Higgs Sensitivity Committee Findings

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Committee co-chairs

Blessing Talk

CDF Meeting

3 July 2003

Summary Note: CDF 6353

Participants

Committee members

Tommaso Dorigo (Padova)
Tom Junk (Illinois)
Joseph Kroll (Penn, co-chair)
Mario Martinez (FNAL)
Pete McNamara (Rutgers)
Fumi Ukegawa (Tsukuba)
Brian Winer (OSU, co-chair)
Weiming Yao (LBNL)

Active participation from

John Conway (Rutgers)
Martin Hennecke (Karlsruhe)
Luca Scodellaro (Padova)

Began work in February 2003

Who Worked on What

If you have questions, these are the experts

Signal and background rates, *b* tagging, and extensions:

Winer, Hennecke, Martinez, Yao

Multiple Interactions: (CDF Note 6446)

Martinez

Dijet mass resolution: (CDF Notes 4527,5517,6450)

Dorigo, Scodellaro

Evaluation of sensitivity: (CDF Notes 6496, 6525)

Conway, Junk, McNamara

Basic Event Selection before b Tagging

Follows SHWG: we have not re-optimized the selection criteria

Use Winter 2003 Conference selection:

- Single isolated lepton (Standard Top/EWK Winter Selection)
  CEM, CMUP, CMX
  $E_T, p_T > 20\,\mathrm{GeV}$
- Missing $E_T > 20\,\mathrm{GeV}$ (uncorrected)
- $Z \to \ell^+\ell^-$ veto (Standard Top/EWK Winter Selection)
- Require 2 or 3 Calorimeter jets (uncorrected)
  A jet has $E_T > 10\,\mathrm{GeV}$, $|\eta| < 2$ (cone 0.4)
- Additional kinematic criteria
  one jet $E_T > 25\,\mathrm{GeV}$, $|\eta| < 2$
  reject if ≥ 3 jets, $E_T > 20\,\mathrm{GeV}$, $|\eta| < 2$
  no jet $E_T > 20\,\mathrm{GeV}$, $2.0 < |\eta| < 2.4$
  veto on 2nd isolated track $p_T > 10\,\mathrm{GeV}$

b Tag Efficiencies

Efficiencies for b tagging listed in Table below

(apply to signal event rates after basic selection)

Higgs Mass (GeV/c^2)	110	115	120	130	140
$\geq$ 1 Secvtx (Win 2003)	0.484	0.491	0.496	0.492	0.499
Double Secvtx (Win 2003)	0.089	0.087	0.090	0.089	0.101
$\geq$ 1 Secvtx	0.552	0.554	0.557	0.568	0.579
1 Secvtx + 1 Secvtx.OR.JetPrb<0.05	0.185	0.184	0.191	0.194	0.202
$\geq$ 1 Secvtx (Extended η)	0.661	0.664	0.664	0.677	0.686
Double Secvtx.OR.JetPrb<0.05	0.279	0.279	0.290	0.300	0.314
SHWG Tight (No Eta Dependence)	0.712	0.712	0.710	0.721	0.723
SHWG Loose (No Eta Dependence)	0.347	0.343	0.351	0.359	0.372

We require 2 b tags: 1 Tight & 1 Loose

Double tag efficiency per event:

- Central b-tag: $(\eta < 1)$ $\epsilon \sim 20\%$
- Extended b-tag: $(\eta < 2)$ $\epsilon \sim 30\%$

Summary of Yields with Extensions

	Case 0	Case 1	Case 2	Case 3	Case 4
WH ($M_H = 110$)	1.34	1.74	2.63	3.51	4.4
WH ($M_H = 115$)	1.09	1.40	2.13	2.86	3.5
WH ($M_H = 120$)	0.93	1.20	1.82	2.44	2.9
WH ($M_H = 130$)	0.56	0.70	1.09	1.47	1.75
WH ($M_H = 140$)	0.29	0.36	0.56	0.76	0.90
W$b\bar{b}$	34.4	52.7	83.6	108.	140.
W$c\bar{c}$	1.13	1.72	2.73	3.52	4.6
Wqq	1.21	1.85	2.93	3.77	4.91
$t\bar{t}$	21.0	19.3	29.1	43.3	51.0
t(W*)	6.26	8.16	13.1	17.5	21.4
t(Wg)	2.32	2.97	4.25	5.72	6.3
WZ	1.75	2.56	4.53	5.90	8.1
Total Bkg	**67.8**	**89.3**	**140.**	**187.**	**236.**
S/$\sqrt{B}$ ($M_H = 120$)	0.11	0.13	0.15	0.18	0.19

Summary of Extensions:

- Case 0 – Standard Tight-Loose Tagging
- Case 1 – Standard Tight-Loose Tagging with Extended Lepton Coverage ($|\eta_e| < 2.$, $|\eta_\mu| < 1.5$)
- Case 2 – Extended Tagging with Extended Lepton Coverage
- Case 3 – Extended Tagging with Extended Lepton Coverage + Isolated Track (missed e, μ, 1-prg τ)
- Case 4 – SHWG Tagging with Extended Lepton Coverage + Isolated Track

Summary of Yields w/ Mass Window

To get a better feeling of S/$\sqrt{B}$ consider events inside a dijet mass window that encloses 90% of the signal.

	Case 0	Case 1	Case 2	Case 3	Case 4	SHWG(QFL')
WH ($M_H = 120$)	0.84	1.08	1.64	2.20	2.7	3.7
W$b\bar{b}$	5.09	7.80	12.4	15.9	20.7	19.7 (24.0)
W$c\bar{c}$	0.17	0.25	0.41	0.52	0.68	-
Wqq	0.18	0.27	0.43	0.56	0.73	-
$t\bar{t}$	5.02	4.62	6.95	10.3	12.2	13.8
t(W*)	1.58	2.07	3.31	4.43	5.4	9.6
t(Wg)	0.56	0.71	1.03	1.39	1.51	3.9
WZ	0.42	0.61	1.08	1.41	1.93	2.3
Total Bkg	12.9	16.3	25.6	35.6	43.1	49.3 (53.6)
S/$\sqrt{B}$ ($M_H = 120$)	0.23	0.27	0.32	0.37	0.40	0.51
S/B	0.065	0.066	0.064	0.064	0.062	0.075 (0.069)

Summary of Extensions:

- **Case 0 – Standard Tight-Loose Tagging**
- **Case 1 – Standard Tight-Loose Tagging with Extended Lepton Coverage**
- **Case 2 – Extended Tagging with Extended Lepton Coverage**
- **Case 3 – Extended Tagging with Extended Lepton Coverage + Isolated Track**
- **Case 4 – SHWG Tagging with Extended Lepton Coverage + Isolated Track**

Determination of Sensitivity

Evaluate sensitivity with two different approaches:

- 1. Similar technique to SHWG (Bayesian)
- 2. Approach used by LEP Higgs Group (CL_S)
- Give roughly similar results (Gaussian regime) but the CL_S is slight more optimistic for nσ excesses.

