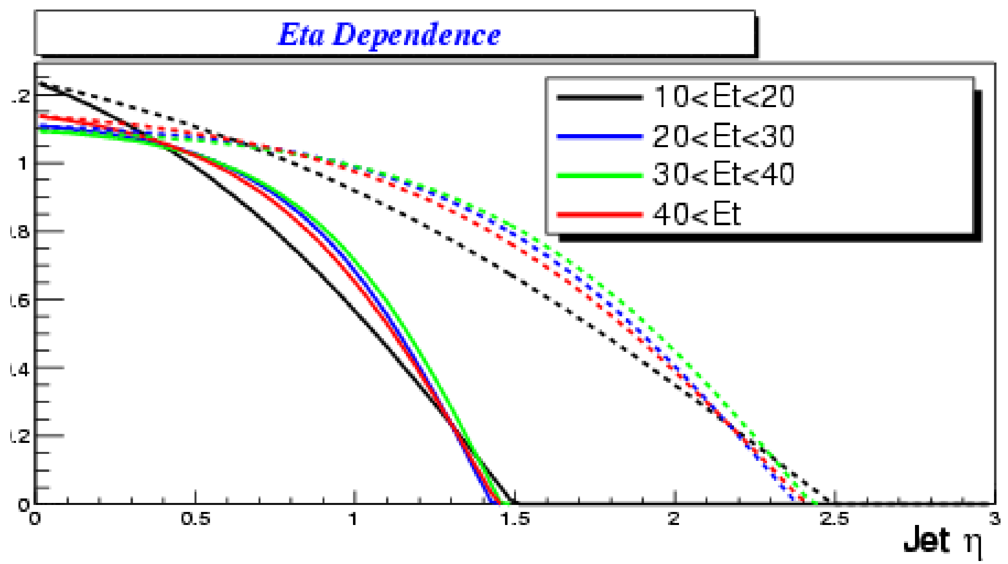
DØ





CDF





b-Quark Tagging: What's Realistic?

Average Double b-Tagging Efficiencies (%)

	$H \rightarrow bb$	non – b sample
DØ RIIB	32.0	0.0024
CDF RIIB	30.0	0.20
DØ RIIA Current	19.0	0.20
DØ RIIA Future	25.0	0.10

- Are these numbers realistic?
  - Quick answer: yes
- We used simple estimates, nothing complicated
  - No fancy b-Tag combinations
  - No SLT
- Bottom line: It won't be easy, but we can achieve this

Changes In Trigger Strategy

- SHWG assumed **100%** efficiency after offline cuts
  - Realistically, we hope for $\epsilon_{trigger} \geq 90\%$
- Need to know trigger efficiencies for all ZH and WH decays to include cross efficiencies
  - Need electron and muon triggers as well as calorimeter triggers