SHWG used counting experiment in a mass window
We fit to the $b\bar{b}$ mass distribution

Methods allow:

- Including systematics on background and signal (more later)
- Constraints, *e.g.*, on background normalization
- Straightforward combination of channels and experiments

Extensions at the End Game

WH Channel:

- No Attempt to Optimize
- SHWG found factor of $\sim$1.8 (scale in lum.) for NN over standard sel.
- Run 1 Analysis (C. Neu) has a factor of 1.6 (scale in lum.) of a NN over previous WH search

  Some improvement from different cuts

  Some improvement from NN
- DØ sees a factor of 2.25 (scale in lum.) in ZH Analysis
- In order to allow for some optimization of WH we took a scale of 1.6

ZH Channel:

- Included contribution of $Z \rightarrow \ell\ell$ by a luminosity scaling by 1.33

Systematics:

- Difficult to estimate - not enough time to evaluate
- We do not include any estimate of systematic errors
- In final plot we make it clear this is STATISTICAL Sensitivity Only

WH Channel (CDF + DØ)

CDF×2 to represent CDF + DØ

(DØ performance taken the same as CDF)

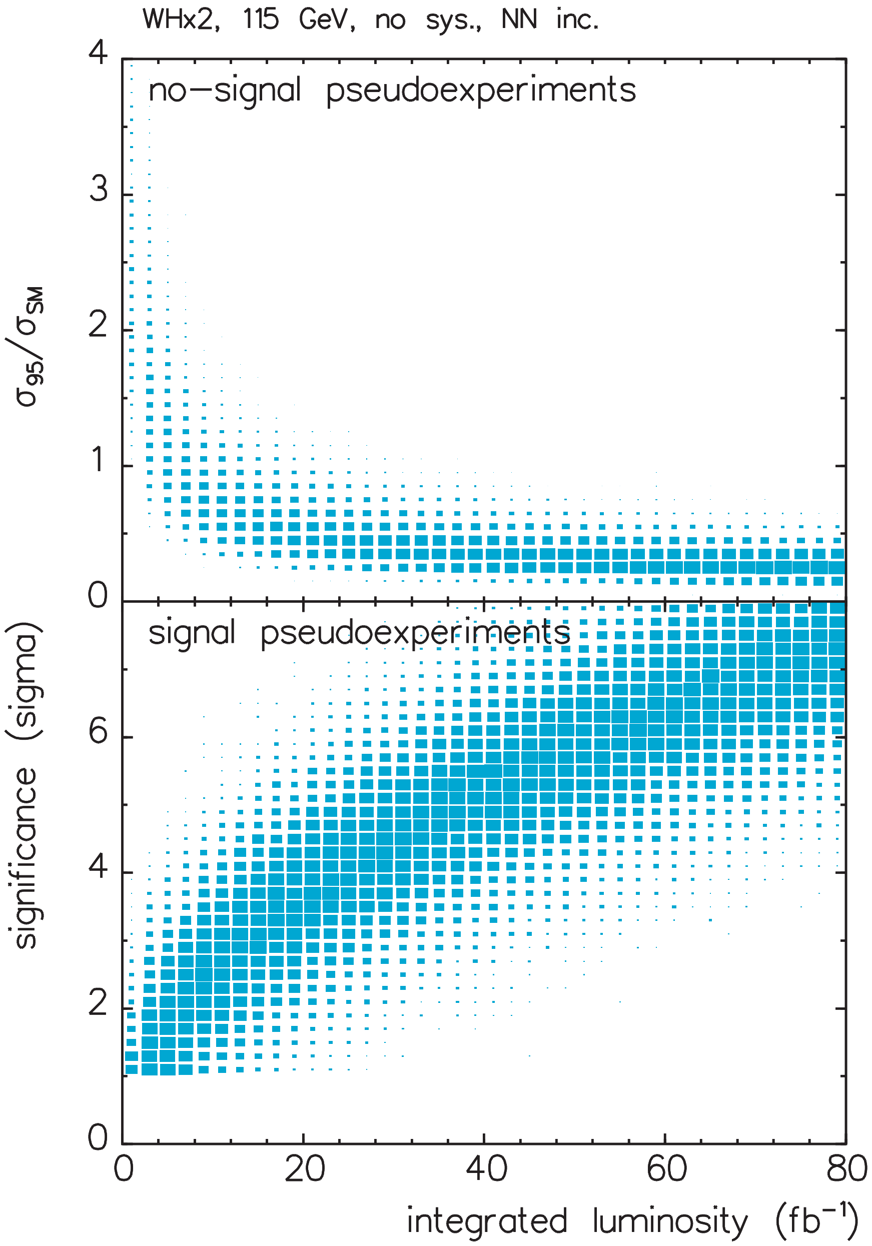
Example: $m_H = 115\,\mathrm{GeV}$

Bayesian Approach:

- Pseudoexperiments
- Event Yield + Opt. Scale Up
- No Systematics

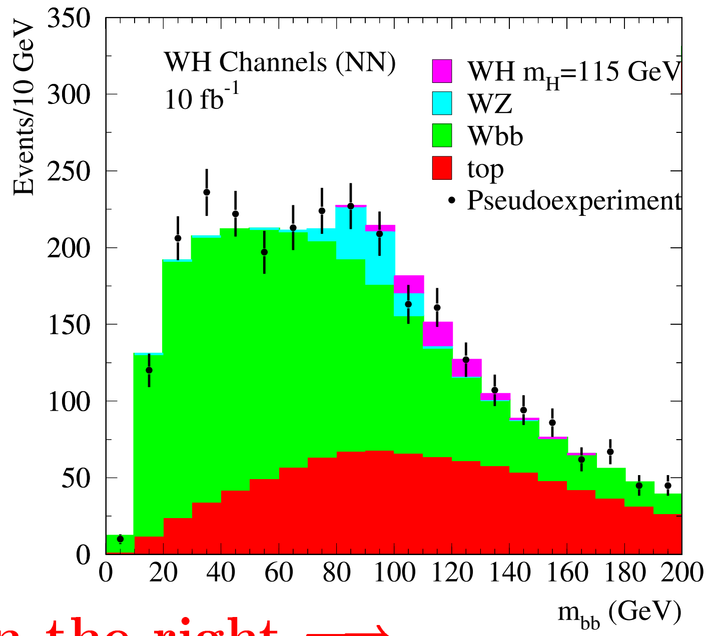
Vertical units:

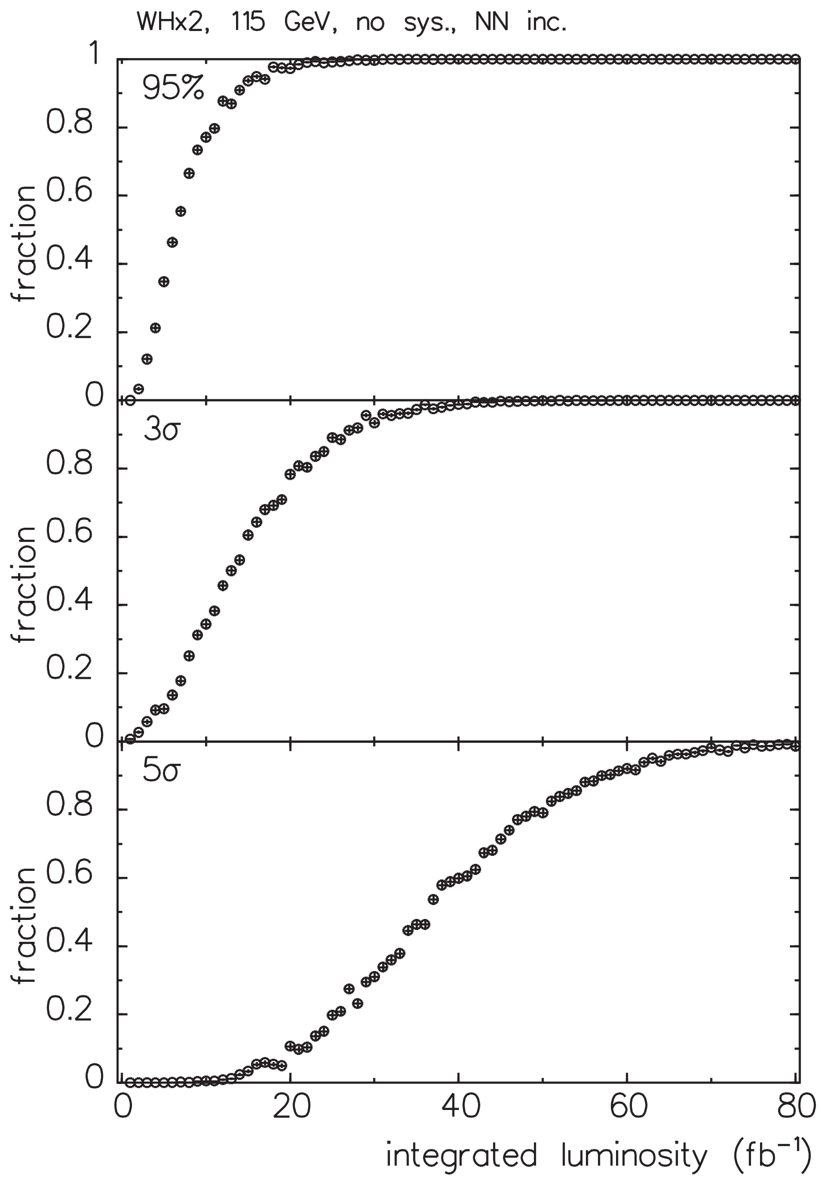
- Upper: SM $\sigma(WH) \equiv 1$
- Lower: signal significance



WH Channel (continued)

Ex. of (unlucky) pseudoexp.
$m_H = 115\,\mathrm{GeV}$





On the right $\Longrightarrow$
Vertical axis is fraction of exp. satisfying particular criteria

inc. 50% to 95% of exp.
Required $\mathcal{L}$ up factor 2–3

ZH Channel (CDF + DØ)

DØ×2 to represent CDF + DØ

(CDF performance taken the same as DØ)

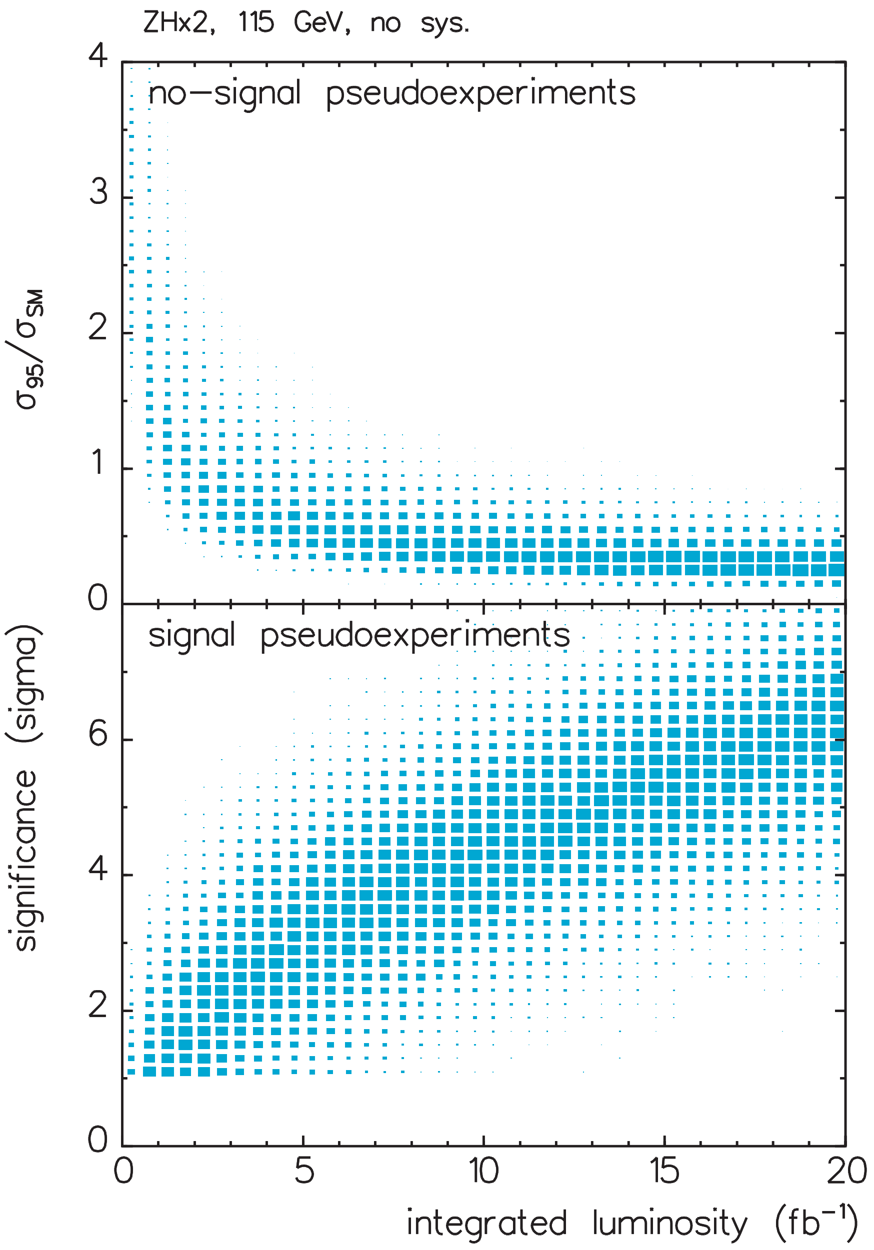
Example: $m_H = 115\,\mathrm{GeV}$

Based on DØ Analysis

- Improved Sensitivity based on NN Analysis
- Scaled up 1.33 to include $Z \to \ell\ell$

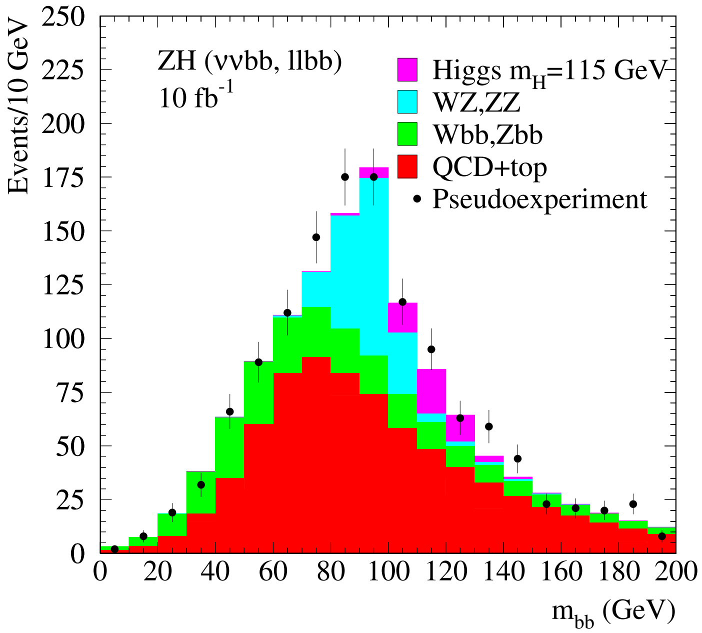
Vertical units:

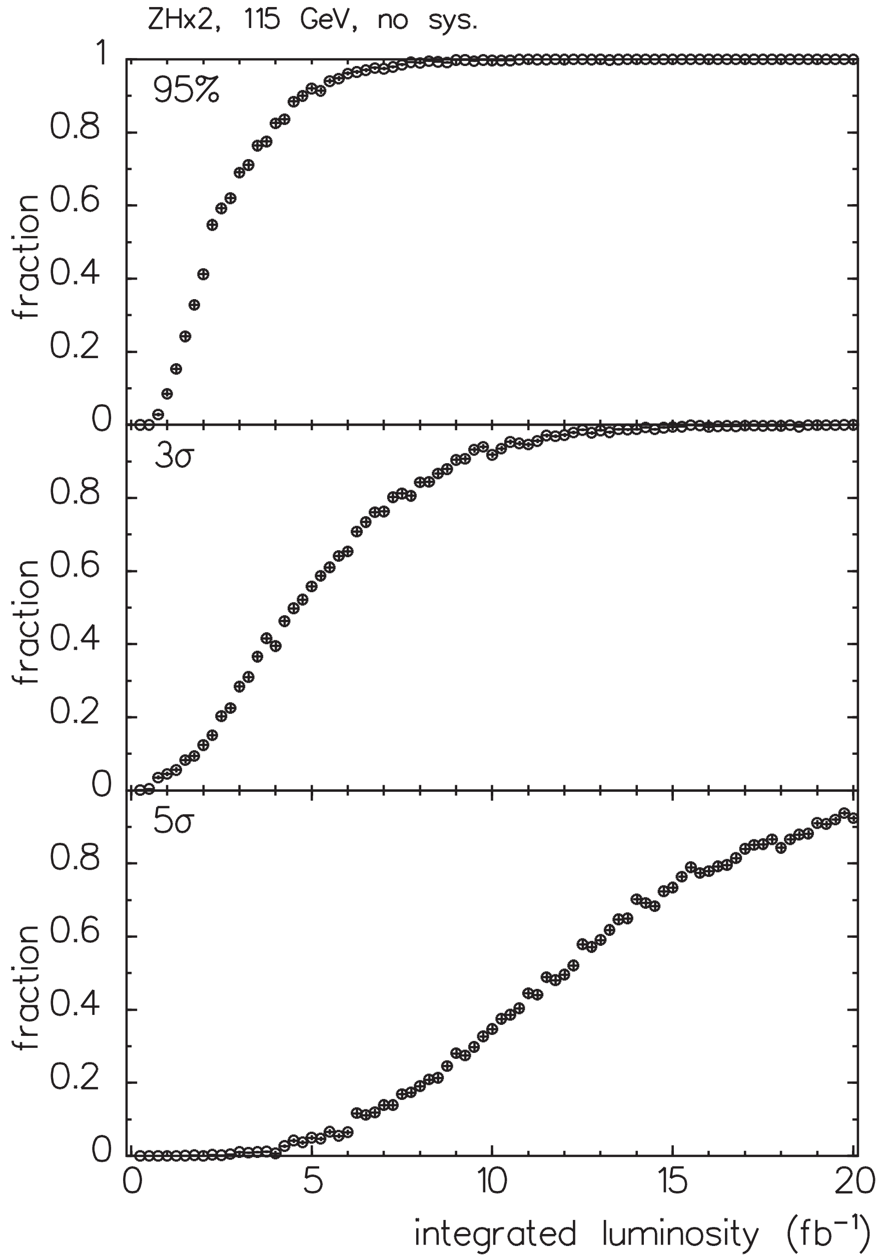
- Upper: SM $\sigma(ZH) \equiv 1$
- Lower: signal significance



ZH Channel (continued)

Ex. of (typical) pseudoexp.
$m_H = 115\,\mathrm{GeV}$





On the right $\Longrightarrow$
Vertical axis is fraction of exp. satisfying particular criteria

inc. 50% to 95% of exp.
Required $\mathcal{L}$ up factor 2–3

Combined WH + ZH (CDF + DØ)

Example: $m_H = 115\,\mathrm{GeV}$

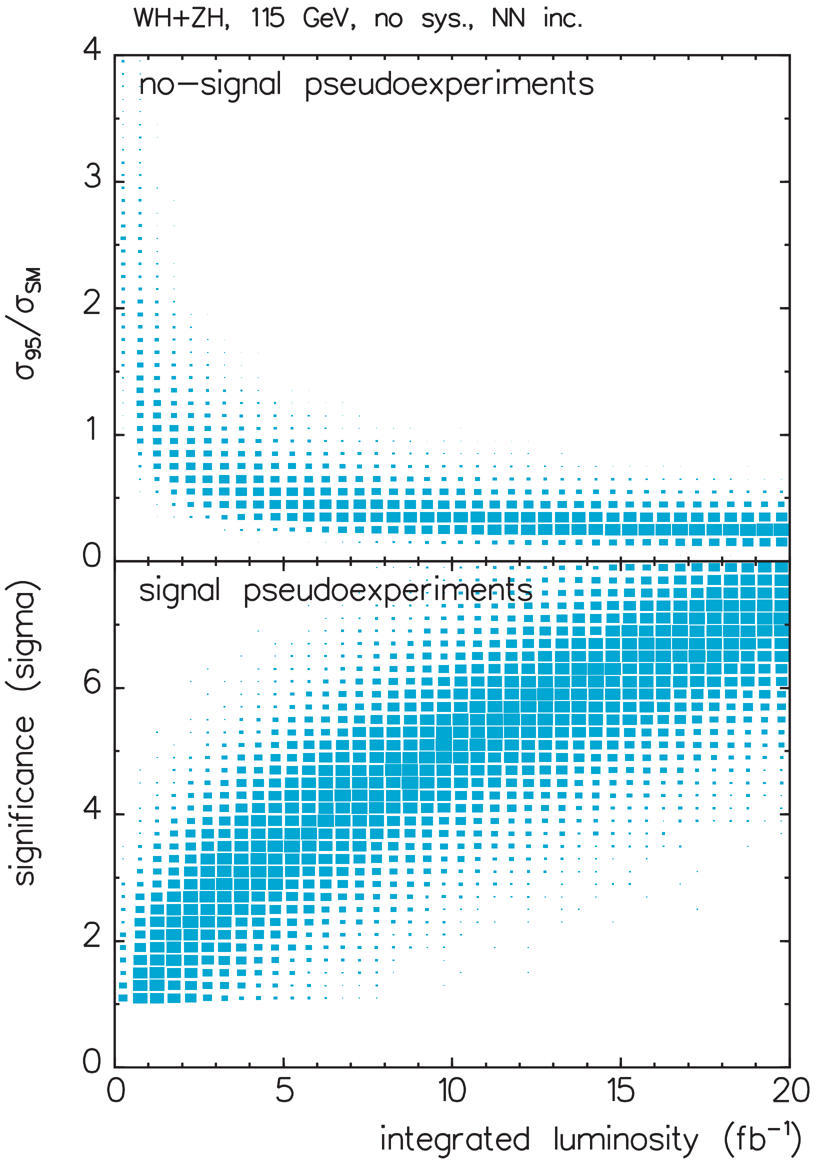
WH: CDF×2
to represent CDF + DØ

ZH: DØ×2
to represent CDF + DØ

Vertical units:

- **Upper: SM $\sigma(ZH) \equiv 1$**
- **Lower: signal significance**

No systematics



Combined WH + ZH (continued)

Based on statistics alone:

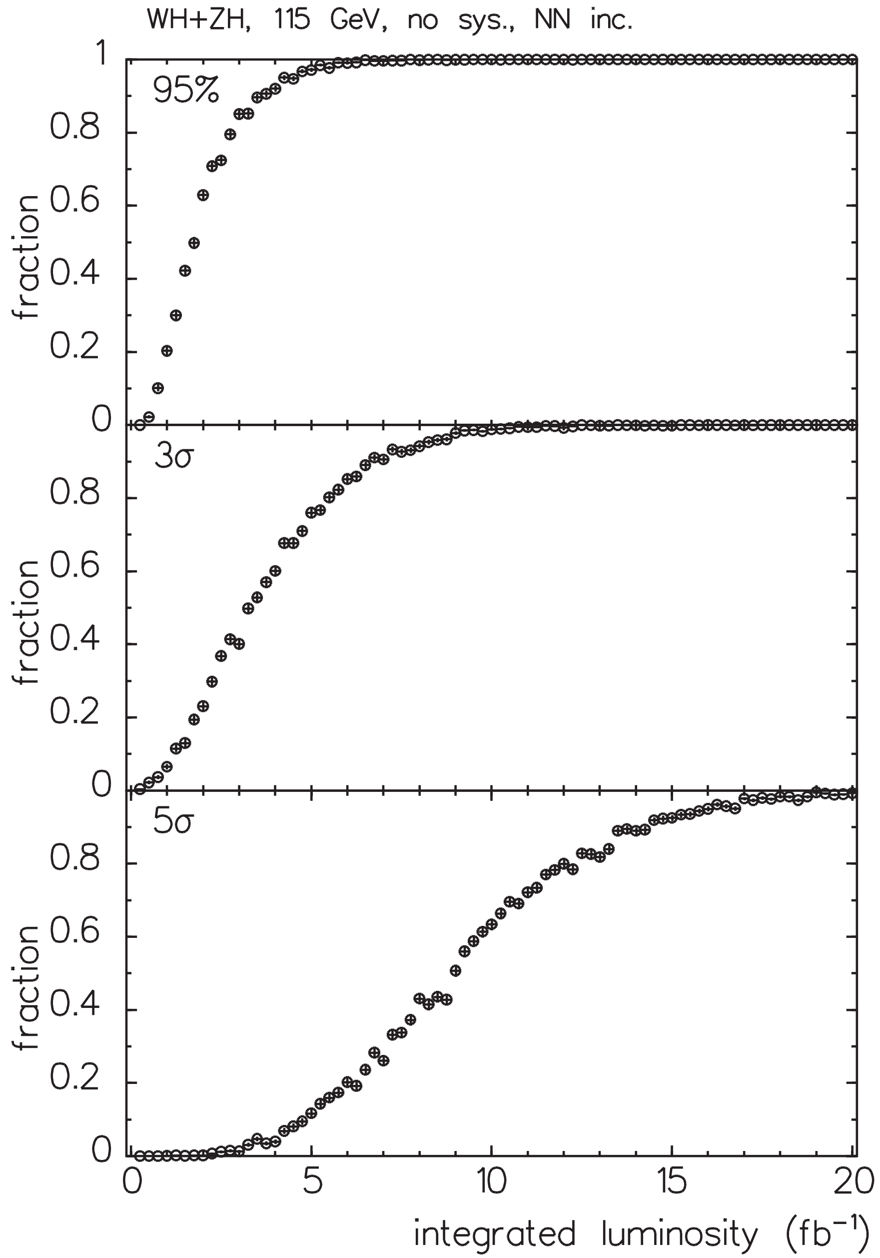
3.25 fb^{-1} and $m_H = 115\,\text{GeV}$

- 80% Chance of a 95% CL Exclusion
- 50% Chance of a 3σ Excess
- $< 2 - 3\%$ Chance of a 5σ Excess

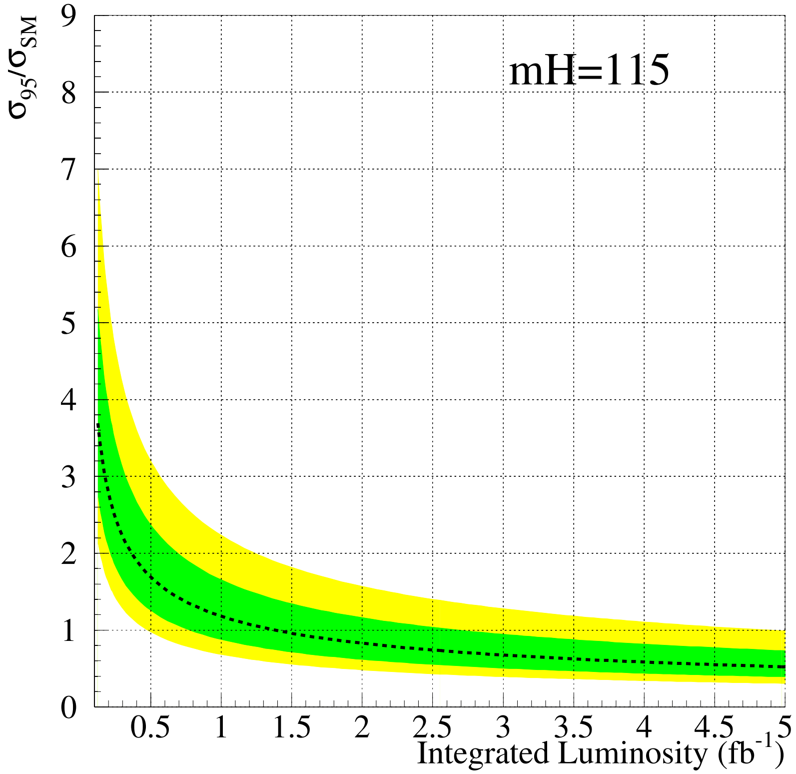
10 fb^{-1} and $m_H = 115\,\text{GeV}$

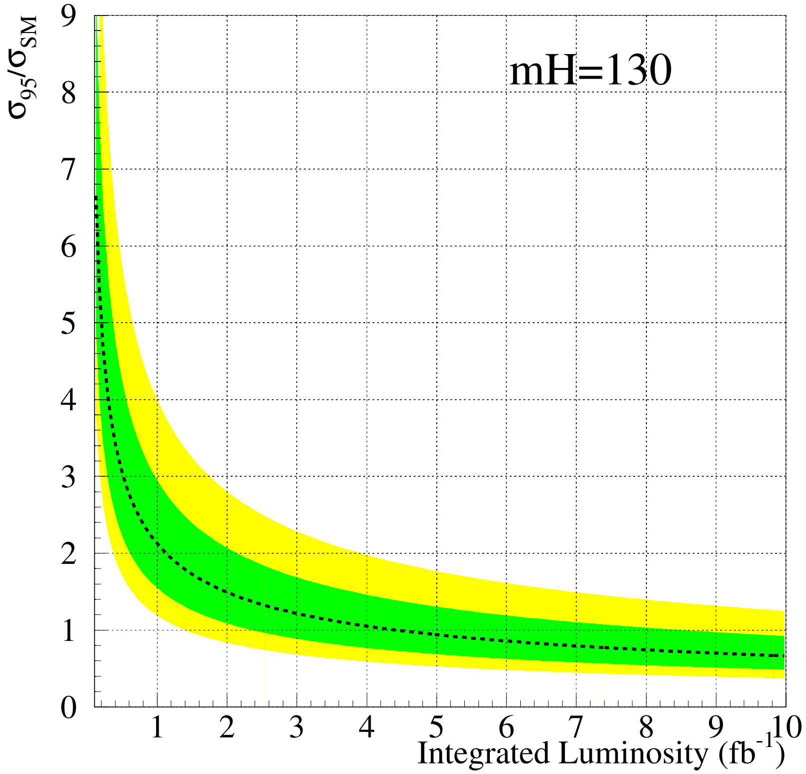
- $\sim$ 100% Chance of a 95% CL Exclusion
- $\sim$ 99% Chance of a 3σ Excess
- 60% Chance of a 5σ Excess