Higgs Trigger Menu

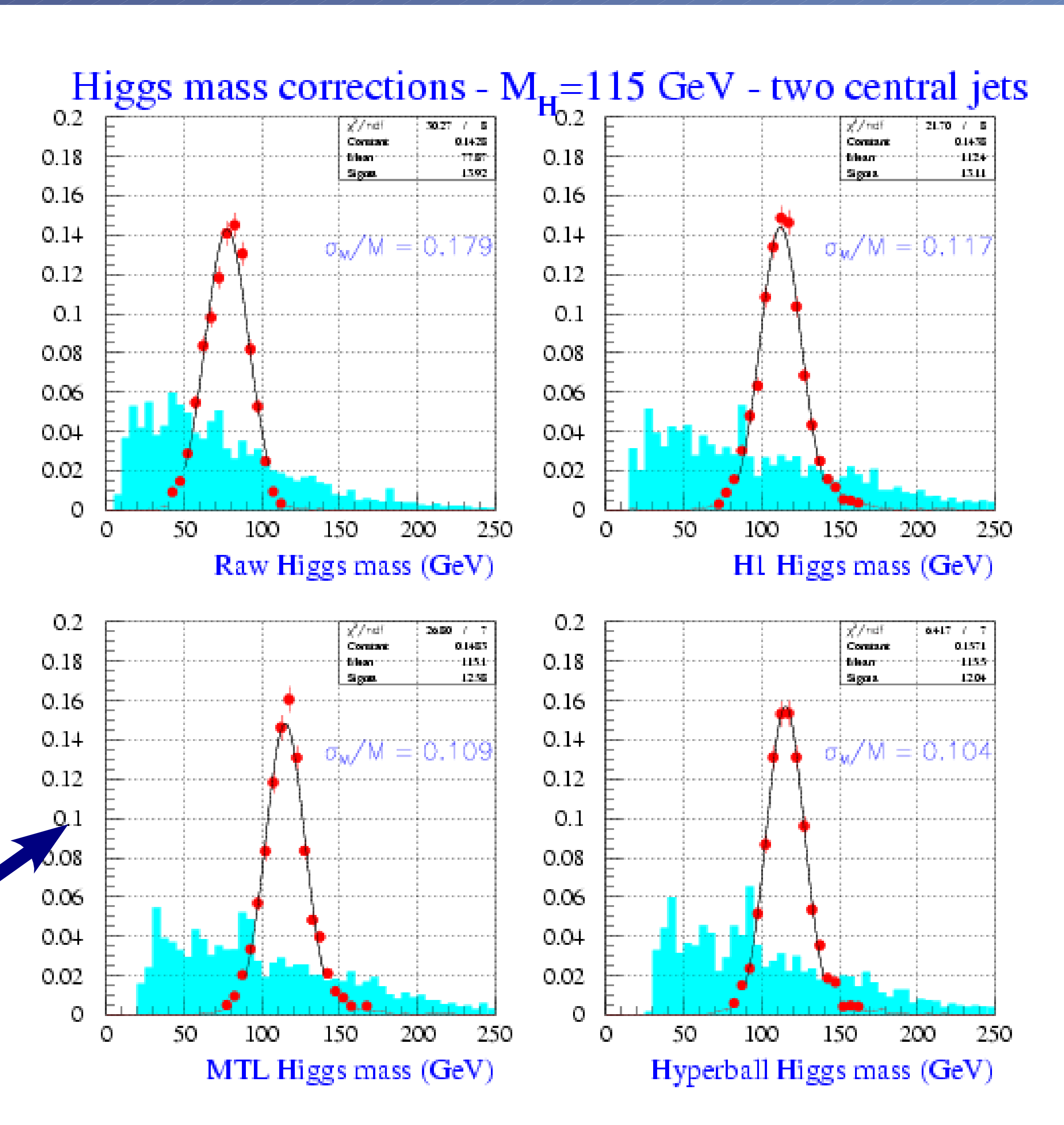
Process	Level 1	Level 2	Total:
$ZH \to \nu\nu bb$:	94	94	90%
$ZH \to eebb$:	99	98	98%
$ZH \to \mu\mu bb$:	94	99	94%

Process	Level 1	Level 2	Total:
$WH \to e\nu bb$:	97	97	94%
$WH \to \mu\nu bb$:	90	98	89%
$WH \to \tau\nu bb$:	93	96	90%

Di-Jet Mass Resolutions

- SHWG used flat 10%
  - Too optimistic?
  - **Rule of thumb:** ±1% in DMR gives ∓10% in sensitivity
- We compare two experiments
  - **CDF:** 10.4% with central jets
  - **D0:** 11% with central jets
- With more time and effort we can do even better!

CDF Measurement of Higgs Mass resolutions



W. Fisher, Princeton

QCD Estimation

- For ZH→$\nu\nu$bb, SHWG estimated QCD background contribution as equal to the sum of all other backgrounds: **QCD =** $\sum(\mathbf{bkgd})_i$
  - Underestimation (or overestimation)?
  - QCD background for WH→lνbb assumed to be small (and it is)
- We can actually measure this today in three steps
  1) Get relative light quark and b quark rates from MC
  2) Measure cross section and acceptances from data
  3) Combine efficiencies to find total contribution
- We find SHWG estimate twice too large: **QCD** $\simeq$ **½** $\sum(\mathbf{bkgd})_i$
  - But we didn't spend any time trying to reduce this contribution!