Systematics could lower percentages significantly



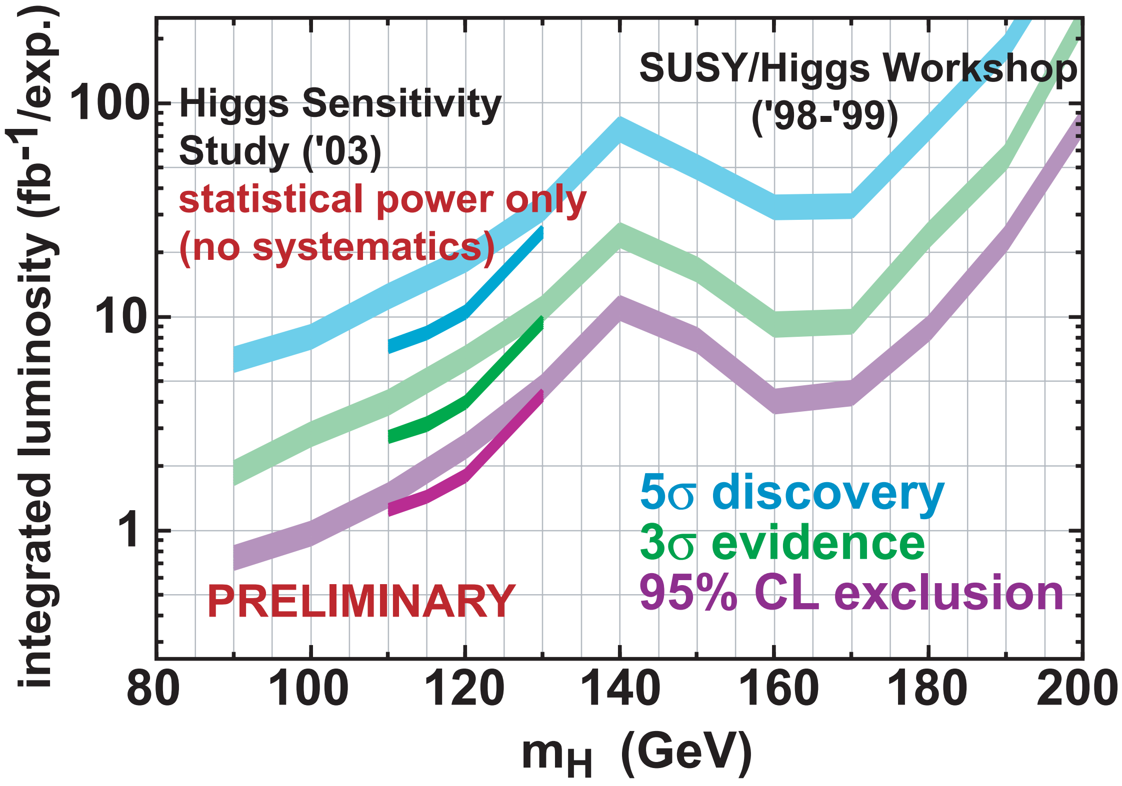
Progress on Exclusion





- **CLs Method**
- **With 3.25 fb^{-1} almost 50% chance of excluding 130 GeV/c^2**
- **Statistical analysis only, no systematics**

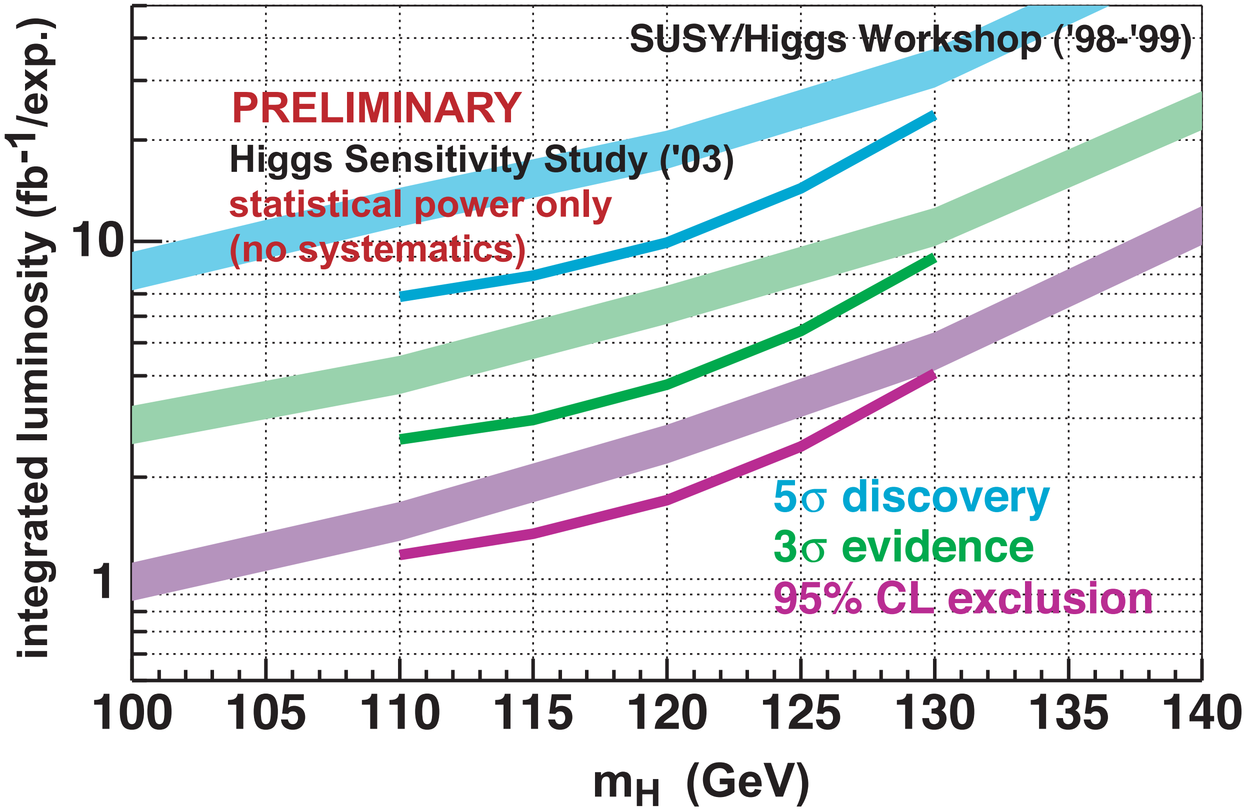
Putting it all together...