Optimization Strategy

- SHWG cuts weren't optimal
  - Must soften them to maximize signal acceptances
- Apply loose kinematic cuts to remove "obvious" backgrounds
  - All acceptances measured using full simulation
  - Includes lepton-ID, jet-ID, etc.
- Let Neural Networks (NN) do the heavy lifting

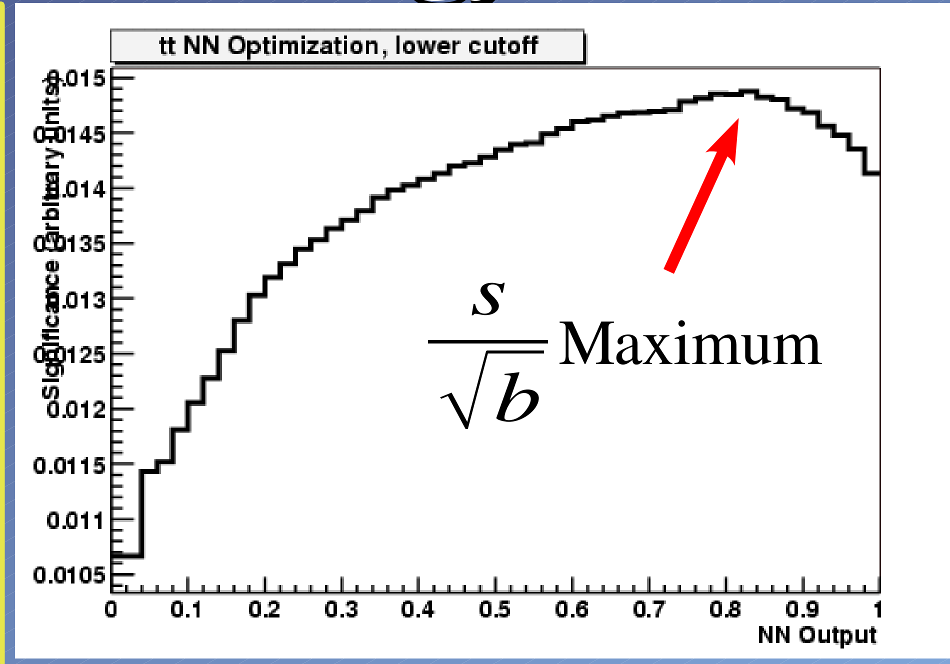
Expected Events in 1 fb^{-1}

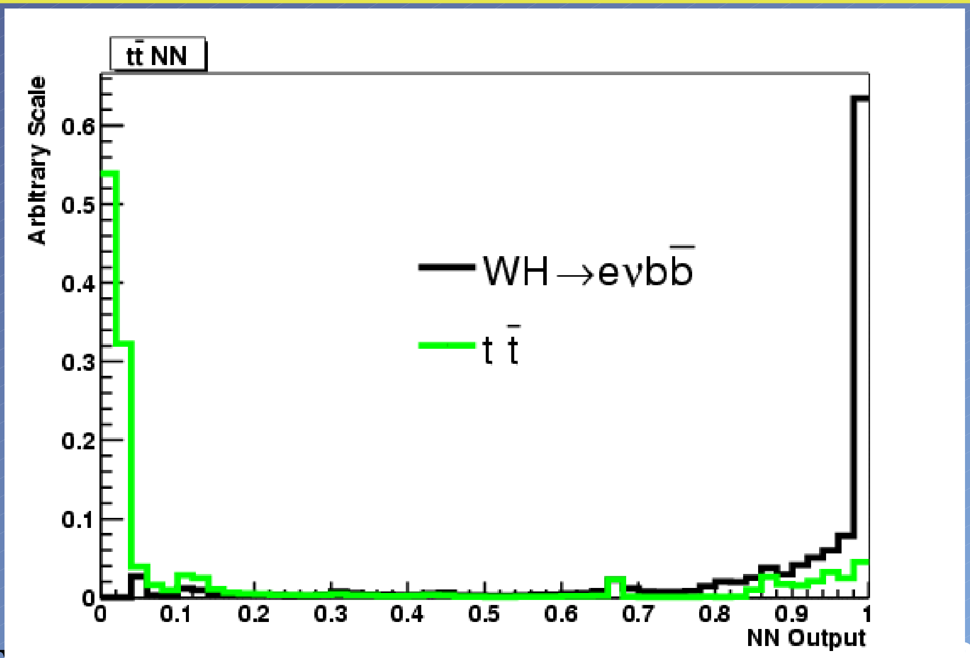
m_H = 115 GeV	ZH→$\nu\nu$bb	WH→lνbb
ZH	3.11	0.2
WH	3.04	3.2
Wbb/Zbb	35.25	69.7
WZ/ZZ	26.03	11.0
tt	58.74	52.1
QCD	102.0	-
Total Signal	6.15	3.4
Total Background	223.25	101.1

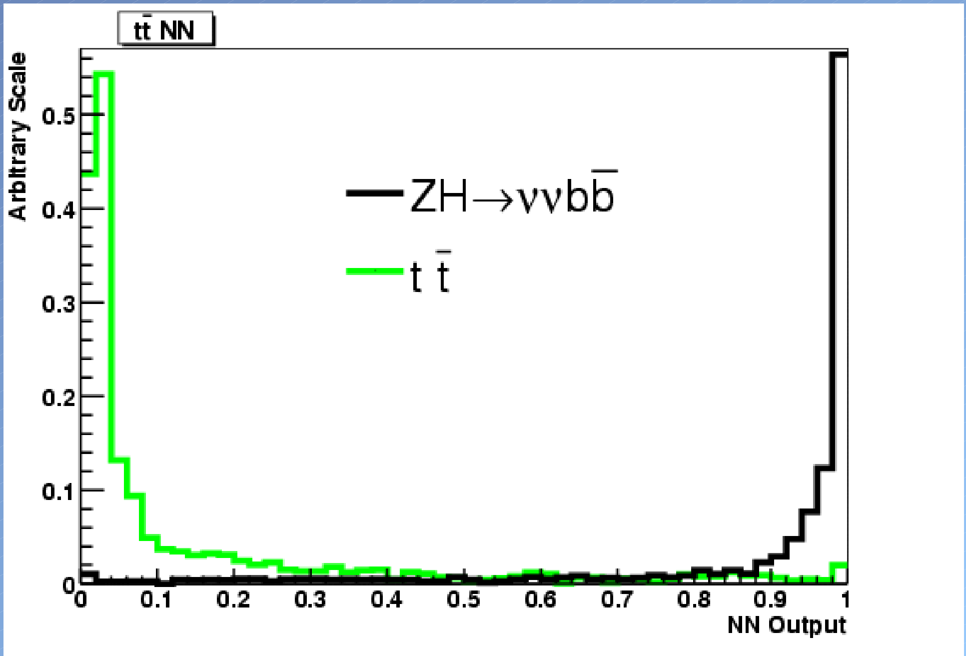
No NN or bb mass window cuts applied!

Optimization Strategy

- ✗ Train NN using WH/ZH signal and top backgrounds
- ✗ Input variables:
  - ✗ MET/JET (+lepton for WH) p_T balance
  - ✗ Fox-Wolfram moments (modified for the transverse plane)
  - ✗ H_T, Aplanarity
- ✗ Use $S/B^{1/2}$ estimator to find optimal NN cut







Applying the NN

$ZH \rightarrow \nu\nu bb$ m_H = 115 GeV	No NN	NN
ZH	3.1	2.5
WH	3.0	1.7
Wbb/Zbb	35.3	22.3
WZ/ZZ	26.0	16.5
tt	58.7	8.8
QCD	112.0	61.2
Total Signal	6.1	4.3
Total Background	233.3	112.2

$WH \rightarrow e\nu bb$ m_H = 115 GeV	No NN	NN
ZH	0.2	0.1
WH	3.2	3.0
Wbb/Zbb	69.7	40.1
WZ/ZZ	11.0	9.1
tt	52.1	19.1
QCD	-	-
Total Signal	3.4	3.1
Total Background	152.0	79.7

No bb mass window cuts applied!