New results from Higgs Sensitivity Study:

- Statistical power only (no systematics)
- including systematics would move curves up
- 10% width of curves due to
  CL_S (lower edge) vs. Bayesian (upper edge)

Zoom in on Low Mass Region



New study: No systematics, 10% width of curves due to CL_S (lower edge) vs. Bayesian (upper edge)

SHWG: lower edge includes systematics
30% width is "safety margin"

Conclusions

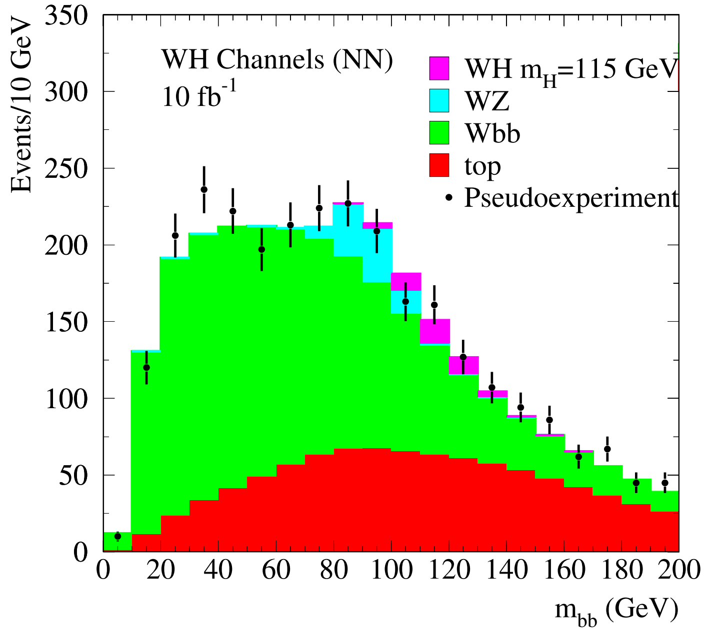
- **Joint study by CDF and DØ to validate/improve work of SUSY-Higgs Working Group (SHWG) using knowledge gained with first Run II data**
- **WH Channel (CDF): unable to reproduce SHWG sensitivity**

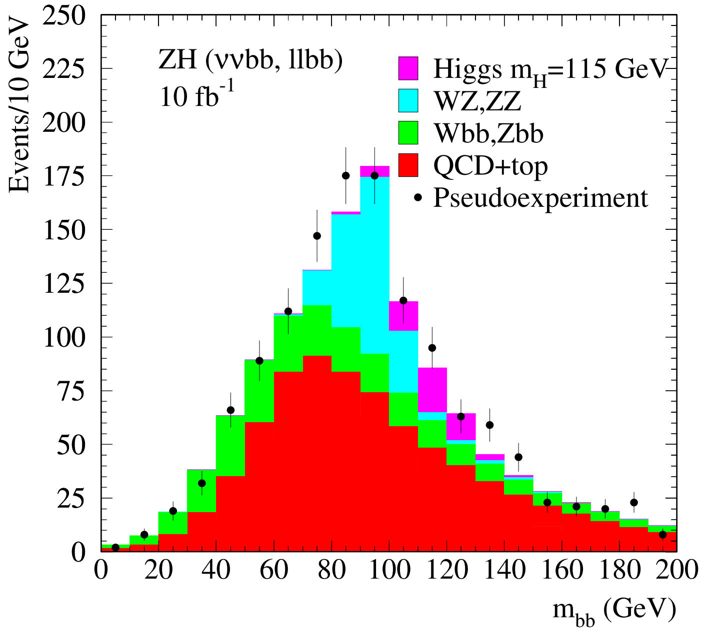
  no attempt to optimize analysis (*e.g.*, using NN)

  Used NN enchancement factor of 1.6 based on Run I CDF analysis
- **ZH Channel (DØ): found improved sensitivity over SHWG**

  Used a NN to gain this sensitivity
- **Net effect: combination is a gain in sensitivity over SHWG**
- **Systematic are a serious concern (see next slide).**
  - **Projecting baseline numbers out 5 years is hard enough ... getting systematics requires more time... the degradation could be large**
  - **As suggested two weeks ago we quote STATISTICAL power only**
  - **Large data samples essential for understanding systematics, backgrounds, efficiencies, etc.**

Concerns





- Background Normalization

  Data Samples (W+Jets, $t\bar{t}$) will be large.

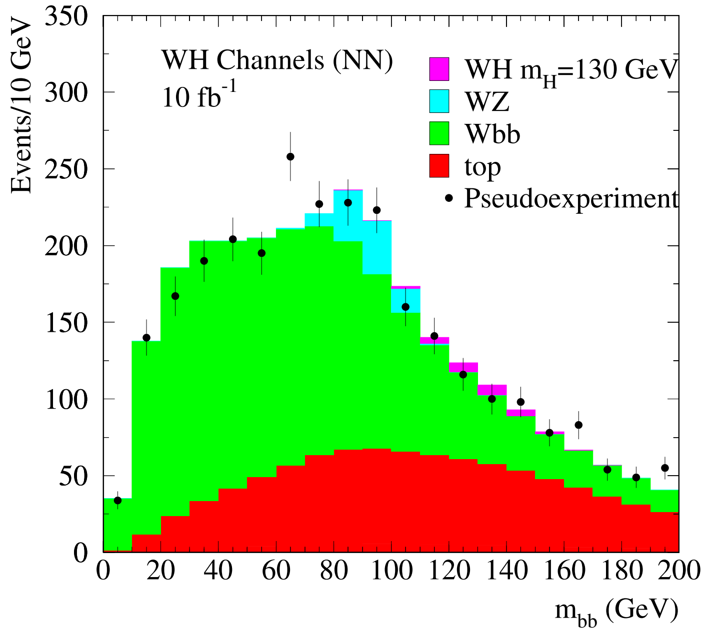
  How well can we determine the normalization?

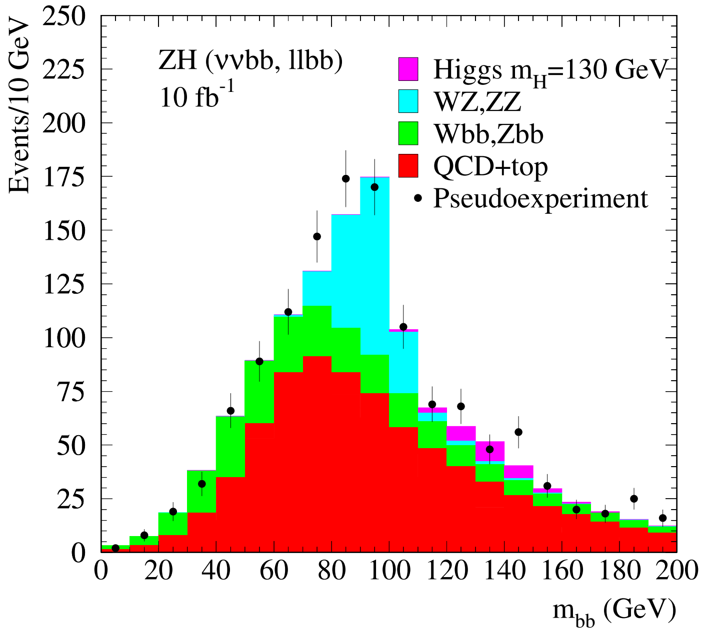
- M_{bb} Shape (Signal & Background)

  MC Generator Kinematics

  Detector Simulation

Pseudoexperiments at M_H=130





Backup Slides with Updated Tables

Luminosity Thresholds: fb^{-1}/exp

m_H (GeV/c^2)	110	115	120	130
95% CL: CLs	1.18	1.36	1.71	4.07
95% CL: Bayesian	1.26	1.46	1.74	4.16
95% CL: +20% Syst.	1.51	1.75	2.09	4.99
95% CL: SHWG	1.30	—	2.20	4.15
3σ: CLs	2.59	2.96	3.76	8.96
3σ: Bayesian	2.88	3.36	4.16	9.83
3σ: +20% Syst.	3.46	4.03	4.99	11.8
3σ: SHWG	3.53	—	5.69	9.67
5σ: CLs	6.85	7.93	9.93	23.69
5σ: Bayesian	7.68	8.89	11.16	26.48
5σ: +20% Syst.	9.22	10.7	13.4	31.8
5σ: SHWG	11.07	—	16.4	28.6