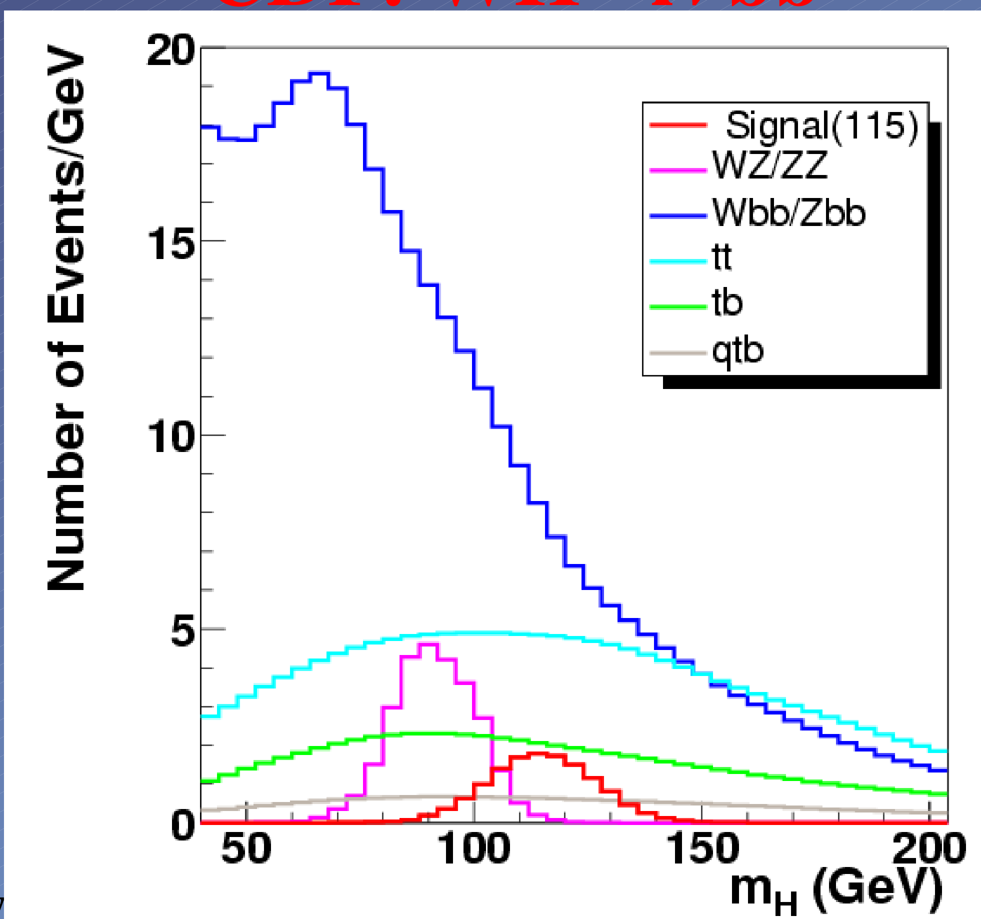
Combination

- To evaluate sensitivity, calculate how much luminosity is needed to:
  - Exclude (95% CL) the SM Higgs at a given mass
    - ie, consistent with background-only expectation
  - 3σ evidence of SM Higgs production
    - signified by an excess of events
  - 5σ observation of SM Higgs production
- Start with full bb mass distributions for each bkgd and signal
  - Allows us to capitalize on the shape of the distributions
- To evaluate these requirements, we use two similar methods:
  - CL_s frequentistic method (used by LEP Higgs Group)
  - Bayesian integration with a flat prior (similar to SHWG)

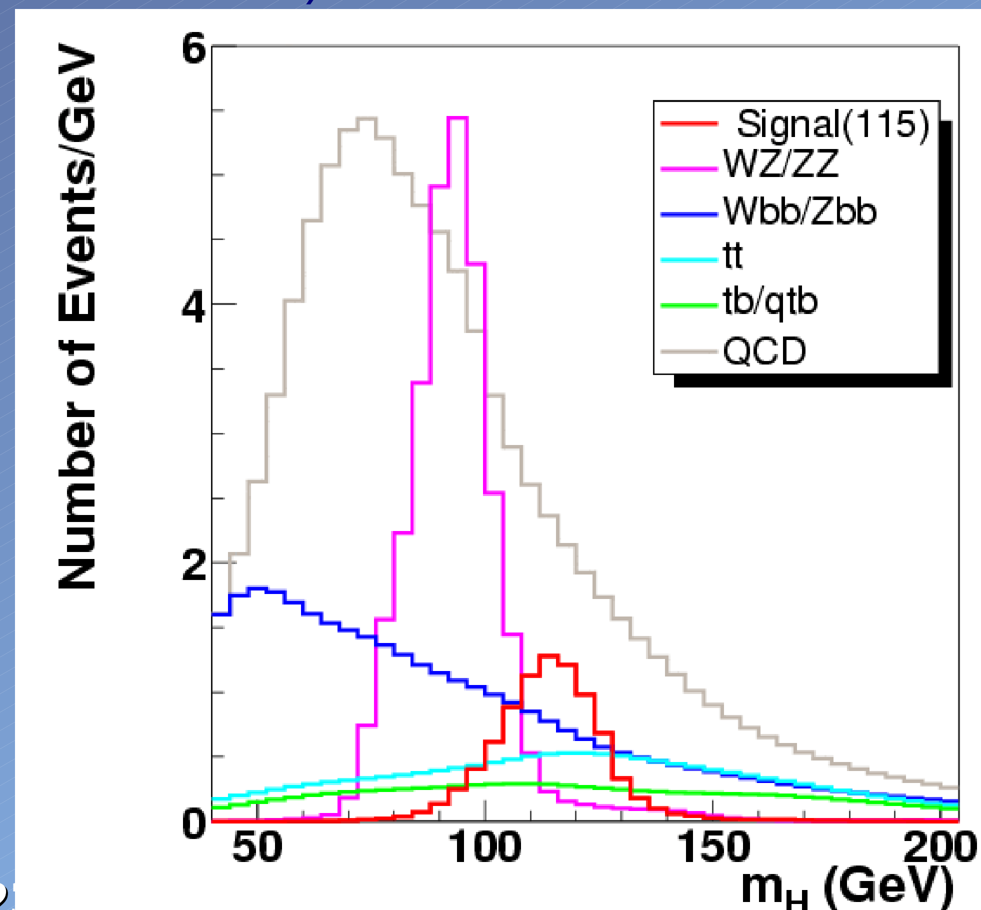
Final Variable Distribution

- CDF provides **WH→lνbb** and DØ provides **ZH→ννbb**
  - **ZH→llbb** contribution added by scaling **ZH→ννbb** by 1.33
    - Consistent with current searches and SHWG