Signal Rates After Basic Selection (before b tagging)

Generate Monte Carlo samples using `ALPGEN`

Higgs Mass (GeV/c^2)	110	115	120	130	140
Cross Section (pb)	0.216	0.186	0.160	0.119	0.0902
Branching Ratio	$0.770 \cdot 0.33$	$0.732 \cdot 0.33$	$0.679 \cdot 0.33$	$0.527 \cdot 0.33$	$0.344 \cdot 0.33$
MC Gen ($WH \to \ell\nu b\bar{b}$)	143100	133718	140354	143006	39599
1 Good e or μ	0.24	0.24	0.24	0.25	0.25
MET > 20 GeV	0.89	0.89	0.89	0.89	0.89
Pass Z^0 Veto	0.99	0.99	0.99	0.99	0.99
Jet Selection	0.77	0.78	0.80	0.80	0.80
Kinematic Selection	0.84	0.84	0.84	0.84	0.82
Acceptance	0.14	0.14	0.14	0.14	0.14
Trigger Efficiency	0.95	0.95	0.95	0.95	0.95
Events in 1 fb^{-1}	7.28	5.95	4.89	2.88	1.42

Reconstructing the Higgs: b$\bar{\text{b}}$ Dijet Invariant Mass

Understand light-q, g jets well: γ/Z vs. jet

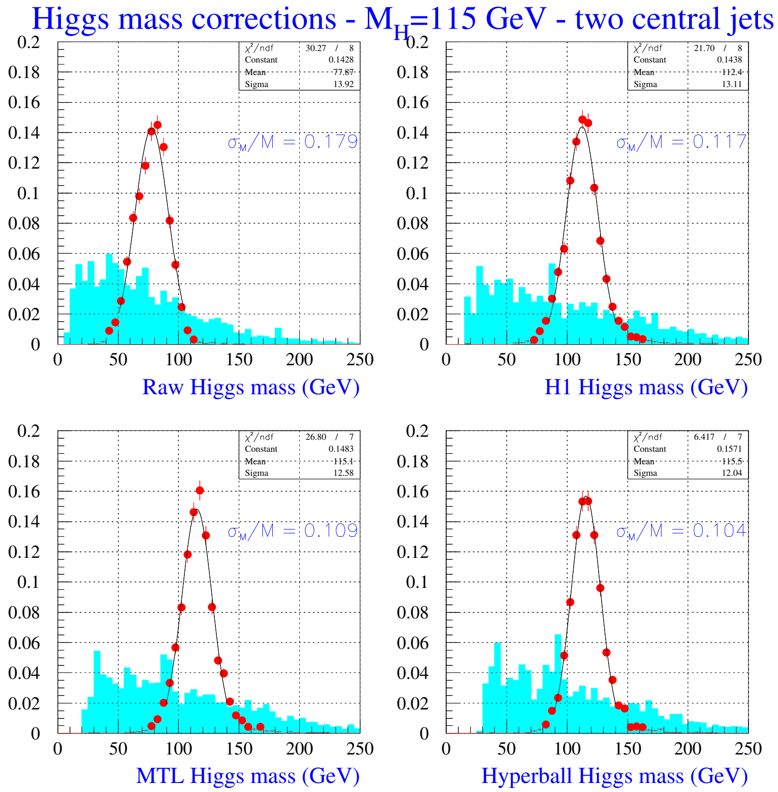
Higgs is special: $b\bar{b}$ system – harder frag., high p_T μ and ν

- **SHWG:** counted events in mass window
  absolute normalization of backgrounds (with systematics)
  assumed $\sigma(m_{b\bar{b}}) = 10\,\%$ (core)
  if $\sigma(m_{b\bar{b}}) = 12\,\%$, requires 20% more int. $\mathcal{L}$
  ultimate resolution: $\sigma(m_{b\bar{b}}) = 8\,\%$ (jet frag., gluon rad., ν)
- **This study:** fit $m_{b\bar{b}}$ spectrum
  Use "sidebands" to help constrain backgrounds
  (expect 20% gain in int. $\mathcal{L}$)
  We have considered $10\% < \sigma(m_{b\bar{b}}) < 20\%$

Considerable effort has gone into improving $\sigma(\mathrm{m}_{\mathrm{b}\bar{\mathrm{b}}})$

Studies of Resolution of $m(b\bar{b})$

- Raw jet energies
  - JETCLU (cone of 0.4)
- H1 Kuhlmann *et al.*
  - CDF Notes 5507, 5416
  - tracking (central)
  - tower
- MTL additions to H1
  - CDF Notes 4527, 5517
  - soft ℓ, AA-like corr.
  - (CDF Note 2469)
- Hyperball New!
  - CDF Note 6450
  - Use global event info.



Background ● Higgs

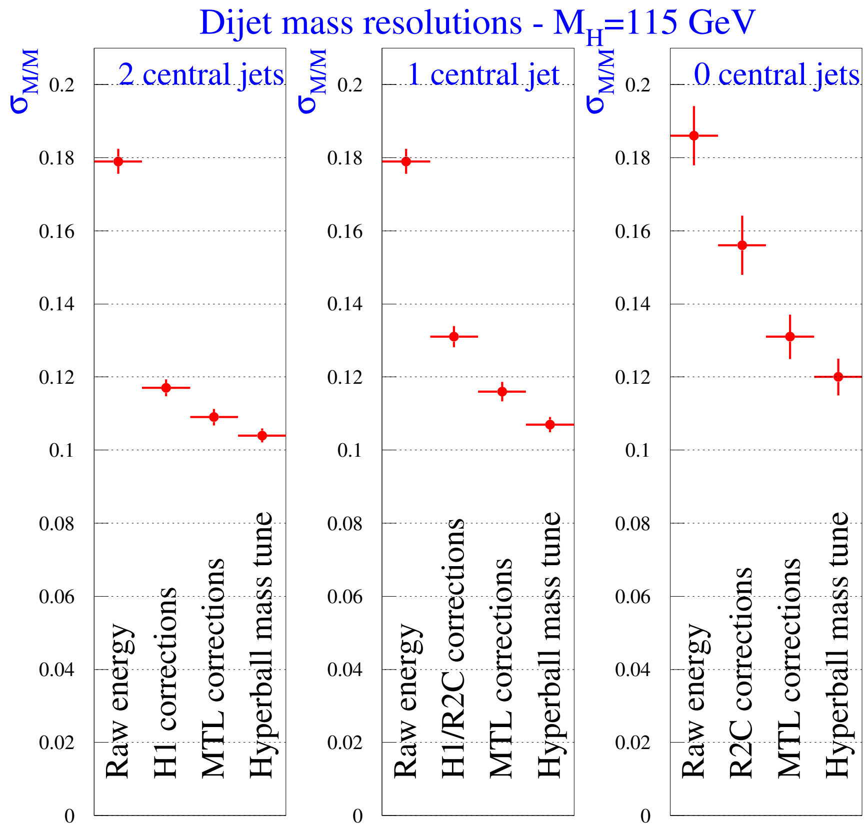
Core resolution

From 18% $\Longrightarrow$ 10%

Performance comparison Central versus Endcap

Previous comparison was both jets Central

Central–Endcap or both Endcap: resolution degrades some



Extrapolations include these effects