CDF: WH→lνbb

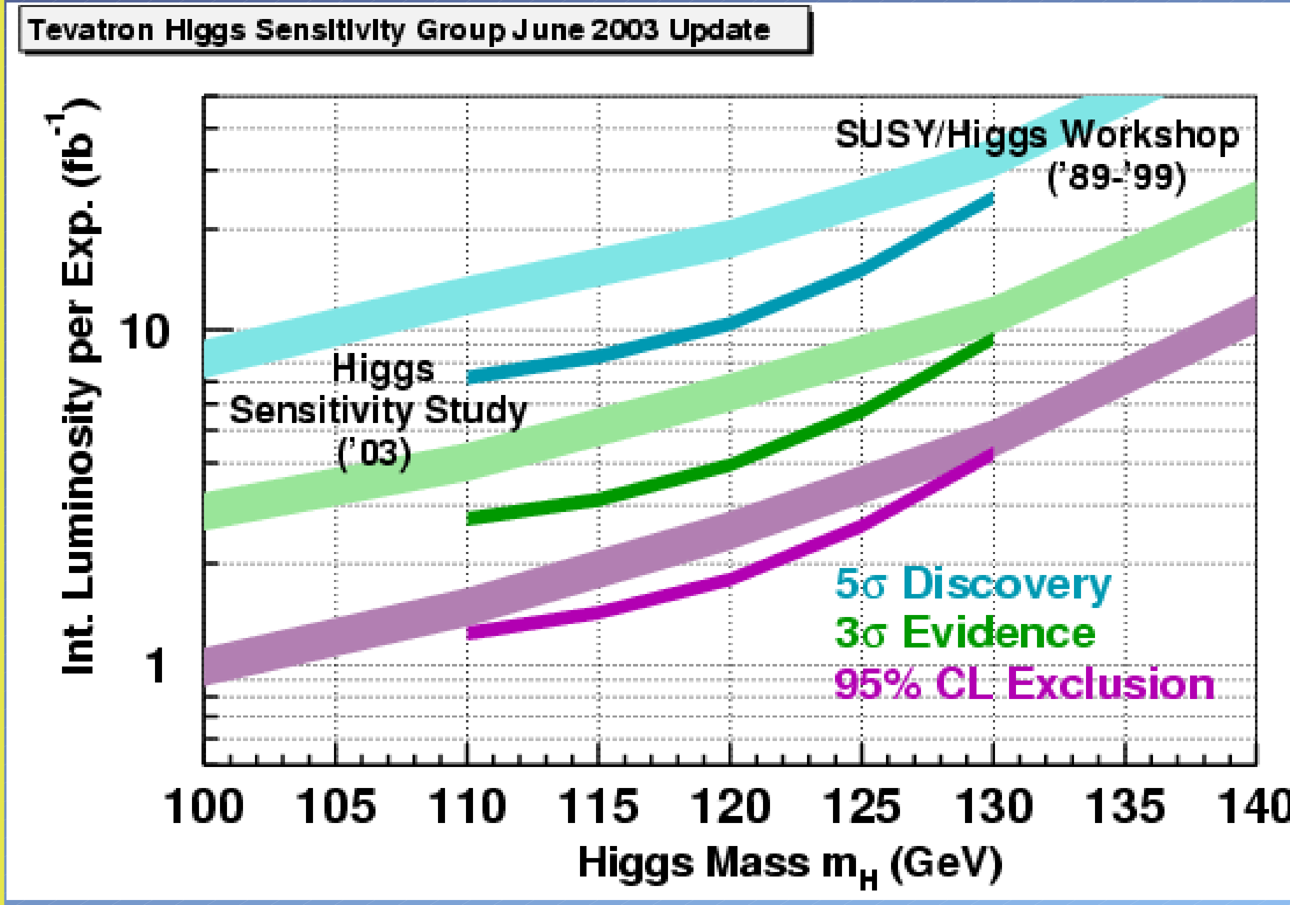


DØ: ZH→ννbb



Combined Results

- Combined DØ/CDF result
  - Assumes luminosity from two experiments
- 10% dijet mass resolution
- Run IIB silicon
- Width of HSG bands determined by method uncertainty
  - No systematics included
- Width of SHWG bands given by analysis uncertainty
- SHWG included $H \rightarrow WW$
  - contributes at high m_H



Is this the best we can do??

- For full sensitivity, we need:
  - Optimized b-Tagging techniques
- Multivariable taggers will help a LOT, but take time and effort
  - Constrained fitting techniques
- Already used in some analyses
  - Matrix Element ratio techniqes
- Effective factor of $\times$2 in lumi for DØ top mass. Expect ~20% for Higgs.
  - Expanded NN optimization
- For this study, not enough time to grind things out
- But we really need to have a CDF/DØ combination
  - Still open to competition, but we can't ignore eachother if we want to discover!

What could we do right now?

- Measurement of WZ/ZZ mass distribution
  - A combination would be sensitive to this with ~250 pb^{-1} per expt
  - Standard candle for dijet mass resolution studies
  - "Dry run" for a Higgs search (also a nice result in itself!)
- Full measurements of systematic errors
  - One of the largest complaints about the SHWG and HSG studies
  - Timescale is good for understanding these issues
  - Can be a huge factor in reducing luminosity requirements!
- Studies of final variable techniques
  - Learn from LEP (b-Tag, constrained fits, etc...)
  - Give this many smart people enough time, a lot can be thought up

Conclusions

- 6 years ago, the SHWG study set the standard for Higgs searches at the Tevatron
  - Many believed this was much too optimistic
- Complete studies of realistic detector performance now allow us to stand on solid ground
  - b-tagging, trigger, dijet mass resolution, QCD background
- We now see that the SHWG was not over-optimistic
  - In fact, we ***exceed*** their expectations
  - Will get even better as we get smarter
- Time is ripe to encourage a CDF/DØ combination for this study
- Please read the full report at **FERMILAB--PUB-03/320-E**